PICTURE sounding rocket telescope

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Overview of talk

- Two {ambitious} sounding rocket concepts sharing a telescope
- OTA overview
- PM development program
- PM figure testing through mount & vibe
- Mirror coatings
- OTA alignment plan

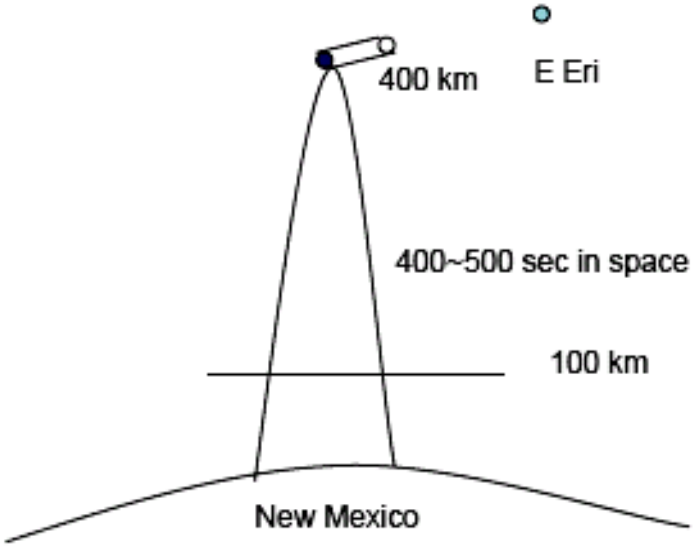
Technology area – lightweight precision optics

- Combination of high precision and light weight allows new missions
  - Small missions with better system performance
  - Larger apertures at high performance with launchable weight
- Working definition – high precision is at least visible diffraction limited; lightweight should be ~JWST mirror weight (~25 kg/m^2), but be careful
  - Areal density is (at least) linear with diameter for fixed stiffness
  - Comparisons among many mirrors can be difficult
- We (or PM vendor ITT{Kodak} have reported on development of the SHARPI/PICTURE PM at previous Tech Days

taken from 7/2005 M. Shao pres. On visible nuller interferometry to TPF-C STDT

PICTURE
AO Coronagraph on a Sounding Rocket

- B.U. (S. Chakrabari), J.P.L., MIT(Lane), GSFC (Rabin), NGST and LMCO
- A mini-version of the TPF-C proposed concept.
  - 1 potential target, Jovian planet around E Eri. (3e-8 contrast)
  - Selected jan 2005, 2 flights jan-feb 2007 and july-aug 2007.
  - CDR july 2005
  - Nuller, with calibration system (no fiber bundle)
    - Working at 1 λ/D
  - 1000 element DM in 1 arm of nuller

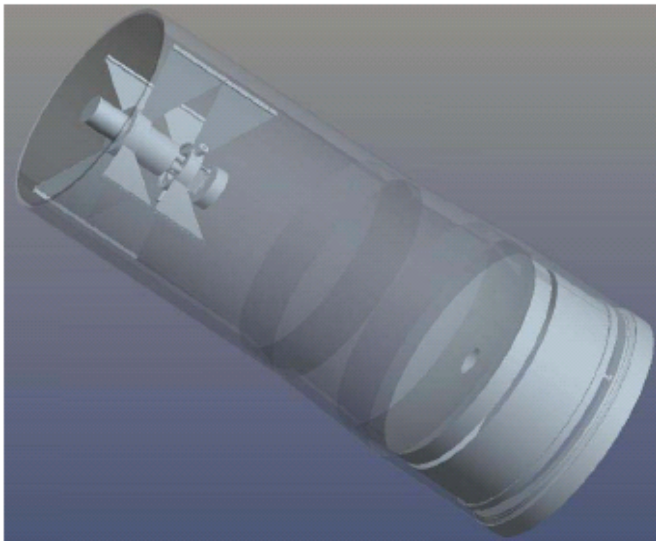


PICTURE is a low cost, high payoff, quick turnaround attempt at direct imaging of an extrasolar planet; it's the ONLY funded exo-planet imaging experiment funded in the aftermath of TPF "deferral"

