Jet Propulsion Laboratory
California Institute of Technology

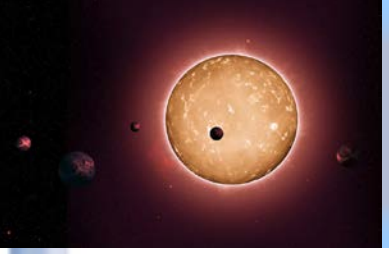
Pasadena Annual Postdoc Retreat
May 11-13, 2016
Lake Arrowhead

Point spread function calibration using Low-order wavefront sensor telemetry

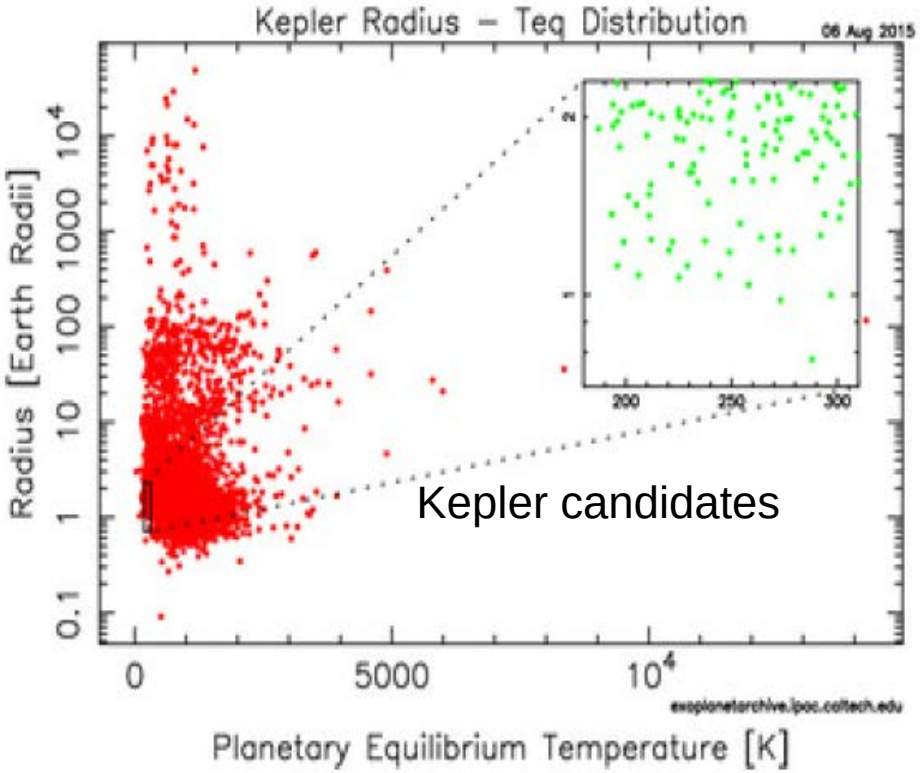
by

Garima Singh

NASA Postdoctoral Program Fellow
Jet Propulsion Laboratory
4800 Oak Groove Dr, Pasadena 91109, CA
garima.singh@jpl.nasa.org, 8183542813



Exoplanets and scientific motivation



Goal:
Characterize atmosphere of planets in habitable zone

Direct detection via:

- Reflected light (visible)
- Thermal emission (infrared)

Challenge:

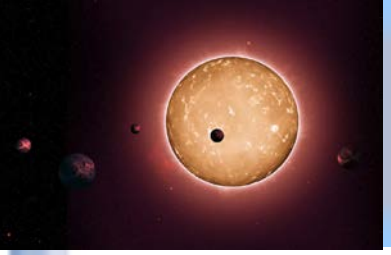
- High contrast
- Small angular separation

Earth-sun system: contrast **10^{-10}** (visible)

Only a handful of massive planets at > 10 AU directly imaged from the ground

Current AO correction is insufficient to detect faint structures at < 10 AU

Requirement: High contrast imaging on the AO corrected PSF



A major challenge in high contrast imaging

Goal of current ground-based instruments. Directly image young planets at angular separation < 10 AU.

