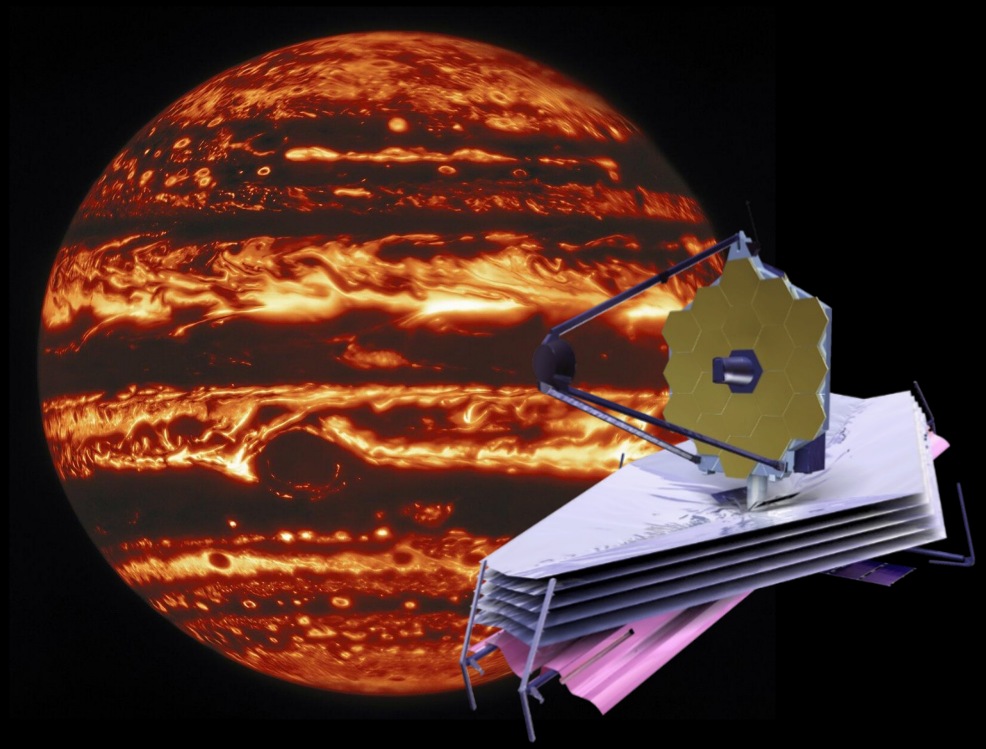
JWST/NIRSpec's transformative capability for direct spectroscopy of exoplanets



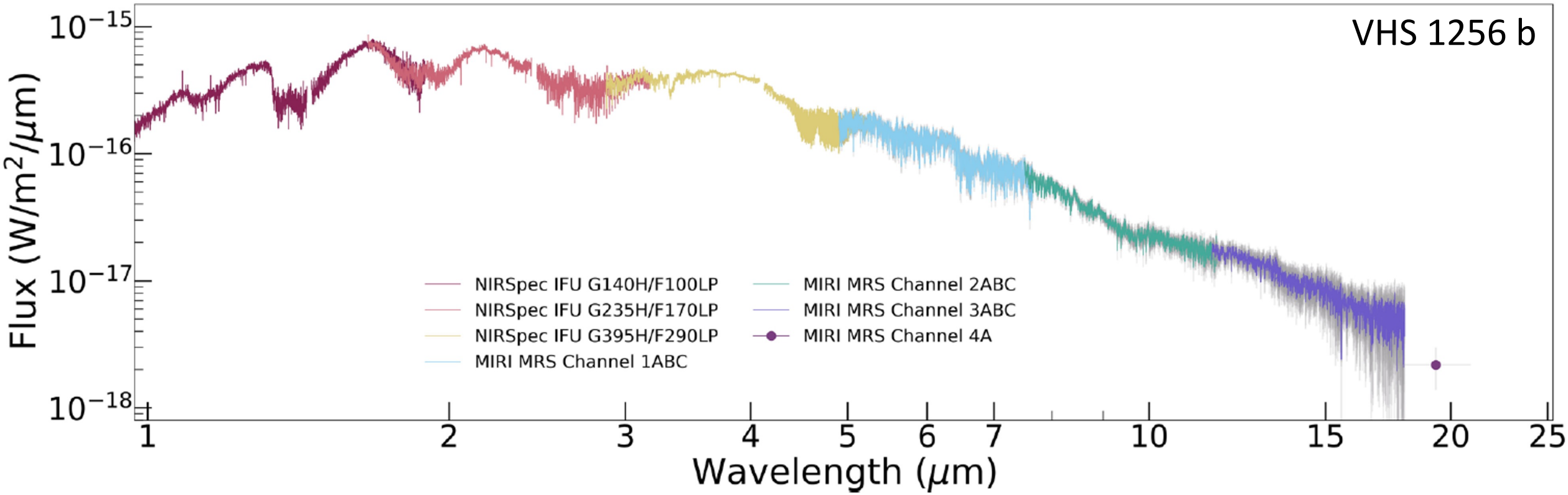
International Gemini Observatory/NOIRLab/NSF/AURA, M.H. Wong (UC Berkeley) et al. Acknowledgments: M. Zamani

Jean-Baptiste Ruffio (UCSD),
Marshall Perrin, Kielan Hoch, Jens Kammerer, Quinn Konopacky,
Laurent Pueyo, Emily Rickman, Christopher A. Theissen, Shubh Agrawal,
the JWST Telescope Scientist Team (TST),
et al.

jruffio@ucsd.edu
https://www.jbruffio.com

Exsocal
12/11/2023

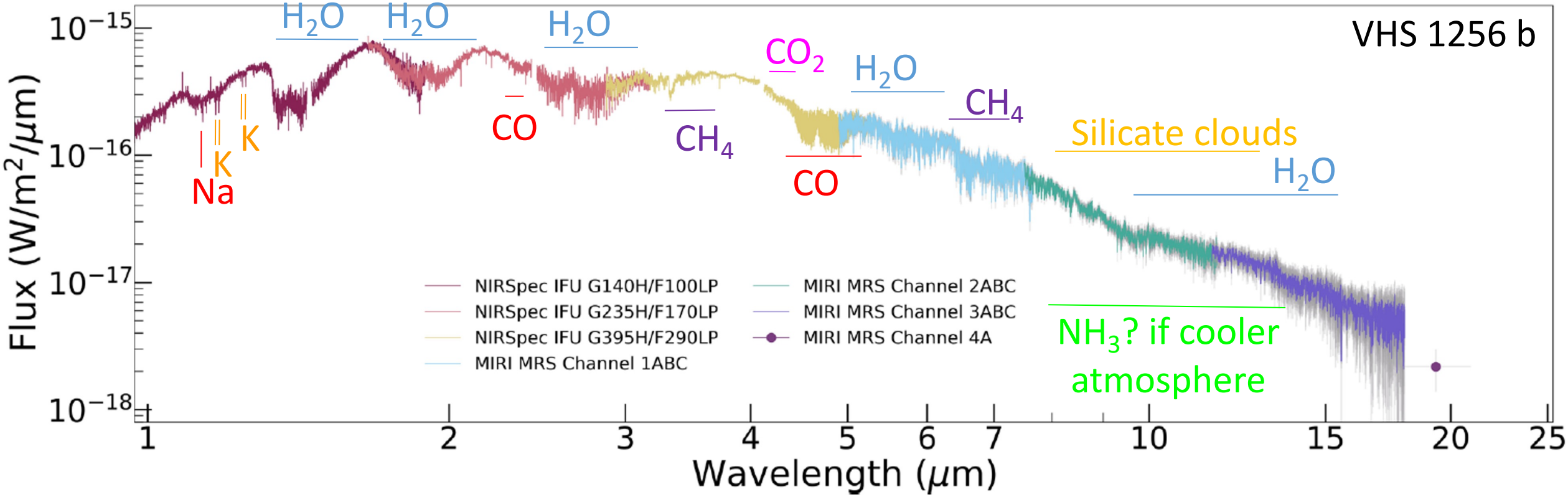
JWST is enabling 1-20 μm moderate resolution (R~2,700) spectroscopy of exoplanets



Miles+2023

ERS 1386 (PI: Hinkley)

JWST is enabling 1-20 μm moderate resolution (R~2,700) spectroscopy of exoplanets

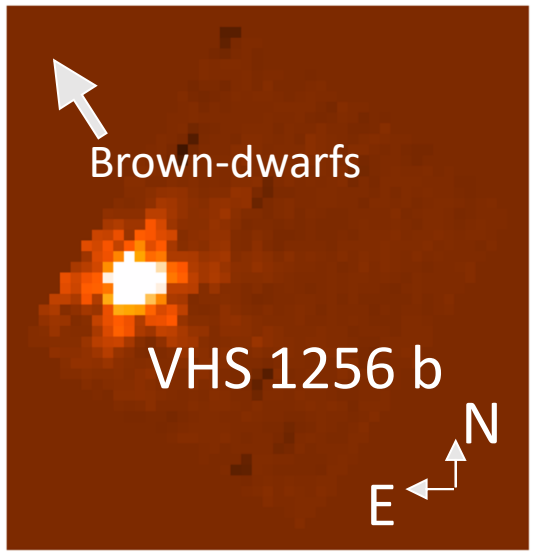


Miles+2023

ERS 1386 (PI: Hinkley)

Spectroscopy of faint companions next to bright stars requires extremely accurate modeling of the host star

NIRSpec IFU slices (~4 μm):



Mass: **~12M_{Jup}**

Flux ratio: **~2x10^{-2}**

Separation: **~7”**

ERS 1386 (PI: Hinkley)

Miles+2023

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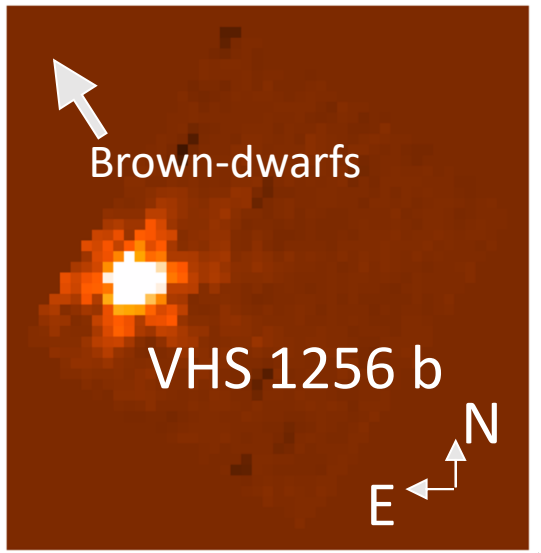
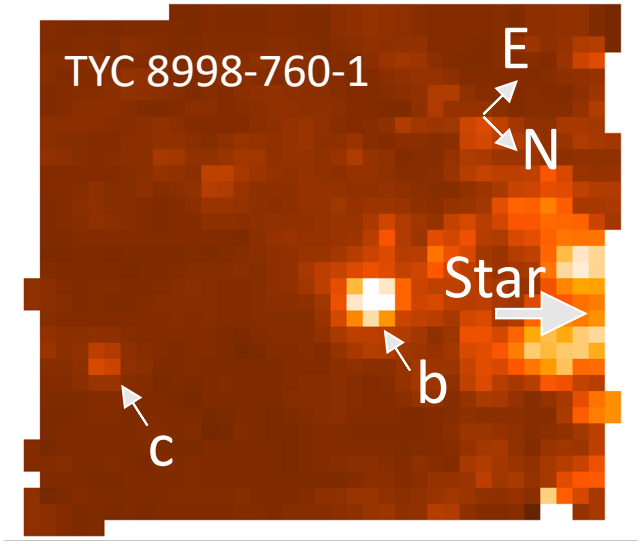




