National Aeronautics and Space Administration

Early Stage Technology Workshop

Astrophysics and Heliophysics

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High Performance Coronagraphy with PIAA

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(Advisor: Dr. Olivier Guyon, NASA mentor: Dr. Ruslan Belikov)

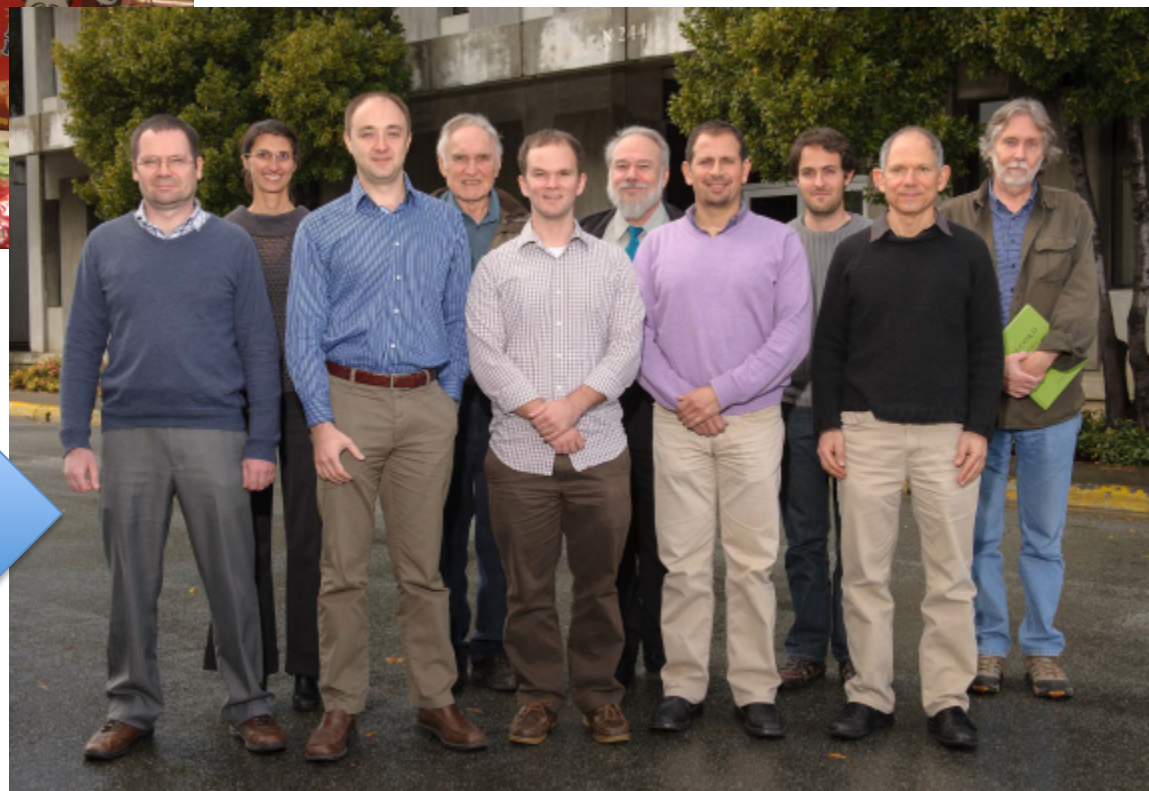
TECHNOLOGY DRIVES EXPLORATION

Non-Proprietary

Research teams: ACE and SCExAO

SCExAO team
~9 members
Hilo, Hi

Ames Coronagraph Experiment
~9 members
Moffett Field, CA



Funding

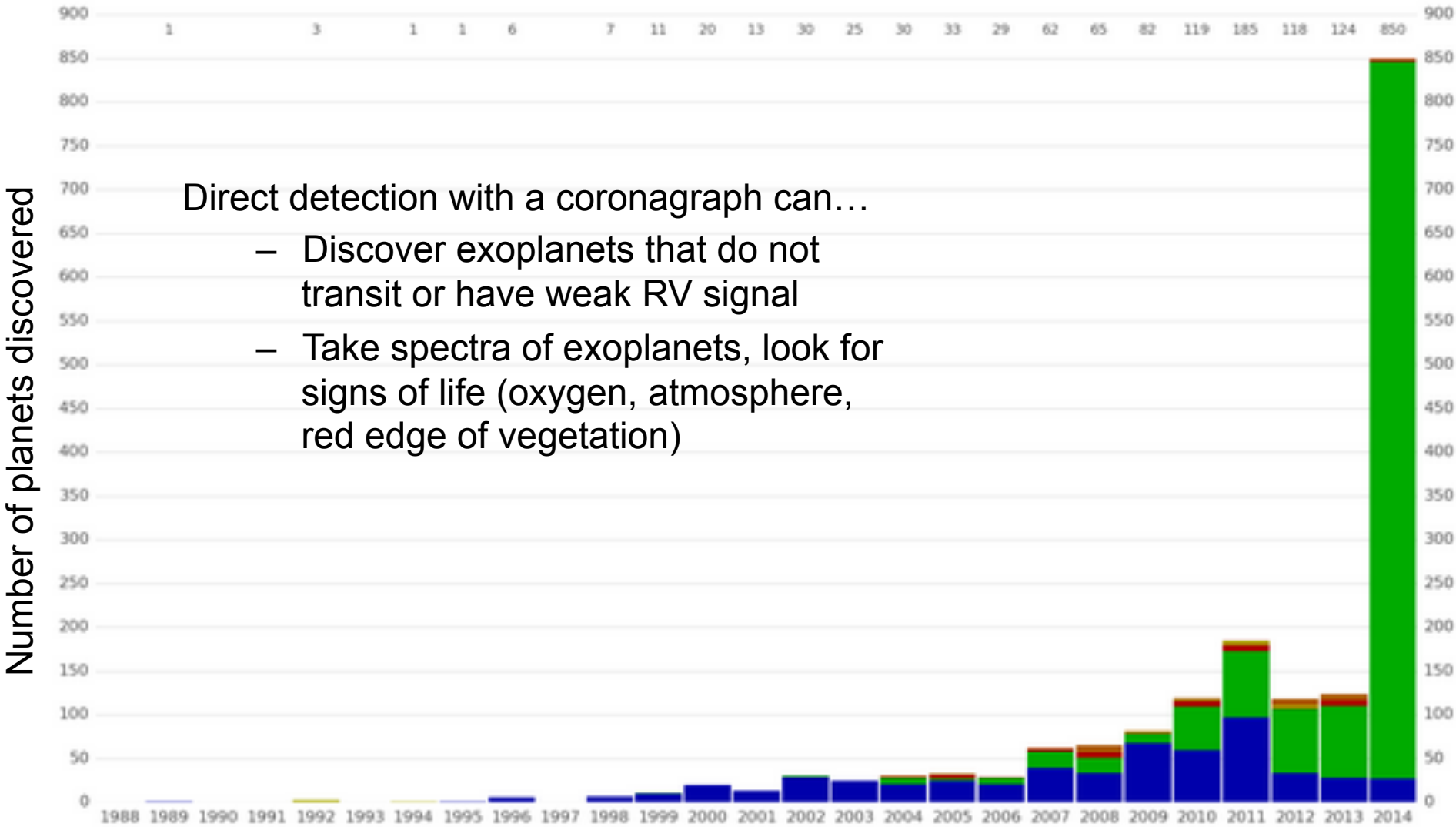
- PIAA and PIAACMC development
  - Current: WFIRST/AFTA, SMD, STMD
  - Past: APRA, TDEM

- NASA Space Technology Research Fellowship
  - Graduation in December 2015!!!

