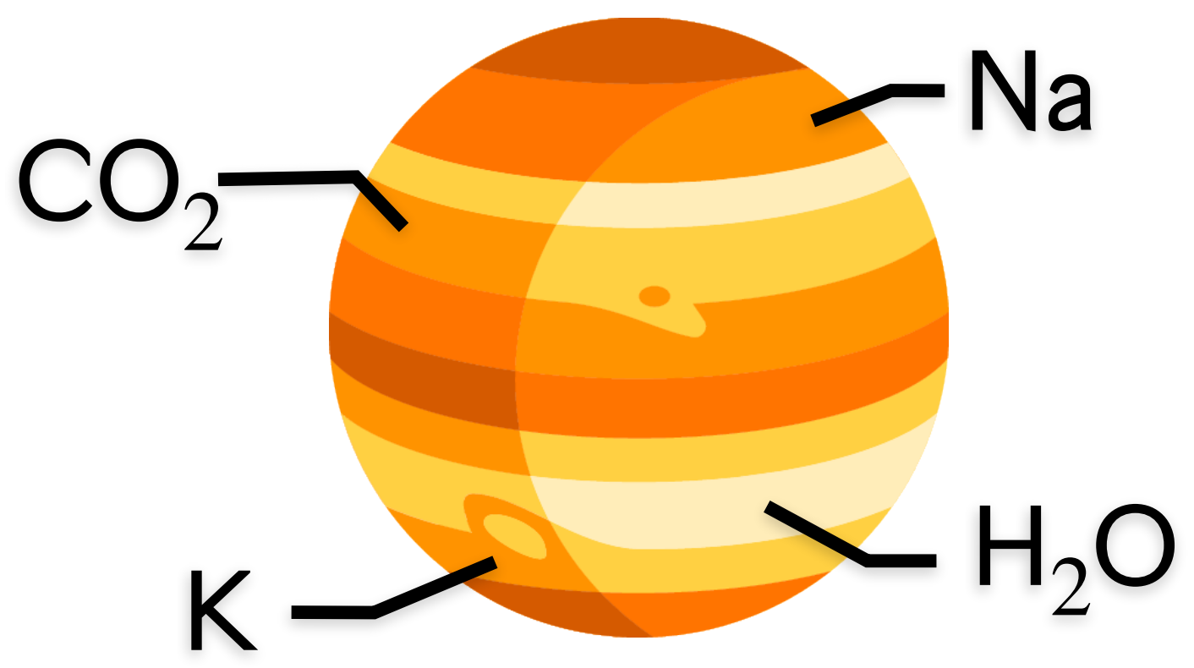
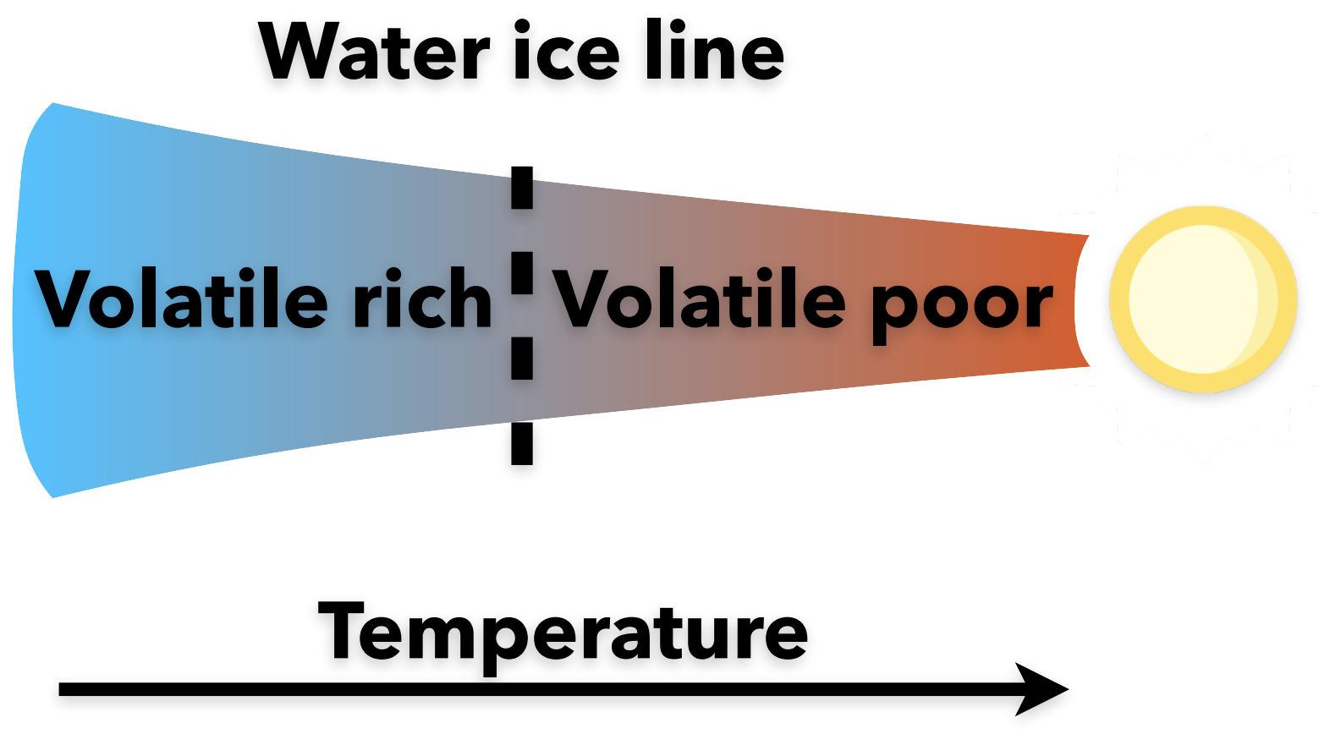
Constraining the origin of giant exoplanets via elemental abundance measurements

