WHAT IS THE OXYGEN ISOTOPE COMPOSITION OF VENUS? THE SCIENTIC CASE FOR SAMPLE RETURN FROM EARTH'S SISTER PLANET

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Introduction: Venus is often viewed as Earth's sister planet, or perhaps more accurately its ugly sister. This familial comparison between the two worlds stems from their approximately equal mass and physical size [1]. Venus is also Earth's nearest planetary neighbor. And yet despite this close proximity Venus currently receives far less attention from space agencies than Mars [2]. It's not hard to work out why. While Mars is a cold frigid world, Venus is the stuff of nightmares, with a surface temperature of 462 °C and a spacecraft crushing surface pressure of 92 bars. Despite such hostile conditions, there remain strong scientific reasons why further exploration of Venus is vitally important [3]. Here we outline the case for a sample return mission to Venus in order to determine at high precision the oxygen isotope composition of its lithosphere ($\Delta^{17}O$) [4]. Such a measurement would have first order implications for our understanding of the origin and early evolution of the inner Solar System. In particular, as previously pointed out by [5], it would provide critical evidence concerning the extent of isotopic mixing in the inner Solar System.

The bimodal Solar System: On plots such as $\varepsilon^{54}Cr$ vs. $\varepsilon^{50}Ti$ and $\varepsilon^{54}Cr$ vs. $\Delta^{17}O$ Solar System materials define two distinct groupings (Fig. 1) [6, 7, 8]. One comprises the carbonaceous chondrites and a minor subset of achondrites, the other is defined by all other Solar System materials. It was suggested by [6] that the carbonaceous chondrite group (CC) may represent material formed in the outer Solar System and the non-carbonaceous chondrite group (NC) in the inner Solar System. The initial formation of this dichotomy may have been related to changes in the nature of the material falling on to the protoplanetary disc, coupled with incomplete mixing between the NC and CC regions [8]. Longer term preservation of these isotopic differences may have been related to the growth of Jupiter, which prevented mixing between these reservoirs [8].

A homogeneous inner Solar System? The diversity displayed by the NC group appears to support an isotopically heterogeneous inner Solar System (Fig. 1). However, this conclusion may be premature. Apart from the Earth, Moon and Mars, the other NC lithologies plotted in Fig.1 are all asteroidal, with the mass in the asteroid belt estimated to represent just 0.04 % that of the Earth [9]. Although much more massive than the asteroid belt, Mars is anomalously small compared to either Earth or Venus. One of the drivers for the formulation of the "Grand Tack" model was to explain the relatively small size of Mars [10]. As a result of the inward and then outward migration of Jupiter, the "Grand Tack" model predicts that the feeding zone for Mars was significantly impoverished. This suggests that Mars may not be fully representative of the inner Solar System. While we have samples from the Moon, the Earth-Moon system probably formed during a giant impact and may subsequently have experienced a high level of isotopic homogenization [11]. There is also evidence that $^{48}Ca/^{44}Ca$ ratios are positively correlated with parent body mass, possibly reflecting secular changes in the composition of the inner protoplanetary disc [12]. A test for such a model would be to have material from two planets of roughly equal size, such as Earth and Venus.

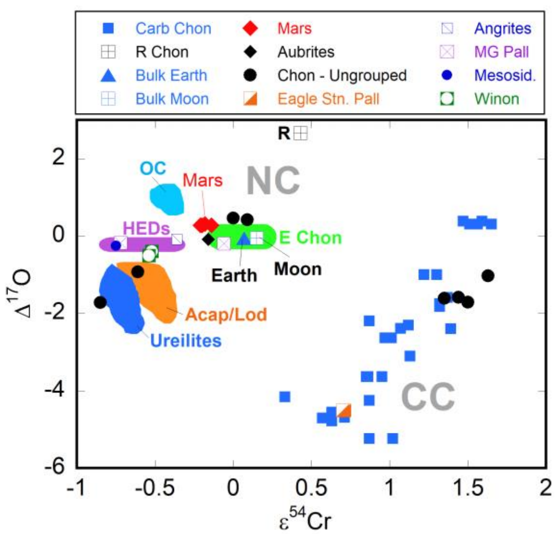

Figure 1 Plot of $\varepsilon^{54}Cr$ vs. $\Delta^{17}O$ for all major Solar System lithologies [modified after 6, 7].

