Examining the atmosphere of the Cloudy, Young Jupiter 51 Eridani b

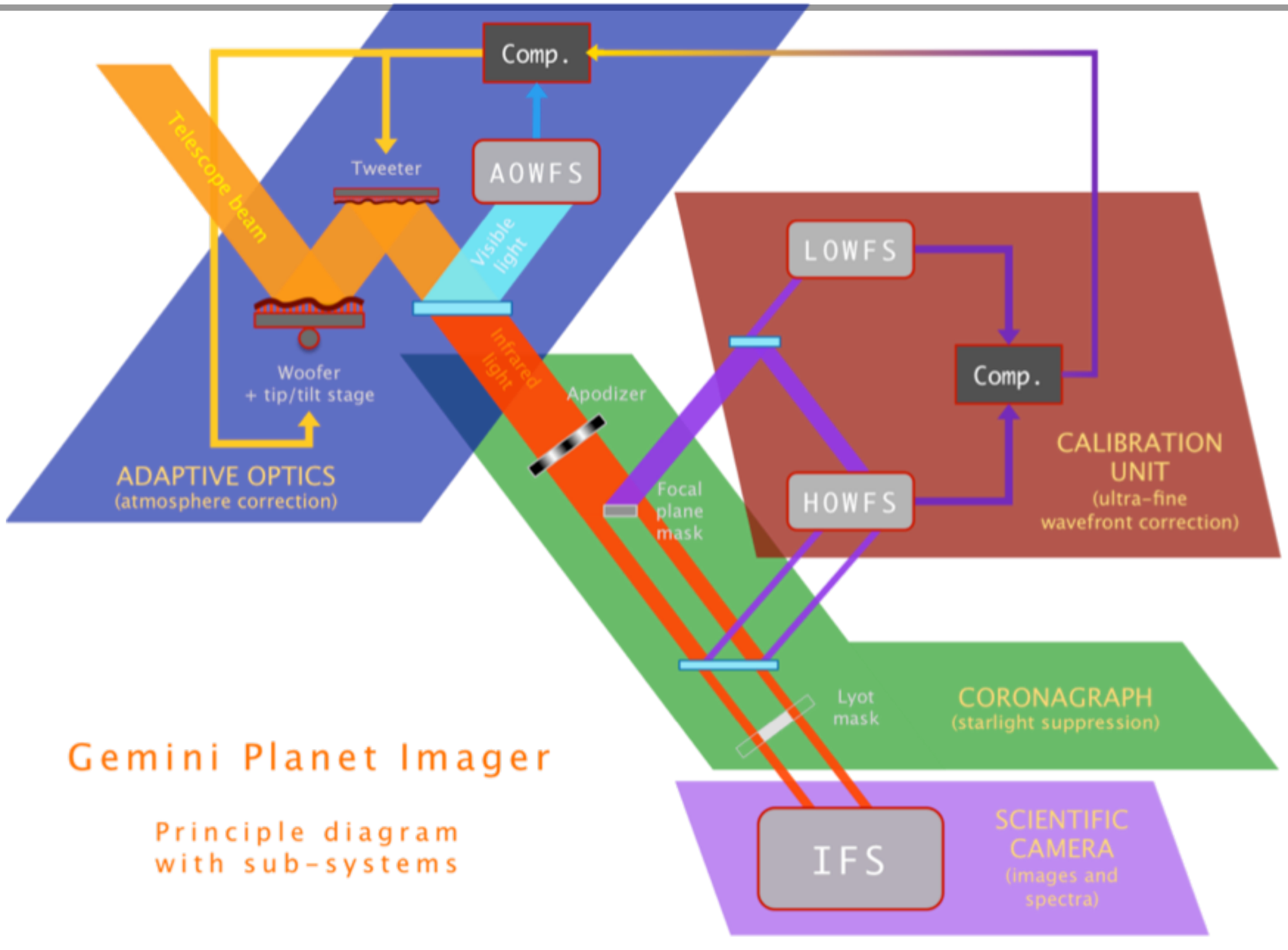
Laurent Pueyo, Abhi Rajan
STScI
And the GPIES team.

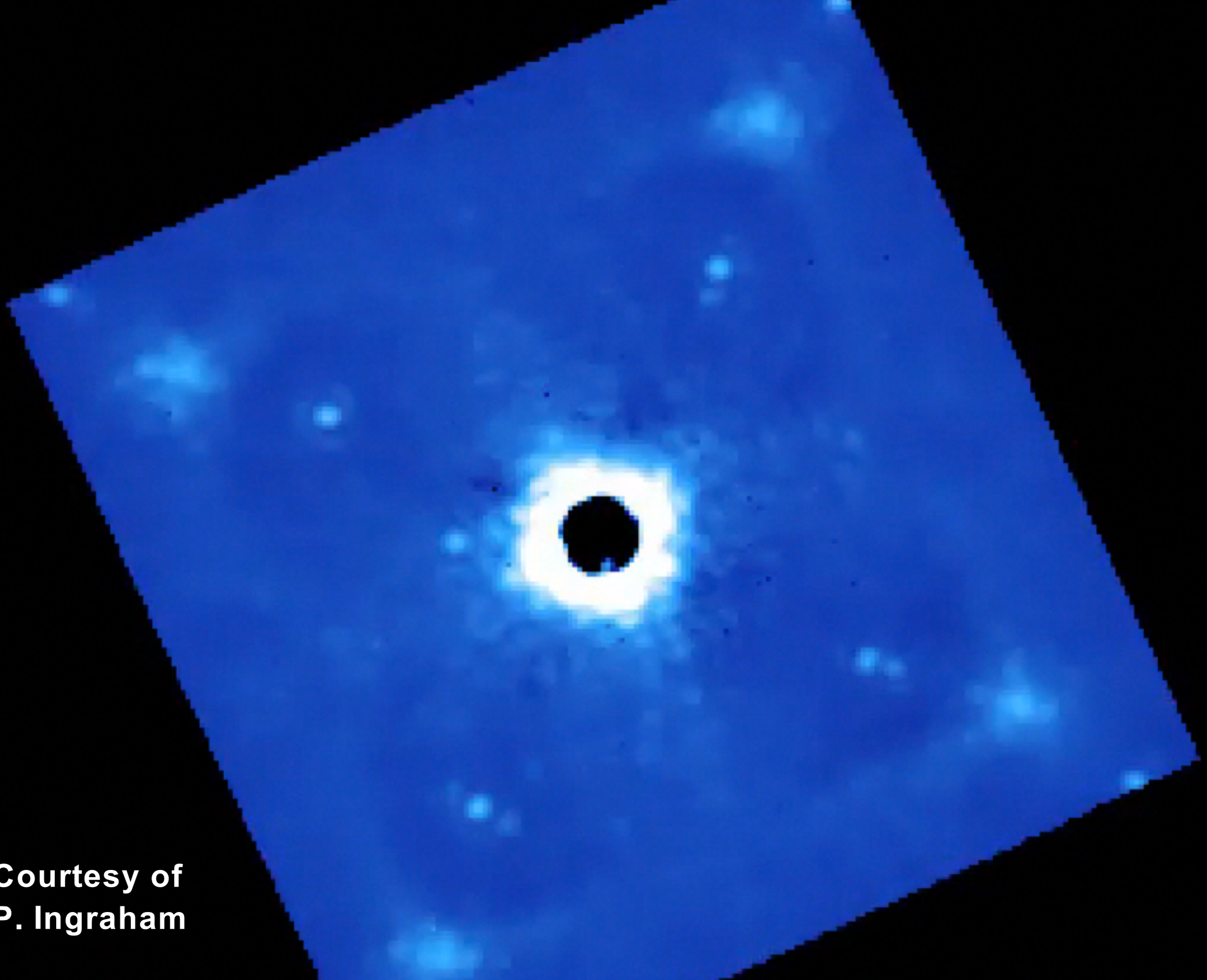
Exoplanet Survey

STScI | SPACE TELESCOPE SCIENCE INSTITUTE

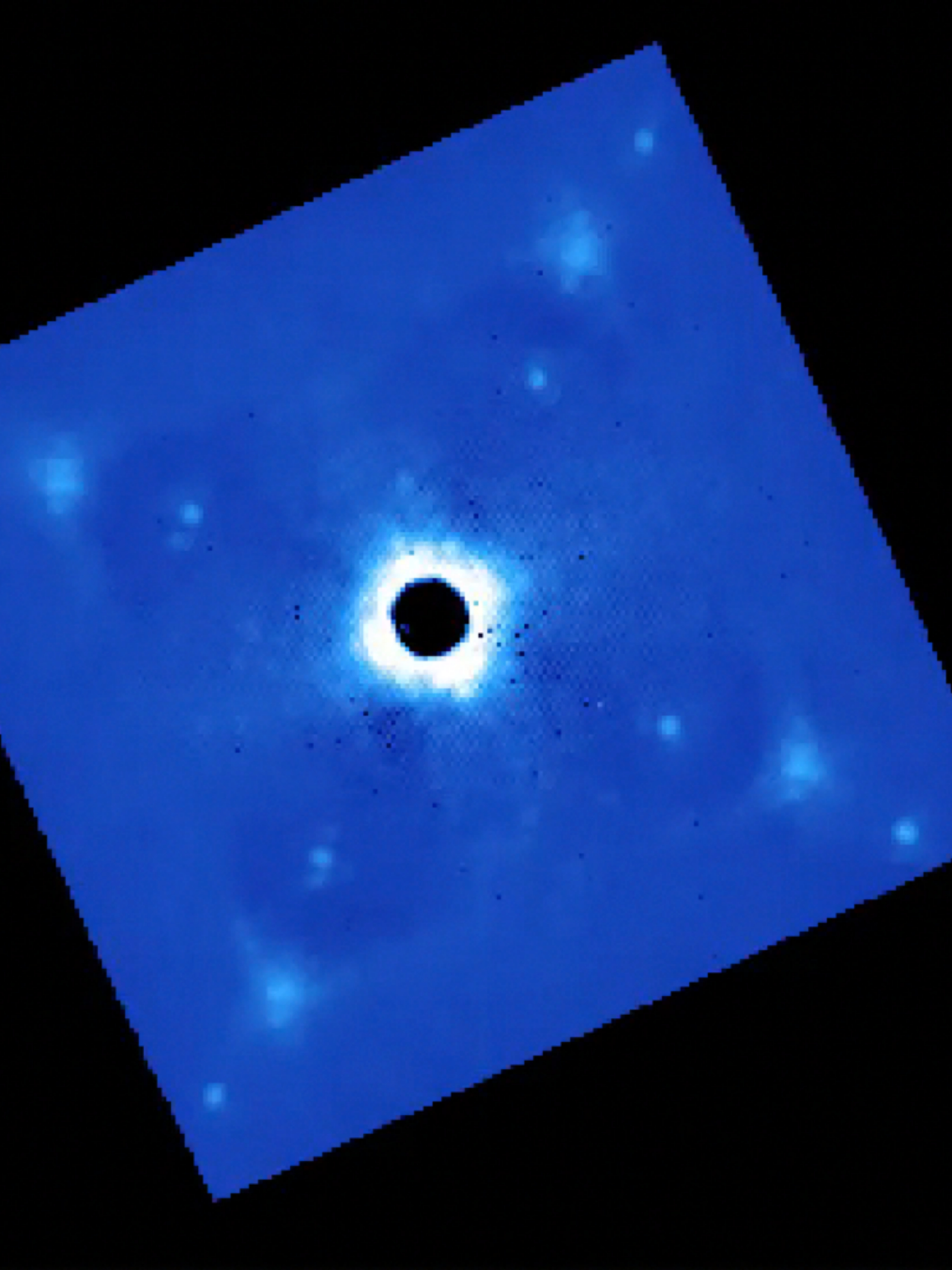
Artist's impression of 51 Eri b
Danielle Futselaar & Franck Marchis, SETI Institute

