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Sodium Signatures of Satellites Orbiting Close-in Gas Giant Exoplanets

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Abstract

Extrasolar satellites too small to be directly detected by nominal searches might be detectable by analogy to the most active body in the Solar System, Io. We describe how sodium gas could be a signature of the geological activity venting from an otherwise hidden exo-Io in a stable orbit. Analyzing a number of close-in gas giants hosting robust alkaline detections, the absorbed tidal energy can drive ~ 10^5 times Io's mass loss. The remarkable consequence is that the column densities produced by an exo-Io can provide ~10^{10} Na/cm^2 averaged over a stellar disk, as roughly required by the equivalent width of the exoplanet transmission spectra. Noting that the observations of both Jupiter's extended (~1000 R_J) Na exosphere and the Na in its atmosphere are exogenic, we fit the "high-altitude" Na at WASP 49-b with an ionization-limited cloud suggesting the possible presence of an exo-Io, encouraging spectroscopic searches for other volcanic volatiles.

1. Introduction

The 1970s discoveries of sodium clouds at Io (e.g,, Brown 1974; Trafton (1975)) motivated the tidal dissipation theory which predicted extreme volcanic activity on Io (Peale et al. 1979) even before Voyager 1's first images. This activity was shown to be global by infrared images, subsequent spacecraft observations, and decades of direct imaging (e.g., de Kleer & de Pater 2016) as well as by direct detection of volcanic sulfur species (e.g., Lellouch et al. 1996). The subsequent observations of volcanic salts in the mm/sub-mm (Lellouch et al. 2003; Moullet et al. 2013) were suggested to be the venting molecules. Since Jupiter's extended Na exosphere (~1000R_J ; Mendillo et al. 1990) and its presence in Jupiter's upper atmosphere is due to Io's products interacting with Jupiter's plasma, the detection of Na at HD209458b (Charbonneau et al. 2002) led Johnson & Huggins (2006) to consider the effect of material from an orbiting moon, gas torus, or debris ring on an exoplanet transit spectra. Because it was thought exo-moons could not be in stable orbits about hot Jupiters, they suggested co-orbiting clouds of neutrals ions might only be observable for giant exoplanets orbiting at >~0.2 AU. While the Na exosphere shrinks to ~ R_J at a hot Jupiter due to the far shorter lifetime, recent understanding of the effect of a stabilizing stellar tide (Cassidy et al. 2009) indicates that exo_Io's can be stable around hot Jupiters. If that is the case orders of magnitude increase in the heating and volcanic outgassing can occur so that exo-Io Na clouds could be discernable about a hot Jupiter. Here we evaluate a number of transmission spectroscopy observations of Na driven also recent evaluations of the uncertainties in the interpretation of the alkali absorption features at hot Jupiters (Heng et al. 2015; Heng 2016). The incomplete interpretations at present suggest that an exogenic Na source might be a reasonable for certain hot Jupiters.

2. Results

Scaling the significantly enhanced tidal heating, as well as thermally driven and plasma driven atmospheric loss processes, to those processes measured at Io, we estimate the possibility that observed Na transmission spectra at a hot Jupiter might be sourced by an exo-Io in a stable orbit or even from a debris ring from a disintegrated moon (Oza et al 2019). Of the 14 systems examined, there are ~ 9 candidates in which there should be sufficient Na absorption in transmission if an exo-Io was present. Of particular interest is the Na doublet transmission spectrum of WASP 49-b

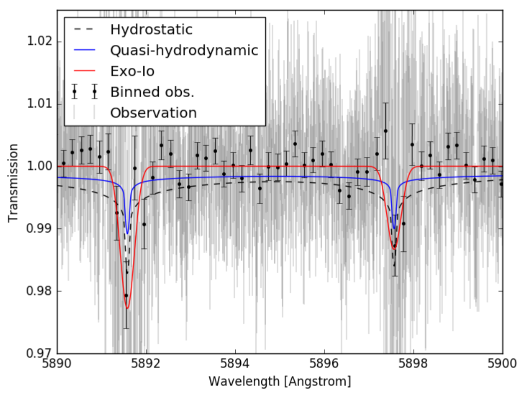

Figure 1: Transmission spectrum for WASP 49-b (reference) with model fits (Oza et al. 2019).

shown in Fig. 1. It is displayed along with model fits: two endogenic models, hydrostatic based on Wyttenbach et al. (2017) and the quasi-hydrodynamic atmosphere of Cubillos et al. (2017). In addition, a fit assuming the Na is from an outgassing exo-Io is shown in red. We note that like HD189733b (Huang et al. 2017) an isothermal profile is unlikely, therefore, we employ a mass loss rate sourced by the tidally-induced volcanic source rate of ~10^5 times that at Io using ~10km/s velocity spread (Burger et al. 2001). Therefore it is seen that, in addition to produce a sufficient source rate, the observed spectrum suggests that the exogenic source is promising. Therefore, we strongly encourage time-dependent ingress and egress monitoring to obtain improved spectroscopic searches for the alkalis and other volcanic volatiles.

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