Making and testing a complete Telescope to Observe Planetary Systems TOPS

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TOPS history

- Based on Guyon PIAA coronagraph
- Introduced as Discovery proposal in 2006
  - 1.2 m telescope to fit $430M ceiling
- Goal
  - Sensitive to nearest terrestrial planets at 10^{-10} at 2 λ/D
- Larger variants (TOPS2) now being worked out

At first look, Lyot would say PIAA made impossible claims

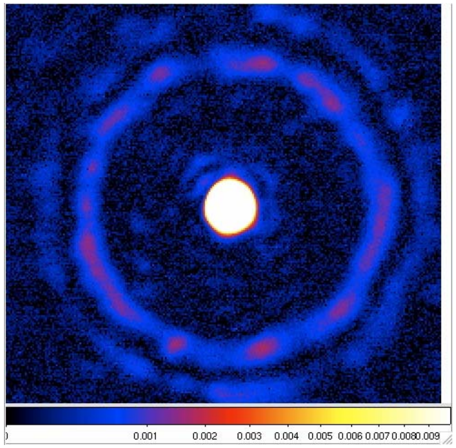
removes Airy rings

all star energy placed in Airy core (> 100% Strehl)

No loss of resolution

Guyon breakthrough:

- possible if requirement for imaging a field is relaxed
- Imaging is restored after star blocked



Guyon recent lab progress

The dark annulus all within the bright ring at radius 4 λ/D

10^{-4} level by simple wavefront flattening

200 times further reduction in dark D

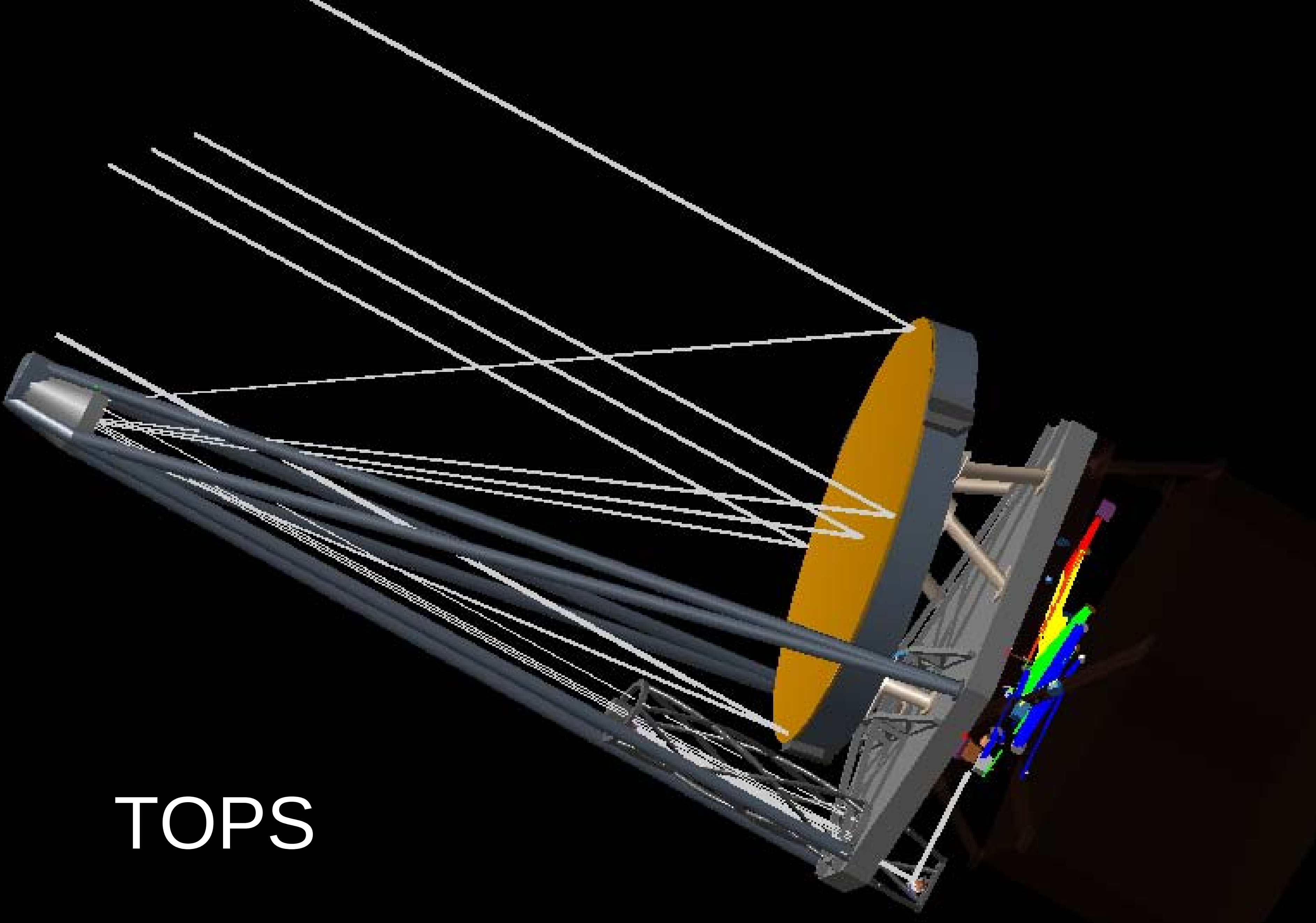
Second generationPIAA to be made

- aimed at demonstrating 10^{-10} at $2\lambda/D$
- About to be purchased by TOPS (Ames funding)
- New PIAA to be tested at Subaru and JPL
- Guyon talk tomorrow morning

Suppose new PIAA gets 10^{-10} in lab

how can we be sure a space telescope system can be built and controlled with quality needed exploit it?

