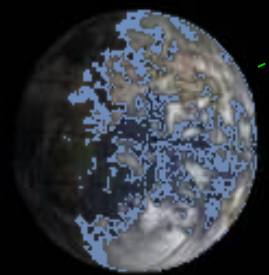
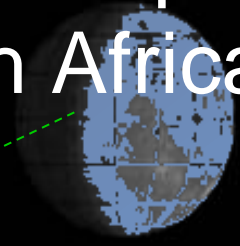
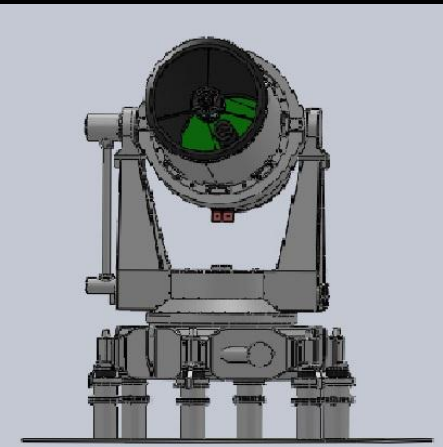




# Challenges and progress with the development of a Lunar Laser Ranger for South Africa



**Ludwig Combrinck**  
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ludwig@hartrao.ac.za

**Space Geodesy Programme**  
**Hartebeesthoek Radio Astronomy Observatory**  
In collaboration with Observatoire de la Côte d'Azur

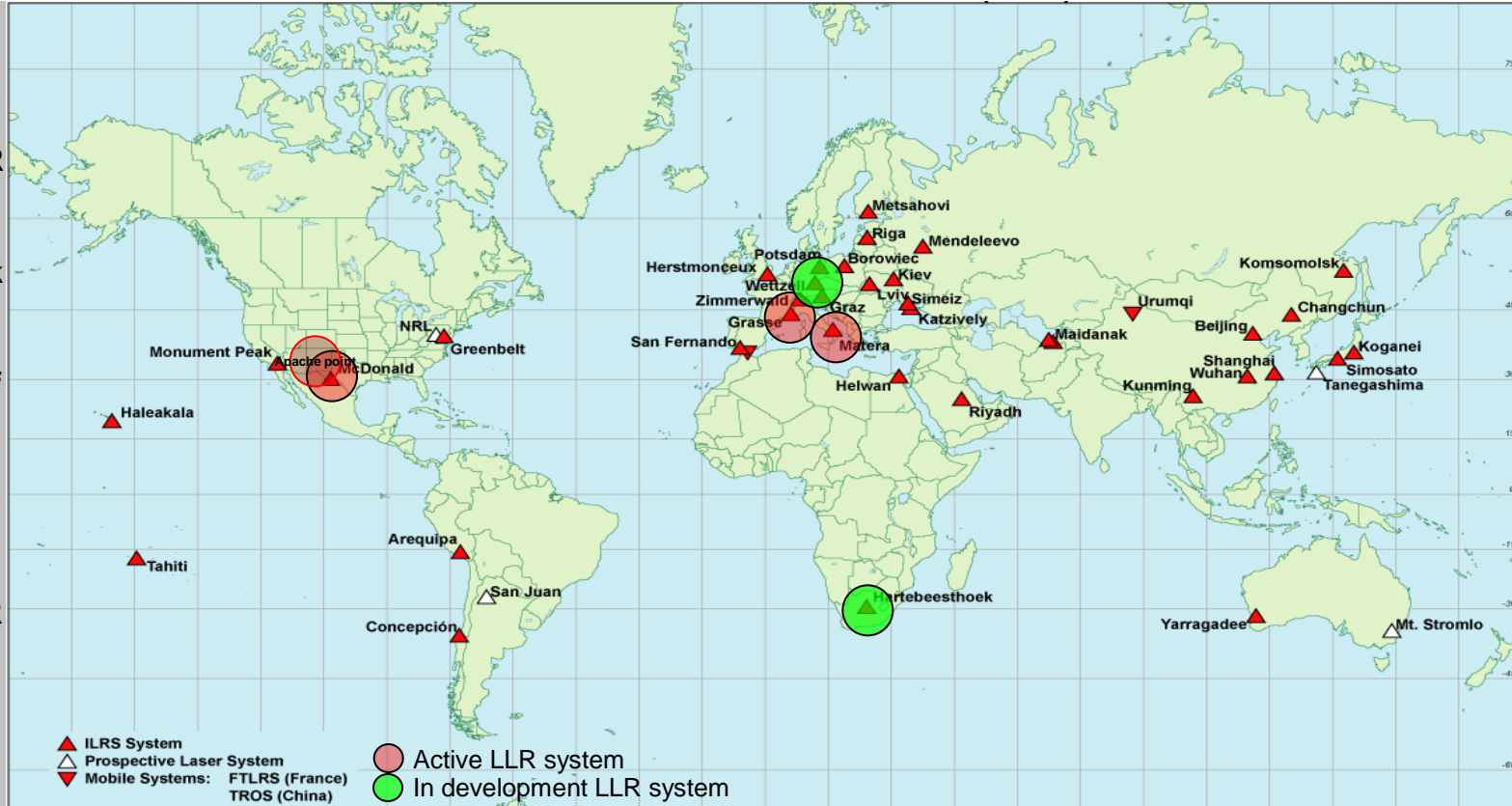
18th International Workshop on Laser Ranging  
- Pursuing Ultimate Accuracy & Creating New Synergies -  
11-15 November 2013 Fujiyoshida, Japan