Henrik Knierim, Sho Shibata, and Ravit Helled (A&A 665, L5)

Introduction





Question

Where do warm Jupiters originate? Can atmospheric abundance measurements by, e.g., JWST help to constrain their formation history?

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Idea

During their formation, planets accrete material from their surroundings, whose composition depends on their location in the disk! Different formation pathways will leave different imprints on the planet's final composition.

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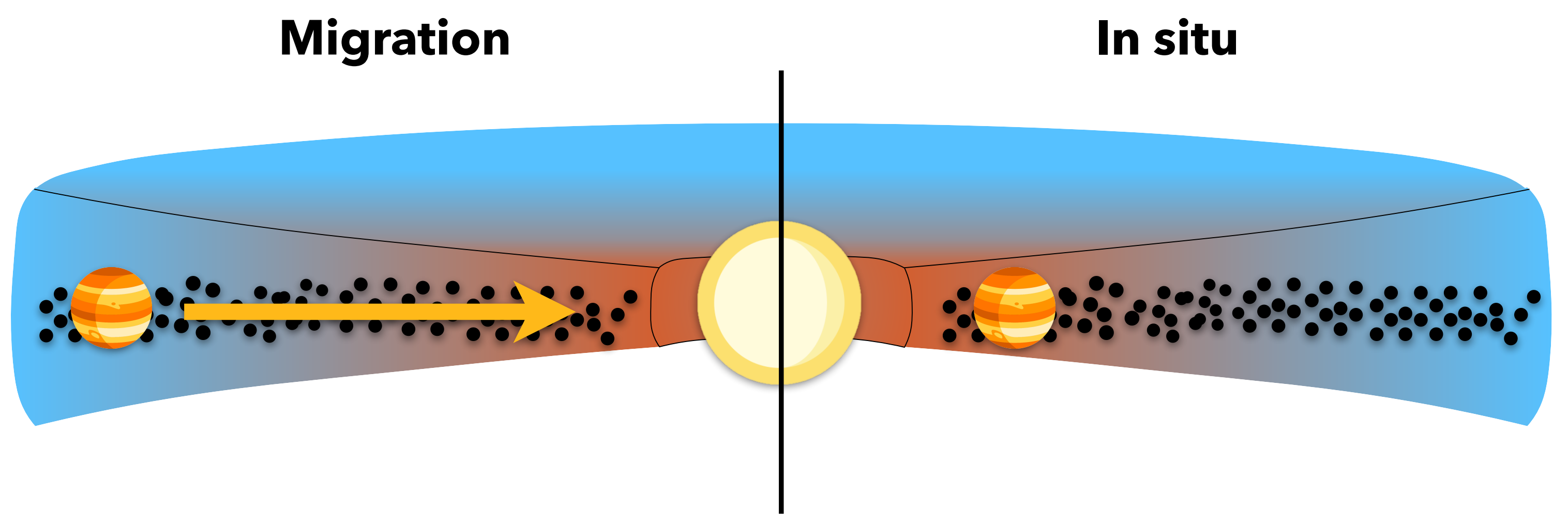
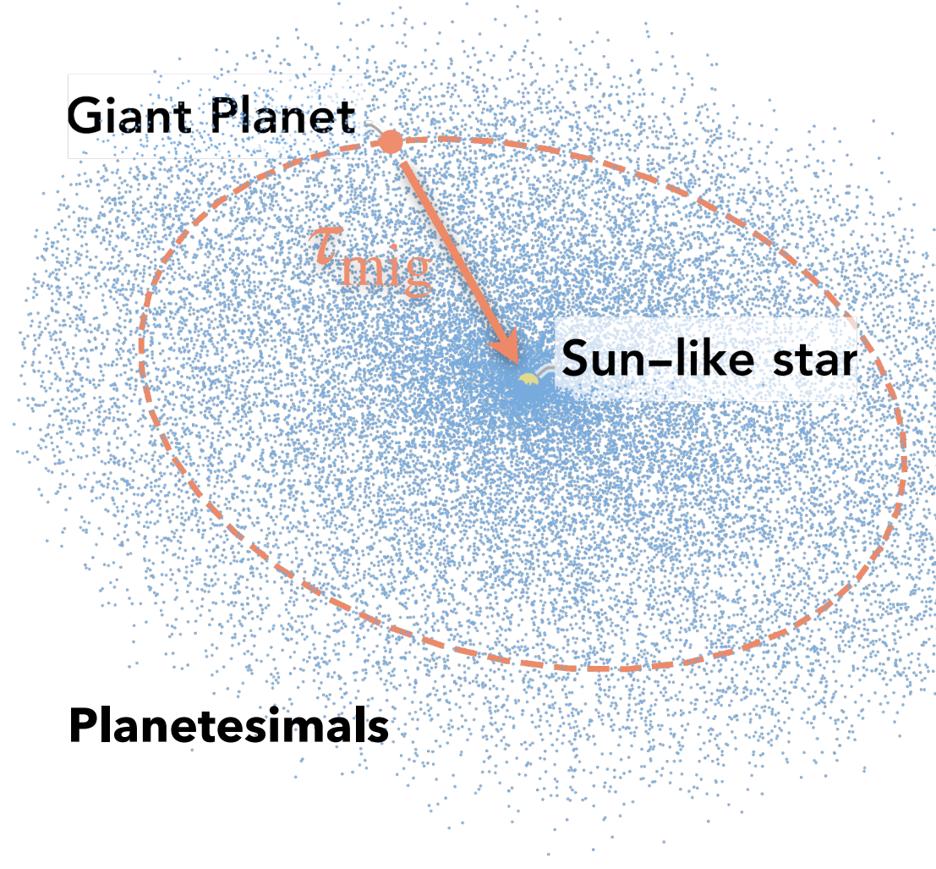
Goal

Predicting observable differences in the composition of warm Jupiters to constrain formation models.

Methods





- A fully formed gas giant is placed in a gas disk where all solids are in the form of planetesimals.
- The gas giants have the same composition as the gas disk at their respective initial location.
- One planet is migrating from the outer disk into the inner disk, the other one is already placed at its finial location.
- The planetesimal's composition changes with distance to the host star. We track their change.
- We perform N-body simulations to compute the accretion of the planetesimals onto the planet.

