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Search for an exosphere in sodium (Na) and ionized calcium (Ca^+) in the optical transmission spectrum of exoplanet 55 Cancri e

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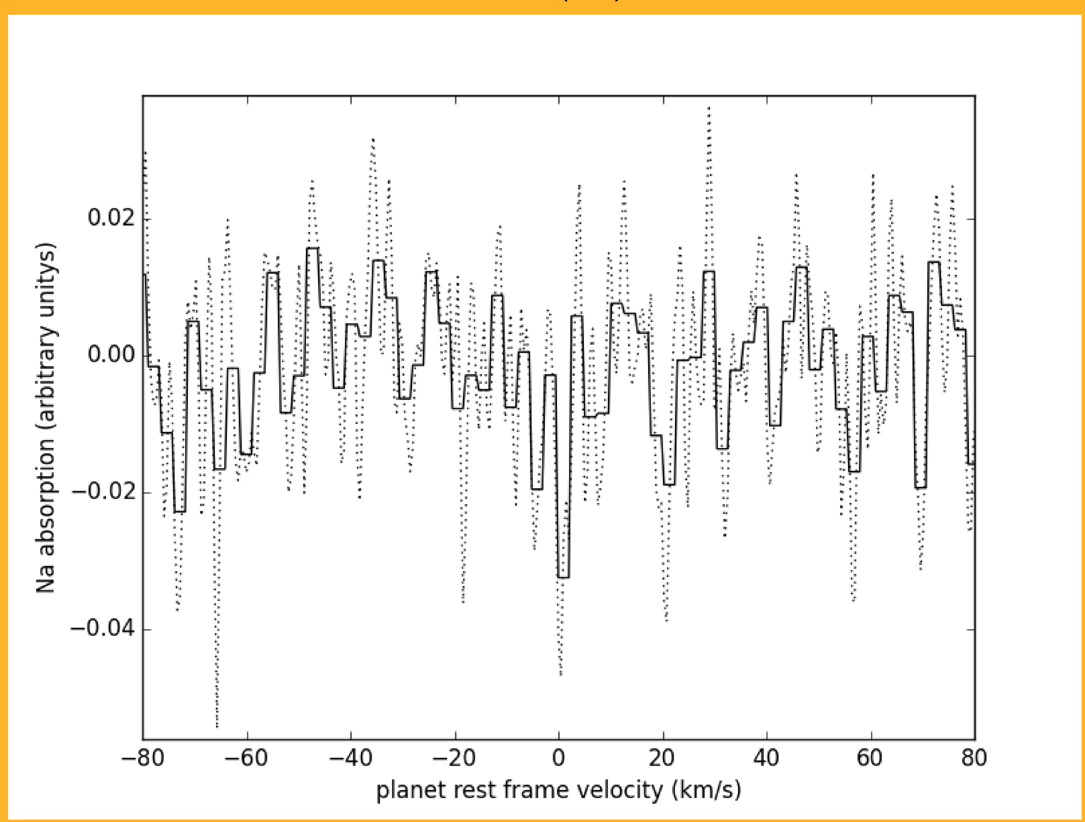
Introduction

The aim of this work was to search for an absorption signal from exospheric sodium (Na) and singly ionized calcium (Ca^+) in the optical transmission spectrum of the hot rocky super-Earth 55 Cancri e (55 Cnc e). This search was motivated by modelling work such as the work carried out Mura et al. (2011) which predicted that hot rocky exoplanets such as CoRoT-7b (or the similar 55 Cnc e) could have a large extended exosphere composed of species such as Na and Ca^+ that were liberated from the planetary surface through the process of sputtering. Sputtering is well known to contribute to the exosphere of Mercury and it is reasonable to expect that the sputtering process could be even more significant on planets such as 55 Cnc e because of their very short orbital distances (~0.015 a.u.). In addition, Schaefer & Fegley (2009) argue that a tidally locked hot rocky super-Earth could have a magma ocean that releases vapours to produce a silicate based atmosphere. Their models show that Na is likely the most abundant constituent of such an atmosphere. Due to the likely connection between species in the exosphere and the composition of the surface, we believe research such as this may prove to be a fast route towards the first characterization of the surface properties of this enigmatic class of planets.

