# Deuterium fractionation of water in the Solar nebula

**Tobias Albertsson, Dmitry Semenov, Thomas Henning** Contact: **albertsson@mpia.de**

**Max-Planck-Institut für Astronomie, Heidelberg, Germany**

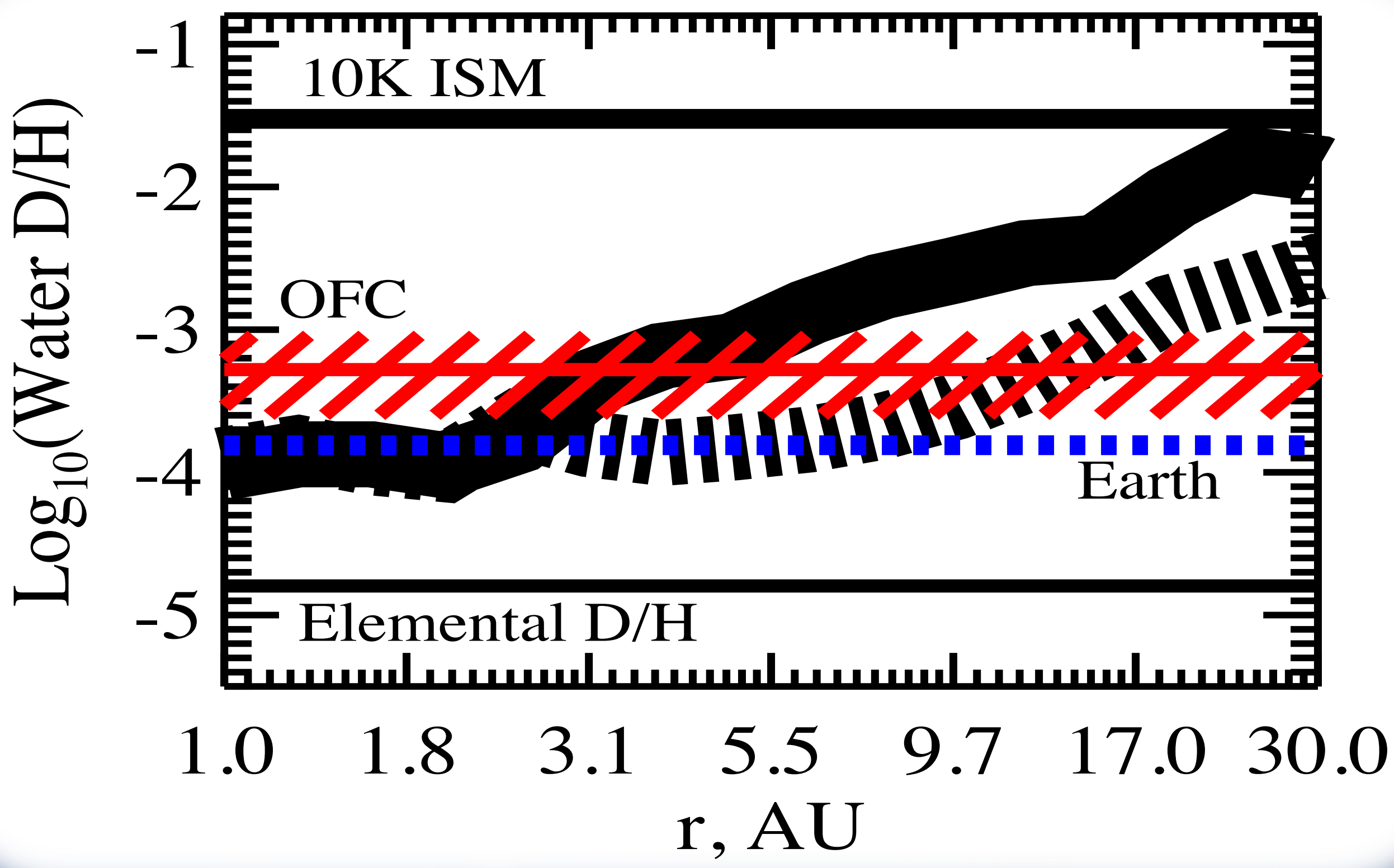
## Summary

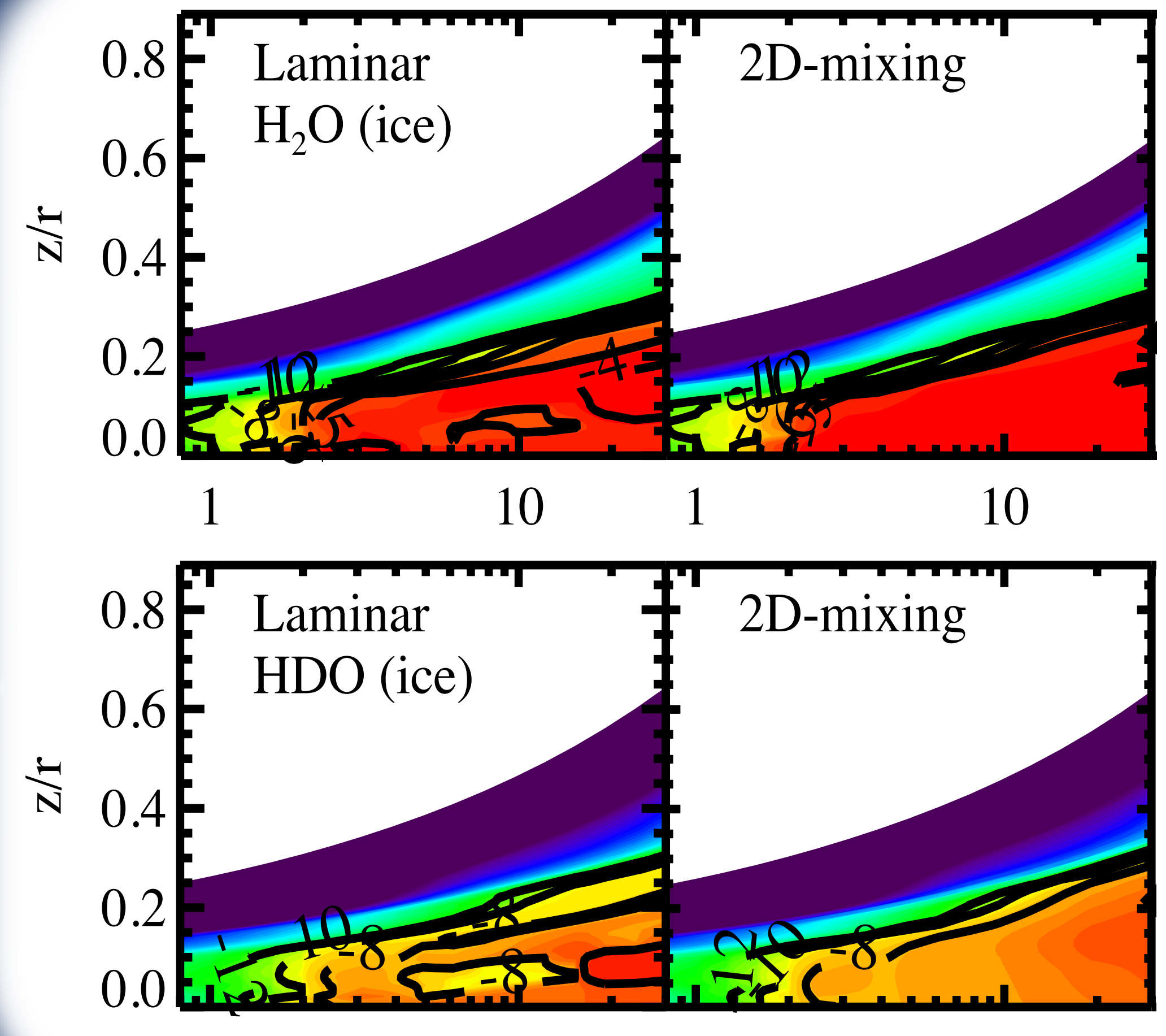
Water evaporates in the inner regions of protoplanetary disks and is frozen onto grains in the outer regions. Therefore its presence in vast quantities on Earth is puzzling. Subsequent delivery through bombardment by primitive bodies formed in the outer icy regions is the favored mechanism. By studying water D/H ratios one hopes to understand whether the water was mainly delivered by comets or asteroids.

