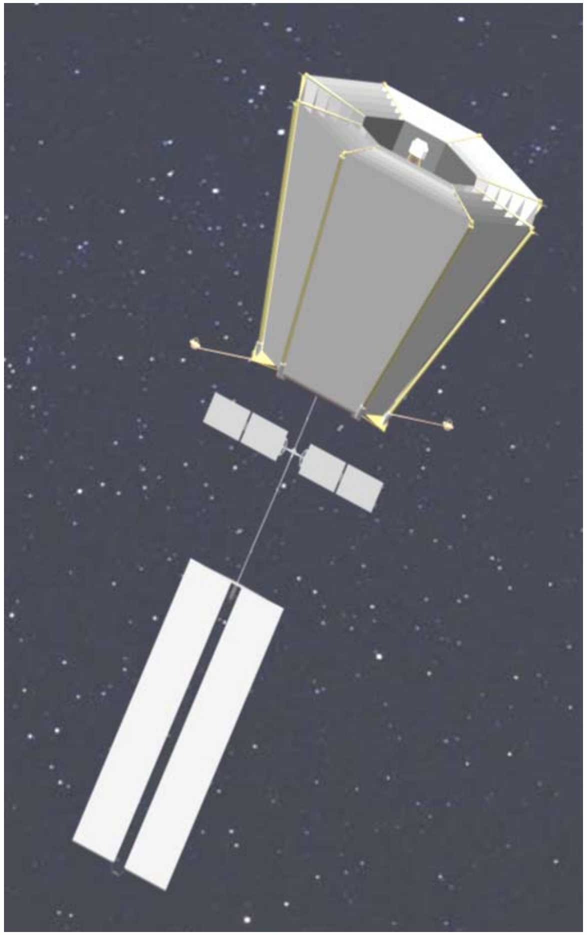
TPF-C University Contracts

Poster Overview

Terrestrial Planet Finder Mission

TPF

- **Contracts**
  - Eight institutions
  - Development of coronagraph technologies
  - Three versions of coronagraph:
    "Classical", Pupil Remapping, Visible Nulling
  - Selected performance parameters
    - Contrast 10^{-10} @ 4 lambda/d IWA (where d is the mirror major axis, assumed to be 8 m, here)
    - Throughput $\geq$ 25%
    - Bandwidth 500 – 800+ nm
    - Number of rolls $\leq$ 3
  - Information contact: Allan Eisenman
- **Coronagraph and Masks**
  - Princeton: Shaped Pupil Coronagraph
  - UC Berkeley: Vector Wavefront Simulation with affiliations
    - Princeton: Mask fabrication and test
    - Ball Aerospace: System simulation
  - NASA GSFC: Vector Optical Modeling
  - SAO: Wavefront Sensing and Control with DM
- **Pupil Mapping**
  - NOAO/U of Hawaii (Subaru): Pupil Remapping using aspheric optics
  - SAO: Hybrid Pupil Mapping with Princeton subcontract
- **Visible Nulling**
  - Boston U: MEMS Segmented Deformable Mirror
  - Penn State/U of Florida: Extremely Coherent Single Mode Fiber Optic Arrays

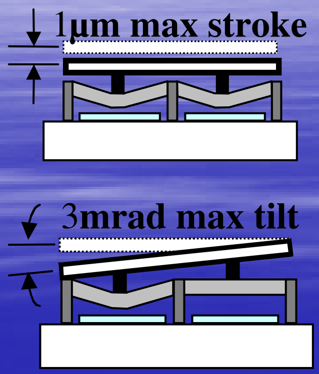


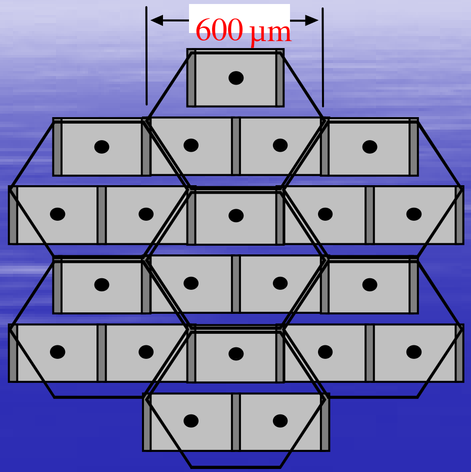
A NASA Origins Mission

Deformable Mirror using MEMS Technology

Boston University

Overview





Fabricate a segmented MEMS deformable mirror array with tip/tilt and piston motion to control wavefront amplitude and phase in the TPF nulling coronagraph architecture

