DESIGN OF LASER RETRO-REFLECTOR ARRAY AND LASER RANGING EXPERIMENT FOR SHENZHOU-IV SATELLITE

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- **The China's fourth unmanned spacecraft "Shenzhou IV" was launched on December 30, 2002**
- **One module of the spacecraft returned to earth on January 6, 2003**
- **The other part, the orbital module, remained in the orbit and carried on some scientific experiment.**
- **One of the instruments on board was the microwave altimeter for sea level measurement**
- **A laser retro-reflector array and a GPS receiver onboard for precise orbit determination.**

Configuration of LRA

Diameter: 20cm

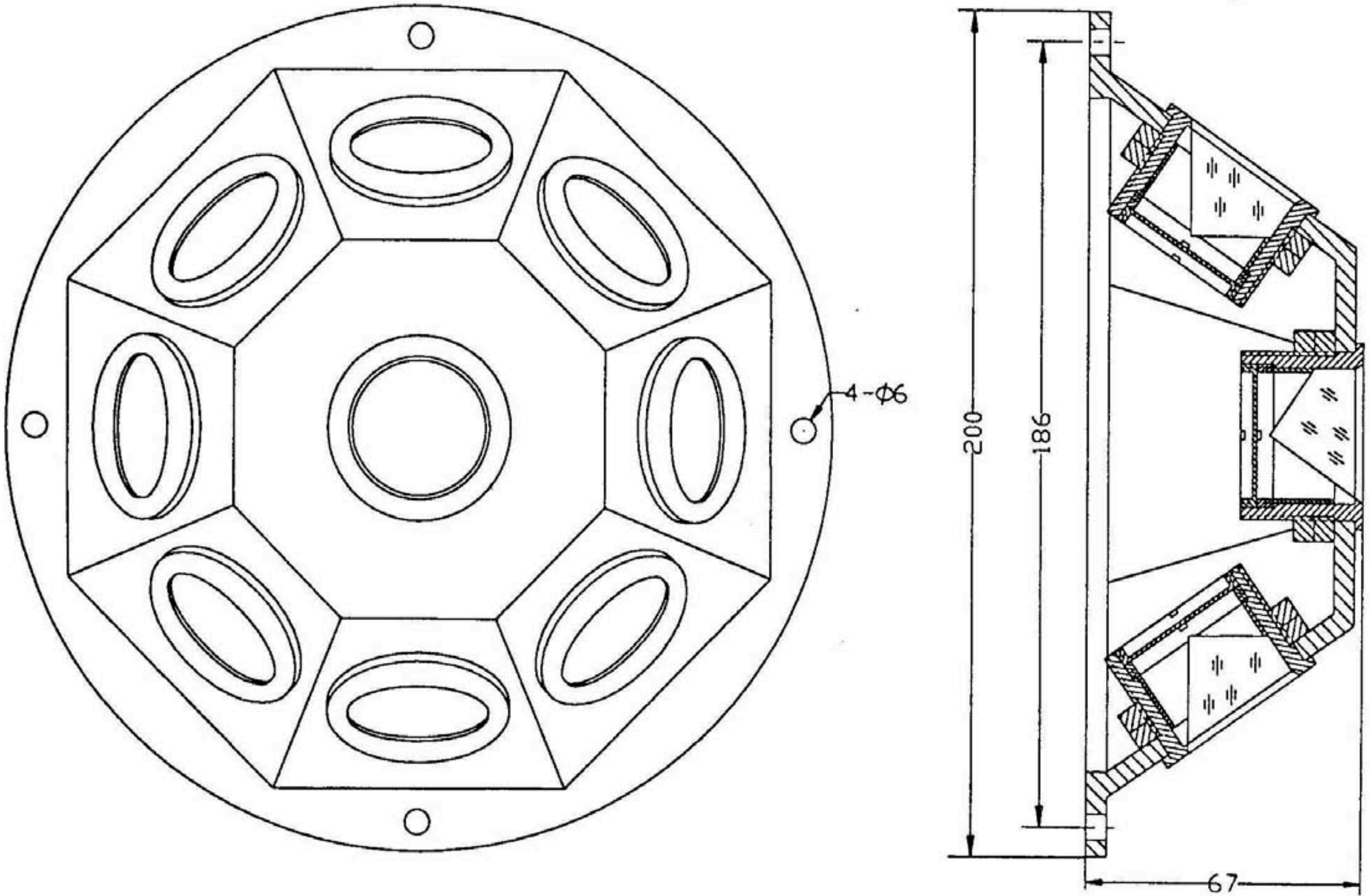
Corner cubes: 9

Material: Fused quartz

Weight: 850g

LRA was designed and manufactured by the Shanghai Observatory

"Shenzhou IV"
Laser Reflector Array



Mechanical Drawing

Calculation of Effective Reflection Area of Shenzhou IV Satellite

1. Calculation for the incidence angle of laser beam with respect to the retro-reflector that has an inclination angle with the normal plane pointing to the Earth's center

n

Effective area of the retro-reflector

The relation between the incidence angle and the relative effective area is given by:

$$\eta = \frac{2}{\pi} \cdot \left(\sin^{-1} \mu - \sqrt{2} \cdot \mu \cdot tg i_r \right) \cos i_0$$

where , $\mu = \left(1 - 2tg^2 i_r\right)^{1/2}$, $\quad i_r = \sin^{-1}\left(\frac{\sin i_0}{n}\right)$

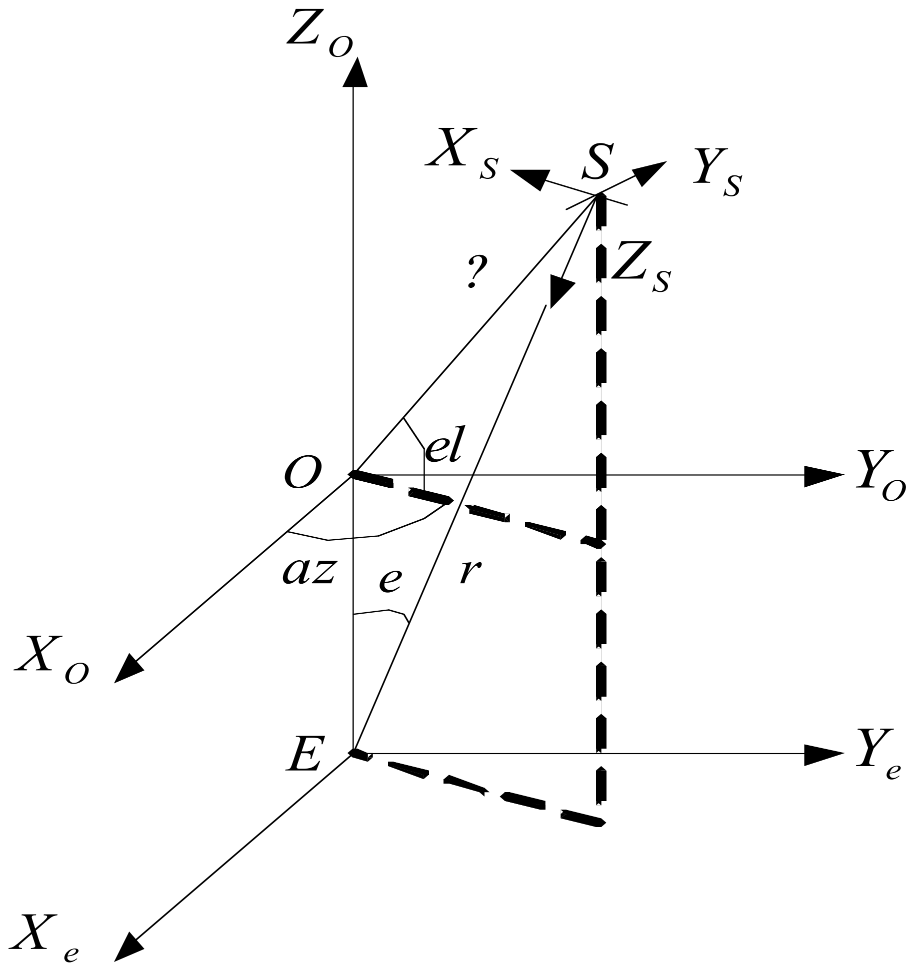
η is relative effective geometric area,

i_0 is incidence angle of laser beam,

i_r is refraction angle of laser beam,

n is index of refraction for retro-reflector, usually the retro-reflector is made of fused quartz (n=1.445).

While i_0=0, then η=1.