Using an extended deuterium chemistry network coupled to a 2D chemo-dynamical disk model, we investigate the evolution of the D/H ratio of water in the young Solar nebula. We find that both the laminar and mixing Solar nebula models show the Earth' ocean water D/H ratio at 2–3 AU. In addition, the 2D-mixing model explains better the water D/H values observed in the Oort- and Jupiter-family comets.

## Model

We used an updated OSU09 chemical network with gas-grain & surface processes and included deuterated reactions (Albertsson et al. 2013, ApJS, accepted). A set of high-temperature reactions from Harada et al (2010, 2012) were added as well as ortho-para states of $H_2$ and $H_3^+$ isotopologues. The flaring disk structure based on a 1+1D steady-state α-viscosity model coupled to the 2D-mixing 'ALCHEMIC' chemical code was utilized (Semenov & Wiebe 2011) for conditions of the early Solar nebula. We run this Solar nebula model with laminar and 2D turbulent mixing chemistry over 1 Myr.





**Upper figure.** The radial distributions of the ice water D/H ratios in the solar nebula between 1-30 AU at 1 Myr are shown, both for the the laminar (solid line) and the 2D-mixing model (dashed line) as well as other measured water D/H ratios in the solar system. The thickness of the lines reflects the uncertainties in the water abundances.

**Left figures.** Distribution of $H_2O$ (top) and HDO (bottom) ice abundances with respect to H between 0.8 and 30 AU. The laminar model is shown on the left panel, the 2D-mixing model is shown in the middle panel. The vertically integrated column densities are compared in the right panel, with the laminar model depicted by solid line and the 2D-mixing model depicted by dashed lines.

## Results

We find that 2D-mixing transport has a significant effect on the abundances of heavy water, and thus the water D/H ratios, at radii >2 AU. Higher HDO abundances and D/H ratios are found in the outer midplane at ~10 AU in the laminar model compared to the 2D-mixing model.

The vertical transport of water towards irradiated warm nebular region layer and the horizontal transport to the hot inner region desorb water to the gas phase. Then, it gets ionized and destroyed by dissociative recombination. As it reforms the high temperatures cause its D/H ratio to get lower, and smoothing out the D/H gradient through the disk

Before Hartogh et al. (2011) cometary water was observed with average D/H ratios of 3 – 6×$10^{-4}$ compared to Earth's ocean water value (1.6×$10^{-4}$). Both the laminar and mixing model can reproduce the Earth ocean' water D/H ratios where carbonaceous asteroids formed (2-3 AU). On the other hand, turbulent transport reduces the water D/H ratios within 10 – 30 AU to the values found in long-periodic Oort-family comets. These comets are believed to have formed close to Jupiter's current orbit and were scattered outwards at later stages of the evolution of the Solar nebula.

Thus our modeling shows that one can explain the origin of water on Earth with both asteroids or comets delivery hypotheses. With regard to the water isotopic composition and the origin of the Jupiter-family and Oort-family comets, the mixing model seems to be favored over the laminar model.

## References

Albertsson et al. 2013, ApJS, accepted
Harada et al. 2010, ApJ, 721, 1570
Harada et al. 2012, ApJ, 756, 104
Hartogh et al. 2011, Nature, 478, 218
Semenov & Wiebe 2011, ApJS, 196, 25

Background credit: Russell Croman