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# 6th Round Table on MNT
# Miniaturisation aspects for future payload technologies: limitations and possible trends

**Stefan Kraft**
**cosine Research B.V.**

esa

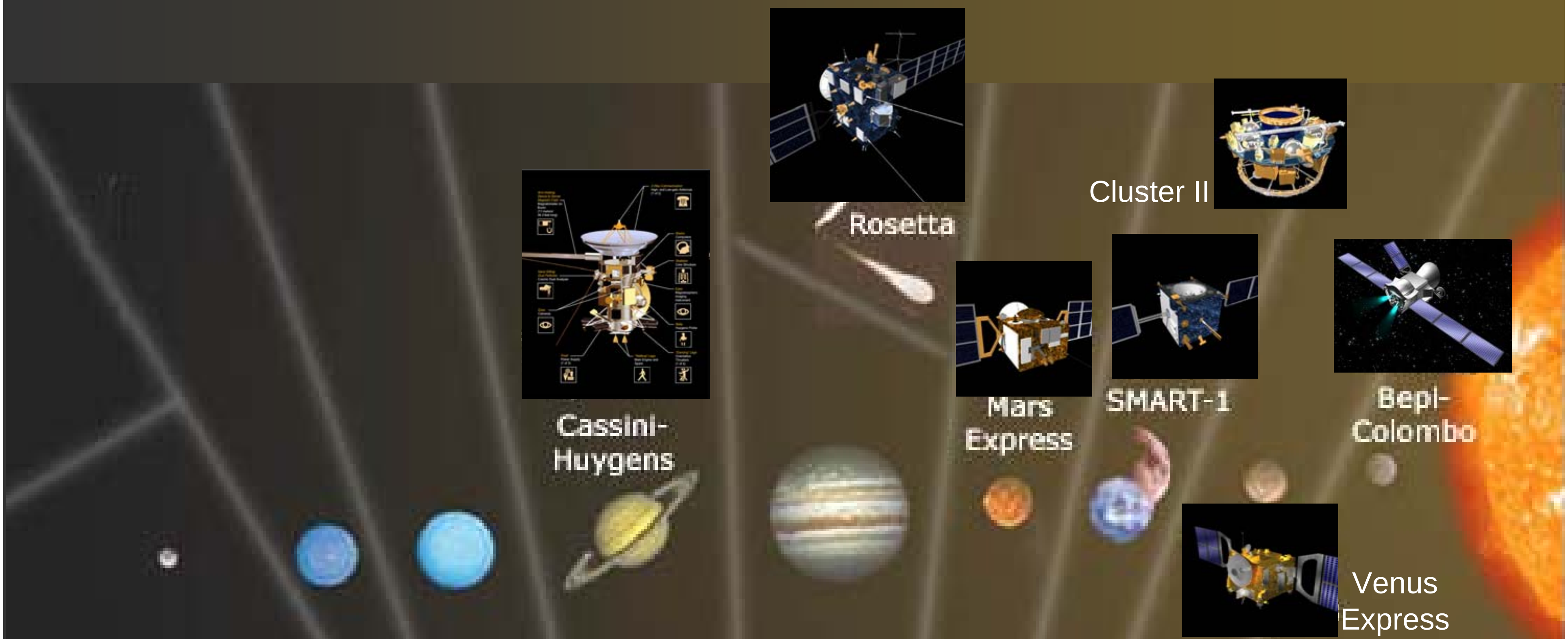
# Company information

- **cosine founded in 1998 as physics consultancy company**
- **2 operating companies**
  - **cosine Science & Computing B.V.**
  - **cosine Research B.V.**
- **Research & development team**
  - **11 PhD physicists**
  - **5 physicists**
  - **1 computer engineer**
  - **3 support staff**
- **Located in Leiden, next to University, NL**
  - **Clean room**
  - **Laser and optics laboratory**
  - **High energy radiation and electronics laboratory**
  - **Powerful IT infrastructure established**
- **cR focussing on advanced instruments and measurement technologies for space**

# Outline

- **Overview of solar system missions**
  - Review of history
  - Overview past and coming launches
  - S/C and P/L configurations
- **Payload technology**
  - Typical payloads
  - Miniaturisation potentials
  - Potential resource reductions by miniaturisation
  - Limitations
- **Some examples**
  - Integrated payload architectures
  - Photon counting laser altimeter
  - Integrated designs and involved miniaturised components
- **Conclusion**

# Spacecrafts in operation or planned – solar system



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# Key data ESA solar system launch history

- Giotto, 1985, Ariane 1, 970kg, payload …
- Cluster II, 2000, Soyuz, 4x1.2t, 4x70kg
- Mars Express, 2003, 1.223 t, Soyuz, payload 116 kg
- SMART-I, 2003, 367kg, Ariane 5, payload 10kg
- ROSETTA, 2004, 3t, Ariane 5, payload ~150kg
- Venus Express, 2005, 1.27 t, Soyuz, payload 104 kg

- BepiColombo, 2013, 2.3t, Soyuz, double launch, payload 60kg

- Jupiter and beyond, S/C to P/L mass ratio even worse
- COSMIC VISION, 2 missions (small, medium), budget ~0.85MEuro
  - **17 member states**
  - **1 planetary mission (likely) + ExoMars**

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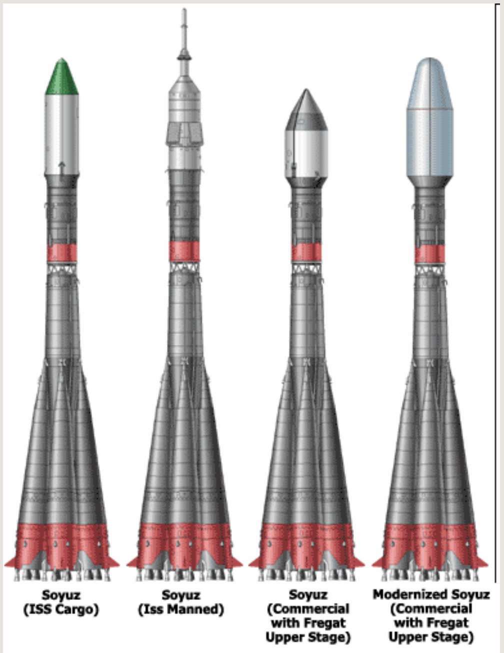
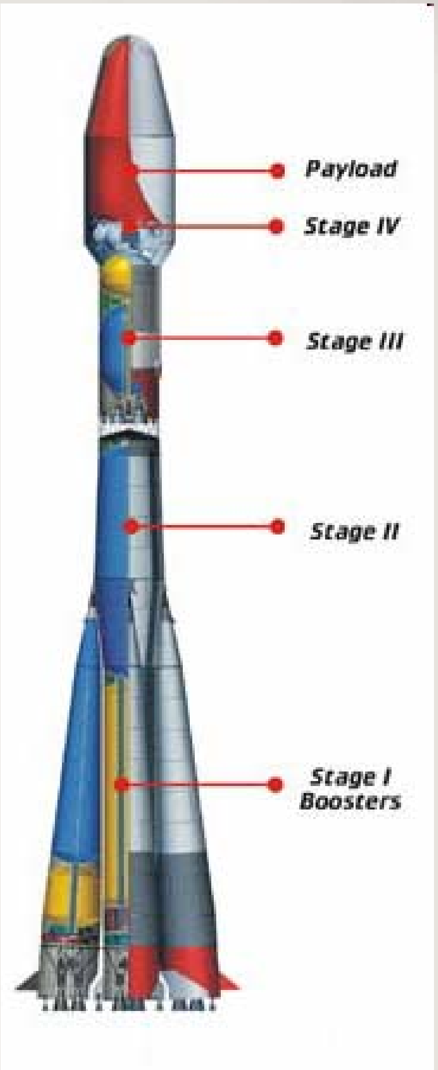
# Most efficient launcher: Soyuz