Results & Discussion

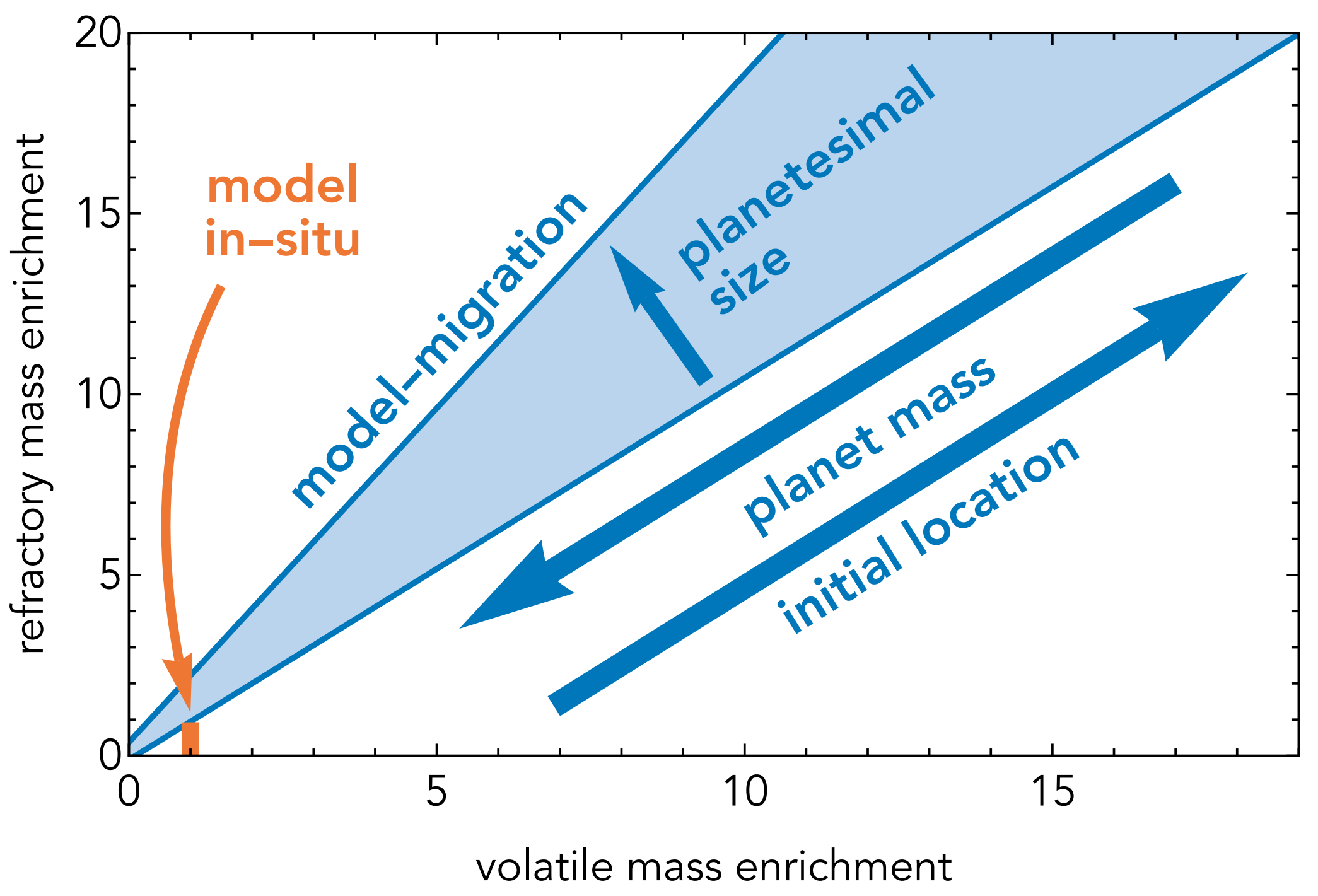


Fig. 1. Refractory mass enrichment vs. volatile mass enrichment for model-in situ and model-migration. The blue region indicates the predicted parameter range and the blue arrows the trend with planetesimal size, planetary mass, and formation location.

Absolute Enrichment

- Migrating planets can enrich their envelope by over an order of magnitude above stellar composition in refractories and volatiles.
- Migrating planets can reach envelope metallicities of up to ten times the stellar composition (ignoring contributions from a heavy-element core).
- Planets growing in situ remain refractory poor.