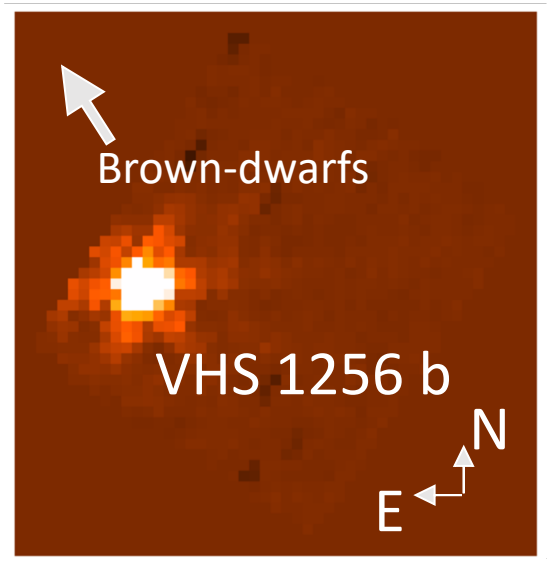
Mass:	**~12M_{Jup}**	**~6M_{Jup}**	**~14M_{Jup}**
Flux ratio:	**~2x10^{-2}**	**~6x10^{-4}**	**~10^{-2}**
Separation:	**~7”**	**~3.3”**	**~1.7”**

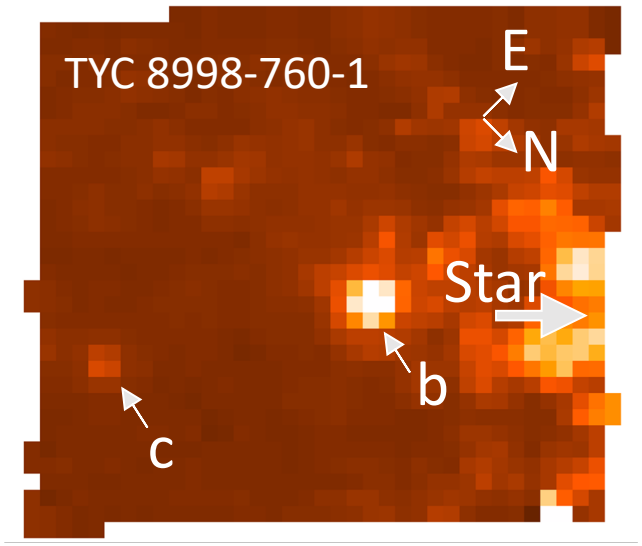
ERS 1386 (PI: Hinkley) *GO 2044 (PI: Hoch)*

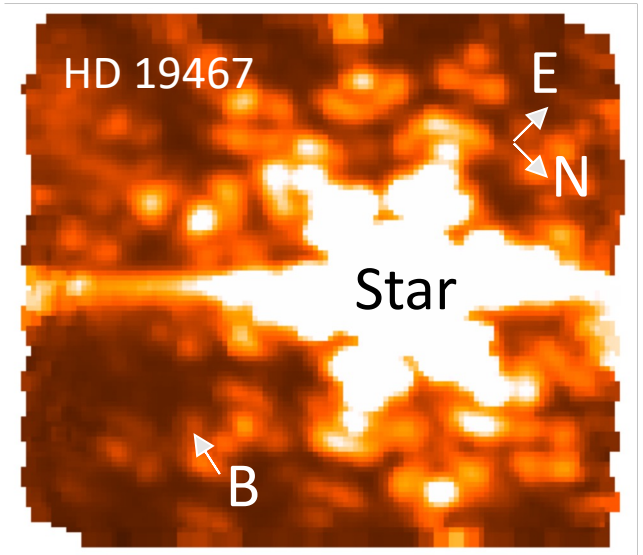
Miles+2023

Spectroscopy of faint companions next to bright stars requires extremely accurate modeling of the host star

NIRSpec IFU slices (~4 µm):



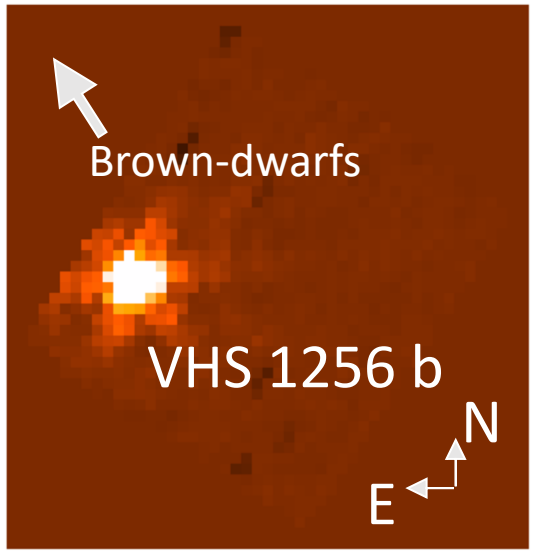


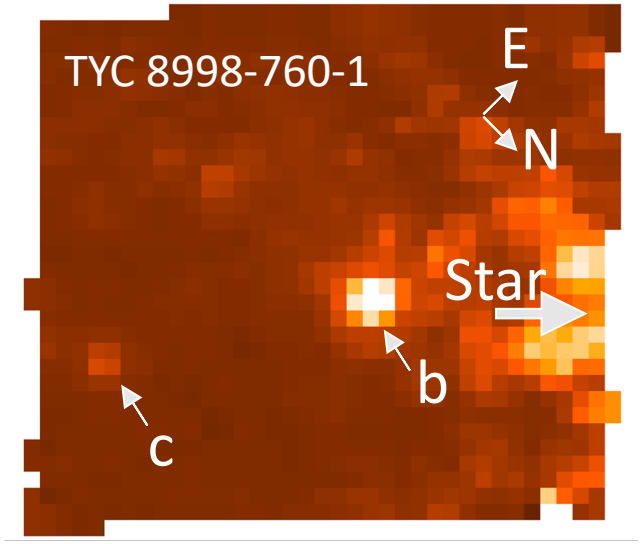


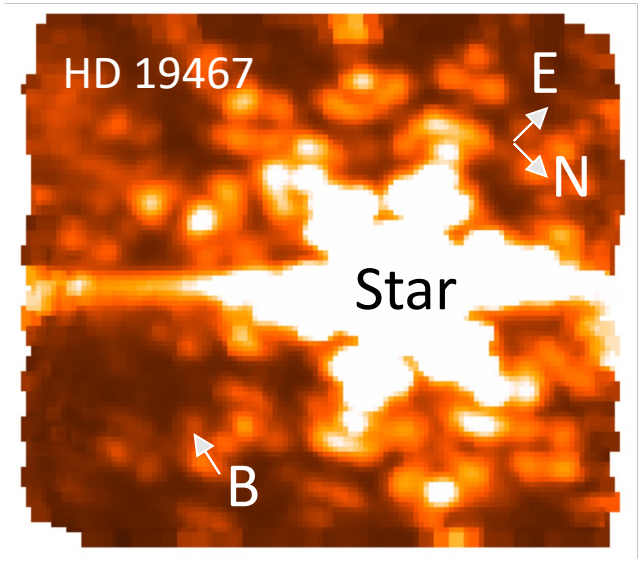
Mass:	**~12M_{Jup}**	**~6M_{Jup}** **~14M_{Jup}**	**~70M_{Jup}**
Flux ratio:	**~2x10^{-2}**	**~6x10^{-4}** **~10^{-2}**	**~10^{-4}**
Separation:	**~7”**	**~3.3”** **~1.7”**	**~1.6”**
ERS 1386 (PI: Hinkley) Miles+2023		*GO 2044 (PI: Hoch)*	*GTO 1414 (PI: Perrin) Ruffio+(submitted) & Hoch+(in prep.)*

Spectroscopy of faint companions next to bright stars requires extremely accurate modeling of the host star

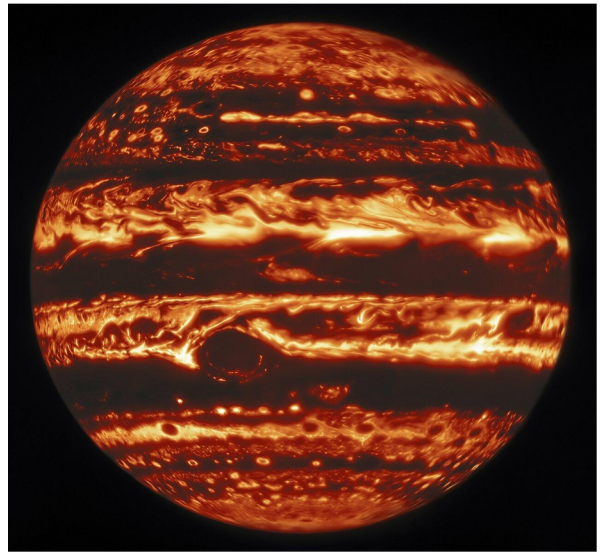
NIRSpec IFU slices (~4 µm):







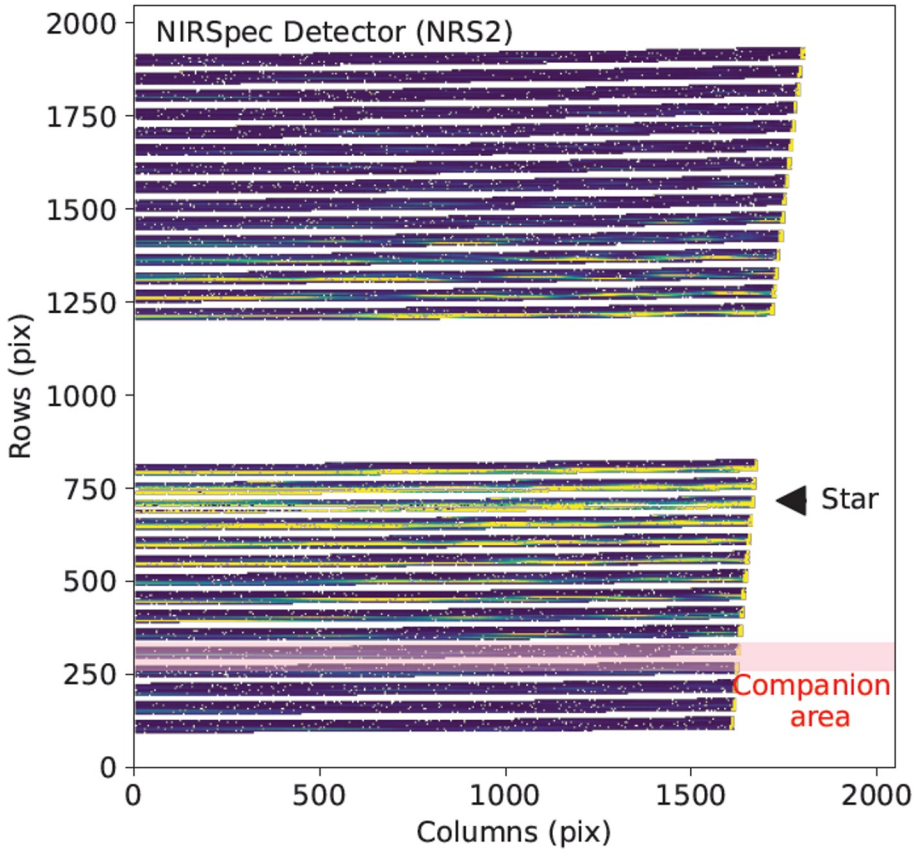
Enabling direct spectroscopy of Jupiter analogs