Three coordinate systems

The unity length vector of the laser beam both in station coordinate system and in geocentric coordinate system is the same:

$$\vec{L} = \begin{bmatrix} \cos(el)\cos(az) \\ \cos(el)\sin(az) \\ \sin(el) \end{bmatrix}$$

In geocentric system, the unity length vector of the satellite position is:

$$\vec{S} = \begin{bmatrix} \sin(e)\cos(az) \\ \sin(e)\sin(az) \\ \cos(e) \end{bmatrix}$$

Here, e is geocentric angle of satellite $\square SEO$ and can be gotten by :

$$e = \arcsin\left[\frac{\square}{r_s} \square \cos(el)\right]$$

Where

- $\square$ **is the slant distance from the station to the satellite.**
- r_s **is geocentric distance of the satellite.**

In satellite coordinate system, the normal vector of retro-reflector is:

$$\vec{n} = \begin{bmatrix} n_x \\ n_y \\ n_z \end{bmatrix} = \begin{bmatrix} \cos\square\sin\square \\ \sin\square \\ \cos\square\cos\square \end{bmatrix}$$

The transformation from satellite coordinate system to geocentric coordinate system is as follows:

$$\begin{bmatrix} x_e \\ y_e \\ z_e \end{bmatrix} = \begin{bmatrix} \cos(az) & \square\sin(az) & 0 \\ \sin(az) & \cos(az) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos(e) & 0 & \sin(e) \\ 0 & 1 & 0 \\ \square\sin(e) & 0 & \cos(e) \end{bmatrix} \begin{bmatrix} \cos(c) & \square\sin(c) & 0 \\ \sin(c) & \cos(c) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_s \\ y_s \\ z_s \end{bmatrix}$$

Where $c = \square\arctan[\tan(az)\square\cos(e)]$

$\vec{N}$

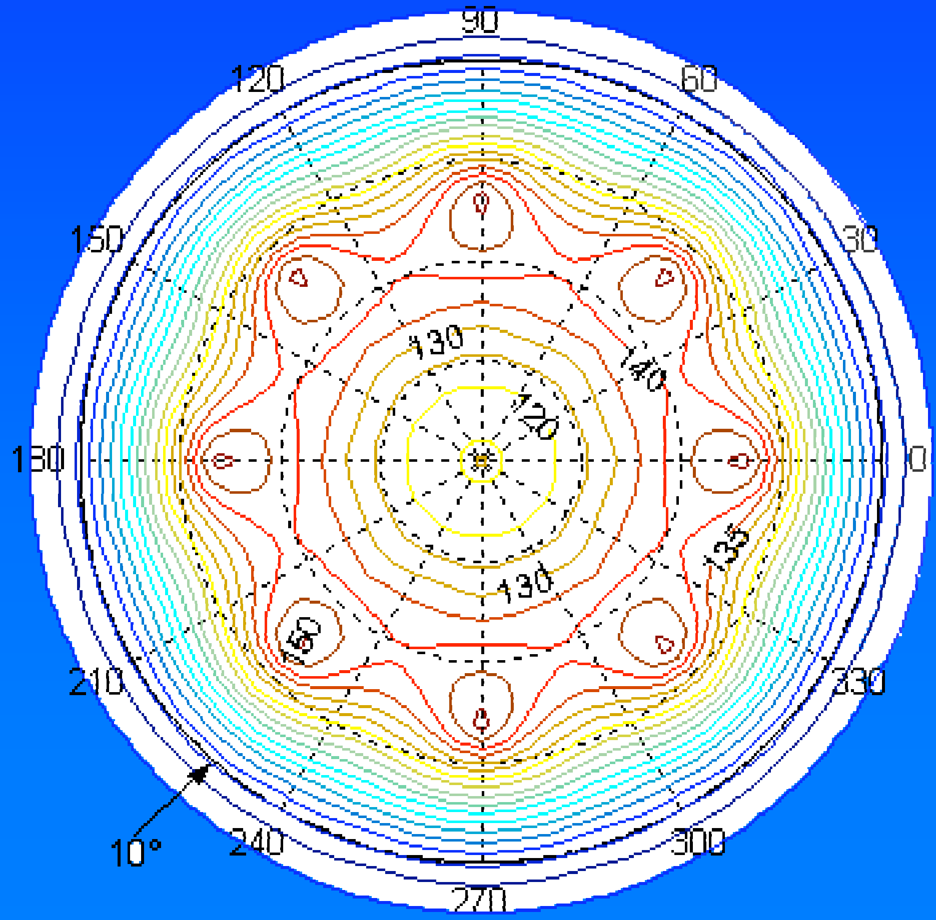
In geocentric coordinate system, the unity length vector of the normal of the retro-reflector $\vec{N}$ is:

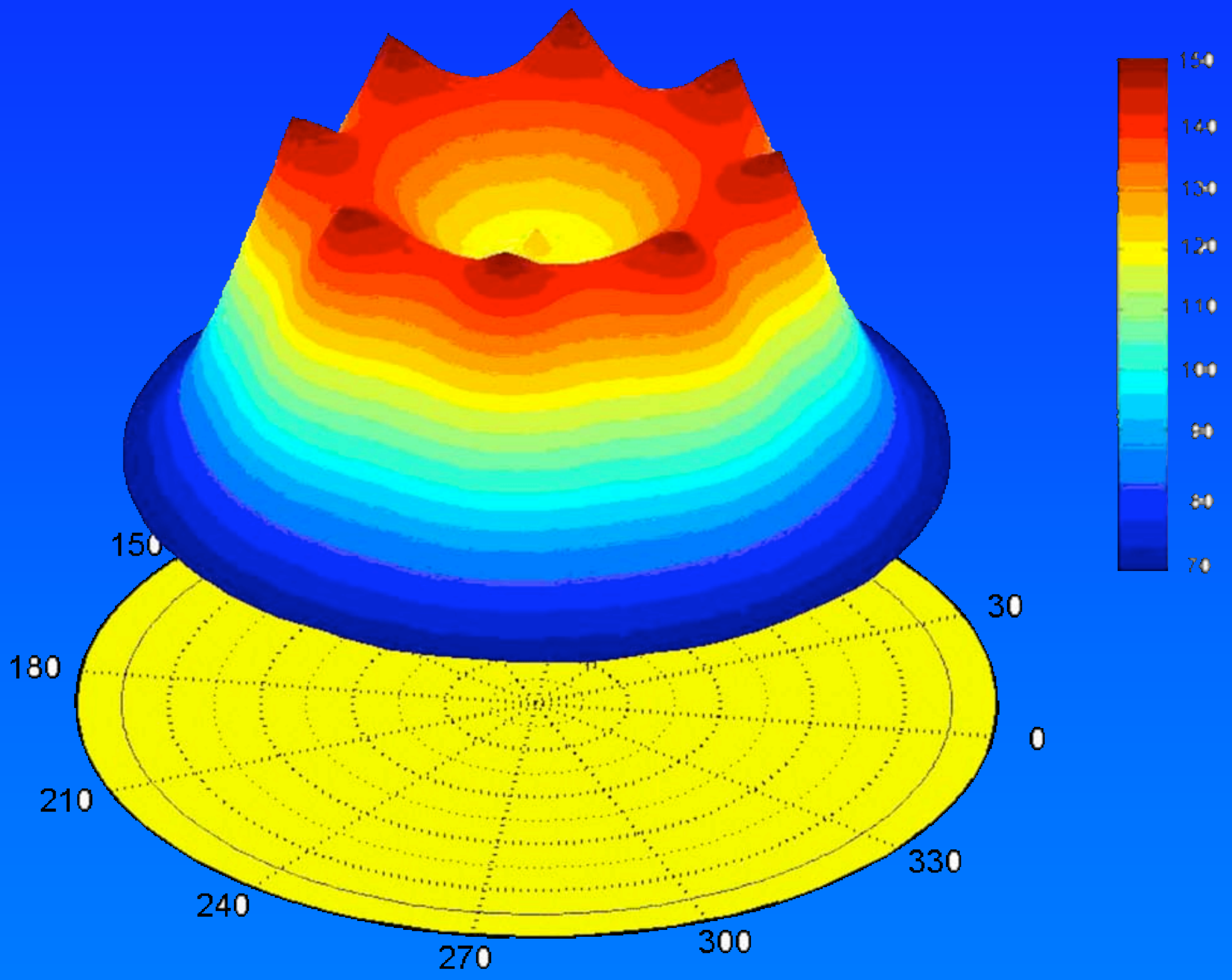
$$\begin{pmatrix} N_x \\ N_y \\ N_z \end{pmatrix} = \begin{pmatrix} \cos(az) & -\sin(az) & 0 \\ \sin(az) & \cos(az) & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos(e) & 0 & \sin(e) \\ 0 & 1 & 0 \\ -\sin(e) & 0 & \cos(e) \end{pmatrix} \begin{pmatrix} \cos(c) & -\sin(c) & 0 \\ \sin(c) & \cos(c) & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} n_x \\ n_y \\ n_z \end{pmatrix}$$

