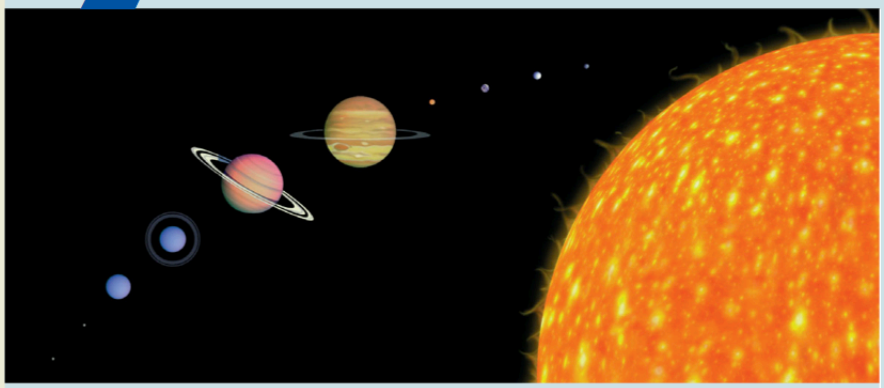
# 7



# Searching for Life in Our Solar System

Searching for Life in Our Solar System

## LEARNING GOALS

**7.1 ENVIRONMENTAL REQUIREMENTS FOR LIFE**
- Where can we expect to find building blocks of life?
- Where can we expect to find energy for life?
- Does life need liquid water?
- What are the environmental requirements for habitability?

**7.2 A BIOLOGICAL TOUR OF THE SOLAR SYSTEM: THE INNER SOLAR SYSTEM**
- Does life seem plausible on the Moon or Mercury?
- Could life exist on Venus or Mars?

**7.3 A BIOLOGICAL TOUR OF THE SOLAR SYSTEM: THE OUTER SOLAR SYSTEM**
- What are the prospects for life on jovian planets?
- Could there be life on moons or other small bodies?

THE PROCESS OF SCIENCE IN ACTION

**7.4 SPACECRAFT EXPLORATION OF THE SOLAR SYSTEM**
- How do robotic spacecraft work?

**7.X OBSERVATIONAL TECHNIQUES**
- What methods do we apply to observe the solar system?
- What can we learn about planets from spectroscopy?
- What are some of the unmanned space missions?

## Requirements for Habitability

Habitability refers to environment in which some form of life could persist; we expect these required conditions will most likely be met **on planets and moons**

### 1. Elements of Life

- Produced by stars; "metals" make up 2% of mass of solar system!
- Oxygen, carbon, nitrogen, hydrogen make up 96% of life on Earth
- Life does not need to be carbon based, but we think it will be

### 2. Energy for Life

- Fuels metabolism; some photosynthesis, others secondary
- Starlight is most obvious form of energy
- Decreases in intensity as square of distance
- Metabolism is temperature dependent, so farther from sun, cooler environments have slower metabolism (if they are out there)

Light from stars is major energy source
Energy decreases with square of distance

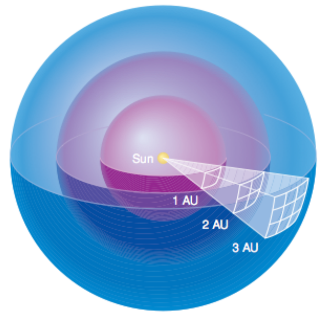



Figure 7.2
Any given amount of sunlight is spread over a larger area with increasing distance from the Sun. As shown in this diagram, the area over which the sunlight is spread increases with the square of the distance: At 2 AU the sunlight is spread over an area $2^2 = 4$ times as large as at 1 AU, and at 3 AU the sunlight is spread over an area $3^2 = 9$ times as large as at 1 AU. (Recall that 1 AU is the average Earth–Sun distance, or about 150 million kilometers.) Thus, the energy contained in sunlight (per unit area) decreases with the square of the distance from the Sun.

## Requirements for Habitability

### 3. Transport Medium

Metabolism (energy cycle of living matter) requires a medium in which to operate; a fluid is optimal

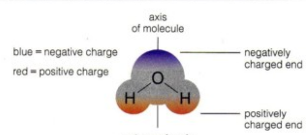
Does it need to be water? 4 reasons water is best candidate

1. Water has the largest range of temperatures over which it remains a liquid.
2. Temperature range over which water is liquid is highest of ammonia, methane, and ethane- chemical reactions in water proceed fastest
3. Water has strong electric polarity- molecules with charge separation dissolve in water
4. Water-ice is less dense than liquid water- thus frozen ponds, etc. do not freeze all the way through, killing everything! Water is unique in this way due to the **"hydrogen bond"**

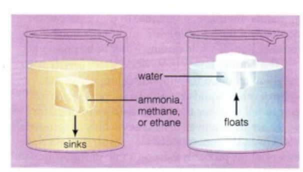
The need for water may be the most important of the 3 requirements for life, because the other two will probably be present if liquid water is sustainable

**Table 6.1 Companion of Potential Liquids for Life.** Freezing and boiling points (under 1 atmosphere of pressure) for common substances that may be found in liquid form in our solar system. The last column gives the width of the liquid range, found by subtracting the freezing point from the boiling point.

| Substance | Freezing Temperature | Boiling Temperature | Width of Liquid Range |
|---|---|---|---|
| Water ($H_2O$) | 0°C | 100°C | 100°C |
| Ammonia ($NH_3$) | –78°C | –33°C | 45°C |
| Methane ($CH_4$) | –182°C | –164°C | 18°C |
| Ethane ($C_2H_6$) | –183°C | –89°C | 94°C |




Within individual water molecules, the electrons tend to be distributed in a way that makes one side have a net positive charge and the other side have a net negative charge.

