The Diversity of Cold Worlds: Age and Characterization of the COCONUTS-2 T9 Brown Dwarf

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Getting ages for low-mass stars, is a current unsolved problem in Astrophysics

Methods to estimate ages of high-mass stars (>0.8 $M_{\odot}$):

For low-mass stars:

• Isochrone fitting	Small change in luminosity and Teff during it's lifetime to get a precise age.
• Asteroseismology	No evidence of pulsations yet. According to theory they should exist.
• Gyrochronology	No gyrochronology relation yet. We know rotation period is related to age.
• Empirical and statistical age relations	Key to understand evolution of low-mass stars

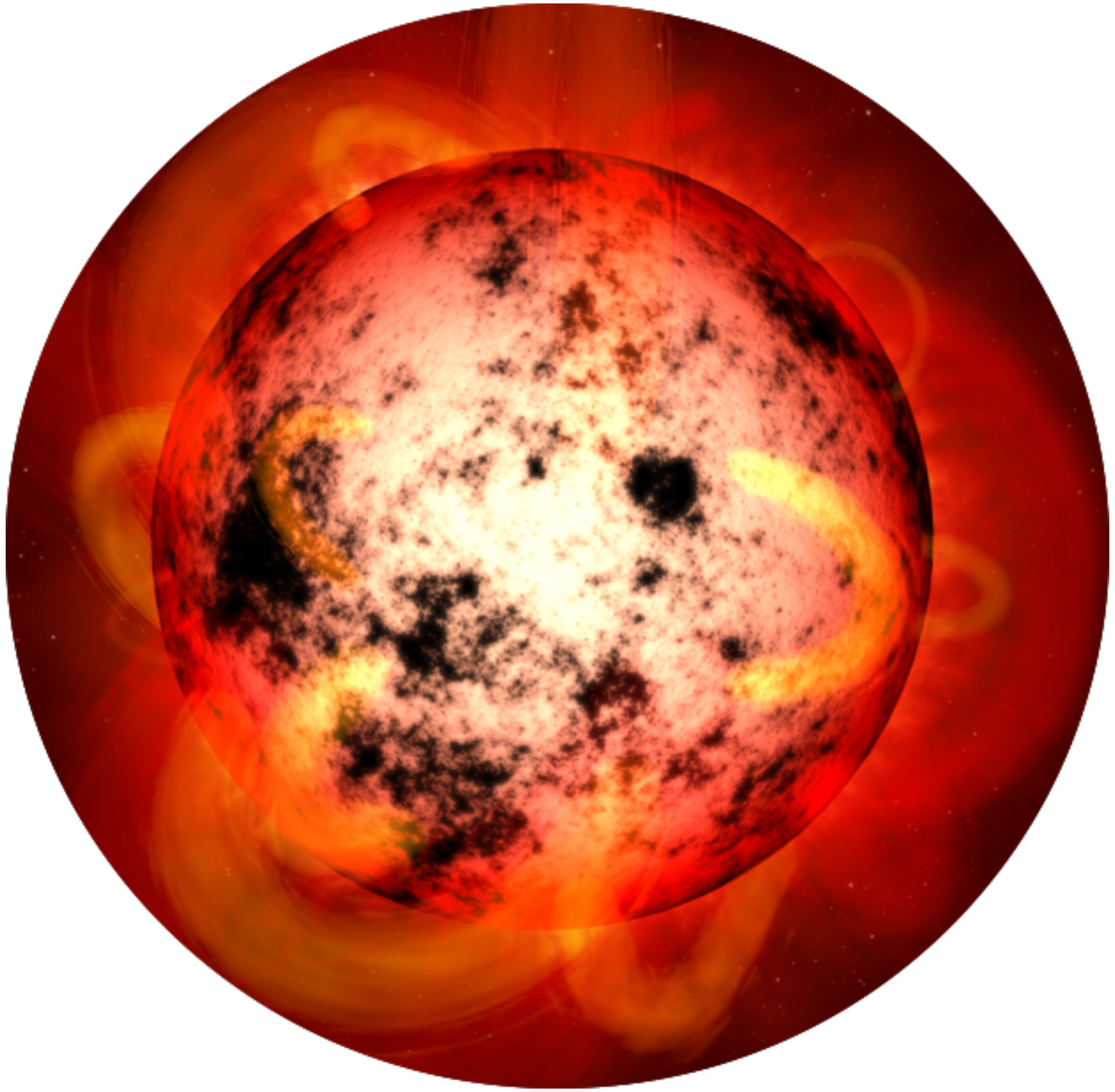
We use different measurable properties of M dwarfs to estimate ages

