Directly imaged host star abundances as tracers for planet formation and occurrence

Contributed Talk
Know Thy Star, Know Thy Planet 2

Aneesh Baburaj, Quinn Konopacky,
C. A. Theissen, S. Peacock, L. Huseby,
Benjamin Fulton, R. Gerasimov, T. Barman,
K. Hoch

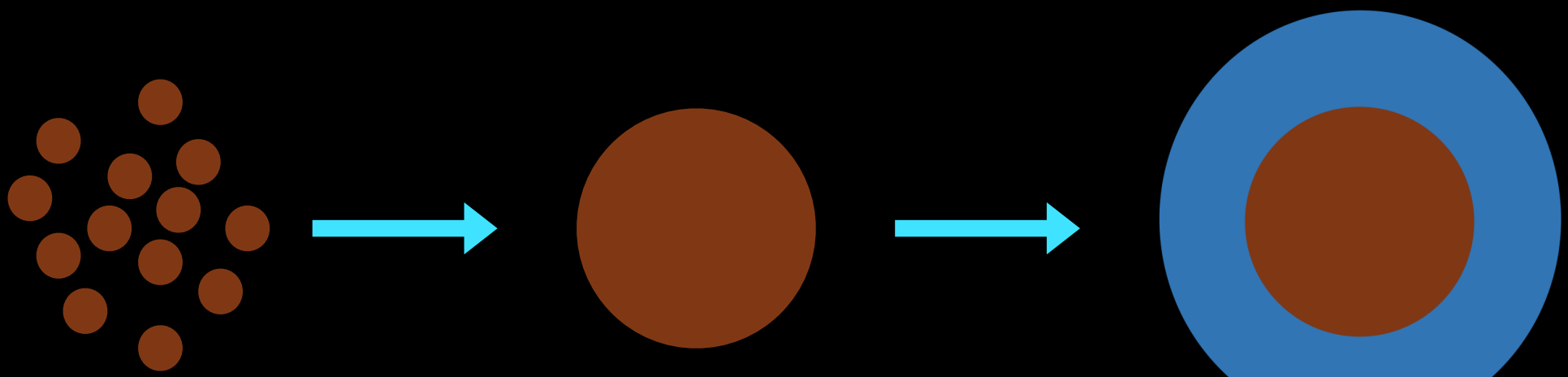
UC San Diego
SCHOOL OF PHYSICAL SCIENCES
Department of Astronomy and Astrophysics

Planet formation pathways:

- There are two major pathways proposed for planet formation:
  - Core accretion (Pebble and planetesimal)
  - Disk instability

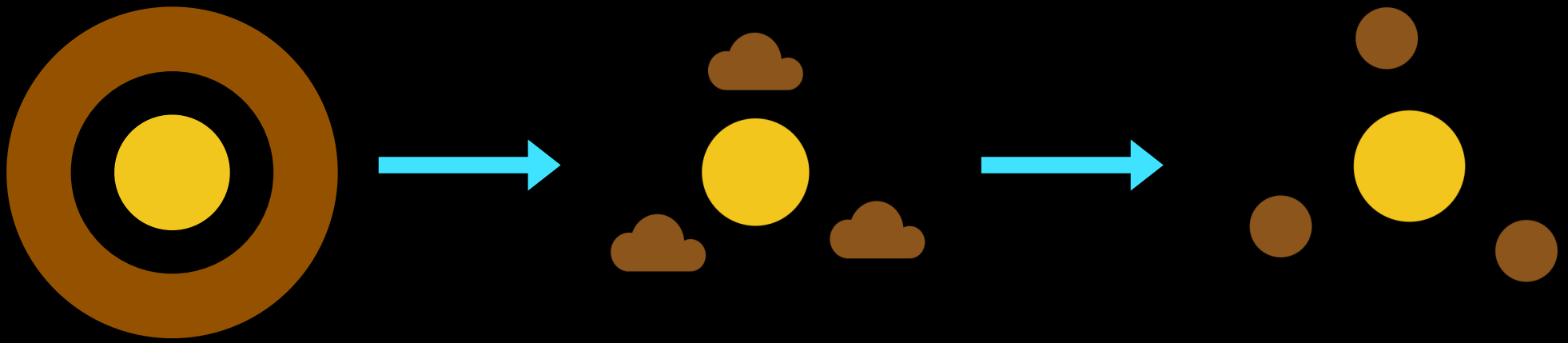
Planet formation pathways:

- There are two major pathways proposed for planet formation:
  - Core accretion (Pebble and planetesimal)
  - Disk instability



Planet formation pathways:

- There are two major pathways proposed for planet formation:
  - Core accretion (Pebble and planetesimal)
  - Disk instability



