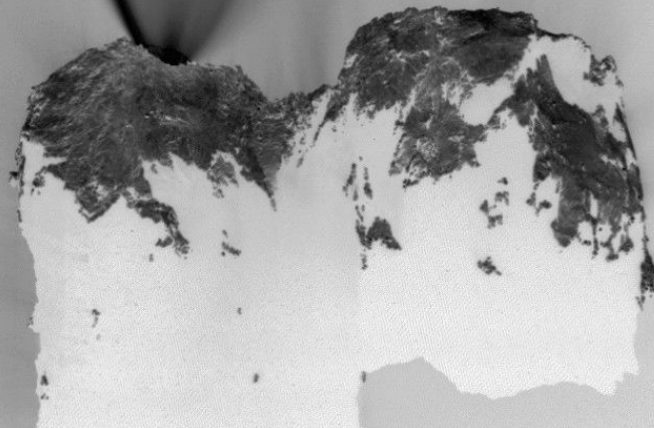




EE-584
Spacecraft Design & Systems Engineering

Lecture 4 - Space Science & Instrumentation

MOXIE : Mars OXYgen ISRU Experiment



TUESDAY
08 | Oct. | 2024



15h30 -16h30



EPFL Campus
BC 420



SPEAKER:

Dr. Jeff Hoffman

EPFL



<https://memento.epfl.ch/event/moxie-mars-oxygen-isru-experiment/>



Dr. Stephan Hellmich

After 10 years at the German Aerospace Center (DLR), studying long-term orbital dynamics of minor planets in the solar system and spending many nights with photometric observations of asteroids and comets, Stephan has joined the EPFL Laboratory of Astrophysics to work on the physical characterization of orbital debris.

■ **Laboratory
of Astrophysics**



DLR

Deutsches Zentrum
für Luft- und Raumfahrt
German Aerospace Center



Beihang University delegation

Space Ranger Project - CubeSat for Space Debris Surveillance

Co-winners of the [Space Universities CubeSat Challenge \(SUCC 2.0\)](#) with the EPFL SpaceCraft Team



Important Announcements

- Fewer staff available in the next two weeks for project sessions
- MCR approaching (more info after)
- Register for the optional hands-on if you want, but [answer the survey anyway](#) !
- Course feedback in week 5 ! Please fill it when open !



Current schedule

We are here

Lecture	Date	Title	Guest lecturers
L01	09.09.2024	Welcome: Mission Design & Spacecraft Systems Engineering	Ared Schnorhk (former ESA)
Jeûne Fédéral			
L02	23.09.2024	System level thinking intro, conceptual design and trade-offs	Arno Regg (NASA Ames)
L03	30.09.2024	Spacecraft Environment & Astrodynamics	
		SSA and orbit determination	Jean-Noël Pittet (Swiss Space Domain)
L04	07.10.2024	Space Science & Instrumentation (objectives)	Stephan Hellmich (EPFL LASTRO)
		Space Ranger team from Beihang University	Beihang University delegation
L05	14.10.2024	Fundamentals of Space Propulsion	Hiro Koizumi (University of Tokyo + Pale Blue Inc.)
Holidays			
L06	28.10.2024	Space Sustainability (EOL management) & Life-Cycle Assessment	
MCR		Mission Concept Review (presentation)	
L07	04.11.2024	Telecommunications & Ground Stations & operations	Hannes Bartle (EPFL MAG)
		Telemetry, Command, & Data Handling, Avionics	
L08	11.11.2024	Intro to Spacecraft Operations (Clearspace)	Kees van der Pols (Clearspace)
		Avionics	Michael Juillard (Swissto12)
L09	18.11.2024	Spacecraft Structures & Mechanisms	Gilles Feusier
		Optional practical session I (4:15pm-6pm)	
L10	25.11.2024	Spacecraft Thermal Design & Control	
		Electrical Power System	
		Optional practical session II (4:15pm-6pm)	
L11	02.12.2024	Spacecraft Configuration Engineering	Yannick Delessert (Swissto12)
L12	09.12.2024	Launch vehicles and launch operations	Alessandro Netti and Alberto Sánchez (Beyond Gravity)
MDR	16.12.2024	Mission Design Review	

EPFL Mission Concept Review

Reminder

Your mission will be evaluated through a Mission Concept Review on **October 28th**. [20% of your final grade]

What to expect:

- You have **4 min per group** to perform a pitch of your mission.

What's the goal? Convince the evaluation panel of the **value and impact** of your mission.

- We want to see you have thought things through.
- That you are aware of major trade-offs, constraints, and risks within your mission concept design (awareness! not necessarily solved)

What to include? Check the [MCR Evaluation Rubric on Moodle](#) as a reference.

Check next slide for hints...

- Presentations shall be submitted [on Moodle](#) by **27 October 2024, 23:59 CET** (check instructions)
- Check Timetable on [Moodle](#).



EPFL Mission Concept Review

It is all about **clarity**. Keep what's **relevant**, remove the rest. Learning to **remove the clutter**, in both your writing and presentations is a skill worth honing.

Every sentence matters. Don't rush through your speech. It isn't about packing as much info in 4min as possible.

- Use ~5 slides max (+ backup slides in anticipation for the Q&A).
- Think about **visuals** (drawings, sketches, images, animations) better than text: 2x info retention in audio-visuals than text.
- Build a **story**!
- The presentation shall include at least:
 - A clear mission statement, defined from an identified problem
 - A ConOps, realistic mission duration and launch date
 - A function tree, SMART requirements, KPI(s) to call your mission a success
 - At least 1 trade off presented, justification of results, clearly defined assumptions

Be on time (max 4 min), all team members shall speak, clear and clean slides, clear talk



5-sec framework for better storytelling

The 3 ingredient recipe

Intention



Someone wants something

"...Ewoks to continue living peacefully in Endor"

Obstacles



But there are hurdles to overcome

"..the darkside is strong in this one"

Stakes



And failing at it has consequences

"..superweapons may be used and Endor may be destroyed"



You still think it cannot be done...



EPFL Learning Outcomes

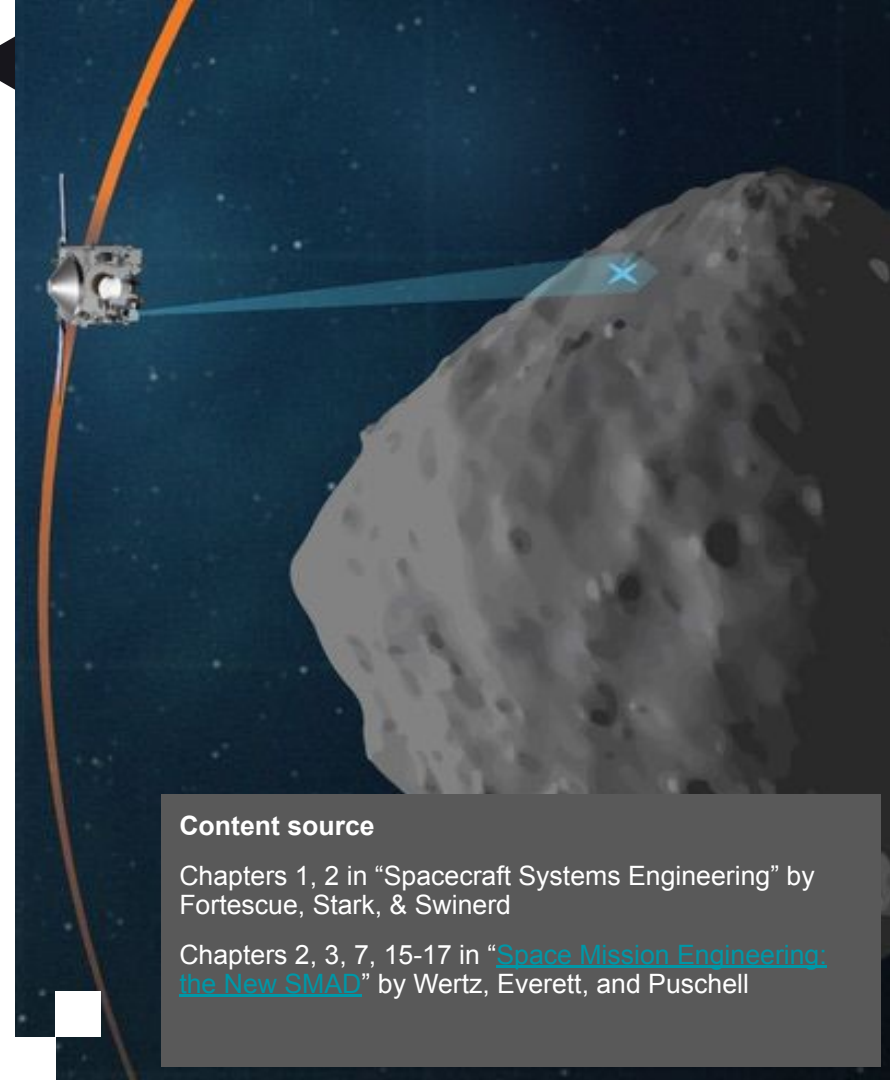
By the end of this lecture you should be familiar with...