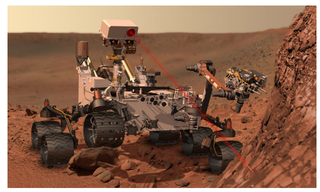


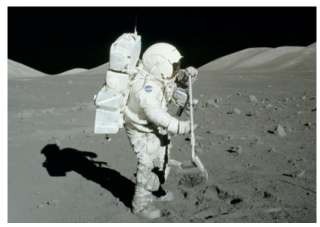

Most substances are denser as solids than as liquids, so when solid and liquid forms exist together, the solid form sinks through the liquid. Water is a rare exception in that ice floats because it is less dense than liquid water.

## Exploring the Solar System

### 3 Observational Techniques…

1. Observations from Earth using telescopes on the ground and in Earth orbit
2. Send robotic spacecraft to study a world up close, in some cases returning samples to Earth
3. Send humans to explore



Humans have only visited one other world- The Moon.

12 astronauts walked the surface from 1969 to 1972

Mars is 200 times further away and poses many technological and biological challenges and hurtles

## Exploring the Solar System

### Technique 1: Telescopes

Telescopes can perform two basic types of data collection

**Imaging**

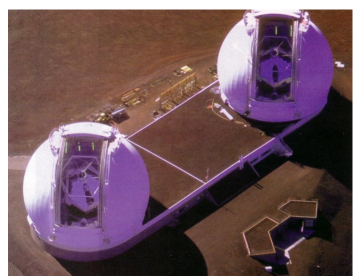
Imaging is basically picture taking- one want a big mirror for greater light gathering power and higher resolution

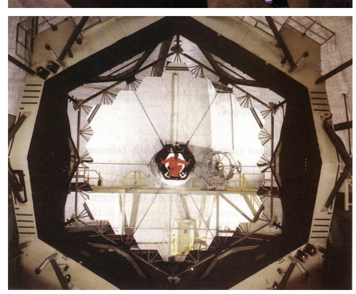
LGP ~ diameter$^2$ resolution ~ $\lambda$/diamater

**Spectroscopy**

This is the spreading of the light into its rainbow of colors. This is the most powerful method because one can determine chemical compositions, temperatures, densities, and other physical quantities.

"A picture may be worth 1000 words, but a spectrum is worth 1000 images."





One of the biggest ground based telescopes on Earth. This is the Keck I and II Telescopes. The mirror is 10 meters in diameter comprising 36 hexagonal 1-meter mirrors.

# Exploring the Solar System

## Technique 1: Telescopes and the Earth's Atmosphere

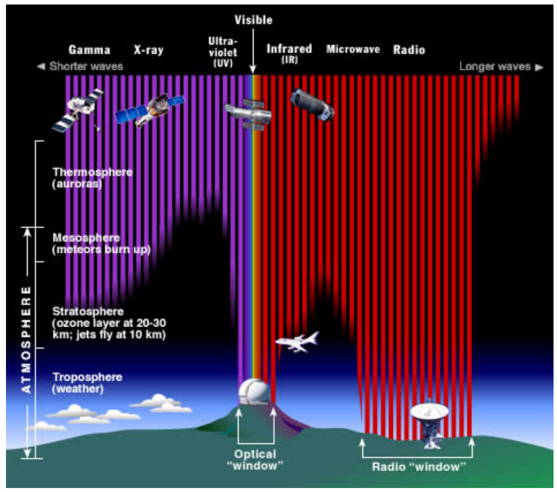
The transparency of the Earth's atmosphere dictates which parts of the electromagnetic spectrum we can study from the ground and which parts are studied high in the atmosphere, and which parts must be studied from space.

Ground:
- visible
- microwave
- radio

Planes:
- infrared

Balloons:
- gamma rays
- x rays

Space:
- gamma rays
- x rays
- ultraviolet
- visible
- Infrared
- microwave

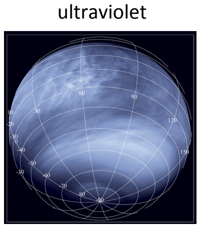



# Exploring the Solar System

## Technique 1: Telescopes and Imaging

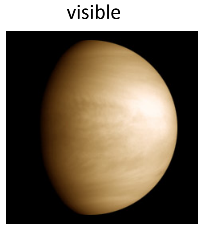
An example of the differences in images of Venus seen in different parts of the electromagnetic spectrum.

