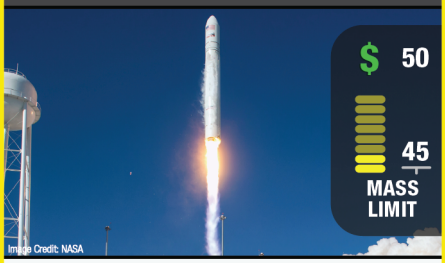
Light-Lift Rocket I



This rocket can lift a misson that has up to 45 mass units.

✔ **PROS:**
- Low cost
- Low risk: works 5 times out of 6

✘ **CONS:**
- Lifts small, lightweight missions with few science tools

1

Light-Lift Rocket II

This rocket can lift a misson that has up to 90 mass units.

✔ **PROS:**
- Lifts medium-size missions due to add-on thrusters

✘ **CONS:**
- Costs more than Light-Lift Rocket I due to additional thrusters
- Medium risk: works 4 times out of 6

2

Medium-Lift Rocket A

This rocket can lift a misson that has up to 125 mass units.

✔ **PROS:**
- Lifts large missions with more science tools

✘ **CONS:**
- Costs more than Light-Lift Rockets
- Medium risk: works 4 times out of 6

3

Medium-Lift Rocket B

This rocket can lift a misson that has up to 125 mass units.

✔ **PROS:**
- Able to lift large missions with more science tools
- Low risk: works 5 times out of 6

✘ **CONS:**
- Costs more than Light-Lift I & II and Medium-Lift Rocket A

4

Heavy-Lift Rocket

This rocket can lift a misson that has up to 200 mass units.

✔ **PROS:**
- The most powerful on Earth! Able to lift very large missions with the most science tools

✘ **CONS:**
- High risk: works 3 times out of 6

5

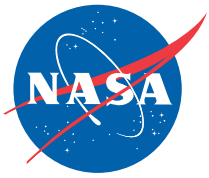
Rocket Nose Cone

Protects your spacecraft during launch. Required for all missions!

✔ **PROS:**
- Low cost
- No power needed

✘ **CONS:**
- Medium mass

6



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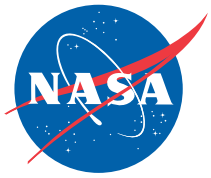

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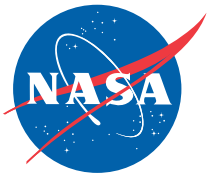

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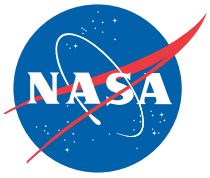

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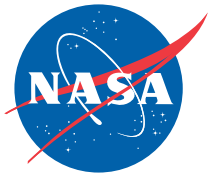

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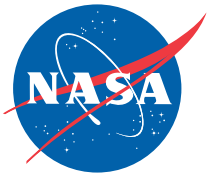
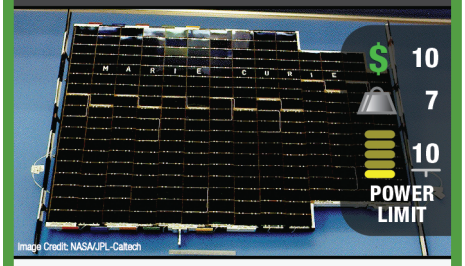


Astrobiobound!

Low-Power Solar Panel



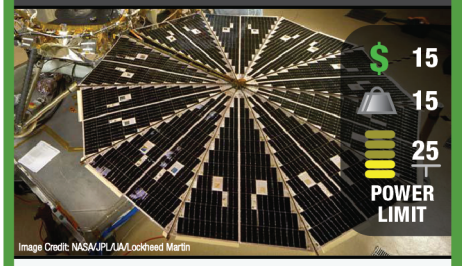
Gives your mission electricity

✔ **PROS:**
- Low cost, low mass
- Lasts a few years

✘ **CONS:**
- Only works during daylight, needs the Sun
- Only usable on Mars missions near equator
- Requires on-board battery (card #10)

7

Medium-Power Solar Panel



Gives your mission electricity

✔ **PROS:**
- Low cost, medium mass
- Lasts a few years

✘ **CONS:**
- Only works during daylight, needs the Sun
- Only usable on Mars missions near equator
- Requires on-board battery (card #10)

8

High-Power Solar Panel

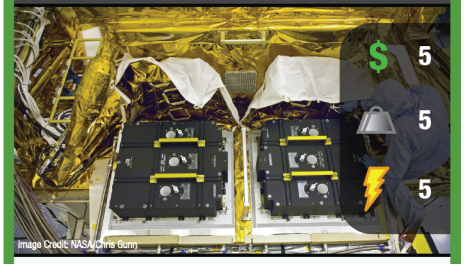
Gives your mission electricity

✔ **PROS:**
- Medium cost, medium mass
- Lasts a few years

✘ **CONS:**
- Must have sunlight, only works during daylight
- Requires on-board battery (card #10)

9

On-board Battery



A battery is required for all solar-powered missions

✔ **PROS:**
- Stores power collected by solar panels so your mission can survive when the Sun is not visible

✘ **CONS:**
- Increases the cost, mass, and power points for your mission

10

Fuel Cell

Gives your mission electricity

✔ **PROS:**
- Does not need the Sun or a battery
- Provides more power than solar panels
- Works everywhere

✘ **CONS:**
- Lasts a few months
- Costs more than solar panels

11

Radioisotope Power System

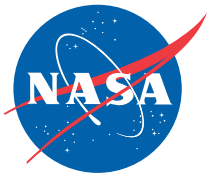
$ 75
30
75
POWER LIMIT

Gives your mission electricity

✔ **PROS:**
- Does not need the Sun or a battery
- Provides the most power of all
- Works everywhere
- Lasts over a decade

✘ **CONS:**
- Costs the most
- Has the most mass

12



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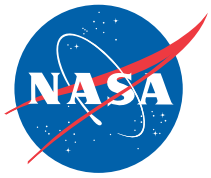

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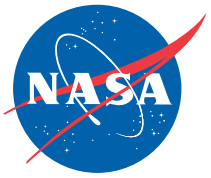

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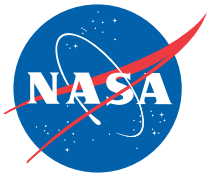

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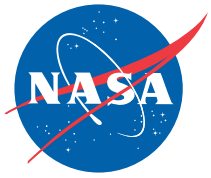

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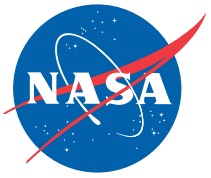
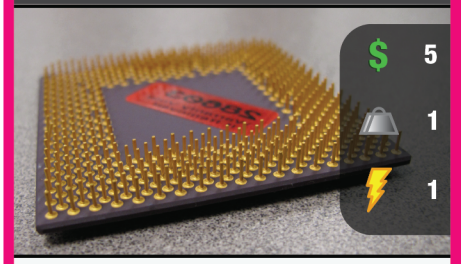


Astrobiobound!

Standard Microprocessor



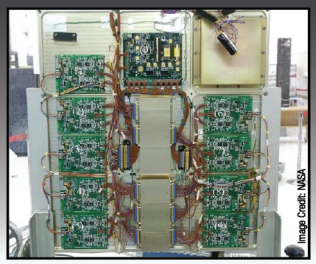
At least one microprocessor is required for all missions

PROS:
- Provides mission "brainpower"
- Low cost, mass, and power usage

CONS:
- Provides only basic functions needed to receive commands and send data

13

Advanced Microprocessor



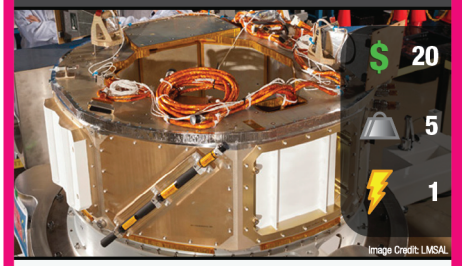
At least one microprocessor is required for all missions

PROS:
- More "brainpower" lets the spacecraft make simple choices without commands from Earth

CONS:
- Costs more and uses more power than the standard microprocessor

14

Main Bus



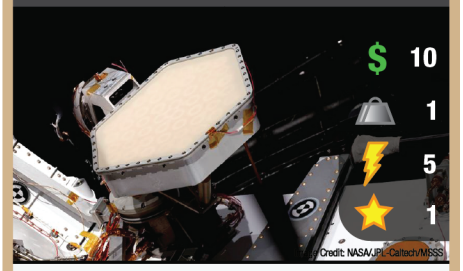
Connects science tools with the onboard computer so they work
Required for all missions!