Objective

Develop a silicon fabrication process to manufacture reliable, lightweight, low-power, robust DMs with thousands of degrees of freedom, sub-nanometer positioning resolution and optical quality.

- **Use silicon foundry micromachining for production**
- **Employ successful BMC designs for actuation**
- **Produce unprecedented pixel flatness using Epi-poly process**

Team

- **PI:** **Dr. Thomas Bifano**
  Boston University
  Tel: (617) 353-5619
  Email: tgb@bu.edu
- **Co-I:** **Paul Bierden**
  Boston Micromachines Corporation (BMC)
- **Co-I:** **Dr. Timothy Cook**
  Boston University

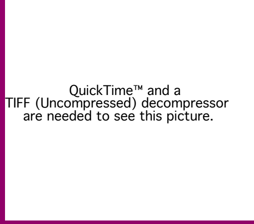
Products

Silicon microfabrication process and prototype device

- **Segmented DM with 11mm clear aperture**
- **600μm pitch, 329 elements, 99.2 % fill factor**
- **987 electro-static actuators, 3 per micro-mirror**
- **< 1nm RMS flatness, 1μm stroke, 3mrad tilt**
- **Motion resolution = 0.1nm piston, 0.06arcsec tilt**
- **Suitable for TPF-C flight**

Pupil Remapping Coronagraph

NOAO/University of Hawaii - Subaru



Stephen Ridgway (NOAO) - PI
Olivier Guyon (Subaru Telescope) - Co-PI

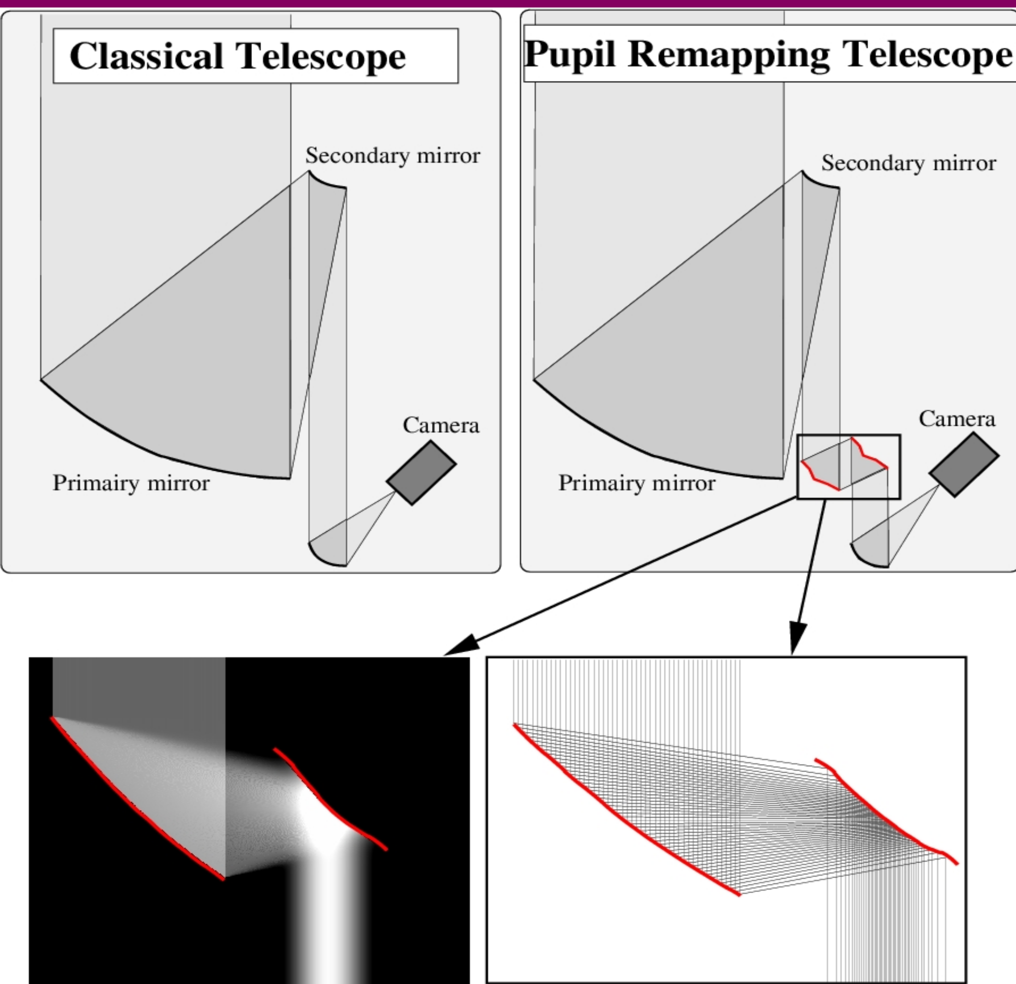
Goals of the project:

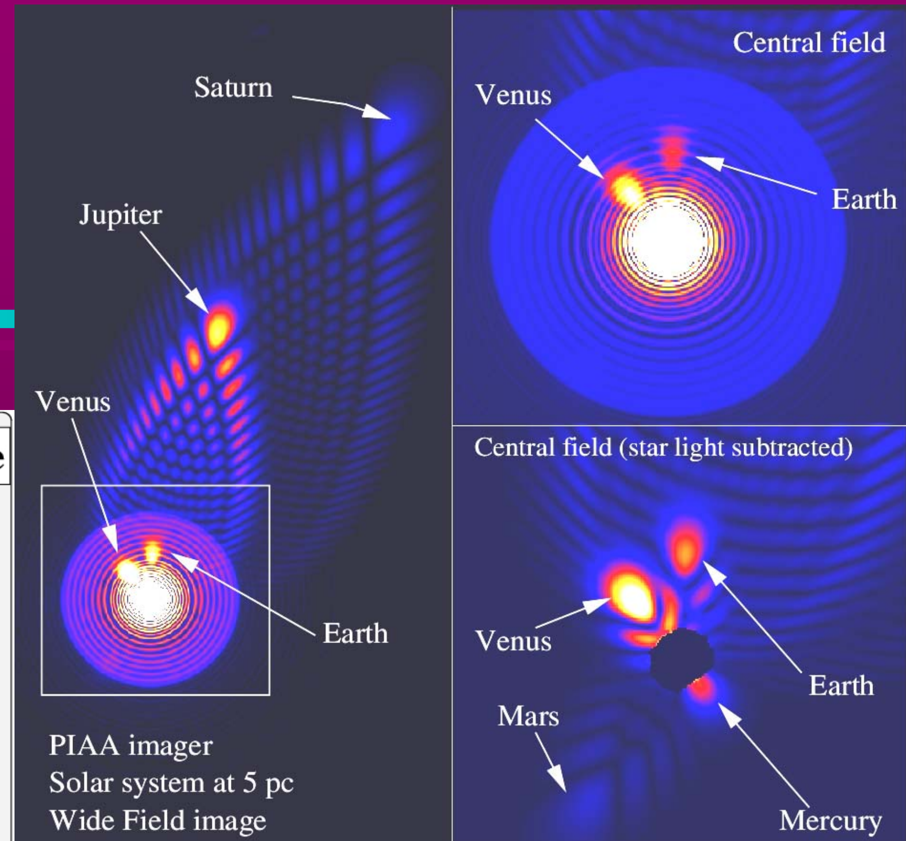
- Design and fabricate aspheric optics
- Validate the Pupil Remapping Coronagraph concept in the lab:
  - demonstrate lossless apodization of a beam
  - achieve 10e-6 PSF contrast at 3l/d
- Simulate in the computer a pupil remapping coronagraph
  - use the simulation to reproduce lab results
  - demonstrate in the simulation performance to the level required for TPF

