Origin and isotopic composition of water in fluid inclusions from meteorites

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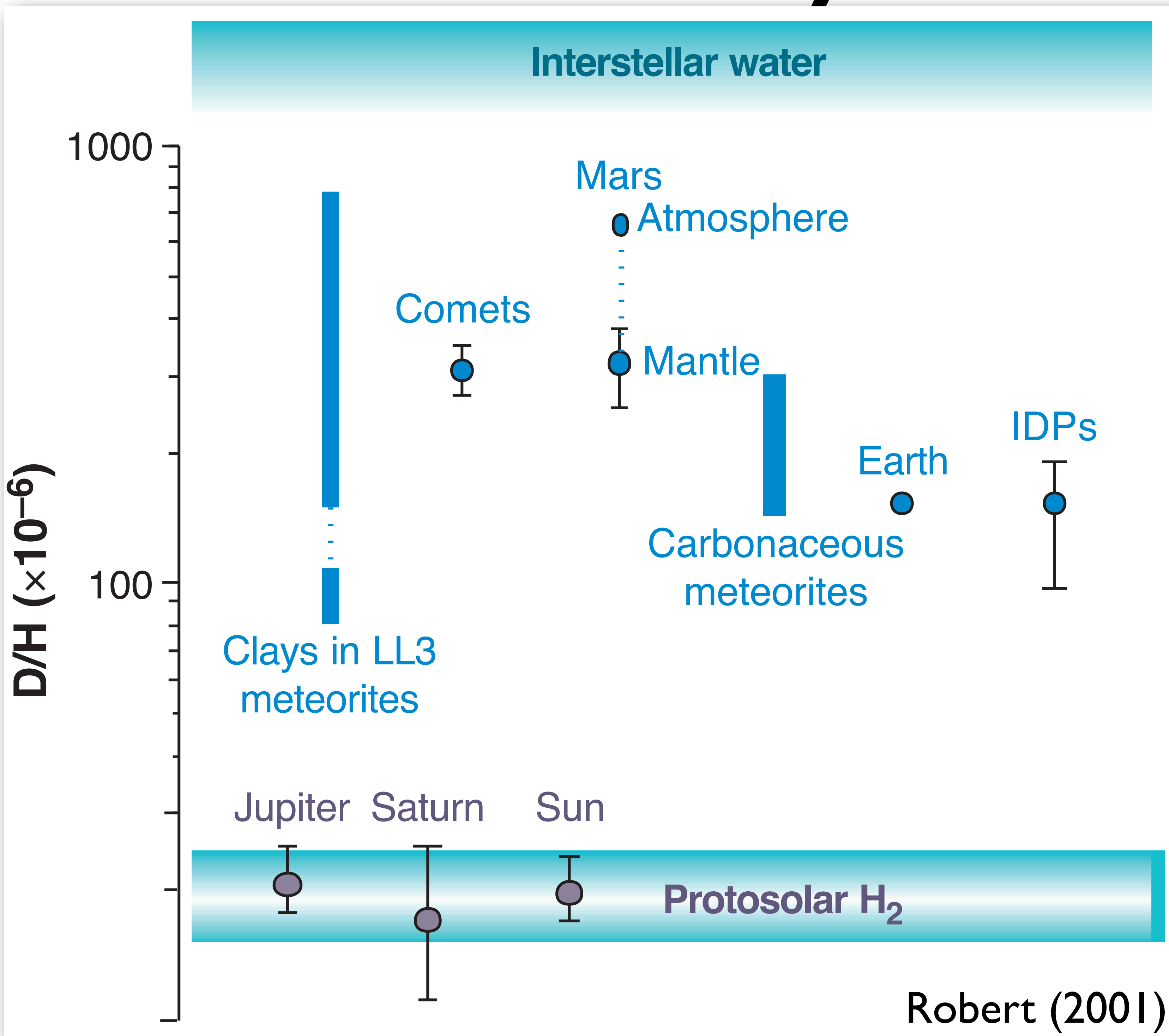
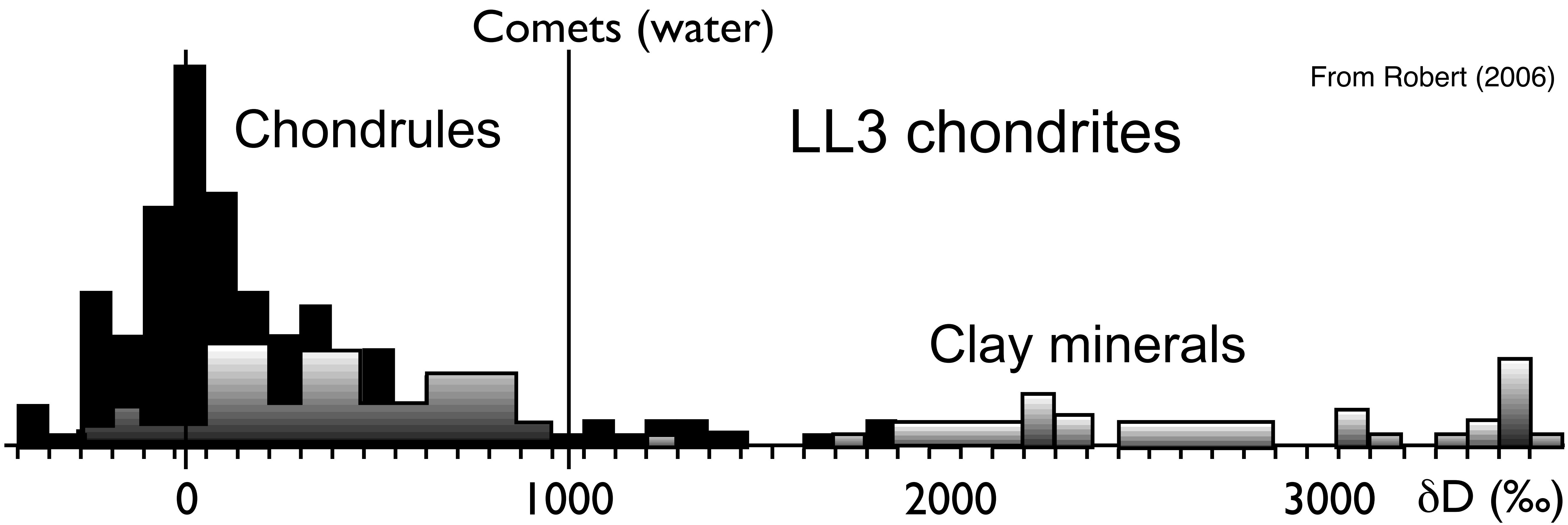
Micrograph of halite from Zag

Introduction

- The origin of water of inner solar system objects is an unsolved issue because those were mainly accreted inside of a snow line.
- On the other hand, we have become increasingly aware of the isotopic characteristics of water for the various occurrences.
- Hydrogen isotopic composition of water is determined by hydrous minerals because they are alteration products from anhydrous minerals by interactions with water.

H isotopic compositions in the solar system





- Large variations of δD have been observed in hydrous minerals from chondrites.
- Comet and interstellar water is highly D-rich.
- High δD signature of hydrous minerals is a heritage of cloud or outer solar disk chemistry.
- Low δD signature of hydrous minerals is a heritage of pristine water of asteroids (e.g. Robert, 2006).

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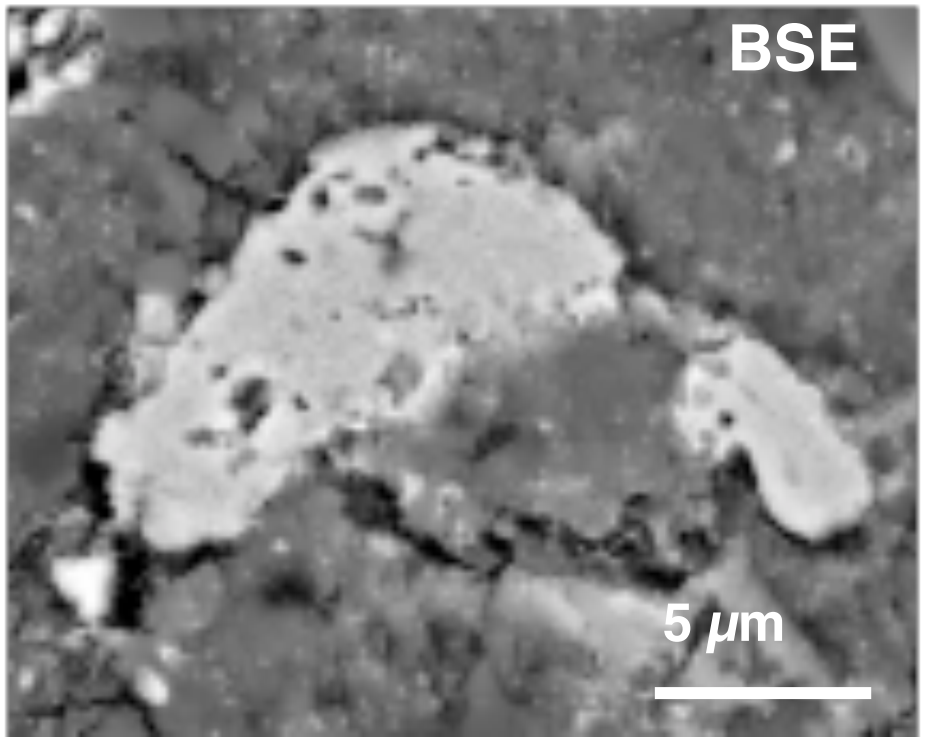
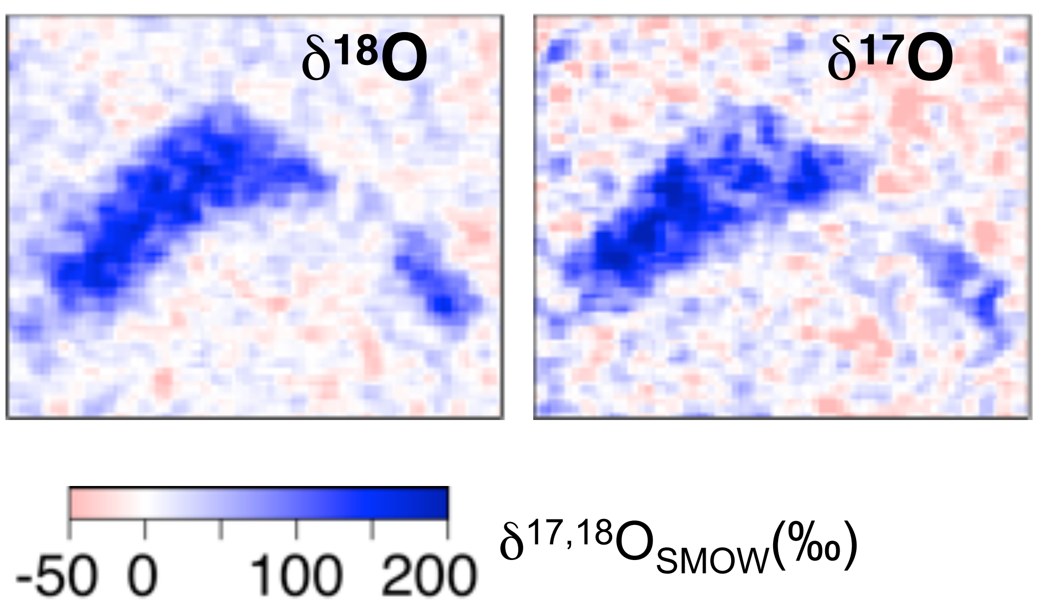
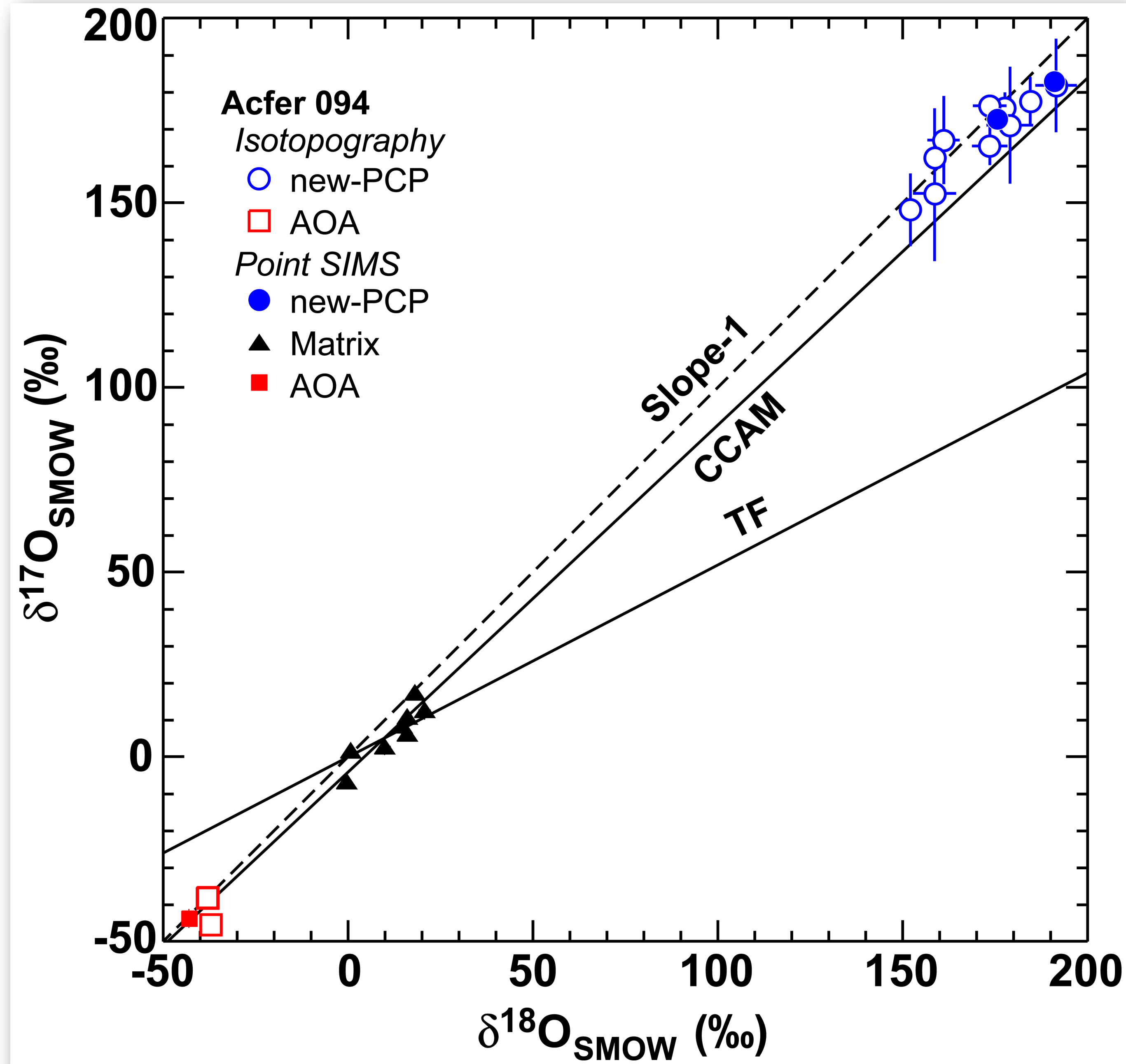
- Oxygen isotopic composition of extraterrestrial water is determined by aqueous alteration of metals and sulfides, e.g., by magnetite (Choi et al. 1998, Sakamoto et al., 2007).
- The oxygen isotopic compositions of these water tend to be depleted in ^{16}O.

