**NASA 2018 PI IN THE SKY CHALLENGE!**

Choose 5 problems to solve. For each problem correct, there will be assessment bonus points available! <https://www.jpl.nasa.gov/edu/nasapidaychallenge/>

**1 - Solar Sleuth**

Exoplanets are worlds that orbit other stars. Using the Kepler Space Telescope, scientists can study distant stars and search for the exoplanets around them. When Kepler measures repeated dips in the brightness of a star, it can mean that an exoplanet is passing in front of that star from Kepler’s point of view. Scientists can then determine the size of the exoplanet based on how much the star’s light dipped when the planet passed in front of it. This dip in brightness detected by Kepler is expressed as a percentage of the star’s light that is blocked by the planet – with large planets blocking out more of the star’s light and small, Earth-size planets blocking less. This percentage equals the ratio of the area of the planet’s disk to the area of the star’s disk. If the Kepler detects a 0.042% drop in brightness from the star Kepler-186, which has a disk area of 416,000,000,000 km2, **what is the radius of the exoplanet, known as Kepler-186f?**

## 2 - Helium Heist

With a radius of 70,000 km, Jupiter is our solar system’s most massive planet. About 10% of the volume from Jupiter’s cloud tops to 20,000 km below is helium, with the rest being mostly hydrogen. Circulation in this molecular hydrogen layer causes some of that helium to be depleted as it moves into the liquid metallic hydrogen layer beneath. The tremendous pressure inside Jupiter condenses helium into droplets that fall like rain through the less dense liquid metallic hydrogen. The presence of helium rain inside Jupiter helps explain why scientists observe less helium in the clouds than expected.

**If 10% of the helium volume in Jupiter’s molecular hydrogen layer has been rained out since the planet formed, what is the volume in cubic km that has rained out?**

**Given that Earth’s radius is 6,371 km, about how many Earth-size spheres of helium have been rained out?**

**3 - Quake Quandary**

During a seismic event on Mars, or a “marsquake,” a type of seismic wave called surface waves travel outward from the epicenter, across the planet in all directions. Scientists expect these surface waves to arrive at NASA’s InSight lander, designed to study the quakes, at three different times: R1, when the first wave arrives, having traveled the shortest distance from the epicenter to the lander; R2, when the second wave arrives, having traveled the other way around Mars; and R3, when the first wave again impacts the lander, having traveled all the way around Mars. Let’s imagine InSight records marsquake waves at the following Earth times:

**R1** = 08:38:09.4 UTC

**R2** = 10:04:48.2 UTC

**R3** = 10:25:43.0 UTC

\*Note times are in UTC, which is written in hh:mm:ss format.

**Use the formulas below to determine the velocity (U) in rad/s of the surface wave, the distance in radians on the sphere from InSight to the epicenter (Δ), and the time the marsquake occurred (t0).**



## 4 - Asteroid Ace

Asteroid 'Oumuamua is a uniquely-shaped interstellar object discovered in October 2017. It’s the first visitor from outside our solar system to be detected. Preliminary analyses indicate that 'Oumuamua is quite elongated, about 10 times as long as it is wide. It was first detected after it had passed Earth at a high speed on its journey out of our solar system, traveling at about 85,700 miles per hour.

So scientists could make detailed observations of the interstellar visitor before it sped too far away, they had to quickly re-plan their schedules. By monitoring how the brightness of the asteroid fluctuated as it spun on its axis, scientists estimate that 'Oumuamua rotates once every 7.3 hours.

**Given these findings, what's the angular rotation rate of asteroid 'Oumuamua in rad/s?**

**How does this compare with Earth's rotation rate?**

## 5 - Crater Curiosity

Craters form when an object hits the surface of a planet or other body. The impact creates a round impression surrounded by material, called ejecta, that gets blasted out of the crater. Scientists study ejecta because it contains clues about what’s below a planet’s surface. When an object hits Mars at an angle under 20 degrees, the crater is less circular and the ejecta settles in a butterfly shape. Some areas around the crater contain no blast material. Finding craters that formed this way can help scientists understand how meteor impacts change the surface of a planet. To do this, they measure a crater’s circularity ratio. If the ratio is less than 0.925, it suggests that an object impacted at an angle under 20 degrees and created a butterfly ejecta pattern.

**Using the circularity ratio formula, 4πA /p2, determine which of the following craters would have the butterfly ejecta pattern.**

**Aveiro crater** (shown in the front of the above illustration on website)

* A (area) = 67 km2
* P (perimeter) = 30 km

**Unnamed crater** (shown in the back of the above illustration on website)

* A (area) = 32 km2
* P (perimeter) = 21 km

## 6- Epic Eclipse

When sunlight hits the moon (which has a radius of 1,738 km), a cone-shaped shadow is created. During the total solar eclipse on August 21, 2017, the distance from the center of the moon to the center of Earth (which has a radius of 6,378 km) will be 372,027 km. On that day, if the moon’s shadow were not intersected by the surface of Earth, it would extend 377,700 km from the moon to its vertex.

