Identical to Fraternal Twin Switch in Binary Host Stars XO-2N and -2S?

Constraining Giant Exoplanet Compositions via Host Star Abundances of Planet-Building Elements

Johanna Teske (Carnegie DTM/OCIW), Katia Cunha (Observatório Nacional), Simon Schuler (U. Tampa), Verne Smith (NOAO), Caitlin Griffith (UA)

TWEET: @johannateske XO-2 binary host star abuns ~same. Diffs due to diff plnt form (1 HJ vs. 2 cooler massive plnts)? Hard to tell. #toe2014

Motivation/Background

- Planets preferentially form around (main sequence) stars with higher [metals/H] abundances.
- Some studies suggest that planet formation selectively depletes or enriches specific elements the stellar envelope (e.g., Meléndez et al. 2014; Ramírez et al. 2009)
- Binary star systems provide a method for decoupling these two potential effects as the stars have experienced very similar environments over their lifetimes (e.g., Kratter 2011).
- Recently, RV monitoring of the southern component of the wide (~4600 AU) binary XO-2 revealed two giant exoplanets (Desidera et al. 2014). XO-2N was already known to host a transiting hot Jupiter. This is one of only a few known binary systems in which both stars host planets. **See Table 1.**
- Teske et al. (2013) found that XO-2N and -2S were similar in their stellar parameters and abundances, with XO-2N perhaps being more enriched than XO-2S, though both stars have the same C/O ratio of ~0.60.

Are the chemical abundances of host stars indicative of different types of planet formation, and/or does planet formation change host star abundances?

Observations and Methodology

- Subaru/HDS observations in Feb. 2012, R~60,000, ~4450-7100Å.
- Stellar parameters were derived as described in Teske et al. (2013) and Teske et al. (2014), using the EW measurements of Fe I and II in a traditional excitation and ionization equilibrium balance analysis with respect to the Sun implemented with MOOG. **See Table 2.**
- Elemental abundances were derived from equivalent width measurements on continuum-normalized spectra with SPECTRE, with line lists primarily from Schuler et al. (2011) and Melendez et al. (2014). The relative (XO-2N - XO-2S) abundances reflect the line-by-line mean and standard deviation for each element.

Table 1

Parameter	XO-2Nb[1,2]	XO-2Sb[3]	XO-2Sc[3]
M sin i (M_{Jup})	0.57	0.26	1.37
a (AU)	0.04	0.13	0.48
P (d)	2.6	18.2	120.8
e	0	0.18	0.15

Table 2

Parameter	XO-2N	XO-2S
Teff (K)	5343 ± 32	5547 ± 59
log *g* (cgs)	4.49 ± 0.25	4.22 ± 0.24
[Fe/H] (dex)	0.39 ± 0.14	0. 28 ± 0.14
Microturb. (km/s)	1.22 ± 0.09	1.24 ± 0.07

Results

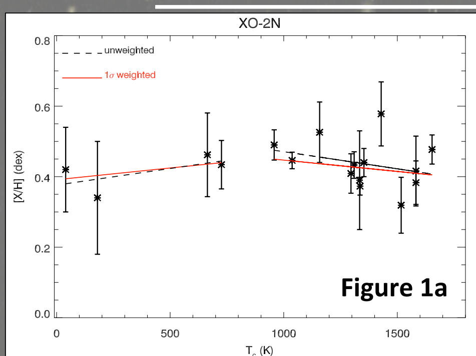
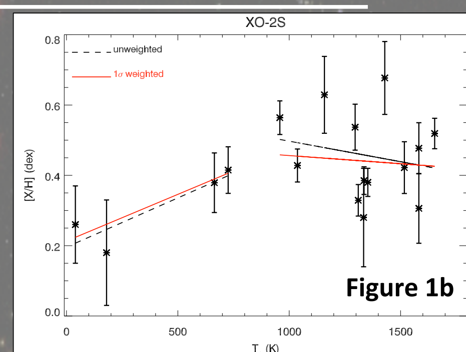
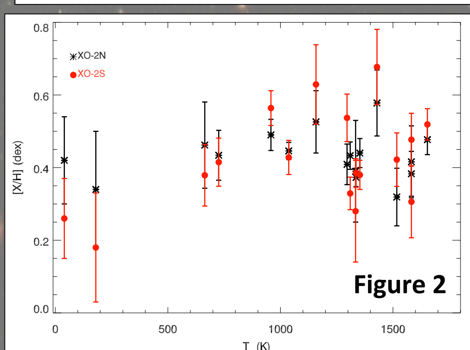
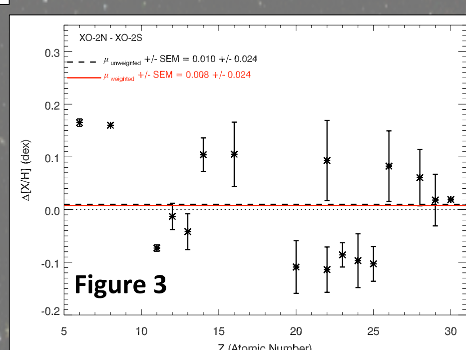


