ExEP Infrastructure for Technology Demonstrations at JPL

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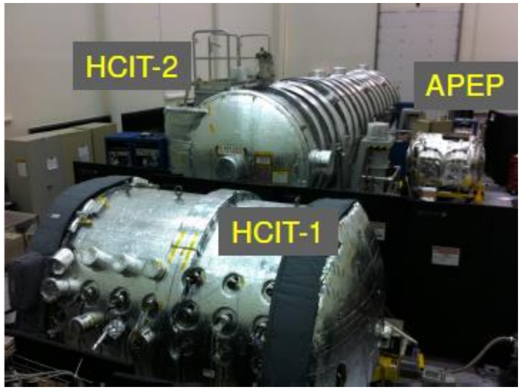
Pre-Proposal TDEM 13 Briefing
01/21/14

JPL Infrastructure for Technology Demonstrations

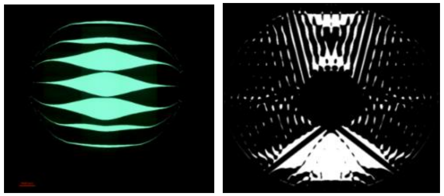
- **The following presentation provides an overview of JPL infrastructure available to support your TDEM proposal.**

- **There is no obligation to conduct your TDEM at JPL; the available infrastructure, however, if appropriate for your needs, may help reduce your proposal costs and schedule.**



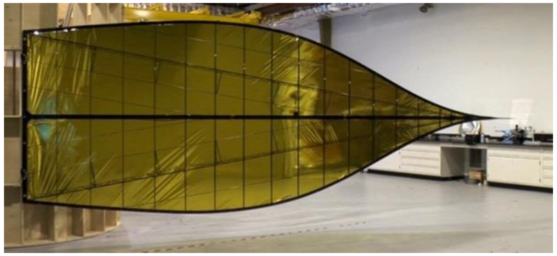
Unavailable or limited infrastructure at JPL for TDEM 13

- High Contrast Imaging Testbeds (HCITs) and Wavefront Sensing & Control



Available infrastructure at JPL for TDEM 13

- Apep Vacuum Chamber
- Vacuum Surface Gauge
- Coronagraph modeling
- Microdevices Laboratory (MDL)
- Large deployable structures infrastructure
- Starshade modeling
- Mach-Zender interferometer (new)



Unavailable or Limited Infrastructure at JPL for TDEM 13

Large High Contrast Imaging Testbeds (HCIT) and Wavefront Sensing & Control

Facility

- Vacuum Chamber: P = 1 mTorr ; Seismically isolated; stabilized ~ 10 mK @ room temp.
- Achieved 3×10^{-10} contrast (narrowband)
- Wavefront control with 32x32mm Xinetics Deformable Mirrors w/ 1mm pitch. Also 64x64mm & 48x48 mm.
  - New 16-bit electronics for FY12
- Fiber/Pinhole "Star" Illumination
  - Monochromatic: 635, 785, 809 and 835 nm
  - 2, 10 and 20% BW around 800 nm center
  - Medium and High Power Supercontinuum Sources
- Low-Noise (5e$^-$) CCD camera, 13 μm pixels
- Complete computer control w/ data acquisition & storage
- Safe & convenient optical table installation/removal
- Parallel in-air preparation & modifications to coronagraphs
- Remote access through FTP site

Deformable Mirrors

- Xinetics DMs available for single and 2 DM tests:
  - 32x32mm (3) & 64x64mm (1)
  - 48 x 48 mm (2) – but no electronics available
  - Continuous Fuse Silica facesheet polished to $\lambda/100$ rms
  - Surface stable to 0.01 nm rms over > 6 hours in vacuum

Test Capability

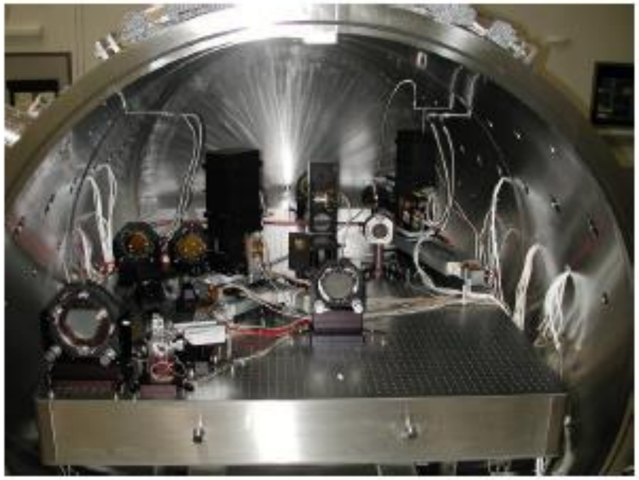
- Proposed experiments can capitalize on existing WFS&C capabilities to complement starlight suppression demonstrations