2 VLBI antennas, VLBI2010 antenna  
construction starting 2014



# No LLR currently in Southern Hemisphere; The SA LLR will be part of the GGOS network and part of the NASA SLR network

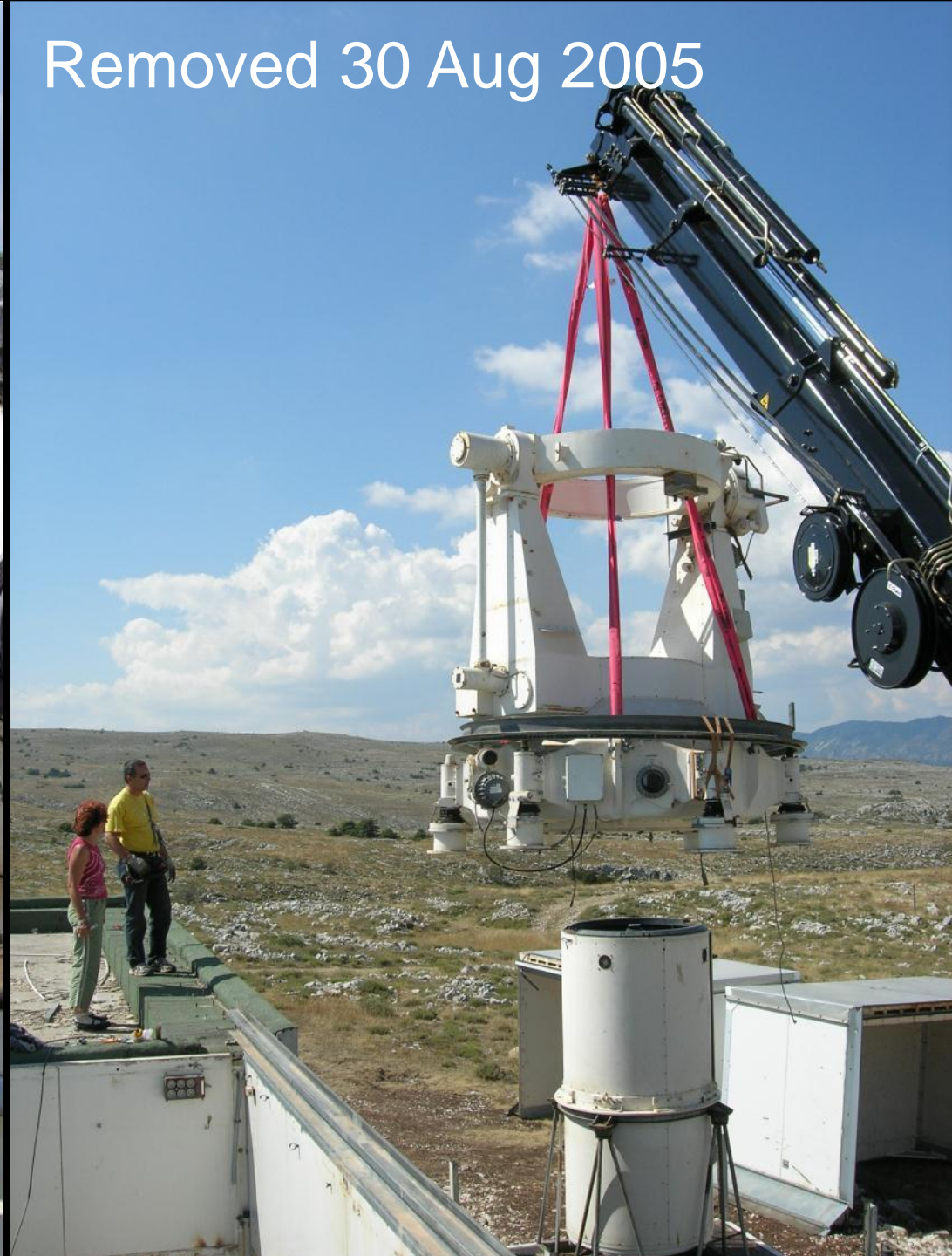
- A Southern Hemisphere LLR will strengthen the geometry of the LLR network and should improve the determination of the orientation of the Moon
- A dual system S/LLR will provide added coverage of SLR data in an area very sparsely covered
- Currently 4 active LLR systems, 2 in development



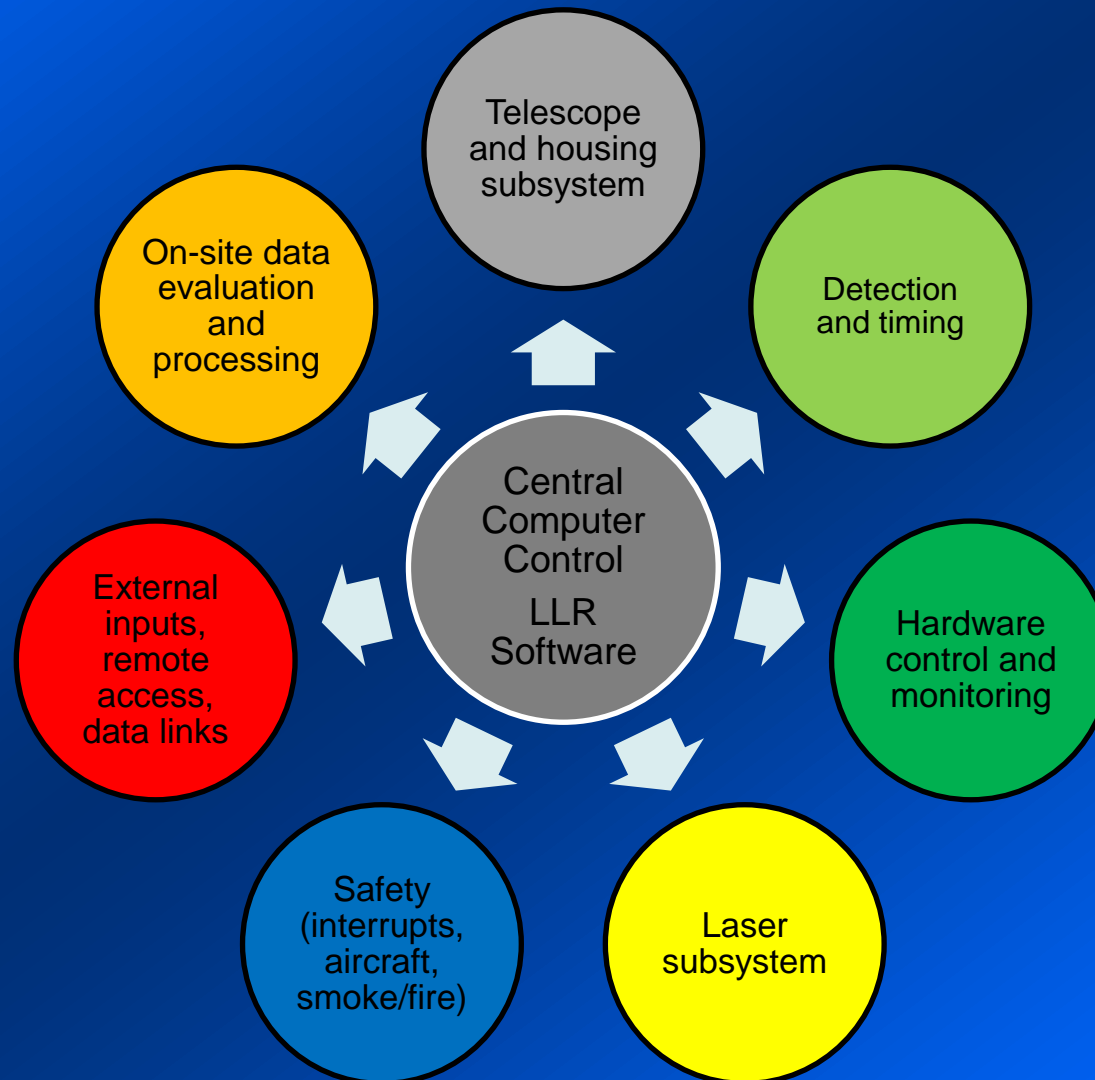
The concept of an LLR for the southern Hemisphere was discussed at the 13<sup>th</sup> International ILRS Workshop (October 2002) in Washington at an LLR breakaway meeting, where community support was given in principle. I had previously discussed the idea with Etienne Samain (OCA, France). Originally I had tried to obtain use of a 30" telescope at Sutherland, South Africa, proposal at SAAO meeting 26 April 2003.