Oxygen isotopic composition of Cosmic Symplectite (COS)







Sakamoto et al. (2007)

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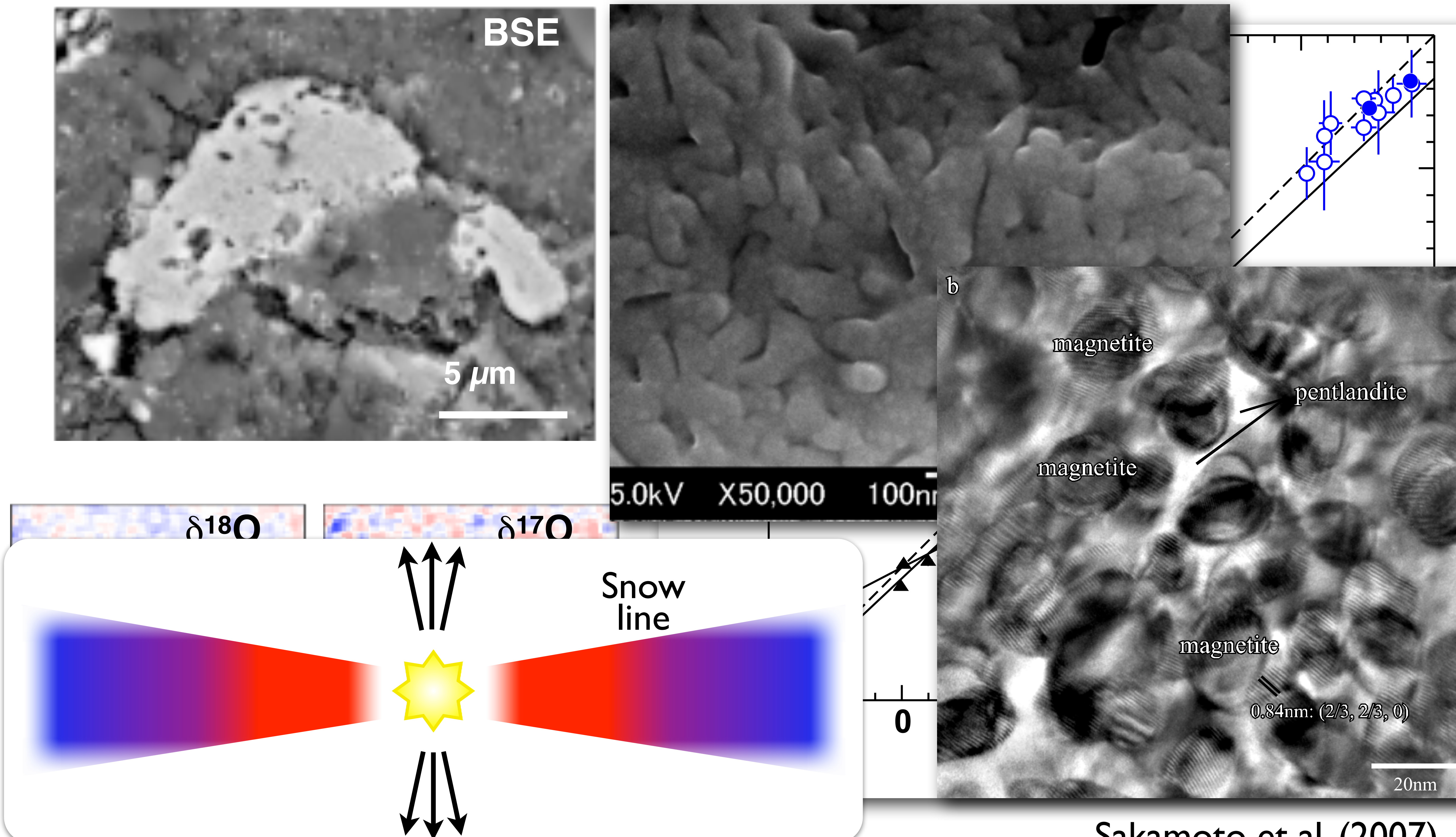
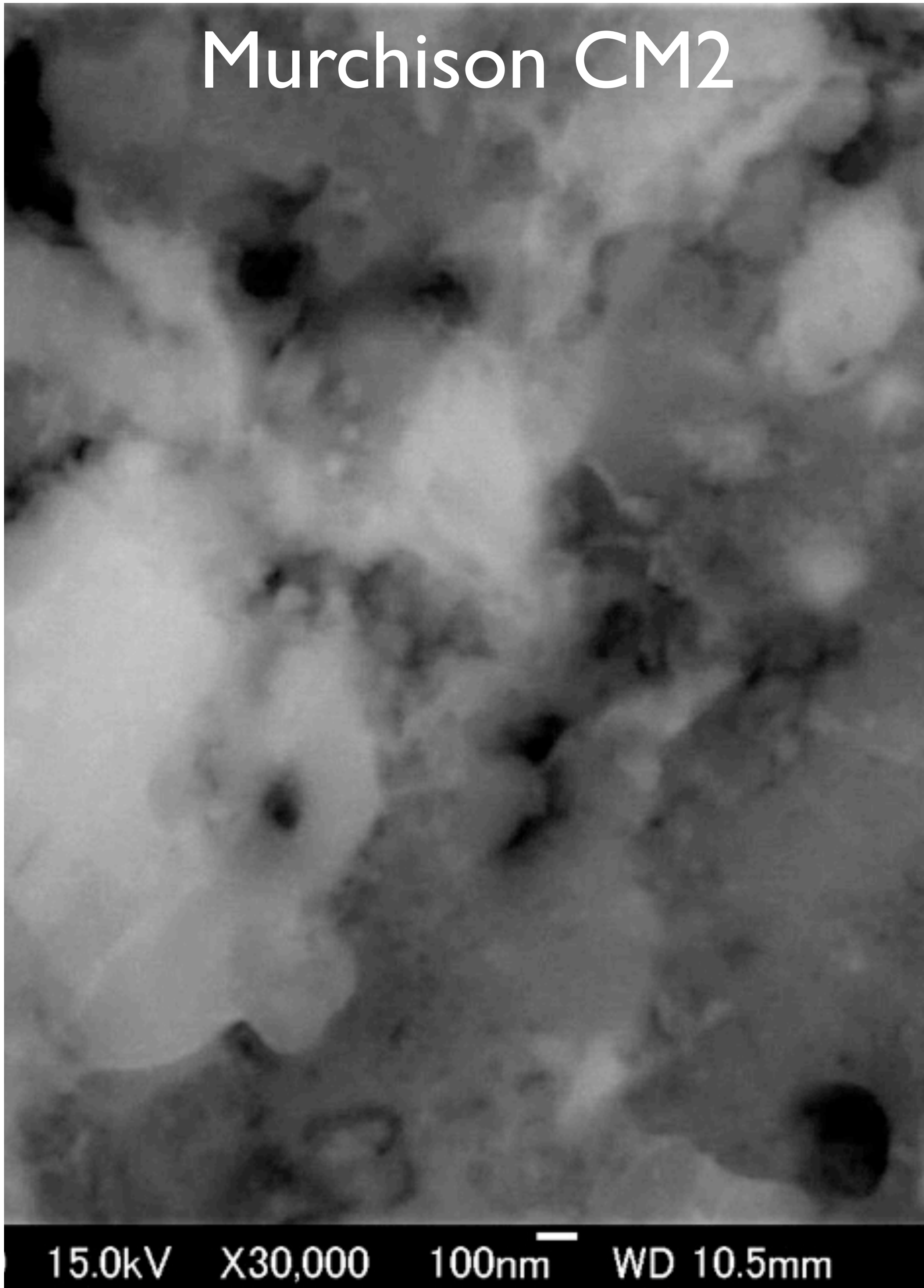
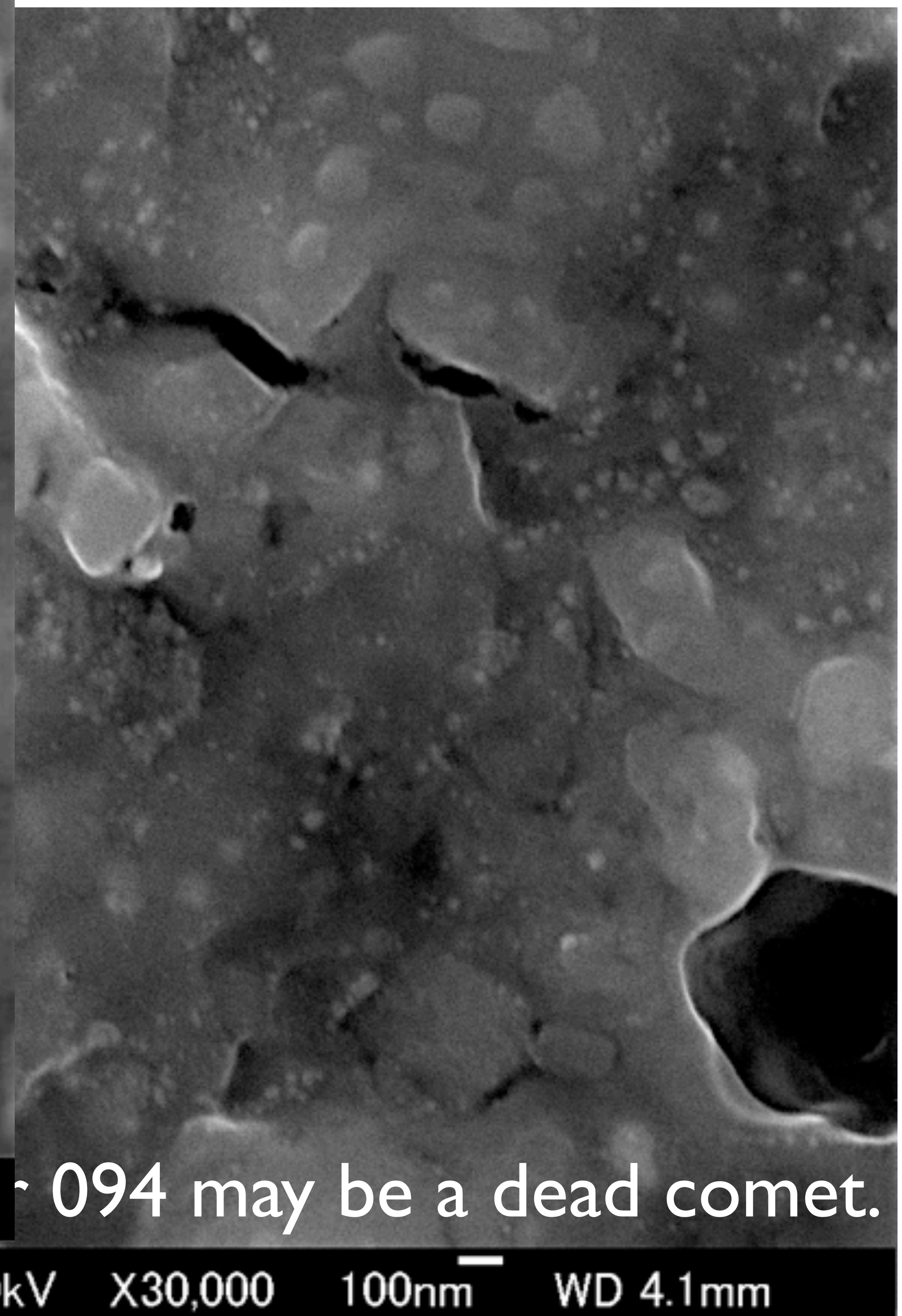


Sakamoto et al. (2007)

xture of Acfer 094





r 094 may be a dead comet.

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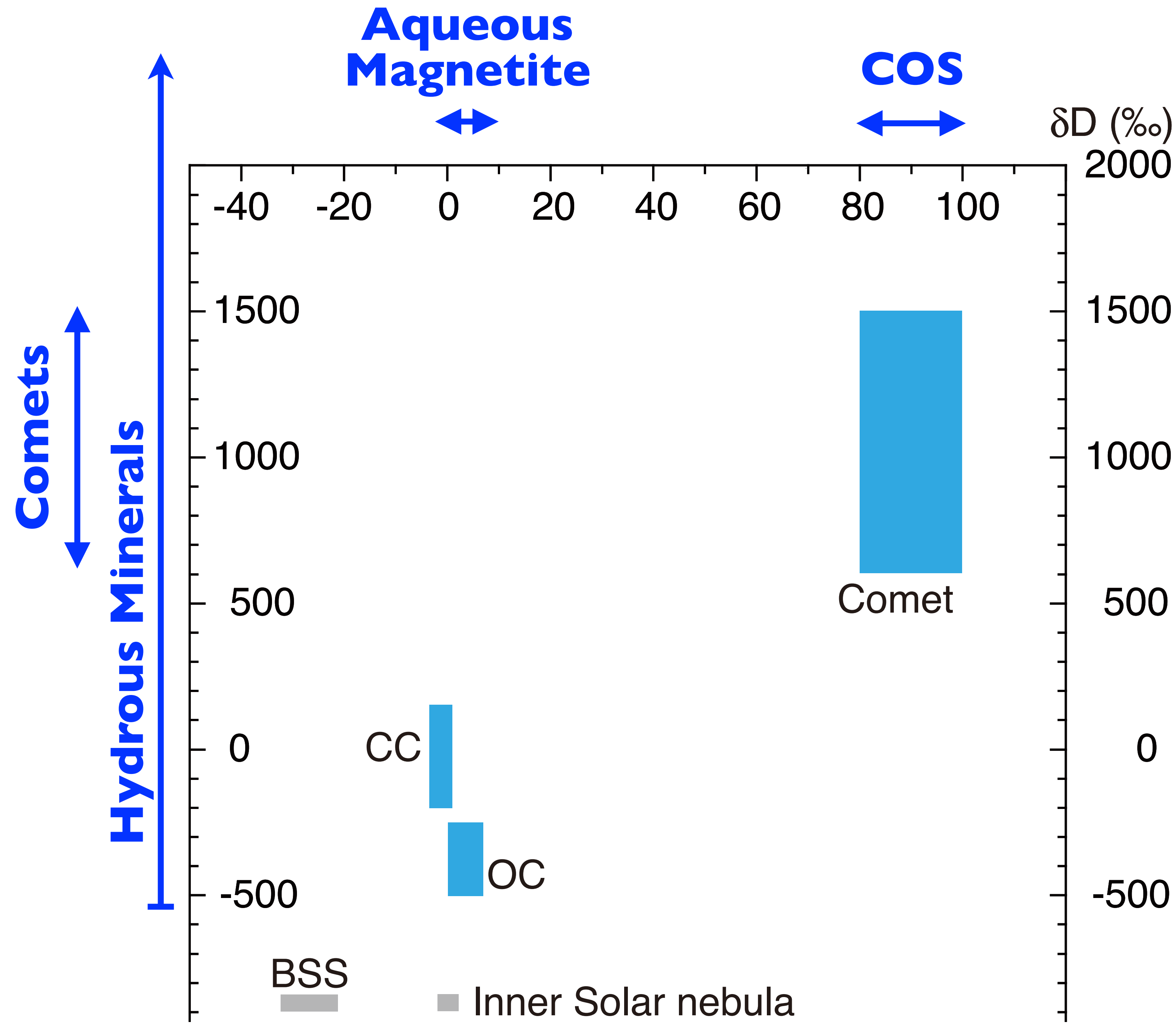
- The oxygen isotopic compositions of these water tend to be depleted in ^{16}O.
- A problem is that isotopic correlations between H and O cannot directly be demonstrated because most minerals do not dominant in water-origin H and O at the same time.

