

### Henrietta:

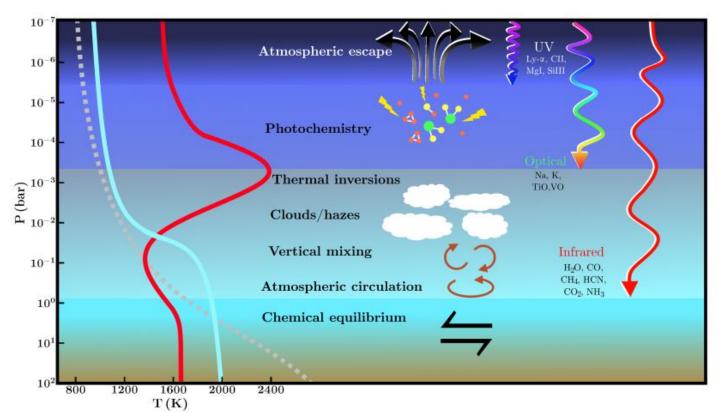
A new, near-infrared exoatmospheres spectrograph for the 1-m Swope Telescope (+ a review!)

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ExSoCal 2025

## Exoplanet Atmospheres and Instrumentation

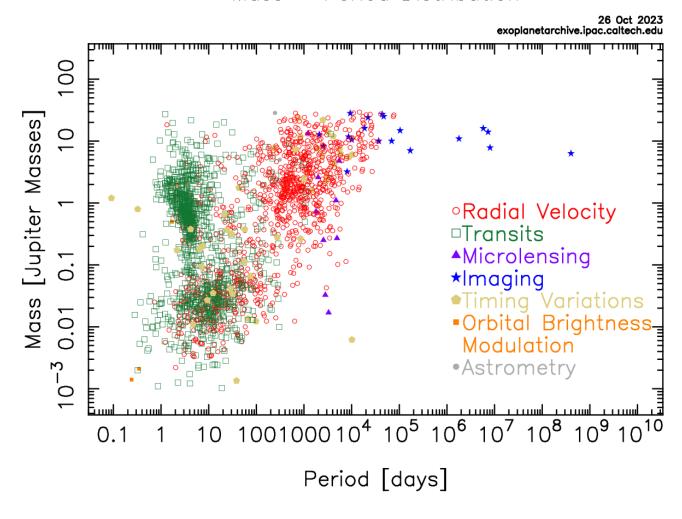
Spectra provide a rich characterization of an exoplanet, beyond what can be determined by mass and radius alone.

Using different instruments, we can probe different parts of a planet's atmosphere and understand the physics and chemistry happening in the planetary atmosphere.



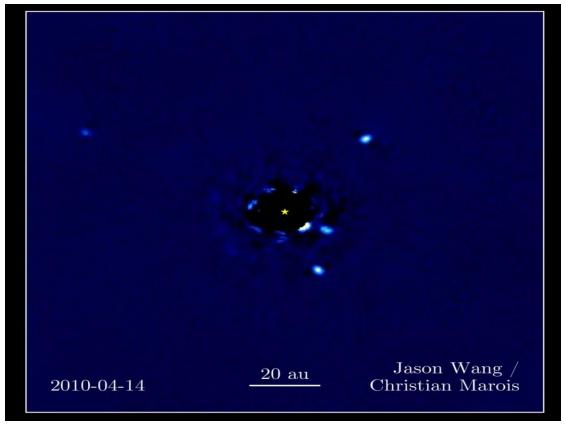
#### Produces spectroscopy for planets at wide-orbits

Mass - Period Distribution



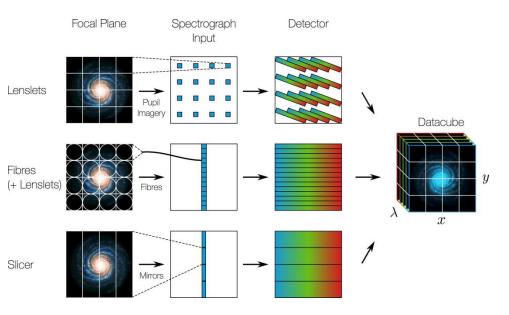
Detectability of atmosphere relies on contrast ratio of planet-to-star at a wavelength

Coronographs block incoming starlight (that has been corrected by AO) to increase the planet-to-star contrast ratio to detect the planet.

