Carbon Isotope ratio Measurements of a Hot Jupiter with IGIRNS-2/Gemini-North

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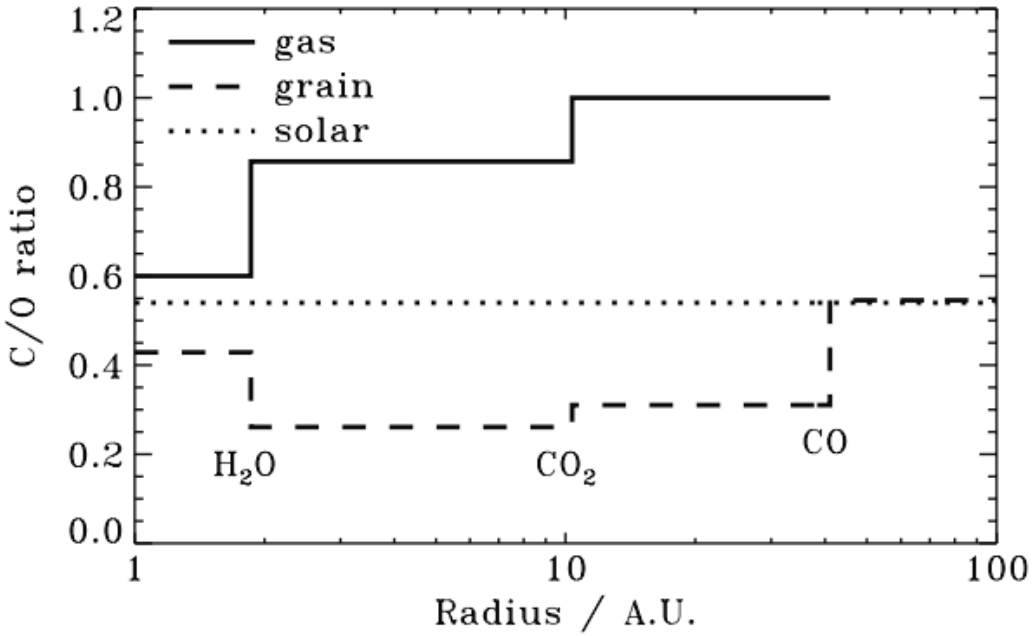
+4 co-Is

