Formation of Jupiter's envelope from supersolar gas in the protoplanetary disk

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Abstract:
The formation mechanism of Jupiter is still uncertain. Multiple volatile accretion scenarios can reproduce its metallicity. We use a viscous disk accretion model to compute the composition of the protosolar nebula (PSN), and compare it with the recent measurement of O abundance in Jupiter's envelope by Juno. We find that the composition of the gas phase of the PSN is compatible with that of Jupiter's envelope, from which it possibly formed.

Model overview

Our protosolar nebula (PSN) model:

- 1D α-viscous disk of H_2-He;
- Midplane temperature budget:
  viscous heating, background radiation;
- Trace species are in the form of **pebbles** (μm to m size) or **vapor**, radial transport due to advection and diffusion;
- With radial motion, trace specie may **sublimate** or **condense**, leading to the formation of **icelines**.

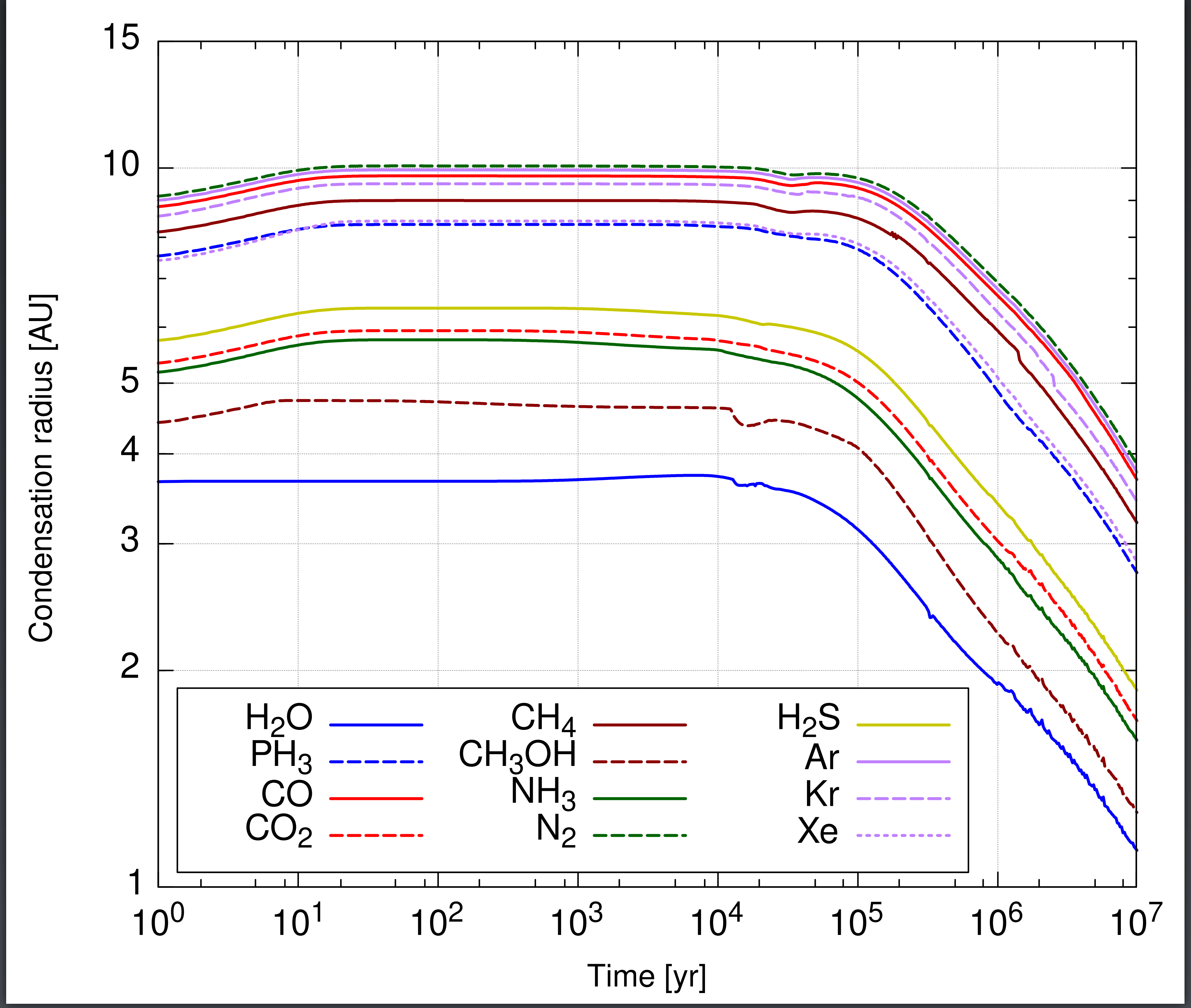


Figure 1: Position of **icelines** as a function of time during the evolution of the PSN.