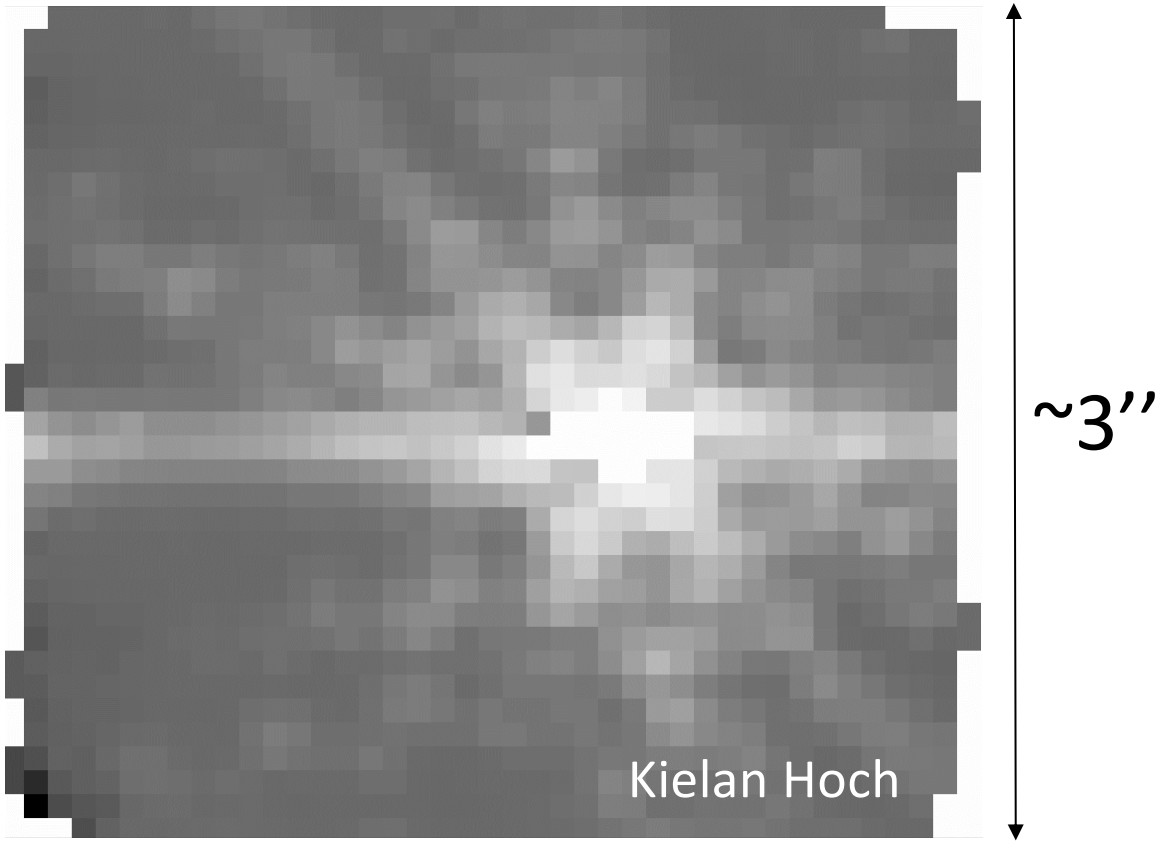


Mass:	~12M_{Jup}	~6M_{Jup}	~14M_{Jup}	~70M_{Jup}	<1M_{Jup}
Flux ratio:	~2x10^{-2}	~6x10^{-4}	~10^{-2}	~10^{-4}	<10^{-6}
Separation:	~7”	~3.3”	~1.7”	~1.6”	<1”
	ERS 1386 (PI: Hinkley) Miles+2023	*GO 2044 (PI: Hoch)*		*GTO 1414 (PI: Perrin) Ruffio+(submitted) & Hoch+(in prep.)*	

JWST/NIRSpec includes an integral field spectrograph

Spectral cubes can be reconstructed from 2D detector images.

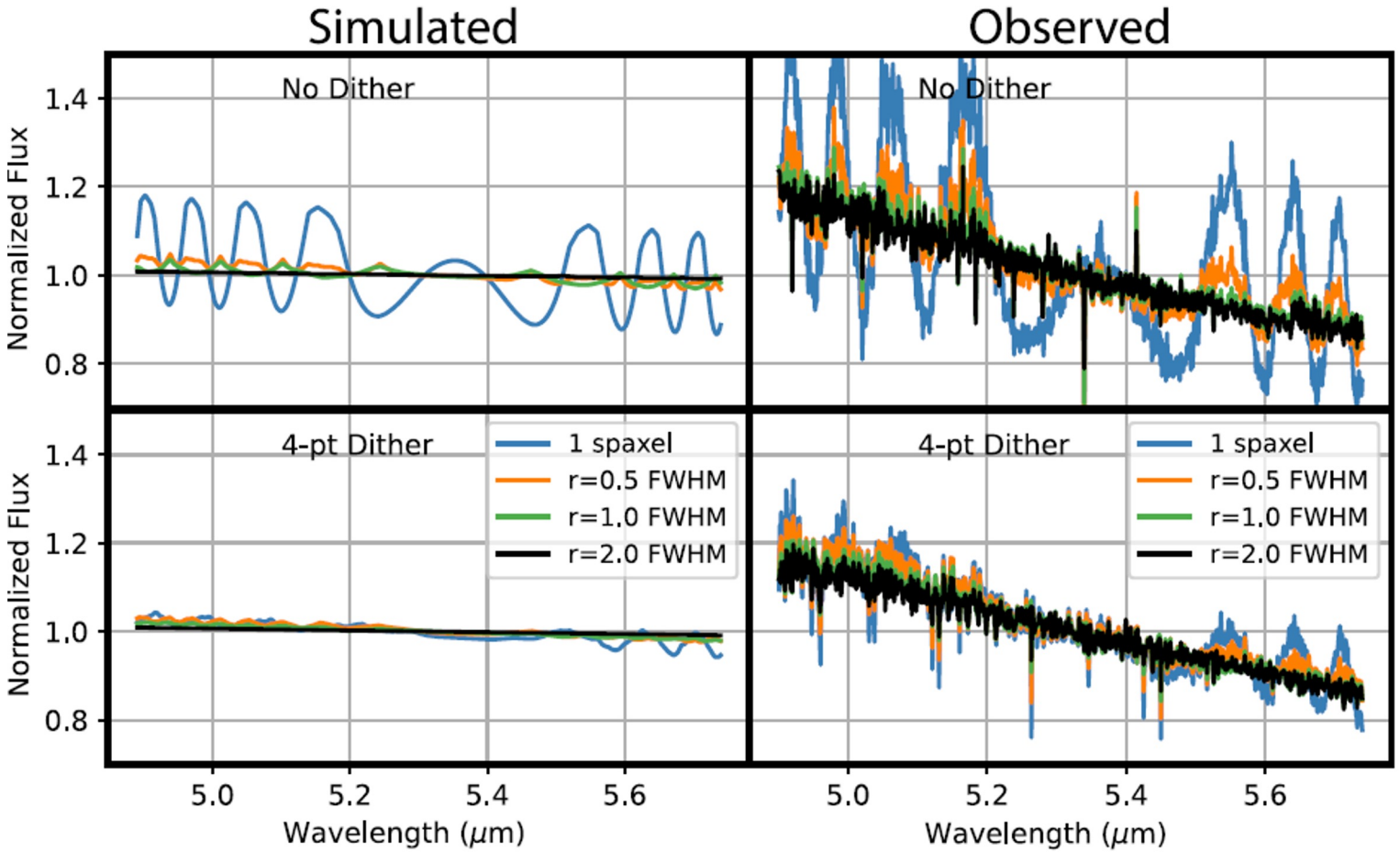




Moving through wavelength axis

What is the main challenge?

The spectral cubes feature high level of systematics as a result of spatially undersampled IFUs

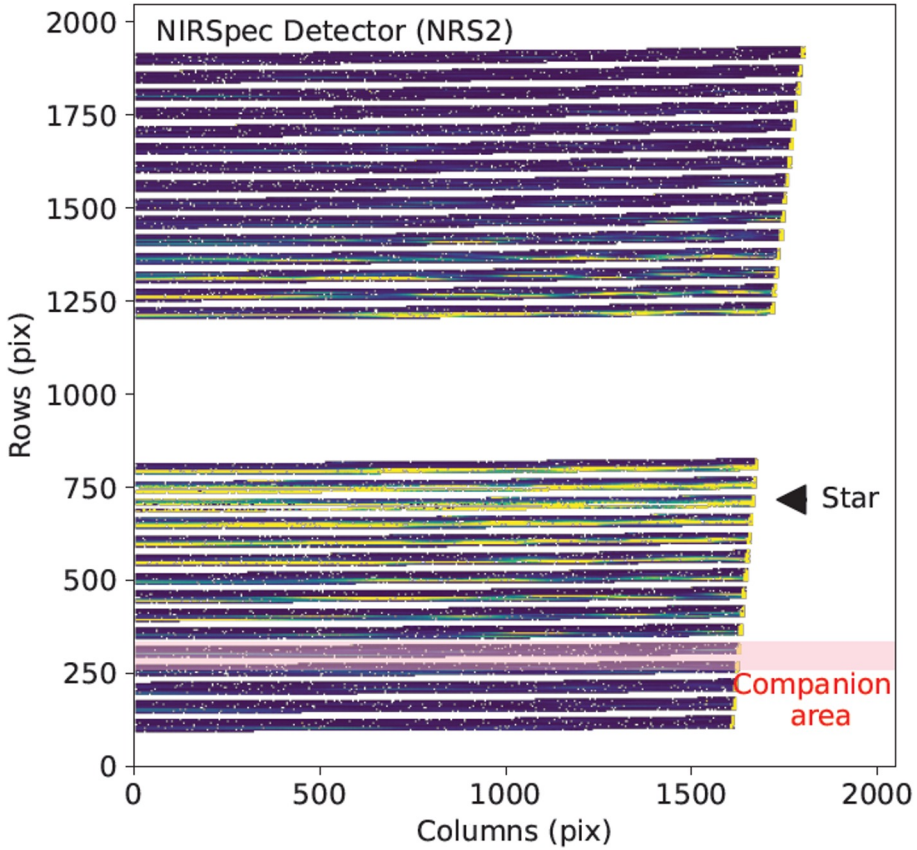


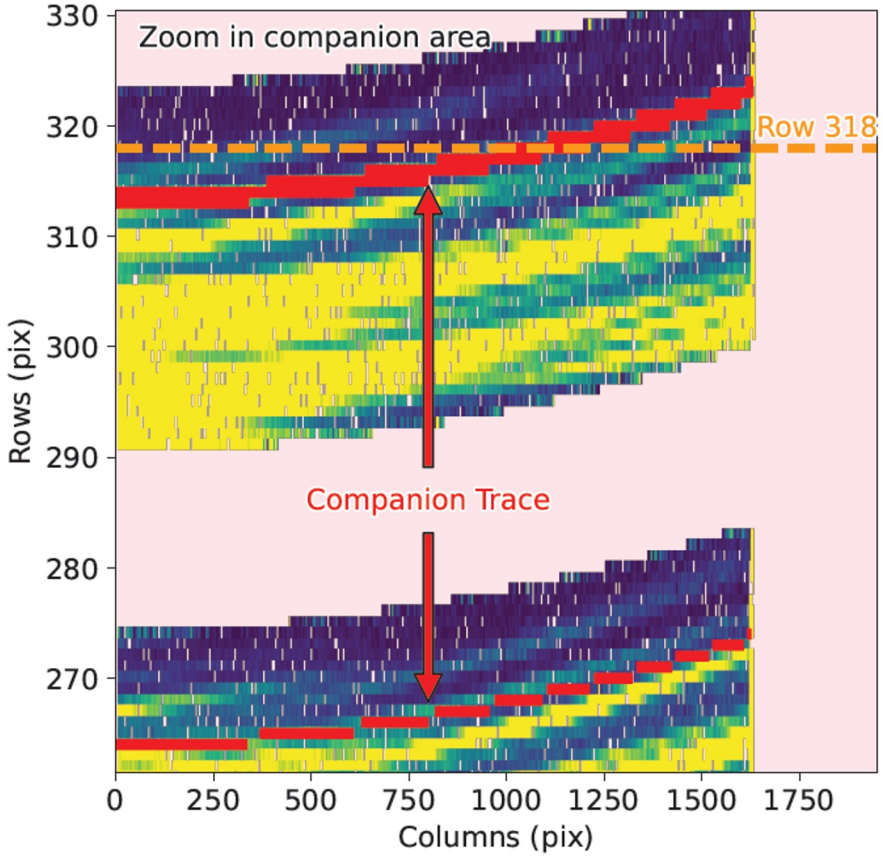
Law+2023

➡ Need specific mitigation strategies for high contrast or blended sources

Where do the oscillations come from?

