Binocular Observing 101:

A guide to binocular observing at LBT

481s625f 23-March-2014

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LBT Technical Director

Outline of the presentation

- Introduction to Telescope Control
- Concepts of Binocular Observing
- Passive Scheduling of Dither Positions
- Details of Binocular PCS
- Details of PSF and Collimation

See the User's Meeting poster by the same title


INTRODUCTION TO THE LBT
TELESCOPE CONTROL
SYSTEM

Telescope Control System (TCS)
(really - Observatory Control System)

- High Level Sub-systems on Linux servers in mountain Control Room
- Gigabit+ ethernet communications
- Graphical User Interfaces
- Other distributed computers for hardware interface: PLC or VxWorks
- Real-time digital servos for Mount Control System

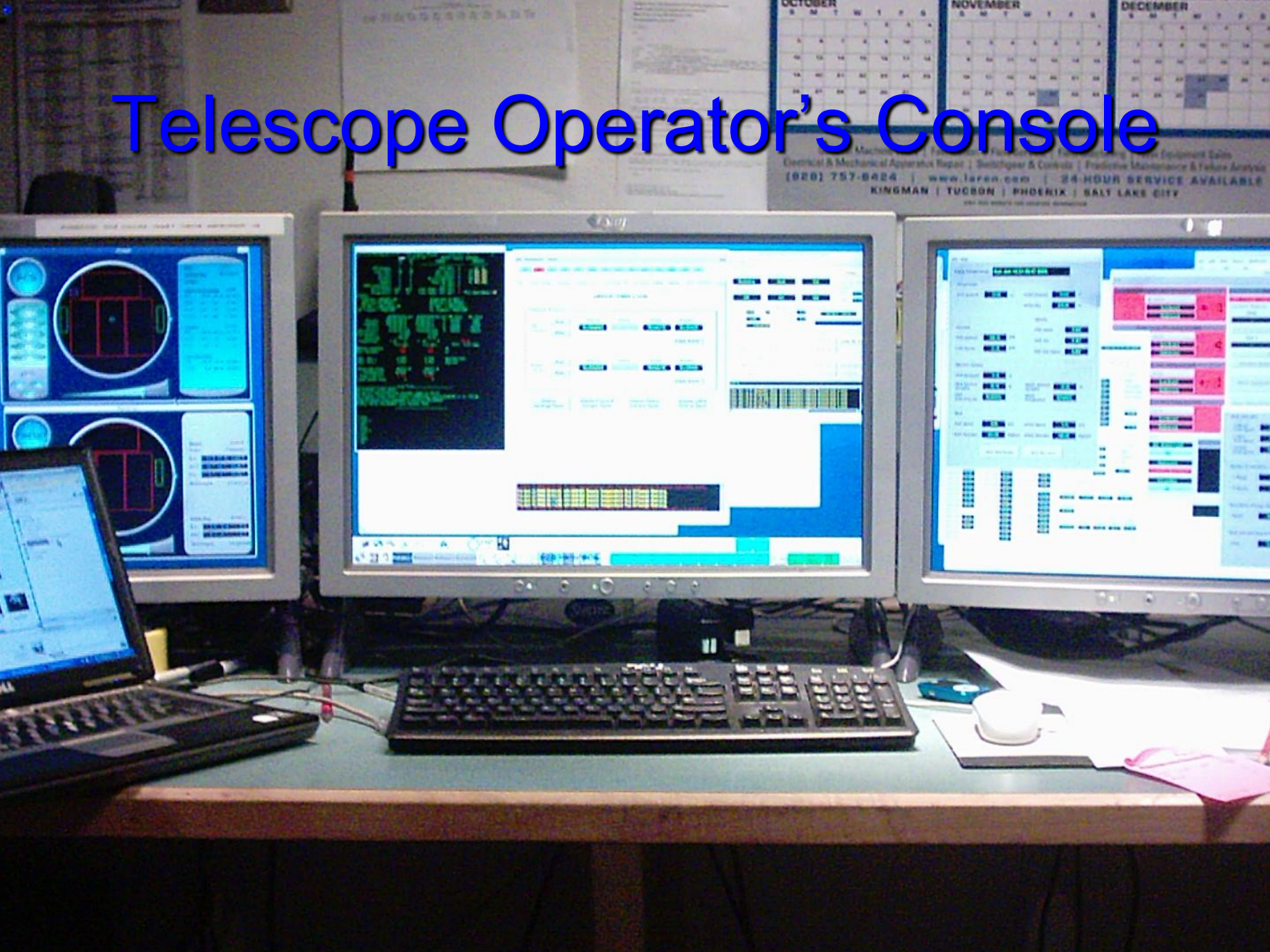
Monocular TCS Sub-Systems
(just like “regular” telescopes)

- Mount Control System (MCS)
  - Tracks mount in altitude/azimuth
- Pointing Control System (PCS)*
  - Generates tracking polynomials
- Enclosure Control System (ECS)
- Telemetry Sub-System (TEL)
- Instrument Interface (IIF)
  - Command Sequencer

Binocular TCS Sub-Systems
(deployed in pairs)

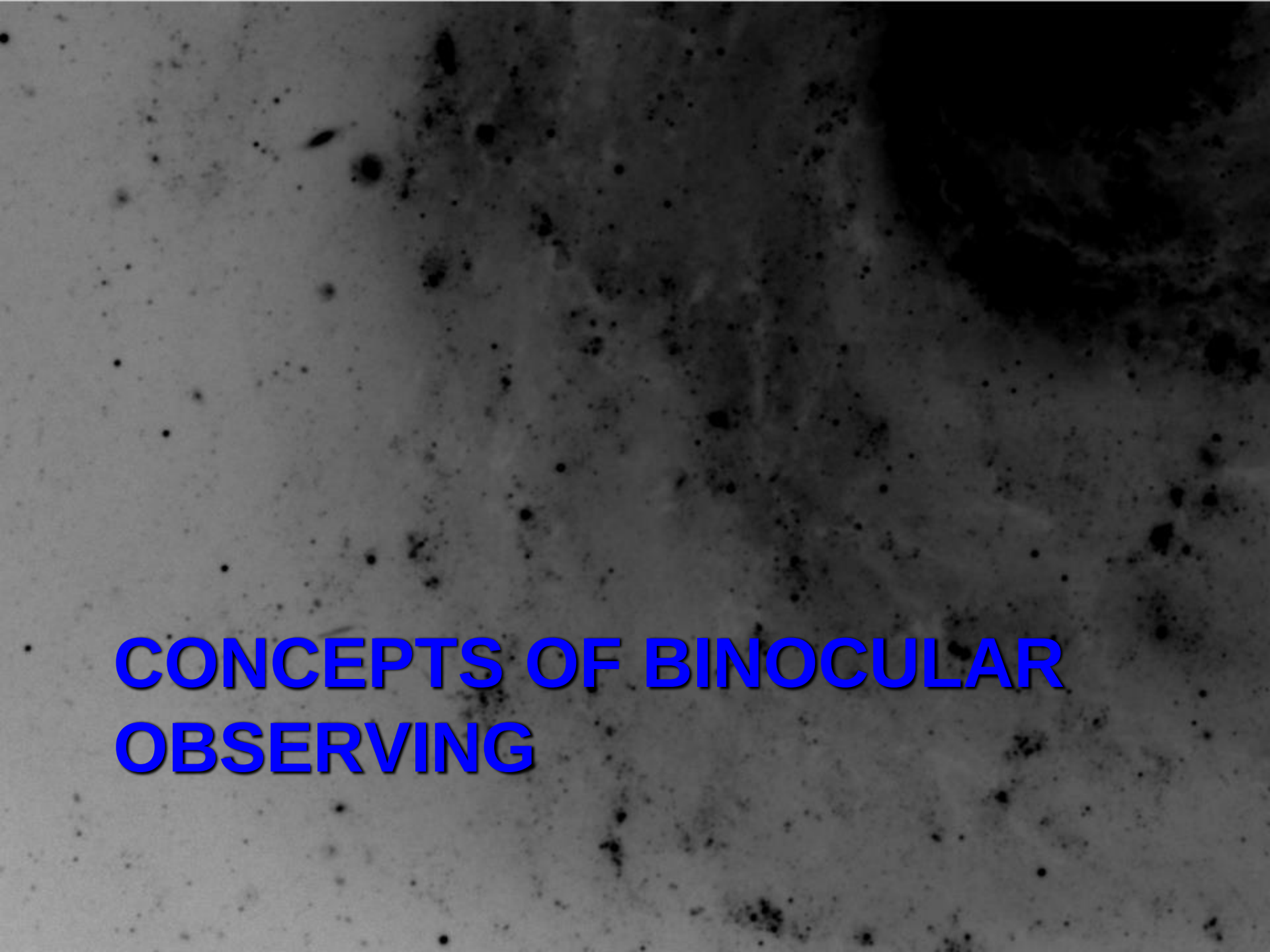
- Guiding Control System (GCS)
  - Off-axis Guiding
- Point Spread Function (PSF)
  - Active Optics and Collimation
- Primary Mirror Cell (PMC)
- Optical Support Structure (OSS)*
- Adaptive Optics System (AOS)
  - Fast Wavefront Correction

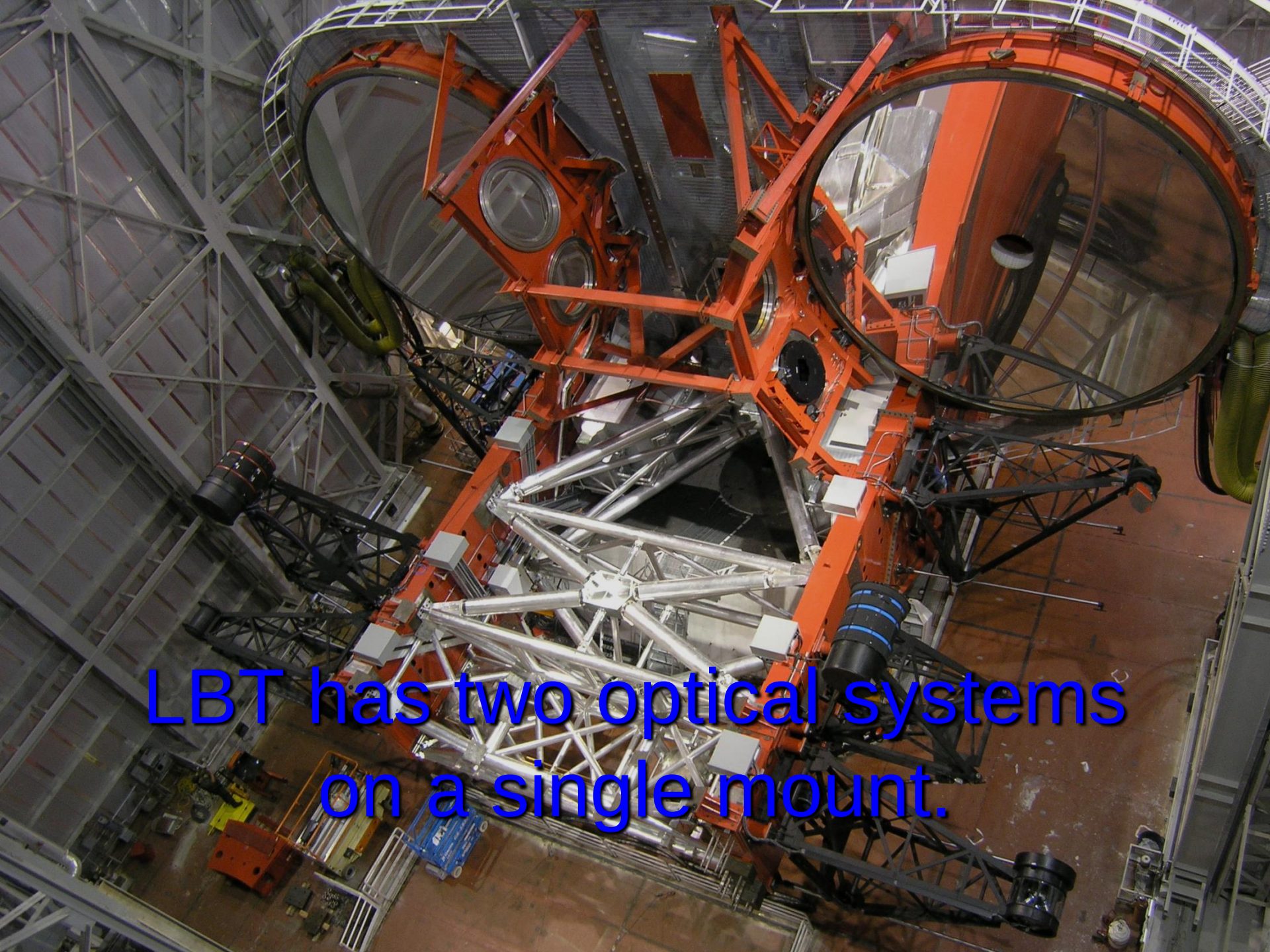
Telescope Operator's Console



Telescope Control System Status

- Basic TCS software sub-systems are complete including monocular PCS.
- Binocular Pointing Control System (PCS) is under development since Summer 2010, and is now being used by several pairs of instruments.
- This presentation describes how binocular observations work in practice from the TCS perspective.

