Detailed Analysis of composition, formation and geochemistry on Earth Like extrasolar planets

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January 31, 2022

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1 Introduction

The bulk chemical composition and interior structure of rocky exoplanets are of fundamental importance to understanding their long term evolution and potential habitability. There are numerous exoplanets to study, which can help in to model Earth-sized planet and Earth like geochemistry. As of now, we have a total of 4500 exoplanets.[8] Our aim of these work is to improve our current understanding of how the abundances of elements led to the formation of Earth System took place. The more data is still coming from various missions and our understanding is improving more on daily basis.

2 Background

Over 4500 exoplanets have been confirmed and exoplanet statistics suggest that close to 100 perentage of Sun-like (FGK) stars harbor planetary systems[8]. The occurrence of planets with radii between 0.5 and 1.5 Radius of Earth orbiting in the conservative habitable zone (HZ) of stars with effective temperatures between 4800 and 6300 K, η, is estimated 0.38.[1] Available data for presumably rock-dominated exoplanets, however, are typically limited to mass and/or radius, and orbital parameters. Observations of the chemical compositions of rocky bodies in the Solar System and of polluted white dwarfs lend support to the idea that the chemical composition of "terrestrial" (silicate+metal dominated) planets generally reflects that of their host stars for refractory elements, whereas this expression breaks down for volatile elements This discrepancy can be explained by devolatilization processes that occurred during the formation and early evolution of the terrestrial planets of our best star-planet sample, the Solar System.[2]

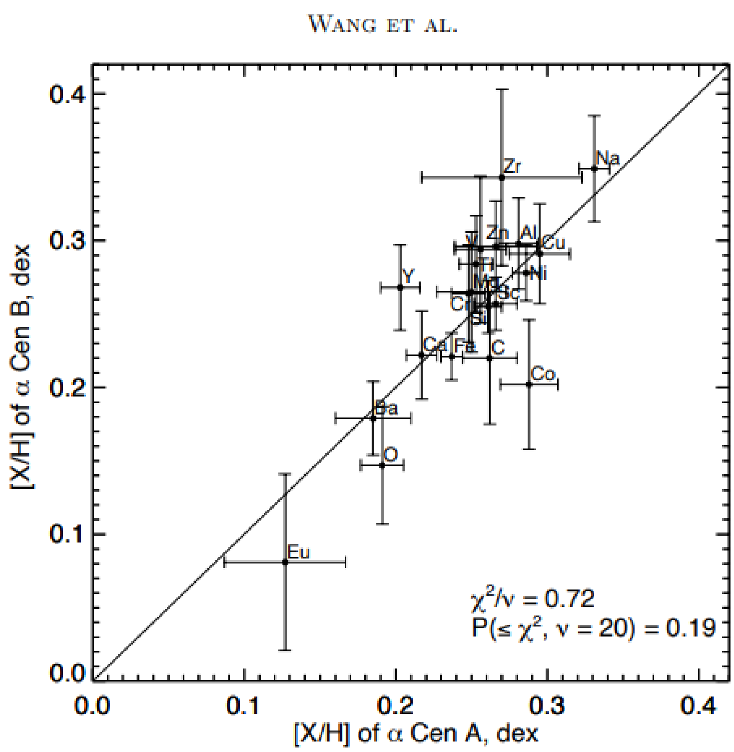
In case of polluted white dwarfs the direct approach to understand extrasolar geochemsitry is oxygen fugacities. Oxygen fugacity is a measure of rock oxidation that influences planetary structure and evolution. Most rocky bodies in the Solar System formed at oxygen fugacities approximately five orders of magnitude higher than a hydrogen-rich gas of solar composition[9]. Oxygen fugacity is also a measure of the degree of oxidation in the rocks. Oxygen fugacities of rocky planets are often reported relative to the reference Iron-Wüstite (IW) equilibrium reaction Fe (Iron) + $\frac{1}{2}$ O2 = FeO (Wüstite), such that ΔIW log(fO2) log(fO2) IW [7] Discoveries continue with legacy data from missions like Kepler, ongoing space observations by TESS, ground-based radial velocity surveys (e.g., HARPS, CARMENES), JWST. With more new technology like in JWST,[8] more datasets will appear and more approaches will arrive to study and understand geology of earth-like exoplanets.

