ExoPlanet Exploration Program

Technology Development for Exoplanet Missions (TDEM)

TDEM-2009 Status Report

Peter Lawson, ExEP Program Technologist

Marie Levine, ExEP Technology Manager

Jet Propulsion Laboratory

California Institute of Technology

ExoPAG Meeting, Austin, TX

Saturday, 7 January 2012, 12:00 pm

Programmatic Updates

ExoPlanet Exploration Program

Technology Milestone Whitepapers from TDEM 2009 and all background material available at

http://exep.jpl.nasa.gov/technology/

Updated Technology Plan: Fall 2011

Now revised for the 2011 ROSES Strategic Astrophysics Technology Solicitation

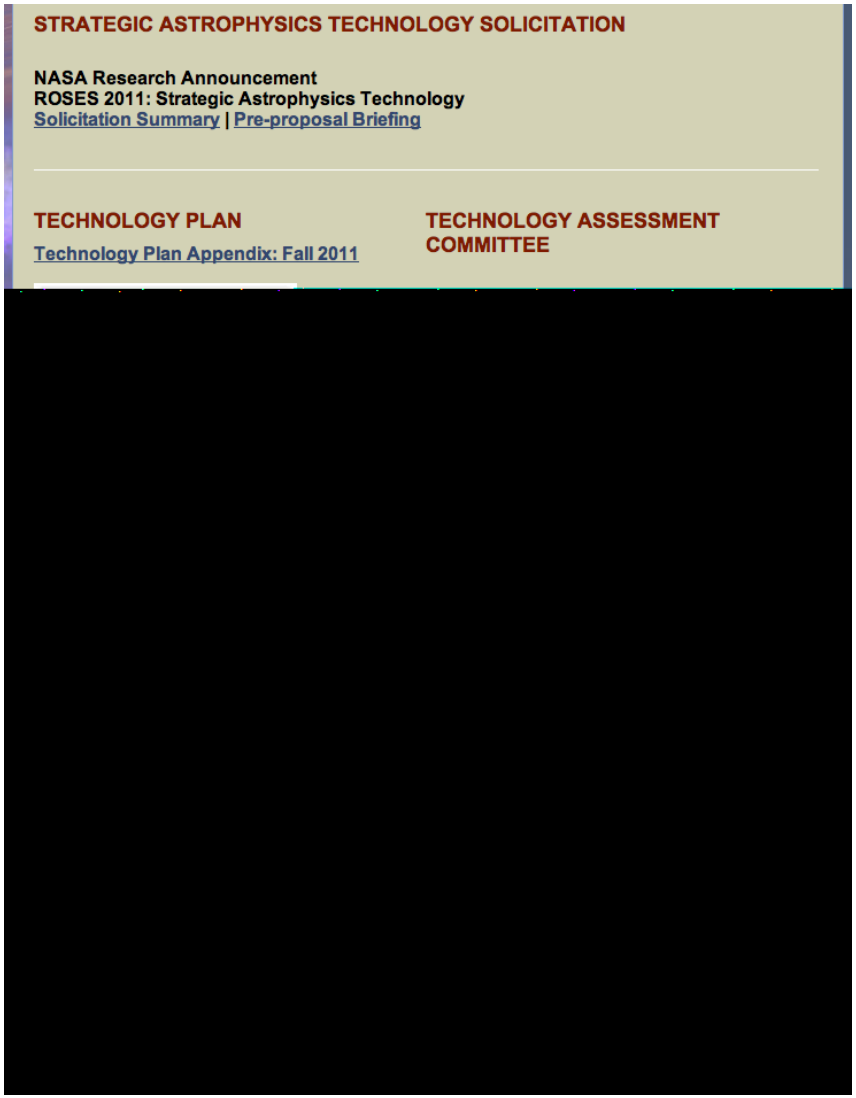
Amended *Strategic Astrophysics Technology* (SAT) Solicitation

