Facilities for Proposing for Precursor Science Opportunities

- K. Colon (TESS)
- J. Domber (TBT/Ball)
- E. Ford (NEID)
- S. Gaudi (Roman)
- D. Gelino (Keck)
- S. Golwala (LCT)
- S. Howell (High Res. Imaging)
- J. Kegley (MSFC XRCF)
- J. Mather (ORCAS)
- A. Mattioda (ICEE)
- P. Plavchan (MINERVA)
- F. Salama (COSmIC & OCF)
- A. Seifahrt (MAROON-X)
- M. Shetrone (Lick/APF/Shane)
- J. Sobeck (CFHT)
- J. Zmuidzinas (Palomar)

Chair: Eric Mamajek (NASA ExEP, Jet Propulsion Laboratory\California Institute of Technology)

Precursor Science Workshop II, October 12, 2022 CL#22-5564

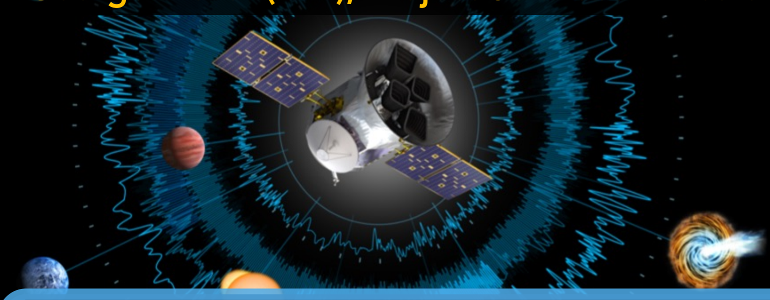
Transiting Exoplanet Survey Satellite

tess.gsfc.nasa.gov
tess.mit.edu

Principal Investigator: George Ricker (MIT), Project Scientist: Knicole Colón (NASA GSFC)

Extended Mission 2 (Sept 2022-2025) observing capabilities encompass:

- approximately 27 day continuous observations in a single broad bandpass (0.6-1.0 microns)
- 200-second cadence full frame images (FFI) providing millions of targets in survey images (24 x 96 degree full field of view)
- 13,000 2-minute cadence and 3,000 20-second cadence postage stamp target slots with science pipeline light curves and full noise mitigation
- 21 arcsec pixel scale
- photometric precisions of ~10-15 ppm for bright stars
- stacked FFI limiting magnitudes of *I* > 21
- rapid data availability at MAST within a few days of downlink



TESS survey operations enable Precursor Science for the future Great Observatories:

- **Exoplanet Discovery and Characterization:** Transiting Exoplanets, Precise Exoplanet Radii, Nearby Potentially Habitable Exoplanets, Young Planetary Systems, Exoplanet Demographics, Multi-Planet System Architectures and Dynamics, Circumbinary Planetary Systems, Multi-Star Planetary Systems
- **Stellar Investigations:** Asteroseismology, Stellar Activity, Flares, Rotation Periods, Long-Term Activity Cycles
- **Extragalactic Studies:** Explosive and Variable Sources, AGN, Accretion Disks, Supernovae, Multi-Messenger Transient Astrophysics

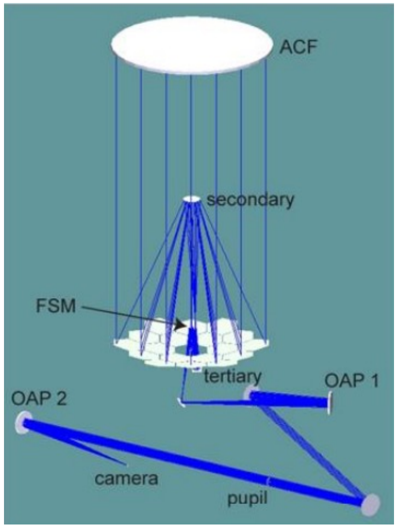
TESS Guest Investigator Program awards up to $3M in grants per year and offers flexible programs for the community:

- Mini Programs for short cadence target slots and no funding
- Small, Large, or Key Project Programs for funding projects of various scopes (~$70K to $250K)
- Ground-Based observing programs that support TESS data analysis and interpretation
- Joint GI programs:
  - Swift/NICER time awarded through the TESS GI Program
  - Short cadence TESS target slots awarded through the Fermi/HST GI/GO Programs
- DDT program available
- No data proprietary period

JWST TESTBED TELESCOPE (TBT) AT BALL AEROSPACE (BOULDER, CO)

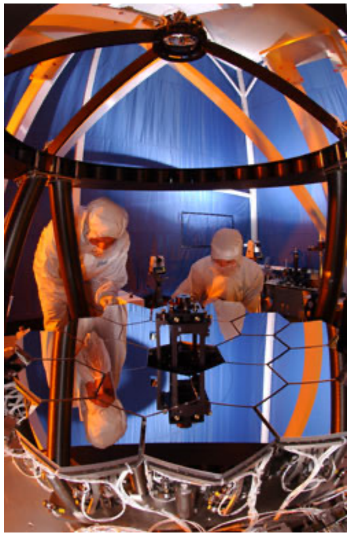
The TBT is a ~1/6th scale flight-traceable optical test platform developed for JWST

- The TBT has a meter class, 18 hexagonal segment primary mirror with flight-traceable optical design and actuation.
- A trunk circuit has access to system pupils and image planes, emulating the functionality of NIRCam or other instruments.
- Used to validate the JWST commissioning process to TRL6
- For more details, see:
  - Lee D. Feinberg, et.al., "TRL-6 for JWST wavefront sensing and control," Proc. SPIE 668708 (2007).
  - Lana K. Kingsbury, Paul D. Atcheson, "JWST testbed telescope: a functionally accurate scaled version of the flight optical telescope element used to develop the flight wavefront sensing and control algorithm," Proc. SPIE 5487 (2004).