ultraviolet



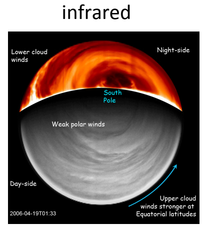
Emission from cloud layers of upper hot atmosphere

visible



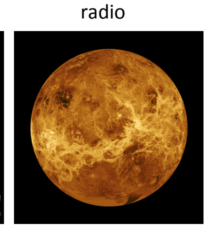
Reflected visible sunlight off of upper cloud layers

infrared



Night side only: thermal emission from cloud layers of different depths

radio

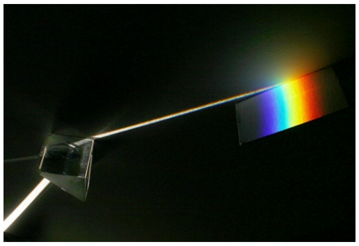


Radio passes right through the atmosphere, so see the surface directly

When you view an object in different parts of the electromagnetic spectrum, you observe light coming from different processes occurring in different locations – to get the full picture of an object, images in all spectral regions is desired

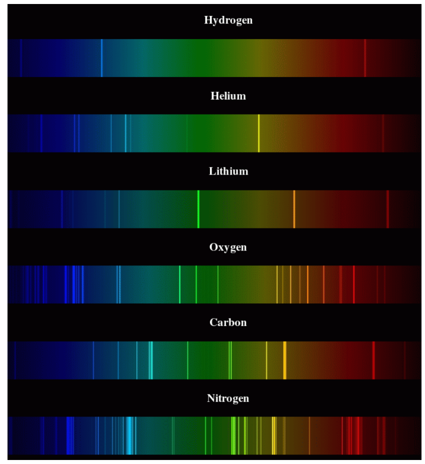
## Exploring the Solar System

### Technique 1: Telescopes and Spectroscopy



A beam of light comprises light of different wavelengths (colors), and each color can have a different intensity (brightness).

Each element interacts with light in a unique way, so that each element has a "spectroscopic fingerprint".

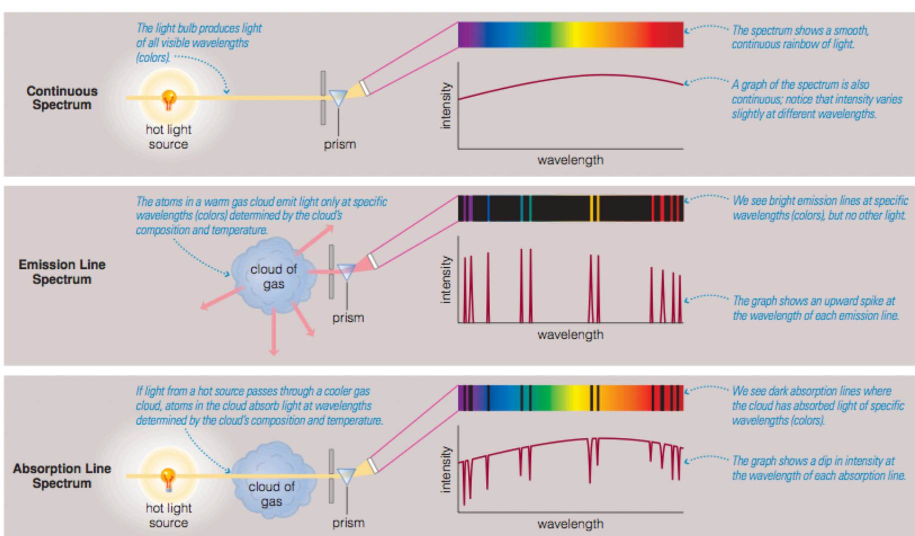



The "spectroscopic fingerprints" (emission lines) of several different common elements; if you see the pattern of a given element in the spectrum of a star or planet, then you can measure the abundance of that element in the object based upon how bright the emission lines are.

## Exploring the Solar System

### Technique 1: Telescopes and Spectroscopy

Take a spectrum of a planet or star and you can determine what elements are in its atmosphere, and the temperature and pressure of the atmosphere!!

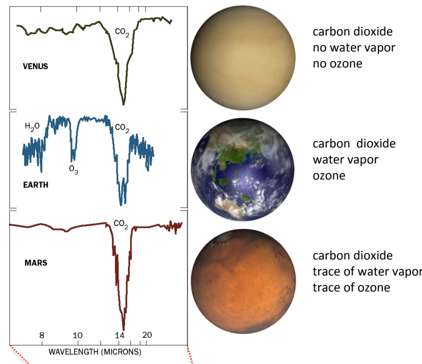


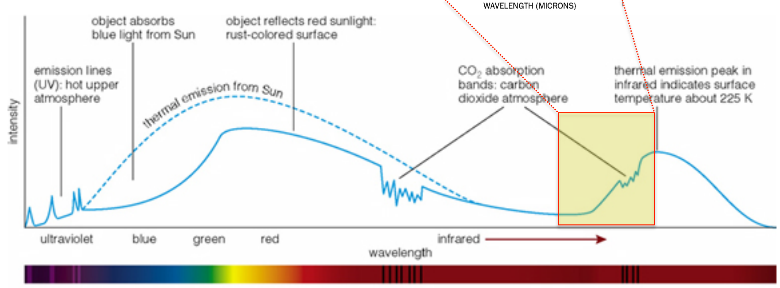
## Exploring the Solar System

### Technique 1: Telescopes and Spectroscopy

There are clear differences in spectra of Venus, Earth, and Mars in the infrared part of the electromagnetic spectrum, and the details provide the abundances of carbon dioxide, water vapor, and ozone in their atmospheres.

