Technology Development to find Earth 2.0

The Decadal Survey Testbed:

Design & Hardware Description

Presenter: Keith Patterson (NASA JPL/Caltech)

NASA Exoplanet Exploration Program

Exoplanet Science Strategy Final Report

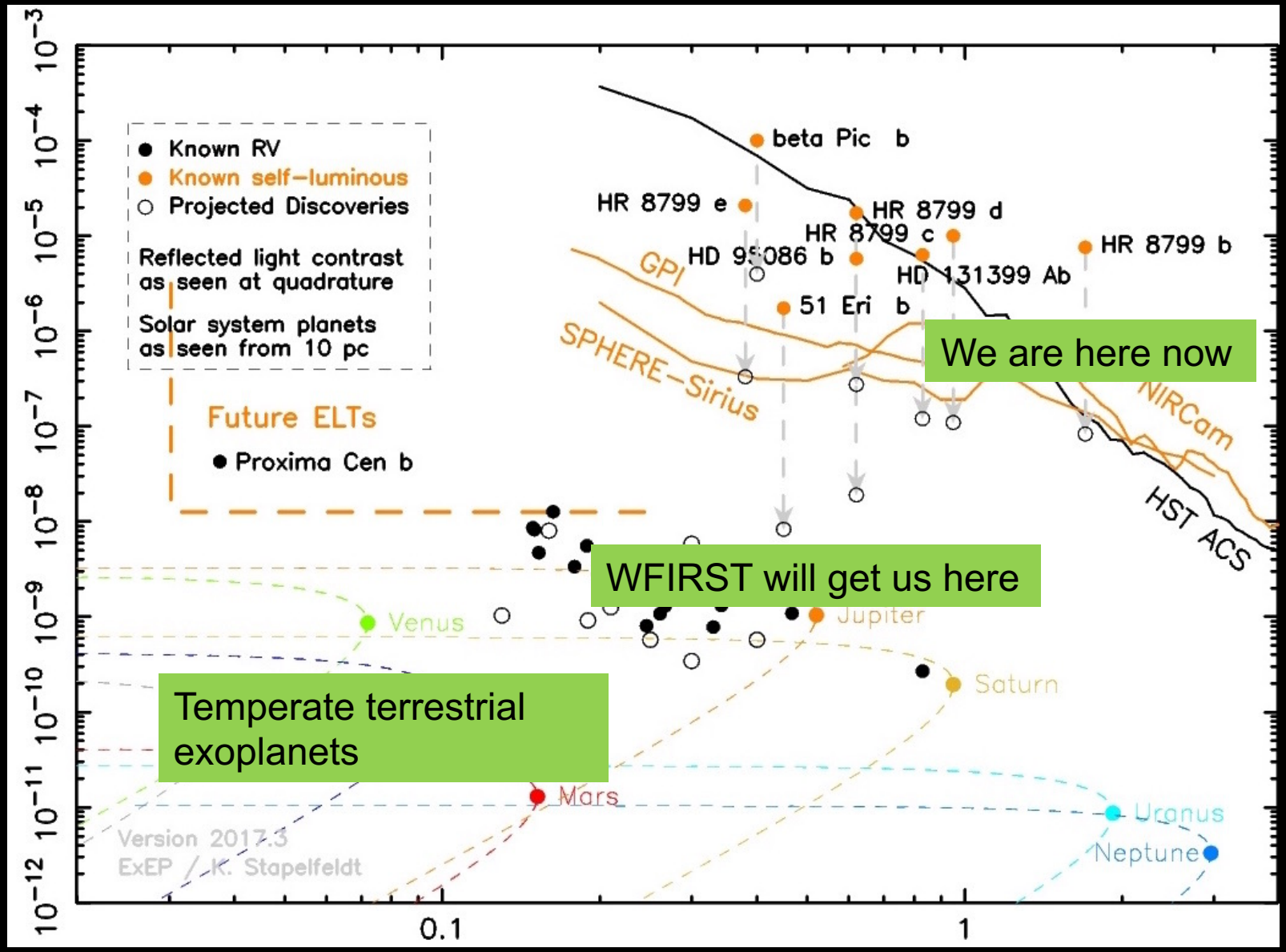
Released September 5, 2018 by the National Academies

Recommendation #1:

NASA should lead a large strategic direct imaging mission capable of measuring the reflected-light spectra of temperate terrestrial planets orbiting Sun-like stars.

David Charbonneau (Harvard) Scott Gaudi (Ohio State University)

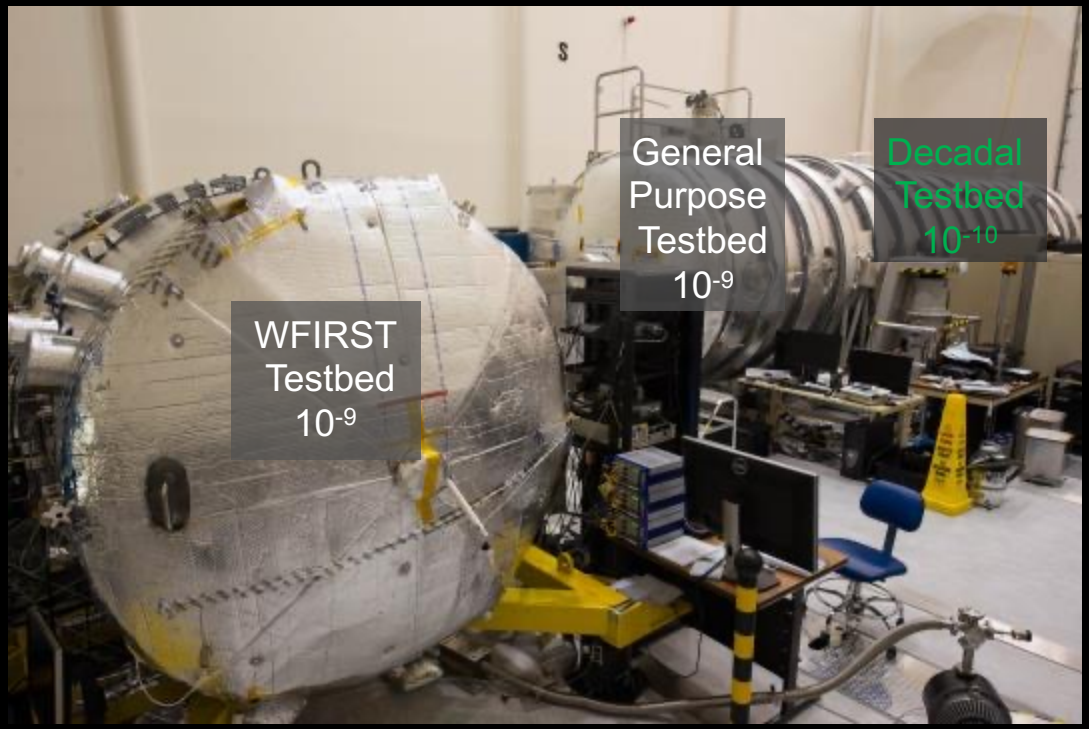
→ Starlight suppression is needed → Coronagraphs


