HERA SATURN ENTRY PROBE MISSION

Unveilling the Depths of Saturn with a Shallow Probe through an International Mission

Olivier Mousis, David H. Atkinson and the Hera team

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Hera: Saturn Entry Probe Mission

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THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 32: 737–755, 1976 December

PARTICLES, ENVIRONMENTS, AND POSSIBLE ECOLOGIES IN THE JOVIAN ATMOSPHERE

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Received 1975 December 11; revised 1976 June 1

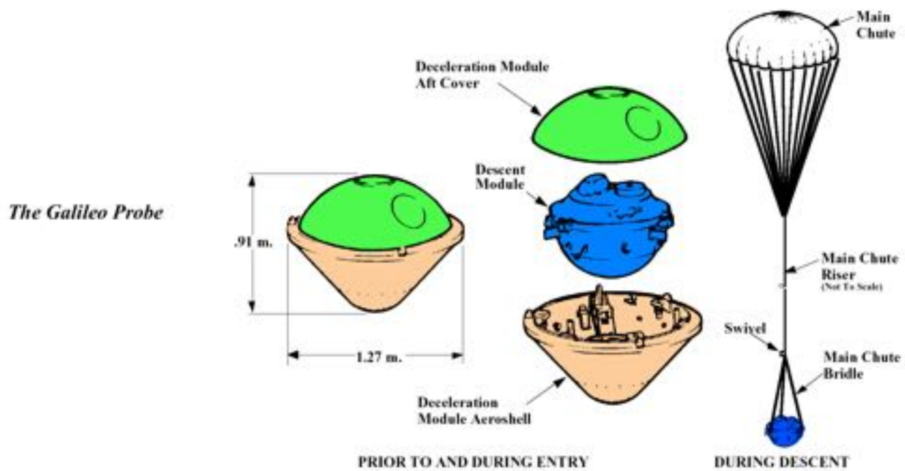
ABSTRACT

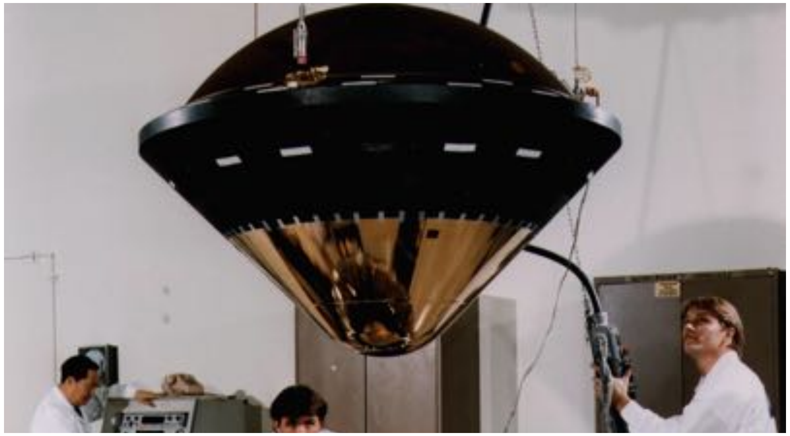
The eddy diffusion coefficient is estimated as a function of altitude, separately for the Jovian troposphere and mesosphere. The growth-rate and motion of particles is estimated for various substances: the water clouds are probably nucleated by NH_4Cl, and sodium compounds are likely to be absent at and above the levels of the water clouds. Complex organic molecules produced by the Lα photolysis of methane may possibly be the absorbers in the lower mesosphere which account for the low reflectivity of Jupiter in the near-ultraviolet. The optical frequency chromophores are localized at or just below the Jovian tropopause. Candidate chromophore molecules must satisfy the condition that they are produced sufficiently rapidly that convective pyrolysis maintains the observed chromophore optical depth. Organic molecules and polymeric sulfur produced through H_2S photolysis at $\lambda > 2300$ Å probably fail this test, even if a slow, deep circulation pattern, driven by latent heat, is present. The condition may be satisfied if complex organic chromophores are produced with high quantum yield by NH_3 photolysis at $\lambda < 2300$ Å. However, Jovian photoautotrophs in the upper troposphere satisfy this condition well, even with fast circulation, assuming only biochemical properties of comparable terrestrial organisms. Unless buoyancy can be achieved, a hypothetical organism drifts downward and is pyrolyzed. An organism in the form of a thin, gas-filled balloon can grow fast enough to replicate if (i) it can survive at the low mesospheric temperatures, or if (ii) photosynthesis occurs in the troposphere. If hypothetical organisms are capable of slow, powered locomotion and coalescence, they can grow large enough to achieve buoyancy. Ecological niches for sinkers, floaters, and hunters appear to exist in the Jovian atmosphere.

