Greening of the brown dwarf desert

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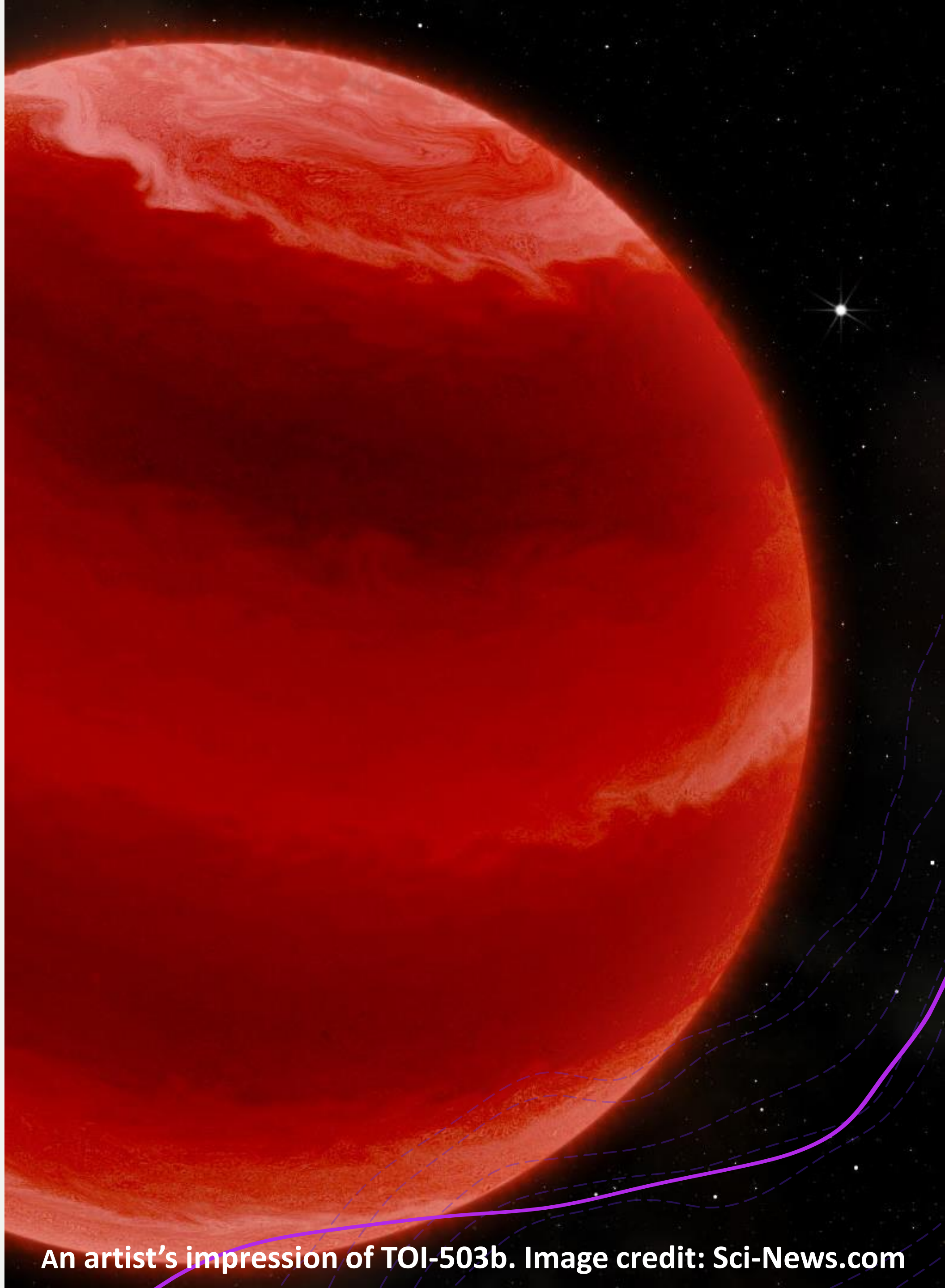
Brown dwarfs (BDs)

+ loosely defined as the objects that separate giant planets from low-mass stars
+ based on the mass of BDs
+ from 11 – 16 MJ to 75 – 80 MJ



An artist's impression of TOI-503b. Image credit: Sci-News.com

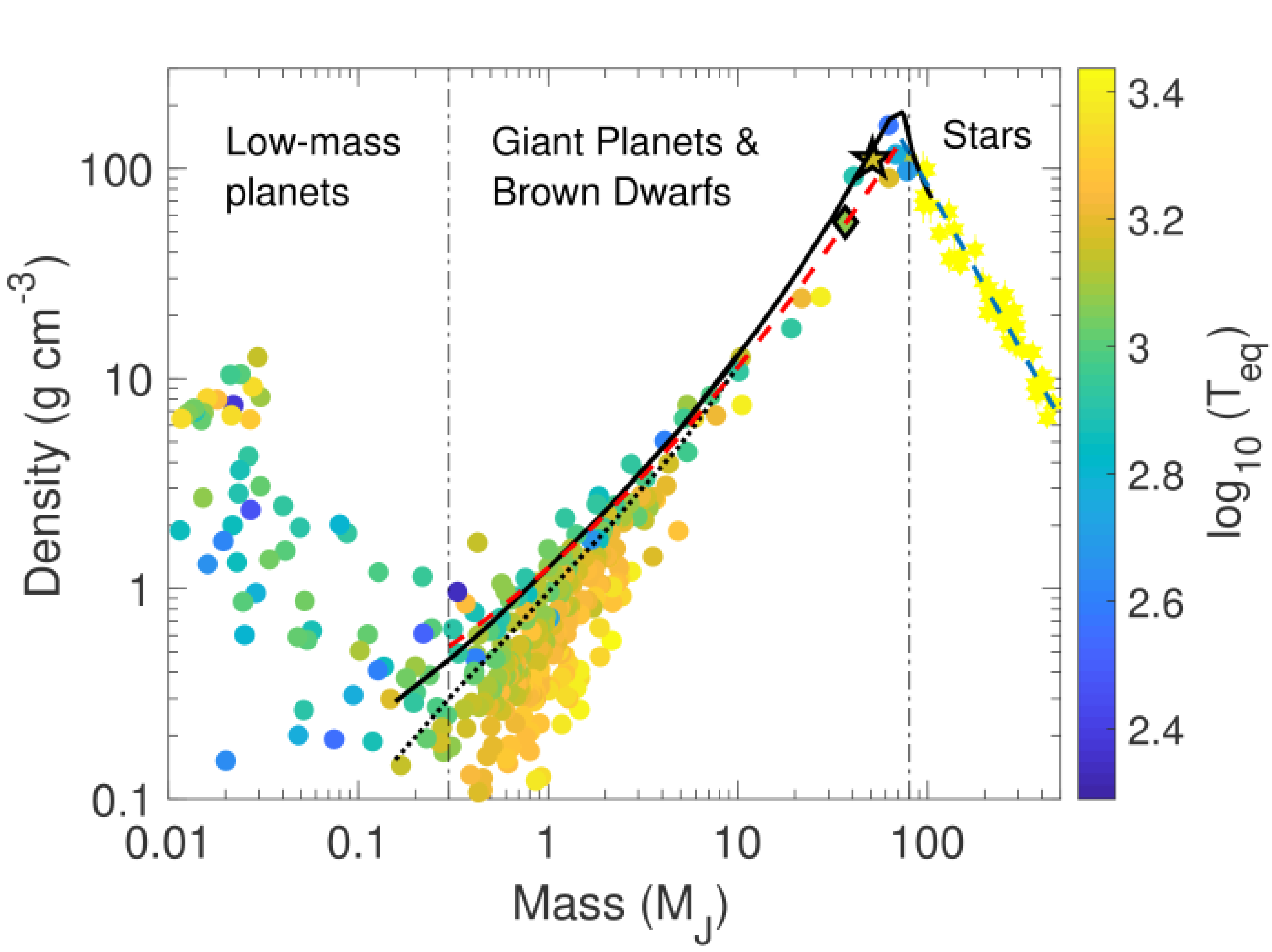
Different definitions

Formation processes

+ BDs are considered to form like stars from gravitational instability
+ GPs form on a longer timescale by core accretion
+ by this definition BDs and GPs overlap 3Mj – tens of Mj

- BDs should not be distinguished from hydrogen-burning stars as they have more similarities to stars than planets (Whitworth 2018).