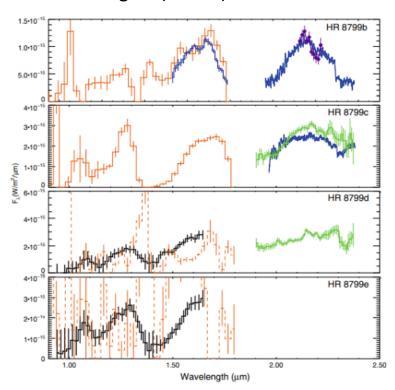


Light is fed from these coronographs to integral field spectrographs.

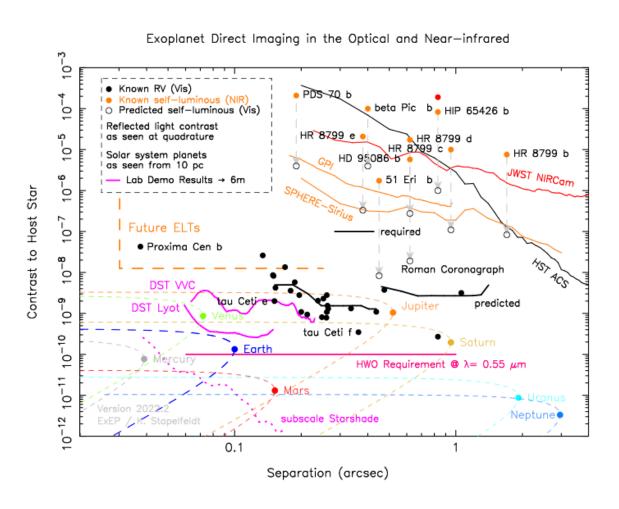
IFSs provide a spectrum for each spatial pixel.



Spectra reveal thermal emission (at long wavelengths) and reflection at shorter wavelengths (< 1um).

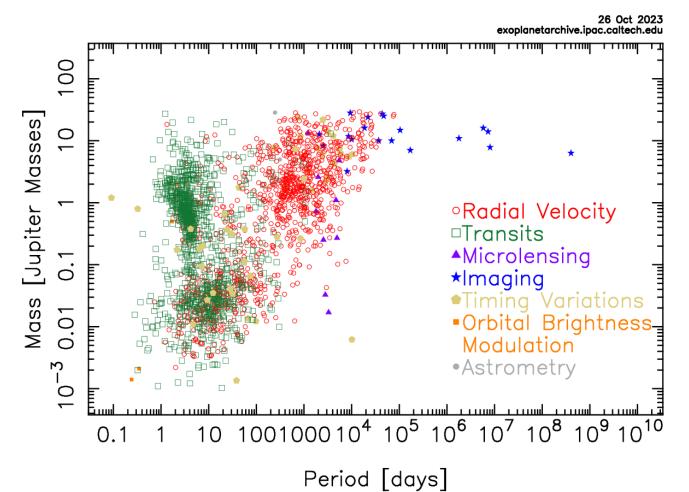


Nancy Grace Roman Telescope, instruments on ELTs, and space-based coronographs will unlock direct imaging optical spectroscopy



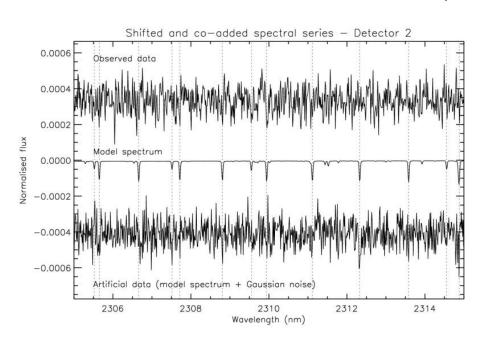
Produces spectroscopy and robust atomic/molecular detections for giant planets (transit or nontransiting)

Mass - Period Distribution



Ability to remove stellar flux is limited by the planet-to-star contrast, so S/N is boosted cross-correlated molecular templates with the observed spectrum.

Cross-correlation produces function that not only signals detection of a molecule, but also rich dynamical information.