Science goals: finding exo-Earths

Image credit: Hugh Jones, theepochtimes.com

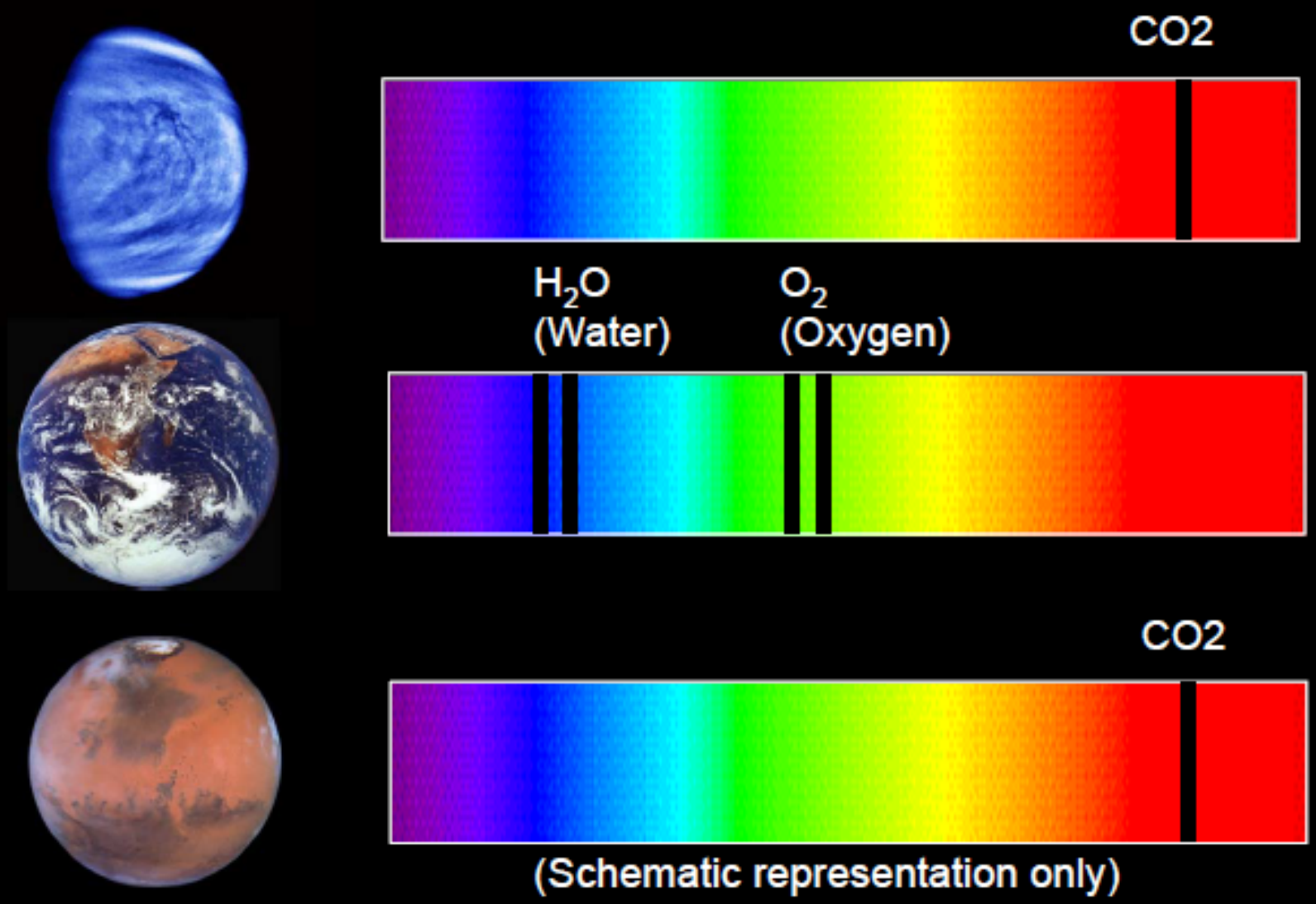
Exoplanet discoveries by year



Direct detection with a coronagraph can…

- Discover exoplanets that do not transit or have weak RV signal
- Take spectra of exoplanets, look for signs of life (oxygen, atmosphere, red edge of vegetation)

Spectroscopy: detecting biomarkers



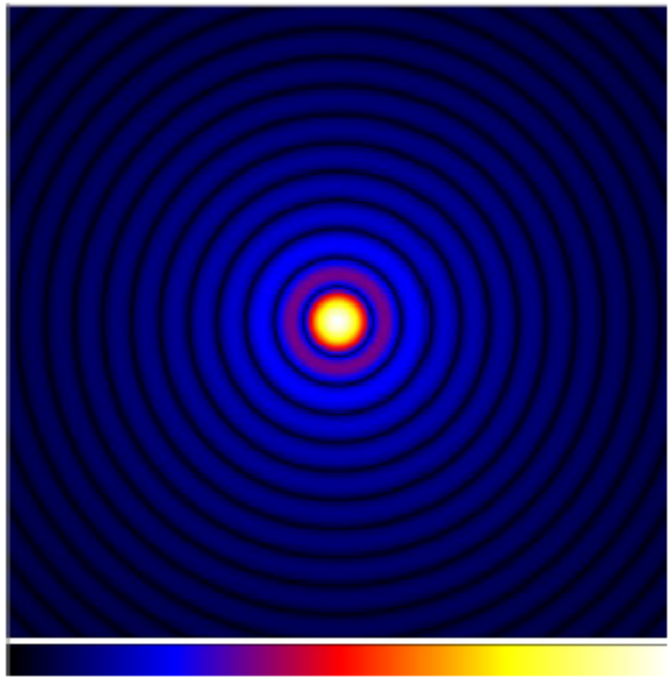
Detecting atmospheric oxygen and water likely indicates life

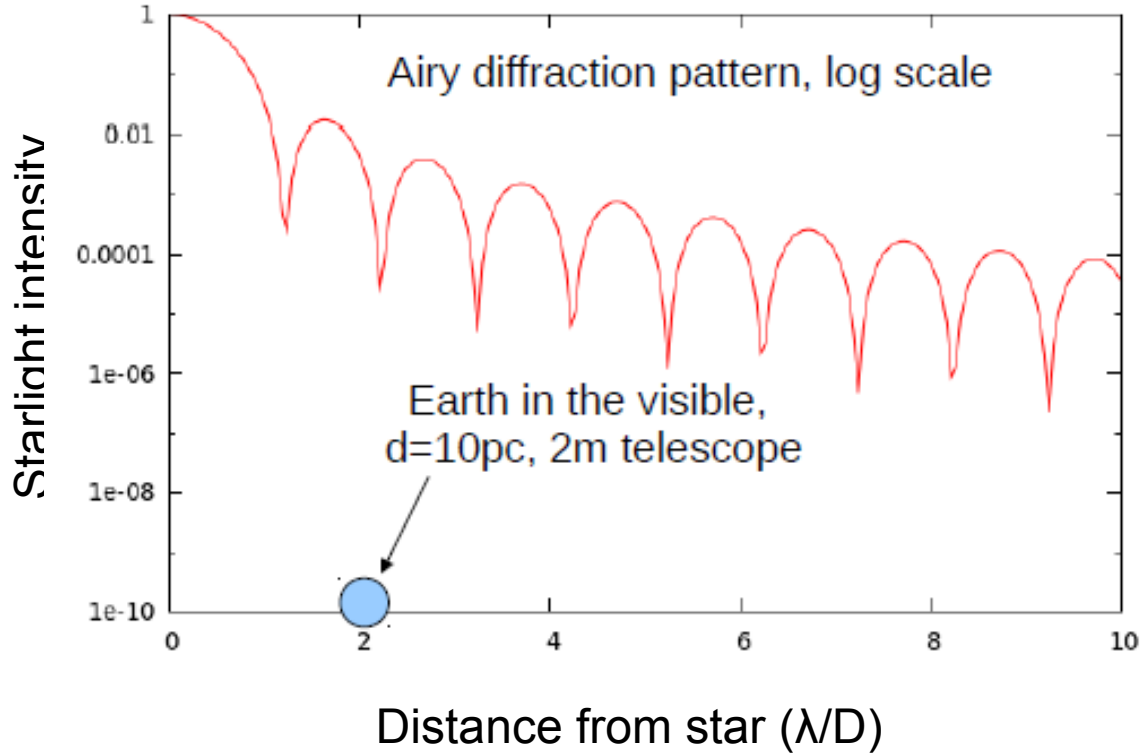
(because very few non-biological processes can sustain an oxygen atmosphere)

Coronagraph basics

Bernard Lyot, 1939, at Pic du Midi
French Astronomer
Inventor of the Coronagraph

Why is direct detection difficult?