System test required now
– subject of this talk



TOPS

key spacecraft system elements

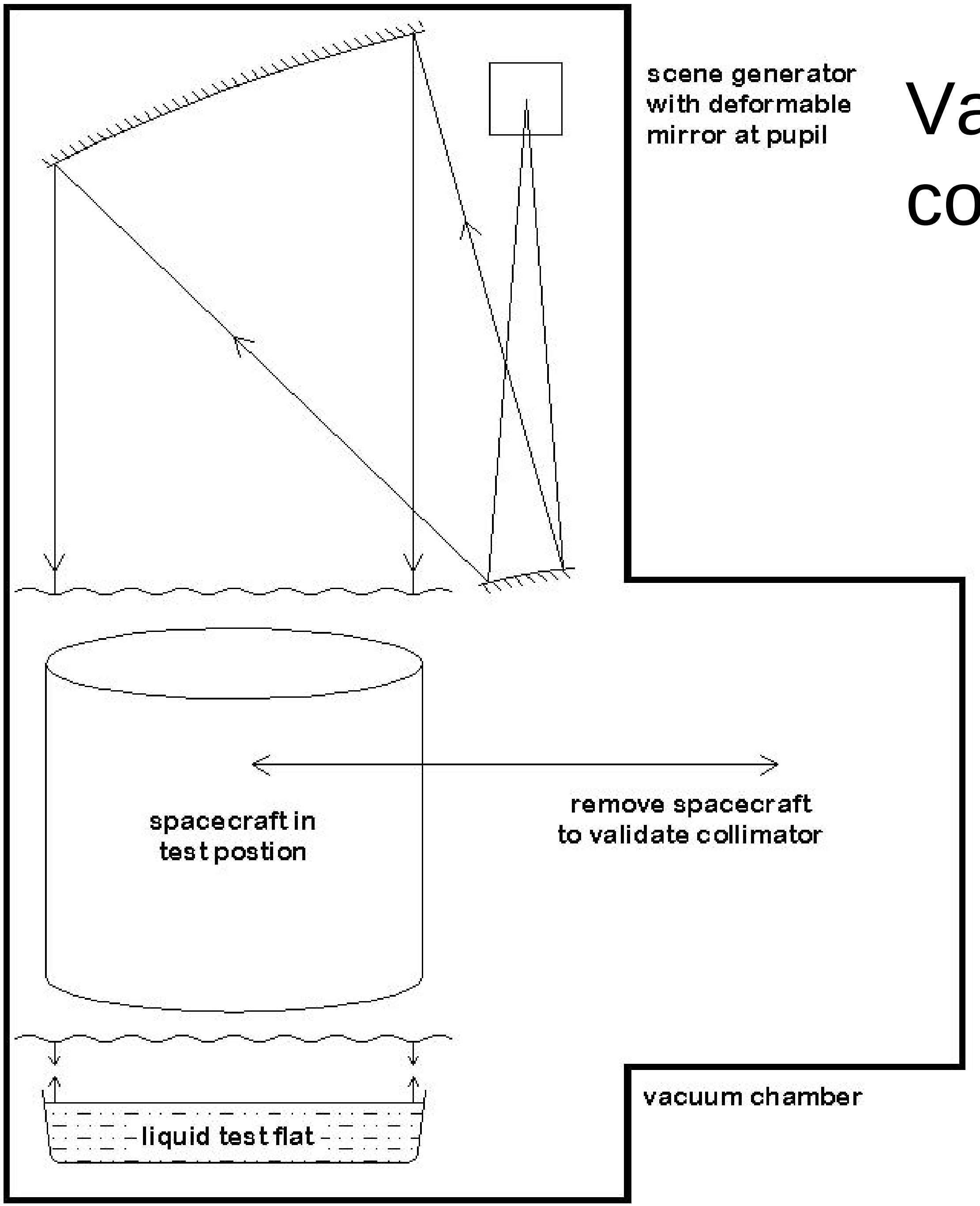
- PIAA
- Off-axis primary
- Milliarcsec pointing control
- On-orbit wavefront sensing and correction elements
  - Sensitivity to exo-zody
- Camera, spectral band separation

full spacecraft testing needed before launch

- Need to close the loop with full wavefront sensing and correction system
  - Image 10^{-10} planet at 2 λ/D in scene with simulated zodiacal background
- Scene generator is doable
  - requires off-axis mirror of same quality and size as telescope primary
  - doesn’t have to have be 10^{-10} contrast
  - its errors corrected along with primary

Need for 1 g test has implications for system design

- Space telescope system architecture must be designed from the start (now) to allow for 1 g test
- Active primary to counter 1 g a big advantage
  - Not doing this has been huge cost driver for JWST – let's learn!
- Study by Angel and Worden *:"Testable space telescopes*" - SPIE



Vacuum test configuration

The test beam is produced by an off-axis collimator.

Apertures 1.2 - 8 m

diameter.

By moving the spacecraft to one side, the beam is validated against a liquid flat.

Mirror requirements

- Primary mirror
  - Its errors must be actively corrected either at the mirror itself or at a reimaged conjugate mirror
  - Better to make correction at the primary
    - Avoids chromatic propagation effects – simpler wavefront controller
    - Correct 1g bending errors at source for ground test
- Test collimator mirror
  - Prototype of flight primary
  - Correctable to same level
  - System servo will take out both collimator and primary errors

