Oxygen Isotopic Consequences of Giant Planet Migration

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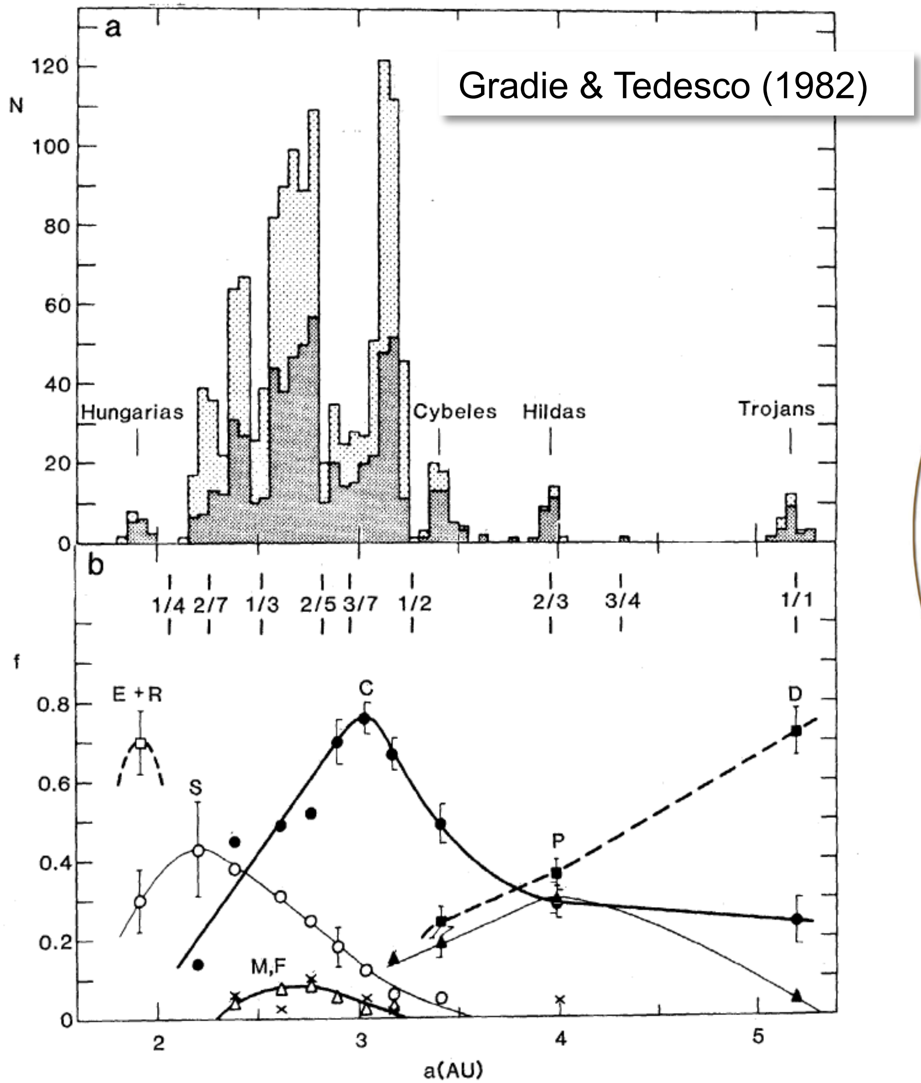
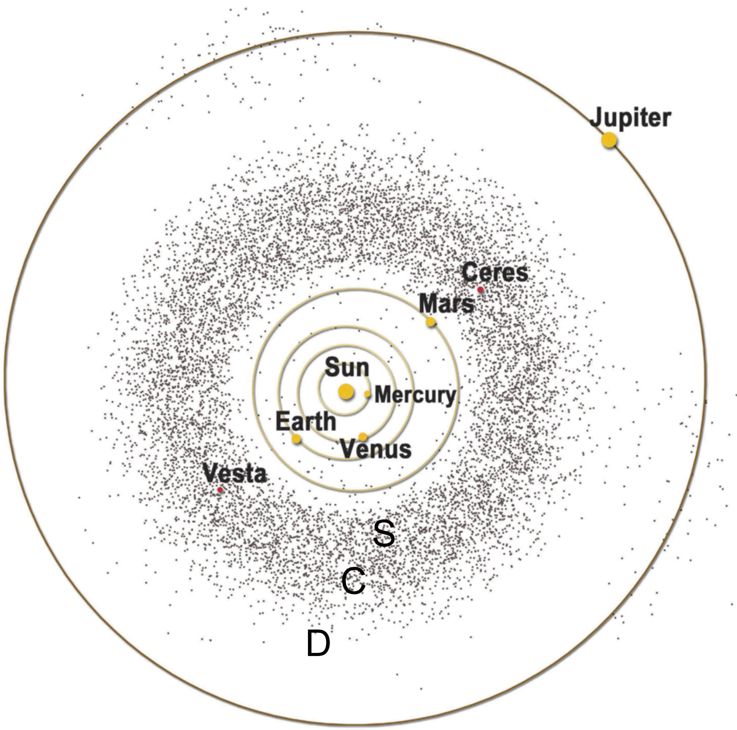
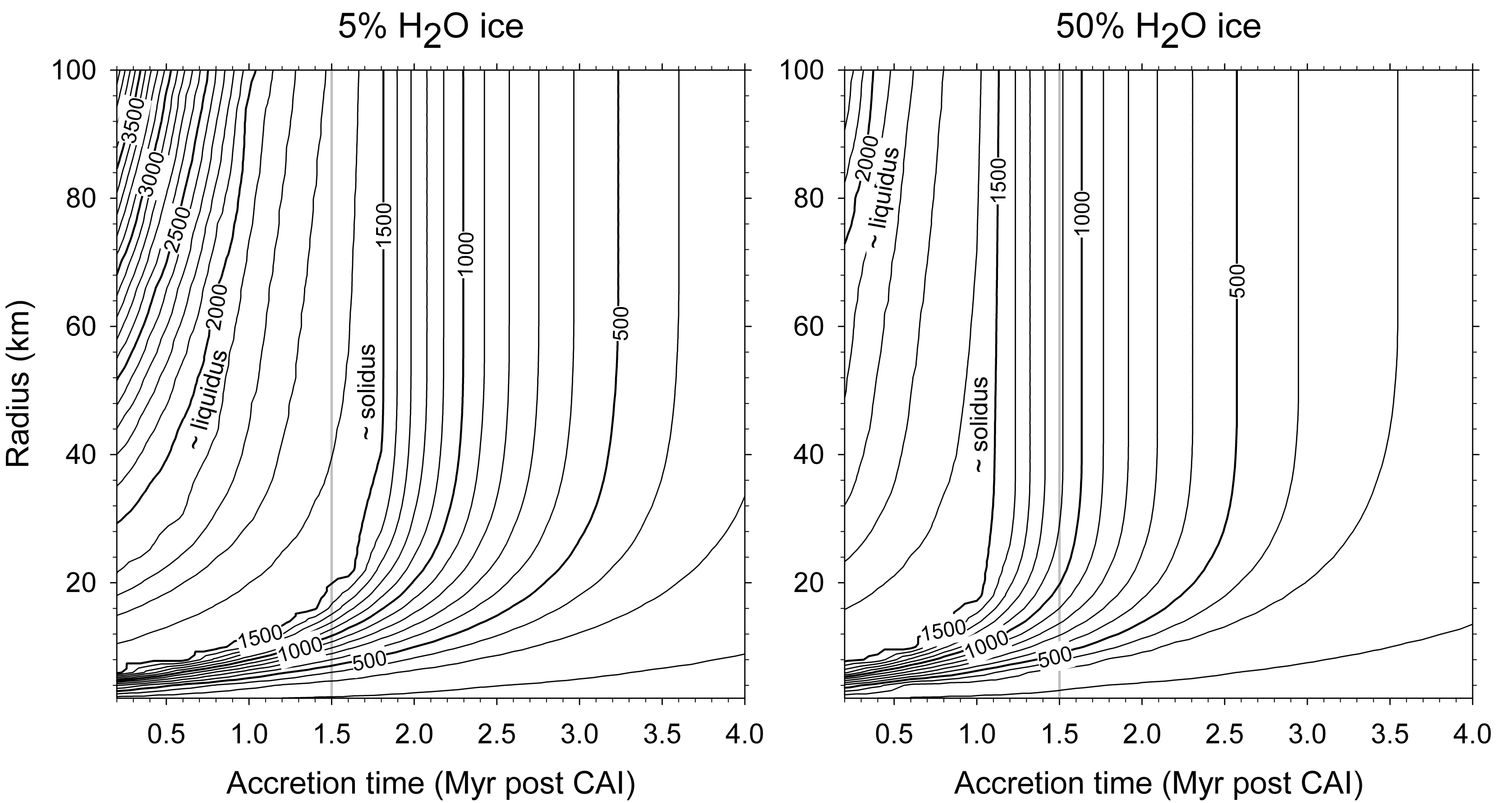
Asteroid belt stratigraphy

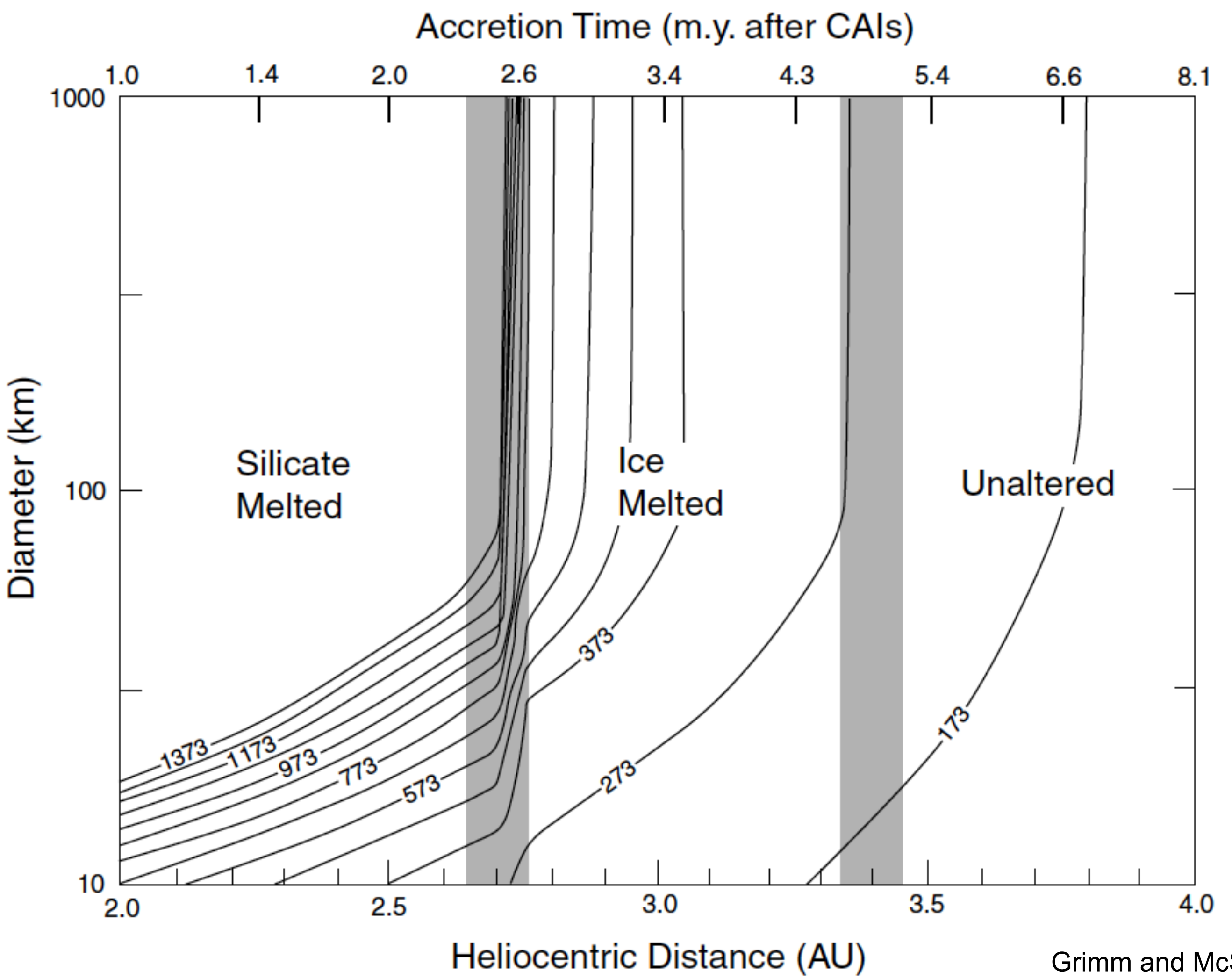




Thermal models



Diachronous accretion – equating distance with time



Grimm and McSween (1993)
McSween et al. (2002)