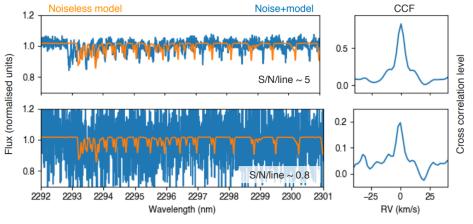


Table 1

High-resolution Cross-dispersed Echelle (grating) Spectrographs with Wide Instantaneous Wavelength Coverage

Name	Telescope	Resolving power	Wavelength Range (nm)	Status	Reference(s)
HARPS	ESO 3.6 m	120,000	378-691	Active	Mayor et al. (2003)
HARPS-N	TNG	120,000	378-691	Active	Cosentino et al. (2012)
ESPRESSO	VLT	70,000-190,000	378-691	Active	Pepe et al. (2014)
CARMENES	CAHA 3.5	80,000-100,000	520-1710	Active	Quirrenbach et al. (2010)
GIANO	TNG	50,000	950-2450	Active	Origlia et al. (2014)
CRIRES+	VLT	50,000-100,000	Y, J, H, K, L, M bands	Under development	Follert et al. (2014)
UVES	VLT	40,000-110,000	300-1100	Active	Dekker et al. (2000)
NIRSPEC	Keck	25,000	960-5500	Active	McLean et al. (1998)
PEPSI	LBT	43,000-270,000	383-912	Active	Strassmeier et al. (2015)
HDS	Subaru	90,000-165,000	298-1016	Active	Noguchi et al. (2002)
EXPRES	DCT	150,000	380-844	Active	Fischer et al. (in prep)
HIRES	ELT	100,000	397-2500	Under development	Zerbi et al. (2014)
NIRPS	ESO 3.6 m	80,000	974-1809	Under development	Wildi et al. (2017)
SPIRou	CFHT	70,000	980-2440	Active	Donati et al. (2018)
iShell	IRTF	75,000	J, H, K, L, M bands	Active	Rayner et al. (2016)
IGRINS	HJS	40,000	1450-2450	Active	Park et al. (2014)

High-Resolution spectrographs on ELTs with low-read noise detectors will push observations towards smaller planets!

**ELTs** 



Low Read noise detectors (Skipper CCDs seem promising in the optical, MAYBE linear mode avalanche photodiodes in the NIR?)

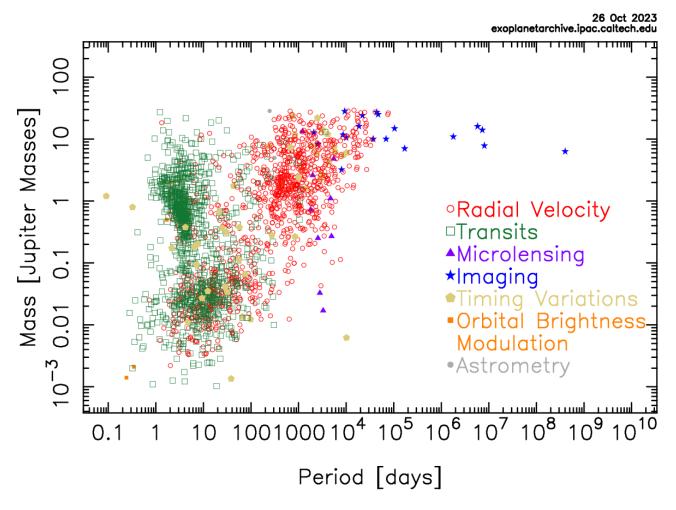




## Low Resolution Transit/Emission Spectroscopy

#### Recovers atomic/molecular abundances for transiting planets

Mass - Period Distribution

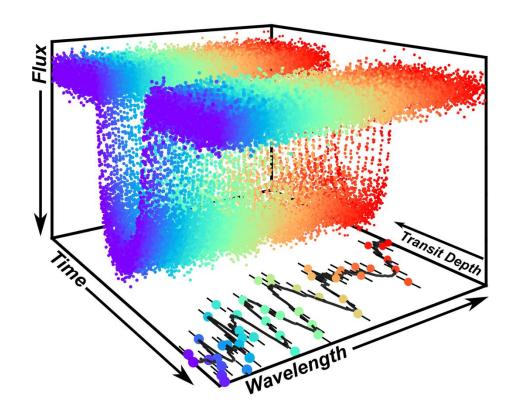


## Transit/Emission Spectroscopy

Variation from atmosphere is 1 - 100s of parts-per-million, high S/N required!

S/N 

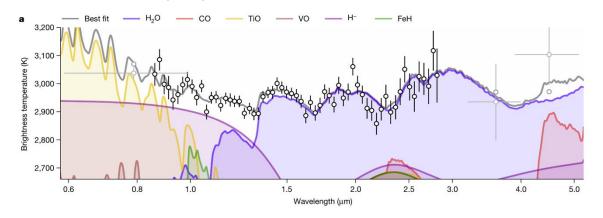
√Transit Duration, so low resolution on large telescopes is key to boost signal to noise.