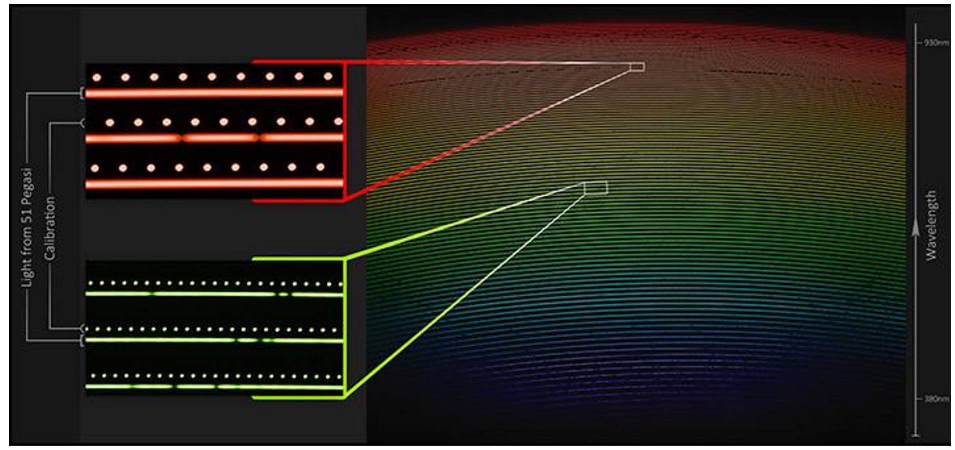
Optical Layout

Hardware Testbed



Interested parties should contact Jeanette Domber (jeanette.domber@ballaerospace.com)

NEID on WIYN & NEID Solar Telescope



High-resolution, ultra-stabilized Echelle spectrograph
R~90k (high-resolution) & R~60k (high-efficiency) modes
Unusually broad spectral grasp from NUV to NIR
Laser Frequency Comb & FP Etalon calibrators
Instrumental precision: <50cm/s
Queue scheduled observations

Existing NEID Programs:

- GTO Program ~40 targets for ~5 years (Gupta+ 2022)
- Numerous GO Programs
  (NASA, NOIRLab, Partner institution TACs)
- 9 Standard Stars
  - ~1-3 standard stars each usable night.
  - No proprietary period!
- NEID Solar Observations:
  - ~200 x 55sec exposures / clear day
  - >40,000 solar observations public

Blog: https://neid.psu.edu/

Instrument: https://www.wiyn.org/Instruments/wiynneid.html

Data:
https://neid.ipac.caltech.edu/search.php &
https://neid.ipac.caltech.edu/search_solar.php

Documentation: https://neid.ipac.caltech.edu/docs/NEID-DRP/

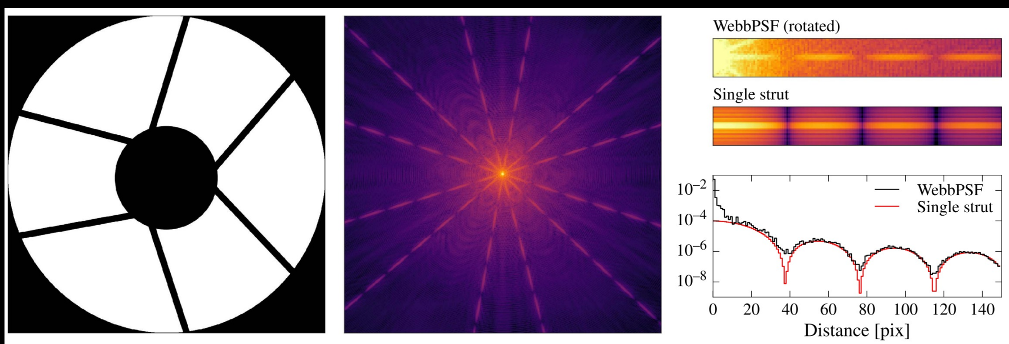
Questions: neid_info@noirlab.edu

Contacts:
Suvrath Mahadevan (Instrument PI)
Jason Wright (Project Scientist)
Eric Ford (NEID Solar Observations)

Image Credit: Guðmundur Kári Stefánsson/Princeton University/Penn State/NSF’s National Optical-Infrared Astronomy Research Laboratory/KPNO/NSF/AURA

High-precision Astrometry with Roman -
Potential Pathfinder for Astrometry with IR/O/UV

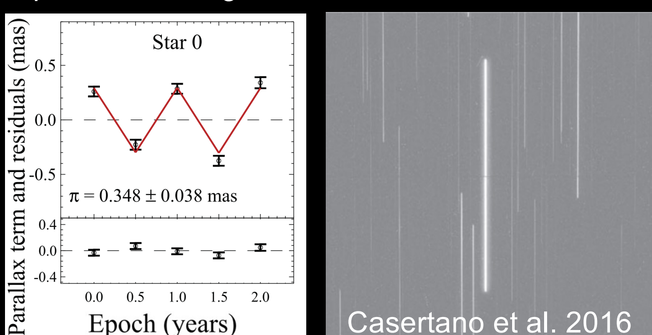
Centroiding Diffraction Spikes



Melchior et al. 2018

Can achieve $\sigma \sim 10\ \mu as$ astrometric precision (1D) in a single 100s exposure of a $R_{AB} \sim 6$ star. This corresponds to 10^{-4} of a pixel → need exquisite control of systematics.