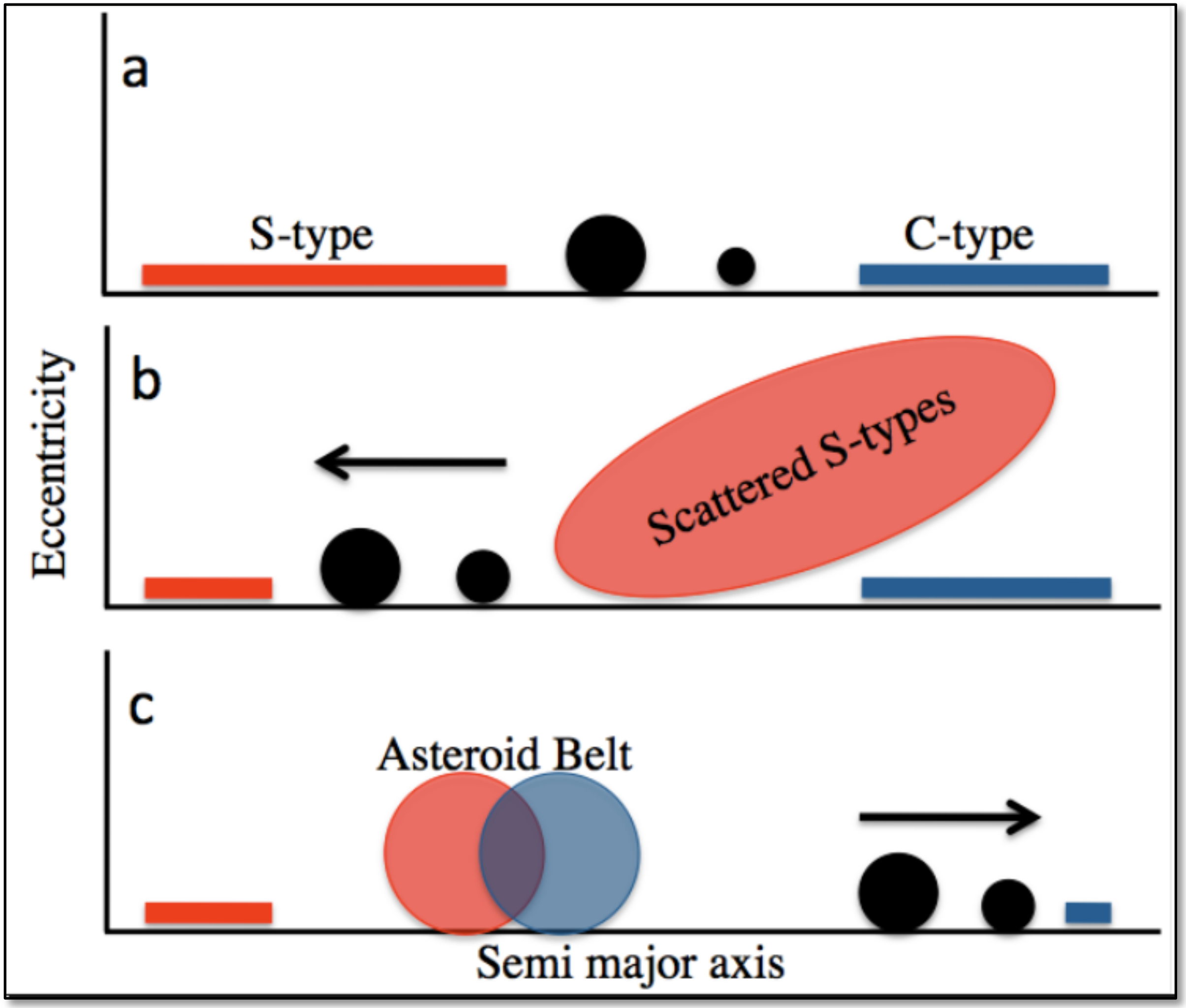
Room for refinement:

For example, Grimm & McSween '93 assume the same accretion time for all sizes, but timescale of accretion depends on size, among other factors, and is diachronous with respect to planetesimal size

$$\tau \simeq \frac{r\rho}{\Sigma\,\Omega}$$

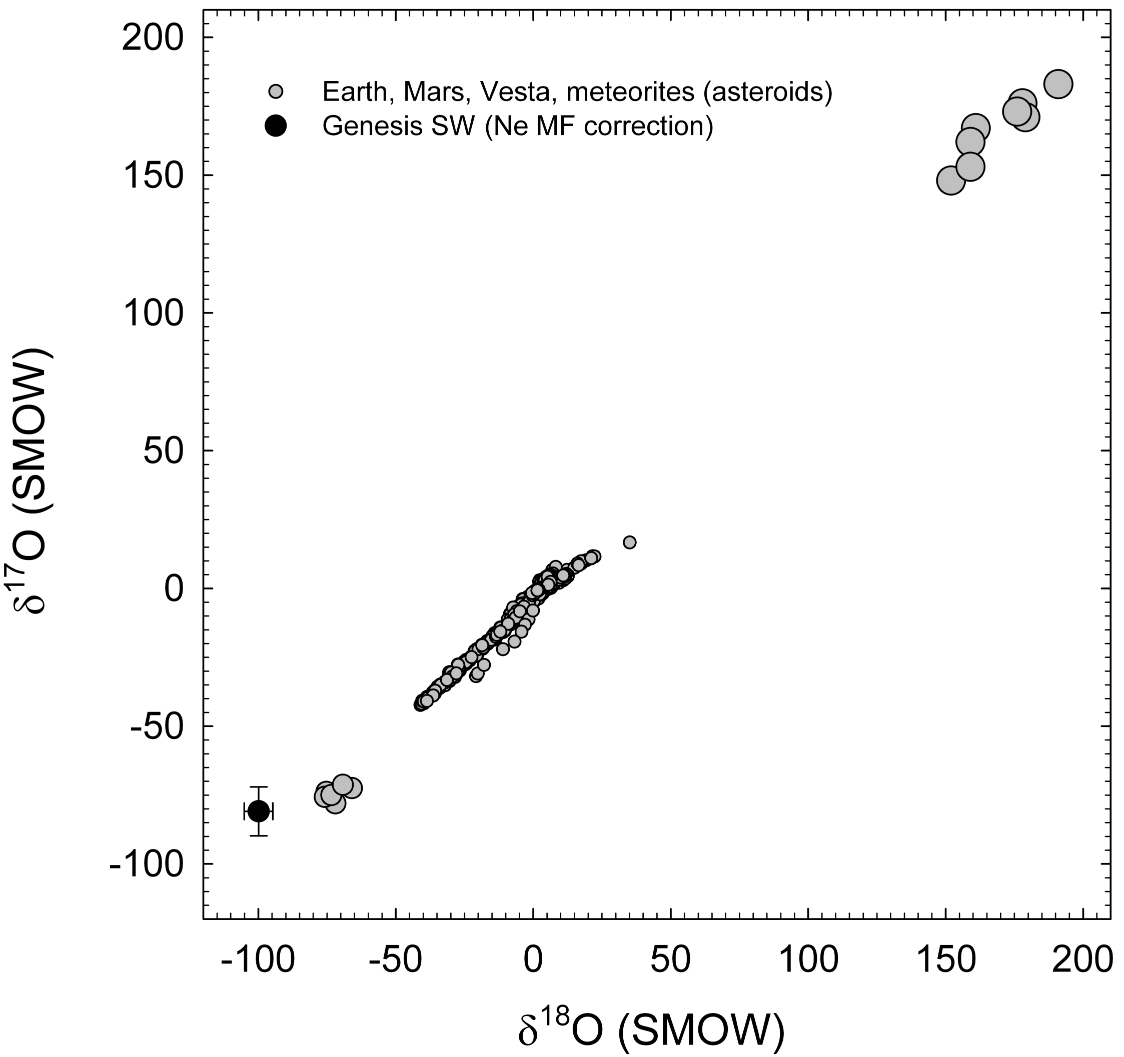
so the mapping of accretion time onto heliocentric distance is not unique *even in the absence of giant planet migration*.

Motivation

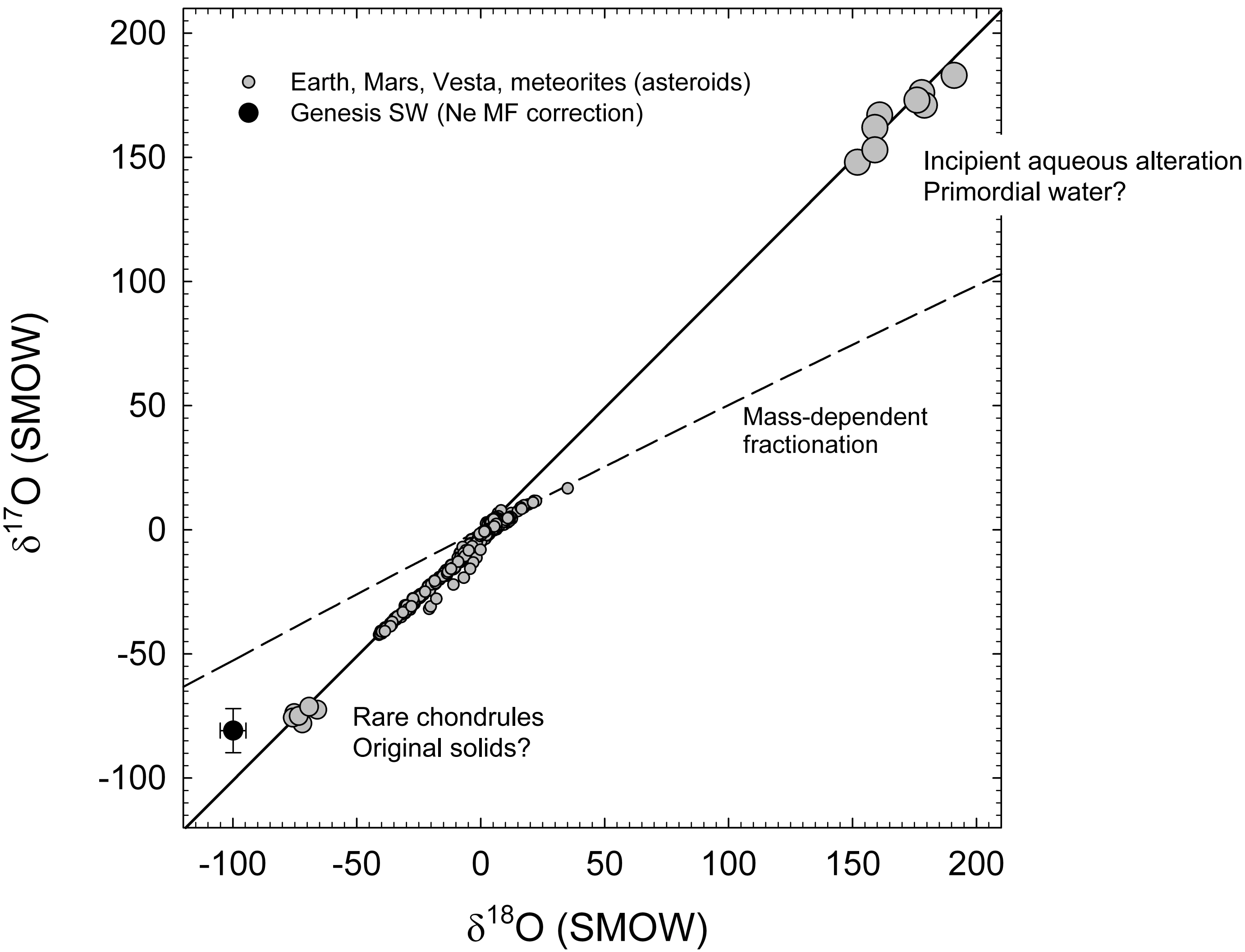


Grand Tack
Walsh et al. (2011)

