Planetary Evolution along the Stellar Evolution

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Destroyed via Engulfment

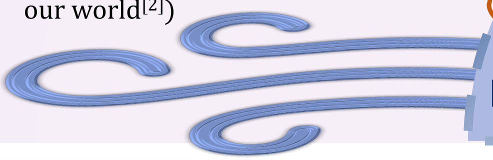
Gas-giant planets
Terrestrial planets

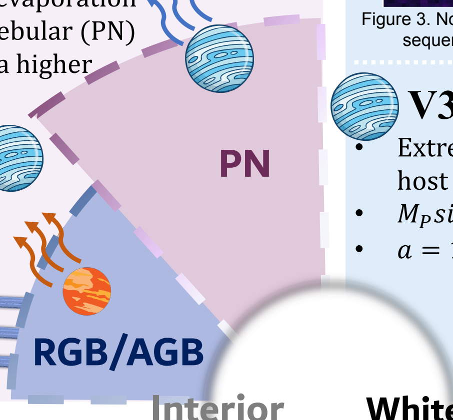
Classical Fates [1]

- A rocky planet at $a < 3-5$ au will be engulfed during the red giant branch (RGB) or the asymptotic giant branch (AGB) phase.
- A gaseous, Jupiter-like planet can survive at 3 au during the AGB phase. Then, a heavy evaporation is established, during the planetary nebular (PN) phase. A more massive host requires a higher planetary mass for it to survive.

Mass Loss Saves Planets

- Increase the orbital radius of the planet (but not helpful to save our world[2])





Gaseous Survivors

MOA-2010-BLG-477Lb

- Planet discovered via microlensing [5]
- Host confirmed as a white dwarf (WD) [6]
- $M_P = 1.4 M_J$
- $a = 2.8\ au$

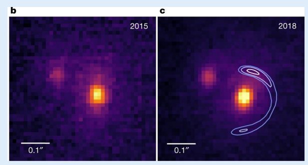


Figure 3. Non-detection rules out a main sequence (MS) as the host [6]

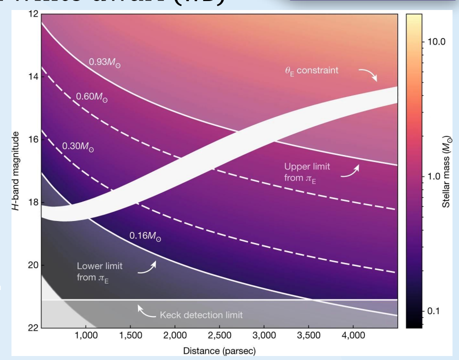


Figure 4. Lensing rules out a brown dwarf, a neutron star, nor a black hole as the host [6]

V391 Peg b [7]

- Extreme horizontal branch host star
- $M_P \sin i = 3.2 M_J$
- $a = 1.7\ au$

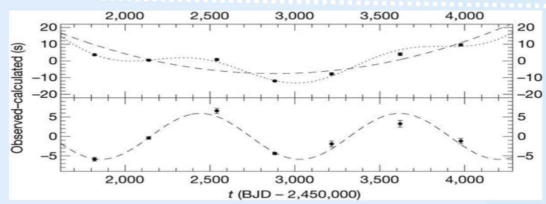
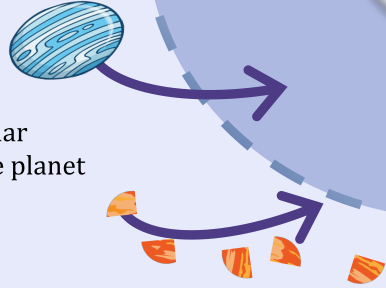


Figure 5. The O-C diagram to infer orbital parameters for V391 Peg b [7]

Destroyed via Orbital Instability

Tidal Interactions

- Reduce the orbital angular momentum, and pull the planet inward



Terrestrial Debris

- A rocky planet will be tidally disrupted when it approaches the Roche's radius, resulting in the circumstellar debris;
- At least **27%**[3] WDs are accreting terrestrial debris;
- Light curves with multiple transits

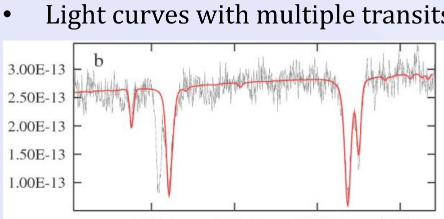


Figure 1. An example spectrum of the Si contamination of a WD [3]

