Exploring the Solar System II – Spacecraft

How Do We Get There?

What Do We Do Then?

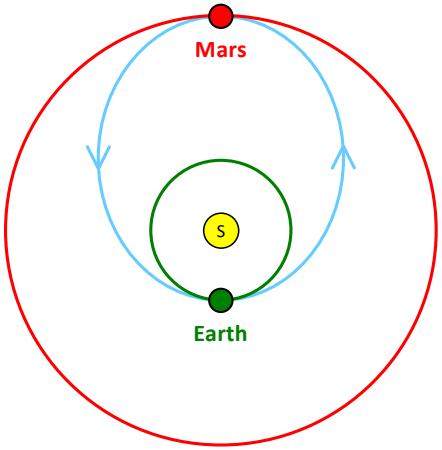
How Do We Get Images Back?

What Next?

70 Years of Spacecraft

Sputnik 1	Luna 10	Zond 7	Pioneer Venus 1	Genesis	PROCYON
Sputnik 2	Surveyor 1	Apollo 12	Pioneer Venus 2	CONTOUR	DSCOVR
Explorer 1	Explorer 33	Apollo 13	ISEE-3	Hayabusa	ExoMars
Vanguard 1	Lunar Orbiter 1	Venera 7	Venera 11	Beagle 2	OSIRIS-REx
Luna 1	Pioneer 7	Luna 16	Venera 12	Spirit rover	InSight
Pioneer 4	Luna 11	Zond 8	Venera 13	Opportunity rover	Queqiao
Luna 2	Surveyor 2	Luna 17	Venera 14	SMART-1	Parker Solar Probe
Luna 3	Luna 12	Apollo 14	Venera 15	Rosetta/Philae	BepiColombo
Pioneer 5	Lunar Orbiter 2	Salyut 1	Venera 16	MESSENGER	Chang'e 4
Venera 1	Luna 13	Mars 2	Vega 1	Deep Impact	Beresheet
Vostok 1	Lunar Orbiter 3	Mars 3	Vega 2	Mars Reconnaiss	Chandrayaan-2
Ranger 1	Surveyor 3	Mariner 9	Sakigake	Venus Express	Solar Orbiter
Ranger 2	Lunar Orbiter 4	Apollo 15	Giotto	New Horizons	Mars Hope
Ranger 3	Venera 4	Luna 18	Suisei	Hinode	Zhurong rover
Ranger 4	Mariner 5	Luna 19	Phobos 1	STEREO	Perseverance rover
Mariner 2	Surveyor 4	Luna 20	Phobos 2	Phoenix	Chang'e 5
Ranger 5	Explorer 35	Pioneer 10	Magellan	SELENE	Lucy
Mars 1	Lunar Orbiter 5	Venera 8	Galileo	Dawn	DART
Luna 4	Surveyor 5	Apollo 16	Hiten	Chang'e 1	CAPSTONE
Cosmos 21	Surveyor 6	Apollo 17	Ulysses	Chandrayaan-1	Danuri
Ranger 6	Apollo 4	Luna 21	Yohkoh	Lunar Reconnaiss	Artemis 1
Zond 1	Pioneer 8	Pioneer 11	Mars Observer	Solar Dynamics Obs	Hakuto-R 1
Ranger 7	Surveyor 7	Explorer 49	Clementine	Akatsuki	JUICE
Voskhod 1	Apollo 5	Mars 4	WIND	PICARD	Chandrayaan-3
Mariner 3	Zond 4	Mars 5	SOHO	Chang'e 2	Luna 25
Mariner 4	Luna 14	Mars 6	NEAR Shoemaker	Juno	Aditya-L1
Zond 2	Zond 5	Mars 7	Mars Global Surv	GRAIL	SLIM
Ranger 8	Apollo 7	Mariner 10	Mars 96	Fobos-Grunt	Psyche
Voskhod 2	Pioneer 9	Luna 22	Mars Pathfinder	Yinghuo-1	Peregrine One
Ranger 9	Zond 6	Luna 23	ACE	Curiosity rover	Nova-C Odysseus
Luna 5	Apollo 8	Helios-A	Cassini-Huygens	Van Allen Probes	DRO A/B
Luna 6	Venera 5	Venera 9	Lunar Prospector	IRIS	Queqiao-2
Zond 3	Venera 6	Venera 10	Nozomi	LADEE	Chang'e 6
Luna 7	Mariner 6	Viking 1	Deep Space 1	Hisaki	Hera
Venera 2	Apollo 9	Viking 2	Mars Climate Orb	Mars Orbiter	Europa Clipper
Venera 3	Mariner 7	Helios-B	Mars Polar Lander	MAVEN	
Luna 8	Apollo 10	Luna 24	Deep Space 2	Chang'e 3	
Pioneer 6	Luna 15	Voyager 2	Stardust	Chang'e 5-T1	
Luna 9	Apollo 11	Voyager 1	2001 Mars Odyssey	Hayabusa2	