ExEP Starlight Suppression Facilities

Testbed sizes

HCIT-1: 5'x8'

HCIT-2: 6'x10'


HCIT with Lyot Coronagraph Installed

Availability expected no earlier than beginning of FY16, possibly FY17.

Available Infrastructure at JPL for TDEM 13

Small Vacuum Chamber (Apep)

Currently configured for visible nulling light suppression.

Vacuum facility co-located w/ HCIT & MAM

- Optical layout as shown on the right
- Includes DM, pupil and science cameras
- Leverages technology development from TPF-I, Gemini Planet Imager, and SIM

16-Bit DM Electronics for Vacuum

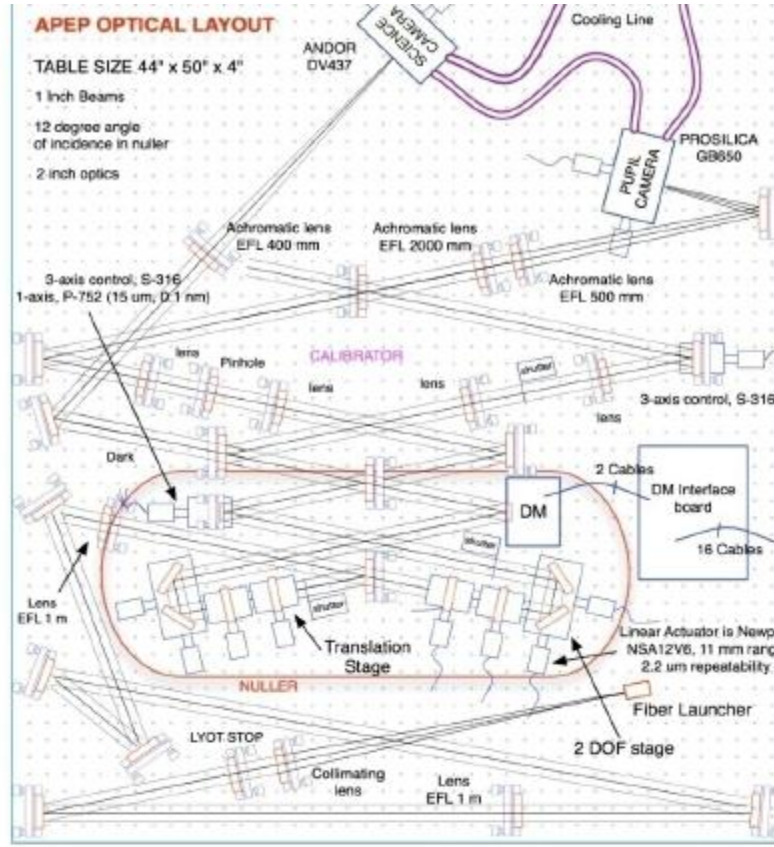
- Minimizes feed-throughs into vacuum tank
- Designed for Boston Micromachines segmented DM
- Conductively cooled electronics and chassis

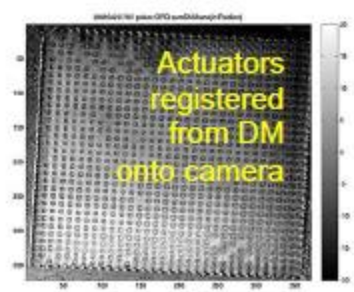
Coherent Fiber Bundle and Lens Array

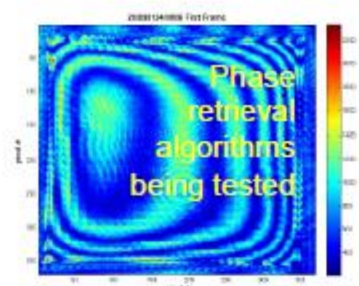
- Prototype of 217 fibers, with map of fiber positions
- Fiber bundle & lenslet array now integrated
- System performance demonstrated