Subject headings: planets: atmospheres — planets: Jupiter

Heritage and previous studies

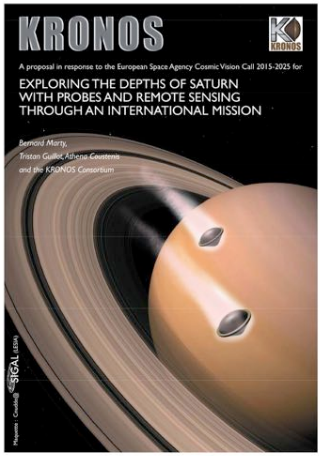
Galileo probe

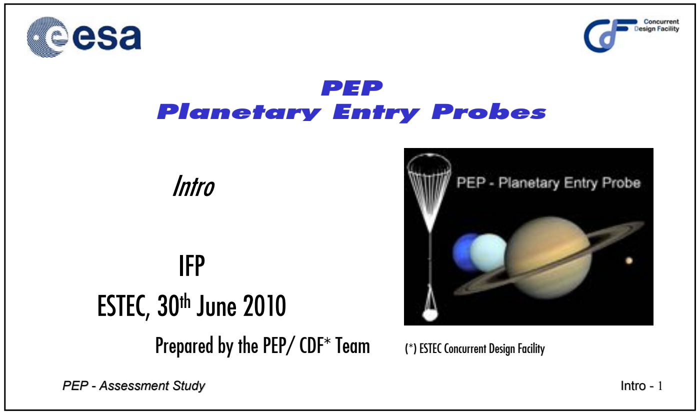




KRONOS ESA proposal

ESA Huygens probe





ESA PEP study

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** when used 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 our understanding of Jupiter, but one can wonder if these measurements are really representative or not of the **whole set of giant planets of the solar system**.

Space Exploration of gaseous giant planets

GALILEO
Orbiter
System exploration

CASSINI
Orbiter
System exploration

JUNO
Internal structure

CASSINI
Proximal Orbits
Internal structure

GALILEO Probe
Atmospheric
structure and
composition

SATURN Probe
Atmospheric
structure and
composition

Measurements of the volatile abundances in the giant planets of the Solar System

Element	Jupiter/Sun	Saturn/Sun	Uranus/Sun	Neptune/Sun
He	0.8 – 0.9	0.6 – 0.8	0.9 – 1	0.9 – 1
Ne	0.07 – 0.12	?	?	?
O	0.2 – 0.5	?	?	?
C	3.2 – 5.4	8.6 – 10.6	20 - 30	30 - 50
N	2.0 – 6.1	1.6 – 3.9	?	?
S	2.2 – 3.5	12.05	?	?
P	2.9 – 3.7	9.9 – 12.5	?	?
Ar	1.7 – 3.4	?	?	?
Kr	1.6 – 2.75	?	?	?
Xe	1.5 – 2.70	?	?	?
Isotope	**Jupiter**	**Saturn**	**Uranus**	**Neptune**
D/H	2.6×10^{-5}	2.3×10^{-5}	4.4×10^{-5}	4.1×10^{-5}
$^{3}He/^{4}He$	1.7×10^{-5}	?	?	?
$^{14}N/^{15}N$	430	>500	?	?