From Earth To Mars



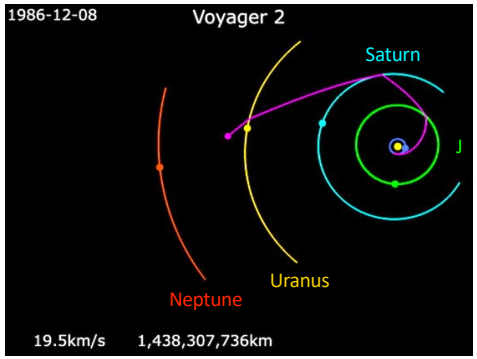
Not to scale

Gravity Assists

What about getting to other planets in the solar system?

In the 1960s it was realised that flying a spacecraft close to a planet can 'slingshot' it onwards at higher velocities.

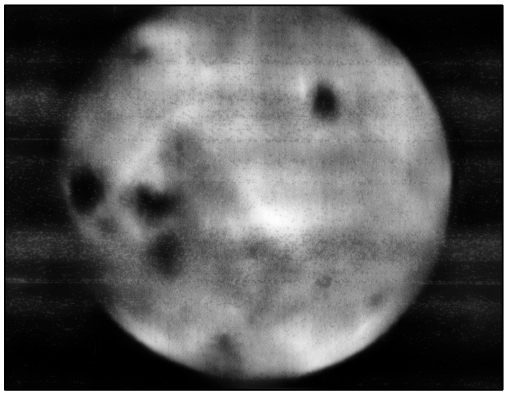
Hence exploring the outer solar system can be carried out faster and cheaper.



UNIVERSITY OF LIVERPOOL 5

Imaging Technology

Luna 3



Far side of the Moon – Oct 1959

UNIVERSITY OF LIVERPOOL 6

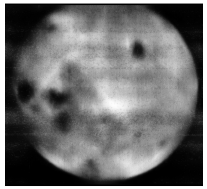
Imaging Technology

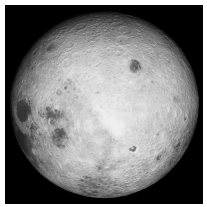
After exposure, the **film** was developed, fixed and dried.

The developed film was then **scanned** by a CRT (cathode ray tube) spot projected through the film onto a photomultiplier.

The signal from the photomultiplier was then **transmitted** to the Earth to allow an image to be constructed (like a fax machine).

For comparison, an image taken 50 years later from the NASA Lunar Reconnaissance Orbiter (LRO).