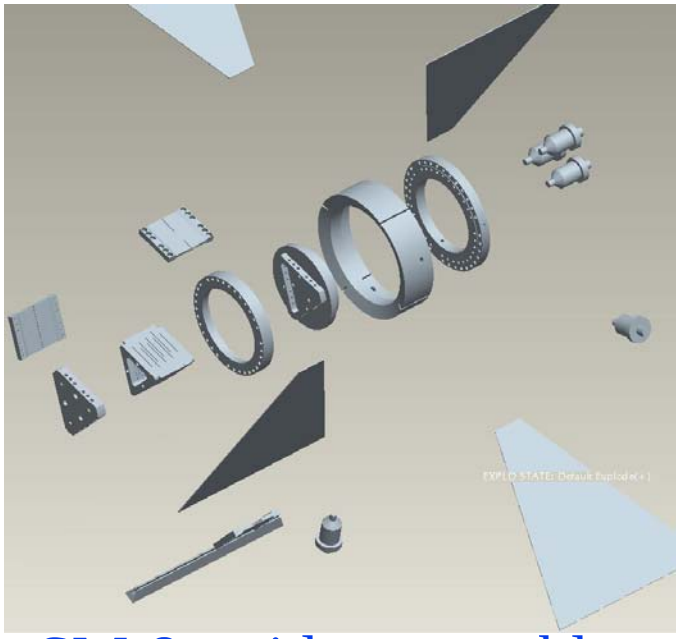
SHARPI is a concept using same hardware for ~1/4 arcsec solar UV imaging

Overview of OTA hardware

- SM from SSG/Tinsley SBIR-02-II
  - SiC w/ Si cladding, also 20kg/m^2, 11cm clear aperture, 3 nm rms figure
  - Ti, Al pieces for SM mount in fabrication (BU design)
  - Tolerances for SM come from JMEX phase A studies in 2001/2004
- Structure is Ti and composite metering structure w/ rocket skin outside
  - Star tracker is mounted in front of secondary
  - SM on 4-vane spider
  - Adjustsments for ground alignment only
- 0.5m PM is largest to go on a sounding rocket



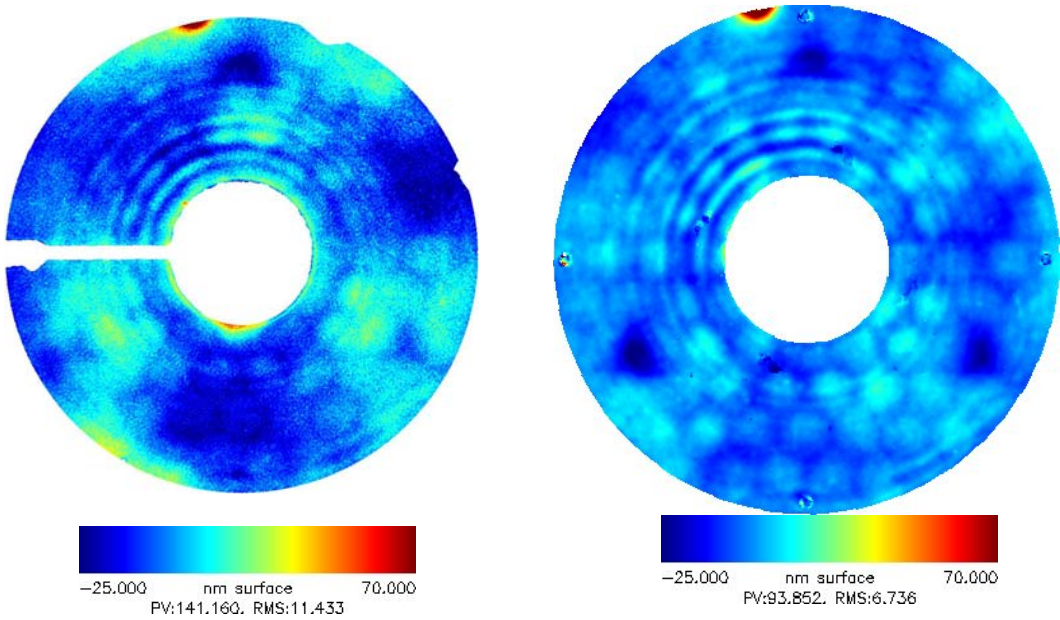
Telescope assembly



SM & spider assembly

PICTURE telescope development overview

- PM completed with help of Kodak IR&D; their measurement of figure quality over 0.508m CA was 7 nm rms with 1g vertical effects backed out; SM completed in early 2006 by SSG/Tinsley
- Over the last year we have coated, mounted, vibration tested, figure qualified, and begun OTA integration on the PM; also we have coated and tested the SM
- Figure test uses Parks method of separating test error from mirror error
  - Data taken at 12 rotated positions of PM relative to test beam
- Subsequent steps and rough schedule, details below
  - Complete PM horizontal test [August]
  - Integrate SM [September]
  - Deliver [October]



