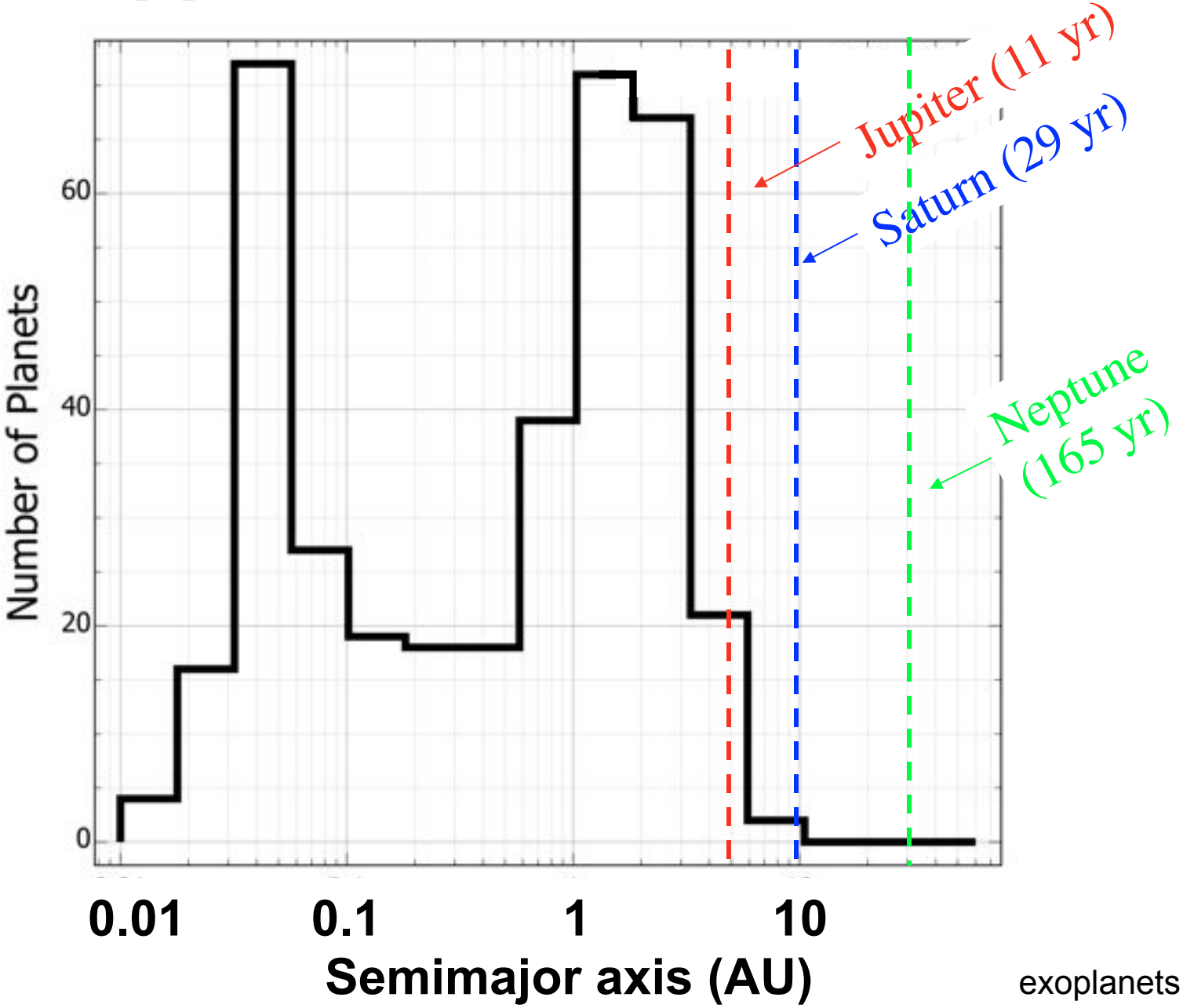
Gemini Planet Imager: Direct Detection of Exoplanets

James R. Graham (Dunlap Institute) for the GPI Instrument Team

B. Macintosh, R. Doyon, D. Gavel, D. Palmer, J. Larkin, B. R. Oppenheimer,. L. Saddlemyer, J. K. Wallace

September 13, 2011

Doppler Planet Histogram

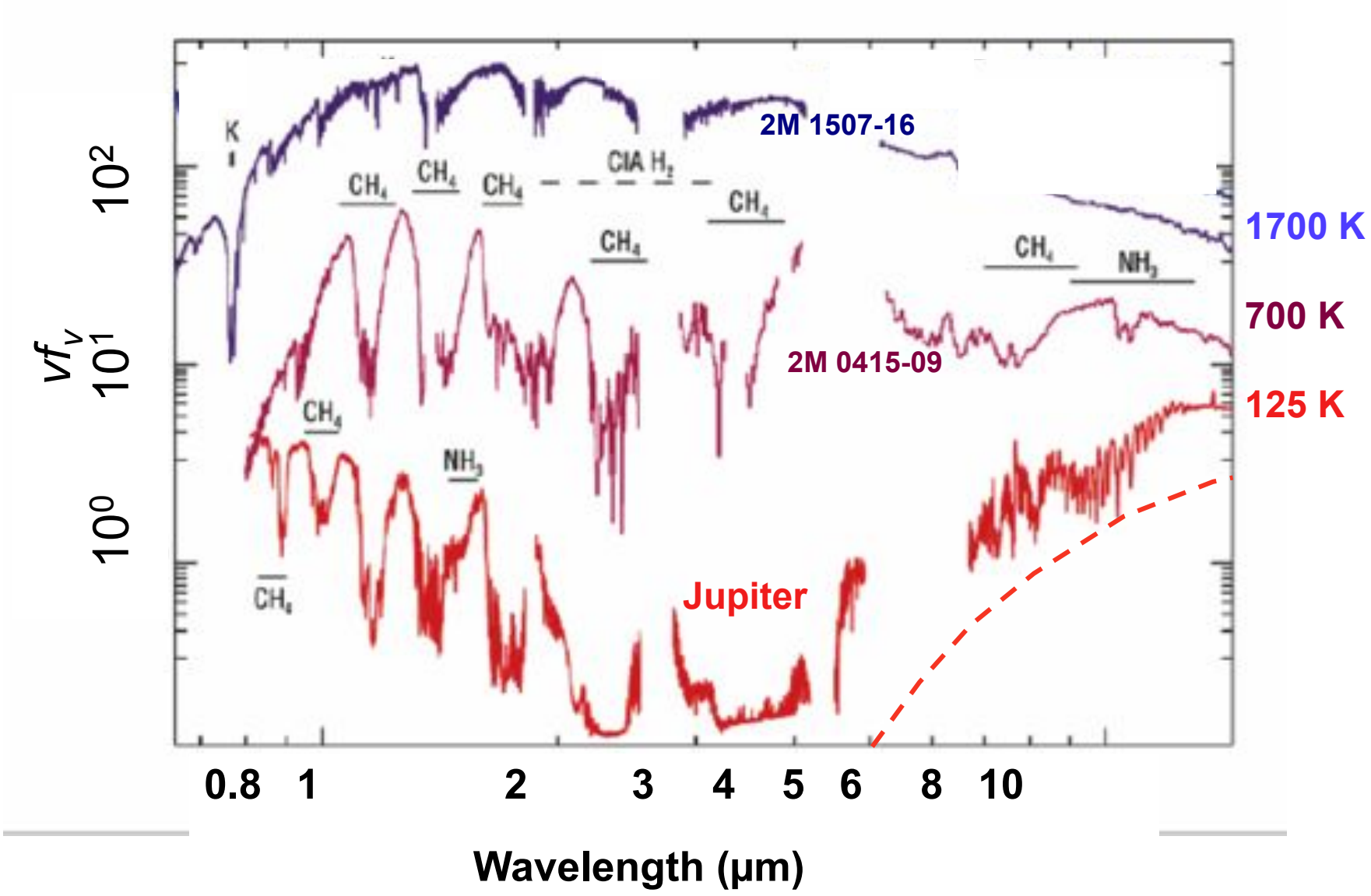


exoplanets.org

Exoplanet Science

- How do planetary systems form & evolve?
  - What stars have planetary systems?
  - What mechanism(s) make Jovian planets
  - How does dynamical evolution redistribute these planets?
- Physics of planets
  - Planetary atmospheres
    - Unexplored regime of 120 K < T < 600 K
      - Domain of NH_3 & H_2O & clouds