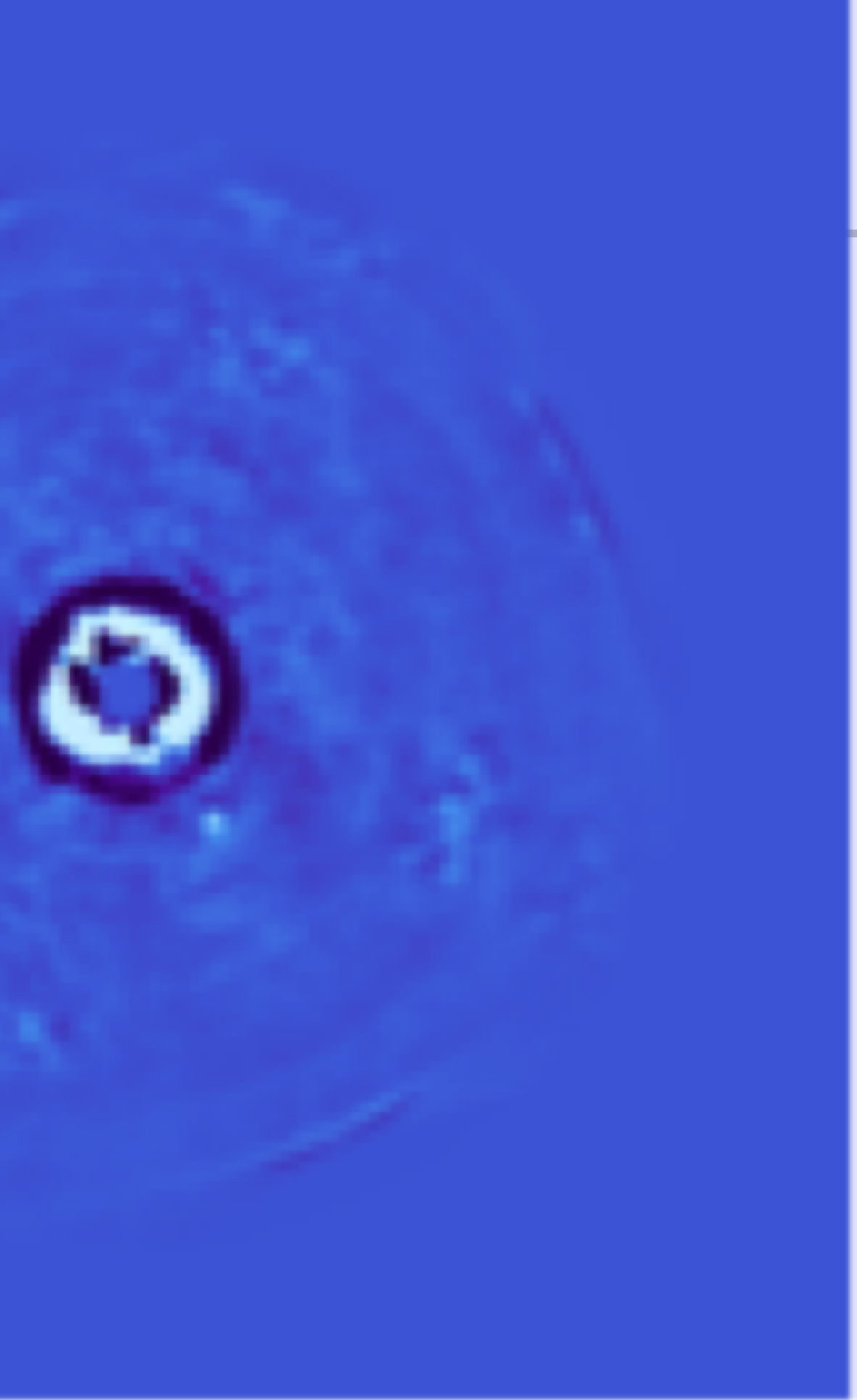
GPI Overview



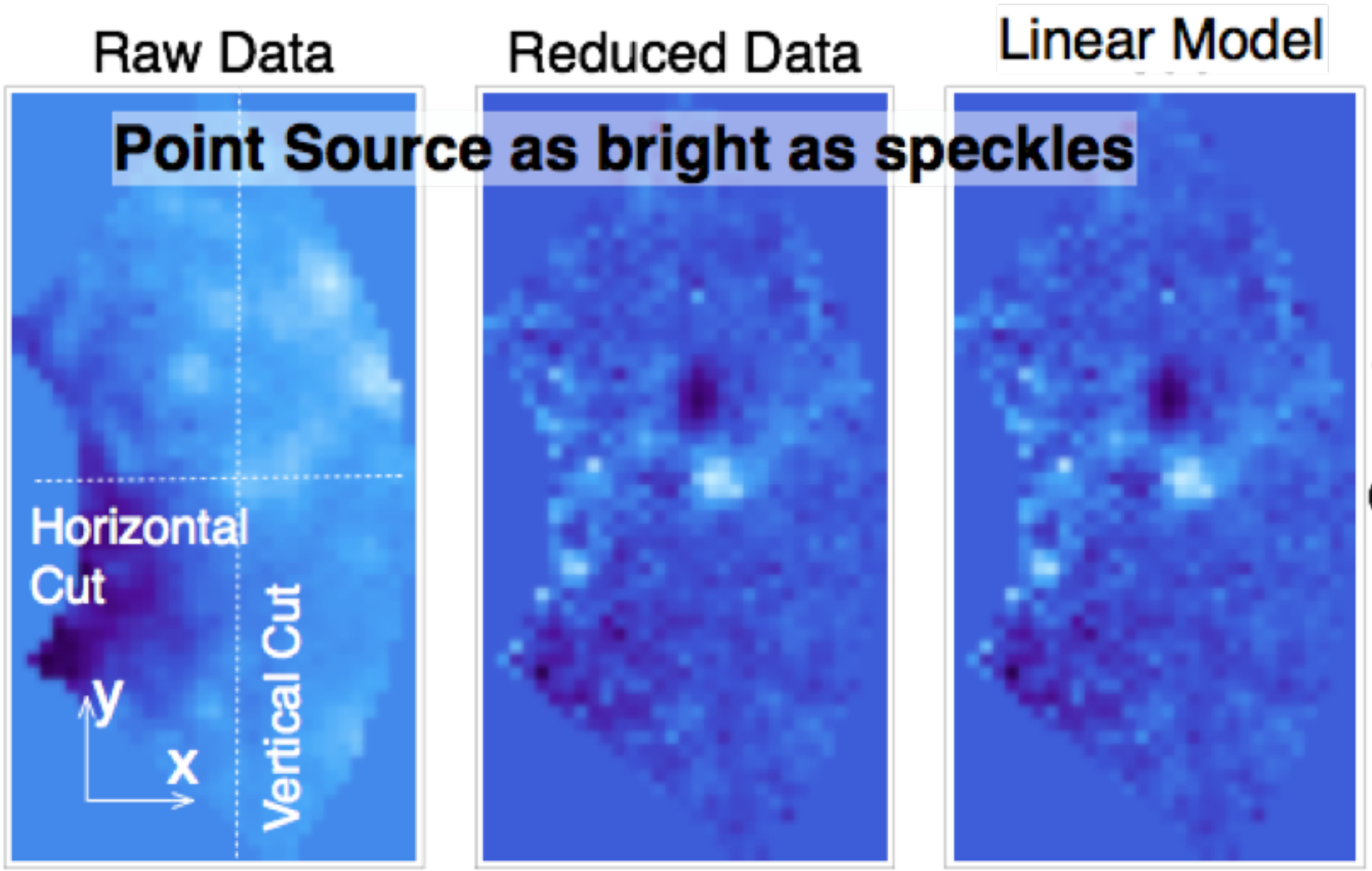


Courtesy of
P. Ingraham





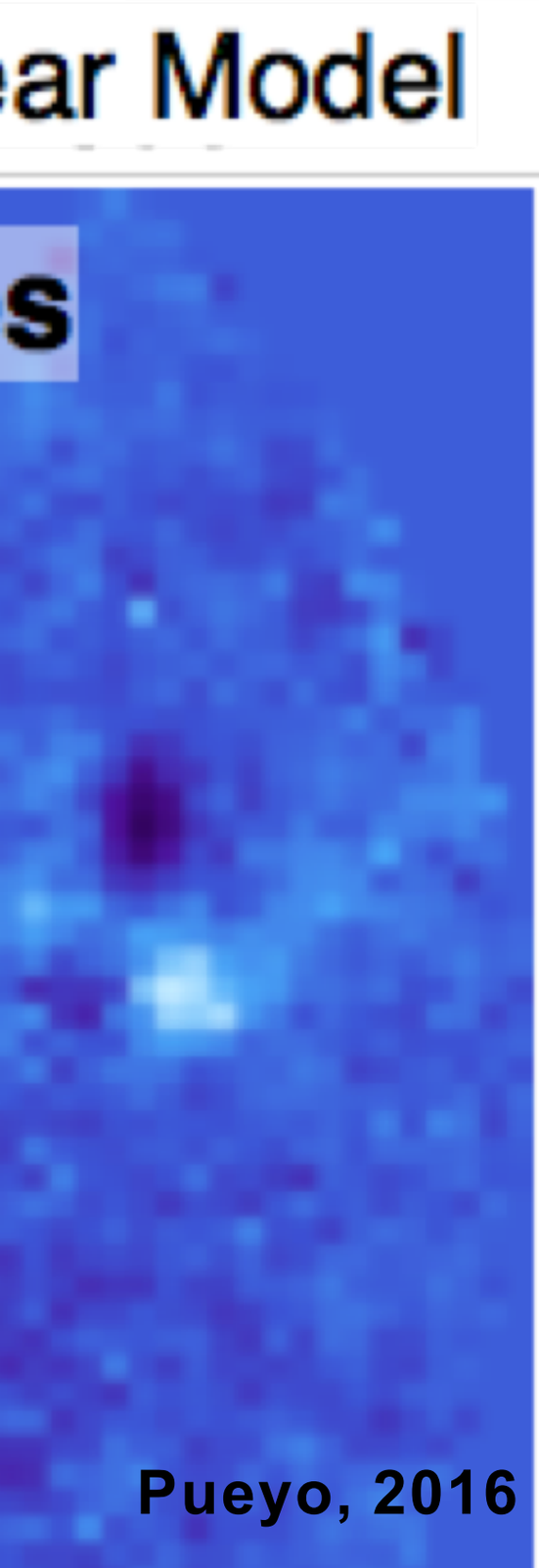
Challenges of data analysis with GPI

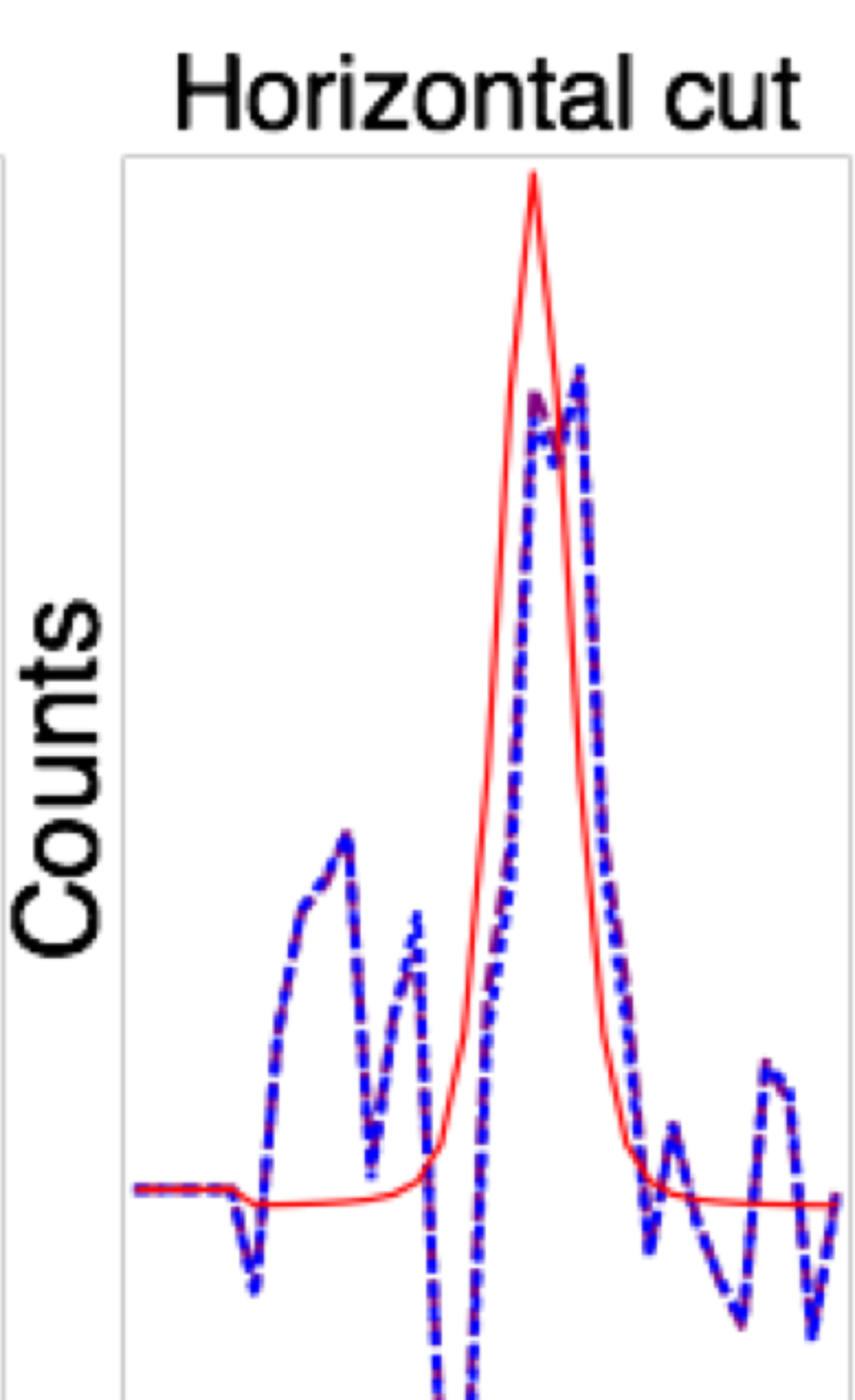


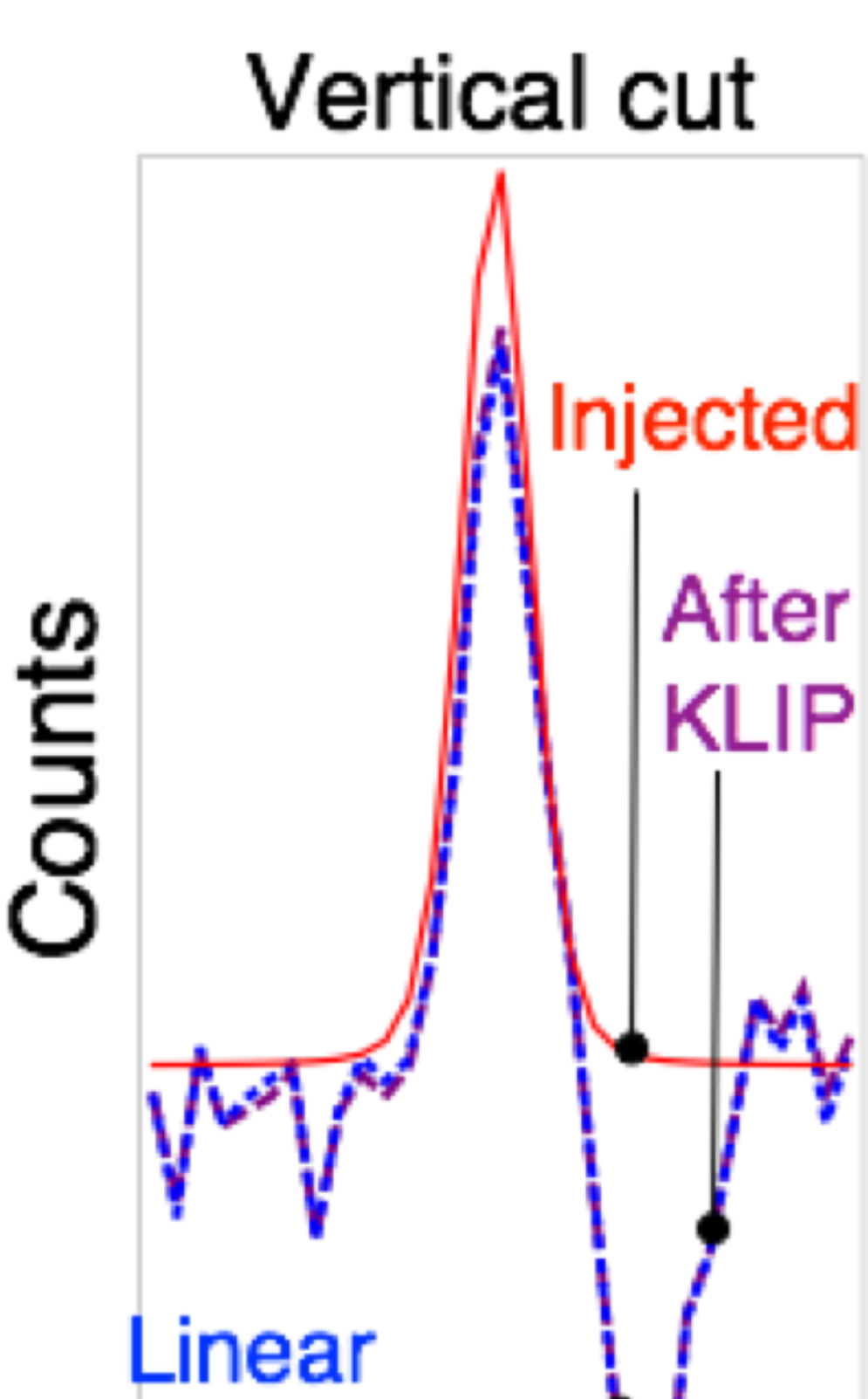
Non aggressive reduction: $\mathbf{N_r = 5,\ N_\phi = 4,\ N_{Corr} = 30,\ K}$

