Progress on ice giant missions in Europe

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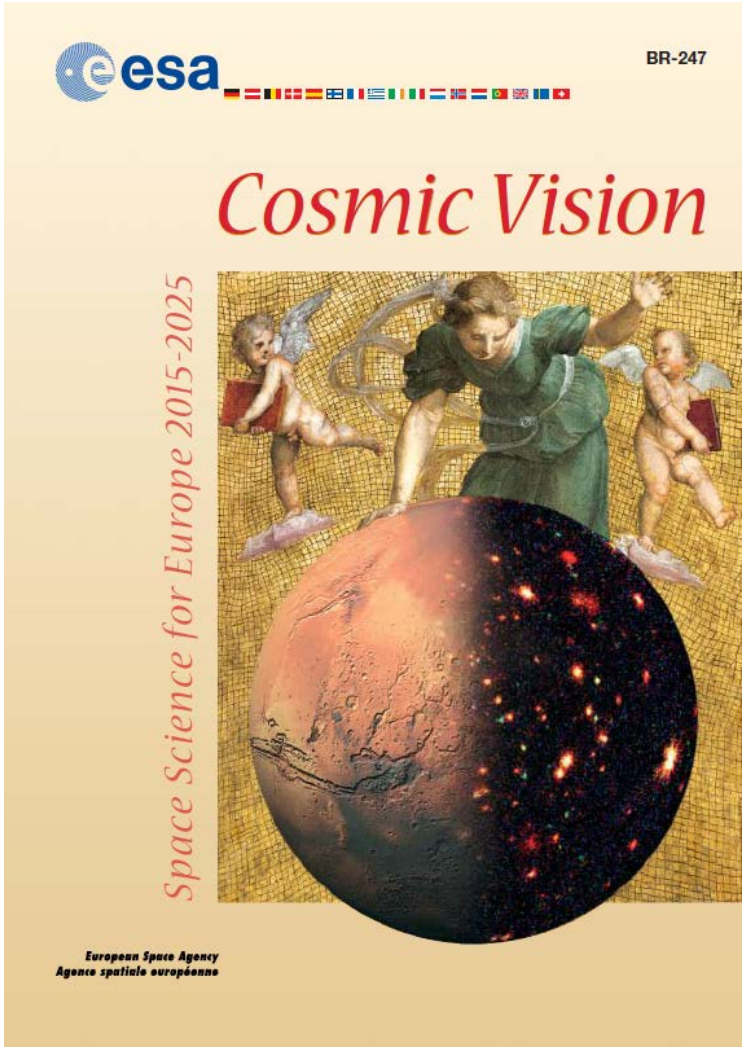
Overview of the Cosmic Vision

- 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.



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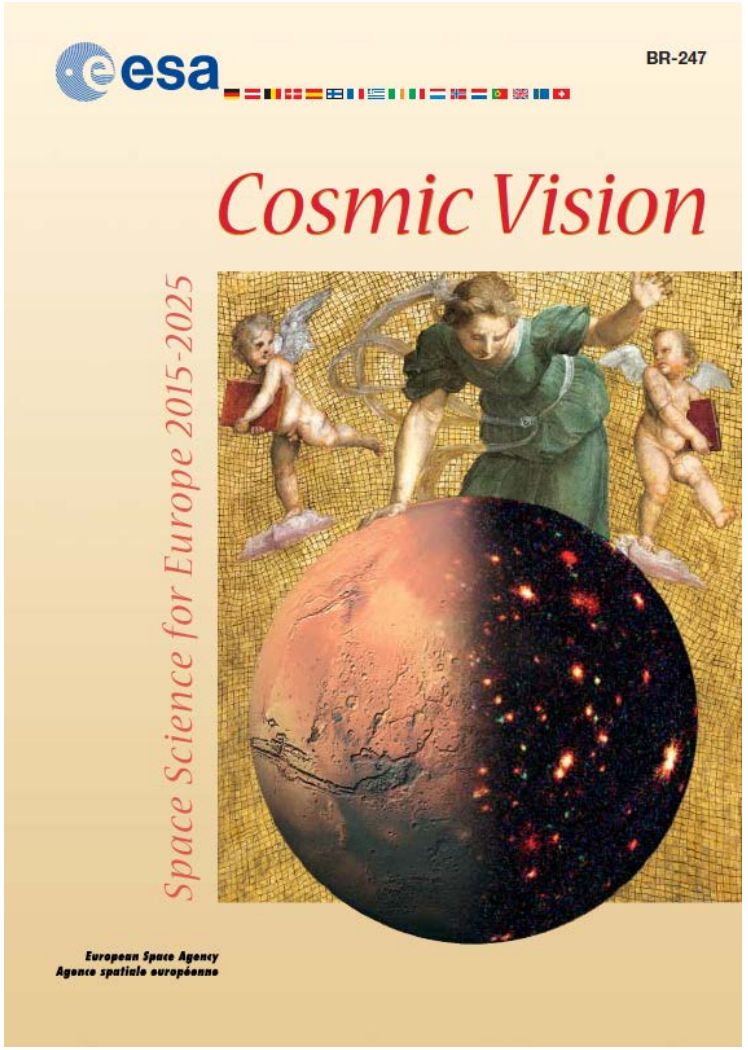