Relative Brightness
Planet/Star
Known RV
Known self−luminous
Projected Discoveries
Reflected light contrast as seen at quadrature
Solar system planets as seen from 10 pc
Future ELTs
Proxima Cen b
beta Pic b
HR 8799 e
HR 8799 d
HR 8799 c
HR 8799 b
HD 95086 b
HD 131399 Ab
51 Eri b
GPI
SPHERE−Sirius
NIRCam
HST ACS
We are here now
WFIRST will get us here
Temperate terrestrial exoplanets
Venus
Jupiter
Saturn
Mars
Uranus
Neptune
Version 2017.3
ExEP / K. Stapelfeldt
0.1
1
Angular Separation (between planet and star, arcsec)

High Contrast Imaging Testbed Facility

Managed by the NASA Exoplanet Exploration Program

- Cleanroom highbay facility located on JPL campus
- Over 10 years of coronagraph technology development
- Two large vacuum testing chambers
  - Space-like environment
  - Provides stability needed for coronagraph studies
- Currently supporting WFIRST CGI, in addition to R&D efforts such as the Decadal Survey Testbed (DST)



Purpose of the DST

- Improve the chances that a large telescope exoplanet concept be recommended by the 2020 Decadal Survey by demonstrating that 1e-10 is achievable

- Commission a testbed that can host technology development activities for any selected coronagraph mission

Additional Benefits

- Lessons learned regarding coronagraph masks, hardware, and algorithms etc. shared between WFIRST CGI and DST teams (primarily the same personnel)

- Potential opportunity for WFIRST CGI to piggyback 10^-10 capable ‘demonstration’ masks in flight instrument

Decadal Survey Testbed

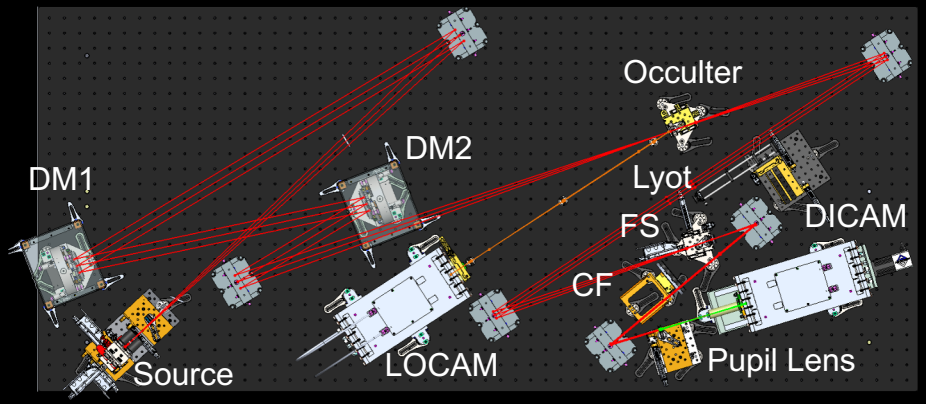
DST advances compared to prior HCIT testbeds:

- Extensive thermal control
- Vibration isolation
- Low-order wavefront active control available
- Minimum # of surfaces (no folds)

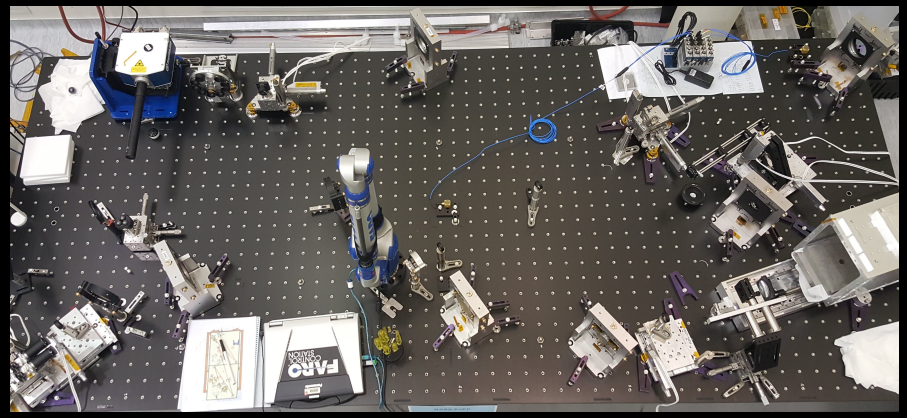
Configuration:

