Ninth International Workshop
on
Laser Ranging Instrumentation

incorporating a

Symposium on Western Pacific Laser Ranging Network

WPLS '94

Canberra 1994

VOLUME 3

Compiled and edited by John McK. Luck
with assistance from Georgina R. Luck, Mark J. Elphick, Robbie Horn

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Convenor: Hiroo Kunimori

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SYMPOSIUM

WESTERN PACIFIC LASER RANGING NETWORK

WPLS'94

Convenor : Hiroo Kunimori

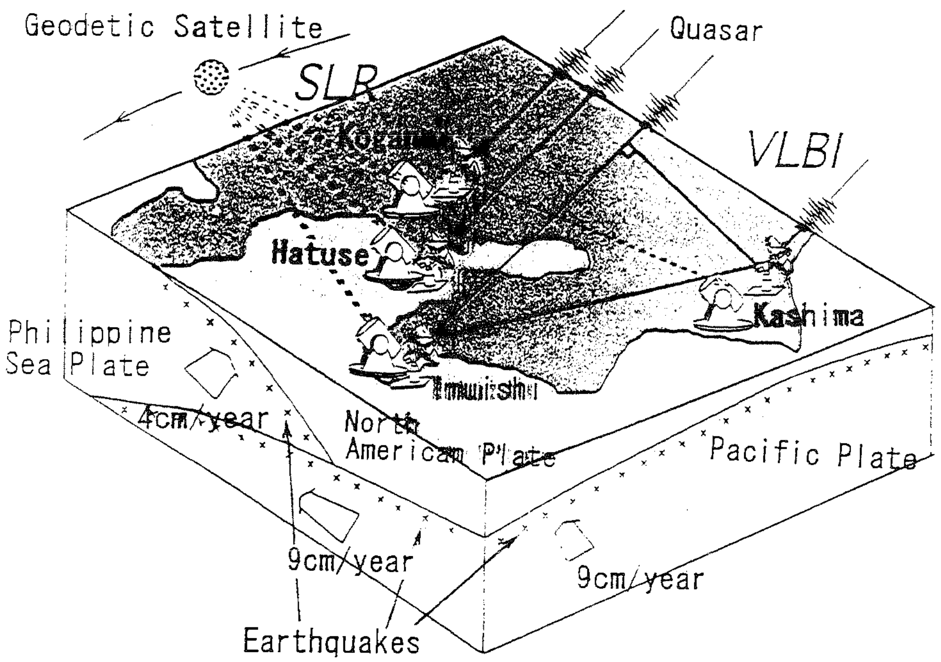
Sensitivity Analysis of the Keystone Network

Bret Engelkemier, Toshimichi Otsubo, Hiroo Kunimori
Communications Research Laboratory - Japan

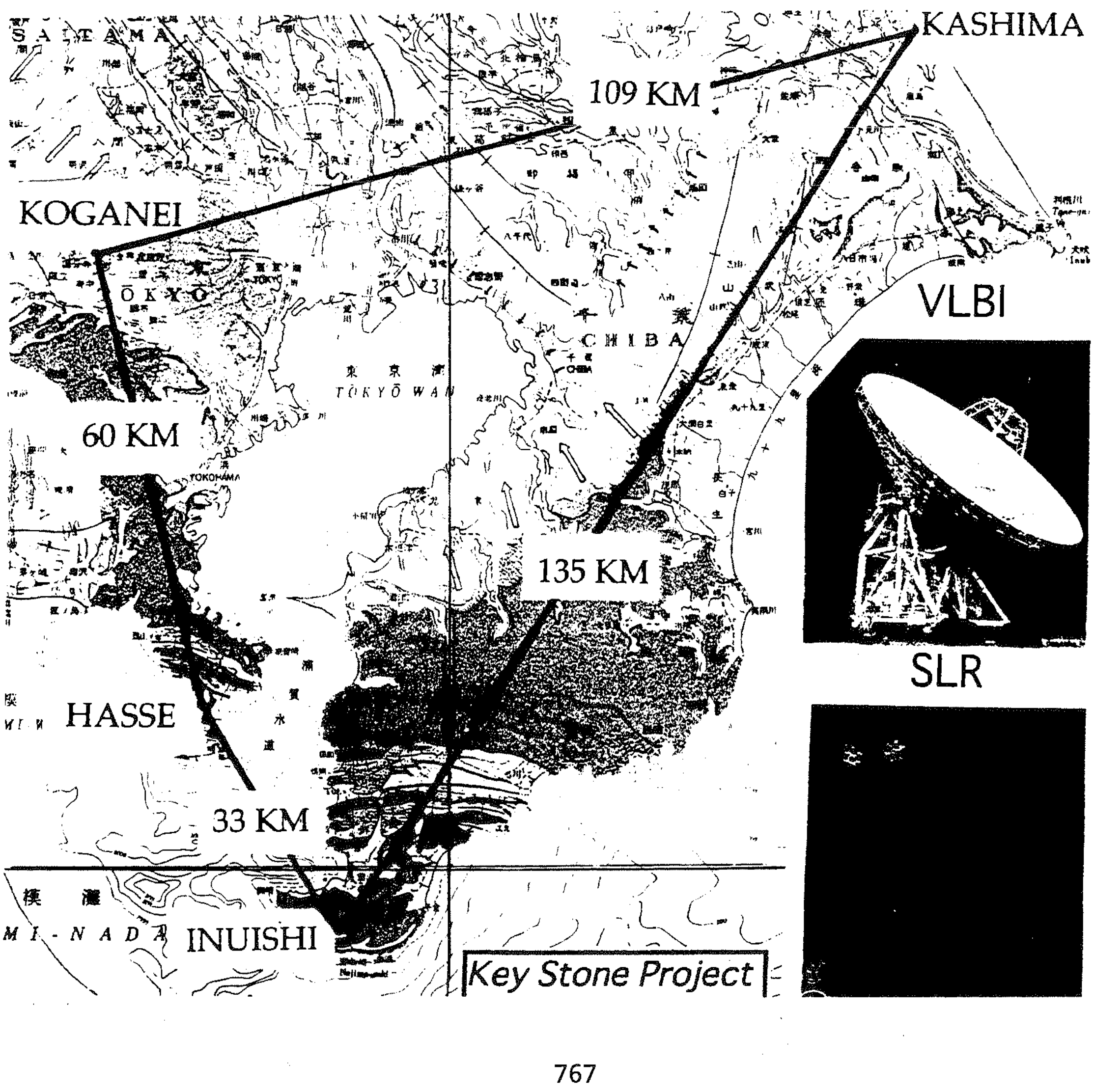
9th International Workshop on Laser Ranging Instrumentation

Canberra, Australia

Crustal Deformation Monitoring Network in the Tokyo Metropolitan Area



Four VLBI/SLR colocated stations is being deployed in the Tokyo Metropolitan Area

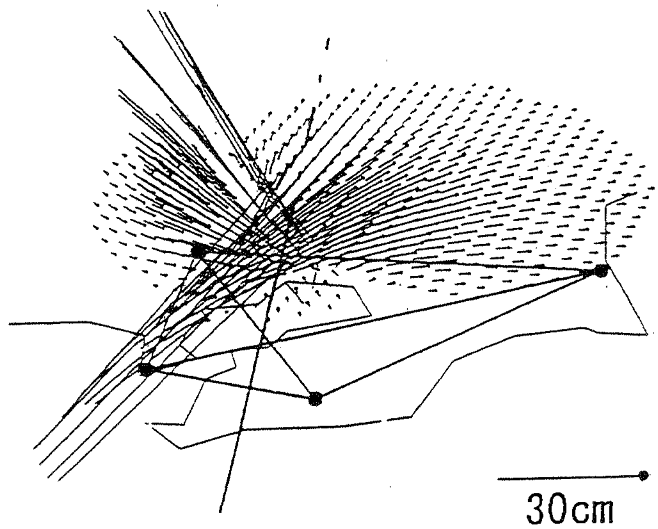


Construction Schedule

Key-Stone Project

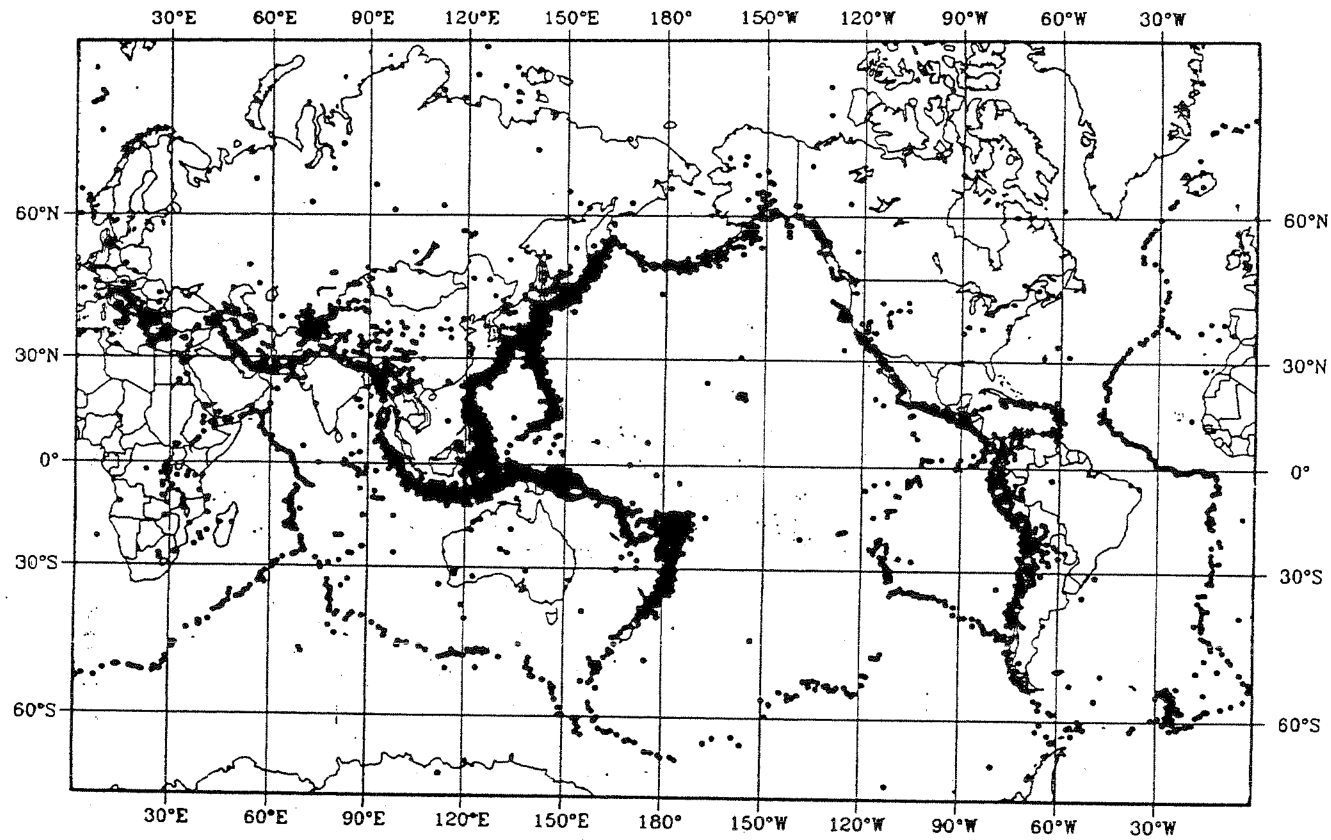
	1993	[redacted]	1995	1996	1997	1998
VLBI	Koganei	Hatsuse	Inuishi			
	Kashima					
SLR				Kashima	Koganei	Inuishi
					Hatsuse	

Crustal deformation assuming M7 earthquake under the Tokyo-Metropolitan Area



- Displacement of the ground is simulated.
- Several percent of the above dispacement is expected as the precursor of earthquake.

Earthquakes with Magnitudes ≥ 5.0: 1980-1990



U. S. Geological Survey
National Earthquake Information Center, 1990

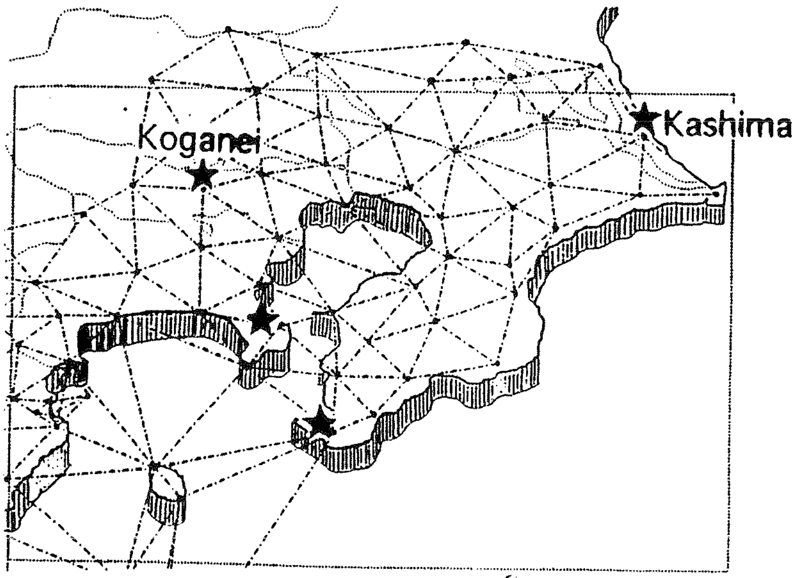
Performance of SLR System

- Tracking Accuracy 2 arcsec
- Altitude of the Satellites 5 0 0 - 2 2 , 0 0 0 km
- Ranging Error < 1 cm (LAGEOS, 2 minutes)
- Jitter in Synchronous Ranging <100ns
- Real Time Calibrartion for Ranging
- Multi Stop Function for Multi Color Ranging
- 24hrs operable
- Automatic Operation

Key Stone Project

Connection with the GPS Network of GSI

Key Stone Project



- VLBI/SLR network (Key Stone Project) is connected at Koganei and Kashima with the GPS network operated by GSI (Geographical Survey Institute). Dense geodetic network is expected to monitor the crustal deformation.

Dynamical - Consecutive Pass Analysis

0 ≡ ranged X ≡ did not range rms errors are in *mm !!*

Station / Pass	1	2	3	4	U-D rms error	E-W rms error	N-S rms error	
Koganei	0	0	0	0	0.0	0.0	0.0	Control Case
Kashima	0	0	0	0	2.0	2.0	1.3	
Miura	0	0	0	0	2.0	2.0	1.3	
Inuishi	0	0	0	0	2.0	2.0	1.3	

Koganei	X	0	0	X	0.0	0.0	0.0	Random Pass Observation Case
Kashima	X	X	0	0	6.4	6.4	4.6	
Miura	0	X	X	0	7.3	6.1	4.5	
Inuishi	0	0	X	X	6.8	3.6	3.8	

Koganei	0	0	0	0	0.0	0.0	0.0	Only Two Stations Observing Case
Kashima	0	0	0	0	2.0	2.0	1.3	

Koganei	0	0	X	X	0.0	0.0	0.0	Only 2 Passes Observed Case
Kashima	0	0	X	X	2.4	2.5	1.8	
Miura	0	0	X	X	2.4	2.4	1.8	

SRD Analysis Results

Model Assumptions:

- 2 body force model
- the calculated satellite orbit was perturbed at each observation by 10cm Guassian distributed noise
- each observation had an independent random error of 2cm
- each baseline is determined independently of each other

Koganei - Kashima baseline (errors are in *mm!!*)

# passes observed	U-D rms error	E-W rms error	N-S rms error
1 pass	23.9	71.2	50.1
2 passes	2.3	2.5	1.9
3 passes	2.2	2.4	1.5
4 passes	1.7	2.3	1.3

OVERVIEW

Compare the "SPORT" method with "SRD" by:

- ***the effect of observer geometry on the solutions***
- ***comparison of single satellite vs. multiple satellite solutions***
- ***effects of range biases on the respective solutions***
- ***effects of coordinate error in the "fixed" ground station***

Analysis Methodology

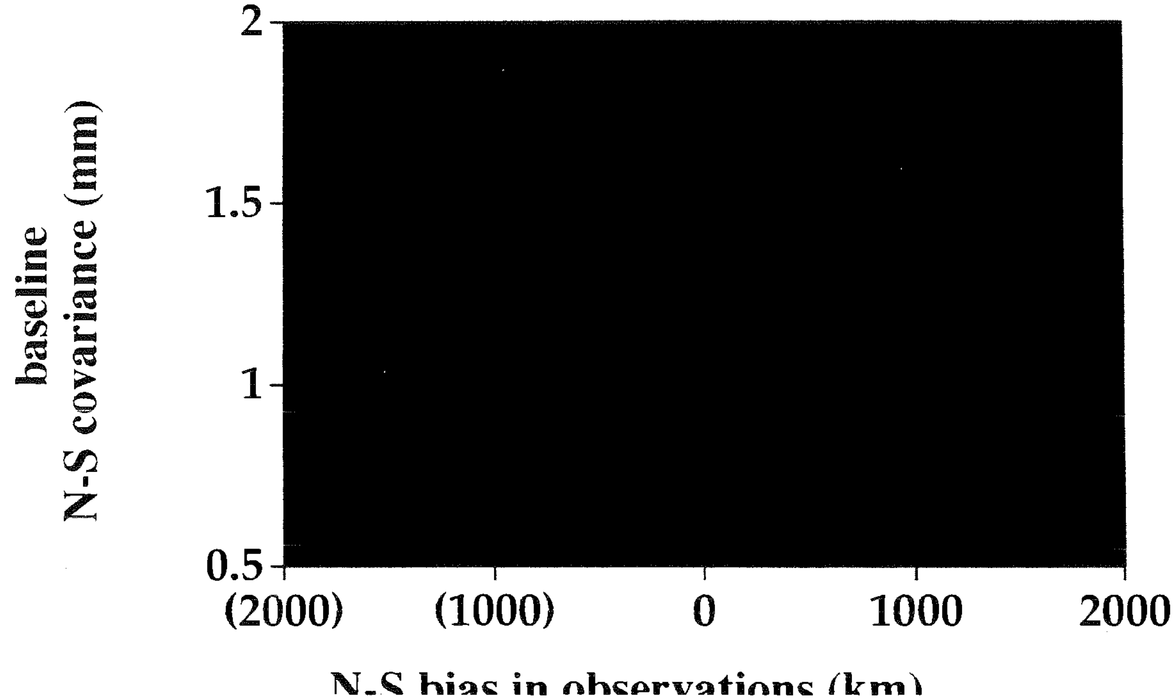
- *assume no orbital error or station coordinate error*

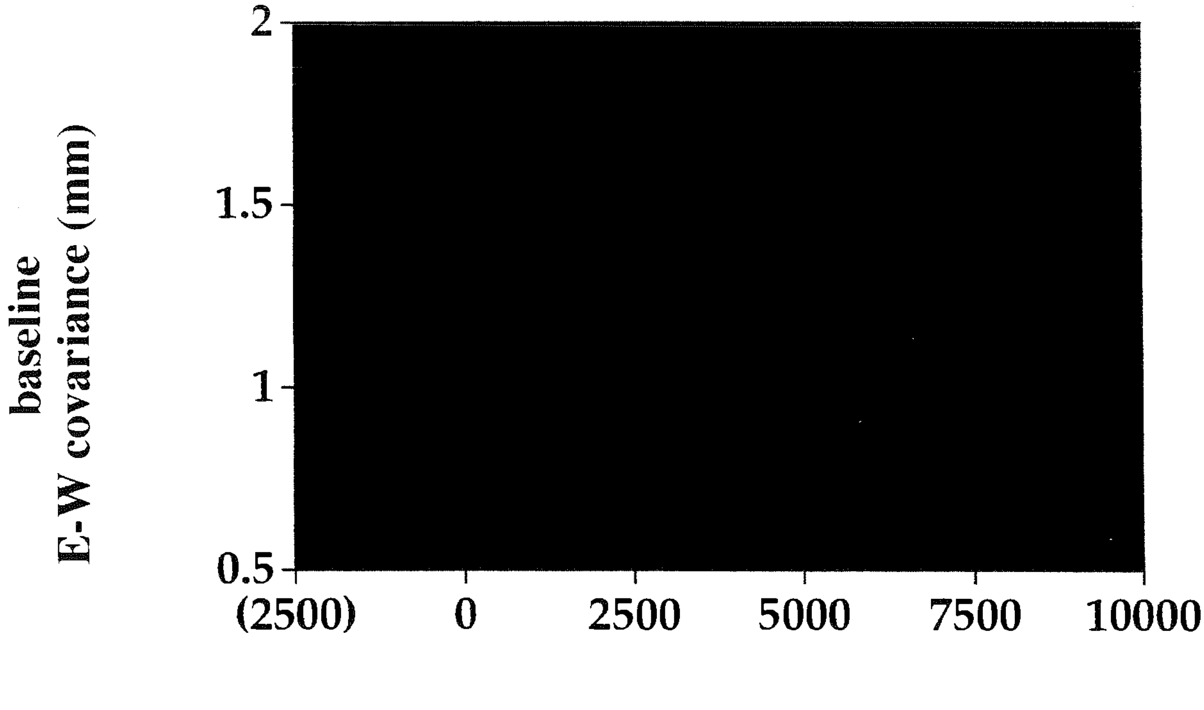
"SPORT" Method: estimate satellite parameters and station coordinates >>> baseline covariance

"SRD" Method: single range difference (Pavlis, 1985), estimate the 6 baseline vectors between the stations

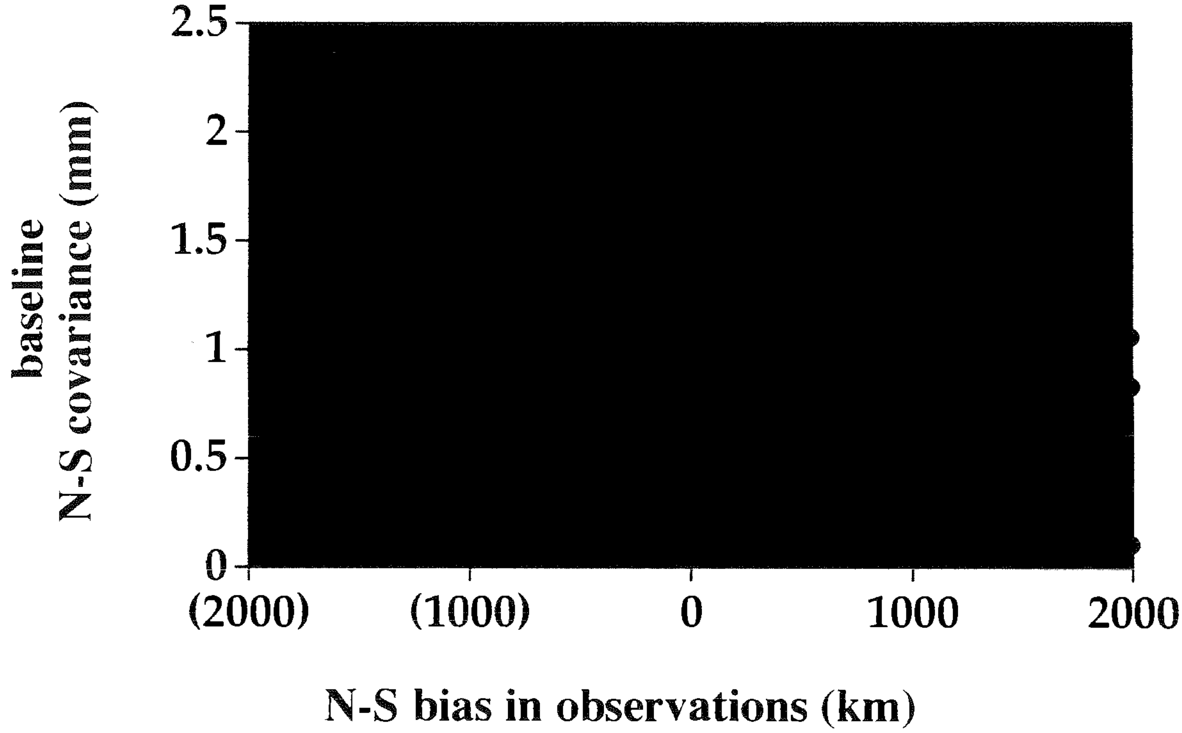
- *use consider covariance analysis to determine the effect of non-estimated parameters on the solution*
- *range bias error have $\sigma = 5mm$*
- *"fixed" station coordinate errors have $\sigma = 5mm$ in each direction*

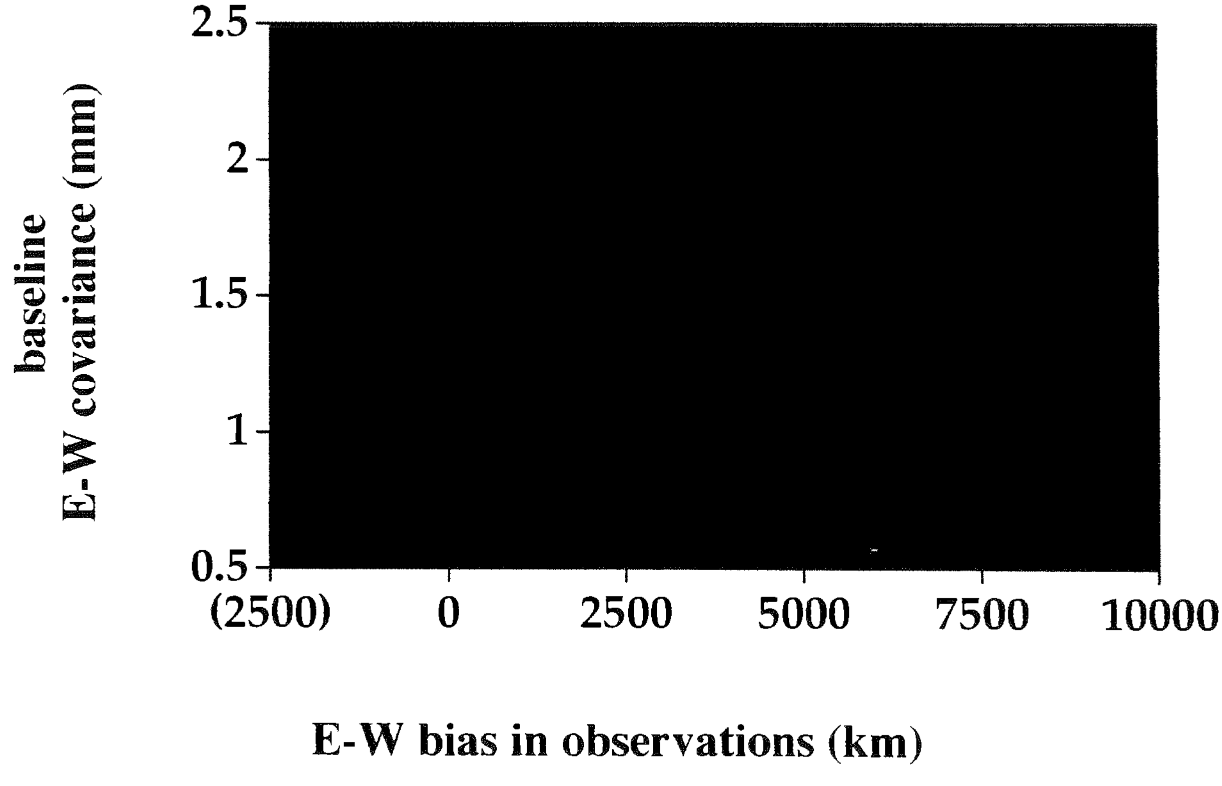
Geometry Bias for SRD with Multi-Satellite Solution





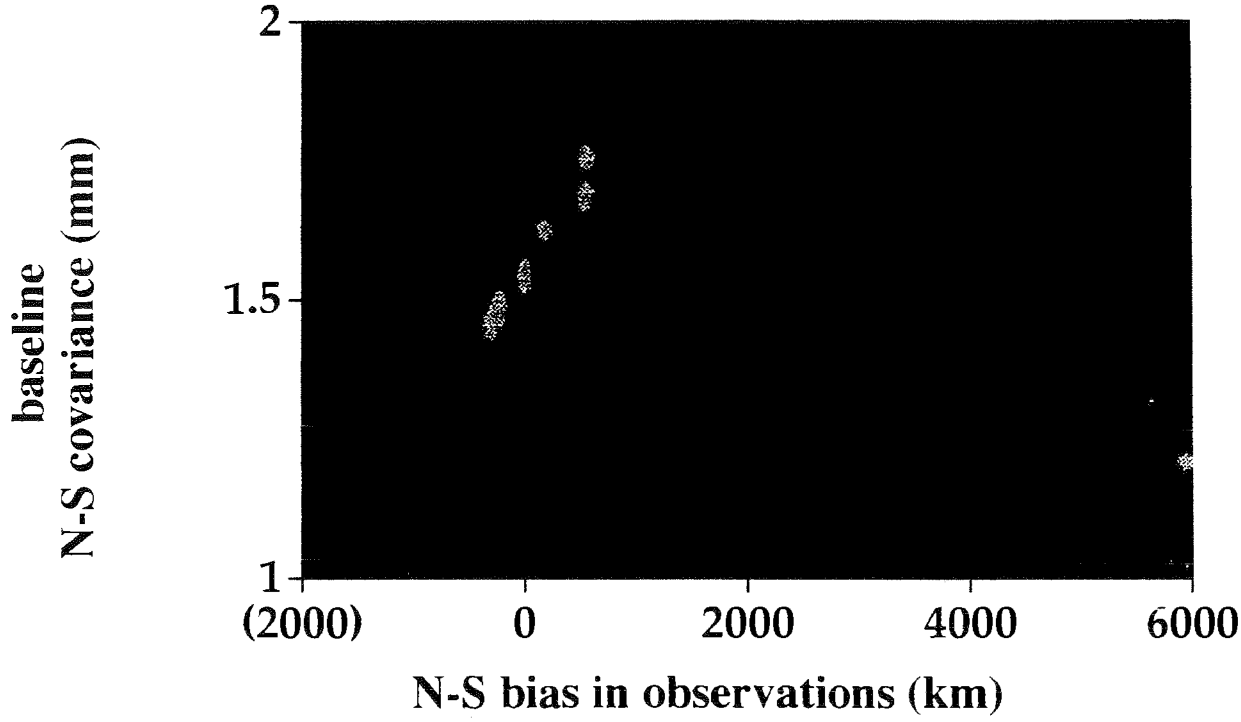
Geometry Bias for SPORT with Multi-Satellite Solution

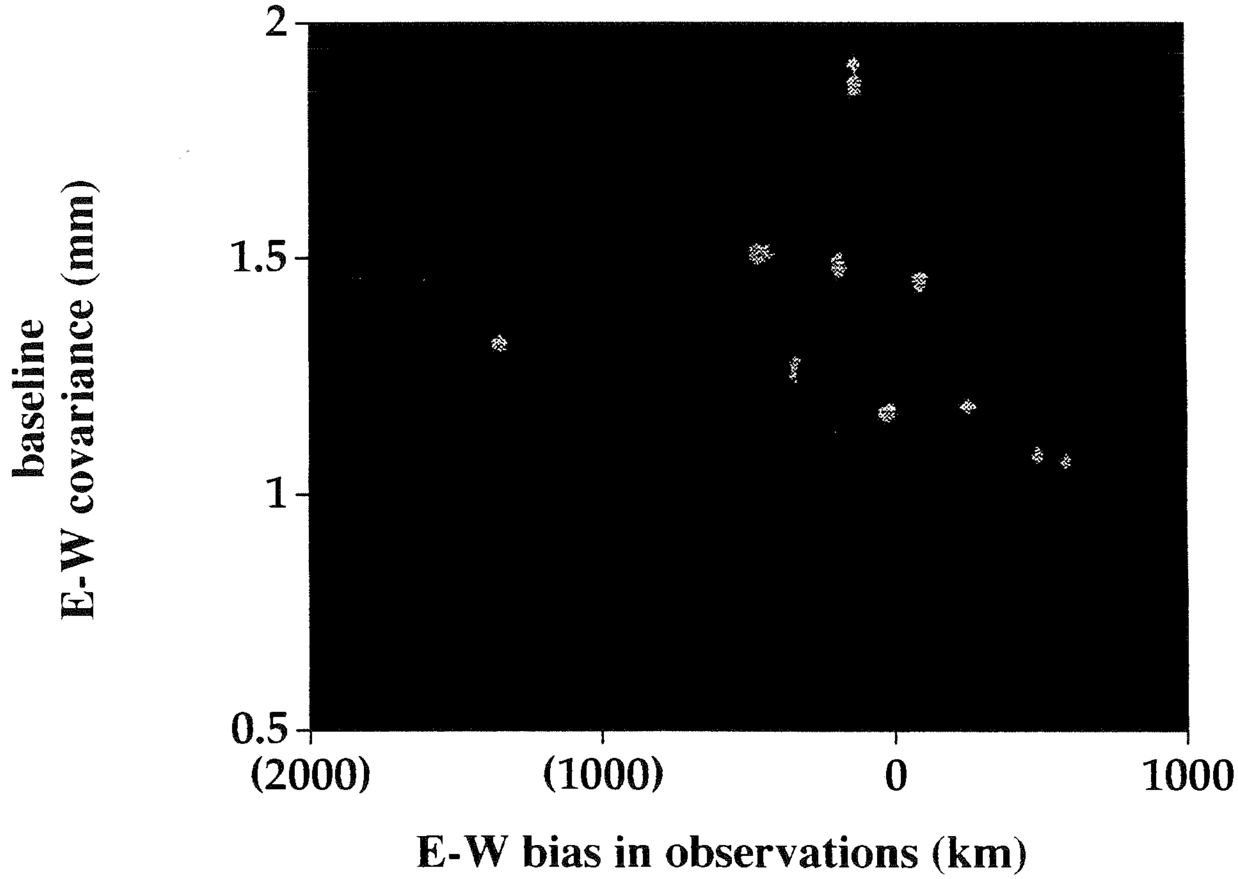




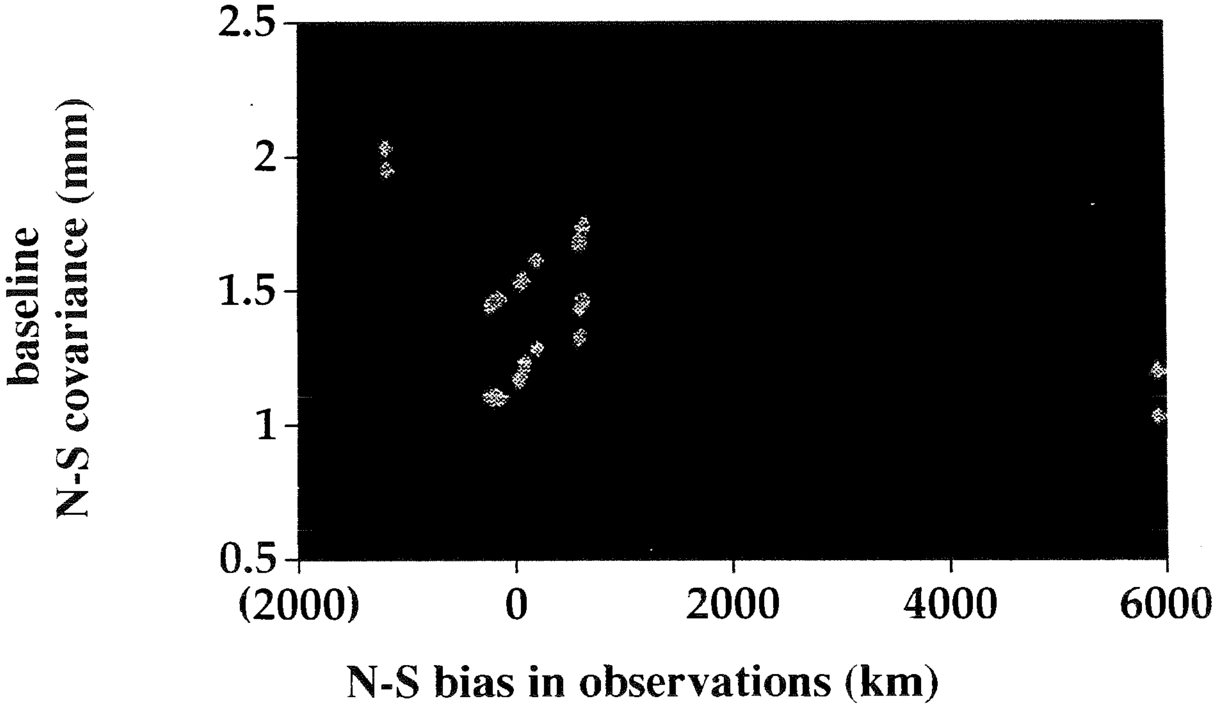
SRD Geometry Bias

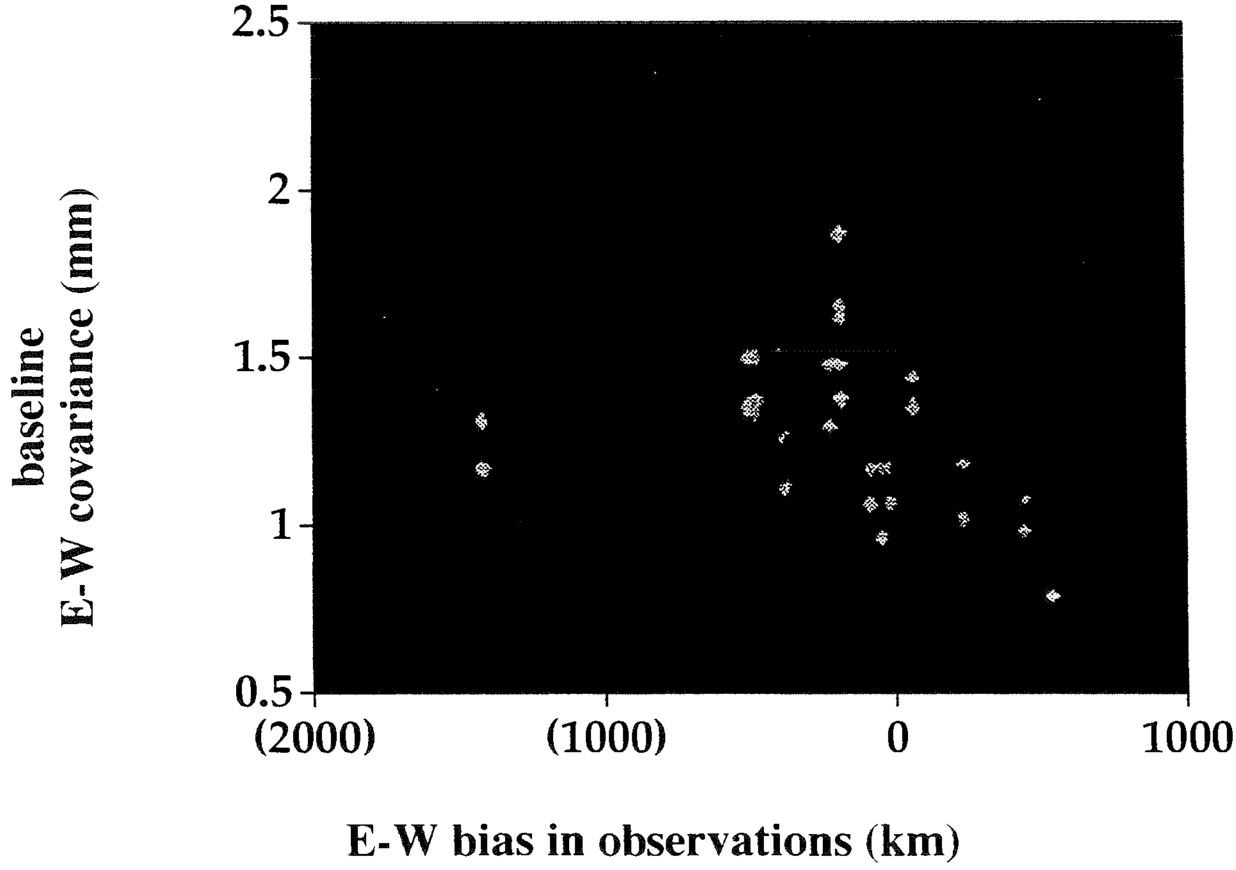
[redacted]



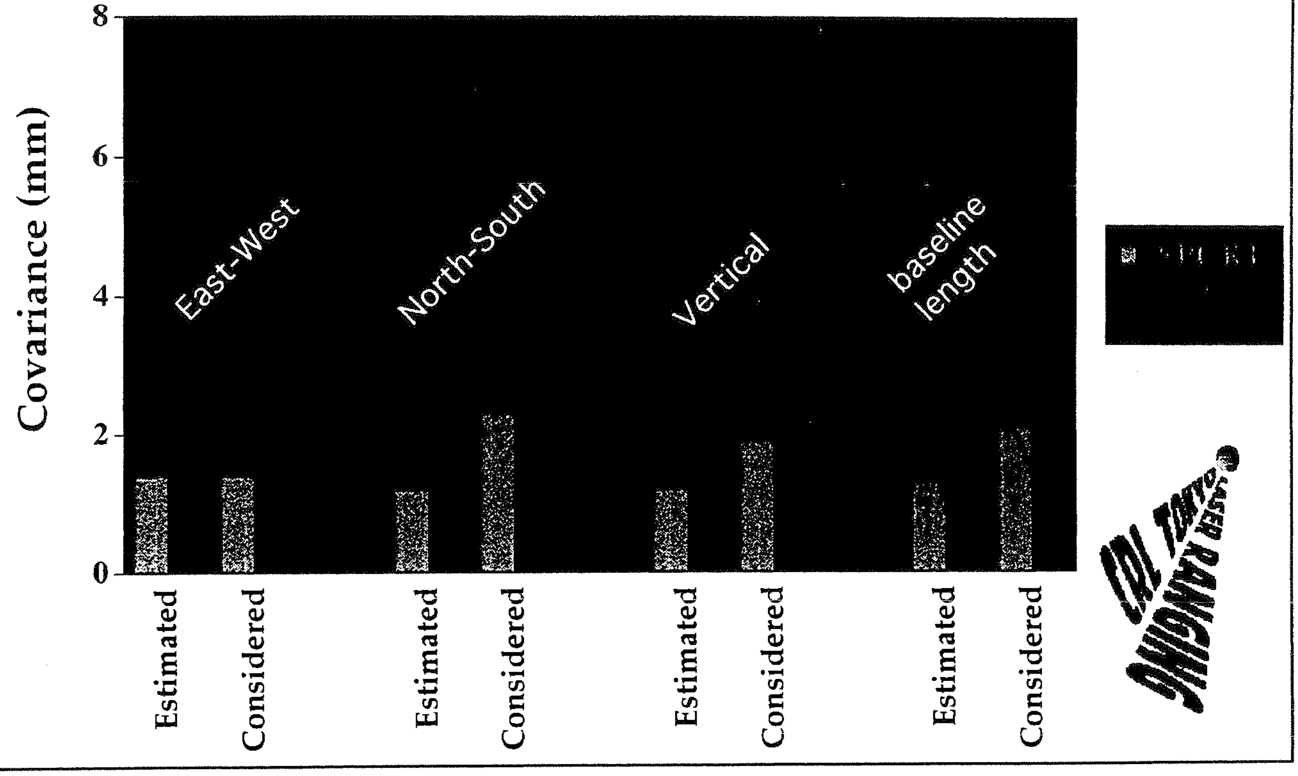


SPORT Geometry Bias

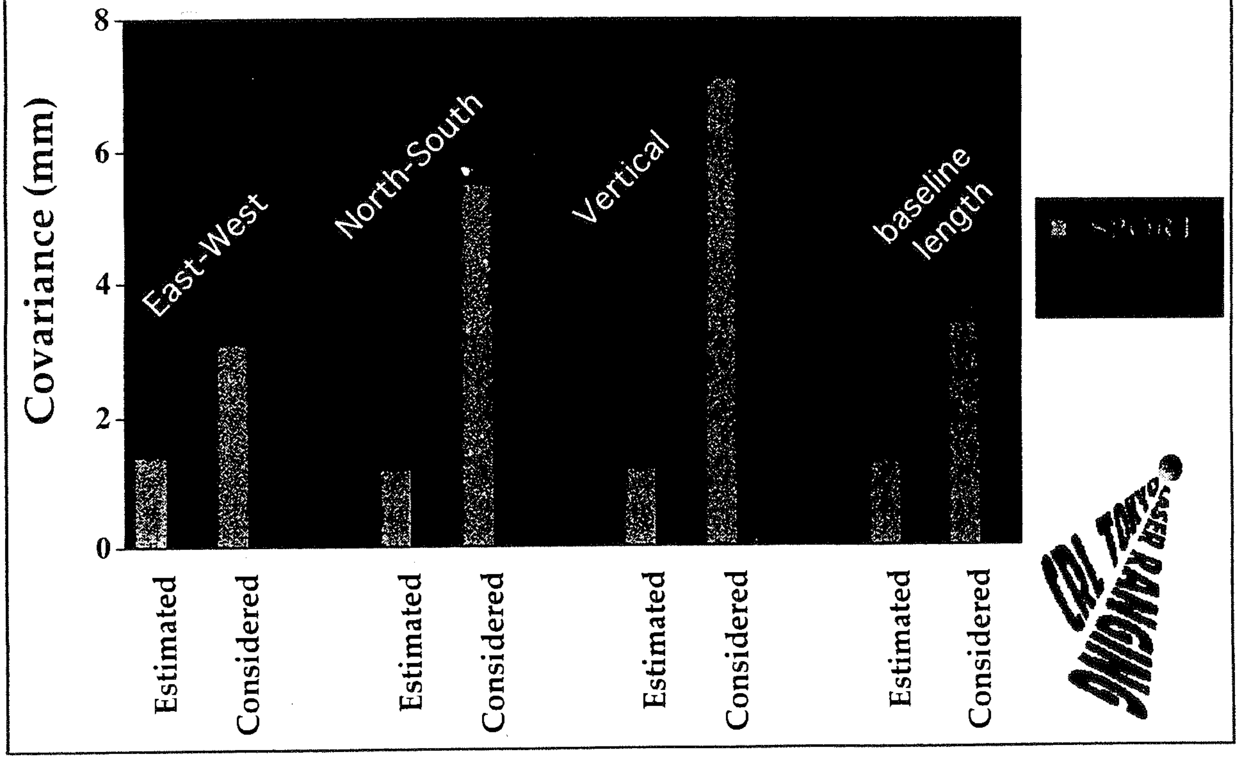




Effect of Position Errors in the "Fixed" Station on the Baseline Covariance



Effect of Range Bias on the Baseline Covariance



SUMMARY

- *because of geometrical biasing of the solution, an optimal observational selection algorithm could be formulated*
- *use of multiple satellite solutions for regional baseline determination eliminates geometrical bias*
- *the covariance of SRD is more sensitive to errors, although other studies have shown SRDestimates to be very accurate*
- *errors easily get absorbed into the vertical & N-S compontents!!*

Ajisai Tracking Campaign "SLR JAPAN '94" Results

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Shanghai Observatory, CHINA

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Science Research Institute for Precision Device Engineering, RUSSIA

1. Introduction

A laser ranging network in eastern Asia region is being established as the number of stations increases and ranging systems improve. This region is expected to enhance its role in the global laser ranging network. The first tracking campaign was performed from January to March 1994, with seven stations participating. This paper provides its analysis results from the viewpoint of geodetic interest.

2. "SLR JAPAN '94" Campaign

Participating stations are shown in Table 1 and Figure 1; 7308 Tokyo, 7838 Simosato, 7323 Makurazaki (mobile), 7840 Shanghai, 7237 Changchun, 7249 Beijing and 1868 Komsomolsk. The purposes of this campaign were:

1. concentrated tracking of Ajisai, launched in 1986 by Japan
2. local application of short-arc analysis methods
3. synchronous ranging test for the two-way time transfer experiment

This paper deals with the first and second points. The last point is described by Kunimori, et al., in this proceedings.

CDP Number	Station Name	# Passes	# Shots
7308	Tokyo	50	98669
7838	Simosato	63	91347
7323	Makurazaki	22	2314
7837	Shanghai	28	10249
7237	Changchun	21	9010
7249	Beijing	3	189
1868	Komsomolsk	25	8179

Table 1. Participants in the SLR JAPAN '94 campaign.

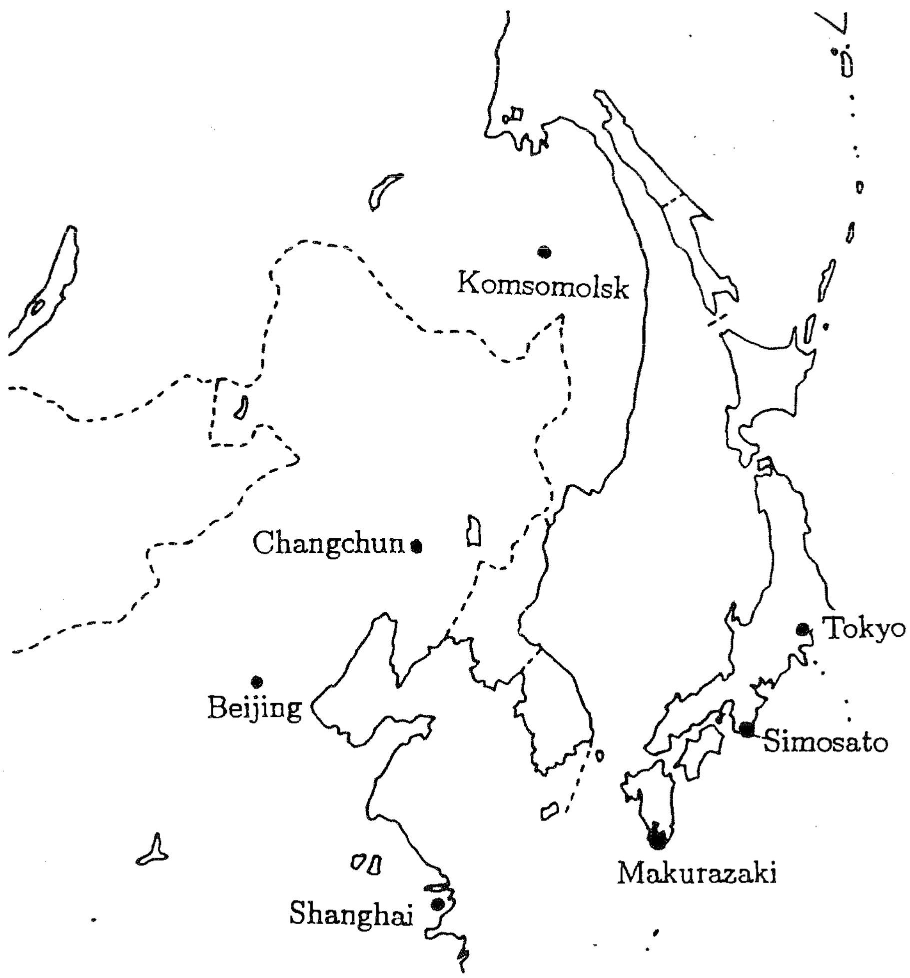

Figure 1. Laser ranging network in eastern Asia.

3. Data Analysis and Results

Two short-arc methods were applied to the data processing, using "CONCERTO," the orbit analysis software at CRL Tokyo (Otsubo, et al., 1994):

1. Single-pass analysis (reference: Sinclair and Appleby, 1993)
2. Simultaneous range differences (SRD) analysis (reference: Pavlis, 1985)

In the first method, satellite motion is determined by the estimation of along-track and radial components from the initial state vector determined by global and long-arc analysis. It requires the laser stations to observe the common satellite pass. Because of the lack of data on common passes, the station coordinates of Makurazaki and Beijing could not be determined in this study.

The second method uses the range difference for observation value. Since the measurement epoch is not generally synchronized, an interpolation process is needed to generate the "simultaneous" range difference. It can not determine the satellite's orbit very well. Data availability is limited, and the range should be measured around a certain epoch. Because Ajisai is a low altitude satellite, the common view is small on Earth. As a result, the estimation could be performed only between Tokyo and Simosato stations in this study.

The analysis results are shown in Table 2. Simosato's position is fixed and the three-dimensional position of other stations is free. Among the solutions by single-pass method, Tokyo's position was

Station		Coordinates	Internal Error	Deviation from ITRF 9	Error in ITRF 92	(Analysis)
Tokyo (7308)	*x*	-3942020.074	0.007	0.085	0.116	(Single-pass)
	y	3368097.479	0.007	-0.067	0.112	
	z	3702191.094	0.007	0.044	0.138	
Tokyo (7308)	*x*	-3942020.066	0.015	0.093	0.116	(SRD)
	y	3368097.464	0.017	-0.082	0.112	
	z	3702191.093	0.005	0.043	0.138	
Shanghai (7837)	*x*	-2831087.946	0.025	-0.004	0.011	(Single-pass)
	y	4676203.317	0.024	-0.021	0.011	
	z	3275172.789	0.026	0.018	0.012	
Changchun (7237)	*x*	-2674386.952	0.031	-0.048	0.084	(Single-pass)
	y	3757189.569	0.026	0.067	0.068	
	z	4391508.492	0.024	-0.150	0.053	
Komsomolsk (1868)	*x*	-2948543.462	0.850			(Single-pass)
	y	2774313.435	0.496	Not listed in ITRF 92		
	z	4912307.097	1.026			

Simosato fixed

UNIT: METERS

Table 2. "SLR JAPAN '94" campaign: geodetic results.

determined most precisely with the internal error of sub-centimeter. The deviation from ITRF '92 is considered to come from errors in ITRF '92 itself, and Changchun's deviation can be explained likewise. Shanghai, whose error in ITRF is relatively small, was found to have coinciding results within about 3 cm. Determination of Komsomolsk's position was hard because of the shortage of data and its ranging precision. The SRD result for Tokyo agrees with its single-pass result within 2 cm in spite of the completely different analysis algorithms. Thus, the determination of station co-ordinates is possible at the centimeters level using only Ajisai, which has an orbit altitude as low as 1,500 km.

4. Future Plans

This paper is the first report on the laser network in eastern Asia. In the future, we aim to increase our cooperation by:

1. Annual Etalon ranging campaign in this region.
2. Support to positioning of mobile station (ex. JHD's HTLRS).

The short-arc analysis methods will also be applied to other satellites, more stable results are expected by the processing of high altitude satellites such as Lageos and Etalon.

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- ☐ A. T. Sinclair and G. M. Appleby: "Short-Arc Method for Determination of Station Coordinates and Baselines Applied to the Mediterranean Area," *Space Geodesy to Geodynamics: Crustal Dynamics Geodynamics 23*, pp. 389-396, 1993.
- ☐ E. C. Pavlis: "On the Geodetic Applications of Simultaneous Range Differences to LAGEOS," *Journal of Geophysical Research*, Vol. 90, No. B11, pp. 9431-9438, 1985.
- ☐ H. Kunimori, et al.: "Timing Control Precision for Synchronous Laser Ranging to Ajisai at Station of CRL and JHD," *this proceedings*, 1994.

Chinese SLR Network Upgrades and Future Project

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Abstract

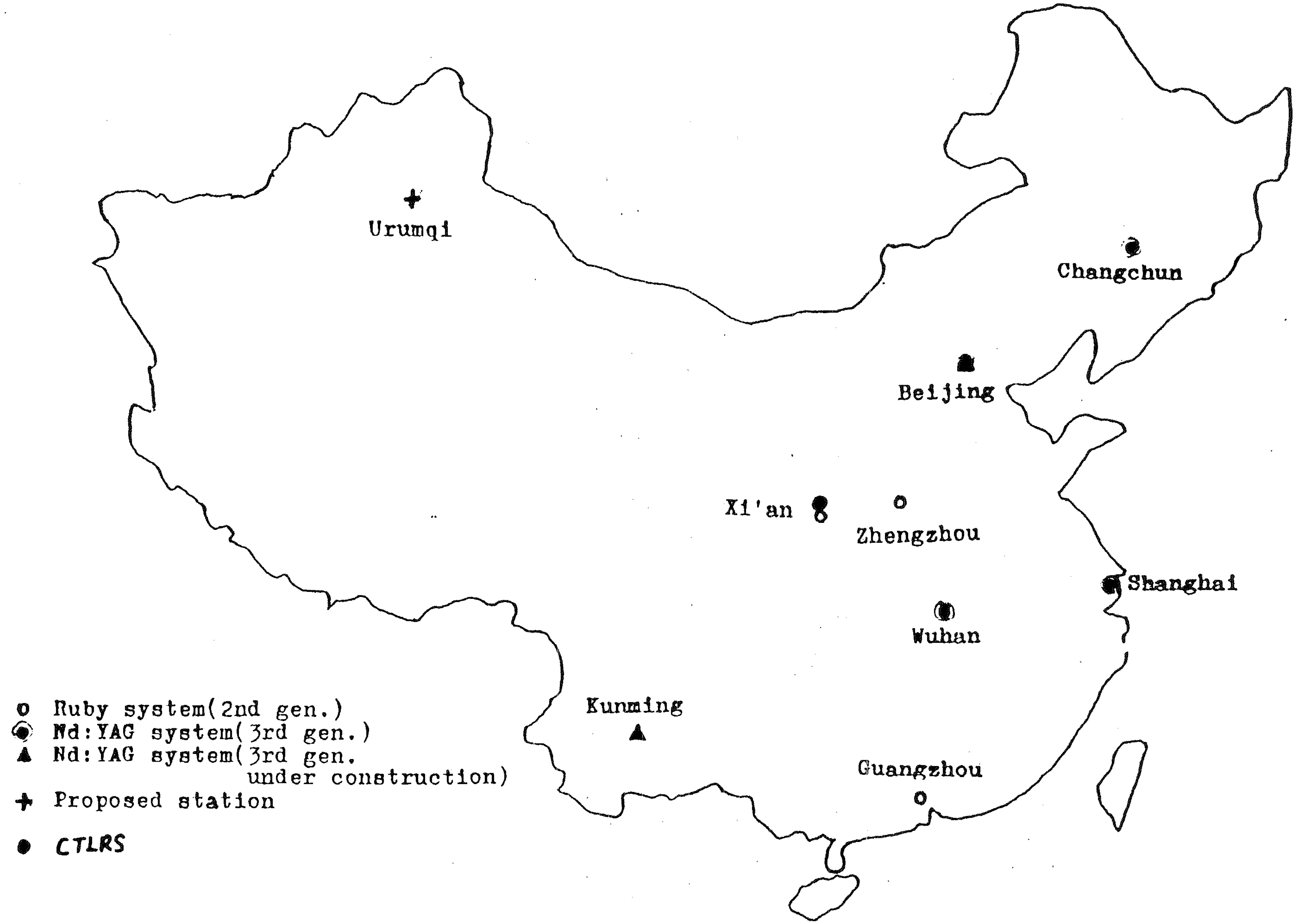
This paper describes the recent performances and the summary of the observation of the Chinese SLR stations. The same PC real time control system and the software for the prediction and data preprocessing are adopted in all stations. The future plans for improving the network is presented.

Characteristics of the Chinese SLR Stations
(November 1994)

City	Shanghai	Wuhan	Changchun	Beijing	Kunming	CTLRS
ID	7837	7236	7234	7249	*	**
Aperture of Receiving Telescope	60 cm	60 cm	60 cm	60 cm	120 cm	35 cm
Aperture of Transmitter	15 cm	10 cm	15 cm	16 cm	120 cm	35 cm
Mount and Pointing Accuracy	Alt-Az 5 arcsec	Alt-Az 10 arcsec	Alt-Az 5 arcsec	Alt-Az 5 arcsec	Alt-Az 2 arcsec	Alt-Az 10 arcsec
Pulse Energy (532 nm)	50-100 mJ	50-100 mJ	100 mJ	100 mJ	150 mJ	30 mJ
Pulse Width	100 ps	200 ps	200 ps	200 ps	200 ps	100 ps
Repetition Rate	2-4 Hz	2-4 Hz	2-4 Hz	2-4 Hz	2-4 Hz	1-5 Hz
Type of Receiver	SPAD	MCP-PMT	PMT, (MCP-PMT in test)	PMT		MCP-PMT
Time Interval Unit	HP 5370B	HP 5370B	HP 5370B	HP 5370B	Event Timer	SR 620
Ranging Precision	2-3 cm	2-3 cm	5 cm	5 cm		3 cm
Routine Operation	Since 1983	Since 1985	Since 1992	Since 1994	1996	1995

Organization:

7837 Shanghai Obs. Chinese Academy of Sciences
7236 Institute of Seismology, National Bureau of Seismology, in collaboration with the Institute of Geogesy and Geophysics, CAS
7234 Changchun Satellite Observatory, CAS
7249 Academy of Surveying and Mapping, National Bureau of Surveying and Mapping
* Yunnan Obs. CAS
** Xian Institute of Surveying and Mapping



Chinese SLR Network

Some Features of Chinese SLR Network

- Same PC computer control systems, including interfaces and real time control function.
- Same software for prediction and data preprocessing
- Same type of GPS receivers for time synchronization
- Data Center: Shanghai Observatory
- Analysis Centers: Shanghai Observatory and the Institute of Geodesy and Geophysics, Chine Academy of Sciences.

Status of Beijing SLR Station

- The whole SLR system, except PDP 11/44 computer and PMT(RCA 8850), was designed and manufactured by the North China Research Institute of Electro - Optics, and was installed and tested at the station in December 1991. A few returns from Ajisai was received, but system was very unstable.

- In May 1992, the PDP-11 computer system and control software was replaced with a PC computer control system, the same as the other chinese SLR stations.

- 93 passes from several satellites (most from Ajisai) were detected from December 1992 to December 1993.

- New timing system including HP 5370B counter and discriminator (TC 454) was adopted in early Spring 1994.

- New encoder electronics for both azimuth and elevation were installed and tested in Spring 1994.

- 250 passes have been recorded from Jan. to Oct. 1994.

- System routine operation from April 1994.

Summary of the Observations of Chinese SLR Network in 1994

	SHANGHAI pass/obs.	WUHAN pass/obs.	CHANGCHUN pass/obs.	BEIJING pass/obs.	TOTAL PASS/OBS.
LAGEOS-1	43/15116	31/4867	34/3634	39/14250	147/37867
LAGEOS-2	52/22177	21/2816	64/13884	24/11870	161/50747
TOPEX	80/29954	33/15841	170/42062	42/7160	325/95017
ERS-1	32/3053	20/1895	91/7499	3/360	146/12807
AJISAI	98/39541	48/18443	171/48526	65/26930	382/133440
STARLETTE	30/4840	14/3072	116/21027	14/1990	174/30929
STELLA	10/1203	11/889	94/9212	8/772	123/12076
ETALON-1	2/454		18/676	2/1270	22/2400
ETALON-2	5/1151		10/336	1/130	16/1617
METEOR-3	30/5595	23/4110	89/9039	27/5930	169/24674
MSTI				1/132	1/132
TOTAL	382/123084	201/51933	857/155895	226/70794	1666/401706

* Up to Oct. 31, 1994

Future Plans of the CSN

- Improvement of the data communication capability

- Upgrade of the automation
  - multi–satellite interleave tracking
  - PC 486 for on–site data pre–processing

- Upgrade of the ranging precision
  - Changchun – ITT 4129f MCP–PMT in testing
  - Beijing – maybe APD

- Six stations operation by the end of 1995
  - Kunming – laser will be installed by the Spring of 1995. system test in the second half of 1995.
  - CTLRS – assembly and test in 1995
  - Urumqi station – still waiting for finance support (Urumqi VLBI station already operational)

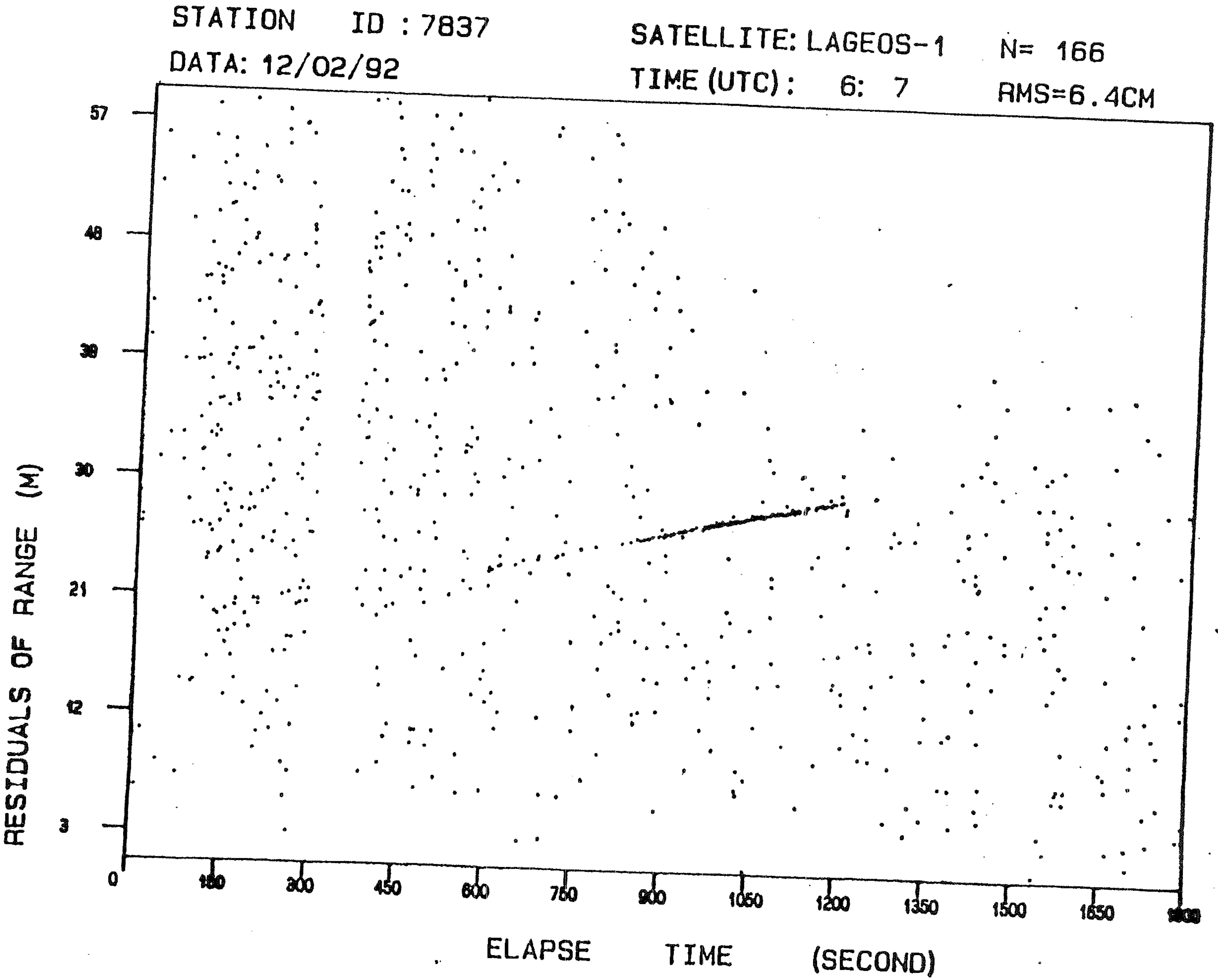
- Improvement of the system reliability
  - laser and power supply for all stations
  - servo electronics for mounts (Shanghai, Changchun)

- Daylight tracking capability

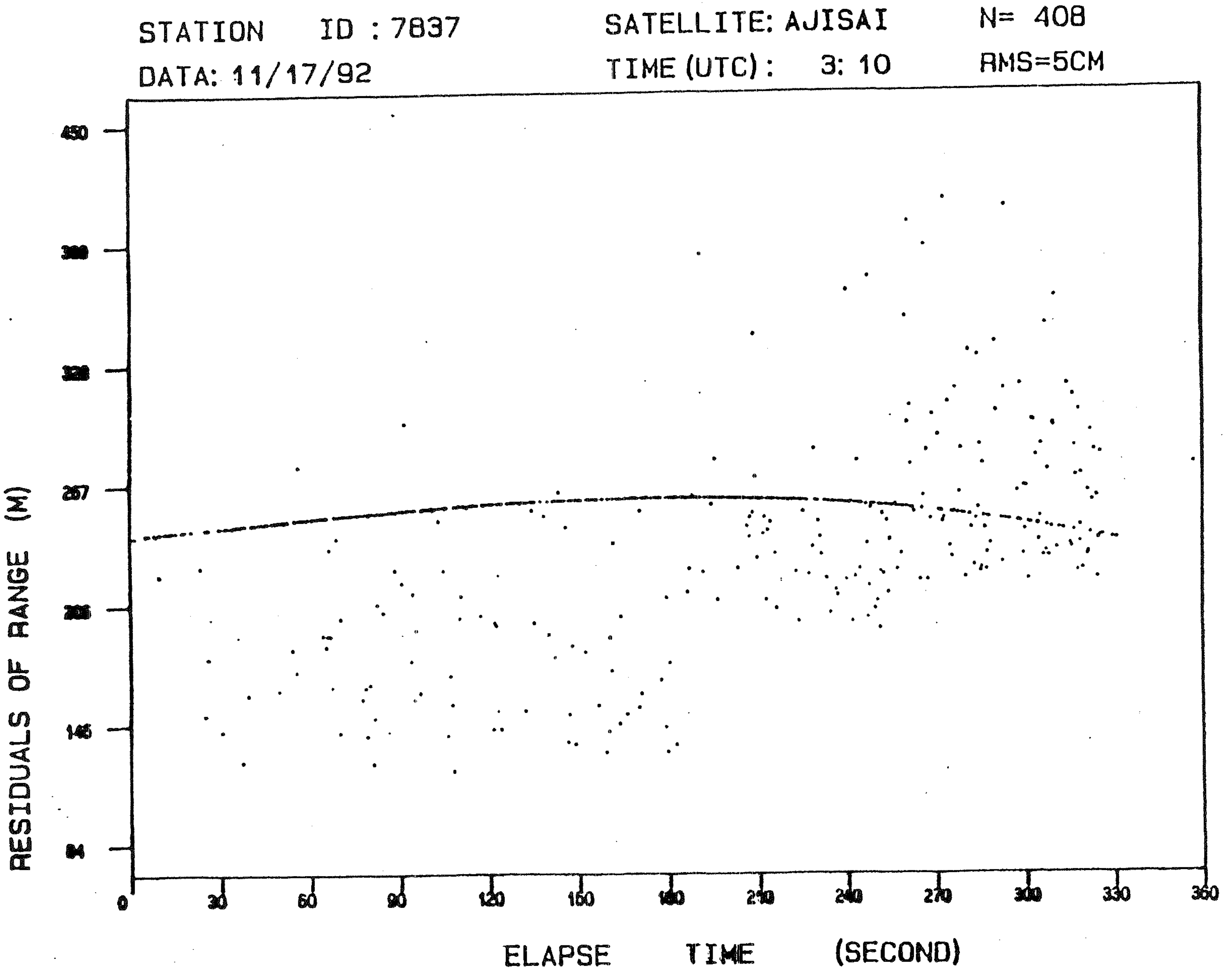
- New observation houses for Wuhan (1995) and Shanghai (1996)

- Data yield ~~product~~: expecting passes in 1995
  - Changchun > 1000
  - Beijing 600 – 800
  - Shanghai 600
  - Wuhan 400

- Others. Circular scan streak tube + Real time readout at Shanghai Obs. (in testing) ([illegible] circular Reticon Array from EG&G)



Daylight Tracking to Lageos-1 (local time 14^h07^m)



Daylight Tracking to Ajisai (Local Time 11^h10^m)

SHANGHAI STATION

CHANGCHUN ARTIFITIAL SATELLITE OBSERVATORY CHINESE ACADEMY OF SCIENCES

The ChangChun Artificial Satellite Observatory is located at JingYuetan Hills, on the southeastern surburb of ChangChun city of JiLin province, at 43° 47′ N and 125° 26′ E. It is equipped with the SLR system(60cm), JSZ–4 dual–frequency Doppler receiver, GDJ printing tracking theodolite and Rubidium clock.

The station was founded in 1957, and expanded in the ensuing years, especially in the past ten years, the station has come into a new time of development. In 1982, the 3rd generation satellite laser ranging system was set up. It has been put into use in the international joint observation project since that time. Now, it become a comprehensive station and important one of the SLR network stations(43) in the world. According to the amount of data,it is the 10th seat in the network of the world last year. We can observe all satellites with prisms and acquire more than a thounsand passes data every year.

There are a few experts have been invited to our station and visited the SLR system,such as Ph.D.John J.Degnan(USA), DR.Taizoh Yohino (Japan), S.K.Tatevian(Russia), etc. They all think the system is very good and express to be glad to strengthen the cooperation in the future. Now, we keep touch with the NASA and ESA on work. We welcome every expert and professer to visit our station with enthusiasm.

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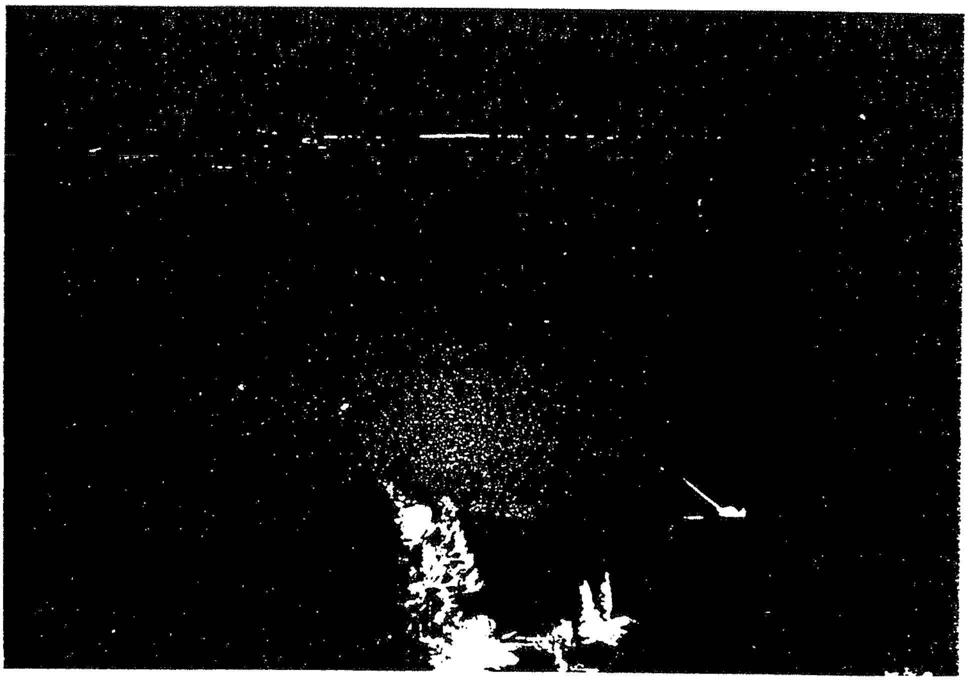
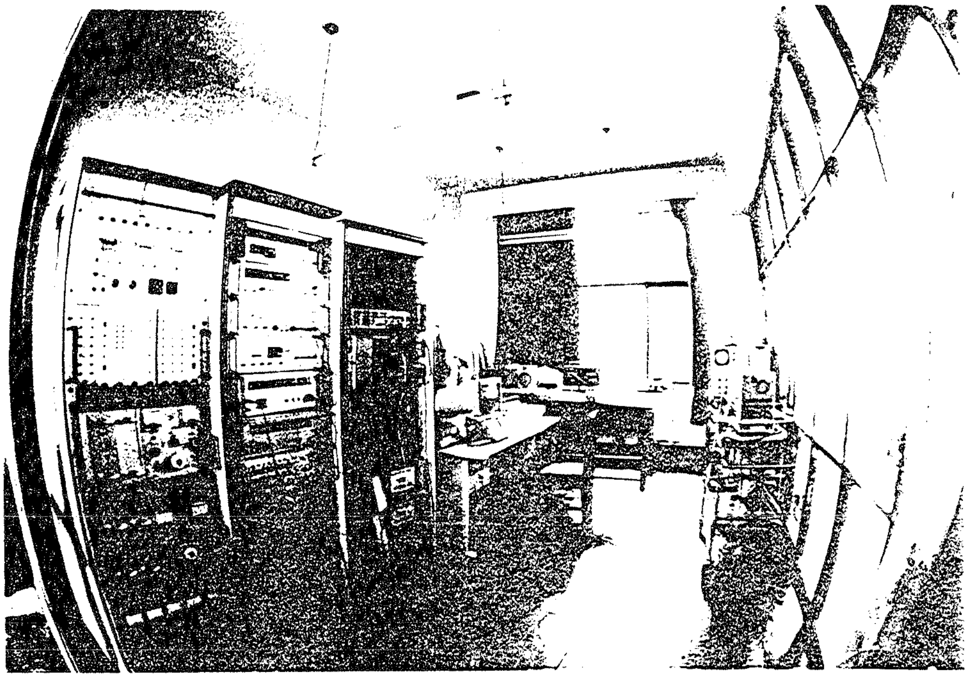
President: DR.Chui,Douxin

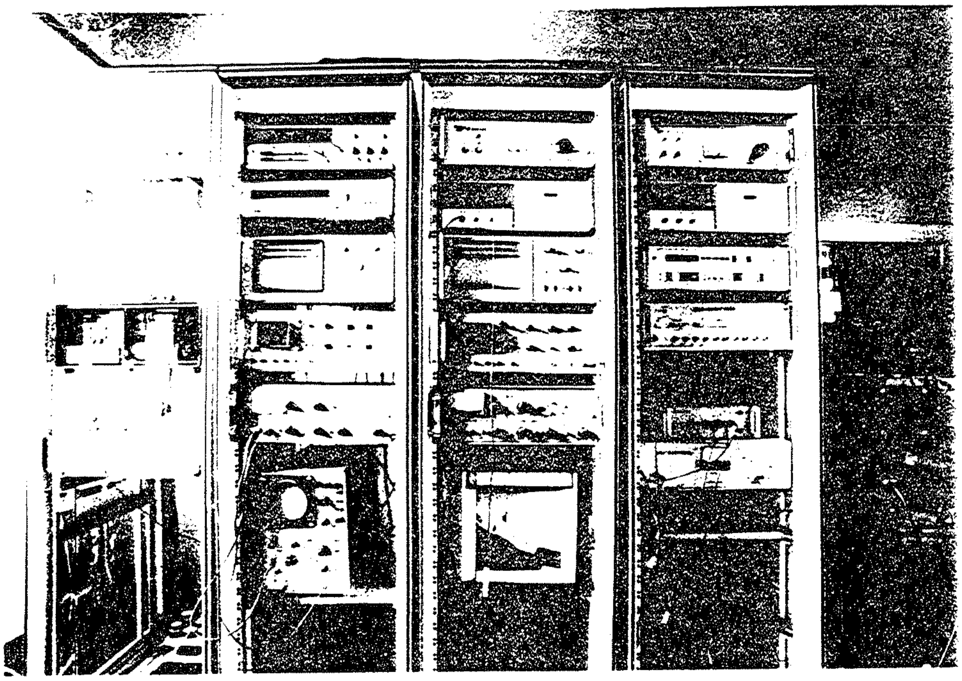
A Bird's-eye View of ChangChun
Satellite Observing Station



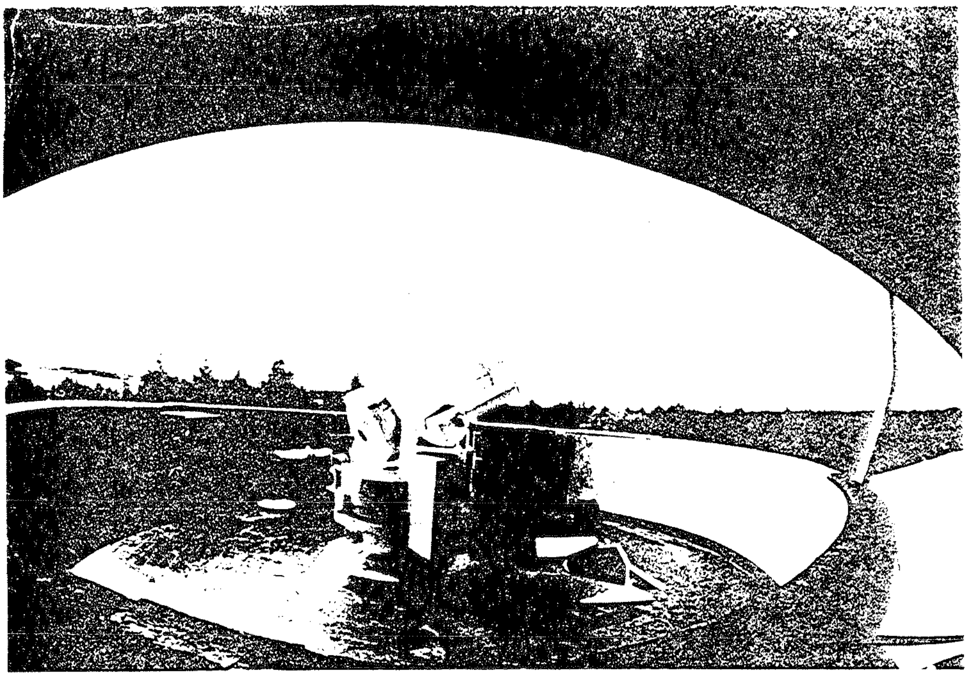
The working SLR system of
ChangChun Station



The control room of the 60cm SLR



The time service system with Rubidium clock

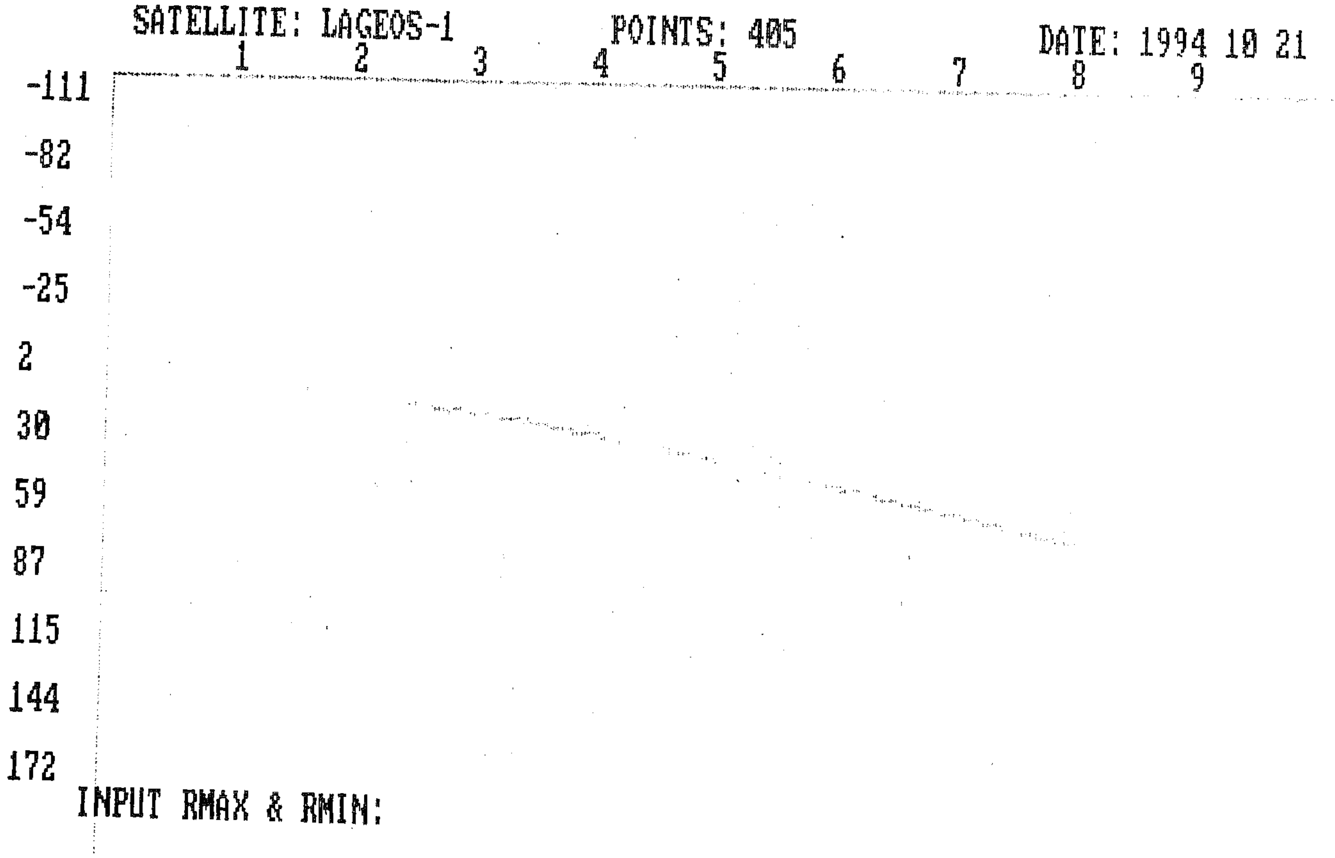


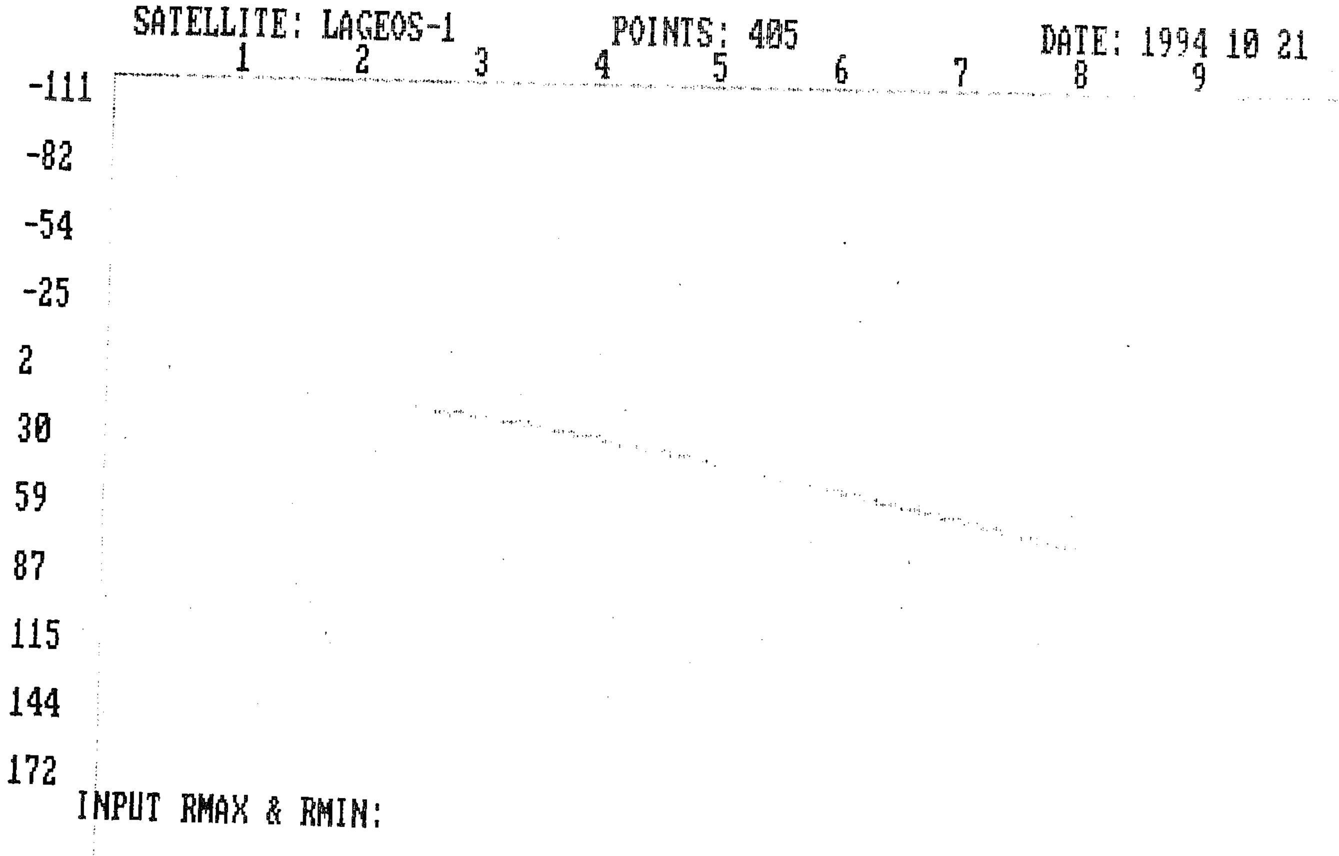
The 60cm mount

The working mode-locked Nd:YAG Laser

Specification of the Satellite Laser Ranging system at ChangChun

Subsystem	Specification
Mount	
configuration	elevation—azimuth
Tracking Velocity	
Azimuth	0.001° —12° per second
Elevation	0.001° —10° per second
photo-electric encode	resolution 1,25 arcsec
Drive	DC torque motors
orthogonulity	±2 arcsec
Laser	
type	Nd:YAG
Wave length	0.5320 um
Energy	50mJ
Pulse-width	220ps
repetition	1,2,4,pps
Receiving telescope	
Type	CaSSegrain
Diameter	60cm
Field-view	7′
Filter	2.7nm
Transmitting telescope	
Type	Calilean
Diameter	10cm
Beam divergence	0.34′—3.4′
Recerving electronics	
PMT	GDB49A
Amplifier	HP8447E
Discriminator	Tc454(eoh)
UTC clock	
Type	Rubidium P01
Stability	1×10E-11
Accuracy	2us
Time interval counter	
Type	5370B
Resolution	20ps
Control computer	Ast286


SATELLITE: LAGEOS-1
POINTS: 405
DATE: 1994 10 21
1 2 3 4 5 6 7 8 9
-111
-82
-54
-25
2
30
59
87
115
144
172
INPUT RMAX & RMIN: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POINTS: 405
DATE: 1994 10 21
1 2 3 4 5 6 7 8 9
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-82
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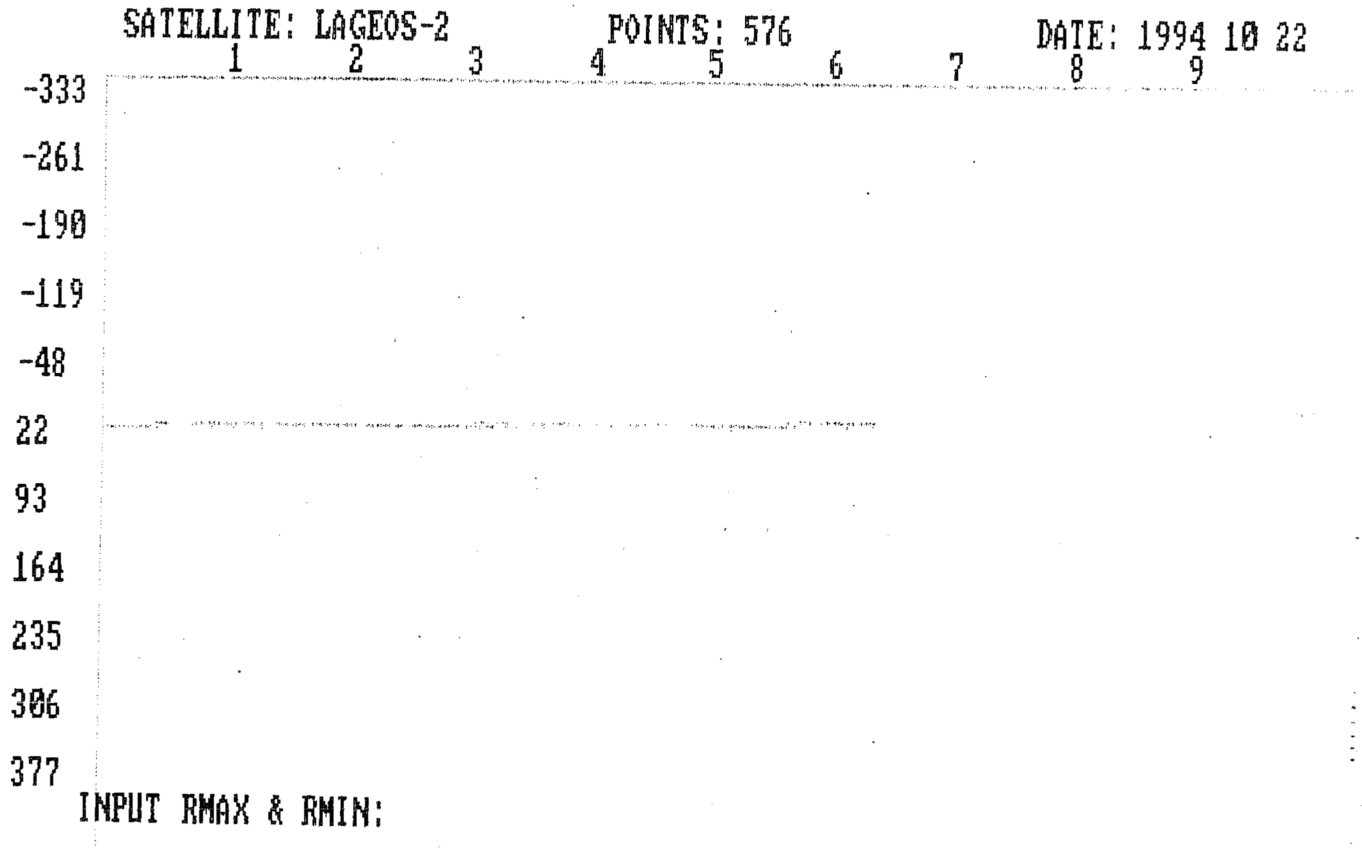
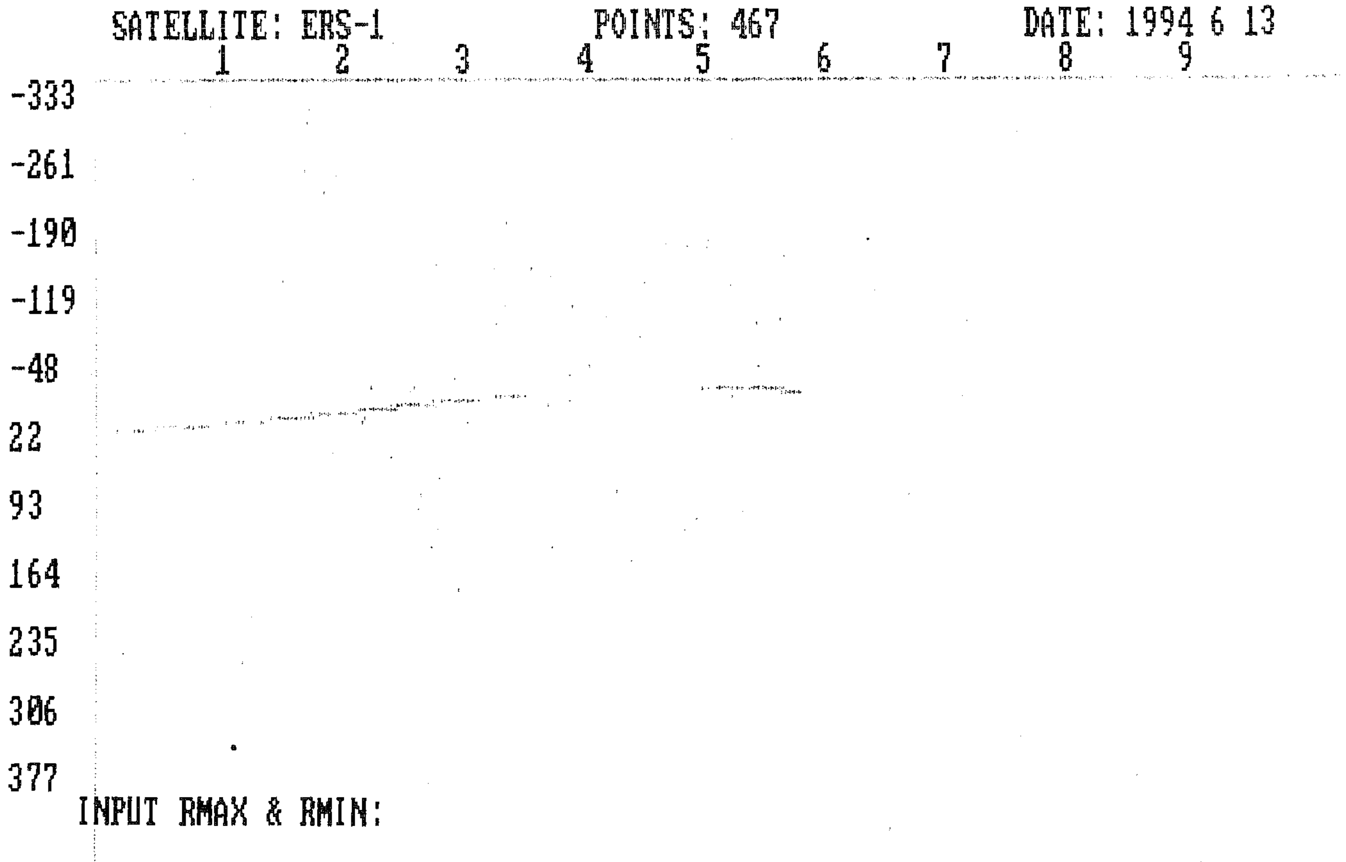
INPUT RMAX & RMIN:


SATELLITE: LAGEOS-2
POINTS: 576
DATE: 1994 10 22
1 2 3 4 5 6 7 8 9
-333
-261
-190
-119
-48
22
93
164
235
306
377
INPUT RMAX & RMIN:


SATELLITE: ERS-1
POINTS: 467
DATE: 1994 6 13
1 2 3 4 5 6 7 8 9
-333
-261
-190
-119
-48
22
93
164
235
306
377
INPUT RMAX & RMIN:

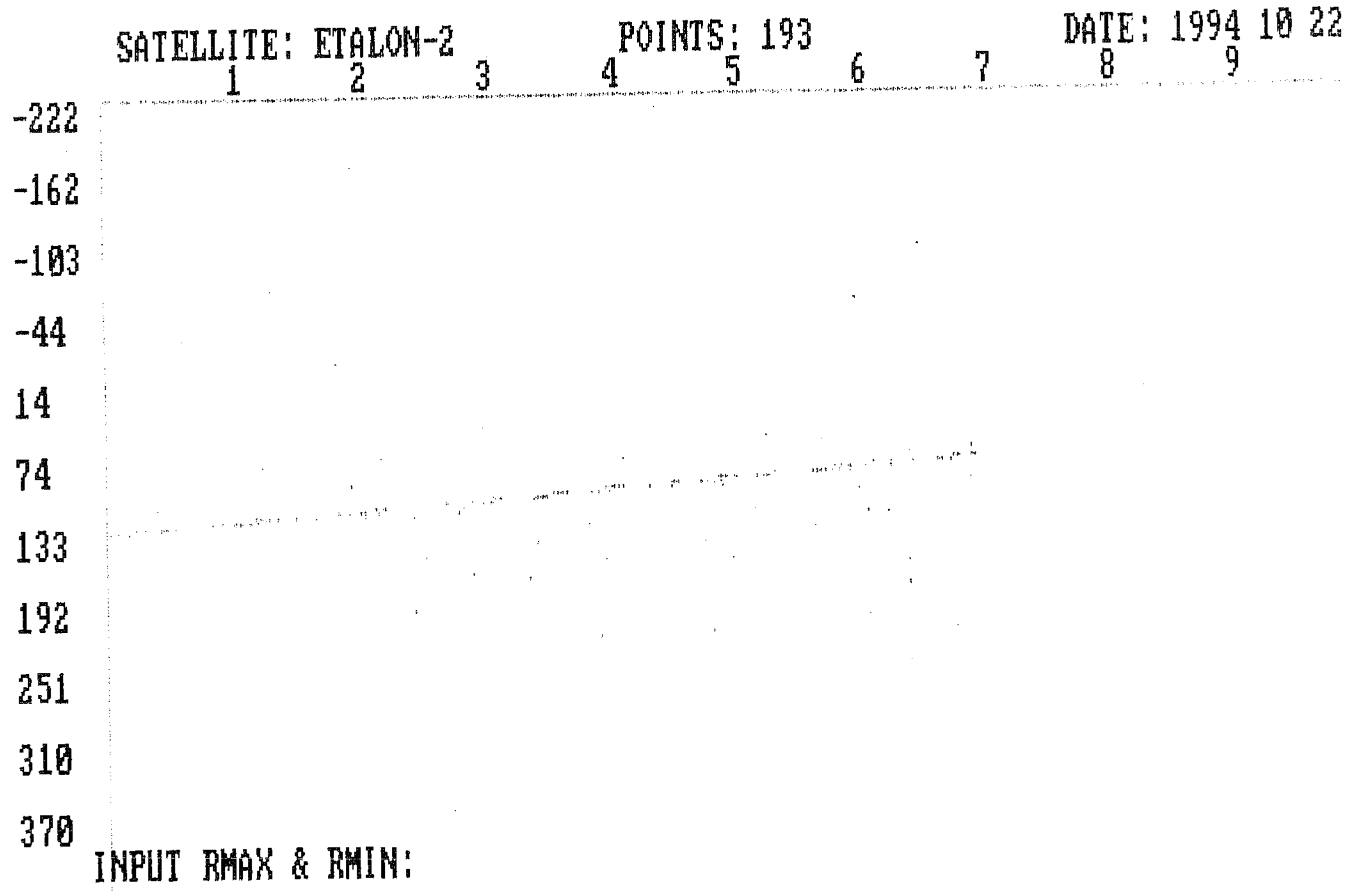


Table 2: Statistics Data of ChangChun SLR Station .China

(1991------1994)

(PASSES POINTS)

YEAR	ETALON_1	ETALON_2	ERS_1	LAGEOS_1	LAGEOS_2	TOPEX	STELLA	METEOR_3	AJJSAI	STARLETTE	TOTAL
1991				55 3580							55 3580
1992	8 1414	2 378	27 1325	131 17706	2 113	34 11558			131 37738	62 8943	339 79175
1993	30 1171	27 2009	83 7981	138 28786	90 39969	160 40445	9 1029	0 0	164 41181	97 12909	798 175779
1994	18 676	10 336	91 7499	34 3634	64 13884	170 42062	94 9212	89 9039	171 48526	116 21027	855 155895
TOTAL	56 3561	39 2723	201 16805	358 53706	156 53966	364 94065	103 10241	89 9039	466 127445	275 42879	2047 414429

Table 1: Statistics data in 1994

(passes/points)

Mon	ETALON-1	ETALON-2	STARLETTE	ERS-1	LAGEOS-1	TOPEX	AJISAI	STELLA	METEOR-3	LAGEOS-2	Total
Feb	2/ 65	1/ 25	0/ 0	4/ 159	4/ 269	10/ 3082	19/ 5324	7/ 632	5/ 286	3/ 626	55/ 10468
Mar	10/ 336	5/ 151	38/ 3982	16/ 1086	5/ 116	62/15814	48/16511	20/ 1340	24/ 2158	22/ 5971	250/ 47465
Apr	3/ 41	1/ 12	13/ 1500	11/ 474	0/ 0	27/ 6965	2/ 260	8/ 526	9/ 769	12/ 2514	86/ 13061
May	0/ 0	0/ 0	5/ 876	10/ 868	0/ 0	3/ 535	28/ 9127	11/ 896	15/ 1134	10/ 1677	82/ 15113
Jun	2/ 221	0/ 0	36/10883	18/ 2186	1/ 86	7/ 4008	24/ 7520	12/ 2395	14/ 2520	10/ 808	124/ 30627
Jul	0/ 0	0/ 0	0/ 0	9/ 849	2/ 94	12/ 1604	3/ 586	8/ 592	0/ 0	0/ 0	43/ 3725
Aug	1/ 13	0/ 0	7/ 688	10/ 904	5/ 1110	32/ 5830	23/ 5143	10/ 1070	3/ 287	0/ 0	81/ 15045
Sep	0/ 0	0/ 0	5/ 339	3/ 150	0/ 0	2/ 152	12/ 1497	8/ 381	2/ 71	0/ 0	32/ 2590
Oct	0/ 0	2/ 137	12/ 2759	10/ 823	16/ 1904	15/ 4072	12/ 2558	10/ 1380	14/ 1651	7/ 2288	98/ 17572
Nov											
Dec											
Tot	18/ 676	9/ 325	116/21027	91/ 7499	33/ 3579	170/42062	171/48526	94/ 9212	87/ 8876	64/ 13884	851/155666

Development of Active Satellite Tracking System for RIS

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1. Concept of Active Satellite Tracking System for RIS

RIS (Retroreflector In-Space) is one of the sensors of ADEOS (Advanced Earth Observing Satellite) which will be launched in February of 1996[1]. RIS is a corner-cube reflector for earth-satellite-earth laser long path absorption measurements of atmospheric trace species using CO_2 lasers [2-3]. This measurement is possible only when a very precise optical tracking of the satellite is achieved. Since ADEOS is a low altitude satellite (~ 800 km), its orbital elements supplied 3 times a week by space agency (NASDA) may not be adequate for precise tracking.

One of the way to achieve good tracking is to determine accurate orbital elements with the aid of SLR network. Another way is to track the image of the satellite during the observation. However, the satellite is not always visible (ADEOS is a sun synchronous sub-recurrent satellite). Therefore, in order to track the satellite at any time, illuminate the satellite by visible laser to detect the image[4].

Table 1. Characteristics of the ADEOS orbit

Category	Sun synchronous sub-recurrent
Local Sun Time	10:30±15
Recurrent Period	41 days
Altitude	797 km
Inclination	98.6 °
Period	101 minutes
Duration of Observation	160 seconds

2. Scheme of Active Tracking

A 1.5m telescope at CRL will be used to track/observe RIS. It is an alt-azimuth telescope made by Contraves (U.S.A.) which is used for many purposes (satellite-ground optical telecommunication; astronomy; satellite tracking; satellite laser ranging). Nd:YAG/SH laser is used to illuminate the satellite. Nd:YAG laser is directed at the satellite by the main telescope and the return signal is received by a 20cm guiding telescope. A CCD camera with a high-speed gated image-intensifier is equipped at the focus and the observed image is digitized by a frame grabber to detect the precise position of the satellite. A 532μm band-pass filter is attached to reduce the background light from sky. The control program of the telescope calculates the tracking error from this position and keep the image at the correct position. The improved orbital elements are obtained, too.

Figure 1 shows the schematic diagram of active tracking system.

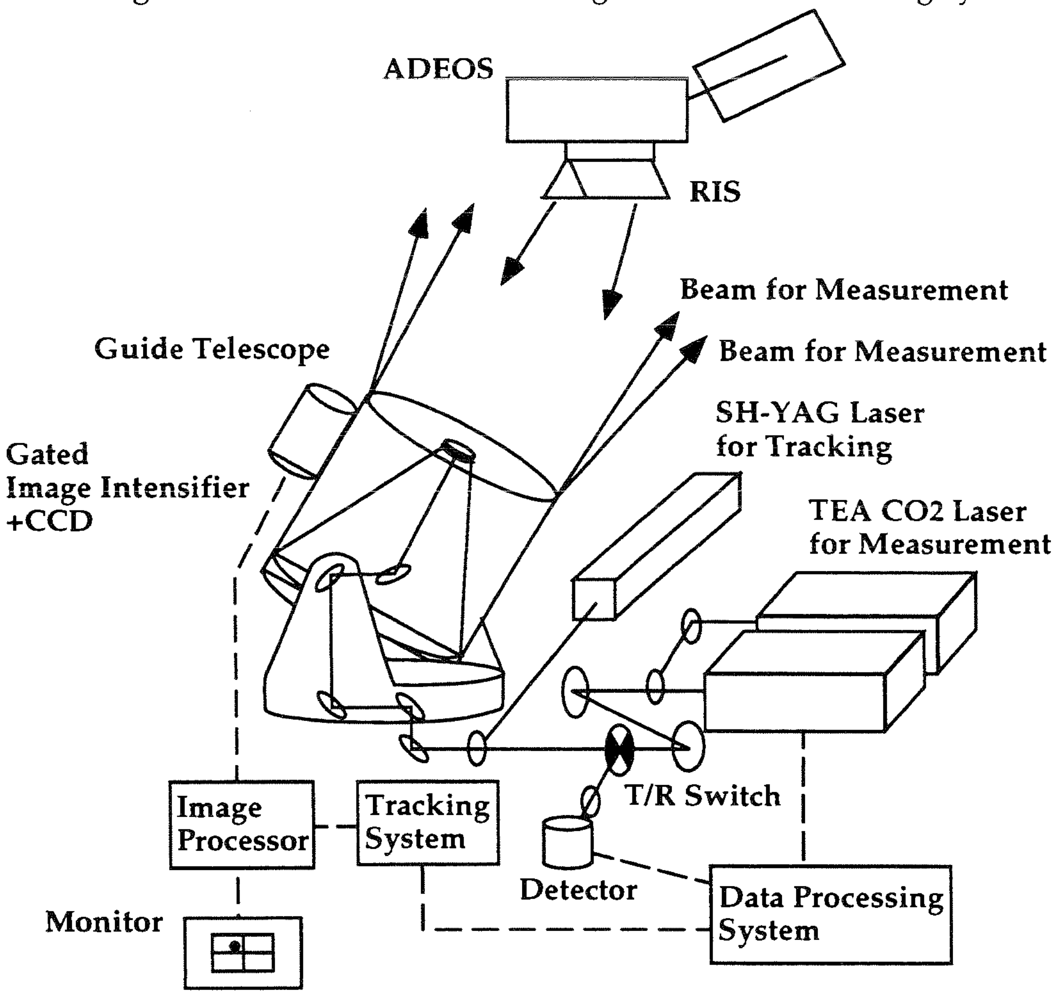

Figure 1. Concept of Active Tracking of RIS

3. CRL 1.5m Multi-Purpose Telescope Facility

The 1.5m telescope at CRL is an alt-azimuth telescope made by Contraves (U.S.A.) in 1988. It is used for many purposes (satellite-ground optical telecommunication; astronomy; satellite tracking; satellite laser ranging).

Table 2 and table 3 summarize the characteristics of the tracking system.