Δ¹⁷O vs δD of Solar System Water



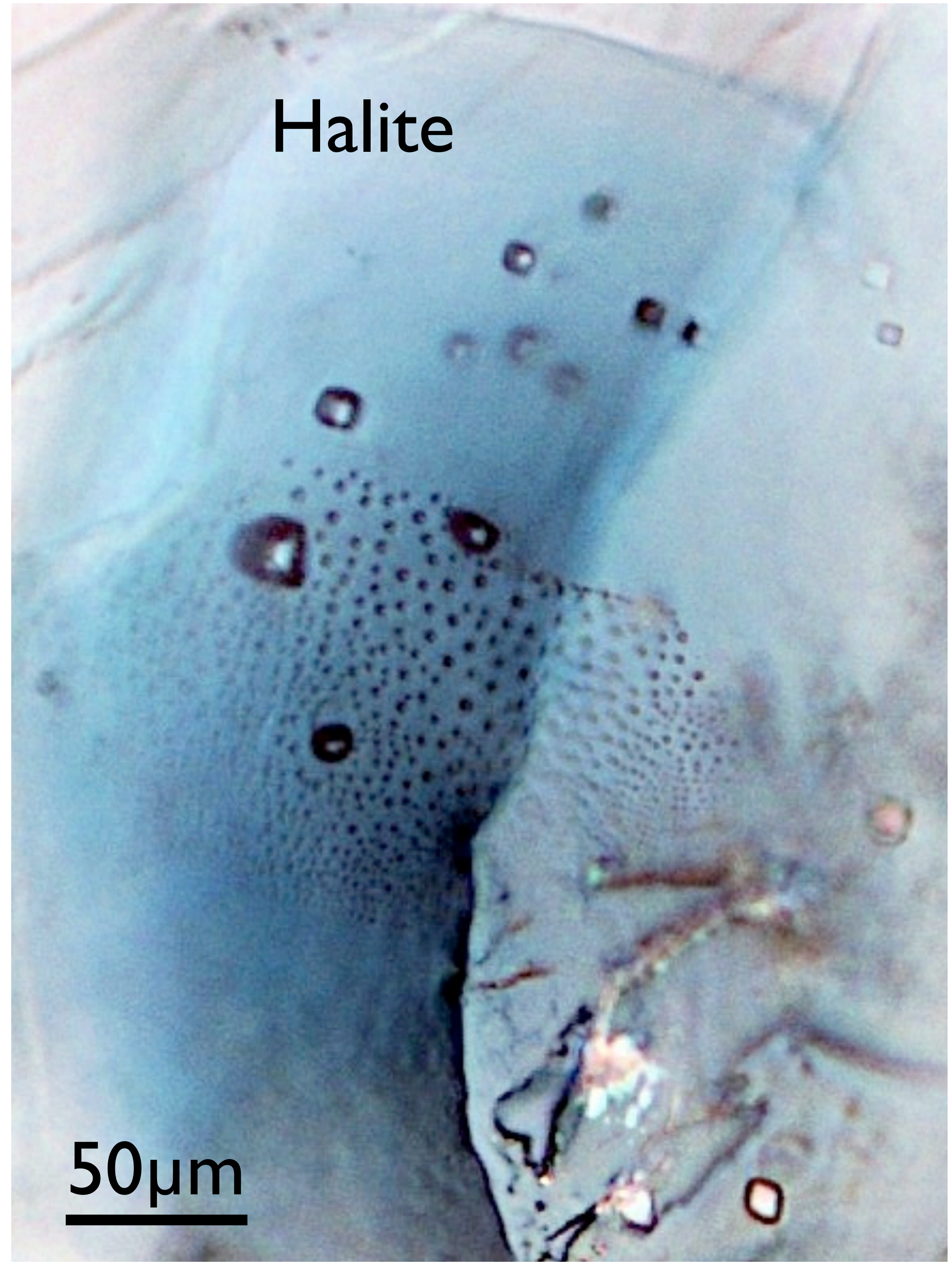
- Here We present Hydrogen and Oxygen isotopic compositions by direct measurement of asteroidal aqueous fluid, and discuss the origin of water of inner solar objects.

Asteroidal Water samples

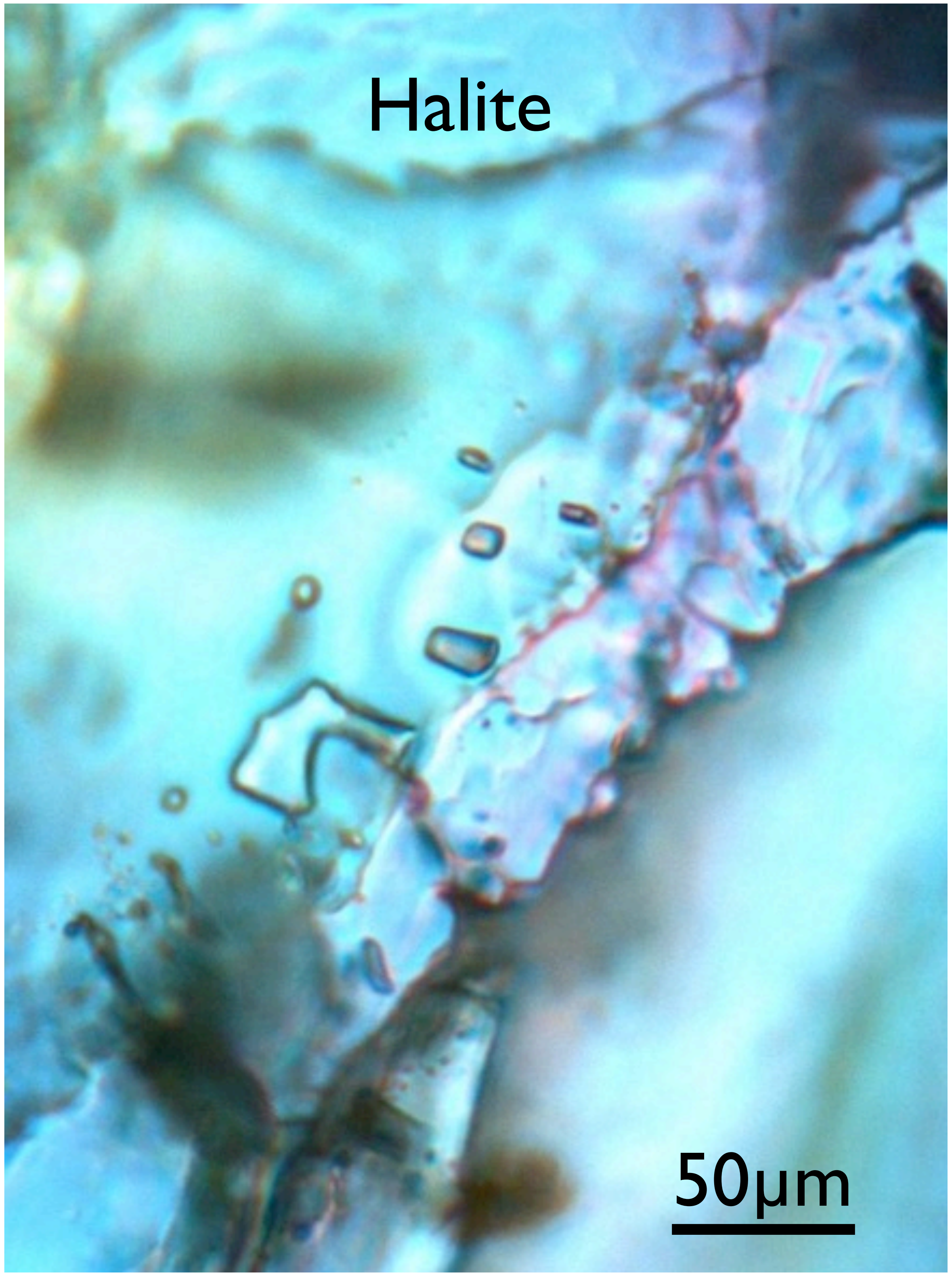
Zag H3-6

1mm

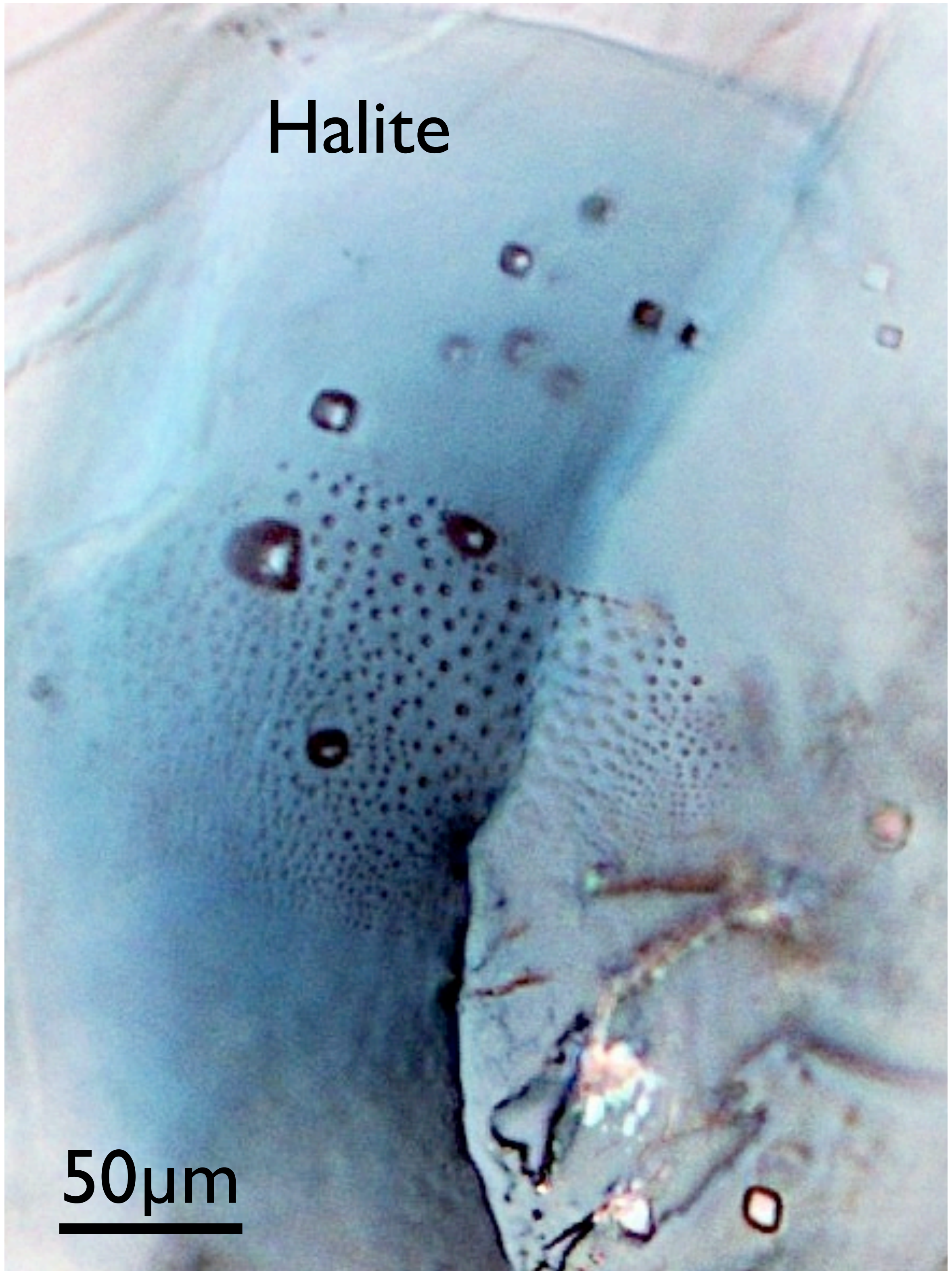
From http://www.nyrockman.com/science/zag.htm