The incidence angle of laser beam to the reflector is given by:

$$i = \arccos(\vec{L} \cdot \vec{N})$$

2. Calculation result of distribution of effective reflection area on Shenzhou-IV LRA





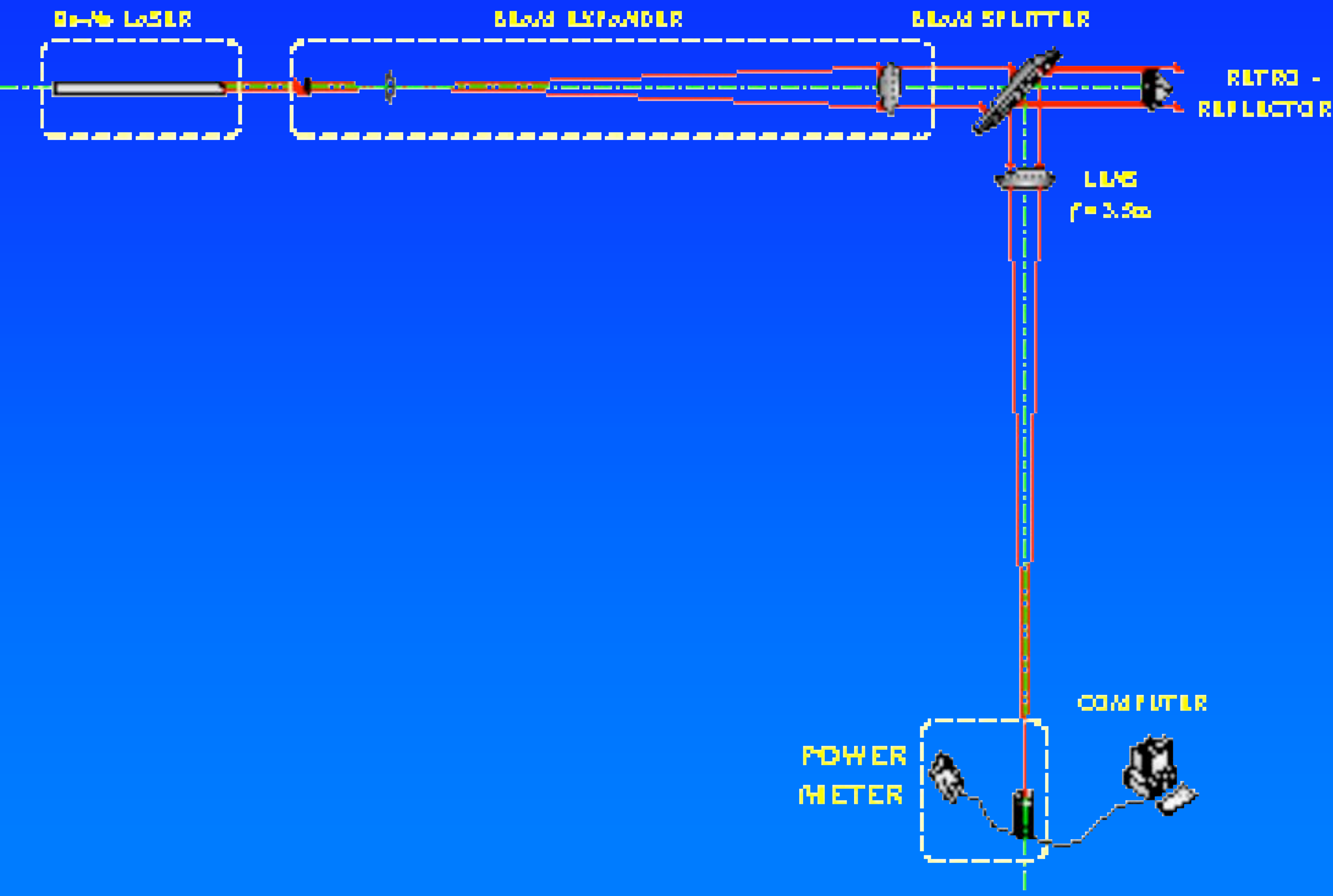
3-D distribution pattern of effective reflection area of LRA

Optical Tests of LRA

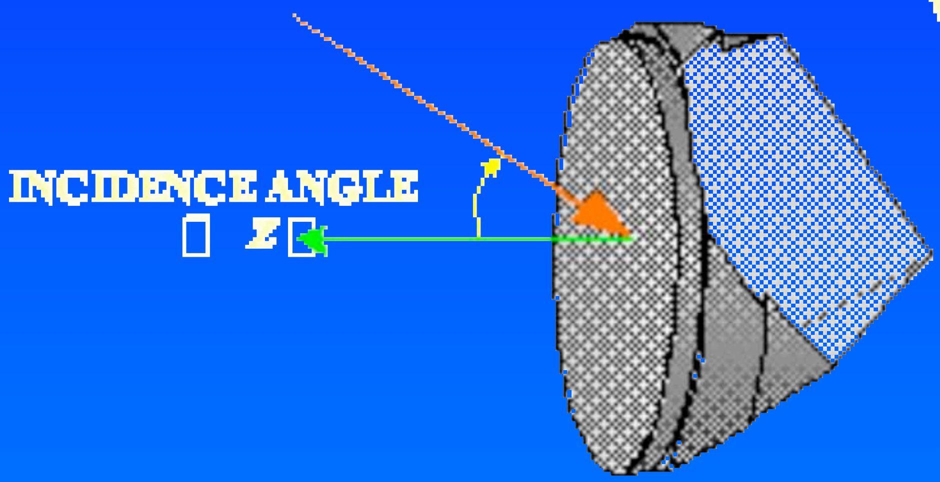
1. Test of the surface flatness and divergence of LRA are with ZYGO Interferometer.

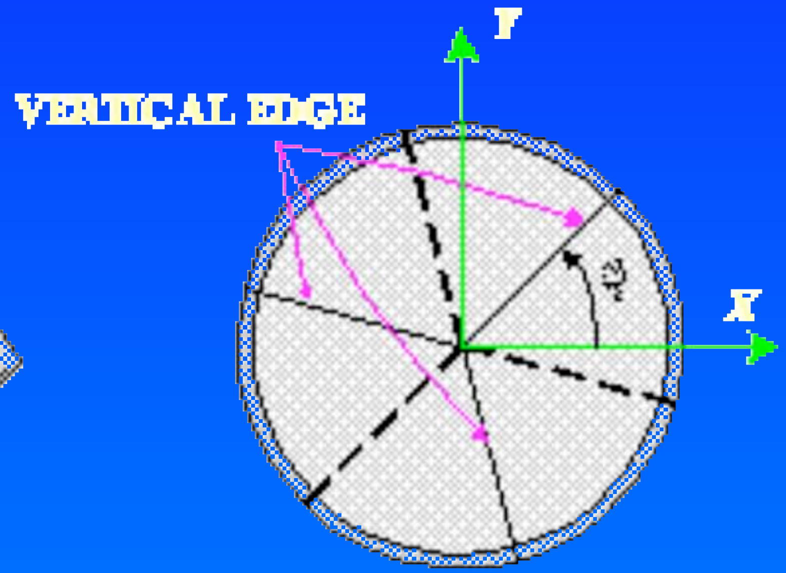
   Divergence of reflectors are 10-16 arcsec.

