Analysis of Spitzer and K2 phase curves shows evidence of a rock vapor atmosphere on the lava planet K2-141 b

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Introduction

Ultra-short period planets (USPs) i.e., planets with P_{orb} **< 1 day**

- **rare**, found around <1% of stars
- majority of them are smaller than two Earth radii
- are blasted with stellar radiation
  - **obliterates primordial H/He-rich atmosphere**
  - melts the dayside surface into a magma ocean
  - outgassing of **tenuous rock vapor atmospheres from surface magma oceans**
- **Past observations of USPs** have yielded several surprising results:
  - **55 Cancri e:** measurement of an offset hotspot in the thermal phase curve → may indicate a thick atmosphere has survived
  - **Kepler-10 b:** a high Bond albedo → suggests the presence of unusually reflective lava on its surface

Analysis

Fitted the K2 and Spitzer data with

- a **toy heat redistribution model** for planetary thermal emission
- **Lambertian law** for the reflective contribution

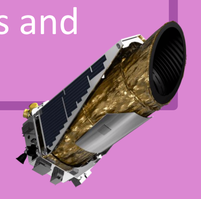
Findings:

- no significant thermal hotspot offset (inconsistent with the Spitzer observations of 55 Cnc e at a 3.9σ level)
- a dayside temperature of $T_{p,d}$ = 2050 +/- 360 K and a night-side temperature consistent with zero ($T_{p,n}$ <1712 K at 2σ)
- models with a steep dayside temperature gradient provide a better fit to the data than a uniform dayside temperature
- evidence for a nonzero geometric albedo A_g = 0.28 +/- 0.07

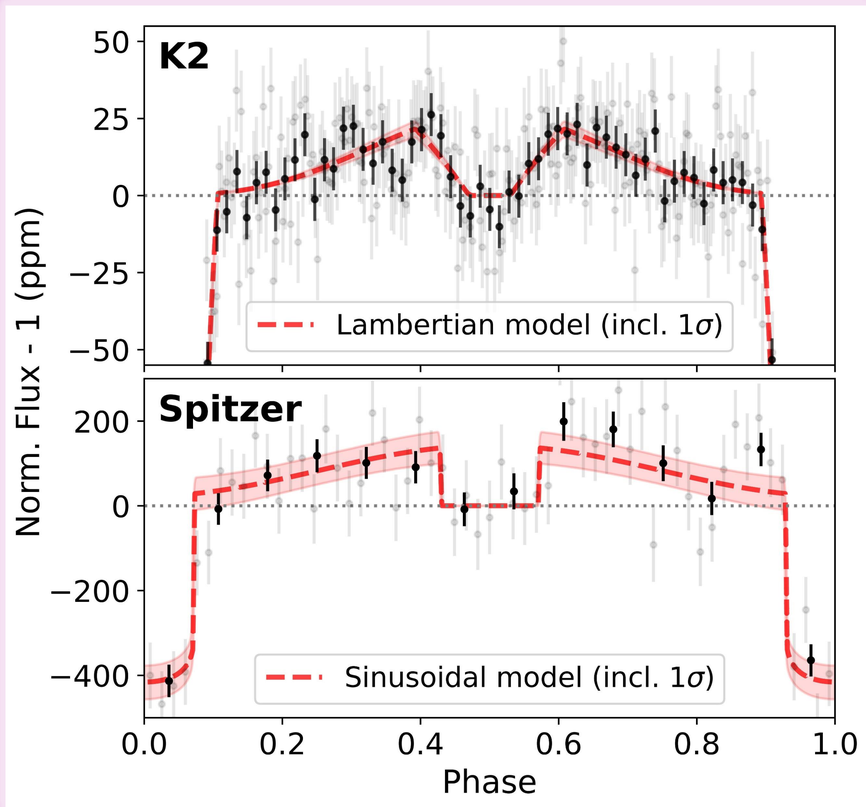
Observations

Spitzer: **65 hours of continuous observations** at 4.5 μm spanning ten full orbits of the planet.

Kepler: collected during **two** separate **K2 campaigns**, C12 and C19, spanning 79 days and 7 days, respectively.