- Mass production
- One launch about every month
- 1725th launch last Wednesday from Baikonur
- Reliable, cheep
  (30 to 45MEuro),
- Good capacity
  (~7t into LEO),
- Low *g*
- Fairing external diameter:
  4.11 m
- length:
  11.4 m



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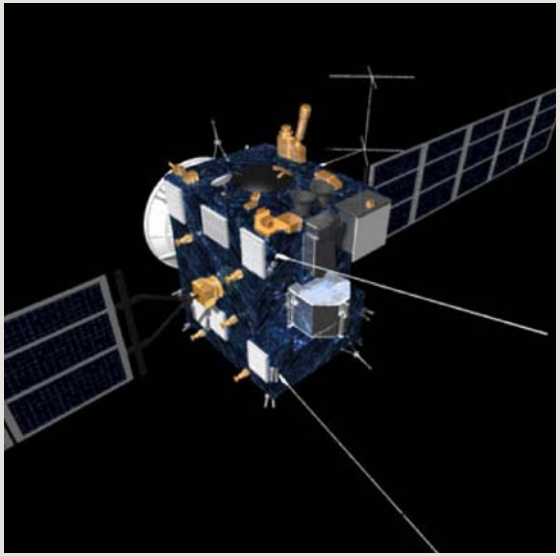
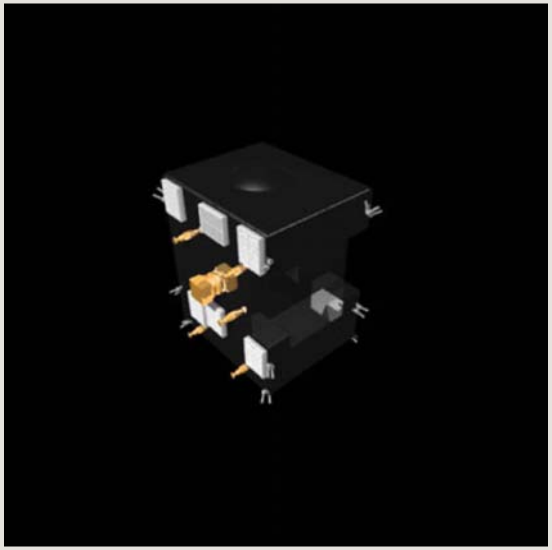
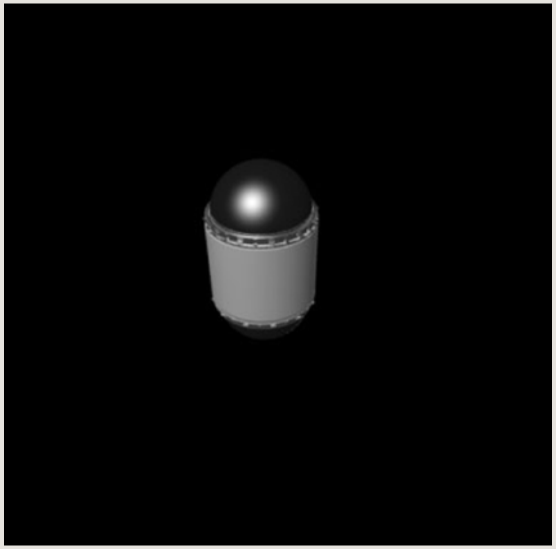
# ROSETTA spacecraft