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C	3.2 – 5.4	8.6 – 10.6	20 - 30	30 - 50
N	2.0 – 6.1	?	?	?
S	2.2 – 3.5	?	?	?
P	2.9 – 3.7	?	?	?
Ar	1.7 – 3.4	?	?	?
Kr	1.6 – 2.75	?	?	?
Xe	1.5 – 2.70	?	?	?
Isotope	**Jupiter**	**Saturn**	**Uranus**	**Neptune**
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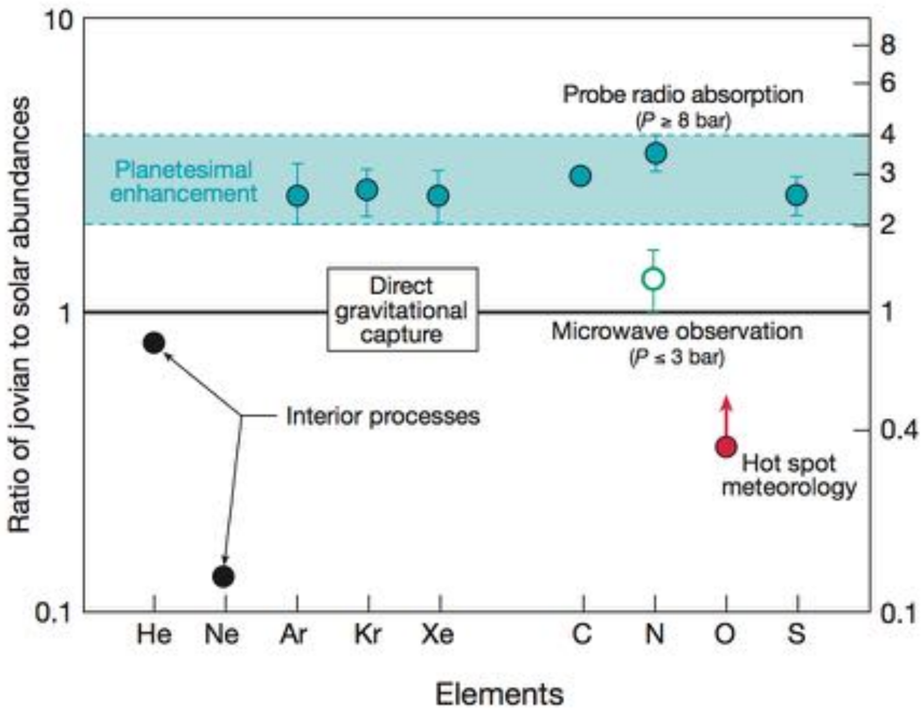
$^{3}He/^{4}He$	1.7×10^{-5}	?	?	?
$^{14}N/^{15}N$	430	>500	?	?

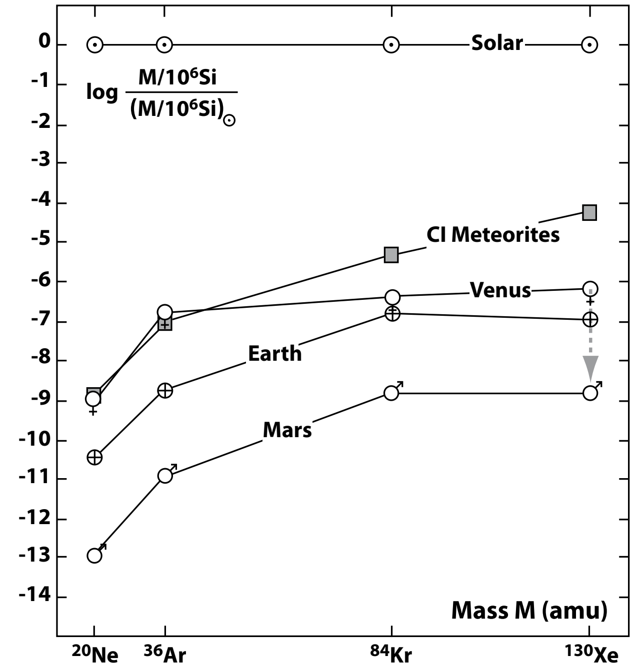
Isotopic ratios measured in Jupiter and Saturn

	Jupiter			Saturn		
Isotopic ratio	Measurement	Uncertainty	Ref.	Measurement	Uncertainty	Ref.
D/H (in H_2)	2.60×10^{-5}	0.70×10^{-5}	[50]	1.70×10^{-5}	$^{+0.75}_{-0.45} \times 10^{-5}$	[51]
				1.80×10^{-5}	$\pm 0.5 \times 10^{-5}$	[52]
$^{3}He/^{4}He$	1.66×10^{-4}	0.05×10^{-4}	[50]	-	-	
$^{12}C/^{13}C$ (in CH_4)	92.6	$^{+4.5}_{-4.1}$	[49]	91.8	$^{+8.4}_{-7.8}$	[41]
$^{14}N/^{15}N$ (in NH_3)	434.8	$^{+65}_{-50}$	[32]	-	> 500	[60]
$^{20}Ne/^{22}Ne$	13.0	2.0	[31]	-	-	-
$^{36}Ar/^{38}Ar$	5.6	0.25	[31]	-	-	-
^{128}Xe/total Xe	0.018	0.002	[28]	-	-	-
^{129}Xe/total Xe	0.285	0.021	[28]	-	-	-
^{130}Xe/total Xe	0.038	0.005	[28]	-	-	-
^{131}Xe/total Xe	0.203	0.018	[28]	-	-	-
^{132}Xe/total Xe	0.290	0.020	[28]	-	-	-
^{134}Xe/total Xe	0.091	0.007	[28]	-	-	-
^{136}Xe/total Xe	0.076	0.009	[28]	-	-	-