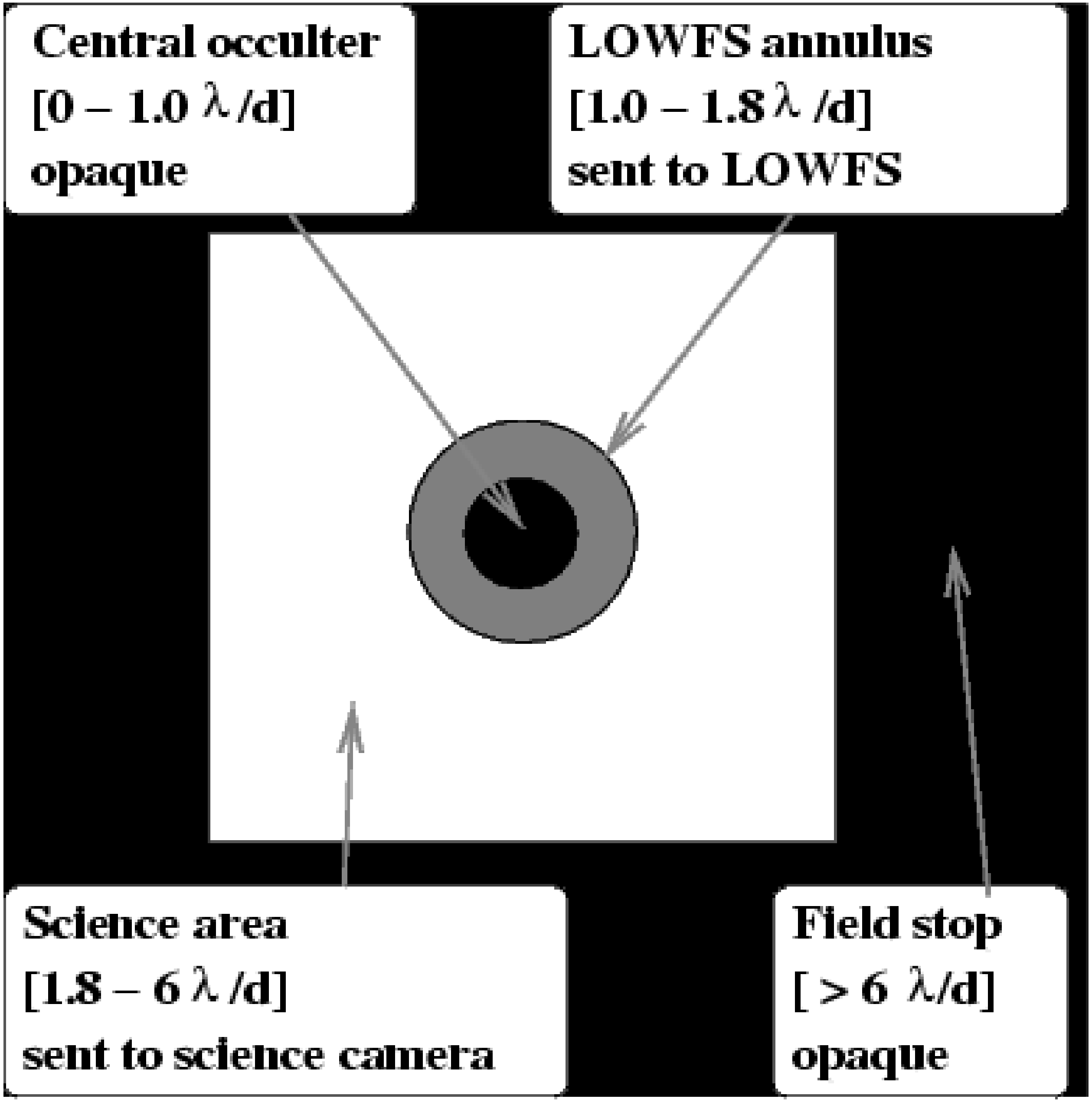
Other major requirement for PIAA – Exquisite control of low-order aberrations

Low IWA coronagraphs require smaller low-order aberration (especially true for tip-tilt).

Larger IWA coronagraphs (CPA for example), tolerate larger aberrations but **cannot detect them unless they are large.**

<u>We can always expect low-order aberrations to be at the level where they start to impact contrast at the IWA.</u>

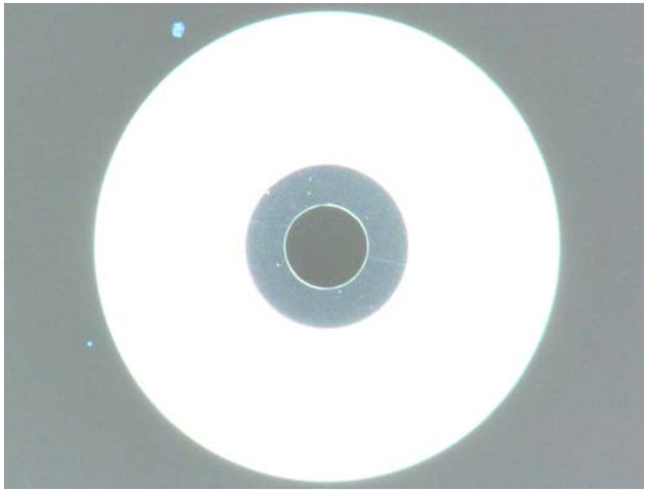
UNLESS... we use the light on the focal plane occulter