Table 2. Characteristics of the CRL 1.5m Telescope

Location	Koganei, Tokyo, Japan
Longitude & Latitude	E139° 29' 21.29" N35° 42' 36.31"
Altitude	120 m
Primary Mirror	
Aperture / Focal Length	1.5 m / 2.25 m
Material	Zerodur with Aluminum Coating
Secondary Mirror	
Focus	Nasmyth/Cassegrain/Modified Cassegrain/Coude
System F	∞ for Coude / 18 for Other Foci
Coude Pass Diameter	15 cm
Mount and Control	
Structure	Azimuth / Elevation Direct Drive
Encoder Resolution	0.0001°
Tracking Velocity	15° sec^{-1} (Az) / 5° sec^{-1} (El)

Table 3. Specifications of the Measure/Tracking System

Laser for Measurement	CO_2 laser 10 µm / 5µm / 3 µm
Transmitted Beam Divergence	0.1 mrad
Laser for Tracking	Nd:YAG/SH 0.532 µm
Transmitted Beam Divergence	3 mrad
Guiding Telescope	
Mirror Design	Schmidt Cassegrain
Aperture & Focal Length	20 cm / 200 cm
Gated Image-Intensifier	Hamamatsu C4078+C4412
CCD Camera	Hamamatsu C4346
Filter	0.532 µm band-pass filter

4. Preliminary Active Tracking Experiment of Ajisai

Japanese geodetic satellite Ajisai was observed utilizing the laser-ranging system of CRL. A gated II-CCD camera was installed at the Coude focus of the 1.5m telescope and the laser-illuminated image of Ajisai was recorded during daytime. Figure 2 shows the block diagram of the system and figure 3 shows the detected image of Ajisai. In this preliminary results, there exists considerable noise (white specks in the figure). We will install this camera at the focus of the guide telescope and attach a narrow band filter in order to reduce the background noise.

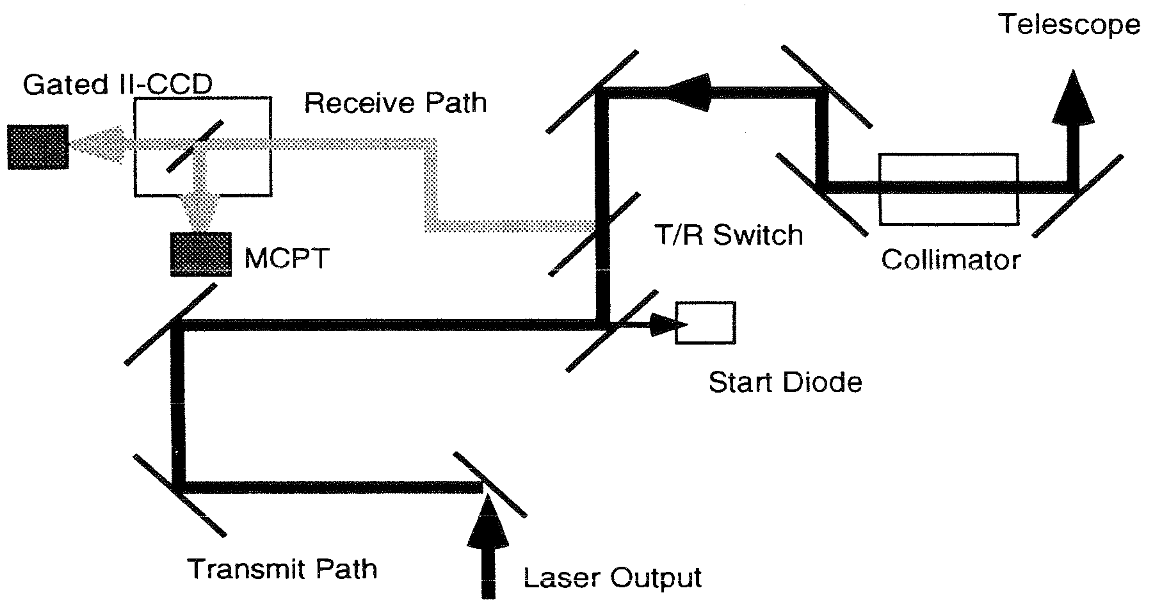

Figure 2. Block Diagram of Preliminary System

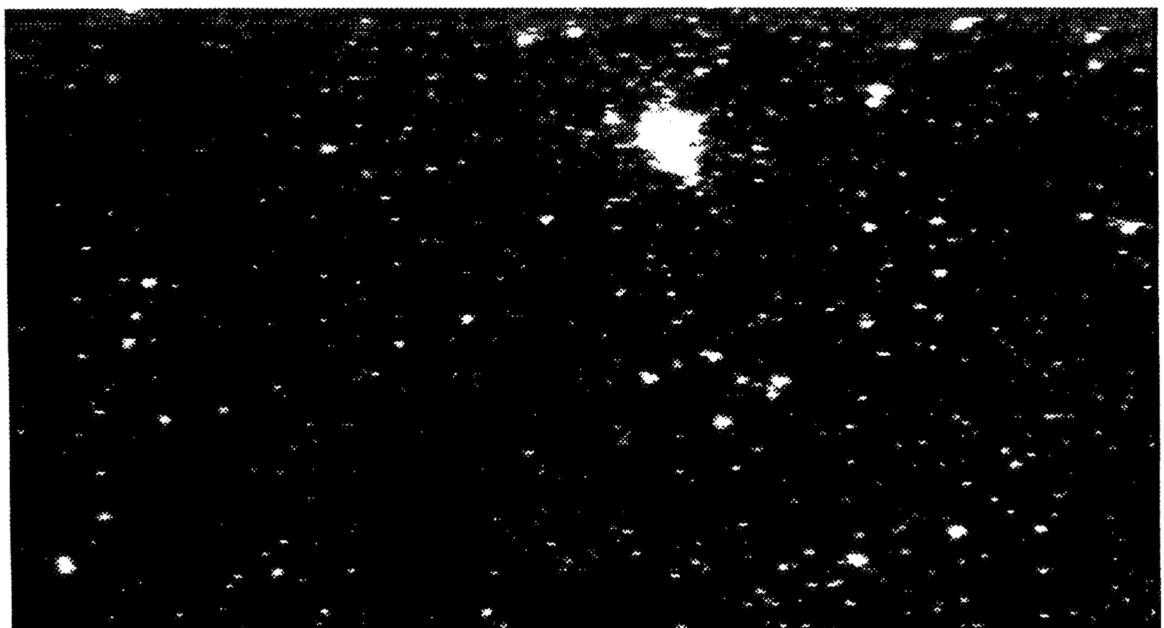

Figure 3. Laser-illuminated image of Ajisai

5. Conclusion

We are developing active tracking system to track RIS precisely so that we can measure atmospheric trace species using CO_2 lasers. RIS will be illuminated by a Nd:YAG laser and the image of the satellite will be detected using a high-speed gated image-intensifier CCD camera. The precise position of the image will be used to track the satellite and to improve the orbital elements of the satellite.

6. References

[1] National Space Development Agency of Japan (NASDA), ADEOS pamphlet (1992).

[2] Sugimoto, N. Minato, A., and Sasano, Y., "Retroreflector in space for the ADEOS satellite", in CLEO '91. Baltimore, (1991) 450.

[3] Sugimoto, N. Minato, A., and Sasano, Y., "Spectroscopic method for earth-satellite-earth laser long-path absorption measurements using retroreflector in space (RIS),", 16th Int. Laser Radar Conference. NASA 3158, (1992) 659.

[4] Sugimoto, N. Minato, A., Sasano, Y., Itabe, T., Hiromoto, N., and Takabe, M. , Proc. COMEAS, IEEE #93 TH 0519-9, (1993) 104.

Symposium on Western Pacific Satellite Laser Ranging Network
WPLS'94 November 7-10, 1994, Canberra, Australia

POSSIBLE GEODYNAMIC TARGETS BY SLR IN THE WESTERN PACIFIC REGION

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Abstract

Geophysical problems to be solved by SLR observations in the Western Pacific region are reviewd by classifying them into global, regional and local issues. The instantaneous motions of the Philippine Sea plate and the Australian plate still need to be better constrained by SLR/VLBI. Space geodetic measurements of the movements of the South China and the Sundaland blocks are important to discuss the Indian-Asian collision tectonics in the eastern Asia. As the local problems, a longer term monitoring of the displacement of the Simosato station, Southwest Japan is needed to detect precursory movements of that region before the Nankai earthquake which is supposed to occur there in the middle of the next century.

1. GLOBAL ISSUES

Tectonic Plate Motion ~ *The Phillipine Sea Plate*

~ *The Pacific Plate Rigidity*

~ *Reversal Time Scale Revision*

Height Variation ~ *Detection of Sea Level Change*

2. REGIONAL ISSUES

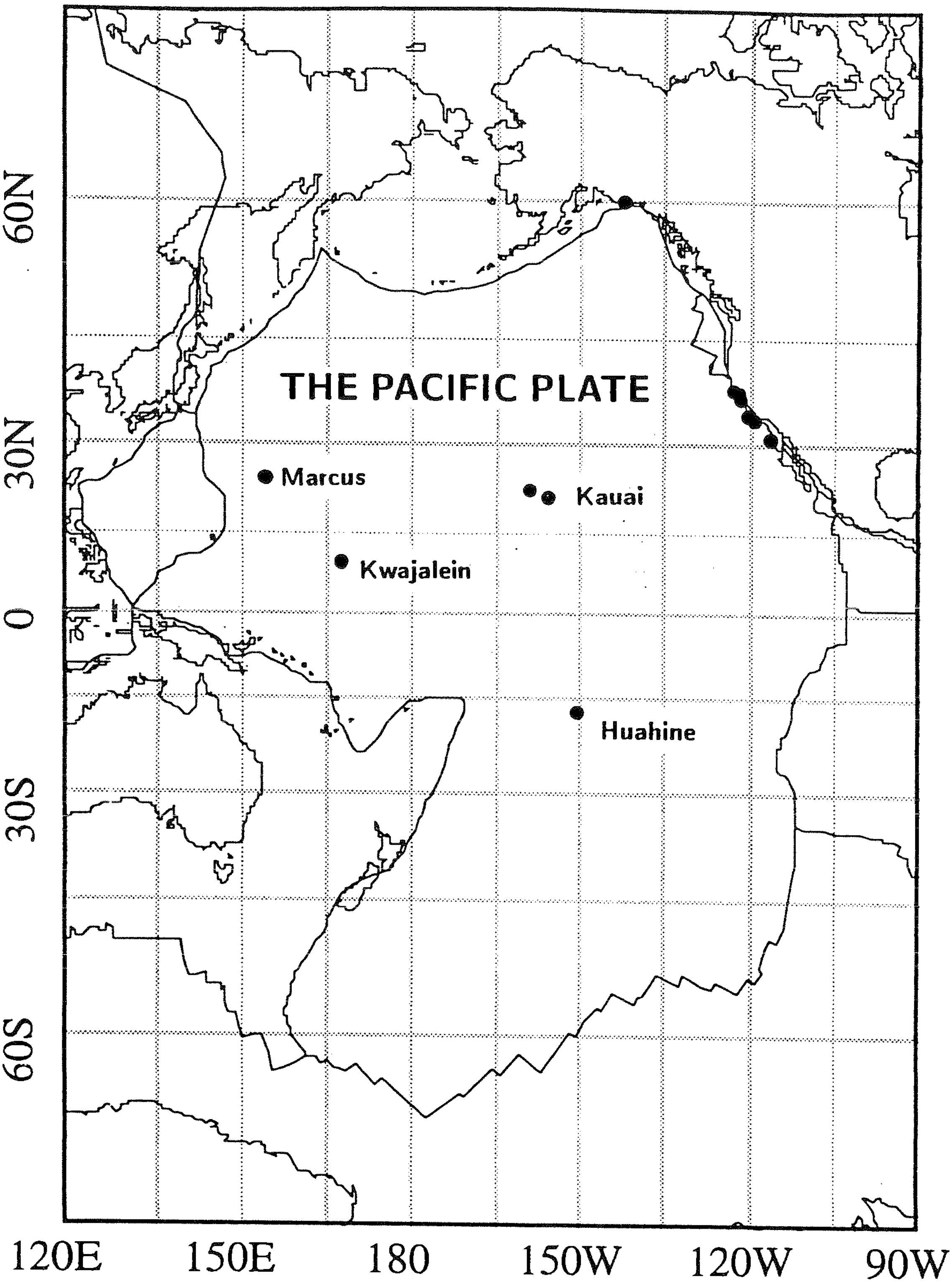
Movements of Crustal Blocks ~ *South China, Sundaland*

Hypothetical Minor Plates ~ *the Amuria / Okhotsk Plates*

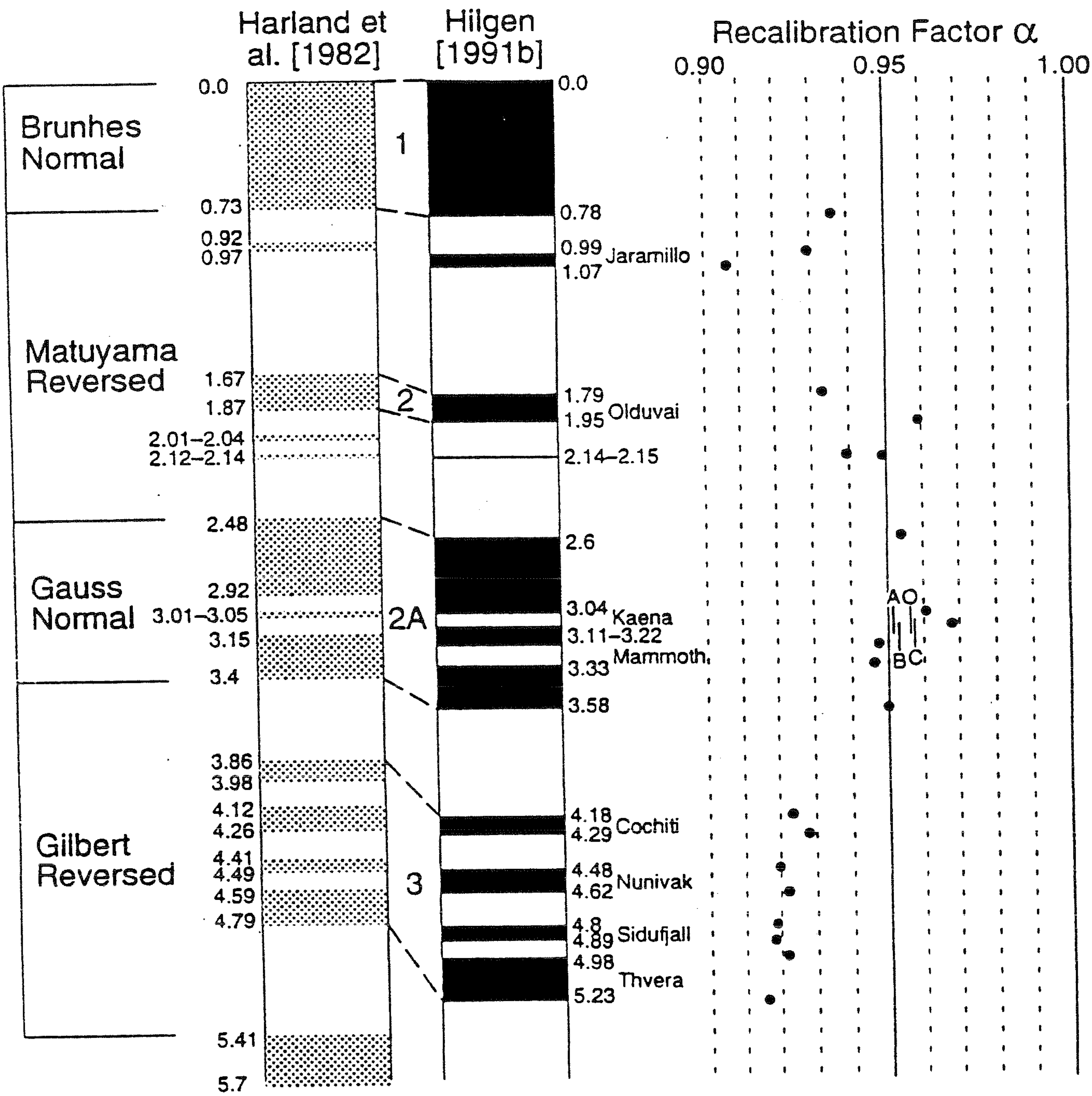
3. LOCAL ISSUES

Straining of Island Arcs ~ *Partition between Elastic and Plastic Deformations*

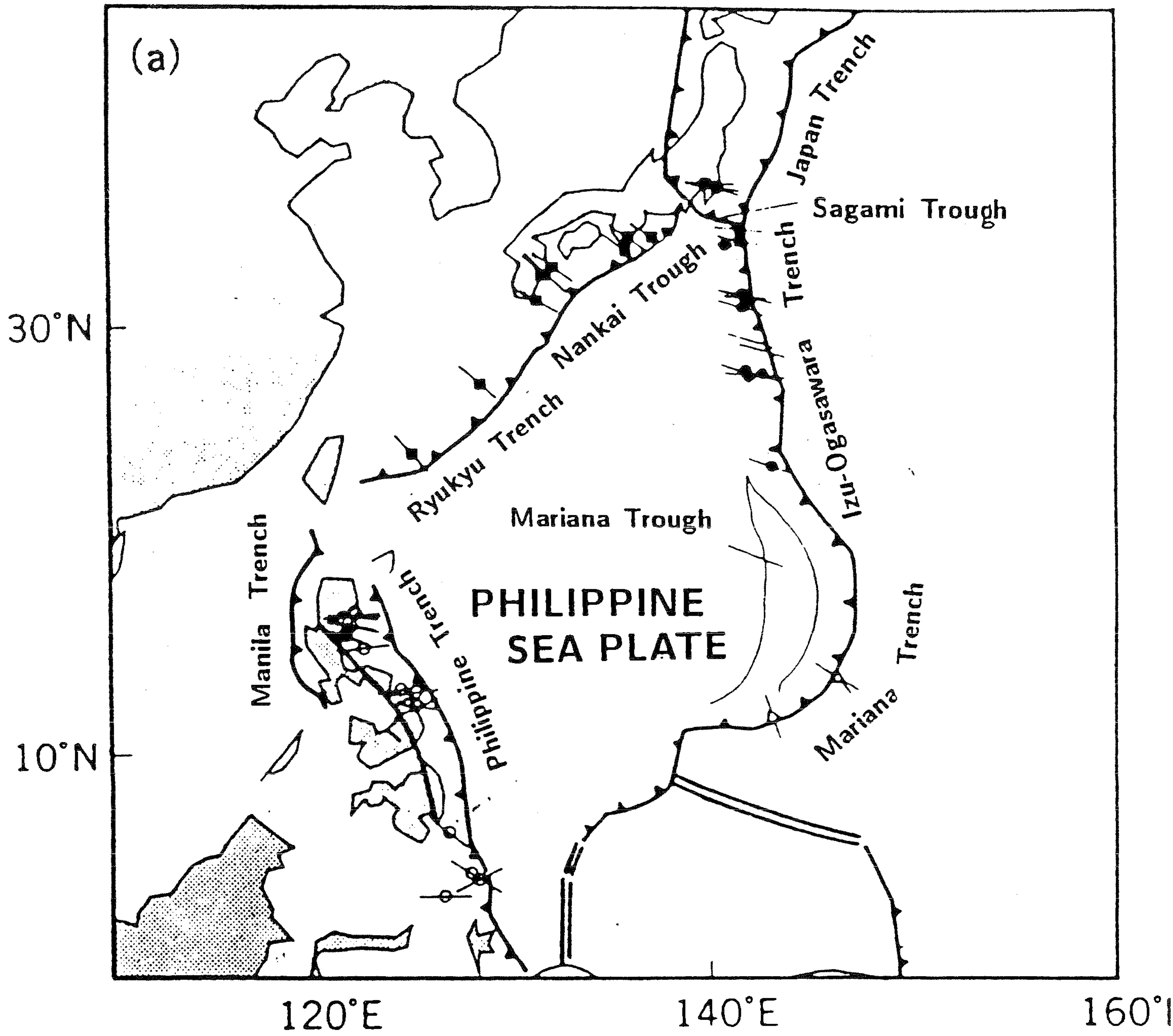
Earthquake Prediction ~ *Precursory Uplift*



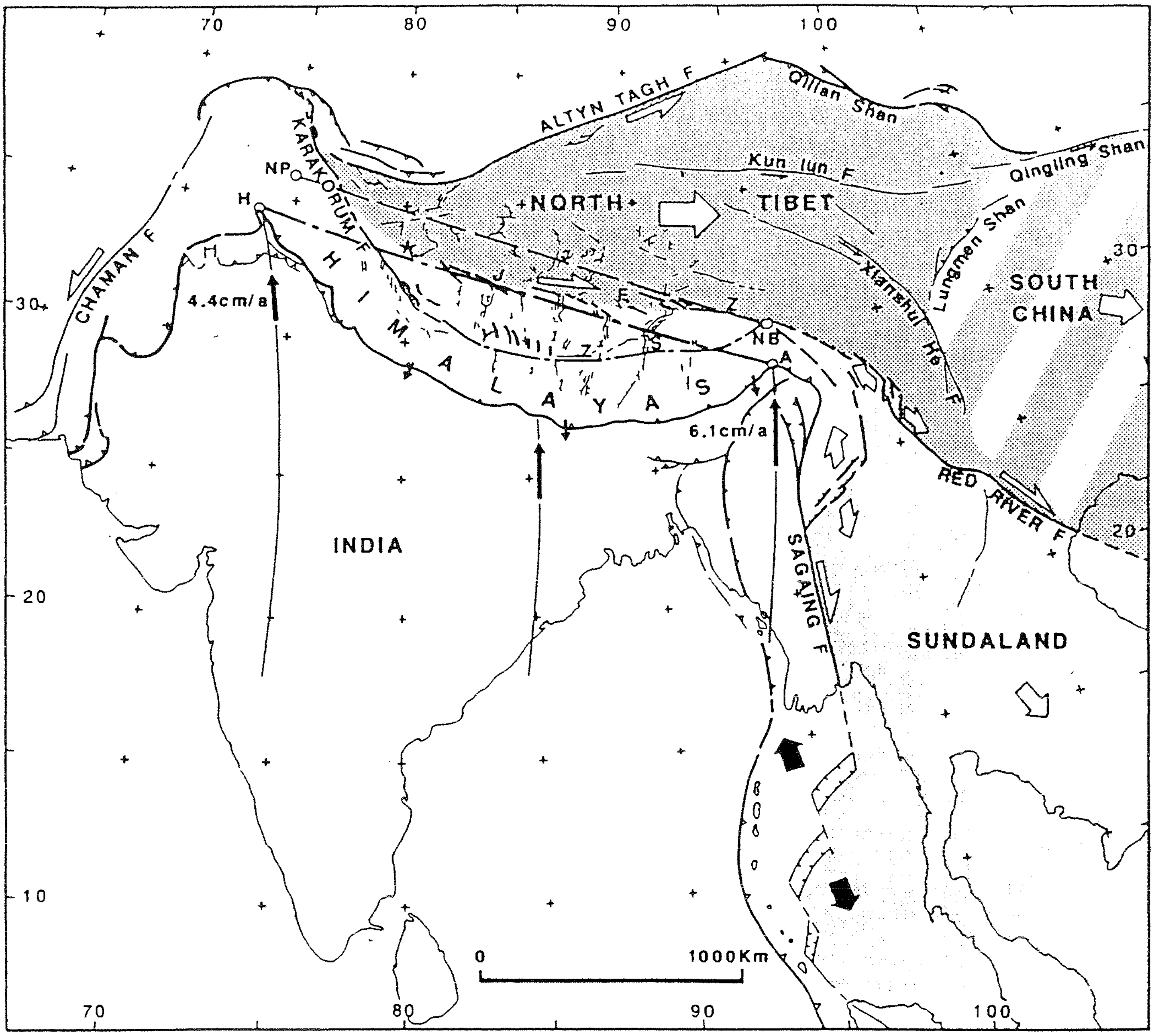
The Pacific plate is the largest oceanic plate. Studying the relative velocities among space geodetic sites on this plate will clarify how rigid a plate can be. VLBI/SLR data over the last 10 years from Kauai, Kwajalein, Marcus and Huahine have not been able to reveal any statistically significant deformation within the Pacific plate.



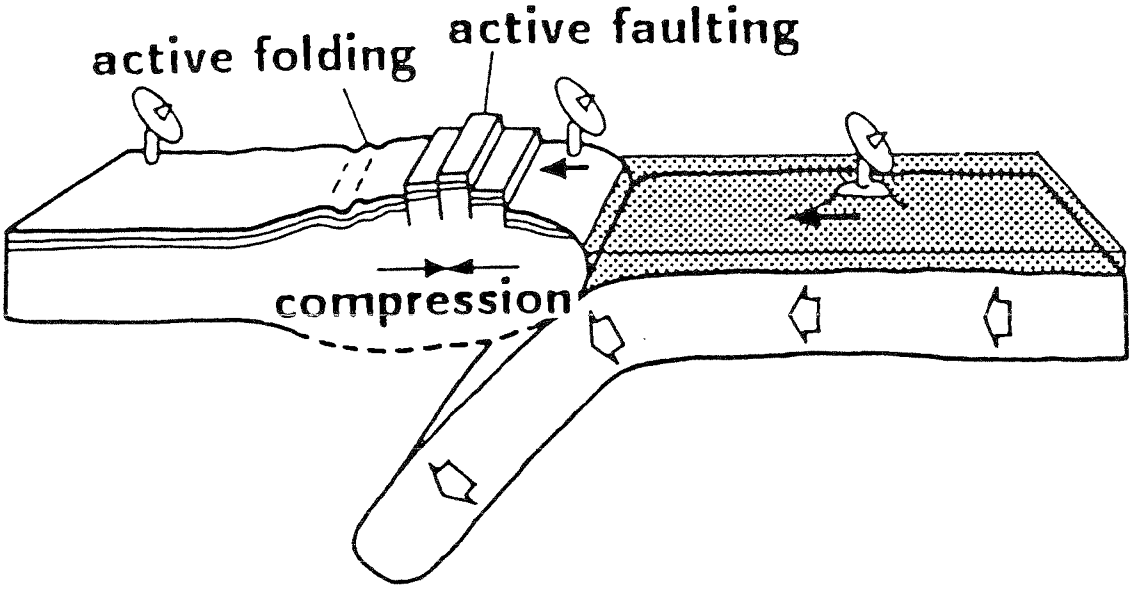
After DeMets et al. [1994]. Astronomically calibrated reversal time scale requires the whole NUVEL1 velocities scaled down to 95–96 % (the revised model is referred to as NUVEL1a). Space geodetic measurements of plate velocities over 10–20 years are capable of detecting this small revision. Several studies have already suggested that NUVEL1a fits better to the combined SLR/VLBI relative site motions [e.g., Harrison, 1994; Smith et al., 1994].



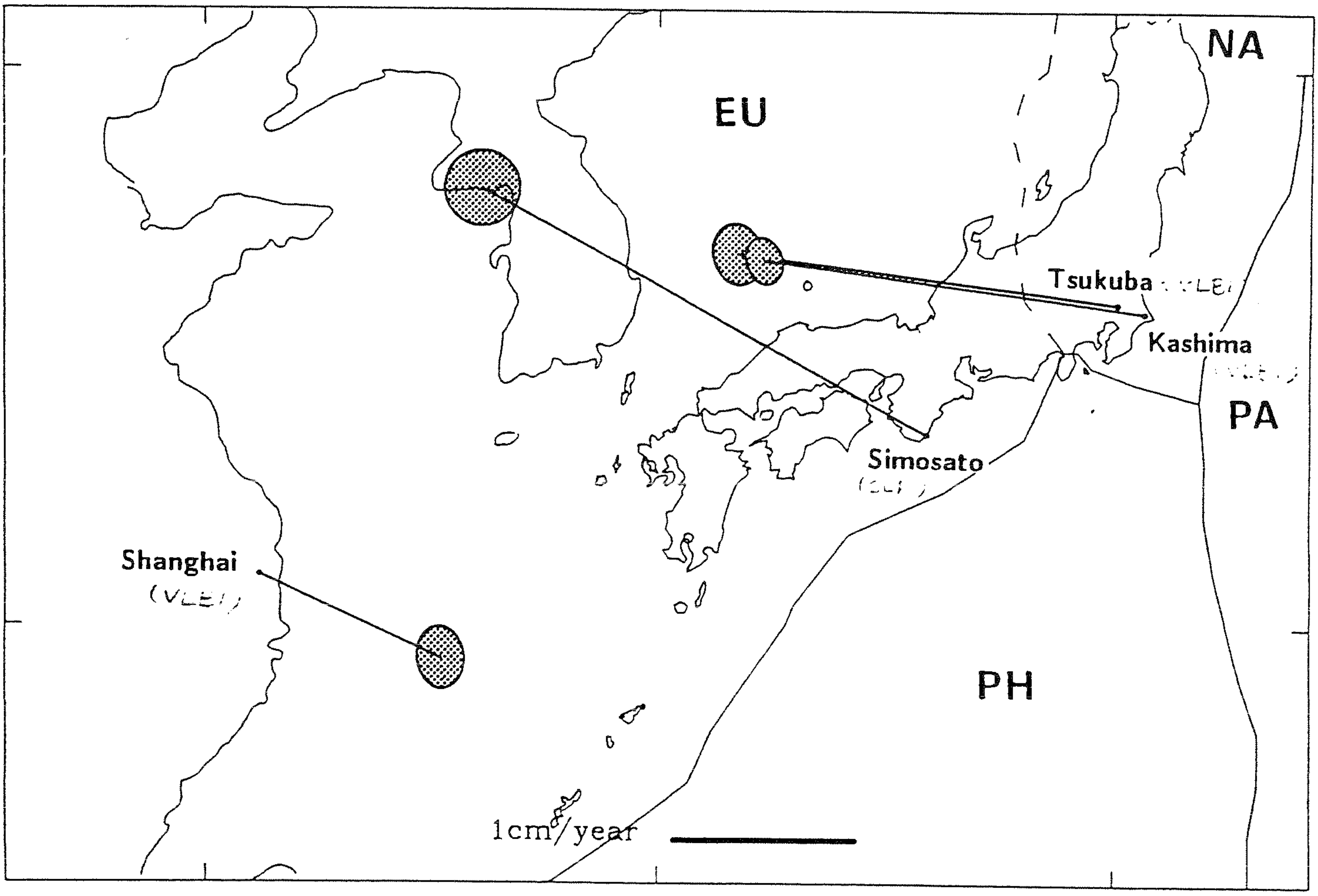
After Seno (1993). The Philippine Sea plate is surrounded by convergent boundaries and it has been difficult to determine its instantaneous Euler vector with the conventional method (only the earthquake slip vectors have been available for this purpose). Space geodetic measurements of the velocities of points on this plate are especially important to constrain its movement closely. The velocities of several island sites have been reported so far by VLBI [Matsuzaka et al., 1990; Amagai et al., 1994] and by GPS [e g. Hirahara et al., 1994; Tsuji, 1994; Chachin et al., 1994].



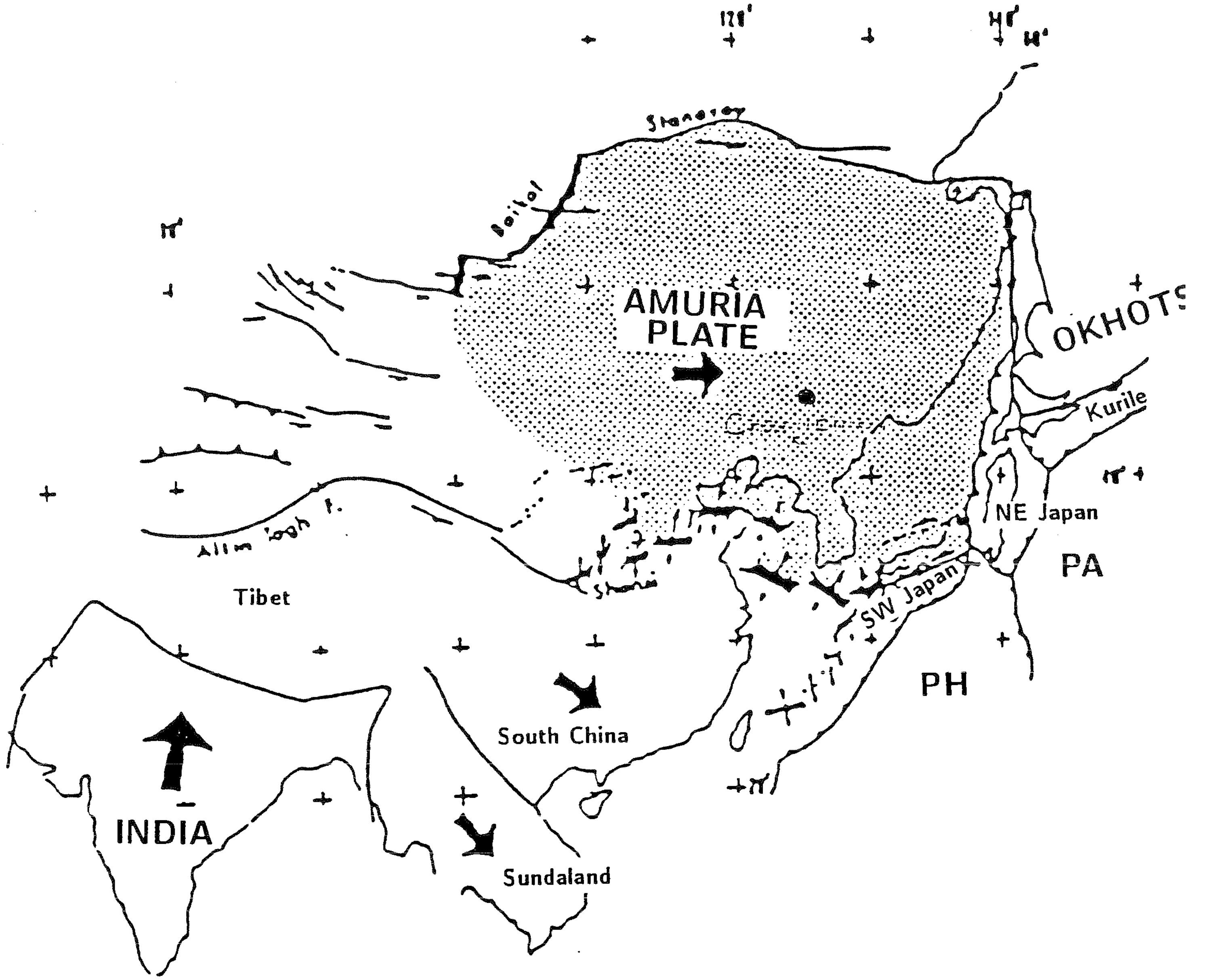
After Armijo et al. [1989]. Extrusion of crustal blocks in Central and Eastern Asia caused by the Indian-Asian collision. No space geodetic measurements of the velocities have been avilable for the Indian plate, the Tibet / Sundaland blocks. The east-southeastward movement of the Shanghai VLBI station of about 1 cm with respect to the Eurasian plate, is consistent with the velocities of the South China block inferred by geophysical [Houseman and England, 1993] and geological [Avouac and Tapponnier, 1993] studies.



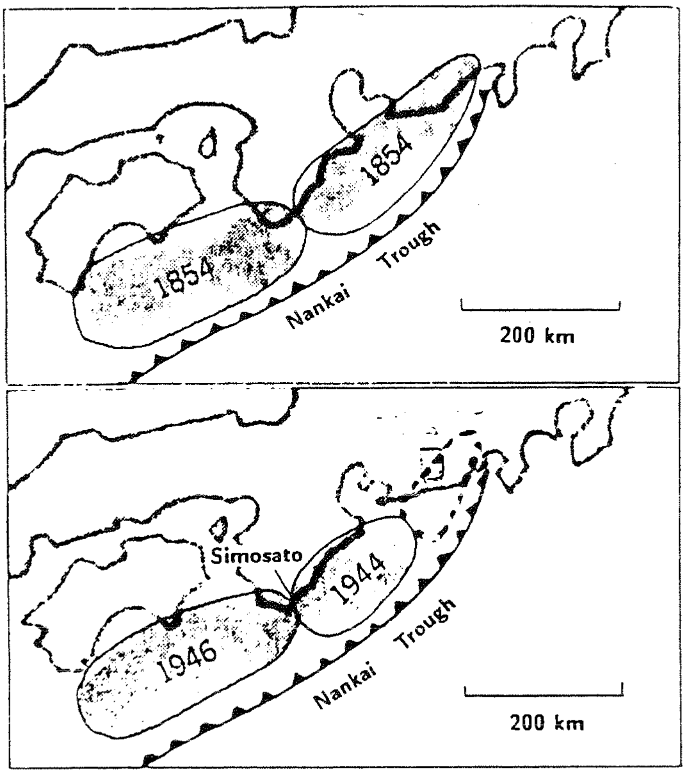
After Heki et al. [1990]. Compressional stress fields due to subducting oceanic plates cause (1) elastic straining (interseismic crustal deformation) and (2) plastic deformation (on-going orogeny) of the overriding plate (i.e. island arc). VLBI/SLR stations on the arc move landward whichever the cases are.

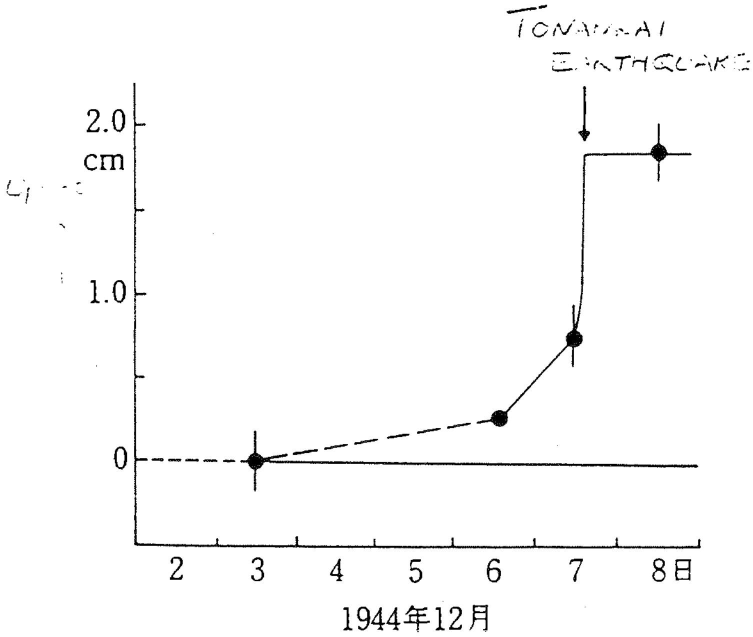


Movements of the Kashima, Tsukuba and Shanghai VLBI stations and the Simosato SLR station with respect to the Eurasian plate. Errors are one-sigma. The movements of Kashima, Tsukuba and Simosato indicate elastic/plastic straining of island arcs due to the oceanic plates subducting nearby. The movement of Shanghai may indicate the eastward extrusion of the South China block caused by the Indian-Asian collision [Molnar and Tapponnier, 1975].



After Kimura et al. [1986]. The existence of the Amuria plate is assumed in the shadowed region by several researchers. The Changchun SLR station in Northeast China will provide information of the relative movement of this plate. The Okhotsk Sea region is also suggested to be an independent plate (the Okhotsk plate).





After Mogi [1983]. Terrestrial surveying (levelling) happened to have been conducted in the region near Kakegawa-city, Shizuoka Japan, for a few days before the occurrence of the Tonankai earthquake (M=7.9). It recorded an abnormal uplift of about 9 mm in 2 km just before the earthquake, which has been considered as the most reliable case of the detection of the earthquake precursors. It is highly probable that the Simosato SLR station will detect such a pre-seismic signal just before the next earthquake expected to recur in the middle of the next century.

SLR Status in the Hydrographic Department of Japan

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Abstract

The Satellite Laser Ranging (SLR) observation has been continued at the Simosato Hydrographic Observatory since 1982 and the total amount of range data to LAGEOS-1, LAGEOS-2, AJISAI, STARLETTE, BEACON-C, ERS-1, TOPEX/POSEIDON and STELLA reached 5626 passes and 3,421,300 shots by the end of 1993. As the up-grade for the fixed SLR system, the laser transmitter was replaced from GTE Sylvania to Quantel YAG 460-5 in 1990 and the receiving electronic circuit was changed in 1993. As the result of the improvements, the range precision decreased from 10 cm to 4cm level.

A transportable laser ranging station named HTLRS was also developed by the Hydrographic Department in 1987 in order to determine precise position of isolated islands in Japanese territory. The field observation started in 1988 and the locations of 9 major islands and two points in Hokkaido (north Japan) were determined in high precision by the end of 1993. The ranging to LAGEOS-1, LAGEOS-2, AJISAI, STARLETTE and T/P has been made by HTLRS and the total observation is 531 passes and 236,300 shots. The range precision of the station is 3-4cm level.

1. Introduction

The SLR observation by the Hydrographic Department of Japan (JHD) has been carried out in the framework of the Marine Geodetic Control Network around Japan since 1982 (Kubo, 1988). The purpose of this project is to demarcate the boundaries of the jurisdictional sea, such as the territorial sea or the exclusive economic zone. In this project, the Simosato Hydrographic Observatory was assigned as the Mainland Control Point, while 14 points in major off-lying islands and some coastal regions were assigned as the First Order Control Points (Figure 1).

In the Mainland Control Point, Simosato, the fixed-type laser ranging station, named JHDLRS-1, was equipped in 1982 and the observation has been continued since then. On the other hand, a transportable laser ranging station, named HTLRS, was developed to determine precise positions of the First Order Control Points. The observation by HTLRS started in 1988 in Titi Sima and has been carried out at 9 major islands and 4 coastal regions so far.

In this paper, a SLR status in the viewpoint of hardware and data acquisition history for JHDLRS-1 and HTLRS is briefly reported.

2. JHDLRS-1

The JHDLRS-1 was first equipped in the Simosato Hydrographic Observatory in 1982. The original specification of the system is reported in Sasaki et al.(1983). During the course of the observation history, several improvements in the system have been made.

In 1985, a Micro-Channel-Plate photomultiplier was introduced. A GPS clock for adjusting the time with UTC was introduced in Dec.1988 in place of the Loran C receiver. The laser transmitter was replaced from GTE Sylvania to Quantel YAG 460-5 in 1990 and the receiving electronic circuit was changed in 1993. The present principal specifications are listed in Table 1.

Figure 2 shows the tracked number of passes for each year during 1988-1993. In 1988, the tracked satellites are only 3; LAGEOS-1 (USA), AJISAI (Japan) and STARLETTE (France). Since 1991, however, it has increased every year, and in 1993, it reached 7 satellites: additionally LAGEOS-2 (USA/Italy), ERS-1 (Germany), TOPEX/POSEIDON (USA/France) and STELLA(France). In the beginning of 1994, another satellite named METEOR-3 launched by Russia was added to the schedule.

Figure 3 shows the temporal variation of the number of passes (1986-1994) for AJISAI, LAGEOS-1 and STARLETTE. It exhibits the seasonal variation which reflects the weather condition. The variation of the range rms for AJISAI and LAGEOS-1 is shown in Figure 4. As clearly seen in this figure, the rms decreased from 10cm to 6cm level in 1990 and again down to 4cm level corresponding to the upgrades of the system mentioned above.

3. HTLRS

The JHD has been carrying out SLR observations using the transportable laser ranging station (HTLRS) since 1988. The principal specifications of the HTLRS are listed in Table 2 (see Sasaki (1988) in detail) . There has been no substantial change in the hardware system so far.

Sites and periods of observations already performed by HTLRS are listed as follows:

Jan. - Mar.	1988	: Titi Sima (TIT)
Jul. - Sep.	1988	: Isigaki Sima (ISG)
Jan. - Mar.	1989	: Marcus (MCS)
Jul. - Sep.	1989	: Okinawa Sima (OKN)
Oct. - Nov.	1989	: Tusima (TSM)
Sep. - Oct.	1990	: Oki Syoto (OKI)
Dec.1990 - Feb.	1991	: Minami-Daito Sima (MDT)
Aug. -Nov.	1991	: Tokati (TKT)
Jan. - Mar.	1992	: Iwo Sima (IWO)
Aug. -Oct.	1992	: Wakkanai (WAK)
Jan. - Mar.	1993	: Hatizyo Sima (HAT)
Jan. - Mar.	1994	: Makurasaki (MAK)
Jul. - Oct.	1994	: Oga (OGA)

The site distribution and the observation year are also shown in Figure 1.

Figures 5 and 6 show the number of data and range rms for LAGEOS-1 and AJISAI until Hatizyo Sima observation in 1993. From Figure 5, it should be pointed out that there has been almost no data for LAGEOS-1 after Oki Syoto observation in 1990, though the data acquisition depends significantly on the weather condition. The range rms shown in Figure 6 implies that the original range precision of HTLRS was less than 4cm. However, it has been aggravated lately for both LAGEOS-1 and AJISAI. These features appearing in both panels may result from a damage in the receiving optics of the system.

4. Conclusion

This paper summarizes the SLR status for JHDLRS-1 at Simosato and for HTLRS, focusing on the hardware and data acquisition history. Since the project of Marine Geodetic Control Network will be over in a few years, the JHD is presently at the stage of heading for a subsequent project using the SLR technique. One of major targets should be a relative plate motion and its velocity perturbation or crustal deformation within a plate at the boundary region, on the basis of repeated observations by HTLRS. For this purpose, the present system needs to be renewed or upgraded in order to acquire more ranging precision and more amount of data.

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Table 1. Principal Specifications of JHDLRS-1

Subsystem	Specification
Mount configuration	elevation over azimuth/Coude path
Angular resolution	20bits (1.2 arcsec)
Transmitter diamete	17 cm
Receiver diameter	60 cm
Laser wave length	532 nm
Output energy	125 mJ
Laser pulse width	100 ps
Repetition rate	4 pps
Receiver detector	Micro-Channel-Plate PMT (9% Q.E. and 300 ps rise time)
Flight time counter	20 ps resolution
Frequency standard	Rubidium oscillator
Time comparison	GPS
Computer	32 - bits personal computer with hard disks, 3.5 inch floppy disk drivers, printer, CRTs an modem

Table 2. Principal Specifications of HTLRS

Subsystem	Specification
Mount configuration	elevation over azimuth/Coude path
Angular resolution	20bits (1.2 arcsec)
Transmitter diameter	10 cm
Receiver diameter	35 cm
Laser wave length	532 nm
Output energy	50 mJ
Laser pulse width	50 - 100 ps
Repetition rate	5 pps
Receiver detector	Micro-Channel-Plate PMT (7% Q.E. and 300 ps rise time)
Flight time counter	20 ps resolution
Frequency standard	Rubidium oscillator
Time comparison	GPS
Computer	two 16 - bits personal computers with hard disks, 3.5 inch floppy disk drivers, printer, CRTs and a modem

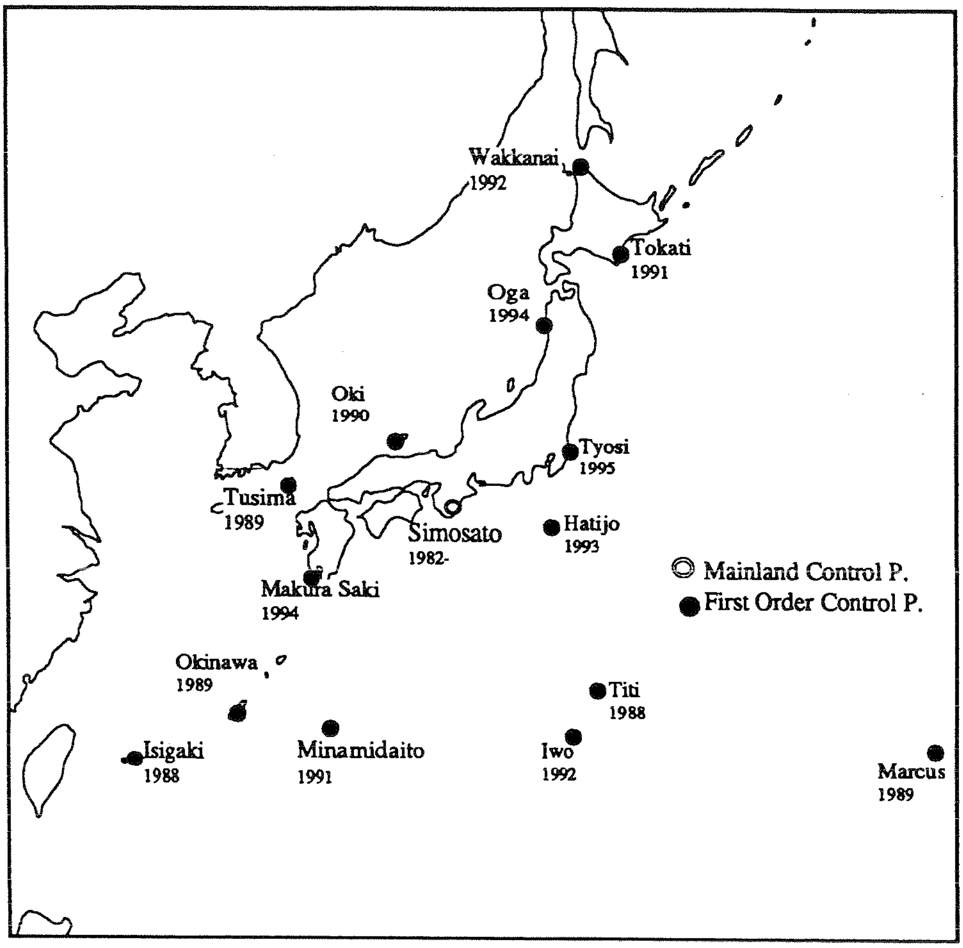


Figure 1. Marine Geodetic Control Network by JHD

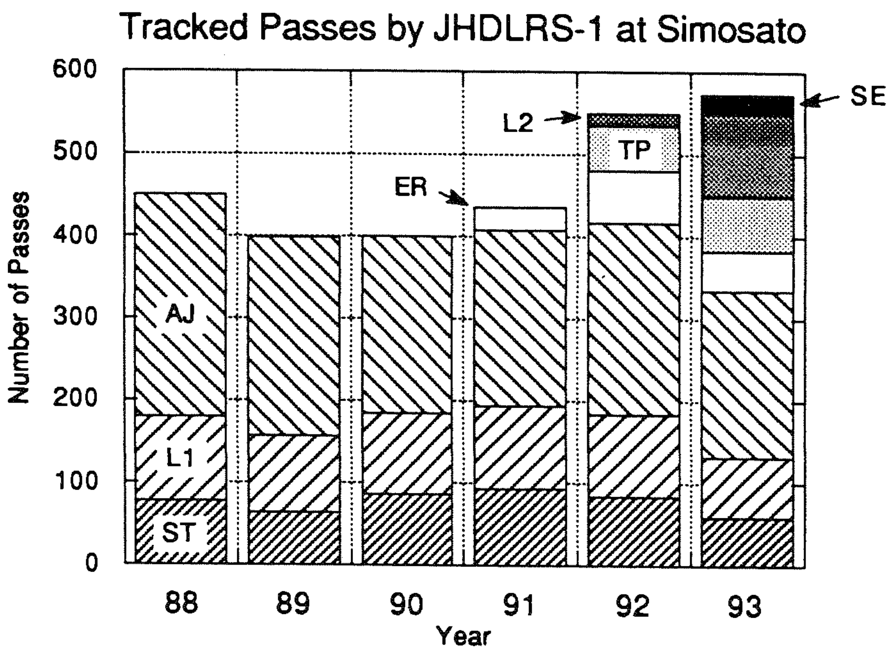


Figure 2. Number of passes for each tracked satellite in Simosato (1988 - 1993)

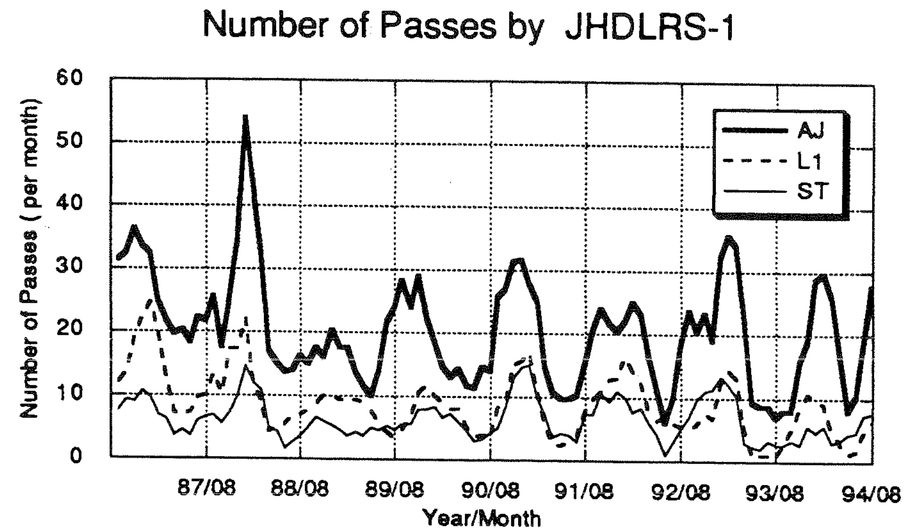


Figure 3. Variation of number of passes (3-month moving average) in Simosato for AJISAI, LAGEOS-1 and STARLETTE.

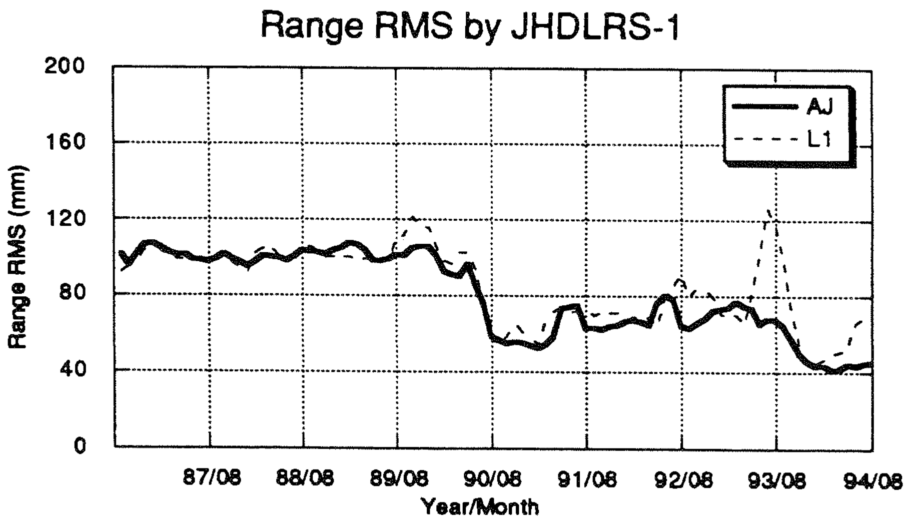


Figure 4. Variation of range rms (3-month moving average) in Simosato for AJISAI and LAGEOS-1

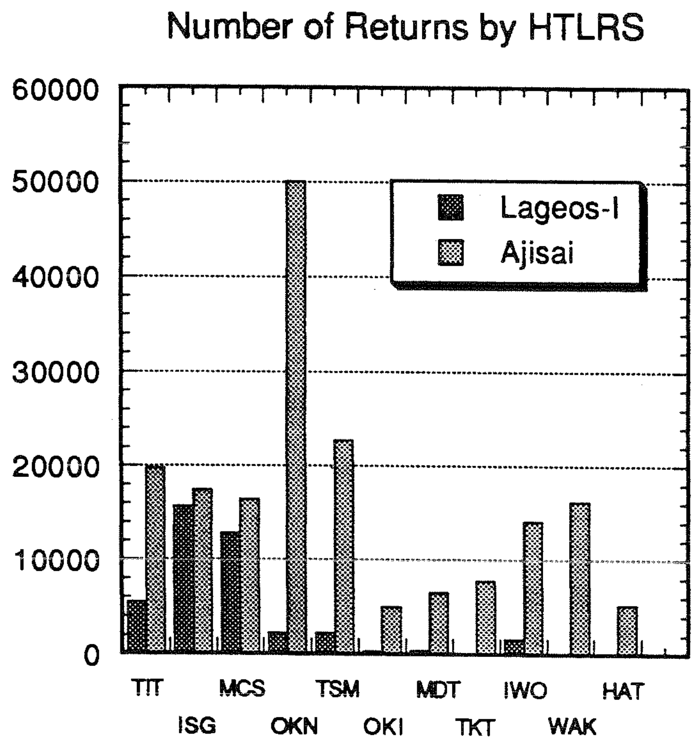


Figure 5. Number of Returns for LAGEOS-1 and AJISAI obtained by HTLRS.
See the text for the site abbreviation.

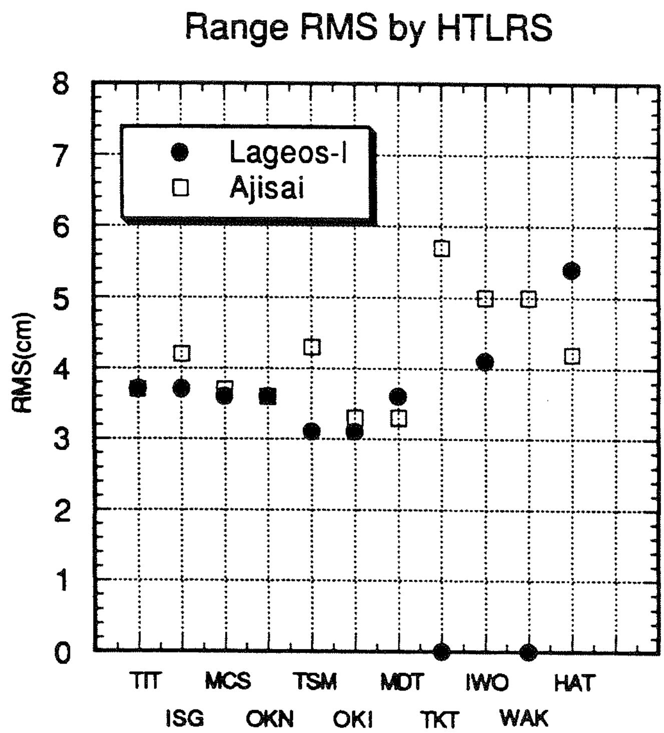
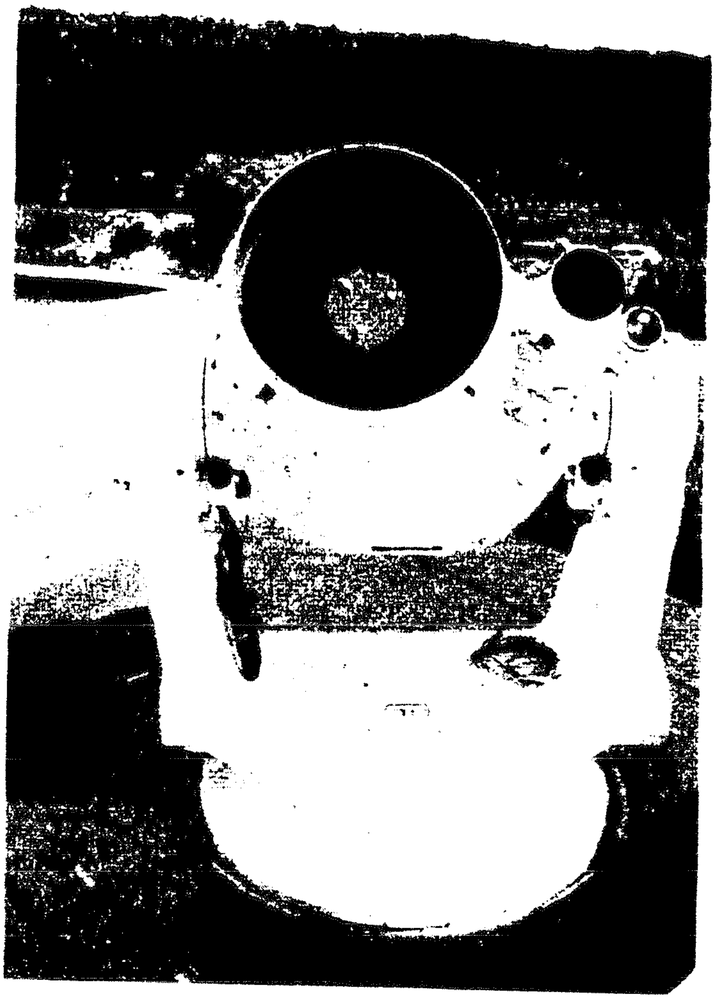
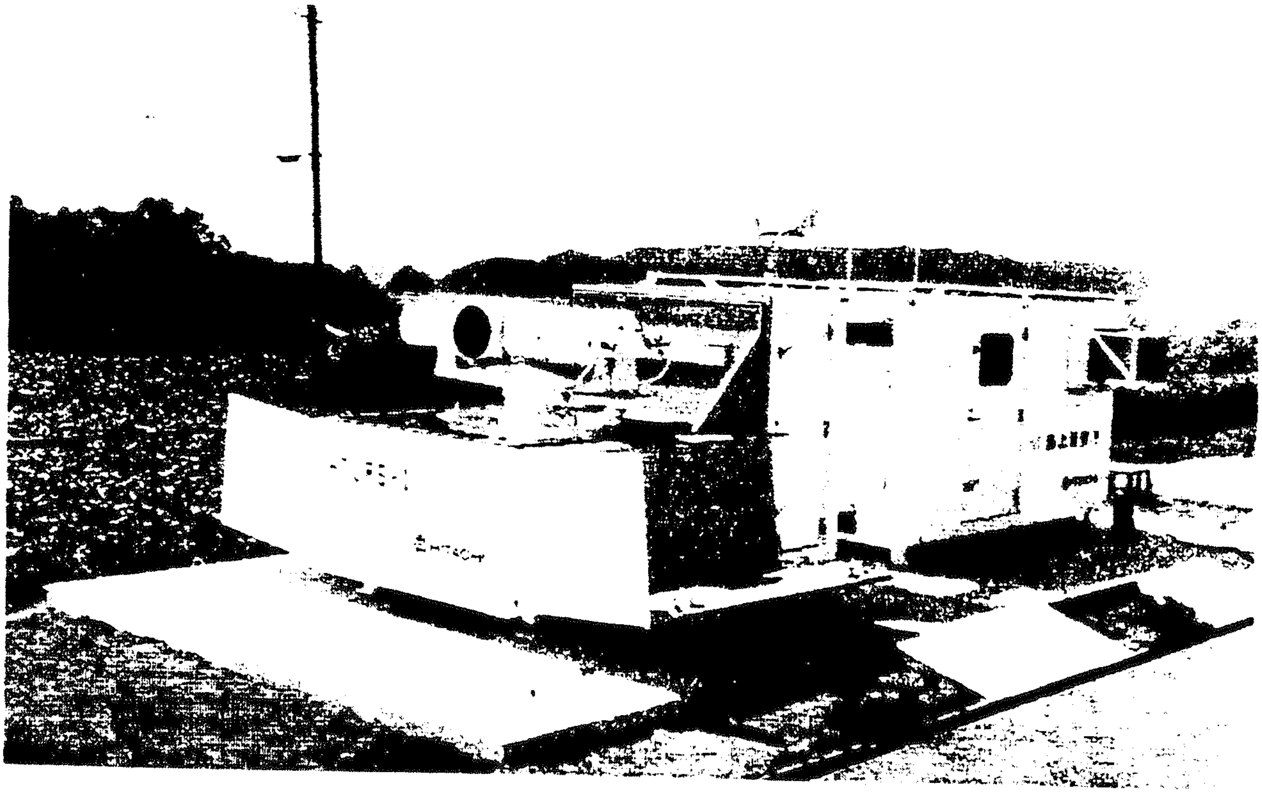


Figure 6. Range rms for LAGEOS-1 and AJISAI obtained by HTLRS.
See the text for the site abbreviation.

JHDLRS-1
at Simosato
since 1982



HTLRS
since 1988



Timing Control Precision for Synchronous Laser Ranging to AJISAI at CRL and JHD Stations

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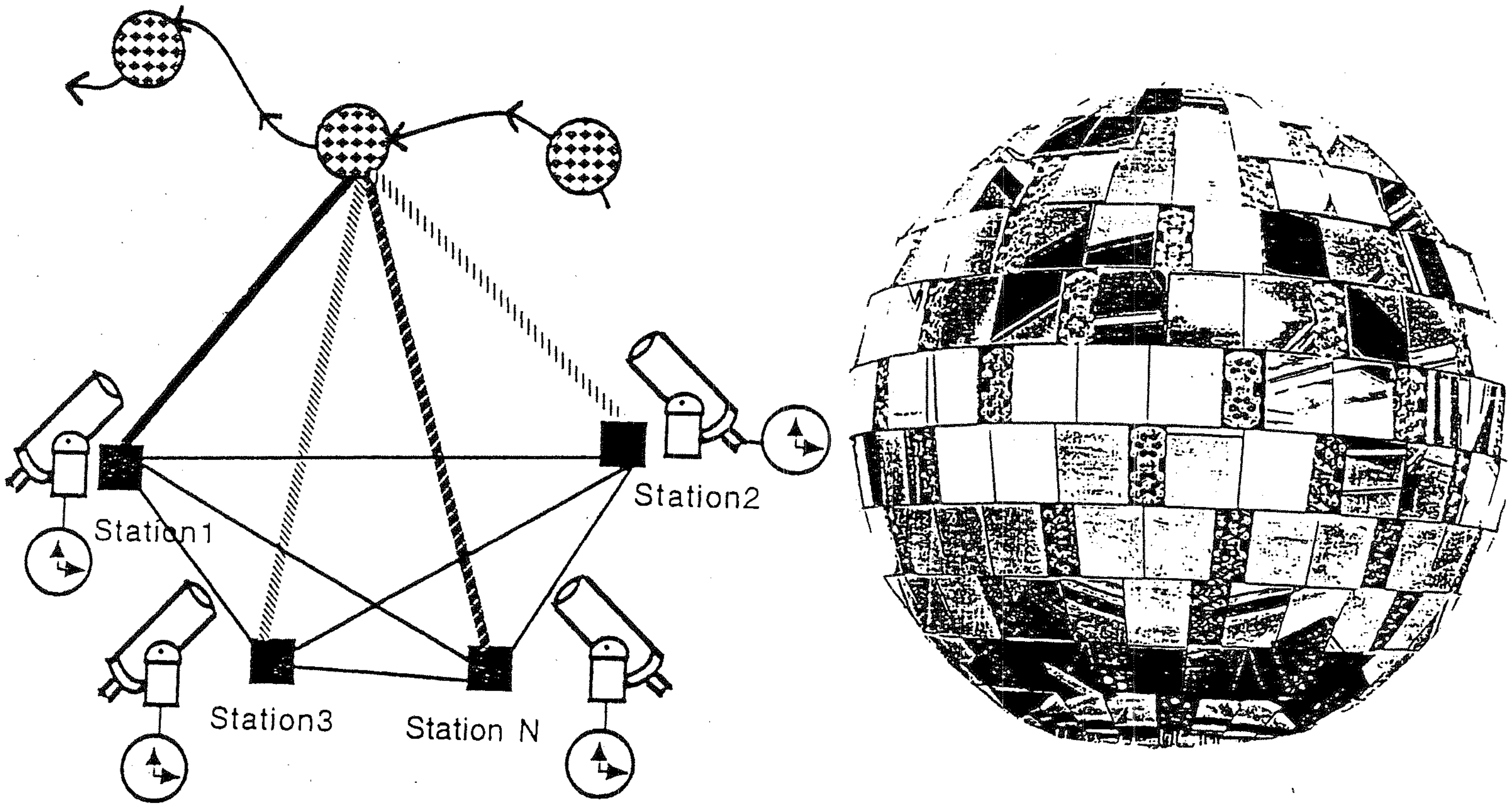
T.May (Electro Optic Systems)
K.Matsumoto(Japan HydroGraphic Department)
Y.Suzaki(Hitachi Co.Ltd)

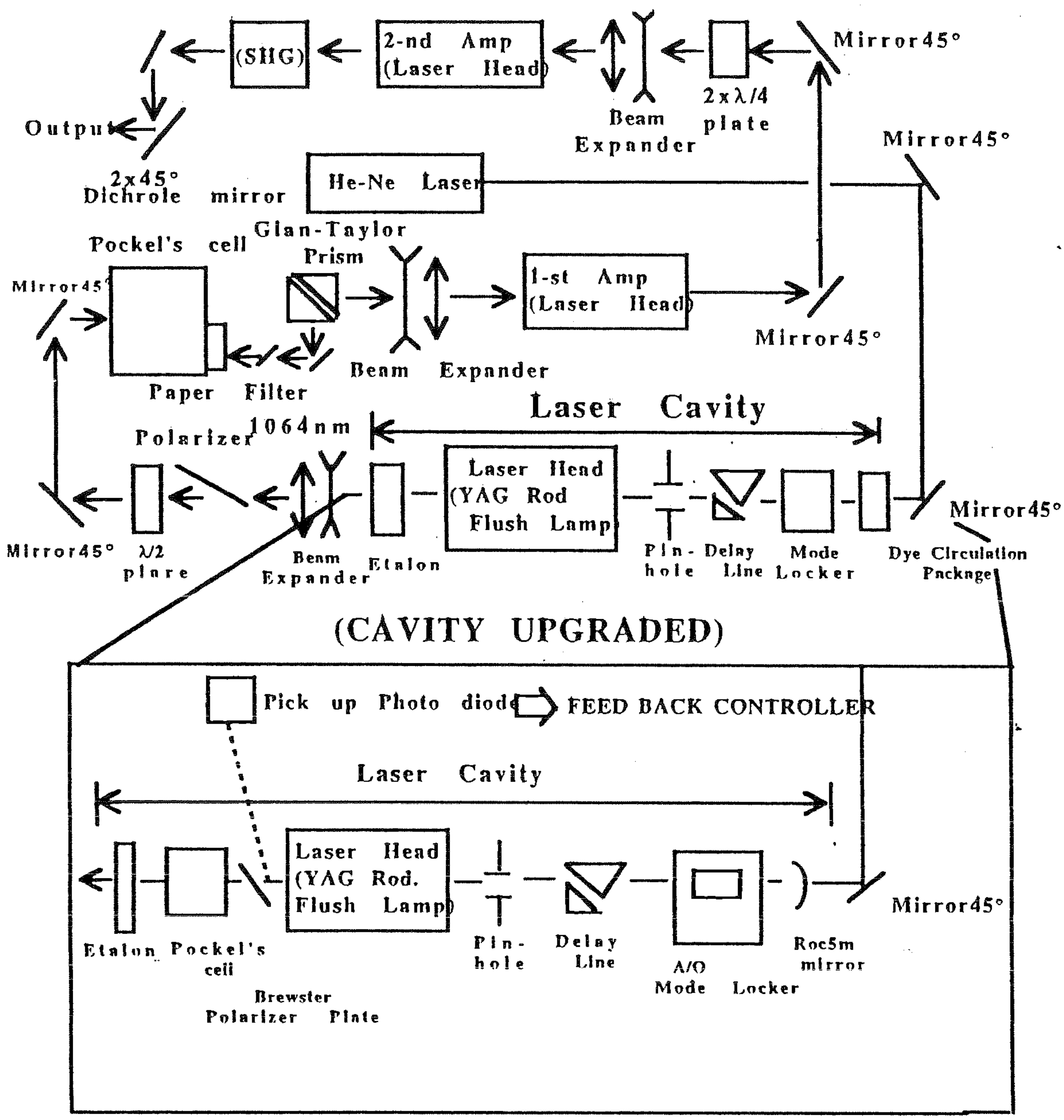
Synchronous Ranging Objectives
Short Arc Orbit Analysis
Time Transfer
Remote Spin/Altitude Analysis

Laser Fire Control

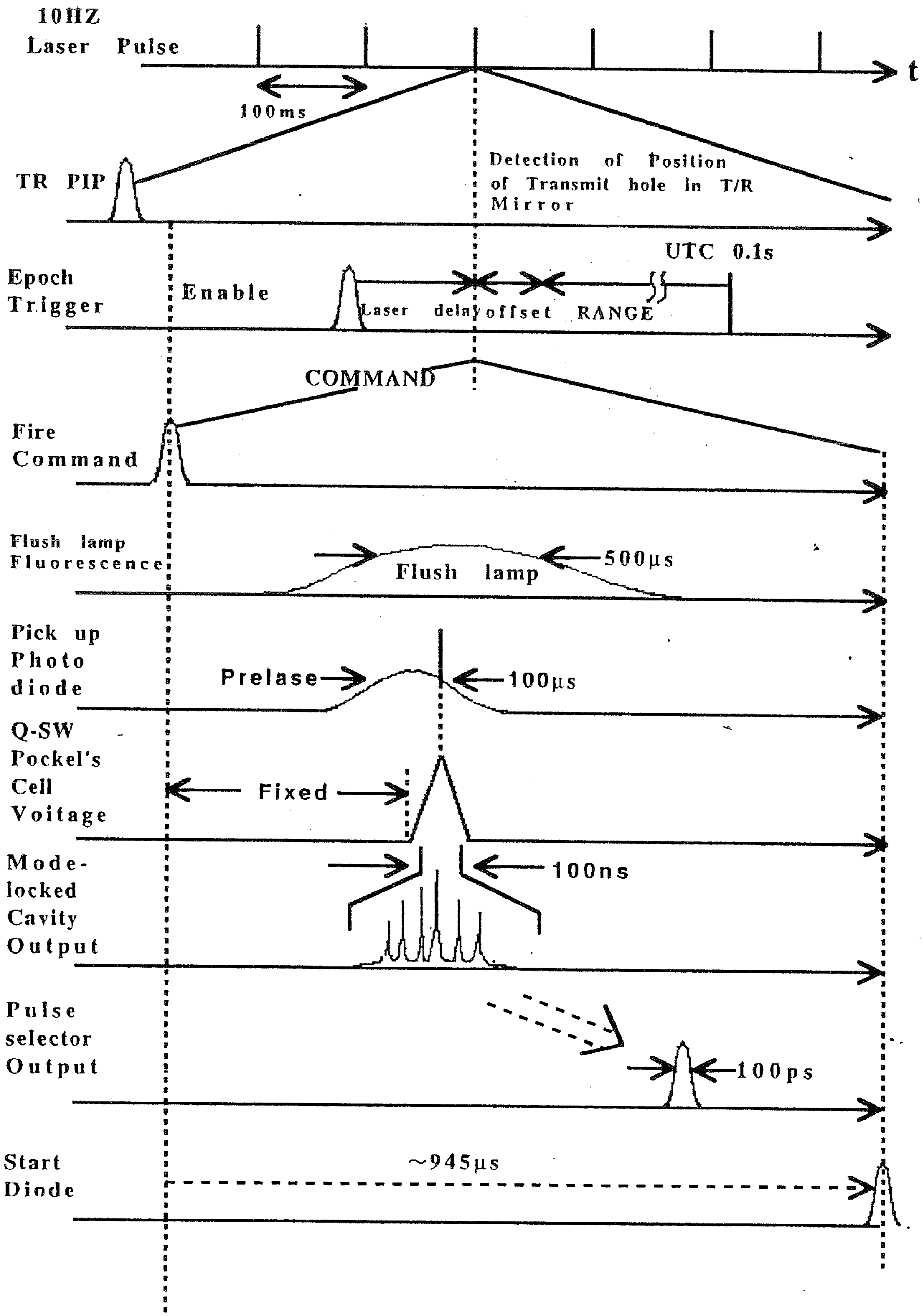
Preliminary Test to Ajisai at CRL and JHD



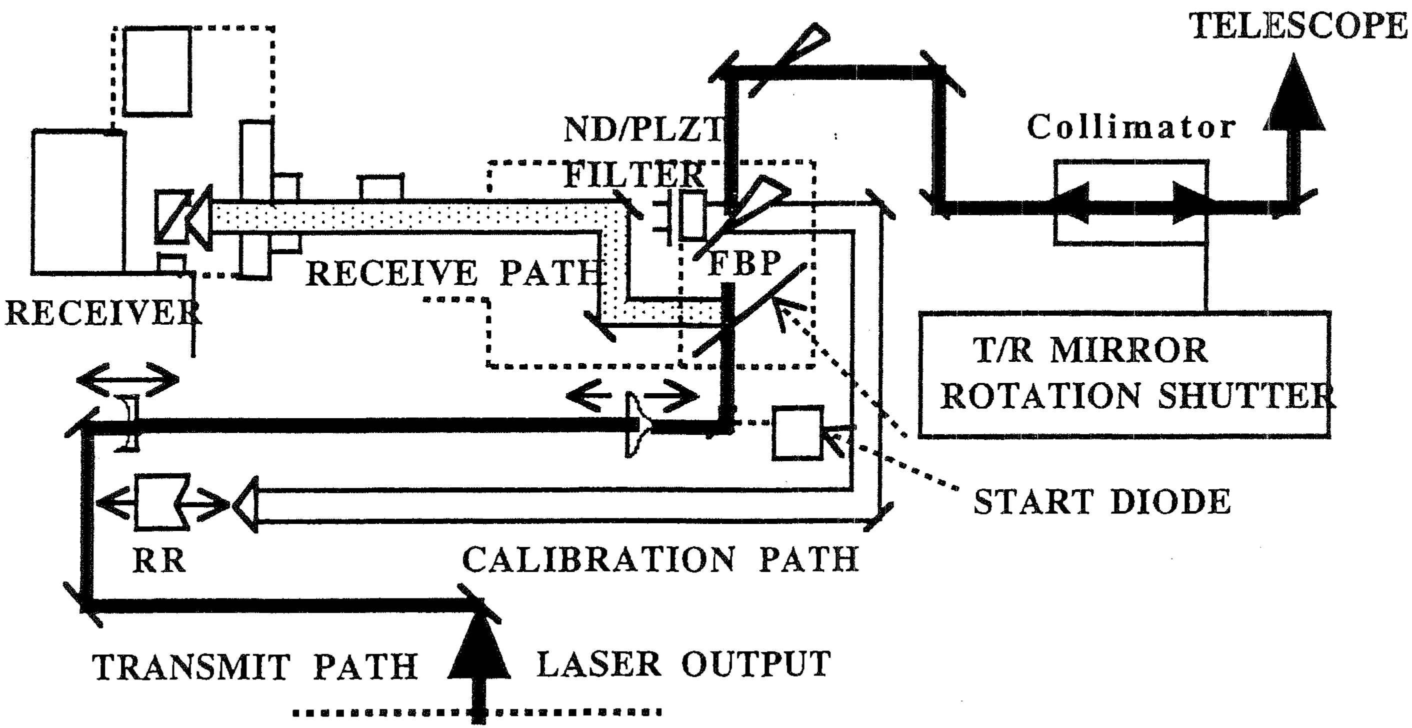
The concept of synchronous SLR network. and geodetic satellite AJISAI



The schematic diagram of active Q-switched mode-locked Nd:YAG laser

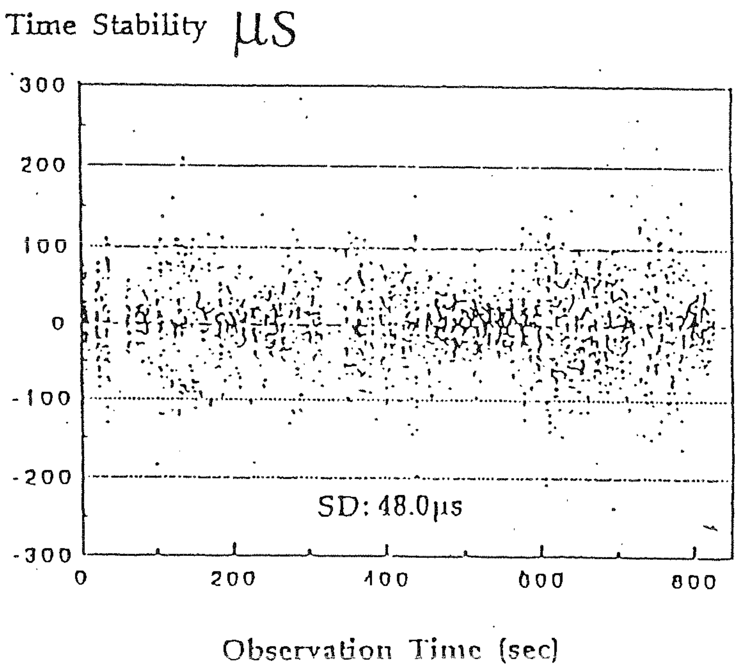


The timing sequence of synchronous laser firing

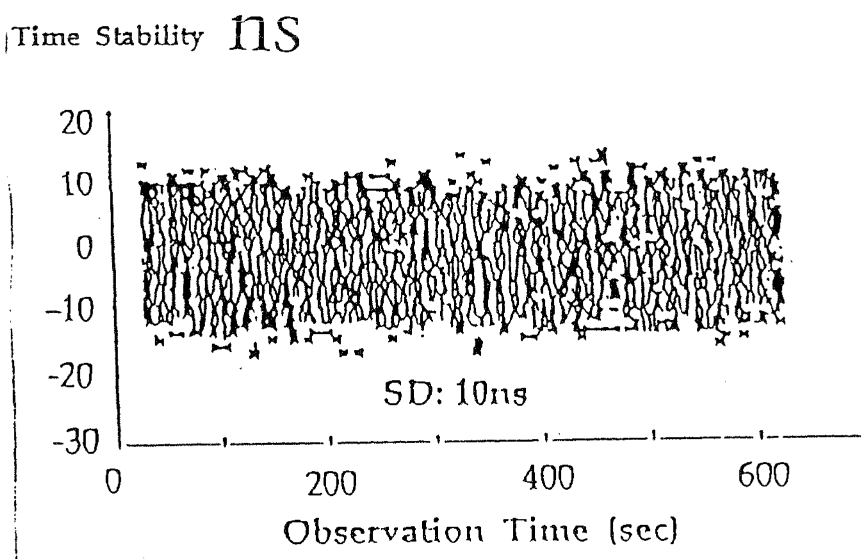


RR : Retro Reflector
PLZT : Lead Lanthanum Zirconate Titanate filter
FBP : Feed Back Plate
ND : Neutral Density Filter
MCP : Micro Channel Plate

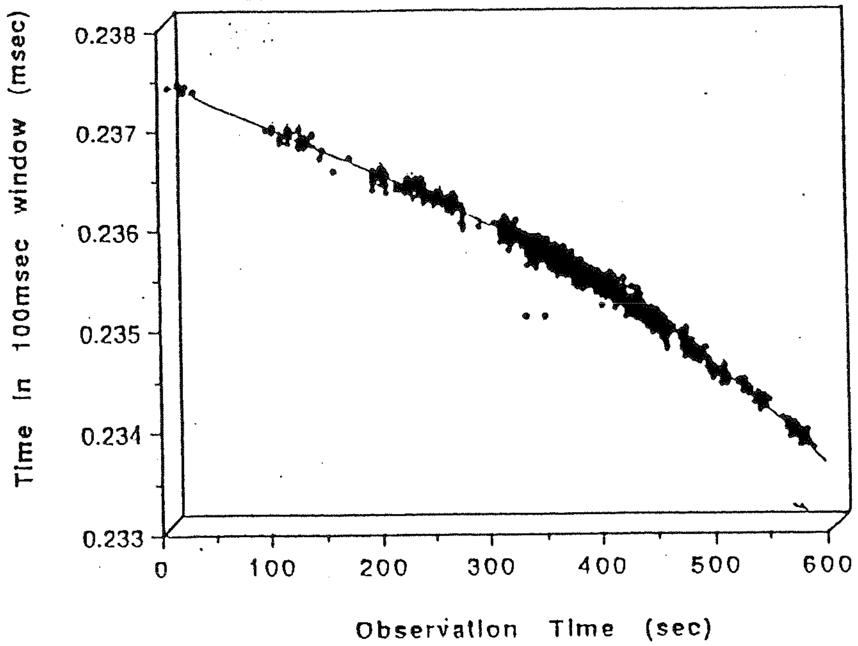
The optical layout of Transmitting/Receiving path.



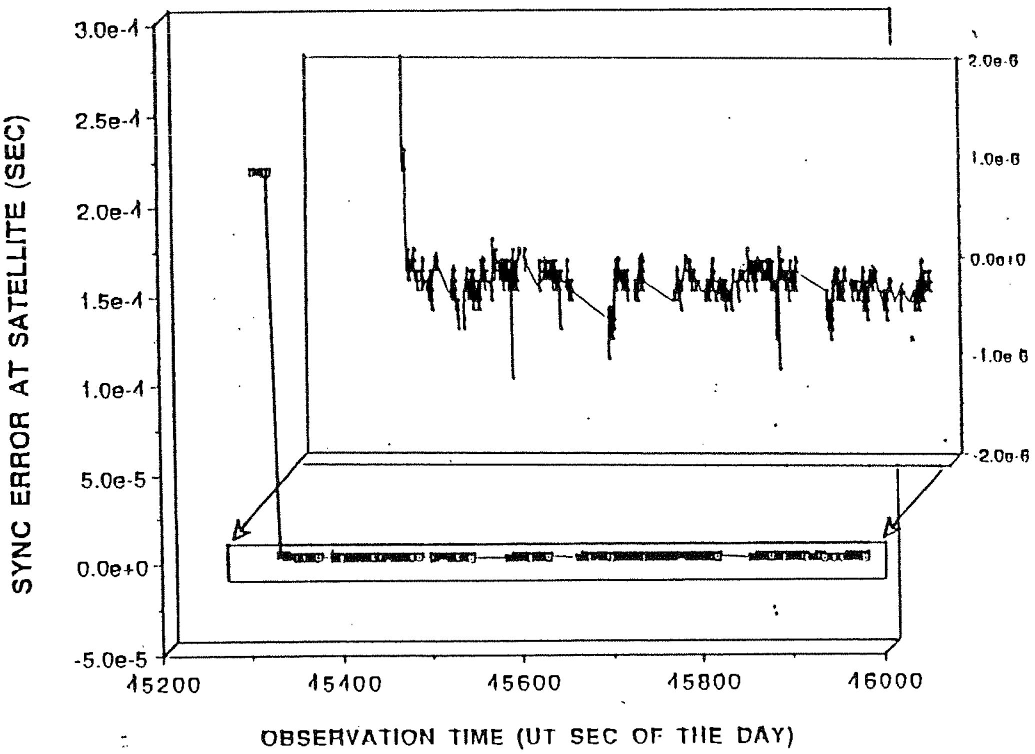
The timing error of laser delay in active-passive Nd:YAG laser
(Before modification, 10 Hz to fixed target)



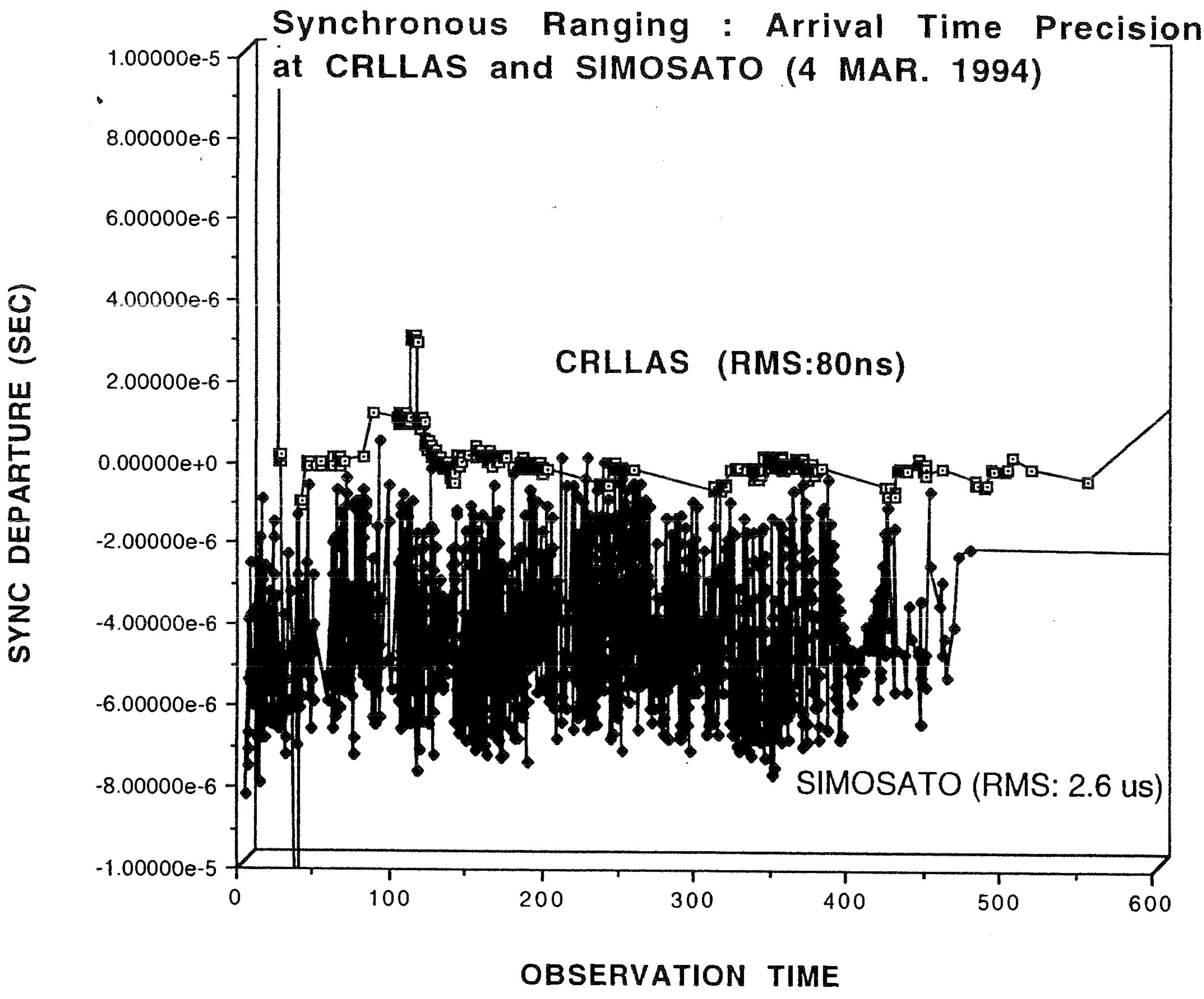
The timing error of laser delay in active-Q-switched mode locked Nd:YAG laser
(After modification, 10 Hz to simulated satellite corrected by predicted range)



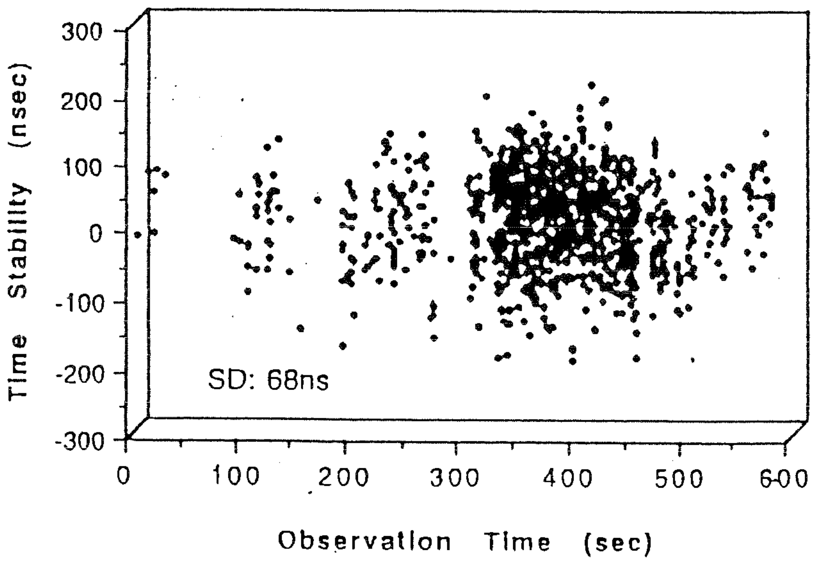
The timing error of the arrival time with respect to 0.1 second on the satellite (After modification, 10 Hz to Ajisai corrected by measured range)



The example of timing error control by manual during the run (Ajisai, 4 March 1994)



Synchronous Ranging : Arrival Time Precision
at CRLLAS and SIMOSATO (4 MAR. 1994)
1.00000e-5
8.00000e-6
6.00000e-6
4.00000e-6
2.00000e-6
0.00000e+0
-2.00000e-6
-4.00000e-6
-6.00000e-6
-8.00000e-6
-1.00000e-5
SYNC DEPARTURE (SEC)
CRLLAS (RMS:80ns)
SIMOSATO (RMS: 2.6 us)
0
100
200
300
400
500
600
OBSERVATION TIME



The final timing jitters of the synchronous laser fire demonstration
(Removing offsets and systematic change by polynomial curve fitting of order three)

Using SRD Method to Measure the Regional Crustal Deformations

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Abstract Satellite Laser Range (SLR) with centimeter precision has become one of the most efficient techniques for measuring the present-day plate motion and regional deformation. However, in the usual dynamic satellite method, the error in determining the satellite orbit which comes from inadequate modeling and non-modeling of dynamic forces has limited the further improvement of the accuracy and resolution. One possible alternative is the SRD method adopted in this paper, i.e. the semi-dynamic and semi-geometric method, which efficiently minimizes the influences of orbital modeling errors on the determination of baseline vectors.

Using laser ranging observations to LAGEOS satellite collected during 1985-1990, the change rate of the baseline vector between QUINCY and MNPEAK stations has been estimated by means of the SRD method. The results are:

$$\begin{aligned} dBx &= -15.0 \pm 3.4 (mm/yr), \\ dBy &= -20.2 \pm 2.5 (mm/yr), \\ dBz &= -15.2 \pm 2.6 (mm/yr), \\ dB &= -26.9 \pm 2.1 (mm/yr). \end{aligned}$$

The standard error (repeatability) of the baseline length determined by one day observation is 3.0mm, or 3.4e-9.

The results show that this method does offer a good alternative for studying regional crustal deformation with high accuracy and especially with high temporal resolution.

Keywords: SLR, SRD, Crustal movement.

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1. Introduction

In the recent years the single shot laser measurement precision has reached an order of 1-5 cm. The systematic errors of the observational data for most SLR stations have also decreased under cm level. The precision of the normal point data which are pretreated is more higher. The system error of observation data is also below the centimeter level. The data of the high precision laser range to LAGEOS accumulated for more than 10 years provided the dependable guarantee of measuring the crustal movement. In the last few years,the SLR technique has contributed significantly to the determination of the present-day plate tectonic motions and has become one of the most effective methods in doing this[1]. It sould be pointed out that the improvement of the accuracy the accuracy and resolution in the SLR geodynamic determination has been limited due to inadequate modeling and non-modeling force pertorbations. For example, the most precision of determining LAGEOS' orbit (about a few day arcs) is about 5 cm. This is far inferior to the precision of the single laser range to LAGEOS. It has been known that the errors of the gravitational and the LAGEOS satellite's drag-like perturbation can exert influences (1-3 cm) on baselines measured. So, in order to measure a few centimeters of a baseline vector variation, the SLR data for least 3-4 years must have been accumilated. We can say that the accuracy and temporal resolution acquired by using SLR dynamic method for measuring regional crustal motions has almost reached its limit due to the orbital errors, of which the substantial improvement is difficult.

Generally, the measured motions by the space geodetic techniques (VLBI,SLR) are in good agreement with the geologic tectonic motion rate models drived by Minster and Jorden(1978)[2], or by DeMets et al.(1990)[3]. The disagreement between these models occurs mainly in the plate-boundary areas. Actually, this is the deformations in these boundary areas and the intraplate motions which are of more geophisical interest. It is a most typical example to measure the baseline changes between QUINCY station (on North America plate) and Peak Mounment station (on Pacific plate) located on both sides of San Andres fault. The result The result of the measurement by the space techniques is that the two stations are being close with the velocity 2-3 cm/yr. The difference between the measurement value and the predicted value 5.3 cm/yr of geological model is fair-sized. The situation of these disagreements is especially noticeable. Such differences between both measuring and modeling await understanding is the field of geophysics, which is intimately related to the understanding of how and why earthquakes occur in these regions. In order to fulfil the requirement of geodynamics, the regional crustal motion must be measured with more accuracy and with higher temporal resolution. It is very difficult to use the usual SLR dynamic method for satisfying the requirement. Now, the problem is whether any potentialities will be exploited from the data accumilated for more than 10 years with very high precision in measuring the crustal movement.

An attractive alternative is to use the Simultaneous Range Difference method (SRD). The method was introduced in here. This method can efficntly minimize the influences of orbital modeling errors on the estimation of baseline vectors, and may improve the accuracy and temporal resolution of measuring regional crustal motions. For the usual single range method the effect of the orbital error on the "computed" measurement is

$$b = -\frac{\vec{\rho}}{\rho}\Delta\vec{r} \qquad (1)$$

where $\vec{\rho}$ is the range vector,$\Delta\vec{r}$ is the orbital error. In the SRD method the effect of the orbital error on the "computed" measurement (now Δb is the range difference!) becomes

$$\Delta b = \left(\frac{\vec{\rho_j}}{\rho_j} - \frac{\vec{\rho_i}}{\rho_i}\right)\Delta\vec{r} \qquad (2)$$

where the subscripts j and i represent the stations in SRD.

The average (in rms sense) value of b indicates the absolute positioning precision achieved by the usual dynamic method, while the average value of Δb reflects the relative positioning precision of the SRD. Generally, Δb is much smaller than b, when two stations are not far away from each other. So, the relatively positioning precision by using the SRD method is higher than that by using the usual SLR dynamic method. The closer the two relevant station are, the more accurate the baseline will be. When the length of a baseline is beyond the altitude of a satellite, the SRD method will not be significant. In other words, SRD is only suitable for local and regional deformation measurement, but not for global movement measurement. This method has already been studied in the similar environment, see e.g. Pavlis (1985)[4]. In the present study some difficulties have been removed, and improvements have been made in order to apply it for real data processing.

2. Actual realization of the SRD

2.1 Forming the data of the simultaneous range differences

Since LAGEOS is a passive satellite, it is generally impossible to obtain rigorous simultaneous laser range from two stations in practice. But the SLR technique has been developed into the third generation. The dense data can be acquired with the third generation laser range system without any difficulty. The vast majority of the global stations usually have have the capability to provide thousands of full-rate data per pass. If the two stations have an overlap for one pass in observing time, then it is possible to create quasi-simultaneous events. A succesful way generating them requires the detection and rejection of outliers in the full-rate data, the correction of all kinds of system errors, and smoothing and suitable interpolating of data. In our experiment simultaneous range data for a pair of co-observing stations have been created in the process of generating normal point from full-rate data, in which Chebyshev polynomials or spline functions have been applied for interpolation according to the extent of datum's density. As the data are dense, Chebyshev polynomials have been used. As the data are sparse, Spline functions have been used. When one of the both stations only has tens observations per pass, the data of another station must be dense and exceed hundreds observations per pass. The data of later might be smoothed and interpolated. Then the simultaneous data will be created.

In accordance with our experience, the precision of SRD by above the process can usually be superior to the level of the real errors. For example the simultaneous ranges created for QUINCY and MNPEAK both stations have the precision superior to 1 cm.

2.2 Estimation of baseline vectors

In this method the "measurements" are the (quasi) simultaneous range differences, i.e. $\Delta\rho_{o_{ij}} = \rho_{o_i} - \rho_{o_j}$. The equation estimating the three baseline vector components is shown

$$\Delta\rho_{ij} = \Delta\rho_{o_{ij}} - \Delta\rho_{c_{ij}} = \left(\frac{\vec{\rho}_{c_i}}{\rho_{c_i}} - \frac{\vec{\rho}_{c_j}}{\rho_{c_j}}\right)(\Delta\vec{r} - \Delta\vec{R}_j) - \frac{\vec{\rho}_{c_i}}{\rho_{c_i}}\Delta\vec{R}_{ij} + \varepsilon \qquad (3)$$

where $\vec{r} = (x, y, z)^T$ is the satellite position vector, $\vec{R}_i = (X_i, Y_i, Z_i)^T$ is the ith station position vector and $\vec{R}_j = (X_j, Y_j, Z_j)^T$ is the jth station position vector,

$\vec{R}_{ij} = \vec{R}_i - \vec{R}_j$ is the baseline vector between the ith station and the jth station. For convenience' sake, the vectors discussed are in earth-fixed coordinate system. The subscript "o" represents measurements, the subscript "c" represents computed measurement; $\vec{\rho}_{c_i} = \vec{r} - \vec{R}_i$, $\vec{\rho}_{c_j} = \vec{r} - \vec{R}_j$, $\Delta\rho_{o_{ij}} = \rho_{o_i} - \rho_{o_j}$; is measurement of SRD, $\Delta\rho_{c_{ij}}$ is relevant computed measurement.

In equation (3), the value of the first term's coefficient $(\frac{\vec{\rho}_{c_i}}{\rho_{c_i}} - \frac{\vec{\rho}_{c_j}}{\rho_{c_j}})$ decreases with the satellite altitude's increase and the minimization of the distance between the ith and jth stations. Here, in the example of determining the baseline between QUINCY and MNPEAK, this coefficient's maximun value is not beyond 0.1. In accordance with the precision of the determining satellite orbit (superior to 10 cm) and the determining station coordinates (superior to 5 cm), the affection of the first term in (3) is not beyond 1 cm. Neglected the term, the equation (3) can be simplified:

$$\Delta\rho_{ij} = -\frac{\vec{\rho}_{c_i}}{\rho_{c_i}}\Delta\vec{R}_{ij} + \varepsilon \tag{4}$$

Precisely, the equation (4) is just the equation of the determination baseline vector with the SRD method. The adjusted parameters are only the corrections of the three baseline vector components. It is very convenient to solving the parameters.

In this method, corrections used in the usual dynamic method are applied here, such as tide deformation, tropospheric correction. Satellite positions and velocities and the ith station coodinates are fixed to a previous dynamic solution. To ensure obtaining high accuraty and the high temporal resolution's solutions of the baseline vector, the satellite orbit and the measuring station coordinates must reach the level of a precision required. As stated in Section 1 the SRD is only less affected by the orbit errors, but not unaffected by them. Therefore it is necessary to determine a priori orbit as accurate as possible. The 5 day arc orbit is adopted in this experiment, which has been processed for the routine Earth orientation Parameter determinations from LAGEOS data. The accuracy of the determination of the orbit of LAGEOS satellite is about 5 cm for each 5-day arc from the overall weighted RMS fit of the laser observations to the orbits. In the process of solving, measuring station coordinates were acquired from International Terrestrial Reference Frame ITRF91 founded by International Earth Rotation Service IERS. To ensure that every solution of baseline vector is independent of each other, the satellite orbit used here is inadvisable to fit long arc orbit.

There is a problem that the data of how many passes might be used to solve an independent baseline vector. This does ensure that the solution has not only stable but also high temporal resolution. According to our experiences, if the data of a single pass is used to estimate the baseline components, the solution is not stable. There are high correlations between the three unknowns (as high as 0.98). Consequently, the data from two consecutive passes are used to generate one set of solution. In this case the solution is not only stable (less correlation) but also more reliable, as the effects of orbital errors and other error sources are further reduced. Using the data of more than two passes has not very influences on increasing the stability, but that decreases the temporal resolution. So, using the data of two passes to generate a stable and independent solution of a baseline vector is suitable. Especially using the data of two consecutive passes, we can acquire more high accurate solution of a baseline vector due to offsetting each other a kind of influences of orbital errors, etc..

2.3 The maintenance of the terrestrial reference frame

In the SRD method, because the measurement is simultaneous, the variation of the terrestrial reference frame has no influence on the determination of the baseline length between the stations. However, in order to monitor the regional crustal deformation's feature, it is requirement that not only the baseline length's rate but also the variable rates of the three baseline vector components be determined. Therefore the terrestrial reference frame used in this method must be a self-consistent and unitary. The problem of the maintenance of the terrestrial reference frame must be considered carefully in the SRD method. In our research work, the coordinates $\vec{r}_{(t)}$ of the global stations maintaining the terrestrial reference frame were calculated as follows:

$$\vec{r}_{(t)} = \vec{r}_{t_0} + \dot{\vec{r}}(t - t_0) \tag{5}$$

where the station coordinate $\vec{r}_{(t_0)}$ on epoch t_0 and the velocity of the station coordinate $\dot{\vec{r}}$ are taken from ITRF91[5] and its associated velocity field.

3.Results and Analyses

As a test of using the SRD method to monitor regional deformations, we determined the baseline change rate between QUINCY and MNPEAK stations located on both sides of San Andres fault with the full-rate data from 1985 to 1990 of LAGEOS satellite laser range. Table 1 to Table 5 gives the overall changes of the baseline components and the baseline length from 1985 to 1990. From these tables we can see that the precision (repeatability) of the baseline vector determined from each two-pass solution is very high: about 1cm for baseline component and 3-4mm for baseline length; since the latter is not affected by the reference frame error, its accuracy is better than the former.

From above the results solved, the variations of the baseline vector are:

$$dBx = -15.0 \pm 3.4(mm/yr), dBy = -20.2 \pm 2.5(mm/yr),$$
$$dBz = -15.2 \pm 2.6(mm/yr), dB = -26.9 \pm 2.1(mm/yr).$$

As a comparison, table 6 gives the results derived from the geologic models: M/J AM0-2, NNR-NUVEL1; the results acquired from the SLR data of LAGEOS for more than 10 years: SSV(CSR)91L03 of the Center Space Research of Texas university of the United States, SSC(DUT)91L01 of Delft university of the Netherlands[6], and ITRF92 of combined solutions (included VLBI,SLR,GPS) of IERS[7].

Using 16 baseline solutions within the time span of 49 days of table 4, the baseline change rate estimated is -0.2055mm/day (-7.5cm/yr) with standard error 0.043mm/day. Fig.1 gives the variation of the baseline length in the 49 days. From Table 4 and Fig.1

we can see that even some "fine structure" of the variations at sub-centimeter level could be determined in a relatively short time. Currently we are still not sure whether it is real "geophysical information" or only the noise. Besides, the "secular change" determined in 1988 are different from that of the overall solution. It might indicate that the baseline vector does not change linrarly.

All these show enough the potential capabilities of the SRD method in measuring the regional crustal deformations with very high precision and temporal resolution and demonstrate clearly that the SRD methodis really a very attractive way for monitoring regional and local deformations.

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THE SATELLITE LASER RANGING SYSTEM AT WUHAN STATION

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Abstract

This paper discribes briefly the 3rd generation Satellite Laser Ranging System at Wuhan station including its hardware and software. Through the observation practive over three years, it can be concluded that, first, the 3rd generation system can observe all laser satellites at night, is also has some observation ability in Earth's shadow, and the single shot ranging accuracy may come up to 2—4 cm, second, through real-time track and control by using a PC computer, the automatic level and hit-rate of the observation are improved obviously, third, an urgent need is strongly felt to develop the day-time ovservation technology, so as to increase the observation quantity and improve the time distribution of the ranging data.

Key words: SLR station, performance improvement.

Introduction

At the end of 1986, according to the necessity of earthquake prediction research, geodesy and the actual conditions, Institute of Seismology, State Seismological Bureau and Institute of Geodesy and geophysics, Chinese Academy of Sciences, decided to upgrade the 2nd generation Satellite Laser Ranging System[1] developed by Institute of Seismology to the 3rd generation, the ranging accuracy of the new system was expected to be improved from 15cm to 5~7cm. First return signals from ultra-short pulse transmitted to the LAGEOS satellite are received on the 4th June, 1988. The single shot accuracy reached 8. 2cm. After the improvement of part of the optics and electronic circuits, and adoption of realtime tracking with a micro computer, the observing accuracy has been further improved. By the first half of the of 1989, the accuracy was stabilized at 5~7cm. Meanwhile, the development of a set of data processing software system was completed including the prediction of observing period, data preprocessing, and the designing of the format for data sending. Therefore the Wuhan SLR. station was possessed of a condition for the routine observation. After a long time test operation of the hardware and software, the observing data has been sent formally to NASA Goddard Laser Tracking Network (GLTN) since August, 1989. In April of 1990,ETALON Satellite in an orbit at an altitude of 20,000km launched by the former U. S. S. R. was observed. In the meanwhile, the single shot accuracy reached 2~4cm with model PM2233B photo-multiplier replaced by Model F4129 micro-channel plate (MCP) photo-multiplier[2]. In August, 1991, ERS-1 satellite launched by the European Space Agency was also tracked and observed. Because the satellite has a sun-synchronous circular orbit, when observed at night, it is always in the earth's shadow. The successful observation of the ERS-1 satellite shows that our equipment has a capability of tracking in earth's shadow.

This paper introduces briefly the hardware and software system of the Wuhan's 3rd generation SLR system and provides the general situation of the ovservation for LAGEOS in 1992.

Hardware System

Laser

The laser is a mode locked Nd:YAG system with doubled frequency. The total device includes an oscillator,a pulse slicer,first-stage, second-stage and third stage amplifiers and a frequency-doubling KDP crystal. The produced pulses have repetition rates of 1—5pps, The energy, wavelength and width of each pulse are 50mj, 532nm and 150ps, respectively. Laser beams are aimed at the satellite through a coude path and a transmitting telescope of Galilean Constraction.

Mount

A horizontal structive with two axes is used for the mount. The left and right yoke arms support the receiving telescope (diameter 60cm),trasmitting telescope (diameter 10cm) and guiding telescope (diameter 15cm) In order to track LAGEOS visually, the mount is equipped with a SIT TV system. The rotation axes of elevation and azimuth are driven by two dc-torque motors. The elevation and agimuth positions are displayed by two axis-angle synchronistic inductor with a resolution of one arcsec.

Receiving electronic equipment

Receiving electronic equipment consist of a MCP photomultiplier tube (ITT F4129), two amplitiers (H/P 8447D), two constant fration discriminators (Canberra 1428A) and a time interval counter (HP 5370B resolution 20ps). The start pulse is detected by a photodiode (hamamatsu S—2381) at just after first mirror of the Coude path. The external frequency standard of the counter is provided by a cesium clock.

The UTC time system and frequency standard.

Time and frequency are yielded from HP 5061A cesium-beam frequency standard. A long-term comparision of the primary cesium clock with a Loran-C receiver and two other cesium frequency standards comfirms that its stability and accuracy are better than 3.10^{-12}. The cesium clock, when compared with the portable clock in the Astronomical Observatory of the U. S. Navy has an auuracy better than 5μs in UTC time. Since 1994 a GPS timing receiver is also used as a UTC time standard.