A highly desirable measurement: the noble gases in Saturn's atmosphere



Owen et al. (1999)

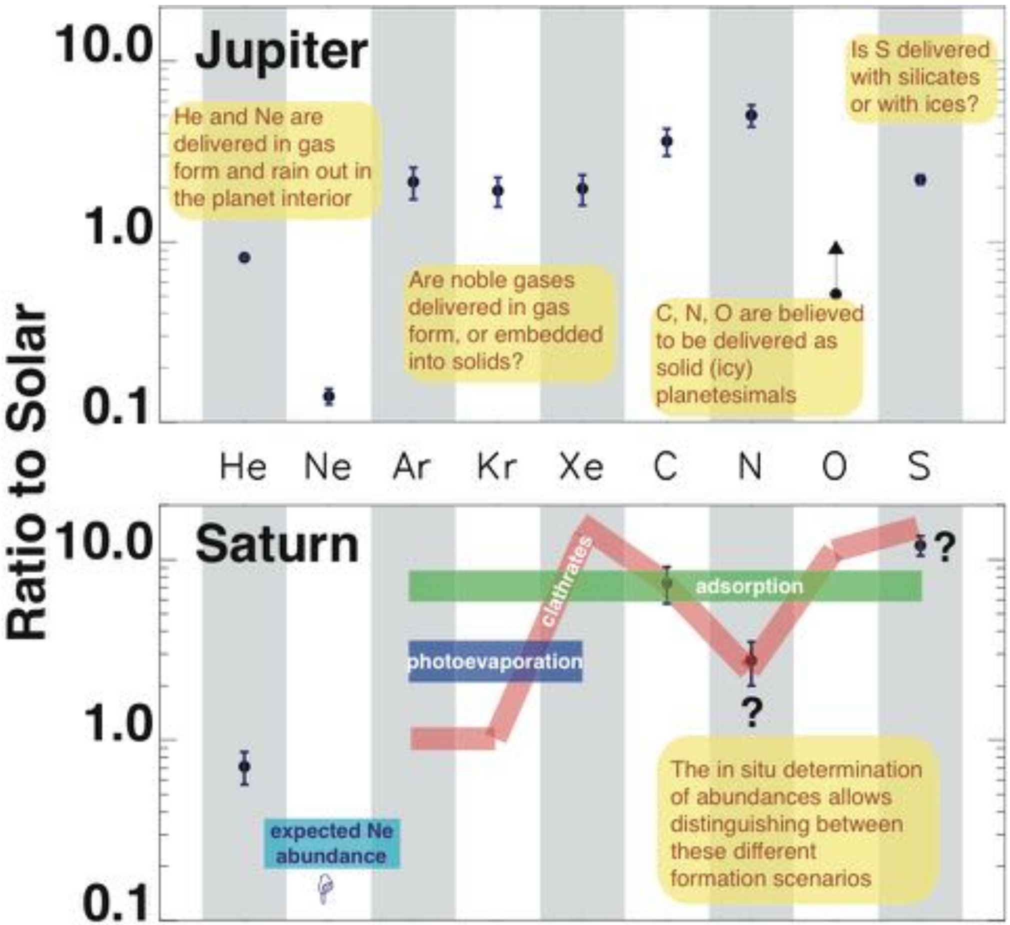


Mousis et al. (2010)

- ❑ Noble gases have been measured in telluric planets, in meteorites and in Jupiter
- ❑ In situ measurements by Huygens have shown that Titan is impoverished in Ar, Kr and Xe
- ❑ Despite many attempts, no firm detection of noble gases in comets

=> **The noble gases measurements in Saturn are expected to provide strong constraints on its formation conditions as well as on the origin of the outer solar system**

