Uranus – Swiss Flagship?!

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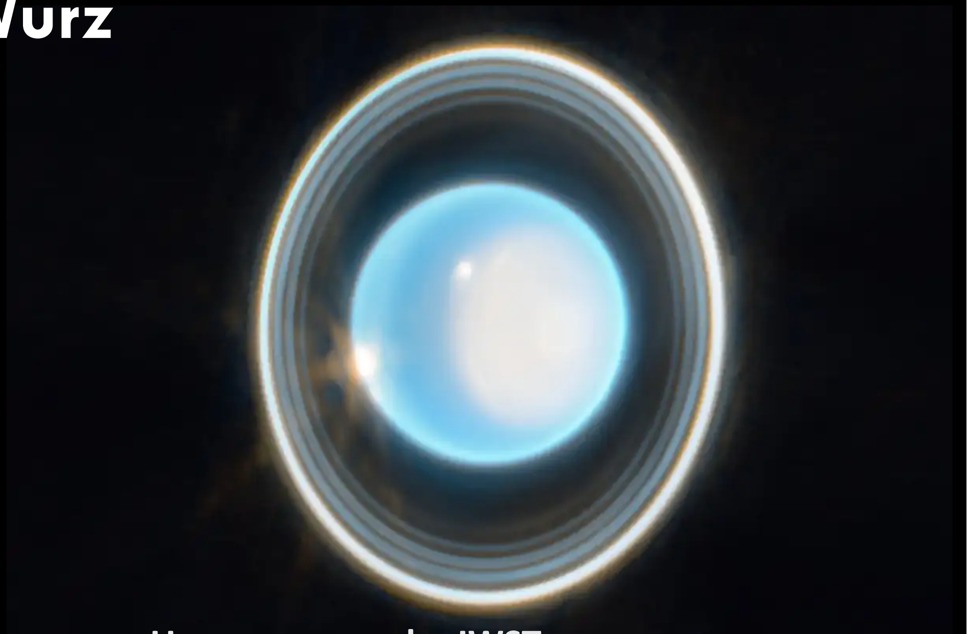
UNIVERSITÄT BERN

Yann Alibert, Ravit Helled, Peter Wurz

……



Uranus as seen by JWST
NASA, ESA, CSA, STScI/J. DePasquale (STScI)

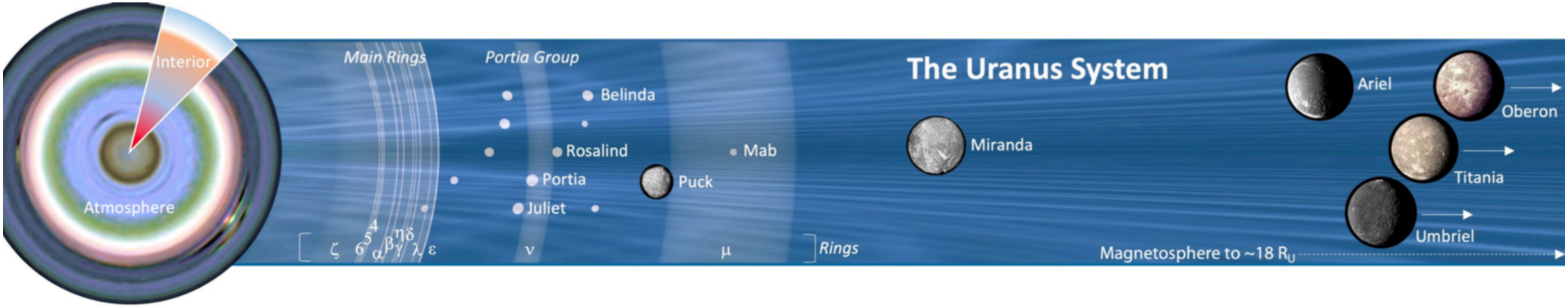
Uranus

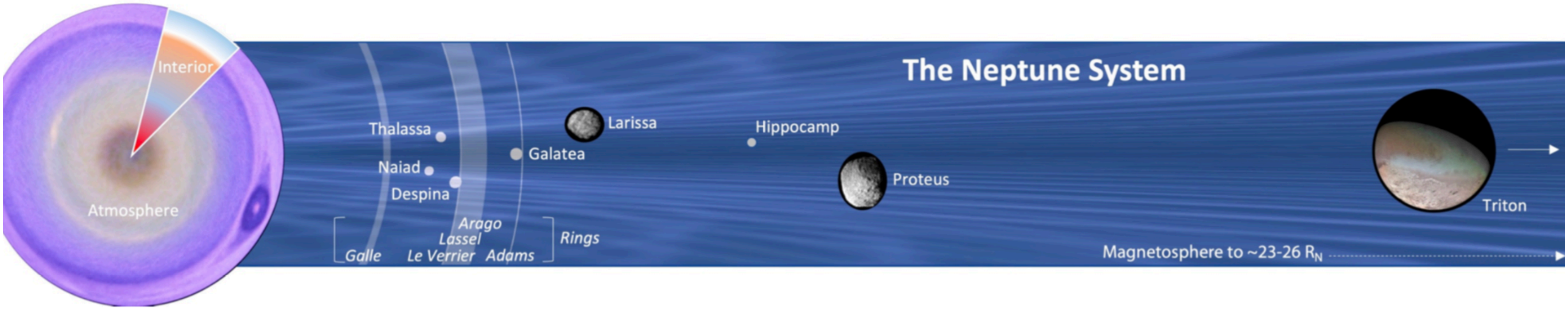
Uranus (and Neptune) represents a unique unexplored planetary class

Many open fundamental questions:

- How do planets like Uranus form & evolve?
- What is Uranus made of?
- What is the reason for Uranus' low luminosity?
- Why is Uranus tilted? How did the regular moons form?
- ....

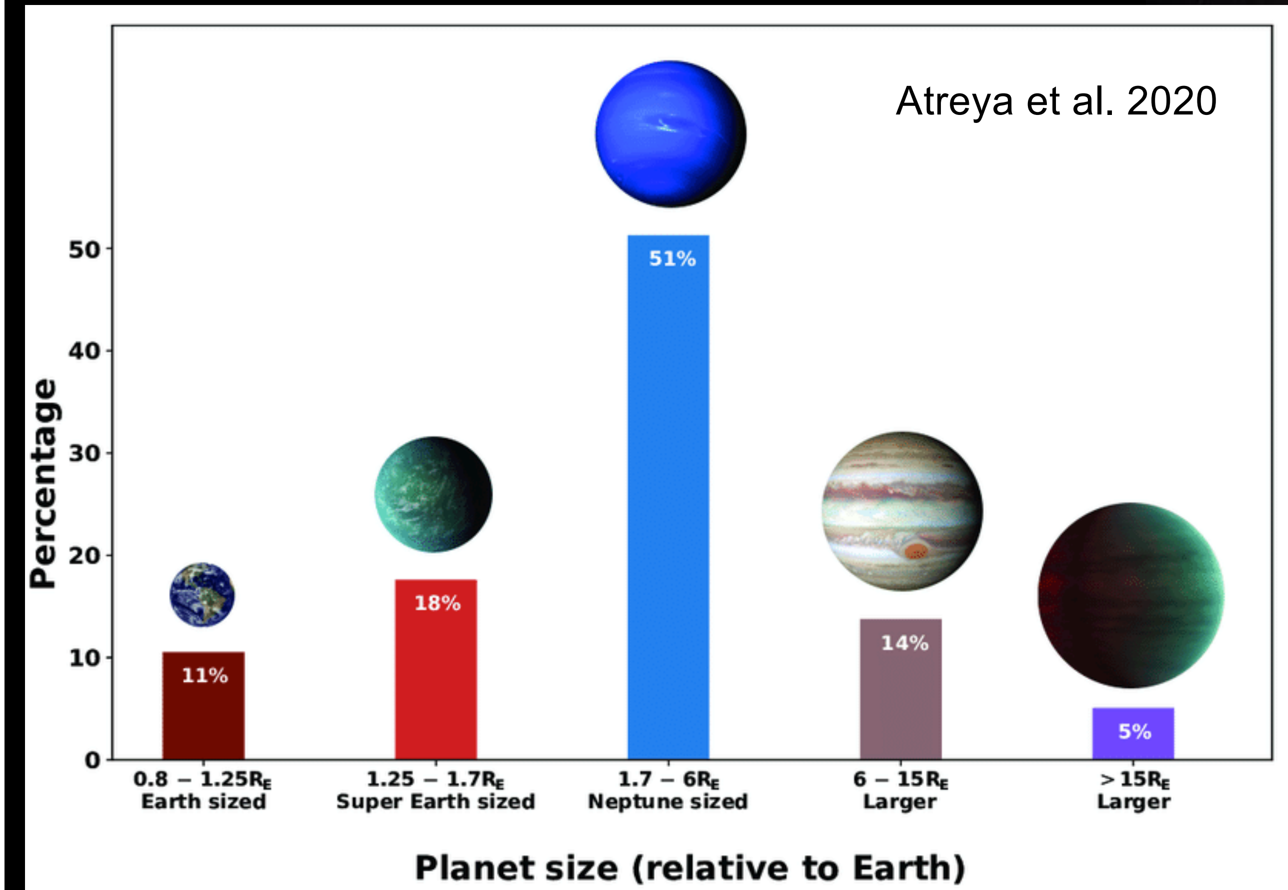
Both planets exhibit rich systems from the mysterious interiors, atmospheres and magnetospheres, to diverse satellites and rings



