SCHOOLS TUNE INTO MARS

# Topic V

# Space mission to Mars

Egg drop

Going to Mars

Solar energy, a sustainable source of energy

# Egg drop

## 1. Introduction & Pb

The landing phase of a probe is one of the most critical phases of a mission. This is why scientists model these phases in the laboratory before launching. We will take the case of the Insight mission that landed on Mars a few months ago.

To survive the intense friction forces that characterize entry into the atmosphere, the InSight probe is protected by a large diameter heat shield. The latter is covered with tiles made of a special material, which will absorb the impressive amount of energy due to the resistance of the atmosphere to the passage of InSight.

After atmospheric entry, the second stage of InSight's landing consists of a parachute descent. The latter will be deployed at an altitude of about 9 kilometres.

Finally, at an altitude of about 1.3 kilometres, while still flying at a speed of 224 kilometres per hour, InSight separated from its parachute, and found itself in free flight, falling like a rock towards the rusty surface of Mars and quickly moving away from the rear shield it had left behind (and to which the parachute had remained attached).

But very quickly, half a second after this event, the landing gear turns on its retrorockets, to brake and stabilize.

Drawing showing the InSight probe during the final (propelled) stage of landing on the equatorial plain of Elysium.

(© IPGP/Manchu/Bureau 21).

Engineering activities give kids a chance to develop problem solving and observations skills, to work with interesting and engaging tools and materials, and to learn how to work as a member of a team. When you drop something, it falls to the ground. This is because it is pulled by the gravity of the Earth. You'll notice that some things drop faster than others, this is because of air resistance. Try dropping a piece of paper and a lego brick. Which drops the fastest?

## 2. Age of students    6-17 years

## 3. Objectives

- Describe and define material properties.
- Identify the forces of gravity, drag, and the term air resistance
- Design and build a system that will protect an egg from a 1-meter drop.

## 4. Primary subjects

Physics

## 5. Additional subjects

## 6. Time required

1 hour

## 7. Key terms.

design process, landing, egg drop competition

## 8. Materials

eggs
big zip bags
cotton-wool
pencils/paper or computer
any construction materials from students' homes

## 9. Background

When you drop something, it falls to the ground. This is because it is pulled by the gravity of the Earth. You'll notice that some things drop faster than others, this is because of air resistance. Try dropping a piece of paper and a lego brick. Which drops the fastest?

If you tried dropping paper and a lego brick or similar, the paper should have dropped to the floor more slowly than the brick, this is because the paper has a larger surface area, so has to push against more air as it drops, which means the air resistance is greater and it drops more slowly.

You need to create something that can absorb the energy the egg gathers as it accelerates towards the ground. A hard surface will crack the egg so you have to think carefully about how you can protect it. Something that will cushion the egg at the end of its fall is a good place to start, you want the egg to decelerate slowly so it doesn't crack or smash all over the ground. You'll need to run a few trials so have some eggs.

## 10. Procedures

The idea is to wrap the egg in a layer of cotton-wool that will protect it from landing. Put the egg wrapped in cotton-wool in a zippered bag and allow it to fall from about 1 m high. If the cotton layer is thin the egg will crack.

## 11. Discussion of the results and conclusions

After the experiment, analyze your data. In an egg drop project, you will determine how well your design performed. If the egg broke after the first drop, you know that revisions need to be made. However, this does not mean the experiment was a bad one. In science, all results are good results, because all results offer an opportunity to learn. When something goes wrong or does not work the way it is expected, it provides a chance to find out why and correct it. If an egg breaks, look at the data, assess the performance of your design and use it to figure how it can be made better.

## 12. Follow up activities

## 13. Explore More (additional resources for teachers)

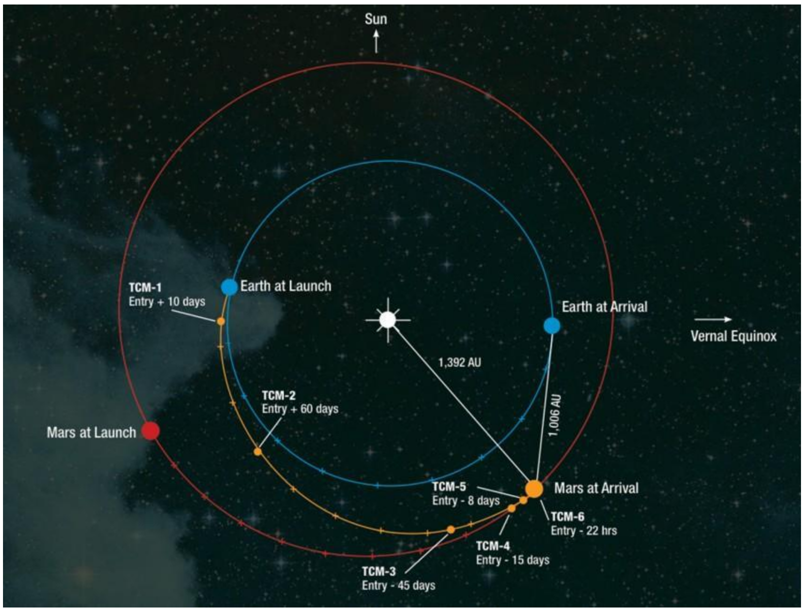
STEM activities websites

- https://www.seis-insight.eu/fr/public/la-mission-insight/atterrissage
- "Mars in a minute" du Jet Propulsion Laboratory (© JPL-Caltech/IPGP).

# Going to Mars

## 1. Introduction & Pb

Finding the relative position of Earth and Mars which correspond to the optimal spacecraft travel path in terms of energy consumption, using planetary position data and advance algebra concept, all in order to determine the next launch opportunity to Mars.




Orbit followed by the InSight probe between Earth and Mars (© NASA)

## 2. Age of students 15-17 years

## 3. Objectives

The objective is to determine the next launch window to Mars from the relative position of Earth and Mars that corresponds to the optimal trajectory of the spacecraft in terms of energy consumption and using planetary position data and the concept of advanced algebra.