Pueyo, 2016

Challenges of data analysis with GPI

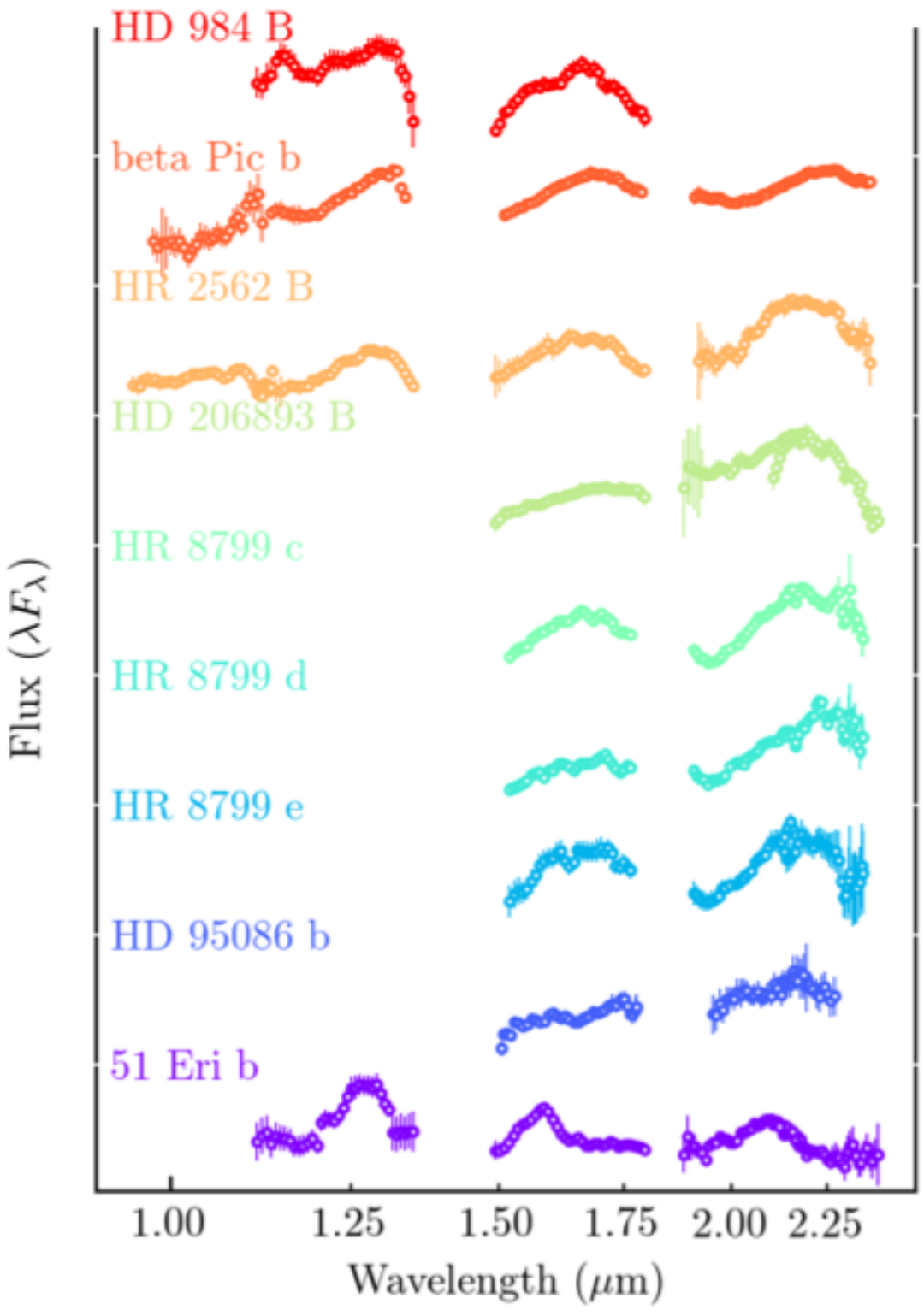


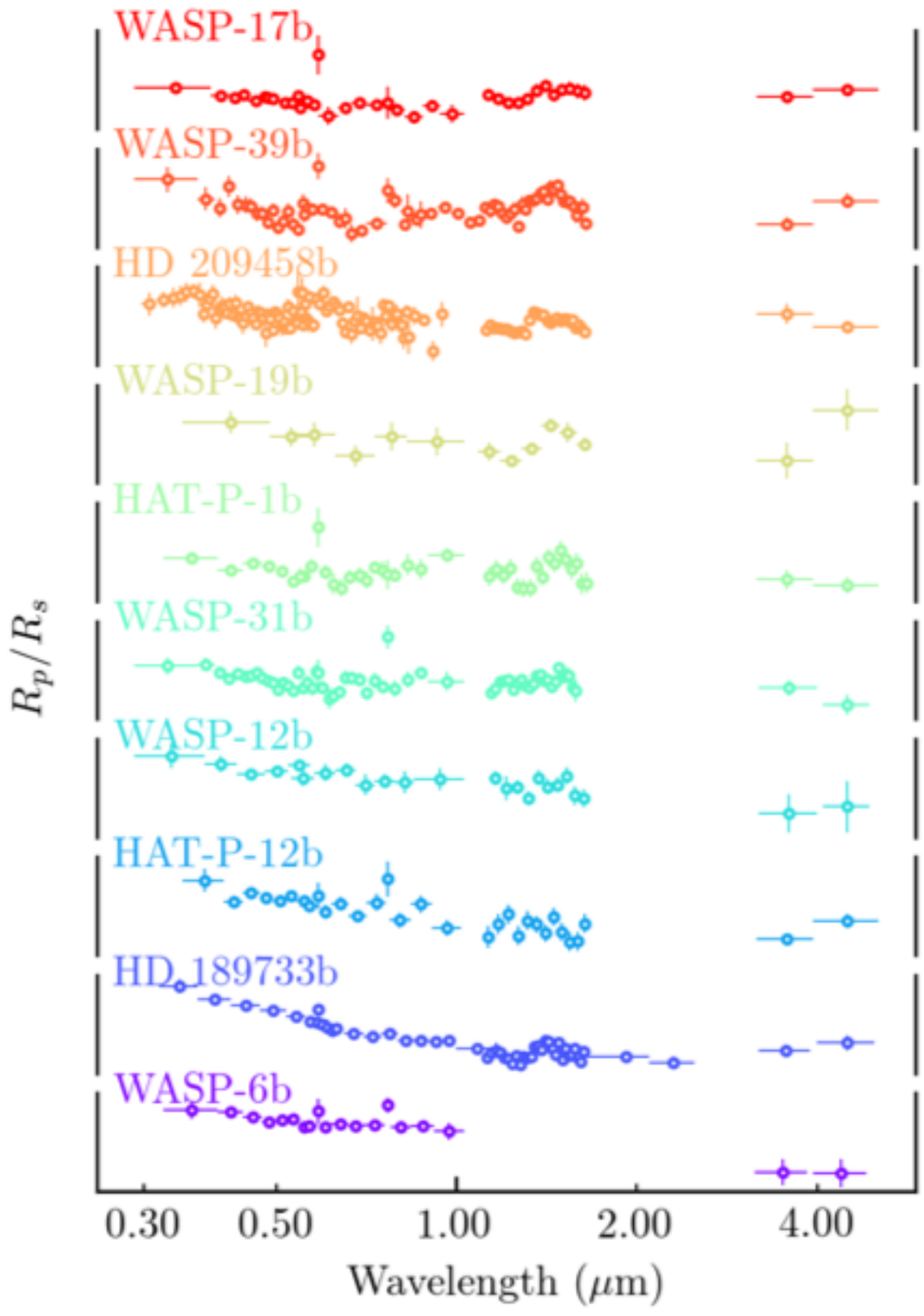




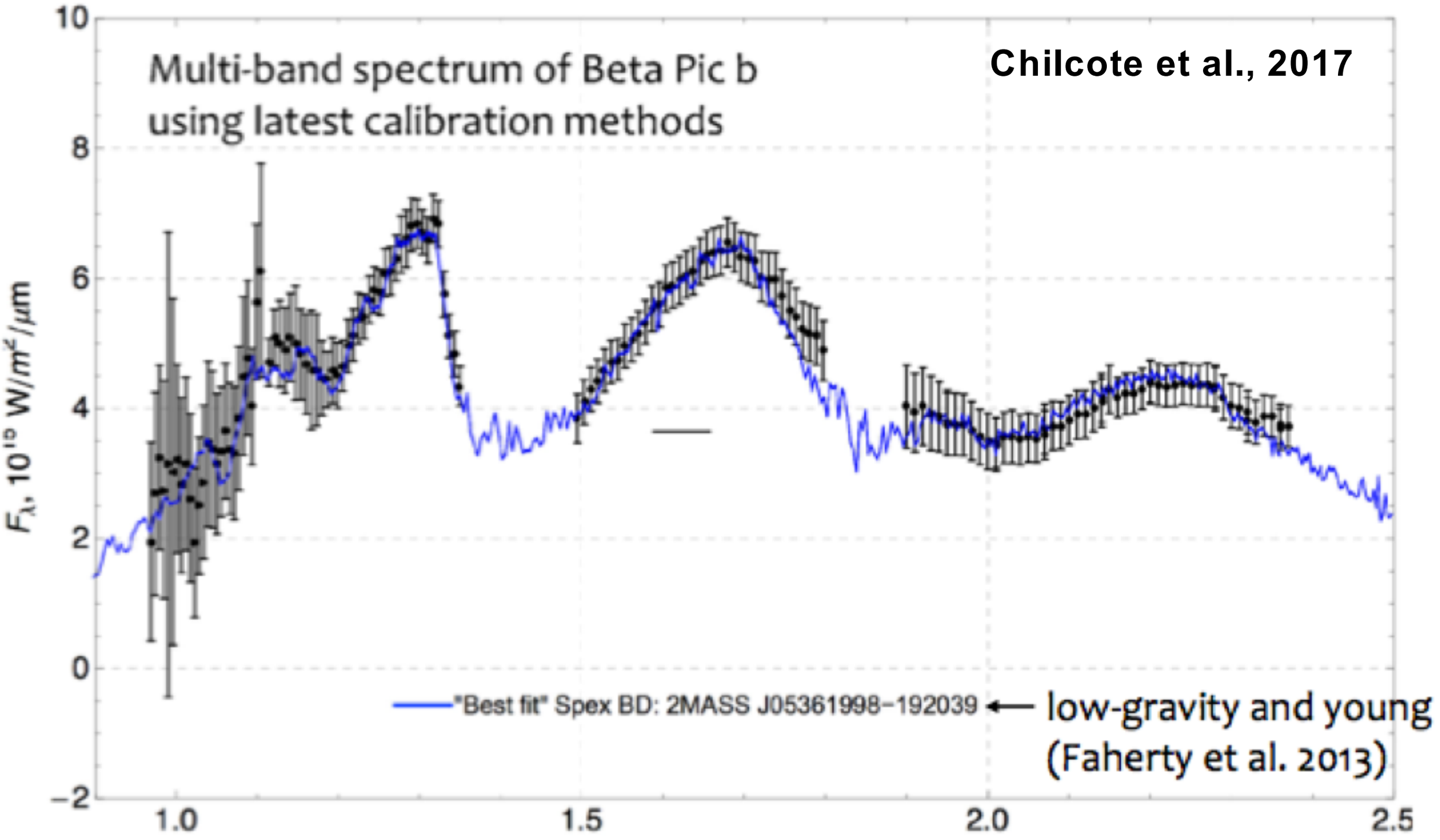
GPIES spectroscopy

Courtesy of R. De Rosa, J. Rameau





GPI spectroscopy of Beta Pictoris b



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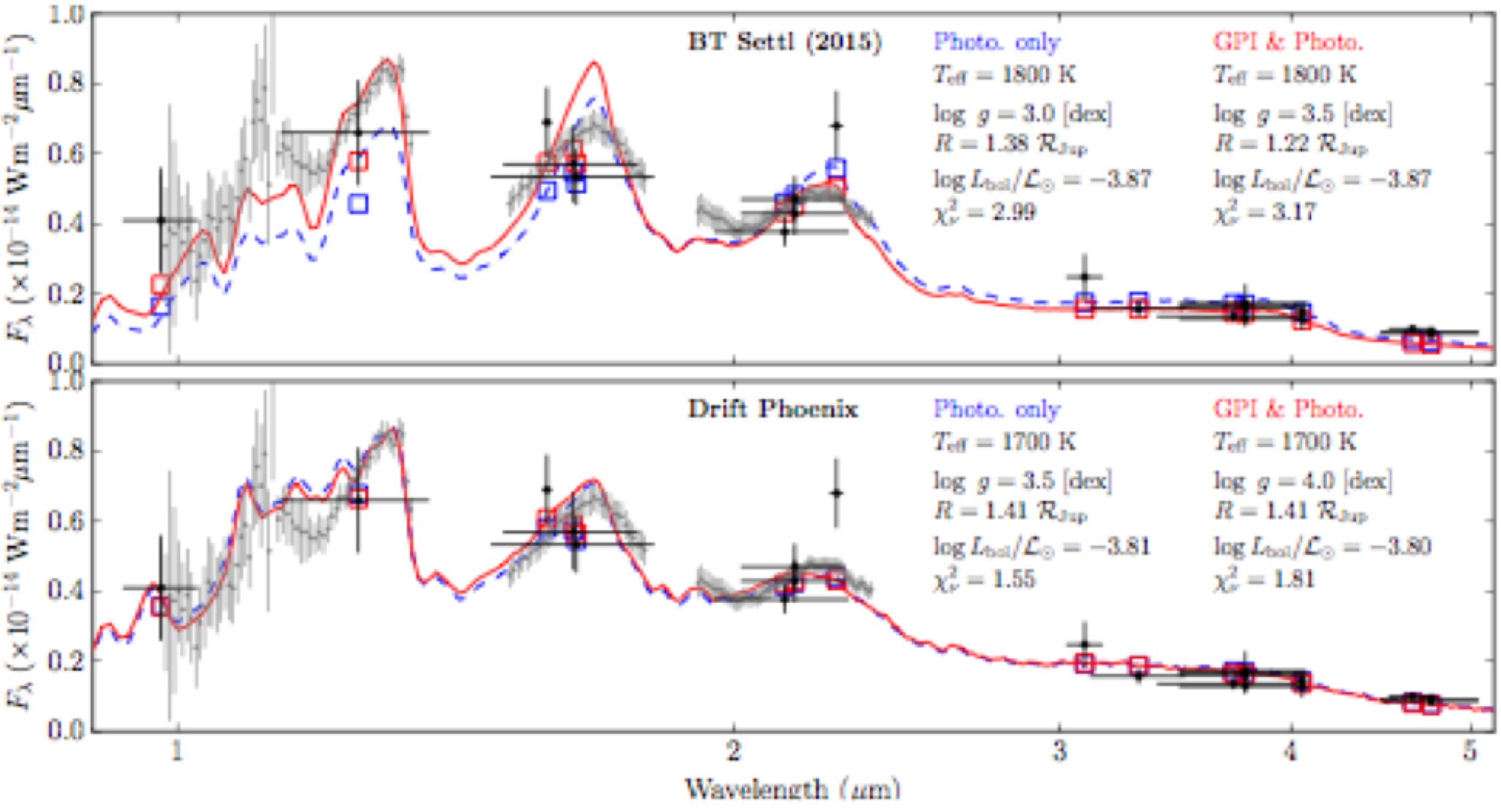
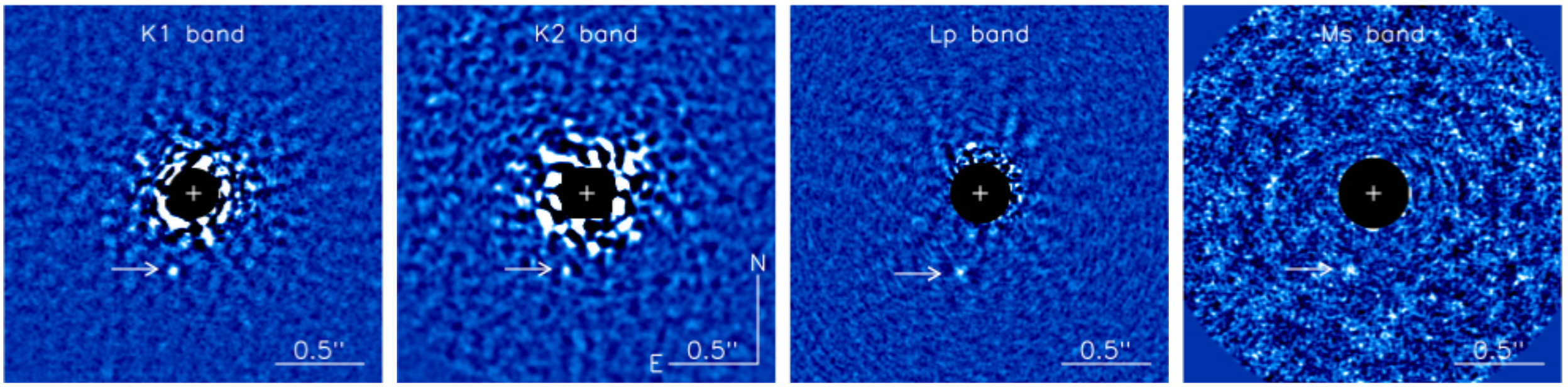


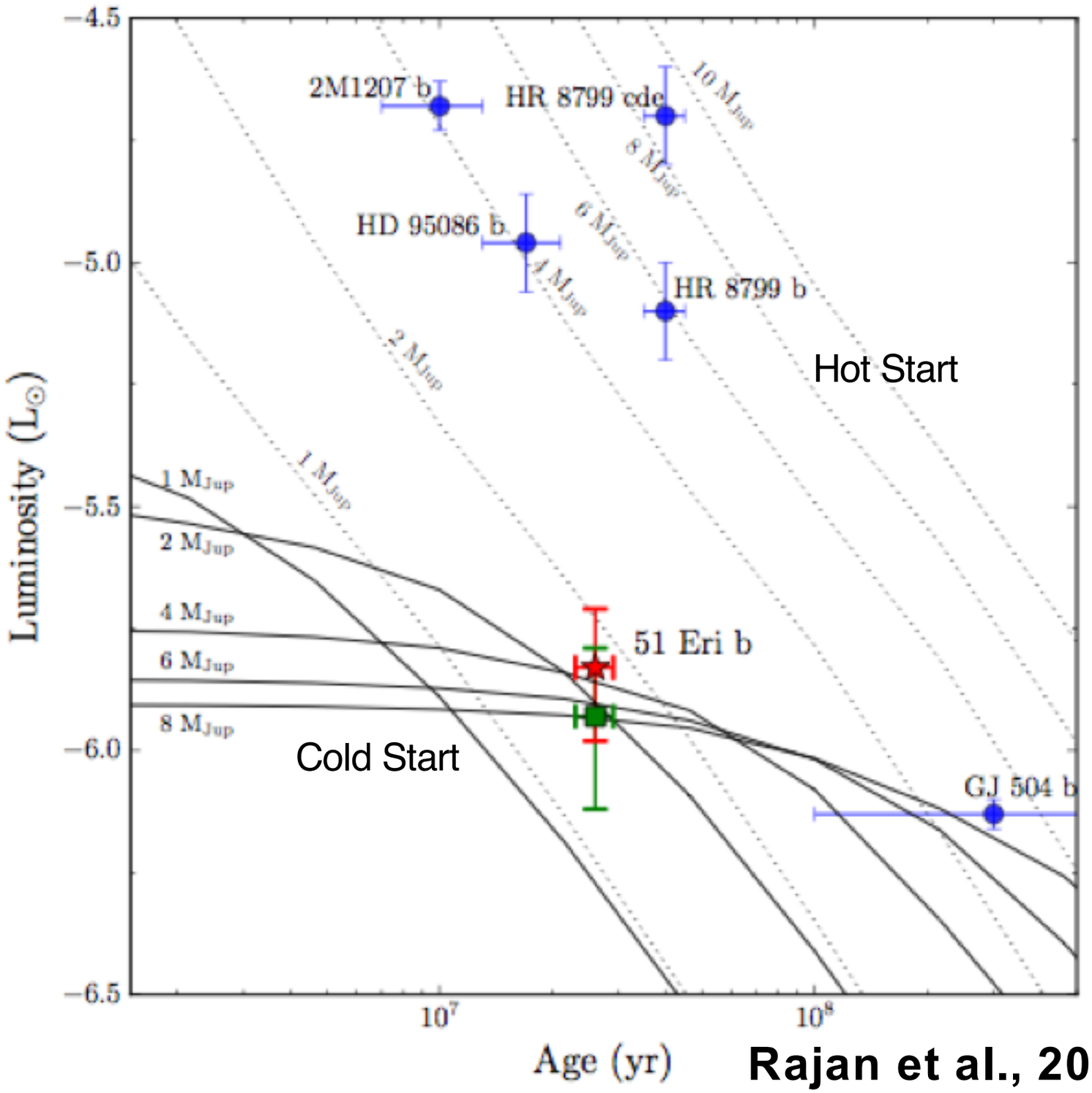
51 Eridani b

- First planet detected by the GPIES survey in Dec 2014 (Macintosh et al. 2015).
- Discovery paper used a combination of GPI J+H spectra and Keck-Lp photometry to characterize the planet.
- Rajan et al. obtained new GPI K1+K2 spectra, a second epoch of Keck Lp data as well as a detection in the Ms band.



Rajan et al., 2017

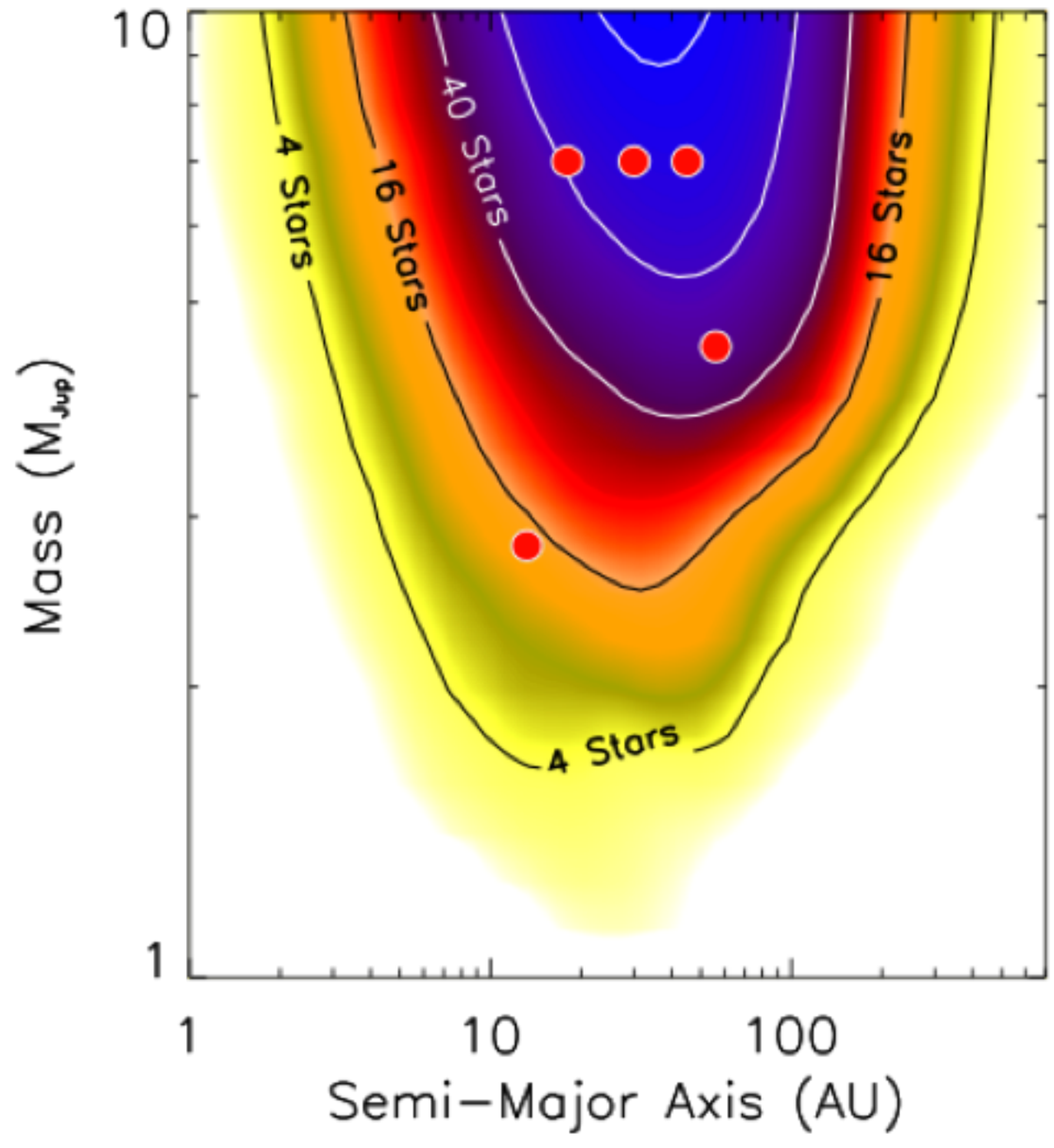
51 Eridani b: Hot or Cold Start?

