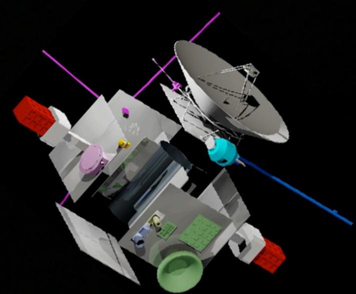
A European perspective on Uranus mission architectures

Chris Arridge[1,2]

1. Mullard Space Science Laboratory, UCL, UK.
2. The Centre for Planetary Sciences at UCL/Birkbeck, UK.

Twitter: @chrisarridge



Ice Giants Workshop – JHU Applied Physics Laboratory, MD, USA – 30 July 2014

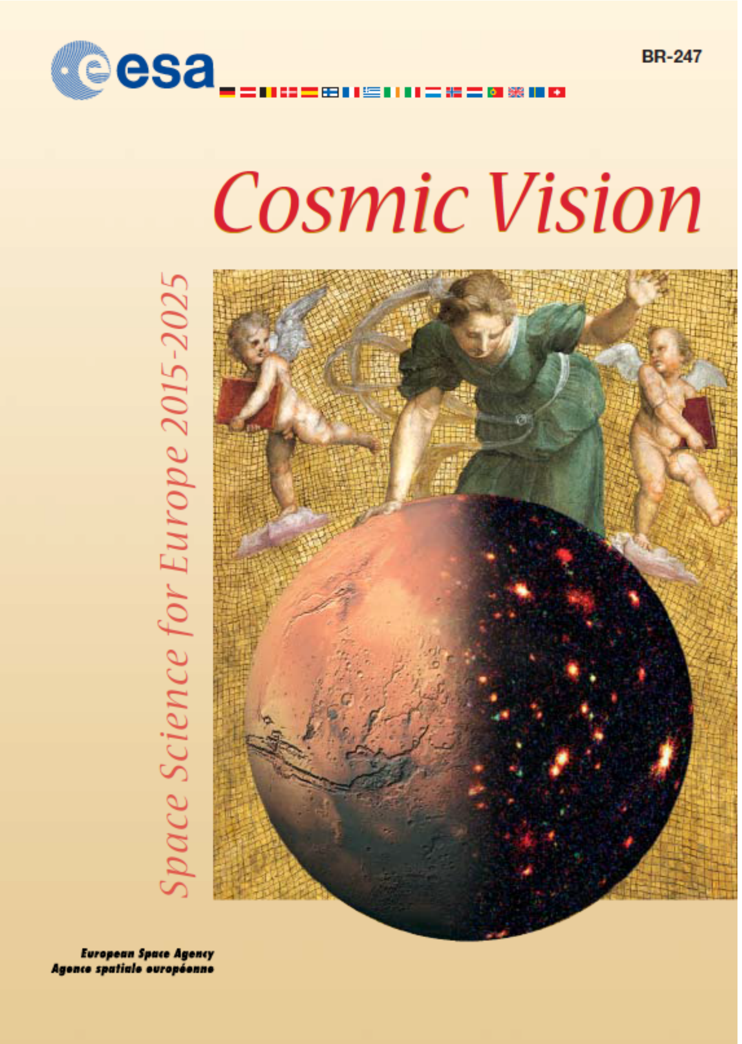
Overview of the Cosmic Vision

- Originated with Horizon and Horizon+ programmes.
  - Missions born from that programme include Mars Express, Venus Express, ROSETTA, HERSCHEL, Huygens, HST.

- Cosmic Vision driven by scientific themes:
  1. What are the conditions for planetary formation and the emergence of life?
  2. How does the Solar System work?
  3. What are the physical fundamental laws of the Universe?
  4. How did the Universe originate and what is it made of?

- Part of ESA's mandatory programme – contributions from member states weighted by GDP,

- Operate according to a set of guidelines that broadly-speaking demand a programmatic balance (between scientific domains) and due return.



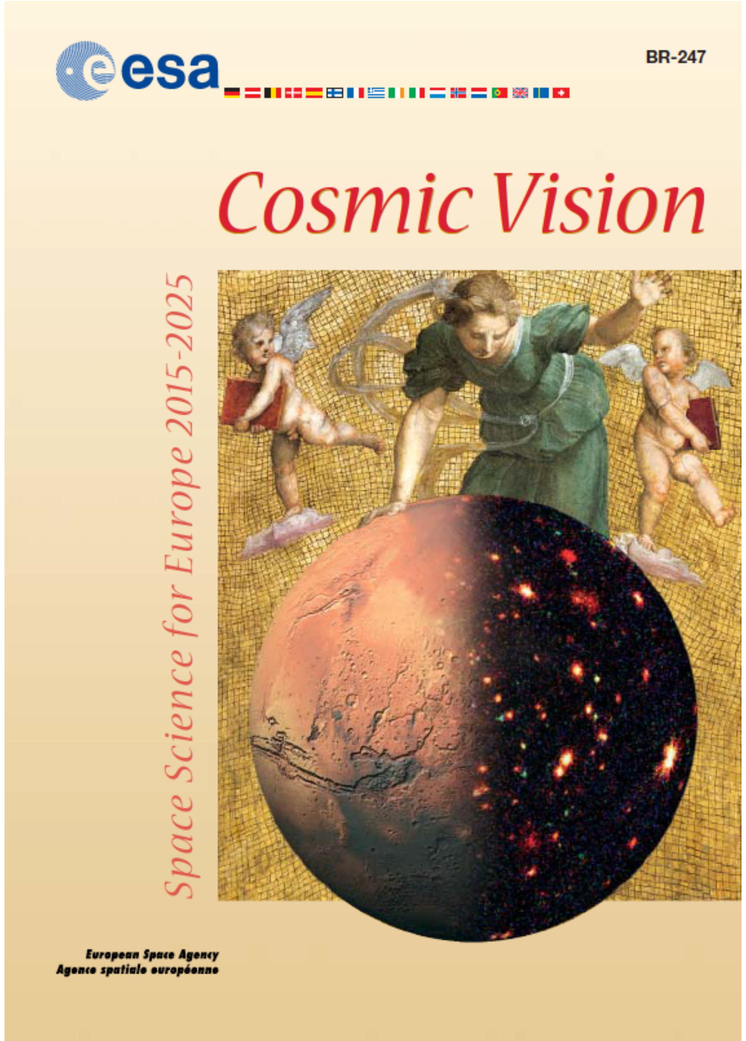
Overview of the Cosmic Vision

- Originated with Horizon and Horizon+ programmes.
  - Missions born from that programme include Mars Express, Venus Express, ROSETTA, HERSCHEL, Huygens, HST.

- Cosmic Vision driven by scientific themes:
  1. **What are the conditions for planetary formation and the emergence of life?**
  2. **How does the Solar System work?**
  3. **What are the physical fundamental laws of the Universe?**
  4. How did the Universe originate and what is it made of?

- Part of ESA's mandatory programme – contributions from member states weighted by GDP,

- Operate according to a set of guidelines that broadly-speaking demand a programmatic balance (between scientific domains) and due return.



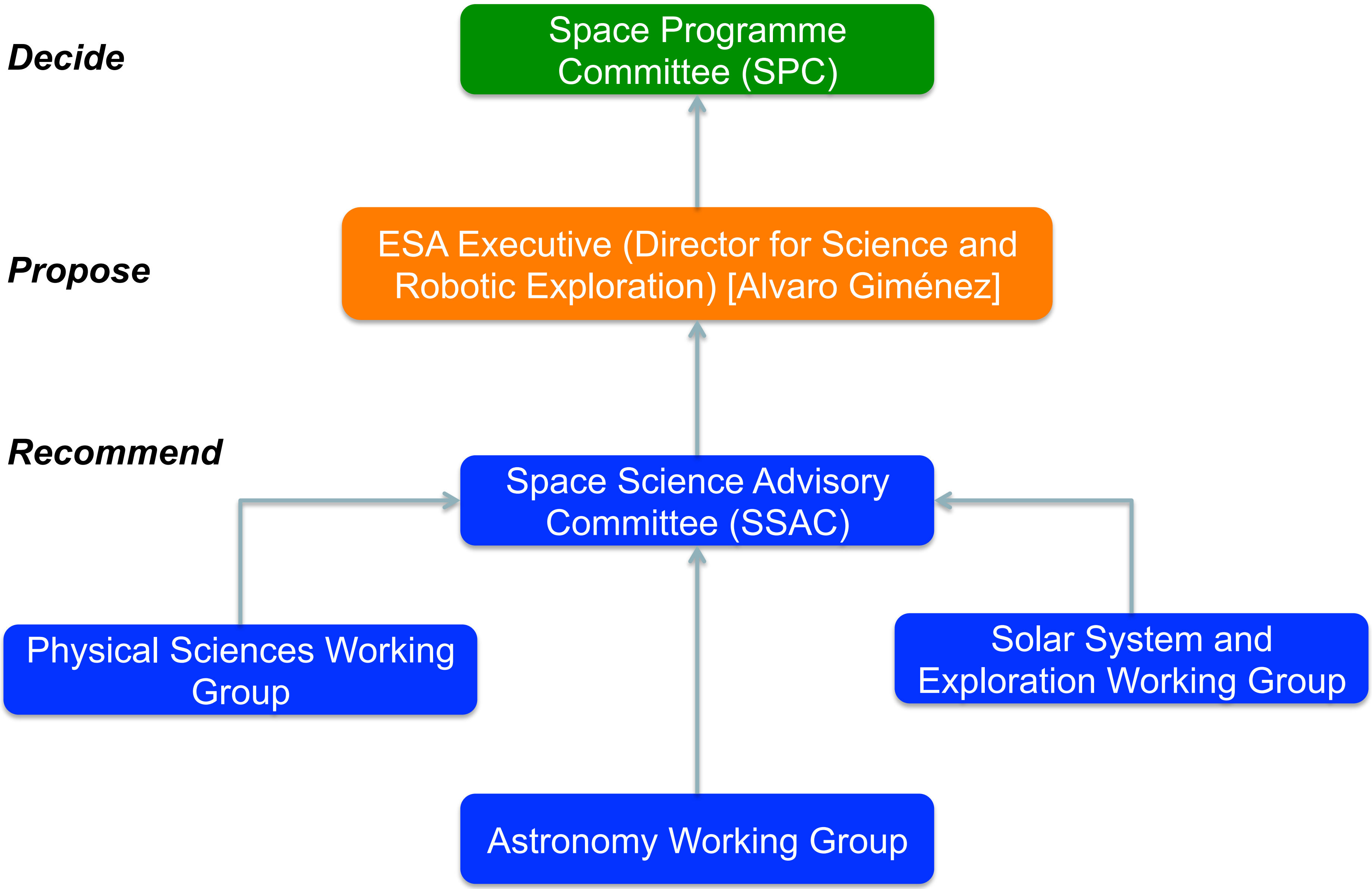
Mission classes

- Medium “M”-class: 500 M€ - example Solar Orbiter.
- Large “L”-class: ~1000 M€ - example JUICE
- These figures are the cost at completion (CaC) numbers and include study phase, launch vehicle, spacecraft, operations, an ESA management top-slice, but **not instruments**.
- The expected cost breakdown is roughly: 55% spacecraft industrial activity [260M€], 15% launch (assuming Soyuz-Fregat) [70M€], 20% ground segment [90M€], and 10% for the project [47M€].

