Gemini Planet Imager

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U. Montréal: **René Doyon***, Jerome Marie, Simon Thibault (Immervision)

Boston Micromachines: Steven Cornelissen

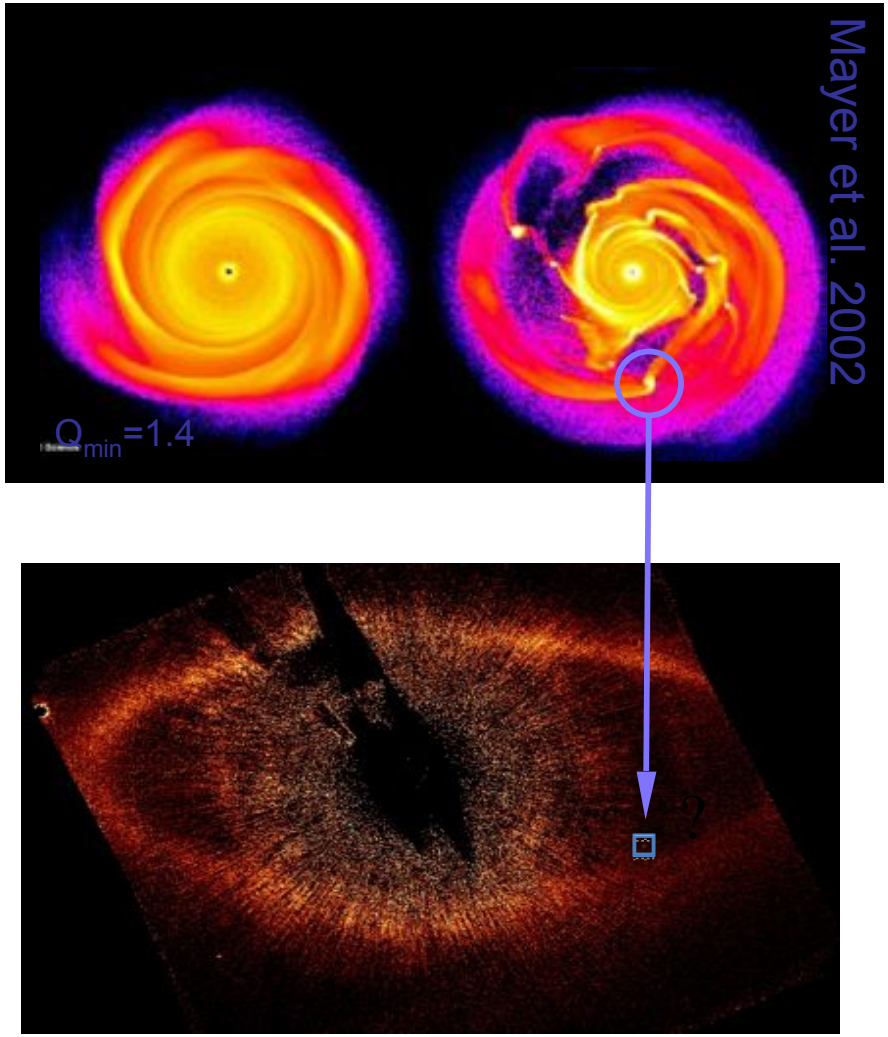
Science: Inseok Song, **Travis Barman***, **Michael Fitzgerald***, **Sasha Hinkley***, **Jennifer Patience***, Franck Marchis, **Paul Kalas***, **Emily Rice***, **Gautam Vasisht*, Sloan Wiktorowicz***

* Lyot 2010 meeting attendee

Science Motivation

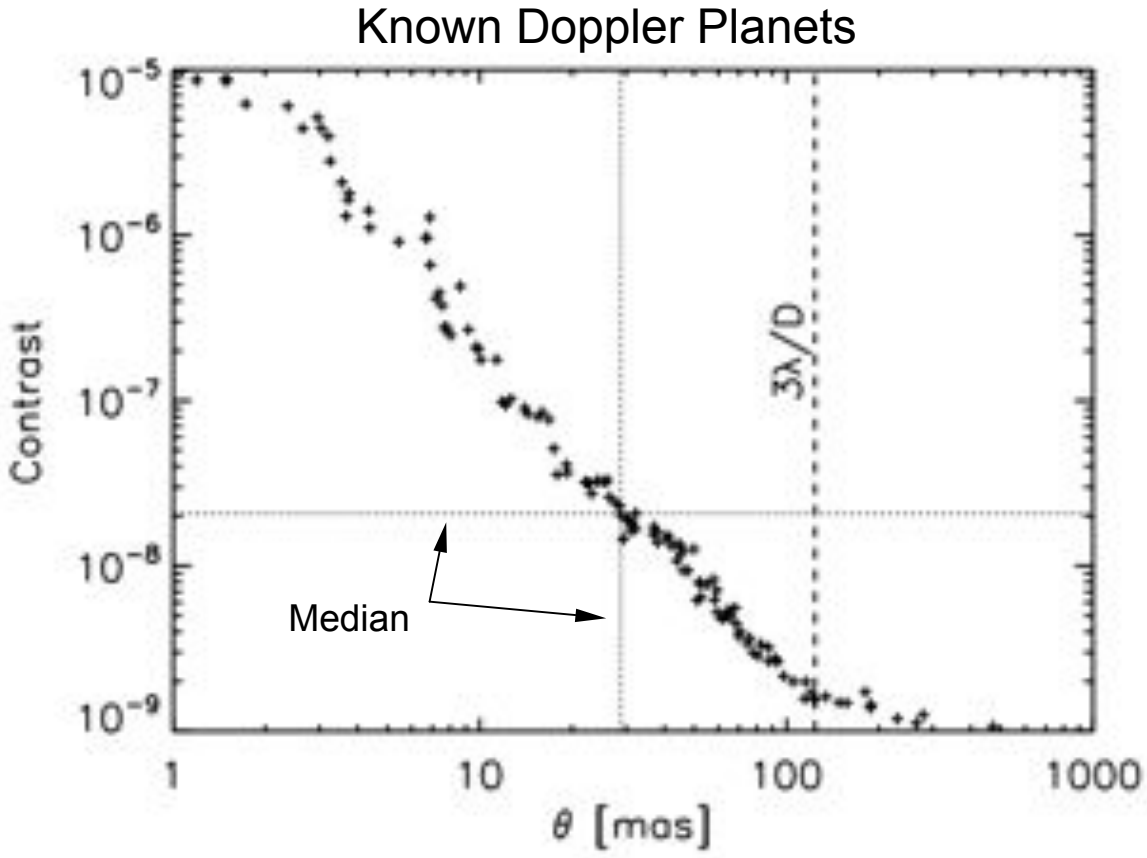
Solar System Imaging

- Fast alternative do Doppler
  - Improved statistics
    - 4–40 AU *vs*. 0.4–4 AU
- Search for exoplanets > 4 AU
  - Uniqueness of solar system?
  - Sample beyond the snow line & explore outer disks
    - Protostar disk radii are 50-80 AU
  - Do planets form by gravitational instability (30–100 AU)?
  - Vestiges of planetary migration
- Relation to debris disks
- Resolve *M* sin *i* ambiguity



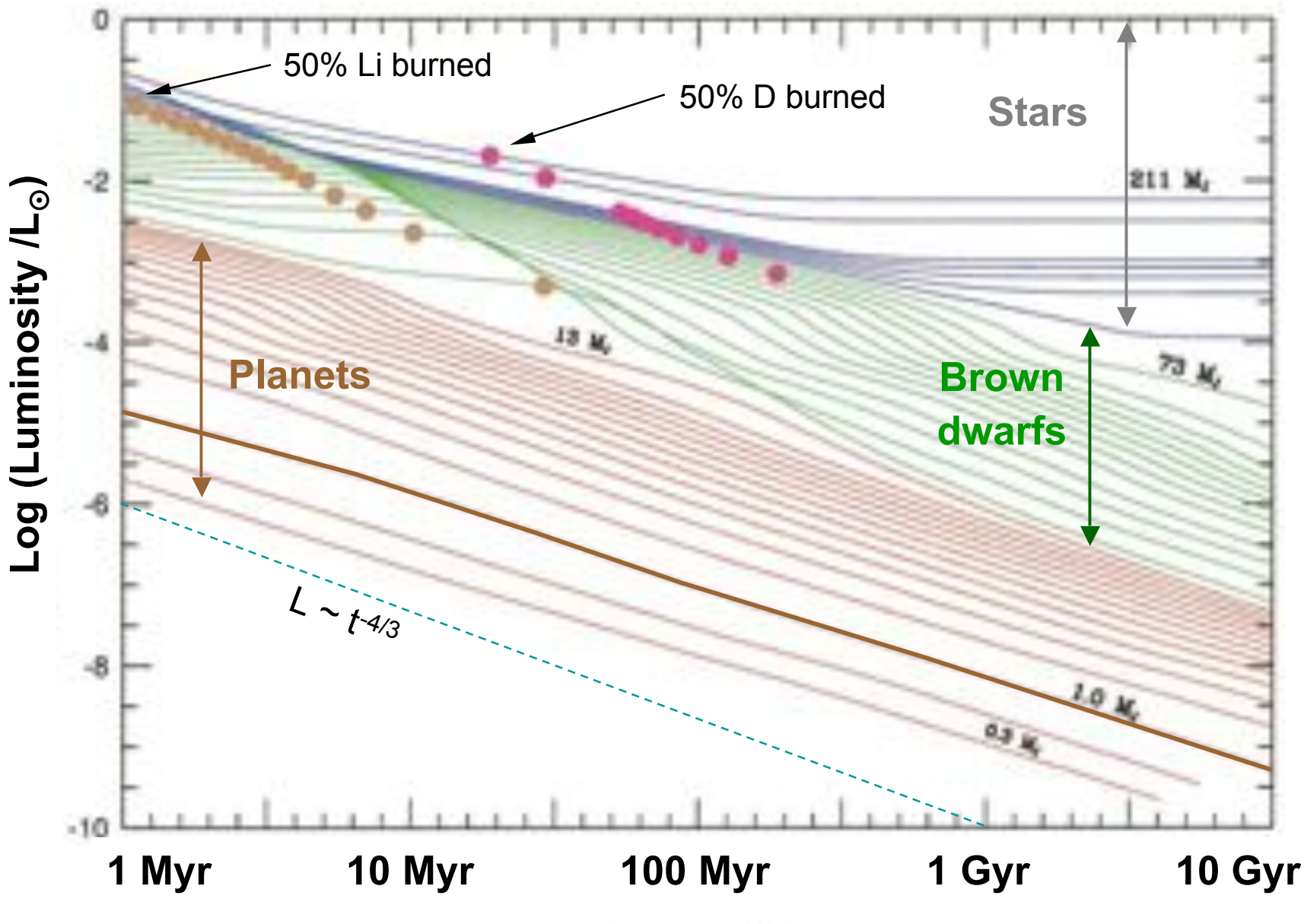
Detect Reflected Starlight?

- Predicted median contrast & angular separation for cataloged Doppler planets is 2×10^{-8} at 30 mas
  - $3\lambda/D$ = 130 mas @ 1.6 μm on a 8-m telescope



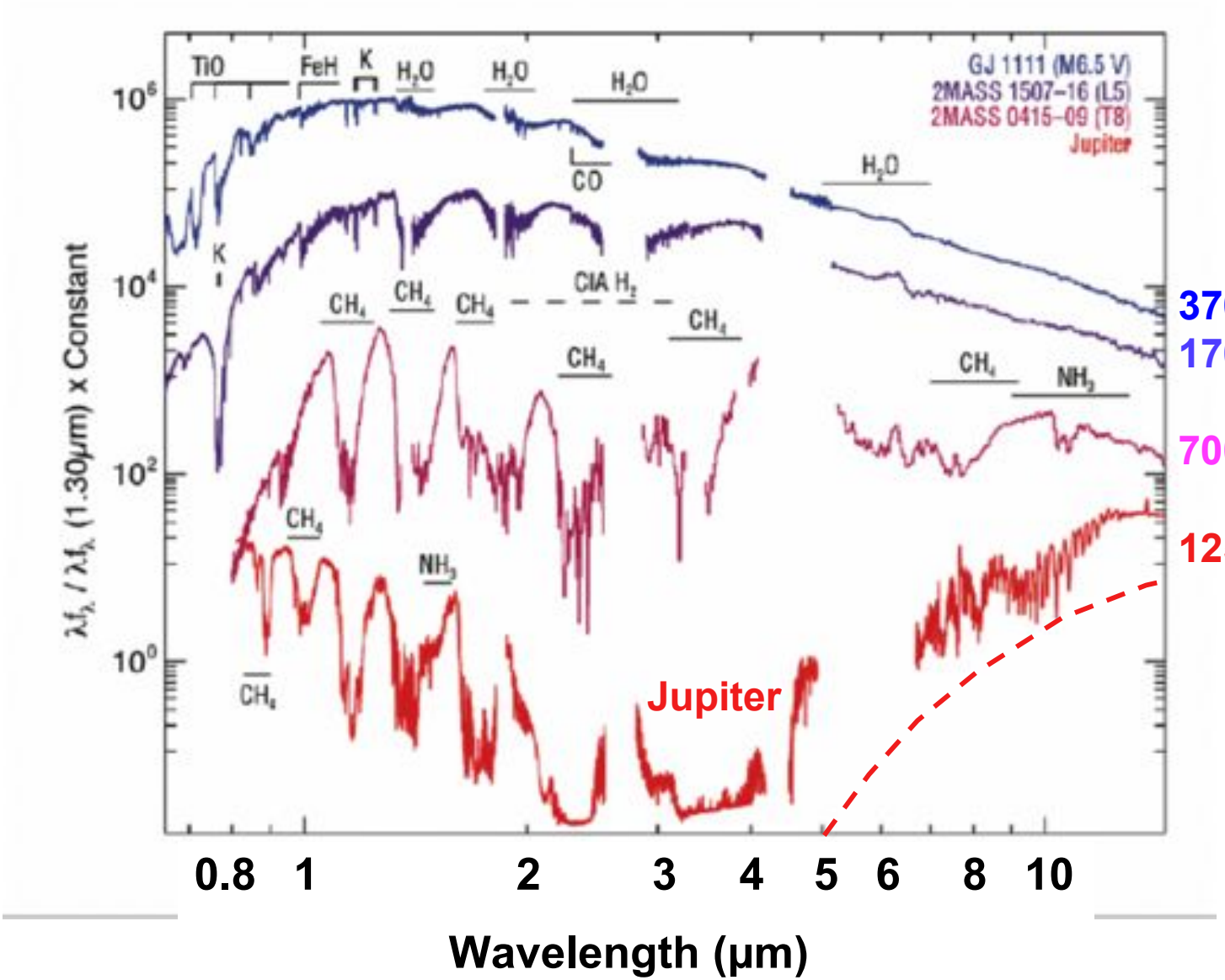
From the ground—target self-luminous planets between 4–40 AU