Computer and numerical guide system

An IBM PC 386 Computer is used as the control center of the satellite laser ranging system at Wuhan Observatory. Real-time clock, range gate controller, data acquistion and shooting controller etc. are combined on two extending circuit boards to be installed on the extension slots of IBM computer. The prediction calculation of satellite observing time and every observing pass, data processing, numerical track guiding, software managing etc. are all transplanted to this computer. While working, the telescope is automatically guided towords the satellite by track contral part with the calculating results from ephemeris. In order to improve tracking accuracy, the tracking parameters (UTC time, azimuth, elevation) can be displayed and corrected in real-time during the observation, so that, some of the status of the system and computed results are shown on CRT colorfully and in picture.

Table 1. shows the specification of the satellite laser ranging system at Wuhan.

The Processing Software System of the Routine Data

Companying with the improving of the hardware, we developed a set of data processing software system to satisfy the needs for the routine work of the satellite laser ranging. It includes the prediction of satellite observing time and every pass observing data dispatching format edit etc[3]. Because this software improves the ephemeris by using the observational data of the single station and single pass, the accuracy of prediction is raised. Meanwhile, because of using the method of the deleting noises with interval rate limitations, inhance a great reduction of observing noise and a higher signal-noise resolving ability. This software also can inspect some breakdowns of the hardware, such as the problems of the jump of the counter, the multi pulse phenomena and UTC time sub-system error etc. Thus it enhances the

Table 1. the specification of the satellite laser ranging system at Wuhan

Subsystem	Specification
Mount	
Configuration	elevation-azimuth
Tracking velocity	18 arcsec-5°per second
Synchronistic inductor	resolution 1 arcsec
Drive	DC torque motors
Orthogonality	±4 arcsec
Laser	
type	Nd:YAG
Wave length	532nm
Energy	50mj
Pulse width	150ps
Repetition	1-5pps
Receiving telescope	
Type	Cassegrain
Diameter	60cm
Field of view	1′—6′ or 1°(use for guiding satellite)
Filter	1nm
Transmitting telescope	
Type	Galilean
Diameter	10cm
Beam divergence	0. 6′-3′ can adjustable
Guiding telescope	
Diameter	15cm
Field of view	3°
Receiving electronics	
PMT	ITT F4129 MCP
Amplifier	H/P 8447D
Discriminator	Canberra 1428A
UTC clock	
Type	Cesium H/P 5061A and GPS
Stability	1×10^{-12}
Accuracy	$<$300ns
Time interval counter	
Type	5370B
Resolution	20ps
Micro computer	IBM PC/386

development of the whole equipment system. The following is a brief introduction of the main programmes.

The prediction of the observing period

Based on the ephemeris of satellite published by GLTN every week and the station coordinates, this program can calculate every satellite's horizon plane coordinates in the station and whether it is in the earth shadow, mark the number of passes which every satellite could exceed the height limit above the station, then list and output the results in the table according to the time order. (including the beginning and end time of every pass, the highest altitude and if it was in the earth shadow). This program can predict twenty satellites simulaneously, in general once every month.

The observing prediction for every pass

This program set runs before observing. According to the beginning and end time of the satellite for every pass predicted, the program calculates the satellite's horizon plane coordinates at a certain time interval (such as a second), and the distance between the satellite and the reference point of station, and then make a file stored on computer. These data are used in real-time tracking of the satillites or the preprocessing of the observation data. Base on the different prediction format this program set provides the metnodes of the numerical integral or analytics. It also provides the correction of the atomsphere refraction and the flying time of the laser pulse.

The program set for observing data preprocessing

This program set runs after the observation of every pass. Its main functions are: to reject the observing noise, to estimate the observing accuracy and the ephemeris correction value.

"The method of the deleting noises with interval-rate limitations" is employed in the processing of rejecting noise[4], which was advanced by ourselves combined with the method of the polynomial fitting, this method has stronger signal-noise resolving ability. The ephemeris correction values obtained by the estimation have obviously improvement for the pridiction of next pass. The program set makes effective observation results and ground target, meteorology data, etc. into a file for sorting out and transmitting.

The program set of sort out the data

According to the requirment of GLTN, this program set will make a quick-look data or normal point telex file with effective observing data of every pass and targeting, meteoroloy data. After adding correction of the time system, it makes the effective observing data of every month into a file based on the internationally prescribed forms (MERIT-Ⅱ), so as to be memorized and exchanged easily on disk.

The LAGEOS Oberving Situation of Wuhan Station in 1992

Since 1990, we can have observed all laser satellite which were appointed in international agency. Tab. 2 lists the ovserving situations of LAGEOS satellite in 1992 at Wuhan station. The quick-lock data analysis center of the Delft technology university, Netherland, monitors the crustal deformation of the Mediterranean are using the LAGEOS data all over the world. Every week they issue a bulletin in which they list the adopted data and the observational accuracy through reduction. Tab. 2 shows that the ovservating accuracy is on the level of 2—4cm. On the other hand, it can be seen that the adopting rate of the observation points (contain telex error) is very high. So it has proved that the software of processing data at Wuhan station is good.

Figure 1 shows the accuracy ERS-1 observation since July 1991, the results is achieved from the GFZ/D-PAF in Germany.

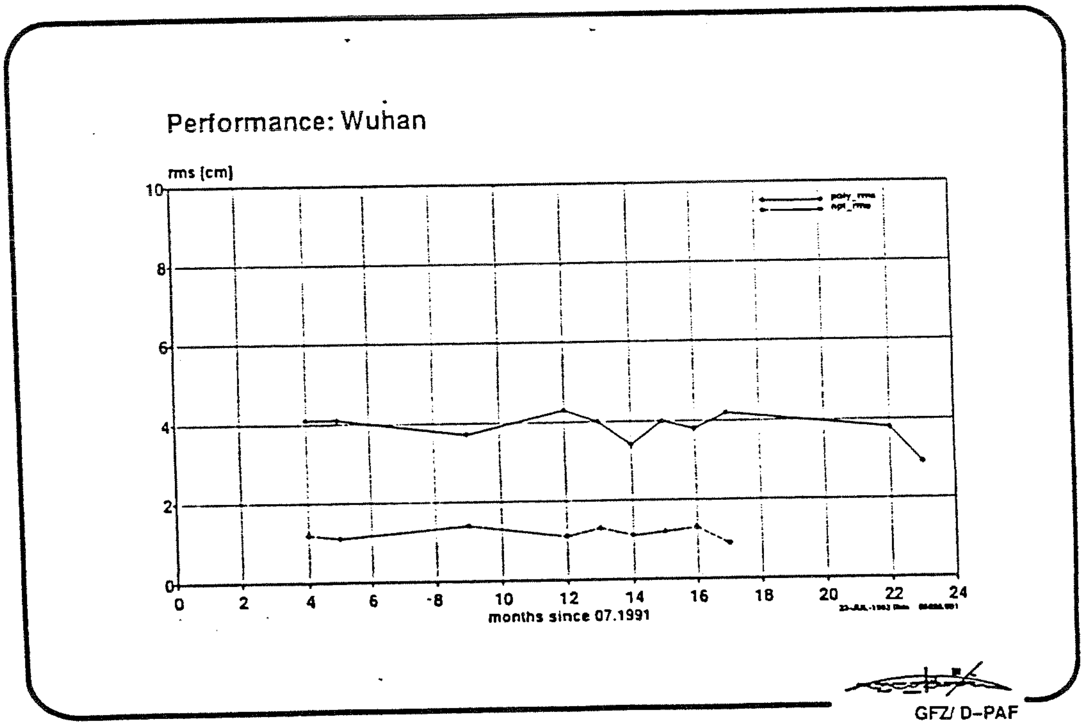

Figure 1 The accuracy of ERS-1 observation since July, 1991.

Conclusion

Based on the practical observation of the SLR system at Wuhan station

Tab 2. The observation situation of Wuhan station in 1992 for LAGEOS

Data	No. of passes	Q/L points sent	Q/L points adopted	RMS_1 (cm)	RMS_2 (cm)
LAGEOS-1					
1992. 1. 15-16	2	88	86	2. 7	0. 9
2. 24	2	96	93	2. 0	0. 8
4. 4	1	52	52	2. 1	1. 3
5. 10	1	50	49	2. 0	0. 9
6. 4-8	3	140	139	1. 9	1. 1
7. 29-2	2	86	77	1. 8	0. 1
8. 16-19	2	101	100	2. 1	0. 9
8. 29	1	42	41	4. 3	1. 4
9. 22-24	2	84	82	2. 7	0. 8
9. 30	1	49	49	2. 0	0. 7
10. 8	1	49	47	1. 2	0. 5
10. 18-26	3	140	133	2. 6	1. 9
10. 26-29	4	after here the normal points are sent			
10. 31	1				
11. 9-12	3				
11. 13-17	3				
11. 20-22	3				
12. 16	1				
LAGEOS-2					
10. 18-26	1	50	50	2. 1	1. 7
10. 26-29	2	after here the normal points are sent			
11. 9-12	3				
11. 13-17	2				
11. 20-22	2				
12. 16	2				

over three years, it may be concluded that.

(1) The 3rd generatior system can observe all laser satellites at night, it also has some observation ability in earth's shadow and the measureing range and accuracy of the system come up to 20, 000km and $\pm 2-4$cm respectively.

(2) Through real-time track and control by using a pc computer, the automatic level and hit-rate of the observation are improved obviously.

(3) An urgent need is strongly felt to develop the day-time observation technology, so as to increase the observational quantity and improve the time distribution of the ranging data.

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Determination of the Gravitational Coefficient of the Earth from Lageos

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September 25, 1992

Introduction

The value of the gravitational coefficient of the Earth (GM) is an important parameter in the determination of the scale of the coordinate system realized by satellite observations. With improvement in satellite laser ranging and with the orbiting of satellite such as Lageos, which was designed to minimize the effects of non-gravitational forces, the ability to estimate GM has improved significantly. More recently the GM of the Earth has been determined by the University of Texas Center for Space Research [Ries,Eanes and Huang etc].

the purpose of this paper is only a test to determining the GM from 60 days of laser ranging to Lageos in the estimation method called "multistage-multiarc".

Analysis of Error Sources

The precision of determining the value of GM with the SLR technique depends mainly on both measurement and satellite dynamical model errors.

(1).Observation error: In the recent years the single short laser measucment precision has reached an order of 1-5cm, for normal point even better.

(2).Satellite dynamical model errors: In the presence of observational data available in quantity and quality, the error of determining satellite is the major error source in determining the GM with SLR. Such an error comes from the inadequate modeling and unmodeling of dynamic factors. For example, the error of the GEM-T1 earth gravity model affects the GM measurement.

(3). Error of the GEM-T1 earth gravity model: It should be considered whether the M in the parameter GM includes the mass of the atmosphere before the GM is determinedfrom a multi-arc solution using laser range to near-Earth satellite. In order to evaluate a gravity field model, the data of satellite ranging and altimetry and the earth's surface data of free air gravity anomalies must be used. The value of GM used in the earth's surface data should be different from that used in calculating the perturbation of the satellite orbiting. On the basis of the potential theory, the M in the GM used in the earth's surface data does not include the mass of the atmosphere, and it is only the mass of the solid Earth.

The mass of the atmosphere may be neglected in the earth gravity field. But in the long-arc orbit determination of satellite, that is needed. Usually the gravitational force perturbation of the mass of the atmosphere surrounded by the orbit surface of the satellite was neglected. The mass of the atmosphere out of the near-circle orbital surface of the satellite does not cause any gravitational force perturbation to the satellite.

The Multistage-Multiarc Method

In the usual long-arc solution of the satellite motion, the precise satellite state, the Earth orientation parameters, and dynamical parameters(including the GM) are all estimated simultaneously. These adjustable parameters can be divided into three groups: (1) The global parameters include the station coordinates and certain geophysical constants, such as GM, that are adjusted in the entire long arc (several months) in order to obtain stable and reliable results. (2) The first-stage local parameters, such as the orbit elements, are separately adjusted in different subarcs (10 or 15d) so as to reduce the effect of some unmodeled perterbations and obtain stable solutions. (3) The second-stage local-subarc (1-5d) to the next so as to model properly their variation.

For this big, time-consuming job, we designed a software package embodying a "multistage-multiarc" procedure in order to save running time and storage on the computer[Miaofu,Wenyao and Chugang].

Let $X(i.j)$ be the state correction vector of the second-stage local parameters in the ith sub-subarc of the jth subarc; $Y(j)$ be the state correction vector of the first-stage local parameters in the jth subarc; Z be the state correction vector of the global parameters. Here $i=1,2,\ldots,n$; $j=1,2,\ldots,m$; n and m are the number of sub-subarcs in each subarc and the number of subarcs in the whole long arc, respectively.

The adjustment for whole long arcs is to be accomplished step by step from one sub-subarc to the next.

Applying a series of Givens-Gentleman orthogonal transformation to the data of a sub-subarc, we obtain the following normal equation:

$$D_{ij}^{1/2}\begin{bmatrix} U_{X(i,j)} & R_{Y(j)X(i,j)} & R_{ZX(i,j)} \\ & U_{Y(j)} & R_{ZY(j)} \\ & & U_Z \end{bmatrix}\begin{bmatrix} X_{(i,j)} \\ Y_{(j)} \\ Z \end{bmatrix} = D_{ij}^{1/2}\begin{bmatrix} B_{X(i,j)} \\ B_{Y(j)} \\ Z_Z \end{bmatrix},$$

$$D_{ij}^{1/2} = \begin{bmatrix} D_{X(i,j)}^{1/2} & & \\ & D_{Y(j)}^{1/2} & \\ & & D_Z^{1/2} \end{bmatrix},$$

where $D_{X(i,j)}^{1/2}$, $D_{Y(j)}^{1/2}$, $D_Z^{1/2}$ are the nonsingular diagonal matrices, and $U_{X(i,j)}$, $U_{Y(j)}$, U_Z are the unit upper triangular matrices. Following the calculation for the ith sub-subarc, the values obtained $D^{1/2}_{X(i,j)}$,$U_{X(i,j)}$,$R_{X(i,j)Y(j)}$,$R_{X(i,j)Z}$ and $B_{X(i,j)}$ related to *X(i,j)* are stored which have no influence on the next sub-subarc, while the following matrix and vector that have been calculated for the jth subarc

$$\begin{bmatrix} D^{1/2}_{Y(j)} & \\ & D^{1/2}_{Z} \end{bmatrix} \begin{bmatrix} U_{Y(j)} & R_{ZY(j)} \\ & U_Z \end{bmatrix} \; and \; \begin{bmatrix} D^{1/2}_{Y(j)} & \\ & D^{1/2}_{Z} \end{bmatrix} \begin{bmatrix} B_{Y(j)} \\ B_Z \end{bmatrix}$$

are taken as the a *priori* information of *Y(j)* and Z in the process of next sub-subarc.

After the processing of the jth subarc, i.e. finishing the nth sub-subarc,the information $D^{1/2}_{Y(j)}U_{y(j)}$, $D^{1/2}_{Y(j)}R_{ZY(j)}$ and $B_{Y(j)}$ related to *Y(j)* is stored and these will have no effect on the next subarc.

The process runs through the whole long arc from the 1st sub-subarc of the 1st subarc to the nth sub-subarc of the mth subarc. After processing the whole long arc, the best linear, unbiased, minimum variance estimation of $\hat{X}(i,j)$,$\hat{Y}(j)$,and$\hat{Z}$ will be determined by the following expression:

$$\begin{aligned} \hat{Z} &= U_Z^{-1}B_Z, \\ \hat{y}(j) &= U^{-1}_{Y(j)}(B_{Y(j)} - R_{ZY(j)}\hat{Z}), \\ \hat{X}(i,j) &= U^{-1}_{X(i,j)}(B_{X(i,j)} - R_{YX(i,j)}\hat{Y}(j) - R_{ZX(i,j)}\hat{Z}), \end{aligned}$$

and the corresponding covariance matrices can be expressed as

$$\begin{aligned} P_{X(i,j)} &= (U^T_{X(i,j)}D_{X(i,j)}U_{X(i,j)})^{-1}, \\ P_{Y(j)} &= (U^T_{Y(j)}D_{Y(j)}U_{Y(j)} + \textstyle\sum_{i=1}^{n} R^T_{Y(j)X(i,j)}D_{X(i,j)}R_{Y(j)X(i,j)})^{-1}, \\ P_Z &= (U_Z^T D_Z U_Z + \textstyle\sum_{j=1}^{m} R^T_{ZY(j)}D_{Y(j)}R_{ZY(j)} \\ &\quad + \textstyle\sum_{j=1}^{m}\sum_{i=1}^{n} R^T_{ZX(i,j)}D_{X(i,j)}R_{ZX(i,j)})^{-1}, \end{aligned}$$

It can be proved that the results obtained using this technique are the same as those from the overall adjustment of the whole long arc.

Determintion of the value of GM by Lageos Laser Ranging

Owing to the current accuracy achieved by SLR, the realization of the reference system and the force modeling in the data reduction process have to attain comparable accuracy. In our work, the following models have been adopted.

Reference Frame:

Mean equinox and equator of J2000.0; Station coordinates SSC(sha)90 L01; IAU 1976 precession; DE200/LE200 planetary ephemerides; TAI as the coordinate time scale of the earth-centered.

Force Model:

GEM-T1 earth gravity field; luni-solar and planetary gravity perturbation; Wahr solid earth tides; Schwiderski ocean tides; Solar radiation pressure (Cr adjusted); Drag or drag-like perturbation (Cd adjusted); Atmospheric tide; Earth's radiation pressure; Earth's rotation deformation perturbation; Moon's oblateness perturbation.

Measurement Model:

Marini-murray refraction model; Solid earth tides displacement; Ocean loading site displacement; Relativistic correction.

Using the above multistage-multiarc method, the GM, satellite states, Cd, Cr and EOPs were adjusted simultaneously for each long arc. The results and the overall RMS fit of the laser observations to the orbit for each long arc are in Table 1.

Table 1. The value of GM and the RMS fit of the laser observations

Time	GM(km^3/sec^2)	σ	RMS(m)
90.09.19-11.17	398600.43600	0.00001	0.0774
90.05.02-06.30	398600.43600	0.00001	0.0859

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Russian Space Agency

Russian Institute for Space Device Engineering

Science Research Institute for Precision Device Engineering

STATE
and development conception of SLR stations network of Russia and collaborating CIS countries

Prof. V.D. Shargorodsky
Prof. V.P. Vasilyev

RISDE, Moscow, 1994

State and development conception of the SLR network in Russia and collaborating CIS countries

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Prof. V.P Vasilyev, Moscow, RISDE

During the last decade in the framework of the National space geodesy and navigation programs two SLR networks were established by the Russian Institute of Space Device Engineering (RISDE) based on second generation stations with range limits of 3,000 km and 40,000 km. The main purpose of these stations was in-flight laser calibration of regular on-board and ground radio-frequency ranging systems used for measurements of orbital parameters of spacecrafts and satellites. Now they are used for metrological control of spacecrafts with stable orbits.

With the development of international collaboration in two last years some of these stations are taking part in research and applied space geodesy, geodynamics and geophysics programs raising high demands to the measurements accuracy. Therefore a modernization of ranging equipment is done at the regularly operating Maidanak and Komsomolsk-on-Amur stations bringing the accuracy of measurements to a third-generation level, and in the new Russian Space Agency SLR network modern fourth-generation laser rangers will be used with a full-day operation mode.

As the SLR stations in the Ukraine and Kazakhstan will return to the operation, they also will undergo necessary modernizations.

The collection and processing of the measurements data from SLR stations in Russia and the collaborating CIS countries as well as the data exchange with other world centers, is being done by the Flight Control Center in Kaliningrad (near Moscow).

For timing of measurements the GLONASS receivers are used. The data are transmitted by means of E-mail or rented channels.

The RISDE has placed optical retroreflectors on board of more than 30 satellites used for space geodesy, navigation, and research (Ethalon, GEOIC, Meteor, GLONASS, GPS, etc.)

Purpose of the Russian network of optical-laser stations

Precise laser ranging of satellites is used for fulfillment of the following tasks:

In the field of fundamental problems of geophysics and geodynamics

- Centimeter accuracy of geocentric coordinate system
- Specifying of components of Earth's gravity potential
- Study of global changes of solid Earth

In the field of application tasks of astronautics

- In-flight calibration of radiotechnical systems for trajectory measurements of precise space systems
- Metrology control of orbits of navigation spacecraft. Specifying of the model of non-gravity forces influencing spacecraft.
- Operative determination of Earth rotation parameters with higher accuracy for use in space navigation
- Regional tectonics. Earthquakes prognosis

RSA concept of development of SLR stations network

1. Engagement of all SLR stations of CIS created by Russian enterprises in the work according to the agreed program.

2. Assistance for modernization of 2nd generation stations with the purpose to achieve 3rd generation accuracy.

3. Assignment of Mission Control Center (near Moscow) as a center for collection and processing of laser measurements of orbits and for exchange of data with other world centers.

4. Creation in 95-99 of 3 new stations of 3rd and 4th accuracy generations, with implementation of the latest achievements of laser technology and telescope design in the following regions:

- Altay (Russia, Siberia, Zmeinogorsk)
- Cape Gamova (Russia, the South of the Far East)
- near Moscow

5. Support for installation of laser reflectors on board of satellites belonging to navigation and other precise space systems

Operating SLR stations of CIS

LOCATION	Accuracy Generation	Range (km)	Note
Komsomolsk-On-Amur (Russia)	II	40000	1
Maidanak-2 (Uzbekistan)	III	40000	
Balkhash (Kazakhstan)	II	40000	2
Kaziveli (Ukraine, Crimea)	III	20000	
Simeiz (Ukraine, Crimea)	III	20000	
Eupatoria (Ukraine, Crimea)	II	40000	2
Mendeleevo (Russia, Moscow)	II	3000	
Sarapul (Russia, Udmurtia)	II	3000	

COMMENTS:

1. Upgrading for switching to the 3rd accuracy generation is completed
2. Temporary off. Modernization is planned

Laser Ranging Stations of RUSSIA and C.I.S.

(G) Network of the stations "GEOIK"

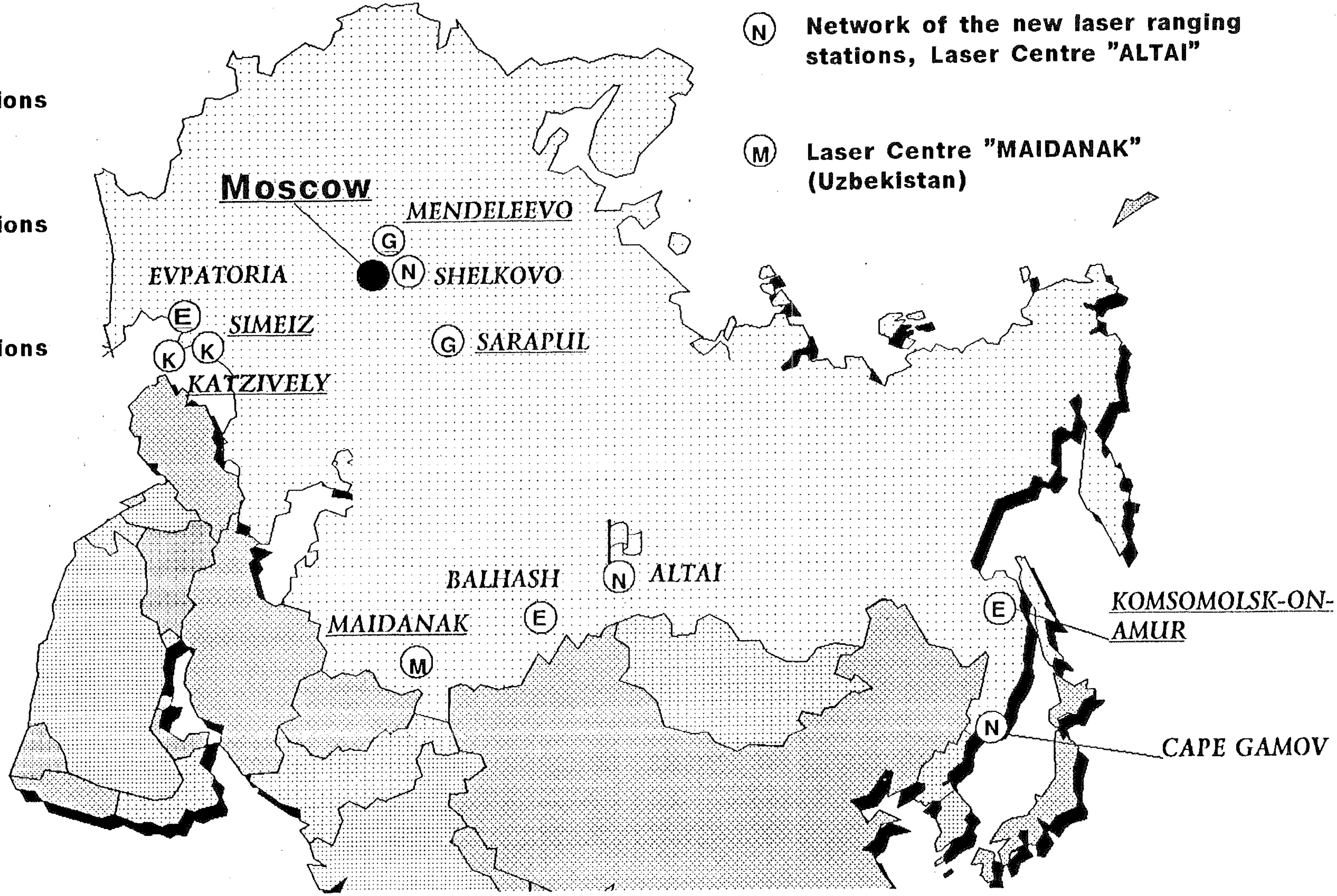
(E) Network of the stations "ETALON"

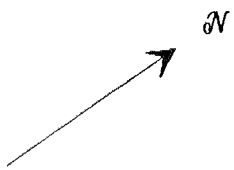
(K) Network of the stations "KRIM"

— SLR acting now are underlined

(N) Network of the new laser ranging stations, Laser Centre "ALTAI"

(M) Laser Centre "MAIDANAK" (Uzbekistan)





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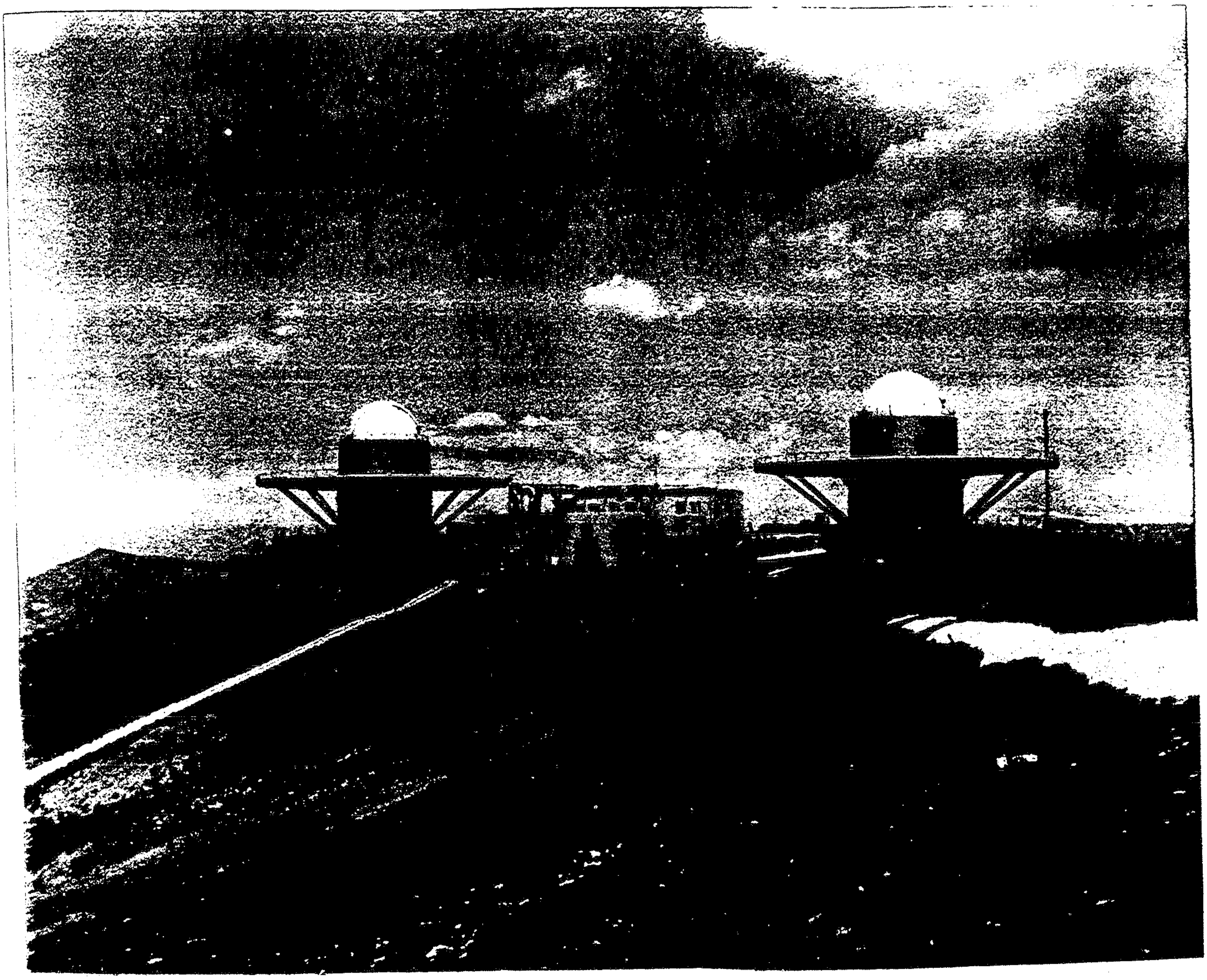
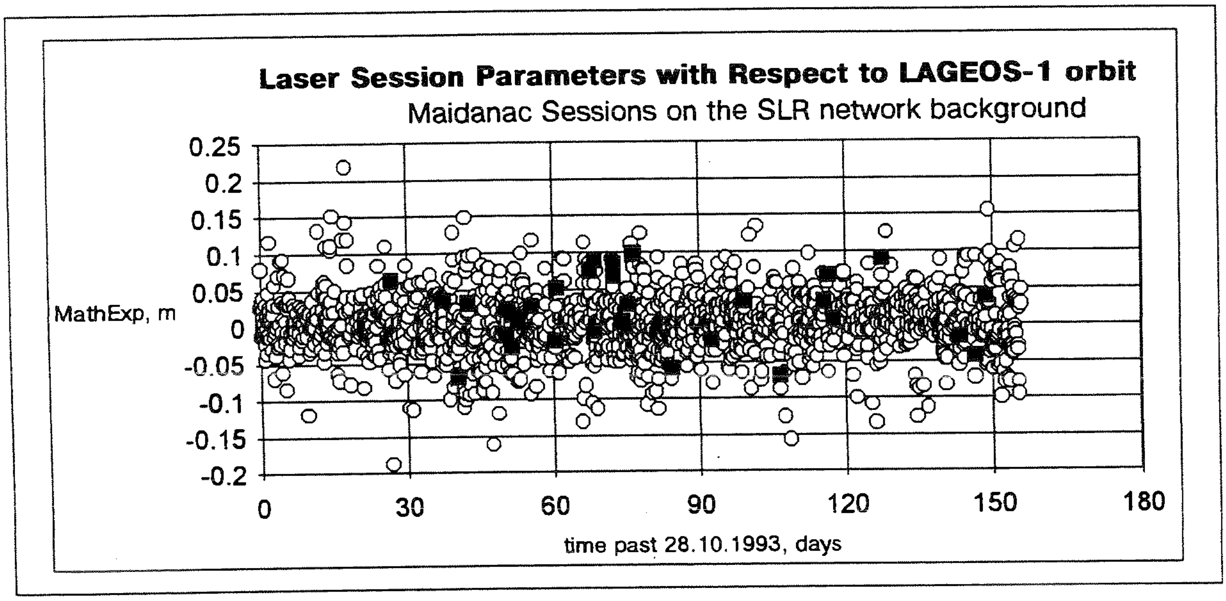
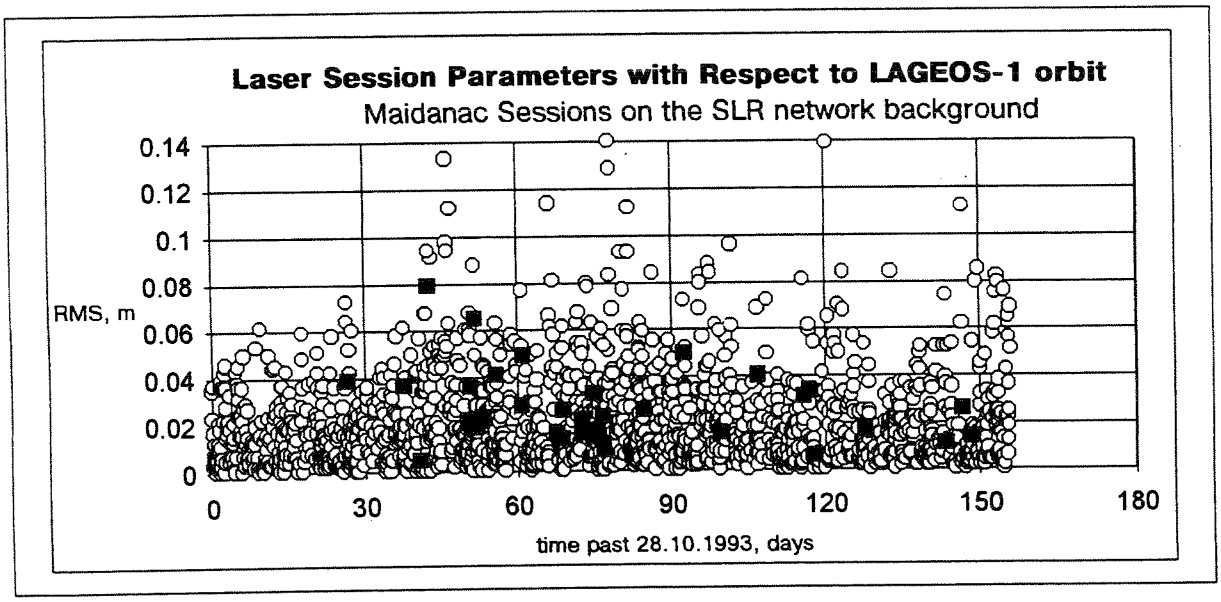


SLR station Maidanak
Outline view of the complex

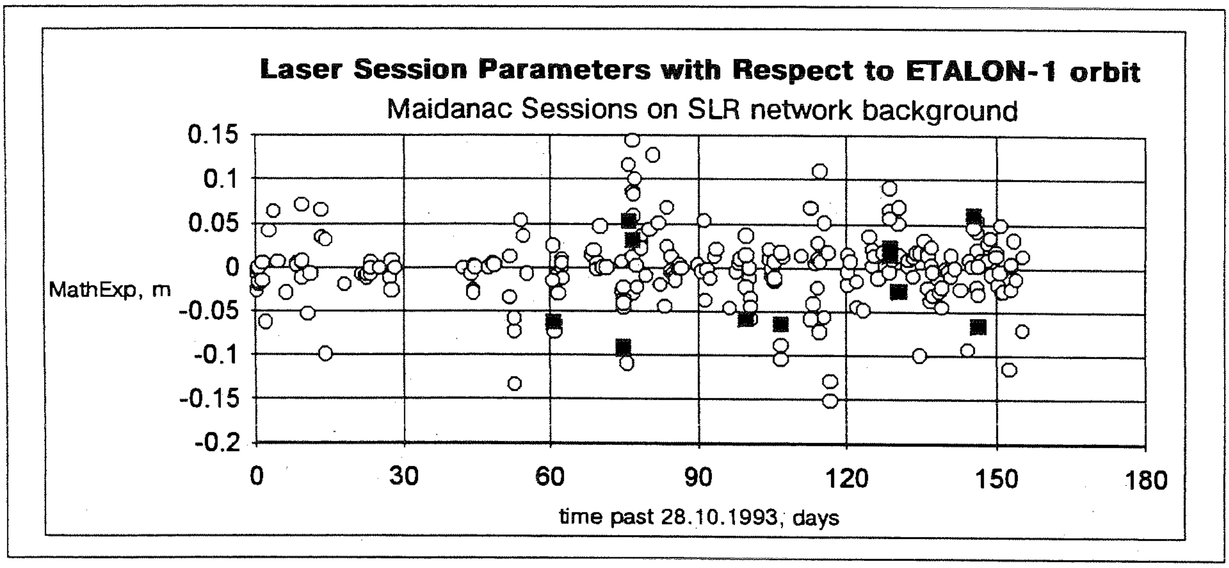
SLR station Maidanak
Telescope

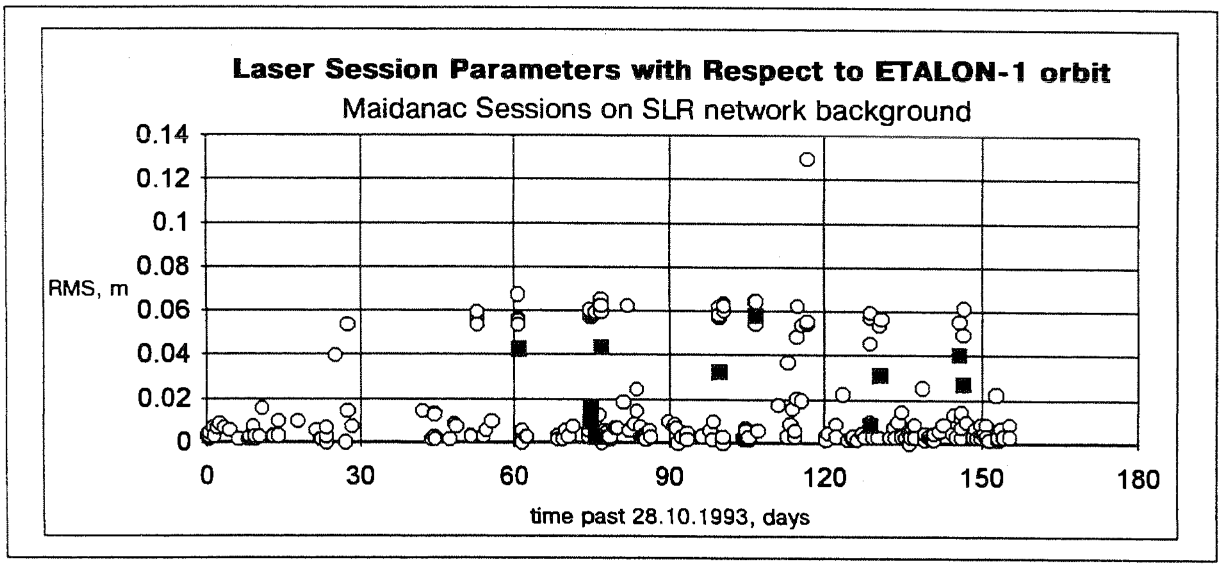


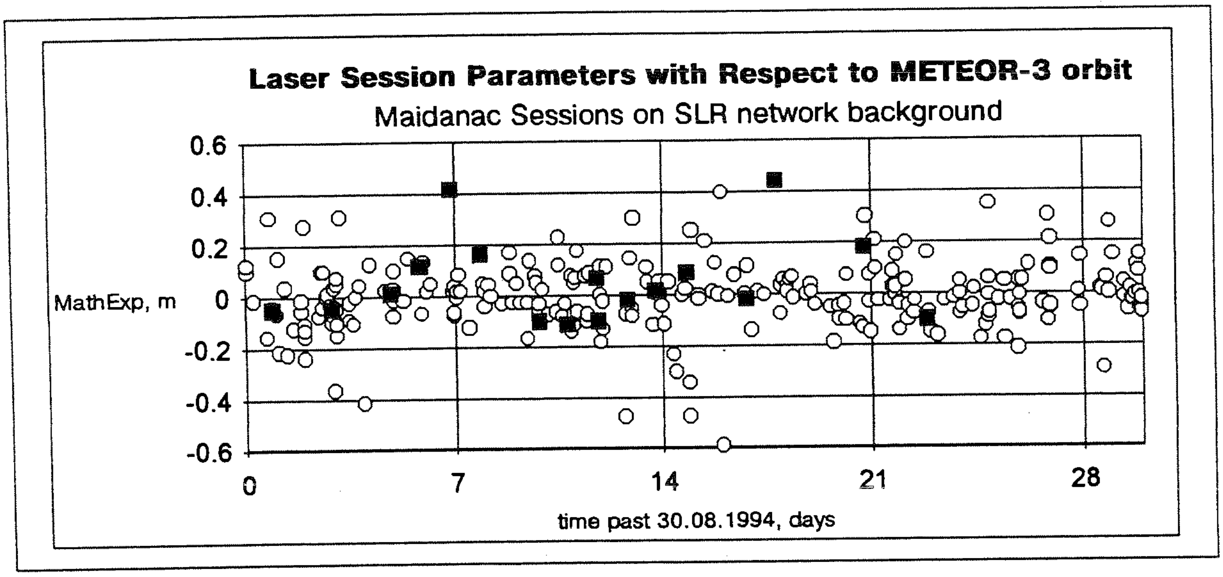
Laser Session Parameters with Respect to LAGEOS-1 orbit
Maidanac Sessions on the SLR network background
MathExp, m
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0
30
60
90
120
150
180
time past 28.10.1993, days

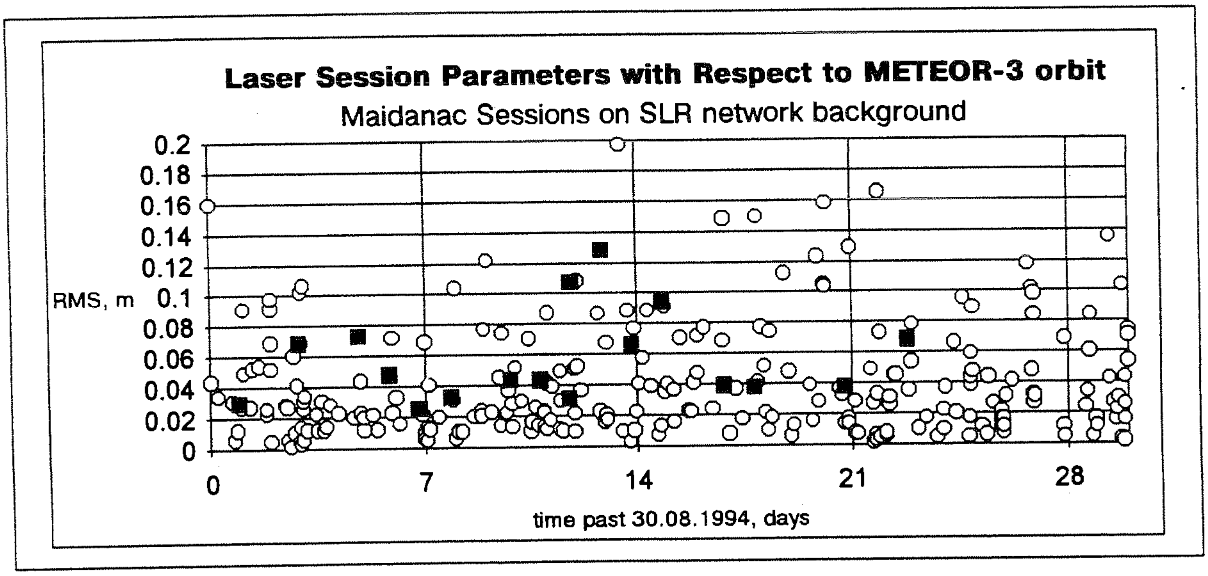


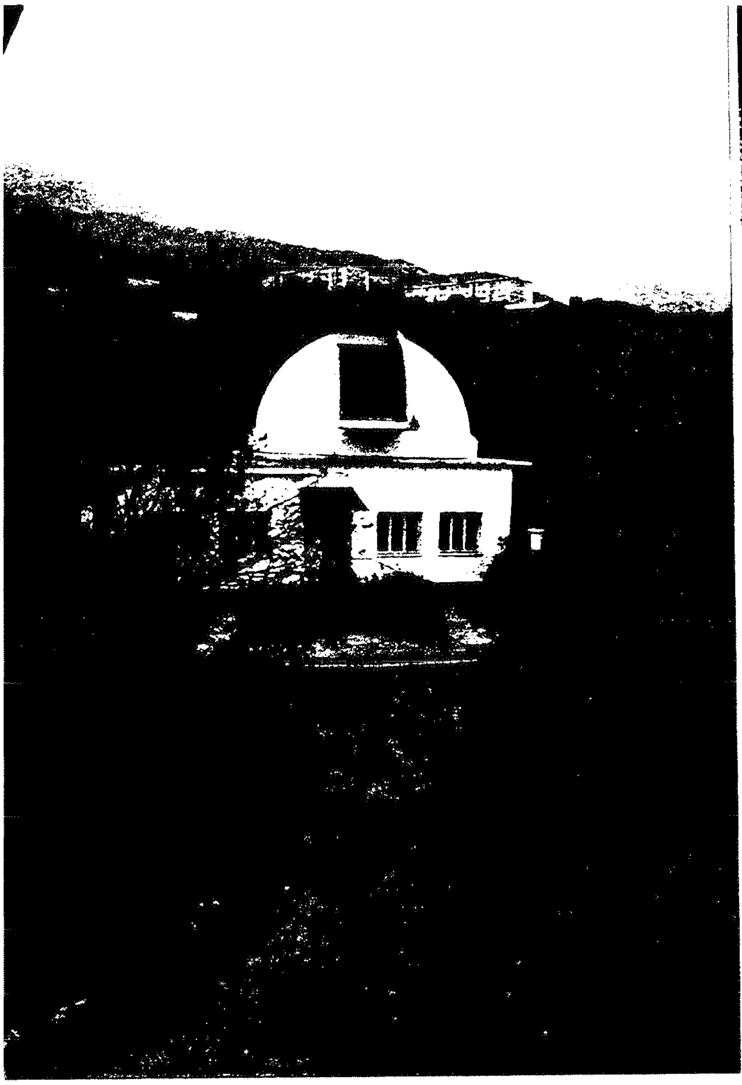
Laser Session Parameters with Respect to LAGEOS-1 orbit
Maidanac Sessions on the SLR network background
RMS, m
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
30
60
90
120
150
180
time past 28.10.1993, days

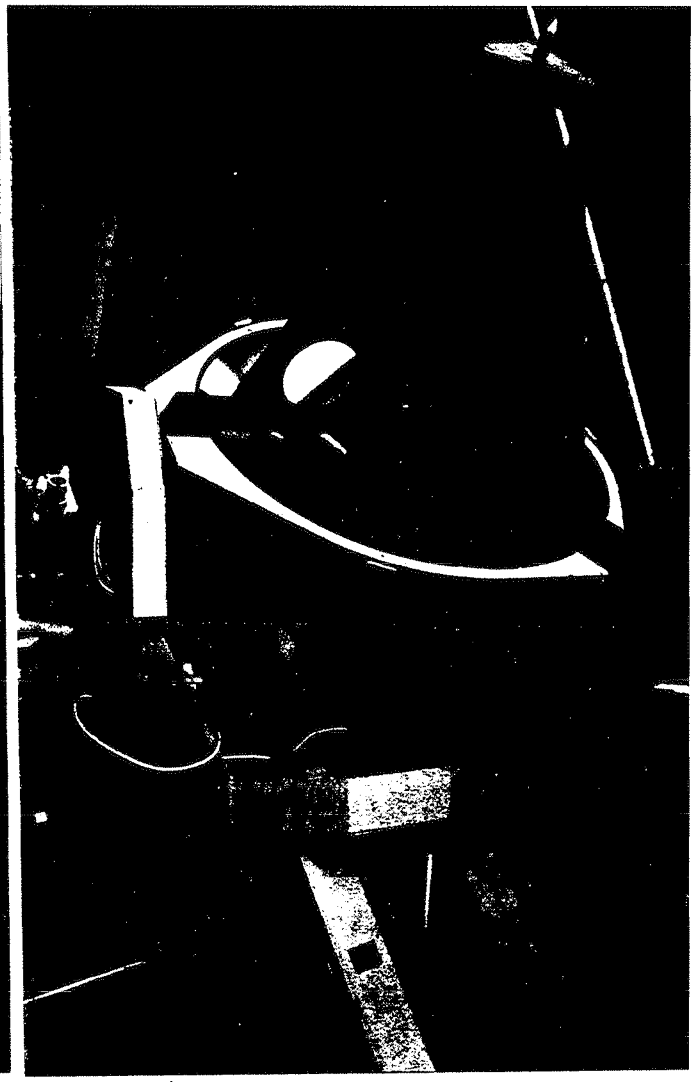

Laser Session Parameters with Respect to ETALON-1 orbit
Maidanac Sessions on SLR network background
MathExp, m
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0
30
60
90
120
150
180
time past 28.10.1993, days


Laser Session Parameters with Respect to ETALON-1 orbit
Maidanac Sessions on SLR network background
RMS, m
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
30
60
90
120
150
180
time past 28.10.1993, days

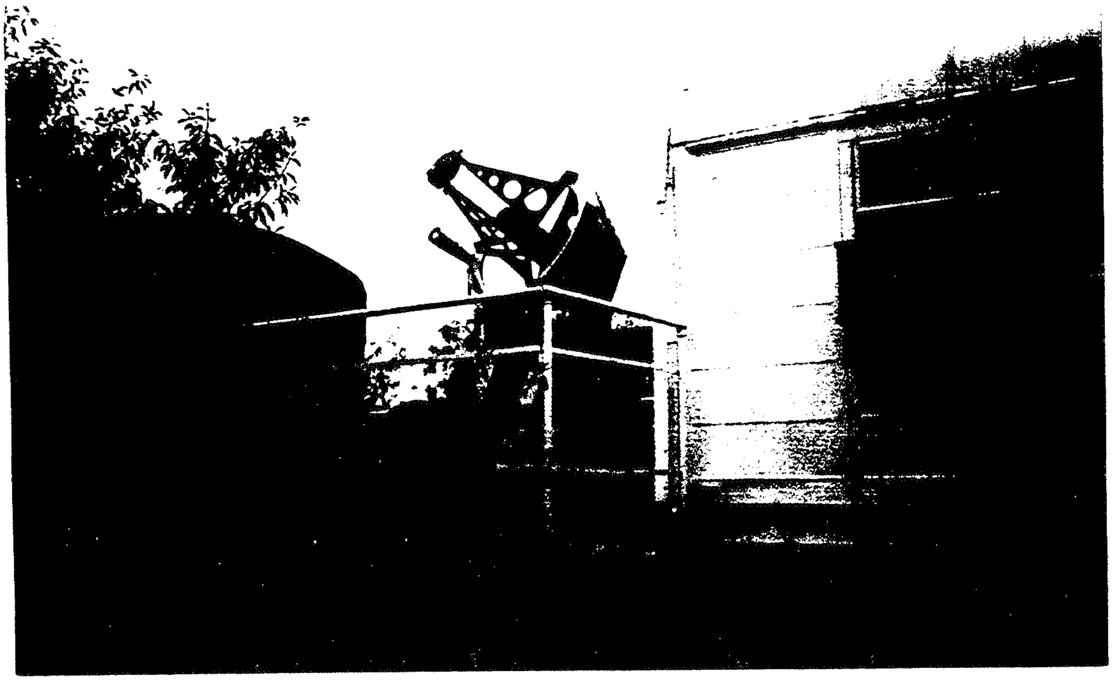

Laser Session Parameters with Respect to METEOR-3 orbit
Maidanac Sessions on SLR network background
MathExp, m
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
7
14
21
28
time past 30.08.1994, days


Laser Session Parameters with Respect to METEOR-3 orbit
Maidanac Sessions on SLR network background
RMS, m
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
7
14
21
28
time past 30.08.1994, days

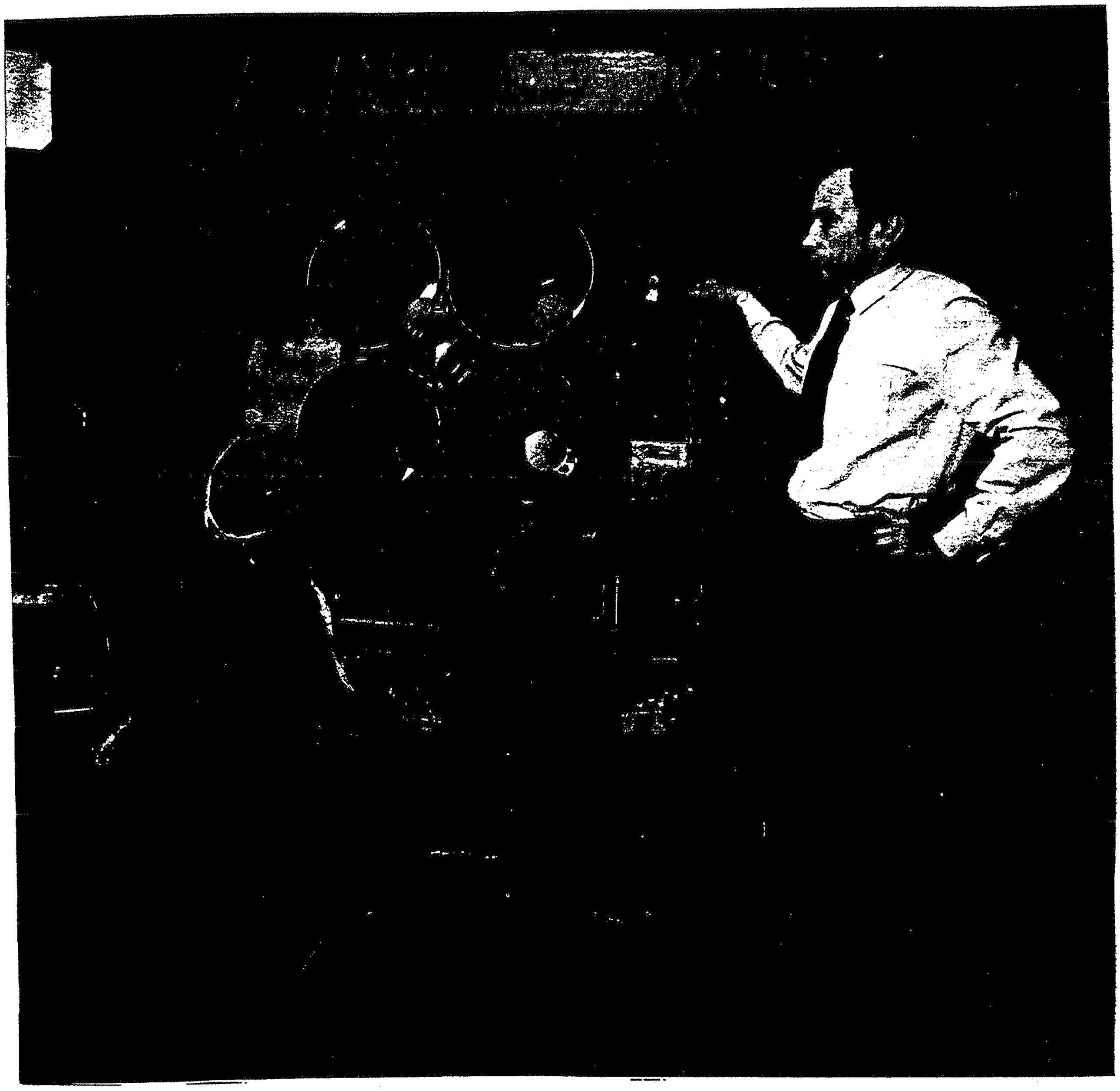




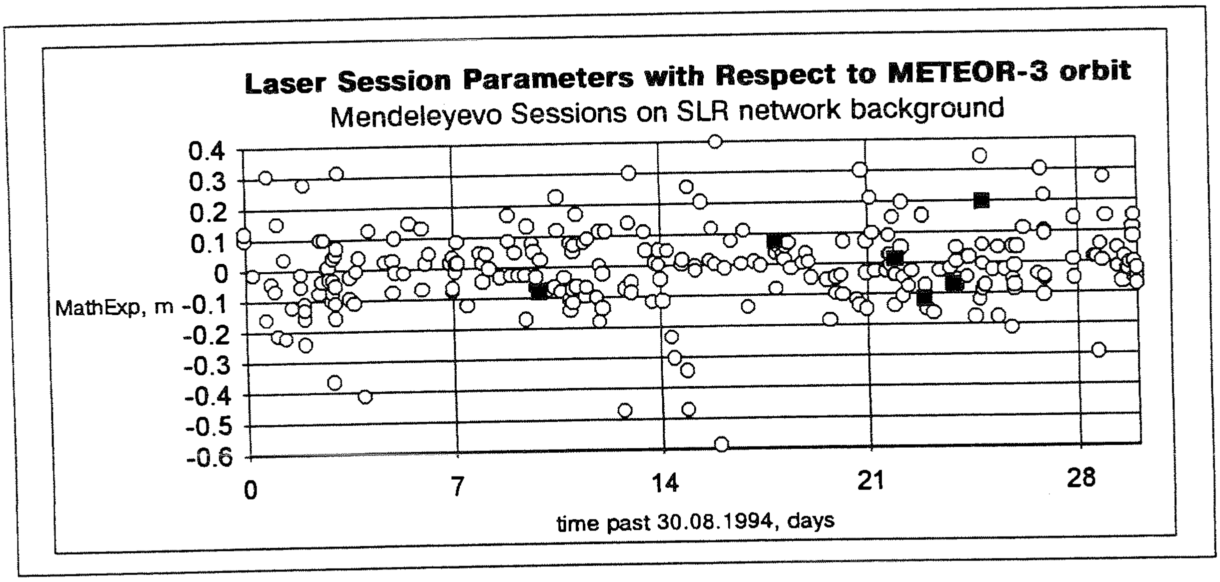
SLR station Crimea - 1

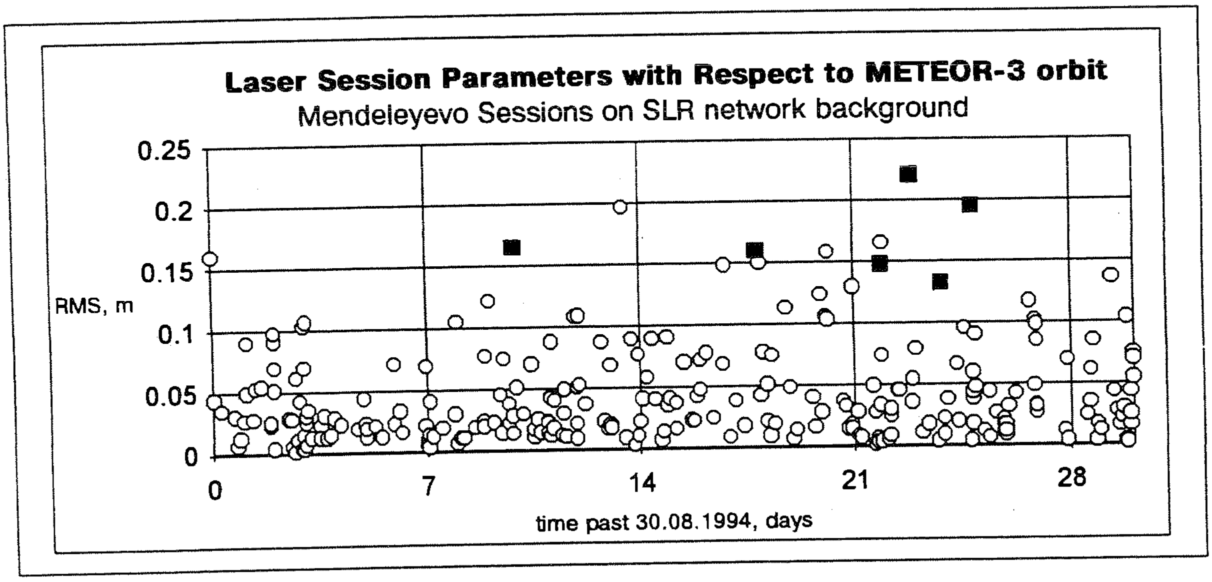


SLR station Crimea - 4



SLR station Sarapul
Optical system


Laser Session Parameters with Respect to METEOR-3 orbit
Mendeleyevo Sessions on SLR network background
MathExp, m
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
0
7
14
21
28
time past 30.08.1994, days

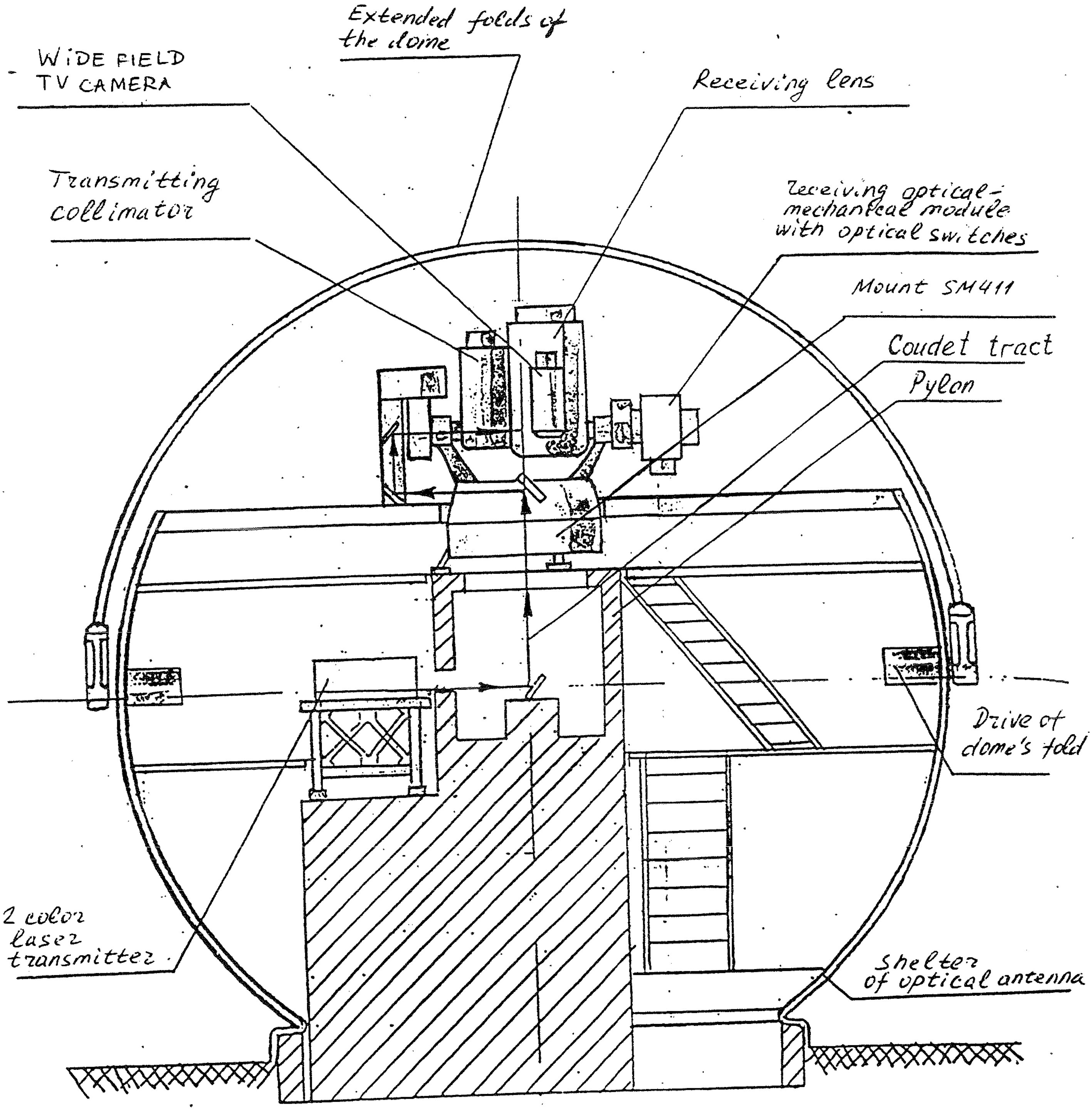

Laser Session Parameters with Respect to METEOR-3 orbit
Mendeleyevo Sessions on SLR network background
RMS, m
0.25
0.2
0.15
0.1
0.05
0
0
7
14
21
28
time past 30.08.1994, days

Main parameters of 4th generation Russian Laser Ranger

• distance measurement error Poly RMS	- 3-5 mm
• working wavelength, basic	- 0.532 μm
additional	- 1.064 μm
• frequency of probing pulses	- 5 Hz
• working FFDPs	- 10-60 arc sec
• diameter of receiving lens	- 60 cm
• error of pointing to a S/C, not more	- 5 arc sec
• maximum angular velocity of S/C tracking, not less than	- 5 °/s
• working elevation range	- 20-85 °
• sensitivity of TV system,	
wide field	- 14^m
narrow field	- 16^m
• error of measurement of angular coordinates for S/C with orbit heights:	
more than 20000 km	- 1-2 arc sec
less than 20000 km	- 5-7 arc sec

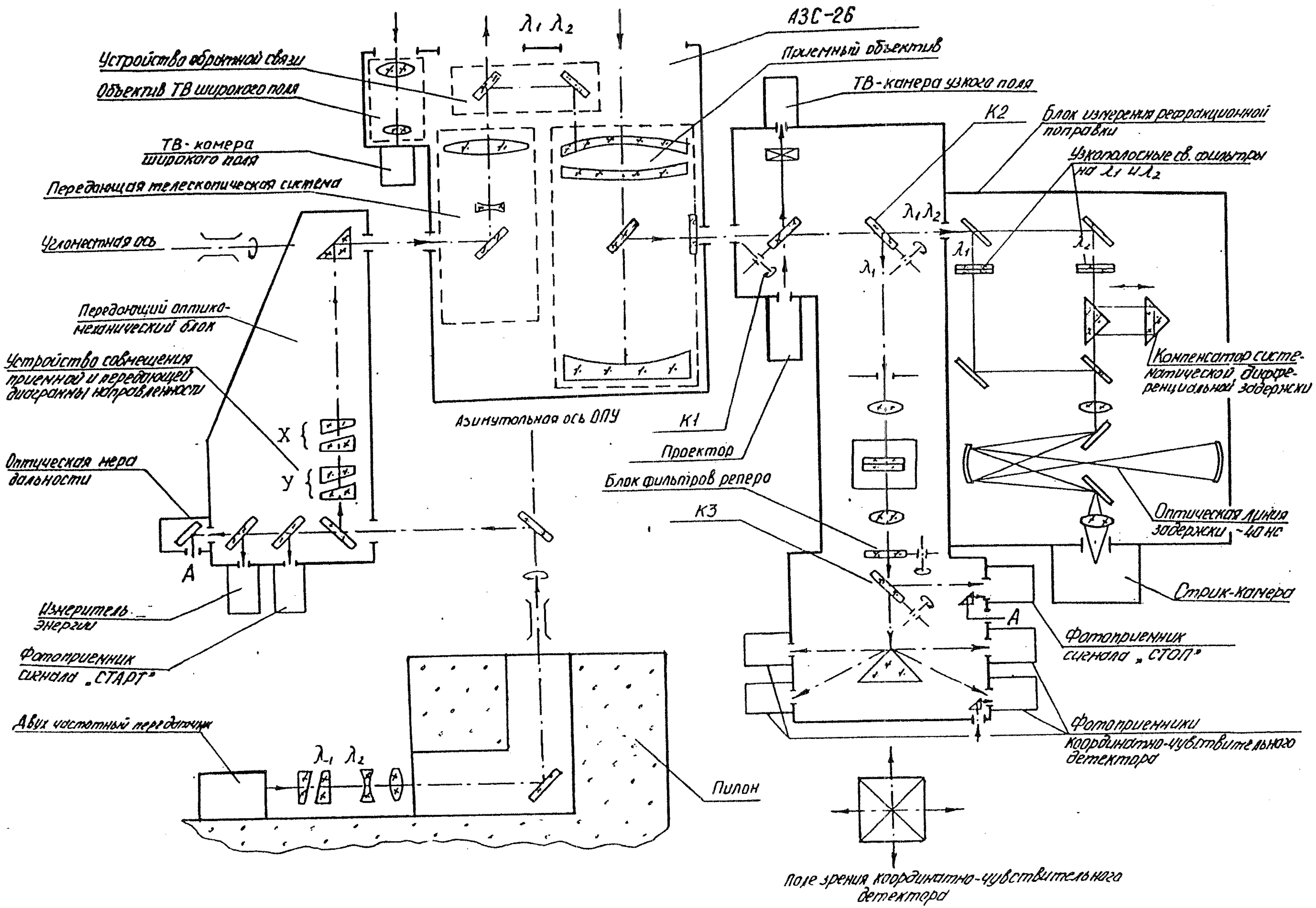
Design features:

- rigid azimuth-elevation mount;
- high-torque drive of the mount;
- automatic superposing of transmitting and receiving direction patterns;
- two-frequency method of measurement of refraction correction based on strike-camera with linear scanning
- automatic tracking correction using reflected signal and information from TV system;
- system for detection of reflected signal adaptive to the background noise, providing ranger's day time operation
- in-built distance equivalent



Optical antenna and its shelter of the 4th generation Russian laser ranger

Structural diagram of the 4th generation Russian laser ranger



Russian Space Agency

Russian Institute for Space Device Engineering

Science Research Institute for Precision Device Engineering

Laser station in Komsomolsk-on-Amur. State and modernization plans

Prof. V.D. Shargorodsky

RISDE, Moscow, 1994

Laser station in Komsomolsk-on-Amur. State and modernization plans.

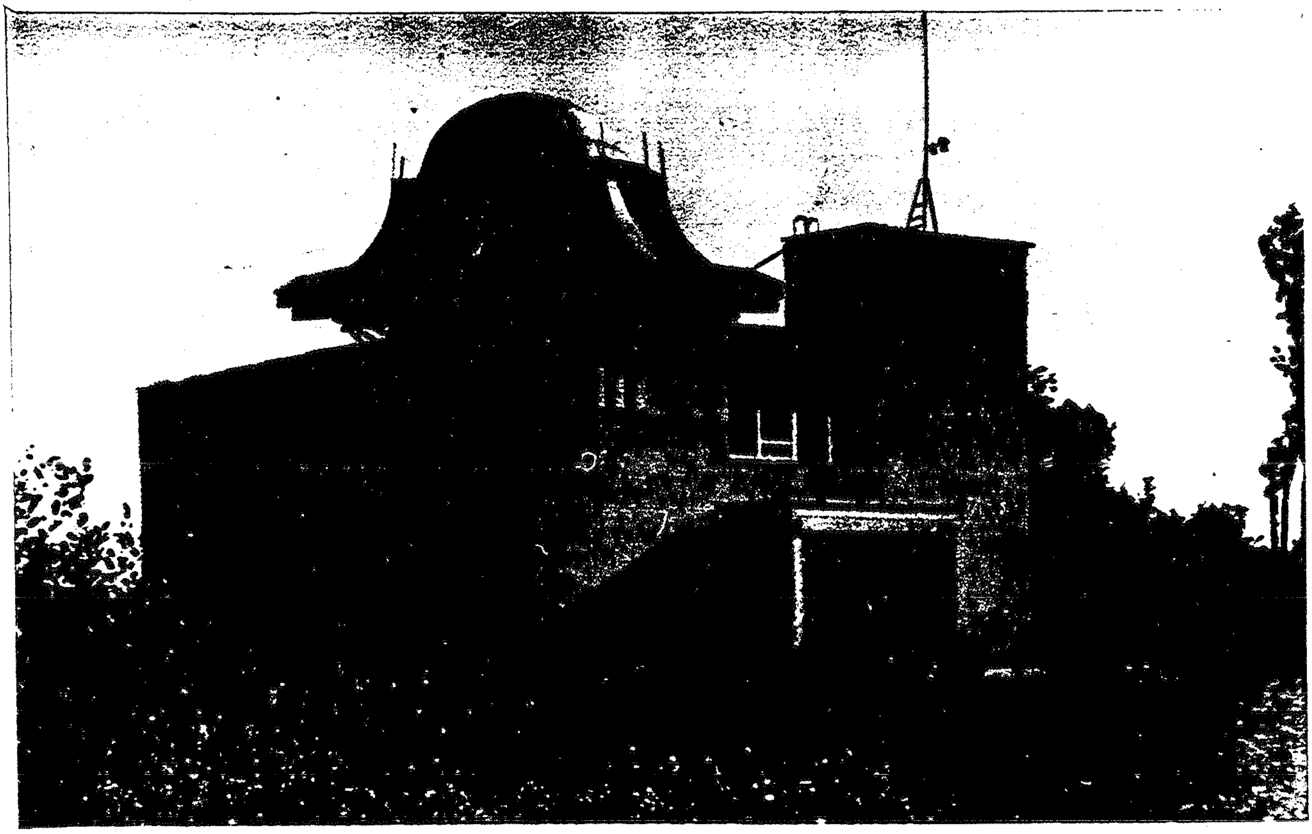
Prof. V.D. Shargorodsky, RISDE, Russia.

In 1992 in village Solnechny near the town Komsomolsk-on-Amur operation of the fourth station of 2^{nd} accuracy generation and with range limits 40,000 km was started. Like three earlier operated stations in Dunaevtsy and Eupatoria (Ukraine) and also on the coast of Baikal lake (Russia), this station was established in the framework of National program for space navigation.

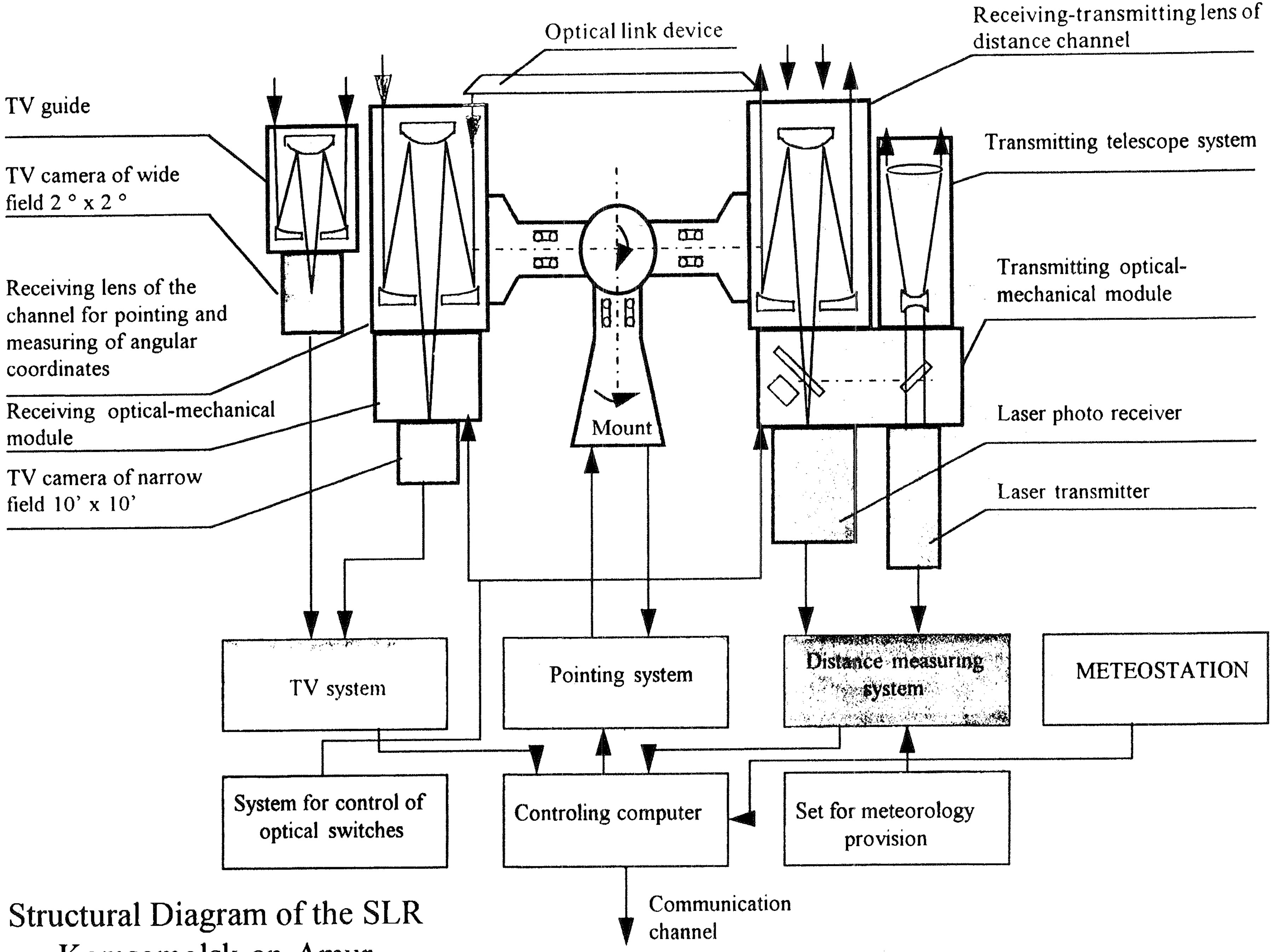
The primary tasks of the station on the initial stages of work were in-flight laser calibration of spacecraft GLONASS radioranging system, metrology check of orbits of navigation satellites, and study of model of orbital motion of Ethalone-1 and -2 satellites.

As this station is involved in the number of international space geodesy programs requiring higher accuracy, a modernization aimed to raise an accuracy up to the 3rd generation is carried out at present time.

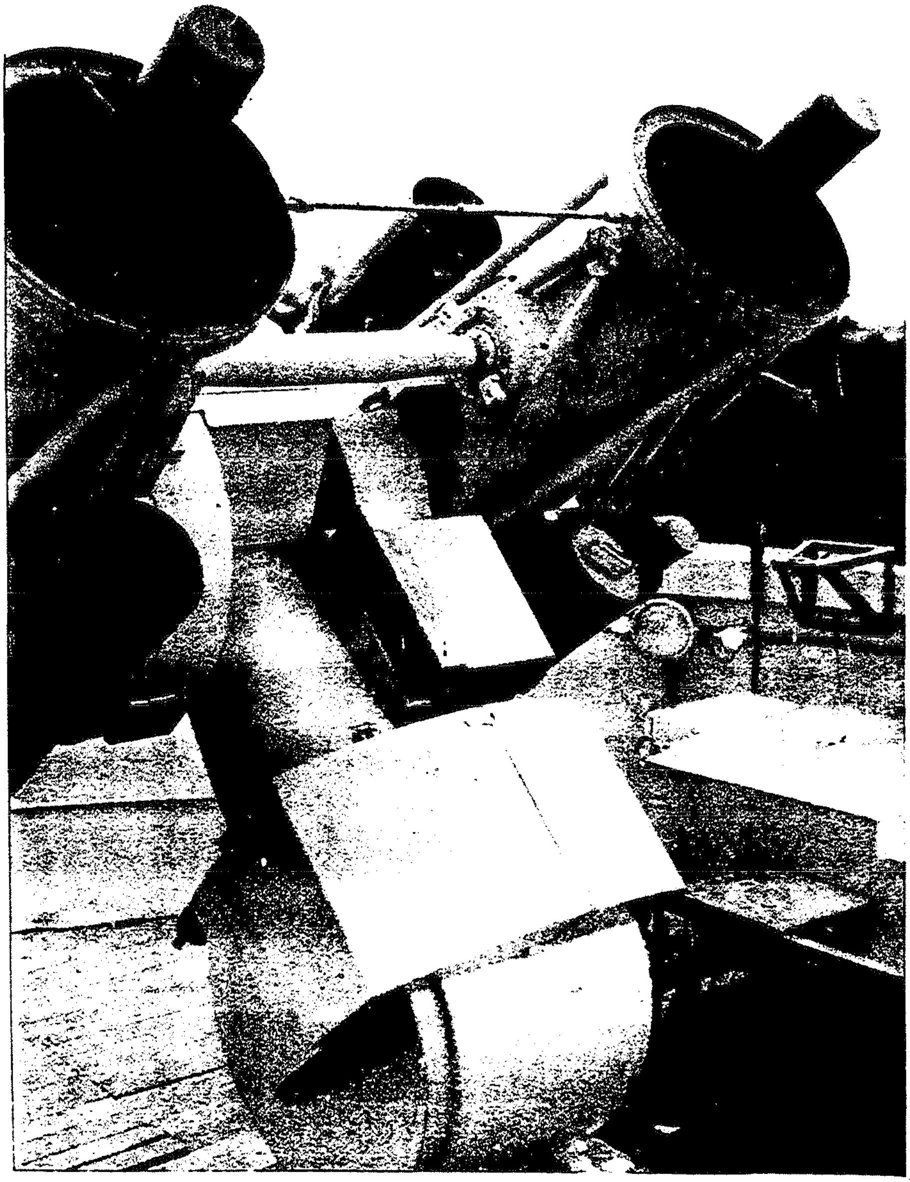
General technical characteristics of a telescope, ranging and angle measuring systems, timing system and system for transmission of data to the collection and processing center, are given.



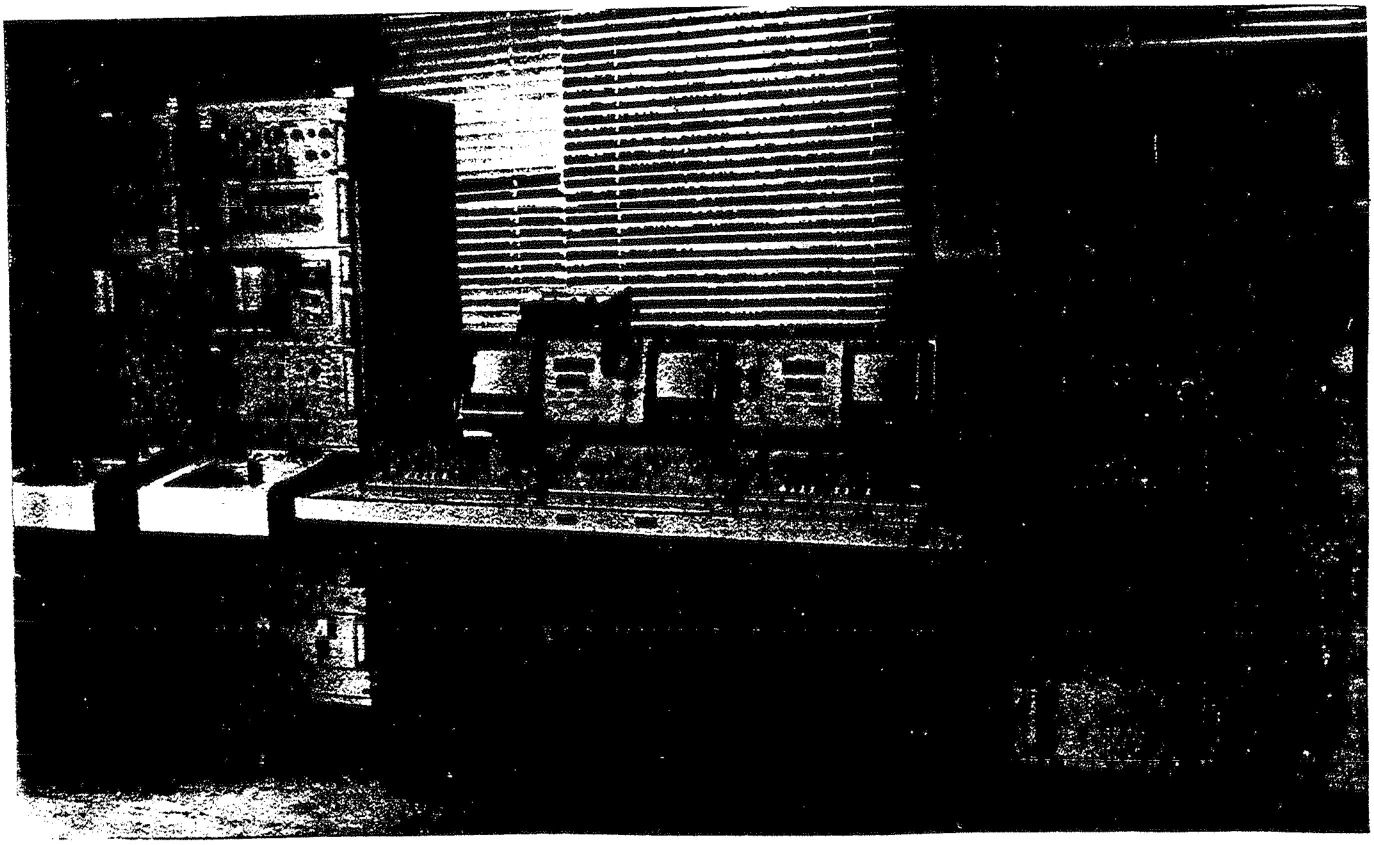
SLR station Komsomolsk-on-Amur
Technical building



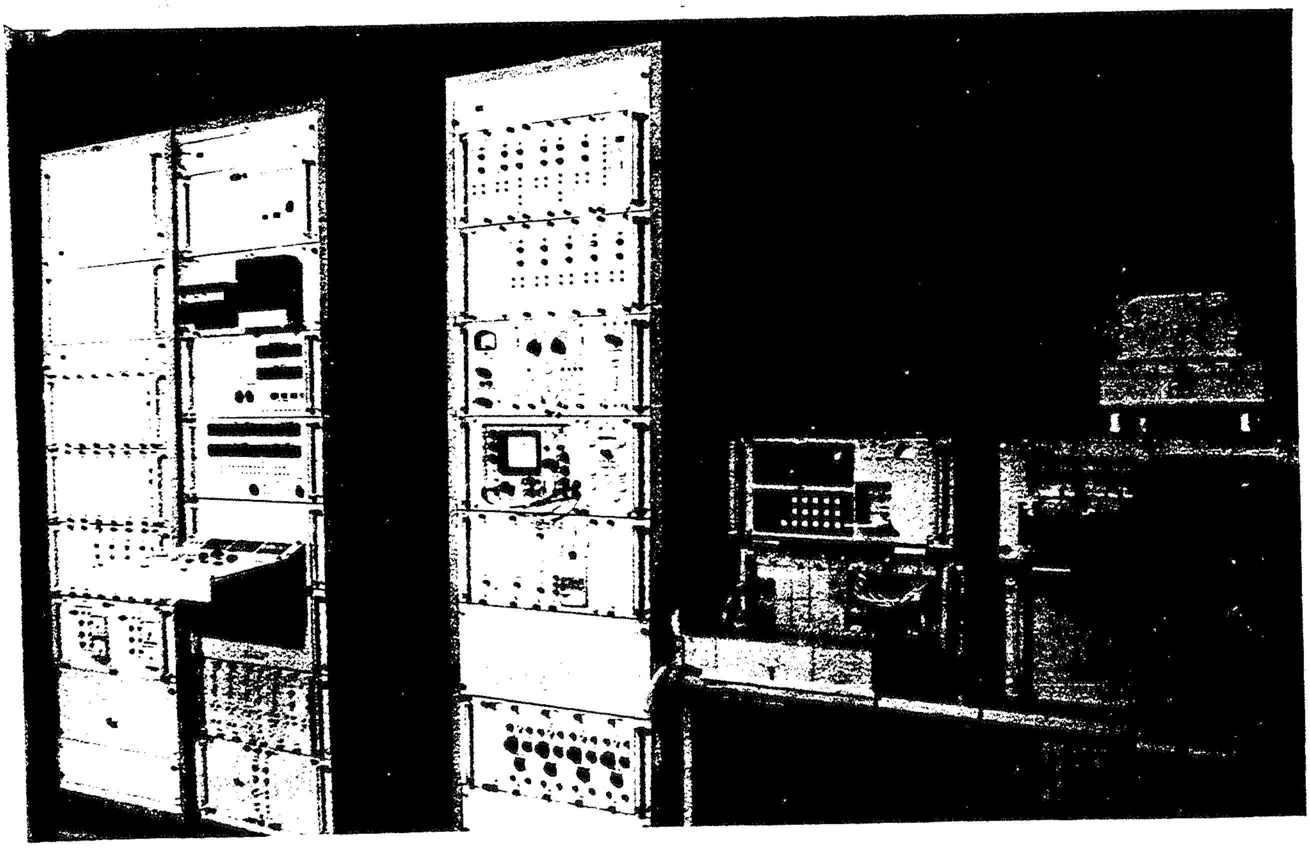
Structural Diagram of the SLR
Komsomolsk-on-Amur



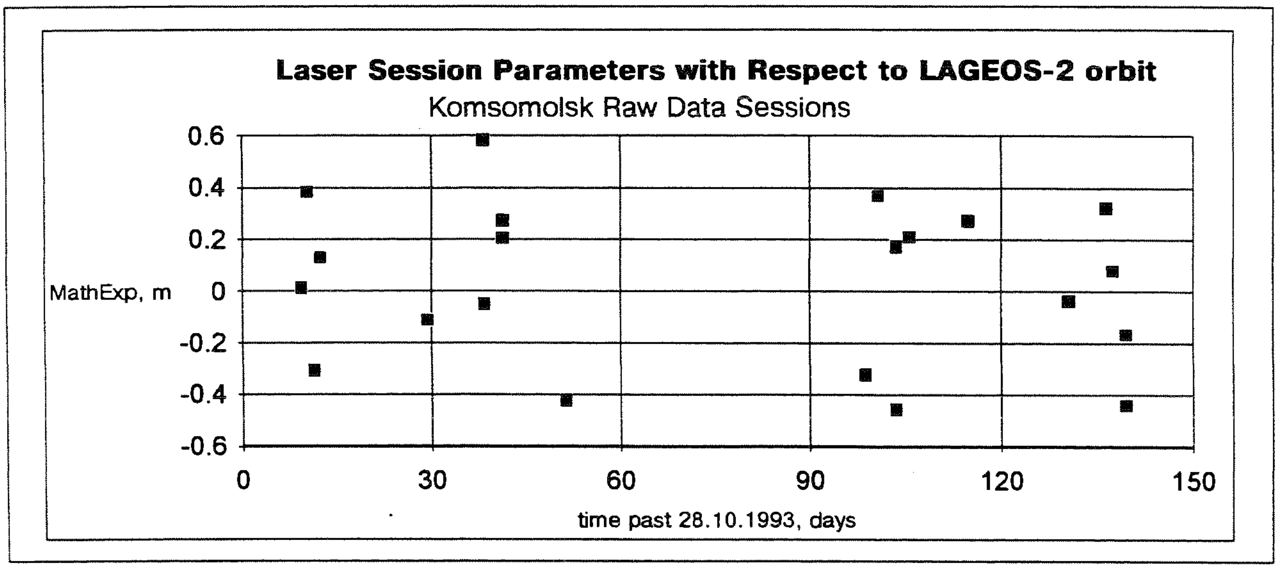
SLR station Komsomolsk-on-Amur
Optical system

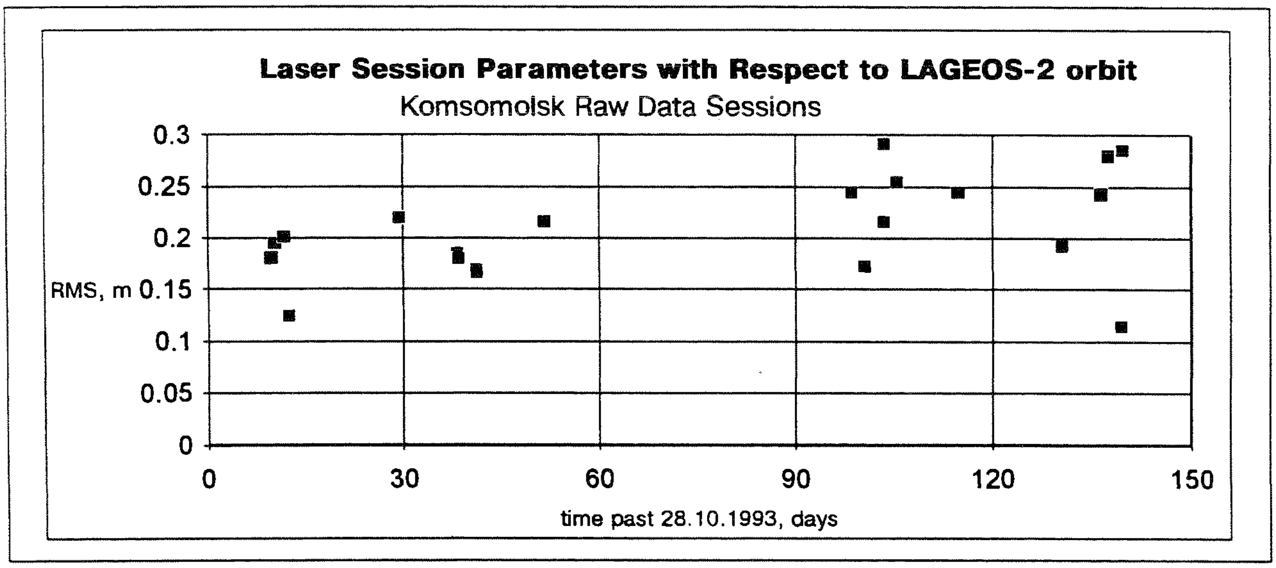


SLR station Komsomolsk-on-Amur
Electronic system



Geo-ZUP Company





SLR Komsomolsk-on-Amur

Main technical parameters

Measurements of distance	Measurements of angular coordinates
S/C orbital height: 0.4 ... 40 thousand km	S/C orbital height: 19 ... 40 thousand km
RMS of measurements:	Sensitivity of TV system:
Poly RMS (cm) < 20 (5) NPT (cm) < 6 (1.5)	in the main optical system (10'x10') - 14 ^{m}
	in the wide field (2°x2°)- 12 ^{m}
(Values in brackets - error after modernization)	Measurement error 1 ... 2 arc. sec.

Design features

1. Equatorial telescope with two main mirror optical systems with aperture of 500 mm and focal length of 8100 mm, one of them is used for laser ranger and another one - as a lens for TV telescope.
2. Completely openable dome with wind protective device.
3. Laser is installed on the transmitting lens.
4. Either main lens with diameter 500 mm (divergence 10-20 arc. sec.) or additional collimator with diameter 200 mm (divergence 1-7 arc. min.) is used for collimation of laser light.
5. Link to time scale is done by GLONASS user's receiver.

STATUS OF ORRORAL LASER RANGING SYSTEM

John.McK. Luck and Gordon Oliver
Orroral Geodetic Observatory
Australian Surveying and Land Information Group
PO Box 2, Belconnen ACT 2616, Australia

The upgraded Orroral station was deemed operational from 1 January 1992. It currently has full day/night ranging capability to all satellites from ERS-1's altitude to ETALON and GPS, and has successfully ranged to the geostationary satellite OPTUS B1. Tracking priorities have followed recommendations of the CSTG SLR Subcommission. Lunar ranging is still planned. Single shot precision to LAGEOS has been 10mm since November 1993. Ground target ranging indicates system calibration accuracy of 5mm, and LAGEOS range biasses are stable at the 20mm level, although there is an unexplained constant error of 51mm. Return rates are lower than expected.

Recent improvements include:

- Gated-gated Tennelec discriminator configuration, from Yarragadee in November 1993.
- Avalanche diode detector from Wettzell, tested in July 1993 and installed in August 1994 in such a way that it, or the ITT MCP, can be used for any pass, but not both.
- A variable optical attenuation module (OAM) was installed in the satellite return path in July 1994, to reduce signal strength from TOPEX/POSEIDON and other strong targets.
- 1 Angstrom bandpass, 74% transmission filter through Grasse, installed September 1994.
- Synchronous ranging software from Electro Optic Systems (EOS) installed October 1994.
- Automation and remote control of dome rotation, telescope focus and divergence, PLZT, MCP high voltage, OAM density, MCP/avalanche diode selection.
- Target selection management and pass interleaving.

while improvements under way include:

- Replacement secondary mirror, to improve the telescope's optical performance.
- Remote control software by EOS.
- OAM to further control intensity from internal calibration and ground targets.
- Independent assessment by University of New South Wales, of calibration constants and ties to ground target and survey monuments, obtained by precision geodetic surveys in 1987 and 1989, and the terrestrial survey/GPS connections between the SLR points at Orroral and the VLBI points at Tidbinbilla and Hobart.
- Replacement control system for the telescope drive.
- Microwave link to replace old phone lines for communications.

Orroral is preparing to participate fully in the West Pacific Rim SLR Network, and has reorganised its tracking priorities to concentrate more on ETALON, GPS, LAGEOS and OPTUS. The feasibility of expanding operations considerably is under active discussion led by the Orroral Observatory Advisory Committee. AUSLIG's position with respect to the proposed Asia-Pacific Space Geodynamics (APSG) program is being evaluated.

Status of CRL SLR station

H. KUNIMORI
Communications Research Laboratory
4-2-1 Nukui-kitamachi, Koganei 184, Japan

Abstract

CRL SLR station in Koganei, Tokyo (CRLLAS) has started observation in February 1990. The system is based on Contraves, USA 1.5m telescope system and EOS, Australia, SLR system. It has obtained about 300 passes in total for major geodetic satellites up to October 1994 while the station is for multi purpose and has not been set in routine observation. Precision history shows 2cm to 1cm by real time calibration and in-pass precision analysis. The global position of a station in CRLLAS has been determined by using the data obtained in the Etalon campaign in September - November 1990. The station has collocated 7 times with VLBI since 1988 and connected to Kashima VLBI station. Major upgrade has been done to have a synchronous laser ranging capability in Q-sw mode locked laser and control system in 1993 and 1994.

Title: **Operational Testing of 2 ps Event Timers: A Multi-Station Comparison**

Authors:

Greene B. and Guilfoyle J.	EOS Australia
Luck J.	AUSLIG Australia
Kunimori H.	CRL Japan
Fahad al Hussein	KACST Saudi Arabia

Session: Timing Devices and Calibration

Date: 1330 Tuesday 8 November

Chairperson: H. Kunimori

Abstract:

As precision, accuracy, and repetition rate requirements increase, time interval techniques are being increasingly abandoned in favour of event (epoch) timers. The current generation of event timers have resolutions of 10 ps and accuracies around 2 ps. The next generation of these devices will require 5 ps precision and 1 ps accuracy.

This paper reviews the field performance of 4 current generation timers, fielded over the past 4 years, to determine whether the design principles are delivering the inherent lifetime calibration suggested in earlier laboratory tests. The systems participating in these tests were EOS Version 3D systems delivered to CRL (Japan), KACST (Saudi Arabia), Auslig (Australia), as well as EOS' own operational timing system.

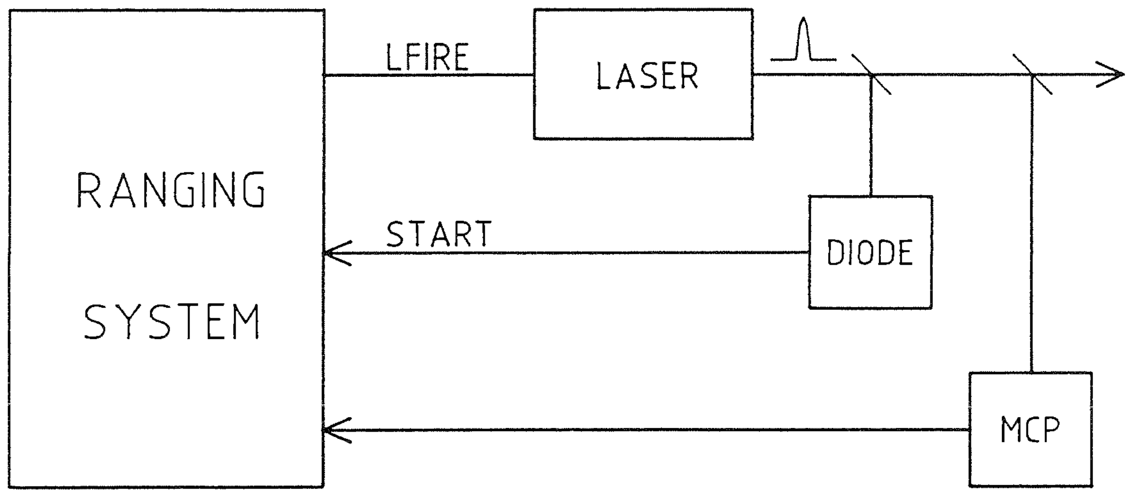
One of the key applications of these multi-channel timers is in 2 colour ranging. It has been long established through both analysis and experimental results [Greene & Herring] that the technique of 2 colour ranging using electronic timing is inherently less prone to bias than optical techniques (streak cameras). The translation of these results to fully operational systems has not been proven before.

The results of these tests, conducted on 3 continents over 3 months, confirm the long term stability of these devices, and their ability to provide 2 ps systematic error for high resolution normal points, as used in 2-colour ranging.

Deployment of these systems for synchronous ranging systems, in which the baseline accuracy is ultimately limited only by the system bias, is discussed.

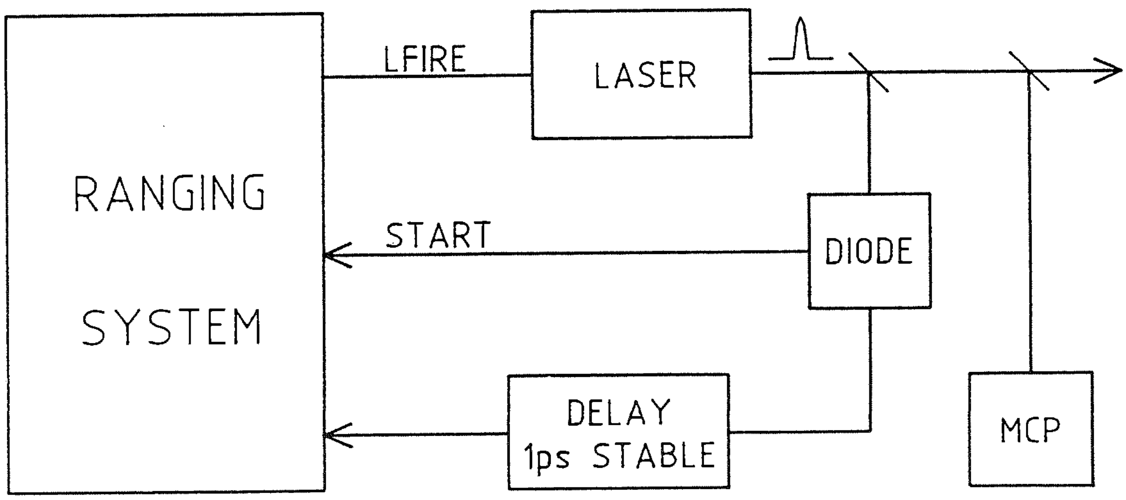
C.R.L. TEST SETUP - NORMAL

JULY 1994

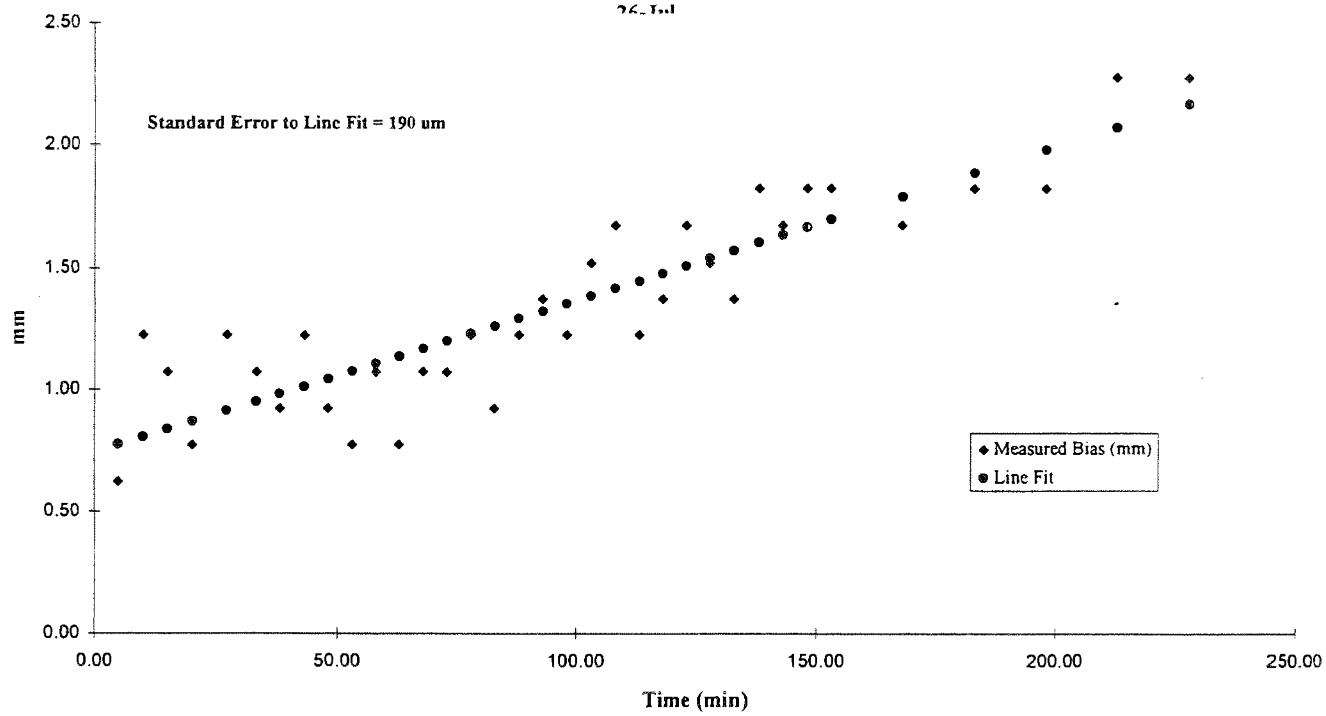


C.R.L. TEST SETUP - TEST

JULY 1994

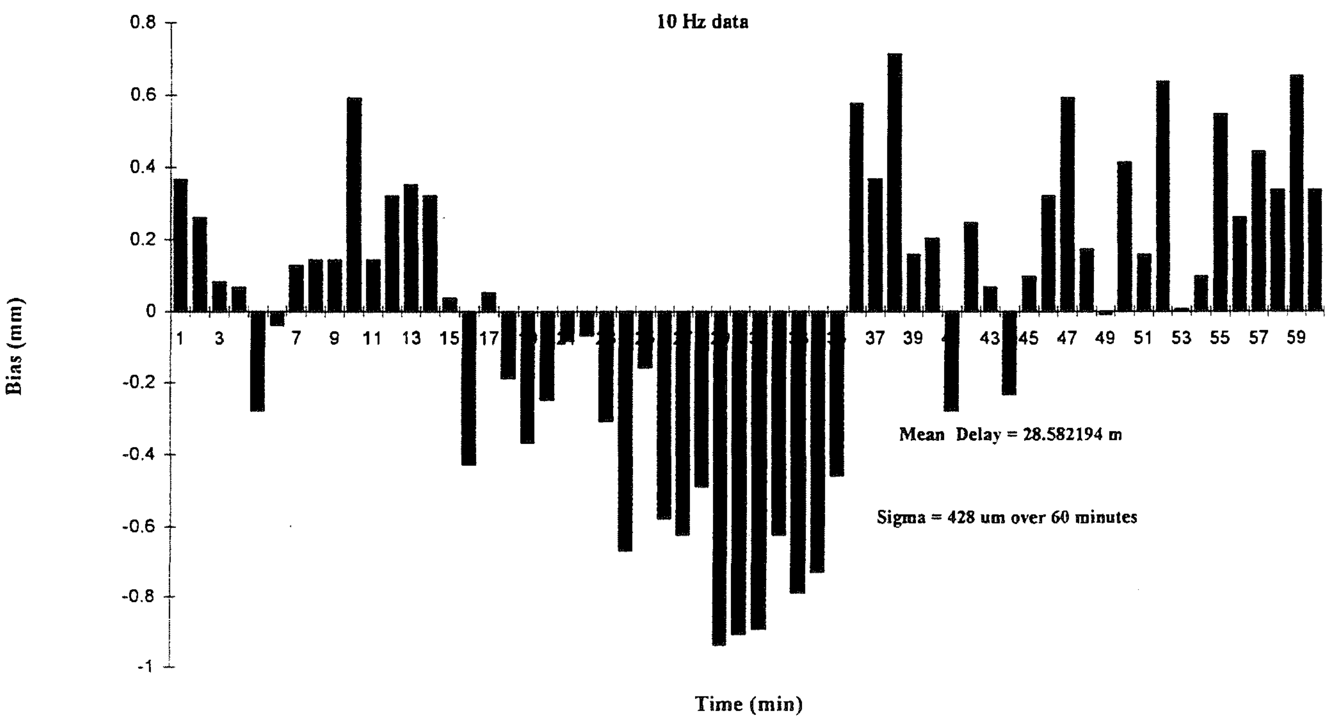


CRL BIAS STABILITY TEST



CRL26JUL.XLC 8/11/94

CRL LRS STABILITY - 28/7/94



CR28JUL1.XLC 8/11/94

FIGURE 2

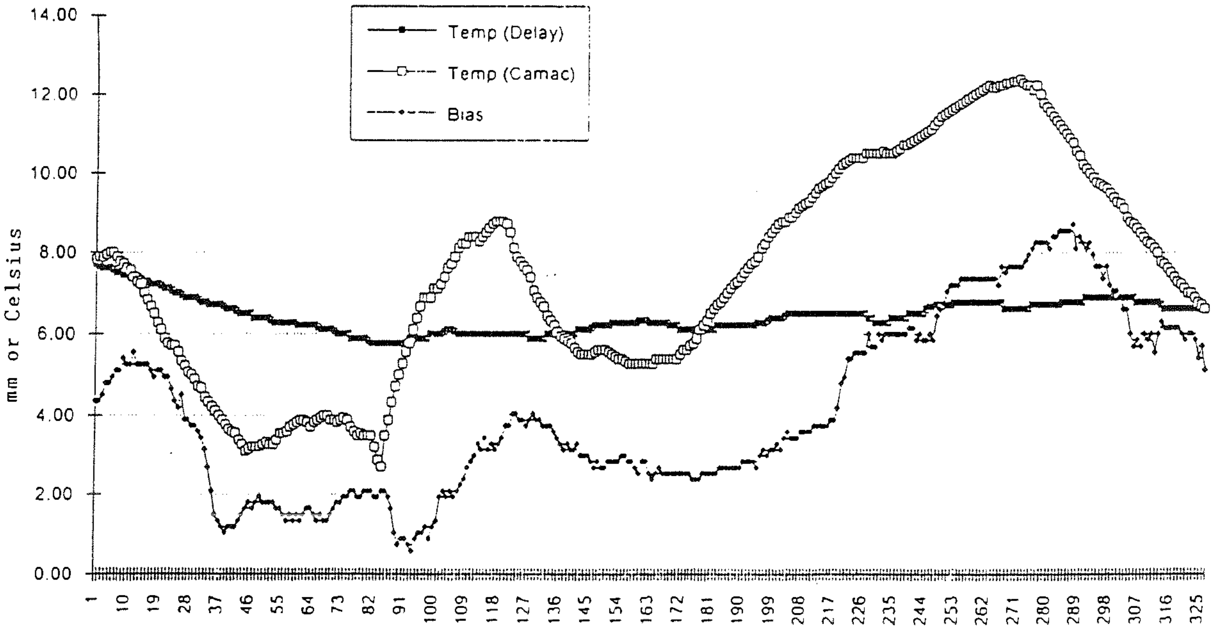
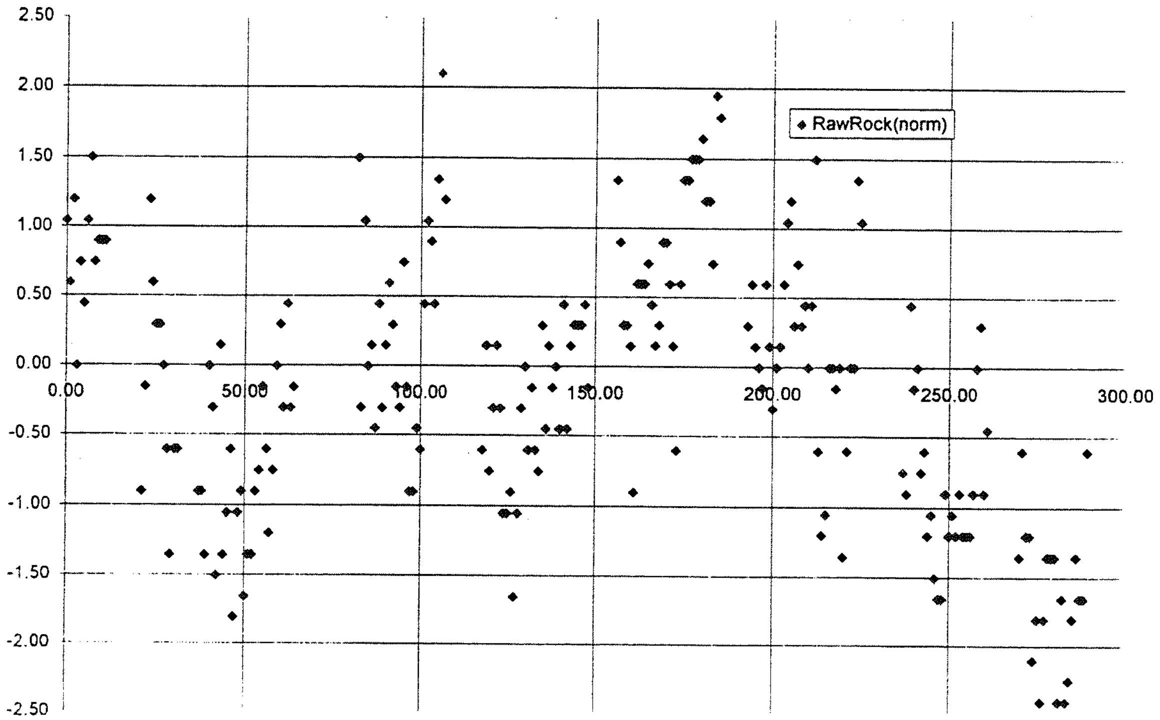
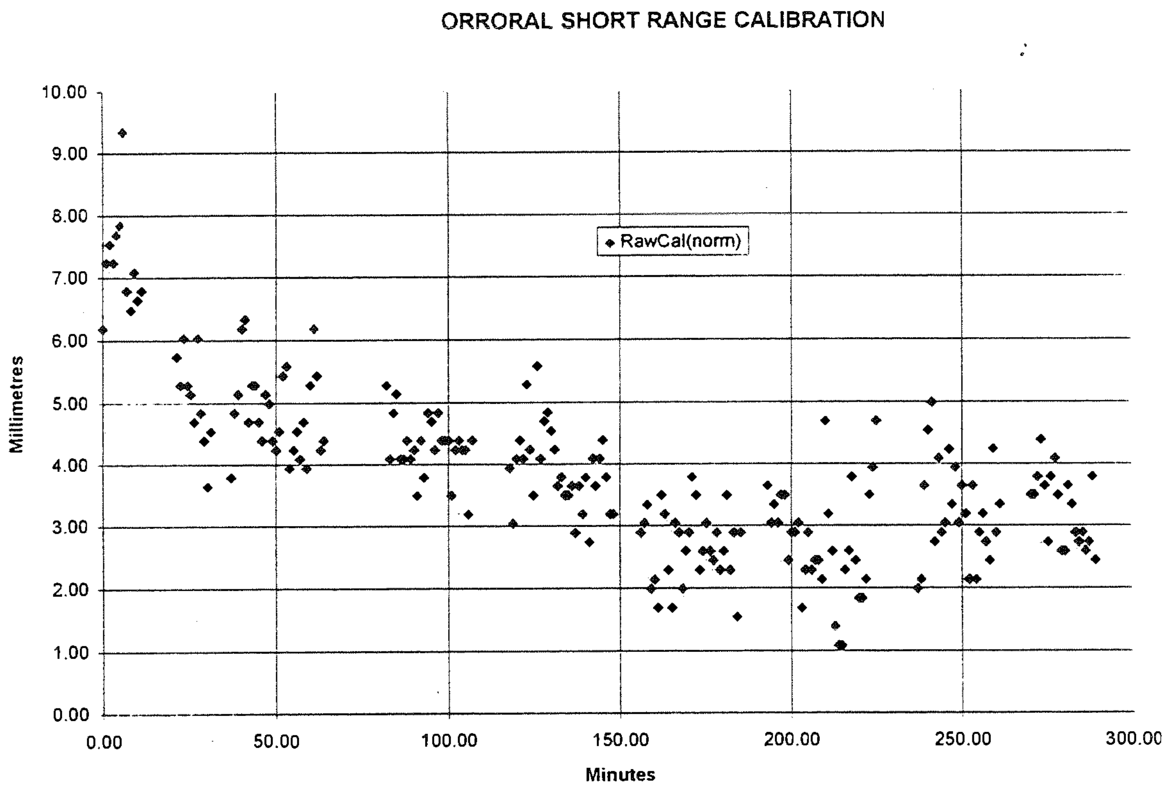


Chart3

RawRock(norm)



Page 1


ORRORAL SHORT RANGE CALIBRATION
RawCal(norm)
Millimetres
Minutes
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00

Title: **Satellite Laser Ranging at Eyesafe Wavelengths**

Authors:

Greene B.	EOS Australia
Hamal K. and Prohazka I.	CTU Czech Republic
Kunimori H.	CRL Japan
Kirchner G	Graz Austria

Session: Eyesafe Systems

Date: 0830 Wednesday 9 November

Chairperson: Dr J. Luck

Abstract:

The importance of eyesafe SLR systems to the future of the SLR community is unquestioned. As announced at the Eighth International Workshop on laser Ranging Instrumentation in 1992, EOS has since 1991 committed a significant proportion of both internal SLR R&D and allocations of EOS research grants to third parties towards development of eyesafe SLR technology. Projects supported embrace a wide range of developments and tests, including electronics, detectors, software, optics, and testing of each element and ultimately the entire system. Some of these developments are reported elsewhere.