The absorption is from that gases in their atmospheres. The emitted light is from solar reflection of from the planet's thermal emission.




## Exploring the Solar System

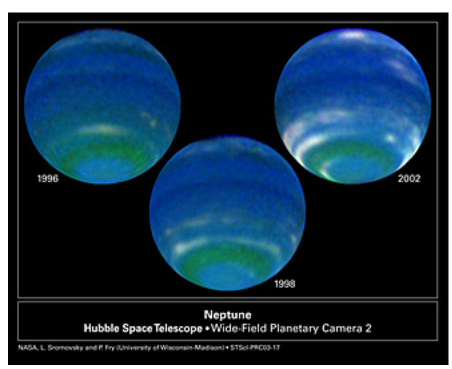
### Long Term Monitoring

Most imaging and spectroscopic studies are undertaken in small research programs by individual scientists or small teams of scientists. However, sometimes a large team will undertake a program for a long period of time.

**Long Term Monitoring**

May involve imaging, spectroscopy, or both.
Long term monitoring is conducted over an extended time period for long durations to address how properties change with time.

For example:
- Weather patterns
- Seasonal climate
- Seasonal dust storms
- Evolution of Jupiter's red spot
- Changes in geology of moons
- Migration of ring particle orbits

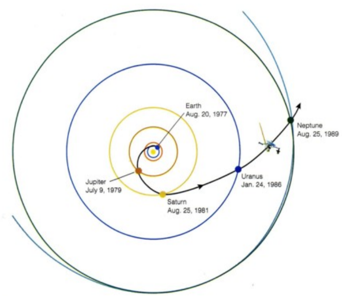


## Exploring the Solar System
### Technique 2: Robotic Spacecraft

- **Flyby:** A space craft on a flyby goes past a world just once and then continues on its way.
- **Orbiter**: An orbiter is a spacecraft that orbits the world it is studying, allowing longer-term monitoring during its repeated orbits.
- **Lander or Probe:** These spacecraft are designed to land on a planet's surface or probe a planet's atmosphere by flying through it. Some landers have carried rovers to explore wider regions.
- **Sample Return Mission:** A sample return mission requires a lander of probe designed to return to Earth carrying a sample of the world it has studied.

**Flyby Example**
*Voyager 2*

| | |
|---|---|
| Jupiter | July 9, 1997 |
| Saturn | Aug 25, 1981 |
| Uranus | Jan 24, 1986 |
| Neptune | Aug 25, 1989 |




1. Discovered Jupiter's rings
2. Active volcanoes on Io, Jupiter's moon
3. Details of Saturn's, Uranus' and Neptune's rings
4. Measured magnetic fields as function of distance
5. Gravitational effect by moons measure moon densities

*Some of these measurements are "backlit" from the sun, i.e. in silhouette- cannot be done from Earth at all*

## Exploring the Solar System
### Technique 2: Robotic Spacecraft

**Orbiter Example**
*Cassini Saturn Orbiter*

| | |
|---|---|
| Launched | Oct 15, 1997 |
| Entered Orbit | Jul 1, 2004 |

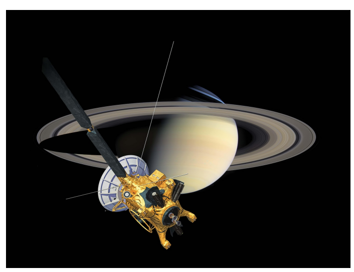
https://www.youtube.com/watch?v=fAQM9rfZq7w
Introduction to *Cassini* Mission

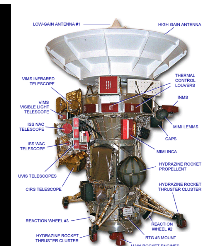
Before Cassini reached Saturn, we had only one flyby mission (*Voyager 2*), and no detailed images or measurements of Saturn's many moons

https://www.youtube.com/watch?v=VDNP_GIFuqM
Short interview about *Cassini* discoveries

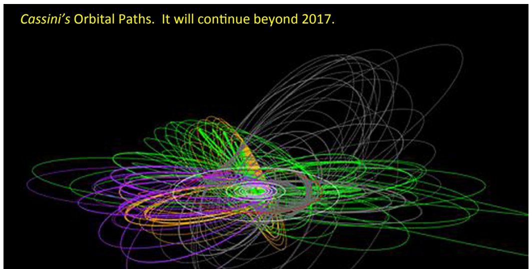
https://www.youtube.com/watch?v=0mDWRdbziWM
Short report on Encelades

Found:
- Methane oceans on Titan
- Water volcanoes on Encelades





*Cassini's* Orbital Paths. It will continue beyond 2017.



*Cassini's* prime mission, completed in 2008, is shown in green. Its first mission extension, which was known as the Equinox Mission and ended in 2010, is shown in orange. The completed orbits of its second mission extension, known as the Solstice Mission, are shown in purple. Orbits after *Cassini's* 15th anniversary of launch, on Oct. 15, 2012, appear in dark gray. These include orbits that pass inside Saturn's innermost ring, which start in April 2017.