Young Planets are Luminous



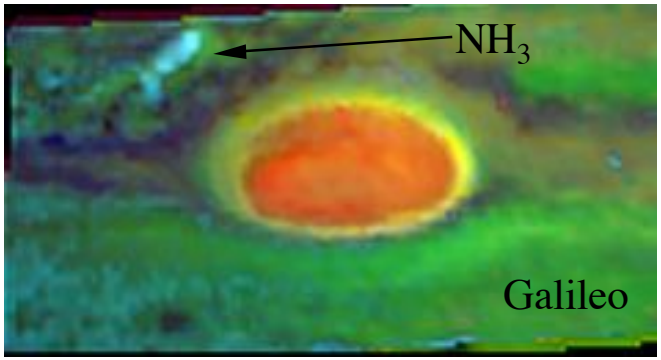
Burrows et al. 1997 ApJ 491 856

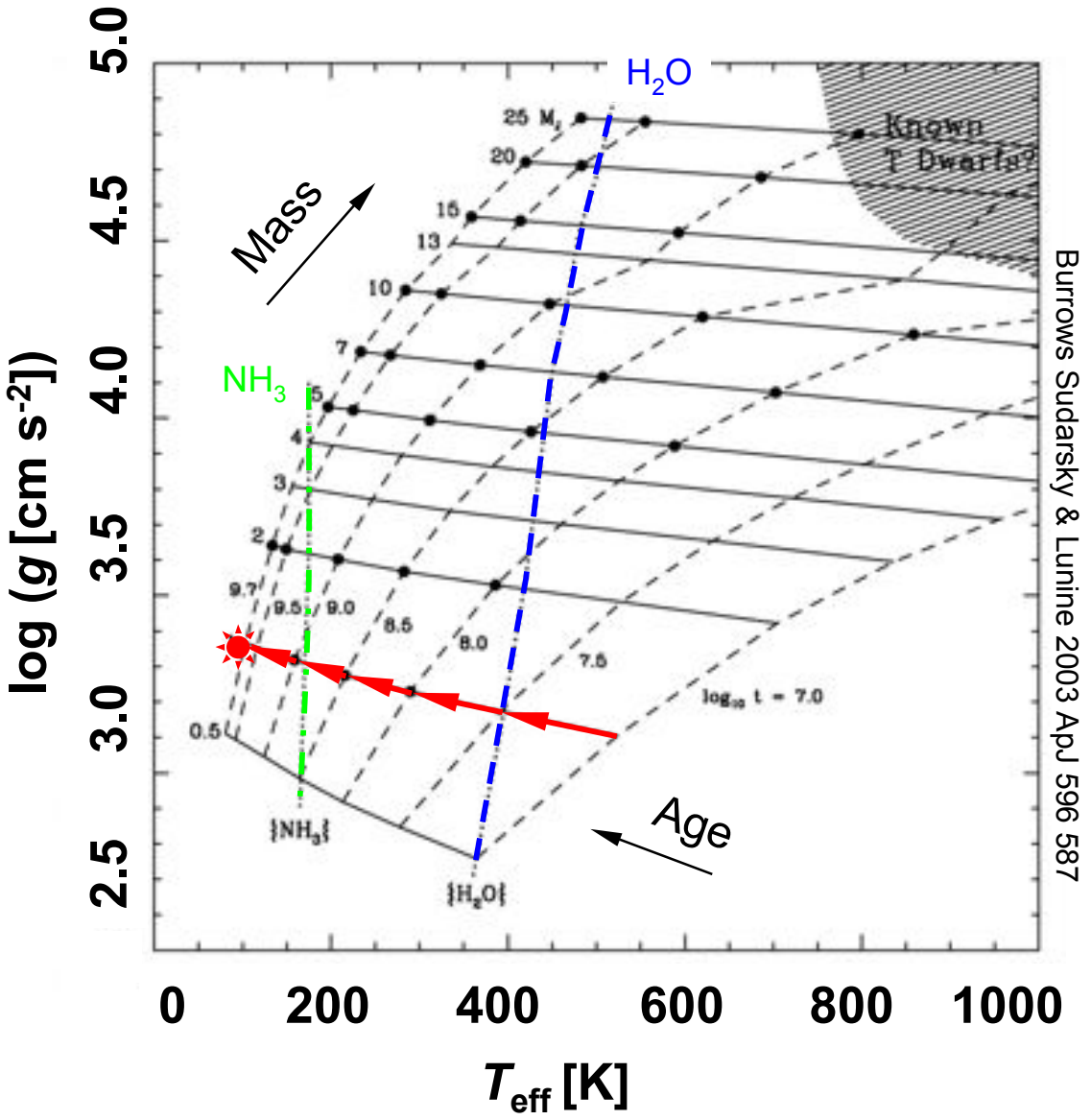
Spectra: Stars, Brown Dwarfs, & Planets



Exoplanet Atmospheres

- Exoplanets will occupy a unique location in (log g, $T_{\rm eff}$) phase space
  - Over 4.5 Gyr a Jovian mass exoplanet traverses the locus of H_2O & NH_3 cloud condensation
- Last frontier of classical stellar atmospheres

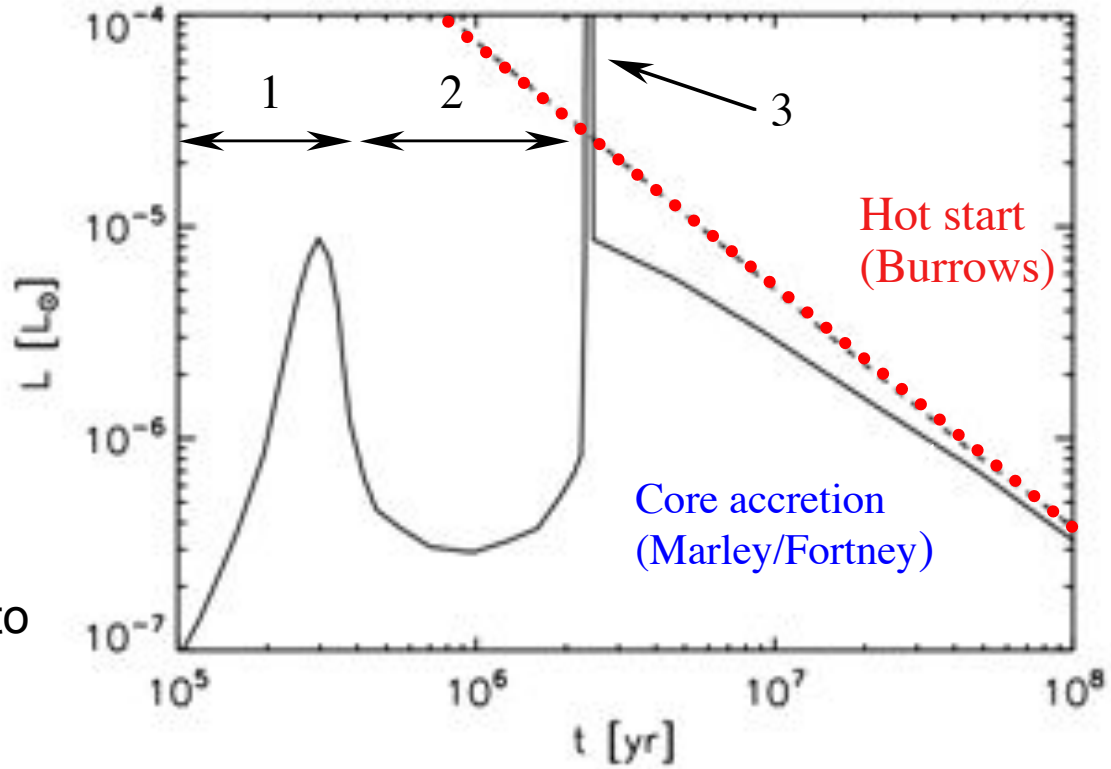




Burrows Sudarsky & Lunine 2003 ApJ 596 587

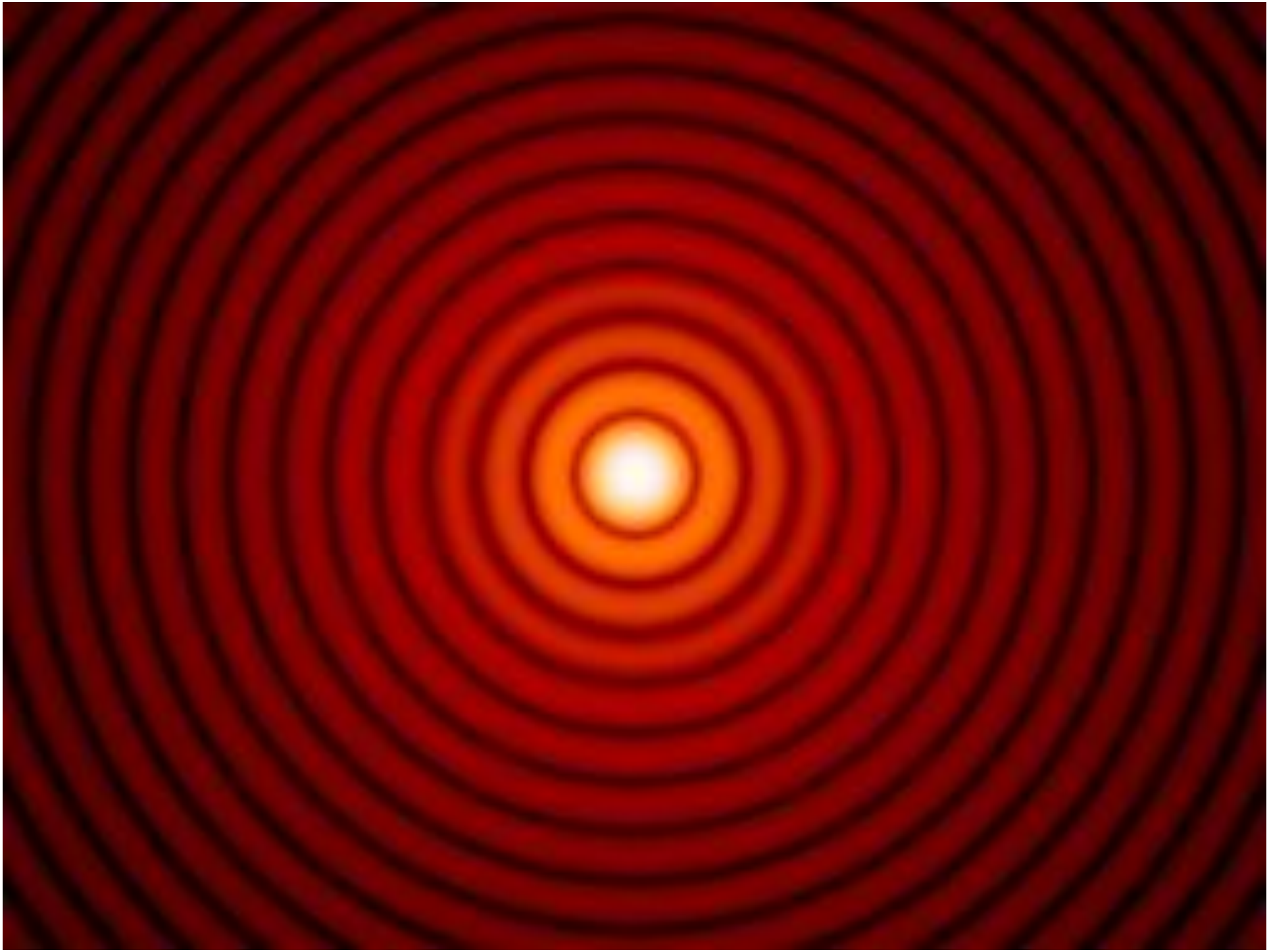
Thermal Evolution Reveals History

- Luminosity including the effects of core accretion
  - Planet is formed by 2 Myr
  - The gas accretion luminosity spike lasts about 0.04 Myr
    - The spike may be broader & dimmer due to slow accretion across the gap formed by the proto-planet
- The dashed line is a "hot start" cooling track

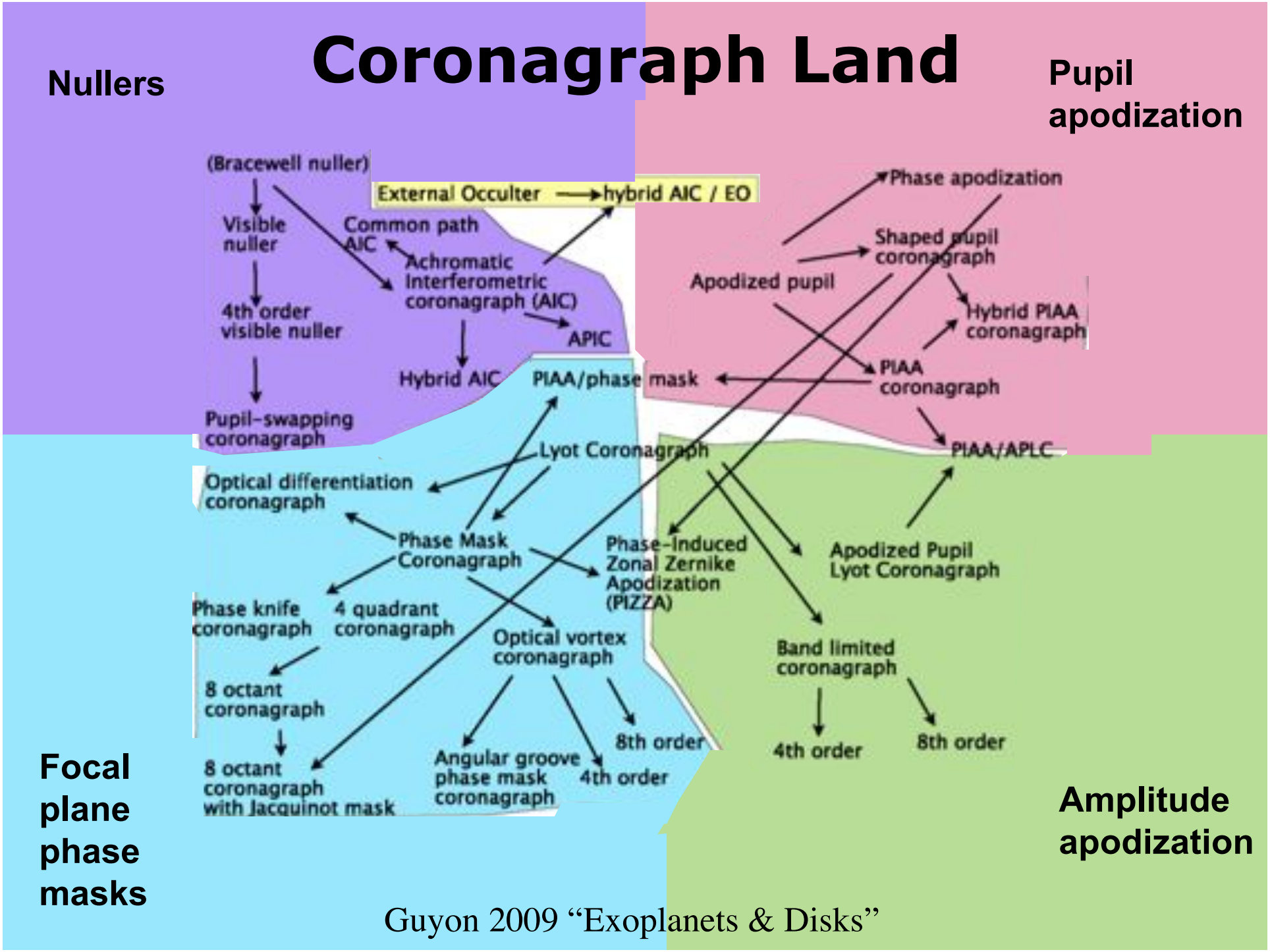


1) Accretion of solids
2) Hydrodynamic (gas) accretion
3) Runaway gas accretion

Diffraction



Coronagraph Land

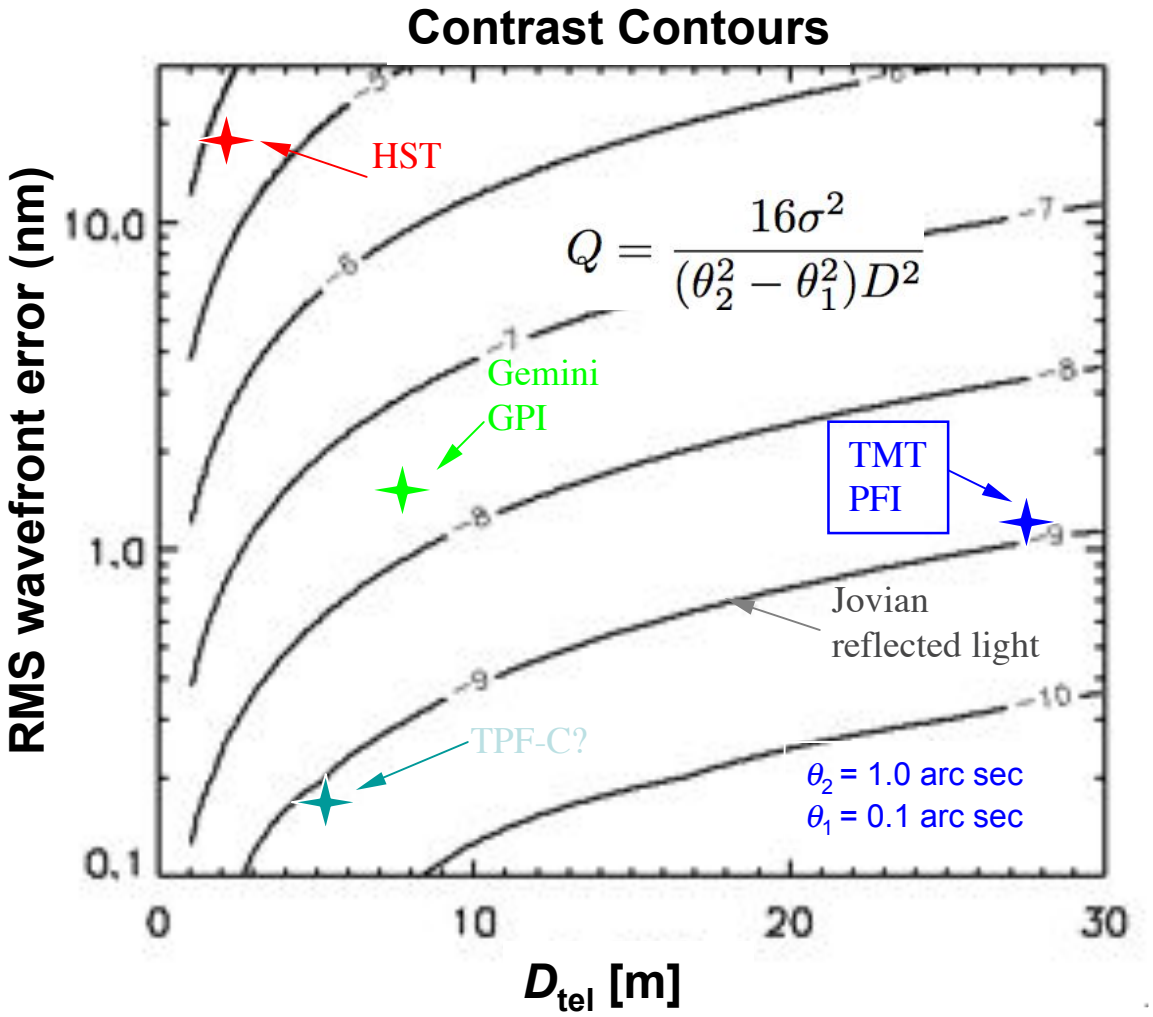


Guyon 2009 "Exoplanets & Disks"