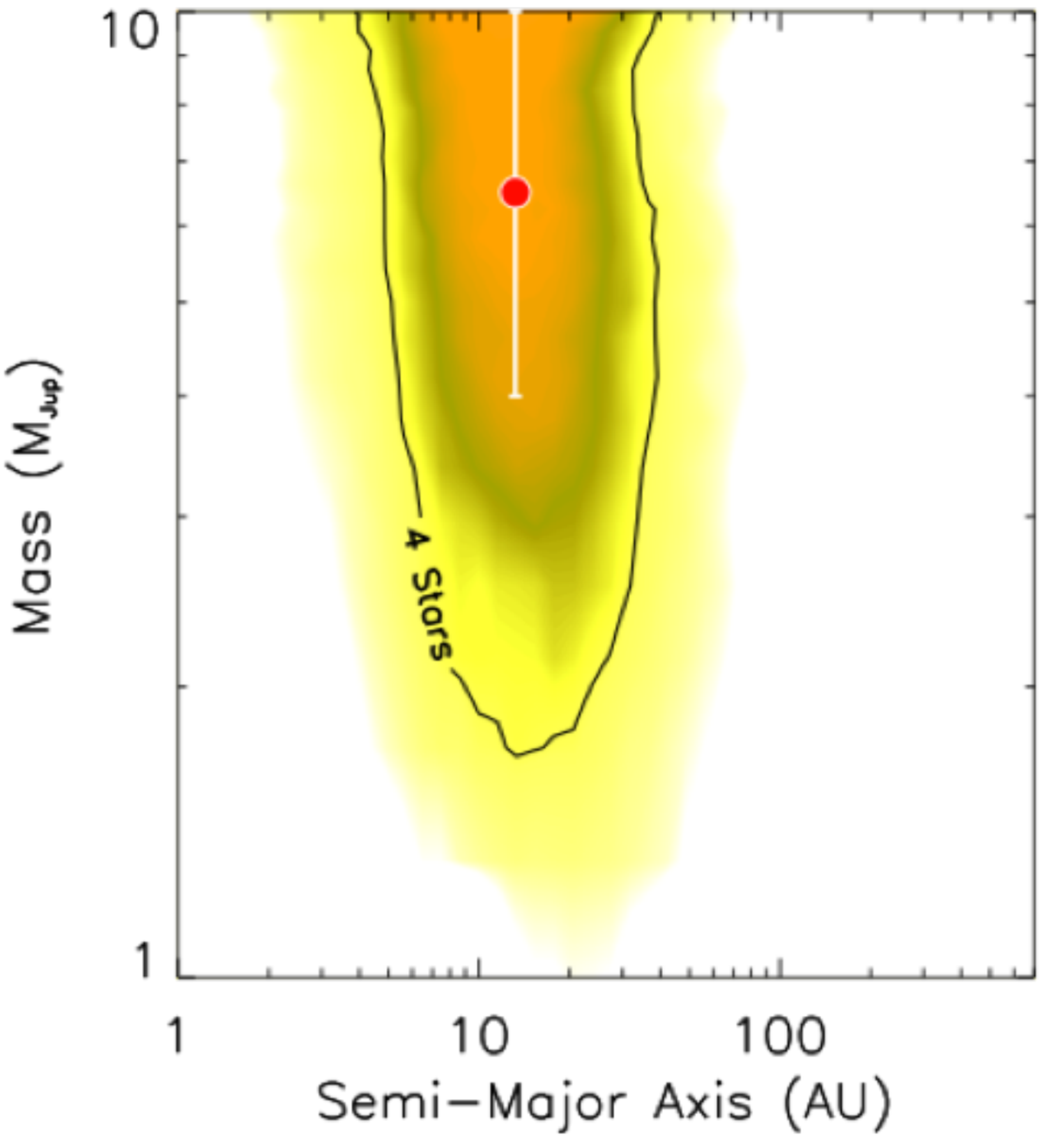


Rajan et al., 2017

51 Eridani b: Hot or Cold Start?

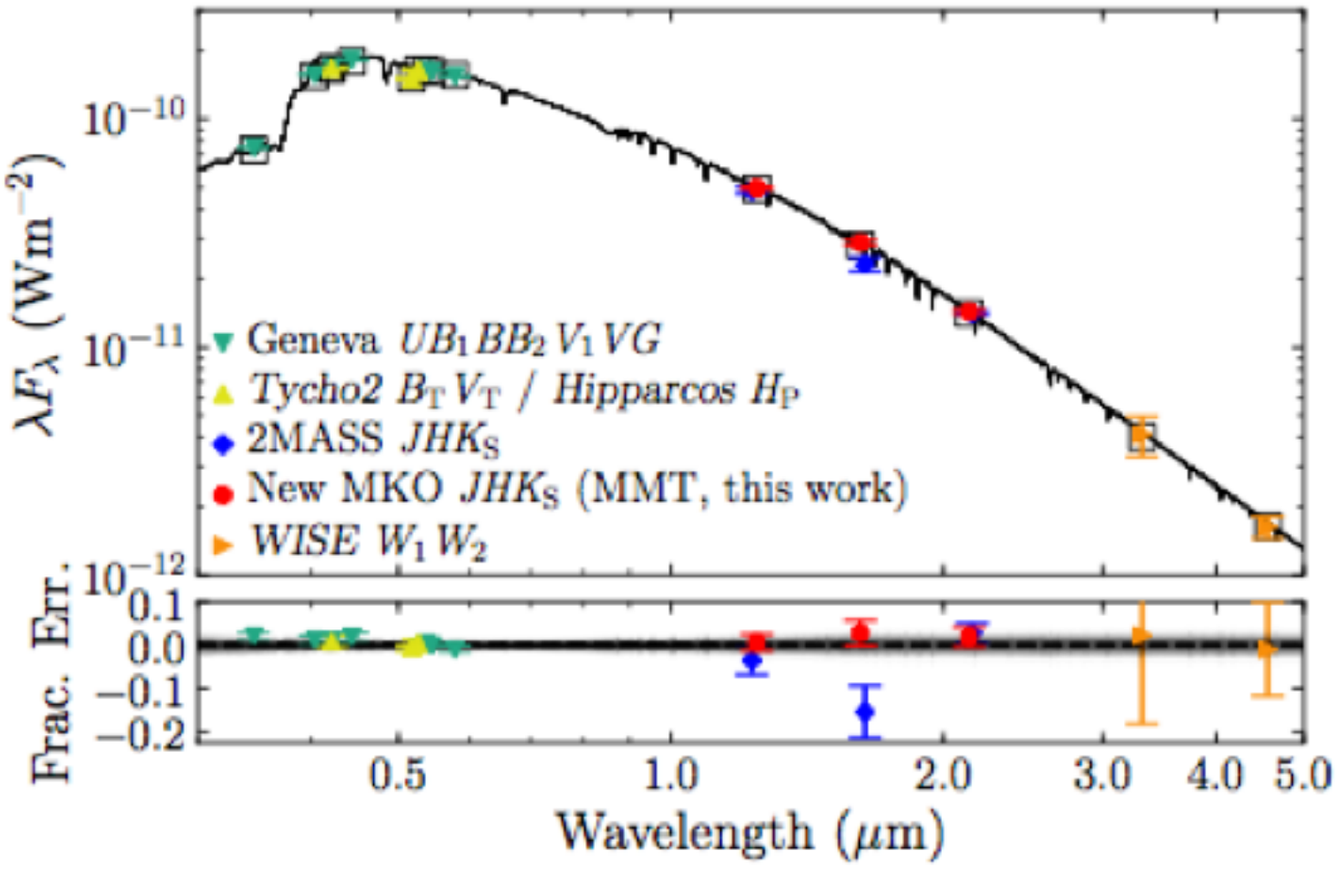
Courtesy of E. Nielsen





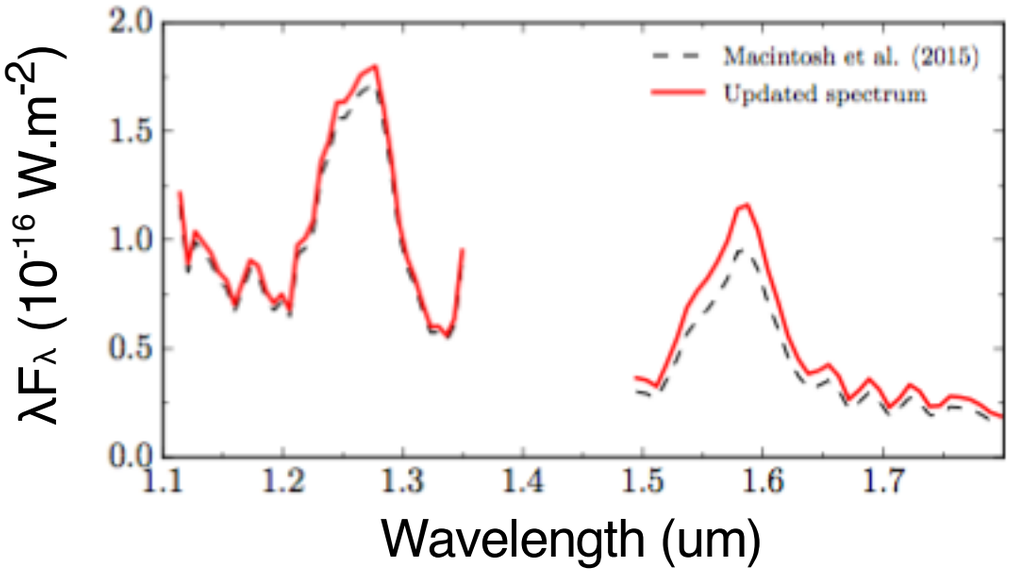
51 Eridani A: Revising the Photometry

- 2MASS J and H photometry for the star is flagged as having poor quality.
- We measured the stellar photometry in J, H and Ks (MKO) with the 6.5m MMT.



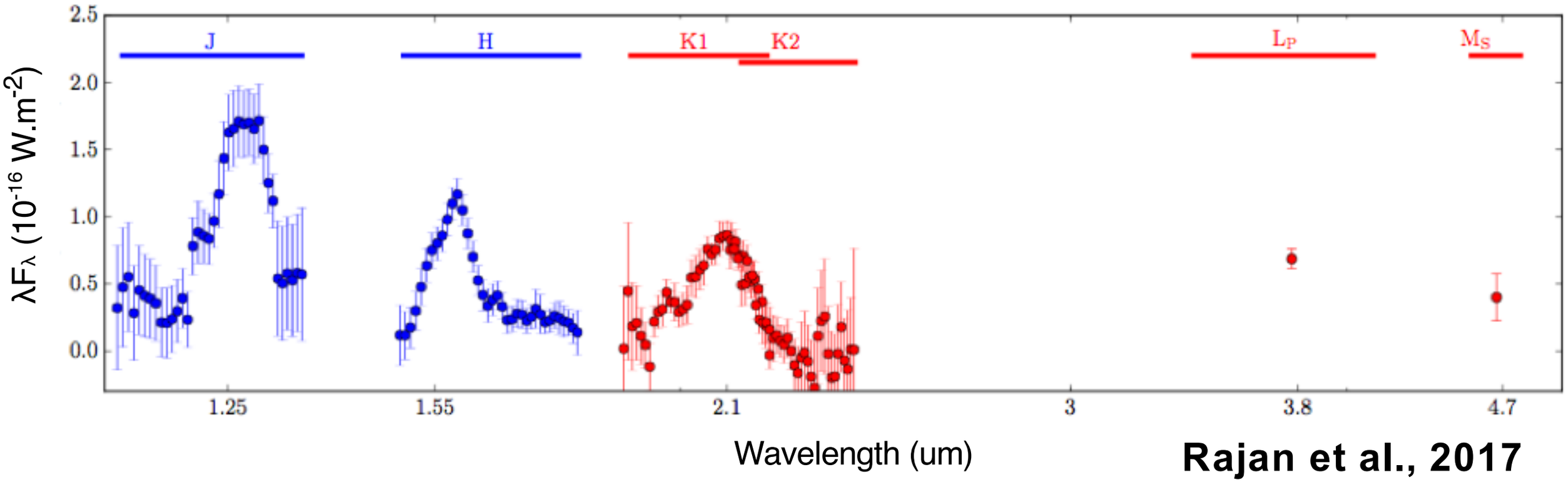
Band	51 Eri Original (mag)	51 Eri revised (MKO) (mag)
J	4.744 ± 0.037	4.690 ± 0.020
H	4.77 ± 0.076	4.562 ± 0.031
Ks	4.537 ± 0.024	4.546 ± 0.024
Lp	4.54 ± 0.21	4.604 ± 0.014
Ms	—-	4.602 ± 0.014

Rajan et al., 2017



51 Eridani b: Spectrophotometry

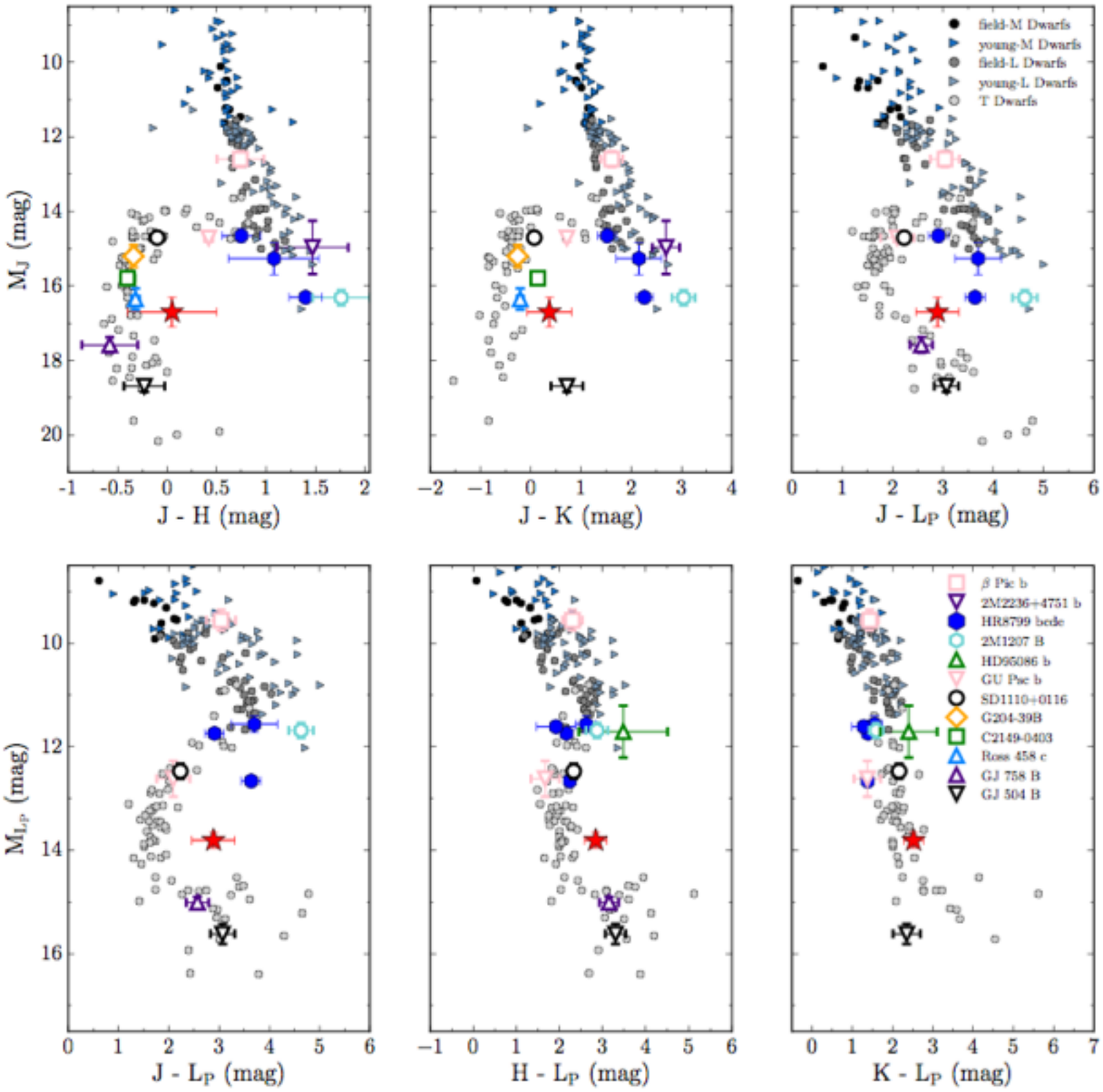
- Multiple K1 sequences were obtained in Nov 2015, and Jan 2016.
- A single 2hr K2 sequence was observed in Dec 2015.
- Both datasets were analyzed using multiple reduction pipelines, including pyKLIP, TLOCI, cADI.
- New Keck Lp and Ms data were taken over multiple epochs.



Rajan et al., 2017

51 Eridani b: Color Magnitude Diagram

Rajan et al., 2017



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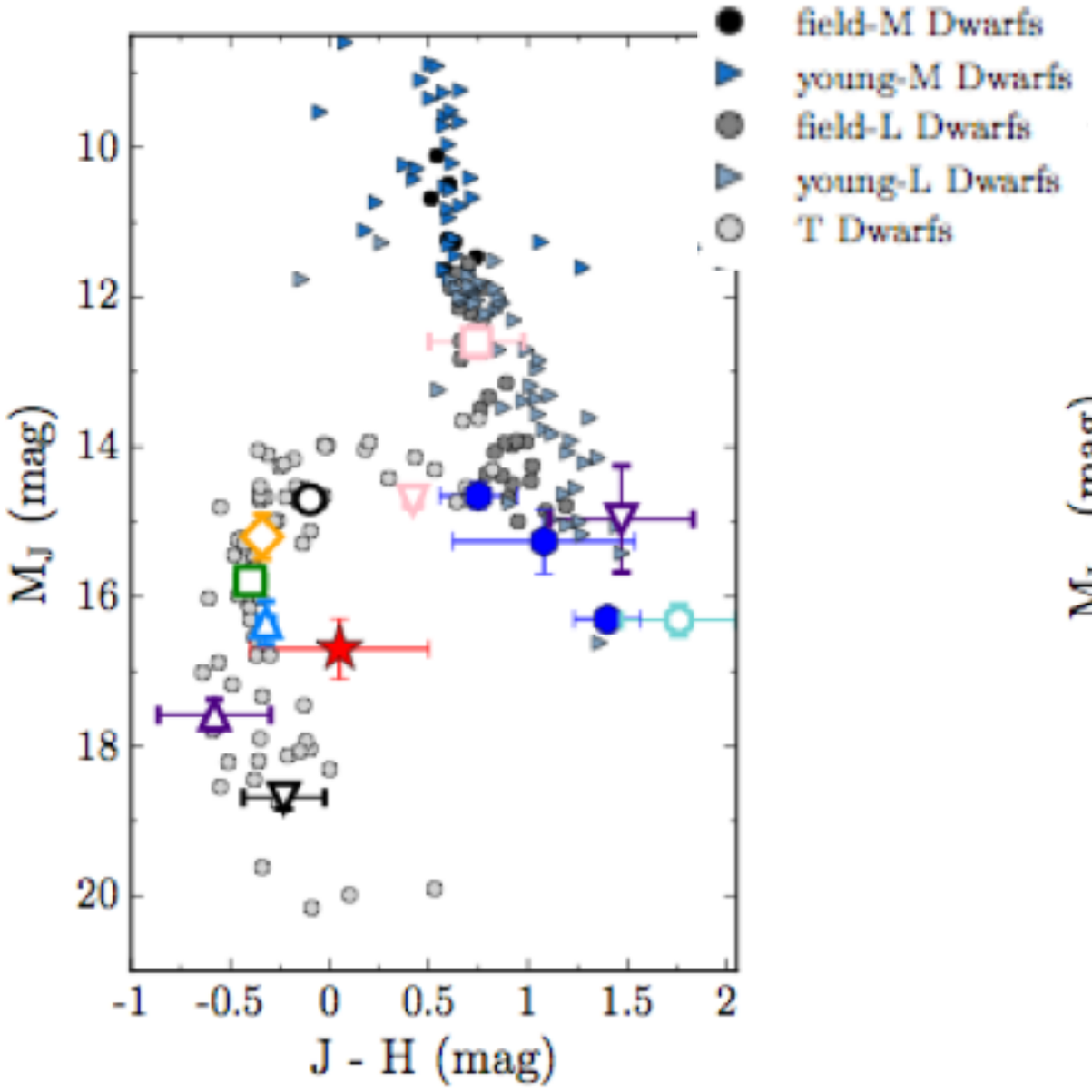