PROS:
- Low power usage
- Allows you to make discoveries with your science tools

CONS:
- Medium cost and mass

15

High-Gain Antenna



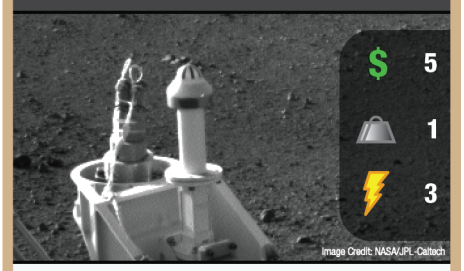
At least one antenna is required to communicate with Earth.

PROS:
- Sends large amounts of data at one time

CONS:
- Costs more and uses more power than the Low-Gain Antenna

16

Low-Gain Antenna



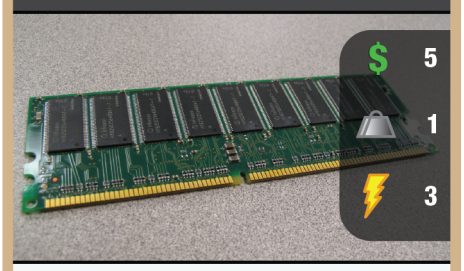
At least one antenna is required to communicate with Earth.

PROS:
- Low cost and power
- Can be used as a backup for the High-Gain Antenna

CONS:
- Cannot send much information at one time

17

Main Memory Card

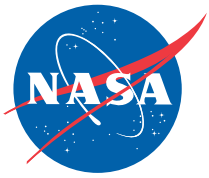


Stores all data until it can be sent back to Earth. Required for all missions!

PROS:
- Low cost, mass, and power usage

CONS:
- None! Your mission does not have a continuous link with Earth, so you need a way to store your data

18



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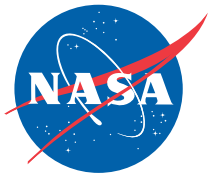

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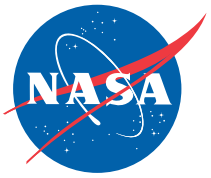

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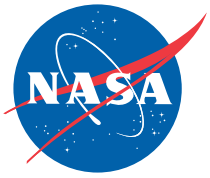

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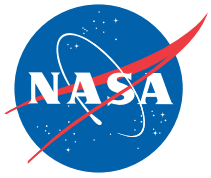

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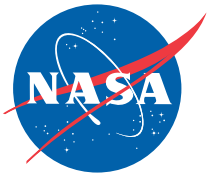
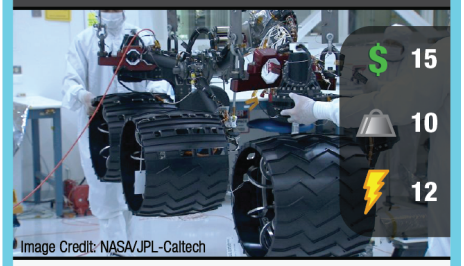


Astrobiobound!

Wheels



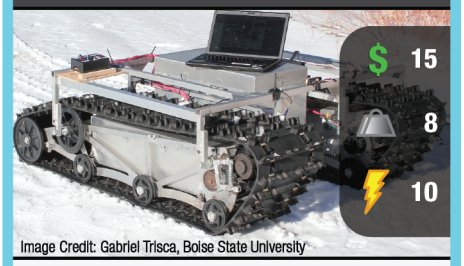
Either wheels, tracks, or cliffbot are required for rover missions

PROS:
- Wheels carry rovers to discoveries beyond their landing site
- Medium speed and work on rocky terrain

CONS:
- Have a little more mass, and use a little more power than tracks

19

Tracks



Either wheels, tracks, or cliffbot are required for rover missions

PROS:
- Have less mass and use less power than wheels

CONS:
- Can make it harder to climb over some obstacles
- Less precise steering

20

Titan Boat

The boat is required for missions that explore the methane lakes of Titan

PROS:
- Can sample liquids
- Can visit multiple locations
- Low mass

CONS:
- Untested technology, high risk

21

Cliffbot

Required for accessing skylights, recurring slope lineae, and polar ice cliffs

PROS:
- Can get to areas other rovers cannot
- Medium speed and work on rocky terrain

CONS:
- Untested on another planet/moon, high risk

22

Cryobot

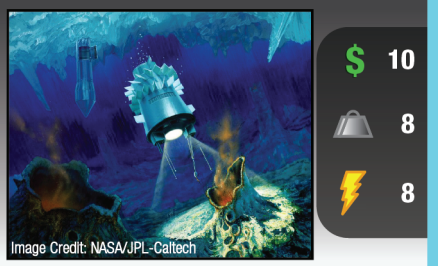
Required for traveling through ice

PROS:
- Uses heat to drill though ice, no moving parts

CONS:
- Only works on ice
- A rocky layer may stop it
- Untested on another planet/moon, high risk

23

Hydrobot

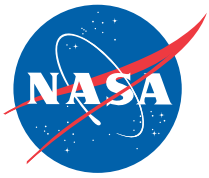


Required for exploring subsurface water

PROS:
- Navigate subsurface lakes or oceans

CONS:
- Autonomous operation only
- Untested on another planet/moon, high risk
- Also requires Cryobot (#23)

24



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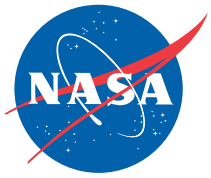

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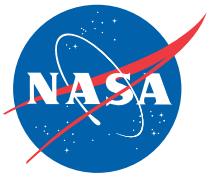

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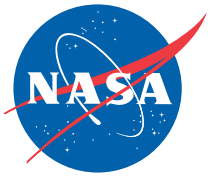

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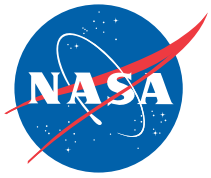

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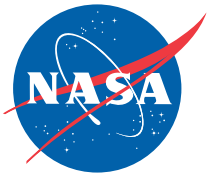


Astrobiobound!

Robotic Arm

$ 5
8
1
1

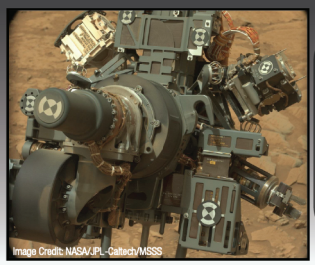
Collects samples and carries one science instrument

✔ **PROS:**
- Doesn't use much power
- Low cost

✘ **CONS:**
- Medium mass

25

Rotating Instrument Mount



$ 5
3
1
1

Provides flexible structure for up to 4 science instruments. Requires Robotic Arm Card (#25)

✔ **PROS:**
- Allows the Robotic Arm to be more efficient

✘ **CONS:**
- Added complexity increases risk of malfunction

26

Drill

$ 5
3
5
1

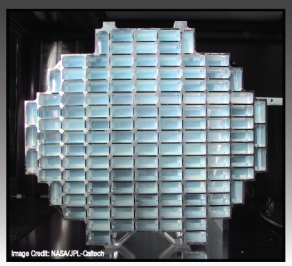
Collects samples by drilling into rock and ice. Requires Robotic Arm Card (#25)

✔ **PROS:**
- Low cost, low mass
- Provides an added science point

✘ **CONS:**
- Medium power

27

Aerogel



$ 15
2
1
1

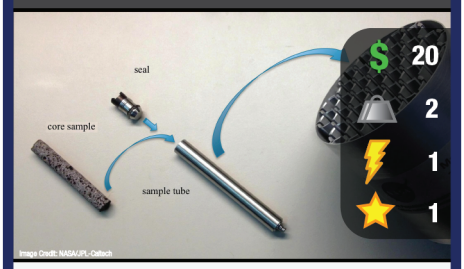
Required for sampling material from orbit