Solar system oxygen isotopes



Solar system oxygen isotopes



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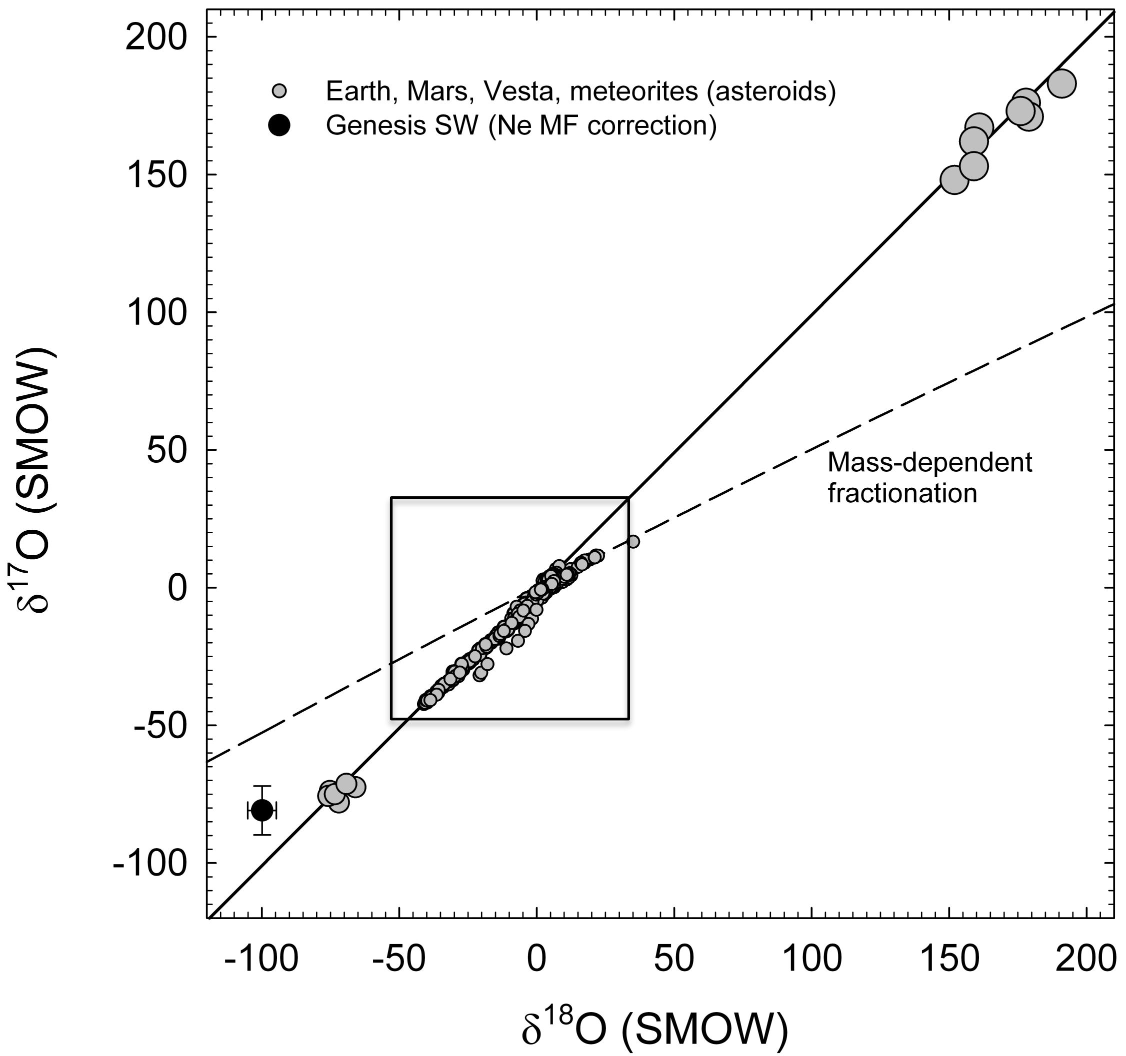
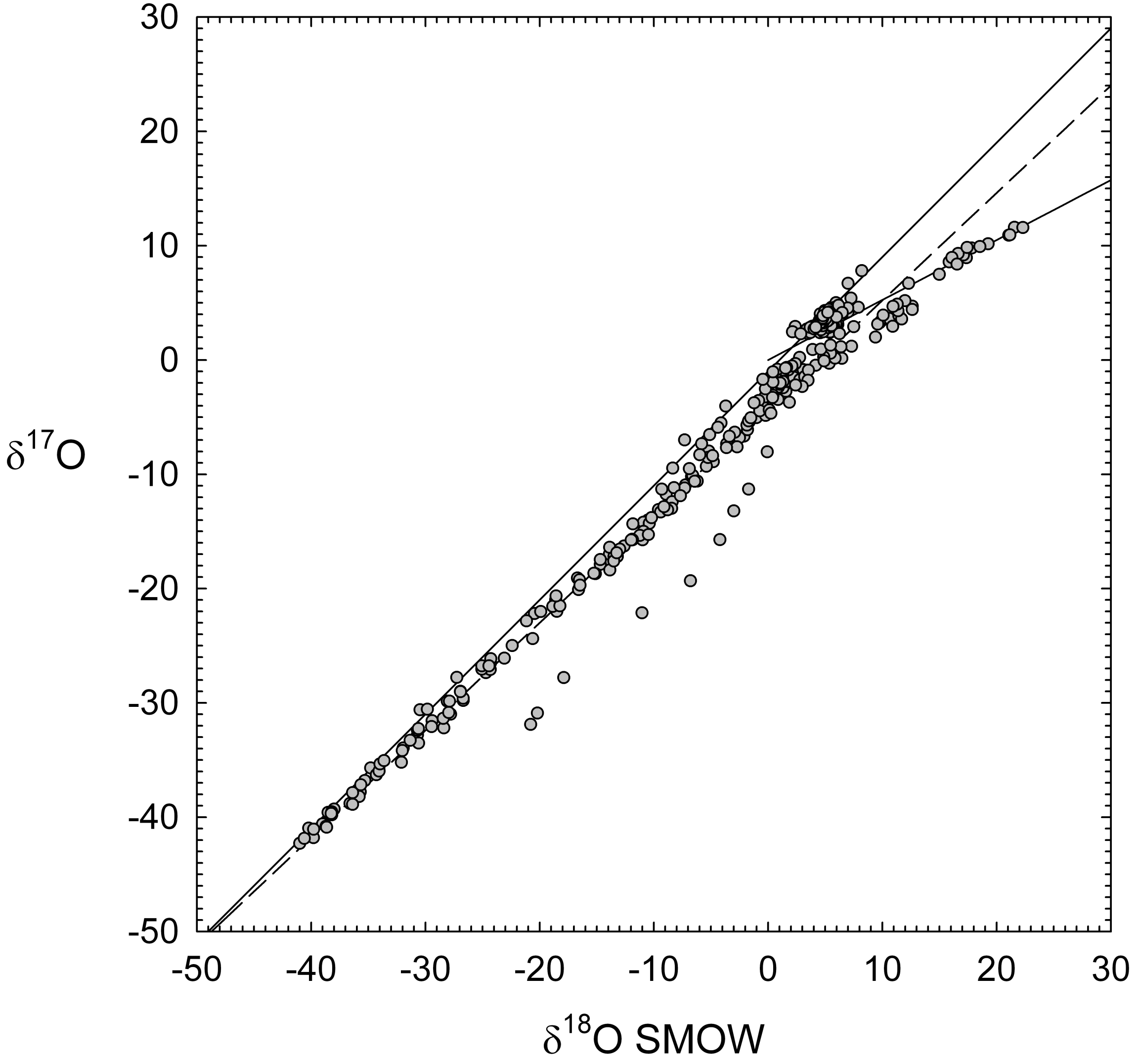
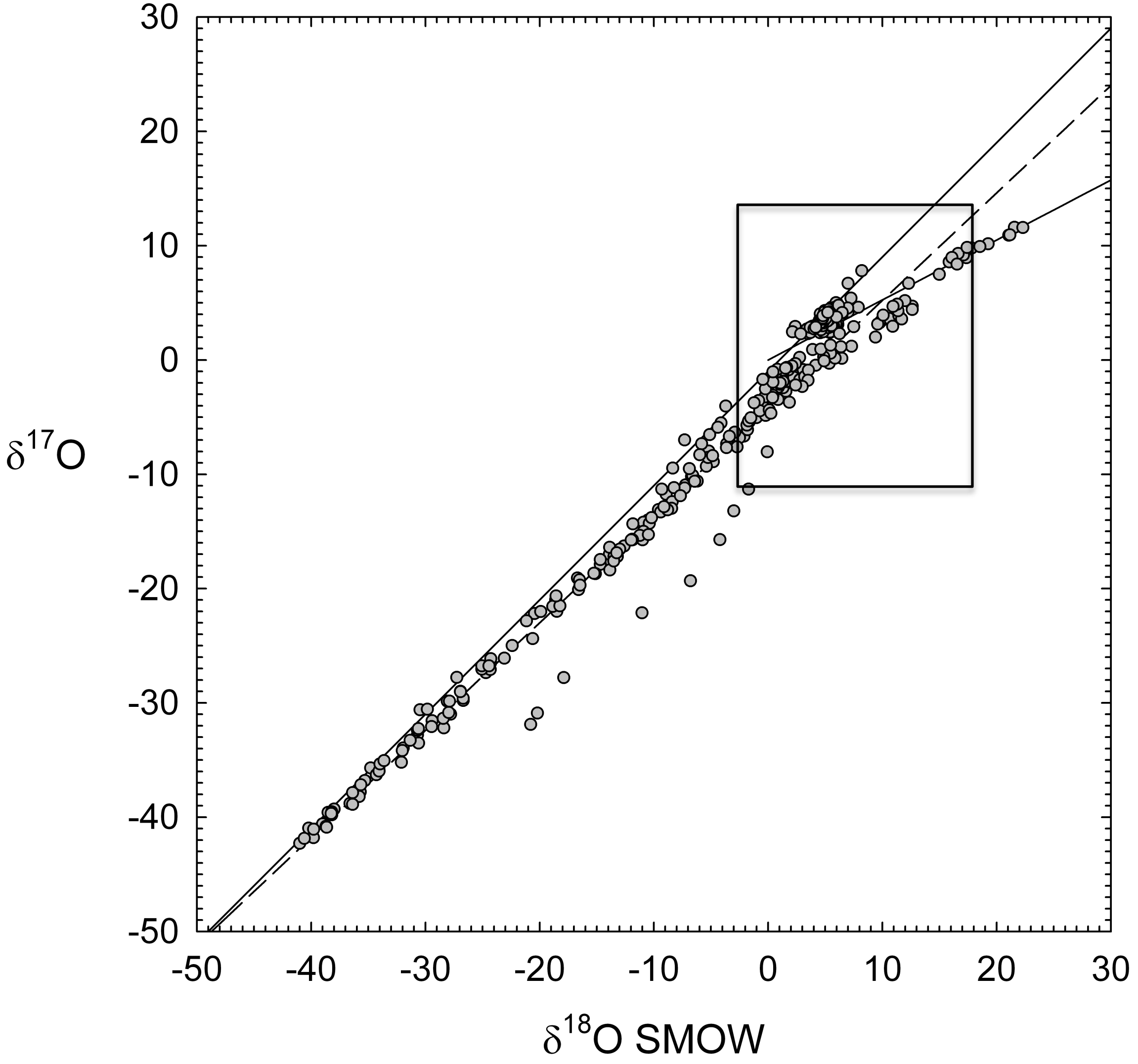


