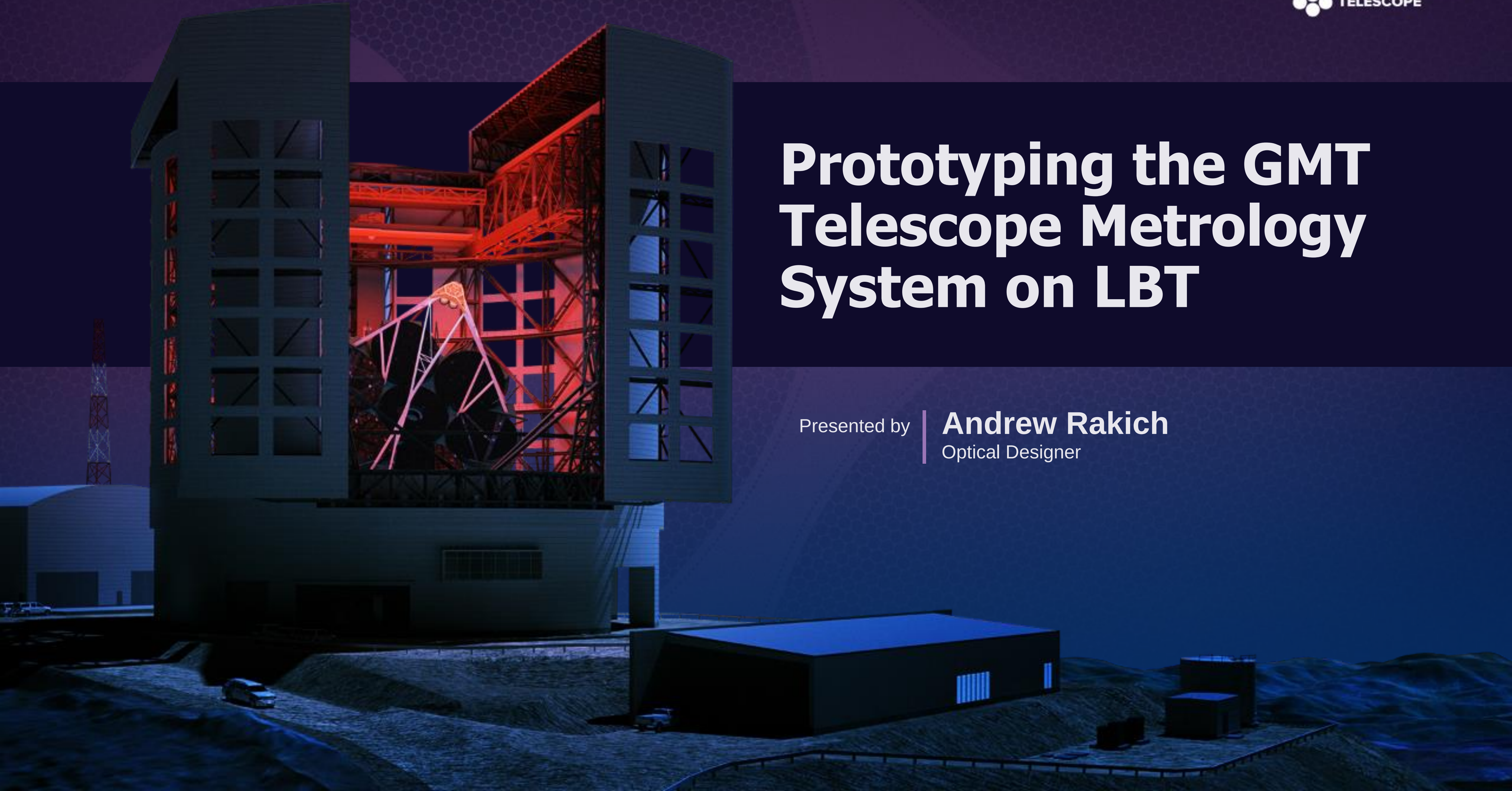
GIANT MAGELLAN TELESCOPE



Prototyping the GMT Telescope Metrology System on LBT

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Summary

- Description of Laser Truss Metrology System
- Etalon Absolute Multiline Technology
- Prototyping on LBT
- Results to date
- Future work

The GMT Telescope Metrology System

Degree of Freedom	Requirement (1σ)	Design Estimate (1σ)
M1 x,y	≤ 75 μm	1.4 μm
M1 z	≤ 75 μm	0.87 μm
M1 Rx, Ry	≤ 0.375 arcsec	0.068 arcsec
M1 Rz	≤ 0.375 arcsec	0.054 arcsec
M2 x,y	≤ 75 μm	8.2 μm
M2 z	≤ 75 μm	1.5 μm
M2 Rx, Ry	≤ 3 arcsec	0.64 arcsec
M2 Rz	≤ 3 arcsec	3.0 arcsec

Etalon Absolute Metrology Technology (EAMT)

- A commercial absolute distance measuring interferometer system was selected for the laser truss.
  - Up to 800 independent metrology channels.
  - Measurement uncertainty (in air) 0.5 µm/m
  - Maximum measurement frequency > 500 kHz (can be used as vibrometer with much higher accuracy for high frequencies)
  - Measurement length > 30 m
  - Simple measurement channel consisting only of telecom fiber, collimator and triple reflector (no electrical systems on telescope)
  - Almost unlimited fiber length possible (several kilometers)
  - Eye safe infrared radiation
  - Metrological traceability by gas absorption cell
  - All componentry based on “industry hardened” high I/O telecom equipment.