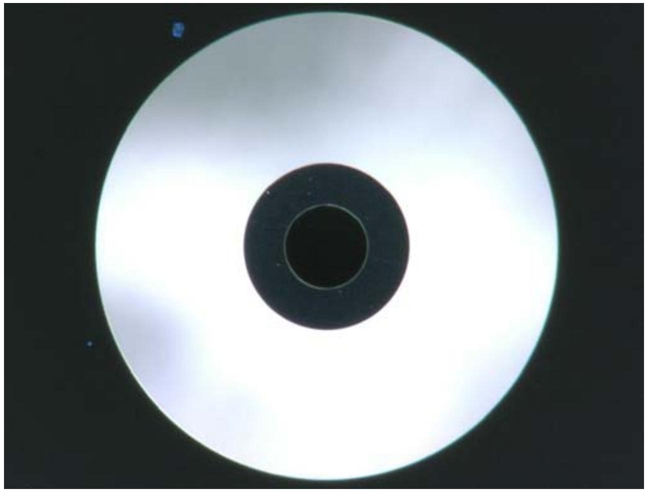


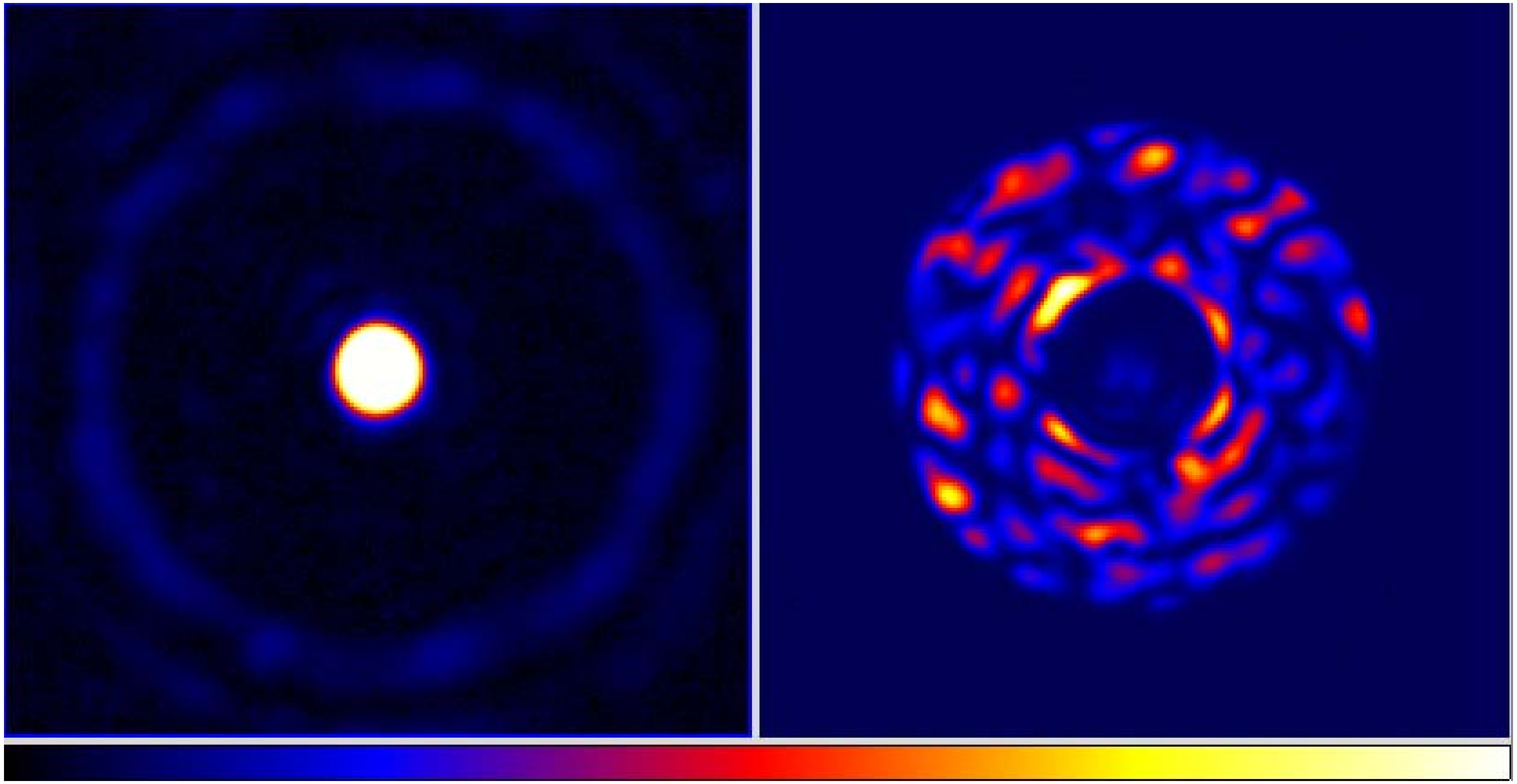
Focal plane assignment with dedicated Low-Order Wavefront Sensor

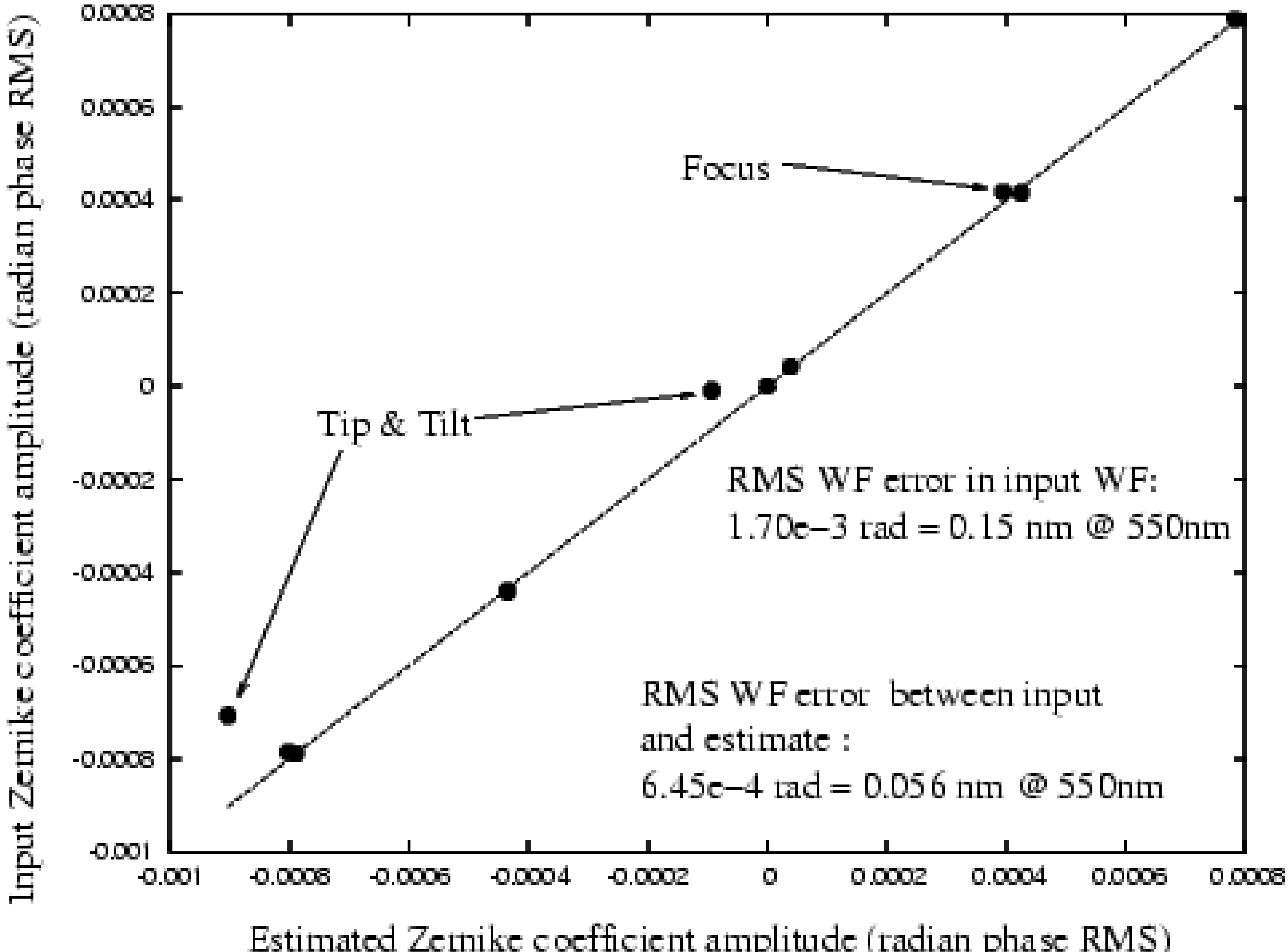
Use phase diversity on "for free" light from central star

