Big Planets, Big Questions, Big Data: Planetary remote sensing data challenges

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Magellan SAR Mosaic, 2025 m/pixel

Planetary science data gathering

Why

- What are the the big, driving scientific questions behind space exploration?
- What controls the science requirements that dictate mission architectures?

How

- The basics of planetary remote sensing – what we measure and why
- How we (currently) prioritize, collect and apply scientific observations

Decadal Scale Investigations (2013-2022)

Building new worlds

How did the planets form, and what controlled their positions, compositions and water supplies?

Planetary Habitats

Do/did other planets host environments amenable to life?

Where did/does organic synthesis occur?

Workings of the solar system

How do the physical, chemical, geological and/or biological systems observed throughout the solar system inform us about our own planet, and visa versa?

So how do we answer these questions?

- Measure the compositions of a planetary surface
- Measure atmospheric properties

- Model interior structure and dynamics
- Describe geologic processes through (deep) time
- Monitor atmospheric processes – loss, weather, climate

- Interpret processes and conditions to understand planetary evolution

Deepening levels of inquiry need progressively detailed data sets

Data Acquisition – Step 1: Send a mission

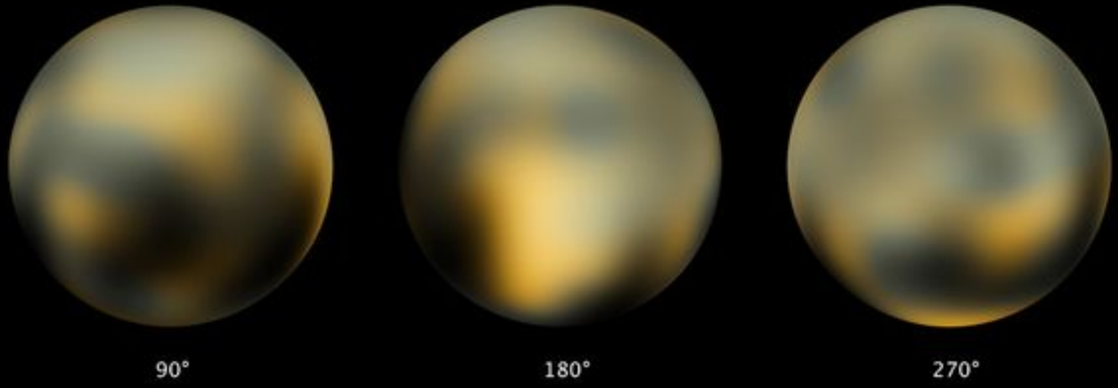
Mercury	Venus	Mars	Jupiter	Saturn	Neptune/ Uranus	Dwarf Planets/ Small bodies
- Mariner 10 - MESSENGER - [BepiColombo]	- Mariner 2,5 - Venera 4-16 - Pioneer-Venus 1, 2 - Vega 1, 2 - Galileo - Magellan - Venus Express	- Mariner 5, 6,7,9 - Mars 2,3 - Viking 1, 2 - Mars Global Surveyor - Pathfinder - Odyssey - Mars Express - Spirit - Opportunity - Mars Reconnaissance Orbiter - Phoenix - Curiosity - Mars Orbiter Mission - MAVEN - Trace Gas Orbiter - Insight	- Pioneer 10,11 - Voyager 1, 2 - Galileo - Juno	- Pioneer 11 - Voyager 1, 2 - Cassini/ Huygens	- Voyager 2	- Dawn - New Horizons - Chang'e-2 - OSIRIS-Rex - Rosetta - Hayabusa 1, 2

There is an inequity in this list…

Pink = landed

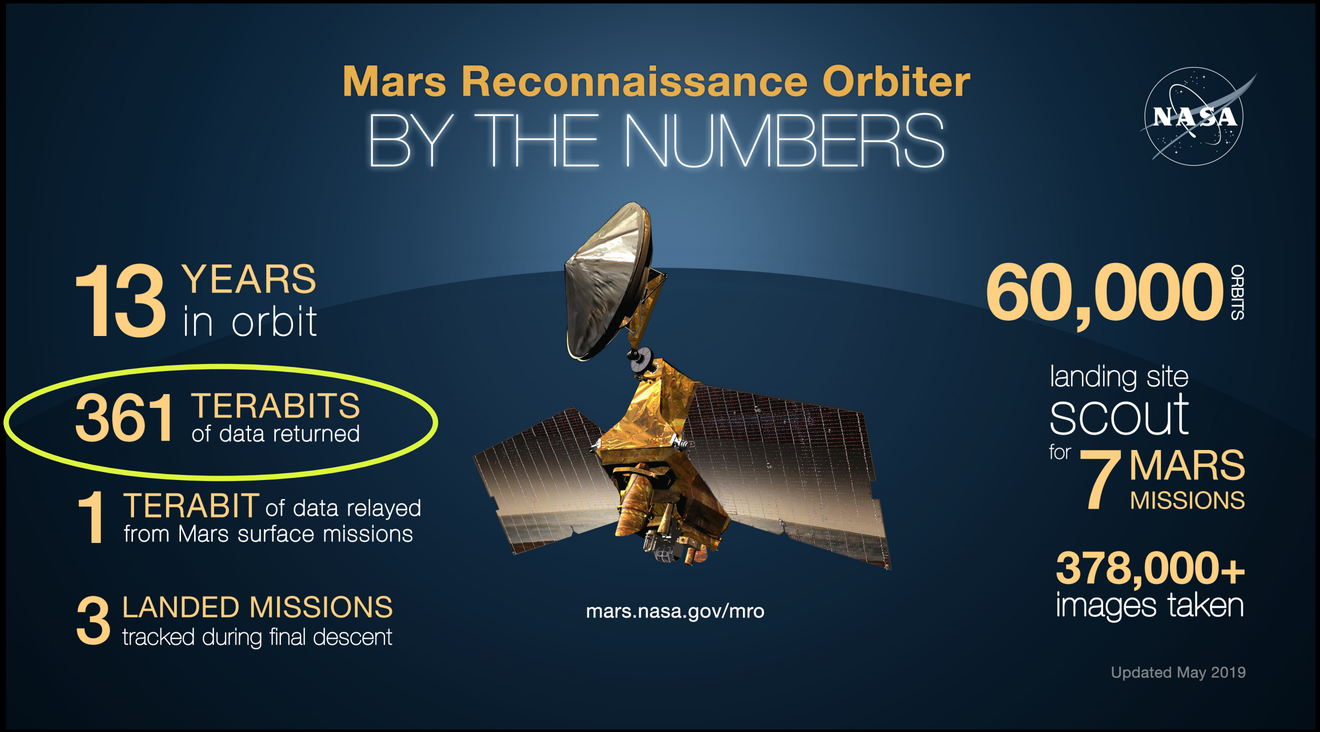
Every bit counts

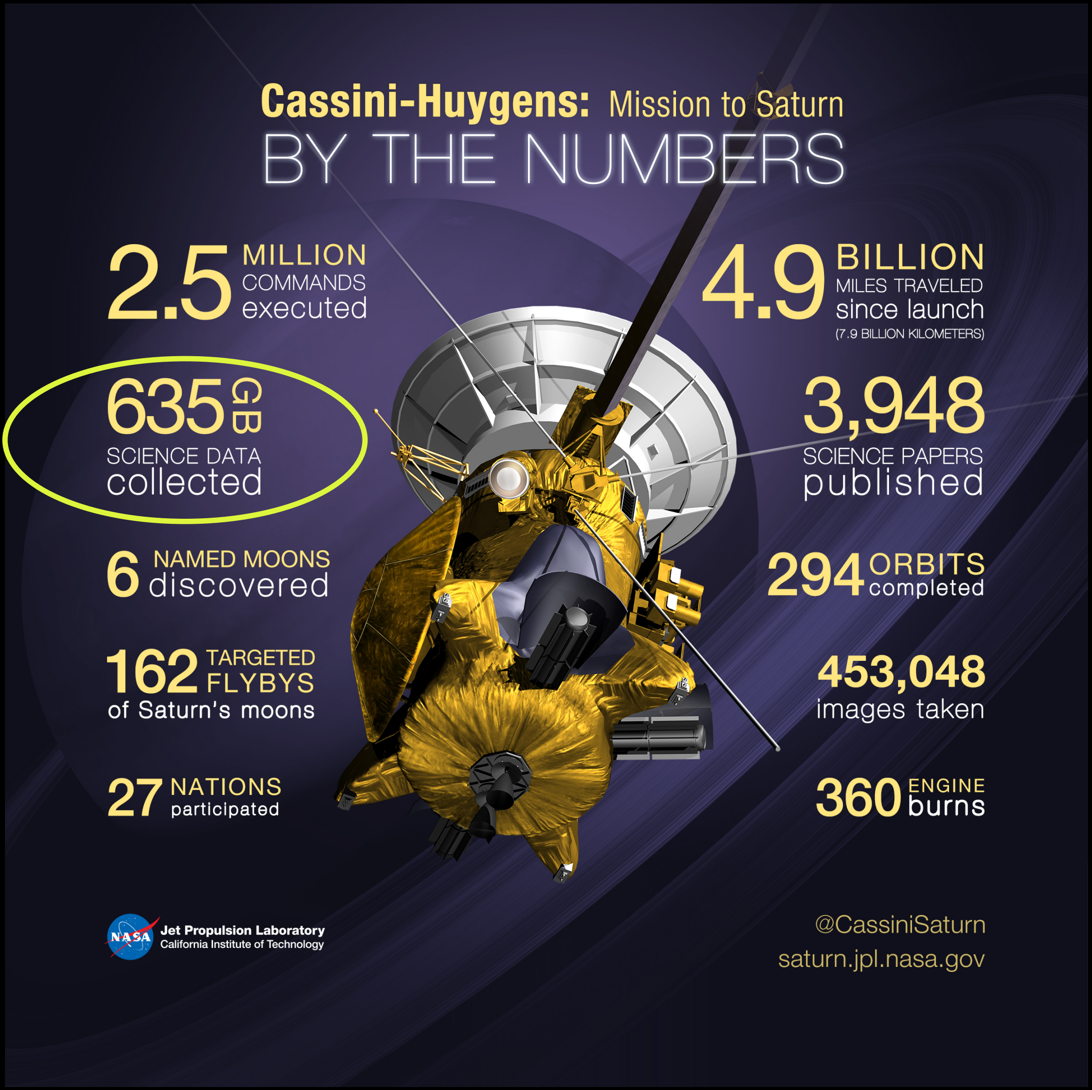
Pluto, Hubble 2012



New Horizons, 2015
6.25 GB data returned

Time, technology and distance





(635 GB = 4.96 Terabits)