Figure 1 (left and right): Abundances [X/H] of XO-2N (a) and -2S (b) vs.condensation temperature (T_c) from Lodders et al. (2003). Included are fits to elements with T_c < and ≥ 900 K, and fits weighted by the formal abundance errors (solid red, total error) and unweighted (dashed black). Both stars show a slope > 0 for T_c ≥ 900 K and a slope < 0 for Tc < 900 K. Following Ramírez et al. (2009), the negative slopes for [X/H] vs. T_c ≥ 900 K in might suggest an even greater fraction of refractory elements were extracted from the disk to make up planetary material than in the Sun.







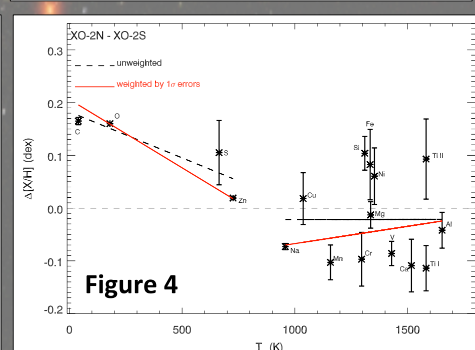


Figure 2: [X/H] for XO-2N and -2S versus T_c, showing both XO-2N (black asterisks) and XO-2S (red filled circles) on the same plot. **Figure 3**: The (XO-2N–XO-2S) mean relative abundances and σ(N-S) errors versus *Z*, including the weighted (solid red) and unweighted (dashed black) fits. The dotted black line is at Δ[X/H]=0. XO-2N and -2S are similar in their abundances spanning a larger number of elements than covered by Teske et al. (2013).

Figure 4: The (XO-2N–XO-2S) mean relative abundances versus T_c, including fits to elements T_c < and ≥ 900 K, and fits weighted (solid red) and unweighted (dotted black) by the line-by-line σ(N-S) for each element. Here, some small differences are evident. XO-2N appears to have less refractories than (or at most the same amount as) XO-2S, save Si, Fe, Ni, and Ti II. Interestingly, XO-2N may also be enhanced in C and O versus XO-2S. Perhaps this makes sense if one thinks of XO-2S "losing" more "planet-building" elements to the planet formation process, as it hosts two massive planets (and maybe a third, see left), whereas XO-2N is only known to host one massive planet.

Caveats/Extra Information

- The error bars in **Figs. 3-4** are just the standard deviation of the line-by-line scatter for each element. For example, the C error is only based on 2 lines, and the O error is 0 because only the 6300.3Å [O I] line was measured. Thus the significance of the enhancement of C and O in XO-2N may be reduced.
- Desidera et al. (2014) found 6σ level evidence in the RV signal of XO-2S for a long-term trend of 0.053 ± 0.009 m s^{-1} d^{-1}, which they suggest is a third companion (whose nature remains unknown).

References: (1) Butler et al. 2006, ApJ, 646, 505 (2) Burke et al. 2007, ApJ, 671, 2115 (3) Desidera et al. 2014, A&A, 567, L6 (4) Kratter et al. 2011, ASPC, 447, 47 (5) Lodders et al. 2003, ApJ, 591, 1220 (6) Meléndez et al. 2014, ApJ, 791, 14 (7) Ramírez et al. 2009, A7A, 508, L17 (8) Schuler et al. 2011, ApJ, 732, 55 (9) Teske et al. 2013, ApJL, 768, 12 (10) Teske et al. 2014, ApJ, 788, 39

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