Instrumentation - Payload Selection Considerations

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Short Course on Ice Giants, IPPW-16

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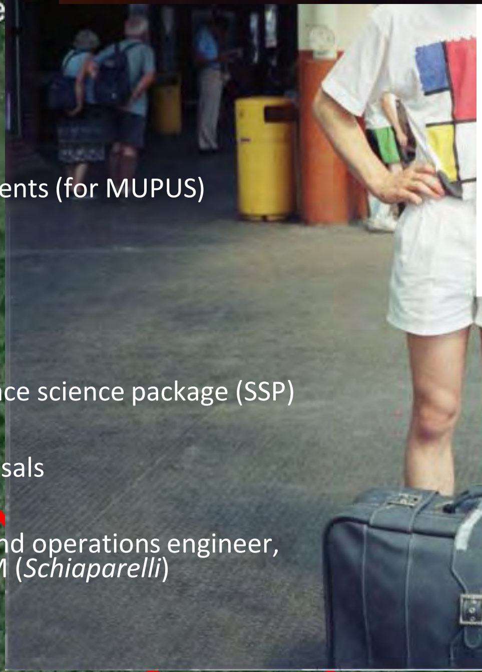
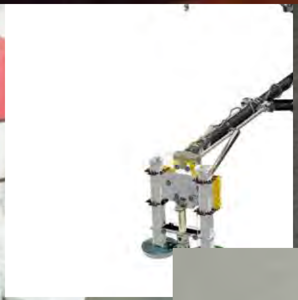
Outline Biography

- Natural Sciences (mostly Physics…) Bachelor degree (U. of Cambridge)
- M.Sc. in Spacecraft Technology and Satellite Communications (UCL)
- Ph.D. in development of instruments for physical properties measurements (for MUPUS) on the *Rosetta* comet lander *Philae* (U. of Kent)
- Postdoc work at ISSI (Bern, Switzerland) and U. Münster (Germany), then return to UK (Open University)
- Participated in IPPW 2003, 2006-present
- Member of *Huygens* atmospheric structure instrument (HASI) and surface science package (SSP) experiment teams for encounter in 2005
- Involved in early proposals for *ExoMars* experiments (2003-) and proposals for small NEO missions and penetrators.
- At ESA ESTEC since Oct 2008 as *ExoMars* payload instrument systems and operations engineer, taking care of interfaces for science experiments on *ExoMars* 2016 EDM (*Schiaparelli*) and instruments on *ExoMars* Rover





Abstract

- I plan to cover (from a payload accommodation/interface and instrument systems point of view) critical aspects examined during technical assessment of payloads for ice giant probes, during proposal, selection and subsequent reviews. These include:
  - Technology Readiness Level;
  - Mass, volume, power/energy;
  - Accommodation (fixation, allowable envelope, FoV, deployments);
  - Electrical (harness, EMC, power i/f);
  - Data interface (protocol, rate/volume);
  - Operational sequence, s/w requirements, auxiliary data;
  - Environmental test (mechanical, thermal) and challenges for ice giant atmospheres;
  - Planetary Protection and Cleanliness and Contamination Control;
  - Margins.

Science Traceability Matrix – example from JPL D-100520, 2017

Table 3-2. Science Traceability Matrix.