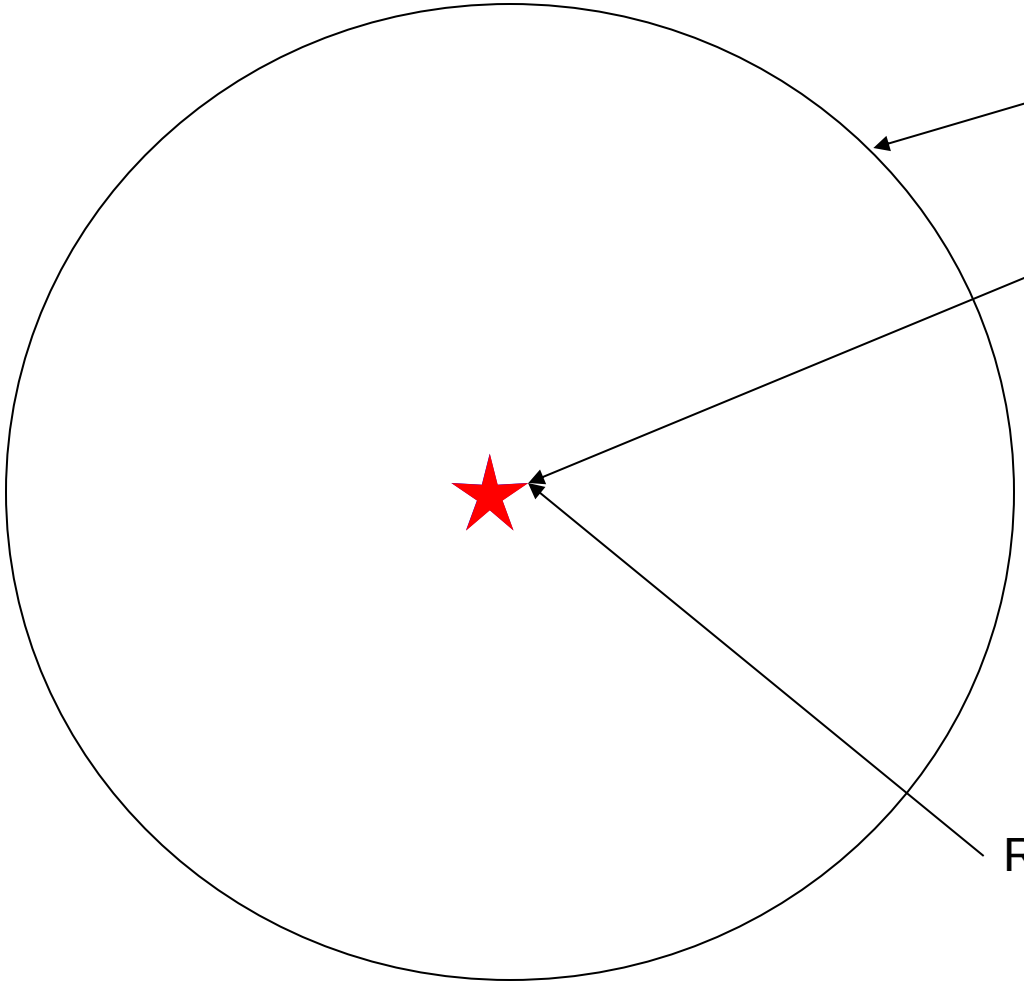

CONCEPTS OF BINOCULAR
OBSERVING


LBT has two optical systems
on a single mount.

Binocular Key Concept #1
Co-Pointing

- The two telescope sides of LBT always point at the same general part of the sky as they are located on the same telescope mount.
- However, the two sides are not required to have precisely the same target, wavelength, position angle, offset, pointing model, etc.
- They are **co-pointed** within a certain angle on the sky limited primarily by the range of travel of the optics.

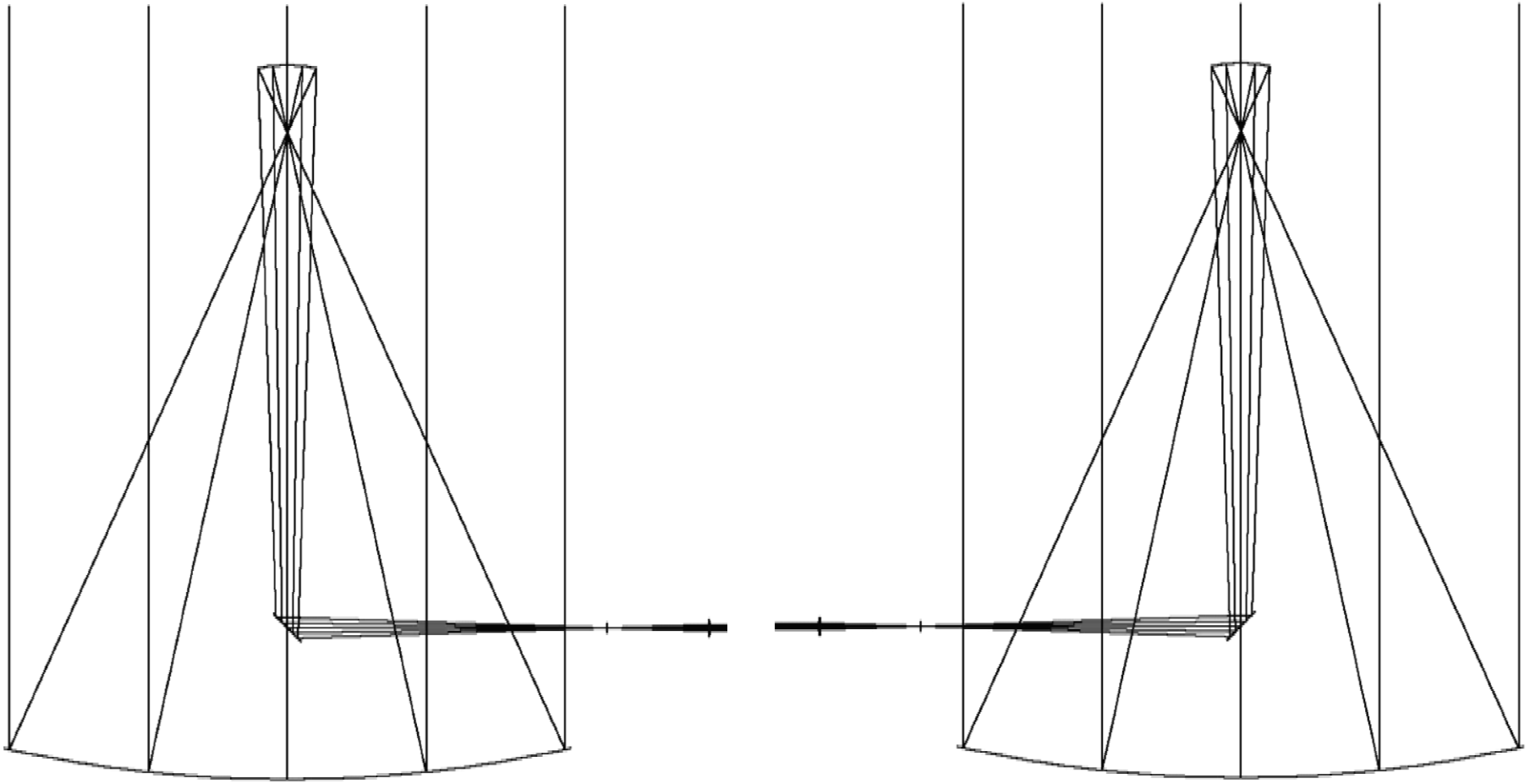
View on the Sky - pure co-pointing



Both telescopes sides are usually pointed at exactly the same target.

Where are the optics?

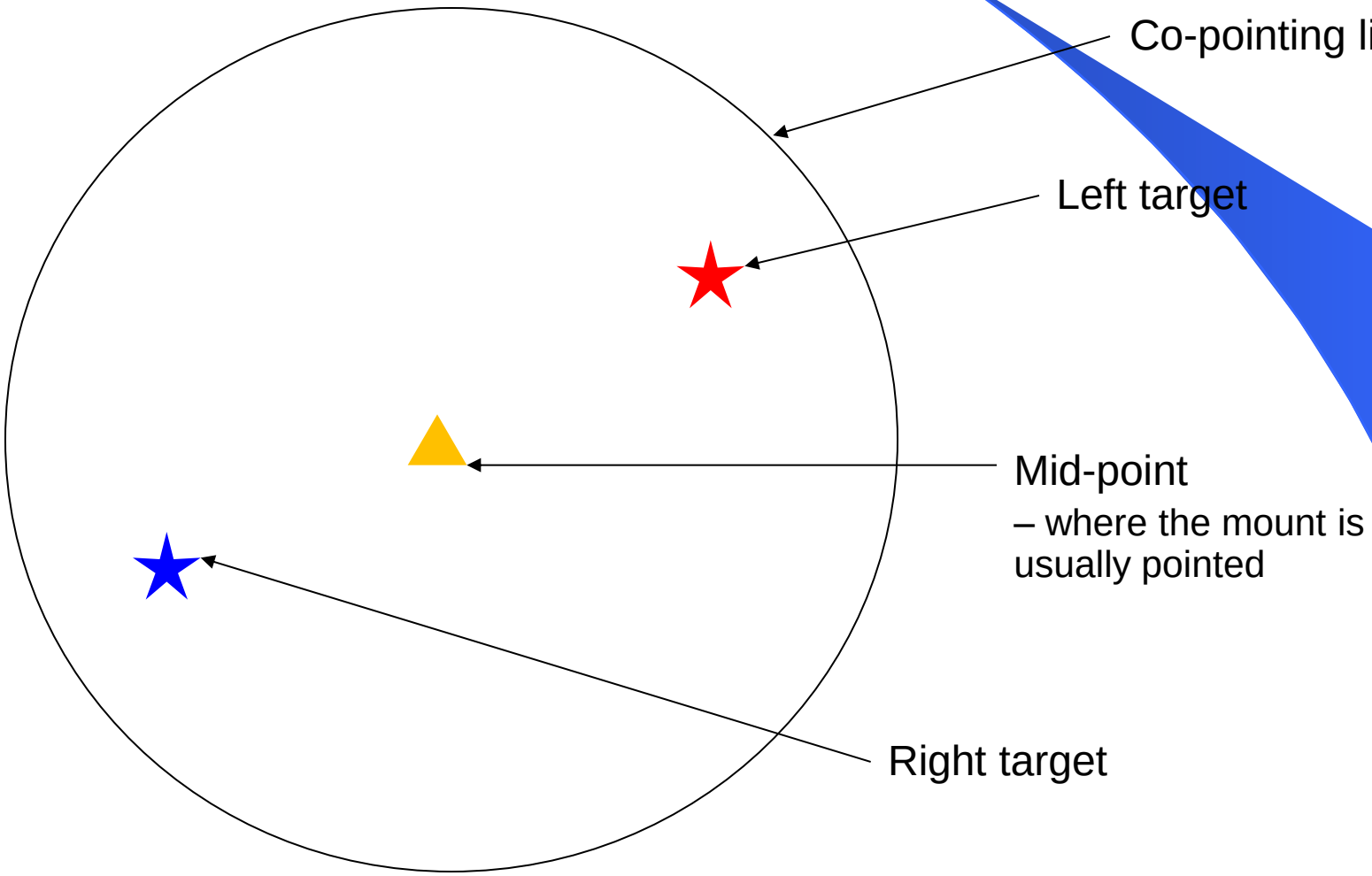
For pure co-pointing the optical axes of the two telescopes are parallel.