Spatial Scanning



Distributes the flux over many pixels, increasing the signal and suppressing systematics

Parallaxes accurate to ~40 μas have been measured with HST on V~10 stars (Reiss et al. 2015, Casertano et al. 2016); expect to do better with Roman because of larger detector and non-destructive reads, also brighter stars, up to H_{AB}~4

Expect a measurement precision (1D) of ~10 μas with Roman (Sanderson et al. 2019)

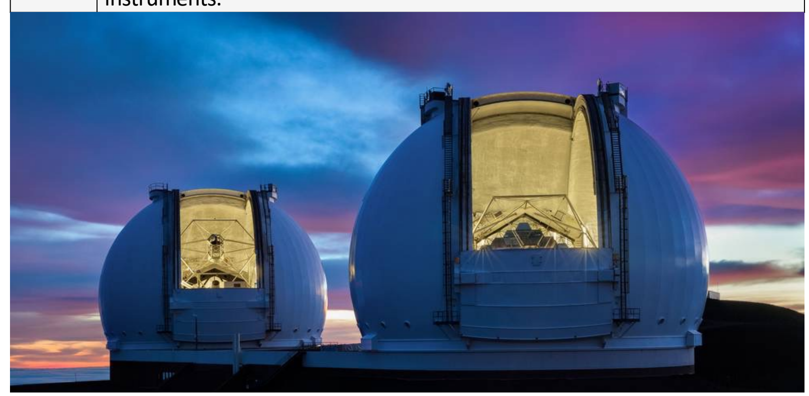
Precursor Science Workshop #2

W.M. Keck Observatory

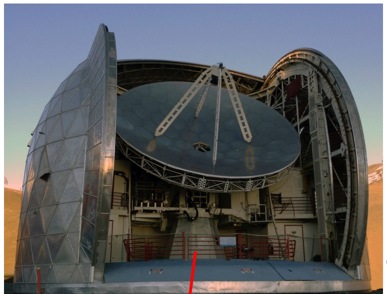
Twin 10m telescopes on Maunakea in Hawaii

Current instrumentation suite as of 2022A semester	
Name	**Capabilities**
LRIS	Low Resolution Imaging Spectrometer. Multi-object, 310 to 1000 nm dual-beam spectrometer/imager. Long slit, multi-slit, R = 300 to 5,000, imaging 6' x 8' FOV, polarimetry.
HIRES	High Resolution Echelle Spectrometer. Single object, 320 to 1000 nm echelle spectrograph; R = 30,000 to 80,000. 4k x 6k detector.
MOSFIRE	Multi-Object Spectrometer for Infra-Red Exploration. ~0.9 to 2.5 µm spectrometer/imager. Multi object up to 46 slits over a 6.1′ x 3′ field with R ~3,300 or a 6.14′ x 6.14' FOV
OSIRIS	OH-Suppressing IR Imaging Spectrograph. Near IR integral field spectrograph (0.9 µ to 2.5 µ), simultaneous diffraction-limited imaging and R ~ 3,900 spectroscopy behind the Keck I AO system.
KI AO	Adaptive Optics System. Natural guide star and laser guide star modes available for use with OSIRIS. 22-Watt solid state 589 nm laser for the LGSAO system.
ESI	Echellette Spectrograph and Imager. Single object, 390 to 1000 nm imager (to 2' x 8' field) and spectrograph (R = 1,000 to 32,000).
DEIMOS	Deep Extragalactic Imaging and Multi-Object Spectrograph. 400 to 1000 nm imaging (17' x 5' FOV) and R up to 6,000, long slit, multi-object spectroscopy.
KCWI	Keck Cosmic Web Imager. visible band (350-600 nm), seeing-limited integral field spectrograph, moderate to high spectral resolution R=900-18,000, configurable field of view and image resolution, 40 arcsec FOV.
NIRSPEC	Near Infrared Spectrometer. Single object, 0.95 to 5.5 µ spectroscopy (R = 2,500 and R = 25,000) with 1k x 1k detector.
NIRES	Near-Infrared Echellette Spectrometer. Single object, prism cross dispersed near-infrared spectrograph, simultaneous J, H and K band R-2700 spectra in five orders from 0.94 to 2.45 µm.
NIRC2	Near Infrared Camera 2. 1 to 5 µm high resolution imager (0.01" to 0.04" pixel scale, 10" to 40" field) and R = 5,000 spectrograph.
KII AO	Adaptive Optics System. Natural guide star and laser guide star modes available for use with NIRC2 and NIRSPEC. 22-Watt solid state 589 nm laser for the LGSAO system.

