In Situ Exploration of the Giant Planets: a Horizon 2061 Perspective

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Planetary Exploration 2061

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Motivation and Background

- Giant planets **have played a significant role in shaping the architecture of our planetary system and the evolution of the smaller, inner worlds**.

- The efficiency of **remote sensing observations has some limitations**, especially to study the bulk atmospheric composition.

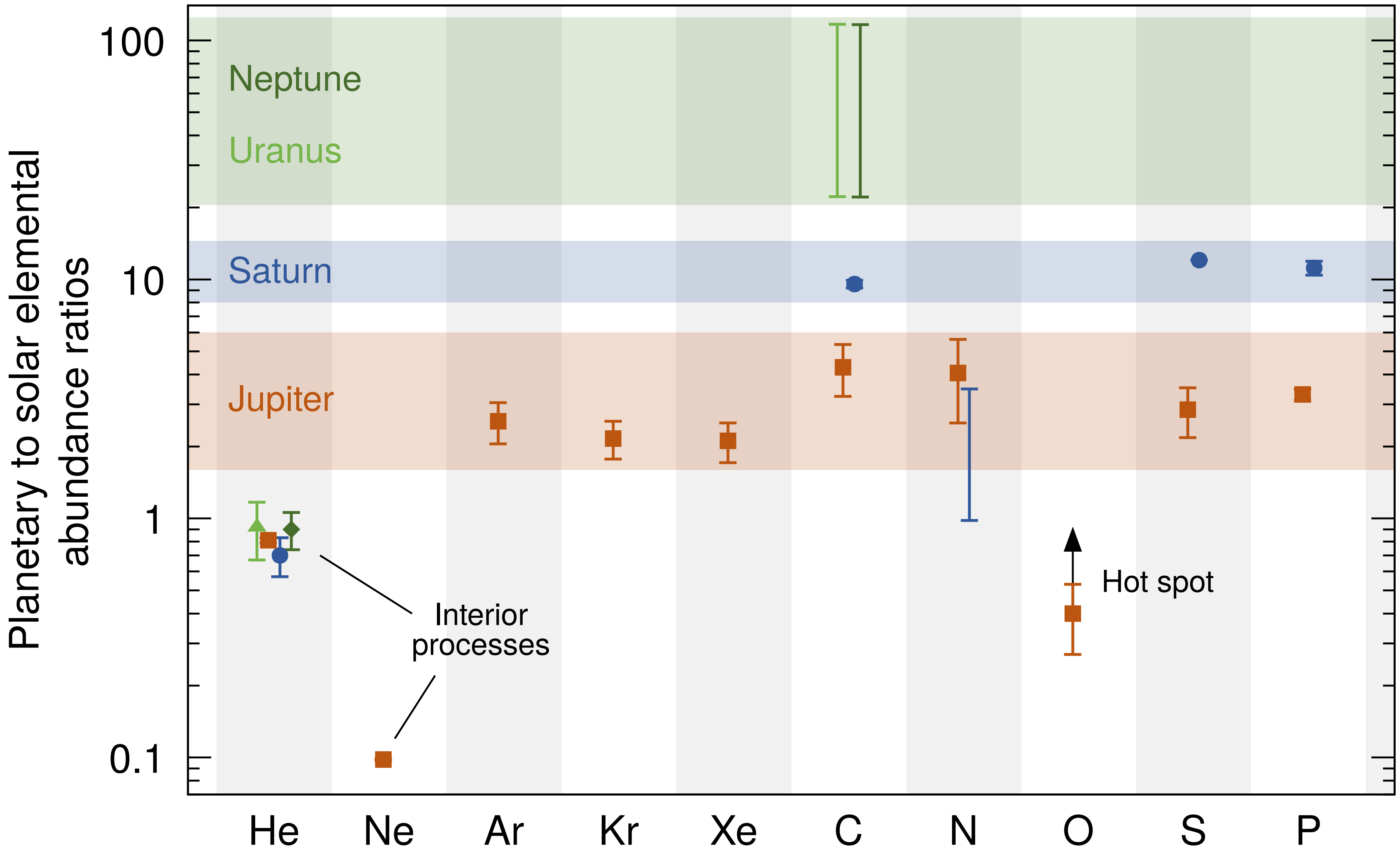
- Example of these restrictions: exploration of Jupiter, where **key measurements such as the determination of the noble gases and helium abundances** have only been made in situ by the Galileo probe.

- The Galileo probe provided a giant step forward regarding our understanding of Jupiter. However, it is not known whether these measurements are representative of the **whole set of giant planets of the solar system**.

What is needed?

