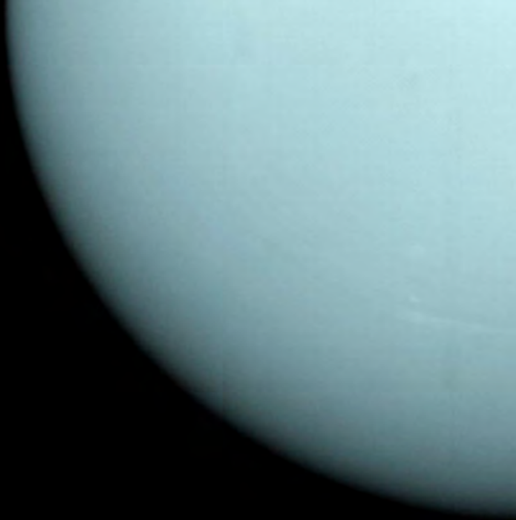


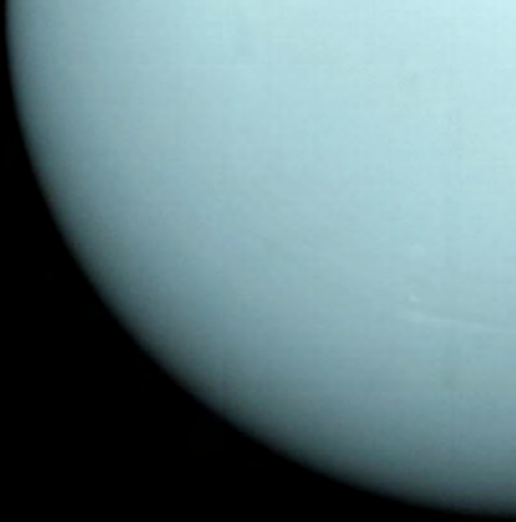
Imperial College London

Magnetic Fields of the Ice Giants

A. Masters

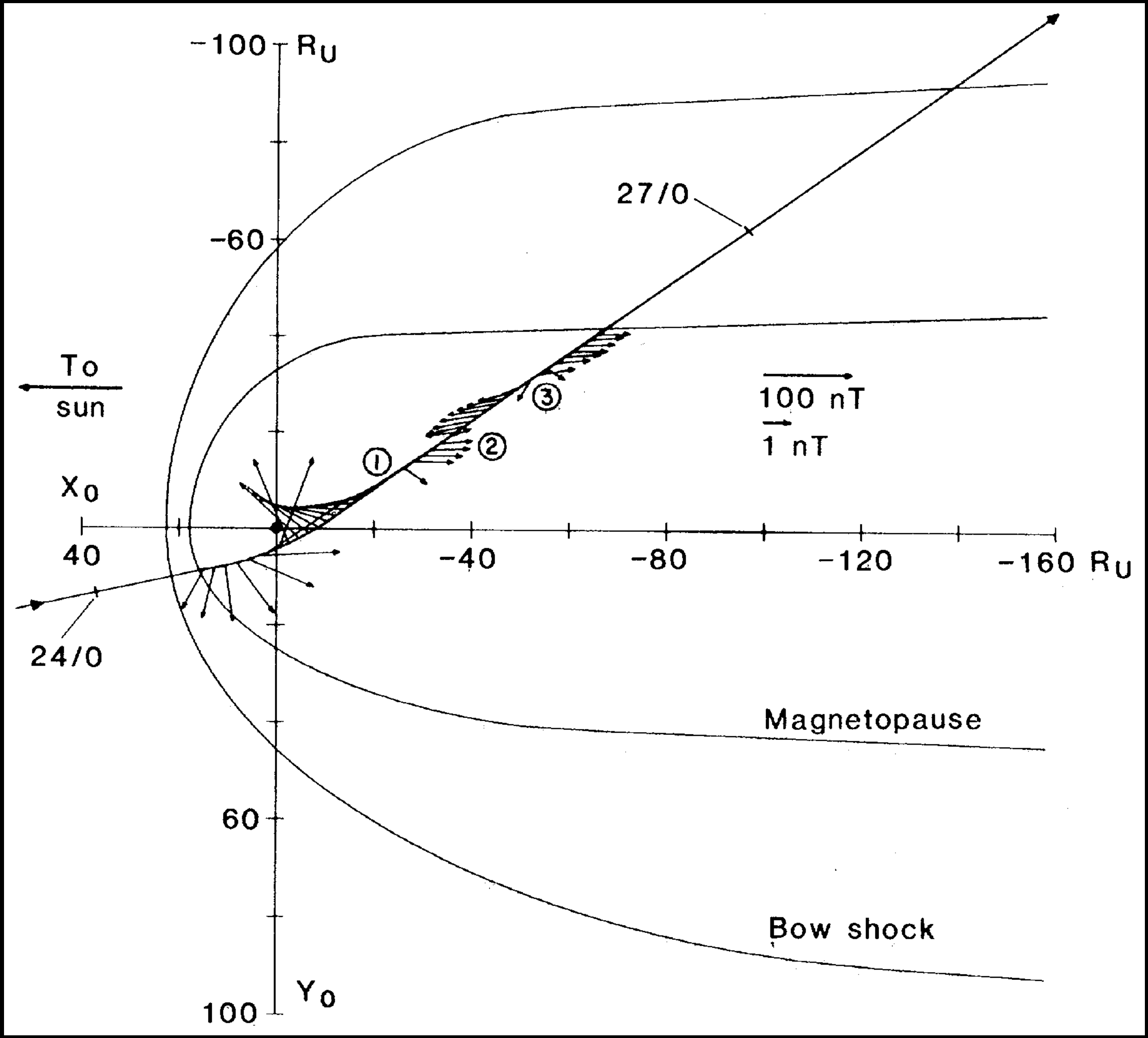
Image credits: NASA/JPL-Caltech.

