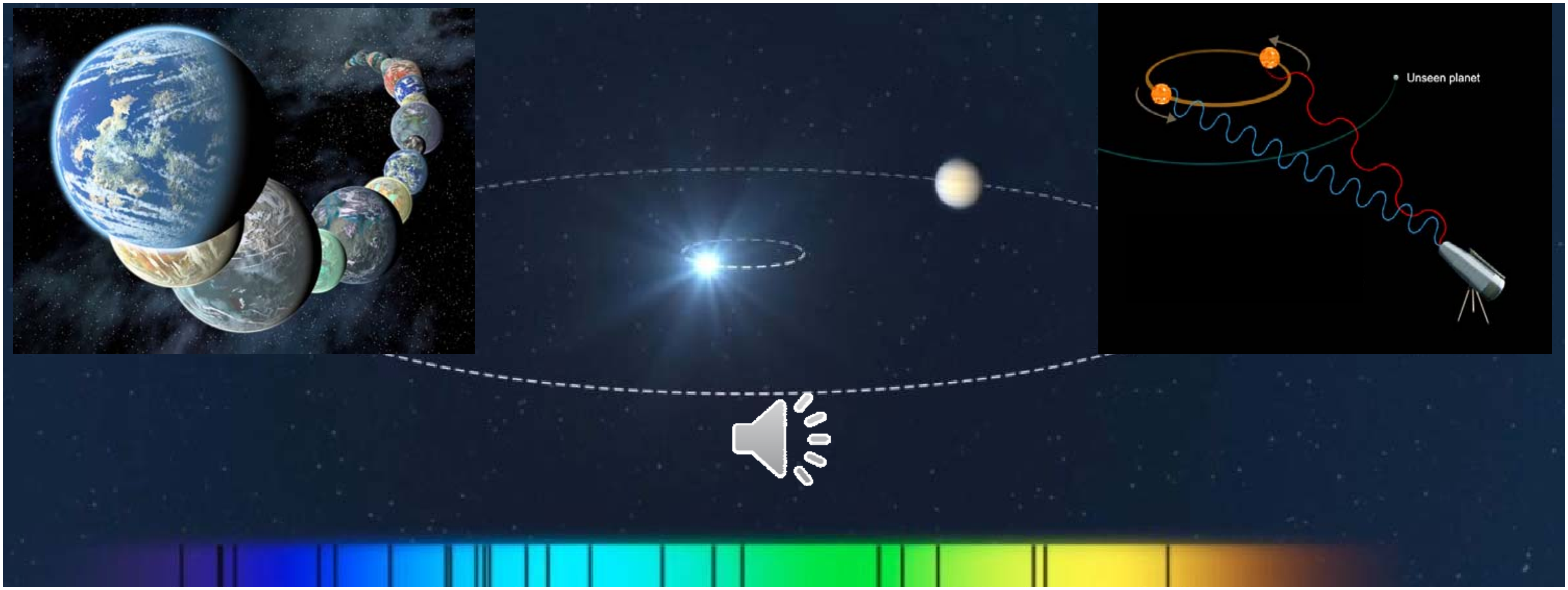

Virtual Research Presentation Conference

MICRORESONATOR-BASED ETALON FOR VISIBLE LIGHT PRECISION RADIAL VELOCITY MEASUREMENTS

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Program: (Topical)

Jet Propulsion Laboratory
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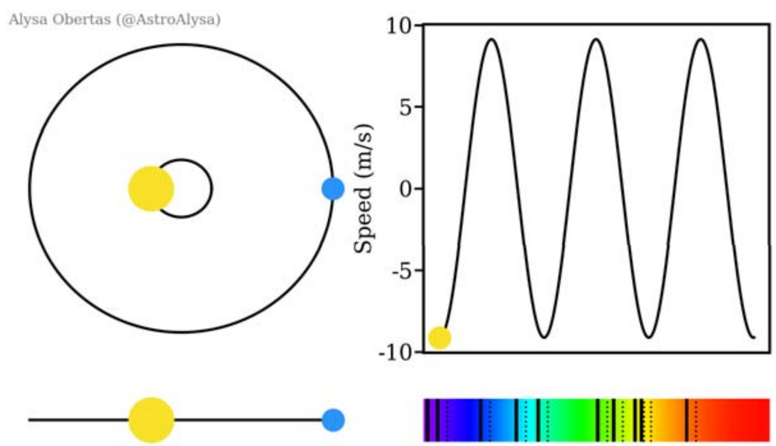
Introduction