- What a payload is
- Basic characteristics of electromagnetic radiation
- Wave-particle duality of light
- Common scientific instruments used in space
- Some instruments used in the types of mission you are designing

- Today's project work



Source: NASA



Content source

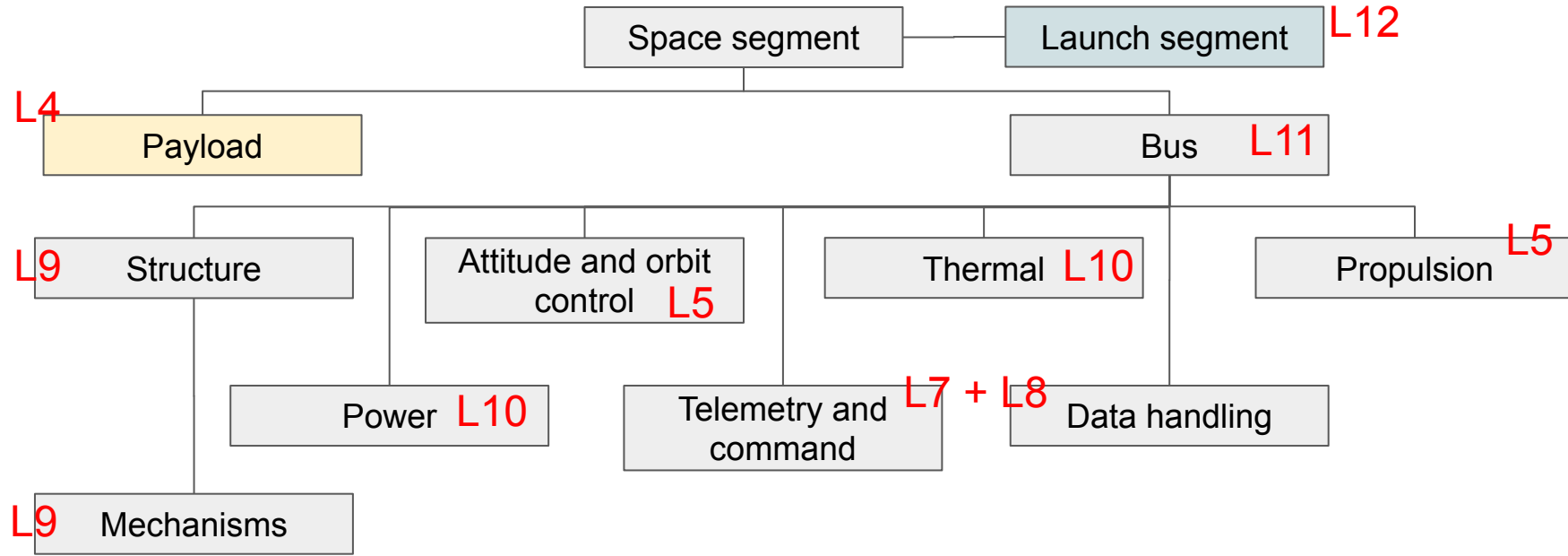
Chapters 1, 2 in "Spacecraft Systems Engineering" by Fortescue, Stark, & Swinerd

Chapters 2, 3, 7, 15-17 in "[Space Mission Engineering: the New SMAD](#)" by Wertz, Everett, and Puschell

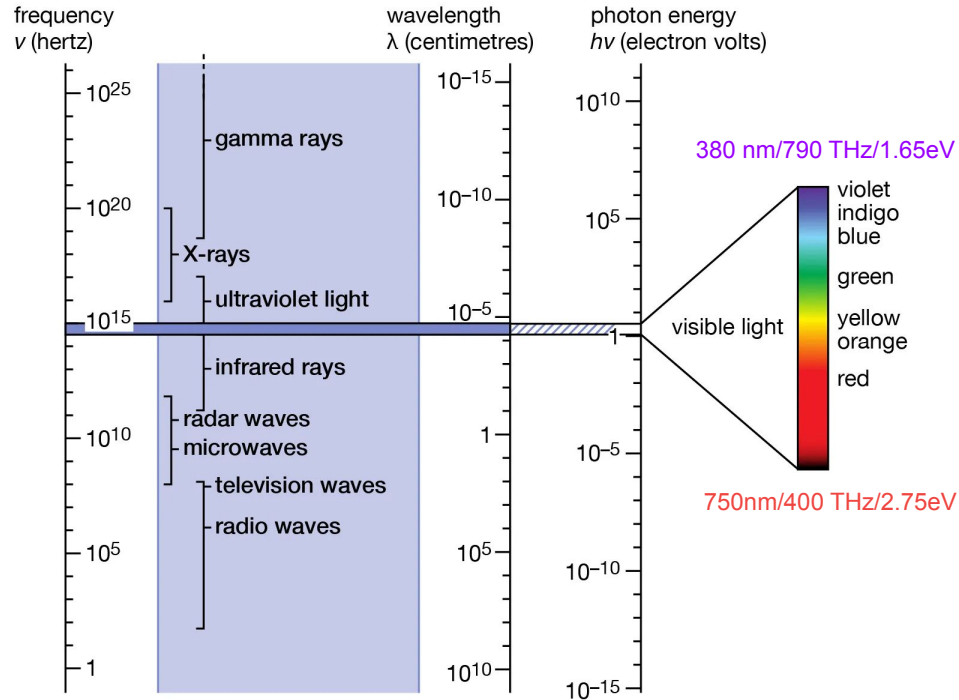
EPFL Payloads

The payload = the motivation for the mission itself

The bus (platform) = the vehicle providing resources so the payload functions



Everything in the universe emits some kind of 'light' (electromagnetic radiation) but often it's not the kind of light that we are used to



© Encyclopædia Britannica, Inc.

We can “observe” distant objects and study their behavior based on the spectrum of light they emit, absorb or reflect → **Spectroscopy**

Planck's law $E = h\nu$

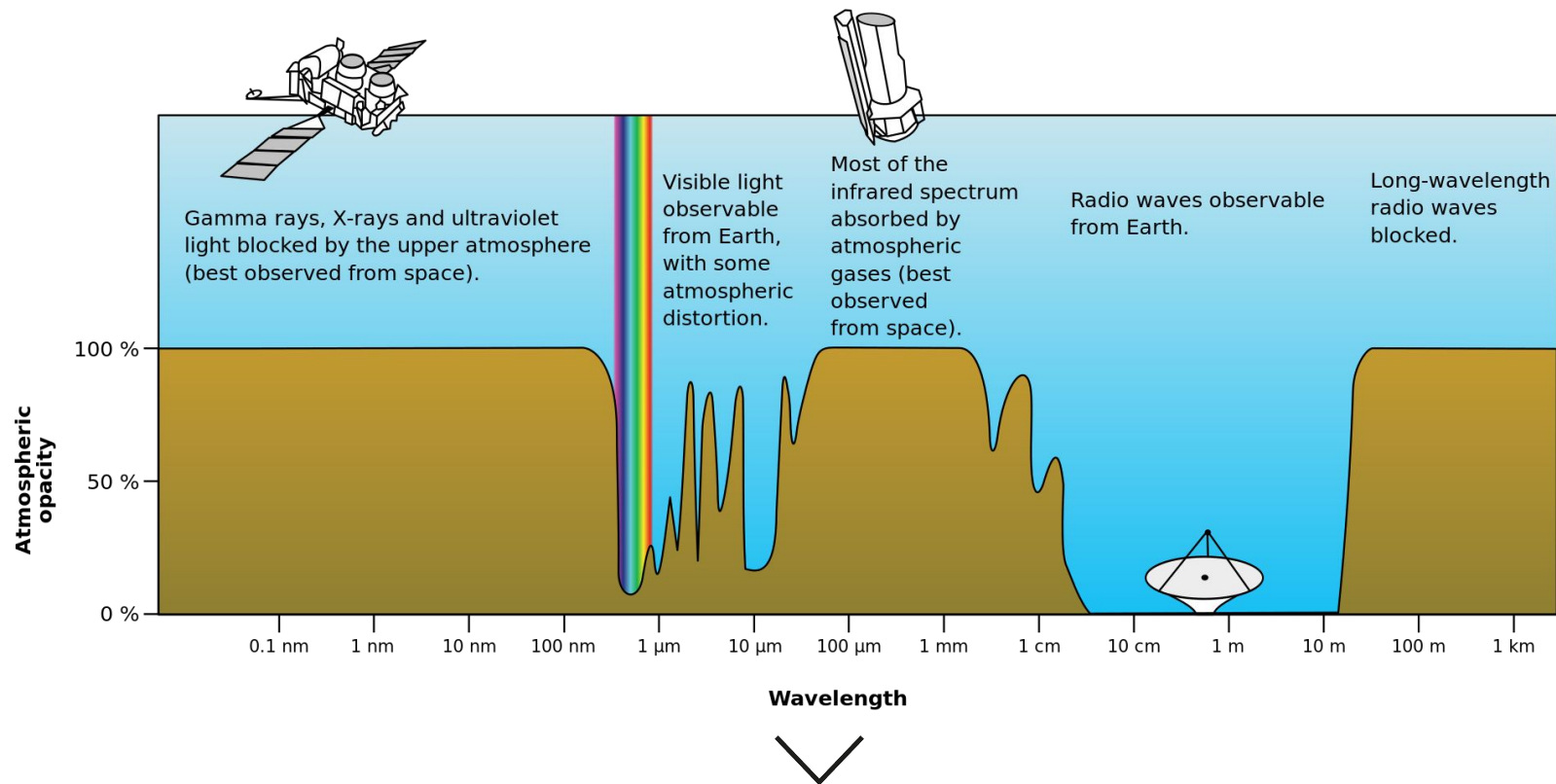
h = Planck's constant (6.626×10^{-34} Js)