- Simplified HLC layout
- LOWFS/C capable

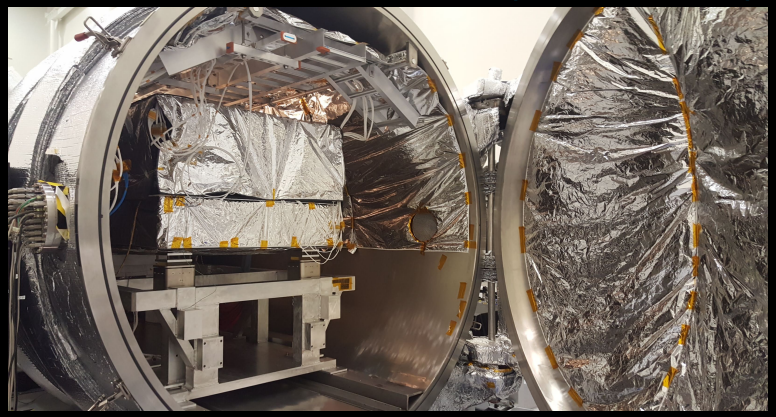
Optical Layout and Testbed Design



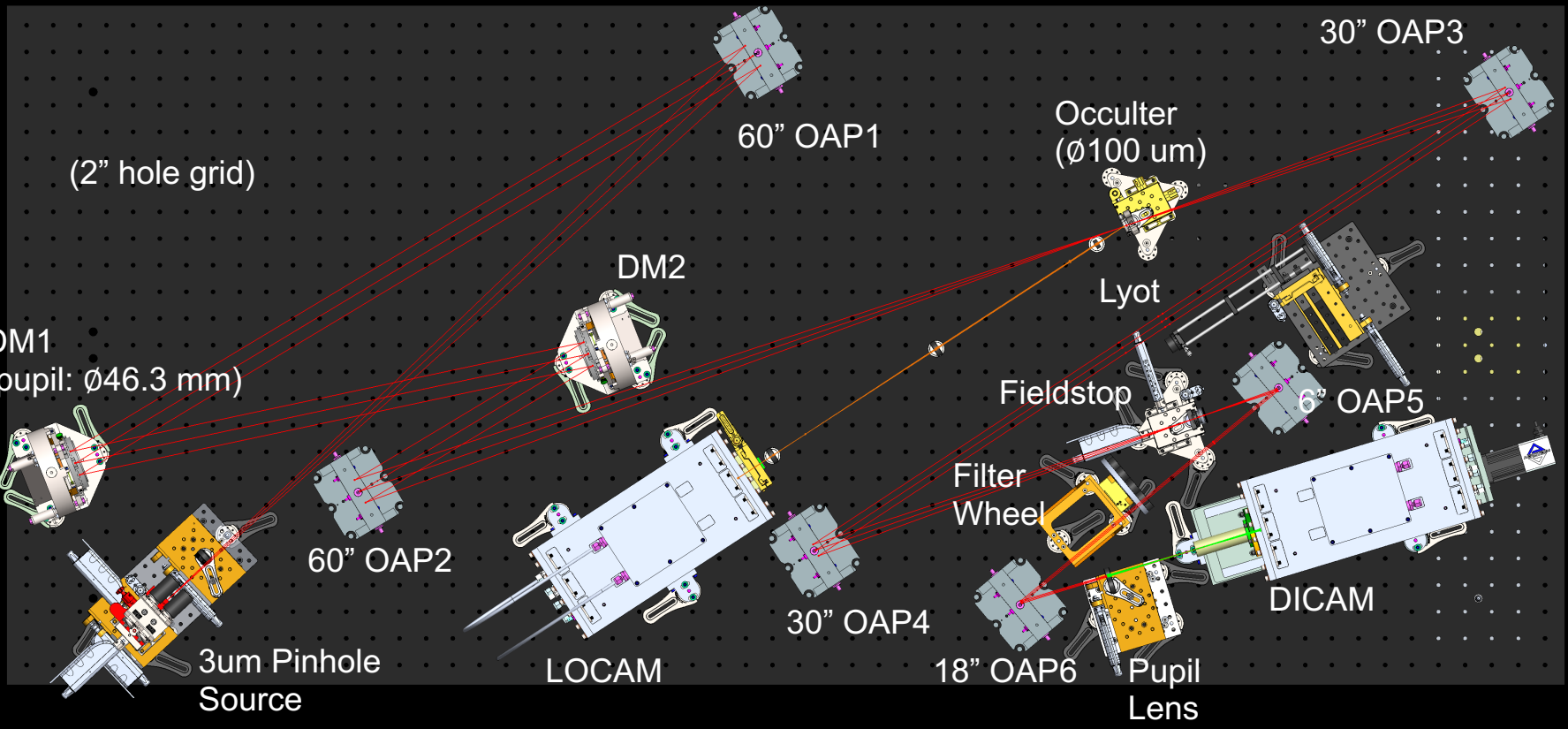
Build and Alignment



Into Vacuum Chamber (June 2018)



Optical Layout



~3.0 meters

Center wavelength: 550 nm

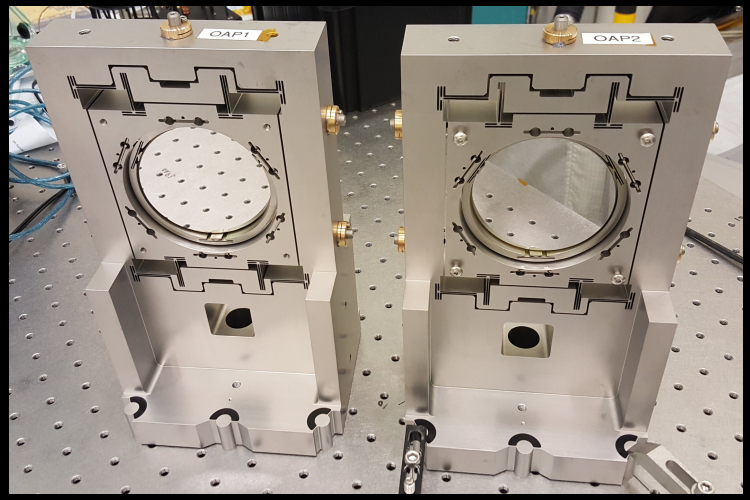
Optical Bench

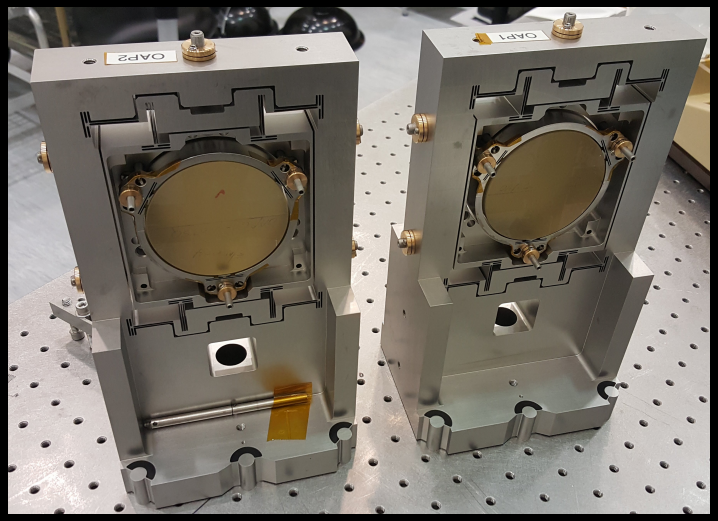
- Procured from CarbonVision in Germany
- 3 m x 1.5 m x 0.3 m
- ~200 kg
- Fully carbon composite construction, including ribs
- Recessed ¼”-20 threaded inserts on a 2” grid
- Vacuum compatible epoxy
- First mode >200 Hz with 250 kg of optics weight
- Supported on 3 MinusK vibration isolator legs + RTV insulation pads