Direct Imaging of Self-Luminous Planets



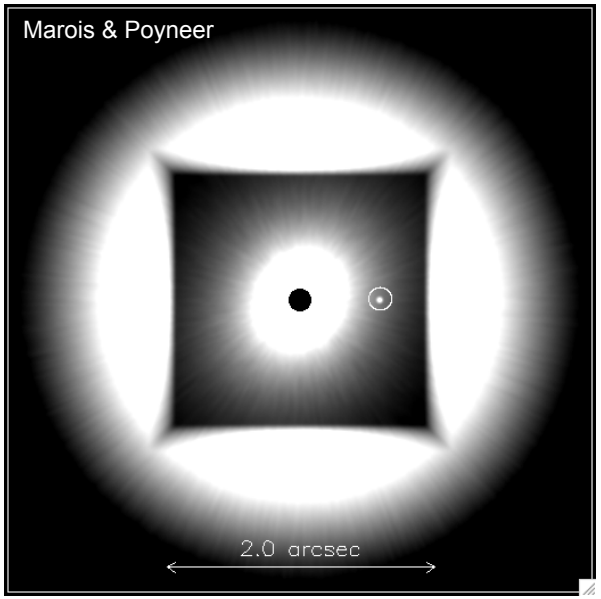
Marley & Leggett 2009

Recipe for High Contrast Imaging

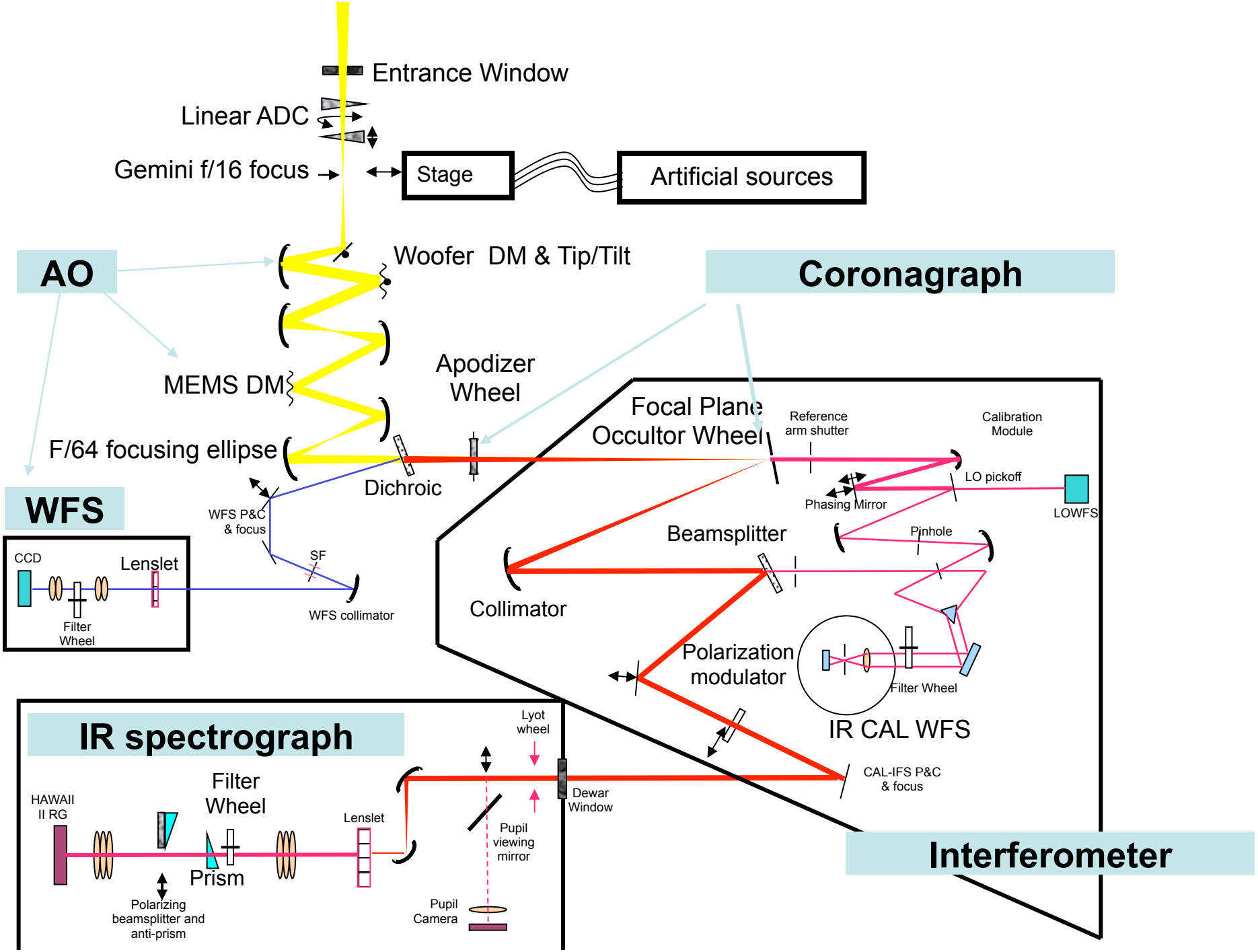
- Precise & accurate wavefront control
  - Advanced AO to control of dynamic (atmosphere) and static (telescope) aberrations
    - Few nm rms to reach contrast of 10^{-8}
    - Need ~ 1000 degrees of freedom to make a big dark hole
    - kHz bandwidth to keep up with atmosphere
  - Amplitude errors must be small or controlled
- Control of diffraction to target contrast level
  - Pupil apodization to reduce side-lobes at a few λ/D
- Stable platform for differential imaging
  - Field rotation: Cassegrain focus on Alt/Az telescope
  - Spectral differencing: integral field spectrograph

Gemini Planet Imager

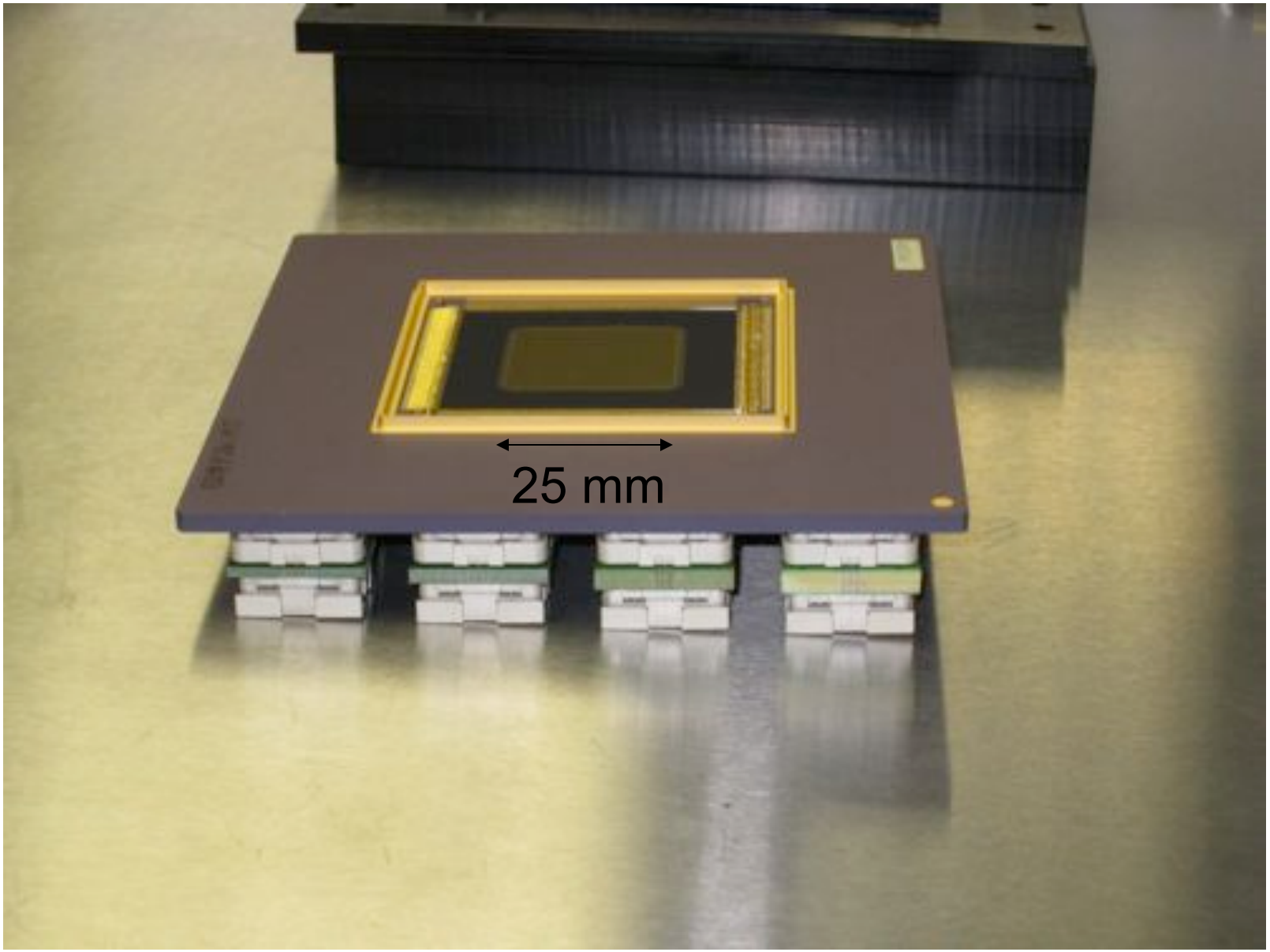
- 1800-actuator AO system
- Strehl ratio ~ 0.9 at *H* for the Gemini 8-m telescope
- Super-polished optics & precision calibration system
- APLC coronagraph
- Integral field spectropolarimeter