## 4. Primary subjects

Mathematics - Physics – Earth and Space Science

## 5. Additional subjects

## 6. Time required

30 min – 1 hour

## 7. Key terms.

Orbits, Earth, Mars, space missions, launch windows, graph

## 8. Materials

Calculator, push-pins, graph paper, quadrille ruled, planetary heliocentric longitudes data sheet

## 9. Background

To get a spacecraft from Earth to any planet, you need to consider the curved travel path resulted as a combination of spacecraft velocity and planet gravitational pull. To get the most from this scenario scientists need to "work" with these forces and travel as much as possible with engines off, so lowering the cost of the mission.

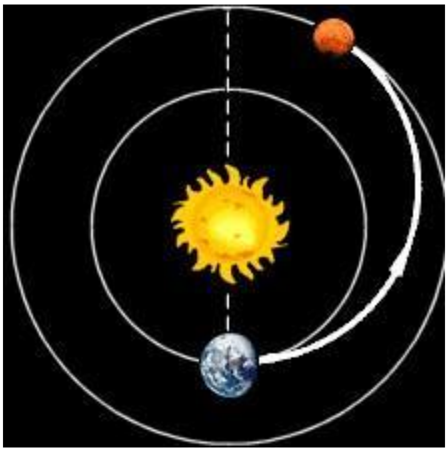
As in many similar scenarios (e.g: passing a ball to a running football teammate) what essentially need to be considered is the initial impulse given to the spacecraft (the launch equivalent to the ball throw) the position of the targeted planet in any moment (described by its orbit) and then the gravitational pull.

Even if the spacecraft could take a variety of curved paths from the launching point to the landing planet, one is considered to be the most efficient in terms of energy consumption - Hohmann transfer orbit.

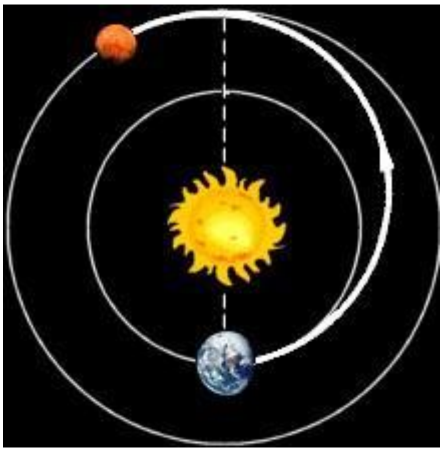
In the case of Earth to Mars travel path, the Hohmann transfer is an elliptical orbit with the sun at one focus of the ellipse that intersects the orbit of the target planet. Launch occurs when Earth is at Hohmann perihelion (the point of the Hohmann orbit that is closest to the sun). Arrival occurs when Mars is at Hohmann aphelion (the point of the Hohmann orbit that is farthest from the sun).

This is a simple explanation for a far more complex scenario where scientists need to take into account a variety of parameters that are more or less constant. What need to be clearly understood is that a specific launching time window have to be calculated and validated through multiple simulation way before the launching. This will allow a proper launch window, so the spacecraft will arrive in the planet's orbit just as the planet arrive at the same place.

**A**



**B**



In A, the respective positions of Mars and Earth at the time of launch. In B, the respective positions of Mars and Earth during landing (Crédit photo : © Philippe Labrot).

## 10. Procedures

Students will be explained that a space station must have an elliptical trajectory around the sun to reach the same point at the same time as the planet Mars. What they should do next is to figure out what the launch time should be so that this intersection will take place.

Students will be explained that the most efficient orbit from the point of view of energy consumption needed for the trip must be calculated, called the Hohmann transfer, in which the spacecraft will travel half of one orbit about the sun, leaving Earth at the orbit's perihelion and arriving at Mars (or any outer planet) at the orbit's aphelion.

Bring into discussion the Kepler's Second Law also tells us that planets travel at different rates of speed in their elliptical orbits, moving faster when they are closer to the sun and slower when they are farther from the sun.

To make possible the complex mathematical task of launching a spacecraft while considering he orbital dynamics of the planets, mention to students three assumptions, actually some unrealistic simplifications but that will allow us a sufficiently accurate calculation of the launch window

The orbits of Earth and Mars are circular and centered on the sun. (Earth's orbit is more circular than Mars' orbit, but they are both slightly elliptical.)

Earth and Mars travel at constant speeds. (They do not. See Kepler's Second Law).

The orbits of Earth and Mars are in the same plane. (They are close but slightly out of plane with one another).

Explain to students the concept of heliocentric longitude. Just as longitudes on Earth measure position with respect to a fixed point (the prime meridian), heliocentric longitudes measure position in space along the ecliptic with respect to the vernal equinox.

Knowing that Earth is, on average, 1 astronomical unit (AU) from the sun and Mars is, on average, 1.52 AUs from the sun have students find the length of the semi-major axis of the transfer orbit in astronomical units (AU).

Using the string and pushpins have students draw the assumed-circular orbits of Earth and Mars about the sun, and the approximation of the Hohmann transfer orbit on graph paper

Determine the period of the Hohmann transfer orbit and then the travel time to Mars along this orbit using Kepler's Third Law (Law of Harmony)

Kepler's Third Law states that the square of the period of any planet is proportional to the cube of the semi-major axis of its orbit. An equation can represent this relationship:

$P^2=ka^3$ with k being the constant of proportionality

Using Earth as an example, we can measure P in years and a in astronomical units so P = 1 year and a = 1 AU. Thus, $P^2=ka^3 \rightarrow k=1 \Rightarrow P^2=a^3$

$P^2= (1.26\ AU)^3 \Rightarrow P \sim 1.41$ years ~ 517 days

The full period of this Hohmann transfer orbit is 517 days. Travel to Mars encompasses half of one orbit, so approximately 259 days.

Considering the daily motions of Earth and Mars, compute the ideal relative position of both planets during the launch.