Future Instrumentation the Final Construction Phase	
Name	**Capabilities**
KPF	Keck Planet Finder. Fiber-fed, single object, high-resolution (R = 90,000) optical spectrometer covering 445-870 nm and is specifically designed to measure precise radial velocities (RVs) with a precision of 50 cm/s or better.
KCRM	Keck Cosmic Reionization Mapper. Red beam upgrade to the KCWI instrument extending the wavelength coverage of KCWI to 1 µm
LFC	Laser Frequency Comb for the infrared. Picket fence calibration spectrum covering the 900-2400 nam range suitable initially for use with NIRSPEC and eventually for HISPEC
KAPA	Keck All-sky Precision Adaptive-optics. Upgrades the KI LGSAO system with a new laser divided into three laser guide stars for more complete atmospheric correction, upgraded hardware for real-time wavefront corrections, and the camera that measures the atmospheric turbulence. Improves performance for OSIRIS and dovetails with Liger and VisAO instruments.

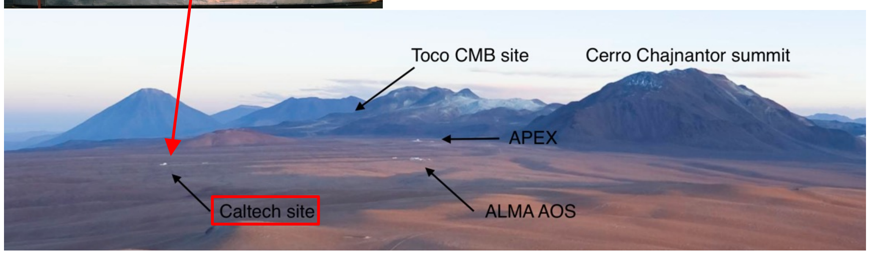


Far-IR Precursor Science with the Leighton Chajnantor Telescope (LCT)



LCT

move of the 350μm-capable, 10.4m Leighton Telescope of the Caltech Submillimeter Observatory to the Caltech/CBI site inside ALMA



Timeline

2022: Telescope removal, shipment to Chile

2023: Reassemble and refurbish at San Pedro

2024: Move to Chajnantor and recommission

2025: First light (future ROSES-Precursor)

Contact: Sunil Golwala, golwala@caltech.edu

Science

- Detect the bottom of the SF Main Sequence at peak of submm SED:
  350μm conf lim = PACS 100/160μm conf lim
  (current, future 350μm cameras)
  → Forecasts for Far-IR continuum survey yields
  → Assessment of diversity of SEDs:
  mean and scatter in L-T relation, AGN contribution
- [CII] luminosity function, total [CII] emission, and high-z SFR history at z = 5-8; CO luminosity function and molecular gas history at Cosmic Noon
  (TIME and future TIME/SuperSpec line intensity mapping)
  → Data on high-z and Cosmic Noon ISM conditions to inform forecasts for far-IR spectral lines

Technology Development

- Large-format imaging arrays
- Large-format spectroscopy including spectroscopy-on-a-chip into the FIR

NASA Hi-Resolution Imaging Program - Speckle Interferometry on Large Telescopes

Provides the highest angular resolution of any telescope

High speed and accurate timing

Available filters:
- u, g, r, 467, 562, Hα
- i, z, 716, 832

- Full frame readout at 1MHz
  - 1024 X 1024 EMCCDs
- Dual plate scale
  - 0.01” or 0.07” / pixel

- High-resolution (20mas)
- High-contrast
- Wide Field – up to 56”
- Targets to r=20th mag

- State-of-the-art image reconstruction: contrasts near 12 mag (10^-5)

Fast ms imaging → **Diffraction-limited** → **Optical dual-channel**

Available to the Community

Propose thru NOIRLAB

- https://www.wiyn.org/Instruments/wiynnessi.html
- https://www.gemini.edu/instrumentation/alopeke-zorro

Contact Instrument PI

Steve B. Howell, NASA Ames
steve.b.howell@nasa.gov

MSFC's X-Ray & Cryogenic Facility

An adaptable space environment simulation facility enabling science missions since 1991

As the world's largest X-Ray optical test facility, the XRCF supports development, performance, and calibration testing of grazing-incidence optics, detectors and telescopes.

As the Agency's premier cryogenic optical test facility, the XRCF facilitates the development and pre-flight evaluation of large direct-incidence telescope mirrors and structures in relevant thermal environments.

<u>Space Simulation Chamber</u>

- 20ft dia x 60ft space simulation test volume; < 10^{-7} Torr; optically clean
- Full thermal shroud (-200F to +200F) with zone control
- Motion stages for test articles and detectors
- 5400 ft^2 ISO6 cleanroom

<u>X-Ray Test Capabilities</u>

- 500m beamline; beam dia = 1.46m; divergence = 1.39 mrad half-angle
- Multiple energies, flux rates

<u>Cryogenic / Cryogenic Optical Test Capabilities</u>

- Temperatures to 15K
- Optics up to ~ 4.25m dia

Notable Programs to date

(development through pre-flight verification)

