Constraining small planet compositions with catastrophically evaporating rocky planets*

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* *MNRAS*, 528, 1249, doi: 10.1093/mnras/stae095

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SCAN FOR PAPER

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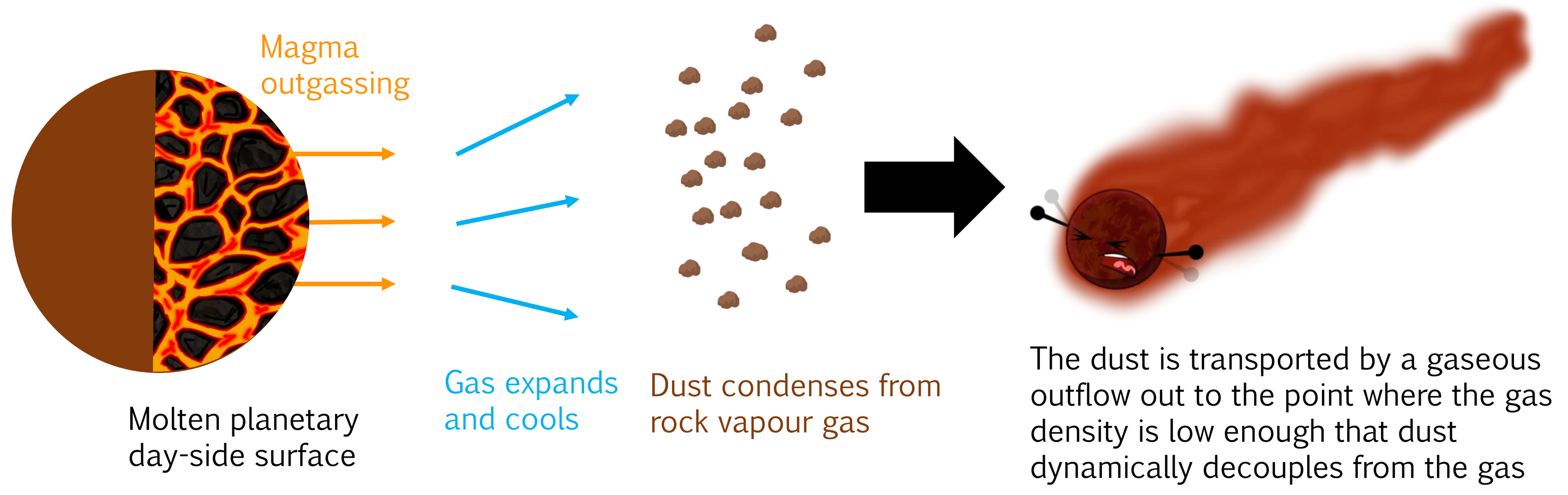
CATASTROPHICALLY EVAPORATING ROCKY PLANETS ARE...

...highly irradiated, ultra-short-period, low-mass ($\leq M_{Mercury}$) rocky planets which undergo evaporation to the point where they completely disintegrate in stellar lifetimes. These planets present comet-like tails of dust which create peculiar light curves (see Figure 1). So far, 3 of these planets have been observed: Kepler-1520b, KOI 2700b and K2-22b.



Catastrophically evaporating rocky planets provide a unique opportunity to study the composition of small planets. The surface composition of these planets can be constrained via modelling their comet-like tails of dust.

