
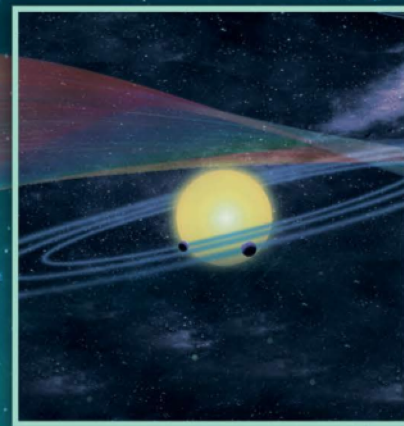
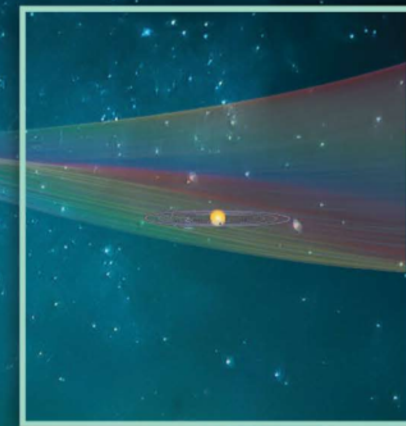

# The NEID precision radial velocity spectrometer: project overview and status update

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# The NEID Team

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NASA NSF

# Overview & Capabilities

**Telescope:** 3.5m WIYN Telescope @ KPNO

**Waveband & Resolution:** 380 – 930 nm, complete coverage, R=100K

**Expected Precision:** 30 cm/s initial w/ path to 10 cm/s

**Expected On Sky:** mid-late 2019

***Available to the Public!***


**Two Observing Modes:**

- HR (R~100,000)
  - Highest precision RVs on bright targets (V<12, e.g. TESS)
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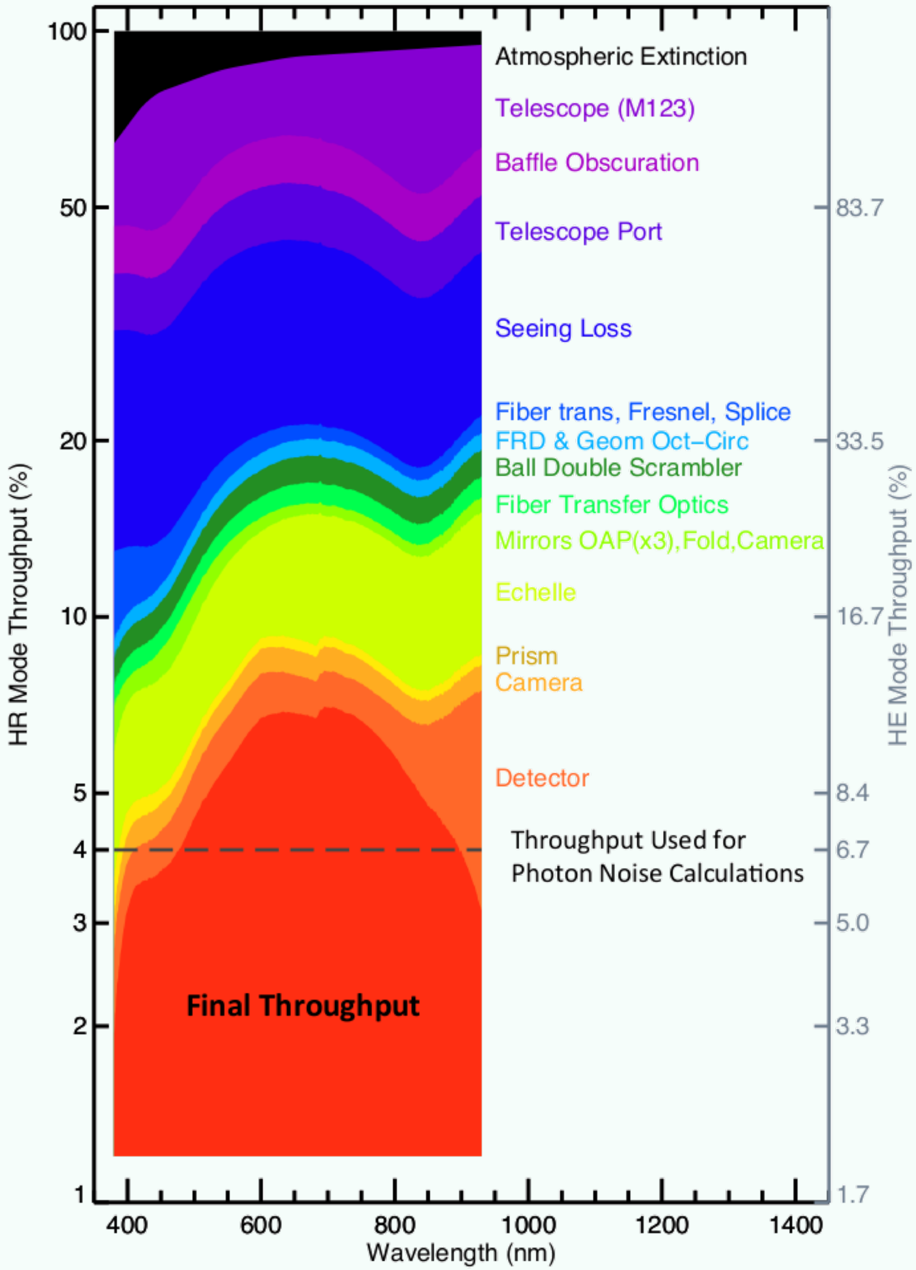
**Follow us at:**

http://neid.psu.edu

Twitter @NEID_at_WIYN

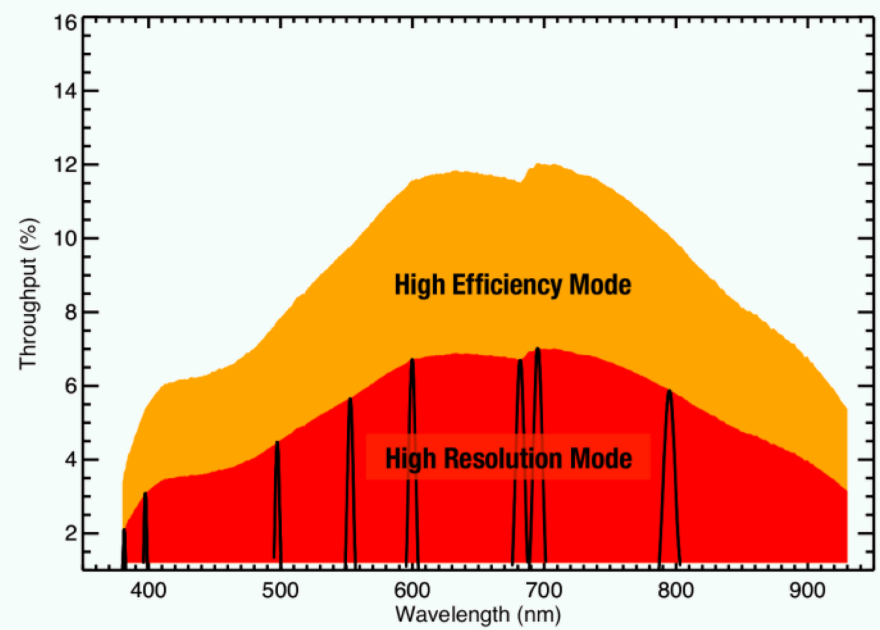
# Throughput Flowdown




**Total System throughput:**

- **HR: >4% for most of bandpass**
- **HE: >8% for most of bandpass**

**Spectrometer throughput ~40%**



# Radial Velocity Error Budget

CBE = Current Best Estimate
MEV = Max Expected Value (Baseline)
MPV = Max Possible Value = MEV( 1+ 50% margin)

