National Aeronautics and Space Administration

Phase Induced Amplitude Apodization (PIAA) Coronagraphy: Recent Results & Future Prospects

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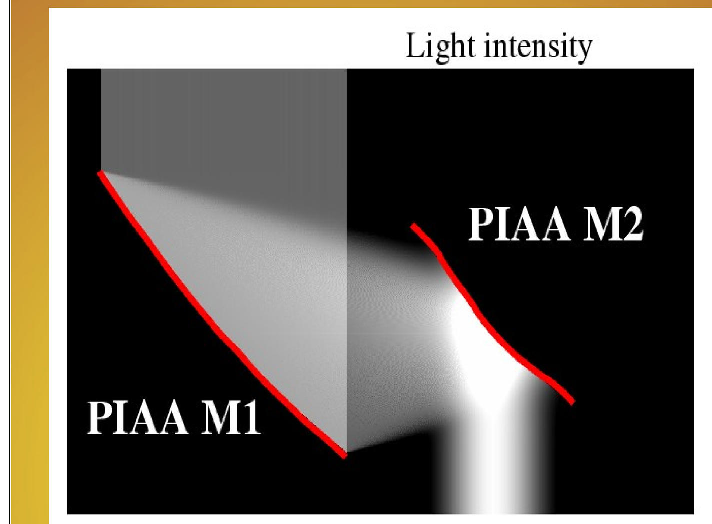
The Phase Induced Amplitude Apodization (PIAA) coronagraph offers full throughput, high contrast and small inner working angle (IWA), and is therefore ideally suited for space-based direct imaging of potentially habitable exoplanets. We are aiming at demonstrating PIAA corography in the laboratory to 1e-9 raw contrast at 2 λ/D separation. Recent results from the High Contrast Imaging Testbed (HCIT) at NASA JPL demonstrate contrasts approaching this goal. We have also recently validated instrument pointing control at the milli-λ/D level with a PIAA coronagraph – a key requirement for high contrast coronagraphy at small inner working angles. In parallel with these demonstrations, we are developing and testing new designs to further reduce inner working angle and improve performance in polychromatic light. Our new low-IWA design, the PIAA complex mask coronagraph (PIAACMC), can deliver sub-l/D IWA at a contrast only limited by wavefront aberrations, and is fully compatible with segmented and centrally obscured pupils. The PIAACMC is also ideally suited for direct imaging of spectroscopy of habitable planets around nearby M-type stars with ground-based Extremely Large Telescopes (ELTs).

What is PIAA ?



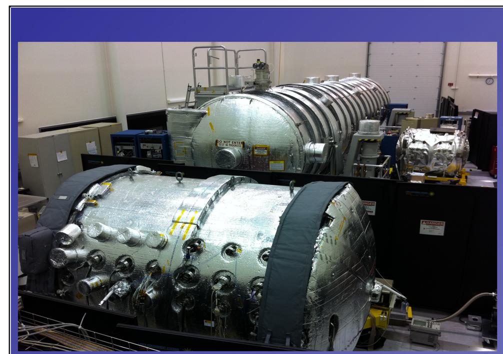
One technique to obtain high contrast imaging is pupil apodization (making the edges of the beam gradually fainter), but it removes a lot of the incoming light and reduces the telescope angular resolution.

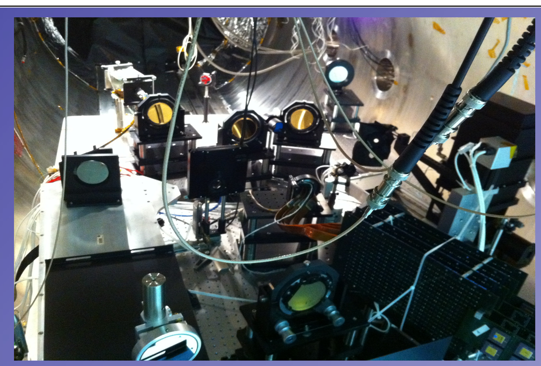
PIAA uses lossless beam apodization with aspheric optics (mirrors or lenses) to concentrate starlight in a single diffraction peak (no Airy rings).