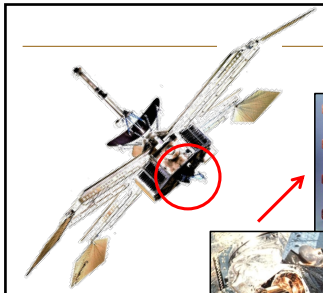




LRO 2009

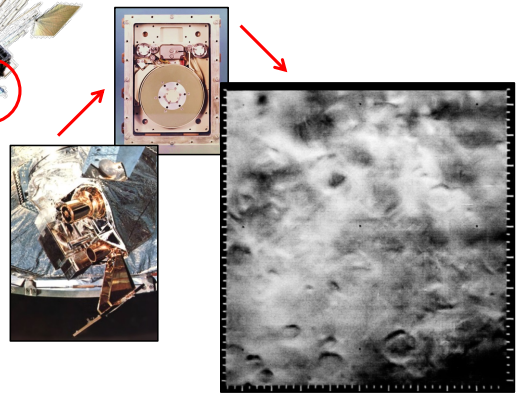
UNIVERSITY OF LIVERPOOL 7

Imaging Technology



Mariner 4

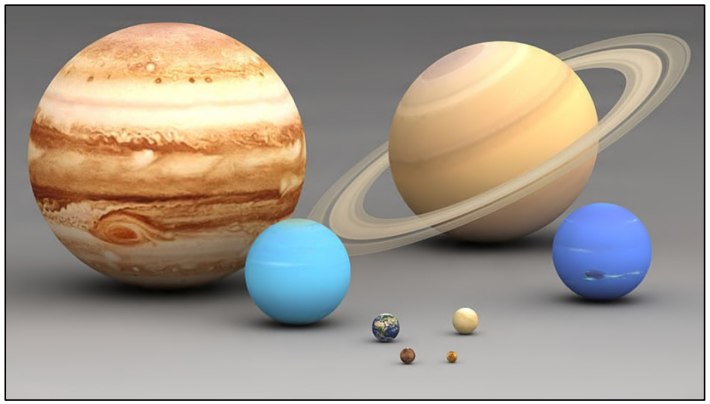
World's first **digital** camera



Mars – July 1965

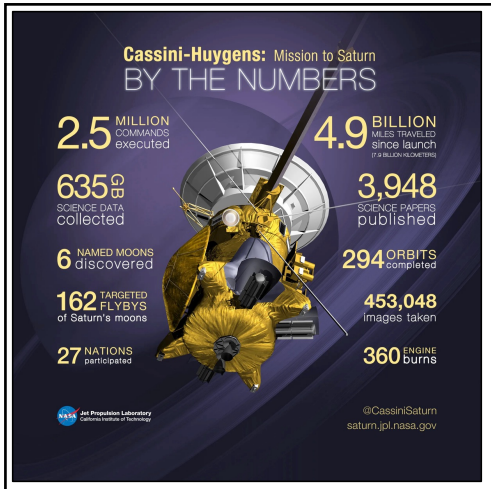
UNIVERSITY OF LIVERPOOL 8

Planets of the Solar System

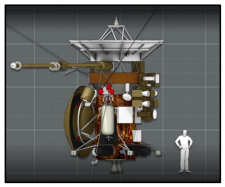


UNIVERSITY OF LIVERPOOL 9

Cassini

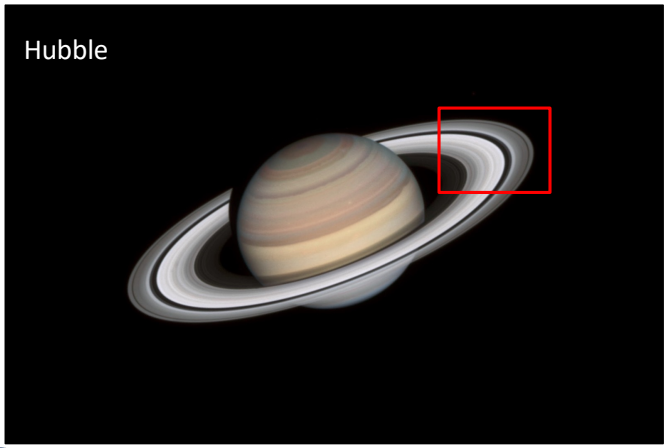


Cassini explored Saturn and its rings and moons from 2004 until it was crashed into Saturn in 2017.