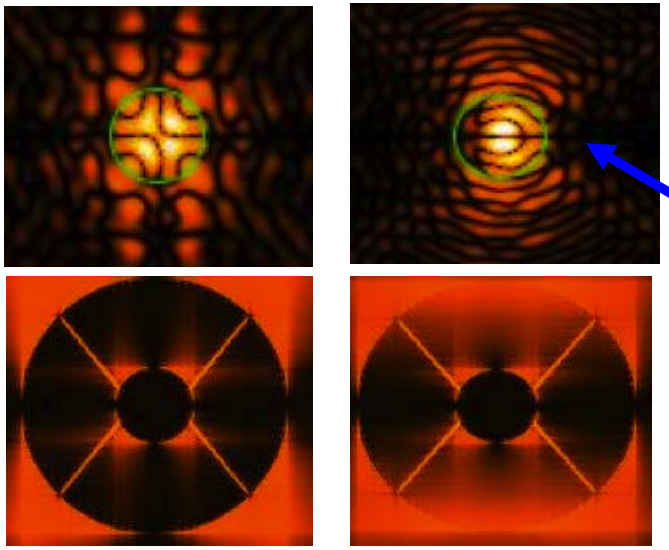
What we need. (1) SR > 90%, (2) Residual of < 50 nm, (3) Raw contrast of ~ 1e-4 in IR and (4) wavefront calibration to ~ 1e-6 contrast at ~ 1 λ/D.

Technical challenge. How well the low-order wavefront aberrations upstream of a coronagraph are controlled and calibrated.

Simulation with a FQPM coronagraph

Coronagraphic PSF (no aberration)