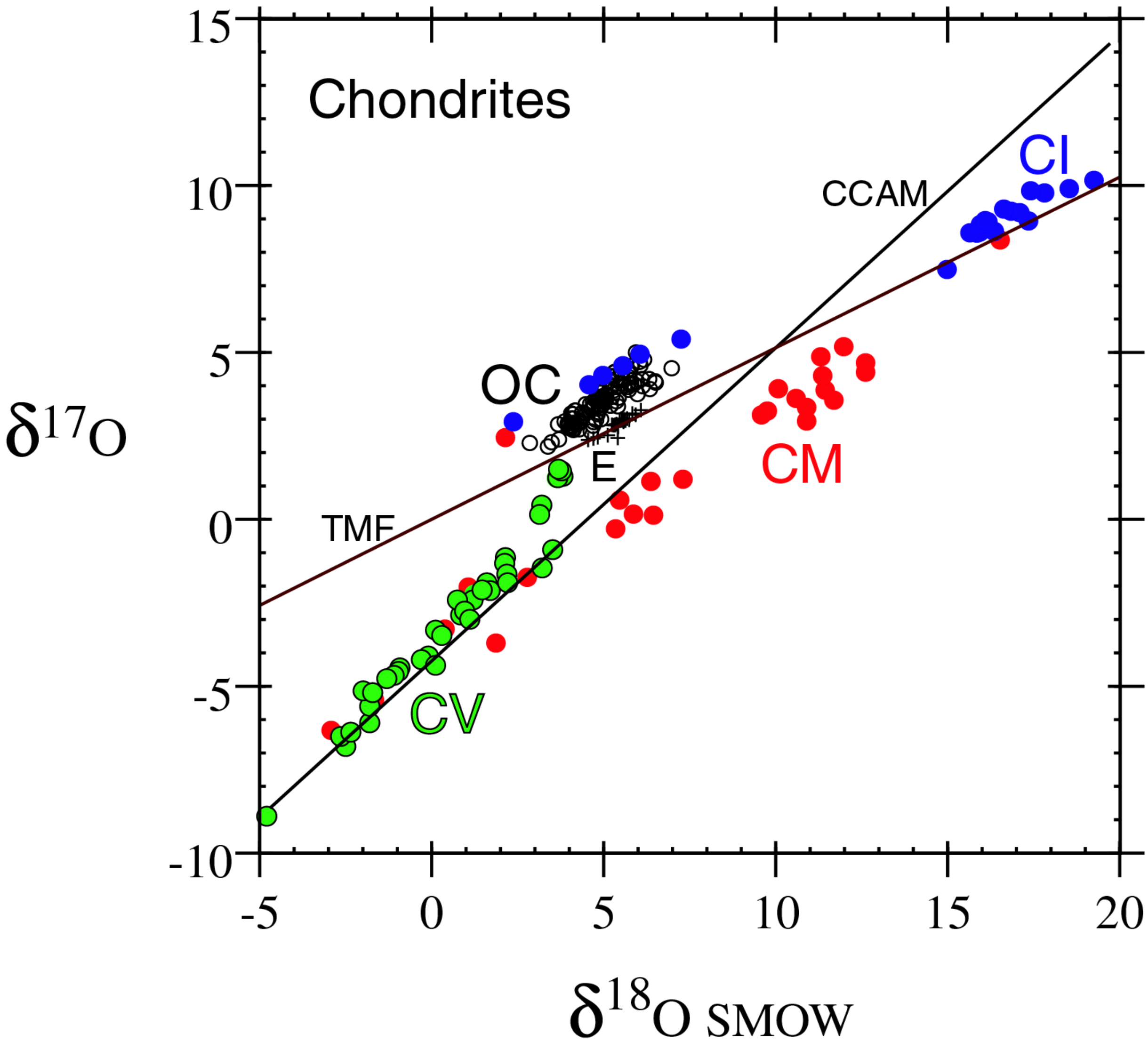
Solar system oxygen isotopes



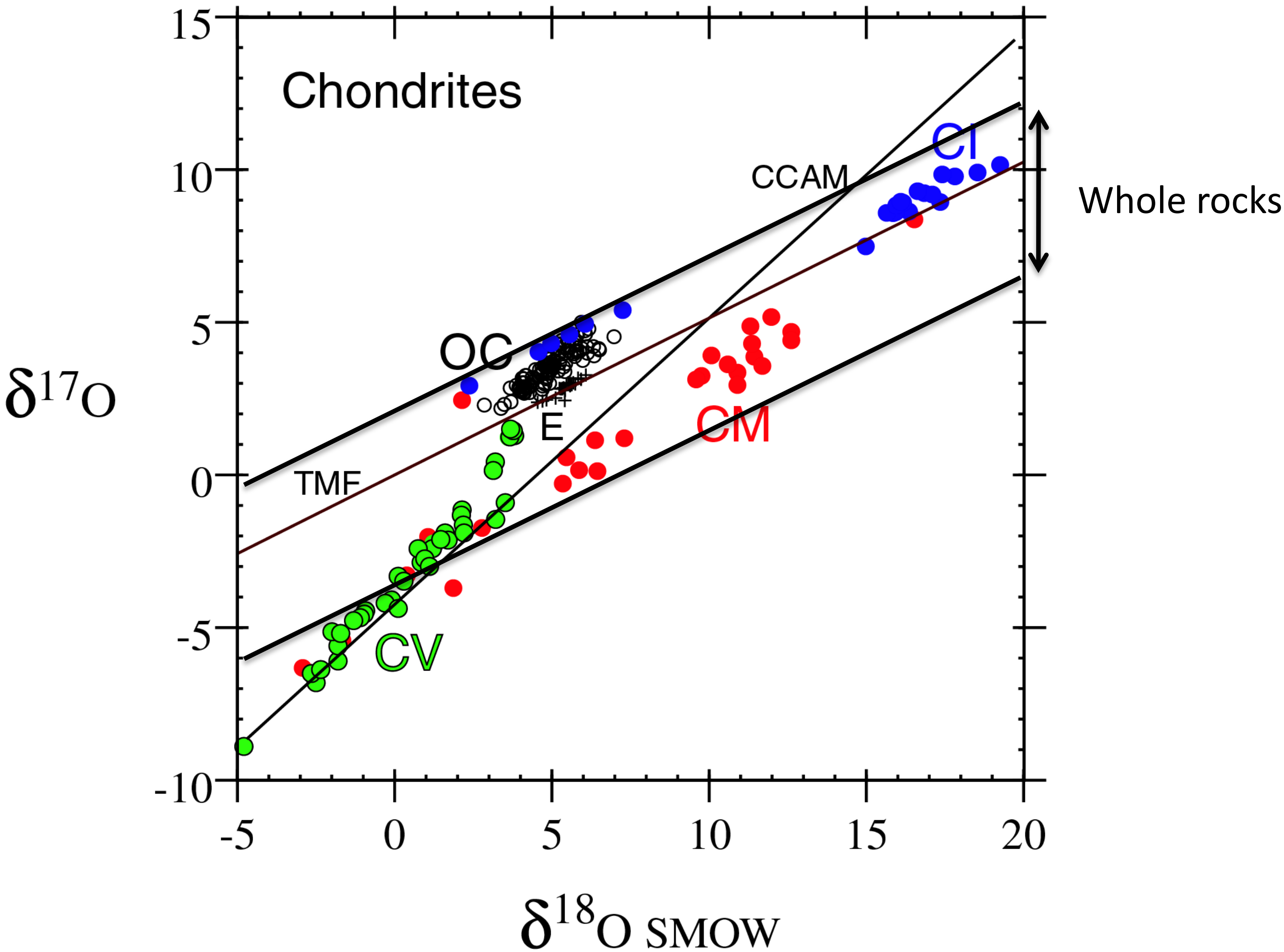
Solar system oxygen isotopes



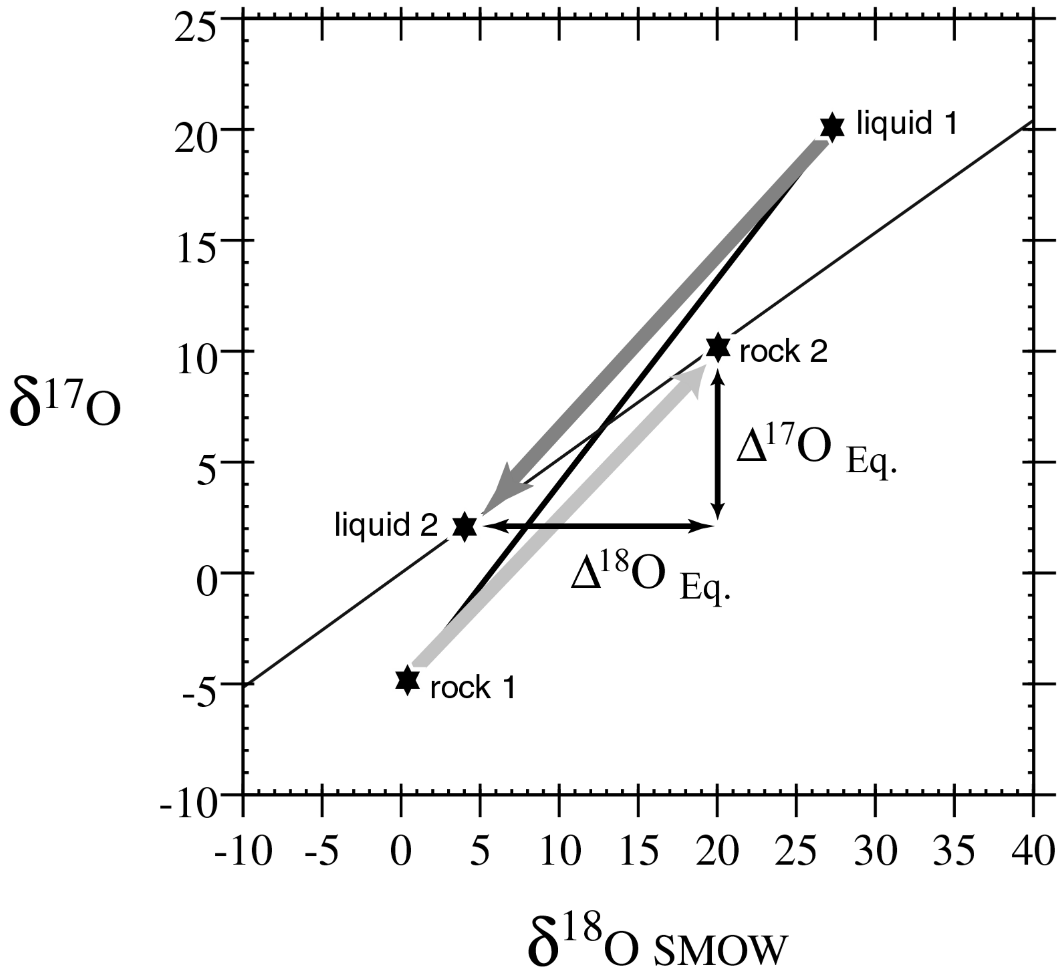
Solar system oxygen isotopes



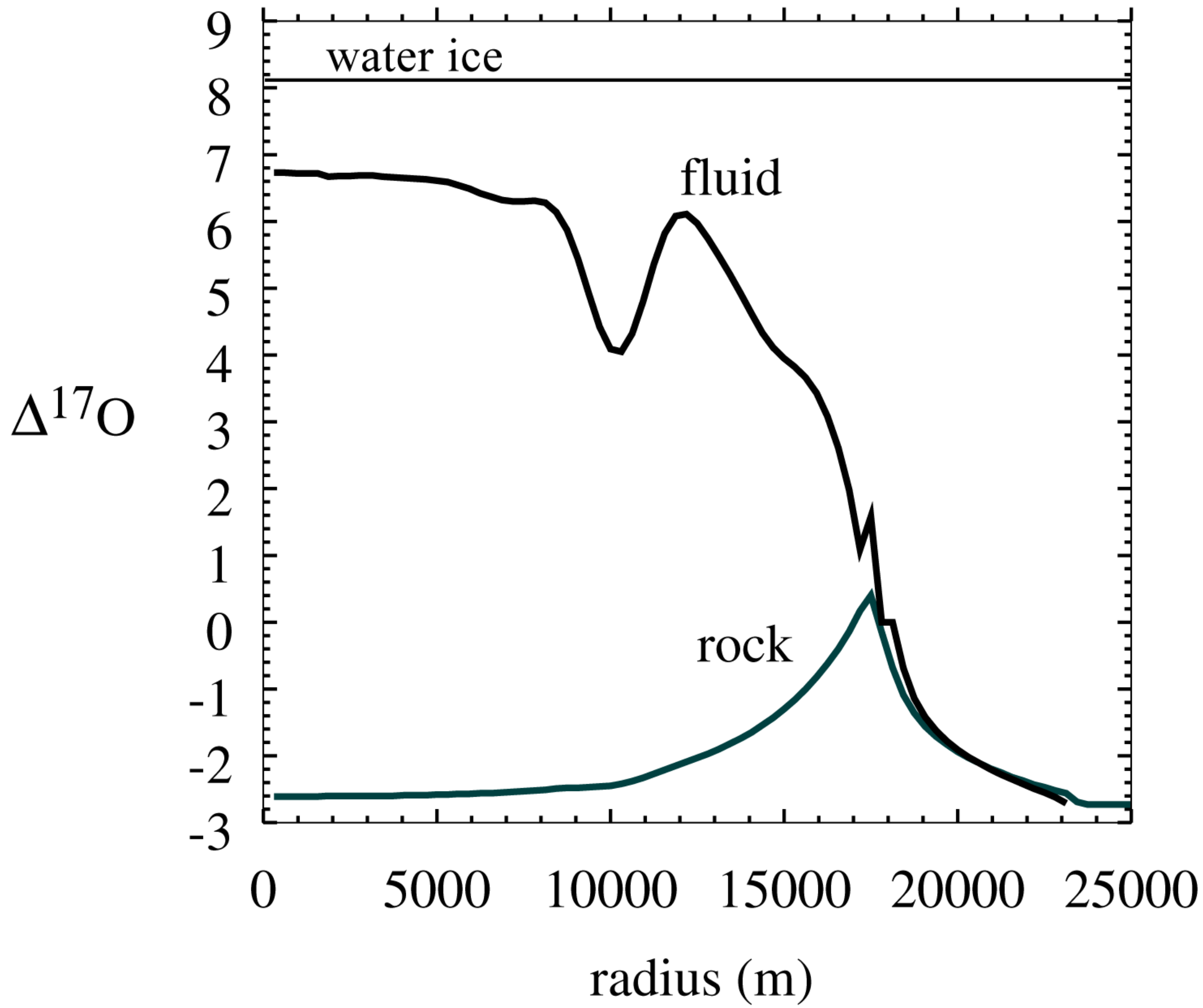
Solar system oxygen isotopes



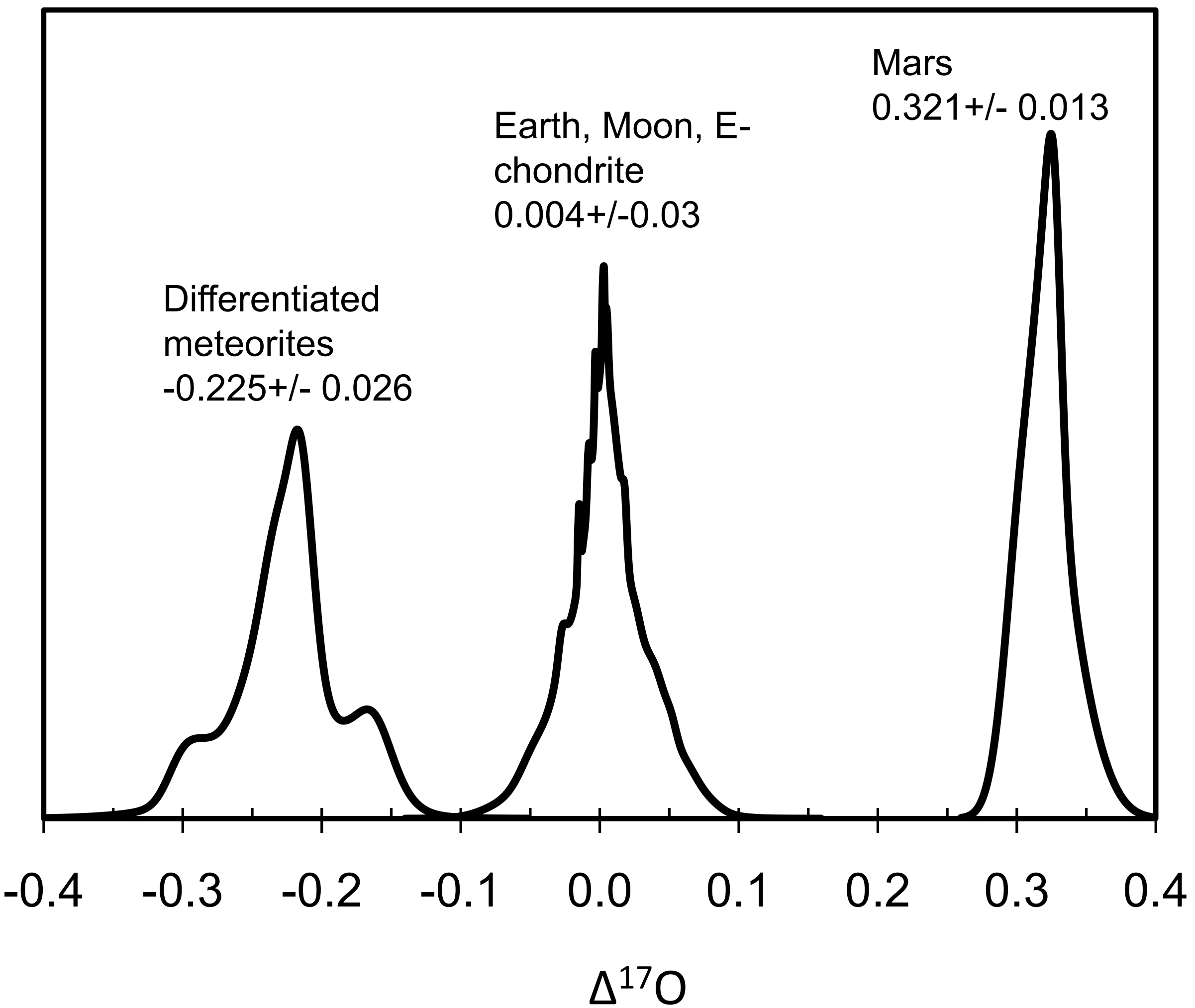