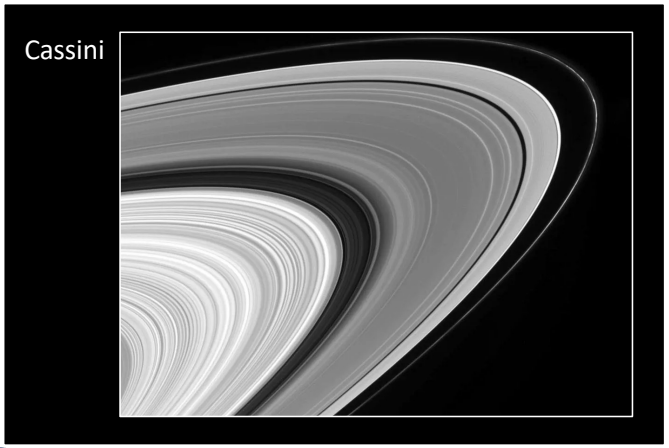
UNIVERSITY OF LIVERPOOL 10

Saturn

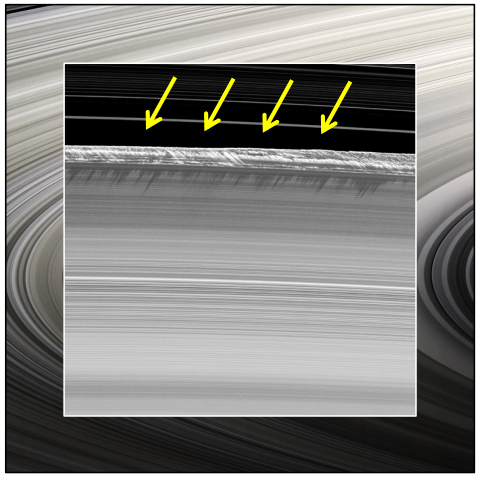


UNIVERSITY OF LIVERPOOL 11

Saturn's Rings



UNIVERSITY OF LIVERPOOL 12



Saturn's Rings

The ring system is very flat: more than 250,000 km in diameter, but only a few metres thick.

When the Sun was in the plane of the rings, some ring particles cast long shadows.

The 'bumps' are ~ km in height.

UNIVERSITY OF LIVERPOOL

13

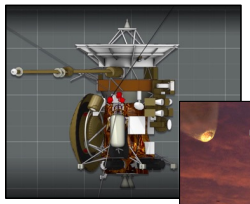
Saturn

Cassini took this image as it flew into Saturn's shadow – a view not possible from telescopes on Earth.

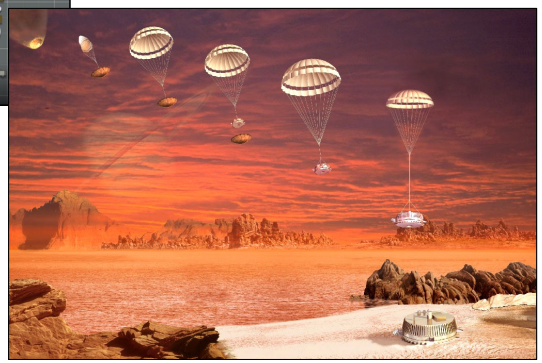
UNIVERSITY OF LIVERPOOL

14

Cassini–Huygens



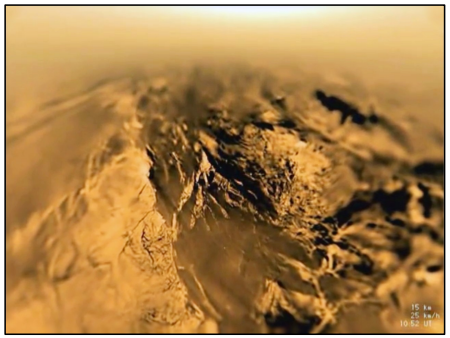
Huygens hitched a ride on Cassini and was released in 2005 to land on the moon Titan.