1 Mars revolution = 687 days => 0.524 degrees/day => 136 degree/259 days

To calculate the position of Mars at the time of launch, subtract the amount of its motion during the spacecraft's travel time (136 degrees) from its point of arrival (180 degrees). 180 degrees – 136 degrees = 44 degrees.

Using the planetary heliocentric longitudes, approximately when is the next opportunity for a launch to Mars?

## 11. Discussion of the results and conclusions

What happens if the estimation of the launching window is shorter or longer that it should be? Can we estimate an average length?

Do you know how these launching windows have been calculated in the early times of space missions?

## 12. Follow up activities

Make a short phyton script that will subtract heliocentric longitudes for Earth and Mars to simplify launch window calculations.

## 13. Explore More (additional resources for teachers)

Stomp Rockets Activity

https://www.jpl.nasa.gov/edu/teach/activity/stomp-rockets/

When Computers Were Human https://www.jpl.nasa.gov/edu/news/2016/10/31/when-computers-were-human/

Mars in a Minute Video Series https://www.jpl.nasa.gov/edu/teach/activity/mars-in-a-minute/

**Acknowledge** This activity was inspired from the JPL Education Program

# Solar energy, a sustainable source of energy

## 1. Introduction & Pb

NASA uses several different technologies for providing energy for space exploration. Each technology meets the requirements for different types of exploration. For space exploration close to the Sun (near the inner planets—Mercury, Venus, Earth, and Mars), solar power with battery backup is often an optimal option. This problem-based learning PBL will explore the use of solar panels as a power source. In the process, students will learn core classroom concepts related to energy, energy transformation, electricity, and circuits.

Solar cell technology is improving rapidly. The solar cells used on the ISS are about 12 percent efficient. Those developed for the Mars Rovers are about 26 percent efficient. Current solar cells have higher efficiency. The students will have to do some research to determine the efficiency. When NASA engineers plan a mission, they have to know all the specifications for all of the components, and the components have to be space tested. Sizes, electrical characteristics, masses, and connections must be known at the beginning of the planning. Since a mission might take 10 years to plan and construct, equipment might be 10 or more years "outdated." Your students will have to work with the same restrictions. They will be required to use solar cells that are currently available. They will have to research current technology.

NASA's InSight lander, which touched down on Mars Nov. 26 and successfully extended its large solar arrays hours later, is already setting records. During its full first day on the Red Planet, the solar-powered lander generated more electrical power in one day than any previous Mars vehicle has, mission team members said. "It is great to get our first 'off-world record' on our very first full day on Mars," Tom Hoffman, InSight project manager at NASA's Jet Propulsion Laboratory (JPL) in California, said in a statement. "But even better than the achievement of generating more electricity than any mission before us is what it represents for performing our upcoming engineering tasks," Hoffman added. "The 4,588 watt-hours we produced during sol 1 means we currently have more than enough juice to perform these tasks and move forward with our science mission." The 4,588 watt-hours InSight generated on its first sol, or Martian day, from solar power is well over the 2,806 watt-hours generated in a day by NASA's Curiosity rover, which runs on a nuclear system called a radioisotope thermoelectric generator. Coming in third was the solar-powered Phoenix lander, which generated around 1,800 watt-hours in a day, according to NASA officials.

## 2. Age of students

15-17 years

## 3. Objectives

1. Given solar cells or panels, students list variables that affect the operation of solar panels and explain how these variables affect the power production of solar panels.

2. Through computer simulations or laboratory investigations with electricity, students create parallel and series circuits, calculate power, and apply this knowledge to solve a theoretical problem.

3. By analyzing the power requirements of their own homes, students design a solar system that could supply the power to their home.

4. Using their own models, students propose and defend a design to provide power for a Martian research habitat for six explorers.

## 4. Primary subjects

Mathematics - Physics – Earth and Space Science

## 5. Additional subjects

Computer Science

## 6. Time required

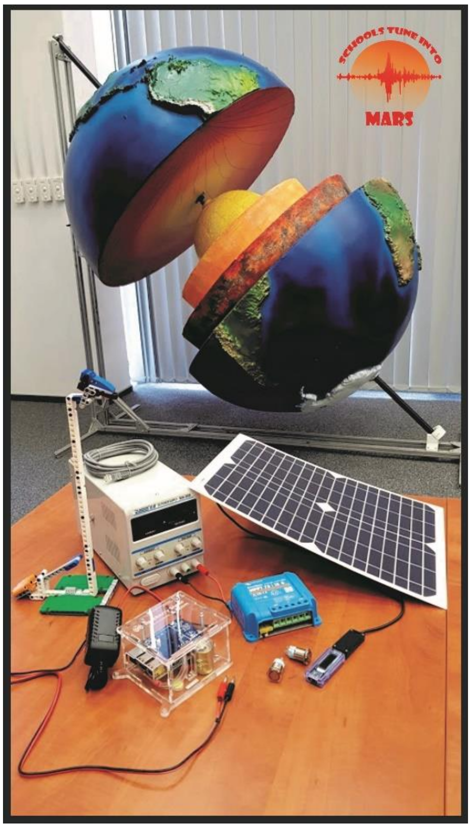
1 hour – 2 hours

## 7. Key terms

Solar panels, Solar energy, Earth, Mars, space missions

## 8. Materials

Solar panel. Solar charger (optional). Voltmeter. Calculator. Red, Green, and Blue transparency film. Electrical wire to connect solar cell and the electric devices. Notebooks and pencils. 12v bulb and battery (optional).



## 9. Background

A number of variables affect solar cell operation. Students will brainstorm, predict, and test variables in **Activity 1: Investigating Solar Cells.** The critical variables that affect solar cell performance—other than the efficiency of the cell itself—affect the intensity of light on the solar cell.

There are several factors that affect intensity:

**Blocking** - Natural conditions can block solar radiation from reaching the solar cells. Earth's atmosphere can partially block incoming solar radiation. The amount of light reaching Earth above the atmosphere is about 1366 Watts per square meter. When the Sun is directly overhead at the Equator, the intensity of solar radiation reaching Earth's surface is between 800 and 1,000 Watts per square meter. On the Moon and on Mars, solar panels can be blocked by dust. It was expected that the solar panels on the NASA Mars Rovers would become covered with dust and cease to provide energy for the systems. A chance dust devil swept the panels clean. Dust devils occur frequently enough on Mars that Rover panels are kept relatively clean.

