Revisiting the Iconic Spitzer Phase Curve of 55 Cancri e: Hotter Dayside, Cooler Nightside and Smaller Phase Offset

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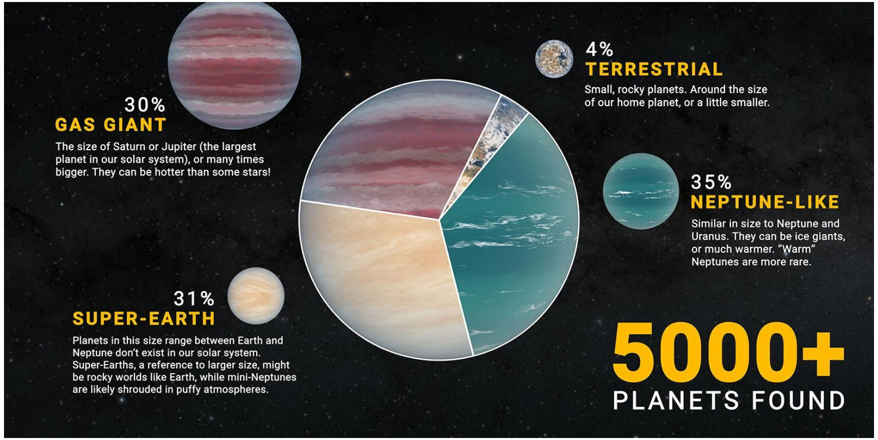
A Brief Introduction

- 55 Cancri e has been analyzed several times to learn more about whether or not the planet has an atmosphere and what such an atmosphere might consist of.
- In this paper, a code known as Spitzer Phase Curve Analysis (SPCA) is used to look at 55 Cnc e, producing a phase curve that allows us to learn more about the planet's potential atmosphere.
- Their goal is to reproduce results from previous analyses of 55 Cnc e that suggest the possibility of an atmosphere.

What is 55 Cancri e?

- An exoplanet
  - Planets outside of our solar system
  - Orbit stars
- Ultra-short period
  - Period ~0.7 days
  - Tidally locked
- Super-Earth
  - ~1.9x the size of Earth
  - ~8x the mass of the Earth
- Orbits a bright star
  - This is why we can observe the planet
  - Causes some issues

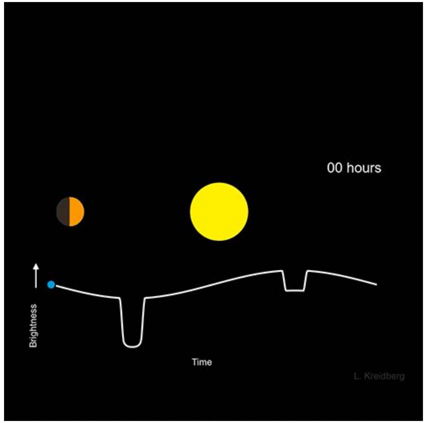
Credit: Wikimedia Commons



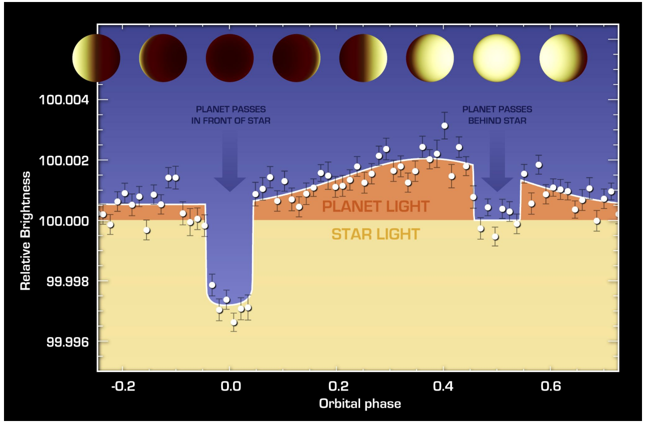
Credit: NASA/JPL-Caltech

How Do We Study Exoplanets Like 55 Cnc e ?