A Saturn probe – clues to the origin of the Solar System



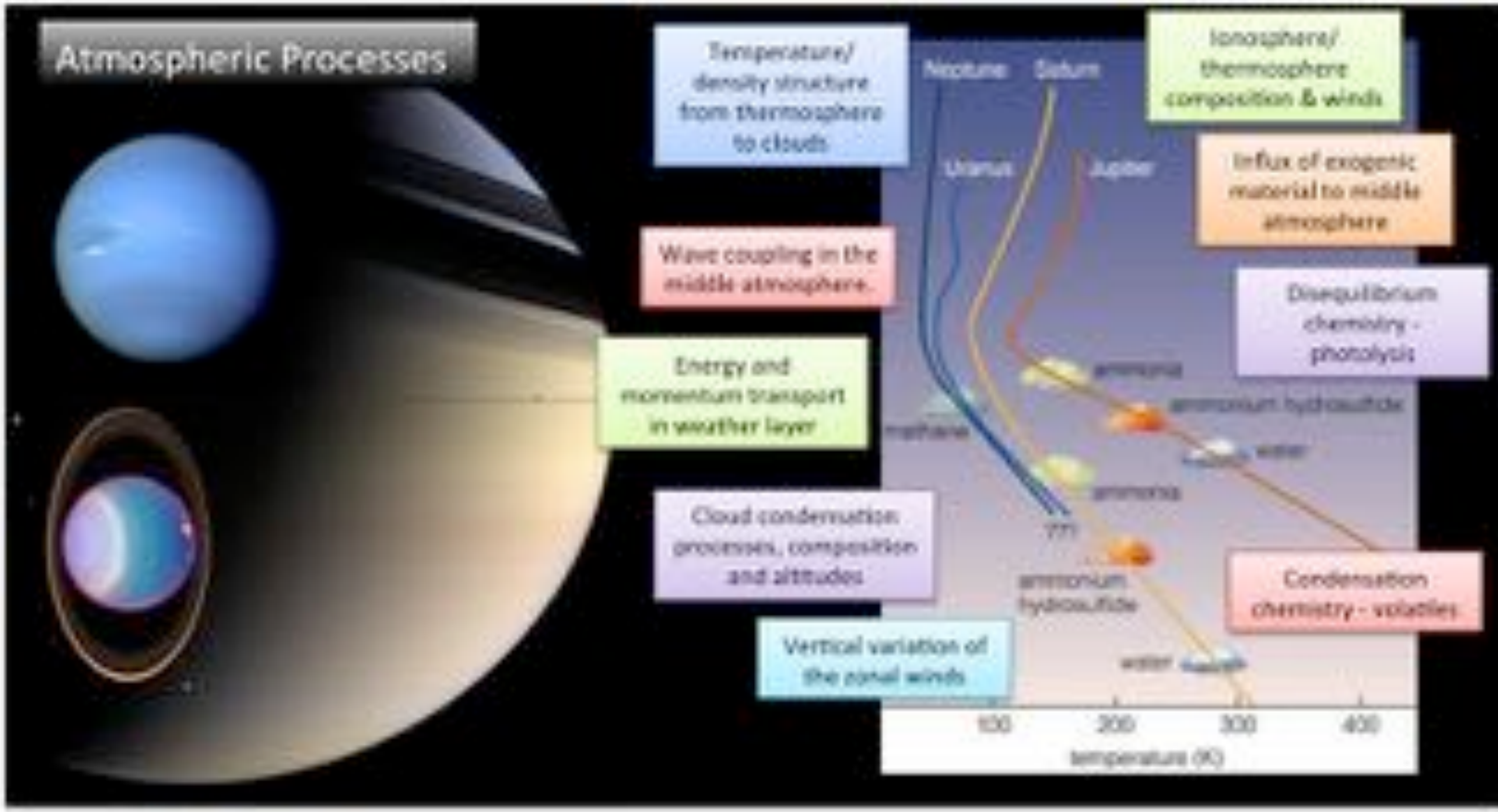
Adapted from Marty et al. (2009)

- Did Saturn form following the core accretion model or via the gravitational collapse scenario?
- Did Saturn form with Jupiter, or after?
- Did Saturn form at its current heliocentric distance?

Saturn's composition and its comparison to Jupiter is a key to understand the processes (condensation, clathration, photoevaporation) that occurred in the outer part of the protosolar nebula