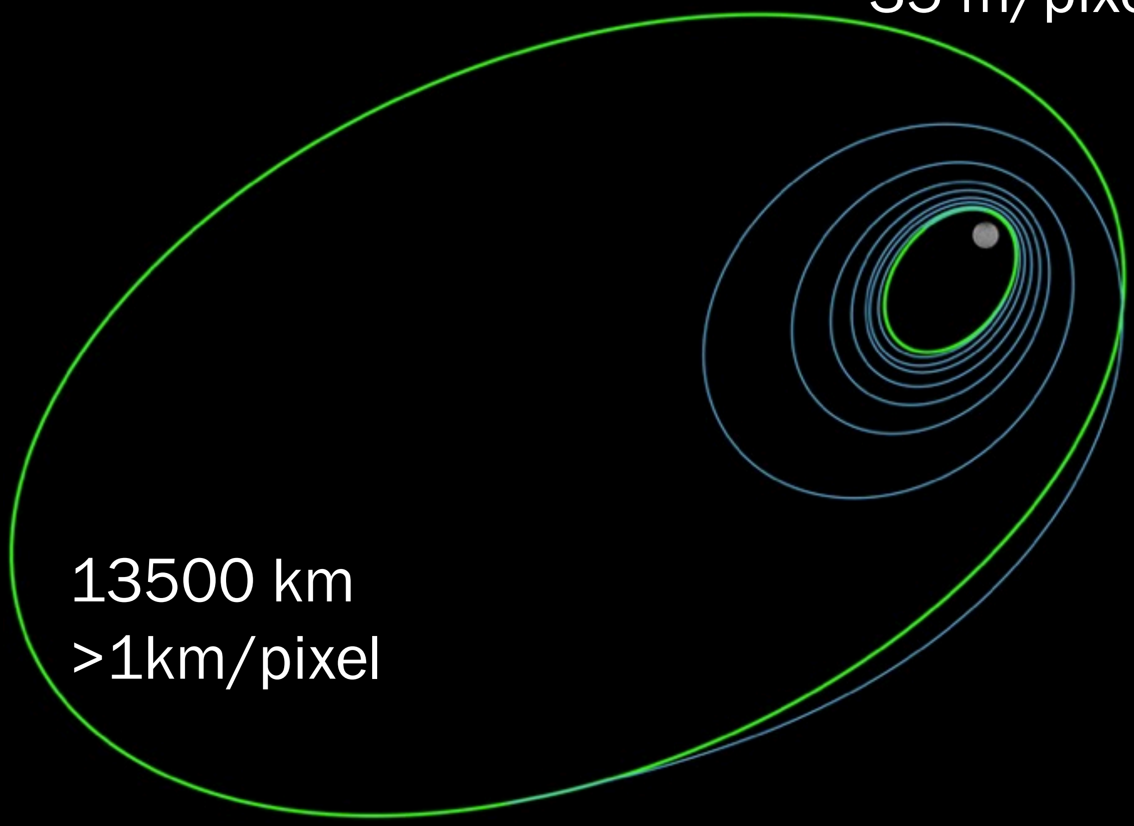
Magellan: 3.65 terabits

Resolution: What is it and how is it controlled?

- Information per bit

- Field of view
- Distance to target

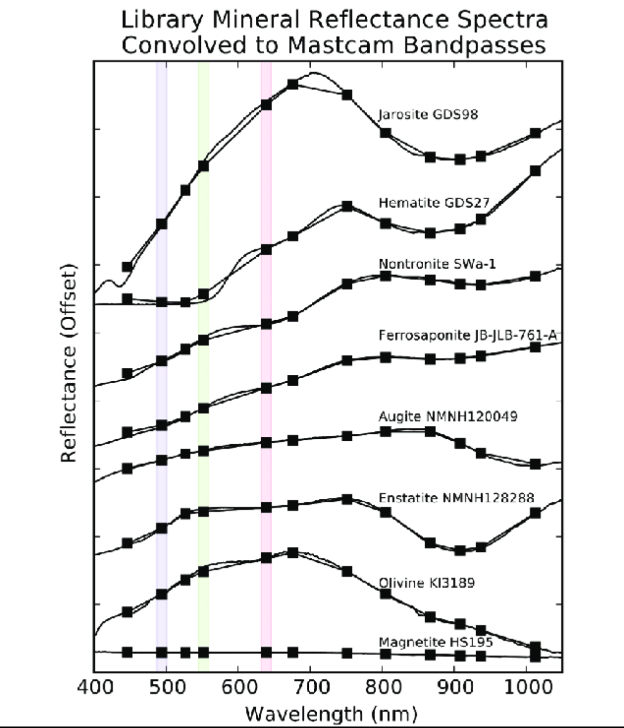
- Number of channels and band passes

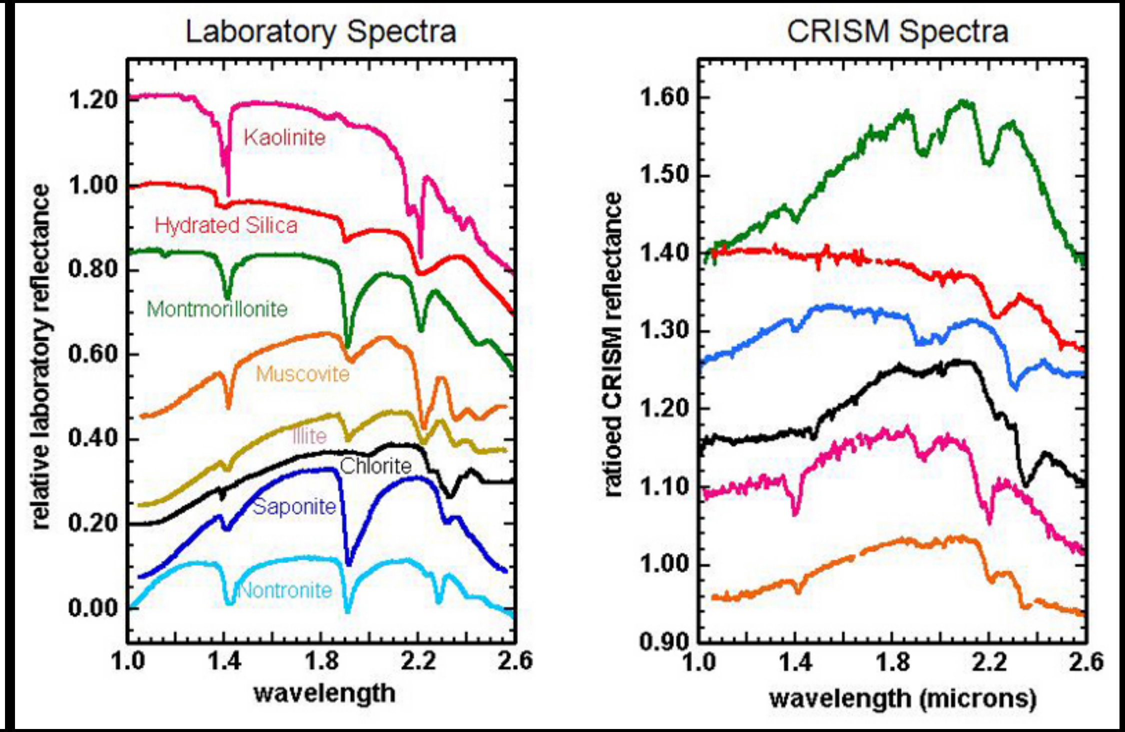


Resolution requirements drive mission constraints and data volumes
Orbital mission constraints drive resolution capabilities

Resolution: What is it and how is it controlled?

