EXTREME PRECISION RADIAL VELOCITY SCIENCE AND TECHNOLOGY

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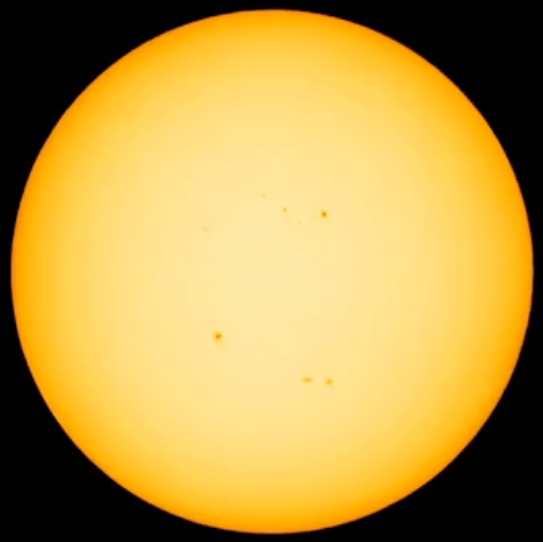
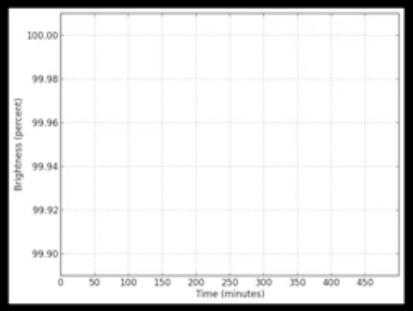
AN INVESTMENT IN LASER FREQUENCY COMBS

BY THE WILF FAMILY FOUNDATION

EXOPLANETS DETECTED WITH THE TRANSIT METHOD





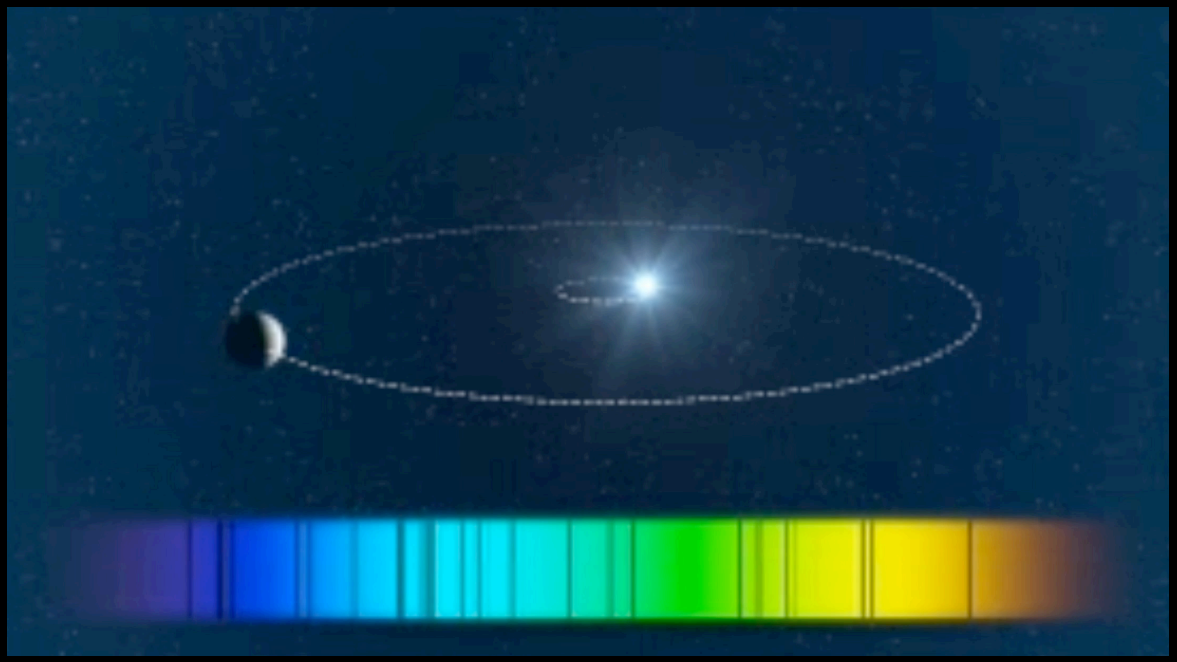
Transits (observed with space missions like Kepler and TESS) give radius, orbital period, atmospheric composition