Mission classes

- Medium “M”-class: 500 M€ - example Solar Orbiter.
- Large “L”-class: ~1000 M€ - example JUICE
- These figures are the cost at completion (CaC) numbers and include study phase, launch vehicle, spacecraft, operations, an ESA management top-slice, but **not instruments**.
- The expected cost breakdown is roughly: 55% spacecraft industrial activity [260M€], 15% launch (assuming Soyuz-Fregat) [70M€], 20% ground segment [90M€], and 10% for the project [47M€].
- Implication is that ESA member states can delay the programme if they can’t afford to supply the instruments.
- Also includes S-class missions and Missions of Opportunity.

ESA Structure

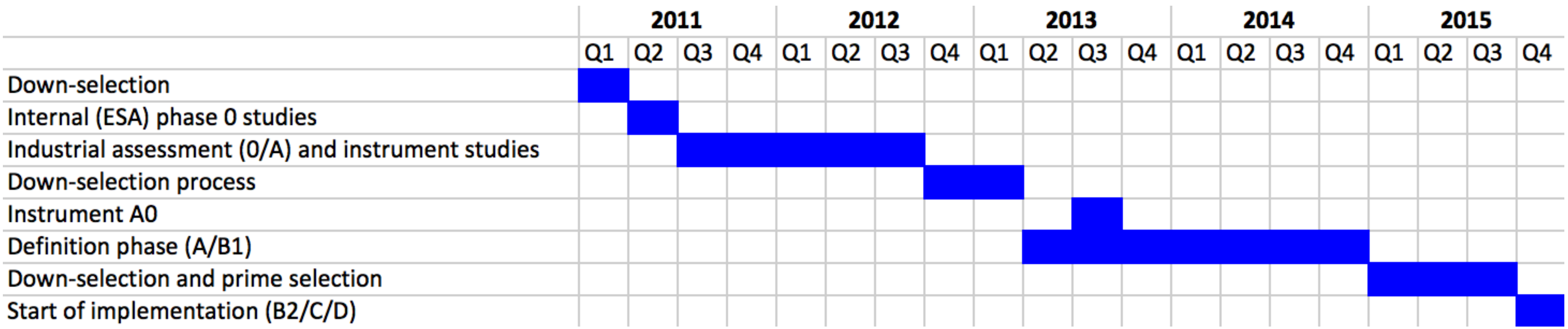


Missions currently in the pipeline

- L1: JUICE (Jupiter/Ganymede) [2021]
- L2: Athena+ (X-ray observatory at L2 point) [2028]
- L3: eLISA (gravitational wave observatory) [2035]

- M1: Solar Orbiter (solar and solar wind mission to go to 0.3 AU) [2017]
- M2: EUCLID (dark energy/dark matter) [2020]
- M3: PLATO (exoplanet hunter) [2023]

- S1: CHEOPS (high precision photometry of exoplanet transits) [2017]



Missions and programmatic balance

	Solar System (11)	Astrophysics (12)	Fundamental Phys. (2)
2030-2035	M6 [2031/2032?] M7 [2034/2035?]		eLISA [2035]
2025-2029	M4 [2025/2026] M5 [2028/2029?]	Athena+ [2028]	
2020-2024	JUICE [2021]	EUCLID [2020] PLATO [2023]	
2015-2019	BepiColombo [2016] Solar Orbiter [2017]	CHEOPS [2017] JWST [2018]	
2010-2014		GAIA [2013]	Lisa Pathfinder [2014]
2005-2009	Venus Express [2005]	Planck [2009] Herschel [2009]	
2000-2004	Cluster II [2000] Mars Express [2003] Smart 1 [2003] ROSETTA [2004]	Integral [2002]	
1995-1999	SOHO [1995] Huygens [1997]	ISO [1995] XMM Newton [1999]	
1990-1994	Ulysses [1990]	HST [1990]	

Missions and programmatic balance

	Solar System (11)	Astrophysics (12)	Fundamental Phys. (2)
2030-2035	M6 [2031/2032?] M7 [2034/2035?]		eLISA [2035]
2025-2029	M4 [2025/2026] M5 [2028/2029?]	Athena+ [2028]	
2020-2024	JUICE [2021]	EUCLID [2020] PLATO [2023]	
2015-2019	BepiColombo [2016] Solar Orbiter [2017]	CHEOPS [2017] JWST [2018]	
2010-2014		GAIA [2013]	Lisa Pathfinder [2014]
2005-2009	Venus Express [2005]	Planck [2009] Herschel [2009]	
2000-2004	Cluster II [2000] Mars Express [2003] Smart 1 [2003] ROSETTA [2004]	Integral [2002]	
1995-1999	SOHO [1995] Huygens [1997]	ISO [1995] XMM Newton [1999]	
1990-1994	Ulysses [1990]	HST [1990]	

Missions and programmatic balance

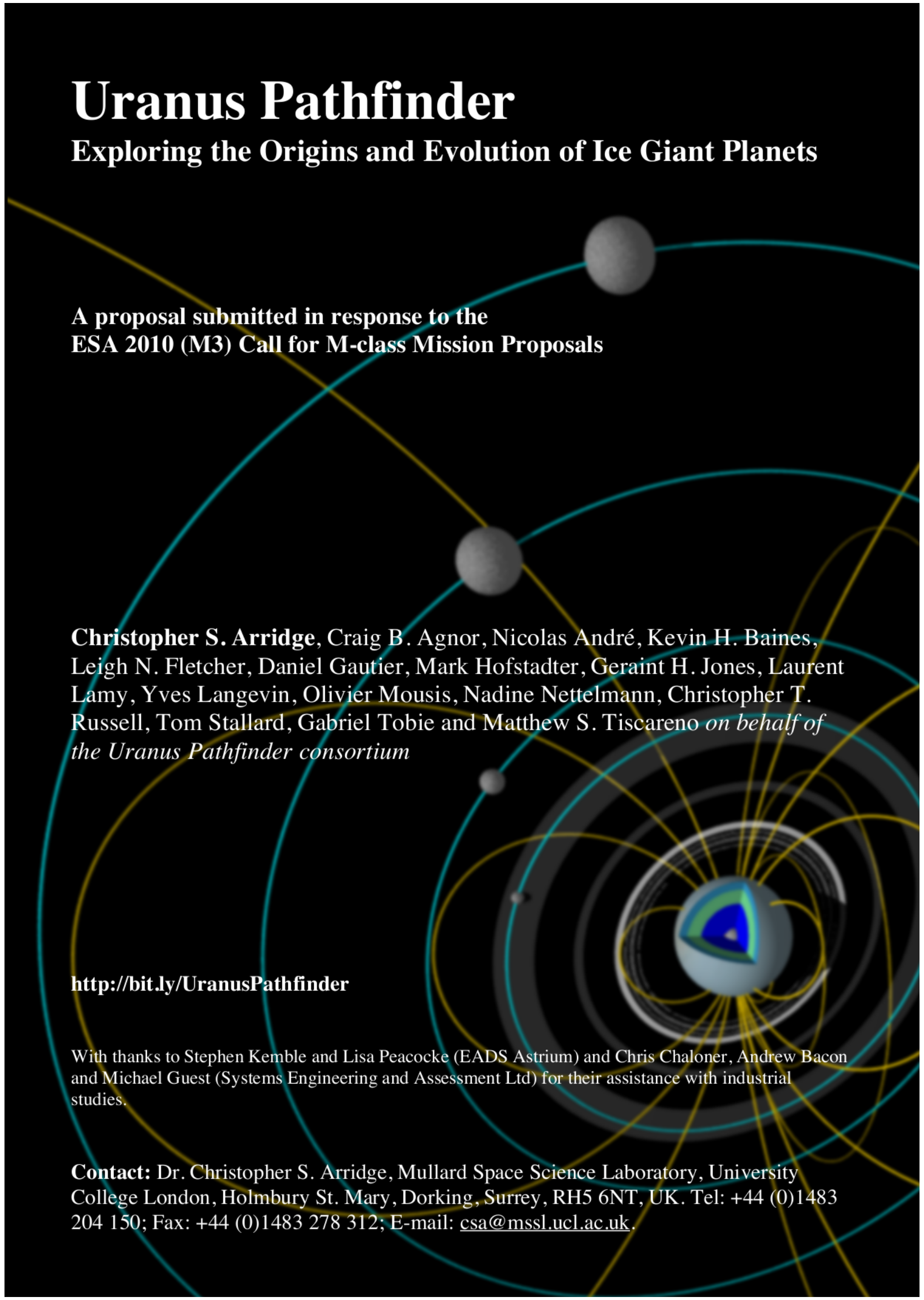
	Solar System (11)	Astrophysics (12)	Fundamental Phys. (2)
2030-2035	M6 [2031/2032?] M7 [2034/2035?]		eLISA [2035]
2025-2029	M4 [2025/2026] M5 [2028/2029?]	Athena+ [2028]	
2020-2024	JUICE [2021]	EUCLID [2020] PLATO [2023]	
2015-2019	BepiColombo [2016] Solar Orbiter [2017]	CHEOPS [2017] JWST [2018]	
2010-2014		GAIA [2013]	Lisa Pathfinder [2014]
2005-2009	Venus Express [2005]	Planck [2009] Herschel [2009]	
2000-2004	Cluster II [2000] Mars Express [2003] Smart 1 [2003] ROSETTA [2004]	Integral [2002]	
1995-1999	SOHO [1995] Huygens [1997]	ISO [1995] XMM Newton [1999]	
1990-1994	Ulysses [1990]	HST [1990]	

Missions and programmatic balance

	Solar System (11)	Astrophysics (12)	Fundamental Phys. (2)
2030-2035	M6 [2031/2032?] M7 [2034/2035?]		eLISA [2035]
2025-2029	M4 [2025/2026] M5 [2028/2029?]	Athena+ [2028]	
2020-2024	JUICE [2021]	EUCLID [2020] PLATO [2023]	
2015-2019	BepiColombo [2016] Solar Orbiter [2017]	CHEOPS [2017] JWST [2018]	
2010-2014		GAIA [2013]	Lisa Pathfinder [2014]
2005-2009	Venus Express [2005]	Planck [2009] Herschel [2009]	

- **Next L4 launch opportunity won't be until 2042.**

Uranus Pathfinder (UP) in M3



Uranus Pathfinder

Exploring the Origins and Evolution of Ice Giant Planets

A proposal submitted in response to the ESA 2010 (M3) Call for M-class Mission Proposals

Christopher S. Arridge, Craig B. Agnor, Nicolas André, Kevin H. Baines, Leigh N. Fletcher, Daniel Gautier, Mark Hofstadter, Geraint H. Jones, Laurent Lamy, Yves Langevin, Olivier Mousis, Nadine Nettelmann, Christopher T. Russell, Tom Stallard, Gabriel Tobie and Matthew S. Tiscareno *on behalf of the Uranus Pathfinder consortium*

http://bit.ly/UranusPathfinder

With thanks to Stephen Kemble and Lisa Peacocke (EADS Astrium) and Chris Chaloner, Andrew Bacon and Michael Guest (Systems Engineering and Assessment Ltd) for their assistance with industrial studies.