✔ **PROS:**
- Aerogel can capture material that hits the collector as the spacecraft flys through a geyser plume
- Previously used on Stardust mission

✘ **CONS:**
- May be hard to determine if a sample has been collected

28

Sample Cache



$ 20
2
1
1

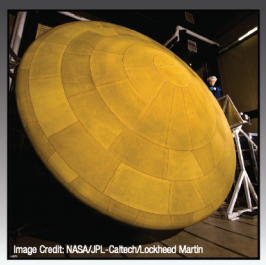
Required for sampling material from the surface

✔ **PROS:**
- Can store up to 31 samples
- Samples can be analyzed on Earth using the latest instruments

✘ **CONS:**
- Untested technology, high risk

29

Heat Shield



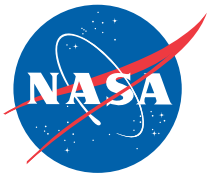
$ 5
10
0

Required to protect all missions traveling to the surface of bodies with atmospheres

✔ **PROS:**
- Very low cost
- Does not use power

✘ **CONS:**
- Medium mass

30



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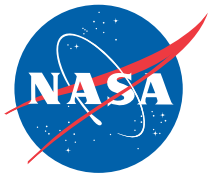

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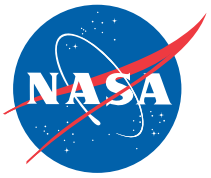
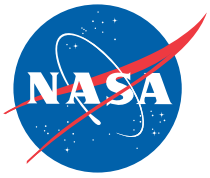
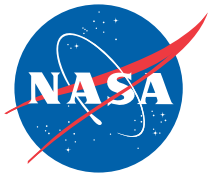


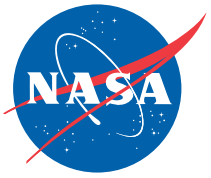
Astrobiobound!



Astrobiobound!



Astrobiobound!



Astrobiobound!

Sky Crane

$ 40
15
0

Either airbags or sky crane are required for surface missions

PROS:
- Slows the spacecraft for a controlled landing
- Smaller landing ellipse than airbags

CONS:
- Higher cost and mass than airbags

31

Airbags

$ 10
8
0

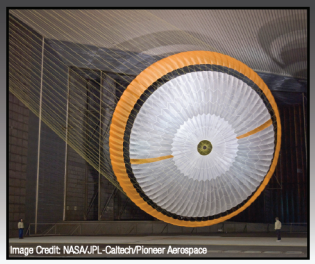
Either airbags or sky crane are required for surface missions

PROS:
- Protects spacecraft from impacts on rocks and slopes
- Lower cost and mass than sky crane

CONS:
- Precise landings are difficult because the airbags bounce

32

Supersonic Parachute



$ 5
8
0

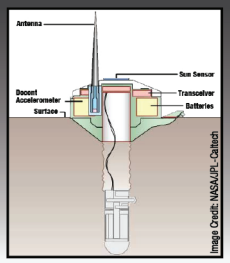
Required for all missions traveling to the surface of bodies with atmospheres

PROS:
- Slows the spacecraft down prior to using airbags or retro rockets
- Low cost
- Does not use power

CONS:
- Medium mass

33

Impact Probe



$ 10
5
0
1

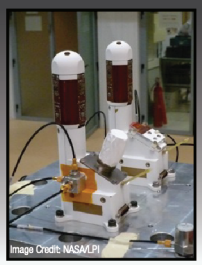
Probes can be added to enhance discoveries below the surface

PROS:
- Penetrates the surface at high speeds to collect data from below the surface
- Does not use power

CONS:
- Adds cost and mass to your mission

34

Atmosphere/Wind Sensors



$ 5
2
2
1

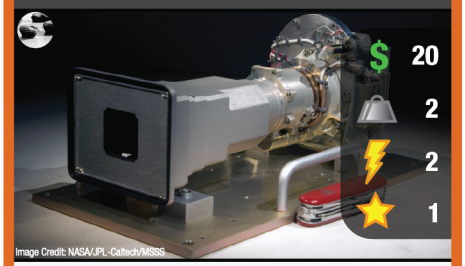
Monitor the weather around the lander

PROS:
- Collects detailed data about wind speed, wind direction, air temperature, and pressure
- Very low cost, mass, power usage

CONS:
- Required for all surface missons to Mars

35

Color Stereo Camera



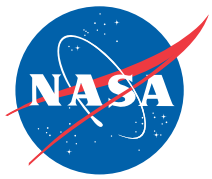
$ 20
2
2
1

Acquires images of the surface

PROS:
- Provides a 3D experience of the surface by combining images acquired by a pair of cameras
- Low mass and low power usage

CONS:
- Medium cost

36



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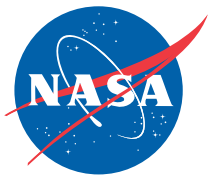

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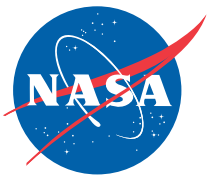
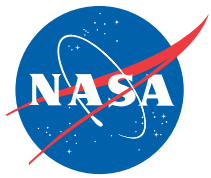


Astrobiobound!



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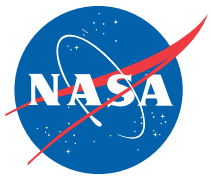

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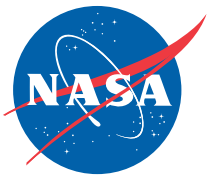
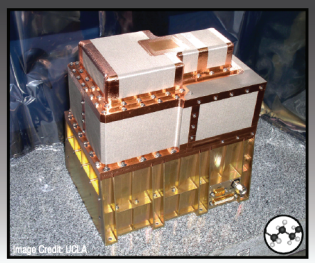


Astrobiobound!

High-Energy Spectrometer



$ 30
4
5
1

Provides information on minerals and chemistry of the surface

PROS:
- Helps show where a place has water, which is essential to life
- Low mass and low power usage

CONS:
- High cost

37

High-Resolution Camera

$ 40
3
4
1

Acquires images of the surface

PROS:
- Shows the highest detail of all

CONS:
- Images a tiny area
- Highest cost
- Has more mass and uses more power than other cameras

38

Life Sciences Laboratory

$ 60
8
25
2

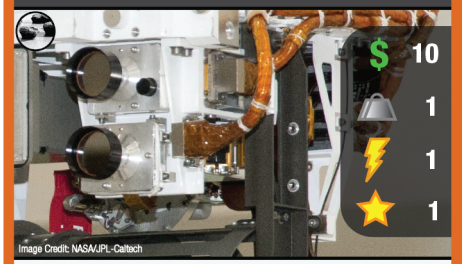
Helps discover signs of past or present microbial life

PROS:
- Helps find out if Earth is the only place that supports life

CONS:
- Highest cost, most mass, and uses the most power
- Requires Robotic Arm card (#25)

39

Medium-Resolution Camera



$ 10
1
1
1

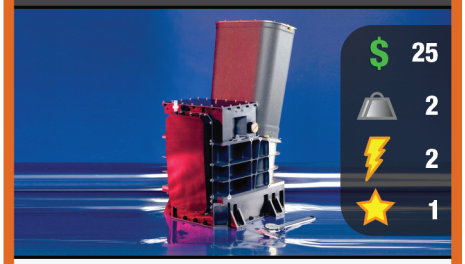
Acquires images of the surface

PROS:
- Images a very wide area
- Low cost, mass, and power

CONS:
- Shows moderate detail compared to the Color Stereo Camera

40

Medium-Resolution Camera



$ 25
2
2
1

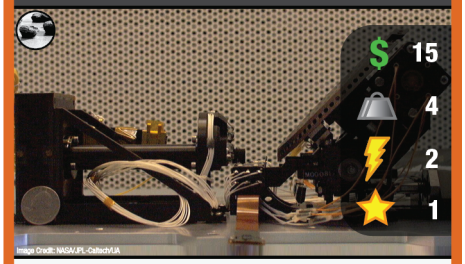
Acquires images of the surface

PROS:
- Shows a wide area of the surface
- Low mass and low power usage

CONS:
- Shows moderate detail compared to the High-Resolution Camera

41

Microscope



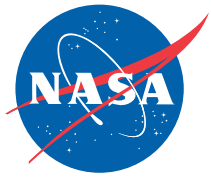
$ 15
4
2
1

Identify very small objects

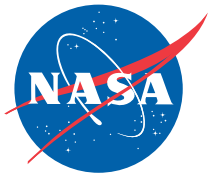
PROS:
- Can see objects as small as the thickness of a cell wall with an Atomic Force Microscope (AFM) and the diameter of a red blood cell with the Optical Microscope (OM)

CONS:
- Can only see a small area
- Requires Robotic Arm card (#25)
- Medium cost

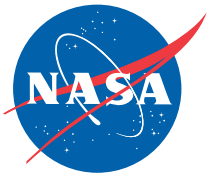
42



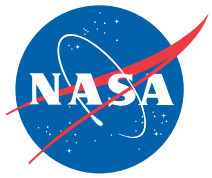
Astrobiobound!



