EPSC Abstracts
Vol. 13, EPSC-DPS2019-1714-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Extrasolar Volcanic Activity on the Magmatic Super Earth 55 Cancri-e

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Abstract

55 Cancri-e (55 Cnc e) is an eccentric super-Earth orbiting in a $<$ 18 hour orbit about a G-type star. The stellar proximity at $\sim 0.015 AU$ subjects these tidally-locked ultra-short period exoplanets to intense irradiation fields: 600× the ion density and XUV radiation at Mercury, more than capable of driving atmospheric loss as observed in the Jovian magnetosphere. Furthermore, if the observed eccentricity $e \sim 0.05$ is forced with an Io-like rheology, the expected tidal dissipation is many orders of magnitude greater than that at Io. Remarkably, a Spitzer observation at 4.5 μm has revealed thermally-driven dynamics on the rocky planet of unknown origin [1]. Here we seek to describe these dynamics not with a general circulation model, but rather with a simple analytic model describing the atmospheric evolution of a tidally-locked body coupled with our recent geophysical knowledge of irradiated molten bodies [2,3]. The surface-atmosphere coupling we describe then, is quite similar to an outgassing Io which has extensive remote and in-situ observations of volcanic volatiles notably in the thermal infrared near $4 \mu m$ [4]. In the following we rely heavily on Solar System observations of both Io and Mercury as to predict the expected outgassed species by transmission spectroscopy in 55 Cnc e's exosphere.

Surface-Exosphere Model

An enigmatic part of the thermal observations of [1] is the $\sim \pi/4$ offset from the substellar point in Figure 1B, where a dynamic non-silicate wind has been invoked as a possibility. The offset in wind models depends on the ratio of the radiative and advective timescales. Remarking on the observed day ($T_d \sim$ 2600K) and night ($T_n \sim$ 1600K) temperatures [1], rapid day-night *migration* should occur from a strongly thermally-outgassed species resulting in a peak in column density which is strongly offset by from the substellar point. As shown for the tidally-locked bodies Europa and Ganymede [2] this peak in column density is offset by $\sim \pi/4 - \pi/2$ regardless of a wind, and is simply a result of migration coupled with the revolution of the body, driving a Coriolis-like wind. The apparent degeneracy between a collisional and collisionless medium is due to surface-atmosphere coupling, which is then imprinted in the collisionless exosphere. In the case of Europa and Ganymede these imprints are observed as oxygen aurorae [2]. The consequence of this effect is illustrated in Figure 1, along with estimated outgassing rates in Table 1.

Observational Implications

Plasma Torus at the orbit of 55 Cnc-e

Due to its extreme proximity to its host star, 55 cancri-e's atmosphere is expected to be constantly blasted with high levels of stellar radiation, where an ionosphere may be expected. The energetic bombardment may further generate a plasma torus, due to the rapid orbital speed of the planet $v_{55Cnce}/v_{Io} \sim 13.2$ feeding an azimuthal current due to mass loss and ionization, inducing a toroidal magnetic field. The dynamics of ionized particles venting from the planet's atmosphere will then be dominated by this plasma torus. In this work we explore the physical conditions in which this scenario is plausible and its implications for ions detected in transit observations [7]. Table 2 lists relevant plasma parameters.

Surface-Exosphere Species

Future observations will be key in identifying the processes responsible for both the features observed in the infrared with Spitzer and the variability observed in the infrared and the visible. In Fall 2019, the ESA mission CHEOPS will be launched and will monitor 55 Cnc e over sufficient time to measure the variability timescale and evolution of transit/occultation parameters. From 2021, JWST will enable us to pinpoint the composition of the material surrounding the planet, notably the silicate feature at 15 μm.

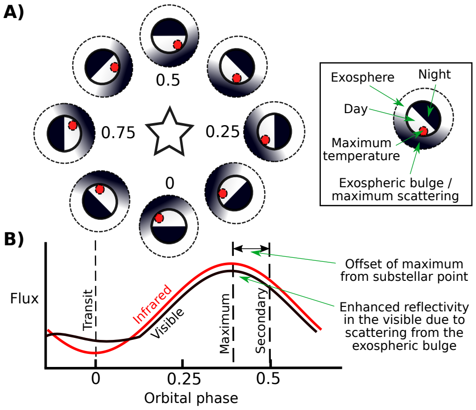

Figure 1: Surface-Exosphere coupling as described by our model.

Table 1: Computed volatile mass loss rates driven by upper-atmospheric heating $\dot{M}_U$ and plasma-driven atmospheric sputtering $\dot{M}_P$. Where source-limited escape $\dot{M}_S$ is found to be negligible. The mass loss rates source a total line of sight column density as provided. The column densities are compared to observational (Obs) constraints for 55 Cnc-e and Io.

Body	$\dot{M}_U$	$\dot{M}_P$	$< N_{SO2} >$
	[kg/s]	[kg/s]	[cm^{-2}]
55 Cnc-e (T$_d$)	$\sim$10^6	$\sim$10	10^{13}
55 Cnc-e (T$_n$)	$\sim$10^5	$\sim$1	10^{12}
55 Cnc-e (Obs)[7]	$\sim$10^6	–	10$^{12.5}$ - 10$^{14.5}$
Io (Obs) [4]	–	$\sim$10^3	10^{15} - 10^{16}

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Table 2: Relevant plasma parameters for 55 Cnc-e versus Io. v$_{orb}$ is the orbital velocity of the planetary body, τ_{Na} is the lifetime for atomic sodium to gauge the ionic contribution to a putative plasma torus, and n$_i$ is the ionic density due to the stellar wind or in Io's case, Jupiter's field.

Body	v_{orb}	τ_{Na}	n$_i$	T$_{eq}$
	[km/s]	[min]	[cm^{-3}]	[K]
55 Cnc-e	228	$\sim$ 1	7 $\times$10^4	1644-2573
Io	17.3	$\sim$ 120	2 $\times$10^3	110 -1600
Mercury	47.4	$\sim$60	1.1 $\times$10^2	200-340

Acknowledgements

A.V.O. acknowledges the support from the Swiss National Science Foundation under grant BSSGI0_155816 "PlanetsInTime". Parts of this work have been carried out within the frame of the National Center for Competence in Research PlanetS supported by the SNSF.

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