Contact: Dr. Christopher S. Arridge, Mullard Space Science Laboratory, University College London, Holmbury St. Mary, Dorking, Surrey, RH5 6NT, UK. Tel: +44 (0)1483 204 150; Fax: +44 (0)1483 278 312; E-mail: csa@mssl.ucl.ac.uk.

- Uranus proposal was submitted to M3 call in 2010.
- Note this is a 50 page proposal where ~4 pages is on the mission concept.
- Specified a Uranus orbiter.
- One of ~30 submissions.
- UP reached the final eight.
- Four of these were selected for a phase 0 study leading to PLATO.
  - EChO, Marco Polo-R, STE-Quest, LOFT.
- Other missions with UP who lost out include Alfvén, EVE, and Titan mission.

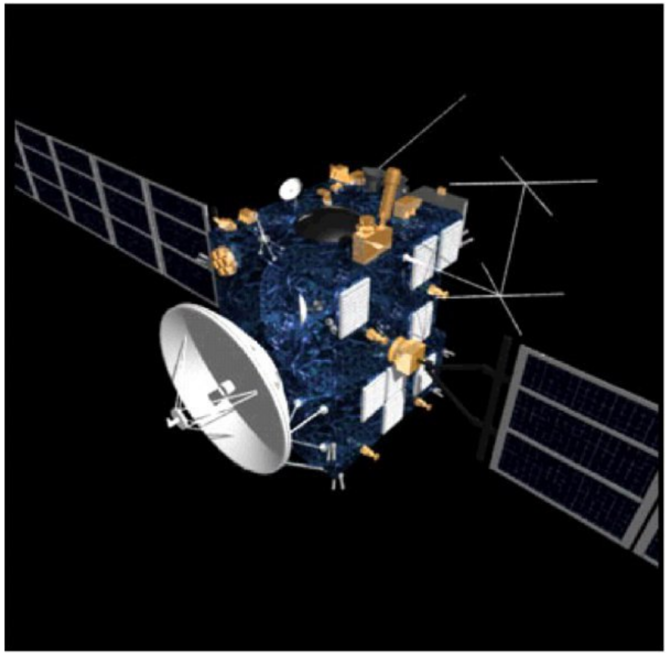
Platform

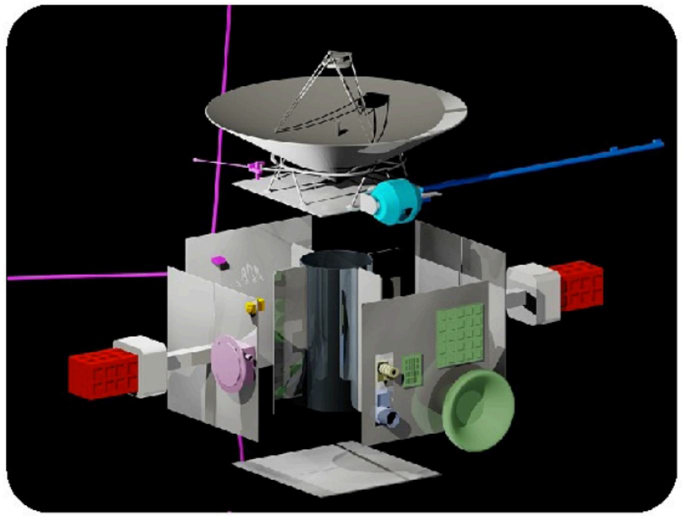
- Rosetta/Mars Express-type platform:
  - Total dry mass (with margin) 836 kg.
  - Total wet mass (with margin) 1530 kg.
  - This mass doesn't include escape stage.

- Science payload comprises 63 kg (with margin).

- Power: 200 W provided by ^{241}Am-based RPS (192 kg – very low specific power partly due to margins).

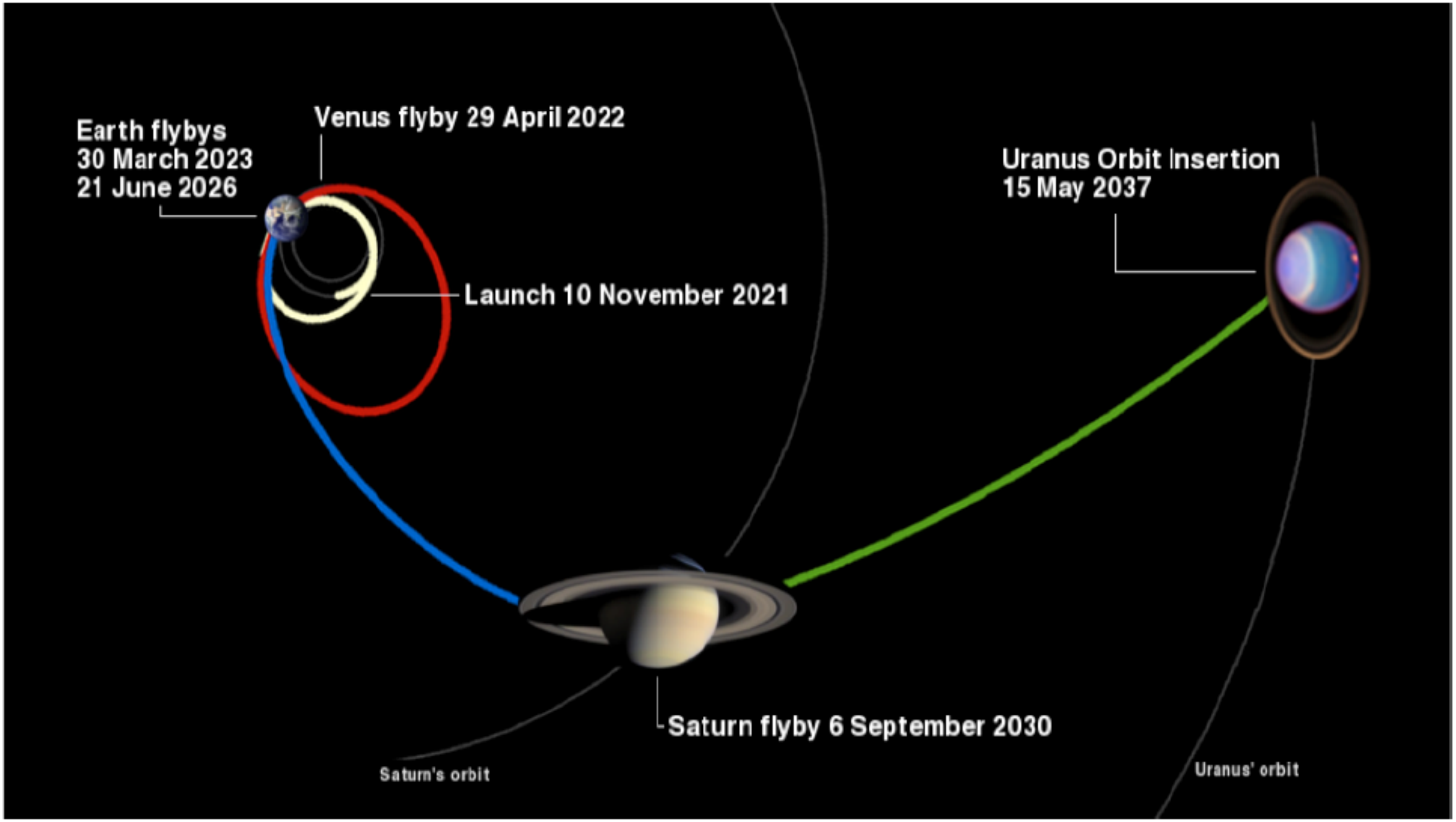
- Telecommunications were an issue: we estimated 3-9 kbit/s to a 35m ESA ground station.





Interplanetary transfer

- Soyuz-Fregat launch.
- One studied option: VEES transfer with duration of 15.5 years.
- Capture orbit: r_p=1.8 R_U periapsis (45000 km), r_a=391 R_U (10^7 km), P=313 d.



Model payload instruments

Instrument	Mass (kg)	Power (W)	DMM	TRL	Heritage	Potential instrument providers
Magnetometer (MAG)	2.1	5.0	5%	Sensors: 9 Electronics: 5	Cassini/MAG, Double Star/MAG Rosetta/RPC Solar Orbiter	IC, UK TUB, Germany UCLA, USA
Plasma and Particle Science (PPS)	6.0	6.4	20%	8 / 9	Rosetta/RPC-IES Cassini/CAPS-ELS New Horizons/PEPPSI THEMIS/SST	MSSL/UCL, UK IRF, Sweden CESR, France SwRI, USA UCLA, USA JHU-APL, USA
Radio and Plasma Wave Experiment (RPW)	5.7	7.1	10%	8 / 9	Cassini/RPWS, STEREO/Waves, RBSP, Bepi-Colombo/MMO/PWI	LESIA, France U. Iowa, USA
Microwave radiometer (MWR)	12.0	15.8	20%	7 / 8	Juno/MWR	NASA/JPL, USA
Thermal Infrared Bolometer (UTIRM)	1.0	4.0	30%	5	LRO/Diviner BepiColombo (detectors)	Oxford University, UK Cardiff (filters) Reading (filters) IPHT, Germany (detectors) NASA/JPL, USA
Visual and Near-Infrared Mapping Spectrometer (NIR/MSIC)	10.5	7.1	10%	>5	New Horizons/RALPH Mars Express/OMEGA Juno/JIRAM Rosetta/VIRTIS Dawn/VIR	Southwest Research Institue, USA NASA/GSFC, USA Ball Aerospace, USA IFSI, Italy
Ultraviolet Imaging Spectrometer (UVIS)	5.0	12.0	20%	>5	BepiColombo/PHEBUS Mars Express/SPICAM-UV Venus Express/SPICAV-UV	LATMOS, France Boston University, USA
Narrow Angle Camera (NAC)	10.0	12.7	20%	>5	EJSM-JGO/HRC Mars Express/SRC New Horizons/LORRI	DLR, Germany MPS, Germany JHU-APL, USA
Radio Science Experiment (RSE)	1.5	5.5	5%	9	Venus Express/VeRa Rosetta/RSI	U. Bundeswehr München, Germany

Table 6: Reference payload for Uranus Pathfinder. The DMMs have not been applied to the mass and power values here but are applied to the appropriate spreadsheets in tables 7 and 8.