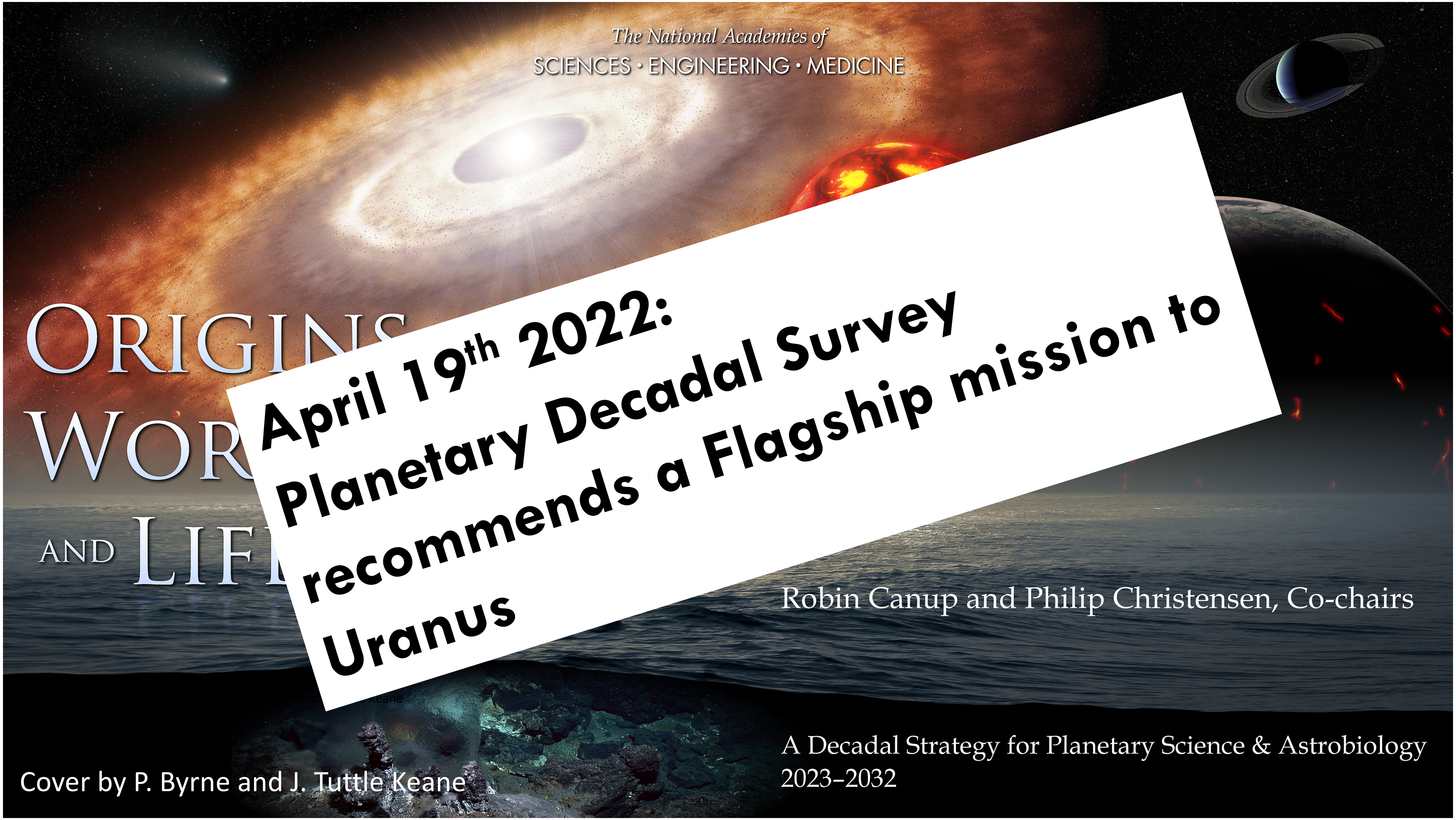


Fletcher, Helled et al., 2021

Exoplanet context



ESA/Hubble, M. Kornmesser


The National Academies of
SCIENCES · ENGINEERING · MEDICINE
AND
April 19th 2022:
Planetary Decadal Survey
recommends a Flagship mission to
Uranus
Robin Canup and Philip Christensen, Co-chairs
A Decadal Strategy for Planetary Science & Astrobiology
2023–2032
Cover by P. Byrne and J. Tuttle Keane

Technical readiness differs substantially

Uranus Orbiter and Probe

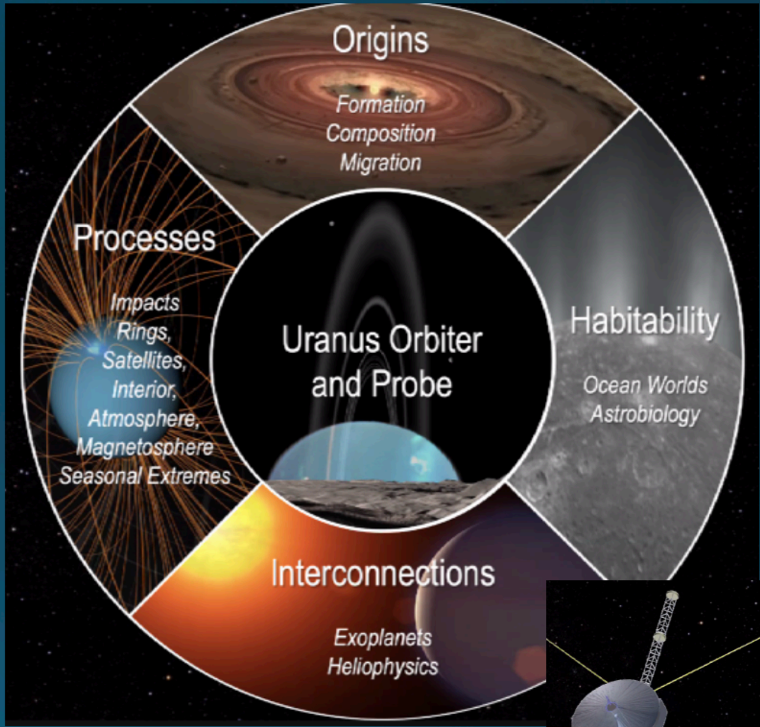
- End-to-end viable mission concept on currently available launch vehicle
- Flexible launch dates starting in 2031 through **2038+**
- **No new technologies required**
- Low-Medium risk (only large mission TRACEd to receive this)

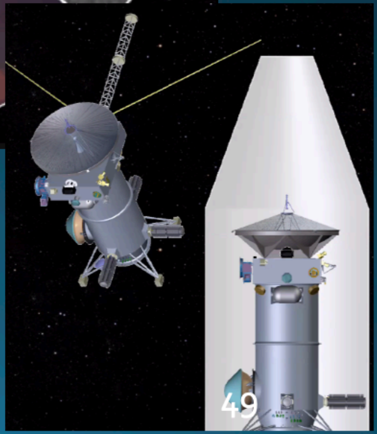
Highest priority new flagship: Uranus Orbiter and Probe

- In situ probe & multi-year orbital tour: atmosphere, interiors, magnetosphere, rings, and satellites
- First dedicated study of class of planets that may be most common in the universe
- Technically ready to start now
- Launch on Falcon Heavy Expendable