SDT Science Objective (First two are highest priority, others all of equal priority)	Scientific Measurement Requirements		Instrument	Instrument Requirements	Mission Requirements	Comment
	Physical Parameters	Observables				
1. Constrain the structure and characteristics of the planet's interior, including layering, locations of convective and stable regions, internal dynamics	Planetary oscillations	Top-of-atmosphere radial velocities, temperatures, or geoid	Doppler Imager or similar seismology instrument	Detect velocities of a few cm/s with a spatial resolution of ~100 pixels across the disk of the planet.	Allow imaging on approach for tens-of-days with a 1- to 2-minute cadence (to achieve micro-Hz frequency resolution).	Oscillations may also be detectable through studies of the rings.
	Magnetic field geometry and time variability	Magnetic field strength and orientation	Magnetometer		Magnetic cleanliness of spacecraft	
	Gravity moments, J2-J6 (not a driver at Uranus)	Perturbations to s/c orbit (also useful to make astrometric observations of rings and satellites)	USO		Close periapse passess	Gravity is still of interest at Uranus, but of lesser importance for interior structure than at Neptune. If Doppler tracking is a problem (dangerous to fly close to planet), can investigate astrometry further.
2. Determine the planet's bulk composition, including abundances and isotopes of heavy elements, He and heavier noble gases	Atmospheric composition	CH_4, noble gases (He, Ne, Ar, Kr, Xe), and isotopic abundances (C, Ne, Ar, Kr, Xe) at two tropospheric pressure levels such as 1 bar and 10 bars, N, S, and O isotopes to 20 bars. NH_3, H_2S, H_2O below their respective cloud bases.	Probe with mass spec (and TLS if pressures >10 bar)	Probe to 10 bars for noble gases, CH_4 and most isotopic ratios. Probe to 20 bar for N, S, and O isotopes. Probe to > several kilobars for NH_3, H_2S, and H_2O. All measurements ±10%	Probe relay. Instrument survival and performance in the extreme p,T environment, especially if deployed to >10 bar.	Probe to 10 bars will not give well-mixed H_2S, H_2O, S and O isotopes, and NH_3 only marginally. Probe to 100 bars could give NH_3 and H_2S, but not H_2O. Probe to 10's-100's kilobars is required to confidently get H_2O, especially if an ionic ocean is present, as predicted by models and lab work.
3. Improve knowledge of the planetary dynamo	In situ magnetic field direction and magnitude	Magnetic field direction and magnitude	3-axis Magnetometers on boom	0.1 to 20,000 nT, 1 second cadence	Multiple close orbits; longitude and latitude coverage for degree and order at least 4, preferably 15	
	Remote sensing of magnetic field footprint.	UV and IR emission from auroral and satellite footprints	IR, UV spectral imager(s)	1600-1800 Ang imaging and 3.4–4 micron imaging.		Should not drive the UV or IR instrument, but should be considered regarding instrument capability and operations
		Auroral radio emission	Radio Receiver, at least 2 axis electric antenna	10 kHz to 1 MHz, direction finding ability	Multiple close orbits, good longitude and latitude coverage	
4. Determine the planet's atmospheric heat balance	He/H_2 abundance	He/H_2 abundance	Probe mass spectrometer	He/H_2 ± 5%	Measure at $P \geq 1$ bar	Solar uncertain by 2%; protosolar somewhat greater, hence ±5%.
	Net thermal emission	Broadband thermal IR emission	Thermal IR bolometer	5–900 cm^{-1}, accuracy 1%	Full phase angle coverage	Range based on ~1% of peak for Neptune, accuracy based on 0.1% of peak, See Li et al, 2010, Fig. 1 as reference
	Bond albedo	Visible wavelength bond albedo	Photometer, or suitably calibrated imager or spectrometer	0.3–1.6 μm, accuracy 1%	Full phase angle coverage	Range based on ~10% of peak flux of Sun, and similar to Voyager IRIS shortwave radiometer bandpass. Accuracy assumed to reduce error bars to 1% of total. May be too stringent.
5. Measure planet's tropospheric 3-D flow (zonal, meridional, vertical) including winds, waves, storms and their lifecycles, and deep convective activity	Vertical, zonal, and meridional profiles of wind speed	Repeat maps of cloud tracers at multiple wavelengths including methane bands	Visible/Near-IR imager, 8 channels	30km/pixel spatial resolution, 3 emission angles (nadir,near limb, intermediate), 425 ± 25nm, 500 ± 25nm, 619 ± 5nm, 653 ± 25nm, 727 ± 5nm, 750 ± 5nm, 890 ± 10nm, 925 ± 5nm, repeat one rotation later, Absolute I/F's to 5%, SNR:50 for all but SNR:100 for 750nm & 653nm for winds	Global mapping and feature tracking. Each region viewed at 3 emission angles on 2 consecutive rotations.	
		In situ wind speeds to 15 bars (100	Probe USO for Doppler	Velocity to 20 m/s	Probe relay to 15 bars (100 bar goal)	

