

SCIENCE HIGHLIGHTS FROM RECENT
JPL/IPAC USE OF PALOMAR
OBSERVATORY
FEBRUARY, 2022

- Rob Zellem
- Gautam Vasisht
- David Ciardi
- Fede Marocco
- Dan Stern
- Thomas Connor
- Joe Masiero
- Bonnie Buratti
- Jana Chesley

NESSI
(New Mexico Exoplanet
Spectroscopic Survey
Instrument)

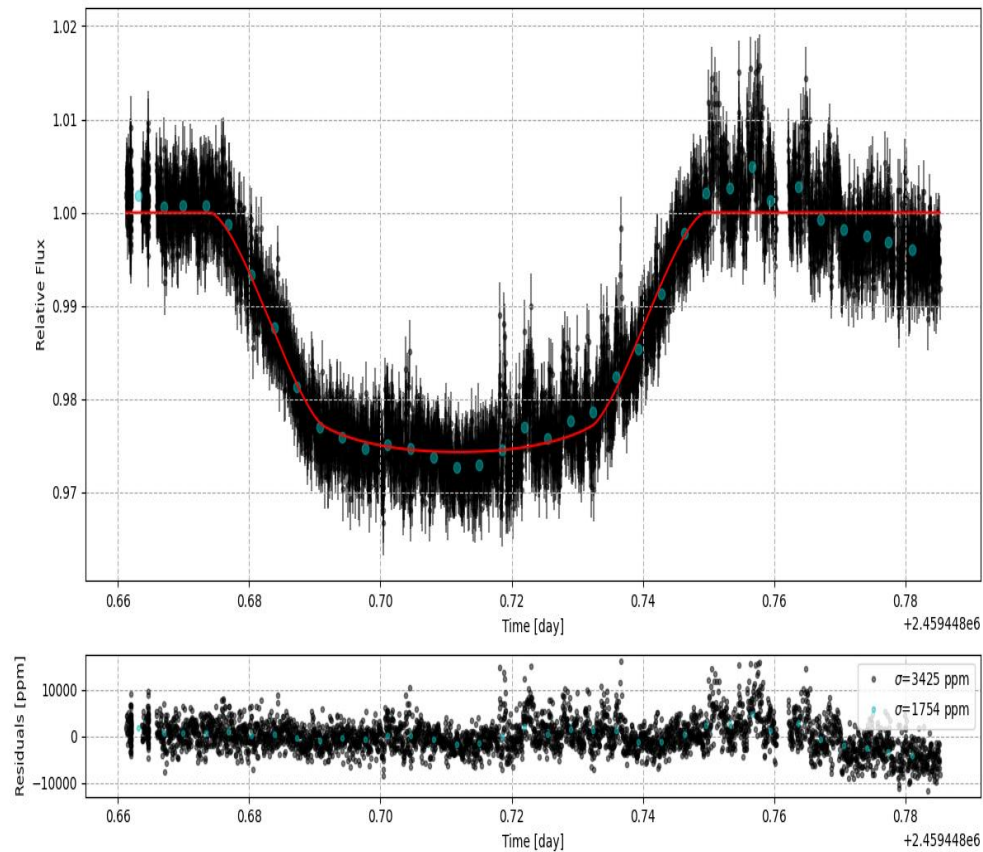
Rob Zellem, for the NESSI team



What is NESSI?

- NESSI is a wide field imaging and spectroscopic near-IR instrument operated at the prime focus of the 200-inch
- It has a H2RG with a $\sim 7'$ field of view
- Main instrument modes are simultaneous JHK spectroscopy ($R=250$) or single-band J, H, or K spectroscopy ($R=1100$)
 - Also capable of imaging in these bands
- NESSI is a new instrument at Palomar and has been undergoing commissioning
- The main science thrust is transit spectroscopy of exoplanet atmospheres

NESSI Measurement of transit of HD189733b



PARVI Commissioning and Science - Gautam Vasisht

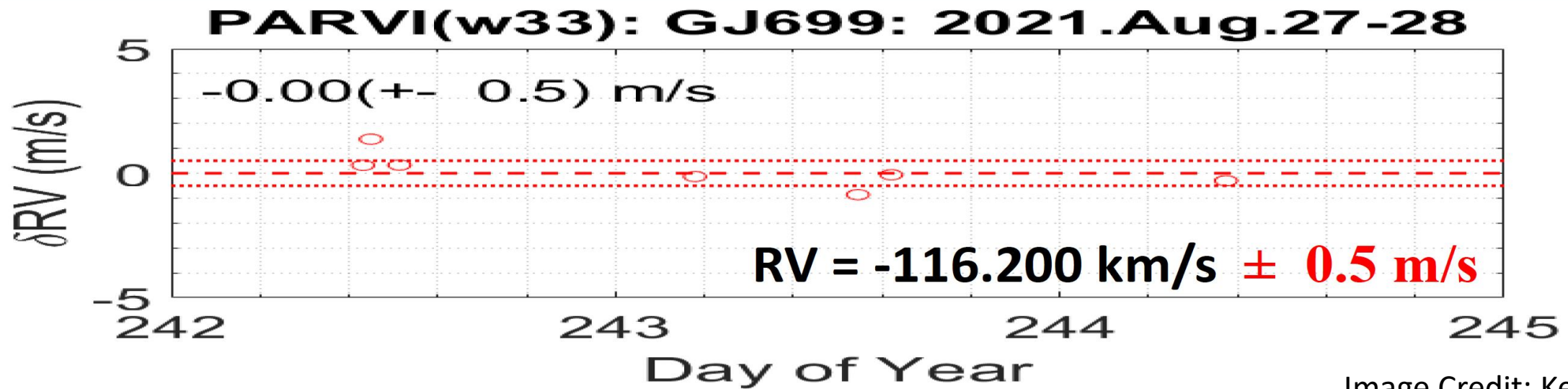
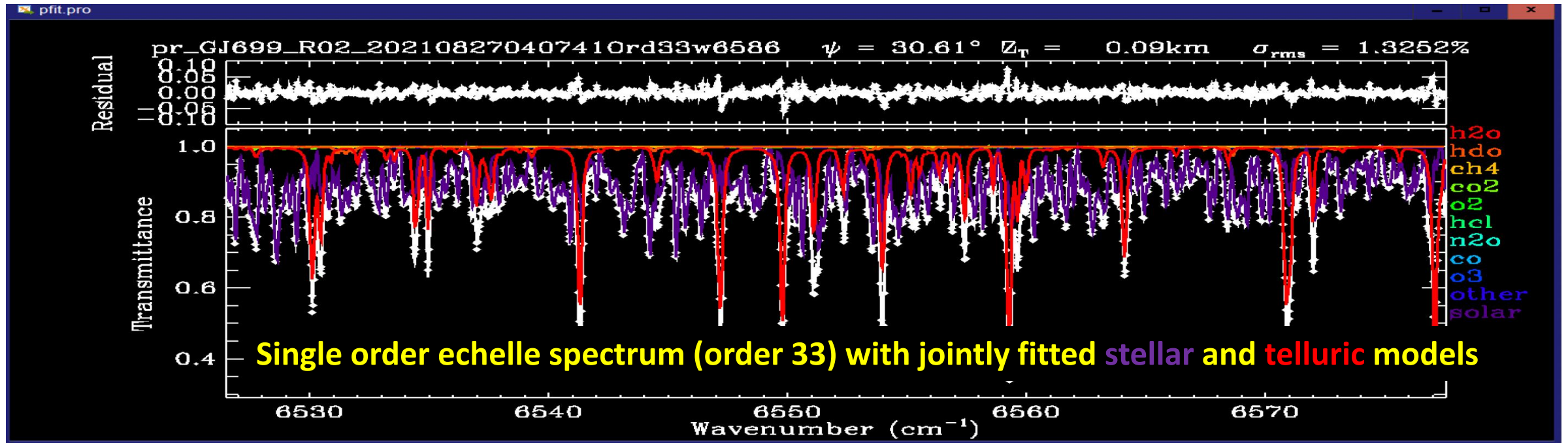
- **Goals**

- To commission the Palomar Radial Velocity Instrument; an AO and SM-fiber fed $R=10^5$ spectrograph (near infrared 1100 – 1760 nm)
- Demonstrate precision radial velocity operations with laser frequency comb standard