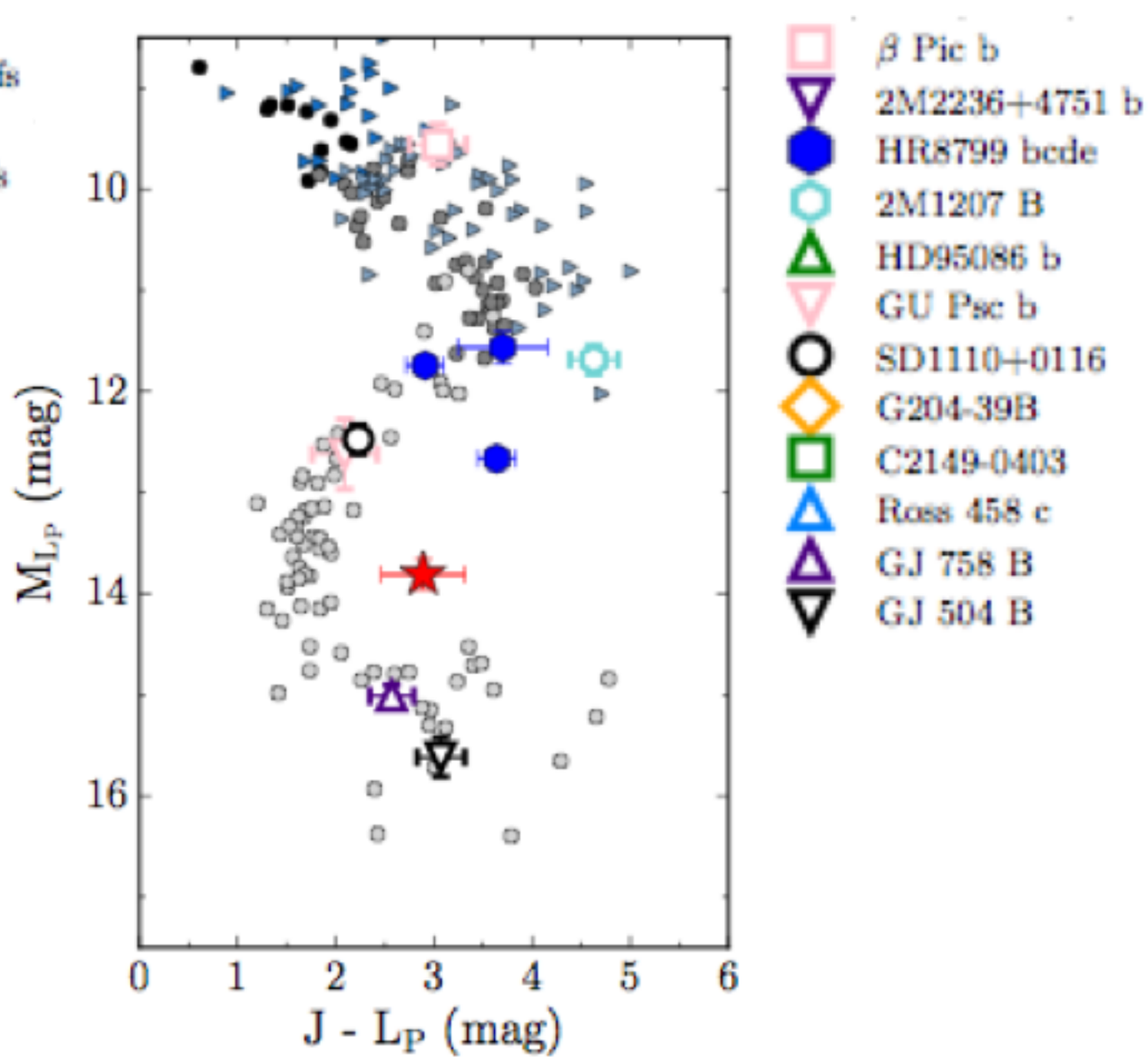

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51 Eridani b: Comparison to BDs

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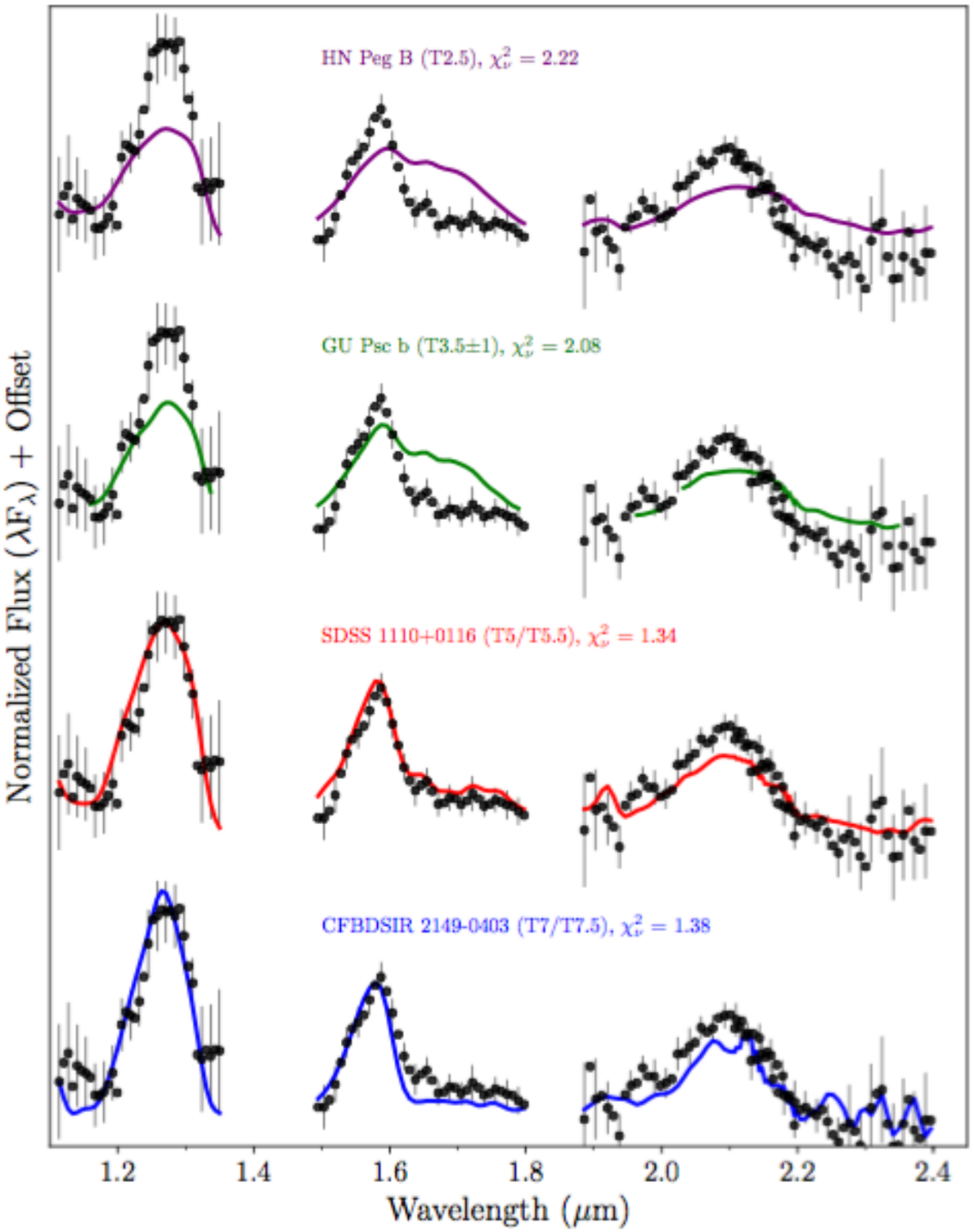
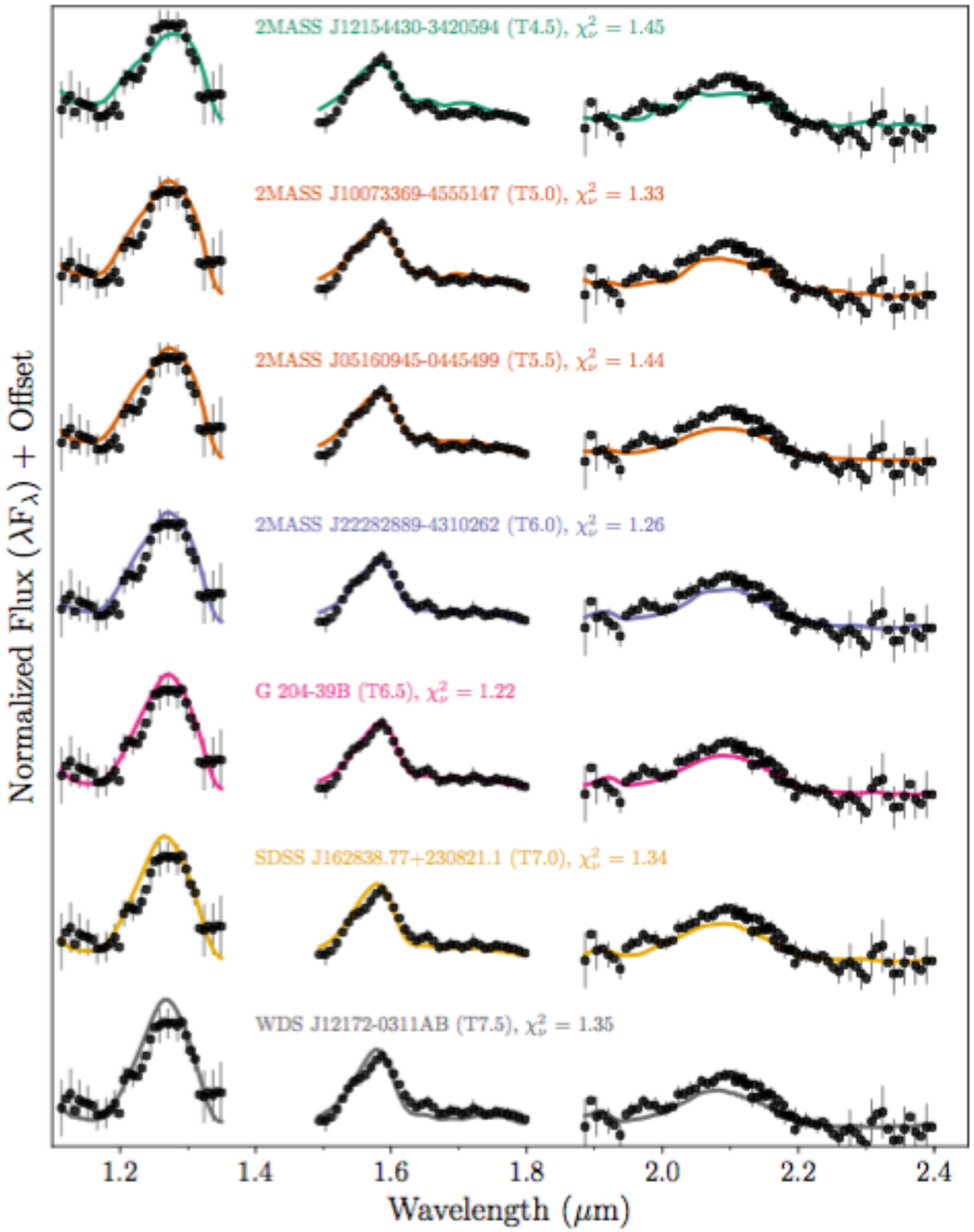
Young BDs

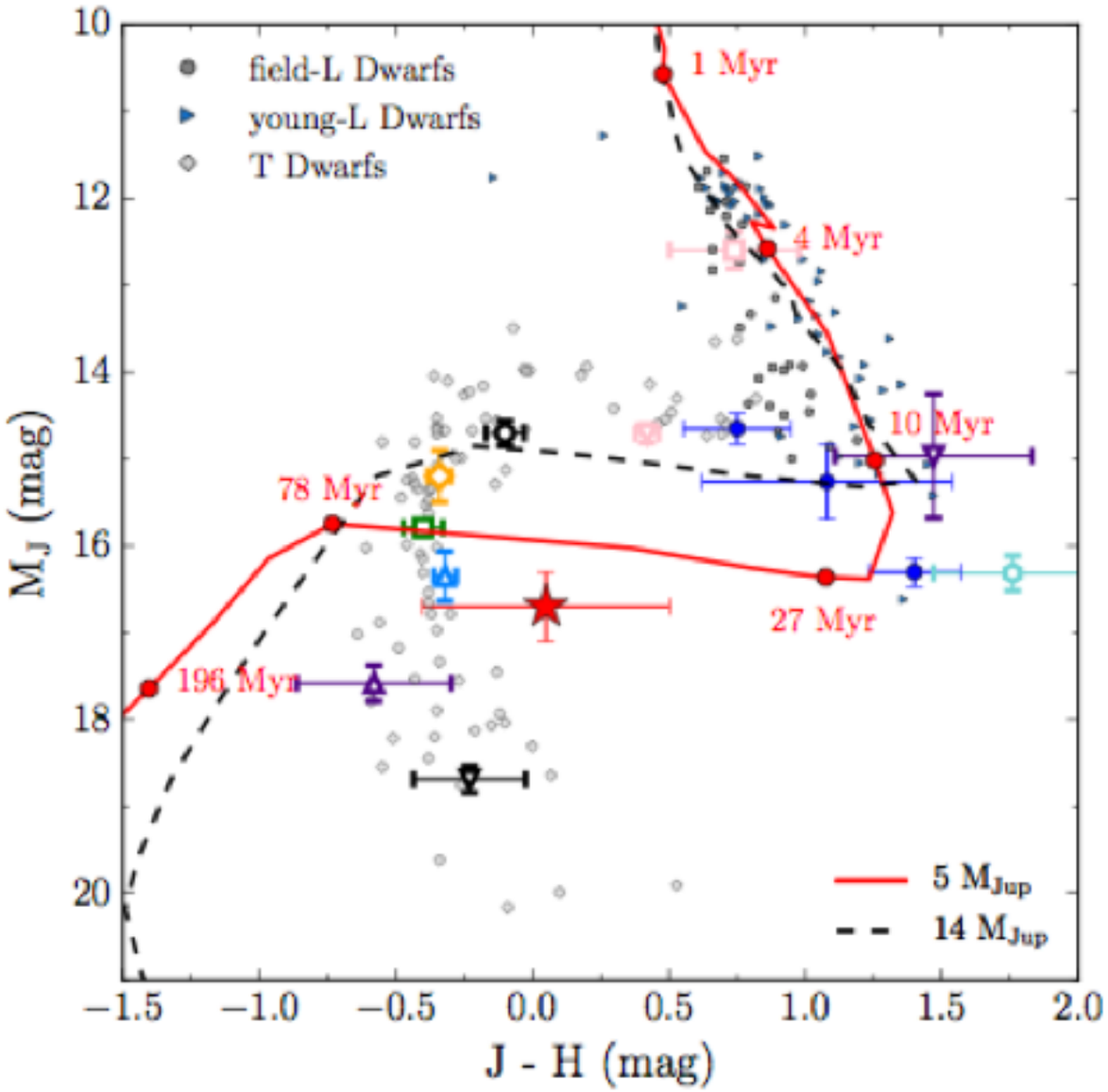


Field BDs



51 Eridani b: A red T-type or an L-T transition planet?

- 51 Eri b is redder than the field brown dwarf sample.
- Could be due to the presence of greater cloud opacity in the atmosphere?
- Or, the planet could be transitioning from the L to T sequence.
- If true, this would make the planet an ideal target for variability studies.



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51 Eridani b: Modeling the Atmosphere

- To model the atmosphere, we used three grids from Mark Marley, Caroline Morley and Didier Saumon.

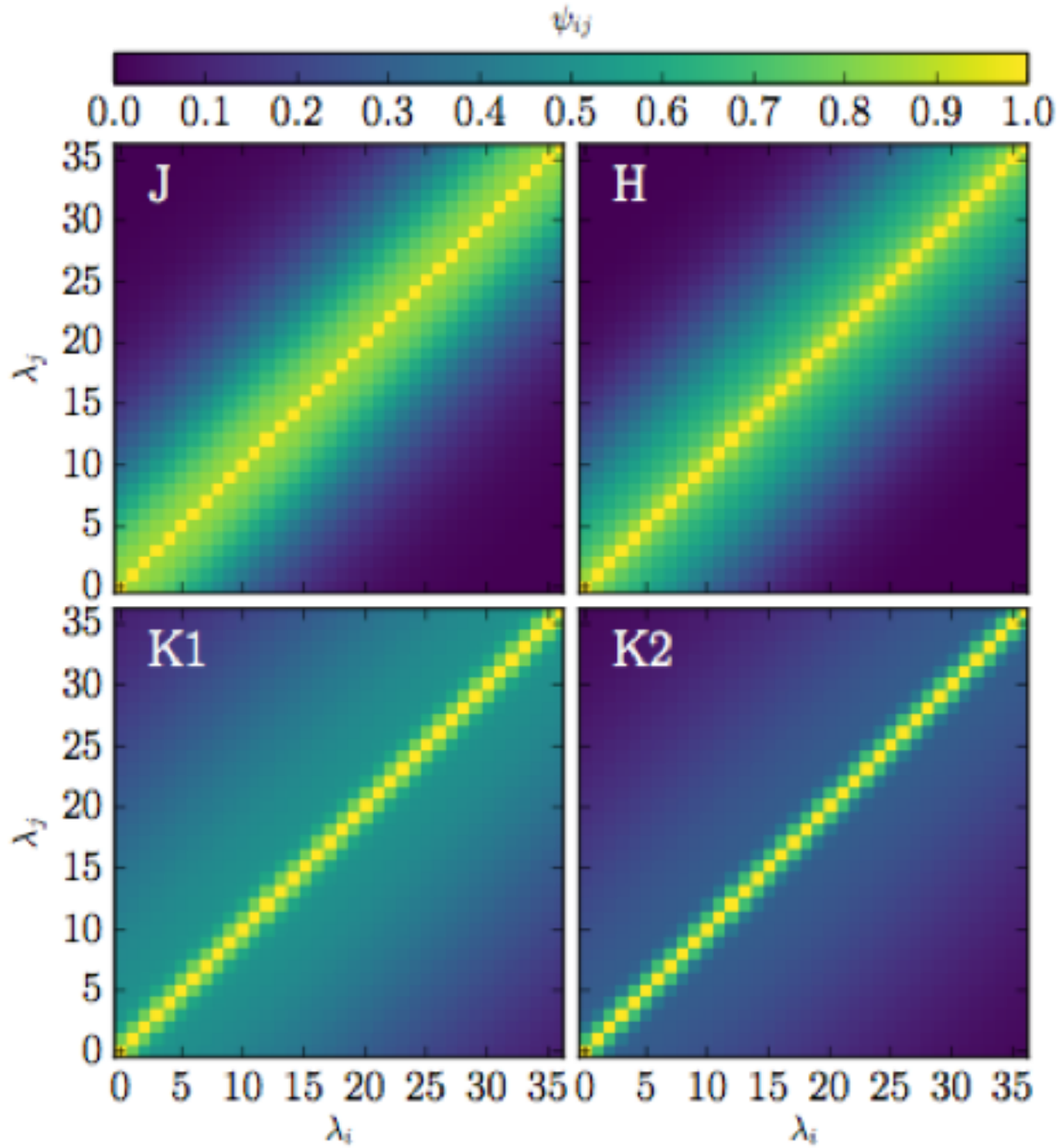
Model Name	Effective Temperature (K)	Surface Gravity ($\log g$)	Metallicity [M/H]	Cloud Parameter (f_{sed})	Cloud Hole Fraction (%)
Iron/Silicate Cloud Grid	600–1000	3.25	0.0	2	0–75
Sulfide/Salt Cloud Grid	450–900	3.5–5.0	0.0, 0.5, 1.0	1, 2, 3, 5	–
Cloudless Grid	450–900	3.5–5.0	0.0, 0.5, 1.0	no cloud	–

- We also estimated the covariance from the final spectral cubes (*JHK1K2*), using the prescription given in Greco & Brandt 2016, in estimating the best fitting model.