Contingency = sqrt(MEV²-CBE²)
Reserve = 1 - MPV² / Threshold² = 22%

| | CBE | Cont. | MEV | MPV |
|---|---|---|---|---|
| INSTRUMENT TOTAL [cm/s] | 16.0 | 24.4 | 29.2 | 44.1 |

| % Contribution to Final MEV | | CBE | Cont. | MEV | MPV |
|---|---|---|---|---|---|
| 0.8% | **Instrument [cm/s] (calibratable)** | 6.7 | 15.6 | 17.0 | 41.3 |
| 0.5% | **Thermo-mechanical** | 5.3 | 13.0 | 14.0 | 38.7 |
| 0.4% | Room Thermal Stability [K] | 0.1 | 0.3 | 0.3 | 0.5 |
| | Vacuum Thermal Stability [mK] | 0.6 | 1.7 | 1.8 | 2.7 |
| 0.2% | Thermal Stability (XD)[cm/s] | 3.0 | 8.5 | 9.0 | 13.5 |
| 0.1% | Thermal Stability (Echelle)[cm/s] | 1.8 | 5.1 | 5.4 | 8.1 |
| 0.0% | Thermal Stability (Bench)[cm/s] | 0.6 | 1.7 | 1.8 | 2.7 |
| 0.1% | Opitcal Elements (Decenter)[cm/s] | 2.3 | 6.4 | 6.8 | 34.0 |
| 0.0% | Optical Elements (Tilt)[cm/s] | 0.4 | 1.1 | 1.2 | 1.8 |
| 0.0% | Vibrational Stability[cm/s] | 1.0 | 2.8 | 3.0 | 4.5 |
| 0.0% | Pressure stability[cm/s] | 0.1 | 0.3 | 0.3 | 0.5 |
| 0.0% | LN2 fill transient[cm/s] | 0.1 | 1.0 | 1.0 | 1.5 |
| 0.1% | Zerodur phase change[cm/s] | 3.0 | 4.0 | 5.0 | 7.5 |
| 0.2% | **Detector** | 4.2 | 8.6 | 9.6 | 14.4 |
| 0.0% | Pixel inhomogeneities [cm/s] | 0.1 | 1.0 | 1.0 | 1.5 |
| 0.0% | Electronics Noise [cm/s] | 0.1 | 1.0 | 1.0 | 1.5 |
| 0.1% | Stitching error [cm/s] | 2.0 | 5.7 | 6.0 | 9.0 |
| 0.0% | CCD thermal Expansion [cm/s] | 1.0 | 1.7 | 2.0 | 3.0 |
| 0.1% | Readout Thermal Changes [cm/s] | 2.5 | 4.3 | 5.0 | 7.5 |
| 0.1% | Charge Transfer Efficiency [cm/s] | 2.5 | 4.3 | 5.0 | 7.5 |

| % Contribution to Final MEV | | CBE | Cont. | MEV | MPV |
|---|---|---|---|---|---|
| | fraction of instrument error propogated through: | 15% | | | |
| | **From Instrument [cm/s] (calibratable)** | 1.0 | 2.3 | 2.5 | 6.2 |
| 15.5% | **Calibration Source: LFC** | 6.6 | 9.4 | 11.5 | 17.2 |
| 3.8% | **Calibration Accuracy** | 4.3 | 3.7 | 5.7 | 8.5 |
| 1.9% | stability [cm/s] | 2.8 | 2.9 | 4.0 | 6.0 |
| 1.9% | photon noise [cm/s] | 3.2 | 2.4 | 4.0 | 6.0 |
| 11.7% | **Calibration Process** | 5.0 | 8.7 | 10.0 | 15.0 |
| 11.7% | Algorithm and Software [cm/s] | 5.0 | 8.7 | 10.0 | 15.0 |
| 42.7% | **Instrument (Un-calibratable)** | 10.2 | 16.1 | 19.1 | 28.6 |
| 24.7% | **Fiber and Illumination** | 8.2 | 12.0 | 14.5 | 21.8 |
| 0.7% | calibrator modal noise [cm/s] | 1.0 | 2.3 | 2.5 | 3.8 |
| 0.7% | science modal noise [cm/s] | 1.0 | 2.3 | 2.5 | 3.8 |
| 5.9% | calibrator fiber FRD (2-5%)[cm/s] | 5.0 | 5.0 | 7.1 | 10.7 |
| 5.9% | science fiber FRD (2-5%)[cm/s] | 5.0 | 5.0 | 7.1 | 10.7 |
| 2.9% | stray light [cm/s] | 1.0 | 4.9 | 5.0 | 7.5 |
| 2.9% | Scattered light Cal to Sci [cm/s] | 2.0 | 4.6 | 5.0 | 7.5 |
| 0.5% | Residual Fiber Polarization[cm/s] | 1.0 | 1.7 | 2.0 | 3.0 |
| | near-field scrambling* [GAIN] | 20000 | 2x | 10000 | 5000 |
| 2.9% | far-field scrambling*[cm/s] | 2.0 | 4.6 | 5.0 | 7.5 |
| 0.0% | Fiber Input (Rotation)[cm/s] | 2.2 | 3.7 | 4.3 | 6.5 |
| 0.4% | **Barycentric Correction** | 0.7 | 1.6 | 1.7 | 2.6 |
| 0.1% | Algorithms [cm/s] | 0.1 | 1.0 | 1.0 | 1.5 |
| 0.1% | Exposure midpoint time [cm/s] | 0.7 | 0.7 | 1.0 | 1.5 |
| 0.1% | Coords and proper motion [cm/s] | 0.1 | 1.0 | 1.0 | 1.5 |
| 5.9% | **Detector cal vs. sci fiber** | 3.5 | 6.1 | 7.1 | 10.6 |
| 2.9% | Readout Thermal Changes [cm/s] | 2.5 | 4.3 | 5.0 | 7.5 |
| 2.9% | Charge Transfer Efficiency [cm/s] | 2.5 | 4.3 | 5.0 | 7.5 |
| 11.7% | **Reduction Pipeline** | 5.0 | 8.7 | 10.0 | 15.0 |
| 11.7% | Software Algorithms [cm/s] | 5.0 | 8.7 | 10.0 | 15.0 |

| % Contribution to Final MEV | | CBE | Cont. | MEV | MPV |
|---|---|---|---|---|---|
| 17.6% | **Telescope** | 5.7 | 10.8 | 12.2 | 18.3 |
| 1.4% | Guiding* [RMS arcsec] | 0.05 | 0.09 | 0.10 | 0.15 |
| 1.4% | Guiding* [cm/s] | 0.9 | 3.39 | 3.5 | 5.3 |
| 5.7% | ADC* [Peak to Valley arcsec] | 0.10 | 0.17 | 0.20 | 0.30 |
| 5.7% | ADC* [cm/s] | 3.1 | 6.21 | 6.9 | 10.4 |
| 2.9% | Focus [cm/s] | 2.5 | 4.33 | 5.0 | 7.5 |
| 7.5% | Windshake* [cm/s] | 4.0 | 6.93 | 8.0 | 12.0 |
| 23.5% | **Atmospheric** | 8.5 | 11.3 | 14.1 | 21.2 |
| 11.7% | Micro-Telluric Correction [cm/s] | 8.0 | 6.0 | 10.0 | 15.0 |
| 11.7% | Sky Fiber Subtraction [cm/s] | 3.0 | 9.5 | 10.0 | 15.0 |
| 41.0% | **External Errors** | 10.3 | 15.6 | 18.7 | 28.0 |

Our **Error Budget** is a compilation of sources of error, which add quadratically to inform the final performance baseline.

Total Instrument Error:
**29 cm/s**

| | |
|---|---|
| Instrument: | 43% |
| Atmosphere: | 23% |
| Telescope: | 18% |
| Calibration: | 16% |
| Calibratable Inst: | 1% |