- **Current performance**

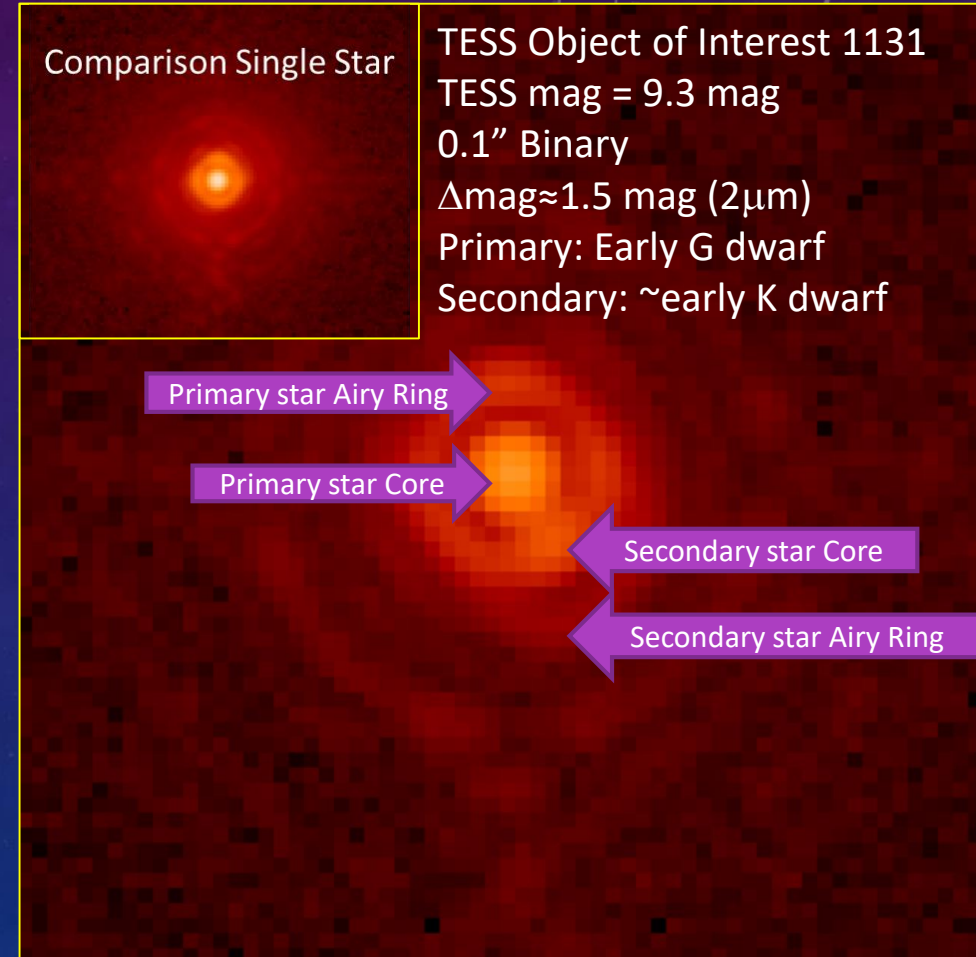
- Detection sensitivity: SNR = 100 in 1800 sec on an H=8 star
- Resolving power: $R = 75,000$, limited by spectral extraction procedure
- Radial velocity performance: 1-2 m/s on H=5-6 RV standards with careful frequency comb calibration
 - Calibration is limited by unanticipated and recently-diagnosed polarization effects which we are trying to fix

GJ699 radial velocity standard

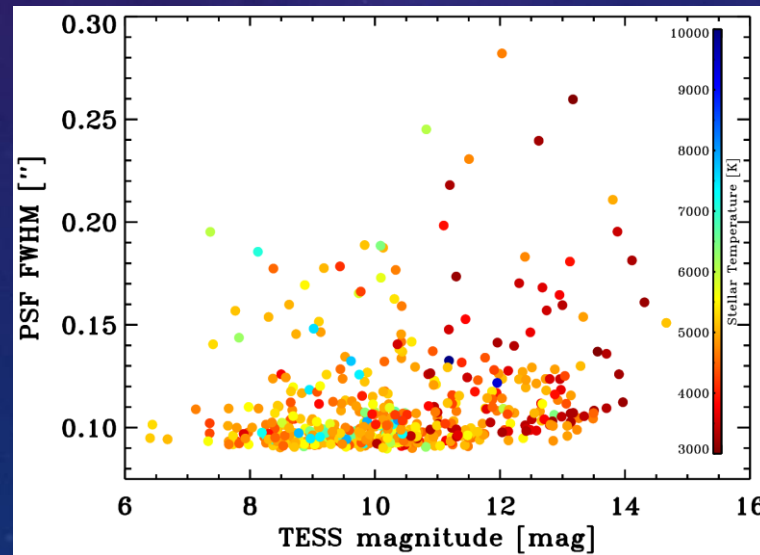
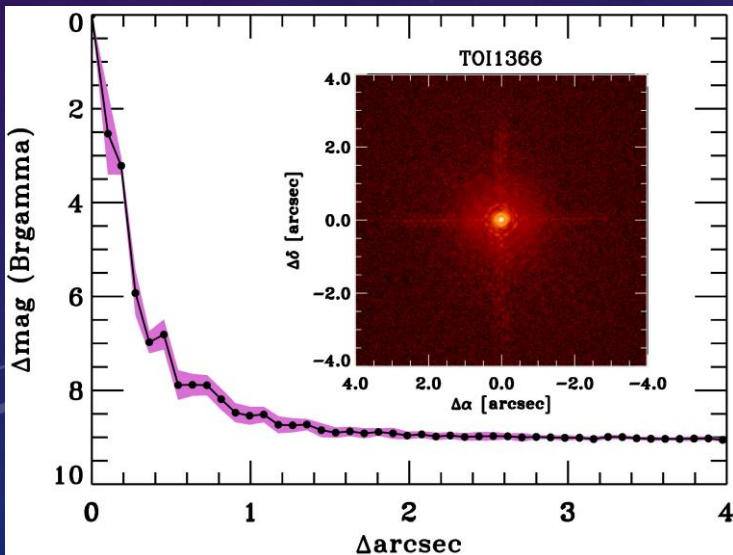


Palomar AO+PHARO Program to Detect Stellar Companions Around Planet Hosting Stars – David Ciardi, IPAC

- Long running program to search for stellar companions around Kepler, K2, and TESS planet host stars
 - Yields more precise planet radii by identifying blends
 - Enables studies of planets in systems with multiple stars
 - Contributes to the validation and confirmation of transiting exoplanets
- Palomar has contributed more NIR AO observations to the community than any other system in the world (nearly 1000 stars)
- Contributions to 45 refereed publications since 2011 (10 in the last year alone)
- Recent improvements in Palomar AO system has enabled us to reach diffraction limited performance on stars as faint as V=16th magnitude

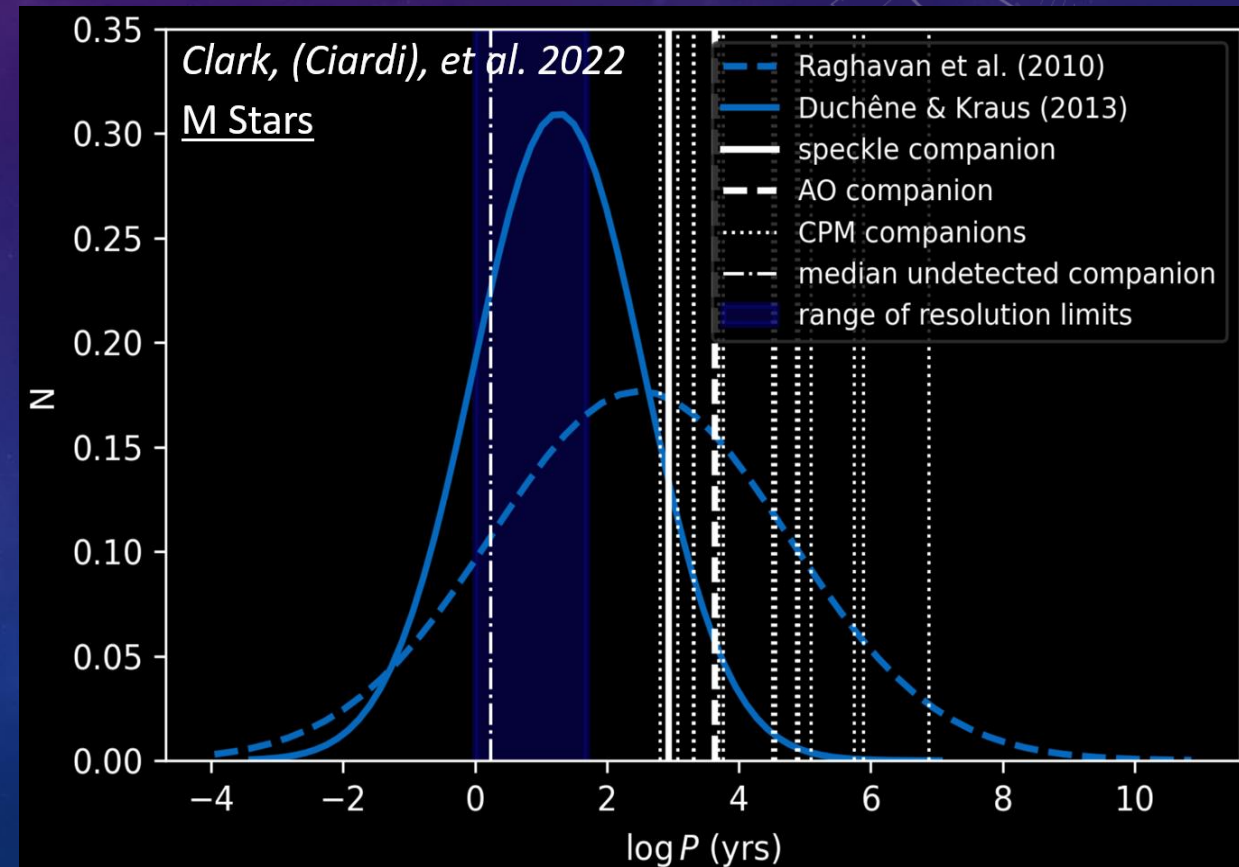
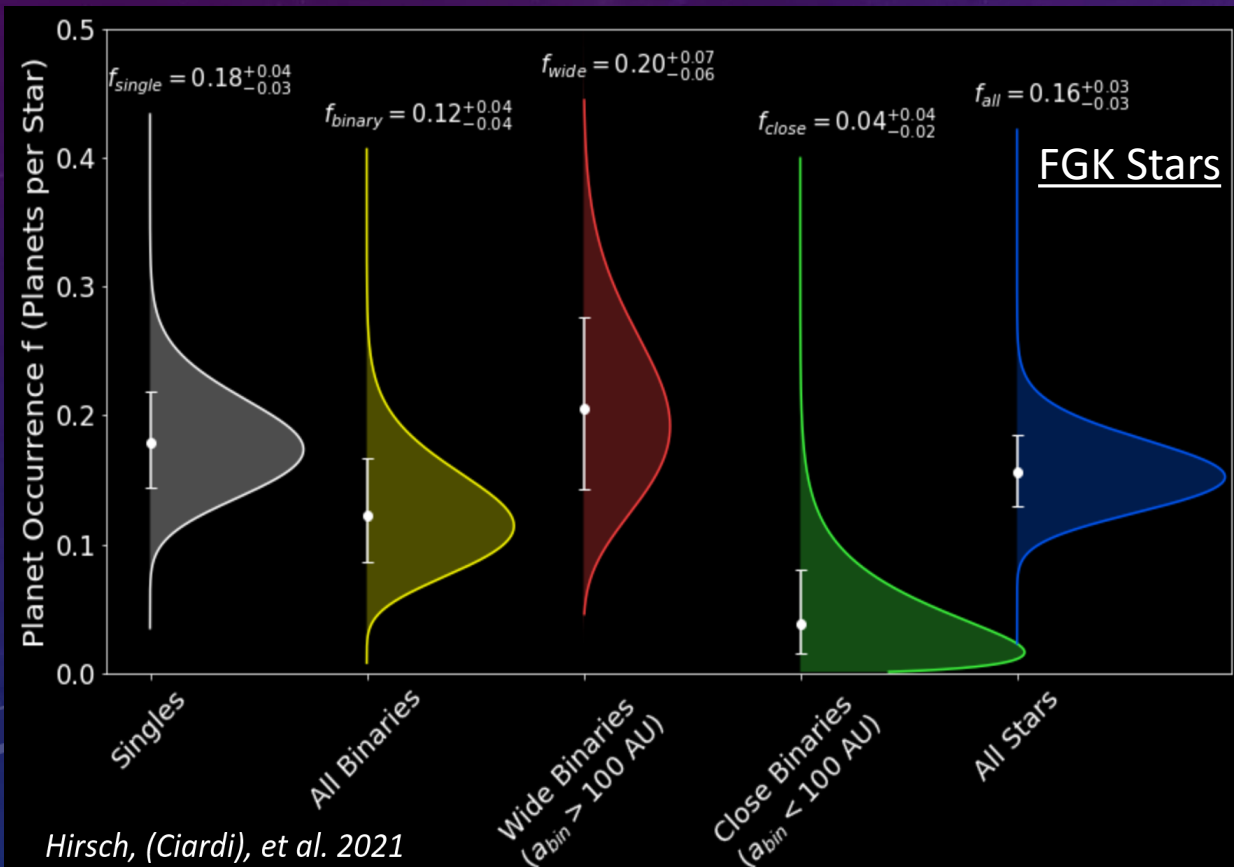