EXTREME PRECISION RADIAL VELOCITY (EPRV) IS NEEDED TO DETECT AND CHARACTERIZE HABITABLE ZONE EARTHS

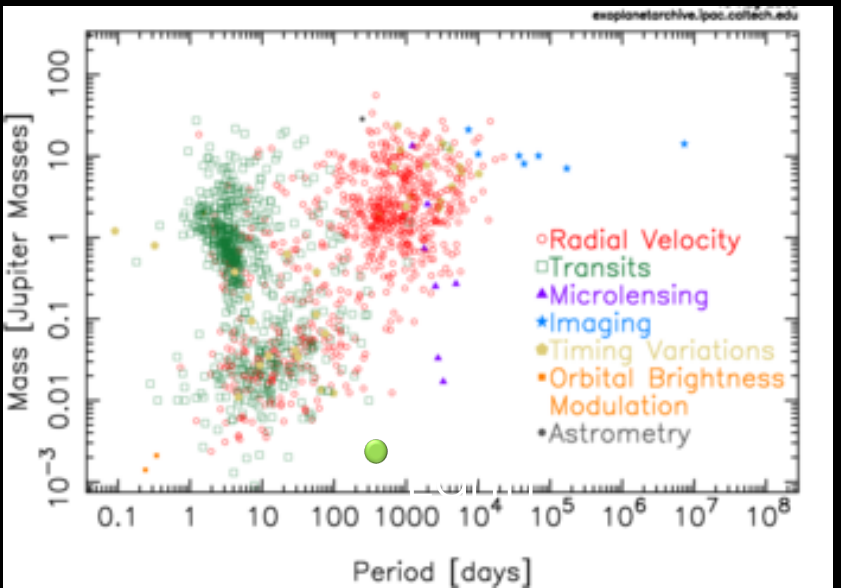
There are two ways to determine exoplanet mass,

…and only one from the ground:

- ~~Astrometry~~
- Radial Velocity



ESO/L. Calçada