- Information per bit





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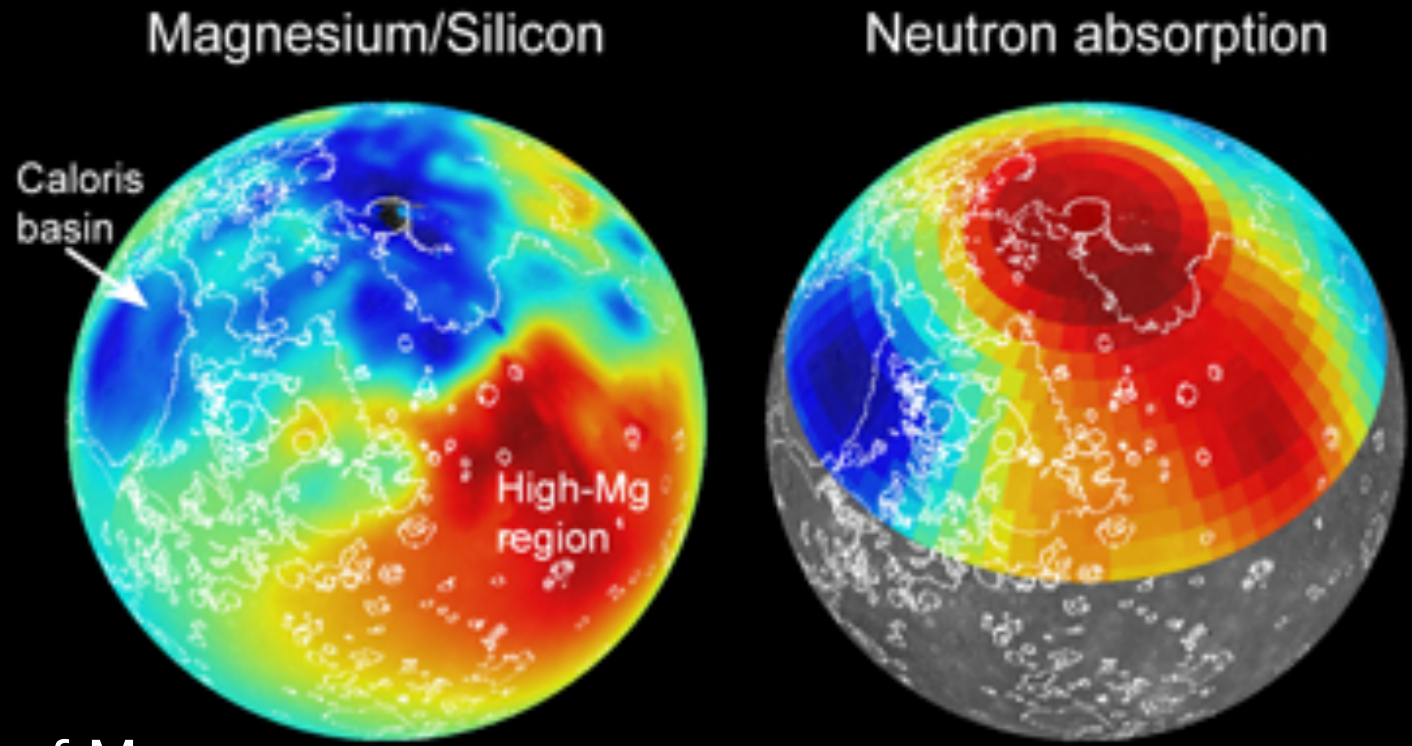
Resolution requirements drive mission constraints and data volumes

Orbital mission constraints drive resolution capabilities

Exploring the planets with the electromagnetic spectrum

Elemental composition

10^{-12}	10^{-10}	10^{-8}	10^{-6}	10^{-5}	10^{-2}	10^{3}
meters						
Gamma	X-ray	UV	Visible	IR	Microwave	Radio



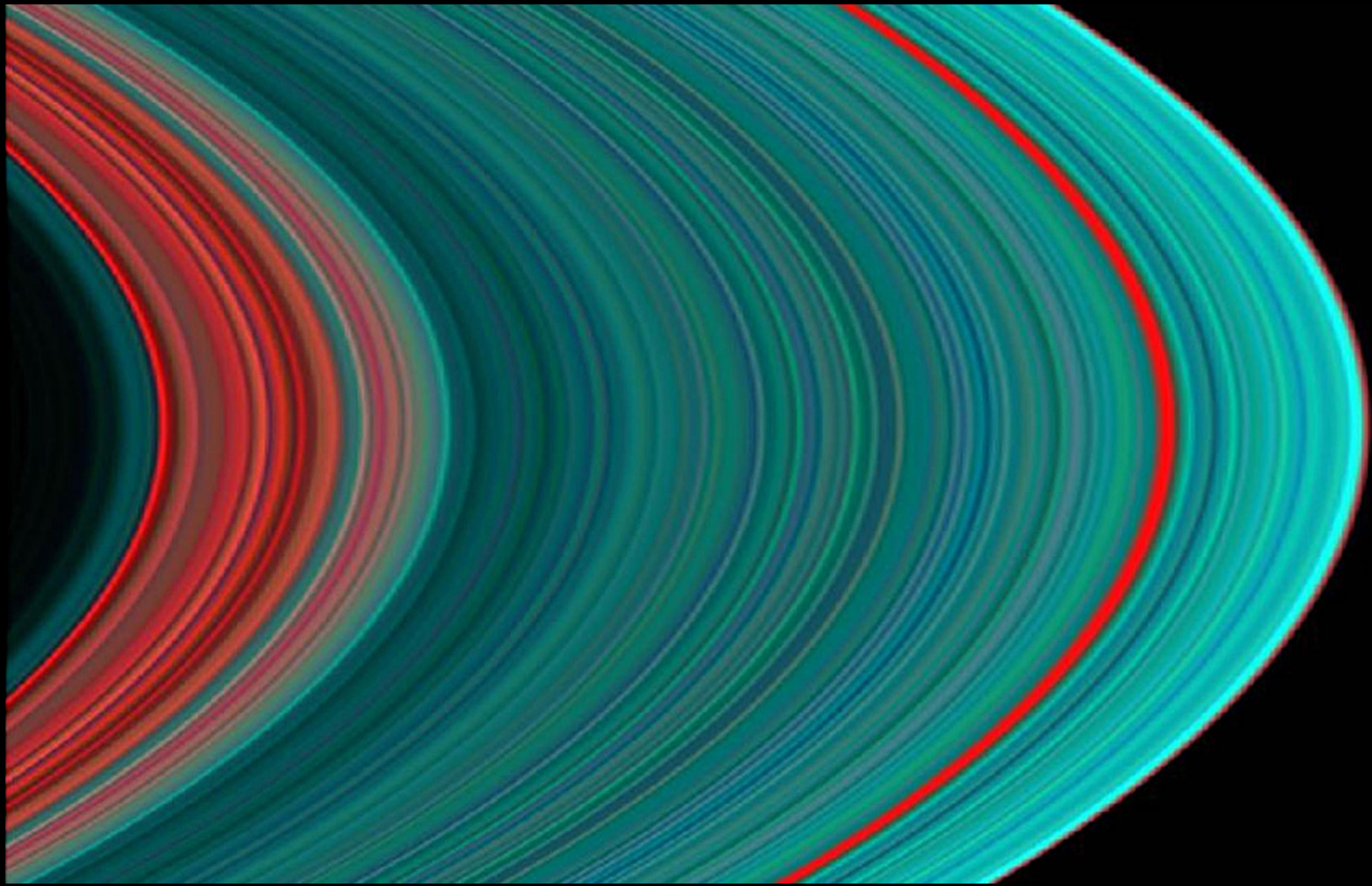
Chemical makeup of Mercury:
MESSENGER XRS and GRS instruments (FOV 12˚)

Exploring the planets with the electromagnetic spectrum

Atmospheric Gases, ices, organics

10^{-12}	10^{-10}	10^{-8}	10^{-6}	10^{-5}	10^{-2}	10^{3}
Gamma	X-ray	UV	Visible	IR	Microwave	Radio

meters

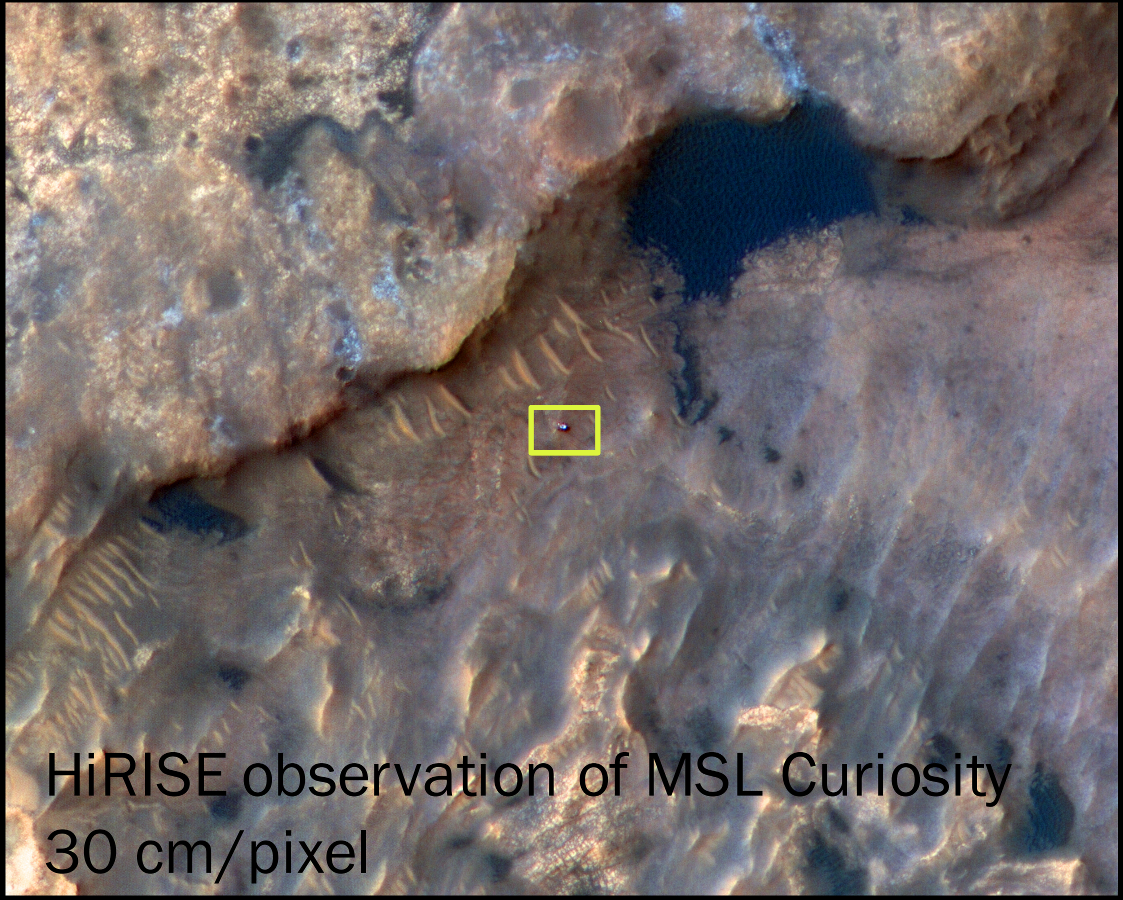


Saturn's rings, Cassini Ultraviolet Imaging Spectrometer (FOV ~3.6˚)