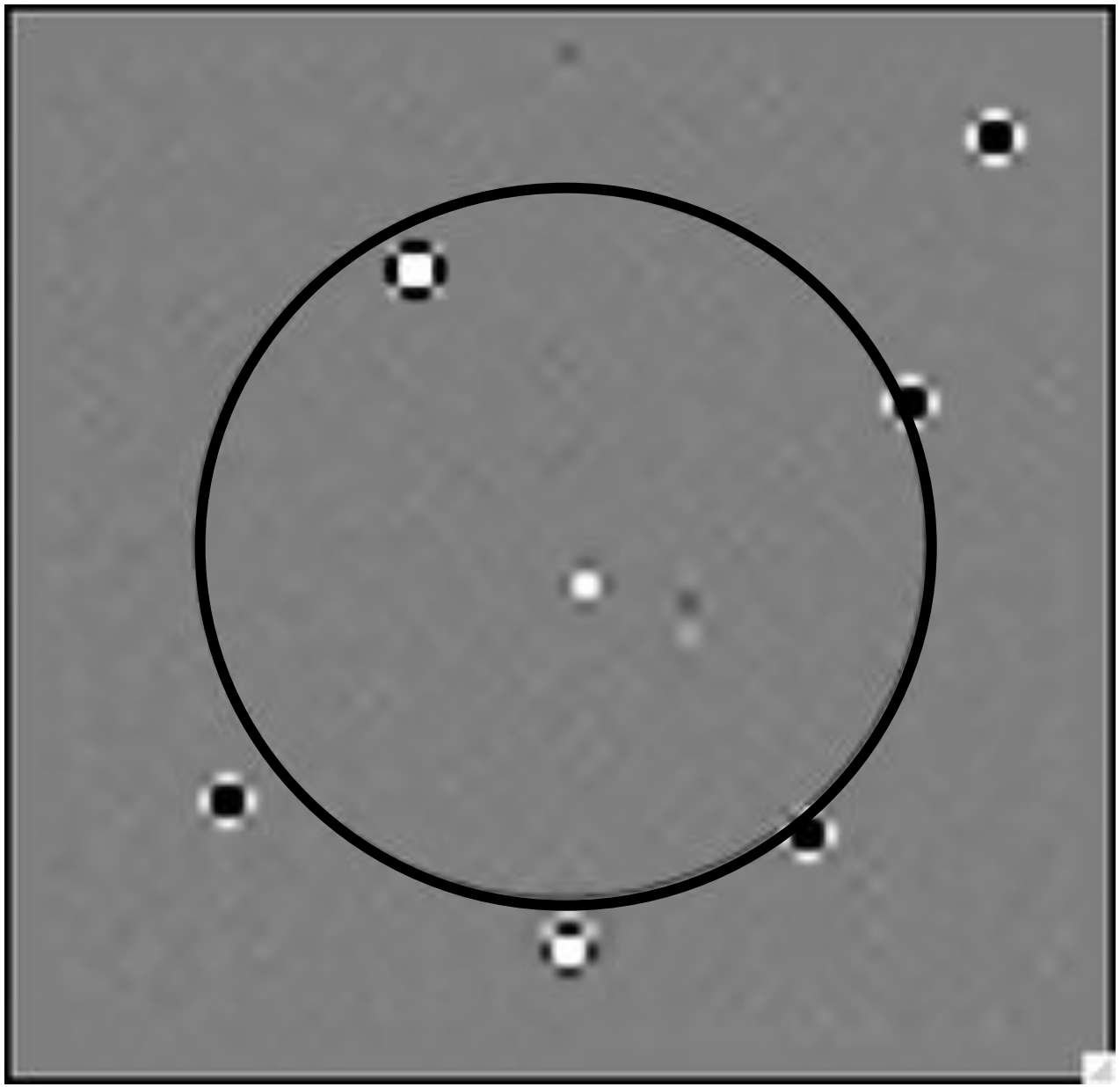
LLNL: ***Macintosh***-PI/management/ AO
AMNH:***Oppenheimer***-Coronagraph masks
HIA: ***Saddlemyer***-Optomechanical/software
JPL: ***Wallace***-Interferometer
UofT: ***Graham***-Project scientist
UCLA: ***Larkin***-IR spectrograph
UdM: ***Doyon***-Data pipeline
UCSC: ***Gavel***-Final integration & test


Entrance Window
Linear ADC
Gemini f/16 focus
Stage
Artificial sources
AO
Woofer DM & Tip/Tilt
Coronagraph
MEMS DM
Apodizer Wheel
Focal Plane Occultor Wheel
Reference arm shutter
Calibration Module
F/64 focusing ellipse
Dichroic
LO pickoff
Phasing Mirror
LOWFS
WFS
WFS P&C & focus
SF
Beamsplitter
Pinhole
CCD
Lenslet
Collimator
Filter Wheel
WFS collimator
Polarization modulator
Filter Wheel
IR CAL WFS
IR spectrograph
Lyot wheel
CAL-IFS P&C & focus
Filter Wheel
HAWAII II RG
Lenslet
Dewar Window
Pupil viewing mirror
Prism
Polarizing beamsplitter and anti-prism
Pupil Camera
Interferometer