Color-magnitude diagram position

Rotation

Kinematics

Magnetic fields



Ages of stars are key in this exciting era to study exoplanets and brown dwarfs

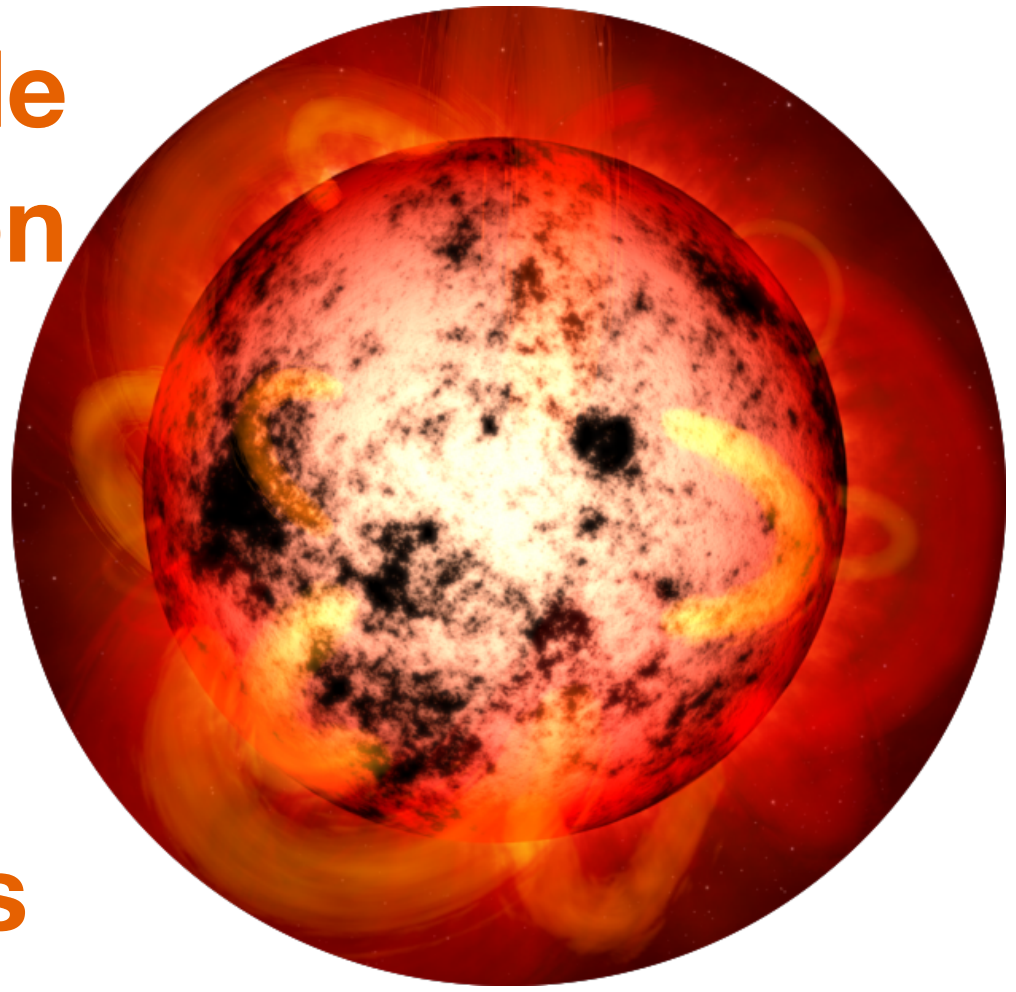
Low-mass stars ⟺ Brown dwarfs   Exoplanets