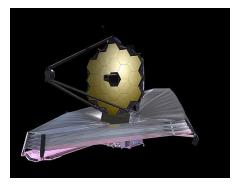
## Transit/Emission Spectroscopy

Primarily use space-based instrumentation, where photon-noise limited performance has routinely been achieved.

## Brightness temperature spectrum of WASP-18b Coulombe et.al (2023)



#### **JWST**

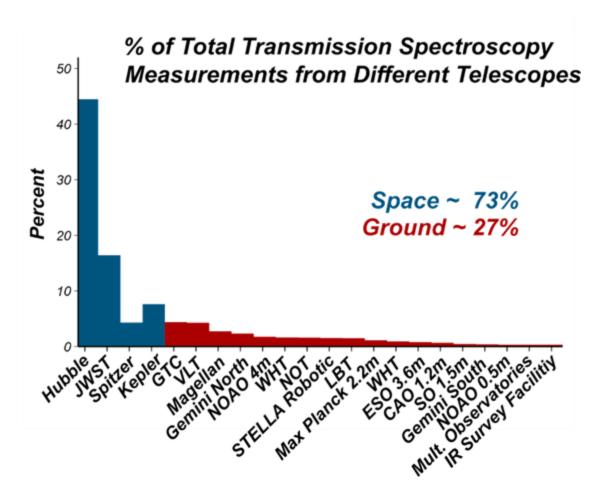


Ariel



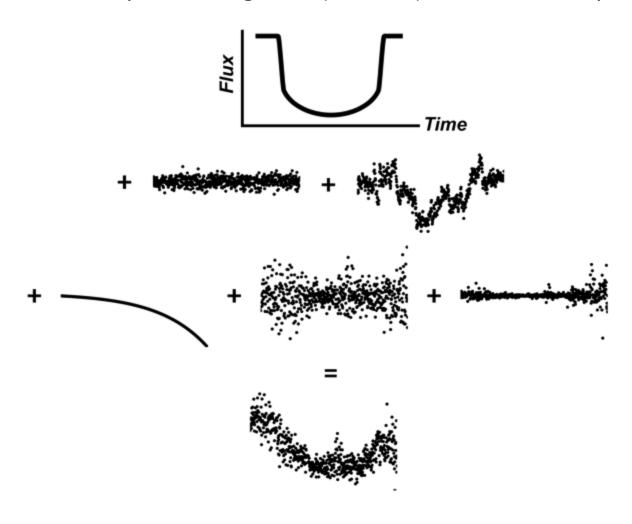
## The need for ground-based observations

Despite more observational resources existing on the ground, poor precision has limited what atmospheres can be observed.



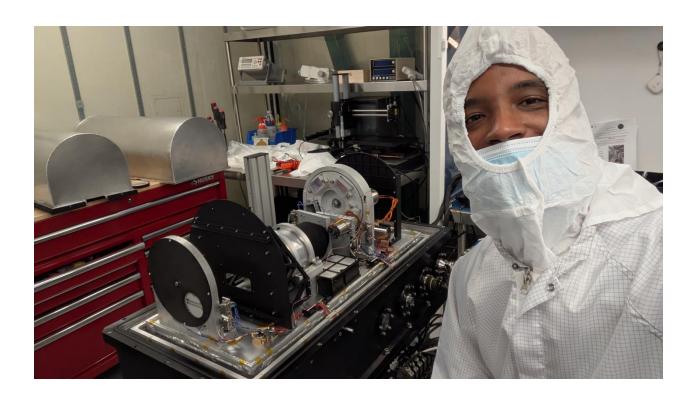
## High S/N ground-based spectroscopy is challenging

Earth's atmosphere interacts with instruments in a variety of ways that make it difficult to produce high S/N (> 10000) time-series of spectra.

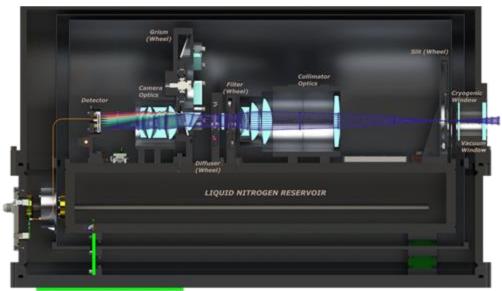


## Introducing Henrietta

Henrietta is a new ground-based exoatmospheres spectrograph that is designed to <u>routinely</u> detect atmospheres in the near-infrared.