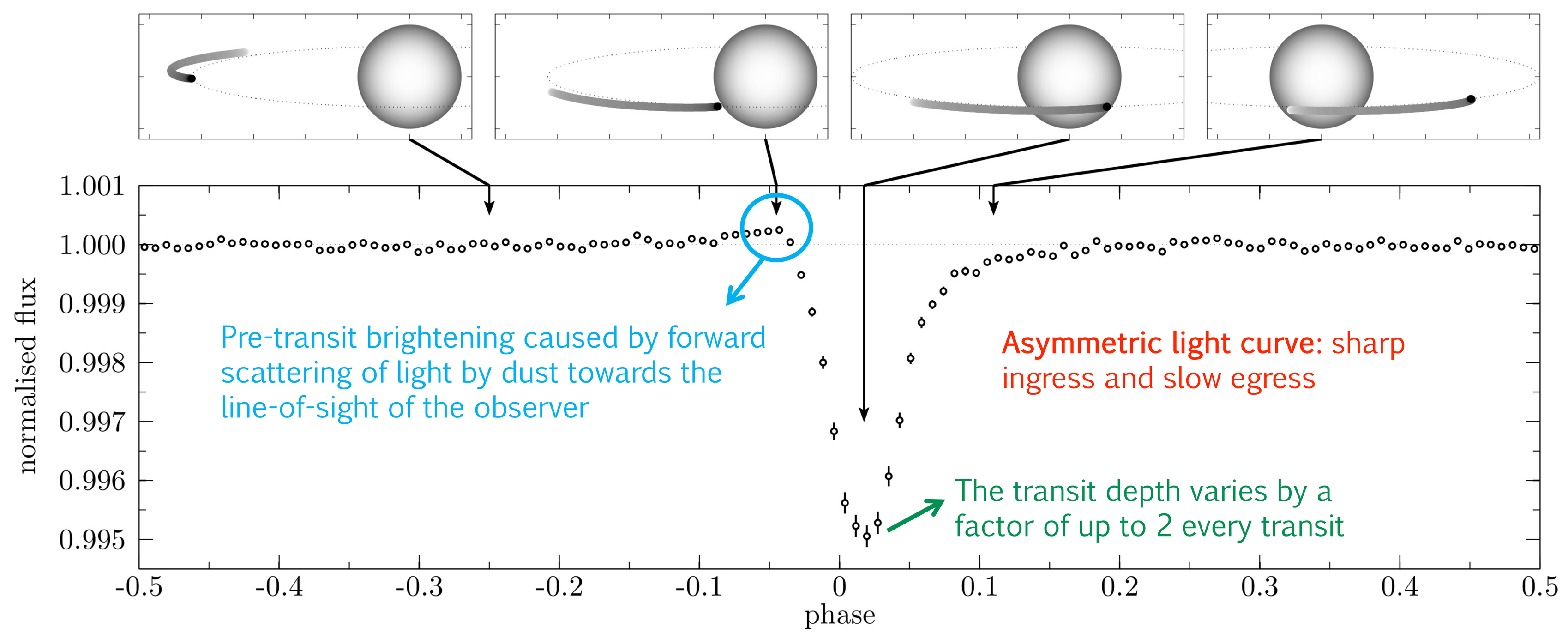


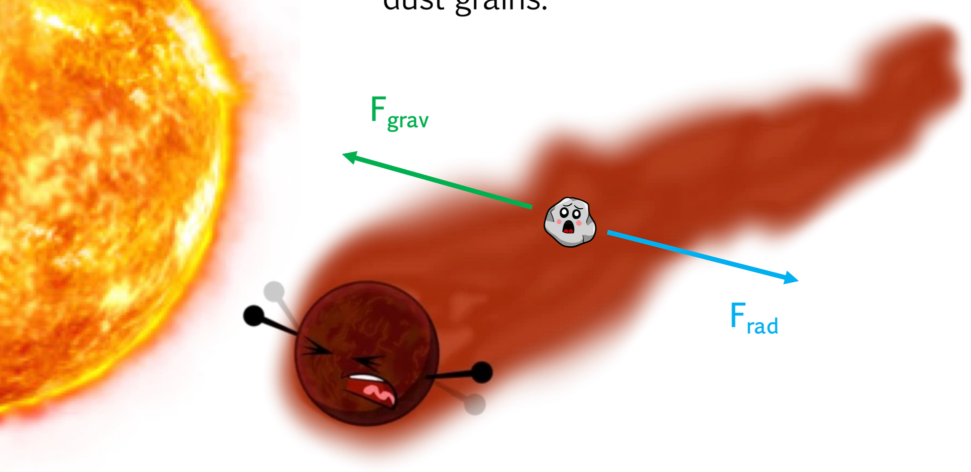
Figure 1: The phase-folded long-cadence Kepler light curve of Kepler-1520b (bottom), and a schematic of the system at different orbital phases (top), showing how a comet-like dust tail can explain the observed light curve.

A SELF-CONSISTENT MODEL OF THE DUSTY TAILS

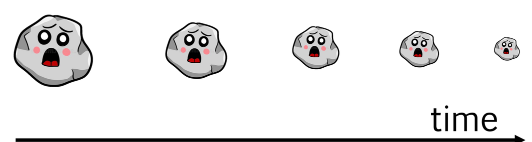
We built a new self-consistent model of the dusty tails: we physically model the trajectory of the dust grains **after they have left the gaseous outflow** including (for the first time) an on-the-fly calculation of the dust cloud's optical depth. We model two catastrophically evaporating planets: Kepler-1520b and K2-22 b. **In this poster we present the results for Kepler-1520b.**

MOTION

The stellar radiation pressure force and the stellar gravity dominate the trajectory of the dust grains.