Binocular Key Concept #2
Co-Pointing Limit

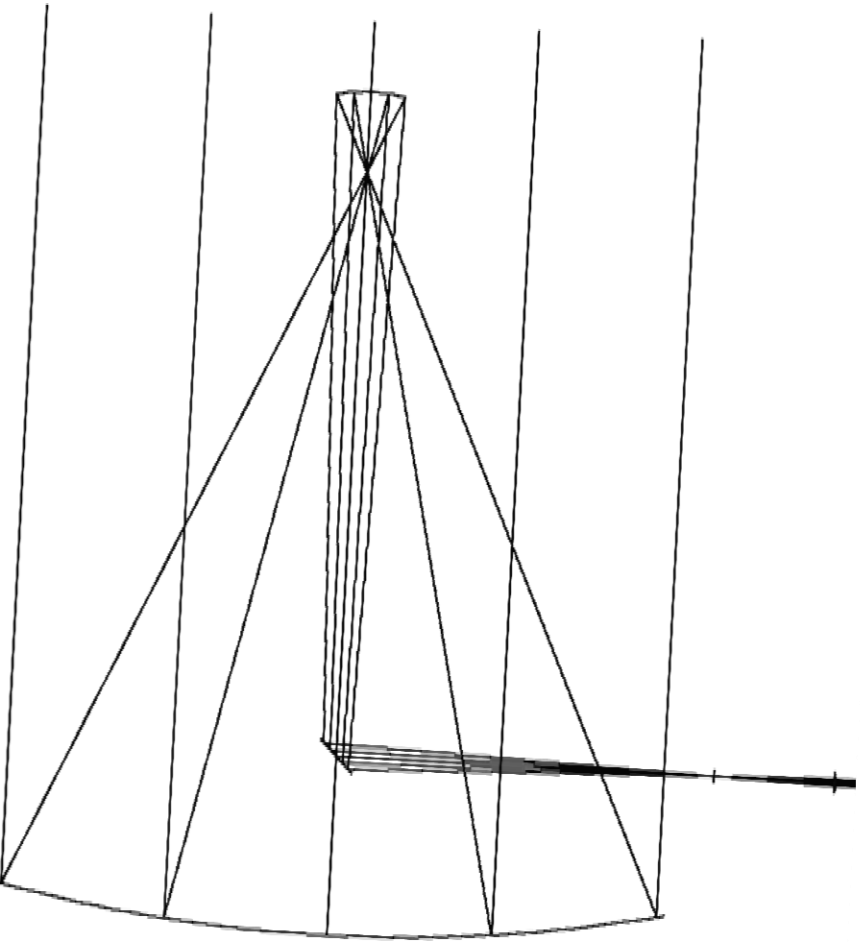
- The two sides of LBT are always able to deviate from pure co-pointing by a radius of ~20* arcsec on the sky == the **Co-Pointing Limit**.
  - Neither side should request a target (including offsets) which is farther than this limit from the **mid-point** between the two (left & right) targets.
  - *The final numerical value of this **Co-Pointing Limit** has yet to be determined.
  - The physical limits of co-pointing, set by M1/M2 collimation limits and/or image quality, may be larger than the guaranteed **Co-Pointing Limit** discussed here. (See 481s066 by A. Rakich for technical details.)

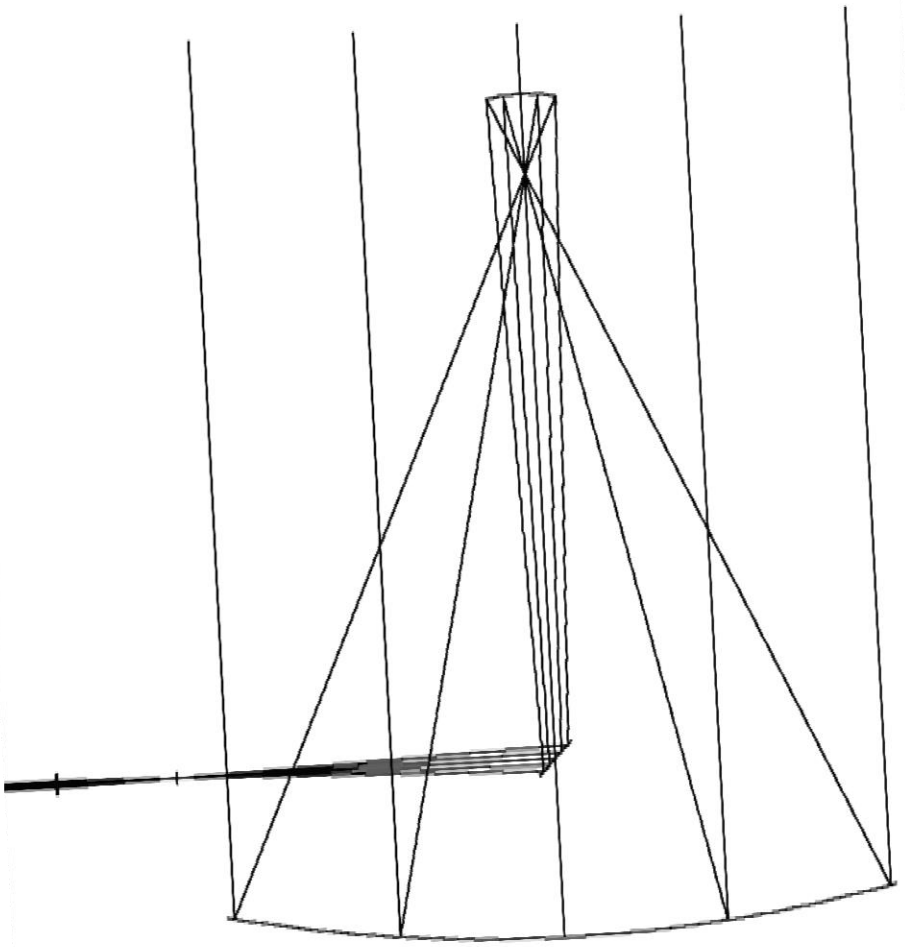
View on the Sky – separated targets



Where are the optics?

Mode 1 Re-pointing rotates the sided telescope optics as a unit.





M3 doesn’t actually move in the present implementation.

Binocular Key Concept #3
No Interruptions

- The instrument on one side of the telescope should not be allowed to interrupt / disrupt observations happening on the other side.
- **Asynchronous presets** (without any Binocular Control flags) allow small motions of the optics on one side of the telescope without any impact on the other side
  - Asynchronous presets or offsets to a location farther away than the **Co-Pointing Limit** are not recommended. See the BinocularControl (CLEARPRESET) flag if you must do this.

Binocular Key Concept #4
Synchronized Commands

- **Synchronized presets** (or offsets) should be used when both sides of the telescope are to be moved a long distance compared to the **Co-Pointing Limit**.
  - The BinocularControl command tells the TCS that you really want to move both sides, so it should wait until a preset command is received from each side before acting on your preset.
  - Each side should send a BinocularControl (SYNCPRESET) flag in advance of its preset.

Binocular Presets & Offsets

- Normally not using a single side=BOTH preset
  - For reasons of flexibility and recoverability from errors
- **Synchronized** sided presets to set a new target
  - Side=LEFT BinocularControl (SYNCPRESET)
  - Side=LEFT Preset
  - Side=RIGHT BinocularControl (SYNCPRESET)
  - Side=RIGHT Preset
- **Asynchronous** sided presets
  - Resend one side of a failed synchronized preset
  - One new sided preset within the same target field
- Offsets work in the same fashion
  - See 481s620 by D. Thompson

Sample Observation: New Target

time

- Left side sends **BinocularControl** (SyncPreset)
  - IIF starts waiting for the right SyncPreset flag.
- Left side sends **Preset**
  - IIF saves target info and continues waiting.
- Right side sends **BinocularControl** (SyncPreset)
  - IIF starts waiting for two preset commands.
- Right side sends **Preset**
  - PCS checks co-pointing of the new targets.
  - Telescope slews to new location, and optics move.
  - Both of the presets complete.
  - Each instrument may integrate as soon as its sided preset is complete.

Binocular Key Concept #5
Graceful Fallback to Monocular Mode

- If one side of the telescope is disabled, observations may continue on the other side by authorizing the disabled side of the telescope as instrument NONE.
  - The same instrument scripts or observing blocks may be used without modification.
  - The IIF knows to ignore all BinocularControl flags when only one side is authorized.

CONCEPTS OF PASSIVE SCHEDULING

Binocular Key Concept #6
Simple Scheduling

- Since the IIF always waits until the second of a pair of synchronized presets or offsets is received, a pair of observation sequences (usually dither positions) can be scheduled (coordinated in time) passively without the need for an intelligent scheduler which is aware of the integration state of both instruments.
  - Each instrument sends its synchronized offset request once it has finished integrating.
  - With suitable planning, LBC imaging can be co-scheduled with LUCI spectra, MODS spectra, etc.

Sample Observation: Passive Scheduling

time

Left

- Integrations at dither position 1 complete
- Send BinocularControl flag (SyncOffset)
- Send Offset command
  - IIF waits until second offset received.
  - Offset command complete
- Begin integrations at dither position 2

Right

- Integrations at dither position 1 complete
- Send BinocularControl flag (SyncOffset)
- Send Offset command
  - Offset command complete
- Begin integrations at dither position 2

See 481s621 by T. Sargent for a detailed example.

Caveats to Scheduling

- This concept of scheduling considers coordinating observations with a time resolution of several seconds to make efficient use of the telescope. There is no consideration of the timing of individual integrations at the millisecond level.
- A planning tool is required to account for the exposure times and instrument overheads to make the dither intervals similar (within seconds) for efficiency on both sides.
- There is no allowance presently for auto-filling of dead time at the end of a dither.