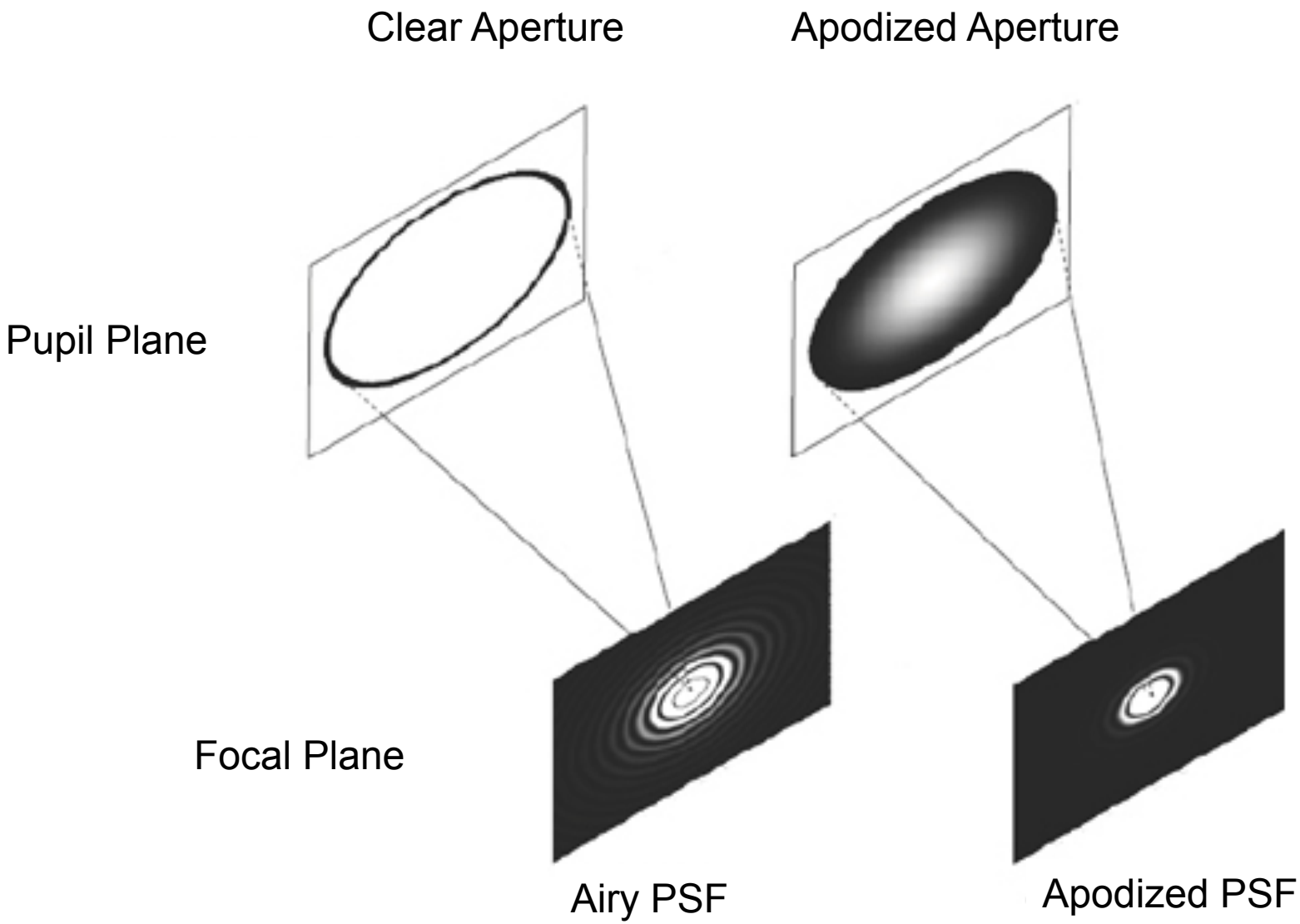




Challenges: angular resolution, contrast

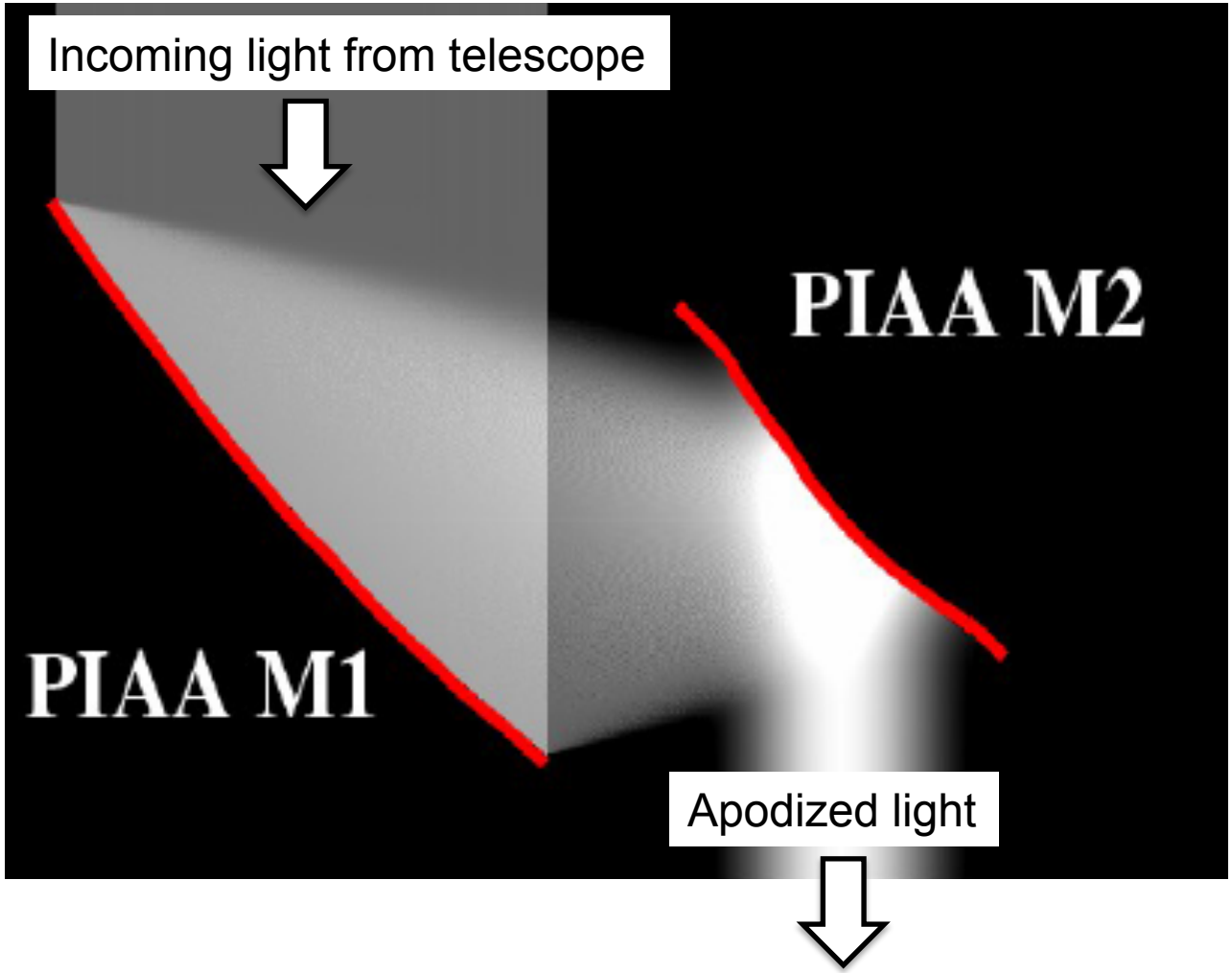
Solutions: use a big enough telescope, use a coronagraph