Traceability

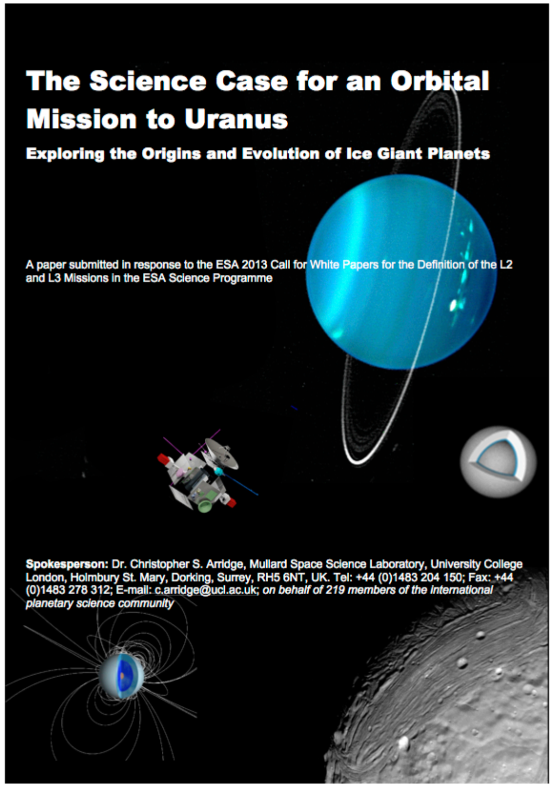
Theme	Science goal	NAC	UVIS	NIR/MSIC	UTIRM	MWR	MAG	PPS	RPW	RSE
Uranus as an ice giant planet	What is the internal structure and composition of Uranus?			2		1	1			1
	Why does Uranus emit very little heat?			2	1	1	3			2
	What is the configuration and origin of Uranus' highly asymmetric magnetic field?						1	2	3	
	What is the rotation rate of Uranus?	2	2		3		1	3	1	
	How is Uranus' weather structure and composition influenced by its unique seasons?	1	2	1	1	1				2
	What processes shape atmospheric chemistry and cloud formation on an ice giant?	2	2	2	1	3				
Uranus' ice giant planetary system	What is the composition of the uranian rings?		3	1						
	How do dense rings behave dynamically?	1	3	2						2
	How do Uranus' dusty rings work?	1						3	2	
	How do the rings and inner satellites interact?	1	3	1						
	What is the nature and history of Uranus' moons?	1	3	1			1	2	2	1
Uranus' asymmetric magneto-sphere	What is the overall configuration of the uranian magnetosphere		1	2			1	1	1	
	How does magnetosphere-ionosphere-Solar Wind coupling work at ice giants?		1	2			1	1	1	3
	How are auroral radio emissions generated at ice giants?		2	2			1	2	1	3
Cruise phase	How does the outer heliosphere work?						1	1	2	
	What can we learn from in situ observations of Centaurs?	1	2	1	2		1	2	2	1

Table 5: Traceability matrix showing how each instrument in the Uranus Pathfinder model payload maps to the key science questions for the science case presented in section 2. The colour and numerical code indicates the importance of that particular instrument in answering each scientific question where red (1) indicates a Tier 1 (essential instrument), orange (2) a Tier 2 instrument (could make important contributions), and green (3) a Tier 3 instrument (would add useful information).

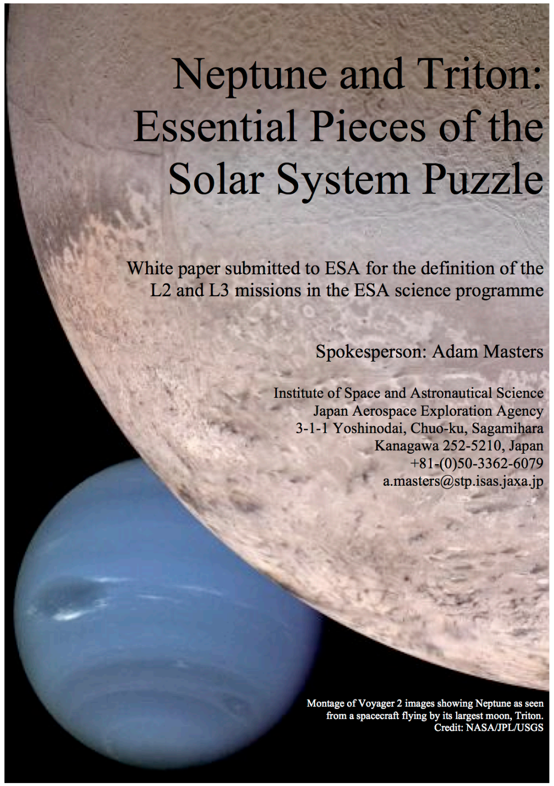
L2/L3 Science theme process

- After JUICE, ESA decided not to run open calls for L2/L3 – instead ran a "science theme" selection process in 2013 via whitepapers.

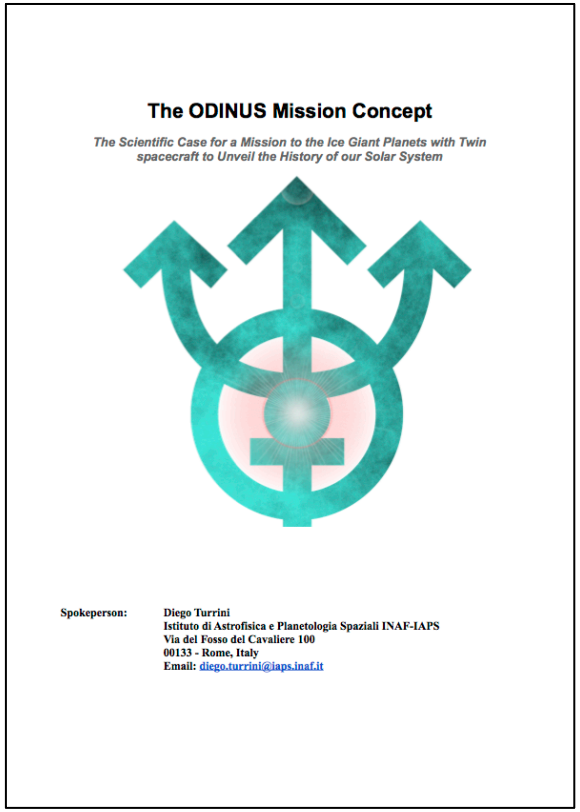
- 32 whitepapers received: three on Uranus and/or Neptune:
  - http://sci.esa.int/cosmic-vision/52030-white-papers-submitted-in-response-to-esas-call-for-science-themes-for-the-l2-and-l3-missions/



Arridge et al. [UK]



Masters et al. [Japan/UK]



Turrini et al. [Italy]

Science at the Icy Giants

Spokesperson: Chris Arridge

Email: c.arridge@ucl.ac.uk / Twitter: @chrisarridge

Three white papers:

- The Science Case for an Orbital Mission to Uranus (*Arridge*)
- Neptune and Triton: Essential Pieces of the Solar System Puzzle (*Masters*)
- The ODINUS Mission Concept: The Scientific Case for a Mission to the Ice Giant Planets with Twin spacecraft to Unveil the History of our Solar System (*Turrini*)

Community of 257 (189 in Europe) scientists world-wide.

L2 and L3 Science Themes Meeting – Paris – 3-4 September 2013

L2/L3 outcome

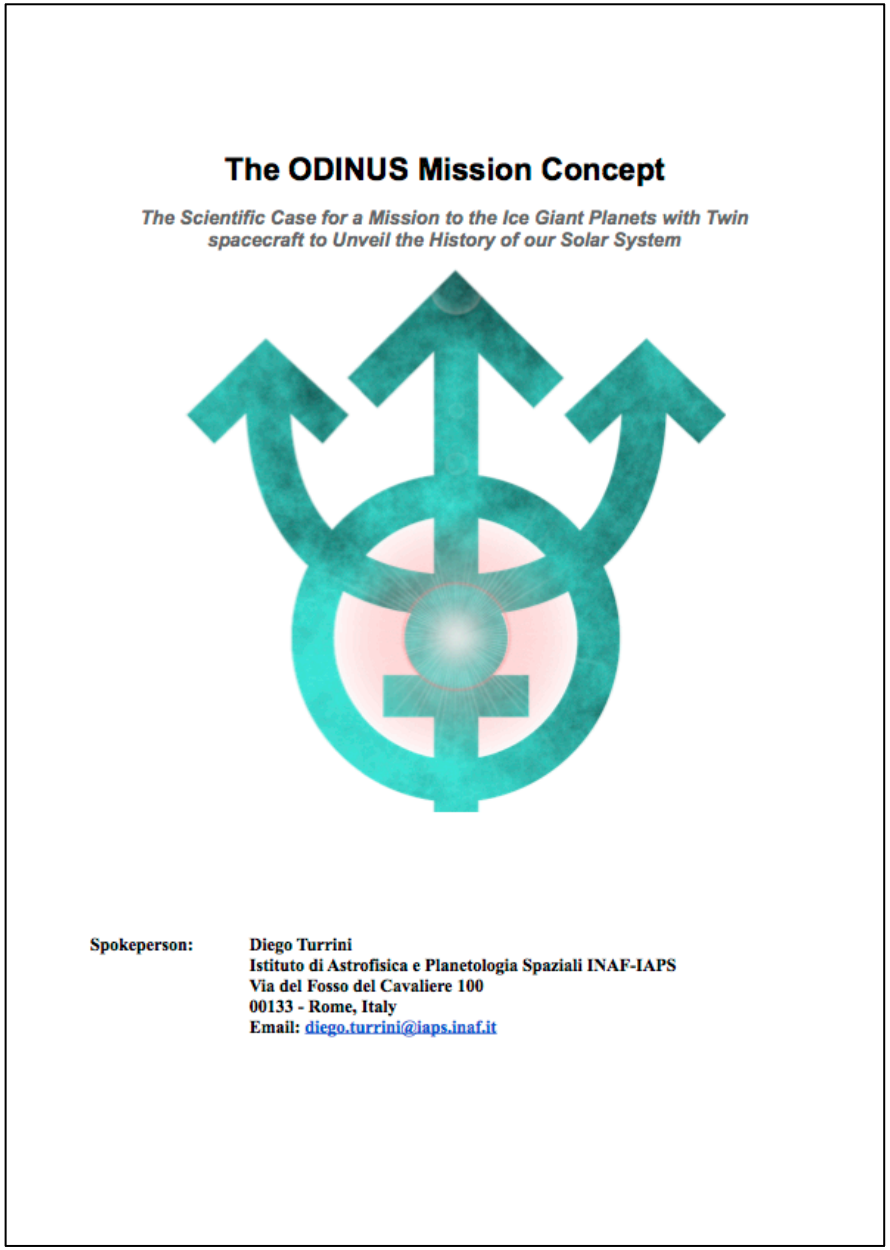
“After the success of the Cassini mission, and after the selection of an exploration mission toward the Jovian system, the **exploration of the icy giants appears to be a timely milestone**, fully appropriate for an L class mission.”