The flux is periodically split between rows due to the curvature of the spectral trace

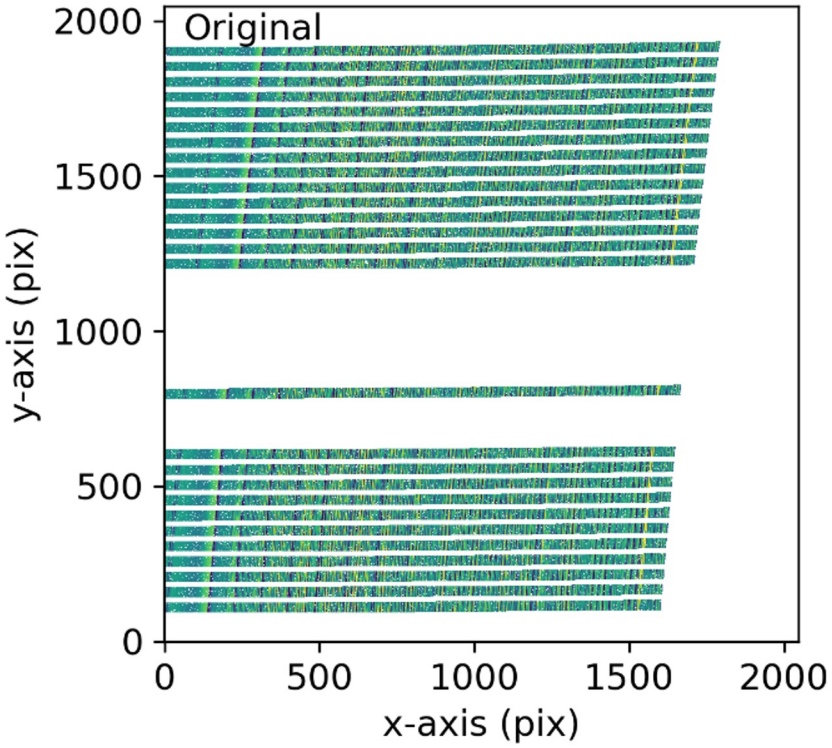


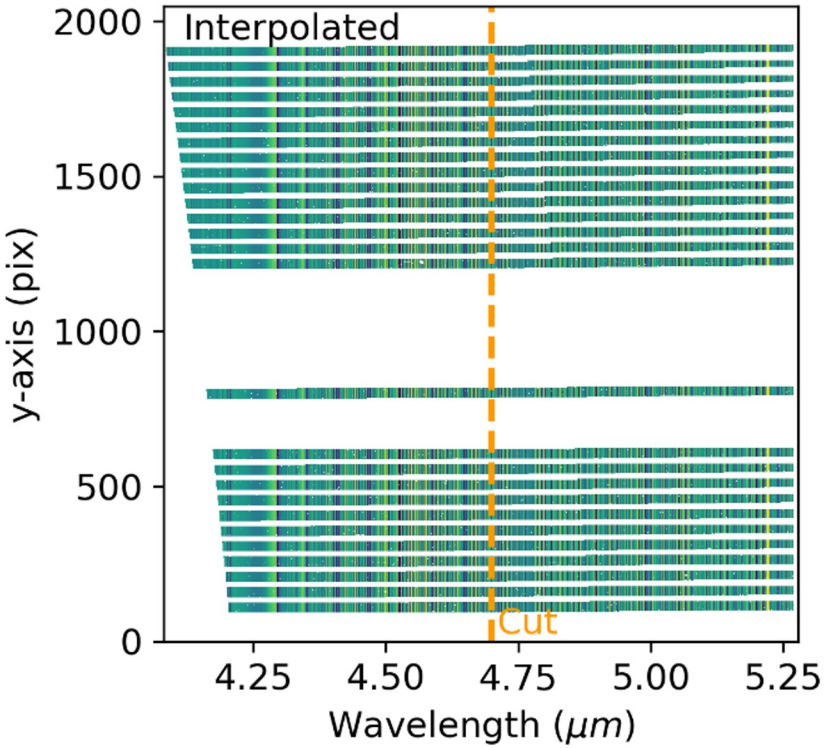


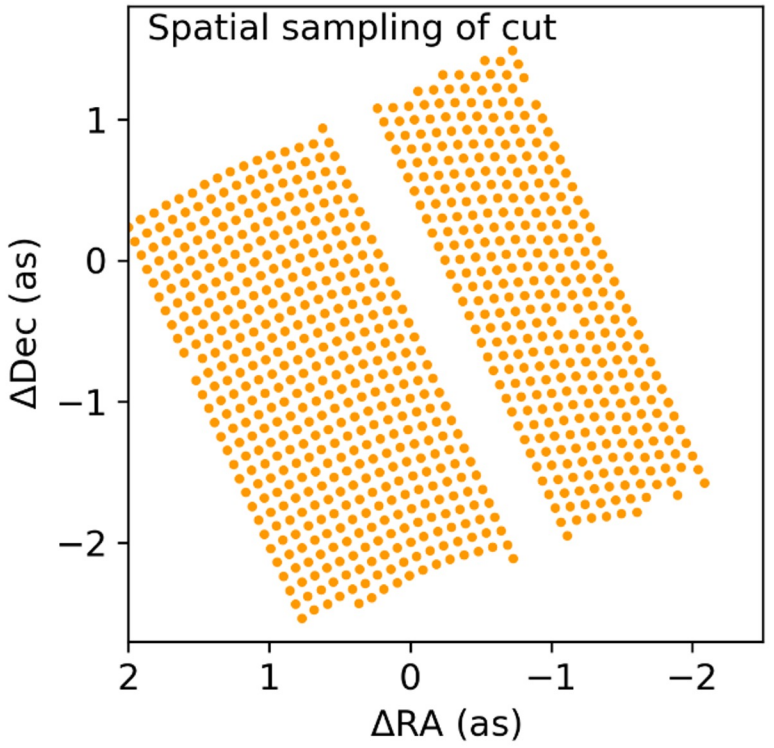
➡ The spectral oscillations are an artifact of the extraction, not a limitation of the data.

Fitting the data in the “point cloud” can mitigate these oscillations

The point cloud $\Leftrightarrow \{x_i, y_i, \lambda_i\}_i \Leftrightarrow$ Detector images

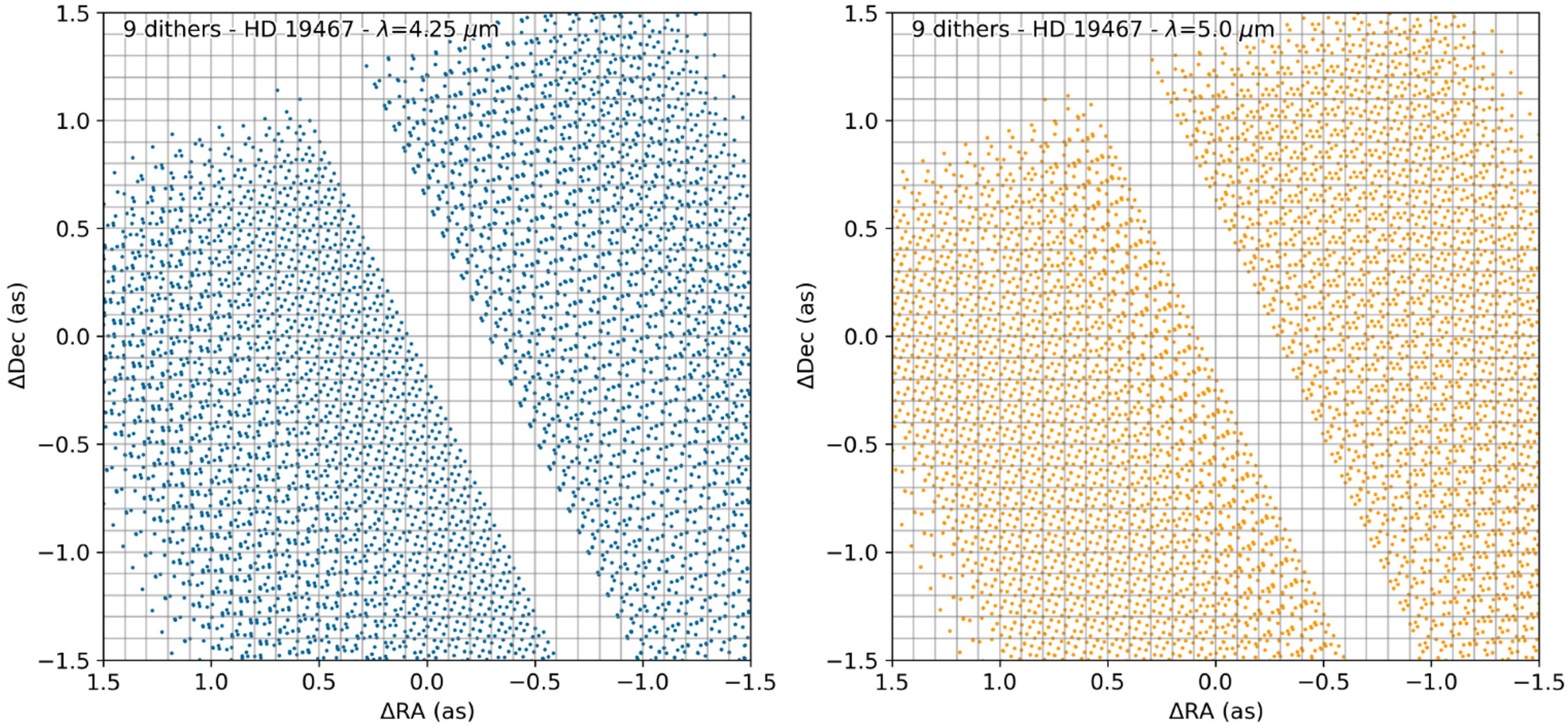




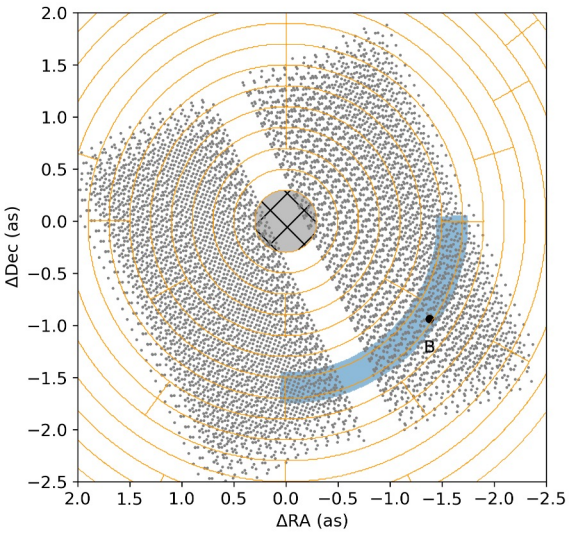


➡ Interpolations come at a cost, so they should be used sparingly.

