Exoplanet Exploration Technology Infrastructure at JPL

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ExEP Infrastructure Support at JPL

Available Facilities

- The following presentation provides an overview of infrastructure available to support your proposal:
  - ExEP Facilities & Testbeds
  - ExEP Models, Software
  - Other JPL capabilities ...

How does one cost the use of ExEP facilities at JPL?

- Some base-funding is provided for access to JPL infrastructure. 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-managd)
  - ➢ 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.

Requesting Infrastructure Support

How to request use of ExEP Infrastructure at JPL?

- Submit Preliminary Statement of Work (SOW) for use of ExEP Infrastructure to Marie Levine **no later than March 1, 2013** at marie.levine@jpl.nasa.gov
- Follow SOW questionnaire on next page
- Schedule telecon w/ Marie Levine the week of 3/04/11 – 3/12/11 to discuss use of the facility of interest and to obtain costing guidelines
- SOW can be revised after discussions and negotiations with Marie Levine
- Marie Levine will evaluate workforce, labor and infrastructure access required across all received SOW. Assessment will be provided to Doug Hudgins for consideration in proposal review process.
- SOWs submitted after the due date 3/1/13 will be addressed *time permitting prior to proposal due date*.
- Marie Levine will supply the Letter of Commitment for use of ExEP Infrastructure.
- PIs are to include both the SOW and the Letter of Commitment in their proposal.

What happens after Proposals are awarded?

- Marie Levine will convene the Community User's Group (CUG) formed of the new and existing TDEM PIs to negotiate testbed schedules.

Statement of Work Questionnaire for use of ExEP Infrastructure

1. Brief description of the proposed TDEM
2. What facility/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 facility/ infrastructure is requested, stating whether in vacuum or air for testbeds. Include any time required for preparatory work.
6. A list of personnel and expertise as supplied by your proposal who will assist in the use of the facility/ infrastructure. Provide level of effort and tasks for each person during the period the facility is being requested.
7. Anticipated changes to the baseline facility/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.

High Contrast Imaging Testbed - HCIT

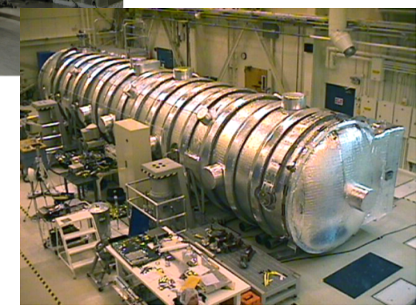
Facility

- Vacuum Chamber – L = 7.5' ; ø = 6' ; P = 1 mTorr Seismically isolated, T-stabilized ~ 10 mK @ room temp.
- Achieved 3x10^{-10} contrast (narrowband)
- Wavefront control with 32x32mm Xinetics Deformable Mirrors w/ 1mm pitch. 64x64mm soon.
- 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

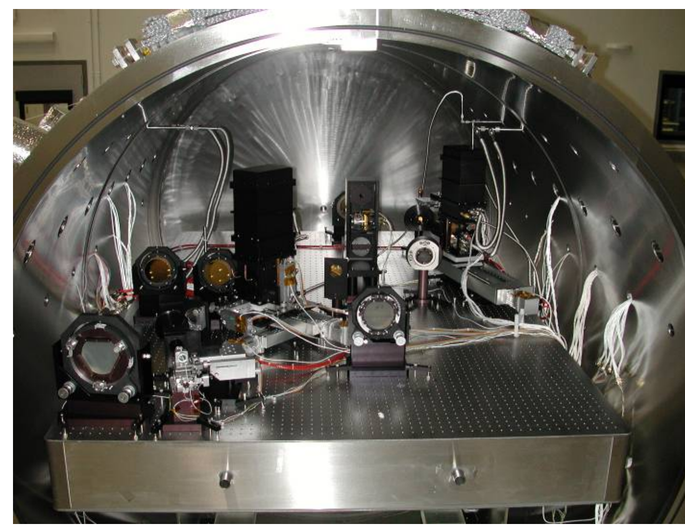
Test Capabilities

- LYOT Coronagraph configuration – Table #1
  - Band-Limited Occulting Masks
  - Shaped-Pupil Masks
  - Vector-Vortex Masks
- Phase-Induced-Amplitude-Apodization (PIAA) Coronagraph – Table #2
- Narrow or broad band coronagraph system demos
- Investigation of novel system configurations (e.g., DM placement)
- Coronagraph model validation & error budget sensitivities