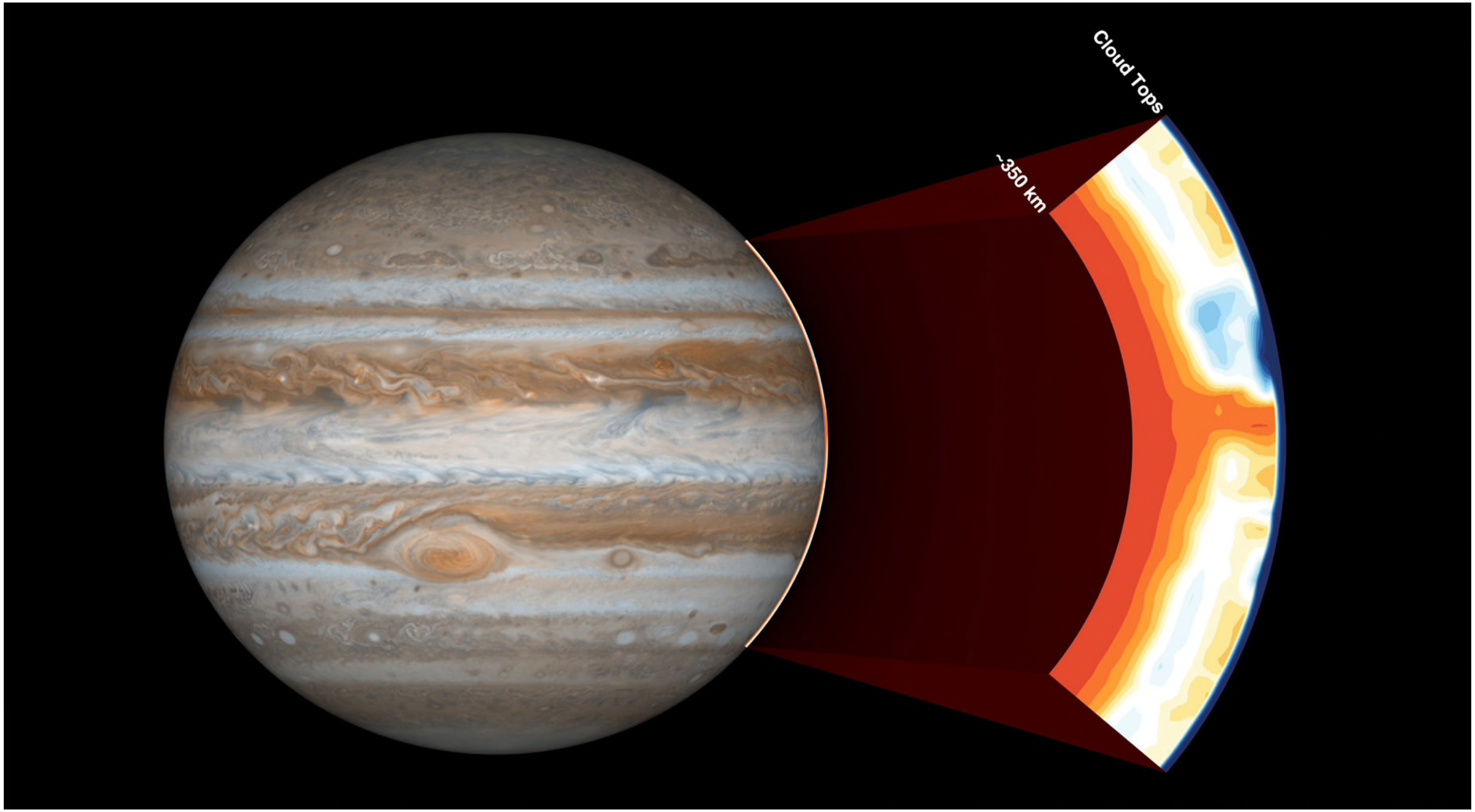
- **Bulk composition**: heavy element (> ^{4}He), abundances (O, C, N, S, Ne, Ar, Kr, Xe)
- **Isotopic ratios**: noble gas isotopes, D/H, $^{13}C/^{12}C$, $^{15}N/^{14}N$
- **He/H$_2$ ratio**: for planetary heat balance and interior processes

What is known



Atreya et al. (2018), Mousis et al. (2018)

What did we learn from JUNO?



Thermochemical equilibrium models predict the base of ammonia cloud in Jupiter at ~0.7 bar. However Juno MWR data show a highly complex distribution of ammonia over Jupiter**: the well-mixed ammonia is reached at atmospheric pressures exceeding 100 bars!!**

In the case of the icy giants, well-mixed water may be found only at several kilobars to tens of kilobars pressure levels (Atreya et al. 2018).

Isotopic ratios measured in Jupiter, Saturn, Uranus, and Neptune

Isotopic ratio	Jupiter	Saturn	Uranus	Neptune
D/H (in H_2)(1)	$(2.60 \pm 0.7) \times 10^{-5}$	$1.70^{+0.75}_{-0.45} \times 10^{-5}$	$(4.4 \pm 0.4) \times 10^{-5}$	$(4.1 \pm 0.4) \times 10^{-5}$
$^{3}He/^{4}He$(2)	$(1.66 \pm 0.05) \times 10^{-4}$	--	--	--
$^{12}C/^{13}C$ (in CH_4)(3)	$92.6^{+4.5}_{-4.1}$	$91.8^{+8.4}_{-7.8}$	--	--
$^{14}N/^{15}N$ (in NH_3)(4)	434.8^{+65}_{-50}	> 357	--	--
$^{20}Ne/^{22}Ne$(5)	13 ± 2	--	--	--
$^{36}Ar/^{38}Ar$(6)	5.6 ± 0.25	--	--	--
^{136}Xe/total Xe(7)	0.076 ± 0.009	--	--	--
^{134}Xe/total Xe(8)	0.091 ± 0.007	--	--	--
^{132}Xe/total Xe(9)	0.290 ± 0.020	--	--	--
^{131}Xe/total Xe(10)	0.203 ± 0.018	--	--	--
^{130}Xe/total Xe(11)	0.038 ± 0.005	--	--	--
^{129}Xe/total Xe(12)	0.285 ± 0.021	--	--	--
^{128}Xe/total Xe(13)	0.018 ± 0.002	--	--	--

(1) Mahaffy et al. (1998) for Jupiter, Lellouch et al. (2001) for Saturn, Feuchtgruber et al. (2013) for Uranus and Neptune. (2) Mahaffy et al. (1998) for Jupiter. (3) Niemann et al. (1998) for Jupiter, Fletcher et al. (2009a) for Saturn. (4) Wong et al. (2004) for Jupiter, Fletcher et al. (2014b) for Saturn. (5-13) Mahaffy et al. (2000) for Jupiter.