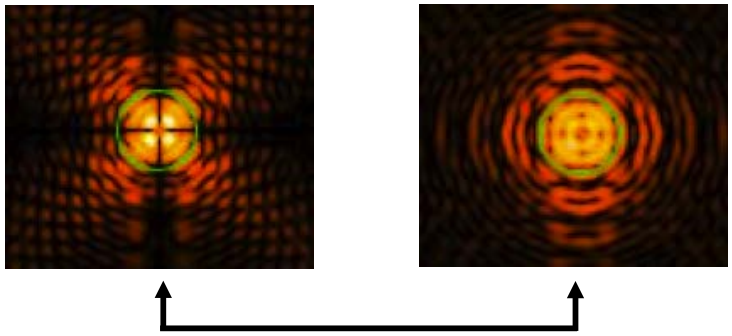
Tip aberration



PSF is de-centered, can easily mimic a companion

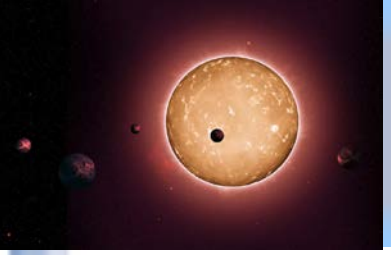
Focus aberration

Astigmatism aberration



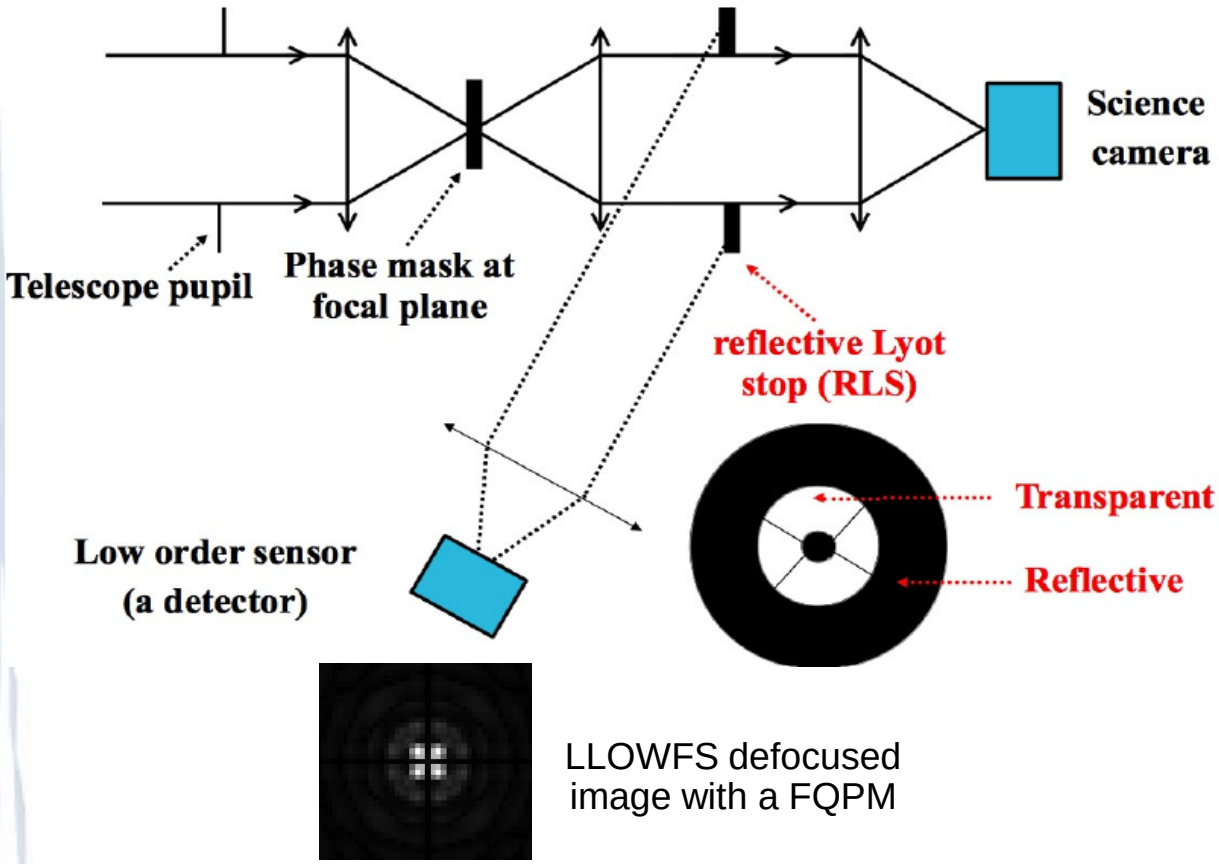
PSF is broadened, can be misinterpreted as a circumstellar feature

Coronagraphs optimized for small inner working angle (IWA) are extremely sensitive to low-order errors!



Lyot-based low-order wavefront sensor[1] (LLOWFS): Concept

No solution existed to address low-order aberrations more than just tip-tilt for PMCs!



