Jet Propulsion Laboratory
California Institute of Technology

The Challenges of Exploring Watery and Icy Worlds in our Solar System

Conference on Autonomy

Cross-fertilization for improving efficiency
Sola Strand Hotel, Stavanger
16 - 17 March 2016

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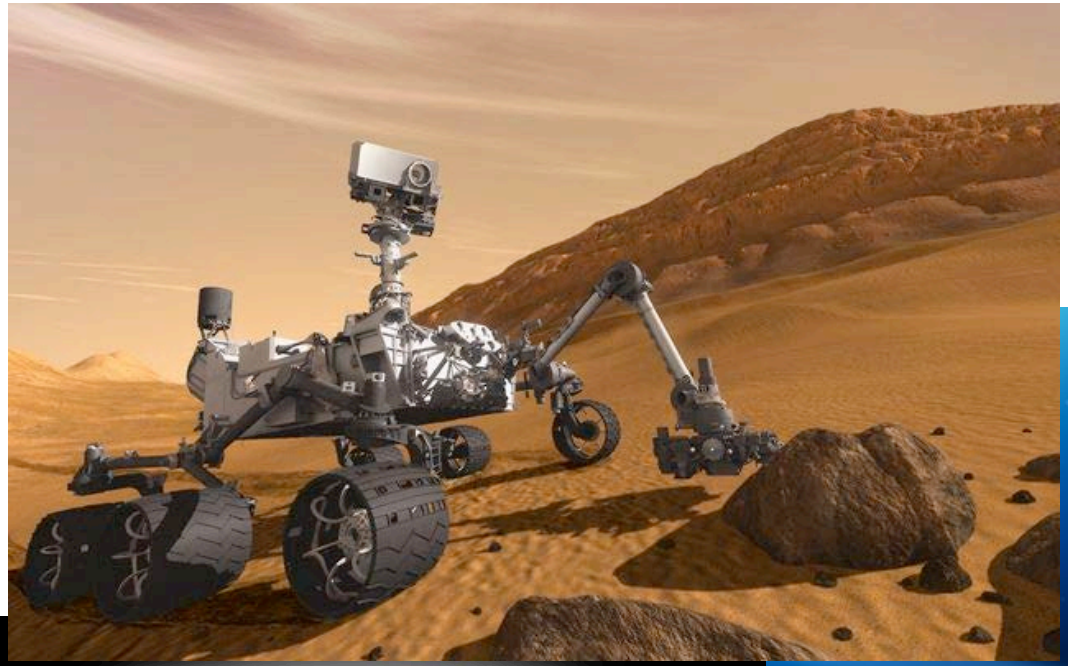
Performing Unmanned Exploration of Space
…including Earth



JPL History

- 1936: JPL started by Professor Theodore von Kármán at Caltech to explore rocket propulsion.
  - First rocket launch in Oct 1936

•1942: von Kármán, Malina and Parson's founded Aerojet Engineering Corp.

- Developed Jet Assisted Take Off (JATO) and Rocket technology during WWII

•Nov 1943: Initial proposal prepared for JPL designed, Army Ballistic Missile Agency & Sperry/Utah built first US ballistic missiles: Corporal and Sergeant.

•Jan 1958: JPL's Explorer 1, first US satellite launched.

-Russian Sputnik launched Oct 4, 1957

-Beginning of transition of JPL from missile to spacecraft emphasis

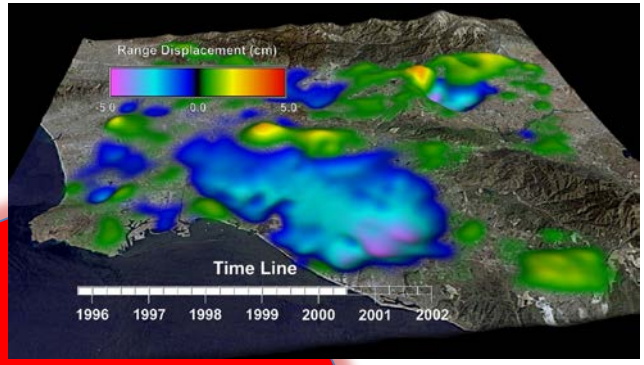
•July 1958: NASA formed with JPL as a field center

JPL's Functional Activity

JPL Mission Operations Center

Design, Build and Operate Observing Systems

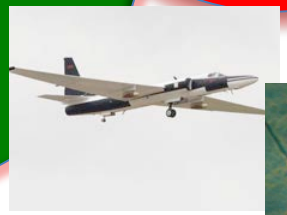
LA Basin Surface Elevation Change

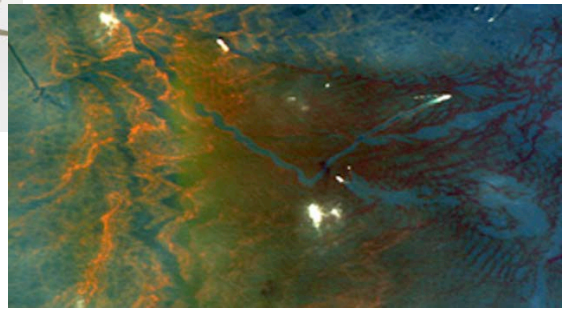


Perform Space Science ...including Earth

JPL Team X Mission Design

Develop Supporting Technology





AVIRIS Instrument Imaging of Macondo spill (17 May 2010)

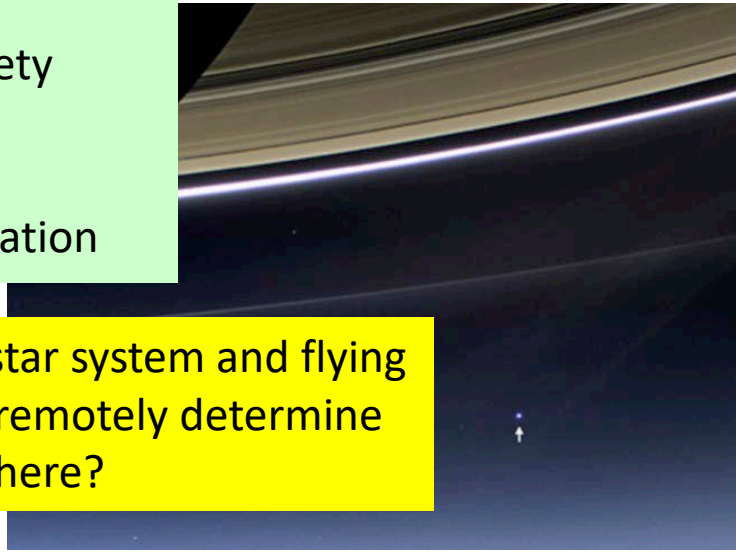
Rio Tinto-Salt Lake City

What are some of the terrestrial (Earth) analog issues we deal with in space…

(Image courtesy OceanflORE)