Wavefront errors

- A wavefront error, spatial frequency *k,* diffracts light according to the condition for constructive interference $\theta = k\lambda/2\pi$
  - *Dynamic* errors
    - Atmosphere
  - (Quasi) *Static* errors
    - Telescope
    - Instrument

Wavefront Errors & Contrast

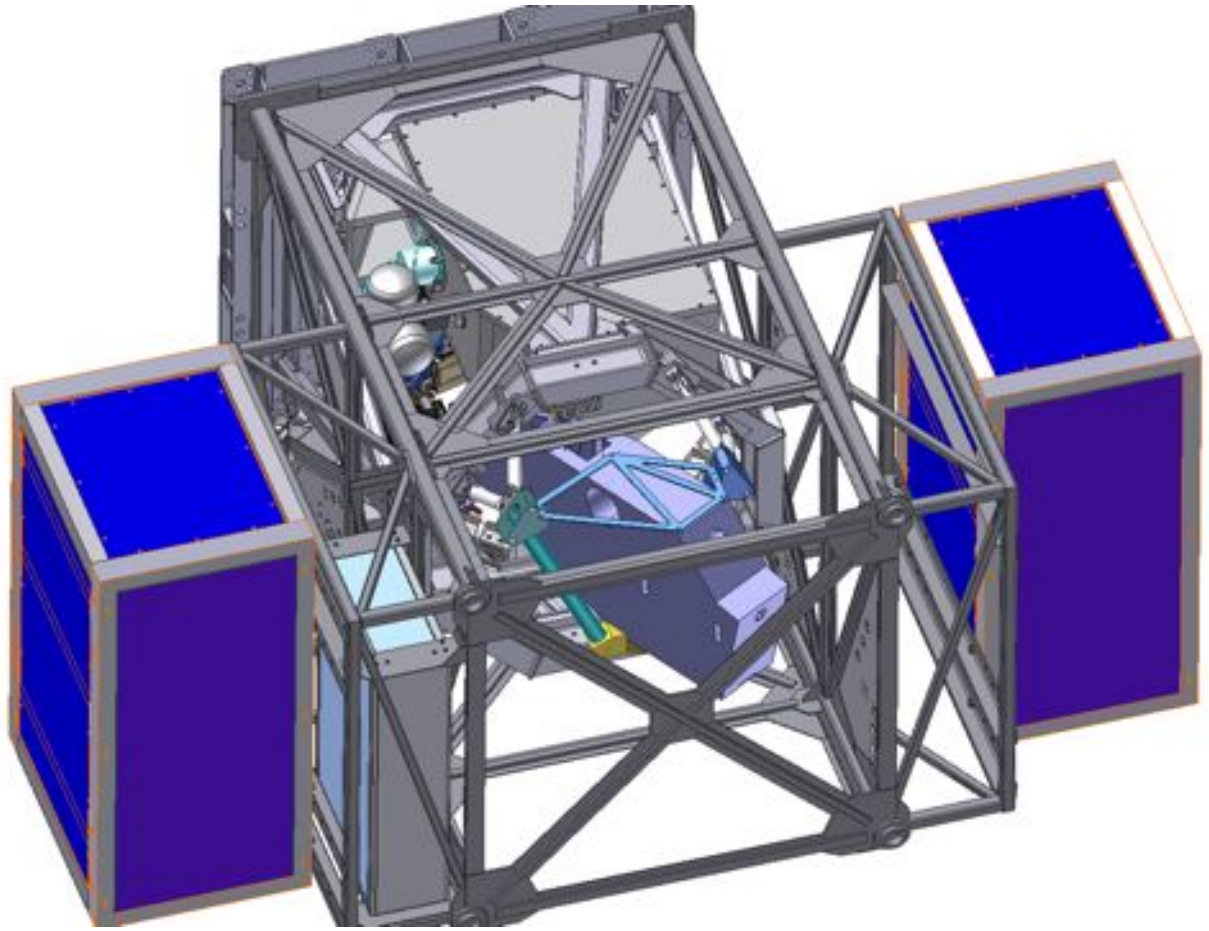


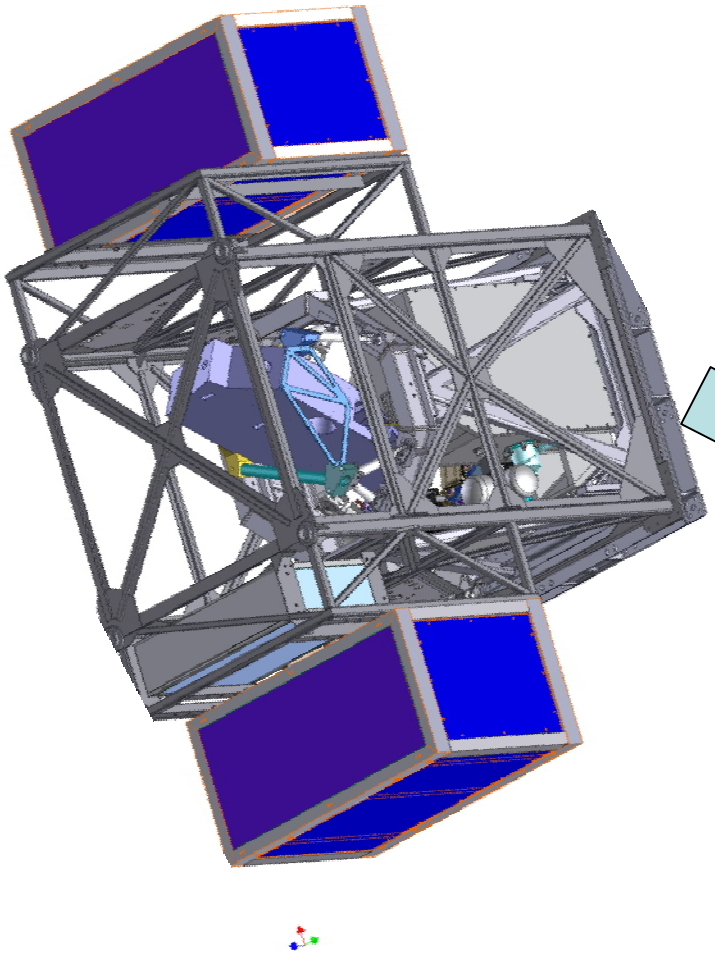
Recipe for High Contrast Imaging

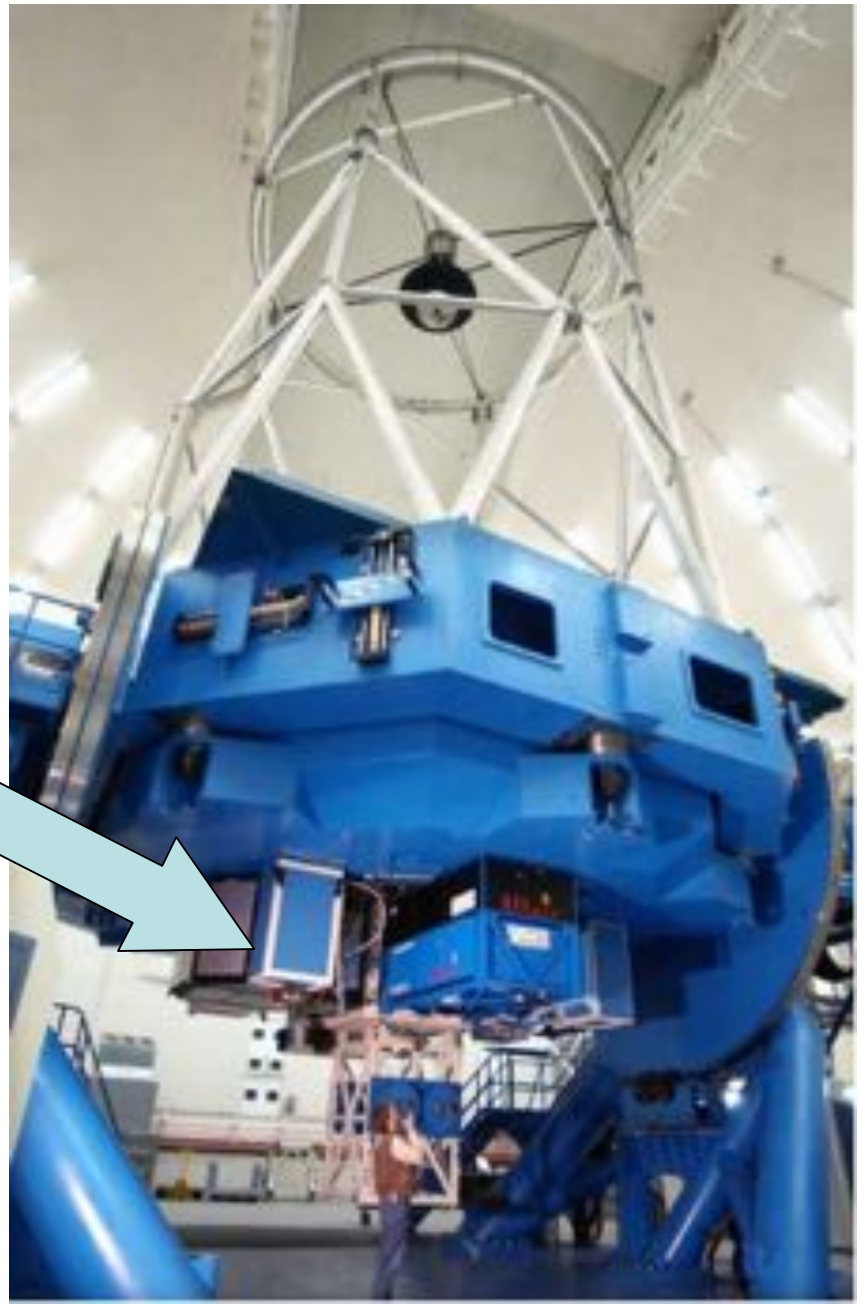
- Precise & accurate wavefront control
  - Advanced AO to control of dynamic (atmosphere) external static (telescope) aberrations
    - Few nm rms to reach contrast of 10^{-8}
    - Need a few x 10^3 degrees of freedom & kHz bandwidth to keep up with atmosphere
  - Amplitude errors must be small or controlled
- Control of diffraction to target contrast level
  - Pupil apodization to reduce side-lobes at angles of a few λ/D
- Stable to enable differential imaging
  - Field rotation: Cassegrain focus on Alt/Az telescope
  - Spectral/polarization differencing: IFS/IFP

Gemini Planet Imager

- 1800-actuator MEMS AO
- Integral field spectrograph/ polarimeter
- Advanced coronagraph
- Nanometer-level wavefront accuracy through calibration and interferometric wavefront sensor