UNIVERSITY OF LIVERPOOL

15

Cassini–Huygens

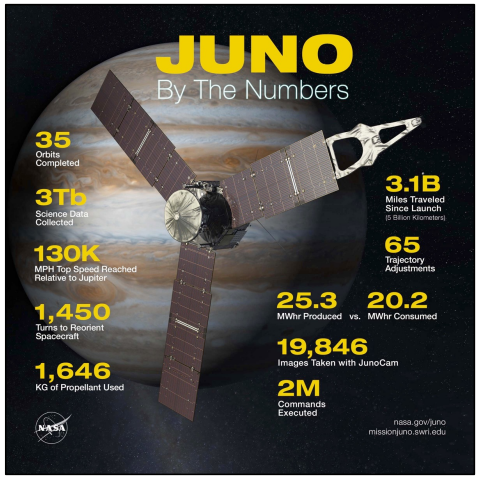


As the Huygens lander plunged through Titan's hazy atmosphere, it took images of a landscape of mountains and lakes.

UNIVERSITY OF LIVERPOOL

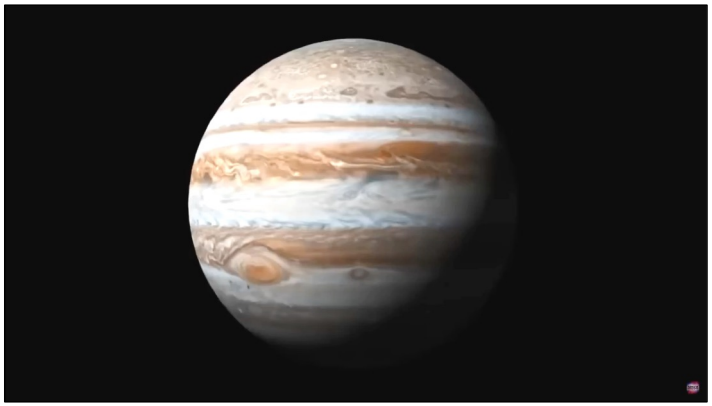
16

Juno



Juno arrived at Jupiter in 2016 after a five-year journey.

Unwrapping Jupiter



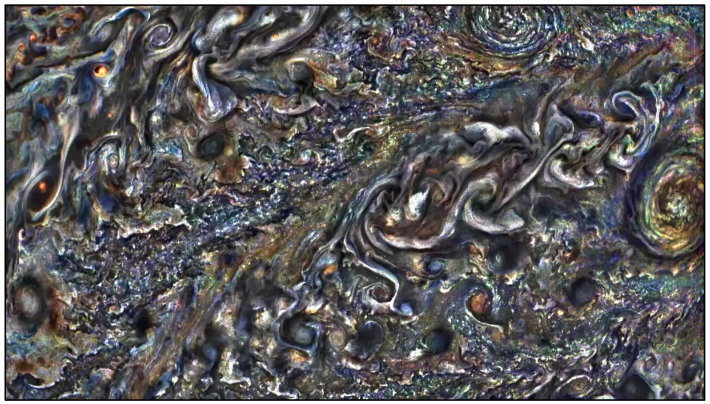
South Pole of Jupiter

Storms On Jupiter

Juno images of Jupiter's storm systems can look like watercolour paintings left out in the rain.

The dark spot is a deep vortex of swirling clouds, imaged when Juno passed only 15,000 km above the cloud tops.