Asteroidal Water samples

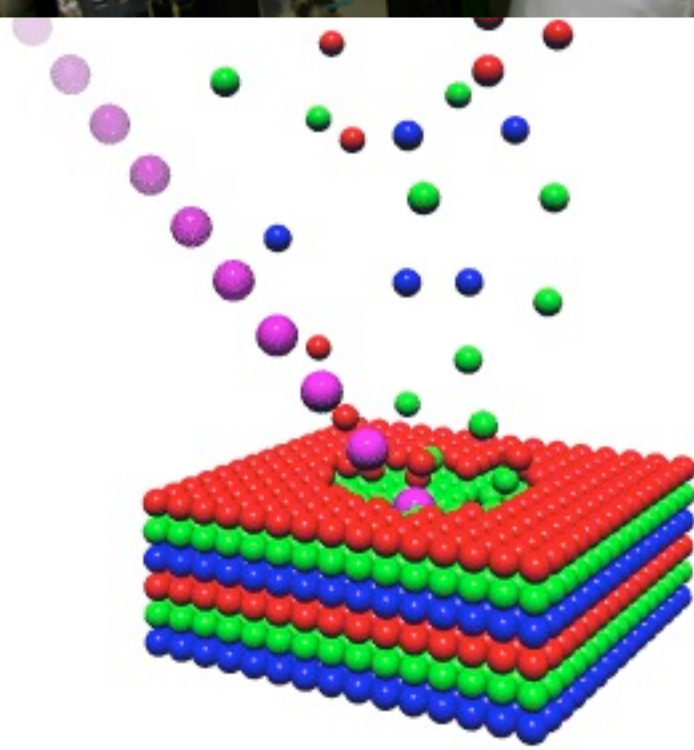


Monahans (1998) H5



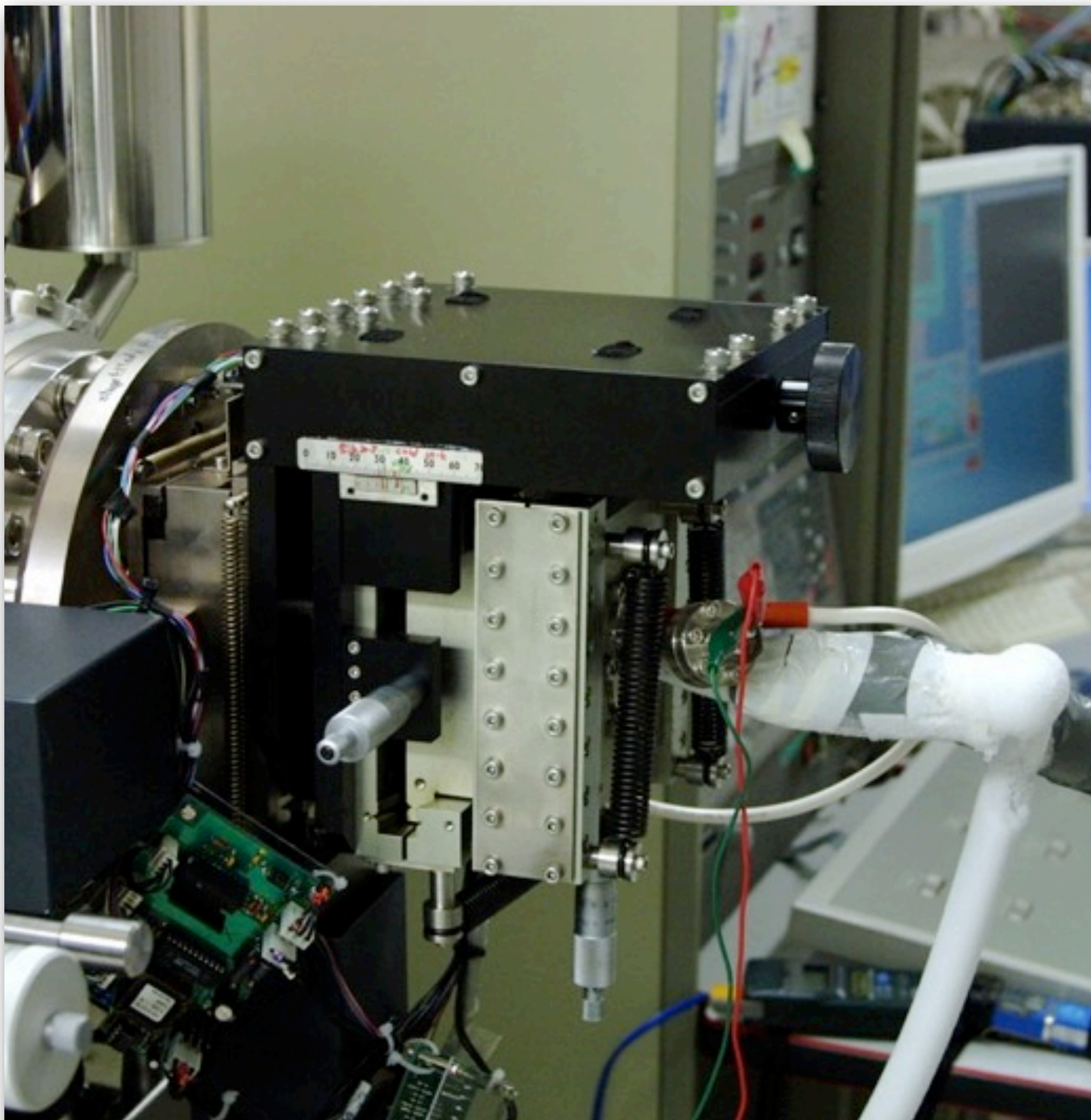
Zag H3-6

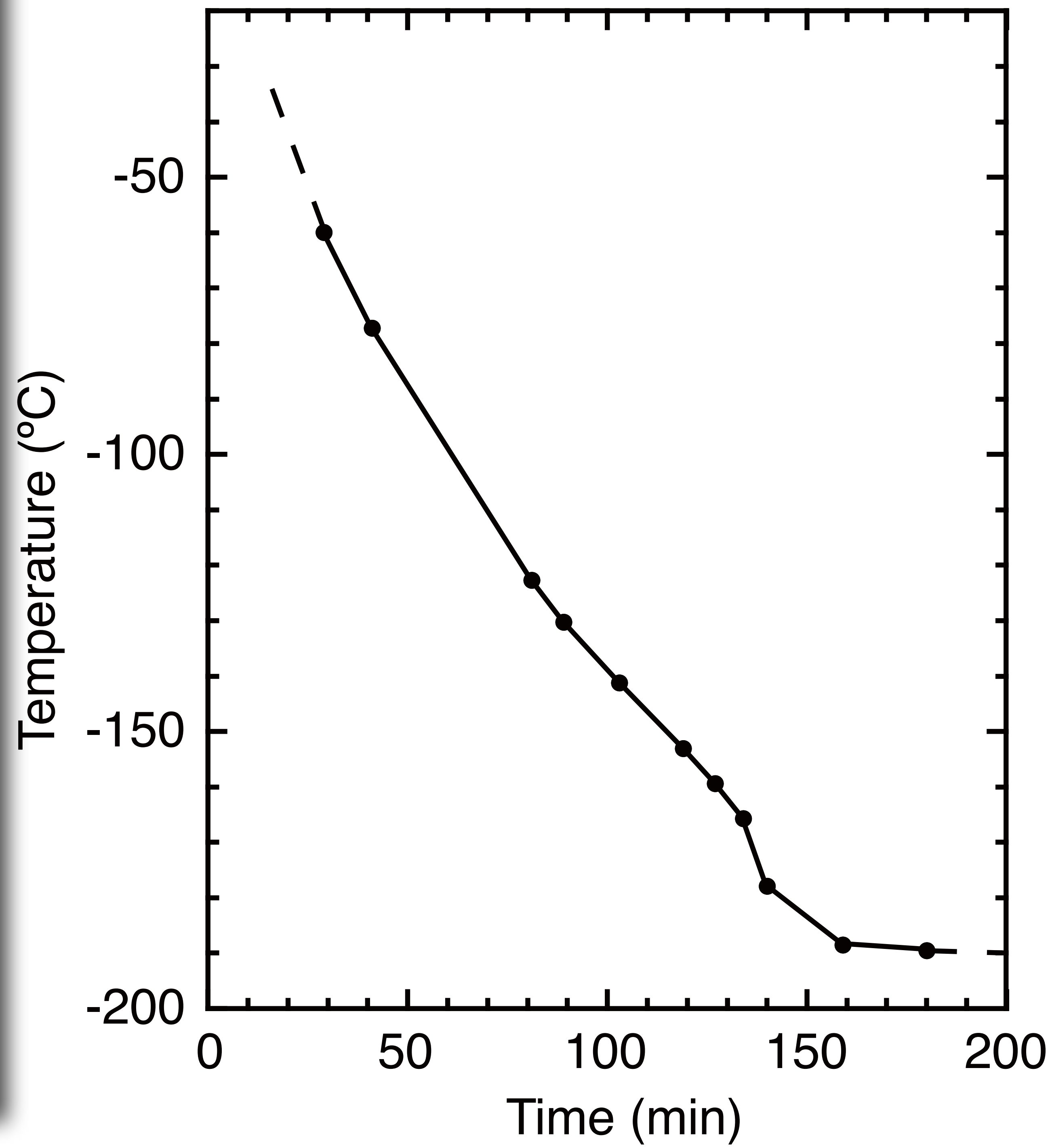
Isotope analysis



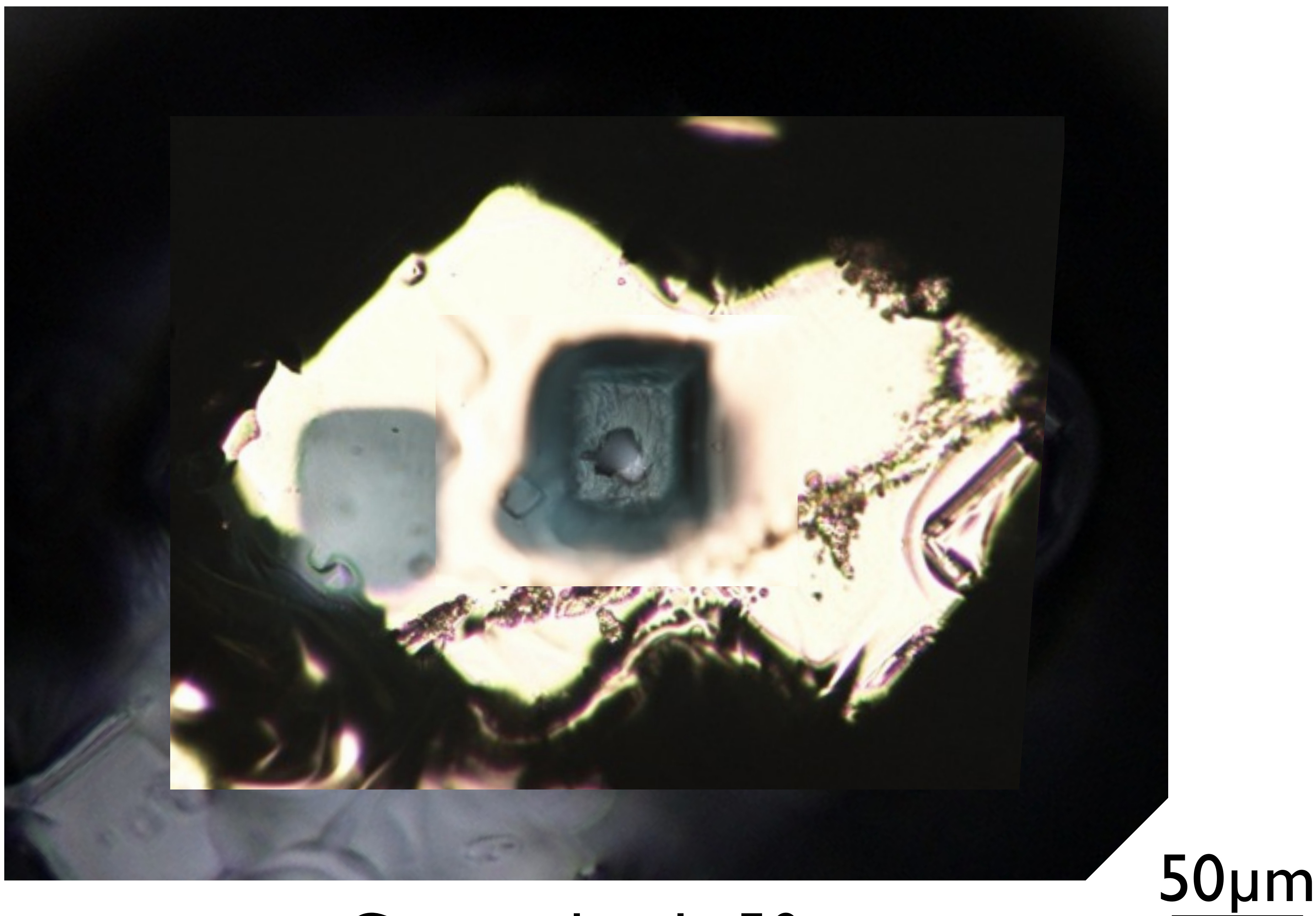
Sample chamber: 10^{-7}Pa

Cryo-sample-stage for Cameca ims-1270

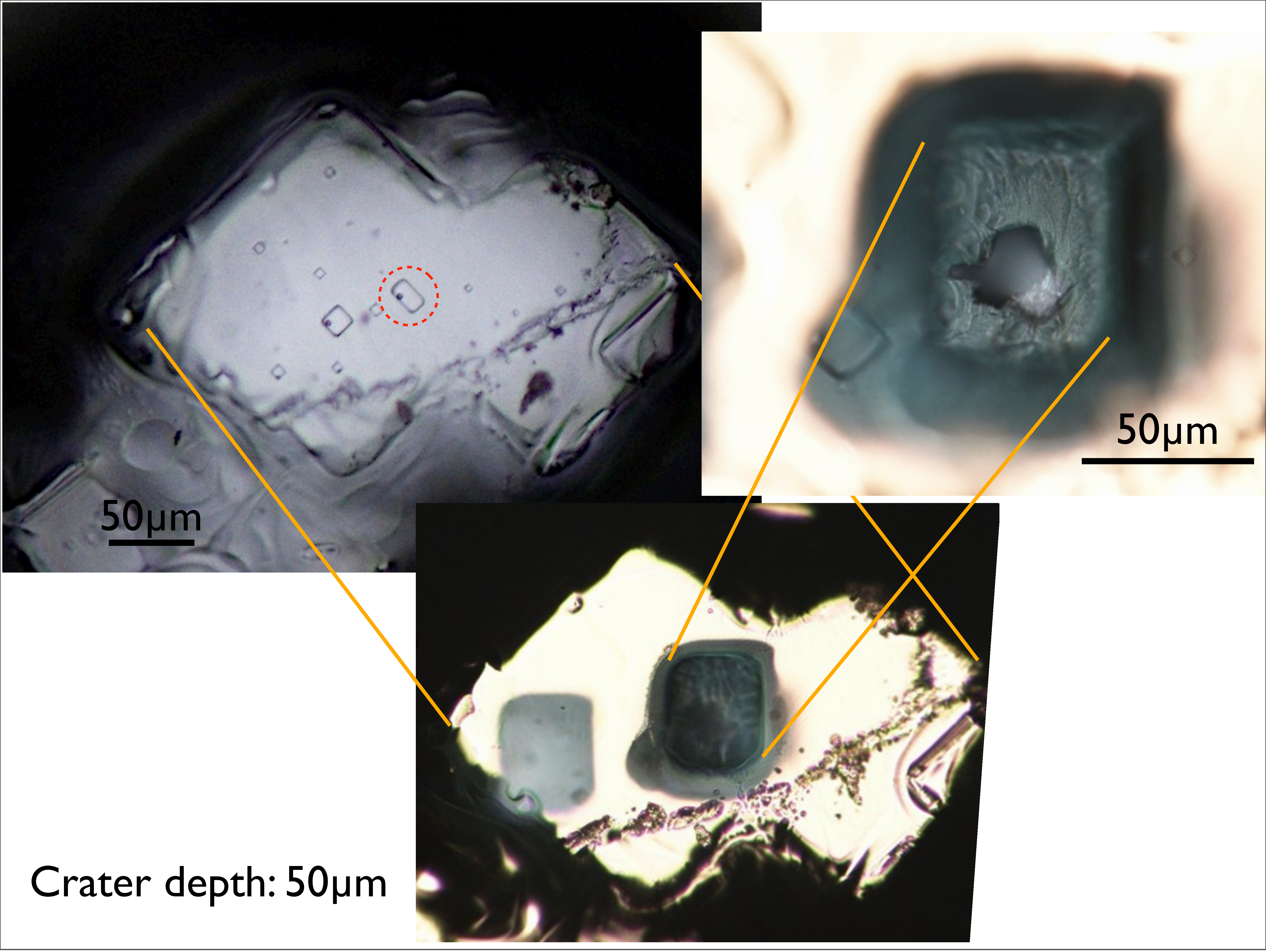




Sputtering Crater and Exposed Fluid Inclusion

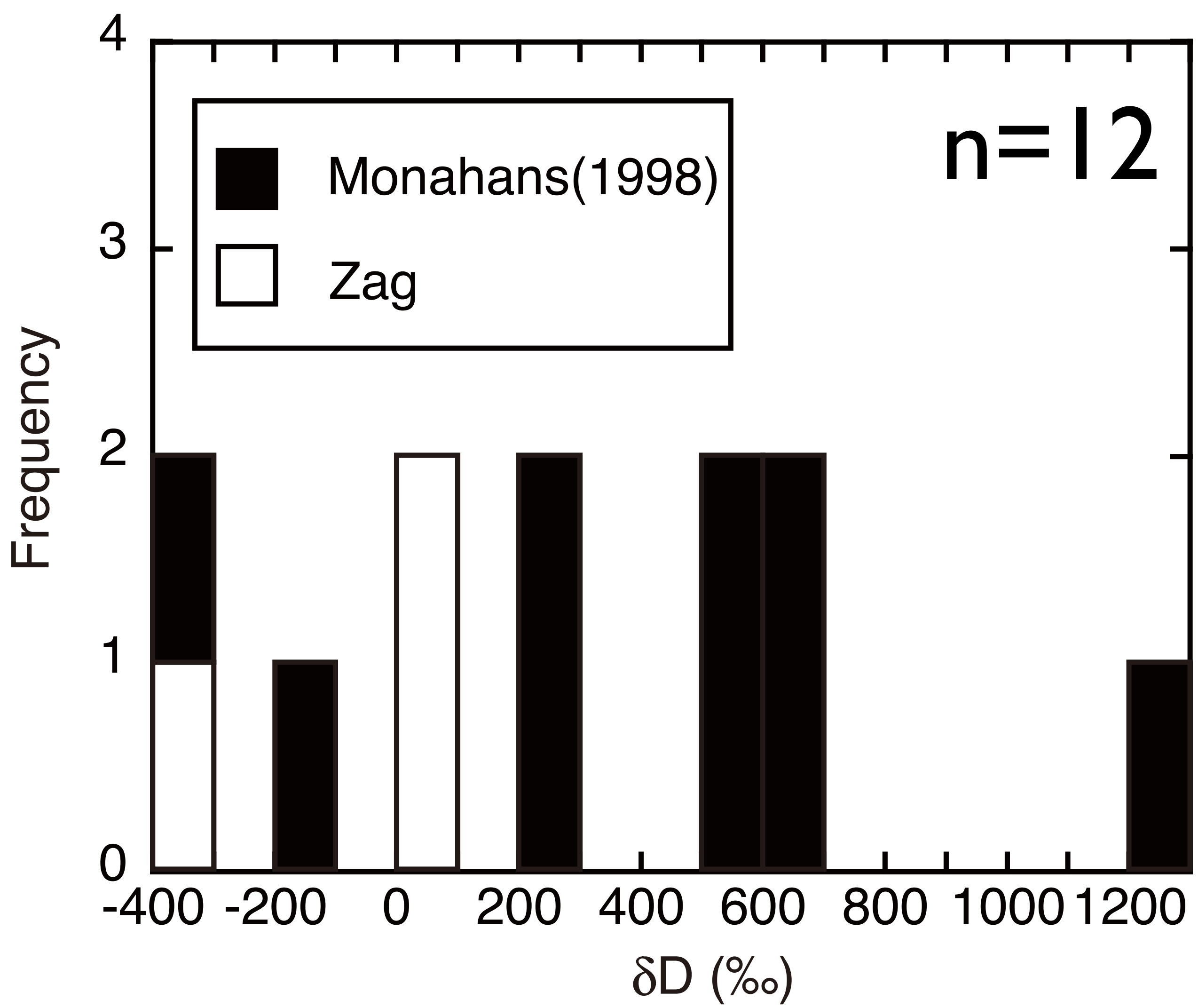