Radial Velocity (RV) is essential for validation, full orbits and masses→ The combination of RV and transits yields bulk density to understand exoplanetary atmospheres

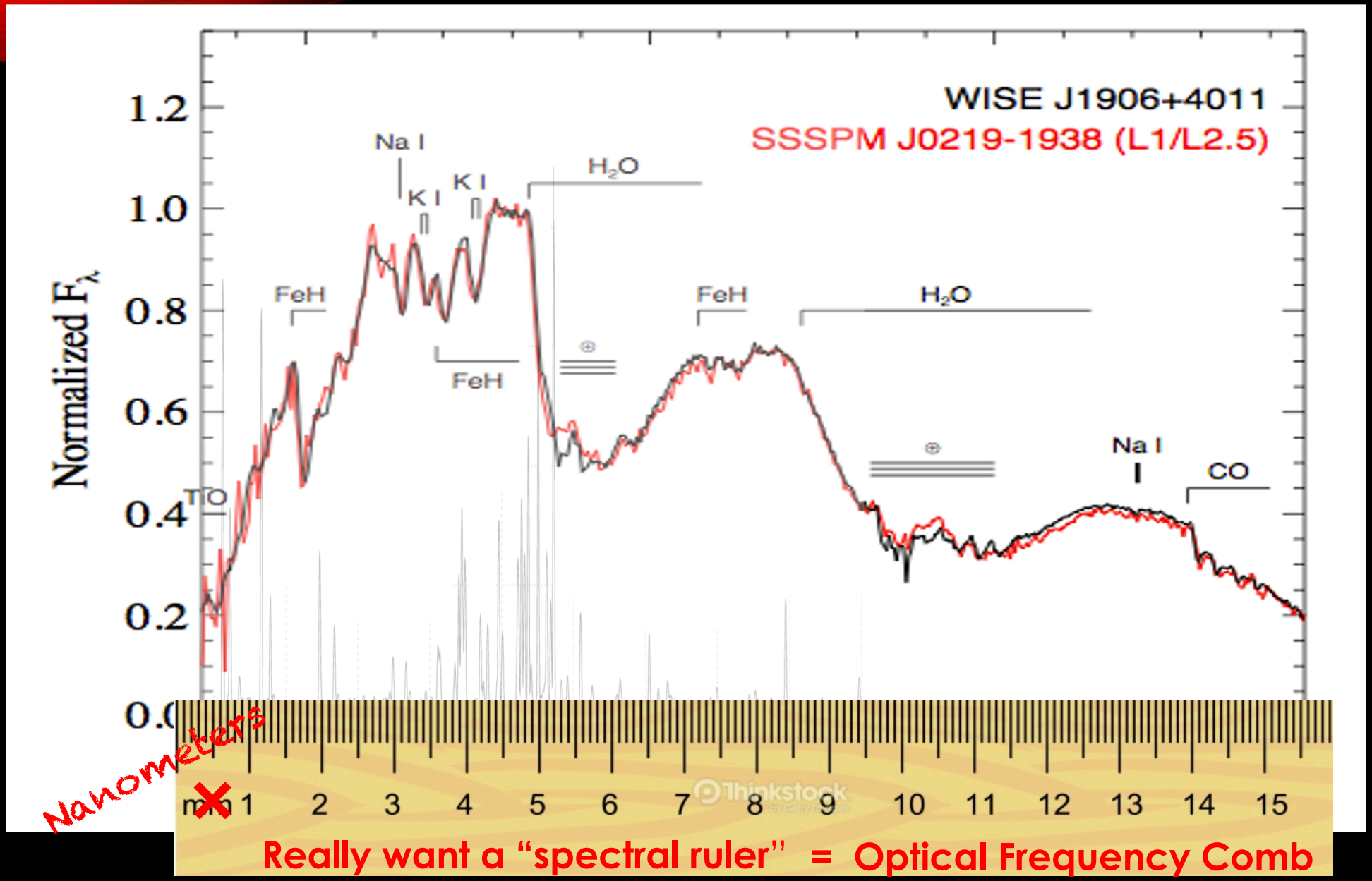
- Habitable Zone Earth orbiting solar twin has ~9 cm/s signature