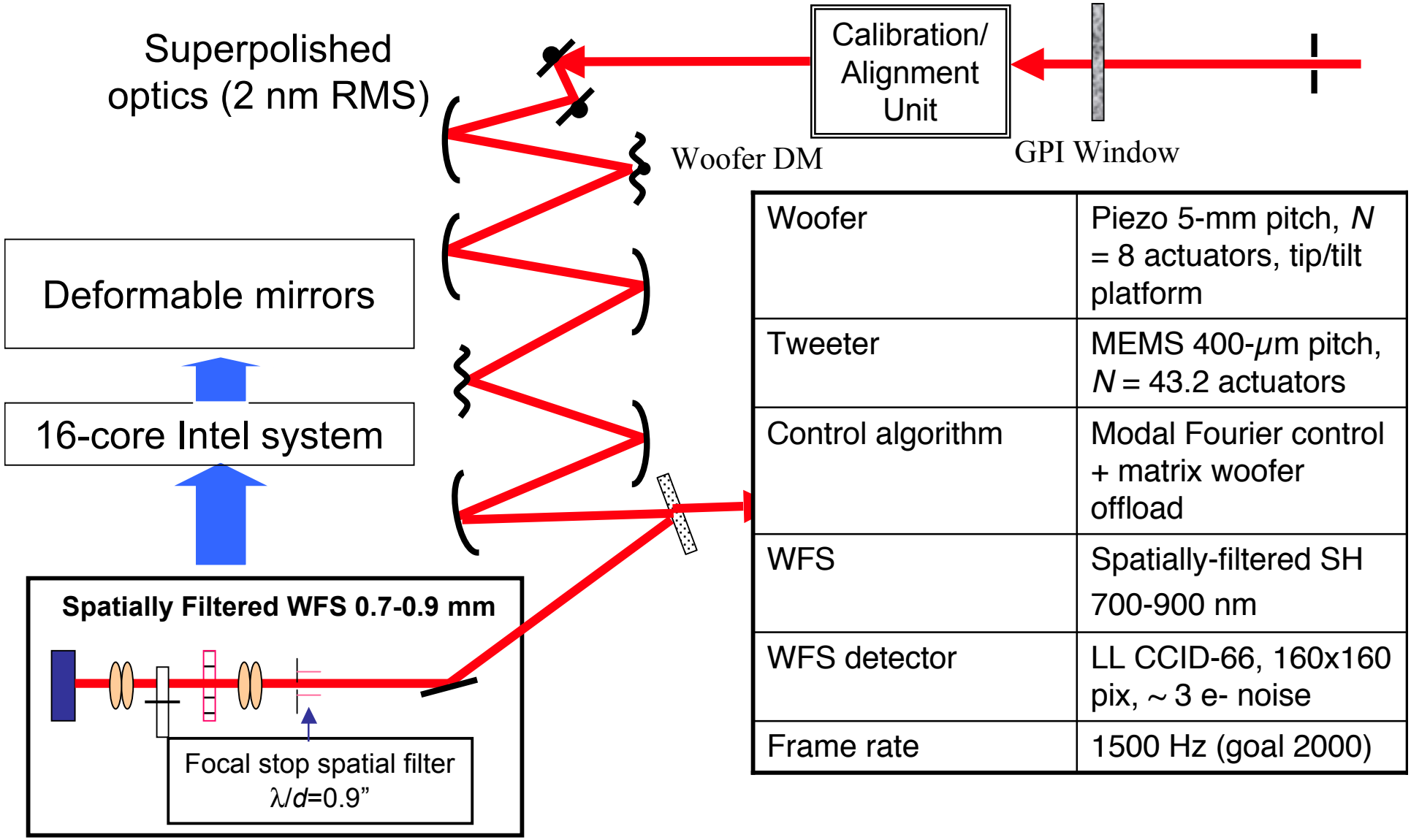






OMSS & FSS at HIA

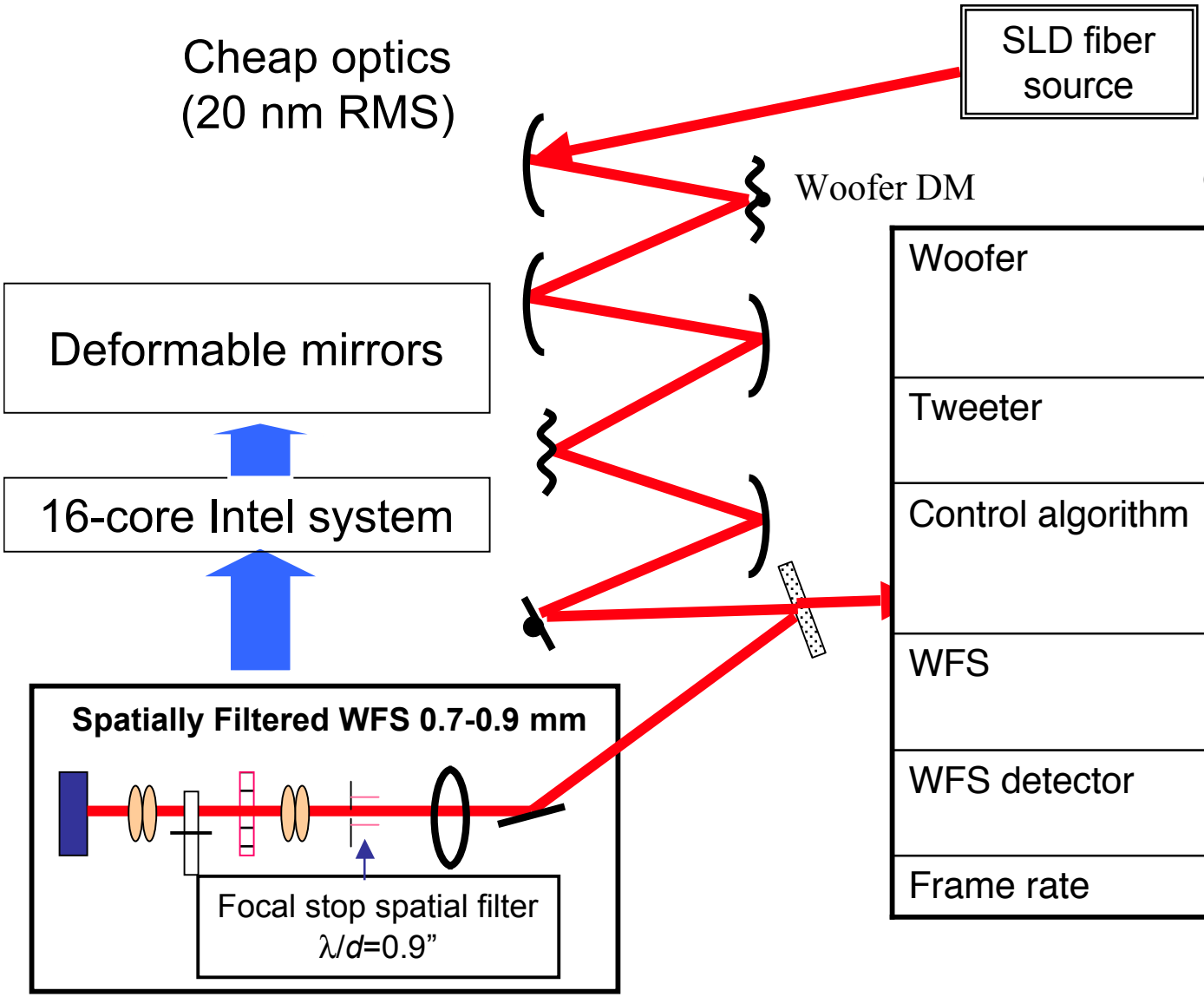
GPI AO architecture



Woofer	Piezo 5-mm pitch, *N* = 8 actuators, tip/tilt platform
Tweeter	MEMS 400-μm pitch, *N* = 43.2 actuators
Control algorithm	Modal Fourier control + matrix woofer offload
WFS	Spatially-filtered SH 700-900 nm
WFS detector	LL CCID-66, 160x160 pix, ~ 3 e- noise
Frame rate	1500 Hz (goal 2000)

LLNL AO Testbed

Cheap optics
(20 nm RMS)



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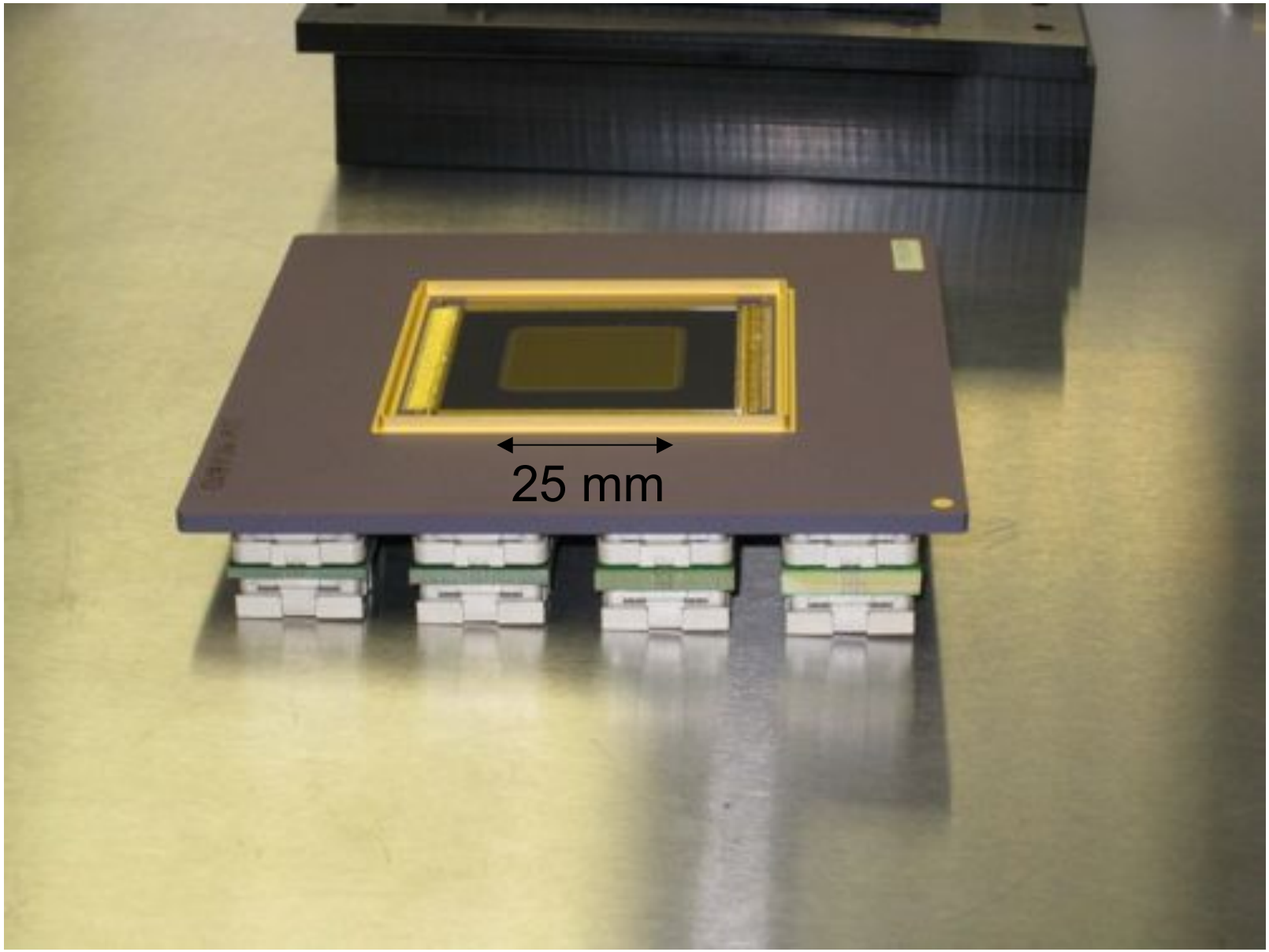
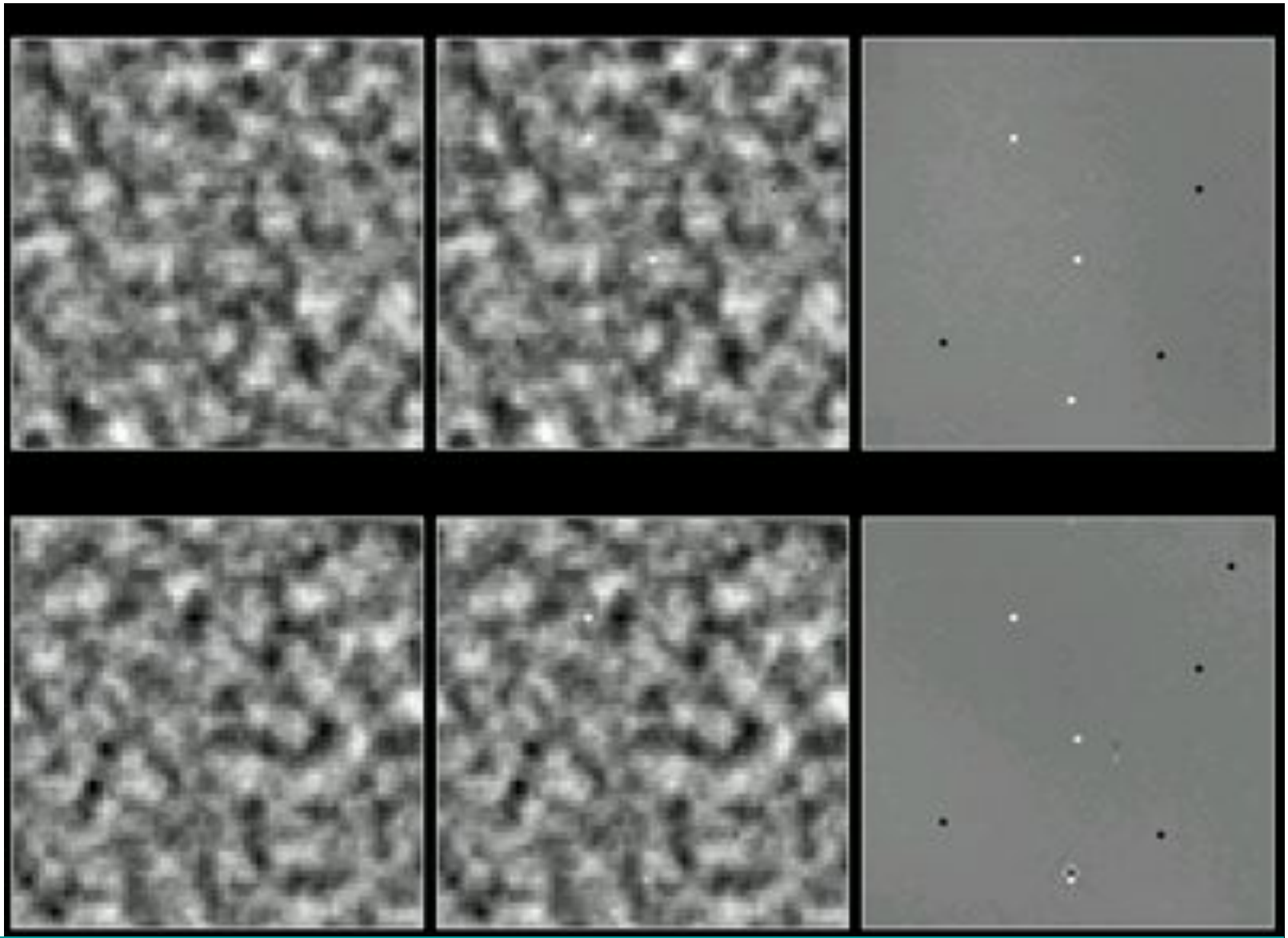
BMC MEMS