Of the various possible ways of achieving eyesafe ranging to satellites, one involves the use of eyesafe (1.5 um) lasers operating at conventional (Gigawatt) intensities. In this case little is known about the response (effective LIDAR cross section) of various satellites. A specific project to characterise SLR targets in respect of their effective cross sections at 532 nm and 1.5 um was initiated by the authors. Progress towards this characterisation is reported.

WPLS'94

Symposium RESOLUTIONS

RESOLUTIONS

This Symposium on the Western Pacific Satellite Laser Ranging Network resolves:

1. That the Western Pacific Laser Tracking Network be established with the following initial characteristics, organisation and powers:

   Initial member countries comprising Japan, China, Russia, and Australia, but with all Western Pacific countries eligible to join.

   An effective establishment date of 11 November 1994.

   A steering committee comprising 2 delegates from each participating country, elected at this forum, but to be ratified in writing within 120 days by the appropriate authority in each respective country, and to be subject to replacement by that authority at any time.

   Working Groups appointed by the Steering Committee, with tasks to include defining network protocols, internal data standards, system configuration requirements, and interface and control protocols.

   A Secretariat to be located for 2 years at a time in a participating country, with the initial host country for the Secretariat to be Japan, with the Secretariat functions to be performed by CRL.

2. That the Steering Committee shall be charged with the responsibility of preparing the mission statement and strategic plan of the WPLTN, for ratification by the individual member countries through their appropriate authority. The Steering Committee shall meet as often as necessary.

3. That the WPLTN shall meet not less than annually, and whenever possible in conjubction with the International Workshop on Laser Ranging Instrumentation.

4. That WPLTN tracking priorities be established collectively by member countries, but with no obligation on any national facility to comply with such priorities at the expense of a national priority. WPLTN affiliated stations shall place a high priority on tracking requests from member countries, and in this context will allocate a high priority to the tracking of RIS.

5. That the WPLTN will seek collaboration with the global laser ranging community through organisations such as CSTG, NASA, and EUROLAS.

6. That this Symposium expresses its thanks to colleagues from NASA, EUROLAS, and other organisations for their support in the formation of this Network.

7. That a vote of thanks be registered with the Science and Technology Agency of Japan for organising and sponsoring this Symposium.

VIEWGRAPH PRESENTATIONS

FUTURE SCIENCE APPLICATIONS

Chairperson : Christian Veillet

The Necessity to Change Current Operational Strategies to Support the Scientific Missions Requiring SLR Data Through the Year 2000

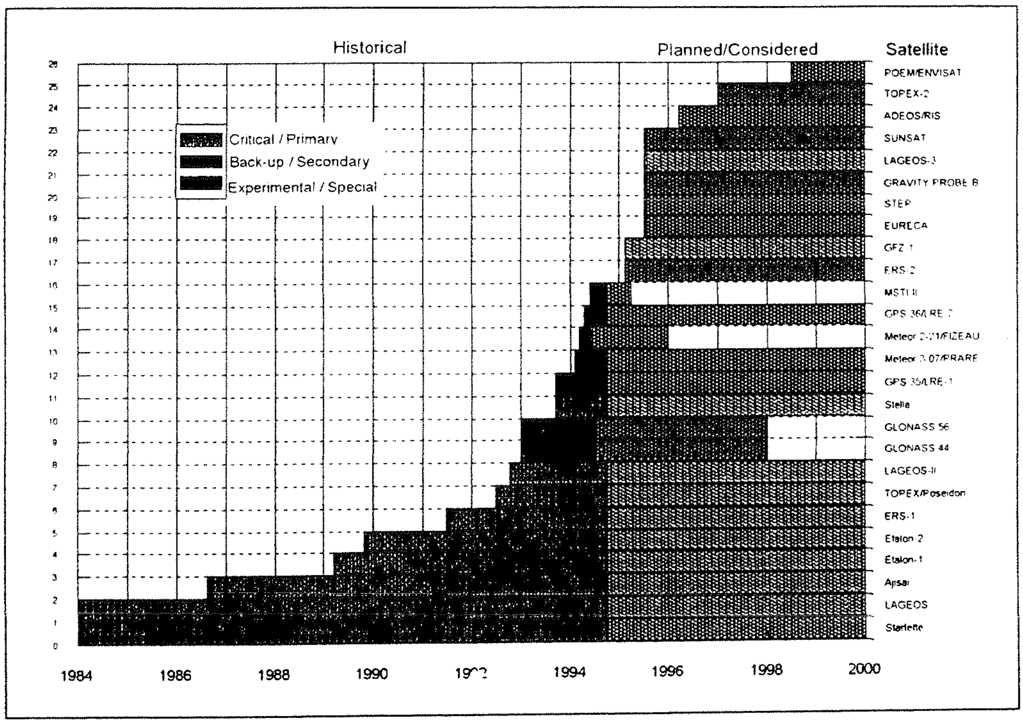
Alan Murdoch, Mark Davis
AlliedSignal Aerospace
AlliedSignal Technical Services Corporation
NASA SLR
7515 Mission Drive
Lanham, Maryland 20706 USA

Abstract - Until 1989, the majority of the stations of the global SLR community operated a single shift, primarily tracking the single geodetic satellite LAGEOS, while collecting data on other satellites such as Ajisai and Starlette.

Since then, the utilization of Satellite Laser Ranging has broadened and now includes the tracking of many geodetic satellites in a wide variety of altitudes and inclinations, the calibration of ocean height altimetry satellites, and the precision orbit determination of these and other terrestrial satellites. To support these requirements, the global tracking priorities and philosophies have changed. As an example, the majority of the NASA SLR stations now operate two shifts and track 13 satellites operationally with priorities determined by the mission parameters and altitudes.

In the next few years, the number and variation of missions requiring SLR support is anticipated to increase dramatically, as is the variation in the scientific, and hence operational SLR requirements. Examples of both the complimentary and conflicting requirements are given and operational solutions are discussed. Lessons learned from the recent tracking of the MSTI-II satellite (altitude 430 km, 97.1° inclination) are presented, and their applications to upcoming mission such as GFZ-1 are described. Critical system developments are examined and the strategies to provide SLR support to the appropriate missions through the year 2000 are identified.

Satellite Laser Ranging Targets



The number and variation of SLR targets is increasing dramatically

SLR Target Parameters

Satellite	Sponsor	Launch (Year)	Altitude (km)	Inclination (Degrees)	Shape	Size (cm)	Retros
Geodetic							
Starlette	France	1975	815	49.8	Sphere	24 (Diam)	60
LAGEOS	U.S.	1976	5,861	109.8	Sphere	60 (Diam)	426
Ajisai	Japan	1986	1,490	50.0	Sphere	215 (Diam)	1436
Etalon-1	Russia	1989	19,117	64.9	Sphere	130 (Diam)	2140
Etalon-2	Russia	1989	19,115	65.5	Sphere	130 (Diam)	2140
LAGEOS II	Italy	1992	5,618	52.6	Sphere	60 (Diam)	426
Stella	France	1993	800	98.6	Sphere	24 (Diam)	60
GFZ-1	Germany	1995	396	51.6	Sphere	20 (Diam)	60
Altimetric / Remote Sensing							
ERS-1	ESA	1991	782	98.5	Hemisphere	18 (Diam)	9
TOPEX/Poseidon	U.S./France	1992	1,337	66.0	Annulus	150 (Diam)	192
ERS-2	ESA	1995	782	98.5	Hemisphere	16 (Diam)	9
ADEOS/RIS	Japan	1996	800	98.6	Hollow Cube	50 (Diam)	1
Experimental / Special							
GPS-35	U.S.	1993	20,135	54.8	Planar Rect	24 x 19	32
GPS-36	U.S.	1994	20,023	54.9	Planar Rect	24 x 19	32
MSTI-2	U.S.	1994	431	97.1	Hemisphere	18 (Diam)	9
Meteor-3/PRARE	Germany/Russia	1993	1,177	82.6	Annulus	28 (Diam)	24
GLONASS 44	Russia	1990	19,117	64.9	Planar Square	120 x 120	396
GLONASS 56	Russia	1992	19,110	64.9	Planar Square	120 x 120	396
Meteor2-21/FIZEAU	Russia	1993	931	82.5	Line	15 (Length)	3
METEOSAT_P2	ESA	1992	35,786	1.4	Cylindrical Rect	~ 40 x 15	~120

There is considerable difference between retro-reflector arrays

WORKSHOP PAPERS

Title: **Simultaneous Tracking Across Multiple Laser Networks**

Authors: Greene B. and May T — EOS Australia

Luck J. — AUSLIG Australia

Kunimori H. — CRL Japan

Yan Foo Min — Shanghai Observatory China

Session: Future Science Applications

Date: 1330 Monday 7 November

Chairperson: Dr C. Veillet

Abstract:

Short arc geometric and quasi geometric solutions have been applied in the past to reduce the effect of orbit errors on the geodetic parameters sought from a particular solution. More recently the concept of true simultaneous laser tracking of satellites by multiple stations as a means of obtaining very high precision and high temporal resolution geodetic baselines has been proposed.

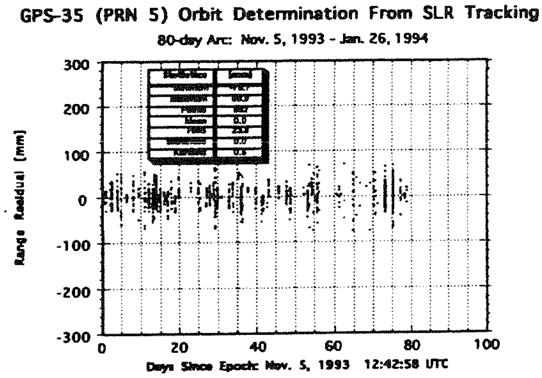
Computer simulations suggest that if laser range measurements are taken such that the satellite is effectively stationary, then the baseline error will be approximately equal to the ranging system error for a correctly configured geometry. Even the atmospheric error normally associated with SLR measurements can be reduced below 1 mm with the correct technique.

This implies that with presently available technology, 1 mm baselines are acheiveable over periods as short as 1 day, provided the baselines are short enough to allow geometric requirements to be met by the available satellites. Intercontinental baselines are more problematic, as the geometry is limited, as is the data density for simultaneous view. Also, as baselines become longer, geometry cannot readily overcome atmospheric errors without averaging which degrades temporal resolution.

Simultaneous tracking can also be used for precise time transfer. Laser techniques for time transfer conventionally use active satellites, or bouncing a laser pulse from one station to another. Synchronous laser stations can transfer time by simply ranging to passive satellites, as the synchronisation error has its own signature in the baseline solution.

One conclusion from this is that SLR may be an accurate and temporally prolific technique for short baselines (up to hundreds of km) than previously considered. Another is that laser time transfer may be more rapidly and easily achieved than previously expected.

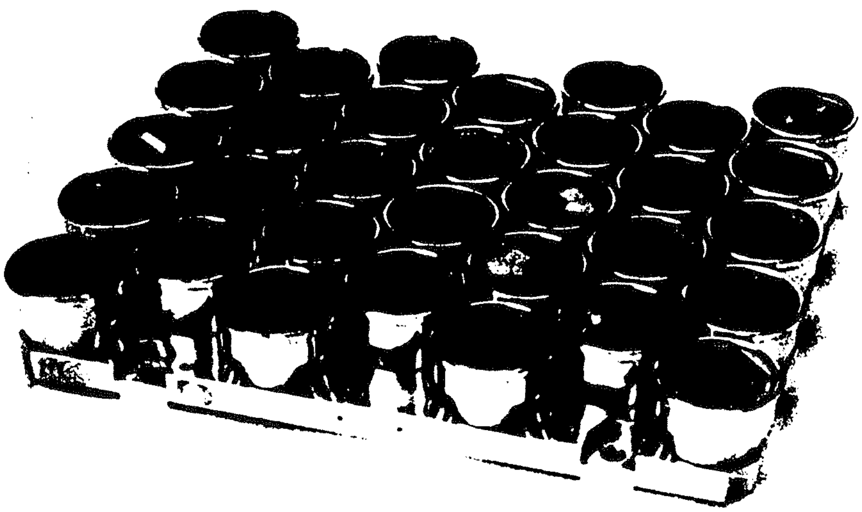
NASA Goddard Space Flight Center
Laboratory for Terrstrial Physics
Space Geodesy Branch Code 926



Comparison of GPS-35 Orbits
From
GPS & SLR Tracking Data

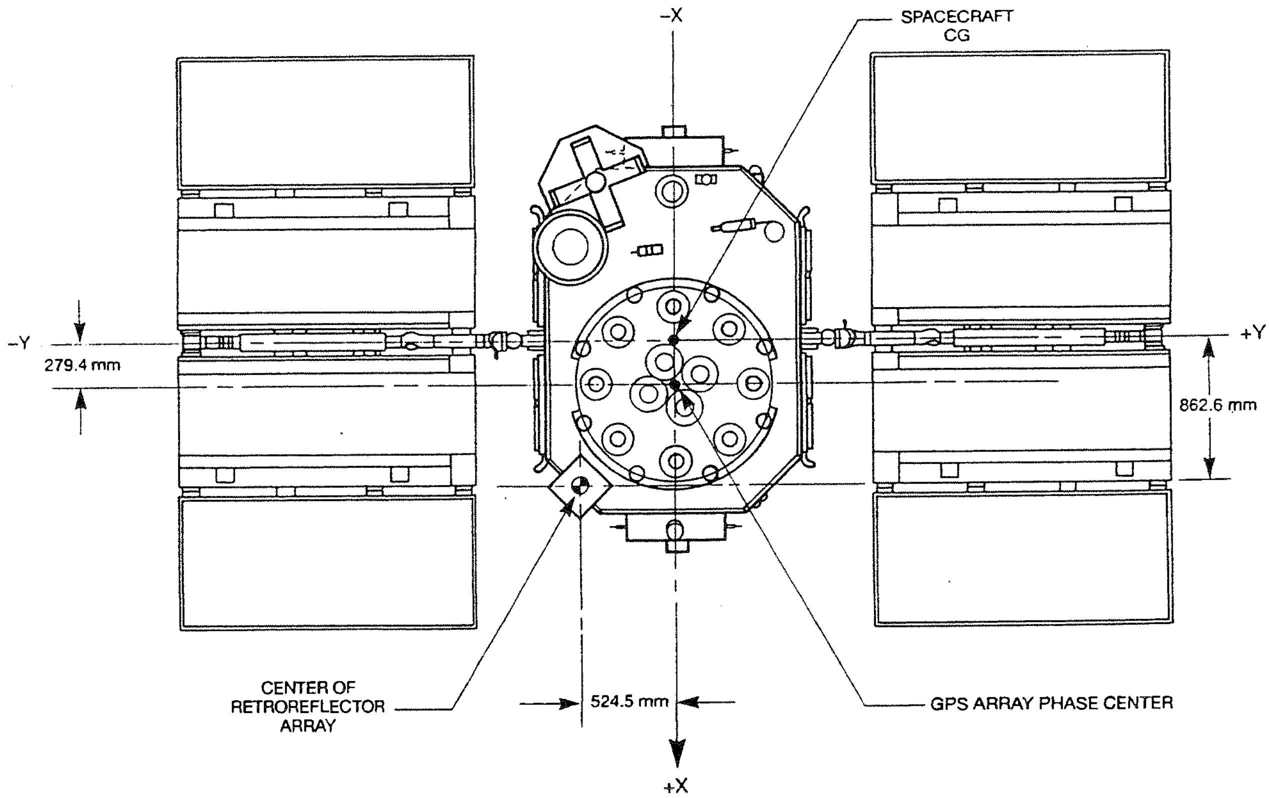
Erricos C. Pavlis
epavlis@ltpsun.gsfc.nasa.gov
9th International Workshop on Laser Ranging Instrumentation
Canberra, Australia November 7-11, 1994

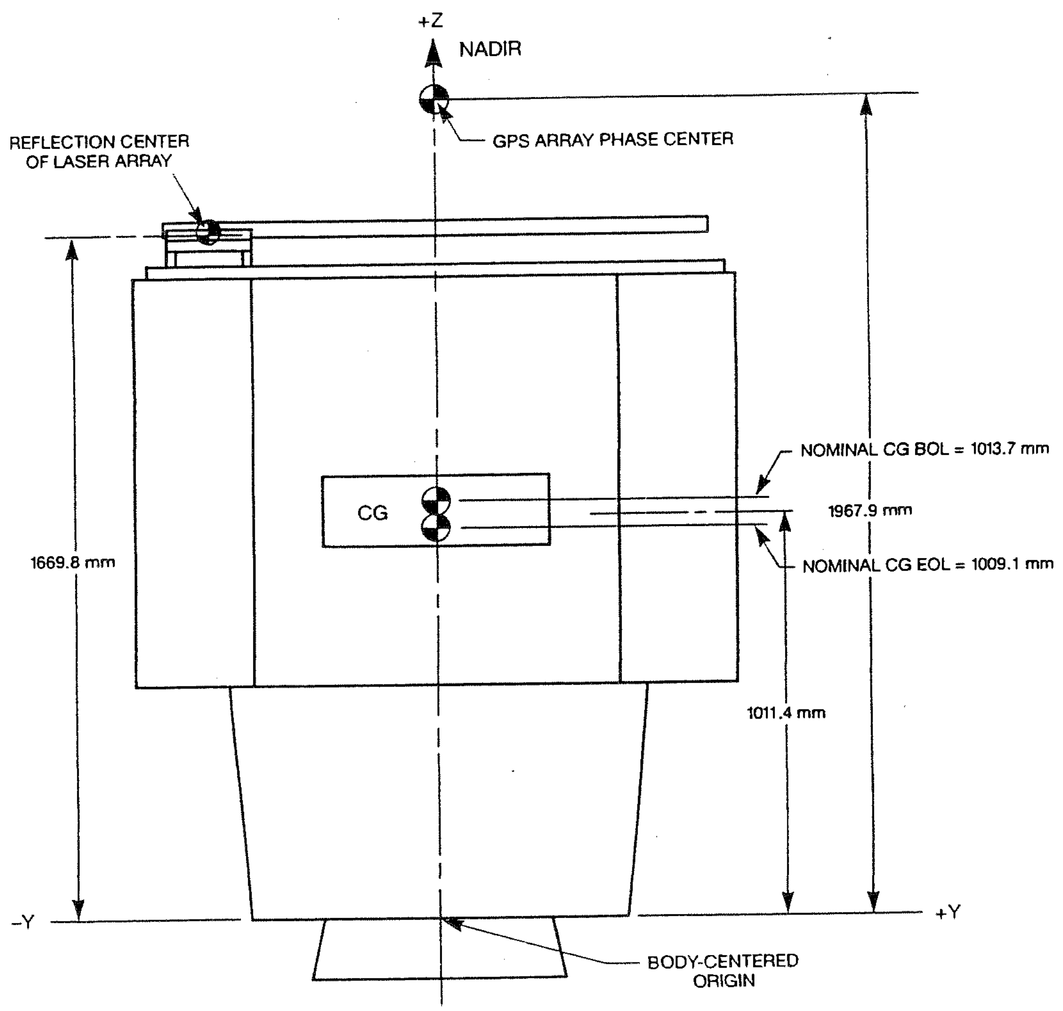
NASA
GSFC



QRA-93-32 Engineering report 7

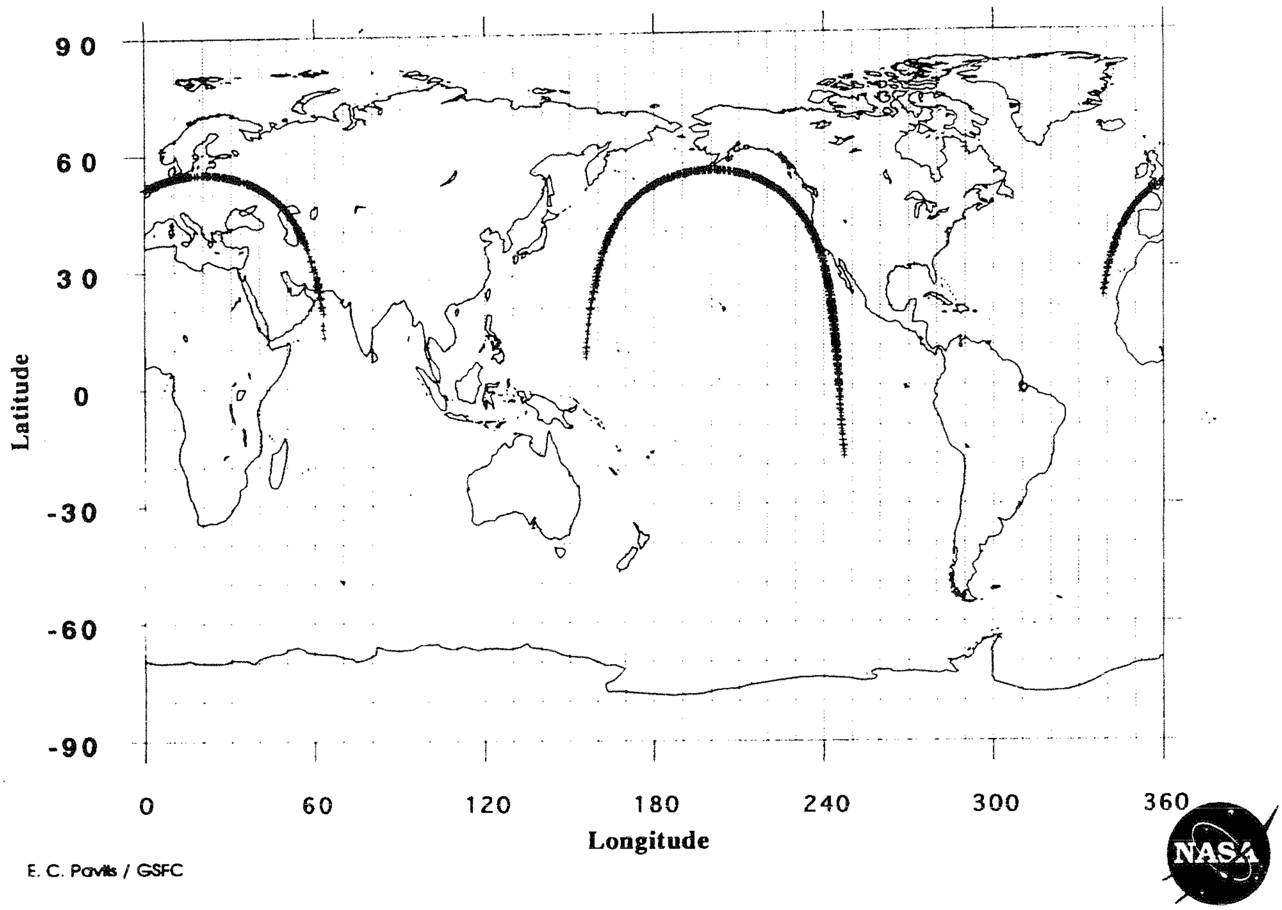
Picture 3.

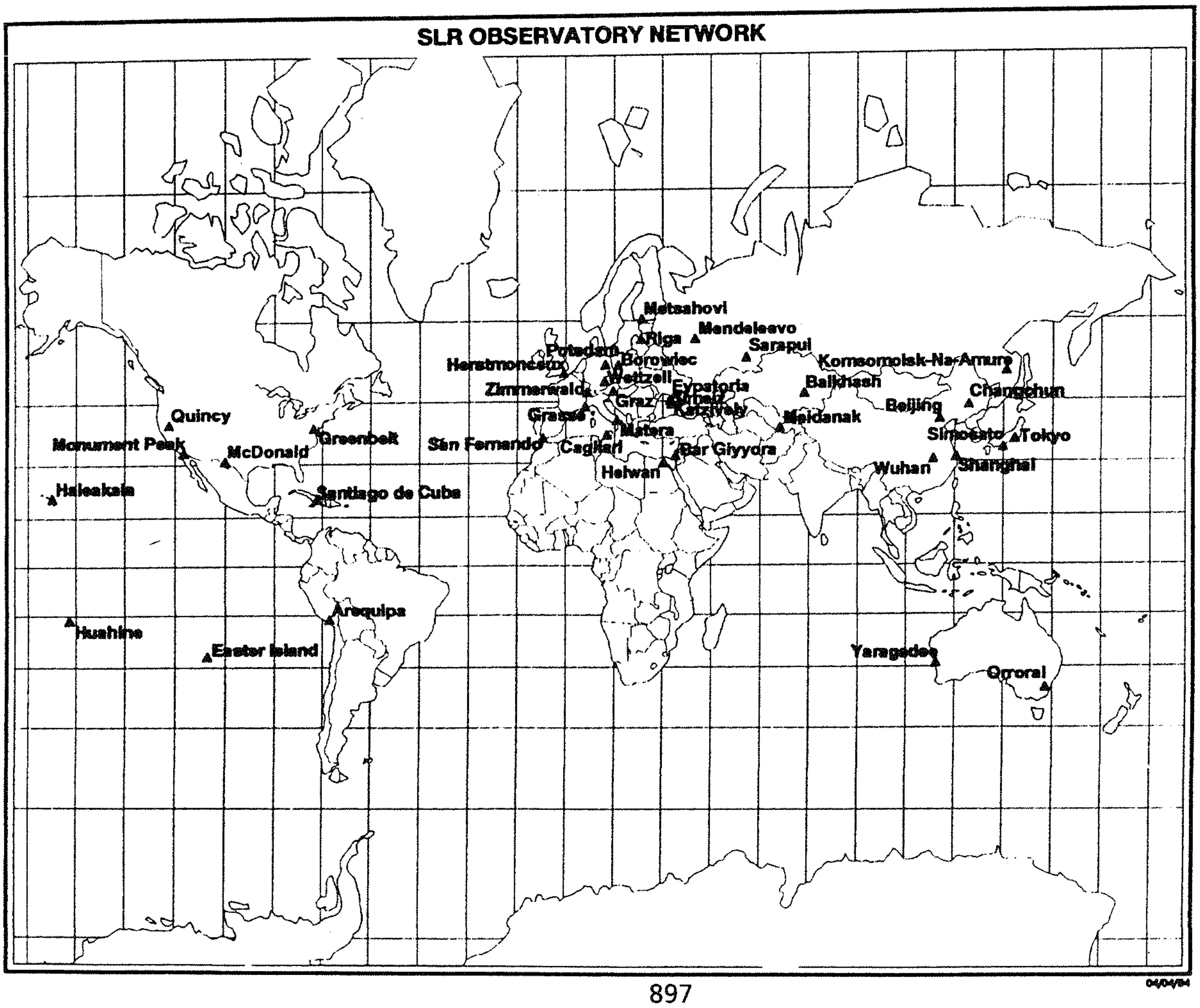

-X
SPACECRAFT CG
-Y
+Y
279.4 mm
862.6 mm
CENTER OF RETROREFLECTOR ARRAY
524.5 mm
GPS ARRAY PHASE CENTER
+X


+Z
NADIR
GPS ARRAY PHASE CENTER
REFLECTION CENTER OF LASER ARRAY
NOMINAL CG BOL = 1013.7 mm
CG
1967.9 mm
1669.8 mm
NOMINAL CG EOL = 1009.1 mm
1011.4 mm
-Y
+Y
BODY-CENTERED ORIGIN

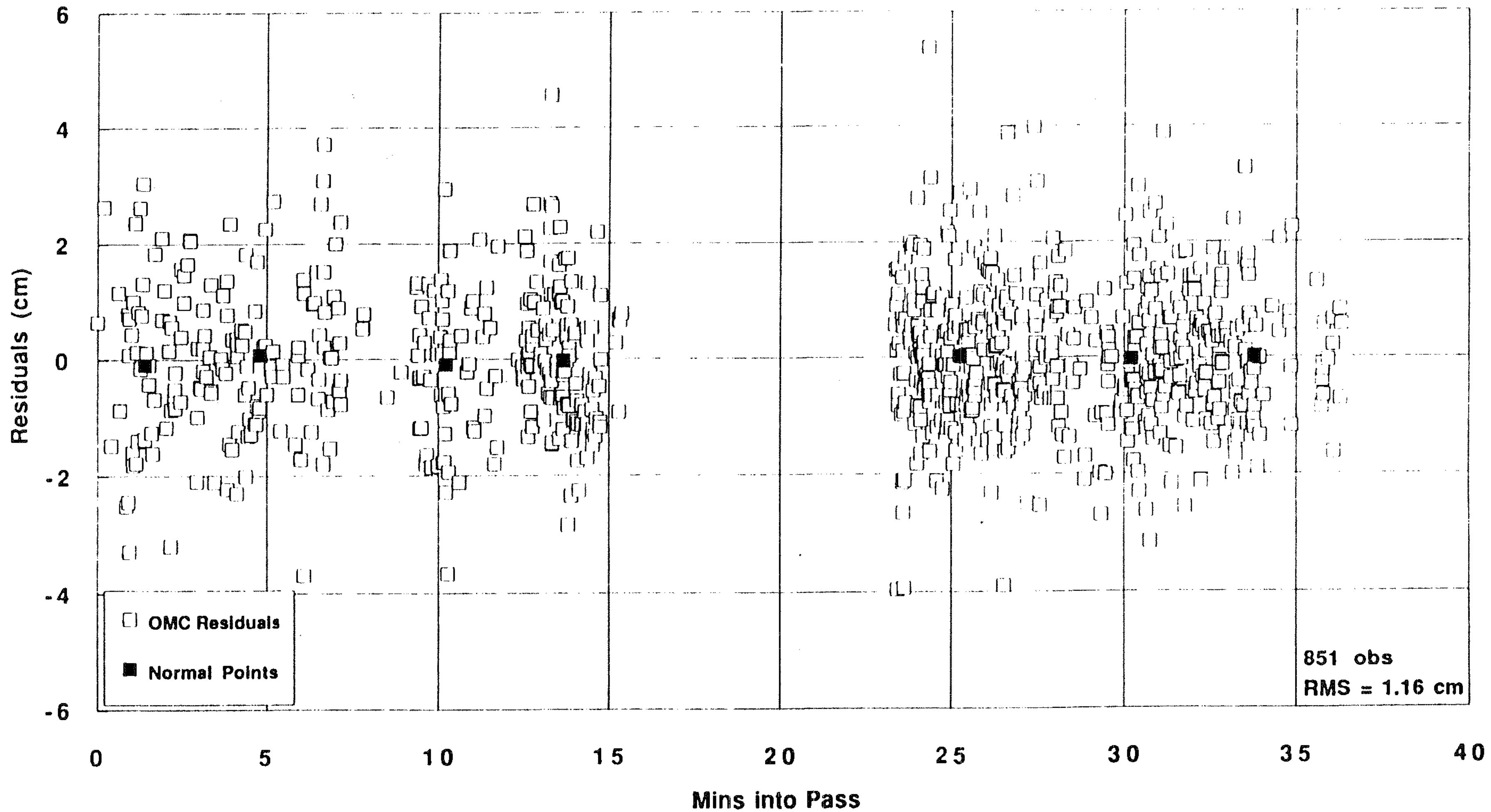
SLR Tracking Coverage of GPS-35

Nov. 5, 1993 - Feb. 16, 1994

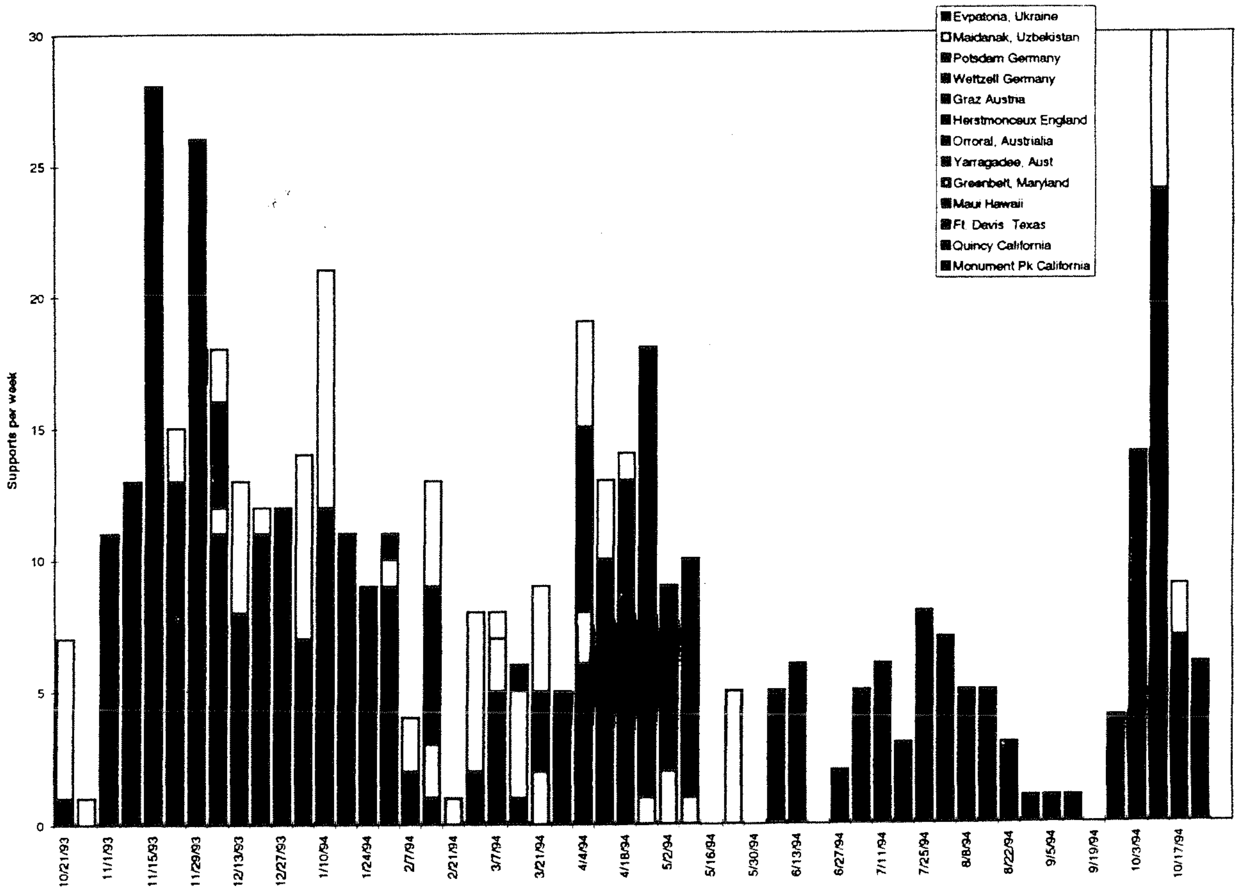




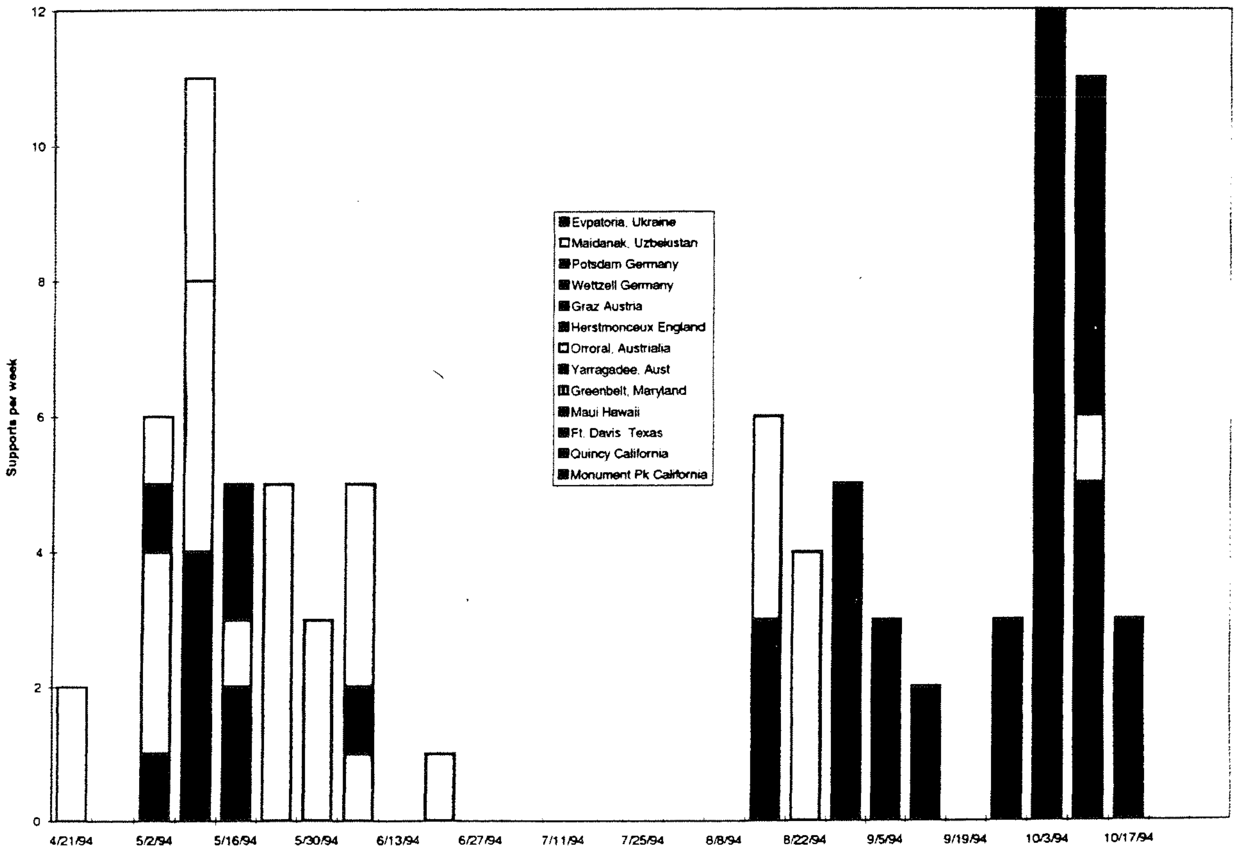
Moblas-4 GPS Mar 09, 1994 at 3:47



GPS-35 Laser Tracking Support



GPS-36 Laser Tracking Support



Statistics of SLR Range Residuals

TABLE 1. Residual statistics for the 104-day SLR-determined arc.

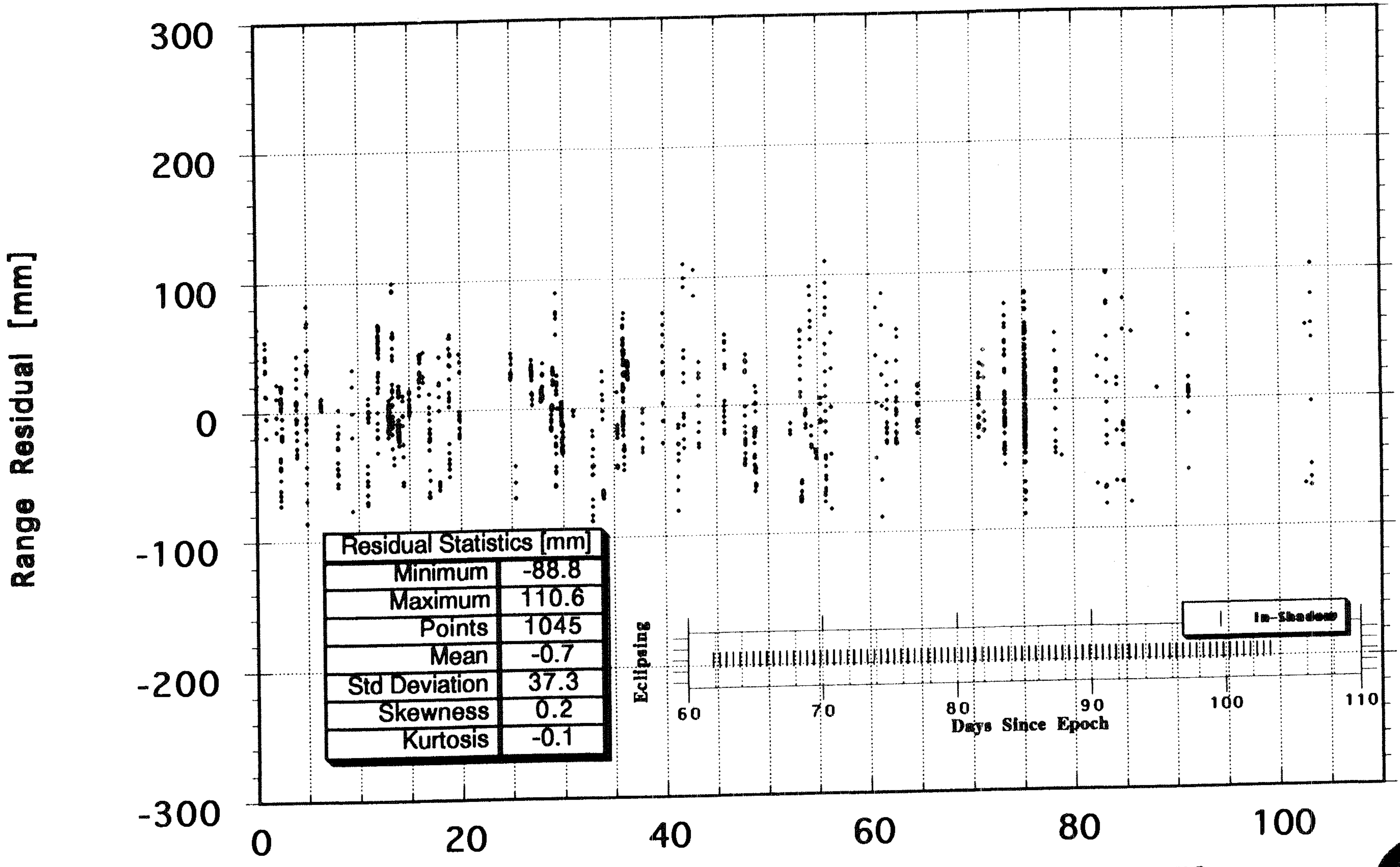
Site	No. of Obs.	RMS [cm]
Monument Peak, CA	311	2.3
Haleakala, HI	215	3.1
McDonald Obs., TX	81	2.7
Quincy, CA	4	0.1
Greenbelt, MD	8	1.0
Graz, Austria	175	2.8
Herstmonceux, U.K.	101	3.4
Potsdam, FRG	47	2.1
Wettzell, FRG	121	3.1
Totals	1063	2.9

TABLE 2. Residual statistics for the two SLR-determined 14-day arcs.

Arc	SLR-1		SLR-2	
Site	No. of Obs.	RMS [cm]	No. of Obs.	RMS [cm]
Mont. Pk., CA	67	2.1	71	1.9
Haleakala HI	61	1.8	60	1.4
McDonld, TX	19	2.5	26	1.4
Quincy, CA	4	0.1	0	—
Graz, Austria	38	1.8	14	3.4
Herstx., U.K.	20	1.4	20	1.8
Wettzell, FRG	6	1.7	10	1.4
Totals	215	1.9	201	1.8

GPS-35 (PRN 5) Orbit Determination From SLR Tracking

104-day Arc: Nov. 5, 1993 - Feb. 16, 1994



Residual Statistics [mm]	
Minimum	-88.8
Maximum	110.6
Points	1045
Mean	-0.7
Std Deviation	37.3
Skewness	0.2
Kurtosis	-0.1

E. C. Pavlis / GSFC

Trajectory Difference Statistics

TABLE 3. Trajectory Differences for the two SLR-determined 14-day arcs.

Component	Position [cm]			Velocity [cm/s]		
Direction	Radial	Cross	Along	Radial	Cross	Along
Mean	5.1	21.8	-19.0	0.0028	0.0002	0.0012
RMS	3.2	37.0	10.9	0.0017	0.0015	0.0059

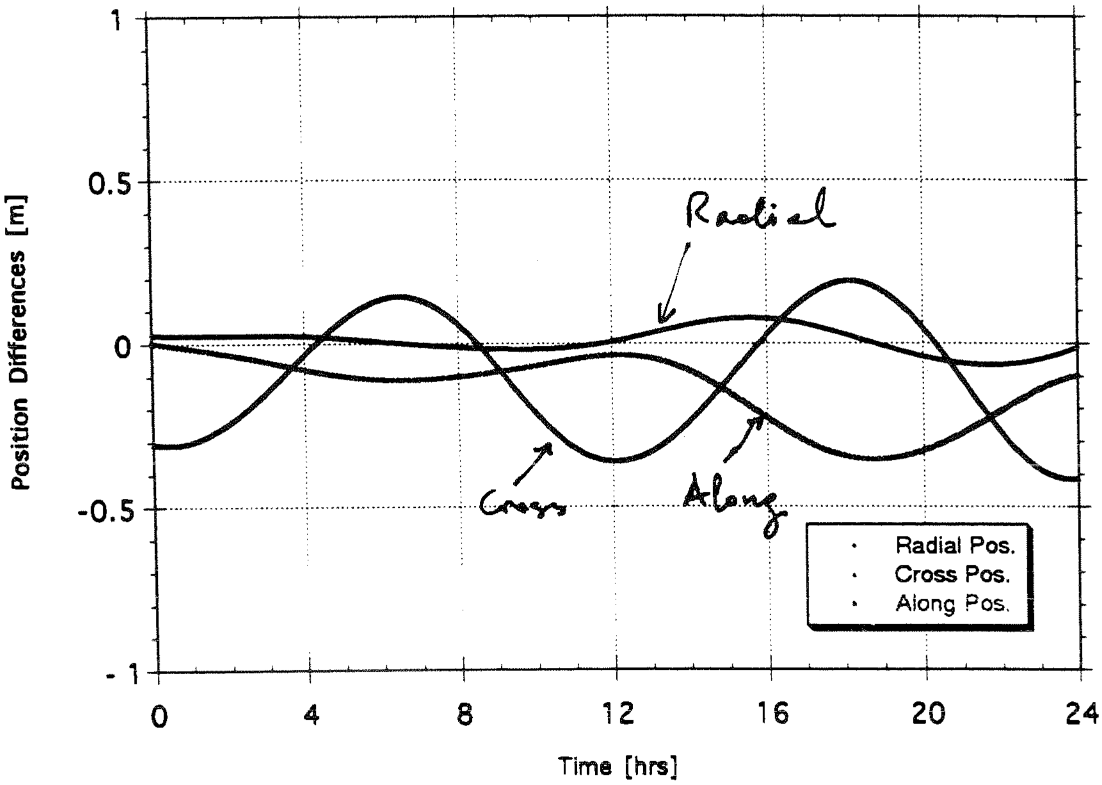
TABLE 4. Trajectory Differences SLR-1 vs. IGS GPS orbit.

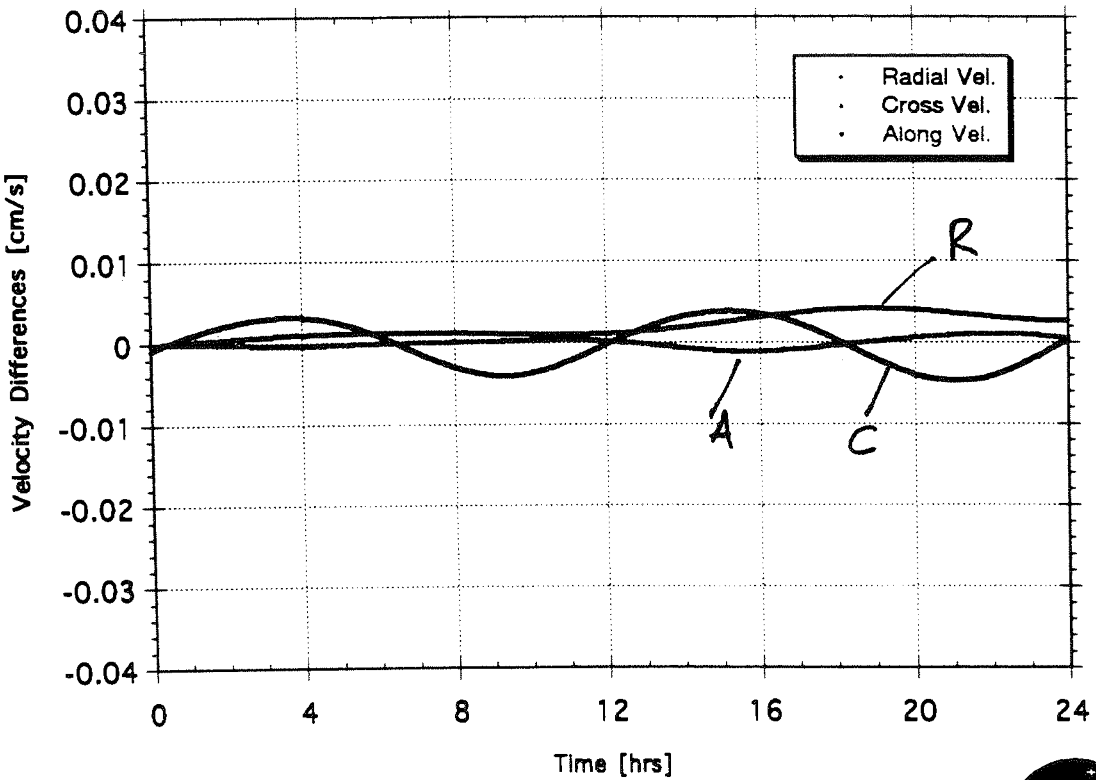
Component	Position [cm]			Velocity [cm/s]		
Direction	Radial	Cross	Along	Radial	Cross	Along
Mean	8.9	63.3	39.7	-0.0054	-0.0001	0.0004
RMS	7.7	56.5	75.1	0.0109	0.0102	0.0087

TABLE 5. Trajectory Differences SLR-2 vs. IGS GPS orbit.

Component	Position [cm]			Velocity [cm/s]		
Direction	Radial	Cross	Along	Radial	Cross	Along
Mean	3.6	41.5	58.7	-0.0082	-0.0003	-0.0008
RMS	9.8	90.9	72.9	0.0103	0.0093	0.0138

Orbit Differences Between SLR-G 104^d Arc and SLR-S2 14^d Arc





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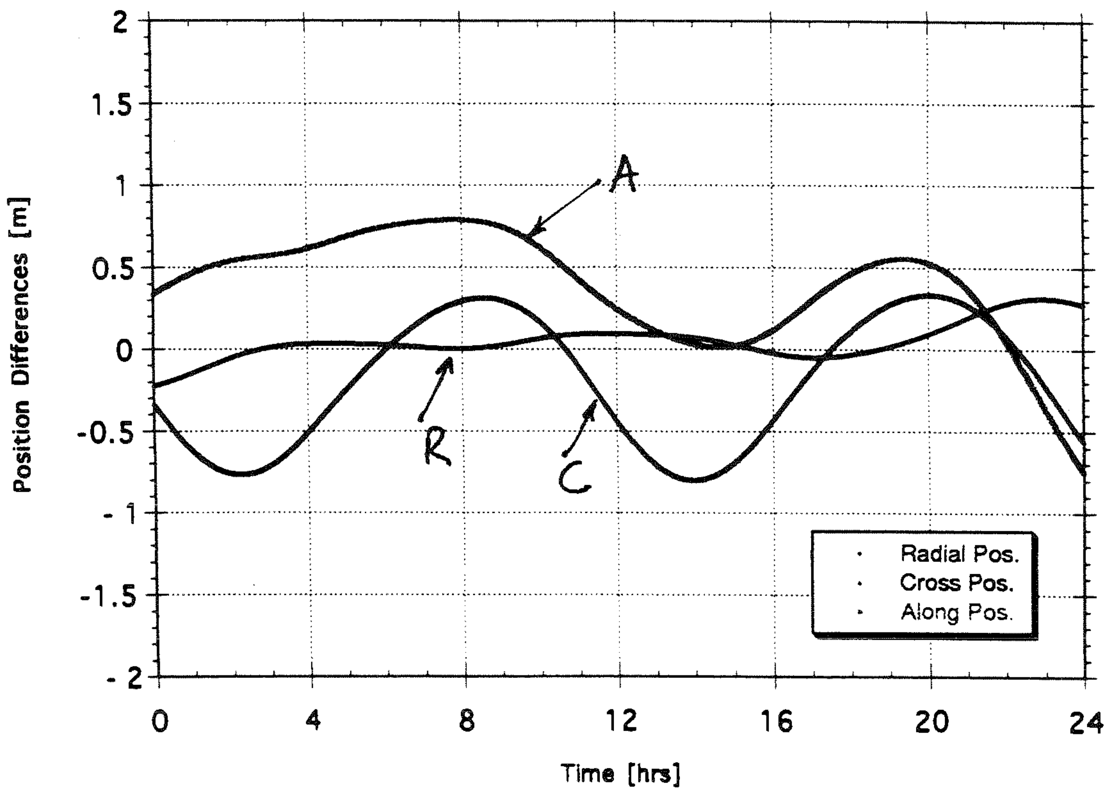
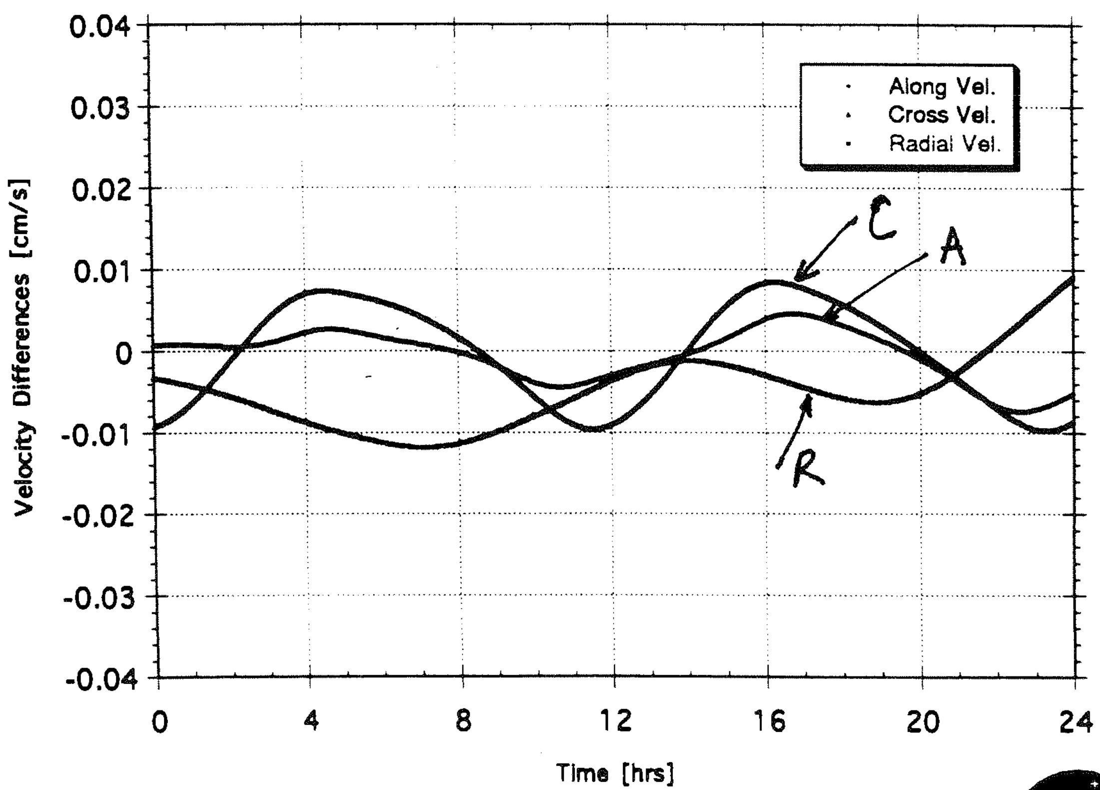
Orbit Differences Between SLR-S2 14^d Arc and IGS 1^d Arc





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Potential Uses of SLR Tracking of GPS s/c

- Independent precise assessment of quality of orbits
- Calibration of satellite clocks (onboard GPS s/c)
- Precise tuning of non-conservative models (e.g. ROCK4)
- Calibration/improvement of troposheric mapping functions
- Calibration of ionospheric models, especially useful for kinematic GPS applications
- Improved station positioning via GPS tracking & SLR-generated ephemerides

NASA
GSFC

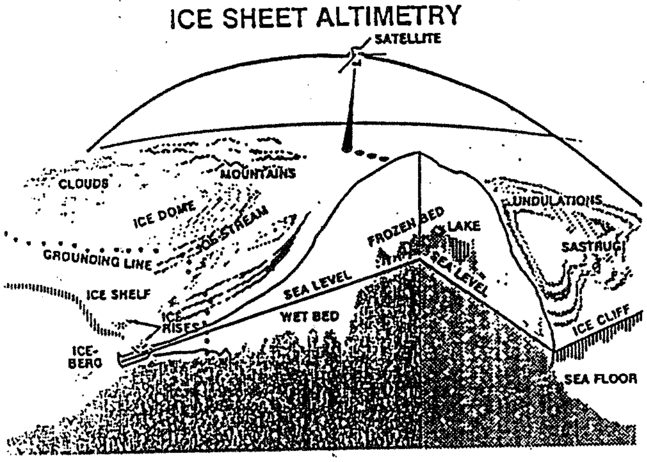
Applications of SLR to a Future Altimeter Satellite: GLAS

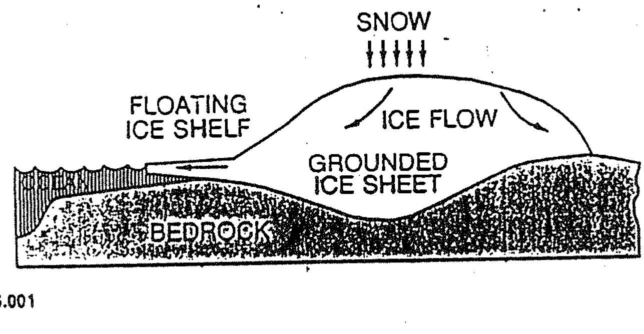
B. E. SCHUTZ
Center for Space Research
University of Texas at Austin

Ninth International Workshop on Laser Ranging Instrumentation
Canberra
November 7-11, 1994

ICE SHEET DYNAMICS

ICE SHEET ALTIMETRY





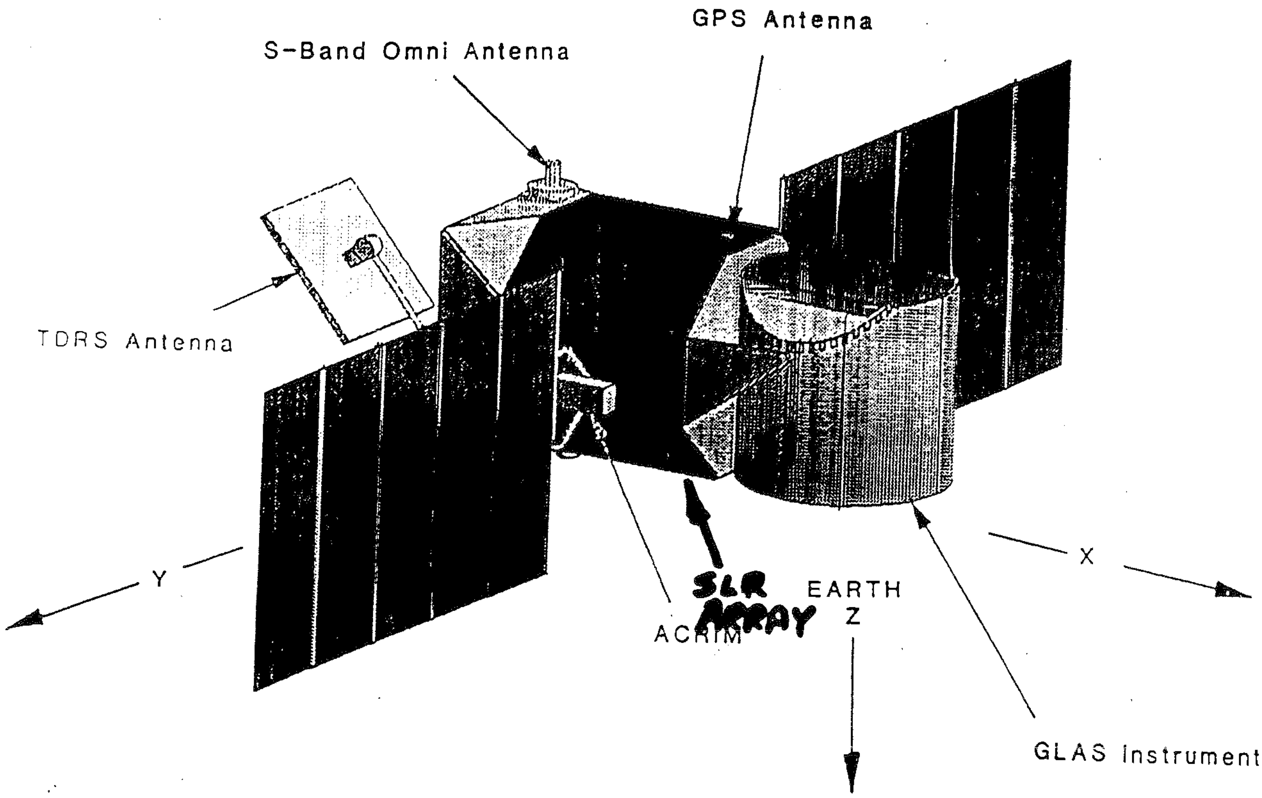
SCIENCE OBJECTIVES:

- DETERMINE CHANGES IN GLOBAL ICE VOLUME
  - PRESENT DAY GROWTH/SHRINKAGE
  - CONTRIBUTION TO SEA LEVEL CHANGE
  - PRECIPITATION CHANGE IN POLAR REGIONS
  - RESPONSE TO CLIMATE WARMING
- INVESTIGATE ICE DYNAMICS AND STABILITY

GREENLAND AND ANTARCTIC ICE SHEETS

AVERAGE THICKNESS	2,100 METERS	23/1 RATIO
SEA LEVEL EQUIVALENT	90 METERS	
AVERAGE MASS INPUT	17 CM/YR ($1/10^4$ PER YR)	
MASS BALANCE UNCERTAINTY	±30% (±2MM SEA LEVEL /YR)	

J76.001

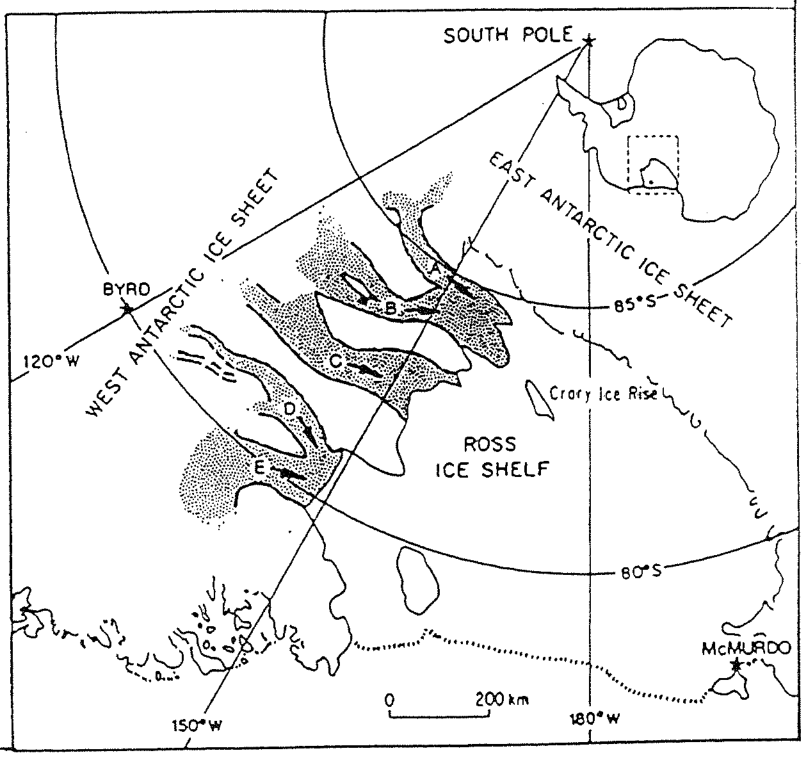


GLAS Concept
Orbit Configuration

Contributed by: Charles Tomasevich
Swales & Assoc., Inc.

ORBIT REQUIREMENTS

- Inclination: 94°
  - Antarctic ice streams
  - Crossover geometry
- Altitude: 705 km
  - Optimize simultaneous MODIS measurements for clouds
- Ground track repeat: 183-day repeat cycle provides twice per year coverage with ~ 2 km track separ. at 83° latitude
- ORBIT ACCURACY
  < 5 CM RADIAL
  < 20 CM HORIZ.



APPLICATIONS OF SLR

- PRECISION ORBIT DETERMINATION (POD)
- VALIDATION OF ORBIT ACCURACY OBTAINED BY OTHER TECHNIQUES, E.G. GPS
- CALIBRATION / VERIFICATION OF ALTIMETER HEIGHT

SLR POD : GLAS

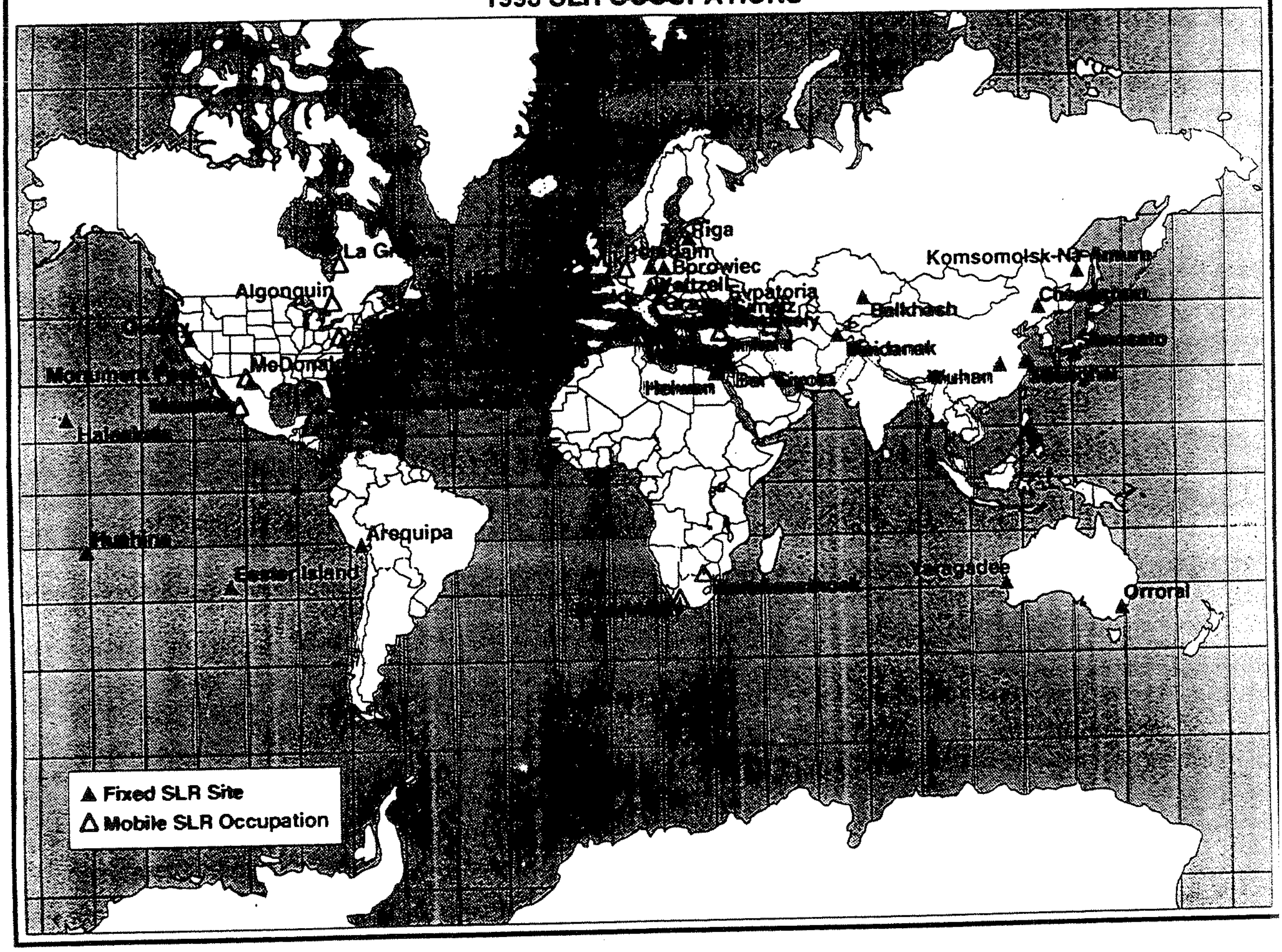
- SLR IS PRECISE (< 1 CM) AND UNAMBIGUOUS; PASSIVE (UNLIKELY FAILURE ON-ORBIT)
- ISSUES:
  - NATURE OF SLR NETWORK IN 2002-2008?
  - LOW ALTITUDE (700 KM) → SHORT DURATION PASSES
  - DIM PROSPECTS FOR SLR IN POLAR REGIONS
  - RELIANCE ON DYNAMIC TECHNIQUE REQUIRES ACCURATE FORCE MODELS (GRAVITATIONAL AND NON GRAVITATIONAL); GRAVITY MODEL IMPROVEMENTS REQUIRED

VALIDATION

- SLR CAN BE USED
  1) VALIDATE THE ORBIT ACCURACY OBTAINED BY OTHER TECHNIQUES, E.G. GPS (EXAMPLE: T/P 6 CM OFFSET IN GPS ANTENNA PHASE CENTER)
  2) IN COMBINATION WITH OTHER TECHNIQUES TO STRENGTHEN THE POD

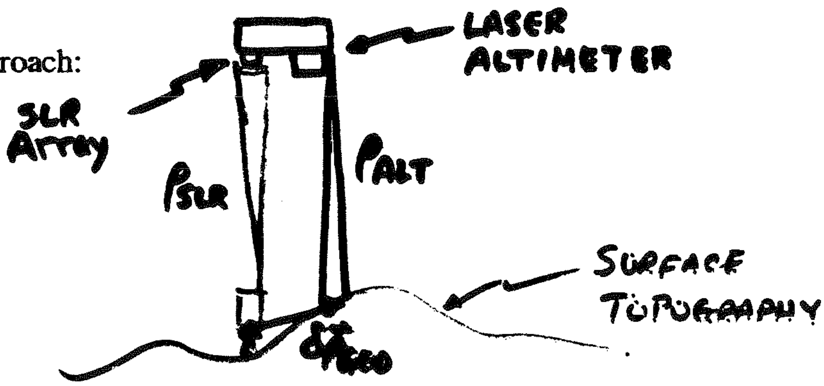
- VALIDATION EXTREMELY IMPORTANT TO ASSURE ALTIMETER MEASUREMENTS CAN BE INTERPRETED AS GLOBAL CHANGES (GEOPHYSICAL SOURCES)

1993 SLR OCCUPATIONS



ALTIMETER CALIBRATION: HEIGHT

- Approach:



Compare $\Delta\rho = \rho_{SLR} - \rho_{ALT} - \delta\rho_{CORR}$

- Desires:
  - Perform calibration with SLR in polar region, both South and North, and other
  - Frequent experiments
  - Direct overflight of SLR station, with well-determined local topography at site

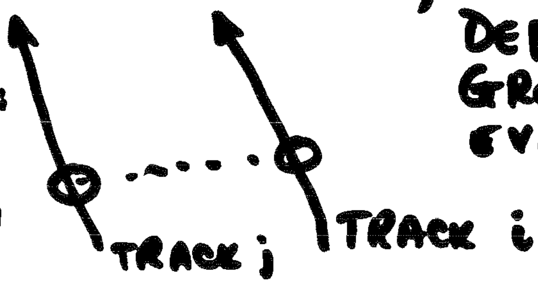
ALTIMETER CALIBRATION: HEIGHT

- Problems:
  - Operation of SLR in polar regions
  - GLAS repeat track cycle is 183 days, which produces ground track separation of ~ 2 km at 80° South/North and ~ 14 km at equator
  - Only two direct overflights per year; possibly four if SLR is located at crossover

CALIBRATION/VERIFICATION

- 180 DAY REPEAT CYCLE MEANS THAT ALL SLR STATIONS WILL EXPERIENCE A NEAR-OVERFLIGHT IN THAT PERIOD (< 14 KM). HENCE ALL STATIONS OFFER CALIBRATION POSSIBILITY
  - — PROBLEM: ALSO NEED LOCAL TOPOGRAPHY
- USE A <u>HIGHLY</u> <u>TRANSPORTABLE</u> <u>SYSTEM</u> TO "LEAD THE TRACKS"; MOVEMENT DISTANCE DEPENDS ON GROUND TRACK EVOLUTION

IDEAL DESIGN AND OPERATION:
- XYZ MOUNT
- OPERATE IN POLAR REGION



CONCLUSIONS

- SCIENTIFIC OBJECTIVES OF LASER ALTIMETER FOR MEASUREMENT OF ICE SHEET CHANGES REQUIRE DETERMINATION OF HIGH PRECISION ORBIT (< 5 CM RADIAL; < 20 CM HORIZONTAL)
- SLR IS ESSENTIAL COMPONENT
  - CONTRIBUTE TO POD
  - VALIDATE THE POD OBTAINED BY GPS
  - CALIBRATE/VERIFY THE LASER ALTIMETER MEASUREMENT

Future possibilities in time transfer

How might 5ps time transfer be achieved ?...

Christian Veillet OCA/CERGA

Time Transfer

- comparison of remote clocks
- through satellites

➡ by looking to the same flying clock(s)
(GPS, LASSO/T2L2)

➡ by using the satellite for time information relay
(two-way, Ajisai laser)

the propagation of an electromagnetic signal...

- radio domain (4-6 GHz, 11-14 GHz, ...)

- light domain (300,000 - 1,000,000 GHz)

➡ with radio, phase carries the time information

➡ with light, an event can be timed

limitation of the radio techniques

- GPS : 500 ps seems possible with new generation receivers (lower noise).

➡ Atmosphere could be a limitation at the same level...

- two way : 200ps precision is nearly done.

➡ Atmosphere is a limitation at 50ps.

➡ The use of a larger frequency difference is limited by available satellites.

how to use light 1/

- as two-way time transfer in radio
  - ➪ the transponder is just a mirror on a satellite relaying the light from one site to the other
  - ➪ the geometry is obtained through retroreflectors

- it can be done using the japanese geodetic satellite Ajisai, equipped with retro-reflectors and mirrors

- the observations are not easy, but the satellite is flying

how to use light 2/

- a clock is flying with ...
  - ➪ a laser detector and timing unit
  - ➪ a retroreflector array

- as LASSO used in monitoring mode

- the observations are easy, but the equipment has to be built and launched

common requirements for the ground stations

- short pulse laser (20ps)
- good detector (avalanche photo-diode)
- accurate timing device (5-10 ps)
- very stable configuration (the most demanding constraint...)

- could lead to 5ps precision in a 1mn observing time

requirement for the flying clock monitoring

- laser detector and timing unit as on the ground will lead to 5ps precision in a 1mn observing time for a ground to space link

- if the monitoring has to be used for time transfer between ground sites without common view, the flying clock has to be stable enough for maintaining the flying time scale on the time needed

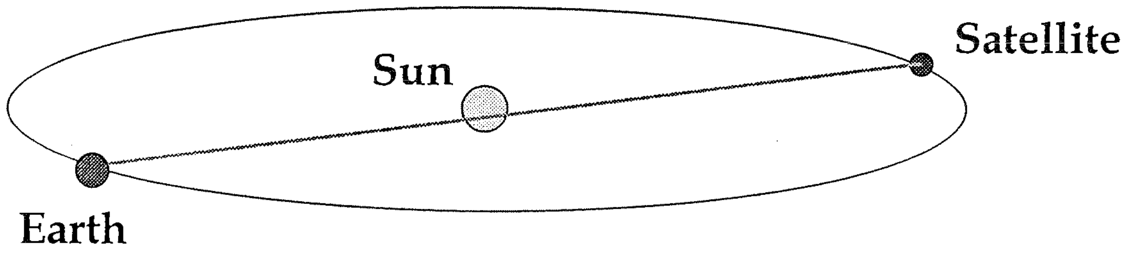
accuracy limitations

- atmosphere : only variations within a short time have to be considered, but they do not limit at 5ps
- modelling : no influence at the 5ps level
- satellite geometry can be measured well enough for 5ps time transfer
- fluctuations of ground station equipment are the most serious limitation (calibration...)
- flying equipment could be stabilized easier than the ground stations

which future ?...

- optical time transfer through satellites can achieve 5Ops precision right now
- 5ps precision requires technological developments already undertaken, to be achieved before yr 2000
- 50ps accuracy is a challenge for the existing laser stations
- 5ps accuracy will be difficult to achieve, mainly due to station metrology monitoring

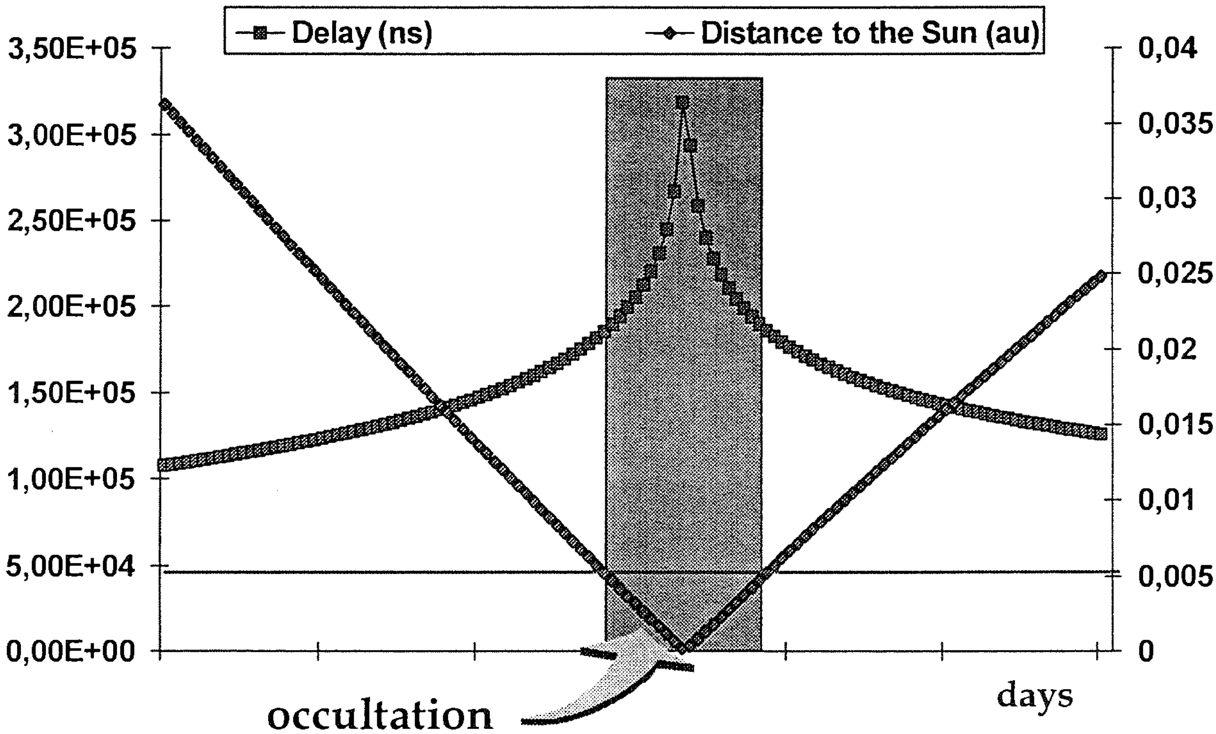
Measuring γ through the "Shapiro effect"



The light passing close to the Sun is affected by the gravitational field of the Sun

➡ gravitational delay to be measured through the one way trip time before and after an occultation by the Sun

an occultation ...



TARGET SIGNATURES AND BIASES

Chairperson : Andrew Sinclair

EFFECTS OF DETECTION THRESHOLD AND SIGNAL STRENGTH ON LAGEOS RANGE BIAS

John J. Degnan
Code 920.1
Laboratory for Terrestrial Physics
NASA Goddard Space Flight Center
Greenbelt, MD 20771 USA

ABSTRACT

The electronic waveform out of a photodetector is the convolution of several functions, i.e. the laser pulseshape, the target signature, and finally the detector input response. Signal detection can be treated mathematically as a two level Markov process where the signal transitions from a value below the detection threshold to a value above the detection threshold. The point on the final waveform at which this "detection" transition takes place is a function of both the detection threshold setting and the return signal strength. Furthermore, the shape of the single shot range data distribution will also depend on the same two parameters. This can lead to small biases in the computation of system delays from calibration target measurements and in the normal points computed from satellite ranges.

In the present paper we provide the mathematical framework in which these effects can be calculated, and use the resulting expressions to estimate the magnitudes of the biases for two cases important to satellite laser ranging, i.e. a single cube calibration target and spherical geodetic satellites such as LAGEOS. It is shown that, in the limit of small signal strength and single photoelectron detection thresholds, the distribution of range data has the shape of the satellite signature and the same centroid. At higher signal strengths the range centroid is shifted away from the satellite centroid toward the leading edge of the pulse, resulting in a signal strength induced bias and a decidedly skewed data distribution. Raising the detection threshold above the single photoelectron level partially compensates for signal strength effects and has the general effect of reducing the observed bias.

ANALYTICAL MODEL

- Threshold detection is modeled as a two state Markov process (SPADs are threshold detectors)
- The transition between states occurs when the received signal exceeds the detection threshold
- To study only the effects of detection threshold and mean signal strength on LAGEOS bias, the laser pulse and detector impulse response are assumed to be infinitely short, i.e. delta functions

DEFINITIONS AND ASSUMPTIONS

Laser pulse profile

$$f(t) = \delta(t)$$

Satellite impulse response

$$s(t)$$

Photoelectrons generated at the photocathode

$$\lambda(t) = n_e \int_{-\infty}^{t} dt' f(t') s(t-t') = n_e s(t)$$

Receiver impulse response

$$h(t) = \delta(t)$$

EXPECTED DATA DISTRIBUTION FOR THRESHOLD DETECTION

Probability Distribution

$$P(t) = \frac{1}{P_D} a(t) \exp\left[-\int_{-\infty}^{t} dt' a(t') \right]$$

Probability of Detection

$$P_D = P(\infty) = 1 - \exp\left[-\int_{-\infty}^{\infty} dt' a(t') \right]$$

Definition of a(t)

$$a(t) = \lambda(t) \frac{\left[n(t)^{M-1} \right]}{(M-1)!} \left[\sum_{j=0}^{M-1} \frac{[n(t)]^j}{j!} \right]^{-1}$$

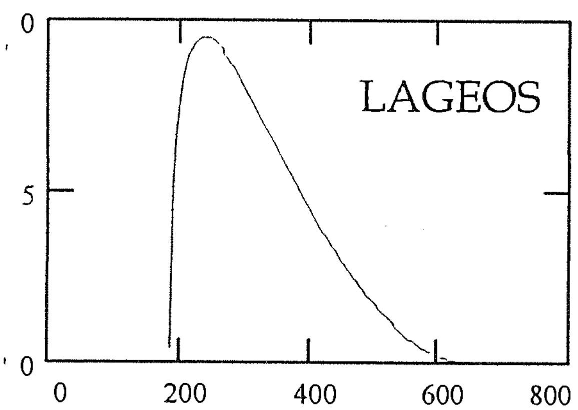
Definition of n(t)

$$n(t) = \int_{-\infty}^{t} \lambda(t') h(t-t') dt'$$

M = detection threshold in photoelectrons

John J. Degnan NASA GSFC

APPROXIMATE LAGEOS MODEL*



- Analytic model based on uniform distribution of reflectors over a sphere
- Provides average response of the satellite to an infinitely short pulse
- *Reference: J.J. Degnan, "Millimeter Accuracy Satellites for Two Color Ranging", Proc. 8th International Workshop on Laser Ranging Instrumentation, Annapolis, MD, 1992

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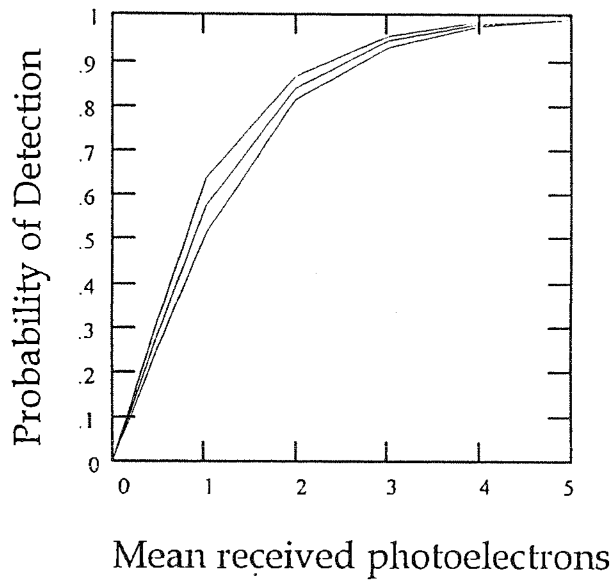
Probability of detection as a function of threshold and signal strength

- Threshold was varied between 1 and 3 photoelectrons
- Mean received photoelectrons were varied between 1 and 25 photoelectrons
- For mean signals above 4 pe, probability of detection for all thresholds is about 95%



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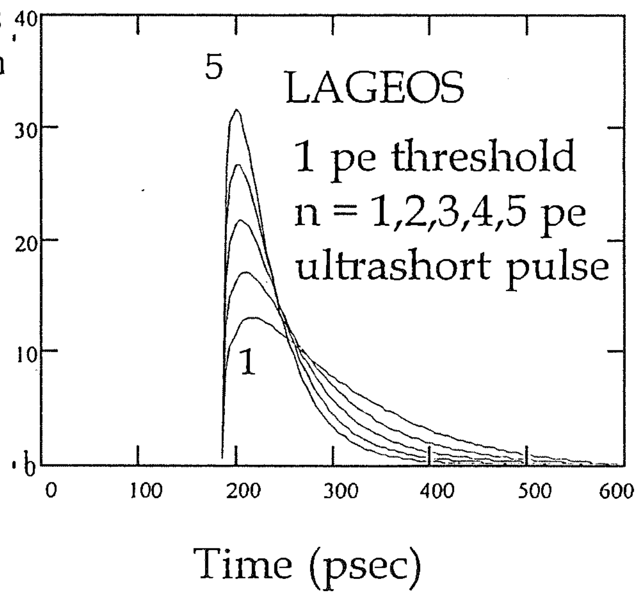
SPAD detection statistics for LAGEOS (ultrashort pulse)

- Peak of data distribution moves forward as mean signal strength increases
- Even for 1 pe signal strength, SPAD data distribution varies substantially from the satellite signature
- **Conclusions:**
  - SPAD introduces signal strength dependent bias.
  - Data RMS should tighten with increased signal strength



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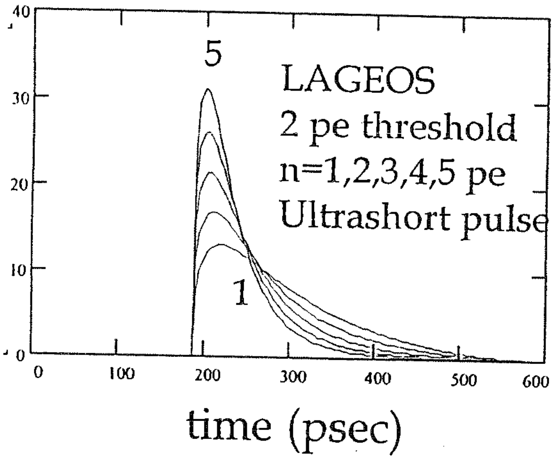
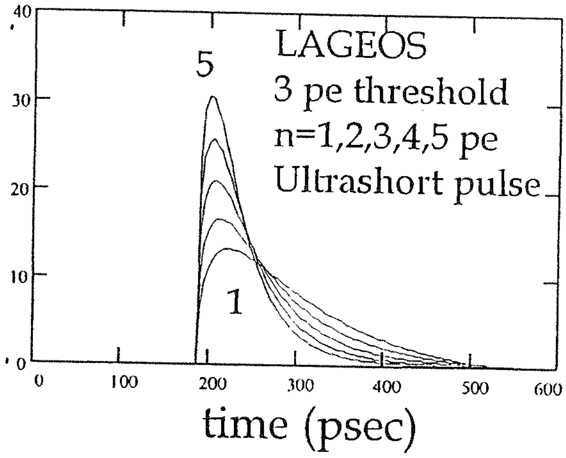
Expected data distributions for 2 and 3 pe thresholds (no CFD)





- For higher thresholds, range data sets are still strongly biased as a function of signal strength

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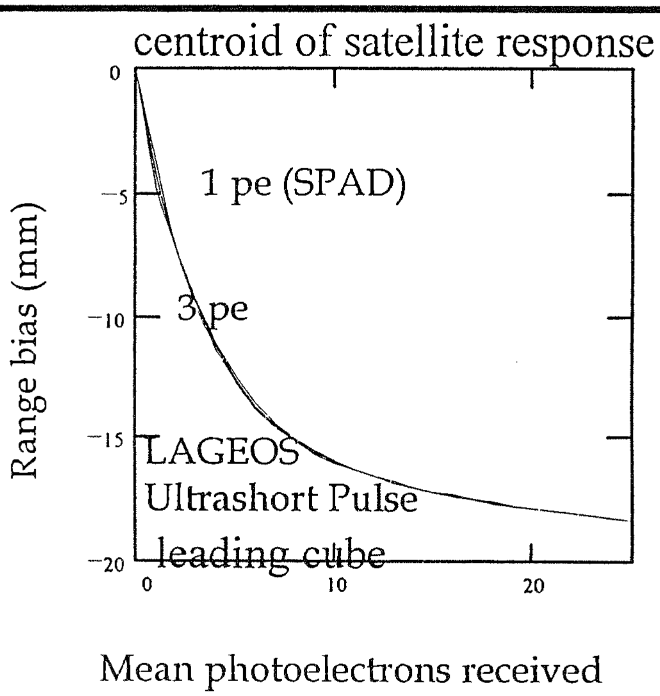
LAGEOS range bias (ultrashort pulse)



- Bias is calculated relative to centroid of the satellite impulse response
- Leading cube reflection point is 20.1 mm in front of centroid
- For signal strengths greater than 2 pe, the bias is almost independent of detection threshold
- For mean signals below 2 pe, the bias is smaller for lower detection thresholds

John J. Degnan NASA GSFC

CONCLUSIONS

- Ultrashort pulse threshold detection of LAGEOS
  - range bias increases with signal strength
  - bias at 1 pe signal level is about -4 mm
  - bias at 5 pe signal level is about -13 mm
  - bias cannot exceed -20.1 mm (front cube)
  - data rms should decrease with increasing signal strength
- Higher threshold systems yield essentially the same bias as a SPAD at mean signal levels higher than about 2 pe

John J. Degnan NASA GSFC

An analysis of data gathered by NASA SLR during testing of the Fizeau effect within the Meteor-2 satellite retro-reflectors

NASA / GSFC
John Degnan

Russian Academy of Sciences
Victor Shargorodsky

ATSC
Christopher Clarke
Mark Davis
Julie Horvath
Alan Murdoch

Presented at the
9th International Workshop on
Laser Ranging Instrumentation
Nov 7 - 11, 1994

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Meteor-2/21 Retro-reflector Configuration

- This Experimental Corner Cube Package is a follow on from a previous mission with:
  - 2 Hollow and 2 Quartz cubes
- Velocity Aberration is supposed to directly compensated by the Fizeau Effect
- 2 Perfect cubes of different materials configured such that only one will produce a response
- Theory -- Flint Glass (F101) cube is capable of producing a higher compensating effect than the Quartz glass (KU-1) cube with respect to velocity aberration

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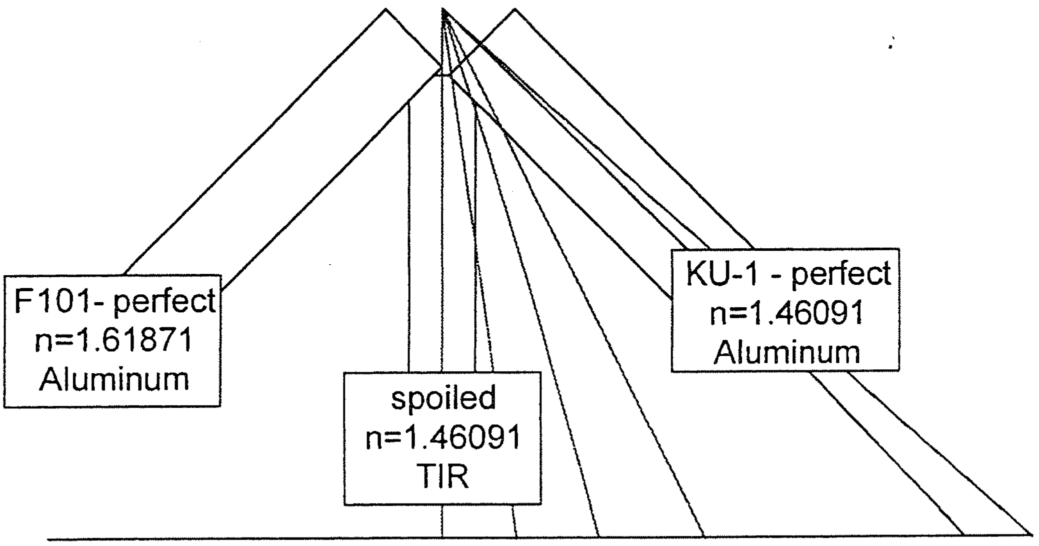

Satellite Nadir Angle	0.0	10.0	17.0	30.0	45.0	53.0
Observer Elevation	90.0	78.0	70.0	55.0	35.0	22.0

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Cube specific Curves

- Normalized cross section curves
  - based on incidence of material (n)
  - based on aluminum or tir coating
- Fizeau Effect for Left and Right Cubes (F101 and KU-1)
  - at 0.5 max n produces 3.0 and 2.6 arcsec of compensation
  - at 0.1 max n produces 10.7 and 6.7 arcsec of compensation
- Velocity Aberration for satellite at 955 KM Altitude
  - 9 to 10 arcsec

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Orbital Geometry

- Near repeat ground trace every 4 days
  (Equivalence classes)
  - similar PCA
  - east/west
  - ascending/descending (earth rotation and inclination)

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Campaign # 1
Moblas 4 and Moblas 7 Collected Data
March 12 to April 10, 1994

- Left and Center Cubes -- in navy blue
- Right and Center Cubes -- in red
- Both Center and Side cube --Light blue
- Green Area's where "shouldn't get returns"
  - Based on general theory and RAS information
  - Center cube +- 17/19 degrees (at 10 percent or HW masked)
  - Side cubes +- 45 degrees (at 10 percent) (see Topex FFDP)
- Clear area is where we should get returns assuming orthogonality between velocity direction vector and cube fixture

Campaign #2

- Moblas 7 / TLRS 4 / TLRS 3
- Moblas 7 / TLRS 4 / MLRS
- MLRS / Moblas 4 / Moblas 8

- Confirm satellite orientation wrt velocity vector
- Improve equivalence class coverage
- Improve low elevation overflights
  - GGAO has a 30 deg restriction for daylight/twilight overflights

Signal Strength

- Photons per Square Meter Desired
  - polarization dependency on aluminum coated cubes
  - temperature effects
  - weather and other atmospherics
- Relative Receive Energy Measured for each shot
  - OAM control of ND wheel on receive path
  - REM calibration very system dependent
  - Analysis difficult to the large sigma on energy values
- Normal Points
  - shots fired vs received
  - Mixing results from different systems
  - see the OAM ND effects of return ratio

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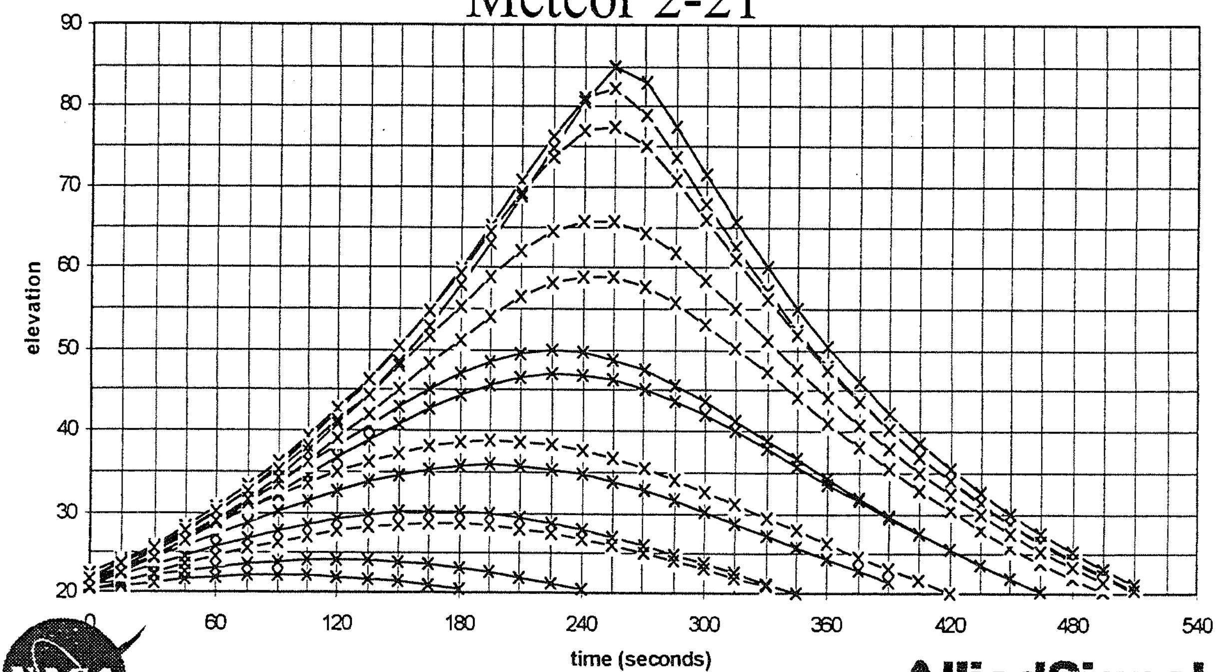
Overflight Geometry at Moblas 7 for Meteor 2-21



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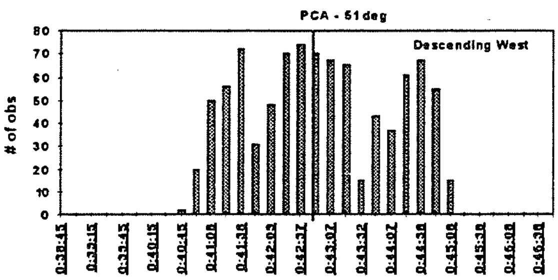
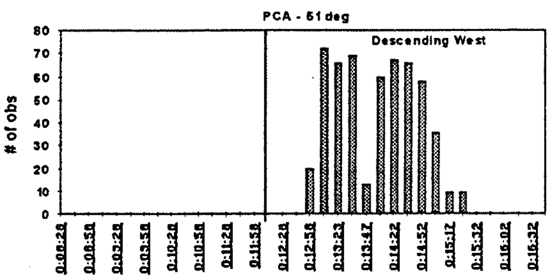
PCA		Upside	Downside		Upside	Downside		PCA		
	Right and Center Cubes									
78	ascending West	7	5	strong	4	6		79	descending east	
77	ascending West	3	7	strong		FAIL		77	descending east	
73	ascending West	3	7	strong	0	4		72	descending east	
71	ascending West	4	13	mix						
						FAIL		69		
					0	7	mix	59		
45	ascending West	0	7	weak	9	12	sharp drop	49		
45	ascending West	7	14	strong	4	8	strong	43		
41	ascending West	7	15							
39	ascending West	FAIL								
27	ascending West	8	10	med		FAIL		24		
25	ascending West	7	7	mixed		FAIL		21		
	Left and Center Cubes									
85	descending west	8	8	strong						
81	descending west	0	6	very weak						
65	descending west	6	6			FAIL		67		
63	descending west	6	8		10	9		67		
55	descending west	8	13							
51	descending west	0	12							
51	descending west	9	10							
37	descending west	3	1		8	4		39		
34	descending west	0	6		10	15		39		full pass 20 to 20
					0	3	very weak	35		
					4	8	strong	23		

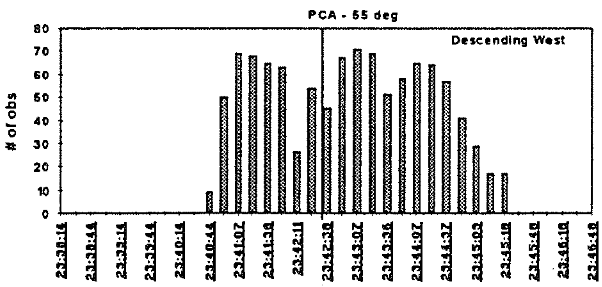
Moblas-7 Fizeau 3/13/94 15 sec bins



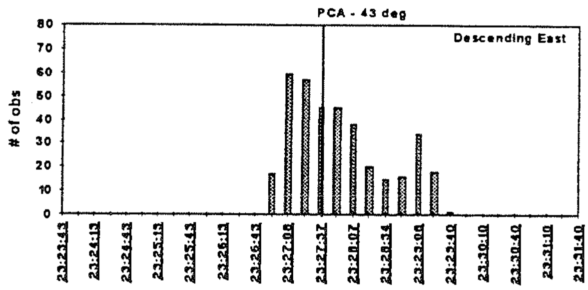
Moblas-7 Fizeau 3/17/94 15 sec bins



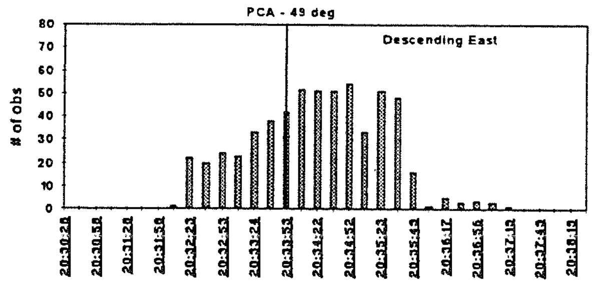
Moblas-7 Fizeau 3/20/94 15 sec bins



Moblas-4 Fizeau 4/5/94 15 sec bins



Moblas-7 Fizeau 4/7/94 15 sec bins



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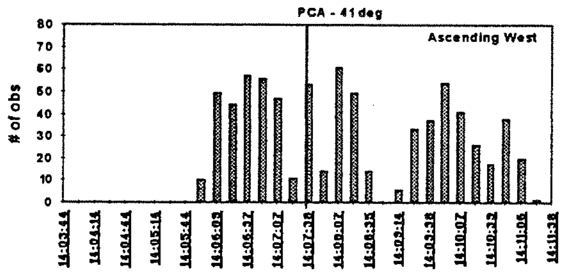
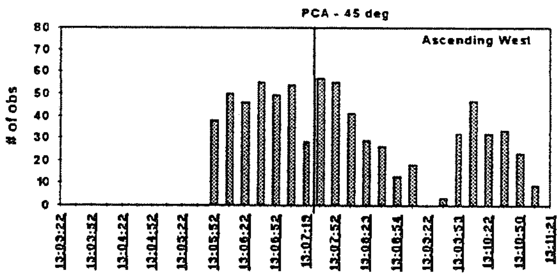
Moblas-4 Fizeau 3/30/94



Moblas-4 Fizeau 4/7/94 15 sec bins



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NEW MOBILE STATIONS

Chairperson : Erik Vermaat

FRENCH HIGLY MOBILE LASER SYSTEM

Technical specifications - Status of the project

****

F.PIERRON- M. KASSER

and

The mobile laser group

****

OCA-IGN-GRGS-CNES

SUMMARY

General specifications
Laser system
Mount
Electronic and software
Status of the project today

Camberra

November 1994

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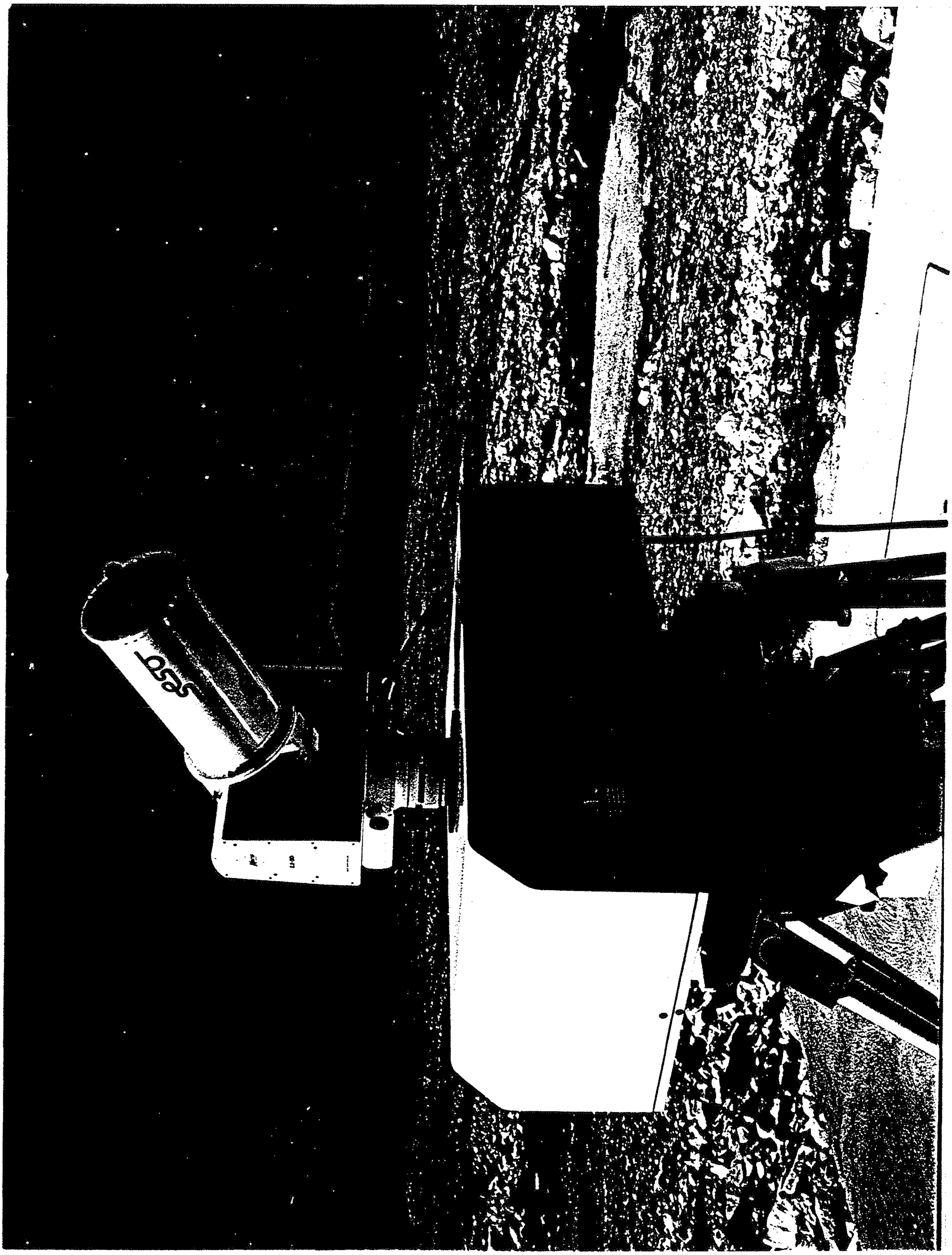


M - 7835_01 *Topex pass- French Higly mobile slr system. November 15 th 1993* 1087 retours

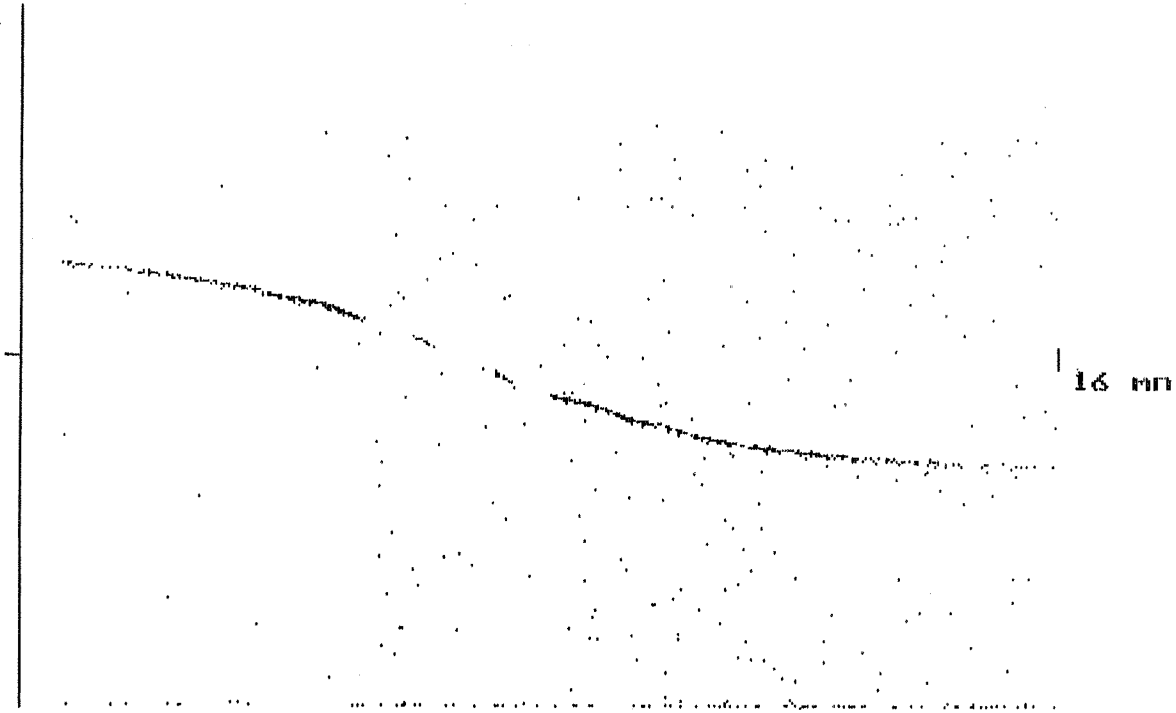
topex/posëidon

i 15 ms

g931115.21u

15/11/93 21:48

+1205 m



-1205 m

17/05/42 00:00

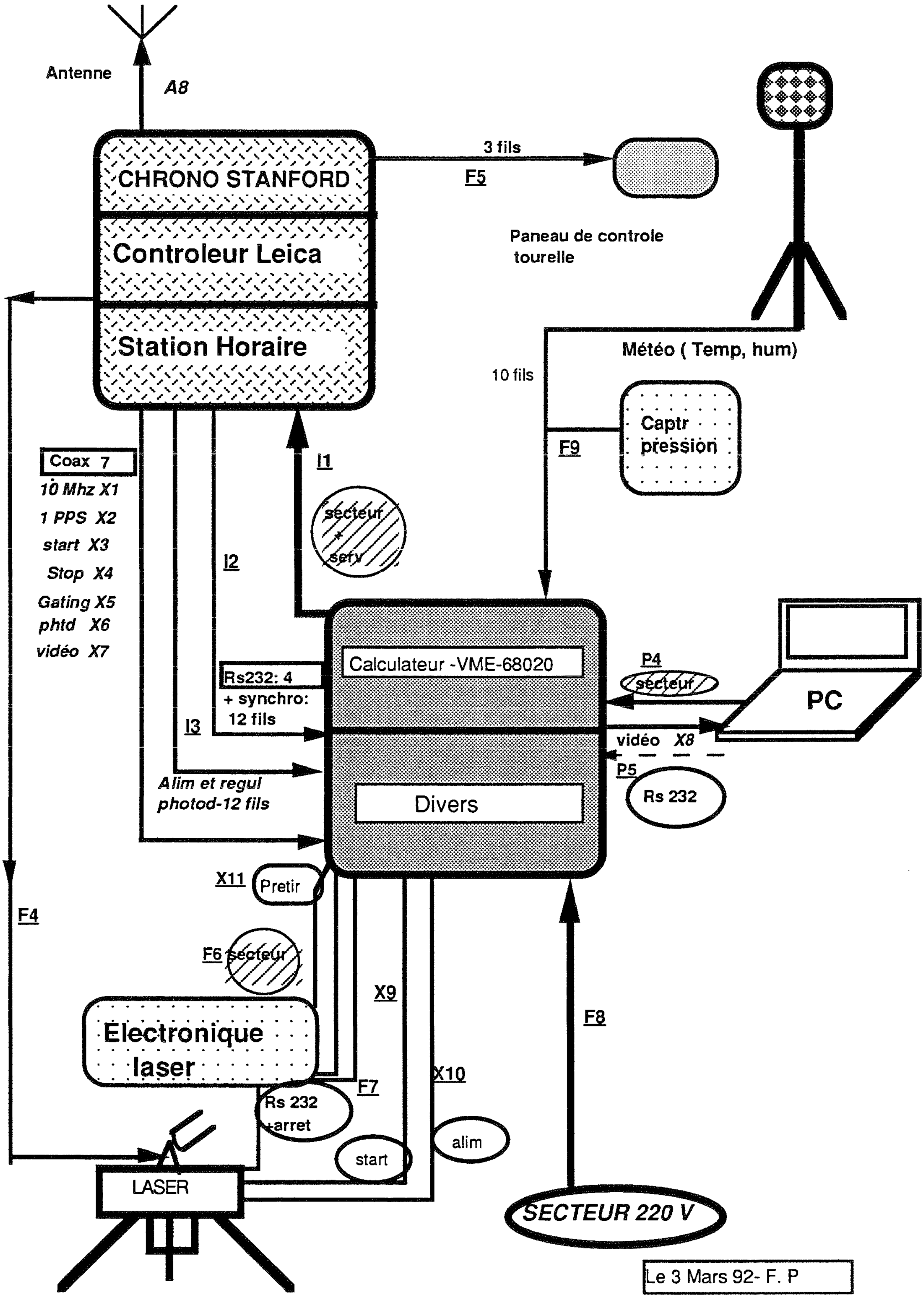
p = 871.7 mb
t = -0.1 C
h = 48 %
15/11/93 21:32

déb prev 21:31

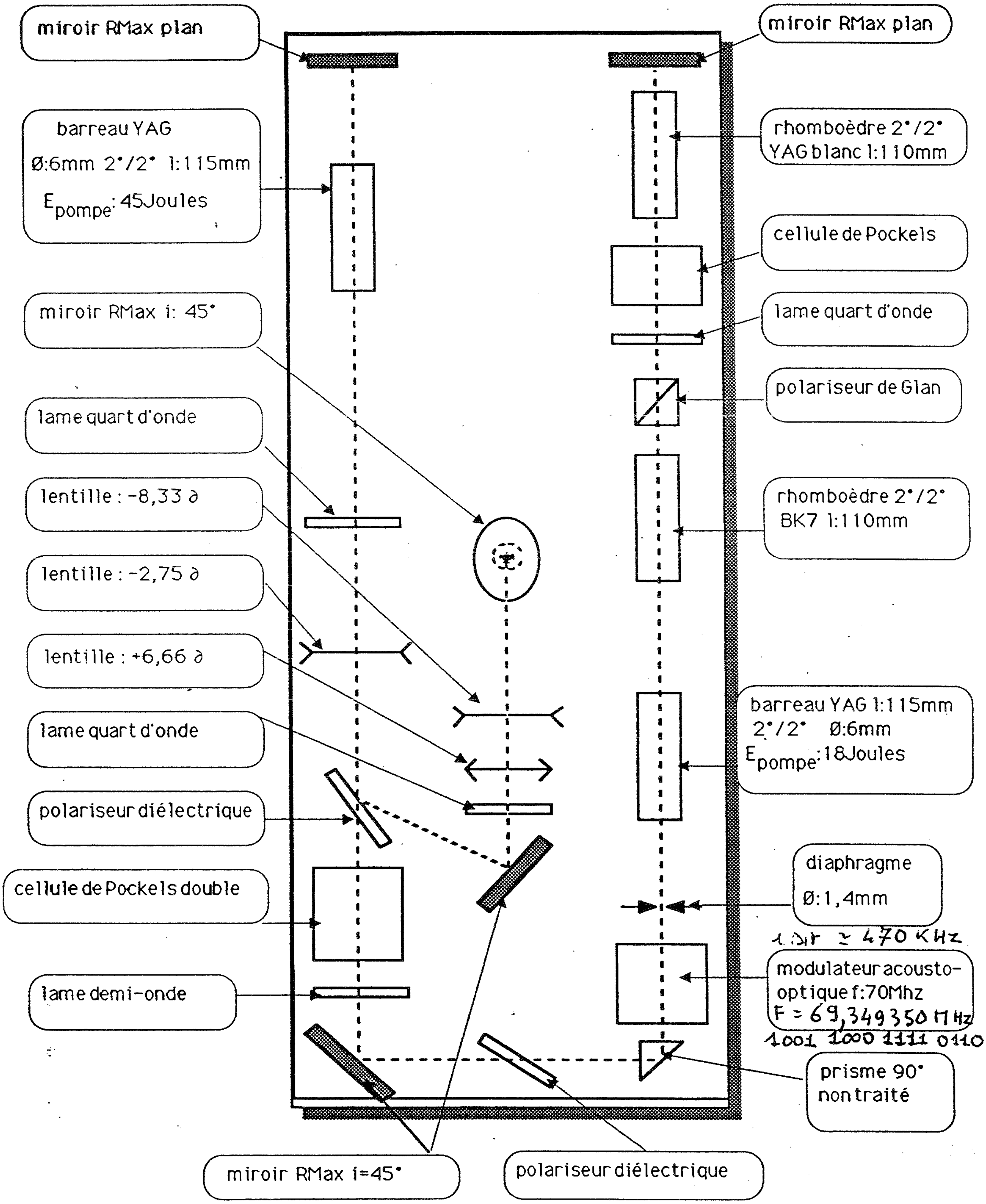
sélection
déb ret 21:32:03
fin ret 21:47:14
1087 points

Voulez-vous : sélectionner une partie du graphe ---------------------- s
corriger le bloc calibration-météo --------------------- c
lire à l'écran les points plotés ----------------------- l
ou les copier dans un fichier formaté ------------------ f
prétraiter le passage ---------------------------------- p
sortir de l'utilitaire LEC ----------------------------- (déf.)