Schedule :

- Lab experiment
  - 2003 -> end 2004 : preliminary lab demonstration with lenses
  - end 2004 / early 2005 : delivery of high quality pupil remapping mirrors
  - 2005 -> early 2006 : demonstration of high contrast imaging
- Simulations
  - 2003 -> end 2004 : scalar propagation simulations
  - 2005 -> 2006 : vector propagation simulations

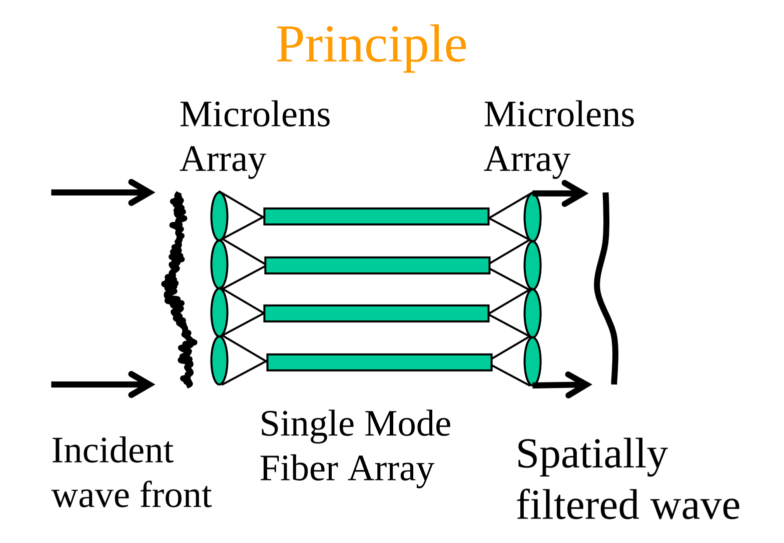
Pupil Remapping Coronagraph (Cont.)





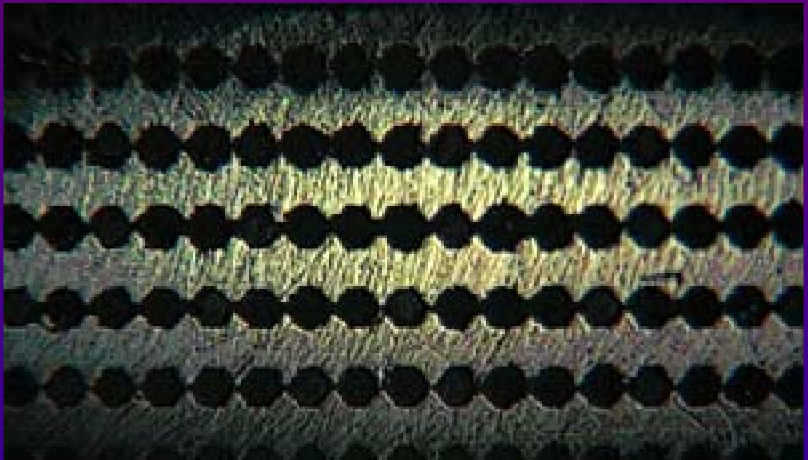
- Simple optical design
- No light absorbed
- Preserved telescope angular resolution
- Achromatic
- Wide-field capability with corrective optics