Delivery of Volatiles to the Giant Planets – Solids

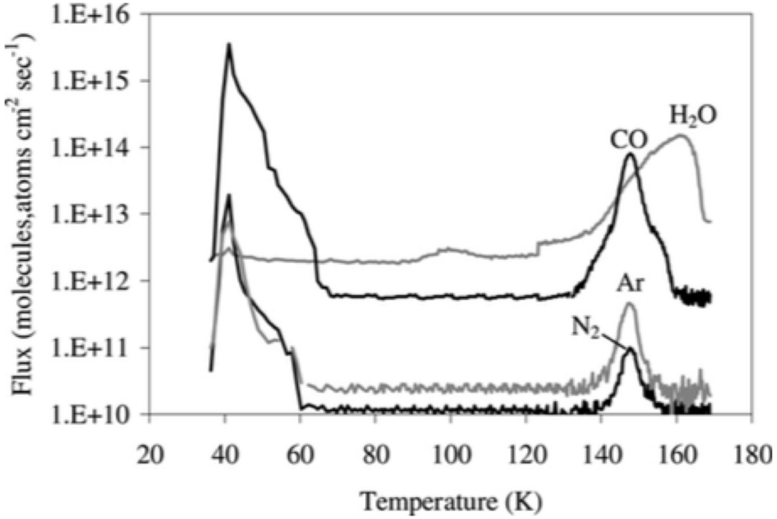
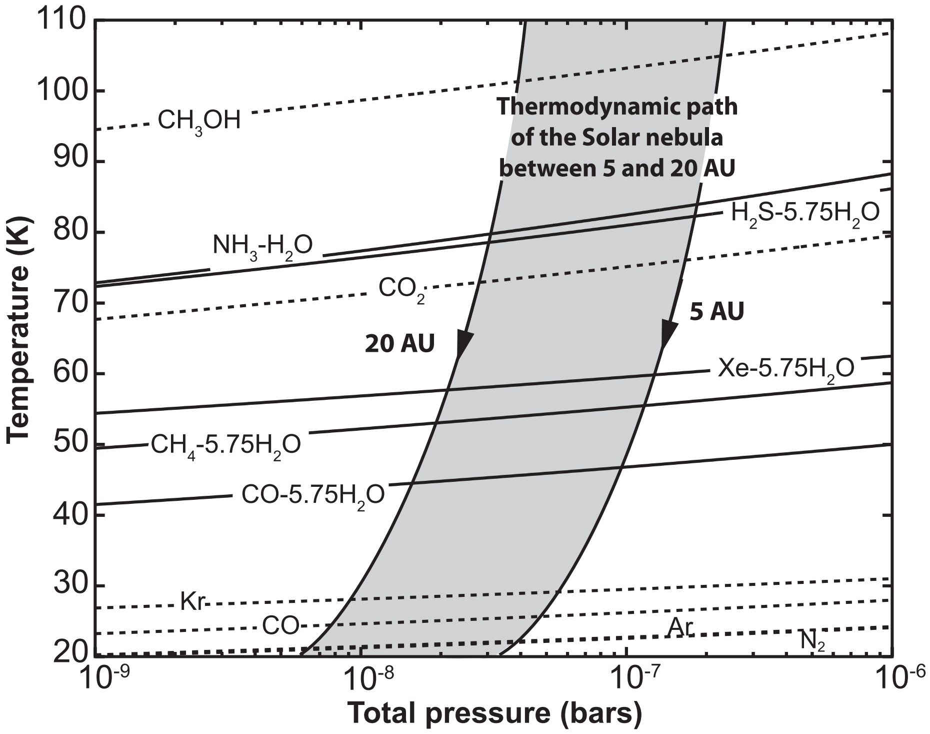


Fig. 1. A plot of the fluxes of evolved CO, N_2, Ar and water during warming up of 0.1 μm ice layer. The gas-laden ice was deposited at 27 K from a H_2O:CO:N_2:Ar = 100:100:14:1, at a rate of 5×10^{-4} μm min^{-1}. At 35–65 K the gas frozen on the ice sublimates. The internally trapped gases are released at 135–160 K during the transformation of the amorphous ice into a high viscosity "liquid" with cubic domains.

Amorphous ice

Owen et al. (1999),

Bar-Nun et al. (2007)