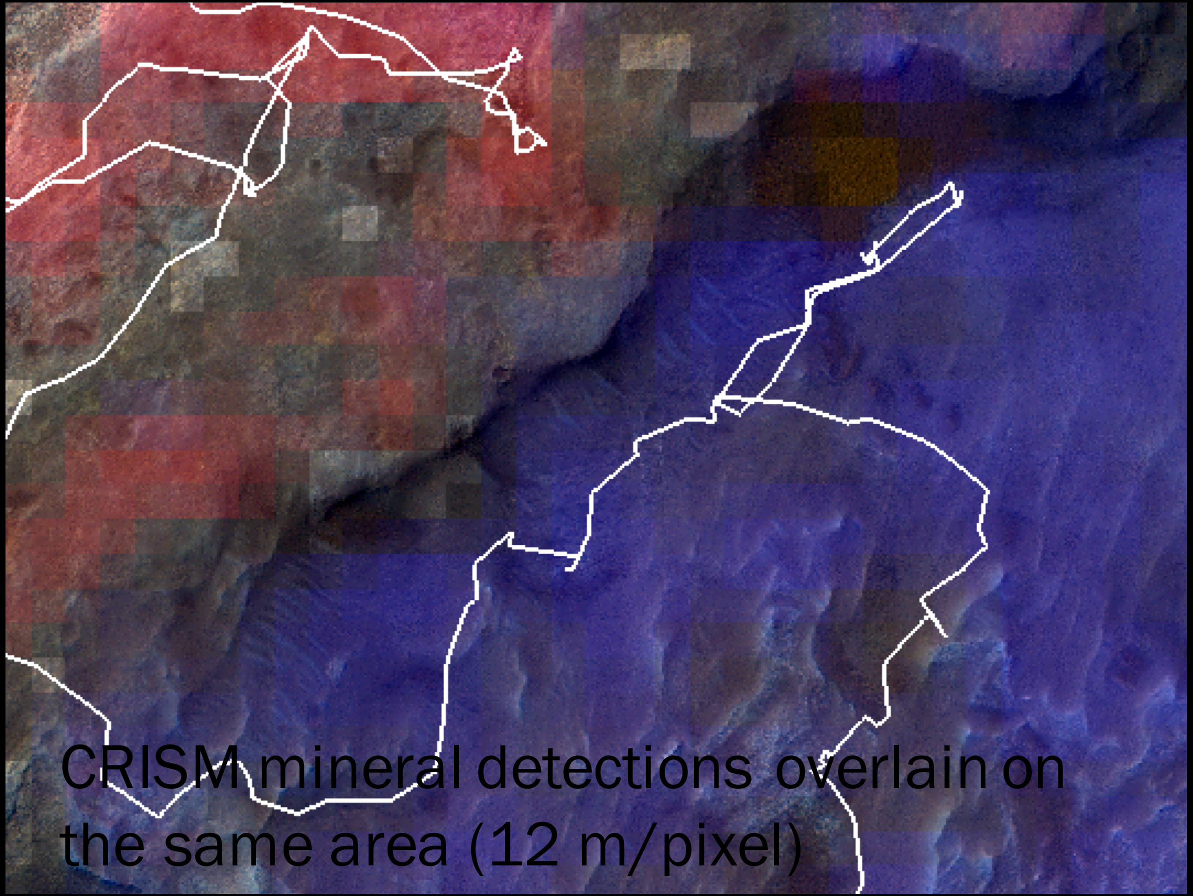
Exploring the planets with the electromagnetic spectrum

Imagery, mineralogy

10^{-12}	10^{-10}	10^{-8}	10^{-6}	10^{-5}	10^{-2}	10^{3}
meters						
Gamma	X-ray	UV	Visible	IR	Microwave	Radio



HiRISE observation of MSL Curiosity
30 cm/pixel



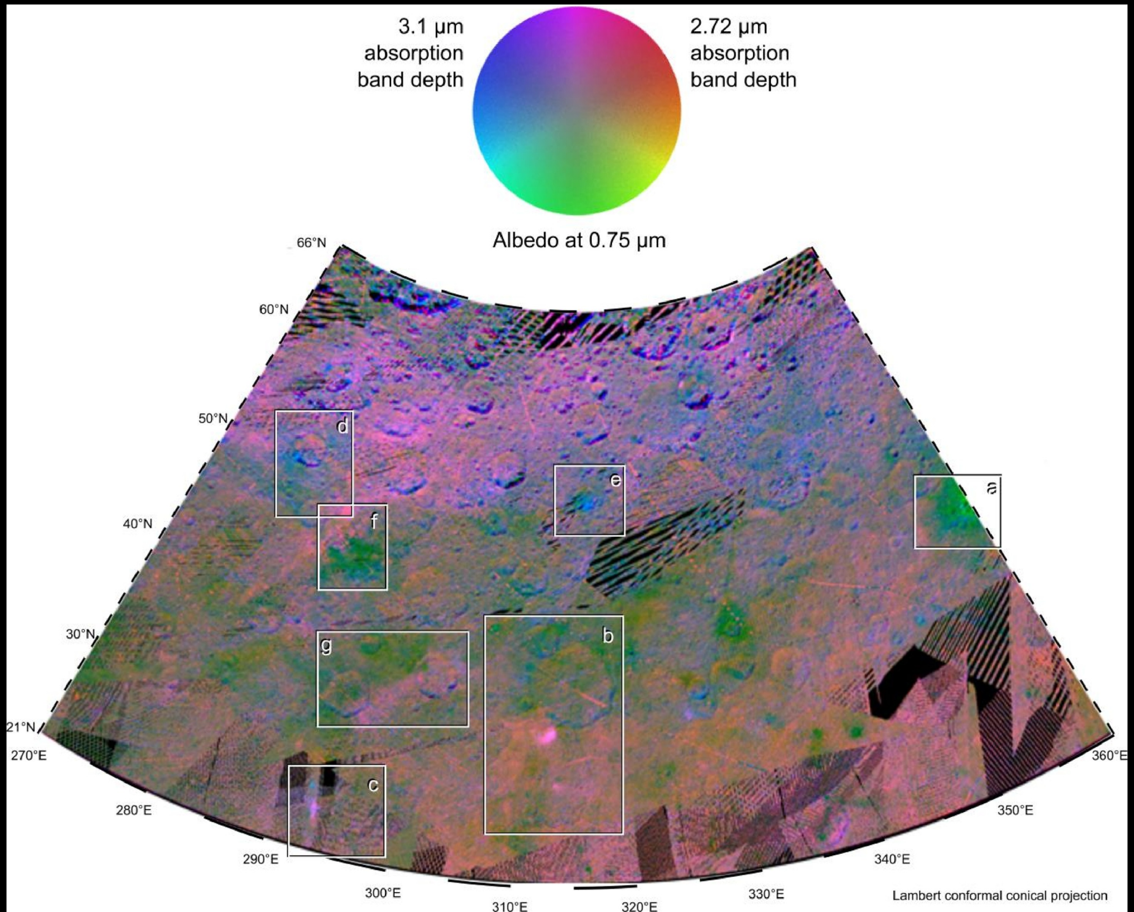
CRISM mineral detections overlain on the same area (12 m/pixel)

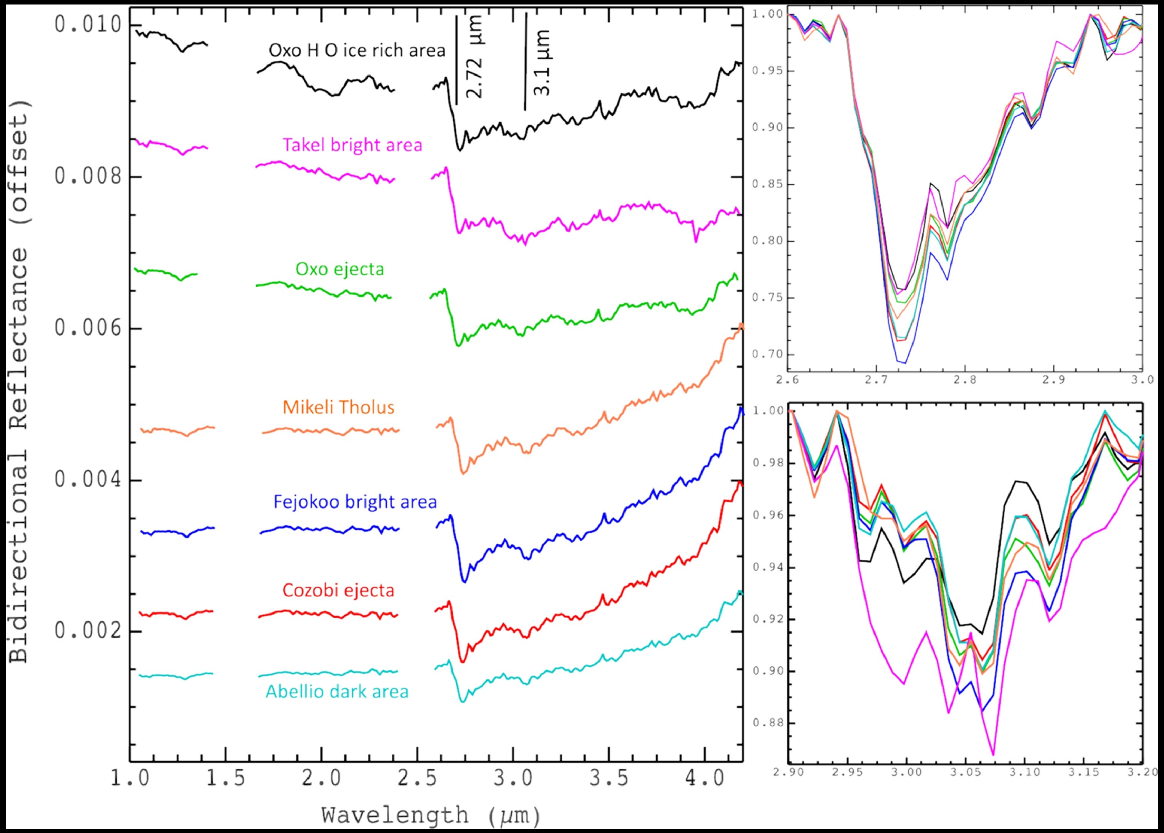
Exploring the planets with the electromagnetic spectrum