ν = frequency of the radiation (in Hz)

All EM waves travel in a straight line at the same **speed in a vacuum** (3×10^8 ms $^{-1}$)

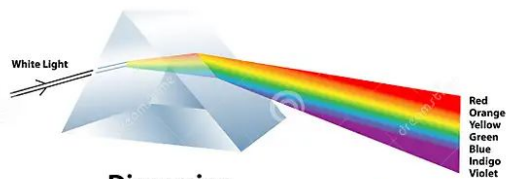


Unfortunately, we cannot “observe” light of all wavelengths from Earth → **Atmospheric opacity**

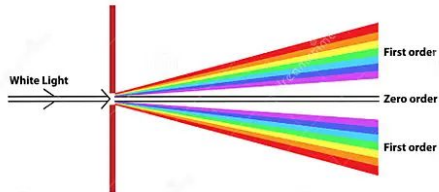


A complete conceptualization of the nature of light includes light as:

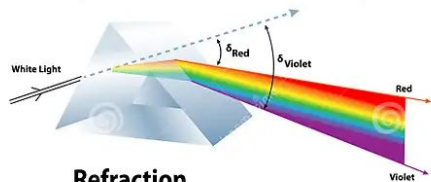
Wave



Dispersion

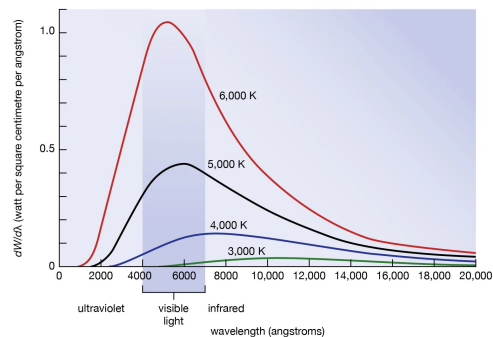
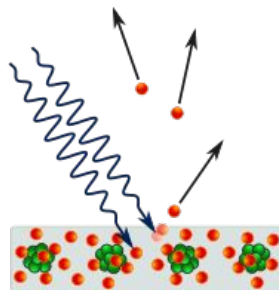


Diffraction

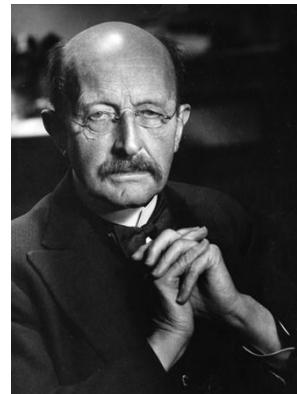
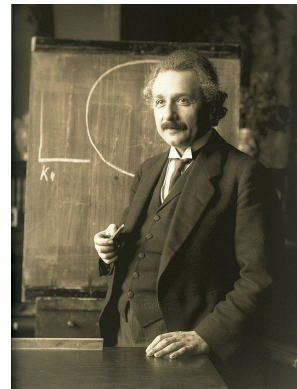


Refraction

Particle



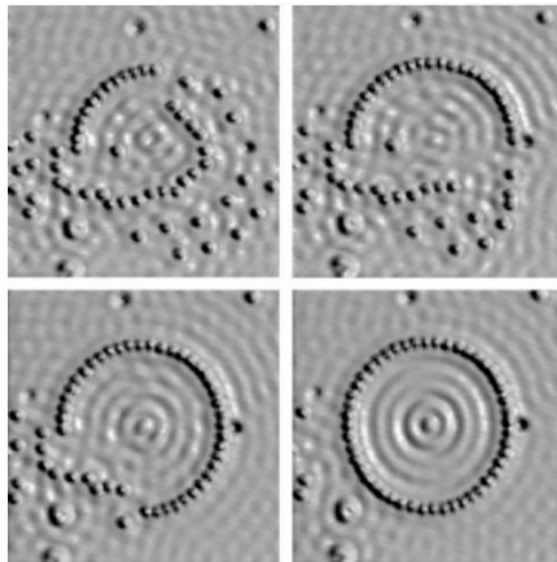
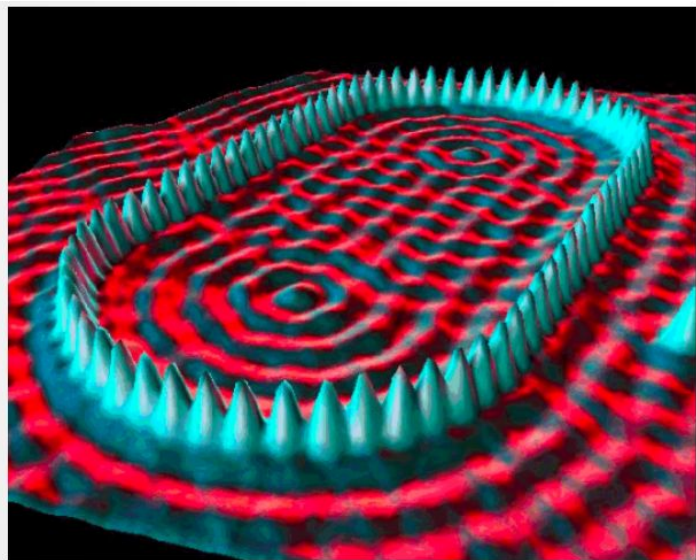
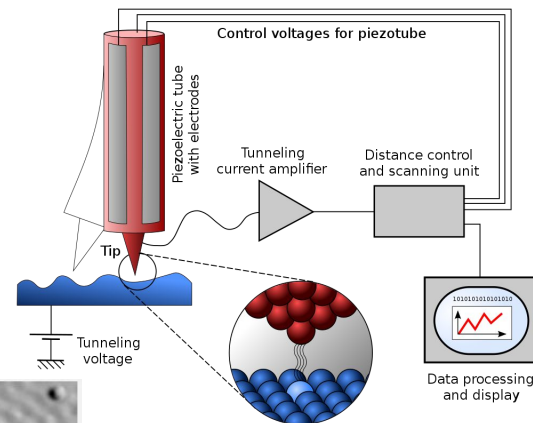
© Encyclopædia Britannica, Inc.



The wave-particle duality of light

Imaging wave-particle duality → quantum corral.

Scanning Tunneling Microscope (STM) [0.1 nm ± 0.01 nm] →



Source: [Iwan Morton-Blake \(CERN\)](#). Original paper: “[Confinement of Electrons to Quantum Corrals on a Metal Surface](#)” by Crommie, Lutz, and Eigler (Science, 1993)

Understanding how things emit, absorb or reflect light is crucial for scientists → instruments



Read more about OSIRIS-REx: [press kit](#) and [main site](#)



Read more about LUCY: [main site](#)



OSIRIS-REx

THE MISSION

WHAT WILL THE OSIRIS-REx MISSION DO?

- Collect a sample from a near-Earth asteroid called Benu, and return the sample to Earth for study.
- Help scientists better determine the orbit of the asteroid.
- Acquire knowledge about the asteroid's composition, which could give clues about how planets formed and how life began.



SCIENTIFIC OBJECTIVES



- Collect a sample and return it to Earth
- Map the asteroid
- Determine Benu's physical and chemical properties
- Measure the orbit deviation caused by sunlight (the Yarkovsky effect)
- Compare observations with data from telescopes

CANADIAN CONTRIBUTION



The OSIRIS-REx Laser Altimeter (OLA) is the Canadian contribution to the spacecraft. OLA will make a 3D map of Benu and sleuth out the best site for a sample.