Bench being loaded into bakeout chamber

Optics

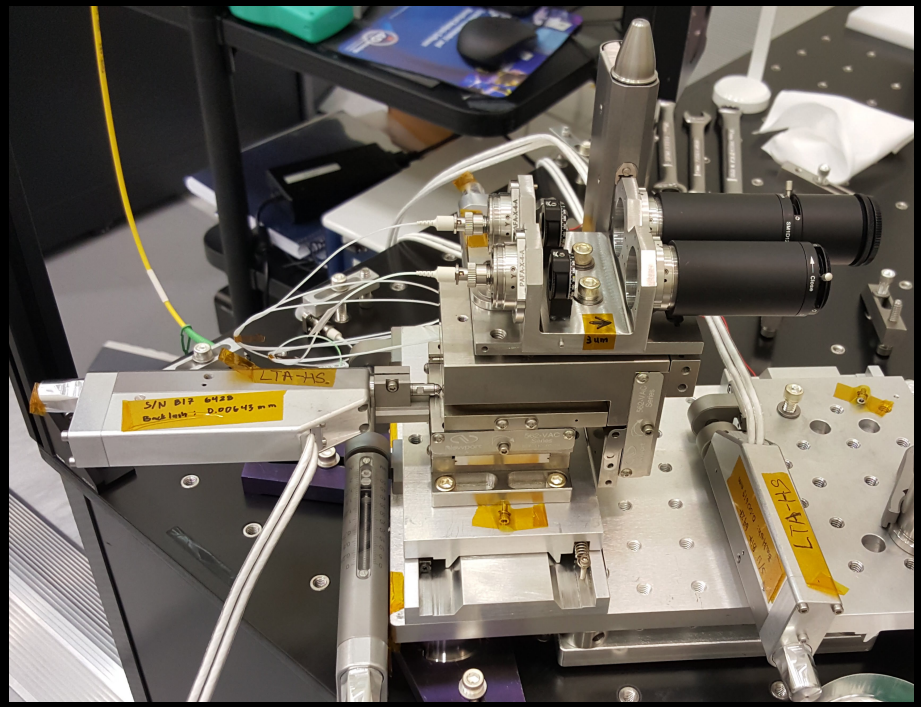
- 6 OAP's procured from SORL
  - ~4 to 6 nm rms surface figure error typically
- No fold mirrors in the system
- Custom titanium 6DOF mounts with 7" beam height





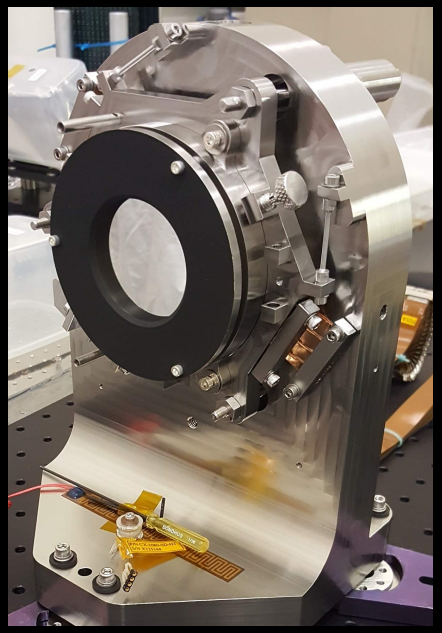
Source Assembly

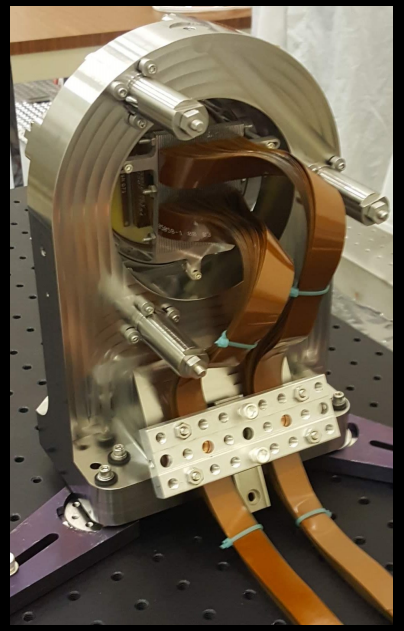
- NKT+Varia super continuum laser source
  - polarized and imaged onto a 3 um pinhole for improved source coherence
- Pinholes custom fabricated in JPL Microdevices Lab in thin silicon nitride membranes. COTS pinholes have been found to not be good enough at high contrast levels
- Dual source heads for performance comparison with varying pinhole sizes
- ~F/30 beam illuminating the first OAP



Deformable Mirrors

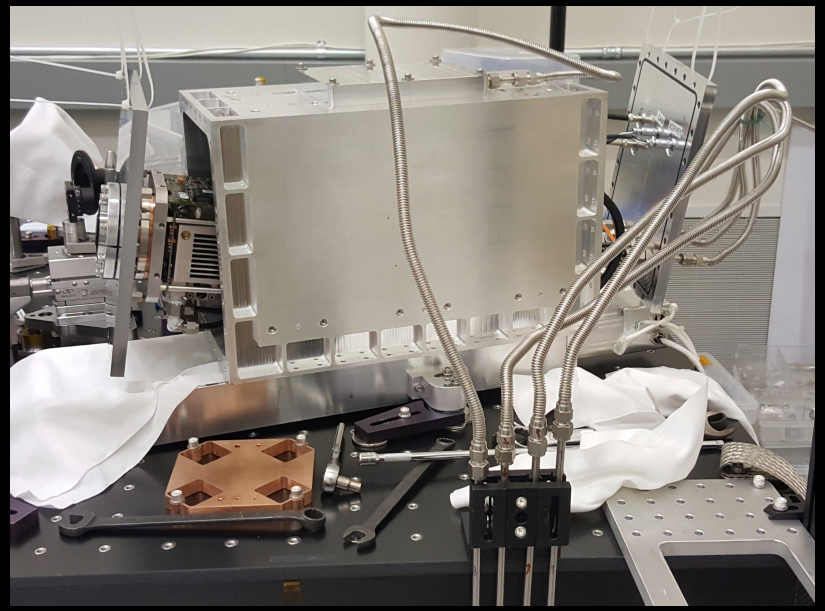
- Dual 48x48 Xinetics mirrors
  - PMN electrostrictors
  - 1 mm pitch
  - ~0.5 um free stroke
- Custom mount
  - 6 DOF adjustment
  - optional piezos for active mirror pointing
  - Dual cable strain reliefs
  - Dedicated thermal heater control