NAS EXOPLANET REPORT CALLS FOR EPRV INITIATIVE

- **Findings:**
  - RV method needed for transiting and directly imaged exoplanet science
  - One of the limitations of the RV technique is imposed by ***instrumental stability and calibration***

- **Recommendation:**
  - NASA and NSF should establish a strategic initiative in extremely precise radial velocities to develop methods and facilities for measuring the masses of temperate terrestrial planets orbiting Sun-like stars.

STELLAR SPECTRA CALIBRATION

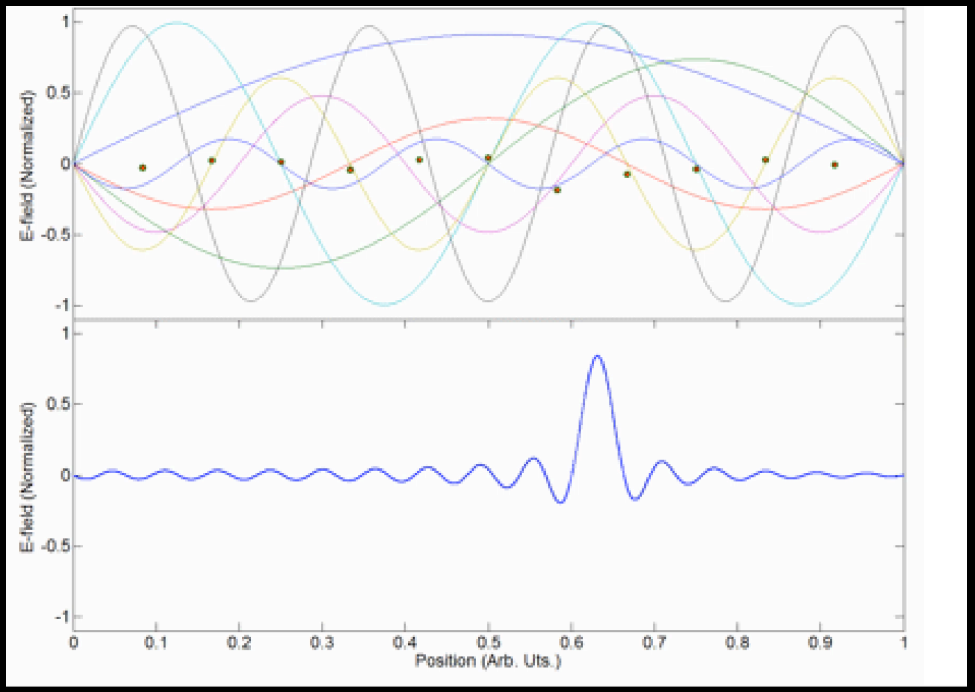


Really want a "spectral ruler" = Optical Frequency Comb

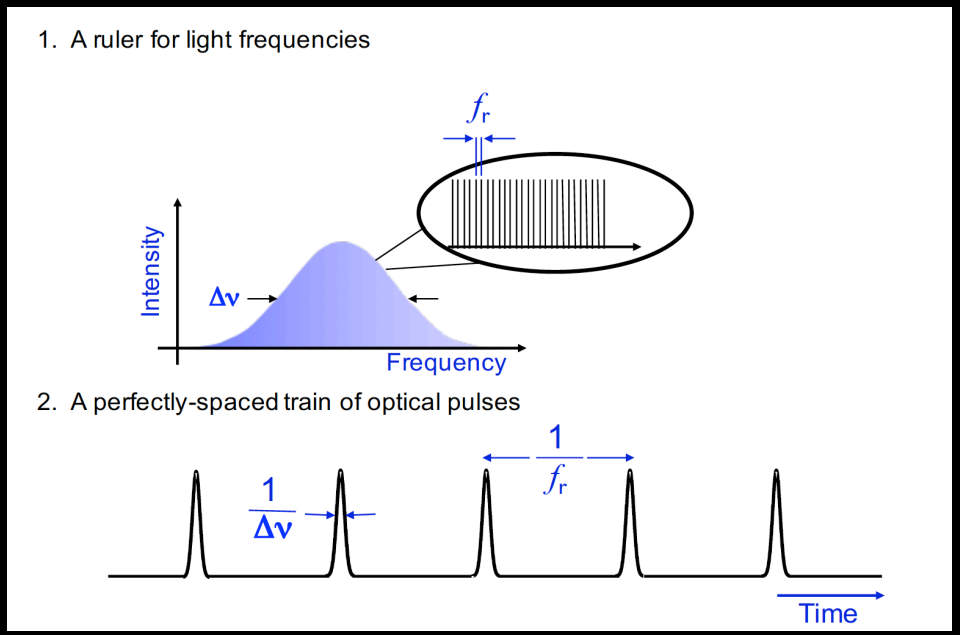
1.https://www.naoj.org/Observing/Instruments/MOIRCS/spec_skyspectra.html,
2.http://pono.ucsd.edu/~adam/wordpress/blog/2011/06/22/first-l-dwarf-in-the-kepler-field/

FREQUENCY COMBS PROVIDE LONG-TERM STABILITY

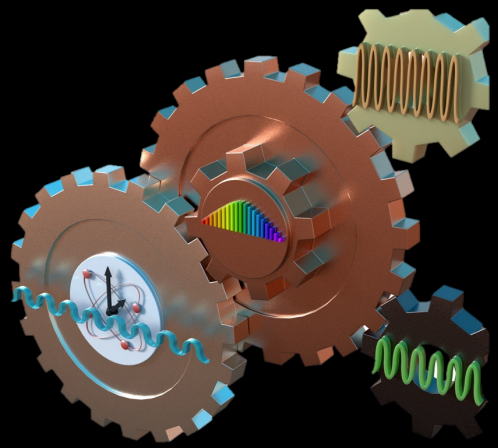
- Mode locked laser, *f-2f* technique, create a "clockwork" between the optical and RF domains so can tie optical frequencies to the definition of the SI second for long term stability