Solar system oxygen isotopes



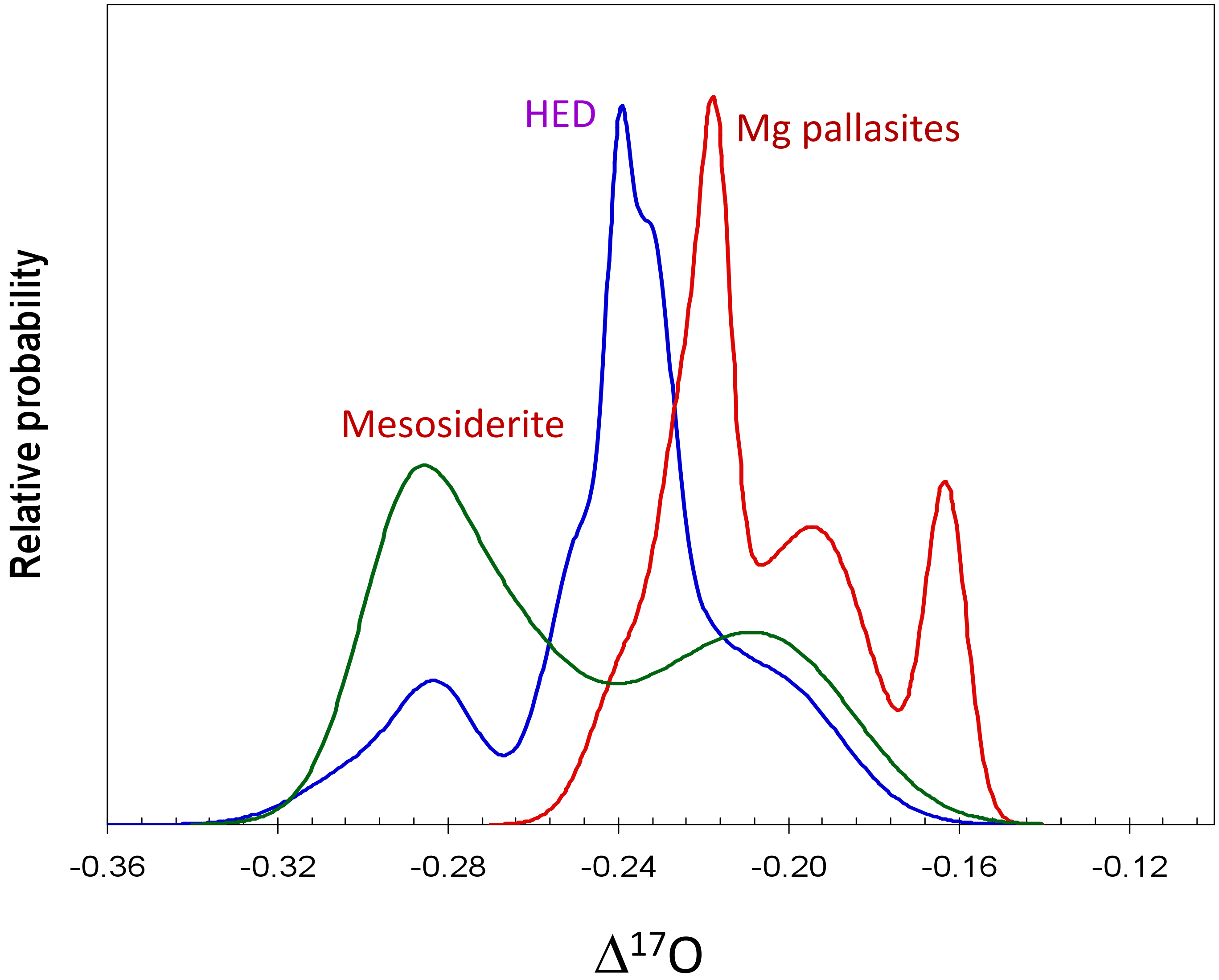
Solar system oxygen isotopes



Solar system oxygen isotopes



Solar system oxygen isotopes



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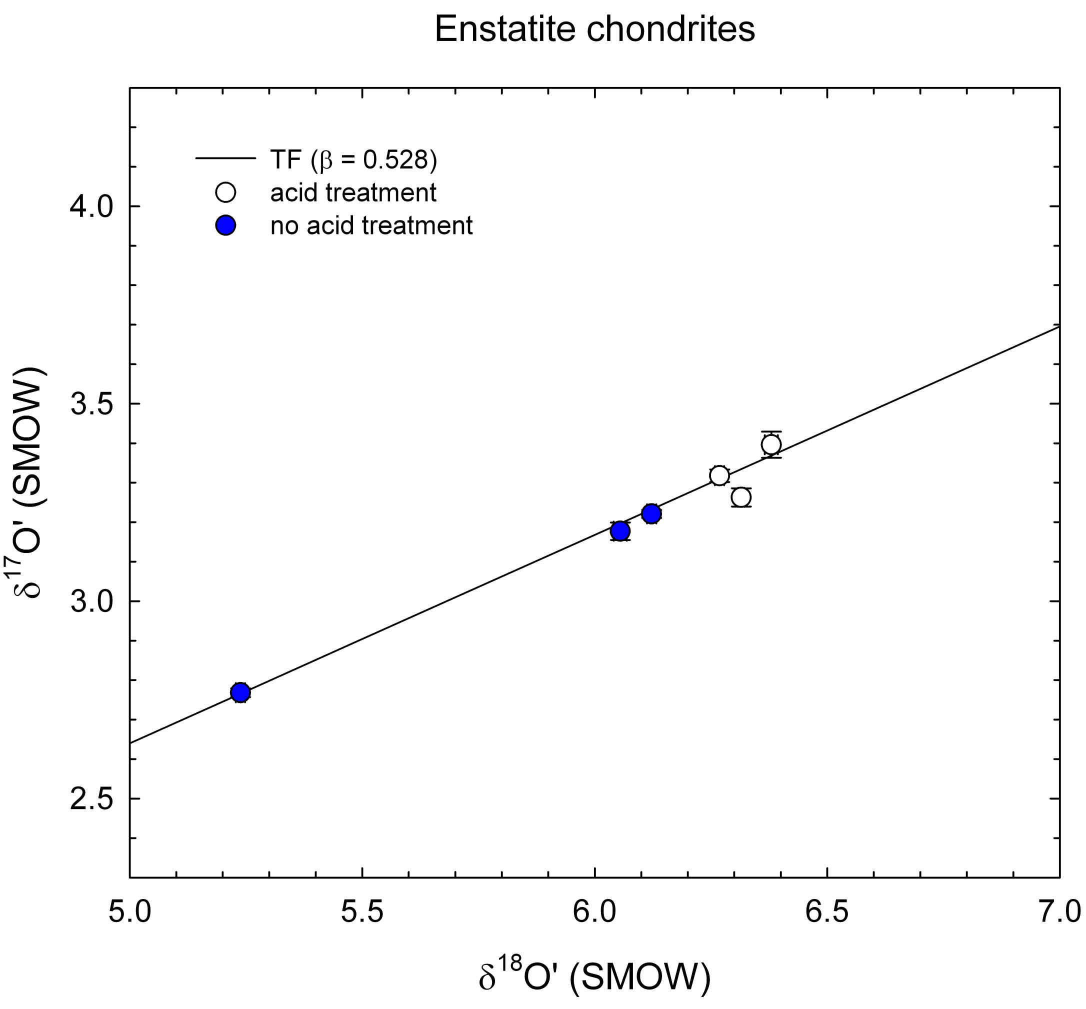
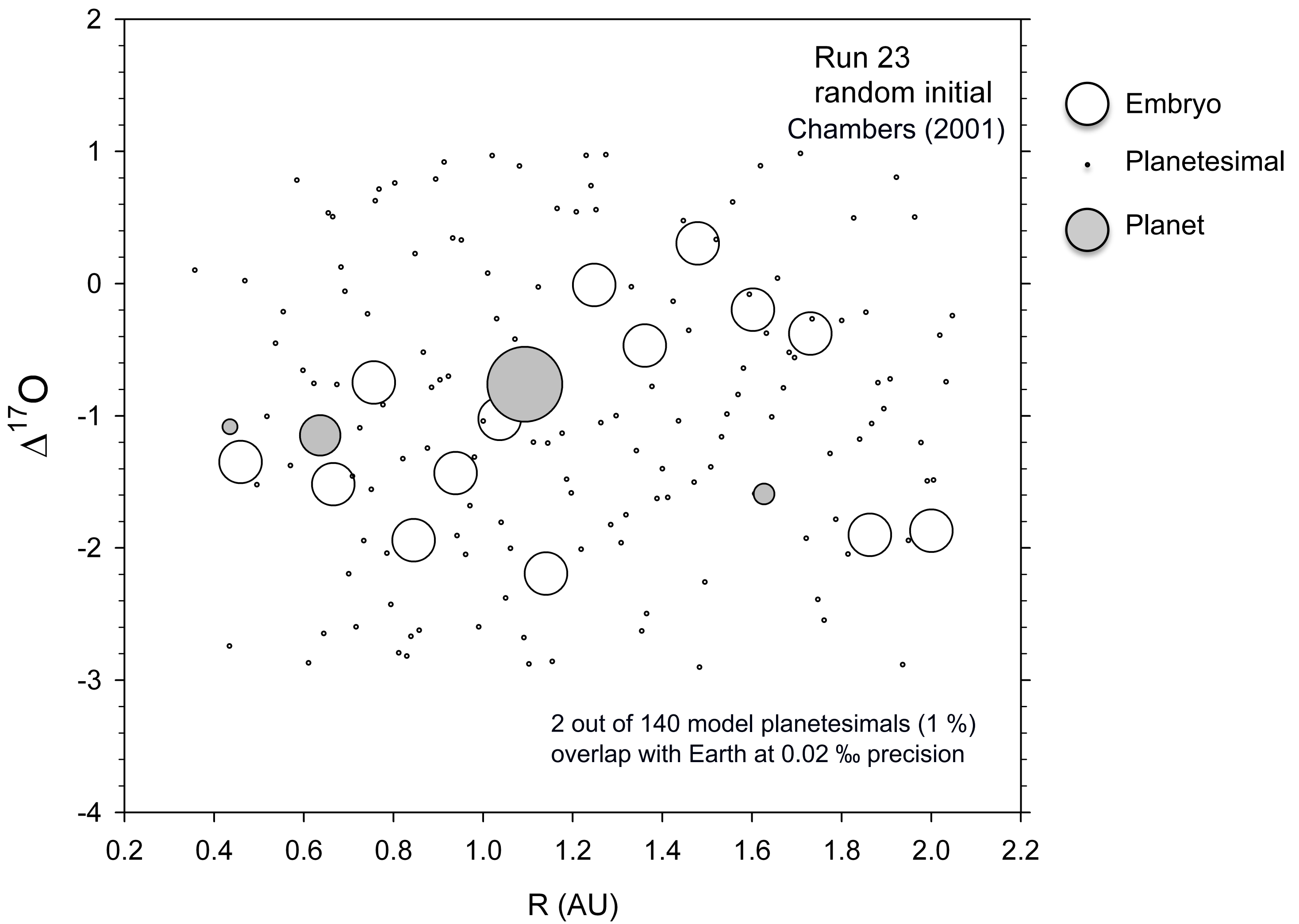
Solar system oxygen isotopes