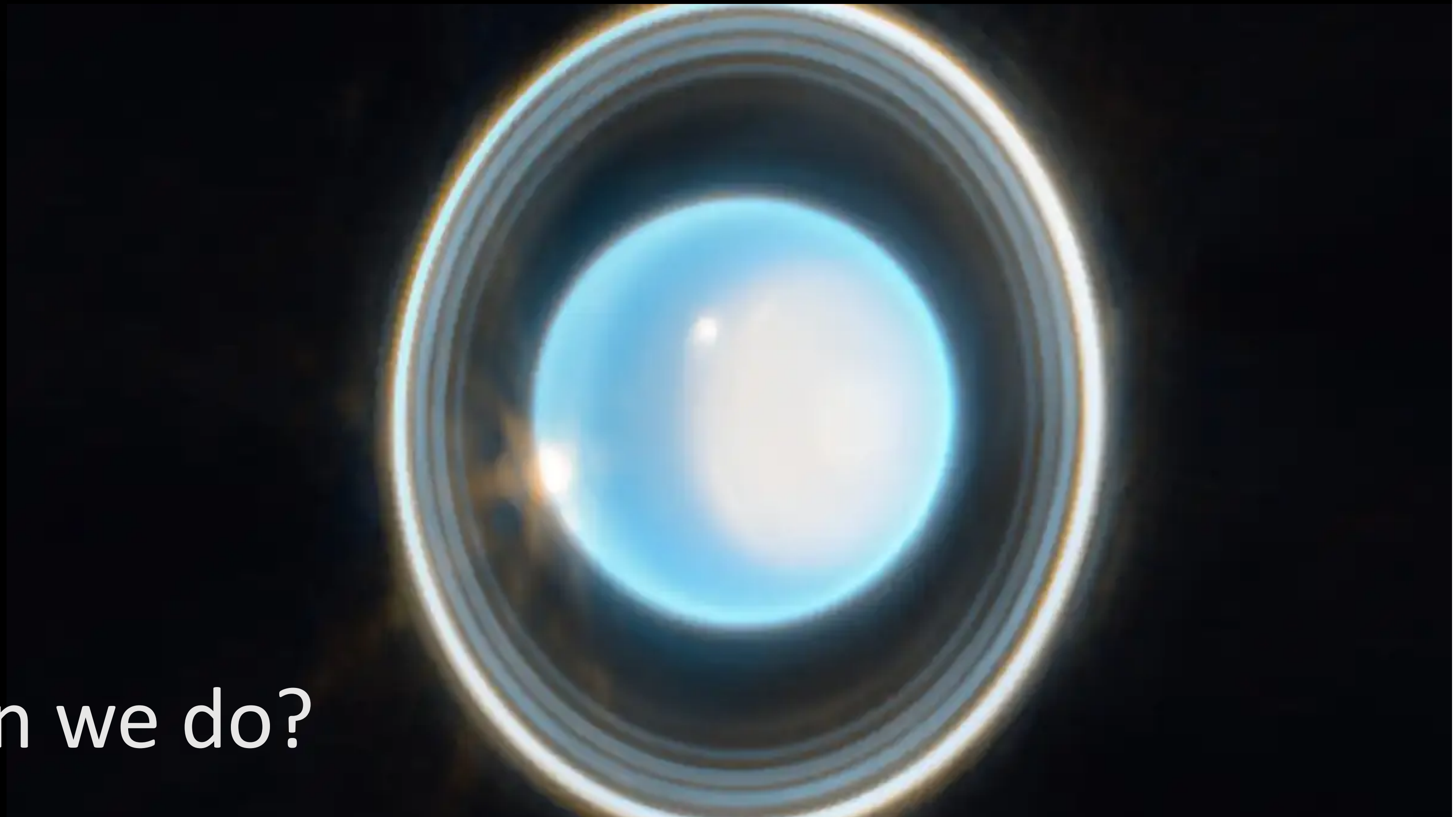
  → Optimal launch in 2031-2032 with Jupiter gravity assist to shorten cruise to 12 to 13 yrs

  - Flexible launch opportunities through 2038 with increased ~ 15 yr cruise and inner solar system gravity assists
- Strong international interest & potential for partnership (e.g., 2021 report of ESA's Voyage 2050 Senior Committee)





But maybe could be a Swiss contribution??



What can we do?

Probe!
Mass spectrometer, hardware…

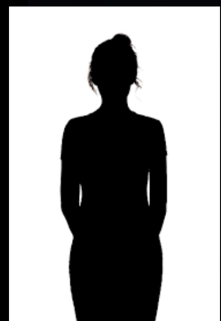
Planet formation models
-> predictions

Gravity science,
Measurement requirements,
Interior models, planet formation..

But more partners are welcome!

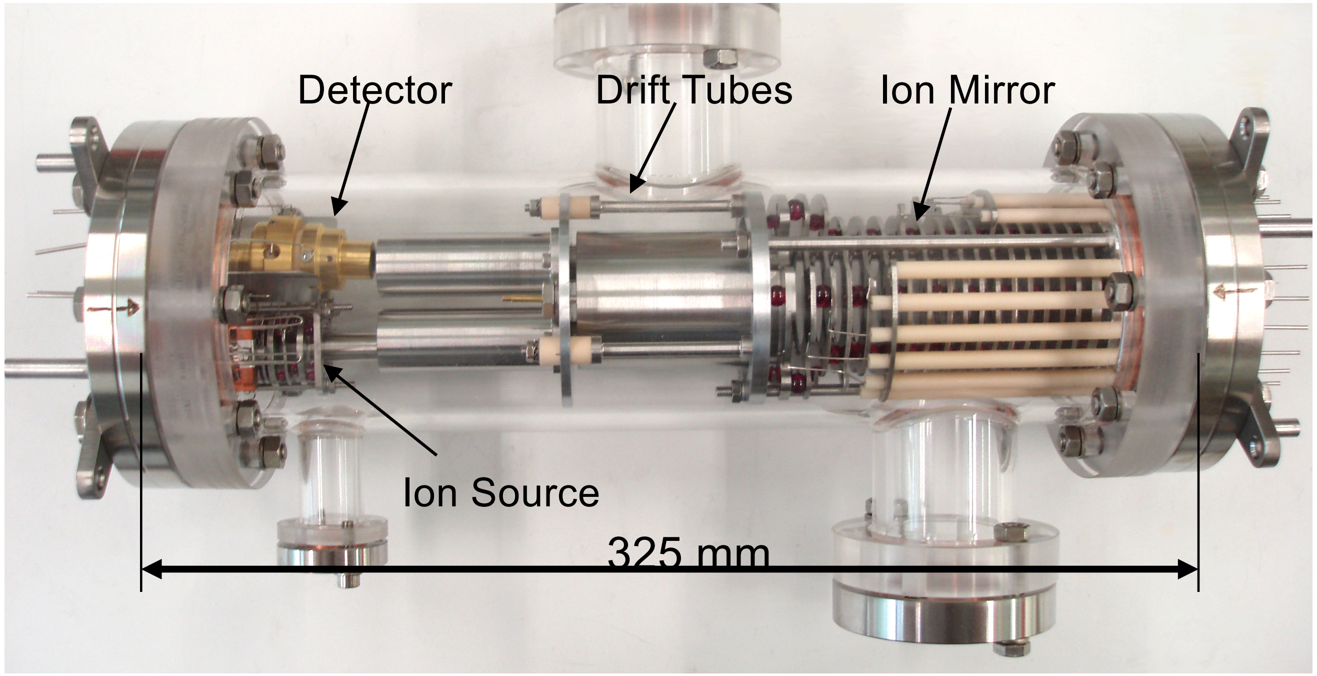
UniGe– support from ground-based observation?

ETH – interior and evolution of moons

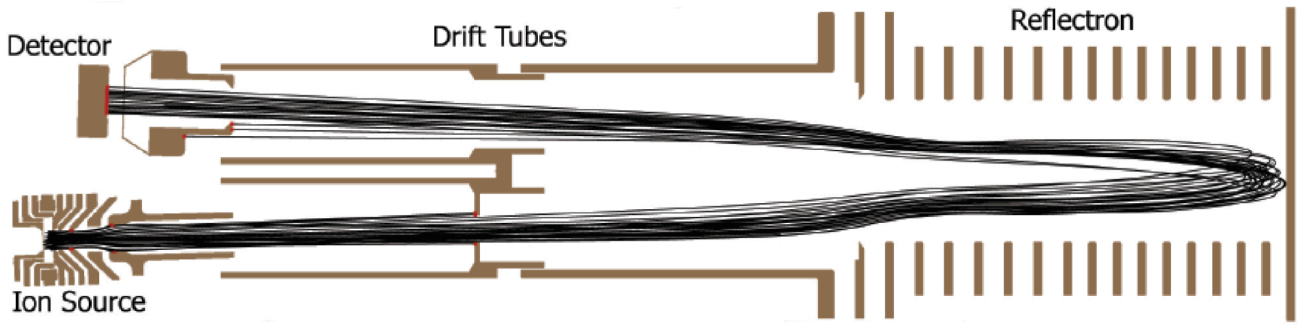


+ ??