WHY ASTEROID BENNU?



1 PROXIMITY TO EARTH

Every six years, Benu's orbit brings it near Earth – less than 450,000 km away. Its orbit allows a spacecraft to travel there and back safely.



2 SIZE

Asteroids less than 200 m wide spin very quickly, which makes it difficult for a spacecraft to safely interact with them. Benu is nearly 500 m in size and revolves once every 4.3 hours, slowly enough to collect a sample.



3 COMPOSITION

Scientists will be able to analyze the asteroid's chemistry and mineralogy to learn more about its composition and how it compares to other asteroids.

MISSION TIMELINE



2016

LAUNCH



2018

ENCOUNTER
19 months
collecting data
and preparing
for sample
collection.



2020

SAMPLE COLLECTION JULY 2020
3 ATTEMPTS
Bringing a sample to Earth will
allow scientists to study Benu
for decades using highly sophisti-
cated instruments and techniques.



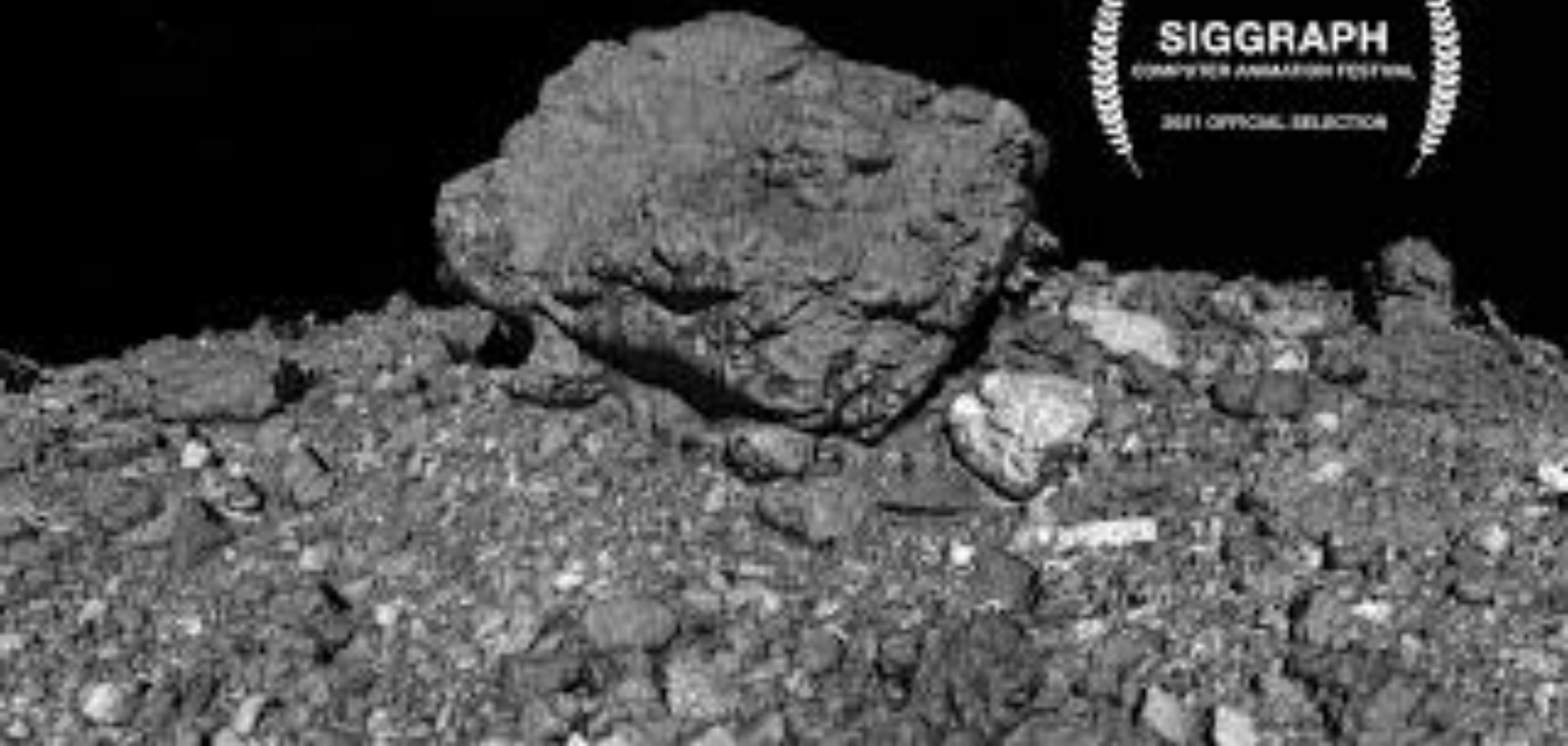
2023

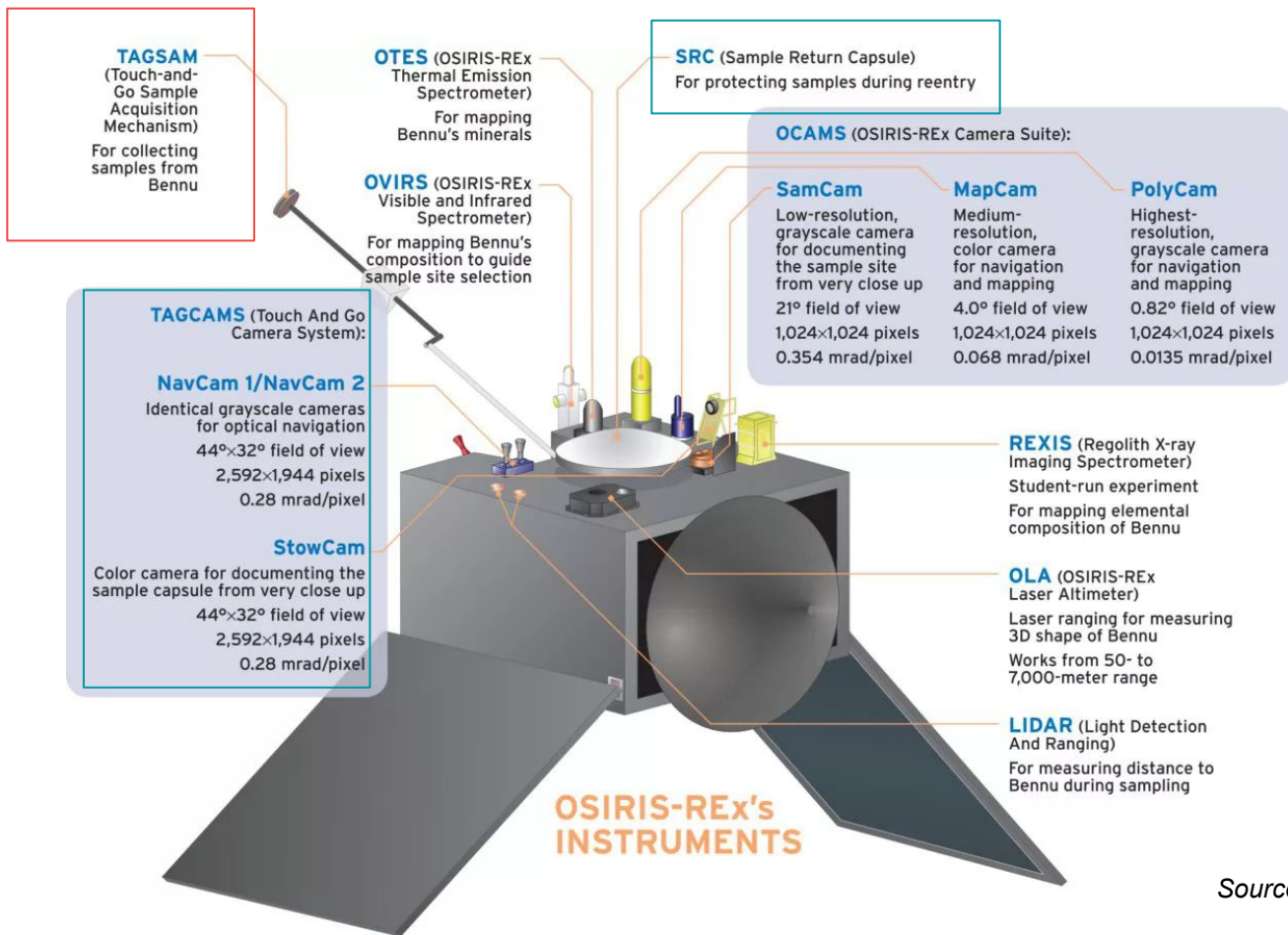
RETURN
TO EARTH



Canadian Space Agency
Agence spatiale
canadienne

Canada



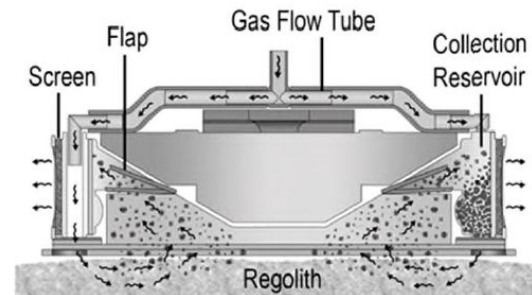
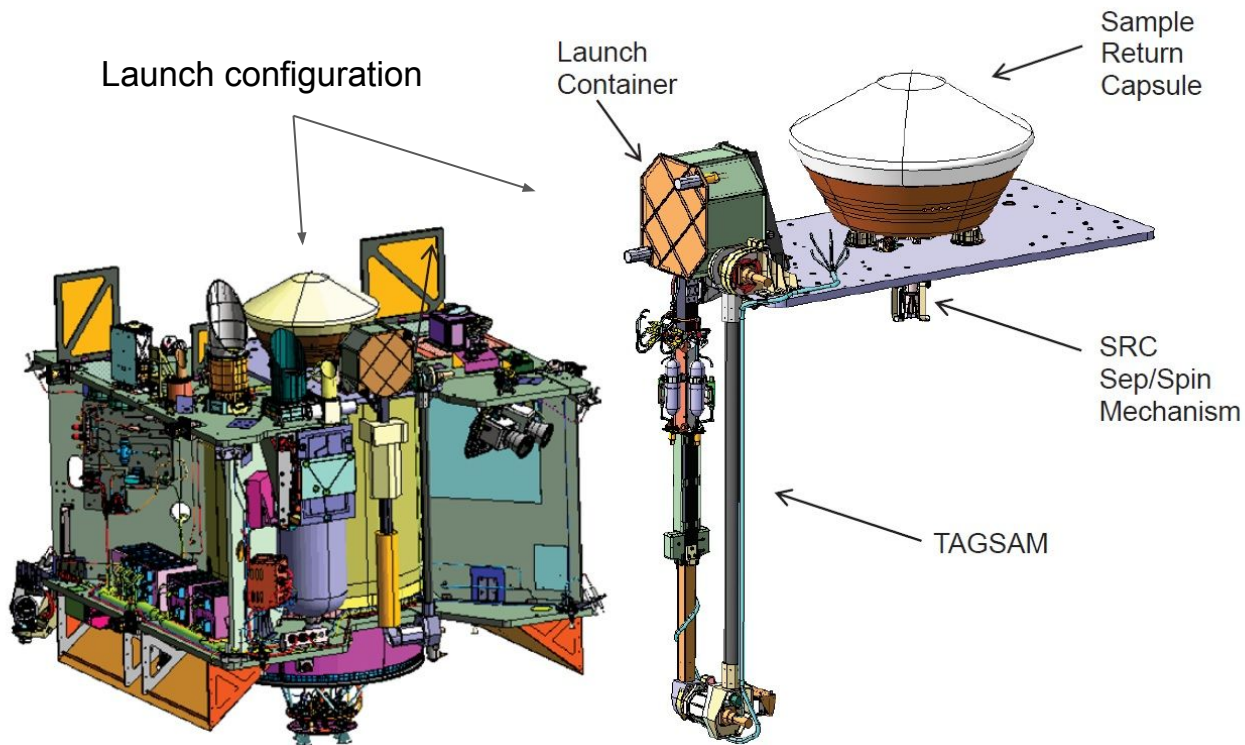


O – Origins
 SI – Spectral Interpretation
 RI – Resource Identification
 S – Security
 REx – Regolith Explorer

[Read more: OSIRIS-REx Science Payload](#)

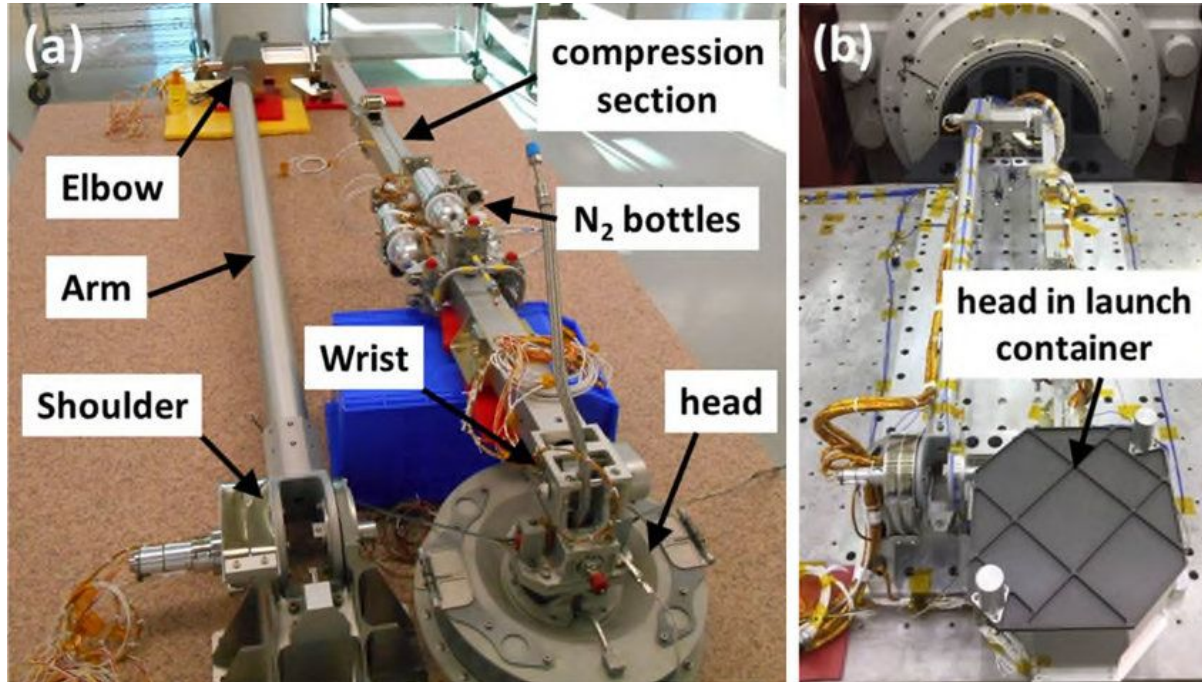
Source: The Planetary Society

TAGSAM (Touch-And-Go Sample Acquisition Mechanism)



EPFL OSIRIS-REx Mission

TAGSAM (Touch-And-Go Sample Acquisition Mechanism)



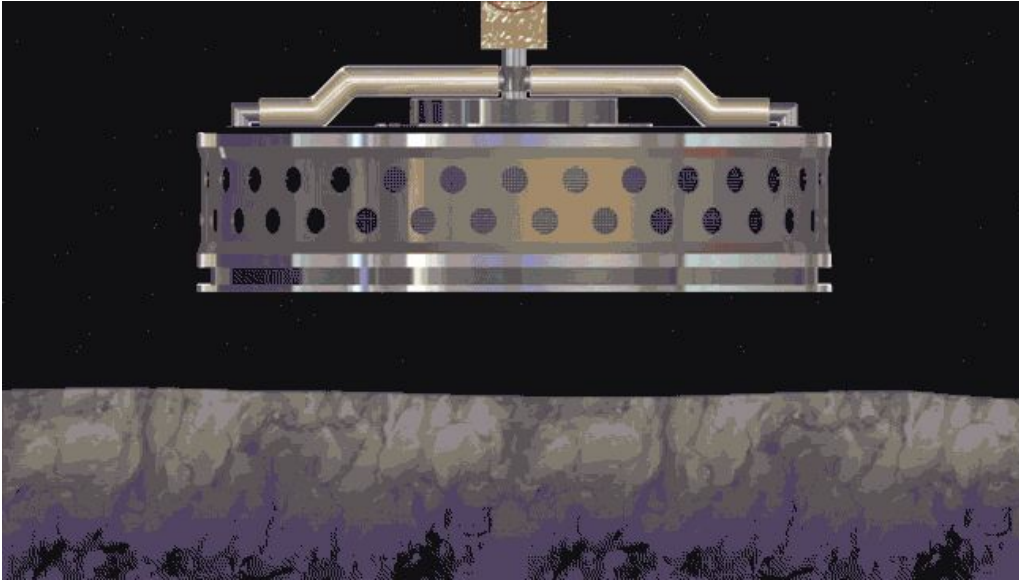
Questions (avoid looking at follow-up slides):

- How do we validate such a system?
- How do we measure how much of the surface of Bennu we have captured?