S/C, solar panels,
2.2 m high-gain antenna

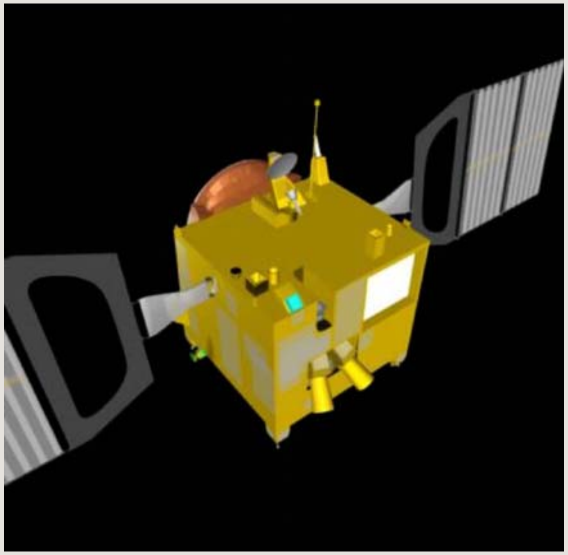


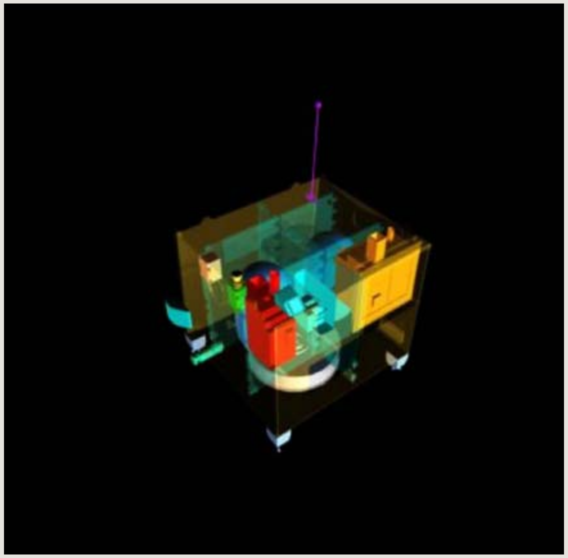
Honeycomb
main platform

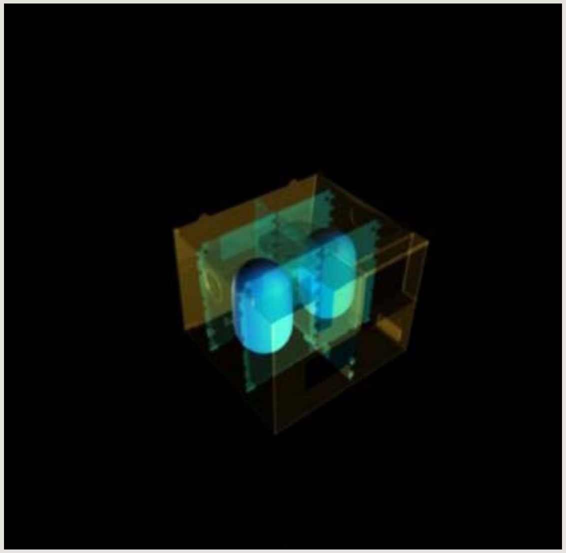


1.19m vertical
thrust tube

# Venus Express







Covered spacecraft

Instruments, thrusters

Al structure
267 l propellant

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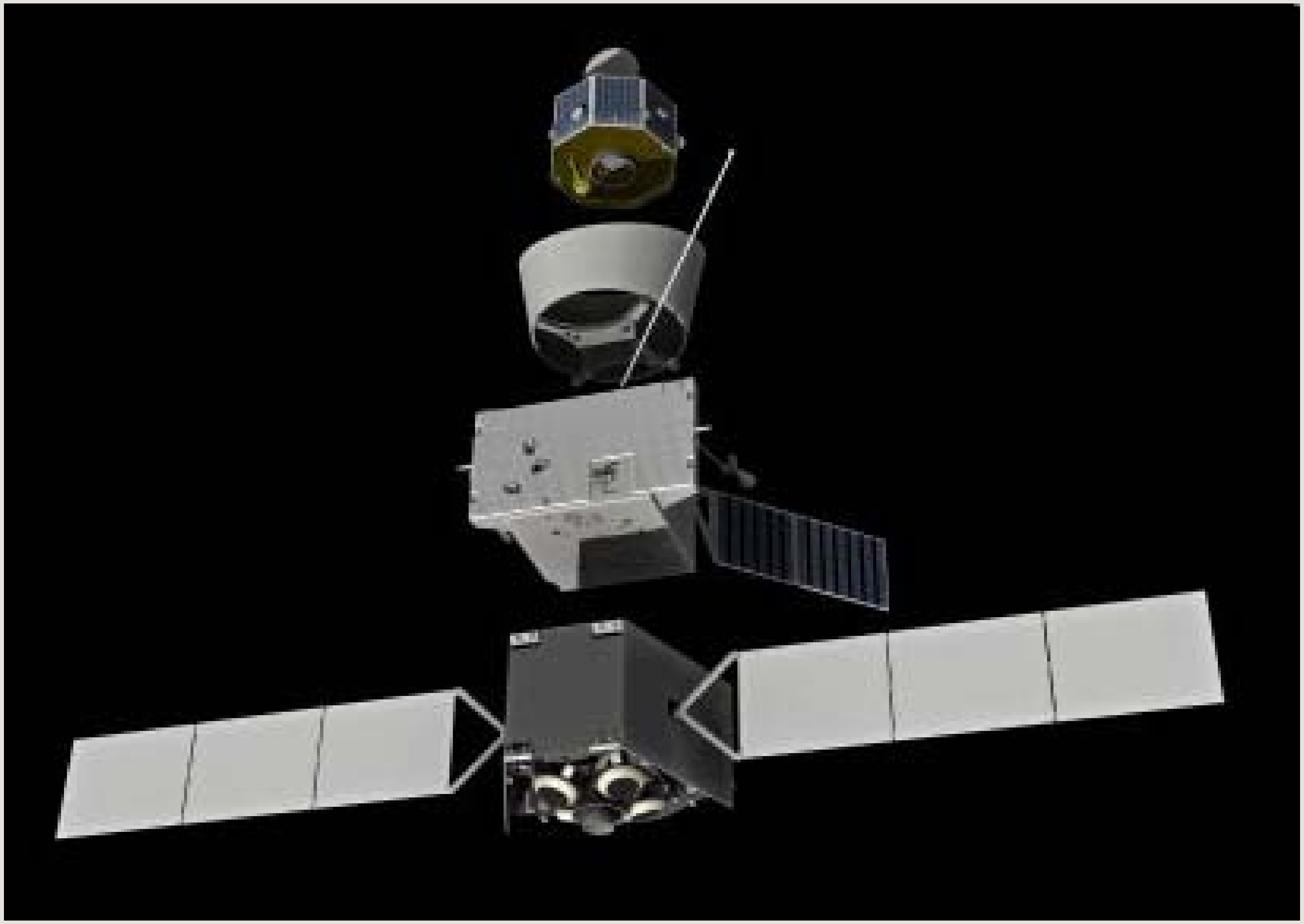
# BepiColombo



- Mercury Magneto-spheric Orbiter
- Sunshield
- Mercury Planetary Orbiter
- Mercury Transfer Module

**Missions to the outer solar system will most likely have a bad S/C to P/L mass ratio**

**Supported by observations from previous missions**

**Miniaturisation and advanced technologies are particularly challenging and stimulate industrial innovations / spin-off**

**Rewarding and exciting profession / attractive to young engineers and technicians**

# Objectives

- Improve
  - **Number of scientific instruments or scientific return**
  - **Performance**
  - **Turnover time**
- Save
  - **Mass**
  - **Power**
  - **Size**
  - **Cost**

**How?**

## Miniaturisation and integration

- Making instruments smaller?
  - **Yes, but does not work always**
  - **Need to collect enough photons from planets**
- What helps is:
  - **To use**
    - **single aperture for larger spectral ranges**
    - **more sensitive detectors**
    - **lighter structures**
    - **common supply units**
    - **less wires**
    - **instrument synergies**
    - **advanced concepts (old and new)**

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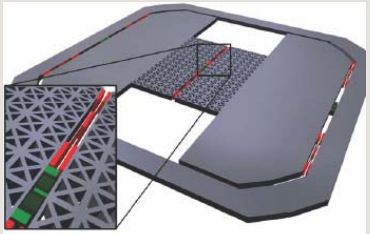
# Typical planetary instrumentation

- Remote sensing
  - **Gamma-ray spectrometer**
  - **X-ray spectrometer**
  - **UV spectrometer**
  - **Imager / camera / stereo**
  - **NIR and MIR spectrometer**
    - **Mineralogy (medium resolution, broad band)**
    - **Atmosphere research (high resolution, dedicated bands)**
  - **Radiometer**
    - **Temperature**
    - **Thermal inertia**
    - **Dynamic flow processes**
  - **Microwave sounder / radar**
- Exotic instruments (body investigation)
    - **Accelerometer / gradiometer**
    - **Laser altimeter**



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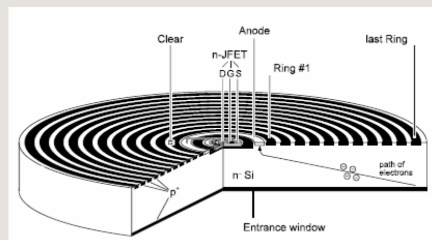
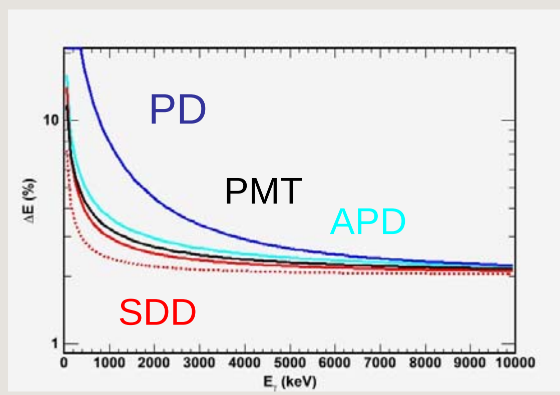
## Identified resource reductions