-> high contrast (limited by wavefront errors)
-> Nearly 100% throughput
-> IWA ~2 λ/D (can be <1 λ/D with PIAACMC)
-> 100% search area
-> no loss in angular resolution
-> achromatic at the 1e-10 level (with mirrors)

Aspheric PIAA mirrors (90mm clear aperture, made by L3-Tinsley)

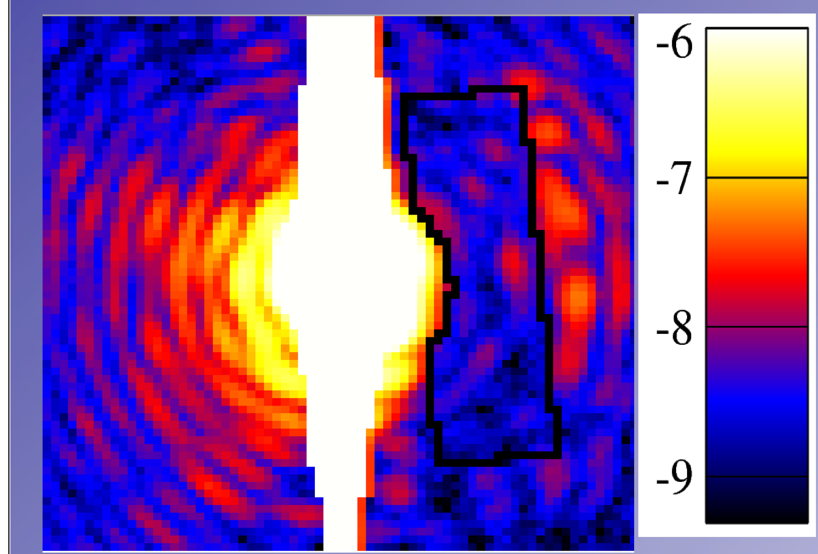
Lab testing – JPL





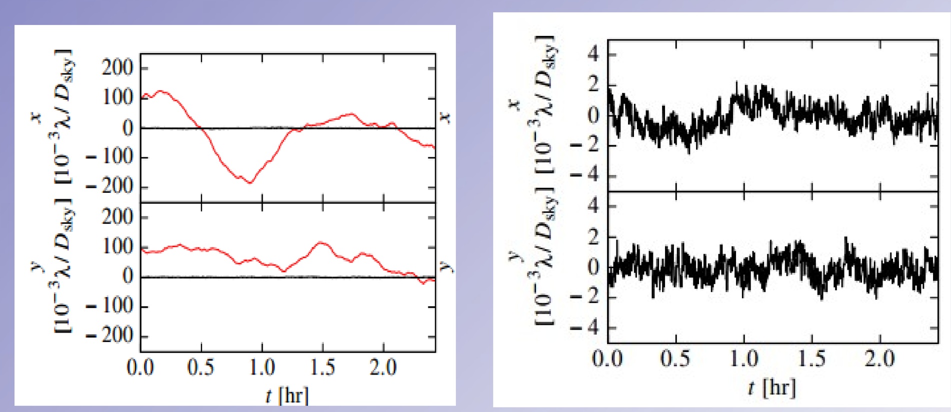
High contrast vacuum testing, to flight performance requirements

Instrument raw contrast at 2 λ/D (TDEM Milestone #1)



~4e-9 RAW contast achieved in vacuum (dark hole from 2.2 to 5.9 λ/D)
(NOTE: preliminary data reduction – photometry is currently uncertain to x2)