Crater depth: 50μm



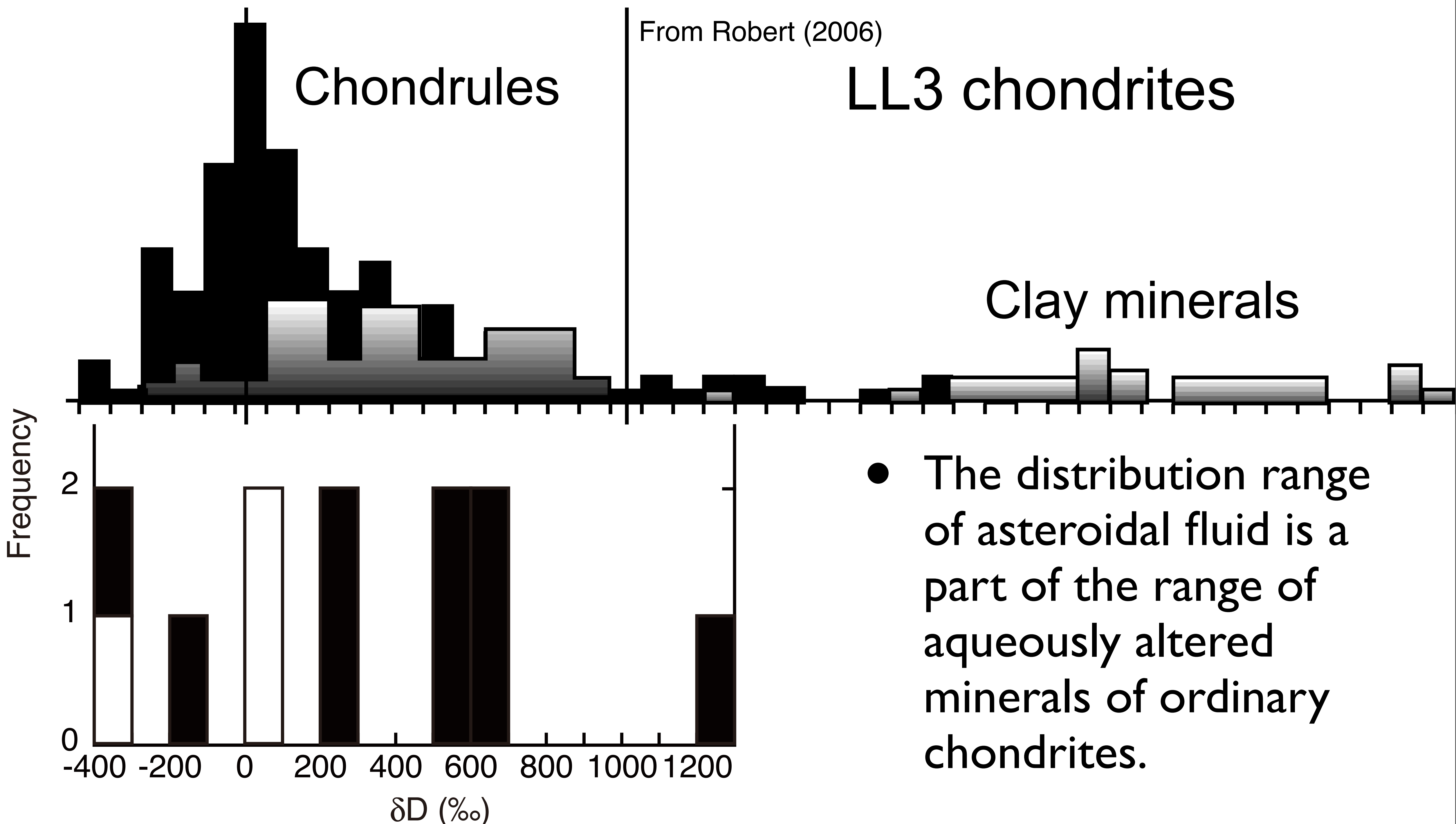
Crater depth: 50μm

δD of OC Asteroidal Fluid



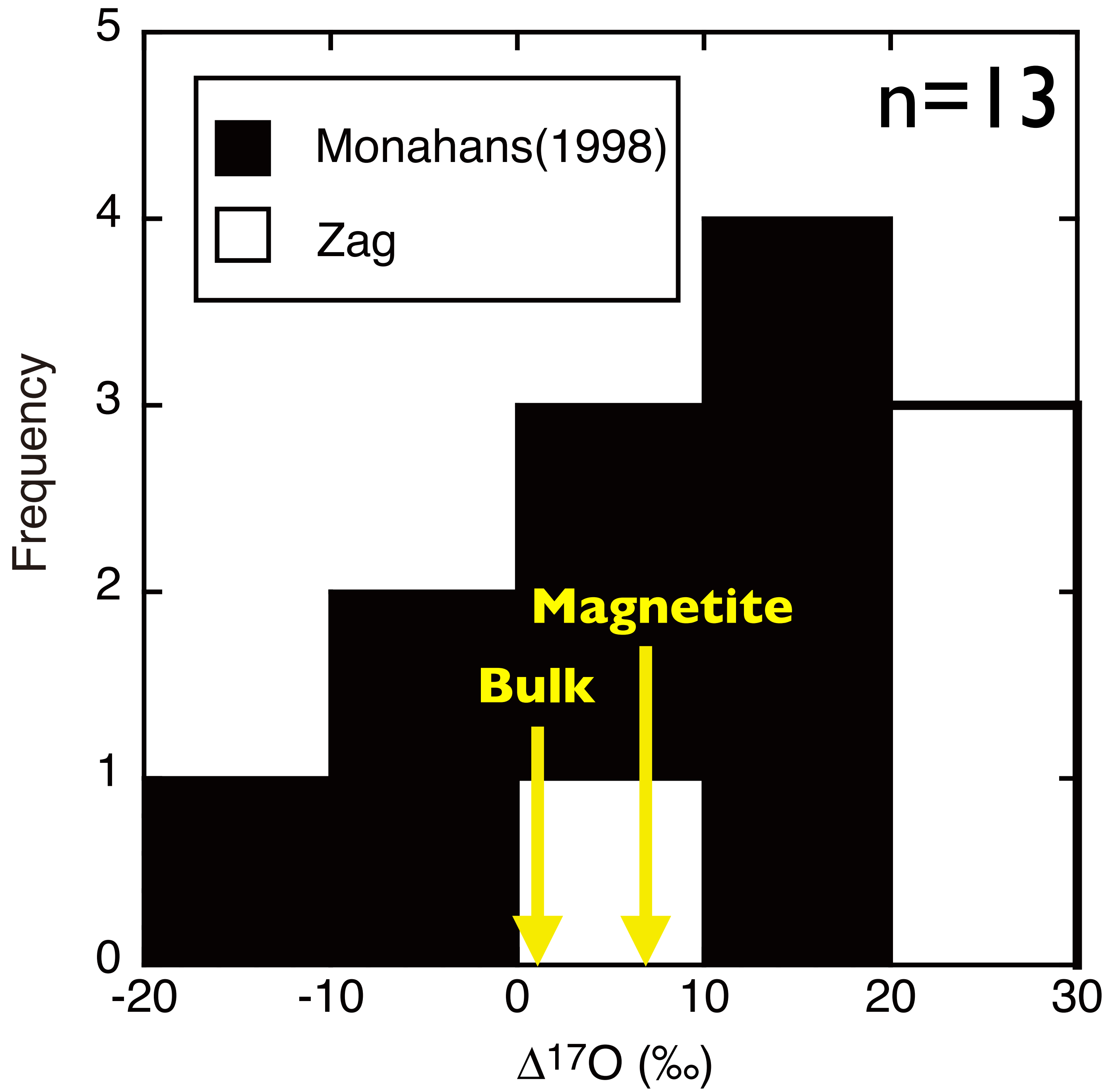
- Hydrogen isotopes of OC asteroidal aqueous fluid have widely distributed over -400 to +1300 ‰.

δD of OC Asteroidal Fluid



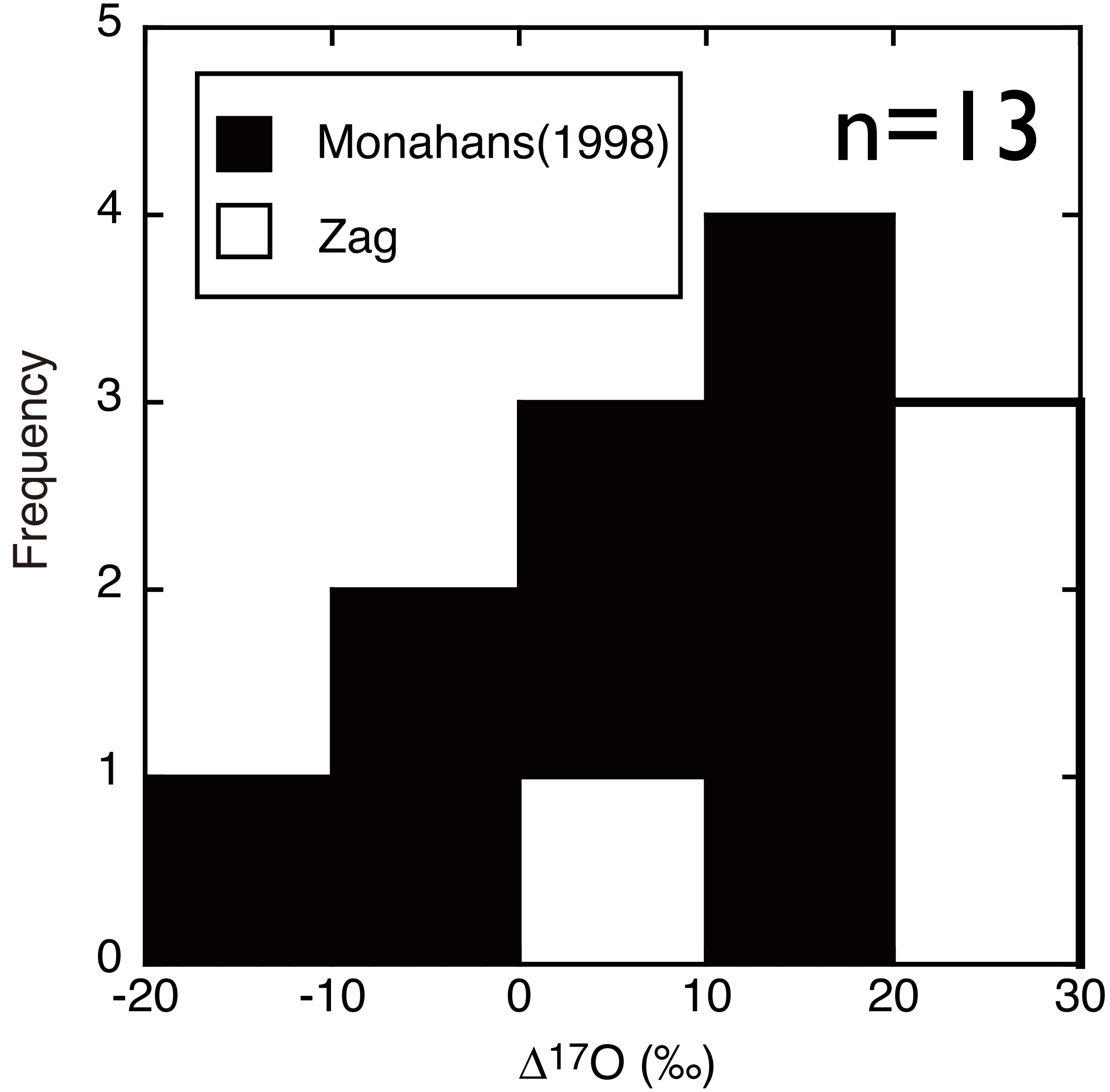
- The distribution range of asteroidal fluid is a part of the range of aqueously altered minerals of ordinary chondrites.