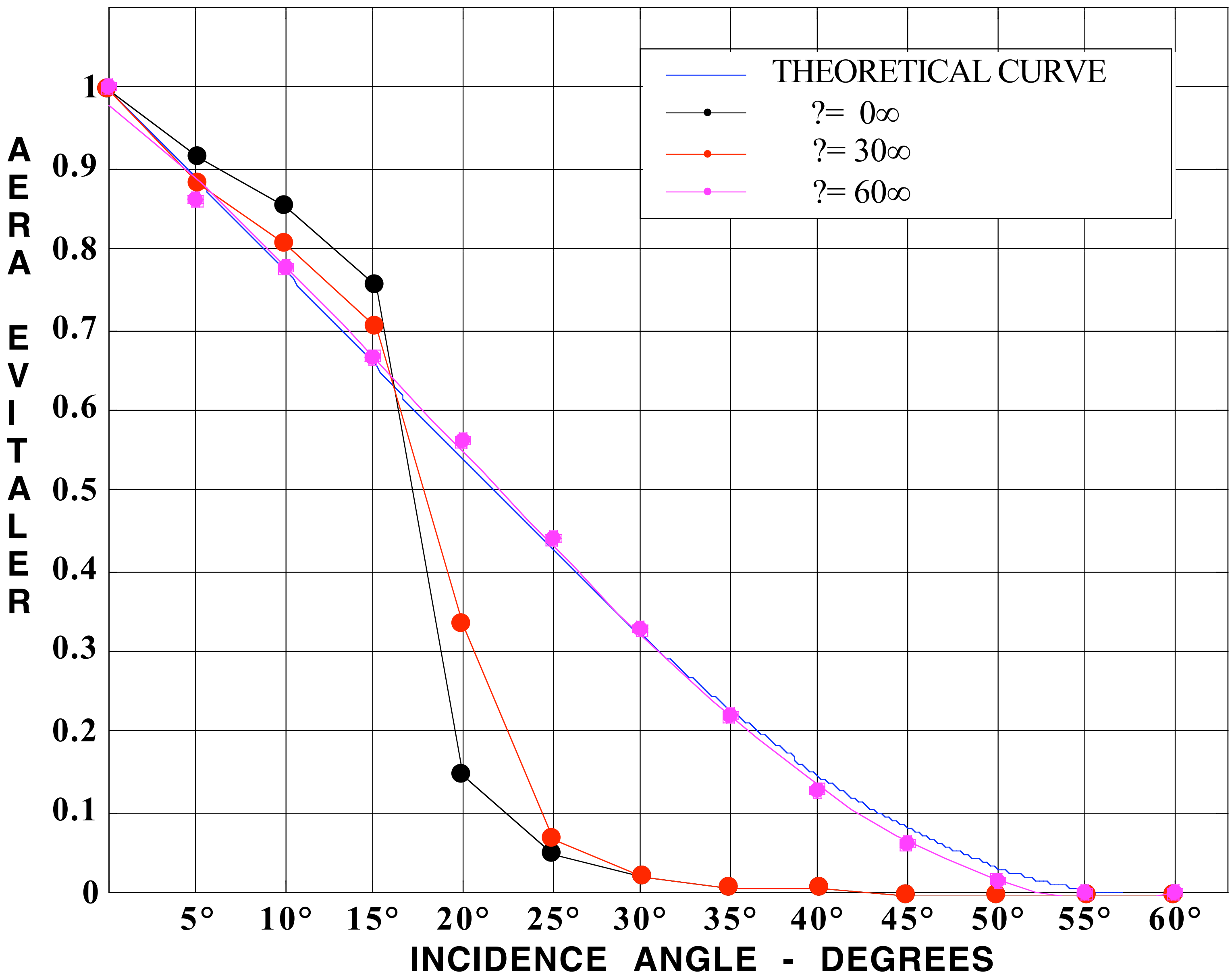
2. Relative Reflection Area Measurement
3. Optical Reflectivity Measurement
4. Far Field Diffraction Pattern Measurement