Japan, November 2013

Removed 30 Aug 2005



# Overall design concept is software-centric



# Software design; shared memory concept

**LLR Steer Check Consolidated Prediction Form**

File size status: No status error  
 CPU Check version: 1.01 File name: D:\Work Data\LLR\Steer\TelCPFF\class.cnt 100101 5011.Hrs  
 Target: COSPAR 760201  
 Target: SIC 1155  
 Target: NGRAD 8021  
 Name: bge01

Sequence number: 5011 Produced by: HTS

Records: number and errors	
Common epoch:	1440 Inbound corrections: 0
Outbound position:	0 Out reliability corr: 0
Inbound position:	0 Outbound offset: 0
Outbound velocity:	0 Inbound offset: 0
Inbound velocity:	0 Inbound offset: 0
Outbound corrections:	0 Earth orientation: 0

Produced on: Year: 2010 Month: 0 Day: 11 Hour: 12 Time (sec) disp: 300  
 Stat: Year: 2010 Month: 0 Day: 11 Hour: 0 Min: 0 Sec: 0  
 End: Year: 2010 Month: 0 Day: 8 Hour: 0 Min: 0 Sec: 0  
 Target type: 1 Compatibility: 1 Reference frame: 0 Rotation type: 0 COM applied: 0  
 Notes: NONE

Header errors and warnings	
No header 1 warning	No header 2 warnings
WARNING: Incomplete header H3	NOTE: No transponder header H4
Header end record OK	H1 column blank OK
H1 OK	H2 column blank OK
H2 OK	H3 column blank OK
H3 OK	H4 column blank OK
H4 OK	H5 column blank OK
H5 OK	H7 IOP: illegal OK
H5 OK	

Matched in- and outbound position records		Number of fields records type 201 (outbound velocity) OK	
Matched in- and outbound position records	No. of fields records type 202 (inbound velocity) OK	Number of fields records type 202 (inbound velocity) OK	
Matched in- and outbound corrections records	No. of fields records type 301 (outbound corrections) OK	No. of fields records type 301 (outbound corrections) OK	
Matched in- and offset records	No. of fields records type 302 (inbound corrections) OK	No. of fields records type 302 (inbound corrections) OK	
Good input on records type 100 (common epoch)	No. of fields records type 401 (out reliability corr) OK	No. of fields records type 401 (out reliability corr) OK	
Good input on records type 101 (outbound position)	No. of fields records type 501 (outbound offset) OK	No. of fields records type 501 (outbound offset) OK	
Good input on records type 102 (inbound position)	No. of fields records type 601 (inbound offset) OK	No. of fields records type 601 (inbound offset) OK	
Good input on records type 200 (outbound velocity)	No. of fields records type 701 (earth orientation) OK	No. of fields records type 701 (earth orientation) OK	
Good input on records type 201 (inbound velocity)	Position record 11112 in sequence	Position record 11112 in sequence	
Good input on records type 202 (outbound corrections)	Velocity record 21122 in sequence	Velocity record 21122 in sequence	
Good input on records type 301 (inbound corrections)	Corrections record 31122 in sequence	Corrections record 31122 in sequence	
Good input on records type 401 (out reliability corr)	Offset record 51122 in sequence	Offset record 51122 in sequence	
Good input on records type 501 (outbound offset)	Body end record OK	Body end record OK	
Good input on records type 601 (inbound offset)	But and inbound position had no same sign	But and inbound position had no same sign	

```

Moon Declination (MoonDec): -9.35370
Angle subtended by Moon (MoonAngleSubtended): 0.54312
Telescope enabled (runflag): 1
Telescope Right Ascension (TelRA): 322.29553
Telescope Declination (TelDec): -9.44678
Telescope Azimuth (TelAz): 277.12853
Telescope Elevation (TelEl): 35.71303
Telescope Steer mode (TelSteerMode): 1
Virtual telescope Local Hour Angle (TelLHA): -54.76892
Julian date (JD): 2456607.02777
Greenwich mean sidereal time (GMST): 15.98870
Sun Right Ascension (SunRA): 225.82347
Sun Declination (SunDec): -17.26971
Angle subtended by Sun (SunAngleSubtended): 0.53848
Moon Right Ascension (MoonRA): 322.60139
Moon Declination (MoonDec): -9.35370
Angle subtended by Moon (MoonAngleSubtended): 0.54312
Telescope enabled (runflag): 1
Telescope Right Ascension (TelRA): 322.29553
Telescope Declination (TelDec): -9.44678
Telescope Azimuth (TelAz): 277.12853
Telescope Elevation (TelEl): 35.71303
Telescope Steer mode (TelSteerMode): 1
Virtual telescope Local Hour Angle (TelLHA): -54.76892
DEC Encoder increments (int): 49174
DEC Encoder increments (str): 49174
DEC Encoder (dec): 0.221283
DEC Encoder (angsec): 53.1079
Julian date (JD): 2456607.02777
Greenwich mean sidereal time (GMST): 15.98870
Sun Right Ascension (SunRA): 225.82347
Sun Declination (SunDec): -17.26971
Angle subtended by Sun (SunAngleSubtended): 0.53848
Moon Right Ascension (MoonRA): 322.60139
Moon Declination (MoonDec): -9.35370
Angle subtended by Moon (MoonAngleSubtended): 0.54312
  