Technology: apodization to remove diffraction rings



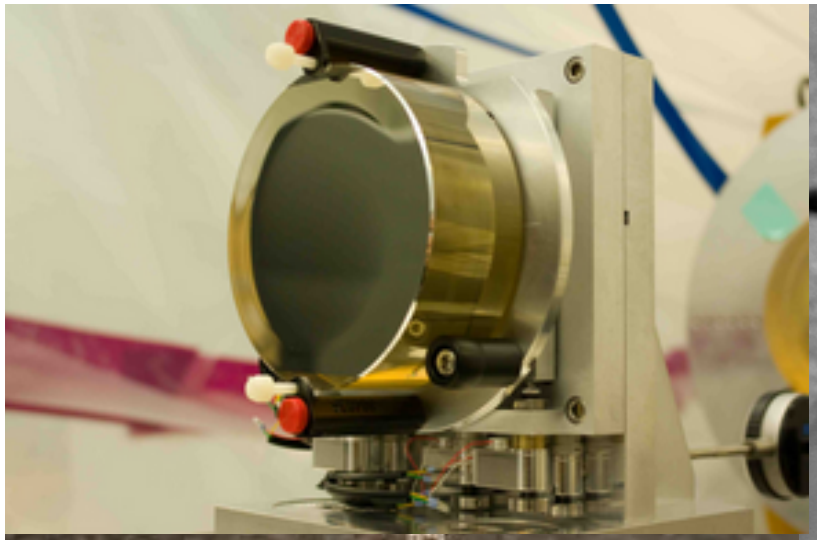
A. Carlotti et al. 2008

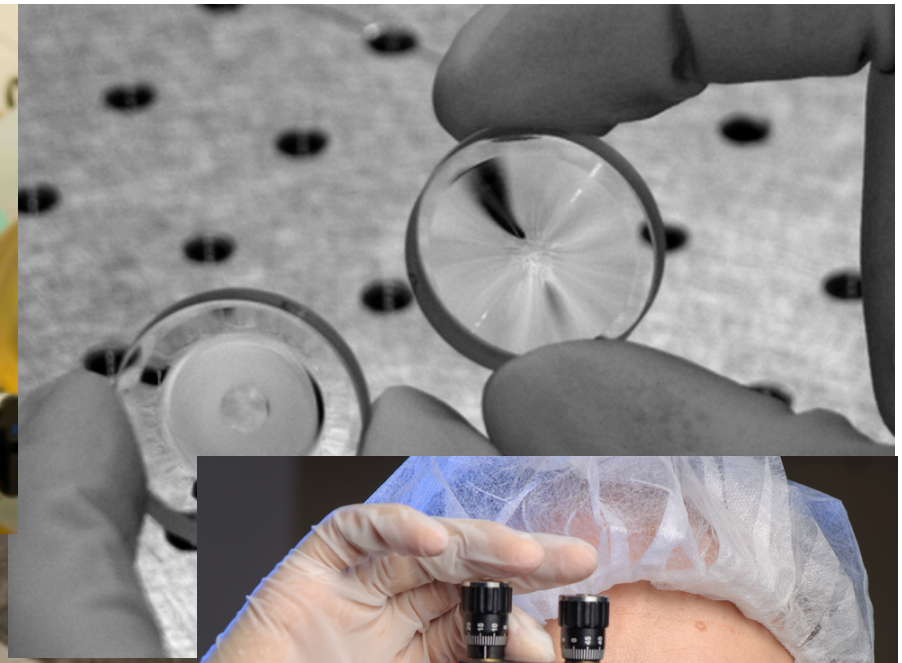
Technology: Phase-Induced Amplitude Apodization (PIAA)

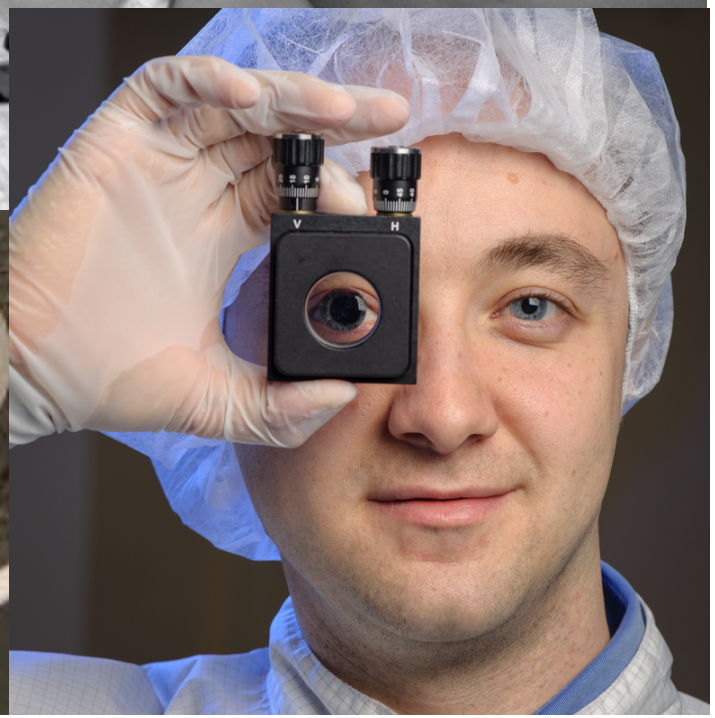


- Uses aspheric optics to redistribute the light in the pupil, moving light from the edges towards the center
- Much more light efficient, almost no loss