- Harsh and Difficult Environments
  - Temperature
  - Pressure
  - Remote locations
  - Communications
  - Hazardous to humans
  - Gravity
- Large data and cyber resilience
- Health, Environment and Safety (HES)
- Natural Resource Characterization

Statoil-Valemon

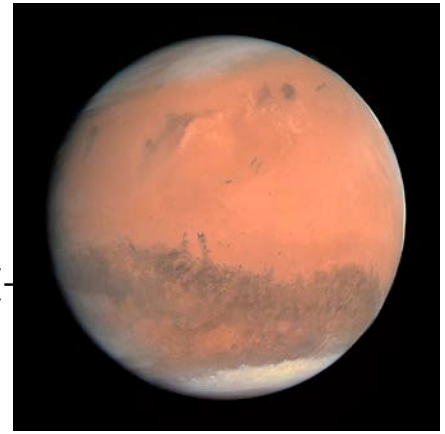


If you were from a distant star system and flying by earth, how would you remotely determine life existed here?

Some of our challenging operating environments of current interest include locations such as…

Venus

- Surface temp=460 °C (860°F)
- Sulfuric acid atmosphere



Mars

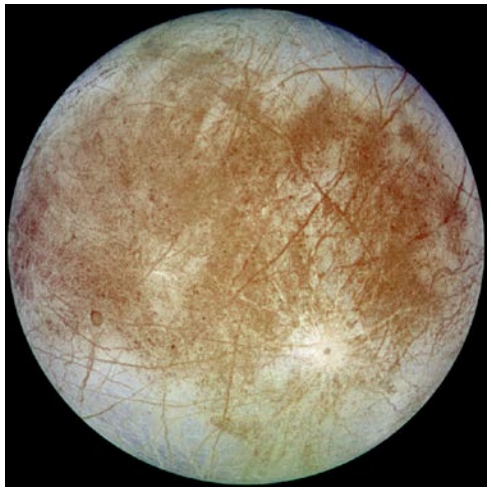
Surface Temperatures=-125°C (-195°F) to 20°C (70°F)

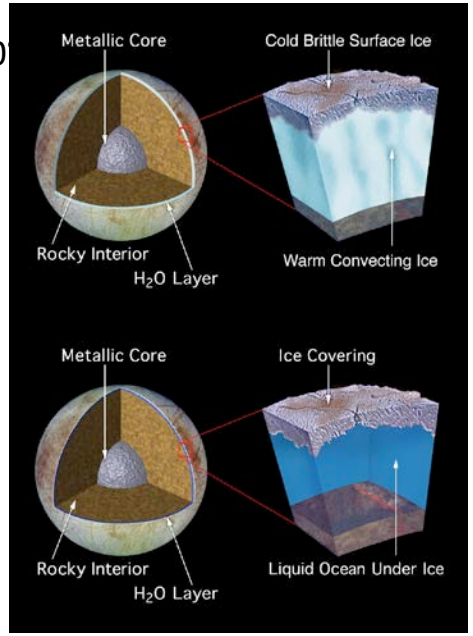
Interstellar Space

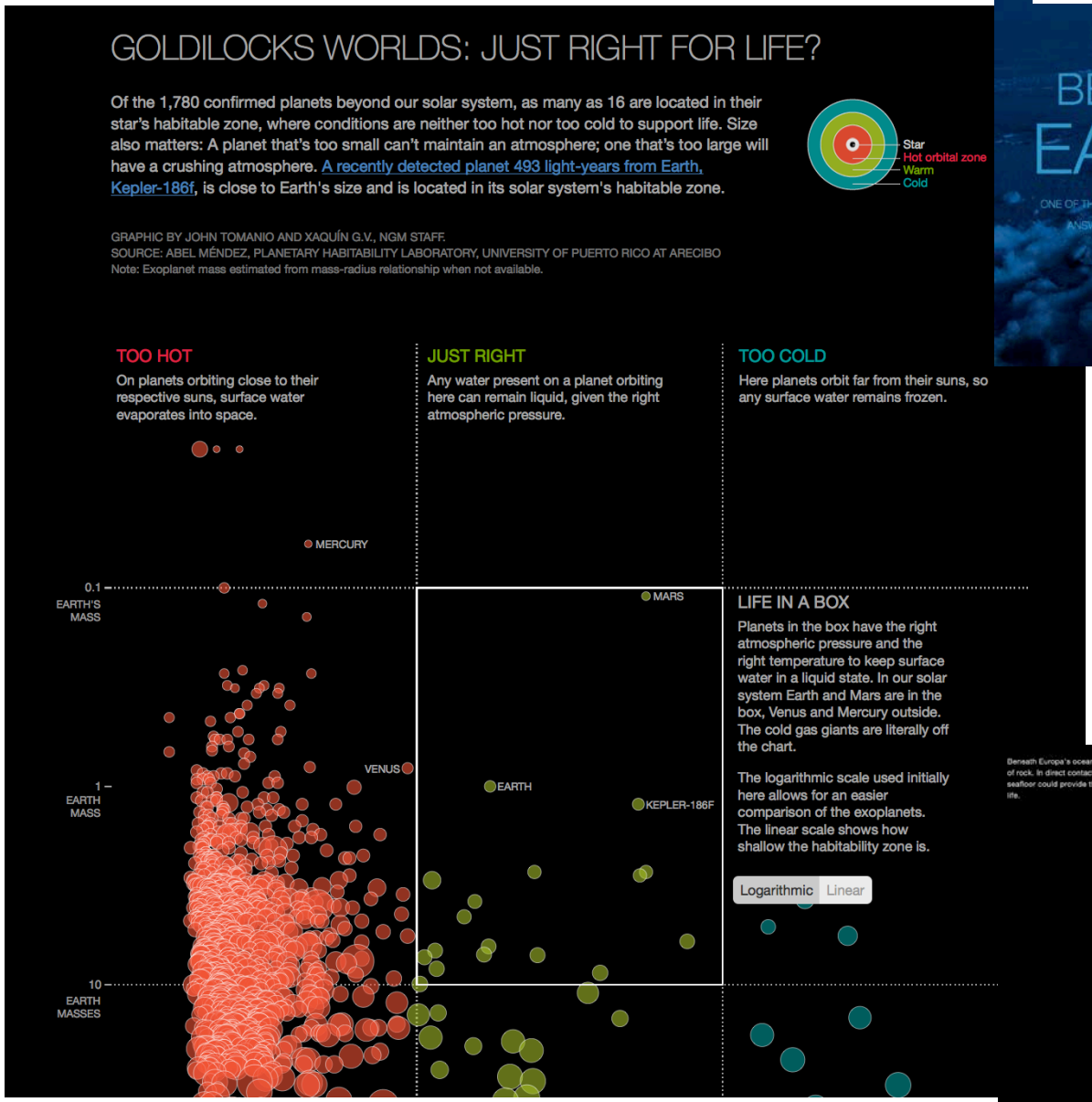
- Temperature =3°K
- Vacuum=10^{-17} Torr