Released 22 December 2011

Pre-Proposal Briefing Scheduled

Tues, 24 Jan 2012, 1:00 pm Eastern

SAT-TDEM Proposals due 23 March 2012



Coronagraph Contrast Performance Achieved to Date

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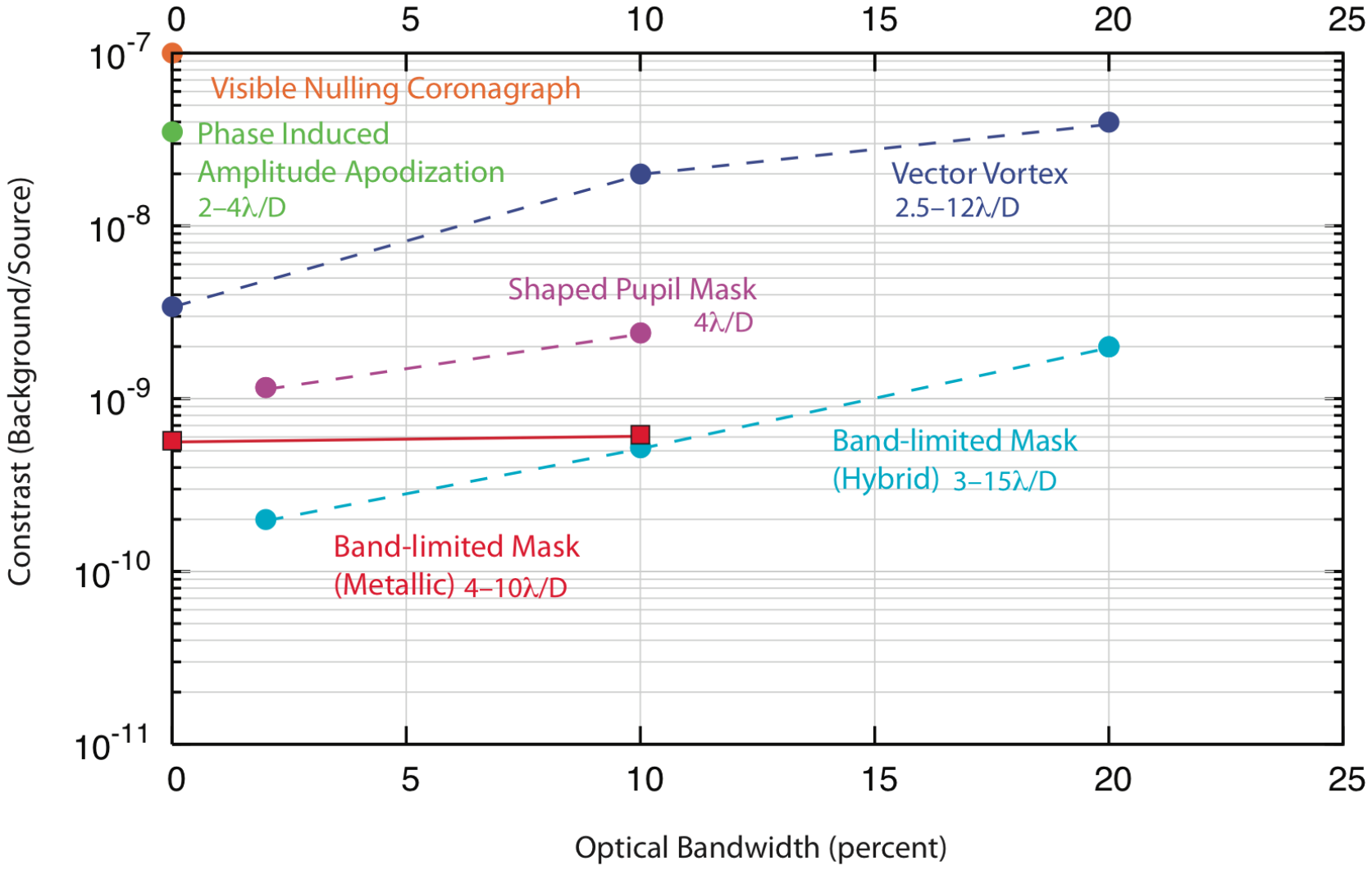

Infrastructure Upgrades in FY'11

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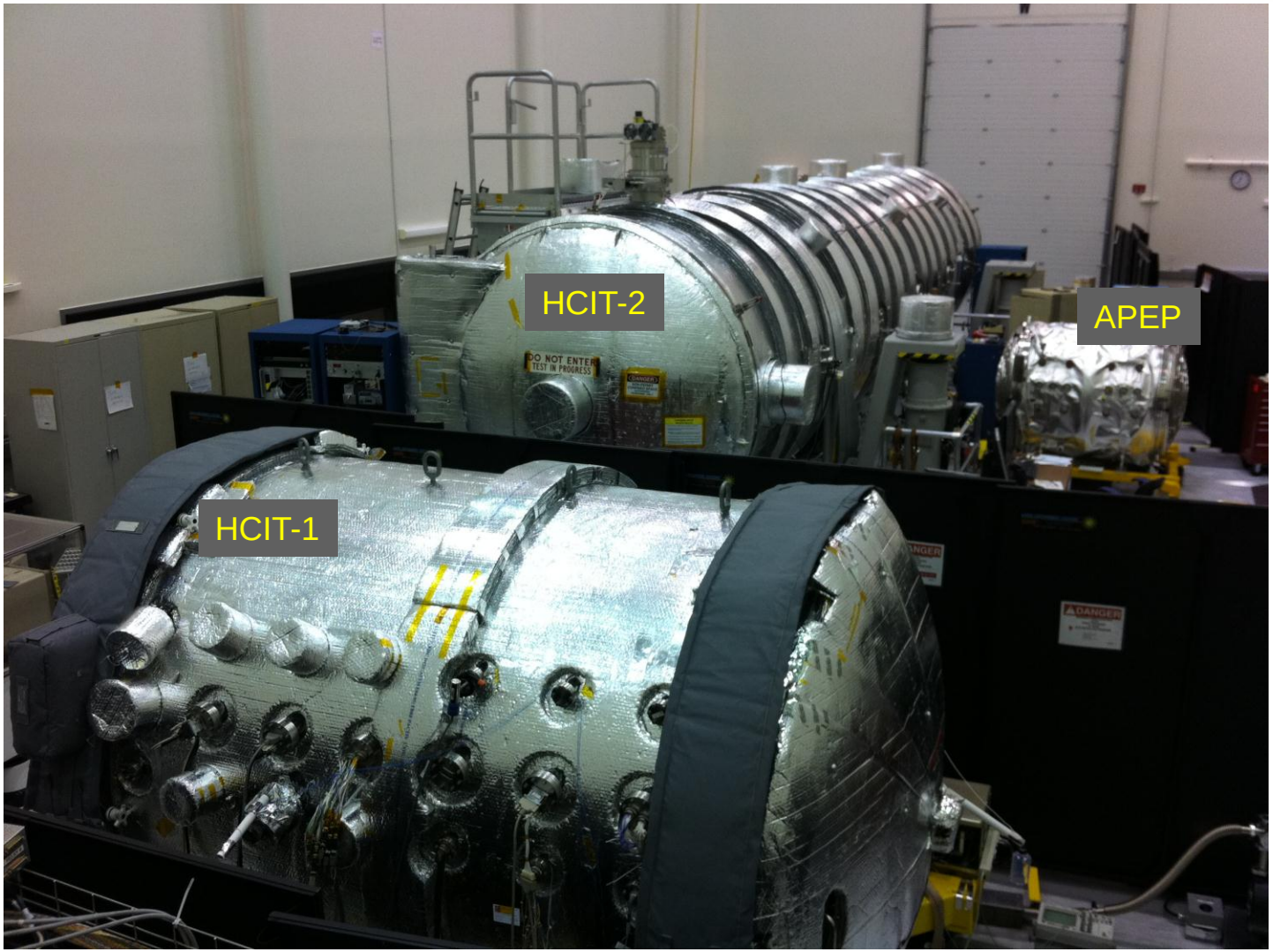