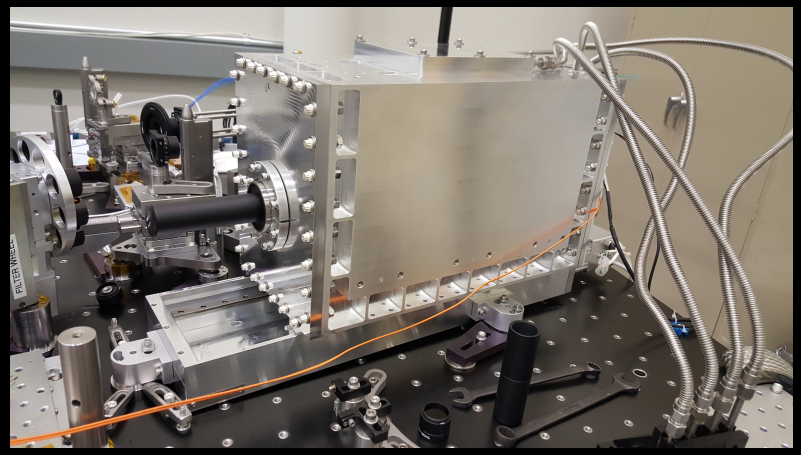




Cameras

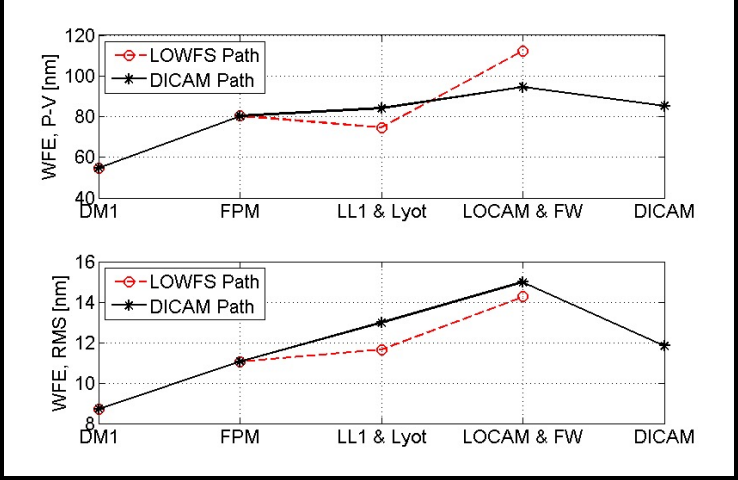
- 2 Andor Neo sCMOS cameras in custom air enclosures with cooling water and fiber optic communication
- DICAM – direct imager
  - Pupil and source (dark hole) imaging modes via removable lens
  - 10” linear stage for phase retrievals
- LOCAM – low order wavefront sensor
  - Installed but ultimately was not needed for 10^-10 contrast levels given passive stability levels

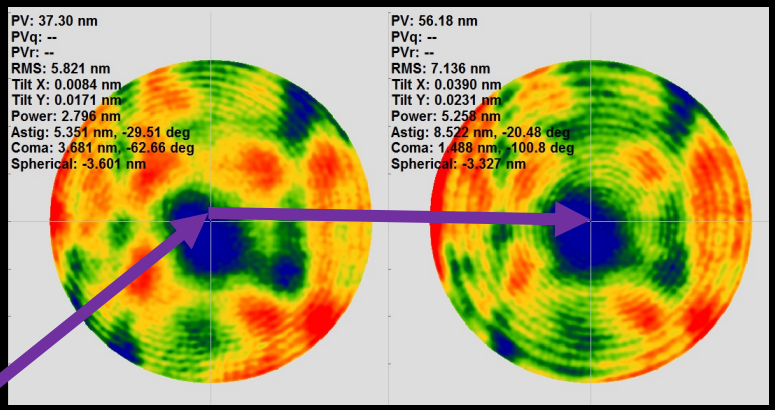


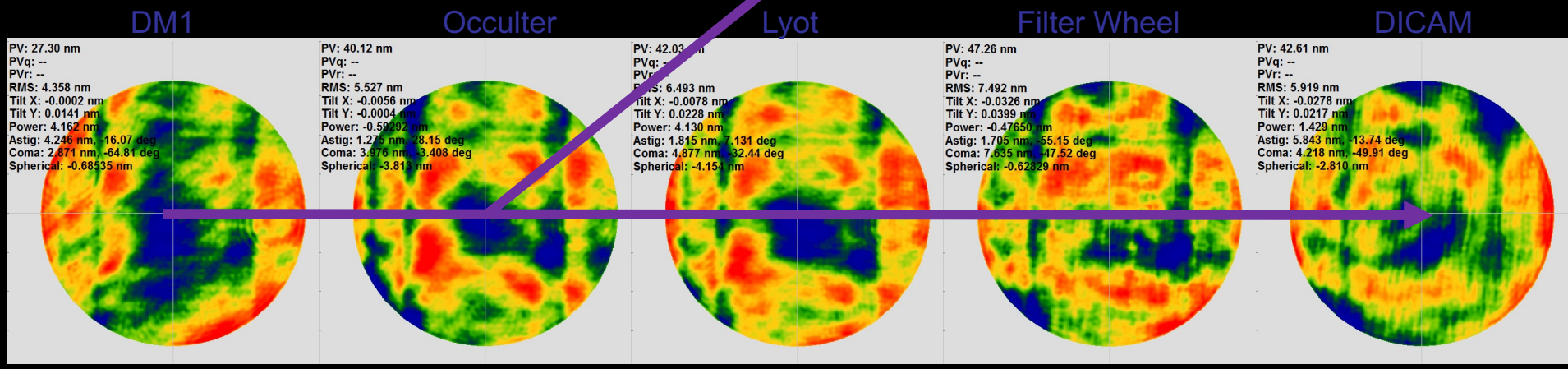


Wavefront Quality

- Aligned in air using 4D Phasecam 6000 to <15 nm RMS WFE, dominated by OAP surface quality