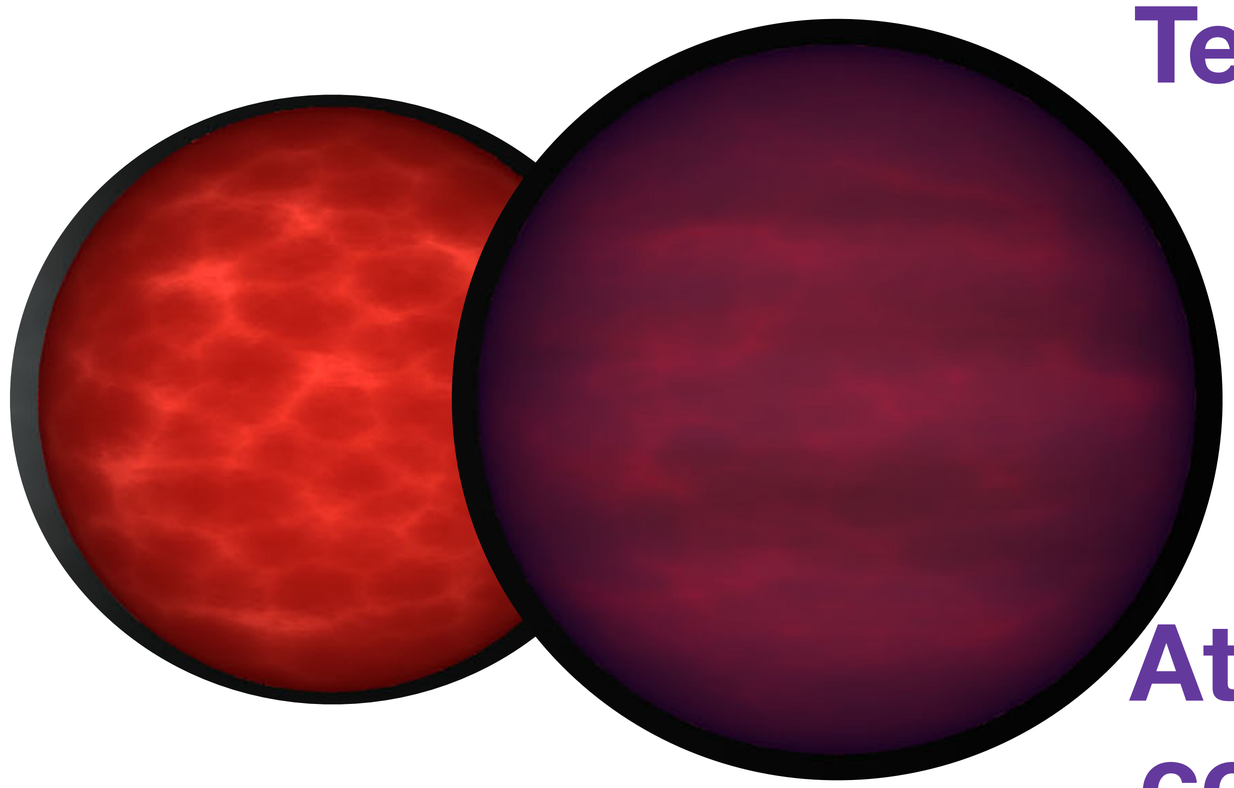
Color-magnitude diagram position

Rotation

Kinematics

Magnetic fields





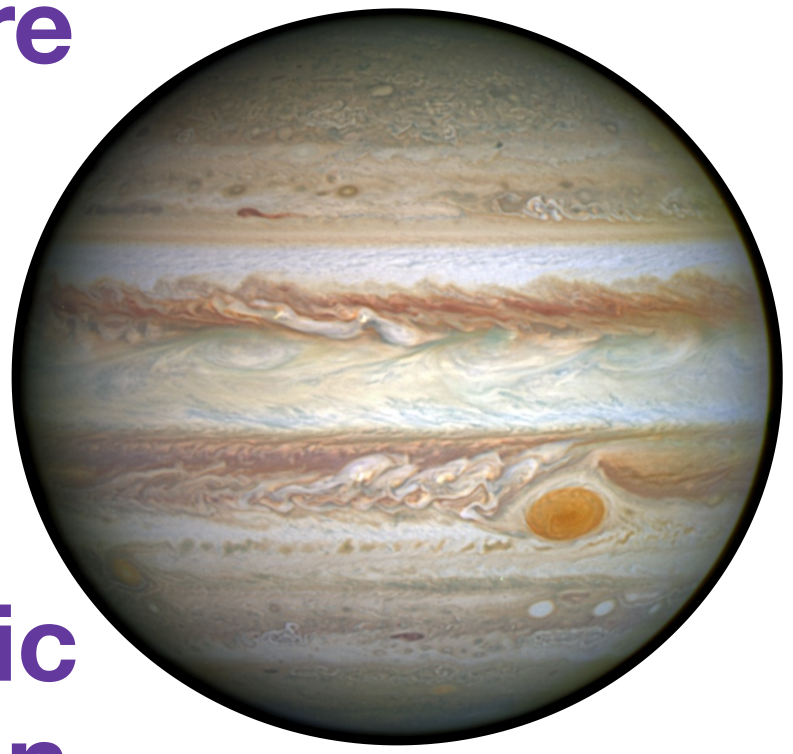
Temperature

Mass

Radius

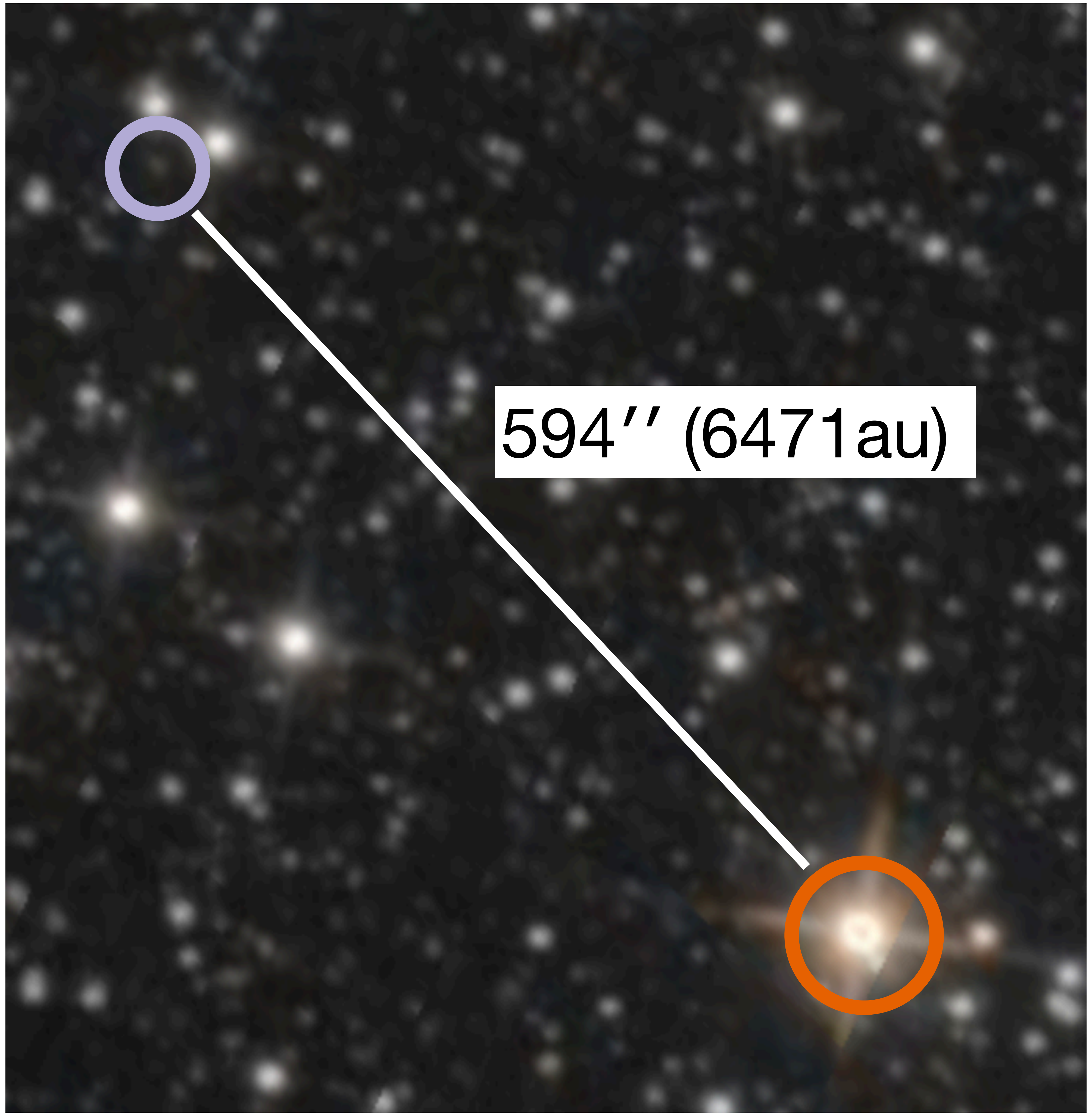
Atmospheric composition

Formation



We can use stellar ages to break the age-mass degeneracy of brown dwarfs