https://en.wikipedia.org/wiki/Mode-locking



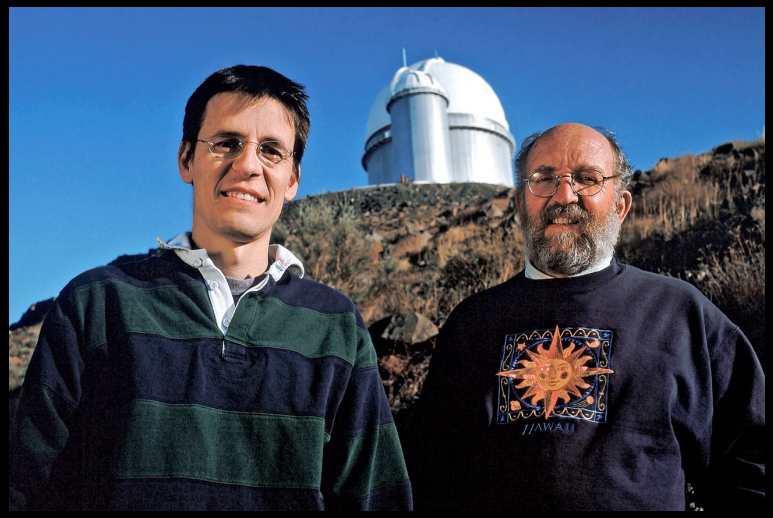
Diddams, 2016

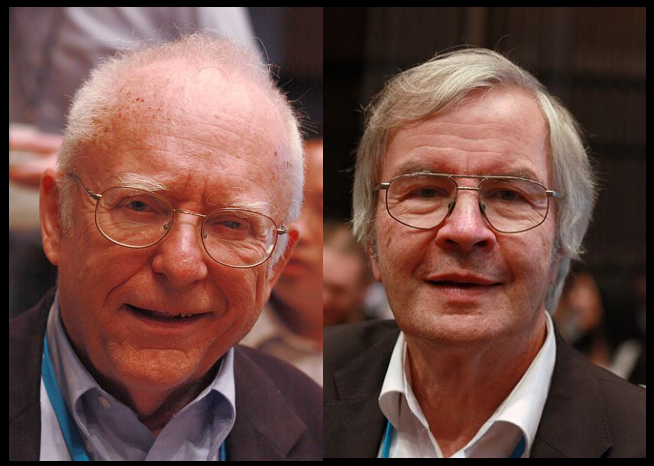


Keck Institute for Space Studies (2018)

TWO RELEVANT NOBEL PRIZES:

2019 **Michel Mayor** and **Didier Queloz** shared half of the prize in physics for their 1995 discovery of an exoplanet, 51 Pegasi b, orbiting a solar-type star using the radial velocity method.





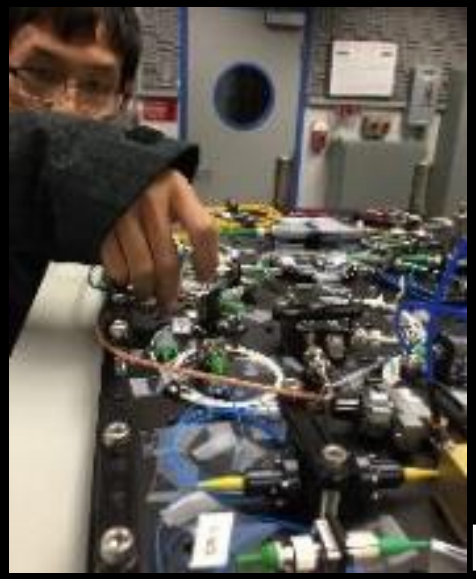
2005 **John Hall** and **Theodor Hänsch** shared half of the prize in physics "for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique."