Typical FWHM: 0.1" with
2 mag contrast at 1 FWHM



Stellar Multiplicity in Planet Hosting Stars

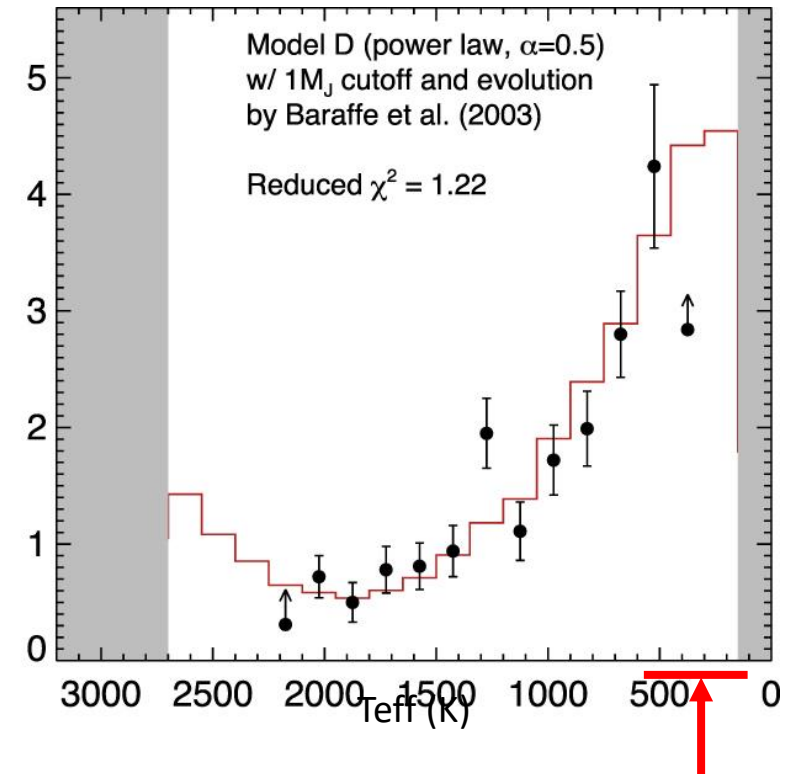
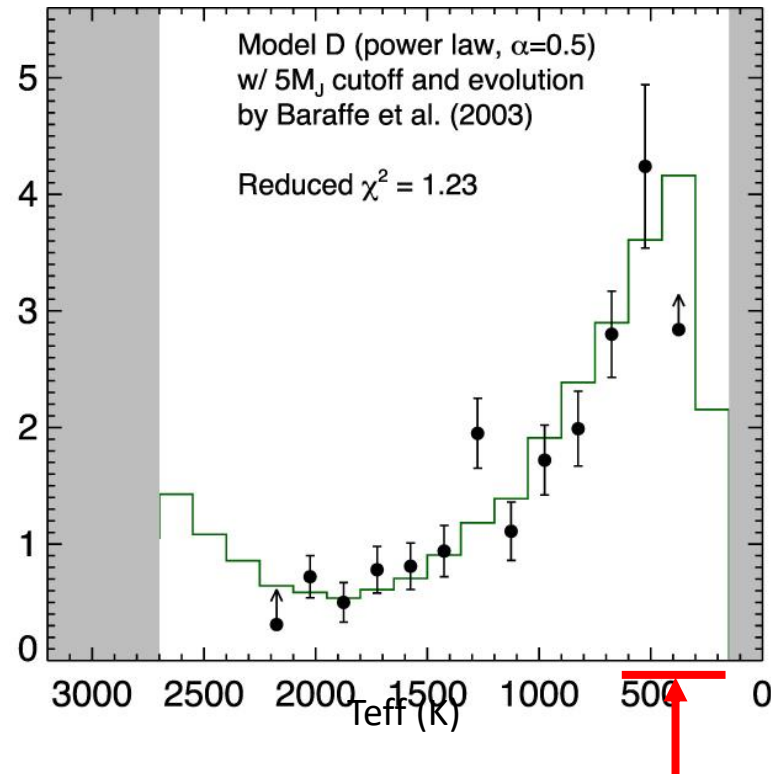
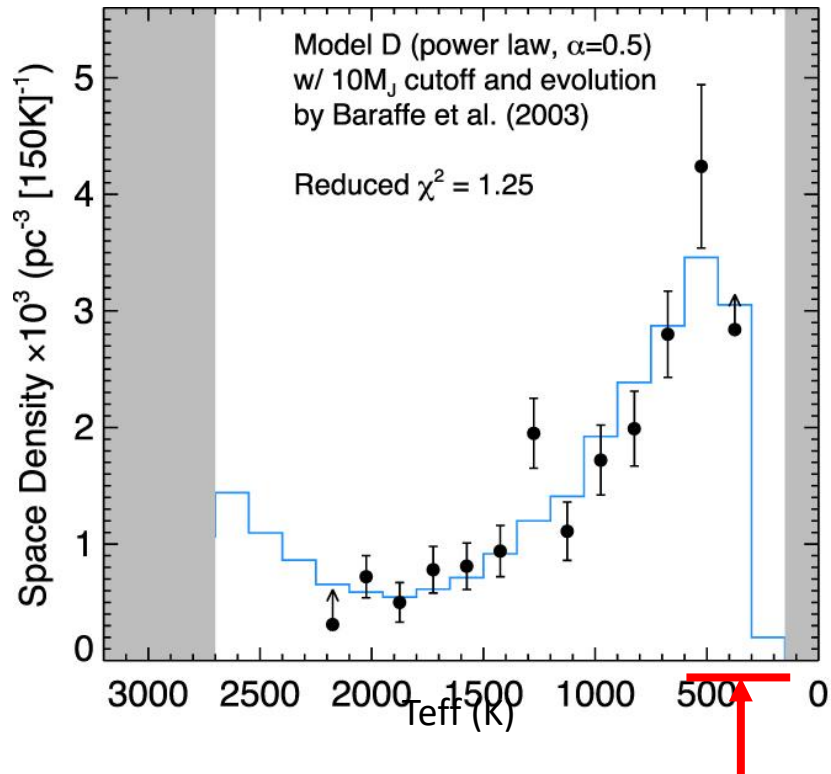
- Palomar AO imaging used to show that planet hosting stars have approximately the same binary frequency rate as solar neighborhood stars BUT the stellar companions are further out (> 100 au)