Rajan et al., 2017

51 Eridani b: IFU spectra are correlated

- Correlations from the residual speckle noise in the final PSF-subtracted image as well as other data processing artifacts.
- Atmosphere modeling without properly accounting for these covariances will lead to biased results.
- We used the formalism from Greco & Brandt (2016) to estimate the spectral covariance and used it in all our analysis.



Rajan et al., 2017

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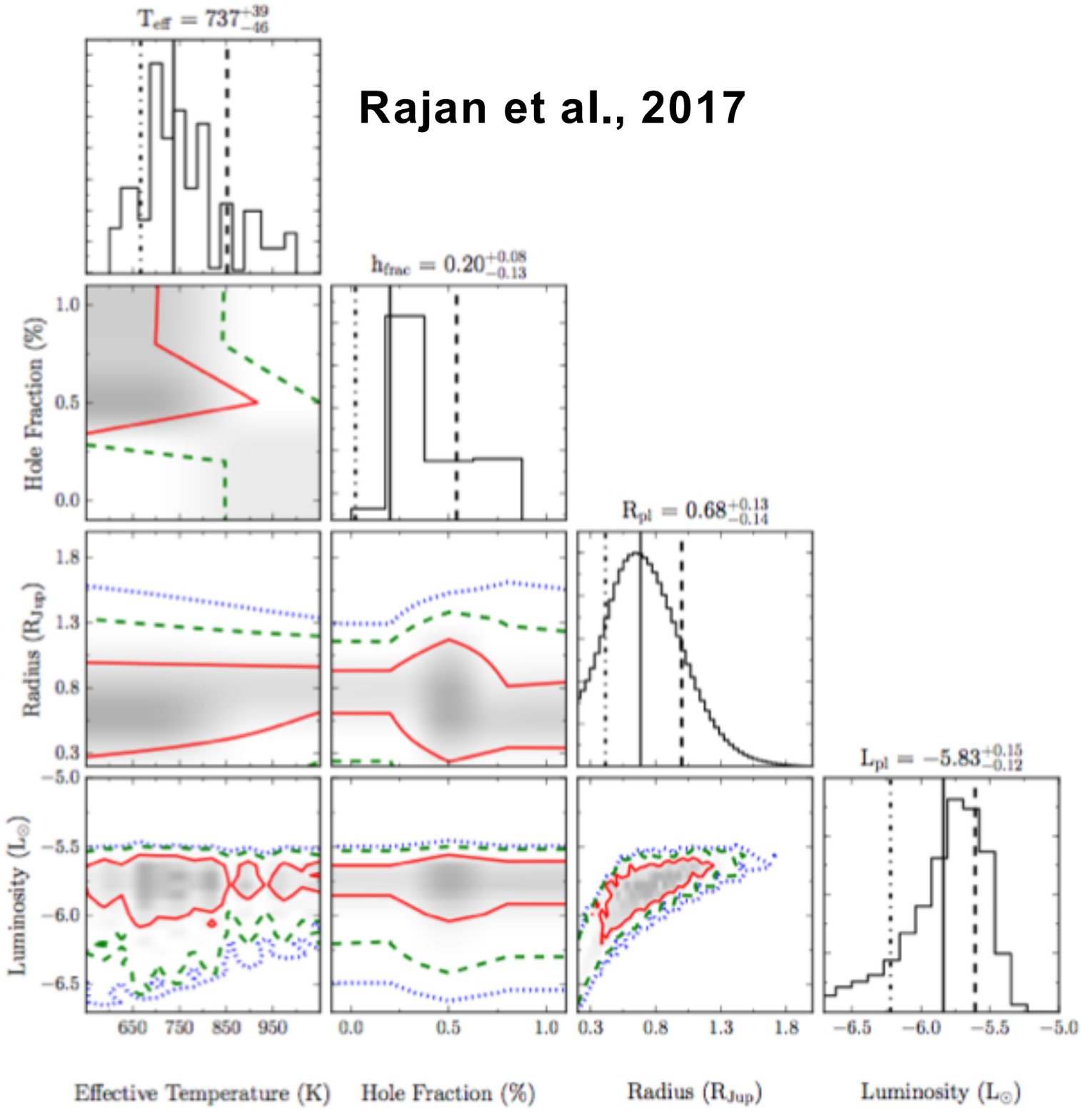

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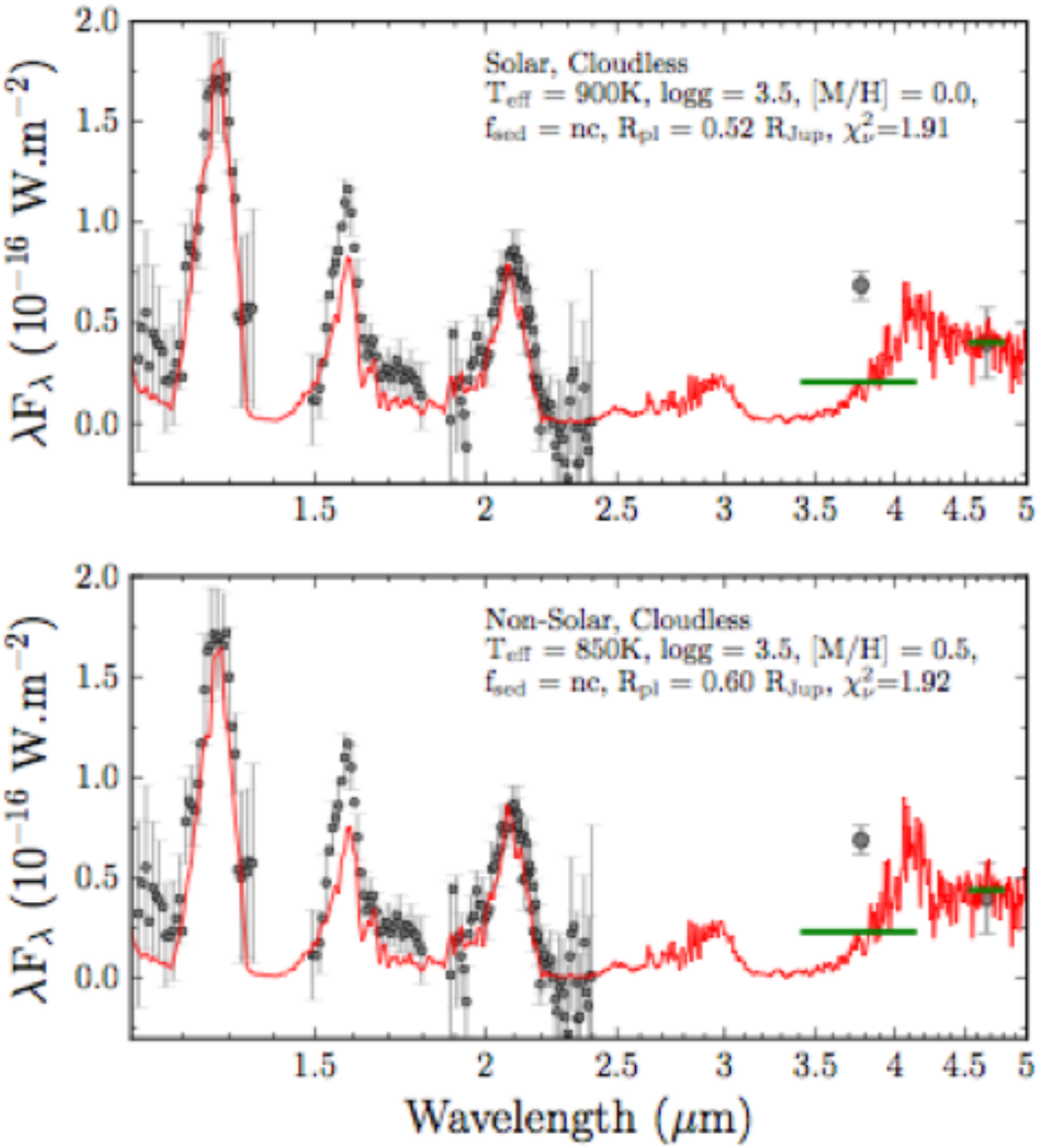

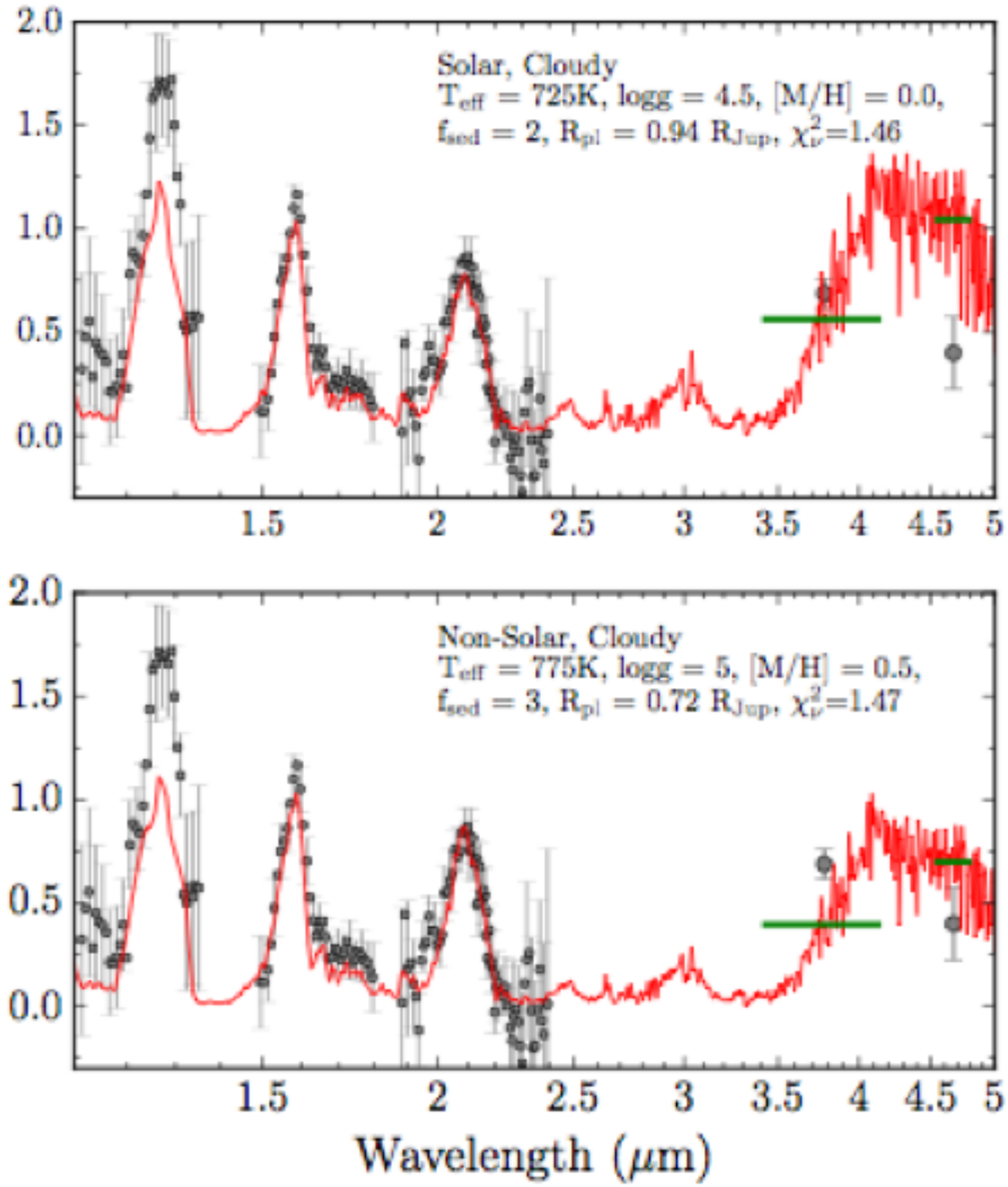

Rajan et al., 2017

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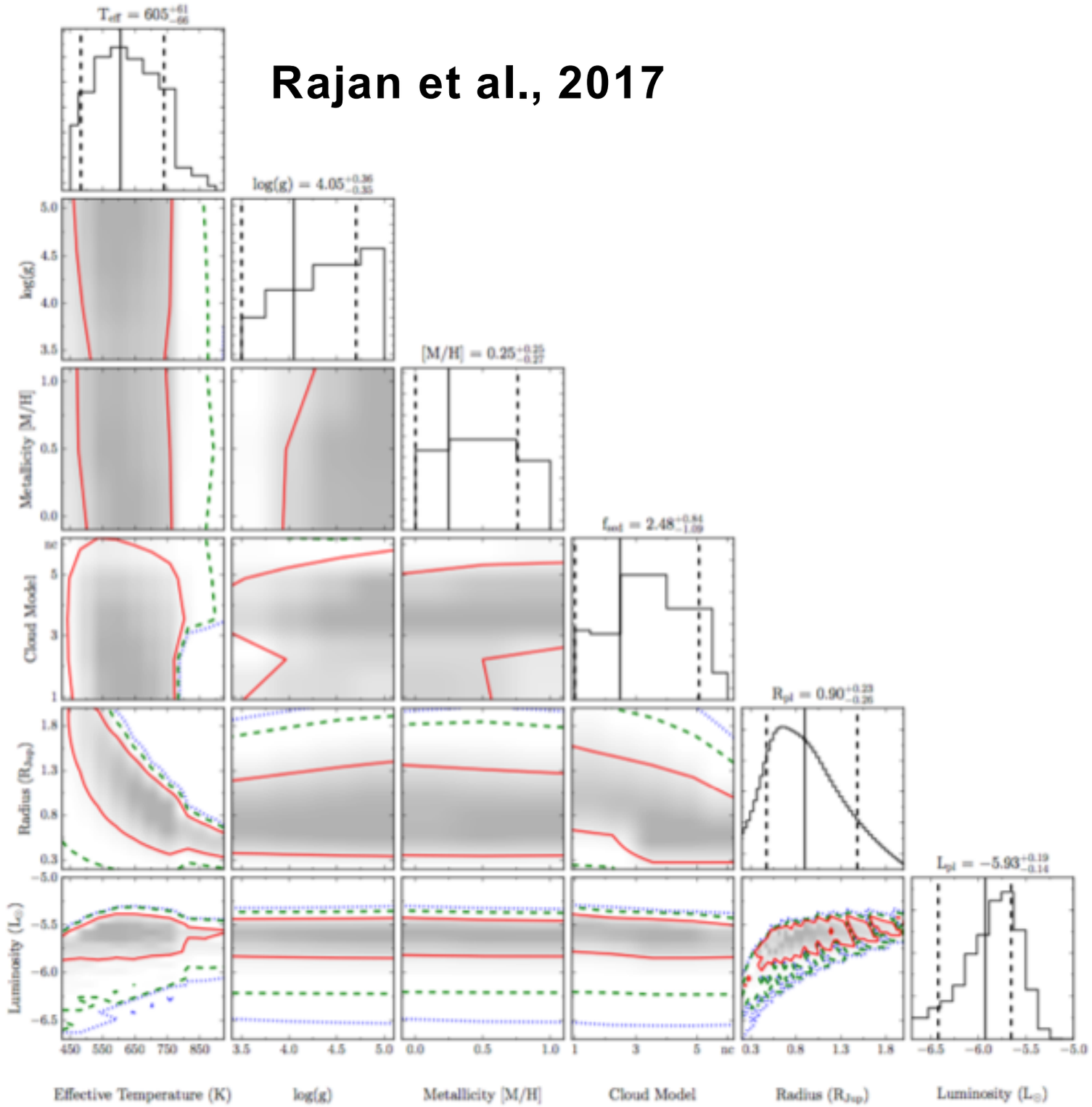


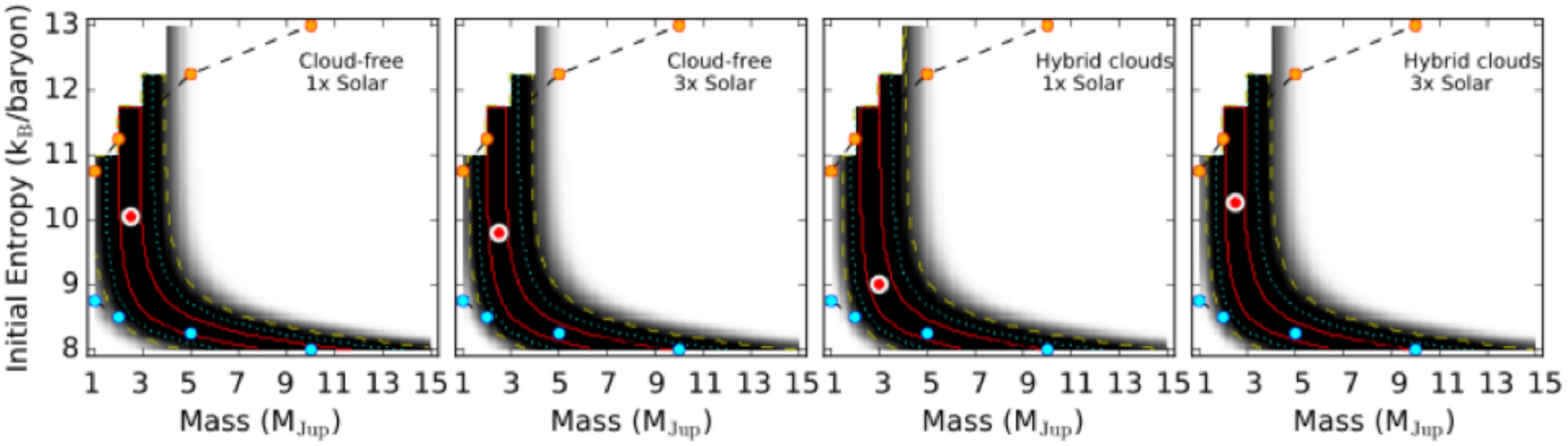
Rajan et al., 2017

51 Eridani b: Warm Start?

- Spiegel & Burrows (2012), proposed warm start models, that explored a wide range of initial entropies aimed at covering the possible range of parameters that govern the formation of planets.