***Halverson et al. 2016, SPIE, 9908.99086P***

# NEID is a precision RV System

Advanced Environmental Control System

Menlo LFC, Etalon, Lamps

White Pupil Spectrometer

e2v Detector

Telescope Port System

Unsliced high scrambling fiber feed

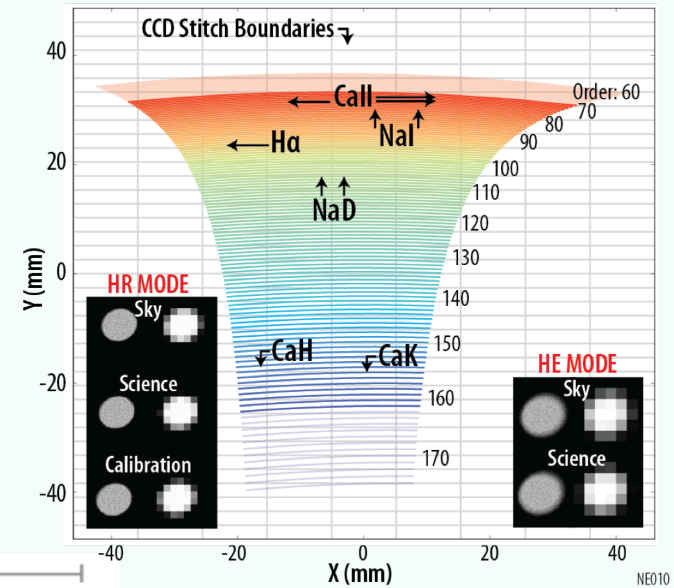
Data Reduction Pipeline

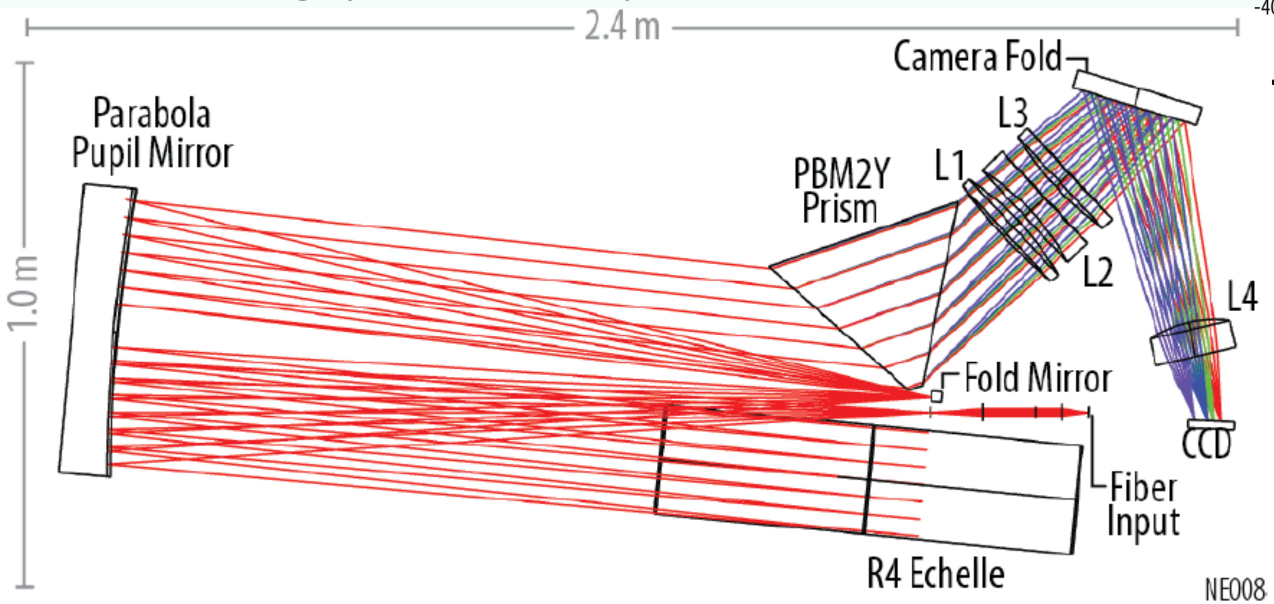
Operations

# Optical Design

**Implementation: Single arm white pupil Echelle**

- Single mirror white pupil relay, 200mm beam
- 2x1 mosaic R4 Richardson Echelle
- Single prism cross disperser: Ohara PBM2Y
- Refractive camera, 4 elements, folded
- Single e2v CCD: 9k x 9k, 10 µm pixels
- 380 – 930 nm, complete coverage
- Throughput: 5.3% @ peak blaze



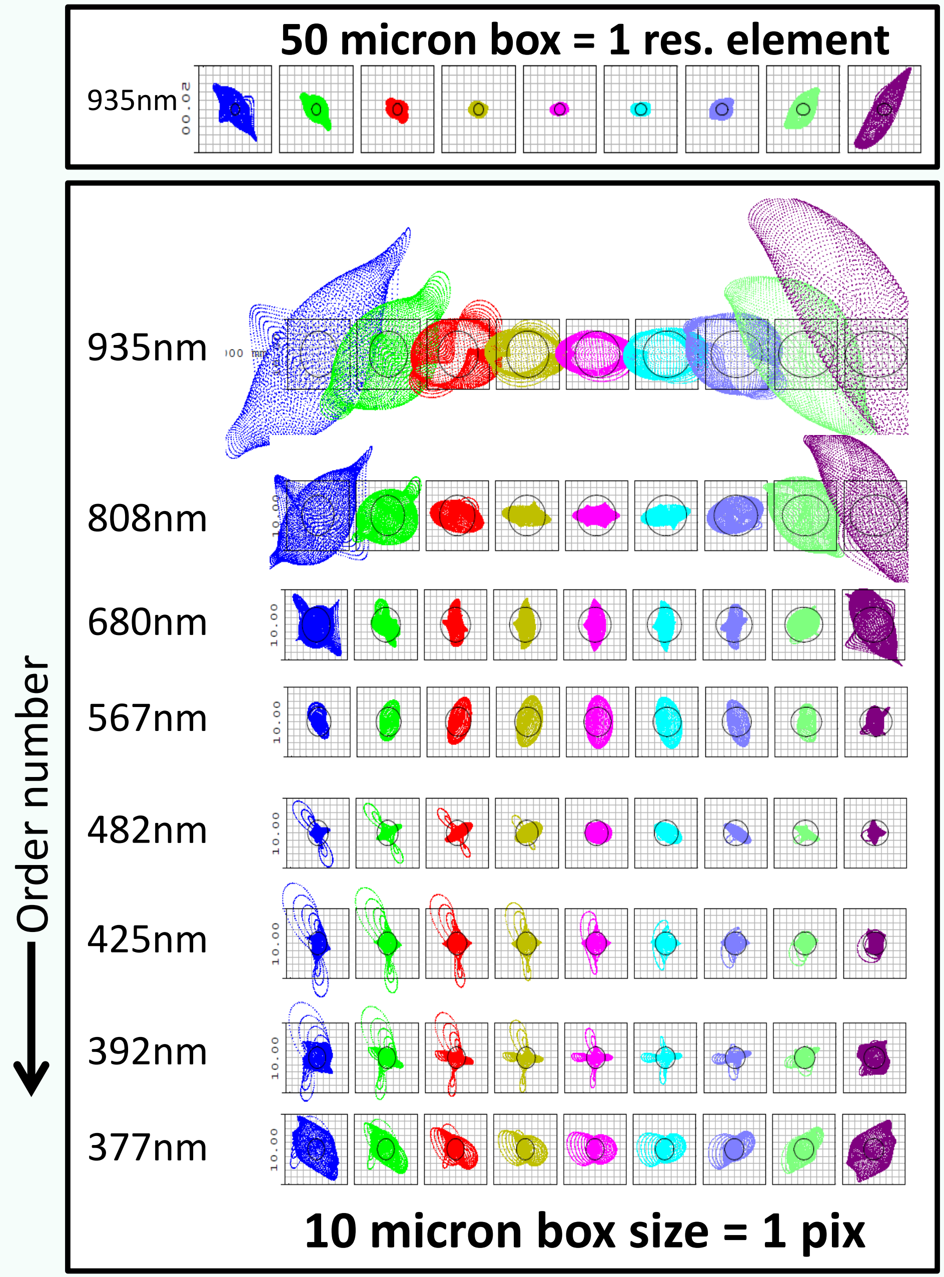




**Two Observing Modes:**

- HR (R~100,000)
  - Highest precision RVs on bright targets (V<12, e.g. TESS)
  - Simultaneous Cal
- HE (R~60,000)
  - Faint targets (V<16)
  - Poor weather
  - e.g. K2

# Spectrometer Needs: Image Quality

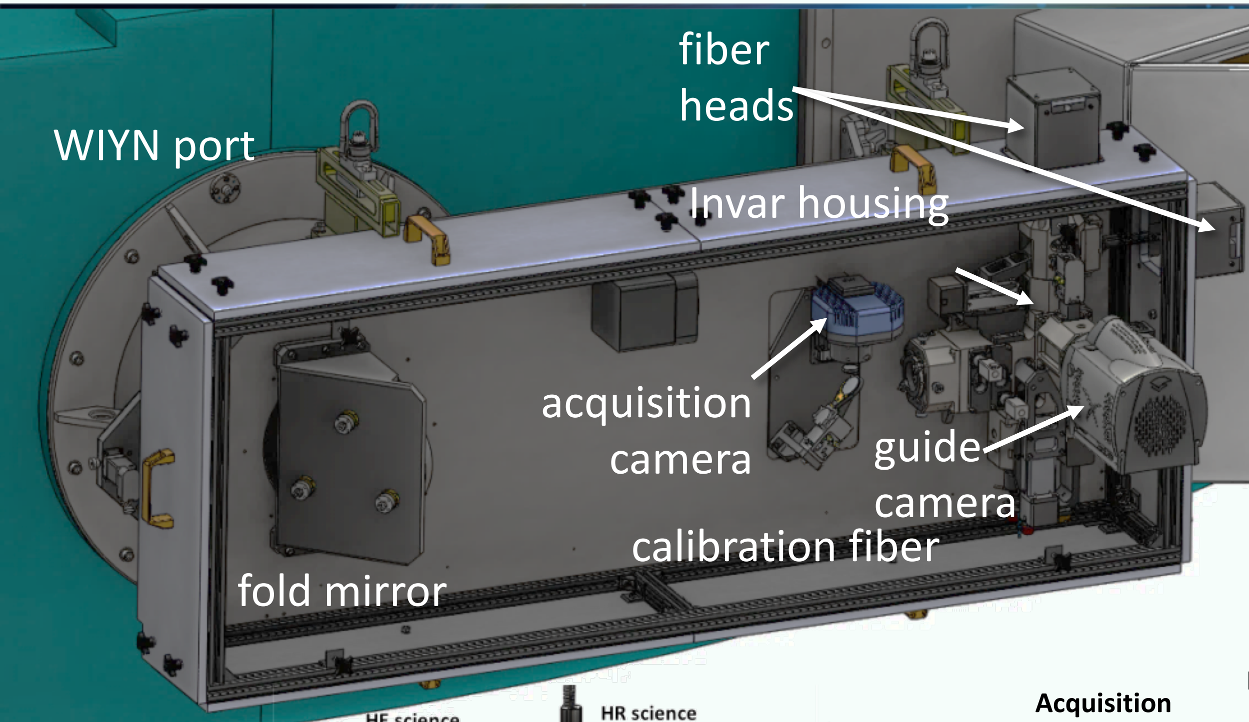
Image quality spots smaller than a resolution element buffer against illumination variation