HCIT-1 for Lyot-type Coronagraphs



HCIT-2 for PIAA Coronagraph



HCIT with Lyot Coronagraph Installed

APEP: Visible Nulling

ExoPlanet Exploration Program

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

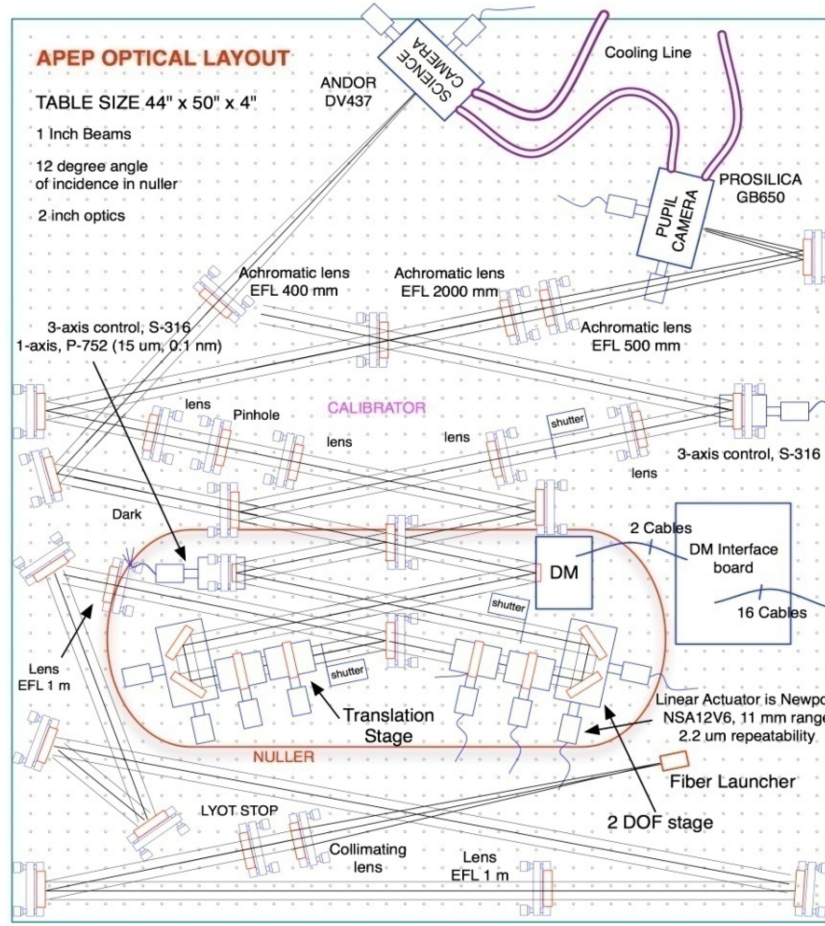
- Minimizes feed-throughs into vacuum tank
- Designed for Boston Micromachines segmented DM
- Conductively cooled electronics and chassis

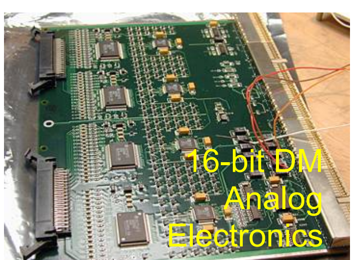
Coherent Fiber Bundle and Lens Array

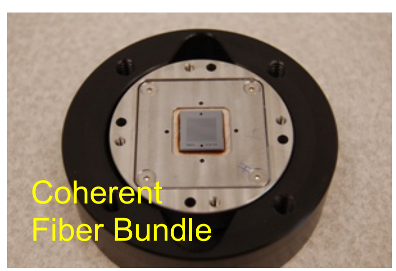
- Prototype of 217 fibers, with map of fiber positions
- Fiber bundle & lenslet array now integrated
- System performance demonstrated