MEMS Surface Tests



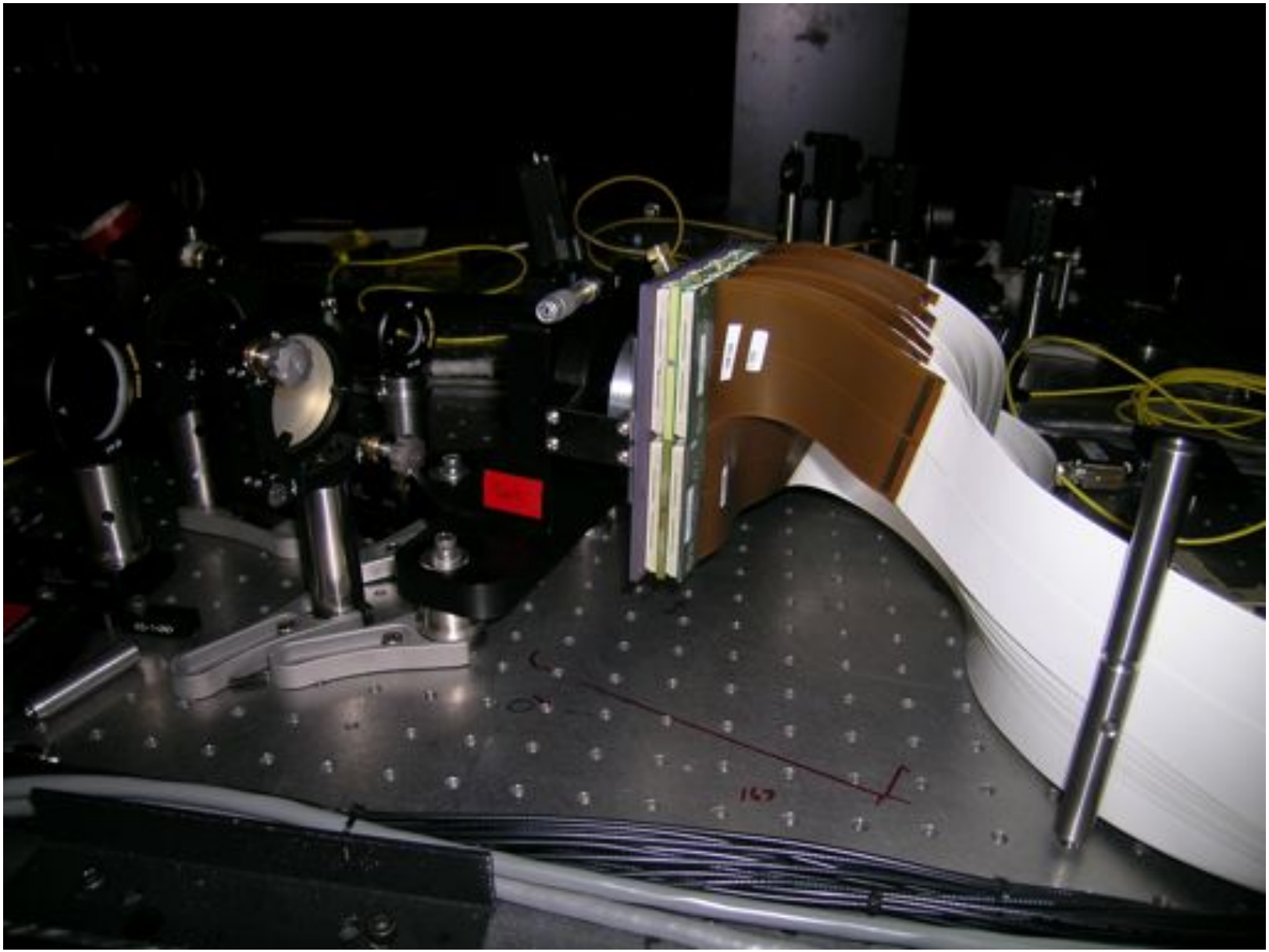
Desired MEMS shape ±1 μm

Measured MEMS shape ±1 μm

Residuals ±100 nm

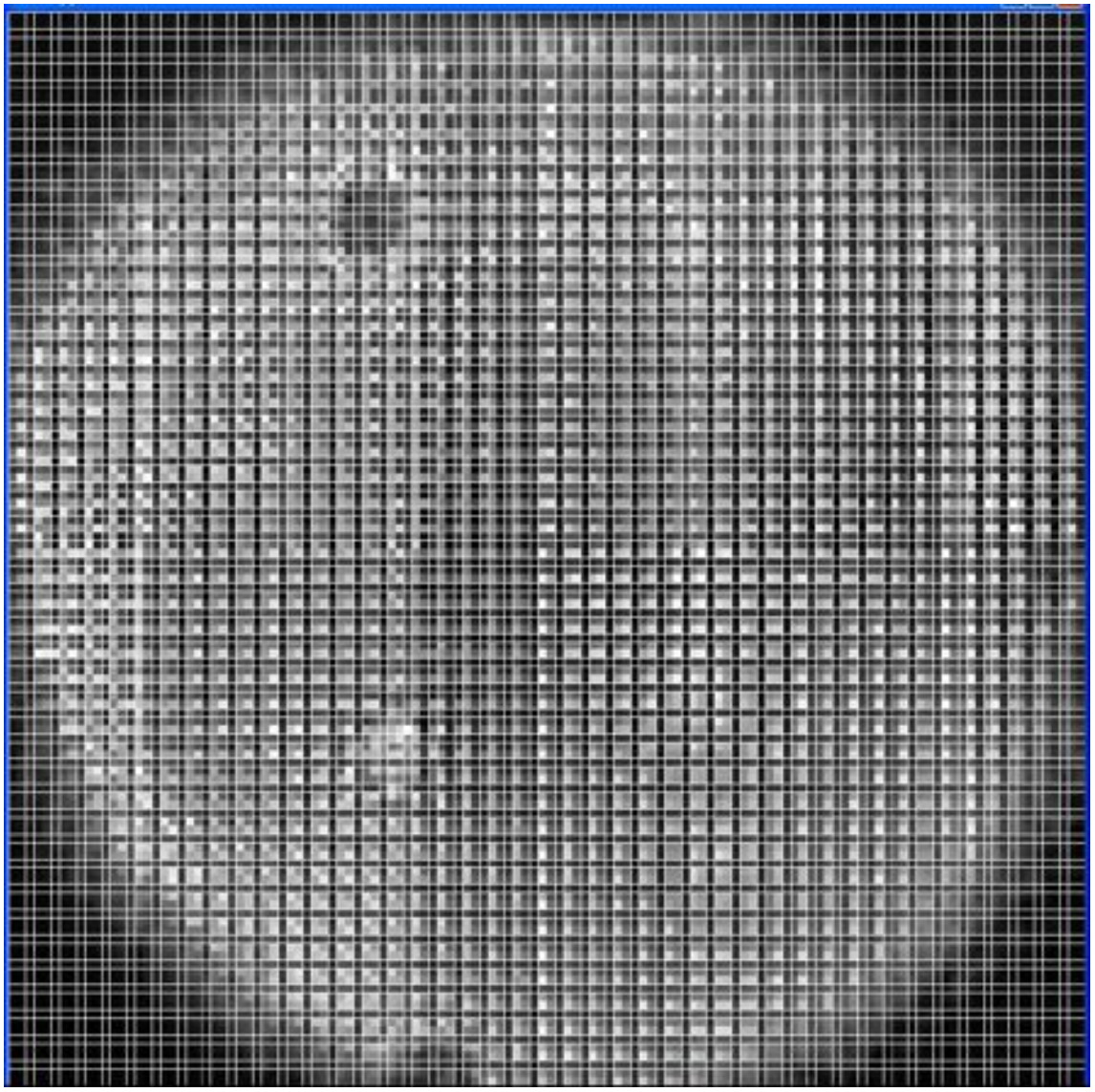
Steve Cornelissen
BMC

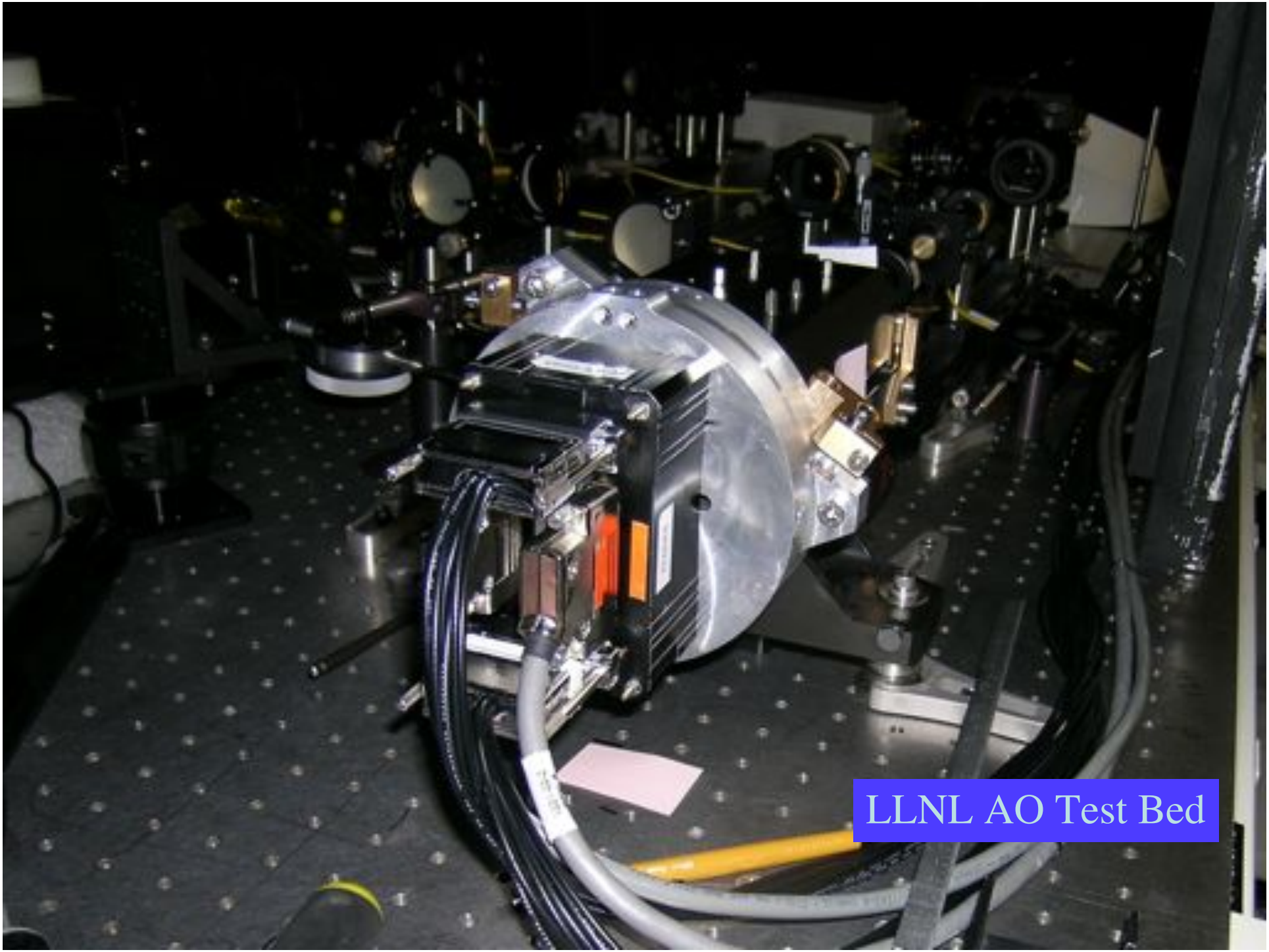
MEMS on LLNL Testbed



Wavefront Sensor

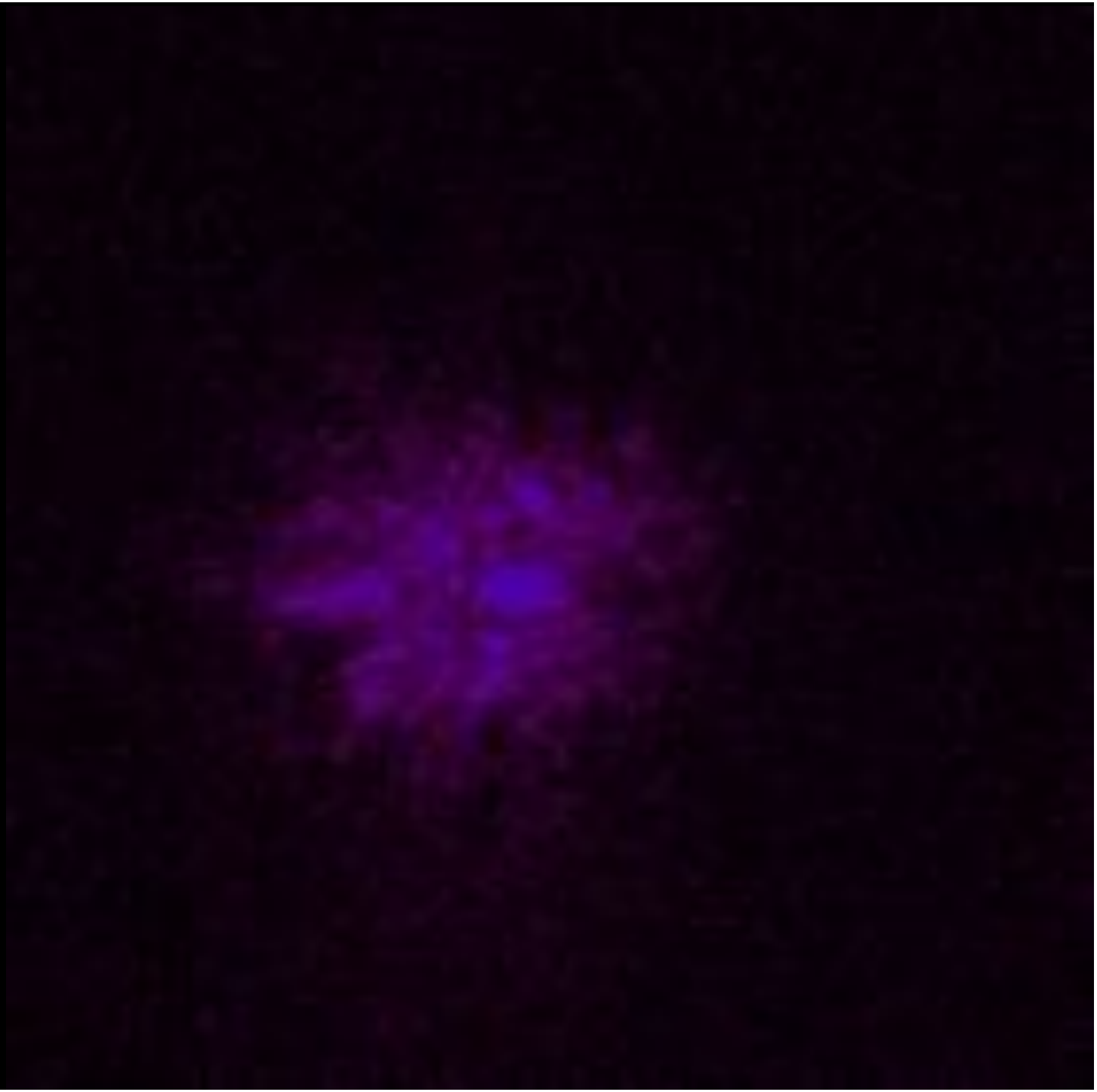
- LL CCID-66
  - 160 x 160 frame transfer CCD
  - 20 port
  - High QE
  - Low read noise
    - 3 e^- rms @ 1 kHz
    - 4-6 e^- rms @ 4 kHz
  - Non-linearity?




LLNL AO Test Bed

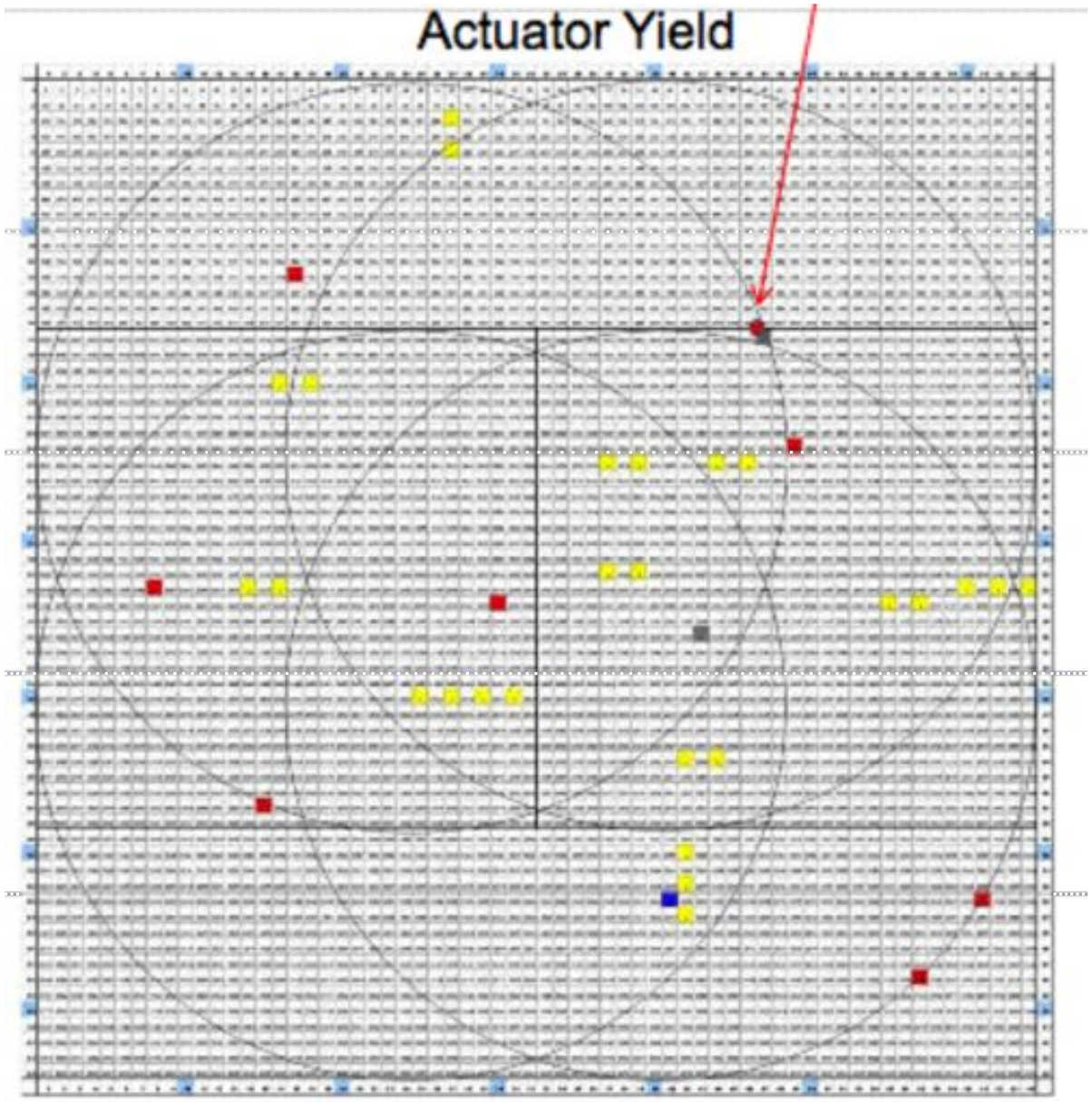
LLNL First Light Closed Loop

- Spinning phase plate simulates median Cerro Pachon r_0 & τ_0
- 1.5 kHz
  - Computational goal
  - Movie x8 real time
- Woofer/tweeter/TT control
  - Fourier mode gain optimizer
  - 50 nm rms errors
- PSF recorded by basic science camera (no coronagraph)

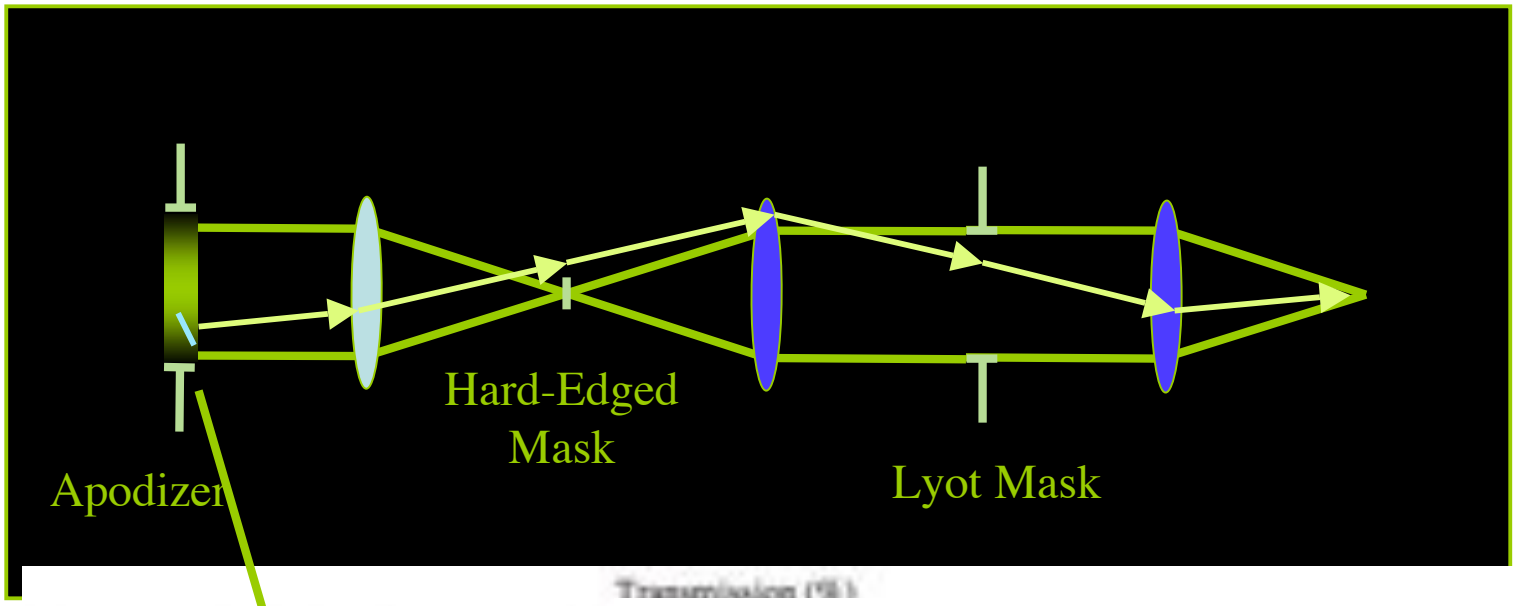


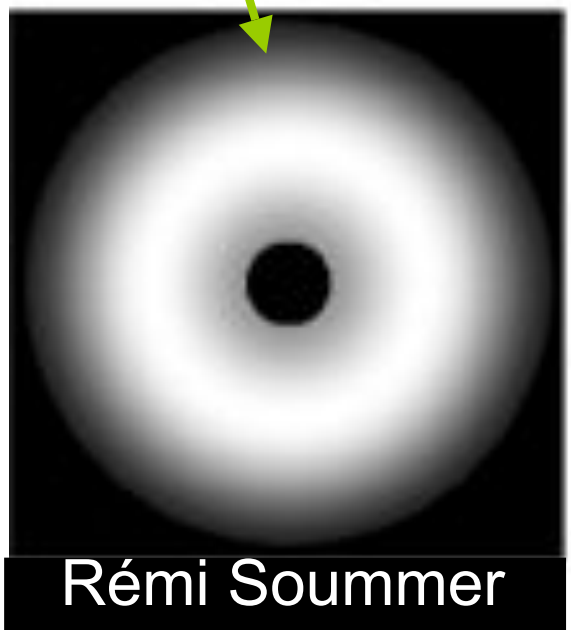
BMC MEMS device #080W001

- Stroke 4 μm
- Scalloping < 10 nm
- Curvature 1-2 μm
- Five candidate science devices
- 99.1% yield
  - 34 anomalous actuators