Sample Observation: Recovery

- Left side sends **BinocularControl** (SyncPreset).
- Left side sends **Preset.**
- Right side sends **BinocularControl** (SyncPreset).
- Right side sends **Preset.**
  - Telescope slews to new location.
  - Right preset fails for fixable reason (i.e. M1 not ready).
  - Left instrument may integrate as soon as its sided preset is complete.
- Re-send Right side **Preset** asynchronously without **BinocularControl** after fixing problem.
  - Right instrument may integrate as soon as its sided preset is complete.

Binocular Instrument Pairs

- LBC-Blue and LBC-Red (many years)
- LBTI (routine operation with AO)
- LUCI1 and LBC-Red (limited use)
- PEPSIPFU (limited testing)
- LUCI1 and LUCI2 (limited testing)
- MODS1 and MODS2 (testing soon)

- Warning: Not all instrument software is fully binocular-aware.

Special Observing Mode

- Pseudo-monocular mode is a special observing mode where one instrument observes as if monocular, and the second instrument follows along passively.
- For example, LBC-Red could take survey images while MODS1 takes spectra on the other side.

What's Next?

- Binocular-aware instrument software
- Binocular-aware planning tools
- Collimation to expand co-pointing limit
- TCS optimization for interferometry

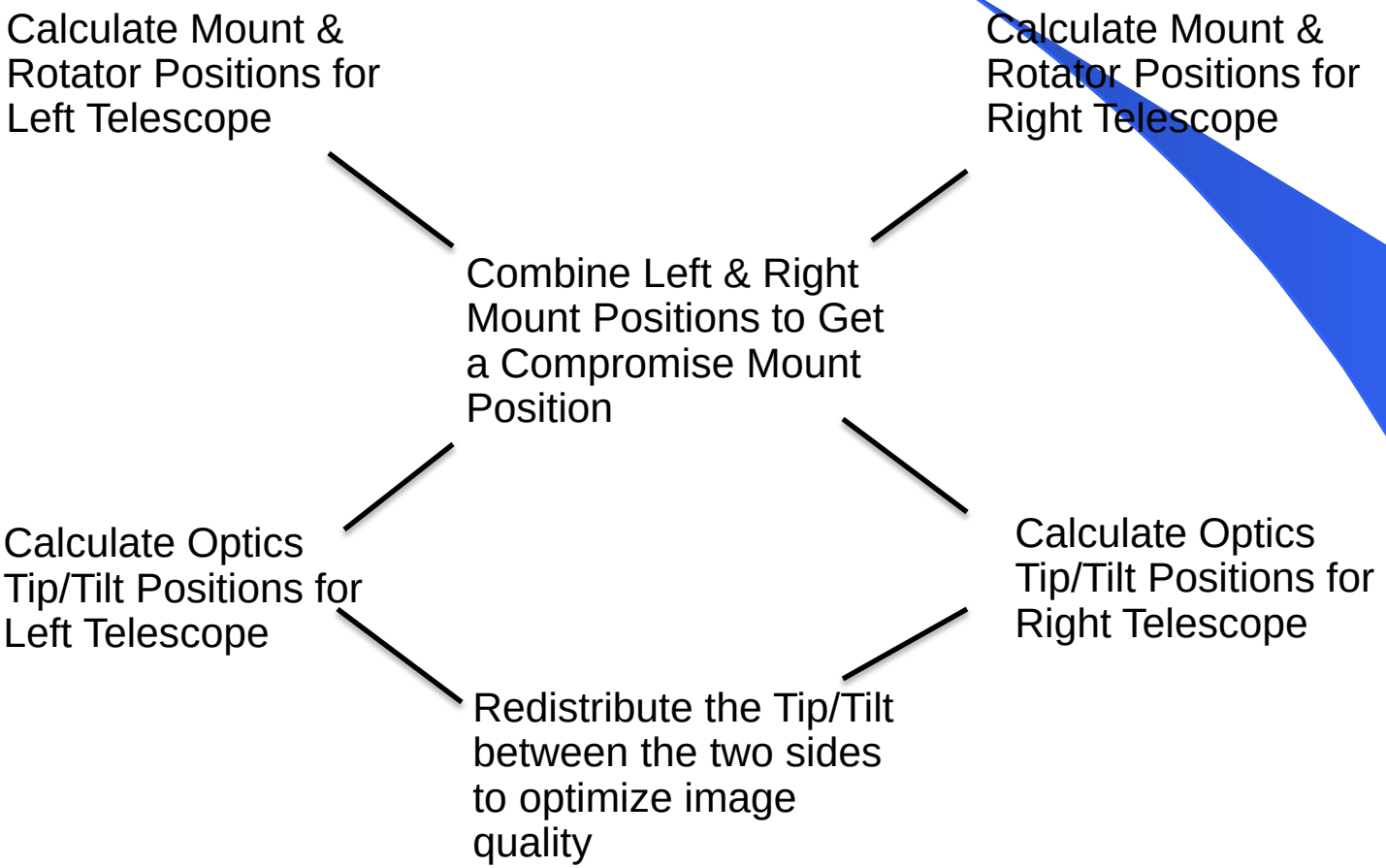
MORE TECHNICAL DETAILS ABOUT THE BINOCULAR PCS SUB-SYSTEM

Pointing Control System (PCS)

- The PCS sub-system controls telescope pointing and tracking.
- It contains the computing engine (kernel) to generate polynomial tracking trajectories for the mount axes and rotators at a rate of 20 Hz.
- It sends optics pointing information (relative to the mount) to both PSF (left/right) sub-systems every few seconds.
  - See De La Peña 481x122

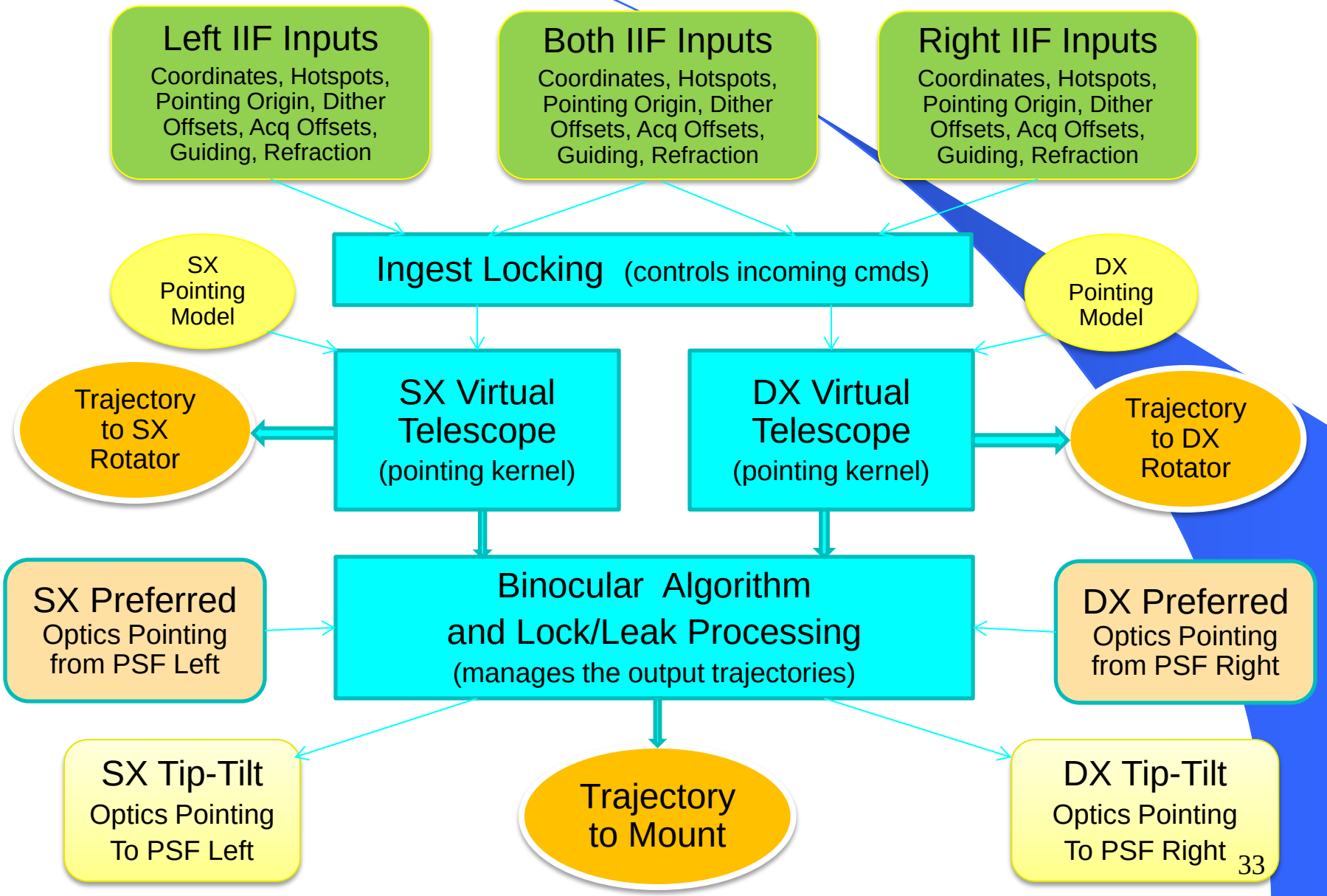
How pointing arbitration works (simplified):

Binocular PCS Pointing Flow



After Figure 1 of Terrett 481x120

Flow Diagram of Binocular PCS



Binocular PCS Main GUI

Binocular PCS Pointing GUI

Mount Locking

- In general, the telescope mount will be pointing near the mid-point between the left and right targets.
- One side making an asynchronous offset or guide correction will move only the optics on that side leaving the position of the mount and the other side optics unchanged.

Leaking and Locking

- After an asynchronous offset occurs, we would like the mount to be pointing at the mid-point between the targets, but locking prevents that in the short term.
- The PCS algorithm for pointing the optics includes a slow leak (configurable in PCSInstrument.conf) that allows the mount point to very slowly move back toward the mid-point.

Co-Pointing Limits

- Only a warning is issued when the co-pointing limit is exceeded relative to the mid-point of the two targets. This limit is deterministic for observation planning purposes.
- An error will be issued when a larger (x2) limit is exceeded relative to the mount point. This limit is not deterministic as it depends on recent history, flexure, leaking, temperature gradients, etc.