A Coherent Single Mode Fiber Optic Array for Rejecting Scattered Light



Principal Investigator: Jian Ge

Staff: Shane Miller & Dan McDavitt


Preliminary Fiber Array with 42 single mode fibers in May 2004

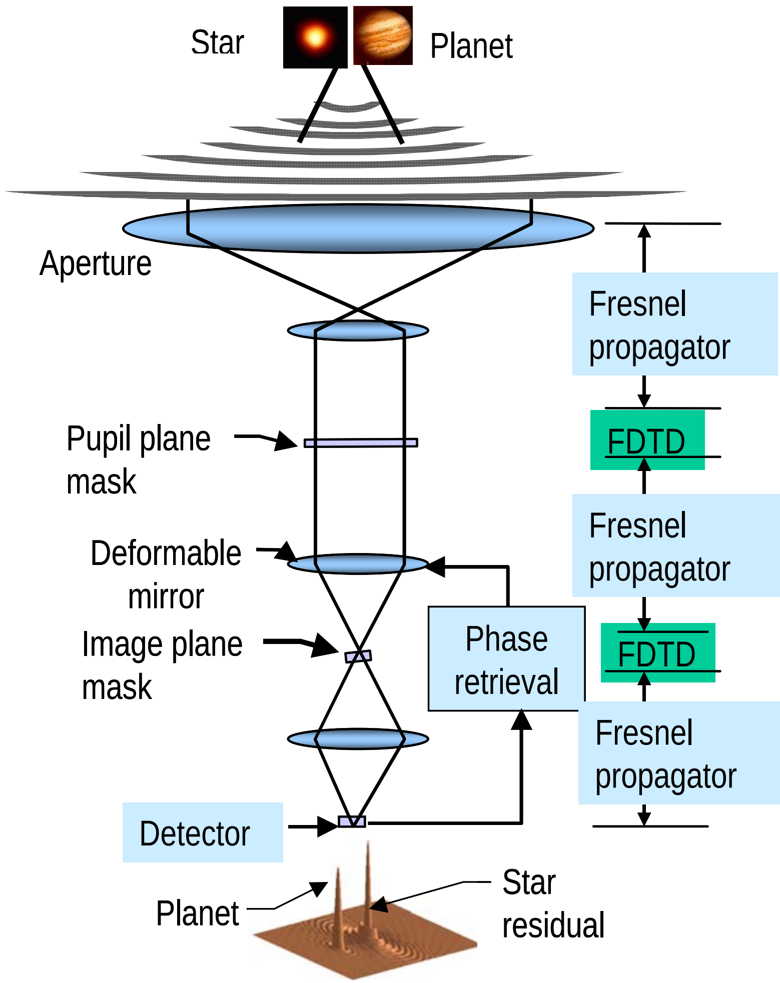
Schedule & Milestones

• Development of V Grooves	4/04
• Preliminary single mode fiber array	5/04
• 10x10 single mode fiber array	12/04
• 32x32 single mode final fiber array	10/06

Note: Contract transferred From Penn State to University of Florida

Vector Wavefront Simulation
University of California Berkeley

- ◆**Goal**
  - •**Model pupil filter vector effects**
  - •**Assess impact on coronograph**
- ◆**UC Berkeley (PI Andy Neureuther, Dan Ceperley and Ta-Ming Shih)**
  - •**Vector scattering from filters**
  - •**FDTD analysis via TEMPEST**
- ◆**Ball Aerospace (Mike Lieber)**
  - •**End-to-end modeling**
  - •**Fresnel propagation with vectors**
- ◆**Princeton (Jeremy Kasdin)**
  - •**Pupil filter design**
  - •**Pupil filter physical structure**



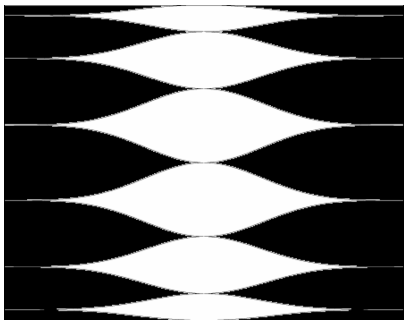
Design and Control of Shaped Pupil Coronagraphs