3 Method used in(A model Earth-sized planet in the habitable zone of Centauri A/B)

They used the method of devolatilization model calibrated with the solar system bodies to the chemical composition of our nearest Sun-like stars – Centauri A and B – to estimate the bulk.composition of any habitable-zone rocky planet in this binary system (“α-Cen-Earth”)[1].

4 Methodology for(A model Earth-sized planet in the habitable zone of Centauri A/B)

1. They applied a fiducial model of devolatization for the analysis of planetary bulk composition, interior and atospheres for a model Earth-sized planet in the habitable zone of a (“α-Cen-Earth”)[1].
2. “α-Cen A B” chemical composition determined with high quality spectra of 22 elements[1] [8].



Comparison of the elemental abundances of α-Cen A and B.

3. Alternatively, they used protosolar abundances to convert the differential abundances to the absolute abundances.They did not consider the effects of microscopic diffusion in α Cen A and B, any changes arising from diffusion can probably be accommodated by the abundance uncertainties[1][6]

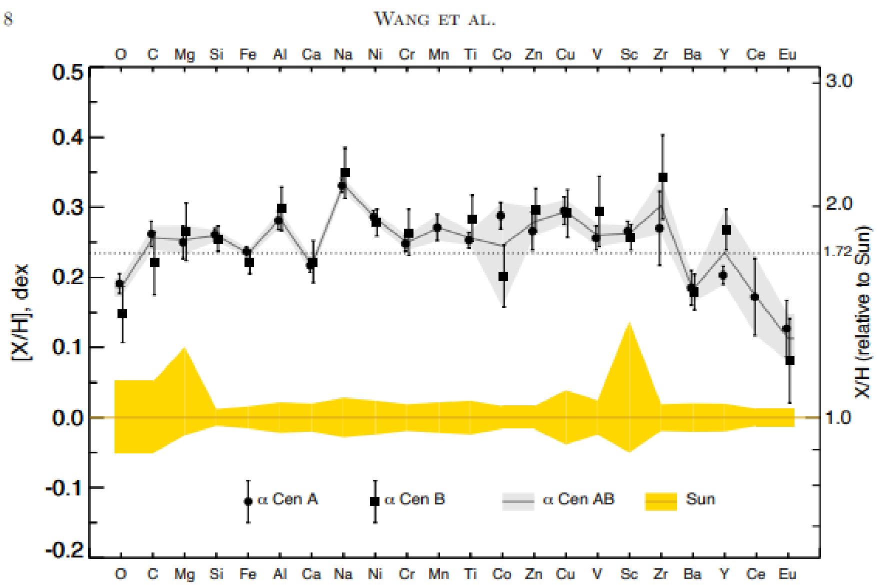
Element	$[X/H]_A$ (dex)	$[X/H]_B$ (dex)	$[X/H]_{AB}$ (dex)	$(X/Al)_{AB}$ (Al=100)
C	0.262 ± 0.018	0.220 ± 0.045	0.256 ± 0.017	9514^{+1251}_{-1106}
O	0.191 ± 0.014	0.147 ± 0.040	0.186 ± 0.013	14735^{+1900}_{-1683}
Na	0.331 ± 0.010	0.339 ± 0.036	0.332 ± 0.010	$72.7^{+5.1}_{-4.8}$
Mg	0.250 ± 0.023	0.265 ± 0.041	0.254 ± 0.020	1192^{+318}_{-85}
Al	0.281 ± 0.013	0.298 ± 0.031	0.284 ± 0.012	100 ± 6
Si	0.261 ± 0.009	0.255 ± 0.018	0.260 ± 0.008	1153^{+39}_{-38}
Ca	0.217 ± 0.010	0.222 ± 0.030	0.218 ± 0.009	$64.2^{+3.4}_{-3.2}$
Sc	0.266 ± 0.014	0.257 ± 0.018	0.263 ± 0.011	$0.042^{+0.016}_{-0.005}$
Ti	0.253 ± 0.011	0.284 ± 0.033	0.256 ± 0.010	$2.86^{+0.18}_{-0.17}$
V	0.256 ± 0.017	0.294 ± 0.050	0.260 ± 0.016	0.32 ± 0.02
Cr	0.248 ± 0.011	0.264 ± 0.033	0.250 ± 0.010	$14.8^{+0.8}_{-0.7}$
Mn	0.271 ± 0.019	–	0.271 ± 0.019	10.5 ± 0.7
Fe	0.237 ± 0.007	0.221 ± 0.016	0.234 ± 0.006	959^{+38}_{-37}
Co	0.288 ± 0.019	0.202 ± 0.044	$0.245^{+0.062}_{-0.087}$	$2.57^{+0.41}_{-0.47}$
Ni	0.286 ± 0.009	0.278 ± 0.019	0.285 ± 0.008	$59.6^{+3.6}_{-3.4}$
Cu	0.295 ± 0.020	0.291 ± 0.034	0.294 ± 0.017	0.62 ± 0.06
Zn	0.266 ± 0.027	0.296 ± 0.031	0.279 ± 0.020	1.48 ± 0.09
Y	0.203 ± 0.013	0.268 ± 0.029	$0.236^{+0.062}_{-0.046}$	$4.78^{+0.77}_{-0.52} \times 10^{-3}$
Zr	0.270 ± 0.053	0.343 ± 0.060	0.302 ± 0.040	0.014 ± 0.001
Ba	0.185 ± 0.025	0.179 ± 0.025	0.182 ± 0.018	$4.50^{+0.29}_{-0.27} \times 10^{-3}$
Ce	0.172 ± 0.055	–	0.172 ± 0.055	$1.09^{+0.15}_{-0.13} \times 10^{-3}$
Eu	0.127 ± 0.040	0.081 ± 0.060	0.113 ± 0.033	$8.36^{+0.71}_{-0.66} \times 10^{-5}$