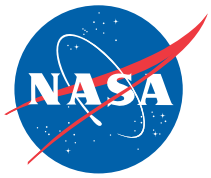
Astrobiobound!



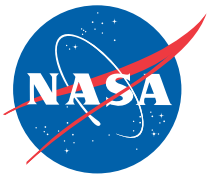
Astrobiobound!



Astrobiobound!

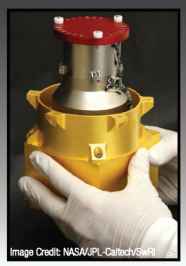


Astrobiobound!



Astrobiobound!

Radiation Sensor



$ 15
1
3
1

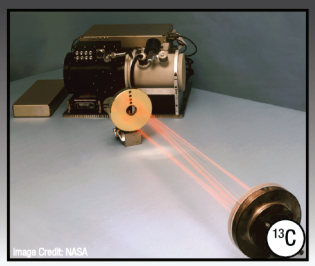
Measures the amount of radiation in the environment

✔ **PROS:**
- Shows how much radiation a surface is currently exposed to
- Low cost, mass, and power usage

✘ **CONS:**
- Cannot tell about past conditions

43

Open Path Laser Spectrometer



$ 15
4
3
1

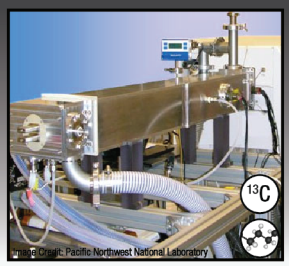
Measure the abundance of atmospheric gases

✔ **PROS:**
- Can detect localized methane emission (where it is coming from)

✘ **CONS:**
- Prototype: Technology has never been used on another planet
- Requires line-of-sight from rover to the lander

44

Liquid Chromatograph



$ 20
3
2
1

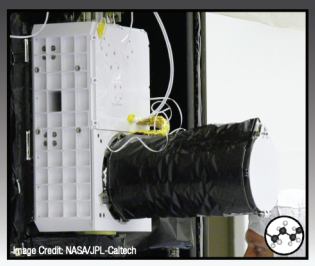
Look for organic compounds

✔ **PROS:**
- Can potentially detect extinct and extant (existing) life

✘ **CONS:**
- Prototype: Technology has never been used on another planet
- Requires water (liquid or ice)
- Requires Robotic Arm card (#25)

45

Imaging Spectrometer



$ 30
2
3
1

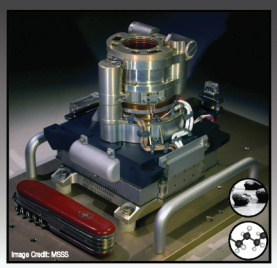
Looks for persistently wet past environments

✔ **PROS:**
- Identifies minerals that form in water
- Low mass and low power usage

✘ **CONS:**
- Low resolution only tells you the general region to look, not the exact spot

46

Hand Lens Imager



$ 15
2
2
1

Identify small objects

✔ **PROS:**
- Can see objects as small as the width of two human hairs
- Includes UV LEDs to identify fluorescent minerals
- Low mass and power

✘ **CONS:**
- Can only see a small area
- Requires Robotic Arm card (#25)

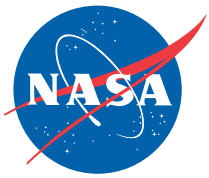
47

Spin-Off: Automobile Sensors

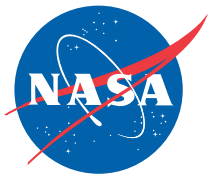
Hooray! Sensors created for your mission help cars become more energy-efficient and easier to maintain!

✔ **EFFECT:**
$25 million for your future research.

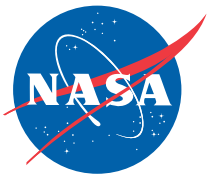
48



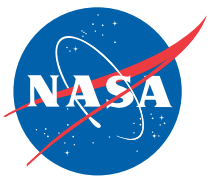
Astrobiobound!



Astrobiobound!



Astrobiobound!



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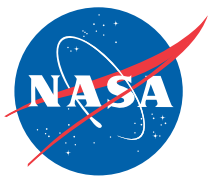

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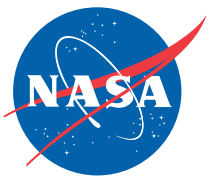


Astrobiobound!

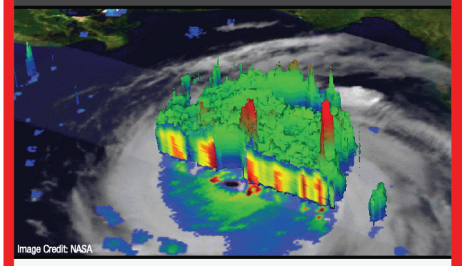
Spin-Off: Communications

Hooray! People around the world can stay in touch more easily by using new communications technologies created for your mission.

✔ **EFFECT:**
$35 million for your future research.

49

Spin-Off: Weather Prediction



Hooray! Your mission discoveries gave new clues about Earth's atmosphere. Scientists can now predict weather better!

✔ **EFFECT:**
$15 million for your future research

50

Budget Cut!

Sorry! Congress reduced NASA's budget

✗ **EFFECT:**
Your mission loses one science tool

51

Rocket Failure!

Sorry! Your rocket failed during testing, you had to buy another one

✗ **EFFECT:**
You cut out two science tools to help pay for the new rocket

52

System Failure!

Instrument Test Software v1.4

Boot: PASS	Storage: FAIL
Memory: PASS	Calibration: FAIL
Input 1: PASS	Voltage: FAIL
Input 2: PASS	Amplitude: FAIL
Output 1: PASS	Frequency: FAIL
Output 2: FAIL	

Sorry! During system testing, one science tool failed to work

✗ **EFFECT:**
Your mission loses one science tool

53

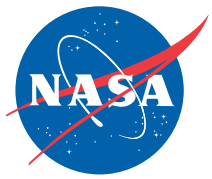
Biosignature: Structures

Micro or macro fossils preserved in rock

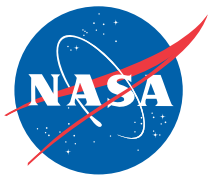
✔ **PROS:**
- Past life could be preserved for millions or billions of years

✗ **CONS:**
- Requires a camera to identify
- Requires a surface mission due to small size

54



Astrobiobound!



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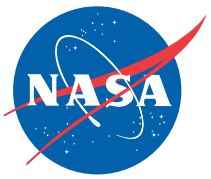

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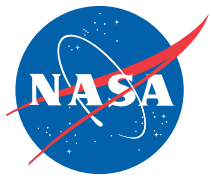
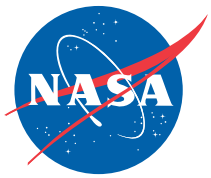
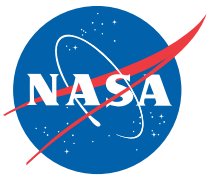


Astrobiobound!