Abundance ratios and formation pathways

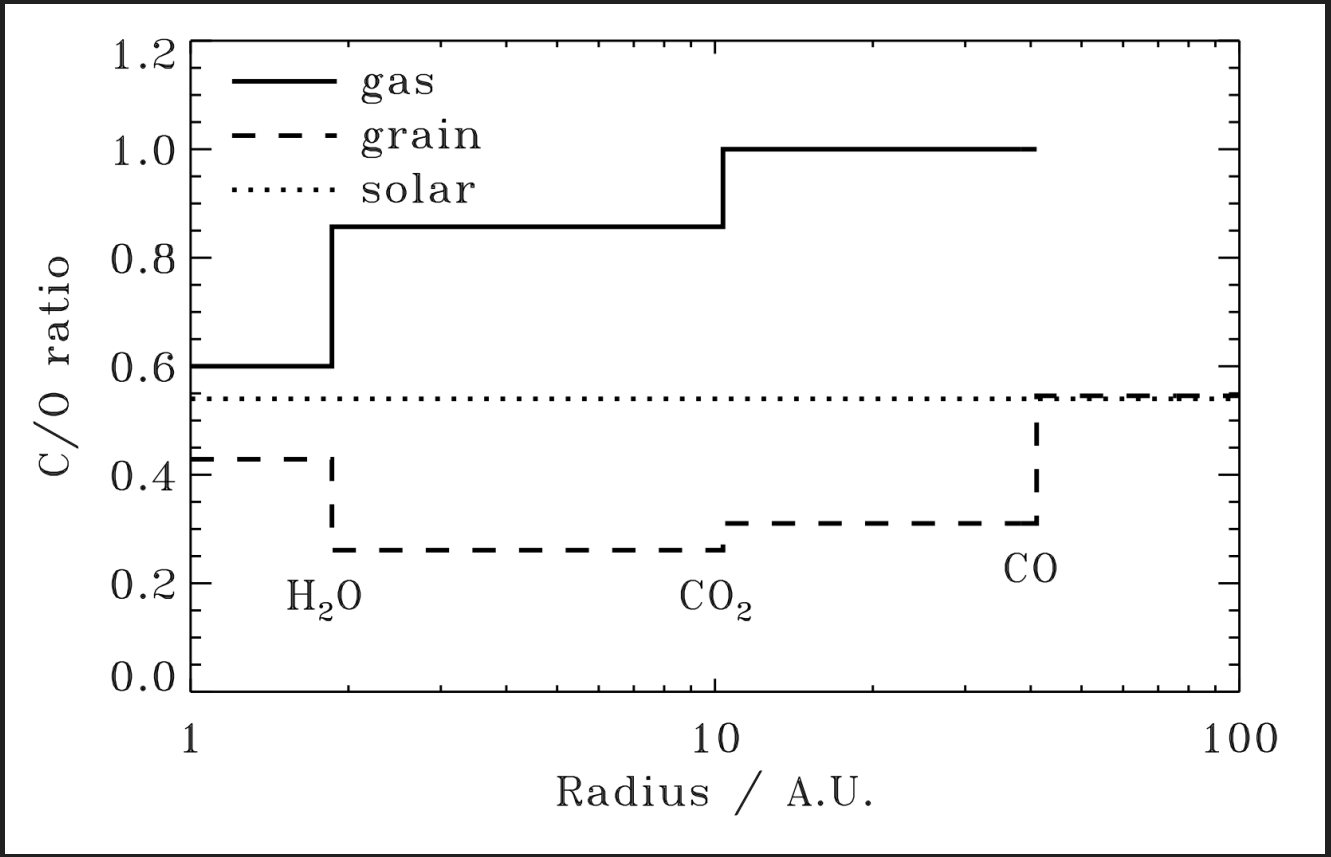


Figure: Oberg et al. (2011)

But how good is the C/O ratio?