Prototyping on LBT

- In 2017 GMTO proposed to prototype the metrology system on LBT.
  - Gives LBTO the opportunity to trial new metrology technology without large capital expenditure.
  - Opportunity for GMTO to gain first-hand and long-term experience with Laser Truss metrology on a working telescope.
  - LBT 22.5 m optical baseline and 8.4 m diameter borosilicate mirrors give the closest match to GMT of any working large telescope today.
  - Conveniently located, not so far from Pasadena, and with a common partner institution in Steward Observatory.
  - GMTO technical staff already very familiar with LBTO active optics systems.
  - A 3-phased prototyping effort began in August 2017.

Prototyping Phases

- The prototyping effort is divided into three phases:
  - Phase 1: Deploy laser truss on the prime focus cameras, measuring each primary mirror with respect to the corresponding corrector. Test hardware, develop software. Integrate with the Telescope Control System (TCS).
  - Phase 2: Deploy Laser Truss for the Gregorian Telescope. Measure M1, M2 and M3 relative to an instrument rotator. Integrate with TCS.
  - Phase 3: Control both Gregorian Telescopes and measure between right and left telescopes for interferometric baseline control.
  - At this stage Phase 1 is basically complete and hardware is en-route for phase 2.

Phase 1 results

ETALON80 - TeamViewer - Free license (non-commercial use only)

MultiLine - Deformation analysis

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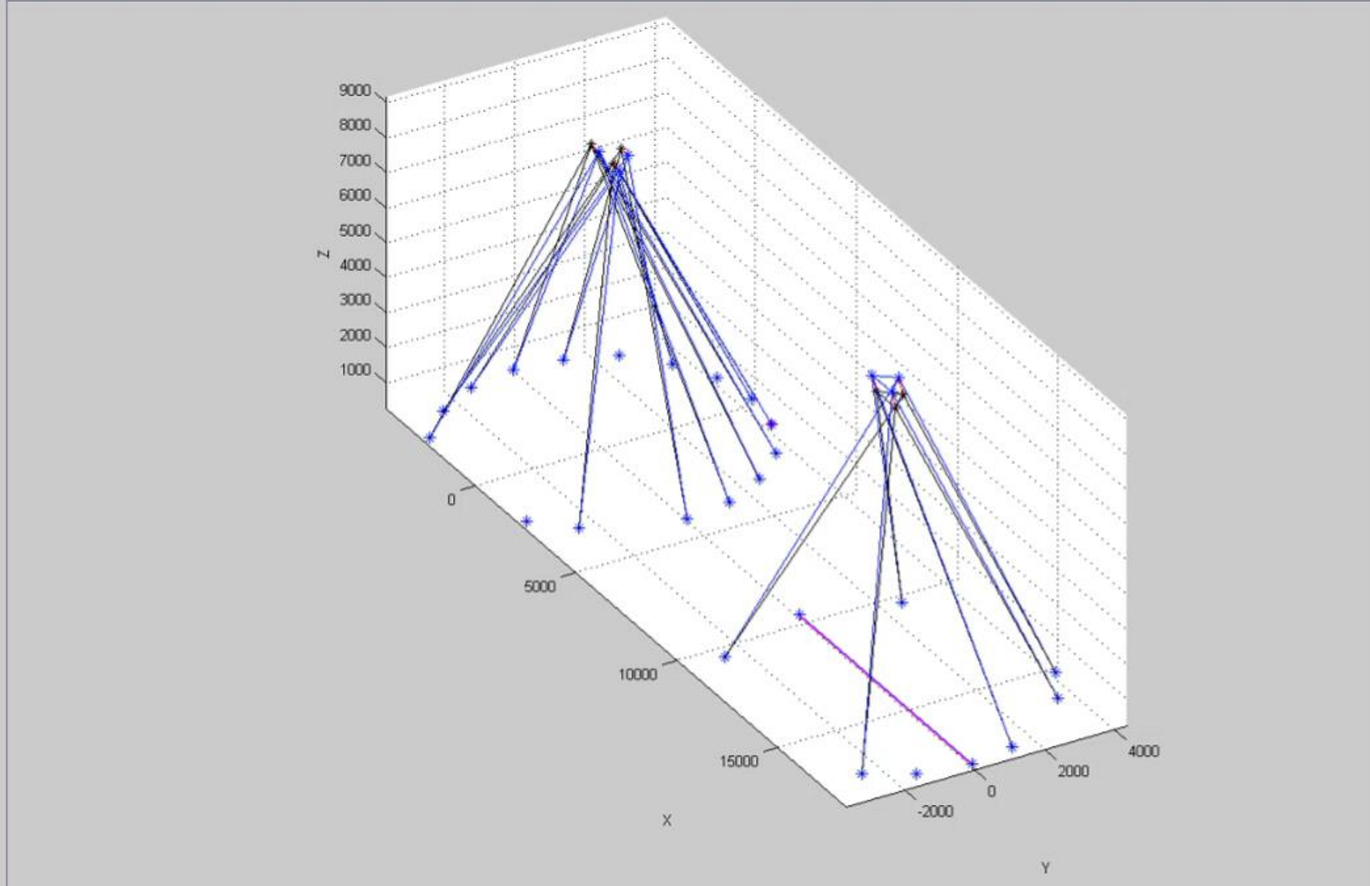
Points

	X [mm]	Y [mm]	Z [mm]	dX [µm]	dY [µm]	dZ [µm]
1	1332	4042	447	0	0	0
2	4	4258	463	0	0	0
3	-1338	4041	459	0	0	0
4	-2533	3447	404	0	0	0
5	-3464	2459	465	0	0	0
6	-4093	1246	400	0	0	0
7	-4273	-108	398	0	0	0
8	-4029	-1444	403	0	0	0
9	-3370	-2632	390	0	0	0
10	-2395	-3555	399	0	0	0
11	2390	-3547	400	0	0	0
12	3372	-2630	419	0	0	0
13	4277	-73	399	0	0	0
14	4088	1253	400	0	0	0
15	3496	2457	419	0	0	0
16	2544	3474	399	0	0	0
17	0	520	8695	253.10...	41.3000	-80.4000
18	-530	-11	8695	250.90...	56	-96.9000
19	530	-10	8694	240.70...	44.1000	-110.1...
20	17385	-2635	392	0	0	0
21	18035	-1437	393	0	0	0
22	18099	1244	400	0	0	0
23	10503	2487	387	0	0	0
24	16554	3438	400	0	0	0
25	15354	4093	355	0	0	0
26	10590	-2632	361	0	0	0
27	18284	0	360	0	0	0
28	9716	0	360	0	0	0
29	14016	487	8668	-176.1...	-17.7000	400.40...
30	13514	4	8667	-159.9...	-34.5000	377.70...
31	14501	-15	8667	-159.2...	-1.5000	380.70...