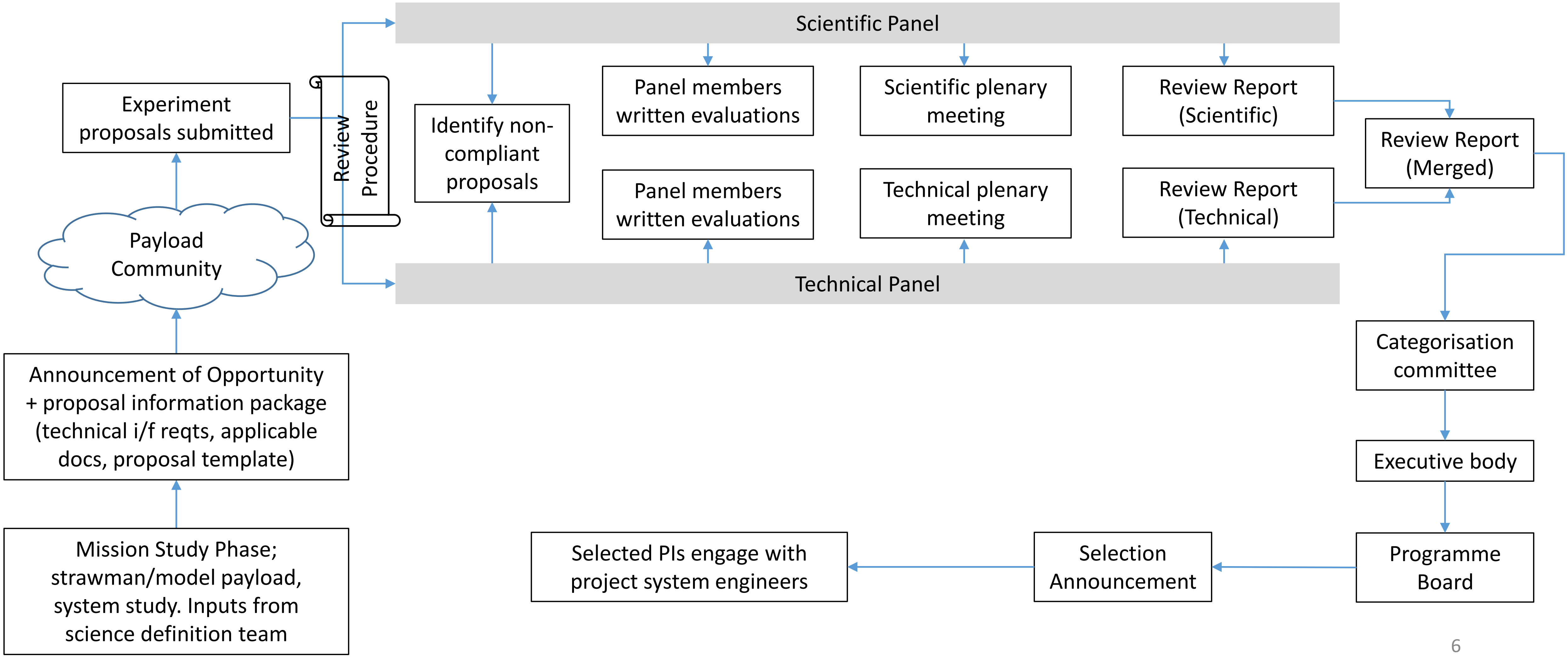
Technology Readiness

- ESA uses ISO standard 16290 TRL definition
- TRL at least 5 (+design & development plan) for selection
- Pool of TRL 8 or 9 equipment for the descent environment is rather limited
- What aspects of the environment are relevant for the particular equipment?

- Long Lead Items

TRL	Level Description
1	Basic principles observed and reported
2	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or characteristic proof-of-concept
4	Component and/or breadboard functional verification in laboratory environment
5	Component and/or breadboard critical function verification in relevant environment
6	Model demonstrating the critical functions of the element in a relevant environment
7	Model demonstrating the element performance for the operational environment
8	Actual system completed and accepted for flight ("flight qualified")
9	Actual system "flight proven" through successful mission operations

Payload Selection – example evaluation process



Mass, Volume, Power/energy

- Key resource constraints for an instrument, with NTE allocations and margins to be managed at instrument and system level during development phase.
  - 20% until PDR passed, then 10% until CDR passed, then 5%.
  - System margin managed by project, e.g. for mass impact of accommodation
- Important to define scope of mass budget responsibility, e.g. for brackets, booms, fixation h/w, thermal straps, etc.
- Power defined vs. instrument mode. Break point at LCL current limit
- Understand where the risks are, and trades vs. performance, etc.

Accommodation

- System study will have defined to some level the payload accommodation possibilities. To define early are parts involving access to the environment, hull penetrations, deployment.
- Who specifies, designs and procures windows and feedthroughs?
- Accessibility for mechanical and electrical integration.
- FoV (or other keep-out measurement volume)
- CAD Model
- Configuration Control

Electrical, data & EMC i/f

- What supply voltage(s) is/are available? regulated/unregulated?, V range, LCL current limit, inrush current, input impedance, UVLO, OVP
- Analogue sensor / FEE to common electronics, or own processor?
- What data i/f protocol?
- Avoid failure propagation – get specialist review of your i/f schematics before you get too far into build phase.
- EMC CS, RS, CE, RE

Operational sequence

- What is the nominal operational timeline and profile in terms of power consumption and data production?
- What requirements or constraints does the instrument place on the system for monitoring, control and processing (nominal and any failure detection, isolation and safing/recovery)?
- Auxiliary data needed for instrument data interpretation?
- Does your instrument need to be reprogrammable after delivery?
- May require delivery of a Software Interface Simulator (code)

Mechanical and Thermal

- Structural model & analysis
- Sine, random, quasi-static, shock: applicable loads at interface from system level (launch, entry, pyro shock, etc.)
- Thermal Mathematical Model / Geometric Mathematical Model, simplified for input to system thermal model.
- Thermal analysis, responding to modelling requirements from system level
- Power vs. mode $\rightarrow$ dissipation
- T range for operative and non-operative conditions

Planetary Protection & Cleanliness & Contamination Control, Product Assurance

- Ice Giant Probes are COSPAR Planetary Protection Category II: PP Plan and reporting only.
- PA: will define reqts for selection and review lists of materials, processes, components (esp. at i/f), mechanical parts, critical items. Also formal processing of waivers, deviations, non-conformances, delivery / acceptance reviews.
- Test Matrix for qualification and acceptance vs. instrument model.
- Tests for calibration (beyond qual./acceptance) may add significant complexity, especially if involving ranges of pressures, flow conditions, exotic compositions.

Reviews

- Preliminary Design Review
- Structural / Thermal Model Delivery Review
- Electrical Interface Simulator Delivery Review
- Critical Design Review
- Engineering (Qualification) Model Delivery Review
- (Proto-) Flight Model & Flight Spare Delivery Reviews
- + System-level reviews