Left –GSFC horizontal data before mounting; Right – ITT data

PM Vertical CGH figure test –

- Zygo GPI folded via MUX cube, PSI down from MUX
- Removable kinematic mount for CGH
- PI Hexapod on rotation bearing with 12 detent positions (30°)
- Previous work did a partial calibration of CGH with good success
  - CGHs not qualified to 2nm rms target uncertainty we aimed for

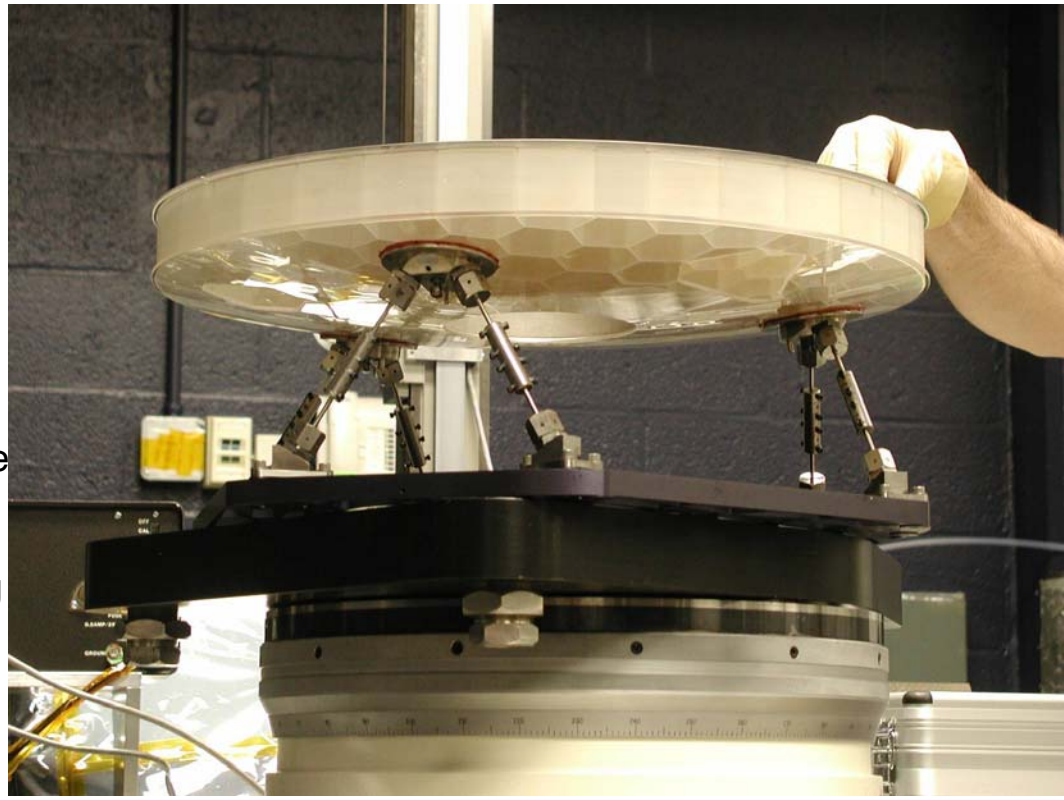
PM figure test, continued

- Tower made from low-CTE carbon fiber tubes; tent gives good thermal isolation
- Analysis complicated by 2 (main) factors
  - Gravity backout is many times the target test uncertainty (i.e. ~60 vs 2 nm rms)
    - Requires strong use of FEM backup up each stage of PM mounting and test
  - CGH introduces significant distortion
- Typically 100 phase averages for each of 12 positions; with alignment tolerances ~20 nm coma, 0.2 arcsec tilt, this took ~ 14 hours for 1 test