Results

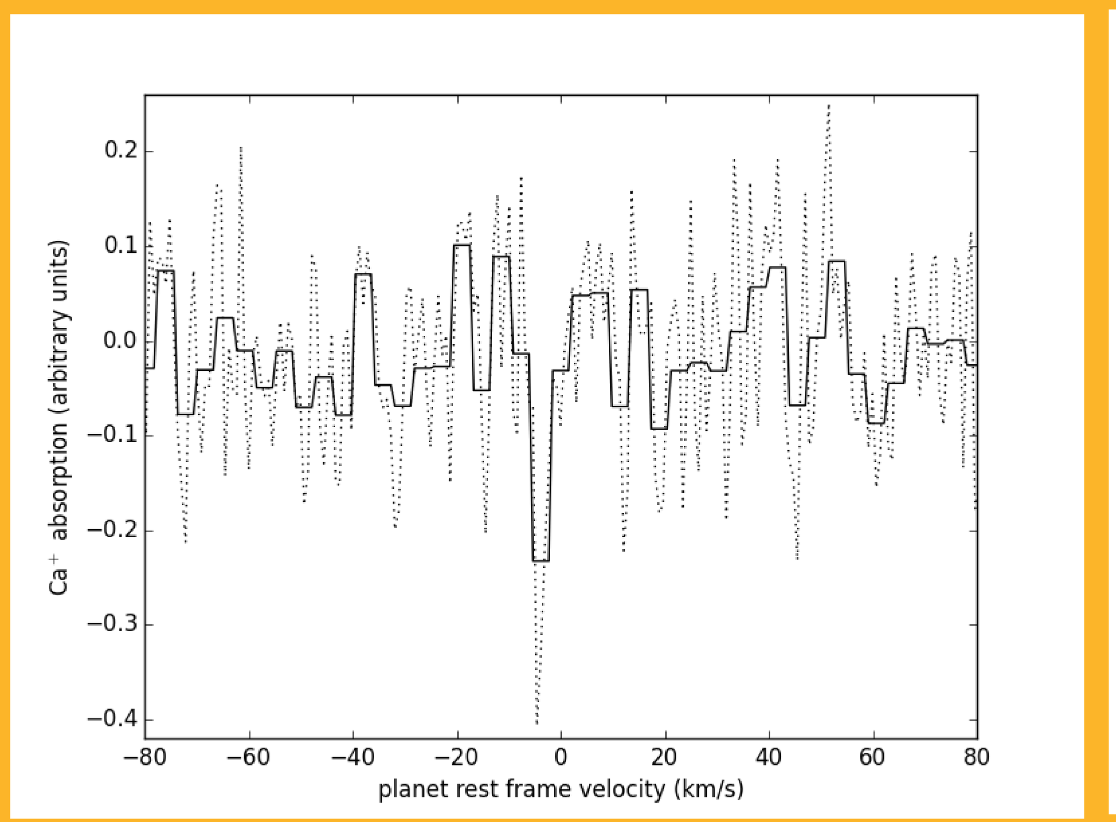
Sodium (Na)