“The SSC **considered the study of the icy giants to be a theme of very high science quality** and perfectly fitting the criteria for an L-class mission. However, in view of the competition with a range of other high quality science themes, and despite its undoubted quality, on balance and taking account of the wide array of themes, the SSC does not recommend this theme for L2 or L3. In view of its importance, however, the SSC **recommends that every effort is made to pursue this theme through other means, such as cooperation on missions led by partner agencies**.”

http://sci.esa.int/cosmic-vision/53261-report-on-science-themes-for-the-l2-and-l3-missions/

ODINUS

- Twin identical spacecraft:
  - "New Horizons-like".
  - 500-600 kg dry mass.
  - RPS.
- 6 instruments:
  - Imaging: WAC, NAC.
  - Visible-near IR imaging spectometer.
  - Magnetometer.
  - Mass spectrometer.
  - Doppler spectro-imager.
  - Radio science package.
- Single Ariane 5 launch or two Soyuz-Fregat launches.



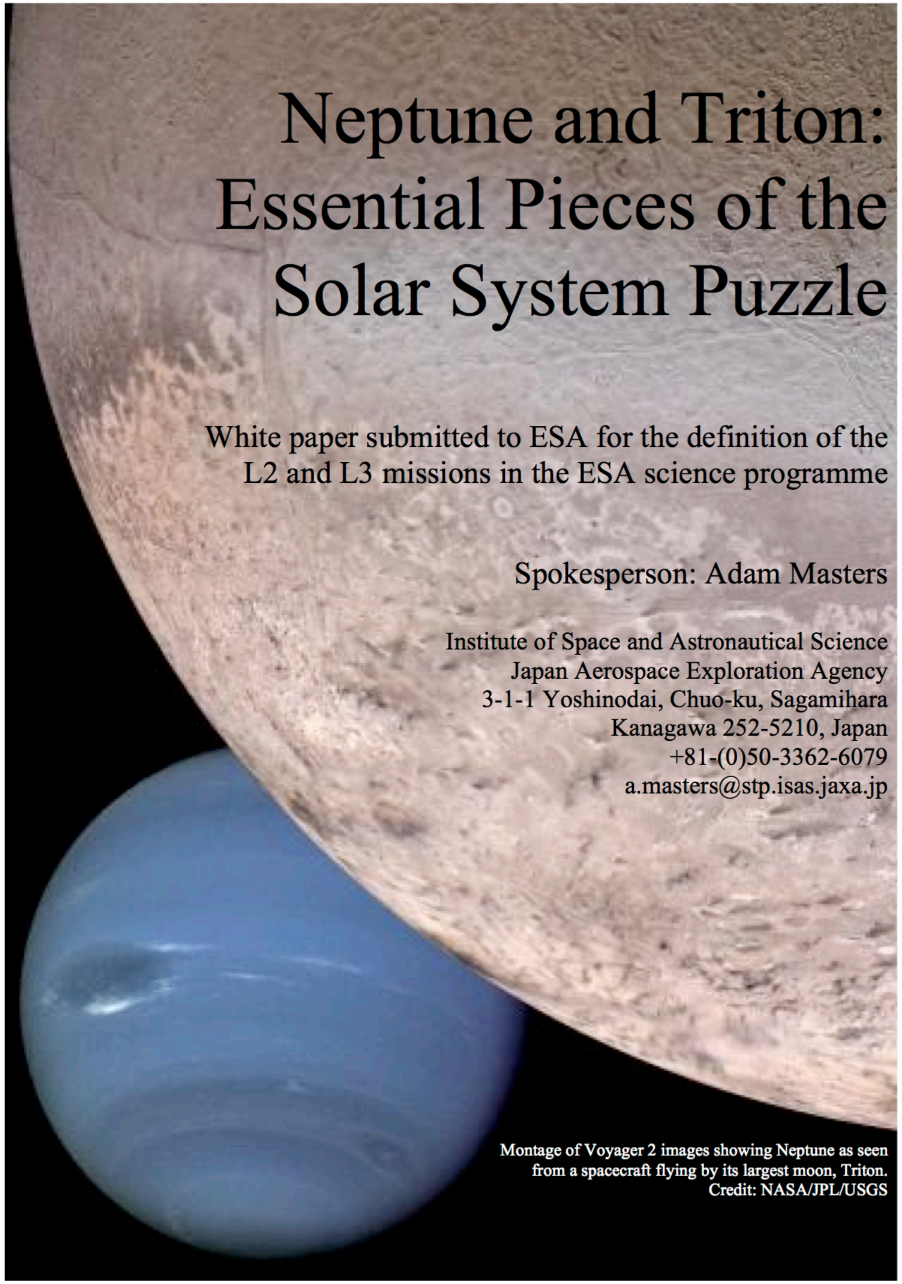
The ODINUS Mission Concept

The Scientific Case for a Mission to the Ice Giant Planets with Twin spacecraft to Unveil the History of our Solar System

Spokeperson: Diego Turrini
Istituto di Astrofisica e Planetologia Spaziali INAF-IAPS
Via del Fosso del Cavaliere 100
00133 - Rome, Italy
Email: diego.turrini@iaps.inaf.it

Neptune and Triton

- Proposal led by Adam Masters (JAXA, now at Imperial College).
- Enabling technology:
  - Extended DSN capability (to improve bit rate above 1-6 kbit/s).
  - RPS.
  - SEP.
- Full mission analysis by former JPL mission designer now at JAXA.


Neptune and Triton: Essential Pieces of the Solar System Puzzle

White paper submitted to ESA for the definition of the L2 and L3 missions in the ESA science programme

Spokesperson: Adam Masters

Institute of Space and Astronautical Science
Japan Aerospace Exploration Agency
3-1-1 Yoshinodai, Chuo-ku, Sagamihara
Kanagawa 252-5210, Japan
+81-(0)50-3362-6079
a.masters@stp.isas.jaxa.jp

Montage of Voyager 2 images showing Neptune as seen from a spacecraft flying by its largest moon, Triton.
Credit: NASA/JPL/USGS

Strawman payload and traceability

Instrument	Mass (kg)	Power (W)	Heritage
Narrow-angle camera (NAC)	9.8	14.0	Mars Express (SRC), New Horizons (LORRI), JUICE (JANUS)
Visible-infrared imager (VIR)	10.1	7.5	New Horizons (Ralph), Mars Express (OMEGA), Rosetta (VIRTIS), BepiColombo (SIMBIO-SYS)
Ultraviolet imaging spectrometer (UVIS)	5.0	12.0	BepiColombo (PHEBUS), Mars Express (SPICAM-UV), JUICE (UVS)
Accelerometer (ACC)	3.5	3.0	GOCE, GRACE, BepiColombo (ISA)
Radio science experiment (including ultrastable oscillator) (RSE)	3.5	45.5	Rosetta (RSI), New Horizons (REX), BepiColombo (MORE), JUICE (3GM)
Magnetometer (MAG)	3.3	3.0	Cassini (MAG), Double Star (MAG), Rosetta (RPC), BepiColombo (MERMAG), JUICE (J-MAG)
Thermal imager (TMI)	7.0	20.0	BepiColombo (MERTIS)
Particle package (plasma, neutrals, energetic neutral atoms) (PP)	23.0	50.0	Cassini (CAPS, MIMI), New Horizons (SWAP, PEPSSI), JUICE (PEP)
Radio and plasma wave system (RPWS)	5.7	7.1	Cassini (RPWS), JUICE (RPWI)
Dust Analyser (DA)	3.2	8.0	Cassini (CDA), Stardust (CIDA)

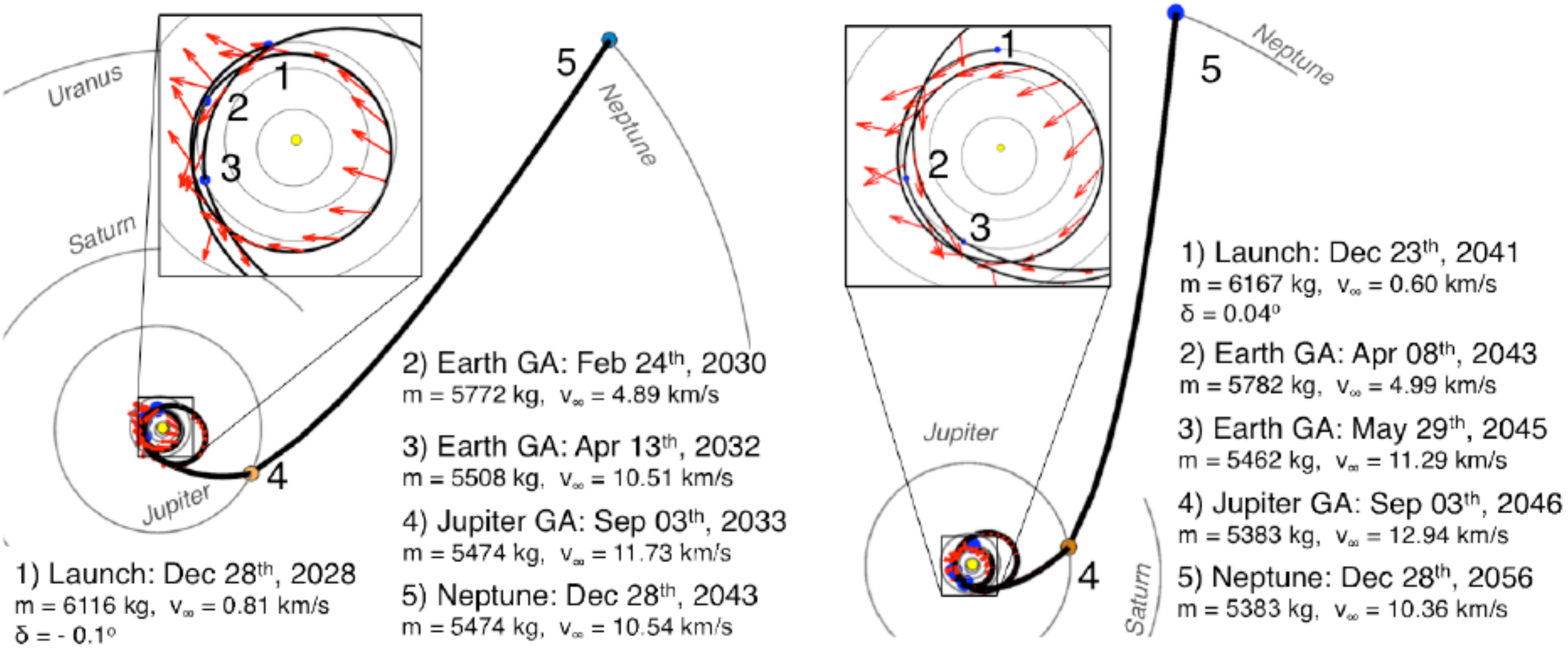
Table 1. Neptune orbiter payload options. All values of instrument mass and power consumption are estimates based on heritage instruments.