Picture of tower w/ tent under construction

PM Mounting

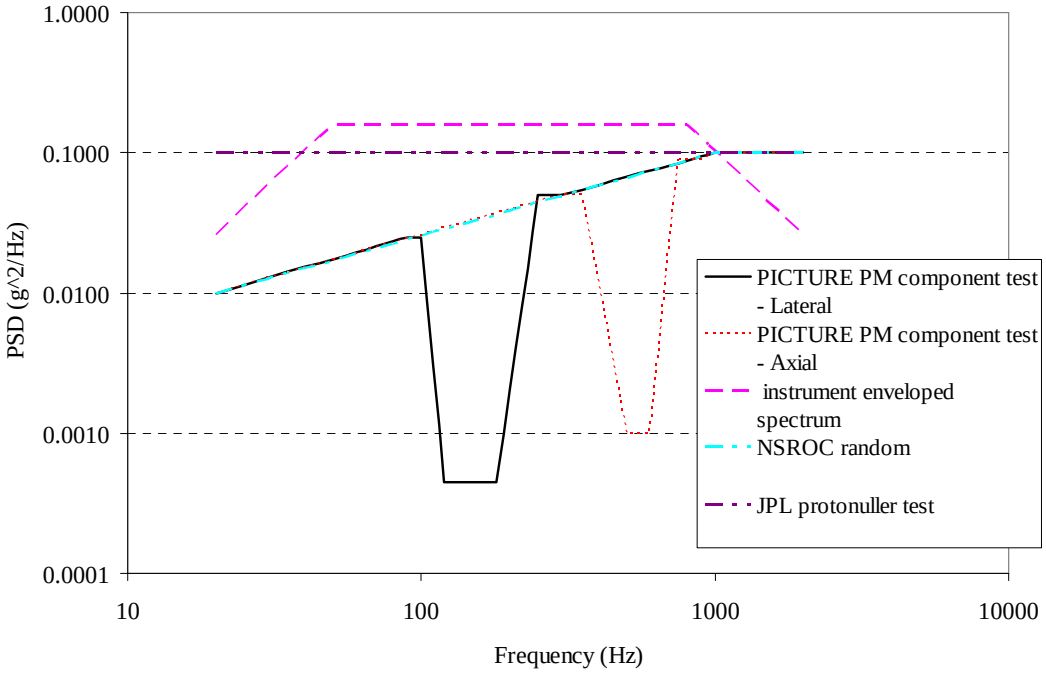
- In-house mount design using adjustable flexures
  - Concept is telescoping, liquid pinned bipod mounts
  - Assembled ‘around and under’ PM in figure test tower
    - Able to watching figure as the mounting progresses
    - Design analyzed & optimized via finite element modeling & iteration
    - Hexapod allows controlled lower of PM onto flight mount while measuring figure
- Iterated procedure twice before potting on 3rd attempt
- Learned along the way that the screw loads for screws holding the strut h/w to the mounting pads imparted significant strain (compared to intrinsic 7nm figure and goal of 2nm uncertainty for the figure test)
- Completed with figure within visible diffraction limit, ~13 nm rms



Mounted PM being measured with Leica laser tracker

PM vibration test at Wallops

- Wallops is tasked with I&T on sounding rocket h/w, price was right
- PM passed vibration test in February 2007
- Test spectrum is notched as we expect resonant mode to be damped in full rocket configuration