- Phase curves
  - A phase curve shows the brightness of the planet-star system as the planet orbits its star. From the phase curve, we can learn about the exoplanet's temperature, reflectivity, and even it's atmosphere.



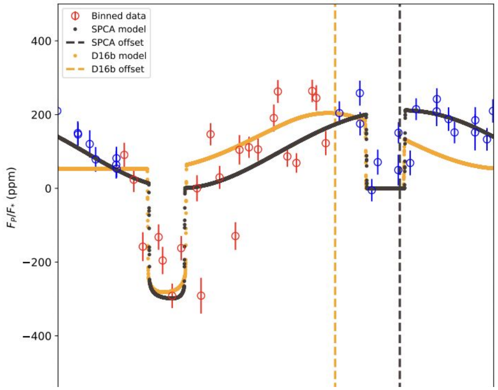
Credit: Laura Kreidberg



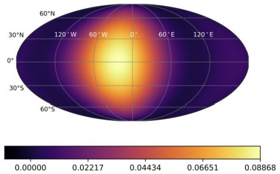
Credit: NASA/JPL-Caltech/Univ. of Cambridge

Its Atmosphere, You Say?

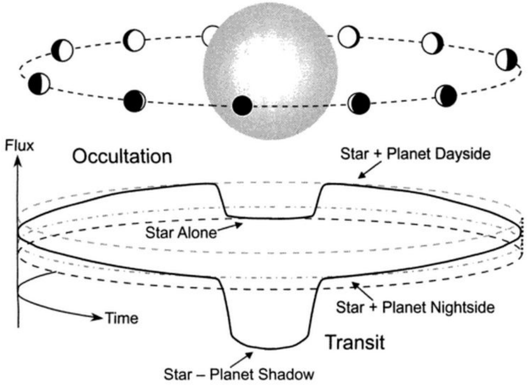
- Yes!
- The phase curve offset and the peak-to-trough amplitude of the transit can both tell us about the planet's atmosphere (or lack thereof).



Credit: Mercier et al.



Credit: Dang et al.[1]

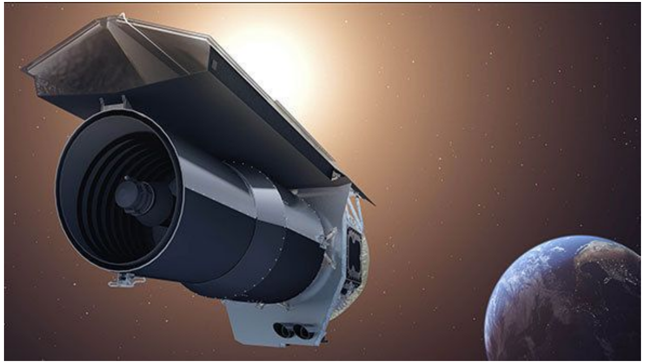


Credit: Josh Winn

Enough background! Let's talk about the paper.

Goals and Challenges

- Reproduce previously published results for 55 Cnc e using SPCA
- However, Spitzer data is notoriously tricky due to a range of systematic errors
  - This is exacerbated by the adjustments that had to be made to accommodate the brightness of 55 Cnc e's star.



Credit: NASA/JPL-Caltech

Results

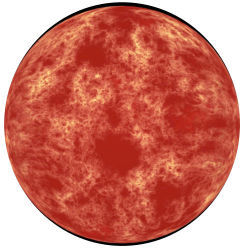
- Found phase offset of 12 +21/−18 degrees west, average dayside temperature of 3,771 +670/−520 K and a nightside temperature of Tnight < 1649 K.
  - **Conclude that there is no significant offset present in the phase variations.**
- Transit depth lines up with most previously published results, but not all
  - Enables them to tentatively excludes a cloud-free hydrogen-dominated atmosphere