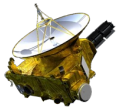
Storms On Jupiter



UNIVERSITY OF LIVERPOOL 21

Solar System

The Solar System is not just the Sun and 8 planets

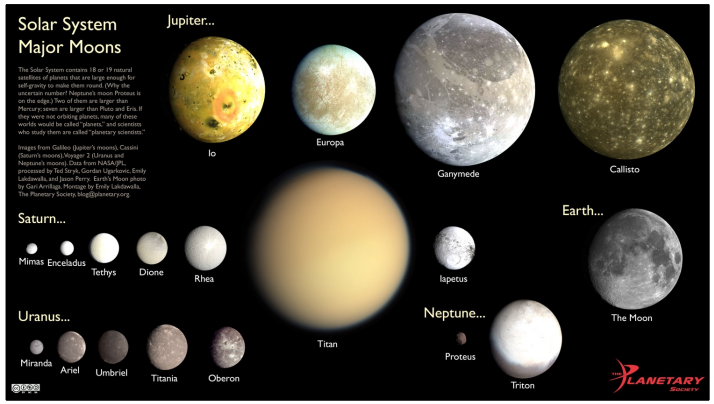


New Horizons is exploring beyond Pluto

There are also over 300 moons!

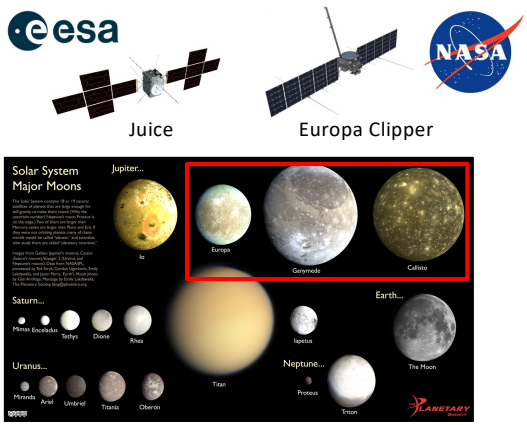
UNIVERSITY OF LIVERPOOL 22

300+ Moons



UNIVERSITY OF LIVERPOOL 23

Future Missions

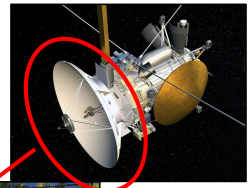


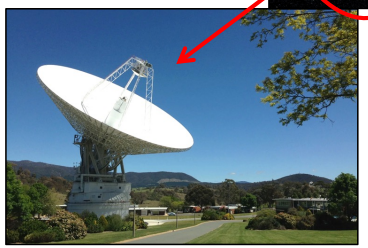
UNIVERSITY OF LIVERPOOL 24

Future Communications

Data is sent back to Earth by radio using a big dish on the spacecraft ...

... and an even bigger radio dish on Earth.



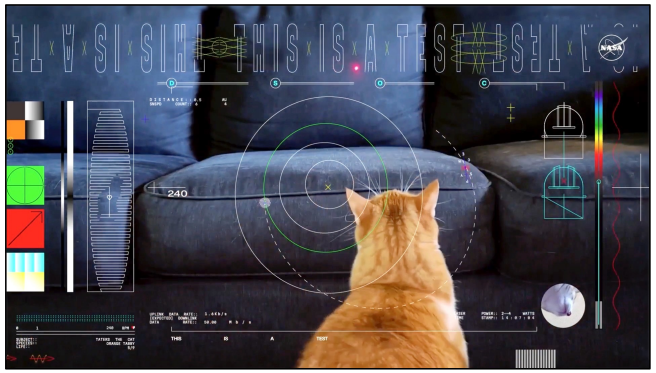


Lasers would provide faster transmission and need less power.

UNIVERSITY OF LIVERPOOL

25

Future Communications



Laser data rates: 260 Mb/s at a distance of 50 million km
8 Mb/s at a distance of 400 million km

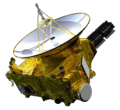
UNIVERSITY OF LIVERPOOL

26

Want To Know More?

ESA.int/Science_Exploration/Space_Science/BepiColombo

science.NASA.gov/mission/cassini



science.NASA.gov/mission/new-horizons

science.NASA.gov/mission/juno

ESA.int/Science_Exploration/Space_Science/Juice

science.NASA.gov/mission/europa-clipper

UNIVERSITY OF LIVERPOOL

27