**Angle** - The angle between the Sun and the solar panel is critical. The intensity of light is measured in Watts (power) per square meter. You can experimentally quantify how the angle changes the intensity. Hold a flashlight directly above a sheet of graph paper. The light source is at 90° to the paper. Count the number of squares illuminated. Keep the flashlight at the same distance from the paper, but tilt the flashlight so that it is at an angle to the paper. This represents a lower Sun angle. Count the squares illuminated again. More squares will be illuminated at the lower angle. The power of the light stays the same, but the area lit increases as the angle gets lower. When the same amount of power is spread over a larger area, the intensity decreases. The 23.5° tilt of the Earth's axis determines the angle of sunlight. The Sun is overhead in June in the Northern Hemisphere at the Tropic of Cancer at 23.5° N. latitude. The Sun is overhead in January in the Southern Hemisphere at the Tropic of Capricorn at 23.5° S. The GEMS (Great Explorations in Math and Science) Guide, The Real Reasons for the Seasons, could be used during this lesson to help students understand how the tilt of the Earth's axis affects the light intensity and the seasons. The axis of Mars is tilted at 25°, so very similar conditions prevail on Mars except the year is longer and each season is longer than Earth's. During the winter on Mars, the Rovers are parked on the slope of a hill to point the solar panels more directly at the Sun. As the International Space Station orbits Earth, the solar panels can be rotated to point more directly at the Sun. At times, the entire space station is pointed in a different direction to improve the angle between the panels and the Sun. For more information see:

What are ISS Attitudes? [http://spaceflight.nasa.gov/station/flash/iss_attitude.html](http://spaceflight.nasa.gov/station/flash/iss_attitude.html).

**Distance from the Sun** - As you know, the further you are from a light source, the dimmer (less intense) the light is. Students can confirm this experimentally and discover that the intensity (I) of light is inversely proportional to the square of the distance (r) from the light source ($I \propto 1/r2$). You will need a light bulb, a meter tape measure, and a light intensity probe. In a dark room, measure the intensity of light at 10 cm, 20 cm, 40 cm, and 80 cm from the light. Plot Intensity versus distance. If you plot this curve on a graphing calculator, you can also obtain the equation for the curve. The intensity decreases because the light spreads out farther away from the source. The Sun emits light energy in all directions. The light of the Sun is spread out over the surface of an imaginary (hollow)

This project is funded by the European Union

sphere with its center at the Sun. The farther the sphere is from the Sun, the bigger the sphere is and the more surface it has (surface area of a sphere = 4πr2). So, the power (energy per second) emitted by the Sun as light spreads over the surface of this imaginary sphere. Close to the Sun, the sphere is small. There is a lot of power per square meter (Intensity). Farther away, the sphere is big. There is less power per square meter. There is an equation that lets us calculate the intensity of light at a distance from a light source.

The equation is**:** **Intensity = Power/(4πr2)** But how can you measure the power of the Sun at its source? You can't. However, scientists have measured the intensity of light at Earth and we know the distance from the Sun to Earth. The intensity of sunlight outside the Earth's atmosphere is 1366 Watts/m2 (It varies slightly with solar output). The distance (r) from the Sun to Earth is 150,000,000 km (kilometers). If you substitute these values into the equation above and solve for Power, the value for the power of light from the Sun is 384.6 x 1024 Watts (Joules/second). Now we can use this value for Power in the equation above and calculate the intensity of light at Mars. The average distance from the Sun to Mars is 227,900,000 km. You can calculate that the intensity of light at Mars is 589.2 W/m2. That is less than half of the intensity at Earth!

But wait! The orbit of Mars is less circular than Earth's orbit. It is more elliptical. At perihelion (closest to the Sun), Mars is 206,600,000 km away from the Sun, and the intensity is calculated to be 717.1 W/m2. At aphelion (farthest from the Sun), Mars is 249,200,000 km away from the Sun, and the intensity drops to 492.9 W/m2.

These differences could be significant to the design of a solar energy system.

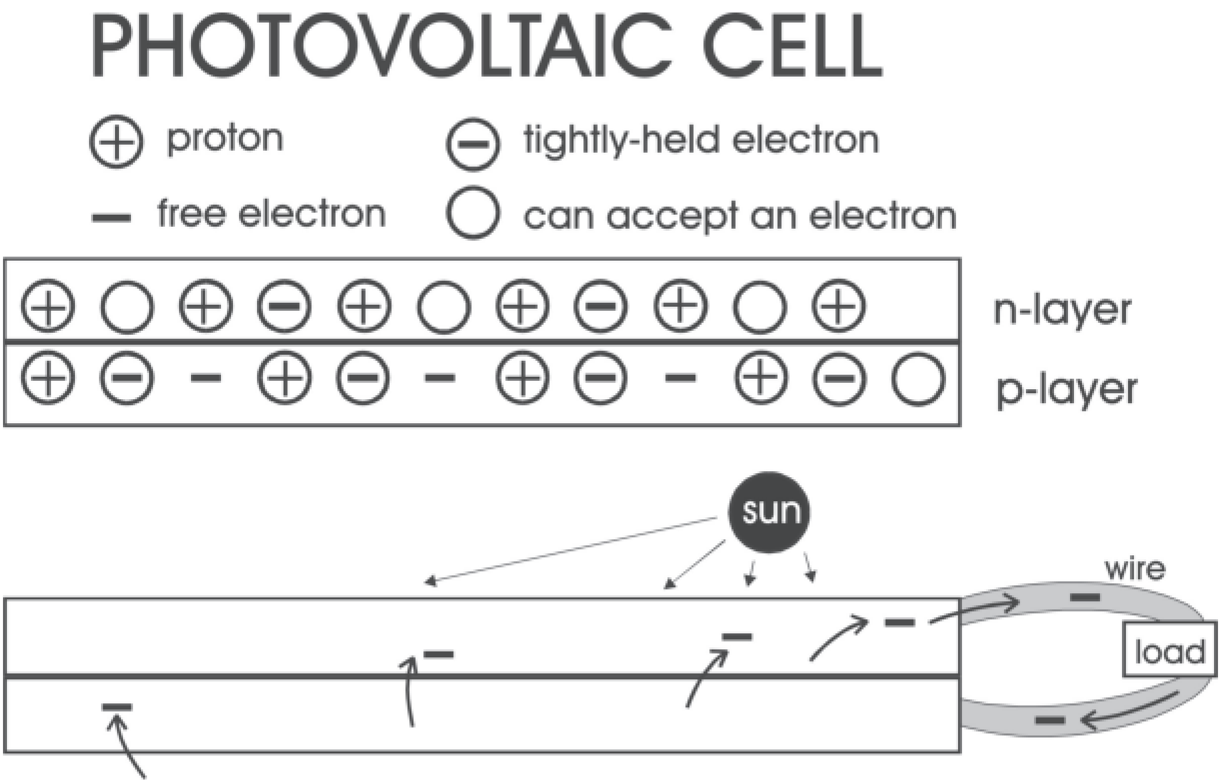
You will have to judge whether your students will be able to understand the math involved.