SIM chamber retrofit (HCIT-2) and new visible nuller chamber (APEP) provide augmented test capacity for starlight suppression demonstrations in JPL Building 318 high bay.

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Olivier Guyon (Univ of Arizona)
Phase Induced Amplitude Apodization

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Coronagraph Technology Milestone #1:
Demonstration of ≤ 10^{-9} contrast with PIAA coronagraph at 2λ/D in laser light

Current Status: 3×10^{-8} contrast @ 2-3 λ/D.

Challenges: Uncontrolled background, image motion.

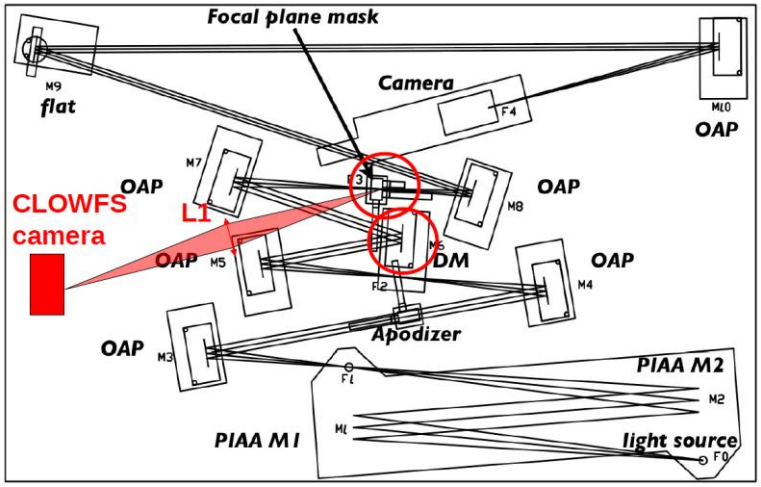
Coronagraph Technology Milestone #2:
Demonstration of ≤ 0.01 λ/D pointing stability w/ Low Order Wavefront Sensor.

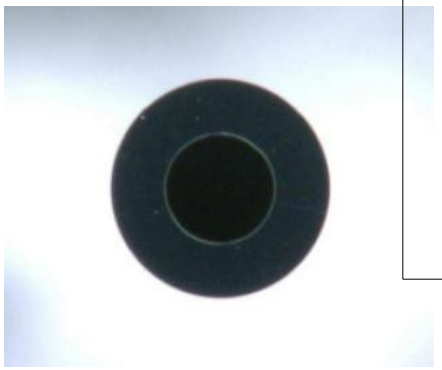
Current Status: Closed-loop tracking at 1.6 Hz, 0.03 f λ/D rms residuals.

Challenges: Hardware for closed-loop control in vacuum.

Facility: High Contrast Imaging Testbed -2 , JPL.

Future Work: Milestone #2 runs in 1/2012. Milestone #1 runs afterwards then proceed with TDEM10 for 10^{-9} contrast at 2λ/D in 10% BWD.





LOWFS uses light blocked by the focal plane mask to measure low order aberrations with high sensitivity

Trauger | Guyon | Krist | Kendrick | Clampin | Kasdin | Figer

John Krist (JPL/Caltech)
End-to-End Coronagraph Modeling

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Coronagraph Technology Milestone #1:

Demonstration of fast & accurate propagator for Hybrid Lyot, PIAA, and Vector Vortex coronagraphs with ≤ 1% errors when compared to more rigorous reference algorithms, ≤ 48 hours to compute 2-DM (48x48) 5-wavelength response matrix on a modern workstation.

Coronagraph Technology Milestone #2:

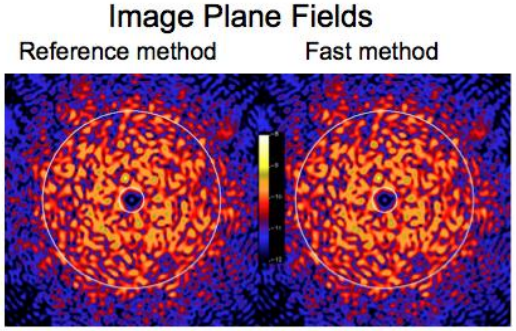
Using propagators from Milestone #1, determine parameters for each coronagraph to achieve ≤ 10^{-10} mean contrast over λ = 500–600 nm in a realistically aberrated system with wavefront control.