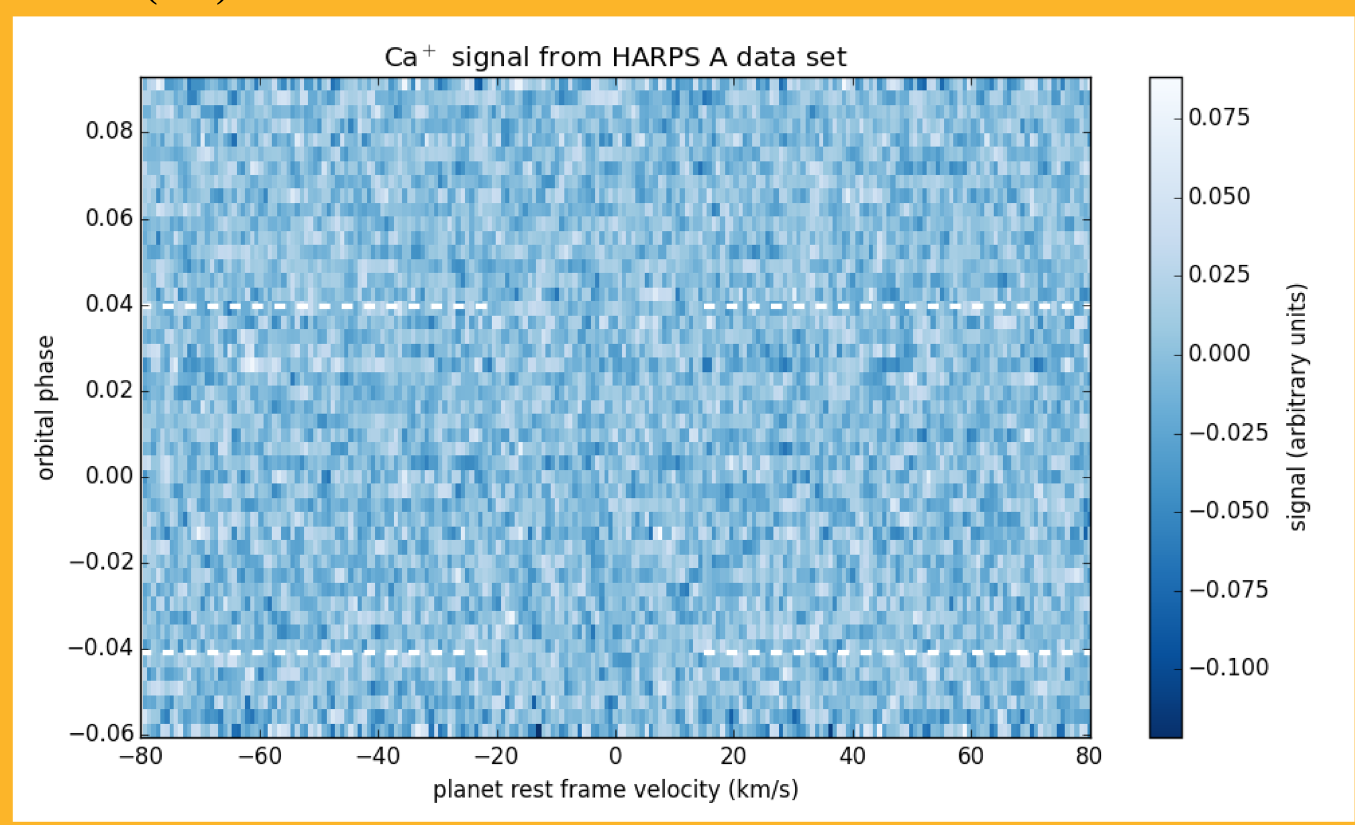
The average signal of sodium from all data sets both not binned (dotted line) and binned (solid black line) every 0.05Å or 3.8 km sec^{-1}. This binning regime results in a detection that has a S/n of ~3.3σ.

3σ detection of Na from average of five data sets.
Absorption of 2.3×10^{-3} relative to stellar spectrum.

Ionized calcium (Ca^+)



The signal of ionized calcium from the HARPS A data set both not binned (dotted line) and binned (solid black line) every 0.05Å or 3.8 km sec^{-1}. This binning regime results in a detection that has a S/n of ~4.9σ.



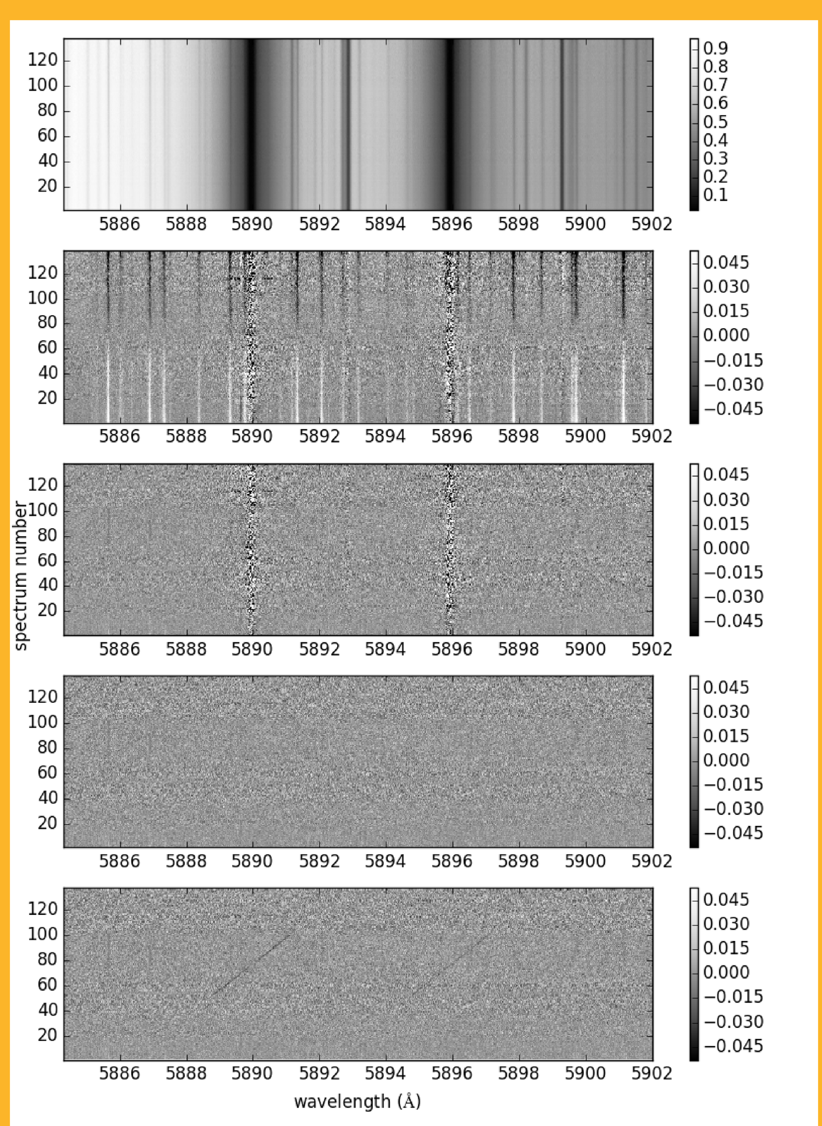
Trace of the signal of Ca^+ from the HARPS A data set across the time-series of spectra in the rest frame of 55 Cnc e. In this frame, the planet signal lies on a vertical line, blueshifted by~4 km sec^{-1}. Dashed horizontal white lines indicate the transit duration.