The elemental abundances of Cen A, Cen B, and the average AB system.

4.Thereafter, they analyzed individual elements and their ratios to understand, how the "α-Cen-Earth" is different from bulk Earth. This helped in to obtain the final bulk composition of model "α-Cen-Earth".

4.1 Data Analysis

1. With their data analysis and model, Carbon to oxygen(C/O) is no longer a valid indicator of rocky planet dominant mineral types[2] [1].
2. Magnesium and Silicon (Mg/Si) is still a good first-order proxy for in a rocky planet around the host star[1] [6] .



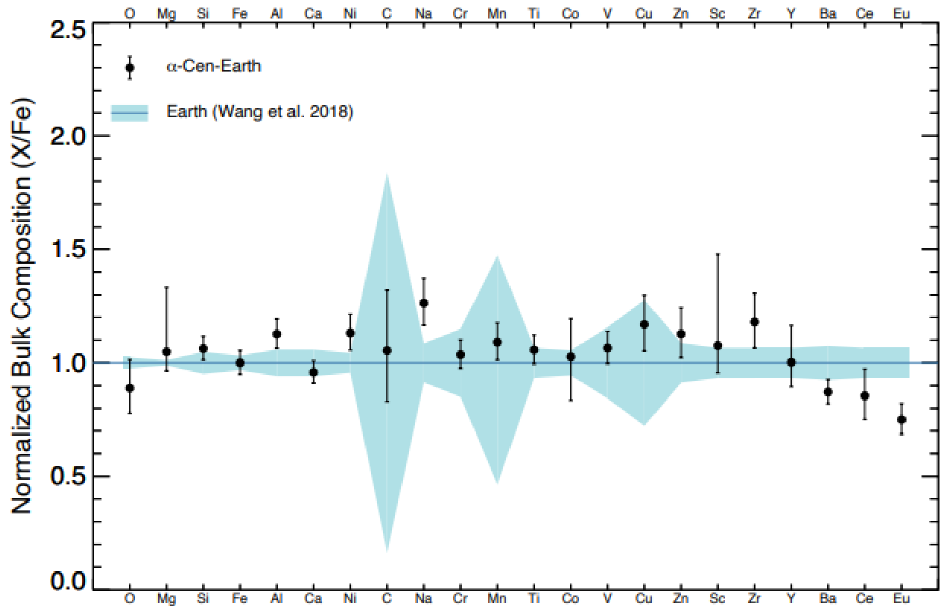
Elemental abundances ([X/H], dex) of α-Cen A and B and of the averaged AB system, in comparison with the protosolar abundances

3. With planetary bulk elemental composition as the only known information (by estimation) in their case, they have no prior knowledge of the distribution of iron in different phases, So they have proposed the bulk (O-Mg-2Si)/Fe as a proxy for fO2 to indicate[3].