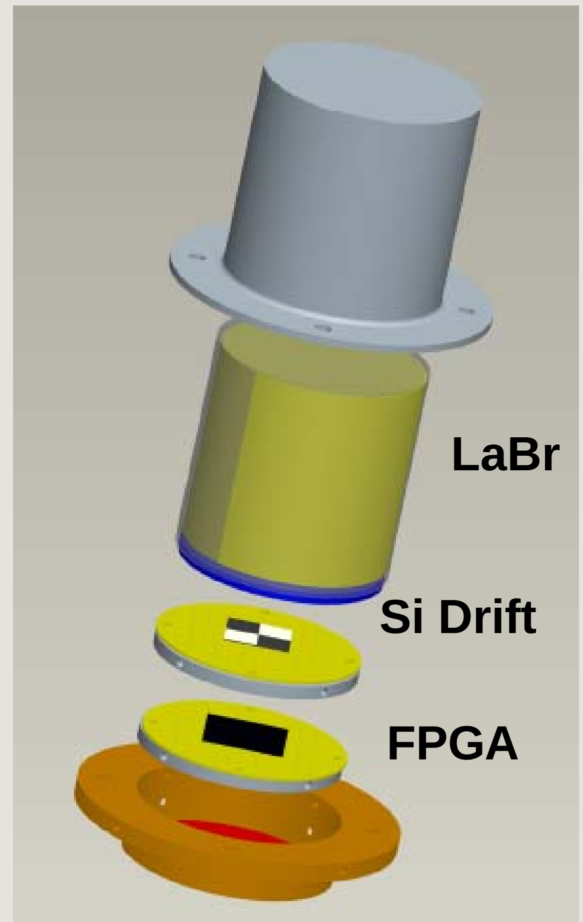
## Some examples

# Gamma-ray spectroscopy

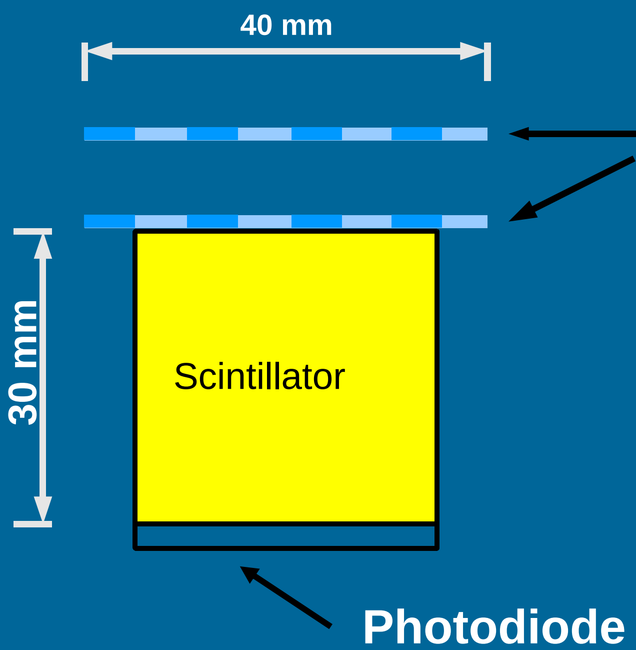
- Room temperature operation
  - **Use of scintillators**
  - **Adapted for BepiColombo**
- Further savings
  - **Use of advanced detectors**
  - **Si drift detector instead of PMTs**
  - **Miniaturised electronics**
- 2.5kg, ~2W

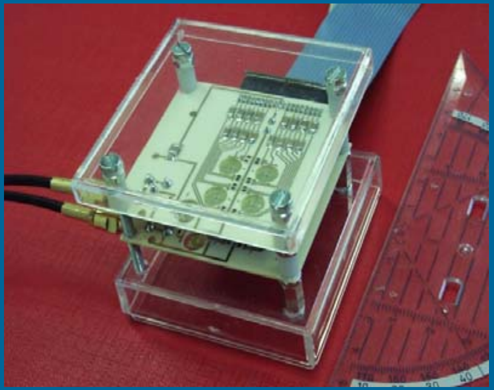


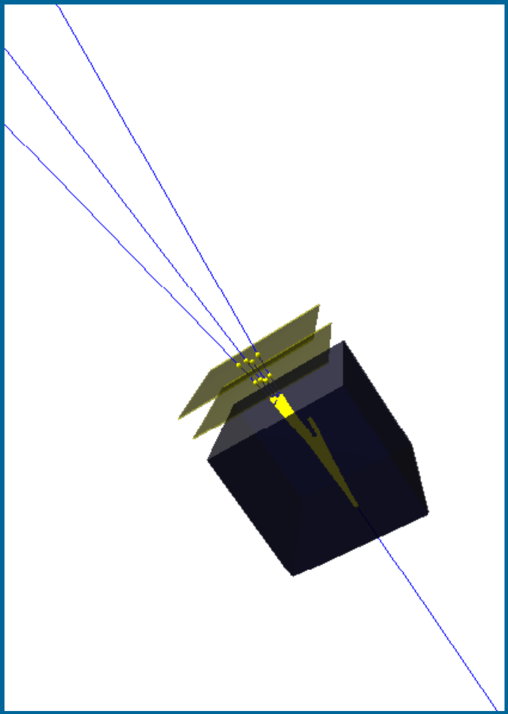



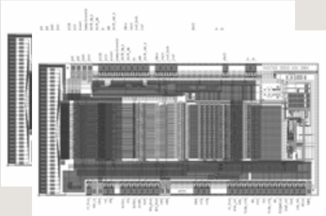
# Multifunctional Particle Spectrometer



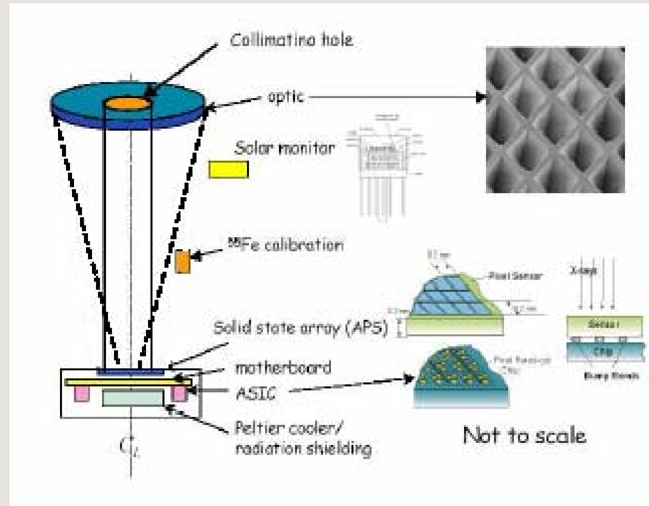


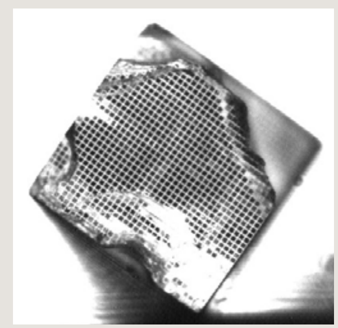
- Example for advanced measurement concepts
- Particle identification by (d*E*/d*x*), particle energy ($\alpha$, $\beta$, $\gamma$, ions) & direction
- Smart configuration and smart readout concept
- Miniaturised electronics using ASICs and FPGA
- ~1kg, ~2W



# Imaging X-ray spectrometry

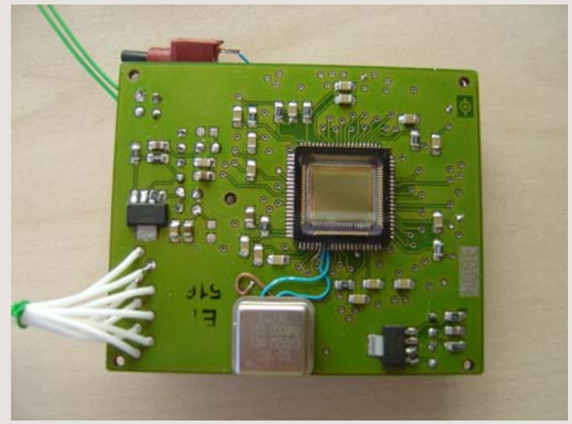
- BepiColombo Mercury Imaging X-ray Spectrometer
- Concept: Wolter-I optics
- Impossible without advanced miniaturisation technologies
  - **Micro pore optics**
  - **Room temperature X-ray detectors with high resolution**
  - **Miniaturised readout electronics**
- Problem: 1m focal length
- Needs to be well integrated into spacecraft
- Suitable for UV spectroscopy / photometer
- Need photon counting UV detectors (MCP with sufficiently sensitive photocathodes over large spectral range)