SUBLIMATION



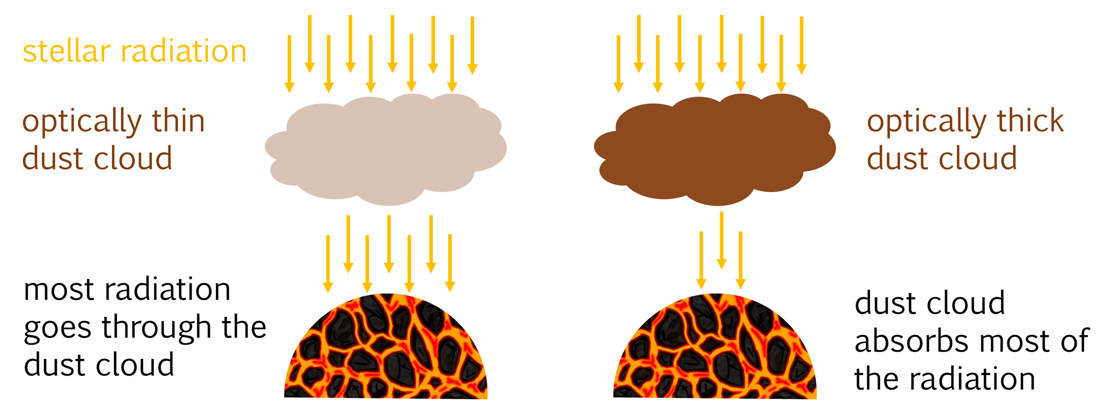
The sublimation timescale of the dust is dominated by the dust's vapour pressure and its optical properties (and therefore the dust temperature).

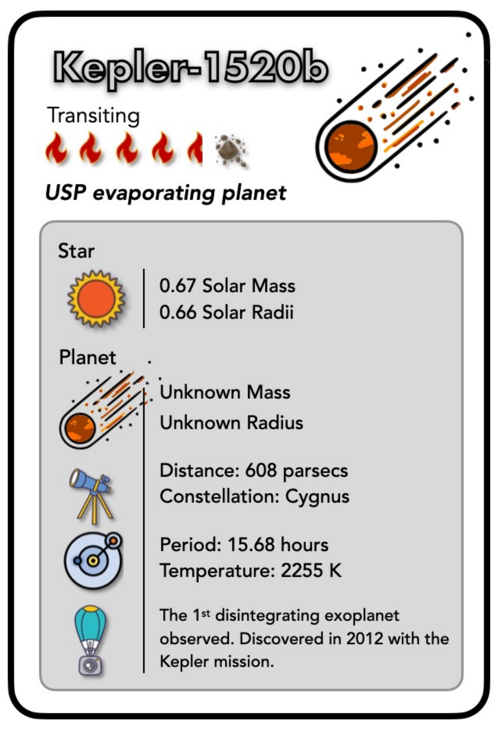
ASSUMPTIONS

1. Constant planetary mass-loss rate.
2. Single initial dust grain size or power-law distributed.
3. Dust is composed of a single type of condensate.

OPTICAL DEPTH

The stellar radiation pressure and the dust temperature are highly sensitive to the optical depth of the dust cloud. Even moderate optical depths can cause significant changes in the morphology of the dusty tail.





planet card inspired by the ExoCup cards

THE DUST COMPOSITION, DUST GRAIN SIZES AND MASS-LOSS RATE CONSTRAINTS

To obtain the parameter constraints we compute synthetic light curves to compare to the observed ones. We constrain the initial dust grain sizes to be 1.25 – 1.75 μm and the average dust mass-loss rate to be $\sim 3\ M_{\oplus}\mathrm{Gyr}^{-1}$. Below is a summary of the results for the different compounds that were tested.

Corundum (Al_2O_3) : Could give origin to the observed light curve with initial dust grain sizes ~3.5-5.5 μm and an average dust mass-loss rate of ~8.0 $M_{\oplus}\mathrm{Gyr}^{-1}$. Such high mass-loss rates would imply unlikely occurrence rates of close-in, catastrophically evaporating small planets. In addition to this, aluminium has a very low cosmic abundance. Therefore, **we find it is unlikely the dust is composed of corundum.**

Iron-free magnesium silicates: forsterite (Mg_2SiO_4) and enstatite (MgSiO3) have low optical to IR opacity ratio and **do not achieve high enough temperatures to sublimate**. The dust survives for multiple orbits, accumulating over time, and the light curve never converges.