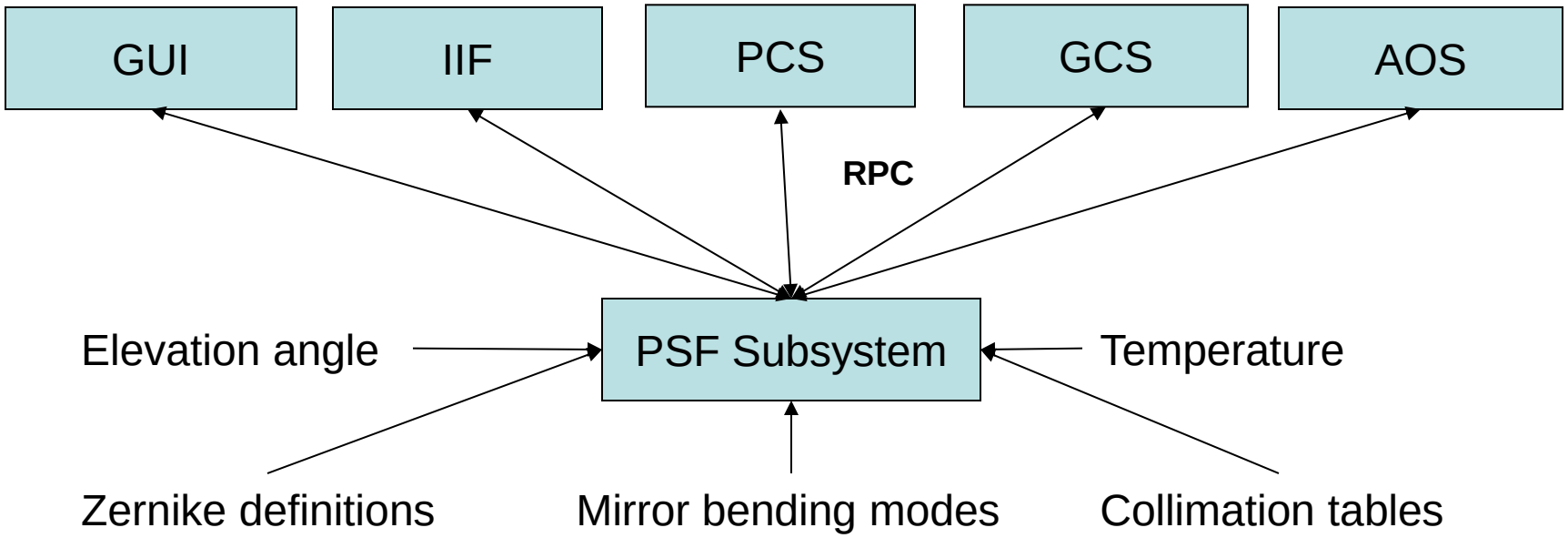
MORE TECHNICAL DETAILS ABOUT HOW THE PSF SUB-SYSTEM WORKS

Point Spread Function (PSF)

- Each of the left and right PSF sub-systems receives input from a variety of sources.
- The Collimation Arbitrator(s) in PSF **sums** all of these inputs to calculate the present commanded position of each mirror.
- These inputs include the optics tip-tilts which are calculated by PCS.
- PSF also reports back to PCS the desired tip-tilt for each side to center the optics in their range of travel (range balancing).

LBT Active Optics - PSF

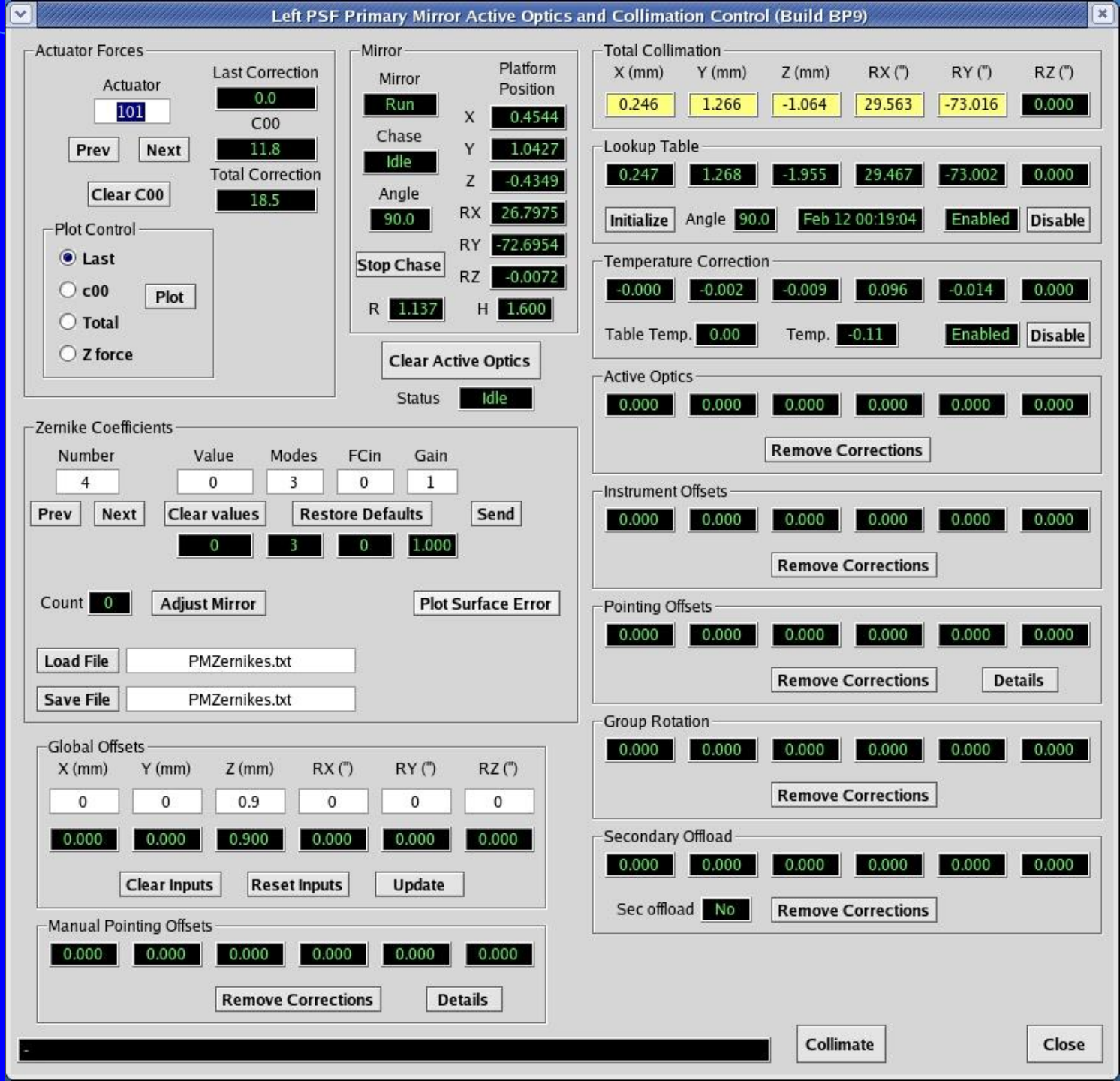
Point spread function control (left/right)