Setup



Lines

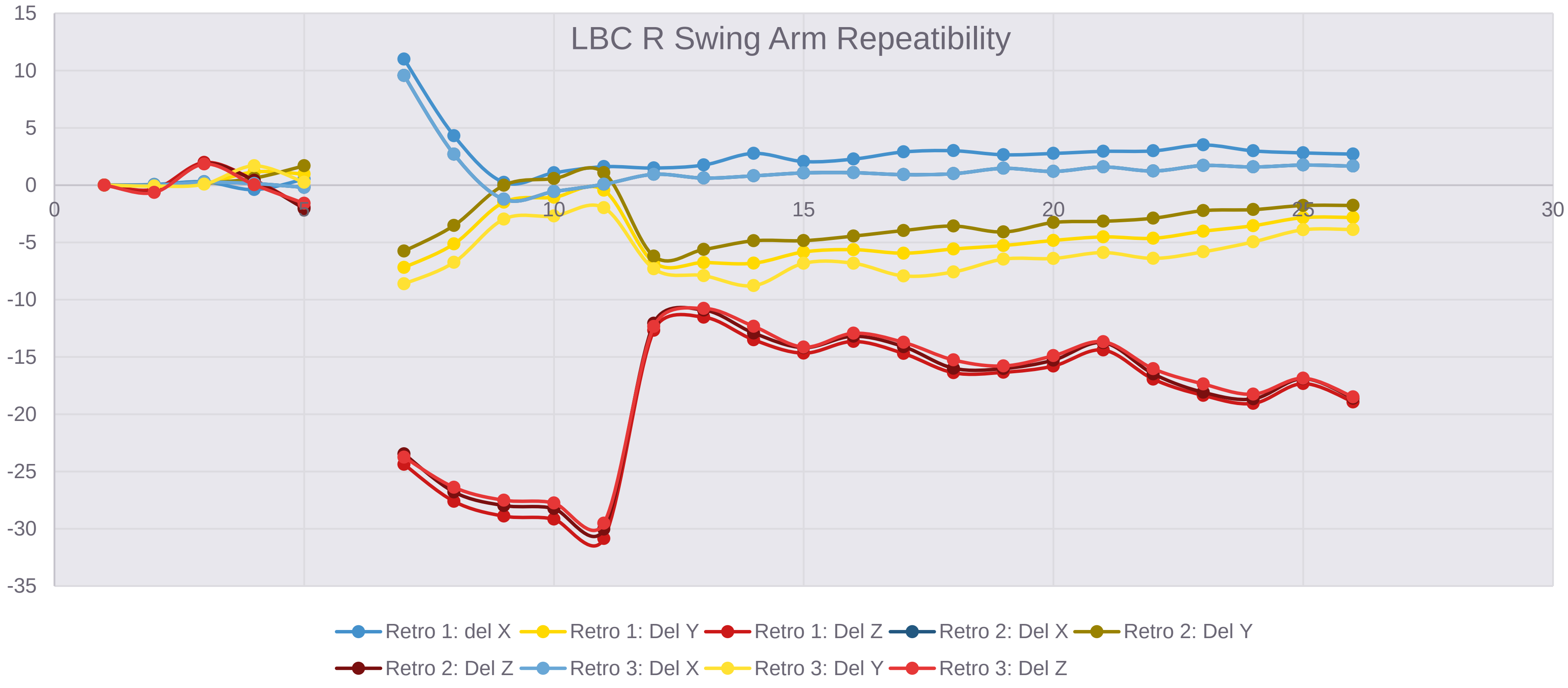
	Channel	Nom [mm]	delta [µm]
1	27	8569	3.2000
2	fixed	697	0
3	fixed	698	0
4	fixed	987	0
5	18	9147	394.2000
6	20	9535	408.9000
7	21	9154	298.5000
8	22	9191	378.5000
9	23	9159	396.1000
10	24	9512	280.5000
11	1	9224	-138.6000
12	2	9287	-104
13	4	9490	-35.2000
14	6	9278	36.5000
15	7	9102	15.5000
16	8	9570	26.2000
17	9	9500	33.2000
18	10	9211	-15.1000
19	12	9134	-162.2000
20	13	9352	-184.5000
21	14	9577	-212
22	15	9528	-204.9000
23	16	9508	-186.3000