COCONUTS-2: Wide brown dwarf-M dwarf binary

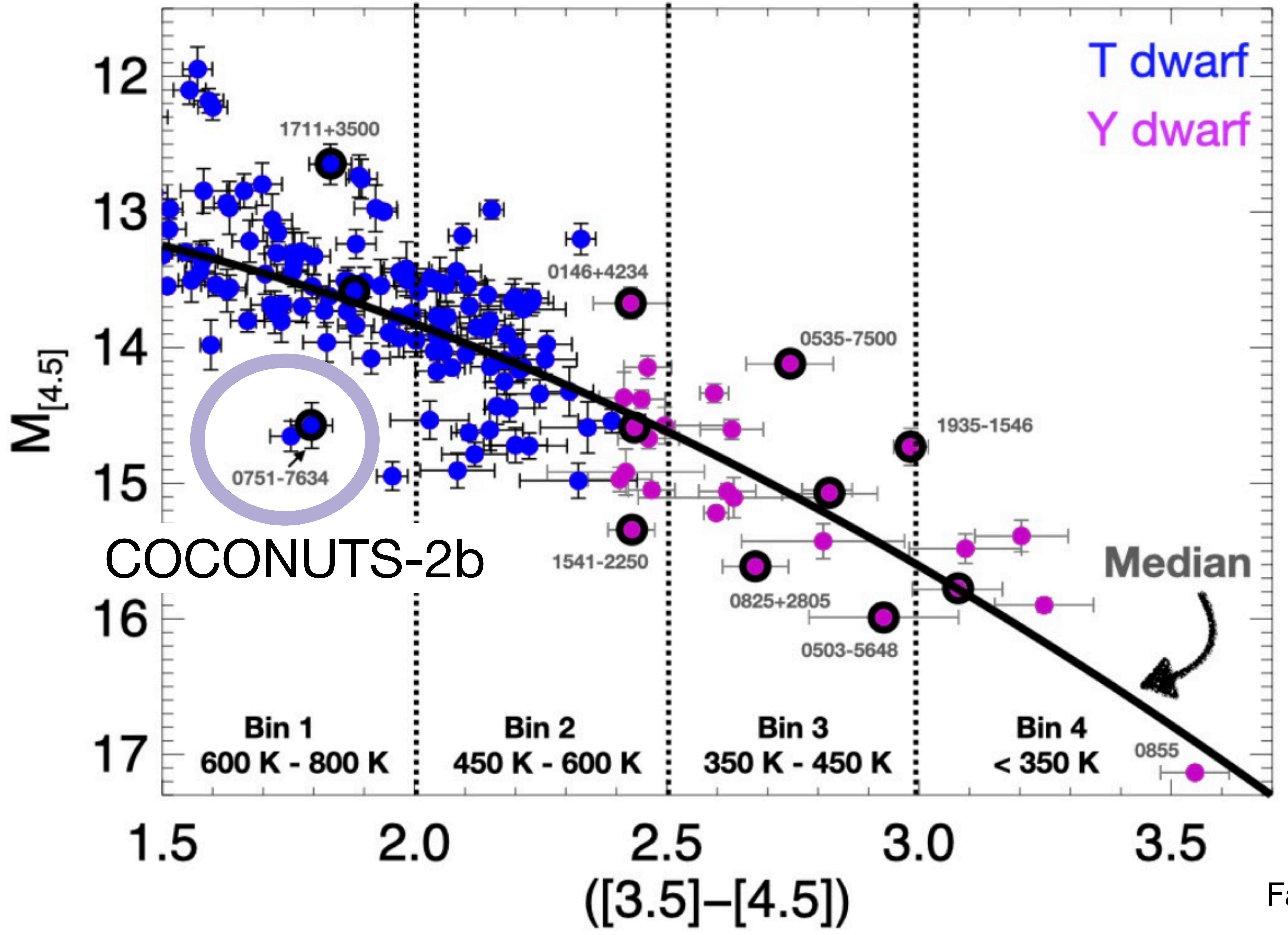


- COCONUTS-2A || L 34-26
- M3
- 91.83 ± 0.02 mas || 10.8 pc
- 150 - 800 Myr

- COCONUTS-2b
  WISEPA J075108.79−763449.6
- T9
- 97.9 ± 6.7 mas || 10.2 pc

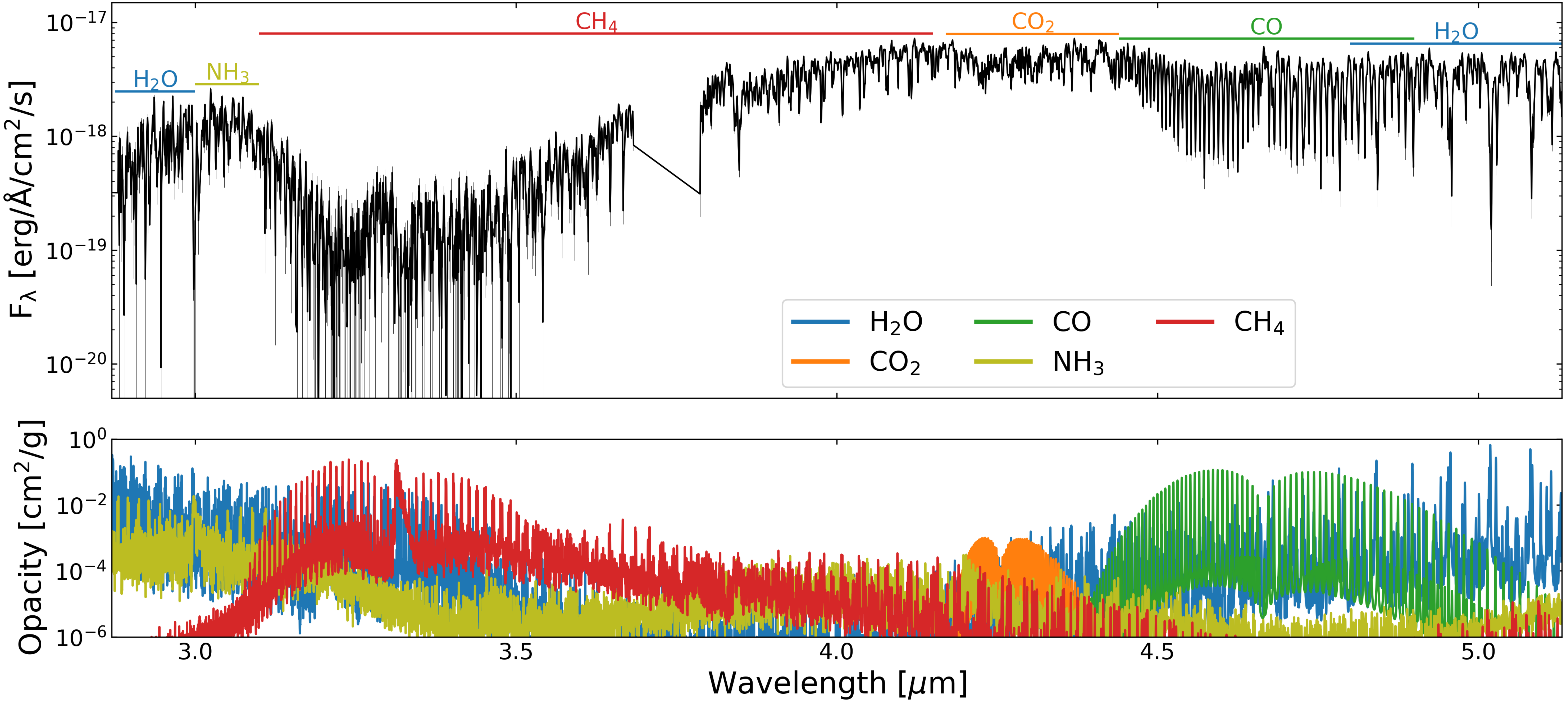
Zhang et al. 2021, 2024, Marocco et al. 2024
Kirkpatrick et al. 2019