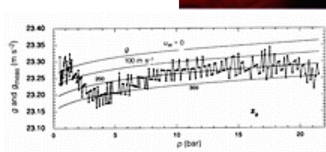
## Exploring the Solar System
### Technique 2: Robotic Spacecraft

**Probe Example**
*Galileo Jupiter Probe*

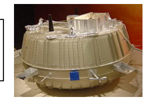
*Galileo Probe* dropped into the atmosphere of Jupiter (Dec 1995)

Collected Data on
- Temperature
- Wind Speeds
- Pressure
- Composition
- Radiation levels

as a function of depth for about an hour before it was died

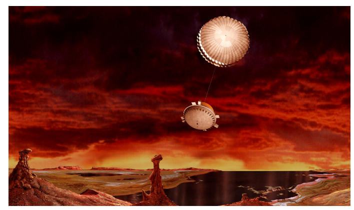



**Lander Example**
*Huygens/Cassini Titan Lander*



*Huygen Lander* dropped into the atmosphere of Saturn's moon Titan (Jan 2005)

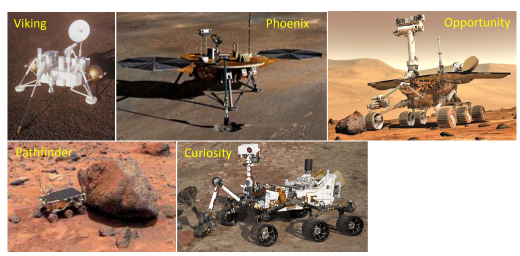
Collected Data on (instruments)
- Atmospheric Structure Instrument
- Doppler Wind Experiment
- Descent Imager/Spectral Radiometer
- Gas Chromatograph Mass Spectrometer
- Aerosol Collector and Pyrolyser Surface Science Package

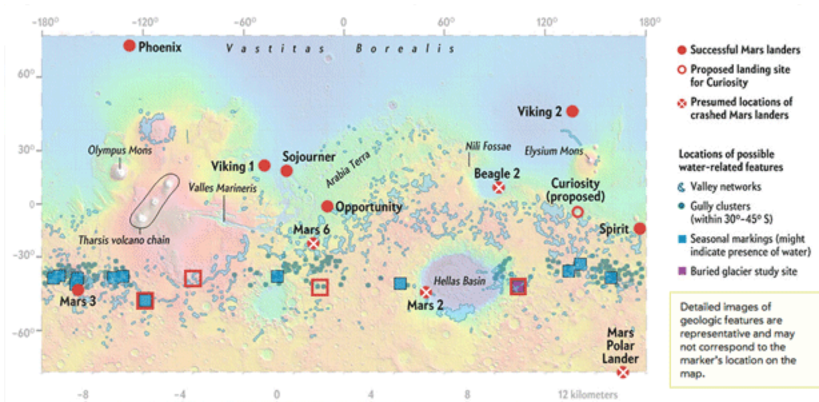


On surface for about an 90 minutes before it was destroyed. It holds the world record for the most distant landing of a man made object.

## Exploring the Solar System
### Technique 2: Robotic Spacecraft

**Lander/Rover Examples**
*Viking 1 & 2*
*Phoenix*
*Opportunity (Rover)*
*Spirit/Sojourner/Pathfinder (Rover)*
*Curiosity (Rover)*