Determining the Low-Mass Cutoff to Star Formation – WIRC

Fede Marocco - IPAC

Kirkpatrick et al. 2021, ApJS, 253, 7K

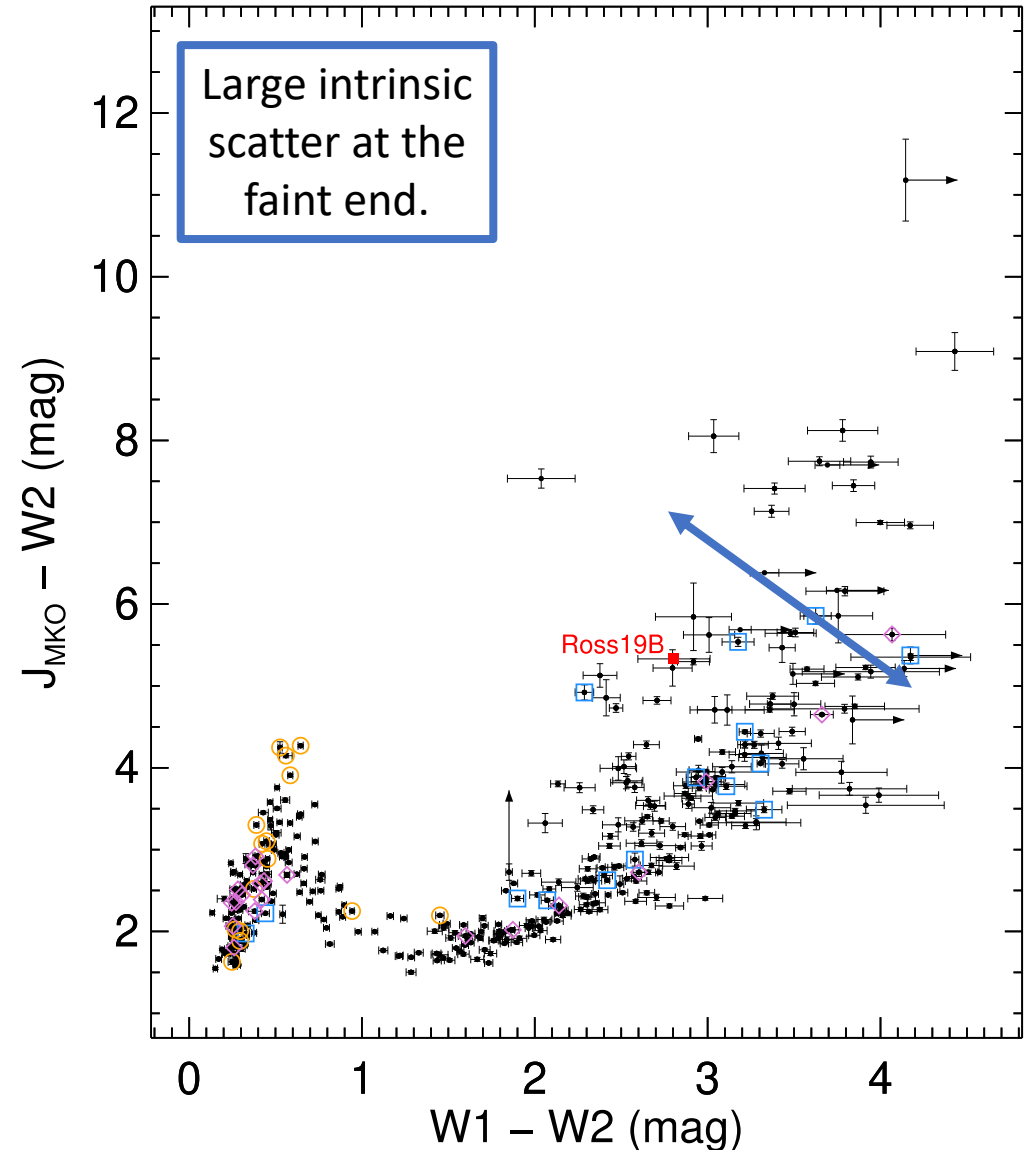


The space density of the coldest brown dwarfs is very sensitive to the low-mass cutoff to star formation. Numerical simulations predict the minimum mass is $\sim 3 M_{Jup}$. Now we can test those predictions! But the space density of the coldest brown dwarfs is poorly constrained...

Determining the Low-Mass Cutoff to Star Formation – WIRC

Three key steps:

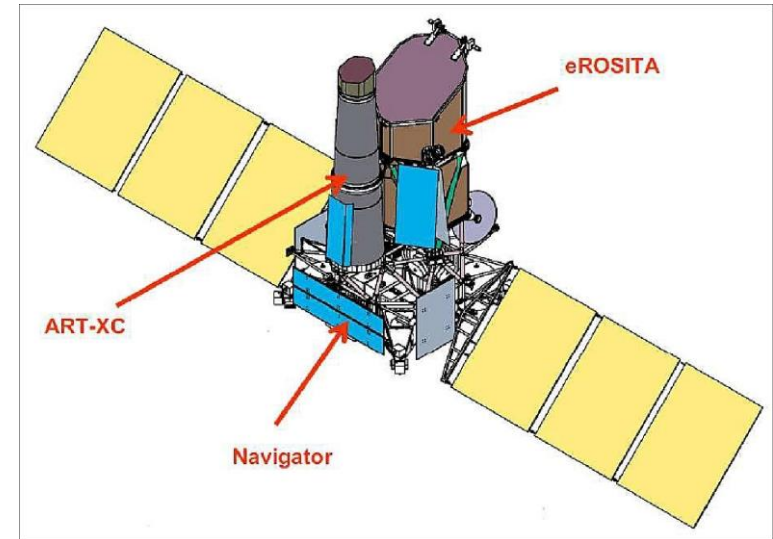
1. Candidate selection (WISE): all-sky, mid-IR, long-baseline survey -> W1-W2 color + proper motion.
2. Confirmation/characterization (WIRC+Keck): J-W2 color is a good proxy for T_{eff} . Better angular resolution allows PM confirmation.
Early results: IR colors become unreliable indicators of distance and luminosity for the coldest brown dwarfs. Parallaxes are fundamental!
3. Parallaxes (WIRC+others): needed to select a volume-limited sample and measure space density. Ongoing multi-telescope parallax program (Palomar/WIRC + GTC/EMIR + VLT/HAWKI) -> parallaxes of ~ 120 cold BDs within 20pc.



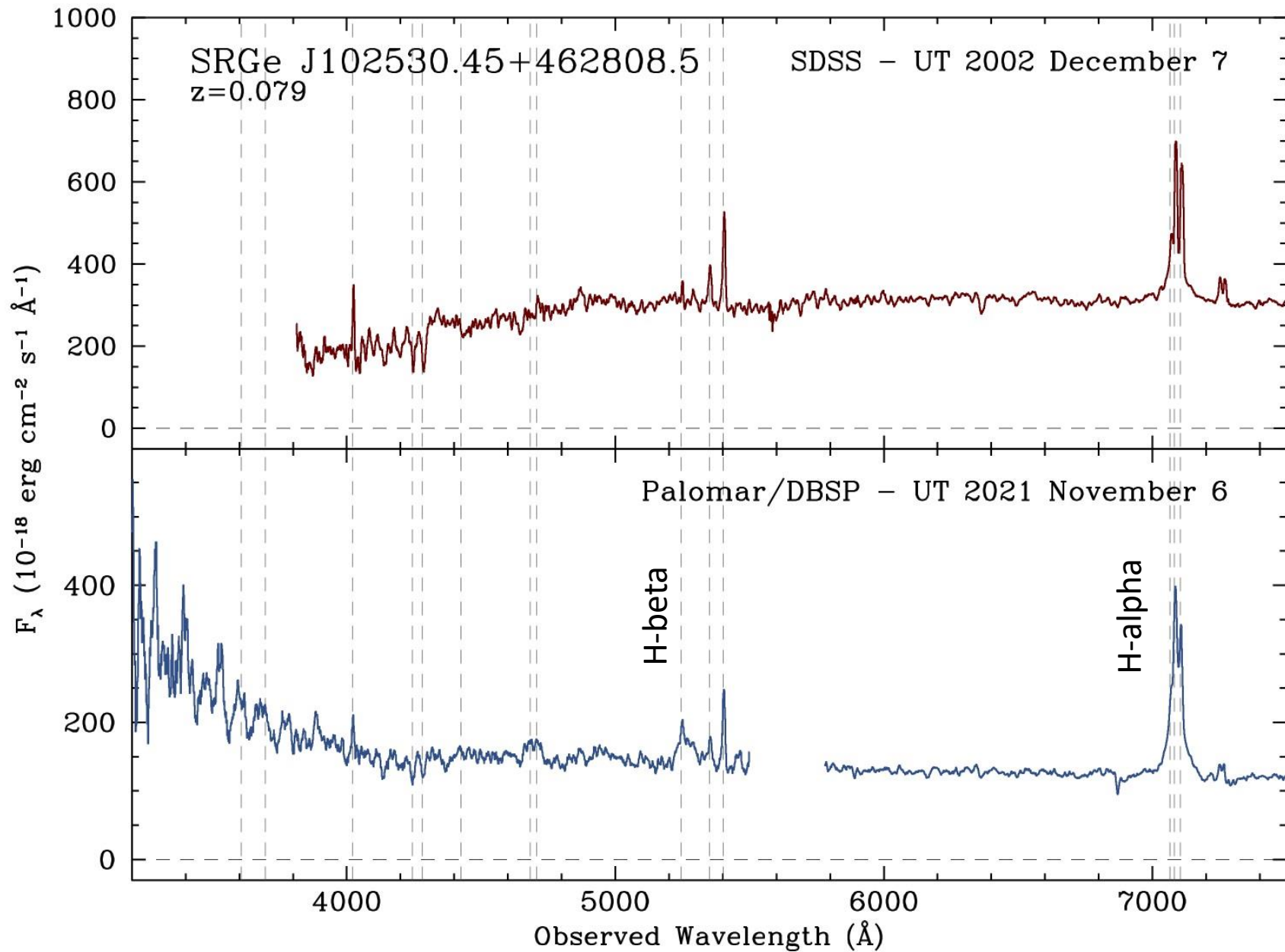
Extreme X-Ray Sources from Spectrum-Roentgen Gamma