2124 JWST program to obtain NIRSPEC spectrum and MIRI photometry for 12 cold brown dwarfs

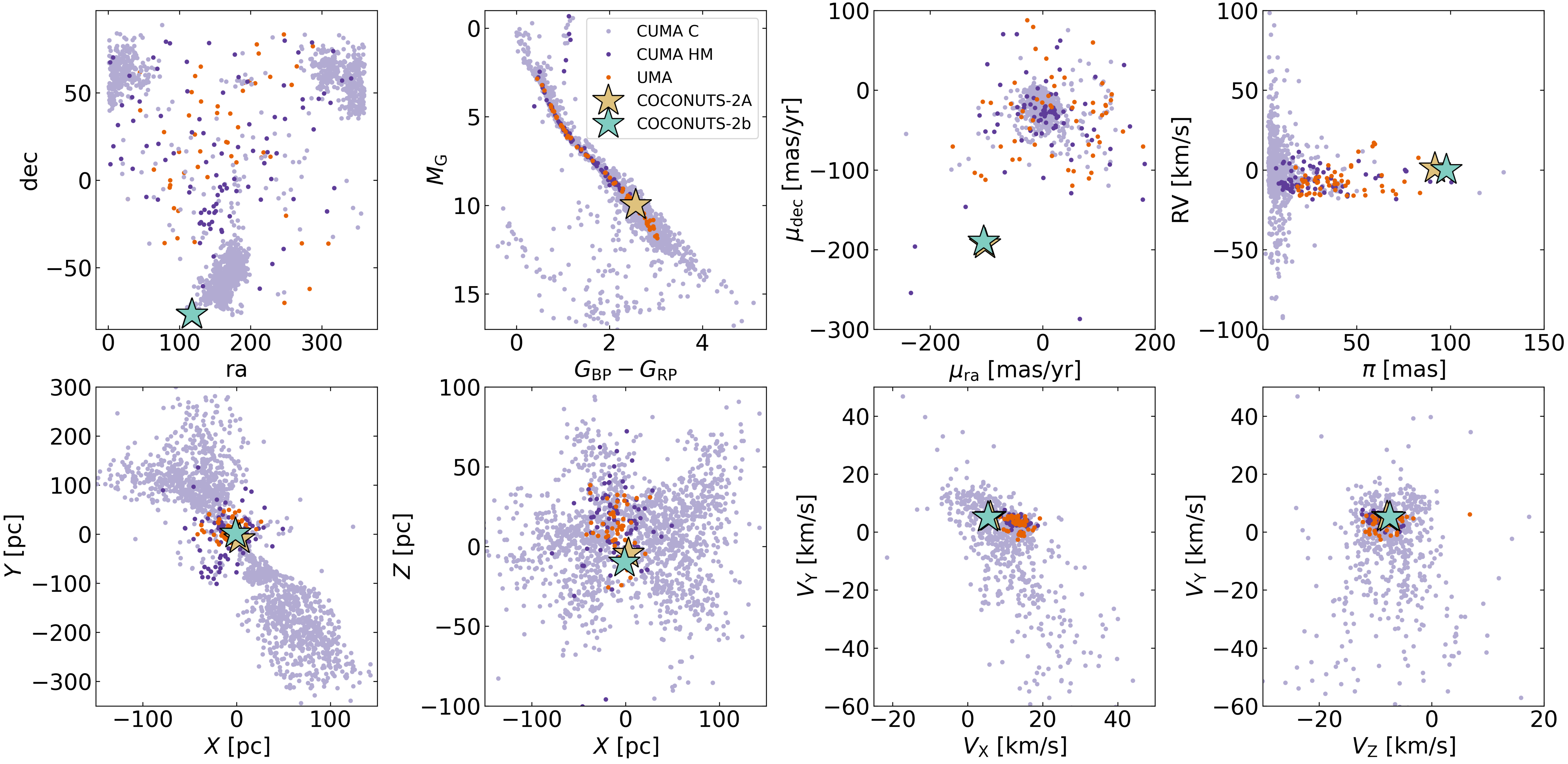


Faherty et al. in prep

Atmospheric composition of COCONUTS-2b

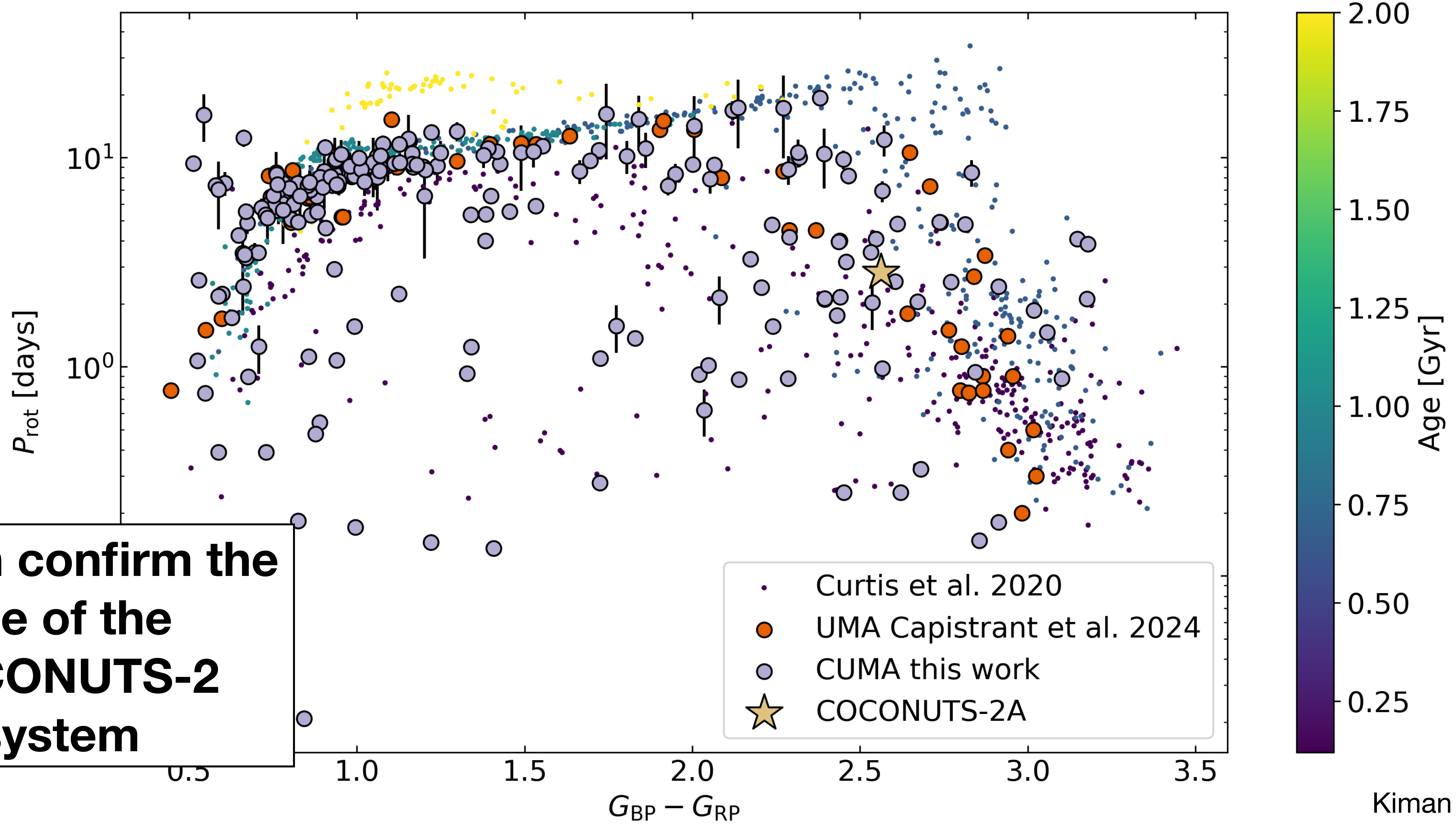


According to BANYAN Σ COCONUTS-2 belongs to the Corona of the Ursa Major (CUMA) moving group: 414.0 ± 23.0 Myr



Kiman et al. submitted