Viewers on Earth who want to witness the eclipse will have to be at a location inside this shadow as it passes over Earth to see the eclipse at totality. **What is the approximate surface area of Earth that will be covered by the disc of the moon’s shadow at any one time during the eclipse?**

**7- Finale Fanfare**

In 2017, after more than 12 years at Saturn, the Cassini mission will come to an end with a plunge into Saturn. The finale is designed to keep Cassini from impacting and possibly contaminating any of Saturn’s scientifically intriguing moons. First, mission operators have planned a daring series of orbits that will take Cassini closer to Saturn than ever before. Cassini will use the gravity of Saturn’s moon Titan to alter its trajectory and fly into the gap between Saturn and its rings. It all begins with a flyby of Titan on April 22, putting Cassini on a new orbital path whose first apoapsis is on April 23. Then, it will complete 22 elliptical orbits with an average periapsis altitude of 63,022 km and an average apoapsis altitude of 1,274,828 km. A final flyby of Titan will place Cassini on a half-orbit trajectory for Saturn impact.

**Use Kepler’s third law below to find approximately how many days each orbit will take. Approximately what day will Cassini dive into Saturn’s atmosphere?**

[](http://www.jpl.nasa.gov/edu/images/activities/cassini_formula.png)

* µcb (gravitational parameter of Saturn) = 3.7931187 x 1016 m3/s2
* aSC = semi-major axis of Cassini's orbit
* TSC = orbital period of Cassini

**8 - Habitable Hunt**

Scientists can learn a lot about planets beyond our solar system by studying their stars. They can calculate an exoplanet’s orbital period by measuring how often its star dims as the planet passes by. They can even find potentially habitable worlds with a few key details. The star’s temperature and luminosity, which are related to its mass, define its habitable zone, the area where liquid water can exist. And the bond albedo, or percentage of light reflected by the exoplanet, helps estimate its temperature.

Scientists recently discovered seven Earth-like planets orbiting the star TRAPPIST-1. **Given TRAPPIST-1’s measurements below, what are the inner and outer radii (r), in AU, of its habitable zone?** Use the formula below.

[](http://www.jpl.nasa.gov/edu/images/activities/trappist1_formula1.png)

**TRAPPIST-1 system:**

* L\* (star luminosity) = 2.0097x1023 watts
* µcb (star gravitational parameter) = 1.06198x1019 m3/s2
* σ (Stefan-Boltzmann constant) = 5.67×10-8 Wm-2K-4
* T (planetary temperature) = 192-295 K
* A (planetary bond albedo) = 0.3

**Given the orbital periods (Tp), for TRAPPIST-1’s planets below, which are in the habitable zone?**Use Kepler’s third law below to find the semi-major axis of each orbit (ap).

[](http://www.jpl.nasa.gov/edu/images/activities/trappist1_formul2.png)

**Orbital periods:**

* TRAPPIST-1b = 1.51087081 days
* TRAPPIST-1c = 2.4218233 days
* TRAPPIST-1d = 4.049610 days
* TRAPPIST-1e = 6.099615 days
* TRAPPIST-1f = 9.206690 days
* TRAPPIST-1g = 12.35294 days
* TRAPPIST-1h = 20 days

## 9- Hazy Halo

With its methane lakes and hazy atmosphere reminiscent of a primordial Earth, Saturn’s moon Titan is an intriguing world – and one that scientists believe may harbor ingredients for life. Though spacecraft have studied Titan up close, and the Cassini mission sent a probe to the surface, much of the moon remains a mystery because a dense, 600-km thick atmosphere masks its rocky surface. To study Titan in more detail, scientists have proposed developing a spacecraft to map the surface of this mysterious moon.

**Given Titan’s radius of 2,575 km, what percentage of the moon’s makeup by volume is atmospheric haze?**

**If scientists hope to create a global map of Titan, what is the surface area that a future spacecraft would need to map?**

## 10 - Round Recon

The Mars Reconnaissance Orbiter (MRO) has been zipping around Mars since 2006, collecting data and images that have led to exciting discoveries about the Red Planet. So scientists can get the data and images they need from MRO, they must know when the spacecraft (traveling in a near-circular, near-polar orbit at an average speed of 3.42 km per second) will reach certain locations around Mars.

Given that Mars has a polar diameter of 6,752 km and MRO comes as close to the planet as 255 km at the south pole and 320 km at the north pole, how far does MRO travel in one orbit\*?

**How long does it take MRO to complete one orbit?**

**How many orbits does MRO complete in one Earth day?**

\*MRO’s orbit is near enough to circular that the formulas for circles can be used.

## 11 - Sun Screen

A transit occurs when a planet passes in front of the disk of a star. As seen from Earth, only Mercury and Venus transit our star, the sun. During a transit, there is a slight dip in the amount of solar energy reaching Earth, which can be found using this equation:



**B%**= 100 \*( )

**B** = percentage drop in the brightness of the sun

**r**= the radius of the planet as it appears from Earth (in arcseconds)

**R** = the radius of the sun as it appears from Earth (in arcseconds)

With many solar-powered satellites orbiting Earth, it’s important to know what impact a dip in solar energy might have.

