Origin of Kepler-1656b's Extreme Eccentricity

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High eccentricity indicates rich dynamical history

One of the big surprises from exoplanet observations is the existence of many planets with eccentricities greater than those found in the Solar System.

One system of particular interest is **Kepler-1656, which hosts a single known planet on a close-in, highly eccentric (e=0.84) orbit**[1]. This places Kepler-1656b on the extreme upper envelope of the e-a diagram. Such an orbital configuration is not a typical outcome of planet formation.

Instead, planets formed in a near-circular orbit can be driven to much higher eccentricities via pathways such as[2]:

- planet-planet scattering
- perturbation from a stellar flyby
- induced by a third outer body via eccentric Kozai-Lidov (EKL) mechanism[3].

Our aim was to understand which scenario led to Kepler-1656's extreme orbital configuration. We also constrain the properties of a potential third body for the case of an EKL-induced eccentricity.

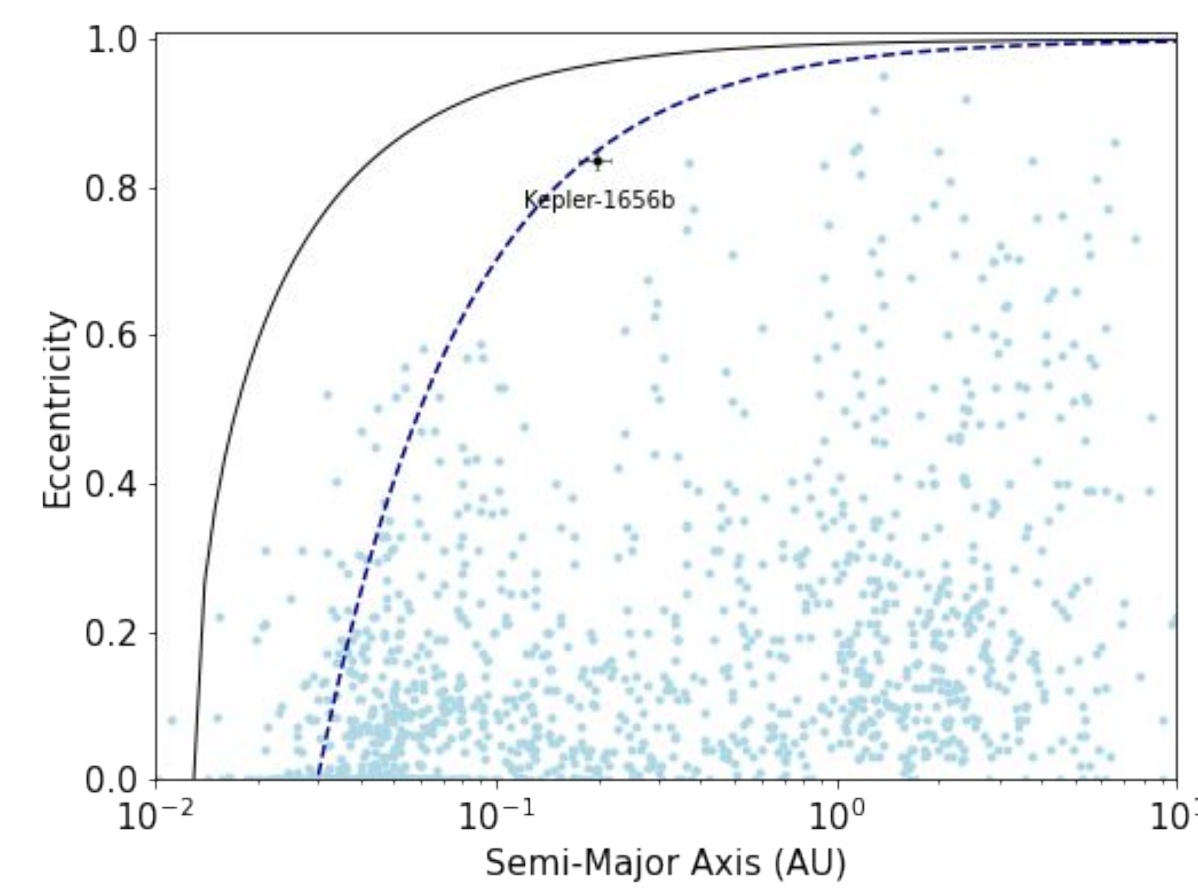

Figure 1: Eccentricity and semi-major axis is plotted for known exoplanets[4]. Kepler-1656b resides relatively close to the upper envelope (black line), set by $a(1-e^2)=2R_{Roche}$, and even closer to the empirical upper envelope set by r_{peri}= 0.03 AU (blue dashed line).