OK | new reference

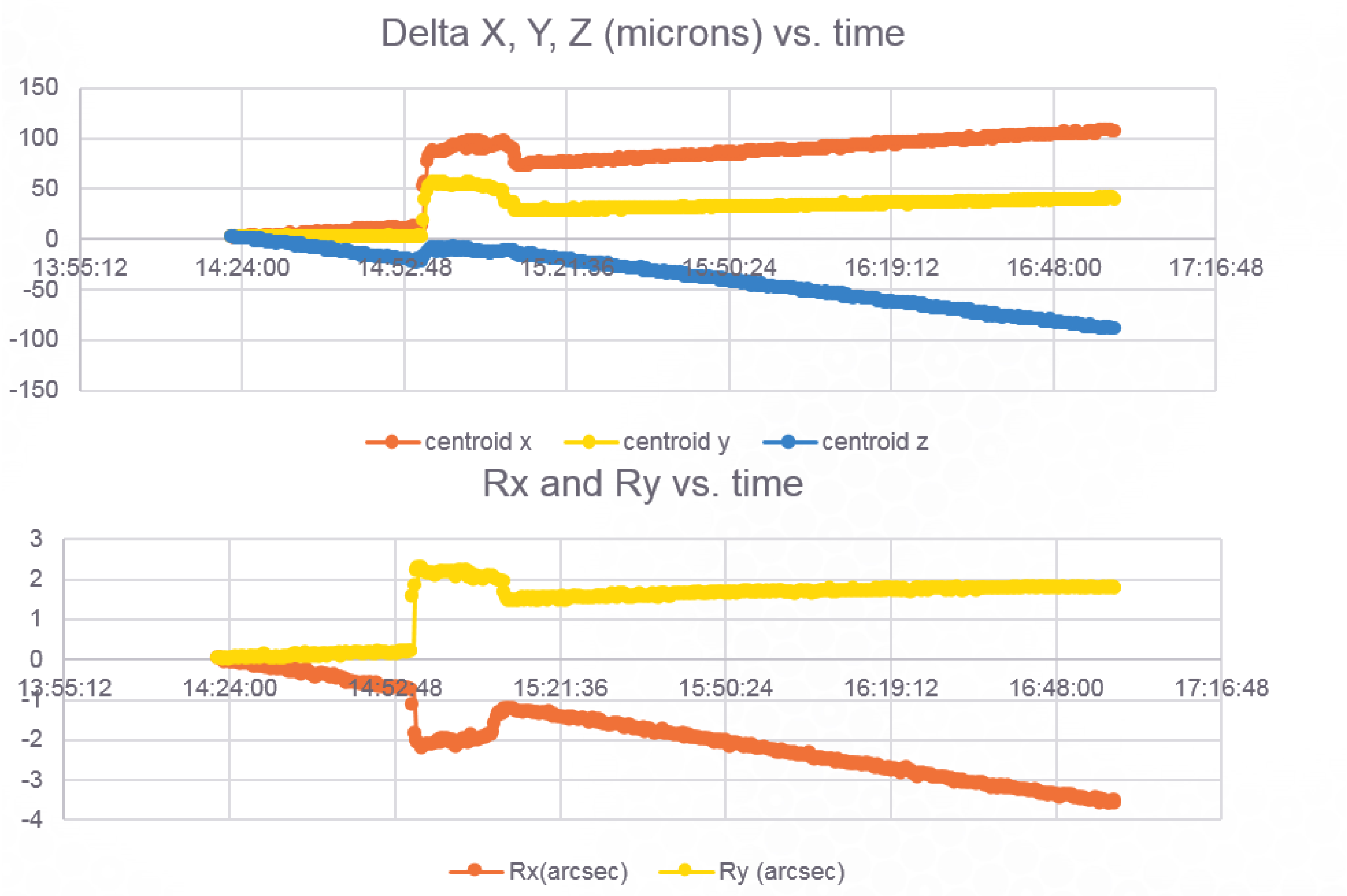
Scale factor 1000

Display: nominal deformed

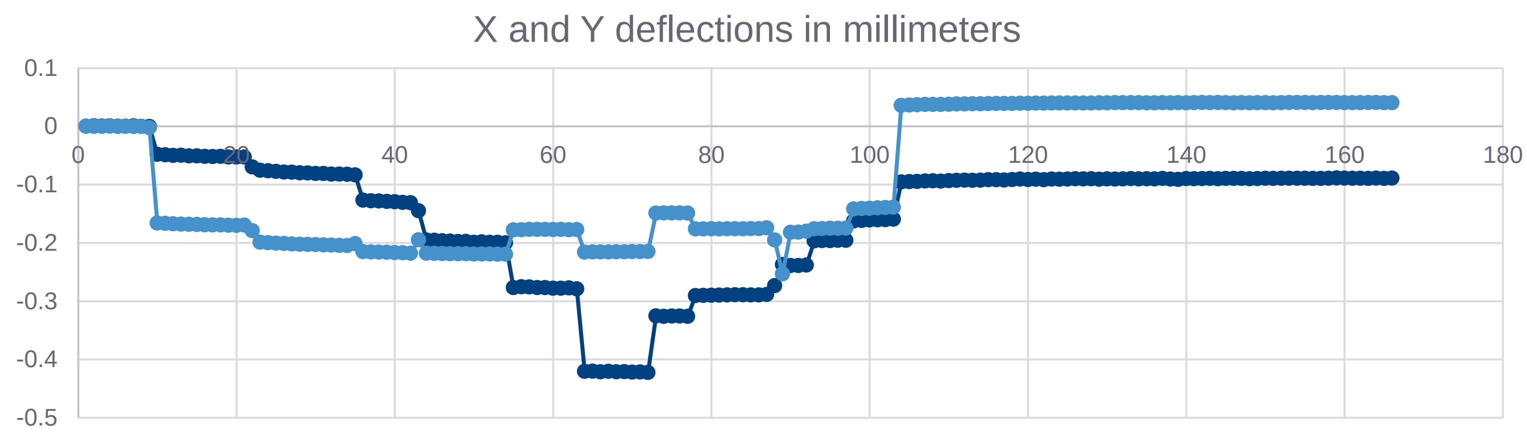
Closed dome measurements: Swing Arm Repeatability