4. (Mg+Si)/Fe is adopted as a proxy for the potential core size of a rocky planet.

5. Since EU is a lithophile element, they therefore adopt Eu/(Mg+Si) as a proxy for indicating the concentration of these long-lived isotopes and the budget of the resultant radiogenic heating production over geologic timescales.

6. 40K is considerably depleted in the modern mantle of our model α Cen Earth.



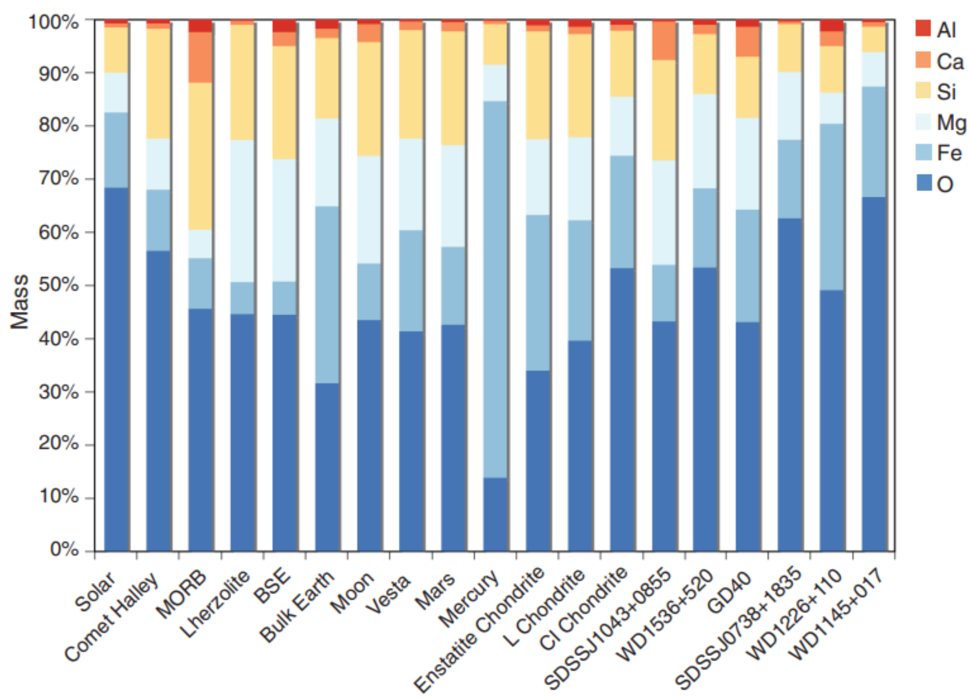
Estimates of bulk elemental composition of the model α-Cen-Earth, as devolatilized from the chemical composition of the average AB system

5 Method for (Oxygen fugacities of extrasolar rocks: Evidence for an Earth-like geochemistry of exoplanets)

They used a direct approach for determining the composition of extrasolar rocks. The method helped in to study the elemental abundances in some white dwarfs(WDs). WD(s) are the remnant cores left behind when a star ejects its hydrogen-rich outer layers after the red-giant phase[3].

6 Methodology used for (Oxygen fugacities of extrasolar rocks: Evidence for an Earth-like geochemistry of exoplanets)

1. They studied observations from the literature of polluting elements in six WDs: SDSS J104341.53+085558.2,SDSS J122859.92+104033.0, SBSS 1536+520, GD 40, SDSS J073842.56+183509 and LBQS 1145+0145 (hereafter, SDSSJ1043+0855, WD 1226+110,WD 1536+520,GD 40, SDSS J0738+1835, and WD 1145+017, respectively)[4] [9].