Linking atmosphere with planet formation

disk

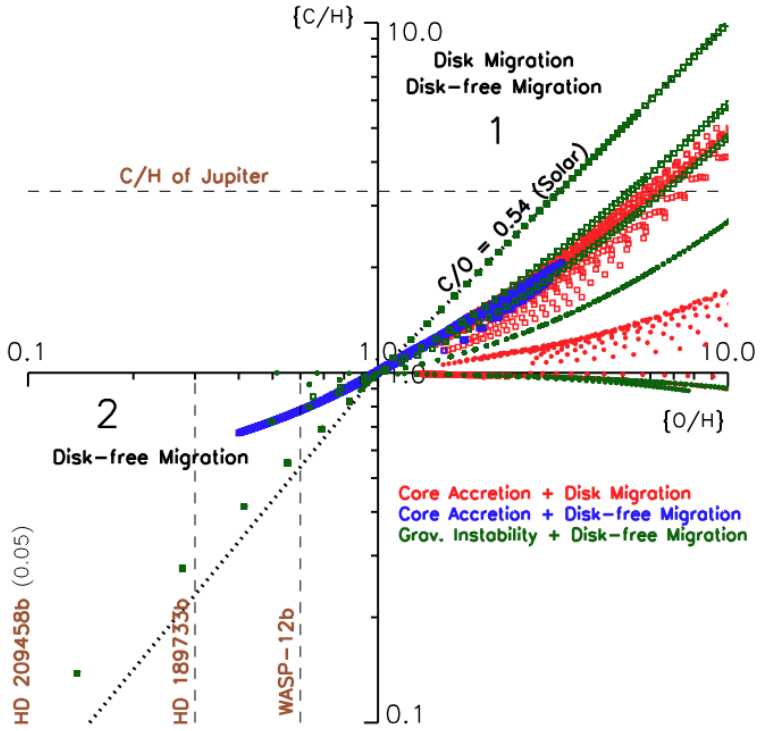


Oberg et al. 2011

formation

infer

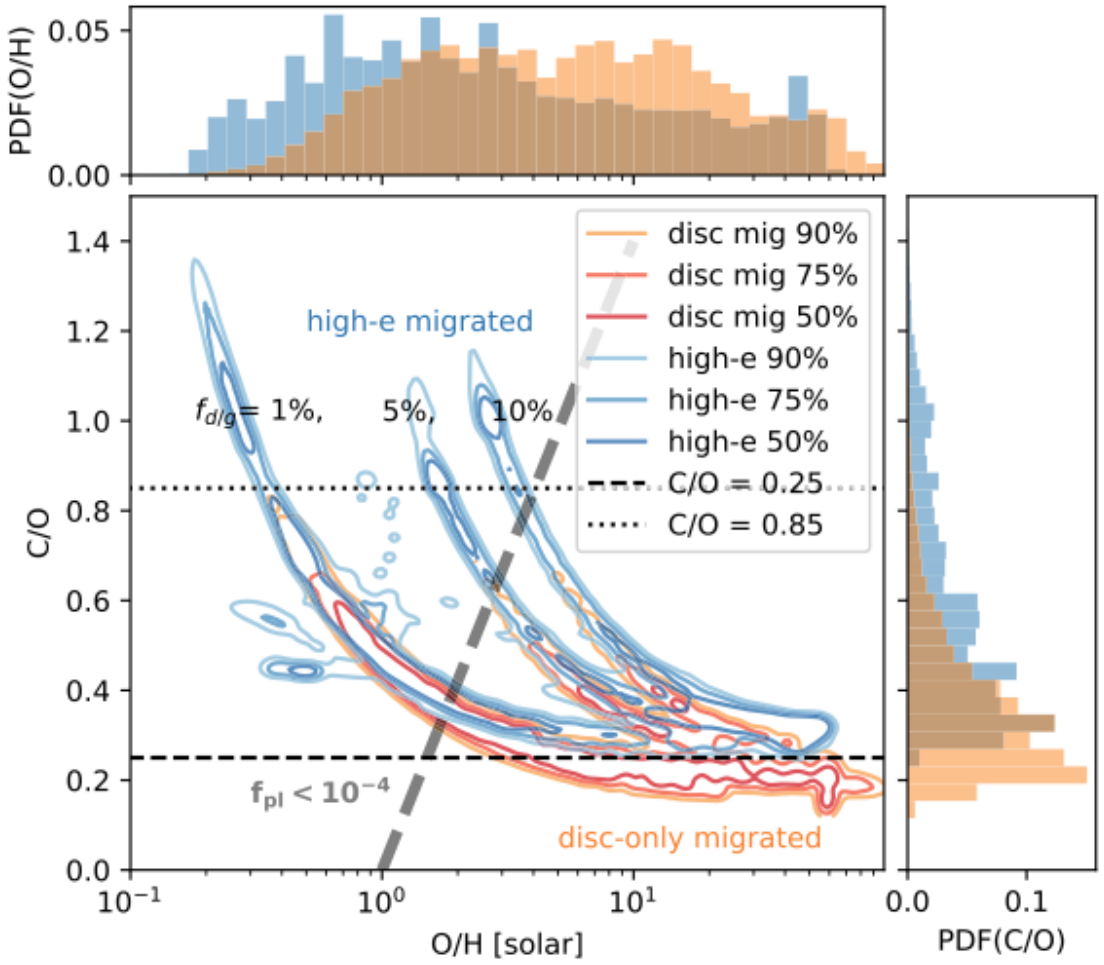
atmosphere

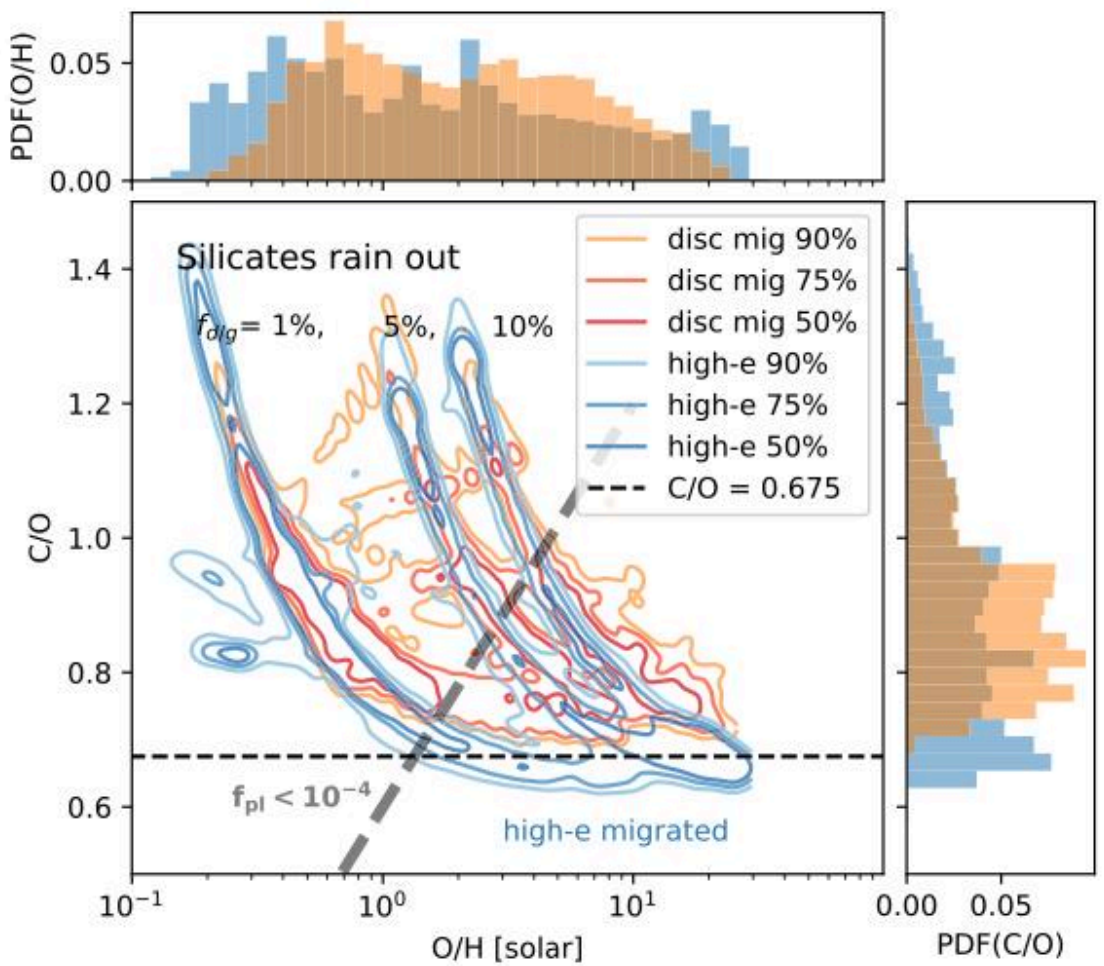


Madhusudhan et al. 2014

Infer where they formed/how they moved

The limitation of C/O and O/H

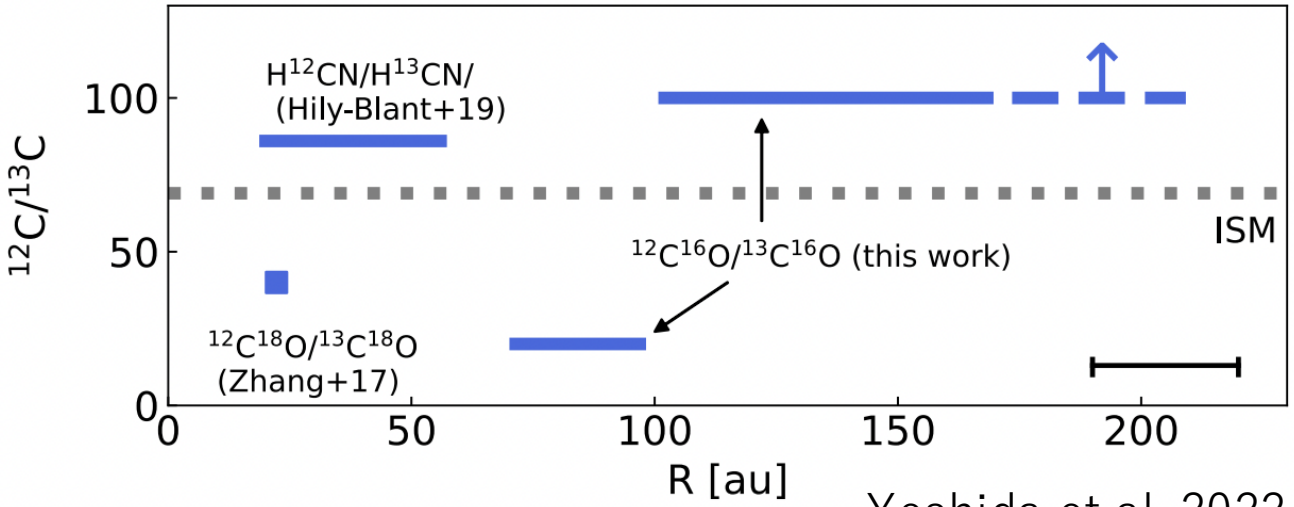




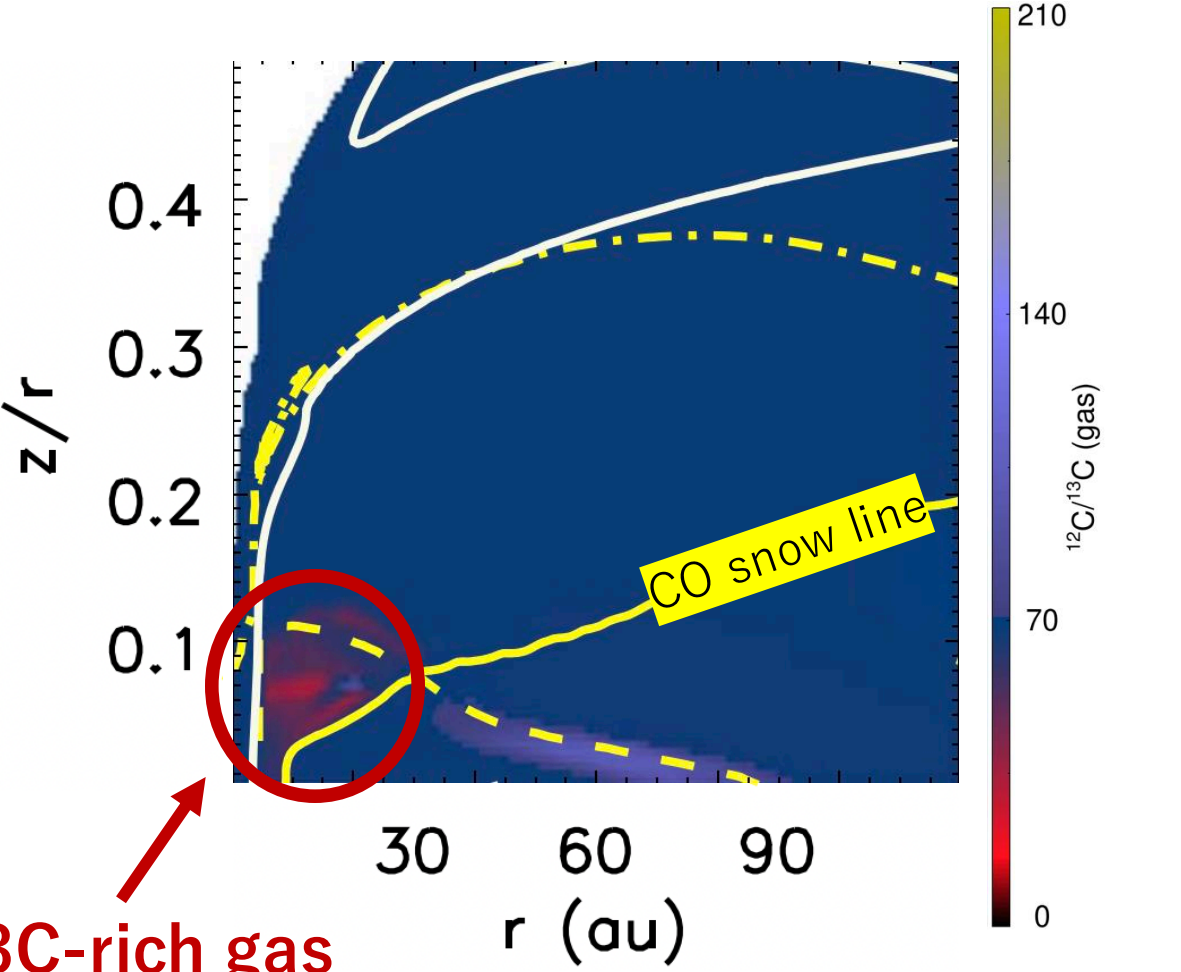
Penzlin+ 2024

→Additional Information is needed

Carbon isotope ratio and planet formation



Yoshida et al. 2022



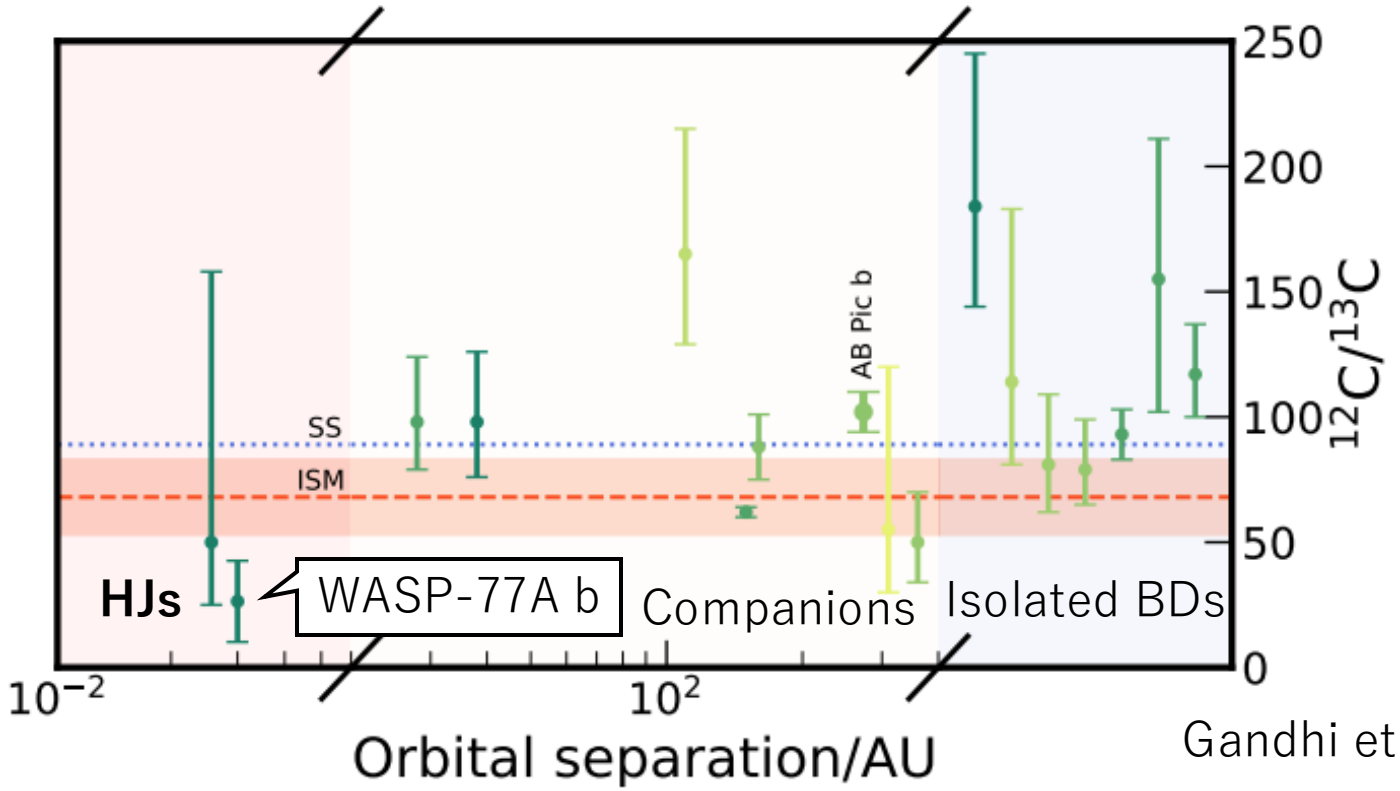
13C-rich gas

Lee, Nomura and Furuya 2024

$$13C^+ + 12CO \rightleftarrows 12C^+ + 13CO + 34.7\ \mathrm{K}$$

Isotope exchange reaction: proceed in <30 K and C/O~1

Carbon isotope ratio observation: current



Gandhi et al. 2025

Wide orbit companions: ~ISM - depleted to 13C

Hot Jupiters :?

Strategy

- Where carbon from?

Noted: hypothesized with simplified model

CO gas at CO iceline vs. Other gas / planetesimal

Outside (> CO2 snowline)

Inside the CO iceline: 13C-rich
Outside: 13C-poor

Low [M/H]

WASP-77A b like
12C/13C~20 (?)