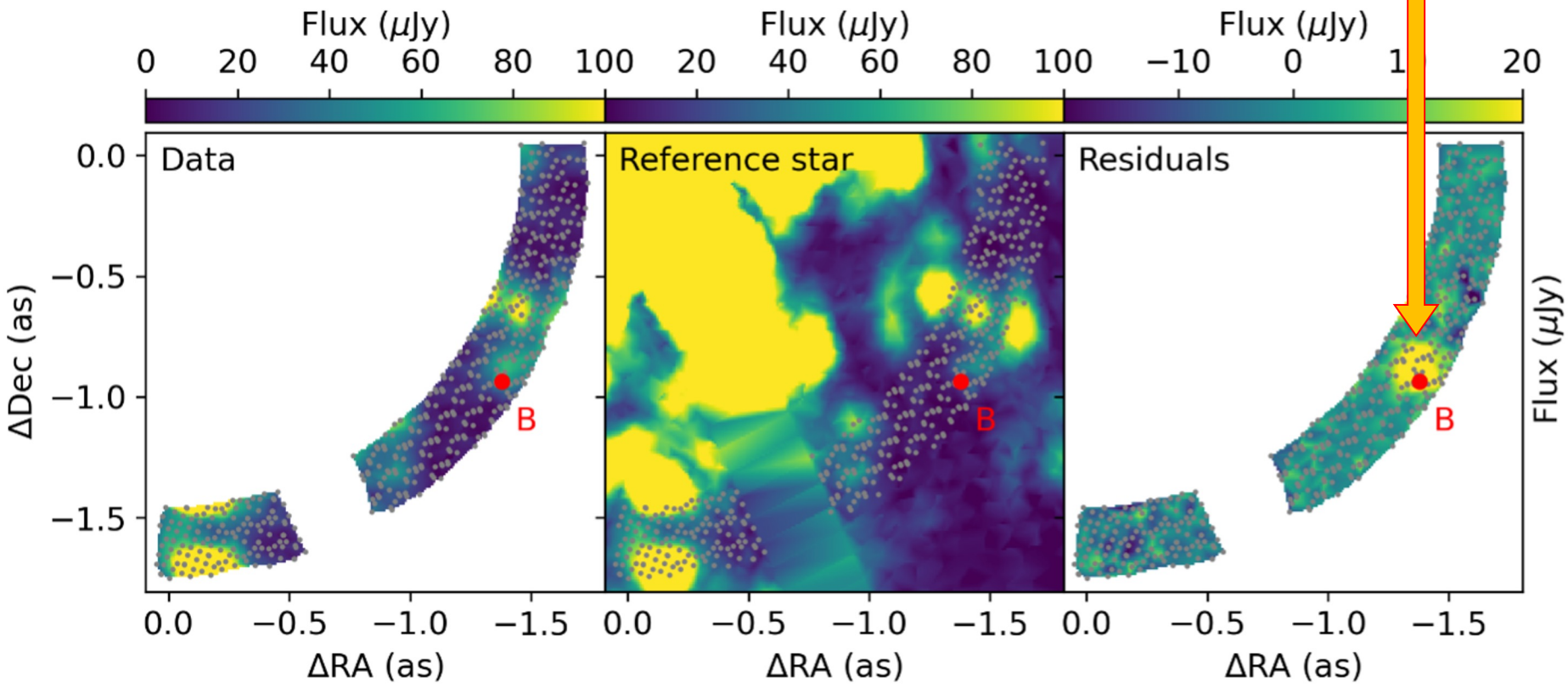
Combining dithers improves the spatial sampling



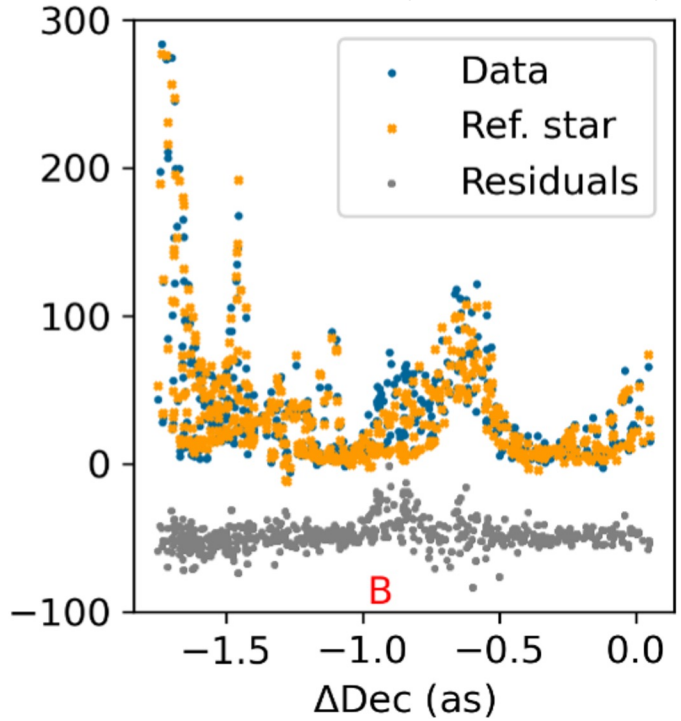
➡ The NIRSpec IFU dithering pattern does not uniformly sample the field of view



PSF subtraction can be done in the point cloud to uncover the faint companion

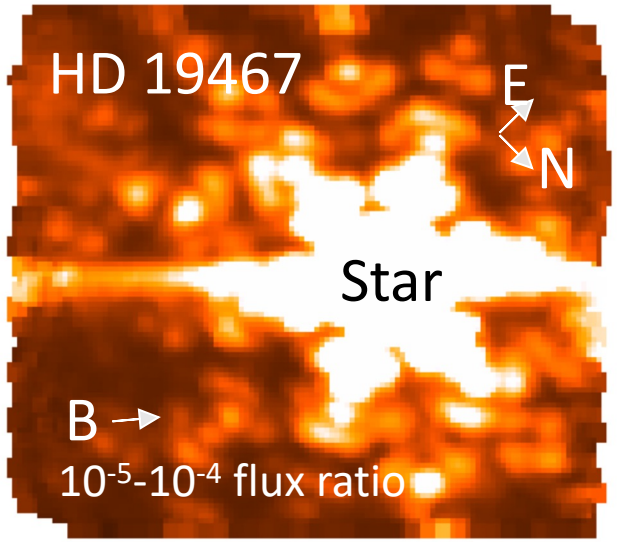


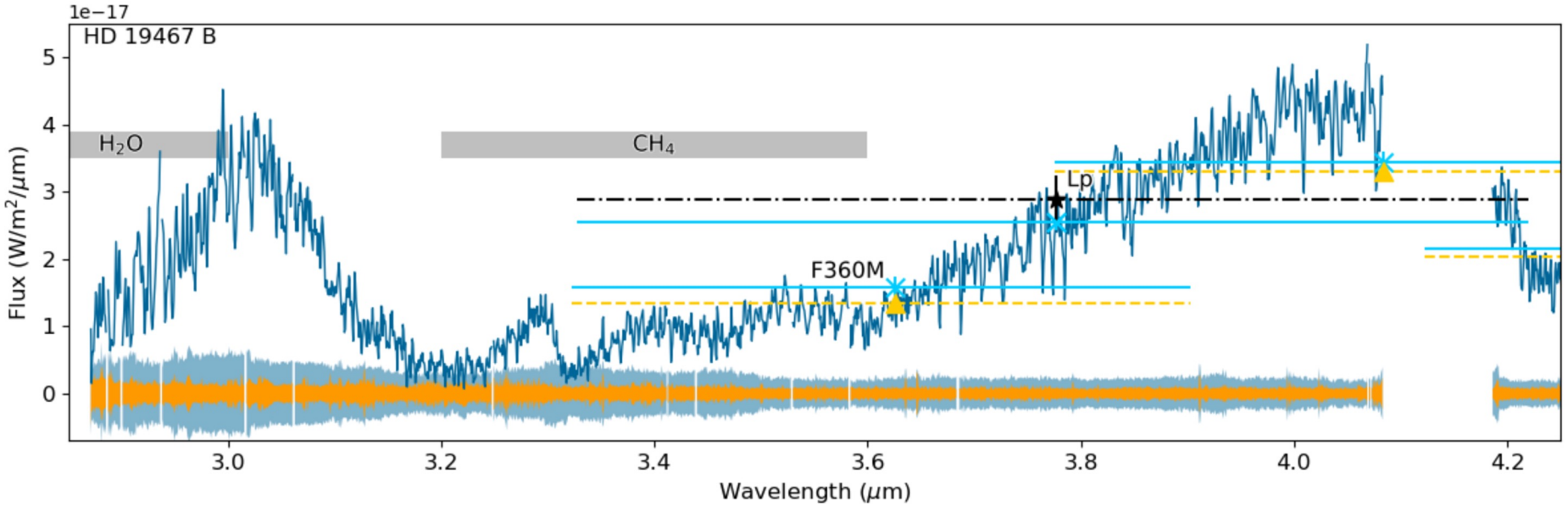
Ruffio+(submitted)

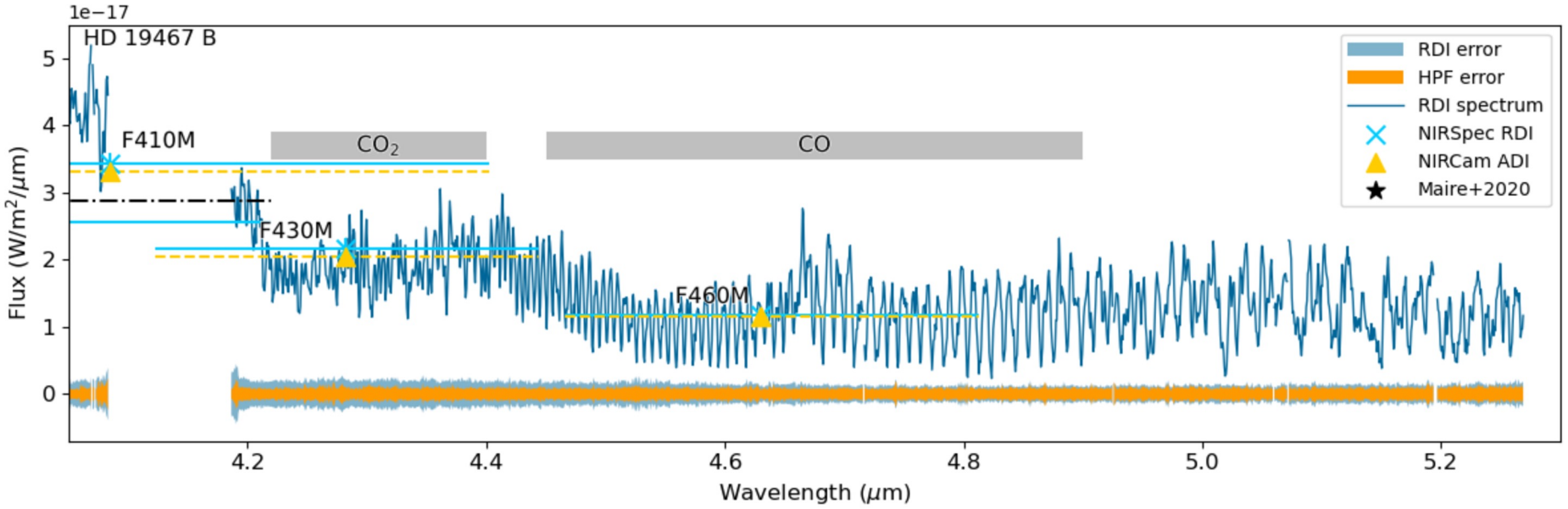


Ruffio+(submitted)

Accurate PSF subtraction for JWST NIRSpec is possible!