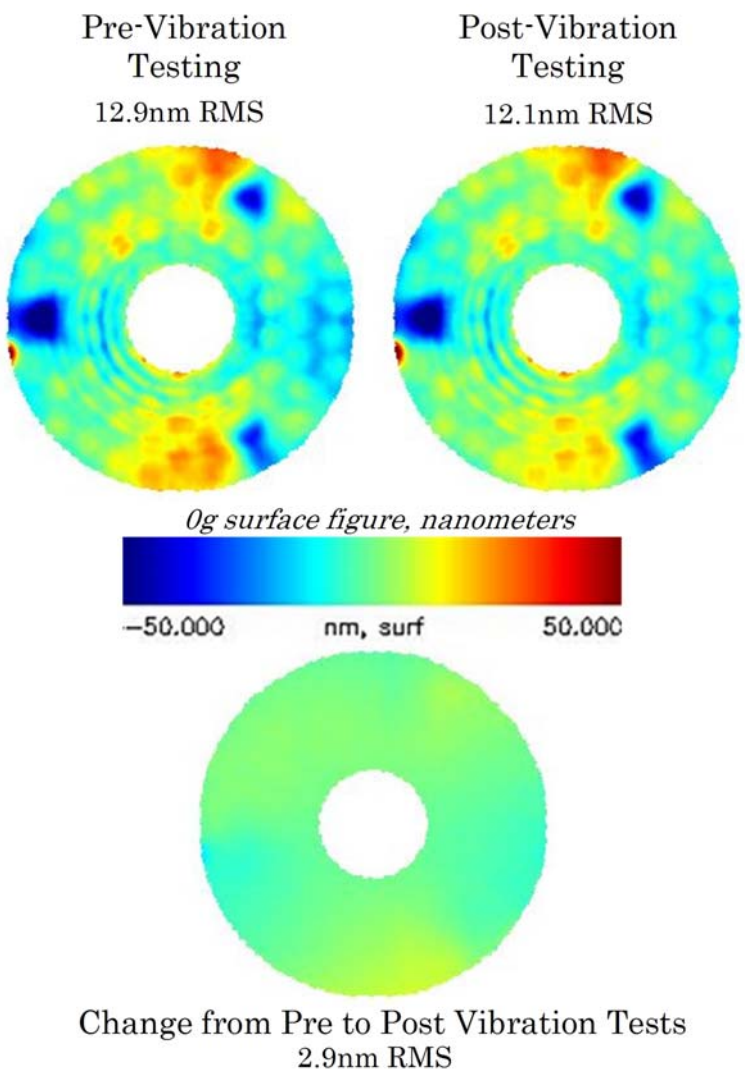


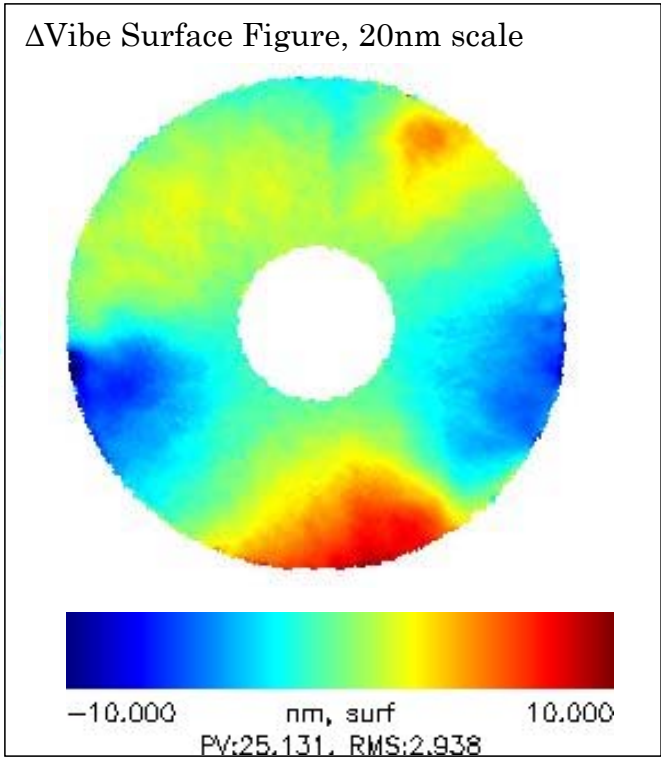
Vibration test levels

PM on shaker table

PM pre & post-vibe figure comparison results

- Change through vibe is ~ at the level of test uncertainty
- Clean pass
- Ready to integrate