Challenges: Design of Hybrid Lyot Masks has taken longer than anticipated.

Current Status:

1st Milestone: PIAA and Vector Vortex completed. Hybrid Lyot still in work.

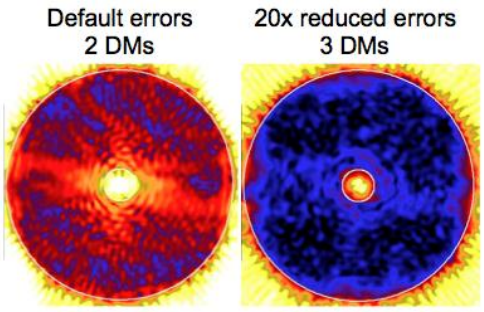
2nd Milestone: PIAA completed, Vector Vortex in progress.



Derived a suitable binary post-apodizer and a means to represent it with limited wavefront sampling.

Developed and optimized propagation codes for both accuracy and speed.

Verified results against reference methods.



Used propagators and wavefront control methods (EFC) to create dark holes around sources.

Determined current PIAA optics need to be 20x better to reach 10^{-10} broadband contrast.

Identified need for 3rd DM after PIAA optics to control optical errors between PIAA and occulter.

Trauger | Guyon | Krist | Kendrick | Clampin | Kasdin | Figer

Stephen Kendrick (Ball Aerospace)
Advanced Speckle Sensing

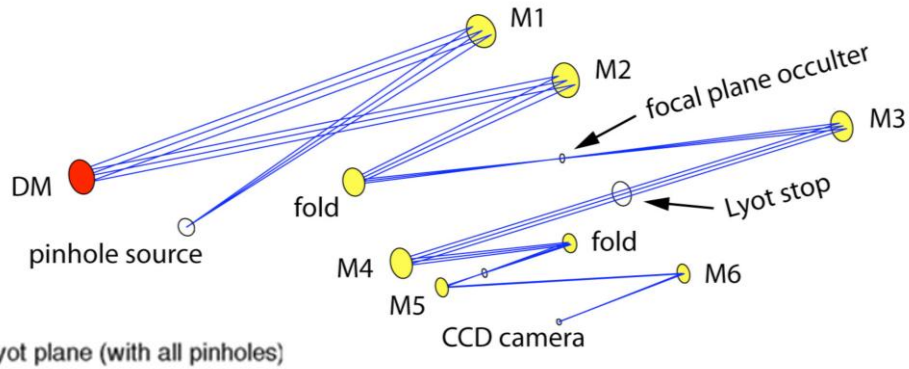
Coronagraph Technology Milestone:
Demonstration of ≤ 20% rms difference between contrast maps obtained using pinhole vs standard DM phase diversity approach, with ≤10^{-8} contrast using Lyot Masks @ 10% BWD.

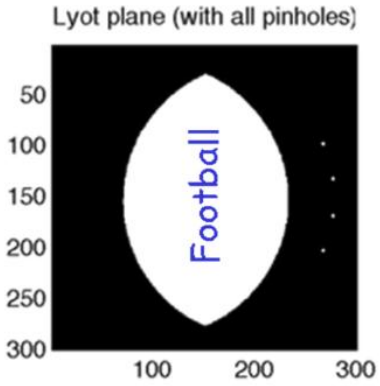
Facility: High Contrast Imaging Testbed 1, JPL.

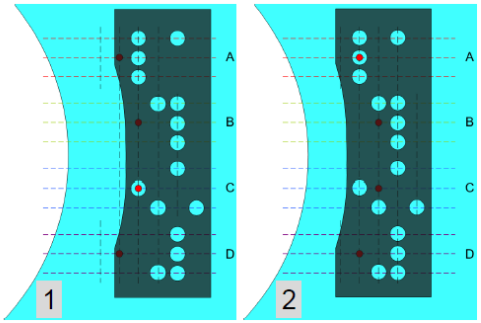
Current Status: ≤10^{-8} contrast, 18 % rms difference at 10% BWD.

Challenges: Bandwidth sensitivity.

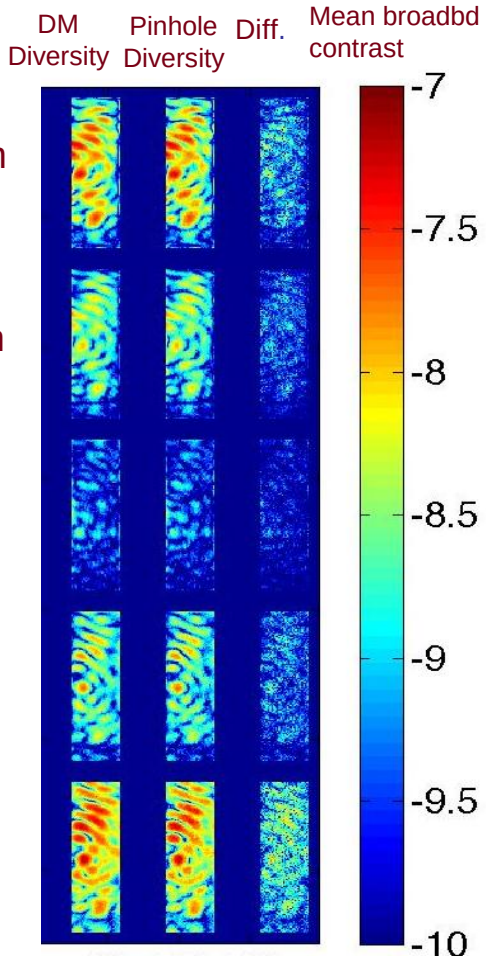
Future Work: Add incoherent background. Milestone runs in 1/2012.