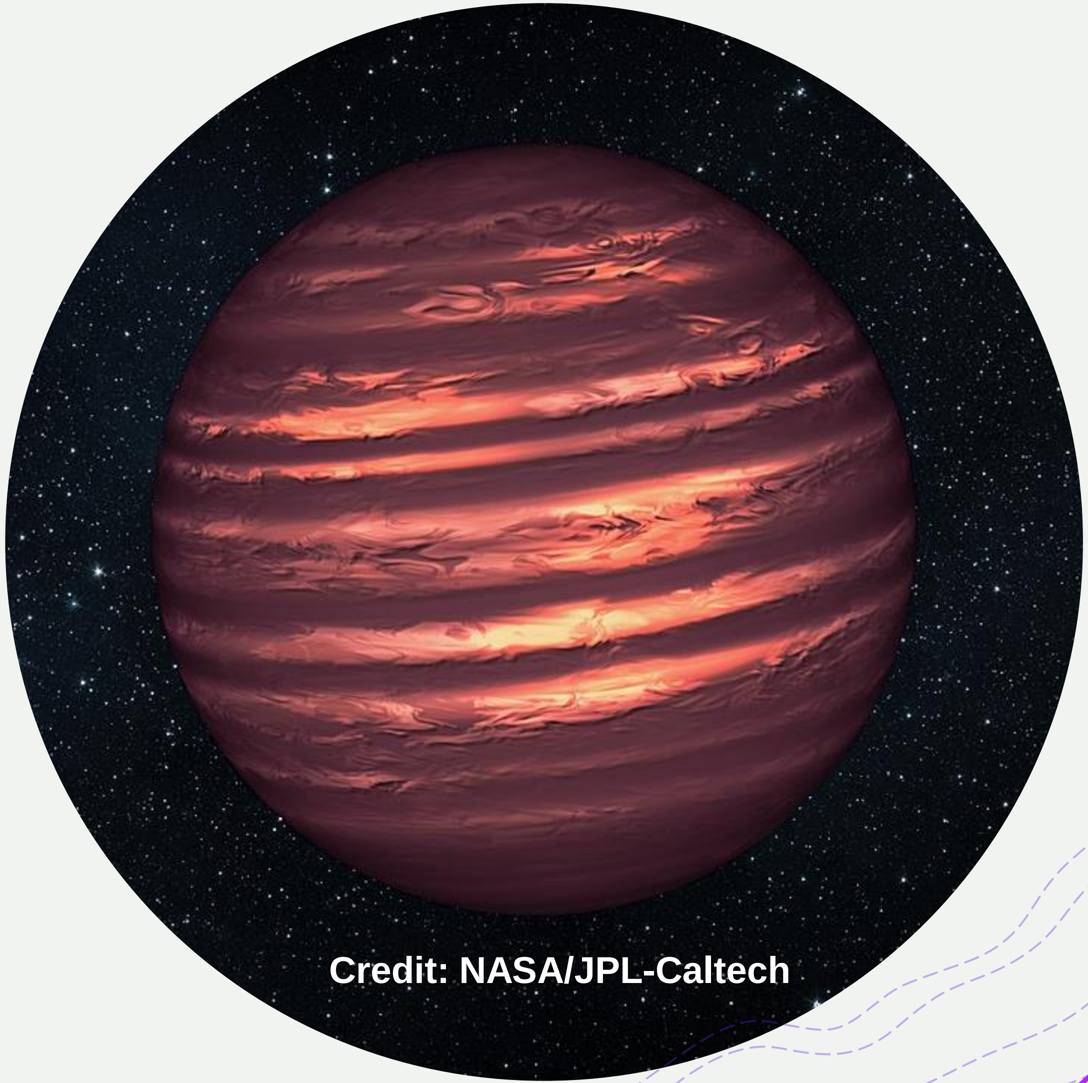
- Hatzes & Rauer (2015), on the other hand, suggest that BDs should be classified as GPs instead of a separate class of their own based on the mass-density relationship.



Persson et al. 2019

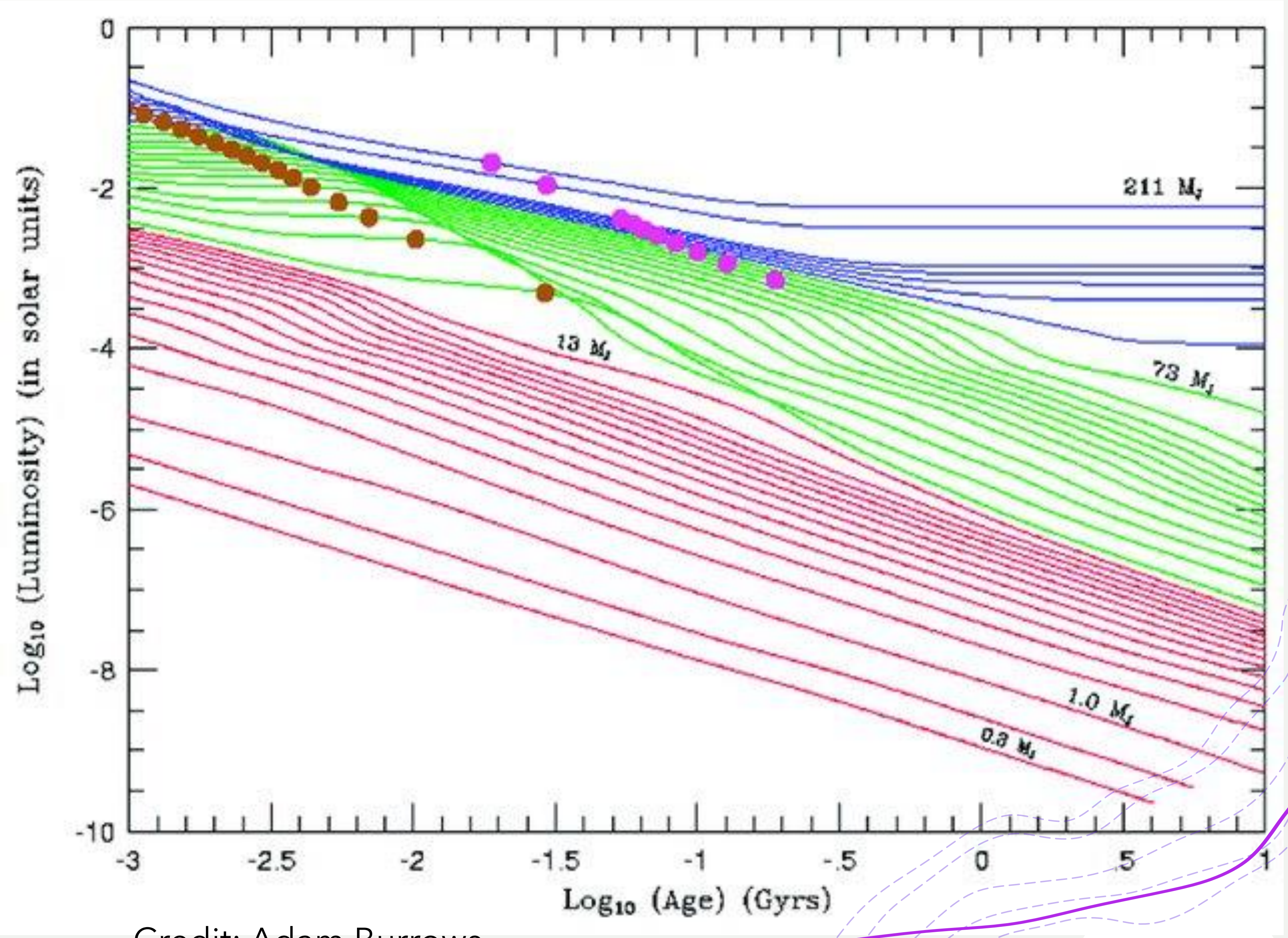
History

- In 1963 University of Virginia astronomer Shiv Kumar theorized that the same process of gravitational contraction that creates stars from vast clouds of gas and dust would also frequently produce smaller objects
- The name “brown dwarf” was suggested in 1975 by astrophysicist Jill C. Tarter
- In the mid 1980s astronomers began an intensive search for brown dwarfs