Lab implementation and results at Subaru







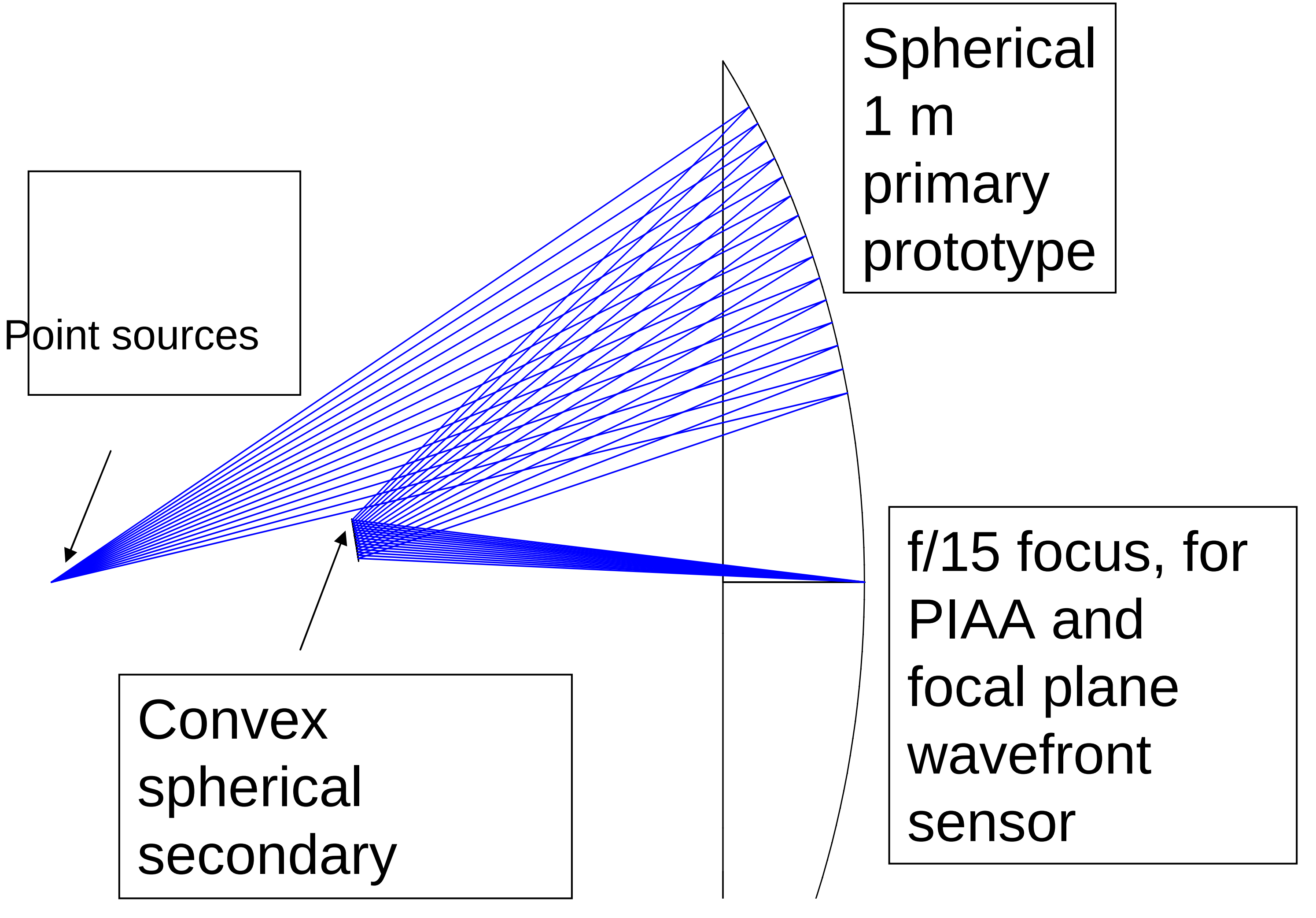


~ 1 sec integration for tip/tilt, focus and astigmatism

Goal of bringing TOPS system to TRL 6

- Putting the system elements together in TOPS continuing program
- Complete system to be vacuum tested
- System goal of of 10^{-10} contrast at 2 λ/D
- System elements include
  - Next generation PIAA
  - Fully illuminated active primary mirror (Lockheed/Arizona/MSFC)
  - reflecting annulus for active sensing of very low order modes
  - Secondary deformable MEMs mirror(s)

For TRL test don't need {and can't afford) full size off-axis primary and collimator – use single spherical mirror surrogate



3 year schedule for TOPS to TRL 6

- Year 1
  - new PIAA built and air tested at Subaru. 40 cm thermal actuated prototype
- Year 2
  - new PIAA tests in vac at HCIT
  - 1 m class active primary and LM large vac test facility prepared
- Year 3
  - full system vac tests