Source: "[The OSIRIS-REx Spacecraft and the Touch-and-Go Sample Acquisition Mechanism \(TAGSAM\)](#)", Space Science Reviews 214(7), 2018



TAGSAM (Touch-And-Go Sample Acquisition Mechanism)

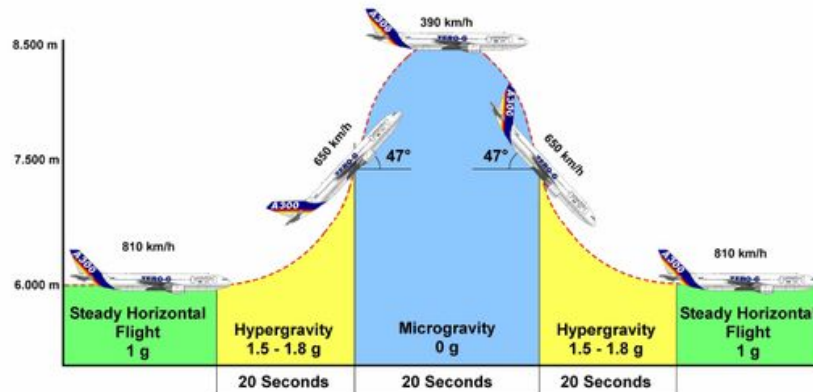


Source: NASA/Lockheed Martin/University of Arizona

TAGSAM (Touch-And-Go Sample Acquisition Mechanism)

Understanding the **dynamics of the regolith in response to gas flow**, in a reduced-gravity environment, is essential to demonstrate the viability of sampling instruments.

But how?



1. Start of head descent to surface.



2. Sample head contact with regolith.



3. Just prior to gas firing.

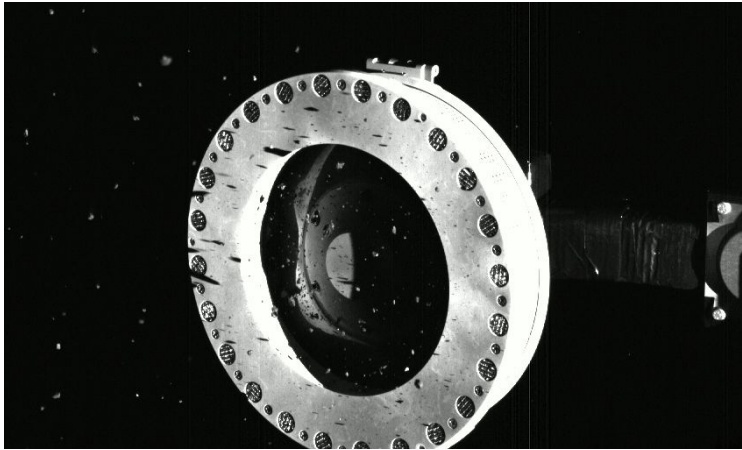


4. Approximate end of gas release.

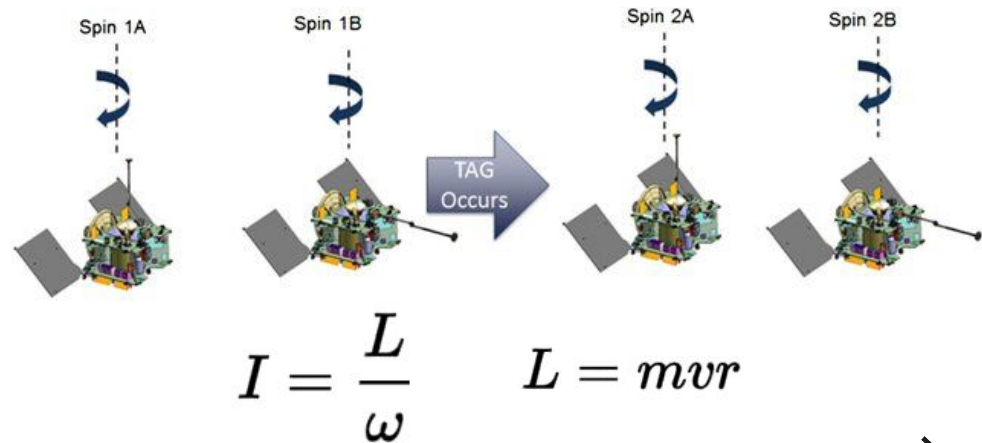
Source: "[The OSIRIS-REx Spacecraft and the Touch-and-Go Sample Acquisition Mechanism \(TAGSAM\)](#)", Space Science Reviews 214(7), 2018

TAGSAM (Touch-And-Go Sample Acquisition Mechanism)

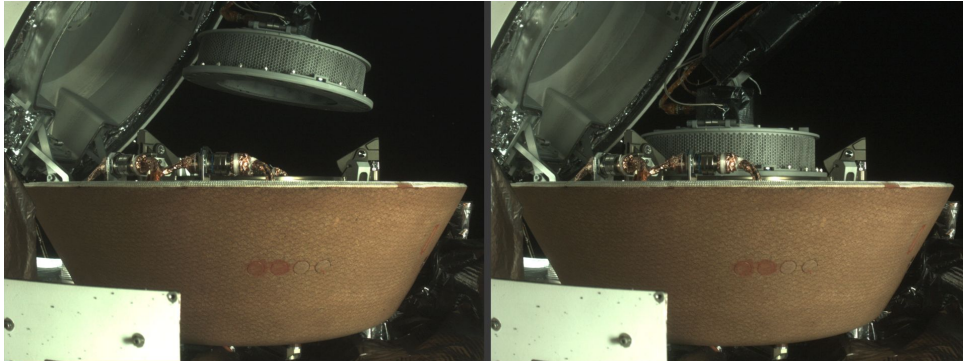
1) Via direct imaging



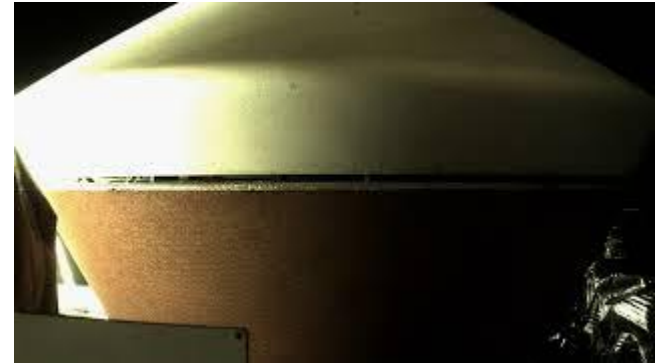
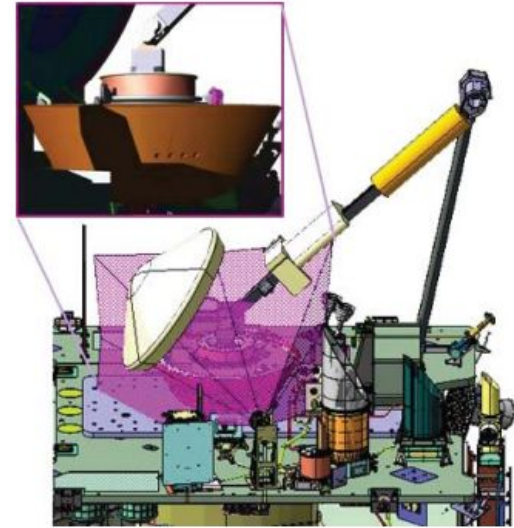
2) Via moment of inertia measurements



TAGSAM (Touch-And-Go Sample Acquisition Mechanism)



When the sample is ready to be stowed, the SRC lid is opened allowing the TAGSAM head to move into position. Alignment is verified through the StowCam and a set of potentiometers in the arm. The sampler head is then detached, the arm returns to its launch configuration, and the SRC lid closes and latches.



Source: "[The OSIRIS-REx Spacecraft and the Touch-and-Go Sample Acquisition Mechanism \(TAGSAM\)](#)", Space Science Reviews 214(7), 2018

EPFL GNSS payloads



What constraints can you think about ?
Which payload / instruments are needed ?