Overview



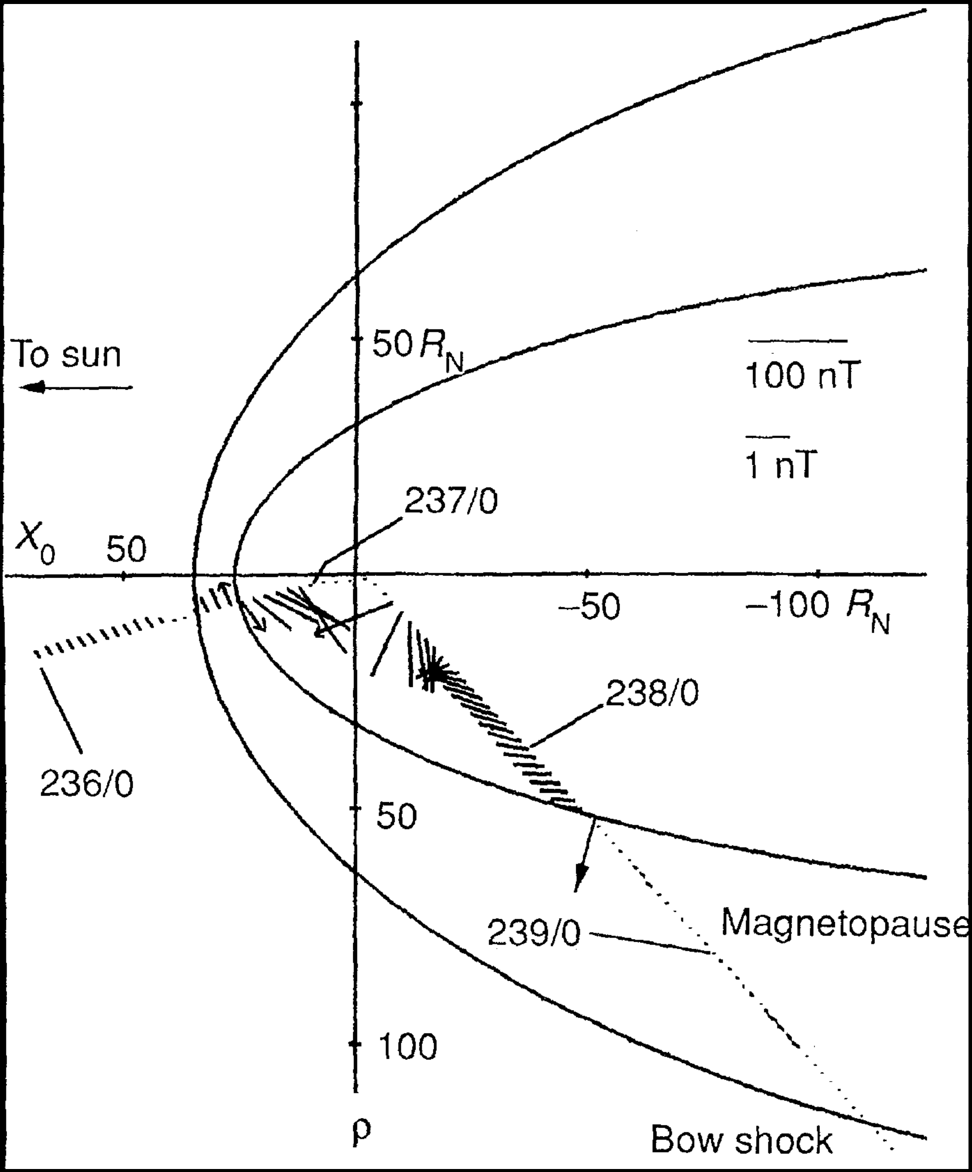
- *Voyager 2* Magnetic field measurements at both Uranus and Neptune
- How we represent the global magnetic field of a planet with spherical harmonics
- Implications of the *Voyager* observations for the ice giant planetary systems
- The impact of future magnetic field measurements from orbiters and probes

Voyager magnetic field measurements: Uranus



From Ness *et al.* (Science, 1986)

