Osiris revived: Confirming solar metallicity and low C/O on HD 209458b

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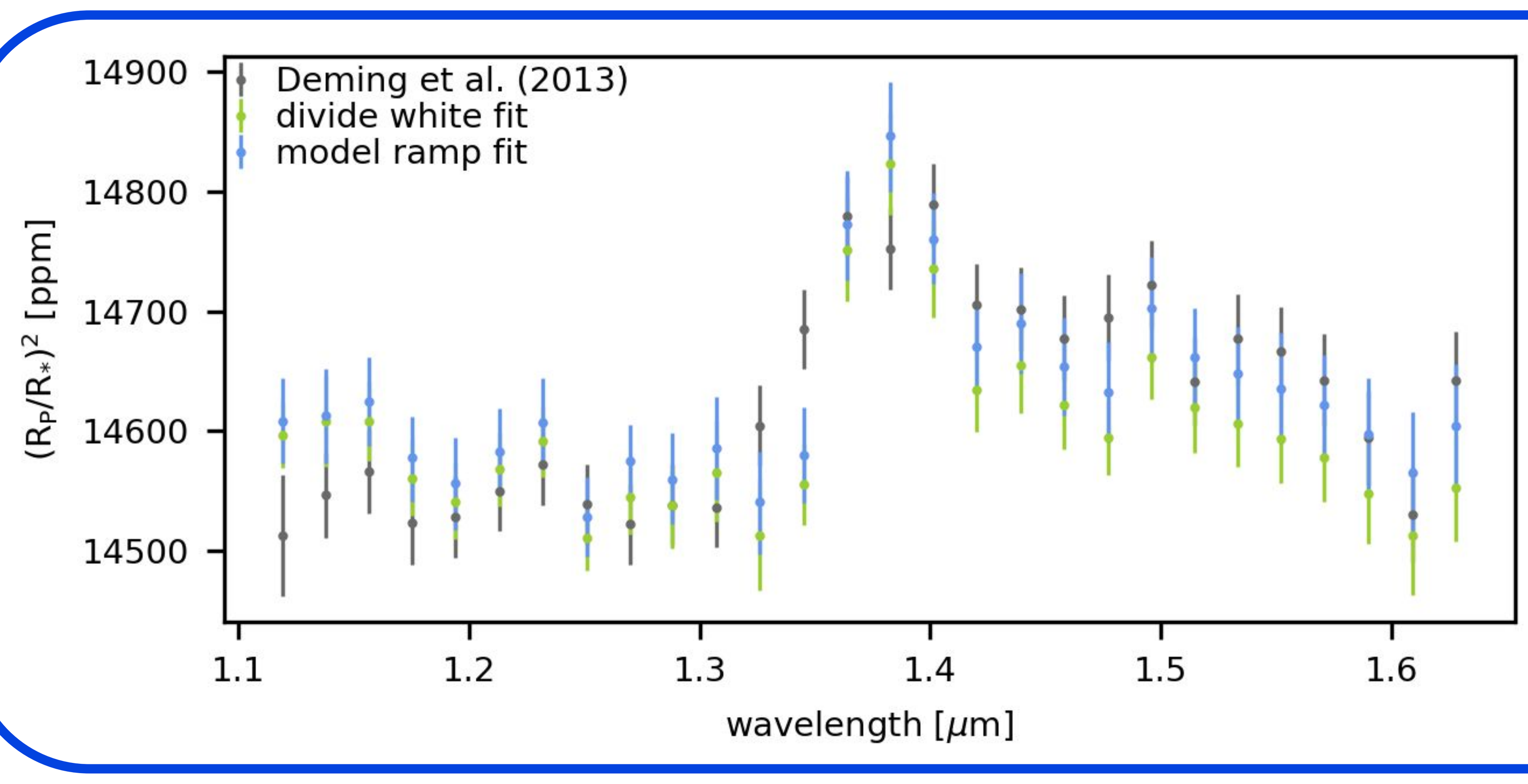
HD 209458b is the prototypical hot Jupiter and one of the best targets available for precise atmosphere characterisation. Now that spectra from both HST and JWST are available, we can reveal the atmospheric properties in unprecedented detail. This allows us to precisely and robustly measure the much-debated H_2O abundance in HD 209458b's atmosphere.
Using the HST/WFC3 spectrum[1], earlier studies reported sub-solar water abundances (< -4.5 in log volume mixing ratio)[2],[3], therefore contradicting most planetary formation models, which predict solar or higher oxygen and water abundances based on core accretion scenarios[4],[5]. However, more recent work has suggested higher water abundances, with some studies reporting solar to super-solar values based on the same data[6],[7].