Control System Based on RTC

- Real-time phase retrieval demonstrated
- DM control better than 5nm



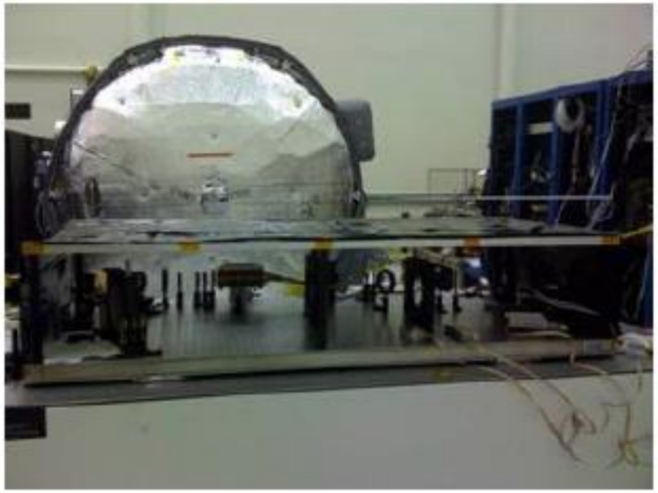




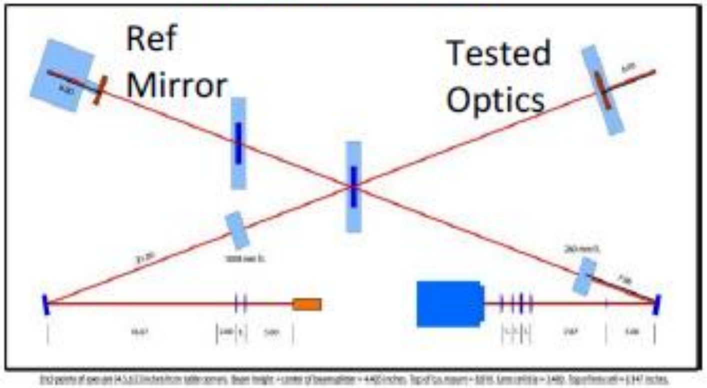
Vacuum Surface Gauge

Capability: Accurate wavefront measurement and deformable mirror calibration

- Customized Michelson Interferometer set-up
  - Reference mirror w/ absolute position feedback
  - Frequency stabilized laser source
- Camera pixel size: 100 microns equiv. on surface to be measured
- Dedicated algorithms for wavefront extraction over > 10^6 pixels
- Demonstrated optical surface measurement Accuracy: << 1 nm rms
- Presently limited to testing optics and deformable mirrors < 4" diameter
- Operates in vacuum within HCIT lower level
  - Concurrent measurement w/ other coronagraph experiments
- Now being used for detailed calibration of Xinetics DMs influence function & linearity
- User provides electronic drivers and feed-through cables



Surface Gauge bench fits into lower mezzanine of HCIT

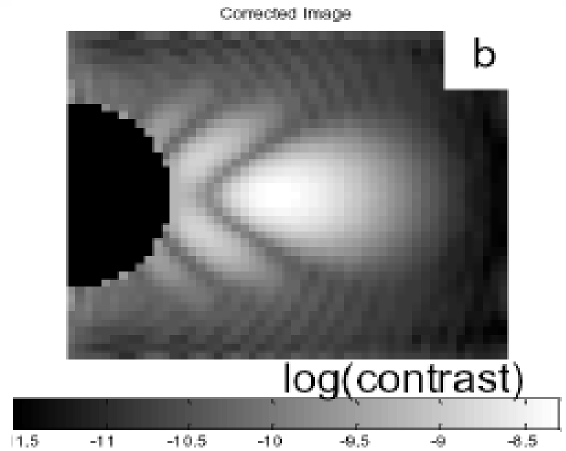


Surface Gauge optical layout

Coronagraph Modeling and Error Budgets

Coronagraph Modeling

- Multiple models and tools are available:
  - Optical diffraction tools with Fresnel propagation and active wavefront control for simulations of broadband contrast performance
    - Includes mask transmission errors, alignment & optical figure errors, nulling algorithms w/ deformable mirror influence functions
    - Lyot and PIAA propagation models are available
  - HCIT Testbed models for Lyot and PIAA
  - Mission simulation, orbit determination, spectra characterization