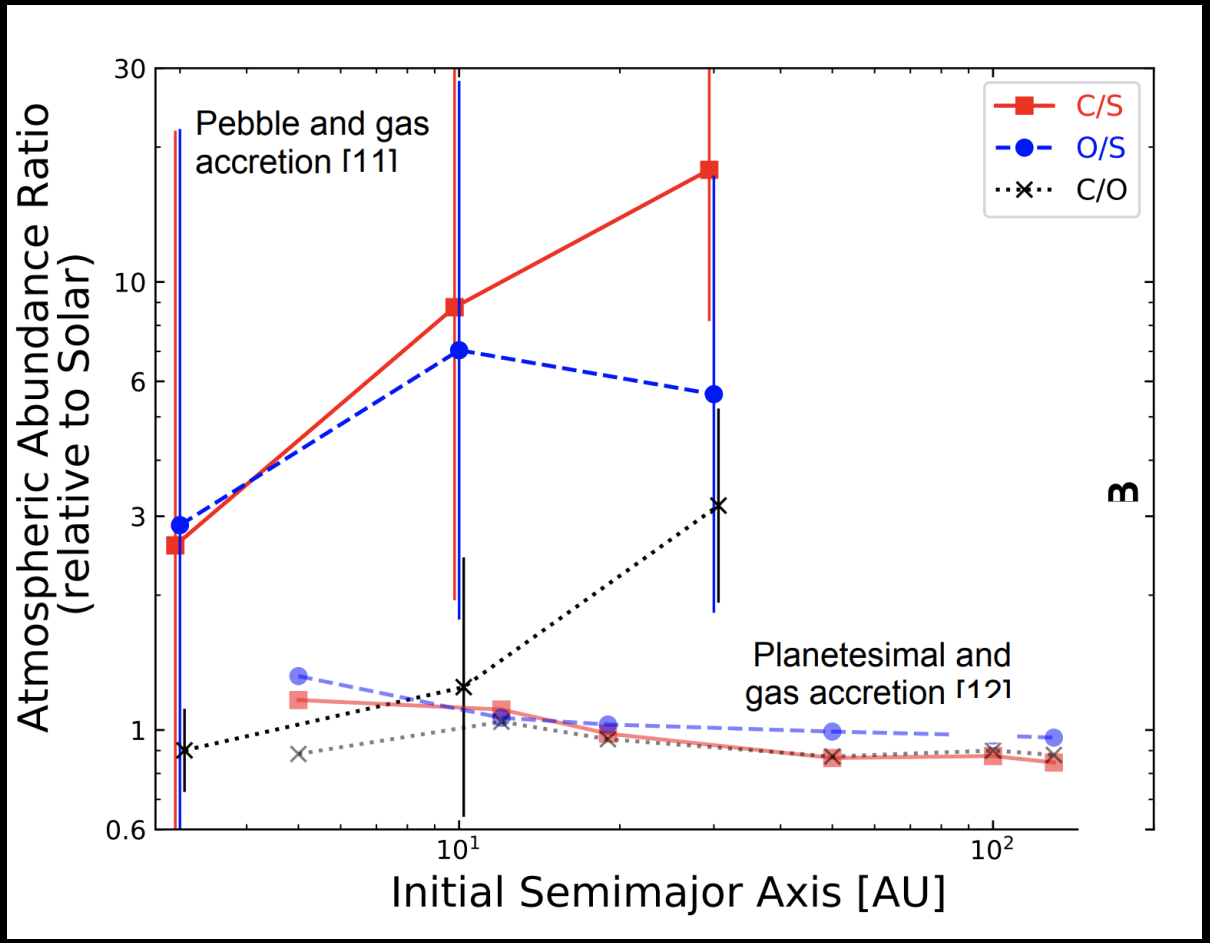


Figure: Crossfield (2023)

We want to move beyond just C/O!

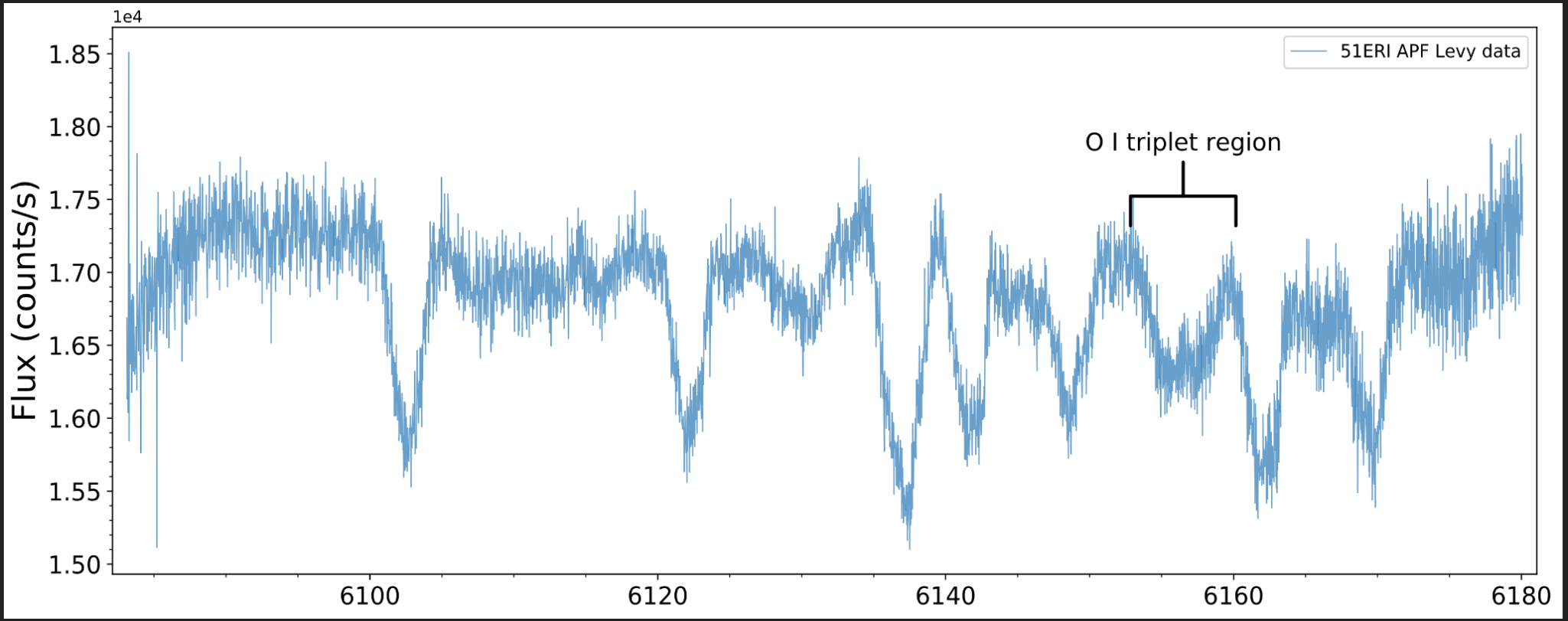
Goals:

- Constrain planet formation by measuring various abundance ratios for host stars!
- Look for trends in planet occurrence with host star abundances

For the host stars, we measure the abundances of 15 elements (**C**, **O**, Na, Mg, Si, **S**, Ca, Sc, Ti, Cr, Mn, Fe, Ni, Zn, Y) and the **C/O**, **C/S**, and **O/S** ratios