Enrichment profiles

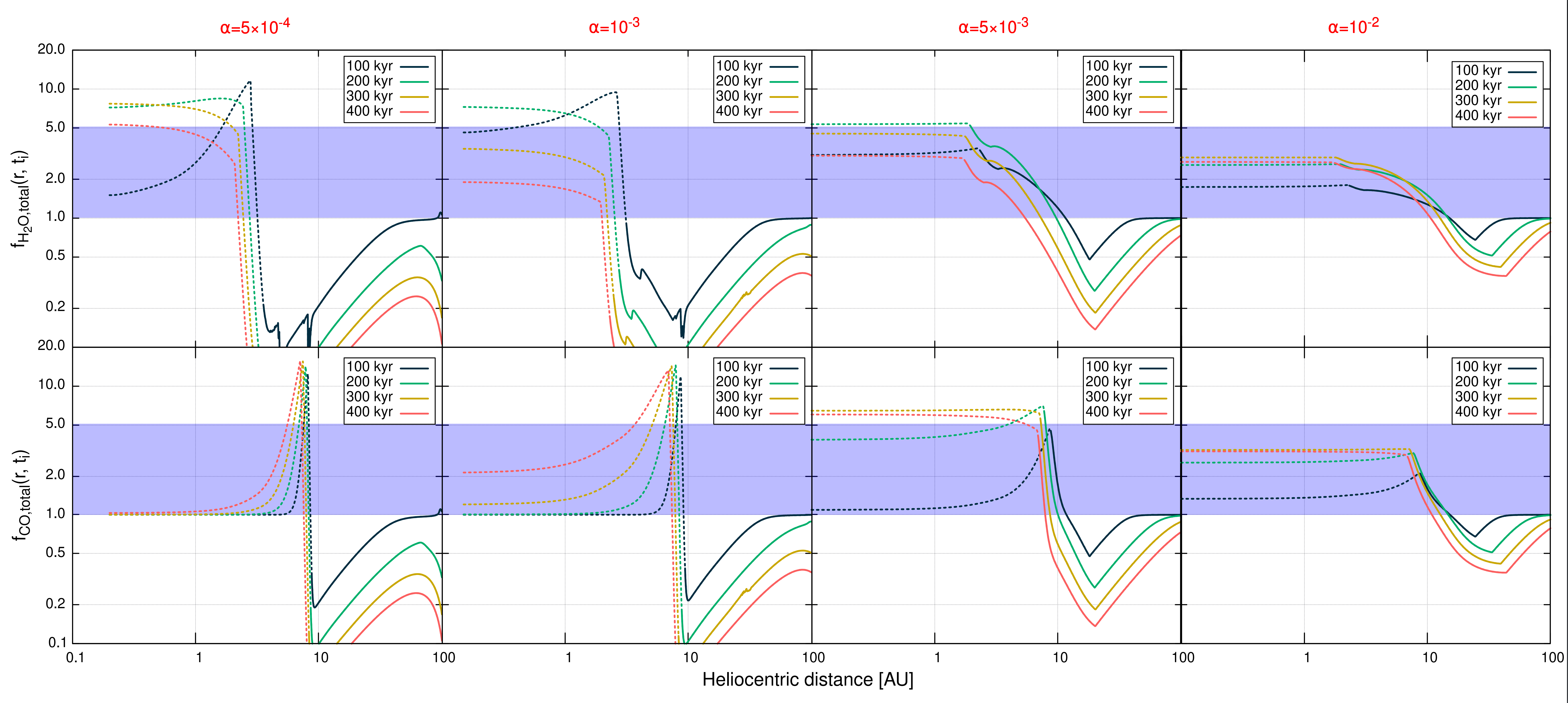


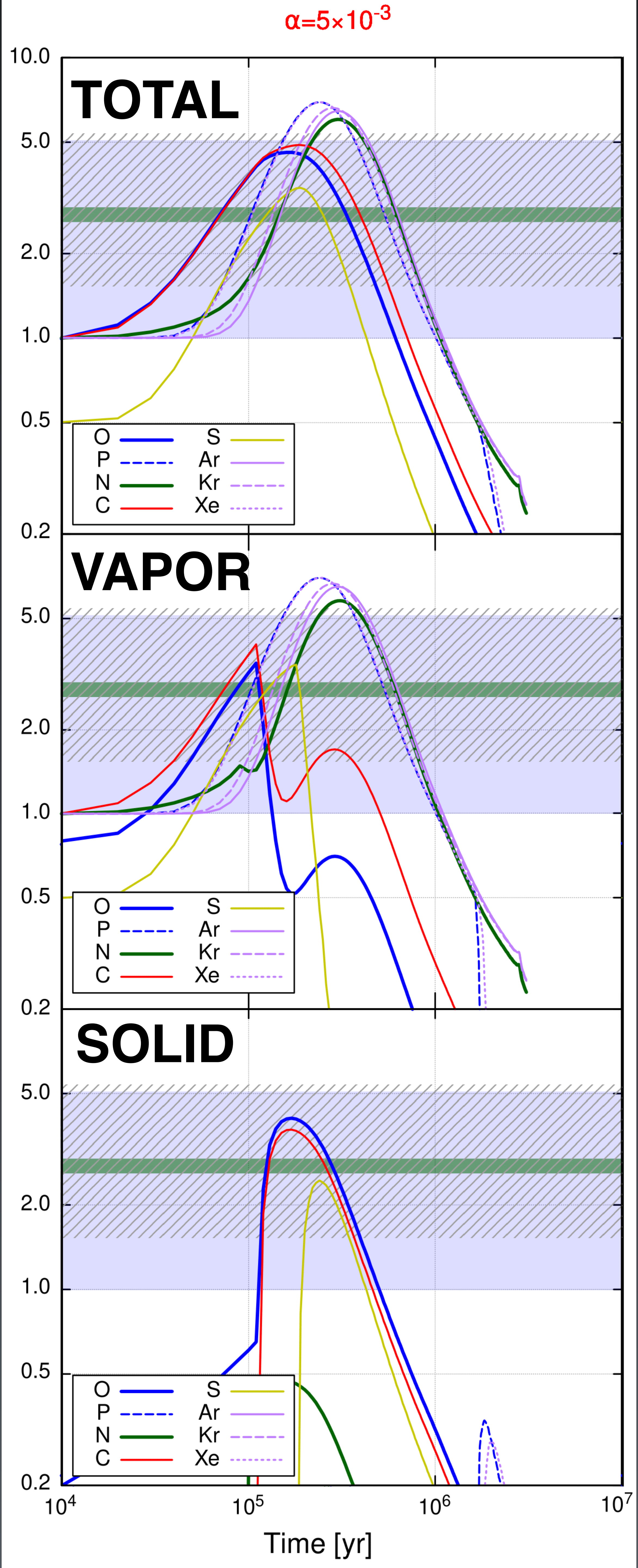
Figure 2: H_2O (top) and CO (bottom) abundance normalized to protosolar.

The **viscosity parameter α** is indicated above.

Solid or dashed lines correspond to **solids or vapors** (resp.).

Blue rectangles correspond to 1-σ abundance of O in Jupiter's envelope (Li et al. 2020).

Pebble inward drift: depletion of the disk in solids, efficient delivery to icelines.
Vapor diffusion: supersolar abundances, uniform enrichments.