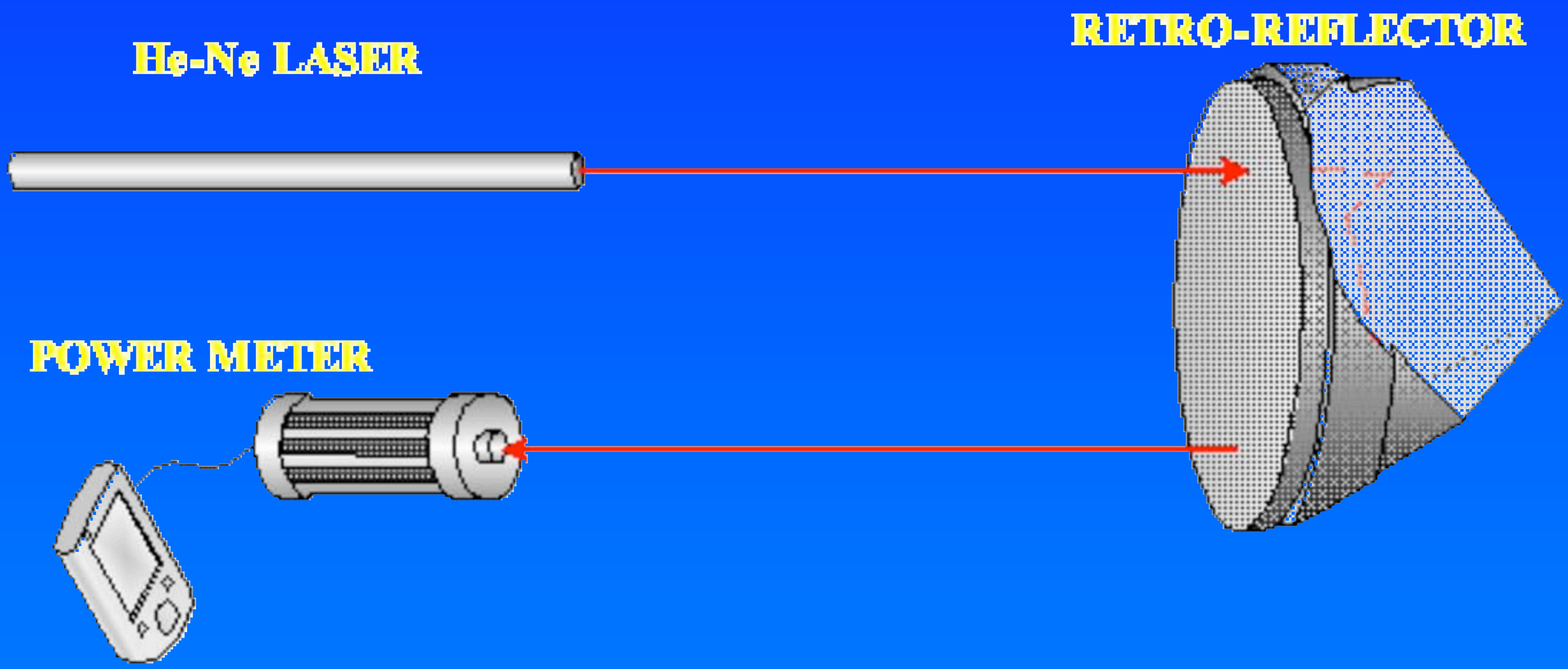
Relative Reflection Area Measurement


INCIDENCE ANGLE
Z

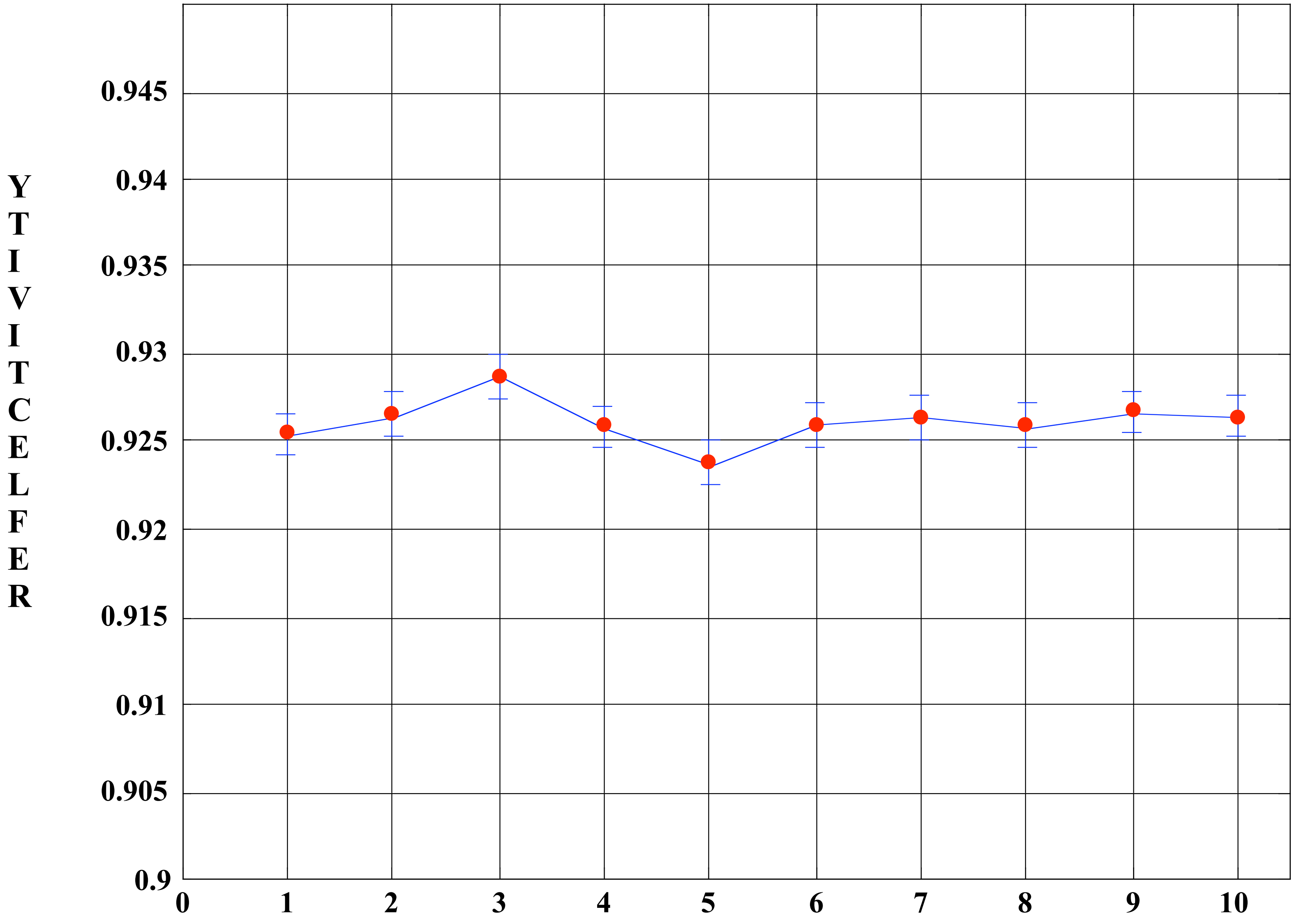

Y
VERTICAL EDGE
X



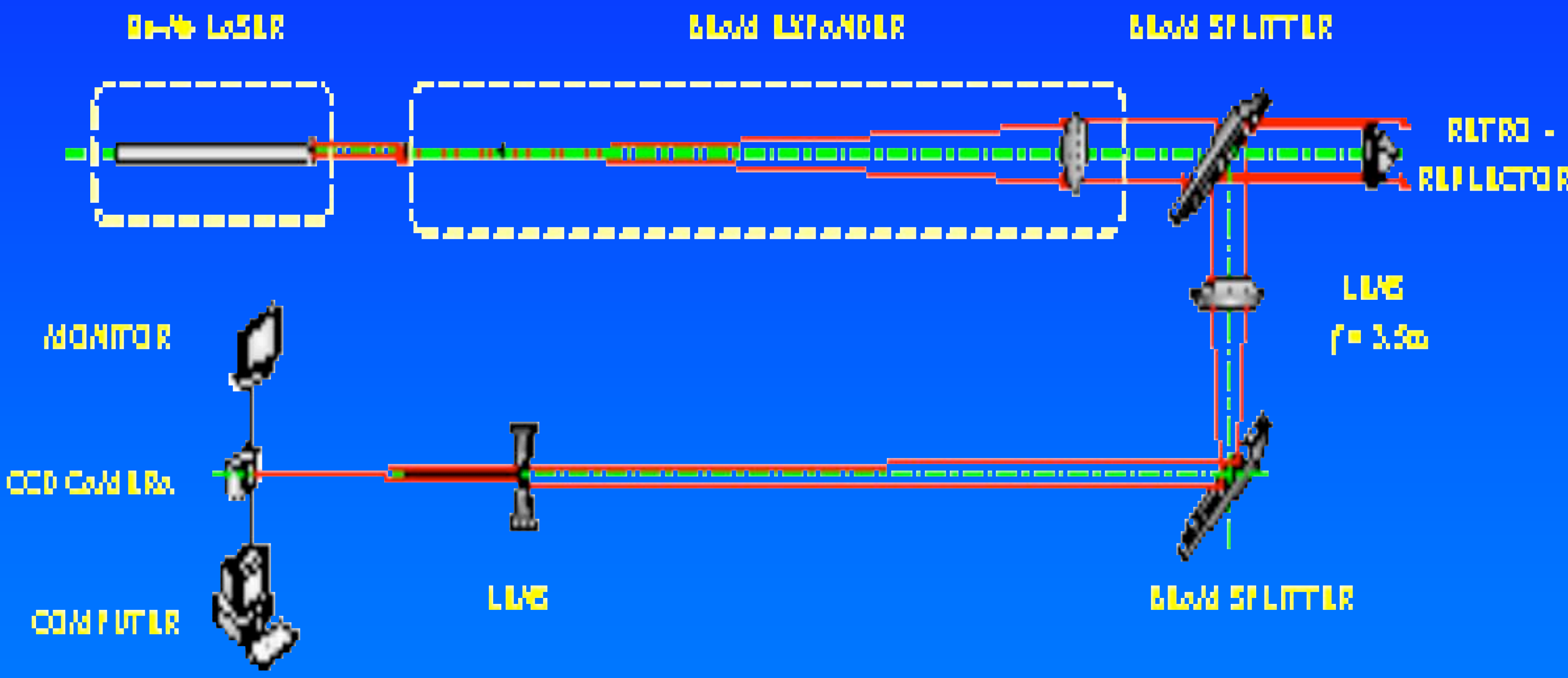
THEORETICAL CURVE
?= 0∞
?= 30∞
?= 60∞
AERA EVITALER
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5°
10°
15°
20°
25°
30°
35°
40°
45°
50°
55°
60°
INCIDENCE ANGLE - DEGREES



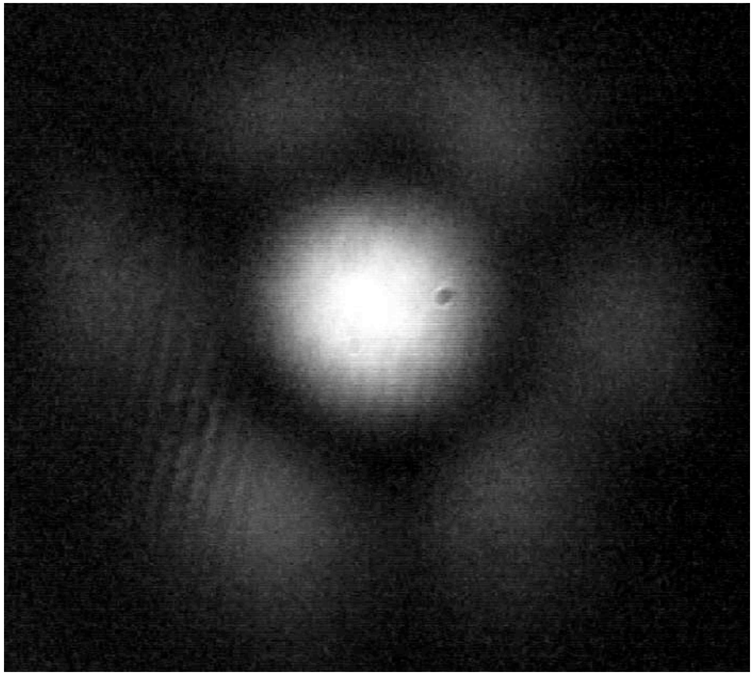
Optical Reflectivity Measurement

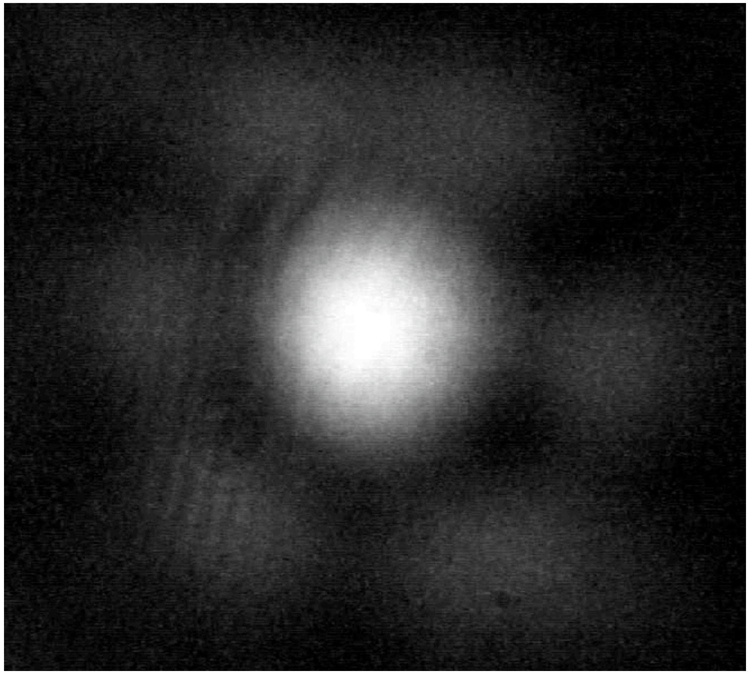


Optical Reflectivity Measurement of LRA



Far Field Diffraction Pattern Measurement





Far Field Diffraction Patterns

Laser Ranging Campaign of Shenzhou IV in China

- Since January 7, 2003, the Beijing, Shanghai, Changchun, Wuhan and BeijingA (Argentina) stations started to track the orbital module at an altitude of 350 KM
- Supported by the USB (United S-Band Ranging and Range Rate) system, and pass by pass precise orbit prediction provided by the Xi'an Mission Control Center, the 5 stations can track the module even in the earth shadow
- 82 passes experimental ranging data were obtained during January-March, 2003.