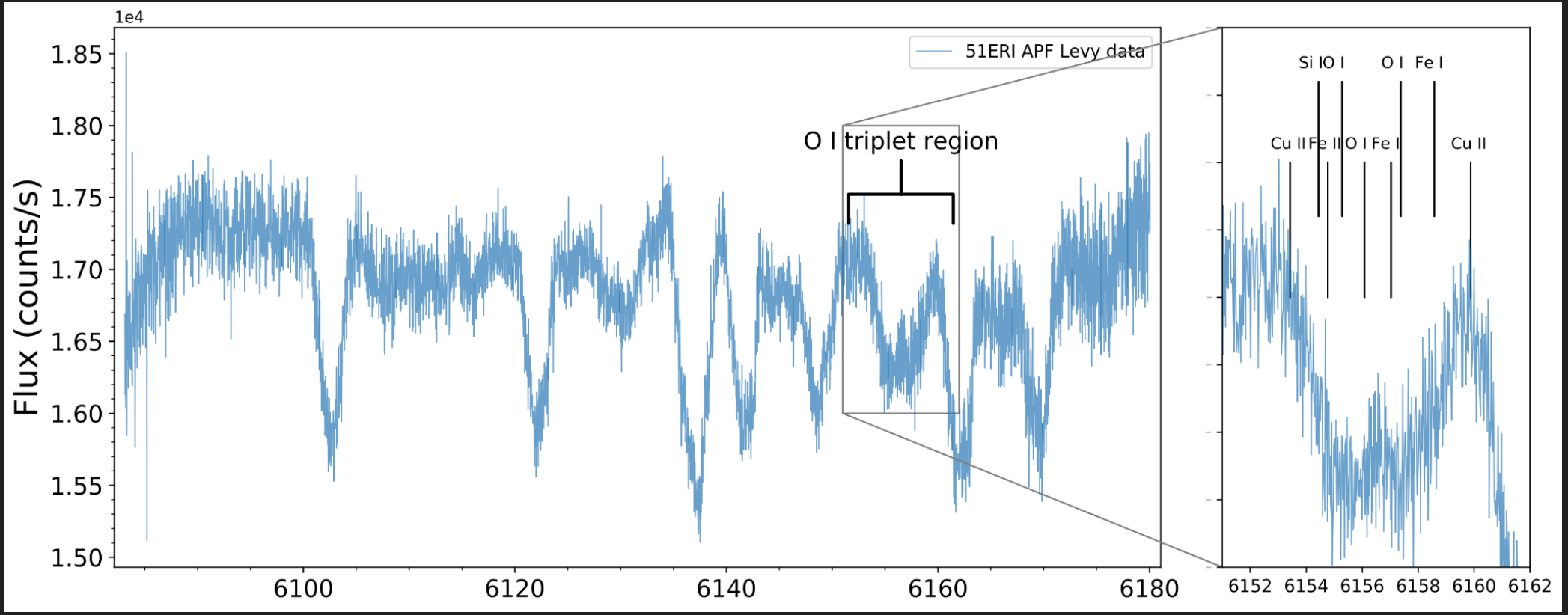
How challenging is it?

51 Eridani: F0 star, vsini ~ 70 km/s

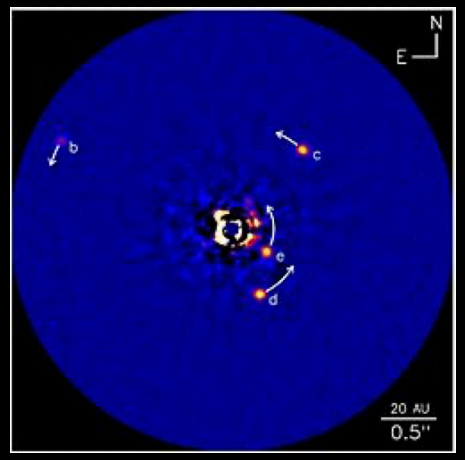


How challenging is it?

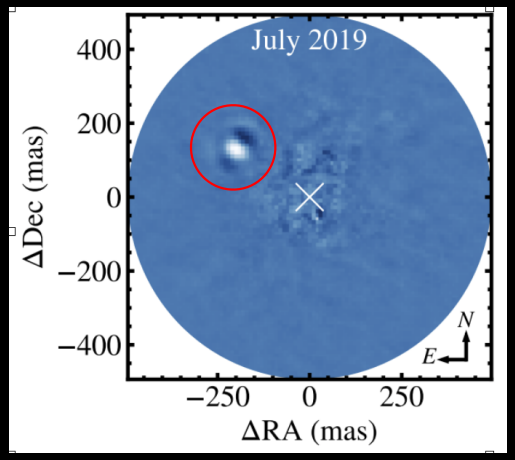
51 Eridani: F0 star, vsini ~ 70 km/s



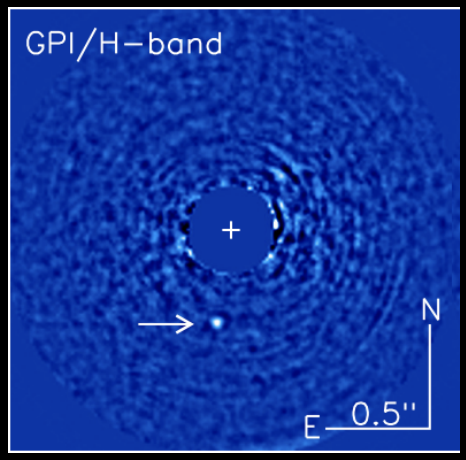
Directly imaged systems (from Baburaj+25)