Confirmation of membership: We measured rotation periods from TESS data



We can confirm the age of the COCONUTS-2 system

Kiman et al. submitted

We can estimate fundamental parameters given that we can break the degeneracy using the age of the system

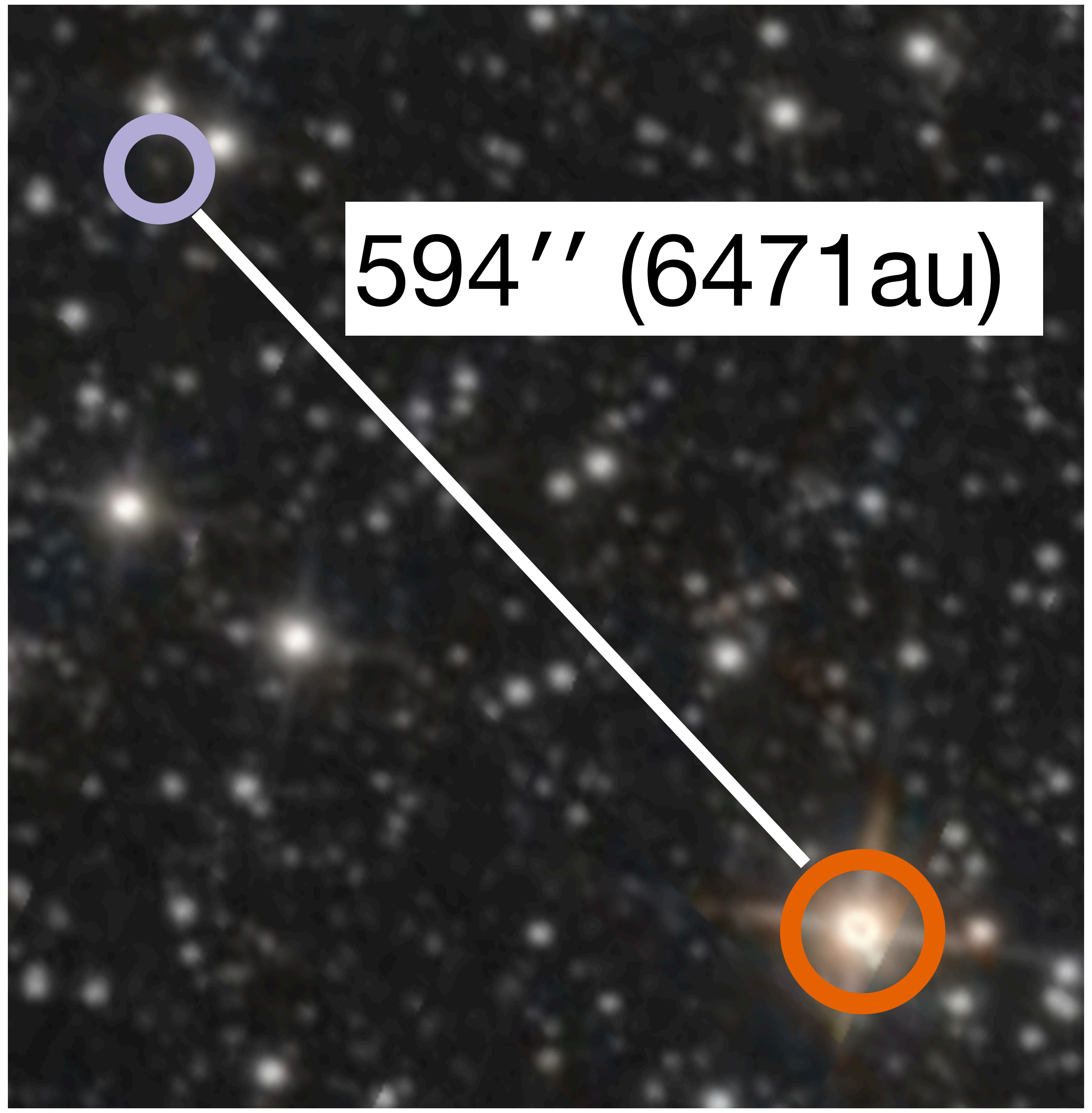
With SEDkit (Filippazzo et al. 2015):

$\log_{10}(L_{bol}/L_\odot)$ = -6.15 ± 0.03 dex
Age = 414.0 ± 23.0 Myr
Teff = 497 +/- 10 K