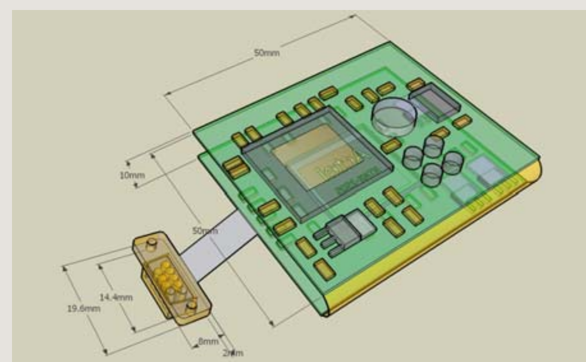


# Imagers / cameras

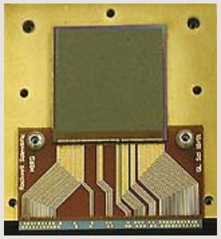
- Typical need
  - **Aperture 50 to 100 mm**
  - **10m resolution @ 400km distance**
  - **Focal length 60mm**
- Limiting factors
  - **Readout noise**
  - **Pixel size**
  - **Fillfactor**
  - **Dark current**
  - **Optical quality**
  - **Radiation hardness**
  - **Size of electronics**
- Solutions
  - **Advanced sensors and 3d packaging or stacking (see IMEC talk this conference)**
  - **Mirror optics (broad spectral range)**
  - **ASIC and FPGA technology**
  - **Combination with other receiver instruments possible (share receiver optics with laser altimeter and/or IR spectrometer or radiometer)**
  - **Integration of stereo function**

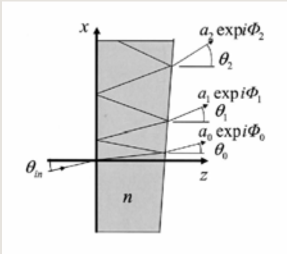


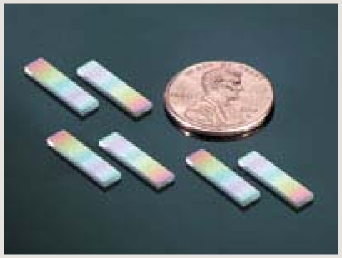


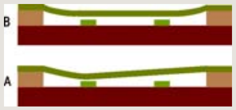
# NIR spectrometers

- Target investigations
  - Mineralogy either NIR or MIR
  - Imaging
    - Spectral resolution of ~1%
  - Atmoshpheric research
    - Spectral resolution 10000
- Technologies needed
  - Low noise CMOS CZT detectors
  - Linear variable filters
  - Tunable gratings (MEMS)
  - Immersed gratings
  - Advanced FTS technologies
  - Micro coolers
  - Integrated radiators
- Most technologies are US dominated technologies
- ESA is catching up



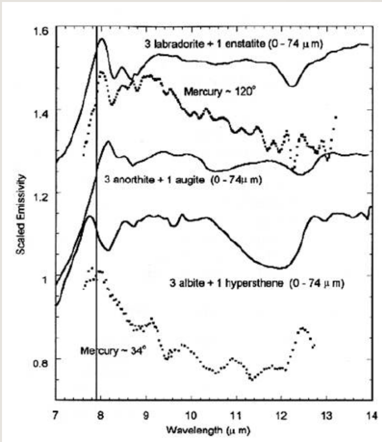


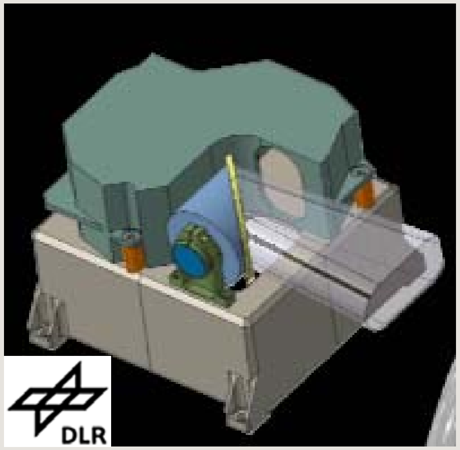






# MIR imaging spectrometer / radiometers

- Target investigations
  - **Thermal inertias**
  - **Surface temperature**
  - **Dynamic processes (thermal imaging)**
- Technologies needed
  - **Micro bolometers**
  - **Micro coolers**
  - **Filter technologies**
  - **Low power scanning mirrors**
  - **Small and accurate blackbodies**
- Problems
  - **MEMS technologies mostly COTS**
  - **Need space qualification in time**
  - **Need to improve the performance**
  - **Not so well suitable for colder objects**



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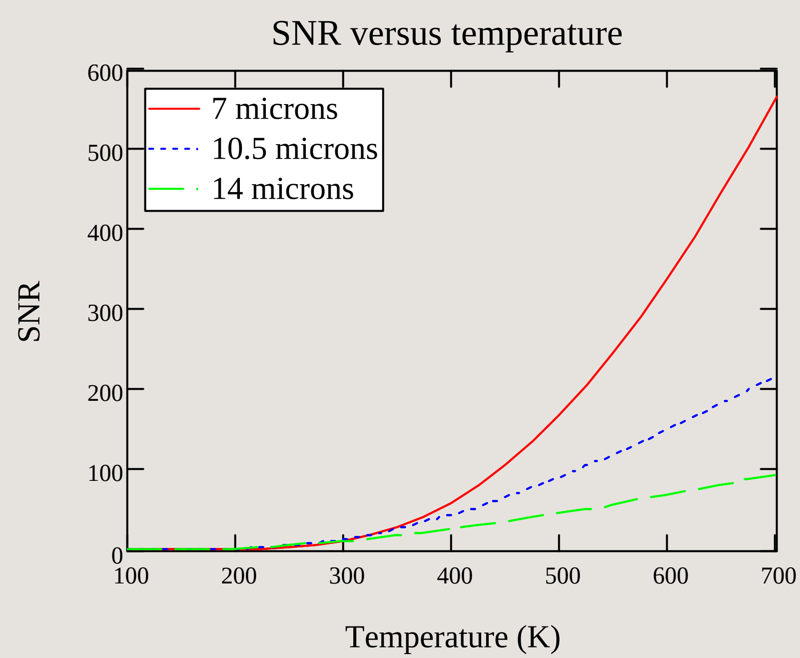
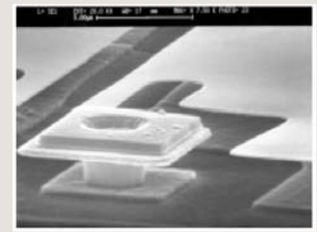
# Uncooled microbolometers