LLOWFS defocused image with a FQPM

Linearity Approximation

If post-AO wavefront residuals << 1 radian RMS, then

$$I_{R(\alpha)} - I_0 = \sum_{i=1}^{n} \alpha_i S_i + \nu_n$$

I_0 = Reference image,

I_R = Reflected image with aberration,

i = low-order modes,

n = total number of modes,

α = amplitude of the modes,

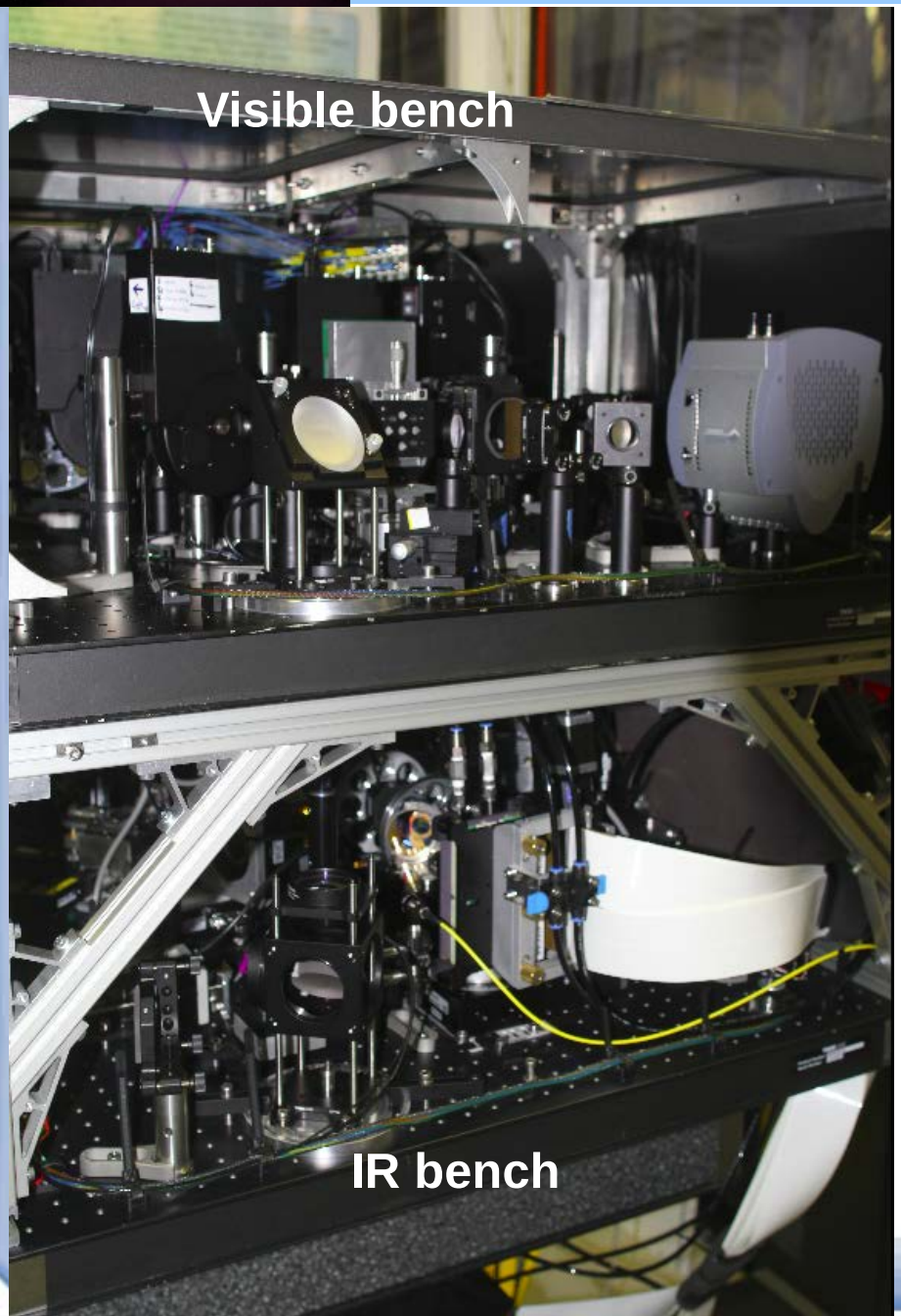
S = calibrated response of the sensor to the low-order modes (Orthonormal images)