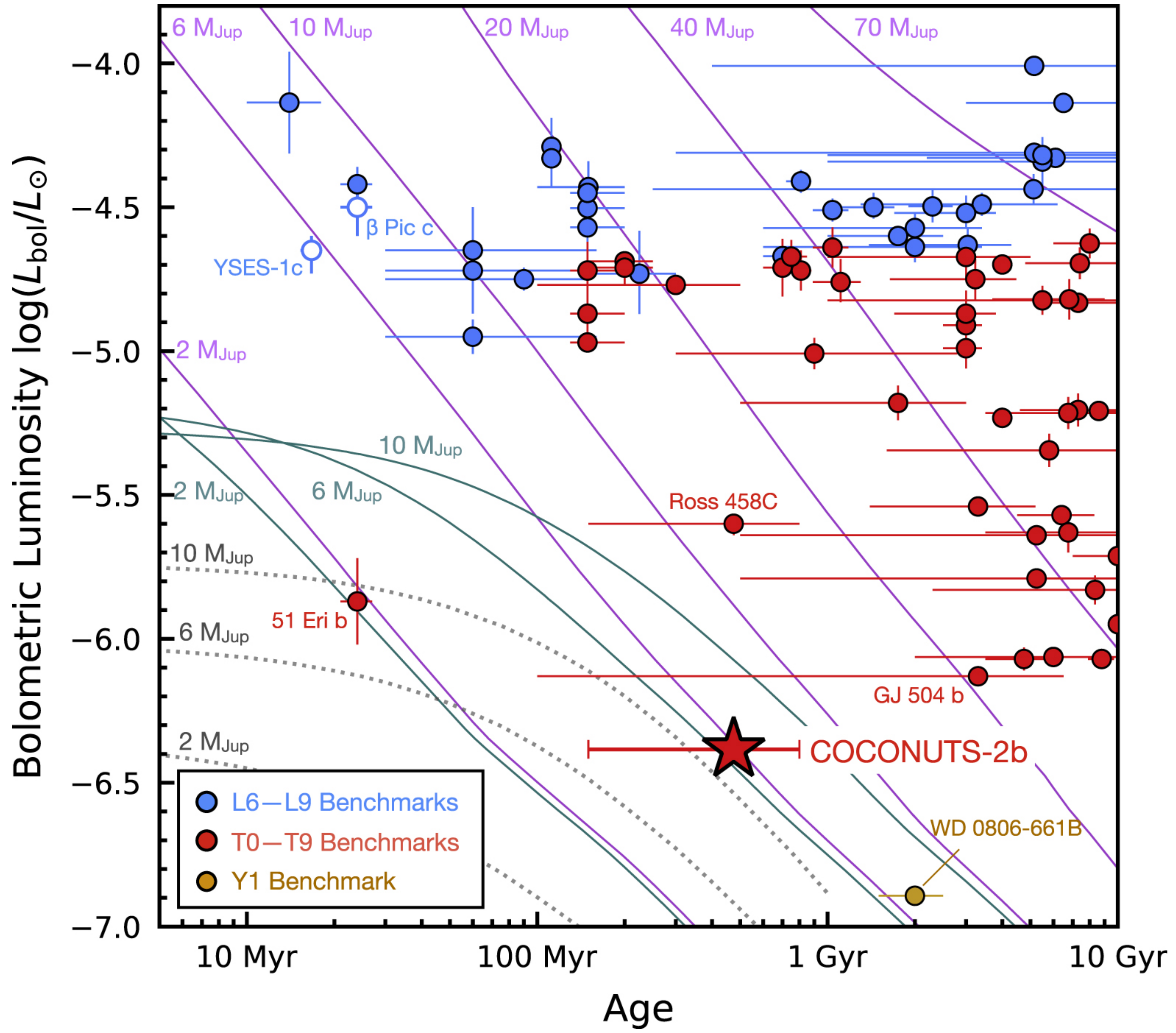
logg = 4.22 +/- 0.09 dex
Mass = 8.30 +/- 1.3 M_J
Radius = 1.107 +/- 0.02 R_J

Kiman et al. submitted

How can we form a system like COCONUTS-2?



Zhang et al. 2021, 2024
- From age and luminosity concluded that it formed like a star



Marocco et al. 2024
- Star
- Planet
- Capture

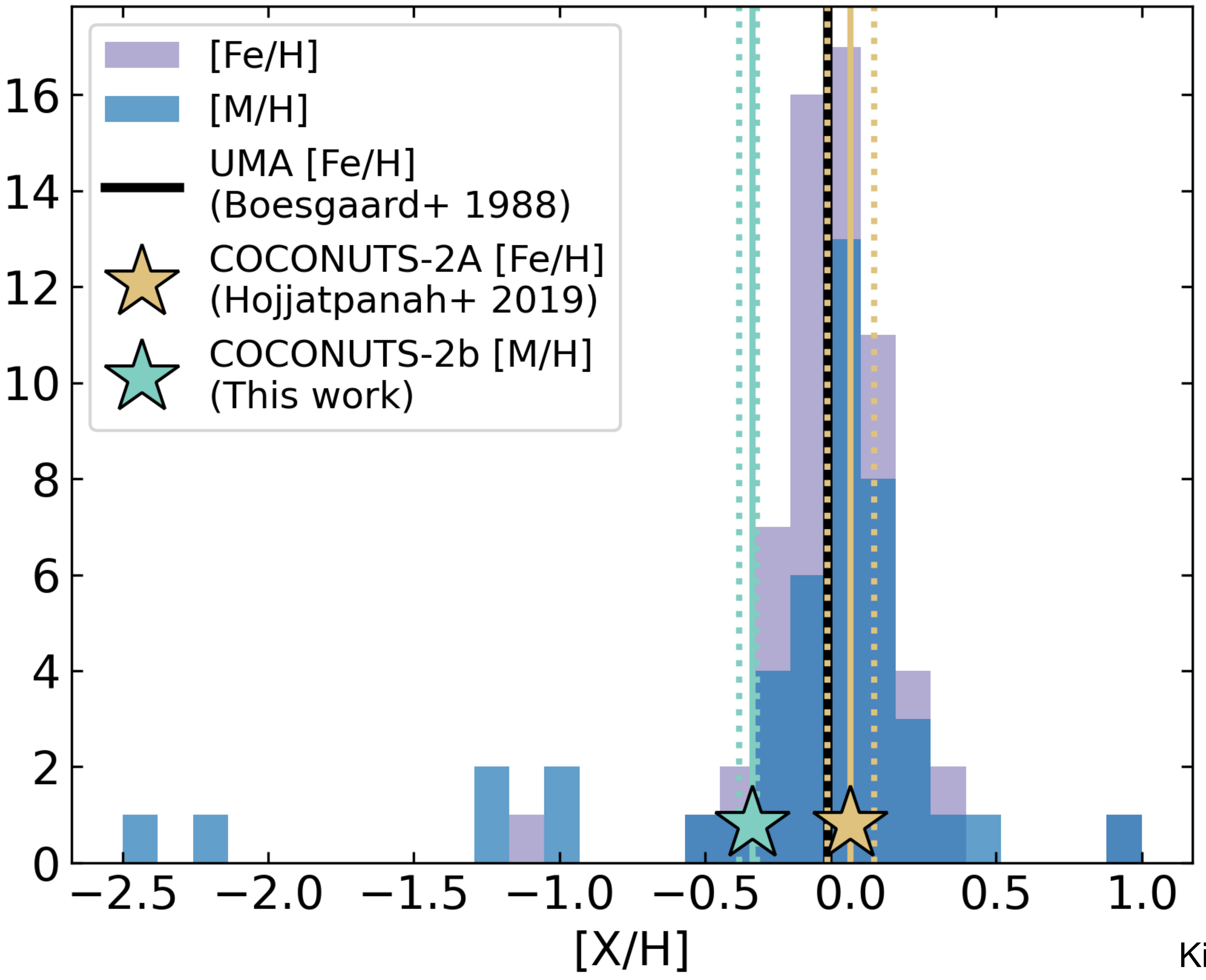
We can use the members of CUMA to answer this question