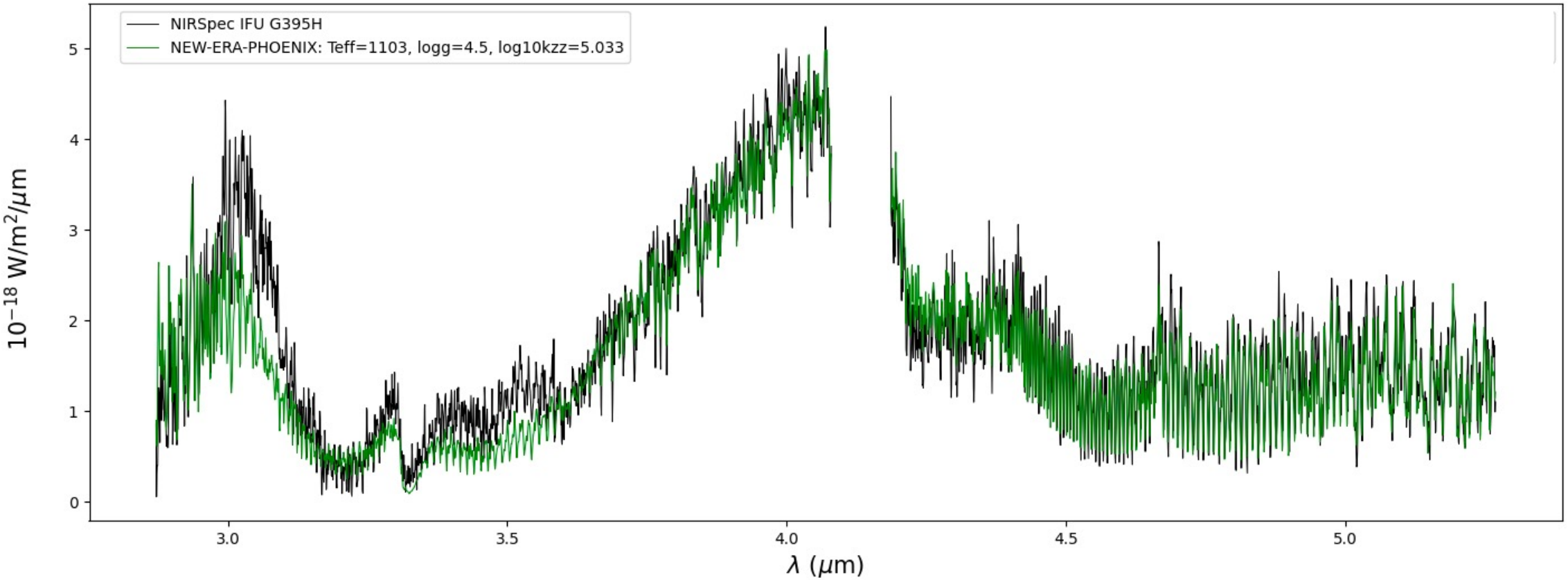




Ruffio+(submitted)

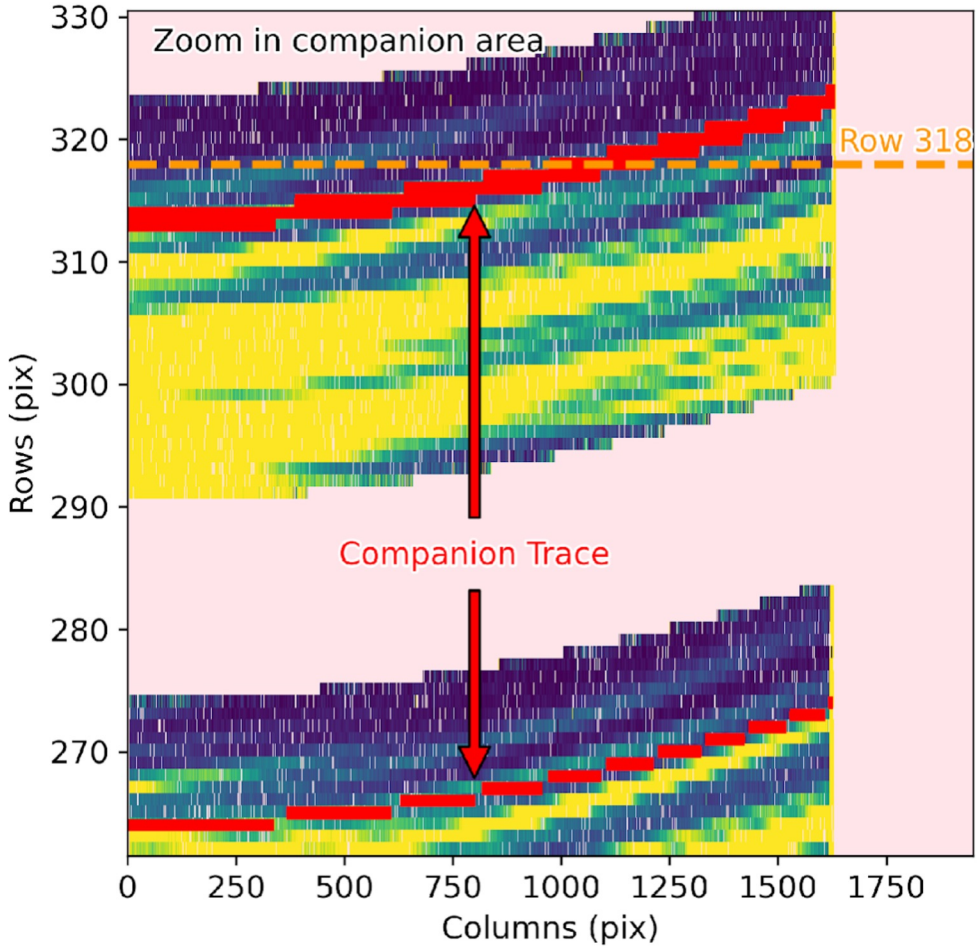
Atmospheric characterization of HD 19467 B is in progress

Best fit model is consistent with solar composition



Hoch+(in prep.)

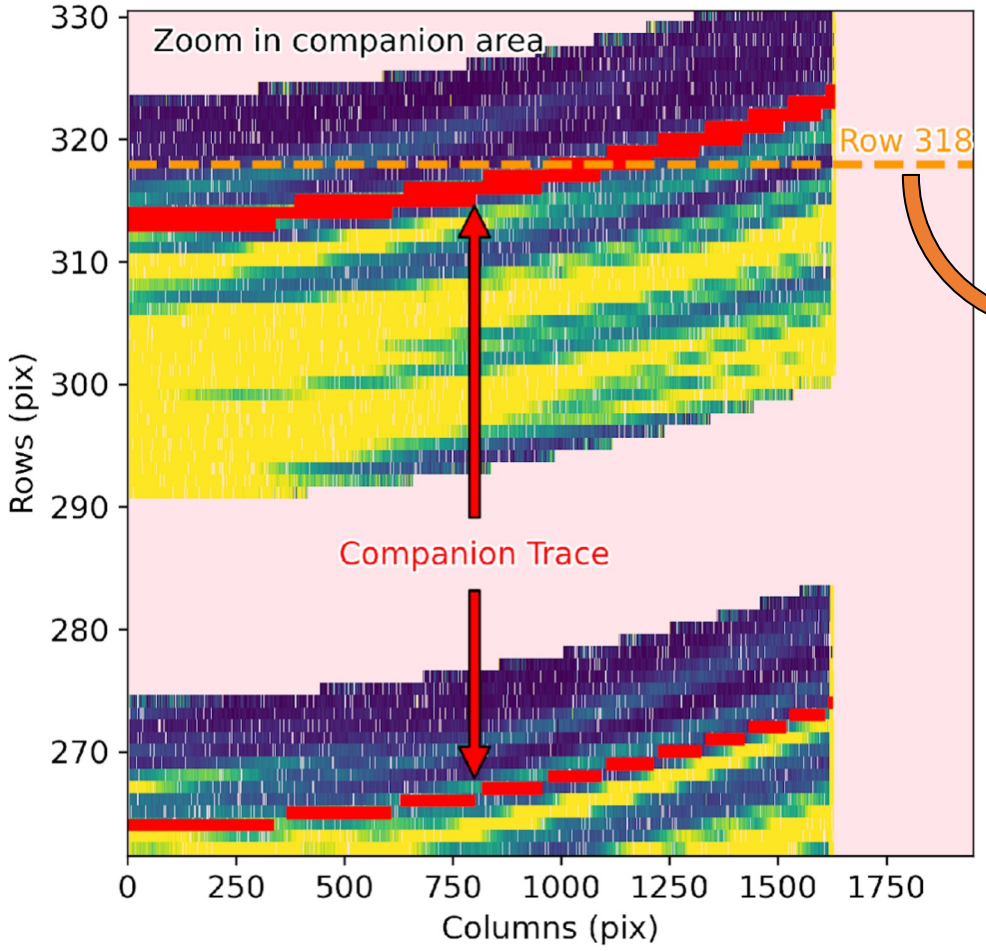
Fully forward modeling detector images is the best way to avoid flux extraction systematics

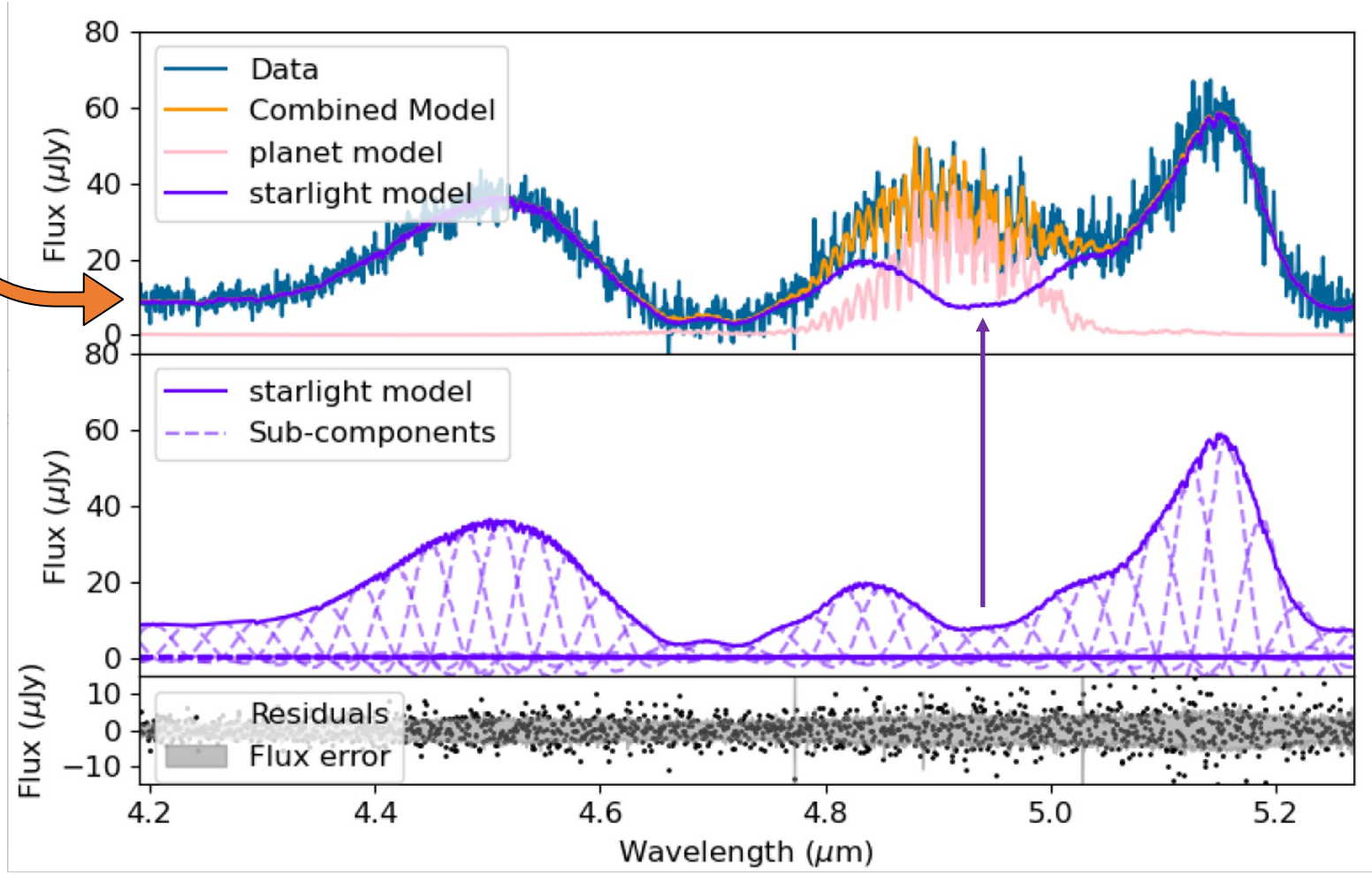


➡ It is not necessary to extract a spectrum in order to detect or characterize an object