Europa (a moon of Jupiter)

Surface Temperatures=-220°C (-370 to -160°C (-260°F)







The Search for Life is about finding liquid water…

Jupiter's Moon Europa is a Principal Candidate

From: National Geographic, July 2014, Life Beyond Earth

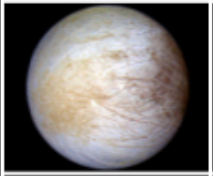
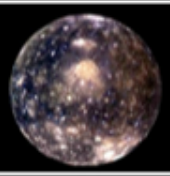
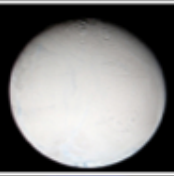
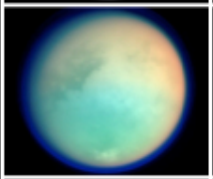
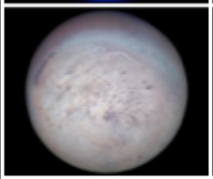
Ocean Worlds

Ocean Worlds Exploration Program

- Science
  - Ocean worlds are possibly the best place to search for extant (living) life and a second, independent origin.
  - We are on the brink of revolutionizing biology.
  - Comparative oceanography (Earth, Europa, Enceladus, Titan) will spark new discoveries and insights regardless of habitability.
- Technology
  - Convergence of launch vehicle, propulsion, landing, and instrumentation needs.
  - Diversity of mission options: some low-cost missions (Titan lake landers, Enceladus plume fly-through) and some larger mission (Europa melt-probes).
  - Win-win of exploring Earth as a bridge to exploring ocean moons.

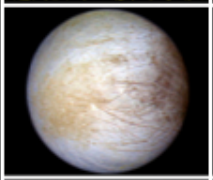
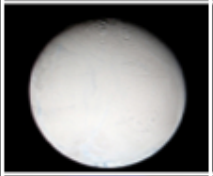
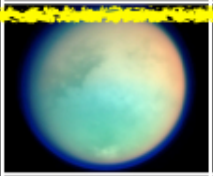
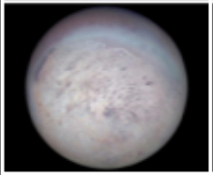
From Dr Kevin Hand, JPL

Ocean Worlds

Moon	Name, Planet	Geophysically & Geochemically Plausible?	Significant tidal energy to help maintain ocean?	Induced Magnetic Field?	Activity Observed?	Ocean in contact with rock?
	Europa, Jupiter	Yes	Yes	Yes	No	Yes
	Ganymede, Jupiter	Yes	~Yes	Yes	No	No
	Callisto, Jupiter	Yes	No	Yes	No	No
	Enceladus, Saturn	???	???	???	Yes!	Yes?
	Titan, Saturn	Yes	No	???	???	No
	Triton, Neptune	Yes?	No	???	Yes	No

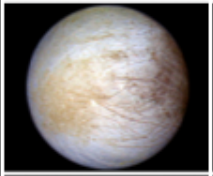
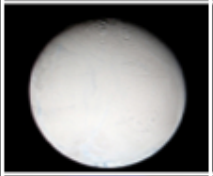
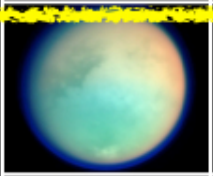
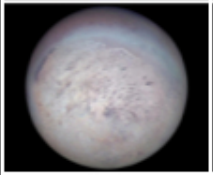
From Dr Kevin Hand, JPL

Ocean Worlds

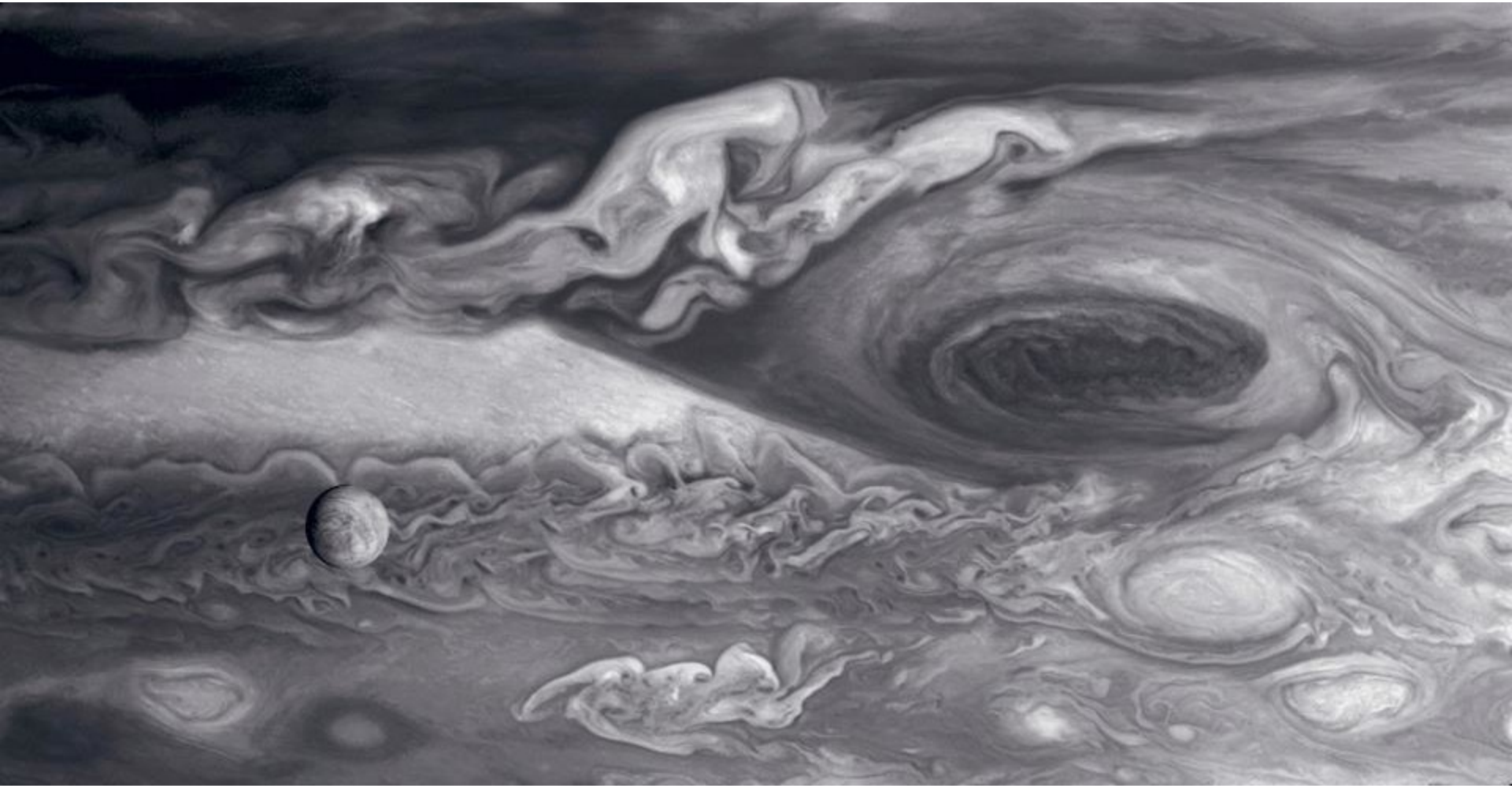
Moon	Name, Planet	Geophysically & Geochemically Plausible?	Significant tidal energy to help maintain ocean?	Induced Magnetic Field?	Activity Observed?	Ocean in contact with rock?
	Europa, Jupiter	Yes	Yes	Yes	No	Yes
	Ganymede, Jupiter	Yes	~Yes	Yes	No	No
	Callisto, Jupiter	Yes	No	Yes	No	No
	Enceladus, Saturn	???	???	???	Yes!	Yes?
	Titan, Saturn	Yes	No	???	???	No
	Triton, Neptune	Yes?	No	???	Yes	No