General synoptic



CONCEPTION OPTIQUE



Compact laser bench

GENERAL SPECIFICATIONS OF THE MOBILE LASER SYSTEM:

****

* Very compact

*Easy to transport by plane or car in containers of 50 Kg max.

* Very reliable, especially the laser system, the mount and the electronic devices

 * Operational cost weak

 ======>two technicians only to operate.

* Accuracy at some centimeters level

* Capability to track a satellite very close of the zenith.

Particularly Oceanographic satellites at an elevation of 89 Deg with an azimuth speed of 50 Deg/sec during some seconds of time to calibrate the altimeter.

LASER EMITTER SPECIFICATION
****

MANUFACTURER: QUANTEL FRANCE

-ND-YAG Laser in active-active mode for the beginning of the operations and active passive today (october 94)

-ONE DOUBLE PASS AMPLIFIER

-ENERGY PER SHOT: 100 milli Joules at 1064 nm

-REPETITION RATE: 10 HZ

-Pulse Width: 100 ps

-Cooling System: Air water exchanger

Operating temperature: -10 deg c to 35 deg c

-Total Weight 80 Kilogrammes.

-Packaging in three pieces:

*The head (40 Kg)

*The power supply (22 Kg)

*The Water-air exch(18 Kg)

COMPACT LASER HEAD:
****

Composition of the laser head:

-Optical components fixed on a carbon fiber bench and included in a presssurized enclosure.

-Oscillator cavity with a servo-tilt on the cavity mirror

-One double pass amplifier

-One pulse selector

-No harmonic generator for doubling frequency to the green color

-Cooling system and capacitors banks are fixed just under the bench.

-Size of this head:

-1.00 m by 0.30 m for the bench by itself

-0.700 m by 0.30 m for the capacitors and cooling system under.

Weight: 40 Kg

POWER SUPPLY OF THE LASER:

-Fully designed in order to minimize the size, the reliability and the weight .

-Size: typically 40 liter

0.40 m by 0.40 m by 0.30 m

-TOTAL WEIGHT: 22 KG

RECEIVING DEVICES, DETECTION PACKAGE
****

*DIAMETER OF THE RECEIVING OPTIC: 13 centimeters

*Infrared detector:

Single Photoelectron Avalanche Photodiode

CCD CAMERA:
****

* A CCD camera integrated in the receiving optics to:

- track the stars in order to get precise orientation of the mount.

- achieve optics alignments on the paths of transmitting and receiving laser beam .

MOUNT:
****

* Built by the swiss company KERN/LEICA on the base of an existing electronic theodolite.

*Especially designed to be operated in the land.

TEMPERATURE

WEIGHT

RELIABILITY

STURDINESS

*MAXIMUM SPEED DURING THE TRACKING: 60 DEG/SEC

in order to calibrate oceanographic satellites

*SUITABLE FOR ACCEPT THE RECEIVING SYSTEM WHITH A TOTAL WEIGHT OF 9 KG.

*** New design for the gearing in 94 in order to have a good quality tracking even at a very high speed.**

Electronic devices and real time process control

Basic principle:

A specialized computer(68020) running with a real time operating system and built of VME cards for interfacing the devices:

- *GPS-synchronized time and frequency system.*
- *Stanford chronometer*
- *Mount control system*
- *Laser*
- *Meteo sensors and temperature control (el cabinets,laser,.)*
- *Dedicated cards (100 ns event timer and range gate generation at 10 ns)*

+

A portable PC computer under DOS operating system in charge of:

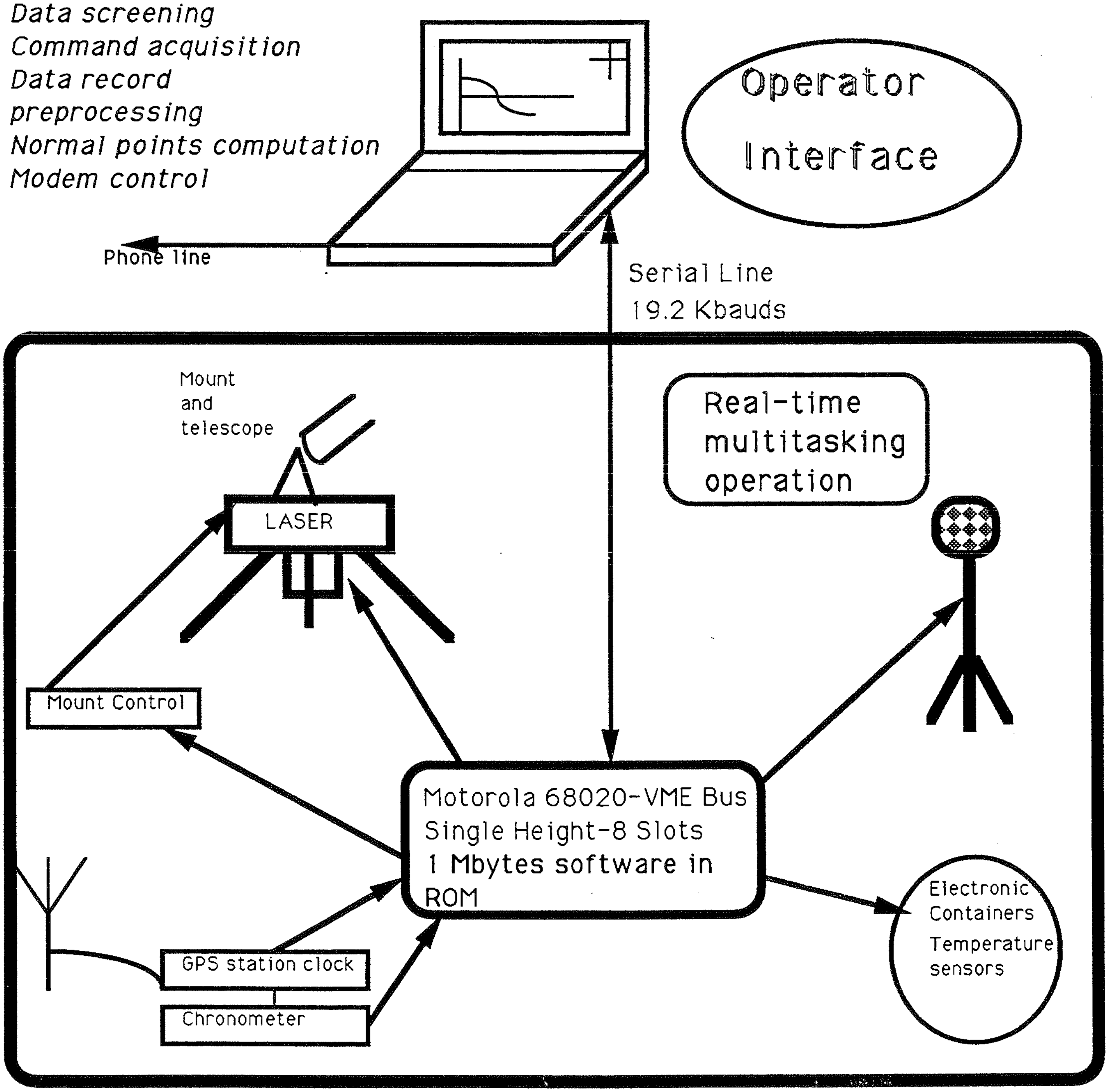
- *Interface " machine-men"*
- *Graphic screening during the pass*
- *Acquisition of the commands of the operator.*
- *Record of the data on the mass storage device.*
- *Preprocessing and normal points computations.*
- *Disemination and reception of the data.*

VME-->PC communication via a standard serial line rs232.

French Mobile Laser
Real Time Process Control

Standard PC

Data screening
Command acquisition
Data record
preprocessing
Normal points computation
Modem control



Real Time Process control

OCA/CERGA- Satellite Laser Ranging- *GRASSE-FRANCE*

Status of the project today (November 94):
****

* Some succesfully passes realized on Topex-Poséidon and ERS1 in november 1993 with a very large divergence (1 minute of arc).

but,...

* Tracking quality very bad:

oscillations of + or - 20 secondes of arc or more depending on the velocity of the mount.

In order to solve the problem,...

An expertise of the gearing showed severe defaults in the design and lead to the conclusion that it was necessary to change some parts in this design in order to have the capability to track higher satellite with a divergence of 10 arc secondes.

The subcontractor Kern from switzerland in charge of this project in 91/92 was been bought for financial arrangements by The company LEICA.

From this date, the only help we can get from this company is the furnishing of the plans and drawings of the mechanic.

A French society is actually doing a new design with a speed reducting gear pair from Harmonic Drive.

First tests of this design: spring 1995 hopefully,...

NEW FIXED STATIONS

Chairperson : Yang Fumin

The Starfire Optical Range

Presented at the
9th International Workshop on Laser Ranging Instrumentation
7-11 November 1994
Canberra, Australia
by

Robert Q. Fugate
Starfire Optical Range

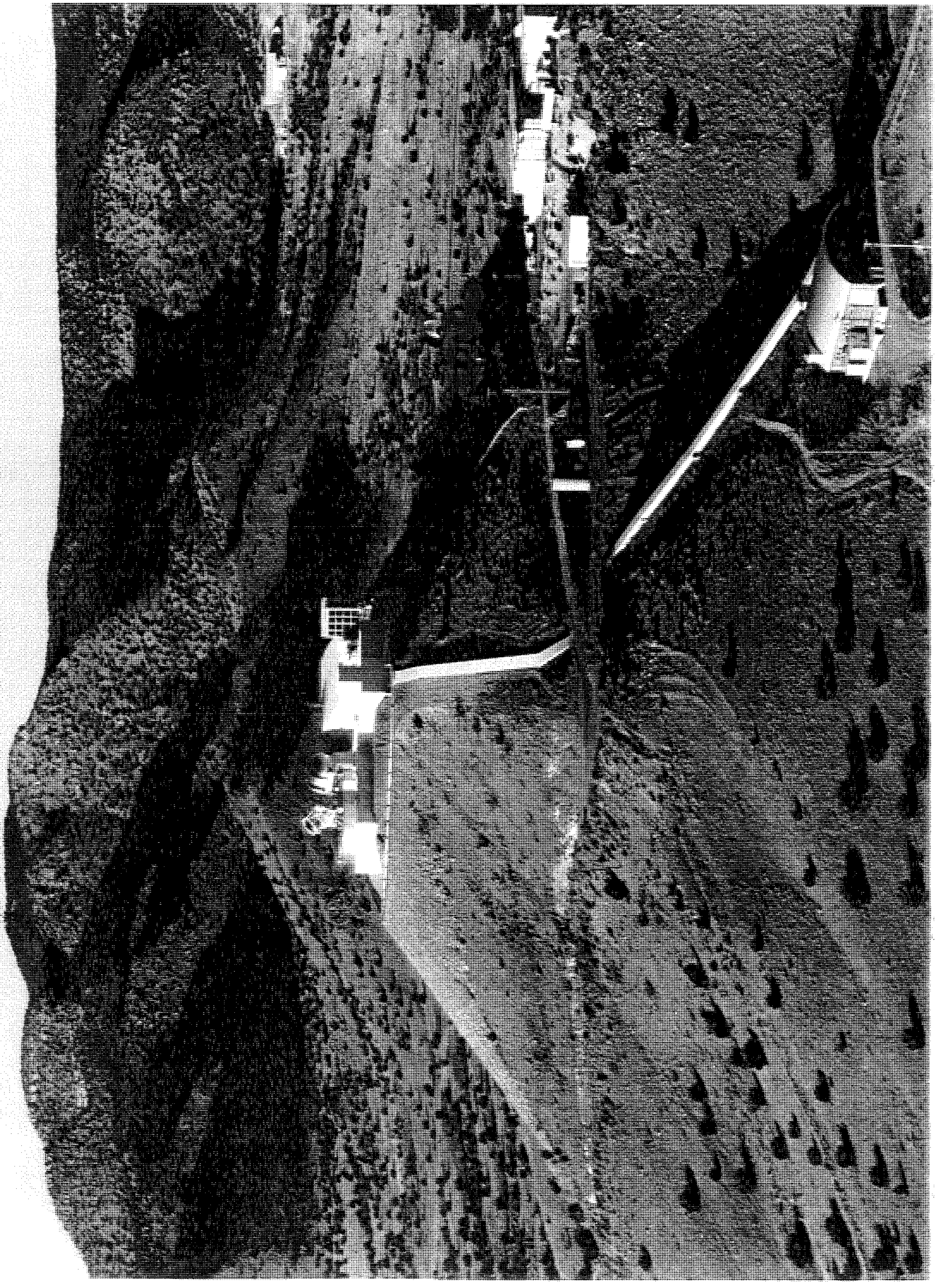
Starfire Optical Range

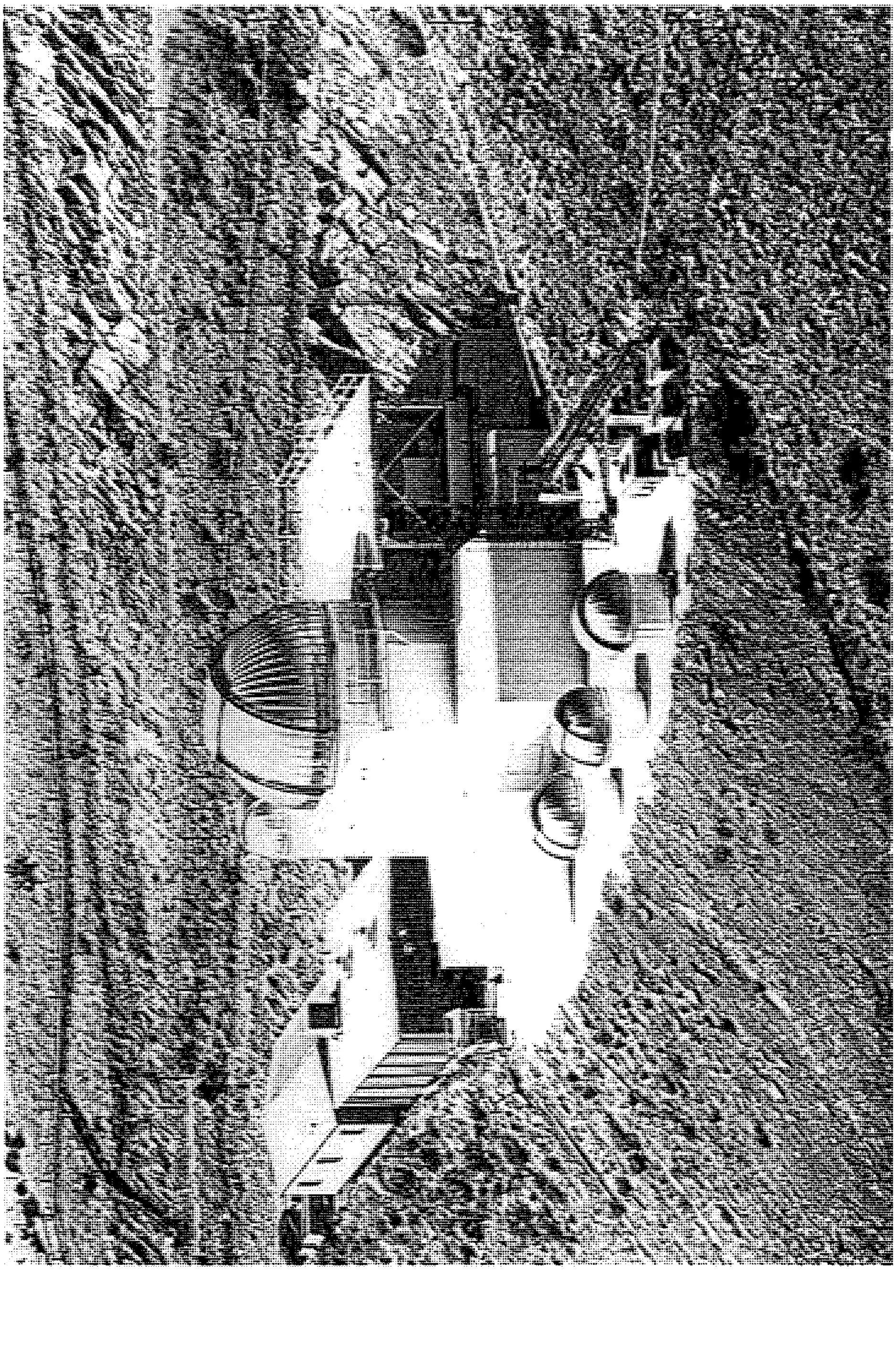
- Operated by USAF Phillips Laboratory
- Located on Kirtland Air Force Base, New Mexico, USA
- Research center for
  - Optical propagation in the atmosphere
  - Adpative optics and atmospheric compensation
  - Imaging
  - Atmospheric effects on laser communications
  - Satellite tracking and orbital mechanics
  - Satellite laser ranging
  - Power beaming research

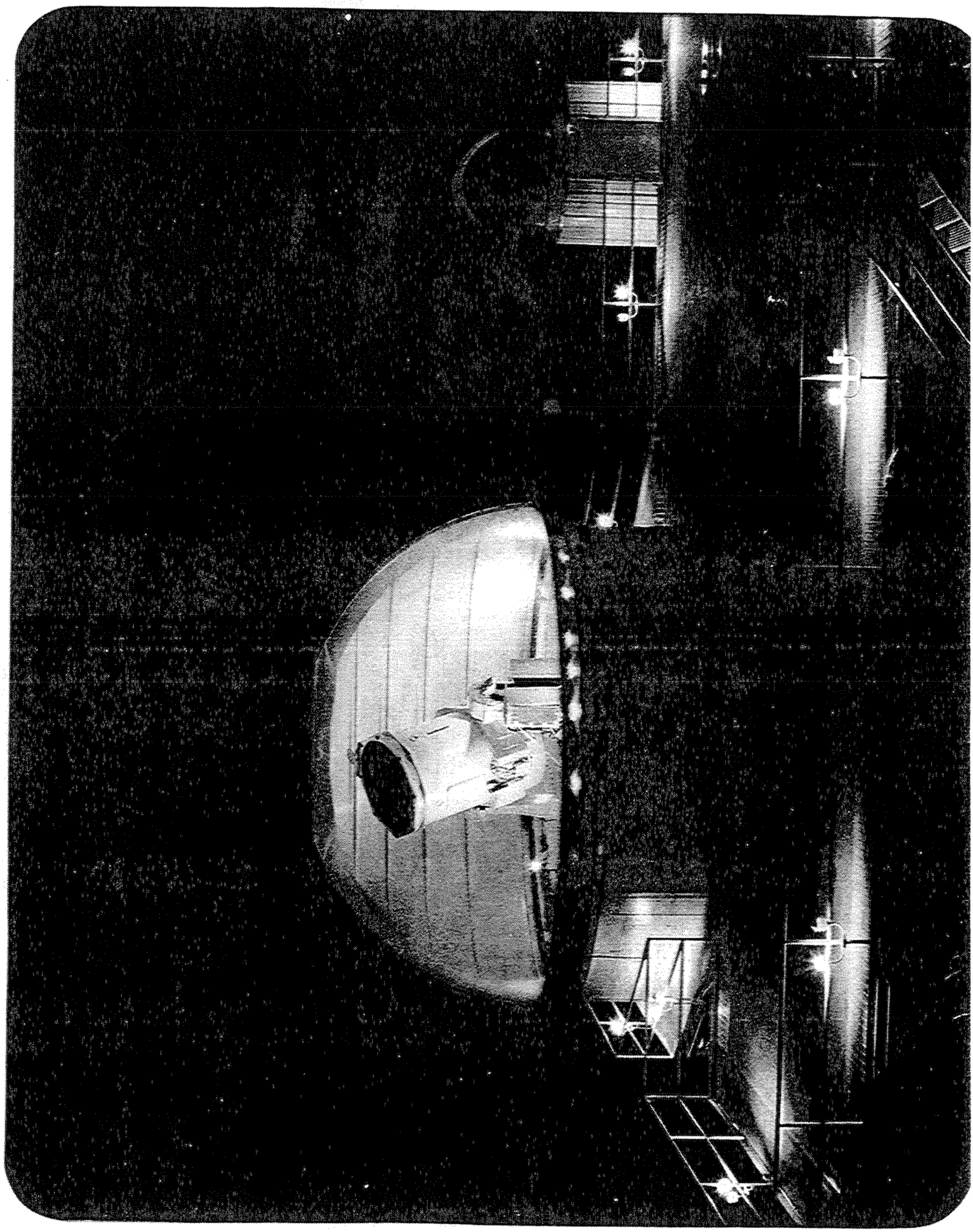
Facilities

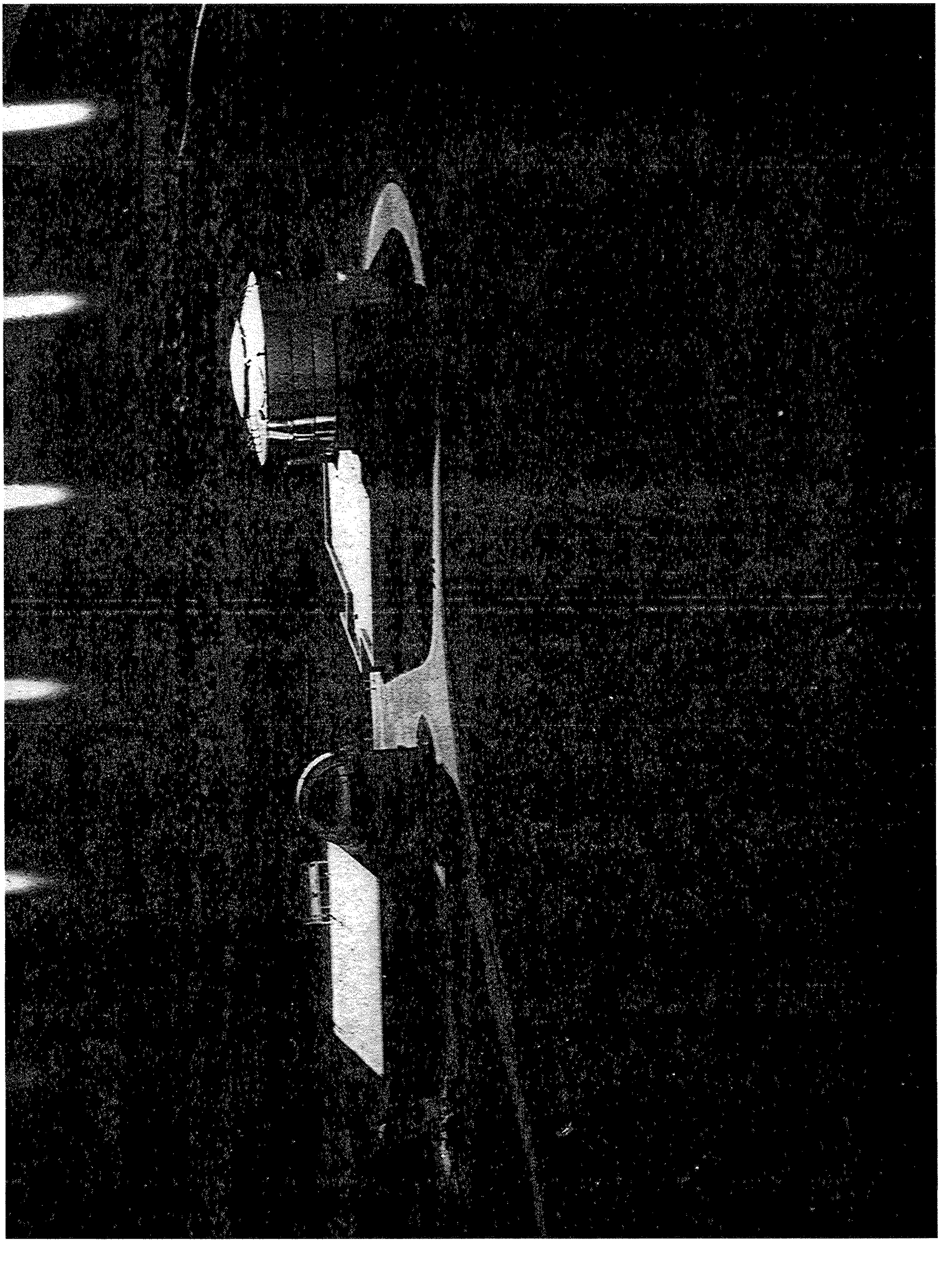
- Located ~20 km from Albuquerque, NM on Kirtland AFB
- Optical mounts
  - 3.5 m telescope with coudé path
  - 1.5 m telescope with coudé path
  - 1.0 m coelostat laser beam director
- Lasers
  - 10 watt, 20 pulse per second (pps) Nd:YAG with frequency doubler
  - 150 watt, 5000 pps copper vapor (beacon for AO)
  - 10 watt, 840 pps sodium frequency (0.589 μm) (beacon for AO)
  - 10 pps, 250 ps frequency doubled Nd:YAG (Naval Research Lab)
  - 10 pps sodium frequency dye laser (Univ of Illinois)

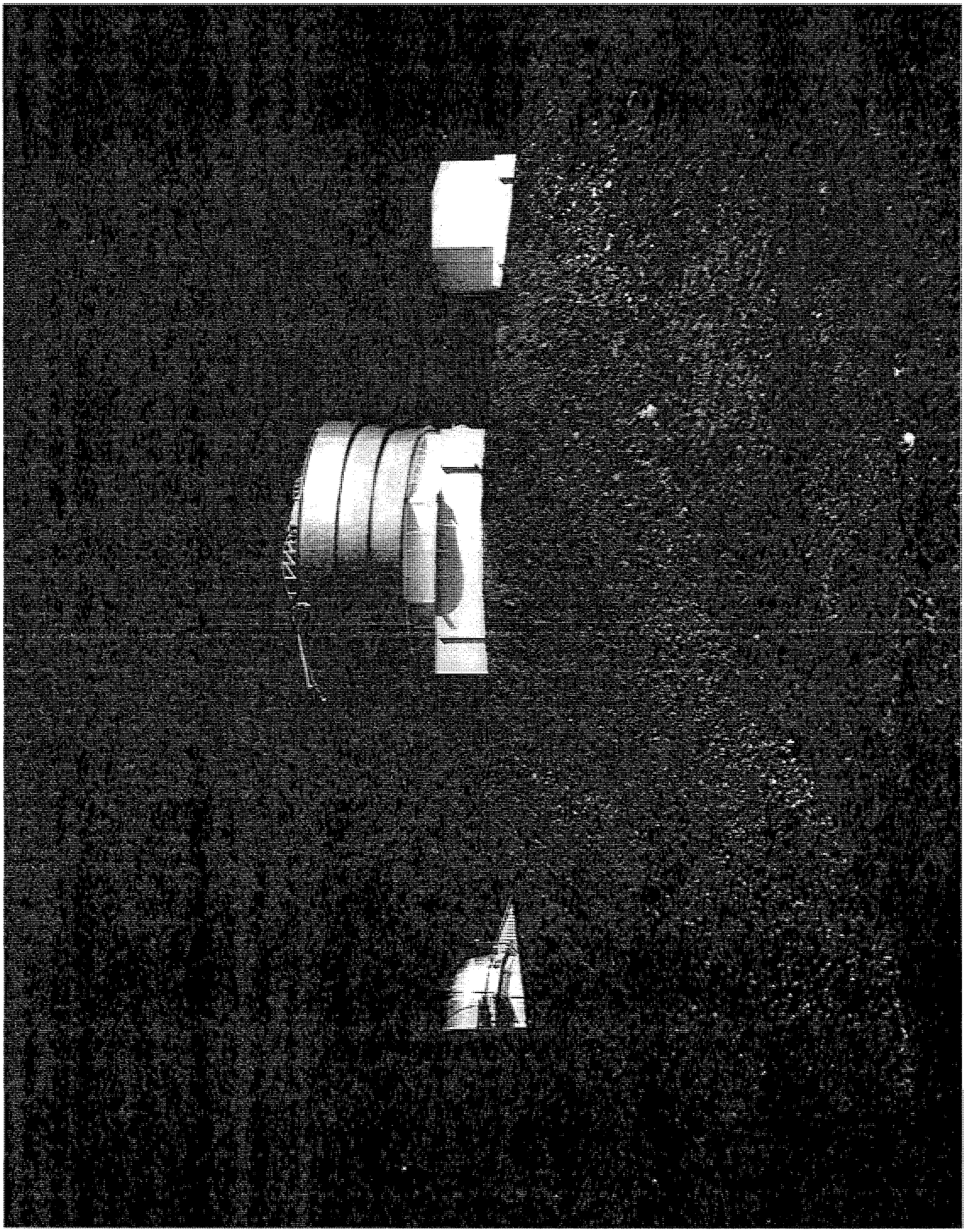
R. Q. Fugate, Phillips Lab, Starfire Optical Range fugate@plk.af.mil

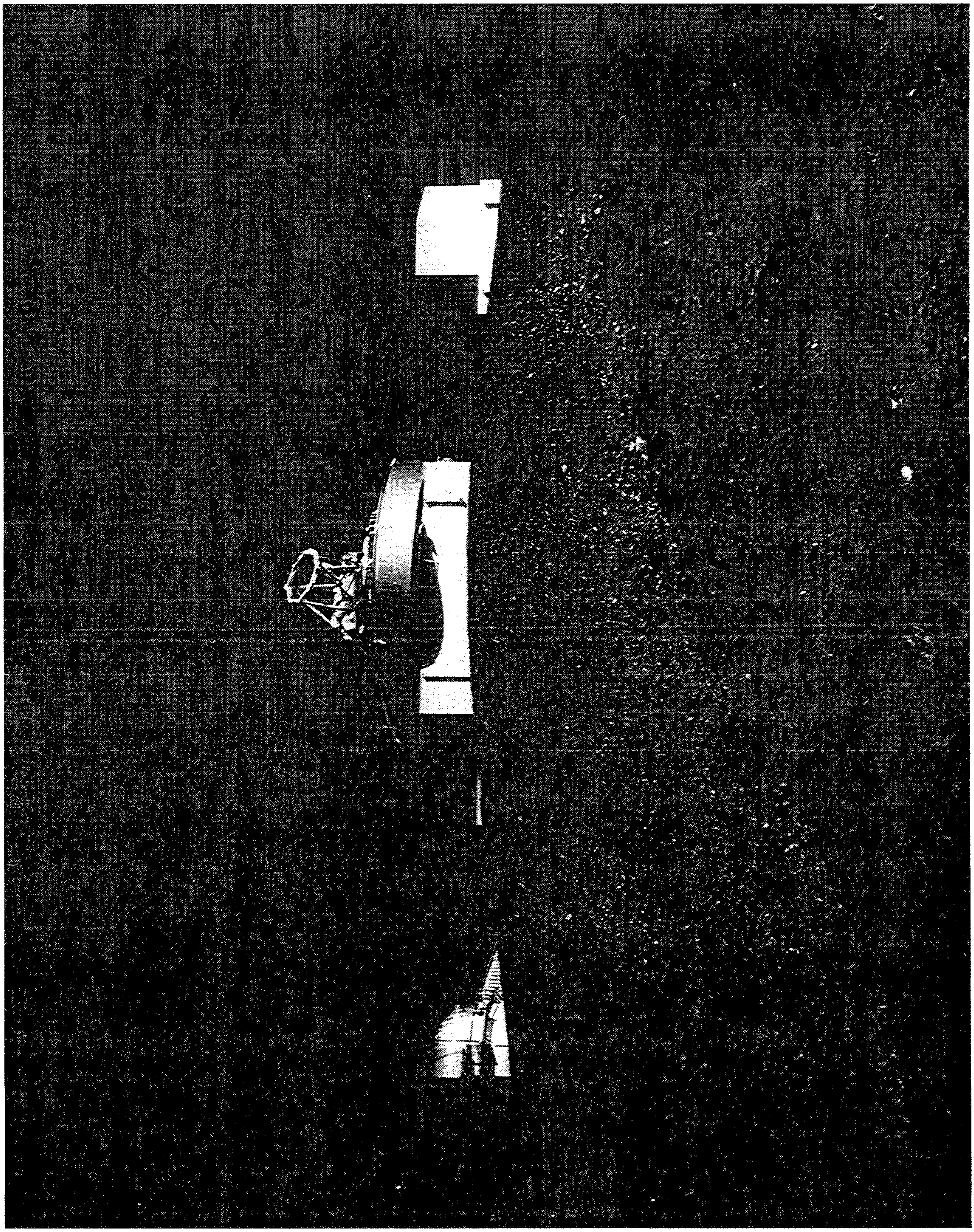


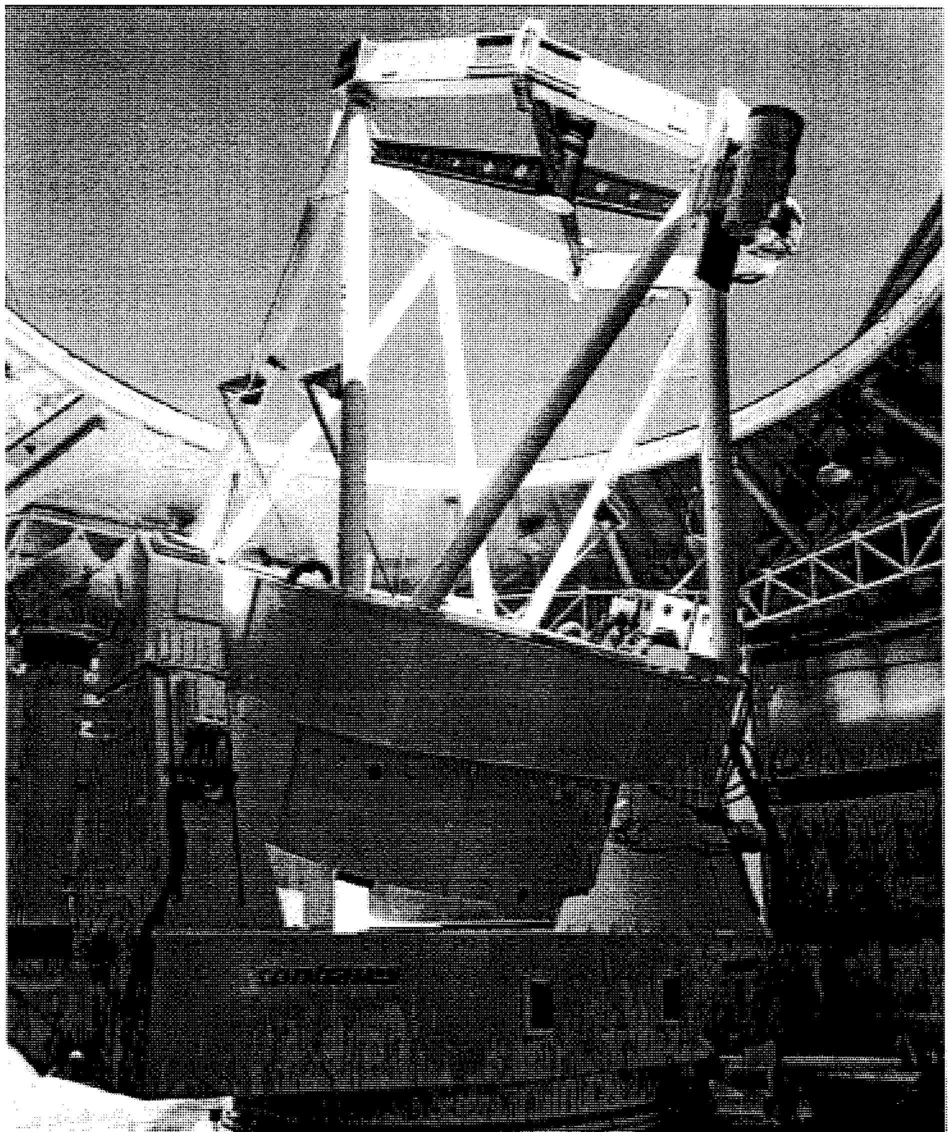












3.5 meter Telescope and Mount

- Approximately 100 tons
- Azimuth Axis
  - –5 deg/sec^2 acceleration and 11 deg/sec velocity
  - –10,000 ft-lb torque direct drive motor, ball bearings, 658 nanoradians of jitter at 10.3 deg/sec
- Elevation Axis
  - –2 deg/sec^2 acceleration, 5 deg/sed velocity
  - –Direct drive sealed roller bearings 1400 ft-lb torque
- Optics
  - –f/1.5 primary mirror $\lambda/30$ at 633 nm
  - –f/85 coudé path to five labs and large coudé room
  - –Primary is actively cooled and supported
- Collapsing dome for ease in satellite tracking

R. Q. Fugate, Phillips Lab, Starfire Optical Range fugate@plk.af.mil

Mount Control

- Starfire Optical Range Acquisition and Pointing System (SORAPS)
- Developed in-house by Richard A. Cleis
- Operates on a Macintosh Quadra 950 computer
- Computes mount positions, velocities and accelerations for satellites in real-time from 2-line element sets
- Updates 2-line element sets in real-time from measured satellite positions
- Can use state vectors or other forms of satellite ephemerides
- Elements for ~7000 satellites stored in RAM instantly available and automatically updated on site server daily
- SORAPS implements point-ahead either open loop or by sensor "track behind"
- Yale Bright Star Catalog (9110 stars) in RAM with search features

R. Q. Fugate, Phillips Lab, Starfire Optical Range fugate@plk.af.mil

Recent Experiments

- GOPEX (Galileo OPtical EXperiment)
  - –Laser pointing demonstration for communicaitons to probes in deep space
- CEMERLL (Compensated Earth-Moon-Earth Relay Laser Link)
  - –Measurement of laser scintillation statistics of two-way laser links between the earth and the moon
  - –Measurement of reduction in scintillation by using adaptive optics to compensate for atmospheric distortions on the uplink
- Satellite Laser Ranging (joint experiment with Naval Research Lab and coordination with NASA)
  - –First venture into high accuracy satellite ranging

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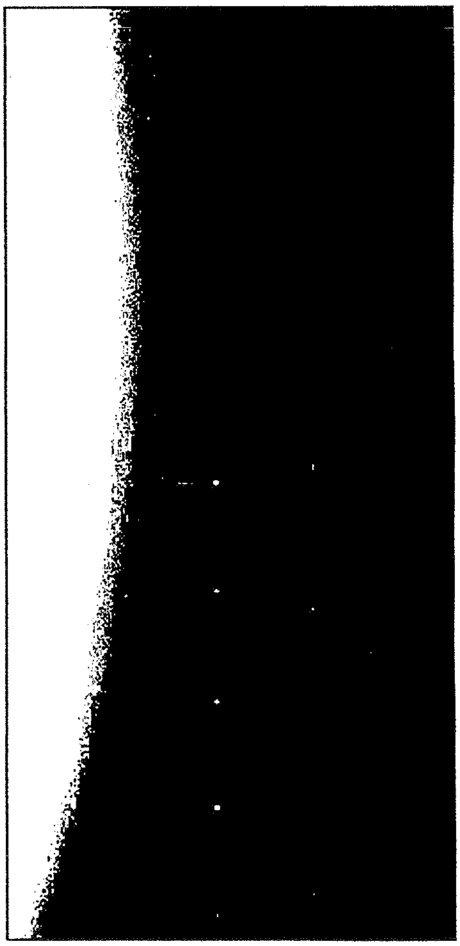
PHILLIPS LABORATORY

Starfire Optical Range

Image from Galileo During GOPEX

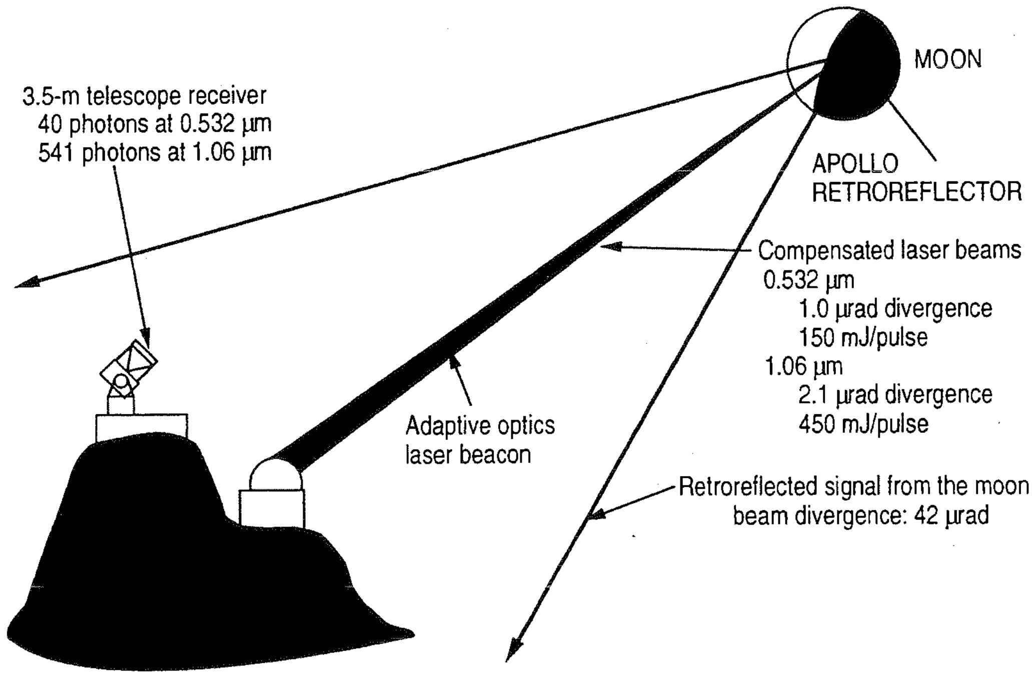
Showing scattered light from the terminator and laser pulses from the Starfire Optical Range and the Table Mountain Observatory.

1.4 million km range.



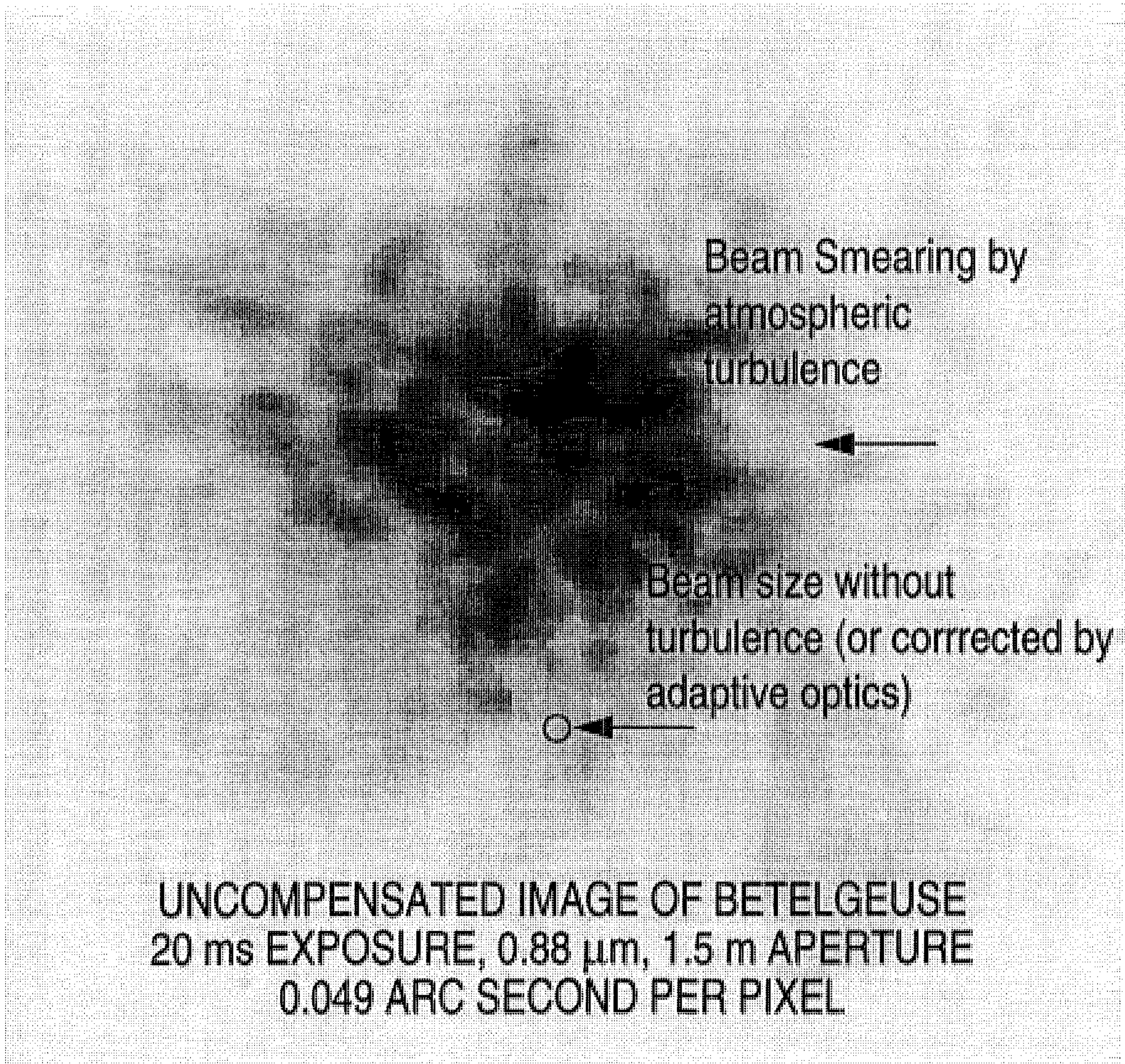
SOR TMO

Earth-Moon-Earth Compensated Laser Beam Communications Experiment



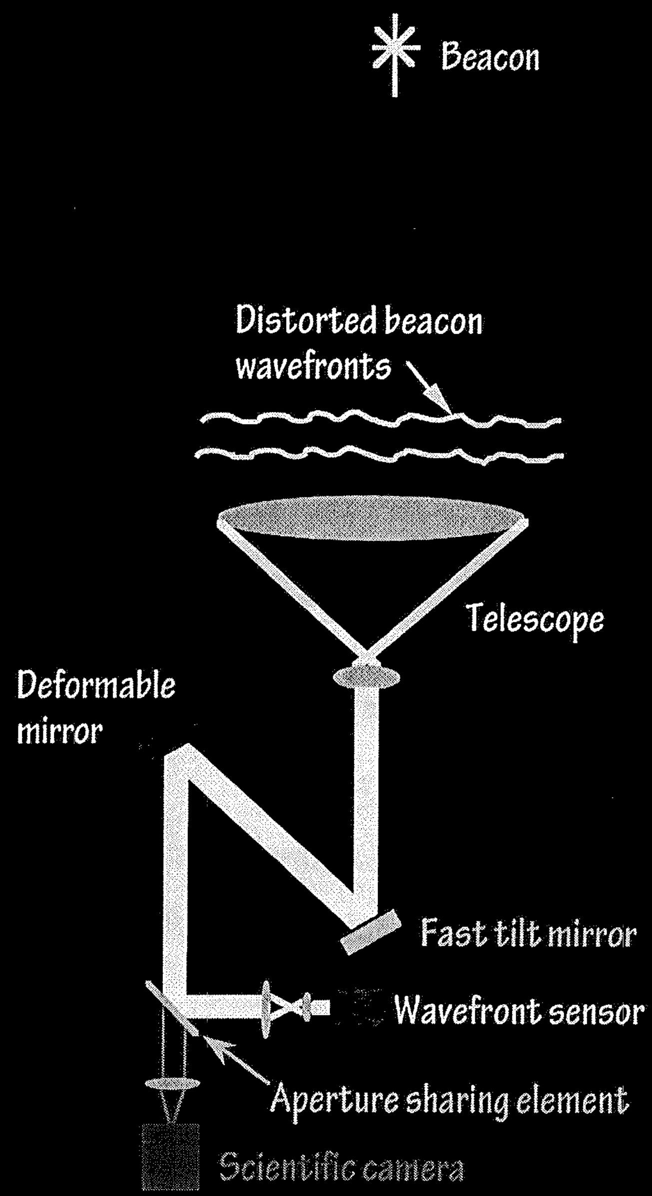
Adaptive Optics

- **Pioneered Laser Beacon Adaptive Optics**
  - **First concept experiments in 1983**
  - **First closed loop experiments on the 1.5 m in 1989**
  - **Only laser beacon adaptive optics system operating routinely**
- **Imaging resolution 0.12 arcsec at 0.85 µm wavelength**
- **Potential for compensating low power outgoing laser beams for satellite ranging on unaugmented satellites**

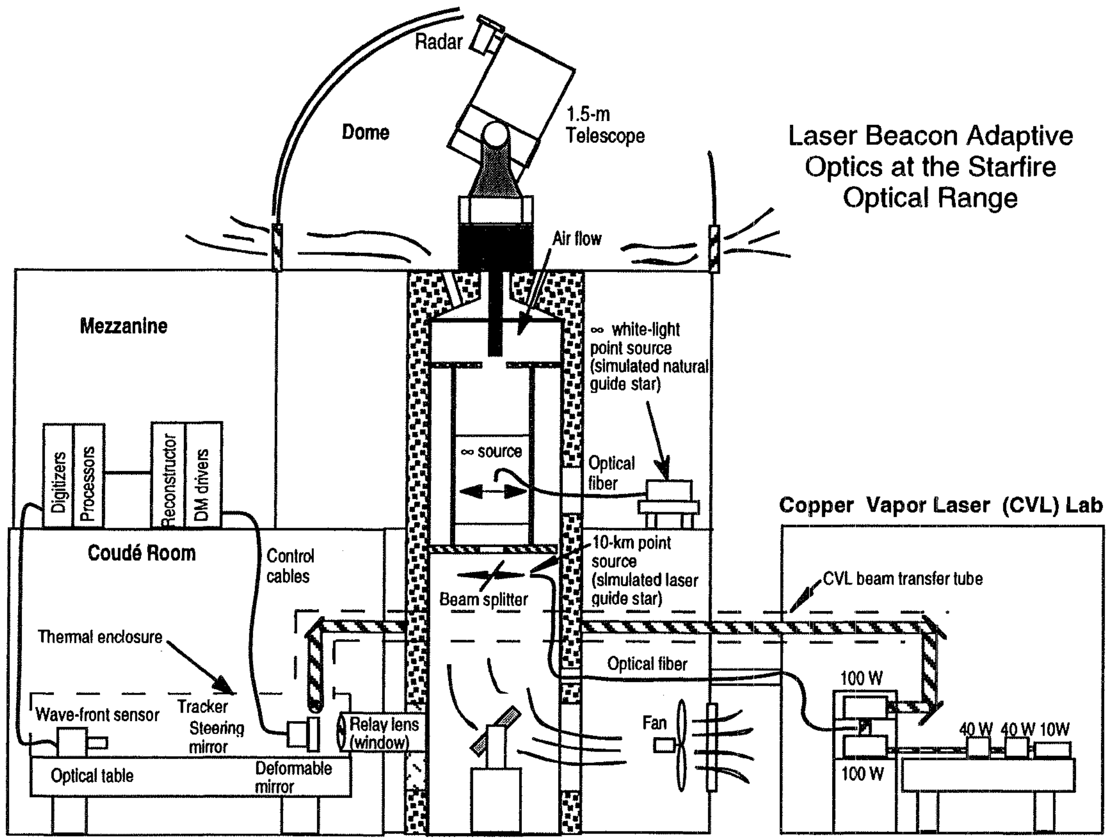

Beam Smearing by
atmospheric
turbulence
Beam size without
turbulence (or corrrected by
adaptive optics)
UNCOMPENSATED IMAGE OF BETELGEUSE
20 ms EXPOSURE, 0.88 μm, 1.5 m APERTURE
0.049 ARC SECOND PER PIXEL

Adaptive Optics

- Suggested by Horace Babcock in 1953
- Concept is
  - Sense the distortion from a beacon
  - Adjust a phase correcting element to cancel the measured distortion
  - Repeat as the distortion changes
- Key elements of adaptive optics are
  - Sensing
  - Correcting

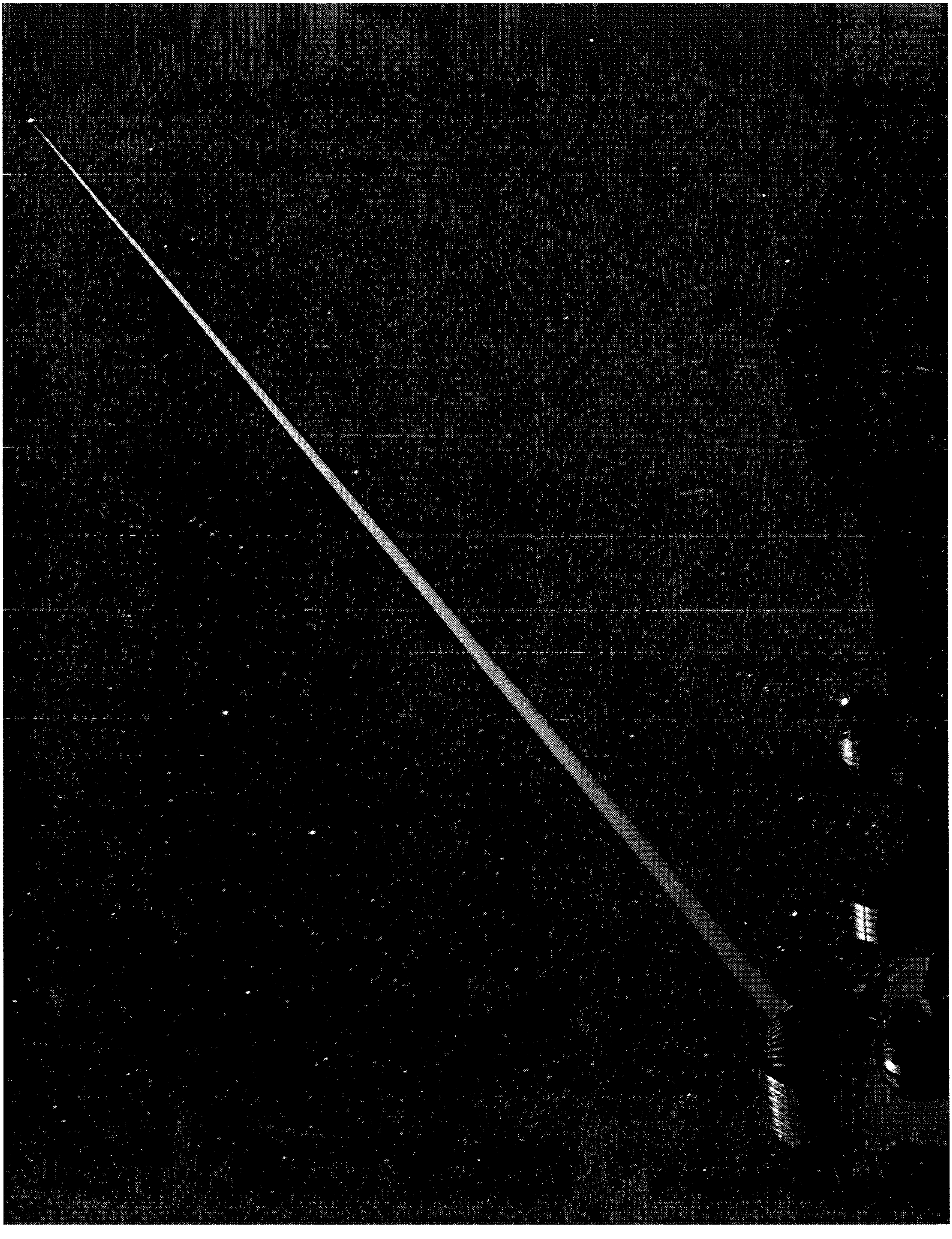


Starfire Optical Range 1.5-m Telescope Laser Guide Star System

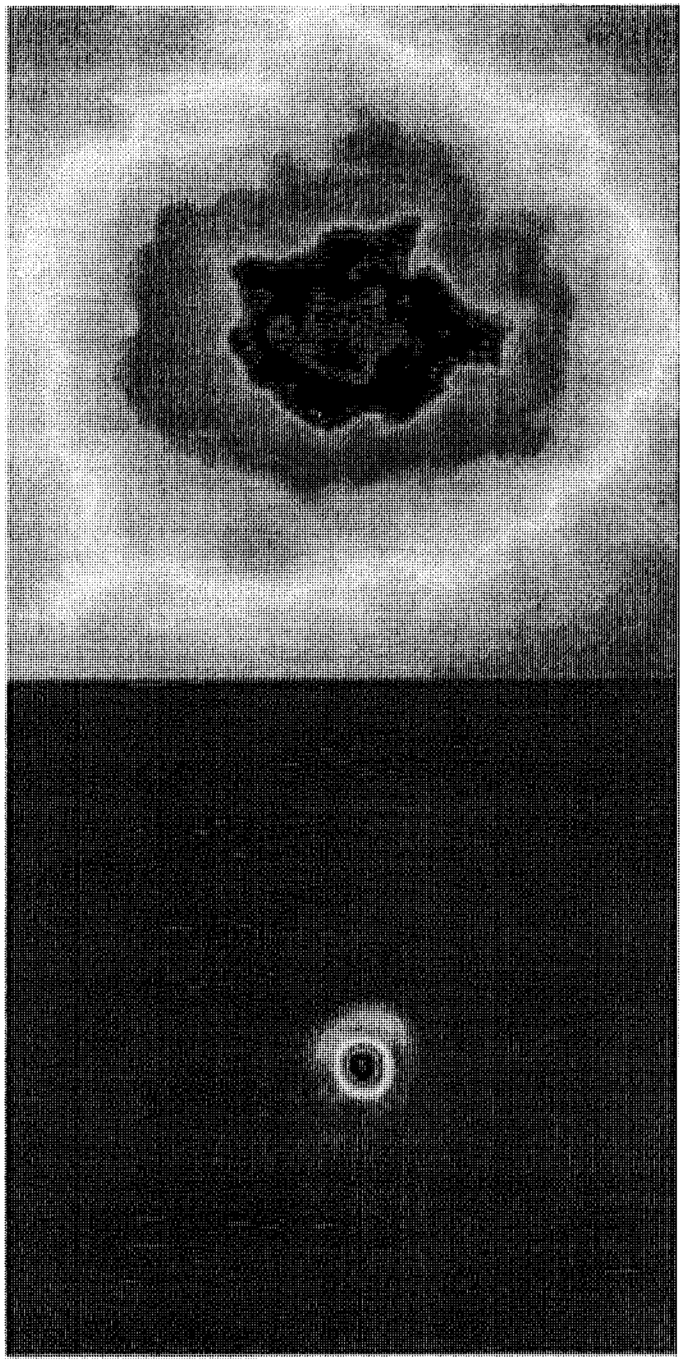


Key Features of the System

- Copper vapor laser Rayleigh guide star at 14 km range
- Continuous facesheet deformable mirror
- 241 controlled actuators
- Range-gated Shack-Hartmann wavefront sensor
- 1667 Hz sample rate
- 100 Hz closed loop bandwidth
- Near IR full aperture tracker



Capella



USAF Phillips Laboratory
Starfire Optical Range
Adaptive Optics Results 1.5 m Telescope

One second exposure tilt only compensation.

2.9 arcsec field

Strehl ratio ~0.033

Image full width at half max 1.8 arcsec

Imaging wavelength = 0.88 μm

10 ms exposure full adaptive optics
Strehl ratio = 0.64
FWHM = 0.13 arcsec

Note slight elongation in central core:
Capella is a binary star with 0.06 arcsec separation and $\Delta m = 0.5$

R. Q. Fugate, fugate@plk.af.mil

SOR Laser Beacon Adaptive Optics Results: β-Del (0.199 arcsec)

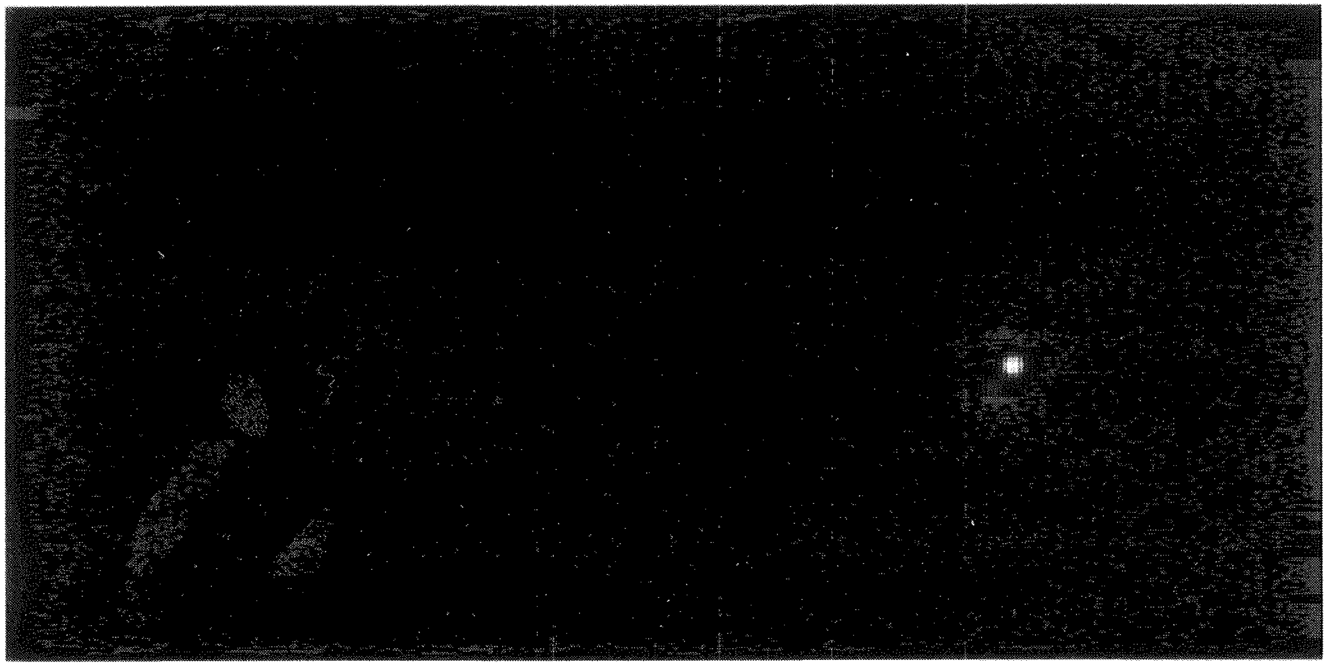


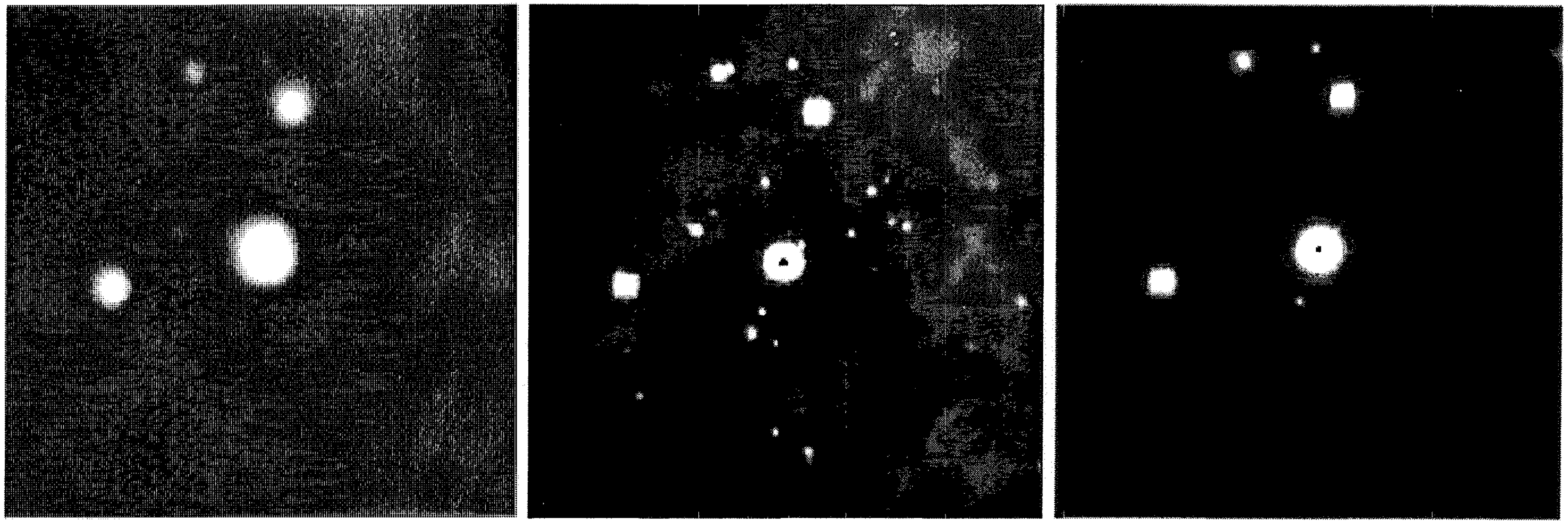
Image through turbulence
Intensity =384

Image with laser beacon AO
Intensity = 3260, raw data

60 second exposures, 3.32 arcsec fields, 0.85 μm imaging wavelength, 1.5 m aperture

SOR 1.5 m Telescope Images — Laser Beacon Adaptive Optics

Trapezium region in Orion
4 minute exposures, 40 arcsec field



H-α light (0.6563 μm)
No compensation

H-α light (0.6563 μm)   Continuum (0.6470 μm)
Images corrected with laser beacon adaptive optics

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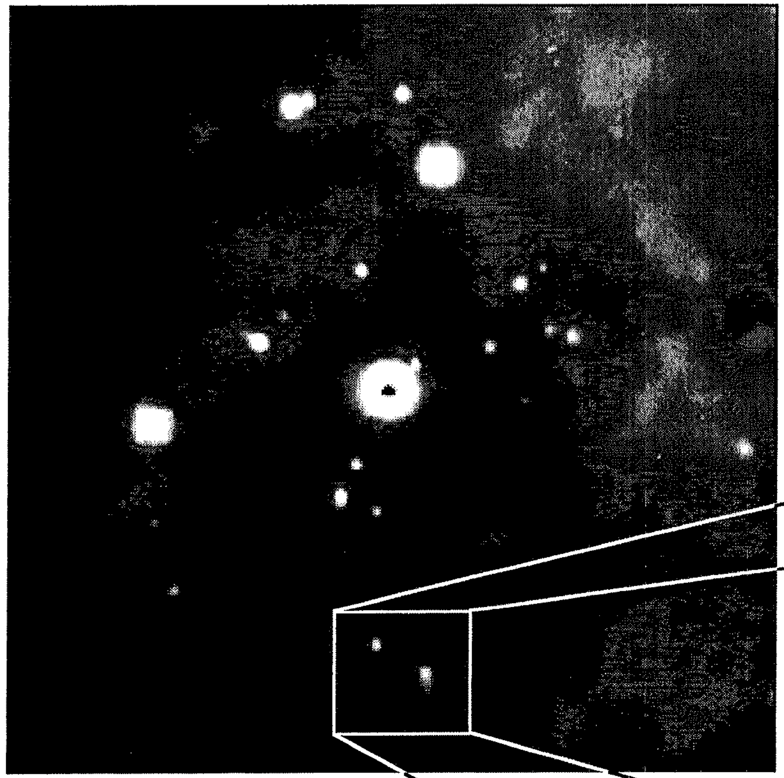
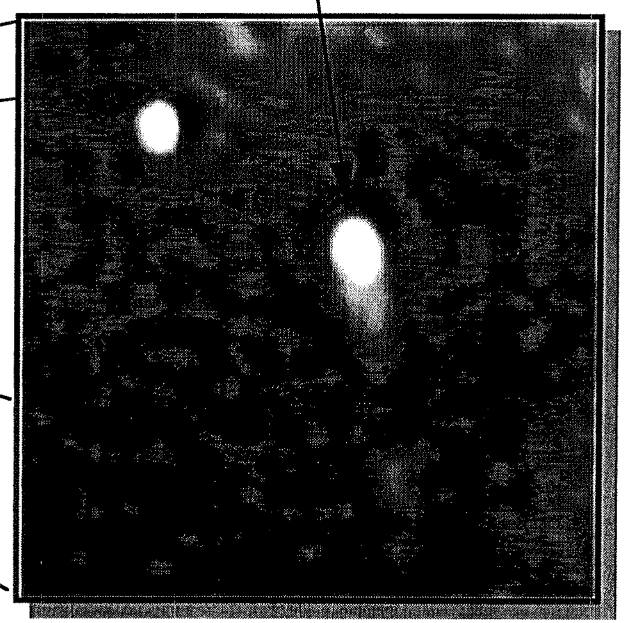
New Star Formation in Orion

USAF Phillips Laboratory Starfire Optical Range 1.5 m Telescope
Laser Beacon Adaptive Optics



Trapezium Region
4 minute exposure, 40 arcsec field
H-α light (0.6563 μm)

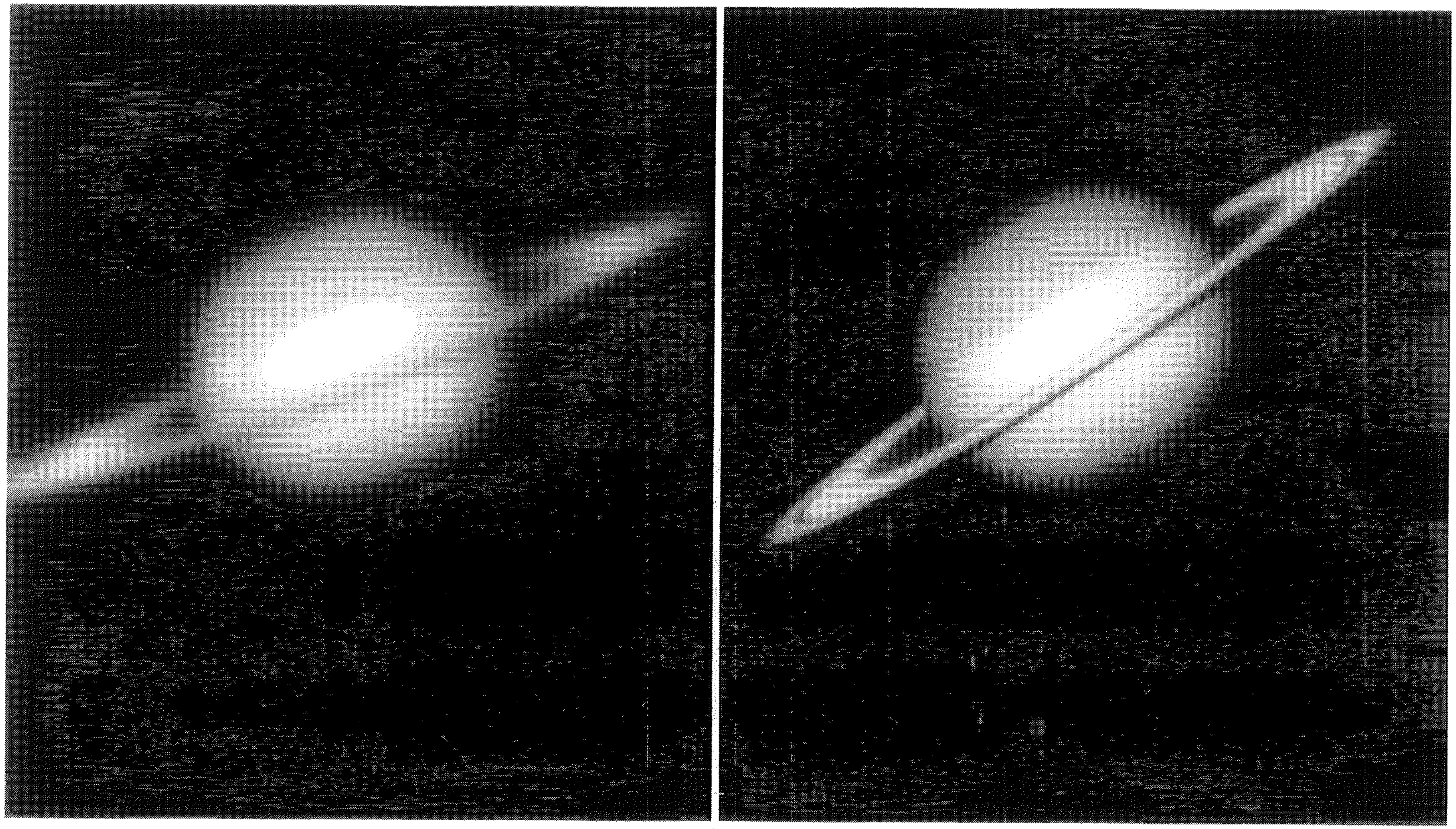
Partially ionized globule
with embedded young star
showing effect of solar wind



R. Q. Fugate, fugate@plk.af.mil

July 19, 1994— Saturn and Titan

Uncompensated vs tilt and full higher-order correction



No tracking, No adaptive optics

IR correlation tracking
Laser beacon adaptive optics

USAF Phillips Laboratory
Starfire Optical Range 1.5 m Telescope

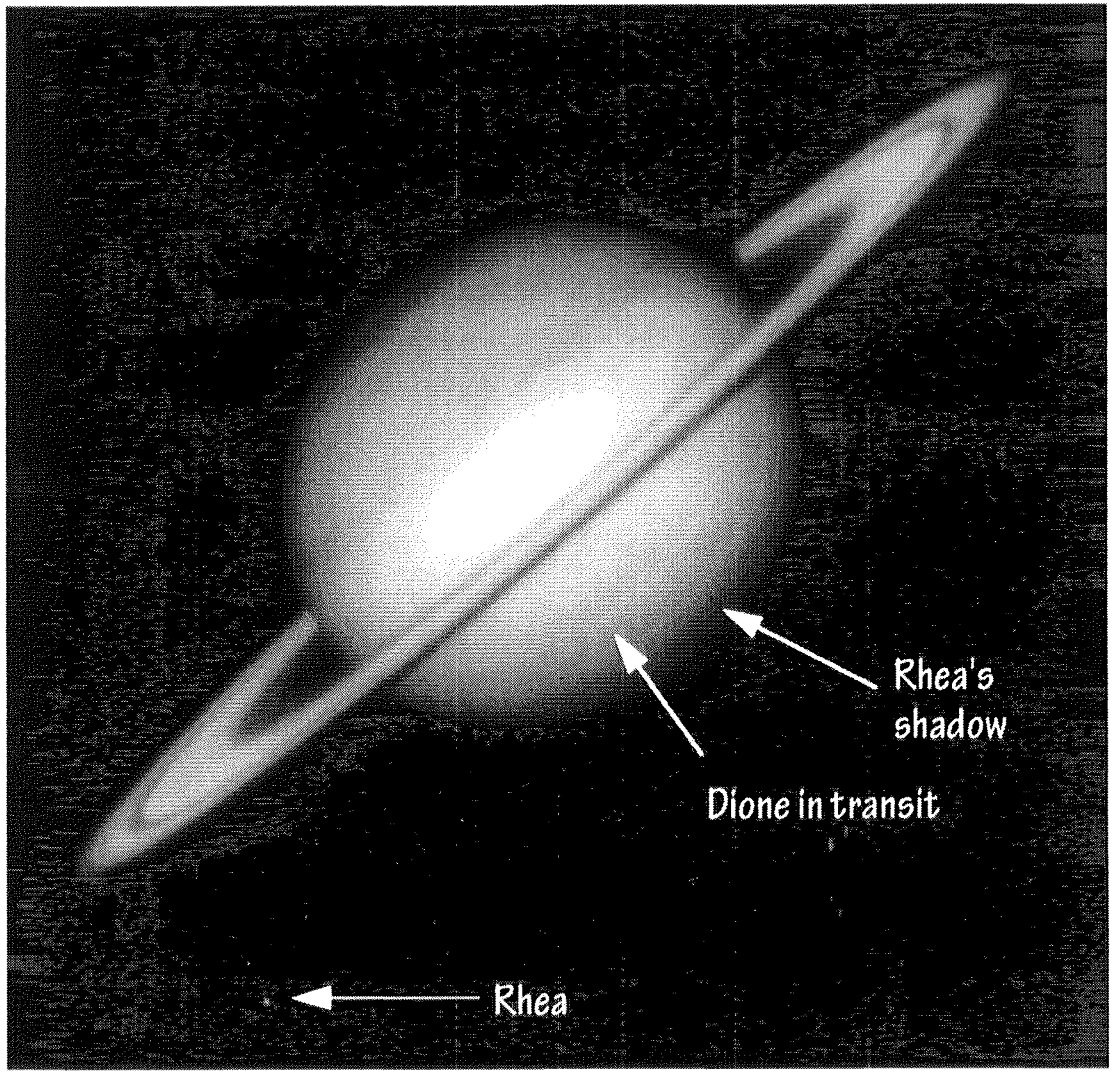
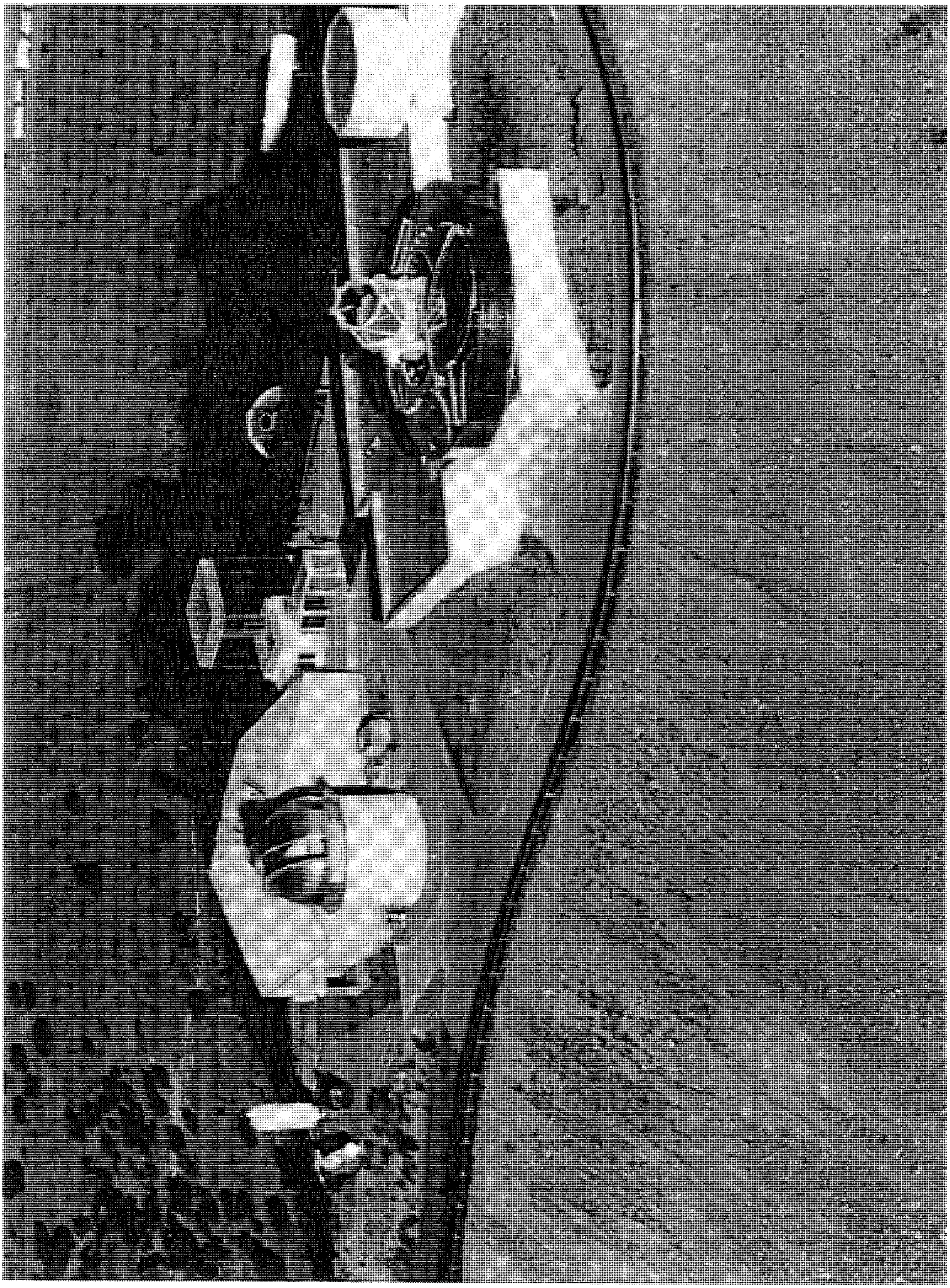


Image compensation using laser beacon adaptive optics
0.65-0.95 μm, 3 sec exposure, July 23, 1994, 10:35 UT

R. Q. Fugate fugate@plk.af.mil



TIMING DEVICES AND CALIBRATION

Chairperson : Hiroo Kunimori

IMPROVING AN HP5370A COUNTER

G. Kirchner, F. Koidl

Institut for Space Research
Austrian Academy of Science
Observatory Lustbühel
A-8042 Graz / AUSTRIA

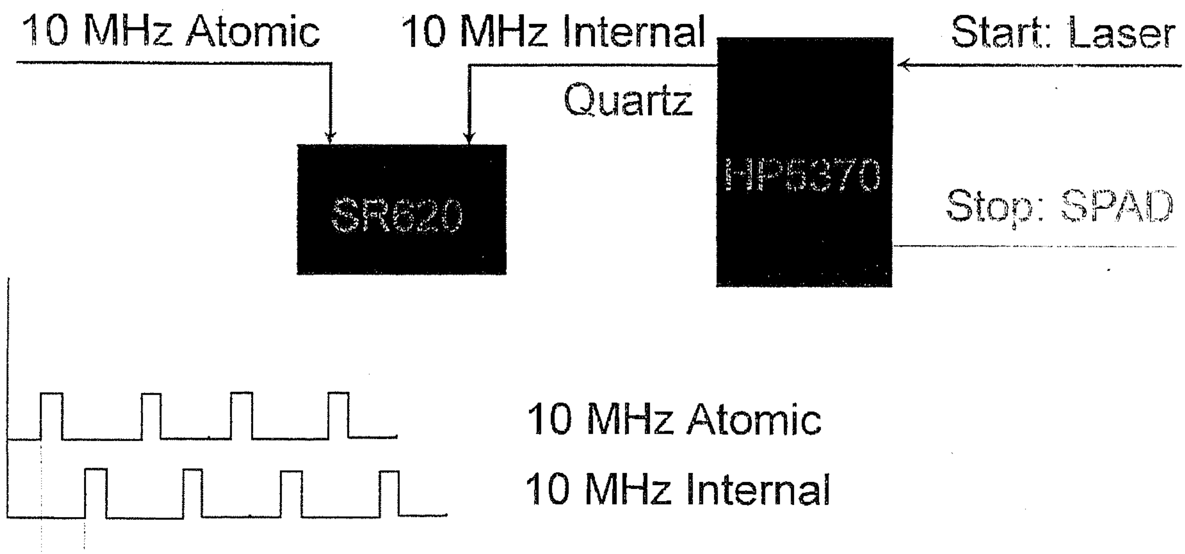
Canberra, 1994-11-08

HP5370A Counter Improvements

- Original RMS value: 30 - 35 [ps]
- Quartz Oscillator: 20 - 25 [ps]
- N1N2 Corrections: Achieved: 15 - 20 [ps]
- N1N2 Corrections: Expected: 10 - 15 [ps]

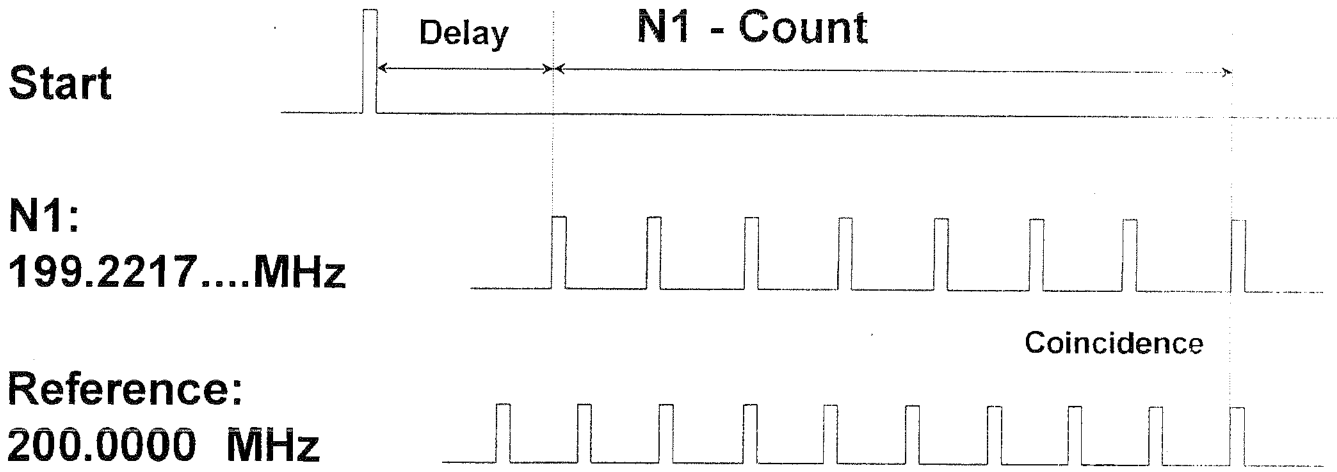
Frequency Difference measurements

Accuracy: 10^{-12}



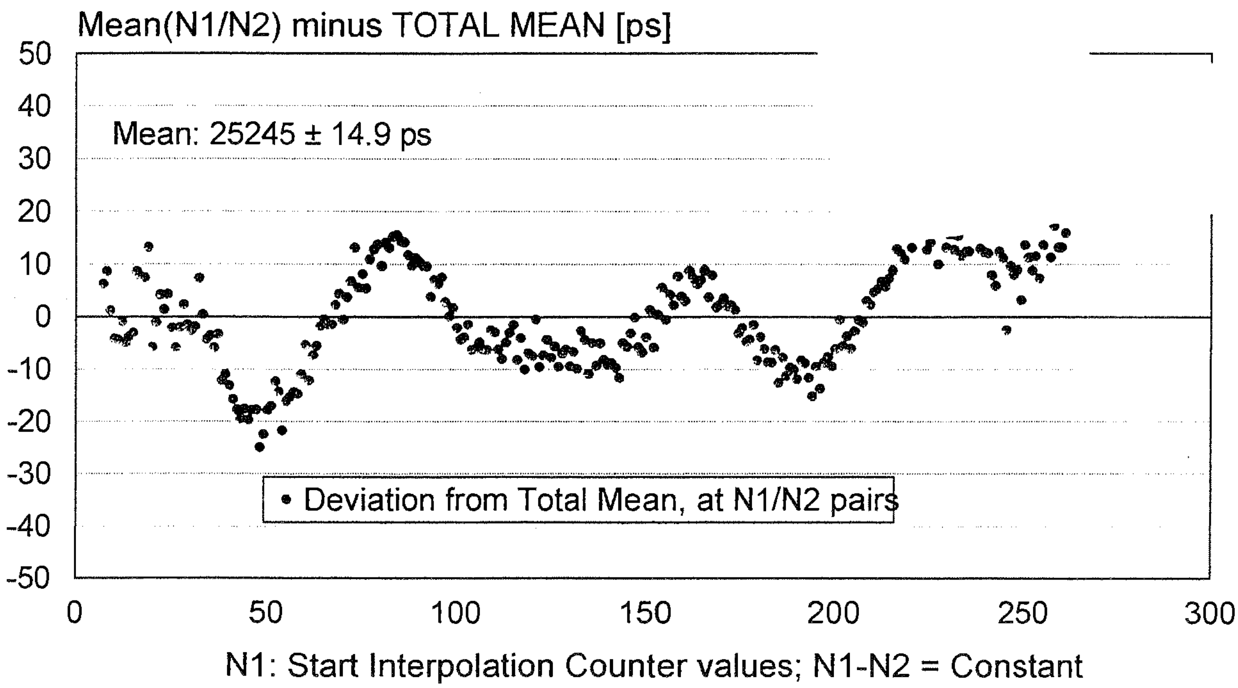
T: Change < 10 ps / 10 s : < 0.1 mm to GPS

HP5370A Counter
N1/N2 Digital Interpolation



<1994-10-27; KG/KF>

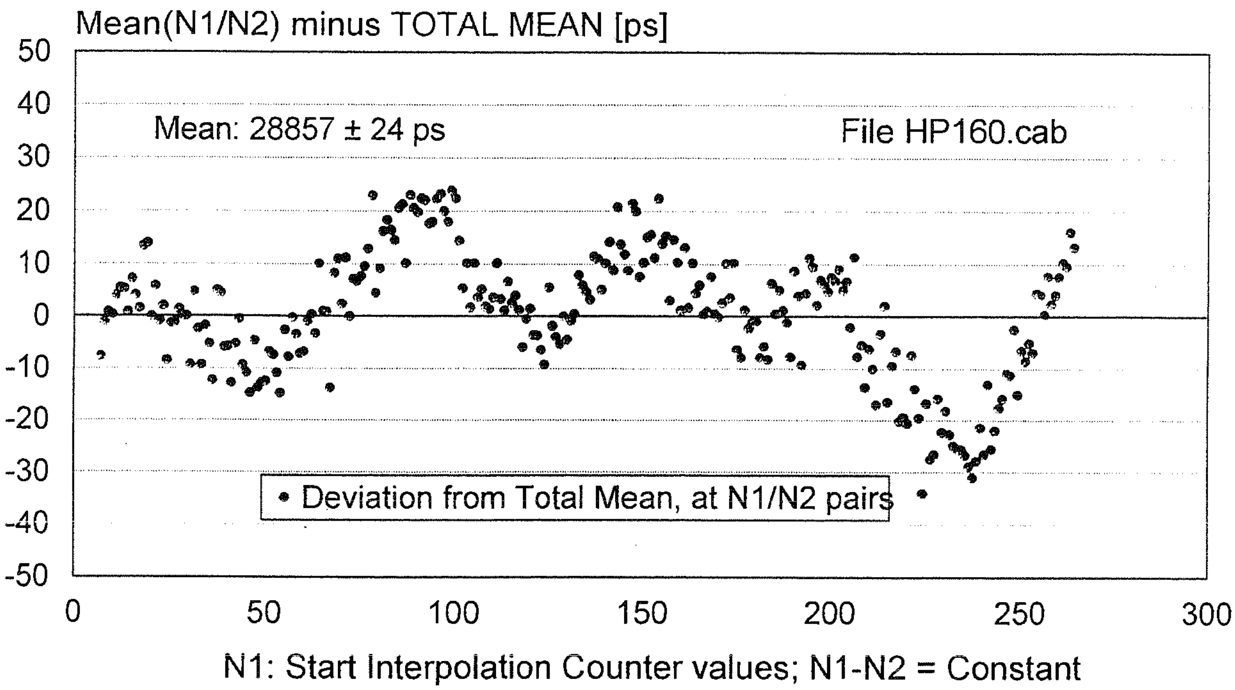
HP5370A: N1/N2
MEAN VALUES for different N1/N2 Combinations



<1994-10-20; KG/KF>

HP5370A: N1/N2

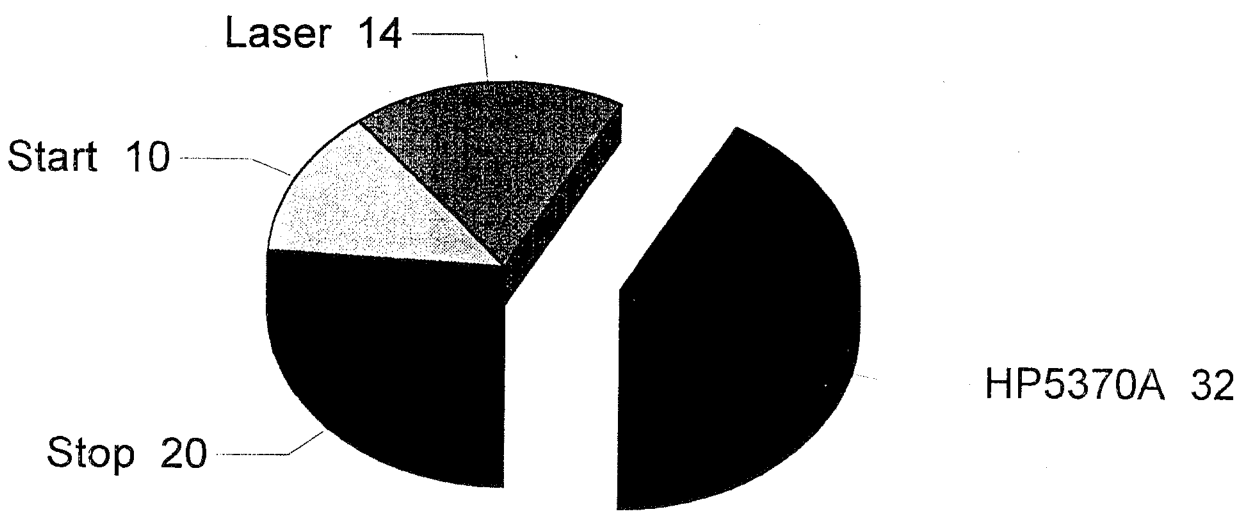
MEAN VALUES for different N1/N2 Comb...