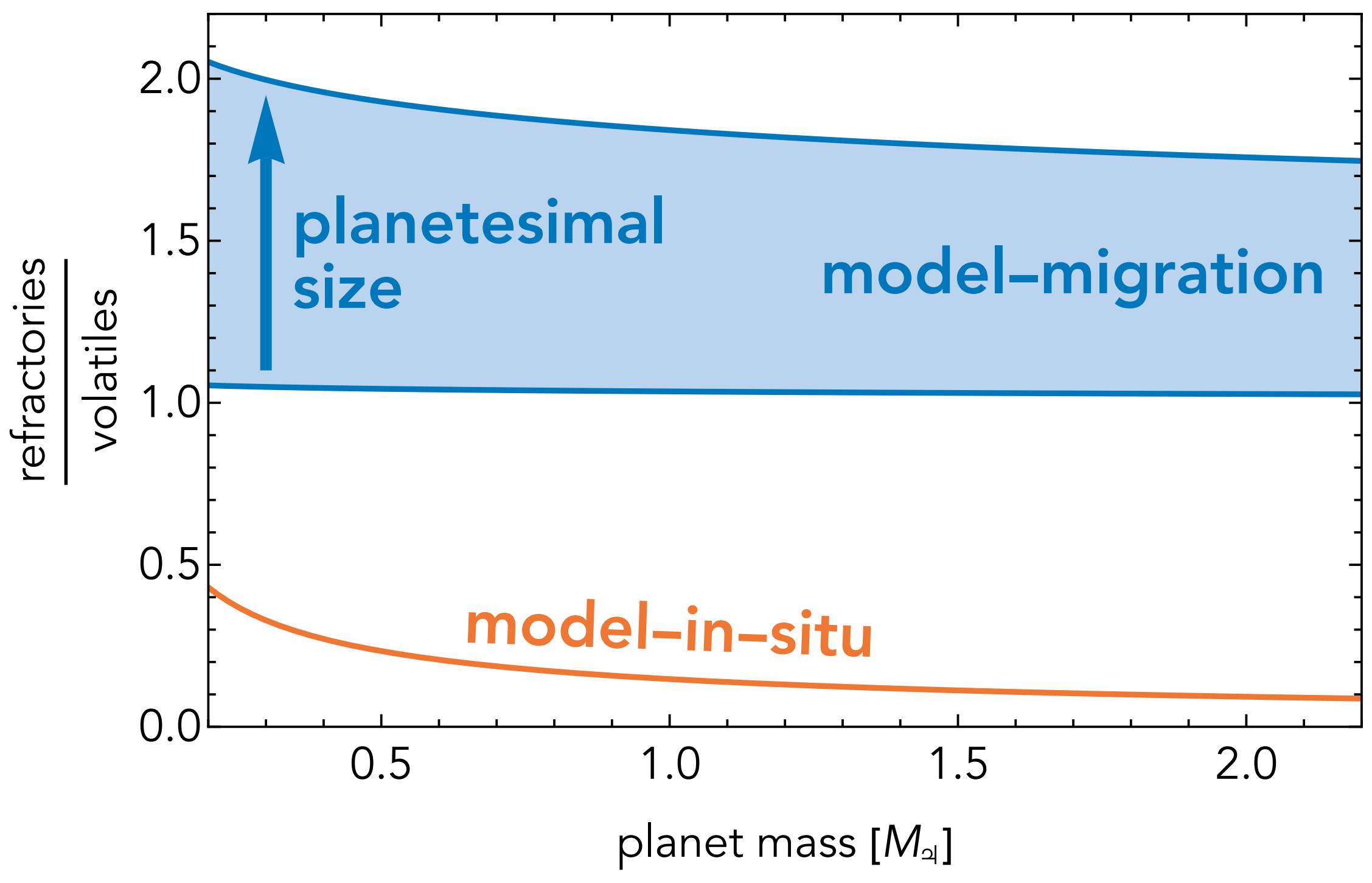


Fig. 2. Normalized refractory-to-volatile ratio vs. planetary mass. Labeling same as in Fig. 1.

Refractory-to-volatile ratio

- The envelope composition of planets forming in-situ is dominated by volatile elements captured during gas accretion. Hence, they are about 2.5 times more enriched in volatiles than refractories.
- Migrating planets are up to two times more enriched in refractories than in volatiles.