Original slide courtesy of C. Biddick

PSF GUI For M1

Displays Inputs to the Collimation Arbitrator in X,Y,Z,rx,ry,rz space




Left PSF Primary Mirror Active Optics and Collimation Control (Build BP9)
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Platform Position
X 0.4544
Y 1.0427
Z -0.4349
RX 26.7975
RY -72.6954
RZ -0.0072
R 1.137
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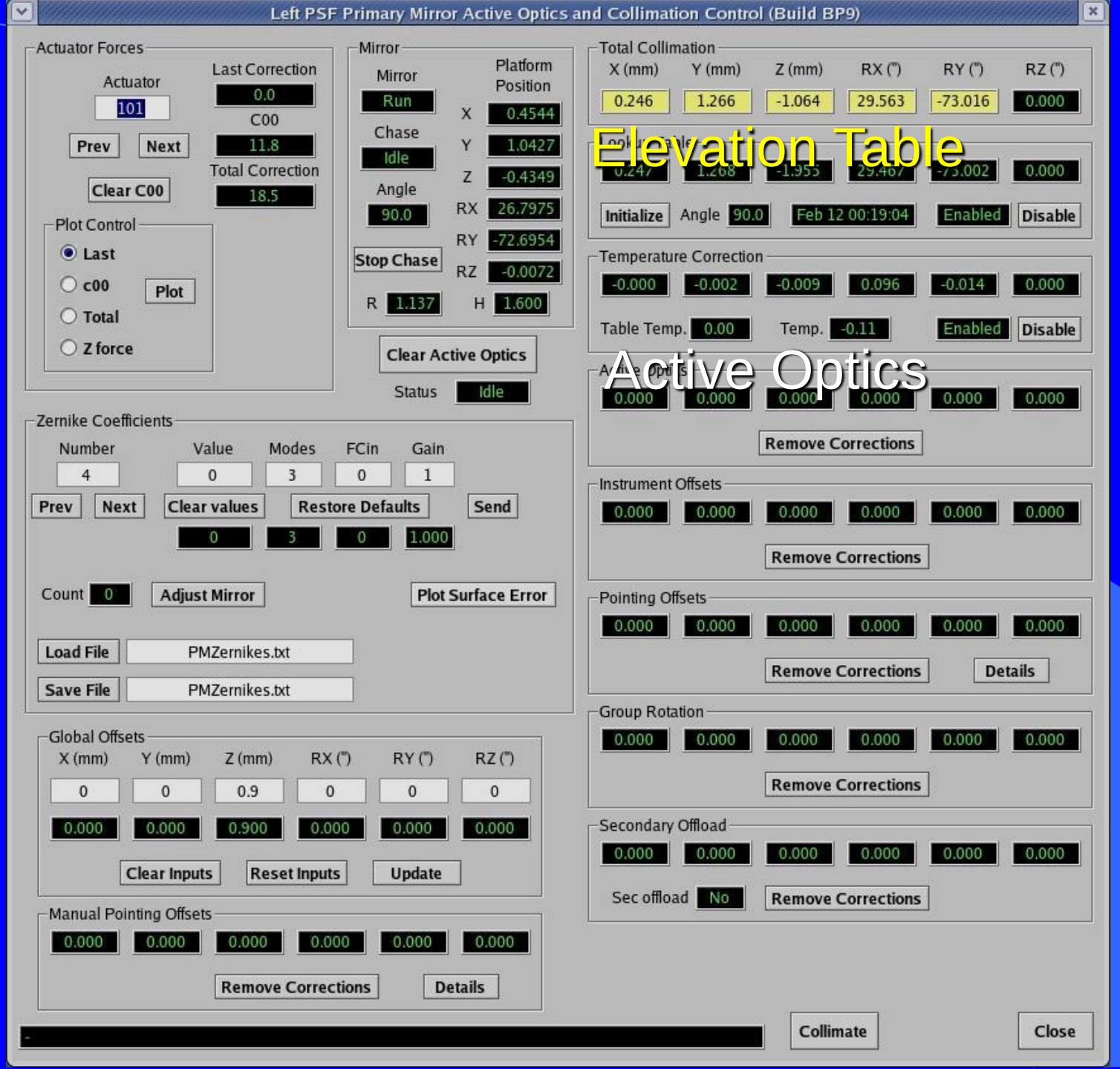
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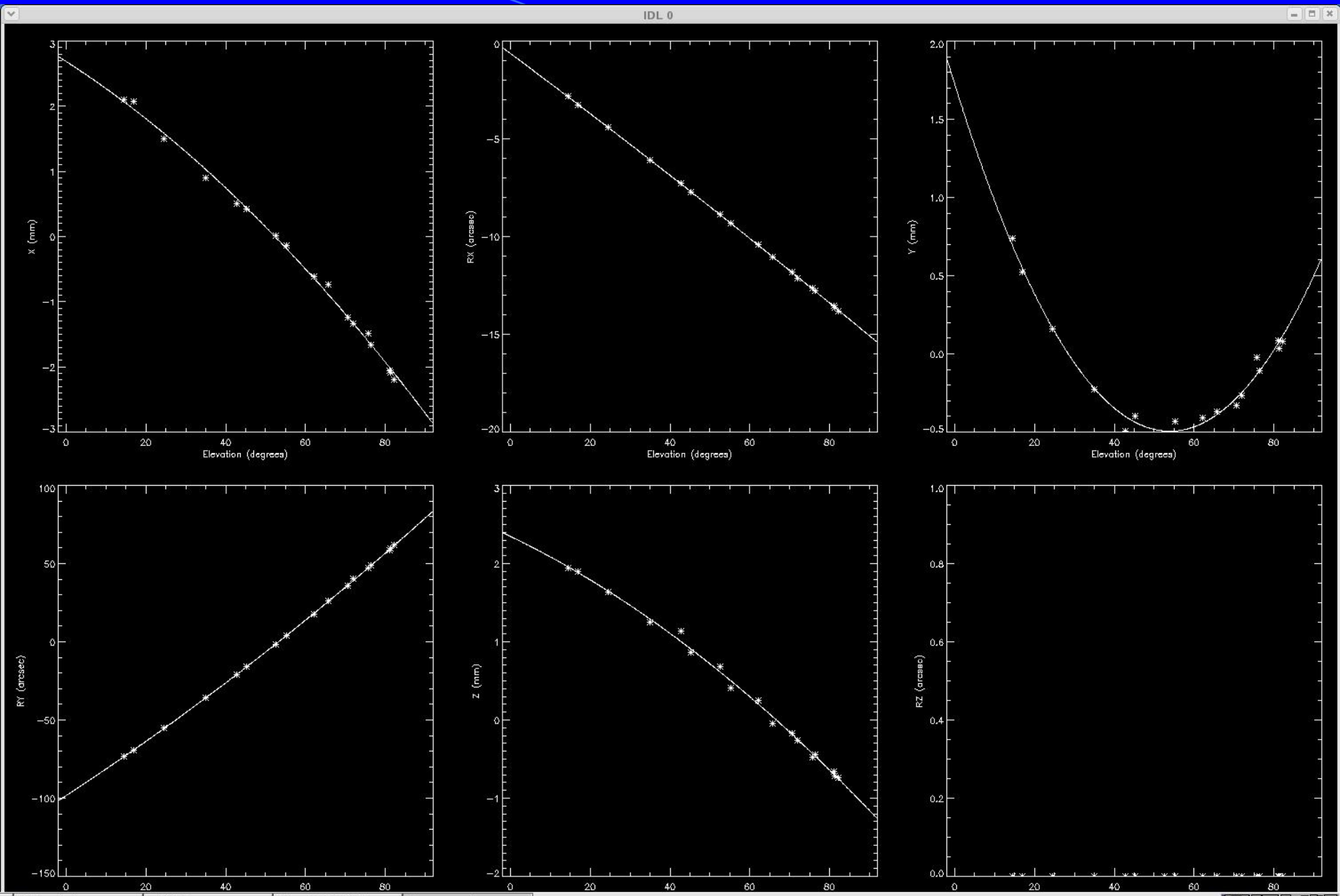
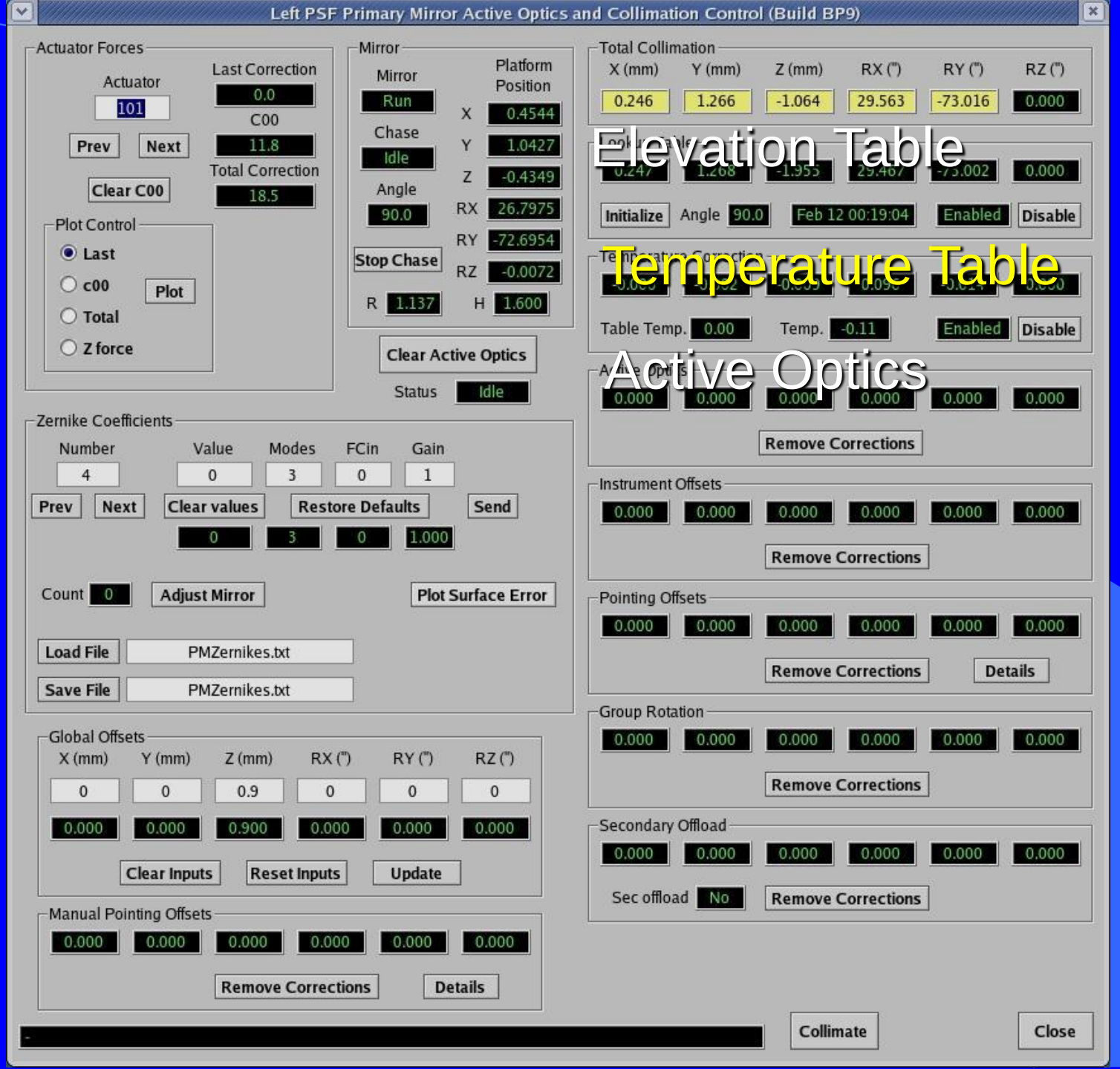
DX M1 Collimation vs Elevation for RFBG