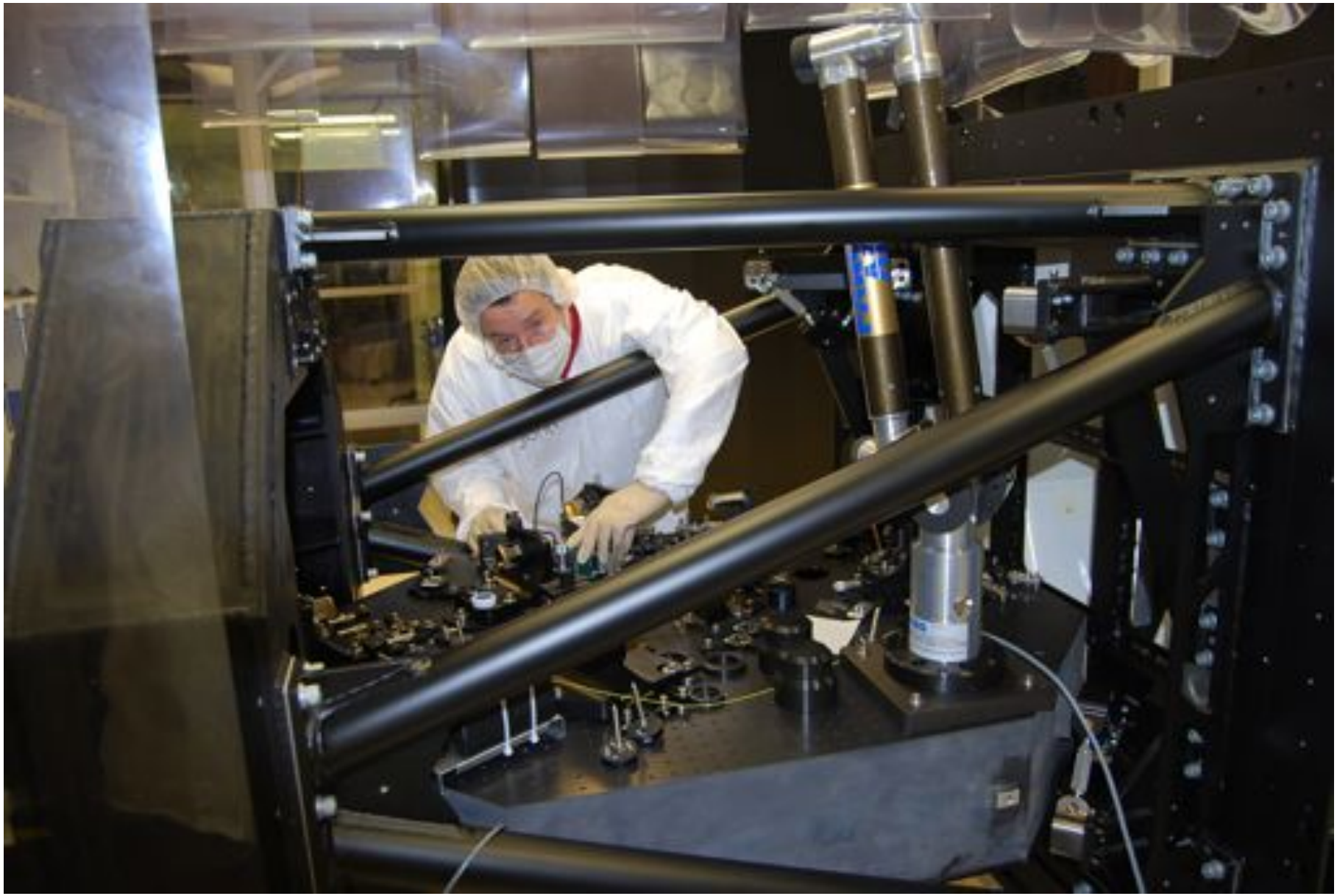
BMC MEMS



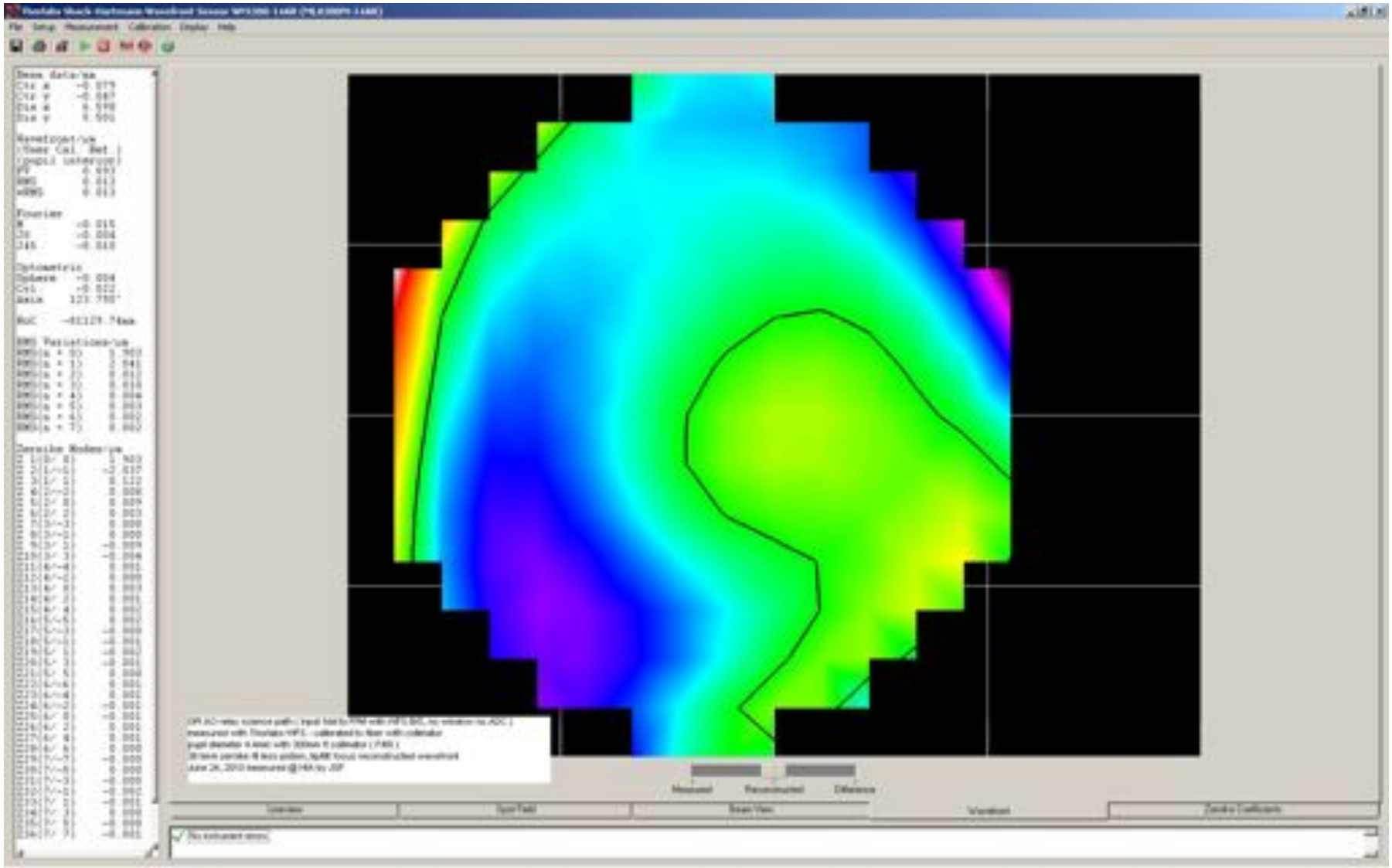
18W080#001
Phase residuals



Optical Bench Alignment @ HIA



13 nm RMS WFE End-to-End



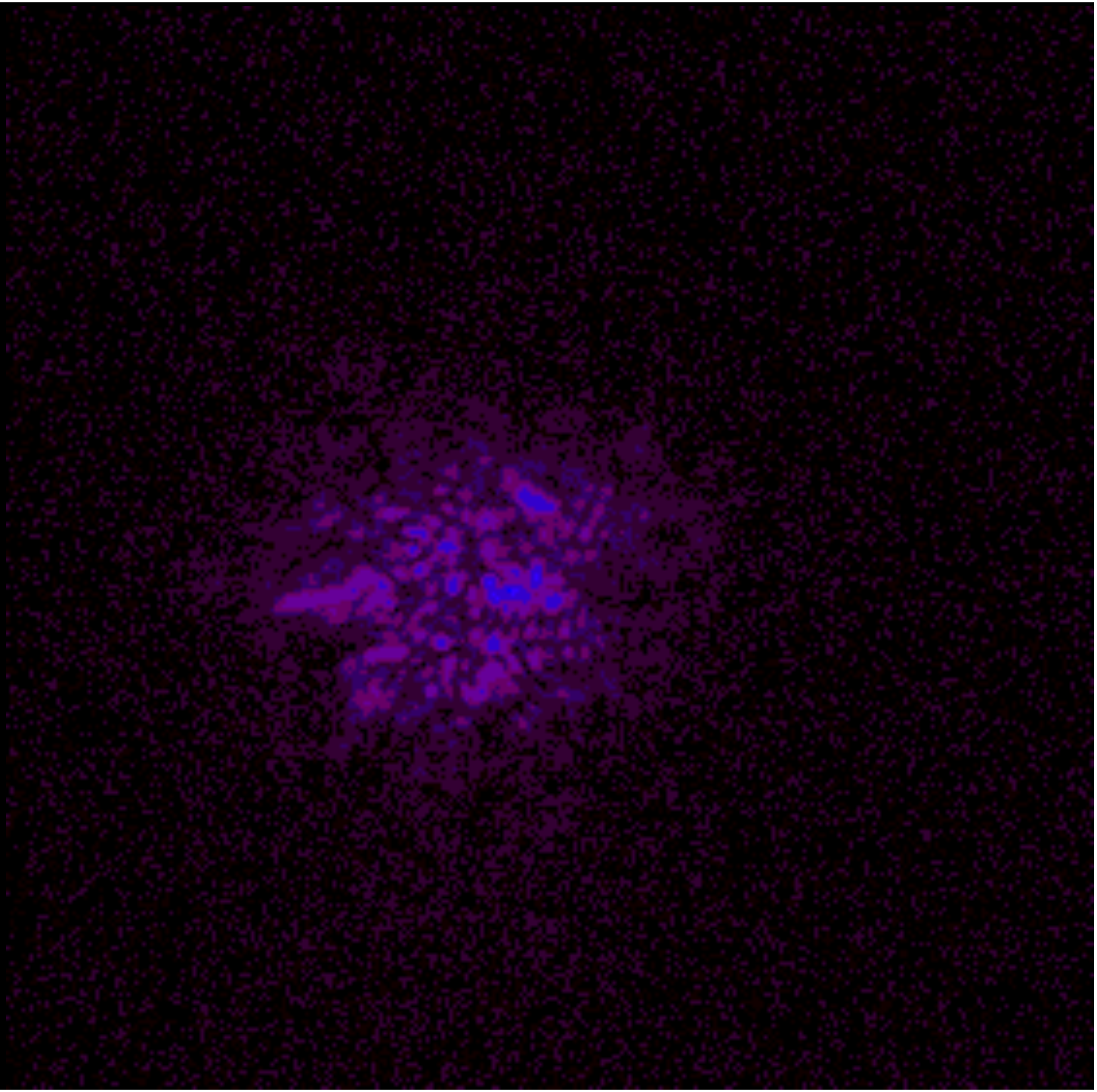
From HIA to UCSC


I&T @ UCSC

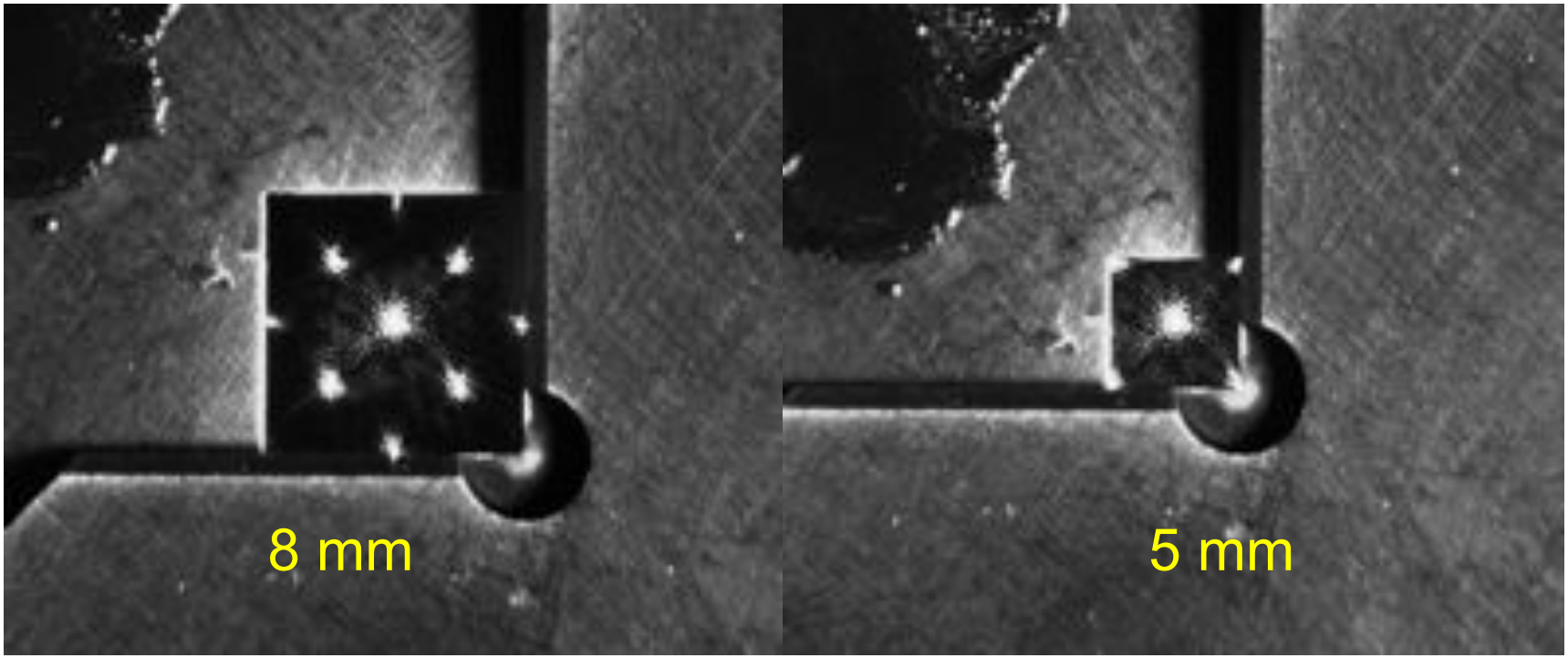
Closed loop wavefront control at LLNL test bed

- Spinning phase plate simulates median Cerro Pachon r_0 & τ_0
- 1.5 kHz
  - Computational goal
  - x8 real time
- Woofer/tweeter/TT control
  - Fourier mode gain optimizer
  - 50 nm rms errors
  - SR = 0.96 @ *H*
- PSF recorded by science camera (no coronagraph)