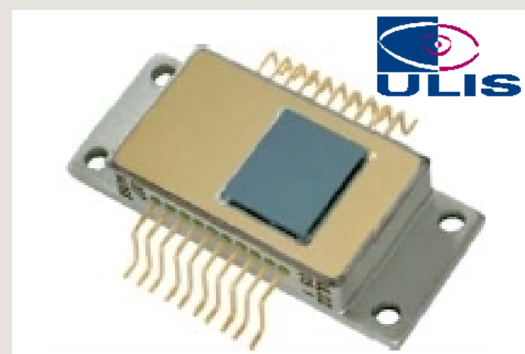
- Development / qualification for BepiColombo
- Best performance achievable, but just about sufficient
  - **Mercury is rather hot**
  - **S/N ratio is fine for temperatures >300K**
  - **COTS device needed still considerable improvement of existing technology**
  - **Thermal stabilisation and packaging rather critical**
  - **Operation at different instrument temperatures needs different calibrations and settings**



# From COTS to Space Qualification

- Sensor enhancements
  - **AR coating required**
  - **Tuning of cavity for particular spectral range**
    - **Needs in principle new bolometer design**
  - **Optimisation of bridge resistance (length, thickness)**
    - **More sensitivity requires smaller bridge**
    - **More fragile and susceptible to vibrations**
  - **Optimisation of electronics readout scheme**
    - **COTS dedicated to video applications**
    - **Space applications demand other frequencies**
  - **Minimisation of electronics noise**
- Filter adaptation required
- Qualification of the device is presently performed
- Used as well for EarthCare (different format)





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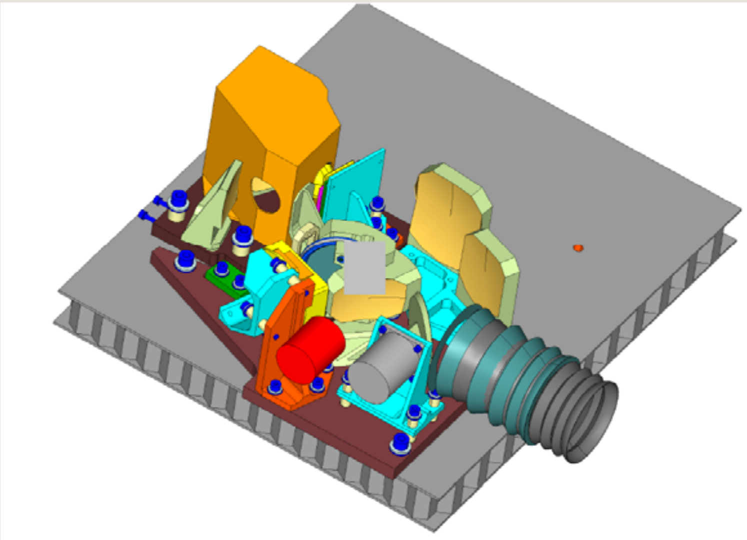
## NIR/MIR spectrometer with radiometric function

- NIR and MIR functionalities can be combined although thermal requirements and cooling requirements are sometimes different
- Calibration more difficult in integrated system
- Considerable mass saving possible
- Usually one spectral range dominating the technical challenge
- ~2kg, 10W



*BepiColombo baseline design*

*NIR branch comes almost for free*

*Radiometry comes almost for free*

**Active remote sensing**

**Microwave and radar technologies rather advanced these days**

**Not our business**

**Therefore, focussing on laser and LIDAR technologies**

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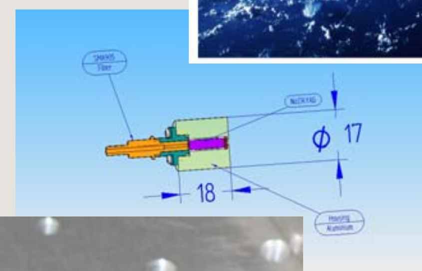
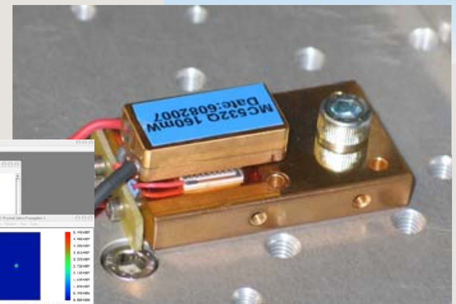
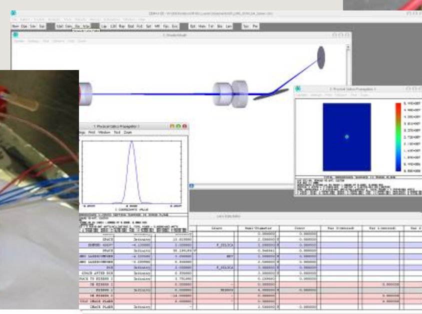
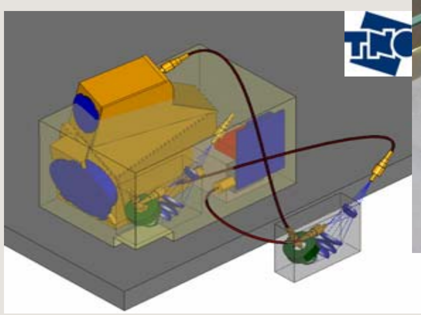
# Laser technologies

- Development of microchip lasers
  - **Laser altimetry / distance measurements**
  - **Laser mass spectrometers**
  - **RAMAN/LIBS**
  - **LIDAR technologies**

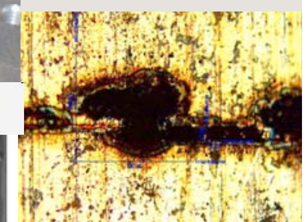
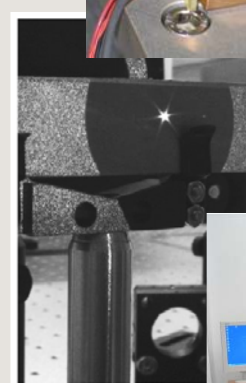
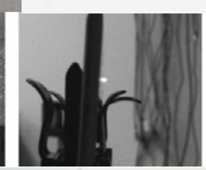







# Microchip laser developments

- Initiated by development of the laser mass spectrometer
- Breadboard existing in the SCI-PAI laboratorium equipped with MicroChip laser
- Several types of laser under investigation for LMS
  - **10 uJ green, 20 uJ red, 40 uJ goal**
- Development of mJ laser under lead of cosine for ExoMars RAMAN/LIBS breadboard (ESA/TNO)
  - **1 mJ, <1W, 100 Hz, M^2 ~1.3, $\Delta$t ~ 1 ns**
- $\mu$J laser can be used for photon counting laser altimeter (verified by calculation)
  - **40uJ, 3W, 10 to 20 kHz, M2 ~1.1, <1ns**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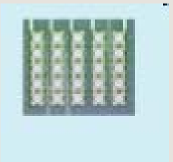
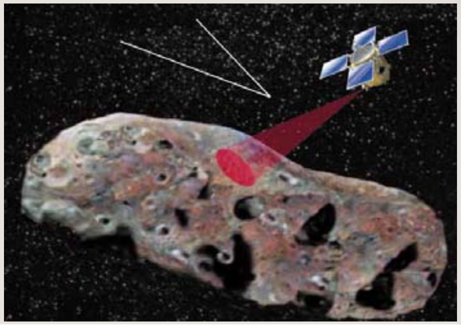
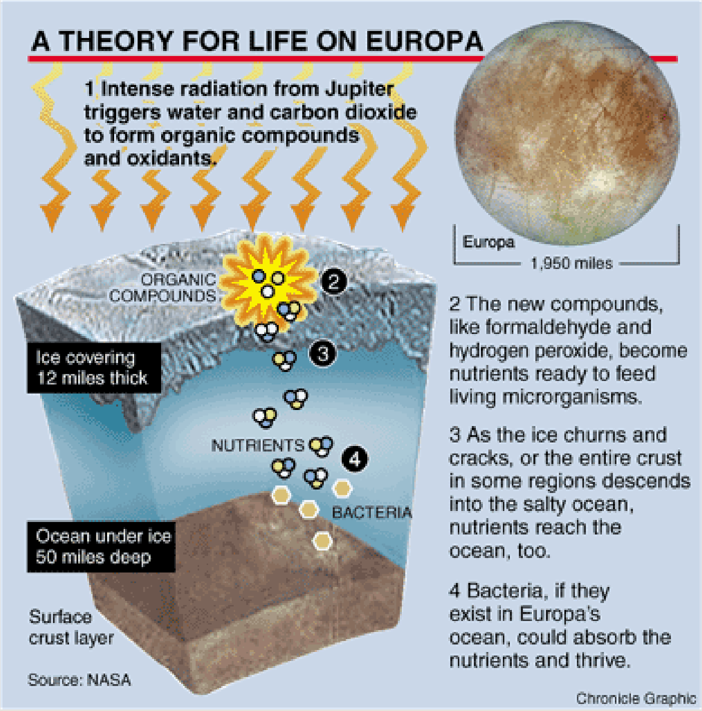
# Advanced laser altimetry