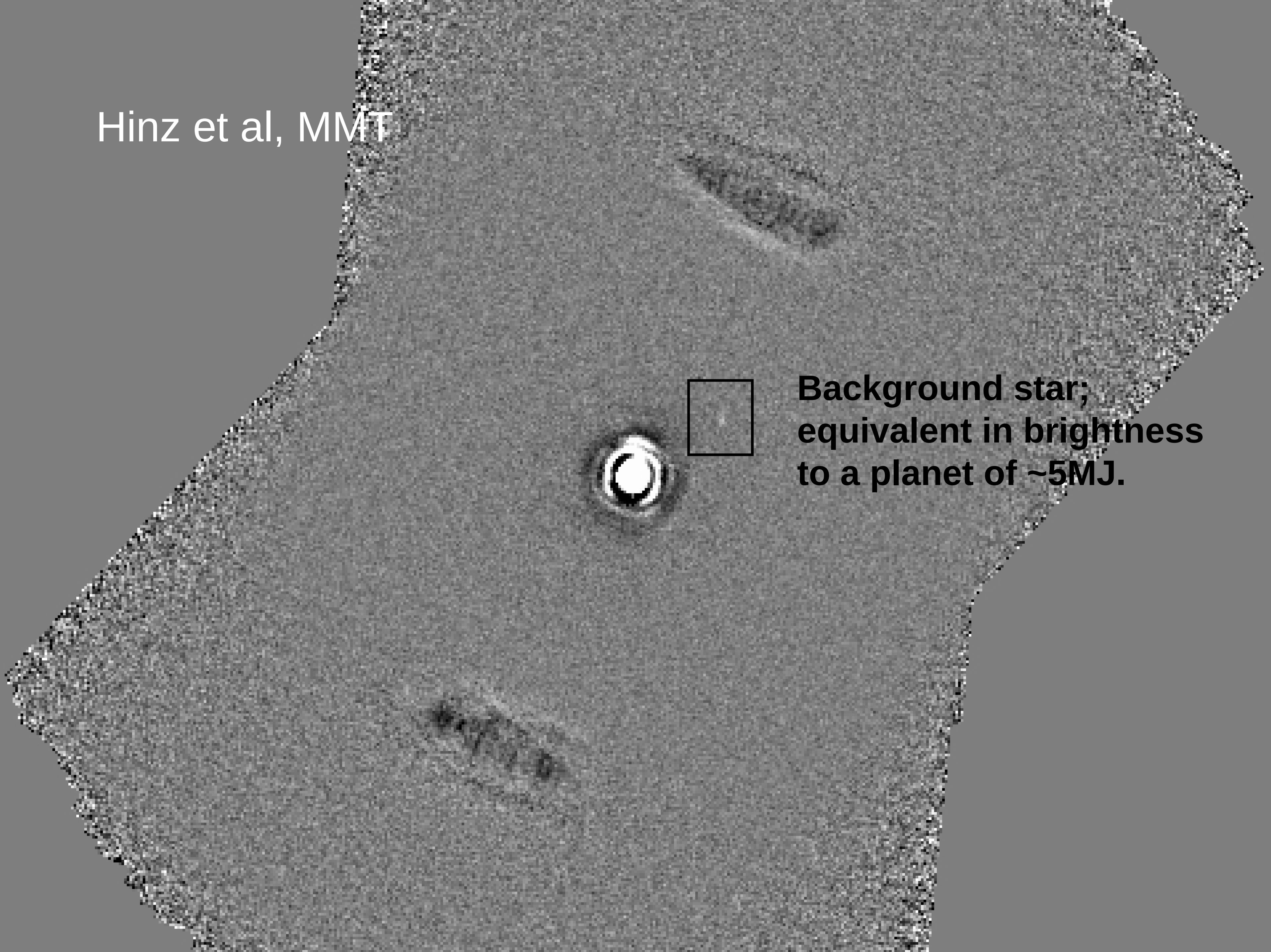
Active primary mirror strategy

- Builds on mirror development at Steward Observatory Mirror Lab
  - MMT deformable secondary
  - Off-axis figuring
  - active thermal figure control for large, lightweight honeycomb primary mirrors

MMT deformable secondary

- 0.64 m diameter
- 336 actuators

- Soon 0.92 m, 672 actuators on LBT

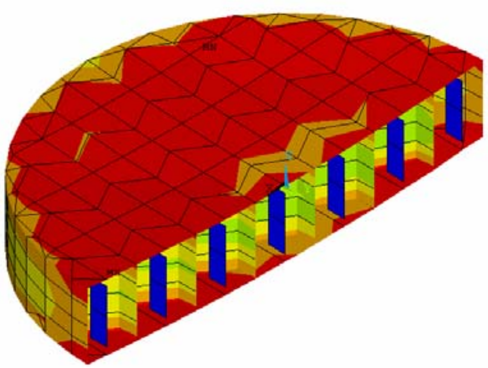

Hinz et al, MMT
Background star;
equivalent in brightness
to a planet of ~5MJ.