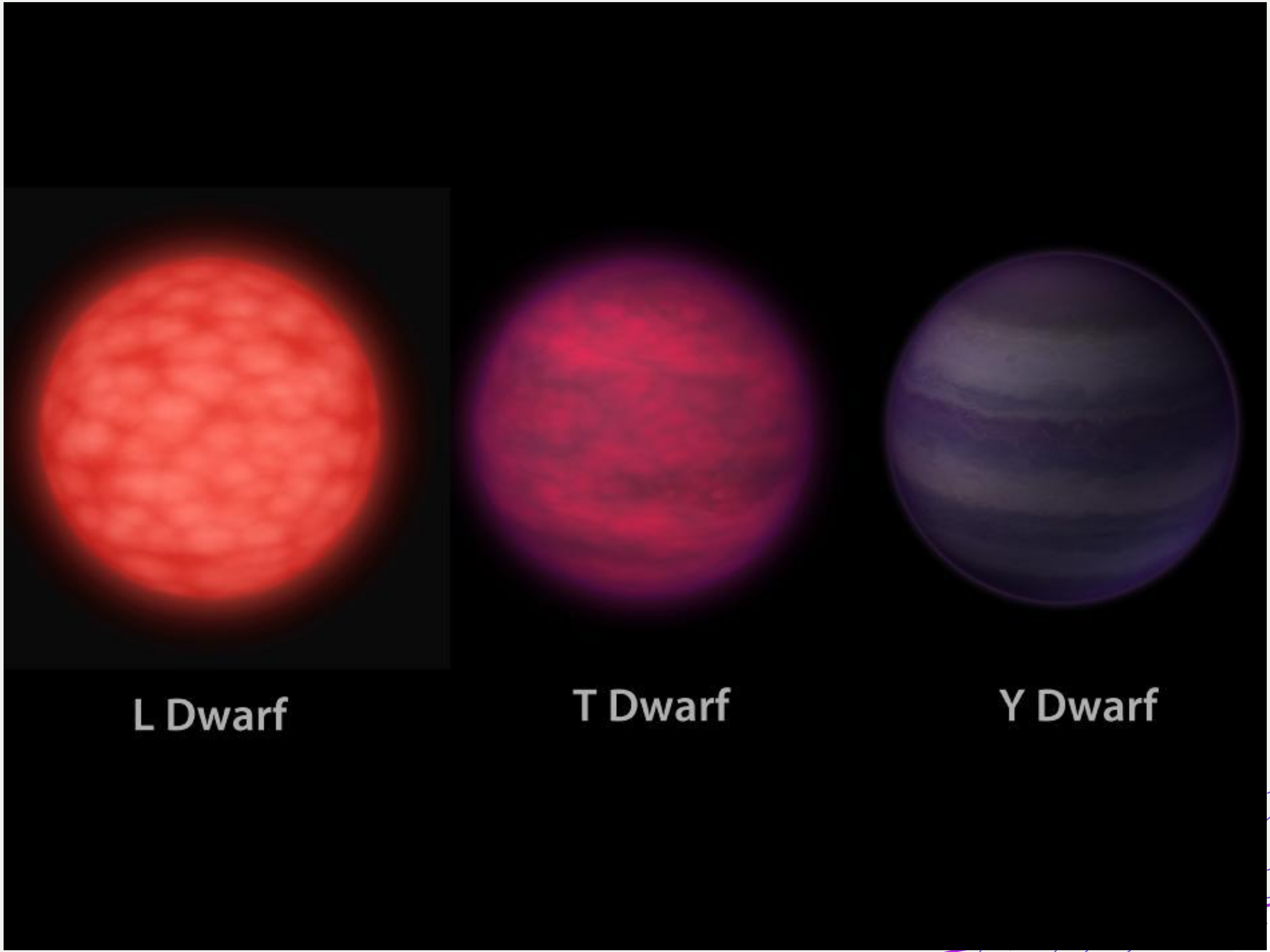


- long and difficult because BDs are so faint
- a good place to look for very faint objects would be close to known stars
- in 1988, Eric Becklin and Benjamin Zuckerman of the University of California reported the discovery of GD 165B, a faint red companion to a white dwarf
- observing motion of the stars by measuring the Doppler shifts in their spectra

+ another good place to look for young objects is in star clusters

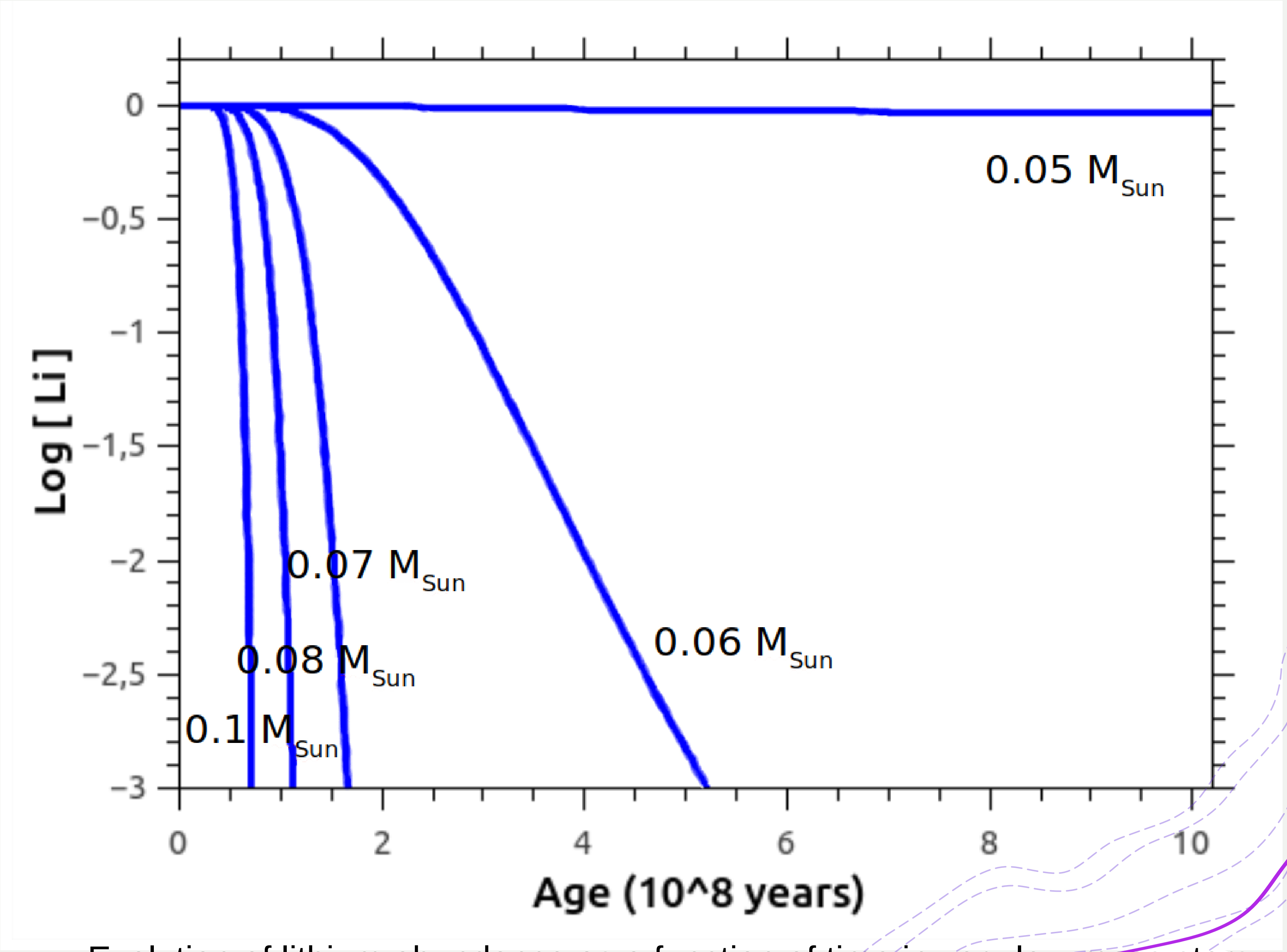


Credit: Adam Burrows



Credit: NASA/JPL-Caltech

- in 1992 RAFAEL REBOLO, Eduardo L. Martín and Antonio Magazzu, IAC: **Lithium test**



Evolution of lithium abundance as a function of time in very low-mass stars and brown dwarfs as predicted by the BT-Settl model by Baraffe et al. (2015).

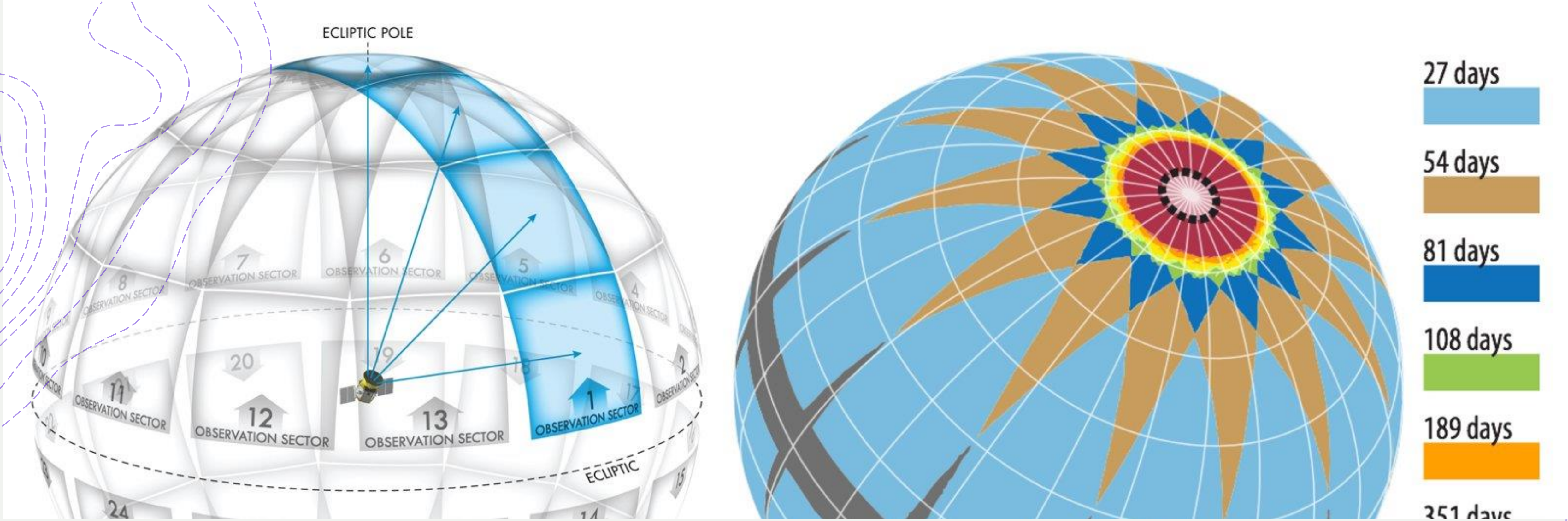
- the first BD confirmed in the Pleiades was Teide 1, a M8 BD with a Teff (2600±150K) and mass (55±15 MJ)