TOF-MS : A Time-of-Flight Instrument

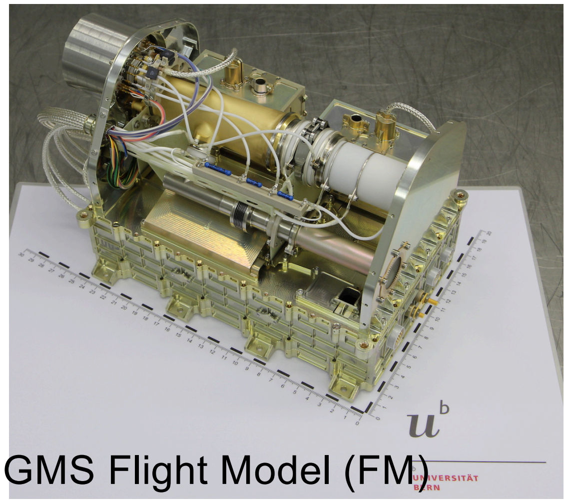


D. Abplanalp,
P. Wurz, et al.,
Adv. Space
Res. 44 (2009)
870–878.

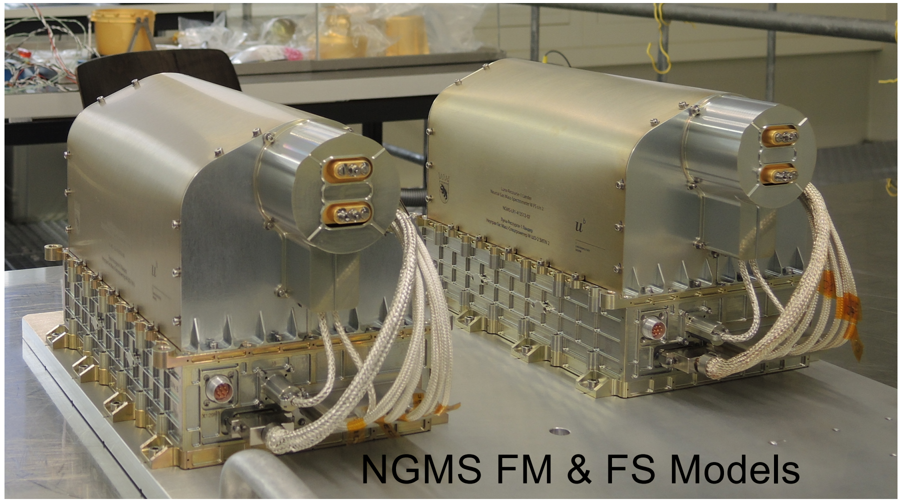


Direct Instrument Heritage

- Laboratory: Nobel gas mass spectrometer
  - Abplanalp et al., J. Mass Spectr. 2010
  - Riedo et al., J. Mass Spectr. 2018
- Stratosphere: MEAP mission, P-BACE instrument
  - Abplanalp et al., Adv. Sp. Res. 2009
- Lunar volatiles in regolith: GC-MS (NGMS instrument)
  - Wurz et al., Planet. Sp. Sci. 2012
  - Hofer et al., Planet. Sp. Sc. 2015
  - Fausch et al., IEEE 2018

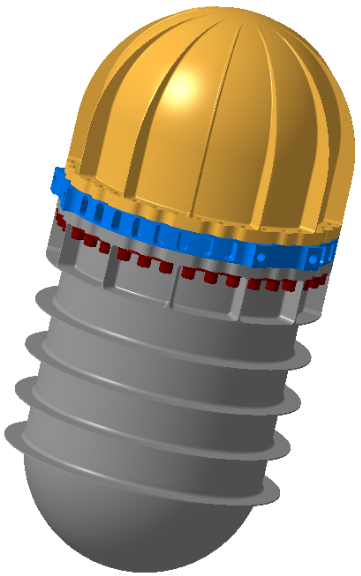


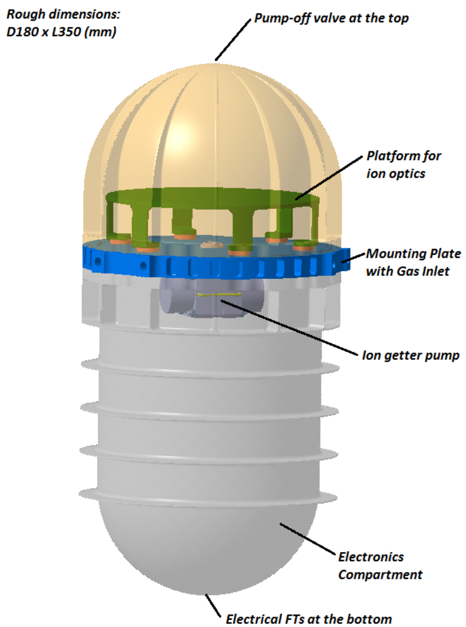
NGMS Flight Model (FM)



NGMS FM & FS Models

Mass Spectrometer System: Envelope Design

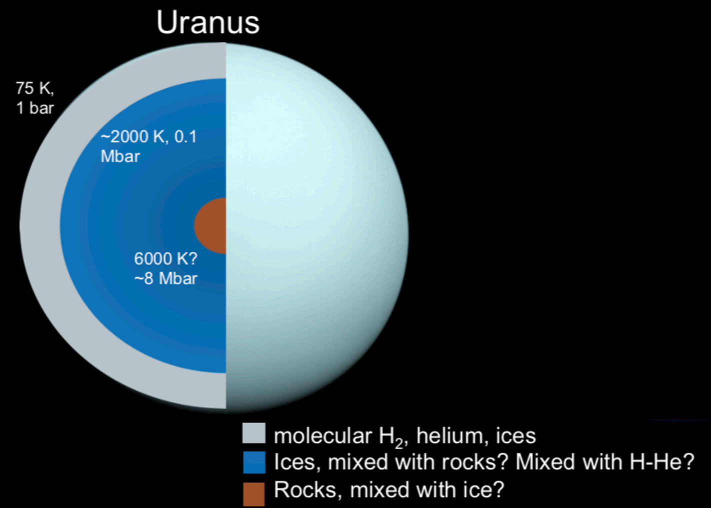


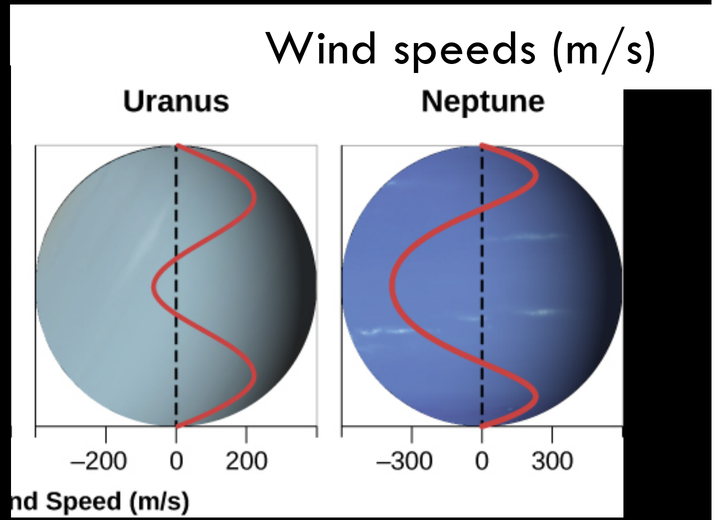


Comparative planetology in the outer Solar System!

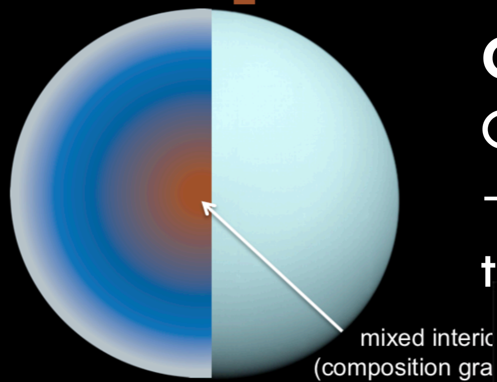
Interior, Wind and Magnetic field

What is U's composition?





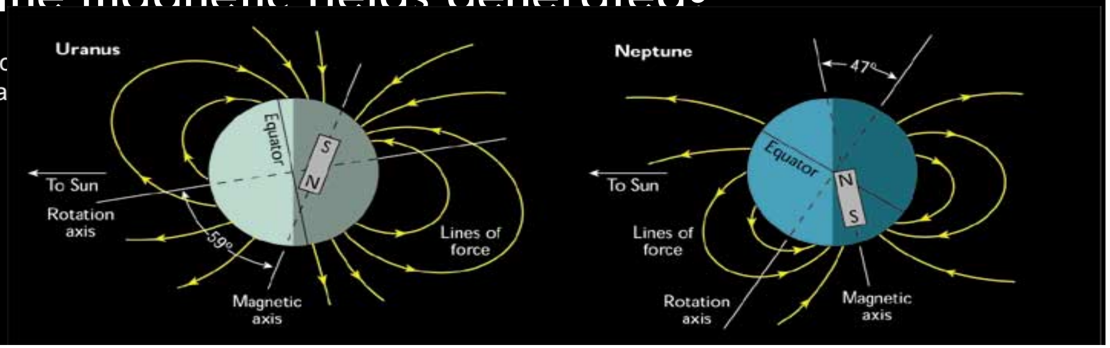
What is the interior like?