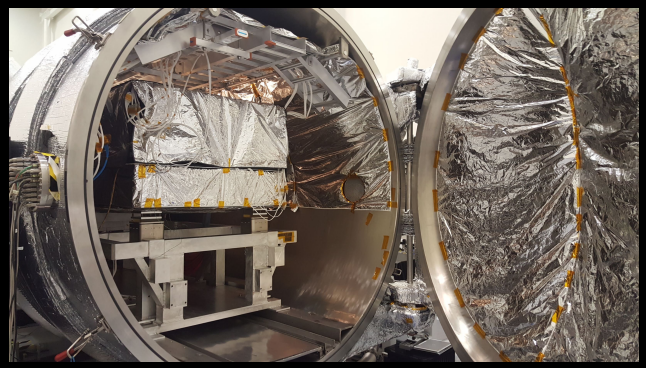


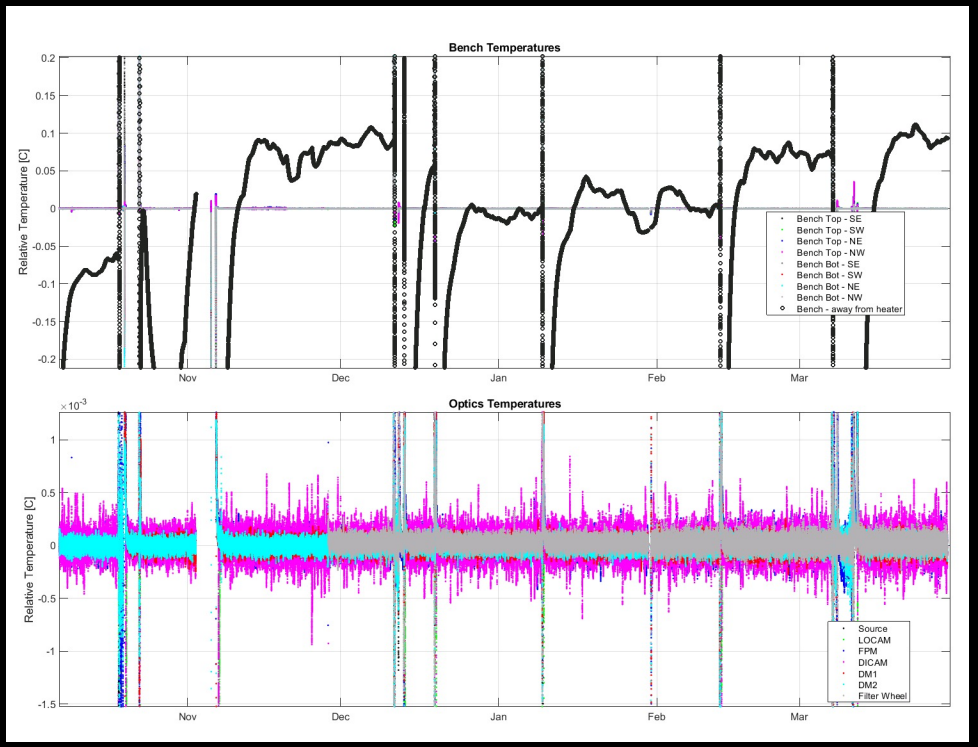




Thermal Stability

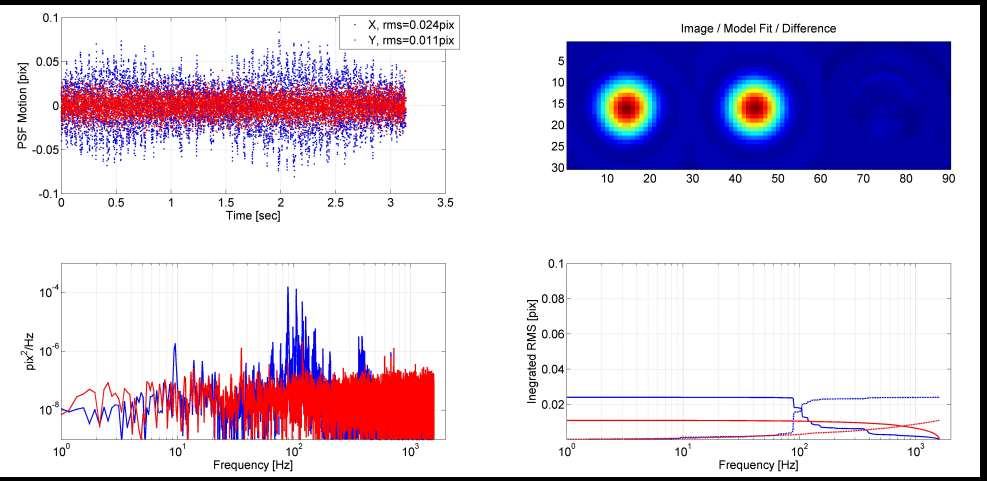
- Temperature Stability
  - Lab air temperature ~0.5 C stability
  - MLI insulations around the testbed and lining the chamber
  - 16 heater zones
    - 8 on the bench, 8 on the critical optics/masks
  - ~1 mK control stability at the heater zones
  - ~10 mK/day and ~50 mK/month stability on the bench away from the heaters
    - dominated by lab environment changes on diurnal and weekly timescales
  - ~5 day thermal settling time after chamber pumpdowns



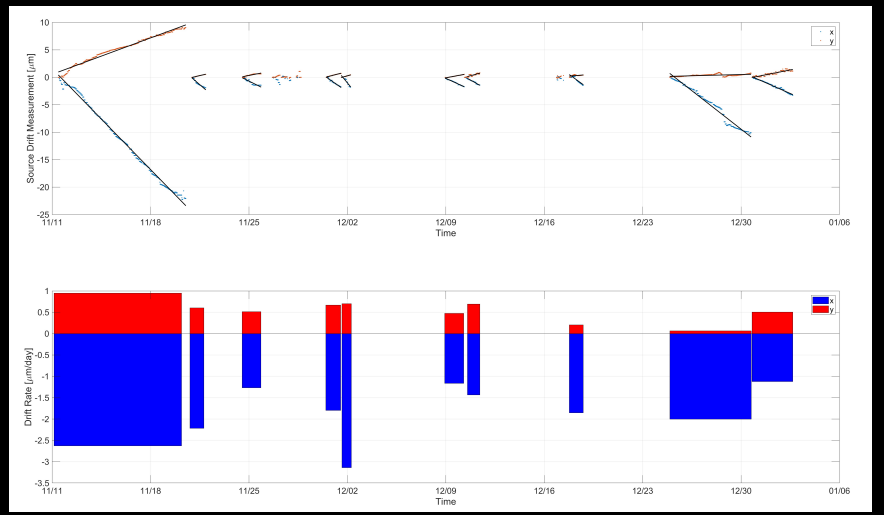


Pointing Stability

- Jitter
  - 3 MinusK isolators provide vibration isolation from the lab environment
  - Typical pointing jitter of <~0.005 lambda/D rms at the occulter
- Drift
  - Secular source drift rate of ~1 to ~2 um (~0.06 to ~0.12 λ/D) per day at the occulter
    - Likely dominated by bench dryout and/or DM RTV bondline creep
  - Passively low enough that active pointing control not needed to achieve 10^-10 contrast levels