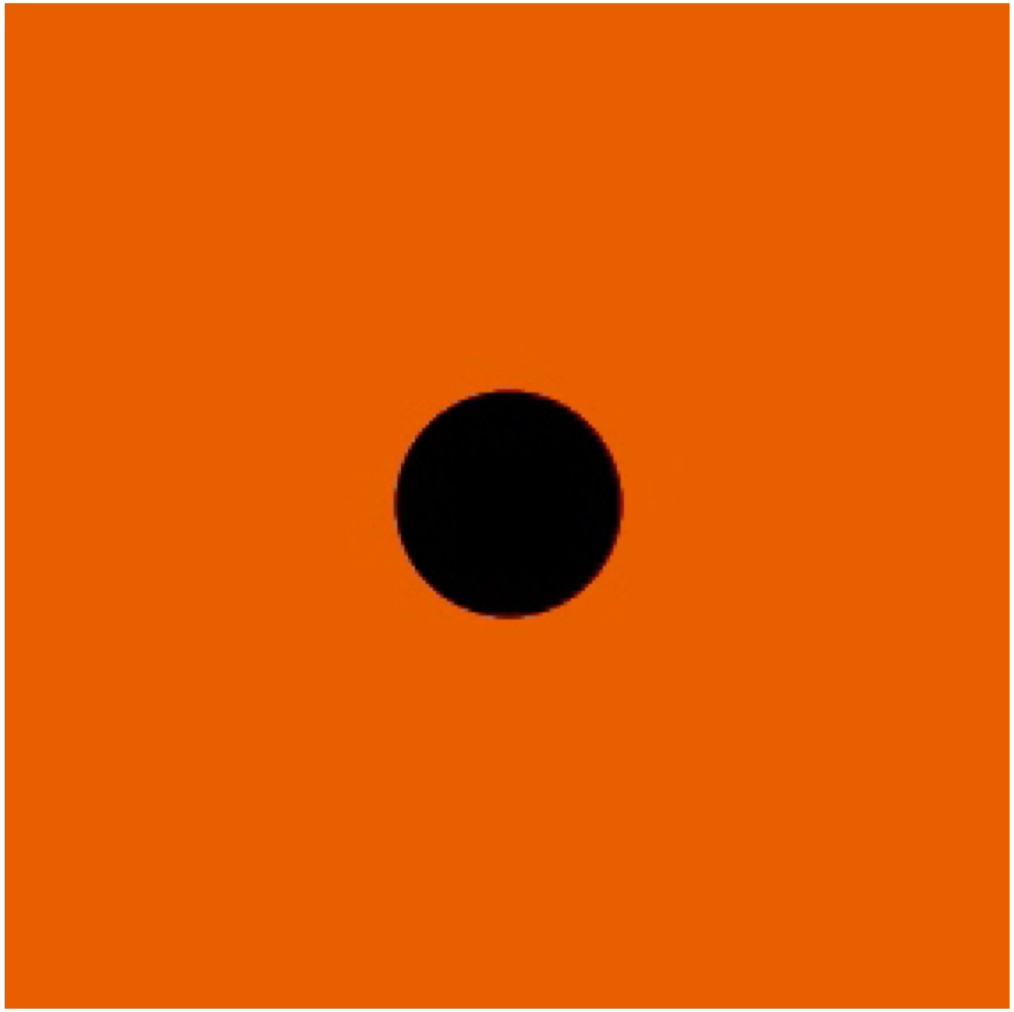


Clathrates + pure condensates

Gautier et al. (2001),

Mousis et al. (2009, 2012)

Gas opening and consequence for the accretion of pebbles/planetesimals



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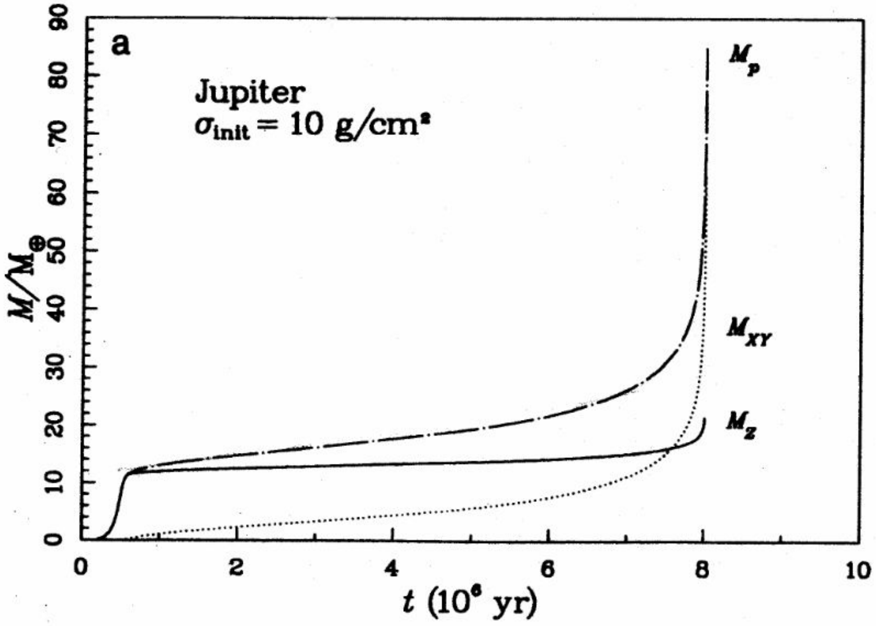
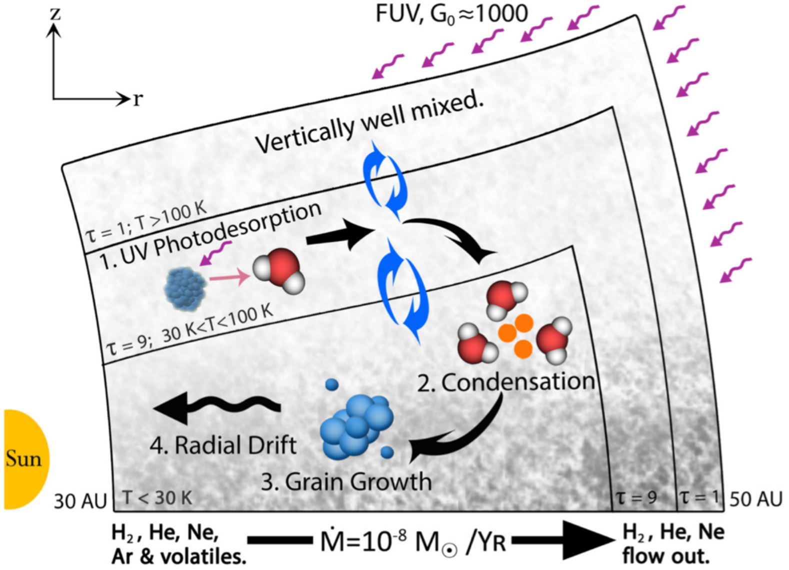


Pollack et al. (1996)

Gap formation halts the accretion of pebbles -> Giant planets supersolar metallicities cannot be acquired during the growth of the envelope!!

