Introduction: Mercury is an extreme end-member among the terrestrial planets. In particular, it formed at a substantially lower oxygen fugacity ($fO_2$) than the Earth, Moon, Mars or Venus (Figure 1; [1,2]). The low $fO_2$ has affected all aspects of Mercury’s evolution, from the size of its core, to the viscosity of its mantle, to the composition of its crust [3]. At such low $fO_2$, exotic, reduced sulfides such as oldhamite (CaS) and niningmite (MgS) become prominent phases. The bonding of Ca and Mg with S happens in response to the decreasing availability of oxygen [4], and results in extraordinarily high S solubilities in silicate melts (up to 15 wt%). And indeed, Mercury’s volcanic surface contains 2-4 wt% S, probably as some mixture of CaS and MgS [5]. Because Mercury is so close to the Sun, it was predicted to be volatile-depleted, relative to the other terrestrial planets. But it is actually quite volatile-rich, with Earth-like K/U and high Na contents in lavas, not to mention the high S [2]. Moreover, pyroclastic volcanism is quite ubiquitous [6]. Apparently, even under adverse conditions, Mercury was able to hold on to a substantial volatile reservoir in its interior. However, Mercury was too small to hold on to an atmosphere. But what if it were larger?

Could there be exoplanets as reduced and sulfide-rich as Mercury, but large enough to retain an atmosphere? Would such super-Mercuries be habitable? To address this, we explore three questions: 1) How abundant are super-Mercury exoplanets?, 2) What sort of gases would be emitted by volcanism into the atmosphere? and 3) Are there plausible scenarios in which super-Mercuries could host liquid water oceans on their surfaces?

**Question 1: How abundant are reduced sulfide planets (super-Mercuries)?** Mercury is thought to have obtained its low oxygen fugacity because of the high abundance of carbon-rich dust that gathered close to the early Sun, where Mercury accreted [7]. The high C/O ratios produced abundant CO, which lowered oxygen activities. Condensation models for the enstatite chondrites suggest that C/O ratios above 0.8 are required to stabilize the reduced sulfides MgS and CaS [8]. However, exoplanet evolution models have generally not predicted the existence of sulfide-rich, Mercury-like planets (though see [9]), despite one existing in our own solar system! Above C/O=0.8, such models have typically predicted that carbon-rich carbide planets would form [10]. Given the paucity of experimental data at such reduced conditions, it is perhaps not surprising there is discrepancy in the current predictive models. More data is needed. What is clear is that reduced sulfide planets would likely form at C/O ratios intermediate between that of Earth-like planets and carbide planets. The exact boundaries between these regimes are not well defined at this time.

A related but complementary question is what range of host star C/O compositions could produce super-Mercuries? Our solar system, with a C/O ratio of only ~0.58 [11], mostly produced Earth-like planets, but C/O varied enough to produce one (small) reduced sulfide planet at the very inner edge of the disc. Our system seems to be near the lower bound of C/O ratios that can form reduced sulfide planets. We hypothesize that the enrichment of carbon-rich dust within protoplanetary discs could allow Mercury-like planets to form around stars with C/O ratios of 0.6 to at least 0.8. Taking this as a conservative range, and comparing it to the C/O ratio of exoplanet host stars, we see that more than 50% of the systems could host reduced sulfide exoplanets (Figure 2). Indeed, it may be that such sulfide exoplanets are more common than the carbide planets!

**Question 2: What gases would be emitted by volcanoes on super-Mercuries?** Equilibrium models suggest N$_2$, CO, S$_2$, CS$_2$, S$_2$Cl, Cl, Cl$_2$ and COS could be the major volcanic gases on planets as reduced as Mercury.
Though such life would have to be very tolerant of high $\text{S}$ concentrations, and likely, wide swings and gradients in the oxygen fugacity.

Conclusions: Reduced, sulfide-rich ‘super-Mercuries’ should be common around host stars with C/O above 0.6. Based on observations of Mercury, such planets should be rich in a range of volatiles, including C, N, S, Cl, Na and K. H$_2$O and CO$_2$ are not expected to be stable, and H in any form should not be abundant. Introduction of ice-rich material from beyond the snow line could provide a pathway to having liquid water oceans on super-Mercuries. The redox gradient between the interior of super-Mercuries and their oceans will be much larger than on Earth, and could provide an abundant energy source for life, if the high levels of S are not fatal.