```



**Virtual and actual telescope**

Object coordinates:

Right Ascension:	Rate:	Azimuth:	Rate (deg/sec)
21h 29m 10.9264s	0h 0m 0.0000s	274.01981	0.0019761607

Declination:

Declination:	Elevation:
-9.4469793	0
	30.071646
	0.0037498177

Telescope coordinates:

Right Ascension:	Rate:	Azimuth:	Rate (deg/sec)
17h 24m 56.1769s	0h 0m 1.0027s	0	0

Declination:

Declination:	Elevation:
0	0
	64.12
	0

Telescope LHA: 0h 0m 0.0000s  
 Virtual LHA: 19h 55m 45.2505s 0h 0m 1.0027s

Coordinate delta's:

Right Ascension:	RA abs rate:	Azimuth:	Rate (deg/sec)
4h 4m 14.7495s	0h 0m 1.0027s	274.01981	0.0019761607

Declination:

Declination:	Rate:	Elevation:
-9.4469793	0	-34.048354
		0.0037498177

Enable telescope 0=Off 1=On  
 Telescope status:  **Telescope status**

Profile 0=Velocity 1=Position  
 Steer Mode:  **Steer Mode**

Solar system lock: 0=Off 1=On  
 Lock status:

Starline lock: 0=Off 1=On  
 Lock status:

Options... Help Close

File Edit Display Tracking Mode Satellite LLE SLR Tracking Telescope Servo Drive Data Processing Help

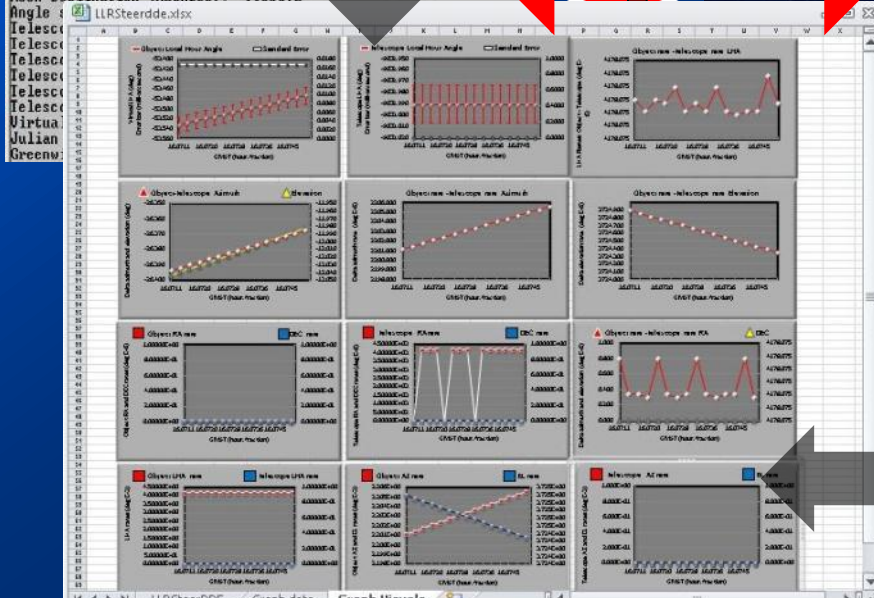
2:06:07 PM South Africa Standard Time Sun 2013/11/10 12:06:07 PM UTC Sun 2013/11/10

Image settings:

Magnification: 1 FOV: 45 Minimum magnitude: 5.5

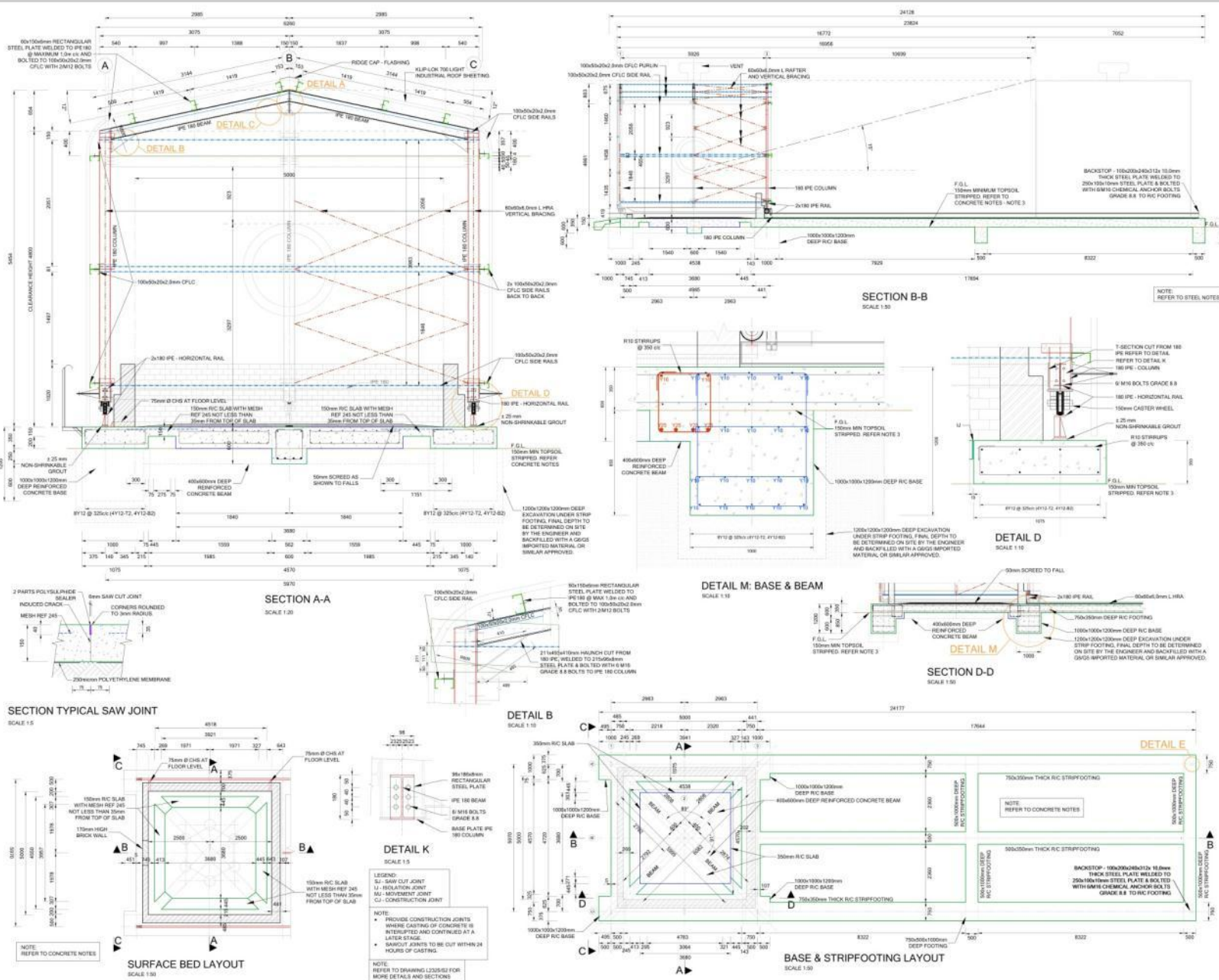
RA

DEC



# Telescope housing

- 2.5 minutes to open and move away
- Can be dismantled and moved to final location
- Large enough to allow maintenance access via crane
- All metal construction
- Steel reinforced massive concrete floor
- Housing runs on tracks via electrical motors
- 1 ton crane to remove gearbox and instruments



AS BUILT PLAN	
DATE/ISSUE	OCTOBER 2010
SCALE/SCALE	AS SHOWN
SCALE REF.	SCALE VARIANTS
CONSULTANT DWG. NO.	CONSULTANT TEX. NR.
P2325/S1	07
CLIENT DWG. NO.	CLIENT TEX. NO.

# 'Temporary foundation'



Telescope housed in run-off enclosure  
Crane to assist in disassembly and refurbishment  
Totally nuts and bolts construction to facilitate future removal to appropriate site  
Stable and massive foundation for tests



# 50 cubic metres of concrete...



**HartRAO**  
Hartebeesthoek Radio  
Astronomy Observatory



# Run-off enclosure on steel tracks





Tie to ITRF via GNSS  
Mount installed 2 June 2011  
Much restoration work ahead!



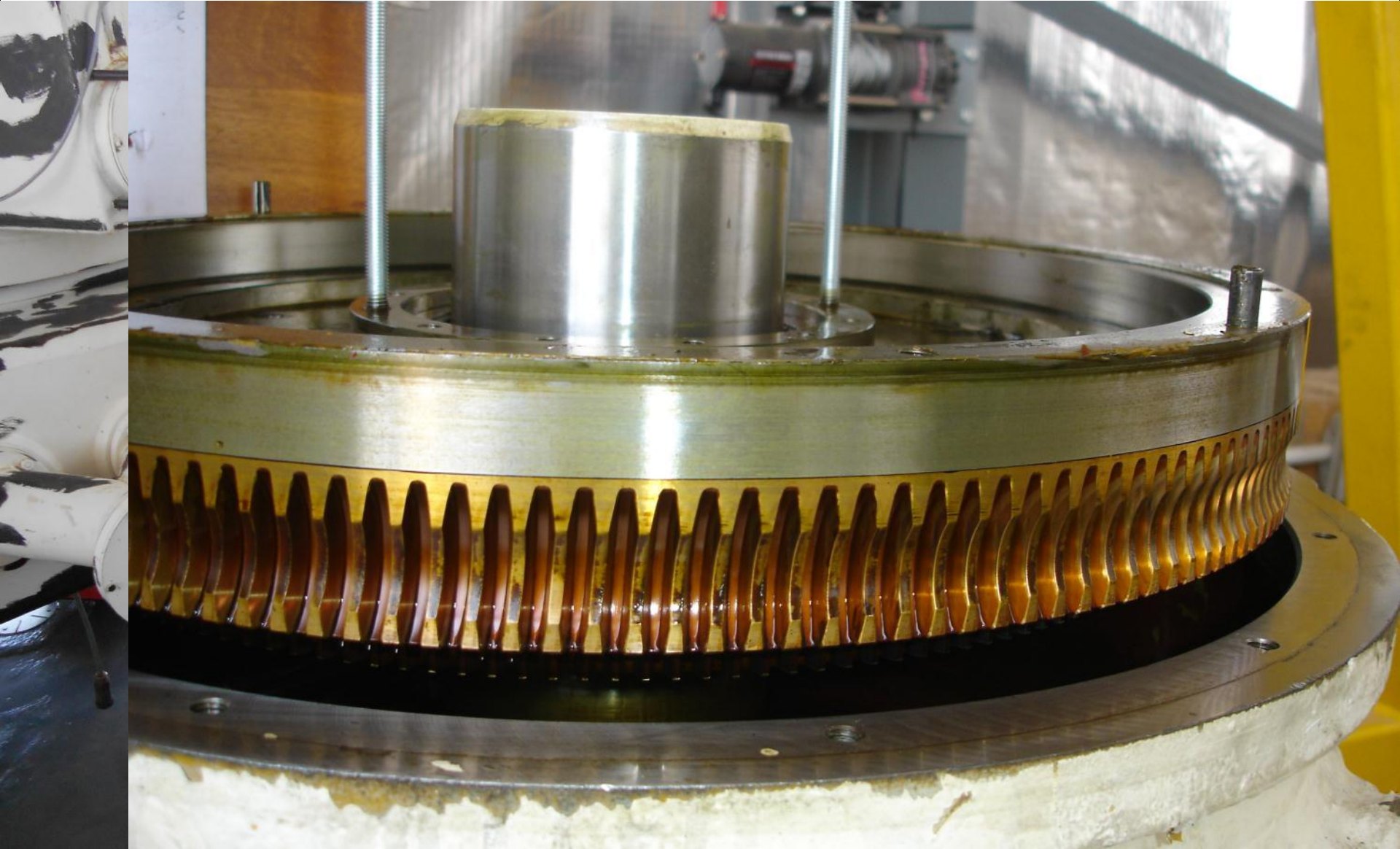
**HartRAO**  
Hartebeesthoek Radio  
Astronomy Observatory