Older n-body simulations of oxygen isotope homogenization



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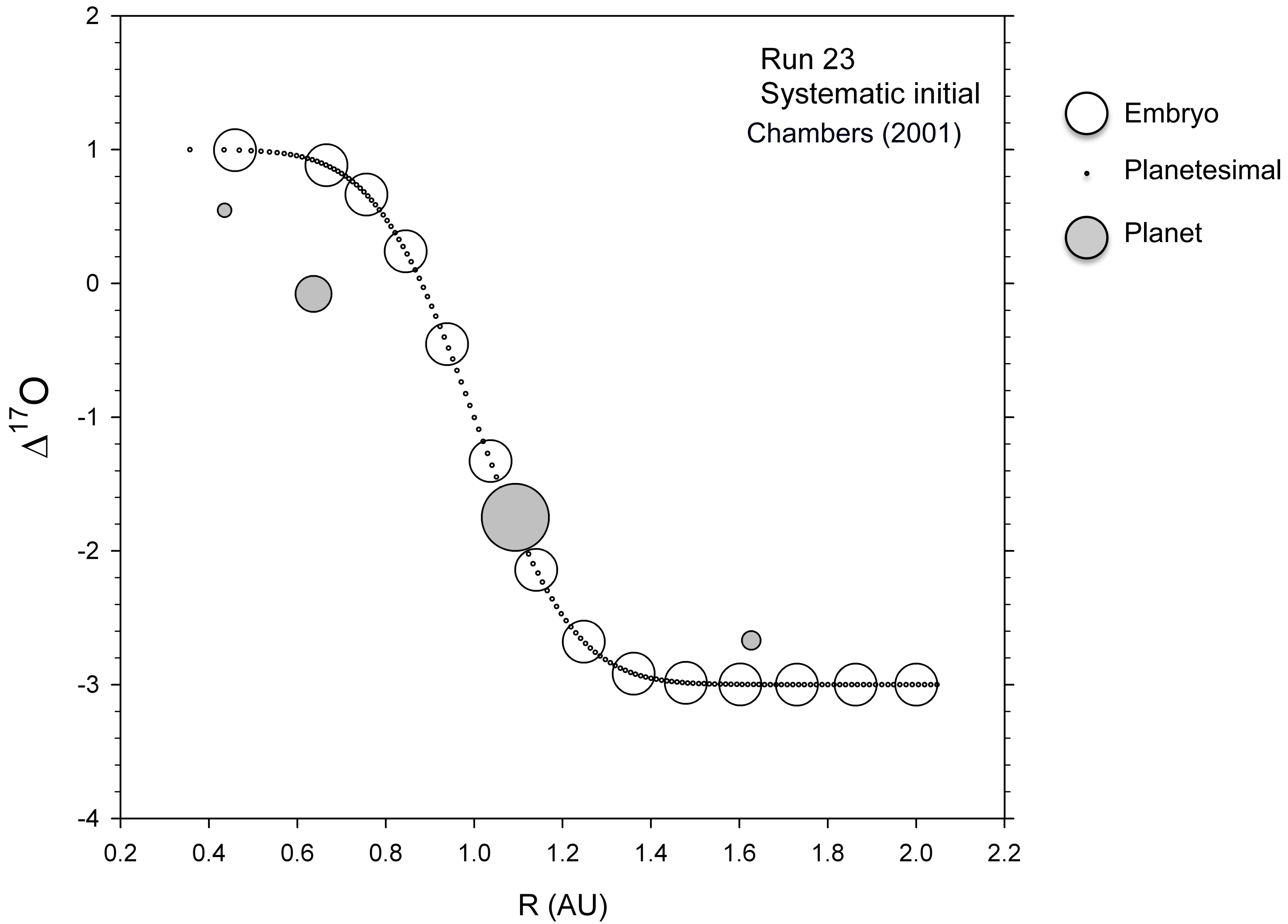
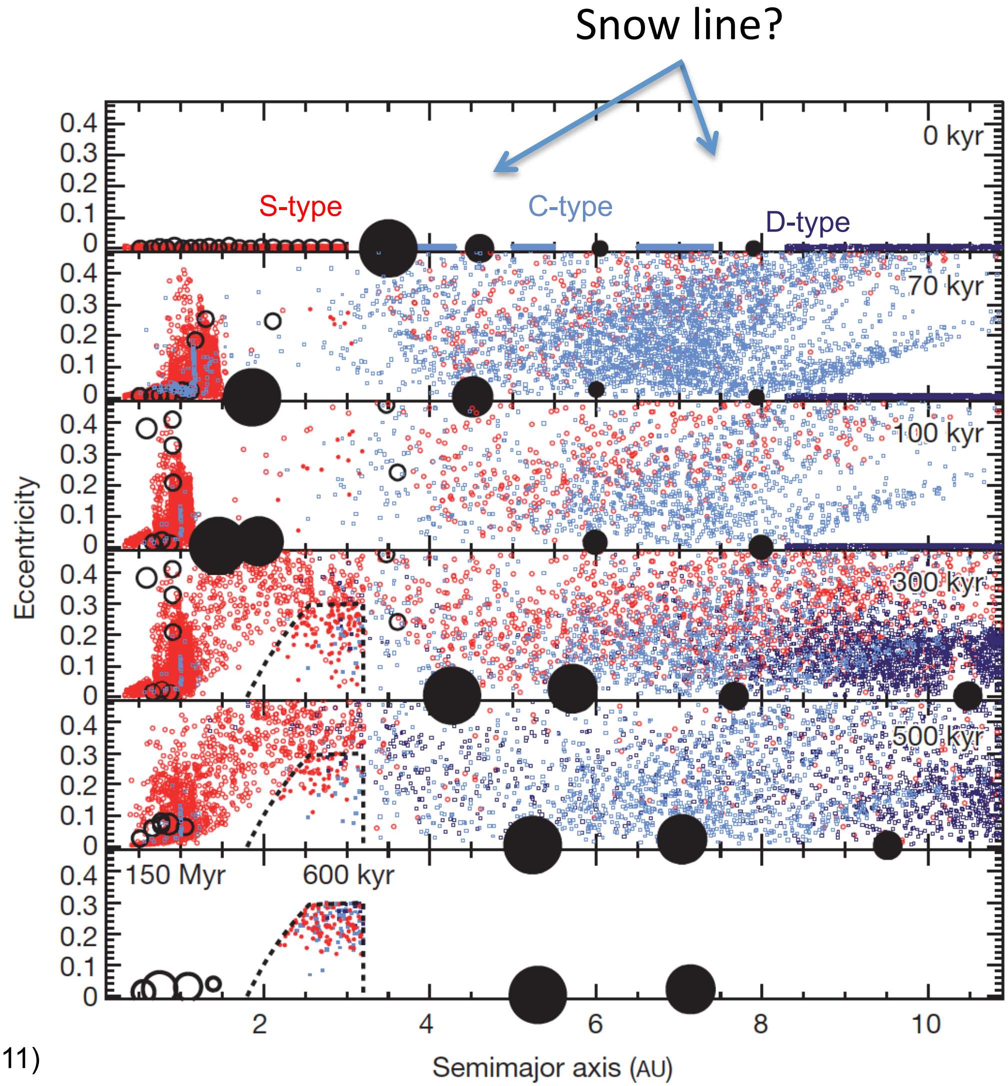
Investigating gradients in $\Delta^{17}O$



Grand Tack – where is the snow line?



Grand Tack
Walsh et al. (2011)

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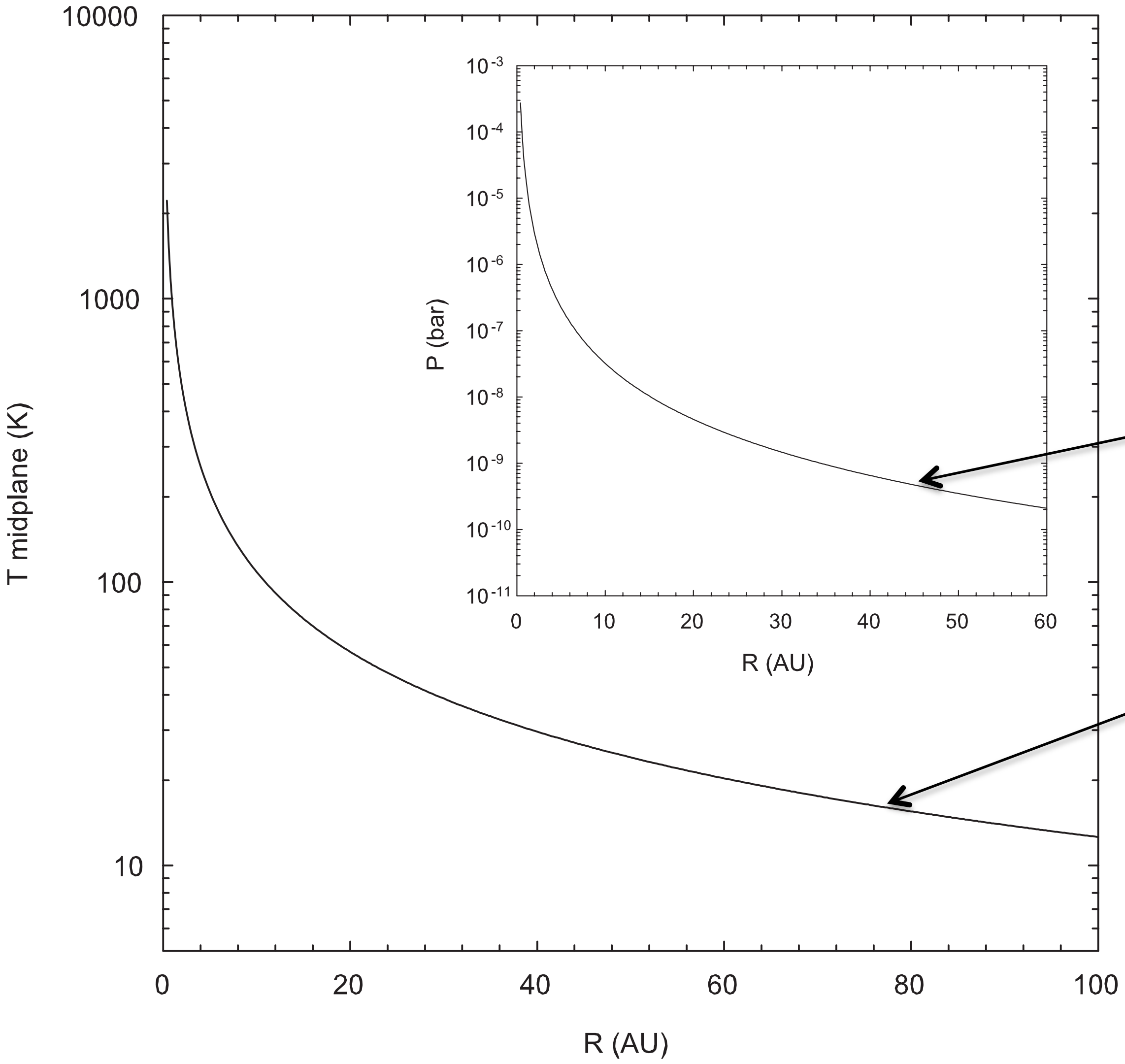
Snow line prescribed by disk evolution



Simple disk model

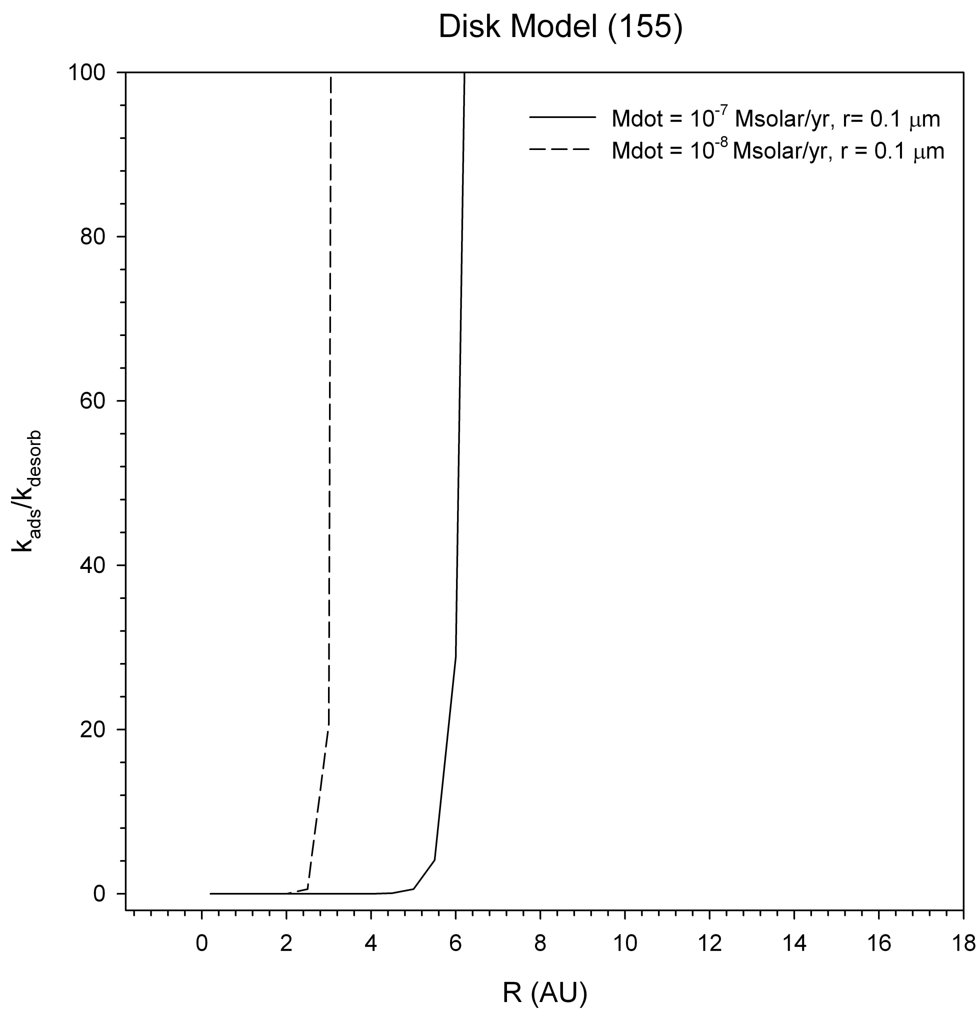
$$H(R) = \frac{c_s}{\Omega} = \sqrt{\frac{k_b T\, R^3}{G\, M_* \mu}}$$

