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Predictions, Observations, and Trends of Exoplanetary Atmospheres

J. Harrington (1) and the UCF Exoplanets Group
(1) Planetary Sciences Group, Department of Physics, University of Central Florida, Orlando, Florida (jh@physics.ucf.edu)

Abstract

The Spitzer Space Telescope has measured numerous eclipses of exoplanets. These measurements give the planetary flux in the observation filter. In combination with the planetary radius, known from transit, one can determine a brightness temperature, $T_{\rm b}$. We compare these $T_{\rm b}$s with the planets' predicted equilibrium temperatures, $T_{\rm eq}$, calculated assuming zero albedo and uniform reradiation of absorbed energy from the entire planetary surface. Measurements deviate from the simplistic $T_{\rm eq}$ prediction because of the composition and thermal profiles present in the atmosphere, but other effects may play important roles as well. We present comparisons of these fundamental observations to both the $T_{\rm eq}$ prediction and to other properties of the planets or their stars.

1. Introduction

Even without resolving an exoplanet from its host star, the flux emitted from an exoplanetary atmosphere can be measured by monitoring the total system flux as the planet passes behind its star during its eclipse. Over 120 planets are known to transit (pass in front of) their stars, and Kepler has identified over 1200 additional candidates. Most of these systems should exhibit eclipses as seen from the solar system.

In 2005, two teams simultaneously published the first measurements of photons from exoplanets [1, 2]. Both teams used instruments on the Spitzer Space Telescope. The planetary flux can be interpreted as a brightness temperature,$T_{\rm b}$, given the radius of the planet as measured during transit, when the planet passes in front of the star. Immediately following these initial measurements, we established a Target of Opportunity (ToO) program to measure eclipses of new planets. Working with the discoverers, we have measured dozens of eclipses. Combining these measurements with those of others, we can now seek trends and groupings in the behavior of exoplanetary atmospheres as a population.

Because most of the successful eclipse measurements have been made in the six photometric channels of the Spitzer Space Telescope (3.6, 4.5, 5.7, 8, 16, and 24 μm), we focus on these data here. There are also eclipses measured by the Hubble Space Telescope and from the ground (e.g., [3, 4]), but these are not yet sufficiently numerous to compare many observations in the same bandpass.

2. $T_{\rm b}$ *vs.* $T_{\rm eq}$

The most basic comparison is between the predicted equilibrium temperature, $T_{\rm eq}$ and the observed $T_{\rm b}$. $T_{\rm eq}$ is a proxy for the stellar flux at the planet. We use it because temperatures are more familiar than flux levels and are more meaningful in terms of their effects on atmospheres and their chemistry. We calculate $T_{\rm eq}$ assuming zero albedo and uniform redistribution of absorbed light around the planet.

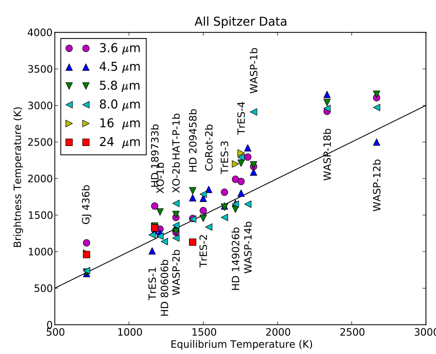

Figure 1: Observed brightness temperature, $T_{\rm b}$, *vs.* predicted equilibrium temperature, $T_{\rm eq}$, for many planets measured in the six Spitzer photometric filters. The line is $T_{\rm b} = T_{\rm eq}$.

Figure 1 shows the Spitzer $T_{\rm b}$ *vs.* $T_{\rm eq}$ comparison for 17 planets. The basic trend confirms that plane-

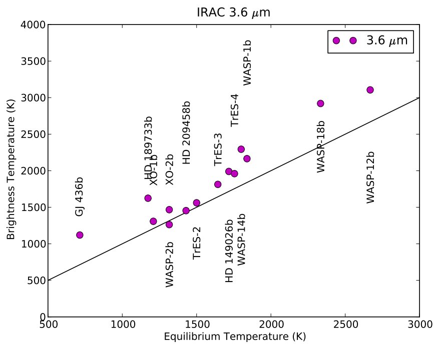

Figure 2: Same as Figure 1, but just for Spitzer's 3.6 μm filter. Note that at both the low and high ends of the temperature scale, all measurements are above the equivalence line. Is this a trend or a statistical fluke? We need more data at the extremes.

tary temperatures are near where we expect them, but with large scatter even for a given planet in different bandpasses. If all the points for a planet are high, it indicates that more than half the received radiation re-emits from the day side, and *vice versa*. Individual high and low points indicate emission or absorption in particular bandpasses, with the former indicating a strong thermal inversion. A tight cluster of points indicates a nearly isothermal atmosphere, with correspondingly little information on structure or composition in the spectrum.

Figure 2 shows just the data at 3.6 μm. At both the low and high ends of the temperature range, all the points lie well above the $T_{\rm b} = T_{\rm eq}$ line, but there is only one point at low temperatures and two at very high temperatures, not enough to establish a trend. We need more data.

3. Other Comparisons

There has been much discussion on the presence of thermal inversions in exoplanetary atmospheres [5, 6, 7] and some on the relationship to metallicity or surface gravity [8]. Surface gravity enters the atmospheric scale height in the denominator, and high gravity would indicate fast-falling precipitation and high rates of convection for a given density contrast. High metallicity would produce more absorbers capable of making a thermal inversion. These hypotheses can now begin to be tested.

4. Summary and Conclusions

The collected atmospheric data from dozens of exoplanets measured by Spitzer are starting to show possible trends and clusters, independent of any interpretive modeling.

Acknowledgements

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