- Users' needs (coverage, precision, relay, ...)
- Requirements for the payload (attitude, power, ...)
- Dedicated constellation or piggybacked payload
- Space, ground, and user segments, compatibility
- Security

EPFL GNSS payloads

Galileo Payload Subsystem including the navigation payload and the SAR payload

- **L-band antenna** transmits the navigation signals in the 1200-1600 MHz frequency range
- Search and Rescue Antenna
- High precision on-board clocks (redundant)
- Backup atomic clocks (redundant)
- Navigation signal generator unit

But also

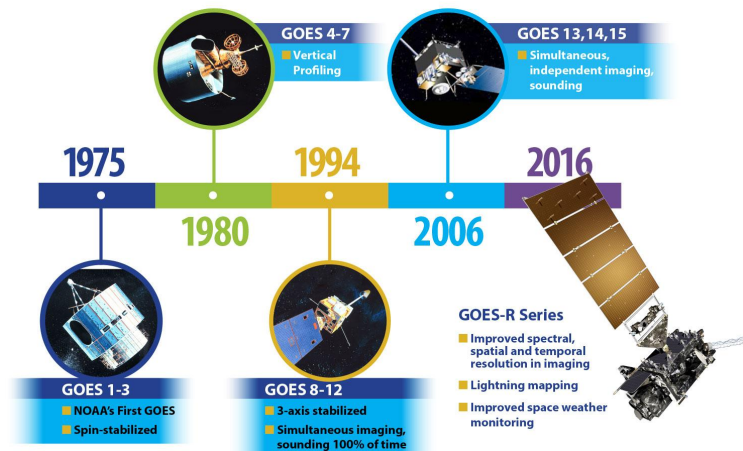
- Other antennas (other frequencies) for mission comm
- **Earth sensors** and the **Sun sensors** both help to keep the spacecraft pointing at the Earth



TECHNICAL SPECIFICATION

	PHM	Mini PHM
Output Frequency	10.00285340MHz (fH/142)	10.00285340MHz (fH/142)
Output Level	+7dBm (main and auxiliary outputs)	+7dBm (main and auxiliary outputs)
Frequency Drift (f/Day)	$\leq 1 \times 10^{-12}$ after 1 week $< 1 \times 10^{-12}$ after 30 days	$\leq 1 \times 10^{-12}$ after 1 week $< 1 \times 10^{-12}$ after 30 days
Allan deviation (5s-10s)	$< 1 \times 10^{-12}$ x $t^{1/2}$ max. $< 7 \times 10^{-13}$ x $t^{1/2}$ typical	$< 1 \times 10^{-12}$ x $t^{1/2}$ max. $< 7 \times 10^{-13}$ x $t^{1/2}$ typical
Freq. sensitivity to temperature	$< 2 \times 10^{-9}/^{\circ}\text{C}$	$< 1 \times 10^{-9}/^{\circ}\text{C}$
Freq. sensitivity to Main Bus Voltage	$\leq 3 \times 10^{-9}/\text{V}$	$\leq 3 \times 10^{-9}/\text{V}$
Dimensions	210 x 500 x 250mm	210 x 485 x 218mm
Mass	18.2Kg	12Kg
Main Bus Voltage	50V ± 1V	50V ± 1V
Power consumption (W)	$\leq 70\text{W}$ at -5°C baseplate $\leq 60\text{W}$ at +10°C baseplate	$\leq 54\text{W}$ at -5°C baseplate $\leq 47\text{W}$ at +10°C baseplate
Qualification Temperature Range	-15°C to +20°C	-15°C to +20°C
Lifetime (MEO Orbit)	>12 years	>12 years
ADEV (Secs)		
1	1.8×10^{-12}	6.5×10^{-13}
10	3.2×10^{-13}	1.4×10^{-13}
100	7×10^{-14}	6.3×10^{-14}
1000	2.2×10^{-14}	2.2×10^{-14}
10,000	7×10^{-15}	7×10^{-15}
50,000	$< 1 \times 10^{-14}$	$< 1 \times 10^{-14}$

What constraints can you think about ?
Which payload / instruments are needed ?



<https://www.goes-r.gov/mission/history.html>

"Conditions **on the Sun and in the solar wind, magnetosphere, ionosphere and thermosphere** that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health."

<https://soho.nascom.nasa.gov/spaceweather/>

→ Different places in space (L1, L4, L5, GEO, ...)

→ Different data (wavelengths, particles)

→ Different sensors and instruments

!\\ Electromagnetic interferences

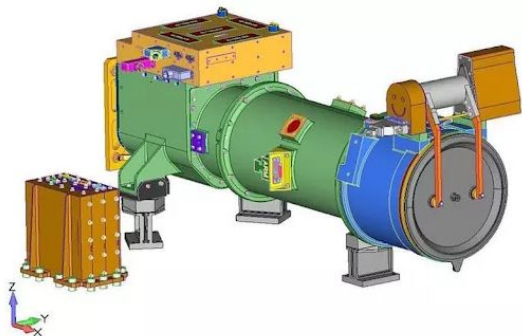
!\\ large amount of data to process and use in early warning (grand segment & data center)

To estimate size, mass, speed, and direction of CMEs

- Compact Coronagraph (CCOR)
- Heliospheric Imager (HI)
- Photospheric Magnetic field Imager (PMI)

To anticipate solar winds

- Plasma Analyser (PLA)
- Magnetometer (MAG)

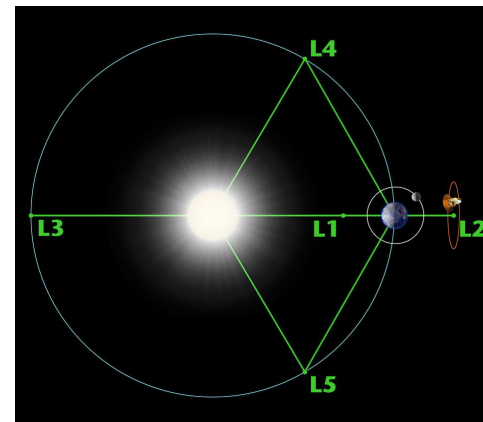


NASA Compact
Coronagraph (CCOR)
for SWFO-L1

<https://www.nesdis.noaa.gov/our-satellites/future-programs/swfo/swfo-instruments>



https://en.wikipedia.org/wiki/ESA_Vigil



https://www.esa.int/Space_Safety/Monitoring_space_weather

What constraints can you think about ?

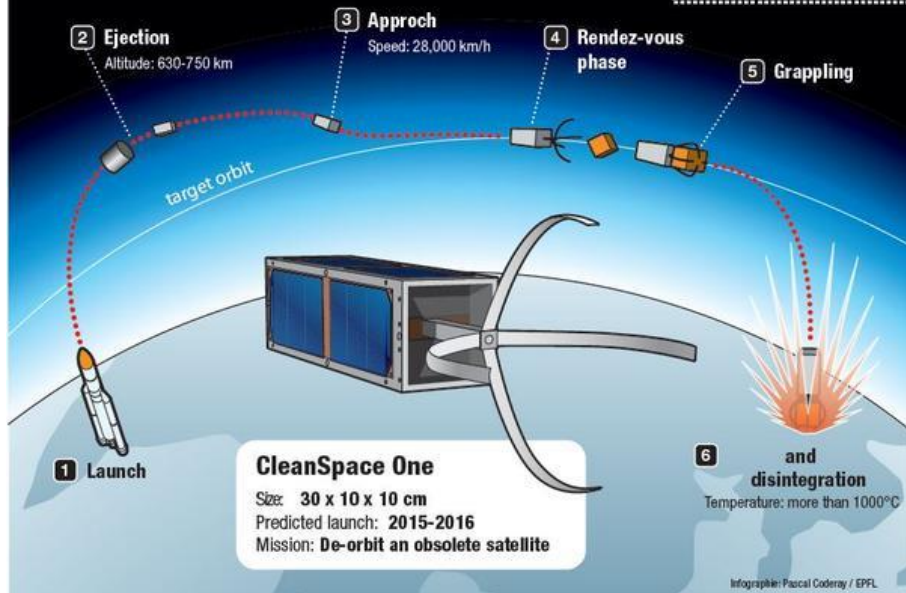
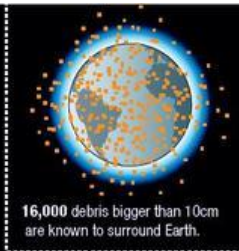
Which payload / instruments are needed ?

- Target-dependent / universal capture system ?
 - Size, shape
 - Material (magnetic ?)
 - Attitude, rotation rate
 - State (damaged ?)
- Requirements for rendez-vous and close proximity operation (RPO)
 - Sensors
 - Computer vision
 - AOCS
 - Contact: Stiffness but also smoothness

CleanSpace One

The first janitor satellite to be sent by EPFL

Space debris represents an increasing risk for operational satellites. Developed at Ecole Polytechnique Fédérale de Lausanne (EPFL), CleanSpace One will be the first janitor satellite to be sent into space.



“CleanSpace One will grab and stabilize [the target] [...] scientists are planning to develop a gripping mechanism inspired from a plant or animal example.”