SATURN

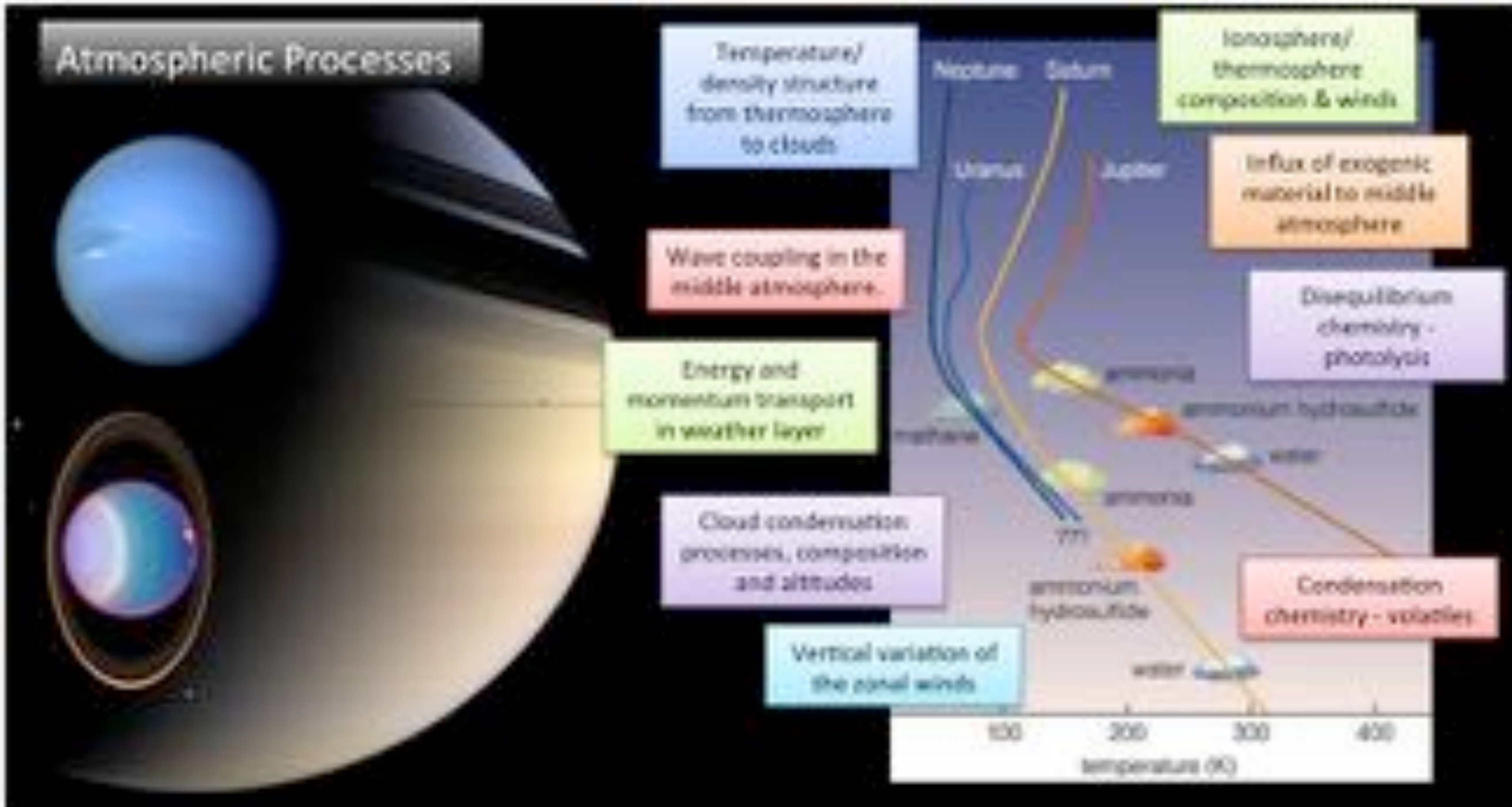
AS A METEOROLOGICAL LABORATORY



- What processes are shaping the dynamics and circulation from the thermosphere to the deep troposphere?
- What are the properties and conditions for cloud formation as a function of depth and temperature in planetary atmospheres?

SATURN

AS A METEOROLOGICAL LABORATORY



In situ studies allow studying the **chemical, dynamical, and aerosol-forming processes at work from the thermosphere to the troposphere below the cloud decks**

Suite of scientific instruments

Instrument	Measurement
Mass Spectrometer (MS)	Elemental and chemical composition Isotopic composition High molecular mass organics
Atmospheric Structure Instrument (ASI)	Pressure, temperature, density, molecular weight profile, lightning
Radio Science Experiment (RSE)	Measure winds, speed and direction Chemical composition
Nephelometer	Cloud structure, solid/liquid particles
Net-flux radiometer (NFR)	Thermal/solar energy

Science Traceability Matrix

<u>Science Priority 1:</u> Saturn's origin
<u>Science Priorities 2 and 3:</u> composition, structure and evolution of Saturn's atmosphere