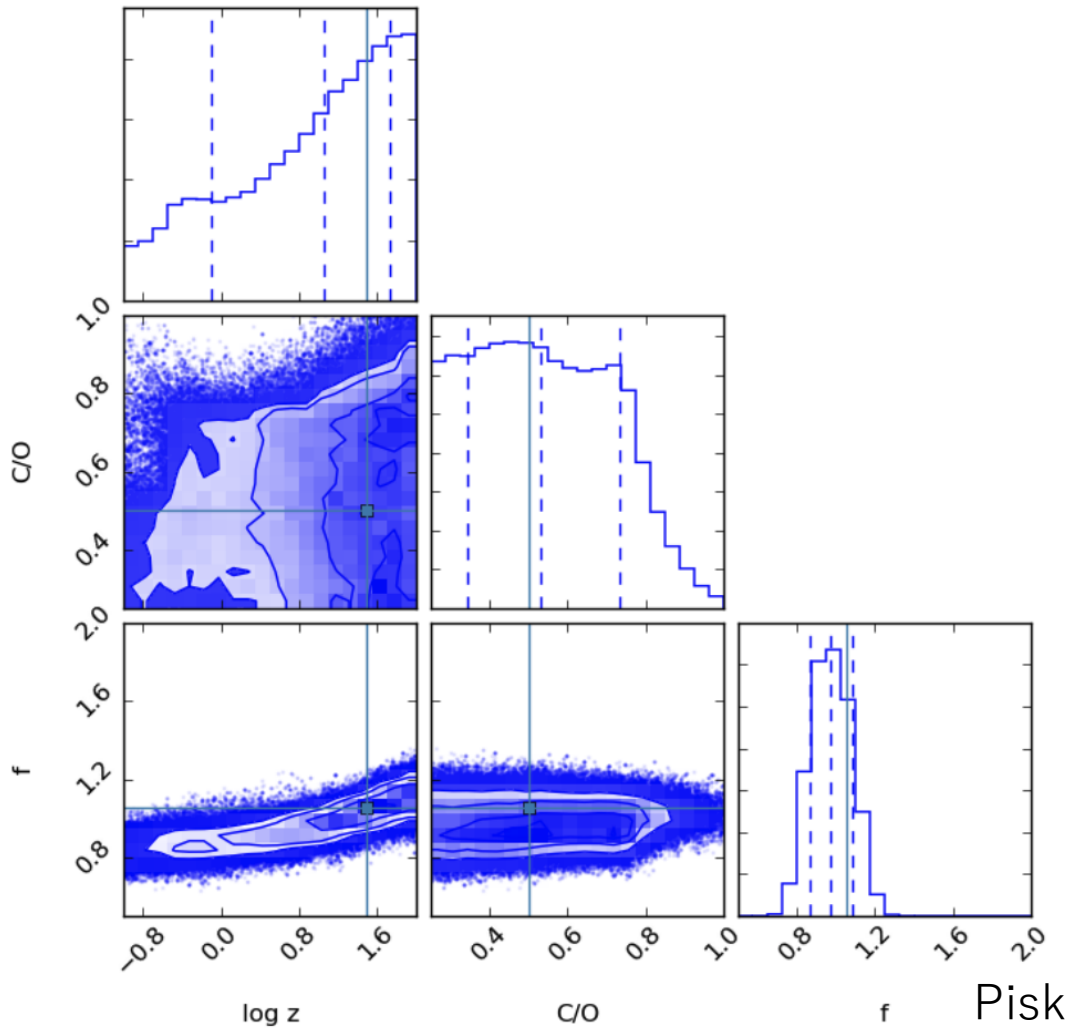
Inside ($<CO_2$ iceline)

No fractionation
due to the high temperature

High [M/H]

ISM like
12C/13C~70 (?)

KELT-2 A b: a high metallicity HJ ?



Piskorz et al. 2018

Based on Keck/NIRSPEC K and L-band + Spitzer

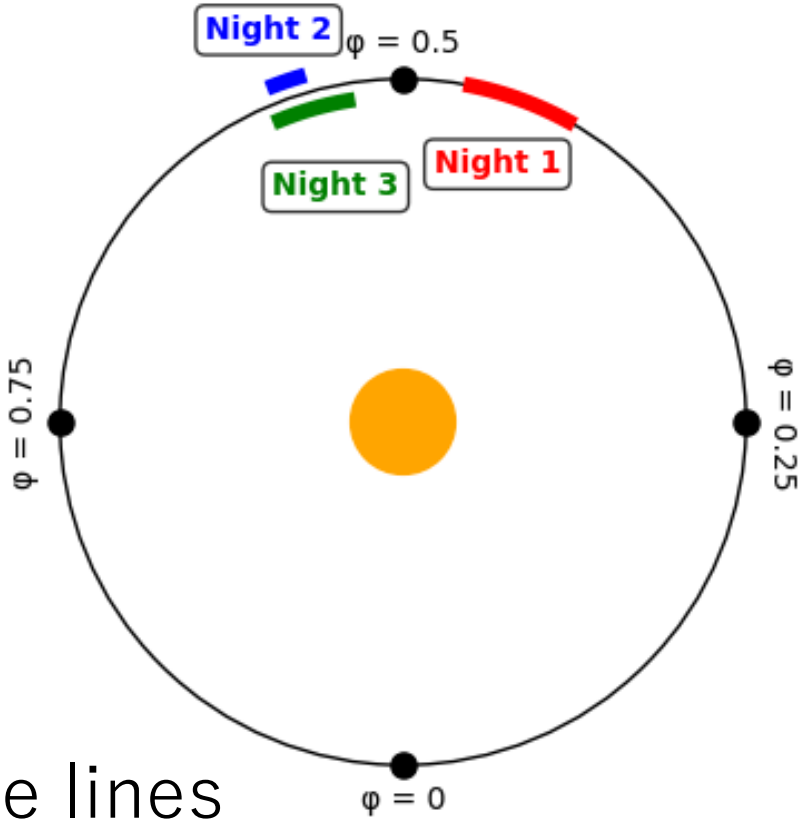
$$M_p\,(M_J) = 1.524 \pm 0.088$$
$$R_p\,(R_J) = 1.290^{+0.064}_{-0.050}$$
$$T_{\rm eq}({\rm K}) = 1712^{+28}_{-20}$$
$$P\,({\rm day}) = 4.114$$

Beatty et al. 2012

Counter part of WASP-77A b!

Observation: IGRINS-2/Gemini-N

- **D = 8.1 m**

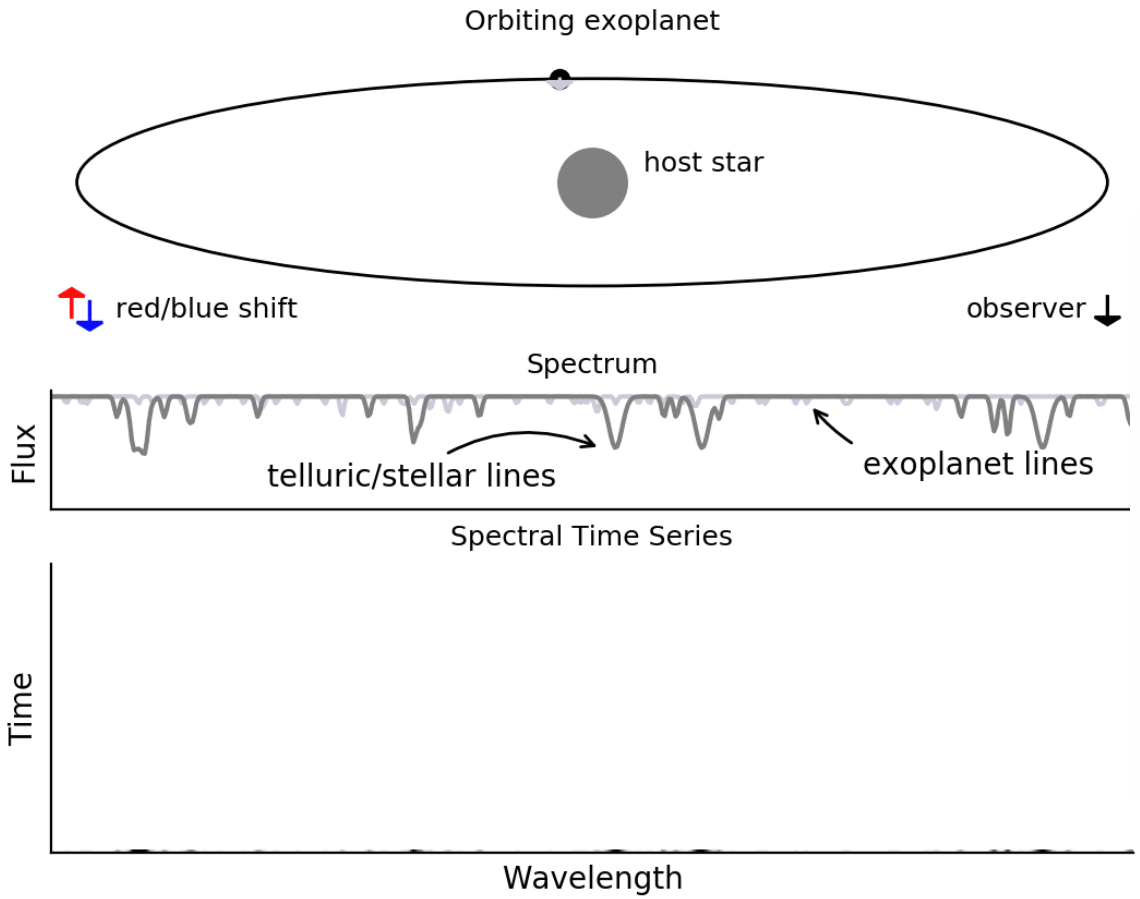


- **H+K simultaneously**
  →H_2O, CO lines
- **R ~ 45 k**
  →Resolve isotopologue lines
- **High Throughput** (>6%)