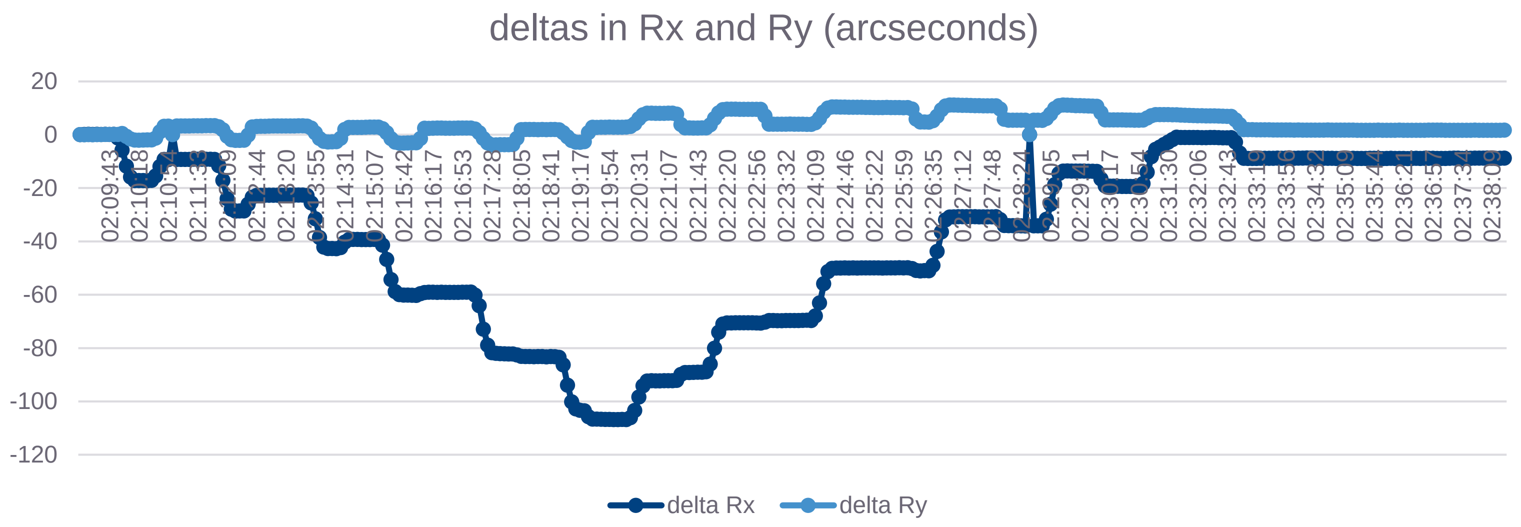


Closed dome measurements: Thermal Drift

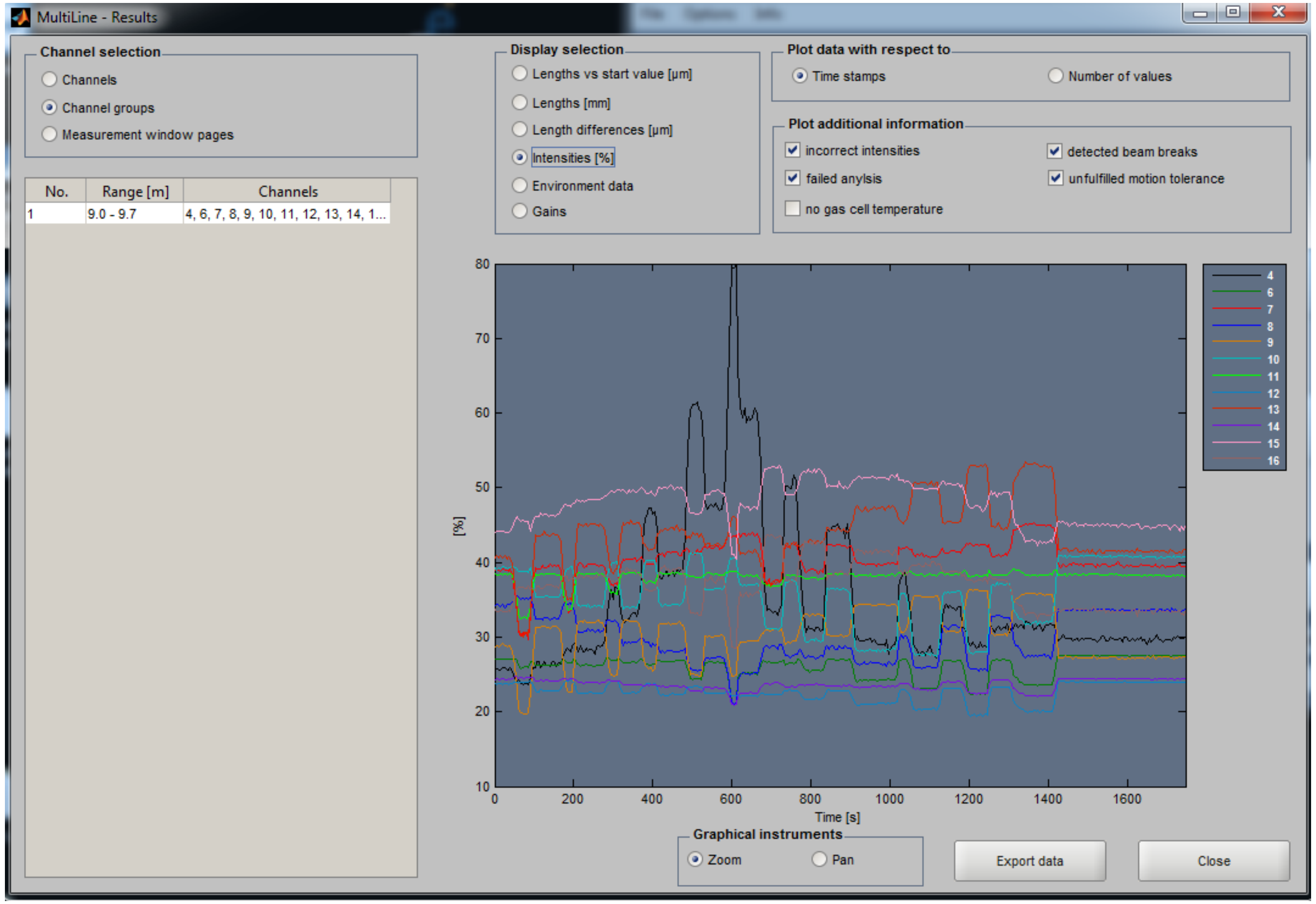


Closed dome measurements: Elevation

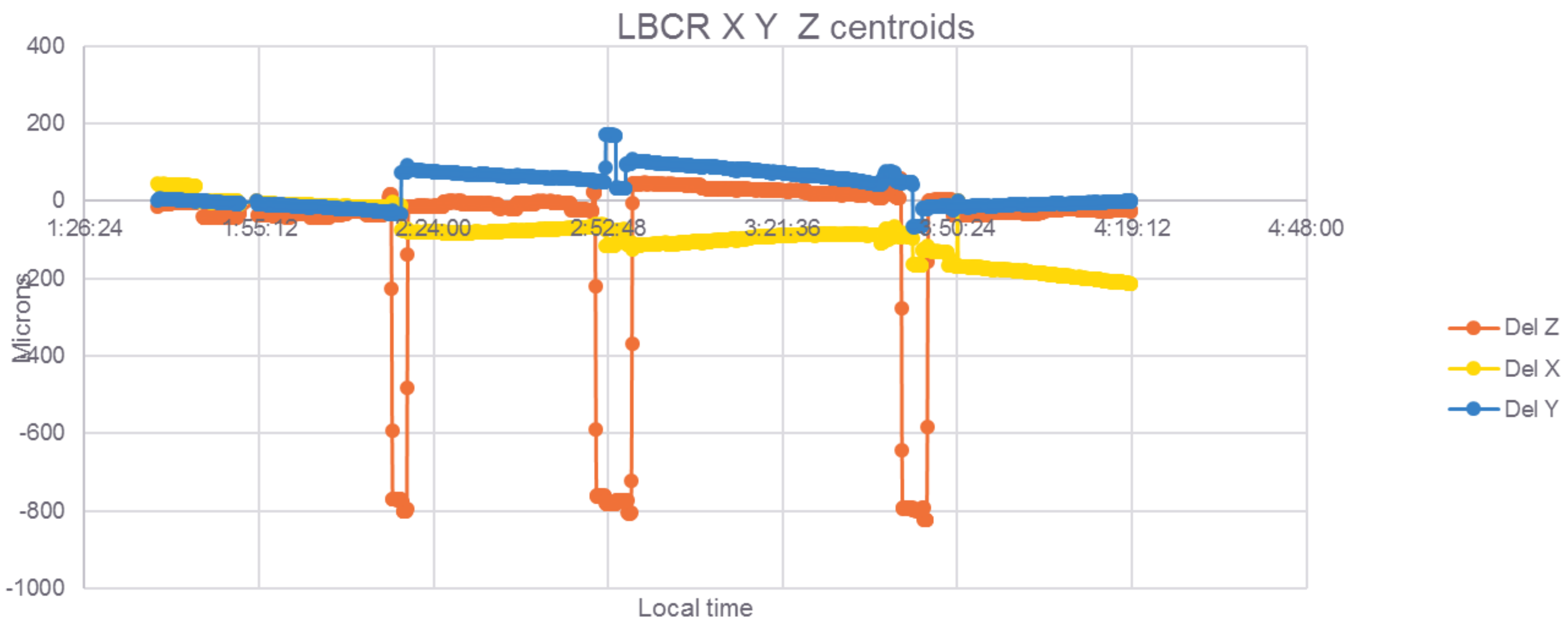




Closed dome measurements: Signal strength over the elevation range

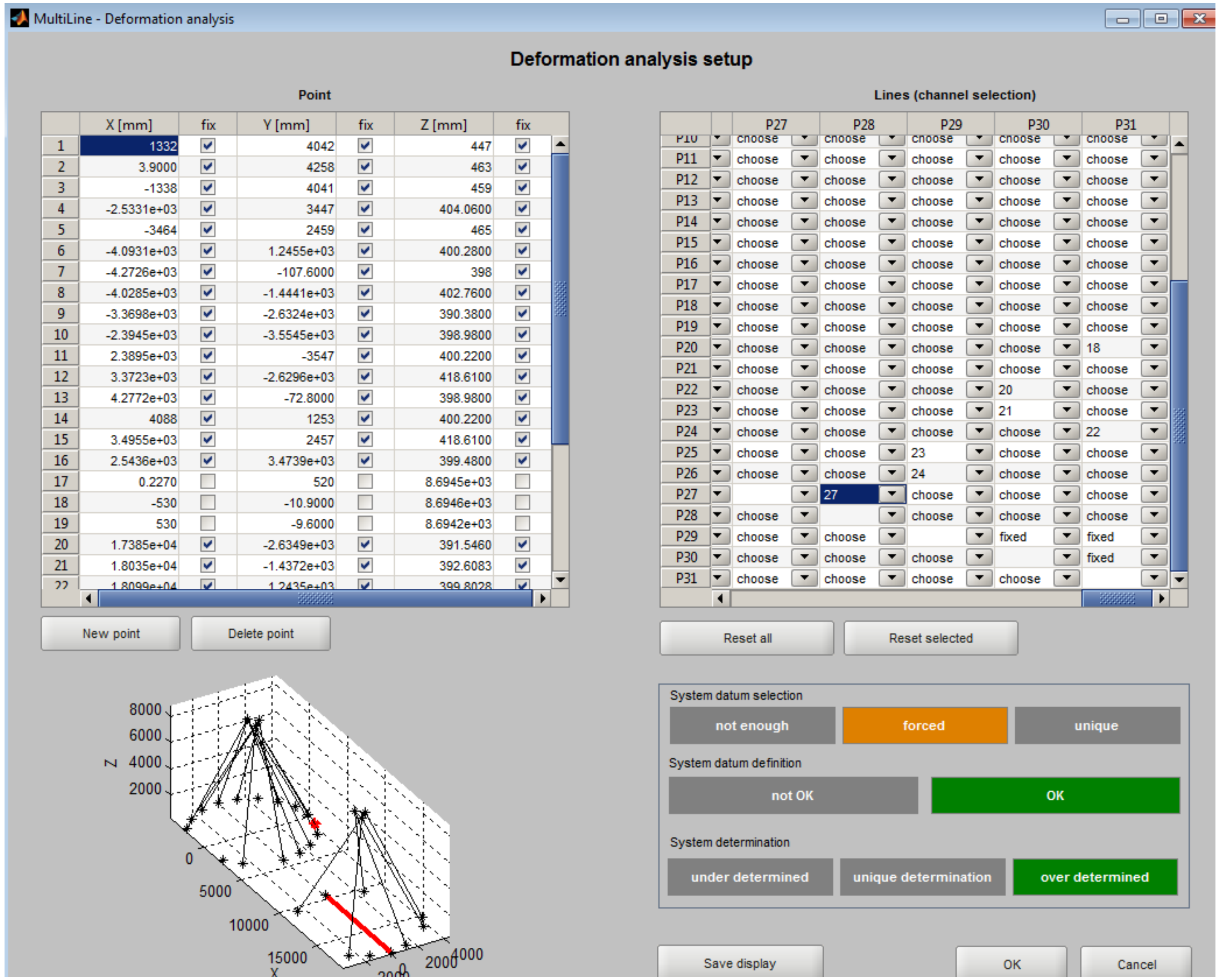


“Passive” Observing



Software

- The EAMT system has its own software that fully controls the unit.