→ Connection to intermediate-mass exoplanets

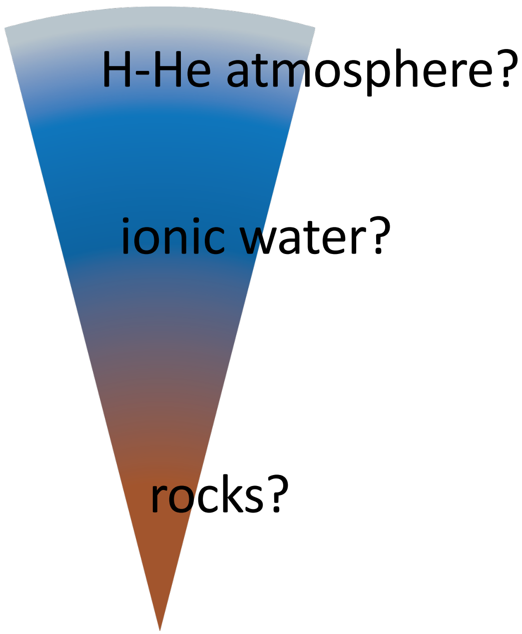
Complex multipolar magnetic fields:

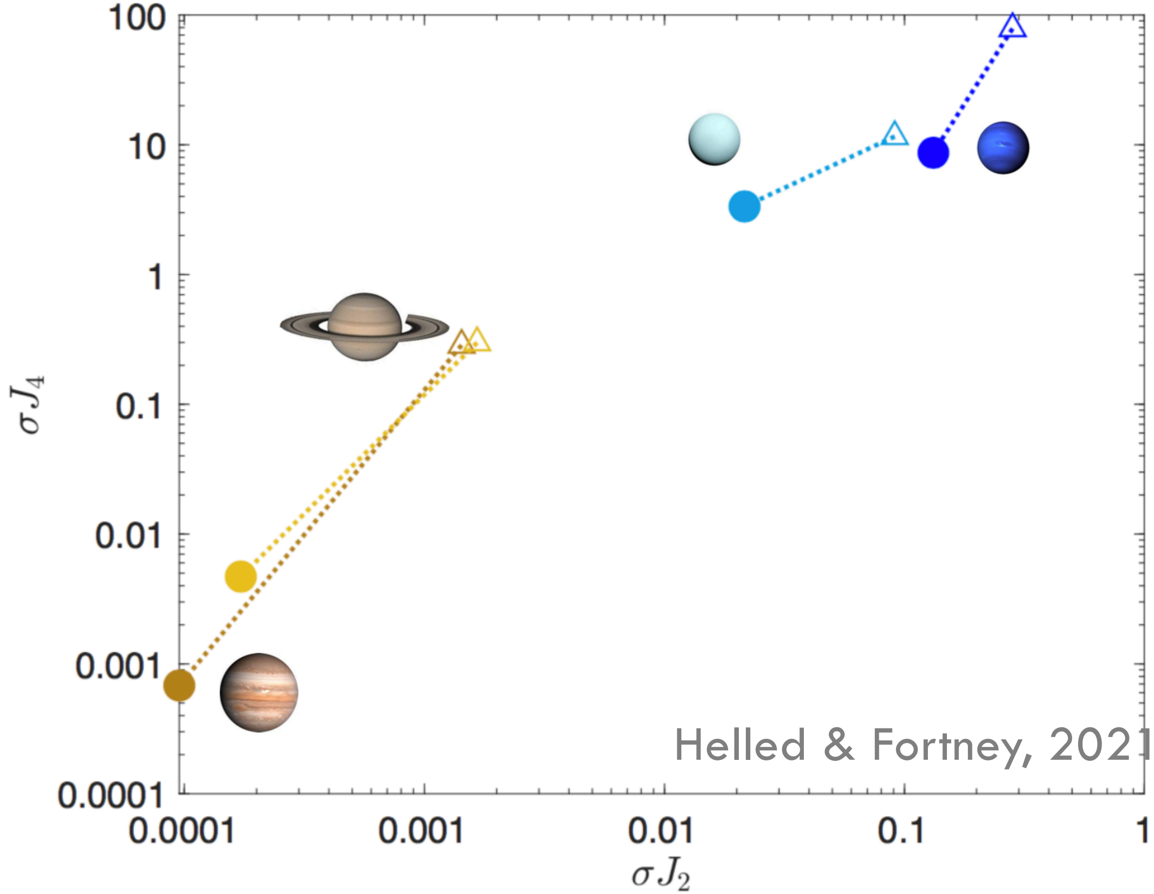
Constraints on interior: convective layer +conducting material → where and how are the magnetic fields generated?



- Only J_2 and J_4 are available with large uncertainties

→ a large range of possible internal structures and compositions

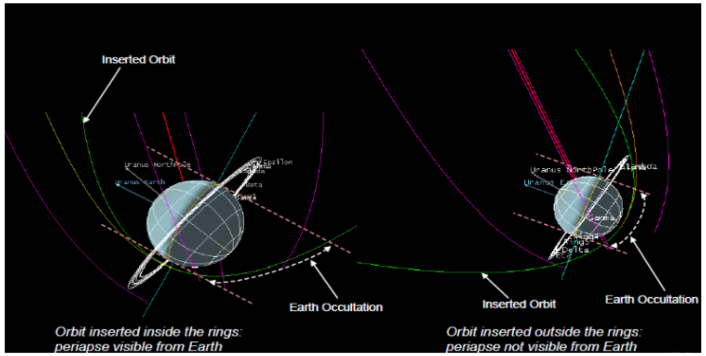


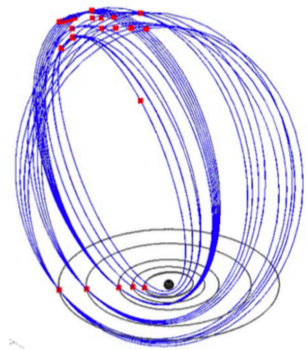


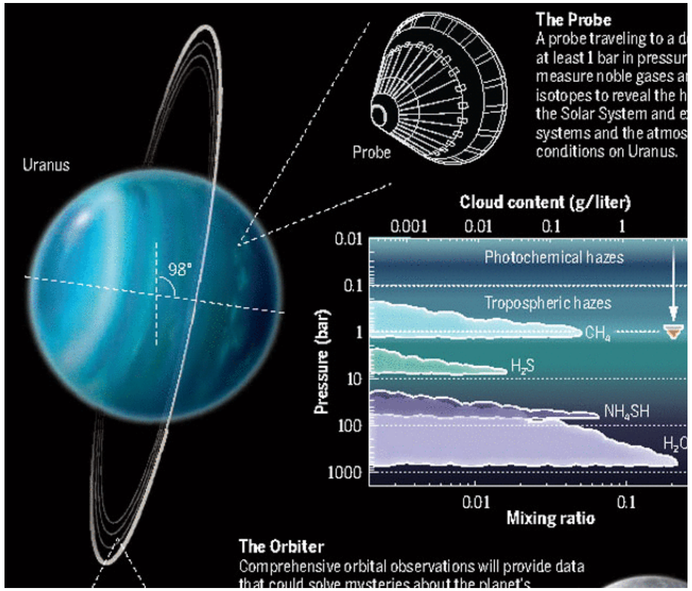
relative observational uncertainties

So what do we plan?

- Requirements for gravity & magnetic measurements to constrain interior
- Requirements for atmospheric composition measurements by the probe: ideal location, required depth, elements, etc..
- Constraints from formation and interior models
- …







