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The Role of Oxygen Abundances in Exoplanet Host Star C/O Ratios: A Case Study of 55 Cnc

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Abstract. We derive the C/O ratio for the exoplanet host star 55 Cnc based on archive Keck/HIRES spectra. The C/O ratio varies widely depending on which oxygen abundance indicator – the 6300.3 Å [O I] line, the 6363.8 Å [O I] line, or the 7774 Å O I triplet – is used, and we find there is still a large uncertainty even based on individual abundance indicators. This case study demonstrates that caution and care are necessary when determining exoplanet host star C/O ratios, and when considering host star C/O ratios in inferring exoplanet compositions.

Keywords. planetary systems: formation – stars: abundances – stars: individual (55 Cnc)

1. Motivation

Precise Mass and radius measurements of super-Earths can be used to constrain composition by comparing them to various interior models. One such case is the transiting super-Earth 55 Cnc e, part of a 5-planet system originally discovered through RV observations (e.g., McArthur *et al.* 2004). Using the most recent mass and radius measurements, Madhusudhan *et al.* (2012) report that 55 Cnc e could have a C-rich interior. This in contrast to previous modeling of 55 Cnc e, which suggests an interior of Fe and silicates below a super-critical water envelope by assuming a solar-like, O-rich interior (e.g., Gillon *et al.* 2012). Madhusudhan *et al.* (2012) assume that the host star 55 Cnc is C-rich, based on the $C/O_{55\mathrm{Cnc}}=1.12 \pm 0.19$ of Delgado Mena *et al.* (2010). Given the weight of this assumption in current theories of 55 Cnc e's interior composition, and recent work that questions previously-measured C/O ratios (e.g. Nissen 2013; Fortney 2012), we examine further the C/O ratio of 55 Cnc and show it is not so easily constrained.

2. Methods

We used archive Keck/HIRES high-resolution echelle spectroscopy of 55 Cnc (PI: Shkolnik) to first derive 55 Cnc's basic stellar parameters following classical/standard techniques. Abundances were then determined differentially by either measuring equivalent widths or using the spectral synthesis technique in 55 Cnc and in the Sun using the archive Keck/HIRES spectrum of Vesta (PI: Marcy).

3. Results

6300 Å [O I] line (synthesis). The [O I] 6300.30 Å line gives the lowest oxygen abundance, resulting in C/O∼0.97. This line is blended with a Ni I line that becomes more important at higher metallicities, for which most high C/O values have been found (Nissen 2013). When determining [O/H], we assumed the Ni abundance measured directly from 55 Cnc, but by changing [Ni/H] within our derived error (±0.05), the C/O ratio varies from ∼0.54-1.4. With the errors determined for C and this O line, assuming the A(Ni)=6.68 value, the C/O ratio ranges from ∼0.5-1.3.

O I triplet with NLTE. The O I triplet is known to suffer from NLTE effects (e.g. Kiselman 2001), for which several groups have published corrections. For varying NLTE corrections (Takeda 2003; Ramírez *et al.* 2007; Fabbian *et al.* 2009), C/O ranges from ∼0.56-0.79, with an error ∼0.2 based on the LTE abundances. However, Schuler *et al.* (2006) pointed out that such NLTE corrections are not reliable for stars as cool as 55 Cnc ($T_{\rm eff} \leqslant$5450 K), which show an increase with decreasing $T_{\rm eff}$, in direct contrast to canonical NLTE calculations.

6363 Å [O I] line (synthesis). The [O I] 6363.78 Å line gives a C/O∼0.8. It is blended with a CN line; while Caffau *et al.* (2013) finds with 3D models that the CN contribution to this line is <20%, CN contributes more in the cooler 55 Cnc (∼30-40%). Moreover, Caffau *et al.* (2013) show that in dwarf stars this line give larger oxygen abundances than the [O I] 6300.3 Å line, although the origin of this discrepancy is still unclear. Again, within the C and O errors (for this line specifically), C/O ranges from ∼0.48-1.06.

4. Conclusions

While previous measurements indicated the C/O ratio of 55 Cnc to be ∼1, we show here that the picture is not so clear. This calls into question the prediction of Madhusudhan *et al.* (2012) that the small-mass exoplanet 55 Cnc e is C-rich, which was based firmly on the star also being C-rich. Measuring O is difficult in solar-type stars, and becomes even more complicated in cooler, metal-rich stars like 55 Cnc. Our case study demonstrates the extreme caution that must be used when determining exoplanet host star (and any star's) C/O ratios, particularly the sensitivity of all three major oxygen abundance indicators to different effects that are not always easy to account for and changes based on stellar parameters.

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