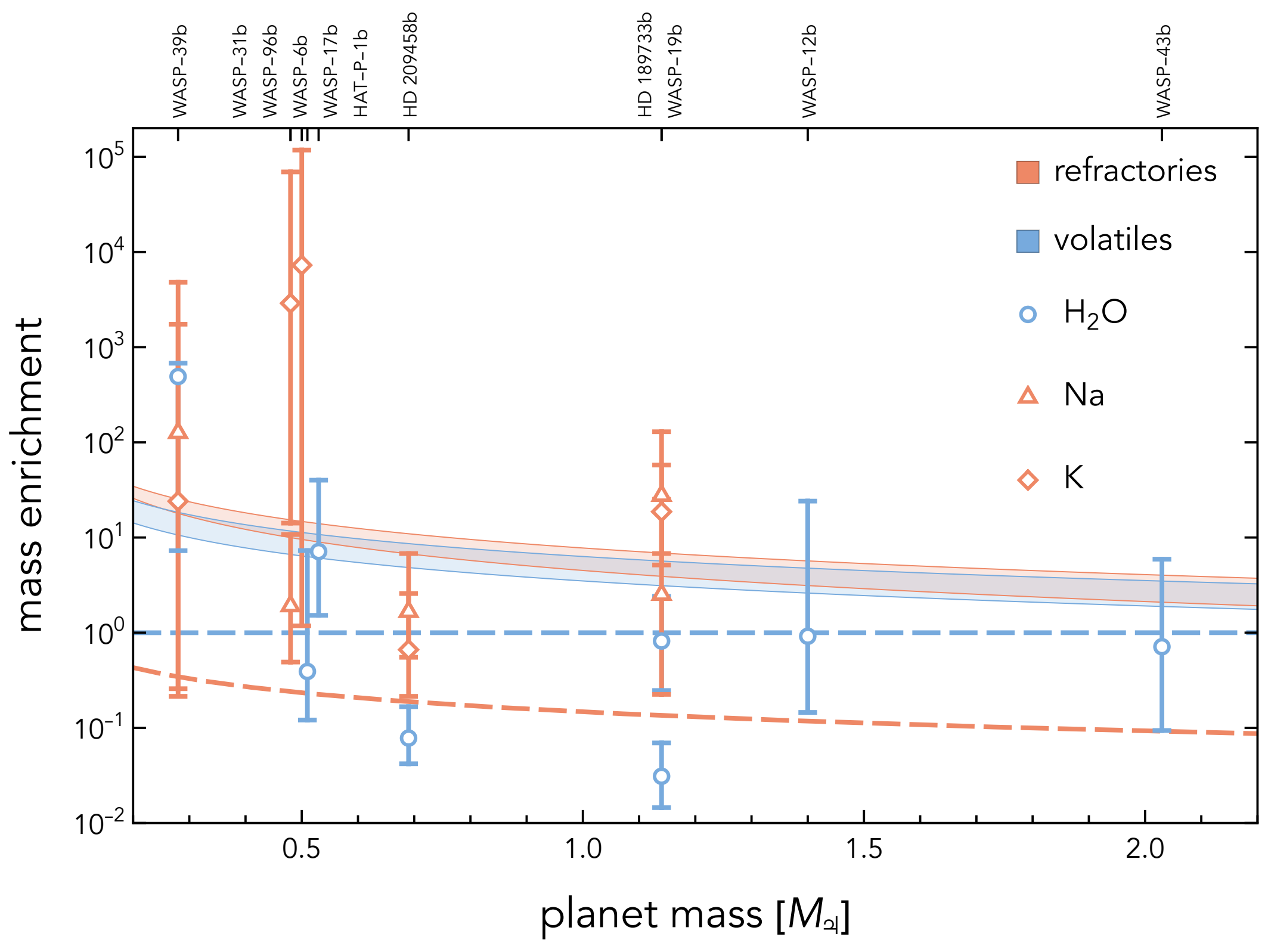