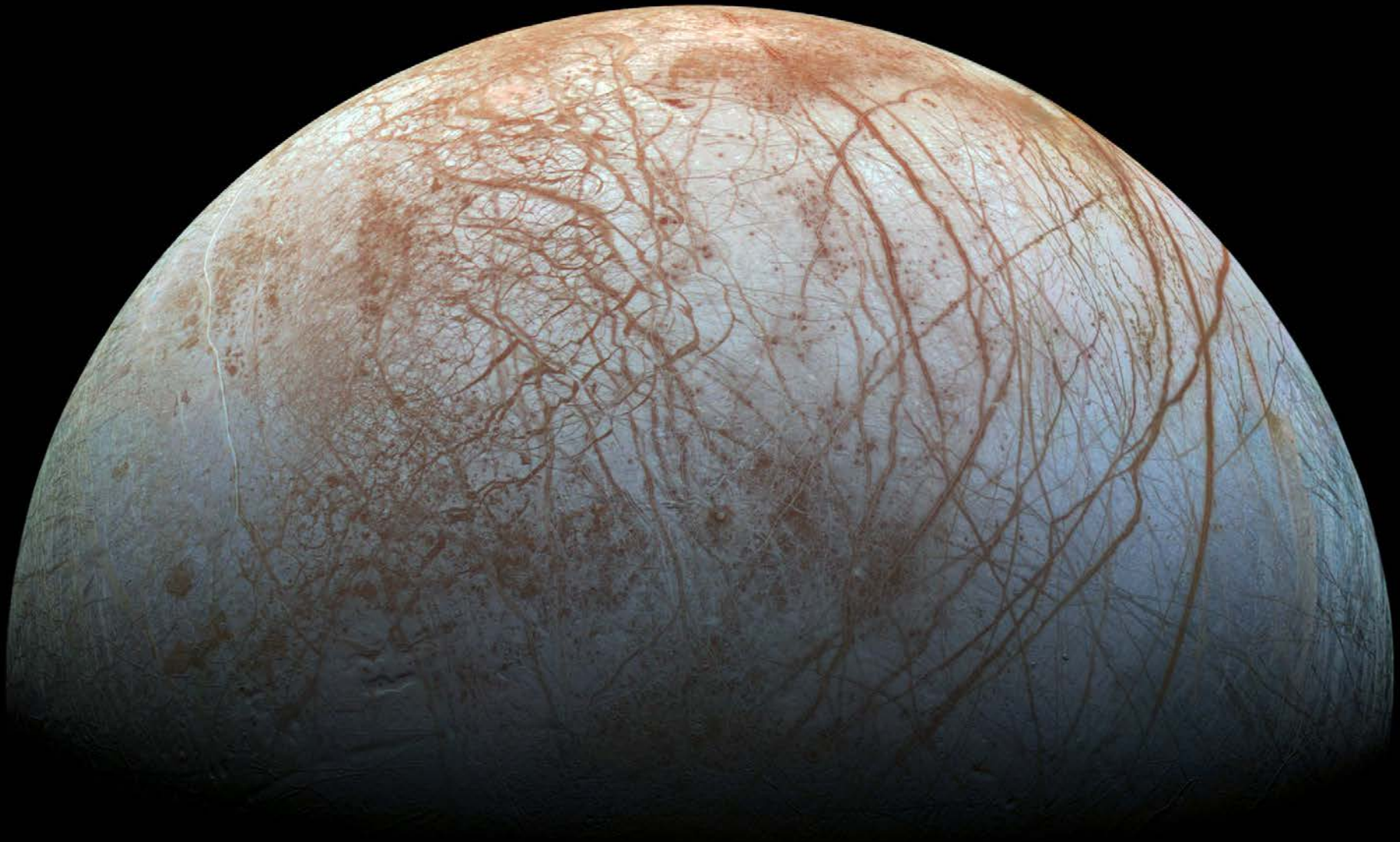
From Dr Kevin Hand, JPL

Ocean Worlds

Moon	Name, Planet	Geophysically & Geochemically Plausible?	Significant tidal energy to help maintain ocean?	Induced Magnetic Field?	Activity Observed?	Ocean in contact with rock?
	Europa, Jupiter	Time: Persistently Habitable? Yes.		Yes	No	Yes
	Ganymede, Jupiter	Yes	~Yes	Yes	No	No
	Callisto, Jupiter	Yes	No	Yes	No	No
	Enceladu Saturn	Time: Persistently Habitable? TBD		??	Yes!	Yes?
	Titan, Saturn	Yes	No	???	???	No
	Triton, Neptune	Yes?	No	???	Yes	No