Magnesium-iron silicates: **We find the best-fit model for Kepler-1520b to be for dust composed of iron-rich Olivine ($Mg_{0.8}Fe_{1.2}SiO_4$)**, with an initial dust grain size between 1.25-1.75 μm and an average dust mass-loss rate of $\sim 3.0\ M_{\oplus}\mathrm{Gyr}^{-1}$ (Figure 2). Other magnesium-iron silicates tested give rise to similar results.

We can directly probe rocky planet compositions because different condensates will give rise to different light curves due to their differing optical properties. We find the dust is likely composed of magnesium-iron silicates (olivine and pyroxene), consistent with an Earth-like composition.

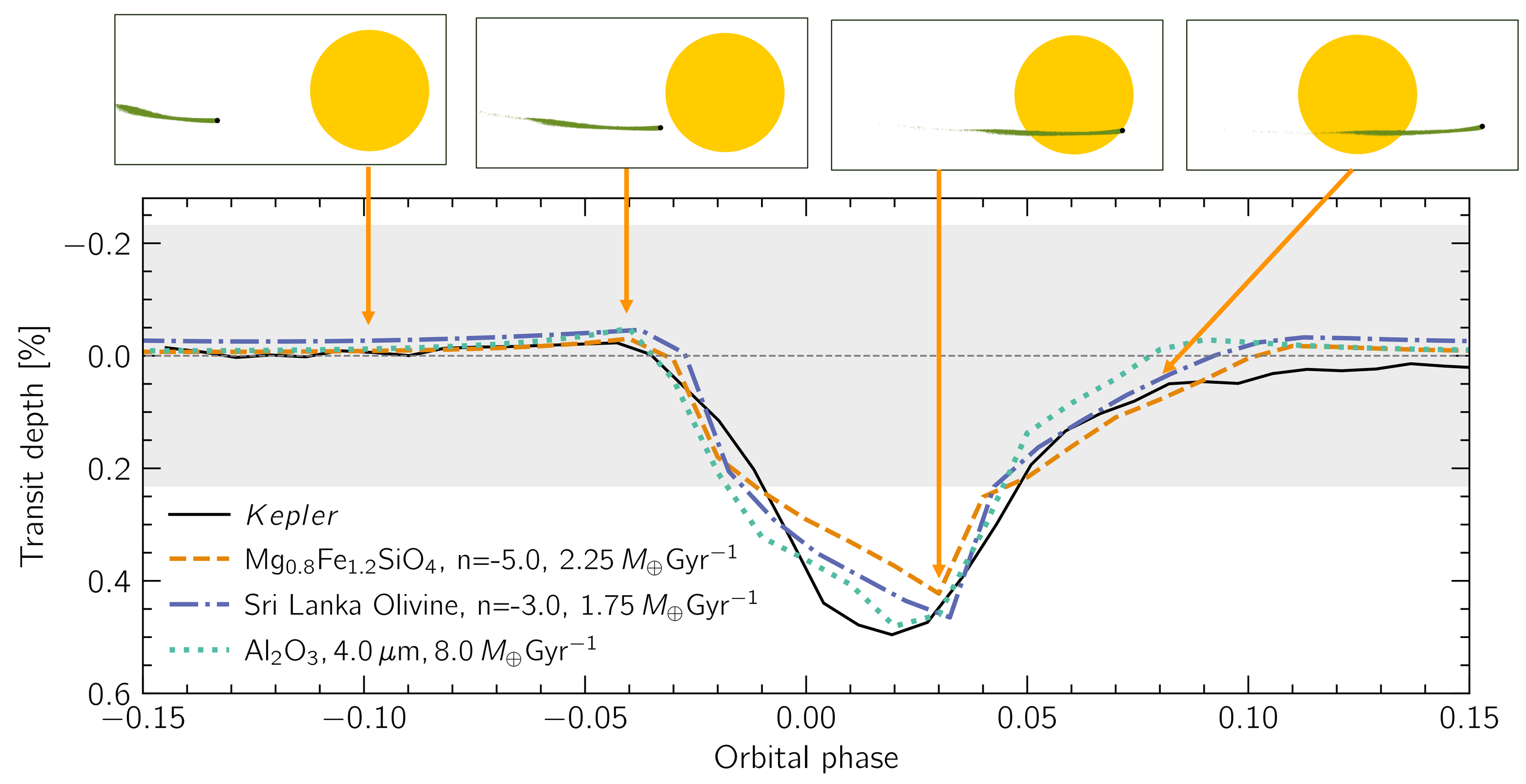


Figure 2: Best-fit synthetic light curves of Kepler-1520b (bottom) and snapshots of the $Mg_{0.8}Fe_{1.2}SiO_4$ simulation (top). The best-fit model for Al_2O_3 is plotted for comparison. The observed *Kepler* light curve is the black solid curve (Rappaport+ 2012). The grey shadowed area represents the spread of the observed excess flux compared to out-of-eclipse observations (van Werkhoven+ 2014).

THE OPTICAL DEPTH

As speculated by Rappaport+ (2012), **we find the dust cloud to be optically thick in the vicinity of the planet** (Figure 3, top). This affects the transit light curve of the planet and its tail in our models, as shown in Figure 3 (bottom).