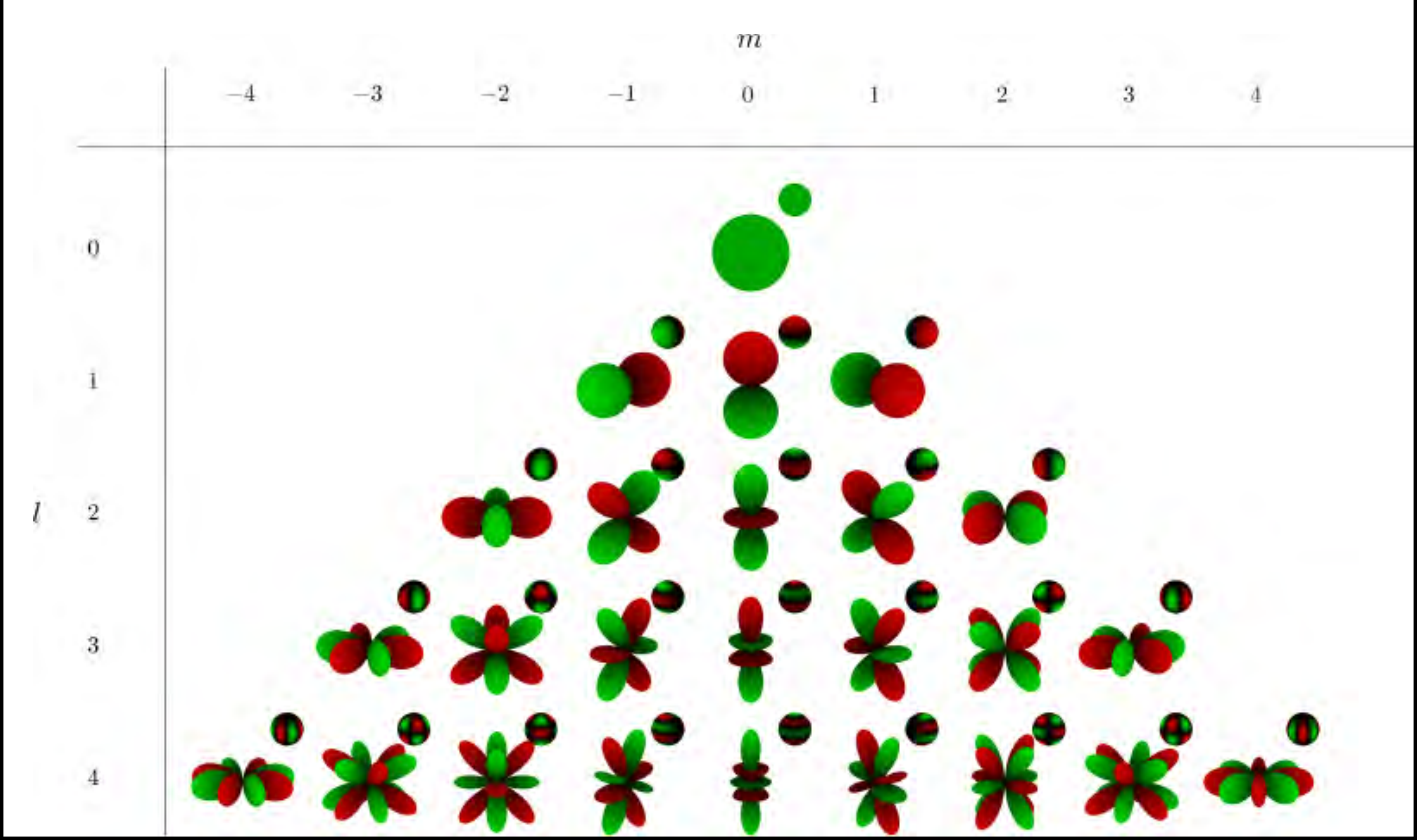
Voyager magnetic field measurements: Neptune



From Ness *et al.* (Science, 1989)

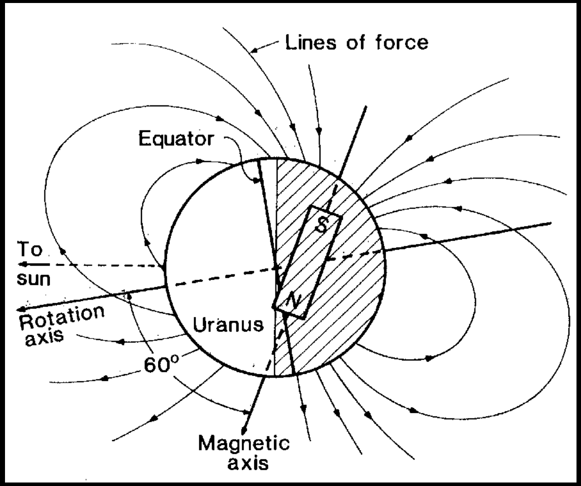
Spherical harmonic models of planetary fields

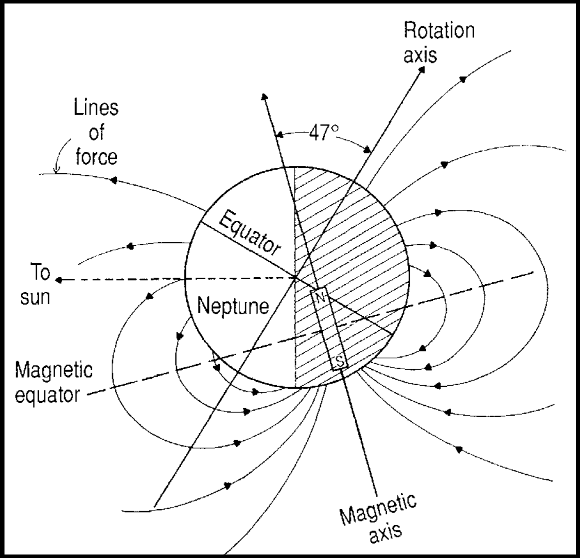
$$V = a \sum_{l=1}^{\infty} \left(\frac{a}{r}\right)^{l+1} \sum_{m=0}^{l} P_l^m(\cos\theta)[g_l^m \cos(m\phi) + h_l^m \sin(m\phi)]$$