<1994-10-20; KG/KF>

Graz: Error Budget to Target; RMS [ps]

1993/94: Before HP5370 A Counter Improvements

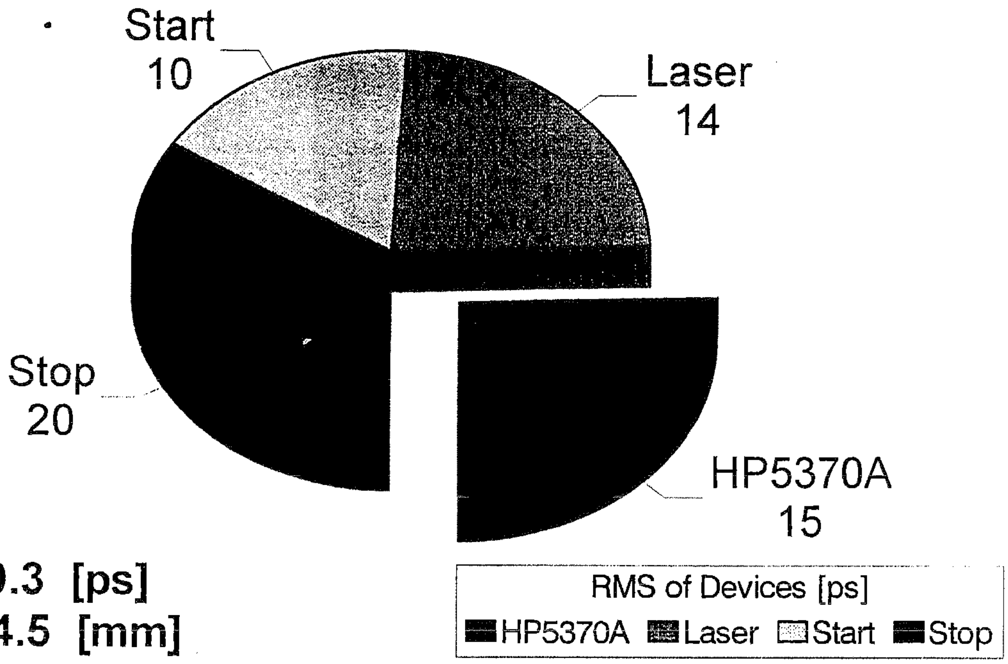


Total: 41.0 [ps]
6.2 [mm]

<1994-10-20; KG/KF>

Graz: Error Budget to Target; RMS [ps]

Expected: After HP5370 A Counter Improvements

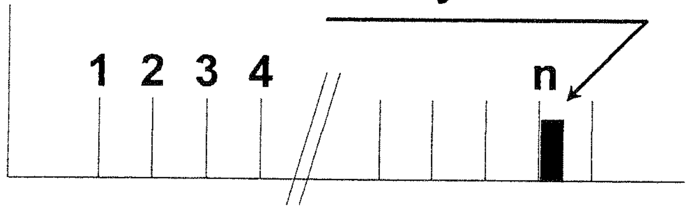


Total: 30.3 [ps]
4.5 [mm]

<1994-10-20; KG/KF>

HP5370A: 10 Hz Ranging up to LAGEOS

- **ASCII Output: Too slow;**
- **Fast Binary: 320 µs maximum Time Interval (Manual)**
- **Reason: 32767 Internal Counter is limiting**
- **After reaching max count (32767), counter restarts at Zero**
- **Solution: Calc. # of 327.67 µs - periods (from predictions); add binary value.**



Period = 327.670 µs
Range = n * Period + Bin Value

Implemented first
by Andrew Sinclair

<1994-10-28; KG/KF>

Current Status of MOBLAS-7 Tracking of Meteosat 3/P2

NASA / GSFC
John Degnan

OCA/CERGA
Christian Veillet
Patricia Fridelance

ATSC
William Bane
Christopher Clarke
Mark Davis
Richard Eichinger
Toniellen Johnson
Mark Levy
David McClure
Thomas Varghese

Presented at the
9th International Workshop on
Laser Ranging Instrumentation
Nov 7 - 11, 1994

AlliedSignal
AEROSPACE

LASSO Background

- 1988 Verify LASSO Package
  - moves from 0 thur 50 deg West
  - Sept/Oct 89- TUG and OCA get echos and datations
- Nov 90- TUG and OCA get triples
- April-Nov 92 MLRS and OCA get triples at 50 West
- Jan 93 plan to move more west --> 72 West
- Sept 93 M7 begins development
  - Satellite decommissioning date scheduled Feb 94
- Mar/Apr 94 MLRS / M7 joint attempts

NASA

AlliedSignal AEROSPACE

GGAO - A Geophysical R&D Facility

- Moblas 7 and 48" Laser Ranging Stations
- Moblas 6 and SALRO
- MV3 VLBI with a Hydrogen Maser
- GPS and GLONASS Receivers
- Many Cesium frequency standards available and monitored
- Time synchronization to USNO
  - clock trips can be frequent
  - TV line 10 technique from ATSC HQ
- Facility wide timing characterization

NASA

AlliedSignal AEROSPACE

Ranging Requirements to MP2

- Link very poor
  - Dynamic Acquisition
  - Singles level detection required
- Accurate epoch measurements to a local clock
- local clock vs. USNO desired for actual transfer of time
- synchronization of laser fire time with satellite rotation desired for 5 Hz rates to improve joint session statistics
  - MLRS and M7 have a 43 deg/ 72ms viewing offset
- Pointing and Gating need to be stable and precise
  - designed for Lageos
  - gate width control large on Moblas controller

NASA

AlliedSignal AEROSPACE

Dynamic Acquisition Techniques

- Optical acquisition required from previous experiments experience
- Receive optics modification to replace existing CCD camera with a ICCD
  - only affected secondary port -- no impact on ranging optics
- Telescope/ICCD coupling and Sky quantification
  - During ideal conditions at GGAO 12.8 Magnitude can be detected
- Framegrabber / IBM 486 PC image analysis
- Beam placement with respect to satellite image
  - 2-way confirmed by LAGEOS, Etalon and GLONASS
  - 1-way confirmed by LASSO detector package
- Phase angle makes Winter/Spring viewing difficult
  - MP2 is at 175 azimuth and 44 elevation
  - Looking directly over the lights of Washington

NASA

AlliedSignal AEROSPACE

2-Way Ranging to Long Distance Targets

- Near single photo electron detectablility needed
  - GPS High Sensitivity Receiver Network Upgrade is near completion
- M7 gate circuits and current controller are limited to approx 100 ms TOF at 5 Hz
  - 250 ms needed for MP2
- PS interfaced to M7 using 2 sets of TOF TIUs and Stanford DG535 DDGs to generate gates at 5 Hz
  - Successfully tested on Etalon at 150 msec
- MLRS 2-way ranging data used to improve range prediction vectors for M7 gate generation

AlliedSignal AEROSPACE

LASSO Detector package involvement

- Satellite configured for detection from 02:30 to 03:30
- Moblas 7 laser detected on satellite 11 evenings
  - Optical feedback analysis
- Moblas 7 and MLRS detected on the same evening
- Satellite Rotation and on-board drift
  - Oscillator drift 10 ns/second but can be independently characterized
  - rotational period of approx 600 ms

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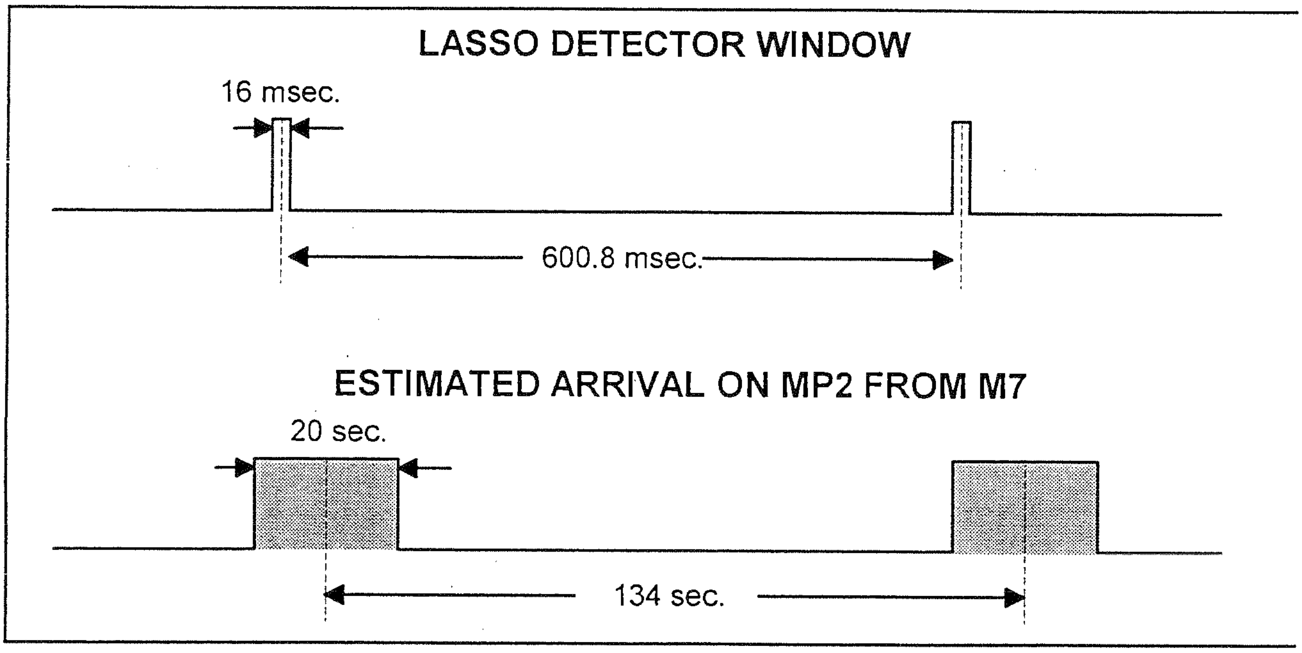
Satellite Synchronization



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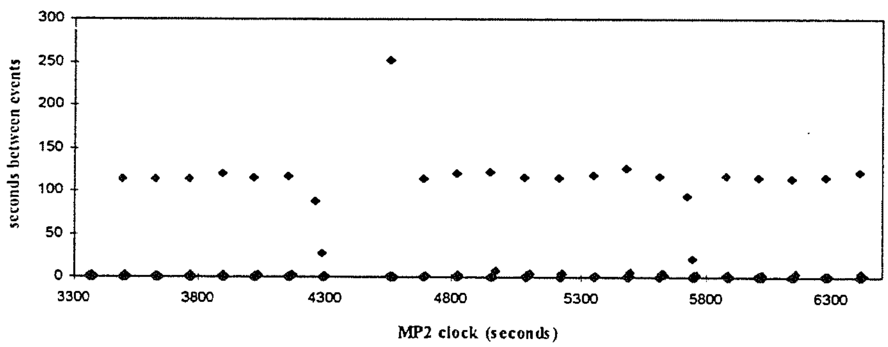
MP2 event differences (doy 071)



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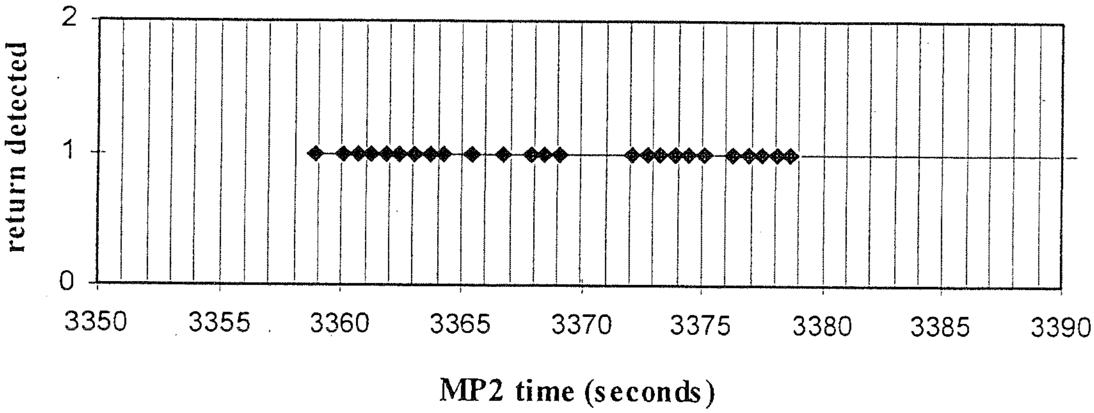
MP2 observations of Moblas7 Laser (doy 71)



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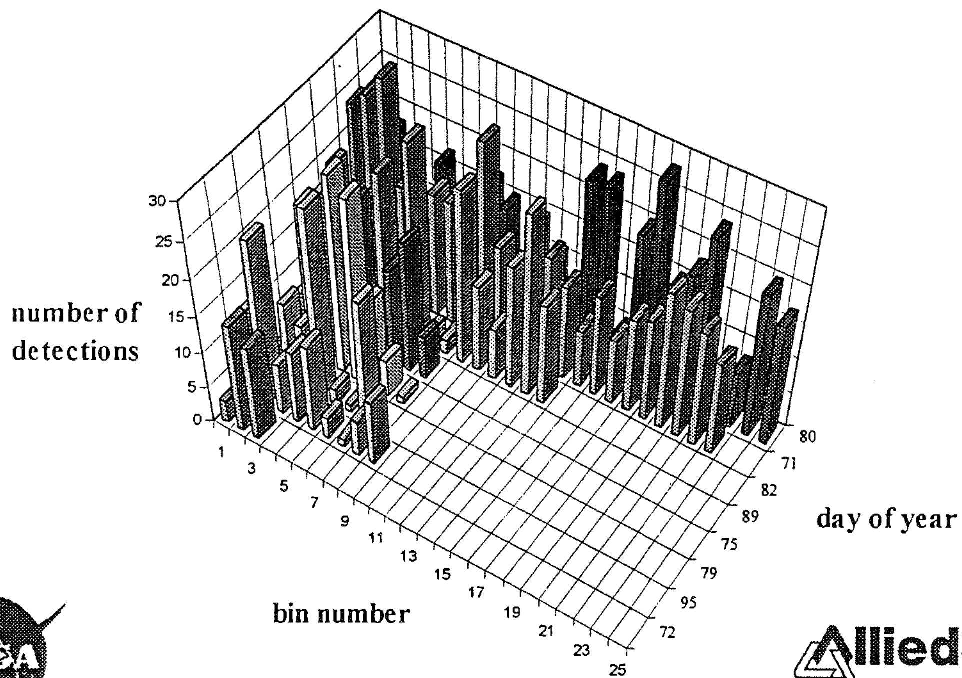
LASSO Detection of Moblas 7 Laser Pulses



NASA

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Epoch Measurements

- GGAO frequency and timing characterization
  - TV-line 10 via ATSC to USNO
  - Hydrogen MASER from MV3
  - M7 and PS Cesium
  - 1 PPS and 5 PPS from M7 TCG used
    - » investigated using precision time codes from Datum TCG and Austron Disc Oscillator
- Moblas 7 transmit delay circuits in the LRC driven by 5 MHz were capable of only 200 ns time resolution
  - (200 ns granularity to M7 CS 1PPS)

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Epoch Measurements continued

- EPOCH Measurement system of Multiple HP 5370's and Stanford DG535 Digital Delay Generators for 5Hz Tdel measurements
  - Epoch measurements system
    - » used 5 TIUs (HP5370 and Stanford SR620) to measure 5PPS transmit delay to 1 PPS
    - » HP and Stanford TIUs were capable of 20ps and 4ps time resolution respectively
    - » TIUs were referenced to station frequency standard driven by low phase noise ATSC distribution amplifier
    - » Topex / ERS / Stella Tracked with high precision epoch and Normal M7 TOF measurement
- Lawrence Berkeley Laboratory event timer is being interfaced to PS so that TIUs can be used for TOF measurements

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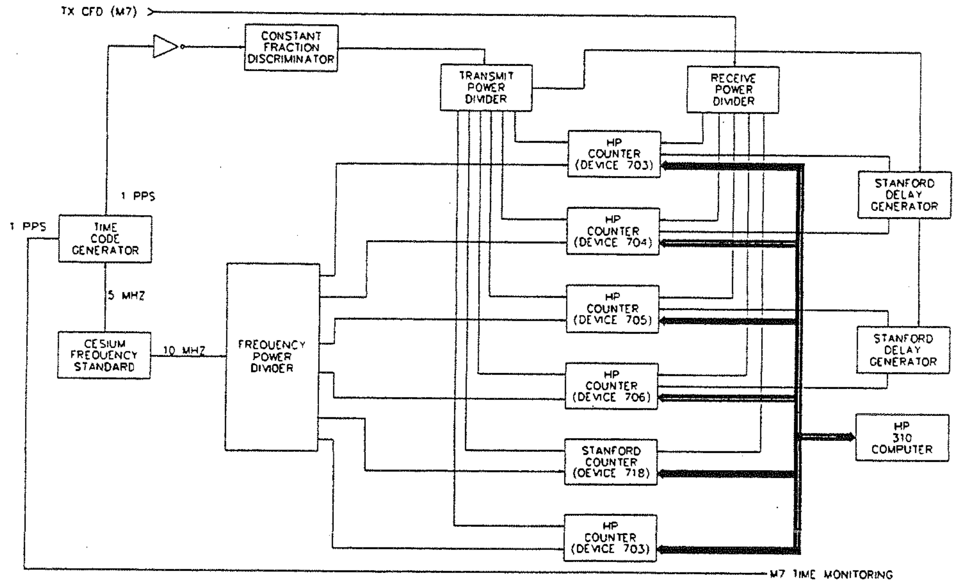
Modified Transmit Delay Configuration



Conclusions

- Possible 3 way (OCA/MLRS/Moblas 7) if satellite moved back to 50 West and remains active
- HS GPS Receiver upgrade
- New Moblas Controller
  - DDG for gate generation
  - Direct interfaces with the CAMAC LBL or other Event timer
- Satellite Decommission date?
  - currently 3 years beyond expected lifespan

EYESAFE SYSTEMS

Chairperson : John Luck

Title: **Eyesafe Laser Ranging - A Review**

Author: Greene B. EOS Australia

Session: Eyesafe systems

Date: 0830 Wednesday 9 November

Chairperson: Dr. J. Luck

Abstract:

The risk of eye damage from an SLR station has increased significantly over the past few years. The increase is due to increases in the number of SLR targets, the upgrade of stations to higher repetition rates, and new stations.

At the same time, there is pressure for significant improvement in station productivity through automation. It is trivial to show that risk associated with current SLR systems is not compatible with system automation, regardless of precautions sych as radar interlock and TV monitoring.

There are thus dual pressures for the development of eyesafe SLR systems, arising from risk reduction criteria and next generation efficiency requirements.

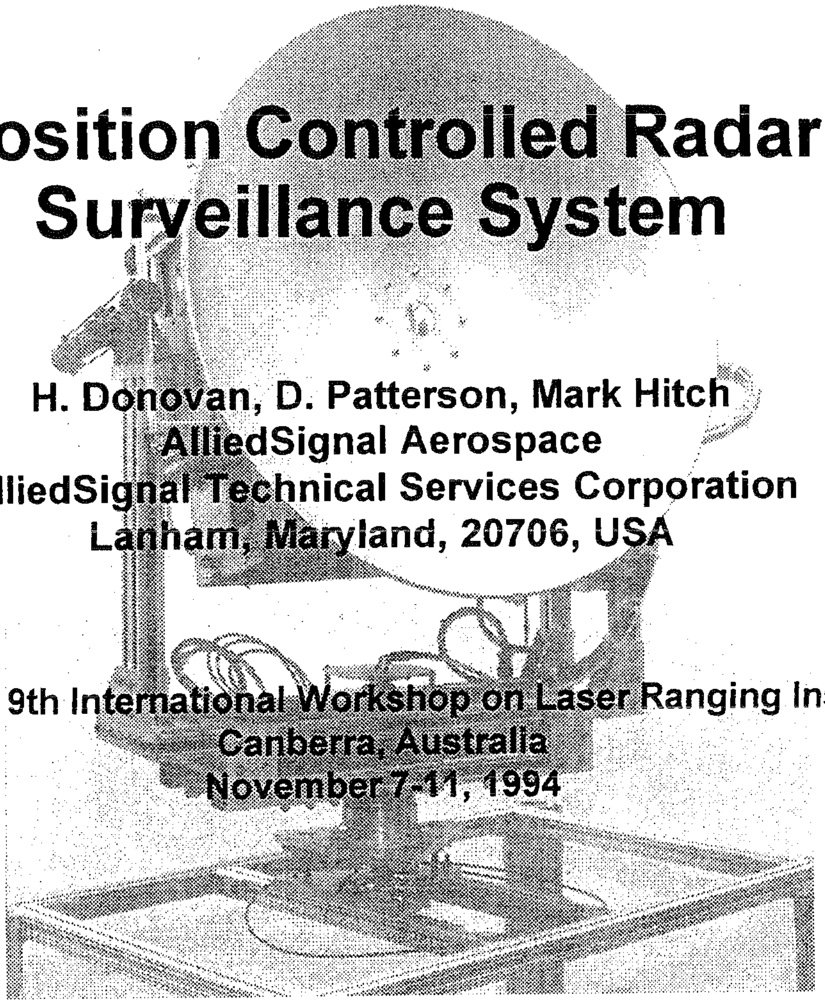
Eyesafe laser ranging has been well developed by military organisations and their supplier infrastructure, on the basis that deployment of non-eyesafe laser rangefinders absolutely prohibits use in exercises and large scale training. It is noteworthy that both US and NATO forces are prohibited from using non-eyesafe laser rangefiders whilst civilian agencies in the respective countries deploy operational systems with far more capacity for damage. This suggests a window which could rapidly close, and which will rapidly close upon the first incident.

The paper addresses the origins and development of eyesafe laser ranging, up to the high power eyesafe SLR systems under development today.

Position Controlled Radar Surveillance System

H. Donovan, D. Patterson, Mark Hitch
AlliedSignal Aerospace
AlliedSignal Technical Services Corporation
Lanham, Maryland, 20706, USA

Presented for the 9th International Workshop on Laser Ranging Instrumentation
Canberra, Australia
November 7-11, 1994



Agenda

- Safety Requirements
- Aircraft Detection Requirements
- Capabilities of Selected Radar
- Hardware Description
- Radar Detection Scheme
- System Overview

Nominal Ocular Hazard Distance For NASA SLR MOBLAS Systems

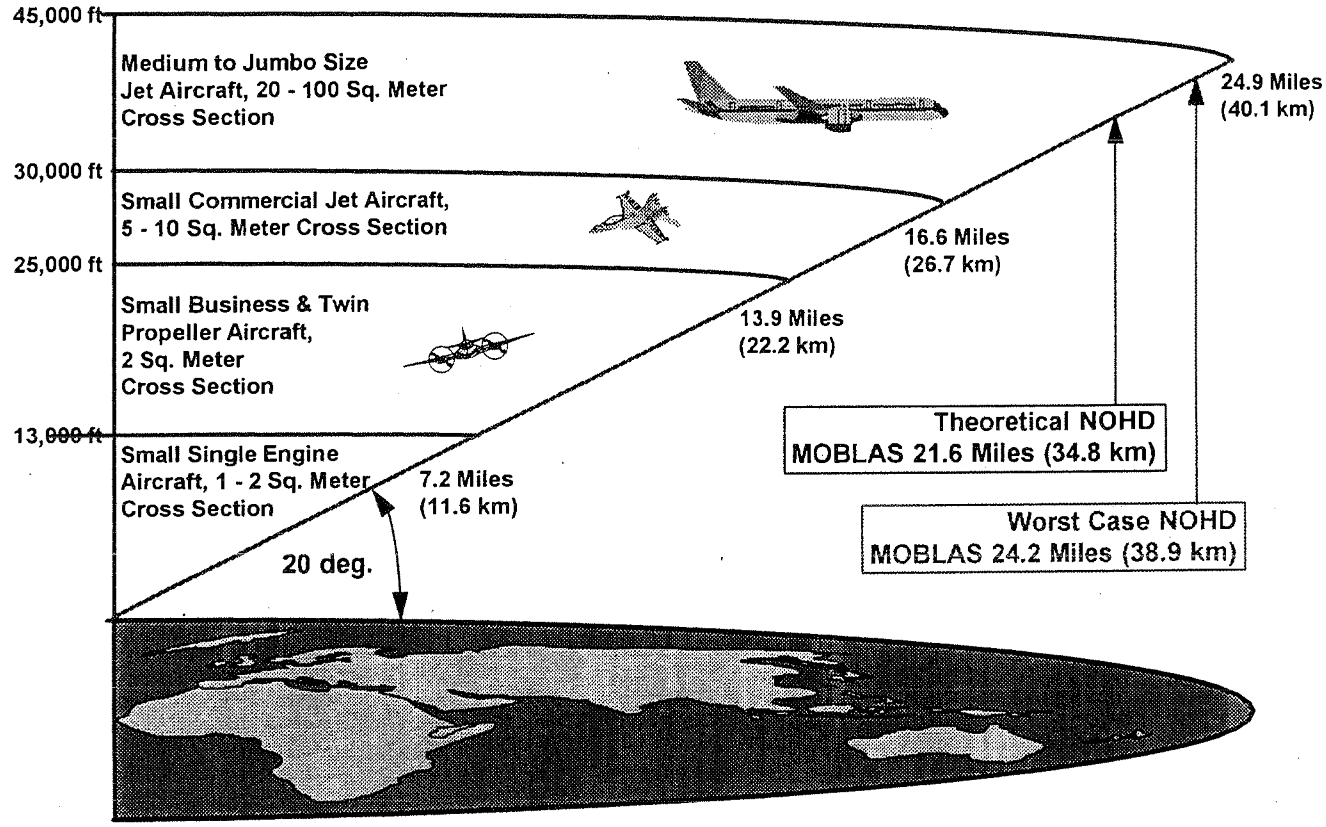
MOBLAS Laser Transmit Beam Characteristics

Power:	100 millijoules
Pulse Width:	200 picoseconds
Frequency:	532 nanometers
Divergence:	0.134 milliradians

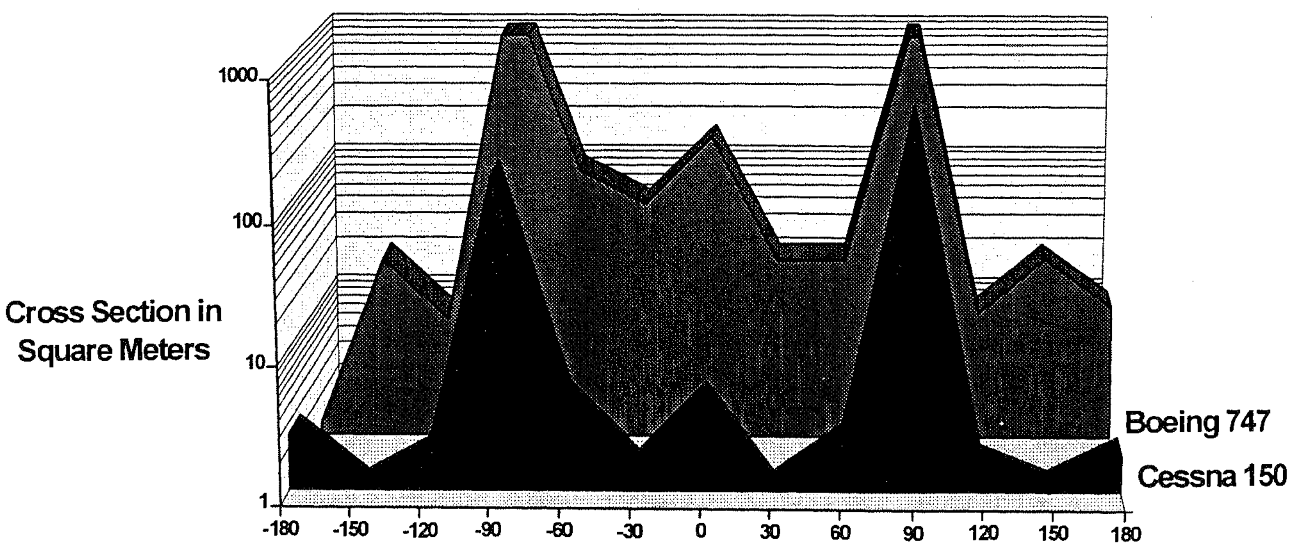
ANSI Z136.1 1986 Requirements

Worst Case:	24.2 Miles (38.9 km)
Theoretical Case:	21.6 Miles (34.8 km)
Estimated Case:	14.7 Miles (23.7 km)
Optimum Case:	8.5 Miles (13.7 km)

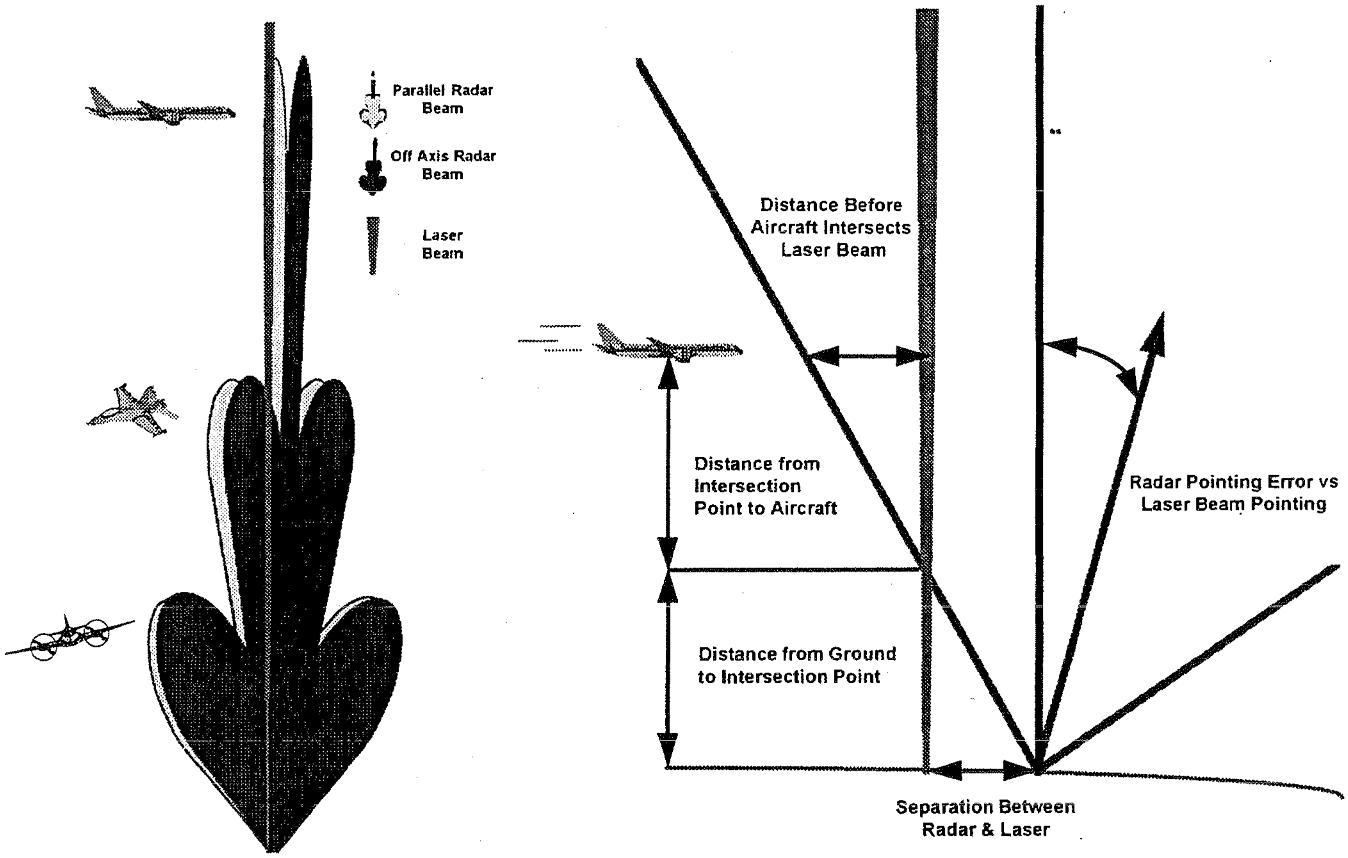
Typical Aircraft Crusing Altitude vs. Slant Range



Radar Cross Section vs Angle of View



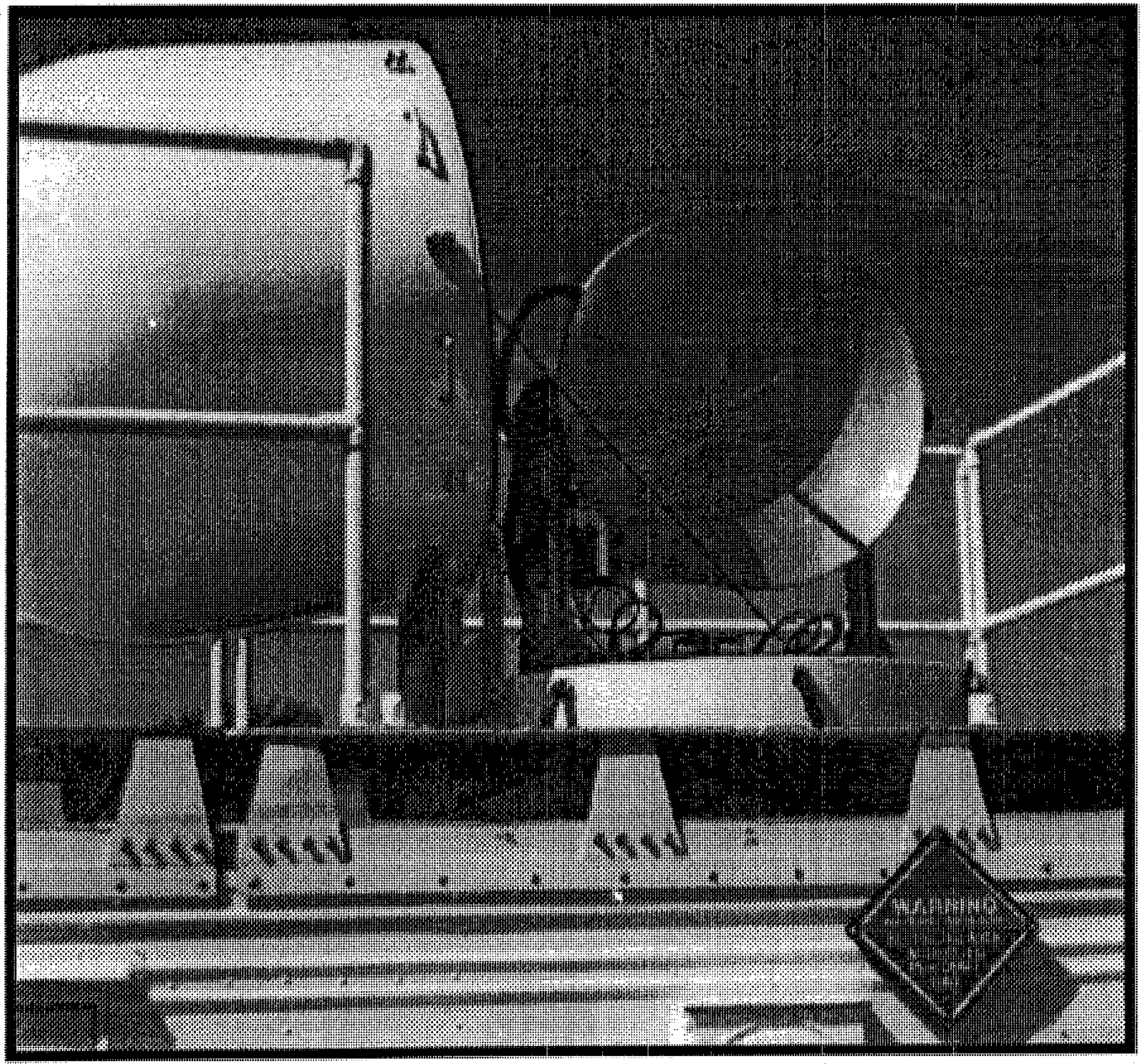
Target Detection vs Beam Overlap



Maximum Pedestal Pointing Error

Plane Speed (mph)	Parallax (feet)	Lobe Width (deg)	Distance to Target (feet)	Distance Past Parallax Int (ft)	Max Radar Hits	Dist to Beam (ft)	Error Angle (deg)
100	40	20	660	433.15	5	11.34	8.5
200	40	20	660	433.15	5	22.70	7.0
200	40	20	800	573.15	6	23.02	7.7
200	40	20	1000	773.15	5	22.95	8.3
200	40	20	1200	973.15	8	23.78	8.6
200	40	20	1400	1173.15	4	22.53	8.9
200	40	20	1600	1373.15	8	23.97	9.0
200	40	20	1800	1573.15	10	24.71	9.1
200	40	12	2450	2069.43	12	25.28	5.3
200	40	12	3050	2669.43	6	23.30	5.5
200	40	12	3700	3319.43	6	23.17	5.6
200	40	8	5000	4427.97	6	23.19	3.7
200	40	8	10000	9427.97	31	32.91	3.8
250	40	6	15000	14236.75	49	49.70	2.8
250	40	6	18000	17236.75	8	30.08	2.9
250	40	5	20000	19083.85	15	33.31	2.4
250	40	6	22000	21236.75	23	37.07	2.9
250	40	5	24000	23083.85	30	40.29	2.4
550	40	5	28000	27083.85	35	94.54	2.3
600	40	5	32000	31083.85	40	108.50	2.3
600	40	6	36000	35236.75	53	123.00	2.8
600	40	6	40000	39236.75	5	68.48	2.9
600	40	6	42500	41736.75	9	72.84	2.9
600	40	5	45000	44083.85	12	76.94	2.4
600	20	5	45000	990541.92	13	77.74	2.4

Radar Pedestal & Dish



Radar Specifications

Radar Unit (Raytheon, Model R20XX)

Transmitter Frequency	9410 MHz +/- 30 MHz
Peak Power Output	4 kW
Pulse Repetition Frequency	750 Hz
Modulator	Solid-state Modulator Driving Magnetron
Duplexer	Circulator
Mixer Protector	Diode Limiter
Mixer	MIC Front End
IF amplifier	Center frequency - 60 MHz Bandwidth - 3 MHz
Overall noise figure	Less than 6 dB
Power consumption	55 W
Temperature range	-15 to +50 deg Celsius

Radome (Magnavox MX-2400)

Commercially available fiberglass radome (48" height x 48" diameter).

Signal loss @ 9.4 GHz	1dB one way (estimated)
Weight	55 lbs

Radar Specifications

Antenna (Seavy Engineering Associates, Model AS33-90)

33" single polarized 9 GHz spun aluminum reflector and a linear polarized X-band feed.

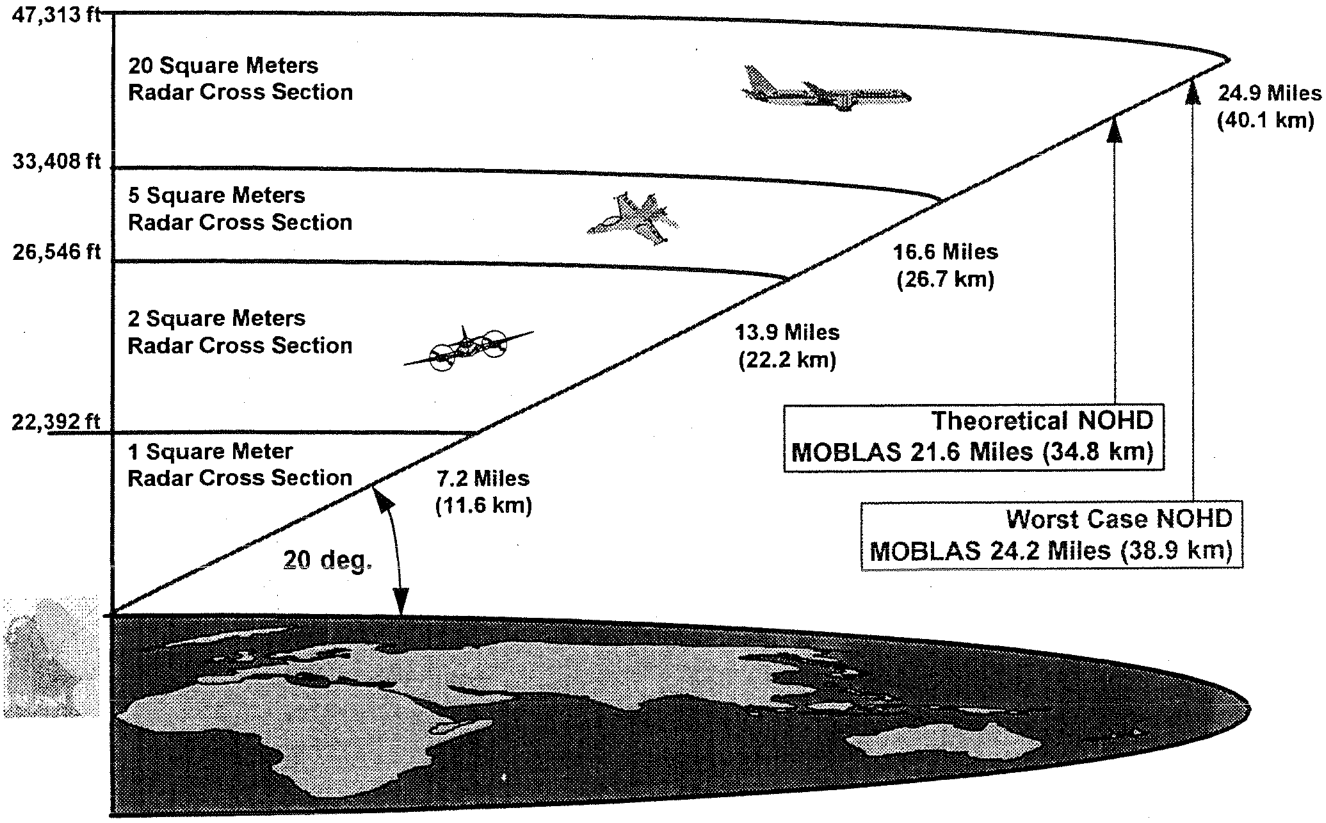
Gain @ 9.4 GHz	36.5 dB
Beam Width @ -3 dB	2.8 deg
Beam Width @ -23 dB, First Side Lobe	12.0 deg
Beam Width @ -30 dB, Second Side Lobe	20.0 deg

Pedestal (ATSC Developed)

A dual axis pedestal driven by DC servo motors with integral tachometers. Position feedback is from frameless resolvers.

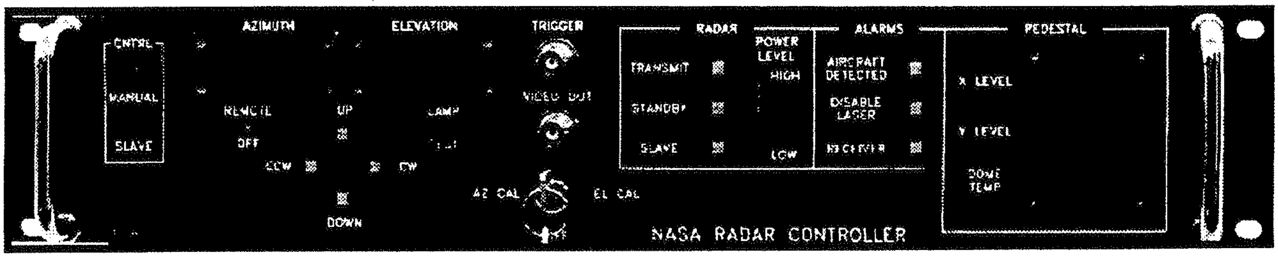
Azimuth Rotation	Unlimited (rotary connector joints)
Elevation Rotation	0 to 180 degrees
Azimuth Velocity	20 deg/sec
Elevation Velocity	15 deg/sec
Position Resolution	0.09 deg (both axis)

Maximum Detection Range for Various Radar Cross Sectional Areas



Radar Pedestal & Dish

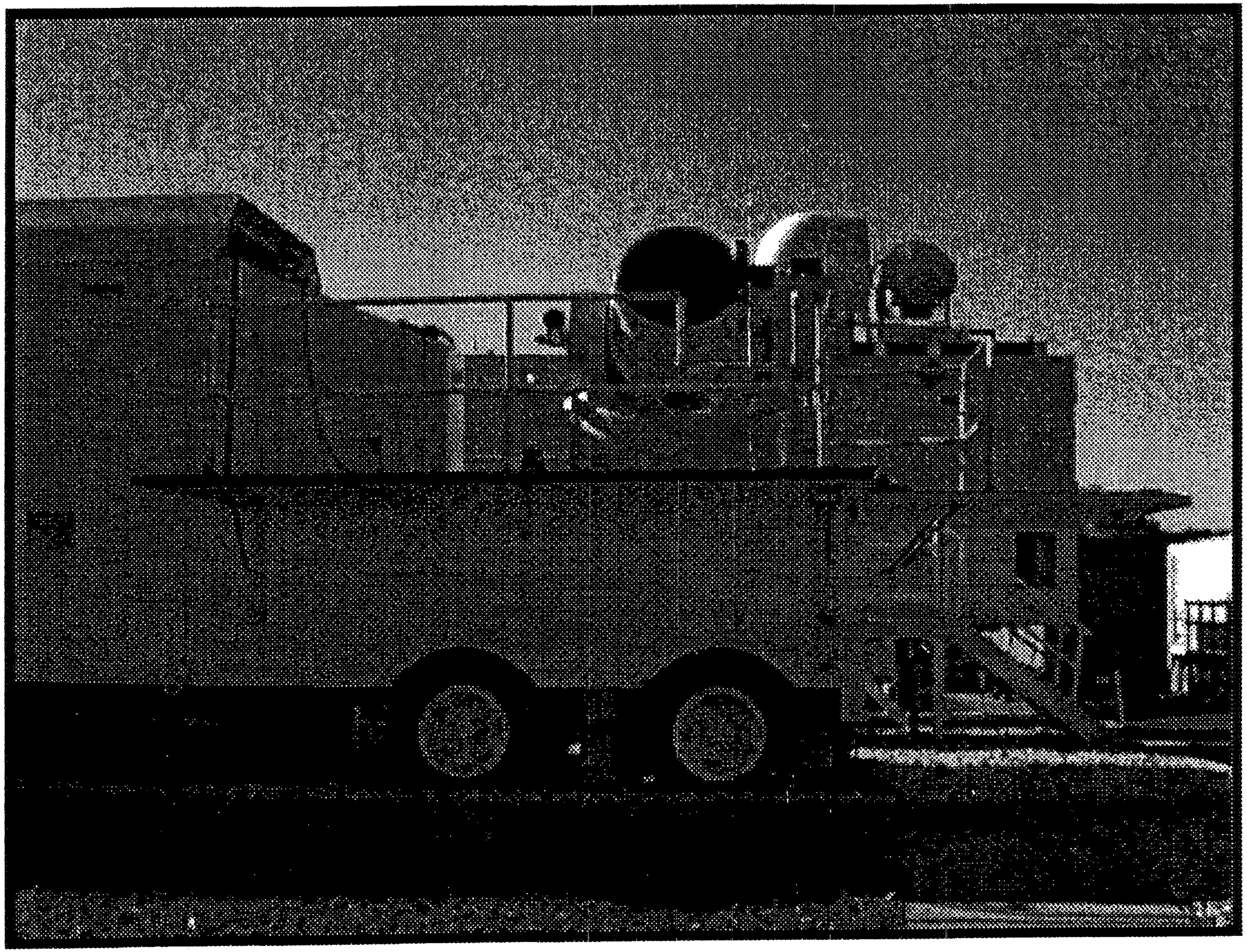
Radar Local Controller



Radar Detection Scheme

- The detection package samples returns in 100nsec bins
- A target detection consists of three consecutive bins with a positive return, thus eliminating false returns generated by noise
- One full return of a transmitted pulse, could supply as many as 7 full bins
- Automatic Gain Control (AGC) is performed every second
- Gain set above background noise
- Tuning voltage automatically adjusted to maintain frequency lock

MOBLAS 7 Mount & Radar System



Position Controlled Radar Surveillance System Specifications & Features

Radar Unit (Raytheon, Model R20XX)

Transmitter Frequency	9410 MHz +/- 30 MHz
Peak Power Output	4 kW
Pulse Repetition Frequency	750 Hz
Modulator	Solid-state Modulator Driving Magnetron
Duplexer	Circulator
Mixer Protector	Diode Limiter
Mixer	MIC Front End
IF amplifier	Center frequency - 60 MHz Bandwidth - 3 MHz
Overall noise figure	Less than 6 dB
Power consumption	55 W
Temperature range	-15 to +50 deg Celsius

Antenna (Seavy Engineering Associates, Model AS33-90)

33" single polarized 9 GHz spun aluminum reflector and a linear polarized X-band feed

Gain @ 9.4 GHz	36.5 dB
Beam Width @ -3 dB	2.8 deg
Beam Width @ -23 dB, First Side Lobe	12.0 deg
Beam Width @ -30 dB, Second Side Lobe	20.0 deg

Pedestal (ATSC Developed)

A dual axis pedestal is constructed of extruded aluminum. Drive is provided by DC servo motors with integral tachometers while position feedback is from a frameless resolver. Gear reduction of 400:1 is accomplished with a harmonic drive set. Pedestal leveling is provided using a three point screw arrangement on the pedestal base.

Azimuth Rotation	Unlimited (rotary connector joints)
Elevation Rotation	0 to 180 degrees
Azimuth Velocity	20 deg/sec
Elevation Velocity	15 deg/sec
Position Resolution	0.09 deg (both axis)

Local Controller (Chassis Mounted in Console Area)

DS5000 microprocessor generates system status and alarms. Serial communication between the local controller and the remote controller uses a half duplex modem at 9600 BPS/FSK. There are three words which are sampled between the units - azimuth position, elevation position, and system status.

Servo Control:	Receives 12 bits of position data per axis from the tracking telescope which are then transmitted via a hi-speed Ethernet serial link to the remote controller which develops command angles to slave the radar pedestal.
Alarm Functions:	Front panel alarm indicators for aircraft detection, low radar transmitter power, low receiver gain, limits exceeded for pedestal level or radome temperature, radar pedestal not slaved to the tracking telescope, and communication link lost between the local and remote controllers.
Laser Control signals:	An inhibit pulse is sent to the laser interlock chassis whenever an aircraft has be detected, or if a status alarm is enabled during satellite tracking.
Displays:	There are front panel displays for azimuth and elevation position, X & Y level, inside radome temperature, radar transmit power and status indicators.
Printer Interface:	Whenever the controller disables or enables the laser, time tag information for each occurrence is sent to a remote printer.
Manual Control:	The radar pedestal can be manually controlled by front panel switches.
Scope Signals:	Radar trigger and video signals provided for viewing on an oscilloscope.
Calibration Key:	Key operated switch is provided to correlate the position of the pedestal to that of the optical telescope.

Remote Controller (Chassis Mounted on the Radar Pedestal)

DS5000 microprocessor processes servo command angles, develops command angles, controls the radar, and determines valid targets.

Target Detection:	The radar transmits at a 750 Hz rate. The period between pulses is sampled at a 10 MHz rate for return echoes within a 40 mile range. If three successive echoes occur a valid target signal is sent to the local controller to disable the laser (one positive target return can yield as many as seven successive echoes).
Radar Controls:	Tuning voltage is automatically adjusted to maintain the IF amplifier to 60MHz. This is accomplished by monitoring a tune indicator voltage and maintaining it at a null by changing the tune control voltage. Gain is also automatically adjusted by sampling the average background noise during the last half of the transmitted pulse and adjusting the gain for a level slightly above the noise. Transmit power is monitored with a small dipole antenna mounted on the edge of the radar dish. The sampled field strength is compared with a set reference point to indicate a relative power.
Radar Status:	A status bit is sent to the local controller to indicate standby or transmit mode and power level. When the radar is first turned 'on' the unit is in the standby mode for 90 seconds before it can transmit.

Radome (Magnavox MX-2400)

Commercially available fiberglass radome (48" height x 48" diameter). Hinged at base to allow access to radar unit.

Signal loss @ 9.4 GHz	1dB one way (estimated)
Weight	55 lbs

DATA ANALYSIS AND MODELS

Chairperson : Giuseppe Bianco

ANALYSIS OF SLR DATA FROM GPS

B. Schutz, P. Abusali, R. Eanes

Center for Space Research

University of Texas at Austin

APPLICATION OF SLR TO GPS

1) USE SLR DATA TO DETERMINE GPS ORBIT

2) USE SLR DATA TO VALIDATE (OR CALIBRATE) THE ORBIT DETERMINED BY RADIO-METRIC SYSTEMS (I.G.S. NETWORK AND ANALYSIS CENTERS)

GPS SLR ANALYSIS

- Compute residual $y = O - C$

  where O = SLR measured range

  C = computed range, based on IGS analysis center and SLR coordinates

- Contributors to y:
  - SLR instrumental error: ~1 cm
  - SLR site coordinate error: ~2 cm
  - Corrections for troposphere, Earth tides, etc: ~1 cm
  - Error in IGS analysis center orbits: ~30 cm
  - Error in location of laser reflection center with respect to center of mass: ~1 cm
  - Error in L1/L2 transmitter antenna phase center location with respect to center of mass: ~1 cm

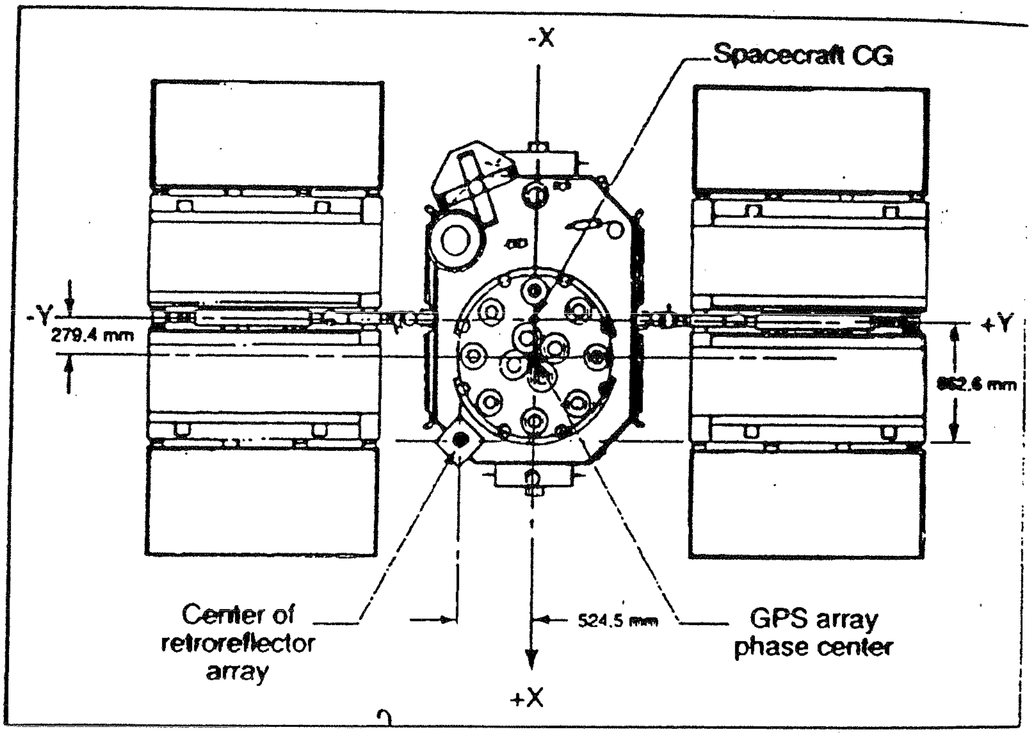
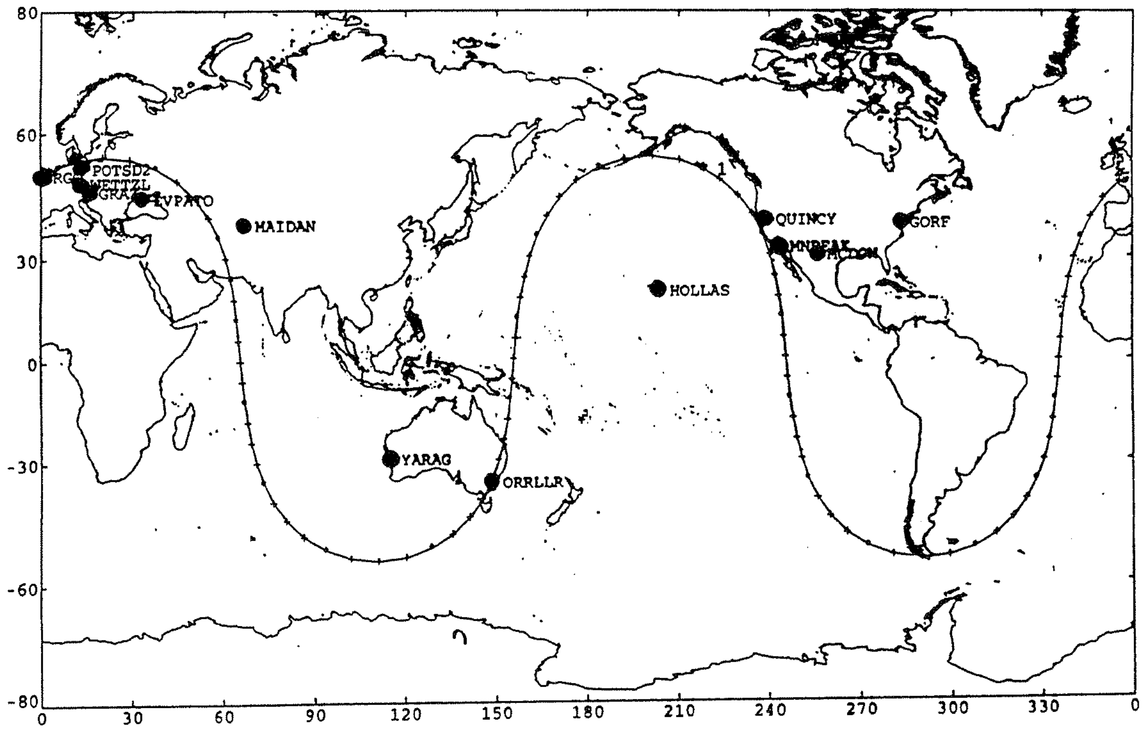
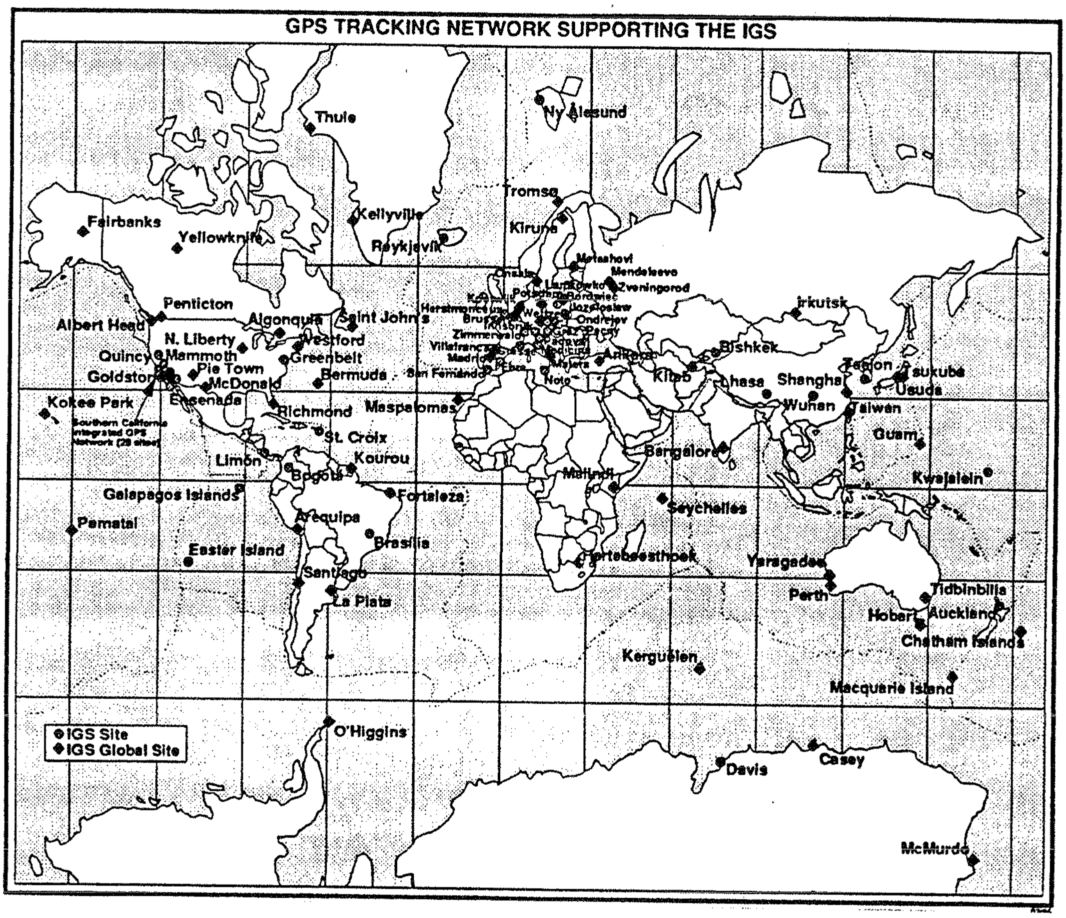


Figure 3. A sketch of a GPS satellite shows the locations of the retroreflector array, antenna array phase center, and the satellite center of gravity (CG). The positive Z-direction points out of the page.

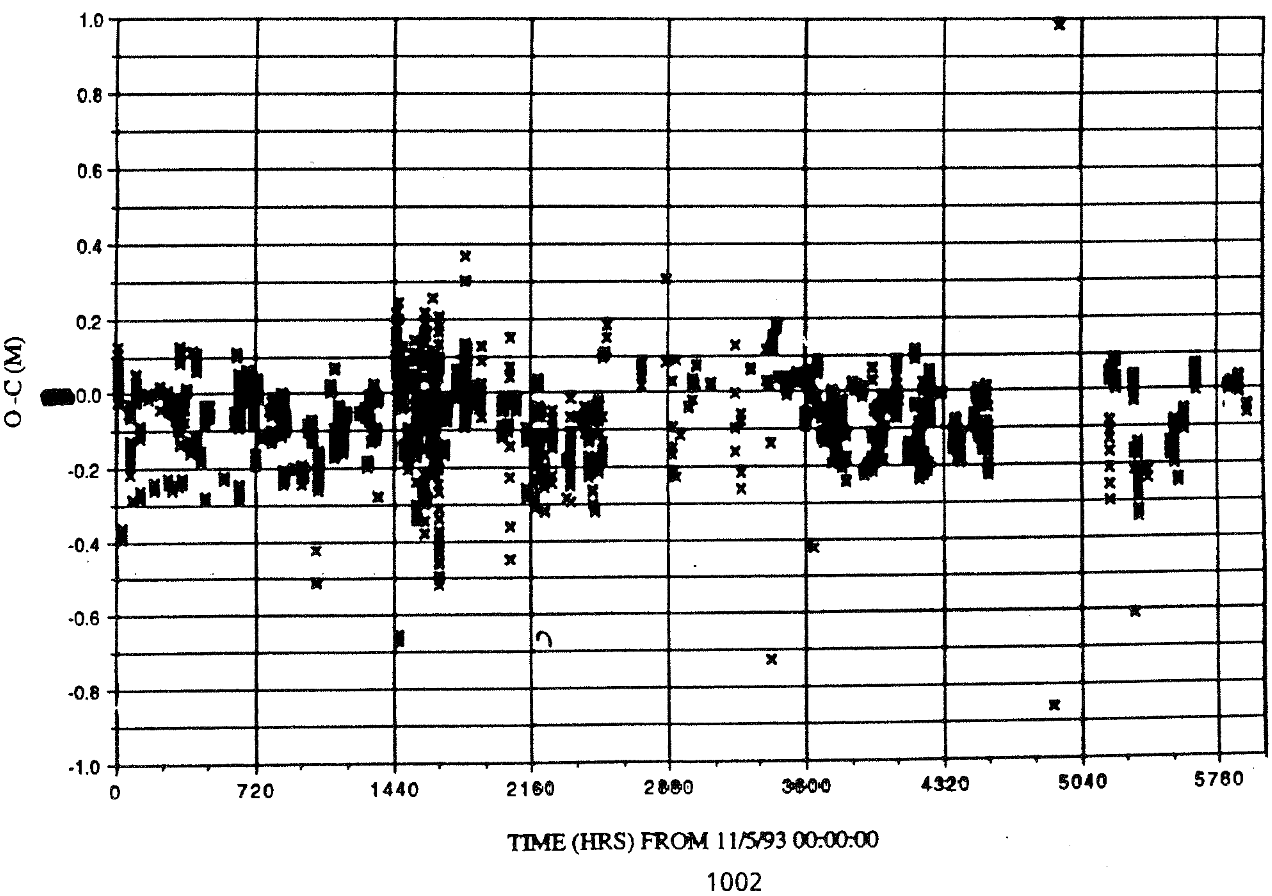
(DEGNAN AND PAVLIS, GPS WORLD)

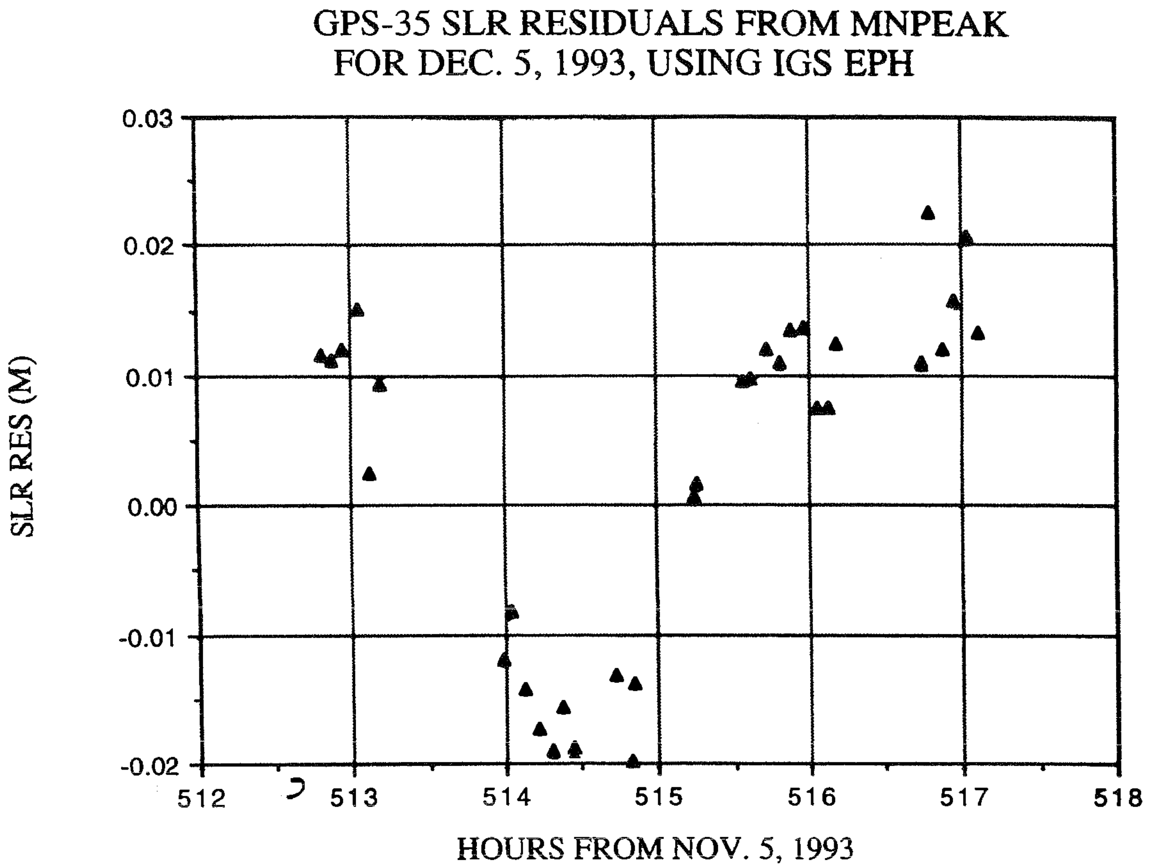


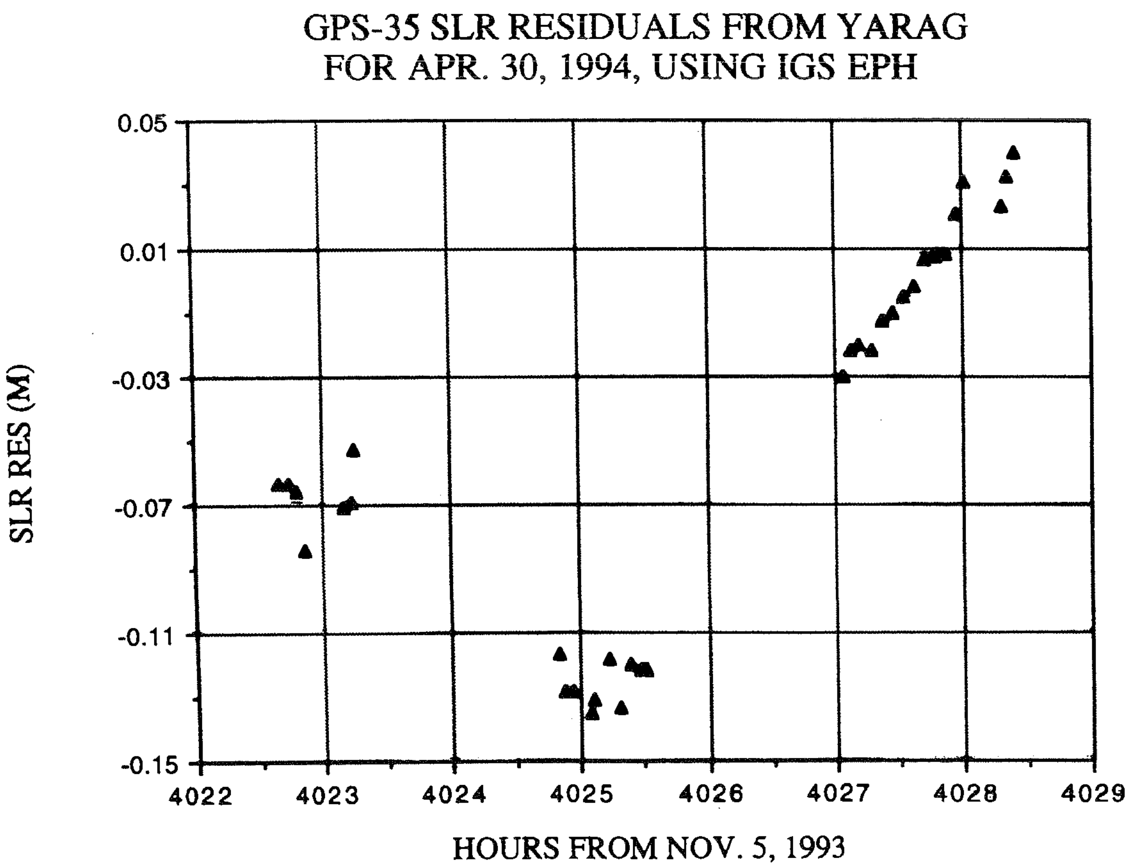
SLR Stations Tracking GPS-35
GPS-35 Ground Track for Nov. 18,93



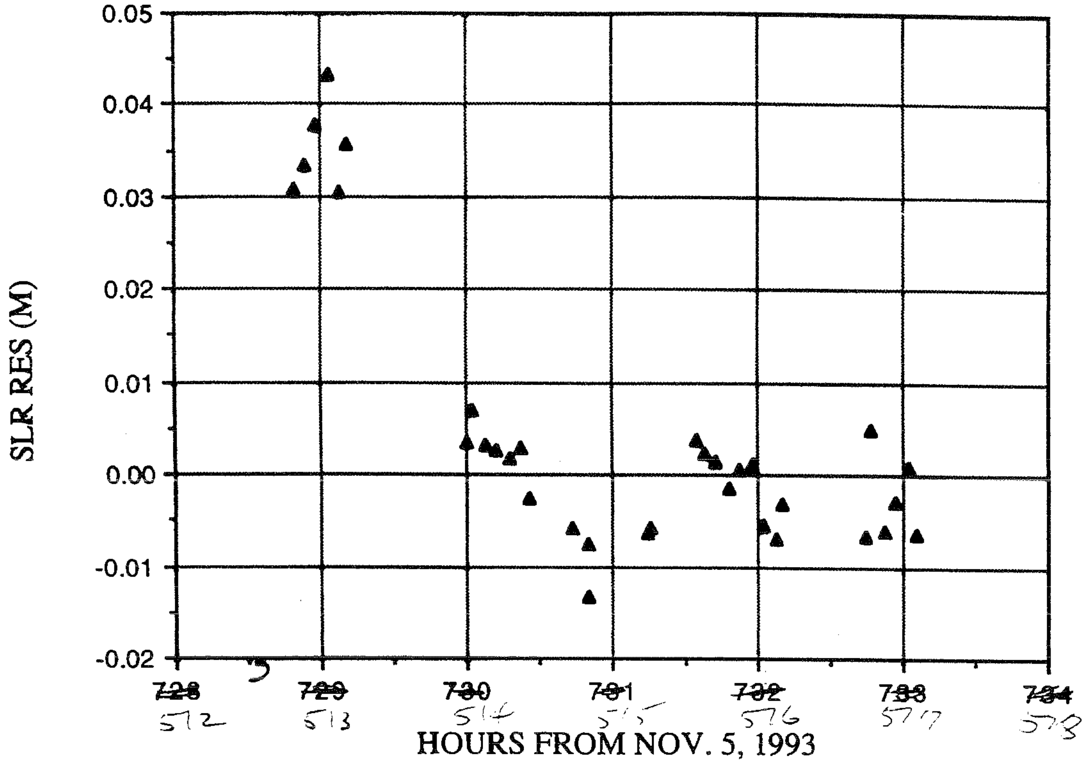
SLR RESIDUALS (< 1M) FROM ALL 13 STATIONS
FOR 247 DAYS, USING JPL EPHEMERIS



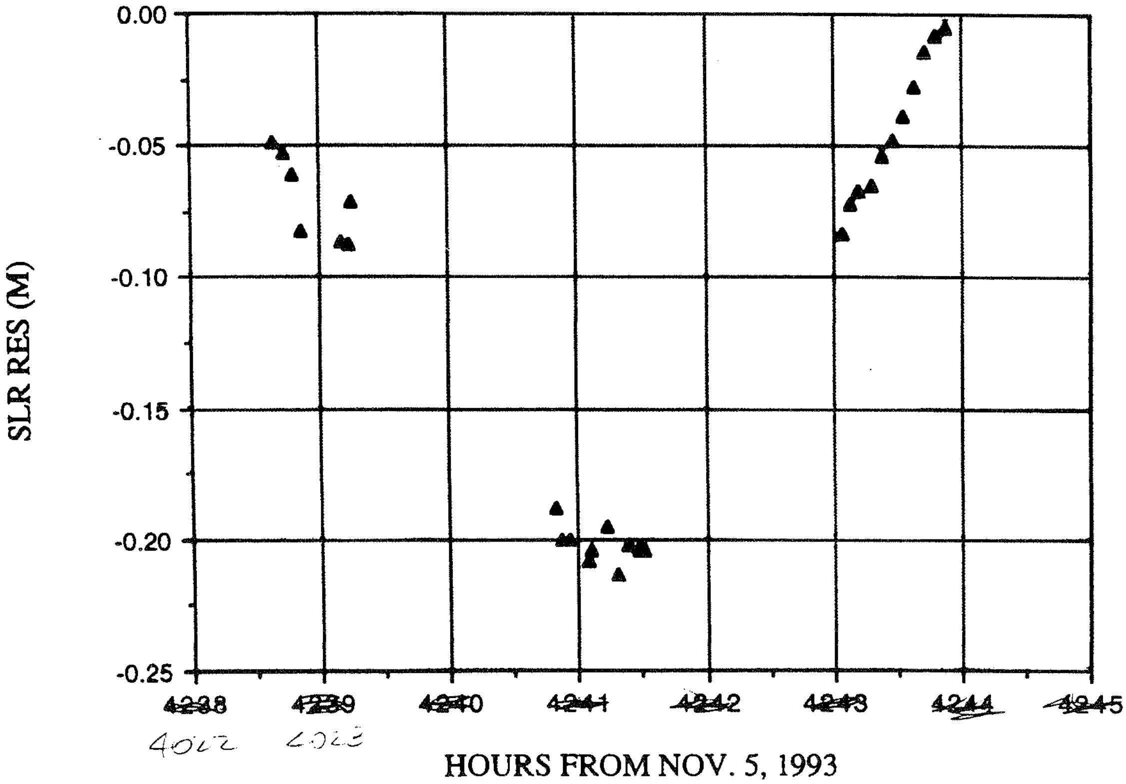

GPS-35 SLR RESIDUALS FROM MNPEAK
FOR DEC. 5, 1993, USING IGS EPH
SLR RES (M)
0.03
0.02
0.01
0.00
-0.01
-0.02
512
513
514
515
516
517
518
HOURS FROM NOV. 5, 1993


GPS-35 SLR RESIDUALS FROM YARAG
FOR APR. 30, 1994, USING IGS EPH
SLR RES (M)
0.05
0.01
-0.03
-0.07
-0.11
-0.15
4022
4023
4024
4025
4026
4027
4028
4029
HOURS FROM NOV. 5, 1993

GPS-35 SLR RESIDUALS FROM MNPEAK
FOR DEC. 5, 1993, USING JPL EPH



GPS-35 SLR RESIDUALS FROM YARAG
FOR APR. 30, 1994, USING JPL EPH



SUMMARY OF GPS-35 SLR RESIDUALS (<1 m) COMPUTED USING EPHEMERIDES OF THE IGS ANALYSIS CENTERS

(WEEKS 721–756)

Analysis Center	No. of Points	W. Mean (cm)	W. RMS (cm)
COD	2251	−8.03	14.96
EMR	2184	−9.50	15.99
ESA	2251	−5.89	15.85
GFZ	2242	−4.77	12.59
IGS	2113	−8.30	14.05
JPL	2251	−7.85	14.60
NGS	2176	−5.09	21.99
SIO[1]	1566	−12.02	18.57
SIO[2]	608	−1.28	15.05

Notes:

1. Using ephemeris at 22.5-min interval
2. Using ephemeris at 15.0-min interval

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THE UNIVERSITY OF TEXAS AT AUSTIN

CONCLUSIONS

- SLR data on GPS-35, combined with IGS analysis center ephemerides, produce residuals:

  Mean ~ −7 cm

  RMS ~ 12 cm to 22 cm

- RMS is consistent with estimates of IGS ephemeris accuracy; cause of mean is unknown.

- RECOMMENDATIONS:
  - MORE DATA -- ESPECIALLY GPS-36
  - SOME PASSES WITH MORE CONTINUITY THROUGHOUT PASS (FEW DAY— WEEK PERIOD/"CAMPAIGN")

AlliedSignal

GPS Laser Ranging and Data Analysis

AlliedSignal Aerospace

Richard A. Eichinger
Mark A. Davis
Brion P. Conklin
Thomas Varghese
Mark Levy

NASA/Goddard Space Flight Center

John J. Degnan

University of Texas at Austin

Randall L. Ricklefs

9th International Workshop on Laser Ranging Instrumentation
Canberra, Australia
7th to 11th of November 1994

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GPS Tracking Issues for NSLR

- Orbit Prediction
- Receiver Loop Gain
- Pointing, Beam Divergence, Mount Modeling
- Spectral, Spatial, Temporal Filtering
- Data Processing

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Orbit Prediction

- SLR Predictions based mostly on SLR range data
  - Improved Geometry
  - Improved Coverage
- GPS 35 and GPS 36 IRV predictions have been good
  - GPS 36 was acquired by Moblas-7 on the first attempt
  - GPS eph 12 for GPS 36 was < 400 ms for 2 months
  - GPS eph 22 for GPS 35 was < 10 ms time bias for 2 weeks

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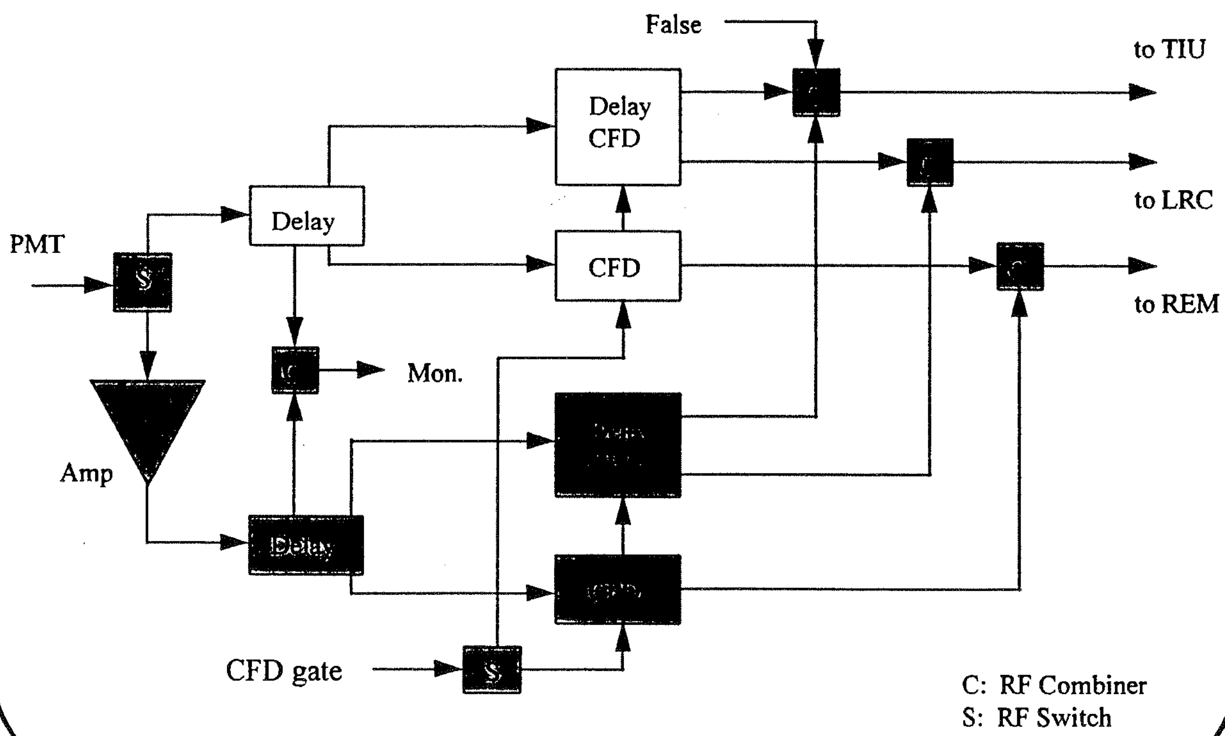
OBJECTIVES & TECHNICAL APPROACH

- Establish a Switchable Dual Receiver Configuration in the MOBLAS to accommodate "Low Link" Satellites.
  - ◊ Electronically Switchable "Bias Free" Scheme.
- Improve the Night Time Yield to Obtain Ranging at Lower Elevations.
  - ◊ Boost the Loop Gain Through an Amplifier (GHz, $\leq$ 10 x Gain).
  - ◊ Adjust Discriminator Threshold to Maximize Data.
  - ◊ Acquire the Satellite Optically Using ICCD (whenever possible).
- Improve the Ability to Obtain daytime Tracking.
- ◊ Narrow Spectral Filtering from 10 Angstroms to 3 Angstroms.
  - ◊ Improve Spatial Filtering to < 3 arcsec.
  - ◊ Improve Temporal Filtering to $\leq$ 200 nsec.
  - ◊ Improve Noise Filtering for Daytime Data Analysis.

Switched & Combined Receiver



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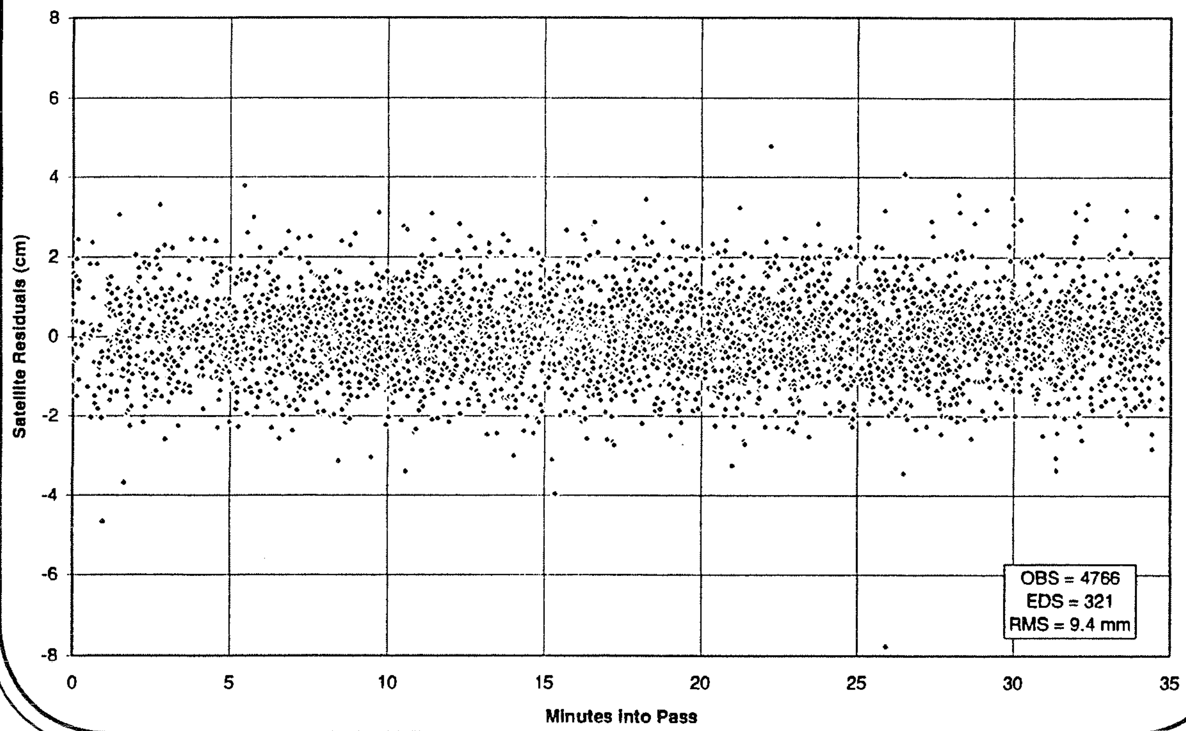
GPS Nighttime Tracking Data

Moblas-7, GPS 36, 28 May 94, 0159Z (9:59 pm)



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Daylight Ranging

- **Moblas-7 Passes**
  - GPS 36, 28 May 94, 0035Z (dusk)
- **Simulated Daylight Noise at Moblas-7**
  - GPS 36, 24 May 94, 0245Z
- **Simulated Single-pe Data at Moblas-8**
  - Lageos-2, 13 Sep 94, 2005Z (ND in Tx)
- **Moblas-8 Daylight Passes**
  - Etalon-1, 20 Sep 94, 1937Z
  - Etalon-2, 26 Sep 94, 1350Z
  - GPS-35, 27 Sep 94, 1241Z

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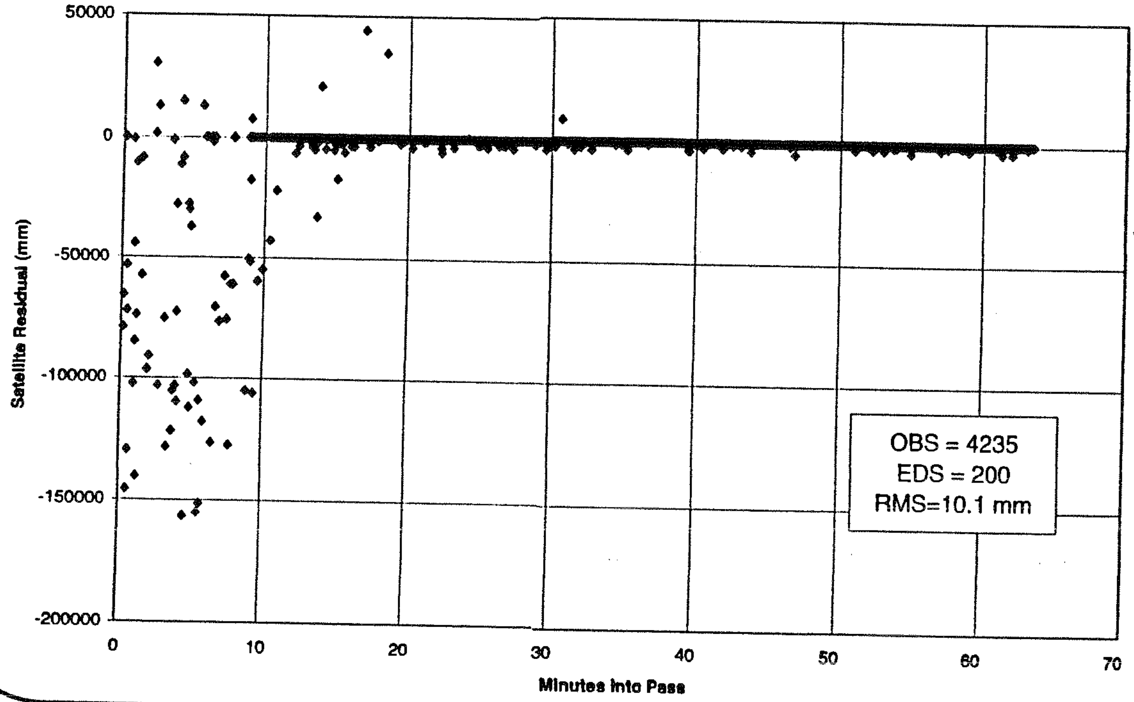
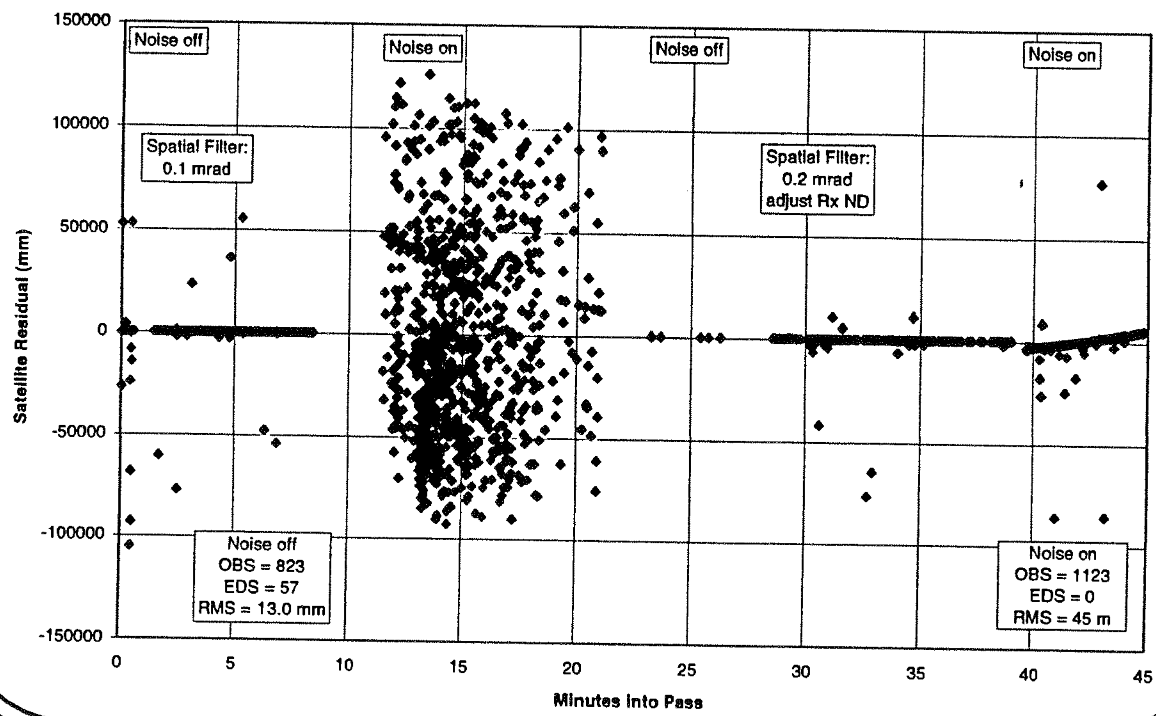
Moblas-7 Pass at Dusk using 3 A Filter

GPS 36, 28 May 94, 0035Z (8:35 pm)



Simulated Daylight Noise at Moblas-7

GPS 36, 24 May 94, 0245Z (10:45 pm)



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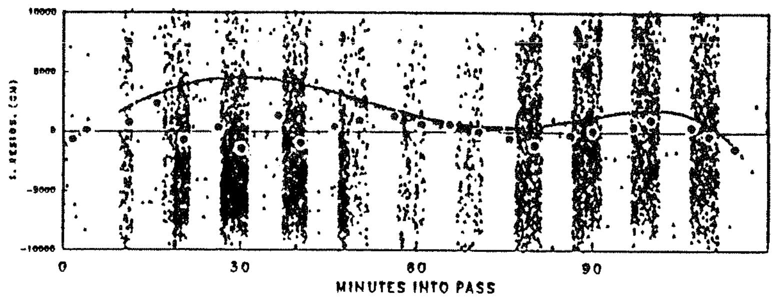
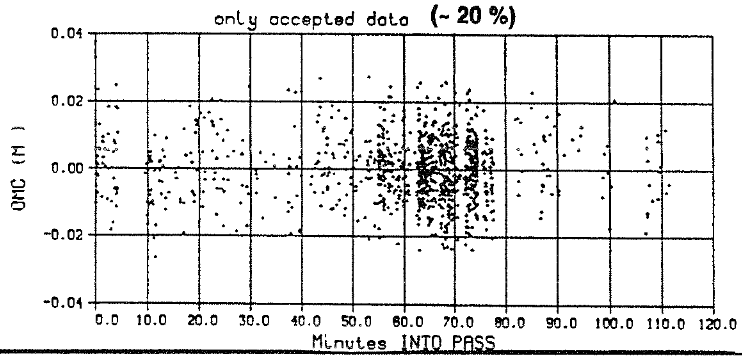
Poisson Filter Result

ML07 GPS36 22May94 AT 01:26 GMT





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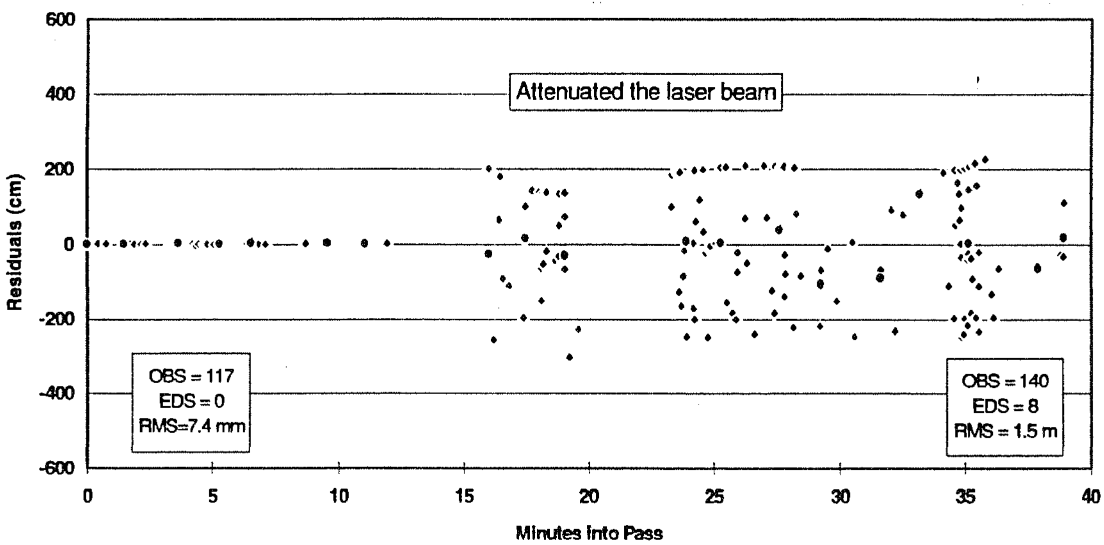
Simulated Single-pe Data at Moblas-8

Moblas-8 Lageos-2 Sep 13, 1994 at 20:03 (1:03 pm)



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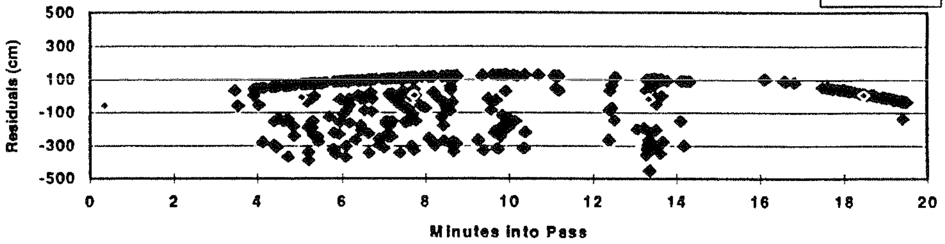
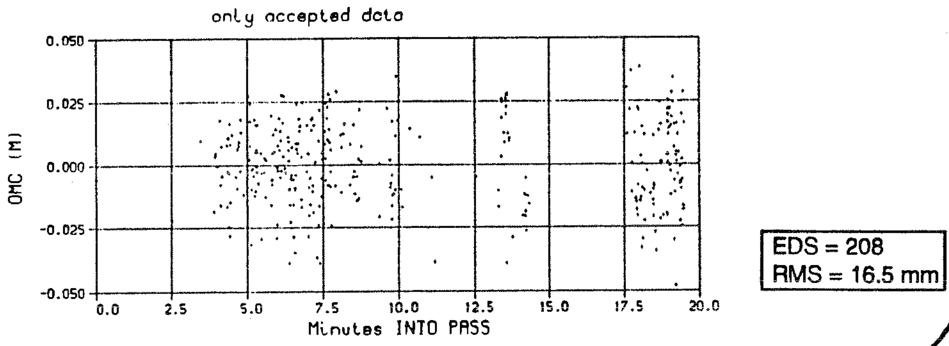
Moblas-8 Daylight Pass

Etalon-2 Sep 26, 1994 at 13:28 (6:28 am)

3 A filter
OBS = 536
EDS = 29
RMS = 1.3 m



Apply Poisson Filter:



AlliedSignal Technical Services Corporation

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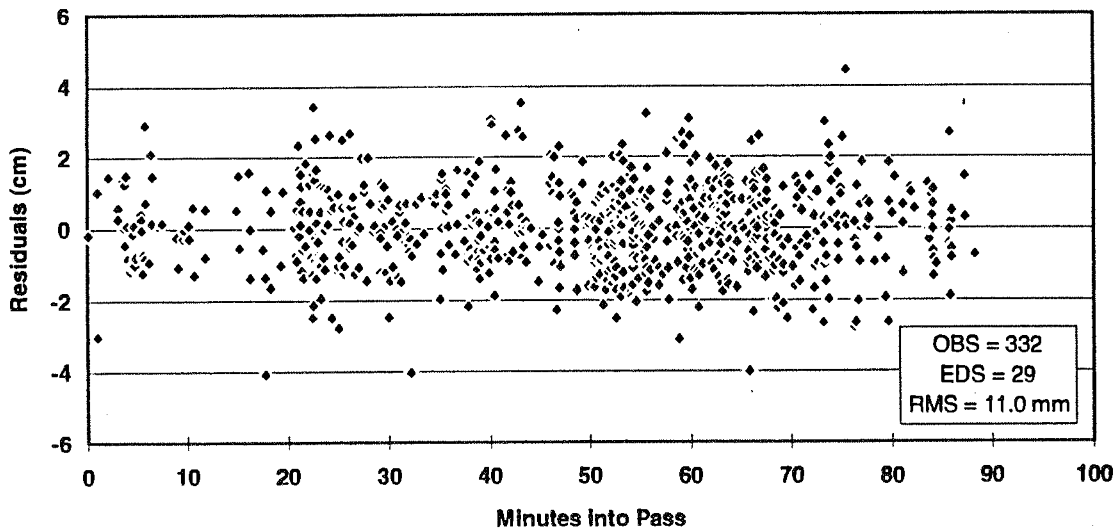
Moblas-8 Daylight Pass

Moblas-8 GPS-35 Sep 27, 1994 at 12:41 (5:41 am)



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Daylight Tracking Issues

- Increase spectral, temporal, and spatial filtering
  - Use oven to control the temperature of the 3 A spectral filter, improve 200 to 900 nm blocking
  - Reduce range gate jitter from 200 ns to 10 ns
  - Improve telescope focus stability, T/R optics alignment precision, beam spot size, spatial filter centering, mount model determination
- Reduce beam divergence
- Improve telescope pointing
- Use new data filtering techniques
- Improve orbit prediction for better pointing and range gating

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Conclusions

- Switchable Dual Receiver configuration established in Moblas to acheive good nighttime GPS data yield and data quality
- Daylight GPS data yield will improve with the engineering enhancements outlined earlier

AlliedSignal Technical Services Corporation

Geodynamics Results from Lageos-1 and Lageos-2

Richard Eanes
University of Texas at Austin
Center for Space Research

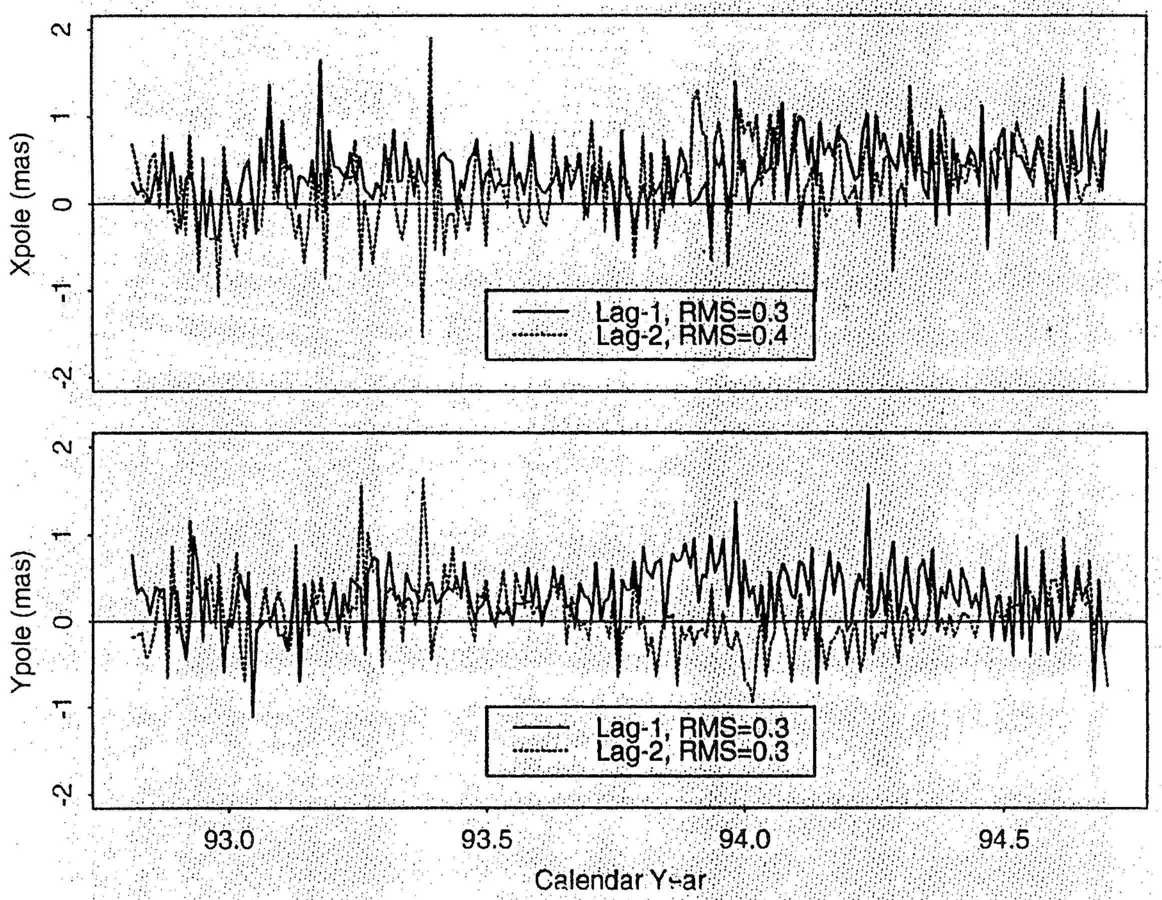
Ninth International Workshop
on Laser Ranging Instrumentation
Canberra, Australia

7-11 November 1994

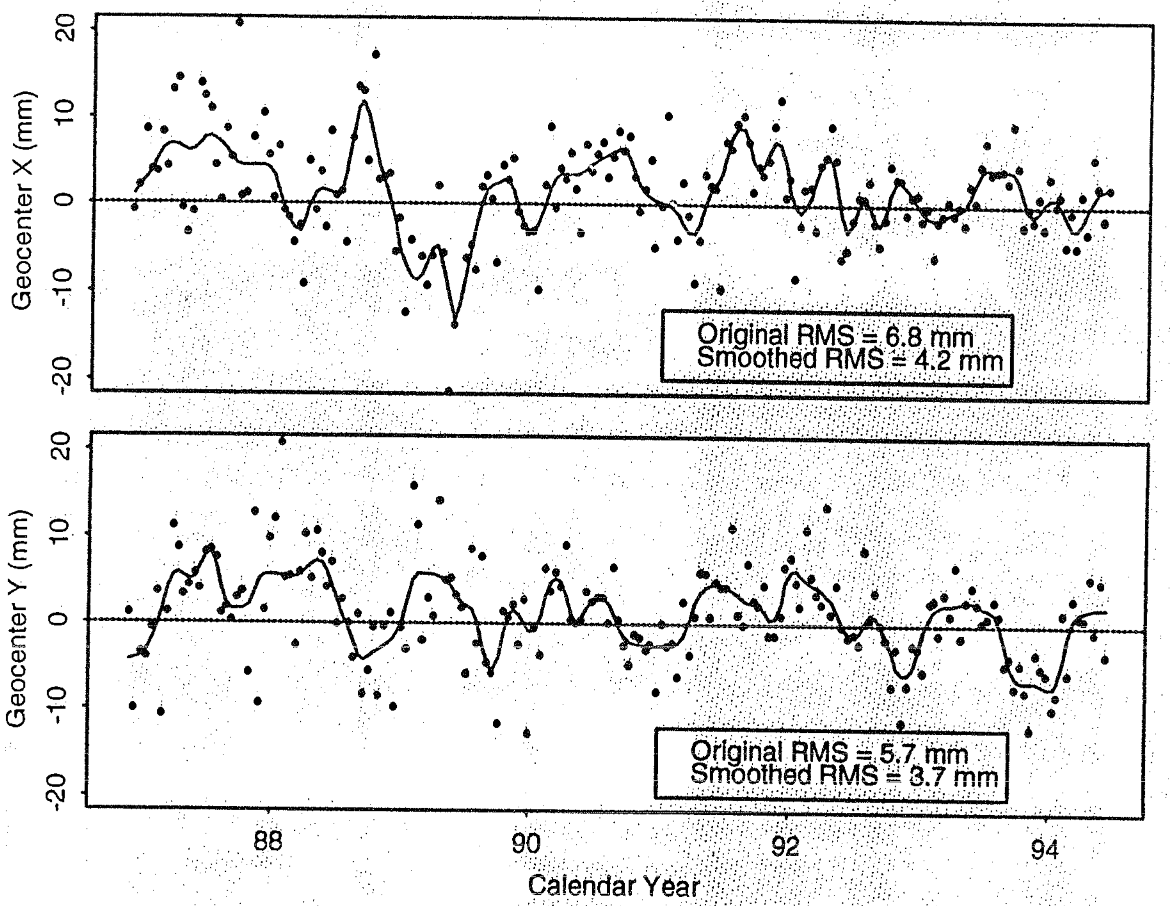
Applications of Lageos SLR Data

* SLR Data Quality Control
* Terrestrial Reference Frame Maintenance
* Earth Orientation Monitoring
* Temporal Variations of the Gravitational Field
* Improve Non-gravitational Force Models

Lageos-1 and Lageos-2 Polar Motion Differences from IERS-C04



Geocenter Variations Determined from SLR to Lageos-1



DEFINITION OF THE EQUINOCTIAL ELEMENT VECTORS

$$\Delta U_r \equiv \Delta a/\bar{a} \;\; ; \;\; \Delta U_l \equiv \Delta u + \Delta\Omega \cos\bar{I}$$

$$\Delta P_r \equiv \Delta e \cos\bar{\omega} - \bar{e}\Delta\omega \sin\bar{\omega} \;\; ; \;\; \Delta P_l \equiv -\Delta e \sin\bar{\omega} - \bar{e}\Delta\omega\cos\bar{\omega}$$

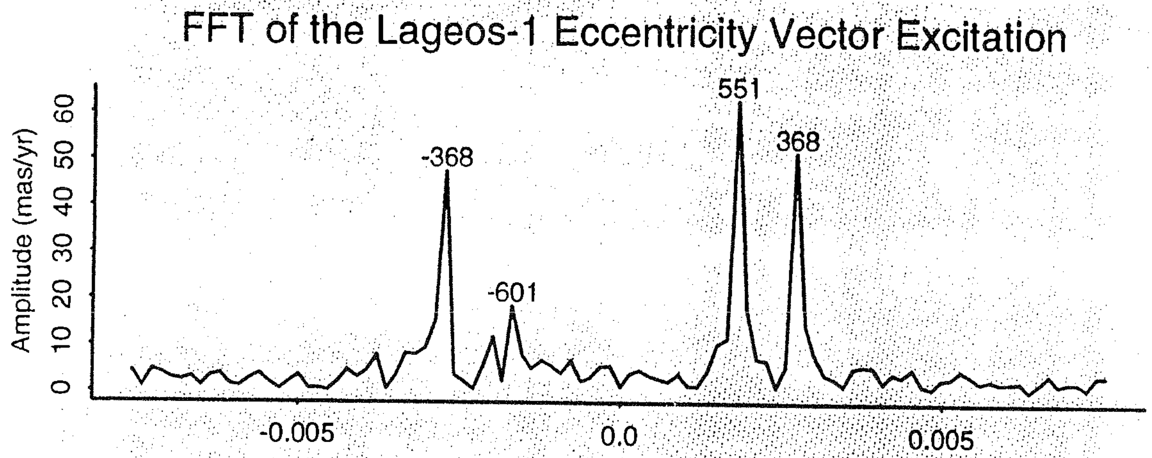
$$\Delta Q_r \equiv \Delta I \;\; ; \;\; \Delta Q_l \equiv -\Delta\Omega \sin\bar{I}$$