Sliding binary mask



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Mark Clampin (NASA GSFC)
Visible Nulling Coronagraph

Coronagraph Technology Milestone:
Demonstration of ≤ 10^{-8} monochromatic contrast through visible nulling.

Facility: Visible Nulling Coronagraph Testbed, NASA GSFC.

Current Status: 1.5 x 10^{-6} @ 2λ/D contrast monochromatic. New DM installed in Dec. 2011.

Challenges: State of the art in segmented DMs.

Future Work: Complete milestone in 2012, follow-on with R. Lyon TDEM.

Focal Plane Image thru Spatial Filter Array

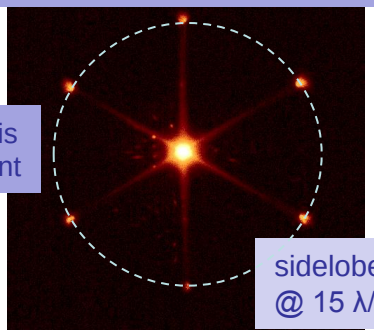
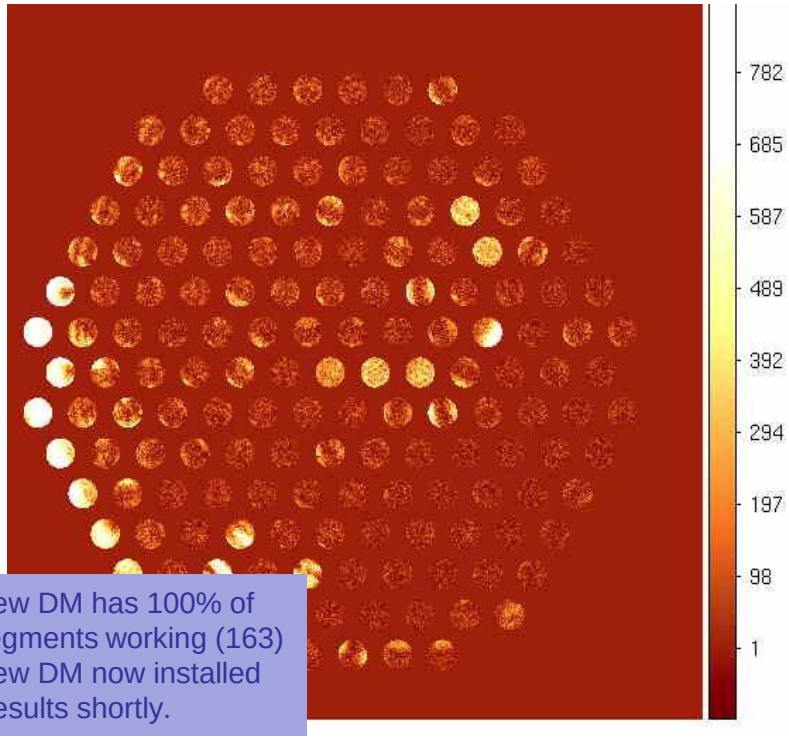
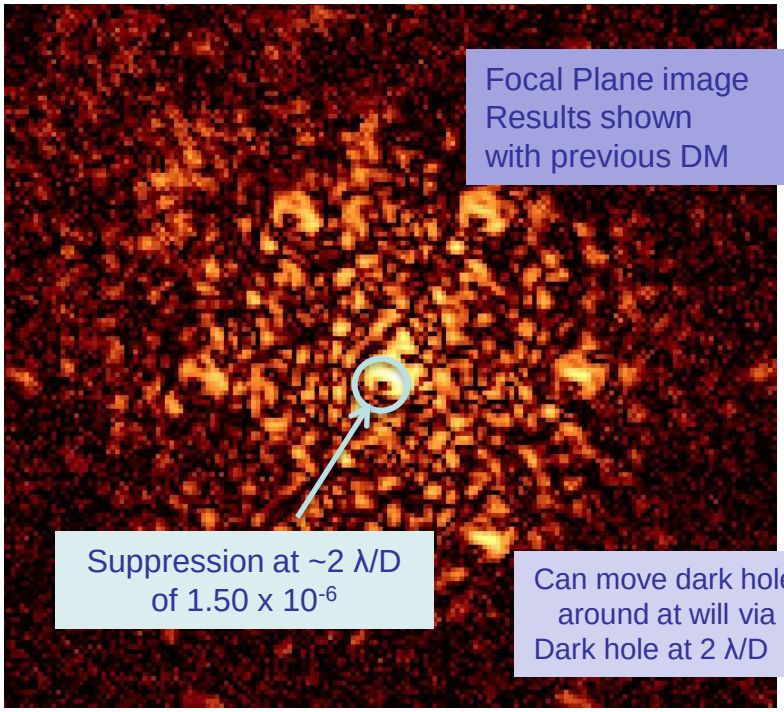


Image is coherent

sidelobes @ 15 λ/D



New DM has 100% of segments working (163)
New DM now installed
Results shortly.