Mission classes

- 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, but **not instruments**.
- 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.

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]	
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2010-2014		GAIA [2013]	Lisa Pathfinder [2014]
2005-2009	Venus Express [2005]	Planck [2009] Herschel [2009]	
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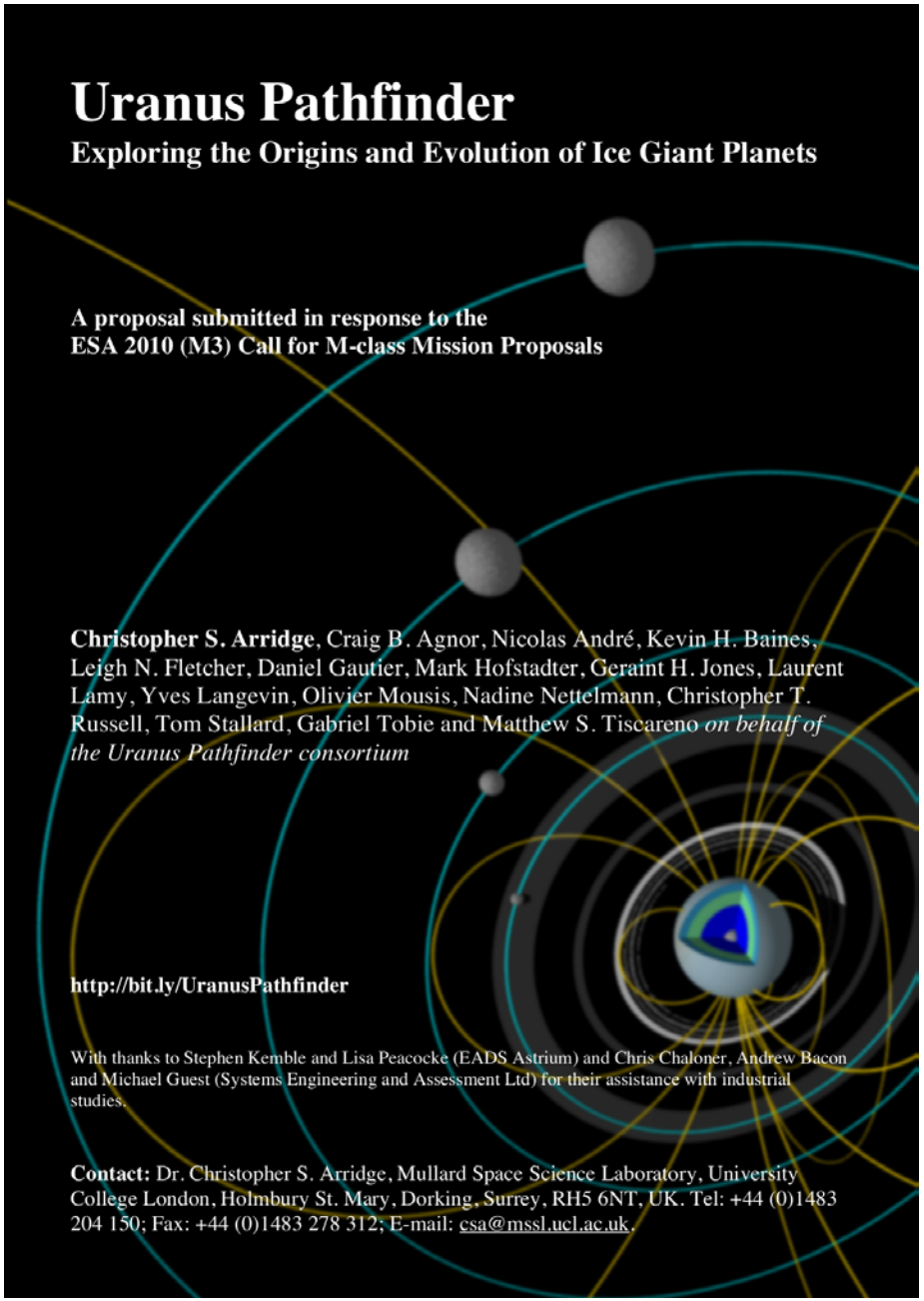
Uranus Pathfinder in M3