Pointing jitter



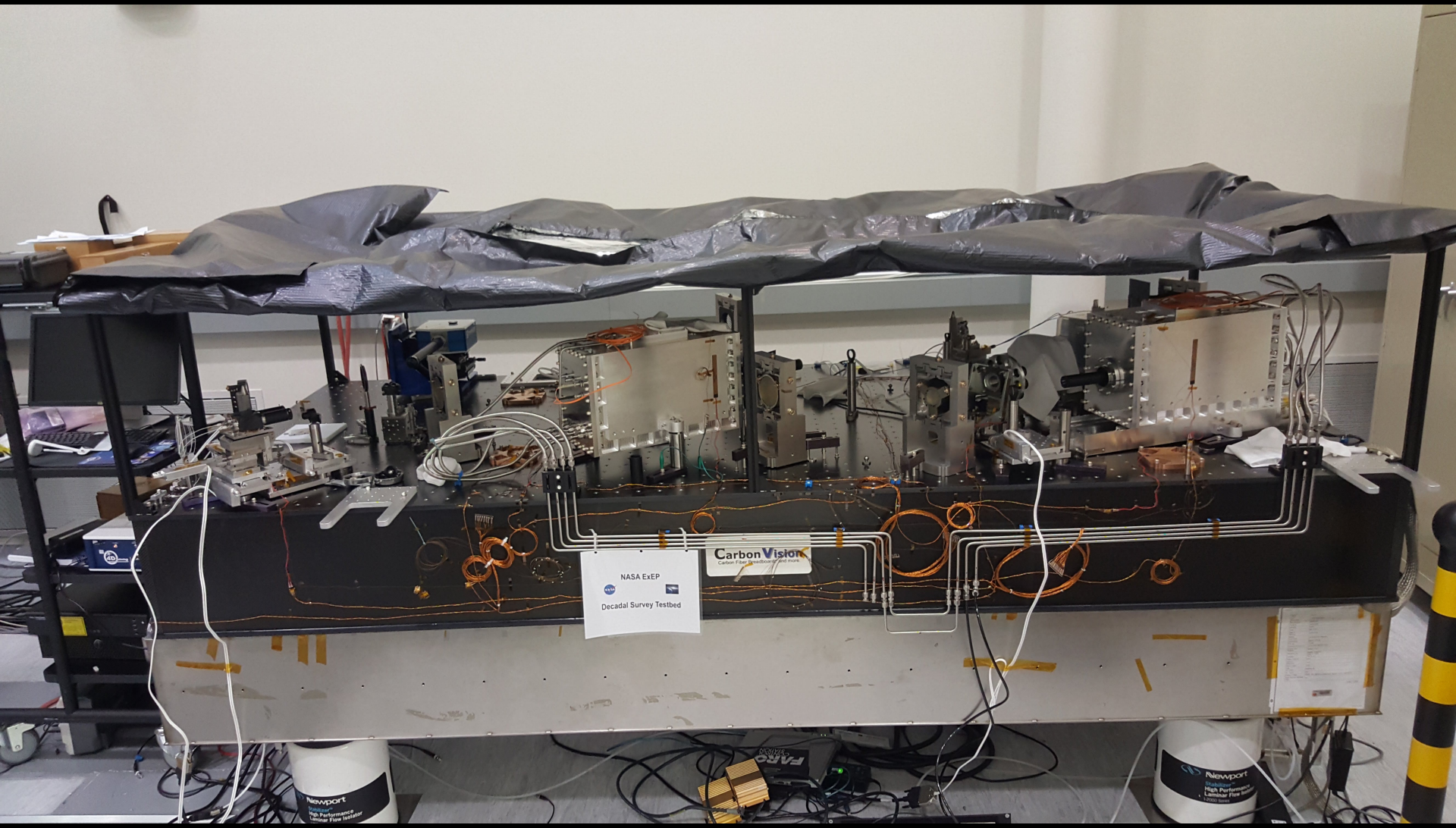
Pointing Drift

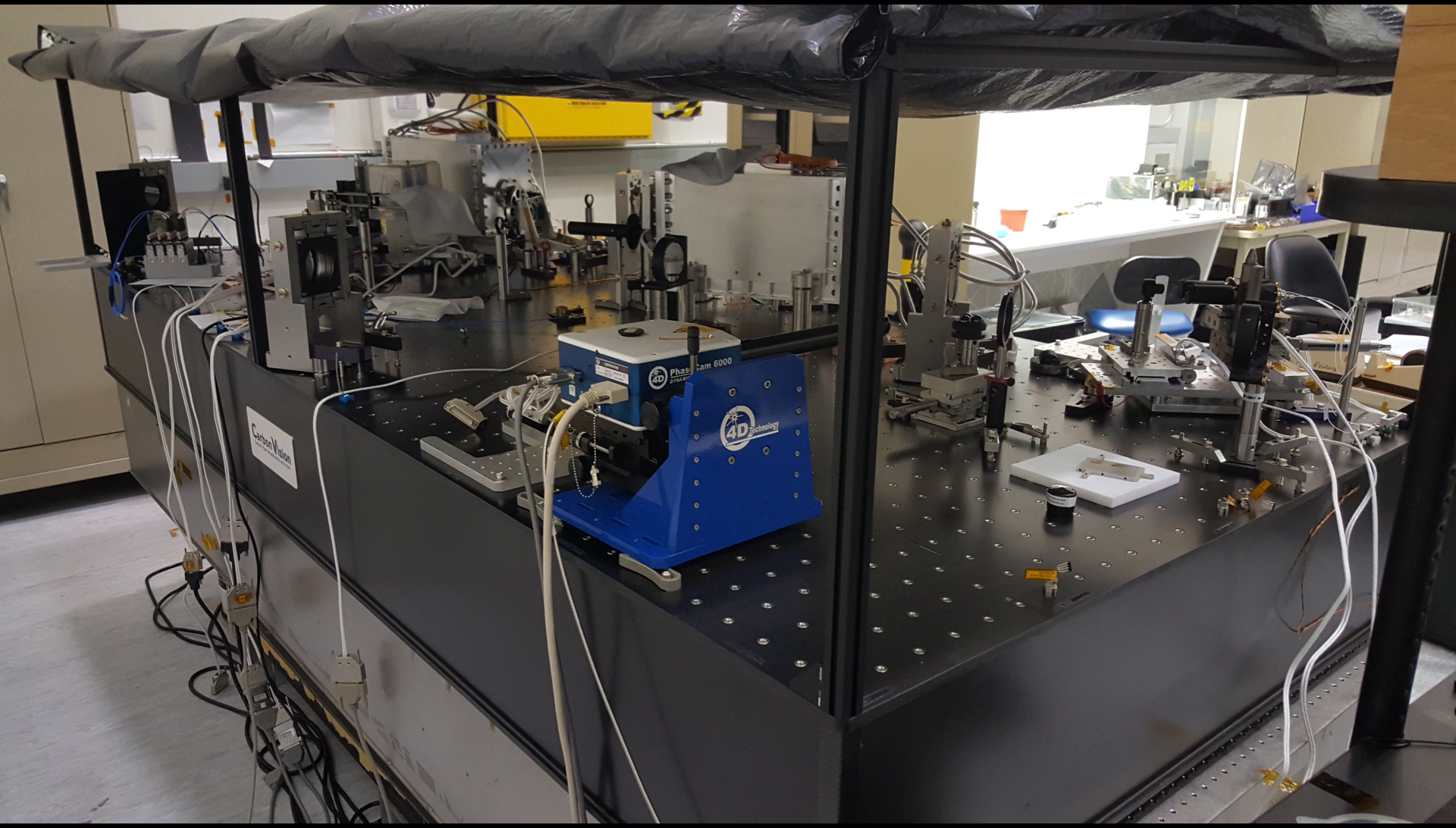
Acknowledgements

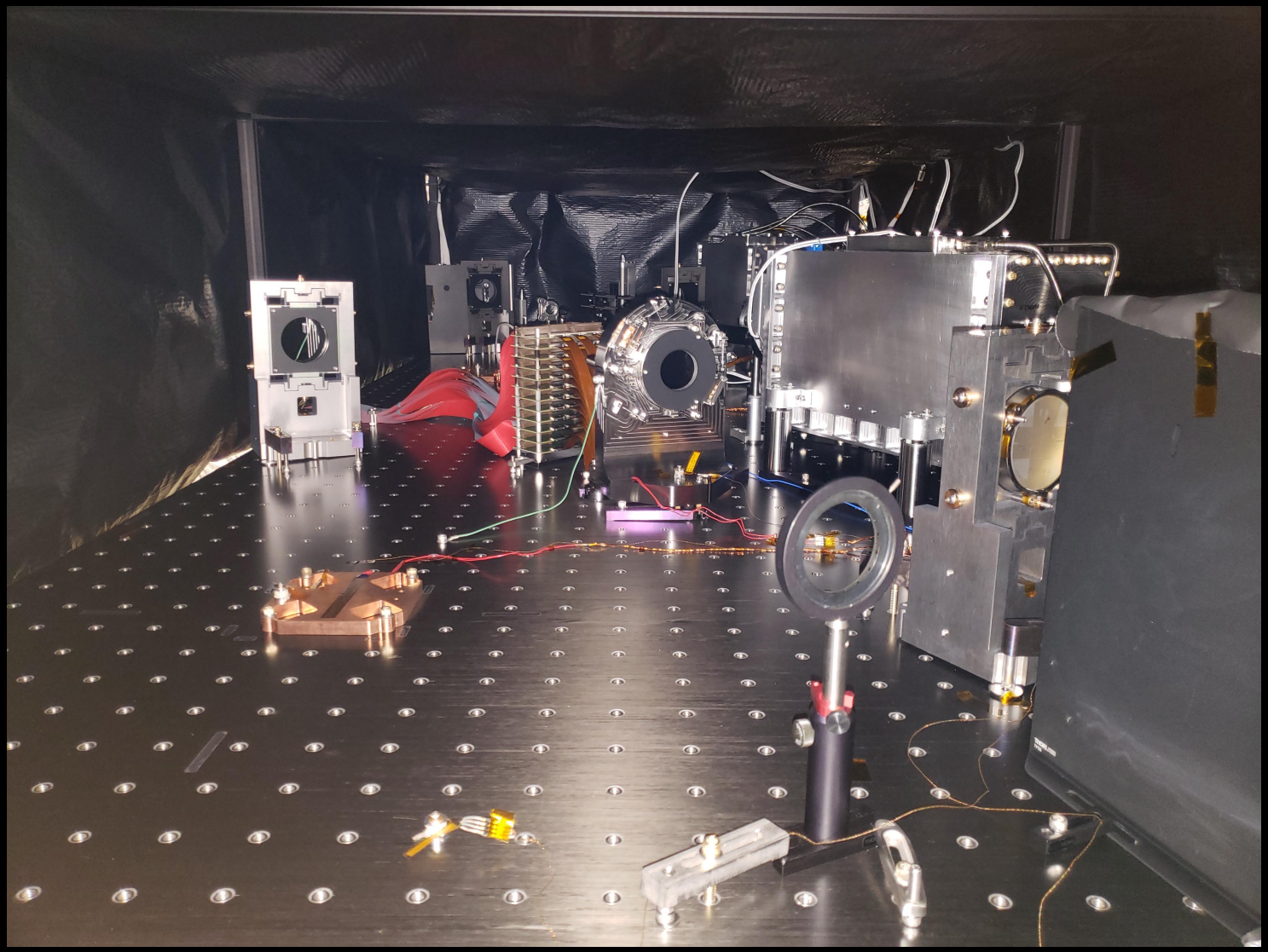
- HCIT and WFIRST-CGI teams especially Hong Tang, Fang Shi, Camilo Mejia Prada, Randy Bartos
- Assembly help from interns Marlon Orta & Jordan Rupp
- HCIT support: Robert Zimmer & John Shaw
- Microdevices lab: Victor White, Dan Wilson, Rich Muller, Bala Balasubramanian
- NASA ExEP office, especially Nick Siegler & Brendan Crill
- Many others

Stay tuned for DST coronagraph results from Joon Seo

Backup


NASA ExEP
Decadal Survey Testbed
CarbonVision
Newport
Newport