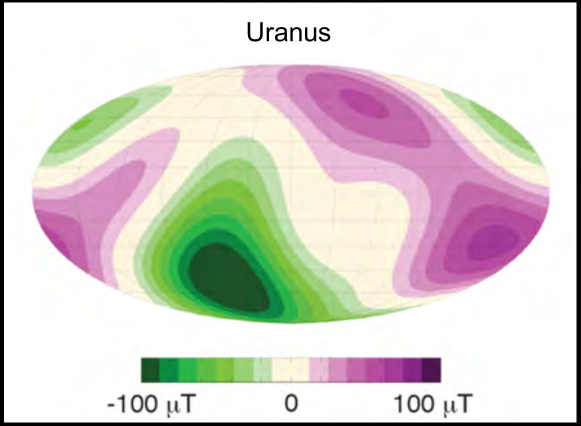
Magnetic fields of the ice giants: Present models

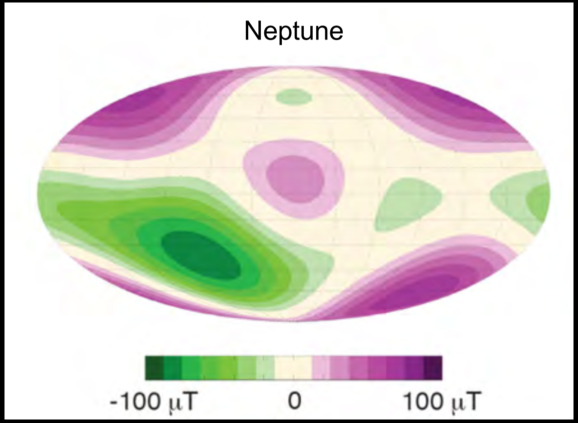
From *Ness et al.* (Science, 1986)





From *Ness et al.* (Science, 1989)



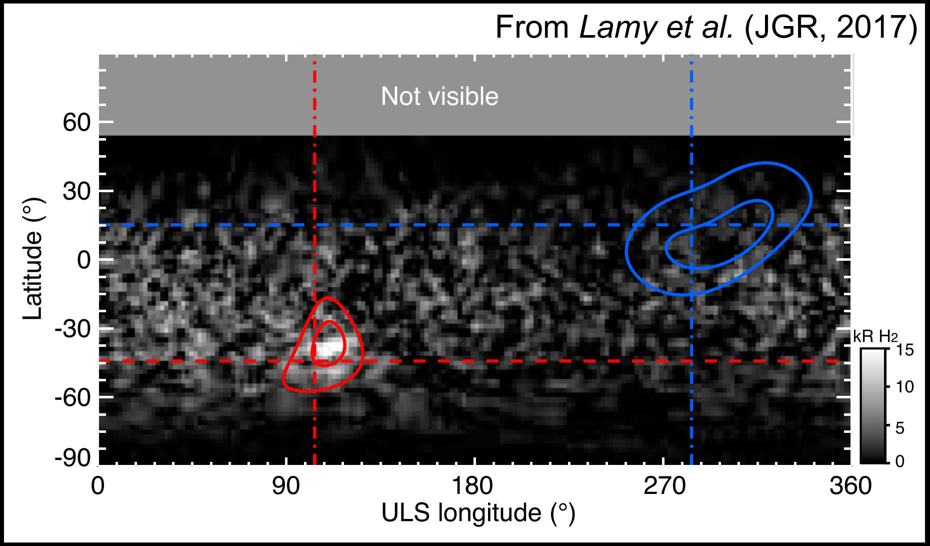


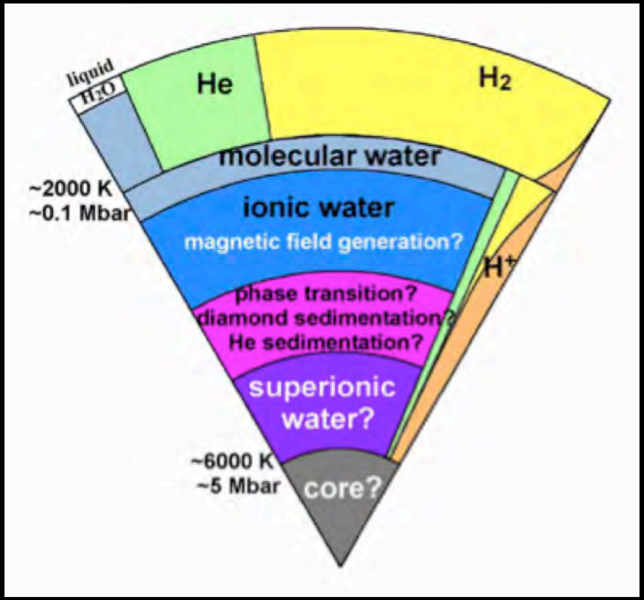
Adapted from *Schubert and Soderlund* (Phys. Earth Planet. Int., 2011)