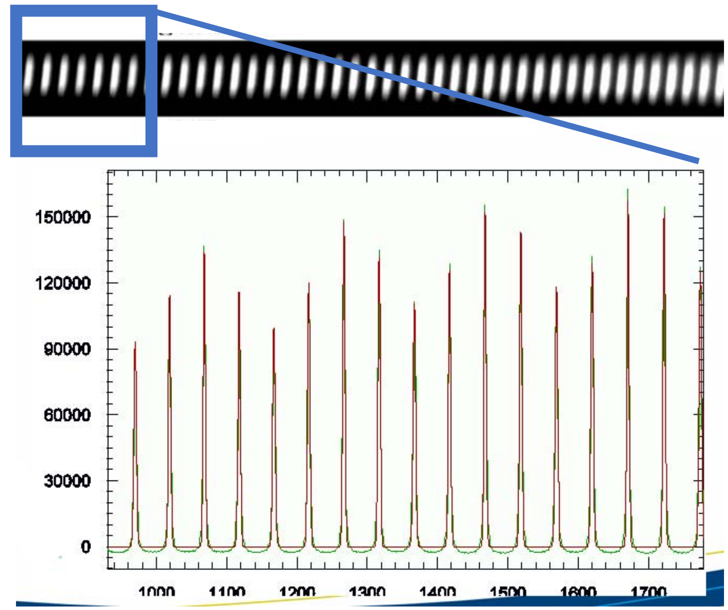
- The challenge of the Extreme Precision Radial Velocity (EPRV) technique is to detect the small, 9 cm/s, Doppler reflex motion of nearby earth analogs.
- The masses and orbits of these planets are critical to interpreting the spectra which will one day be returned by a direct imaging flagship mission
- The objective of this activity is to improve the calibration of optical spectrometers to the <1 cm/s long term stability and accuracy needed to detect Earth-mass planets in the Habitable Zones of solar type stars.



As a planet orbits its host star, the planet tugs on the star producing a shift in the star's Doppler (radial) velocity. The lines shift from red to blue and back again, by amounts that range from many meter/sec for a Jupiter to 9 cm/s for an Earth orbiting a solar type star.

The Challenge of Detecting Other Earths

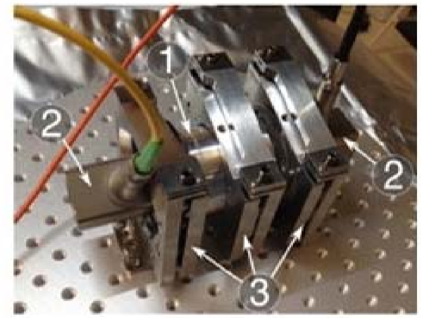
- The field of exoplanets is one of the most exciting in modern astrophysics. The Extreme Precision Radial Velocity (EPRV) technique can detect and then determine the masses and orbits of exoplanets, information critical to interpreting the images and spectra of planets that will be obtained by future direct imaging observatories. **The ultimate goal of these observations is the search for potential signatures of life on Earth-Analog planets using the combination of spectra and masses.**
- Existing spectrometers are not stable enough to achieve this goal without a highly stable wavelength reference. Laser Frequency Combs (LFCs) operating at visible wavelengths and the necessary mode spacings are large, complex, and expensive. Parallel-plate Fabry-Perot etalons have not demonstrated the necessary performance. **We are pursuing a new etalon technology based on mm-scale whispering gallery mode (WGM) resonators referenced to a frequency comb stabilized laser.**
- The goals of EPRV are highly relevant to NASA and JPL. The National Academy of Science called for a major EPRV initiative in observational capabilities along with the necessary theory and technology. JPL has been a leading center for this initiative within NASA and is well positioned to take a long-term leadership role.



An etalon produces a uniform series of spectral lines which can be used to calibrate the spectrum of the star

Methodology

- Our goal is to develop actively stabilized WGM etalons in the visible (400 nm-800 nm) spectrum with an initial goal of <10 cm/s over 1-year long-term stability and with a technology path to better performance. The etalons avoid the mirror coatings of standard parallel plate etalons, and their small scale enables robust, high thermal stability packaging.
- Our approach involves building crystalline CaF_2 or MgF_2 whispering gallery mode (WGM) resonators that, when illuminated with a white light source, operate as very compact etalons giving a series of well-defined spectral lines.
- We balance the thermal sensitivity of the resonator refractive index with its thermo-mechanical properties to produce near-zero sensitivity to ambient temperature changes. We will produce an etalon with a 10~20 GHz free spectral range (0.01-0.02 nm line spacing) which is readily resolvable by astronomical spectrographs without the need for complex mode filtering.