Carbon Vision
4D Technology

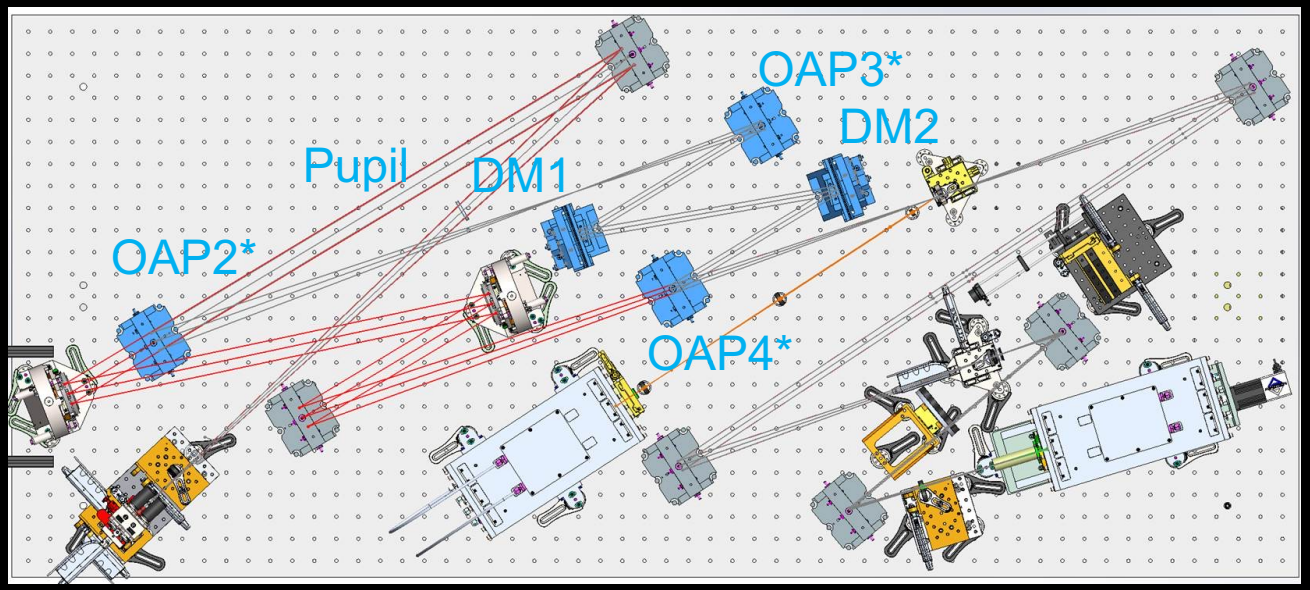


BMC MEMS DM Test Detour

- WFIRST, HabEx, LUVOIR, etc. all have a common need to determine:
  - **Which type of DM is best suited to coronagraphy?**
- WFIRST has a deadline to evaluate the MEMS prior to PDR next summer
- Deal was struck between ExEP and WFIRST to allow for DST testbed time early CY2019

Modified Layout
- Freestanding pupil
- Preserved backend & masks
- Keep original assemblies in place
- Source unchanged

MEMS Performance Risks:
- LSB resolution
- High spatial features
- Actuator yield
- ESD sensitive



Optics in blue would be added for new optical path for BMC DM's