Metallicity of members of CUMA compared to COCONUTS-2

Compilation of metallicities from:

- APOGEE DR17
- GALAH-DR3
- RAVE-DR6
- LAMOST-DR7

Forward modeling analysis to get [M/H] for COCONUTS-2b



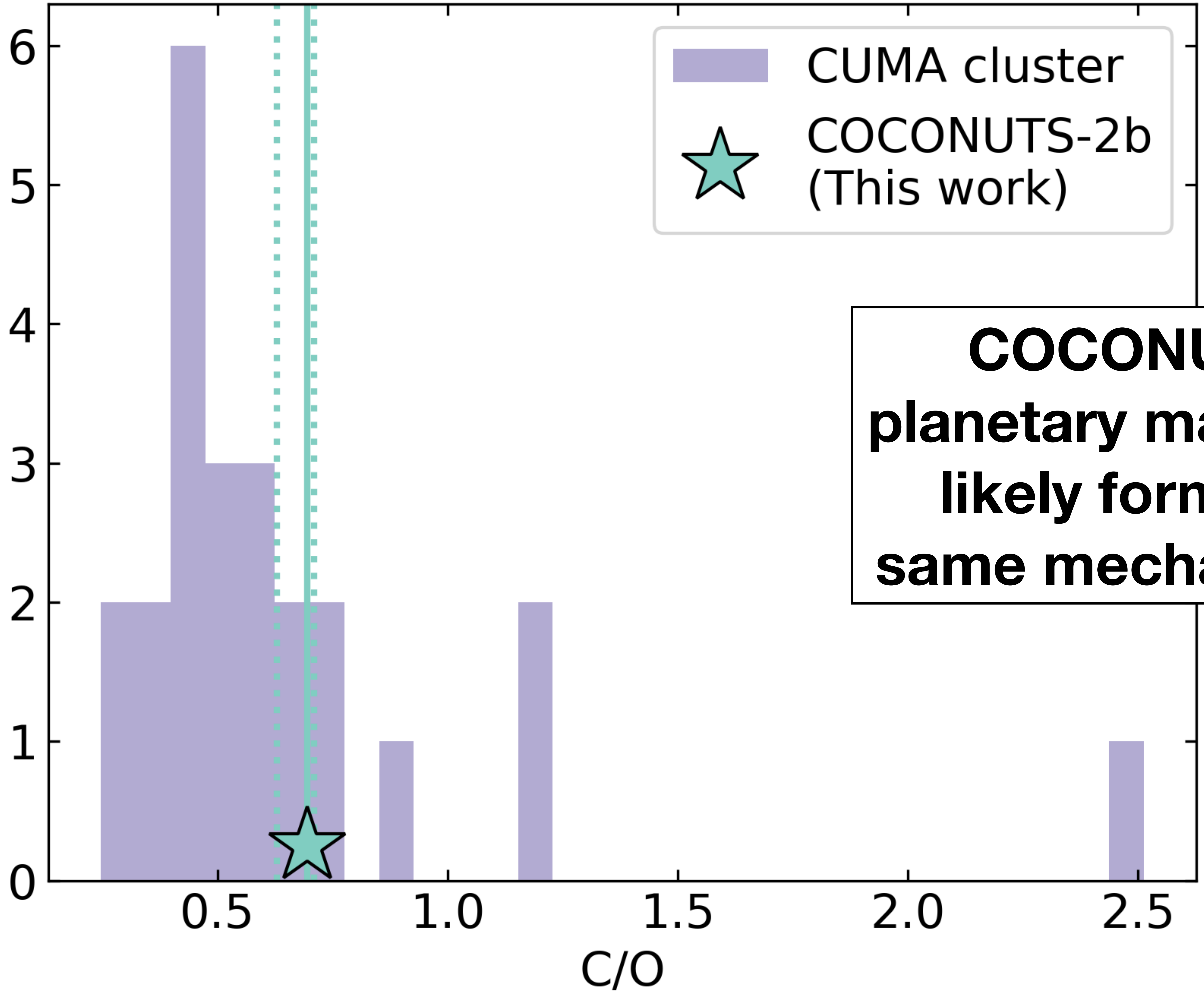
Kiman et al. submitted

C/O ratio of members of CUMA compared to COCONUTS-2b

Compilation of metallicities from:

- APOGEE DR17
- GALAH-DR3
- RAVE-DR6
- LAMOST-DR7

Forward modeling analysis to get C/O ratio for COCONUTS-2b



COCONUTS-2b is a planetary mass object that likely formed with the same mechanism as stars

Kiman et al. submitted

Conclusions

- COCONUTS-2 belongs to the CUMA cluster according to its kinematics (414.0 ± 23.0 Myr), and we confirmed the membership using rotation periods, metallicity and C/O ratio
- We obtained fundamental parameters for COCONUTS-2b with the full SED
- Given its metallicity and C/O ratio, COCONUTS-2b is a planetary mass object that formed like a star
- The comparison of composition of two possible members of CUMA can help to understand vertical mixing

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