- Uranus proposal was submitted to M3 call in 2010.
- Specified a Uranus orbiter launching via Soyuz-Fregat with a 16 year transfer.
- One of ~30 submissions.
- Uranus Pathfinder reached the final eight set of missions.
- 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.

Uranus Pathfinder science themes

- **Uranus as an Ice Giant**
  - What is the internal structure and composition of Uranus?
  - Why does Uranus emit very little heat?
    What is the configuration and origin of Uranus' highly asymmetric magnetic field?
  - What is the rotation rate of Uranus?
  - How is Uranus' weather structure and composition influenced by its unique seasons?
  - What processes shape atmospheric chemistry and cloud formation on an ice giant?
- **The origins and evolution of Uranus' Ice Giant planetary system**
  - What is the composition of the uranian rings?
  - How do dense rings behave dynamically?
  - How do Uranus' dusty rings work?
  - How do the rings and inner satellites interact?
  - What is the nature and history of Uranus' moons?
- **Uranus' aeronomy, aurorae, and highly asymmetric magnetosphere**
  - What is the overall configuration of the uranian magnetosphere?
  - How does magnetosphere-ionosphere-Solar Wind coupling work at ice giants?
  - How are auroral radio emissions generated at ice giants?
- **Cruise phase science**
  - How does the outer heliosphere work?
  - What can we learn from in situ observations of Centaurs?

Model payload instruments

- Narrow- and wide-angle cameras.
- Near-infrared spectrometer.
- UV imaging spectrometer.
- Microwave radiometer.
- Radio science.
- Magnetometer.
- Particle package.
- Thermal infrared.

European interest in Ice Giants

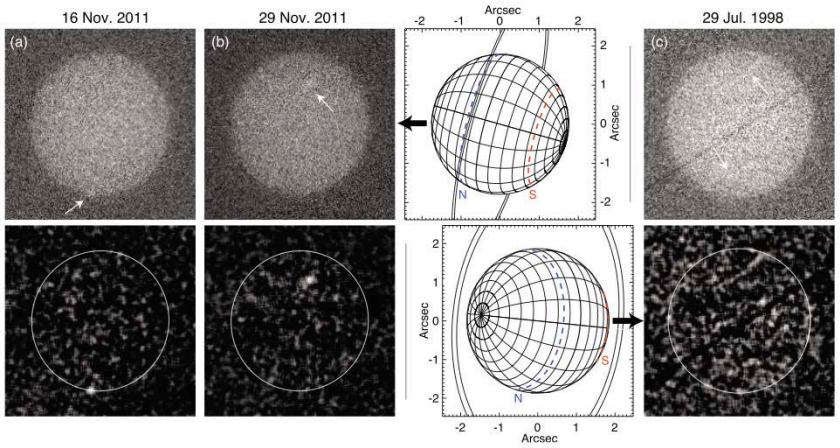
- Uranus workshop held at the Paris Observatory in September 2014.

- SOC led by Laurent Lamy (France) and supported by Nicolas André (France), Chris Arridge (UK), Leigh Fletcher (UK), Daniel Gautier (France), Heidi Hammel (USA), Mark Hofstadter (USA), Anna Milillo (Italy) and Matt Tiscareno (USA).

- Goals:
  1. Provide an occasion to the Uranus community to meet and discuss.
  2. Review our knowledge and identify the remaining questions set by the Uranus system and the outer heliosphere.
  3. Summarise the needed measurements to address them and assess future mission concepts (numerous proposals recently submitted to NASA, ESA, CNES).