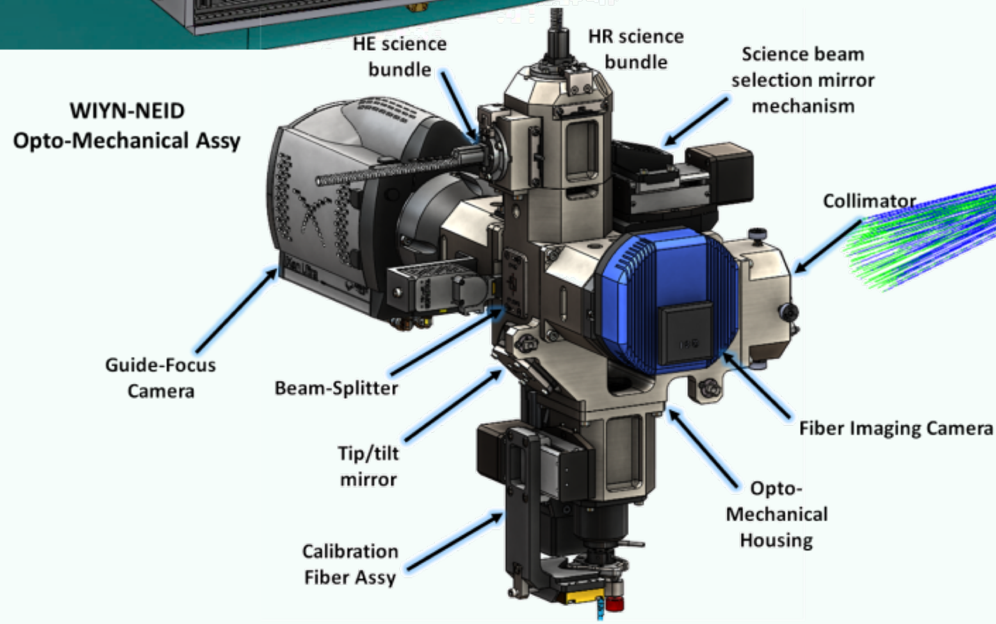


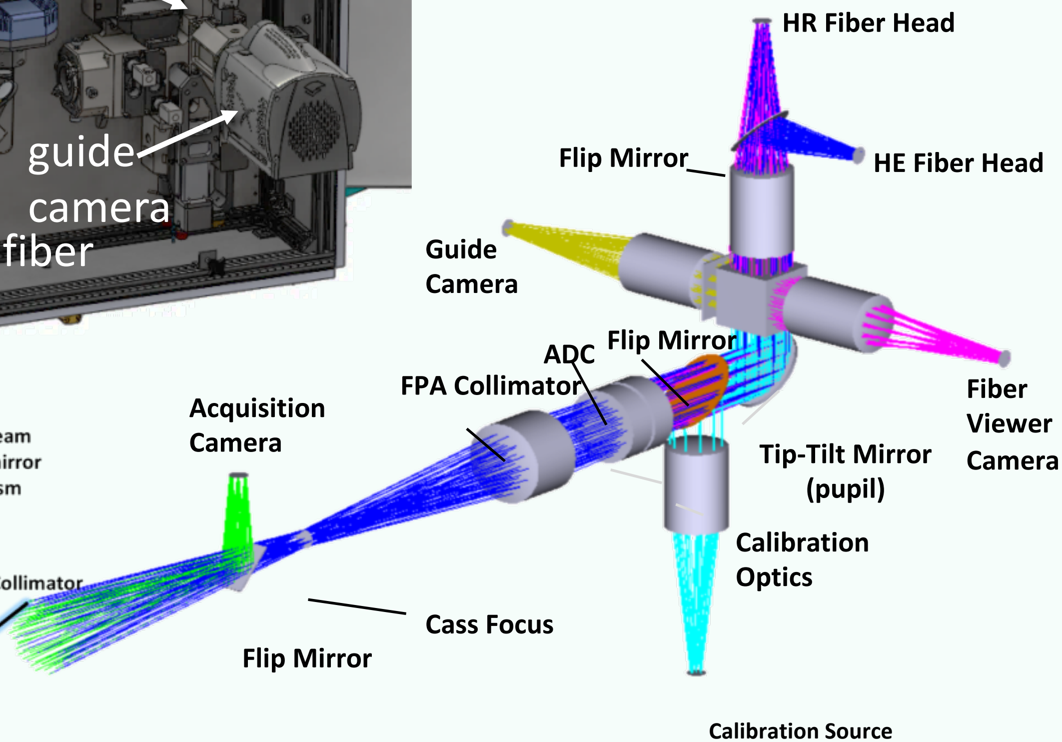

Described in:

Schwab et al. 2016, SPIE, 99078H

# NEID Telescope Port



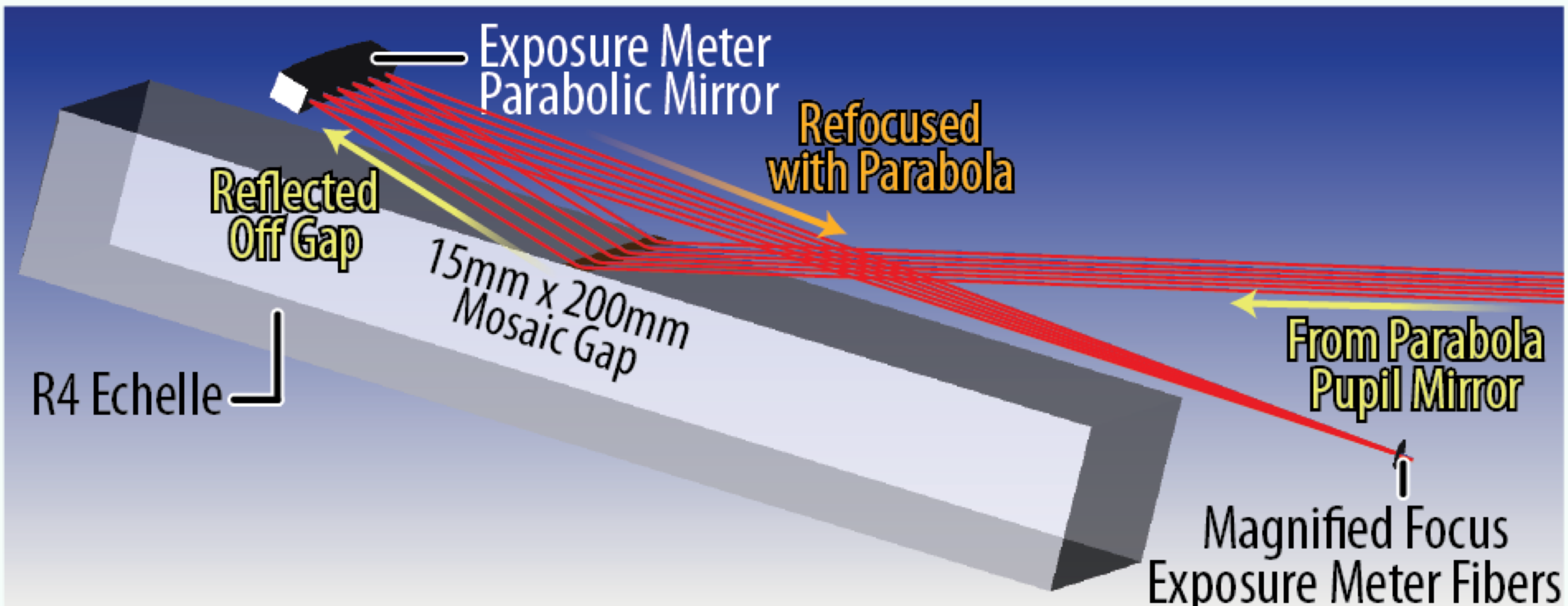




**See SPIE Papers from:**
**Christian Schwab: 10702-257**
**Sarah Logsdon: 10702-226**

# Chromatic Exposure Meter

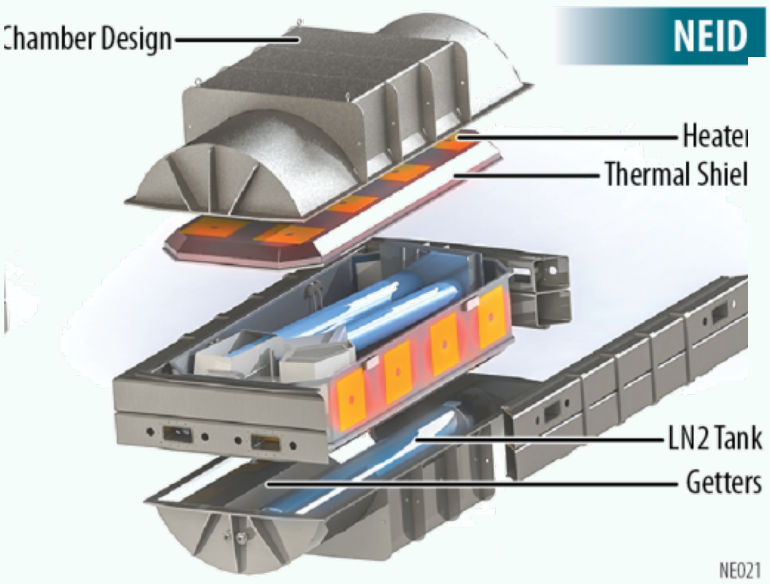
- Real-time feedback of conditions to observer
- Optimizes observing time to the science
- Low-resolution spectra
- Chromatic barycentric correction < 1 cm/s