Mineralogy

10^{-12}	10^{-10}	10^{-8}	10^{-6}	10^{-5}	10^{-2}	10^{3}
Gamma	X-ray	UV	Visible	IR	Microwave	Radio

meters



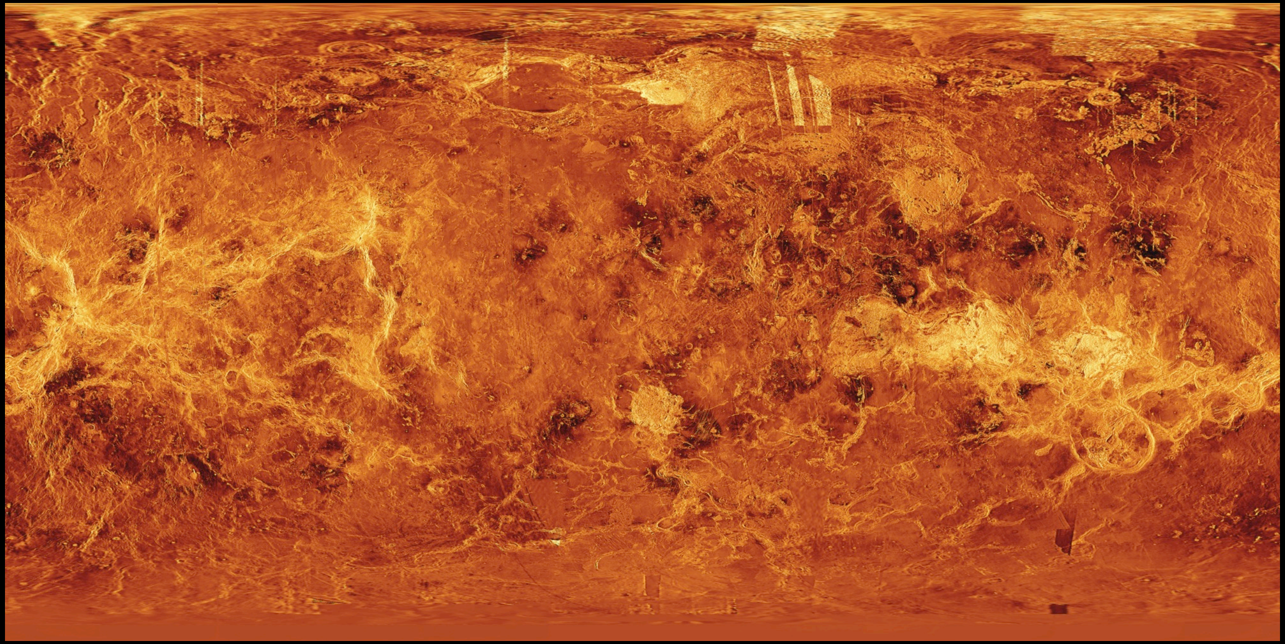


Ceres mineralogy, Singh et al., 2019

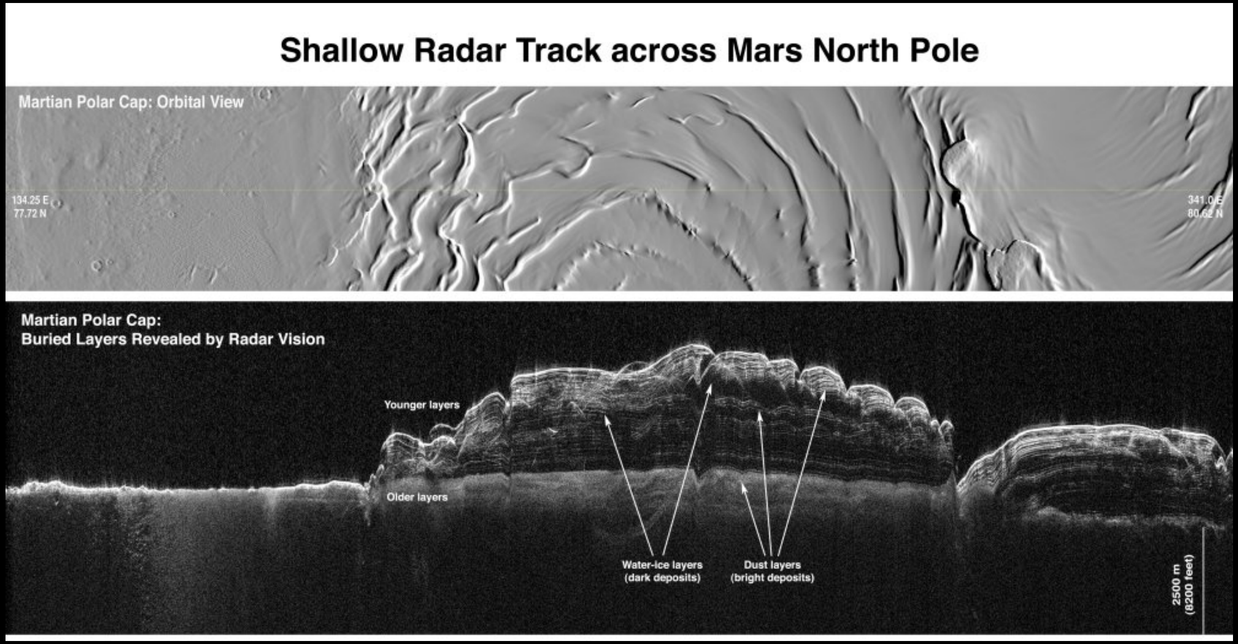
Exploring the planets with the electromagnetic spectrum

Structure (RADAR)

10^{-12}	10^{-10}	10^{-8}	10^{-6}	10^{-5}	10^{-2}	10^{3}
meters						
Gamma	X-ray	UV	Visible	IR	Microwave	Radio



Magellan SAR Mosaic, 2025 m/pixel



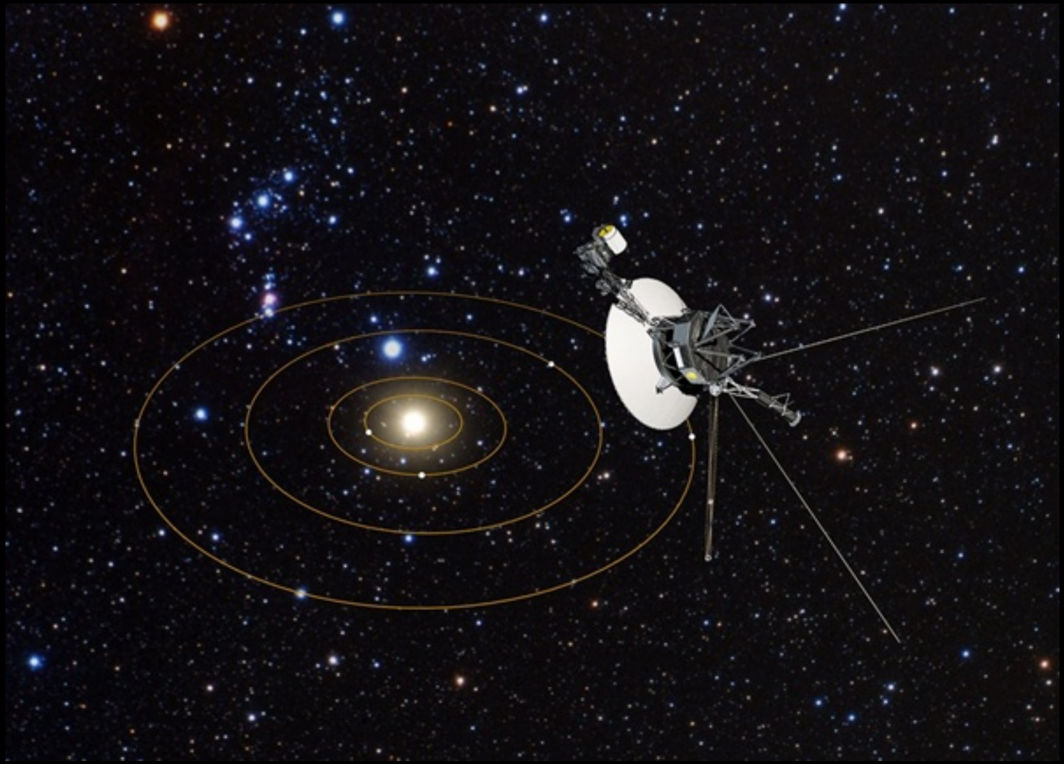
SHARAD ground penetrating Radar, MRO

Exploring the planets with the electromagnetic spectrum

Communication, astronomical observations

10^{-12}	10^{-10}	10^{-8}	10^{-6}	10^{-5}	10^{-2}	10^{3}
Gamma	X-ray	UV	Visible	IR	Microwave	Radio