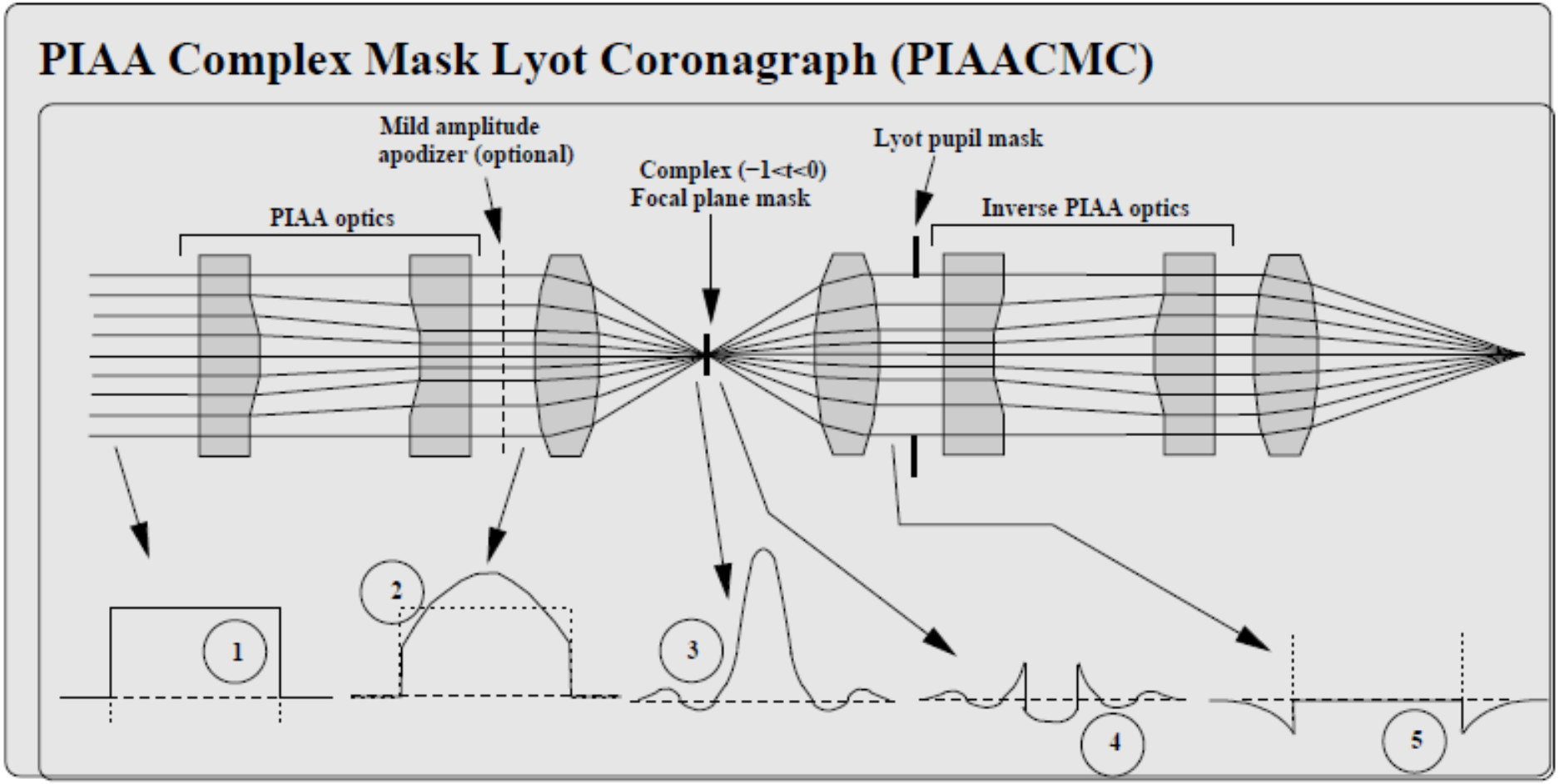
PIAA optics





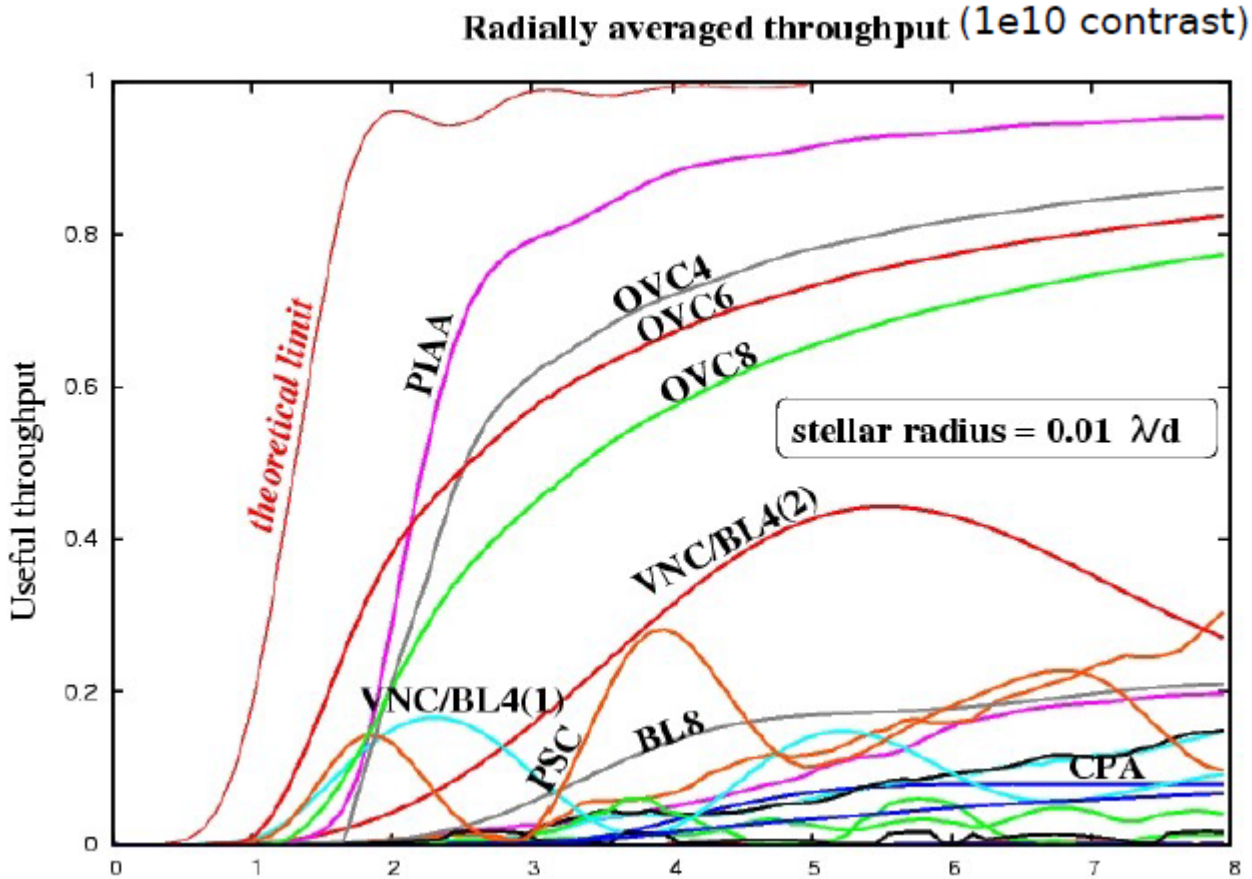


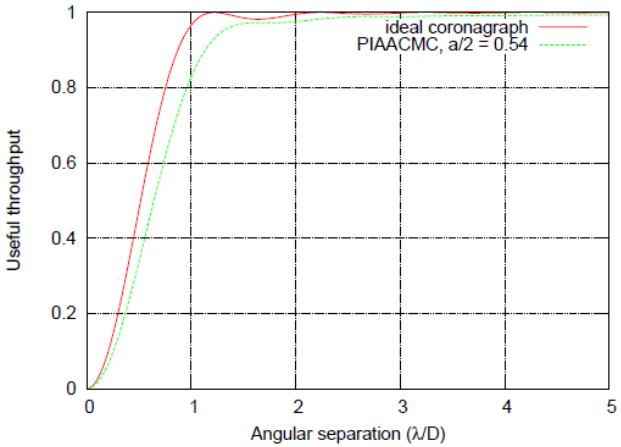
PIAA Complex Mask Coronagraph



Guyon et al. 2010

PIAACMC Performance