$$\Sigma = \frac{\dot{m}}{3\pi\, \alpha\, c_s\, H(R)}$$

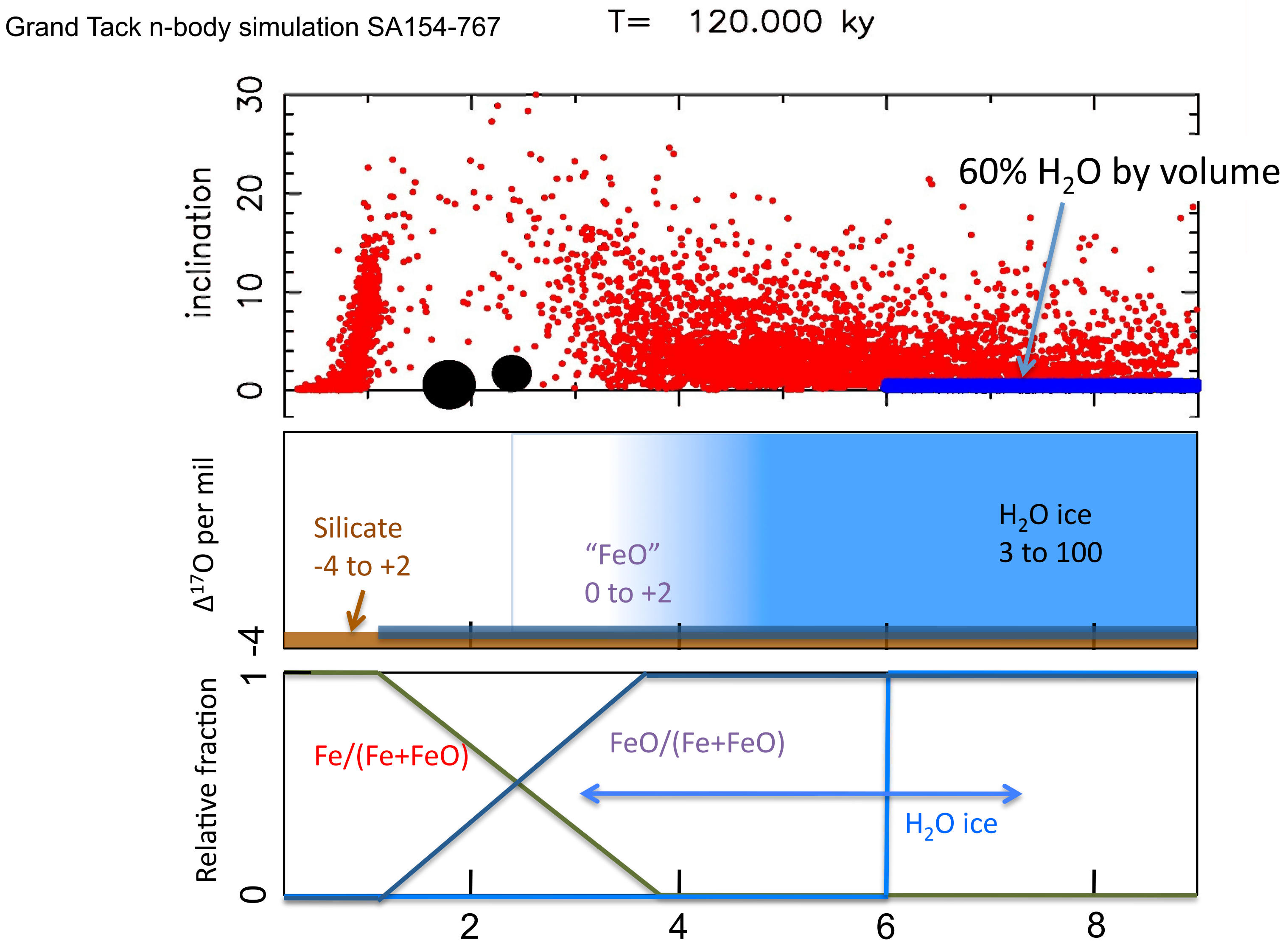
$$P = \frac{\Sigma}{\sqrt{\pi}\ H(R)} \frac{k_b T}{\mu}$$

$$T = \left[\frac{\dot{m}}{8\pi\, \alpha\, c_s H(R)} + 1 \right]^{1/4} \left[\frac{3}{8\pi\sigma} \frac{G M_* \dot{m}}{R^3} \right]^{1/4}$$

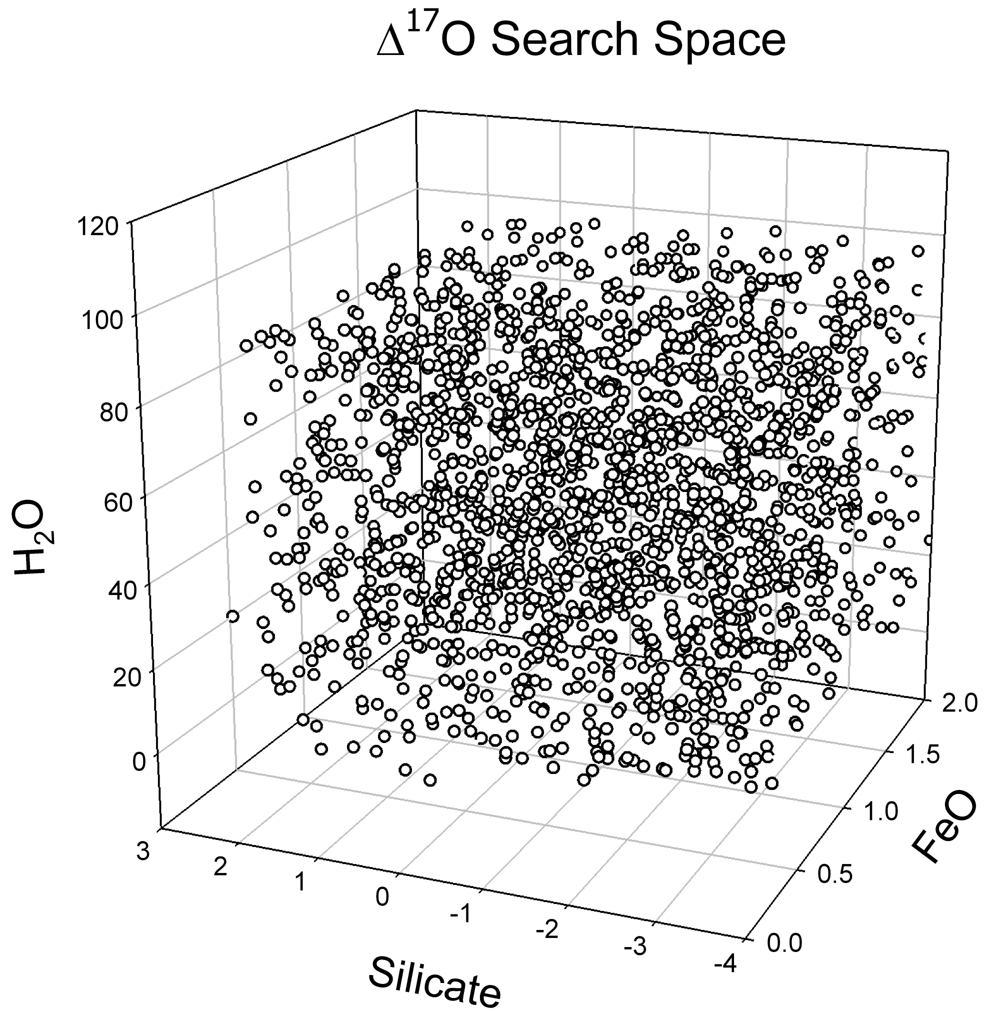
Snow line is diachronous



Oxygen isotope and oxidation state model



Search space



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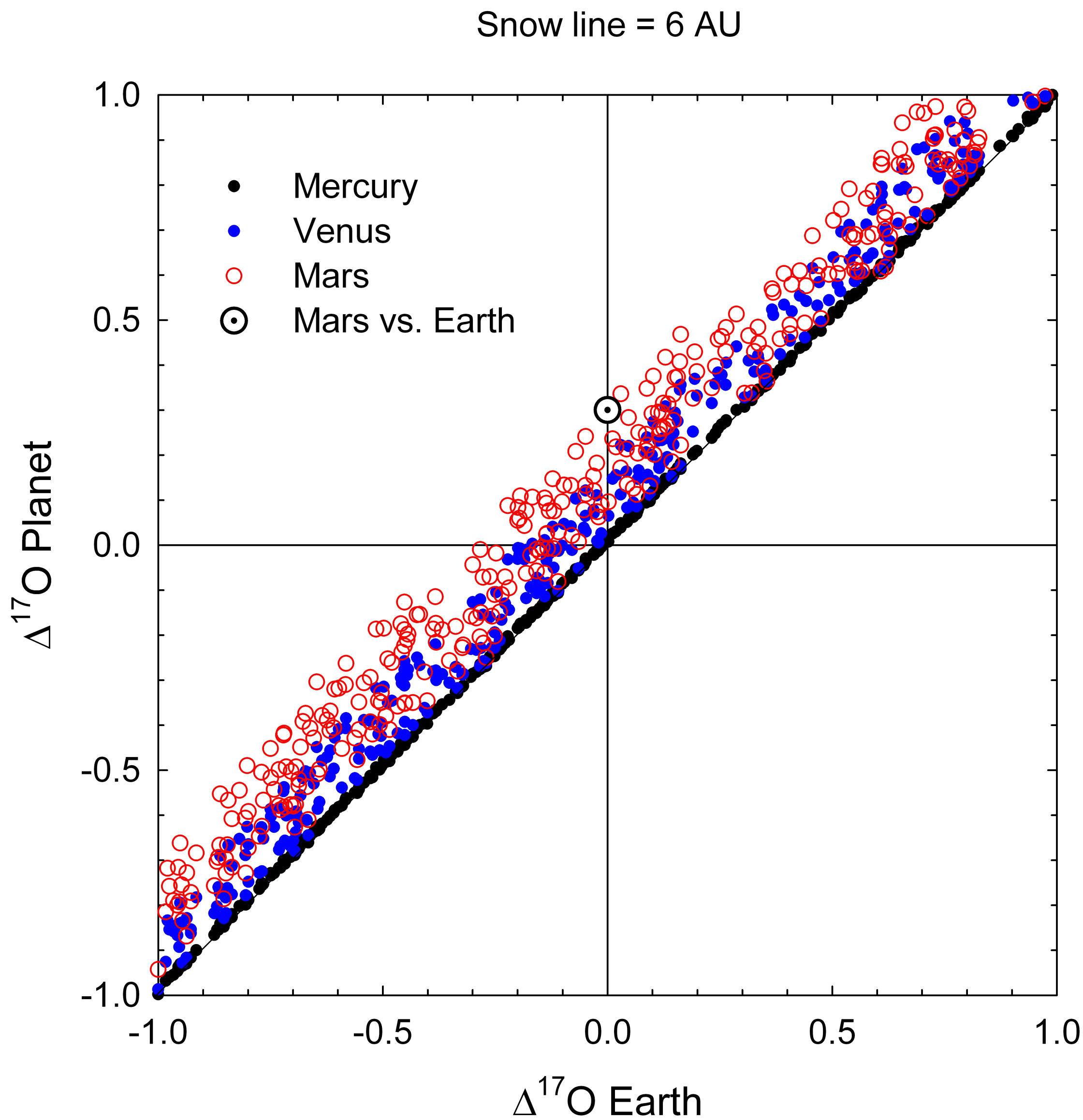
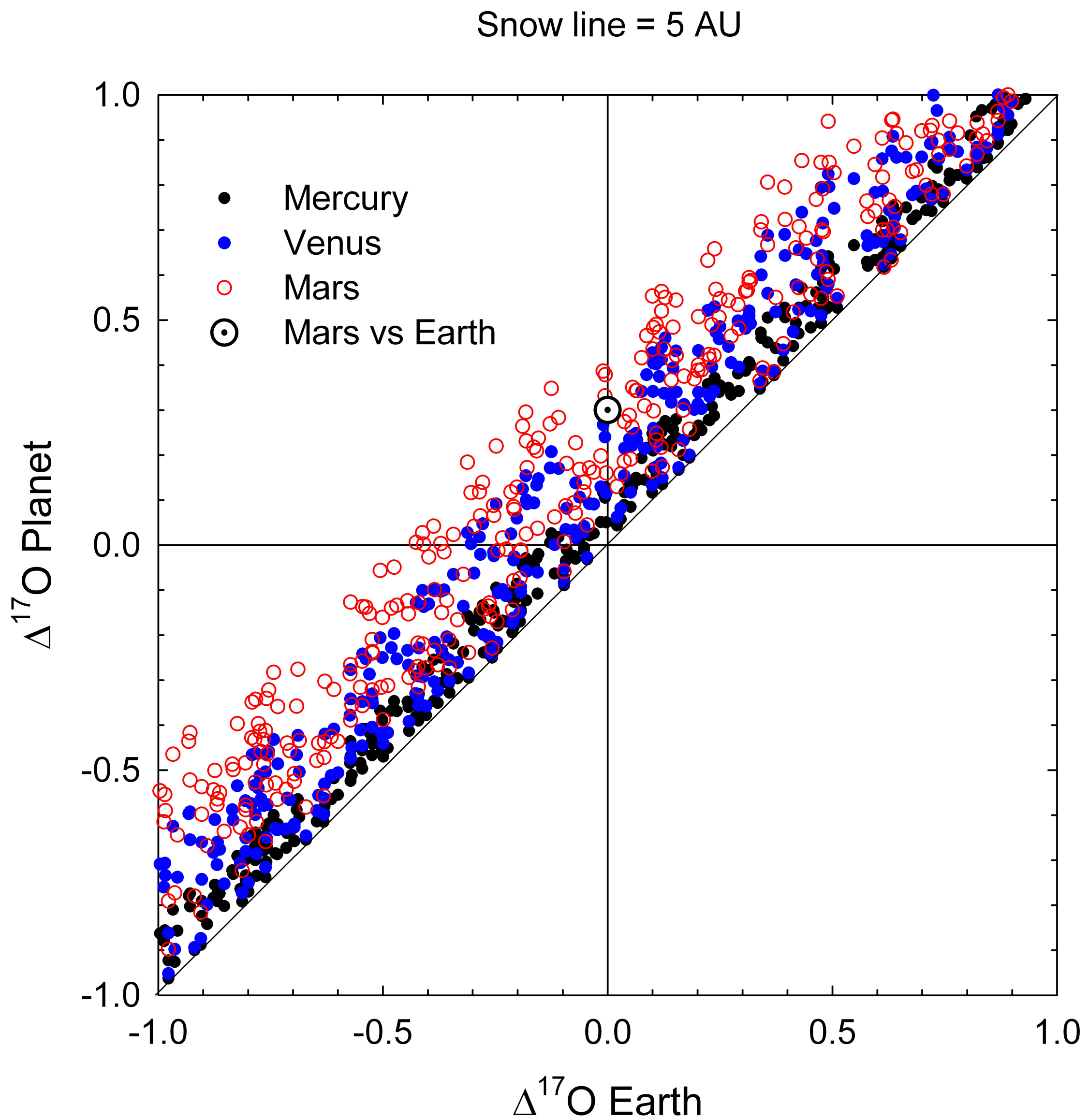
Results