(Rebolo et al. 1995)

- Gliese 229B - detection of methane in its spectrum, Teff (under 1000K) and mass (30-40 MJ)

(Nakajima et al. 1995)

- To date more than 2000 BDs have been detected
- the Two-Micron All-Sky Survey (2MASS; Skrutskie et al. 2006), the Deep Near Infrared Survey of the Southern Sky (DENIS; Epchtein et al. 1997), the UKIRT Infrared Deep Sky Survey (UKIDSS; Lawrence et al. 2007), the Wide-field Infrared Survey Explorer (WISE; Wright et al. 2010) and the VISTA Hemisphere Survey (VHS; McMahon et al. 2013), the Sloan Digital Sky Survey (SDSS; York et al. 2000), the Dark Energy Survey (DES; Abbott et al. 2018), Gaia DR2 (Gaia Collaboration et al. 2018)
- most of the detected BDs are free-floating
- hundreds are found in bound systems at large distances from the primary star



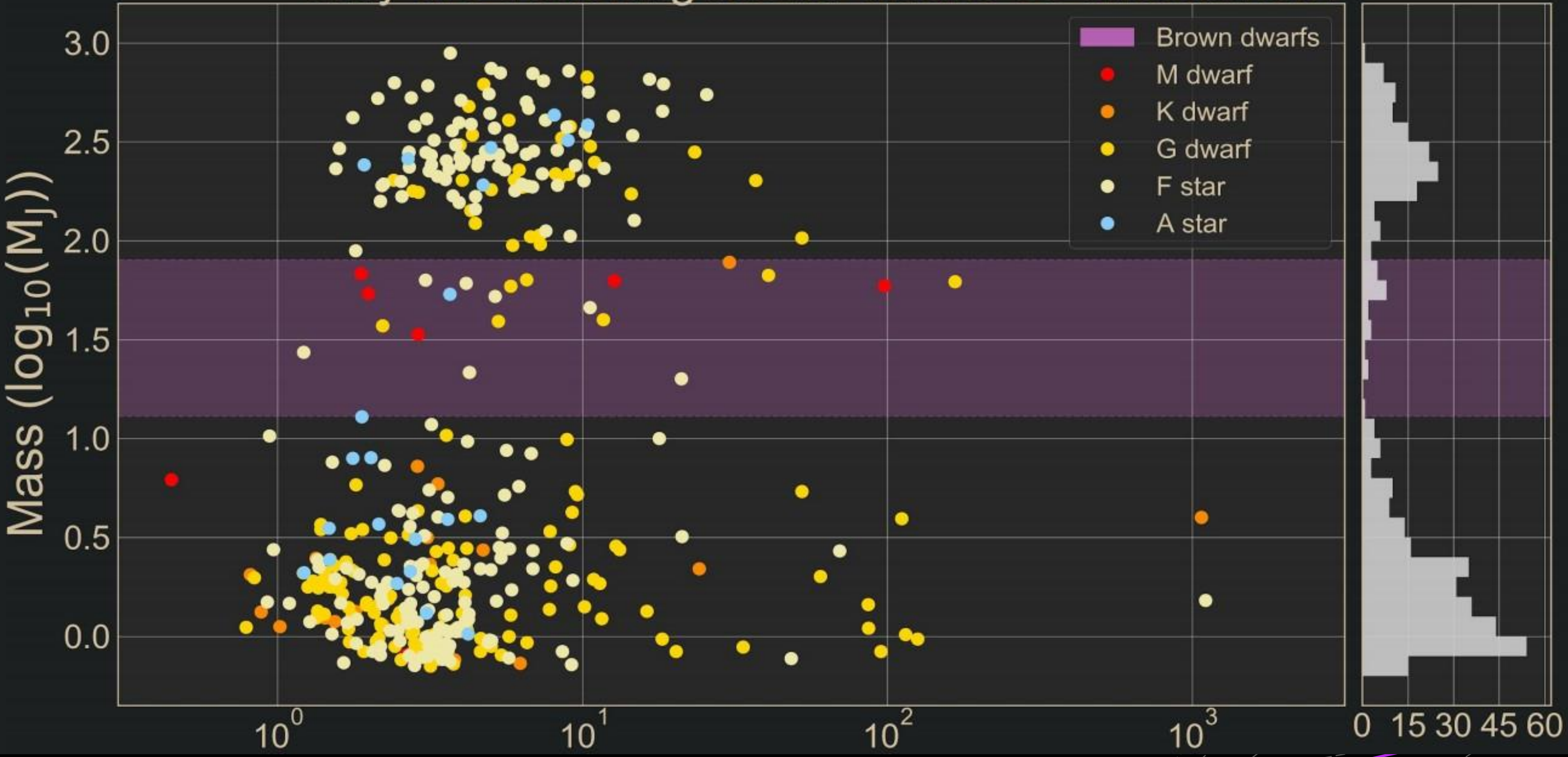
Credit: TESS.mit.edu

TESS

The Transiting Exoplanet Survey Satellite

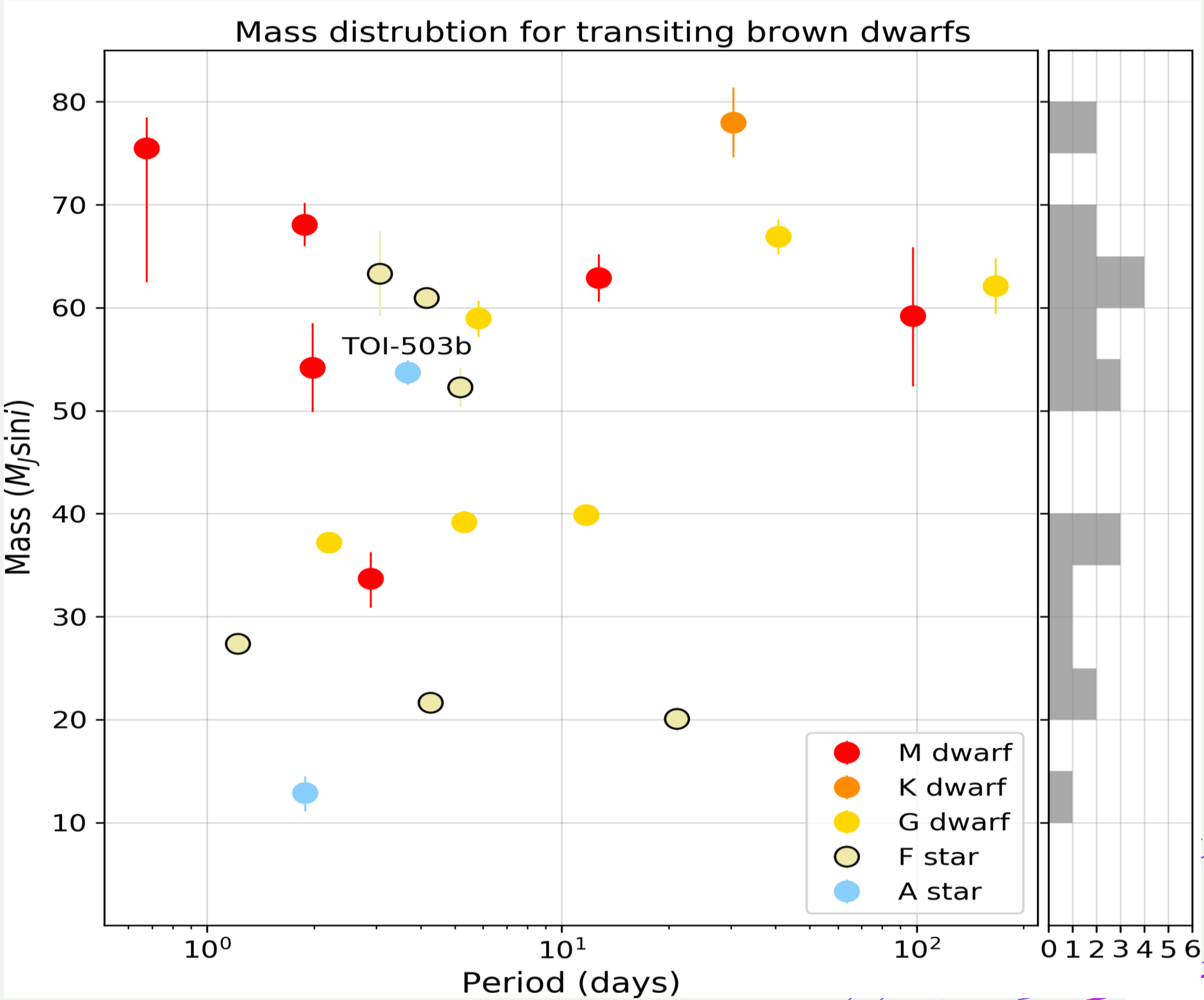
- monitor more than 200,000 stars for temporary drops in brightness
- During Year 3 of the mission (July 2020-July 2021), the southern ecliptic hemisphere is being re-observed.