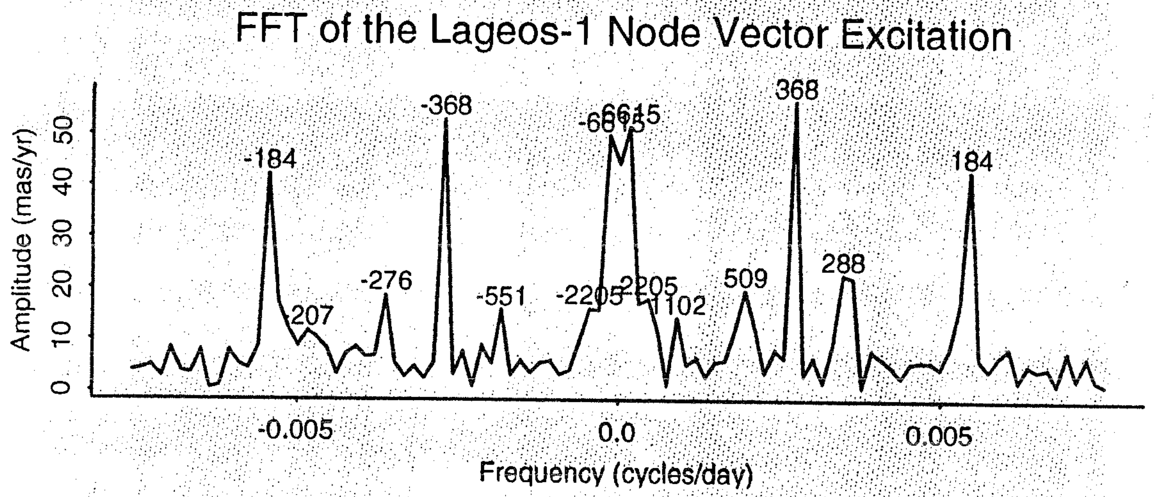
DYNAMICAL EQUATIONS FOR THE EQUINOCTIAL ELEMENT VECTORS

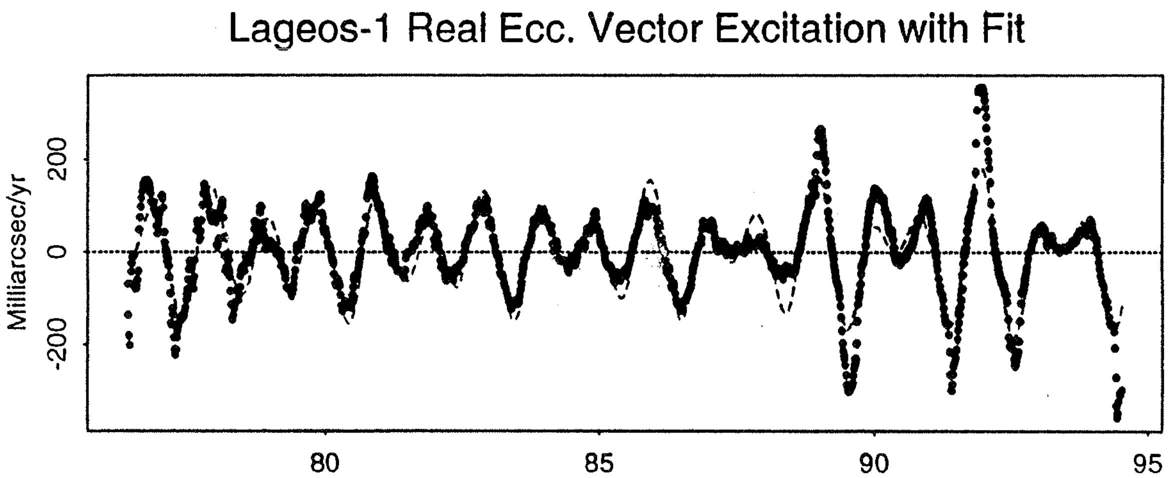
$$\Delta\dot{U}(t) - i\left[-\frac{3\bar{n}}{2} + \dot{\mu}_s\right]\Delta U_r(t) - i\dot{\mu}_I \Delta Q_r(t) \equiv \Psi_U$$

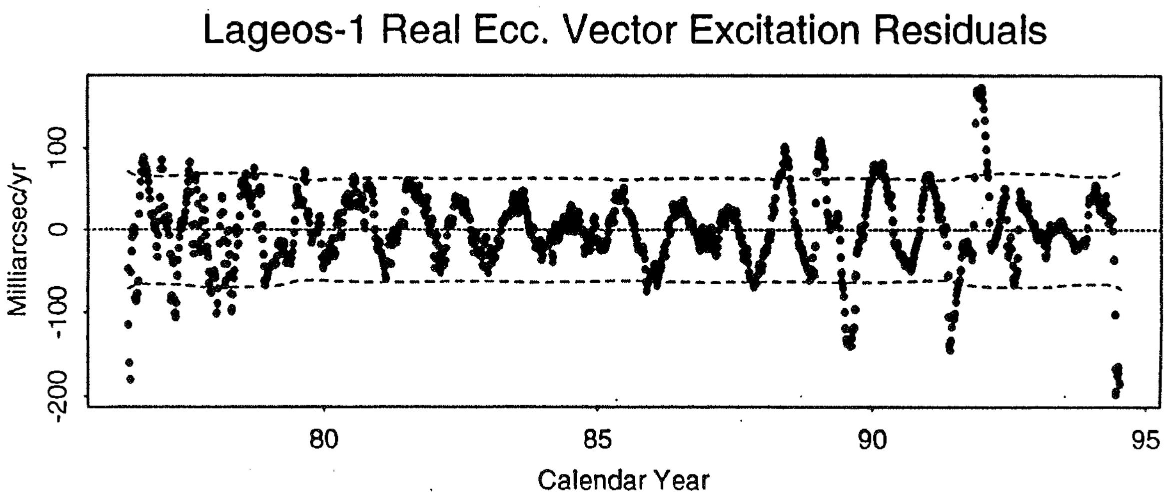
$$\Delta\dot{P}(t) + i\dot{\omega}\Delta P(t) \equiv \Psi_P$$

$$\Delta\dot{Q}(t) - i\dot{\nu}_I \Delta Q_r(t) - i\dot{\nu}_s \Delta U_r(t) \equiv \Psi_Q$$

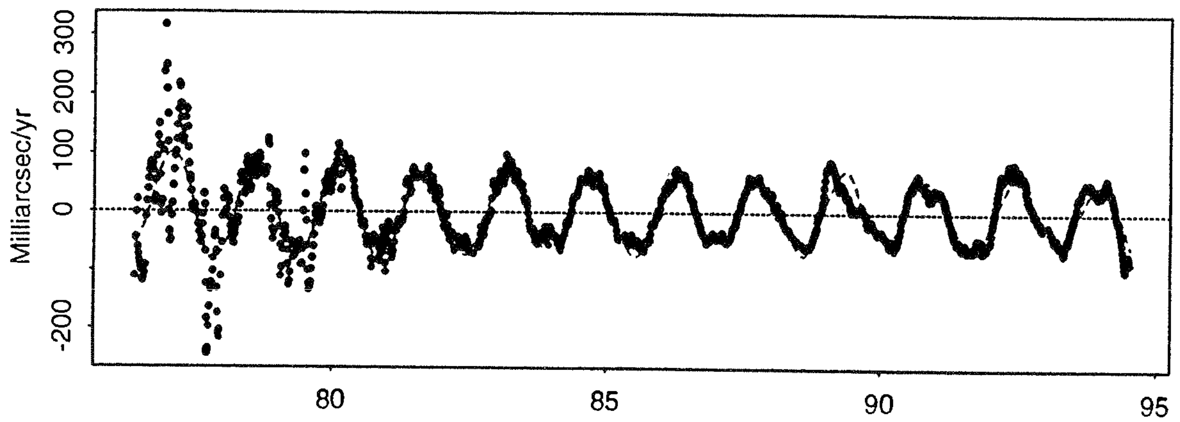

FFT of the Lageos-1 Eccentricity Vector Excitation
Amplitude (mas/yr)
0
10
20
30
40
50
60
-368
-601
551
368
-0.005
0.0
0.005


FFT of the Lageos-1 Node Vector Excitation
Amplitude (mas/yr)
0
10
20
30
40
50
-184
-207
-276
-368
-551
-2205
-6615
6615
2205
1102
509
368
288
184
-0.005
0.0
0.005
Frequency (cycles/day)

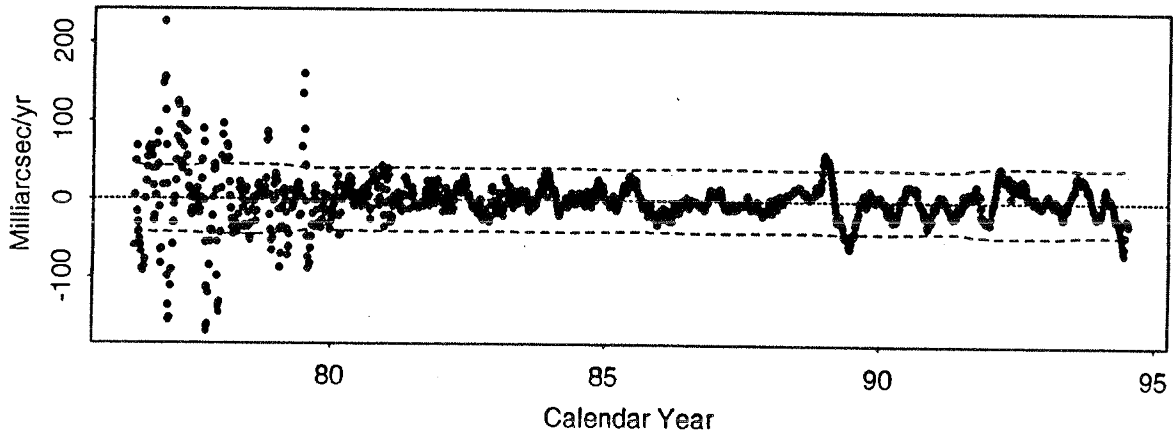

Lageos-1 Real Ecc. Vector Excitation with Fit
Milliarcsec/yr
-200
0
200
80
85
90
95


Lageos-1 Real Ecc. Vector Excitation Residuals
Milliarcsec/yr
-200
-100
0
100
80
85
90
95
Calendar Year

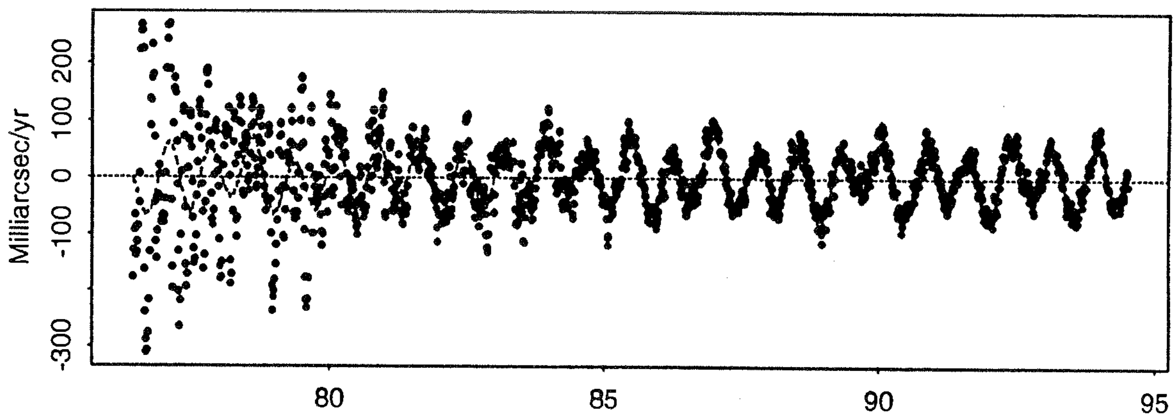
Lageos-1 Imag. Ecc. Vector Excitation with Fit



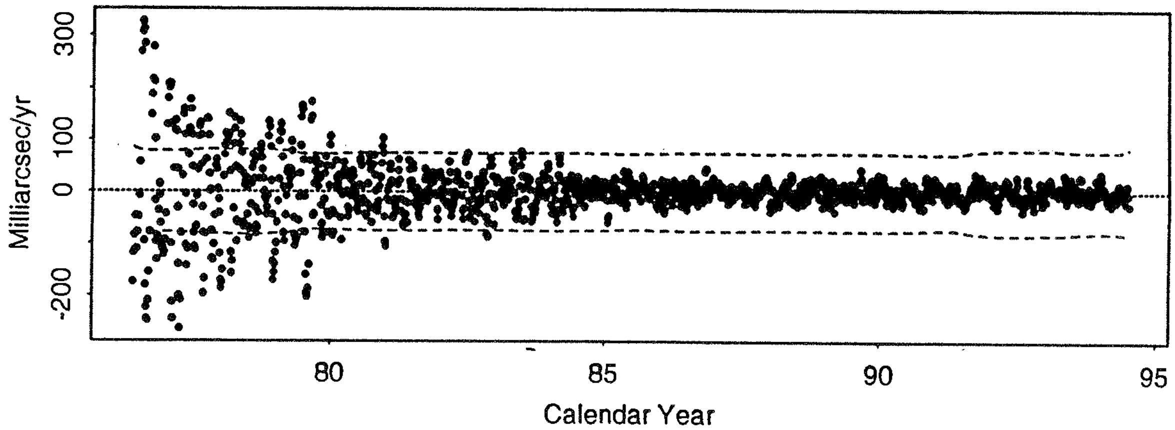
Lageos-1 Imag. Ecc. Vector Excitation Residuals

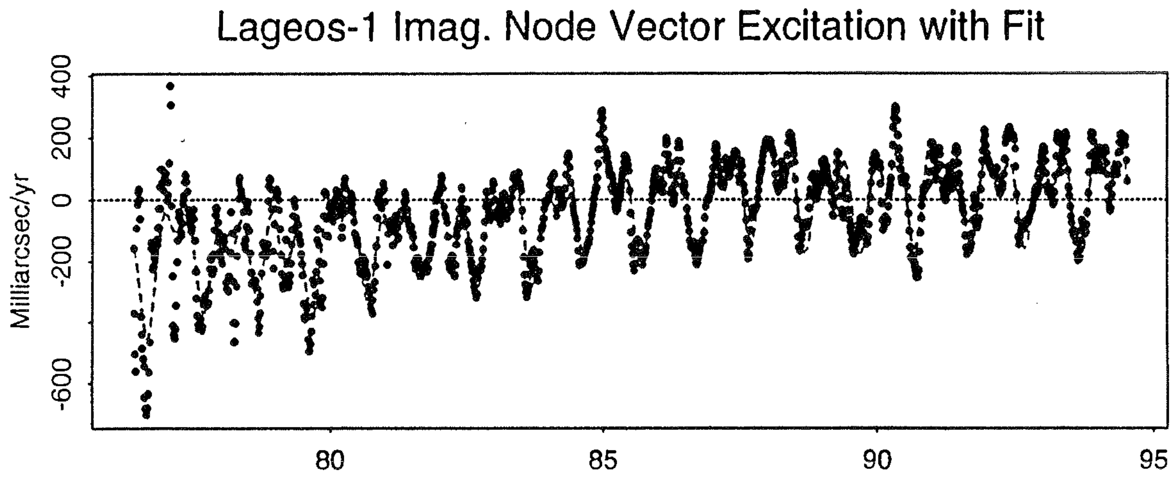


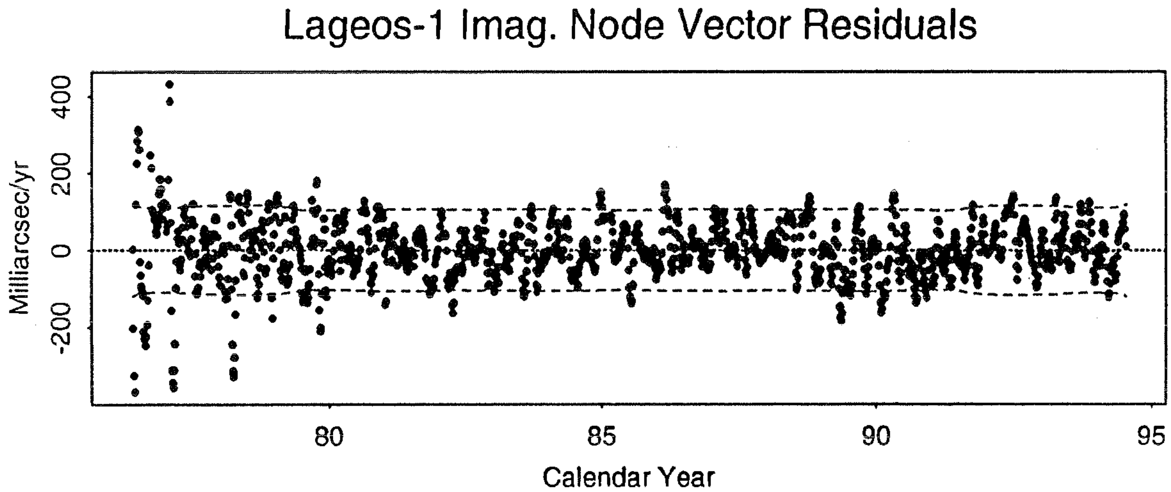
Lageos-1 Real Node Vector Excitation with Fit



Lageos-1 Real Node Vector Residuals




Lageos-1 Imag. Node Vector Excitation with Fit
Milliarcsec/yr
400
200
0
-200
-600
80
85
90
95


Lageos-1 Imag. Node Vector Residuals
Milliarcsec/yr
400
200
0
-200
80
85
90
95
Calendar Year

DUAL SATELLITE ESTIMATES OF LOW DEGREE ZONAL HARMONICS USING THE LAGEOS-1 & LAGEOS-2 COMBINATION

Even Degree Zonals from Node Excitation

$$\delta J_2^D = -0.05844\ \delta\dot{\Omega}_1 - 0.16196\ \delta\dot{\Omega}_2$$

$$\delta J_4^D = +0.80663\ \delta\dot{\Omega}_1 + 0.43714\ \delta\dot{\Omega}_2$$

or

$$\delta J_2^D = +0.06213\ Im(\dot{Q}_1) + 0.20379\ Im(\dot{Q}_2)$$

$$\delta J_4^D = -0.85753\ Im(\dot{Q}_1) - 0.55005\ Im(\dot{Q}_2)$$

Odd Degree Zonals from Real Eccentricity Excitation

$$\delta J_3^D = +1.05077\ Re(\dot{P}_1) - 0.29966\ Re(\dot{P}_2)$$

$$\delta J_5^D = -1.96714\ Re(\dot{P}_1) - 1.12648\ Re(\dot{P}_2)$$

with

δJ_n^D in units of 10^{-11}

$\delta\dot{\Omega}_i$, $\dot{Q}_i$ and $\dot{P}_i$ in mas/yr

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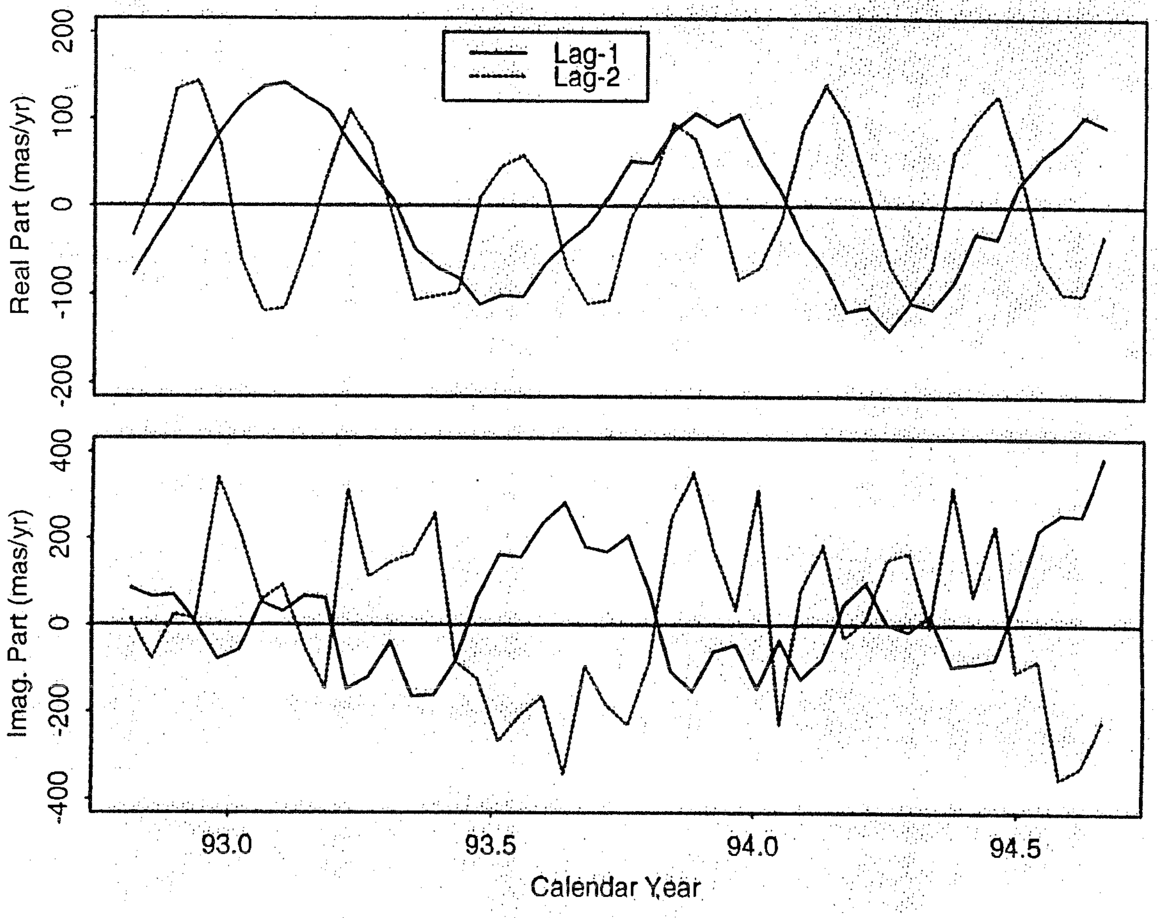
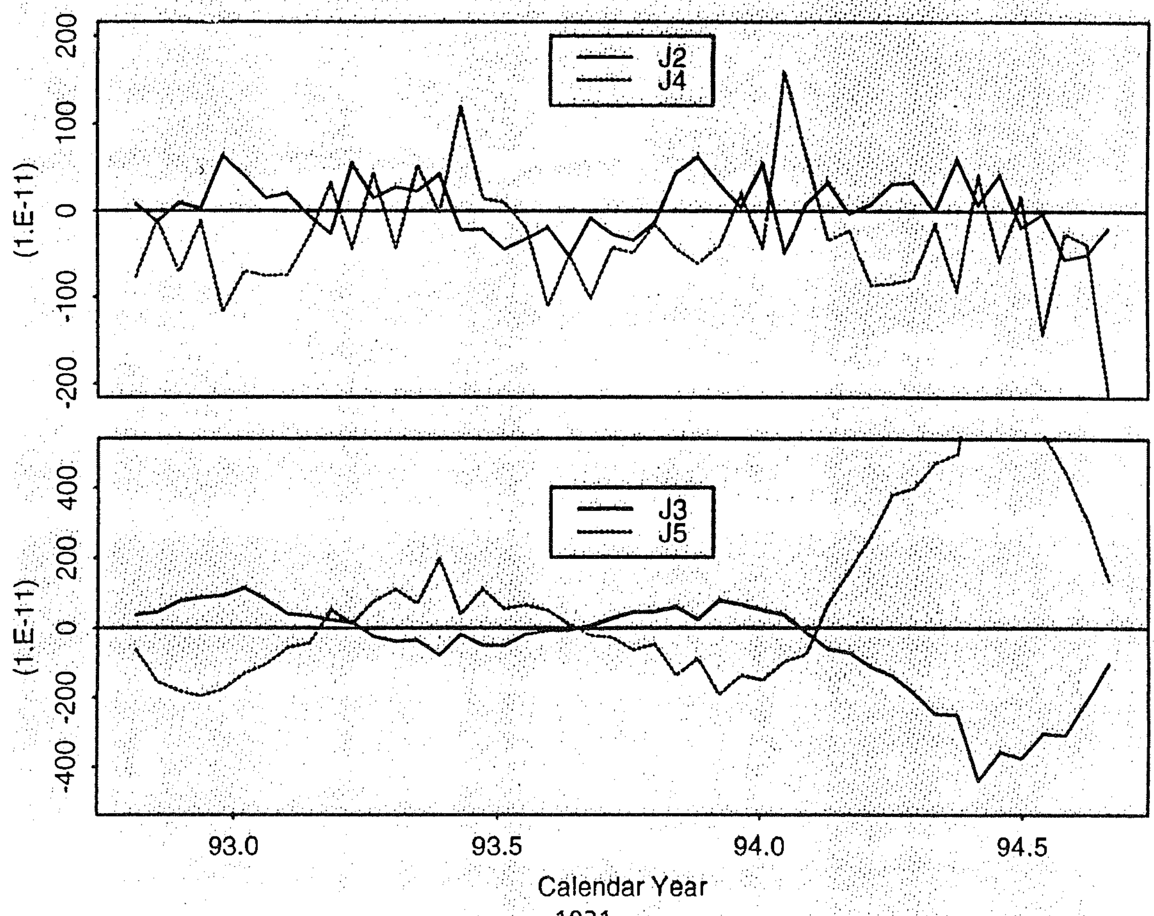
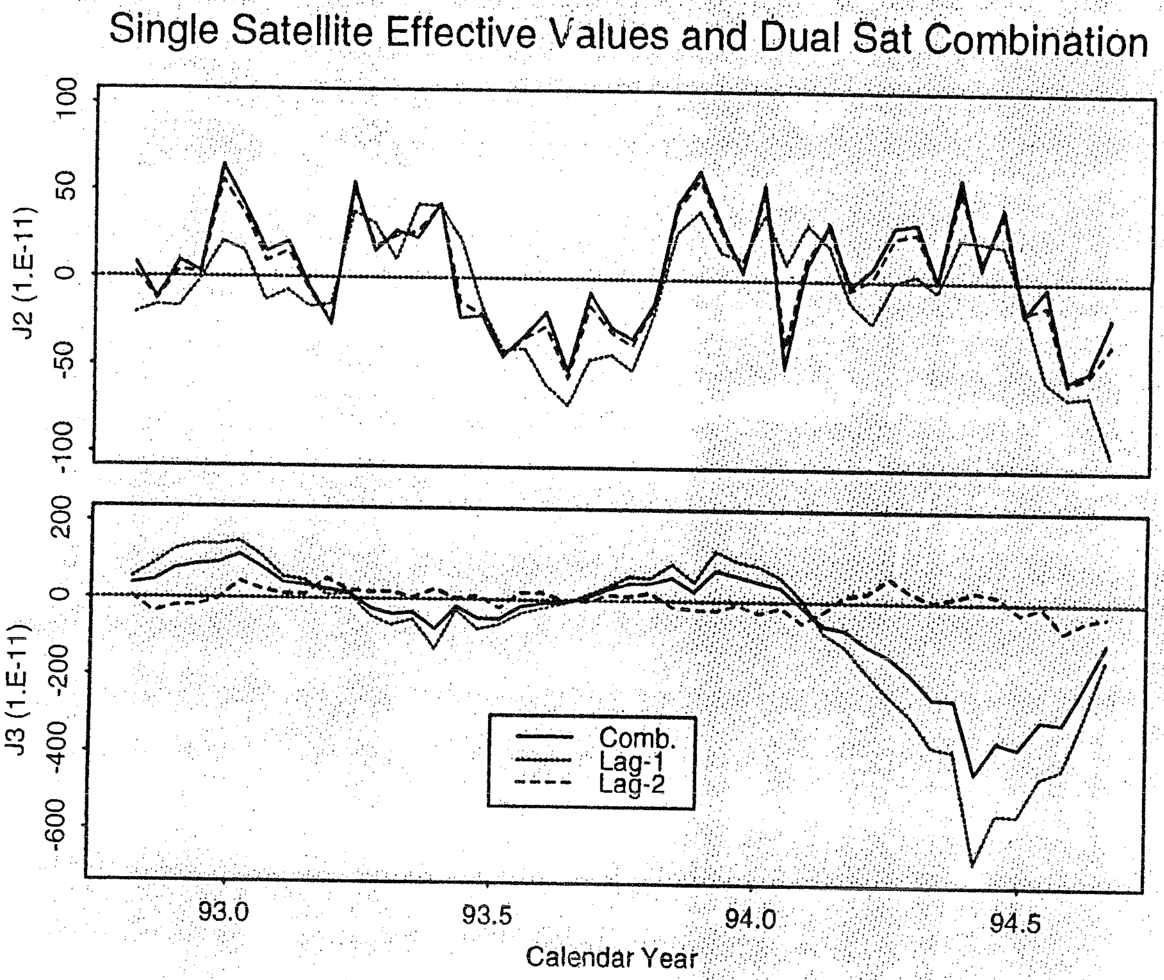
Lageos-1 and Lageos-2 Node Vector Excitations



Zonal Harmonics from Lageos-1 and Lageos-2 Excitations




Single Satellite Effective Values and Dual Sat Combination
100
50
0
-50
-100
J2 (1.E-11)
200
0
-200
-400
-600
J3 (1.E-11)
Comb.
Lag-1
Lag-2
93.0
93.5
94.0
94.5
Calendar Year

PARAMETRIC ANALYSIS OF NASA PORTABLE STANDARD DATA

THOMAS VARGHESE, CHRISTOPHER CLARKE
AlliedSignal

Presented at the 9th International Workshop on Laser Ranging Instrumentation
Canberra, Australia, November, 1994

Portable Standard : Objectives

- Collection of standards
- Reconfigurable System
- Test Bed for New receiver Electronics Technology/Approaches; [recently, we have used in connection with the time transfer experiment on Meteosat]
- Generate High Precision/Accuracy Laser Data to Examine Improved Data Analysis Techniques; [Artificially introduce systematics during a pass or for the whole pass, and examine how well the data analysis/orbit fitting techniques distinguish or absorb the errors]
- Intercomparison with Other Systems to Baseline HW/SW Performance; [Collocation with M7 showed in 1992, -3 mm ± 0.5 mm RMS]
- Laboratory Measurement Tool for Satellite CM Determination; [We have successfully used in the Lageos-2 and Topex Laboratory measurements]
- SLR2000 Electronics Test Bed with a Piggy Backed Telescope to MOBLAS-7 Telescope; [Simultaneous test data, and intercompare].

Portable Standard : Data Analysis

- Examine Dependence on:
  - Signal Amplitudes
  - Elevation
  - Epoch Time Accuracy
  - Data Filtering Techniques
  - Satellite induced Effects - pulse spreading and increased dispersion of the data
- We have begun to examine high precision/accuracy data for systematics
- Data analysis is very preliminary at this time.

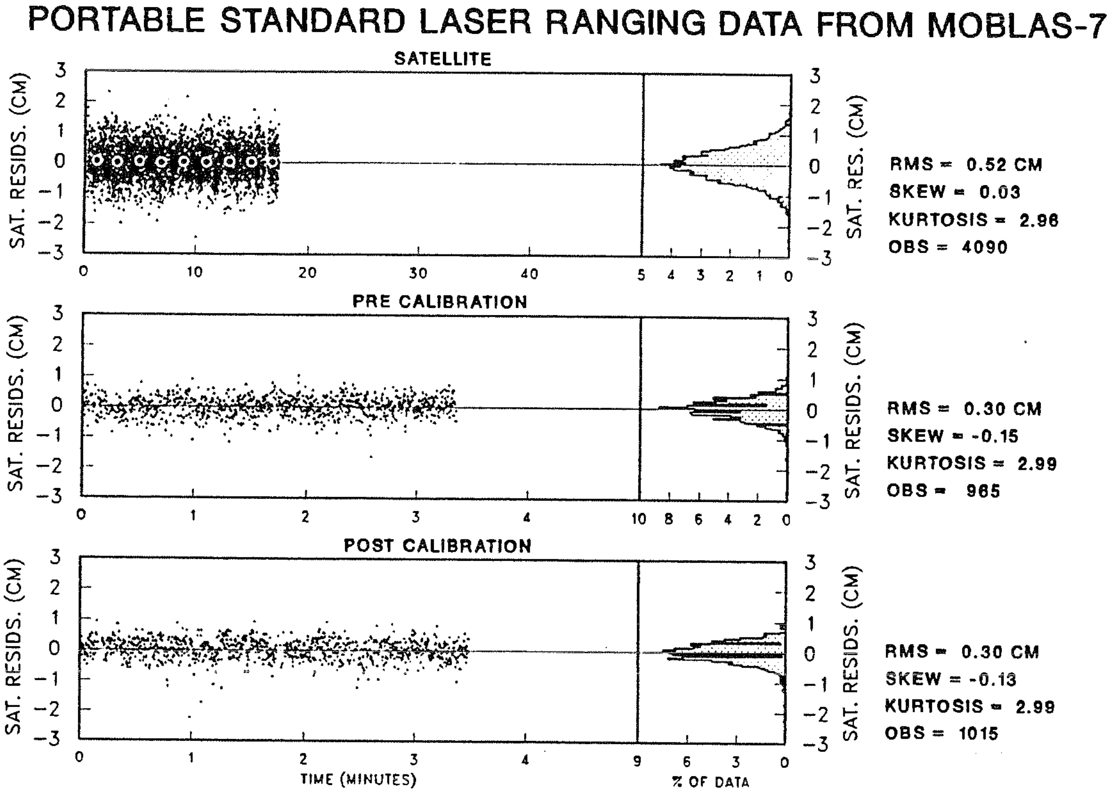


Fig. 2. LAGEOS-2 14Sep93 03:34 GMT

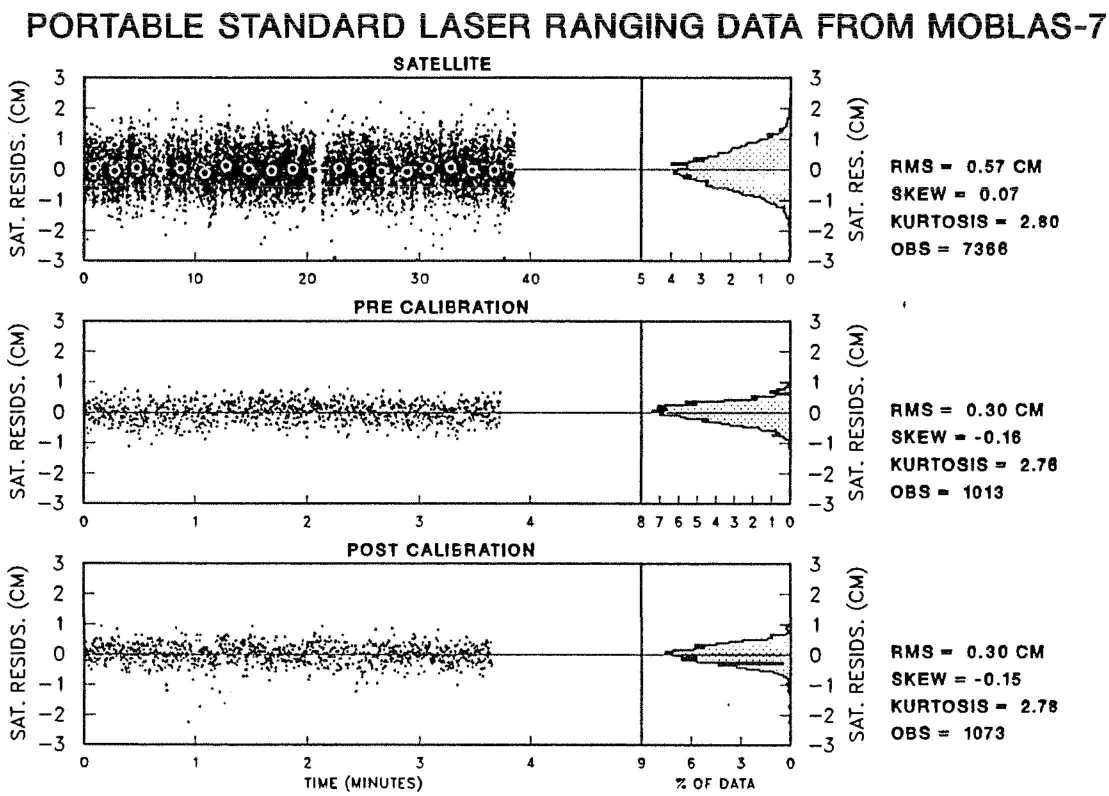


Fig. 3(a). LAGEOS-1 14Sep93 04:52 GMT

ENERGY DEPENDENT ANALYSIS OF PORTABLE STANDARD DATA

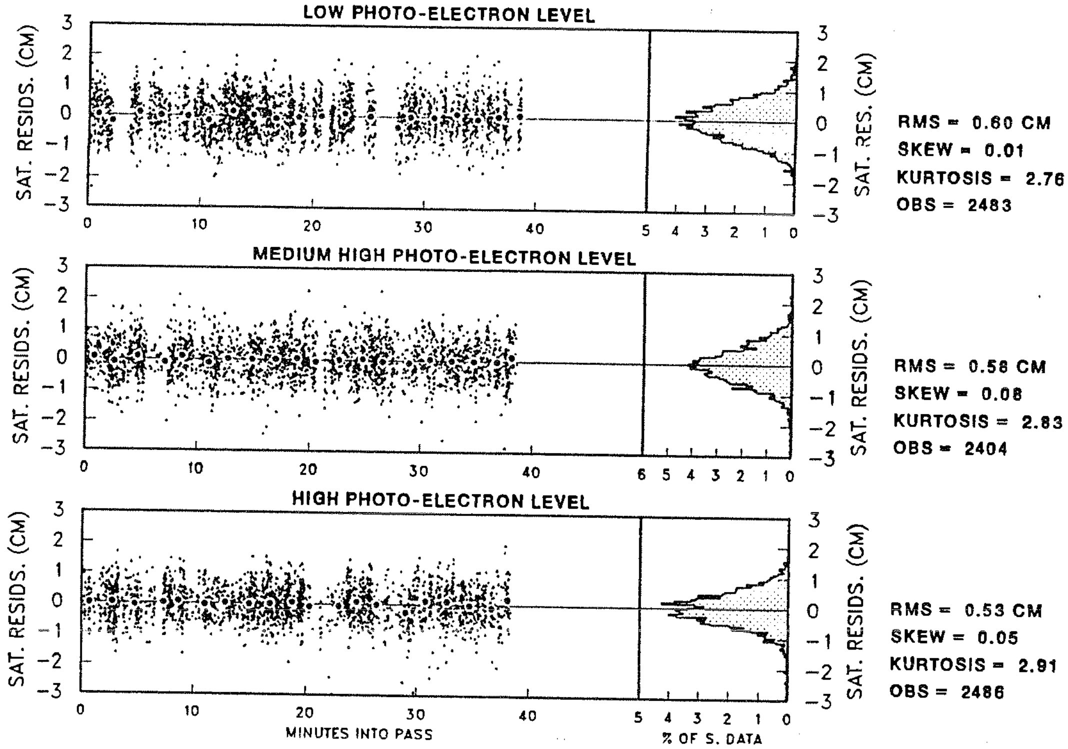


Fig. 3(b). LAGEOS-1 14Sep93 04:52 GMT

ELEVATION DEPENDENT ANALYSIS OF PORTABLE STANDARD DATA

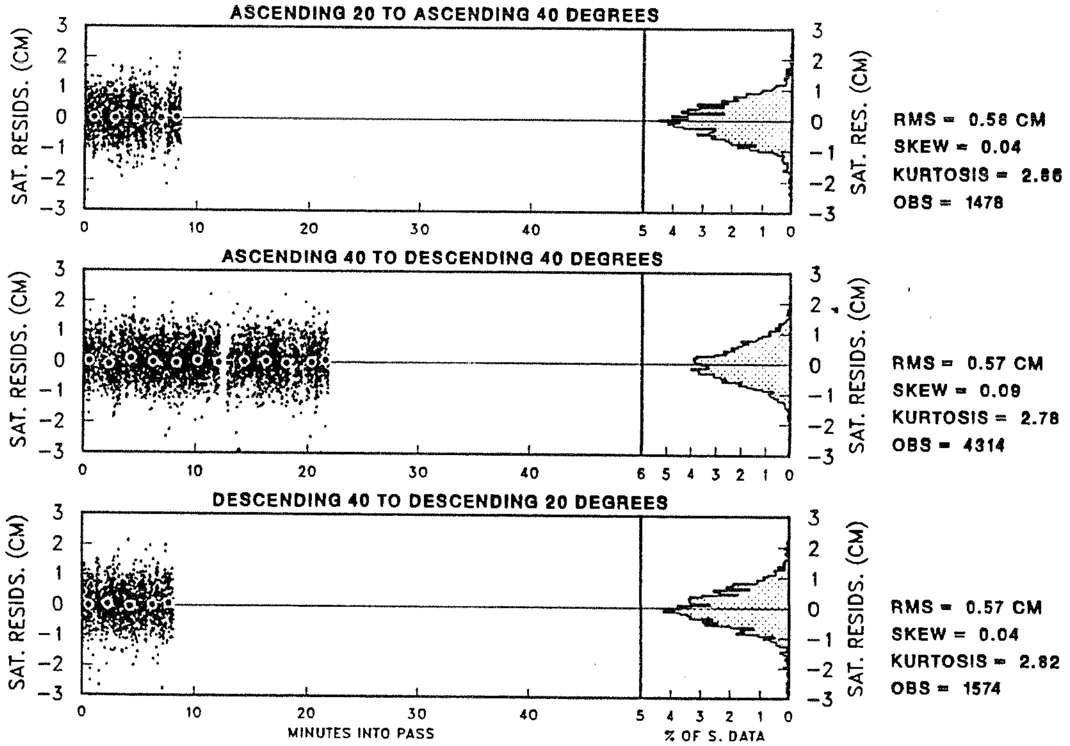


Fig. 3(c). LAGEOS-1 14Sep93 04:52 GMT

PORTABLE STANDARD LASER RANGING DATA FROM MOBLAS-7

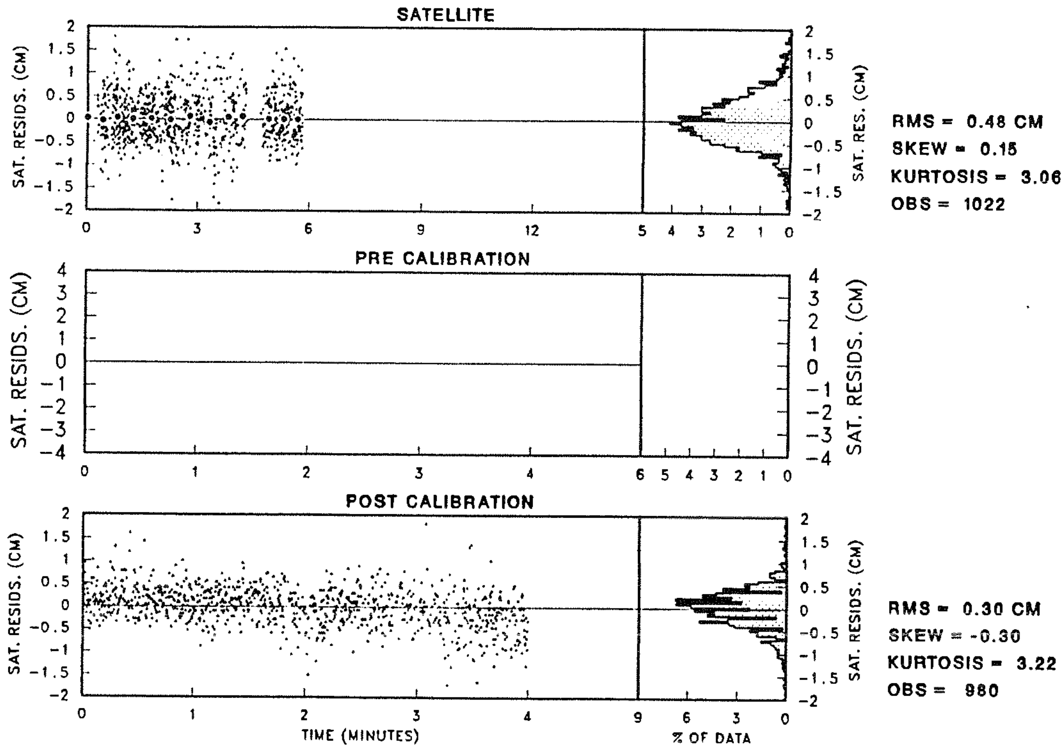


Fig. 4. STARLETTE 14Sep93 18:20 GMT

PORTABLE STANDARD LASER RANGING DATA FROM MOBLAS-7

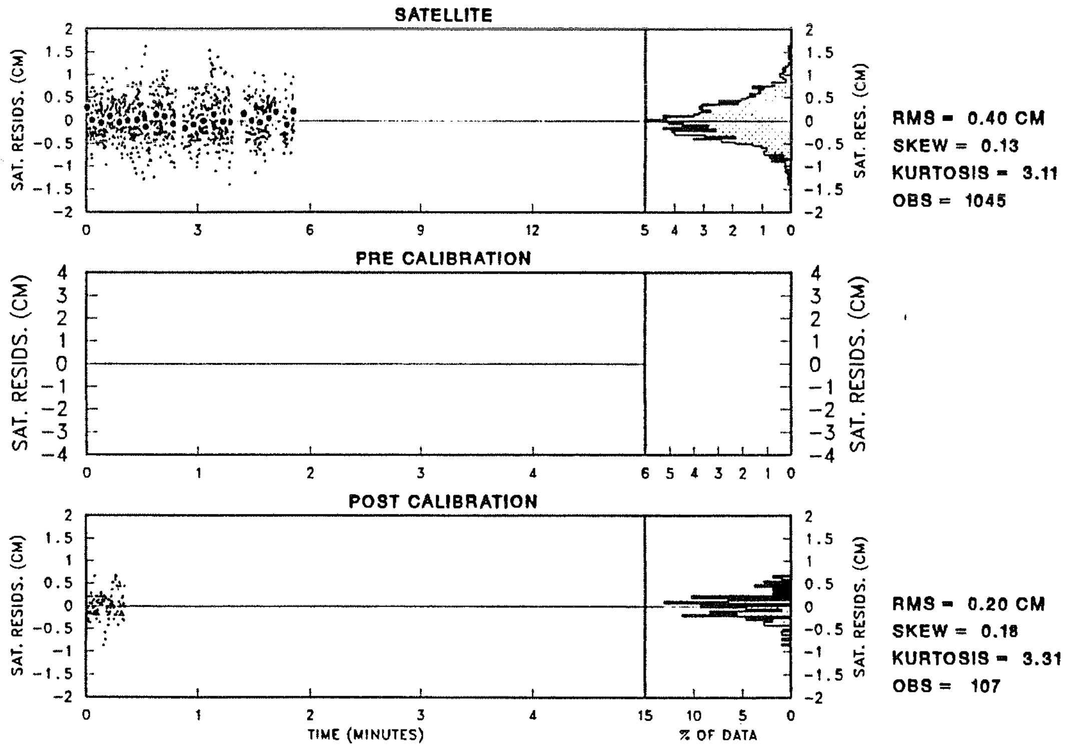


Fig. 5(a). ERS-1 31Aug93 02:25 GMT

ENERGY DEPENDENT ANALYSIS OF PORTABLE STANDARD DATA

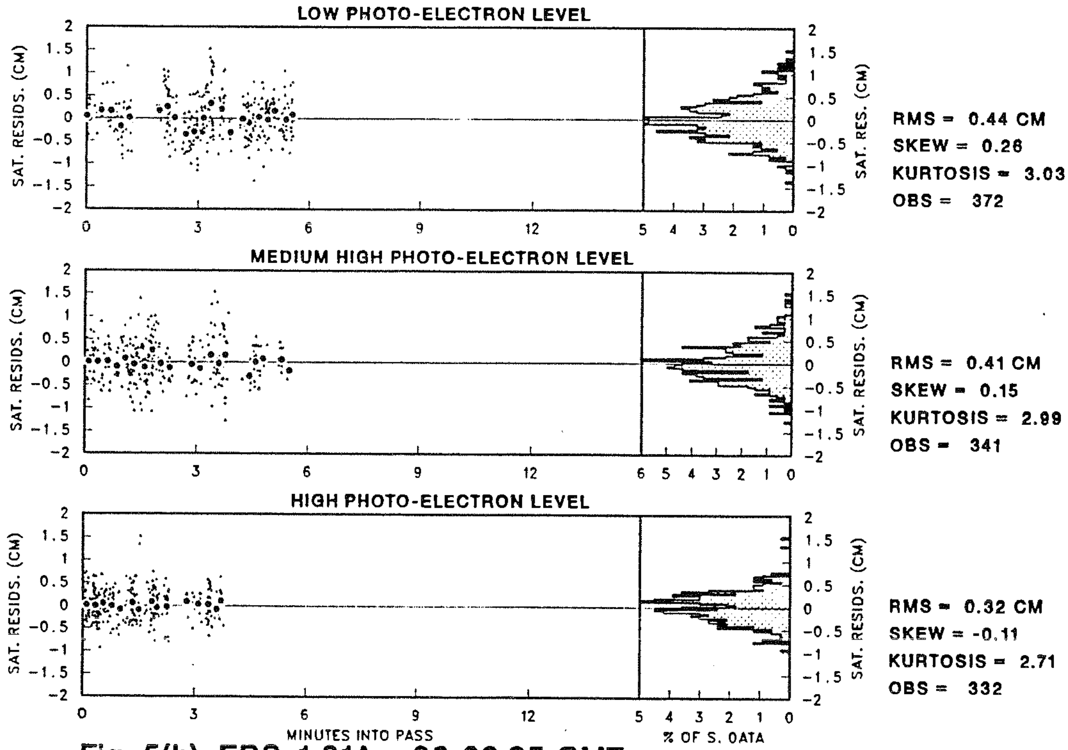


Fig. 5(b). ERS-1 31Aug93 02:25 GMT

PORTABLE STANDARD LASER RANGING DATA FROM MOBLAS-7

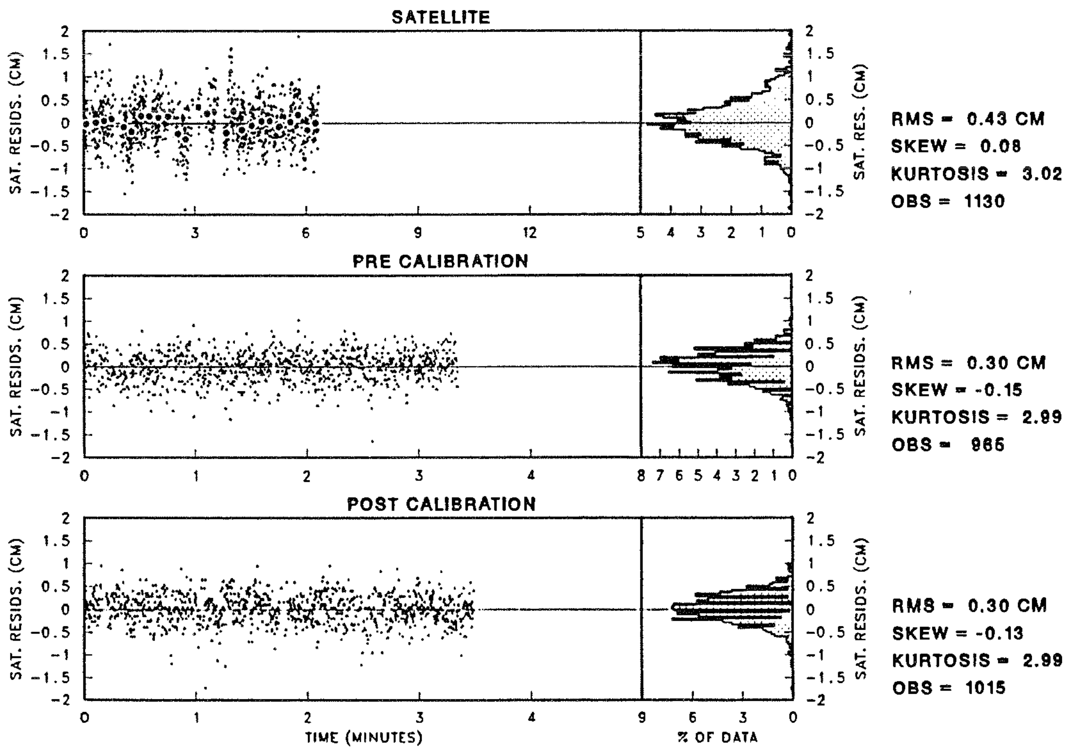


Fig. 6(a). ERS-1 14Sep93 03:25 GMT

ELEVATION DEPENDENT ANALYSIS OF PORTABLE STANDARD DATA

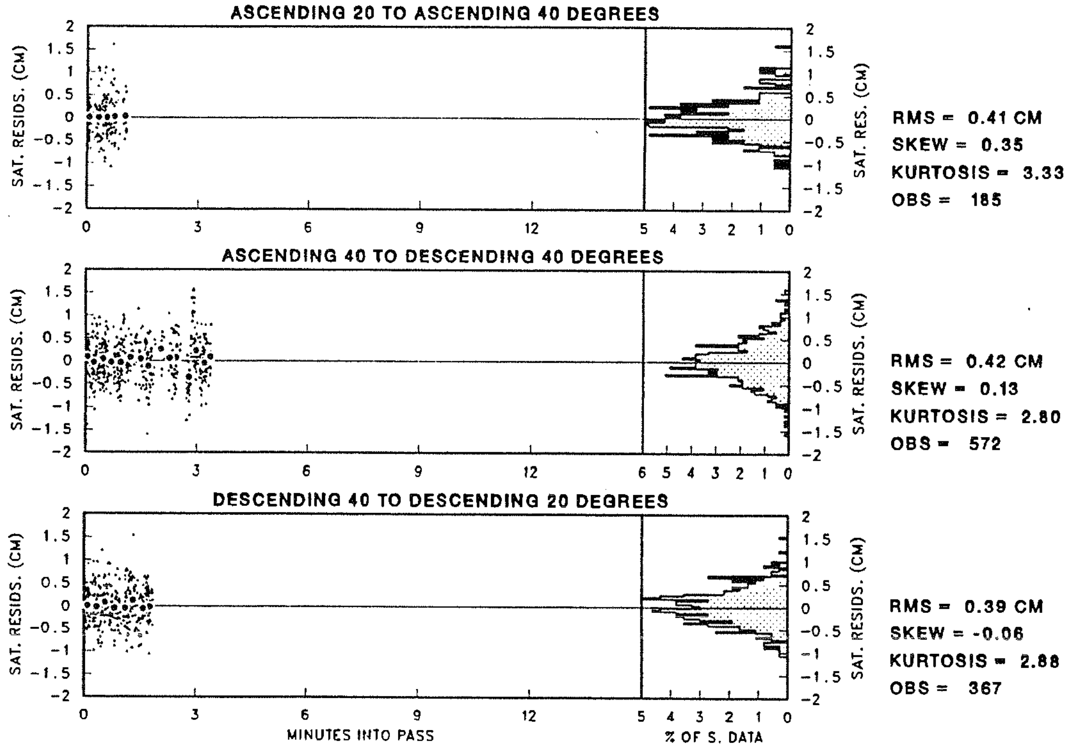


Fig. 6(b). ERS-1 14Sep93 03:25 GMT

PORTABLE STANDARD LASER RANGING DATA FROM MOBLAS-7

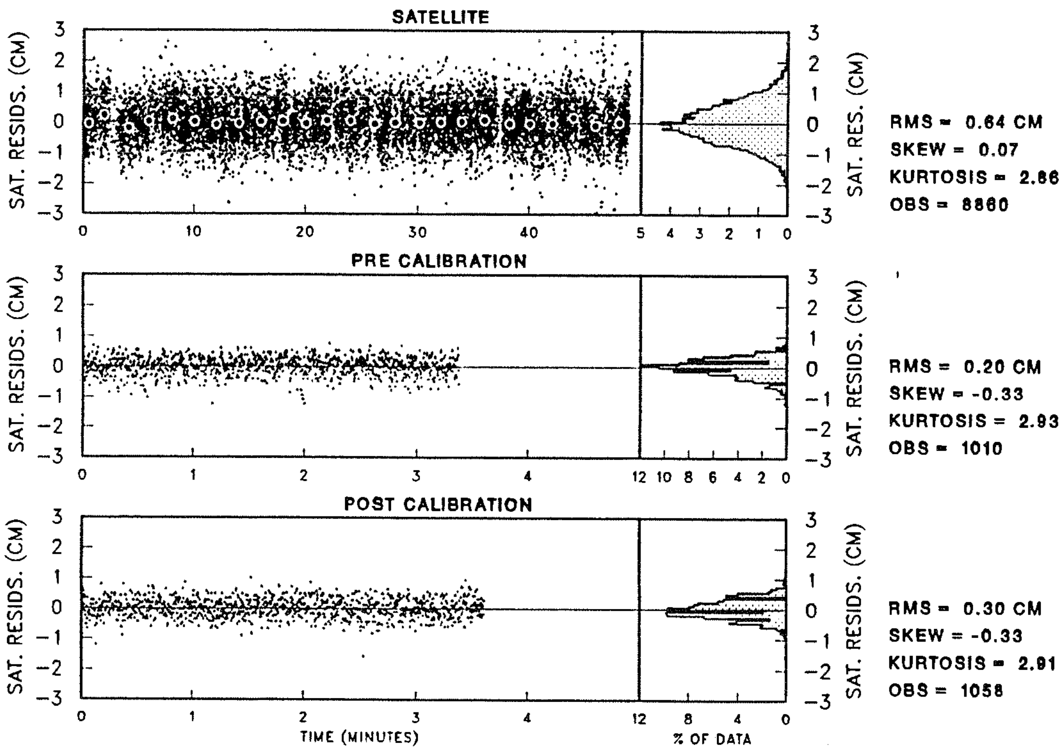


Fig. 1. LAGEOS-1 13Sep93 05:00 GMT

ENERGY DEPENDENT ANALYSIS OF PORTABLE STANDARD DATA

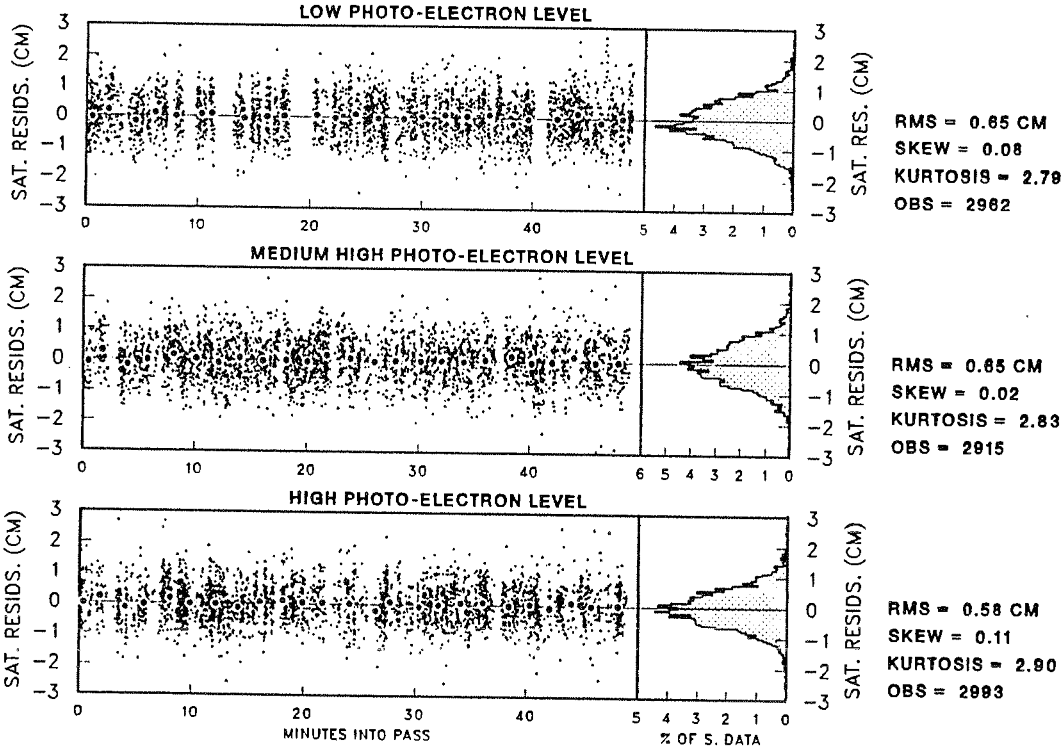


Fig. 1(b). LAGEOS-2 13Sep93 05:00 GMT

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Conclusion

- Satellite Data Residual RMS of 3-5 mm Demonstrated With a Calibration RMS of 2-3 mm.
- Variation of Data Precision on Signal Amplitude Indicates Dependence on Photoelectron Statistics.
- Elevation Dependent Systematic Effects Are Not Seen With the Current Data.
- Significantly Larger RMS Value on Satellite Data Than the Instrument Precision.
  - Epoch Timing
  - Satellite
  - Model
  - Data Fitting
- SLR 2000 Test Bed With a Piggy Backed Telescope to MOBLAS-7.

11/1/94 7:47 PM

SALRO/MOBLAS 7 COLLOCATION RESULTS

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Presented to the 9th International Workshop on Laser Ranging Instrumentation
November 7, 1994

AGENDA

Introduction
SALRO Normal Point Analysis
Collocation Data Set Summary
Data Editing Investigation
Summary

Introduction

Pre-Collocation Period begins on June 28, 1994

* Configurations of MOBLAS-7 and SALRO are frozen
* 24 simultaneous passes are processed and analyzed

Collocation Readiness Review held on August 15, 1994

* Formal Collocation period to start on August 18, 1994
* Updates held bi-weekly
* 60 total simultaneous passes are processed and analyzed
* 25 total LAGEOS type simultaneous passes analyzed

SALRO changes configuration to MCP from SPAD during week of September 12th

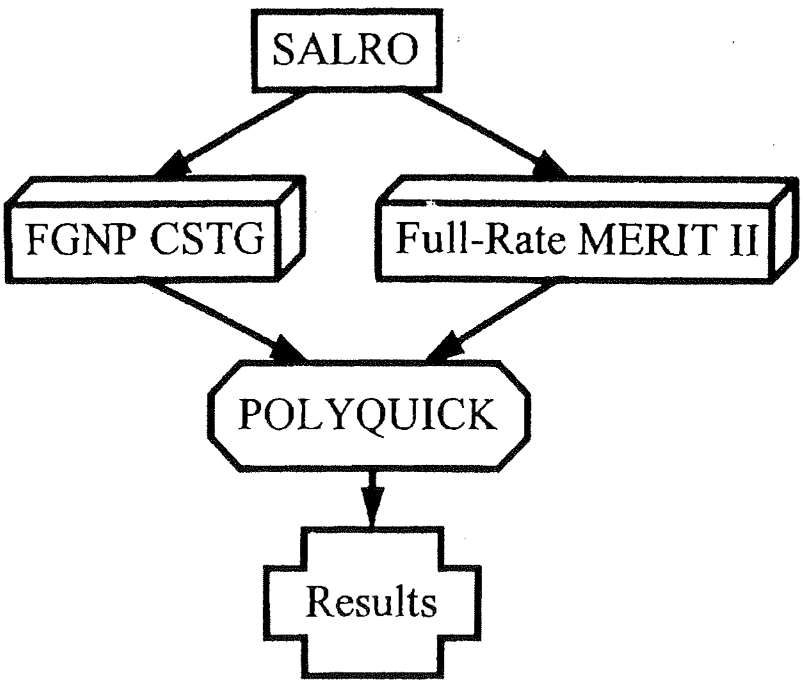
* 2 Ajisai and 2 Starlette passes tracked with MCP

SALRO FIELD GENERATED NORMAL POINT (FGNP) ANALYSIS

ATSC/NASA SLR/SALRO Collocation

November 8, 1994

SALRO FGNP ANALYSIS PROCESS MAP



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SALRO FGNP ANALYSIS SUMMARY

Date	Time	Satellite	Obs	RMS (mm)	NP Mean (mm)	NP RMS (mm)
Aug 30, 94	12:19	LAGEOS-1	1307	13.6	0.0	1.1
Aug 30, 94	14:32	LAGEOS-2	2342	10.5	0.0	1.7
Aug 30, 94	18:46	LAGEOS-2	1846	14.9	0.0	1.7

SALRO FGNP are bias free relative to SALRO FR
SALRO FGNP have RMS's of 1-2mm

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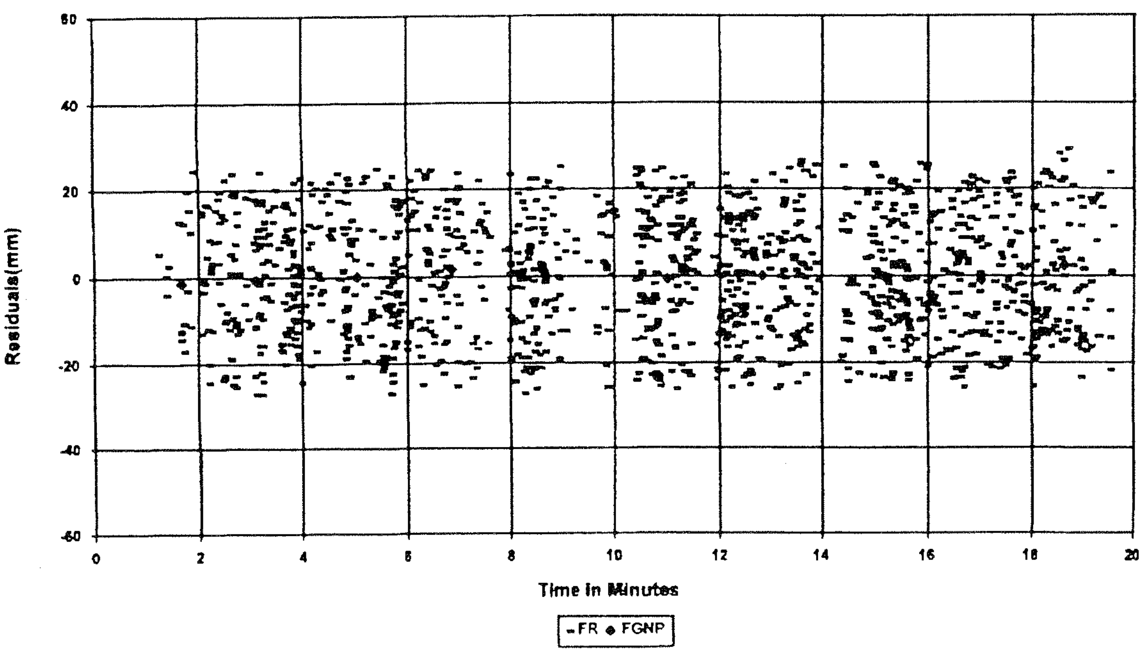
SALRO FGNP vs. SALRO Full-Rate(FR) LAGEOS-1 on Aug 30, 1994 at 12:19



NASA

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Collocation Data Set Summary

NASA

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COLLOCATION DATA ANALYSIS SUMMARY(1)

SALRO Data Results for 2.5 Sigma Processing Only(2)

Satellite	Passes Tracked	Total Good Passes(3)	MOB-7 Mean RMS (mm)	SALRO Mean RMS (mm)	Mean of Biases (mm)	Peak-to-Peak of Biases (mm)
LAGEOS-1	9	9	9.8	15.0	1.2	26.5
LAGEOS-2	16	16	9.6	12.6	-4.3	21.9
STARLETTE	9	7	8.1	16.7	-4.3	19.3
ERS-1	4	4	7.3	13.9	-5.7	19.1
METEOR-3	4	4	7.7	13.1	3.7	25.5
STELLA	1	1	6.8	14.4	-23.0	N/A
TOPEX	4	4	9.6	22.7	-12.0	22.6
AJISAI	13	12	16.1	23.8	-16.5	64.2

(1) Data results only for SPAD

(2) LAGEOS pass tracked on 9/8/94 was processed with POLYQUICK 3.0 Sigma edit from unedited SALRO pass

(3) A good pass is one that contains at least 35% of the total possible overlapping bins for the pass

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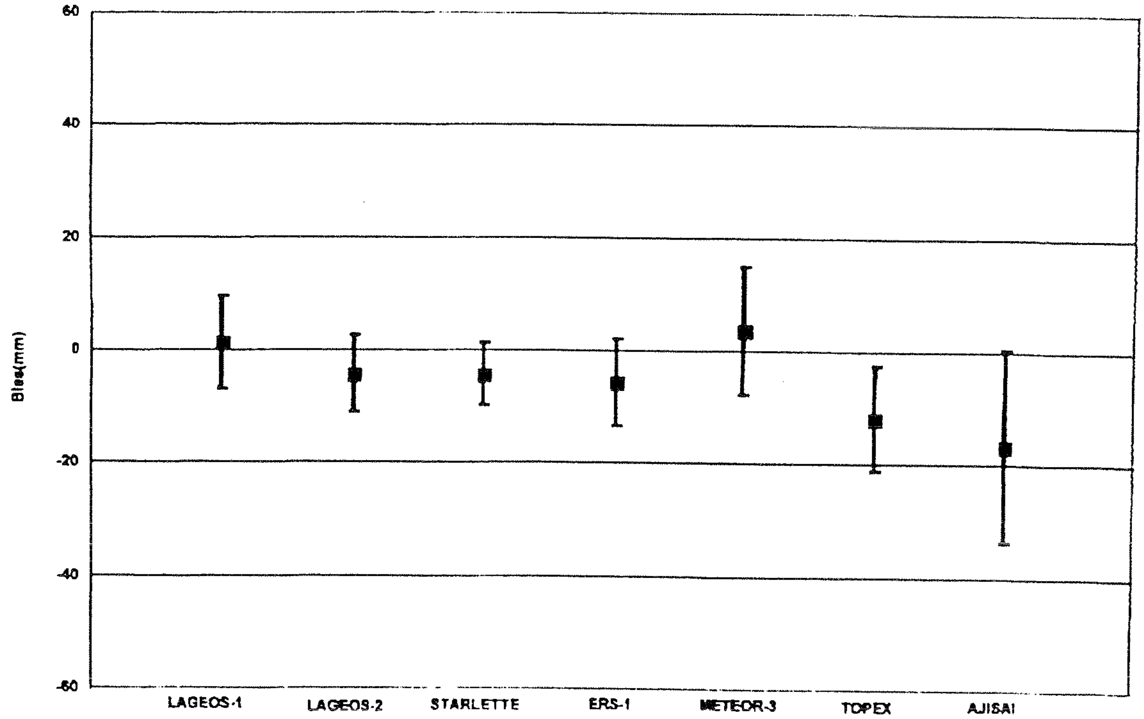
SALRO/MOBLAS-7 BIAS VS. SATELLITE



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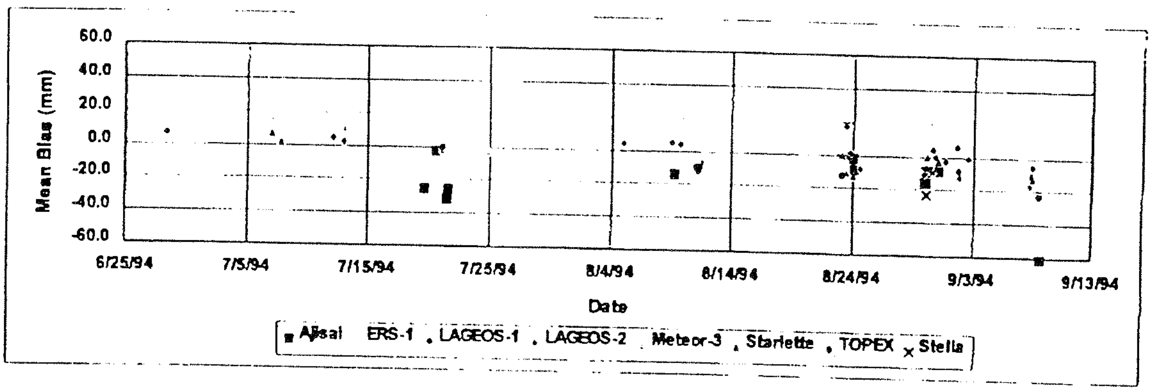
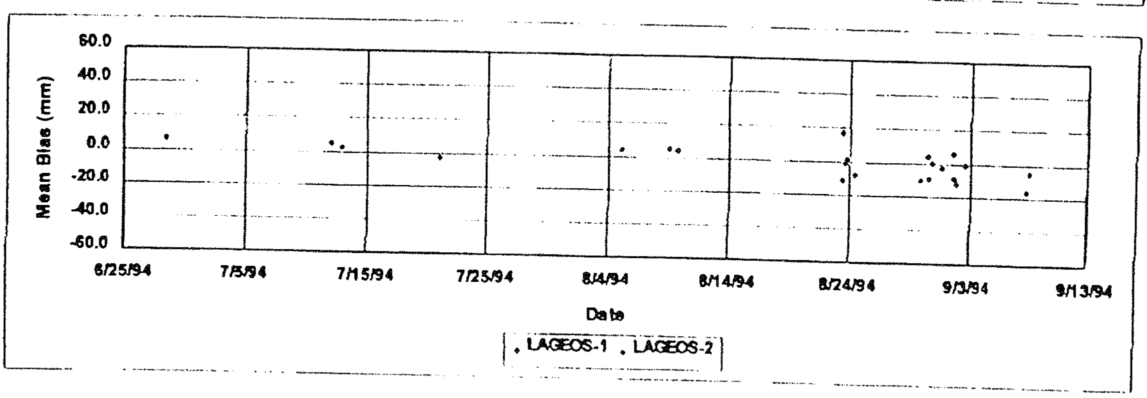
POLYQUICK Mean Bias Results vs. Date





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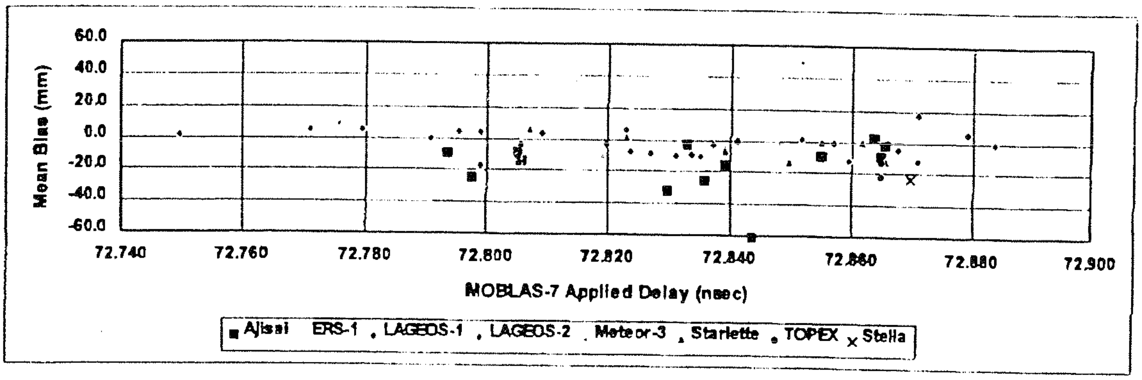
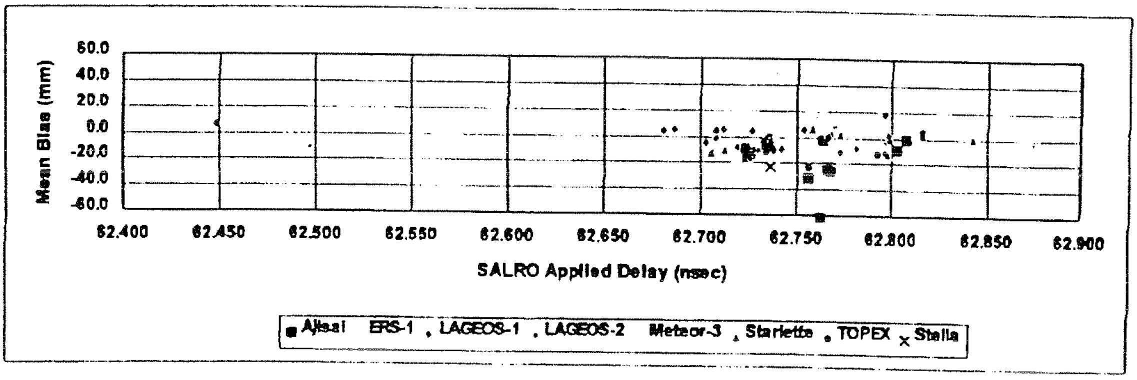
POLYQUICK Mean Bias Results vs. Applied Delay





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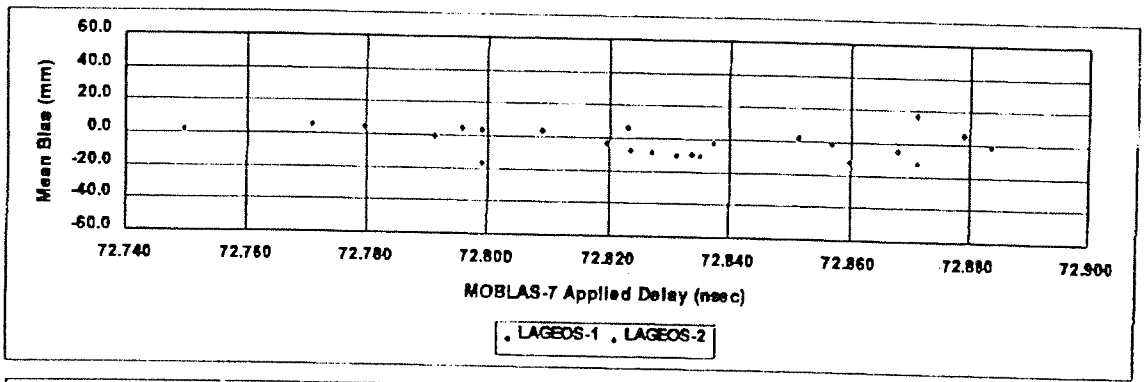
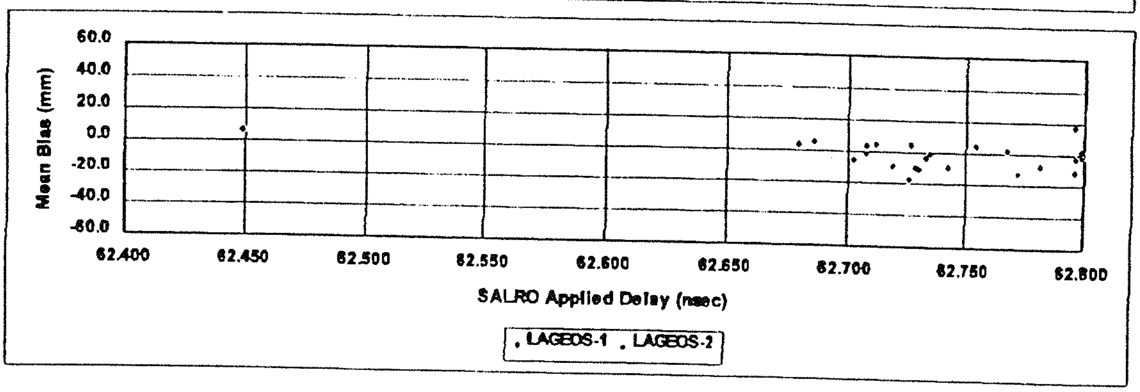
POLYQUICK Mean Bias Results vs. Applied Delay





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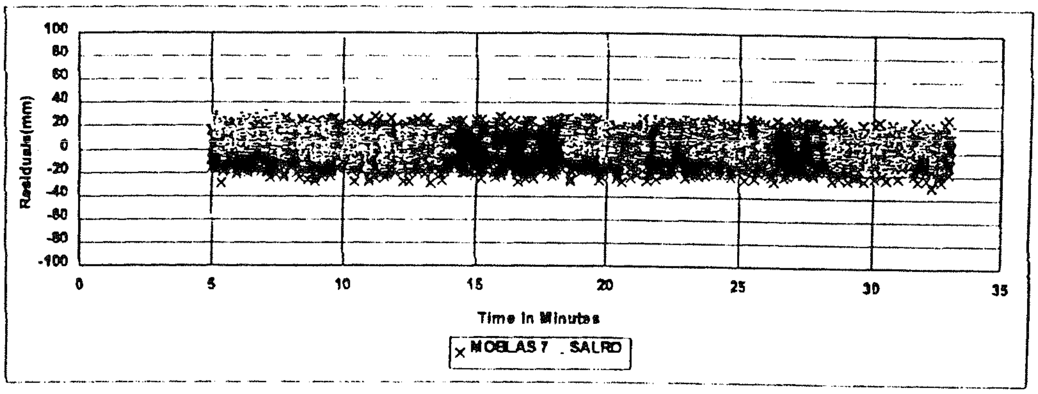
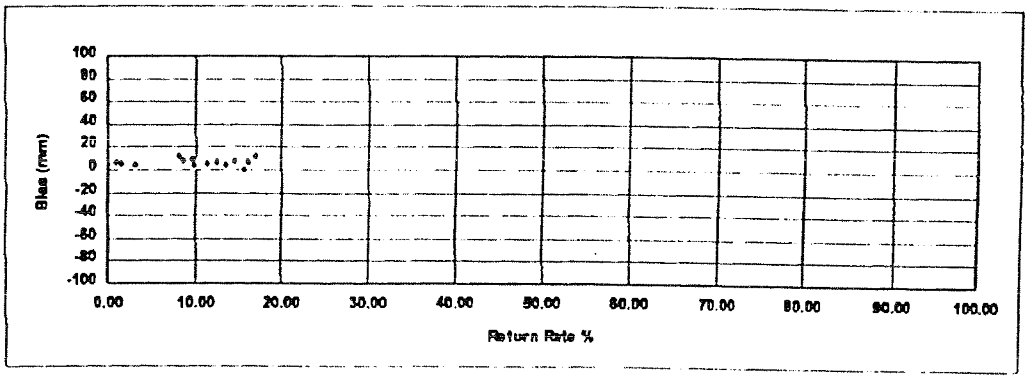
LAGEOS-1 (JUN 28, 1994 at 10:16z)





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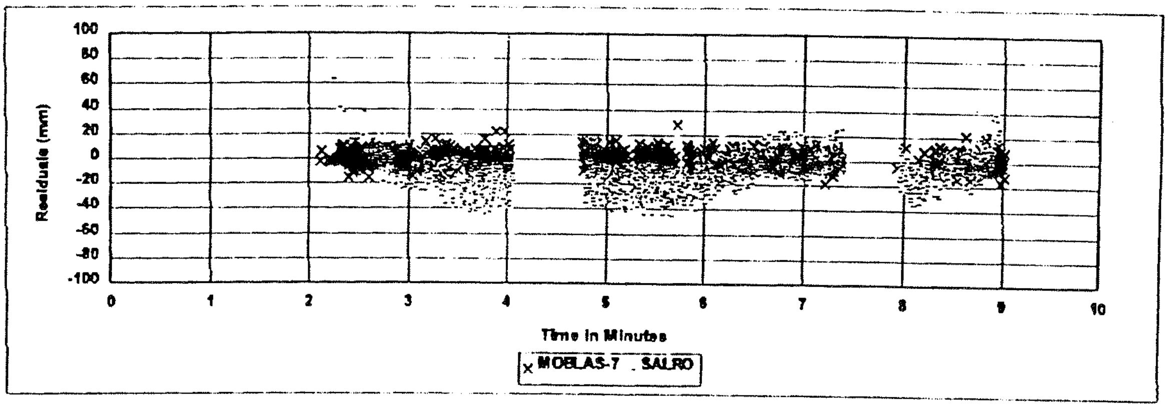
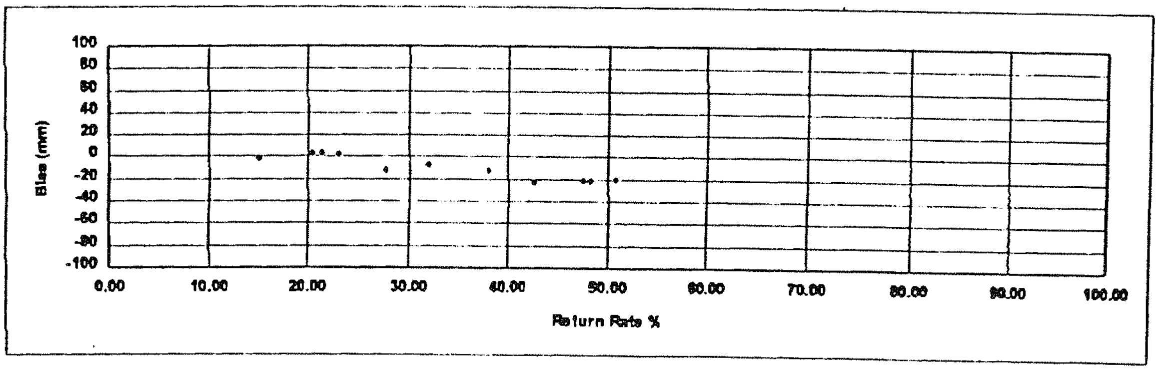
STARLETTE (Aug 24, 1994 at 1:12z)





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Data Editing Investigation

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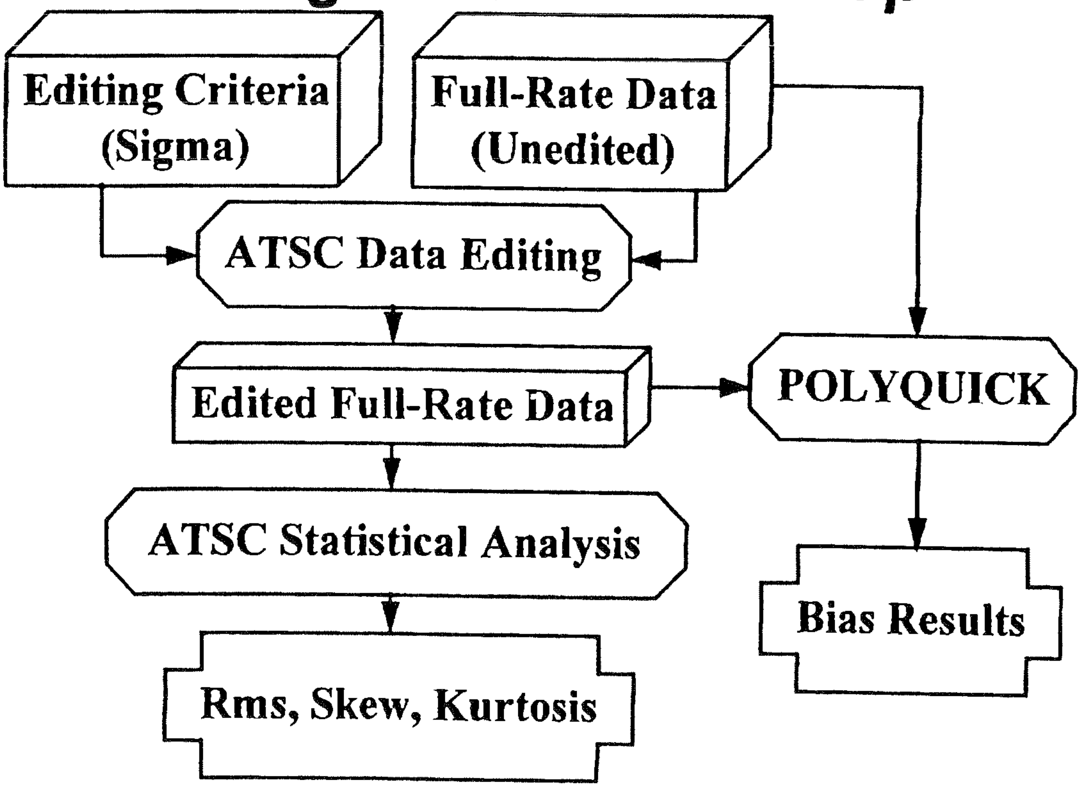
Data Editing InvestigationProcess Map



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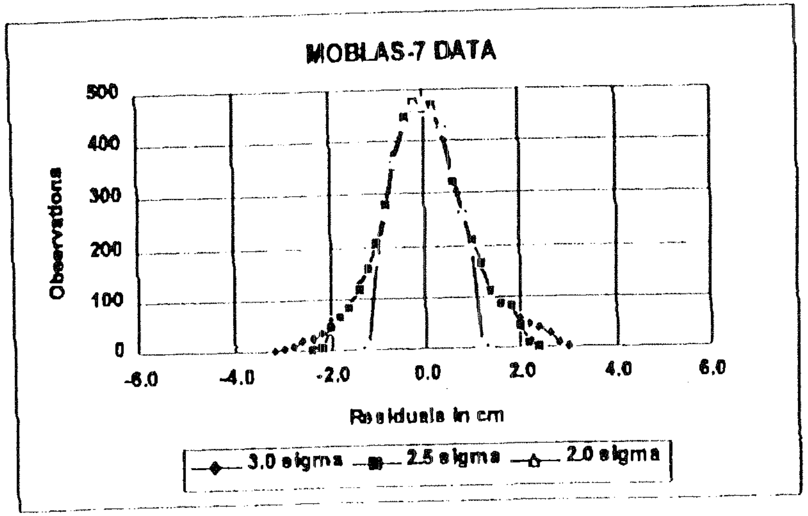
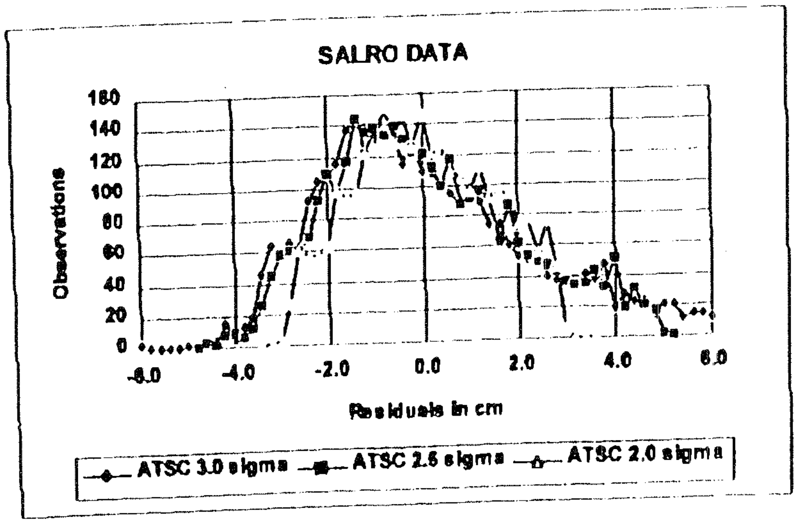
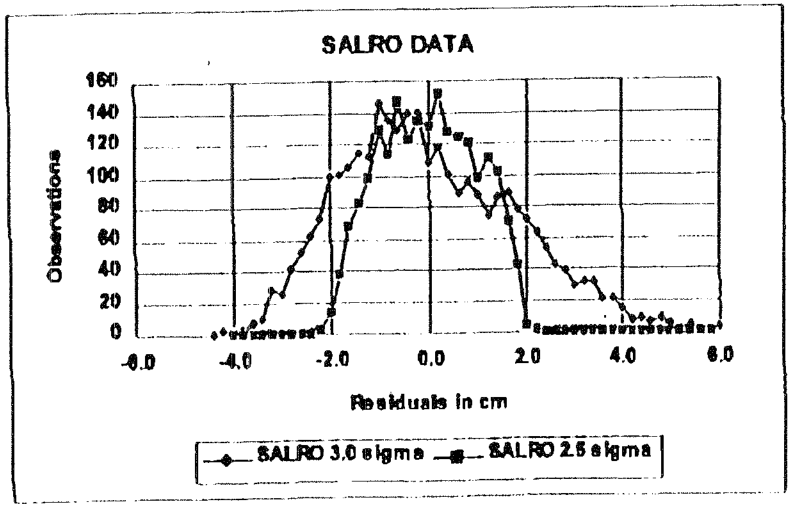
November 8, 1994

LAGEOS-1 Jun 28, 1994 at 10:12z Editing







November 8, 1994

ATSC/NASA SLR/SALRO Collocation

MOBLAS 7 Editing Results

MOBLAS 7 Editing Analysis Summary

LAGEOS-1 on June 28, 94 at 10:12z

Sigma	Obs.	RMS(mm)	Skew	Kurtosis
ATSC 3.0	5059	9.4	0.1	3.2
ATSC 2.5	4849	8.3	0.0	2.8
ATSC 2.0	3860	5.4	0.0	2.1

SALRO Editing Results

SALRO Editing Analysis

LAGEOS-1 on June 28, 94 at 10:12z

Standard Processing Results					*Self Intercomparison (SALRO vs SALRO)*			*MOBLAS-7 Intercomparison (SALRO vs MOB-7)*		
Sigma	Obs.	RMS (mm)	Skew	Kurtosis	Bins	Bias (mm)	Peak-to-Peak (mm)	Bins	Bias (mm)	Peak-to-Peak (mm)
SALRO 3.0	2915	17.4	0.4	2.6	15	-3.1	14.8	15	12.1	13.9
SALRO 2.5	2026	9.6	0.0	2.0	15	-9.4	8.2	15	6.3	10.9
ATSC 3.0	3377	22.0	0.6	2.9	15	0.0	0.0	15	15.5	11.5
ATSC 2.5	3246	19.5	0.4	2.5	15	-2.0	2.9	15	13.5	13.1
ATSC 2.0	2763	14.2	0.1	2.1	15	-6.5	4.1	15	9.1	12.0

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Summary

* FGNP agree to Full-rate
* 60 simultaneous passes tracked and analyzed
* Good bias results on LAGEOS satellites
* SALRO data processed with 2.5 Sigma edit
* Bias depends on SALRO editing level, the tighter the editing, the more negative the SALRO range becomes
* Processing standards need to be set for global data processing

LASER TECHNOLOGY DEVELOPMENT

Chairperson : Karel Hamal

THE Q-SWITCHED MICROLASER: A SIMPLE AND RELIABLE ALTERNATIVE TO MODELOCKING

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Joseph L. Dallas
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Greenbelt, MD 20771 USA

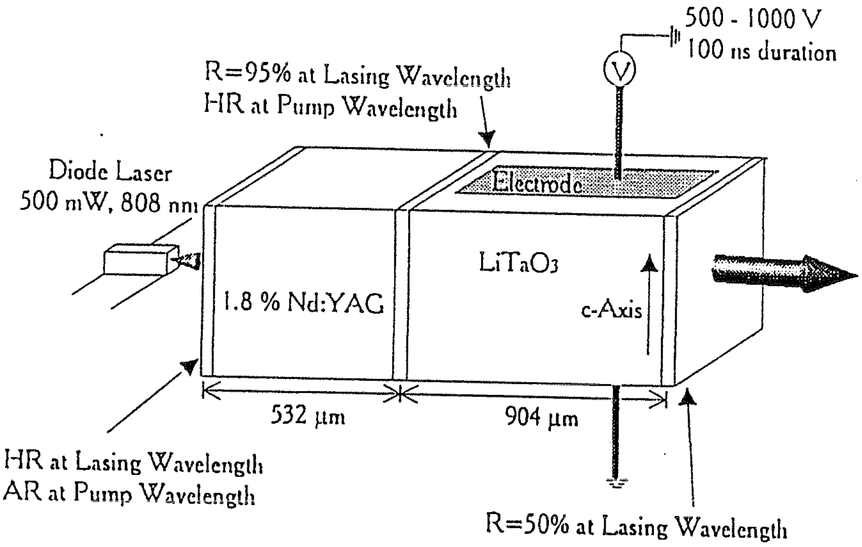
Disadvantages of modelocking

- Long resonators required for switching
- Resonator length must be locked to RF drive frequency for active systems
- Passive systems use carcinogenic dyes which require routine replacement
- Requires single pulse selection via electro-optic switch

Advantages of the Microlaser

- Compact and efficient
- Stable alignment (can be monolithic)
- Can be pumped by a single diode laser
- No pulse selection electronics required
- No high voltages or carcinogenic dyes
- Low energy and multikilohertz repetition rates are ideal for eyesafe systems

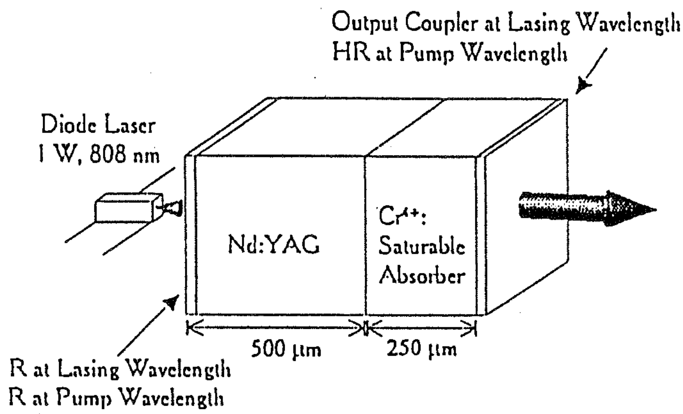
Actively Q-switched Microlaser



- Etalon formed by LiTaO3 acts as variable-reflectivity output coupler.
- Optical length of etalon must be intergral multiple of gain cavity length.

- Shortest pulsewidth: 270 ps, at 5 KHz rep. rate, with 6.8 µJ per pulse.

Passively Q-switched Microlaser

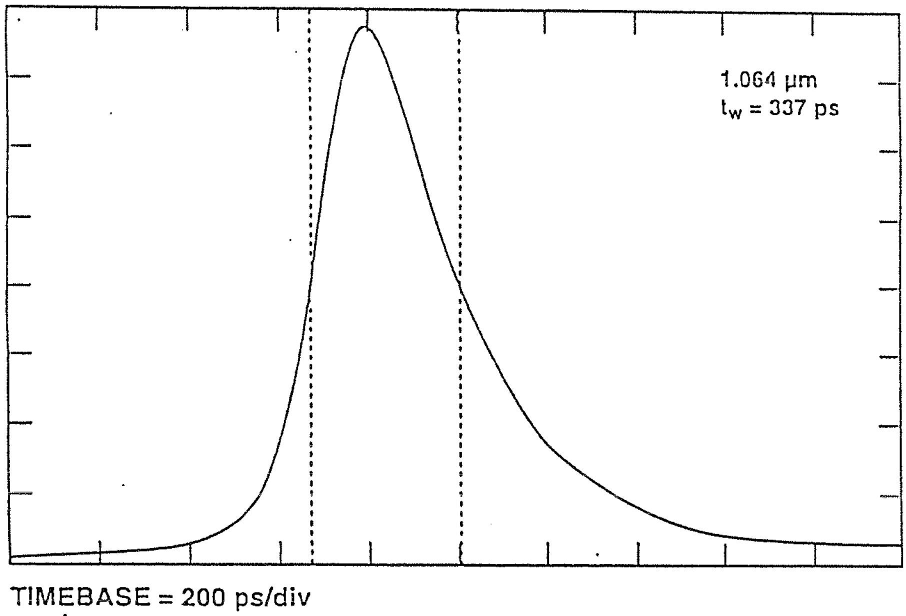


- Repetition rate is dependent upon pump power.

- Shortest pulsewidth: 337 ps, at 12 KHz rep. rate, with 11 µJ per pulse.

Ref: Zayhowski & Dill. Opt. Let. , 1994

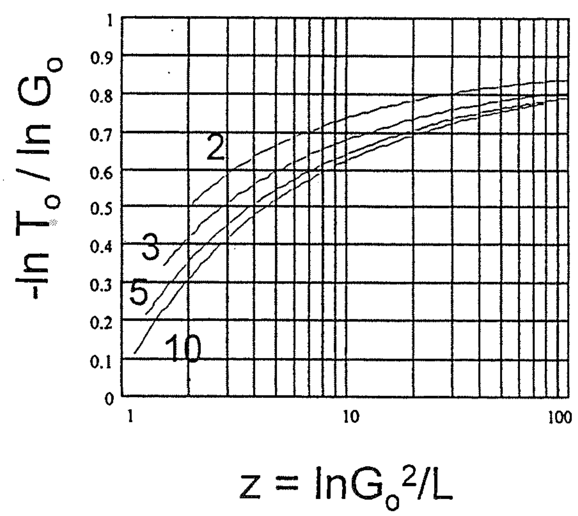
PASSIVELY Q-SWITCHED MICROLASER PULSE



Ref: Zayhowski & Dill. Opt. Let. , 1994

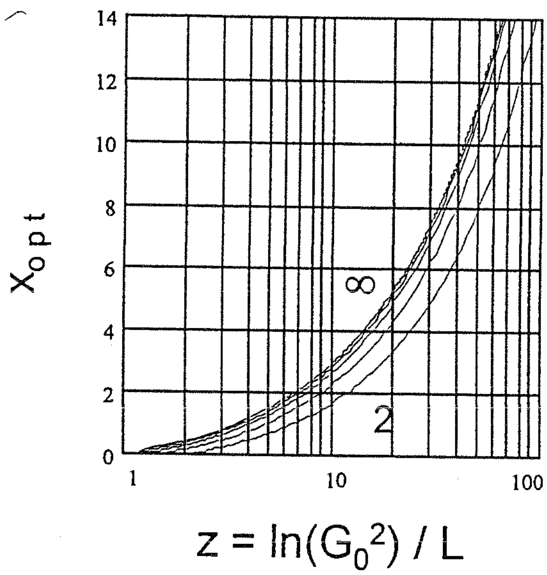
OPTIMUM ABSORPTION VS LASER GAIN

- **Definitions:**
  - To is the unsaturated single pass absorption
  - Go is the unsaturated single pass gain
  - L is the two way dissipative optical loss .
- **Conclusion:**
  - As the gain increases, the unsaturated absorber transmission represents a greater fraction of the initial optical loss, e.g. 30% for z =2 versus 80% for z = 100



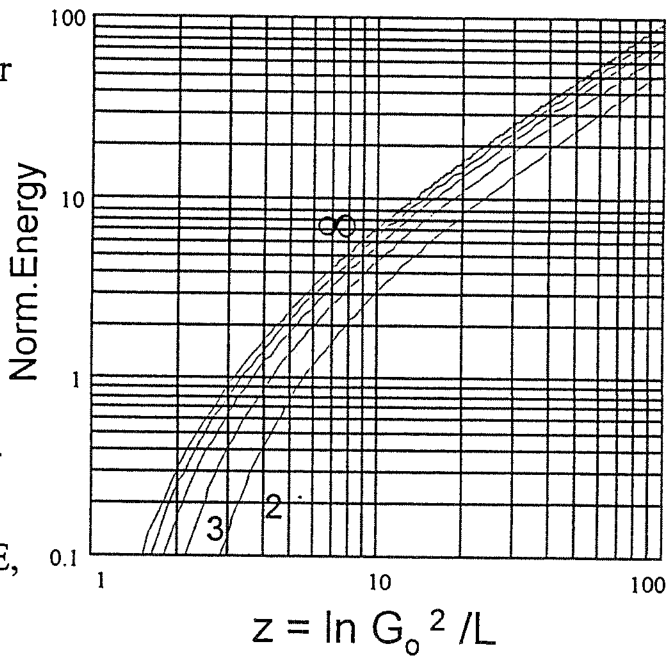
OPTIMUM OUTPUT MIRROR COUPLING VS LASER GAIN

- The optimum mirror coupling is obtained by reading x_{opt} off the graph and computing $R_{opt} = \exp[-x_{opt} L]$ where L is the roundtrip dissipative (nonuseful) optical loss.