- This software can be accessed by other programs on the observatory network via a TCP/IP interface. All of the control, measurement and analysis functions of the native EAMT software can be called by another program over TCP/IP.
- For our prototyping effort a Python script has been written that commands the EAMT to take a measurement, requests the resultant data on differential motion of the target retroreflectors, and does the necessary mathematics to produce a vector of M1 mirror position commands $\{x, y, z, R_x, R_y\}$, such that the mirror is returned to the last "good" position relative to the corrector.
- The Python script then hands this vector to a PERL script that interfaces with the TCS.



Software

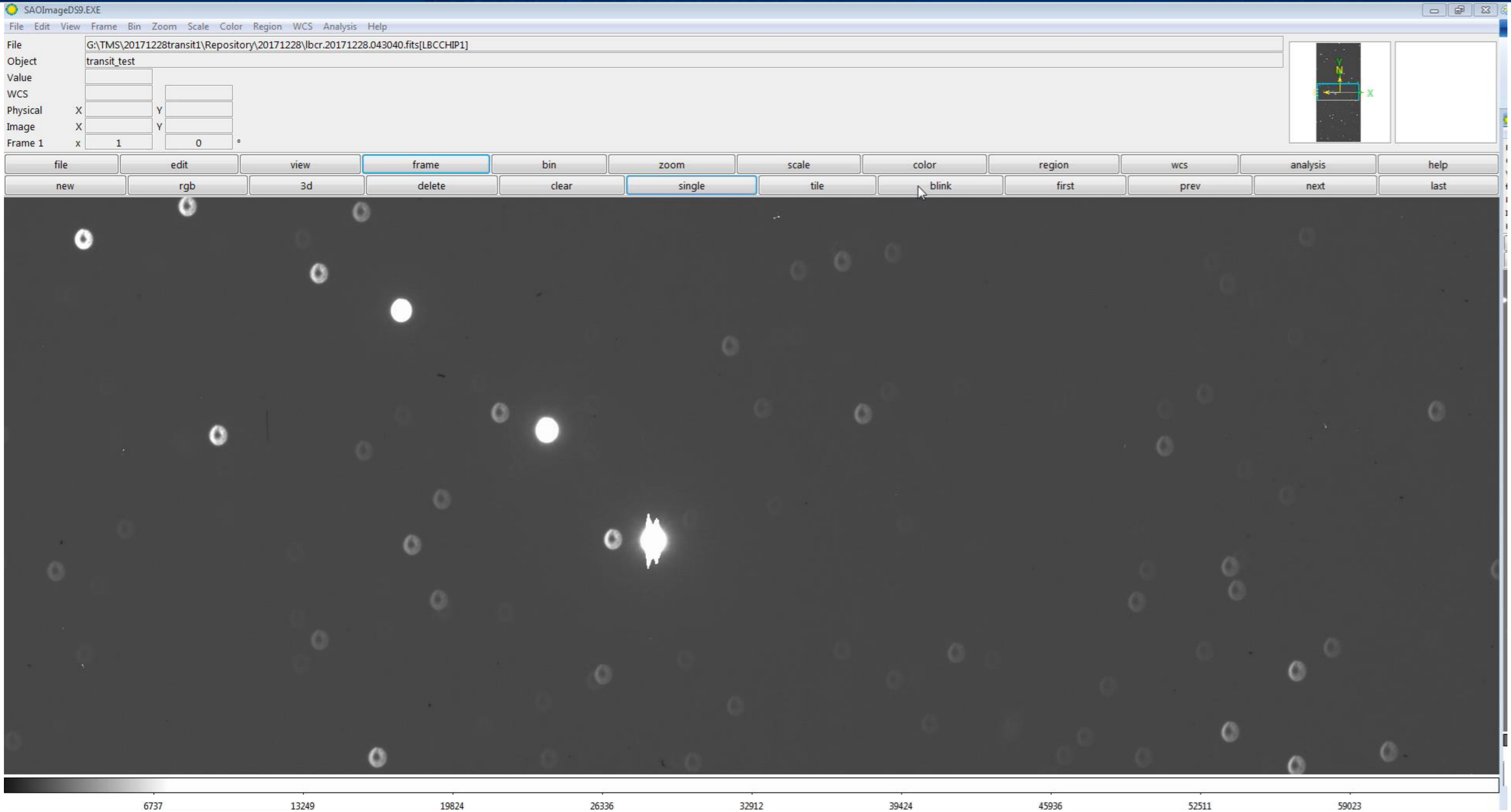
- The change in relative position of the mirror and corrector at a given TMS measurement can be decomposed into "good" and "bad" changes. The good changes are the various commanded mirror position changes that have been applied since the original TMS reference measurement was made.