Possibility of an EKL-induced eccentricity

We considered the relevant dynamical timescales for an example 3-body system containing the host star, Kepler-1656b, and a 100 M_{jup} outer body at orbital separations of 20, 100, and 1000 AU. As shown in Figure 2, **the EKL timescale for such a system is short enough to allow for eccentricity excitations within the lifetime of Kepler-1656b**.

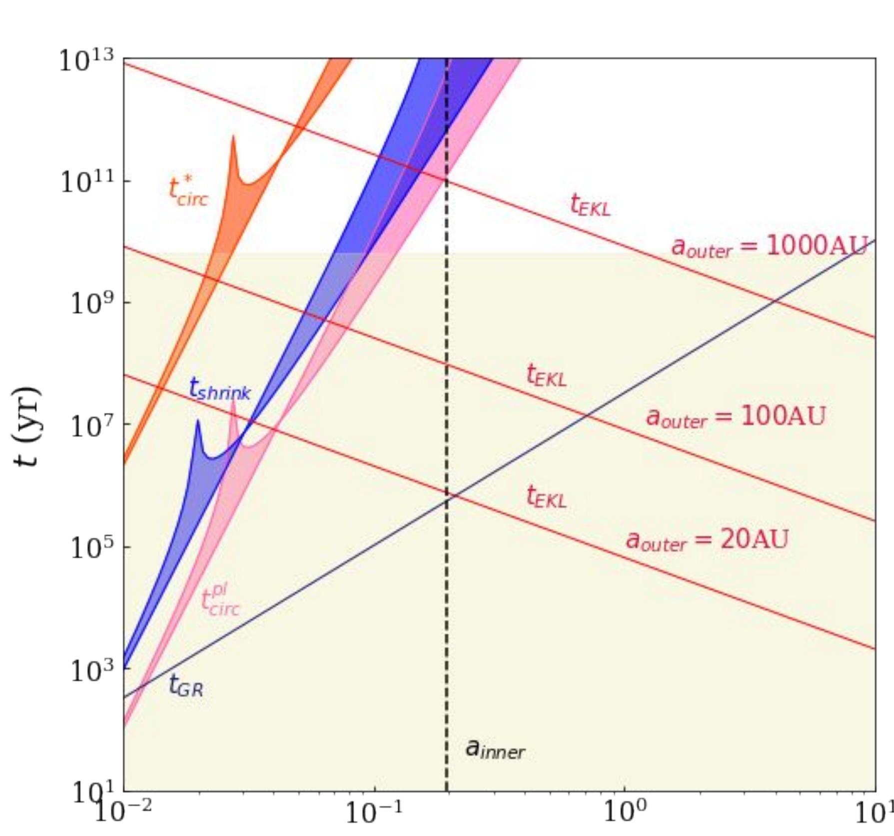

Figure 2: Relevant timescales for this system. The EKL timescale (red), representing the period of eccentricity oscillations induced by the outer body, is shorter than the system age for planets in the shaded region.

Hints of a third planet

We began gathering observations from high-resolution ground-based telescopes to search for a companion to Kepler-1656b. The data so far can effectively rule out companions larger than ~ 1 $M_{\odot}$.