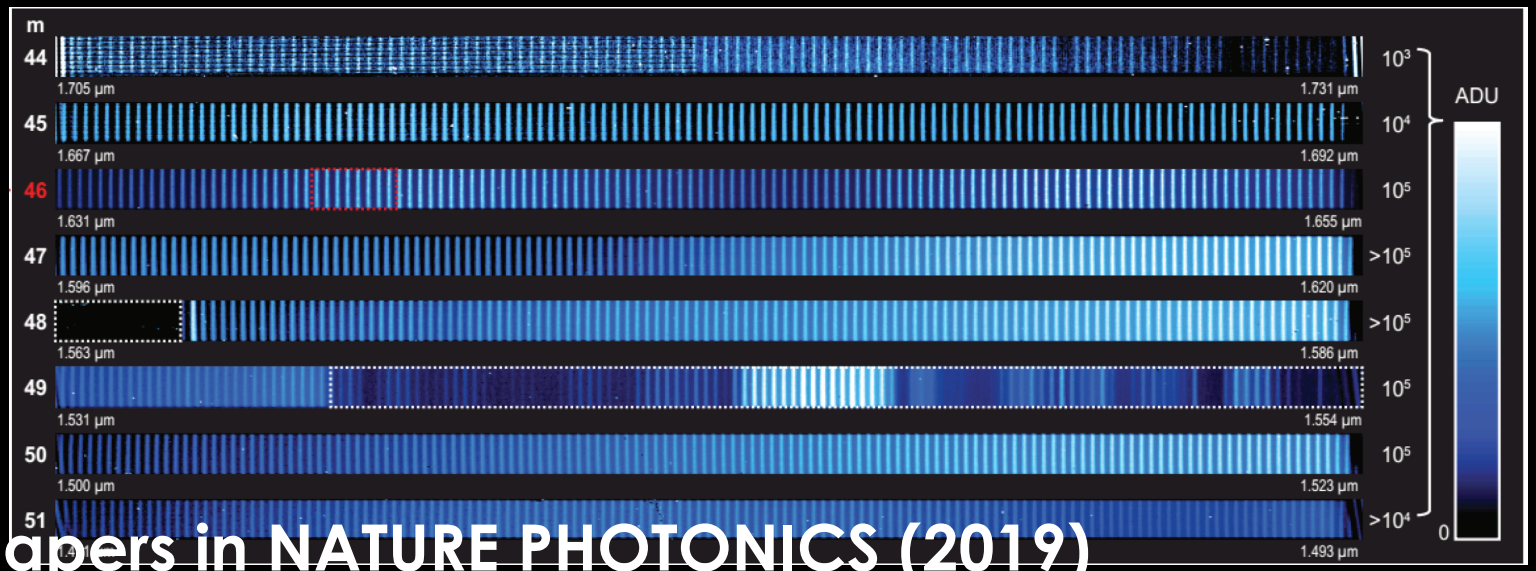
A DIFFERENT TECHNOLOGY PATH

- Current state-of-the-art radial velocity instruments are capable of between about 30-50 cm/s precision.
- How can we do better?
- While there are many factors that limit the jump to 9 cm/s, there are two areas where a strong collaborative effort between Caltech and JPL are allowing us to make progress.

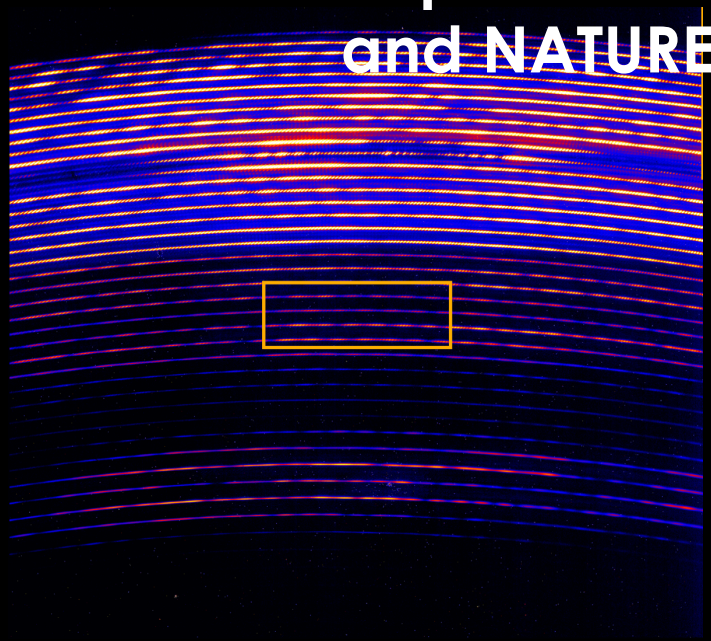
- Spectrographs
- Frequency comb calibration sources