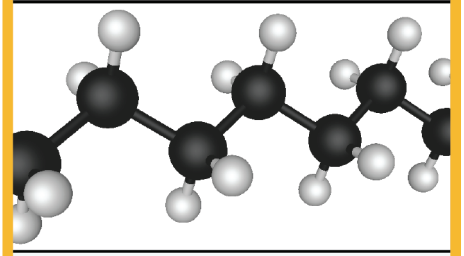


Astrobiobound!



Astrobiobound!

Biosignature: Chemistry



Minerals, chemicals, or molecules that are found when life may be or is present

✔ **PROS:**
- May be able to identify from orbit
- May be able to identify from a distance on the surface

✘ **CONS:**
- Requires complex instruments to identify

55

Biosignature: Organic Material

^{13}C

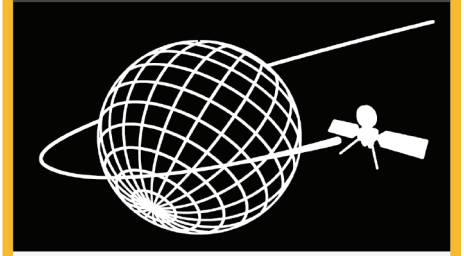
This type of carbon is usually found when life is or was present

✔ **PROS:**
- May identify existing or past life

✘ **CONS:**
- Requires complex instruments to identify
- Requires a surface mission to perform test

56

Mission Type: Flyby



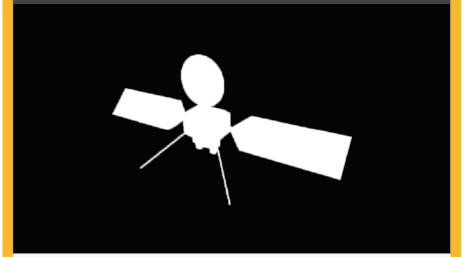
Spacecraft makes less than one orbit around the planet/moon

✔ **PROS:**
- Less complex than orbiting or landing

✘ **CONS:**
- Not much time to study the planet/moon
- Expensive for the amount of science gained

57

Mission Type: Orbiter



Spacecraft orbits around the planet/moon

✔ **PROS:**
- Less complex than landing
- Can see more of the surface than a lander

✘ **CONS:**
- Instruments cannot see as much detail as a surface mission

58

Mission Type: Stationary Lander

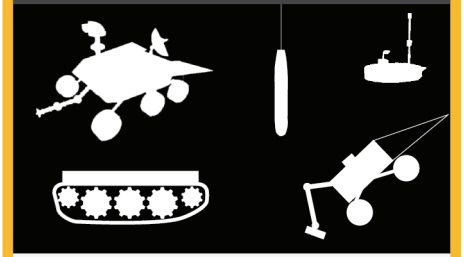
Spacecraft lands on the surface

✔ **PROS:**
- Can see more detail than an orbiter
- Can analyze samples on the surface

✘ **CONS:**
- More complex than an orbiter
- Limited to science found directly around lander

59

Mission Type: Mobile Lander

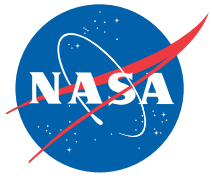


Spacecraft lands on the surface and can move around

✔ **PROS:**
- See more detail than an orbiter
- Analyze samples on the surface
- Visit multiple sites on the surface

✘ **CONS:**
- More complex than an orbiter and stationary lander
- Requires more power than a stationary lander

60



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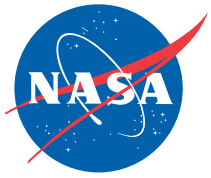

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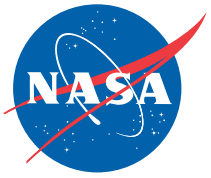

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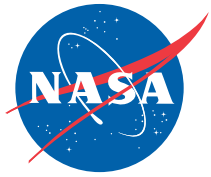

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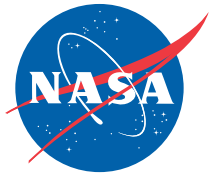

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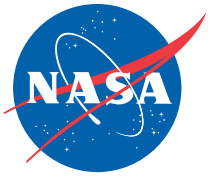

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Mission Target: Mars

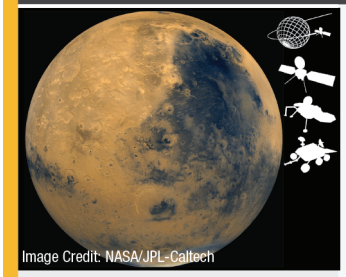
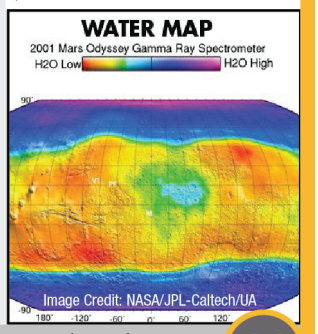


Image Credit: NASA/JPL-Caltech

Why is Mars a good target?
Previous spacecraft have revealed that Mars was once more Earthlike. It was warmer, had a thicker atmosphere, and liquid water flowed across the surface. Currently, Mars has vast reserviours of water ice and salts, places where we find bacteria thriving on Earth.

What biosignatures would we look for?
Instruments in orbit around Mars may detect minerals that can preserve fossils and indicate past wet environments. Some orbital instruments can also detect organic material. Figuring out if the organic material is from current or past life may be tricky and may require a closer look. Other orbital instruments can detect methane, a gas that is the byproduct of some types of life on Earth but it can also be released for non-biological reasons. Therefore, researchers will be looking for biosignatures: organic materials and chemistry.

What type of life are we looking for?
Current and past-life. Minerals suggest where fossils may be preserved and gases may be the product of current life.



Map of the amount of water at or near the surface of Mars. The lowest concentrations are shown in red.

61

Mission Target: Gale Crater, Mars

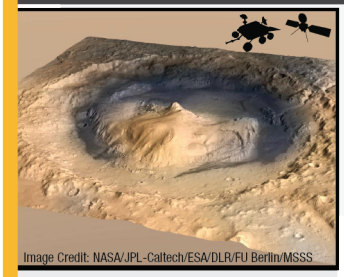


Image Credit: NASA/JPL-Caltech/ESA/DLR/FU Berlin/MSSS

Why is Gale Crater a good target?
Evidence suggests the area was a long-standing, drinkable water lake. The lake may have been able to support bacterial life during that time.

What type of life are we looking for?
Past-life. There is no liquid water present today, so any evidence of life we find will be fossil evidence.

What biosignatures would we look for?
Because the environment in Gale Crater is thought to have been warm and relatively normal compared to Earth, it's more likely that the type of bacteria we would look for are the photosynthetic bacteria, such as stromatolites (blue-green algae). These organisms build pillars in the water and when buried under sediment, tend to look like layered columns. Therefore, researchers will be looking for biosignatures: structures.

Fossilized stromatolite structure, Knosses Locality, Western Australia

62

Mission Target: Polar Ice Cap, Mars

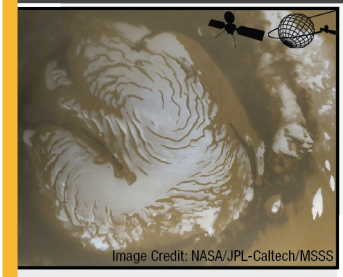
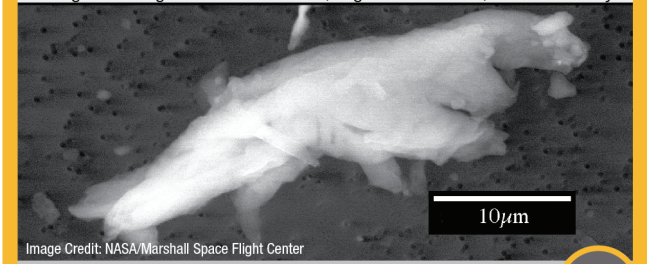


Image Credit: NASA/JPL-Caltech/MSSS

Why are Ice Caps a good target?
The north (left) and south polar ice caps consist of a cap of CO_2 ice and water ice beneath that. Bacteria may be able to use the water now or in the past.