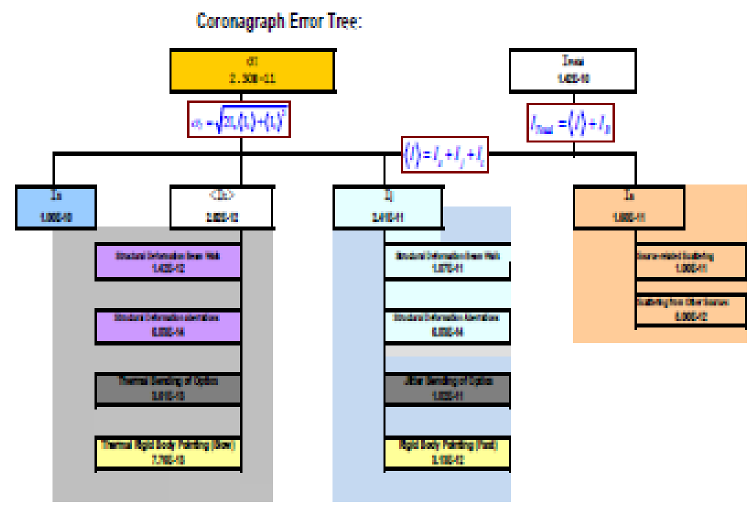
PIAA residual image after DM correction (Shaklan SPIE 2007)

Generalized Error Budget Tool

- Automated error budget tool for any internal coronagraph system:
  - observatory tolerances to back-end contrast
- Based on diffraction analyses of specific coronagraphs (Lyot, PIAA, Vortex) & sensitivities of actual optical prescriptions
- Near-seamless integration of Matlab-code and Excel macros for rapid prototyping

TDEM application

- Specifying Milestone performance goals tied to flight missions
- Defining testbed error budgets and sensitivities for model validation



Coronagraph Error Budget Tool

Microdevices Laboratory (MDL)

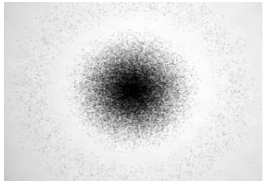


Figure 1. Microscope image (above) and AFM profile (below) of a micro dot patterned mask for JWST NIRCam coronagraph

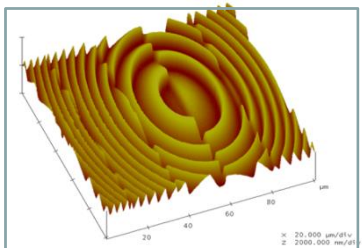
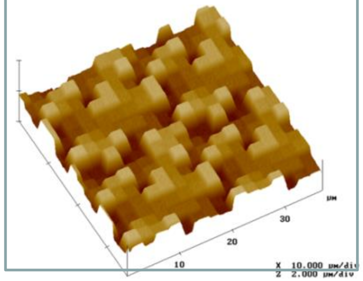


Figure 2. Diffractive optical devices



Advanced fabrication and characterization techniques

- Electron Beam Lithography
- Deep Reactive Ion Etching
- ICP Cryo Etching of Black Silicon microstructures

- Scanning Electron Microscopy
- Precision Optical Microscopy
- Atomic Force Microscopy
- 2D and 3D profilometry

Light suppression mask fabrication processes developed for:

- Micro dot patterned mask for JWST (Figure 1)
- Diffractive optical structures for spectrometer gratings and other computer generated holograms (Figure 2)
- Shaped pupil masks with fine structures and slits for transmission geometry (Figure 3)
- Shaped Pupil masks with black silicon structures in reflective aluminum background (Figure 4, a proposed design)
- LOWFS masks (Figure 5) incorporating a black silicon region (Figure 6) as well as shaped aperture through a silicon wafer
- Achromatic focal plane masks with deep diffractive structures (Figure 7)
- Micro slits for fabricating Hybrid Lyot coronagraph masks
- PIAACMC mask (Figure 8, a proposed design)
- Hybrid Lyot mask for AFTA (Figure 9, a proposed design)