Poyneer

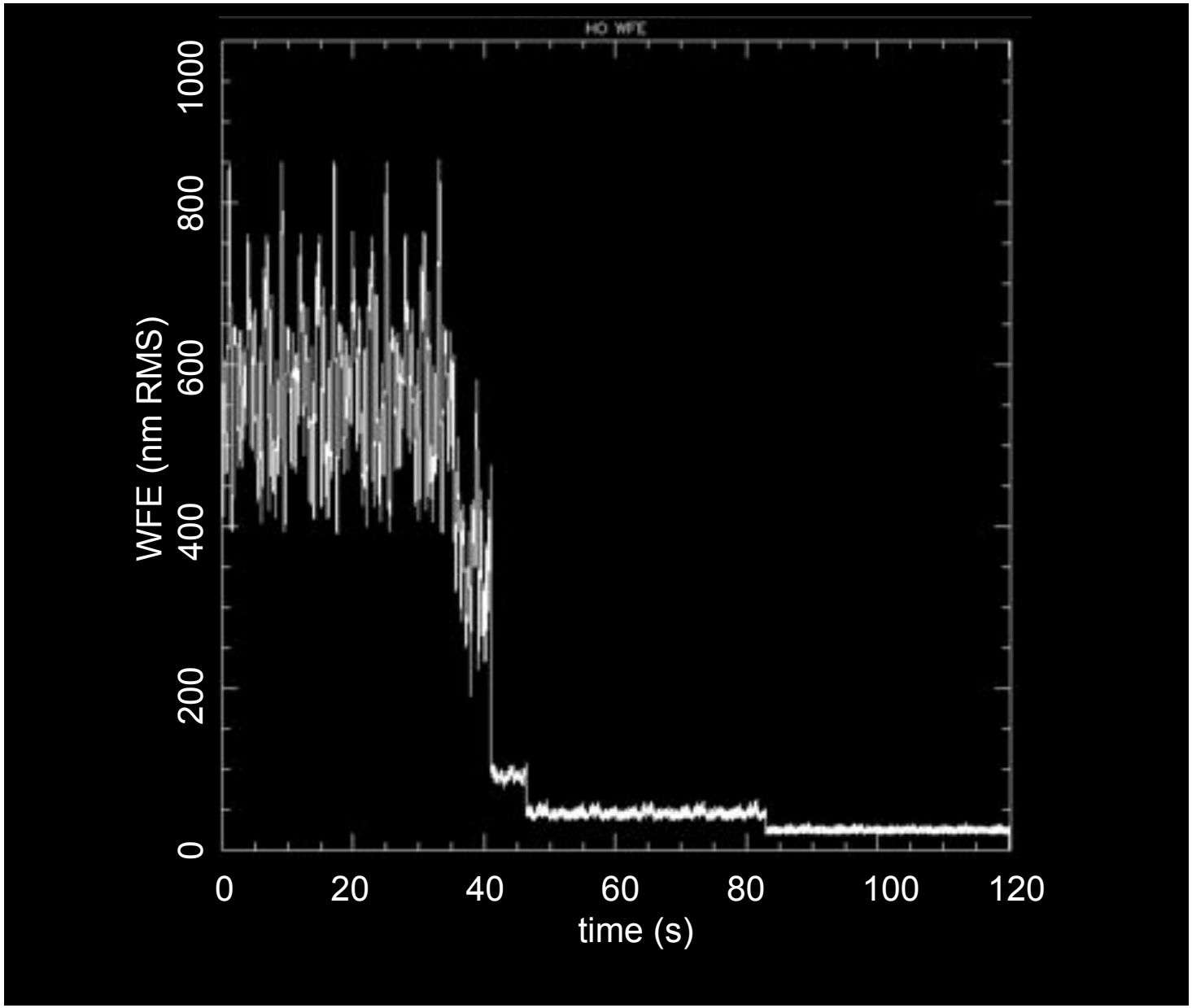


WFS Spatial Filter



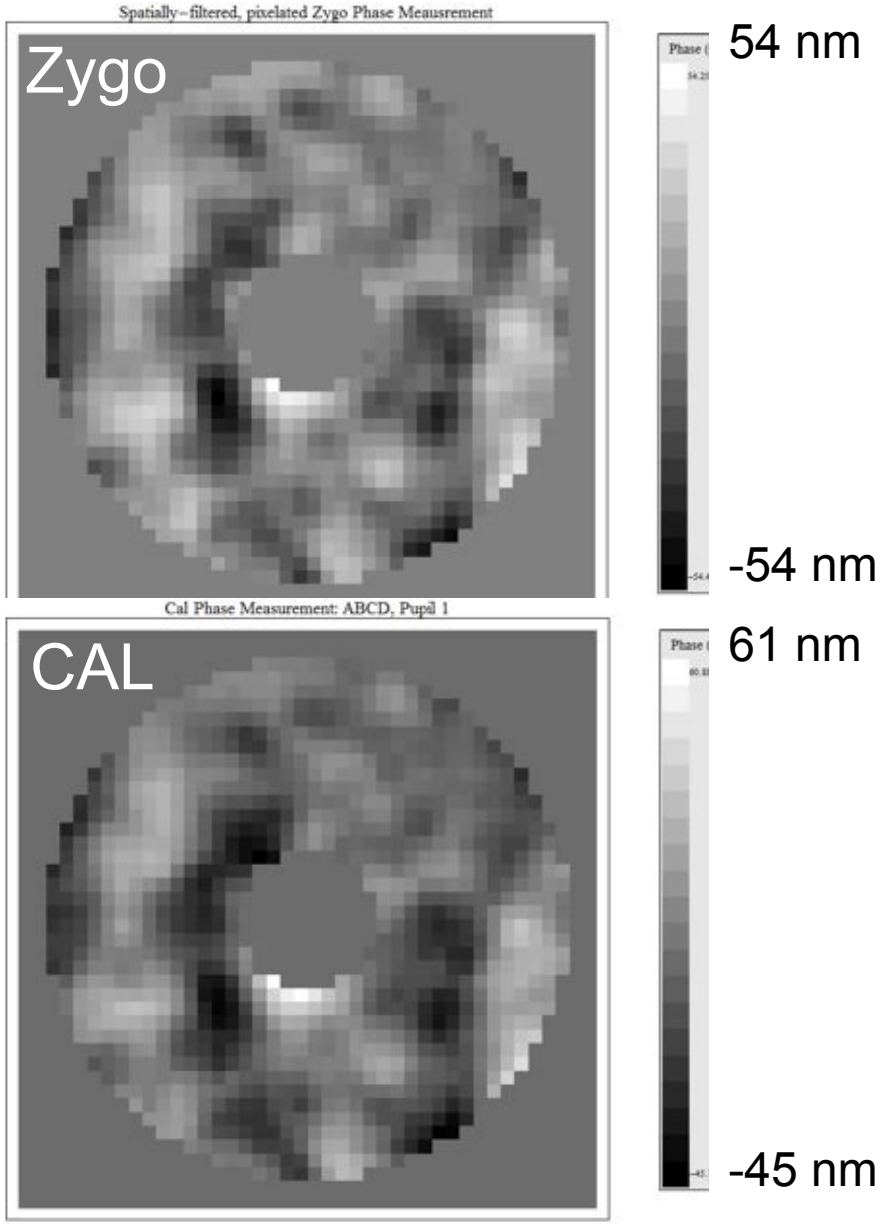
- Spatial filter blades block DM waffle (0.5 μm) & scalloping, eliminating aliasing in the wavefront sensor