Focal Plane image
Results shown
with previous DM

Suppression at ~2 λ/D of 1.50 x 10^{-6}

Can move dark hole around at will via DM
Dark hole at 2 λ/D

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Trauger | Guyon | Krist | Kendrick | **Clampin** | Kasdin | Figer

N. Jeremy Kasdin (Princeton Univ.)
Advanced Starshade Technology

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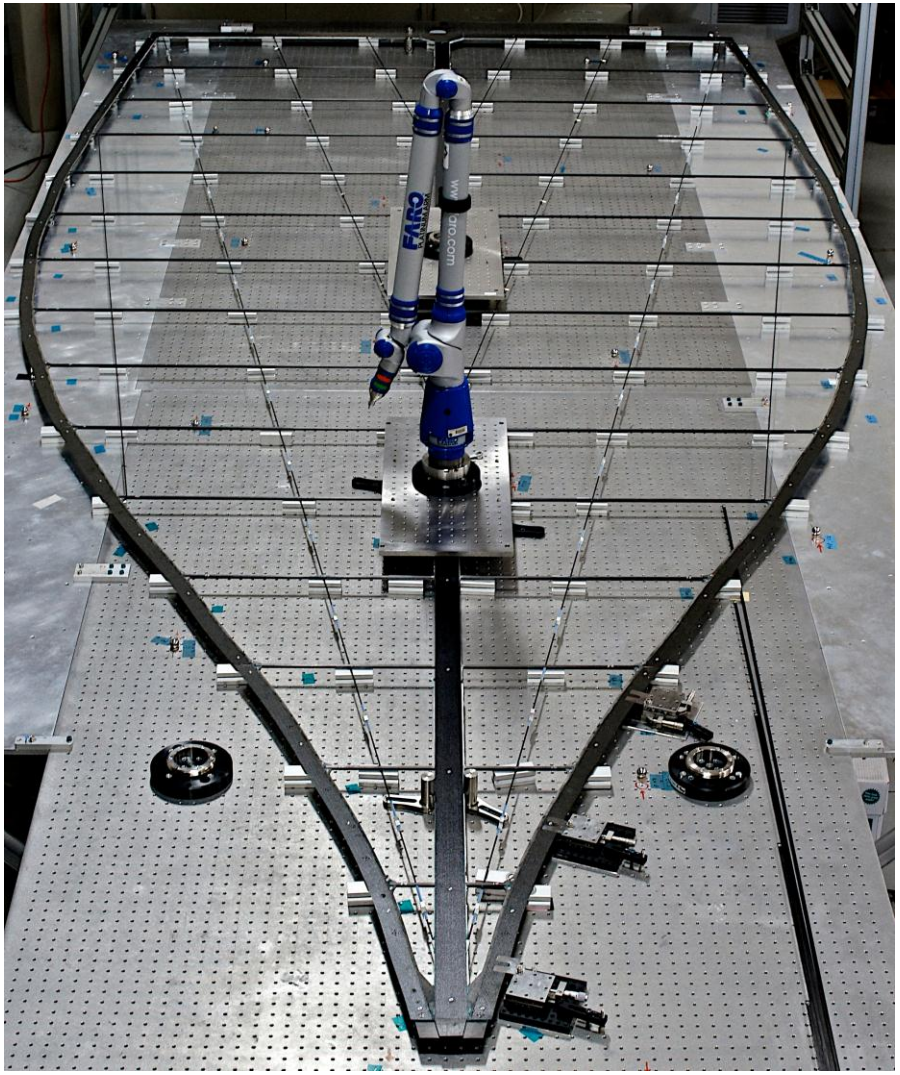
Starshade Technology Milestone: Demonstrate through mechanical measurements on a single petal made of flight-like materials using optical simulations based on those measurements that contrasts of $\leq 3 \times 10^{-10}$ at the inner working angle can be achieved.

Facility: Assembly Handling Facility (Bldg 299), JPL.

Current Status: Mechanical structure complete, and optical edges have been fabricated & installed. The first round of measurements have been completed.

Challenges: Mechanical measurements over a large structure.

Future Work: Milestone measurements to be completed in 1/2012.



Trauger | Guyon | Krist | Kendrick | Clampin | Kasdin | Figer

Donald Figer (Rochester Inst. Technology)
A Photon Counting Detector for Exoplanet Missions

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Detector Technology Milestone:
Demonstrate the performance of a 256 x 256 zero-read noise (Geiger mode) avalanche photodiode after radiation testing. The device must demonstrate a baseline photon detection sensitivity of at least 35% at 350 nm, 50% at 650 nm, and 15% at 1000 nm.

Facility: MIT Lincoln Laboratory and Rochester Institute of Technology

Current Status: A silicon 256x256 diode array has been bonded to a Read Out Integrated Circuit; the array has been hybridized and tested; a first light image has been obtained with good response in the 300–1000 nm range.

Challenges: Scaling to larger number of pixels (1024x1024).
Future Work: Radiation testing in 2012.