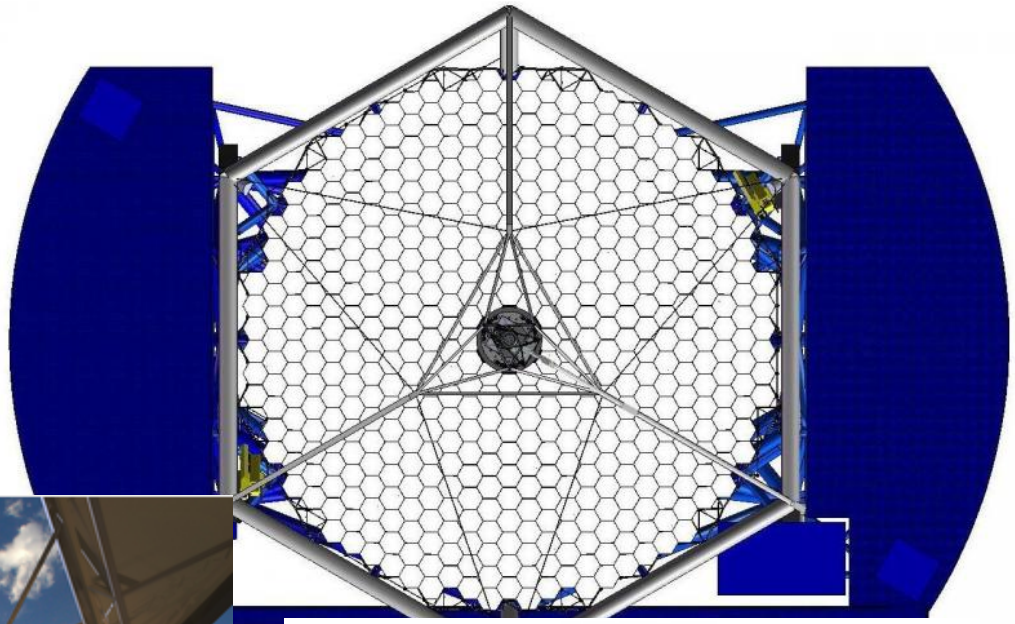
Guyon et al. 2010

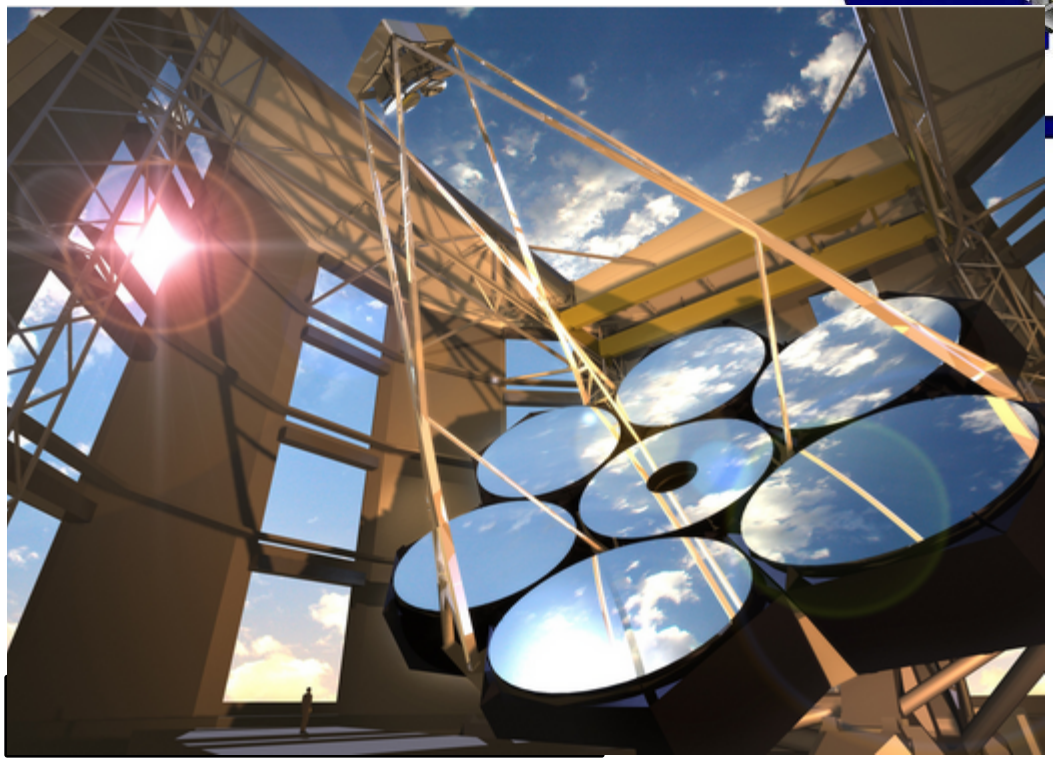
- PIAA and PIAACMC perform well compared with other coronagraph architectures
- Can achieve near the physical limit for direct detection