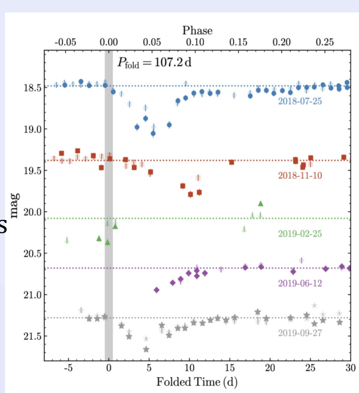


Figure 2.The de-composed transit light curves of J013906.17+5245536 [4]

A Terrestrial Survivor

KMT-2020-BLG-0414Lb

$M_P \approx 1.9 M_E$, $M_{WD} \approx 0.5 M_\odot$

■ The planet is discovered via microlensing in 2020 [8], and the lens light curve infers a low-mass-ratio planet ($q \approx 10^{-5}$) orbiting a subsolar host star. The non-detection of a MS confirms that the host star is a WD accompanied by a brown dwarf[9].

The initial separation of the planet may be of **1 au**, and gradually increases owing to the host's mass loss, in a possible scenario.

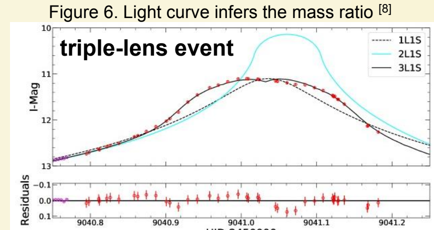


Figure 6. Light curve infers the mass ratio [8]

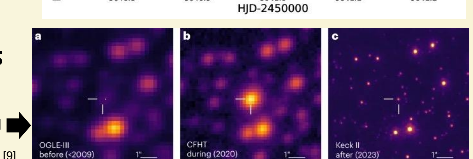
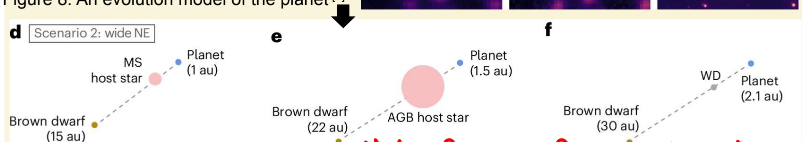


Figure 7. Non-detection of a MS [9]

Figure 8. An evolution model of the planet [9]



A Possible fate of our Earth..?

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[1]Villaver, E. and Livio, M., "Can Planets Survive Stellar Evolution?", *The Astrophysical Journal*, vol. 661, no. 2, IOP, pp. 1192–1201, 2007. doi:10.1086/516746. **[2]**Schröder, K.-P. and Smith, R. C., "Distant future of the Sun and Earth revisited", *Monthly Notices of the Royal Astronomical Society*, vol. 386, no. 1, OUP, pp. 155–163, 2008. doi:10.1111/j.1365-2966.2008.13022.x. **[3]**Koester, D., Gänsicke, B. T., and Farihi, J., "The frequency of planetary debris around young white dwarfs", *Astronomy and Astrophysics*, vol. 566, Art. no. A34, 2014. doi:10.1051/0004-6361/201423691. **[4]**Vanderbosch, Z., "A White Dwarf with Transiting Circumstellar Material Far outside the Roche Limit", *The Astrophysical Journal*, vol. 897, no. 2, Art. no. 171, IOP, 2020. doi:10.3847/1538-4357/ab9649. **[5]**Bennett, D. P., "Masses and Orbital Constraints for the OGLE-2006-BLG-109Lb,c Jupiter/Saturn Analog Planetary System", *The Astrophysical Journal*, vol. 713, no. 2, IOP, pp. 837–855, 2010. doi:10.1088/0004-637X/713/2/837. **[6]**Blackman, J. W., "A Jovian analogue orbiting a white dwarf star", *Nature*, vol. 598, no. 7880, pp. 272–275, 2021. doi:10.1038/s41586-021-03869-6. **[7]**Silvotti, R., "A giant planet orbiting the `extreme horizontal branch' star V391 Pegasi", *Nature*, vol. 449, no. 7159, pp. 189–191, 2007. doi:10.1038/nature06143. **[8]**Zang, W., "An Earth-mass planet in a time of COVID-19: KMT-2020-BLG-0414Lb", *Research in Astronomy and Astrophysics*, vol. 21, no. 9, Art. no. 239, IOP, 2021. doi:10.1088/1674-4527/21/9/239. **[9]**Zhang, K., "An Earth-mass planet and a brown dwarf in orbit around a white dwarf", *Nature Astronomy*, 2024. doi:10.1038/s41550-024-02375-9.

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