30 nm rms Closed Loop AO Operation

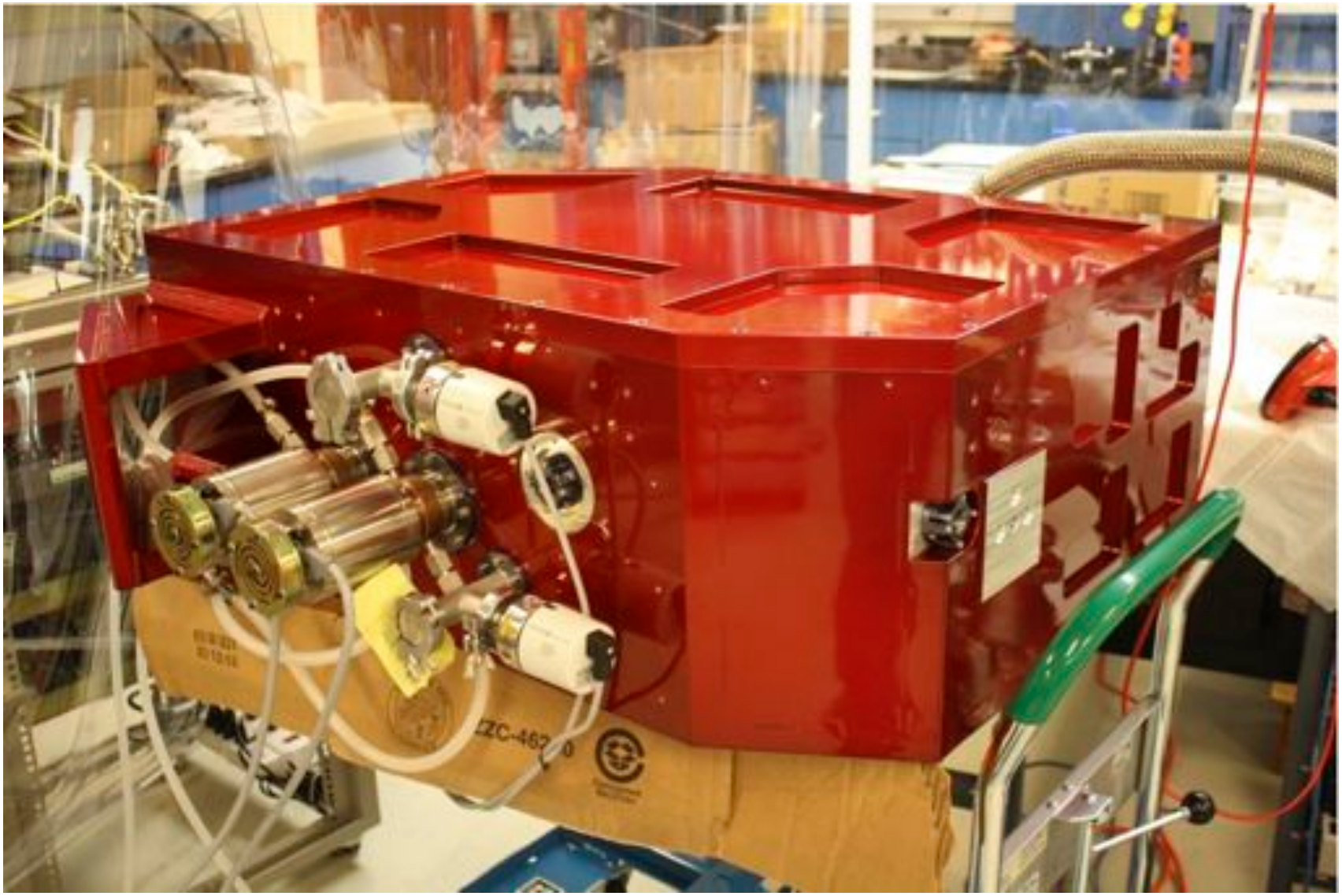


JPL CAL Unit

- 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

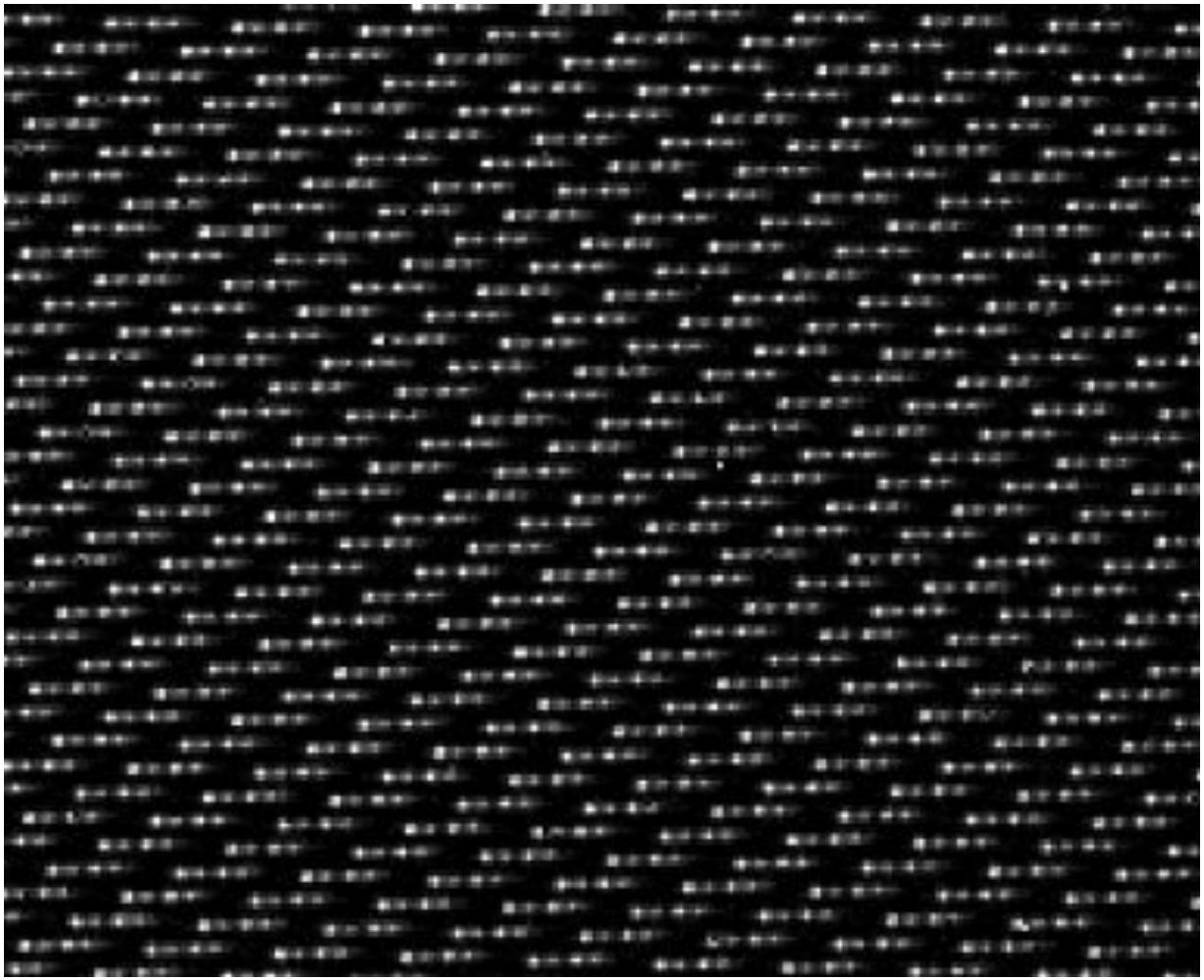


UCLA Integral Field Spectrograph



IFS

- Xe arc at 1.6 μm



GPI Campaign

- In late 2010 Gemini announced an opportunity to propose up to 1400 hours of GPI campaign science
  - Enable large investigations that could not be achieved through the standard proposals
  - 22 LOI submitted in Jan, 2011
- Over 6500 hours requested
  - Asteroids, jovian exoplanets, planet forming disks, brown dwarfs, massive stars, and late type giants

The GPI Exoplanet Survey (GPIES): A Comprehensive Understanding of Planetary System Evolution and Diversity

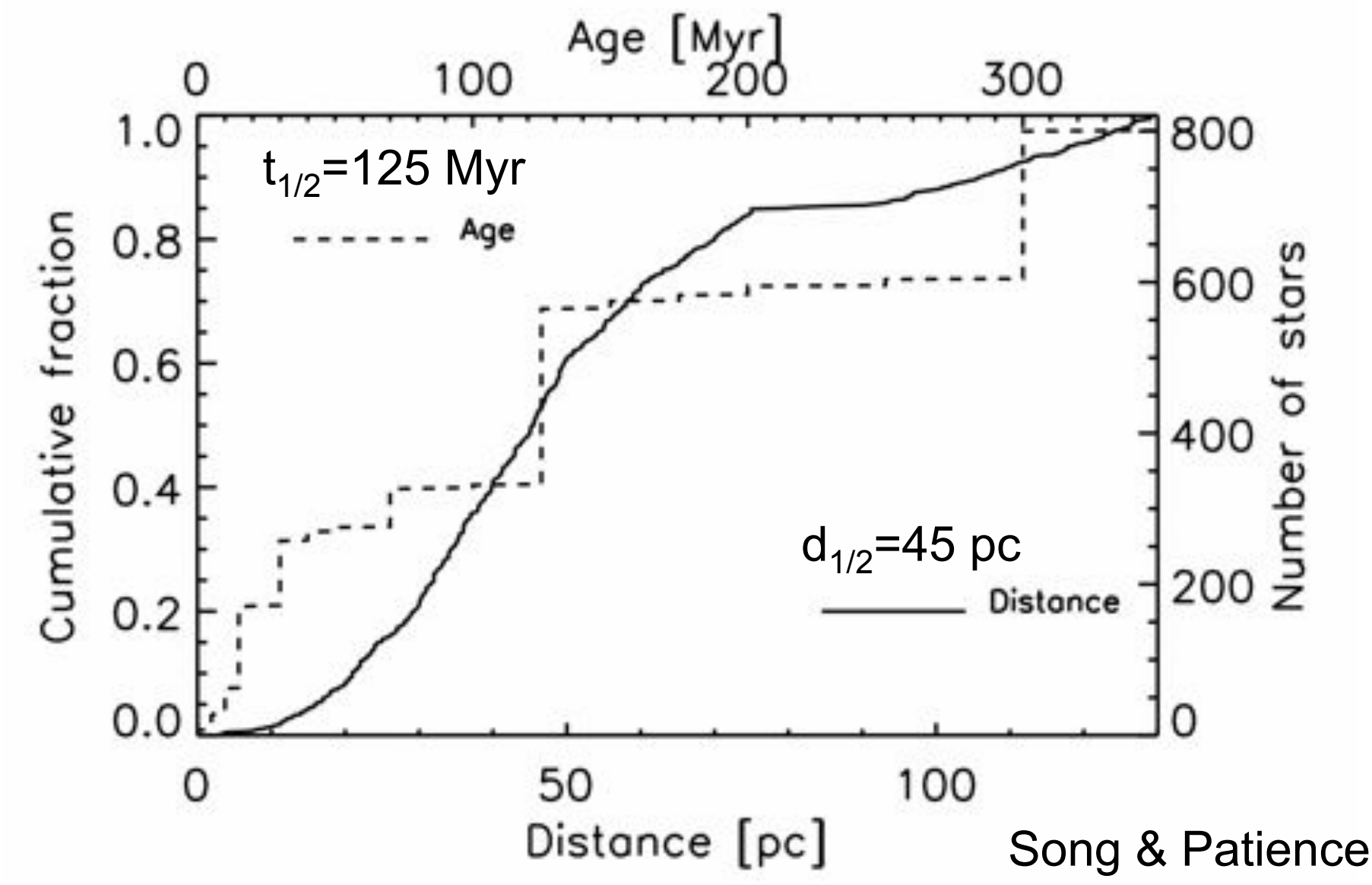
PI: Bruce Macintosh Lead Co-Investigators: James R. Graham, Travis Barman, Rene Doyon, Daniel Fabrycky, Michael Fitzgerald, Paul Kalas, Quinn Konopacky, Mark Marley, Christian Marois, Jennifer Patience, Marshall Perrin, Ben Oppenheimer, Inseok Song

Co-Investigators: *Etienne Artigau, Steve Beckwith, Mike Bessel, Doug Brenner, Adrian Brunini, Adam Burrows, Carolina A. Chavero, Christine Chen, Eugene Chiang, Jeffrey Chilcote, Gaspard Duchêne, Jonathan Fortney, Raphaël Galicher, Sasha Hinkley, Robert King, David Lafrenière, James Larkin, Jérôme Maire, Geoff Marcy, Franck Marchis, Brenda Matthews, James McBride, Ian McLean, Stanimir Metchev, Katie Morzinski, David Palmer, Erik Petigura, Lisa Poyneer, Laurent Pueyo, Ramiro de la Reza, Emily Rice, Patricio Rojo, Robert de Rosa, Maria Teresa Ruiz, Didier Saumon, Gene Serabyn, Adam Schneider, Mike Shao, Remi Soummer, Anand Sivaramakrishnan, Sandrine Thomas, Carlos A. Torres, Gautam Vasisht, Jean-Pierre Veran, Arthur Vigan, Kent Wallace, Sloane Wiktorowicz, & Ben Zuckerman*

GPI Campaign Proposal

- 61 scientists including the GPI instrument team
  - Australia, Brasil, Canada, Chile, UK, & USA
- Approved for a 890 hour campaign spanning six semesters