Through Subaru/Gemini Time exchange Program
PID: S25A-069N/GN-2025-Q-212 (PI: Y. Hayashi)

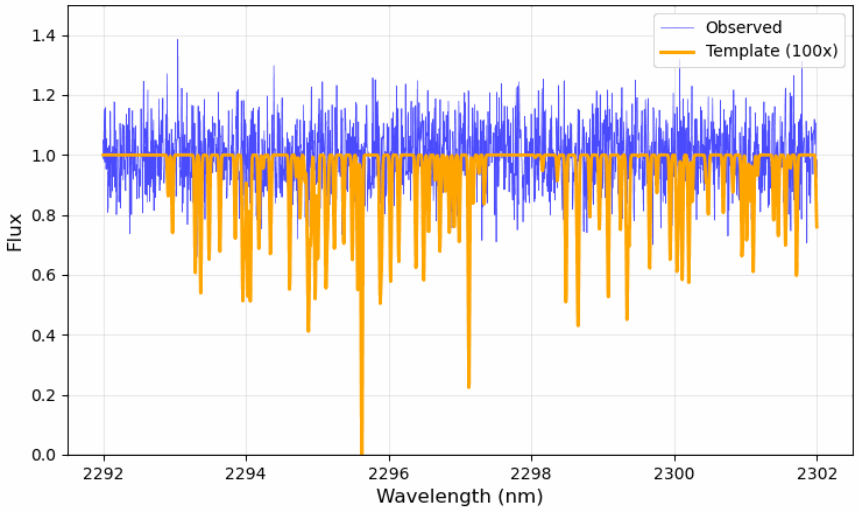
Observed in Feb – Mar, 2025
~10 hrs observation in total

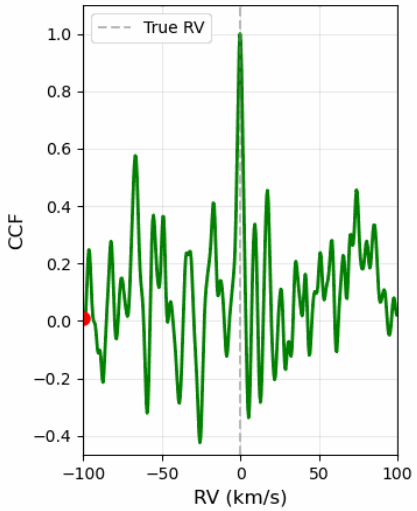
Exoplanet Atmosphere with High Spectral Resolution



Animation by Lennart van Sluijs

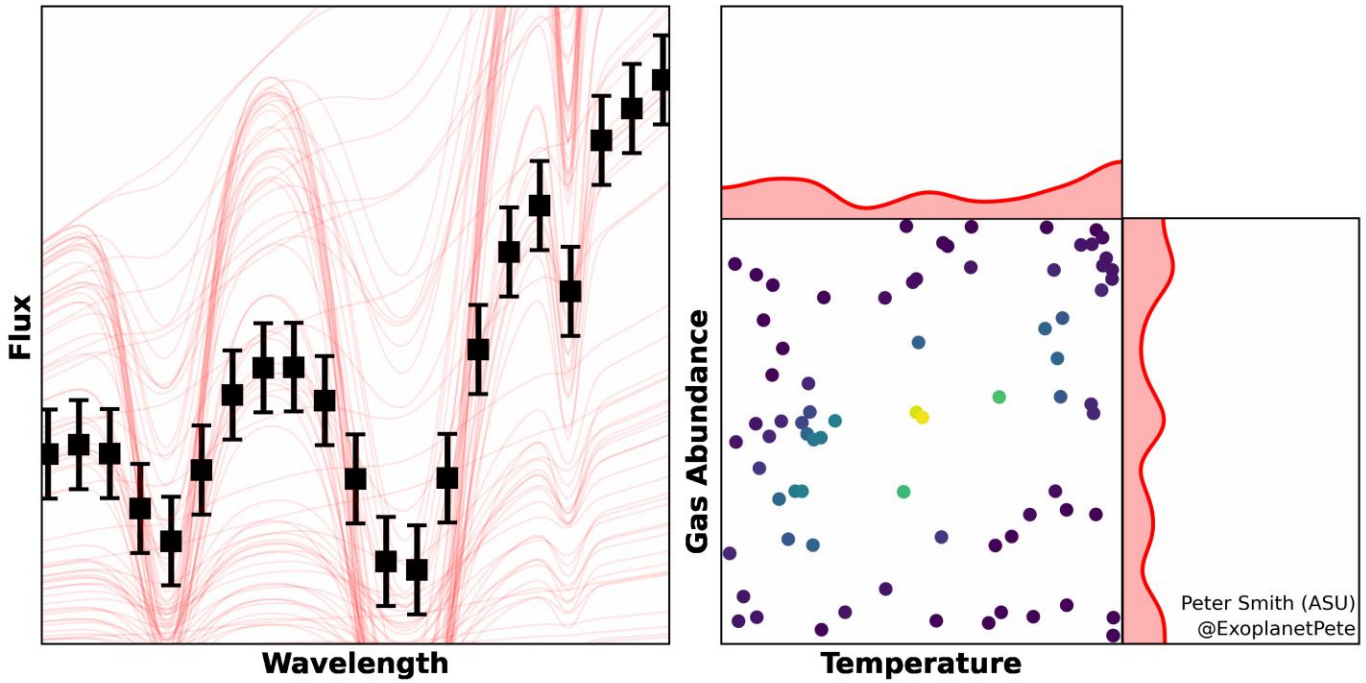
Combine N lines → S/N improve $\sqrt{N}$ times