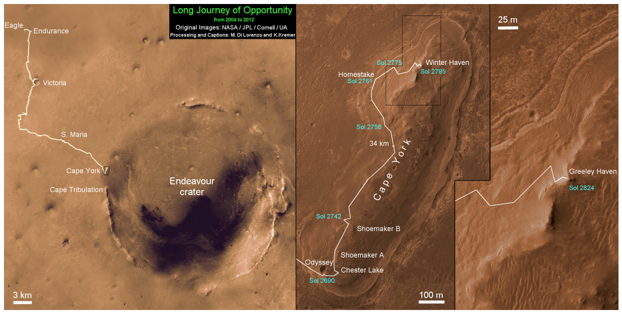


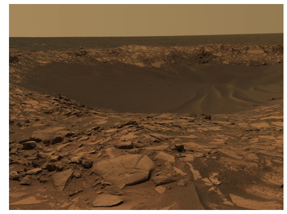



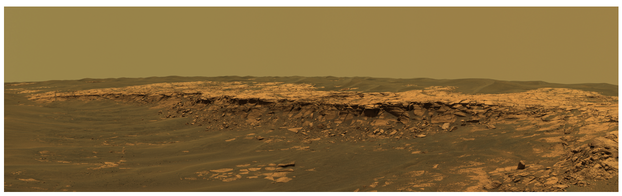
# Exploring the Solar System

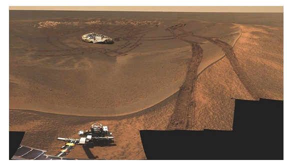
## Technique 2: Robotic Spacecraft

**Lander/Rover Example**
*Opportunity (Rover)*





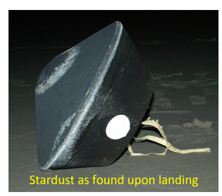


# Exploring the Solar System

## Technique 2: Robotic Spacecraft

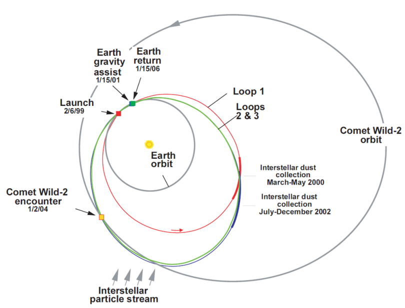
**Sample Return Mission**
*Stardust*

81P/Wild Approach Image

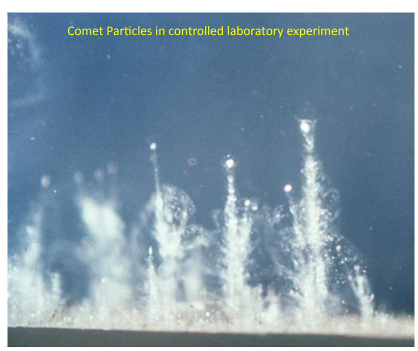


Stardust as found upon landing

Comet 81P/Wild- returned over 1 million comet particles from coma of comet




Mission trajectory



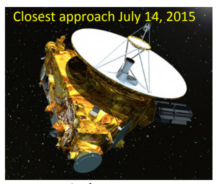
Comet Particles in controlled laboratory experiment

**TABLE 7.2** *Selected Robotic Missions to Other Worlds*

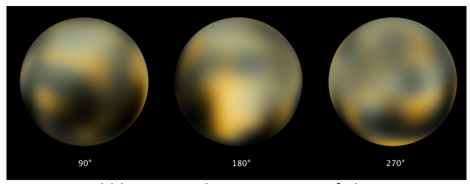
| *Destination* | *Mission* | *Arrival Year* | *Agency** |
|---|---|---|---|
| Mercury | *MESSENGER* orbiter will study surface, atmosphere, and interior | 2011† | NASA |
| Venus | *Magellan* orbiter mapped surface with radar | 1990 | NASA |
| | *Venus Express* focuses on atmosphere studies from orbit | 2006 | ESA |
| | *Akatsuki (Venus Climate Orbiter)* studies atmosphere and surface from orbit | 2011† | JAXA |
| Moon | The United States, China, Japan, India, and Russia all have current or planned robotic missions to explore the Moon | — | — |
| Mars | *Spirit* and *Opportunity* rovers learn about water on ancient Mars | 2004 | NASA |
| | *Mars Reconnaissance Orbiter* takes very high-resolution photos; seeks future landing sites | 2006 | NASA |
| | *Mars Express* orbiter studies Mars's climate, geology, and polar caps | 2004 | ESA |
| | *Phoenix* lander studied soil near the north polar cap | 2008 | NASA |
| | *Mars Science Laboratory* is a large surface rover | 2012† | NASA |
| Asteroids | *Hayabusa* orbited and landed on asteroid Itokawa; returned a capsule in 2010 | 2005 | JAXA |
| | *Dawn* will visit the large asteroid Vesta and the dwarf planet Ceres | 2011† | NASA |
| Jovian Planets | *Voyagers 1* and *2* visited all the jovian planets and have left the solar system | 1979 | NASA |
| | *Galileo's* orbiter studied Jupiter and its moons; probe entered Jupiter's atmosphere | 1995 | NASA |
| | *Cassini* orbits Saturn; its *Huygens* probe (built by ESA) landed on Titan | 2004 | NASA |
| Pluto and Comets | *New Horizons* will fly past Pluto; passed Jupiter in 2007 | 2015† | NASA |
| | *Stardust* flew through the tail of Comet Wild 2; returned comet dust in 2006 | 2004 | NASA |
| | *Deep Impact* observed its "lander" impacting Comet Tempel 1 at 10 km/s | 2005 | NASA |
| | *Rosetta* will orbit Comet Churyumov–Gerasimenko and release a lander | 2014† | ESA |

*ESA = European Space Agency. JAXA = Japan Aerospace Exploration Agency.
†Scheduled arrival year.

http://bit.ly/1zFZVla article on New Horizons

artist's concept



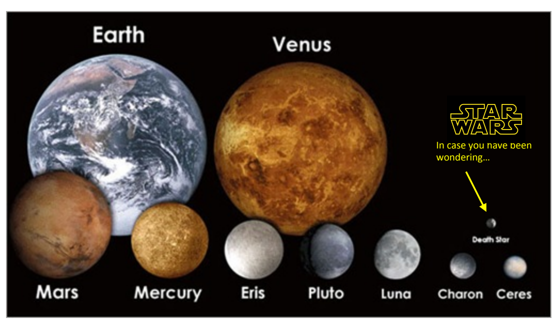
Hubble Space Telescope Images of Pluto

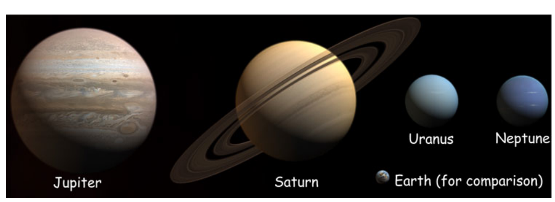
## Biological Tour of the Solar System

- Mercury
- Earth's Moon
- Venus
- Mars
- Small Moons/Asteroids
- Jovian Planets
- Jovian Moons

Are there locations other than Earth in our very own solar system that have the 3 requirements for habitability?