If 1,360.8 w/m2 of solar energy reaches the top of Earth’s atmosphere, how many fewer watts reach Earth when Mercury (diameter = 12 arcseconds) transits the sun (diameter = 1,909 arcseconds)?

## 12 - Gravity Grab

The Juno spacecraft is hurtling toward Jupiter. At closest approach, it will reach a velocity of 57.98 km per second relative to the planet. To get into orbit around Jupiter, Juno will have to brake at just the right time to be pulled in by Jupiter’s gravity or miss its target completely.

**By how much does Juno need to change its velocity relative to Jupiter to get into a 53.5-day orbit around the planet?**

Use these equations to approximate a solution assuming Juno could instantaneously decelerate at perijove:

**T** = 2π√(  )

**E**= 

**T** = orbital period (in seconds)

**E** = total orbital energy

**a**= semi-major axis of the orbit (in km)

**µ** = gravitational parameter for Jupiter (126,686,536 km3/sec2)

**v** = velocity of Juno relative to Jupiter after deceleration

**r**= radius of Juno at perijove (76,006 km)

## 13 - Mars Marathon

The Mars Exploration Rover Opportunity has been driving on the Red Planet for more than 11 years -- not bad for a mission only planned to last for three months! Opportunity has already beat the off-Earth driving distance record of 39 kilometers and is approaching a marathon distance: 42.195 kilometers.

**When Opportunity reaches the marathon mark, how many times will its 25-centimeter diameter wheels have rotated?**

## 14 - Pixel Puzzler

The Dawn spacecraft is orbiting Ceres -- a nearly spherical dwarf planet with an average radius of 475 kilometers -- in a perfectly circular polar orbit. While in orbit, Dawn will snap images of Ceres’ surface to piece together a global map. From its lowest altitude orbit of 370 kilometers, Dawn’s camera can see a patch of Ceres about 26 kilometers on a side.

**Assuming no overlap in the images, how many photographs would Dawn have to take to fully map the surface of Ceres?**

## 15 - Frozen Formula

Scientists have good reason to believe that Jupiter’s moon Europa has a liquid ocean wedged between its ice shell and a rocky sea floor. Though it has a known radius of 1,561 kilometers -- slightly smaller than Earth’s moon -- uncertainty exists about the exact thickness of Europa’s ice shell and the depth of its ocean.

**Assuming Europa’s ice shell is between 2 and 30 kilometers thick and its ocean is between 3.5 and 100 kilometers deep, what is the minimum and maximum volume of its ocean?**

## 16 - Hear Here

The twin Voyager spacecraft, which launched in 1977, are the most distant human-made objects in space. It takes more than 18 hours for a signal from the 12.5-watt X-band transmitter on Voyager 1 to reach Earth, nearly 131 astronomical units away (one astronomical unit, AU, is equal to about 150,000,000 kilometers). The Voyager high-gain antenna, a circular parabolic reflector, transmits a circular radio signal about 0.5 degrees wide.

**At the current distance, what fraction of the Voyager 1 radio beam is received on Earth by a 70-meter-diameter antenna at NASA’s Deep Space Network (DSN)?**

**How many of the original 12.5 watts are received by the DSN antenna?**

## 17 - Satellite Solver

The Soil Moisture Active Passive, or SMAP, satellite is designed to image 1,000-kilometer-wide swaths of Earth from a near-polar, sun-synchronous orbit 685 kilometers above Earth’s surface.

**How many days will it take SMAP to image all of Earth’s surface?**

\*You may disregard any overlap that may occur

## 18 - Roving Riddle

The Curiosity Mars rover doesn’t have an odometer like those found in cars, so rover drivers calculate how far the rover has driven based on wheel rotations. Since landing on Mars in August 2012, Curiosity’s 50-centimeter-diameter wheels have rotated 3689.2 times in 568 sols (Martian days).

**How many kilometers has Curiosity traveled?**

Loose sand, dirt, slopes and rocks can influence the rover’s progress, so engineers use a technique called visual odometry to determine how much Curiosity’s wheels are slipping. On a steep slope covered in loose dirt, engineers note that the distance between the rover’s visual odometry markers is only 143 centimeters.

**What percent are Curiosity’s wheels slipping with each rotation?**

## 19 - Jupiter Jockey

NASA's Juno spacecraft orbits Jupiter in a highly eccentric orbit, allowing very close passes of the spacecraft to the planet. In one orbit, Juno gets as close as 75,800 kilometers (perijove) to Jupiter and passes as far as 2,771,000 kilometers (apojove) from Jupiter.

**How many kilometers does Juno travel in one orbit?**

## 20 - Flying Formula

The Cassini spacecraft was launched to Saturn with its 28-inch spherical hydrazine tank filled to 69 percent of its volume with hydrazine. After many years of studying Saturn, 82 kilograms of hydrazine were used to maneuver around the ringed planet.

**Given the density of hydrazine is 1.02 grams/cubic centimeter, how much fuel remained in the tank at this time?**

\*Assume no fuel is sitting in the fuel lines