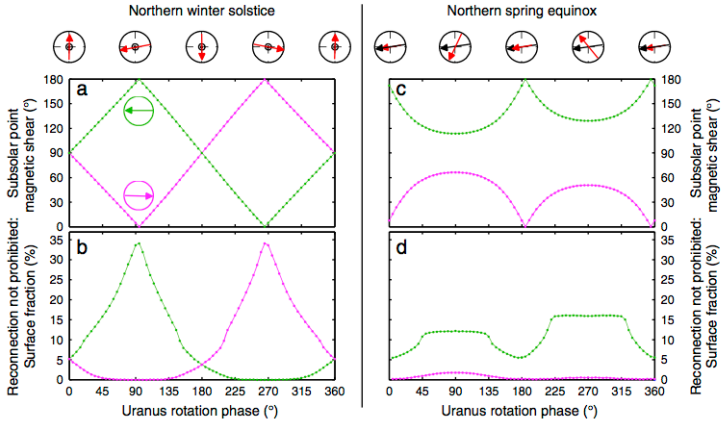
- http://uranus.sciencesconf.org/

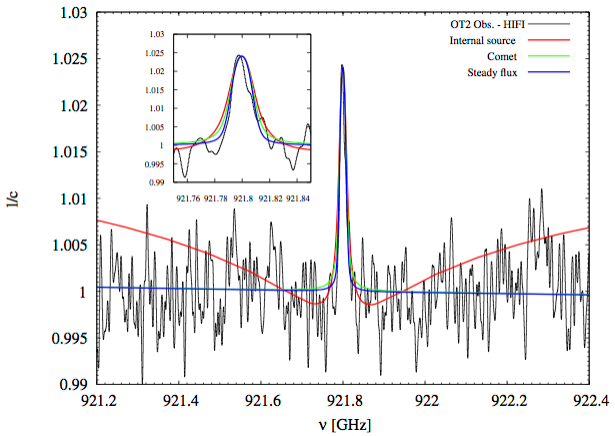
Active science community

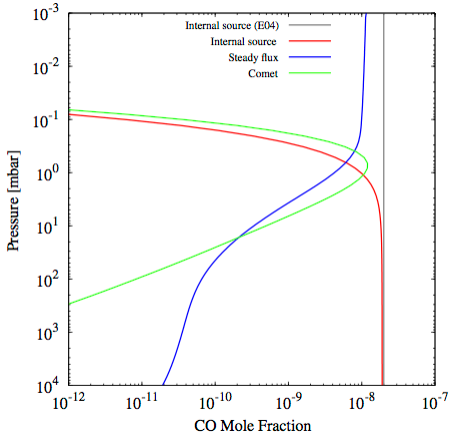


- Lamy et al. (2012, GRL) rediscovery of Uranus' UV aurorae.
- Aurorae brightened at the arrival of a solar wind shock.

- Masters (2014, JGR) theoretical study of coupling between the magnetosphere and the solar wind.
- Shows pronounced seasonal dependence in the efficiency of magnetic reconnection





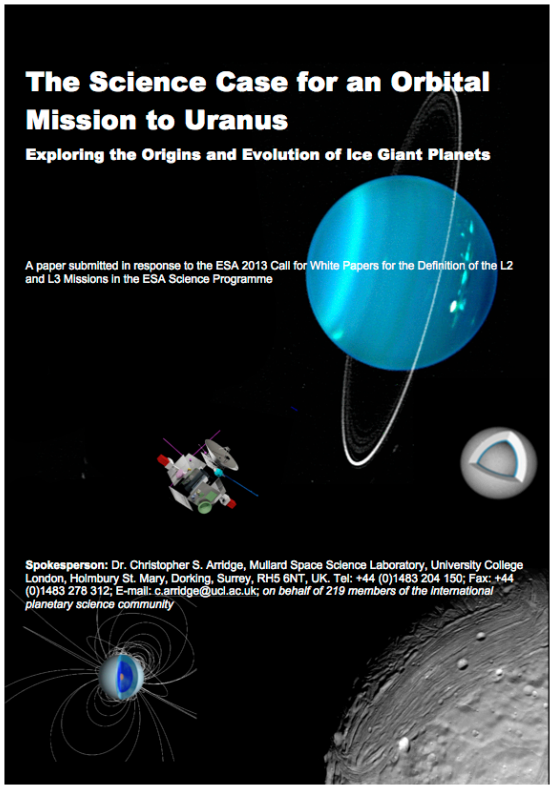


- Cavalié et al. (2014, A&A) Herschel observations of CO in Uranus' stratosphere and troposphere.
- Argues for external source.