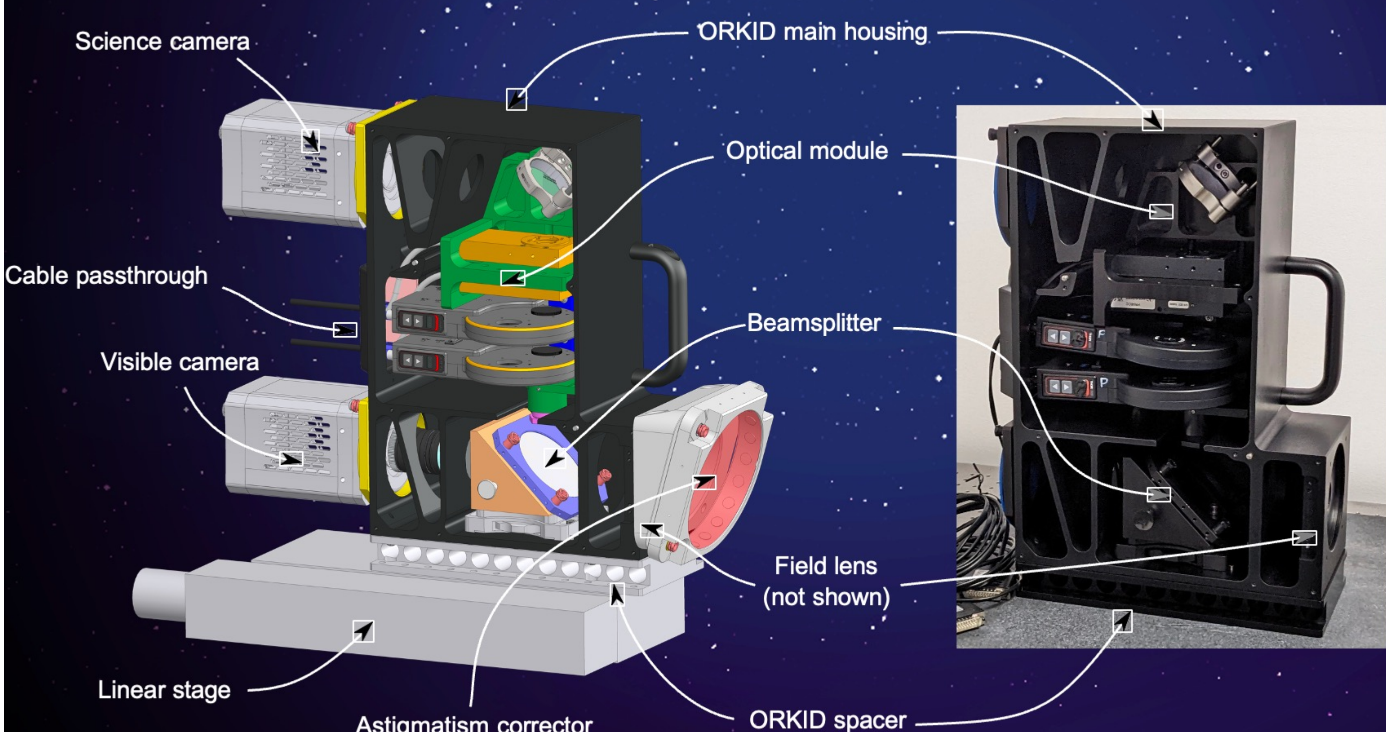
- Chandra X-Ray Observatory
- Webb Space Telescope
- Hinode and GOES X-Ray telescopes
- Facility updates for ATHENA

https://optics.msfc.nasa.gov

jeff.kegley@nasa.gov

ORCAS - Keck Instrument Development – ORKID
Near Diffraction Limited Visible Light Imaging

- Demonstrate and characterize current & future Keck II AO system at visible wavelengths where sky is darkest
- 14 milliarcsec width of PSF core (4x better than Hubble)
- Explore high resolution universe before Next Great Space Observatory
- Step towards high Strehl visible AO, e.g. with Orbiting Configurable Artificial Star (report link)
- Step towards diffraction limited Integral Field Spectroscopy and other visible instruments at Keck
- Installed on optical bench; Contact PI Eliad.Peretz@nasa.gov to participate

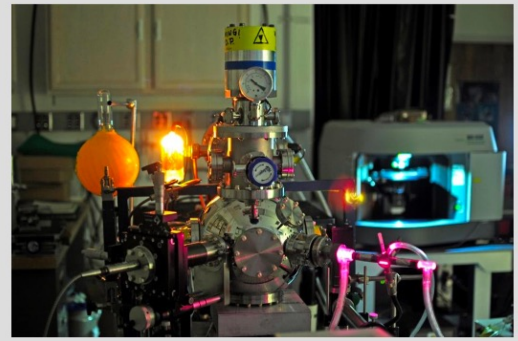


The optical performance of ORKID meets the science goals of having a PSF FWHM <2 pixels at 650 nm. This is achieved by diffraction-limited as-built performance with an RMS wavefront error below 50 nm.

WIDEBAND FILTERS	Min	Max
•27052 R-Band Bessell*	554 nm	696 nm
•27058 i Sloan*	698 nm	843 nm
•27059 z Sloan	830 nm	1000+nm
NARROWBAND FILTERS	**Center**	**Width**
•O[I]*	630 nm	10 nm
•H-alpha Continuum*	640 nm	6 nm
•27002 H-alpha*	656 nm	5 nm
•27012 Jovian Methane	889 nm	18 nm
•CT940/20	940 nm	20 nm