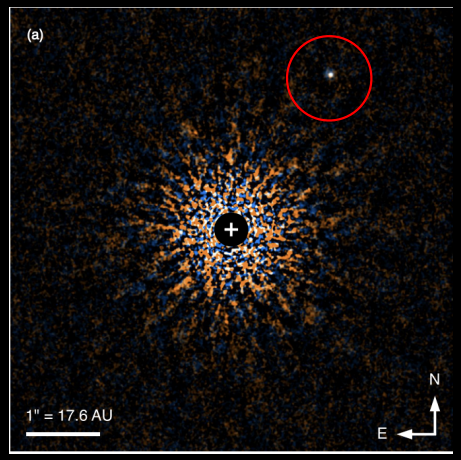
HR 8799



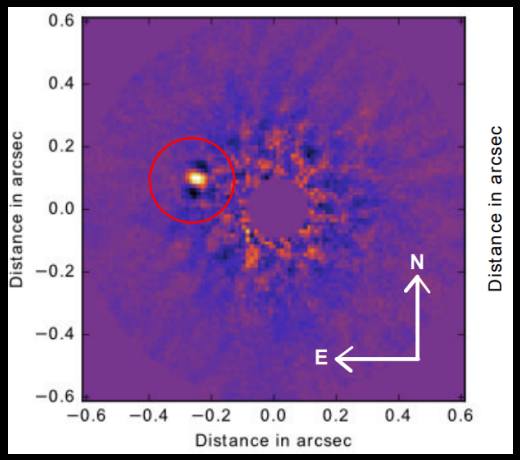
HD 984



51 Eri



GJ 504



HD 206893

Clockwise from top left: Images from Marois et al. (2010), Franson et al. (2022), Macintosh et al. (2015), Milli et al. (2017), and Kuzuhara et al. (2013).

Levy spectrograph at APF (UCO-Lick)

374–900nm

R～120,000

Photo credits: Me

Forward modeling

Two part analysis:

Find the basic stellar parameters like effective temperature (Teff), surface gravity (logg) and metallicity ([M/H]) by fitting PHOENIX models

Custom PHOENIX grid with fixed [M/H], small range of Teff, logg and varying carbon (C) and oxygen (O) abundances used to determine abundance values