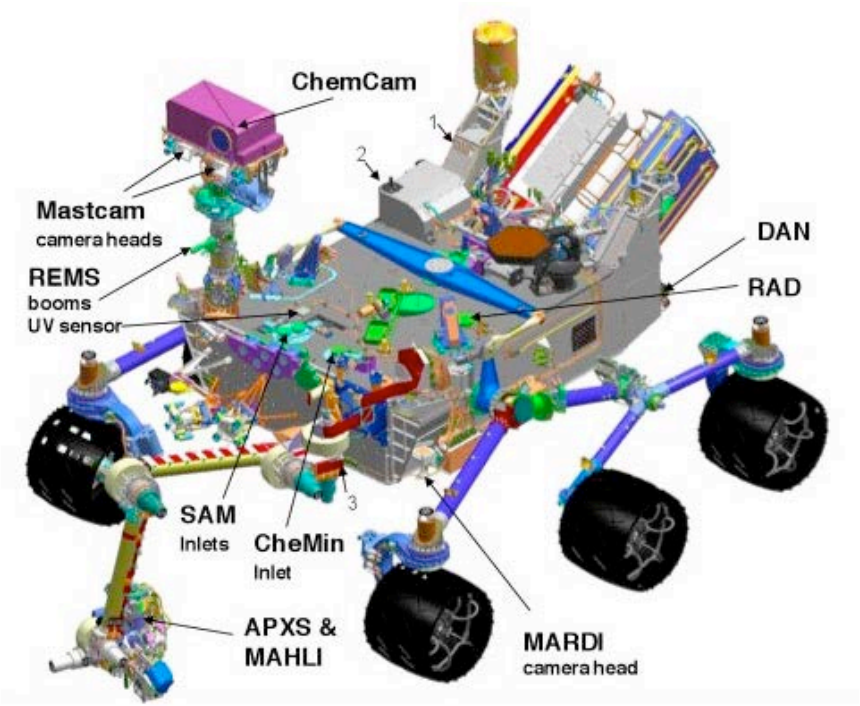
From Dr Kevin Hand, JPL





Back-up slides

The MSL science instruments are state-of-the-art tools for acquiring information about the geology, atmosphere, environmental conditions, and potential bio-signatures on Mars.



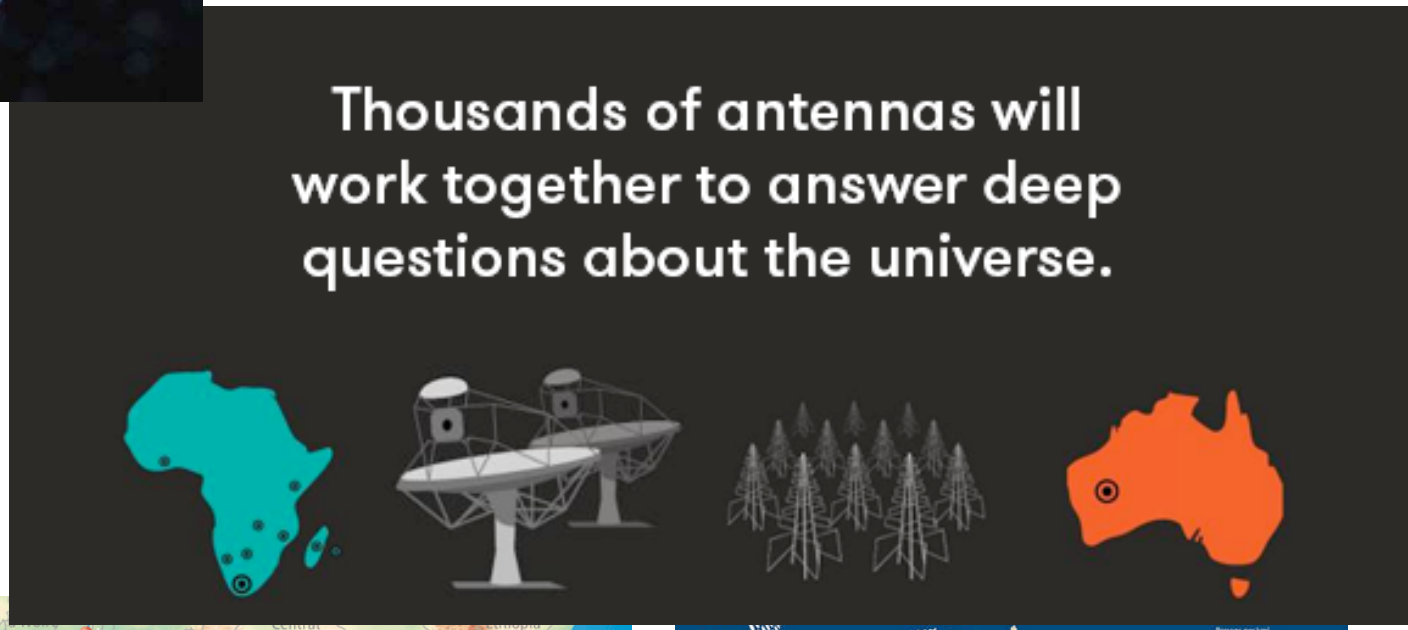
- Cameras
  - Mast Camera (Mastcam)
  - Mars Hand Lens Imager (MAHLI)
  - Mars Descent Imager (MARDI)
- Spectrometers
  - Alpha Particle X-Ray Spectrometer (APXS)
  - Chemistry & Camera (ChemCam)
  - Chemistry & Mineralogy X-Ray Diffraction/X-Ray Fluorescence Instrument (CheMin)
  - Sample Analysis at Mars (SAM) Instrument Suite
- Radiation Detectors
  - Radiation Assessment Detector (RAD)
  - Dynamic Albedo of Neutrons (DAN)
- Environmental Sensors
  - Rover Environmental Monitoring Station (REMS)
- Atmospheric Sensors
  - Mars Science Laboratory Entry Descent and Landing Instrument (MEDLI)