Science theme	NAC	VIR	UVIS	ACC	RSE	MAG	TMI	PP	RPWS	DA
Neptune interior (2.2)				■	■	■			■	
Neptune atmosphere (2.3)	■	■	■				■		■	■
Neptune rings and icy satellites (2.4)	■	■	■		■	■		■	■	■
Neptune magnetic environment (2.5)		■	■			■		■	■	
Triton interior and surface (3.2)	■	■	■	■	■	■	■			■
Triton atmosphere (3.3)	■					■		■	■	■
Triton-magnetosphere interaction (3.4)		■	■			■		■	■	
Cruise science (4)				■	■	■		■	■	■

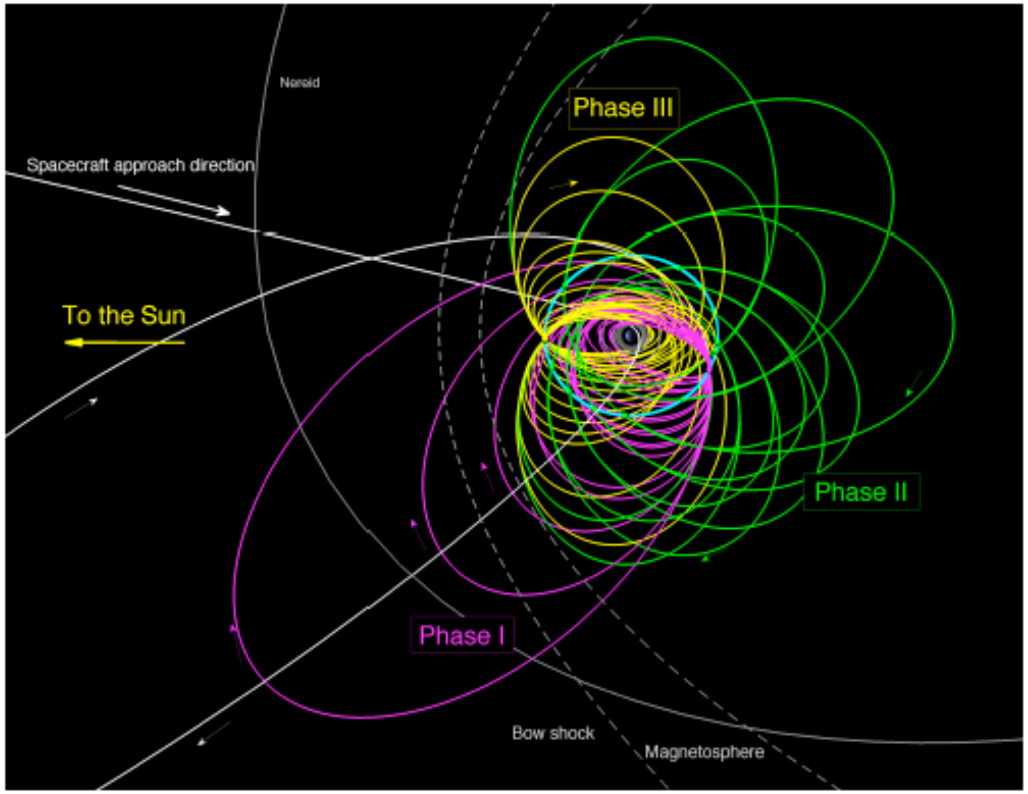
Table 2. Matrix relating science themes to payload options. Numbers given in brackets after each science theme indicate the relevant section/sub-section of this white paper.

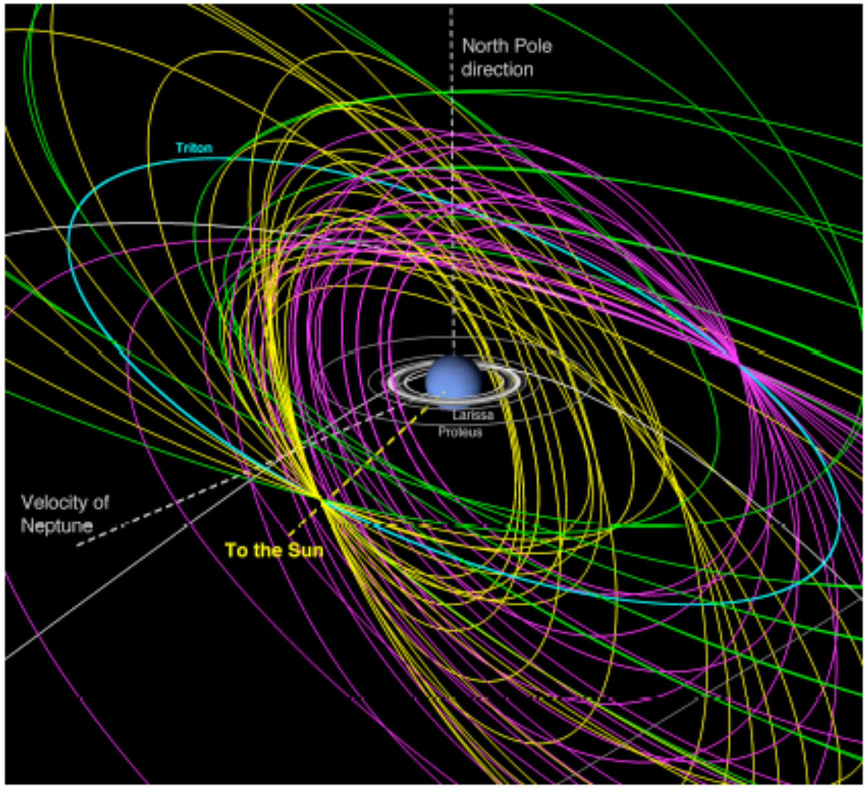
Neptune transfer using SEP

- Launch using Ariane 5 ECA rather than assume future capability – Ariane 5ME or Ariane 6.
- Requires GA from Jupiter or Saturn – but the Jupiter GA is more effective.
- Favourable launch windows were found to exist in 2033 and 2046 (separated by Jupiter-Neptune synodic period of 13 years).
- Inserted mass ~1800 kg similar to NASA Neptune orbiter study (Marley et al., 2010) and JUICE.