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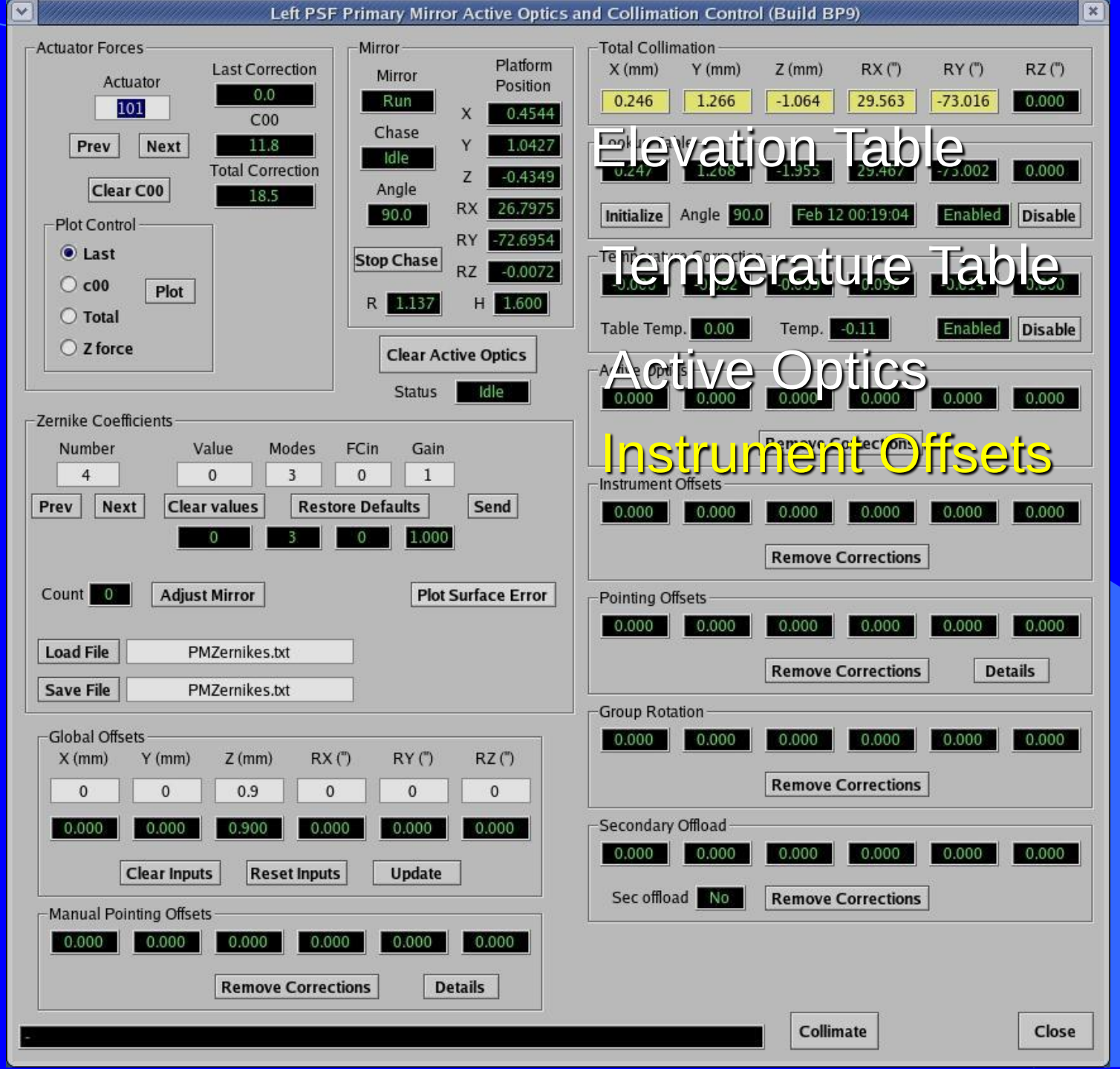
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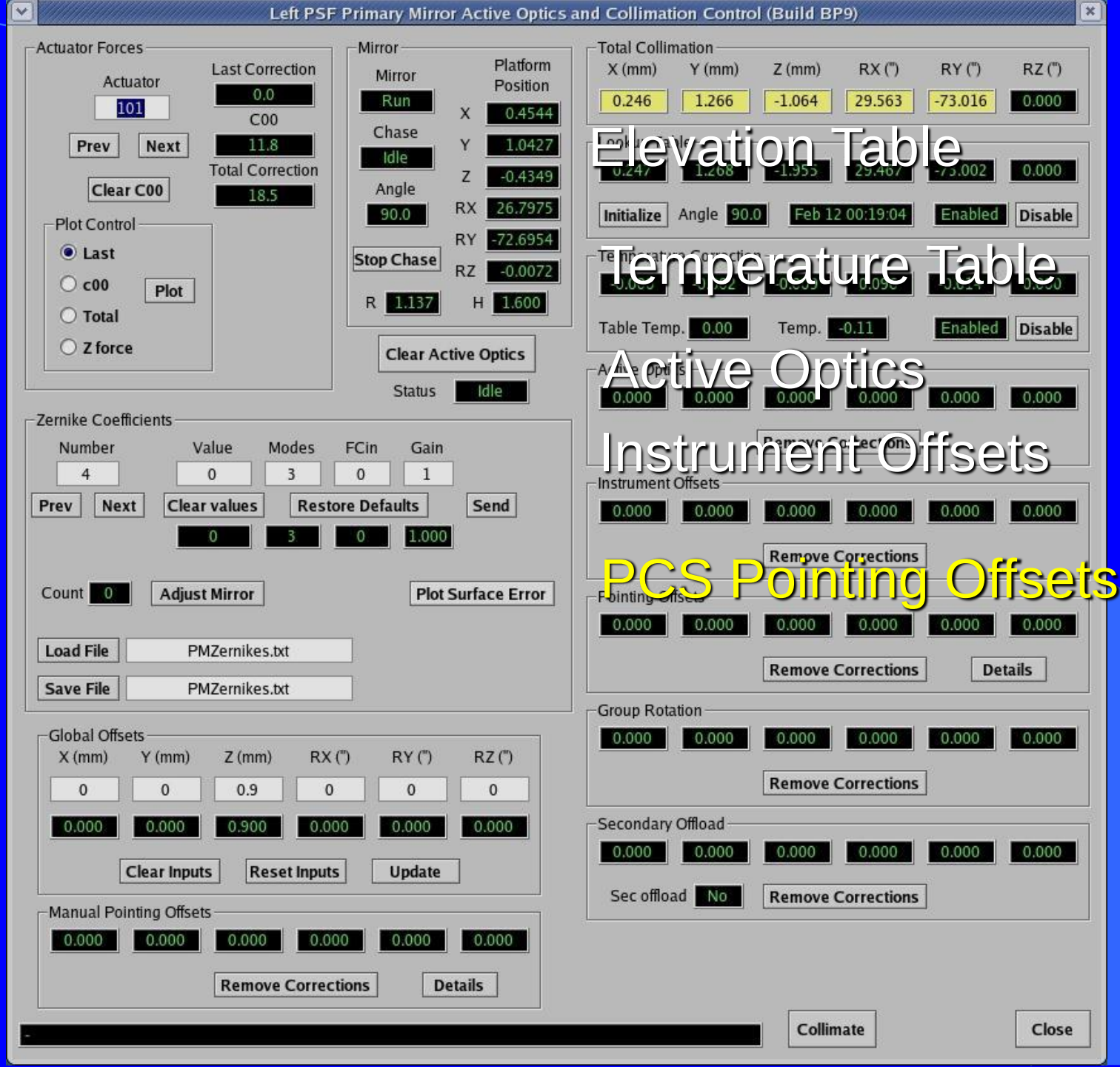
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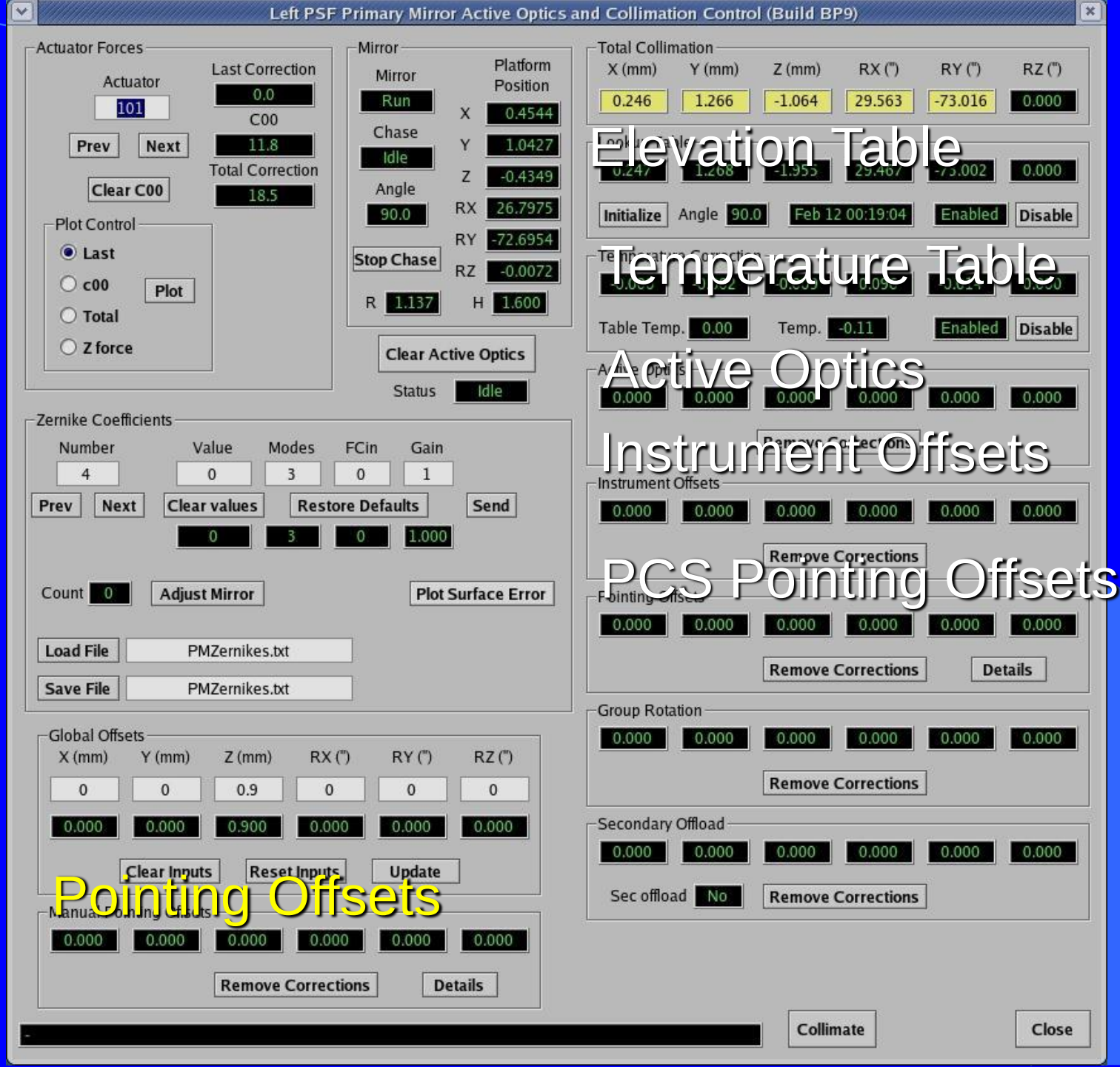
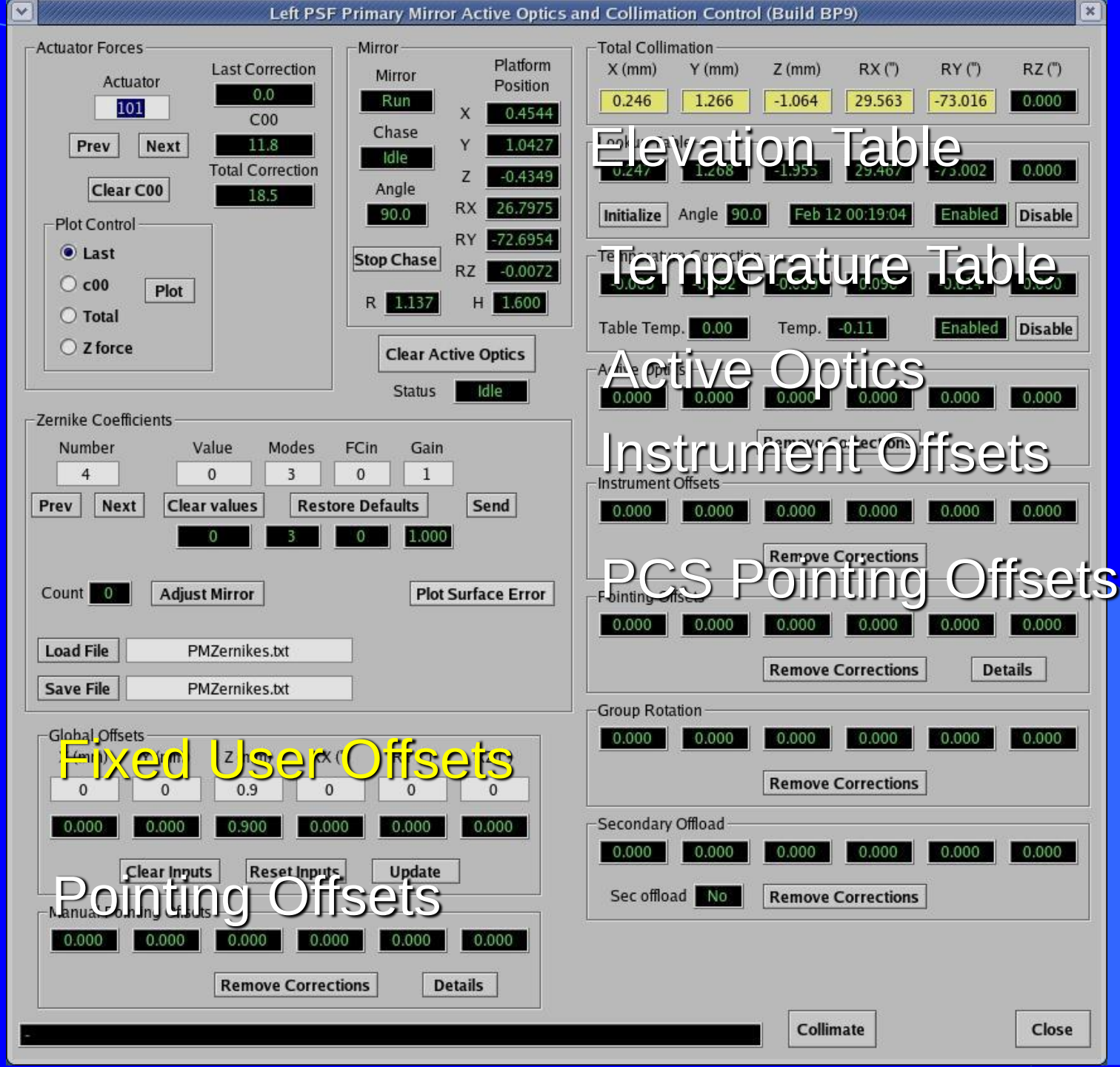
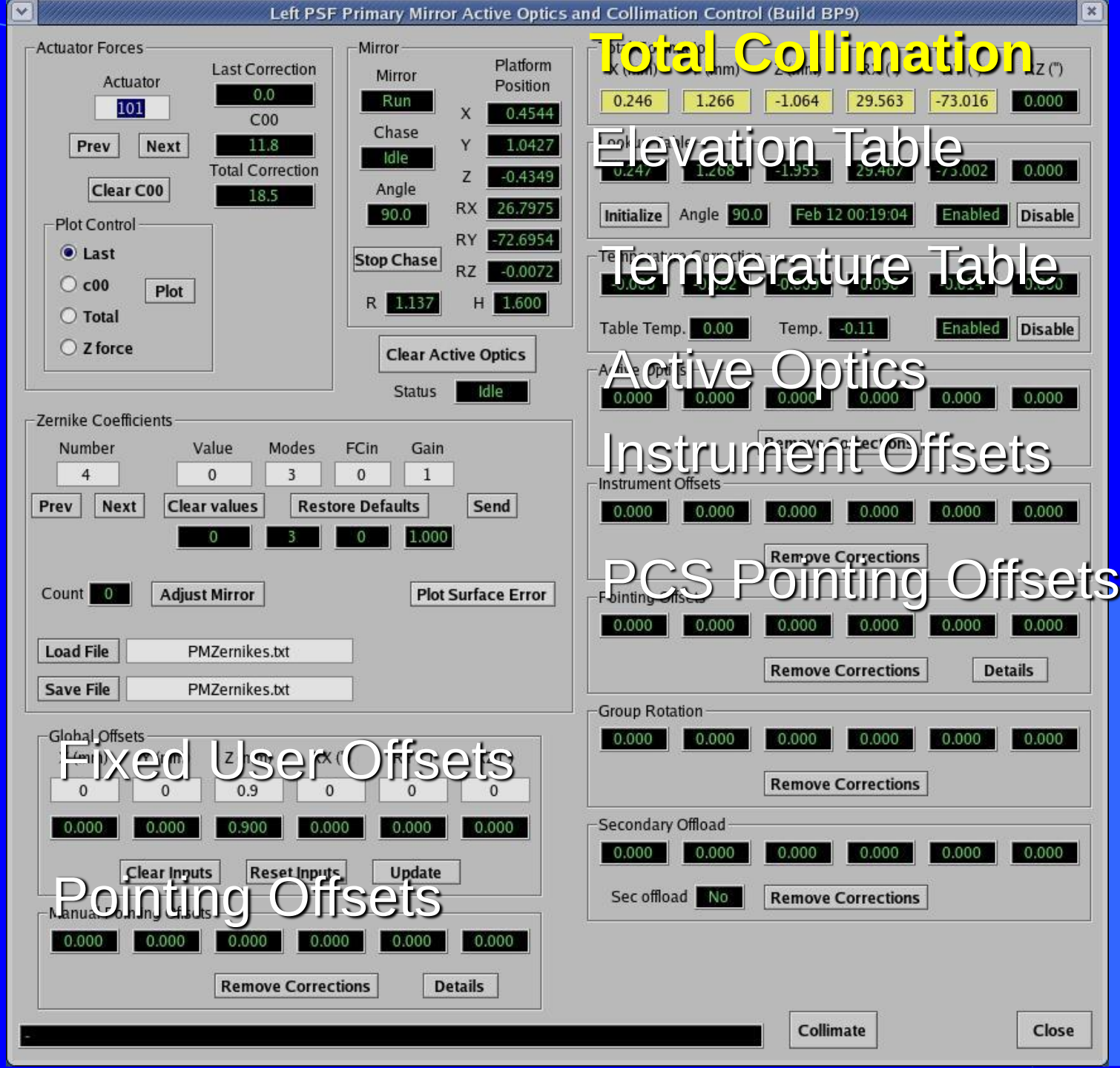
Status Idle
Total Collimation
X (mm) Y (mm) Z (mm) RX (") RY (") RZ (")
0.246 1.266 -1.064 29.563 -73.016 0.000
Elevation Table
Initialize
Angle 90.0
Feb 12 00:19:04
Enabled
Disable
Temperature Table
Table Temp. 0.00
Temp. -0.11
Enabled
Disable
Active Optics
0.000 0.000 0.000 0.000 0.000 0.000
Instrument Offsets
0.000 0.000 0.000 0.000 0.000 0.000
Remove Corrections
PCS Pointing Offsets
0.000 0.000 0.000 0.000 0.000 0.000
Remove Corrections
Details
Group Rotation
0.000 0.000 0.000 0.000 0.000 0.000
Remove Corrections
Secondary Offload
0.000 0.000 0.000 0.000 0.000 0.000
Sec offload No
Remove Corrections
Zernike Coefficients
Number Value Modes FCin Gain
4 0 3 0 1
Prev
Next
Clear values
Restore Defaults
Send
0 3 0 1.000
Count 0
Adjust Mirror
Plot Surface Error
Load File
PMZernikes.txt
Save File
PMZernikes.txt
Global Offsets
X (mm) Y (mm) Z (mm) RX (") RY (") RZ (")
0 0 0.9 0 0 0
0.000 0.000 0.900 0.000 0.000 0.000
Clear Inputs
Reset Inputs
Update
Manual Pointing Offsets
0.000 0.000 0.000 0.000 0.000 0.000
Remove Corrections
Details
Collimate
Close