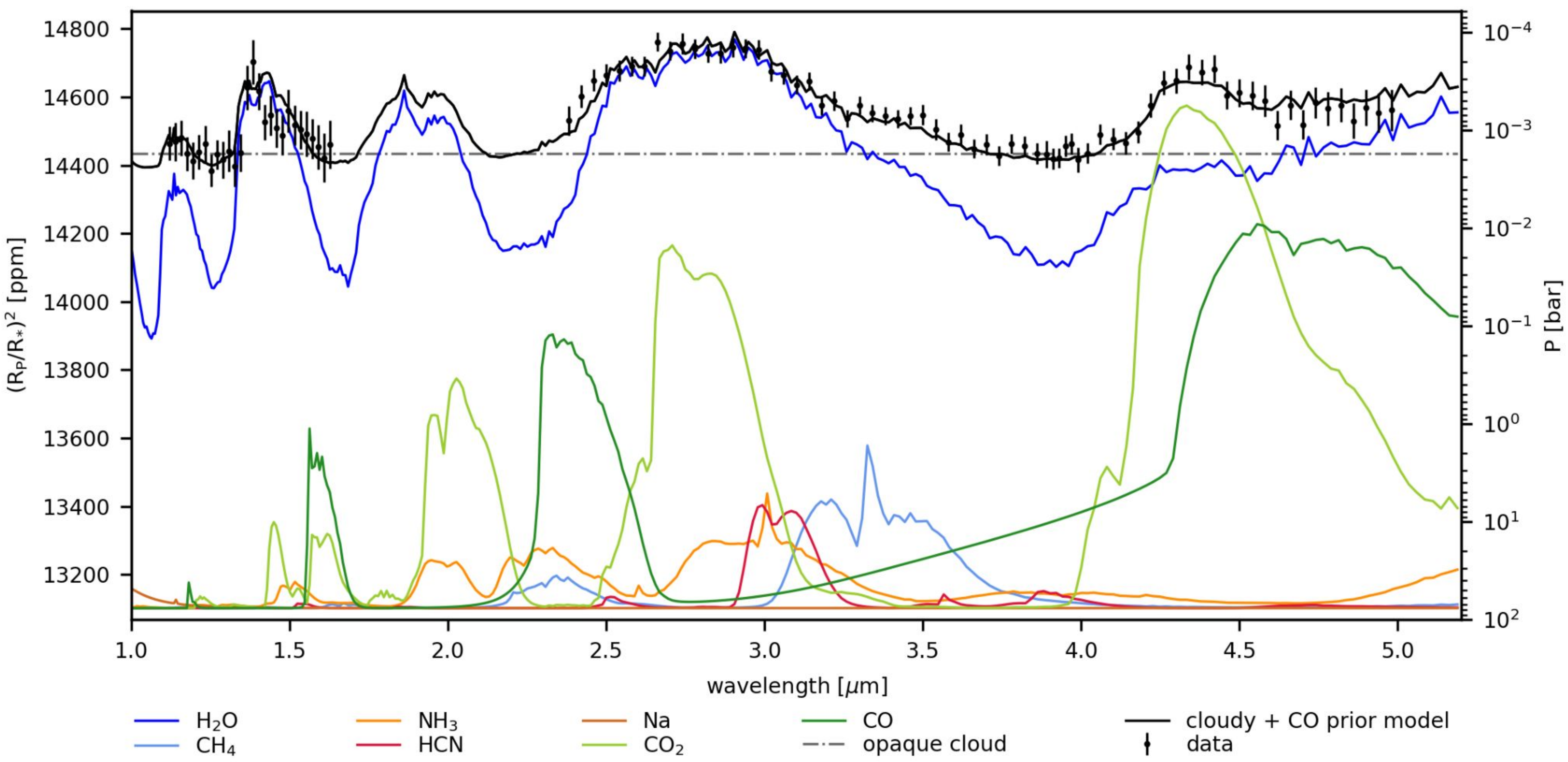


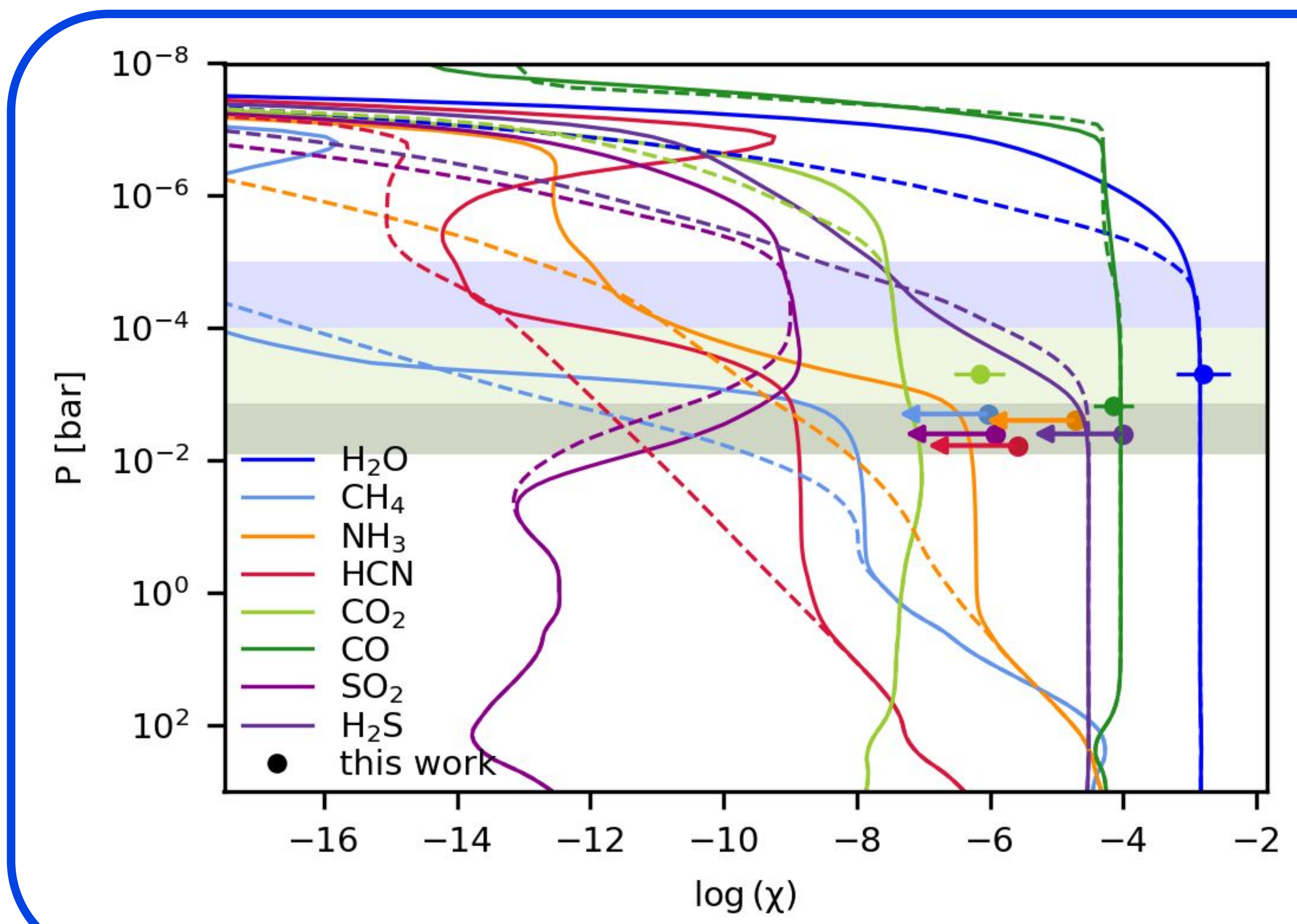
New data reduction for the HST/WFC3 spectrum

We use PACMAN[8] to perform a new data reduction of the original HST/WFC3 spectrum[1], accounting for the **wavelength dependence of the instrument systematics** that was not considered in previous analyses (blue spectrum in the Figure on the left). The green spectrum assumes wavelength-independent systematics in comparison.

Free chemistry retrievals with petitRADTRANS

We combine the our HST spectrum with archival JWST/NIRCam data and run atmospheric retrievals over the 1.0 − 5.1 µm wavelength range. We **robustly detect H_2O and CO_2** (>7σ significance), and find a 3.6σ **preference for cloudy models** compared to a clear atmosphere. For all other tested absorbers (see Figure on the right) we measured only upper limits of abundance. We use Bayesian model averaging to account for a range of different assumptions about the cloud properties, resulting in a **H_2O** volume mixing ratio of **$0.95^{+0.35}_{-0.17}$ × solar** and a **CO_2 abundance of $0.94^{+0.16}_{-0.09}$ × solar.**





Retrieved abundances agree with photochemistry models and give solar metallicity and surprisingly low C/O

Our results are **comparable to predictions from the VULCAN 1D photochemistry model**[9] (Figure on the left − solid lines: photochemical kinetics, dashed lines: thermochemical equilibrium).

We can constrain the CO abundance by using a prior from ground-based high-resolution measurements. Using our retrieved values (including the prior for CO), we derive an overall atmospheric composition **comparable to solar metallicity of [M/H]= $0.10^{+0.41}_{-0.40}$** and **very low C/O of $0.054^{+0.080}_{-0.034}$** with a 3σ upper limit of 0.454. One caveat is that the low C/O is highly sensitive to the ground-based prior on CO abundance. Still, these values indicate a strong enrichment in oxygen during HD 209458b's formation, consistent with an origin farther out in the protoplanetary disk.

References:
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