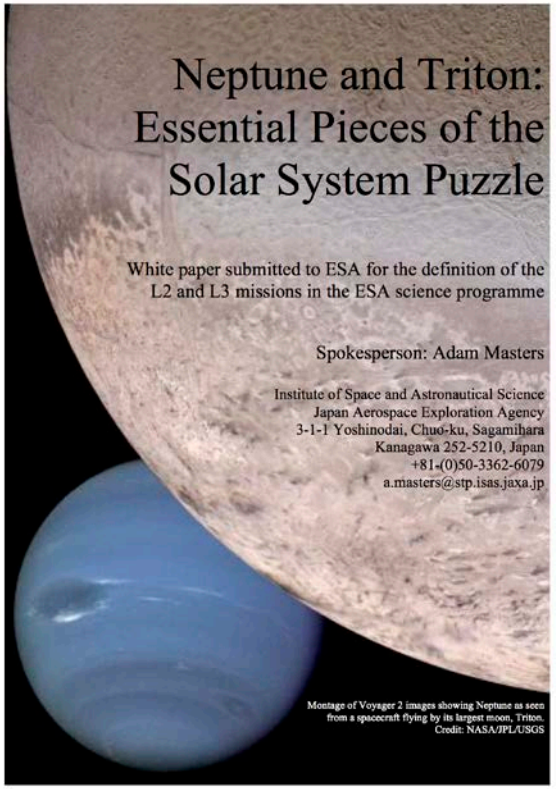
L2/L3 Science theme process

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

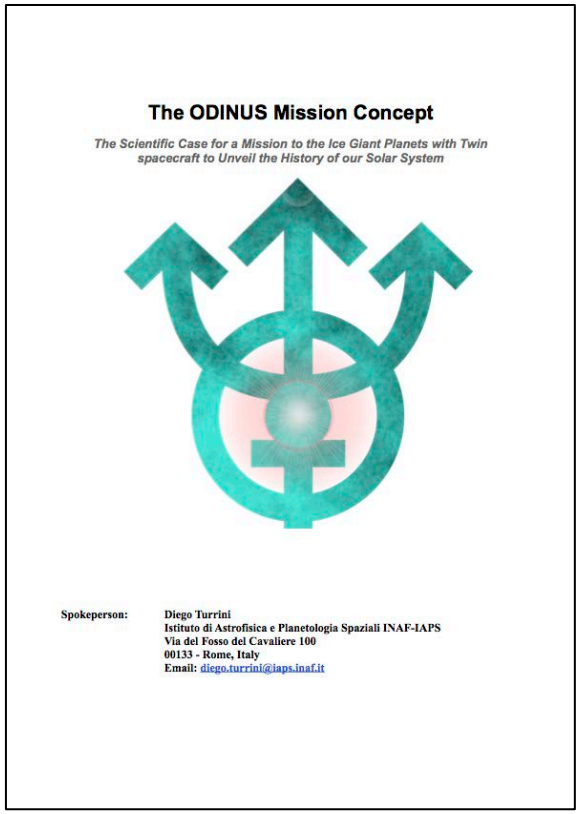
- 32 whitepapers received: three on Uranus and/or Neptune:
  - http://sci.esa.int/cosmic-vision/52030-white-papers-submitted-in-response-to-esas-call-for-science-themes-for-the-l2-and-l3-missions/



Arridge et al. [UK]



Masters et al. [Japan/UK]



Turrini et al. [Italy]

Science at the Icy Giants

Spokesperson: Chris Arridge

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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/

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.