Left PSF Primary Mirror Active Optics and Collimation Control (Build BP9)
Actuator Forces
Actuator
101
Last Correction
0.0
C00
11.8
Total Correction
18.5
Prev
Next
Clear C00
Plot Control
Last
c00
Total
Z force
Plot
Mirror
Mirror
Run
Chase
Idle
Angle
90.0
Stop Chase
Platform Position
X 0.4544
Y 1.0427
Z -0.4349
RX 26.7975
RY -72.6954
RZ -0.0072
R 1.137
H 1.600
Clear Active Optics
Status Idle
Total Collimation
X (mm) Y (mm) Z (mm) RX (") RY (") RZ (")
0.246 1.266 -1.064 29.563 -73.016 0.000
Elevation Table
Initialize
Angle 90.0
Feb 12 00:19:04
Enabled
Disable
Temperature Table
Table Temp. 0.00
Temp. -0.11
Enabled
Disable
Active Optics
Instrument Offsets
Remove Corrections
PCS Pointing Offsets
Remove Corrections
Details
Group Rotation
Remove Corrections
Secondary Offload
Sec offload No
Remove Corrections
Zernike Coefficients
Number Value Modes FCin Gain
4 0 3 0 1
Prev
Next
Clear values
Restore Defaults
Send
0 3 0 1.000
Count 0
Adjust Mirror
Plot Surface Error
Load File
PMZernikes.txt
Save File
PMZernikes.txt
Global Offsets
X (mm) Y (mm) Z (mm) RX (") RY (") RZ (")
0 0 0.9 0 0 0
0.000 0.000 0.900 0.000 0.000 0.000
Clear Inputs
Reset Inputs
Update
Pointing Offsets
Remove Corrections
Details
Collimate
Close


Left PSF Primary Mirror Active Optics and Collimation Control (Build BP9)
Actuator Forces
Actuator
101
Last Correction
0.0
C00
11.8
Total Correction
18.5
Prev
Next
Clear C00
Plot Control
Last
c00
Total
Z force
Plot
Mirror
Mirror
Run
Chase
Idle
Angle
90.0
Stop Chase
Platform Position
X 0.4544
Y 1.0427
Z -0.4349
RX 26.7975
RY -72.6954
RZ -0.0072
R 1.137
H 1.600
Clear Active Optics
Status Idle
Total Collimation
X (mm) Y (mm) Z (mm) RX (") RY (") RZ (")
0.246 1.266 -1.064 29.563 -73.016 0.000
Elevation Table
Initialize
Angle 90.0
Feb 12 00:19:04
Enabled
Disable
Temperature Table
Table Temp. 0.00
Temp. -0.11
Enabled
Disable
Active Optics
Instrument Offsets
Remove Corrections
PCS Pointing Offsets
Remove Corrections
Details
Group Rotation
Remove Corrections
Secondary Offload
Sec offload No
Remove Corrections
Zernike Coefficients
Number Value Modes FCin Gain
4 0 3 0 1
Prev
Next
Clear values
Restore Defaults
Send
0 3 0 1.000
Count 0
Adjust Mirror
Plot Surface Error
Load File
PMZernikes.txt
Save File
PMZernikes.txt
Global Offsets
Fixed User Offsets
0 0 0.9 0 0 0
0.000 0.000 0.900 0.000 0.000 0.000
Clear Inputs
Reset Inputs
Update
Pointing Offsets
0.000 0.000 0.000 0.000 0.000 0.000
Remove Corrections
Details
Collimate
Close

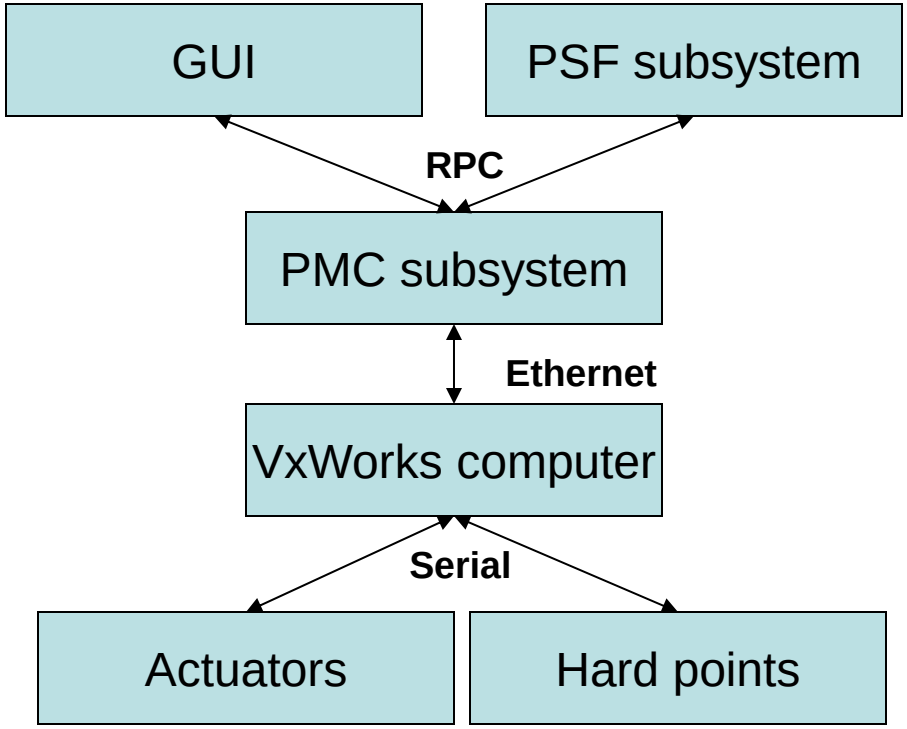

Left PSF Primary Mirror Active Optics and Collimation Control (Build BP9)
Total Collimation
Elevation Table
Temperature Table
Active Optics
Instrument Offsets
PCS Pointing Offsets
Fixed User Offsets
Pointing Offsets
Actuator Forces
Actuator
101
Last Correction
0.0
C00
11.8
Total Correction
18.5
Prev
Next
Clear C00
Plot Control
Last
c00
Total
Z force
Plot
Mirror
Mirror
Run
Chase
Idle
Angle
90.0
Stop Chase
Platform Position
X 0.4544
Y 1.0427
Z -0.4349
RX 26.7975
RY -72.6954
RZ -0.0072
R 1.137
H 1.600
Clear Active Optics
Status Idle
Zernike Coefficients
Number 4
Value 0
Modes 3
FCin 0
Gain 1
Prev
Next
Clear values
Restore Defaults
Send
0 3 0 1.000
Count 0
Adjust Mirror
Plot Surface Error
Load File
PMZernikes.txt
Save File
PMZernikes.txt
0.246 1.266 -1.064 29.563 -73.016 0.000
Initialize
Angle 90.0
Feb 12 00:19:04
Enabled
Disable
Table Temp. 0.00
Temp. -0.11
Enabled
Disable
0.000 0.000 0.000 0.000 0.000 0.000
Instrument Offsets
0.000 0.000 0.000 0.000 0.000 0.000
Remove Corrections
0.000 0.000 0.000 0.000 0.000 0.000
Remove Corrections
Details
Group Rotation
0.000 0.000 0.000 0.000 0.000 0.000
Remove Corrections
Secondary Offload
0.000 0.000 0.000 0.000 0.000 0.000
Sec offload No
Remove Corrections
Global Offsets
0 0 0.9 0 0 0
0.000 0.000 0.900 0.000 0.000 0.000
Clear Inputs
Reset Inputs
Update
0.000 0.000 0.000 0.000 0.000 0.000
Remove Corrections
Details
Collimate
Close

Control of the Optics (under PSF)

- Each of the left and right Primary Mirror Cell (PMC) sub-systems controls the position and support forces on the primary mirrors.
- The Optical Support System (OSS) sub-system controls the positions of the secondary and tertiary mirrors as well as swing arm configuration.
- The left and right Adaptive Optics System (AOS) sub-systems control the shape of the adaptive secondary mirrors.

LBT Active Optics - PMC

Primary mirror cell control (left/right)



Slide courtesy of C. Biddick