meters



Mission Architectures: How Data is collected

Mars Reconnaissance Orbiter

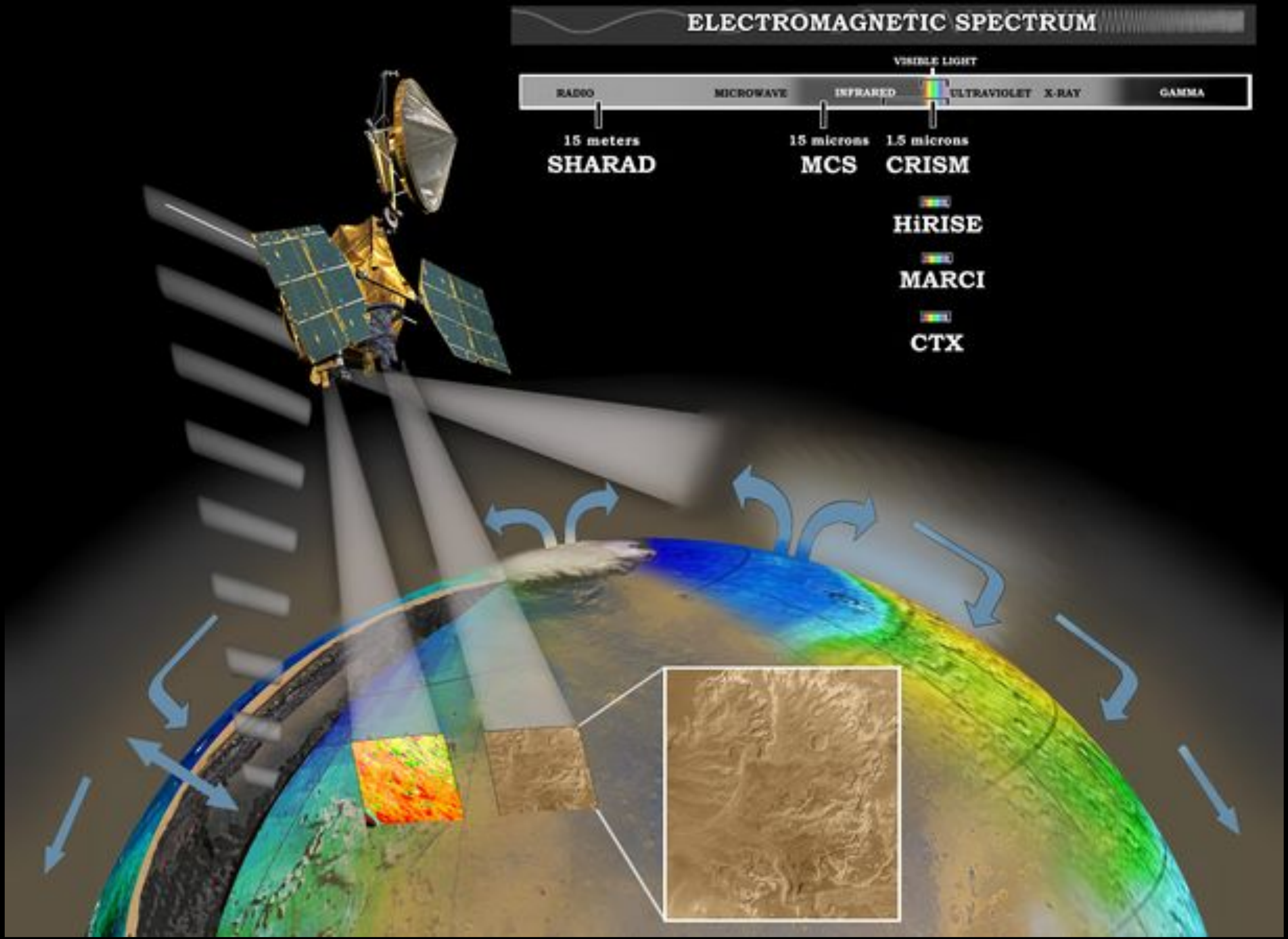
Mars Science Laboratory Curiosity

Mars Reconnaissance Orbiter Science Operations

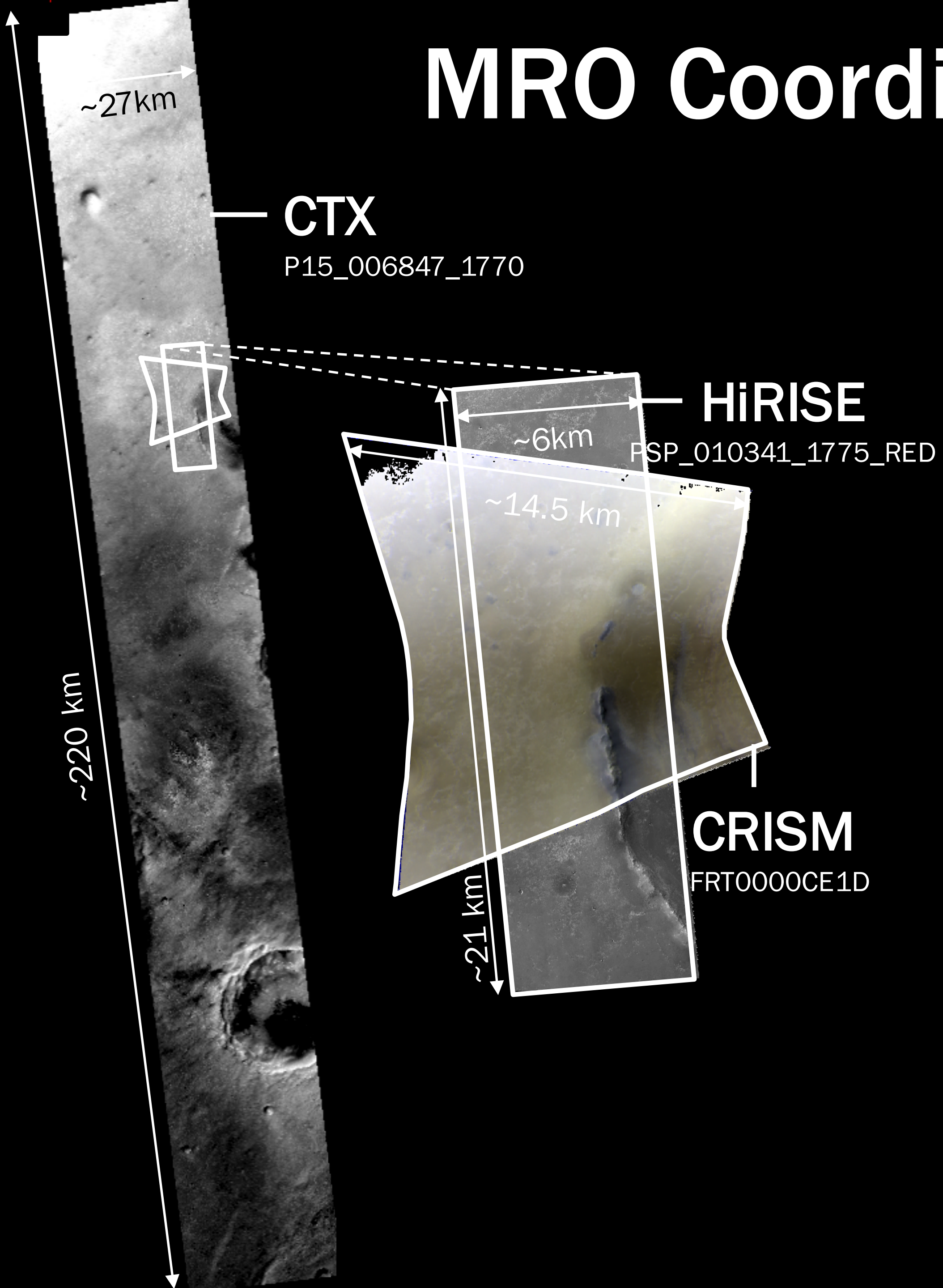
Primary science orbit is nearly circular and ”frozen” – long term ground coverage with ground track spacing of ~5 km
- 12 orbits per day

Instrument platform usually pointed at nadir; can turn off angle for targeted requests.

Planning cycles are ~3 weeks



MRO Coordinated Observations



Context Imager (CTX)

- Images with large areal extent
- 6 m/pixel
- 1 band: 0.5 – 0.7 μm
- **Global coverage**