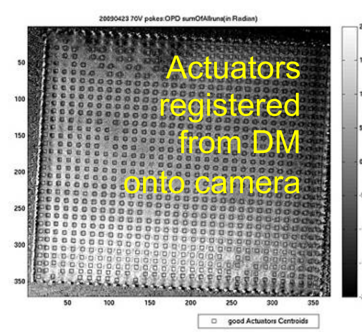
Control System Based on RTC

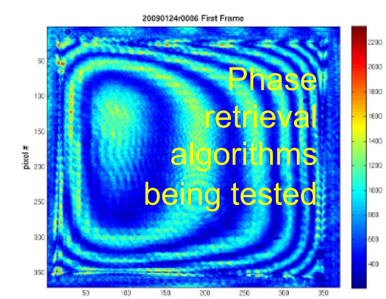
- Real-time phase retrieval demonstrated
- DM control better than 5nm





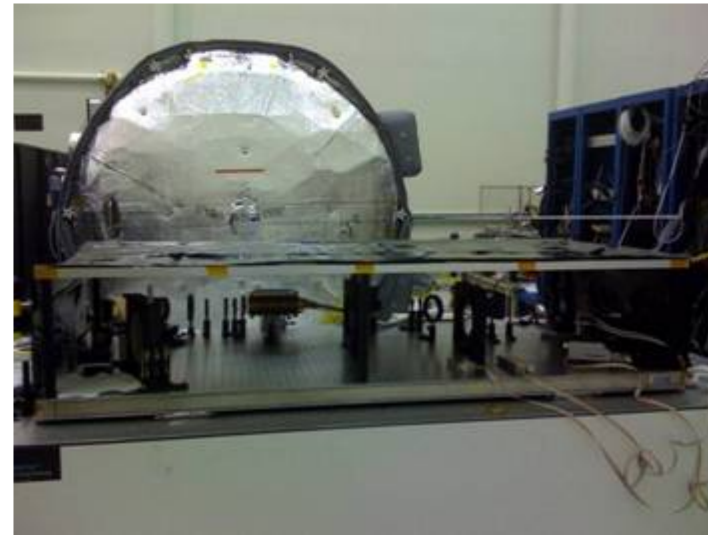




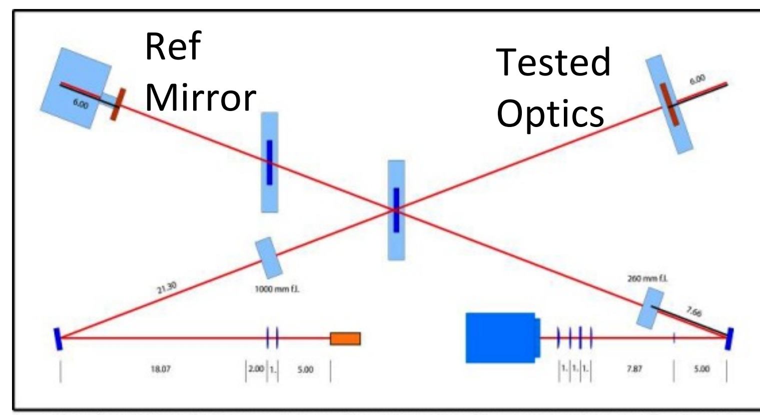


Vacuum Surface Gauge for Accurate Wavefront Measurement and Deformable Mirror Calibration

- 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 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



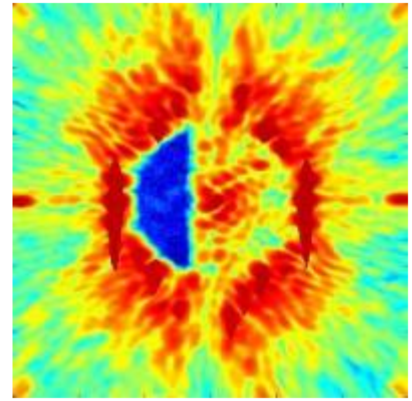
End-points of axes are [4.5,6.5] inches from table corners. Beam height = center of beamsplitter = 4.405 inches. Top of b.s. mount = 8.810. Lens cell dia = 3.480. Top of lens cell = 6.147 inches.