PI: Daniel Stern

Co-I's: Brightman, Gilfanov, Khorunzhev, Medvedev, Sunyaev



- SRG = Russian/German all-sky X-ray survey (next-generation ROSAT, 0.1-2.4 keV)
 - eROSITA (German): 0.3-10 keV
 - ART-XC (Russian): 4-30 keV
- Collaborating w/ Russians (i.e., northern sky) on DBSP follow-up of extreme sources
 - Ultra-hard X-ray sources (i.e., detected by ART-XC, but faint/undetected by eROSITA); tend to be heavily obscured, Compton-thick AGN
 - Approved NuSTAR program for follow-up of most extreme source
 - Extreme faders/risers: AGN that have faded or brightened by 10x between 6-month passes
 - Approved XMM-Newton + NuSTAR ToO program for follow-up of six
 - Highest luminosity X-ray sources: i.e., high-redshift AGN



Example of an eROSITA AGN that brightened by 10x:

SDSS (2002) shows early-type galaxy / type 1.9 AGN (i.e., broad H-alpha, but no broad H-beta)

DBSP (2021) shows blue AGN w/ prominent, broad Balmer lines

Provides insight into how AGN are triggered, timescales on which this happens, and the physics of the central engine.

Mapping the Epoch of Reionization Using **DBSP**

Thomas Connor, JPL

Mapping the Epoch of Reionization

Project led by Thomas Connor, NPP (3266)

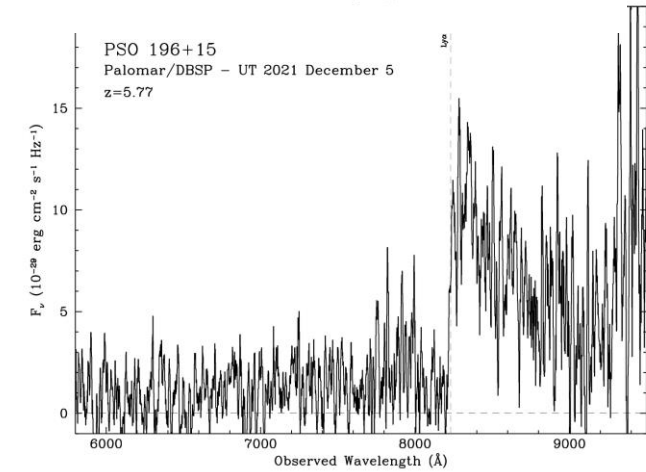
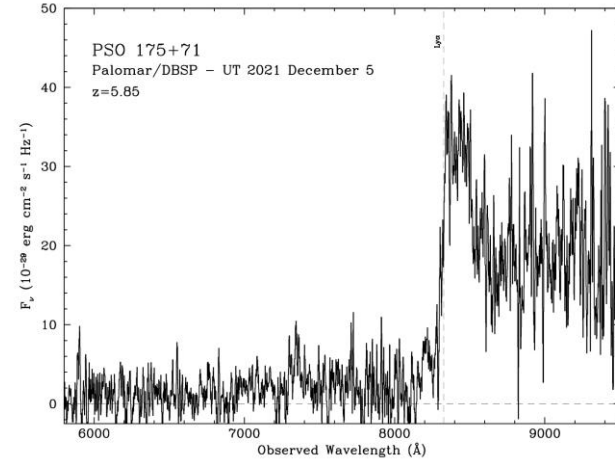
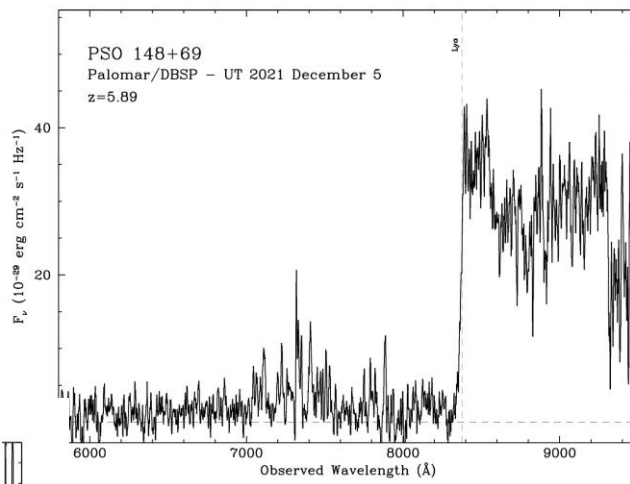
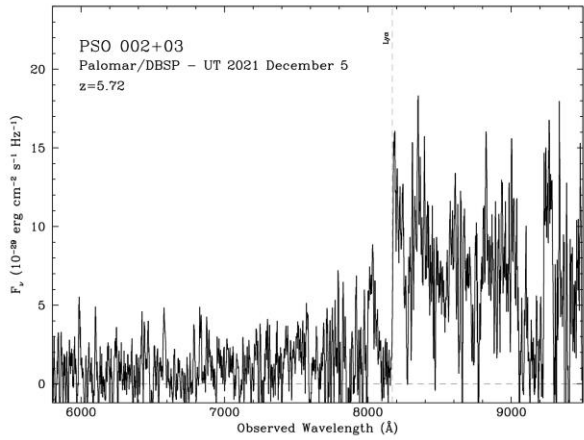
Using **DBSP**

Quasars in the first billion years of the Universe ($z \gtrsim 5.7$) are key indicators of black hole growth, the progress of reionization, the growth of structure, galaxy evolution, and much more

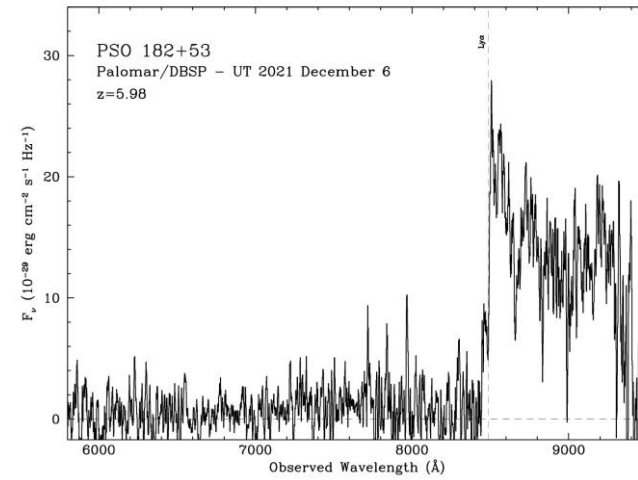
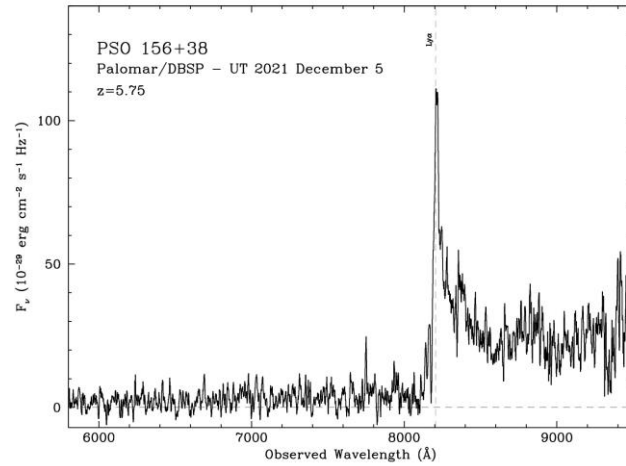
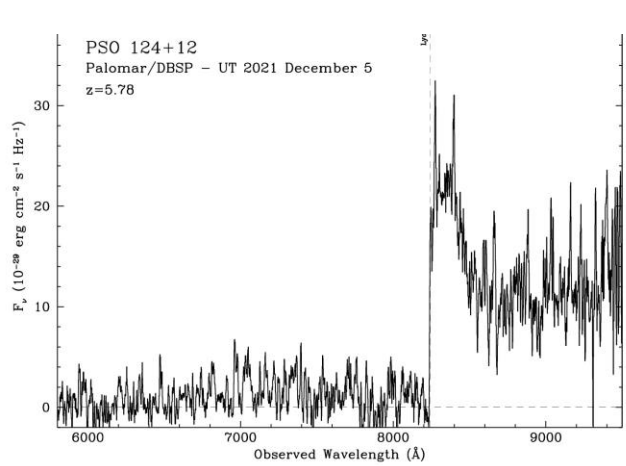
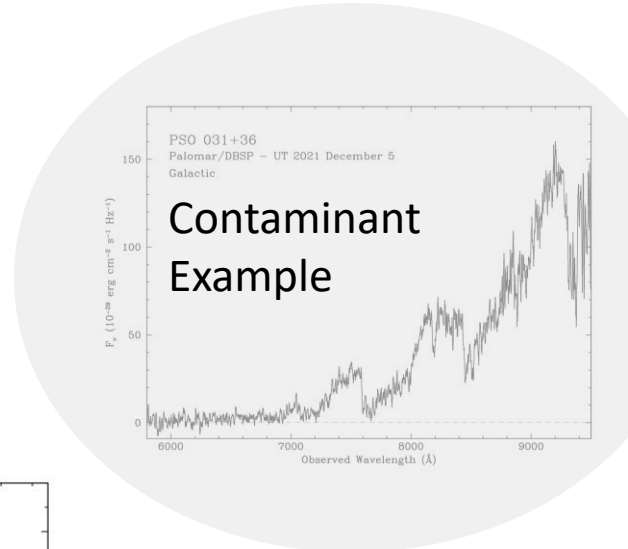
They're tough as the Dickens to find, though. Nothing above $z=5$ before 2000, and only $\sim 300-400$ $z \gtrsim 6$ known to date, most of which in the past few years.