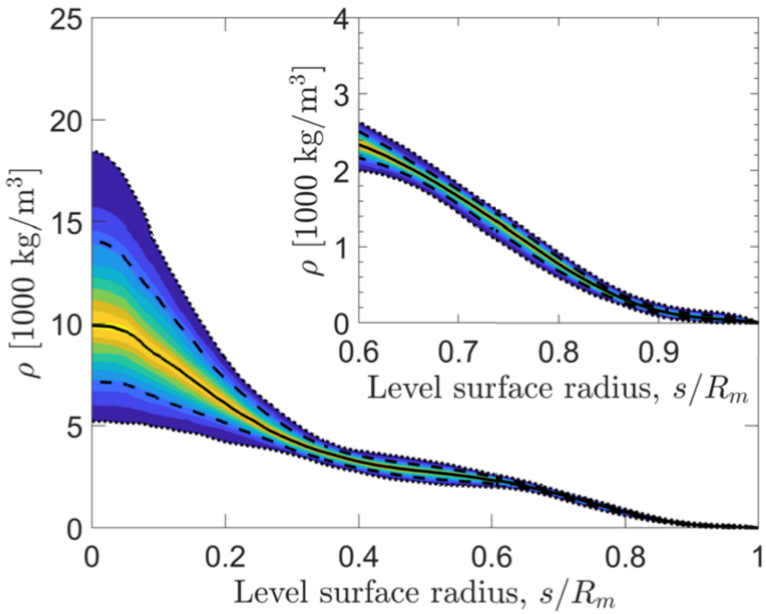
Interior and Formation models

Uranus

46.1 < *J6* < 69.0

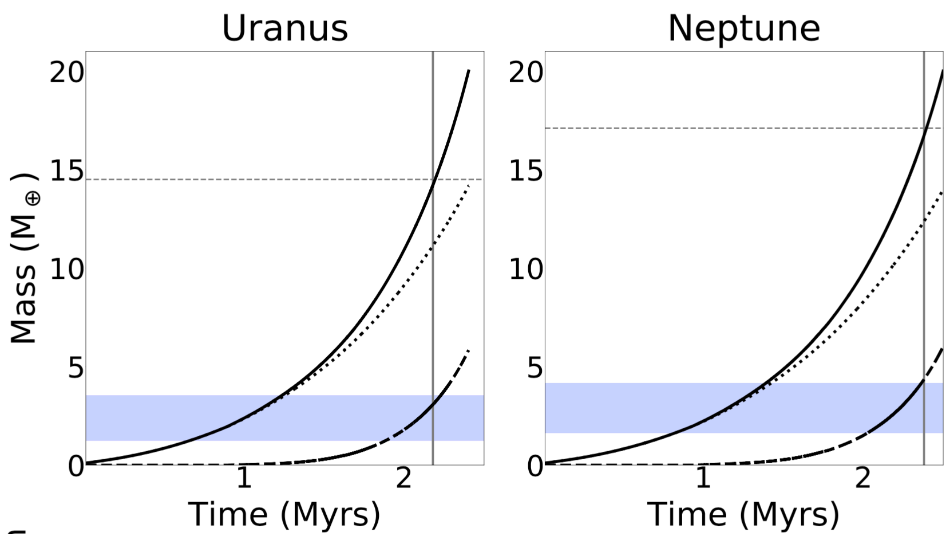
-17.8 < *J8* < -8.4

0.218 < MoI < 0.227



Movshovitz+2022, Neuenschwander & Helled, 2022

Valletta & Helled, 2022

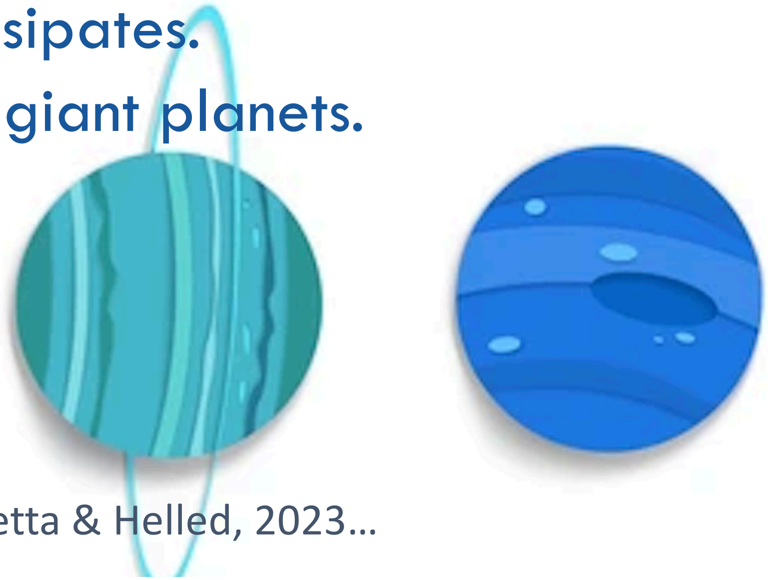


U&N can from in-situ within the disk timescale and have the correct final masses and compositions

Formation of Uranus & Neptune

Uranus and Neptune have 2 $M_\oplus$ and 3 $M_\oplus$ of H-He, respectively. Metallicity of ~ 85% (but model dependent).

- **Similar formation process like J&S but slower: "failed giant planets"?**
  - On one hand, must form before the gas dissipates.
  - On the other hand, should not become gas giant planets.



e.g., Helled & Bodenheimer, 2014 & Venturini & Helled, 2017, Valletta & Helled, 2023…

How can we use the probe to constrain Uranus' formation history?

Uranus elemental bulk composition

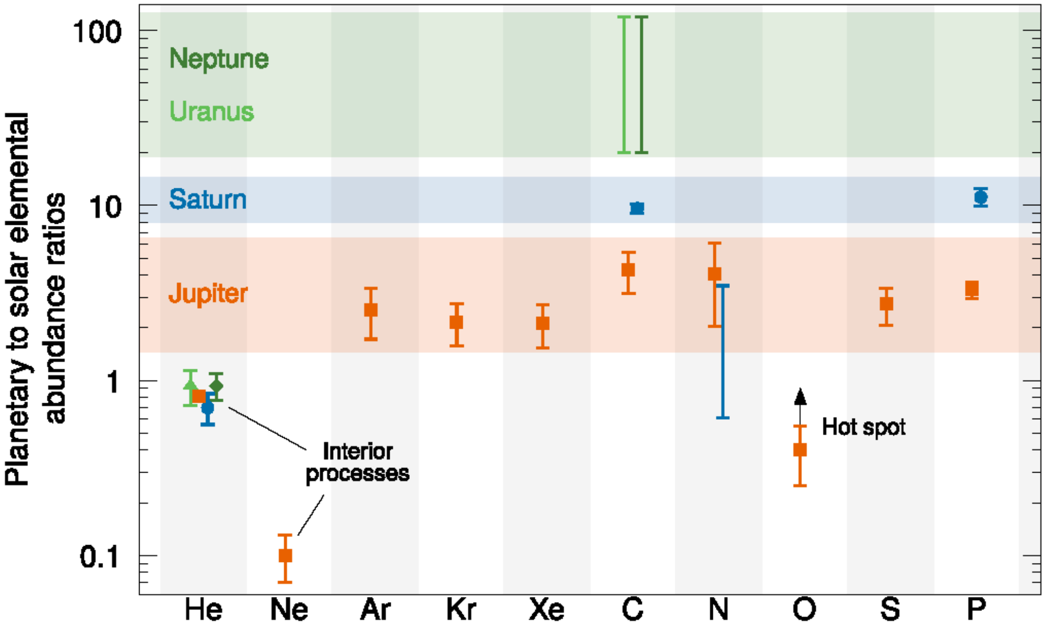


Fig. 1. Enrichment factors (with respect to the solar value) of noble gases and heavy elements in the giant planets. See text for references.

Mousis et al. 2021

<- Ar, Kr, Xe, C, N, O for different formation scenarios

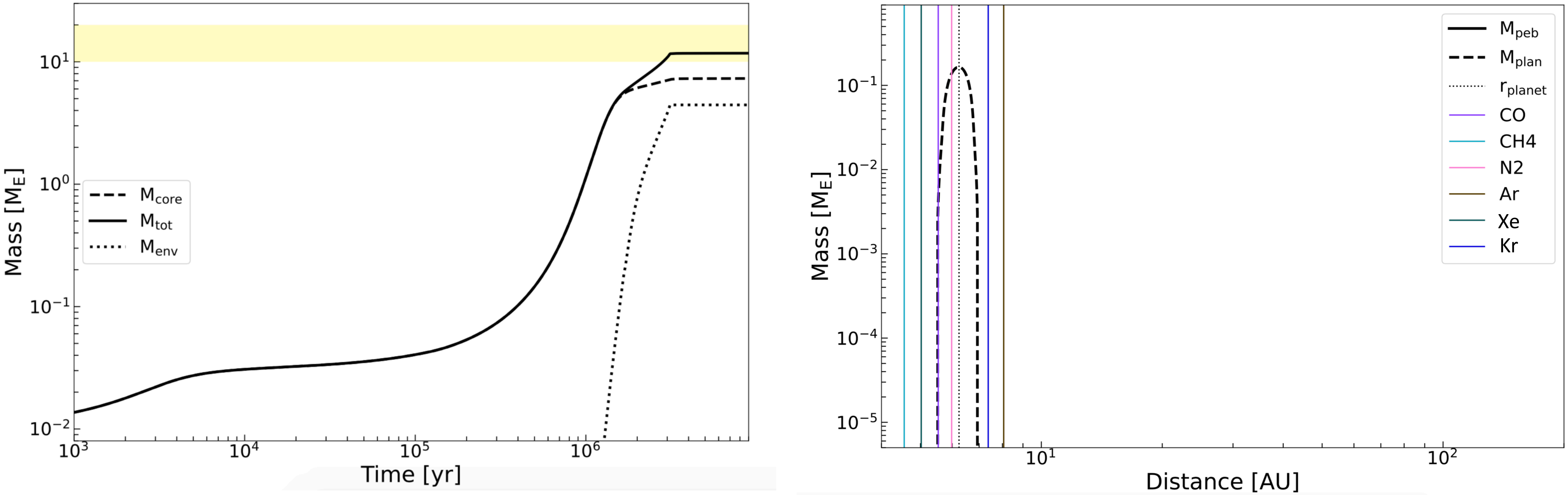
Uranus elemental bulk composition

1- Temperature of the disk

2- Formation location (a la Grand Tack *versus* ~present location)

3- Nature of solid building blocks (planetesimals, pebbles or both)