## Henrietta Specifications





Henrietta will go on the 1-meter Swope Telescope at Las Campanas Observatory in Chile.

Field of View: 25.6' x 3'

Wavelength Range: 0.6 - 2.4

microns

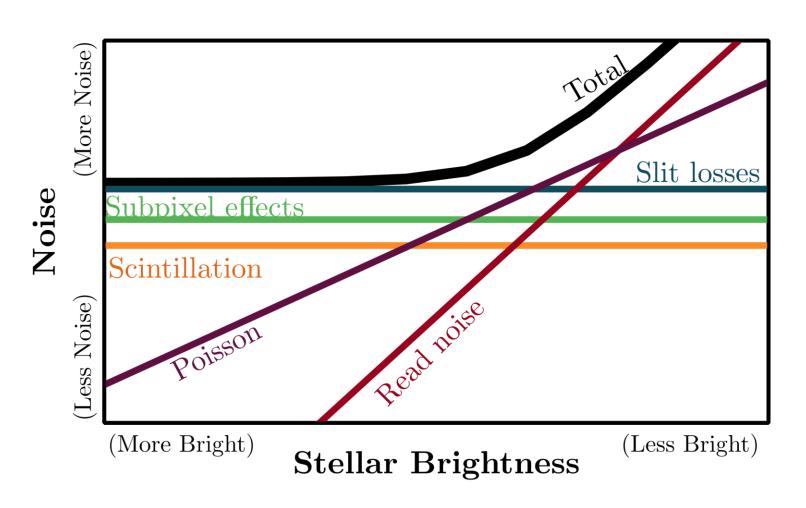
Spectral Resolution: 200-600 (@

center wavelength)

We aim to be on sky anywhere from 75-150 nights/year!

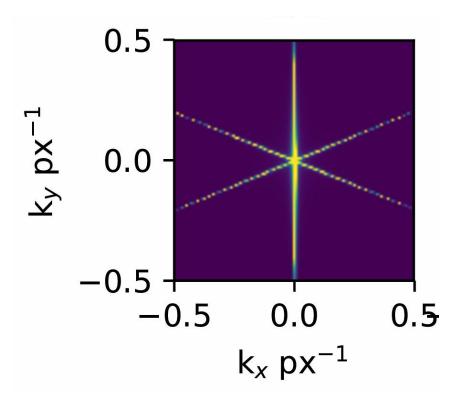
## Typical ground-based low resolution noise budget

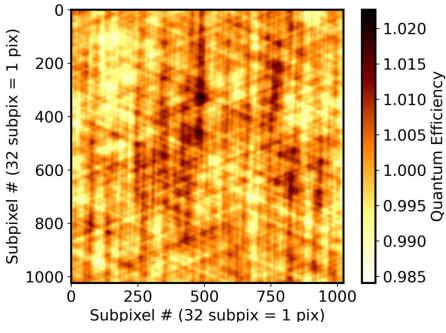
Ground-based noise budgets are dominated by slit losses, subpixel effects, and scintillation for bright targets.



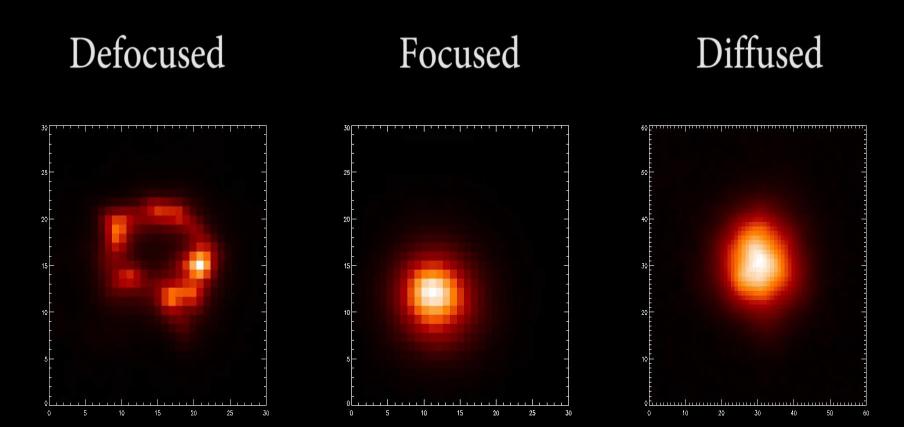
## Subpixel noise from Infrared Arrays

All imaging arrays (but particularly infrared arrays) have variations in their quantum efficiency on subpixel scales. When the <a href="mailto:spectrum/image changes in size/location">spectrum/image changes in size/location</a> on the detector, this imparts a noise.