Mining surveys gets you half way there, but **Brown Dwarfs** are major contaminant – a sudden Ly α break looks the same as a low-temperature blackbody fade out in photometry. Spectroscopy needed to confirm quasars.

DBSP enables us to rapidly work through candidate catalogs. Coverage out to 1 micron and a lot of glass lets us push discovery out to $z \gtrsim 6$.



DBSP is a powerful discovery engine – these are all from our most recent night (Dec 5)



WIRCPOLE Polarimetry of asteroid surfaces

JOE MASIERO

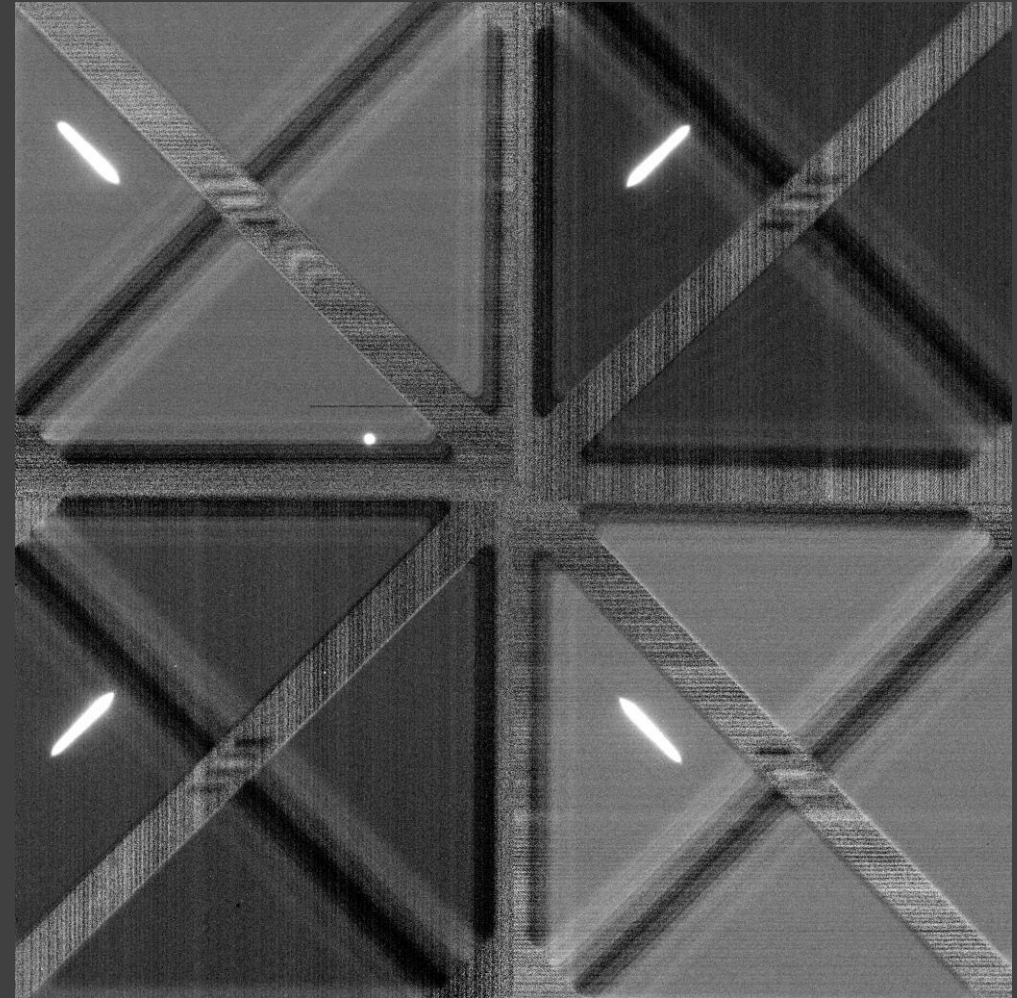
IPAC

Polarimetric Properties of Asteroids in the Near-Infrared Using WIRC+Pol

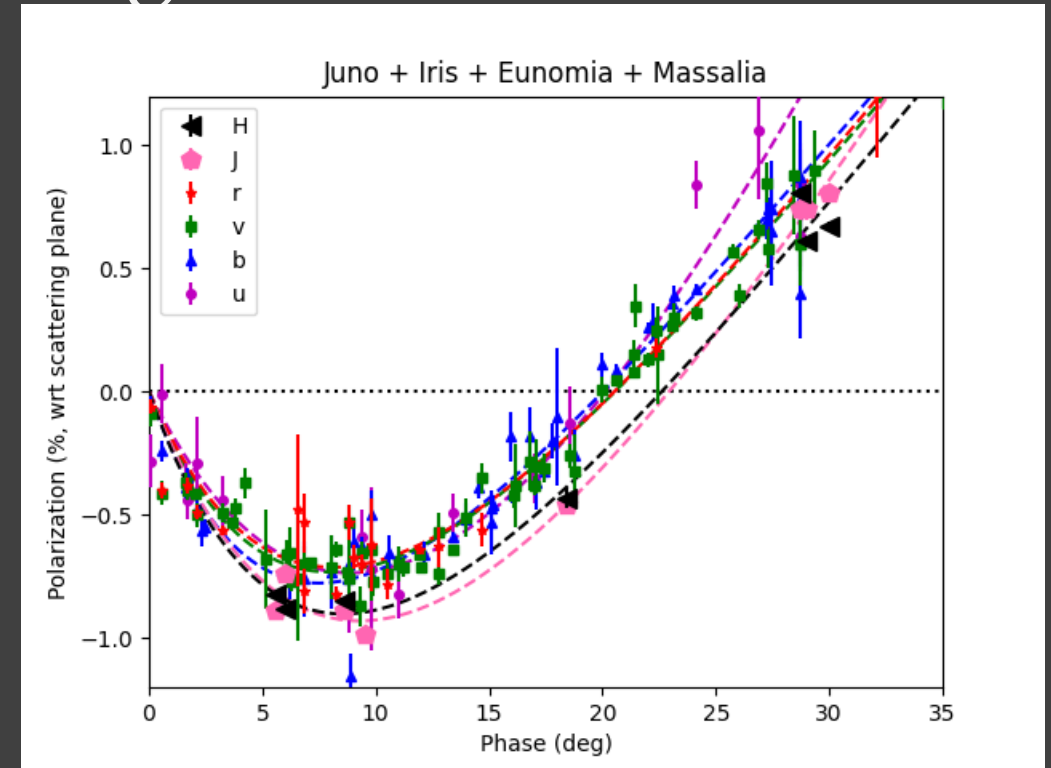
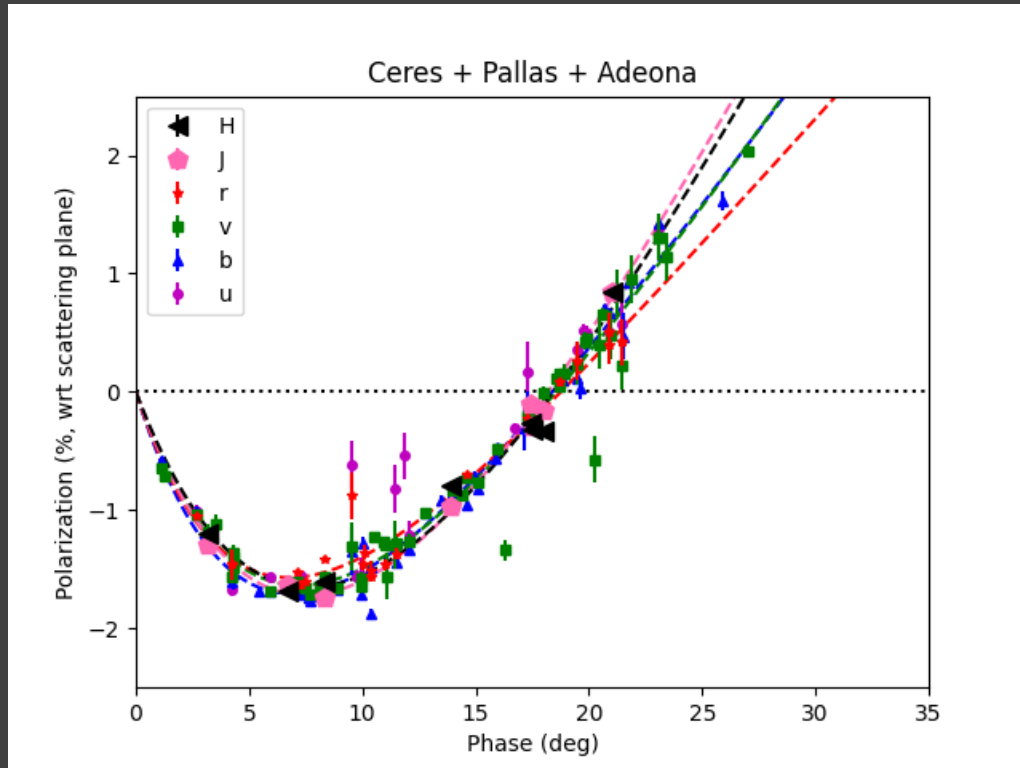
Joseph Masiero (Caltech/IPAC)