K2 and Spitzer phase curves



About the planet

P_{orb} = 6.7 hours
R_p = 1.5 R_e
M_p = 5.3 M_e
a_p/R_s = 2.3
$(R_p/R_s)^2$ = 425 ppm

About the star

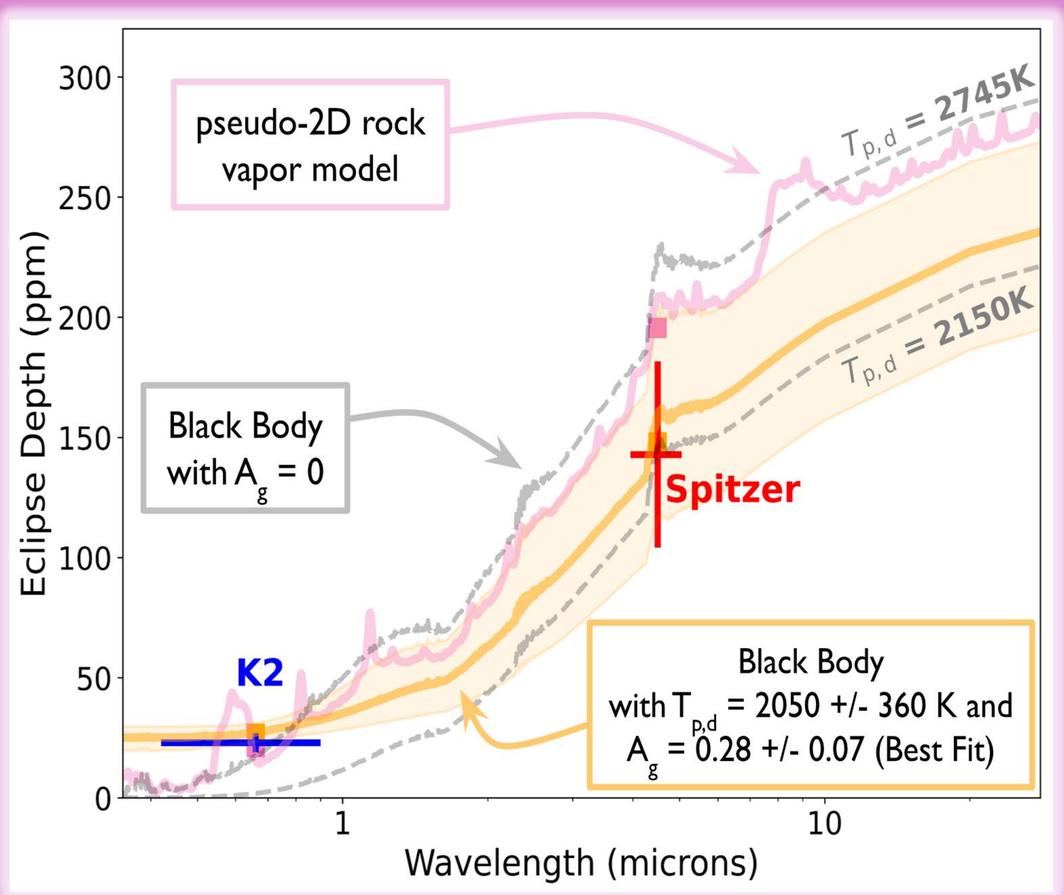
Sp. T = K7V
T_{eff} = 4599 K
R_* = 0.68 R_s
M_* = 0.71 M_s
V = 11.5 mag
K = 8.4 mag
d = 62 pc

There is a second, approximately Neptune-sized, planet in this system, K2-141 c, with P_{orb} = 7.7 days.

K2-141 b vs other USPs

Planet	P_{orb} (h)	Rp (Re)	$T_{subst.}$ (K)
K2-141 b	6.7	1.5	3040
55 Cnc e	17.8	1.9	2760
Kepler-10 b	20.2	1.5	3070

Eclipse depths measured in the Kepler and Spitzer bandpasses compared to different emission spectra of the planet



Both, the rock vapor and the best fit model, produce a larger eclipse depth at optical wavelengths than a single temperature blackbody. Cause of the high optical emission:

- In the toy model: reflected light **from a moderately high albedo**.
- In the rock vapor model: **thermal emission** from a high-temperature **inversion** layer in the atmosphere mostly due to Na.

Conclusions

- **The observed moderately high albedo (roughly 0.3) may be due to a reflective surface, or a thermal inversion in a rock vapor atmosphere.** → High optical emission for other rocky planets like Kepler-10b might be explained by a thermal inversion in a rock vapor atmosphere too!
- The negligible hotspot offset for K2-141 b contrasts with the large offset previously observed for 55 Cnc e which was suggested to have a moderate mean molecular weight atmosphere of a few bars. **K2-141 b either has a high mean molecular weight and low surface pressure or no atmosphere at all.**
- Upcoming JWST phase curve observations with NIRSpec and MIRI will help distinguish between these possibilities.

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Scan me for the arXiv link!