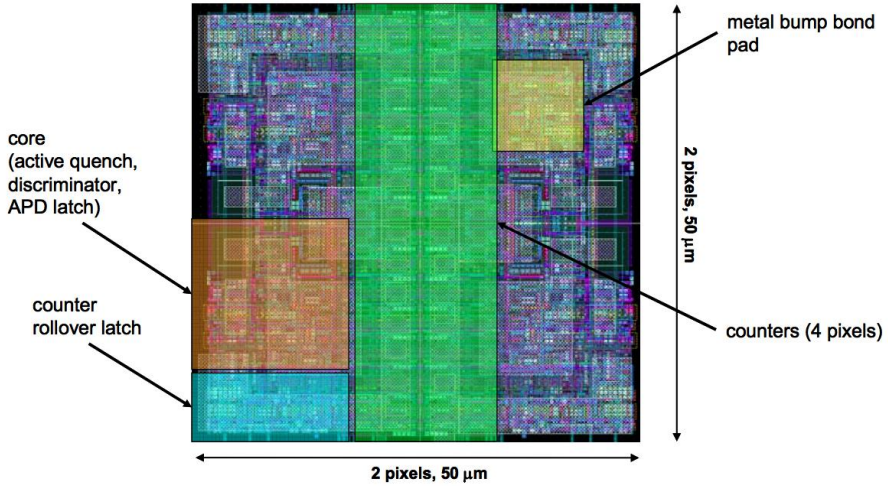

Figure 4. Close-up of the 256×256 ROIC layout, covering a 2×2 pixel area. The counter blocks for all four pixels form a contiguous region. Each pixel has its own isolated core, counter, and bump bond pads, although only one of each is highlighted in this representation.

TDEM 2009 – Reporting of Final Results

- At the end of the TDEM09 demonstrations, Principal Investigators will deliver:
  - Milestone Report

  or
  - Final report describing accomplishments

- All reports will be reviewed by ExEP Technology Assessment Committee (TAC)

- All reports will be posted on the ExEP website
  - http://exep.jpl.nasa.gov/technology/

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TDEM10 – Award Summary

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Principal Investigator	Title	Lead Institution	ExEP Facility
Serabyn	Demonstrations of Deep Starlight Rejection with a Vortex Coronagraph	JPL	HCIT- 1
Shaklan	Coronagraph Starlight Suppression Model Validation: Coronagraph Milestone #3A	JPL	HCIT -1
Kasdin	Integrated Coronagraph Design and Wavefront Control using 2 Deformable Mirrors	Princeton	HCIT-1
Guyon	Advances in Pupil Remapping (PIAA) Coronagraphy: Improving Bandwidth, Throughput and Inner Working Angle (B. Kern)	U of A	HCIT -2
Sandhu	Visible Nulling Coronagraph (VNC) Technology Demonstration Program	JPL	APEP
Kasdin	Verifying Deployment Tolerances of an External Occulter for Starlight Suppression (S. Shaklan)	Princeton	x
Lyon	Compact Achromatic Visible Nulling Coronagraph Technology Maturation	GSFC	x
Bierden	MEMS Deformable Mirror Technology Development for Space-Based Exoplanet Detection	Boston Micromachines	x
Helmbrecht	Environmental Testing of MEMS Deformable Mirrors for Exoplanet Detection	IRIS-AO	x

Coronagraph Contrast Performance Achieved to Date

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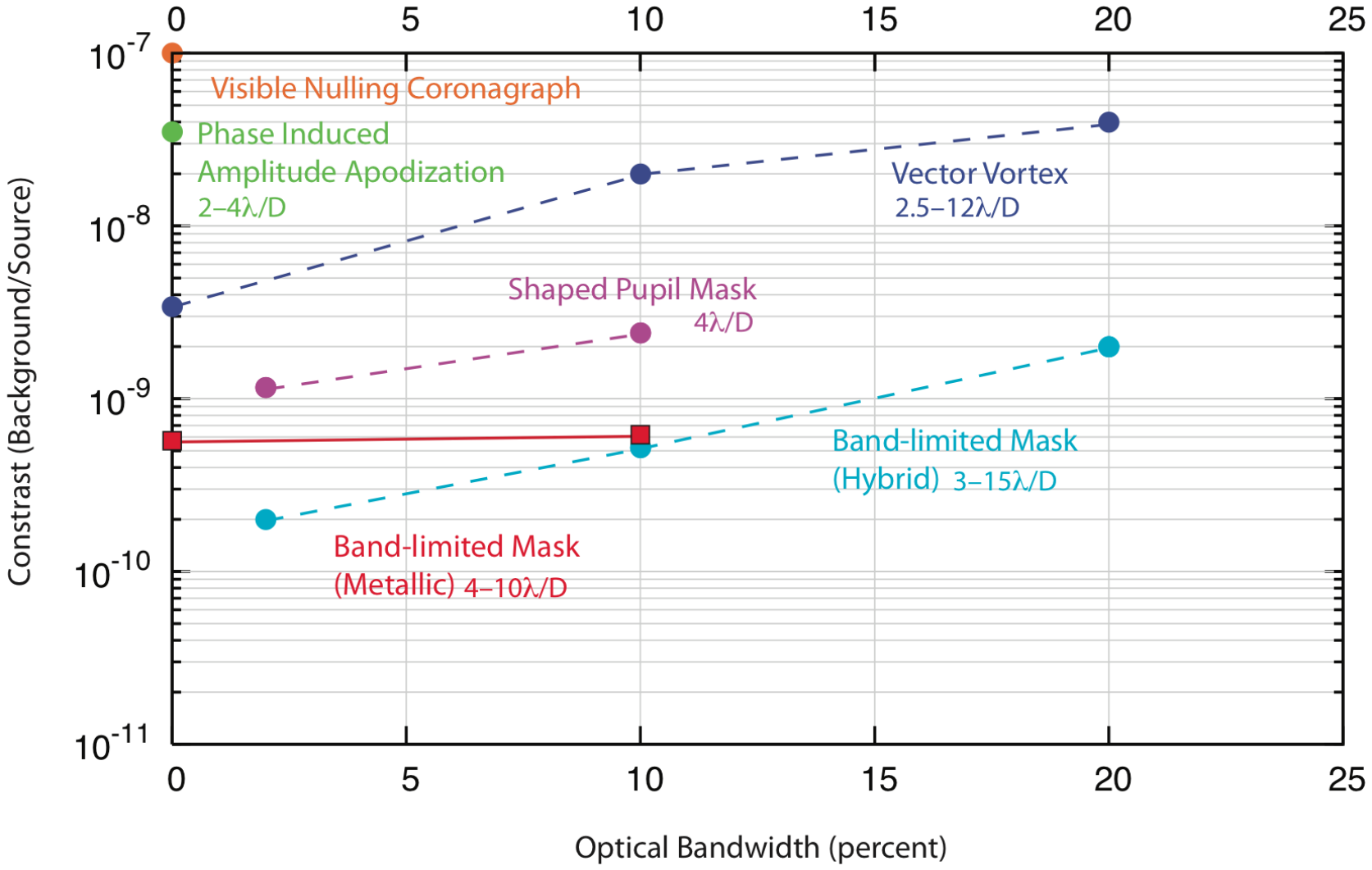