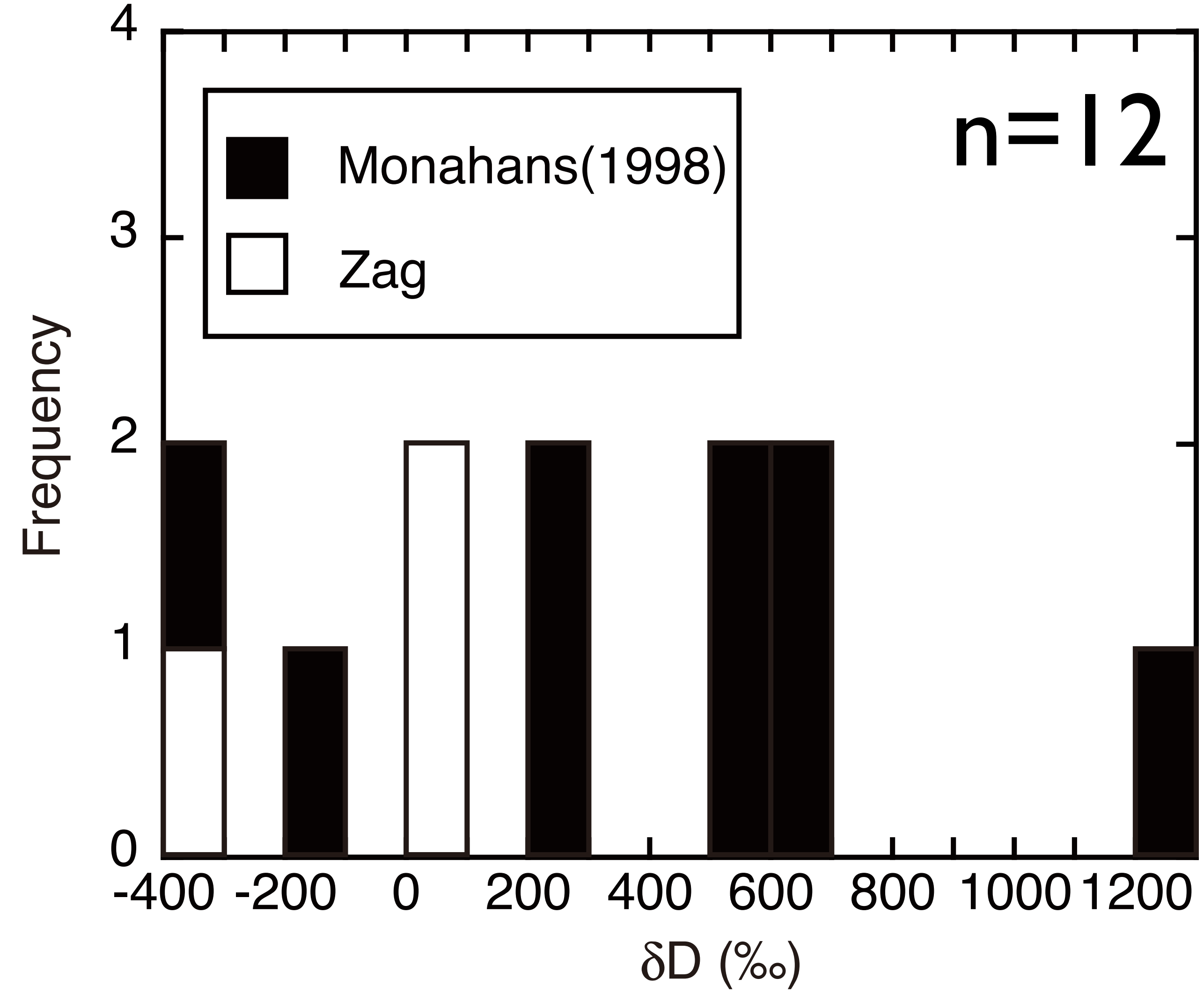
Δ¹⁷O of OC Asteroidal Fluid

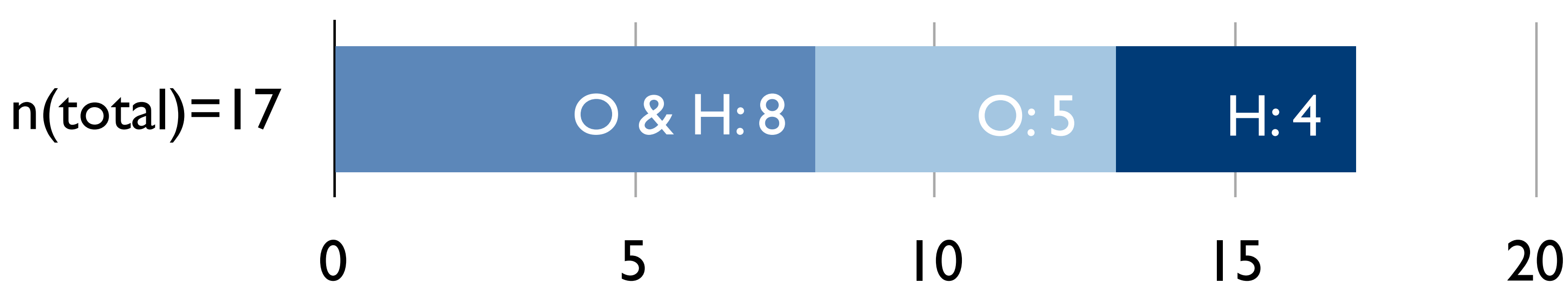


- OC asteroidal fluid is under disequilibrium for oxygen isotopes.
- The distribution shifts to ^{16}O-poor direction.
- The ^{16}O-depletion is larger in asteroidal aqueous fluid than the aqueously altered magnetite.

$\Delta^{17}O$ vs δD of OC Asteroidal Fluid







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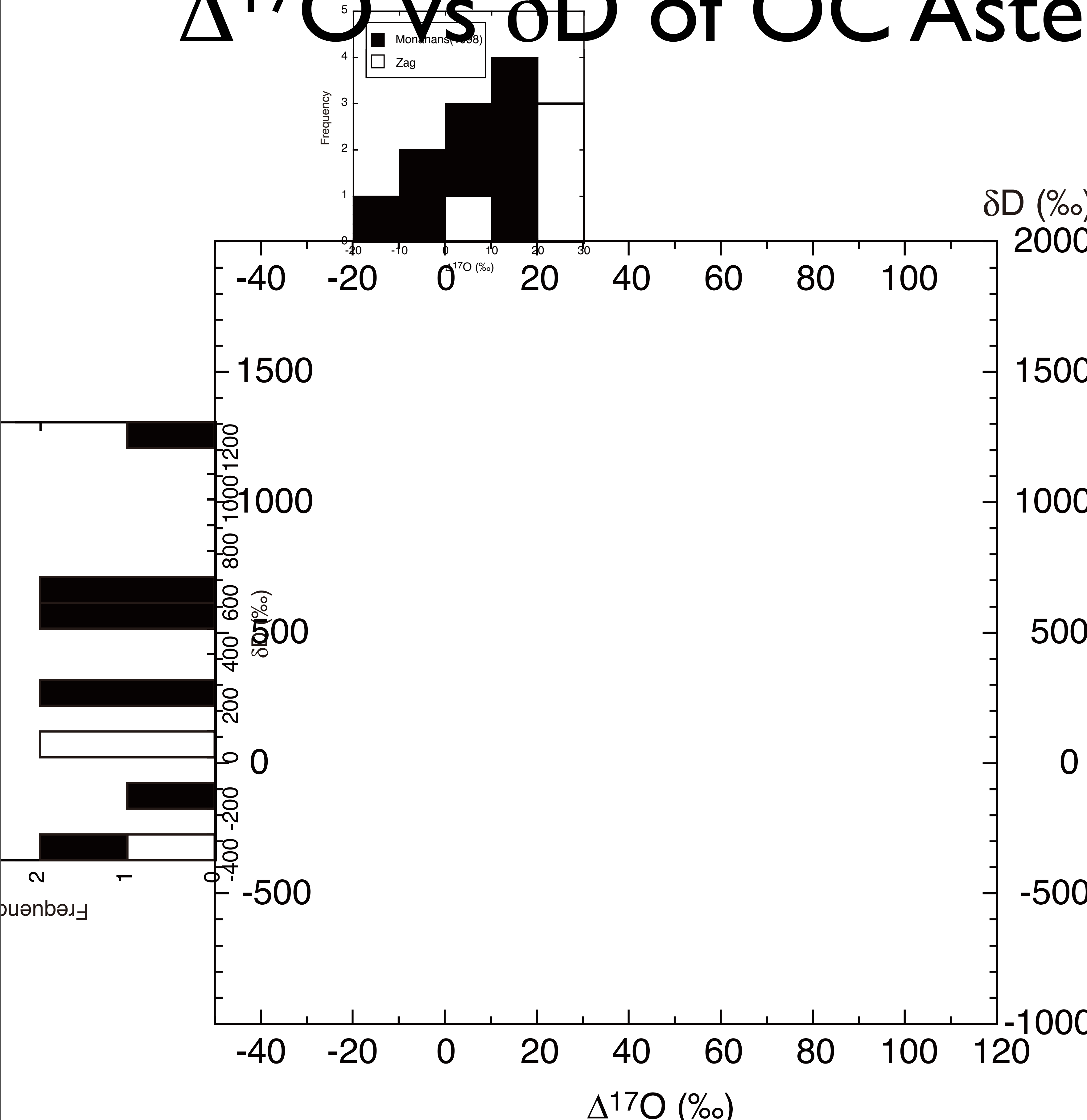

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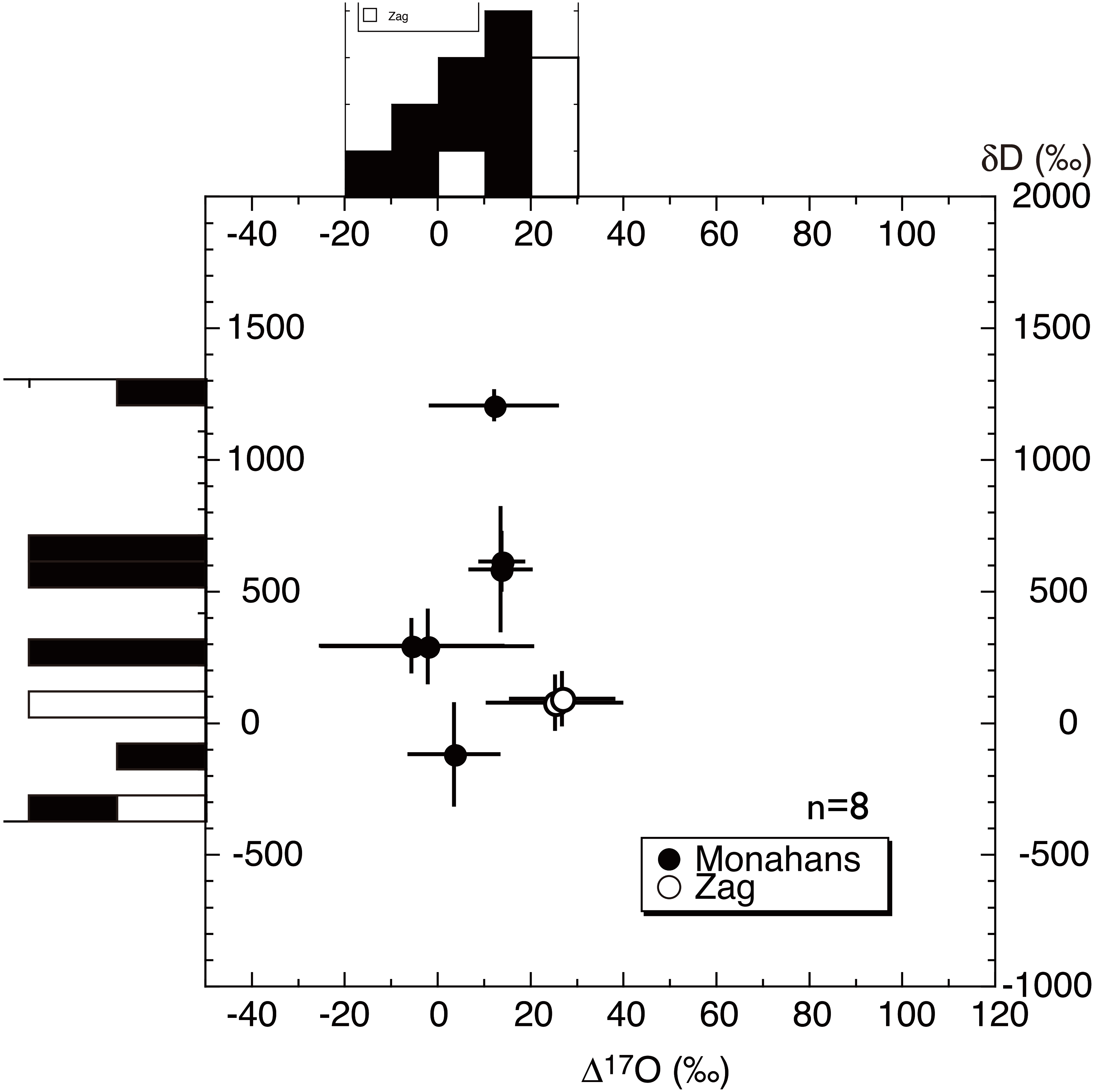
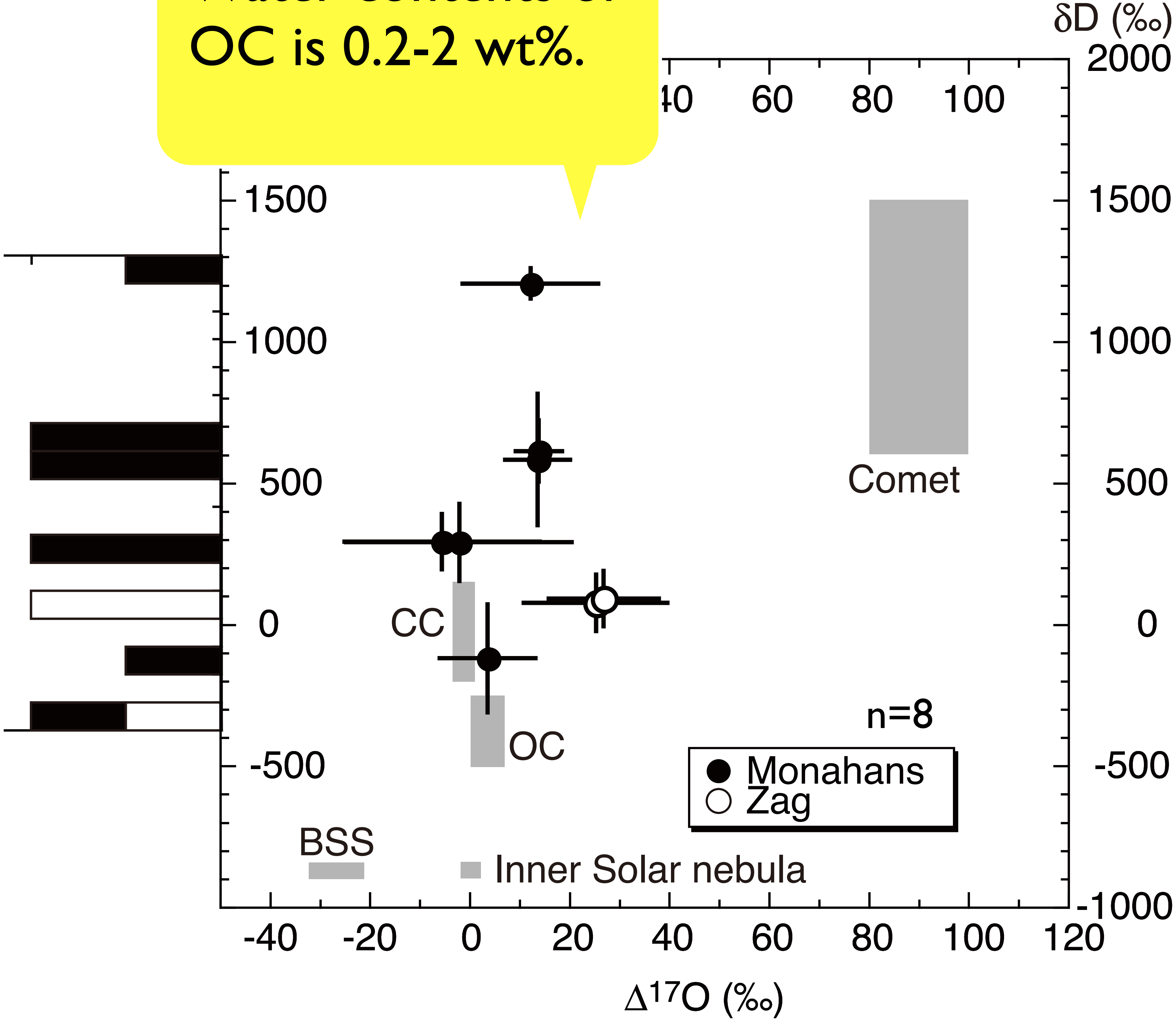


Δ^{17}O vs δD of OC Asteroidal Fluid

Water contents of OC is 0.2-2 wt%.