- The models include cloudy and cloud-free, with both solar and super-solar metallicity.

Comparing model luminosities **Rajan et al., 2017**



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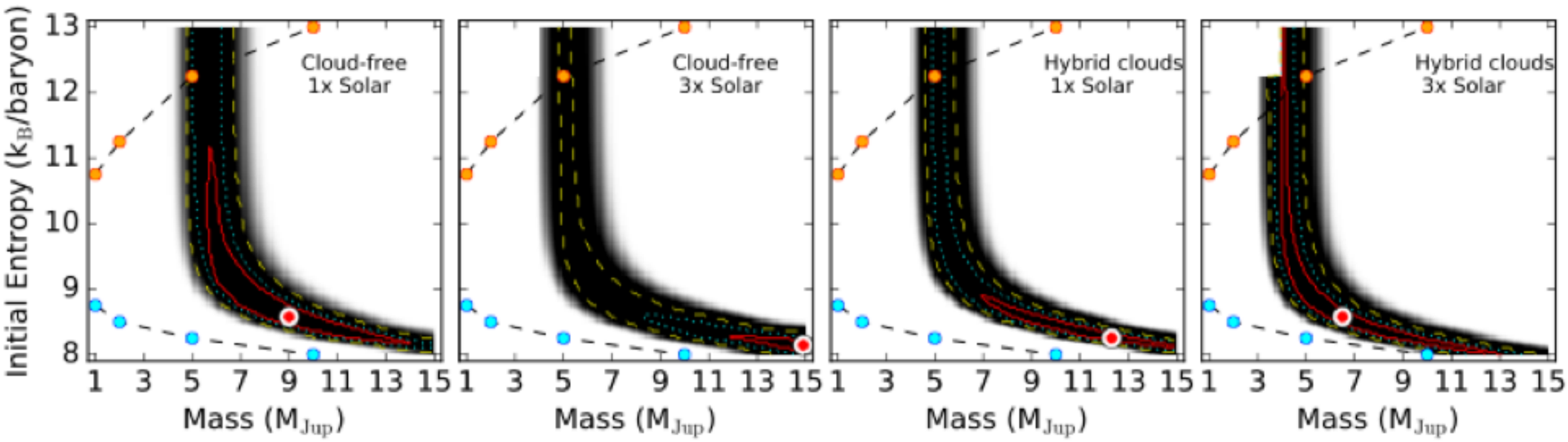
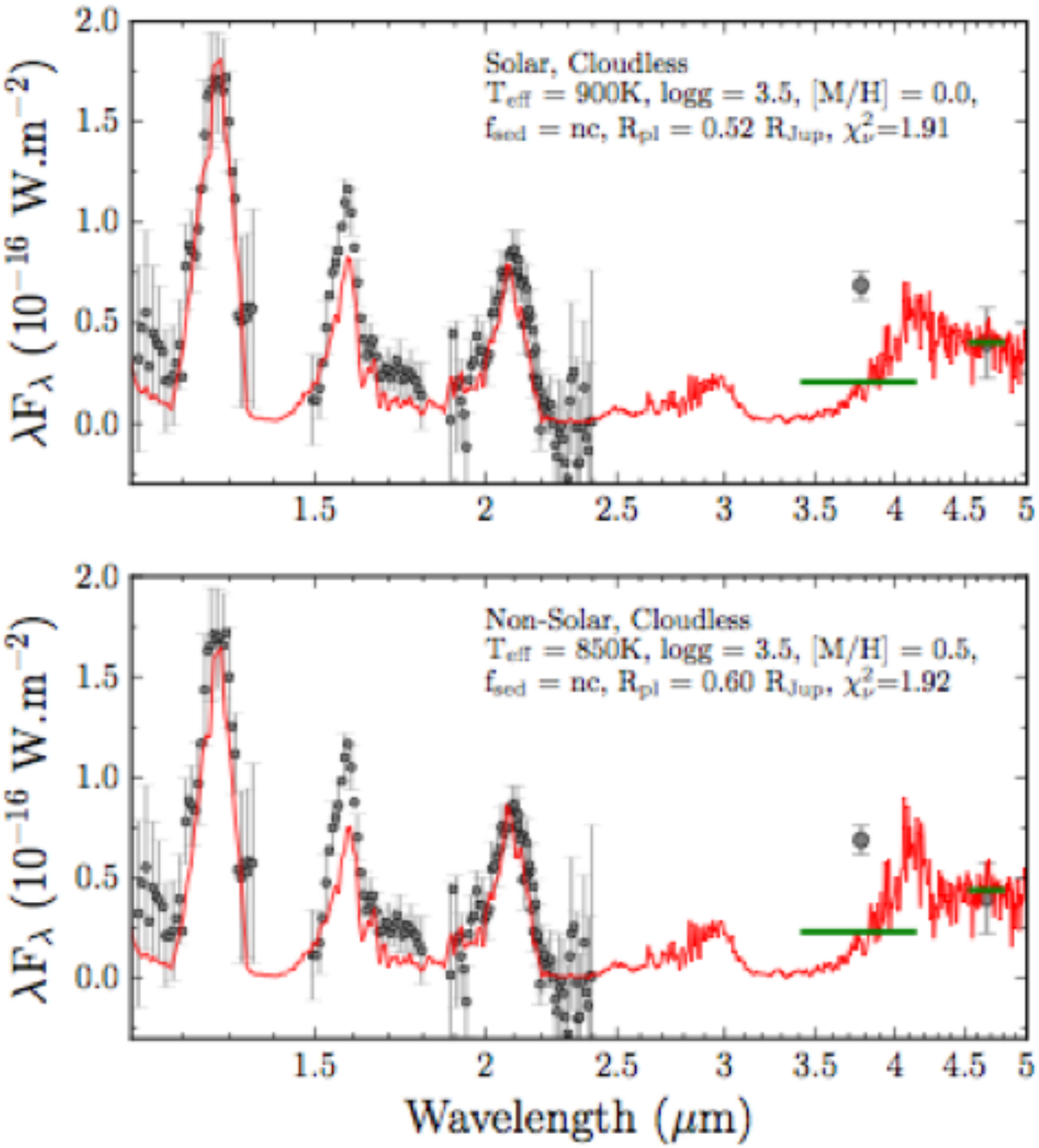
Comparing data and model **Rajan et al., 2017**

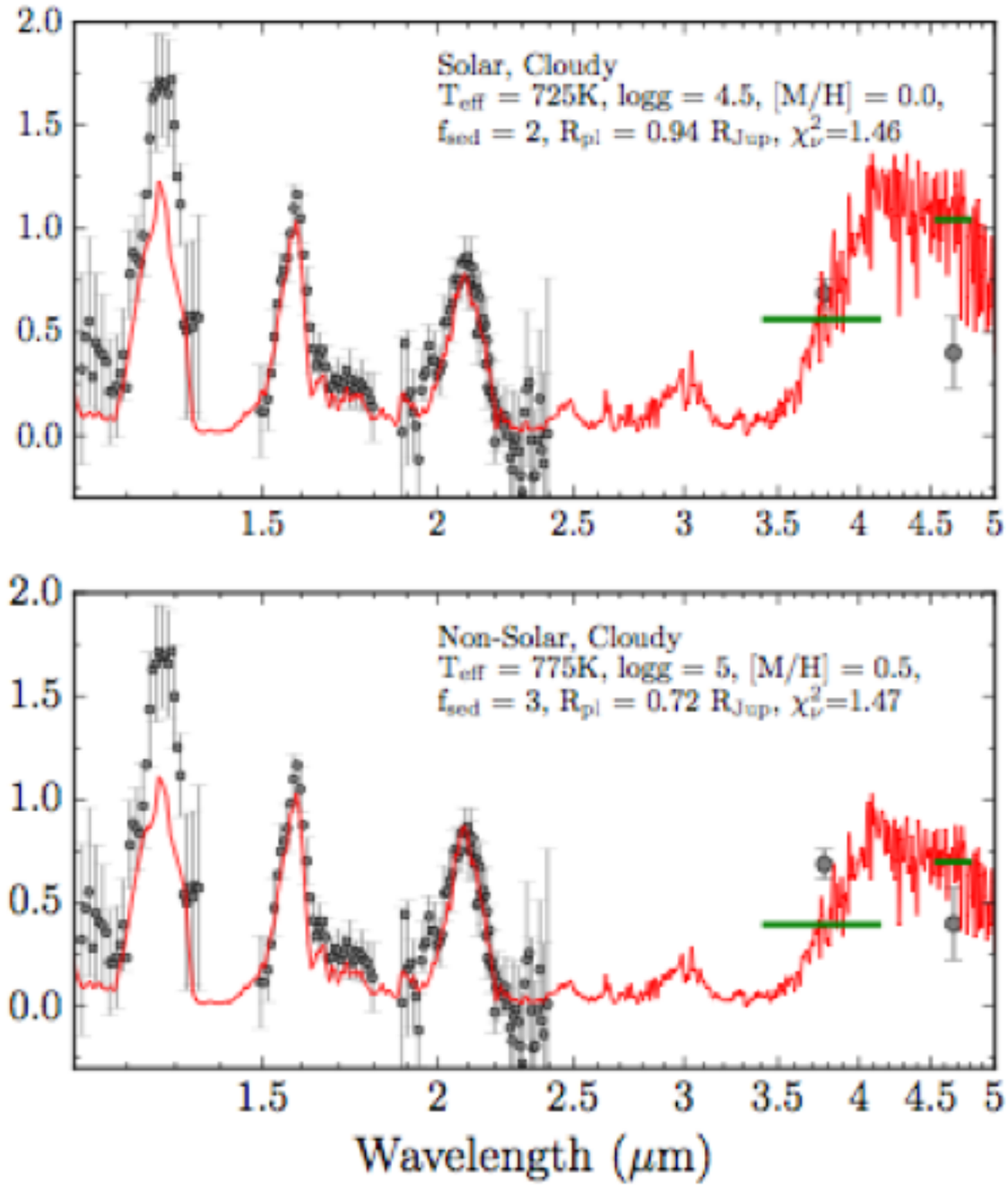


51 Eridani b: Going forward

- Samland et al. (2017) studied 51 Eri b using SPHERE and their results are discrepant when compared to the GPI results, for both the J and K data.
- There is a proposal to reduce both GPI and SPHERE data using common pipelines to help better calibrate the photometry and astrometry for both instruments.
- Observations at longer wavelengths: JWST