Chinese SLR Network

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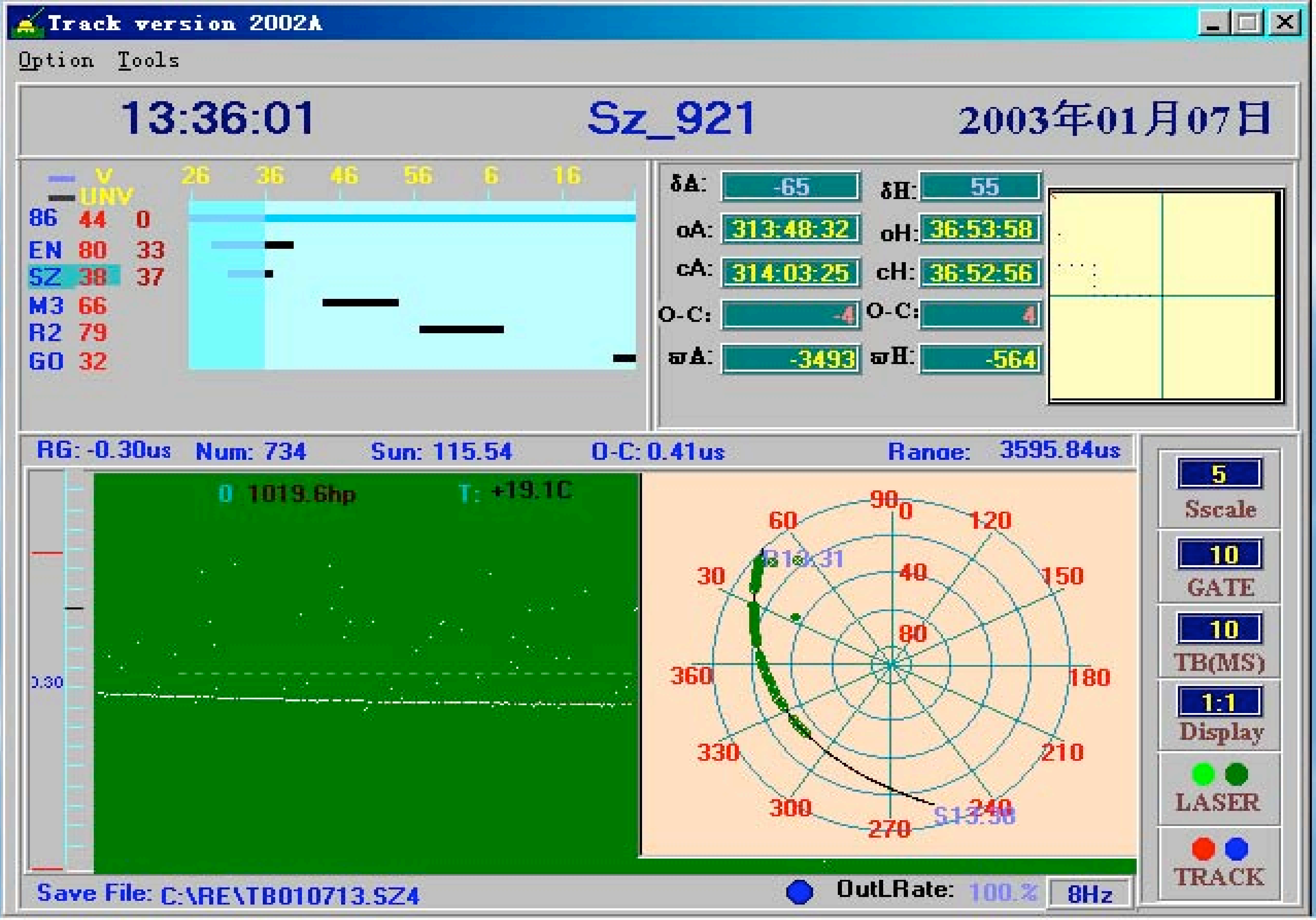
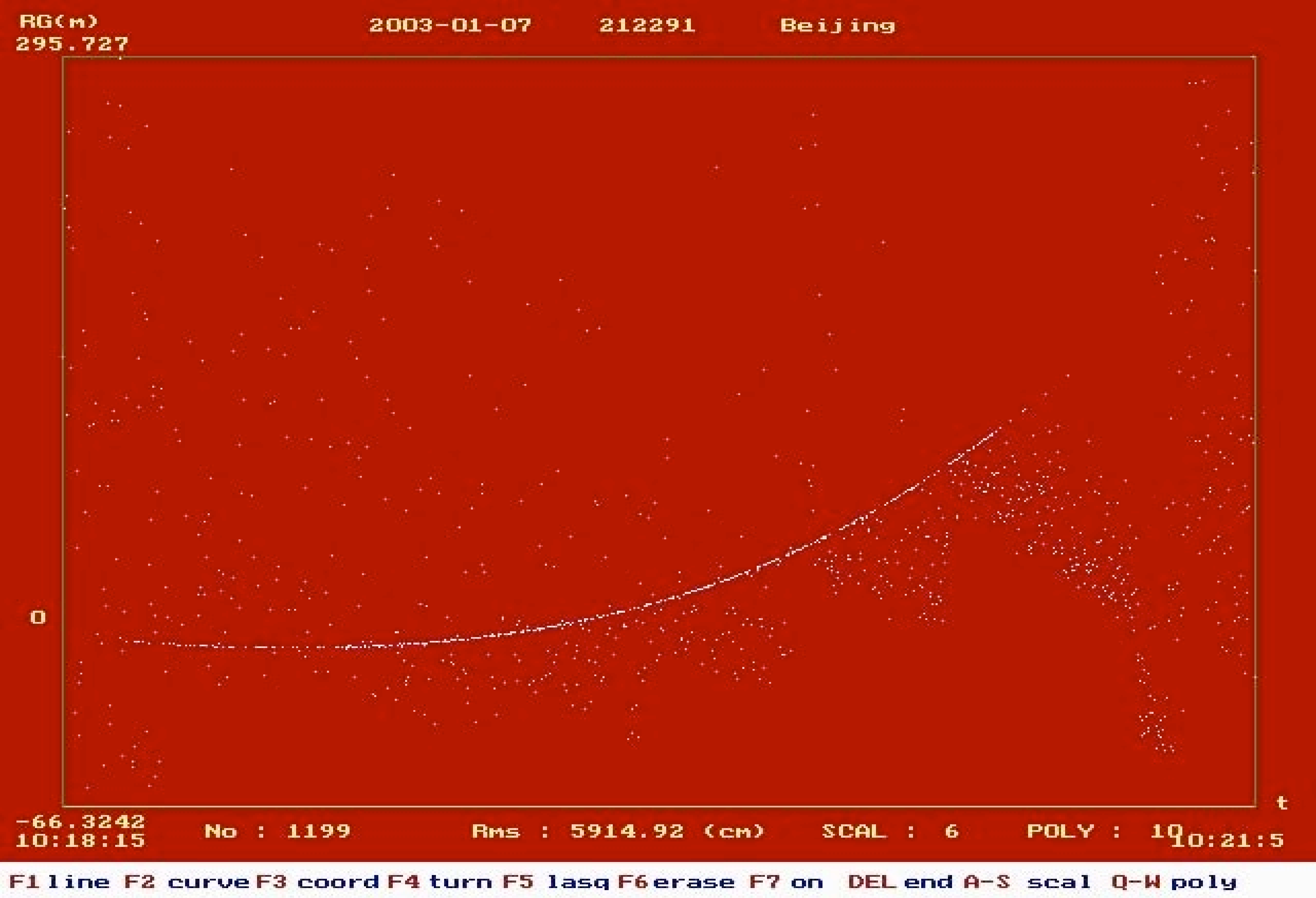
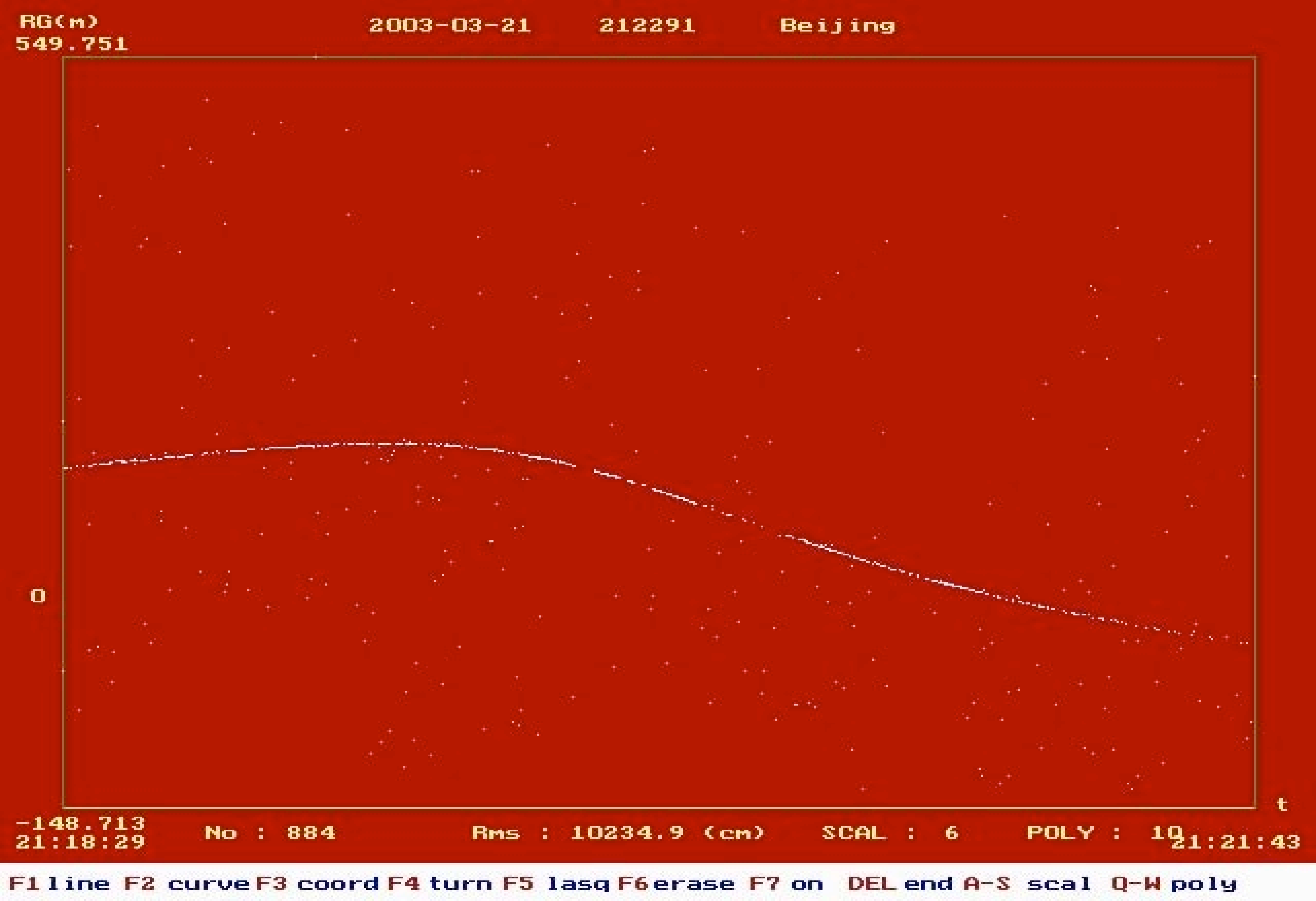