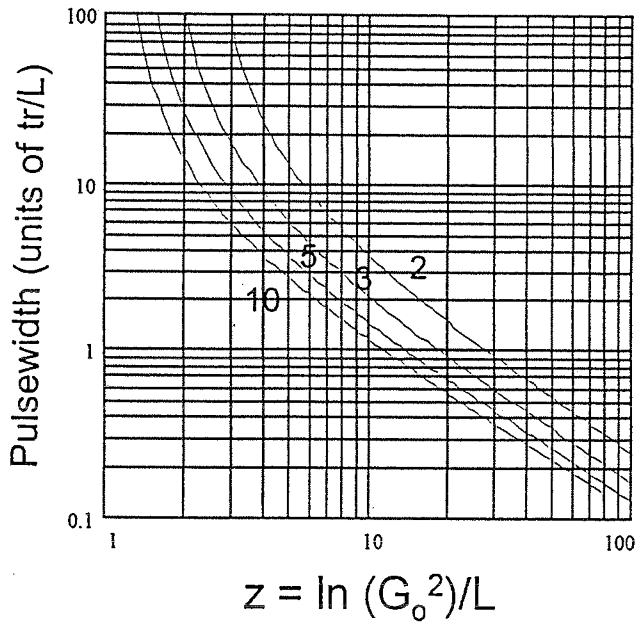
OPTIMUM LASER ENERGY

- Optimum Q-switched laser energy depends on z-parameter
- Passively Q-switched laser energy also depends on laser and absorber crossection ratio
- References:
- J.J. Degnan, "Theory of the optimally-coupled Q-switched laser", IEEE JQE, 1989.
- J.J. Degnan, "Optimization of passively coupled Q-switched lasers", submitted to IEEE JQE, 1994



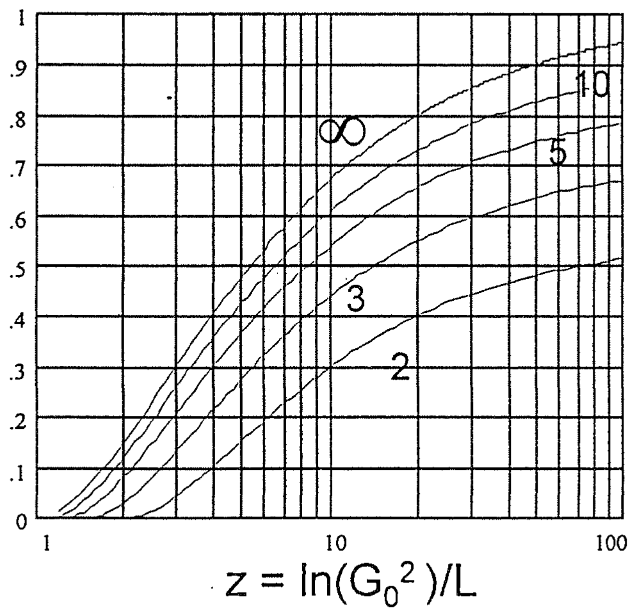
LASER PULSEWIDTH

- Rapidly Q-switched laser has shortest pulsewidths
- Passively Q-switched pulsewidths become longer for lower absorption to gain cross-section ratios
- Scale factor = t_r/L
- Refs: J.J. Degnan, "Optimization of passively Q-switched lasers", submitted to IEEE JQE, 1994



OPTIMUM Q-SWITCHED LASER EFFICIENCY

- Rapidly Q-switched laser is the most efficient (excluding internal losses introduced by electro-optic switch)
- Passively Q-switched laser is almost as efficient for high absorber cross-sections
- References:
- J.J. Degnan,"Theory of the optimally coupled Q-switched laser", IEEE JQE, 1989
- J.J. Degnan, "Optimization of passively Q-switched lasers", submitted to IEEE JQE, 1994



RAPIDLY Q-SWITCHED LASER IN THE HIGH Z LIMIT

SINGLE PULSE ENERGY

$$E = h\nu n_i V / \gamma$$

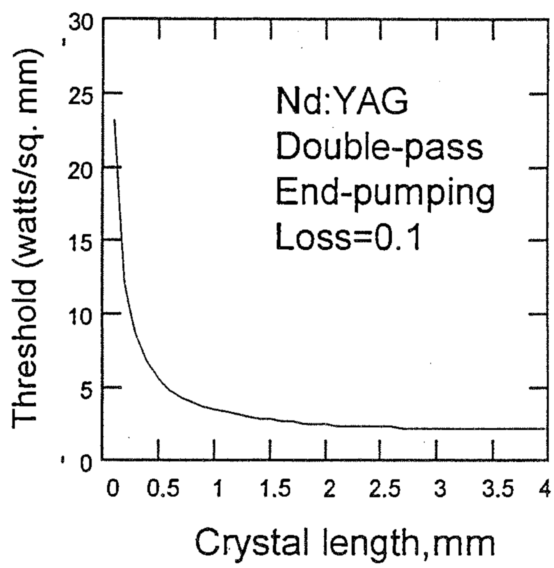
PULSEWIDTH

$$t_p = 9.5 t_r / \ln(G_{rt})$$

- In the limit of high z, the rapidly Q-switched laser approaches these limiting values for single pulse energy and pulsewidth
- G_{rt} is the roundtrip small signal laser gain
- t_r is the roundtrip transit time of the pulse

Effect of microlaser length on pump efficiency and threshold

- **Conclusion:** Nd:YAG lasers longer than about 2 mm increase pulsewidth without significantly improving pump efficiency or threshold



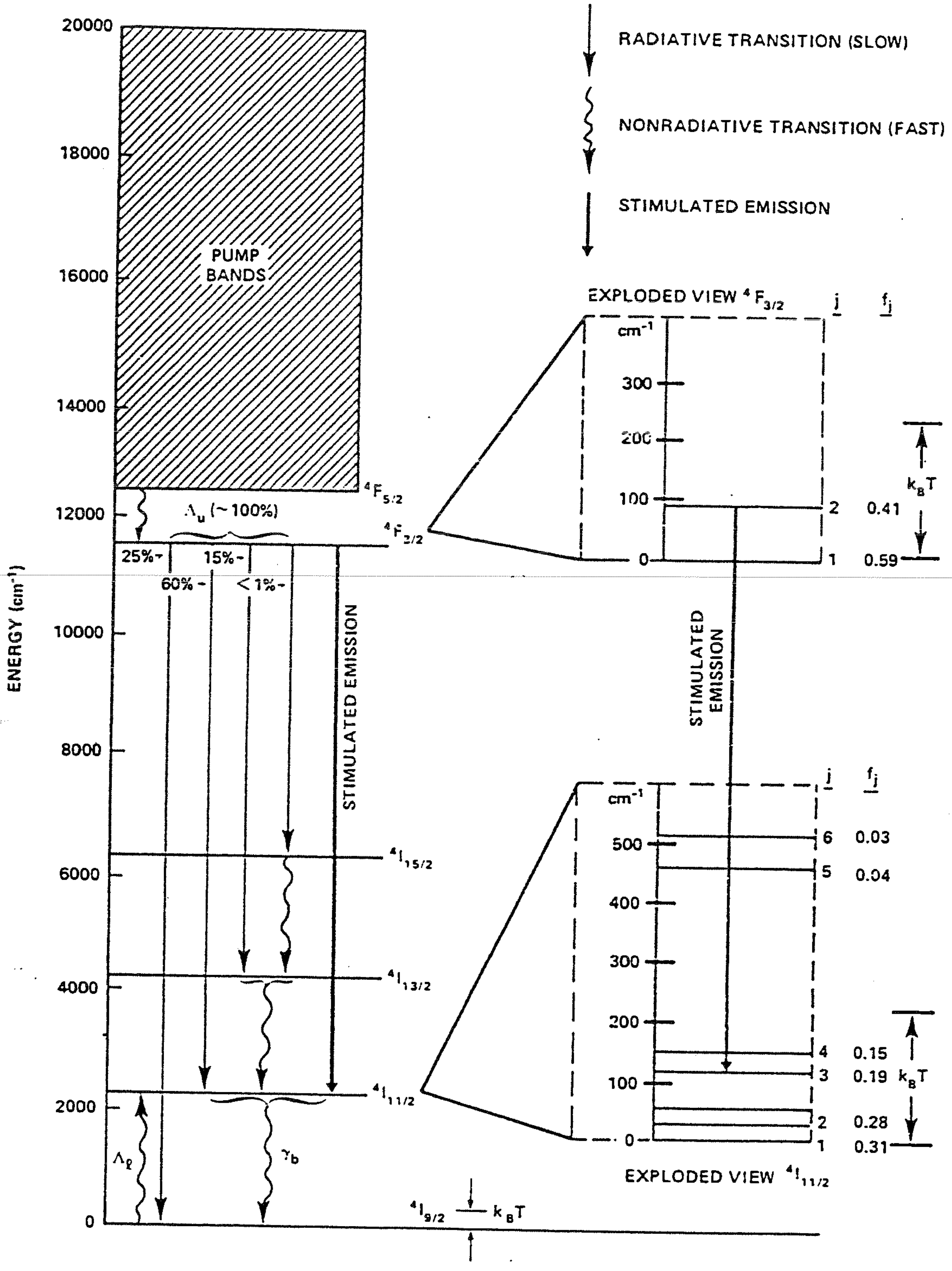


Figure II-6. Pumping and Relaxation Dynamics in Nd:YAG

SLR 2000: STEADY STATE Nd:YAG LASER MODEL

PROCESS	TIME SCALE	POPULATION INVERSION
CYCLE M		n_i
Q-SWITCHING (optimum coupling)	< 1 nsec	$\frac{n_i}{z}$
THERMALIZATION AND LOWER LEVEL RELAXATION	~ 12 nsec < 1 μsec	$n_i\left(1-\frac{f_a}{2}+\frac{f_a}{2z}\right)$
DIODE PUMP	T (~1 msec)	$n_i e^{-\gamma_a T}\left(1-\frac{f_a}{2}+\frac{f_a}{2z}\right)+\frac{\Lambda}{\gamma_a}(1-e^{-\gamma_a T})$
CYCLE M+1		n_i

STEADY STATE CONDITION:

$$n_i = n_i \exp^{-\gamma_a T}\left(1-\frac{f_a}{2}+\frac{f_a}{2z}\right)+\frac{\Lambda}{\gamma_a}(1-\exp^{-\gamma_a T})$$

IMPLIES

$$z = \frac{\frac{f_a}{2}e^{-\gamma_a T}+\frac{2\sigma l \Lambda}{\gamma_a L}\left(1-e^{-\gamma_a T}\right)}{1-e^{-\gamma_a T}\left(1-\frac{f_a}{2}\right)}$$

GLOSSARY

n_i = population inversion at start of Q-switch cycle

$\gamma_a = \frac{1}{\tau_a}$ upper multiplet relaxation rate

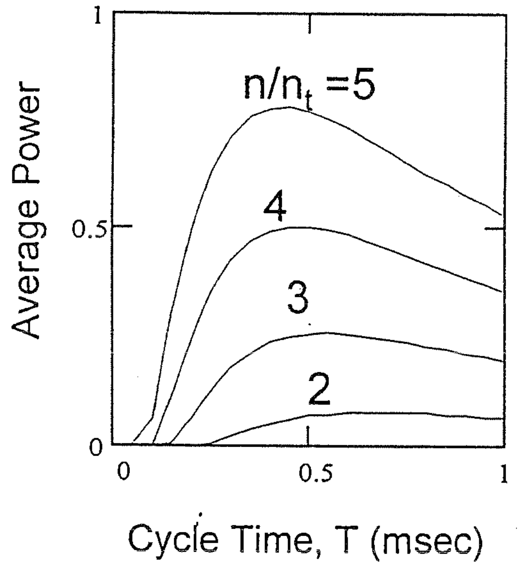
f_a = Boltzmann equilibrium population of upper laser level

$T = \frac{1}{R}$ = period between Q-switched pulses

Λ = CW diode pump rate

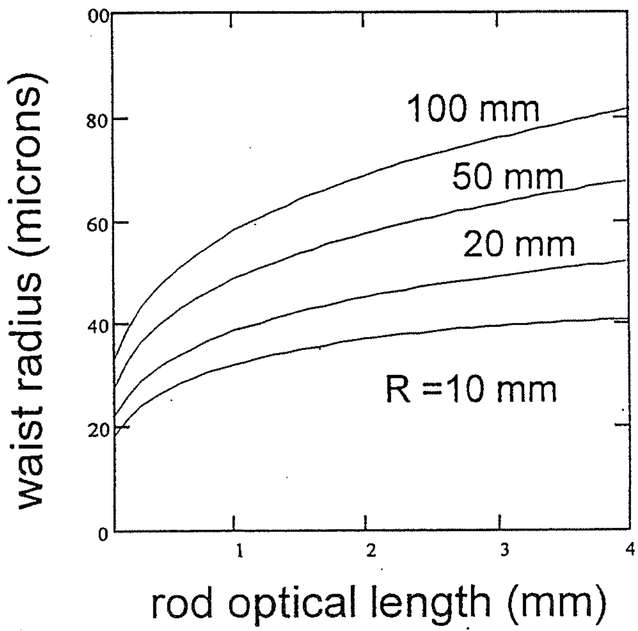
z = dimensionless z-parameter (Degnan, IEEE JQE, 1989)

Optimum Nd:YAG microlaser repetition rate for CW diode pumping



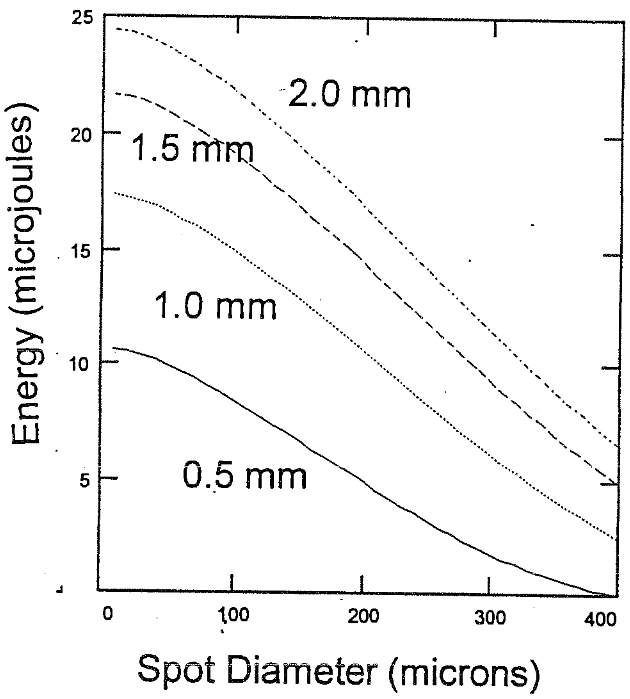
- If the time interval between Q-switched pulses is too short, the microlaser cannot achieve high inversion or single pulse energy
- If the time interval is too long, too much pump power is lost to spontaneous emission
- Average laser power reaches a peak when these two competing effects balance
- For Nd:YAG (230 microsecond lifetime), a repetition rate of 2 KHz is about optimum

GAUSSIAN BEAM WAIST VS ROD CURVATURE AND LENGTH



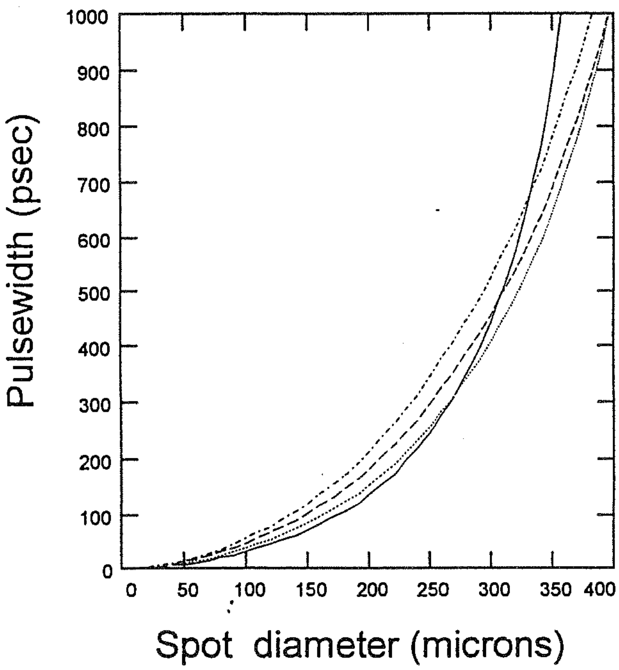
John J. Degnan NASA/GSFC

Laser energy vs pump spot diameter for Nd:YAG microlaser



- Curves apply to Nd:YAG lasers 0.5, 1, 1.5, and 2 mm long
- Laser gain and energy increases with length due to improved pump absorption
- One watt CW diode
- Loss =0.1, T=0.5 msec

Laser pulsewidth vs pump spot diameter for Nd:YAG microlaser



- Pulsewidth shorter for shorter lasers except for low pump densities
- 100 psec and shorter pulses are possible with relatively low pump densities
- 1 Watt CW diode
- Loss =0.1, T=0.5 msec

Theory and Possible Impovements

Comparison of Nd^{3+} Doped Laser Crystals

	Nd:YLF	Nd:YAG	Nd:YVO_4	Nd:S-VAP
Lasing Wavelength (nm)	1047.7	1064.2	1064.2	1065.4
Pump Wavelength (nm)	792	808.1	805.5	809
Loss in Crystal (mm^{-1})	0.0005	0.0004	0.002	0.004
Percent Nd^{3+} Doping (%)	1.1	1.1	1.1	0.38
Bandwidth (GHz)	420	140	212	312
Absorption Coefficient (cm^{-1}) (α)	**7.2**	**4.8**	**31**	**16.9**
Absorption Linewidth (nm)	1.21	0.6	0.8	1.6
Stimulated Cross Section (x 10^{-19} cm^2) (σ)	**1.9**	**2.8**	**15.6**	5
Upper State Lifetime (μs) (τ)	500	240	100	230
Boltzman Factor (f_a)		0.41	0.52	
Figure of Merit = $\eta_p \sigma \tau f_a$		261.7	770.6	
Minimum E-O Q-Switched Pulsewidth (ps)	**76**	**158**	**29**	**43**

J.Dallas/715.1
July 19, 1994
SLR2000.7

CONCLUSIONS

- Microlasers can generate pulsewidths comparable to modelocked lasers at KHz rates
- Optimum repetition rate for CW diode pumping of Nd:YAG is approximately 2 KHz
- Combined with a compact, passive , diode-pumped, double-pass laser amplifier, millijoule energies can be achieved
- Microlasers should require little or no maintenance for long periods
- Microlasers are ideal for low-power eyesafe systems or as seed oscillators in high energy systems

Title: **Eyesafe Lasers for Laser Tracking**

Authors: Greene B. and Gao Y. EOS Australia

Session: Laser Technology Development

Date: 0830 Tuesday 8 November

Chairperson: Dr K Hamal

Abstract:

Lasers for eyesafe tracking may be based on a wide variety of principles. This paper addresses the link budget and yield rate equations to determine the most effective laser design in terms of an abstract parametric description. From this point specific performance features and design criteria are developed, leading to a series of designs, prototypes, and production lasers.

One of the key driving forces in the development of eyesafe SLR systems is the requirement for automated systems. Until a system is eyesafe it will probably not be certified for automated operation by any responsible agency or government. The development of automated SLR systems may require different laser design from earlier systems.

Various automation algorithms will have a lock-in time and probability of success depending upon the single shot signal to noise ratio (SNR), and the signal return rate (SRR). The laser design is of paramount importance in fixing the SNR, and is also a strong influence in the determination of SRR. Thus laser design will be a critical factor in the development of eyesafe and automated SLR systems.

RAMAN LASERS FOR SLR
EYE SAFE RAMAN LASERS FOR SLR

Karel Hamal

submitted to :
9 Workshop on Laser Rangi Instrumentation
Canberra , November 94

Czech Technical University, Prague

GOALS

Raman lasers for SLR

pulse length	10 - 100 psec
pulse energy	1 mJ minimum
rep.rate	10Hz minimum
wavelength	matched to - detector - atmosphere - satellites
features	rugged simple operation reliability
candidates	modelocking injection / seed Raman

K.Hamal, Canberra 94

ALTERNATIVES

Lasers for SLR

- VISIBLE
  Mode locked YAG
  Mode locked YAG / second harmonic generation
  Mode locked YAG / Raman Stokes / antiStokes PICO-PICO
  Diode oscillator / Alexandrite amplifier
  Diode oscillatro / Titanium Sapphire amplifier
  LiSAF oscillator / Titanium Sapphire amplifier

  YAG Q-switch / Briloiun / Raman backward NANO-PICO
  YAG Microlaser / Diode pumped amplifier

- EYESAFE
  OPO
  YAG Q-switch / Brilouin / Raman backward NANO-PICO
  Mode locked YAG / Raman Stokes PICO-PICO
  New 1.54 materials

K.Hamal, Canberra, 1994

TWO WAVELENGTH SATELLITE LASER RANGING

Lasers for SLR

GOAL	1 cm atmospheric correction accuracy
	to double the accuracy, # of echoes x 4
SYSTEM	SPAD based, 38 ps RMS, 10Hz, 100% ret.rate
RANGING	20 deg.elevation, data averaging
	low satellites 50 psec, LAGEOS 70 psec RMS

pair	prec.req. (psec)	# echoes required low/LAG.	aver.time (minutes) low/LAG.	source
0.45/0.68	3.5	200/ 400	1.3/2.6	antiSt/Stokes
0.53/0.68	1.8	770/1500	5.0/10.	Stokes/2H YAG
0.53/1.06	3.0	280/ 550	2.0/4.0	2H/Fund.YAG
0.4 /0.8	6.0	70/ 140	0.5/1.0	2H/Fund.LiSAF Ti Sapphire
0.35/1.06	6.7	60/ 110	0.4/0.7	2H/3H YAG

I.Procházka, K.Hamal, G.Kirchner, CLEO '94, Anaheim, CA, May 1994

K.Hamal, Canberra, 1994

STIMULATED RAMAN SCATTERING
RAMAN LASER FOR SLR

STIMULATED RAMAN SCATTERING
RAMAN LASER FOR SLR

$$\lambda_{RAMAN} = \left(\frac{1}{\lambda_{LASER}} + n\nu_{SHIFT}\right)^{-1}$$

WHERE

n = -1, -2, -3... FOR STOKES

n = +1, +2, +3... FOR ANTISTOKES

λ_{LASER} = 0.532 μ, ν_{SHIFT} FOR HYDROGEN

1. STOKES 0.680 μ

1. ANTISTOKES 0.436 μ

λ_{LASER} = 1.06 μ, ν_{SHIFT} FOR METHAN

1. STOKES 1.543 μ

1. ANTISTOKES 0.897 μ

2. ANTISTOKES 0.655 μ

3. ANTISTOKES 0.550 μ

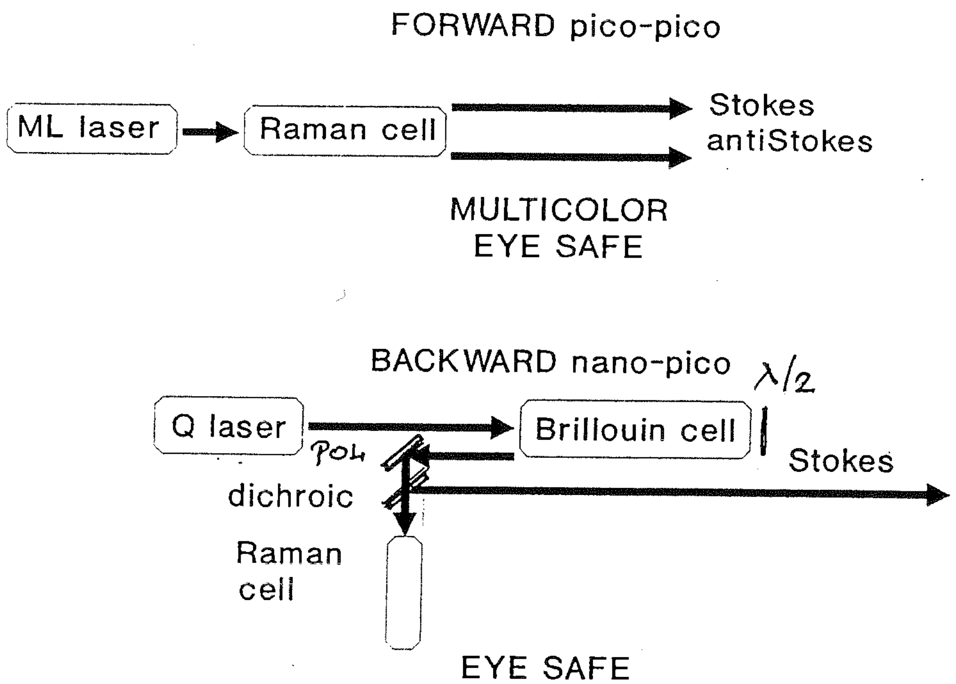
$\lambda_{LASER} \cong$ 0.8 μ, ν_{SHIFT} FOR METHAN

2. ANTISTOKES 1.5 μ

K.Hamal, Canberra, 1994

ALTERNATIVES

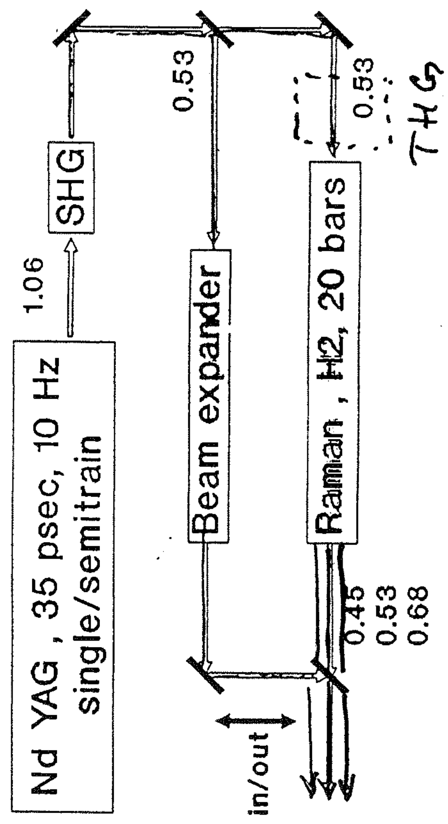
Raman lasers for SLR



K.Hamal, Canberra, 1994

LASER TRANSMITTER

Graz SLR



AVAILABLE WAVELENGTHS

0.36 um	3 mJ / pulse	#1
0.45 um	2 mJ / pulse	2
0.53 um	15 mJ / pulse	3
0.68 um	3 mJ / pulse	4
1.06 um	› 10 mJ / pulse	5

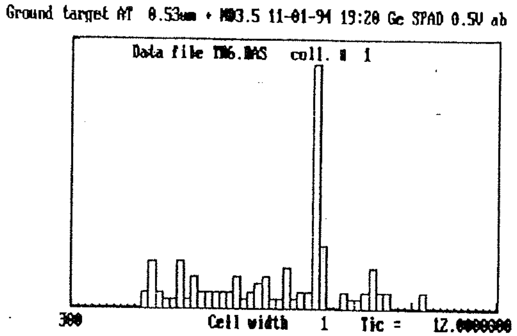
The THG may replace the Raman tube

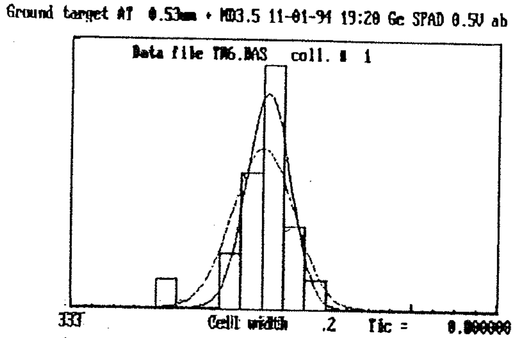
Proch,Hamal,Jel,Kirch,Koidl,Annapolis 1992

Ge SPAD ground target laser ranging

SPAD 0.5 V above break, 250 psec laser

0.53 um wavelength





	Criter.	MEAN	SIGMA	PT #
Limits	331.000 / 337.000	334.006915	0.205418	42
	3*SIGMA	334.053149	0.201392	40
	2.5*SIGMA	334.053149	0.201392	40
	2.0*SIGMA	334.063892	0.146940	35

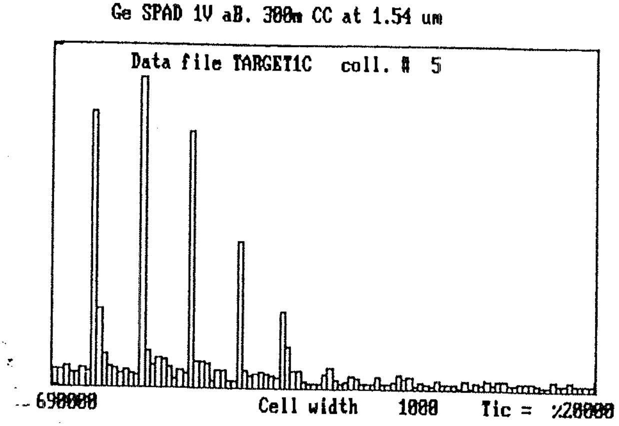
Greene,Guilfoyle,Kunimori,Hamal,Prochazka

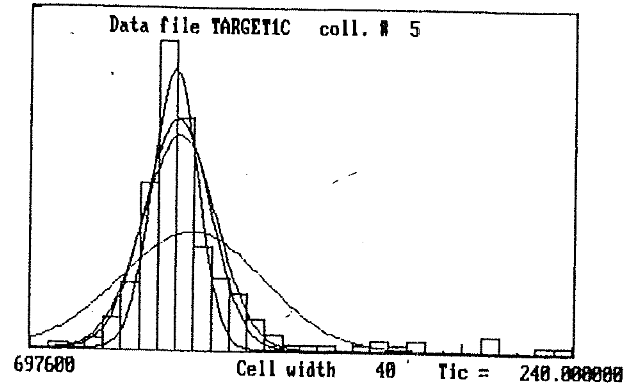
Communication Research Lab.,Tokyo,Nov.94

Ge SPAD at 1.54 um ground target ranging

Satellite Laser Station Graz

Common T/R coude path, 300 m corner cube



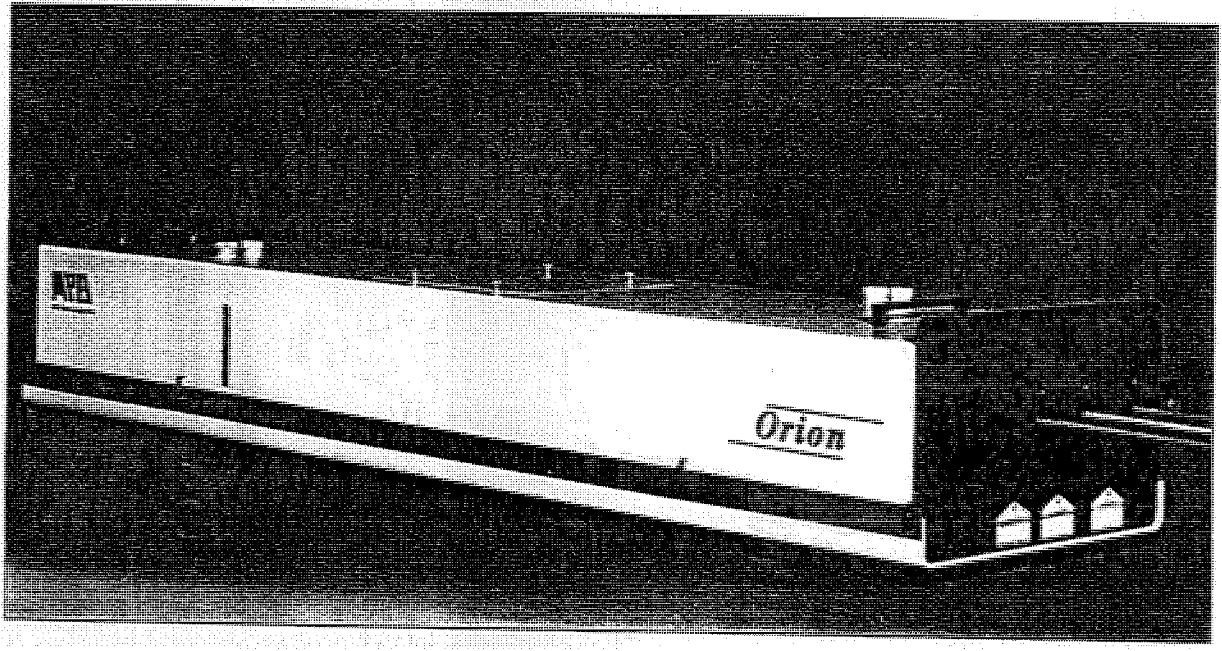


	Criter.	MEAN	SIGMA	PT #
Limits	697600.000 /698000.000	697958.312500	159.899991	227
	3 * SIGMA	697927.375000	81.914482	213
	2.5*SIGMA	697922.312500	73.606606	206
	2.0*SIGMA	697916.687500	58.270054	171

Prochazka,Hamal,Kirchner,Koidl, Sept. 94

ORION - Series
Solid State Laser Systems

MPB TECHNOLOGIES INC.



The Orion series of pulsed lasers are truly unique multiple wavelength and multiple pulselength laser systems which use stimulated Brillouin and Raman scattering to compress and wavelength shift the pulsed output of a Nd:YAG laser oscillator.

The various models in the Orion series differ according to the options (harmonic generating capability, number of stimulated Raman cells, etc.) included in each and these differences in turn determine the wavelengths and pulselengths available, as well as the number of simultaneous outputs.

According to his requirements, a user can configure an Orion laser system to simultaneously yield as many as three precisely synchronized outputs differing in pulselength and/or wavelength. Pulselengths of 8 ns, 0.4 ns and 20 ps and discrete wavelengths spanning the range from 1900 nm to less than 300 nm are available with mJ pulse energies.

The flexibility of the Orion is enhanced by the surprising ease and speed (in most cases, a matter of minutes or less) with which changes in pulse duration and wavelength can be accomplished.

Furthermore, although the Orion provides only discrete tunability, in many applications this can be considered an advantage since the wavelengths are precisely determined and need not be measured.

Orion series laser systems are very versatile and cost effective research tools. A single Orion laser can provide a range of optical pulse parameters that would otherwise require several different laser systems.

Features

- SLM and TEM_{00}-mode Nd:YAG oscillator
- Kinematically decoupled mechanical platform and invar resonator construction for alignment stability
- Up to 3 synchronized outputs with different pulselengths and/or wavelengths
- Pulselengths from 8 ns to 20 ps and wavelengths from 1.9µm to the UV in a single laser
- Excellent beam quality and temporal pulse shape
- Affordable multiple Raman cells for fast and easy change of wavelengths

Applications

- Non-linear optical materials research
- Time-resolved spectroscopy
- Photo-chemistry and photo-biology on the sub-nanosecond scale
- Remote sensing (including DIAL systems)
- Fluorescence spectroscopy
- High-speed time-resolved ("multi-colour" picosecond interferometry
- Laser-tissue interaction studies

GOALS

HELWAN 2 Satellite Laser Station

- satellite laser ranging to all retro equipped satellites
- measuring range 0 - 20 000 kilometers
- ranging precision
  1 centimeter RMS / single shot/
  1 millimeter /normal points spread/
- automatic optical guiding
- visual guiding capability
- all solid state detector technology
- multiple wavelengths, multiple target capability

Hamal,Prochazka,Tawadros, Mikhail,Canberra,1994

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Raman lasers for SLR

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- Hamal et all, CLEO '93, Baltimore, USA
- Prochazka et all, CLEO '94, Anaheim, USA [2]
- Kubecek, Hamal, Prochazka,Valach, Buzelis, Dementev Opt. Communication, Vol 73,1989,251 [3]
- MPB Technologies Inc Data sheet [4]
- Americal National Standard Z 136.1-1986,p32 1.54um only 10E-9 to 10E-6 sec 1.0J/cm2 [5]
- European Community Standard EN60825:1991,p31 1400-10E6 nm for T<1E-9 sec 10E+11 W/m2 [6]
- Hanbook of Lasers, p 528 [7]
- Kirchner, Koidl, Hamal, Prochazka, Sept.1994 [8]
- Kunimori, Greene, Hamal, Prochazka, October 1994 [9]

K.Hamal, Canberra, 1994

Specifications by Wavelength and Pulselength

8 ns pulses

Wavelength[1] nm	Energy mJ	Stability* %
1064	25	± 1
532	15	± 2
355	5	± 4
266	2	± 4

0.4 ns pulses

Wavelength[1] nm	Energy mJ	Stability* %
1064	25	± 3
532	15	± 5
355	5	± 6
266	5	± 6

20 ps pulses

Wavelength[1] nm	Energy mJ	Stability* %
1907	4	± 10
1543	4	± 10
1178	4	± 10
954	2	± 10
771	2	± 10
683	2	± 10
630	2	± 10
607	2	± 10
589	2	± 10
559	2	± 10
555	2	± 10
416	1	± 10
396	1	± 10
366	1	± 10
299	1	± 10
288	1	± 10
273	1	± 10

* Based on 90% of pulses

[1] In some cases, configurations selected to yield a particular wavelength preclude the simultaneous availability of certain other wavelengths. Additional wavelengths and pulselengths (e.g. 4 ps) are available on a custom basis. Consult MPB Technologies Inc. for further information.

General Specifications

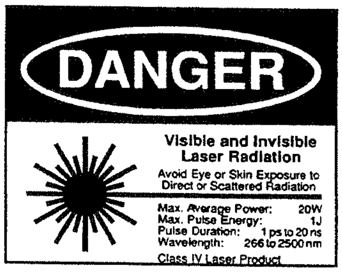
Maximum Repetition Rate	10 Hz
Beam Diameter	5 mm
Beam Divergence	1 mr
Laserhead Dimensions (L x W x H)	1400 x 330 x 250 mm
Weight	60 kg

Background

The Orion series of laser systems are the result of a collaboration between MPB Technologies Inc. and members of the scientific staff at the Vavilov State Optical Institute in St. Petersburg, Russia which has a long history of pioneering research work in the area of pulse compression via stimulated scattering.

Warranty

Orion series laser systems are warranted free from defects in materials and workmanship for a period of 1 year from date of delivery. MPB Technologies Inc. reserves the right to alter specifications without prior notice.



MPB TECHNOLOGIES INC.

MPB Technologies Inc. is a diversified company comprised of six divisions: Communications, Electromagnetics, Fusion Technology, Lasers & Electro-Optics, Space & Photonics, and Telerobotics. For more information on the company, its products, facilities or capabilities, please contact the head office.

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STREAK CAMERA SYSTEMS

Chairperson : Ivan Prochazka

MEASUREMENT AND ANALYSIS OF THE SATELLITE SIGNATURE USING THE NASA 1.2 METER TELESCOPE TRACKING FACILITY'S STREAK CAMERA RECEIVER

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THOMAS W. ZAGWODZKI, JAN F. MCGARRY, JOHN J. DEGNAN
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ABSTRACT:

Picosecond laser pulses (<30ps) in conjunction with a high resolution (~2 ps) single photoelectron streak camera receiver system provides a convenient framework for analyzing the optical signatures of retroreflector-equipped spacecrafts. Such a capability allows accurate on-orbit determination and/or verification of range correction to the center-of-mass of the satellite. Measurements are currently underway at the NASA 1.2 meter ranging facility on spacecrafts such as Topex, Lageos and Ajisai to obtain the waveform data and compare it to known models or laboratory data. The behaviors of satellites such as Starlette, Stella and ERS-1 are also examined to complete the characterization of the far field diffraction behavior. Details are discussed.

A synchro scan streak camera for dualcolor ranging

by

Ulrich Schreiber Stefan Riepl

Forschungsgruppe Satellitengeodäsie
Fundamentalstation Wettzell
D-93444 Kötzting, Germany

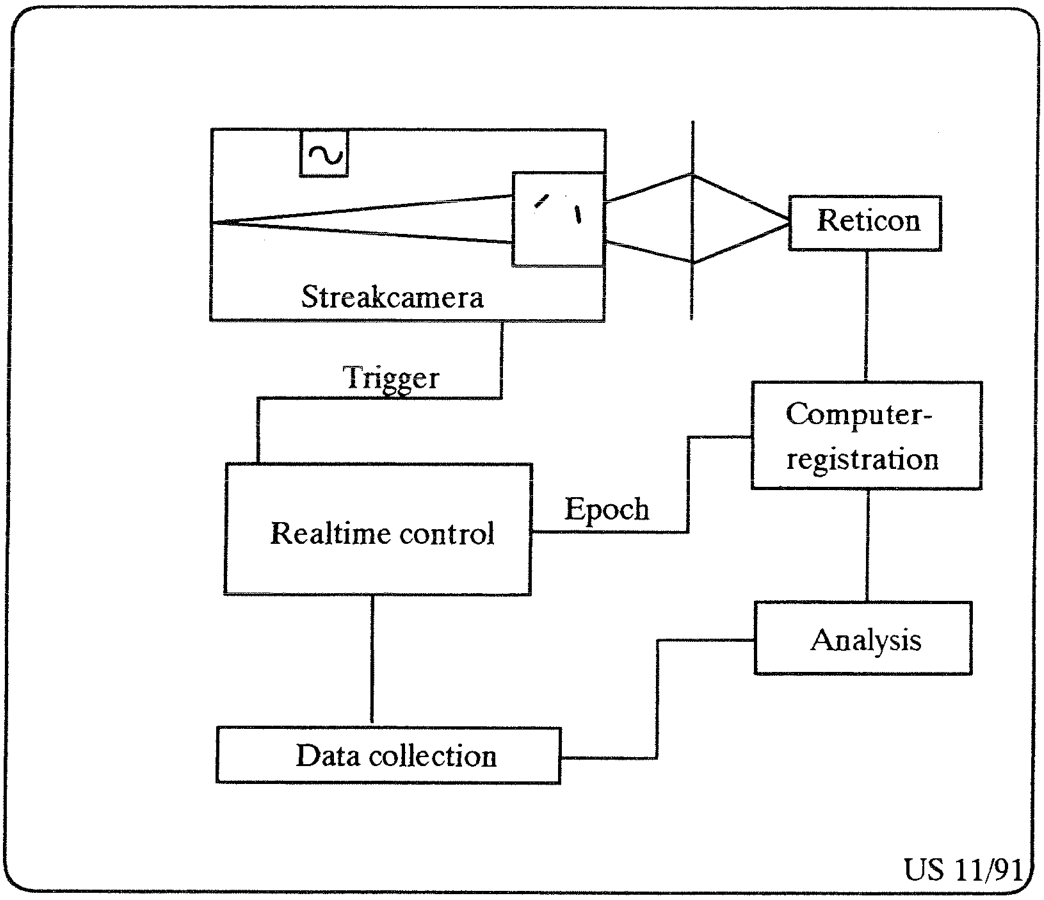
submitted to: 9. Workshop on L.R. Instrumentation

Canberra, Nov. 7 - 11 1994 (Australia)

WLRS

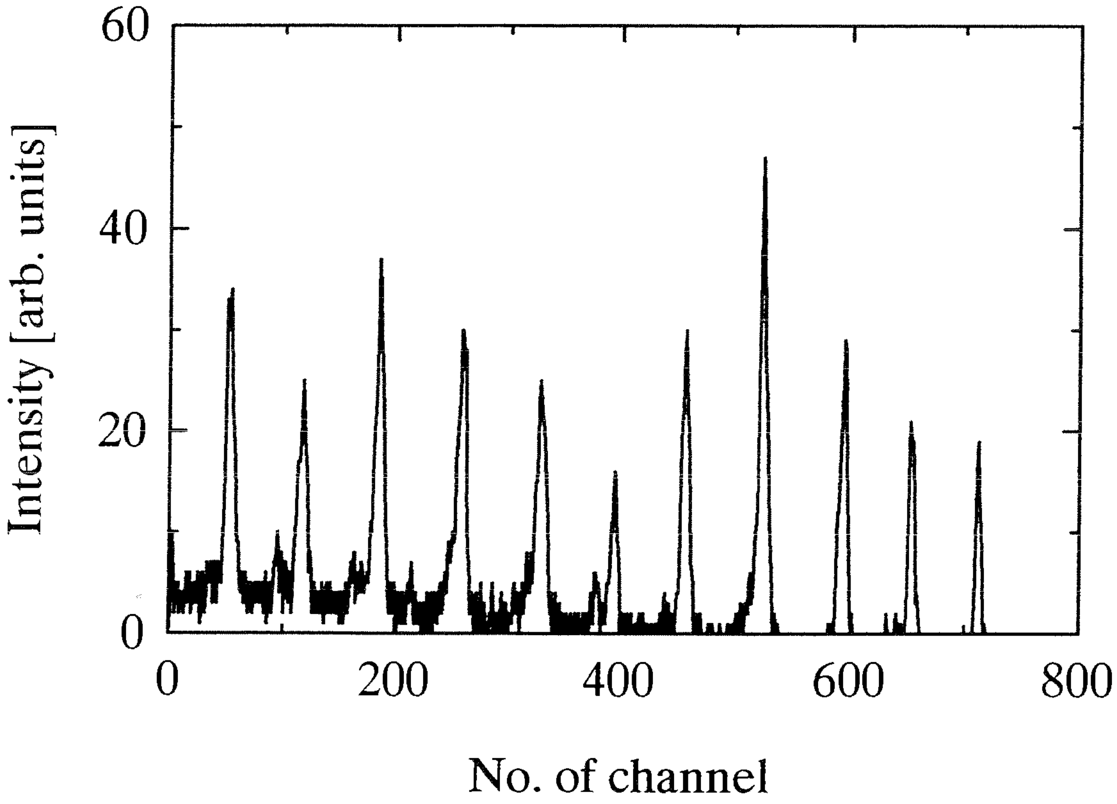
Experimental Demands

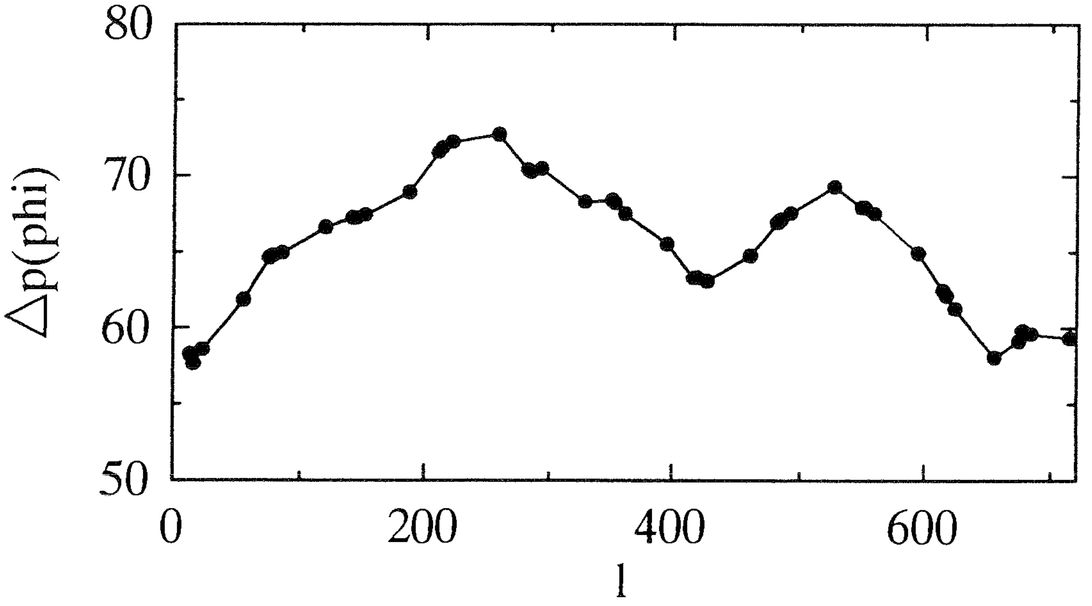
- High resolution in timing short pulse separations
- Insensitive to uncertainties in timing the event
- Evaluation of streak image in realtime

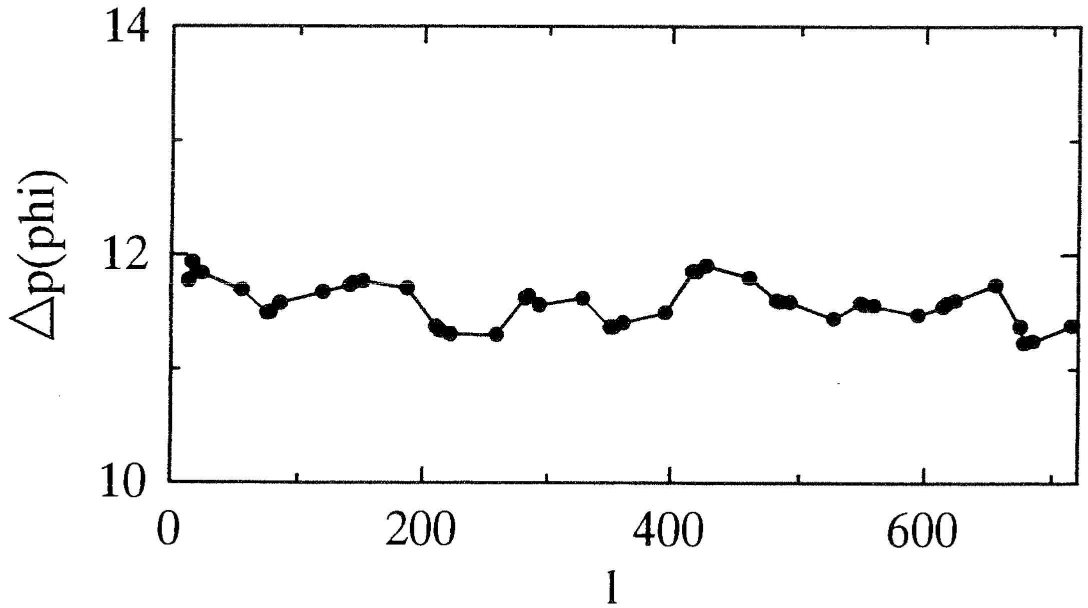


Calibrating the timescale of the streak camera

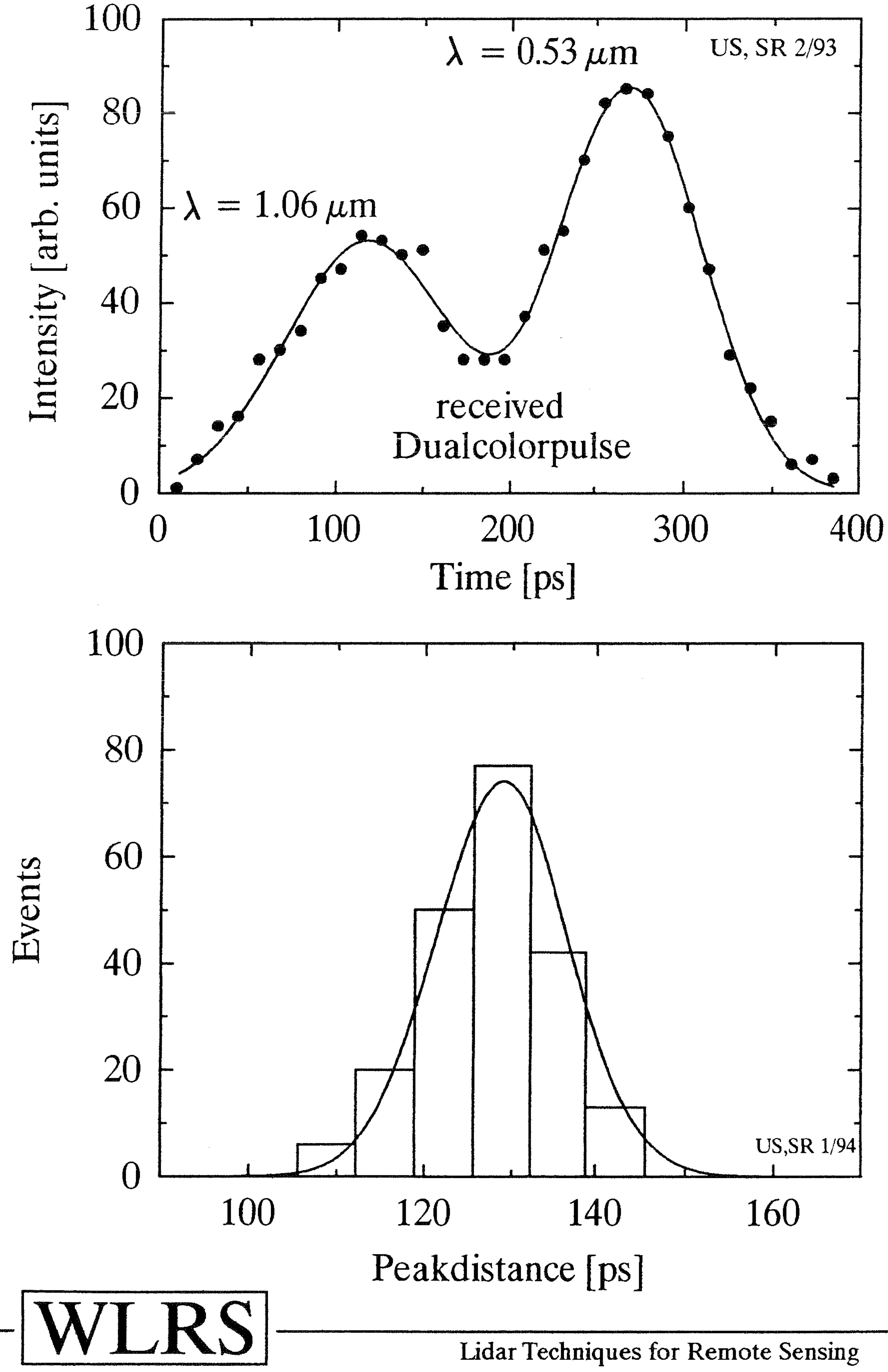
- Picosecond pulser
- Doublepulse from the laser




80
70
60
50
Δp(phi)
0
200
400
600
l

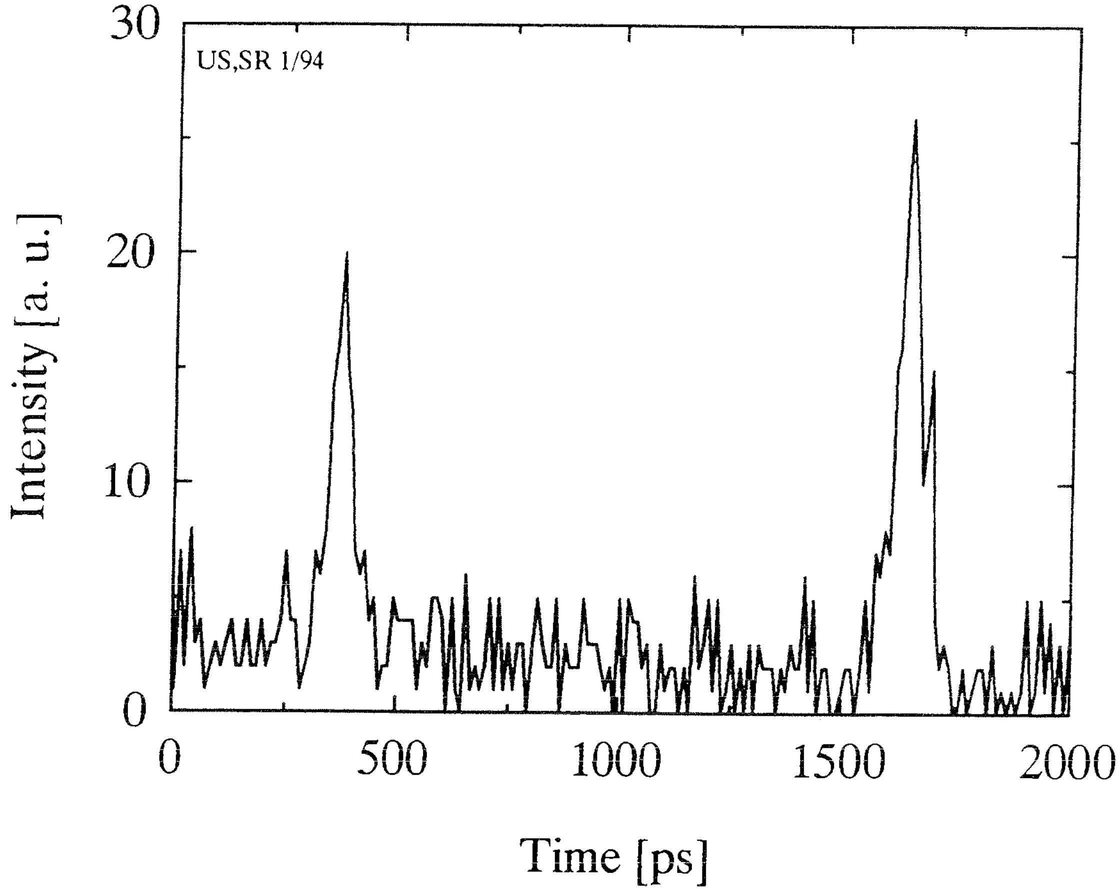

14
12
10
Δp(phi)
0
200
400
600
l

Dualcolor Streakcamera Targetranging (d=2.4 km)



WLRS

Semipulse- Streakcamera Ranging to AJISAI



- IR- Signal was used for ranging
- Laser was operated in Semipulse mode
- GN- Signal was imaged on the Streakcamera

ATMOSPHERIC SENSING AND MODELS

Chairperson : Georg Kirchner

TWO-COLOR WAVELENGTH RANGING AT NASA'S 1.2 METER TELESCOPE TRACKING FACILITY

November 1 9 9 4

Thomas W. Zagwodzki, Jan F. McGarry, John J. Degnan, Arnold Abbot
NASA/Goddard Space Flight Center

Thomas Varghese, Thomas Oldham, Michael Selden, Richard S. Chabot
Jim D. Fitzgerald, Dave A. Grolemund
AlliedSignal Aerospace

Presented at the 9th International Workshop on Laser Ranging Instrumentation
Canberra, Australia, November, 1994

Two-Color Ranging Objectives

- Measure the Atmospheric Velocity Dispersion Difference Between 532nm Light and 355nm Light Using Short (<30 ps) Laser Pulses, Very Accurately (1-2 ps) Using a Streak Camera Receiver.
- Compute the Atmospheric Range Correction (RC) From the Measurement.
- Compare the Measured Atmospheric Velocity Dispersion Difference With a Computed Value Using Surface Meteorological Measurements, and the Marini-Murray Model.

Important Issues:

- Is There True Hydrostatic Equilibrium in the Troposphere on a Local Scale?
- What Are the Diurnal and Seasonal Effects?
- What Effect Does a Local/Global Temperature Gradient Have on Refraction Correction.

11/1/94 10:24 PM

AlliedSignal AEROSPACE AlliedSignal Technical Services Corp.

Receiver Characteristics and Issues

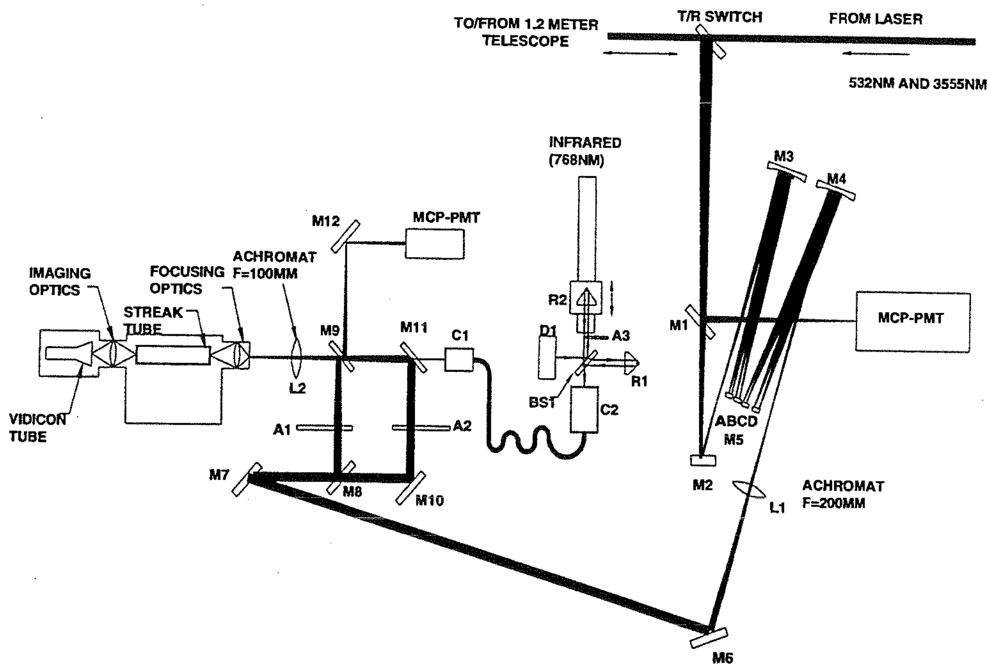
Characteristics:

- High Temporal Resolution and Picosecond Accuracy
- Good Temporal Stability (1 ps)
- High Quantum Efficiency (>10%)
- Single Photoelectron Sensitivity
- Repetition Rate >10 Hz
- Optical Calibration

Questions:

- Is There Sufficient Coupling of UV Light to the Streak Camera to Provide Enough Signal to Make Meaningful Measurements?
- Can We Consistently Track Satellites With UV and Green Light?
- What Satellites Can Provide Sufficient Link to Quantify Atmosphere Refraction Contribution?

Two Color Ranging: Streak Camera Layout



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AlliedSignal AEROSPACE AlliedSignal Technical Services Corp.

Streak Camera Delay and Coupling Optics

COMPONENT	DESCRIPTION	REFLECTION/ TRANSMISSION	ANGLE OF INCIDENCE	COATING
A1,A2	N.D. WHEEL (0 TO 2 NDS)	0 TO 2NDS	0°	NONE
A3	N.D. WHEEL (0 TO 4 NDS)	0 TO 4 NDS	0°	NONE
BS1	BEAM SPLITTER	R=50%	45°	NONE
C1	FIBER OPTIC COUPLER	N/A	0°	A.R. INFARED
C2	FIBER OPTIC COUPLER	N/A	0°	A.R. INFARED
D1	LASER DIODE	768NM	0°	N/A
FO1	FIBER OPTIC PIG TAIL (50UM)	80%	0°	N/A
L1	ACHROMAT, F= 200MM	T=97% @532NM	0°	A.R. VISIBLE MgF2
		T=70% @355NM	0°	A.R. VISIBLE MgF2
L2	ACHROMAT, F= 100MM	T=97% @532NM	0°	A.R. VISIBLE MgF2
		T=70% @355NM	0°	A.R. VISIBLE MgF2
M1	BEAMSPLITTER PELLICLE	R=8%	45°	N/A
M2	MIRROR, DUAL STACK (45°)	R=99% @532NM	10°	RMAX 355 & 532NM @45°
		R=95% @ 355NM	10°	RMAX 355 & 532NM @45°
M3, M4	WHITE CELL MIRRORS, DIA=6"	R=99% @532NM	4°	RMAX 355 & 532NM @0°
	RADIUS OF CURVATURE= 58"	R=95% @ 355NM	4°	RMAX 355 & 532NM @0°
M5A, B, C, D	WHITE CELL MIRRORS,	R=99% @532NM	4°	RMAX 355 & 532NM @0°
	DIAMETER= 1"	R=95% @ 355NM	4°	RMAX 355 & 532NM @0°
M6, M12	MIRROR, ALUM UV ENHANCED	R=90% @532NM	M6=55°	ALUM UV ENHANCED
		R=90% @ 355NM	M12=45°	ALUM UV ENHANCED
M8, M9	DICHROIC BEAM SPLITTER	T=85% @532NM	45°	RMAX 355NM @45°
	RMAX @355NM	R=99% @ 355NM	45°	RMAX 355NM @45°
M10, M11	MIRROR	R=99% @532NM	45°	RMAX 532NM @45°
MCP	MICROCHANNEL PLATE PHOTOMULTIPLIER	Q.E.= 13% @ 532NM	0°	
	TUBE			
R1, R2	RETROREFLECTOR, TIR	BROADBAND	0°	NONE

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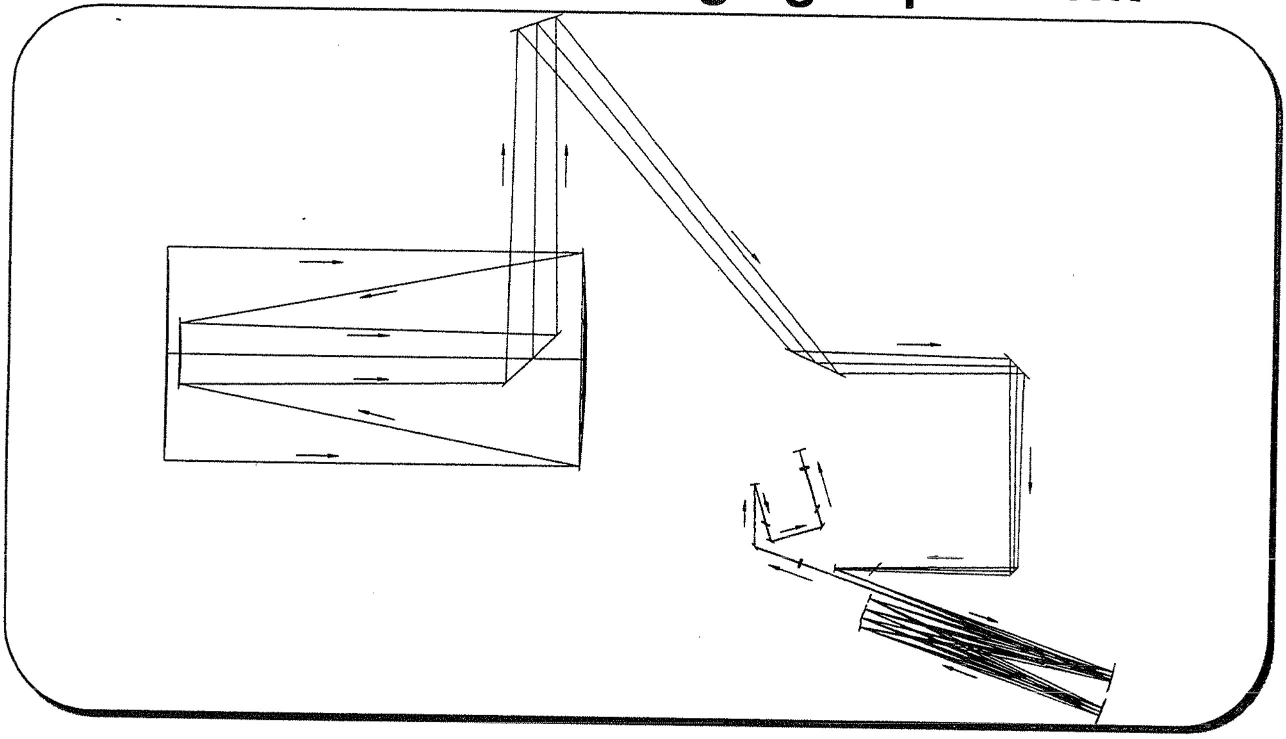
1.2M Two Color Ranging Experiment



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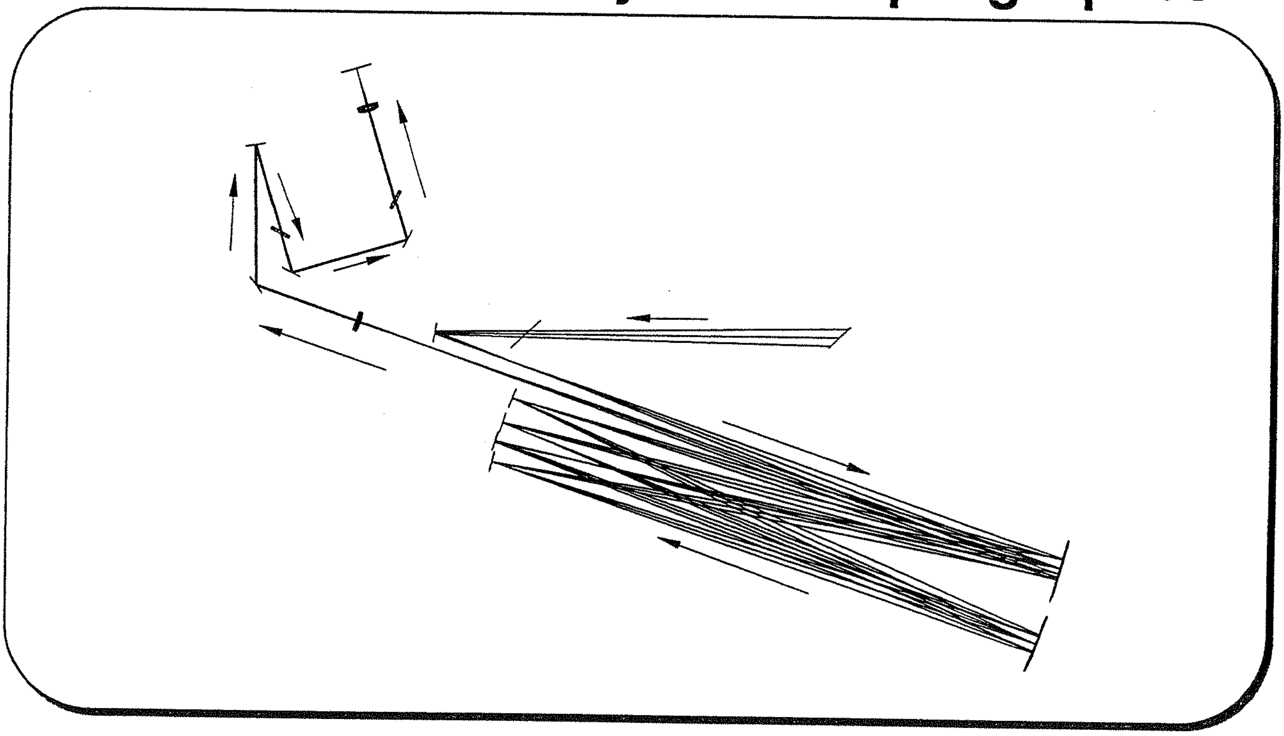
Streak Camera Delay and Coupling Optics



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Experimental Determination of Two-Color Link

- Design an Experiment That Can Be Used to Refine the Two-Color Ranging Operational Issues. Use This Experiment to Verify the Marini-Murray Model on a Coarse Level and Measure the Relative Receive Strengths of the Two Wavelengths From Various Targets.
- Demonstrate the Ability to Perform 2-Color Ranging Using Doubled and Tripled Nd:YAG Frequencies to Spacecraft in Low Orbit and Receive Adequate Return Signals for Streak Camera Use.

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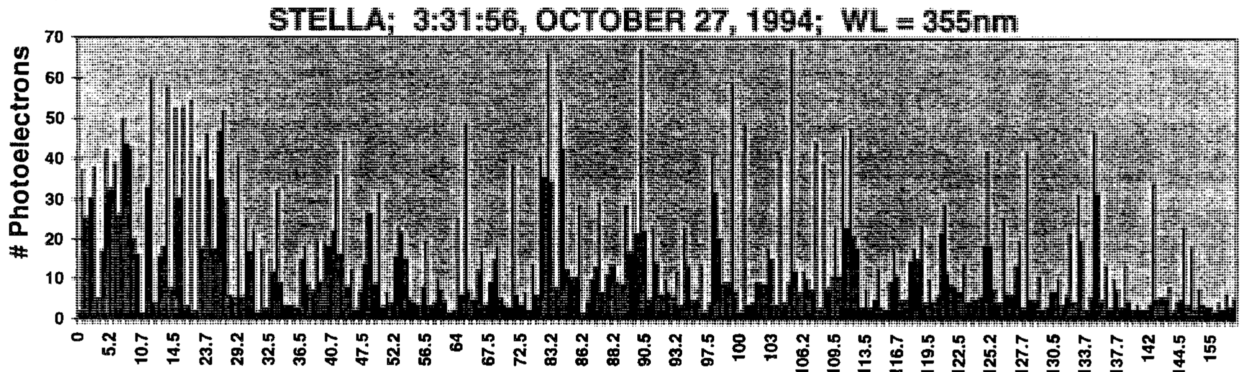
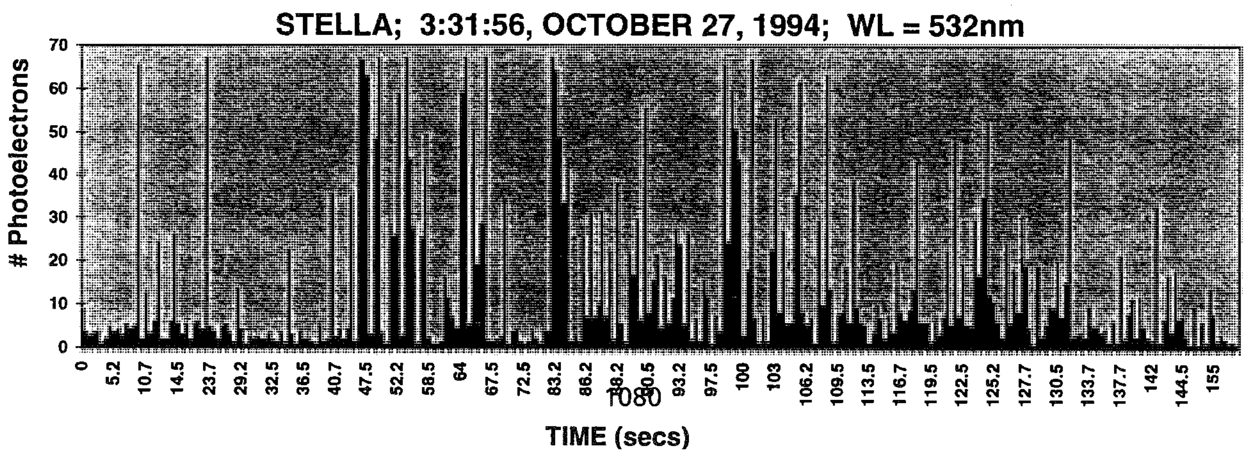
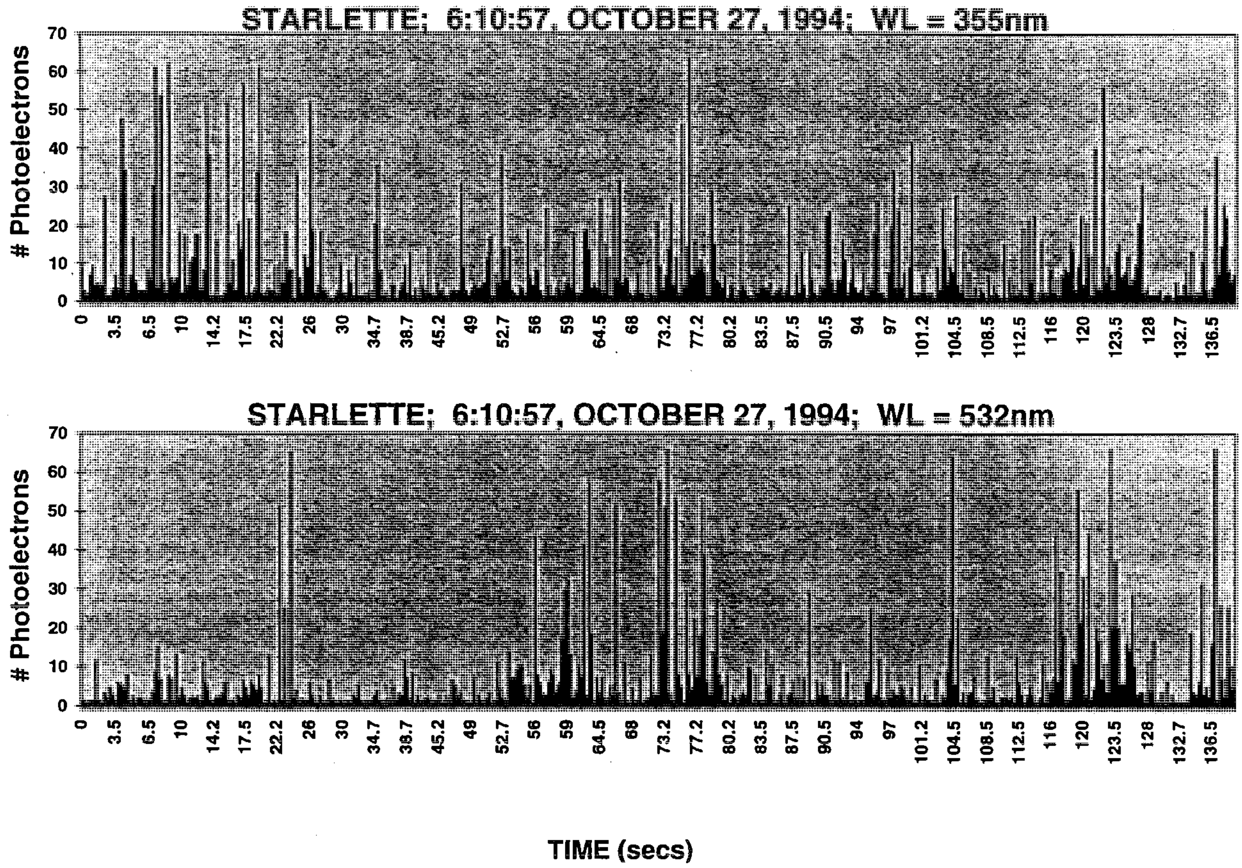
TWO COLOR RETURN SIGNAL STRENGTH IN PHOTOELECTRONS





TWO COLOR RETURN SIGNAL STRENGTH IN PHOTOELECTRONS



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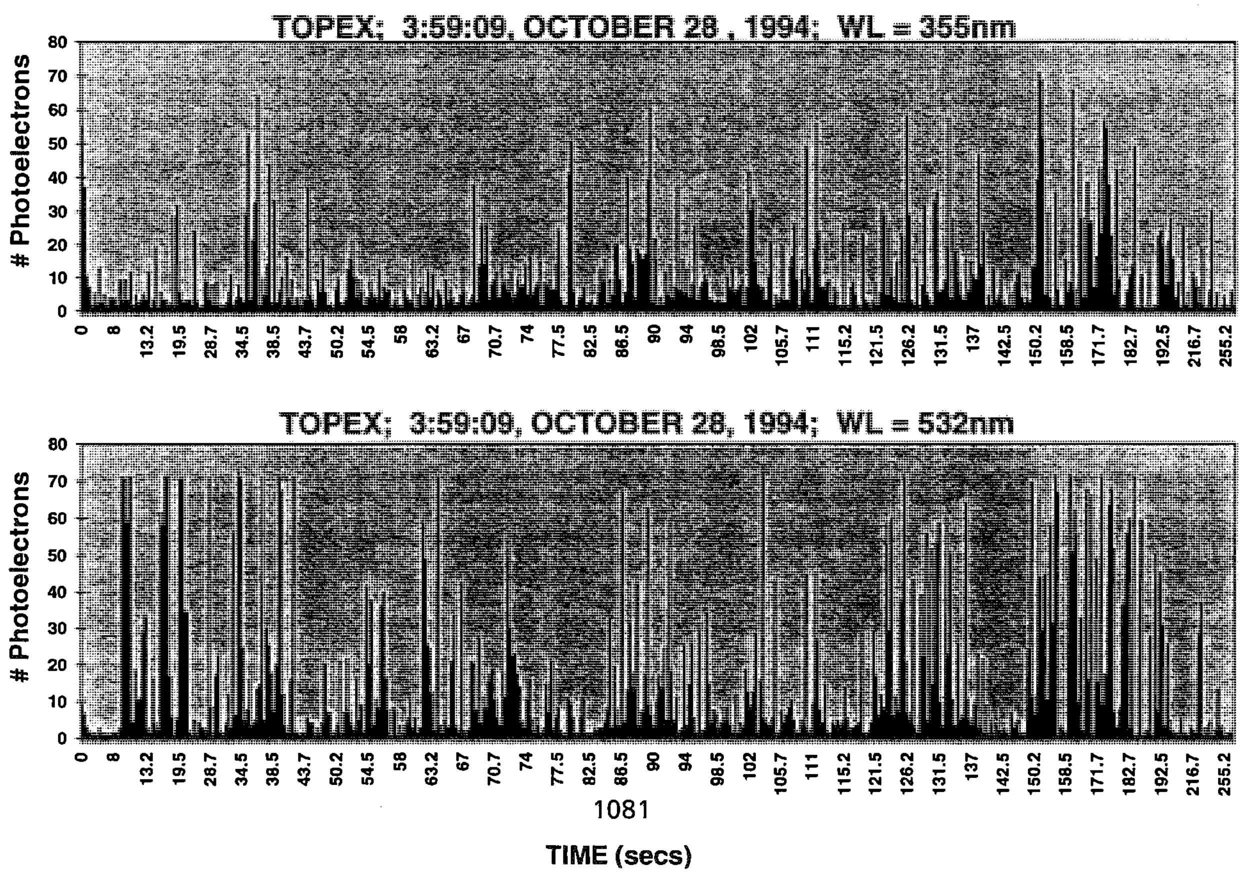

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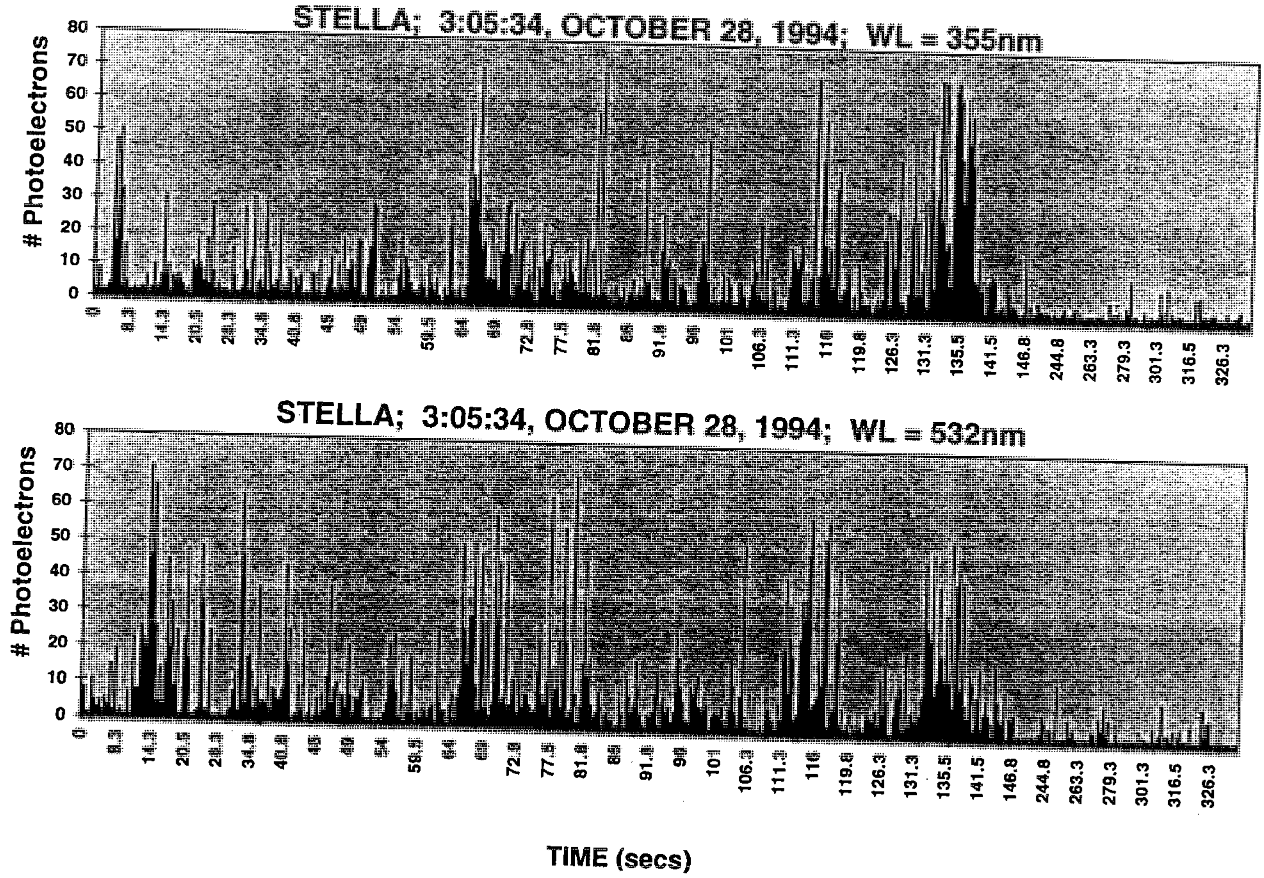

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Data Analysis

- The Tektronix Digitizer Exhibits Both Systematic and Random Behavior. The Resultant Data Has Been Analyzed Using an Assumed Fixed Sweep-Rate Departure of 3% Using Calibration Data. True Systematic Sweep-Rate Departures Have Not Been Removed at the Fine Level, This Will Result in an Improved Data Set.

- Amplitude Information Is Good to a Few Percent.

- NP Analysis Performed to Compare the Experimentally Measured Data with Theory.

Results

- The Observed Data Is in Close Agreement With the Model - to the Level of Accuracy Offered by the Instrumentation.

- The Amplitude Measurements, Combined With Recent Measurements of a Similar Nature, Show That the UV Signal Strength Should Be Sufficient to Perform Meaningful Measurements Using the Streak Camera. The Streak Camera Requires a Minimum of 10 Photoelectrons for the Accurate Determination of the Pulse Envelope.

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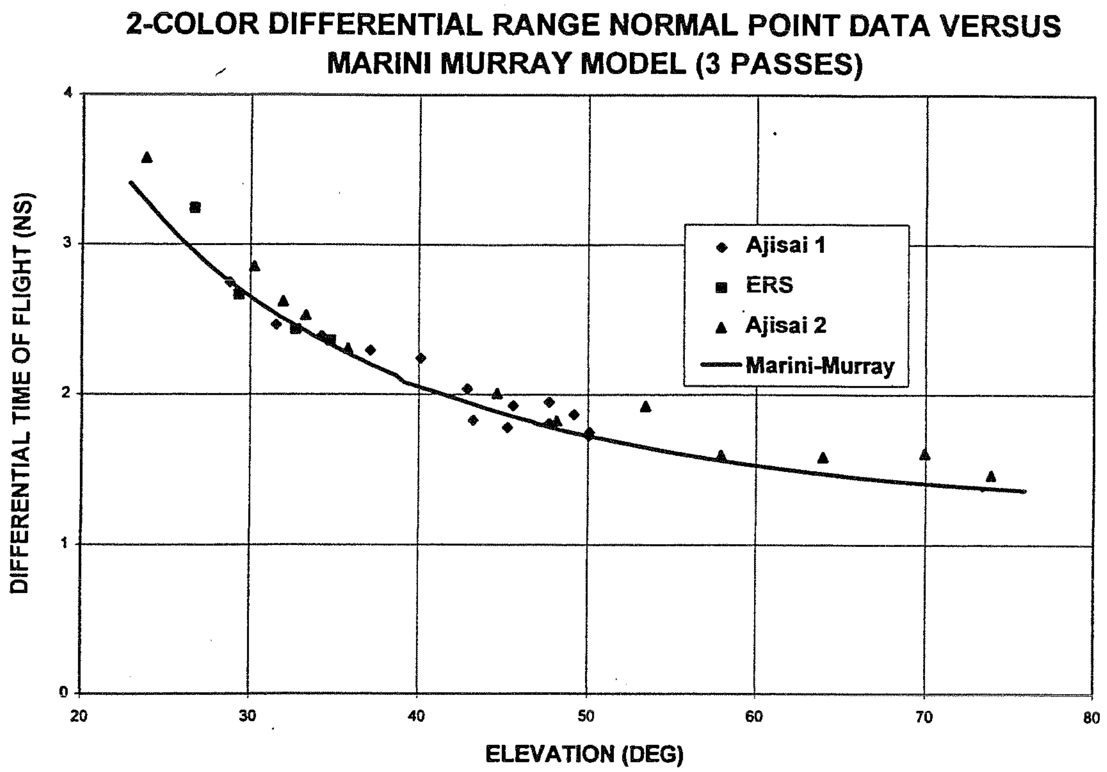
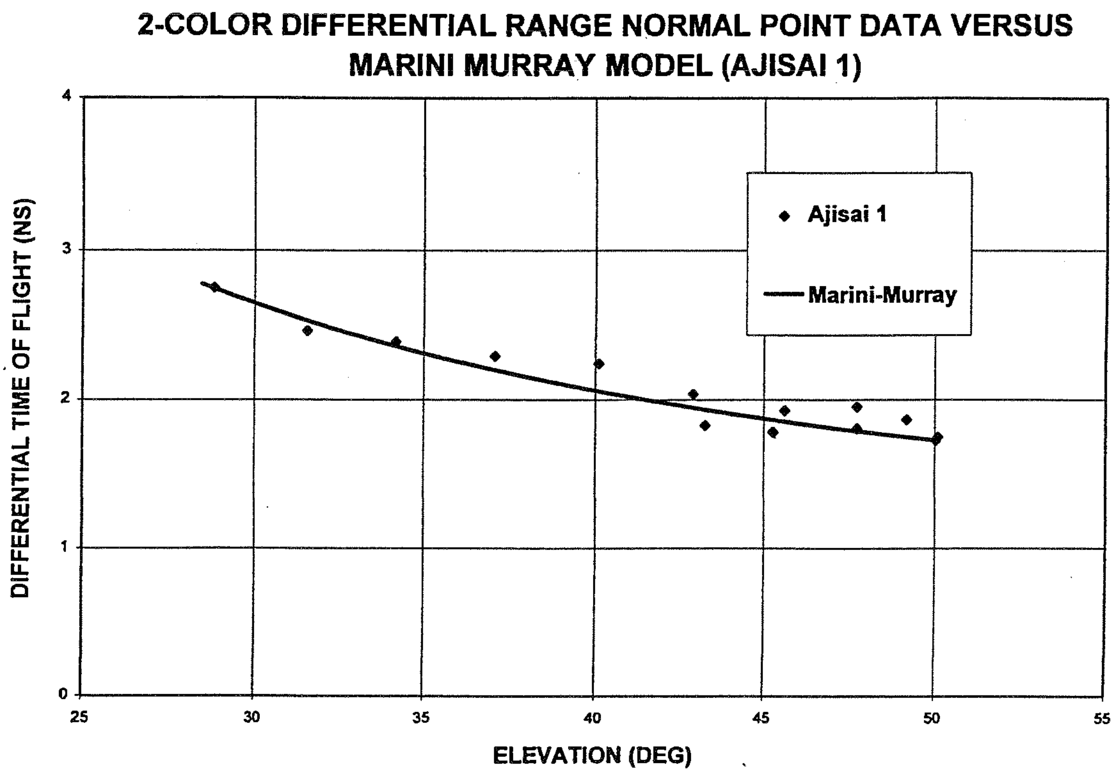


2-COLOR DIFFERENTIAL RANGE NORMAL POINT DATA VERSUS MARINI MURRAY MODEL (3 PASSES)
DIFFERENTIAL TIME OF FLIGHT (NS)
ELEVATION (DEG)
Ajisai 1
ERS
Ajisai 2
Marini-Murray
0
1
2
3
4
20
30
40
50
60
70
80



2-COLOR DIFFERENTIAL RANGE NORMAL POINT DATA VERSUS MARINI MURRAY MODEL (AJISAI 1)
DIFFERENTIAL TIME OF FLIGHT (NS)
ELEVATION (DEG)
Ajisai 1
Marini-Murray
0
1
2
3
4
25
30
35
40
45
50
55

Calibration

- The Waveform Digitizer sweep was measured using 2-color signals from a ground target.
- The relative separation was varied over the entire measurable dynamic region of the sweep and 100 waveforms were acquired for each condition.
- The calibration curve plot shows the sweep speed as a function of sweep position over the entire range.
- Only the central region was used to collect satellite data.

Analysis

- A linear fit was made to the calibration data to produce a uniform correction of 3% for the departure from the ideal digitizer sweep speed. Localized nonlinearities have not been removed.

- Data was acquired using the central (most linear region) of the waveform digitizer sweep.

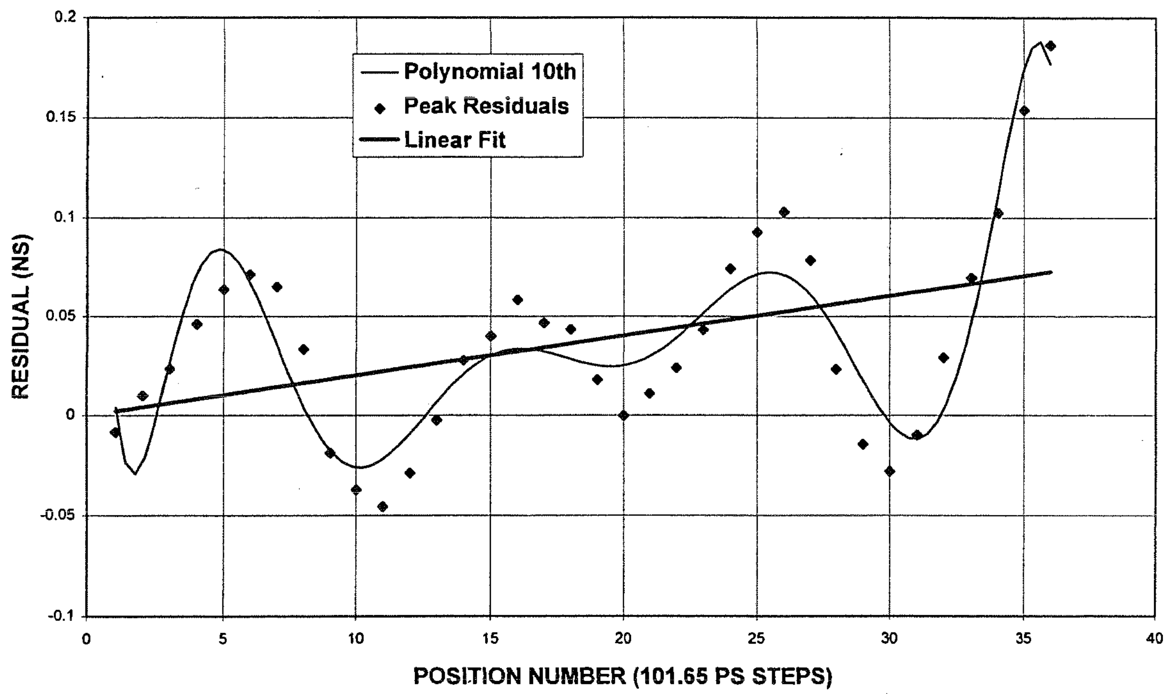
Waveform Plot

- The waveform plots indicate the relative scale of the waveforms.
- Data is shown using the 1 ns/division sweep speed.
- Single pe level is about 50 mV

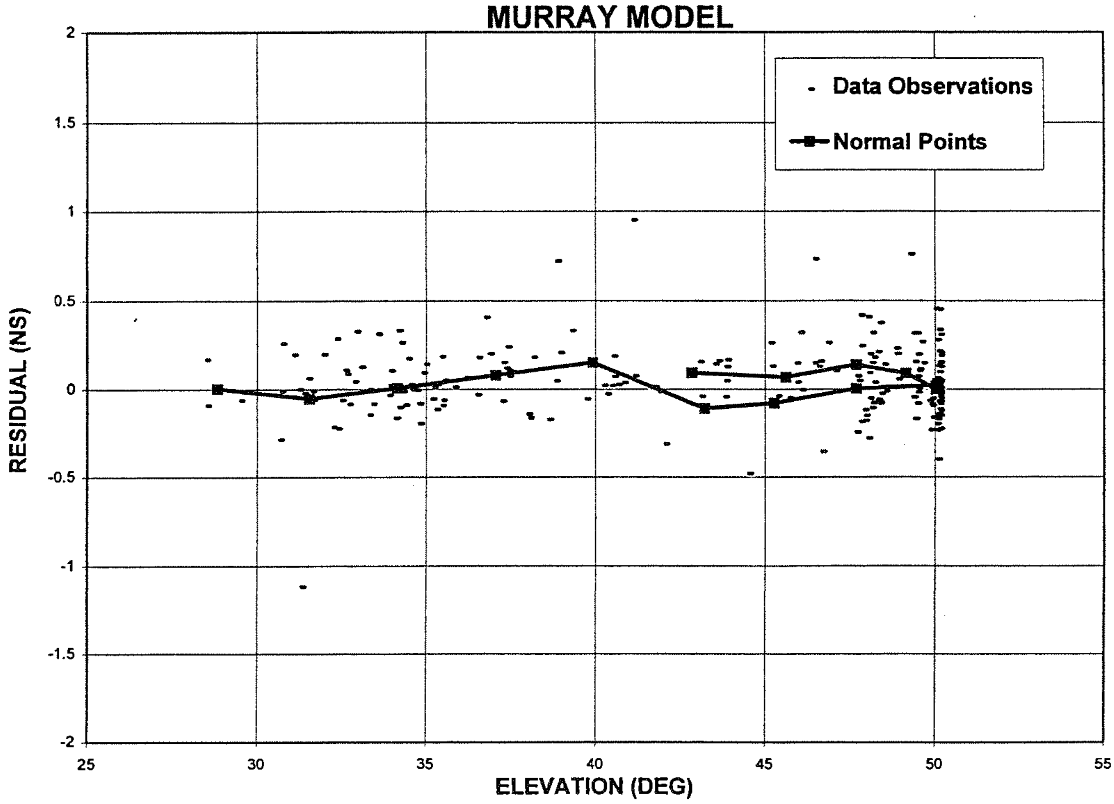
Marini-Murray Comparison Plots

- Individual Satellite Plot contains two segments: Elevation Increasing, Elevation Decreasing.
- Multiple-Pass Plot contains data from 3 passes at different times under slightly different conditions.
- Plots indicate rough agreement with the model.

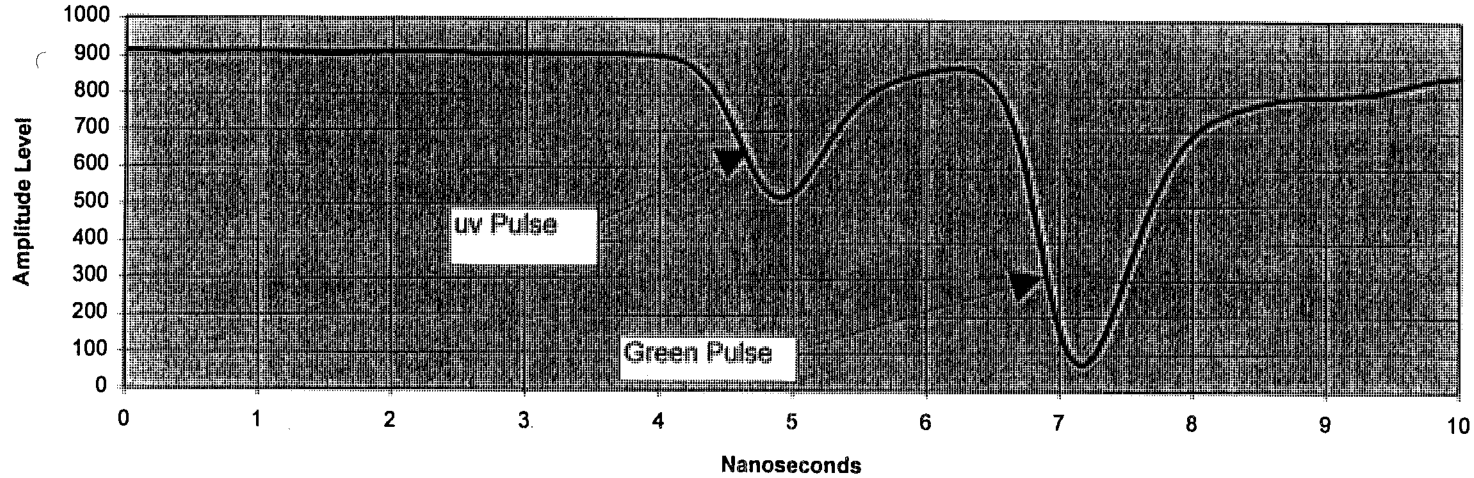
RESIDUALS OF PEAK PROCESSED CALIBRATION DATA JULY 15, 1992

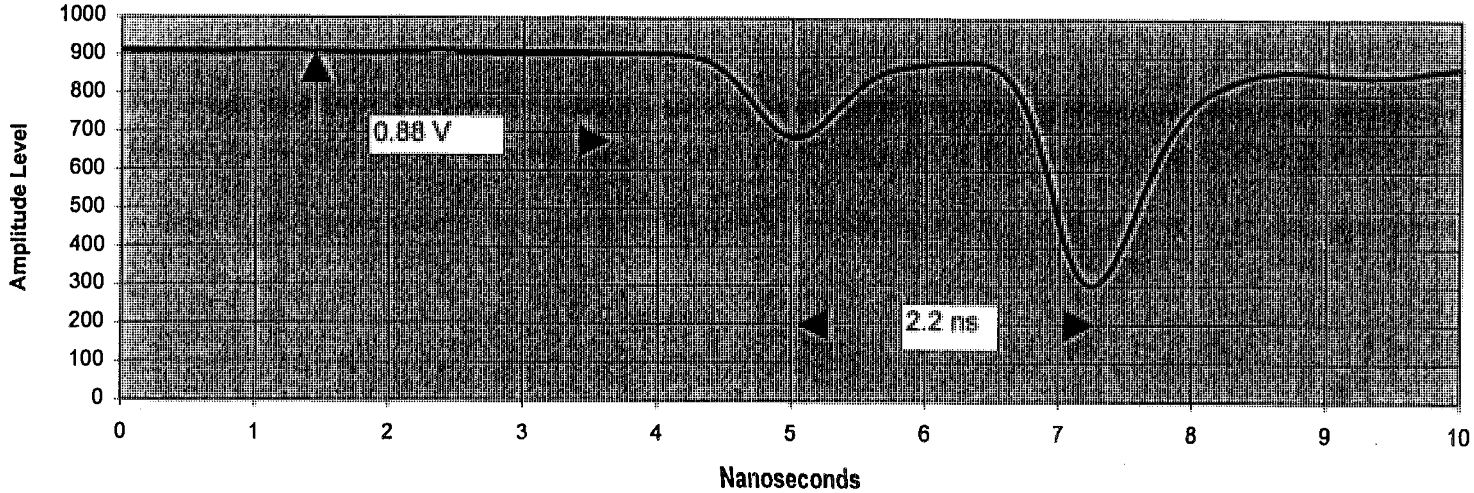


AJISAI (PASS 1) RESIDUALS WITH RESPECT TO THE MARINI-MURRAY MODEL



Digitizer waveforms- STELLA November 28,1994





SYSTEM AUTOMATION AND OPERATIONAL SOFTWARE

Chairperson : Jan McGarry

NSLR PC Software Packages for Normal Point and Acquisition Generation

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*Abstract - Two s*oftware packages for IBM personal computers and their clones has been written and are available on the CDDIS. The first package(PCGNPS) is for the formation of CSTG normal points from MERIT-II full-rate. This package is based upon the NASA/ATSC normal point software that has been producing MERIT-II normal points since 1988. The second package (PCTIVAS) is for the generation of pointing and range predicts from "tuned" IRV's. This software is distributed in both source code and executable form, contains the same integrator as is used to form the IRV's, and is the same software that is used by the NASA SLR HP systems . A technical review of the benchmarks and how the software operates will be presented.

NASA SLR PC Software for Normal Point and Acquisition Generation

Brion Conklin

AlliedSignal Technical Services Corporation

NASA SLR

Ninth International Workshop On Laser Ranging Instrumentation

Canberra, Australia

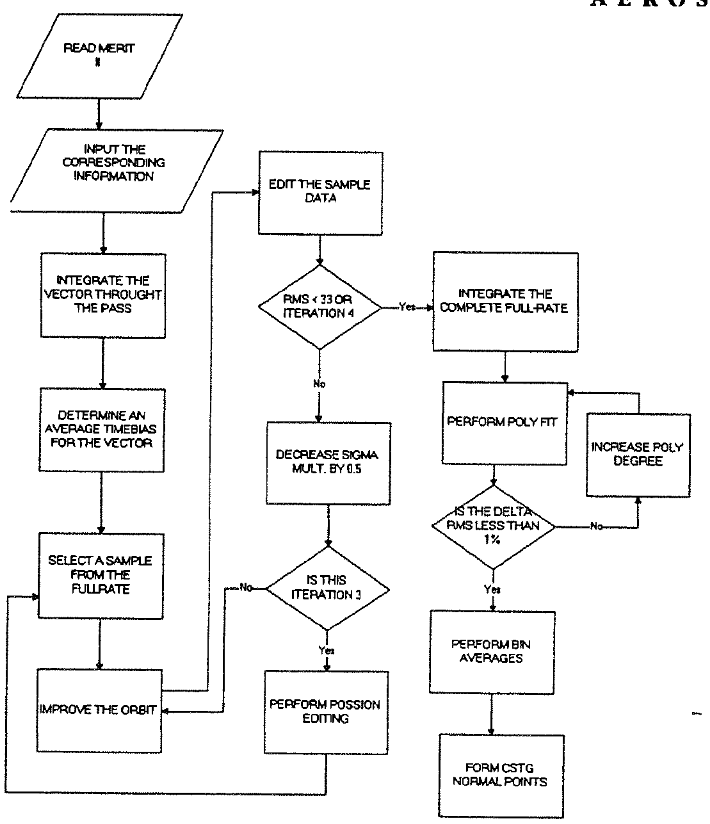
November 7-11 1994

PROJECT OBJECTIVES

- Standardization of Normal Point algorithms and format
- Improve quality of global NP
- Standardization of Acquisition messages to a single format
- Reduce Costs

NORMAL POINT PROJECT STATUS

- VAX based Normal Point software was rehosted to a 80486 PC
- Benchmark completed
- Users guide completed
- Executables and test files released to the CDDIS
- Documentation of the code is in progress



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BENCHMARK SUMMARY

- 20 Global stations used in the benchmark
- December 1993 "A" fullrate release
- 13 of the 20 stations were polyquicked
- 10 satellites
- less than 1 millimeter offset between the PC CSTG NP and VAX MERIT II NP
- less than 1 millimeter offset between the PC CSTG NP and the MERIT II fullrate when compared using polyquick

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ACQUISITION PROJECT STATUS

- Software created to form three types of predictions
- Benchmark completed
- Users guide completed
- Source code and executables with test files released to the CDDIS
- First update to the code due after the conference

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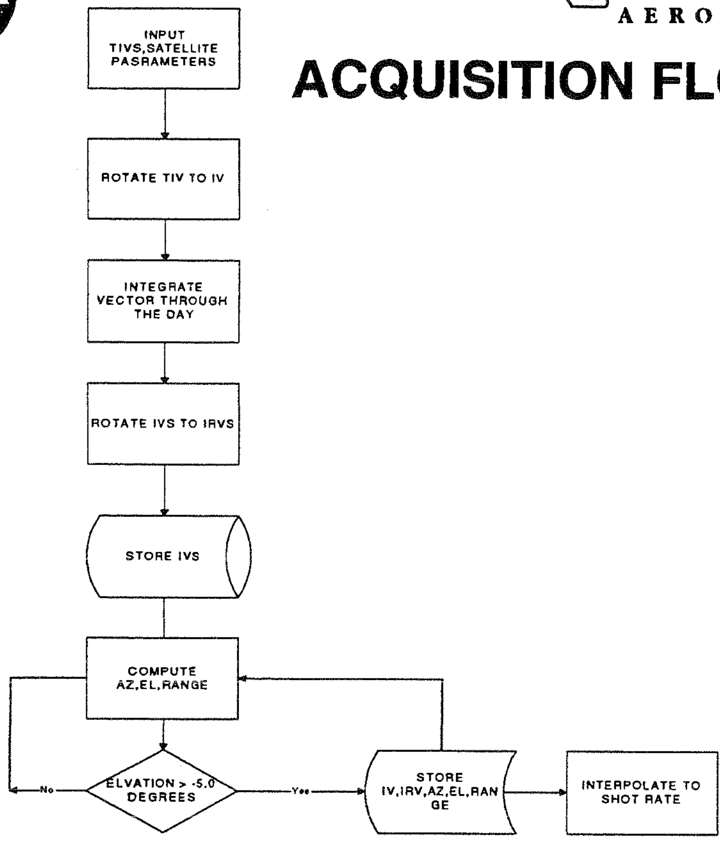
ACQUISITION FLOW



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BENCHMARK

- Acquisition benchmark performed verses the GEODYN ephemeris
- Vectors compared to within the tuned errors

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CONCLUSION

- A PATH TOWARDS STANDARDIZATION HAS BEEN ESTABLISHED FOR QUICKLOOK NORMAL POINTS AND ACQUISITION DATA
- NASA AND ATSC WILL WORK WITH USERS THAT ARE HAVING TROUBLE IMPLEMENTING THE SOFTWARE
- ALL SYSTEMS IN THE WORLD WILL BE PRODUCING NORMAL POINTS IN THE NEAR FUTURE

MOBLAS Controller Upgrade Status

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Abstract - The MOBLAS Controller Upgrade project was begun in 1991 as a means of replacing antiquated ranging control equipment and interfaces that were non-standard and/or difficult to upgrade. These would be replaced with equipment and interfaces that would permit automating MOBLAS subsystems. New automation subsystems can easily be added to the new system such as the mount observer automation system which includes the new radar system and the GPS steered rubidium as well as others. Remote diagnosis of system problems can be easily performed using the IEEE driver to communicated to various subsystems for which extensive diagnostics have been developed. Also, by reducing the size and amount of hardware needed to operate a MOBLAS system and reconfiguring the existing and new equipment into a single trailer, the operator can have control of the entire ranging and analysis system from one location which may one day permit single crew operation.

The prototype design is currently being tested with MOBLAS-7 at the Goddard Space Flight Center through a collocation experiment. Following the successful completion of the collocation, the field implementation system is scheduled to be installed in MOBLAS-7. The current status and future plans for this project are discussed in this paper along with a review of data taken to date.

MOBLAS CONTROLLER UPGRADE STATUS

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Presented for the 9th International Workshop on Laser Ranging Instrumentation
Canberra, Australia
November 7-11, 1994

Agenda

- System Reconfiguration Theory and Method
- System Improvements in the MOBLAS Systems
- Automation Advantages with Controller
- Data Results with the MOBLAS-6 Upgrade

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System Reconfiguration Theory and Method

- OLD LAYOUT REQUIRED TWO VANS
  - INSTRUMENTATION VAN FOR TIMING, HP, AND TDPS TRACKING COMPUTER
  - MOMS VAN FOR TRACKING CONSOLE EQUIPMENT
  - DIFFICULT FOR ONE PERSON TO OPERATE
  - TIMING AND HP WERE IN SEPARATE VANS FROM CONSOLE
  - POSSIBLE UNCERAINTIES IN TRANSMIT DELAY DUE TO LONG TIMING CABLES BETWEEN VANS

- NEW LAYOUT IN ONE VAN
  - ALL HARDWARE CONFIGURED IN ONE VAN (MOMS)
  - EASIER FOR ONE PERSON TO OPERATE
  - REQUIRES LESS OVERALL SPACE
  - HP IN MOMS VAN ALLOWS OPERATOR TO MONITOR HP ACTIVITY
  - TIMING IN MOMS CAN ALLOWS OPERATOR TO MONITOR TIMING

ATSC/NASA SLR/S. Wetzel

November 10, 1994

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SYSTEM IMPROVEMENTS IN THE MOBLAS SYSTEMS

OLD	NEW	ADVANTAGES
12 RACKS IN 2 VANS	6 RACKS IN 1 VAN	* LESS SPACE REQUIRED * BETTER TEMPERATURE STABILITY * EASE OF OPERATION * FUNCTIONAL GROUPING MORE PRACTICAL
TDPS TRACKING RACKS, 486 COMPUTER	486 PC	* SMALLER, TDPS USES 3 USES 9 INCHES * FASTER, ABLE TO SUPPORT
NEW Software		* BETTER INTERFACES, RS232, GPIB, CAMAC, ETHERNET * ALLOWS FOR MULTI-TASKING * ENHANCED DIAGNOSTICS, MANY WILL BE REMOTE

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SYSTEM IMPROVEMENTS IN THE MOBLAS SYSTEMS cont.

OLD	*NEW*	*ADVANTAGES*
IACC CAMAC	CAMAC	* SMALLER, IACC USES 1 RACK, USES 17 INCHES * BETTER TEMPERATURE STABILITY * MAINTENANCE BENEFITS * EXCELLENT DIAGNOSTICS * REMOTE DIAGNOSTICS POSSIBLE
LRC DRAWER TASKS	MODIFIED LRC	* LESS CHIPS, 486 TAKES OVER MANY * LESS POWER NEEDED WITH CMOS CHIPS * REMOTE DIAGNOSTICS ARE POSSIBLE WITH CAMAC & 486 * DIAGNOSTICS TO THE CHIP GROUP LEVEL
SERVO INTERFACE	MODIFIED SERVO INTERFACE RELIABLE	* 1 PLANE FROM EACH REMOVED * LESS CABLING AND MORE * REMOTE DIAGNOSTICS ARE POSSIBLE WITH CAMAC & 486

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AUTOMATION ADVANTAGES WITH THE CONTROLLER

- SUBSYSTEM DIAGNOSTICS
  - CURRENTLY ON STATION TO COMPONENT LEVEL
  - PLANS FOR REMOTE DIAGNOSTICS
  - ALLOWS TROUBLESHOOTING FROM HEADQUARTERS
- AUTOMATED FIELD OF VIEW (FOV)
- RANGE AND TIME BIASES
- TIE-INS FOR NEW PERIPHERALS
  - RADAR
  - BAROMETER
  - STEERED RUBIDIUM
  - AUTOMATED TIMING
  - READ TIME CODE GENERATOR TIME REMOTELY

DATA RESULTS WITH THE MOBLAS-6 PROTOTYPE

- INTERCOMPARISON WITH MOBLAS-7 PRIOR TO MOMS VAN REFURBISHMENT
  - MULTIPLE SATELLITE RESULTS
  - GOOD AGREEMENT TO MOBLAS-7 (<1CM BIAS)
- SYSTEM BACK ON LINE FOLLOWING VAN REFURBISHMENT IN 6 WEEKS
  - MOUNT, LASER & RANGING HARDWARE REINSTALLED, INTEGRATED & TESTED
  - SYSTEM CONFIGURATION WAS MAINTAINED
- MOBLAS-6 IN COLLOCATION WITH MOBLAS-7
  - PRECOLLOCATION DATA SHOWS STRONG RANGING CAPABILITY

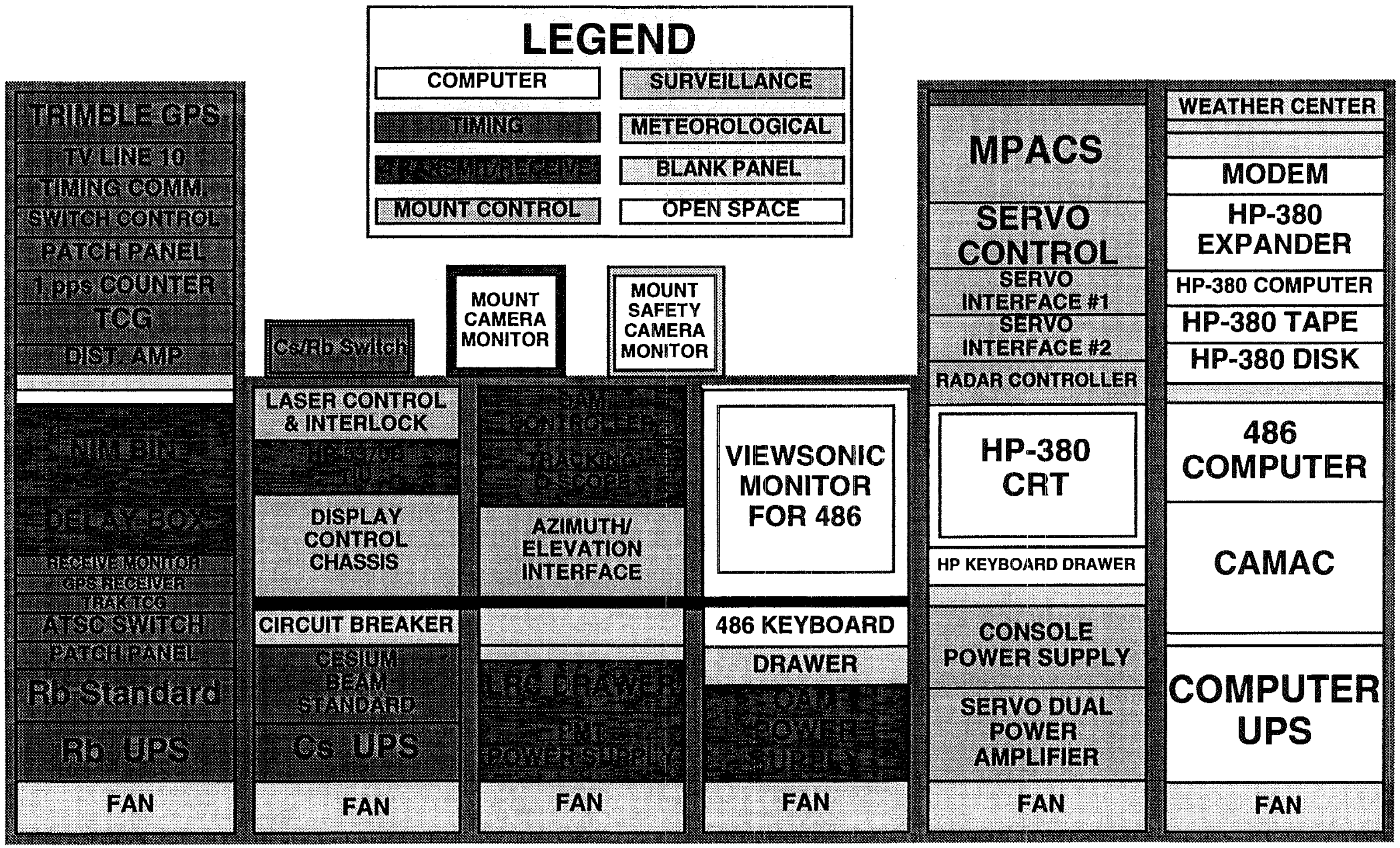
ATSC/NASA SLR/S. Wetzel

November 10, 1994

MOBLAS CONTROLLER UPGRADE FUTURE

- MOBLAS-6 PROTOTYPE INSTALLED AND UNDERGOING COLLOCATION WITH MOBLAS-7
- MOBLAS-7 CONTROLLER UPGRADE STARTING JANUARY 1995
- MOBLAS-6 RETROFIT FOR FIELD IMPLEMENTATION HARDWARE STARTING APRIL 1995
- MOBLAS-4 UPGRADE STARTING MAY 1995
- MOBLAS-8 UPGRADE STARTING AUGUST 1995
- MOBLAS-5 UPGRADE STARTING OCTOBER 1995

NEW MOBLAS RACK LAYOUT



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7–11 November 1994

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