Implications of current understanding

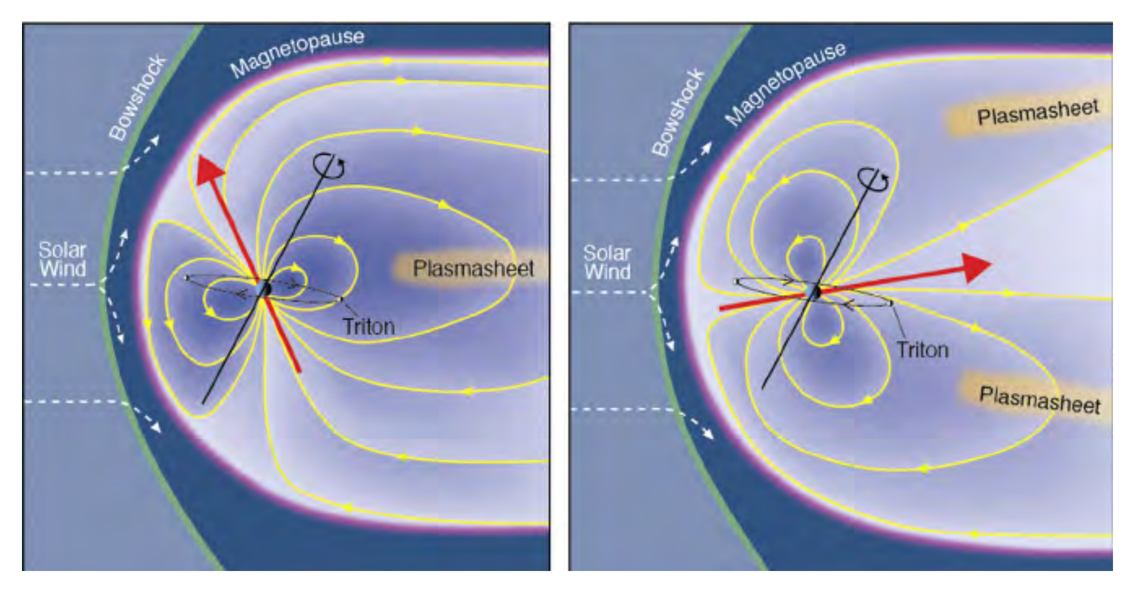
The magnetic field models are relevant for almost all aspects of each system:

- Interior
- Atmosphere
- Magnetosphere
- Moons



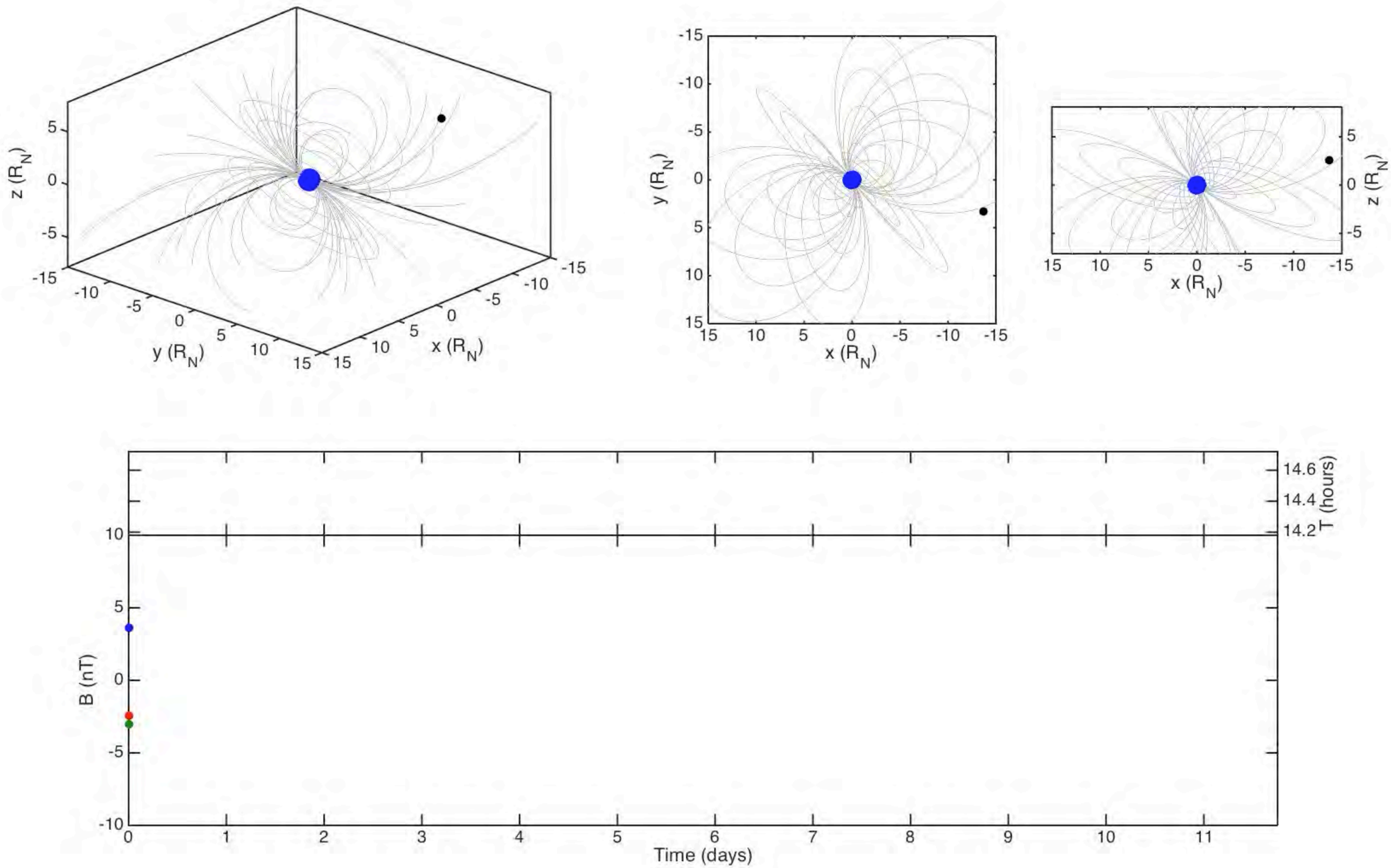


Credit: C. S. Arridge



Credit: F. Bagenal & S. Bartlett

Neptune's magnetic field at Triton



Impact of future magnetic field measurements

- Determination of whether the the ice giant magnetic fields are generated in "shallow" layers of liquid water within the interiors.
- Important constraint on poorly understood interior structures.