v = residual of high-order modes

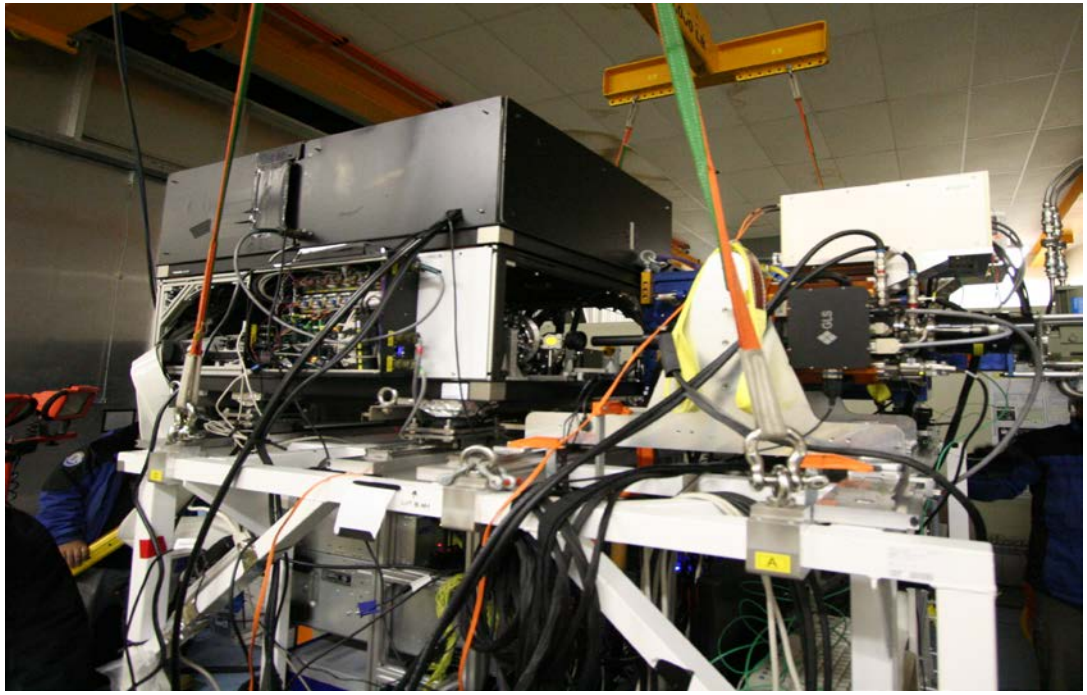
Valid only if I_0 stays constant for the duration of the experiment

