

Laboratory Demonstration of

High contrast imaging at 2 and 1.5 λ /D

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Overview

Goals

- General goal: develop technology for imaging exoplanets, and in particular imaging of exo-Earths with a small telescope (1.4m,)
- Specifically,
- develop the PIAA (Phase Induced Amplitude Apodization) Coronagraph, [1-5]

4m

test wavefront control with MEMS DMs

PIAA coronagraph concept

Original uniformly Corresponding lluminated pupil plane Focal plane



Mission concepts using PIAA



1m

ZODIAC

(Traub et. al.)

Stabilized air enclosure



MEMS **Deformable Mirror**

(DM)



Active thermal control system









- PIAA (phase induced amplitude apodization is an efficient coronagraphic method of suppressing starlight
- Almost full throughput (80%)
- Close to diffraction limited (1-2 λ /D inner working angle)
- This aggressive performance effectively enables telescope size reduction without sacrificing science, as compared to many other coronagraphs [6]
- Potentially enables Earth-like planet imaging with a telescope as small as 1.4m, such as PECO (Pupil-Mapping Exoplanet Coronagraphic Explorer) [7,8]
- Scales well to other missions ranging from balloons and Exlporers to flagships

- Flexible, rapidly reconfigurable facility in air
- Successor to Olivier Guyon's 1st PIAA testbed at Subaru
- Testing a variety of PIAA and related technologies
- Wavefront control system based on a MEMS DM, using the Speckle nulling and EFC algorithms [11,12]
- Active thermal stabilization
- Partnering with JPL's HCIT [10]:
 - ARC: initial validation of lower TRL technologies and concepts
 - JPL/HCIT: higher TRL and vacuum validation
- MEMS DMs are smaller and cheaper than conventional DMs Large actuator count (64x64) available today
- Non-astronomical markets and
 - competition between vendors promotes good procurement, support
 - These advantages have a strong potential to make high contrast
 - imaging from space easier and cheaper

-6.5



- Outside the enclosure, temperature varies by ~ 0.5K.
- Inside the enclosure (active thermal control OFF), temperatures vary by ~ 50mK, causing tip/tilt errors of about 0.1 λ /D
- With ATC ON, can sustain the following root mean square values:
- Air T: 0.9mK

Ames Testbed Description

- Table: 0.4mK
- Water: 0.4mK

Lab Demonstrations at the Ames Testbed

2.5







- Light source: 650nm laser
- Spatially averaged contrast in a dark zone between 2 and 4.8 λ /D is 5.4 x 10⁻⁸
- This result demonstrates the ability of the testbed and wavefront control to provide high contrast at least in monochromatic light
- Limiting factor believed to be ghosts from lenses (dynamically varying because of slight wavelength variations)

Low-cost PIAA Mirrors

System wavefront

performance PIAA mirrors, and more aggressive performance is possible.



• \$3K PIAA mirrors made by JPL, desidned for broadband (but tested in monochromatic light)

• Manufacturing process: diamond turning followed by electron beam lithography to improve residual errors



- Initial testing at JPL High Contrast Imaging Testbed (HCIT) completed • Continued testing is ongoing at the NASA Ames testbed
 - Focus of the current work is to demonstrate high contrast at better inner working angles

(also 3e-8 from 2-4 λ /D demonstrated

at HCIT with these mirrors)

- Inner working angles of 1 I/D with contrasts better than 1e-6 are possible with the PIAACMC concept (hybrid between PIAA and APLC, or Apodized Pupil Lyot coronagraph)
- Limiting factor not yet reached as system is being calibrated and tuned

- 2nd generation PIAA mirrors were designed to provide excellent polychromatic performance
- Manufactured by Tinsley using Narrow Ion Beam Figuring technology
- Surface quality is ~3 nm RMS filtered to 20 CPA. Models indicate that this performance will deliver better than 1e-9 contrast in broadband light between 760 and 840nm.



• Limiting factor was insufficient test time



• Process can deliver good mirrors at least for low-performance PIAA designs (50% throughput) at a fraction of the cost of the high-

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• We are testing and improving a new reflective PIAA mirror set recently delivered by Tinsley Laboratories