- Question: What minerals are the surfaces of asteroids composed of, and how does this material trace their formation?
- Instruments: P200/WIRC+Pol
- Capabilities:
 - WIRC+Pol is the first near-infrared polarimeter with a sufficient design (multi-beam measurements) and calibration ($<0.1\%$ absolute polarization) to investigate the change in polarization of asteroids with viewing geometry
 - WIRC+Pol also provides spectropolarimetric sensitivity simultaneously, another unique capability that is currently being explored

Image: WIRC+Pol frame showing the zero order image (point) and four 1st order spectropolarimetric traces for an observation of asteroid Ceres



Polarimetric Properties of Asteroids in the Near-Infrared Using WIRC+Pol

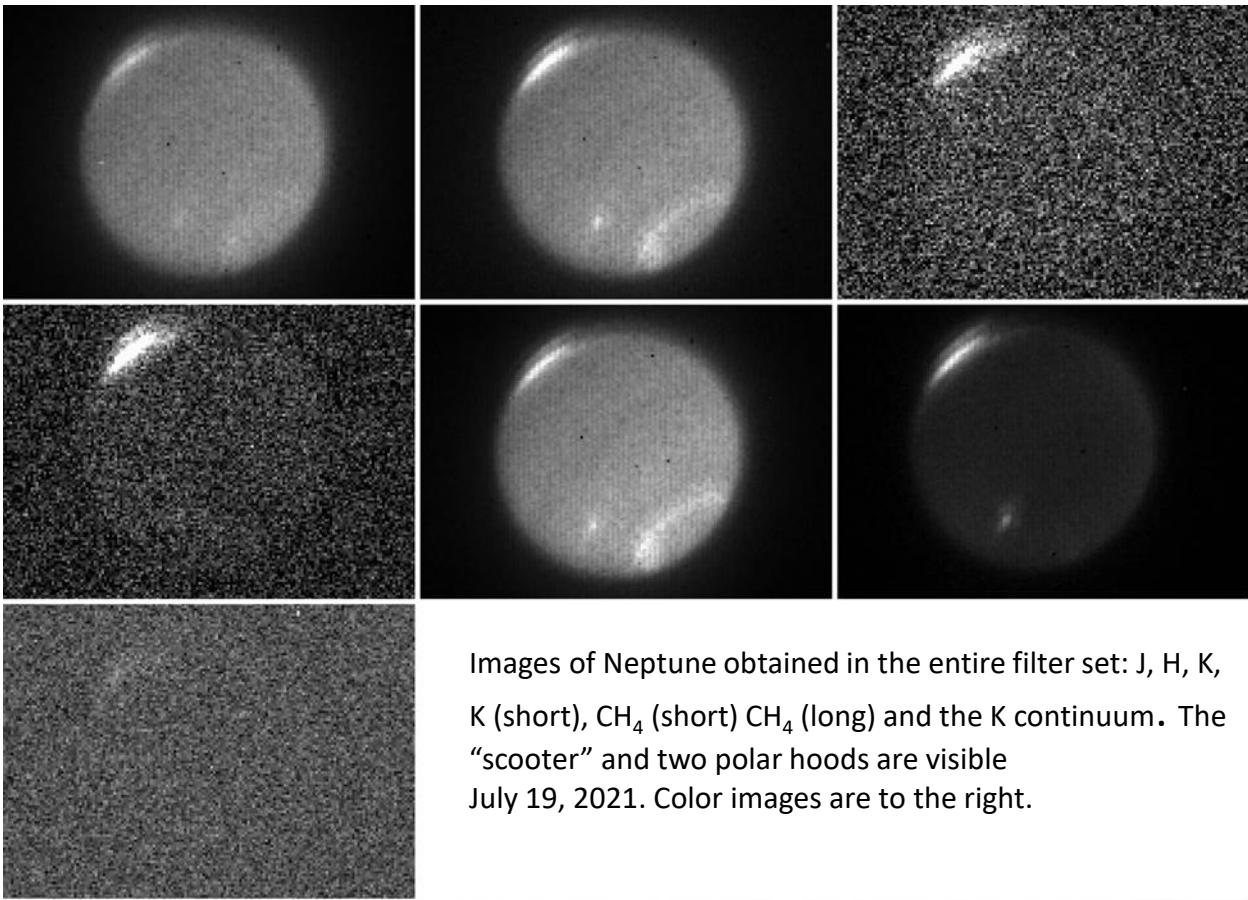


Recent Results: J and H band polarimetric measurements from WIRC+Pol show a close match to the UBVRI polarimetry in the literature for primitive C-type asteroids (left) but have a noticeable offset for silicate-rich S-type objects (right). This demonstrates that C-type objects can be used as NIR polarimetric standards that are superior to stars, and suggests that S-type objects have a shift in the index of refraction of the surface material, which is an important clue to help us determine the mineral makeup of the surface.

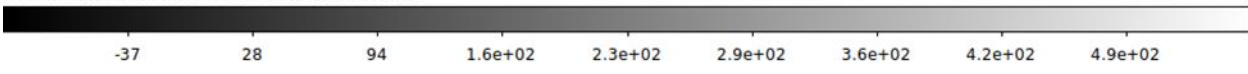
Seasons in the outer Solar System: Uranus and Neptune and their moons, and Titan

PI: Bonnie Buratti; other observers: Michael Hicks, Tom Momary, and Glenn Orton, JPL

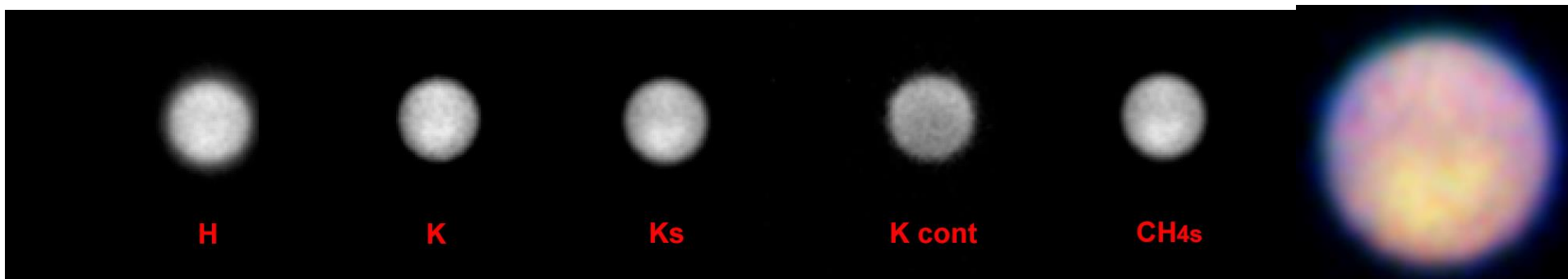
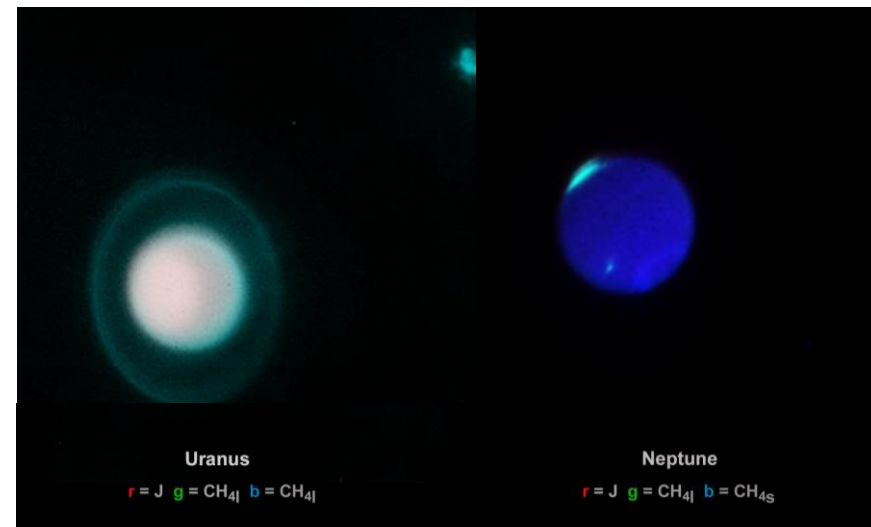
- The Solar System's ice giants - Uranus and Neptune - and their rings and moons are relatively unexplored worlds. They were studied briefly during the *Voyager 2* flybys, and occasional images from *HST* and other instruments have been obtained, but little focused investigation has occurred.
- Ice giants seem to be common in exoplanetary systems
- An ice giants mission is likely to be the next Flagship identified in the Planetary Decadal Report. Long-term ground-based monitoring is required for context to understand cloud motions and seasonal changes on Uranus and Neptune. There is good evidence for seasonal volatile transport on the surface of Triton, the largest Neptunian moon, which is probably a captured Kuiper Belt Object.
- Our preliminary work using the Palomar High Angular Resolution Observer (PHARO) adaptive optics system shows that cloud patterns can be identified on Uranus and Neptune. A seasonal monitoring effort on these two planets plus Triton could be accomplished with a fairly low effort – about 6 nights a year.
- Titan is also being included in this study, as *Cassini* observed clouds, polar hoods, and haze for only a half saturnian year. Not only does the temporal excursion need to be extended, but long term context is required for the *Dragonfly* mission.