- Photon counting principle
- Lower mass by factor of up to 10
- Low power (microchip laser)
- Single Photon Avalanche Diode (SPAD)
- Potential applications
  - **Jupiter's moon Europa**
  - **Landing systems**
  - **S/C formation control systems**
- Useful in other fields
  - **Earth observation (LIDAR, altimetry)**
  - **Environmental screening UAV**
  - **Military**







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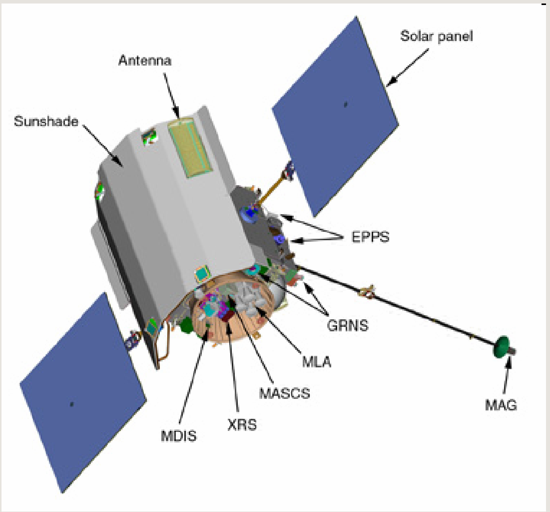
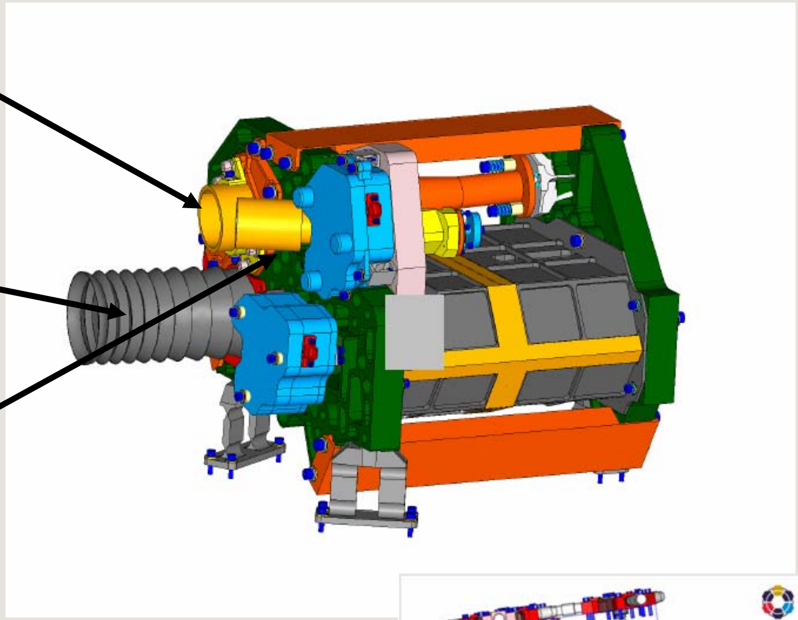
# High integration – small is beautiful

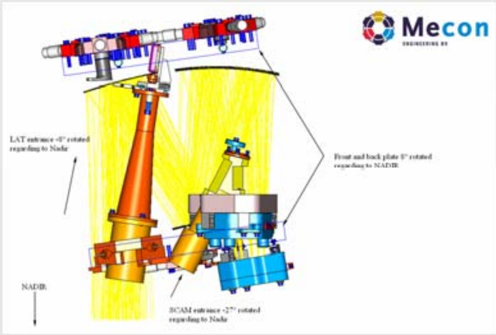
- Advantages
  - **Sharing of resources**
  - **Centralisation of electronics units**
    - **Interesting for shielding purposes**
  - **Use of common entrance port**
  - **Use of common structure**
  - **Coalignment advantages**
  - **Shorter pathes and less wires**
- Disadvantages
  - **Complexer instruments**
    - **Thermal**
    - **Strucutral**
    - **AIV**
    - **Electrical**
  - **More difficult to manage**
- Difficulties remain mainly with payload builders
- Small and competent team can manage integration