$$\mathrm{CCF}(v) = \sum_{i}^{N} \frac{f_i m_i(v)}{\sigma^2}$$

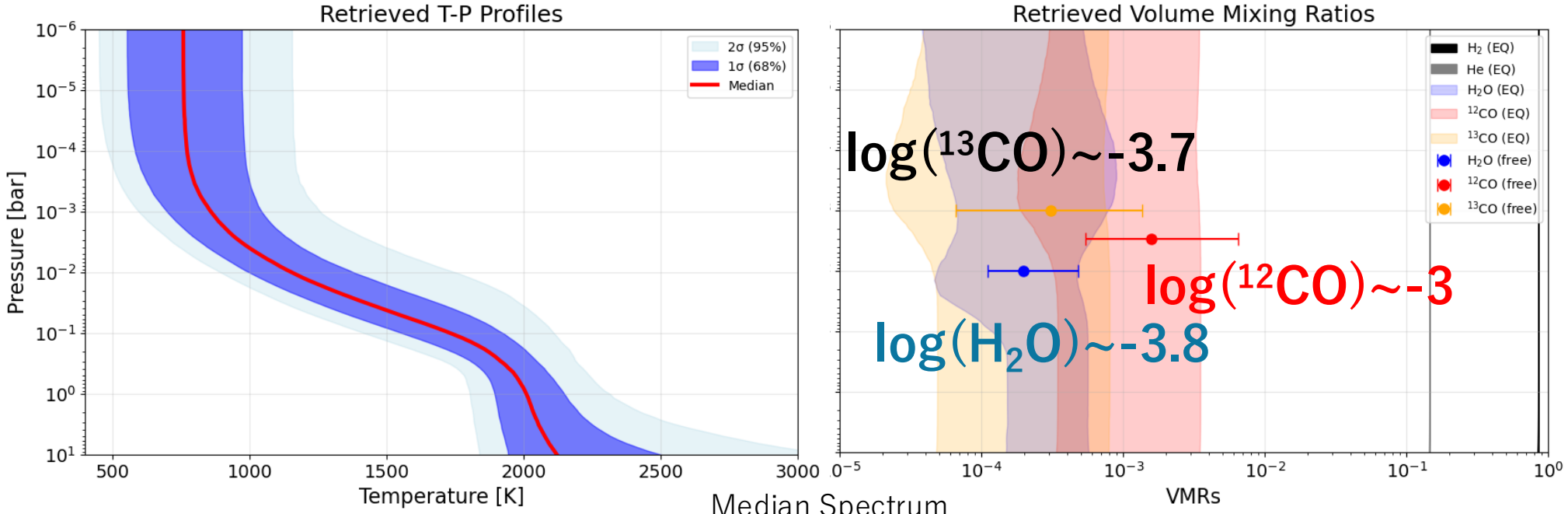
Analysis: Atmospheric Retrieval

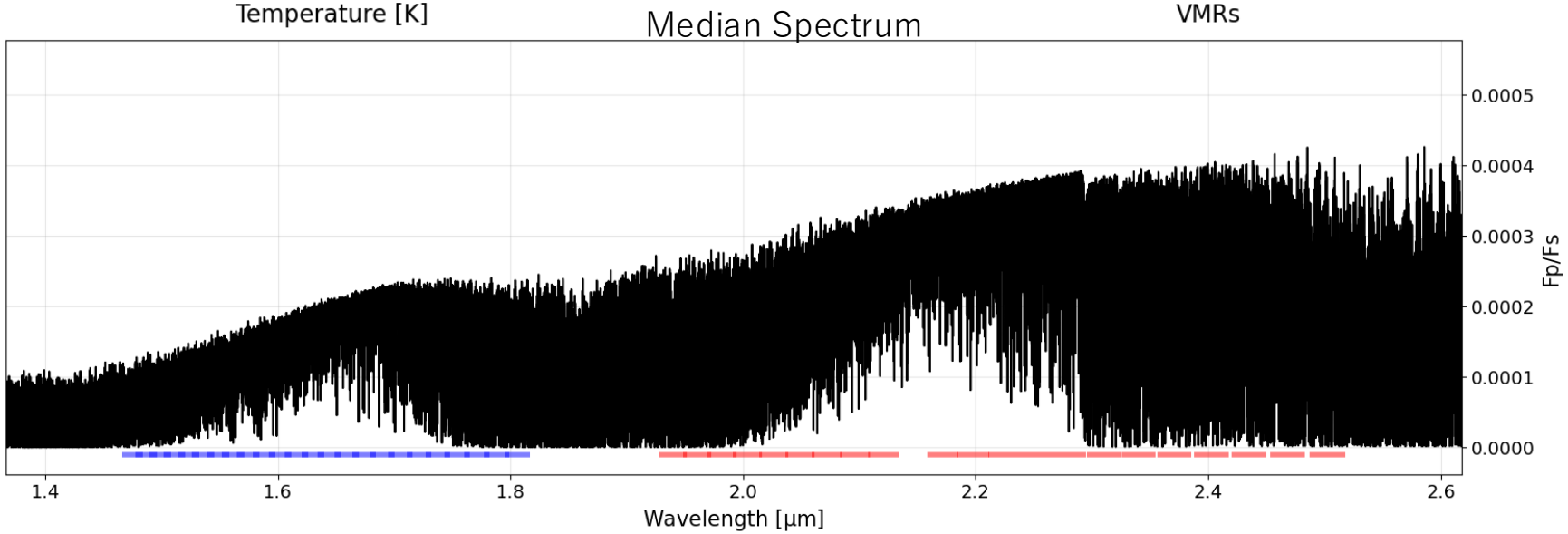


- Compare forward models with observed spectrum
- Bayesian inference
  → constrain model parameters with error bars

  (Abundance, Temperature …)

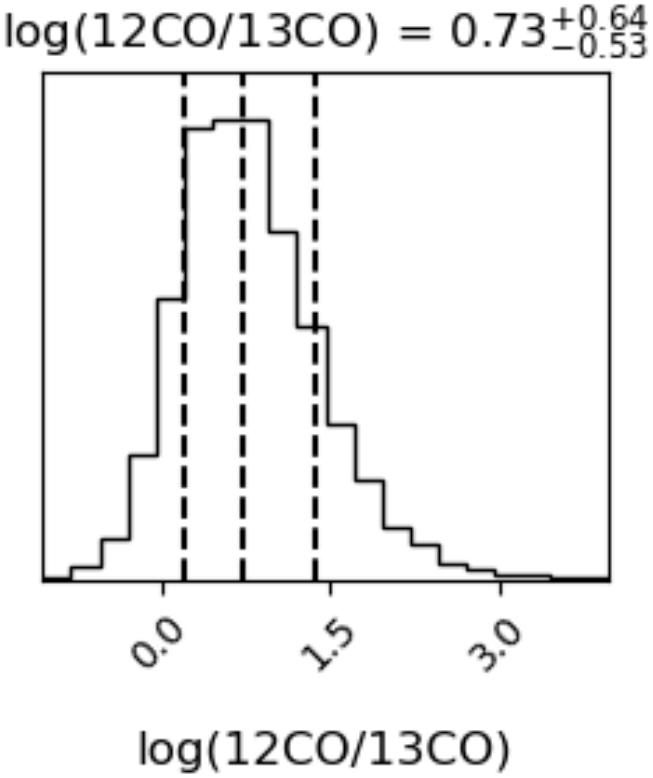
Results: Chemical Abundances and Temperature