Images of Neptune obtained in the entire filter set: J, H, K, K (short), CH₄ (short) CH₄ (long) and the K continuum. The “scooter” and two polar hoods are visible July 19, 2021. Color images are to the right.



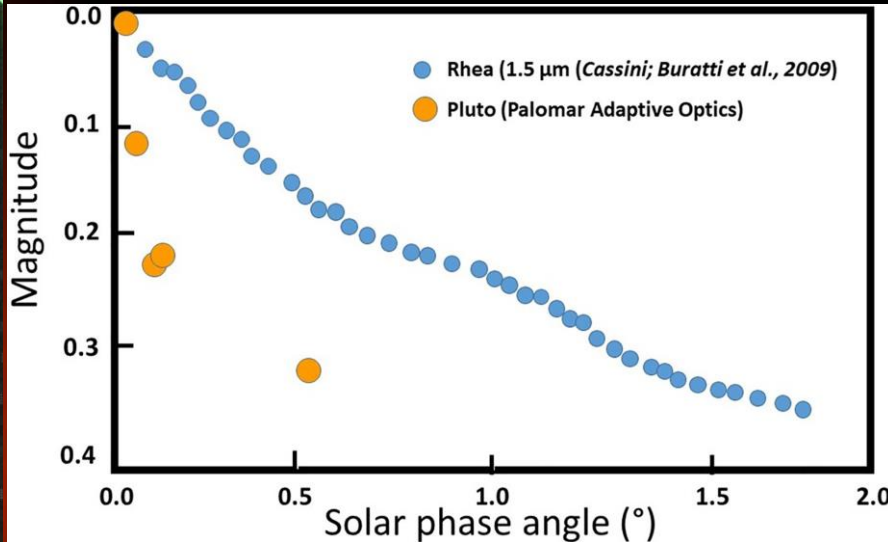
Uranus, its rings and three of its moons in a composite created from the Ch4 short (1.55 μm), Ch4 long (1.65 μm), and K-band. A cloud feature is clearly visible above the Uranian ring. This image was obtained earlier by J. Bauer, near ring-plane crossing.



Images of Titan, showing haze, a polar hood, and the land mass Xanadu



Pluto and Charon with PHARO



A JPL-Caltech team captured a once in a 161-year occurrence of the alignment of the Earth, Pluto, and the Sun to observe a huge increase in brightness as the face of the dwarf planet became fully illuminated. The increase in brightness is sharply peaked, and shown here with the most similar available data, that of Rhea with the Cassini Visual Infrared Mapping Spectrometer (VIMS)

Buratti, B. J, Hicks, M., Bauer, J., Kramer, E., Ciardi, D., Lund, M., and K. Lawrence. Pluto in Glory: Discovery of its huge opposition effect. 2021 *Geophysical Res. Letters* 48. <http://doi.org/10.1029/2021GL092562>

See also: <https://www.space.com/pluto-fully-illuminated-observation-suggests-active-surface>

This work was supported by the NASA Solar System Observations Program

Background: Most planetary surfaces exhibit a huge increase in brightness as their faces become fully illuminated: witness the brightness of the full Moon. This so called “opposition effect” was observed in the Pluto-Charon system in a 161-year event when the nodes of the orbits of Earth and Pluto crossed. This configuration was not observed by *New Horizons* and complements spacecraft observations.

Science question: What is the surface texture and compaction state of Pluto, and what does this observable imply about the geophysical evolution of Pluto and large KBOs?

Data & Results: Observations were successfully obtained by a JPL/Caltech team with the PHARO adaptive optics system on the Hale Telescope on Palomar. Both hemispheres of Pluto and Charon exhibit a 30-35% increase in brightness just as they become illuminated (in the last 0.5° of solar phase angle).

Significance: More observations are required to produce a quantitative model, but this result implies an unusual, tenuous surface texture caused by active geologic processes and seasonal volatile transport.

Characterization of Main-Belt Comets

Jana Pittichová Chesley (JPL/Caltech, NASA),

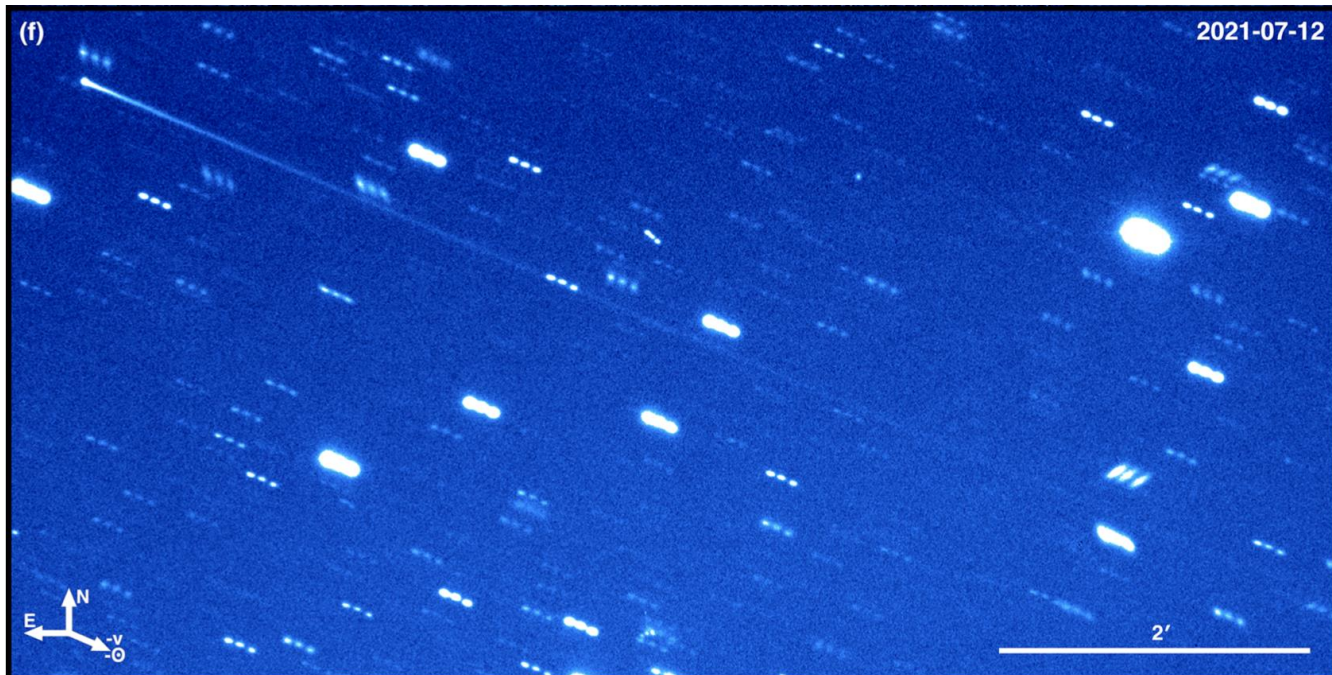
Henry H. Hsieh (PSI)

- Main-Belt Comets are rare objects that are dynamically indistinguishable from main-belt asteroids, yet display cometary activity indicative of sublimating ice.
- Dynamical analyses indicate that icy objects from the main belt, or objects similar to those currently found there, could have played a significant role in the primordial delivery of water to the Earth.
- They represent a potentially powerful means for tracing ice in the asteroid belt, constraining thermal and dynamical evolution models, and gaining insights into the history of our solar system.
- WaSP instrument allows us to characterize these MBCs
 - Lightcurves, colors, astrometry, and deep imaging to constrain activity

Asteroid (248370) 2005 QN137: Asteroid or Comet?

Jana Pittichová Chesley (JPL/Caltech, NASA), Henry H. Hsieh (PSI)

- Hsieh et al., 2021, “Physical Characterization of Main-Belt Comet (248370) 2005 QN173”, *ApJ Letters*
- DPS Press Release – October 4, 2021



Composite image of (248370) 2005 QN173 taken with WaSP instrument on Palomar Observatory's Hale Telescope in California on July 12, 2021.

- Newest known example of a rare type of object in the Solar System – a comet hidden among the main-belt asteroids.
- This so-called main-belt comet is one of only about 20 objects that have currently been confirmed or are suspected to be main-belt comets.
- Only the 8th main-belt asteroid confirmed to have activity on more than one occasion.
- Nucleus size is 3.2 kilometers across, the length of the tail in July 2021 was more than 720,000 km.
- Activity strongly indicating that its due to the sublimation of icy material.
- Extremely narrow tail tells us that dust particles are barely floating off of the nucleus at extremely slow speeds and that outgassing is extremely weak.