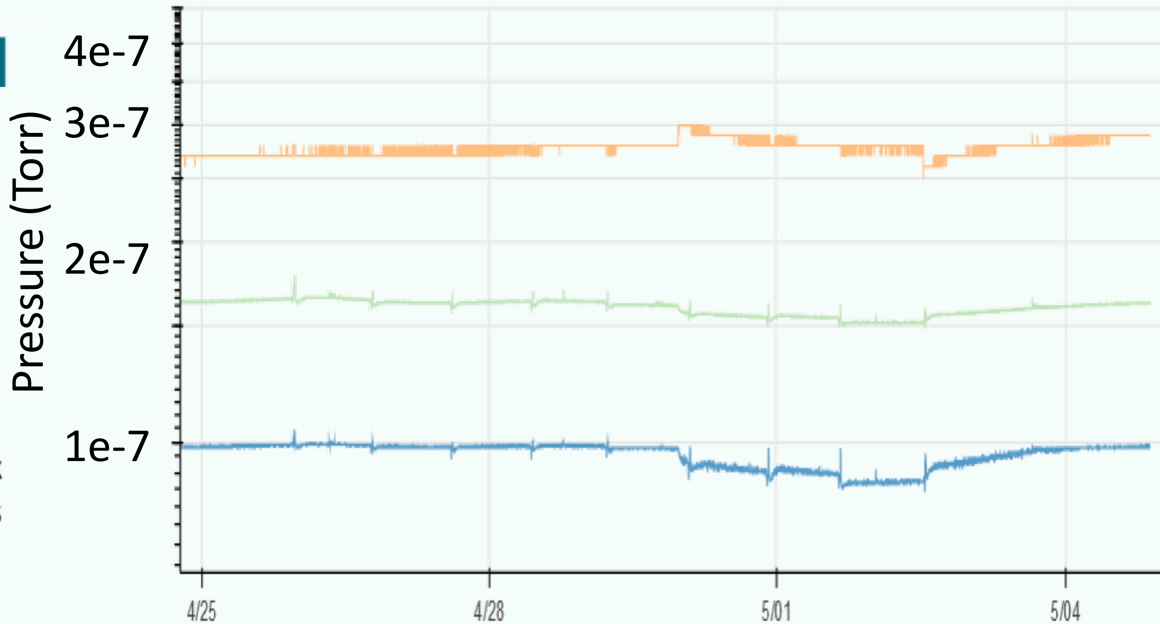


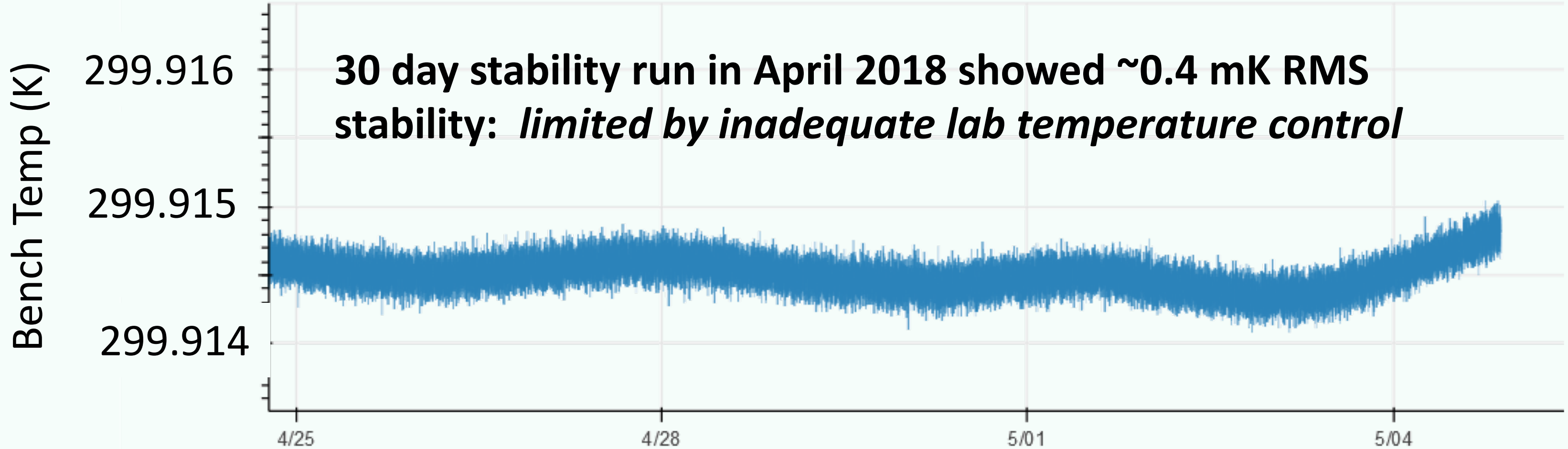

NE030

# Environmental Control

Vacuum chamber inherits HPF design, modified for 300 K operation



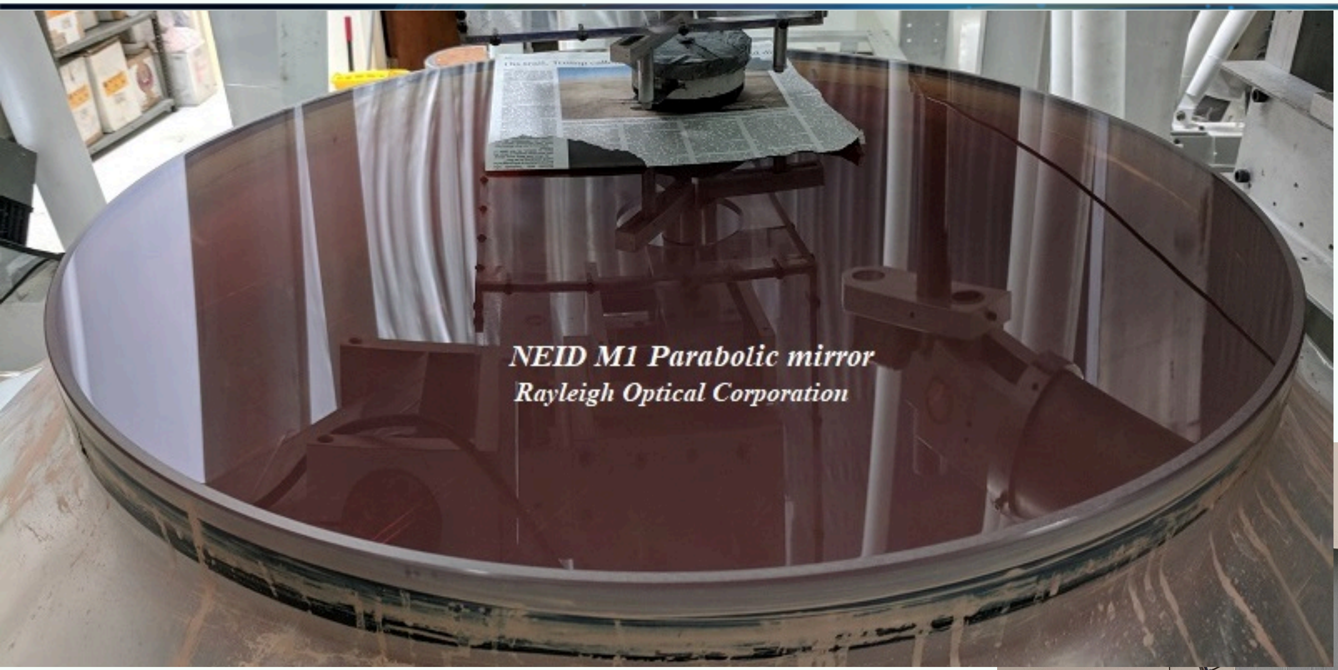



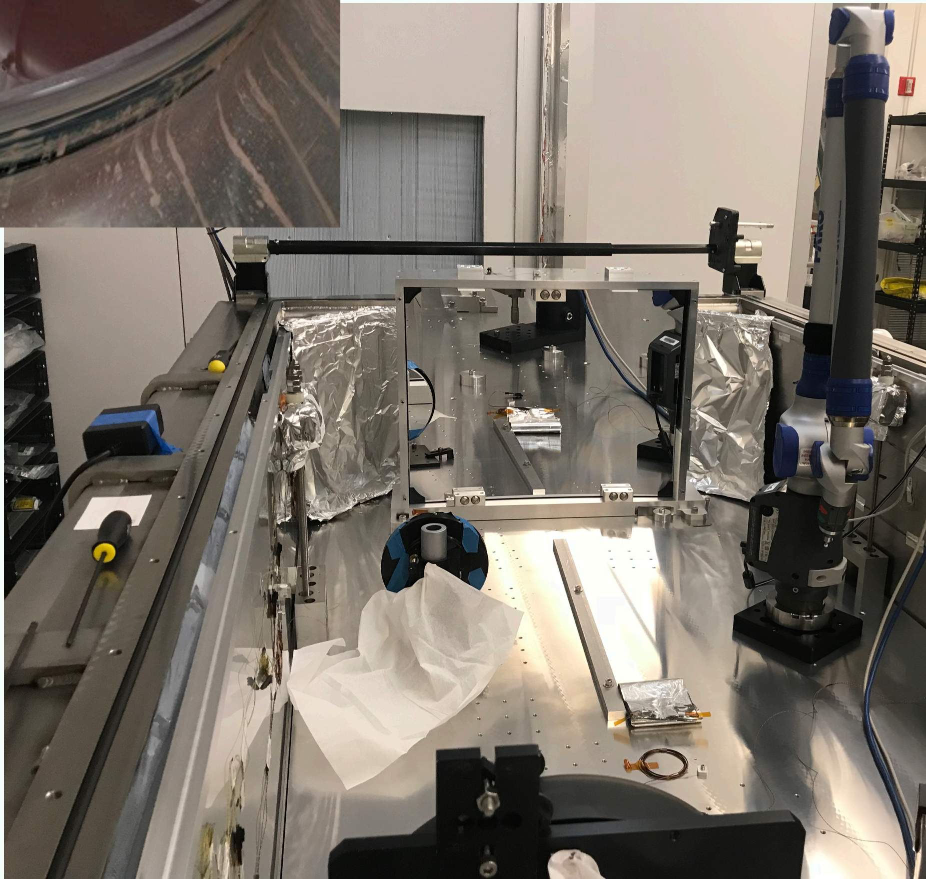




**30 day stability run in April 2018 showed ~0.4 mK RMS stability: *limited by inadequate lab temperature control***

***Robertson et al. 2019, in press***

# Status Update: Imaging Optics



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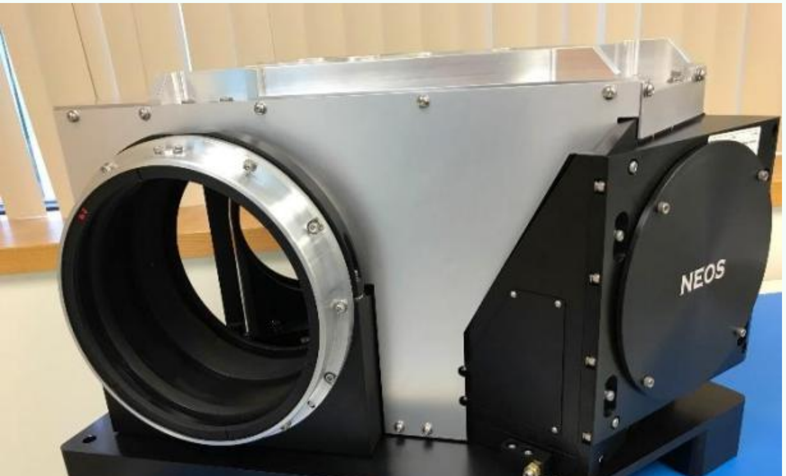
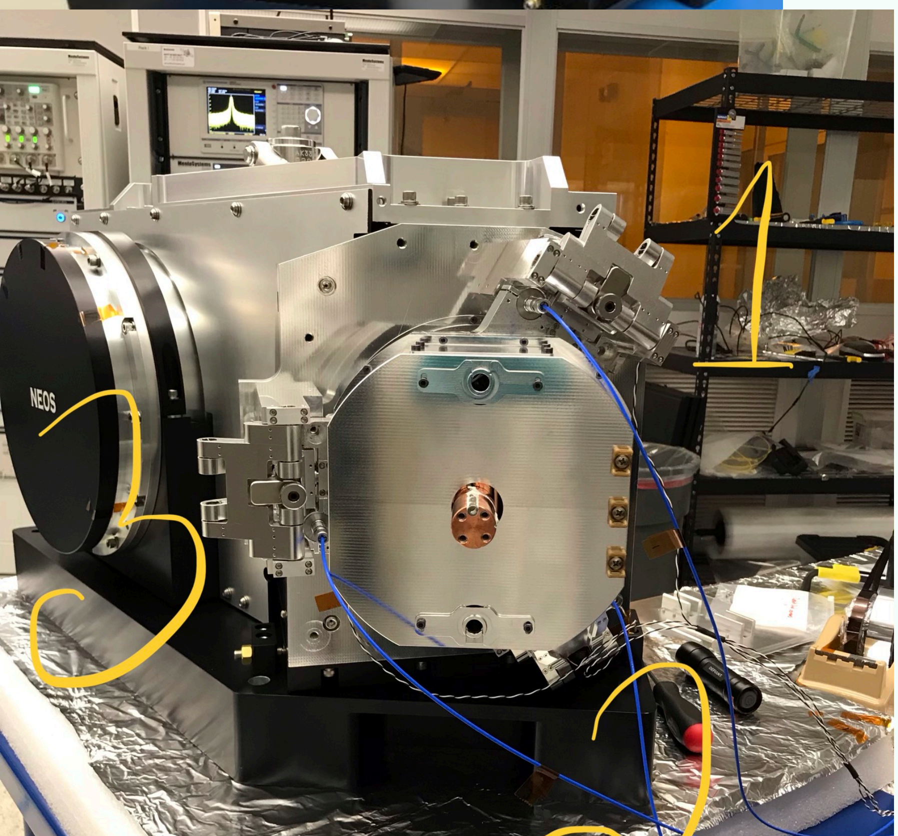
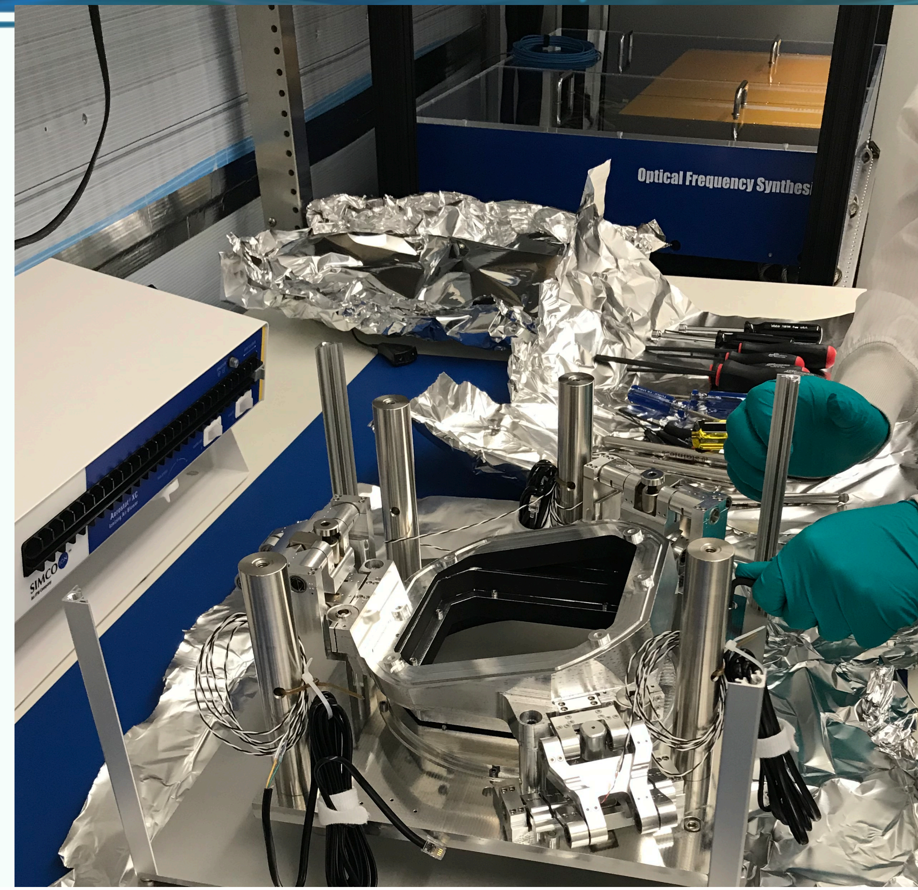
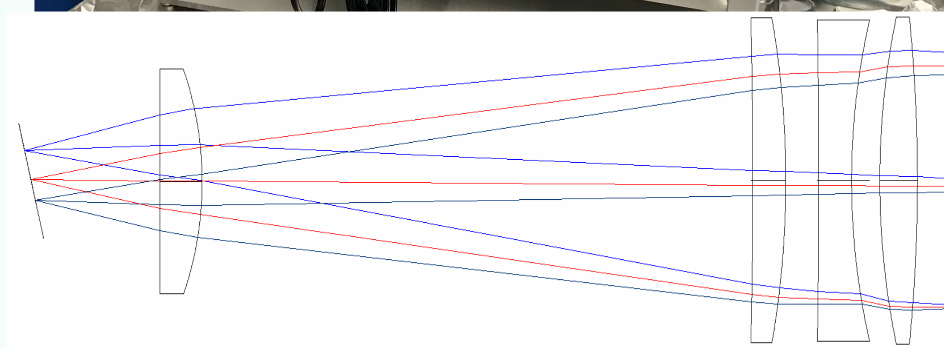