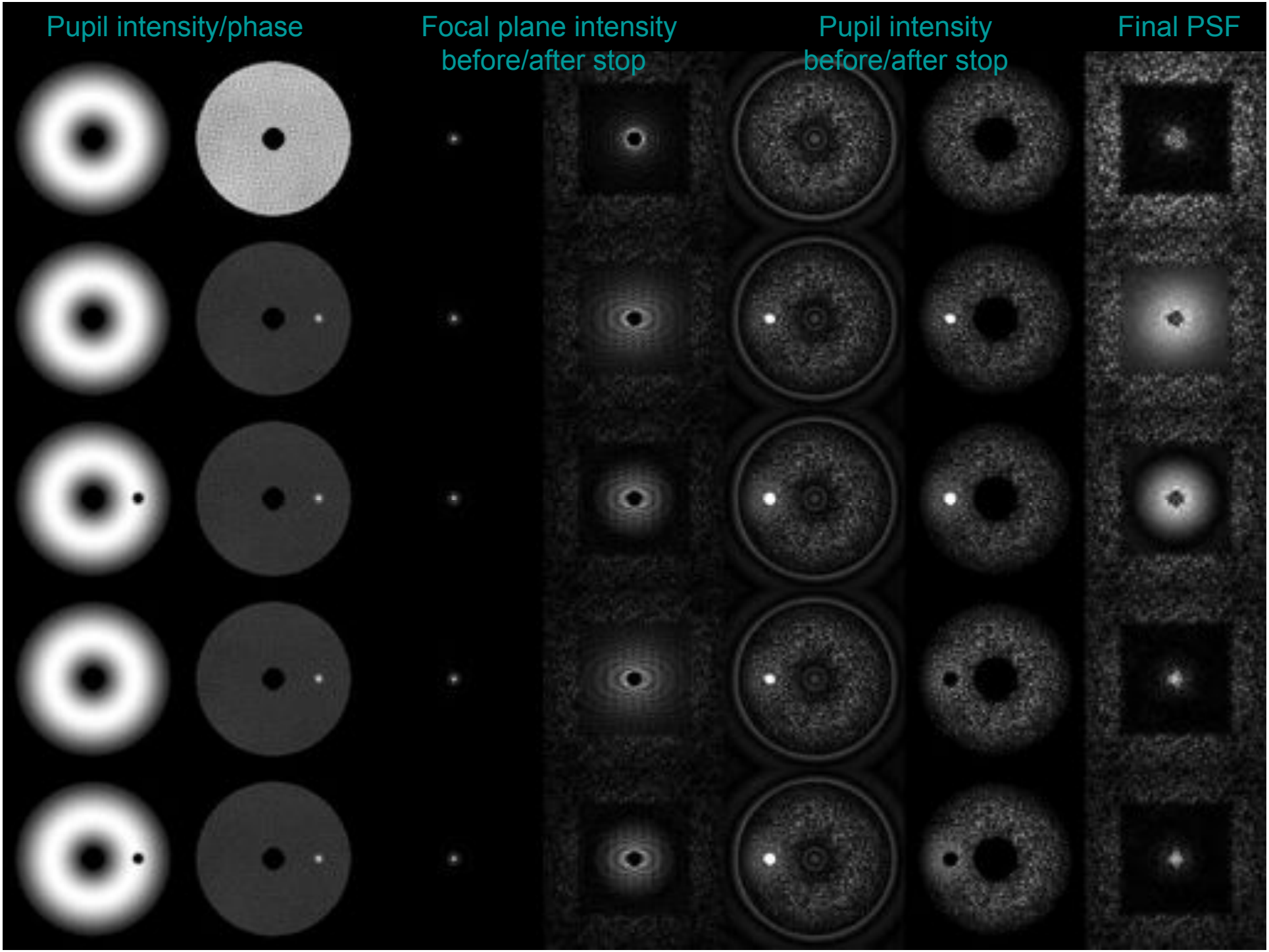


APLC Optimized for Obscured Pupil

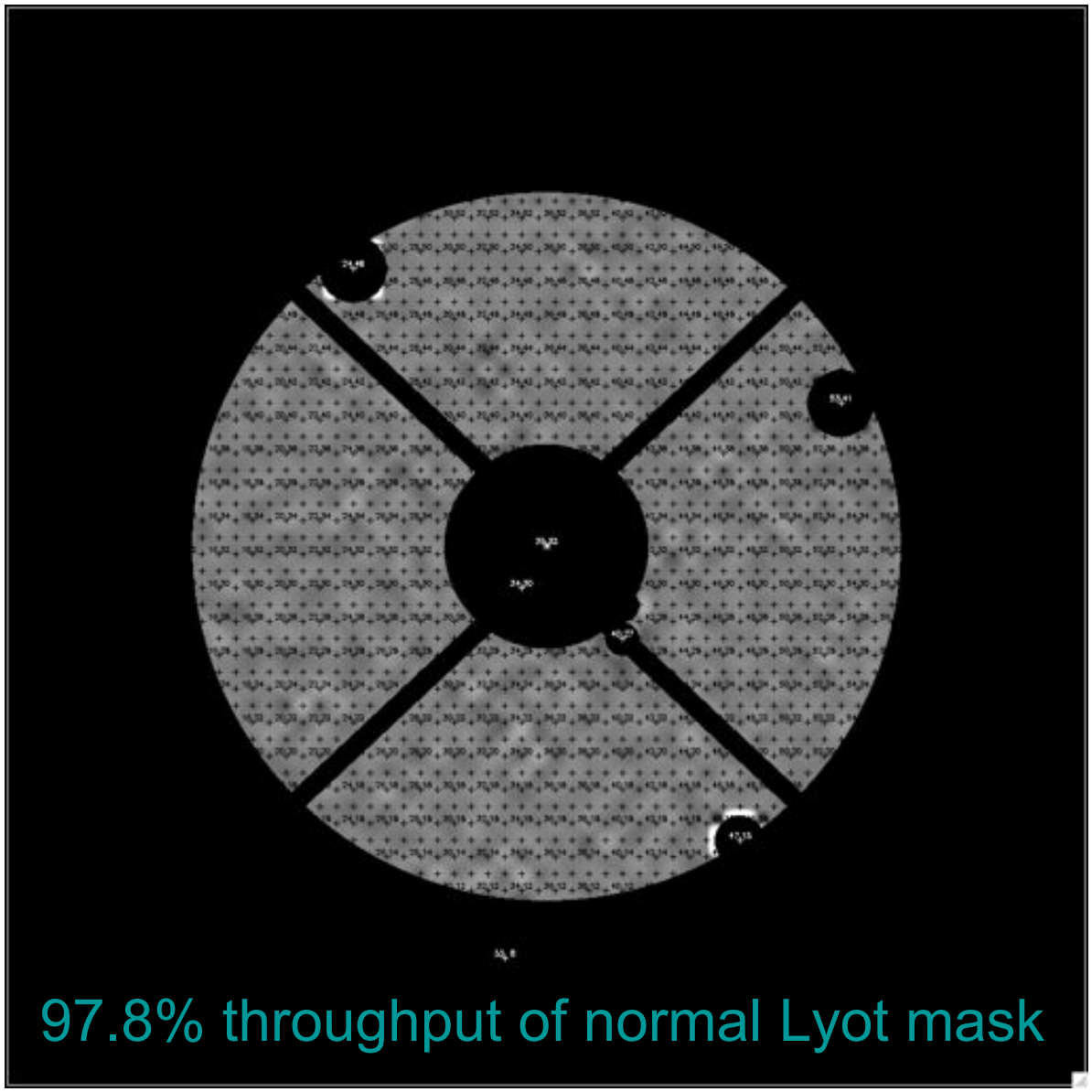




- Mask bad actuators on the conjugate pupil plane
- Isaacs et al 2010 OE (submitted) for Fourier algebra & analysis

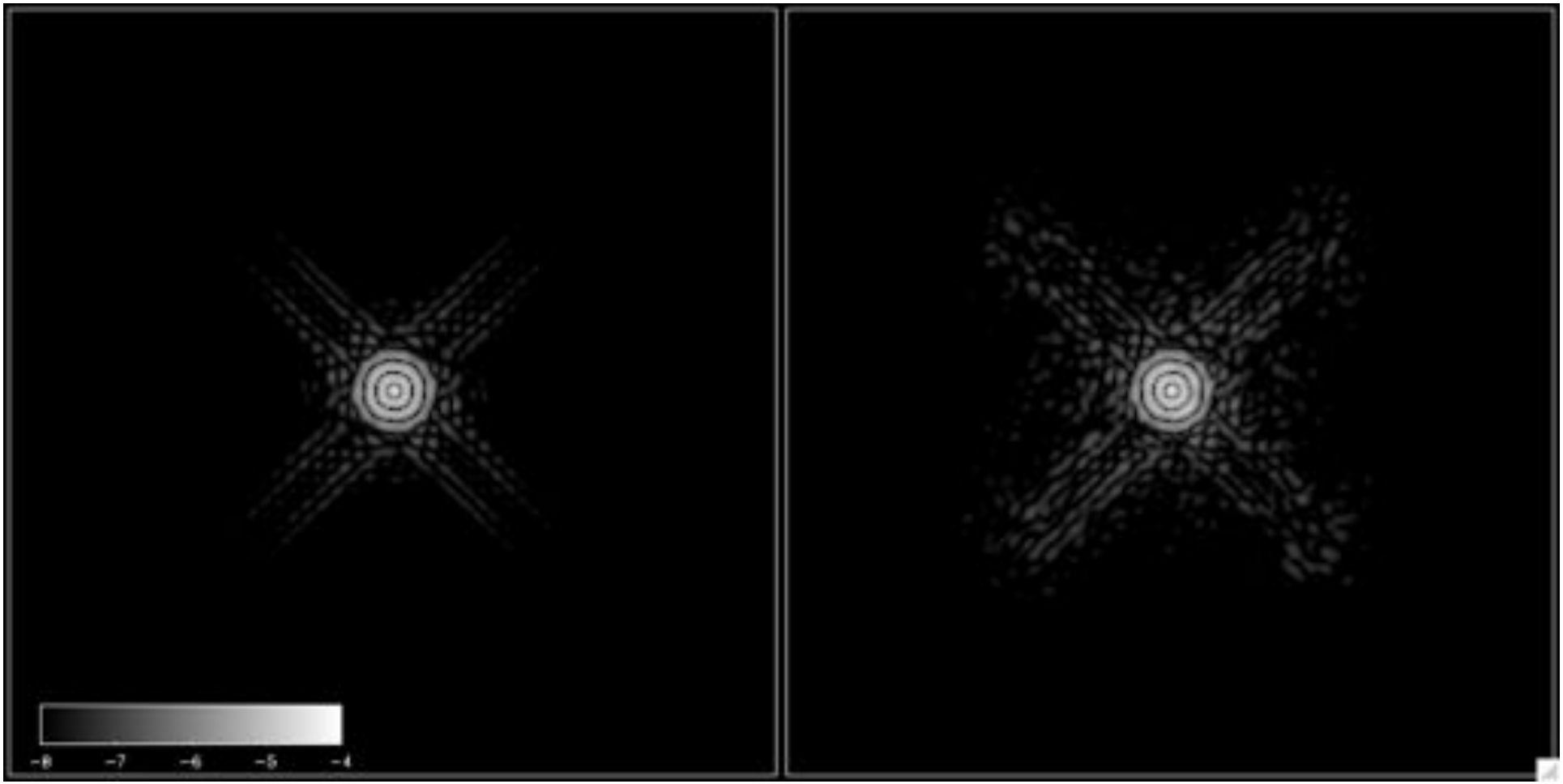

Pupil intensity/phase
Focal plane intensity
before/after stop
Pupil intensity
before/after stop
Final PSF

Lyot Mask & Wavefront Error

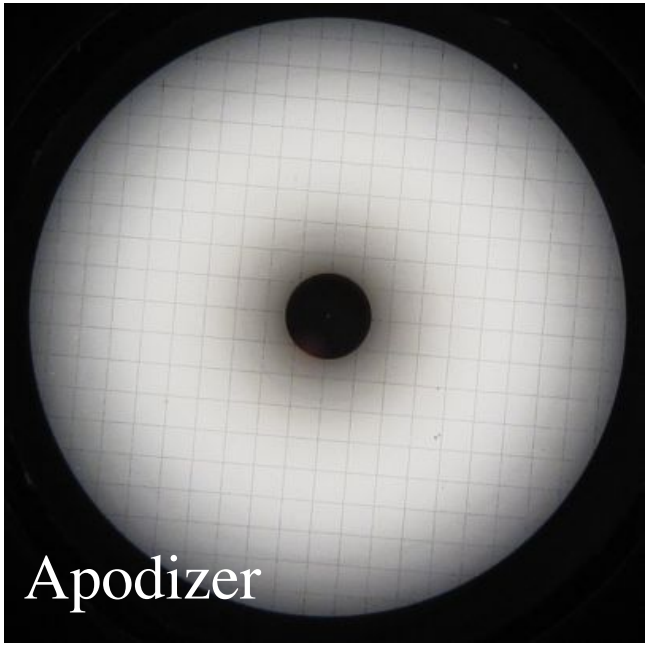


97.8% throughput of normal Lyot mask

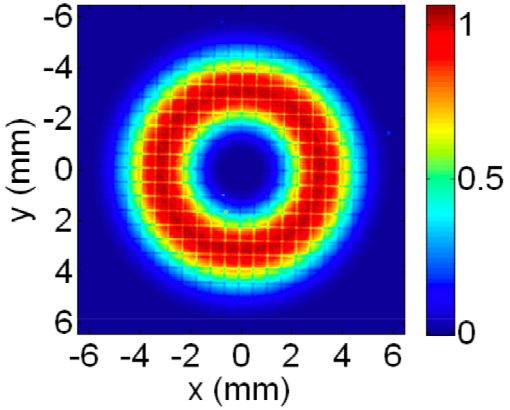
Masked Actuator PSF Comparison (no WFE)