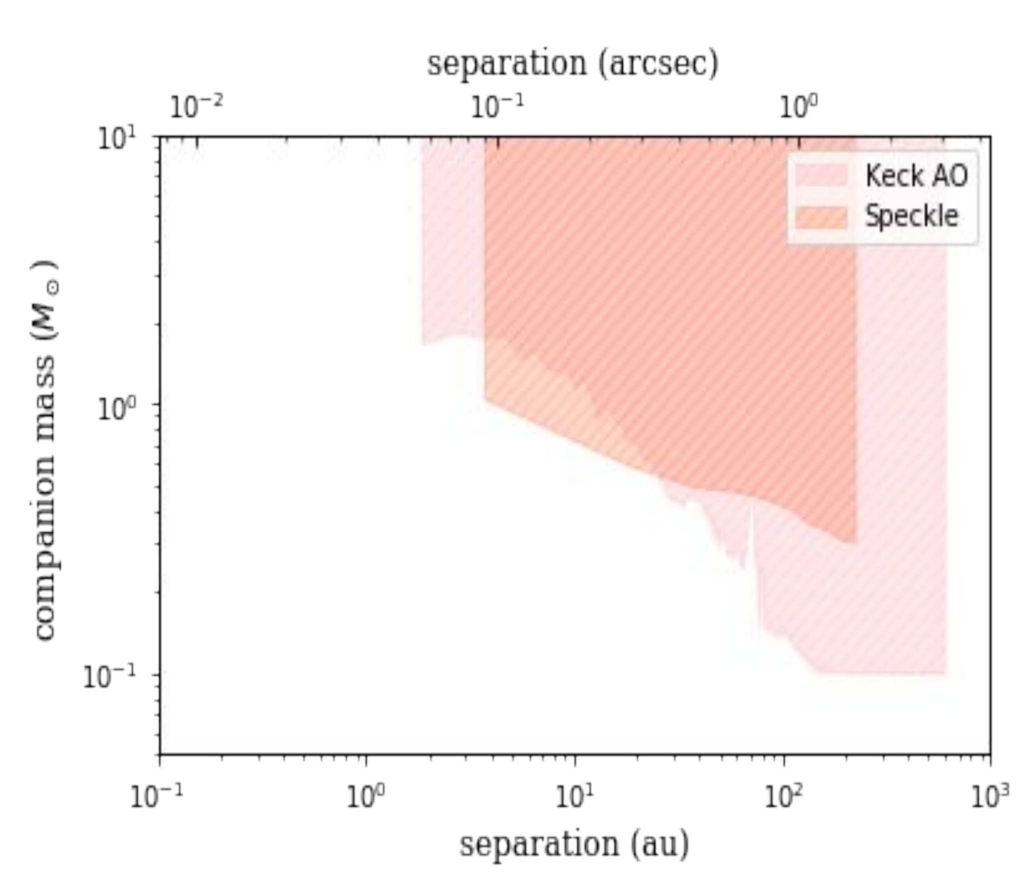

Figure 3 : Regions of mass-separation space in which a companion has been ruled out by observations. The next step is to add constraints from radial velocity measurements and spectroscopic searches for luminous companions.

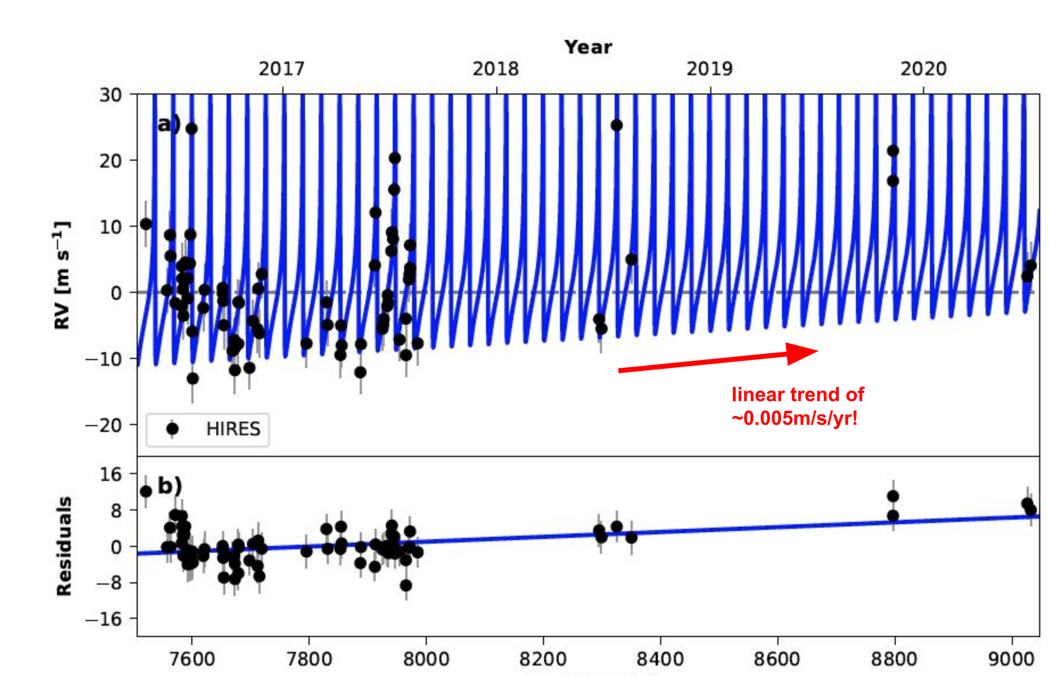

Figure 4: Radial velocity data (top) and residuals (bottom) are plotted versus time in black, model fits are plotted in blue.

Preliminary **radial velocity observations of Kepler-1656 could reveal a ~10-year period companion** to Kepler-1656b. Our next step is to see if simulated EKL evolution of such a system reproduces the system's eccentricity.

References

1 Brady, M, Petigura, E., et al, 2018, ApJ, 156, 147
2 Dawson, R.I. & Johnson, J. 2018, ARA&A, 56, 175
3 Naoz, S., 2016, ARA&A, 54, 441
4 https://exoplanetarchive.ipac.caltech.edu/