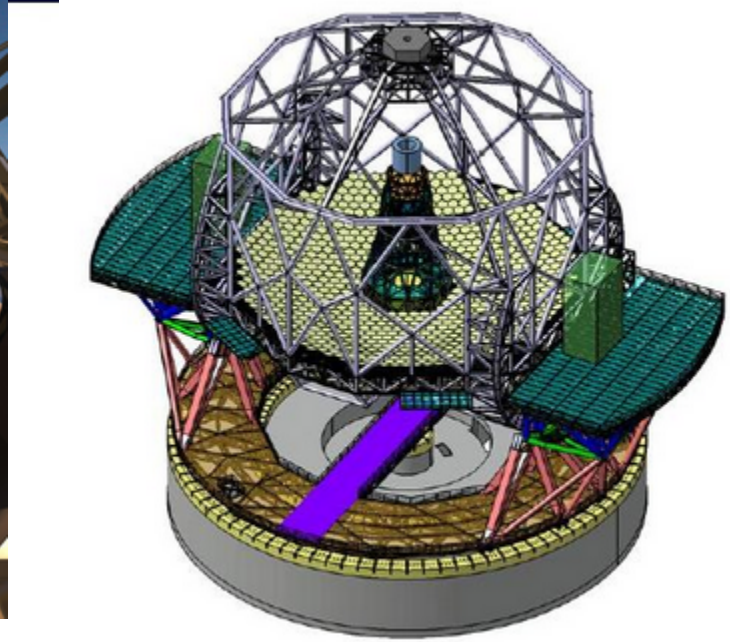
PIAACMC Performance

PIAACMC can be designed for centrally-obscured and segmented telescopes

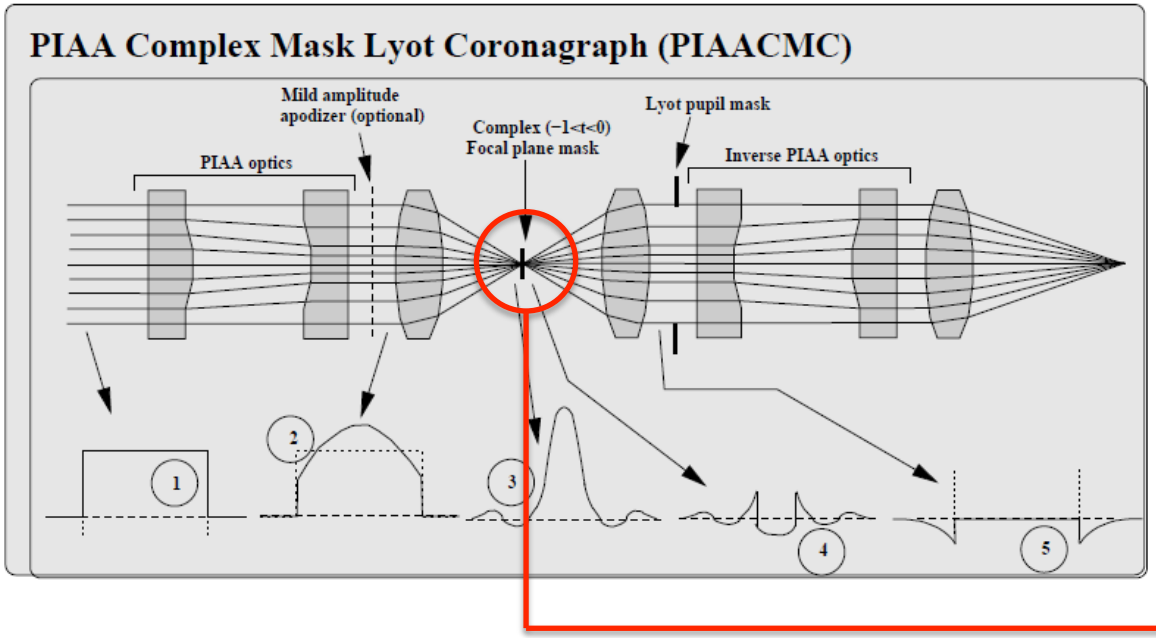
see Guyon et al. 2013

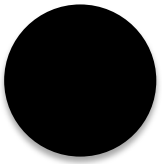






PIAACMC focal plane mask





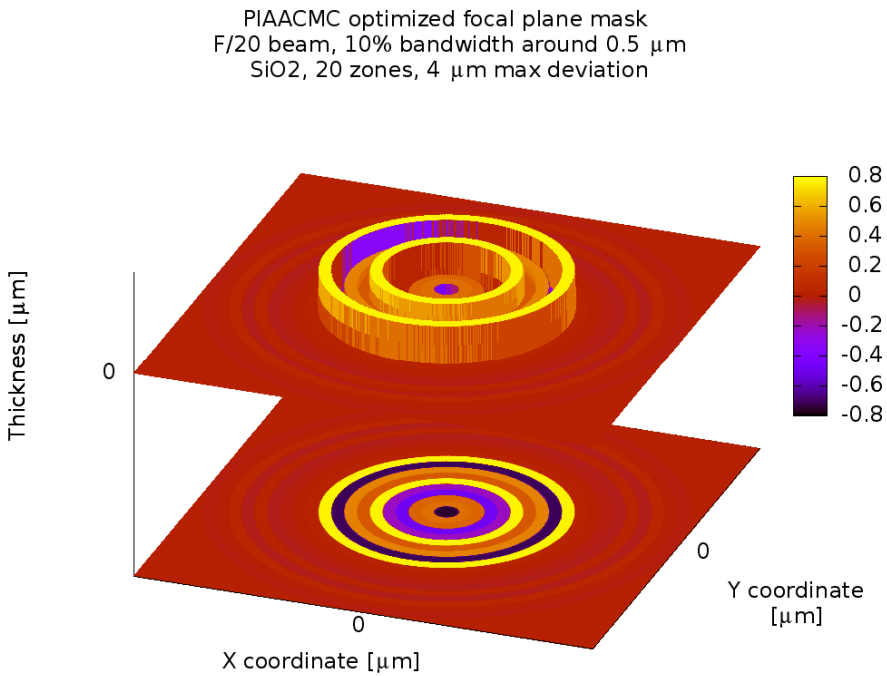
PIAA mask:
opaque disk

PIAACMC mask:
partially transmissive,
phase shifting

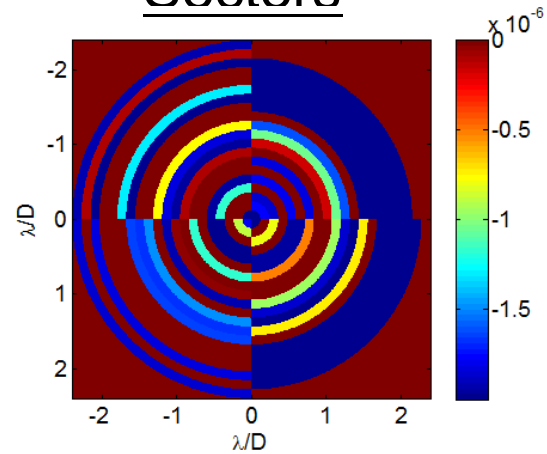
- Focal plane phase masks are a key part of the technology
- It is challenging to make the masks work in broadband
- My job is to develop the phase masks, this includes: design, achromatization, manufacturing, and testing

Designing the focal plane mask

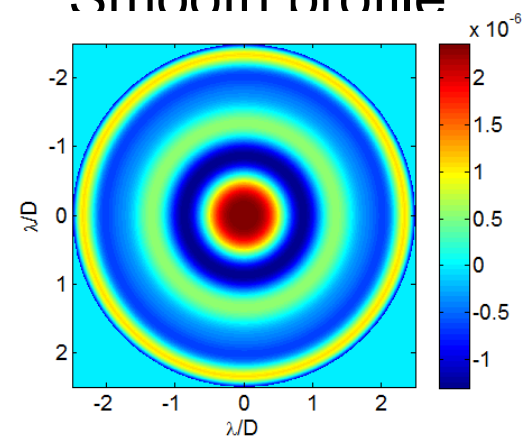
Rings



Sectors

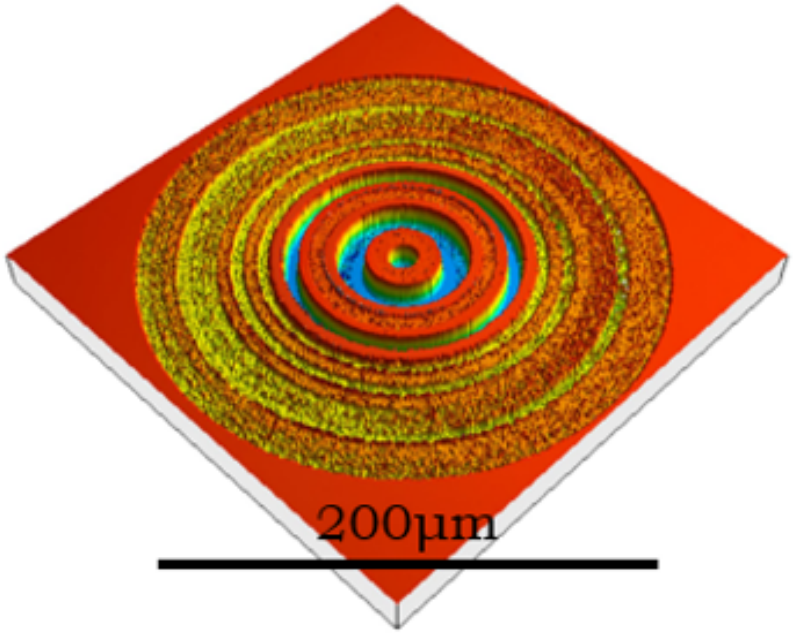


Smooth profile

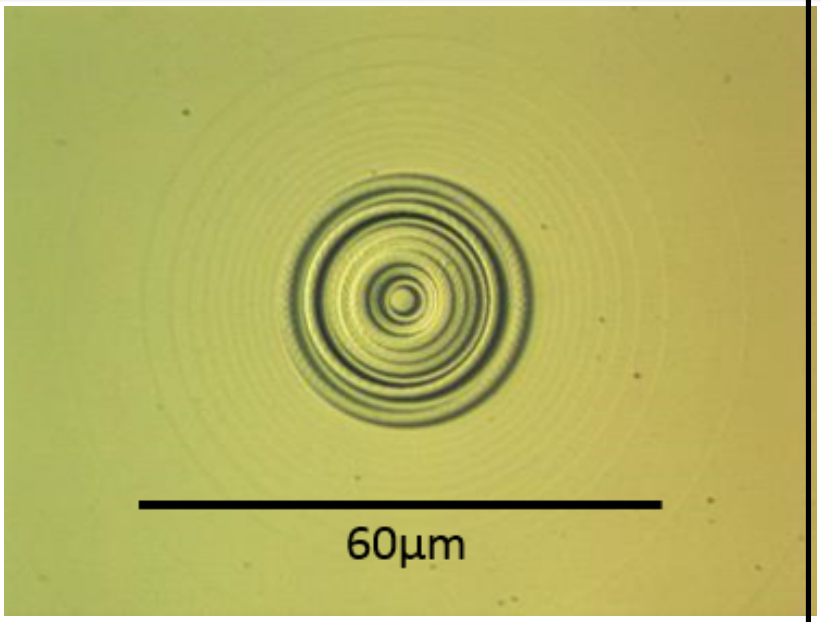


Design involves dividing mask into zones and optimizing the depth of each zone to provide a good achromatic phase shift