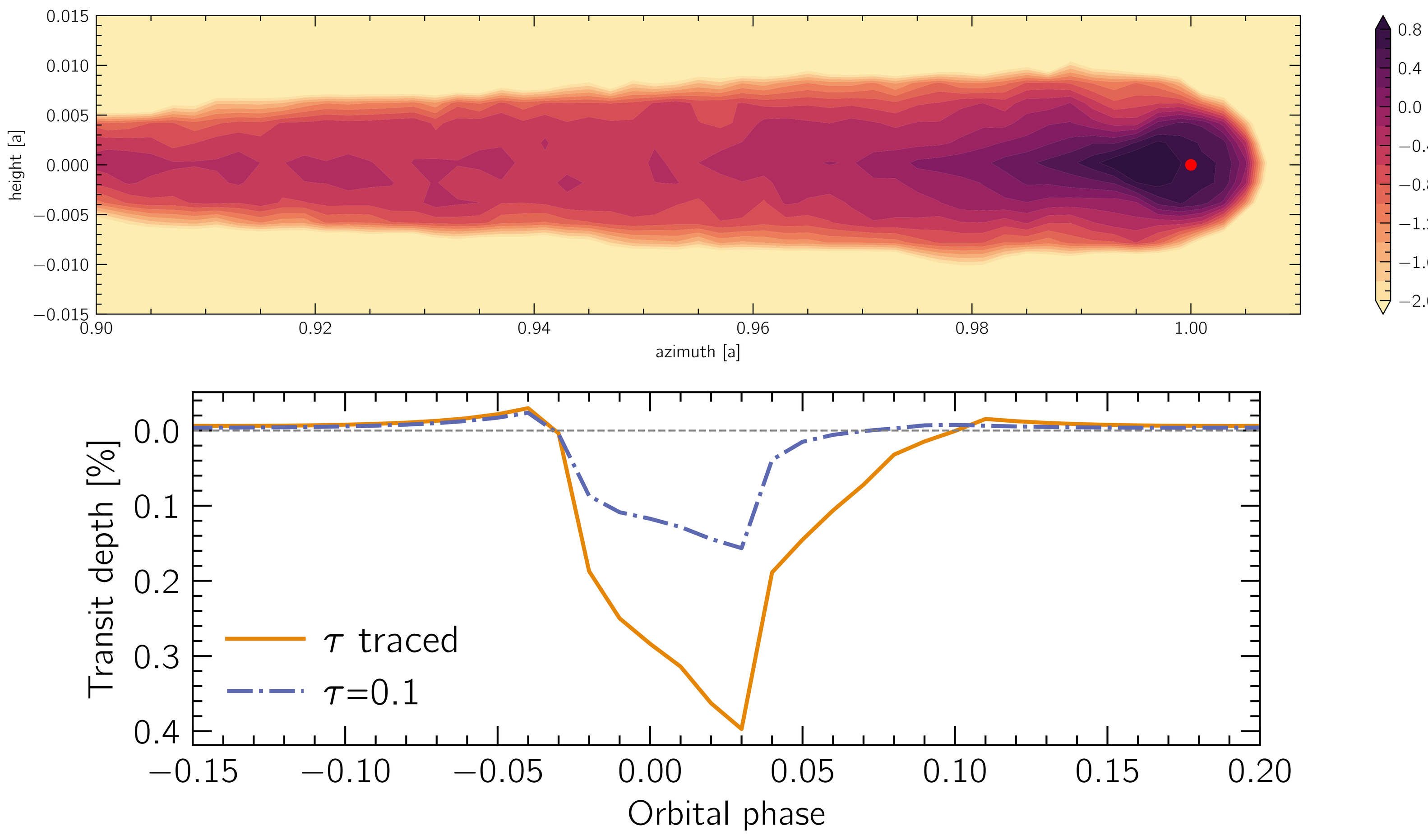


Figure 3: Top: Optical depth density map at the radial edge of the optical depth grid. The red circle indicates the position of the planet. Note the outflow is optically thick in the vicinity of the planet. Bottom: Comparison of two synthetic light-curves for a model where the optical depth is kept thin at 0.1 (dash-dotted curve) and a model where the optical depth is traced (solid curve).

SYNTHETIC JWST SPECTRA: CORUNDUM VS MAGNESIUM-IRON SILICATES

Whilst we argue corundum is an unlikely composition, we suggest that this can be directly confirmed with additional observations. Corundum and magnesium-iron silicates present very distinct absorption features in the near-infrared and mid-infrared regions. In particular, silicates show a very broad absorption