Why are transiting brown dwarfs so uncommon?



Credit: Carmichael

+25 transiting brown dwarfs

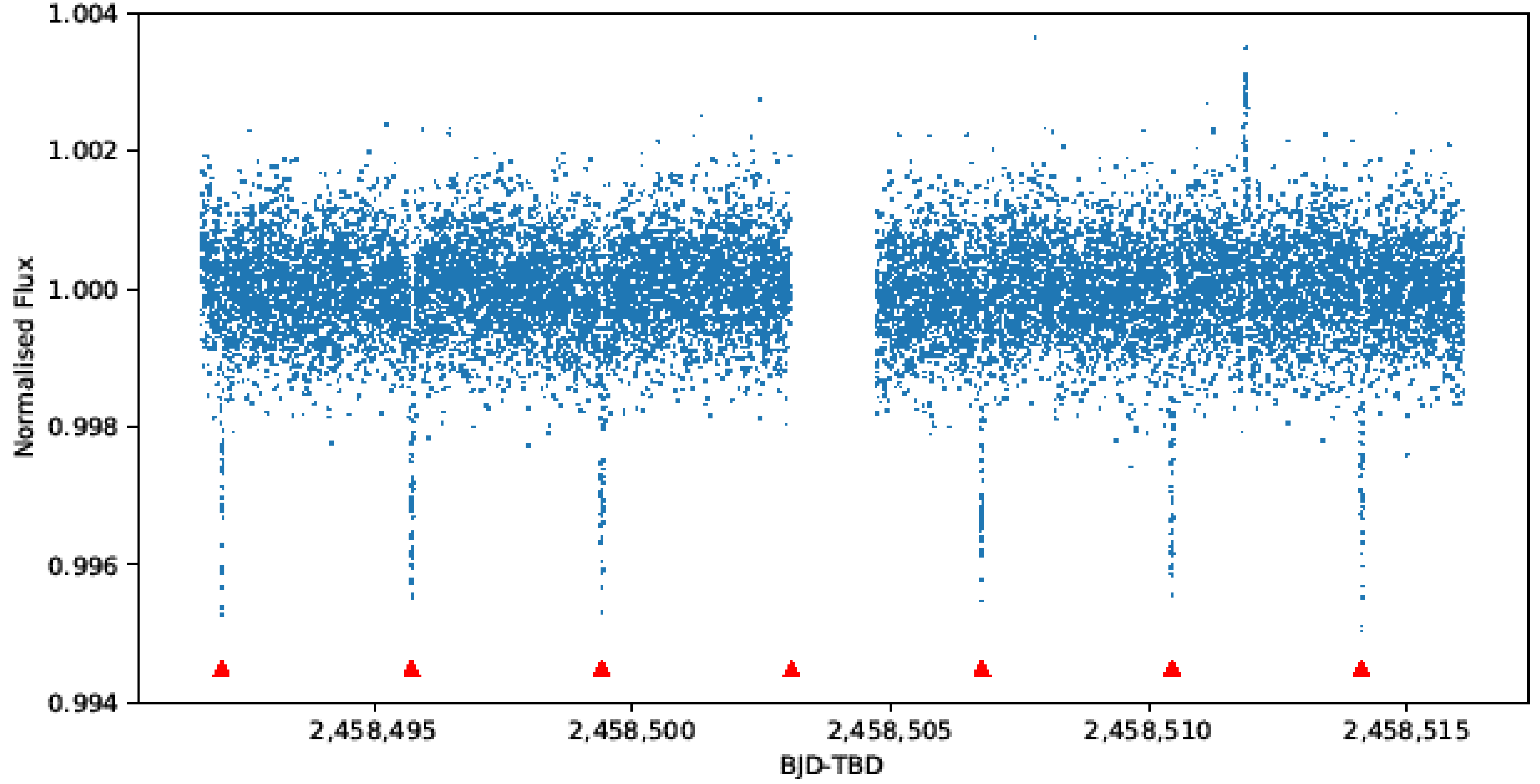


Šubjak, Sharma, Carmichael et al. 2020, AJ

The big questions

- Why haven't more transiting brown dwarfs been discovered?
- How to brown dwarfs form?
  - Like stars?
  - Like planets?

TOI-503 (The first known brown dwarf-Am star binary from the TESS mission)