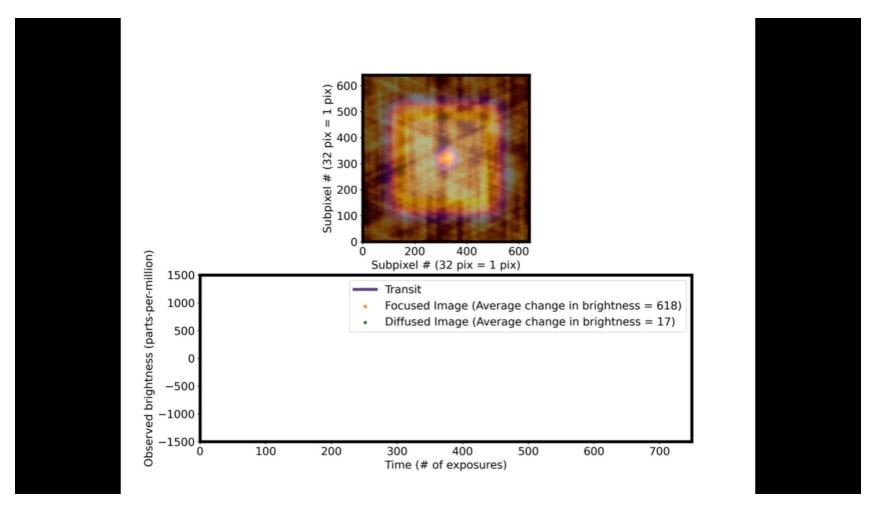


## WIRC PSF comparison



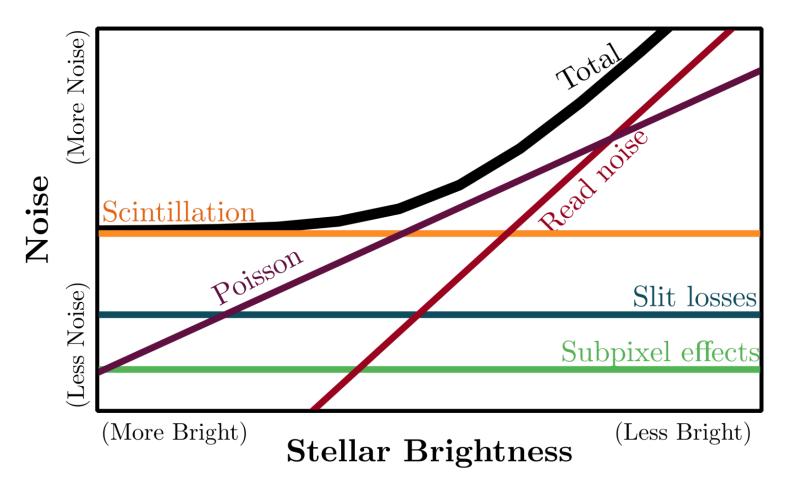
## Diffusing suppresses subpixel noise

Henrietta will diffuse to a 10x10 pixel point spread function, suppressing subpixel noise to below the photon noise for stars up to J = 5.

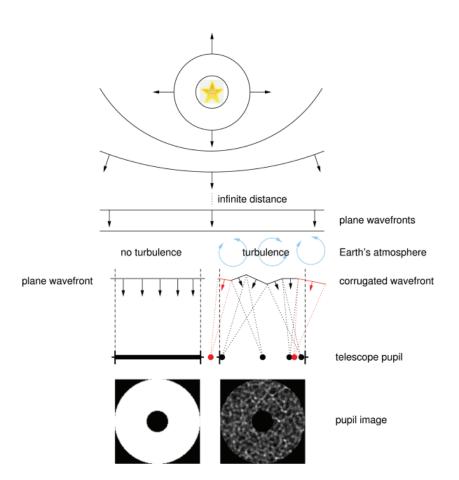


## Henrietta's Final Noise Budget

After suppressing instrumental sources of noise to spectrophotometry (slit losses and subpixel effects primarily), scintillation dominated the noise budget.