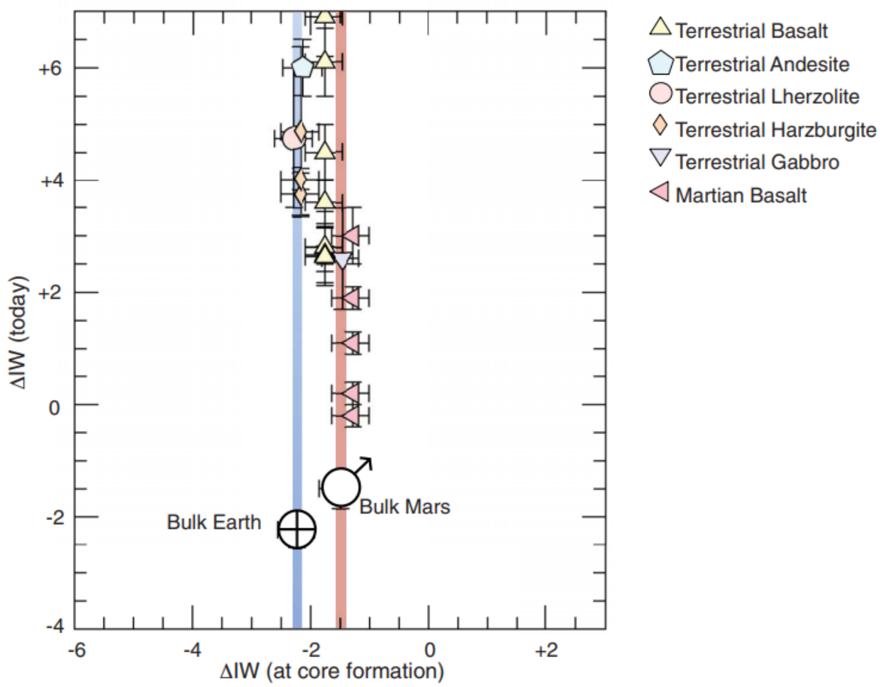


Bulk compositions by mass for six white dwarfs compared with Solar System bodies

2. They use the relative abundances of rock forming elements in polluted WD(s) to determine the effective partial pressure of oxygen, i.e., the oxygen fugacity fO2 of the accreted rocks[3].

3. The oxide components MgO, SiO2, FeO, Al2O3, and CaO describe the compositions of the major minerals that make up the accreting rocks By assigning oxygen first to Mg, then Si, Al, Ca, and finally Fe, they calculated the relative

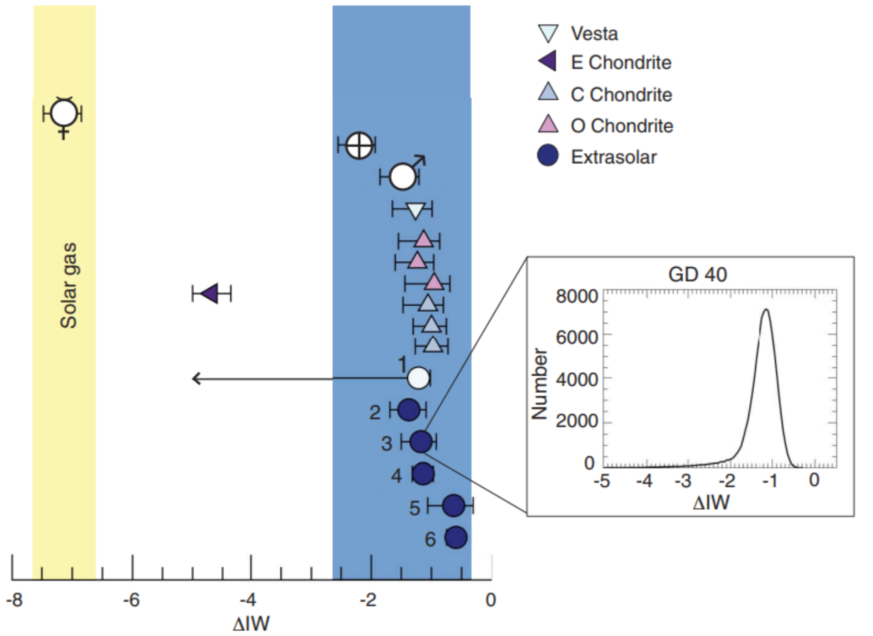
amount of oxidized Fe, as FeO, and assign any remaining Fe to metal representing the core of the body[3].