**Gearboxes were removed,  
disassembled, refurbished, modern oil**



**HartRAO**  
Hartebeesthoek Radio  
Astronomy Observatory



# Tube has been restored



# All panels and Az-El mount repainted with heat reflecting paint



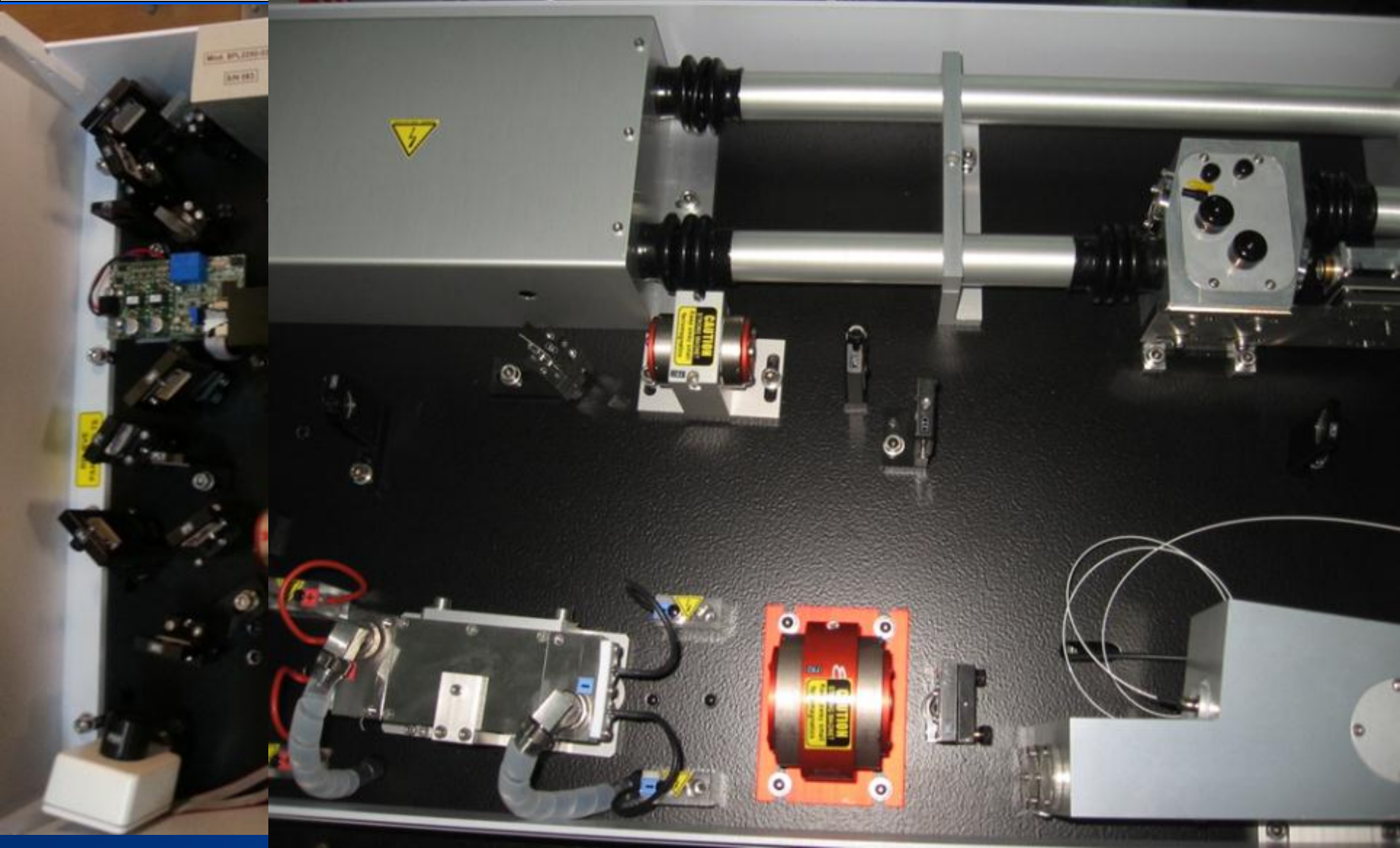


KEEP THIS DOOR  
CLOSED  
FOR REPTILES  
FROM ENTERING



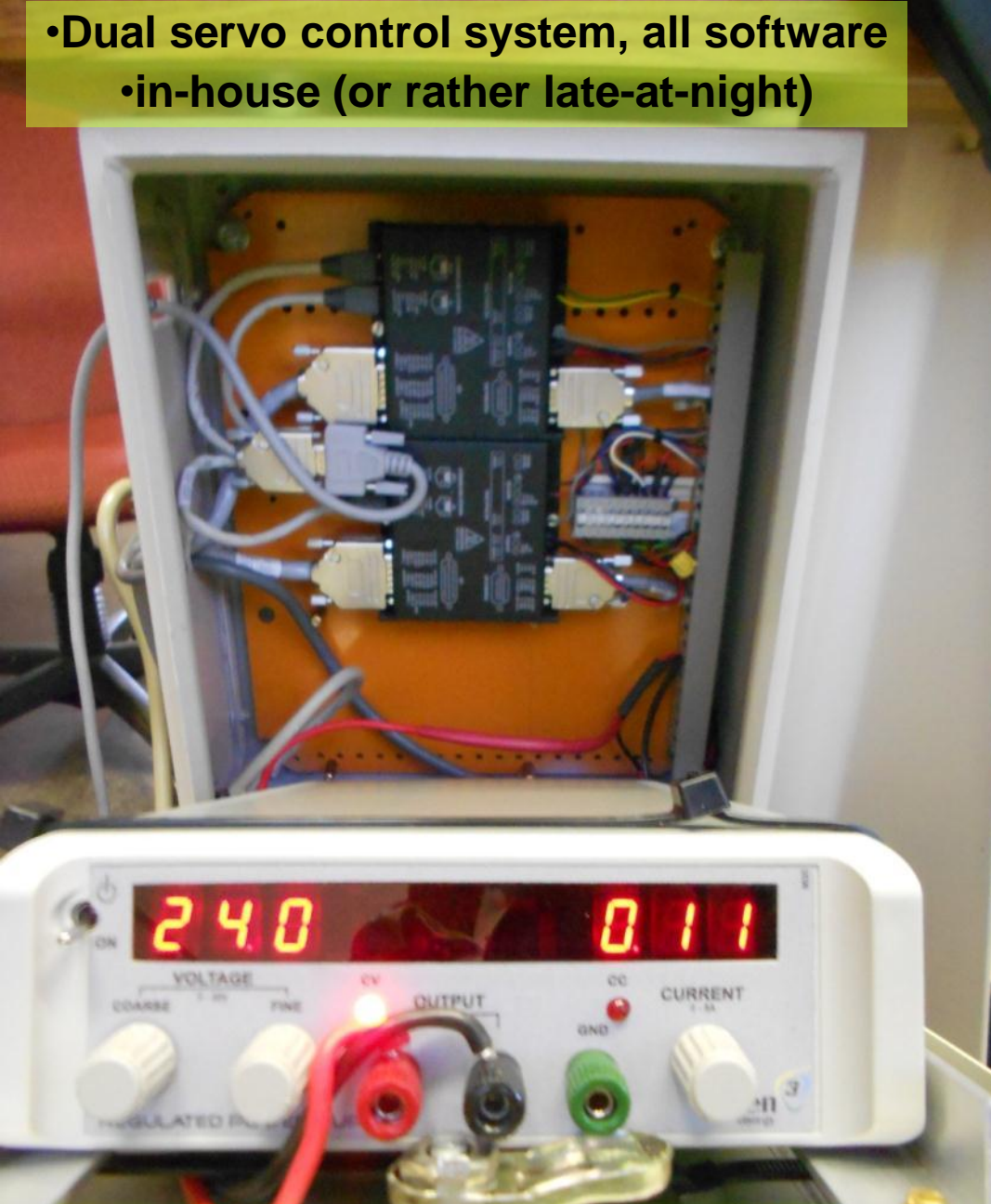
# Laser system by Cybioms Corporation

100 mJ, 20 Hz, <80 ps; 1KHz, 0.5 mJ



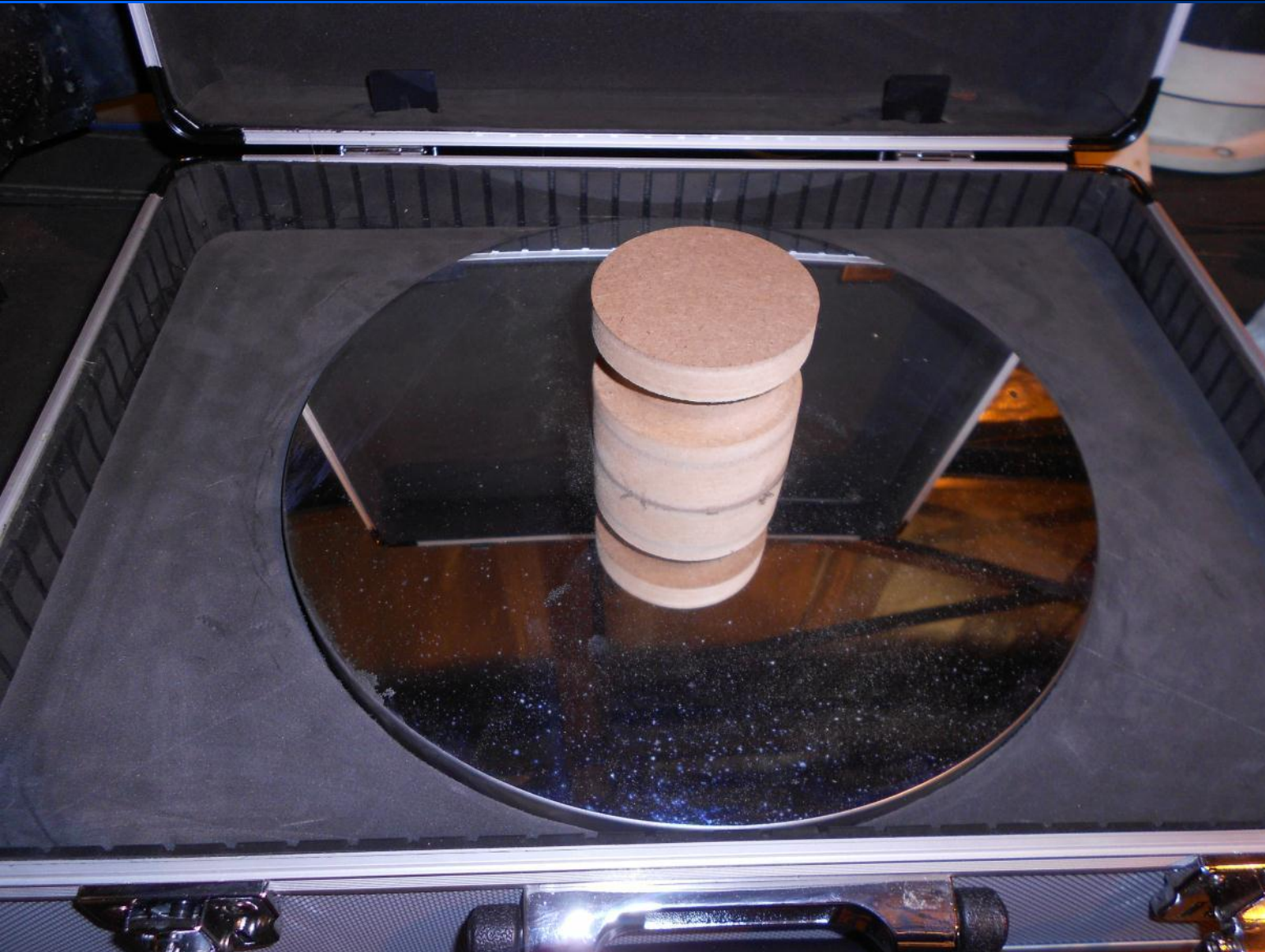
- Micro-processor controlled functions