Science Goals	Science Objectives	Science Priority	Science Questions	Scientific Measurements	Instrument
Understand the formation of the Giant Planets and their roles in the evolution of the solar system	Determine the composition of Saturn's well-mixed atmosphere beneath the clouds	1.1	What is the abundance of helium relative to H_2?	He/H_2 ratio to an accuracy of 2%	MS
		1.2	What are the well-mixed abundances of the noble gases?	Ne/H, Ar/H, Kr/H, Xe/H to a precision of ± 10%	MS
		1.3	What are the abundance profiles of key cosmogenic species?	C/H, N/H and S/H: ± 5%	MS, ASI, RSE/AAbs
		2.1 3.1	What are the most important reservoirs for main isotopes of H, He helium, nitrogen, carbon, oxygen, neon and heavy noble gases?	$^{14}N/^{15}N$, $^{12}C/^{13}C$ D/H: ± 5% $^{3}He/^{4}He$: ± 3% Ne, Ar, Kr and Xe isotopes: ± 1% $^{18}O/^{16}O$, $^{17}O/^{16}O$: ± 1%	MS ASI

Science Traceability Matrix

Understand Giant Planet atmospheric circulation, the processes by which energy is transferred outwards from their interior, and the structure of the cloud layers.	**Determine the compositional, thermal, and dynamical structure of Saturn's atmosphere**	**2.2**	What is the vertical structure of Saturn's atmospheric temperatures and stability?	Pressure: ± 1% Temperature: ± 1 K from the upper atmosphere to 10 bar.	ASI
		3.4	How do atmospheric winds and wave phenomena vary as a function of depth?	Profile of descent probe telemetry Doppler frequencies Zonal Winds: ±1 m/s from 0.1-10 bar	RSE/DWE Camera
		3.2	How do convective motions and vertical mixing shape the vertical distribution of chemical species?	Vertical profiles of NH_3, H_2S, H_2O, PH_3, AsH_3, GeH_4, CO: ±10%	MS ASI
		3.3	What is the vertical structure, composition and properties of Saturn's cloud and haze layers?	Particle optical properties, size distributions, number and mass densities, opacity, shapes, and composition	Nephelo-meter
		3.5	What is the radiative energy balance of the atmosphere?	Up & down visible flux: ~0.4-5µm; Up & down IR flux: 4-50µm; $\lambda/\Delta\lambda$~0.1-100 ΔFlux ~0.5 Wm^{-2}	NFR

Table F.1 Work Breakdown Structure for *Hera* Science Instruments

Instrument			Lead	Support
1.0		**Cameras (on Carrier)**	O. Mousis, PI (FR)	L. Fletcher Co-PI (UK) R. Hueso (ES) ; F.-X. Schmider (FR)
	1.1	Camera optics & mechanics	P. Levacher, System Engineer (FR)	
	1.2	CMOS chip & Electronics	A. Holland (UK)	J. Endicott (UK); M. Leese (UK)
	1.3	Filter Wheels	R. Hueso (ES)	C. Ortega (ES); M. A. Carrera (ES)
	1.4	Electronics box	P. Levacher (FR)	
2.0		**Probe Mass Spectrometer (MS)**	P. Wurz, PI (CH)	J. H. Waite, Co-PI (USA); A. Morse (UK)
	2.1	TOF-MS, MS Swiss element	P. Wurz (CH)	
	2.2	GSES, MS US element	J. H. Waite (USA)	
	2.3	RGS, MS UK element	A. Morse (UK)	S. Sheridan (UK)
3.0		**Probe Atmospheric Structure Investigation (ASI)**	F. Ferri, PI (IT)	A. Colaprete, Co-PI (USA); G. Fischer (AUT)
	3.1	Accelerometers (ACC)		
	3.2	Pressure sensors (PPI)		
	3.3	Temperature Sensors (TEM)		
	3.4	Atmospheric Electricity Package (AEP)		
	3.5	ASI Processor (DPU)		
4.0		**Radio Science (Probe and Carrier)**	D. Atkinson, PI (USA)	T. Spilker (USA)
	4.1	Doppler Wind Experiment	D. Atkinson (USA)	M. Bird (DE)
	4.2	Atmospheric UHF Absorption/NH_3 abundance	D. Atkinson (USA)	T. Spilker (USA)
5.0		**Probe Net Flux Radiometer (NFR)**	M. Amato, PI (USA)	S. Aslam (USA); C. Nixon (USA)
	5.1	Instrument: optics, electronics, mechanical	S. Aslam (USA)	M. Amato, PI (USA)
	5.2	Detector (Germany) and rad hard ROIC (USA)	E. Kessler (DE)	M. Amato, PI (USA)
	5.3	Filters	S. Calcutt (UK)	
6.0		**Probe Nephelometer**	Daphne Stam, PI (NL)	J.-B. Renard, (FR); O. Munoz (ES); D. Banfield (USA)
	6.1	Light Optical Aerosol Counter (LOAC)	J.-B. Renard (FR)	
	6.2	PAVO Optics	C. Keller (NL)	F. Snik (NL)
	6.3	PAVO Detector & Elect.	D. Stam (NL)	