What type of life are we looking for?
Current and past-life. The weight of the ice may melt water at the base of the cap.

What biosignatures would we look for?
Millions to a billion years of ice may trap ancient bacteria or may provide a water source for current life. One type of bacteria that may be present are psychrophiles. Even if the bacteria themselves cannot be found, they may leave clues to their presence in the form of organic material and elements or molecules. Therefore, researchers will be looking for biosignatures: structures, organic materials, and chemistry.



One of the many and larger microorganisms found in a sample of ice collected from Antarctica

63

Mission Target: Recurring Slope Lineae, Mars

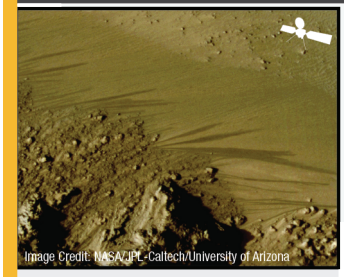


Image Credit: NASA/JPL-Caltech/University of Arizona

Why are recurring slope lineae (RSL) a good target?
Scientists think these features, dark streaks at the base of the rocks, are the result of briney (salty) water flowing on the surface.

What type of life are we looking for?
Past and current-life. There may be microbes currently in the water and there may be fossil evidence preserved in the rocks.

What biosignatures would we look for?
Because salt forms from liquid water, we should look for bacteria that like salt. One example is an extremophile that likes salty conditions, halophiles. Researchers will be looking for biosignatures: structures, organic material, and chemistry.


Image Credit: NASA/Matthew F. Reyes

Colony of salt loving bacteria and archaea found in the Arabian desert.

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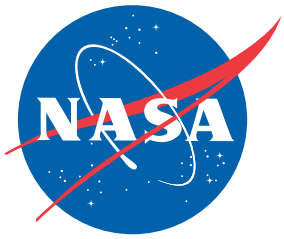

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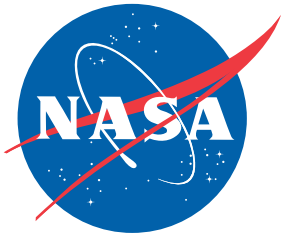

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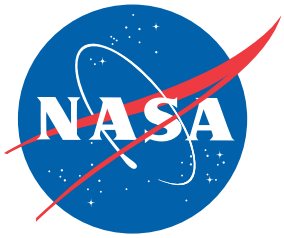

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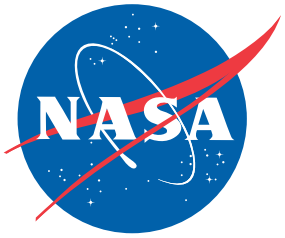


Astrobiobound!

Mission Target: Salt Deposits, Mars

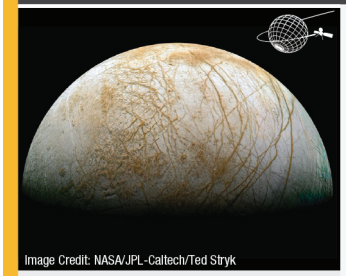
Why is salt a good target?
Salt (white material in the left image) forms from the evaporation of salt water. The water body may have been able to support bacterial life during that time.

What biosignatures would we look for?
Because salt forms from liquid water, we should look for bacteria that like salt and or water. One such example would be stromatolites (blue-green algae) that form pillars or mounds. Another example would be a type of extremophile that likes salty conditions, halophiles. These types can live in water that is 5 to 10 times saltier than Earth's ocean water. Either type of life could be found in and around the salt deposits. Researchers will be looking for biosignatures: structures, organic material, and chemistry.

What type of life are we looking for?
Past-life. There is no liquid water present today, so any evidence of life we find will be fossil evidence.

Microbial mat growing in a sample of salt

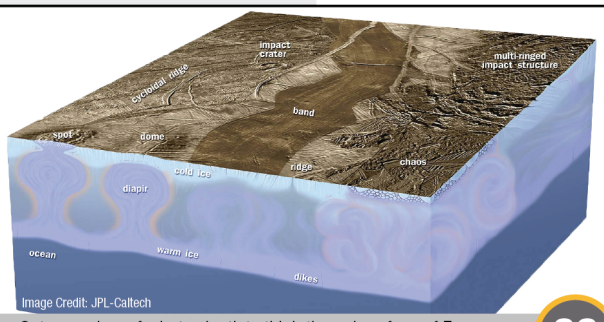
Mission Target: Europa



Why is Europa a good target?
Scientists think the moon has an iron core, rocky mantle, and a surface ocean beneath its icy crust. Tidal heating, caused by the gravity of Jupiter stretching and squeezing the moon during each orbit, may be responsible for the water ocean and produce black smokers on the ocean floor.

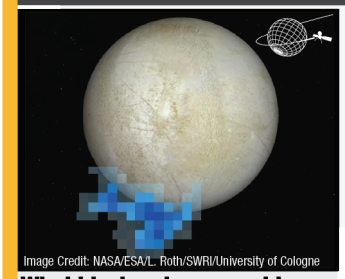
What biosignatures would we look for?
Cold loving psychrophiles on the surface and salt loving halophiles brought to the surface. Researchers will be looking for biosignatures: organic material and chemistry.

What type of life are we looking for?
Past and current-life. There may be microbes currently in the water and ice. Ancient bacteria may be preserved in the ice.



Cutaway view of what scientists think the subsurface of Europa looks like. The surface is an actual image from the Galileo mission.

Mission Target: South Polar Geysers, Europa



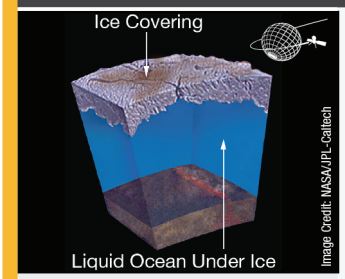
Why are geysers a good target?
Scientists think the geysers are ejecting water (blue pixels) from the interior of the moon. Looking at the water brought to the surface is a lot easier than drilling down to it.

What biosignatures would we look for?
Some bacteria thrive in very cold temperatures. They are a type of extremophile called, psychrophiles. The geysers may also bring to the surface bacteria that exist below the icy crust of the moon. Researchers will be looking for biosignatures: structures, organic material, and chemistry.

What type of life are we looking for?
Past and current-life. There may be microbes currently in the water and there may be fossil evidence preserved in the ice around the geysers.

Castle geyser in Yellowstone National Park

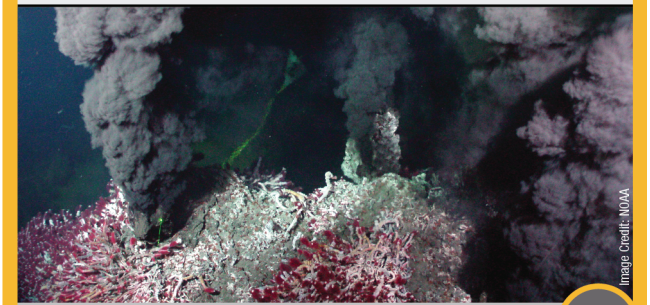
Mission Target: Subsurface Ocean, Europa



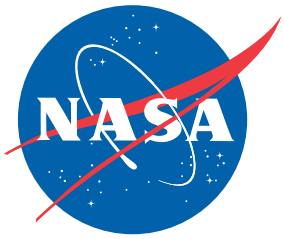
Why is the subsurface ocean a good target?
Scientists think the moon has an iron core, rocky mantle, a surface ocean beneath an ice crust. Tidal heating, caused by the gravity of Jupiter stretching and squeezing the moon during each orbit, may be responsible for the water ocean and cause black smokers on the ocean floor.

What biosignatures would we look for?
A spacecraft able to navigate the subsurface ocean would be looking for signs of current life and preserved fossils on the ocean floor. Researchers will be looking for biosignatures: structures, organic material, and chemistry.

What type of life are we looking for?
Past and current-life. There may currently be thermophiles living around black smokers. Rocks on the ocean floor may contain fossils.