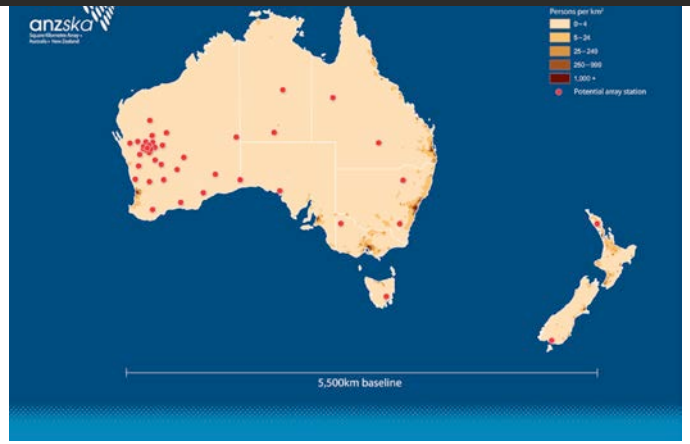
Daily data generation when on-line in 2020 will:

-be more than the entire internet content

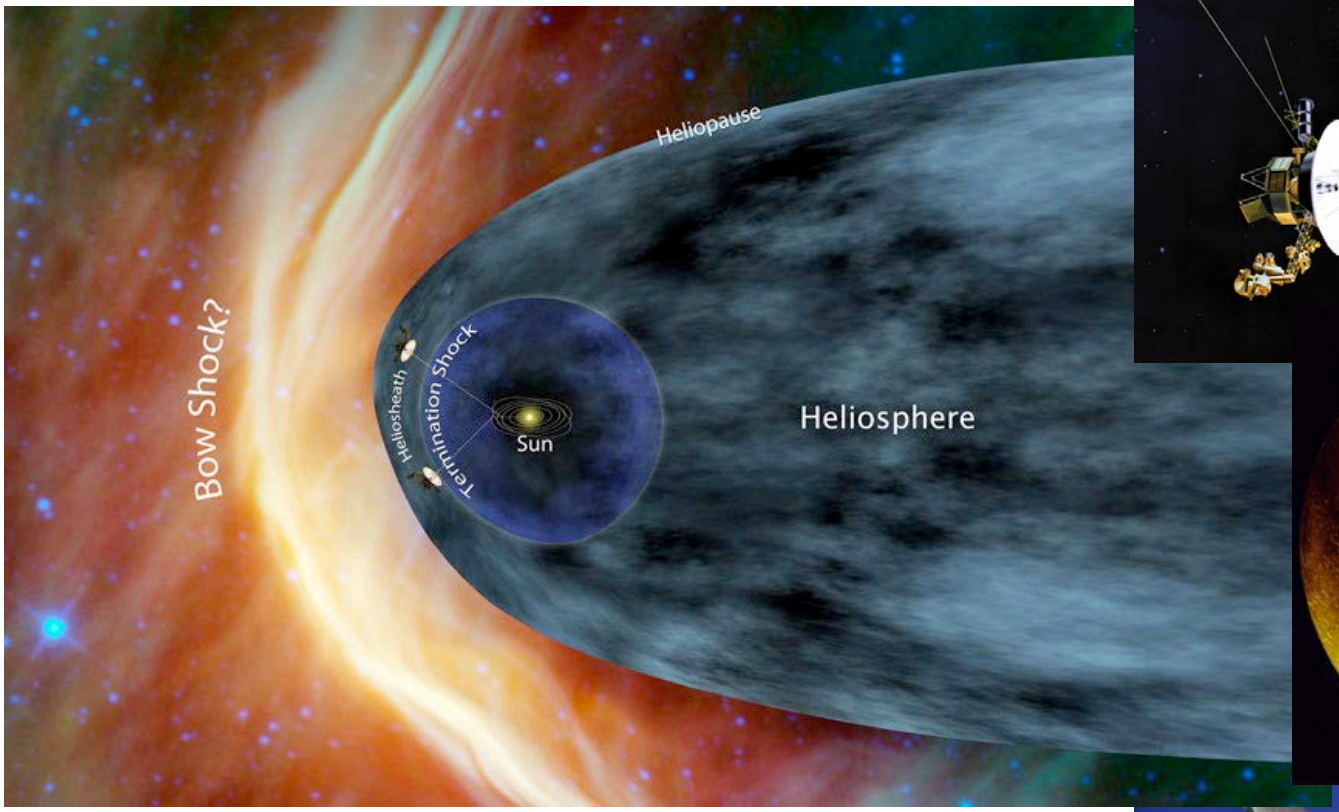
-take 2 million years to play back on an I-Pod

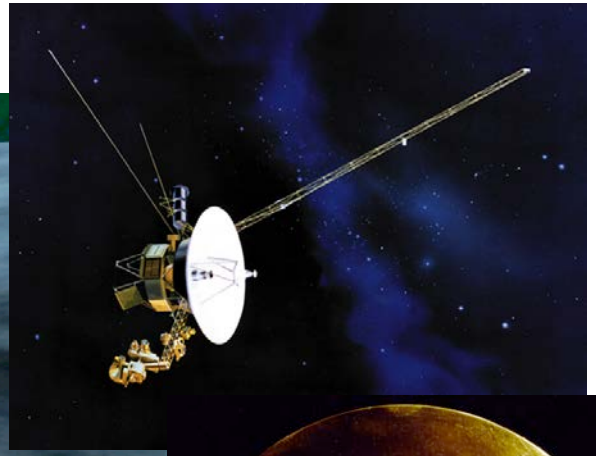
70 Meter antenna of the Deep Space Network inside the Rose Bowl for scale