Mission concepts based on the combination of a NASA CRSC and an ESA SP

Different mission architectures are envisaged, all based on an entry probe that would descend through Saturn's stratosphere and troposphere under parachute down to a **minimum of 10 bars:**

- **Configuration 1: Probe + Saturn Orbiter** (similar to the Galileo Orbiter/Probe). The probe would detach from the CRSC several weeks/months prior to probe entry. The CRSC trajectory would be designed to enable probe data relay during over-flight before its transit to a Saturn orbit to perform orbital science.

- **Configuration 2: Probe + Titan or Enceladus Orbiter** (the opposite of Cassini-Huygens). Same as (1) but the carrier trajectory would be designed to transit to a Titan or an Enceladus orbit to perform satellite science.

- **Configuration 3: Probe + CRSC en route to Uranus/Neptune.** After probe delivery and data relay during over-flight, the carrier would follow its journey towards the icy giants.

Core science mission profile

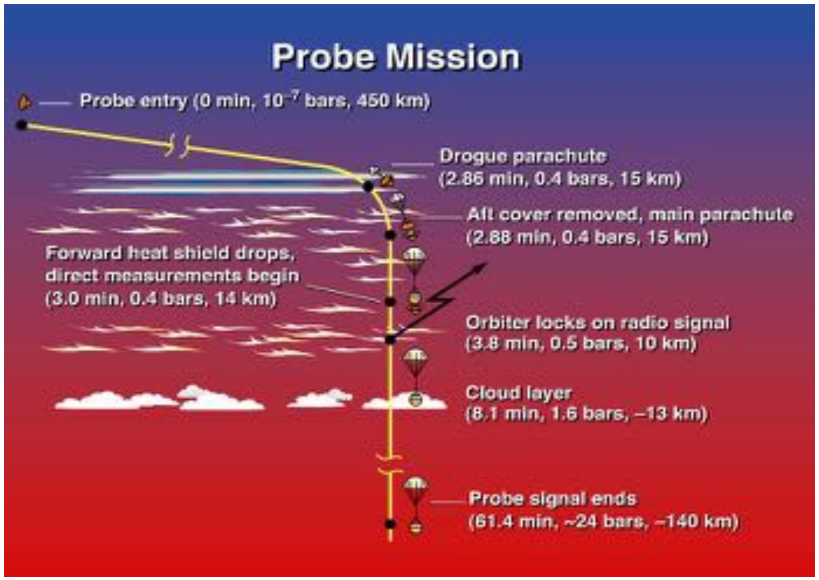


Figure E.1 *Galileo entry, descent and deployment sequence shown above will be the basis for the proposed Saturn mission.*

Table E.1 Entry System Mass Estimates

Entry Flight Path Angle (EFPA), degrees	-8	-19
	Mass, kg	
Entry System (total mass)	216	200
Deceleration module	92.5	76.5
Forebody TPS (HEEET)	40	24
Afterbody TPS	10.5	10.5
Structure	18.3	18.3
Parachute	8.2	8.2
Separate Hardware	6.9	6.9
Harness	4.3	4.3
Thermal Control	4.4	4.4
Descent Module	117.2	117.2
Communication	13	13
C&DH Subsystem	18.4	18.4
Power Subsystem	19.8	19.8
Structure	30	30
Harness	9.1	9.1
Thermal Control	4.3	4.3
Science Instrument	28	28
Separate Hardware	0.9	0.9

Note. *Deceleration of (or Entry System) module 1m diameter aeroshell, 36 km/s inertial velocity, 10 deg latitude). The descent module mass estimate, except for the Science Instruments, are the same as that of Galileo Probe. Additional mass savings are likely when the descent system structure is adjusted for reduction in scale as well as entry g-load. Galileo design-to g-load was 350. Saturn probe entry g-load with 3-sigma excursions will be less than 150 g's.*

Hera Saturn Entry Probe Mission

*A Proposal in Response
to the ESA Call for a
Medium-size mission opportunity
in ESA's Science Programme
for launch in 2029-2030 (M5)*

Olivier J. Mousis,
David H. Atkinson
and the Hera Team

October 5, 2016

http://hera.lam.fr