http://microdevices.jpl.nasa.gov/

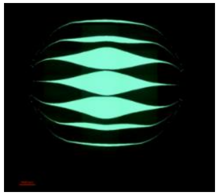


Figure 3. Transmissive slit SP mask

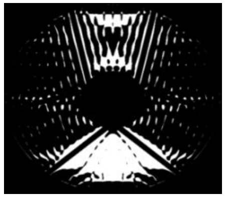


Figure 4. Reflective and absorptive SP mask

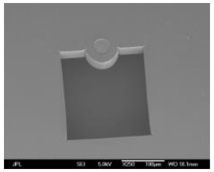


Figure 5. LOWFS mask

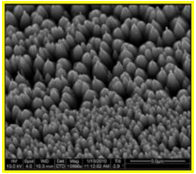


Figure 6. Black Si Microstructure

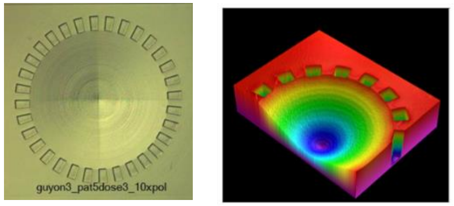
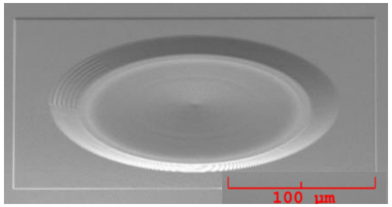


Figure 7 . Achromatic Focal Plane Masks (AFPM)



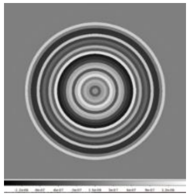


Figure 8 . PIAACMC mask

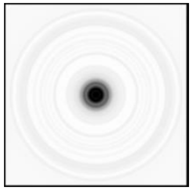


Figure 9 . Hybrid Lyot mask

Jet Propulsion Laboratory
California Institute of Technology

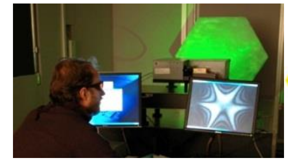
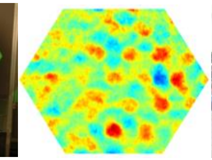
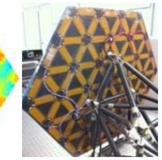
Large Deployable Structures
(Advanced Large Precision Structures Lab)

Facility

- Tests deployment accuracy and stability of large structures
- Dimensions: 10-m x 5-m x 3-m
- Stable environment for testing:
  - Thermal Stability: < 0.01 K/hr, <0.02 K/24 hrs
  - Vibration: < 75 micro-g rms (0-500 Hz)
  - Acoustics: 35 dbA
  - Relative Humidity Stability: 1%
- Cabling Pass thru for external electronics
- Active thermal control
  - <5 min for air temperature stabilization (30 min from cold start)
  - Up to 1 KW heat load while maintaining performance
- Optical table available for additional isolation
- Class 100,000 clean room capable
- Wall and ceiling mounting possible

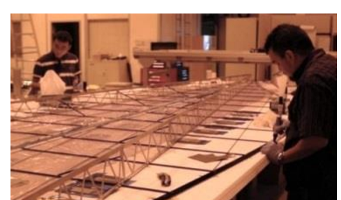
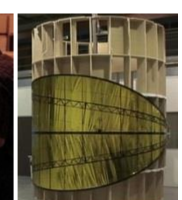
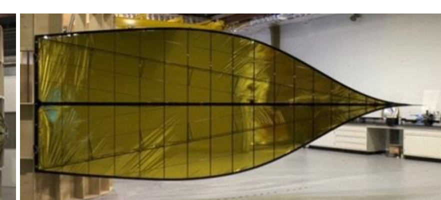
Measurement Capabilities

- Scanning Laser Vibrometer
- Labview data acquisition and control
  - 50 high speed simultaneous sampling for accelerometers
  - Experimental control via custom UI
- Laser Holography system for in-plane or out-of-plane deformations of 10 nm to 25 microns.
- Videometry for <0.5 mm measurements at up to 16 frames/second for 20 min.
- FLIR thermal imaging camera
- Modal test exciters and ID software.
- **Leica laser tracker systems; Faro portable CMM machines up to 2.5m radius reach**
- **Range-gated metrology measures displacement 5 nm and absolute position to sub-micron levels**