GPI Campaign Targets

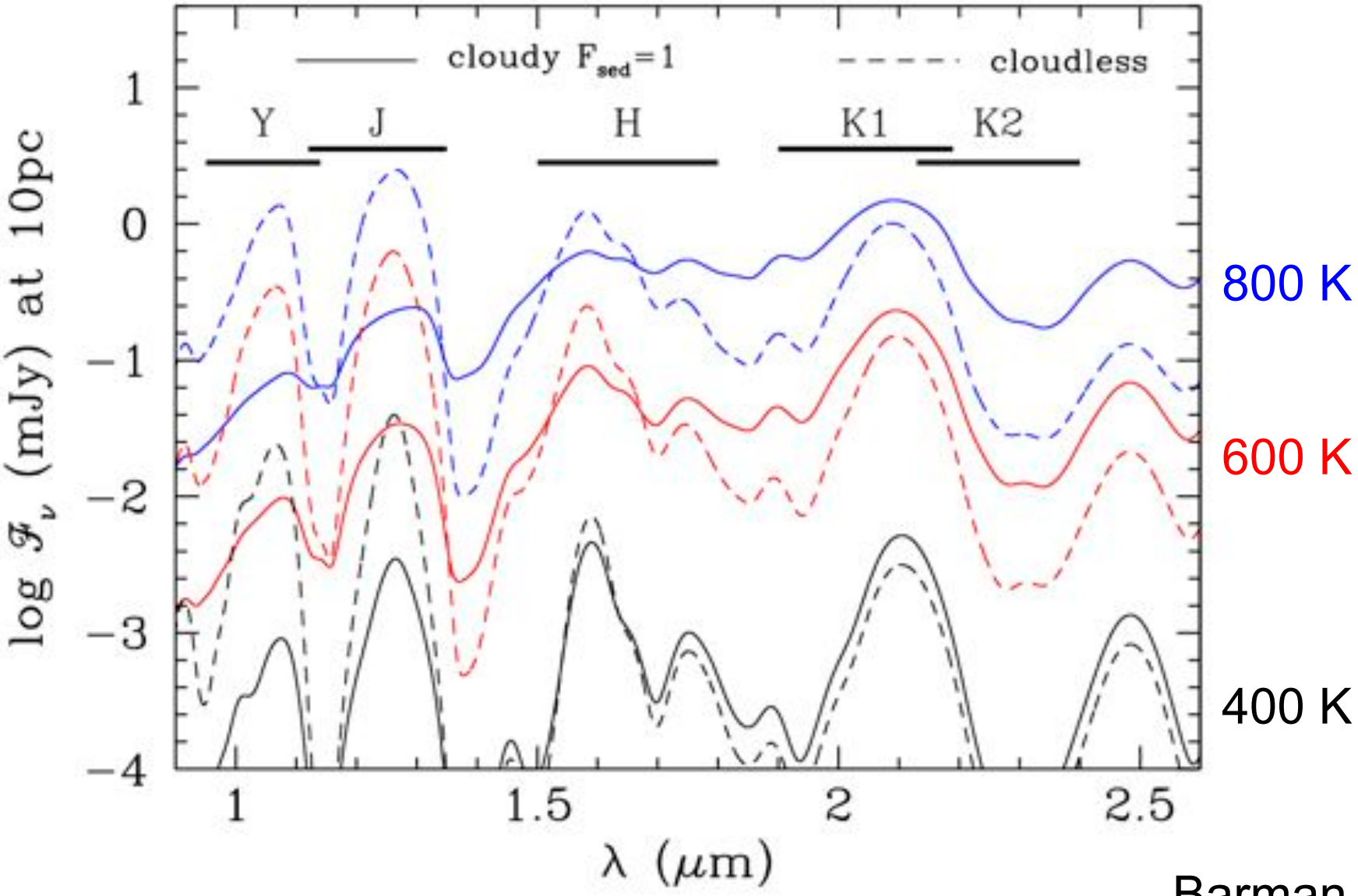


Song & Patience

GPI Campaign Plan

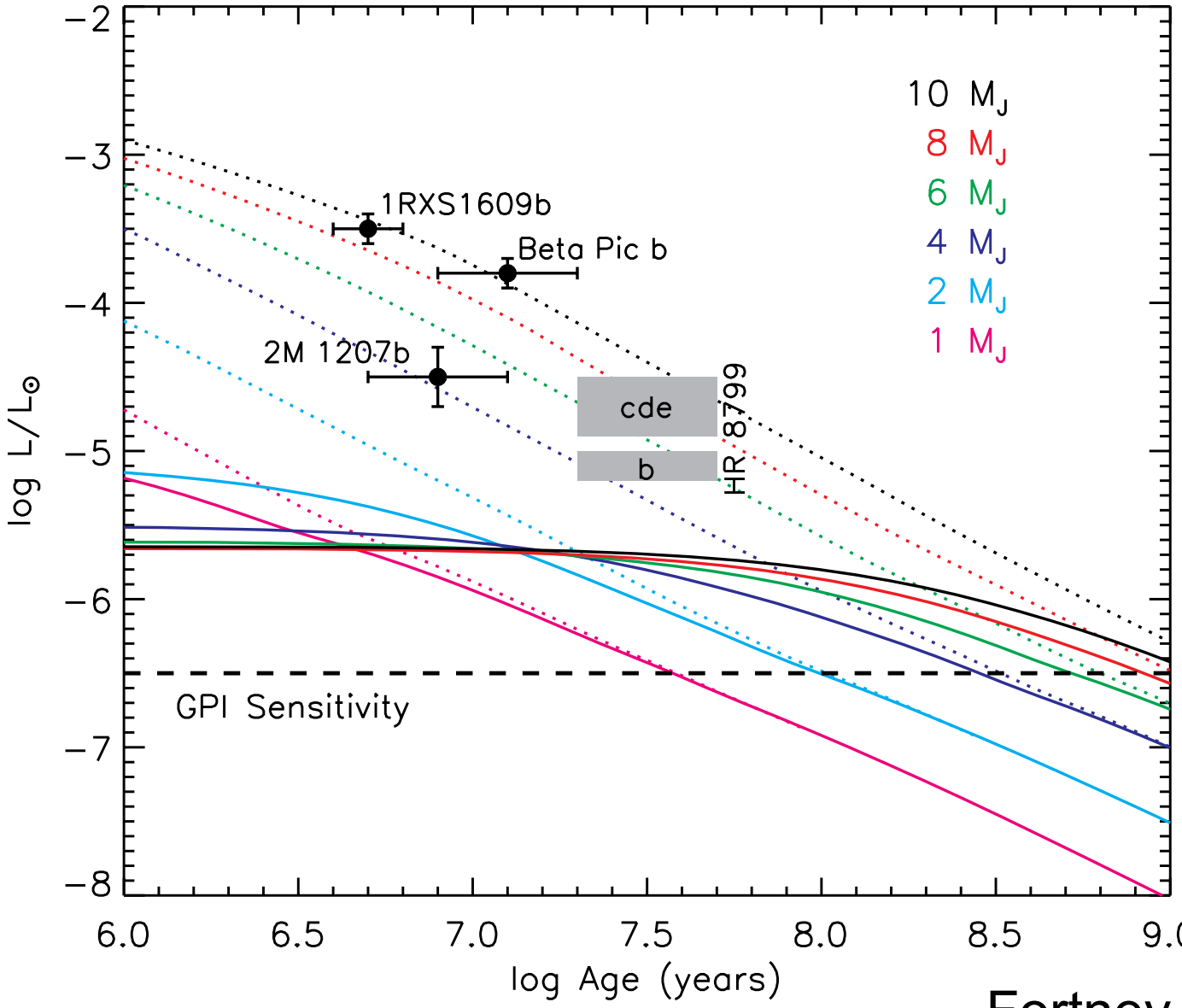
Activity	12B	13A	13B	14A	14B	15A	Total
1st epoch	125	125	125	110	115	0	600
2nd epoch	6	13	17	16	15	9	76
3rd epoch	0	0	0	0	6	23	29
Disks snapshots	2	2	2	2	2	0	10
Planet spectra	10	20	25	30	10	5	100
Deep disk imaging	2	4	6	5	5	3	25
Reserve	5	5	5	10	10	15	50
Total (hours)	**150**	**169**	**180**	**173**	**163**	**55**	**890**