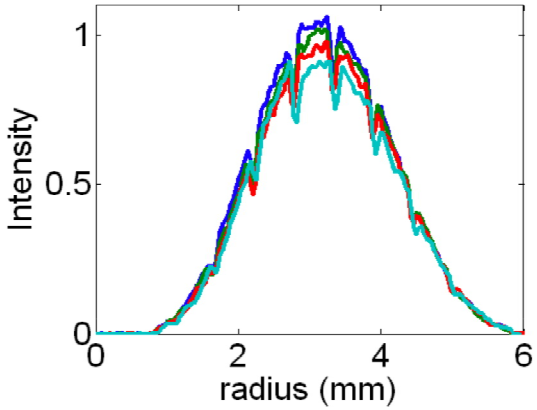


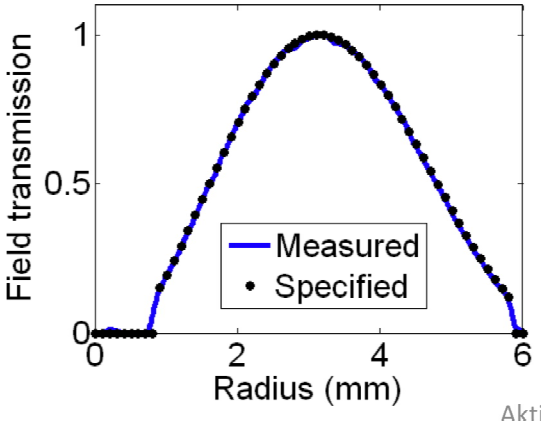
AMNH Masks

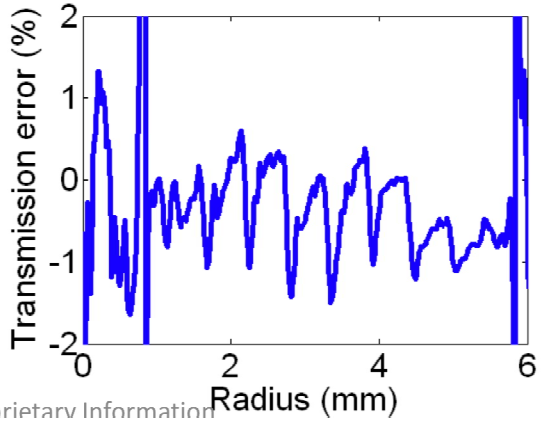


Apodizer profile

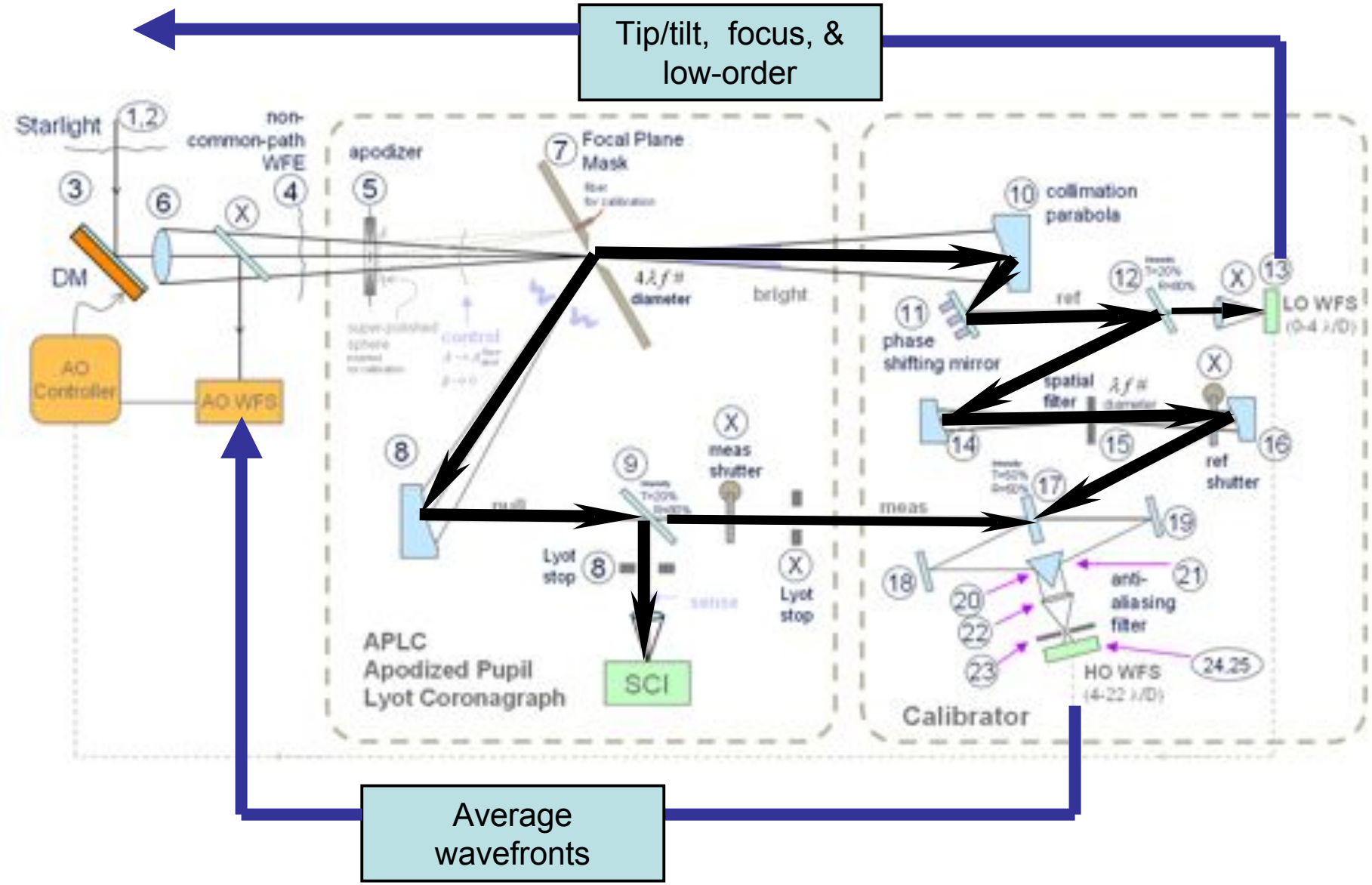






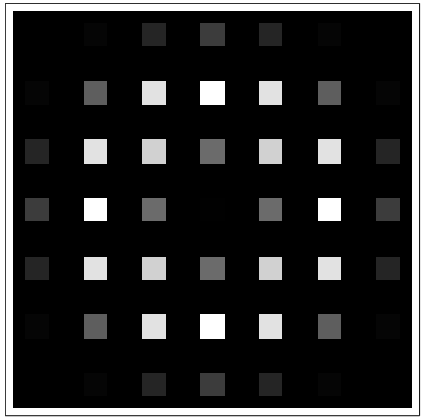


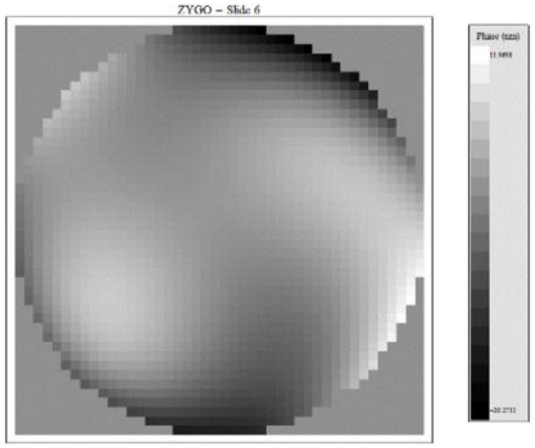
JPL CAL Unit Interferometer Measures Science Wavefront



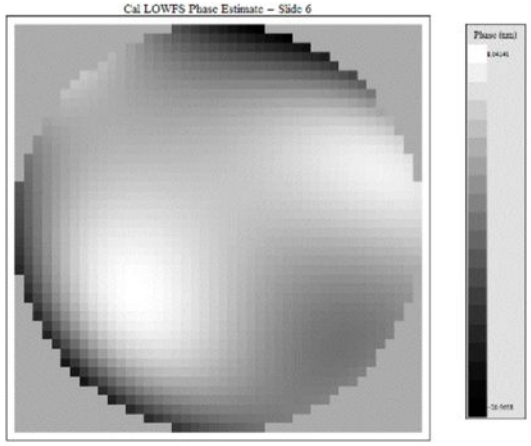
JPL CAL Unit Status

- LOWFS sensor performs at 1 mas & < 5 nm RMS absolute accuracy



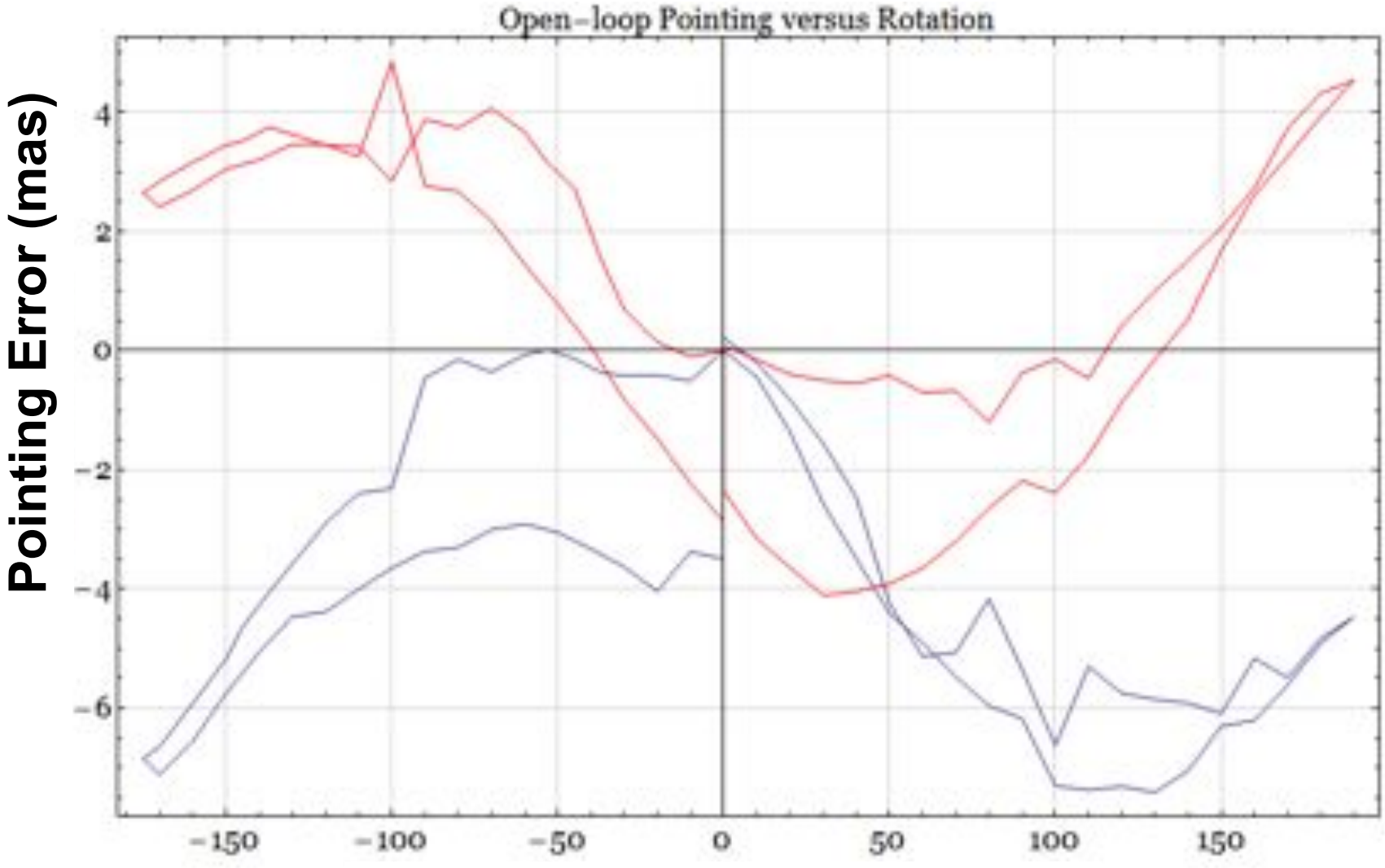


Zygo measurement



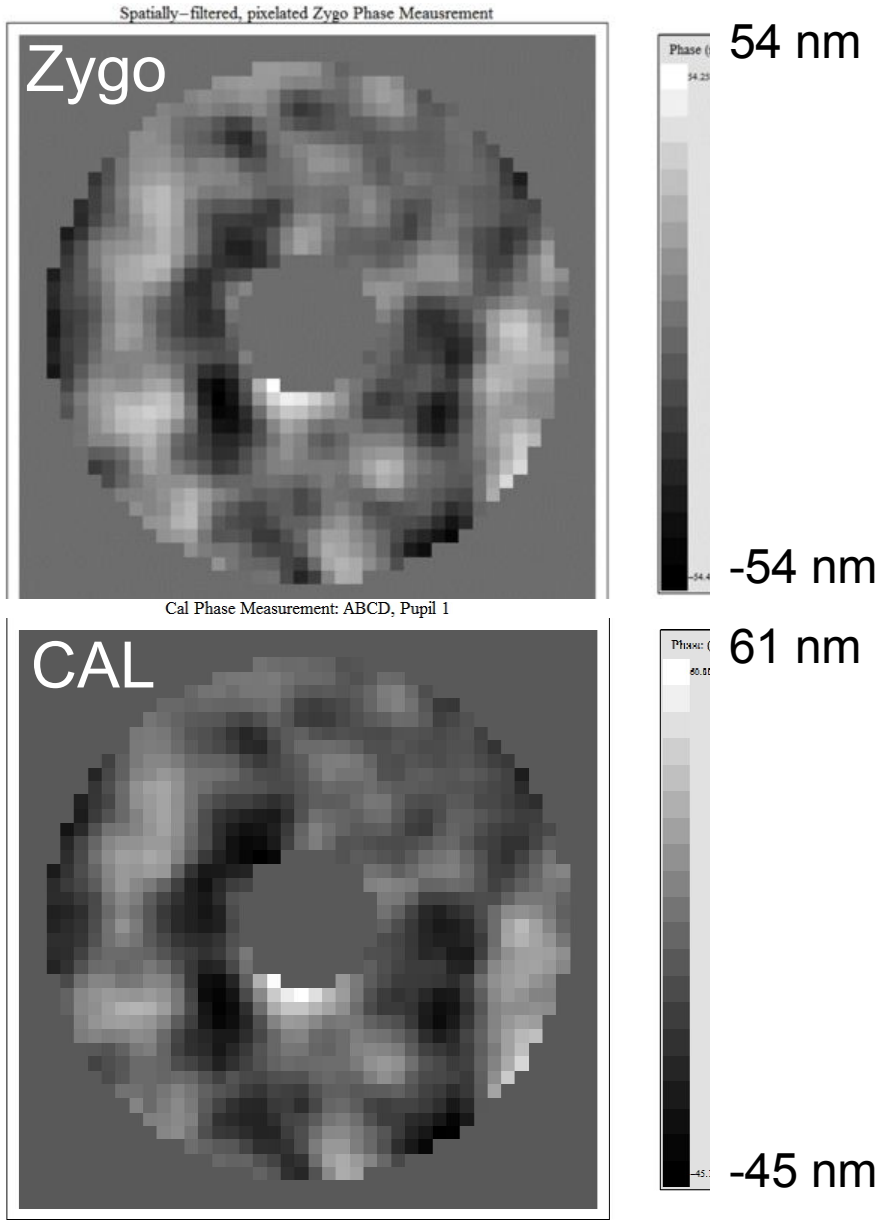
CAL measurement

JPL CAL Unit Status

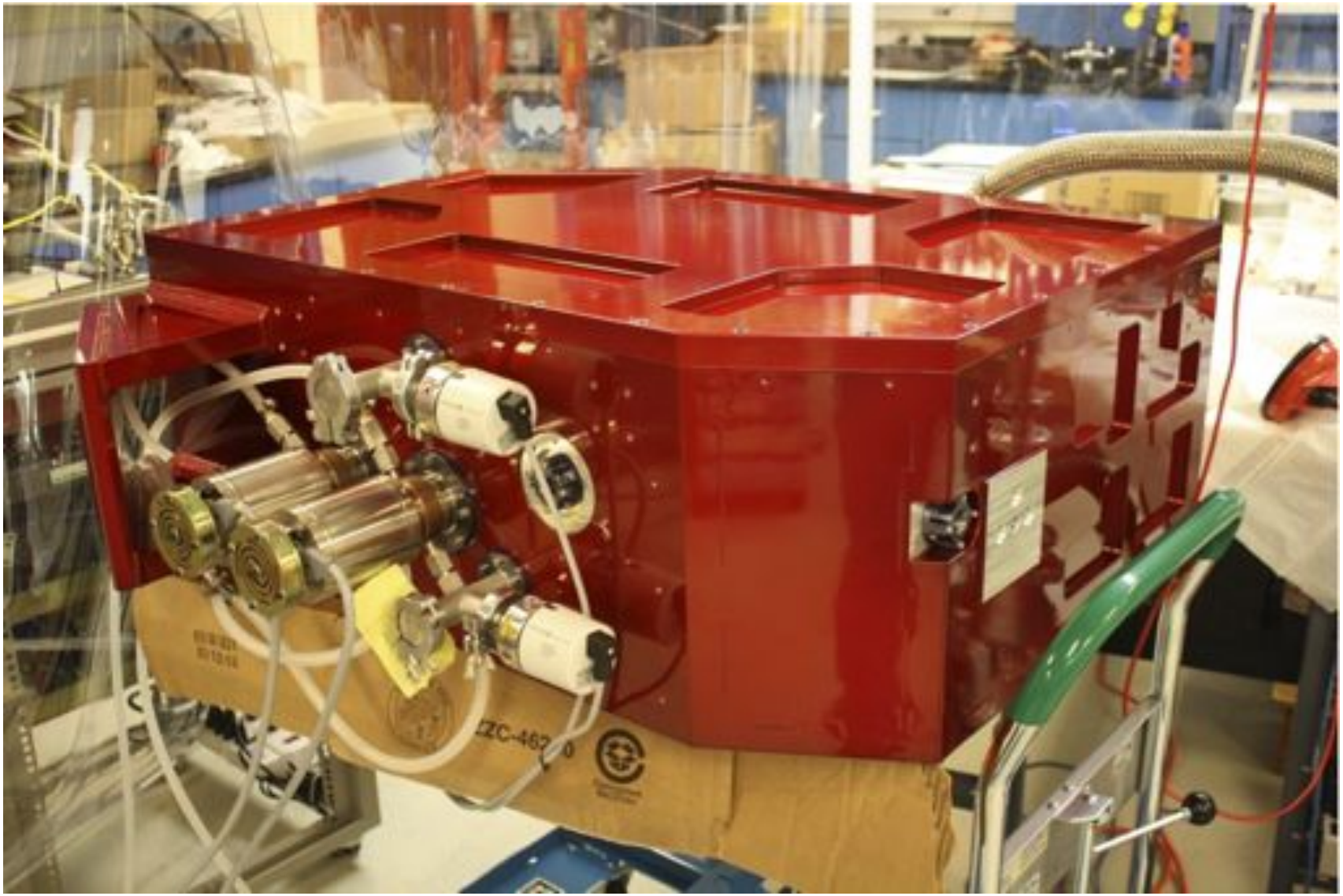


JPL CAL Unit Status

- HOWFS performs at ~ 4 nm RMS absolute accuracy
- Likely that repeatability and precision are higher than this
  - Focal-plane wavefront sensing algorithms for daytime calibration to set wavefront setpoints