- Foundation of our understanding of how each magnetosphere is coupled to the ionosphere, and the resulting energy input to the atmosphere.

- Explanation of how each magnetosphere can re-configure dramatically on a timescale of hours, and what this means for the system.
- Identification of magnetospheric drivers, testing the hypothesis that the solar wind dominates, interacting with both systems in a radically different way.

- Establish if the rings are electrodynamically coupled to each planet.

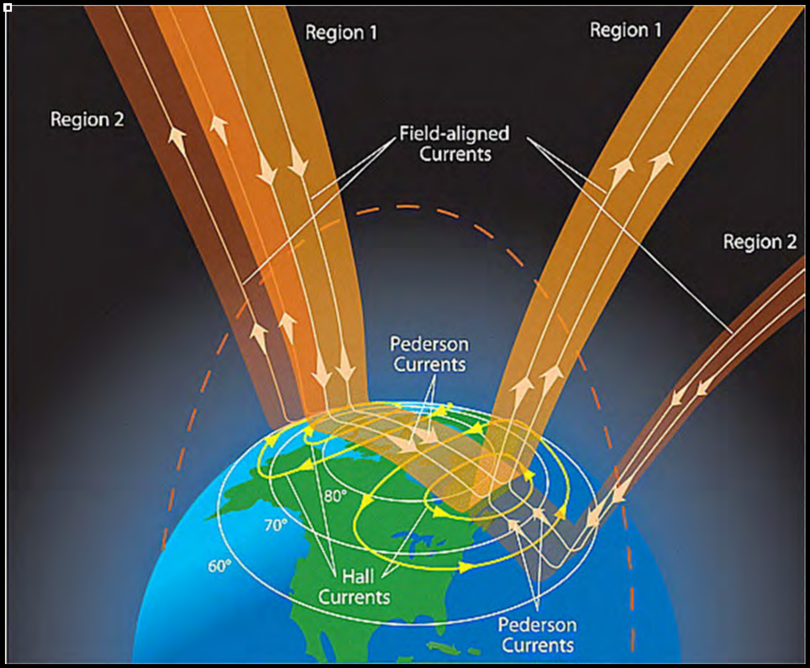
- Carry out passive electromagnetic sounding at planetary moons to search for subsurface oceans of liquid water.

Measurements from different platforms

- **Spacecraft (and potentially sub-spacecraft) during a flyby**
  Limited improvement to global field models, negligible impact on understanding all other areas addressed by magnetic field measurements.

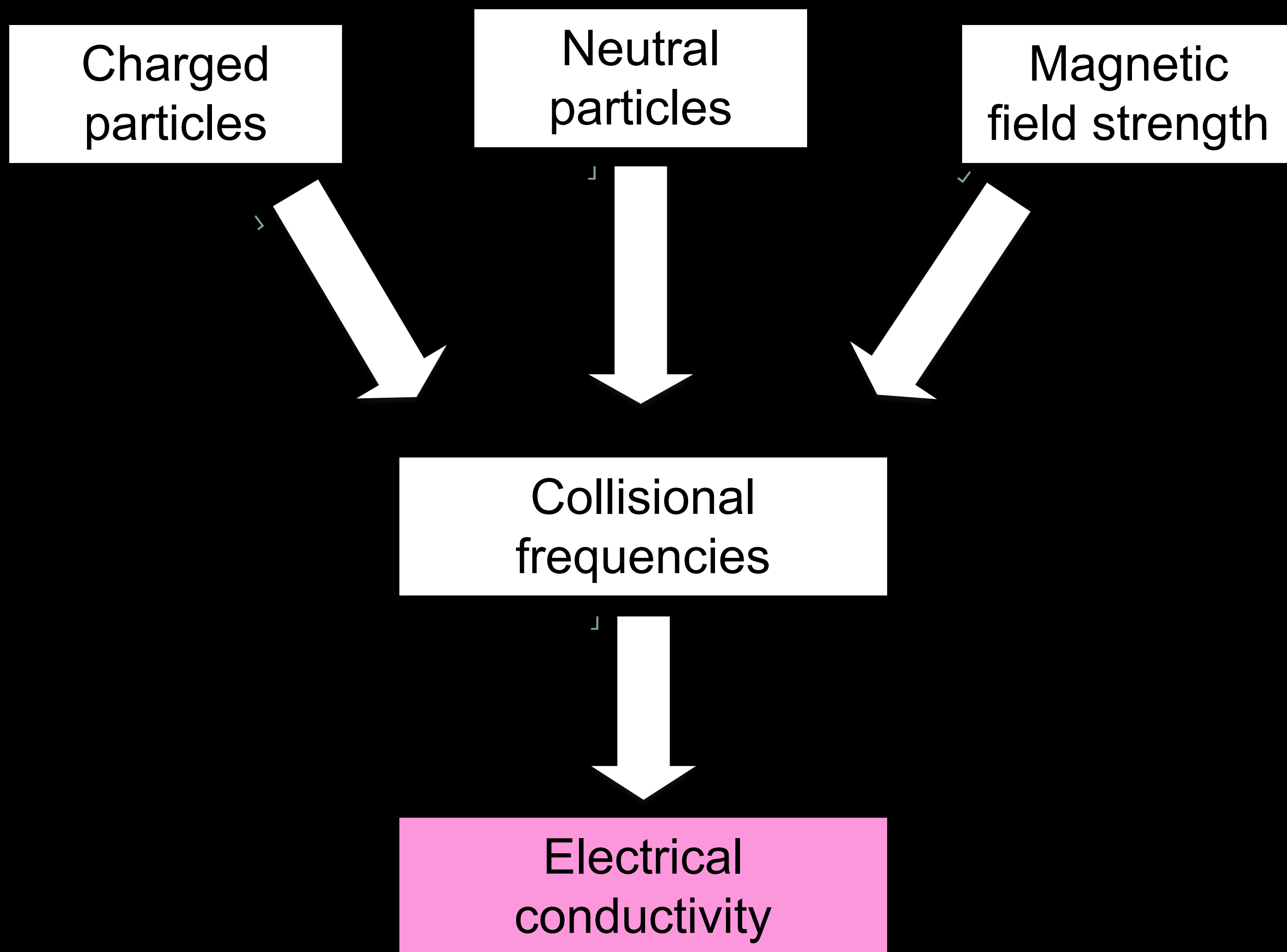
- **Spacecraft during an orbital tour**
  Measurements would have a significant impact, addressing all relevant themes (interior, atmosphere, magnetosphere, moons).