formation at 6.3 AU from local planetesimals in a cold disk



f0_gt_1

formation at 6.3 AU from local planetesimals in a cold disk

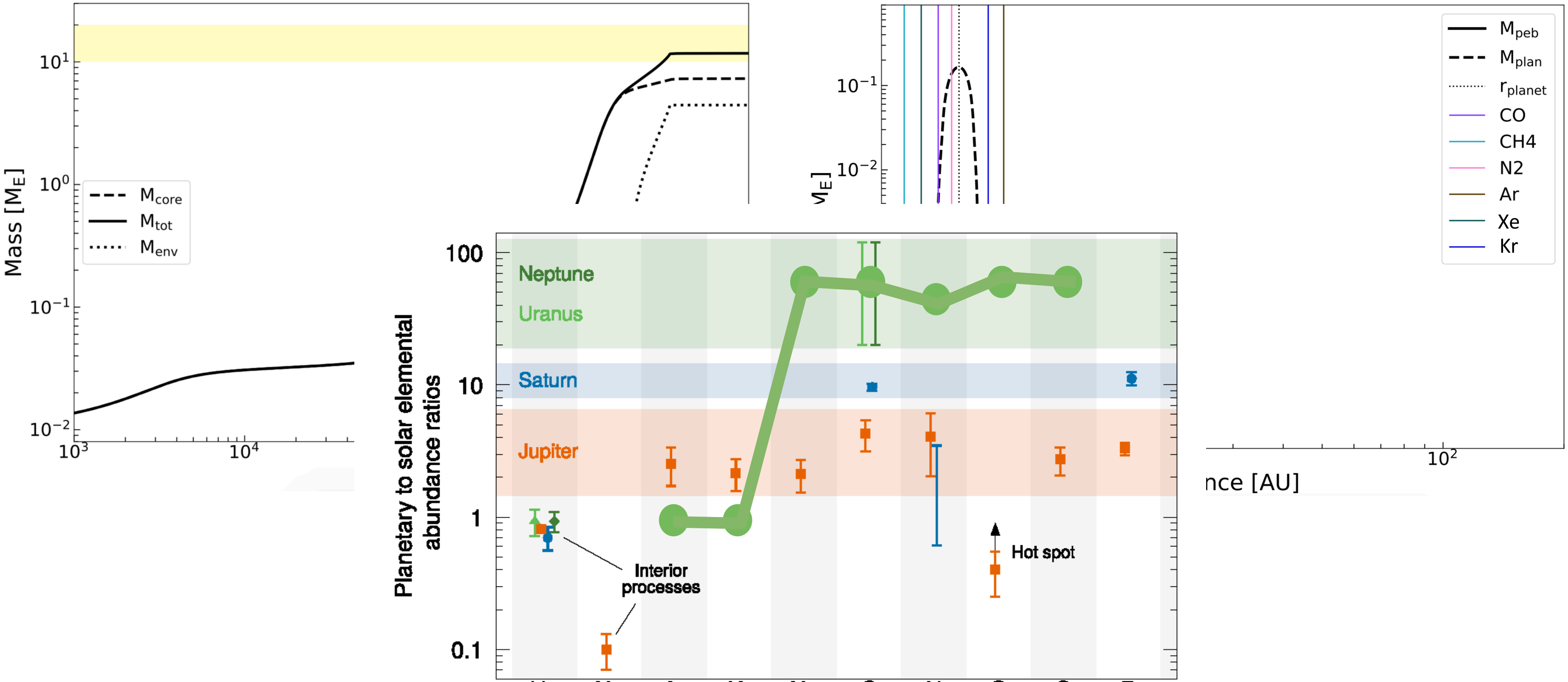
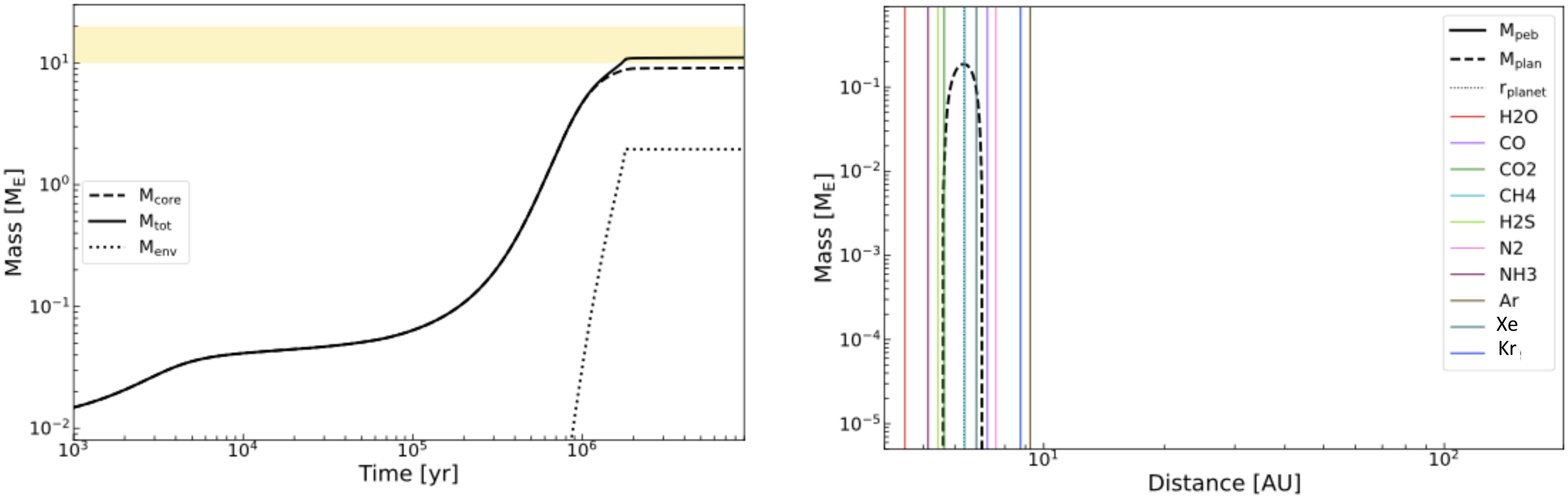


Fig. 1. Enrichment factors (with respect to the solar value) of noble gases and heavy elements in the giant planets. See text for references.

f0_gt_1

formation at 6.5 AU from local planetesimals in a warmer disk



f0_gt_620

formation at 6.5 AU from local planetesimals in a warmer disk

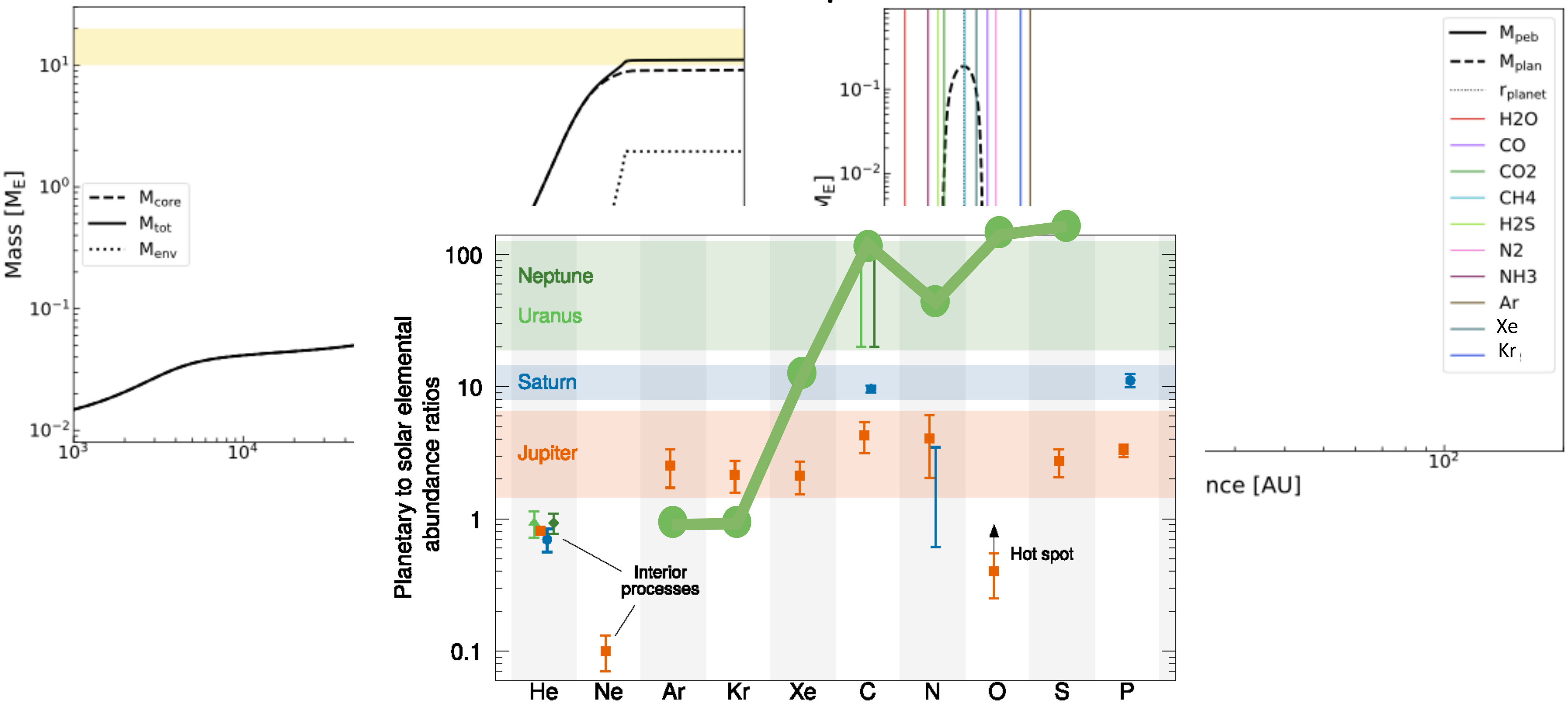
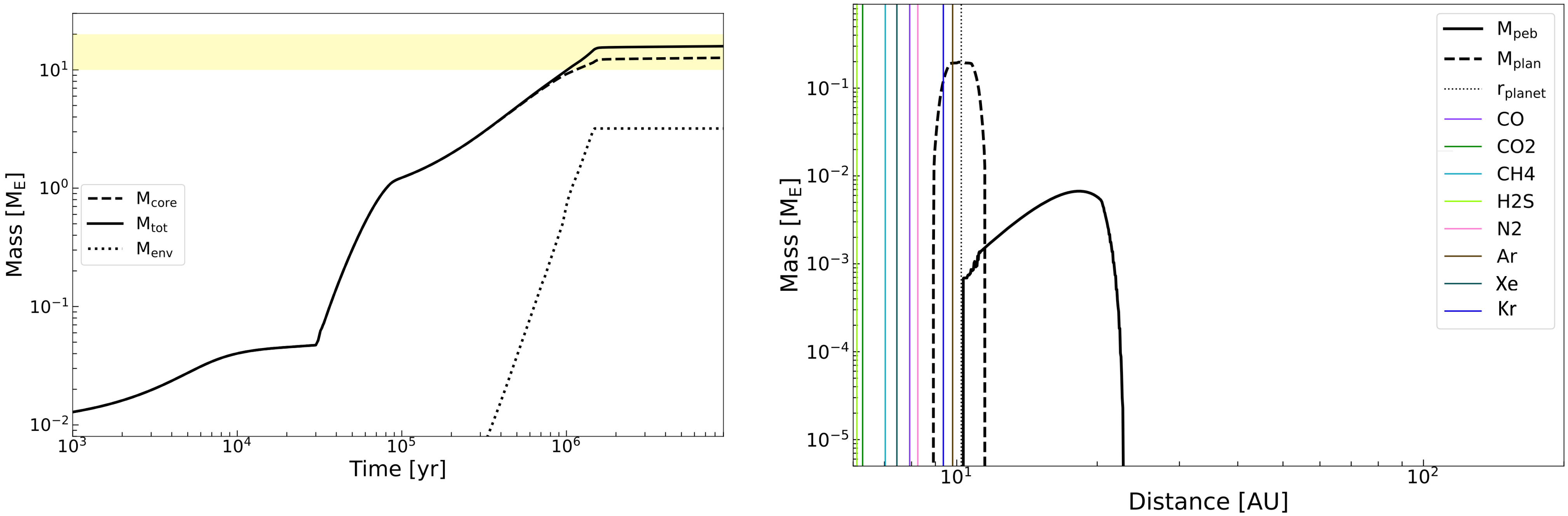