feature at about 10 μm. We produce JWST synthetic absorption spectra (Figure 4) of Kepler-1520b for the $Mg_{0.8}Fe_{1.2}SiO_4$ and corundum best-fit models shown in Figure 2.

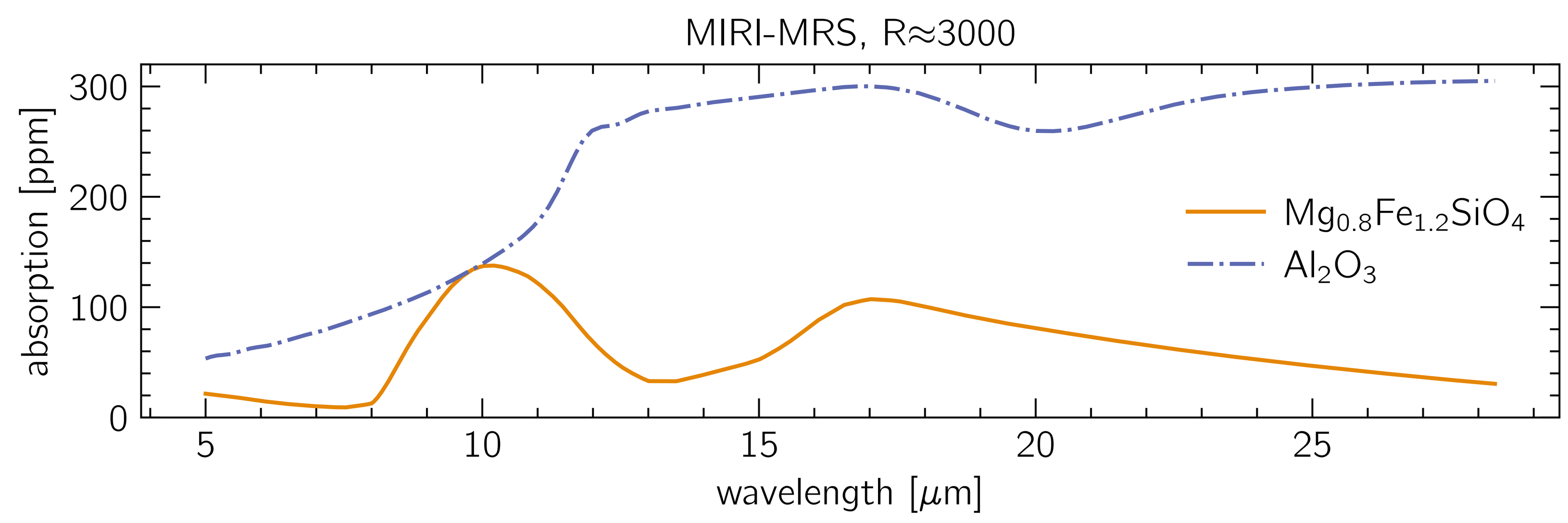


Figure 4: MIRI-MRS synthetic absorption spectra of Kepler-1520b for the best-fit models of corundum and iron-rich olivine shown in Figure 2. The resolution used was 3000. Note the distinct absorption feature of the olivine at about 10 μm. It is likely Kepler-1520b is too faint to perform this experiment with a small number of transits; however, K2-22b may be bright enough.

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Angry planet cartoon:
the-universe-of-the-universe.fandom.com

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement no. 860470.

MARIE CURIE ACTIONS