Table 1. Fixed, Free and Derived Parameters for 55 Cancri e

Parameters	SPCA Values	D16b Values
Fixed Astrophysical Parameters		
i (degrees)	$83.59^{+0.5}_{-0.4}$	$83.3^{+0.9}_{-0.8}$
P (days)	$0.7365474^{+0.0000013}_{-0.0000014}$	0.736539 ± 0.000007
T_0 (days)	$2457063.2096^{+0.0006}_{-0.0004}$	2455733.013 ± 0.007
a/R_*	3.52 ± 0.01	3.514 ± 0.62
e	0.05 ± 0.03	$0.061^{+0.065}_{-0.043}$
ω (degrees)	86^{+31}_{-33}	202^{+88}_{-70}
q_1	0.0286	0.0286
q_2	0.0554	0.0554
Stellar Effective Temperature (K)	5172 ± 18	5250^{+123}_{-172}
Stellar Surface Gravity ($log_{10}(cm/s^2)$)	4.43 ± 0.02	$4.43^{+0.052}_{-0.14}$
Stellar Metallicity (dex)	0.35 ± 0.10 [Fe/H]	0.35 ± 0.10 [M/H]
checkPhase	True	True
Free Astrophysical Parameters		
R_P/R_*	$0.01708^{+0.0016}_{-0.0017}$	0.0187 ± 0.0007
F_P/F_*	$0.000209^{+0.000050}_{-0.000047}$	0.000154 ± 0.000023
Photometric precision (ppm)	$445.4^{+7.5}_{-7.3}$	363
A	$0.493^{+0.04}_{-0.07}$	Unknown
B	0.108 ± 0.18	Unknown
Detector Hyper Parameters		
x knot resolution	84	Unknown
y knot resolution	64	Unknown
Derived Parameters		
Phase Semi-Amplitude (ppm)	110.9^{+17}_{-16}	75.8 ± 17
Phase Offset (degrees east)	-12.43^{+21}_{-18}	41 ± 12
Average Dayside Temperature (K)	3771^{+669}_{-520}	2999^{+188}_{-193}
Average Nightside Temperature (K)	1045^{+302}_{-243}	1380 ± 400
Conservative Nightside Temperature (K)	$(< 1649\ 2\sigma, < 1951\ 3\sigma)$	–

Results, Cont'd

- Hypothesize that 55 Cnc e either has a global atmosphere covering both hemispheres of the planet or a local dayside atmosphere.
- Surprisingly high dayside brightness temperature can be explained with the presence of SiO in the atmosphere
  - Magma oceans evaporating



Credit: NASA

Conclusions

- Different results from Demory et al. (2016a) AKA D16b
  - Most likely caused by using different photometric extraction methods
- Found a phase offset of 12 $+21/-18$ degrees west, compared to D16b who found a large eastward offset, 2σ away from SPCA's findings.
- The meager phase offset and low nightside flux are consistent with weak heat redistribution, while the large dayside flux could be because of SiO absorption of UV and re-emission at 4.5 μm (the wavelength the data was taken in).

Sources

1. Dang, Lisa, et al. “Detection of a Westward Hotspot Offset in the Atmosphere of Hot Gas Giant COROT-2b.” *Nature Astronomy*, vol. 2, no. 3, 2018, pp. 220–227., https://doi.org/10.1038/s41550-017-0351-6.
2. Dang, Lisa. “Lisadang27/SPCA: Spitzer Phase Curve Analysis.” *GitHub*, https://github.com/lisadang27/SPCA.
3. Mercier, Samson J., et al. “Revisiting the Iconic Spitzer Phase Curve of 55 Cancri e: Hotter Dayside, Cooler Nightside and Smaller Phase Offset.” *ArXiv.org*, 21 Sept. 2022, https://arxiv.org/abs/2209.02090.
4. “NASA Exoplanet Archive.” *NASA Exoplanet Archive*, https://exoplanetarchive.ipac.caltech.edu/.
5. *Spitzer Heritage Archive*, https://sha.ipac.caltech.edu/applications/Spitzer/SHA/.