Surface Gauge optical layout

Wavefront Sensing & Control

Nulling Algorithms

- Electric Field Conjugations (EFC) algorithms exist for single and dual DM control
- Demonstrated to < 10^{-9} contrast and 20% BW
- Applicable for Lyot, Shaped Pupil, Vortex & PIAA
- Coupled to HCIT coronagraph models and DM calibration data for optimal efficiency



Best Results to Date

***Band-Limited Coronagraph*:**
6 e-10, @ 3 λ/D with 10% BW
2 e-9, @ 3 λ/D with 20% BW

***Shaped-Pupil Coronagraph*:**
1.2 e-9, @ 4 λ/D with 2% BW
2.4 e-9, @ 4 λ/D with 10% BW

***PIAA Coronagraph*:**
<1e-9, @ 2 λ/d with 0% BW

***Vector Vortex Coronagraph*:**
<1e-9, @ 3 λ/d with 0% BW

EFC Nulling and current performance

Deformable Mirrors

- Xinetics DMs available for single and 2 DM tests:
  - 32x32mm (3) & 64x64mm (1)
  - 48 x 48 mm (2) – but electronics not yet available
  - Continuous Fuse Silica facesheet polished to λ/100 rms
  - Surface stable to 0.01 nm rms over > 6 hours in vacuum
- Boston Micromachines MEMs DMs available in 2014
  - Continous facesheet mirrors w/ 1020 actuators

Xinetics DM

Test Capability

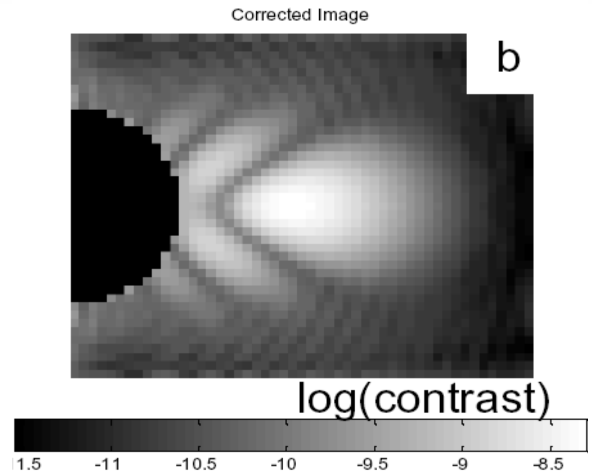
- Proposed experiments can capitalize on existing WFS&C capabilities to complement starlight suppression demonstrations
  - New coronagraph demonstrations w/ existing S/W & DM
  - New algorithm demonstration w/ existing DMs & masks
  - New DM demonstrations on existing coronagraph
    - Proposer to provide DM electronics, calibration data and any new H/W for HCIT optical configuration
  - Apply EFC to novel coronagraph <u>models</u> to determine by analysis if there are any limitations to broadband contrast and to look for advantages/disadvantages of the coronagraph in terms of WFS/C.

Coronagraph Modeling & Error Budgets

ExoPlanet Exploration Program

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



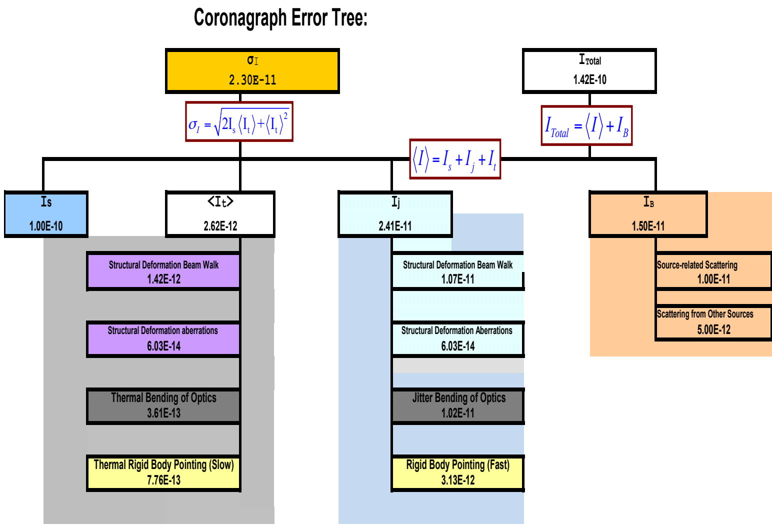
PIAA residual image after DM correction (Shaklan SPIE 2007)

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

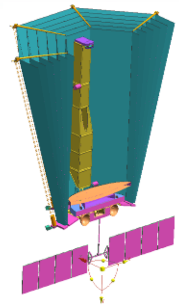


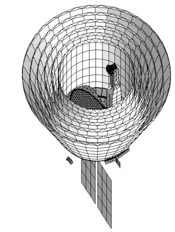
Coronagraph Error Budget Tool Screenshot