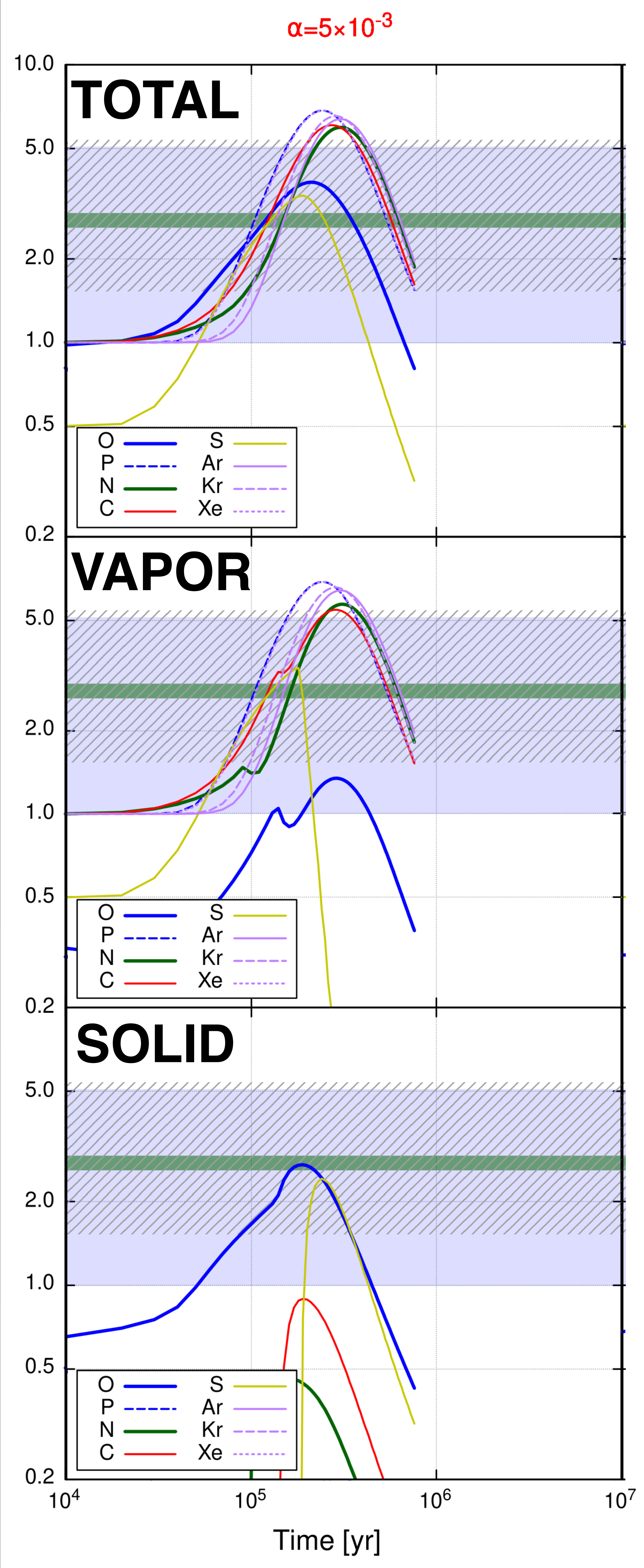


Elemental abundances

Figure 3: PSN to protosolar elemental abundances at 4 AU.
Top to bottom : total, vapor, and solid phases.
Blue, green, shaded regions: O, N, and volatile abundances in Jupiter.

- Elemental abundances at 4 AU: between icelines of H_2O and CO_2
- CO_2/CO = 3 as in 67P/C-G
- CO_2 moves to 4 AU at 100 kyr
- **PSN = Jupiter** at 100–300 kyr, from vapors or vapors+solids, depending on α

First stage: fast delivery of solids to icelines, increase of the enrichment in vapor phase.
Second stage: depletion of the PSN in trace species due to accretion.



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Blue, green, shaded regions: O, N, and volatile abundances in Jupiter.

- Elemental abundances at 4 AU: between icelines of H_2O and CO_2
- CO_2/CO = 0
- **PSN = Jupiter** possible at ~1 Myr with **subsolar O**.

Formation mechanism

If O in Jupiter is **supersolar**

1-σ Juno measurement (Li et al. 2020).

Possible formation scenario:

- **Gravitational instability**
- 3.5 — 5.5 AU
- 100 — 300 kyr
- Accretion of gas enriched in O

If O in Jupiter is **subsolar**

Galileo measurement (Atreya et al. 2003),
or 2-σ Juno measurement (Li et al. 2020).

Possible formation scenario:

- **Core or pebble accretion**
- 3.5 — 10 AU
- ~1 Myr
- Accretion of gas depleted in O

Conclusions

- Volatile content accreted from the vapor phase during formation
- Origin of volatiles constrain the formation location and timescale
- Possibly reconsider: CO_2/CO ratio, dust dynamics
- Similar results for Saturn, but not ice giants

Detailed results and discussion: Aguichine A., Mousis O., Lunine I. J. 2022, PSJ.
Amorphous ice and clathrates: next talk by Schneeberger A.