Ruffio+(submitted) https://github.com/jruffio/breads

Fully forward modeling detector images is the best way to avoid flux extraction systematics

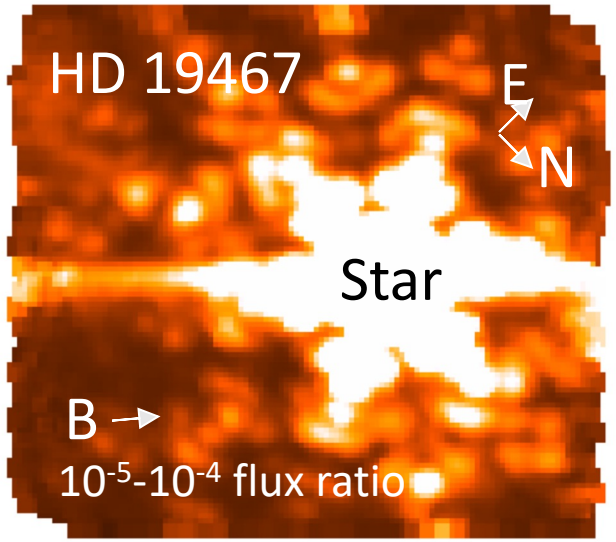


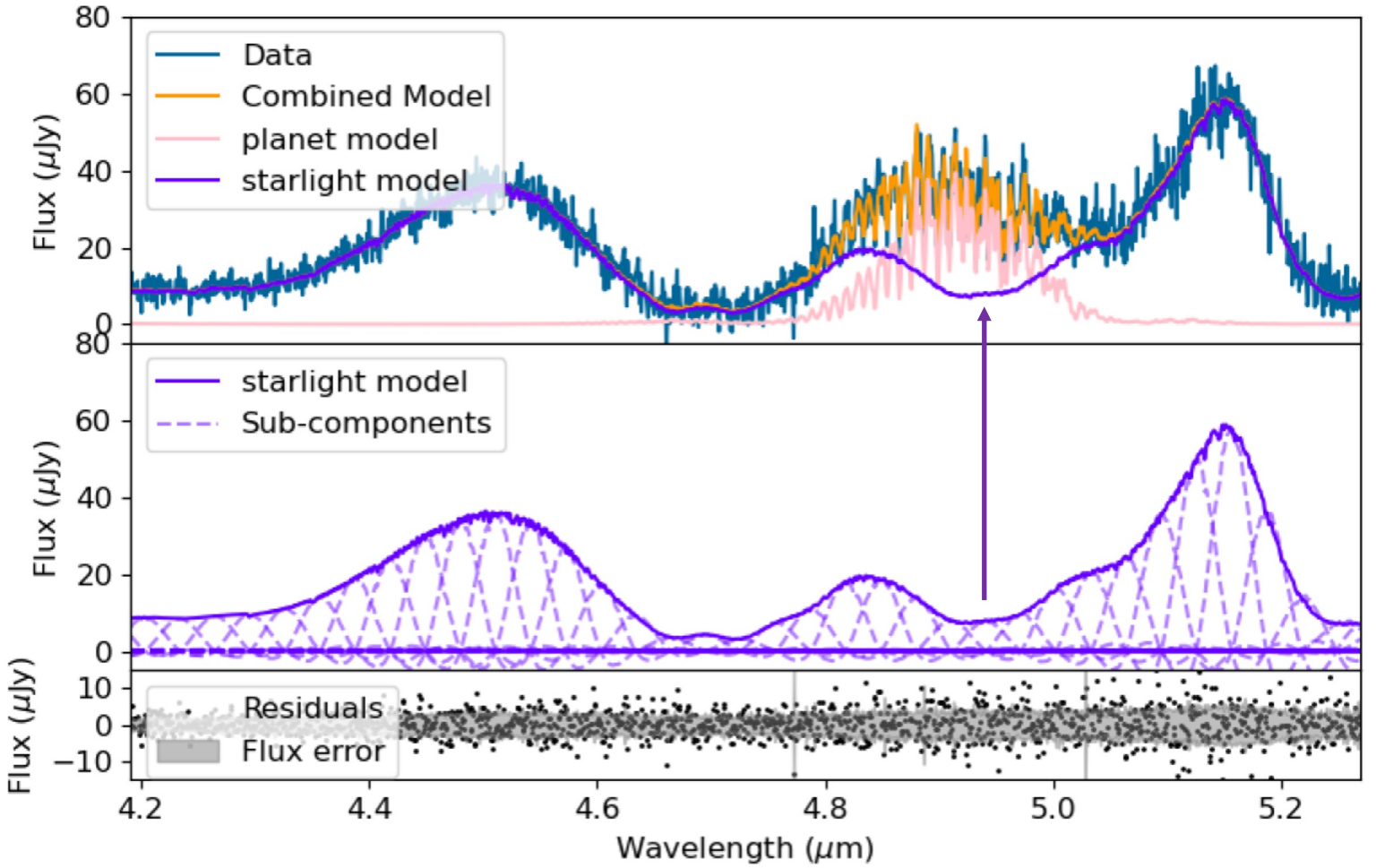


It is not necessary to extract a spectrum in order to detect or characterize an object

Ruffio+(submitted) https://github.com/jruffio/breads

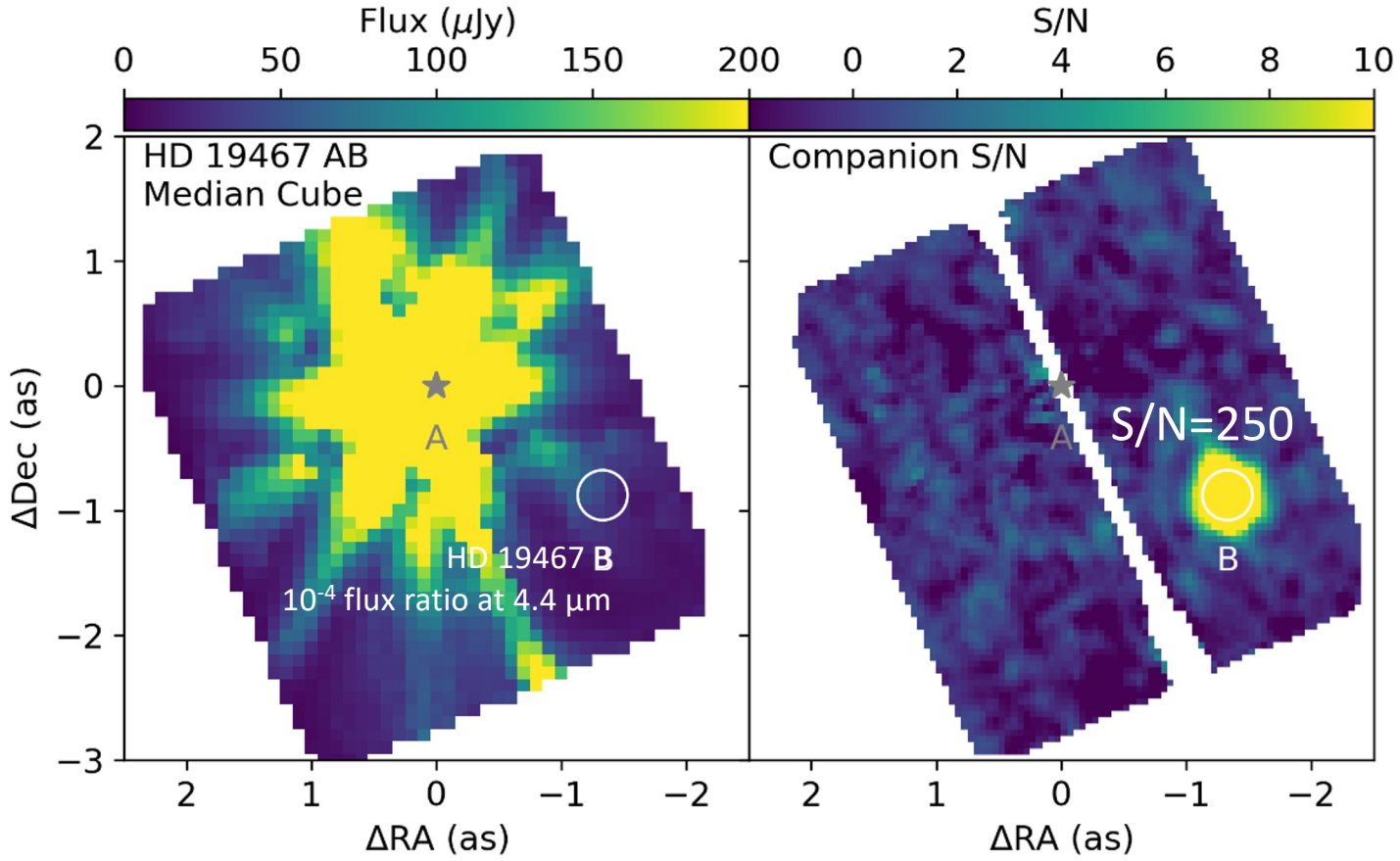
The spectral information makes it easier to detect a companion!