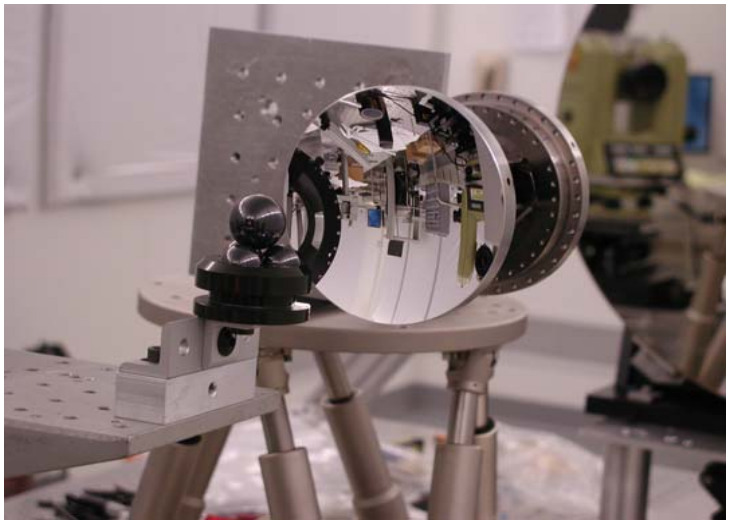




Secondary mirror -- SM

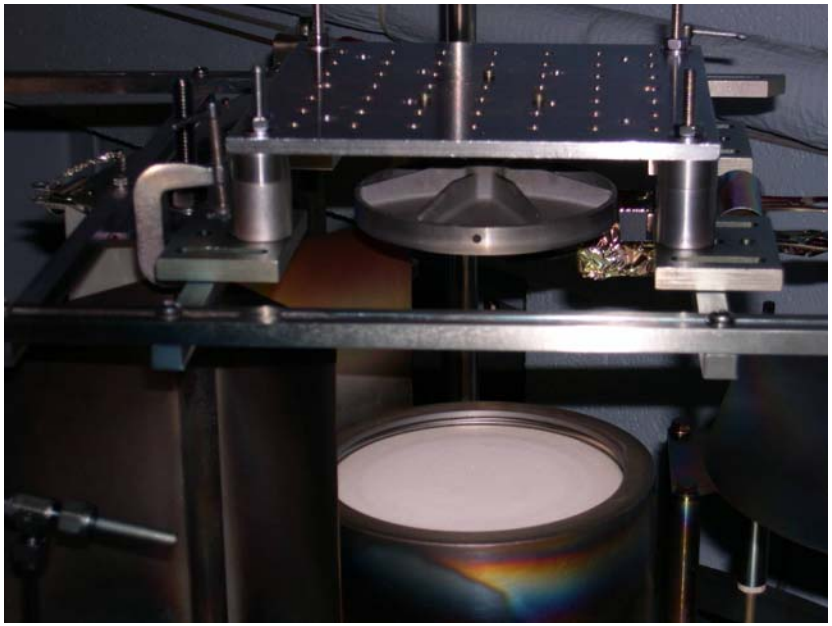
- Fabrication described by SSG; SSG SBIR-2002-II, J. Schwartz
- 122mm aperture concave elliptical asphere, R=226.29, k=-0.6633
  - Mild asphere, ~10□ departure from best fit sphere
- Requirement for surface quality – let us only worry about the PM!
  - 3.0nm rms figure, 1.7nm rms midfrequency {1-10mm band}
  - MET by SSG/Tinsley on Si-clad rbSiC with Invar mount
  - Verified independently by QED
  - Verified at ~5nm rms level after coating at GSFC

SM, pre-coating



SM in test, post-coating

Mirror coatings for exoplanet coronagraph



- Work on TPF-C showed that performance can be very sensitive to mirror polarization depending on spectral bandwidth and speed of optics
  - for TPF-C the choice was custom protected Ag coatings on all fast optics
- Team worked to determine ‘easy’ coatings that could be done cheaply {in-house} and quickly
  - PM: Al SiOx {1≤ x≤2} over ULE fused silica
  - SM: {Cr} Ag Al2O3 SiOx over Si {SSG mirror is Si-clad rbSiC, see their talk}
- Design uses 0.5□ dielectric thickness on SM and 0.25□ on PM
- A few% uniformity is required
- Both coatings completed late CY2006