John.c.mather@nasa.gov
eliad.Peretz@nasa.gov

Institute for Carbon Evolution Experiments
ICEE



ICEE is a multi-component facility consisting of

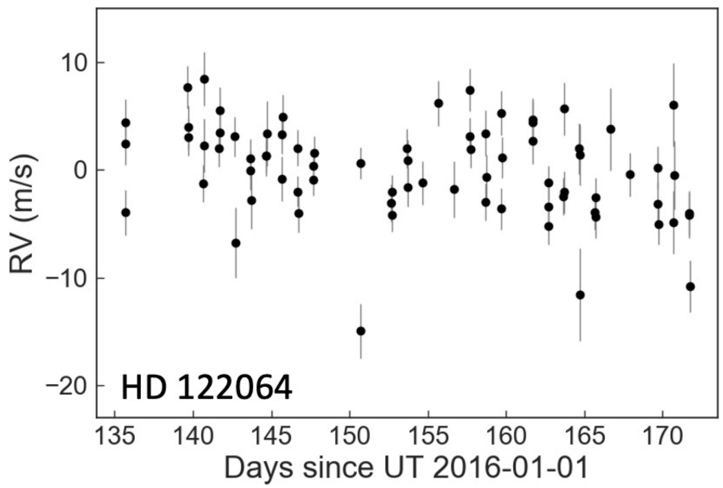
1. **Ultra high vacuum chamber (UHV) with in-situ radiation, FTIR, MS, and Raman capabilities**
2. **Raman Microscope**
3. **DRIFTS Chamber**

Component	Capability	Experiments
Flowing H_2 UV lamp	10.2 eV	UV Photolysis, ionization
Electron gun	1-100 keV	Energetic processes
Raman Microscope	100 to ~5000 cm^{-1}	Molecular Identification
FTIR	150 to 16000 cm^{-1}	Molecular Identification
Mass Spectrometry (MS)	0-300 u	Identification of gaseous species
UHV with Cryo-cooler	10^{-8} Torr 15-300 K	H_2O ice, organics and ice processing, Matrix-isolation
DRIFTS Chamber	600˚C to -150˚C 10^{-6} Torr	FTIR studies of surface and grain catalysis

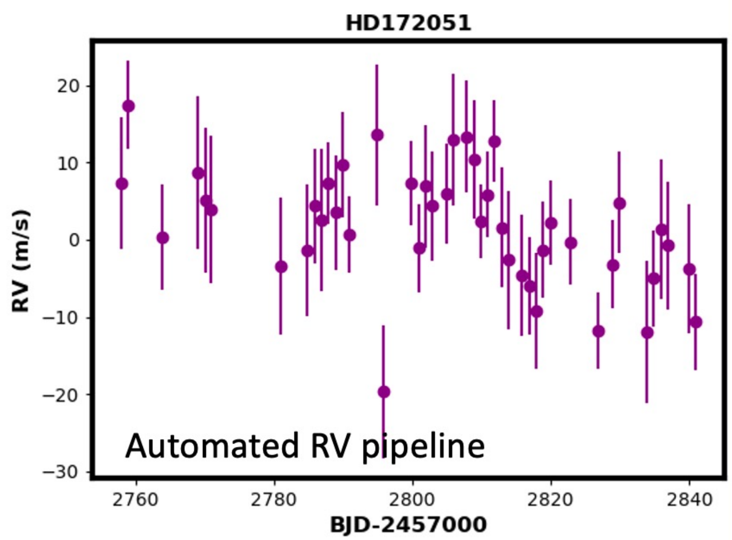
ICEE's objectives are to replicate astrophysical and planetary science relevant processes, collecting spectroscopic data useful to the scientific community.

Contact:
Andrew Mattioda
Andrew.Mattioda@nasa.gov
650-604-1075

ICEE Facility Link



Contact: pplavcha@gmu.edu



MINERVA Global Arrays

- Mt Hopkins, AZ
- Mt Kent, Australia

4-6 x 0.7m dual Nasmyth telescope arrays

Twin R~80,000 500-630nm fiber-fed spectrometers

Optimized for bright V~5 targets PRVs, but can acquire/guide V~11

100% dedicated facilities to exoplanet autonomous high-cadence nightly follow-up

~3-5 m/s demonstrated long-term RMS

Upgradeable! Same basic core spectrometer design as the 50 cm/s MAROON-X

Precursor Science: High cadence nightly RV monitoring of direct imaging target activity and massive planets

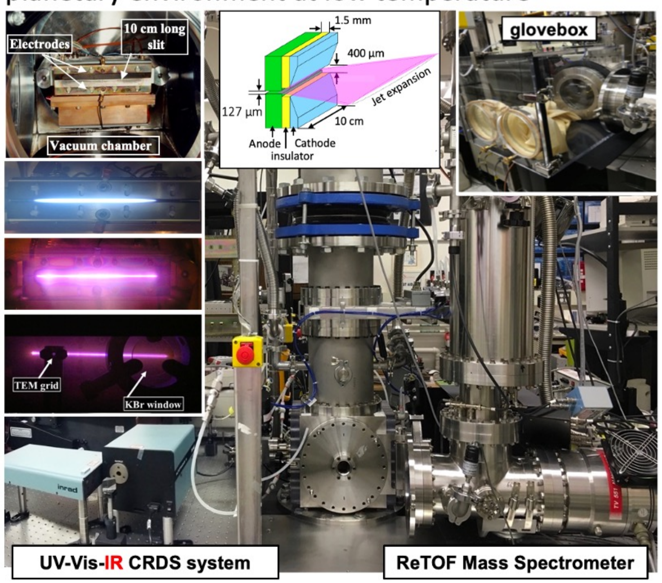
COSmIC and OCF Facilities: interstellar, circumstellar, and planetary

https://www.nasa.gov/ames/spacescience-and-astrobiology/cosmic-facility

SILICON VALLEY
AMES RESEARCH CENTER

Astro 2020: Laboratory astrophysics is essential to the interpretation of astrophysical data" (p. 4-28)