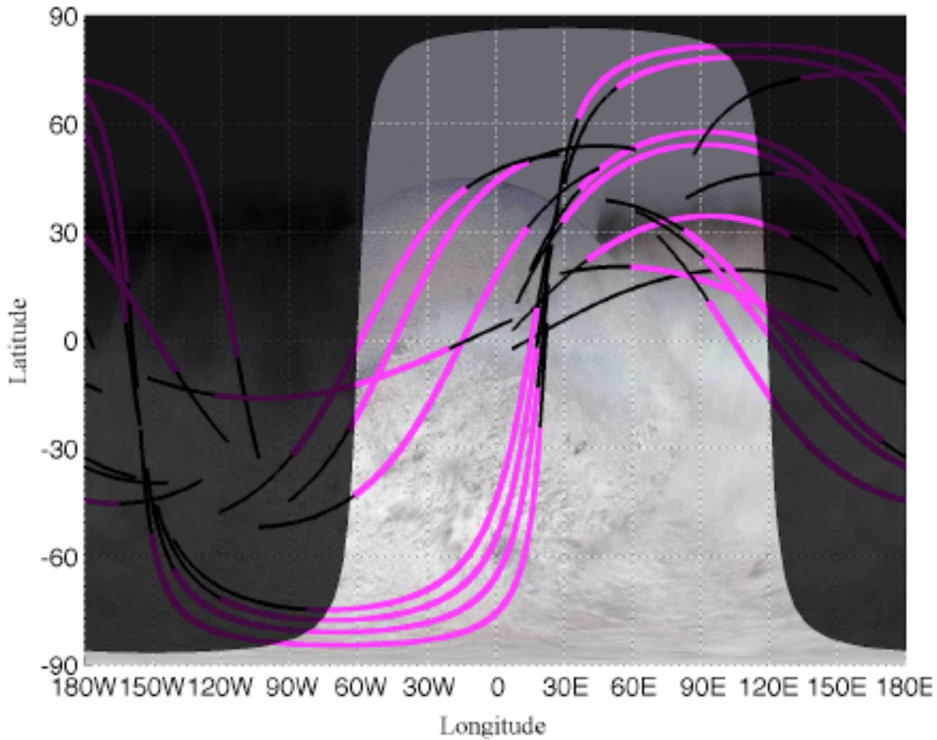
Neptune planetary tour

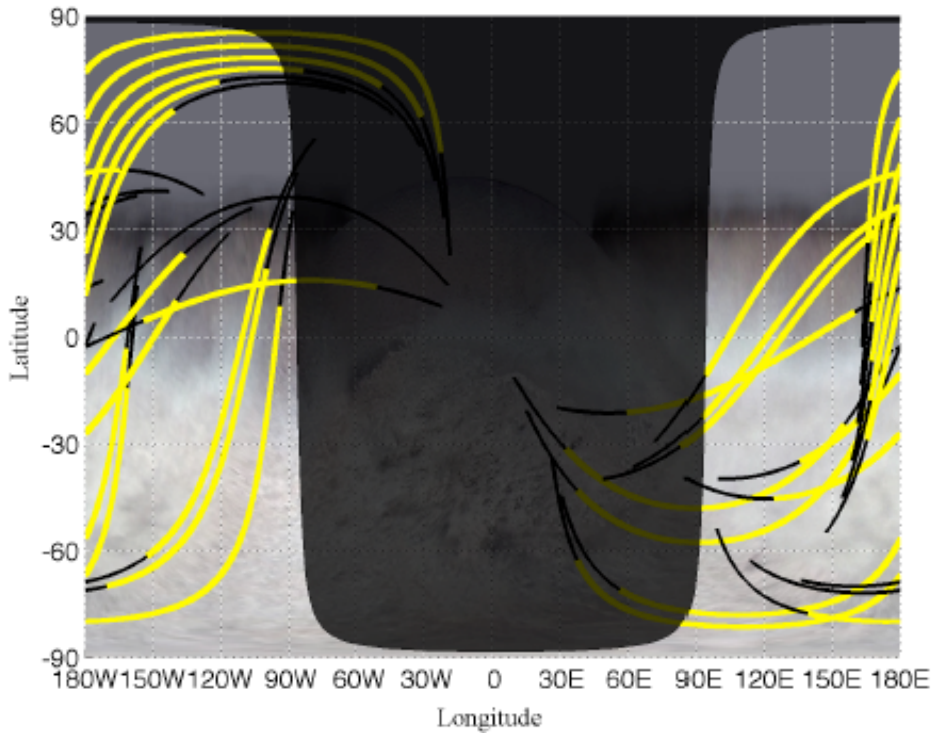




Triton flyby ground tracks and orbit

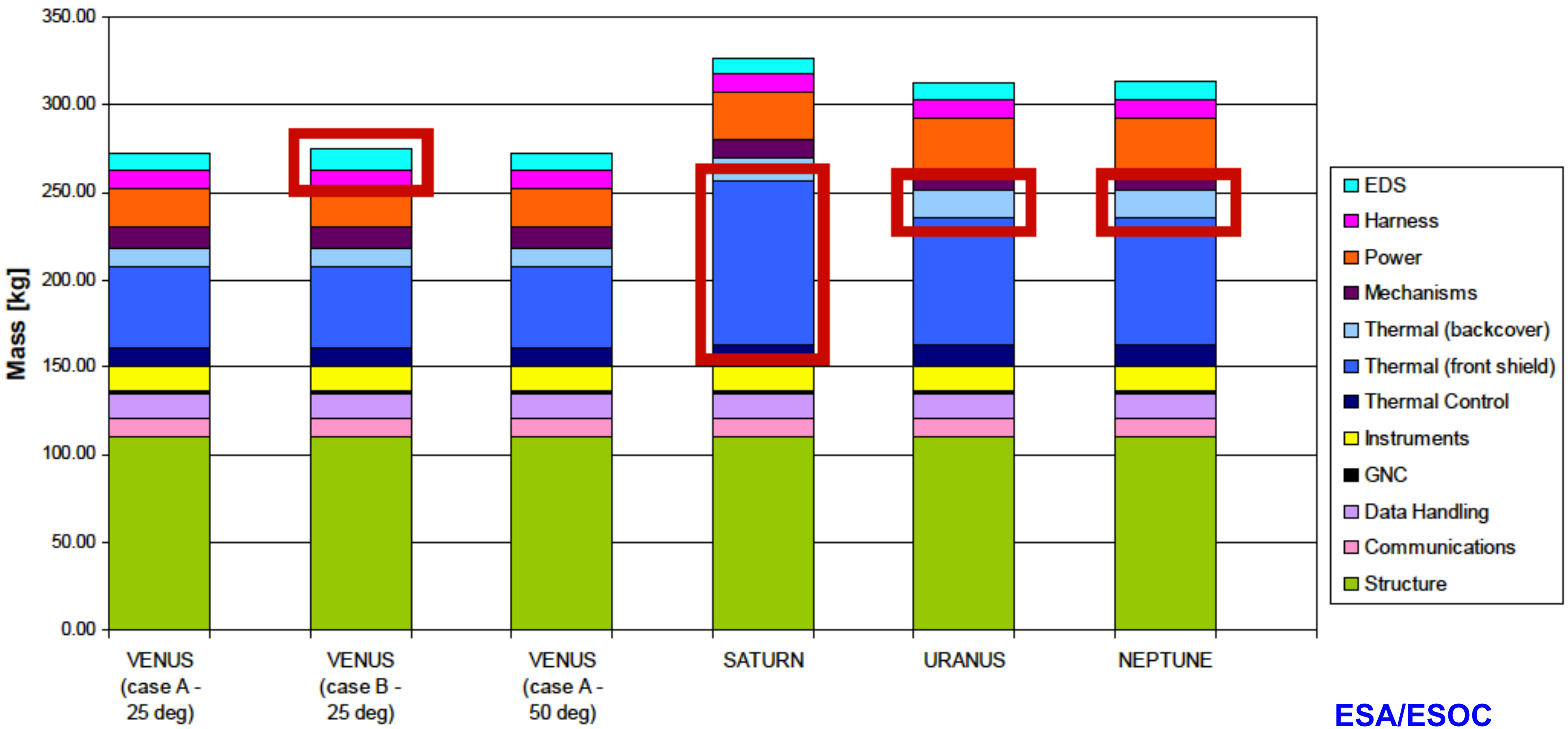
- Tour includes phases where the spacecraft orbits in Triton's orbital plane.
- Flyby altitudes between 150 and 1000 km with sufficient Δv to raise or lower as necessary.
- Also possibility to enter Triton orbit (similar to JUICE at Ganymede) with a Δv~300 m/s.





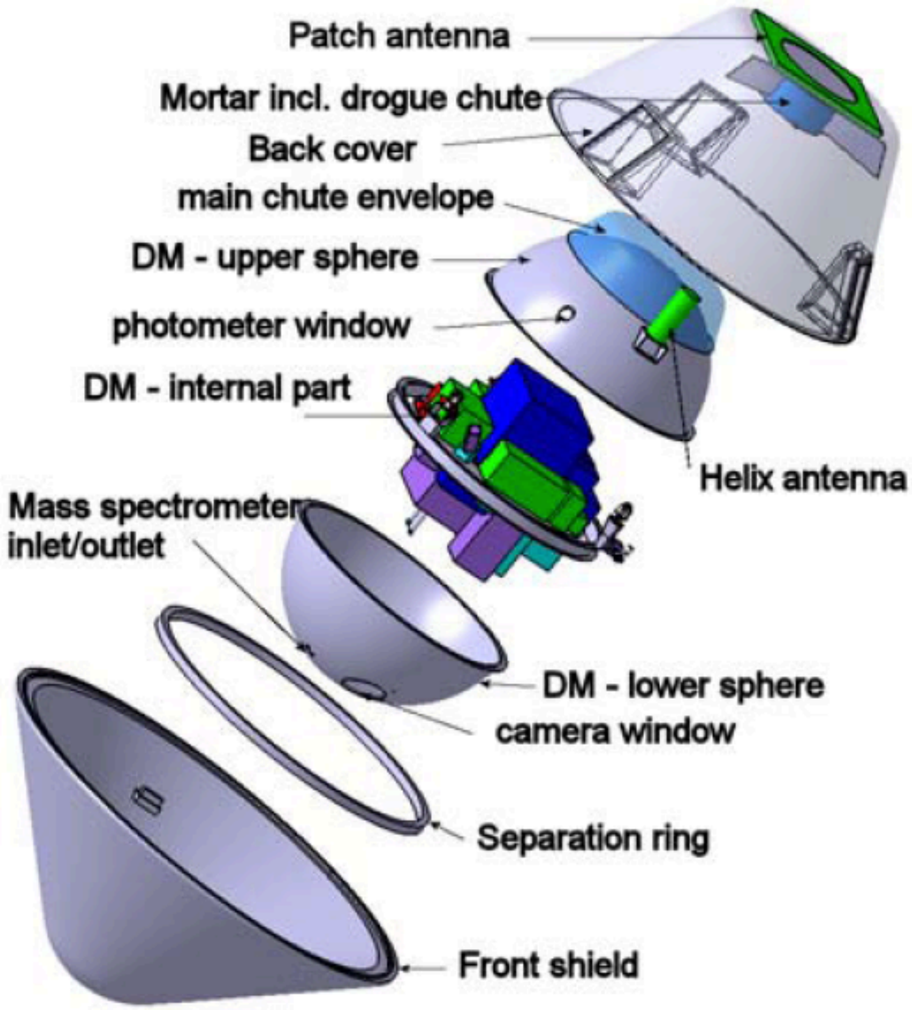
ESA CDF Probe Studies

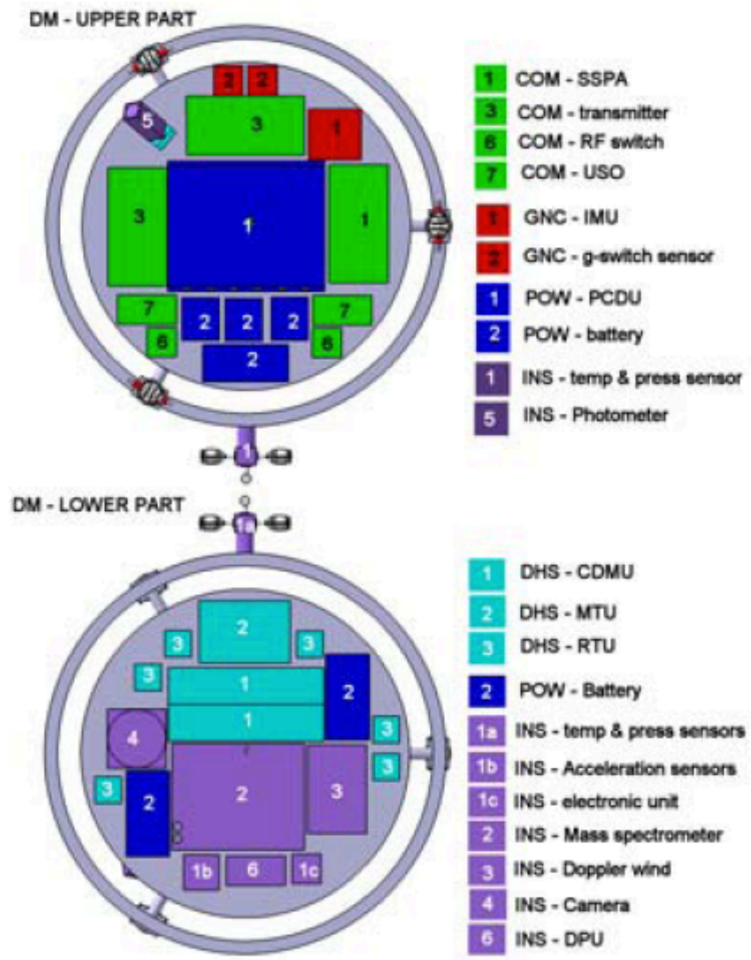
- CDF probe studies aimed at supporting upcoming CV calls.
- Based on Pioneer Venus probe heritage.
- Very little change in probe characteristics from Venus to outer planets.
- 313 kg Uranus probe.