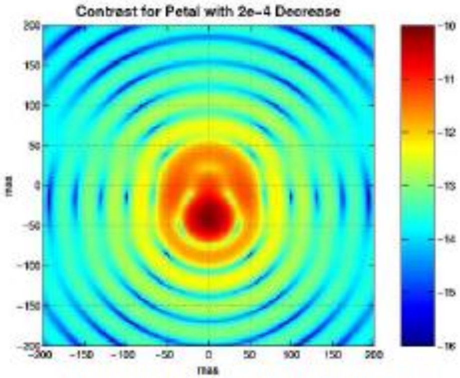
Recent Starshade Activities

- Measurements of minute thermoelastic deformations of the petal profile due to temp changes.
- Photogrammetry and laser tracker deployment accuracy measurements and repeatability of a deployable starshade at NGAS.
- Portable CMM used to precisely assemble graphite composite petal, verifying required manufacturing tolerances.

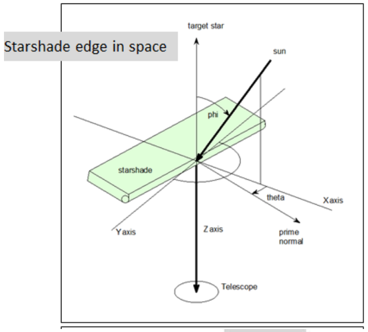




Additional Starshade Infrastructure

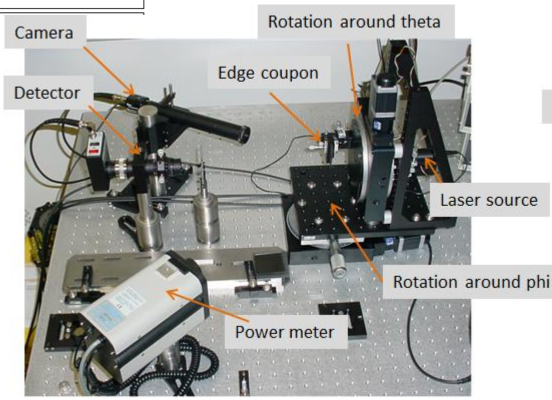
- **Optical Modeling**
  - Large scale optical diffraction models to simulate the effect of petal deformations and imperfections on contrast.
  - Models built for representative designs and validated against other independent models.
  - Efficient algorithm can handle large problems.
  - Seamless hand-off of structural deformation data to optical contrast analysis.



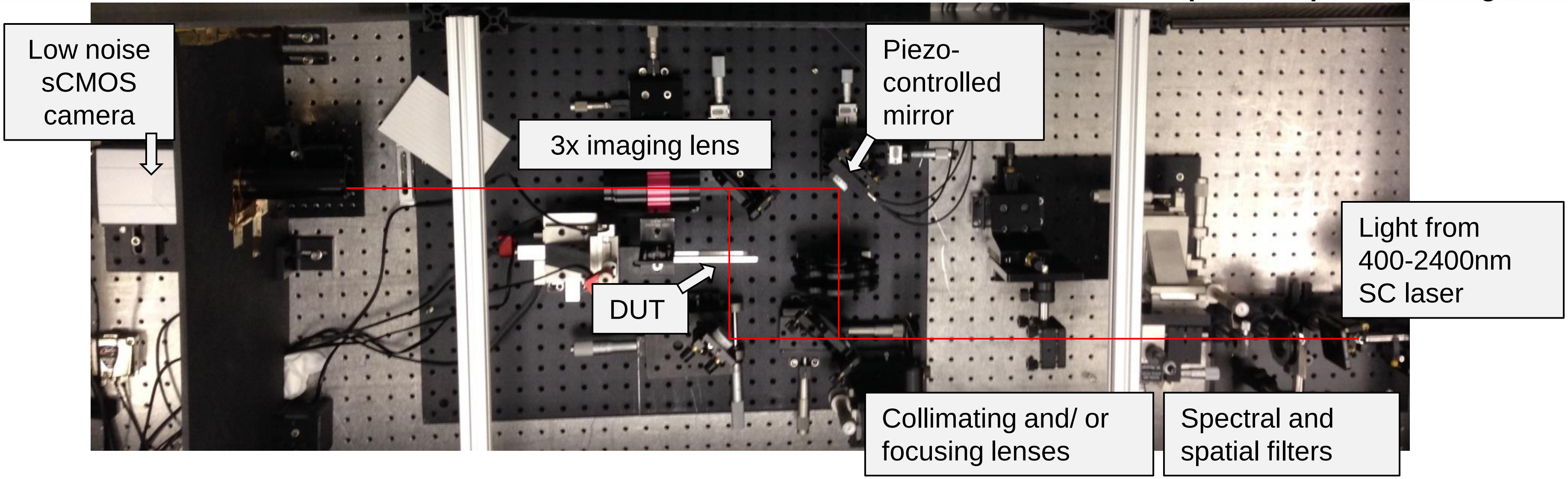
Contrast degradation due to 1mm width change in a single petal (20 petals, 54m tip-tip occulter)