Scientists believe there may be black smokers on the ocean floor. Black smokers on Earth are teaming with life.



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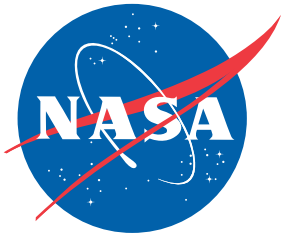

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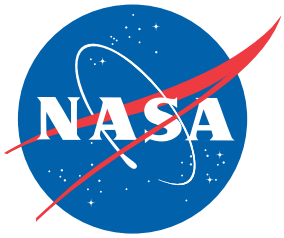

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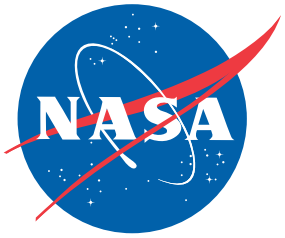

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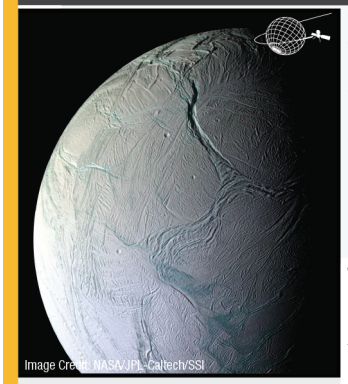
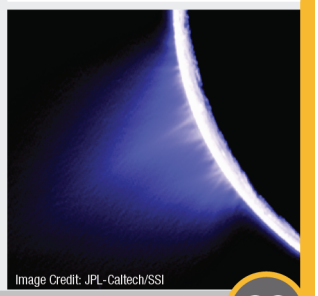
Mission Target: Enceladus



Why is Enceladus a good target?
It is believed there is an ocean of water beneath a thin sheet of ice and cryovolcanoes that shoot water vapor and complex hydrocarbons could also harbor the potential for bacterial life and is an extremely good candidate to search for life.

What type of life are we looking for?
Due to the extremely cold temperatures, scientists will be looking for microbial extremophiles such as psychrophiles and halophiles. Thermophiles may also exist on the ocean floor if there are black smokers. Ancient life may also be preserved in the ice.

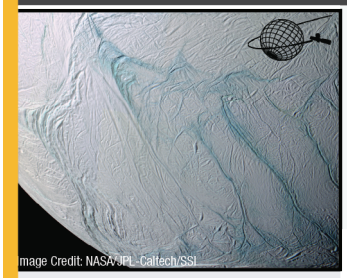
What biosignatures would we look for?
Beneath a thin sheet of ice, scientists believe there is an ocean of salt water. Active processes on the planet can be seen through cryovolcanic eruptions indicating that there is currently water just below the surface. It is more likely scientists will look for present life, therefore they will be investigating biosignatures: chemistry and organic materials.



The top image, shows the scars from the tectonic forces at work on Enceladus. The below image shows geysers lit by the Sun from behind.

69

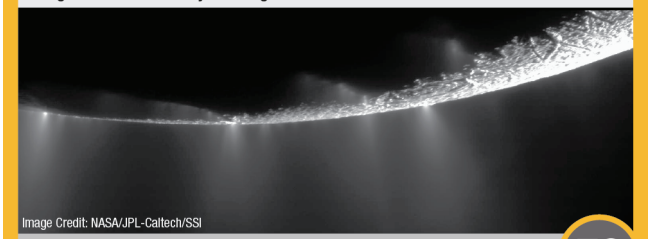
Mission Target: Sulci, Enceladus



Why are sulci a good target?
Active processes on this moon show fresh ice and a number of organic compounds. Since water is an important component to life on Earth and this area is tectonically active, this that leads researchers to believe sulci are an extremely good candidate to search for life.

What type of life are we looking for?
Due to the extremely cold temperatures, scientists will be looking for microbial extremophiles such as psychrophiles and halophiles. Past life may also be preserved in the ice around the sulci.

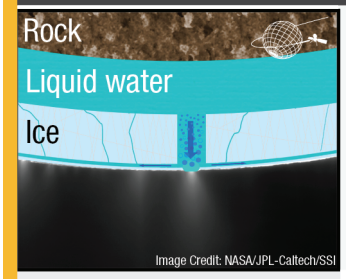
What biosignatures would we look for?
Near these stripes is course-grained water ice, indicating it is freshly developed ice. Carbon dioxide and simple organic compounds have also been found nearby. This area is also where cryovolcanoes can be found, releasing water vapor, methane, carbon dioxide, and nitrogen. Because there are active processes on this moon, it is more likely scientists will look for present life, therefore they will be investigating biosignatures: chemistry and organic materials.



Top image shows the four sulcus (bluish lines) responsible for the geysers seen in the below image.

70

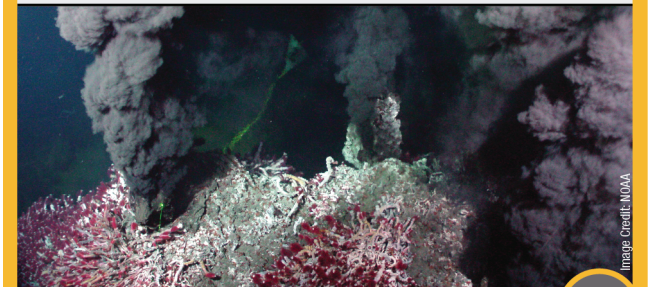
Mission Target: Subsurface Ocean, Enceladus



Why is the subsurface ocean a good target?
Scientists think the moon has an rock-metal core surrounded by liquid water and an ice shell. Radioactive heat and tidal heating, caused by the gravity of Saturn stretching and squeezing the moon during each orbit, may be melting the ice and cause black smokers on the ocean floor.

What type of life are we looking for?
Past and current-life. There may be microbes currently in the water and living around black smokers. Rocks on the ocean floor may contain fossils and past life may be preserved in the surrounding ice.

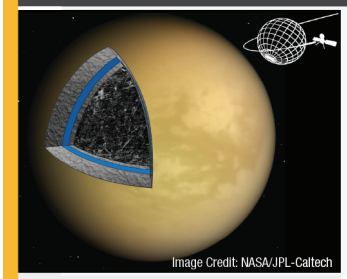
What biosignatures would we look for?
A spacecraft able to navigate the subsurface ocean would be looking for signs of current life and preserved fossils on the ocean floor. Researchers will be looking for biosignatures: structures, organic materials, and chemistry.



Scientists believe there may be black smokers on the ocean floor. Black smokers on Earth are teaming with life.

71

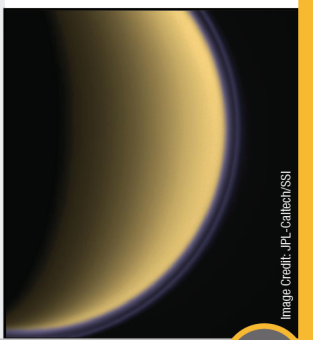
Mission Target: Titan



Why is Titan a good target?
Scientists think the moon has an icy/rocky core, surrounded by a layer of ice, a global ocean, another layer of ice that forms the crust with temporary methane lakes and seas, and finally, a thick atmosphere. Life may exist in the outer two layers.

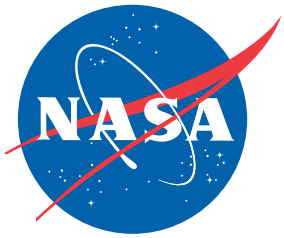
What type of life are we looking for?
Past and current-life. There may be microbes currently in the liquid and ice. Fossil evidence may be preserved in the ice.

What biosignatures would we look for?
Cold loving psychrophiles on the surface and possible bacteria that live in the methane ice. Cryovolcanoes may bring to the surface microbes that exist beneath the surface. Lakes and seas, consisting mostly of liquid methane are another potential habitat for life. Scientists think that impact craters may be a good place to look for past life as they may have created a hydro-thermal like environment. Researchers will be looking for biosignatures: organic materials and chemistry.



The atmosphere of Titan appears as a purple haze in the above image. There are two thin layers with a gap between them.