- Dual servo control system, all software
- in-house (or rather late-at-night)



Testbed 12.5 cm f12.5 refractor (

Main and secondary to be re-aluminized and coated



# Control centre based on 12 m shipping container; clean air filters



# Control centre designed for desert conditions



Insulation panels fitted externally and internally

Rubberised floor

Dedicated air conditioner in laser room

Positive air pressure to keep dust out

# UPS 20 KVA



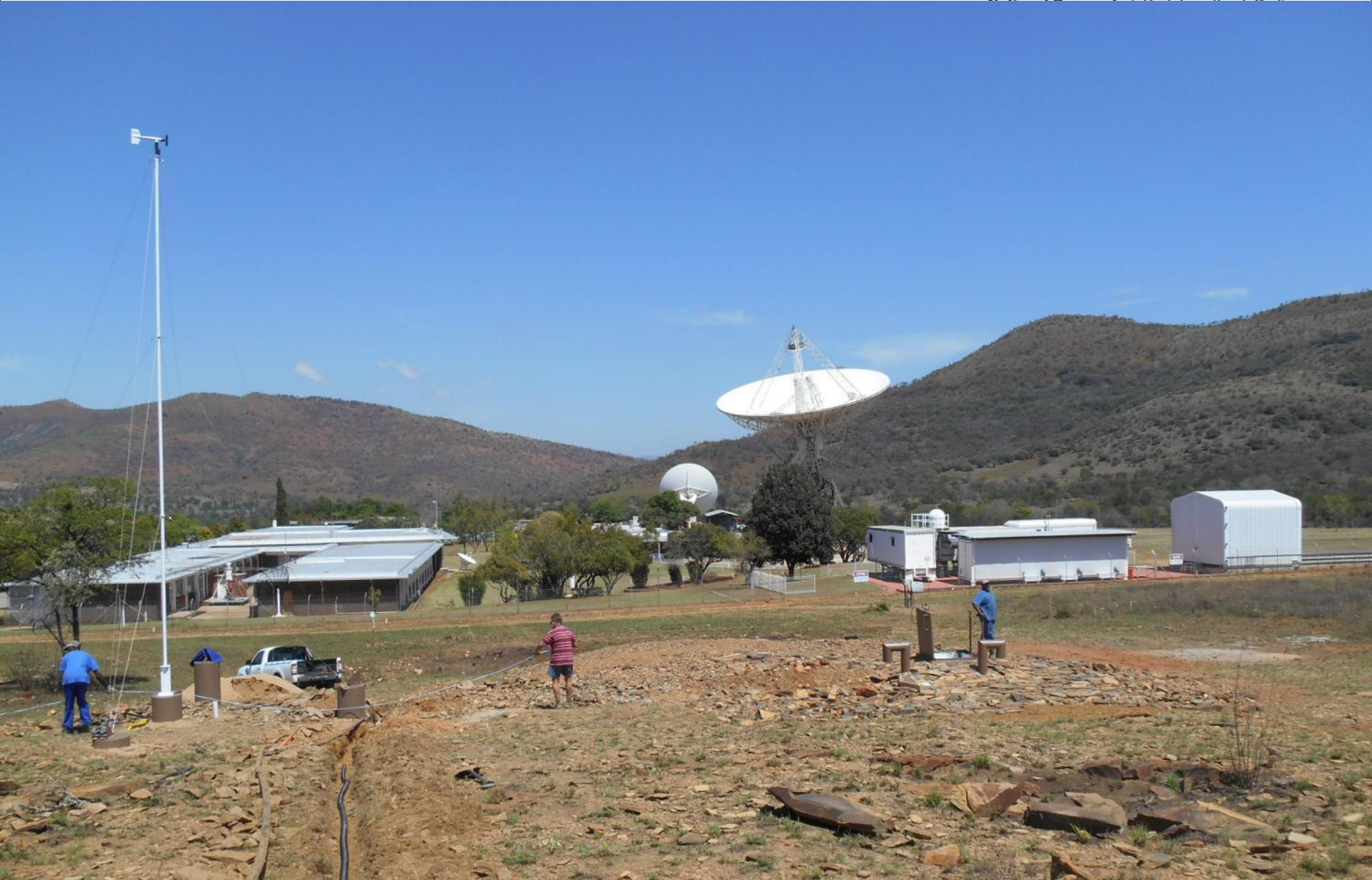
**HartRAO**  
Hartebeesthoek Radio  
Astronomy Observatory



# Control room



Project completion 2015? 2016?  
Where will the system be located?





# Thank you!



## Acknowledgements

**Thanks to the LOC for a fantastic workshop!**

**Projects such as these depend to a large extent on international collaboration. We specifically thank OCA (France), NASA (USA) and Cybioms Corporation (USA).**

**Funding received from the National Research Foundation (NRF), South Africa, towards this project is appreciated. This work is based on research supported by NRF grant IFR2011041500034.**