- **Scatterometer Testbed**
  - Measurements of scatter from edge coupons
  - Geometry scalable to the flight situation
  - Accurate for both specular and diffuse scatter
  - Measures down to ~10^{-23} W/m^2 equivalent in space
  - Optical chopping eliminates background light
  - Separate measurements for s and p polarizations



Mach-Zehnder Interferometer for Characterizing Transmissive Coronagraph Masks



- Phase-shifting Mach-Zehnder interferometer for characterizing coronagraph mask phase and amplitude transmission
  - Can be used for characterizing any transmissive coated or uncoated mask
- Attractive for characterizing high optical density (OD) masks due to single-pass optical propagation
- Phase delay resolution <0.1 rad @ 633 nm (TBR). Post-processing algorithm development ongoing to further minimize instrument noise contribution
- Diffraction-limited spatial resolution of ~3 um, can handle masks up to ~1''x1''
- Option of collimated illumination (for faster characterization) or scanned focused illumination (for characterizing masks with great OD variation). Latter capability still under development.
- Data acquisition and processing largely automated
- Presently set up for air testing only

Gaining Access to the ExEP Infrastructure at JPL

How to Request Use of ExEP Infrastructure at JPL

- **Submit preliminary Statement of Work (SOW) for use of ExEP infrastructure to Nick Siegler no later than March 3, 2014 (nsiegler@jpl.nasa.gov).**
  - SOW submitted after the due date will not be incorporated in this initial assessment, and will be addressed *time permitting*.
- **Follow SOW questionnaire on next page.**
  - SOW can be revised after discussions and negotiations with Nick Siegler
- **Schedule meeting with Nick Siegler between March 3 – 10, 2014 to discuss use of the infrastructure of interest and to obtain costing guidelines.**
- **Nick Siegler will evaluate workforce, labor, and infrastructure access required across all received SOWs.**
  - Assessment will be provided to Doug Hudgins for consideration in proposal review process.
- **Nick Siegler will supply a Letter of Commitment for use of ExEP infrastructure.**
  - PIs are to include both the SOW and the Letter of Commitment in their proposal.

SOW Questionnaire for Use of ExEP Infrastructure

1. Brief description of the proposed TDEM
2. What infrastructure is requested?
3. Milestone (s) to be accomplished and performance goals
4. Description of how the milestone work will be conducted (brief test /analysis plan)
5. Period(s) and preferred dates over which the infrastructure is requested, stating whether in vacuum or air for testbeds. Include any time required for preparatory work.
6. A list of the personnel and expertise as supplied by your proposal who will assist in the use of the infrastructure. Provide level of effort for each person during the period the facility is being requested.
7. Anticipated changes to the baseline infrastructure needed to accommodate your milestone demonstrations.
8. List of items needed for all testbed modifications. Identify items you will be procuring within your proposal's budget and provide approximate cost of needed items. If applicable, state that no additional procurements will be necessary for the use of the infrastructure under consideration.
9. If necessary, provide any other relevant information or constraints.

How to Cost the Use of ExEP Infrastructure at JPL

- **Some base-funding is provided for access to ExEP infrastructure at JPL. However, additional labor and procurements must be costed within a proposal to support the work:**
  - Directly funded through the proposal (PI-managed JPL labor & procurements)
  - Request additional infrastructure support through the Program (ExEP managed labor and procurements)
  - In either case the PI remains responsible for leading the demonstrations

- **Each facility/resource is different and its use must be negotiated directly with the Program.**

- **During the proposal review process, the actual cost for the use of a facility may be adjusted as to make best use of facilities and workforce, as viewed across all awards.**

ExEP Technology Infrastructure POC

For questions concerning use of ExEP technology infrastructure or requests for more detail contact:

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