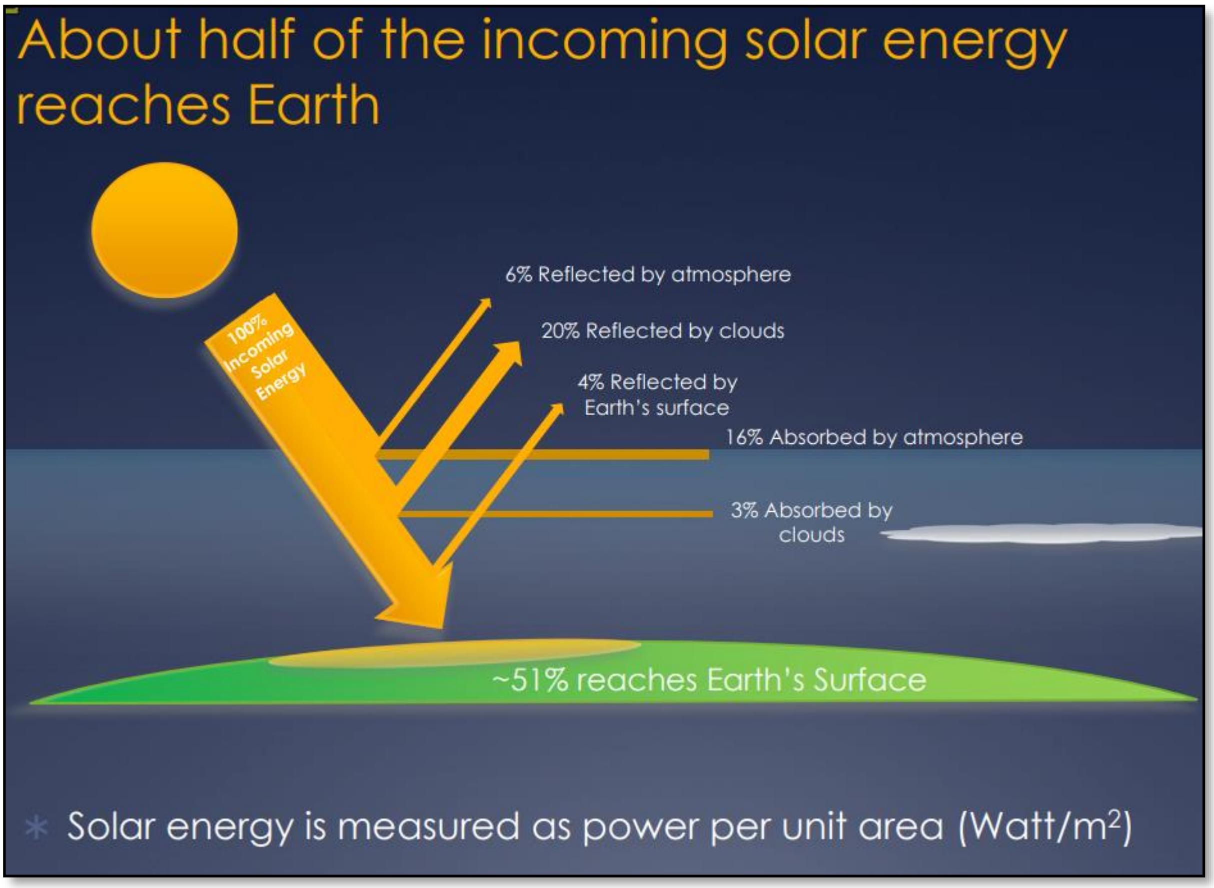
Crédit : Lockheed Martin

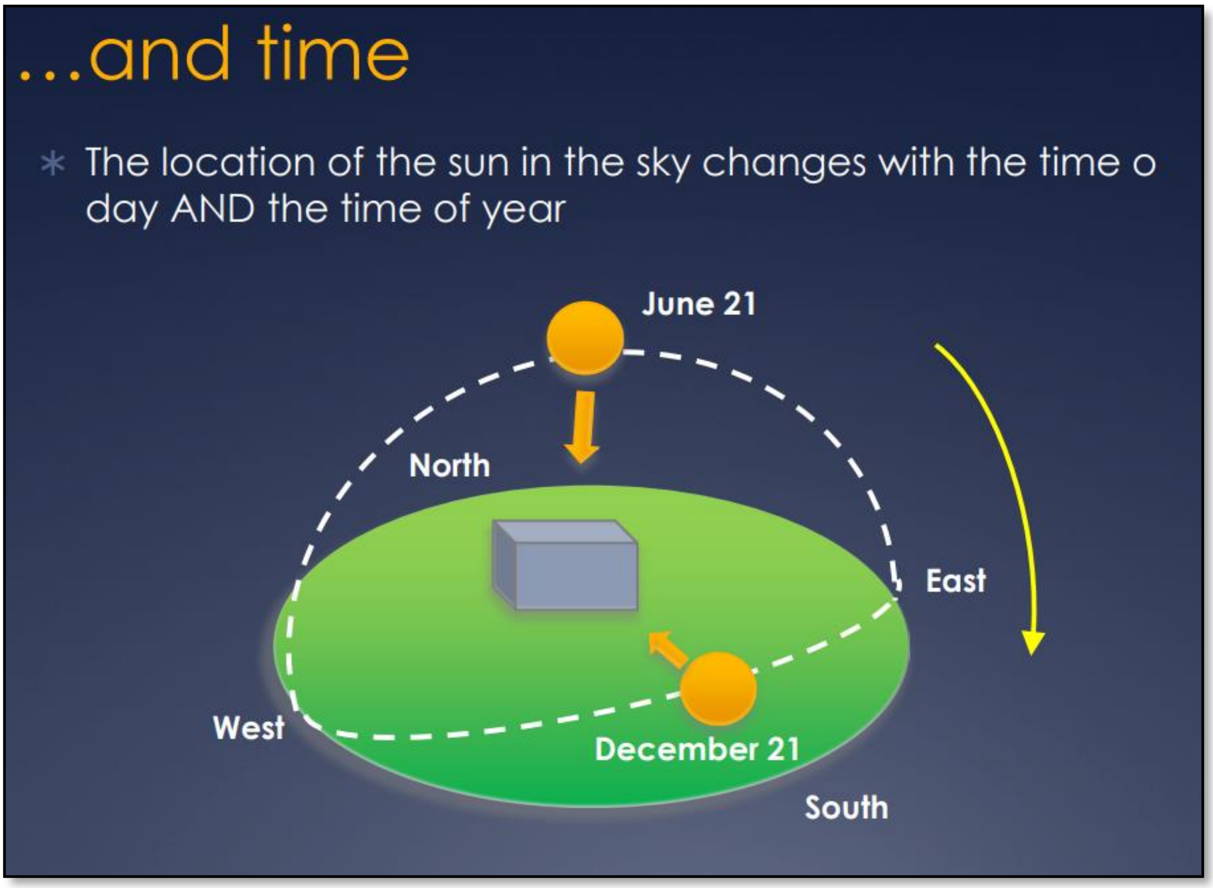
NASA/JPL-Caltech/Lockheed Martin

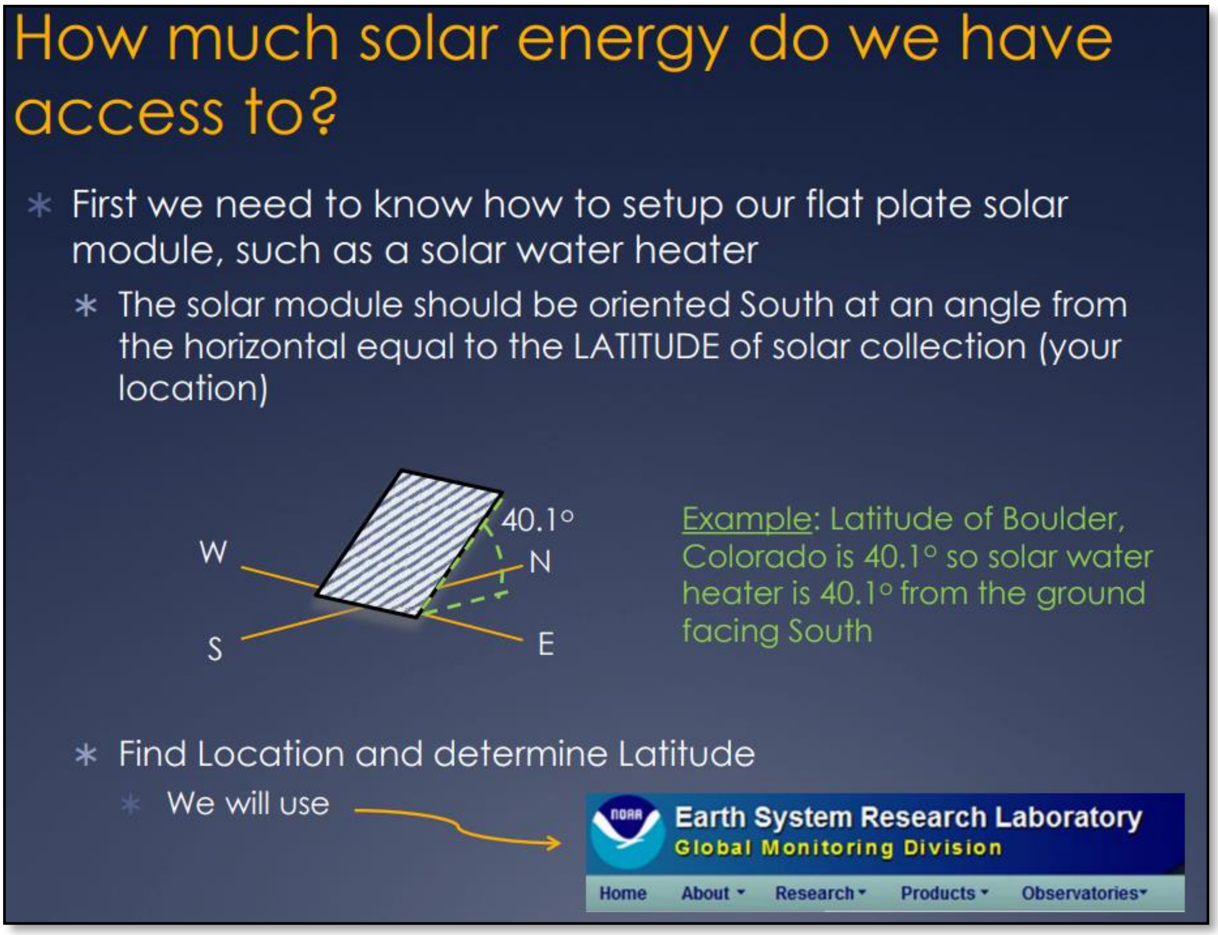
**Activity 2: Solar Panels on Earth.**

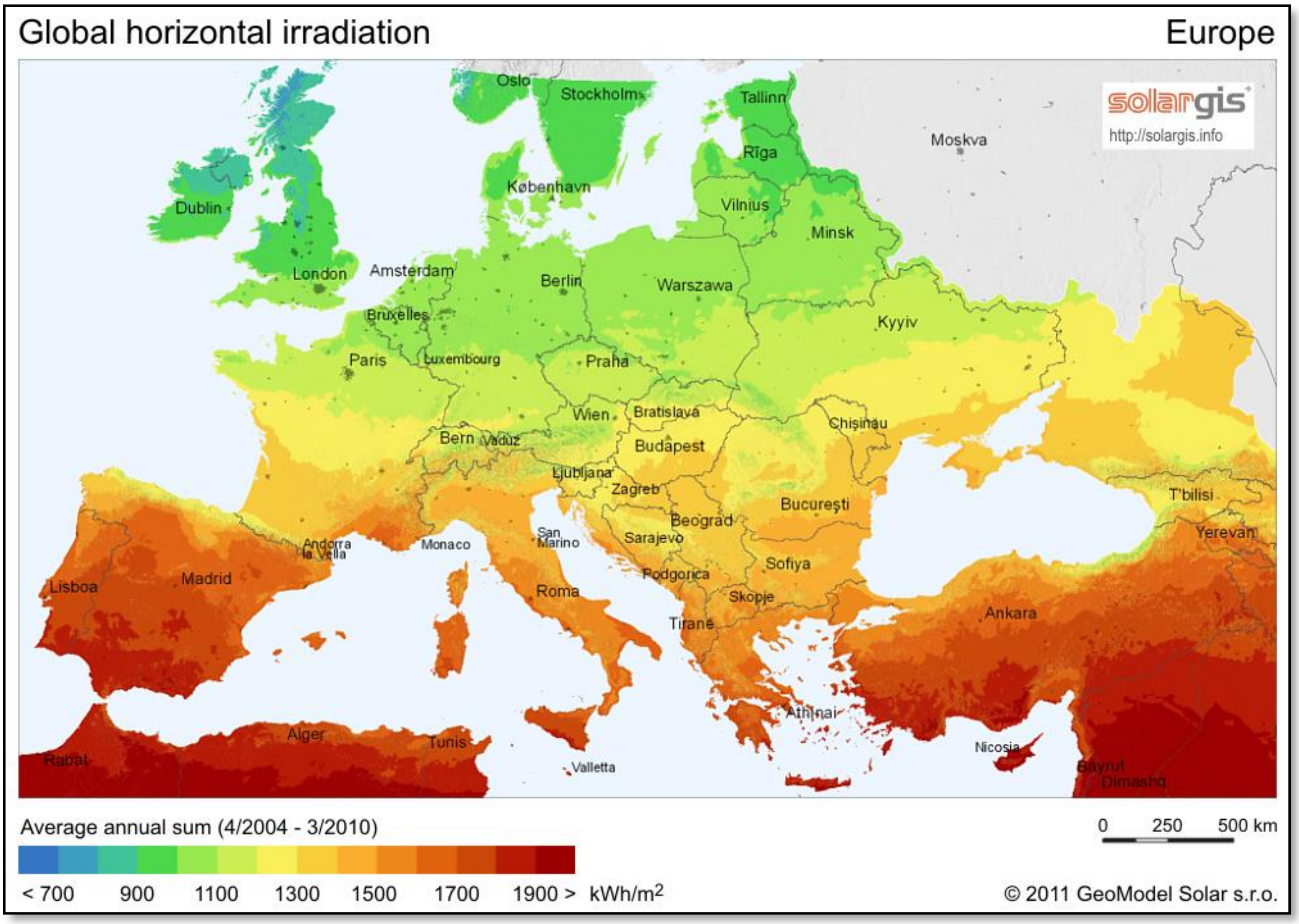
SOLAR ELECTRICITY Solar energy can also be used to produce electricity. Two ways to make electricity from solar energy are photovoltaics and solar thermal systems. The word photovoltaic comes from the words photo meaning light and volt, a measurement of electricity. Photovoltaic cells are also called PV cells or solar cells for short. You are probably familiar with photovoltaic cells. Solar-powered toys, calculators, and roadside telephone call boxes all use solar cells to convert sunlight into electricity. Solar cells are made of two thin pieces of silicon, the substance that makes up sand and the second most common substance on earth. One piece of silicon has a small amount of boron added to it, which gives it a tendency to attract electrons. It is called the p-layer because of its positive tendency. The other piece of silicon has a small amount of phosphorous added to it, giving it an excess of free electrons. This is called the n-layer because it has a tendency to give up electrons, a negative tendency. When the two pieces of silicon are placed together, some electrons from the n-layer flow to the p-layer and an electric field forms between the layers. The p-layer now has a negative charge and the n-layer has a positive charge. When the PV cell is placed in the sun, the radiant energy energizes the free electrons. If a circuit is made connecting the layers, electrons flow from the n-layer through the wire to the p-layer. The PV cell is producing electricity--the flow of electrons. If a load such as a lightbulb is placed along the wire, the electricity will do work as it flows. The conversion of sunlight into electricity takes place silently and instantly. There are no mechanical parts to wear out. Compared to other ways of producing electricity, PV systems are expensive. It costs 10-20 cents a kilowatt-hour to produce electricity from solar cells. On average, people pay about eight cents a kilowatt-hour for electricity from a power company using fuels like coal, uranium or hydropower. Today, PV systems are mainly used to generate electricity in areas that are a long way from electric power lines.