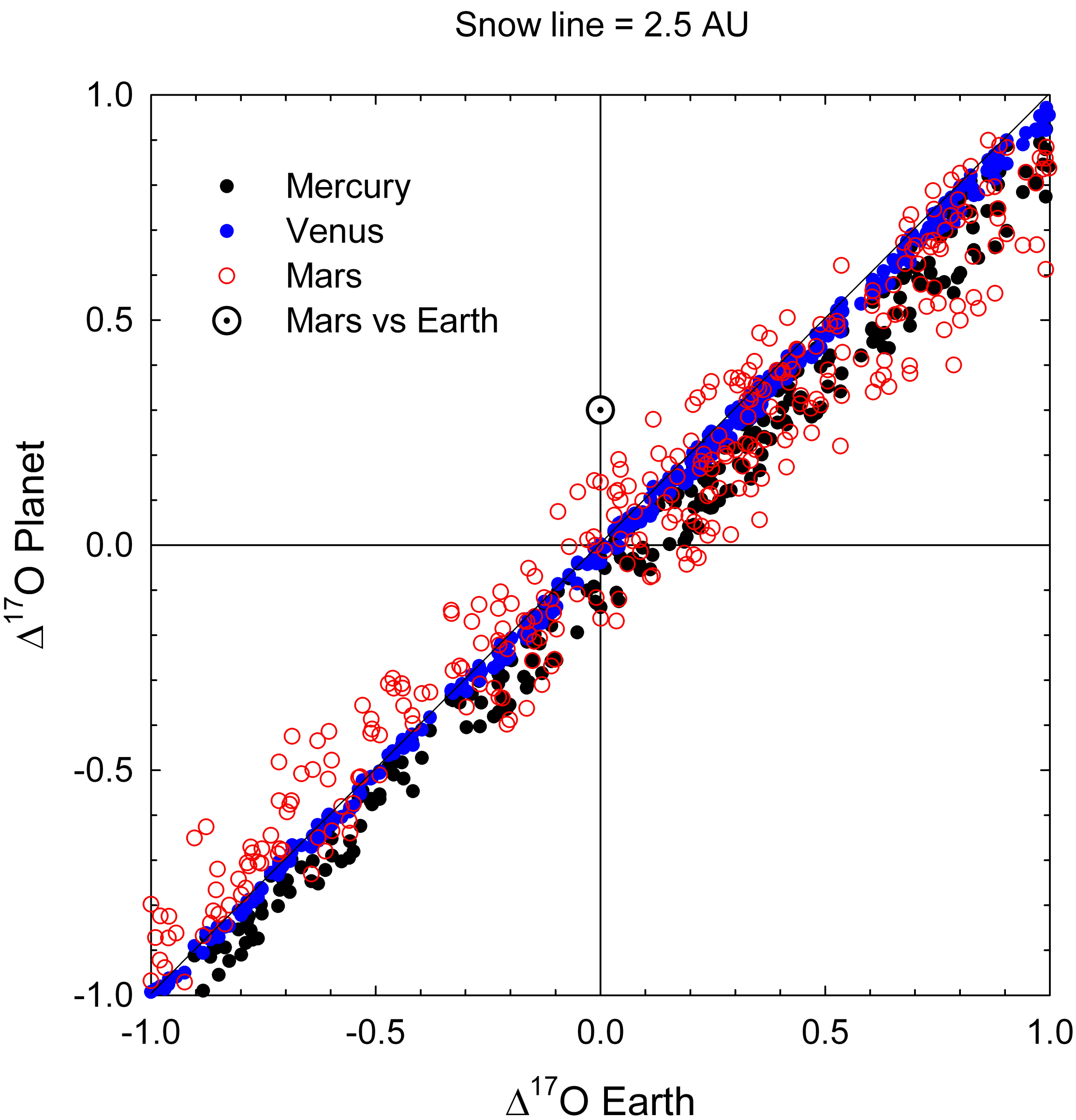
Snow line = 6 AU
Mercury
Venus
Mars
Mars vs. Earth
1.0
0.5
0.0
-0.5
-1.0
-1.0
-0.5
0.0
0.5
1.0
Δ^{17}O Planet
Δ^{17}O Earth

Results



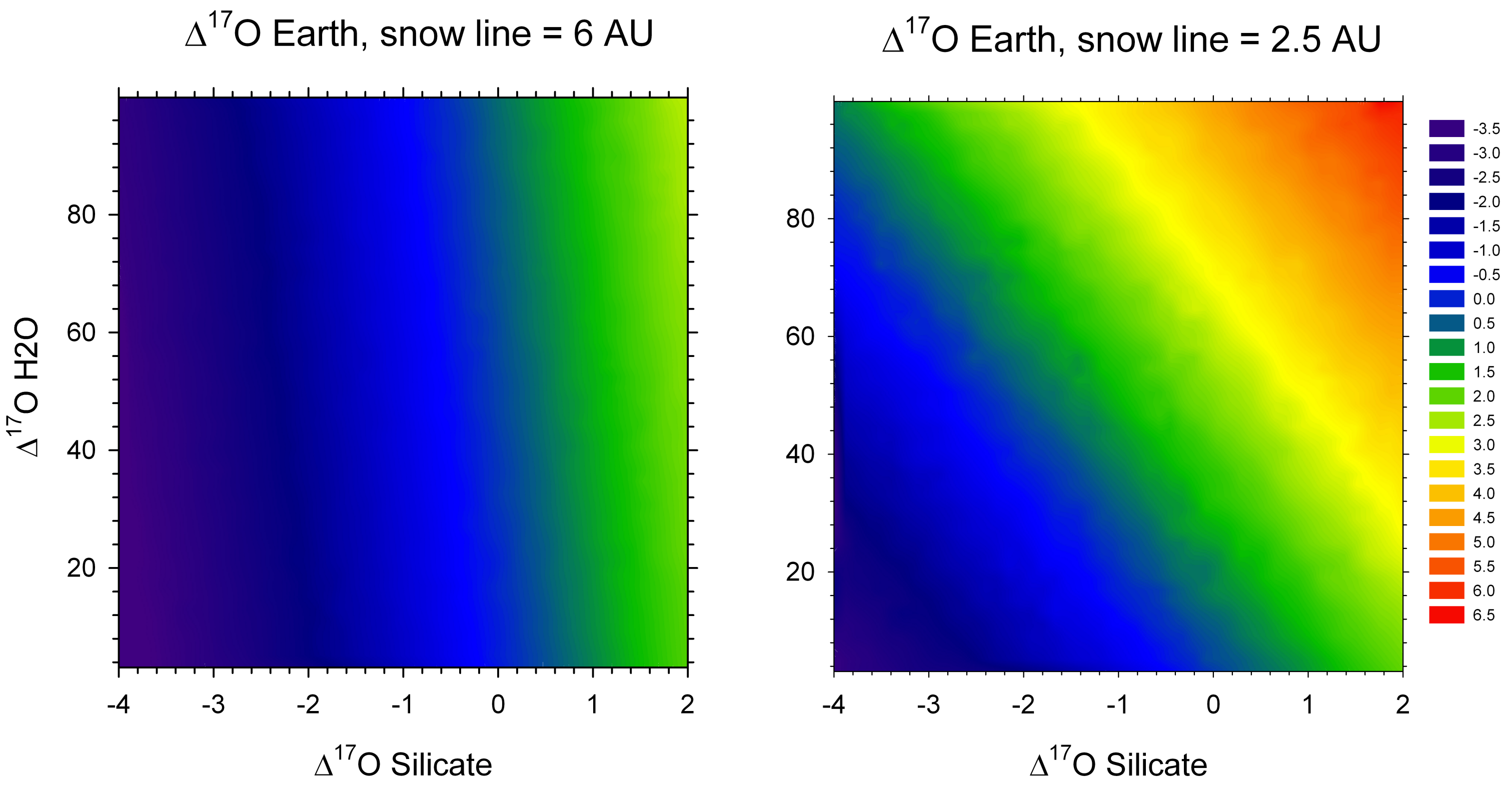
Snow line = 5 AU
Mercury
Venus
Mars
Mars vs Earth
Δ^{17}O Planet
Δ^{17}O Earth
1.0
0.5
0.0
-0.5
-1.0
-1.0
-0.5
0.0
0.5
1.0

Results

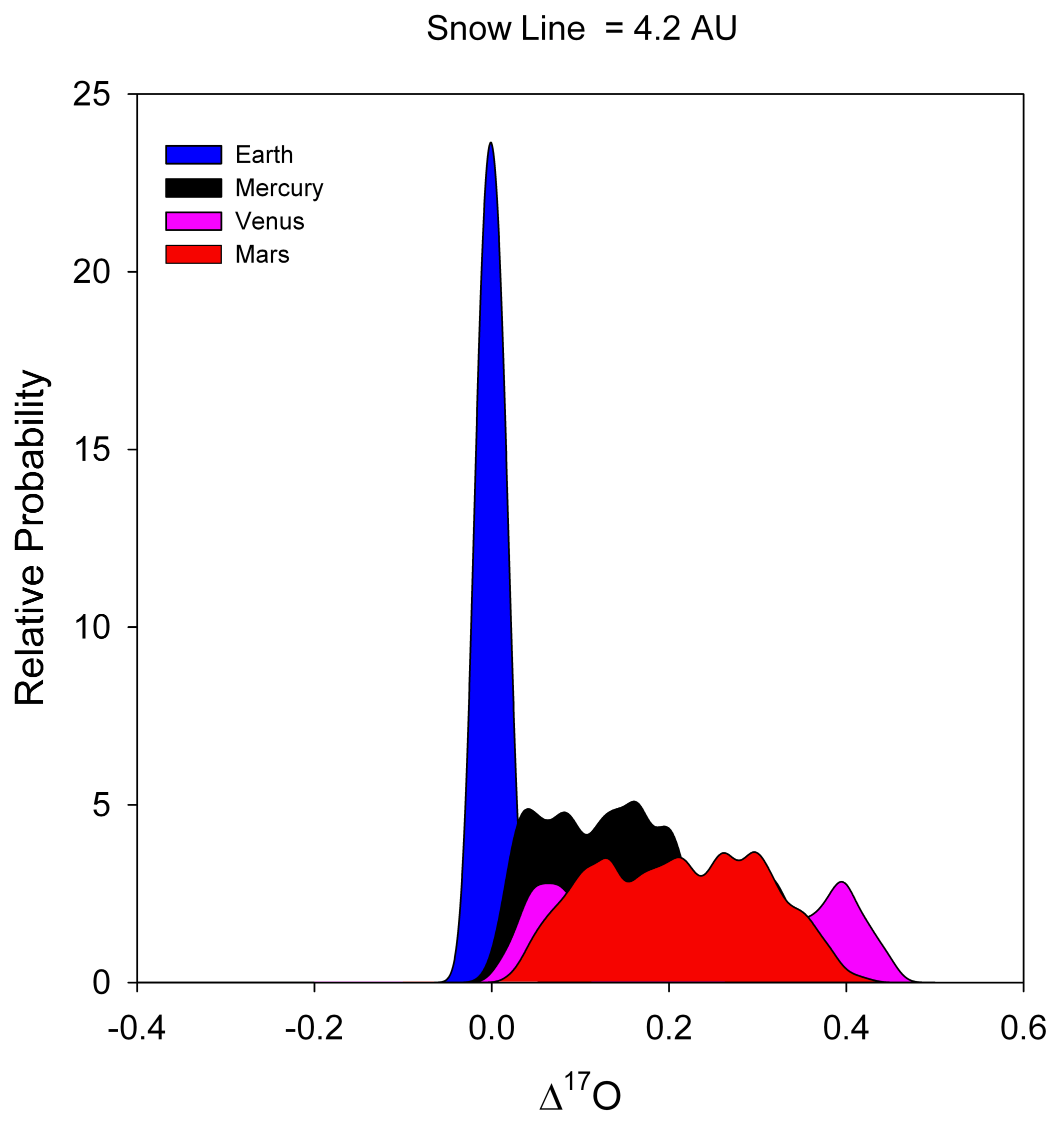


Snow line = 2.5 AU
Mercury
Venus
Mars
Mars vs Earth
1.0
0.5
0.0
-0.5
-1.0
-1.0
-0.5
0.0
0.5
1.0
Δ17O Planet
Δ17O Earth

H_2O vs. silicate



Solutions for Earth $\Delta^{17}O = 0$



Preliminary conclusions

1. Oxygen isotopic composition of inner solar system planets is not monotonic with distance from the Sun if giant planets moved through the disk early

2. Predictions for composition (e.g., oxidation state) can be coupled with predictions for oxygen isotope ratios

3. $\Delta^{17}O$ difference between Earth and Mars is best simulated in the context of the Grand Tack model with a snowline between about 4 and 5 AU