- These must to be taken into account before applying corrections to the mirror position. Essentially the "goalposts" move and this must be taken into account.

- The PERL script interface to the TCS subtracts the following known offsets from the raw measurement and applies the difference to a mirror position command.

- Pointing offsets
- Instrument offsets (filter focus, say).
- Active optics focus offsets.
- Active Optics M1 motions due to Z11 and Z22 (spherical aberration) corrections.
- Guiding offsets.

Active Control

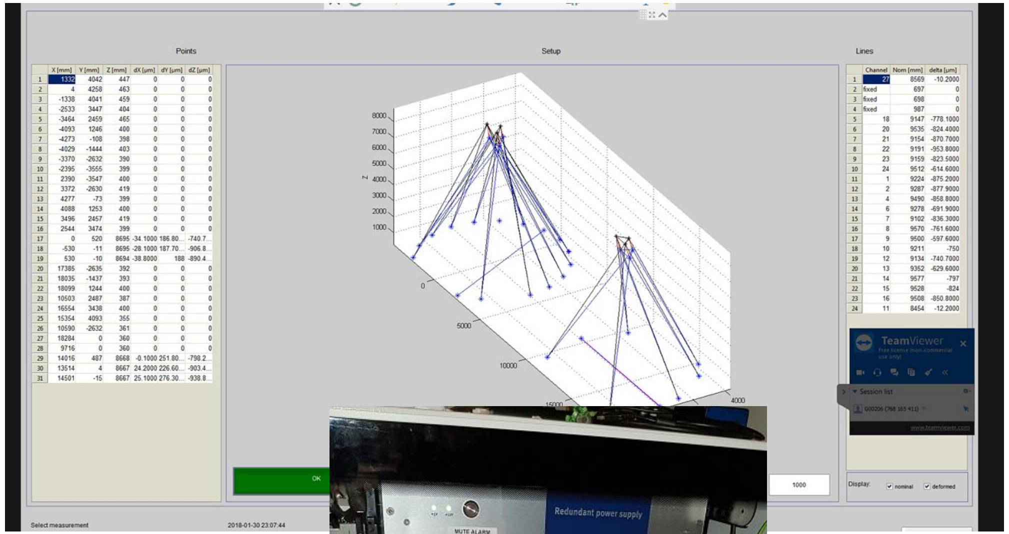


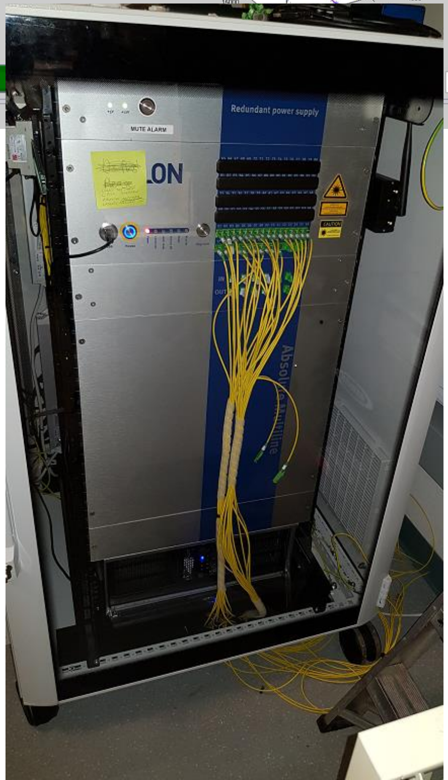
Active Control

- When the variables of telescope and software conspired to work during our limited time in active control of the telescope, the results have been promising.
- After collimating the telescope at a high elevation, and locking optics positions with the TMS, the telescope can be slewed to low elevations with no noticeable misalignment of the optics.
- With the latest modifications to the control software, further engineering time is required to qualify the system for routine use during science operations.

Lessons learned to date.

- Hardware robust and reliable.
- TCP/IP communication and control works well.
- Collimator alignment maintenance is not an issue.
- 1” collimators give superior results to ½” collimators.
- Good signal maintained over collimation model range of LBT.
- There are no measurable stray light issues for science instruments utilizing CCD detectors.
- Achievable accuracies appear to be excellent and as expected.
- Range of temperature from +20C to -10C handled without problems from operability point of view.
- Temperature measurement *in situ* is important.
- System maintenance of relative position of main telescope optics to within several micron level errors seems to be a reasonable expectation.





Future Work and conclusion.

- Hardware has been purchased for the extension to Phase Two and Three prototyping: the control of the Gregorian Telescope.
- More quantitative performance information is expected from these phases because of the superior performance of the Shack Hartman Wavefront sensors in Gregorian modes.
- Gregorian metrology is expected to begin in September 2018.
- Further details of the systems performance such as for mirror radius measurement to sub micron levels and nanometric 3-D vibration trace measurement will be discussed in the paper.
- The prototyping effort to date has yielded valuable information that validates the technological approach to assisting in telescope alignment.

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Development Team

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Thanks

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