Oxygen fugacities relative to IW at core formation versus today

4. They propagate measurement uncertainties for the polluted WD(s) using a Monte Carlo bootstrap approach[4][9].

5. They validated their method using Solar System bodies by converting the composition of these bodies into hypothetical polluted WD(s), as if rocks from the bodies (e.g., Earth, Mars, Mercury) had accreted onto a WD[4].



Calculated oxygen fugacities relative to IW for rocky extrasolar bodies

6.They used typical WD measurement uncertainties for these calculations and recovered the known intrinsic oxygen fugacities for Earth, Mars, Mercury, Vesta, and various chondritic bodies.

7 Softwares

To carry out anaylis, three sets of software are employed: ExoInt for both devolatilization and first-principal interior modeling; Perple X for a detailed modeling of the mantle mineralogy and interior structure; and FactSage 8.0 for calculating the gas speciation from the modeled interiors.

8 Results

Both paper has provided a significant data for understanding the Earth like rocky planets. The first paper focuses on various aspects of the composition of a rocky exoplanet while on the other hand the second paper focuses on only one aspects of a rocky exoplanet using a different method.

8.1 Result of α-Cen Earth

[1][8] 1. Firstly, the AB system is super-solar in metallicity ([Fe/H]), with an enrichment of iron to hydrogen by 72 percentage. The enrichment of other elements, except O, Ba, Ce, and Eu, to hydrogen ([X/H]) are either equivalent or higher.
2. Calculations of C/O and Mg/Si reveals that both of these ratios are consistent with the solar values (within uncertainties).
3.They also note that the most recent solar photospheric abundances are consistent with our adopted protosolar abundances within uncertainties in terms of C/O vs. Mg/Si,[2] while a normalization to the former would lead to a relatively higher C/O that favors our suggestion of the enrichment of carbon-bearing phases in the silicates-dominated mantle of the model planet.
4. The model "α-Cen-Earth has equivalent or relatively higher concentrations of most elements (relative to Fe) and lower concentrations of O, Ba, Ce, and Eu.[5]

8.2 Results of Oxygen fugacities of Earth Like extrasolar rocks

[3] 1. The parent objects that polluted these WDs had intrinsic oxidation states similar to those of rocks in the Solar System.
2.Based on estimates of their mass, the bodies accreting onto WDs were either asteroids that represent the building blocks of rocky exoplanets, or they were fragments of rocky exoplanets themselves.
3. In either case, their results constrain the intrinsic oxygen fugacities of rocky bodies that orbited the progenitor star of their host WD.
4. Their data indicate that rocky exoplanets constructed from these planetesimals should be geophysically and geochemically similar to rocky planets in the Solar System, including Earth.

9 Conclusions

9.1 A model α-Cen-Earth

1. An α-Cen-Earth as modeled should have a reduced (primitive) mantle that is similarly dominated by silicates albeit likely enriched in native carbon species (e.g. graphite/diamond).
2. The planet is also expected to have a slightly larger iron core.
3. The planet should have an equivalent water-storage capacity of Earth.
4. Such a planet may also have a CO2-CH4-H2O-dominated early atmosphere that resembles that of Archean Earth; observationally, this may be tested with a dry, CO2-dominated atmosphere. considering the preferable photolytic destruction to CH4 and H2O and the possibility that.
5. The planet may be in a Venus-like stagnant-lid regime, with sluggish mantle convection and planetary resurfacing, over most of its geological history.

9.2 Oxidation fugacities in extrasolar planets[3]

1. The Solar System bodies span a range in DIW of 6 dex, in agreement with previous studies showing that Mercury and enstatite meteorites have fO2 orders of magnitude lower than those for Earth, Mars, and other chondrite group meteorites.
2. The high oxygen fugacities of these extrasolar rocks, relative to a solar gas, suggest that whatever process oxidized rock-forming materials in the Solar System also operated in these other planetary systems.
3. The high oxidation state of these rocks determined the mineralogy, and therefore the geophysical behavior, of their parent bodies

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