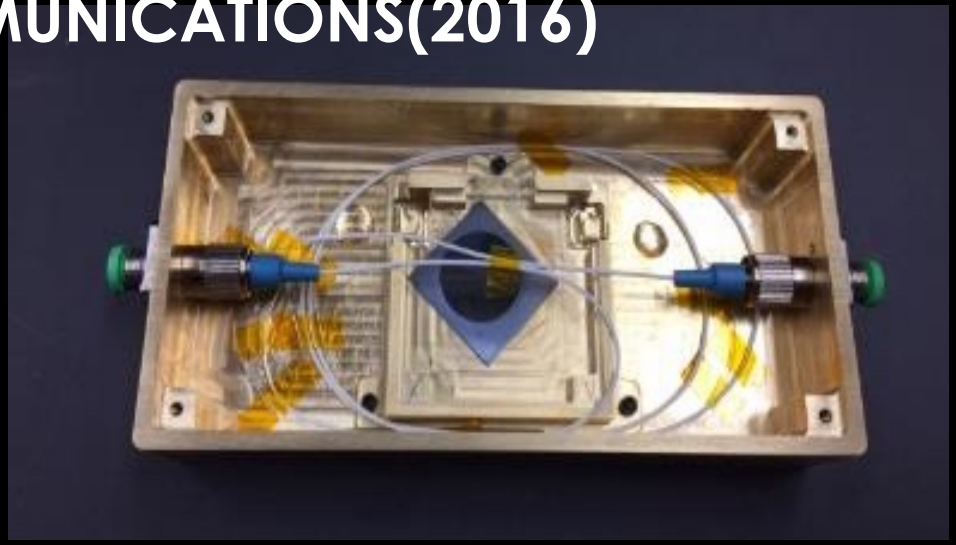
STABLE WAVELENGTH STANDARDS FOR SPECTROGRAPH CALIBRATION SOURCES: OPTICAL FREQUENCY COMBS & STABILIZED ETALONS





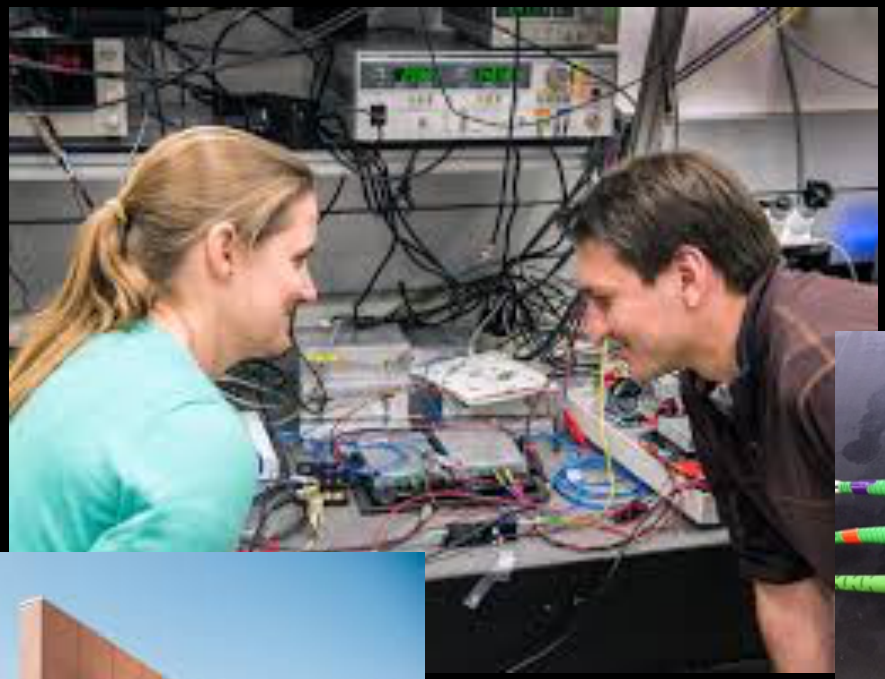
Papers in NATURE PHOTONICS (2019) and NATURE COMMUNICATIONS(2016)