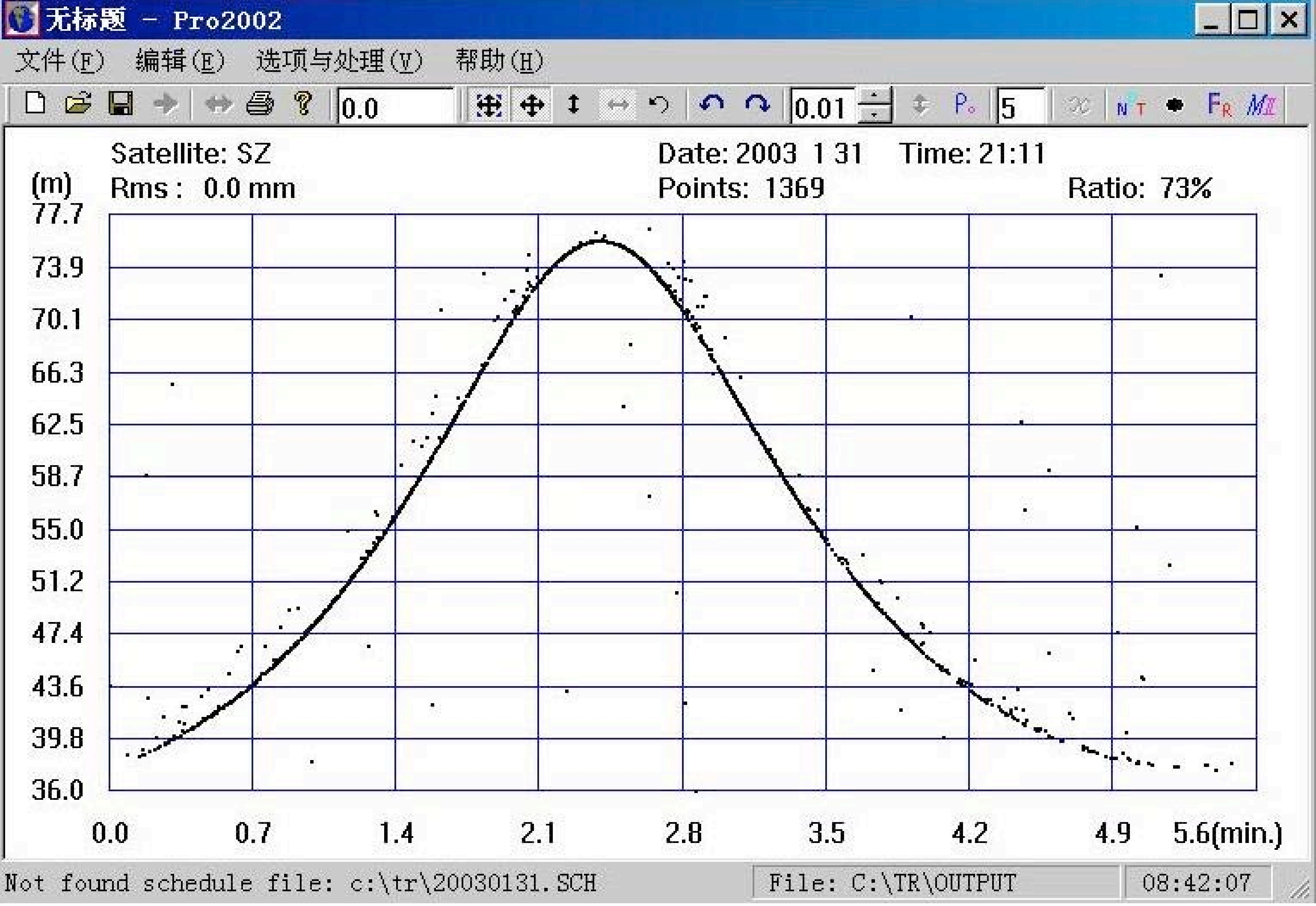
Real Time Display of Shenzhou IV Tracking at Shanghai



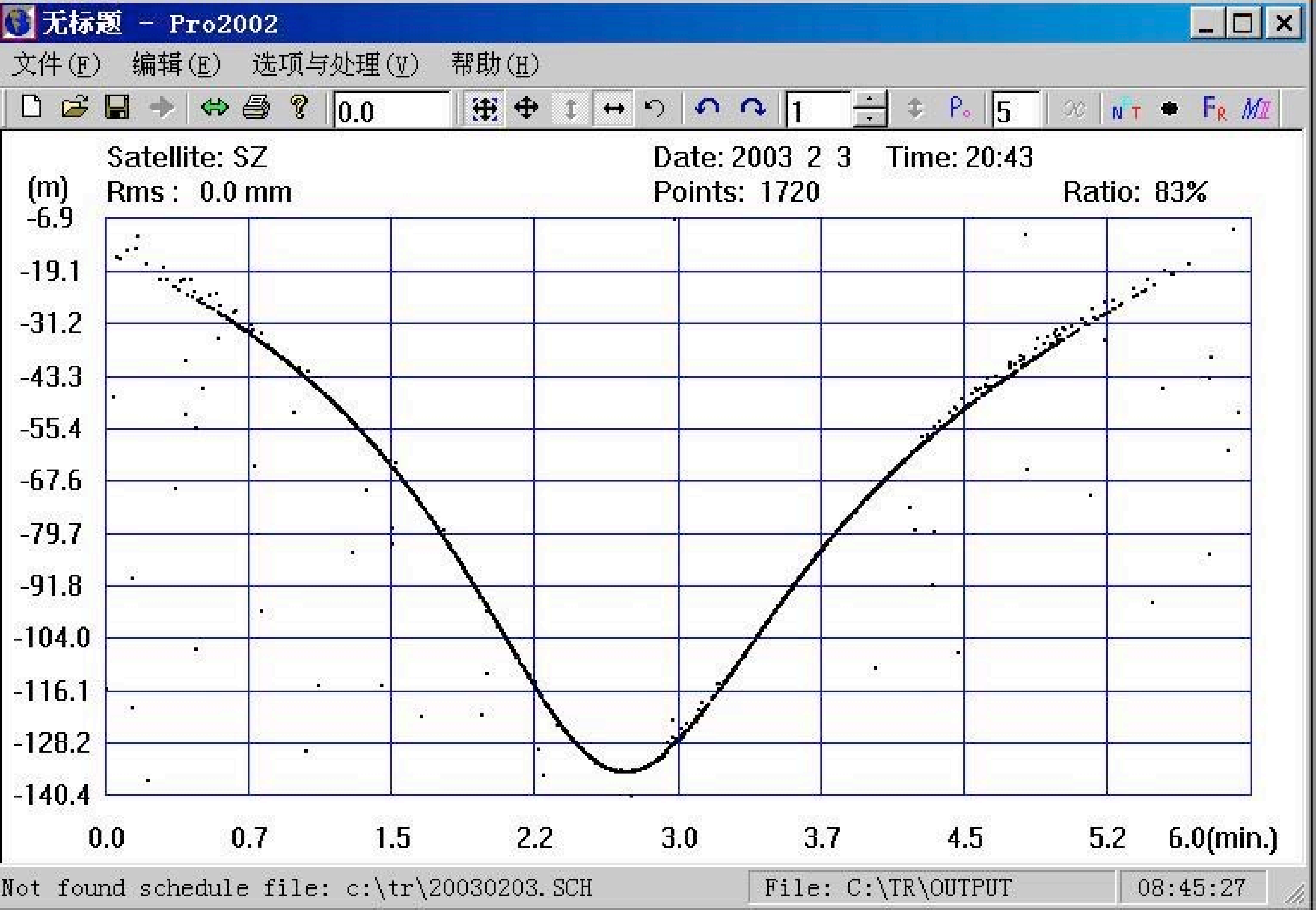
The First Pass at Beijing Station on Jan.7, 2003