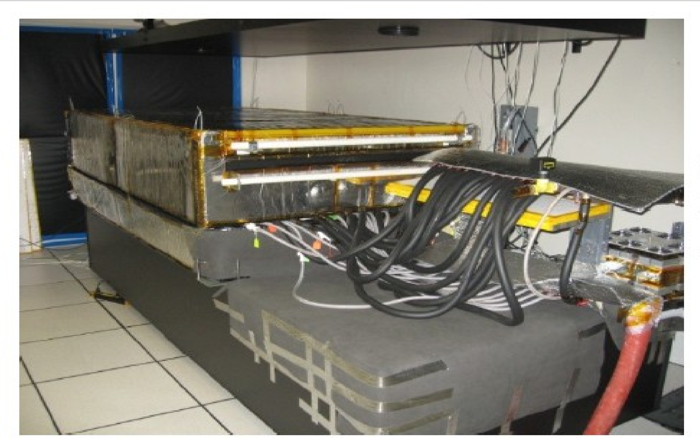
Instrument pointing validation (TDEM Milestone #2)

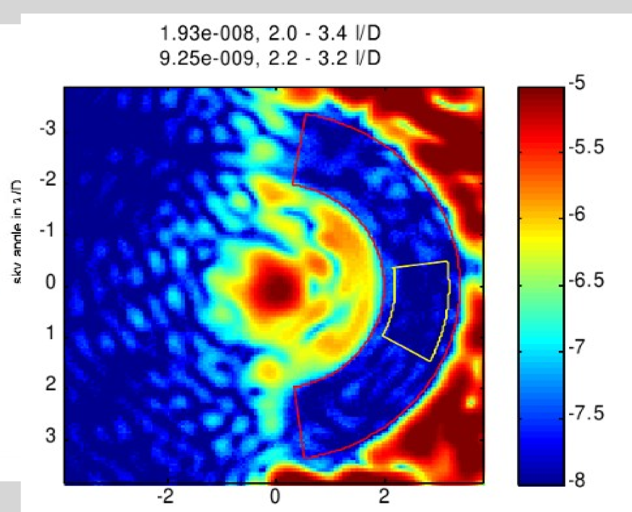


Left panel shown x and y pointing without (red) and with (black) correction. The right panel shows the black curve only (pointing values with correction) with the vertical scale enhanced by 50x. The RMS pointing after correction is 0.00107 λ/D

Lab testing – Ames

Probing new configurations, R&D, at contrast limited by air (~few x1e8). Pushing IWA to 1 λ/D (in support of EXCEDE mission)



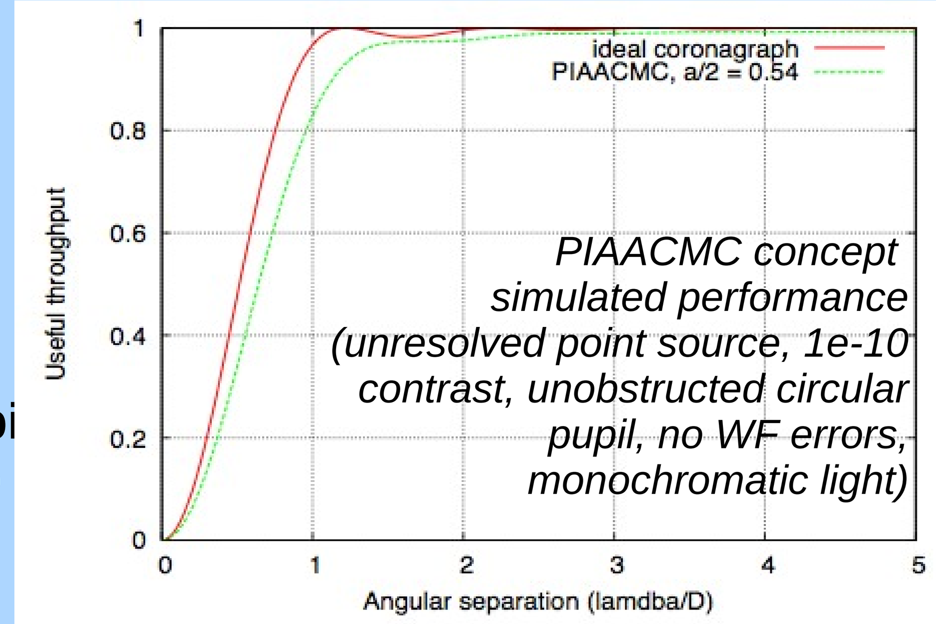


Left: the thermal enclosure of the NASA Ames Coronagraph Testbed. Right: High contrast image taken at the Ames testbed, showing ~10^{-8} contrast in the dark zone