Spectroscopy



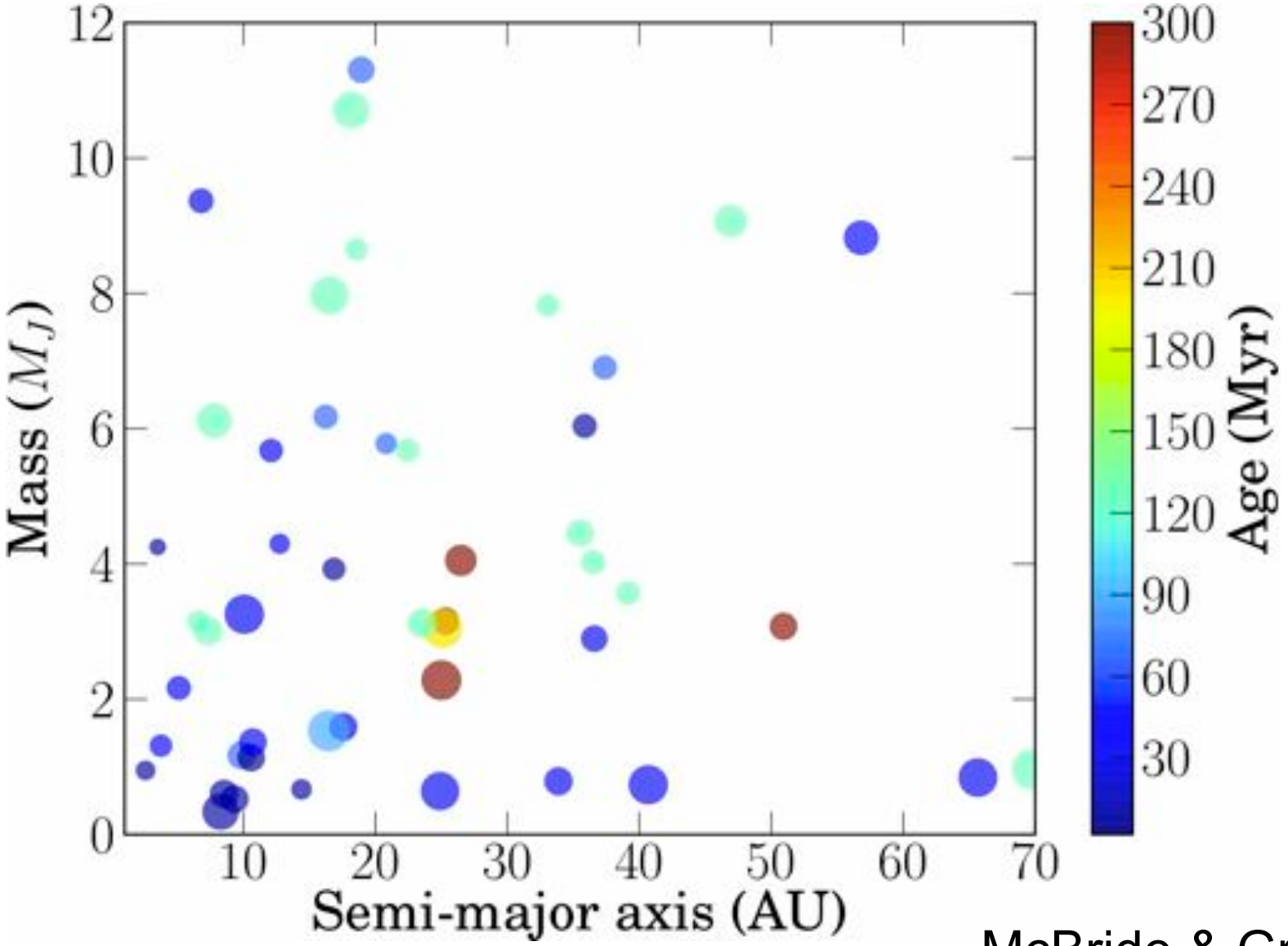
Barman

Thermal History



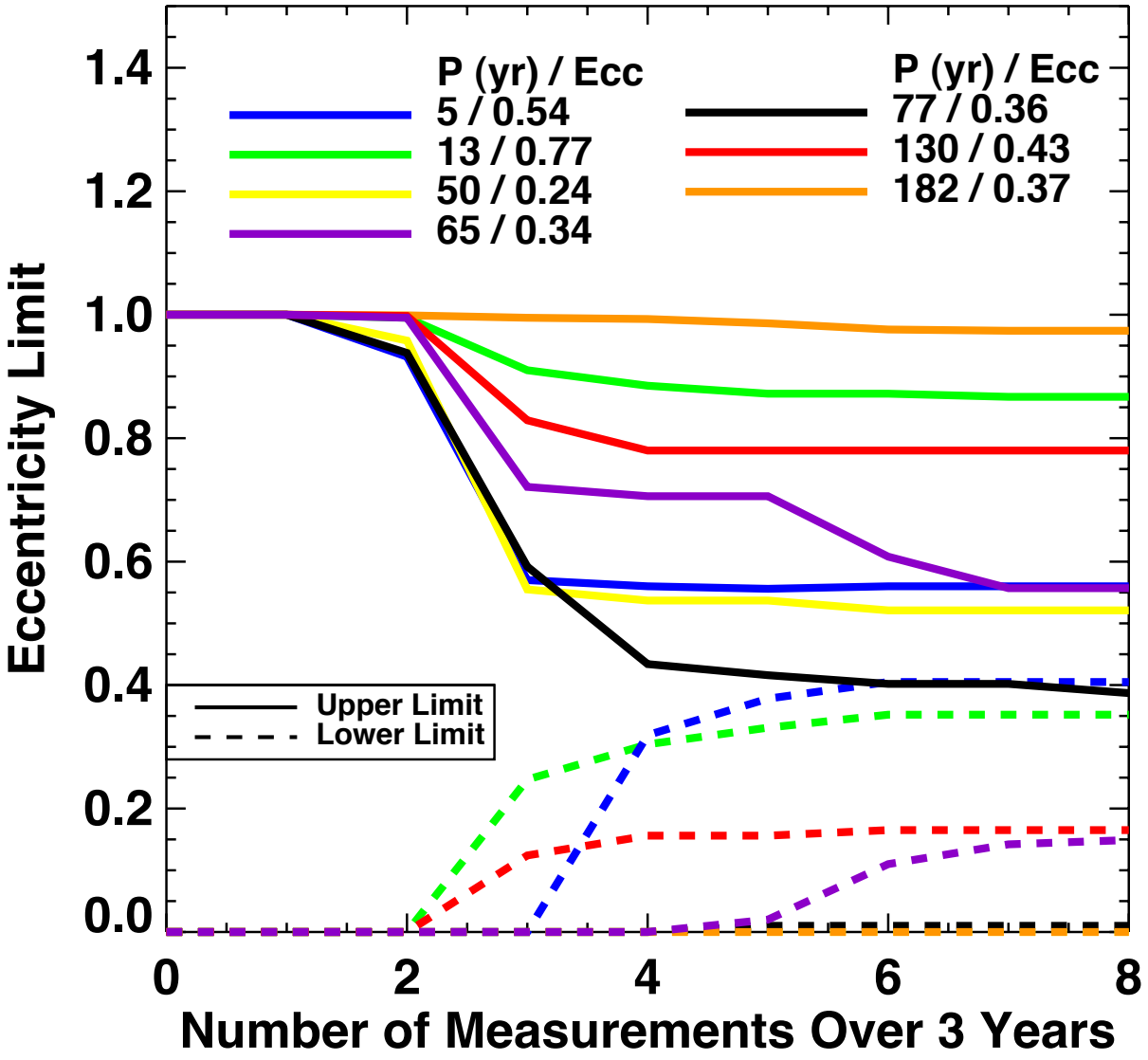
Fortney & Marley

Mass/Semimajor Axis Space



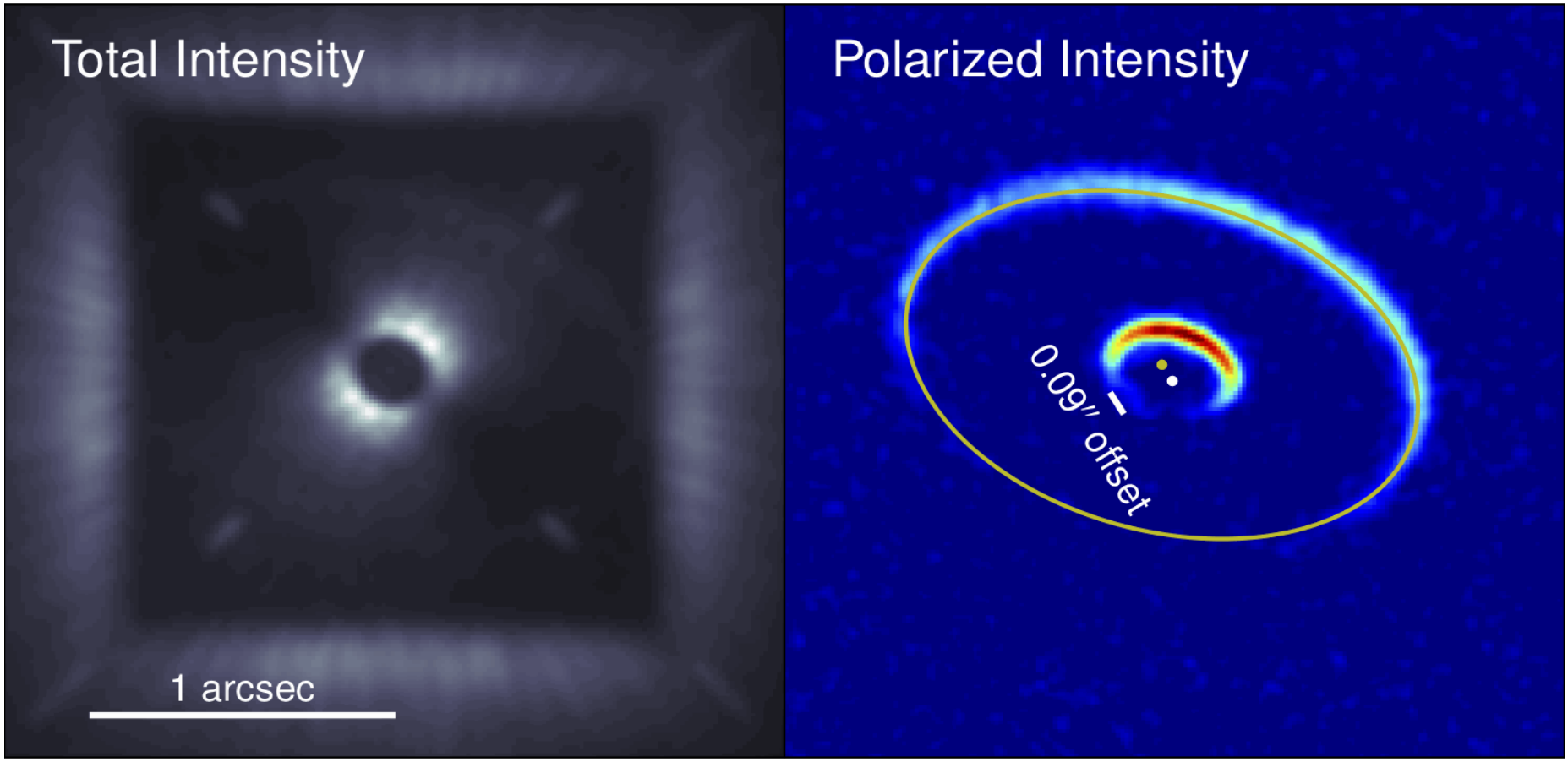
McBride & Graham

GPI Astrometry



Konopacky

Debris Disks



Fitzgerald & Perrin

Road to Gemini…mid-2012