[Emmanuel Barraud. Cleaning up Earth's orbit: A Swiss satellite to tackle space debris \(2012\)](#)



“A giant Pac-Man to gobble up space debris. The space cleanup satellite will deploy a **conical net** to capture the small SwissCube satellite”

[CleanSpace One \(2015\)](#)

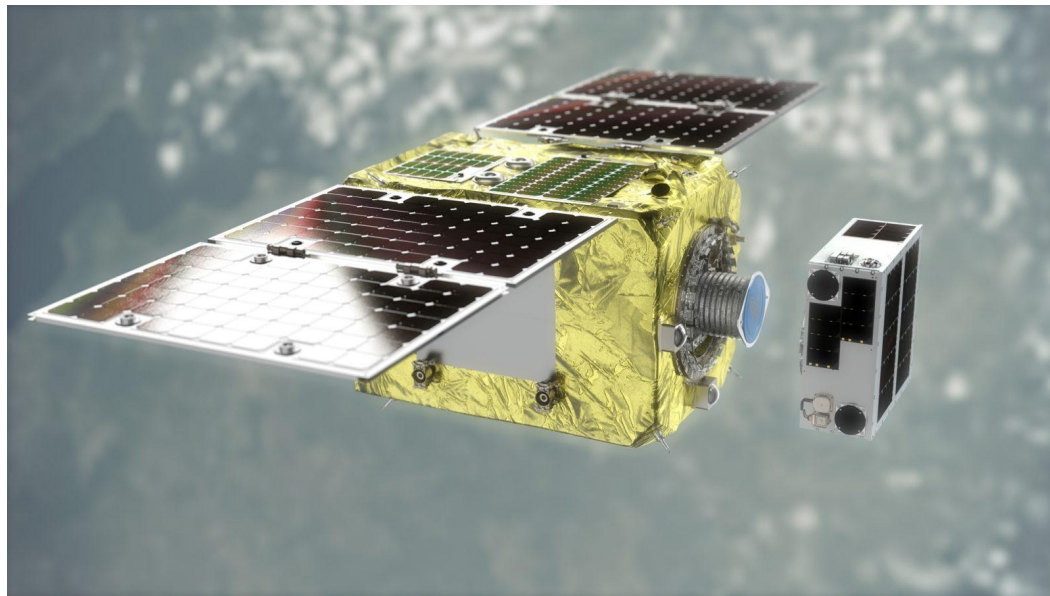
First ConOps ? (2012)



<https://clearspace.today/clearspace-sa-signs-service-contract-with-esa-to-carry-out-the-first-mission-to-remove-space-debris-in-orbit-in-2025/>



<https://clearspace.today/revolutionary-space-debris-removal-mission-advances-to-next-phase/>

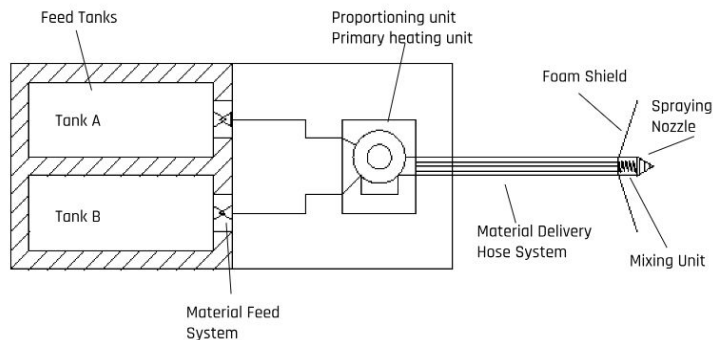


[The ELSA-d servicer is] [...] equipped with [...] a magnetic docking mechanism.

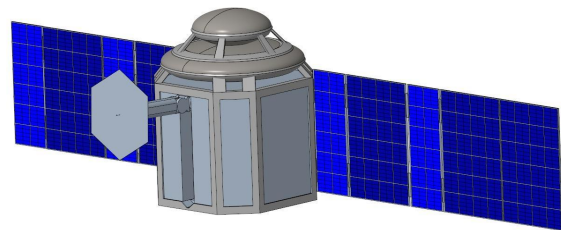
The client satellite is a piece of replica debris fitted with a ferromagnetic plate that enables the docking.

[Astroscale ELSA-d](#) (successful close approach RPO in 2022)

Different solutions being investigated. Even advanced concept like “Polyurethane-Foam Based Space Debris Remediation”

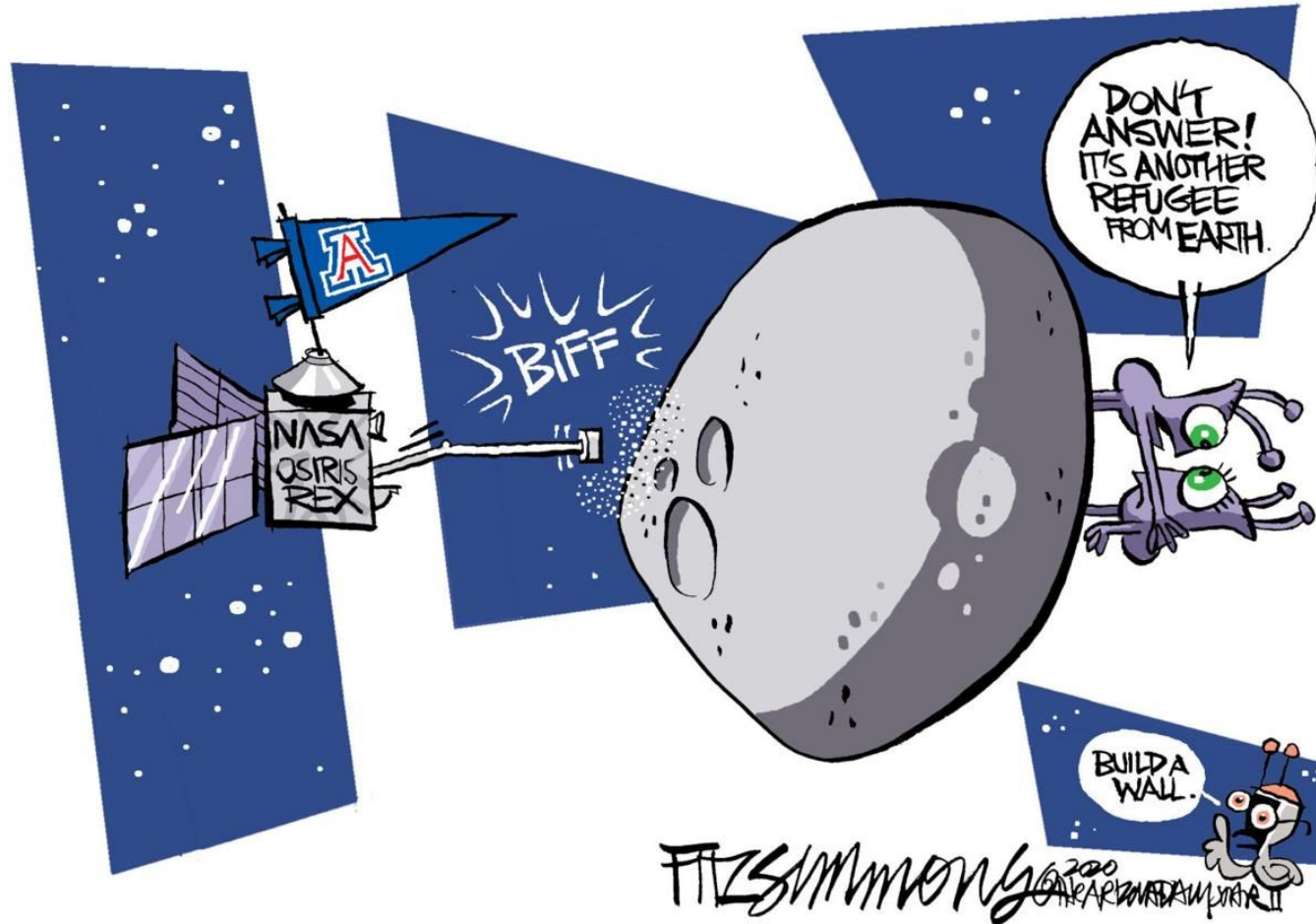


Scheme of the foam spraying mechanism



Visual representation of the deployed satellite with foam spraying arm

→ augmenting the surface area of debris to expedite orbital decay and acting as a protective shield to prevent collision-induced fragmentation



Today's Project Work:

By now you should have a clear idea of what your mission destination, goals, objectives, top-level functions, preliminary mission requirements and constraints, reference mission architectures, and tentative CONOPS are...

- You may have already defined your **mission profile** and calculated the required **delta-V**
- You may have already assessed potential **launch vehicles**, **launch sites**, and **launch windows** for your mission.
- Today you need to start:
 - Thinking about the **desired measurements** to make during your mission and making a **list of desirable (science) instruments / payload**. You can (and probably should) use flown and existing instruments.
 - Start defining the basic characteristics of these instruments
 - **Mass and volume** → start constructing budgets
 - **Power** required → start constructing budgets
 - **Data** volume produce and data rates → start constructing budgets
 - **FoV** required by the instrument (configure your spacecraft accordingly!!) → L11
 - Any other relevant **interface requirements** (operational temperatures, position constraints, mechanical loading, accuracy, etc)



Defining your spacecraft concurrently (more on this in [ENG411](#))