Manufacturing the focal plane mask



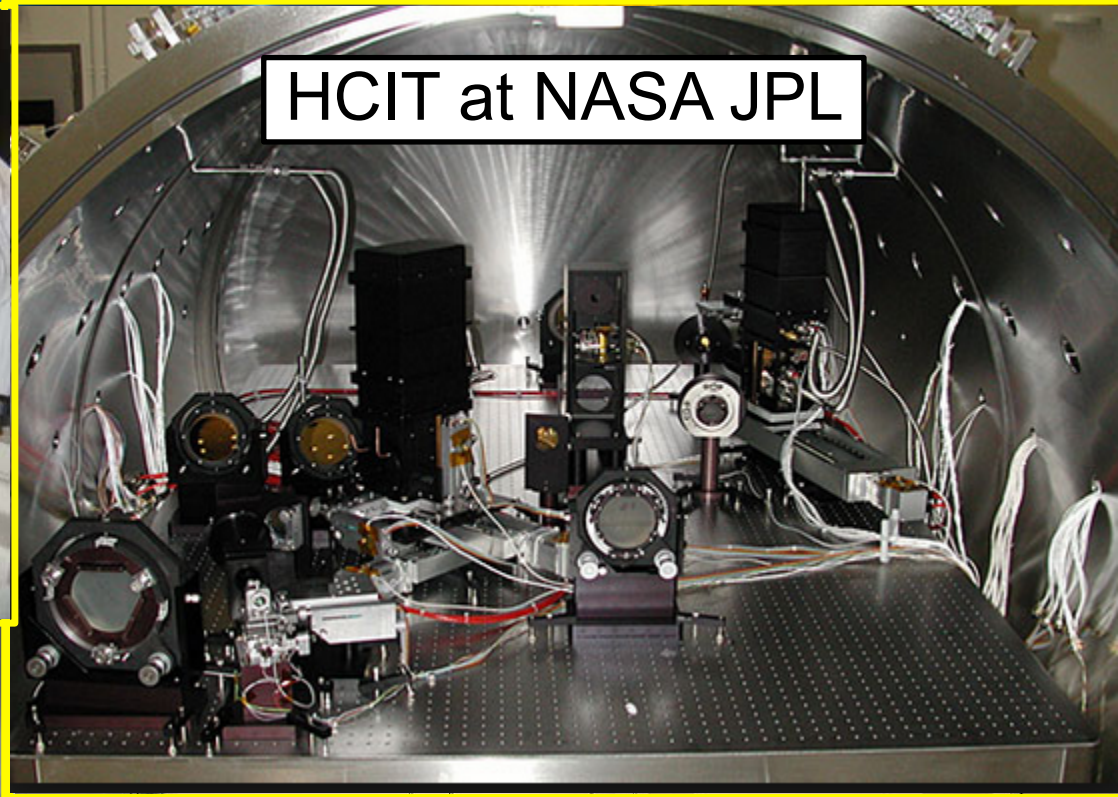
Profilometry measurement of a mask made at the Stanford Nanofabrication Facility

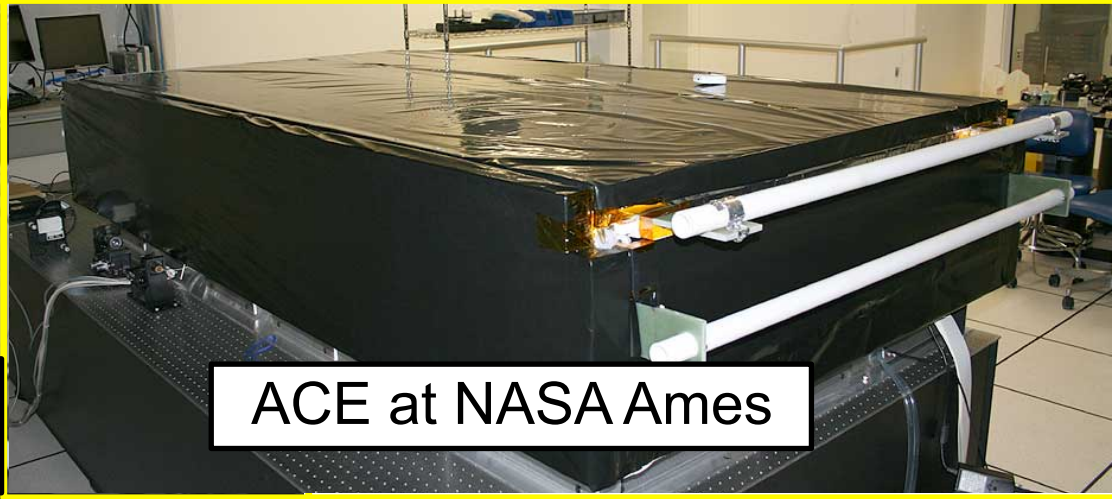


Microscope image of a mask made at the NASA JPL Microdevices Laboratory

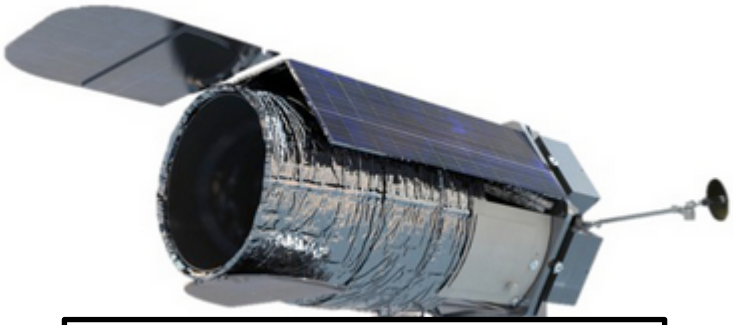
- Two manufacturers: NASA JPL Microdevices Lab, Stanford Nanofabrication Facility
- Start with Si or SiO2 wafers, apply layer of resist
- Write mask pattern into resist using electron beam lithography
- Transfer mask pattern into wafer using etching

Development testbeds

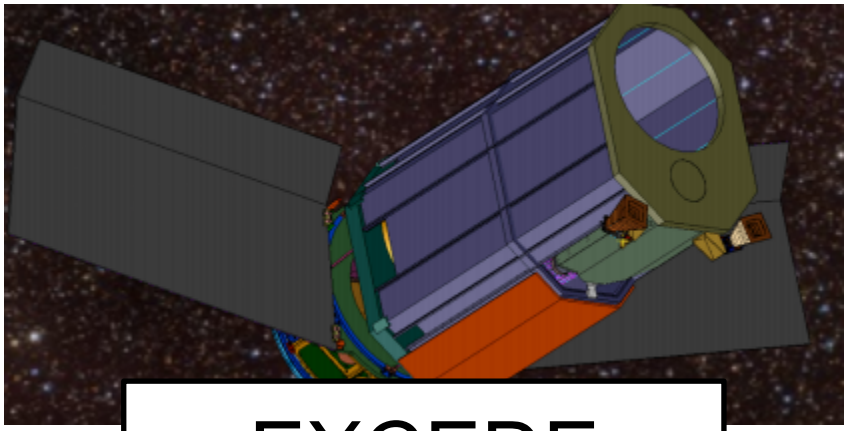




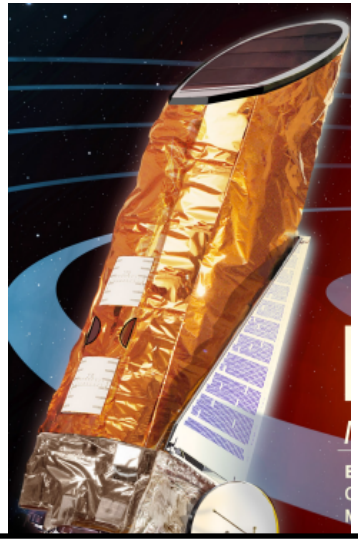
NASA missions that utilize PIAA or PIAACMC



WFIRST-AFTA



EXCEDE



Exo-C

NWT/ATLAST

ACEsat

Overview of Technology

- PIAA and PIAACMC technology enables high performance direct imaging of extrasolar planets
- Currently funded by NASA AFTA
- Currently TRL: 5 (for PIAA mirrors and complex masks, for unobstructed apertures)
- Current TRL for obstructed apertures: 3 (complex masks)
- Development contributions from NASA, University of Arizona, NAOJ, Lockheed Martin
- Direct application to several NASA missions

Contact and additional information

Thank you for your attention!

Email: kevin.e.newman@nasa.gov

For more information…

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Guyon, A&A, 404, 397 (2003)

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