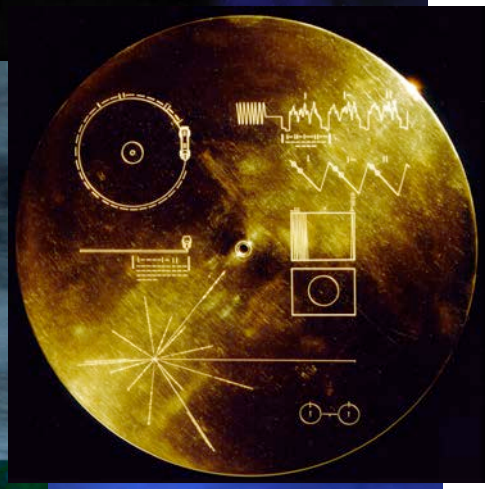




Communications under extremely challenging conditions continue…



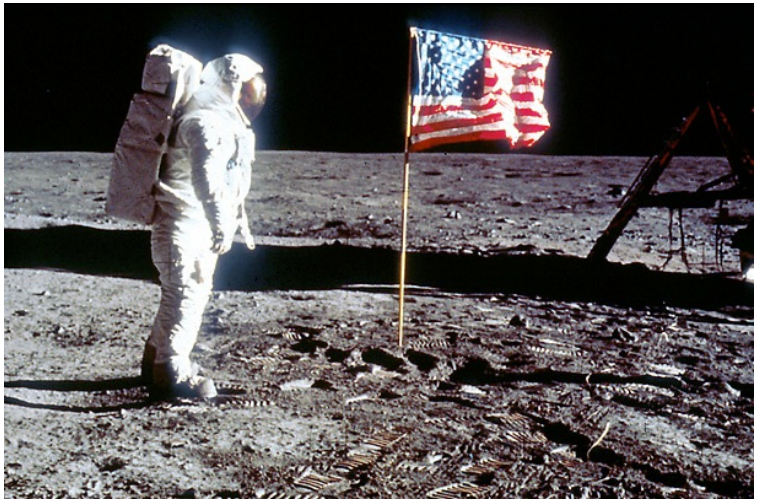


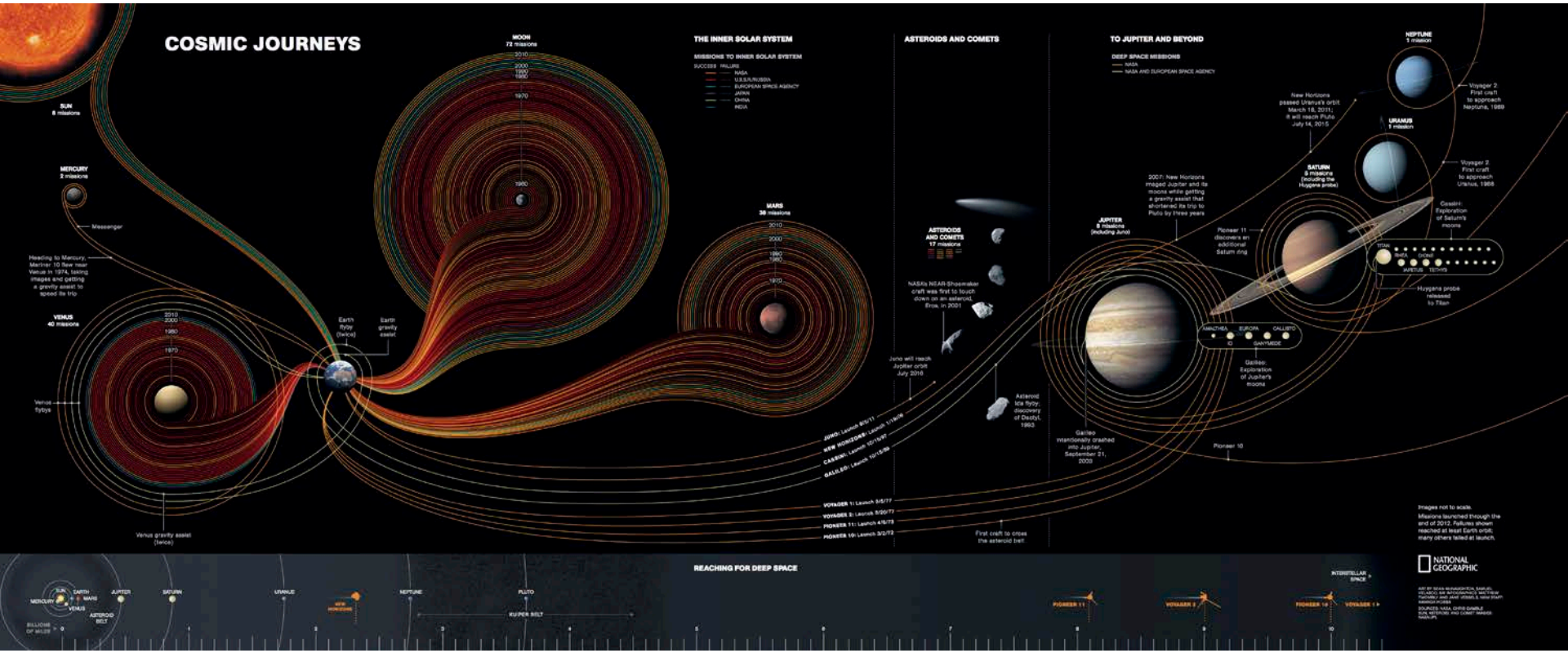
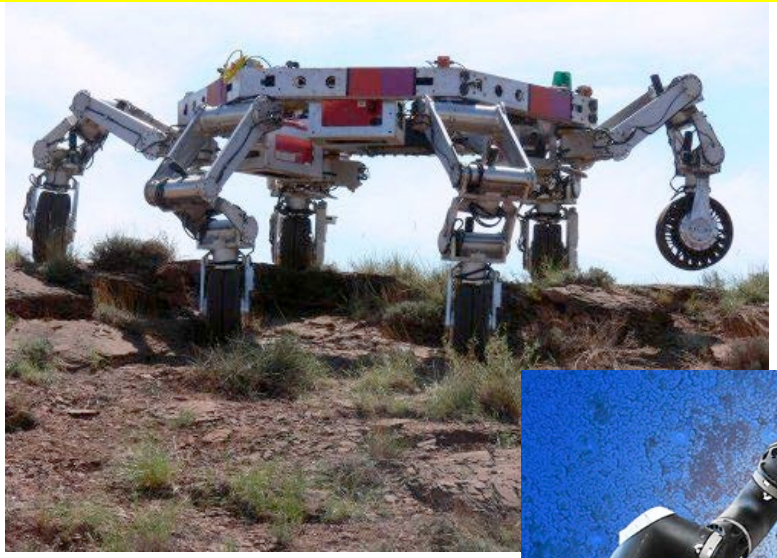
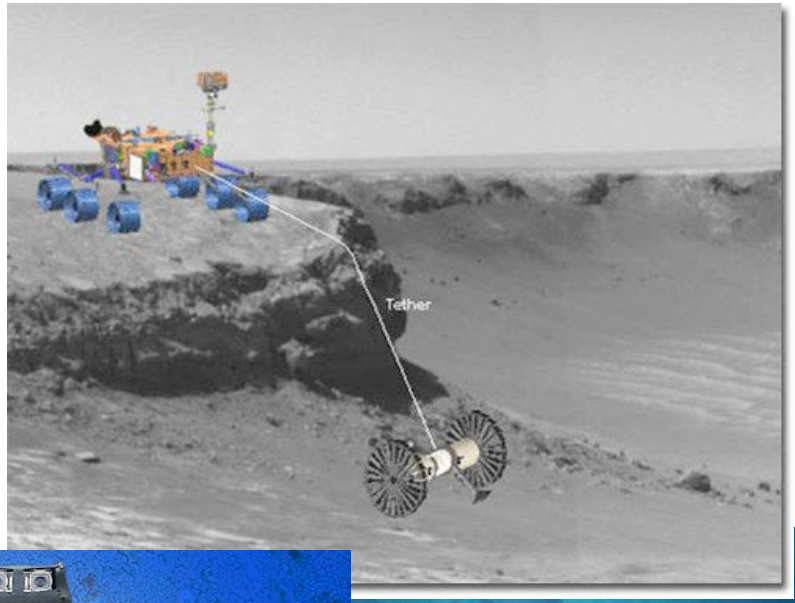
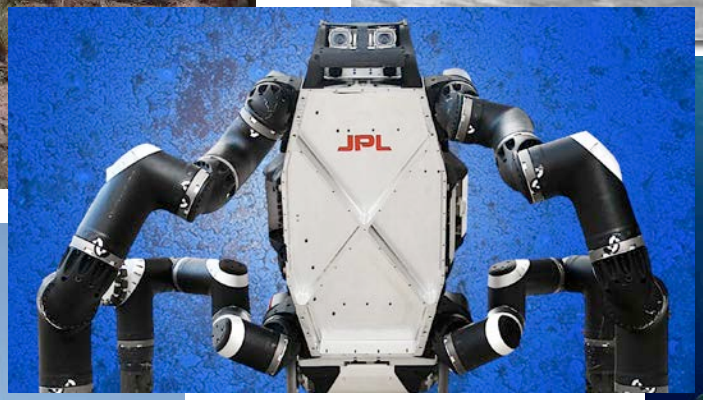
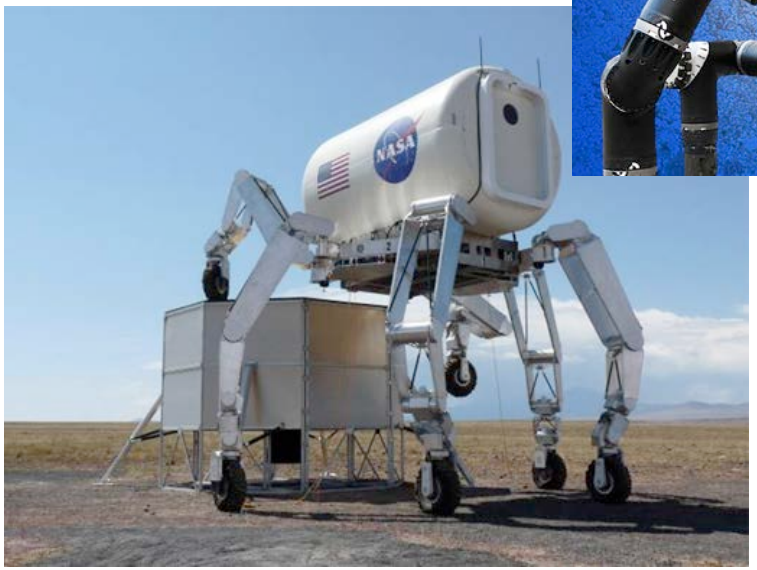