- The isotopic variations seem to be explained by mixing between primary asteroidal water and cometary water.

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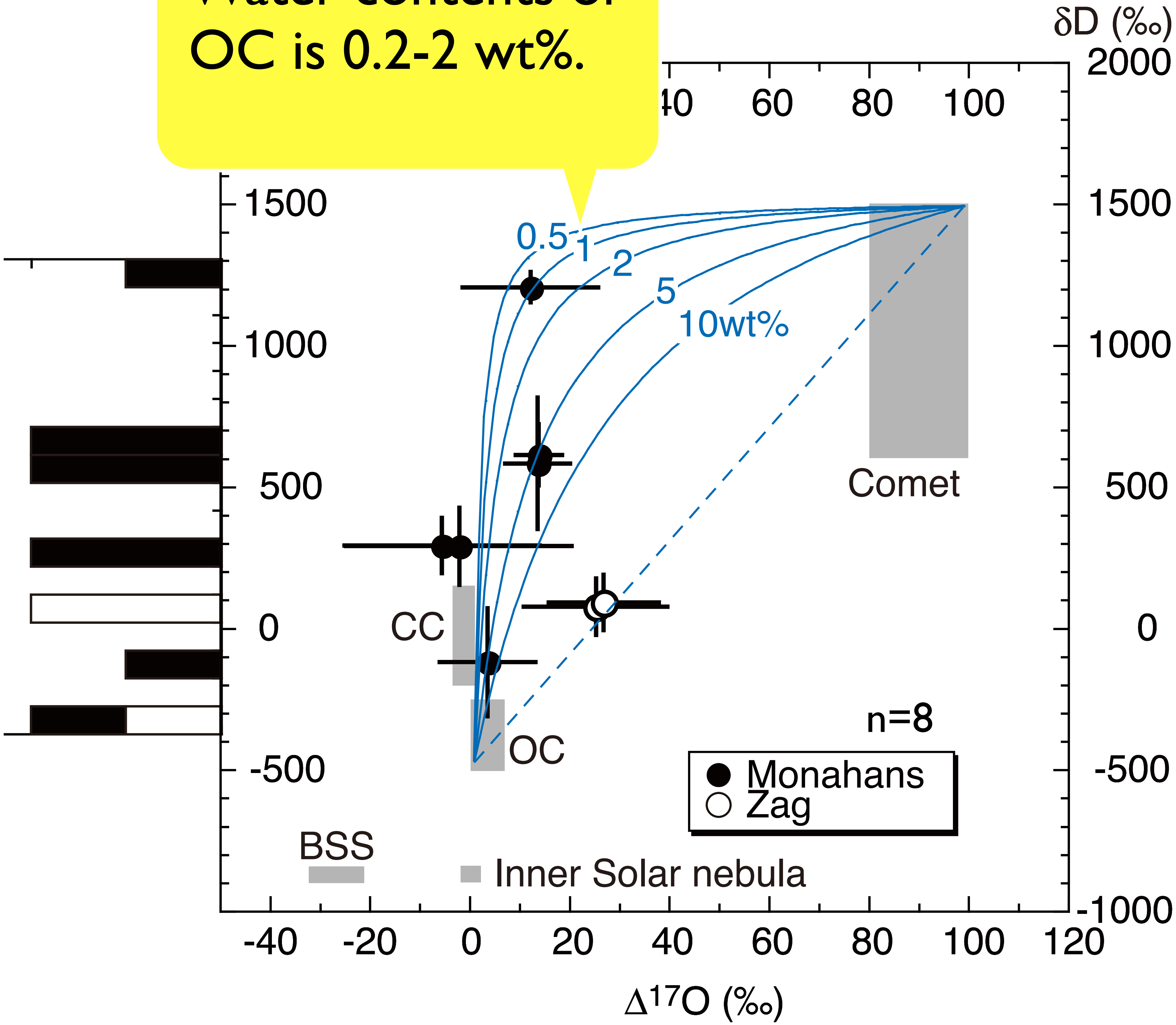

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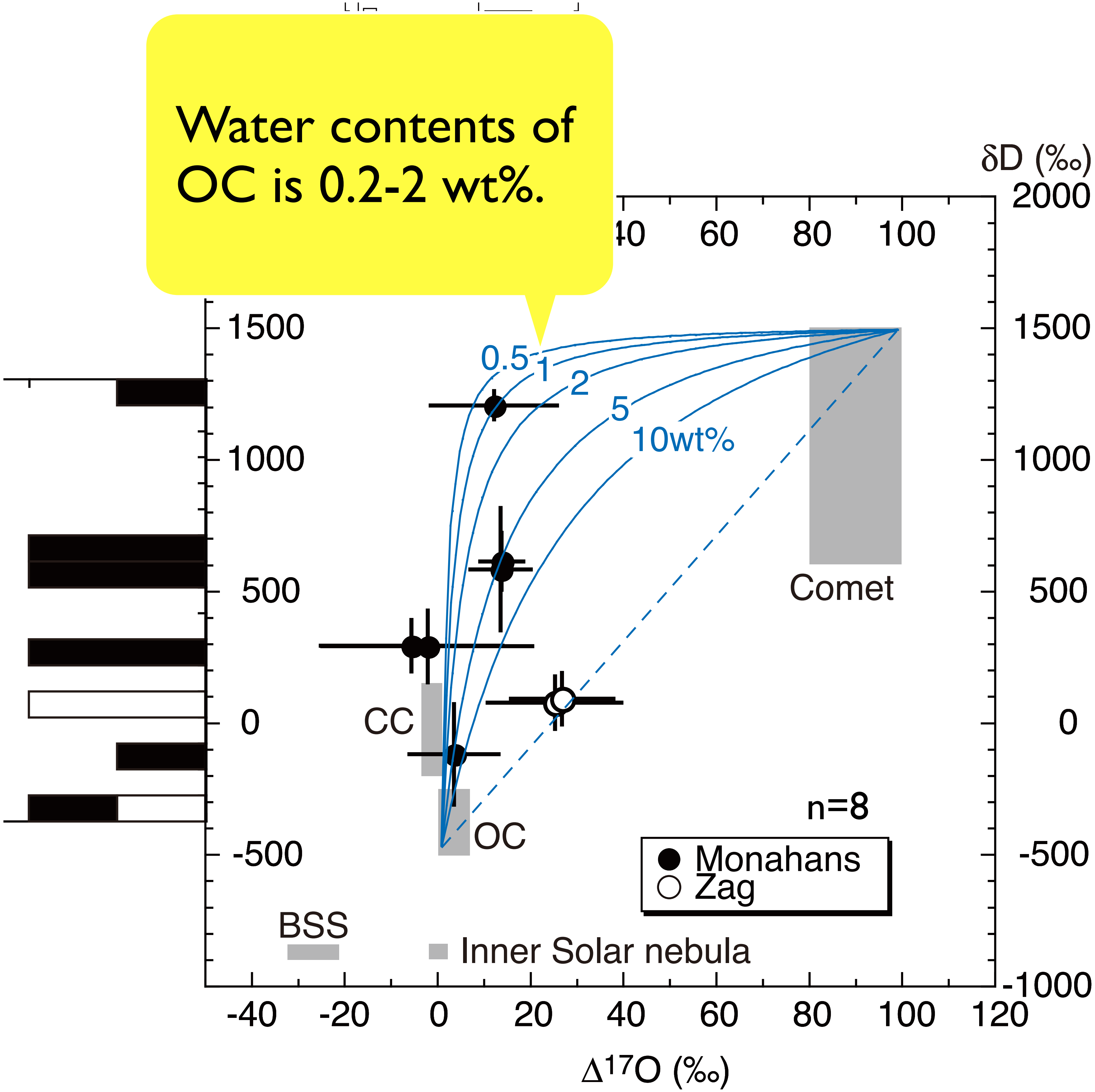

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- Monahans data can be interpreted by a result of water-rock interaction.

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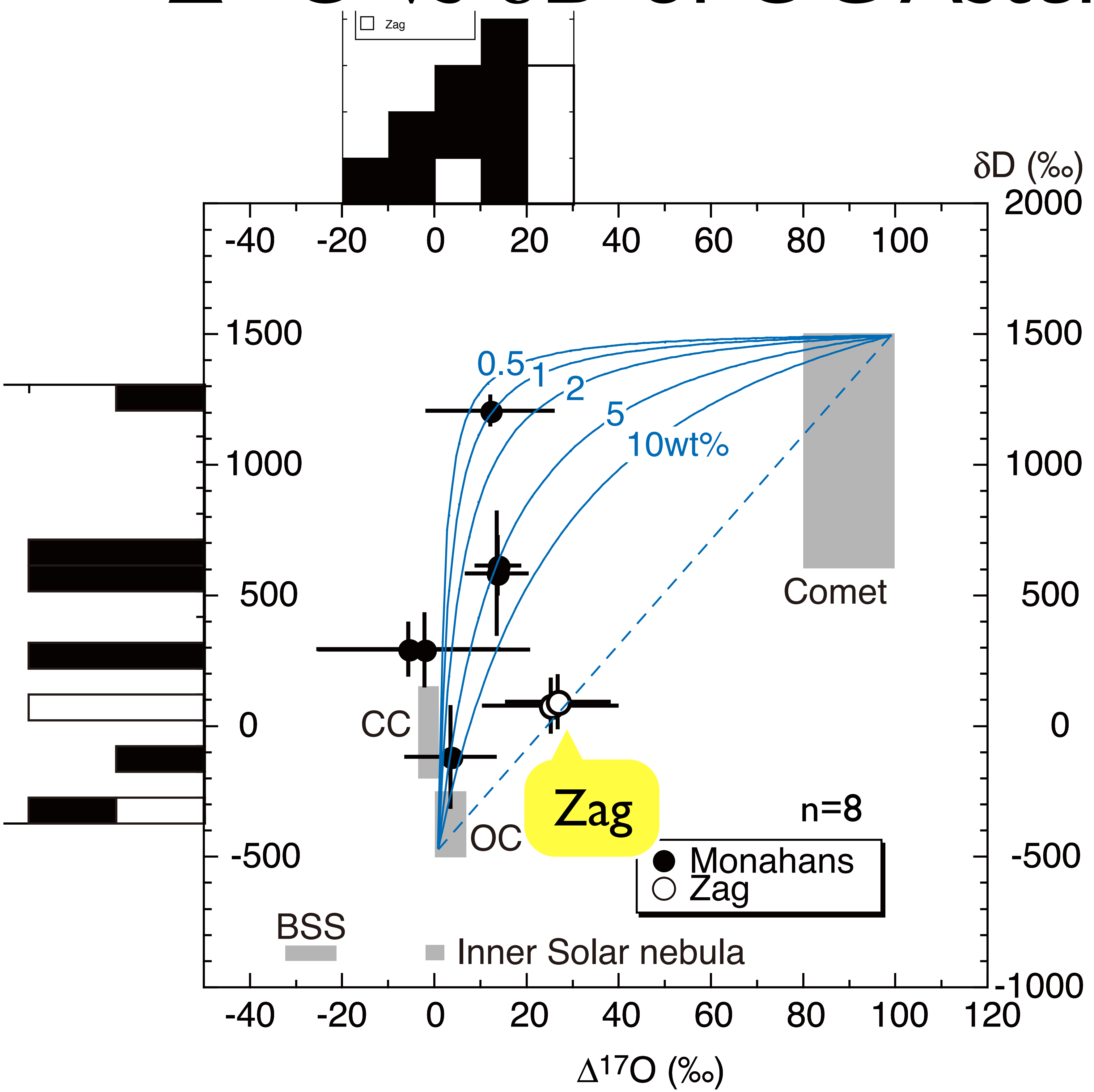
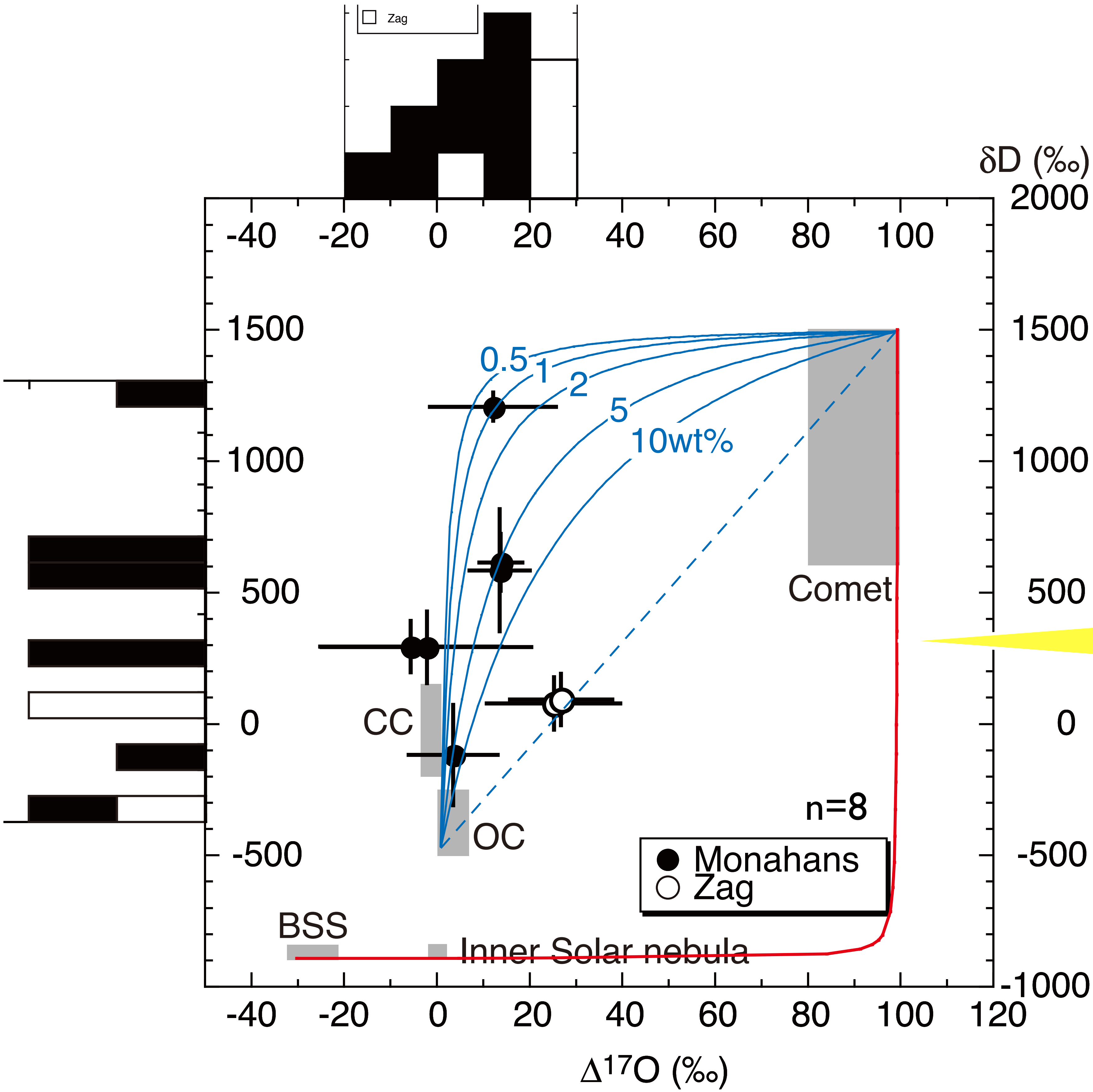


- The isotopic variations seem to be explained by mixing between primary asteroidal water and cometary water.
- Monahans data can be interpreted by a result of water-rock interaction.
- Zag data can be interpreted by a result of direct mixing of water-water.