- **Atmospheric probes**
  Additional input to a global magnetic field model, and enabling the measurement of the electrical conductivity of the ionosphere.



From *Le et al*. (JGR, 2010)

Ionospheric conductivity measured by a probe

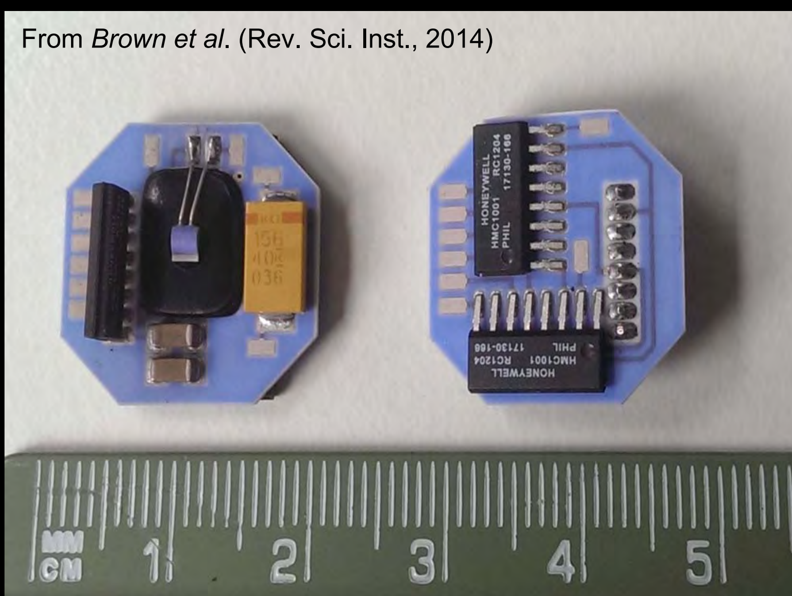


Low-resource magnetometers

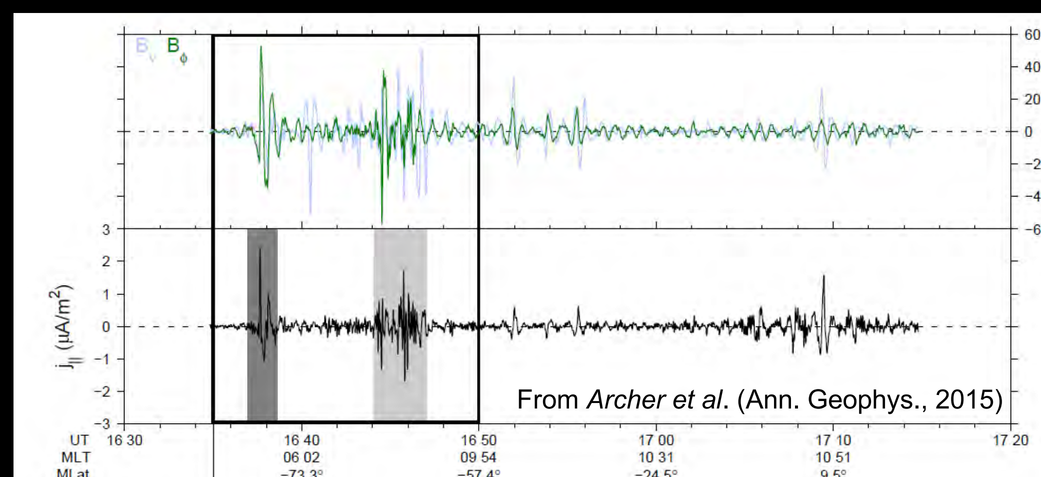
At Imperial we build low-resource solid-state magnetometer sensors based on the magnetoresistance principle: Hybrid Anisotropic Magnetoresistive (AMR) sensors.

Our sensors have flown on CubeSats to low Earth orbit (e.g., *CINEMA*), and ongoing development has led to future flight opportunities (e.g., RADCUBE).

The total mass and power of a two-sensor hybrid AMR instrument is 110 g and 0.7 W.