51 Eridani b: Modeling the Atmosphere

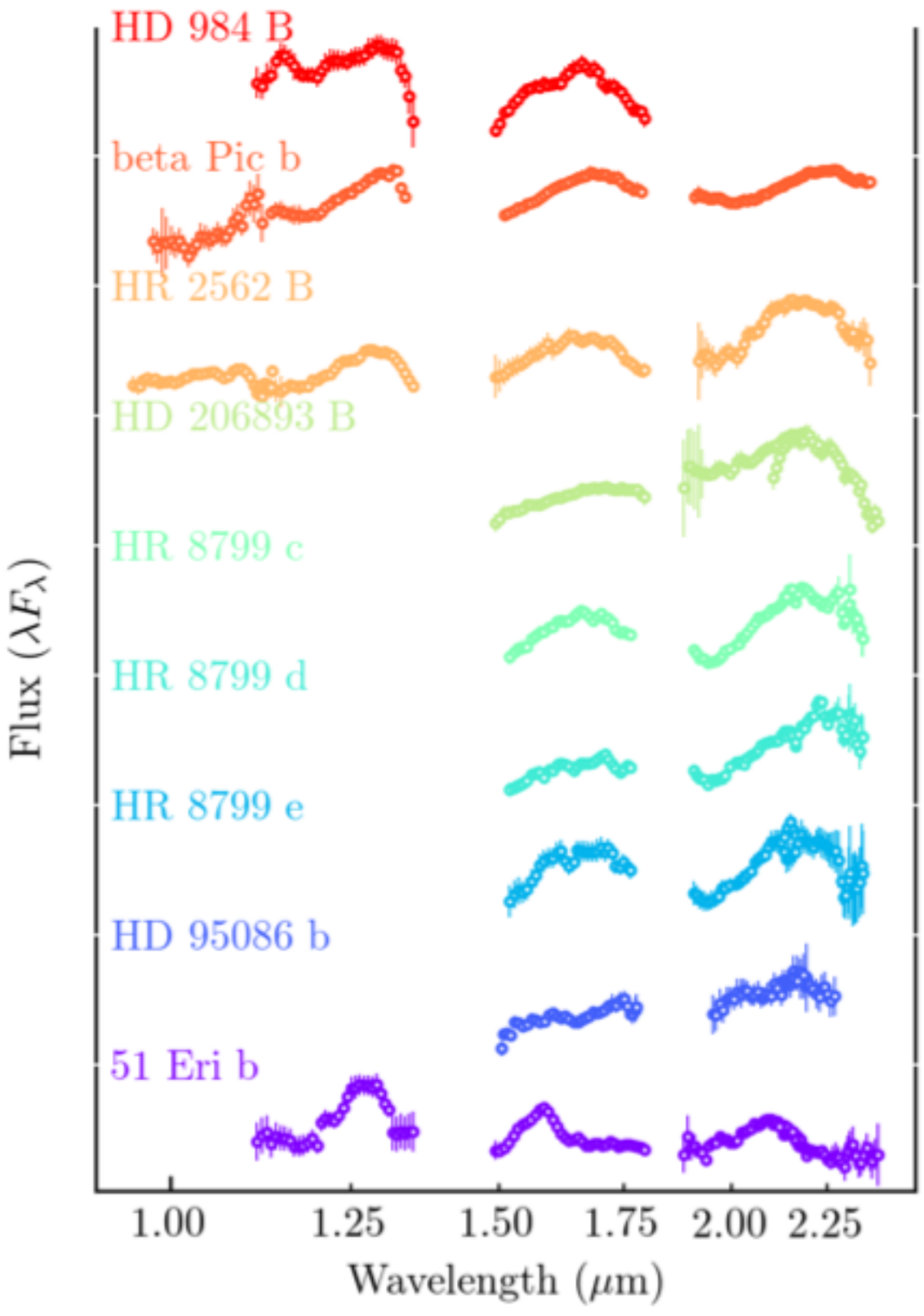


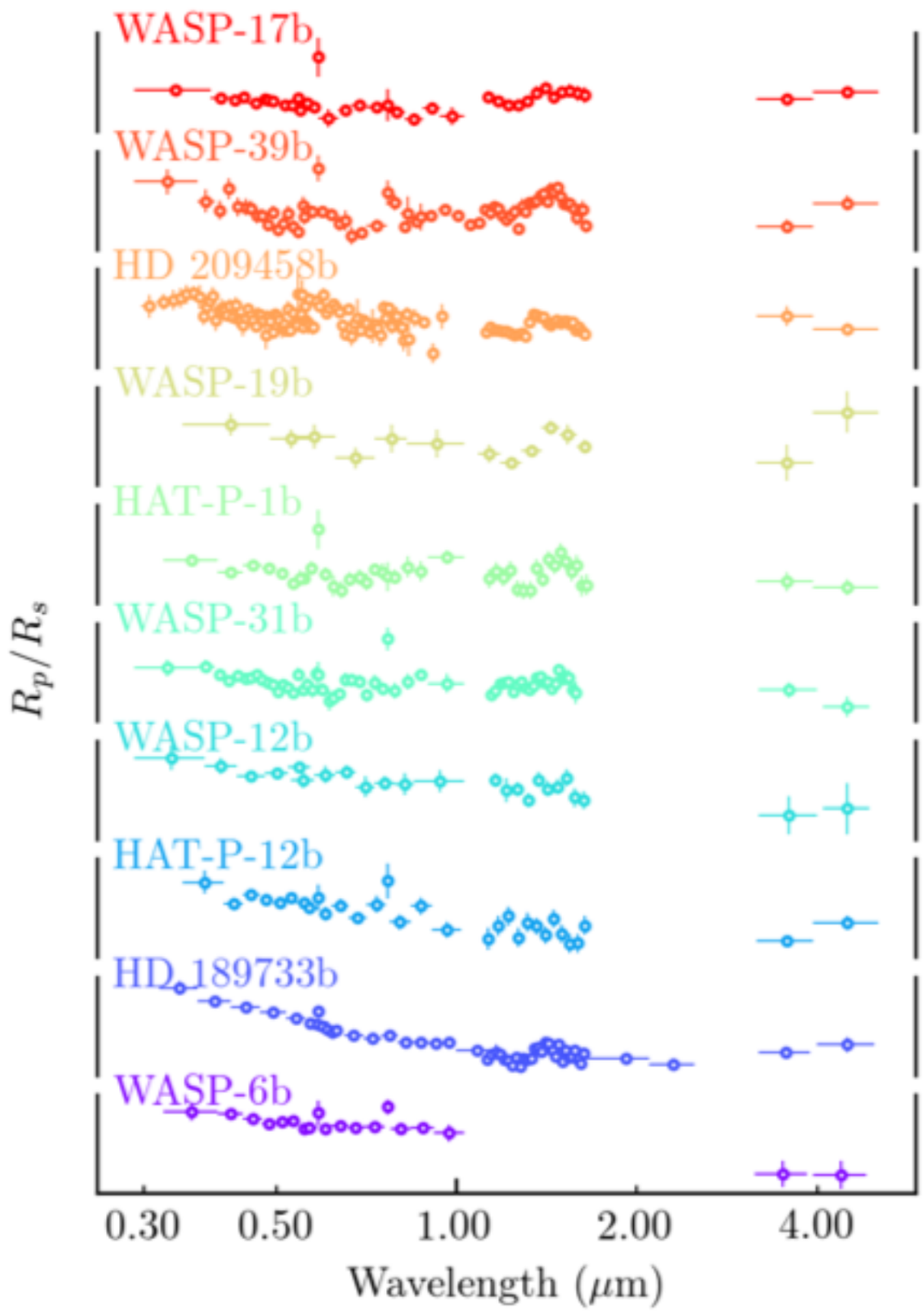


Rajan et al., 2017

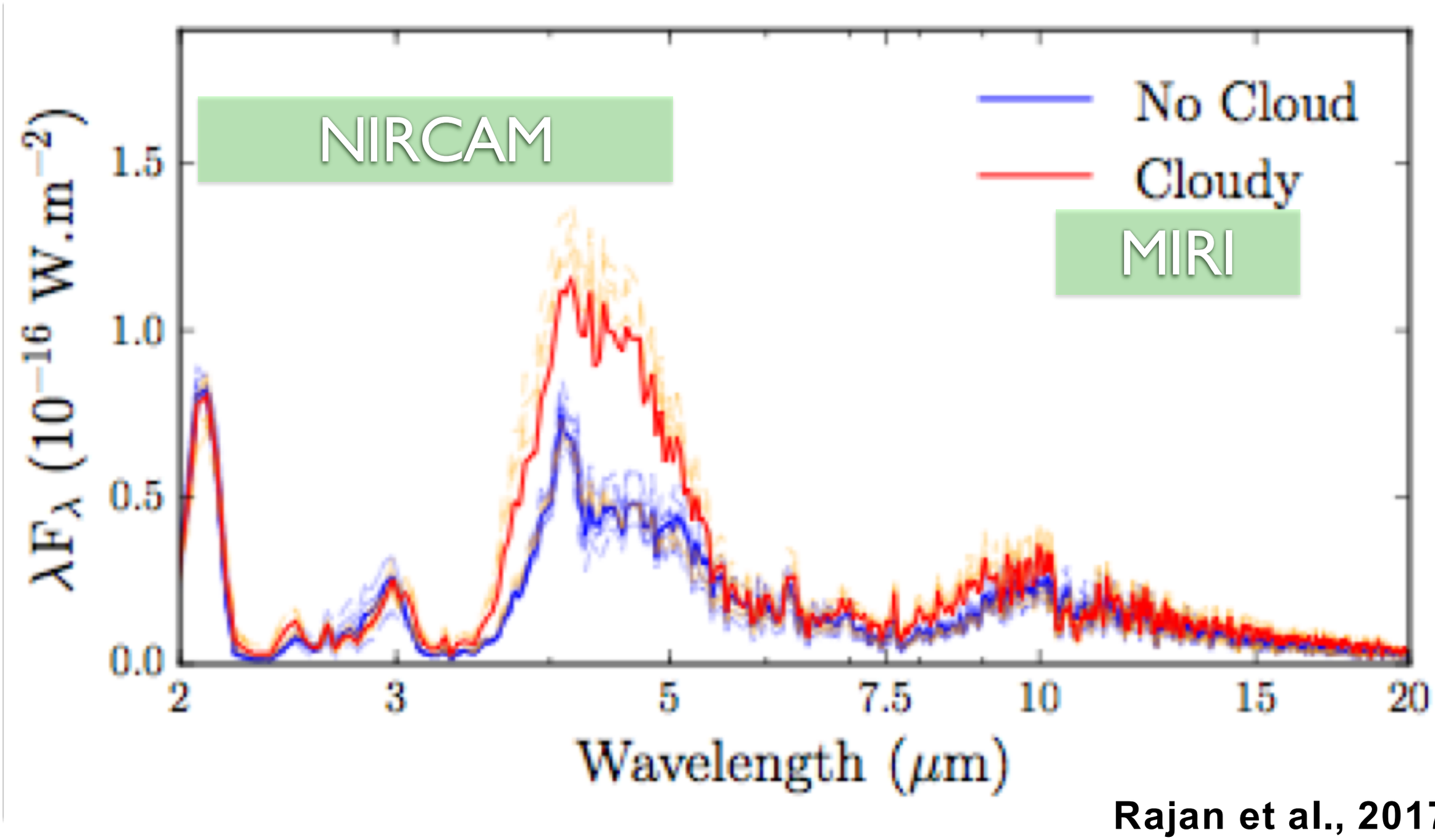
GPIES spectroscopy

Courtesy of R. De Rosa, J. Rameau





51 Eridani b: Going forward …. JWST



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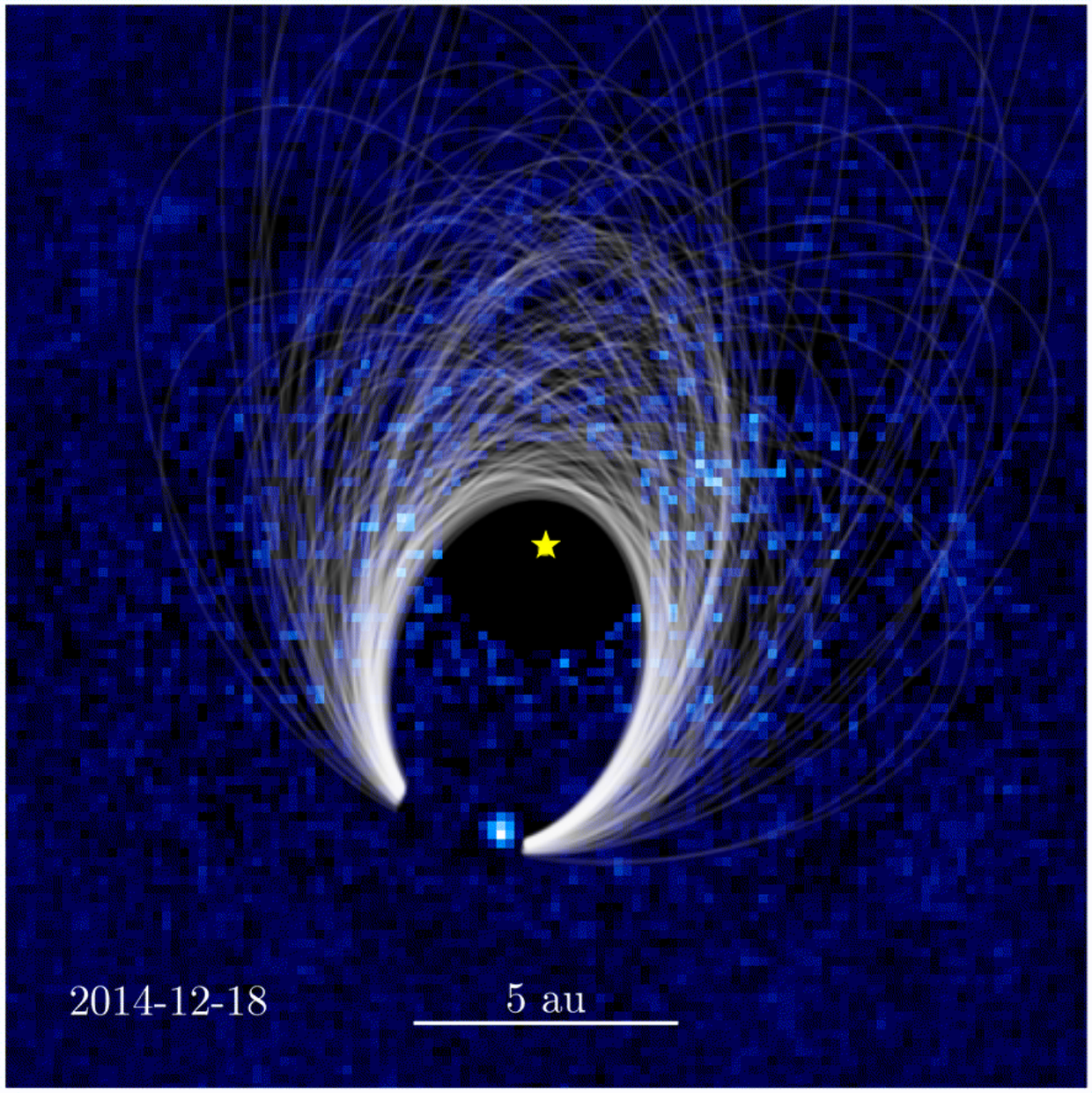

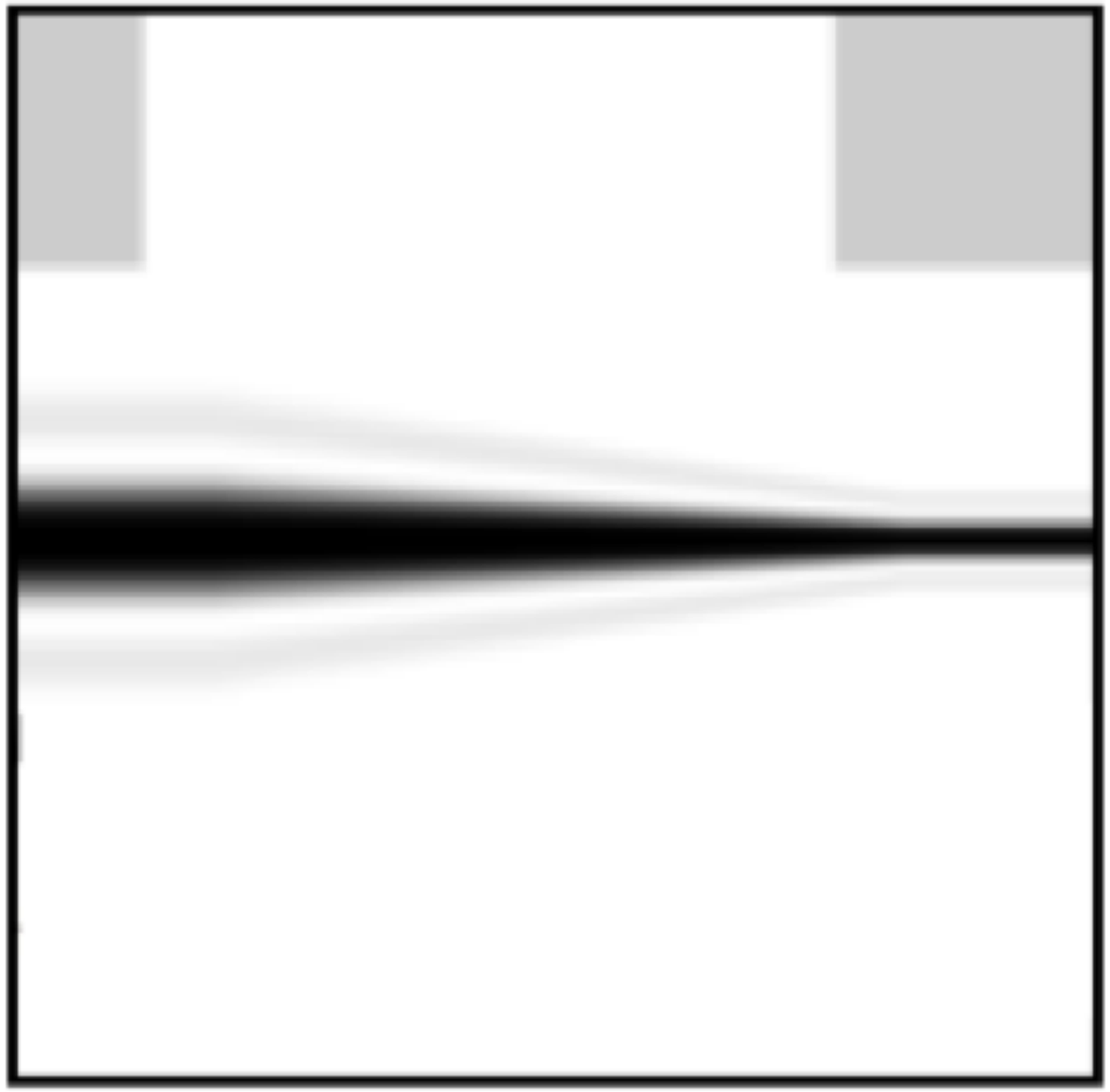

Courtersy of J. Wang, R. De Rosa.

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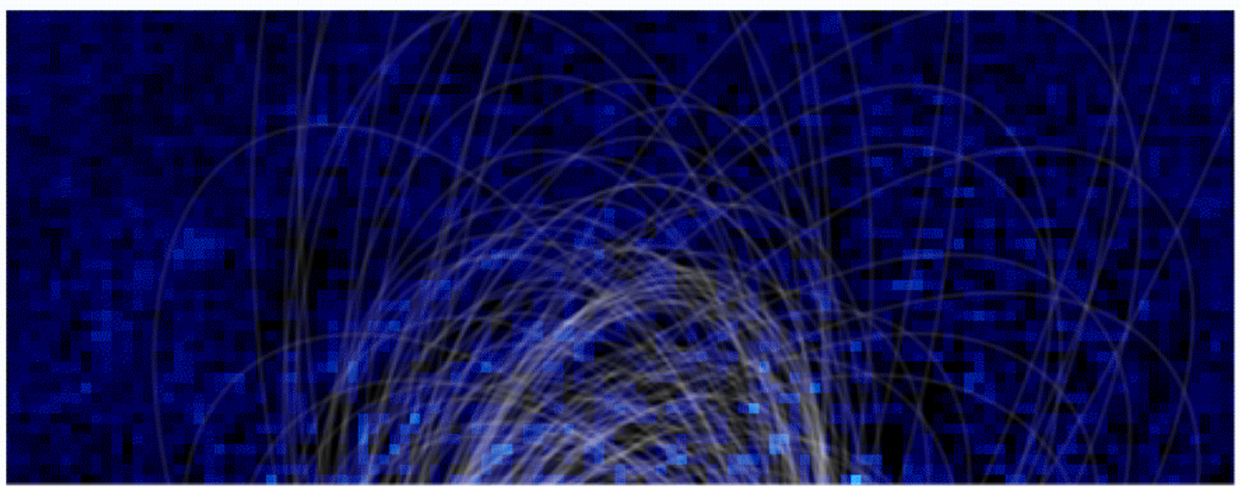
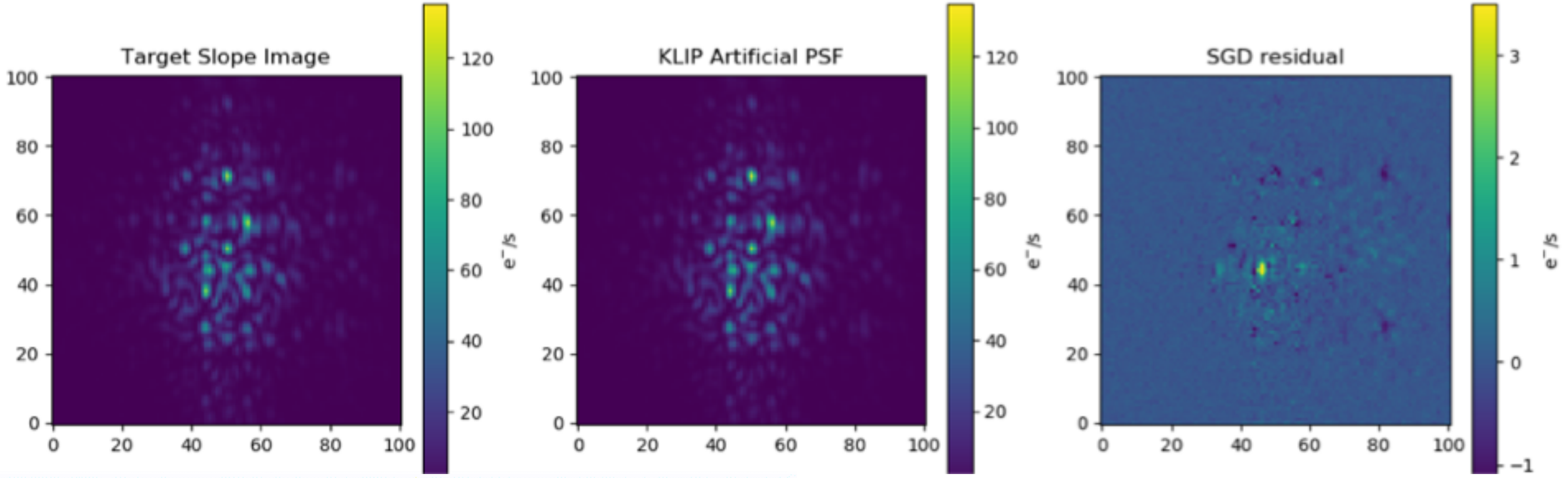
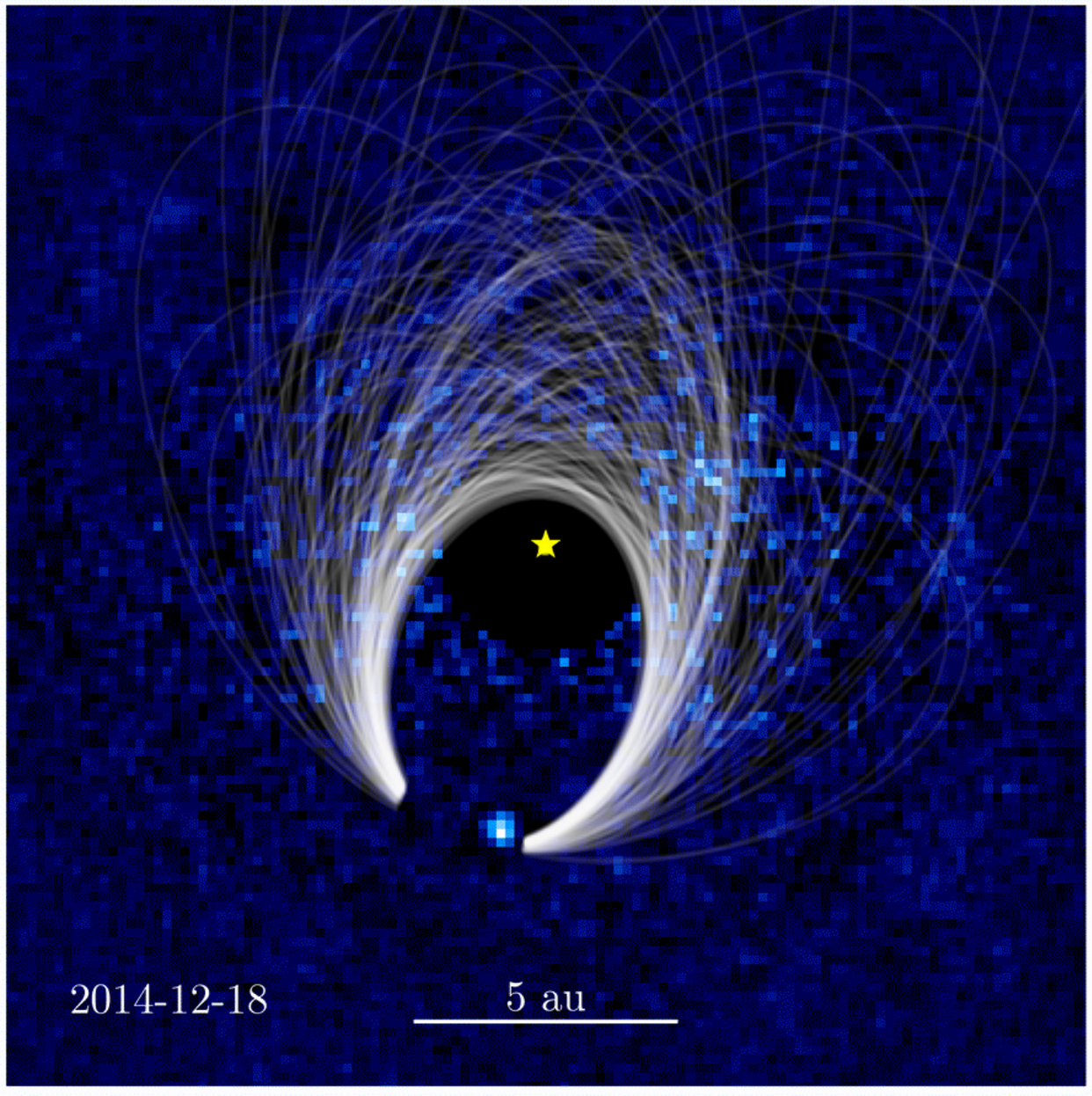




Courtesy of A. Rajan.

Thank you