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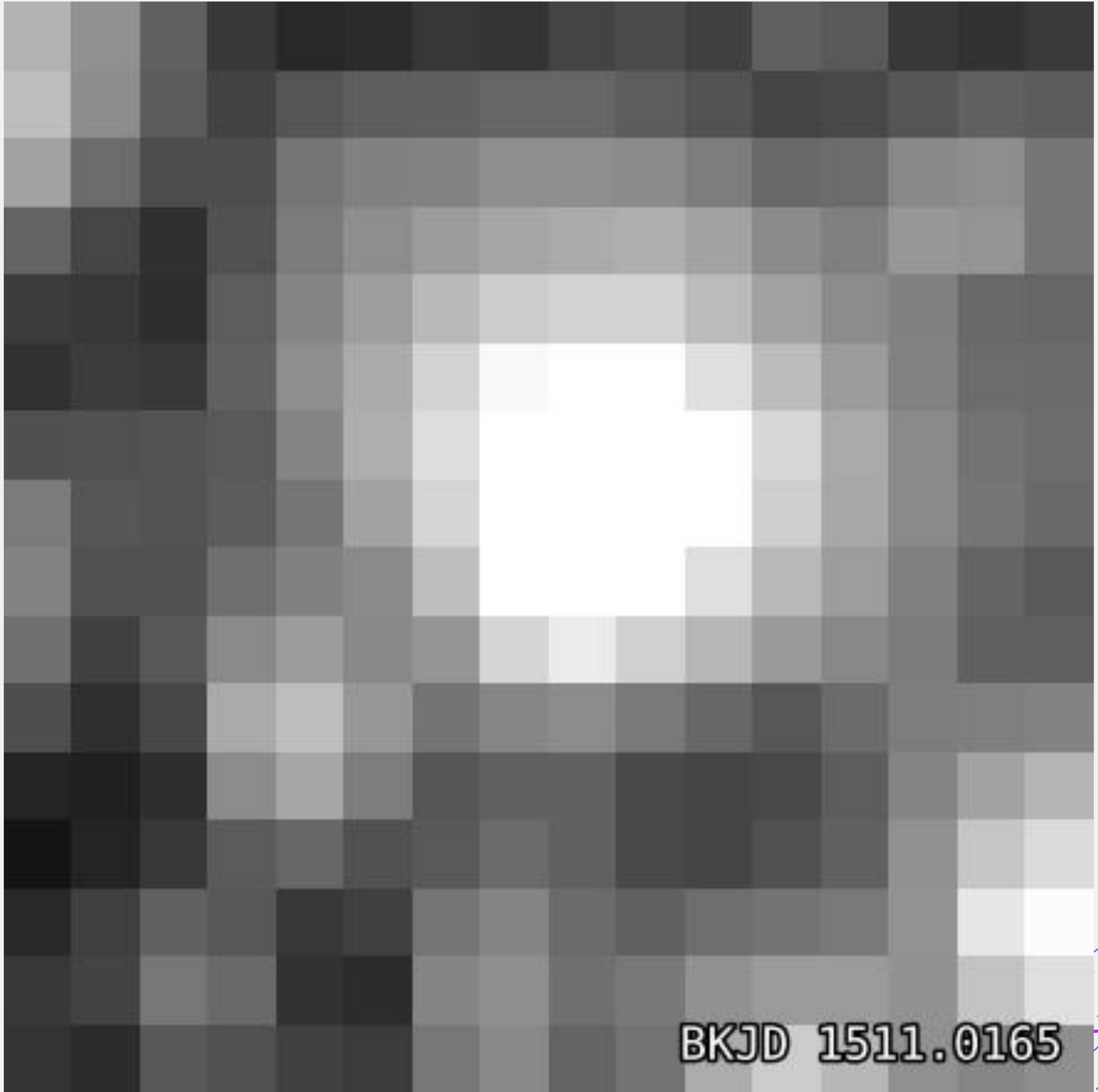
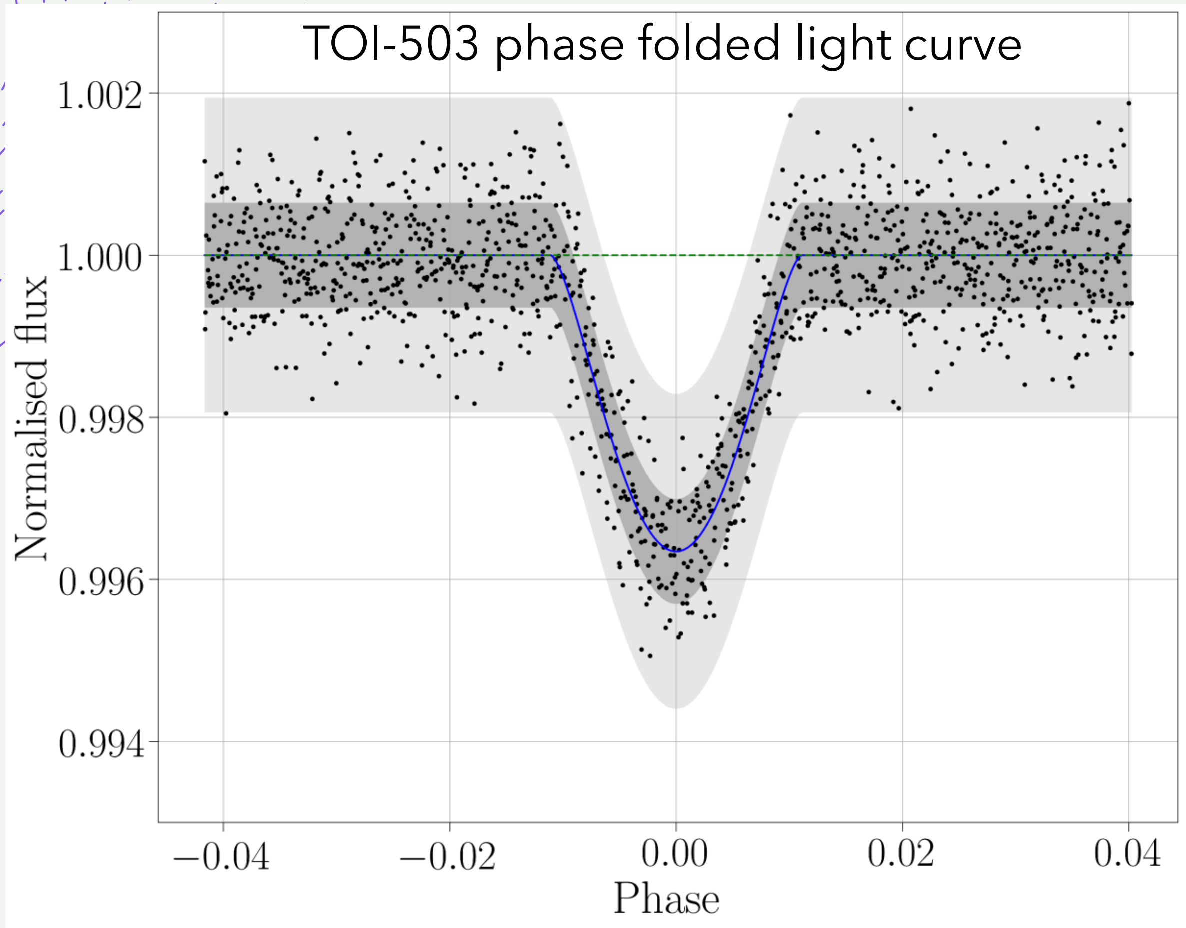
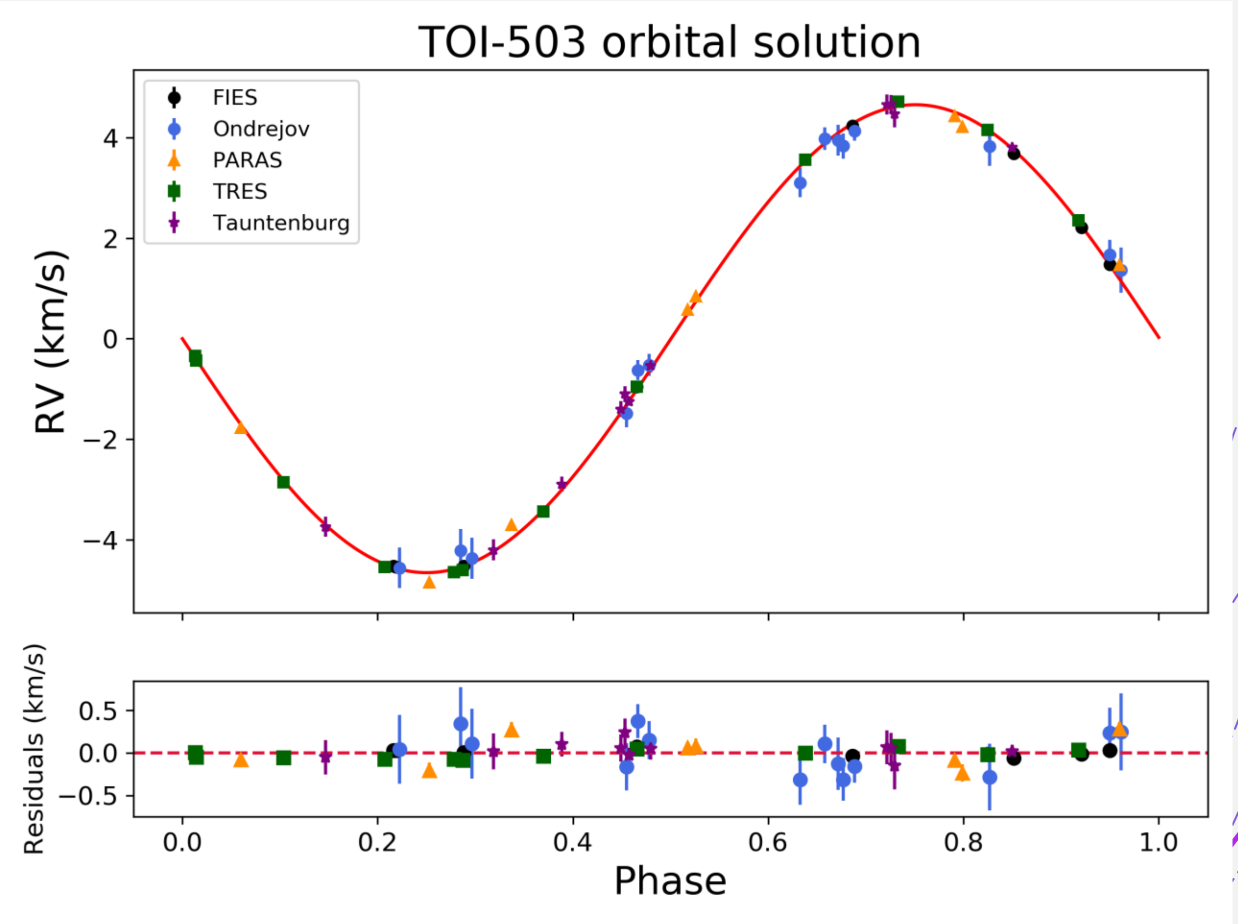

BKJD 1511.0165





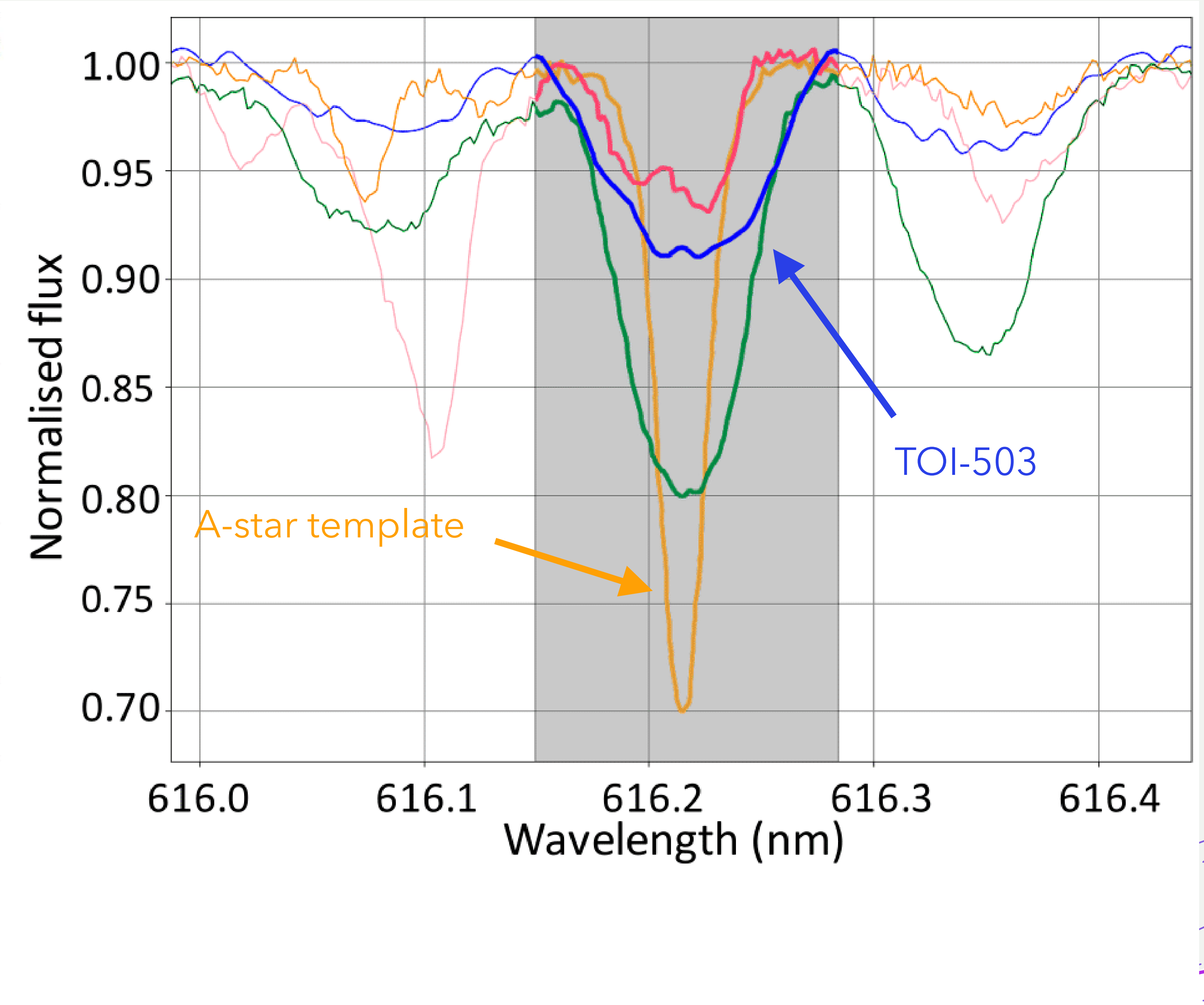
Šubjak, Sharma, Carmichael et al. 2020, AJ