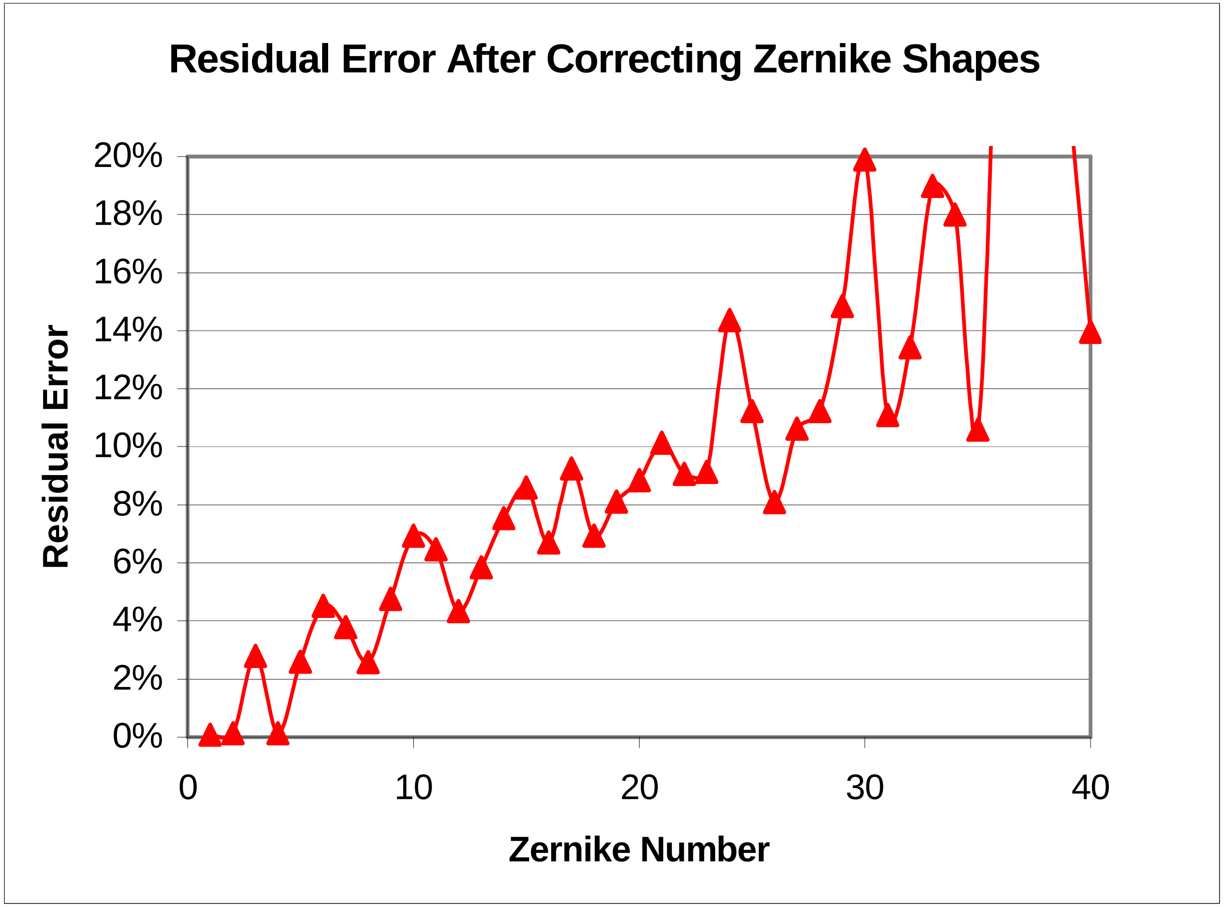
Active primary strategy

- Builds on mature base of ULE honeycomb mirrors in space
- Add thermal actuation with radiative coupling
  - No mechanical disturbance of mirror
- Modify ULE composition to give finite coefficient of ~ 5×10^{-8}
  - Thermal gradients applied to remove residual errors in low order modes
- Corrections made by cooling or heating radiative fingers protruding into the honeycomb cells
- Low order modes controlled by front-to-back gradients (bimetallic strip type bending)
- High order modes by local rib expansion and contraction

Finite element model

- Fractional residual errors
  for n cells, n Zernike terms controllable.