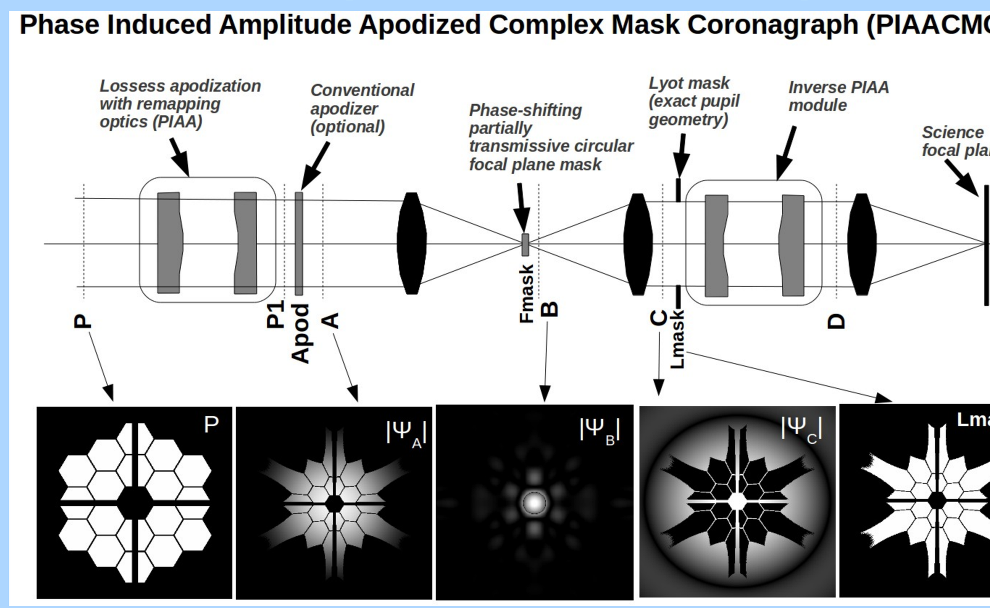
New development: Sub λ/D inner working angle with PIAACMC Compatible with any pupil shape !

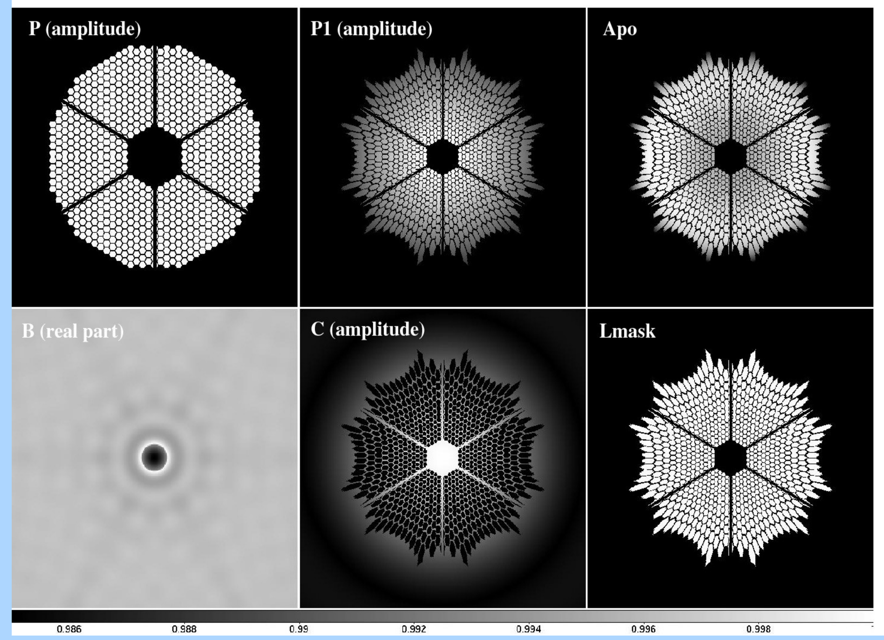
PIAA Complex Mask Coronagraph combines:
- Lossless apodization with PIAA optics
- Phase mask focal plane mask