Integrated Modeling Tool: CIELO

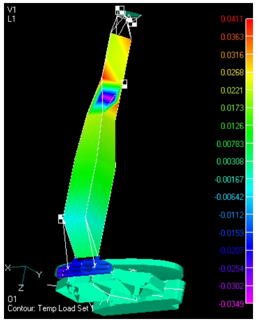
General-purpose finite element computational tool for multi-physics analysis:

Thermal – Structures – Optics - Control

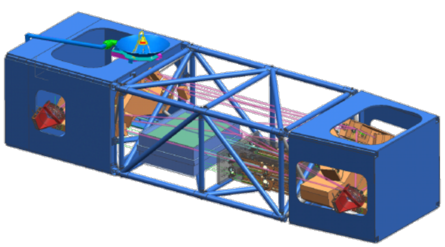




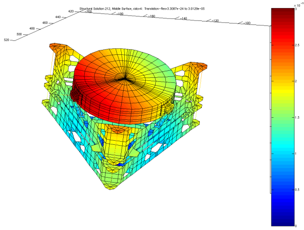
- Unique Attributes:
  - Provides integrated common thermal & structural model w/ subsequent optical aberrations : no "bucket brigade" or mesh interpolation
  - Matlab hosted and Nastran input file driven
  - Runs on serial and parallel machines
  - Eliminates model size limits of COTS thermal codes



- Advantages:
  - Turnaround time improved via common model
  - Wall clock time improved via parallel computing
  - Accuracy improved w/ finer mesh & double precision

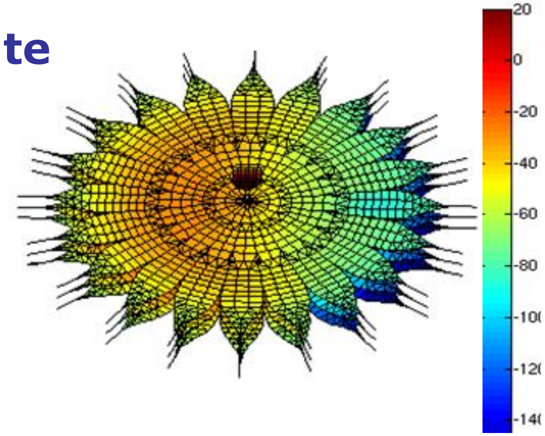


- Unique analysis capabilities
  - Parametric multi-physics sensitivity analysis for performance optimization, uncertainty quantification, error budget tolerancing & verification
  - Multi-physic test/model correlation
  - Integration w/ other domain (eg controls)

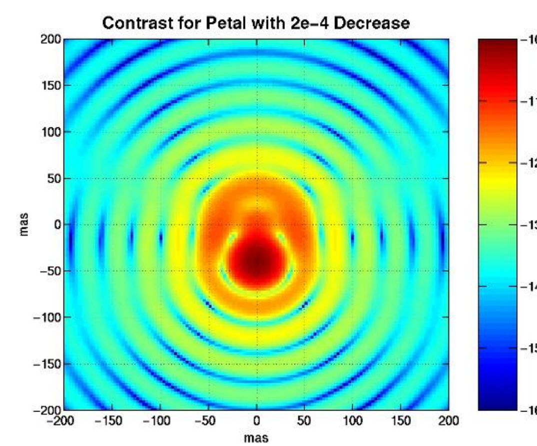


External Occulter Modeling

- **Large scale optical diffraction models to simulate the effect of petal deformations and imperfections on contrast**
  - Models built for representative design and validated against THEIA results
  - Efficient algorithm can handle large problems
- **Thermo-mechanical finite element models using in-house integrated analysis code CIELO**
  - Single model for thermal & structures w/ high fidelity at petals edges – no extrapolation
  - Perform transient slew & settle thermal deformation analysis
  - Investigate damping and nonlinear joint dynamics
  - Perform parametric sensitivity analyses to material property distributions, for performance optimization…
  - Validate models against sub-scale test articles
- **Seamless hand-off of structural deformation data to optical contrast analysis.**



Thermal model (°C) of 3-layer flat external occulter w/ Sun at 5°



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

Exoplanet Program Point of Contact

For questions concerning use of ExEP technology infrastructure contact:

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