72



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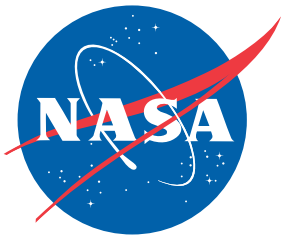

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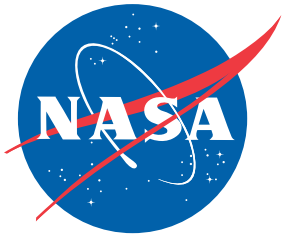

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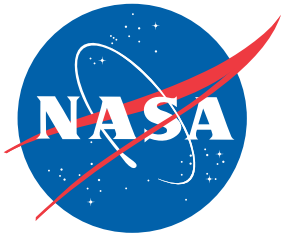

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Mission Target: Cryovolcanoes, Titan

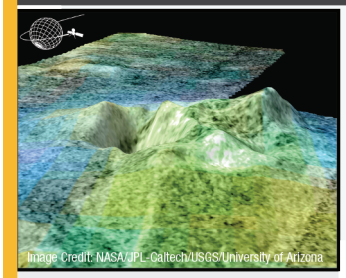
Image Credit: NASA/JPL-Caltech/USGS/University of Arizona

Why are cryovolcanoes a good target?
Liquid and ice "lavas" erupt from these volcanoes bringing to the surface material from underground. The liquid and ice may contain bacteria from below the surface.

What type of life are we looking for?
Current and past-life. There may be psychrophiles and methane eating bacteria living in the ice or preserved past life trapped in the "lava".

What biosignatures would we look for?
Around the cryovolcanos, the spacecraft can sample material that formed on the surface as well as material from deeper in the moon. Current life may be found as well as preserved fossils. Therefore, researchers will be looking for biosignatures: structures, organic materials, and chemistry.

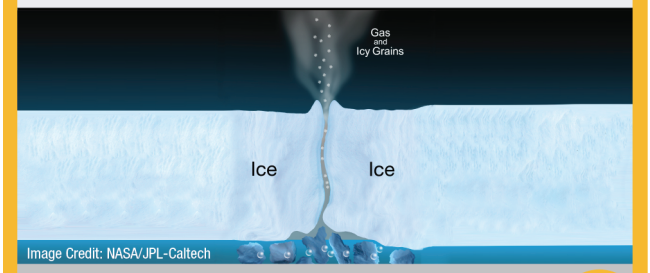

Image Credit: NASA/JPL-Caltech

Illustration of how scientists think cryovolcanism works based on our understanding of Earth volcanoes

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Mission Target: Seas and Lakes, Titan

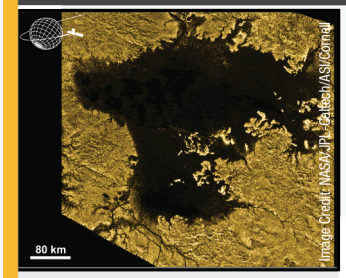

Image Credit: NASA/JPL-Caltech/ASI/Cornell

Why are seas and lakes a good target?
The lakes and seas are thought to contain organic material. Dry lakes may even have organic material trapped in minerals and chemicals left behind.

What type of life are we looking for?
Current and past-life. There may be methane eating bacteria living in the ice or liquid methane and ethane. There may also be past life left in evaporate material.

What biosignatures would we look for?
Instruments can sample the composition of the liquid and search for organic material. Understanding the interaction between the atmosphere and the liquid will help determine the chemistry available for life. Measuring the depths of the lakes and seas will help estimate how much material is available for life. Therefore, researchers will be looking for biosignatures: structures, organic materials, and chemistry.

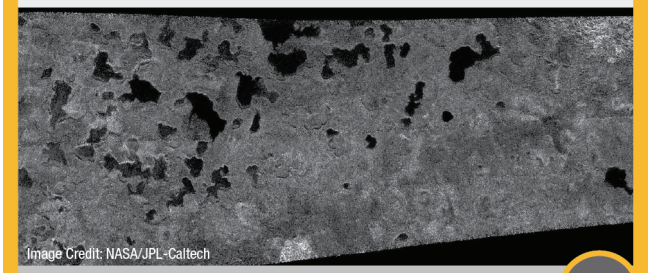
Image Credit: NASA/JPL-Caltech

The largest lakes (dark areas) in the above radar image are around 40 km across. The darker the lake, the fuller it is.

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Mission Definition: Surface Sample Return


Image Credit: NASA/JPL-Caltech

This mission will collect samples from the surface and return the samples to Earth for analysis.

Additional cards needed:
- **Sample Cache (separate spacecraft)**
- **Surface to Orbit Spacecraft**
- **Orbit to Earth Spacecraft**

75

Mission Definition: Orbital Sample Return

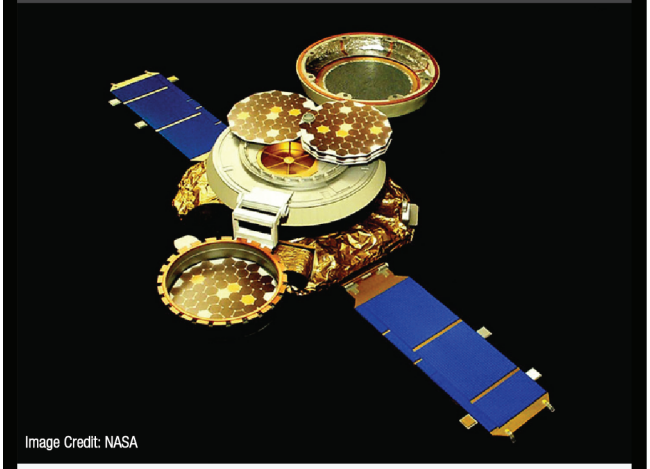
Image Credit: NASA

This mission will collect samples from the orbit and return the samples to Earth for analysis.

Additional cards needed:
- **Aerogel**
- **Orbit to Earth Spacecraft**

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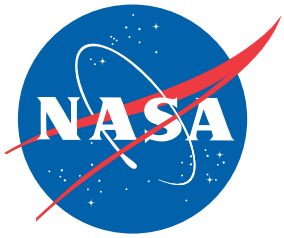
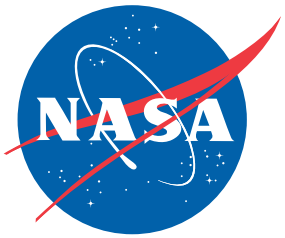


Astrobiobound!



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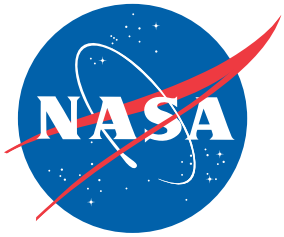

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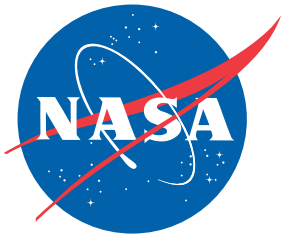

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Surface to Orbit Spacecraft

$ 50
40
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0

Rocket that will transfer the Sample Cache (Rover Team) to the Orbit to Earth Spacecraft (Orbit to Earth Team)

✔ **PROS:**
- Gets the samples from the surface to orbit

✘ **CONS:**
- Untested technology, high risk
- Very expensive

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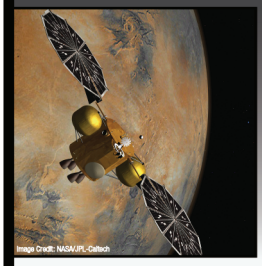
Orbit to Earth Spacecraft



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10
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Contains separate rockets that will allow an orbiting spacecraft to return a sample to Earth

✔ **PROS:**
- Samples on Earth can be analyzed using the most recent technology and saved for future techniques

✘ **CONS:**
- Untested technology, high risk
- Very expensive

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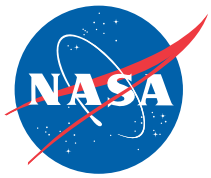

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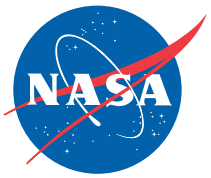

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