The TOI-503 system

- Host star is a metallic-line A star (Am star)
- First Am star known to host a brown dwarf

- [Fe/H] = +0,6
- [Ca/H] = -0,4

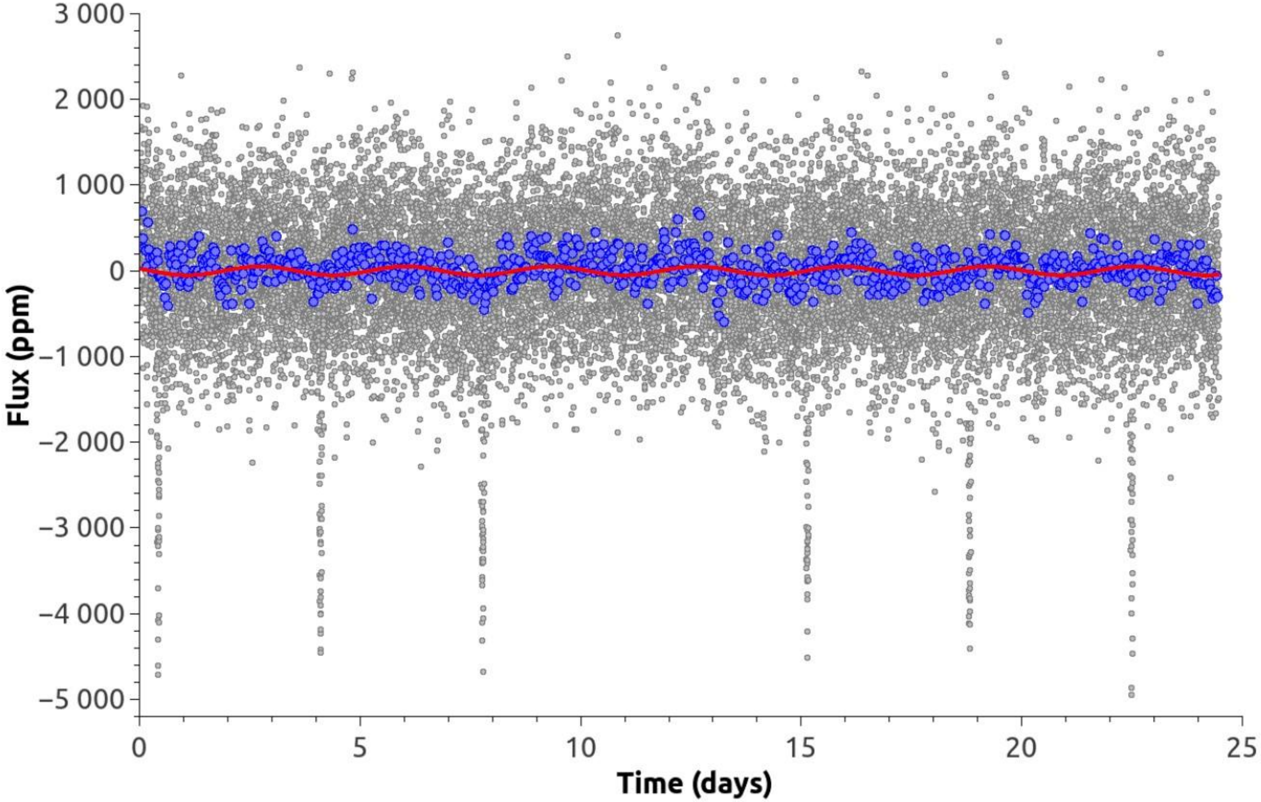
- Depleted in Ca I

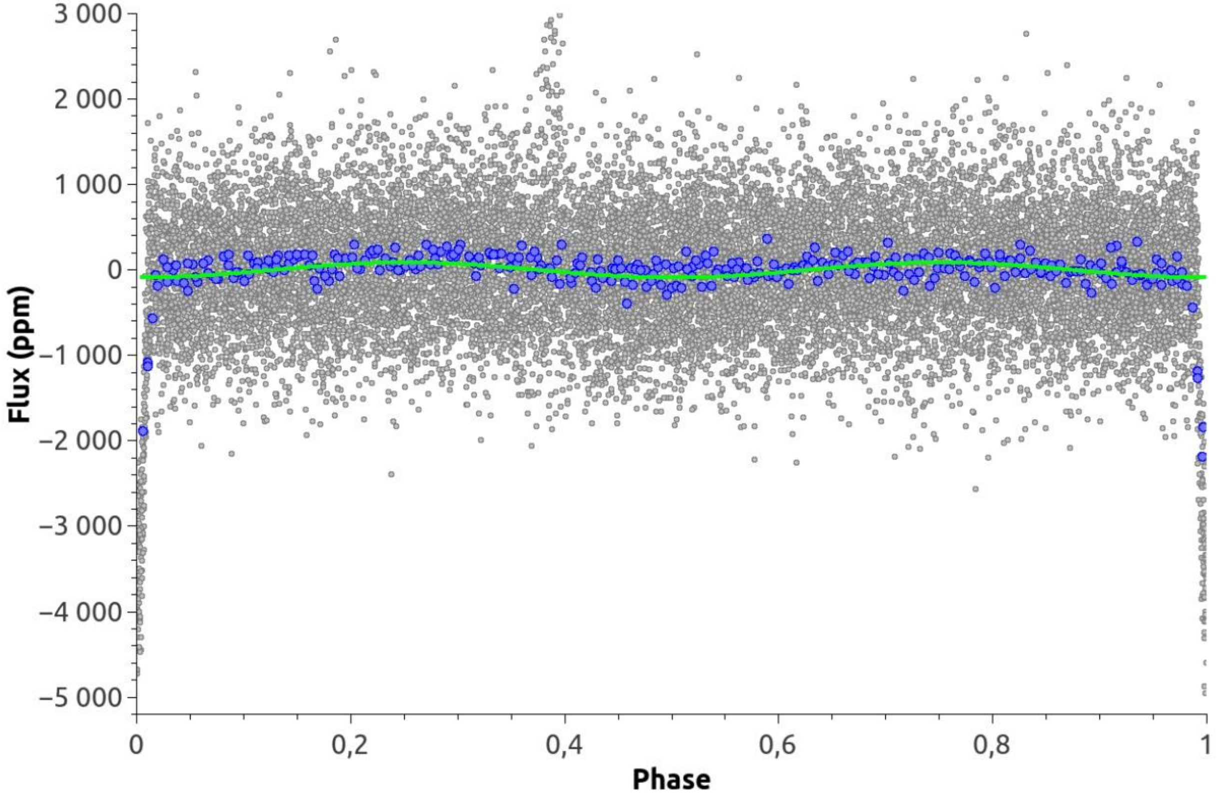


Šubjak, Sharma, Carmichael et al. 2020, AJ

- it is expected that all of the metallic line (Am) and peculiar A (Ap) stars have equatorial rotational velocities less than 120 km s^{-1}, and most of the normal A0-F0 main-sequence stars have equatorial rotational velocities greater than 120 km s^{-1}

- TOI-503 vsini ~ 25 km s^{-1} → P_rot ~ 3,64 days





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Parameter	SPC/EXOFASTv2	iSpec/PARAM 1.3
$M_\star$ ($M_\odot$)	1.80 ± 0.06	1.78 ± 0.02
$R_\star$ ($R_\odot$)	1.70 ± 0.05	1.77 ± 0.04
$\log g$	4.23 ± 0.03	4.17 ± 0.02
$T_{\rm eff}$ (K)	7650 ± 160	7639 ± 105
[Fe/H]	0.30 ± 0.09	0.61 ± 0.07
[Ni/H]	–	0.58 ± 0.09
[Ca/H]	–	-0.40 ± 0.11
[Sc/H]	–	0.10 ± 0.14
[Mg/H]	–	0.25 ± 0.15
$v_{\rm rot} \sin i_\star$ (km/s)	28.6 ± 0.4	25.0 ± 0.3
$P_{\rm rot}$ (days)	3.01 ± 0.09	3.64 ± 0.13
Age (Gyr)	$0.18^{+0.17}_{-0.11}$	0.14 ± 0.04