→ Offers ultimate coronagraph performance:
- no limit in contrast (limited only by WF errors)
- IWA < 1 λ/D at 1e-10 contrast
- full throughput
- works on segmented or centrally obscured pupi
- moderate beam shaping → PIAA optics easy to manufacture
- Focal plane mask can be achromatized with diffractive focal plane mask technique

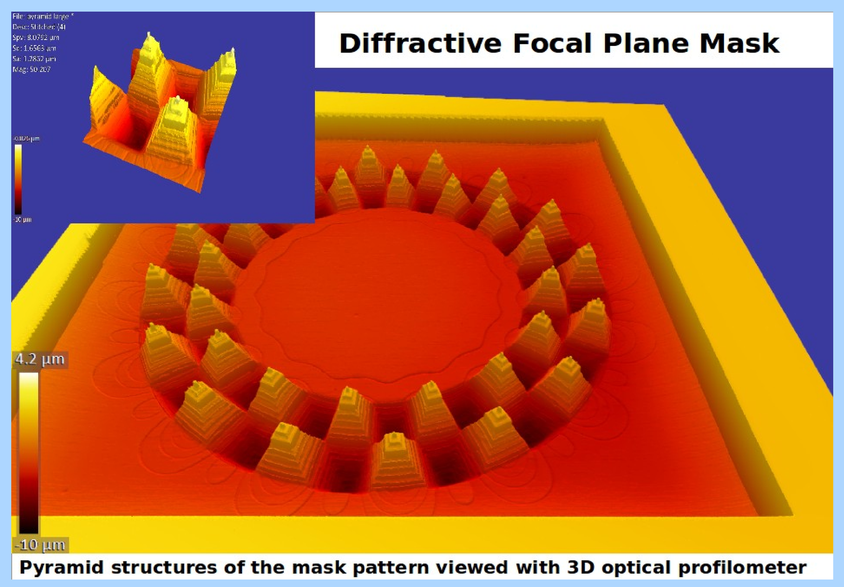


PIAACMC concept simulated performance (unresolved point source, 1e-10 contrast, unobstructed circular pupil, no WF errors, monochromatic light)





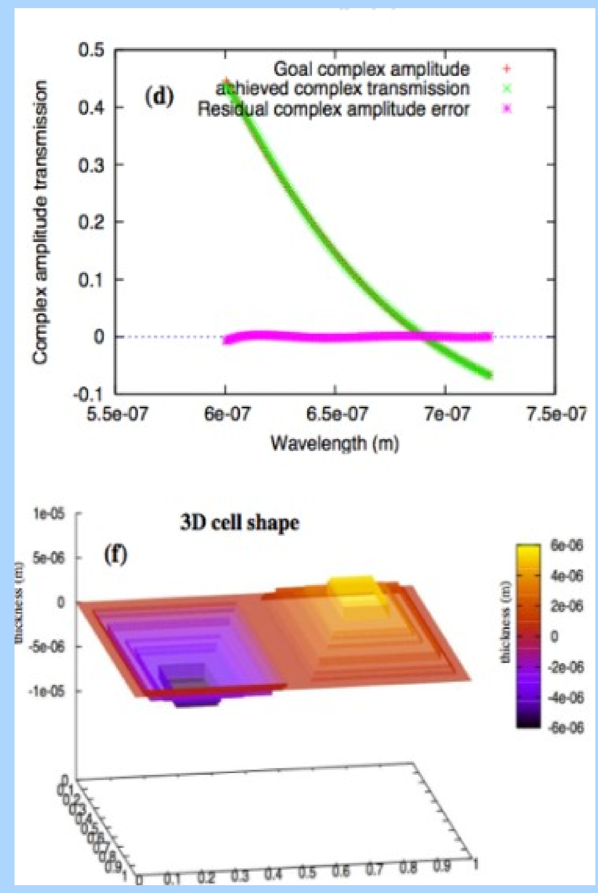
Example PIAACMC design for TMT pupil



Diffractive focal plane mask

Right: Concept, showing different parts of the mask interfere to produce desired chromatic effect