AAS Poster Session: Exoplanet Mission Technologies

ExoPlanet Exploration Program

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Exoplanet Mission Technologies

Poster Session

Monday, Jan 09, 2012, 9:00 AM - 6:30 PM

Exhibit Hall

Monday, 9 Jan 2012
9:00 AM – 6:30 PM

This poster session features papers which highlight technology progress and plans toward space missions which will detect and characterize low-mass extrasolar planets around nearby stars. The main focus is on techniques for starlight suppression, allowing the direct detection of light from an exoplanet and enabling studies based on photometry and spectroscopy of the planet's light. Progress has been made on several distinct techniques for achieving the needed starlight rejection. The session will also include technology developments toward other kinds of exoplanet measurements, such as microlensing, precision astrometry, and transit spectroscopy.

Presentations:

☐ Monday, Jan 09, 2012, 9:00 AM - 6:30 PM
155.01. **Technology Development for Exoplanet Missions**
Peter R. Lawson[1]
[1]*JPL.*

☐ Monday, Jan 09, 2012, 9:00 AM - 6:30 PM
155.02. **A Hybrid Lyot Coronagraph for the Direct Imaging and Spectroscopy of Exoplanet Systems: Recent Laboratory Demonstrations and Prospects**
John T. Trauger[1], D. Moody[1], B. Gordon[1], J. Krist[1], D. Mawet[2]
[1]*JPL,* [2]*ESO, Chile.*

☐ Monday, Jan 09, 2012, 9:00 AM - 6:30 PM
155.03. **Planet Detection Algorithm using Multiple Images with Independent Speckle Patterns**
Elizabeth Young[1], N. J. Kasdin[1], A. Carlotti[1]
[1]*Princeton University.*

☐ Monday, Jan 09, 2012, 9:00 AM - 6:30 PM
155.04. **Designing Shaped Pupils Without Extraneous Constraints**
Robert J. Vanderbei[1], A. Carlotti[1], N. Kasdin[1]
[1]*Princeton Univ..*

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NEW WORLDS TECHNOLOGY FOR THIS DECADE: AAS EVENING SESSION

6:30-8:00 pm, Tuesday, 10 January 2012

NASA's Exoplanet Exploration Program
Jet Propulsion Laboratory
California Institute of Technology

This evening session will review the current state-of-the-art in exoplanet technology and its possible implementation in new smaller mission concepts. A central theme in NASA's science planning is the search for habitable worlds and life beyond our Solar System. Although Earth-like planets would not yet be detectable with current technology, starlight suppression now approaches flight readiness for missions that would image exozodiacal dust around nearby stars and characterize Jupiter-like exoplanets. Mission concepts of various scales based on coronagraph and starshades will be described along with their science objectives and technology requirements.

Agenda

6:30 PM	Introduction & Session Overview	Peter Lawson (JPL/Caltech)
6:40 PM	Coronagraph Technology	
	Probe-class missions	Olivier Guyon (University of Arizona)
	Explorer & Suborbital	Wesley Traub (JPL/Caltech)
7:10 PM	Starshade Technology	
	Probe-class missions	N. Jeremy Kasdin (Princeton University)
	Explorer & Suborbital	Webster Cash (University of Colorado)
7:40 PM	Telescope Technology	
	Design Trades	Rémi Soummer (Space Telescope Science Institute)
7:55 PM	Questions	
8:00 PM	End	

Acknowledgements

Part of this work was conducted at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration

Government sponsorship acknowledged

ExoPlanet Exploration Program