Parameter	EXOFASTv2	GeePea/Systemic Console
M_b (M_J)	53.7 ± 1.2	53.3 ± 1.1
R_b (R_J)	1.34 ± 0.26	1.28 ± 0.29
$R_{b,\rm mode}$ (R_J)	1.27 ± 0.15	–
Period (days)	3.6772 ± 0.0001	3.6775 ± 0.0002
$a/R_\star$	7.22 ± 0.22	7.47 ± 0.19
$R_b/R_\star$	0.0805 ± 0.015	0.0724 ± 0.015
b	0.974 ± 0.022	0.956 ± 0.023
Inclination i (degree)	82.25 ± 0.41	82.65 ± 0.38
e	0 (adopted)	0 (adopted)

Šubjak, Sharma, Carmichael et al. 2020, AJ

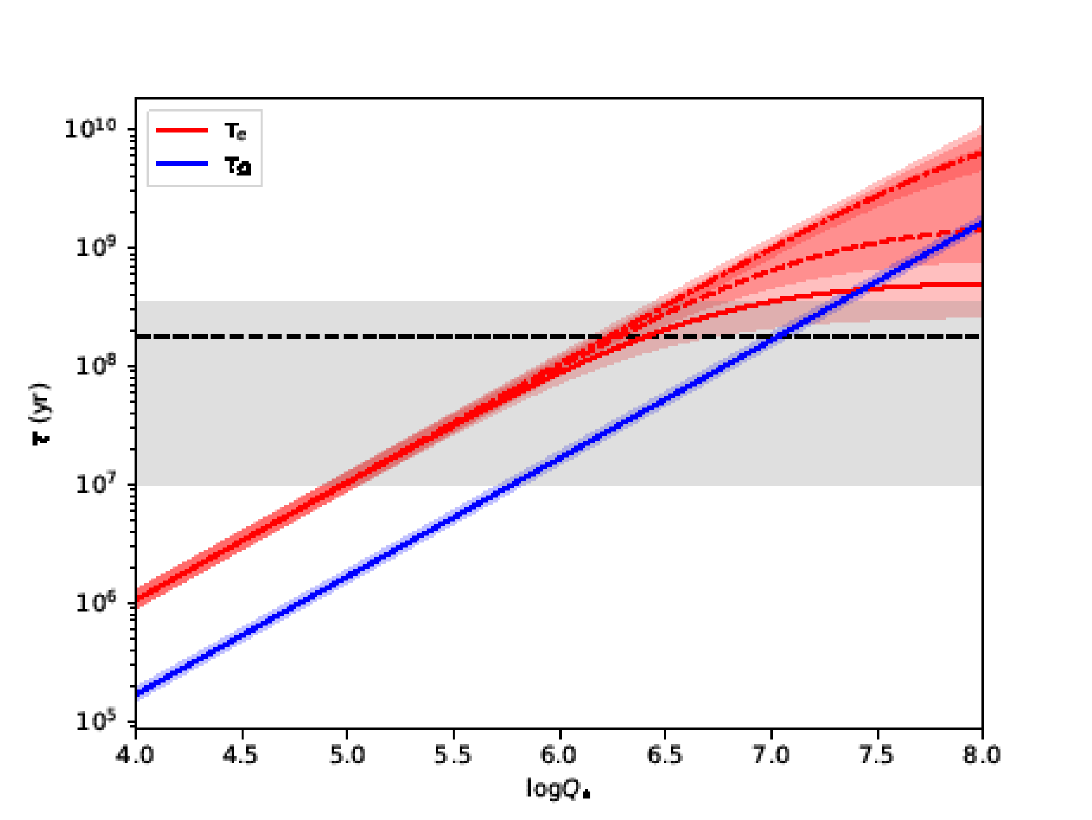
Age

- Stellar isochrones
- Lithium abundance
- Rotational period
- young cluster association

+ circularization, synchronization, spin-orbit co-alignment

$$\frac{1}{\tau_e} = \left[\frac{63}{4}\sqrt{GM_\star^3}\frac{R_{\mathrm{BD}^5}}{Q_{\mathrm{BD}}M_{\mathrm{BD}}} + \frac{171}{16}\sqrt{G/M_\star}\frac{R_\star^5 M_{\mathrm{BD}}}{Q_\star}\right] a^{-\frac{13}{2}}$$ (Jackson et al. 2008)

Q_{BD}, $Q_\star$- tidal quality factors



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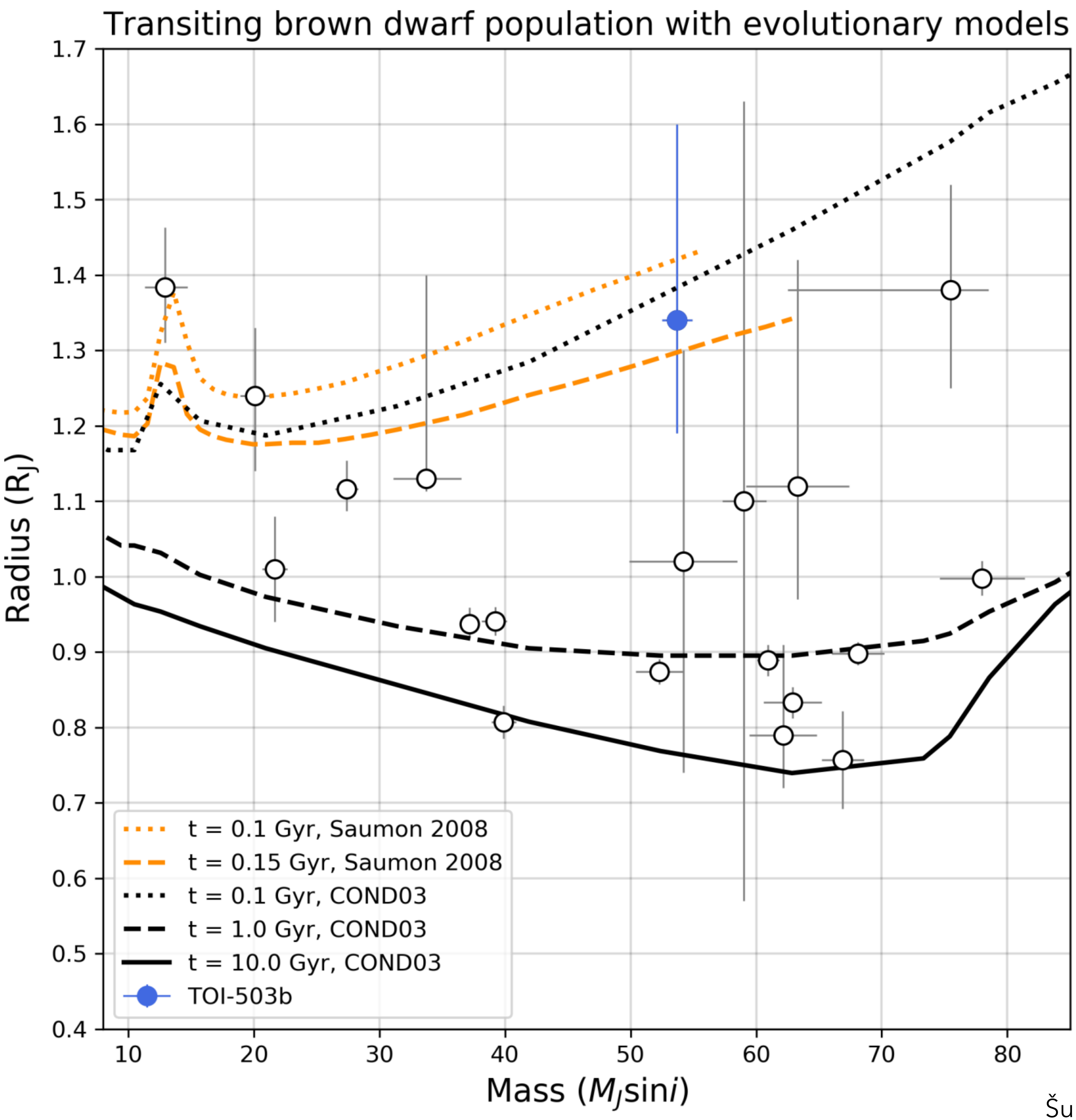

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TESS

+ 4 new transiting BDs
+ TOI-569b (64,1 Mj), TOI-1406b (46,0 Mj) (Carmichael et al. 2020)
+ TOI-811b (55,3 Mj), TOI-852b (53,7 Mj) (Carmichael et al. 2020)
+ Transiting brown dwarfs tell us a lot about their formation and evolution

Thank you for your attention!