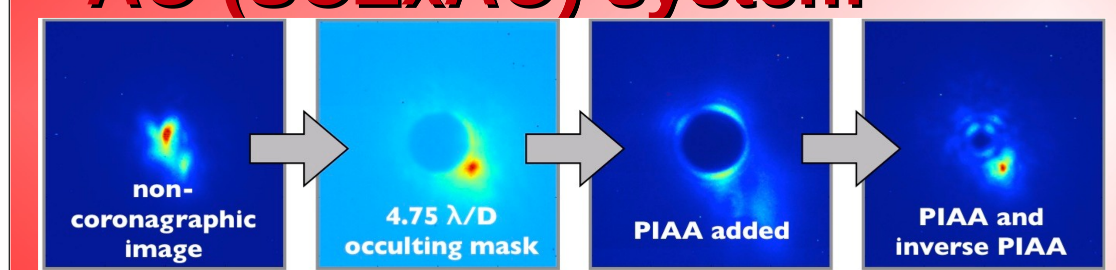
Left: prototype mask manufactured at MDL, JPL



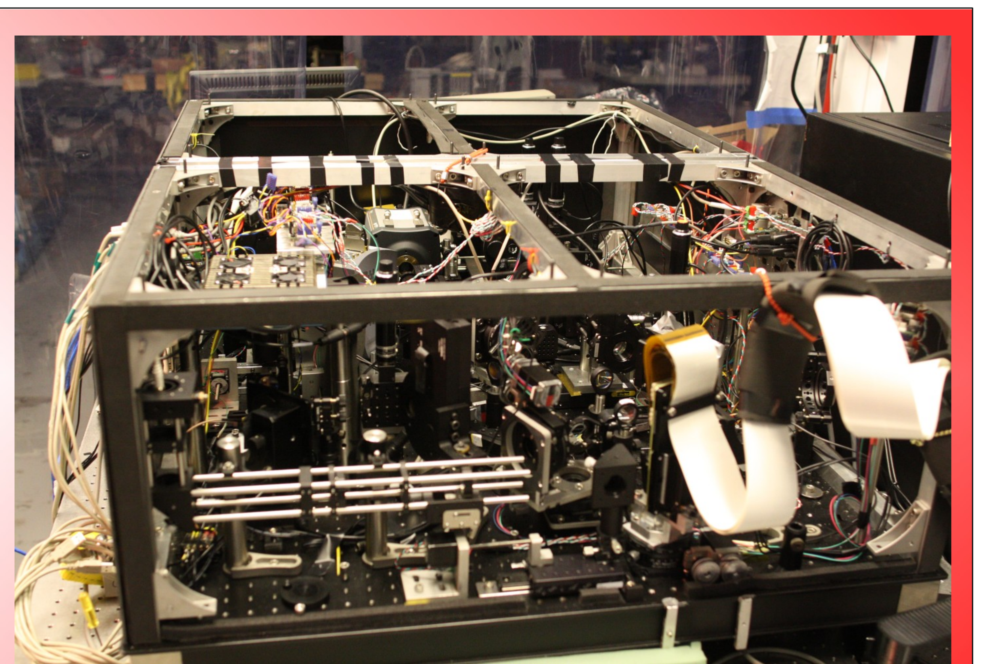
PIAACMC will enable use of general purpose telescopes for high performance coronagraphy
→ direct imaging and spectroscopy of Earth-like planets from space with conventional or segmented telescopes
→ Direct imaging and spectroscopy of habitable planets around M-type stars with ELTs (these targets do not require very high contrast, but are at very small angular separation ~ 1 to 2 λ/D)

Ref: "High Performance PIAA coronagraphy with Complex Amplitude Masks", Guyon et al. ApJS 129, 220 (2010)

On sky demo: Subaru Coronagraphic Extreme AO (SCExAO) system



1 λ/D coronagraphy demonstrated on sky
Pointing control with Low order wavefront sensor validated on sky



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