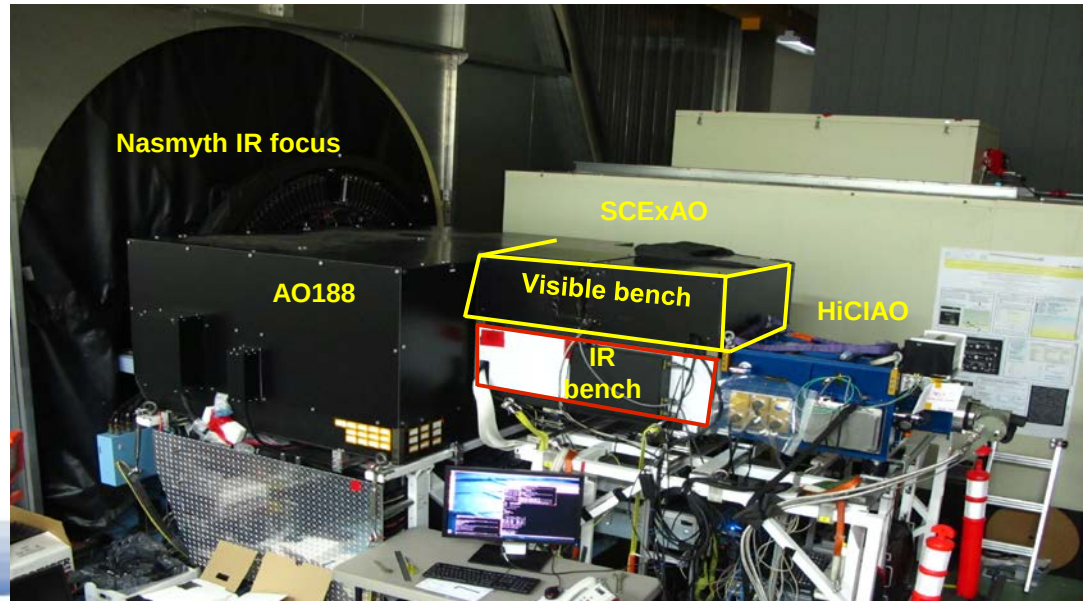
[1] Singh et al. 2014a, 2014b, 2015

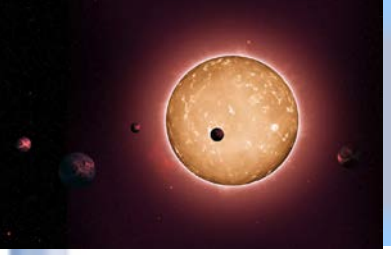
SCExAO instrument at Subaru Telescope



SCExAO instrument at the summit of Mauna Kea







Laboratory results: Improved stability

Standard deviation of the processed frames.

Standard deviation is more stable in closed-loop!

Coronagraph | **Science camera** | **LLOWFS camera**

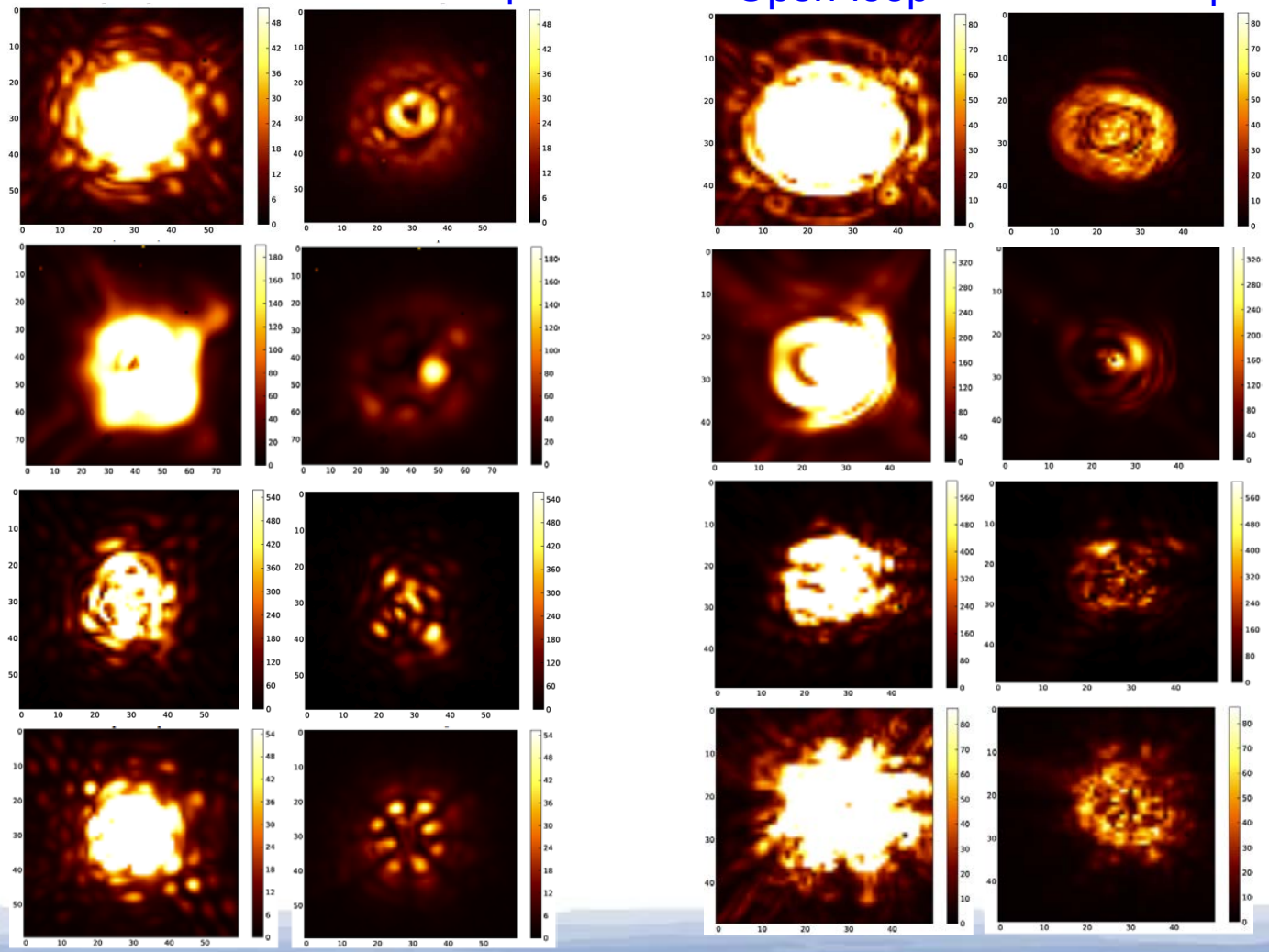
Open-loop | Closed-loop | Open-loop | Closed-loop