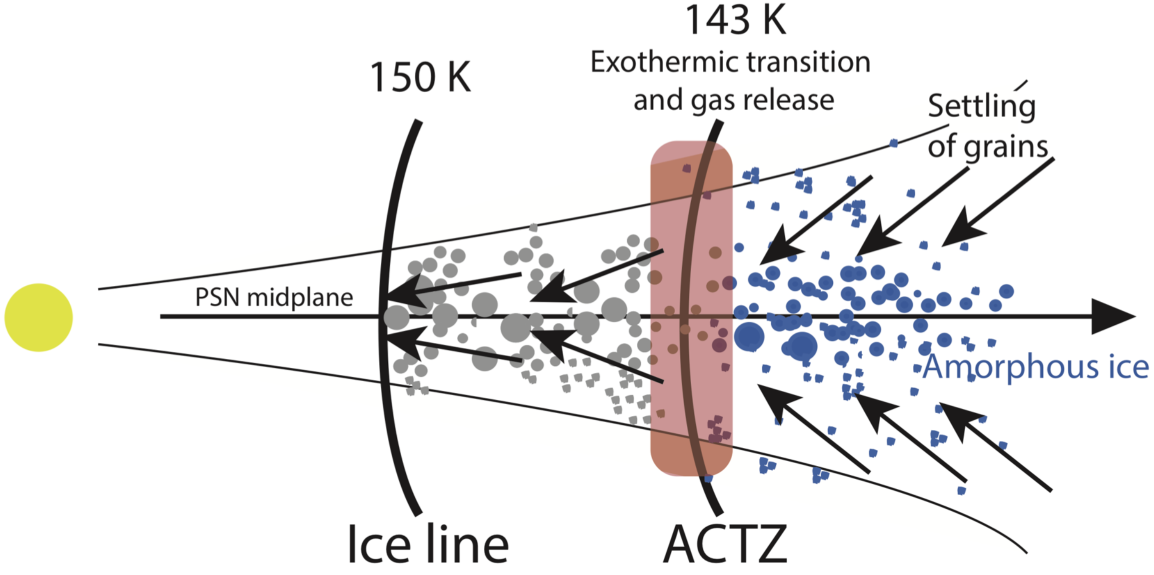
(Lambrechts & Johansen 2014)