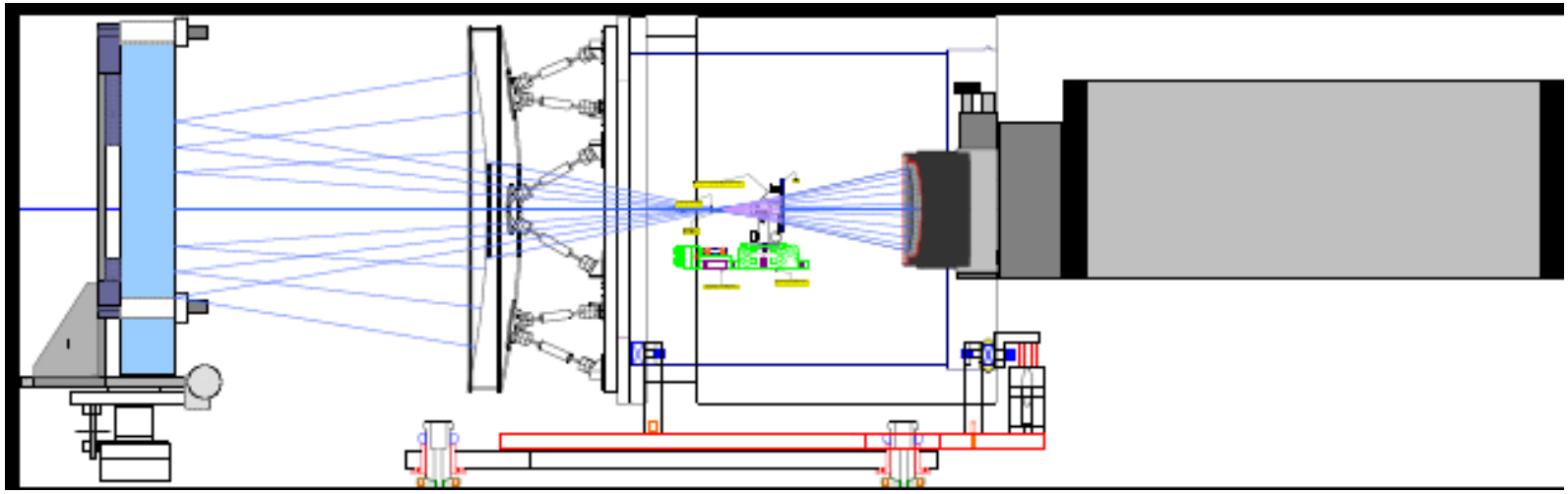
Optical telescope assembly

- Horizontal alignment in AIM cleanroom
  - Advanced Interferometry & Metrology lab
  - Exceptional thermal, acoustic, dynamic stability, 5'x16' actively damped Invar optical table
- We have borrowed & calibrated a 0.5m flat from JPL

View of AIM optical table; 20" flat in near L corner

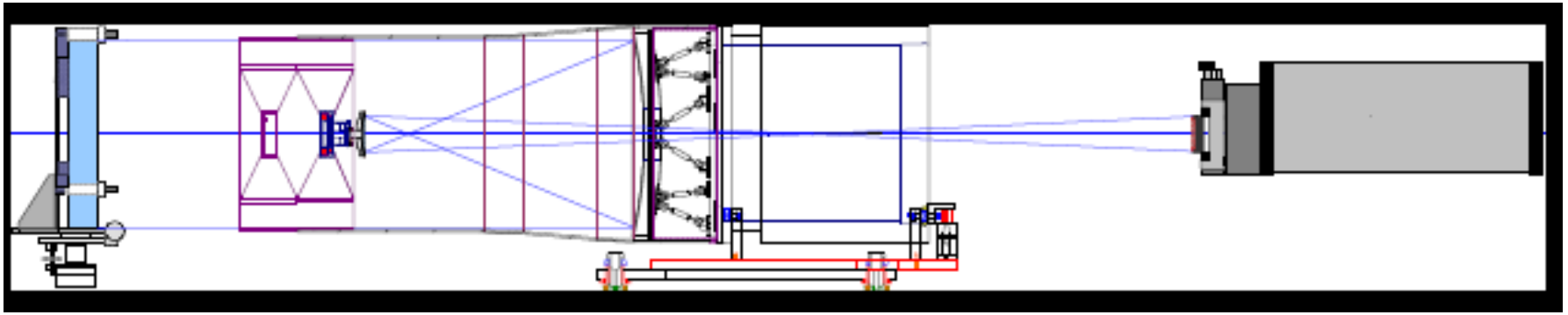
Telescope I&T flow – 1 of 2

- Repeat PM test on strongback in horizontal fixture
  - Folded version of CGH radius-of-curvature test layout used for qualification and mounting
  - Achieves good understanding of PM and test fixture
- Test in multiple gravity orientations (test rotates) so that gravity effects can be mitigated



Telescope I&T flow – 2 of 2

- Bolt on telescope tube
- Move interferometer back (along chief ray of test) to f/11 back focus position
- Move flat away from telescope to collimated space position



- Add JPL alignment transfer device to mark chief ray & focus location
- Ship telescope to BU; ship alignment fixture to JPL

Summary

- Flight build underway; current testing PM in horizontal layout
- We have missed 2007 planet observing season, plan is to do a nulling 'engineering flight' this fall
- Acknowledgements:
  - This has been a long term collaboration with ITT Space Systems, Boston U., and JPL

View of PM in integ-ration & test fixturing