COSmIC simulates interstellar, circumstellar, and planetary environment at low temperature



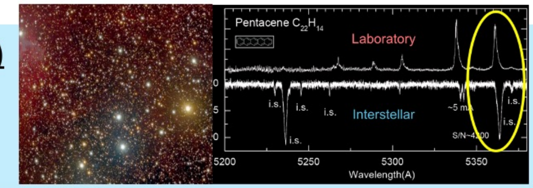
GAS PHASE

High Resolution Cavity Ring Down Spectroscopy (COSmIC)

- **UV-Vis-IR absorption/emission spectra** of molecules at low temperature to interpret observations and identify gas molecules in the ISM (**HST, JWST, FGOs**)

High Resolution Mass Spectrometry (COSmIC)

- Investigate the formation pathways from gas to aerosols/dust at low temp.

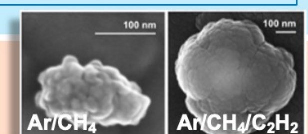


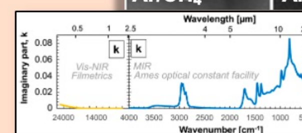
Astro2020 Decadal Survey alignment: *Laboratory measurements of spectroscopic tracers and astrochemical processes.*

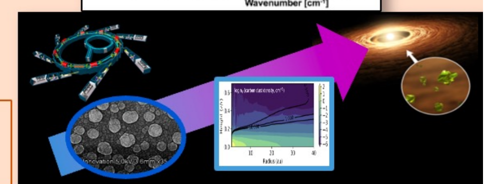
SOLID PHASE

Cosmic grain production, characterization, and processing (COSmIC + OCF)

- Produce analogs of carbonaceous dust grains and (exo)planets aerosols **(COSmIC)**
- Characterize their chemical, physical and optical properties (composition, morphology, optical constants **(OCF)**)
- Investigate X-ray processing of grains to constrain protoplanetary disk models

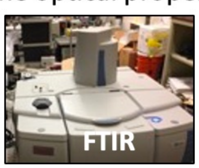


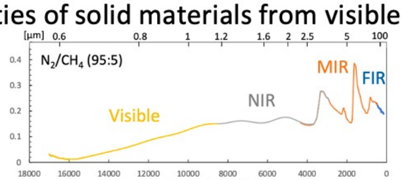


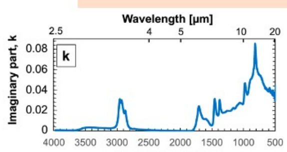


Astro2020 Decadal Survey: *Investigating dust formation and evolution from the CSM to the ISM to exoplanetary atmospheres.*

The Optical Constants Facility (OCF) allows to characterize the optical properties of solid materials from visible to FIR.







COSmIC POC: Farid Salama (farid.salama@nasa.gov)

OCF POC: Ella Sciamma-O'Brien (ella.m.sciammaobrien@nasa.gov)

Identified gaps that can be addressed by COSmIC and OCF:

- Characterizing exoplanet atmospheres (gas + solid phases)
- Extend to FIR to THz/sub-mm range (gas + solid phases)
- X-Ray Spectroscopy of molecular tracers (gas + solid phases)

MAROON-X

MAROON-X is a highly stabilized, fiber-fed echelle spectrograph on **Gemini North**.

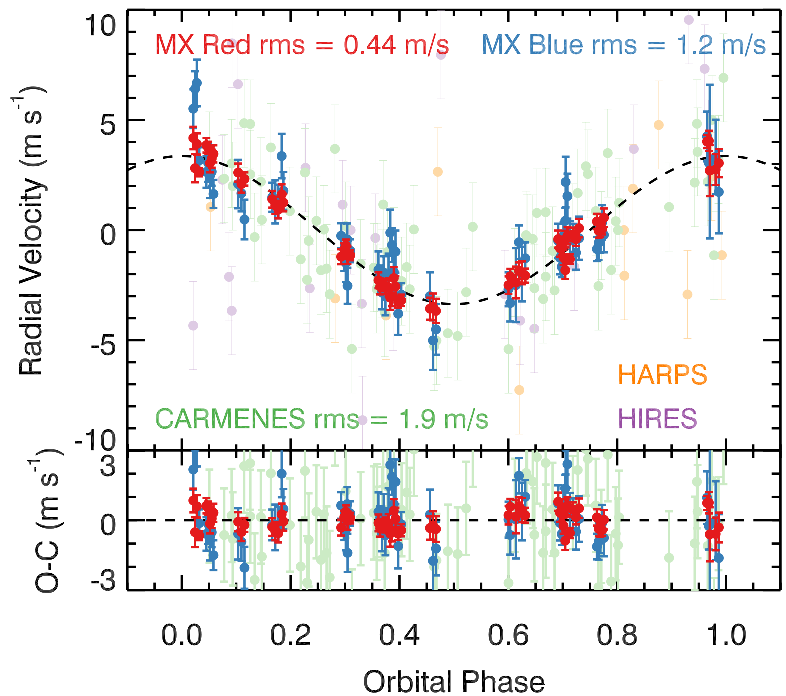
Primary science case: EPRV detections and mass measurements of Earth-sized exoplanets, particularly around M dwarfs.