Forward modeling results: HD 206893

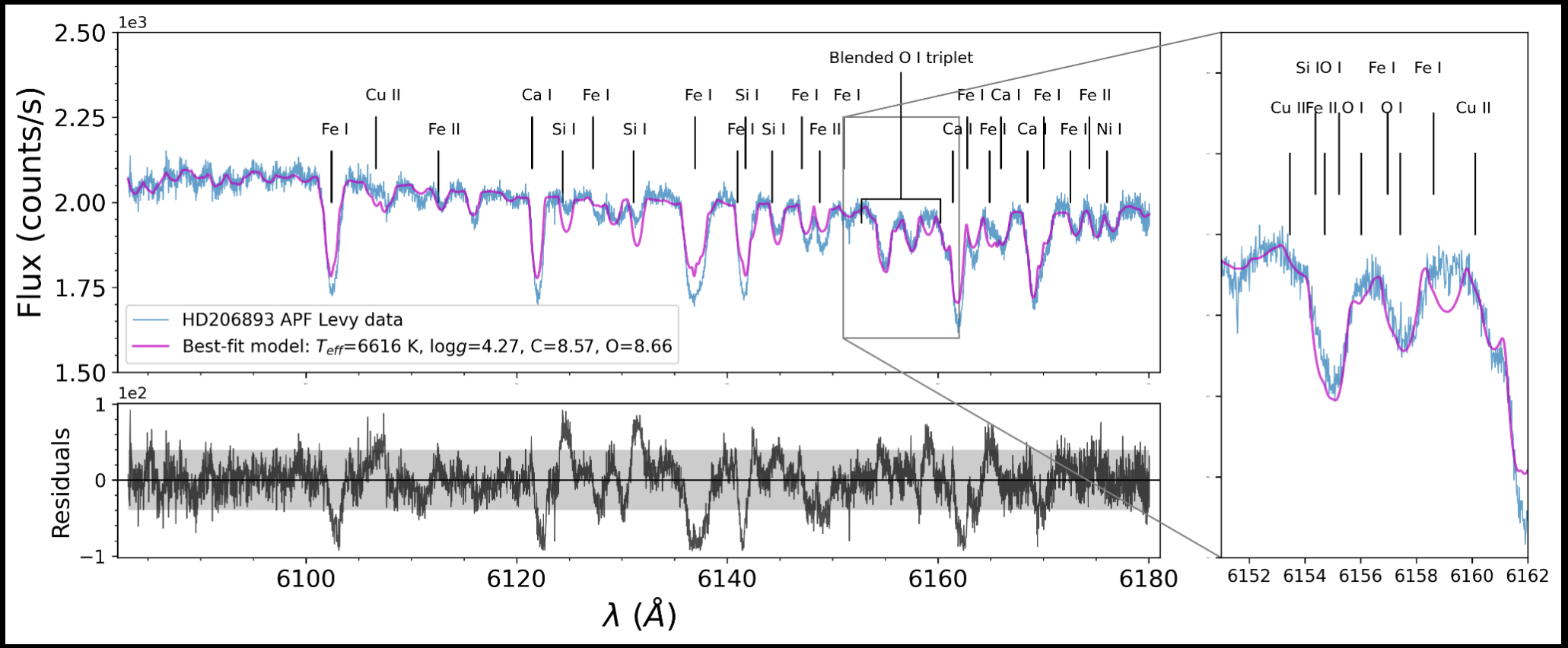
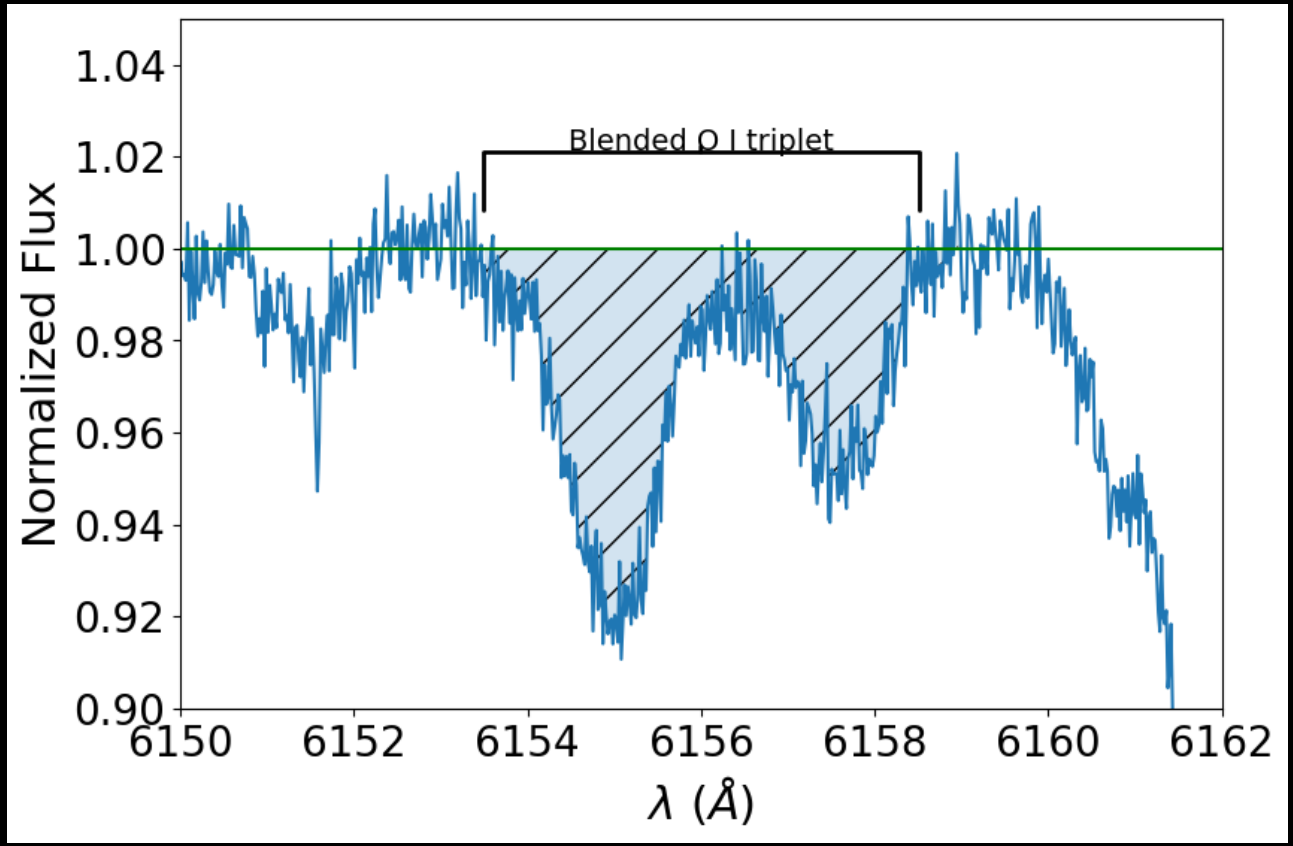


Figure: Baburaj et al. (2025)

Spectral fit C/O: 0.81 ± 0.14 (super-solar at 2σ)

Equivalent width: HD 206893



Eq. Width C/O: 0.69 ± 0.35

Abundance ratios

Abundance ratio	HR 8799	51 Eri	HD 984	GJ 504	HD 206893	Solar
C/O (spectral fit)	0.59 ± 0.11	0.54 ± 0.14	0.63 ± 0.14	0.54 ± 0.14	0.81 ± 0.14	0.55
C/O (equiv. width)	0.47 ± 0.30	0.54 ± 0.29	0.48 ± 0.28	0.42 ± 0.24	0.69 ± 0.35	
C/S	37.15 ± 17.99	19.95 ± 9.19	18.20 ± 8.06	17.38 ± 10.20	25.70 ± 9.92	20.42
O/S	79.43 ± 40.11	37.15 ± 17.80	38.02 ± 25.75	41.69 ± 22.41	37.15 ± 13.53	37.15

Elemental abundance trends

No unexpected trends in elemental abundances noticed for wide-orbit planet host stars