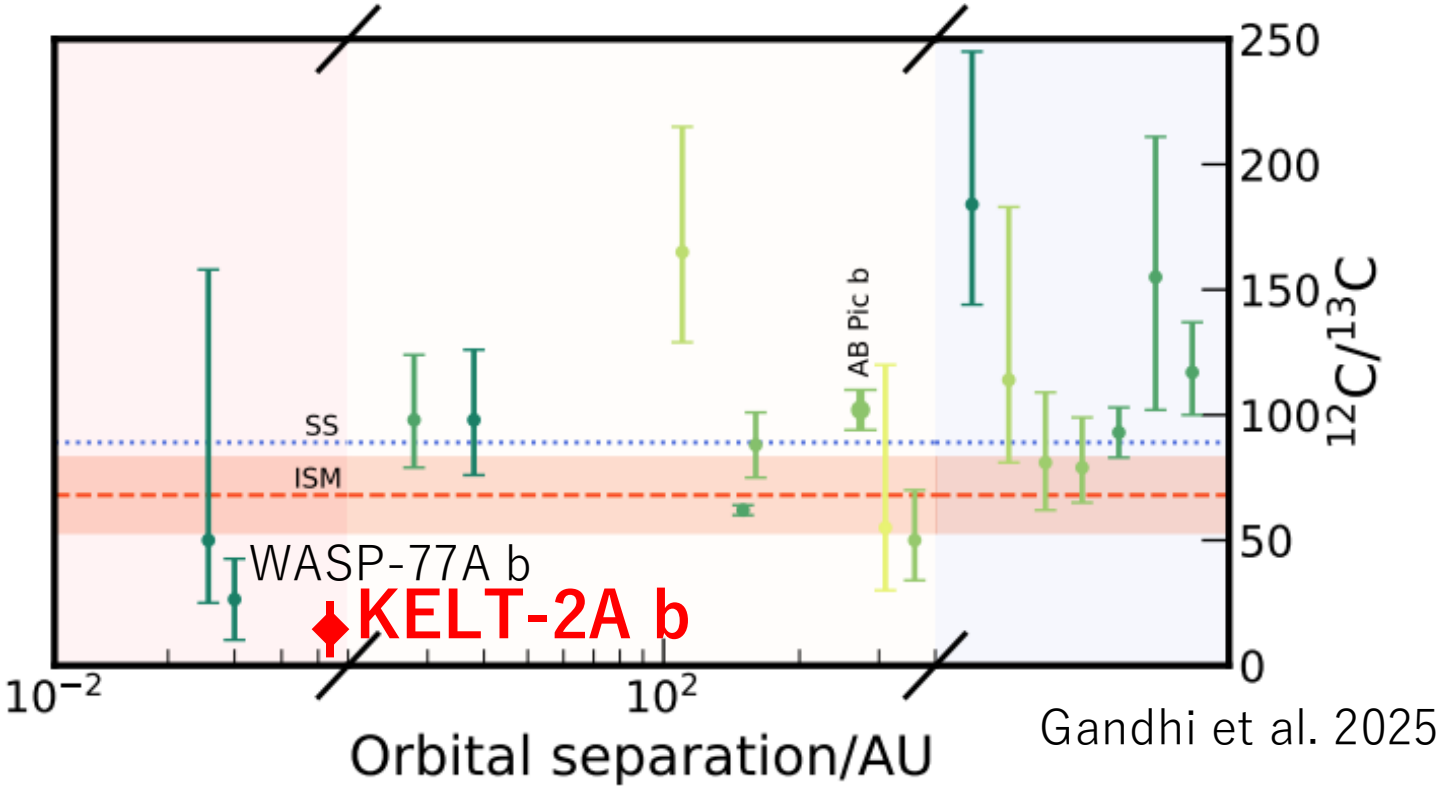




Results: Isotope ratio

$$12CO/13CO = 5.4^{+18}_{-3.8}$$



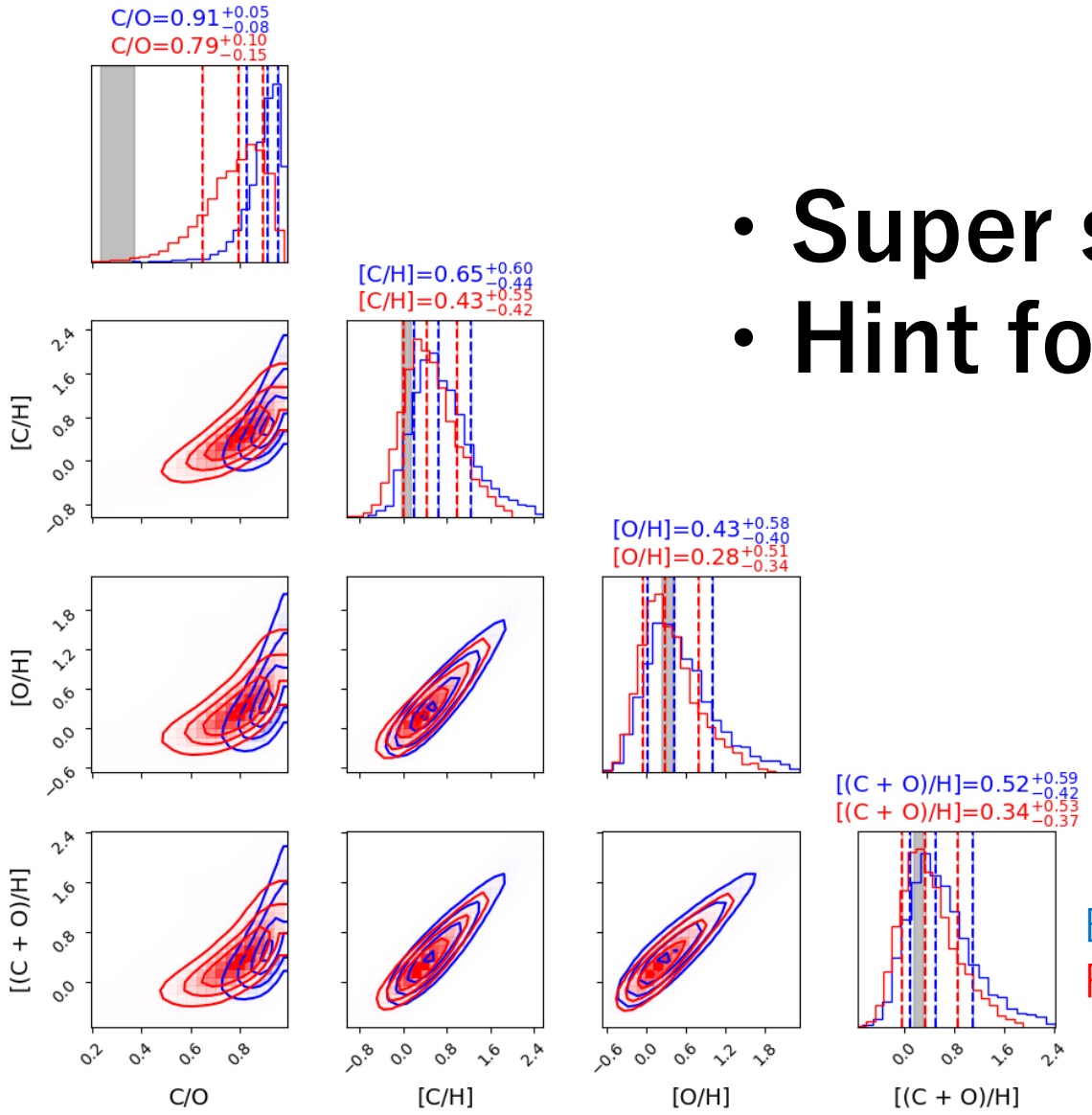


Gandhi et al. 2025

13C-enriched, like WASP-77 Ab

(2nd close-in planet with 12C/13C well bounded constraint)