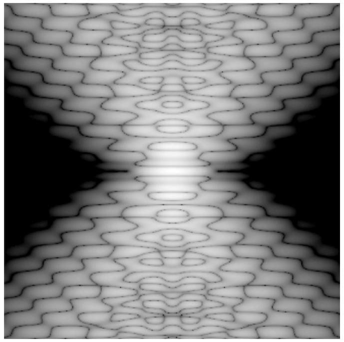
Princeton University

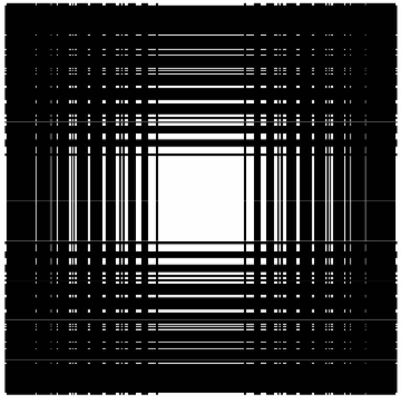
N. Jeremy Kasdin (PI), Robert J. Vanderbei, Michael G. Littman, David N. Spergel

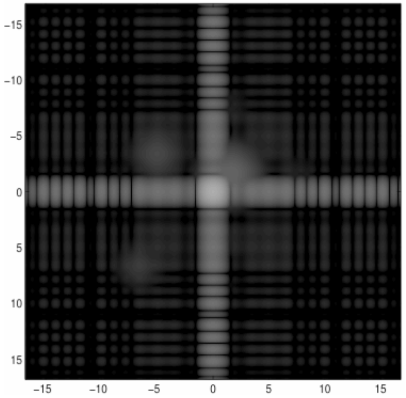
July, 2004

Optimal Shaped Pupil Mask Design

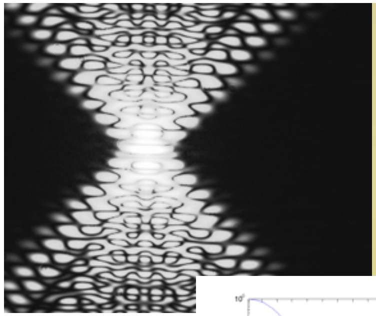


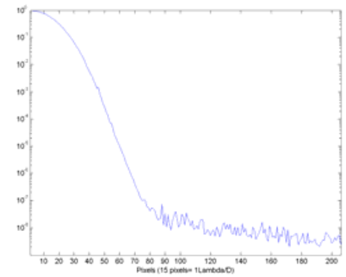




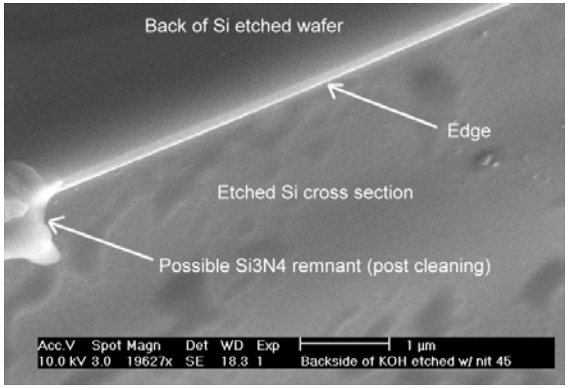


Laboratory Testing



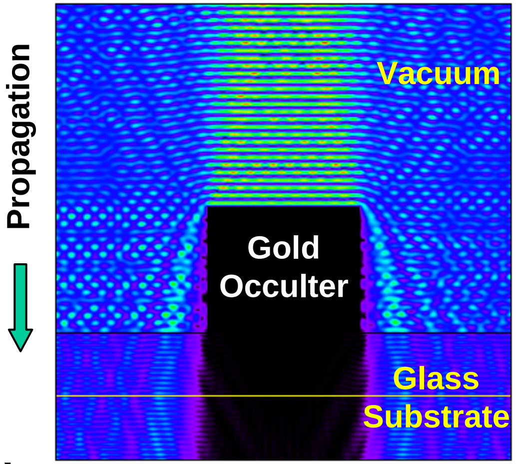


Pupil Mask Manufacturing



Vector Optical Modeling
Goddard Space Flight Center

Products



Products:
1. 3D Vector Model
2. Accurayc of Scalar vs Vector Diffraction
3. Sensitivity analysis & Error Budgets