From *Brown et al*. (Rev. Sci. Inst., 2014)

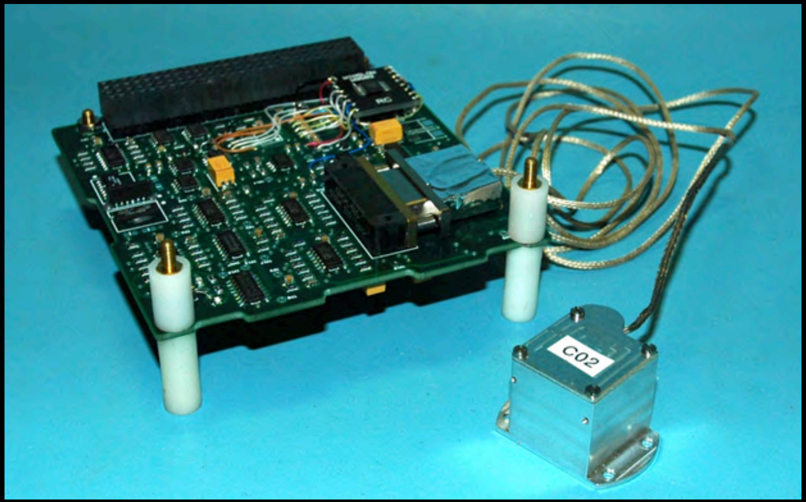


From *Archer et al*. (Ann. Geophys., 2015)

A magnetometer for an ice giant probe

We propose an instrument comprising electronics, harnessing, and two sensors.

- Limited EMC requirements (c.f., *MASCOT/Hayabusa 2)* and no alignment requirements (|B| only)
  → Mounting on a boom not needed.
- MR sensors are more robust than fluxgates → more favourable for bonus science at lower altitudes.



Mass	70 g for electronics, 20 g per sensor (includes sensor head and harness). Total two-sensor instrument mass: 110 g.
Volume	Each sensor head: 21 x 21 x 11 mm^3 Electronics card: 90 x 96 mm^3
Power	0.7 W
Data rate	Normal mode (1 vectors/s): 72 bps Burst mode (10 vectors/s): 704 bps
Radiation	Sensor head not susceptible to at least 100 krad. Electronics COTS, RH parts available.
Thermal	Sensor: +143 to +373 K (-130 to +100 ° C)
Absolute accuracy	1 nT (calibrated)
Noise density	300 pT $Hz^{-1/2}$ at 1 Hz
Digital resolution	0.114 nT
Range	±60,000 nT

Summary

- *Voyager 2* showed that Uranus and Neptune have complex planetary magnetic fields and highly dynamic magnetopsheres
- Future magnetic field measurements at each planet will allow significant progress in understanding many aspects of each system
- Measurements from an orbiting spacecraft are essential and measurements from atmospheric probes enable new science
- We propose a low-resource magnetic field experiment for a probe that would allow the measurement of ionospheric conductivity

Future exploration of the ice giants

Scientific discussion meeting

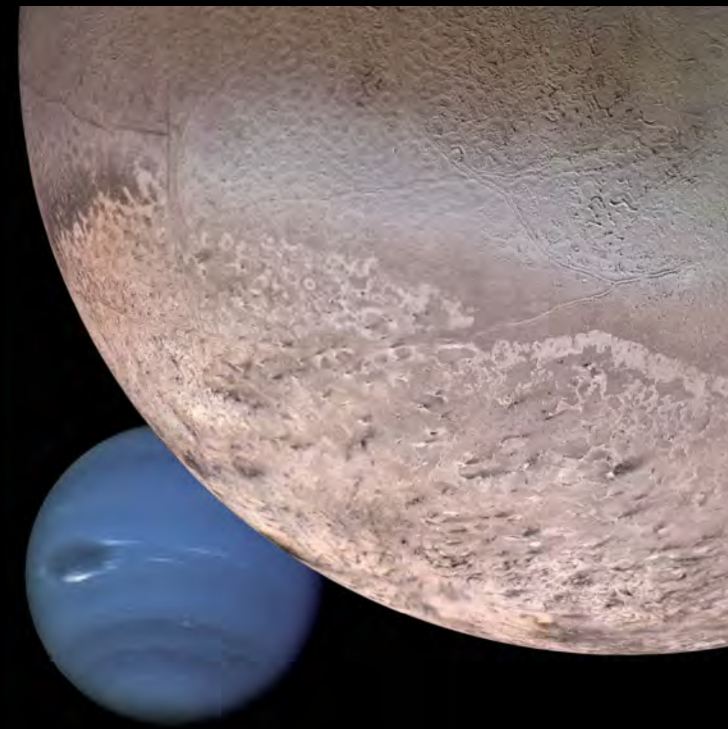
20 – 22 January 2020

Part of the Royal Society scientific programme

#IceGiants2020 @IcyGiants

THE ROYAL SOCIETY

Image: NASA/JPL/USGS.



Plenary Talks: Monday-Tuesday 20/21 January 2020 – Royal Society
Poster Session: Monday 20 January 2020
Splinter Sessions: Wednesday January 22 – Burlington House, London.
Full details: https://ice-giants.github.io/
Registration and Abstract Deadline: December 10th 2019

Science traceability

Science Objective	Measurement Objective	Measurement Requirements	Instrument	Instrument Requirements
Determine the electrical conductivity of the planetary ionosphere	Neutral and charged particle measurements. Using *Cassini* as a reference.			
	Measure the magnetic field within the ionosphere to within one order of magnitude, and resolve altitudinal structure to at least reveal if it is 2-layer.	• Field magnitude accuracy of 2,000 nT. • Range of ±20,000 nT. • Cadence of 6 vectors/min to provide at least 10 measurements between 2,000 and 1,000 km altitude.	Magnetometer comprising Hybrid Anisotropic Magnetoresistive sensors	Accommodation on a probe. Operate at ionospheric altitudes (10,000 km to 1,000 km above the 1 bar level, pressures <0.2 μbar).

Origin of magnetic field accuracy requirement