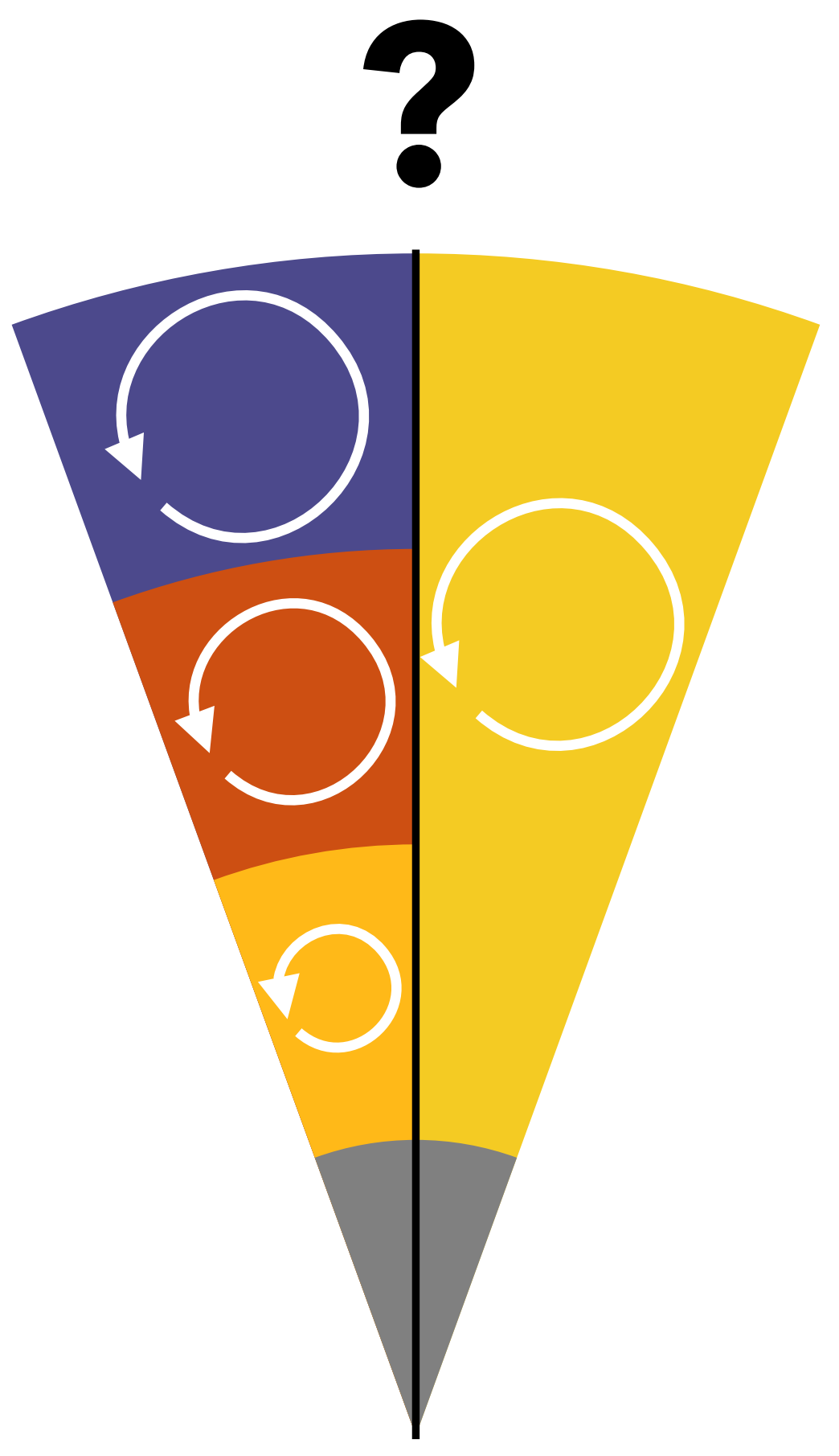