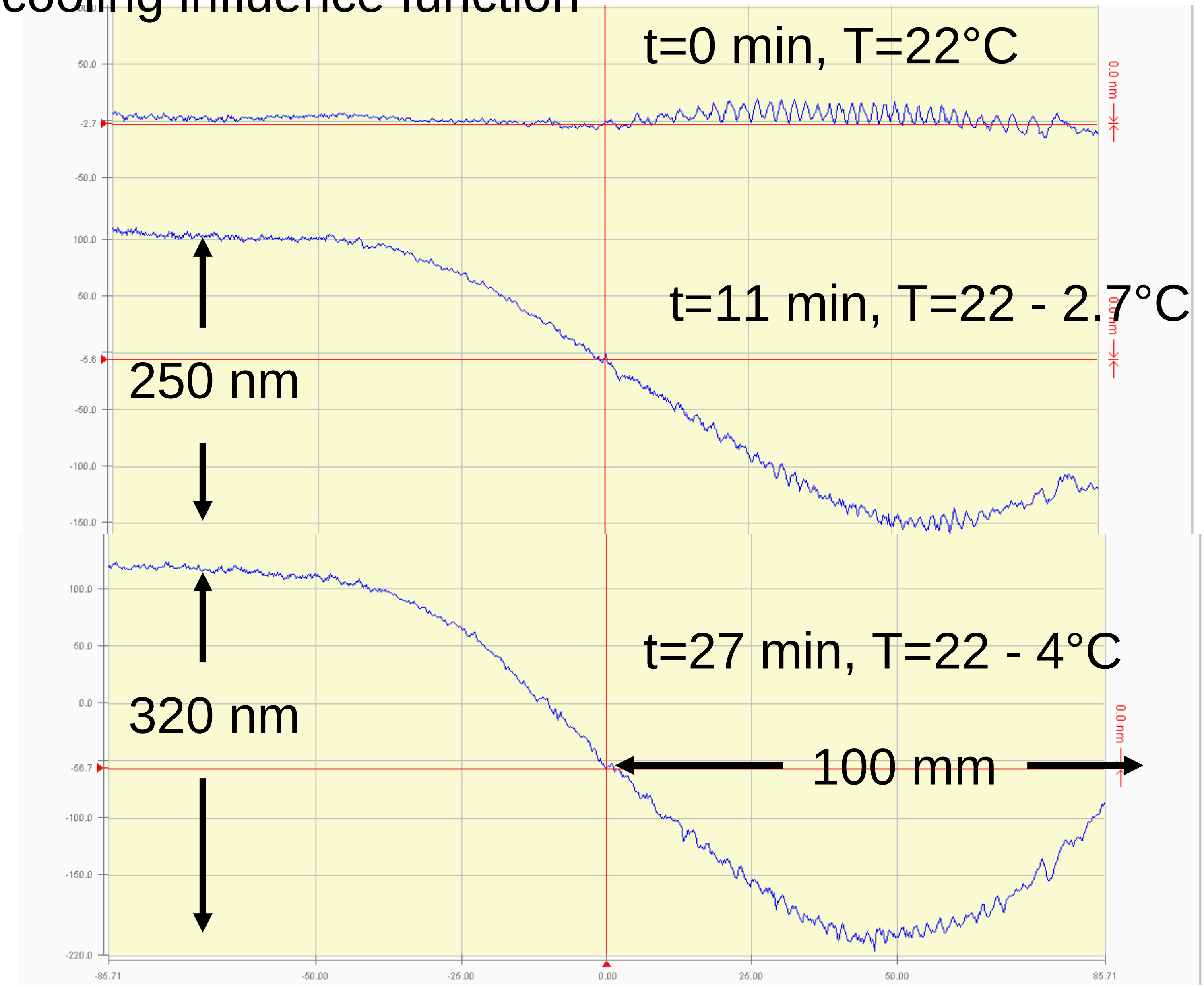




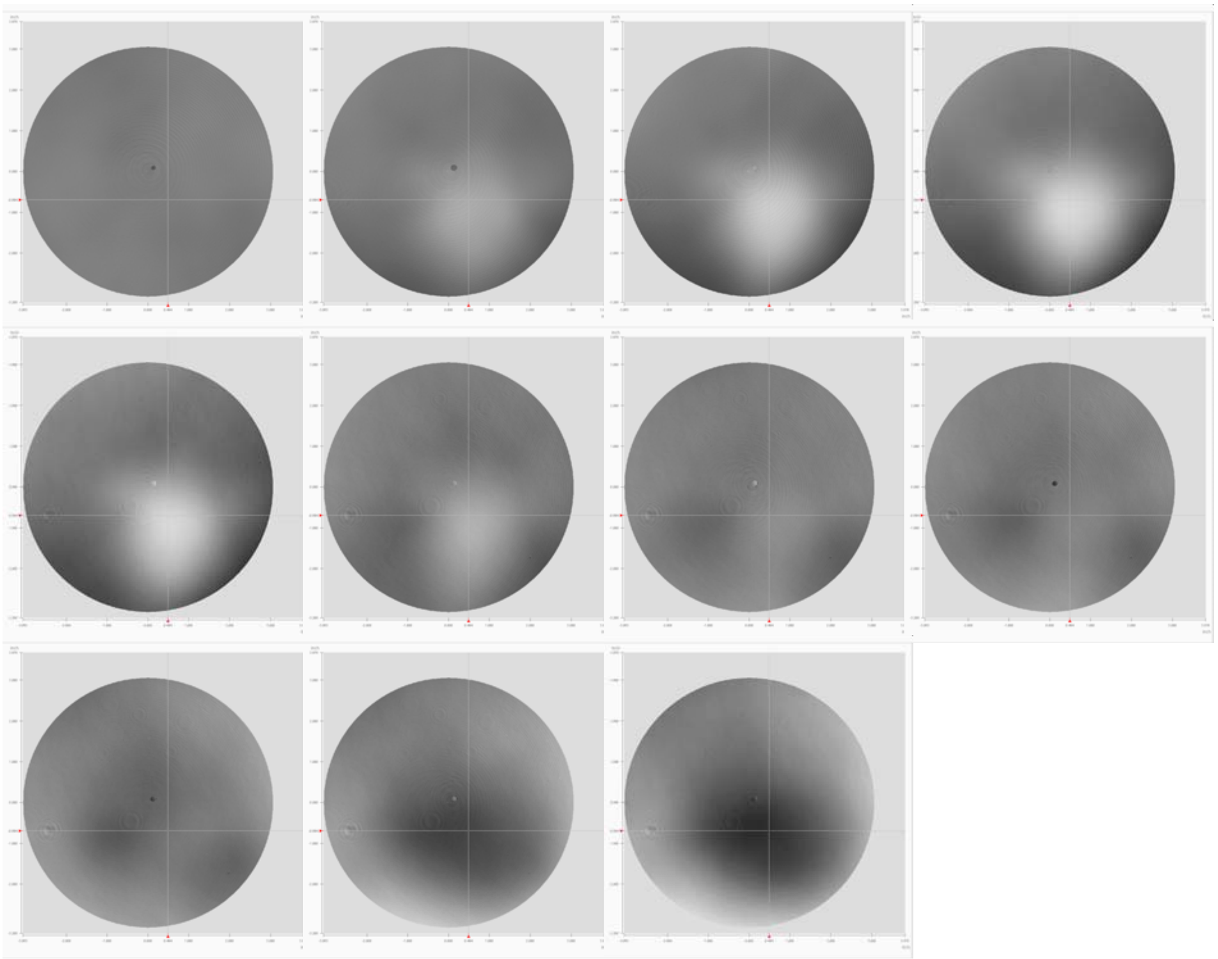
3-cell lab test borosilicate glass coefficient 3e-6

Hextek honeycomb sandwich mirror 2', 2.5'deep, 8 mm ribs

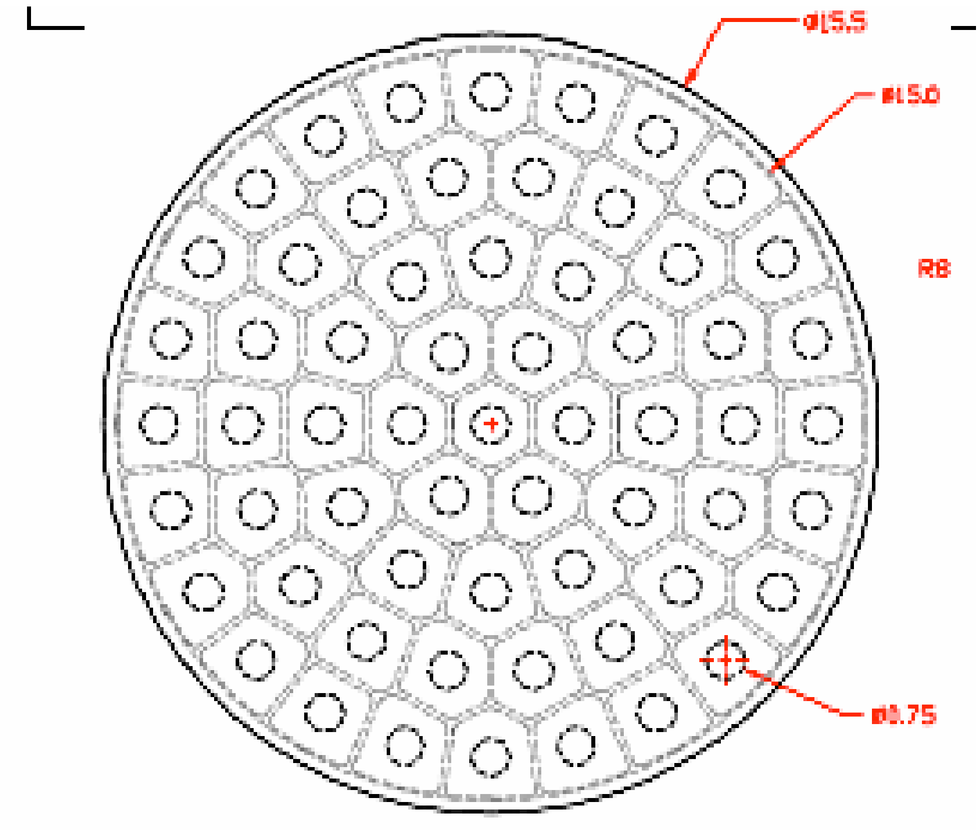
Rib cooling influence function



Influence function from heating and cooling



61 cell spherical mirror for full actuation test to be manufactured this year



1 m modified ULE mirror to be made by ITT for TOPS system test