Results: Derived elemental Ratio

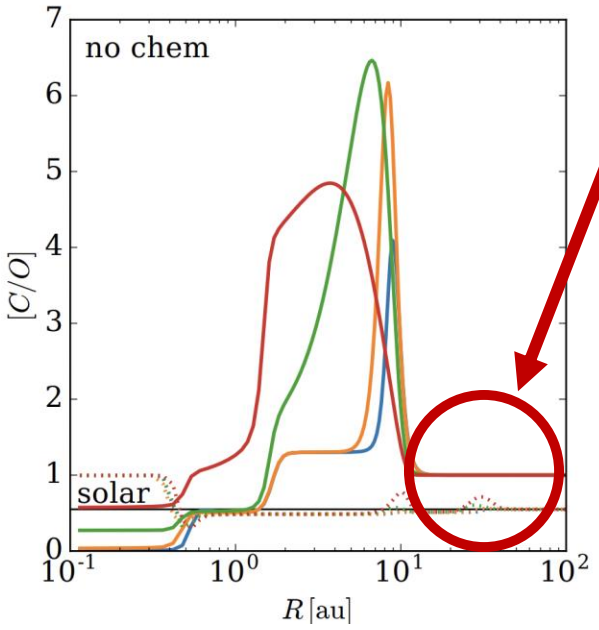


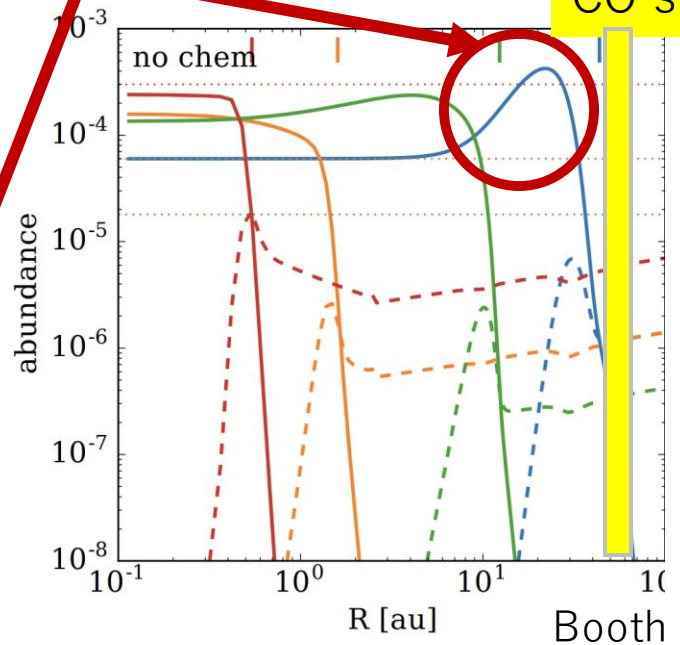
- **Super stellar C/O ratio**
- **Hint for High [(C+O)/H]**

Blue: Derived from Free chemistry
Red: Derived from Equilibrium chemistry

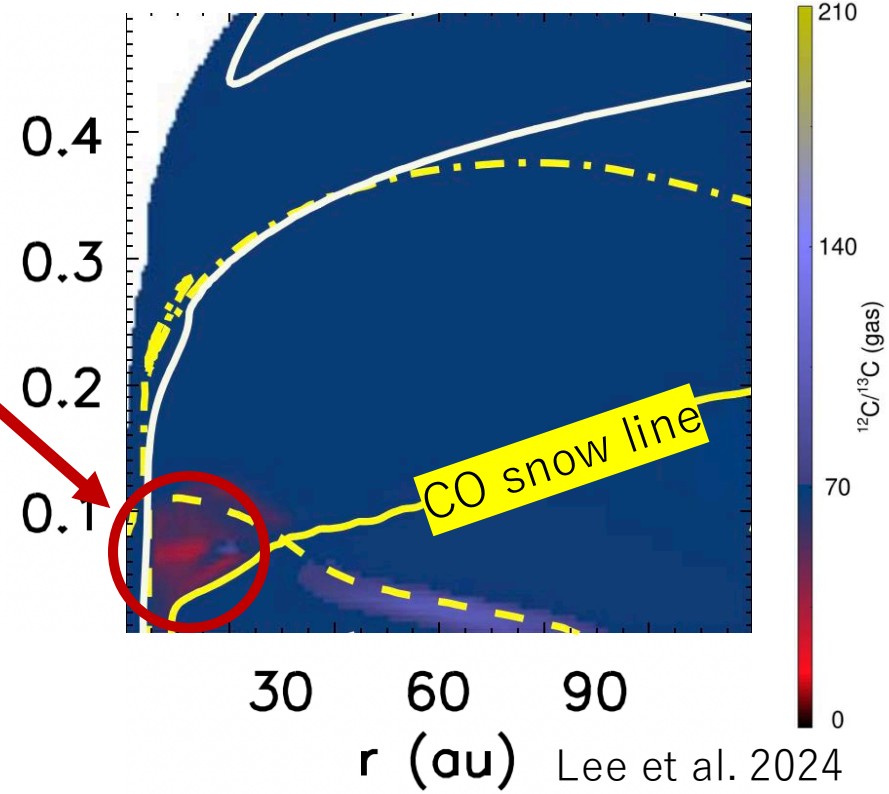
Discussion: Formation History

- 13C-enriched
  → **Accreted gas around CO snow line**
  (Excludes interior to the soot line)
- super stellar C/O (0.8~0.9)
- stellar ~ super stellar [C/H], [O/H]
  →**Pebble drift & CO sublimination**





CO snow line

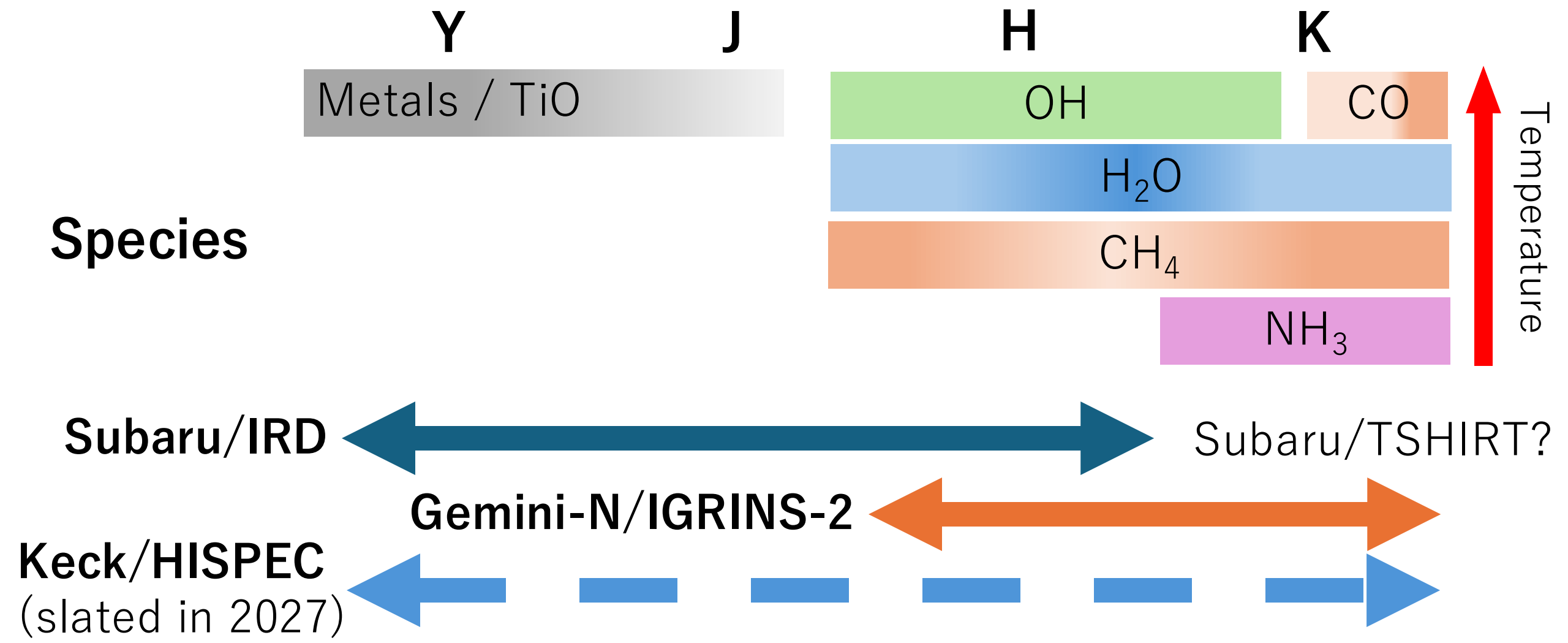


Lee et al. 2024

- **Formation far away (~30 au) & disk free migration**
- **Different [(C+O)/H] vs. W77A b → different formation radii?**

Booth and Ilee 2019

K-band High-Res is necessary !!!



Please expand the time exchange (or TSHIRT?)

Summary

- Isotope ratio can be a new constraint for planet formation
- KELT-2A b is unexpectedly 13C-enriched
  with a super-stellar C/O and hint for a high [(C+O)/H]
- KELT-2A b may accreted its gas around CO snow line
- Population level survey is needed to interpret 12C/13C
- K-band High-Res is needed for exoplanet atmosphere