4.9σ detection of blue-shifted Ca^+ in only one of four data sets (no repeatability).
Absorption of 7.0×10^{-2} relative to stellar spectrum.

Methods

High resolution (R ~ 110000) time-series spectra of five transits of 55 Cancri e, obtained with three different telescopes (UVES/VLT, HARPS/ESO 3.6m & HARPS-N/TNG) were analysed.

Targeting the sodium D lines (5889.95 & 5895.92 Å) and the calcium H and K lines (3933.66 & 3968.47 Å), the potential planet exospheric signal was filtered out from the much stronger stellar and telluric signals by making use of the change of the radial component of the orbital velocity of the planet over the transit from -57 to +57 km/sec. This is shown in the bottom panel of the figure to the right where a strong injected planet signal of Na, injected at a level of 3% relative to the stellar spectrum, forms a diagonal trace.



A visual representation of the processing steps. The vertical axis of each matrix represents the sequence number of the observed spectrum. This figure shows the UVES data, but the HARPS and HARPS-N datasets look very similar. Panel 1: The data around the sodium D lines after normalization and alignment. Panel 2: The residual matrix after dividing through the average star spectrum. Panel 3: The residuals after the PCA analysis. Panel 4: The same after normalizing each column of the matrix by its standard deviation. Bottom panel: the same data, but after injecting an artificial planet signal at a level of 3% of the stellar flux.

Discussion

Based on the lack of repeatability of the Ca^+ signal and the freedom in radial velocity that we could have detected the signal at, we estimated the p-value of the Ca^+ detection to correspond to a detection significance of $<4\sigma$. Also considering the low significance of the Na signal, we do not think these data are yet sufficient to claim definite detections.

However, if these were real detections, the 3σ detection of Na would correspond to an optically thick sodium exosphere with a radius of 5 Earth radii, which is comparable to the Roche lobe radius of the planet.

The 4.9σ detection of Ca^+ in a single HARPS data set would correspond to an optically thick Ca^+ exosphere ~5 times larger than the Roche lobe radius.

If this would be a real detection, it would imply that the exosphere exhibits extreme variability so that it can be detected at some epochs but not others. Given that the exosphere of Mercury is known to be highly variable (Killen et al. 2007), this suggests that 55 Cnc e could be similar to Mercury, and not have a significant atmosphere so that an exosphere could be formed by sputtering of the exposed surface. Interestingly, Demory et al. (2016) measured a full phase curve of 55 Cnc e and one of their more favoured interpretations of their results is that 55 Cnc e could lack a significant atmosphere and have a magma ocean surface, potentially consistent with the idea that 55 Cnc e could have a sputtering induced exosphere.

We are awaiting follow-up observations with UVES to further investigate these tantalising, tentative signals.

References: Demory, B.-O., Gillon, M., de Wit, J., et al. 2016, Nature, 532, 207; Killen, R., Cremonese, G., Lammer, H., et al. 2007, Space Sci. Rev., 132, 433; Mura, A., Wurz, P., Schneider, J., et al. 2011, Icarus, 211, 1; Schaefer, L. & Fegley, B. 2009, ApJ, 703, L113