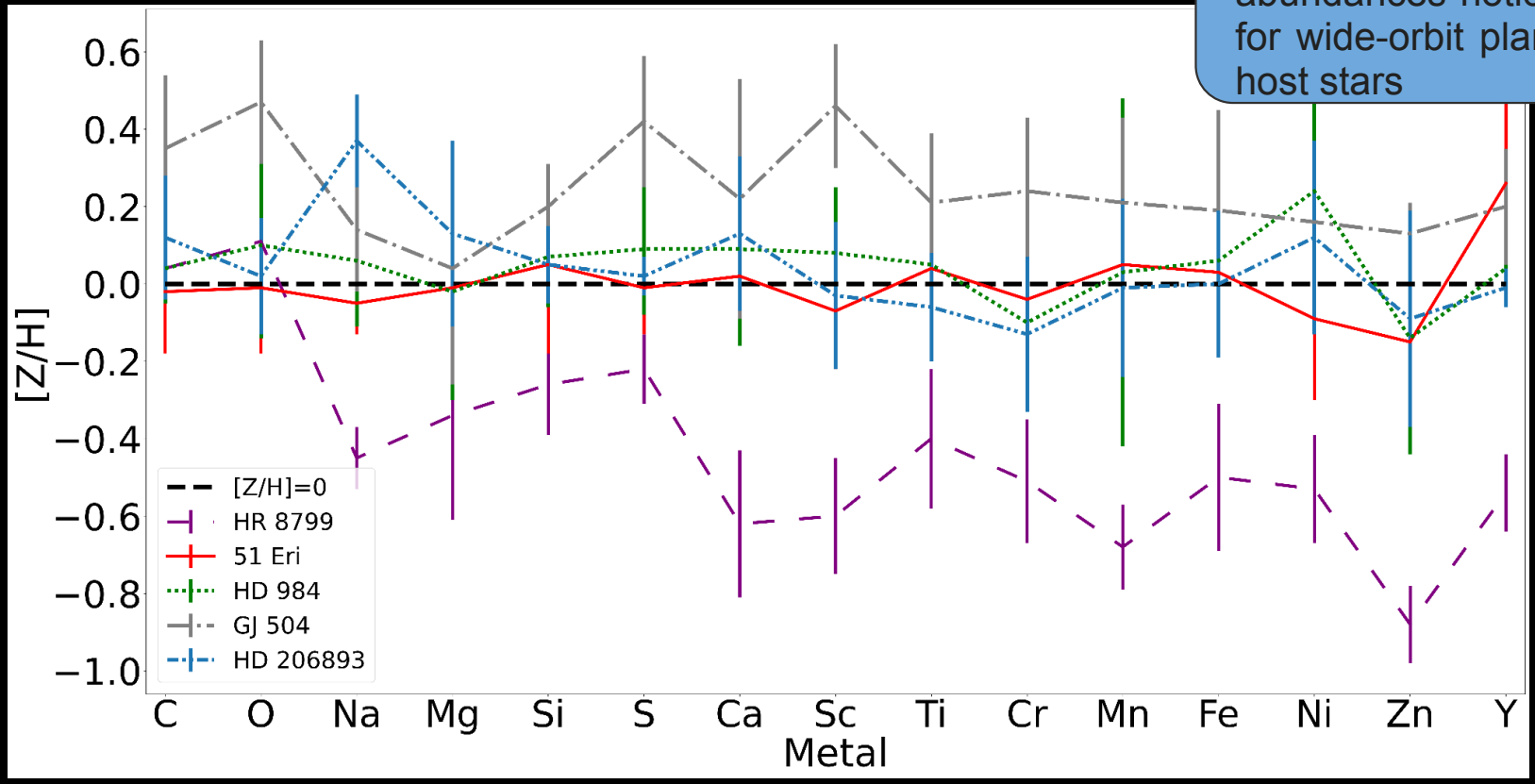


Figure: Baburaj et al. (2025)

