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Evolution of Catastrophically Evaporating Rocky Planets

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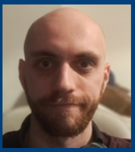
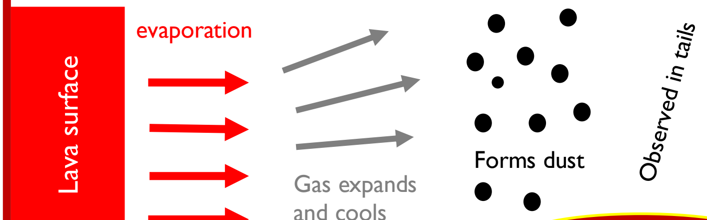


Abstract

The composition of the secondary atmospheres of rocky planets below are greatly influenced by their internal evolution. The dusty tails of catastrophically evaporating planets provide a means of observationally probing these interiors. Here we develop an interior model of these extreme planets, which is essential for interpretation of their observations.

What are catastrophically evaporating planets?



Lava surface

evaporation

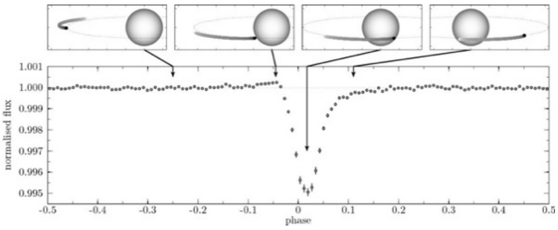
Gas expands and cools

Forms dust

Observed in tails

Poster #: PF-06-0024

See Rappaport (2012), Perez-Becker & Chiang (2013), **Booth et al. (2023)**



Confirmed systems

- Kepler-1520b (formerly KIC-1255b)
- KOI-2700b
- K2-22b

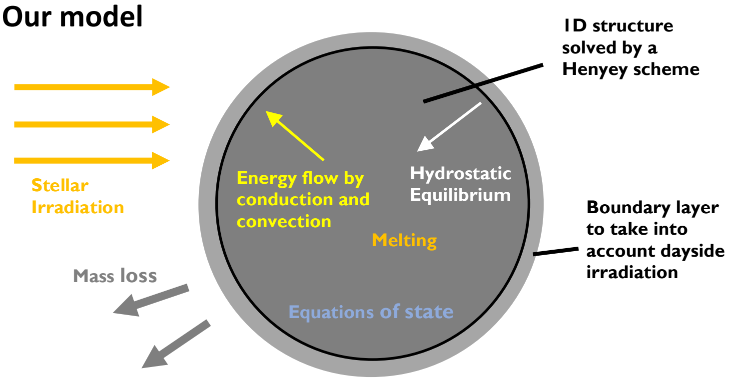
Figure 1: Diagram from van Lieshout et al. (2016) showing the time-averaged lightcurve of Kepler 1520b.

Composition of the dust tails can be inferred from physical modelling of the lightcurves, including dynamics and sublimation. In future it may be possible to detect molecular features in the dust, perhaps with JWST (Bodman, 2018) and atomic gas lines, especially if more examples are found.

Why is an interior model important?

The evolution of the underlying interior will set the composition at the base of the dust and gas outflow. Different evolution histories, particularly the melt fraction, will change what species can reach the surface, and so be seen in the dusty tails. Therefore, an interior model is necessary to make inferences about rocky interiors from observations of the tails.

Our model



1D structure solved by a Henyey scheme

Stellar Irradiation

Energy flow by conduction and convection

Hydrostatic Equilibrium

Melting

Boundary layer to take into account dayside irradiation

Mass loss

Equations of state

Because we solve thermal and structural equations together, we can evolve the planets self-consistently, including their mass loss, through their full lifetimes.

Melt Fraction of the planets

We find that planets have **almost entirely crystalised**, other than a **shallow magma ocean** on the dayside, when the planet reaches its catastrophic evaporation phase. This means the observed dusty winds only sample material from the very surface of the planets, rather than deep in the interior.

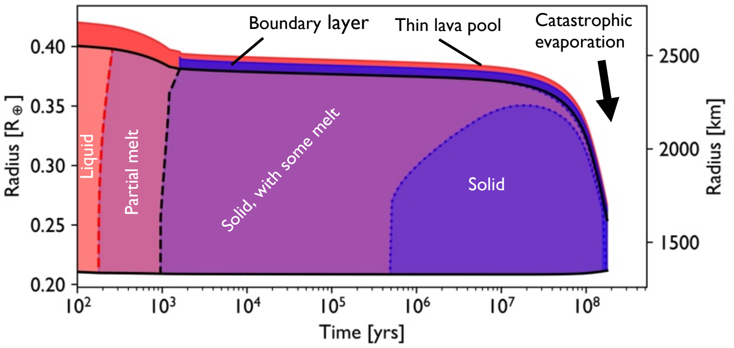


Figure 2: Crystallisation of the mantle of a 0.05 M⊕ planet (~Mercury) with a substellar temperature of 2070 K undergoing mass loss according to Booth et. al (2023).

Occurrence of low mass planets

To be observed today around a ~Gyr old star planets must both initially have been massive enough to not have already evaporated and small enough that they can have a high mass loss rate. We can use the fact that this can only be the case for a limited time infer the number of progenitor planets. We consider planets observable if the models of Booth et al. (2023) – poster #PF-06-0024 - predict dust production. This only occurs in a limited region of parameter space where the planets are hot and small enough to have significant mass loss, but cool enough that dust can form quickly.

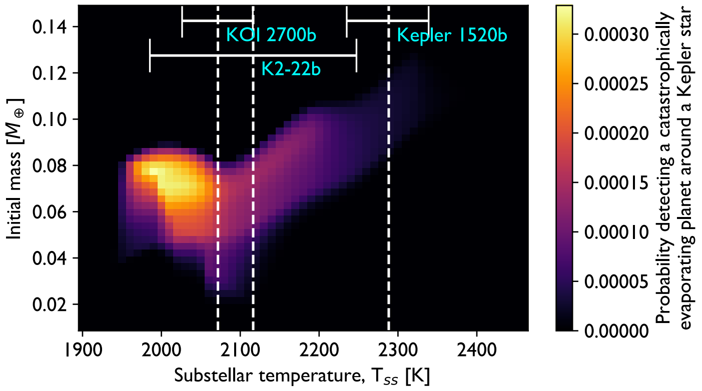


Figure 3: The probability that a planet of a given initial mass would be observable around a star, marginalised over the stellar mass and age distribution of the ~180,000 stars observed in the Kepler primary mission. Dashed lines show the substellar temperatures of the observed systems with associated error bars.

Number of planets per star

To produce the number of observed systems we require **~ one progenitor planet per star.**

Our occurrence rate is **~ 10 x higher than that observed for super-Earths** in the same region of parameter space. We therefore conclude that mechanisms such as scattering may not be required to produce these planets.

Temperatures of the observed planets

As seen in Figure 3, the observations roughly agree with our predictions for the most common temperatures to observe dust.

Future Work

We plan to track chemical changes using the thermal properties derived from our model. This will be able to tell us, for instance, whether all the most volatile species are lost at early times, or can be retained as most of the planet crystallises, then outgas continually as the surface is evaporated.