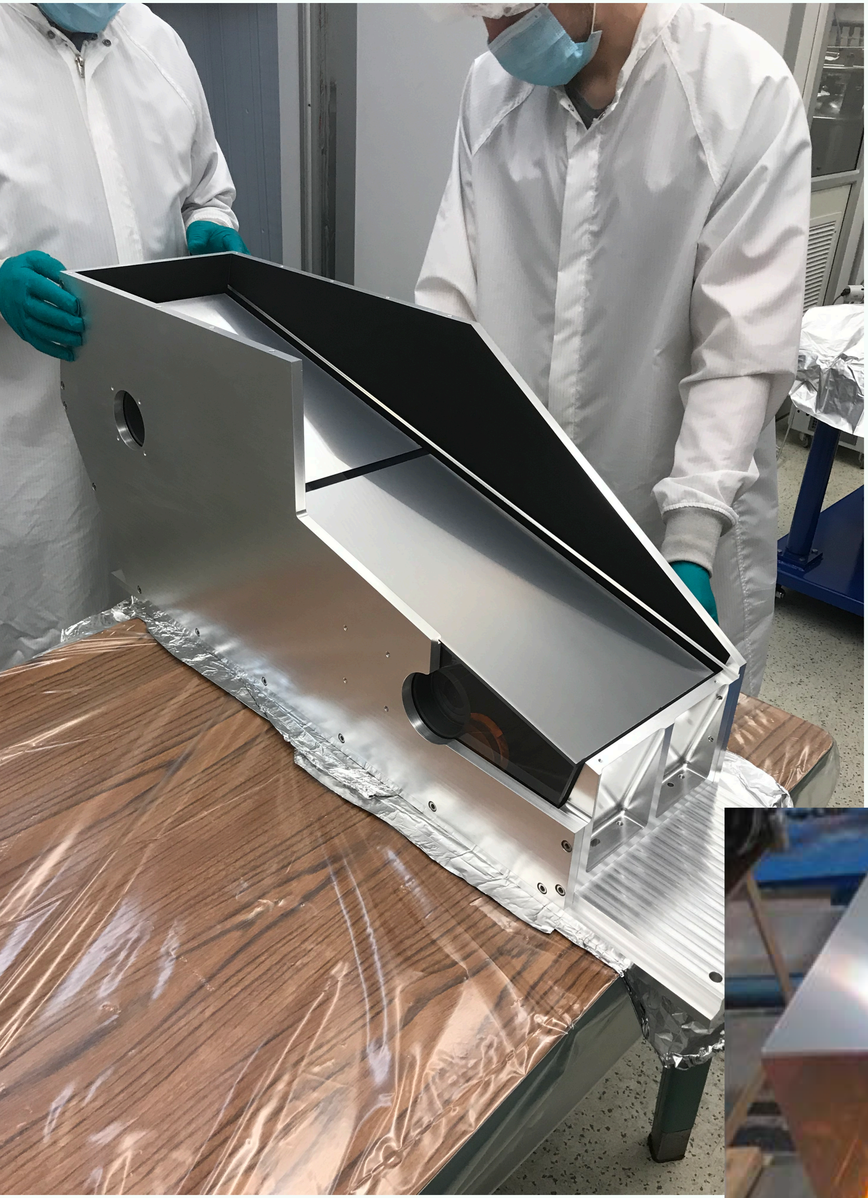





Refractive Camera, all spherical, 260mm diameter

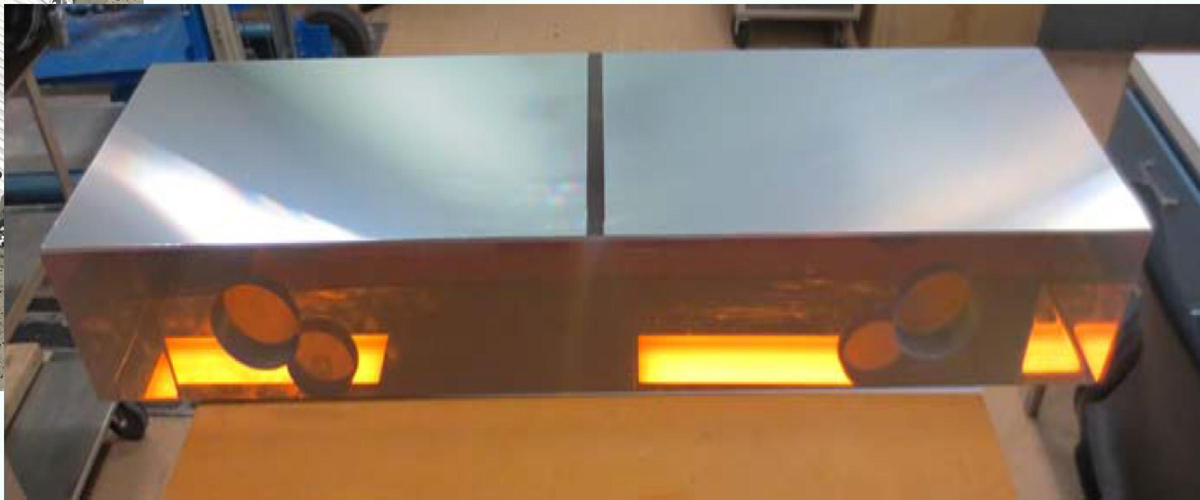
- New England Optical Systems

# Status Update: Dispersive Optics



200x800mm R4 Echelle Mosaic:

- Richardson Grating Lab
- Delivered 8/2017



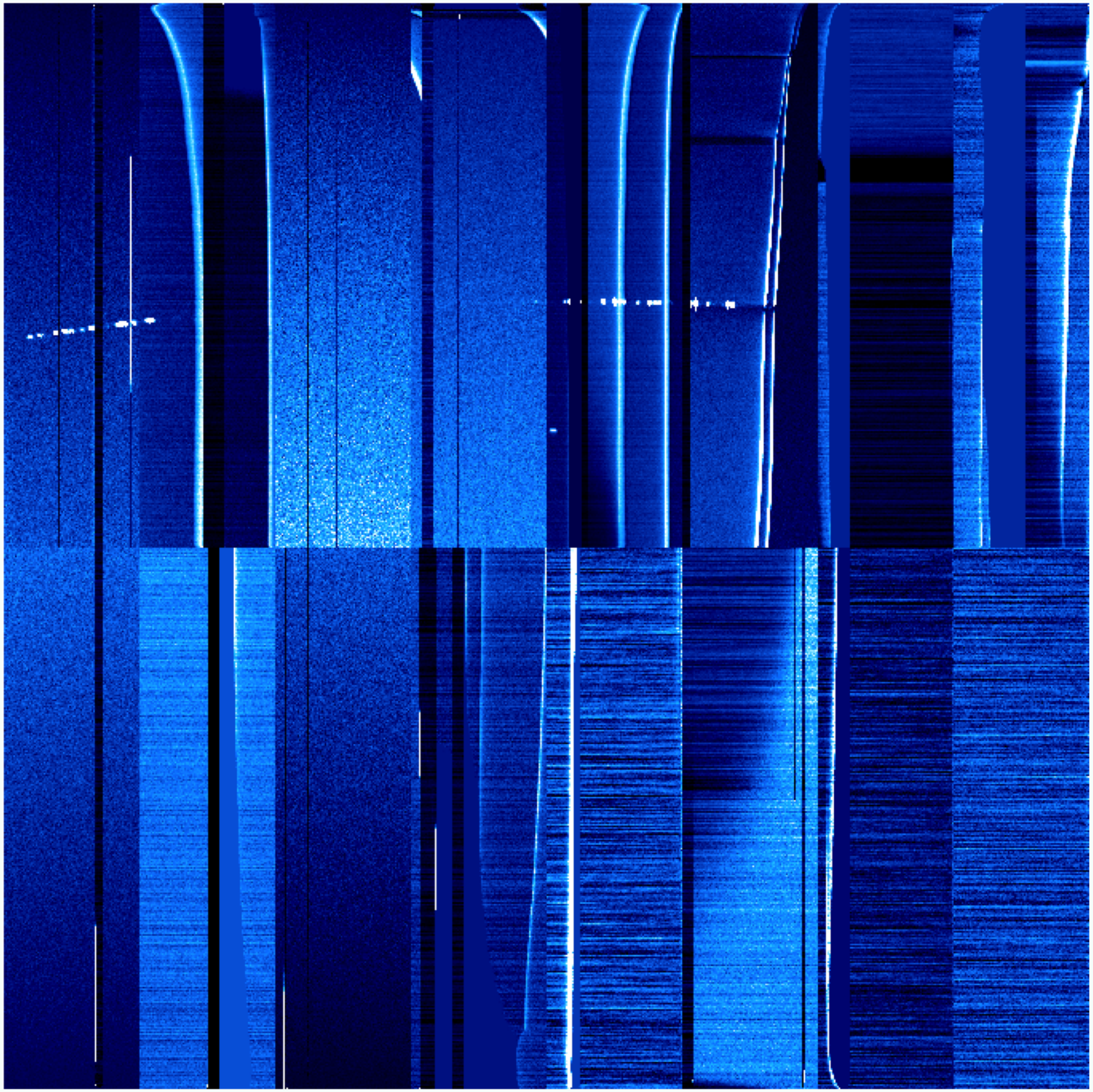
# Status Update: Dispersive Optics

360x240mm PBM2Y Prism:

- Blank slumped by Ohara 2016-2017
- Figured by Zygo in 2017; currently in house

# Status Update: Optics Integration

# NEID "zeroth light"



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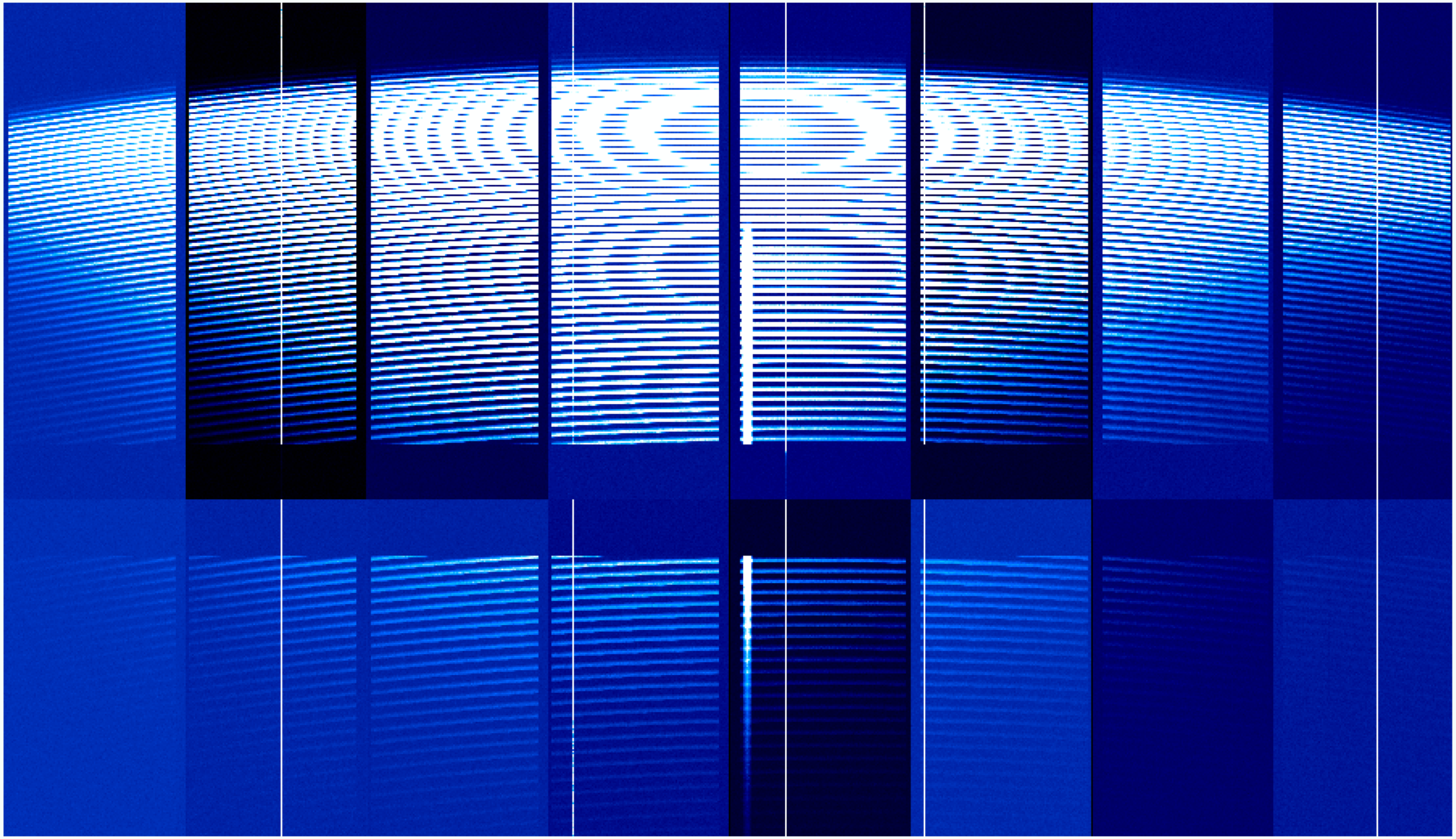

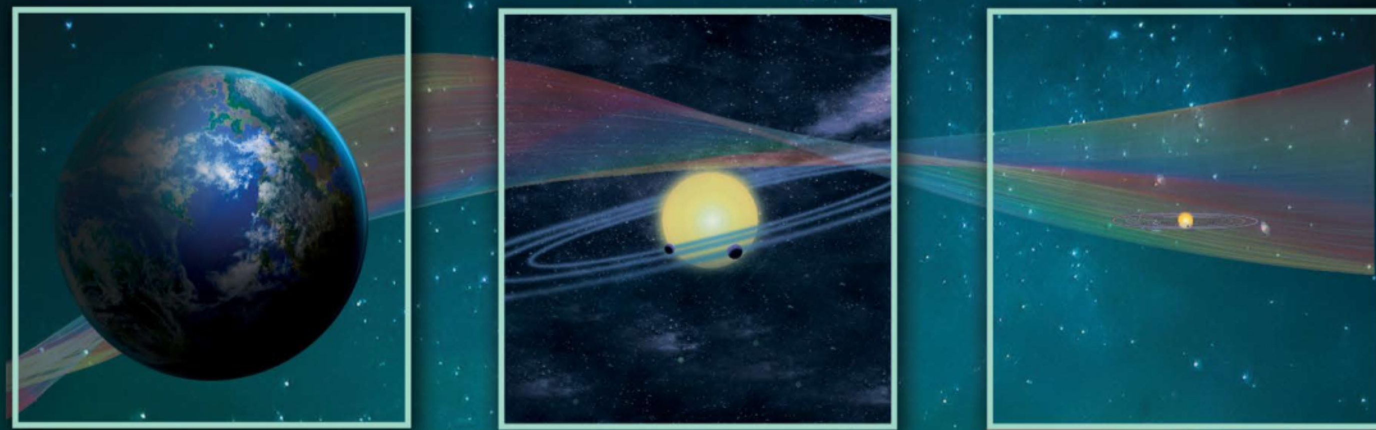

## Status & Schedule:

1. AI&V: Now
2. Shipping: mid 2019
3. Commissioning: Q2-Q3 2019
4. Begin Science Ops: late fall 2019