Comparison of companion and host star C/O

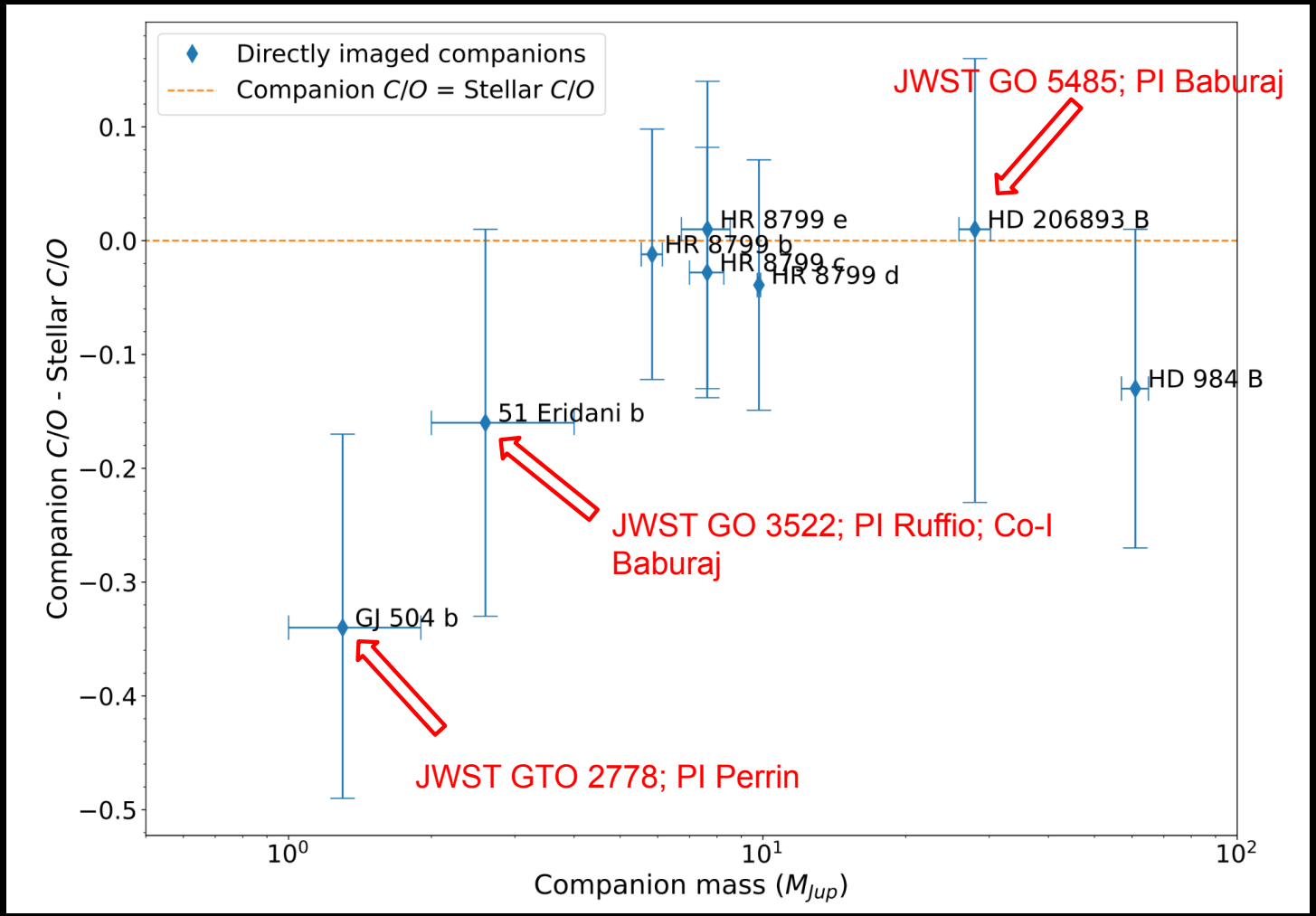
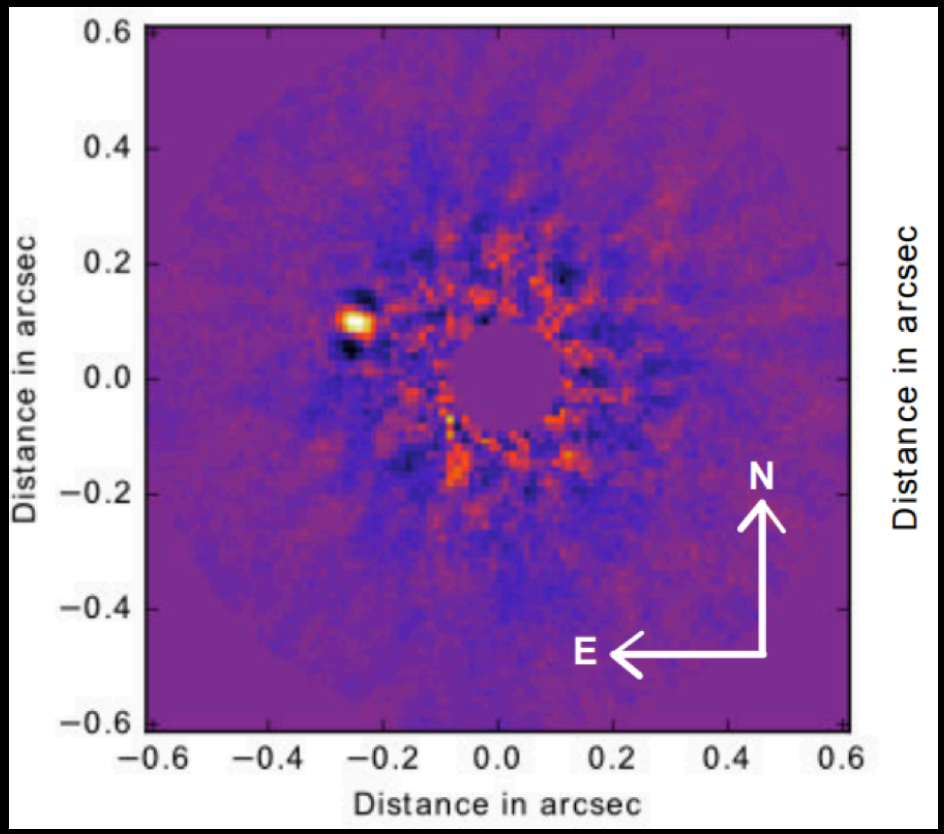


Figure: Baburaj et al. (2025)

HD 206893B (is it a planet?)



- Warm (Teff ～1500K) **28 Mjup** companion **0.2”** from the primary (HD 206893A)
- **Located inside a debris disk!**
- Has a coplanar inner companion (HD 206893c)

Observed using JWST on October 5, 2024 (GO 5485; PI Baburaj)

Image: Milli et al. (2017)

Takeaways

- Constraining planet formation requires abundance measurements for both exoplanets and their host stars
- C/O ratio measurements for five directly imaged companion host stars yielded broadly solar values using spectral fitting and equivalent width
- We need to move beyond C/O ratio and use sulfur-based ratios (C/S and O/S) for stronger constraints on giant planet formation
- No trends were noticed for wide-orbit planet occurrence with host star elemental abundances

I'm on the job market!

ababuraj@ucsd.edu

https://aneeshb97.github.io/