We will defer discussion of the Jovian Moons until Chapter 9



# Biological Tour of the Solar System
## Mercury and Earth's Moon


Mercury and Moon are unlikely to classify as habital

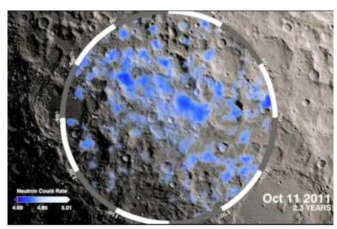
- small, lost internal heat
- no outgassing- no atmospheres
- scared with craters, surfaces are old, geologically dead
- evidence for impacts suggest that some organics and water deposited on these bodies …

# Biological Tour of the Solar System
## Water on Earth's Moon

Evidence for Permafrost Water on Lunar South Poles

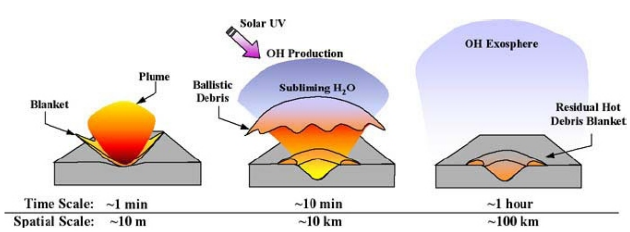
Some craters are permanently shielded from the Sun.

October 9, 2009, NASA crashed LCROSS into this region to create a plume and vaporize the water and then try to measure the water content. NMSU Astronomers made the only definitive detection using the Apache Point Telescope in Cloudcroft! They determined that the plume has 6% water by mass.



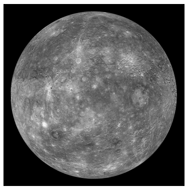
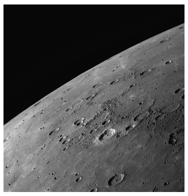
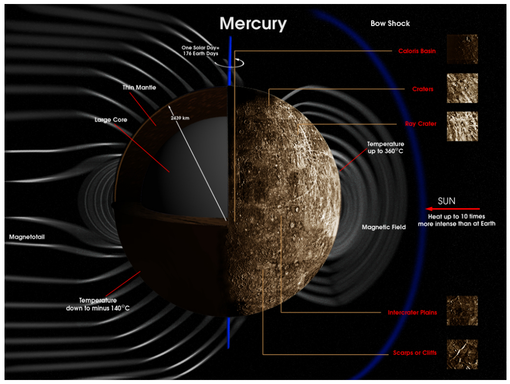

This color-coded map from the *Lunar Prospector* mission shows evidence for water-ice in craters near the Moon's south pole. Used neutron detection techniques. Dark blue and regions have highest hydrogen concentrations, which may be due to water concentrations on or just below the surface.

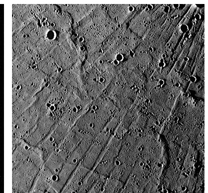
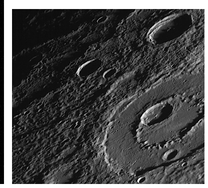
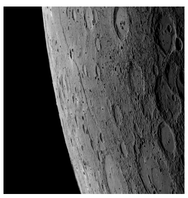
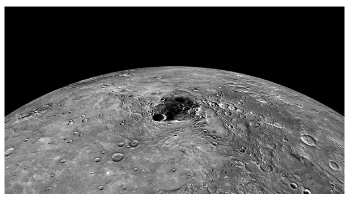
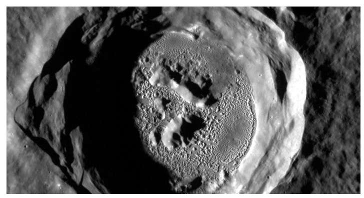
*This is good news for moon colonization!*
**Score: 2/3? But, probability for Habitability negligible ~0%**

## Biological Tour of the Solar System
### Mercury

Studied with the *Messenger* Flyby
**Score: 1/3; Probability of Habitability ~ 0%**

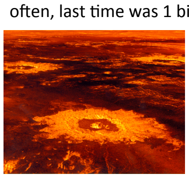
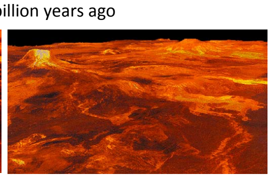
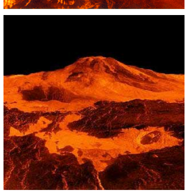
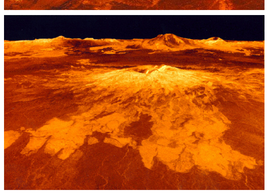
## Biological Tour of the Solar System
### Venus

- 2/3 the distance from Sun as Earth
- 80% mass of Earth
- Early calculations predicted 35C/95F temperature

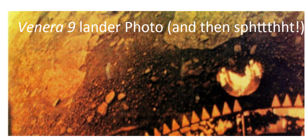
Venus suffers a **runaway greenhouse effect**

Atmospheric carbon dioxide levels:
Earth 1% carbon dioxide
Venus 96% carbon dioxide
**Venus too hot 470C/870F for liquid water, ammonia, methane, or ethane**

Surface is very young, regenerates every so often, last time was 1 billion years ago


*Magellan* Orbiter Radio Maps


*Venera 9* lander Photo (and then sphttthht!)