Fig. 3. Refractory enrichment and volatile enrichment for model-migration (colored regions) and model-in situ (dashed lines) compared to retrievals by Welbanks et al. (2019).

Observable?

- The uncertainties of the retrieved atmospheric abundances are still too large to discriminate between the two models.
- Depending on the study, retrieved abundances for a given planet can vary by orders of magnitude.



Simplifications

- No mixing and settling of the accreted material or of a potential core.
- The disk chemistry model is very simplistic, focusing on the water-ice line. More tracer species can refine the trends shown here.
- The planetesimal size was fixed throughout the simulation, which effects the accretion efficiency.
- No gas accretion, pebble accretion, or giant impacts were considered.

Conclusions

Different Refractory-to-volatile ratio

The inferred normalized refractory-to-volatile ratio for model-migration is between 1 and 2, and below 0.4 for model-in situ.

Different Envelope Enrichment

Giant planets that form in the outer disk and migrate inward are predicted to be more enriched, by a factor of ten or more, than giant planets that form in situ.

Different Metallicities

Migrating warm Jupiters have super-solar envelope metallicities, while warm Jupiters that form in situ have subsolar to solar envelope metallicities.

Interested?

henrik.knierim@uzh.ch

@HenrikKnierim

Universität Zürich^UZH

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References

Welbanks, L., Madhusudhan, N., Allard, N. F., et al. 2019, The Astrophysical Journal Letters, 887, L20
Jupiter and star icon from flaticon.com.

Acknowledgements

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