Fig. 1. Enrichment factors (with respect to the solar value) of noble gases and heavy elements in the giant planets. See text for references.

f0_gt_620

formation at 12 AU from local planetesimals and pebbles



0p5_325

formation at 12 AU from local planetesimals and pebbles

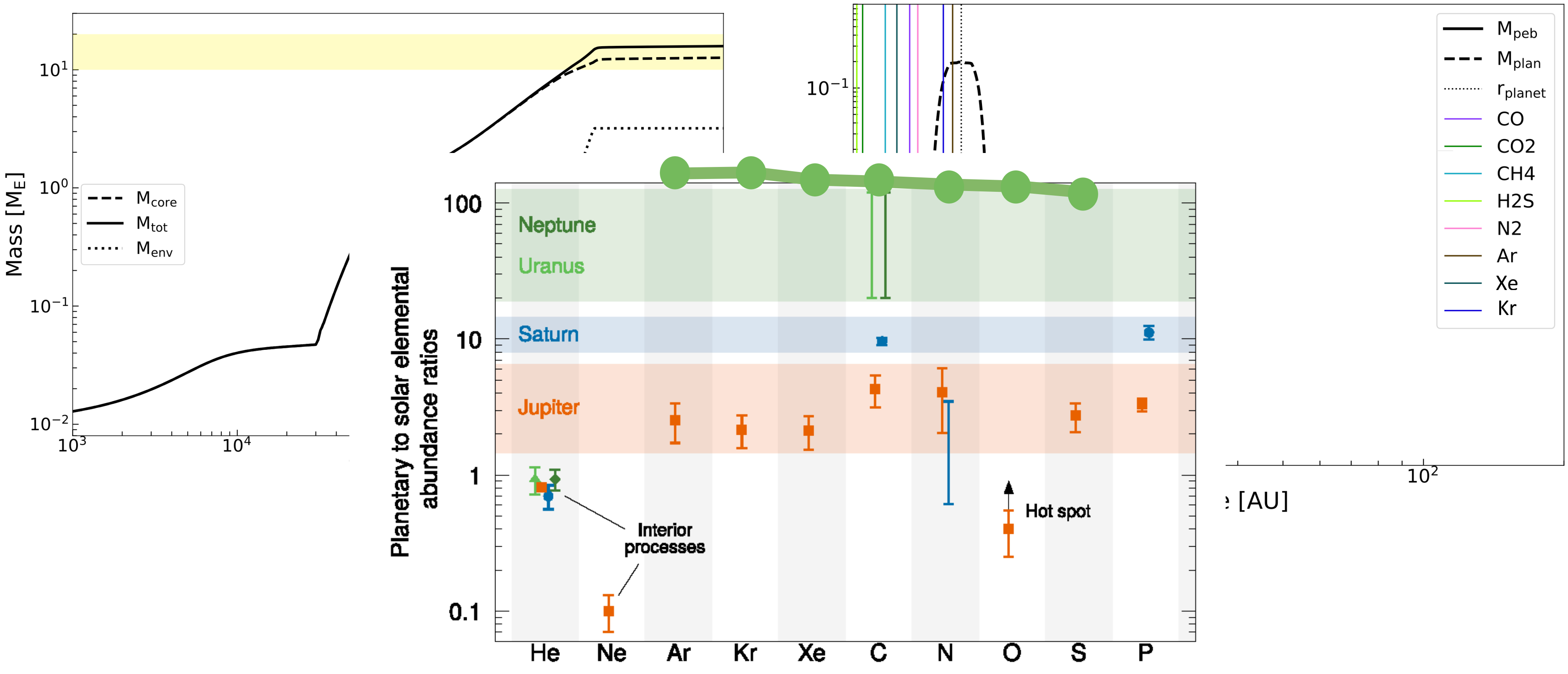


Fig. 1. Enrichment factors (with respect to the solar value) of noble gases and heavy elements in the giant planets. See text for references.

0p5_325

-> Disk temperature, formation location, nature of building blocks can induce large variations in elemental abundances

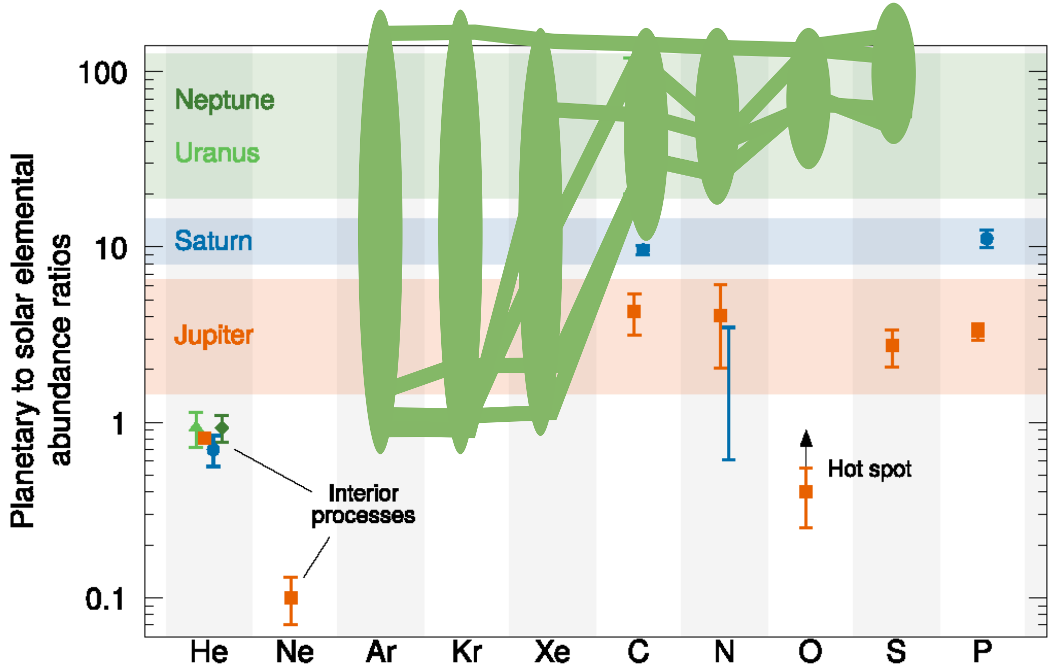


Fig. 1. Enrichment factors (with respect to the solar value) of noble gases and heavy elements in the giant planets. See text for references.

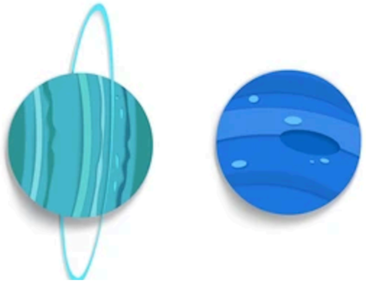
These are *elemental abundances in the whole planet* – need a strategy to recover them from local measurement

Future Research

- Prepare for the upcoming space mission: identify the key measurements and develop the instruments, and theoretical framework for the data interpretation

- Interplay between deep interior, magnetic field, atmospheres, connection to exoplanets…

This is only the beginning…




Yes, we can ☺