MASS AND COMPOSITION CONSTRAINTS ON DISINTEGRATING EXOPLANETS

Jake R. Hanson[1] and Steven J. Desch[1], [1]School of Earth and Space Exploration, Arizona State University (jake.hanson@asu.edu)

Introduction: Recent observations of several short period exoplanets found highly variable transit depths and asymmetric transit profiles indicative of large, comet-like tails trailing behind transiting exoplanets [1,2,3,4]. Preliminary theoretical estimates suggest these disintegrating planets are small, somewhere between lunar and earth mass, yet are losing mass at rates of roughly an earth mass per gigayear [5]. The large clouds of gas and dust that are ejected from these planets provide a unique opportunity to observe planetary material in gaseous rather than solid form. This is especially relevant considering that the extremely low mass of these planets places them outside of any conventional means of observation. However, the use of broadband spectroscopy has yet to reveal any measurable difference in transit depth [3,6,7]. This measurement places a constraint on particle size but only roughly estimates planet mass and composition. As an alternative to spectroscopy, we focus on modeling the atmospheric dynamics responsible for such large mass loss rates and fit the parameters of our models to observations in order to provide constraints on planetary properties.

Theory: Short period exoplanets are found close-in to their host stars, which places them in relatively high radiation environments. If the planet does not have sufficient mass, the thermal pressure gradient in its atmosphere is in disequilibrium with the gravitational force. This process - physically identical to the Solar Wind in our solar system - leads to stationary hydrothermal expansion of the atmosphere which causes the planet to accelerate shells of mass beyond its escape velocity and into the surrounding space. The rate at which a planet loses mass depends on the imbalance between gravity and atmospheric pressure; this means the only necessary parameters are the planet mass and temperature as well as the mean molecular weight of its atmosphere. By obtaining observational estimates of mass loss rates, we can fit the parameters of this model and constrain planetary properties.

Methodology: The classic Solar Wind Model for atmospheres in stationary hydrothermal expansion was designed to accommodate a finite pressure at infinity (namely, that of the interstellar medium) [8]. This means that the pressure gradient must be maintained in the atmosphere at least until the wind reaches the escape velocity, which is accomplished by assuming the atmosphere in this region is isothermal. With this assumption, the mass loss rate as a function of distance is a conserved quantity that depends only on the wind speed and density. The presumption of stationary hydrothermal expansion as the cause of disintegration leads to an equation for velocity as a function of radius for a given planetary mass, but a boundary condition on the density is still required. To handle this, we assume a given surface composition and model how this specific surface evaporates and launches a thermal wind. Thus, for a given temperature, surface composition, and planetary mass, we can calculate mass loss rates and compare the results to observational values.

Modifications: In addition to implementing the basic model presented above, we intend to extend it in two key ways. The first relaxes the assumption of isothermality and deals with *non-stationary hydrothermal expansion*. Using radiative transfer and mineral condensation sequences, we model a given planet as it builds a vapor atmosphere over time. Eventually the atmosphere is dense and hot enough to enable a thermal wind, which then drops the opacity of the atmosphere and begins the process of runaway atmospheric mass loss. This sort of non-stationary process would lead to large, sporadic ejection events not well correlated with the period of the planet itself and could possibly explain anomalous observations such as that of the ‘alien megastructures’ star KIC-1234 [9]

Another feedback process that we plan to consider is the second derivative of the planet mass, or rather, *the rate at which the mass loss rate is changing*. Since the mass loss rate depends on planet mass, one would expect that as the planet loses mass, the mass loss rate increases. In fact, there are already observations that have detected this feature [2]. This measurement provides a crucial theoretical constraint, as it breaks any degeneracy in the two parameter fit for mass and composition. This allows us to confidently determine a single mass and composition for the observed planet.

References: [1] Rappaport S. et al. (2012) *The Astrophysical Journal, 752,* 1-14. [2] Rappaport S. et al. (2014) *The Astrophysical Journal, 784*, 40-56. [3] Sanchis-Ojeda R. et al. (2015) *The Astrophysical Journal, 812*, 112-134. [4] Vanderburg et al. (2015) *Nature, 526*, 546-549. [5] Perez-Becker D and Chiang E (2013) *MNRAS, 433,* 2294-2309. [6] Croll B. et al. (2014) *The Astrophysical Journal, 786,* 100-116. [7] Zhou G. et al. (2017) *MNRAS, 463,* 4422-4432. [8] Parker E. N. (1958) *The Astrophysical Journal, 128*, 664-676. [9] Boyajian T. S. et al. (2016) *MNRAS, 457*, 3988-4004.