### The Last Hurdle: Scintillation

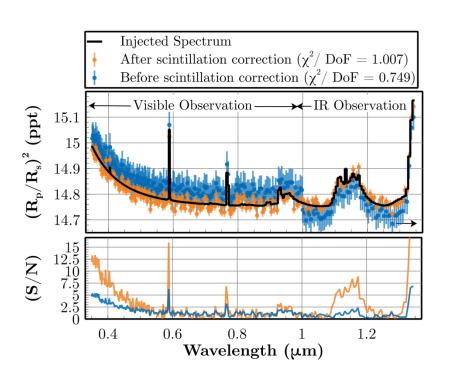


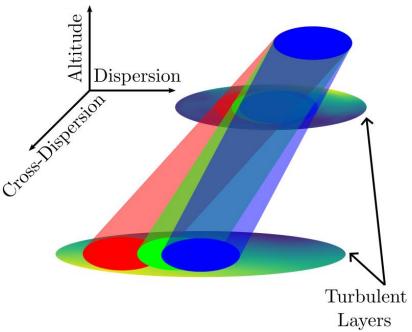
Scintillation noise,  $\sigma_s$ , is produced by high-altitude turbulence and not removed by adaptive optics or reference star photometry.

 $\sigma_s \propto D^{-2/3}$ , so large telescopes no longer act as 'light-buckets' when observing bright targets and will not reach the photon-noise limit.

## Suppressing Scintillation with Spectrographs

Scintillation is nearly achromatic on large telescopes, so spectrographs can remove it effectively when it is the dominant noise source.

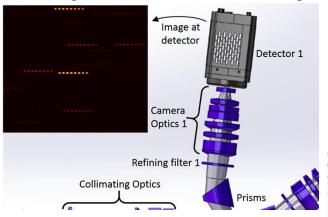




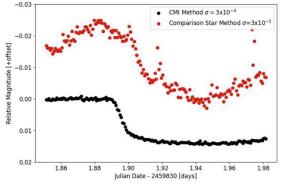
### Confirmation with ETSI

# This idea was recently demonstrated in the optical with ETSI (Exoplanet Transmission Spectroscopy Imager)

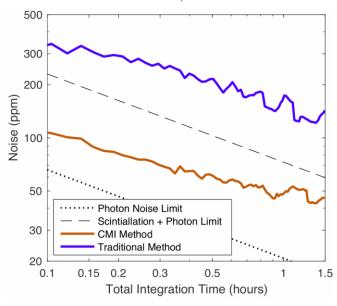
Low resolution (R ~ 20) spectra and a notch filter form images of the star at different wavelengths.



One image at the center of the bandpass is used as a reference wavelength to correct for noise/systematics in the remaining images.

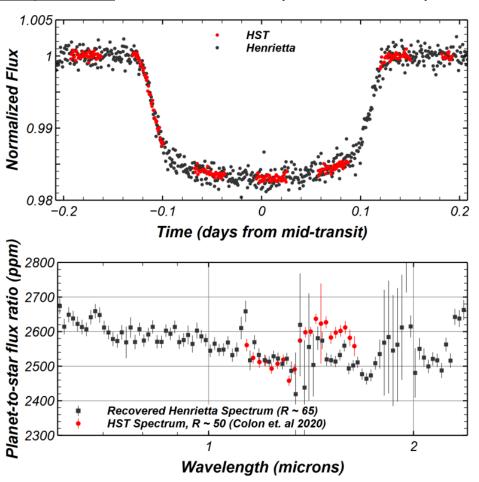


This brings the observations to within 2x of the photon noise limit.



## Henrietta Takeaway

If Henrietta meets its precision goal of 1.3x Photon noise, it will get to within  $\sqrt{2}$  of the precision reported by Hubble, but with <u>substantially more</u> telescope time to observe exoplanet atmospheres.



## Henrietta Timeline

Henrietta's is set to be commissioned in March 2026!



## Summary

- Direct Imaging Spectrographs, along with traditional high/low resolution spectrographs combine to reveal complementary information about exoplanet atmospheres.
- Henrietta is a new, low resolution exoatmospheres spectrograph that aims to perform routine transmission/eclipse spectroscopy at the Photon noise limit for bright stars and pave the path for future ground-based instruments. Set to be commissioned in March 2026 and we are eagerly looking for folks to collaborate with on observations!