Objectives

Scalar vs Vector Diffraction Theory
- Develop Scalar & Vector propagation model of HCIT/TPF
- Component transfer functions for s3D components
- Multiple plane diffraction w/ both models
- Sensitivities and Error Budgets w/Scalar & Vector models

Parallel Vector Optical Modeling
- 3D Tetrahedral Mesh FEM Vector Diffraction Code
- Evaluate Occulters and Pupil Plane Masks
- Develop component transfer functions

Fiber Corrector Modeling
- Modeling of fiber bundles

Amplitude and Phase Rectification
- Couple fiber model with DM models
- Evaluation wavefront, amplitude and polarization correction

Participants

PI: **Richard Lyon**
NASA/GSFC Code 935
301-286-4302
Richard.G.Lyon@nasa.gov
Co-I's:
Ron Shiri - GST
Robert Woodruff - Lockheed-Martin
Roman Antosik - CUNY

Schedule

Task	Year 1 - Milestone	Year 2 - Milestone
Scalar Diffraction	Import HCIT & TPF Models to OSCAR	Suite of parametric cases, sensitivities & error budgets
Vector Modeling	3D tetrahedral input geometries for occulters, finish parallelizing code	Couple transfer functions w/OSCAR, parametric studies
Fiber Corrector	OSCAR Model of fiber bundle, VPI model of fiber bundle	Integrate OSCAR w/VPI, full systems simulations
Phase & Amplitude Rectification	OSCAR Model of phase/amp rectification	System simulation, performance assessment and error budgeting

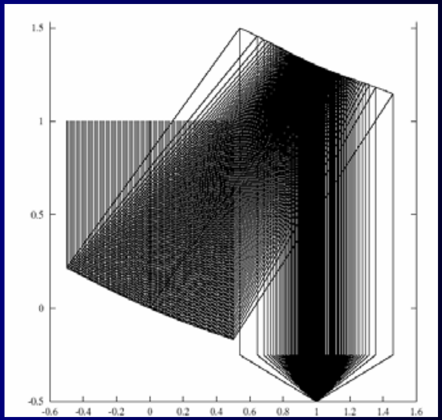
Harvard – Smithsonian
Center for Astrophysics
60 Garden Street, Cambridge, MA 02138

Pupil Mapping, Wavefront Sensing and Control

Smithsonian Astrophysical Observatory

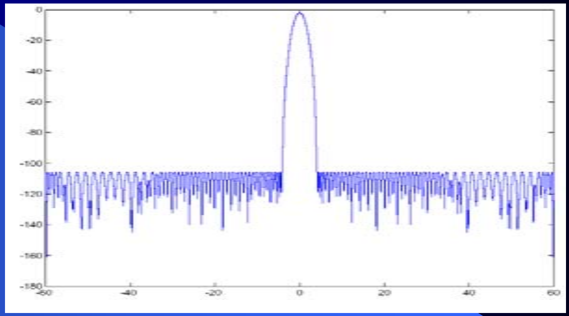
Team

- PI: Wesley Traub - SAO
- Pascal Borde - SAO
- Robert Vanderbei - Princeton University



Pupil Mapping

- Derive 2D mirror shapes
- Rearrange pupil intensity distribution
- Gaussian-like pupil amplitude profile
- Focus for Gaussian-like star image and block with mask
- Detect surrounding planetary system without loss



Wavefront Sensing and Control Algorithms

- Speckle pattern sensing
- Reduce speckle background < 10 exp 10
- Implement with a deformable mirror
- Test Algorithms on JPL Hugh Contrast Imaging Testbed