VVC

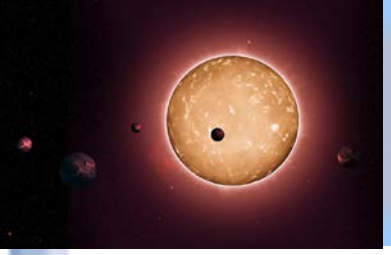
PIAA

FQPM

EOPM

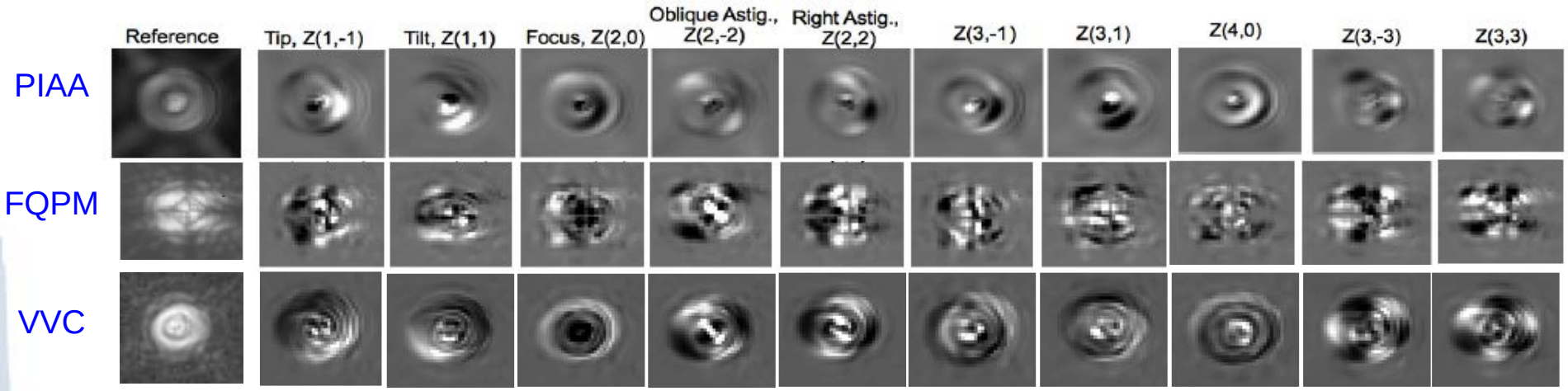


Images are at same brightness scale!



A glimpse of current research

Low-order wave front sensor linear response to low-order aberrations.



PSF Calibration

Using low-order telemetry of the residuals left uncorrected by the control loop to calibrate the amount of starlight leakage at small angular separations.

•Use synchronized LLOWFS measurements and science camera frames to built library of residuals response on the starlight leakage.
•During real-time observation, LLOWFS residuals are fitted with the best match in the library.
•The corresponding science equivalents are then subtracted from the science image to reconstruct the PSF.

Essential for space missions that rely on post-processing to achieve their desired detection level.