Delivery of Volatiles to the Giant Planets – Vapors

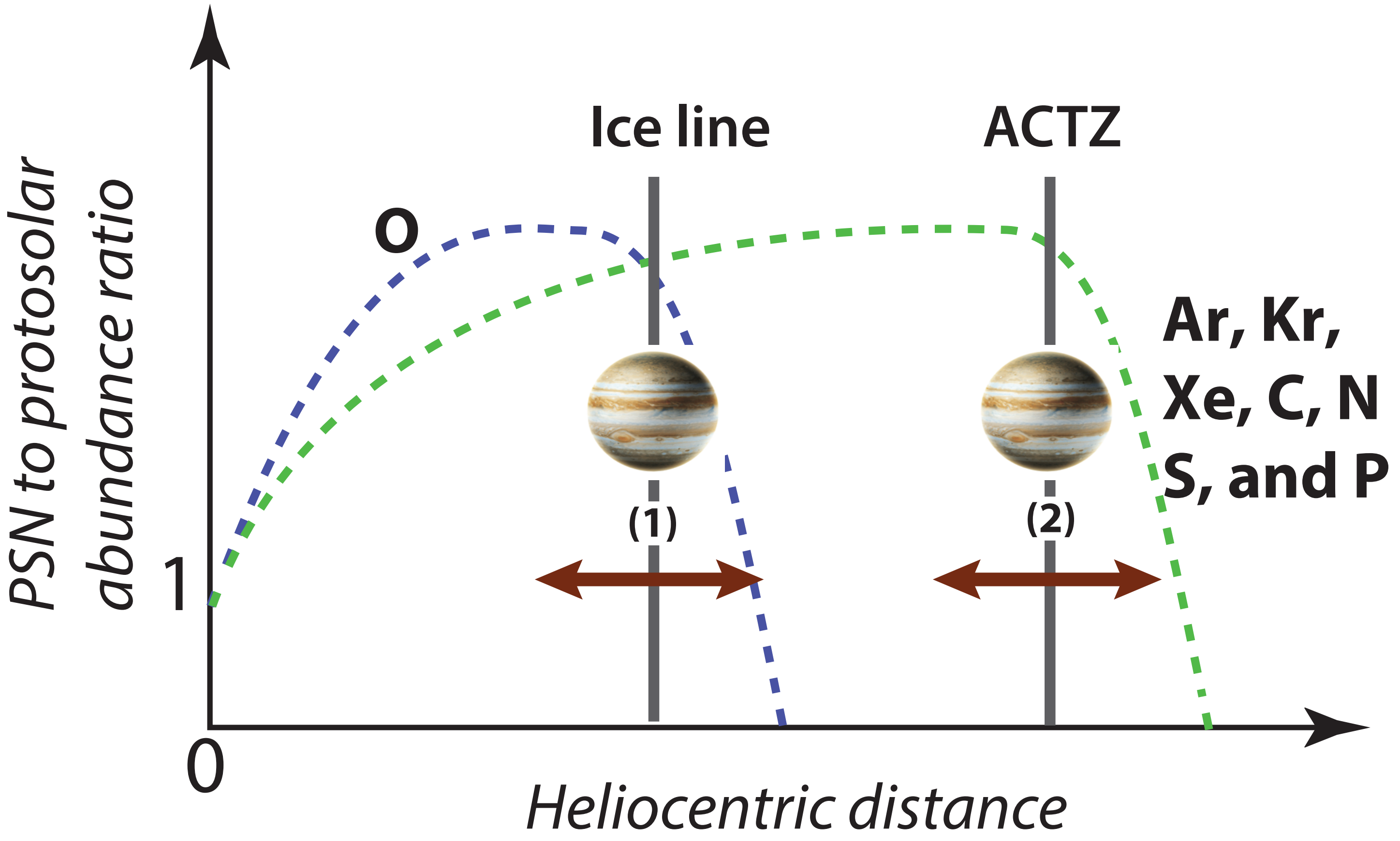


Production of **amorphous ice** via photoevaporation (Monga & Desch 2015)

Release of volatiles at the ACTZ
(Mousis, Ronnet, & Lunine 2019)



Release of volatiles from the ACTZ: the water abundance in Jupiter?

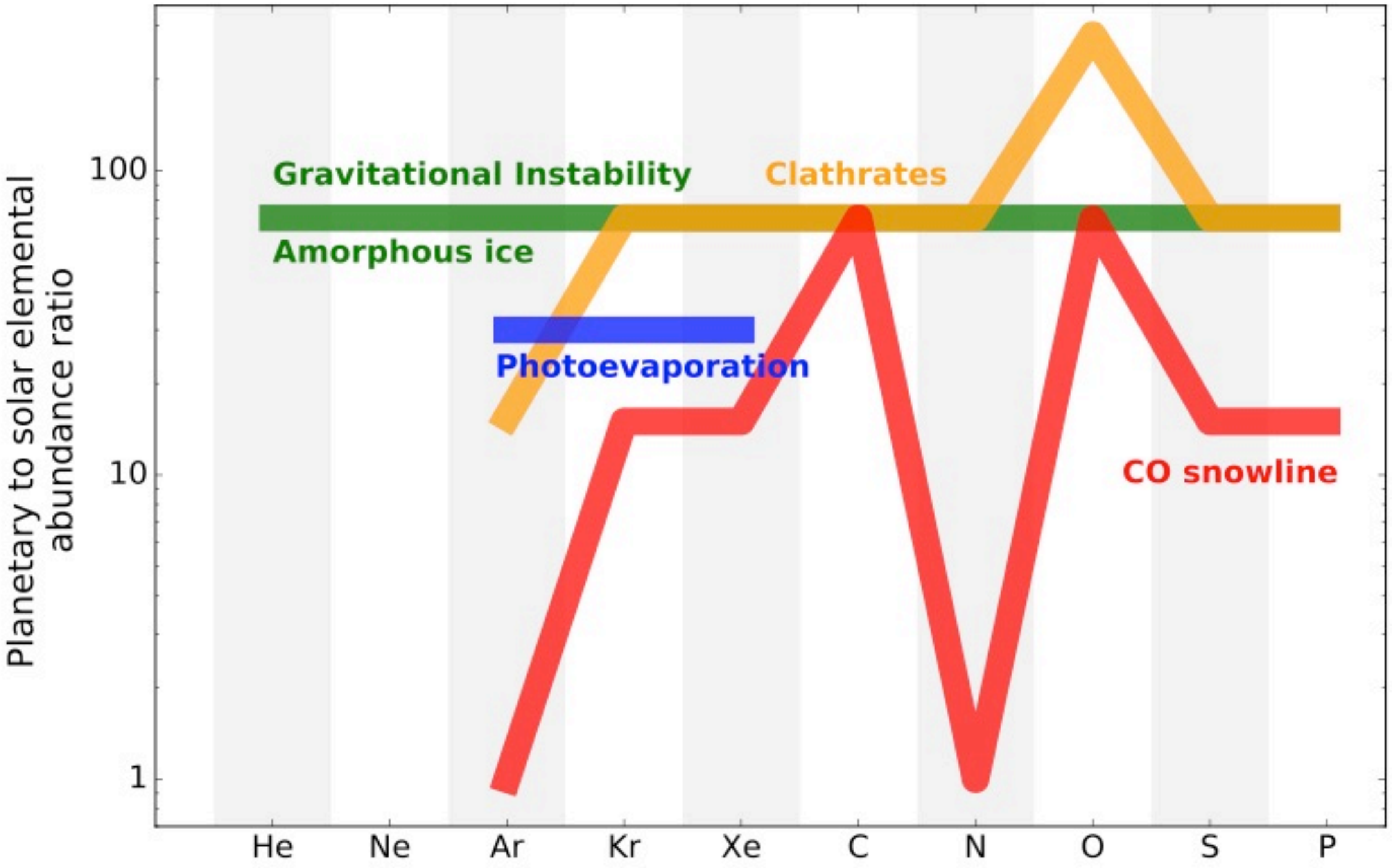


Influence of Jupiter's formation location on the oxygen content in its envelope, assuming that H2O is the main O–bearing volatile in the PSN. Here, Jupiter's feeding zone contains water in both solid and vapor forms while the other volatiles remain exclusively in vapor phase once released from the amorphous particles crossing the ACTZ. Two extreme cases can be envisaged for the oxygen abundance in Jupiter's envelope:

(1) Jupiter's formation around the ice line where the O abundance is supersolar,
(2) Formation around the ACTZ where Jupiter's O abundance is smaller, and eventually subsolar