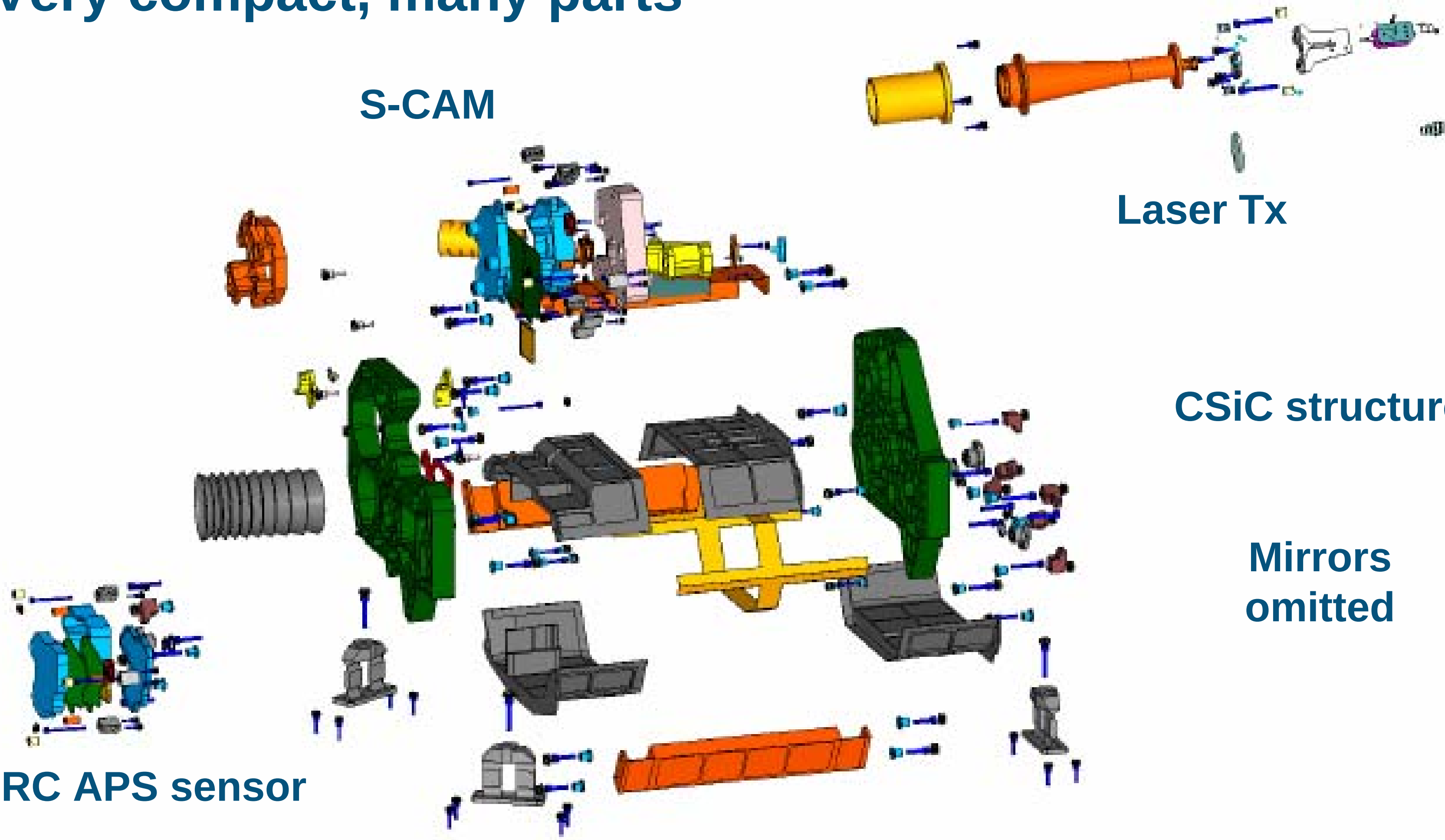
# Example: Stereo Imaging Laser Altimeter

- SILAT
  - Stereo imaging laser altimeter
  - Laser altimeter
    - Photon counting
    - 1ns, 0.3m resolution
    - 10 to 20 kHz
    - 3W laser
  - High resolution camera
    - 10m @ 400km
    - APS 2k x 2k pixels
    - 3 colours
    - 4ms readout
  - Stereo camera
    - APS 1k x 1k pixels
    - 1 colour
    - 27 deg inclined
  - Electronics made extremely compact
  - Mass saving by integration factor ~2
  - Still: Mass increases for radiation environment of Jupiter by factor of ~1.5 to 2



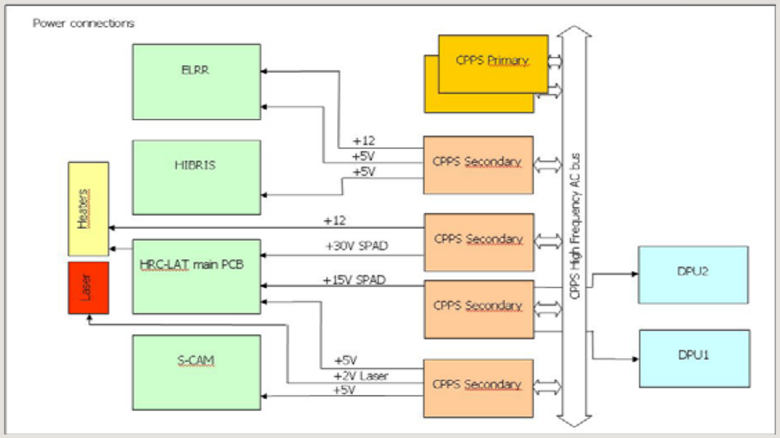


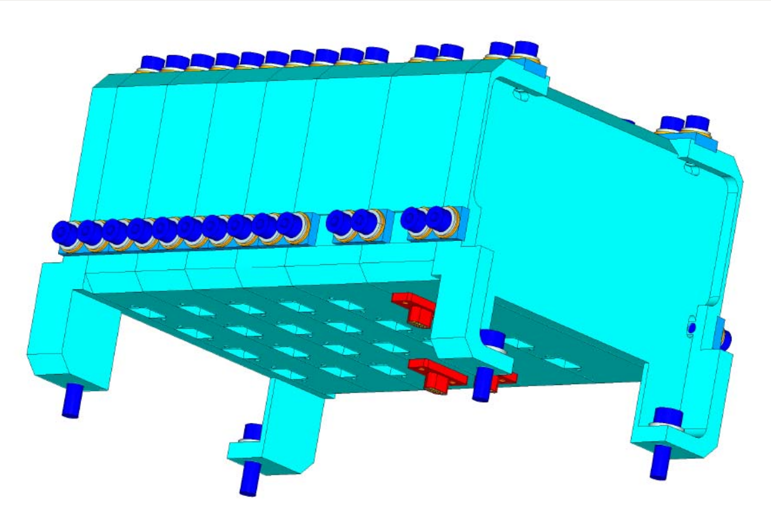
# Very compact, many parts



# Main Electronics Unit

- Common Power Supply
- Redundant DPU
- DPU and front-end fairly miniaturised
- Miniaturisation need: power supply and secondaries



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# Advanced payload technologies – enabling missions of the future

# MicroSatellites – in future perhaps more than a test platform

- Powerful planetary payloads are in principle small enough to fit onto MicroSats and could lead low cost missions with significant science return
- This leads to the possibility of synergies and co-development
- Presently studying 15kg class satellite with sufficient stability and capacity (compare previous talks)
- Train concept offers expandable missions and enhanced coverage

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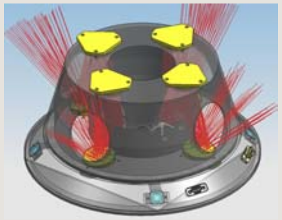

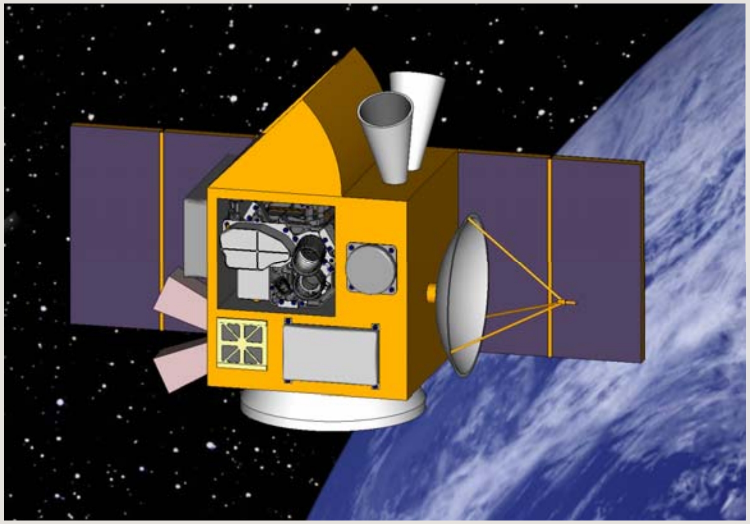

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## Conclusion

- Miniaturisation is very welcome for science missions
- It enables missions to benign places such as Mercury, Jupiter and beyond
- Advanced remote sensing concepts and technologies are still at the very beginning and need to be matured to become applicable
- Need miniaturised standard components (connectors, cables, electronics, supply units)

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