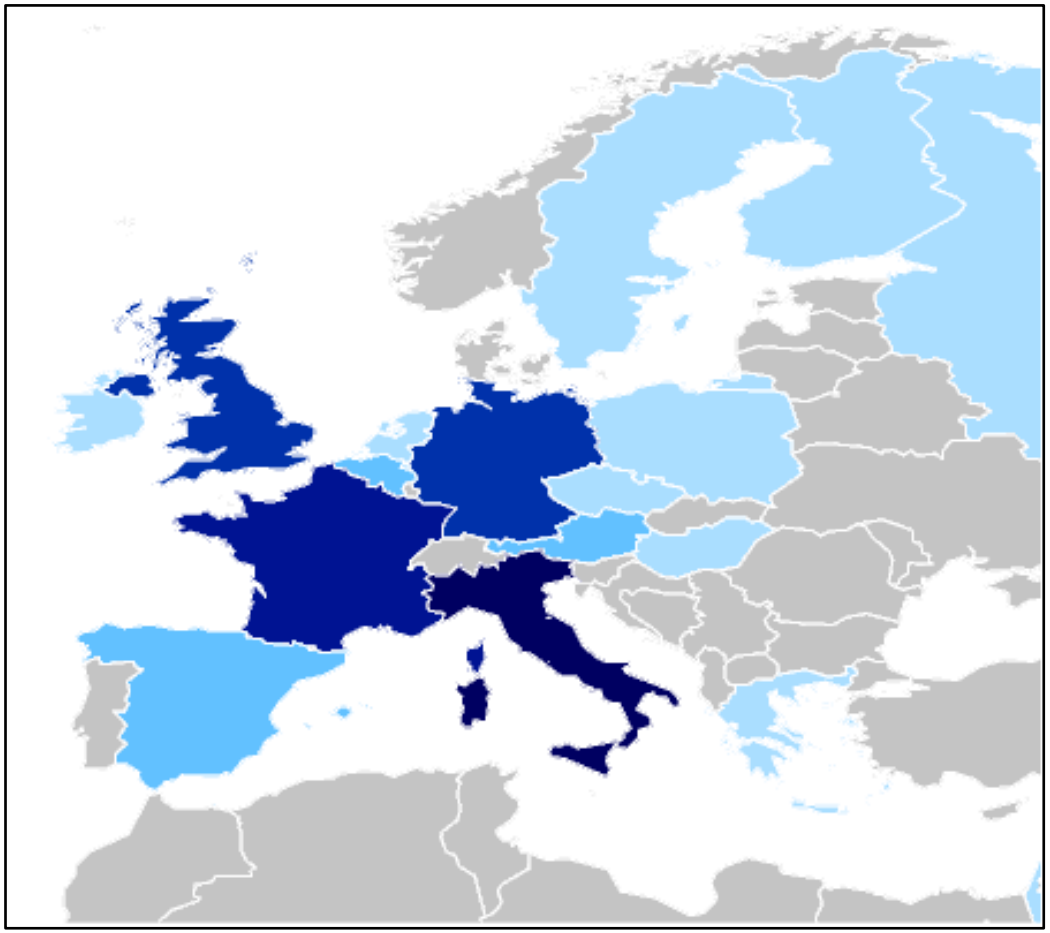
Uranus M4 mission working group

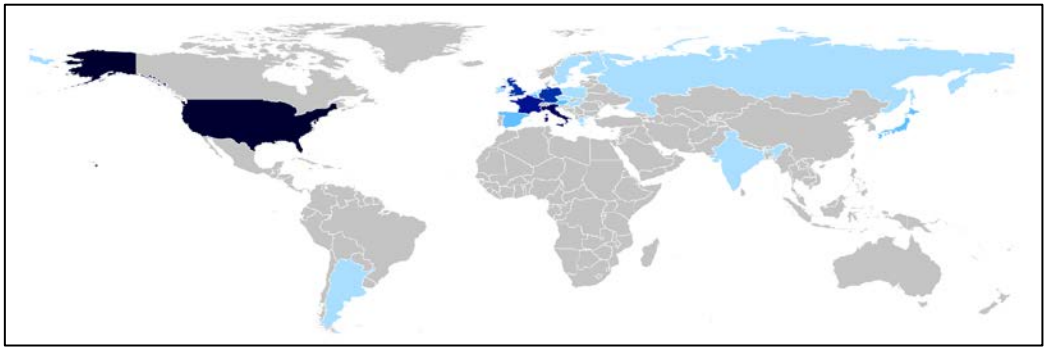
Chris Arridge (UCL)
Nigel Bannister (Leicester)
Leigh Fletcher (Oxford)
Adam Masters (Imperial College)

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)





Current status and activities

- Reduced cost cap necessitates a bilateral mission (also follows L2/L3 committee recommendations) – currently investigating bilateral concepts.
  - ESA costings for L2/L3 missions ~1-1.2 B€ (1.3-1.9 B$).
- Particular attention to costs and programmatic/schedule implications.
- Establish science team.
- UK science workshop early in the fall.
- Study of critical technical issues:
  - Power: European (using ^{241}Am) RPS Vs. MMRTG/eMMRTG/ASRG.
  - Telemetry: largest ESA dish is 35m (~kbit/s downlink).
  - Thermal control: Uranus Pathfinder interplanetary transfer included Venus GA.

Links and papers

- Uranus Pathfinder mission concept paper: Arridge et al. (2012) Experimental Astronomy, 33(2-3), pp. 753-791, doi:10.1007/s10686-011-9251-4.

- L2/L3 white papers:
  - Published by ESA:http://sci.esa.int/cosmic-vision/52030-white-papers-submitted-in-response-to-esas-call-for-science-themes-for-the-l2-and-l3-missions/.
  - Also in forthcoming special issue of Planet. Space Sci. (papers led by Arridge et al., Masters et al., Turrini et al..

- Uranus conference: http://uranus.sciencesconf.org/