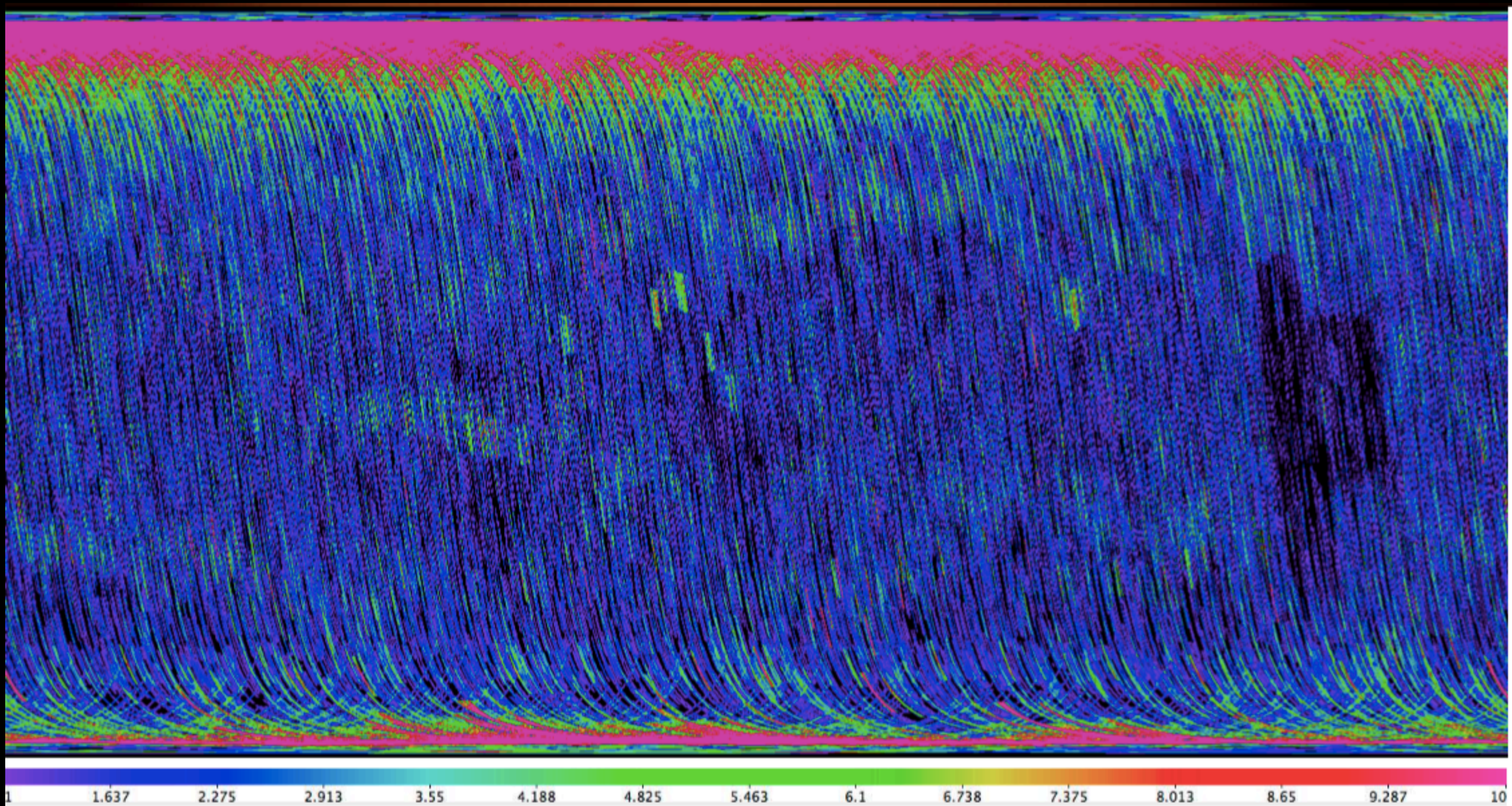
High Resolution Imaging Science Experiment (HiRISE)

- Small scale images
- 0.25 m/pixel
- 3 bands covering wavelengths 0.4-0.6, 0.55-0.85, and 0.80-1.00 μm
- **~4% areal coverage**

Compact Reconnaissance Imaging Spectrometer for Mars (CRISM)

- Hyperspectral images (6.5 nm spacing)
- 18 m/pixel (standard resolution)
- 544 wavelength bands from 0.362 – 3.920 μm
- **97% global coverage at low resolution,**

CRISM 100 m/pixel mapping coverage, spring 2019

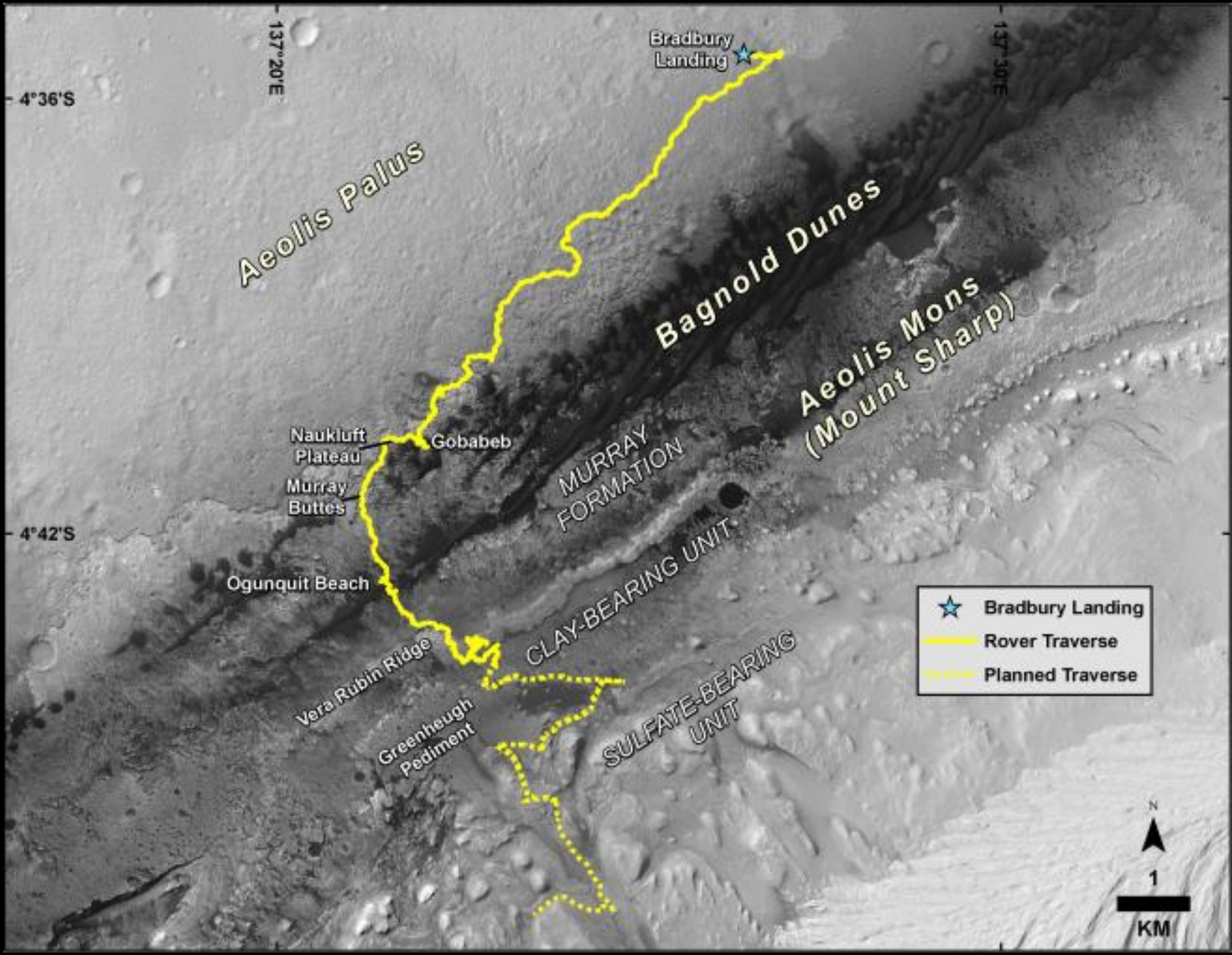


Mars Science Laboratory Curiosity Operations planning

Intensive “ground in the loop” operations

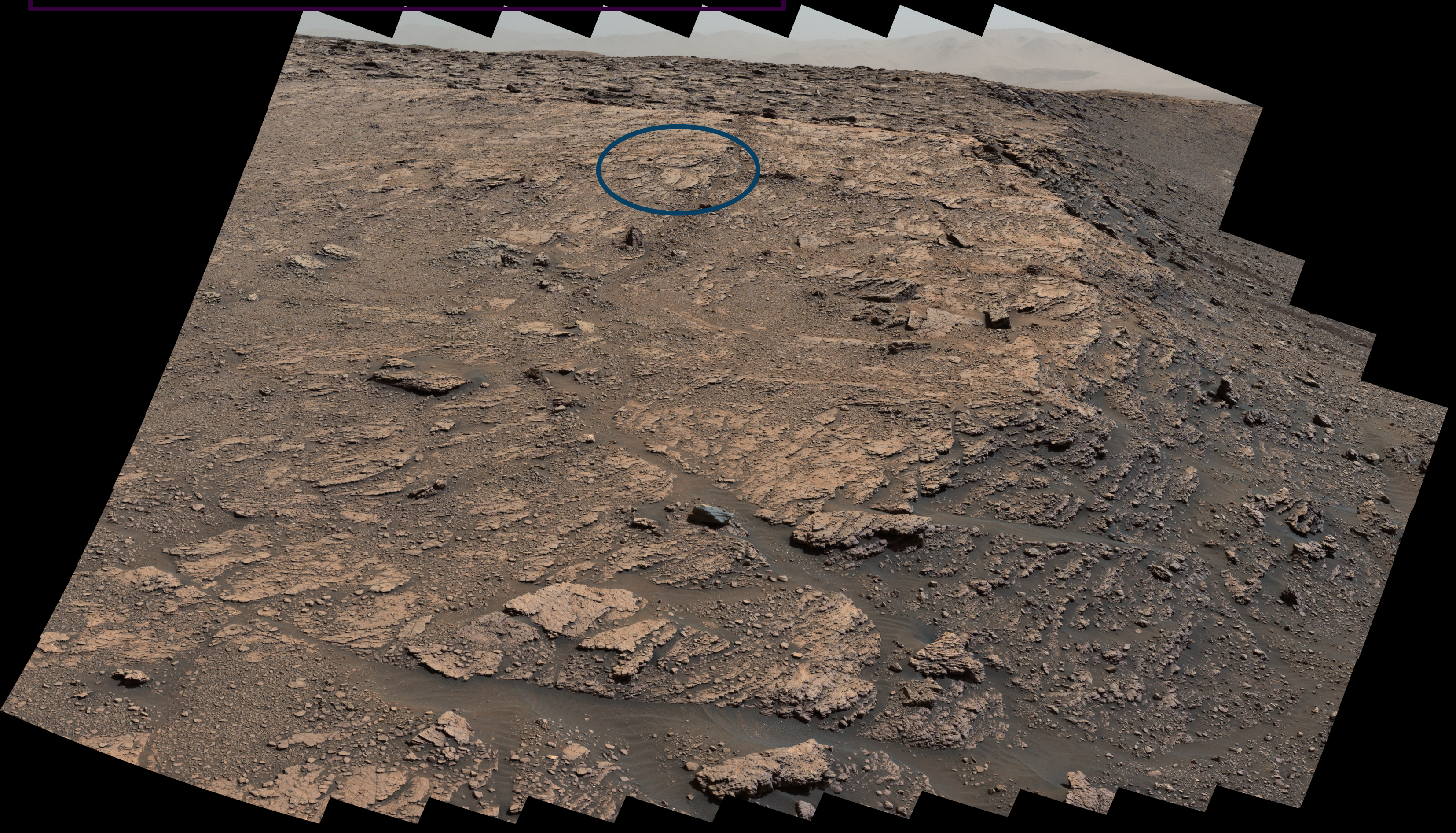
Collects ~850-1300 Mbits per planning cycle, not including engineering telemetry data