Key stats:

- 500 – 920 nm wavelength coverage
- Resolving power ~85,000
- Simultaneous calibration and sky fiber
- Etalon 'comb' for wavelength & drift calibration
- Regular science observations since May 2020
- Upgrade to Menlo LFC in February 2023

Performance:

- 30 cm/s instrument baseline stability over weeks
- Reach down to m_V=16.9mag for late M dwarfs



For questions, please contact Andreas Seifahrt (seifahrt@uchicago.edu)

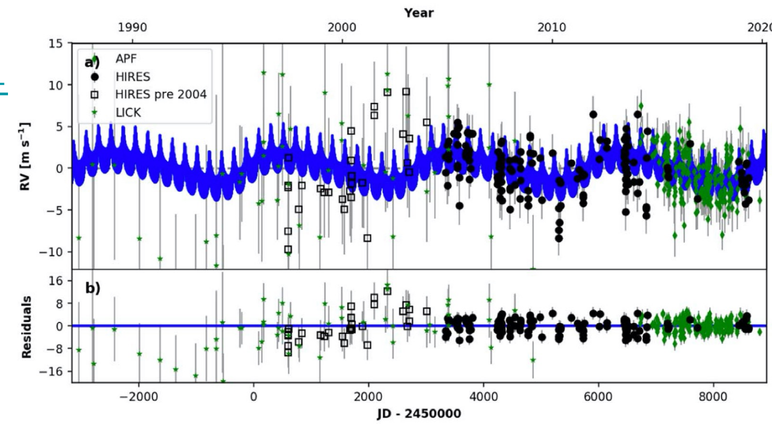
Lick Observatory

https://www.lickobservatory.org

Automated Planet Finder Telescope

https://www.lickobservatory.org/explore/research-telescopes/automated-planet-finder/

- 2.4m telescope designed to find and characterize exoplanets through RVs
- Employs an iodine cell
- Wavelength coverage down to Ca II H&K
- Resolution up to 110k
- Vel err of ~2 m/s for V=9 in 900sec Burt et al. 2015
- Several mature reduction pipelines
- **Fully automated queue allowing cadence observing**
- **Available every night of the year**



HD 95735 from Rosenthal et al. 2021 shows multiple planets and APF **long term stability**, like HIRES.

APF Upgrade Paths Planned

Adaptive Secondary Mirror

- Small improvement in stabilized LSF
- 2x increase in throughput

Fiber slicer scrambler

- 1 m/s improvement in stabilized LSF
- Small increase in throughput

Shane Telescope

https://www.lickobservatory.org/explore/research-telescopes/shane-telescope/

- 3m OIR telescope with multiple configurations
- IR Adaptive Optics with LGS and NGS
- Target vetting and verification using IR AO

Please Contact
Matthew Shetrone
UCO Deputy Director
mshetrone@ucolick.org

Canada-France-Hawaii Telescope Facility

CFHT Current Instrumentation

- **MegaCam** [Wide-field Imager; 1 deg^2 FOV; 0.18" pixels]
- **WIRCam** [Wide-field Infrared Camera; 20'x20' FOV; 0.3" pixels]
- **ESPaDOnS** [Echelle Spectropolarimeter; λ_{range} = 0.37-1.05 μm; R~68000+]
- **SITELLE** [Imaging Fourier Transform Spectrometer; ; λ_{range} = 0.35-0.90 μm]
- **SPIRou** [Near-Infrared Spectropolarimeter; λ_{range} = YJHK; R~75,000]

CFHT Upcoming Instrumentation

- **MSE-Pathfinder**
  - Late 2020's First Light
  - MOS Instrument [N_{Fibers} ~ 1000]
  - Medium Resolution Optical/NIR Spectrographs; IFU Capability

CFHT Next Generation Instrumentation (CFHT → MSE)

- Maunakea Spectroscopic Explorer [MSE]
  - Reuse of CFHT Facility [Minimal Footprint Extension]
  - Late 2030's First Light
  - 14.0-m Primary Aperture
  - MOS Instrument [N_{Fibers} ~ 19000]
  - 1.5 deg^2 FOV

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Palomar/Precursor Support Capabilities

Palomar Observatory is a private facility hosting several optical/near-IR research telescopes:

- Hale Telescope (5-m)/60-inch Telescope (1.5-m)/SOT (1.2-m Schmidt)
- Hale hosts wide-field imaging, AO-corrected imaging, moderate-dispersion spectroscopy, and high-dispersion radial velocity instruments
- P60 & SOT operate robotically with dedicated instruments (SEDM low-dispersion IFU on P60, ZTF 600 m-pix/45 deg^2 imager on SOT) allowing rapid (< one night) follow-up

Palomar has long history hosting novel instrumentation projects, and large-scale observing projects combining multiple assets (e.g. the PTF/ZTF arc of transient astronomy projects)

Key role in validating exoplanet transit candidates with over 150 papers citing AO imaging

New high-throughput optical spectrometer expected on Hale Q3 2023

https://sites.astro.caltech.edu/palomar/homepage.html

PALOMAR OBSERVATORY

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Jet Propulsion Laboratory
California Institute of Technology

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