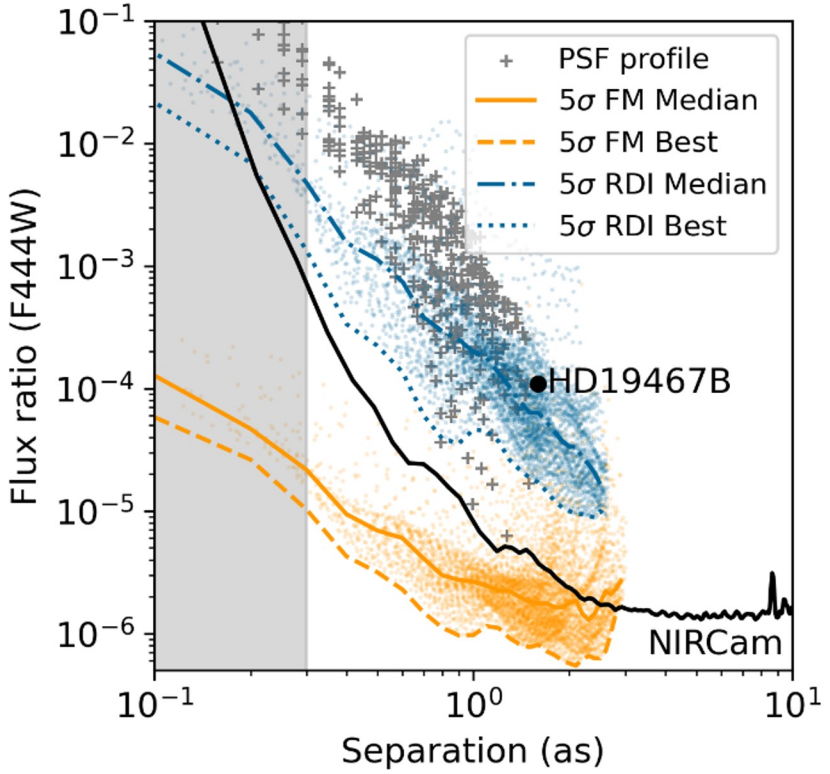




Ruffio+(submitted) https://github.com/jruffio/breads

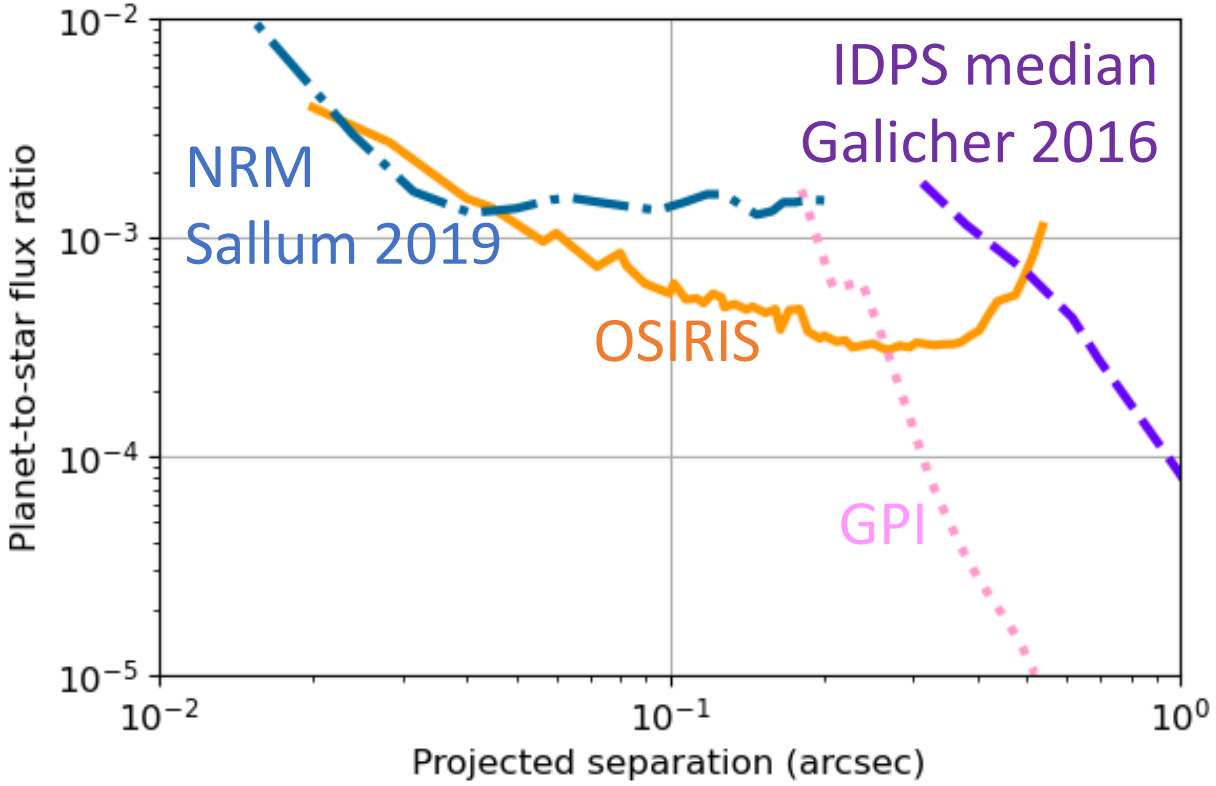
NIRSpec IFU can detect extremely faint companions next to bright stars

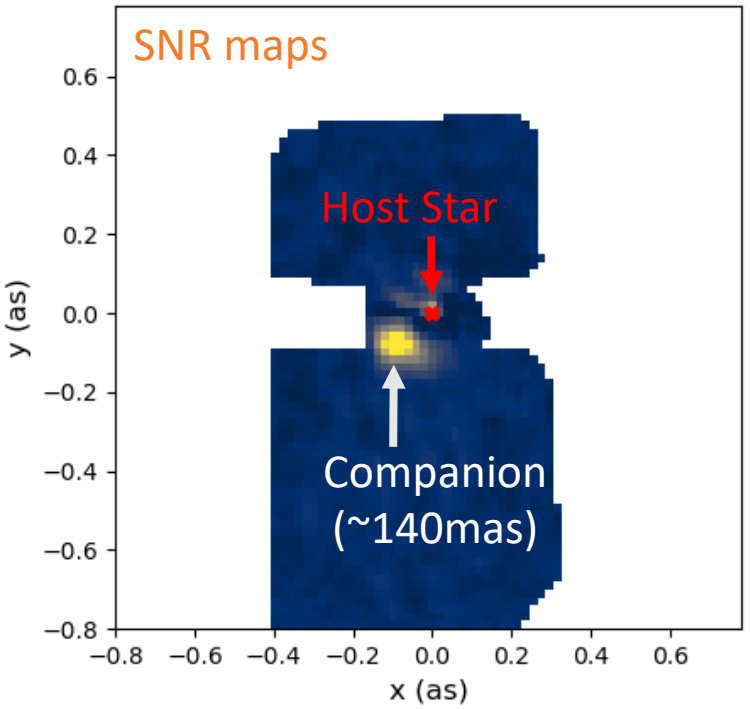




Ruffio+(submitted)

These results are generally consistent with precursor work using Keck/OSIRIS on the ground

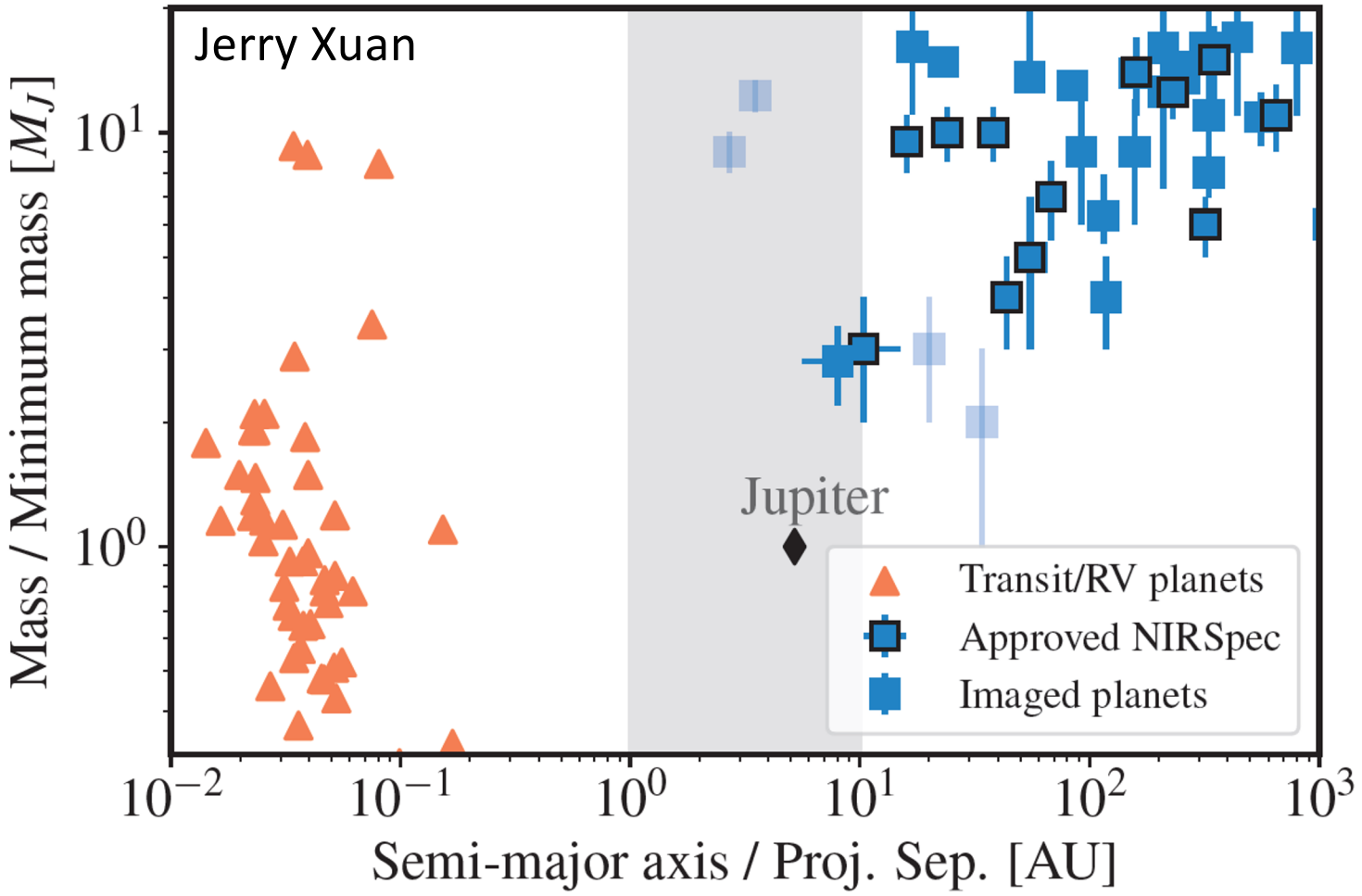


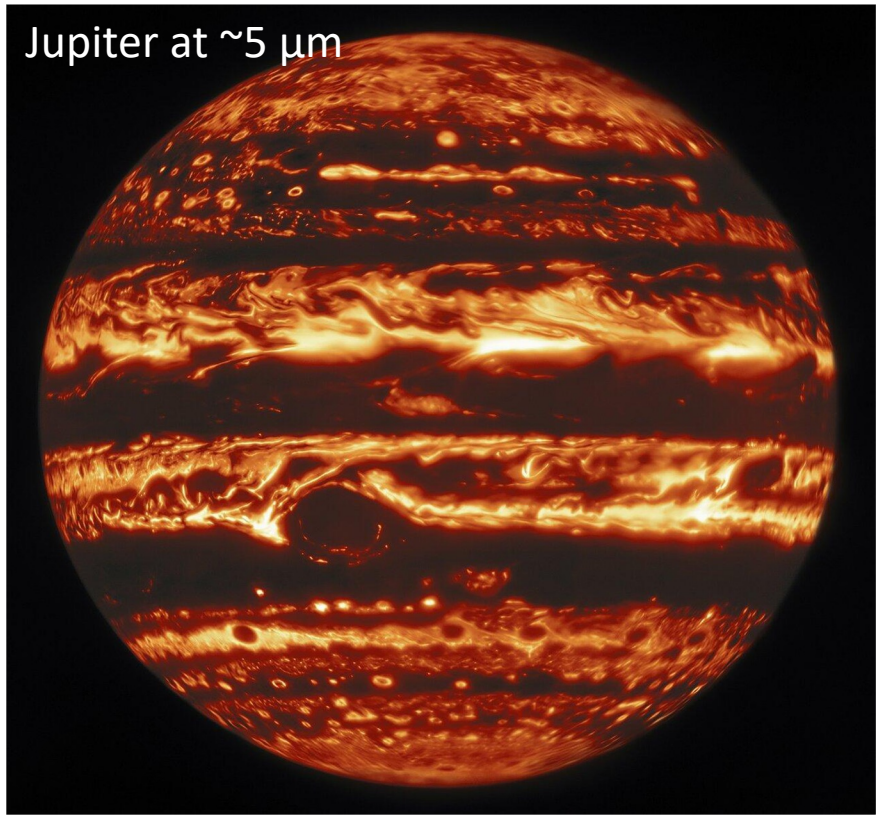


Shubh Agrawal
2nd year PhD
UPenn

40-star pathfinder survey of nearby star forming regions (Ophiuchus and Taurus) with OSIRIS

Based on these results, NIRSpec should enable the direct detection and *spectroscopy* of Jupiter analogs





International Gemini Observatory/NOIRLab/NSF/AURA, M.H. Wong (UC Berkeley) et al. Acknowledgments: M. Zamani

Conclusions:

JWST/NIRSpec is a powerful high-contrast instrument!

- Forward modeling the data in detector images mitigates NIRSpec's systematics.
- **Photon-noise limited 5σ contrast of 10^{-6} at 1''.**
- Spectroscopy of most directly imaged planets now possible with JWST/NIRSpec.
- Even spectroscopy of **sub-Jupiters (**~1 Gyr, 10 pc, 1'').
- **Python package BREADS** in development:
  - https://github.com/jruffio/breads
  - *Currently lacking documentation*