ESA/ESOC

Probe configuration



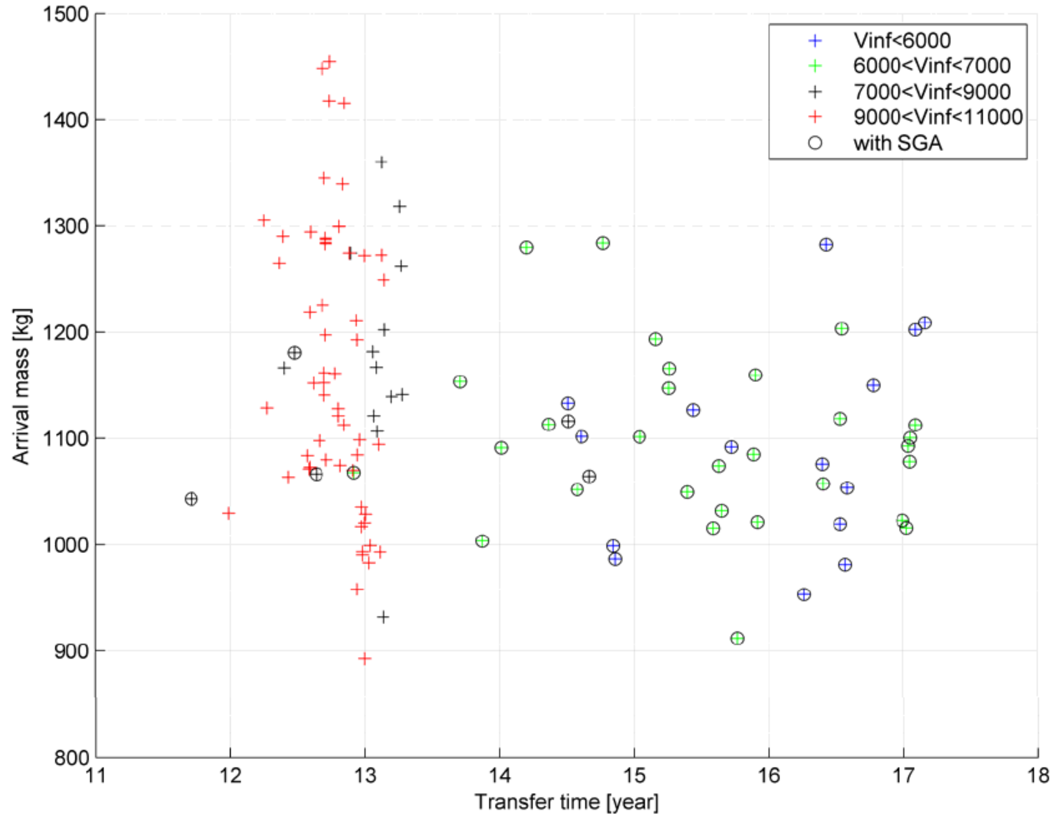


Interplanetary transfers

- Considered delivery platforms in the 2025-2035 timeframe.
- Launch vehicles: investigated Soyuz (three marginal solutions) and Ariane 5 (three good solutions).
- Assumed 300 kg probe.

- **Soyuz**
  - Transfer time 12.7 – 15.8 years.
  - V_{inf} = 6.5 – 10.9 km/s
  - No dual probe solution.

- **Ariane 5**
  - Transfer time ~ 13 years (comparable with decadal study profile).
  - V_{inf} = 4.2 – 6.8 km/s
  - Permits dual probes.



ESA/ESOC

M4 call

- Pre-announcement already made: call due in August, deadline mid-January for a 2025/2026 launch.

- Reduced cost-cap due to missions going over budget and instrument costs for JUICE – now at 450M€.

- European Uranus/Neptune communities have merged (c.f. L2/L3 whitepaper teams) and are working on a Uranus proposal.

- Competition:
  - COrE/PRISM: cosmic microwave background.
  - NEAT: astrometry
  - LOFT: X-ray telescope.
  - SPICA: infrared space telescope
  - EChO: exoplanet characterisation
  - UVMag: UV space telescope
  - EVE/ENVISION: Venus missions
  - Alfvén: space plasma physics mission to look at auroral particle acceleration.

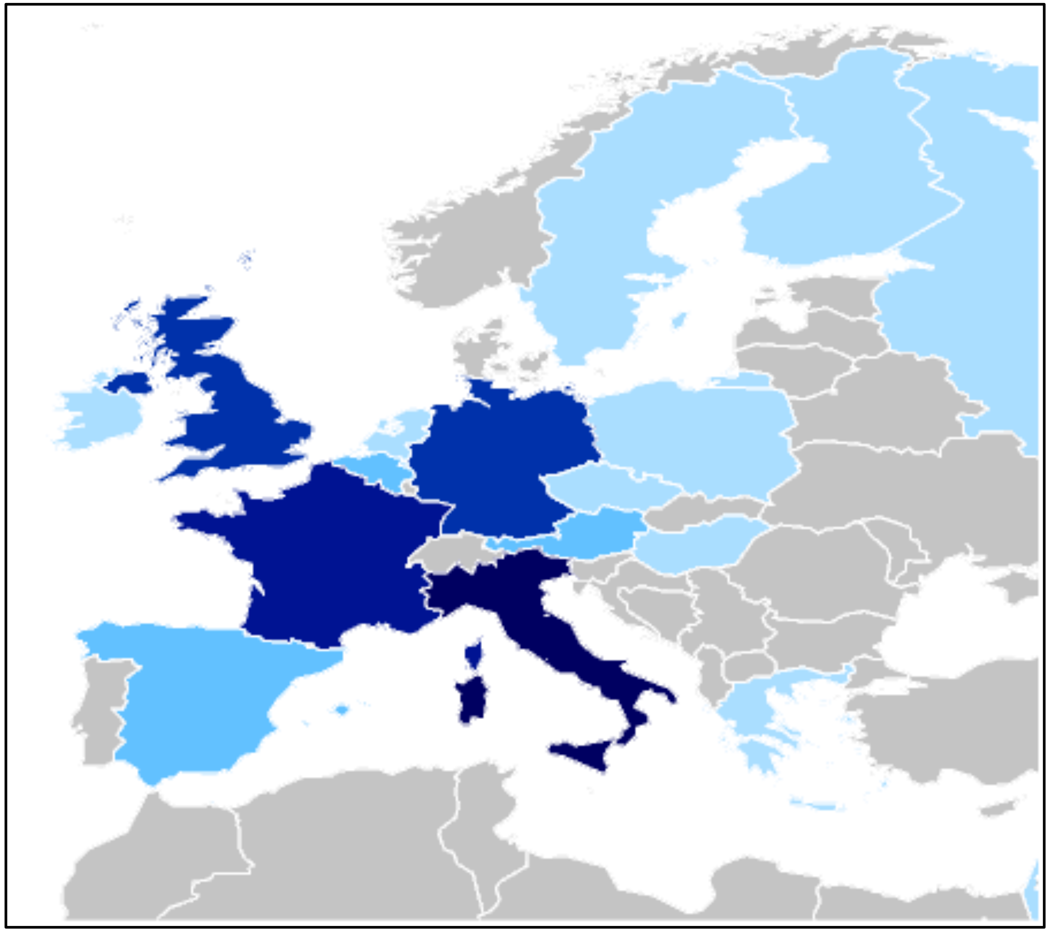
Uranus M4 mission working group

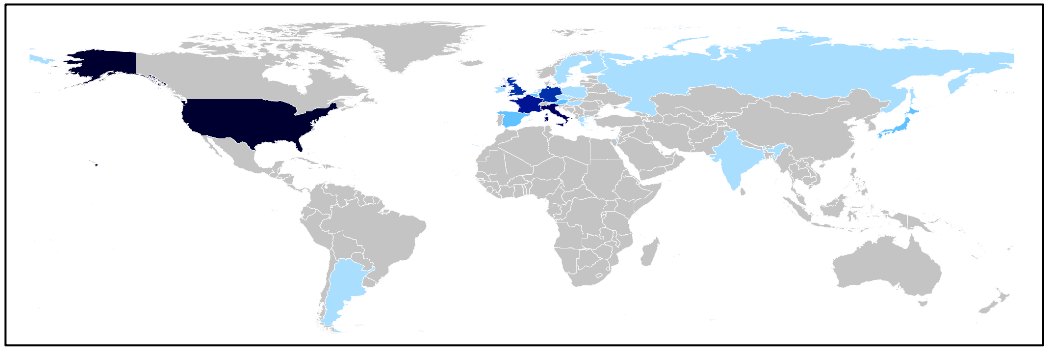
Chris Arridge (UCL)
Nigel Bannister (Leicester)
Leigh Fletcher (Oxford)
Adam Masters (Imperial College)

Laurent Lamy (LESIA)
Nicolas André (IRAP)
Daniel Gautier (LESIA)

Diego Turrini (INAF)
Christina Plainaki (INAF)
Romolo Politi (INAF)

Mark Hofstadter (JPL)
Heidi Hammel (AURA)
Abi Rymer (JHU/APL)





Bilateral configurations

- With a 450M€ cost cap we naturally have to submit a proposal which has bilateral contributions.

- Restricted in launch of nuclear material.

- Options we are considering:
  1. ESA (spacecraft, instruments, operations) - NASA (RPS, launch, instrument contributions).
  2. ESA (RPS, launch, instruments) – NASA (spacecraft, instruments).
  3. ESA (RPS, launch, instruments) – NASA (spacecraft, probe, instruments).
  4. *Probably more – constraining ourselves with the 450M€ cost cap for M4 and 1B$.*

Summary

- Lots of interest in an ice giant mission from European scientists – also interest within ESA of doing such a mission.
- Unless LISA Pathfinder fails (releases the L3 launch slot in 2035) we will have to pursue this in Europe via the medium-class (M) programme.
- Cost caps are challenging.
- In doing planetary science cheaper and avoid the reliance on flagships we think that bilaterals (at least for Uranus/Neptune) are essential.
- Currently a lot of attention is on exactly how to do such a bilateral.