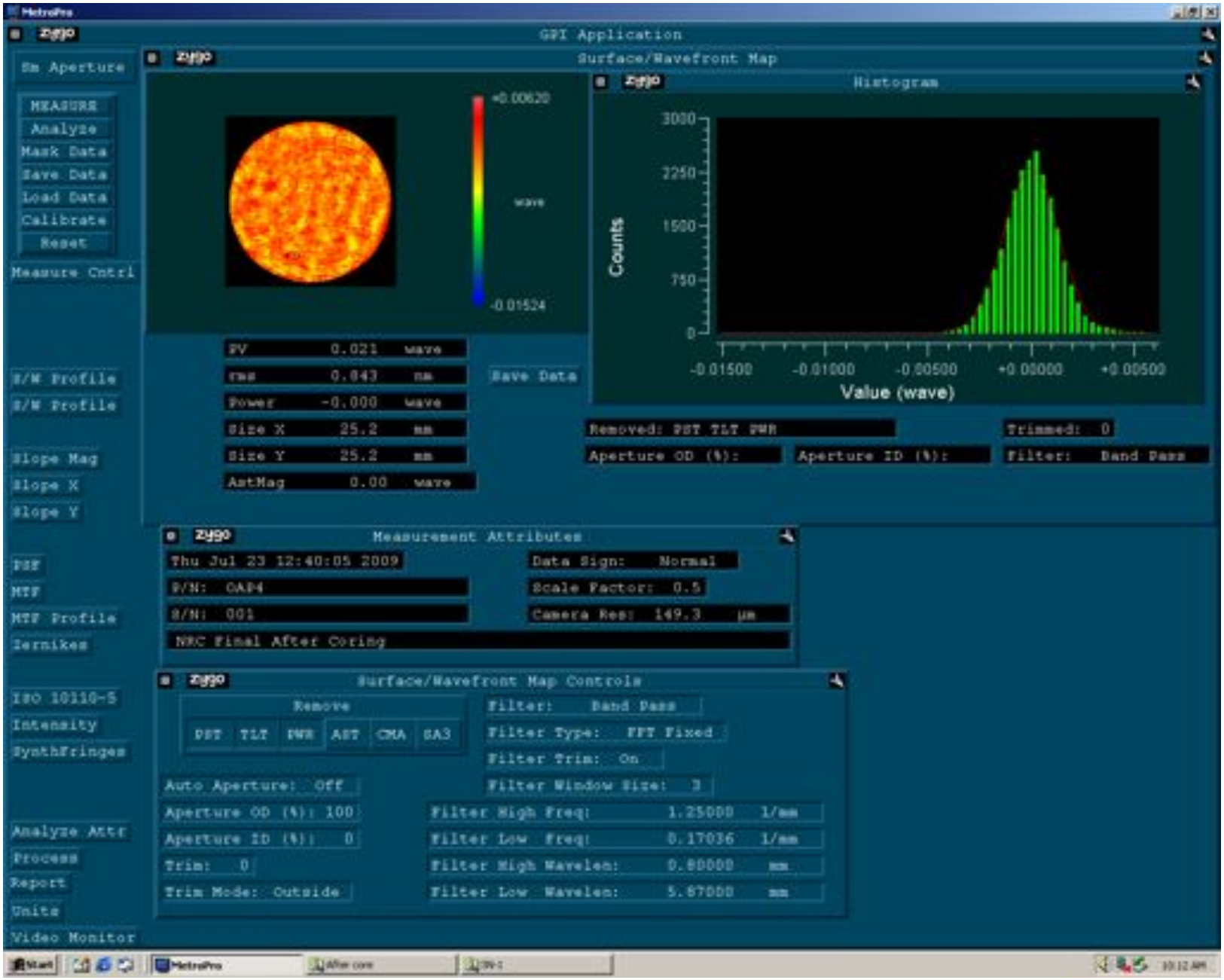


UCLA Integral Field Spectrograph

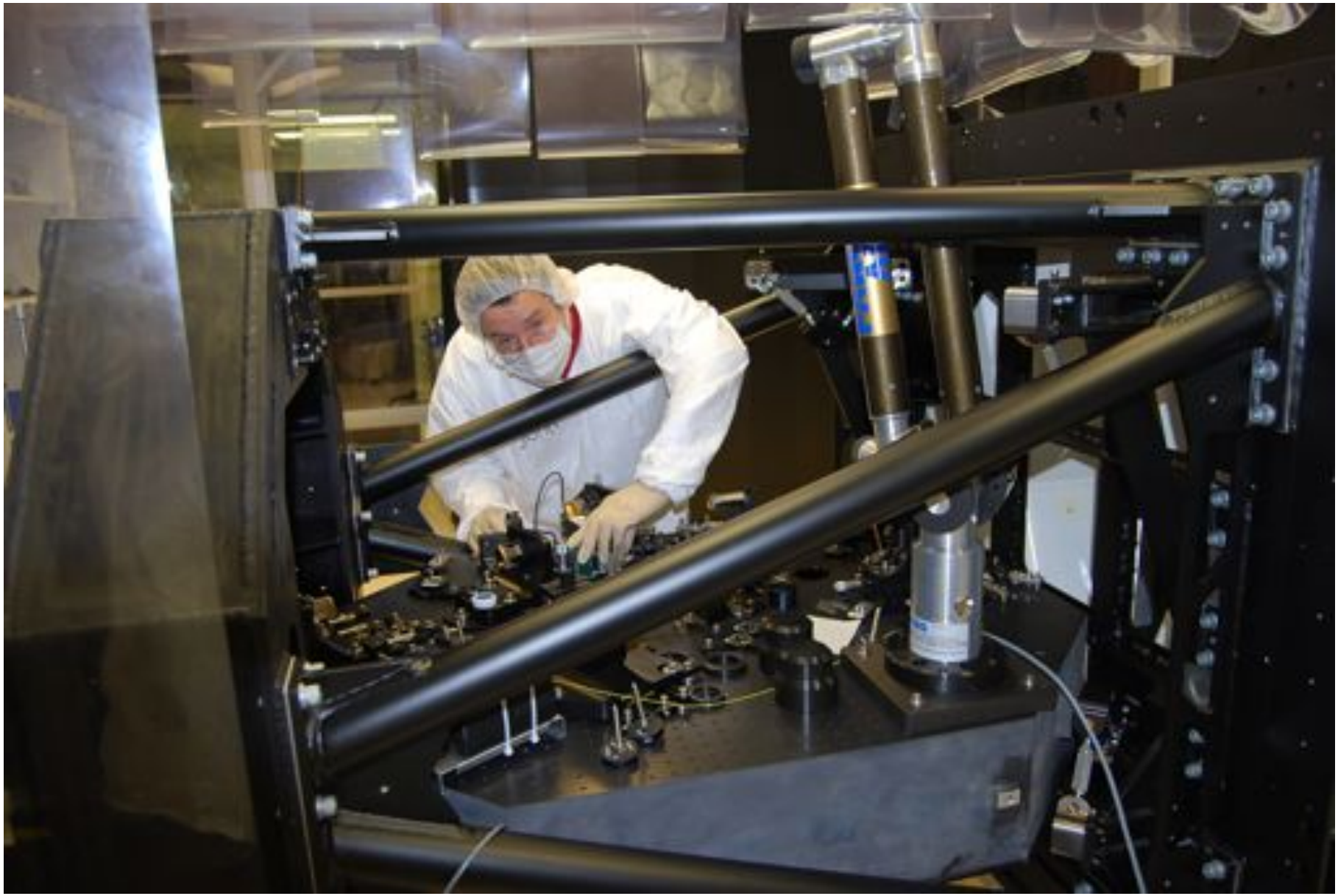


UCLA IFS Assembly

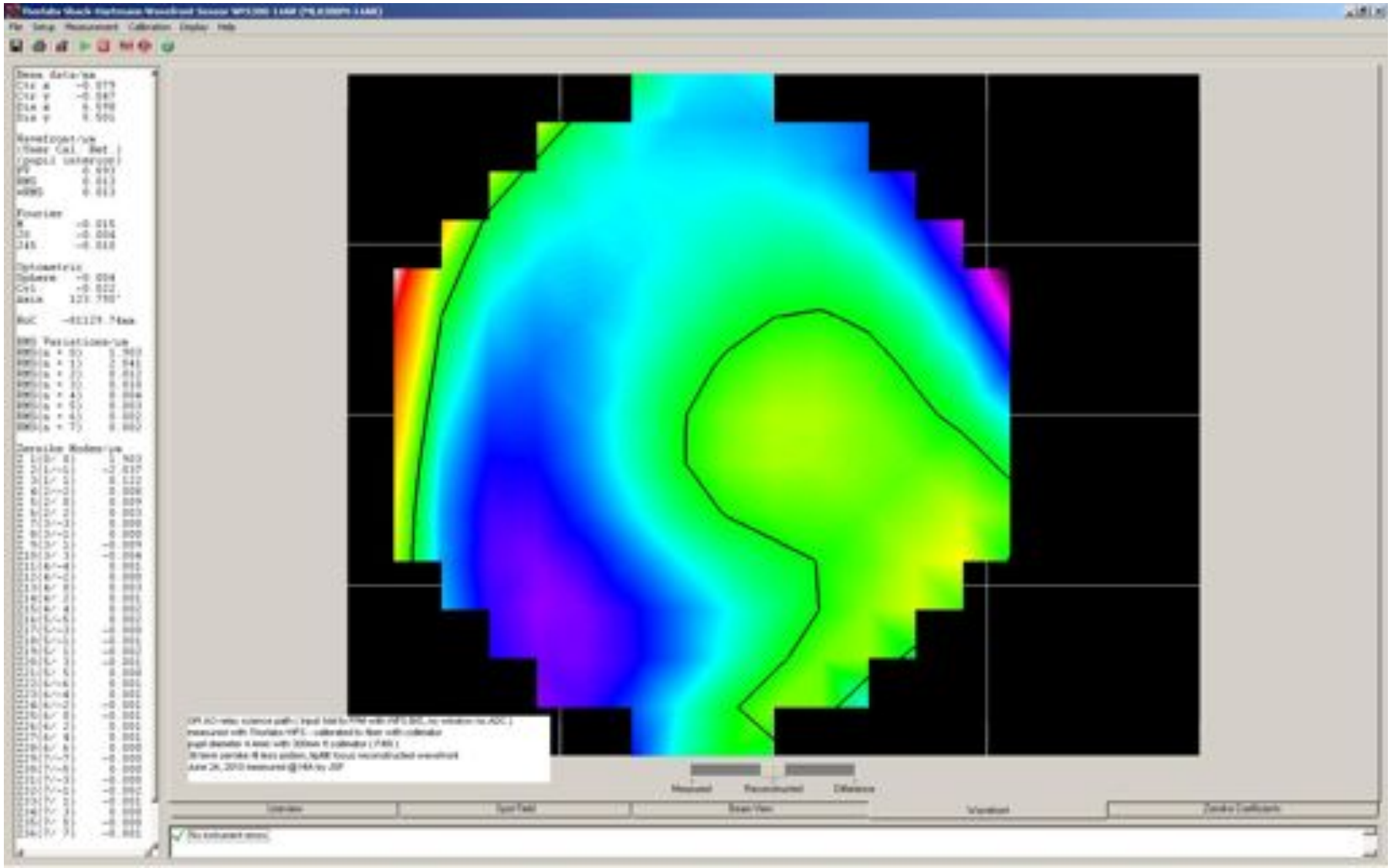
Individual optics < 1 nm RMS



Optical Bench Alignment @ HIA



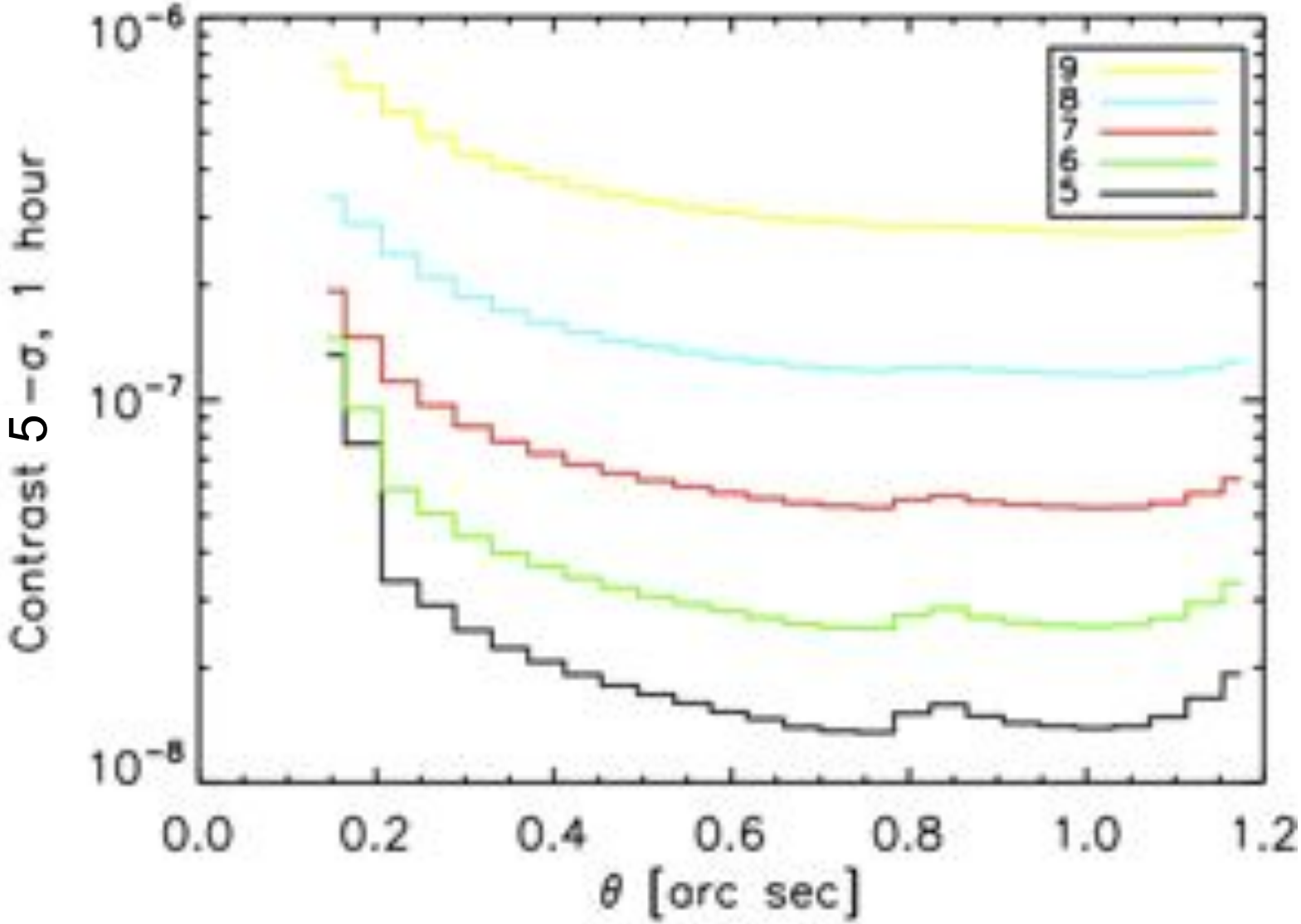
13 nm RMS WFE End-to-End



LAO/UCSC Integration & Test

- Integration & test at LAO/UCSC High Bay clean room (D. Gavel, S. Thomas)
- Subsystem integration
- End-to-end contrast tests with telescope simulator & phase plates
- Performance optimization
- Flexure & environment tests
- Formal acceptance tests

Performance Models @ http://planetimager.org



Road to Gemini…early 2012