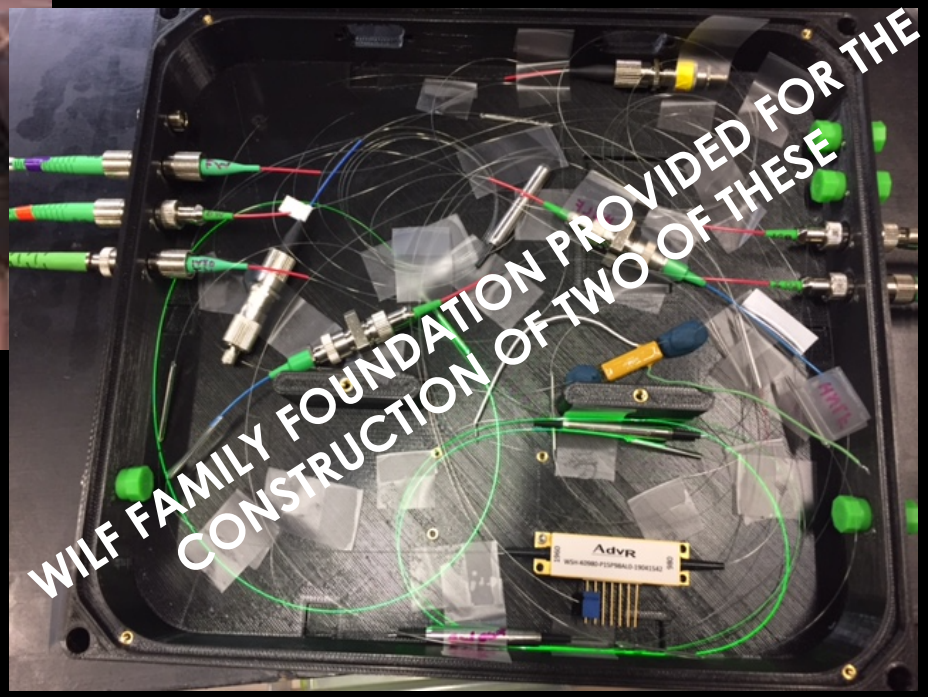


COMPACT FIBER LASER "COMB CAMP" AT NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY (NIST)

- Teaching us to fish…



We can use this to reference the pump laser for the comb at Palomar Observatory….
and the radial velocity precision will improve from ~ 30 cm/s to <10 cm/s!



NEXT STEPS

- The NASA/NSF Exoplanet Initiative:
  - New round of instruments
    - Looking at stars in the Near Infrared :
      - Exploring one for the Keck Observatory (HISPEC), Thirty-Meter Telescope (TMT)
    - And in the visible part of the spectrum too:
      - Keck Planet Finder
- This work will have broad impact on the exoplanet initiative

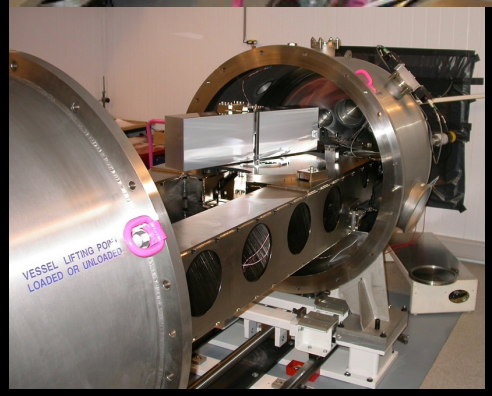
THANK YOU

ANY QUESTIONS?

BACKUP

SMALLER, MORE STABLE, LESS EXPENSIVE SPECTROGRAPHS

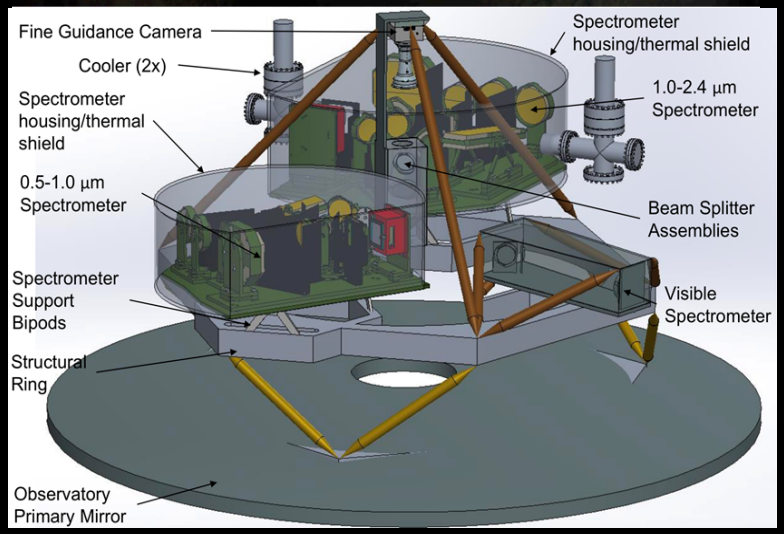
Seeing-limited RV spectrographs



HARPS spectrograph

Diffraction-limited, Adaptive Optics, Single-Mode Fiber-fed spectrograph

Palomar Radial Velocity Instrument (PARVI)

EARTHFINDER: A NASA PROBE STUDY

- **EarthFinder** could eliminate effects from Earth's atmosphere and expand wavelength coverage to UV and NIR to help us correct the RV signal for stellar jitter
- Survey 50 direct imaging candidate target stars for Earth analogs
- 1.45 m telescope with diffraction limited spectrometers and frequency combs