Sorting out the Moon-forming giant impact: Paradoxically a returned sample from Venus should help to settle the origin of Earth's Moon. The canonical giant impact model has become difficult to reconcile with evidence that the Moon and Earth are essentially identical with respect to many isotopic systems, in particular oxygen [13]. However, it has been proposed that, as a result of high levels of mixing in the inner Solar System, the giant impactor Theia and proto-Earth had similar isotopic compositions [14]. If the Earth and Venus are nearly identical with respect to $\Delta^{17}O$ and also other relevant isotopic systems [14], this would indicate that the inner Solar System was well mixed, relaxing the requirement for high-temperature homogenization in the aftermath of the giant impact [14]. Alternatively, a distinct oxygen isotopic difference between Venus and Earth implies a lesser degree of inner Solar System homogenization [13]. Hence, Theia would likely have differed significantly from the proto-Earth, requiring a high energy impact to form the Moon [11, 13].

Additional benefits of Venus sample return: Whether isotopically distinct from, or nearly identical to, Earth, the information provided by a sample from Venus would have profound implications for our understanding of how the terrestrial planets formed [3]. Analysis of such a sample would provide a firm basis for assessing similarities and differences between the evolution of Venus, Earth and Mars [3]. Venus is Earth's planetary twin and deserves to be better studied and understood [2, 3].

Sample return from Venus: Sample recovery from the surface of Venus would clearly be a difficult and costly undertaking. Atmospheric analysis would be less challenging [3]. However, in the case of both Earth and Mars the atmosphere is not in oxygen isotopic equilibrium with the lithosphere and this would almost certainly be the case for Venus. A mission which involved both atmospheric and lithospheric sampling would be of the greatest scientific value. With respect to lithospheric sampling, a grab-and-go sample return scenario has been outlined by [15] (Fig. 2). The overall aim of such a mission would be to return to Earth a 100 g surface sample. A limited set of measurements of the Venusian atmosphere might also be undertaken during such a mission. A refined version of this scenario has recently been presented by [16].

Conclusions: Sample return from Venus, although challenging, is of significant scientific importance. In particular, measuring the oxygen isotopic ($\Delta^{17}O$) composition of Venus would provide critical information relevant to the early evolution of the inner Solar System. Such a measurement would also help to clarify the nature of the Moon-forming giant impact.

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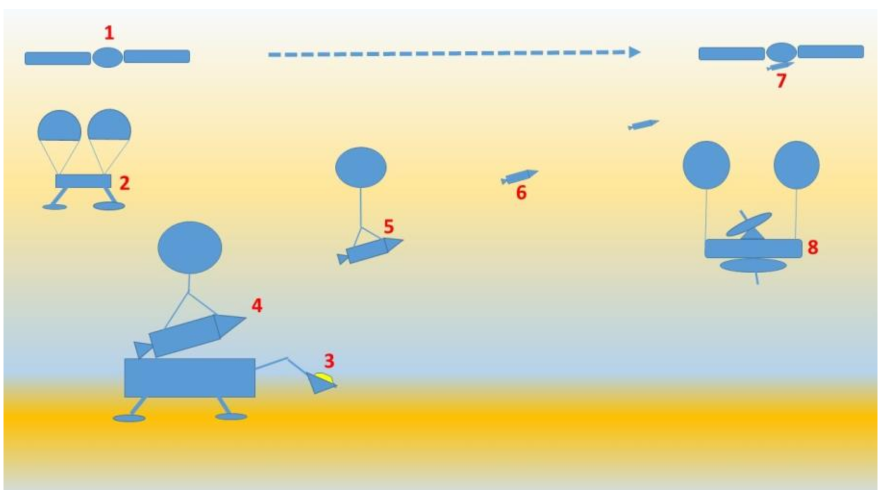

Fig. 2 A "Grab-and-Go" sample recovery mission from the surface of Venus [based on 15]. The original spacecraft would consist of an orbiter and lander module. The orbiter (1) passes over the lander every 93 mins. Once the lander has detached from the orbiter (2) it descends to the surface slowed by parachutes and possibly also rocket motors. On the surface sampling operations take place (3). Sample material is transferred to the ascent stage (4) which is lifted to a height of 66 km by a helium balloon (5). The balloon is jettisoned and the ascent rocket (6) takes the sample back to the orbiter (7). A modified mission could involve atmospheric sampling (8) [3].