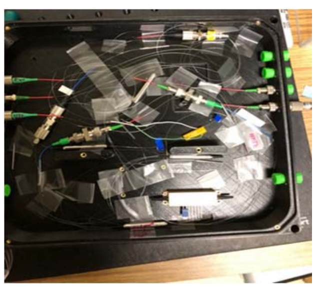
Top) standard etalons are over 50x30 mm in size. Bottom) our WGM resonator etalon sits on top of the column and is only a few mm in size

Results

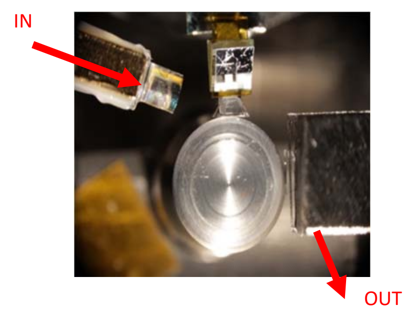
- We have met the milestones described in our proposal as described in Table 1.
- The two most significant milestones were a) demonstrating broadband coupling capability over an octave of spectral coverage with the targeted free spectral range and polarization selectivity, and b) ability to suppress higher order modes through geometry modifications of the resonator.
- In subsequent years we will develop and test a fully packaged microresonator with thermal stabilization

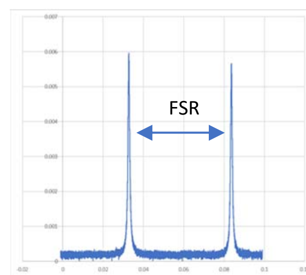
Table 1. Progress against Year 1 Milestones

Milestones/Accomplishments	Status/Progress
Design WGM resonator etalon with 400-800 nm spectral coverage (OEwaves)	Completed tests to determine design path of single-mode or multimode with strong mode suppression to better than 1 part in 10^4. Designed and demonstrated coupling prism geometry to achieve coupling across the full bandpass of 400-800 nm. Demonstrated polarization selectivity/rejection. Added intermediate milestone to deliver representative etalon to JPL. JPL set up testing facility and installed the resonator.
Second Harmonic Generation of fiber laser comb calibrator for etalon (JPL)	Received nonlinear doubling/tripling crystal from AdVR, completed fiber comb pump diode laser driver and power supply breadboard assembly. Demonstrated *f-2f* beat-note from fiber laser comb, and interfaced with FPGA controller for self-referencing.
Fabricate a prototype of the etalon and deliver to JPL (OEwaves)	Delivered "representative" etalon for initial testing at JPL. Etalon with desired FSR and mode extinction ratio delivered in place (due to Covid-19).
Verify spectral coverage of the etalon with white-light source (JPL)	White light source delivered to OEWaves from JPL. EOwaves ordered endlessly single mode fiber from NKT photonics, and had it connectorized for white light test.
Design Packaging for Year 2 (OEwaves)	Completed the packaging design for the Year 2 etalon.



JPL built the Fiber Laser Comb which will be used to stabilize the microresonator





The WGM resonator etalon light coupling at OEwaves (left), etalon spectrum pumped at 1550 nm showing 10 GHz line spacing (center) and with 633 nm light at JPL (right).

References and Publications

REFERENCES

[1] "Exoplanet Science Strategy", National Academies of Sciences, Engineering, and Medicine 2018. Washington, DC: The National Academies Press.

[2] "Rubidium-traced white-light etalon calibrator for radial velocity measurements at the cm s^{-1}level", Stürmer, J., Seifahrt, A., Schwab, C., Bean, J.L. 2017, Journal of Astronomical Telescopes, Instruments, and Systems, 3, 025003

[3] "Extreme Precision Radial Velocity Initiative Plan", NASA's Exoplanet Exploration Program and the EPRV Working Group, 2020,

[4] "EarthFinder Probe Mission Concept Study: Characterizing nearby stellar exoplanet systems with Earth-mass analogs for future direct imaging", Plavchan, P., Vasisht, G., Beichman, C., et al. 2020, NASA Probe Mission concept white paper for 2020 Astrophysics.

PUBLICATIONS

[1] Leifer et al. 2020, "Microresonator-based Etalon For Visible Light Precision Radial Velocity Measurements". SPIE (San Diego), in preparation.