Δ¹⁷O vs δD of OC Asteroidal Fluid



O isotope self-shielding model suggest that isotopic composition of icy elements of solar nebula is controlled by the degree of mixing between BSS gas and cometary ice (Yurimoto & Kuramoto, 2004).

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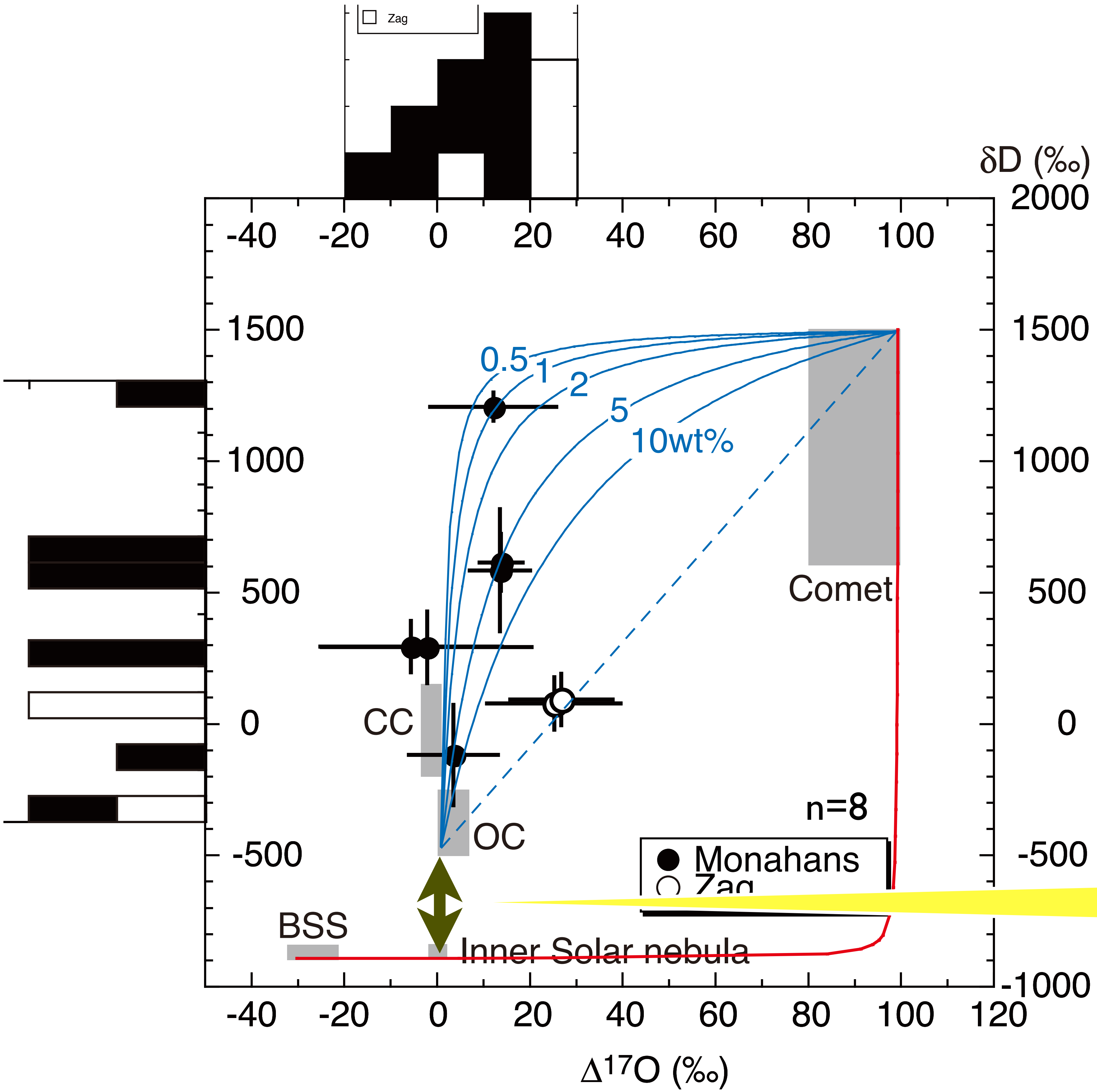
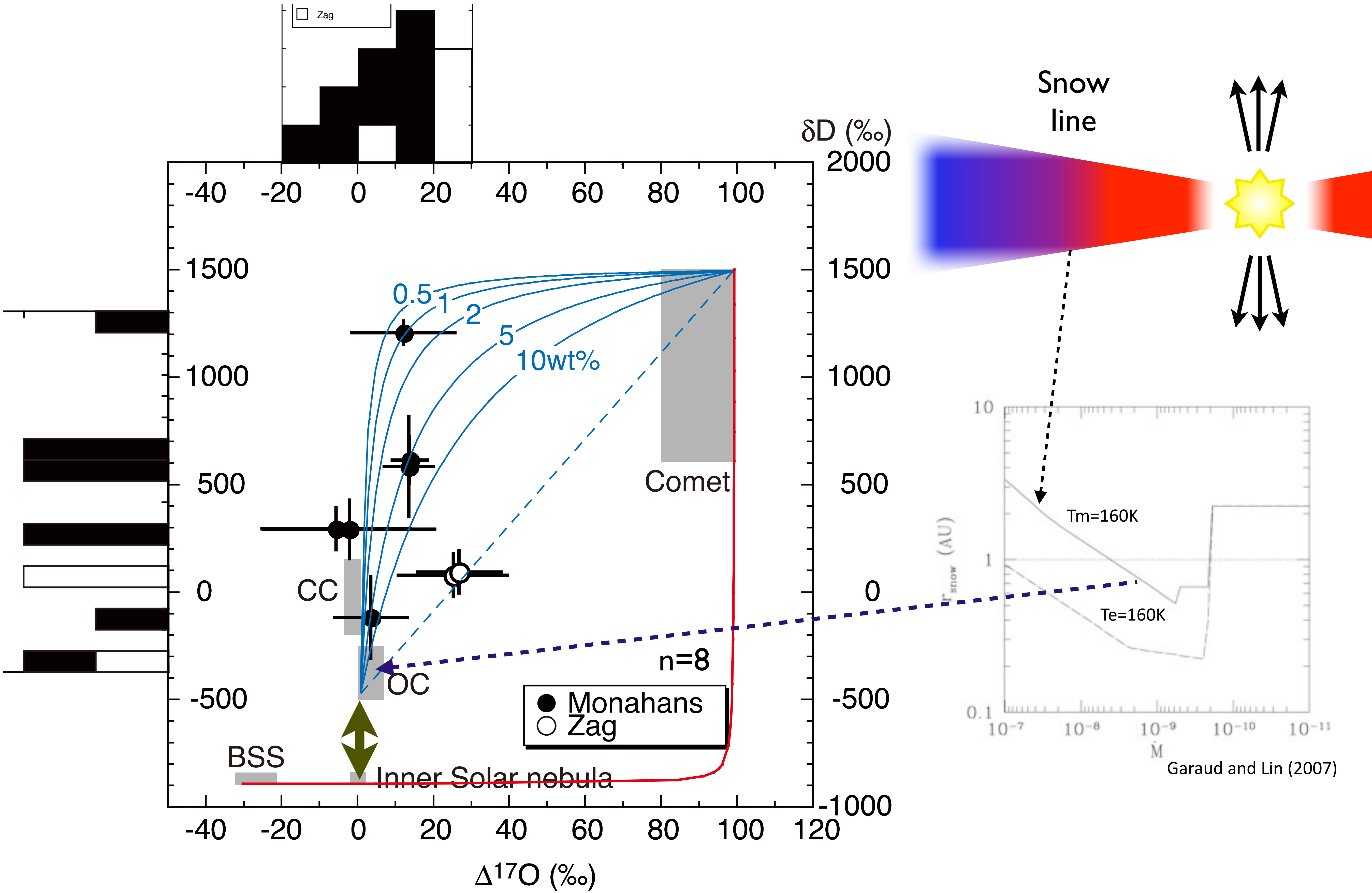


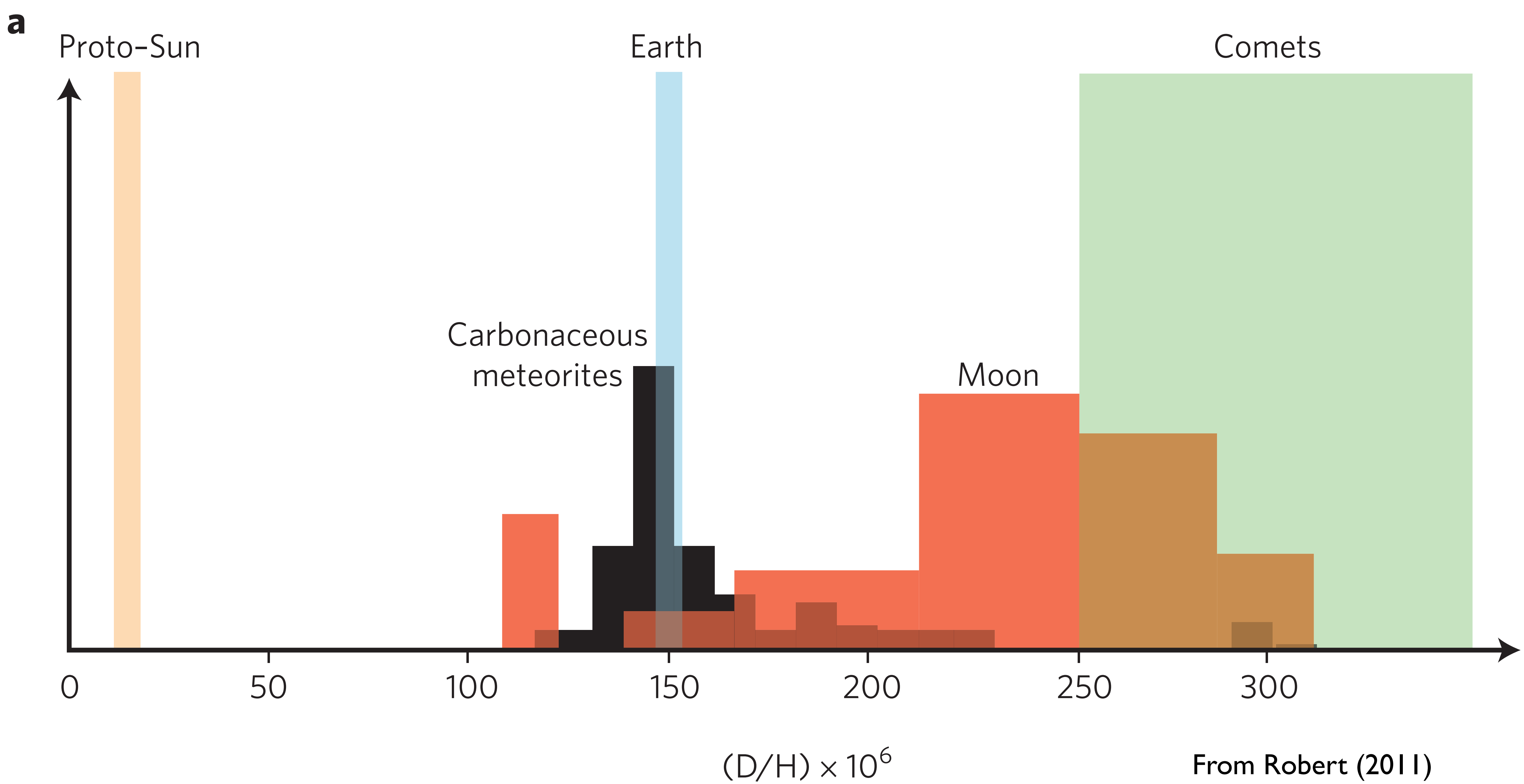
The D/H ratio of primary asteroidal water is different from that of the nebular H_2 gas.

Isotope equilibrium between H_2O vapor and H_2 gas at 250-350K $HD+H_2O=HDO+H_2$ is expected (Deloule et al., 1998).

Δ¹⁷O vs δD of OC Asteroidal Fluid



D/H ratios of lunar water suggest that acquisition of cometary water is important not only for asteroidal water but also for terrestrial planet water (Greenwood et al., 2011).



From Robert (2011)

Conclusions

- Hydrogen and Oxygen isotopic compositions of asteroidal aqueous fluid trapped in halide crystals from ordinary chondrites have been determined by SIMS using cryo-sample-stage.
- The wide variations of H and O isotopic compositions indicate that isotope equilibria were under way in the asteroidal fluid before trapping into halite.
- The asteroidal water is D-rich and ^{17}O-^{18}O-rich, suggesting acquisition of cometary water (pristine nebular water) onto the asteroidal primary water.
- The self-shielding model support that the isotopic compositions of asteroidal primary water is formed in the inner solar nebula as water vapor which originally proposed by Deloule et al. (1998).
- The nebular water vapor would be incorporated on planetesimals as ice when the snow line moved inside of 1 AU.
- The acquisition of cometary water during planet formation modified the isotopic compositions of planetary water towards heavier direction.