Reliant on Odyssey, MRO, TGO and MAVEN relays



Collection Process Example: Mars Rovers

Instruction relay → Data collection → Data return relay/processing → Analysis/Request formulation → Instruction relay



"Typical" Activities:

Choose 1-5 rock targets for ChemCam LIBS

Assign imaging priorities

Pick 1-2 rock targets for "contact science"

Choose next end of drive location

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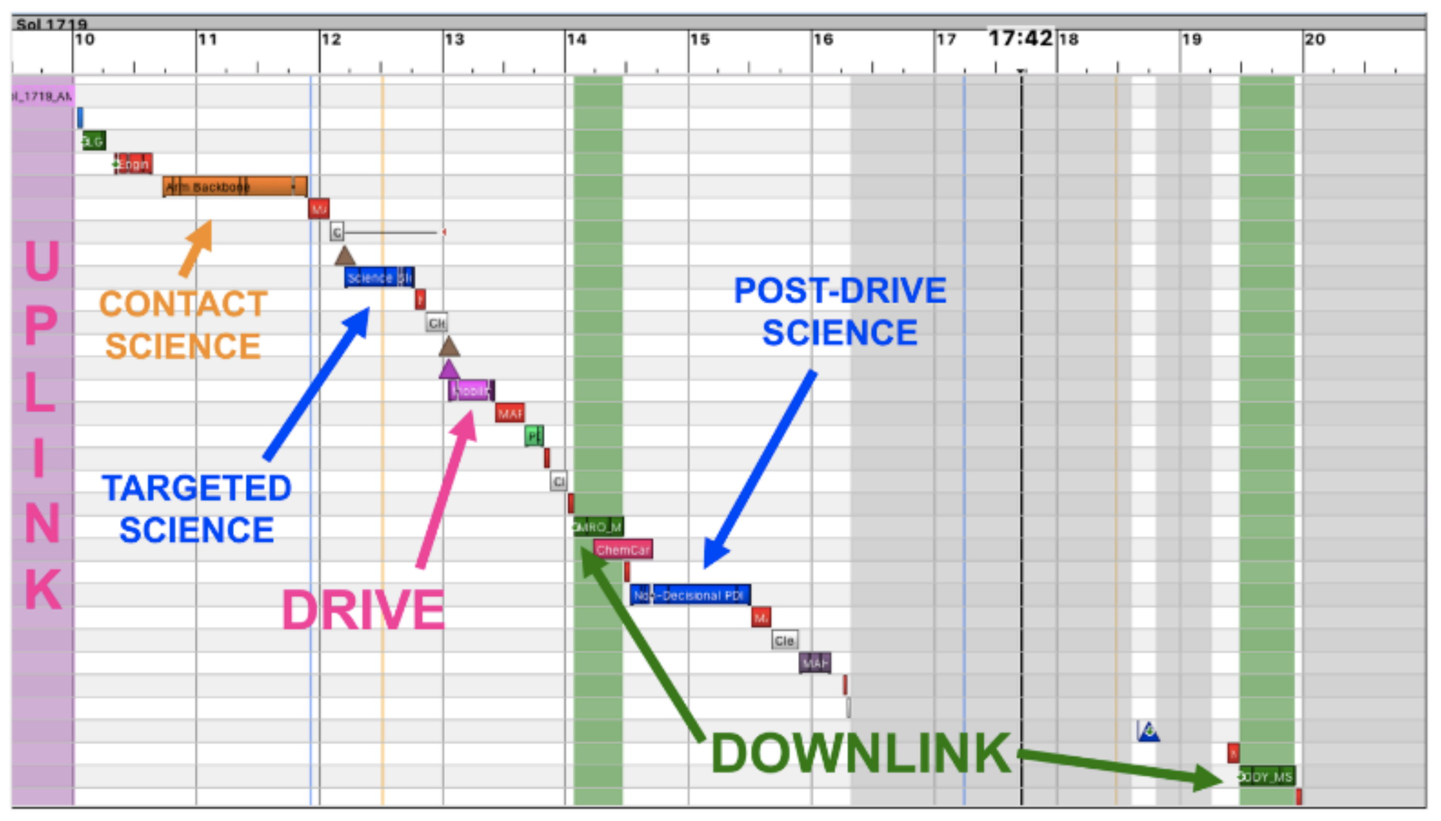

Constraints:

- Power predictions/awake time
- Handover/relay timing
- Planning complexity
- Data expected in the decisional passes
- Instrument consumables

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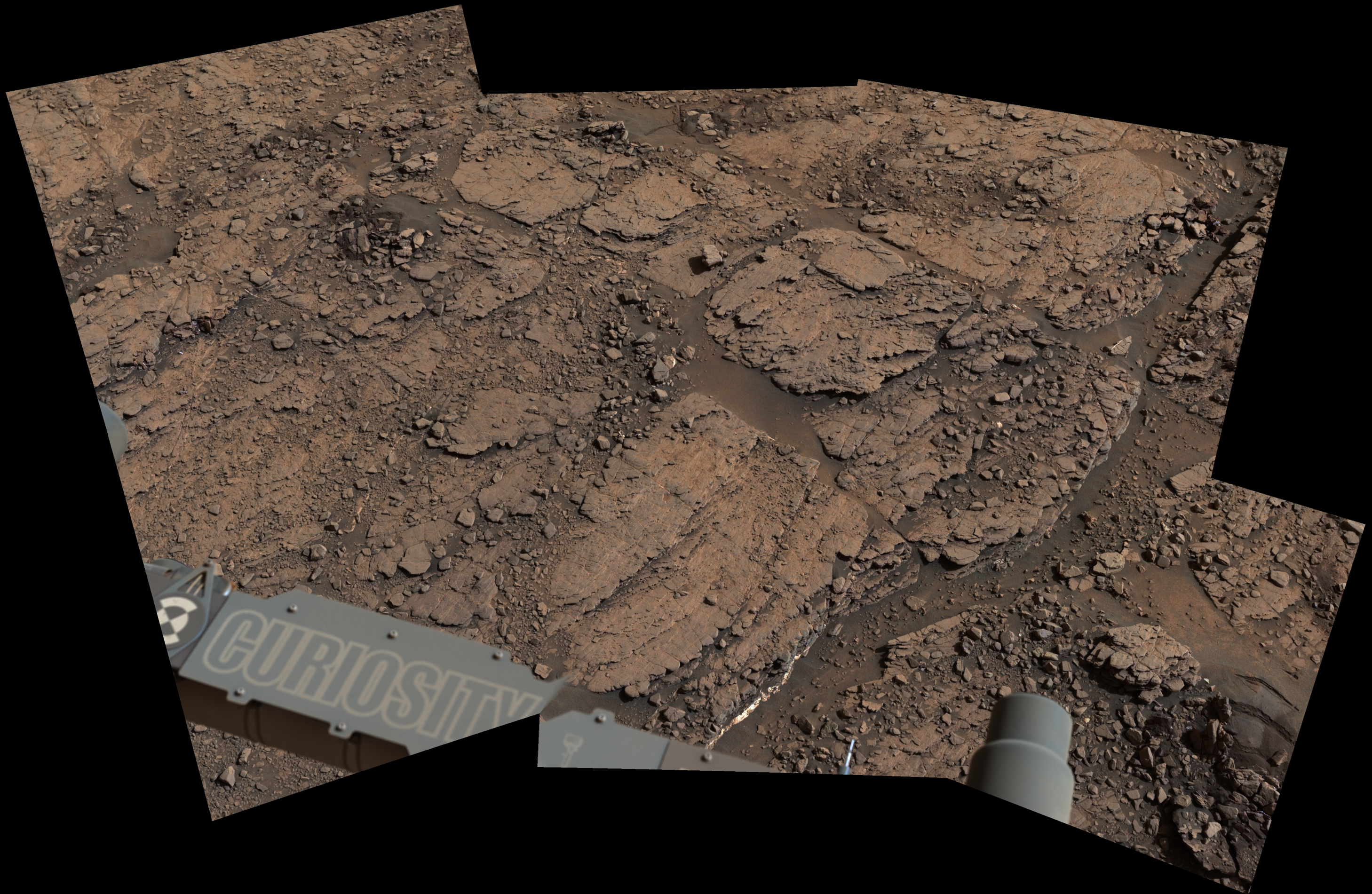

Post processing:

- Quality assessments
- Imaging calibration/mosaicking
- Target localization
- Compositional data reduction

- Today, missions are carefully designed to collect the specific data products needed to investigate carefully curated science investigations within the constraints of data storage and downlink.

  – What happens if we flip that paradigm?

Conclusions

- Every mission ever sent anywhere has revolutionized our understanding of our solar system
- Cumulative data return from most missions is on the order of gigabytes – dependent on mission lifespan and the data storage/transfer technology of the time
- Newer, higher data density instrumentation and mission goals in the future will require increased computing capabilities