Early oceans on Venus?
Discuss implications later…

**Score: 2/3; Probability for Habitability still negligible ~0%**

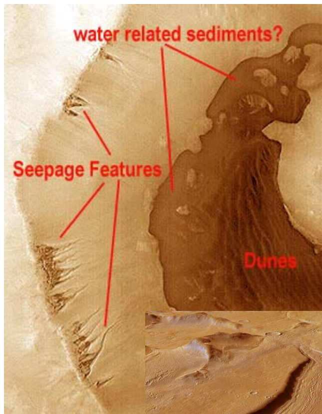
## Biological Tour of the Solar System

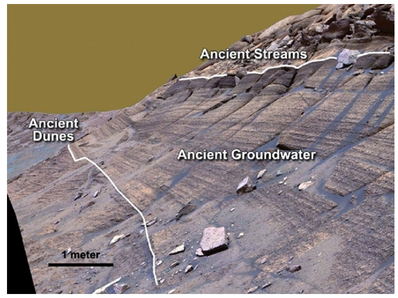
**Score: 3/3 (!)**
**Probability for Habitability high! ~100%**

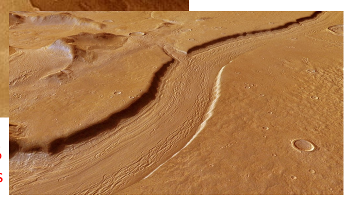
### Mars

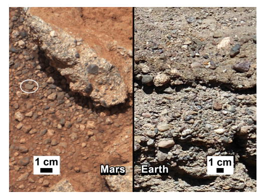
Evidence for water permafrost and liquid water on Mars is very strong!

The temperature on Mars ~20C/**70F** at noon, at the equator in the summer, and a low of about -150C/225F at the poles.






T~70F, but Mars' atmosphere 0.5% as thick as Earth's

## Biological Tour of the Solar System

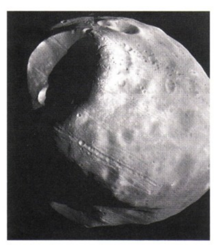
**Score: 0/3**
**Probability for Habitability ~0%**

### Small Moons

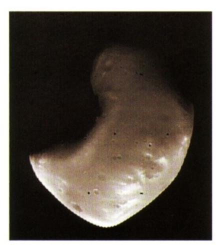
Mars' two moons are **Phobos** and **Deimos**

Small moons like these most certainly lack liquids, though it is currently unknown if they have water permafrost.

These moons are too small to sustain internal heat that could energize metabolism or allow for liquid water.



Phobos

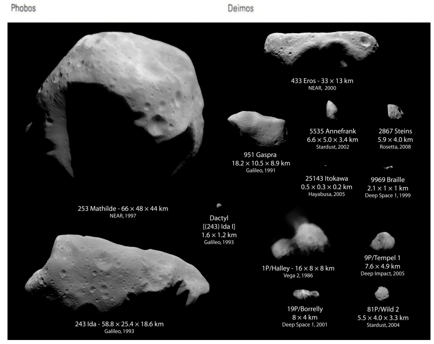


Deimos

### Asteroids

Asteroids must have contained liquid water shortly after their formation before they cooled, and these objects contain organic molecules on them from space (from their formation). Today, even simple life on these bodies would seem very unlikely.

Mars' very small moons and those asteroids that are too far from sun very likely do not have any ice water melting in the current epoch. Further they have too small of masses to retain and atmosphere, which is necessary for liquid water on the surface

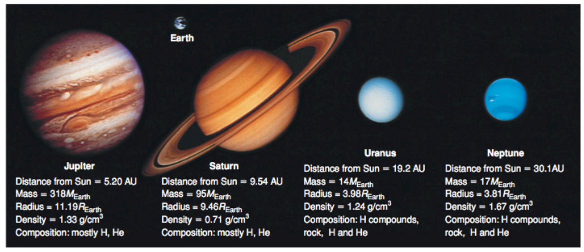


Score: 2/3?
Probability for Habitability ~0%

# Biological Tour of the Solar System

## Jovian Planets

Because these planets are so far from the Sun, temperatures in their upper atmospheres are extremely cold. However, observations show that all must be quite hot in their deep interiors, bringing heat so some altitudes in their atmospheres are warm enough for liquid water. Moreover, chemical reactions powered by frequent lightning that has been observed in their atmospheres could potentially provide energy for life. So is it reasonable to imagine life here?




**Jupiter/Saturn:** good temperatures at some layers, and lots of organic molecules, but high speed vertical winds would destroy them at hotter depths; life unlikely

**Uranus/Neptune:** temperatures too cold in atmospheres, and same wind problem, but liquid water, methane, and ammonia outer cores are of interest; but too cold for metabolism and no energy source; life unlikely