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Phase Curves in the Era of *TESS*

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Abstract

The reflected light signal from a planet throughout its orbit is a powerful probe of a planet's atmospheric properties. There are a number of planets that are conducive to reflected light phase curve studies with present and future space-based instrumentation and here we assess our ability to characterize these worlds. Using simulated *TESS* populations we identify a set of archetypal exoplanets with the potential to be bright in reflected light while still being cool enough to have minimal thermal contamination at optical wavelengths. We compute albedo spectra and analyze the expected contrasts. Our models suggest that Neptune-sized planets with relatively low insolation and small semi-major axes are the most conducive to reflected light phase curve studies.

1. Introduction

Reflected light phase curves measure the longitudinal variation of the albedo and the scattering properties of atmospheric aerosols. Reflected light observations are thus very sensitive to the scattering properties of a planet's atmosphere. The scattering properties are controlled by composition of clouds, particle size, pressure or depth of the scattering layer, and more. In the process of scattering light from its host star, a planet reveals numerous clues about the structure of its atmosphere and key properties of aerosols that often mute transmission observations.

If any *TESS* discovered planets are amenable to detection in reflected light they will furthermore provide an excellent test bed for validation of models that will later be applied to reflected light direct imaging observations. However, the bandpasses from white light photometric missions include a mix of thermal emission and reflected light. There is thus a need to identify which classes of newly discovered planets are most favorable for phase curve followup with missions like *CHEOPS* [3], *PLATO* [5], or *ARIEL* [8].

2. The Sample: The Nine

Two works [7, 1] have created a sample of possible *TESS* planets based on what we know of the instrument, the stars in the galaxy, and planet occurrence rates. Not all of these will be good candidates for reflected light measurements.

We estimate the reflected light and emitted light of the predicted planets. We require the reflected light signal, $F_{\rm R}/F_*$, be greater than 30 ppm to ensure detectability in the *TESS* bandpass and constrain the sample to planets where the ratio between the reflected and emitted light is greater than 10 to minimize thermal contamination. We then use a k-means clustering algorithm to identify archetypal planets predicted by both works according to the parameters of planetary radius, stellar effective temperature, and insolation to generate an artificial sample.

Table 1: The Nine and their properties.

	P d	a AU	$R_{\rm P}$ $R_\oplus$	$M_{\rm P}$ $M_\oplus$	$T_{\rm eq}$ K	g $\rm m\,s^{-2}$	$T_{*,\rm eff}$ K
P	0.515	0.008	1.9	3.7	802	9.835	3300
S	2.027	0.015	3.7	12.7	542	9.123	3141
M	0.920	0.011	3.9	13.9	612	9.076	3099
B	2.070	0.027	7.5	48.4	858	8.419	4147
F	3.948	0.046	11.4	106.0	811	8.033	4232
A	1.488	0.022	11.8	112.8	981	8.003	4227
G	3.328	0.043	12.1	118.6	1032	7.979	5181
L	3.913	0.049	12.7	131.2	1077	7.931	5572
O	2.738	0.037	13.8	499.6	1146	25.705	5508

3. Models

We generate an atmospheric radiative-convective equilibrium thermal profile for each planet assuming solar abundances. We allow the following species to condense: Al_2O_3, Fe, $MgSiO_3$, Cr, MnS, Na_2S, ZnS, KCl, H_2O, and NH_3. These are then used to generate albedo spectra for $f_{\rm sed}$=3, 1, 0.3, and 0.1. The $f_{\rm sed}$ parameter controls the particle size and vertical extent of the cloud layer. These span a range from very extensive clouds to thin cloud decks.

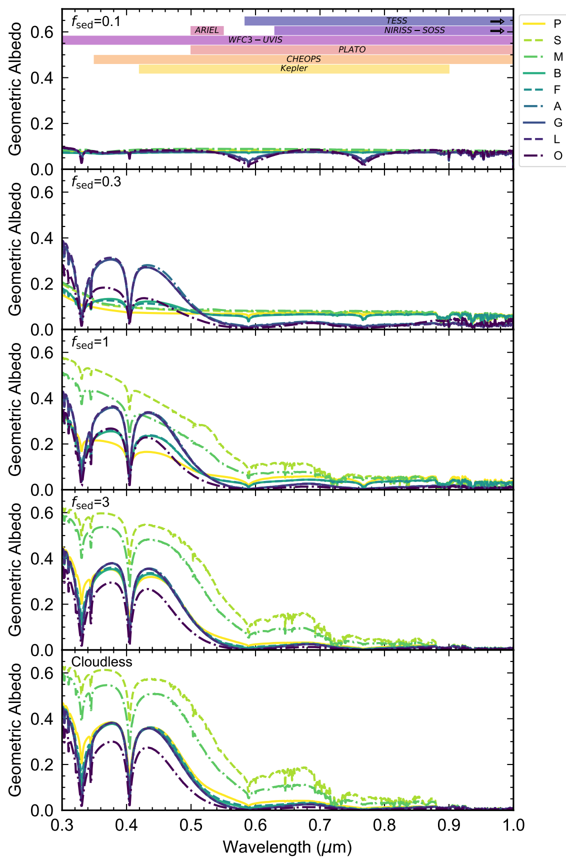

Figure 1: Model geometric albedo spectra for The Nine with varying cloudiness and $f_{\rm sed}$. The colored bars indicate the bandpasses or wavelength coverage of present and future space-based missions for exoplanet discovery and characterization [6, 8, 4, 5, 3, 2].

4. Summary and Conclusions

We modeled the atmospheres of nine planets and generated albedo spectra with varying cloud sedimentation efficiencies. These planets are archetypes for the *TESS* discovered planets that we first estimate and then show will have little to no thermal contamination in the *TESS* bandpass ($< 1\%$ when clouds are present). We compare and contrast the reflected light signal in the *TESS* bandpass with that of a bandpass more focused in the blue and find that contrast ratios are more favorable in a bluer bandpass ($\sim$10–59 ppm and as high as 150 ppm) than in the *TESS* bandpass ($<$10 ppm except in the most lofted cloud scenario where they may be brighter). The planets with the highest, most extensive cloud decks appear darker at bluer wavelengths than cloudless planets because of the low single scattering albedos of their primary constituents.

Future missions should consider bluer bandpasses where the expected contrast is typically higher or ensure they have the necessary precision to make phase curve measurements in a redder bandpass where the contrast will be lower.

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