Mousis, Ronnet & Lunine (2019)

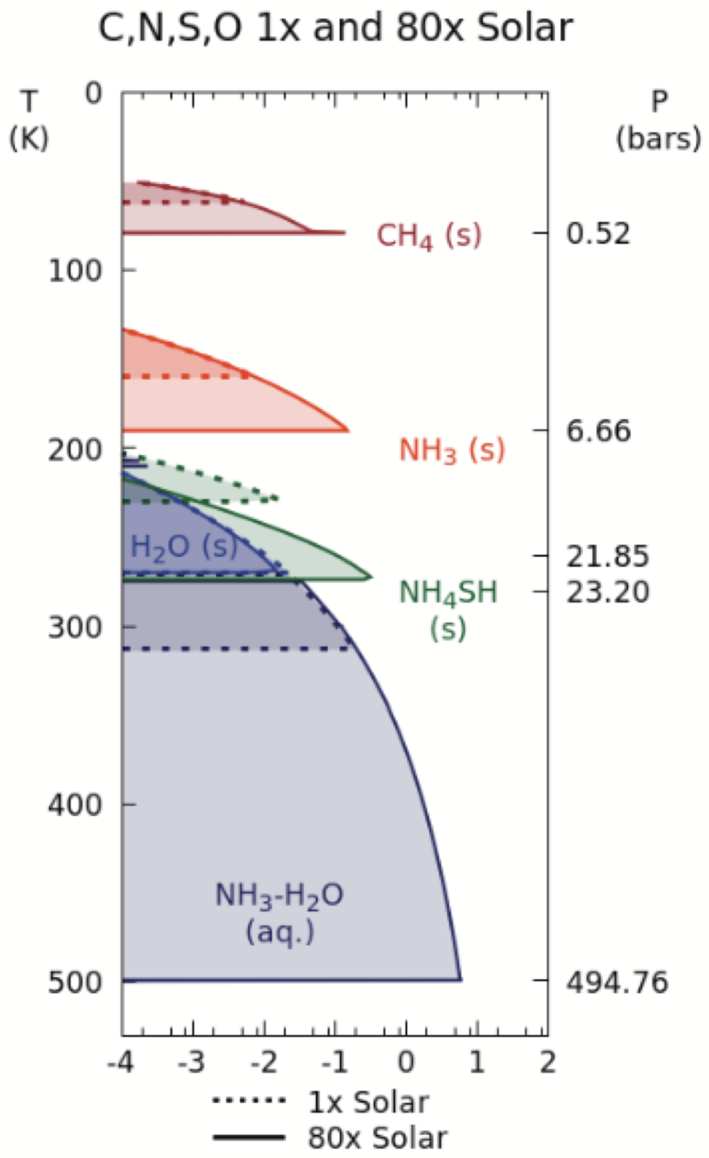
Different scenarios of volatile enrichments in giant planets



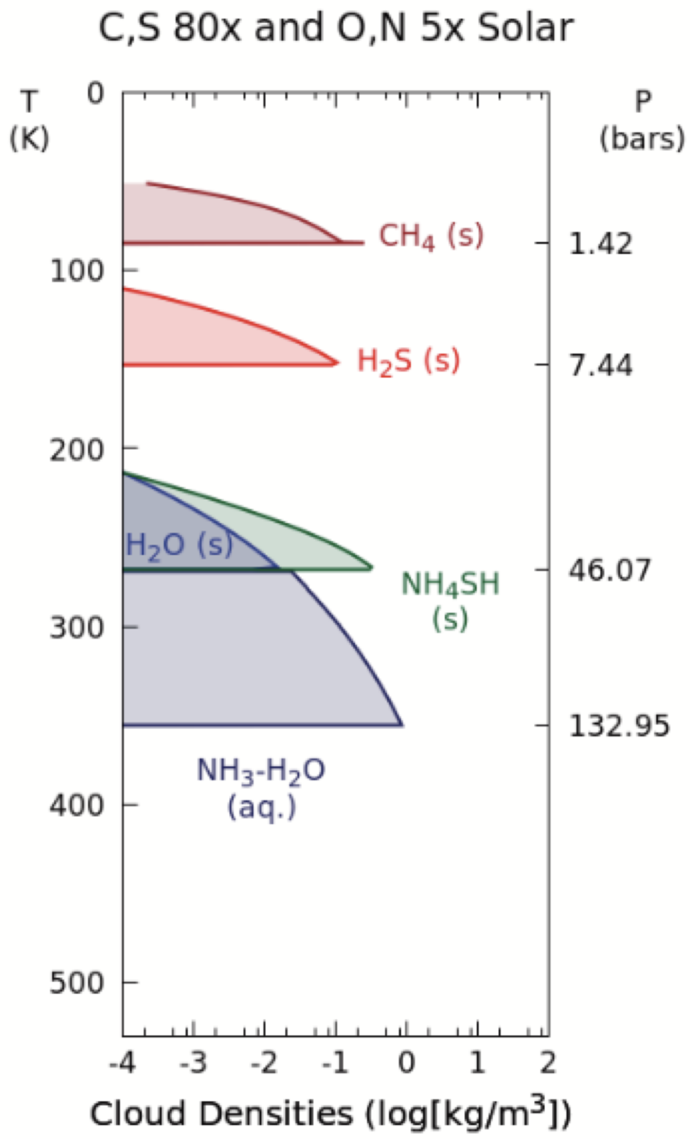
Mousis, Atkinson et al. (2018)

Where does the bulk composition lie? The cases of Uranus and Neptune

C,N,S,O 1x and 80x Solar



C,S 80x and O,N 5x Solar



- **Noble gases and their isotopes**:

Anywhere below 1-bar level

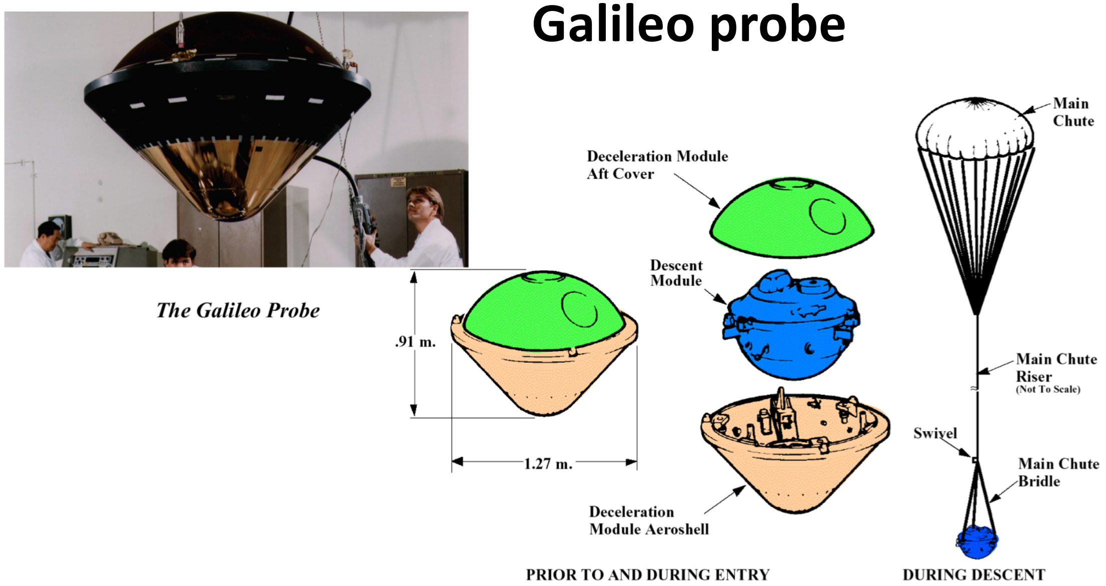
CH_4, NH_3, H_2S, H_2O:

below the cloud. being much colder than Jupiter, the clouds of Uranus and Neptune lie much deeper

Atreya et al. (2018)

Heritage and Previous Studies

Galileo probe


The Galileo Probe


NASA TECHNICAL
MEMORANDUM

N73-30800
NASA TM X-2824

NASA TM X-2824

CASE FILE
COPY

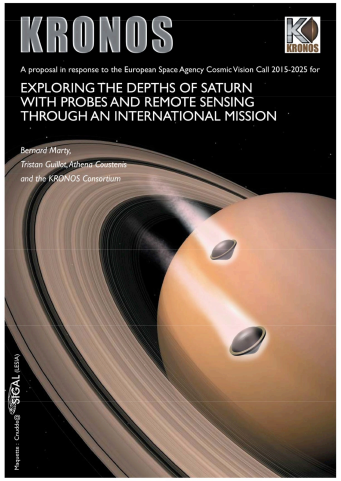
MISSION PLANNING FOR
PIONEER SATURN/URANUS
ATMOSPHERIC PROBE MISSIONS

by Byron L. Swenson, Edward L. Tindle,
and Larry A. Manning

Ames Research Center
Moffett Field, Calif. 94035

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • SEPTEMBER 1973

NASA 1973


KRONOS

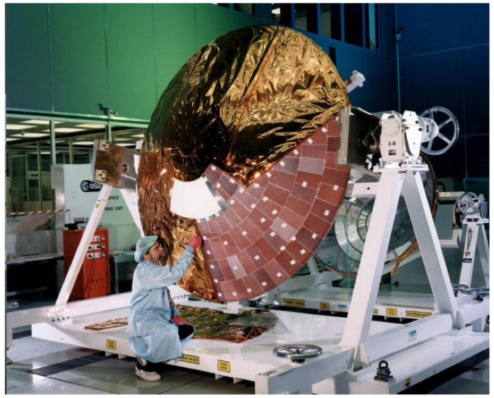
A proposal in response to the European Space Agency Cosmic Vision Call 2015-2025 for

EXPLORING THE DEPTHS OF SATURN
WITH PROBES AND REMOTE SENSING
THROUGH AN INTERNATIONAL MISSION

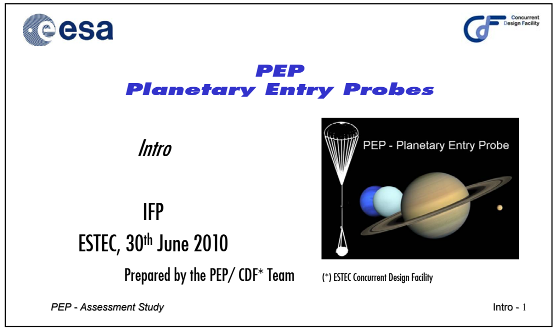
Bernard Marty,
Tristan Guillot, Athena Coustenis
and the KRONOS Consortium

Maquette : Cnudde@ SIGAL (LESIA)

ESA KRONOS proposal



ESA Huygens probe


esa

Concurrent Design Facility

PEP
Planetary Entry Probes

Intro

IFP
ESTEC, 30th June 2010
Prepared by the PEP/ CDF* Team

PEP - Planetary Entry Probe

(*) ESTEC Concurrent Design Facility

PEP - Assessment Study

Intro - 1

ESA PEP study