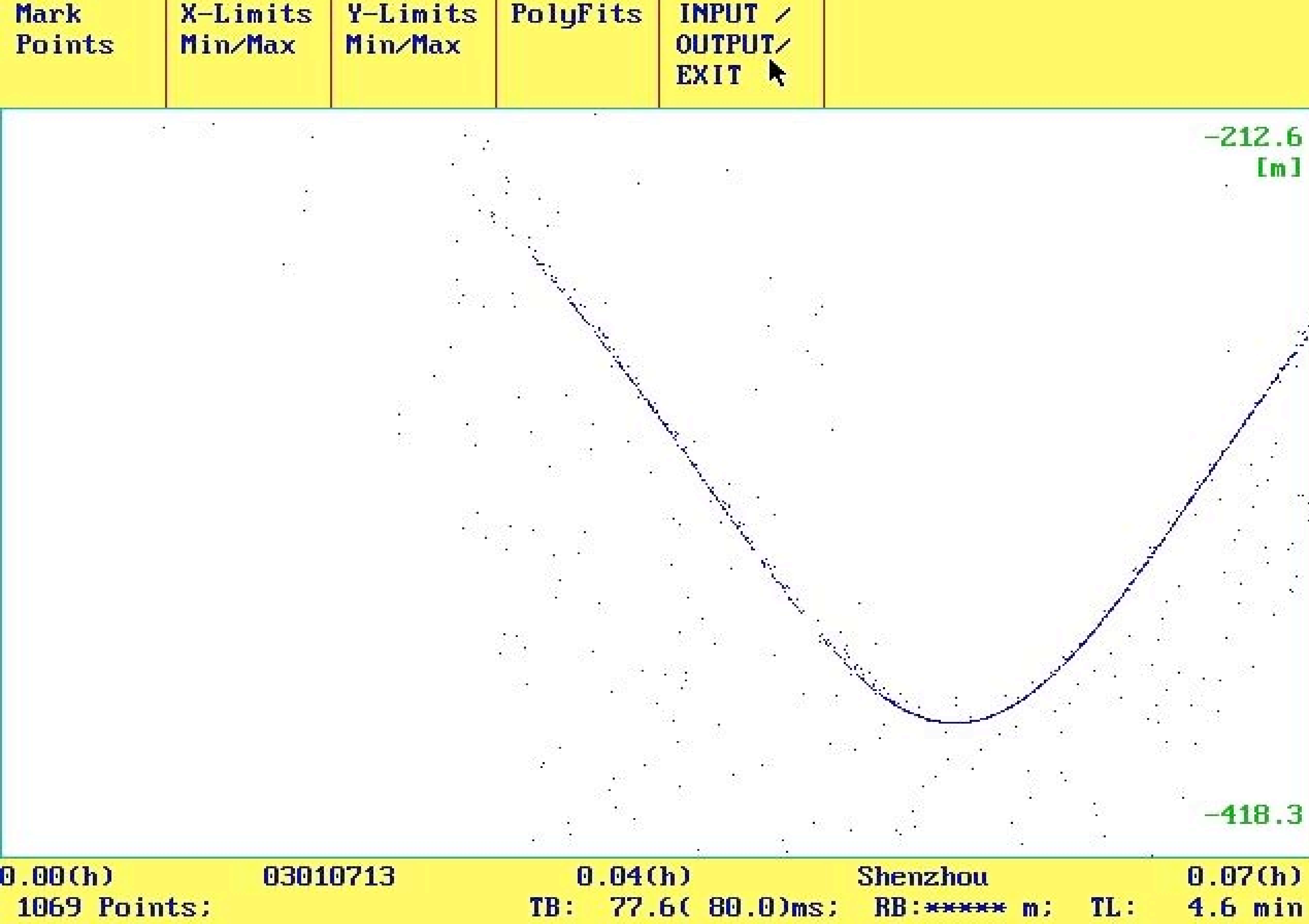
Beijing Station on Mar.21, 2003



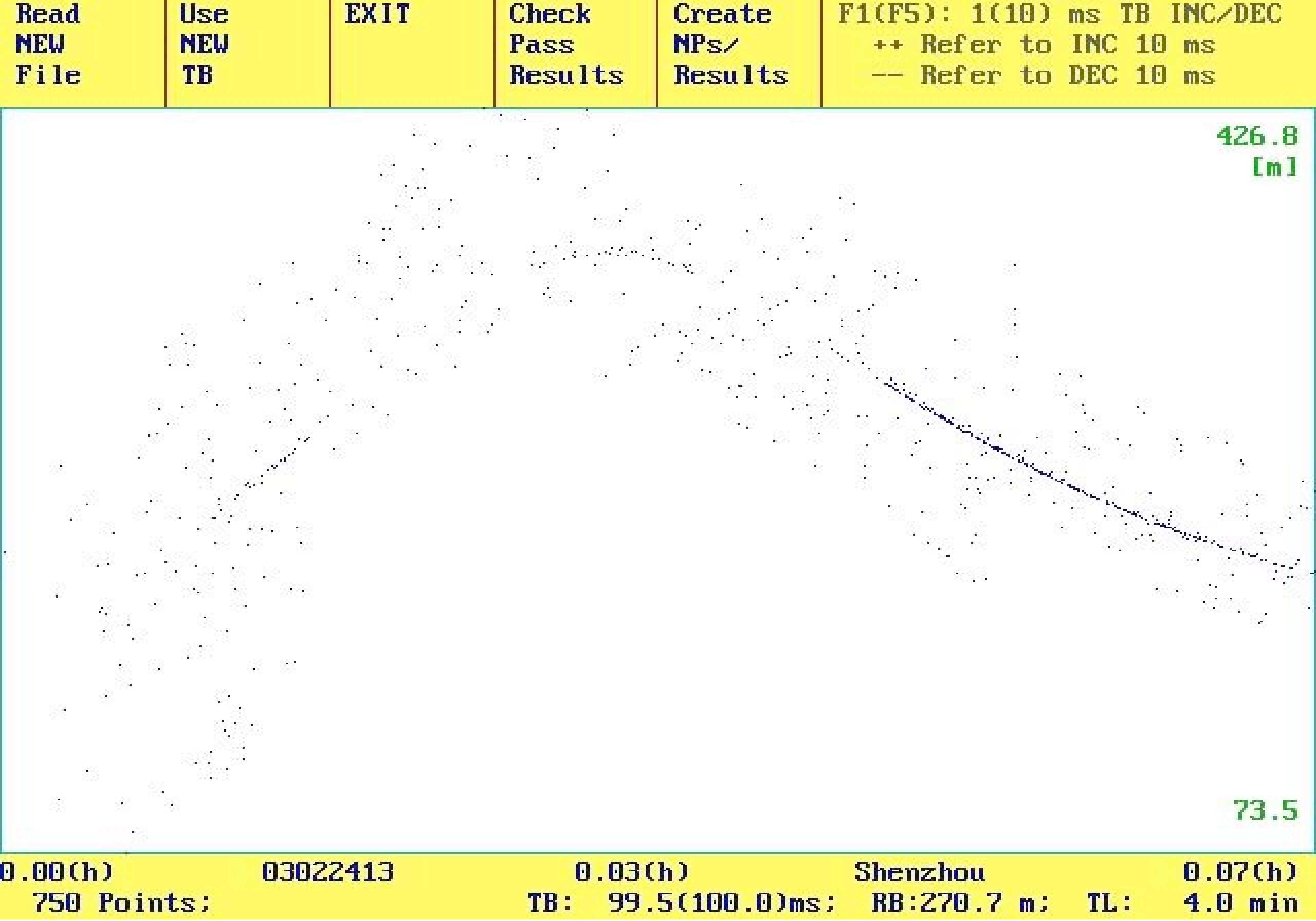
Changchun Station on Jan.31, 2003



Changchun Station on Feb.3, 2003



Shanghai Station on Jan.7, 2003



Shanghai Station on Feb.24, 2003

THANK YOU