Voyager 1 Spacecraft

- Launched in 1977
- 19.8×10^9 km (12.3×10^9 miles) [1] from Earth
- 36 hr 44 min[1] round trip at the speed of light
- 23 Watt RF transmission

[1](as of 10 Sept 2015)




COSMIC JOURNEYS
SUN
8 missions
MERCURY
2 missions
Messenger
Heading to Mercury, Mariner 10 flew near Venus in 1974, taking images and getting a gravity assist to speed its trip
VENUS
40 missions
2010
2000
1990
1980
1970
Venus flybys
Venus gravity assist (twice)
Earth flyby (twice)
Earth gravity assist
MOON
72 missions
2010
2000
1990
1980
1970
1960
MARS
38 missions
2010
2000
1990
1980
1970
THE INNER SOLAR SYSTEM
MISSIONS TO INNER SOLAR SYSTEM
SUCCESS FAILURE
NASA
U.S.S.R./RUSSIA
EUROPEAN SPACE AGENCY
JAPAN
CHINA
INDIA
ASTEROIDS AND COMETS
ASTEROIDS AND COMETS
17 missions
NASA's NEAR-Shoemaker craft was first to touch down on an asteroid, Eros, in 2001
Juno will reach Jupiter orbit July 2016
Asteroid Ida flyby; discovery of Dactyl, 1993
First craft to cross the asteroid belt
JUNO: Launch 8/5/11
NEW HORIZONS: Launch 1/19/06
CASSINI: Launch 10/15/97
GALILEO: Launch 10/18/89
VOYAGER 1: Launch 9/5/77
VOYAGER 2: Launch 8/20/77
PIONEER 11: Launch 4/6/73
PIONEER 10: Launch 3/2/72
TO JUPITER AND BEYOND
DEEP SPACE MISSIONS
NASA
NASA AND EUROPEAN SPACE AGENCY
JUPITER
8 missions
(including Juno)
2007: New Horizons imaged Jupiter and its moons while getting a gravity assist that shortened its trip to Pluto by three years
Pioneer 11 discovers an additional Saturn ring
Galileo intentionally crashed into Jupiter, September 21, 2003
Pioneer 10
AMALTHEA
EUROPA
CALLISTO
IO
GANYMEDE
Galileo: Exploration of Jupiter's moons
SATURN
9 missions
(including the Huygens probe)
TITAN
RHEA
DIONE
ENCELADUS
TETHYS
Huygens probe released to Titan
Cassini: Exploration of Saturn's moons
Voyager 2 First craft to approach Uranus, 1986
URANUS
1 mission
New Horizons passed Uranus's orbit March 18, 2011; it will reach Pluto July 14, 2015
NEPTUNE
1 mission
Voyager 2 First craft to approach Neptune, 1989
Images not to scale.
Missions launched through the end of 2012. Failures shown reached at least Earth orbit; many others failed at launch.
NATIONAL GEOGRAPHIC
REACHING FOR DEEP SPACE
SUN
MERCURY
EARTH
MARS
VENUS
ASTEROID BELT
JUPITER
SATURN
URANUS
NEPTUNE
PLUTO
KUIPER BELT
BILLIONS OF MILES
0
1
2
3
4
5
6
7
8
9
10
PIONEER 11
VOYAGER 2
PIONEER 10
VOYAGER 1
INTERSTELLAR SPACE

High adaptability is a must for unknown and challenging environments…