About half of the incoming solar energy reaches Earth
100% Incoming Solar Energy
6% Reflected by atmosphere
20% Reflected by clouds
4% Reflected by Earth's surface
16% Absorbed by atmosphere
3% Absorbed by clouds
~51% reaches Earth's Surface
Solar energy is measured as power per unit area (Watt/m2)

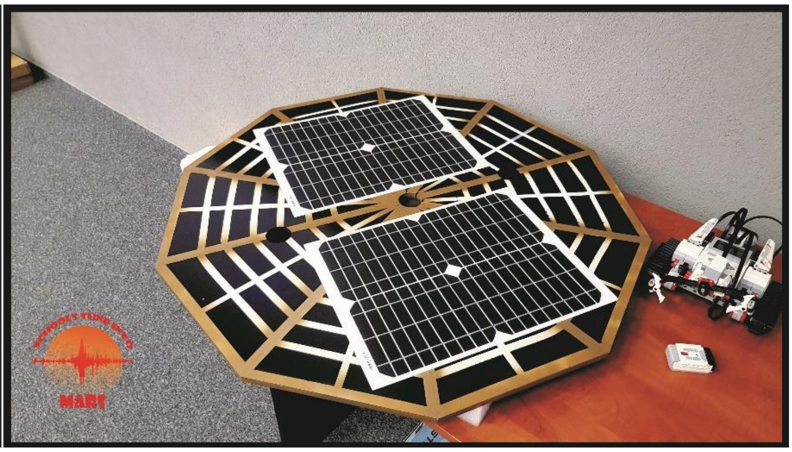

...and time
The location of the sun in the sky changes with the time o day AND the time of year
June 21
North
East
West
December 21
South


How much solar energy do we have access to?
First we need to know how to setup our flat plate solar module, such as a solar water heater
The solar module should be oriented South at an angle from the horizontal equal to the LATITUDE of solar collection (your location)
40.1°
W
N
S
E
Example: Latitude of Boulder, Colorado is 40.1° so solar water heater is 40.1° from the ground facing South
Find Location and determine Latitude
We will use
Earth System Research Laboratory
Global Monitoring Division
Home
About
Research
Products
Observatories




## 10. Procedures

### Activity 1: Investigating Solar Cells.



Questions (students will answer these questions after doing the investigation)

1. What happened when you covered part of the solar cell with black paper? Why?

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2. What is the relationship between the amount of solar cell that is covered and the functioning of the powered electrical devices? Explain.

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3. How did the colored transparencies affect the solar cells ability to function?

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4. What happens when you connect in series multiple solar panels compared with the initial specifications of one solar panel? What about connecting them in parallel?

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## Activity 2: Solar Panels on Earth.

- On the map find your location and determine what color your area corresponds to. Use the Legend to find out the energy range in "$kWh/m^2/Day$" from the "average annual sum $kWh/m^2$ ". Once you have the range, you will average the highest and lowest values on the range to get your energy estimate. For example, in France, the range is 2.7 – 4.4 $kWh/m^2/Day$, the average value is 3.55 kWh/m2/Day.

Energy range for your location:_________ ______ $kWh/m^2/Day$

Average energy:___________________ $kWh/m^2/Day$

- Next, find the amount of solar energy available per unit area of your solar module (for example, a solar water heater), which depends on the time you expose your module to the sun. If you want to test your solar water heater for 1 hour, your duration of sun exposure is '1 hour' (this can be less than one if you test for less than an hour → 45 minutes = 0.75 hours). If you do not already have these values for a solar module, just use the following example values.

Duration of sun exposure:____________ hours (example: 1 hour)

Now you will need to find the energy in units of Watt-hours/m², referred to as '**insolation**':

(kWh/m²/day) x (1 day/24 hours) x (duration of sun exposure [hours]) x (1000 Wh/1 kWh) =

(__ kWh/m²/day) x (1 day/24 hours) x (__ hours) x (1000 Wh/1 kWh) =

________ Watt-hours/m²

- To find the solar energy used by your solar module you will also need its surface area (m²). Say you have a solar water heater that is 1 meter by 1.5 meters, the surface area would be 1.5 m² (you may need to convert feet to meters).

  Solar module surface area:____________________ m² (example: 1.5 m²)

  Next, you need to use your surface area and **insolation** value to find out how much energy enters your solar module. This incoming energy is called **heat energy ($Q_{in}$)** and is in units of Watt-hours:

  $Q_{in}$ = [Insolation (Watt-hours/m²)] x [Surface Area (m²)]

  $Q_{in}$ = (_______ Watt-hours/m²) x (________m²)

  $Q_{in}$ = __________ Watt-hours

- What would be the '**tilt angle'** of your solar module? Why do you want your solar module to face south?

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- How do you think the amount of solar energy available in Arizona for the same month would compare to the value for your location? (Hint: check out the maps, you don't need to calculate anything https://www.nrel.gov/gis/images/solar/solar_ghi_2018_usa_scale_01.jpg) What about the solar energy available in Alaska? In which location (Arizona or Alaska) would it be easier for engineers to use the solar energy available for heating or electricity?

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## 11. Discussion of the results and conclusions

How does dust affect solar panels on Mars?

How are the scientists dealing with this challenge?

What really happened on Mars with the Insight Lander's solar panels?

What can and can't be done for future space missions in this matter?

## 12. Follow up activities

Challenge: Solar Energy for Moon and Mars. Working in small groups, students will choose either the Moon or Mars as the location for a NASA research habitat. Each group will estimate the requirements for the research habitat using what is known about home power requirements and the power requirements for the ISS. Then, each group will propose a design for a solar energy system to meet the energy requirements. This activity could be used as an assessment.

## 13. Explore More (additional resources for teachers)

**Solar Maps**

These solar maps provide average daily total solar resource information on grid cells.

https://www.nrel.gov/gis/solar.html

https://earsc-portal.eu/pages/viewpage.action?pageId=16548947

TeachEngineering is a digital library comprised of standards-based engineering curricula for K-12 educators to make applied science and math come alive through engineering design.

https://www.teachengineering.org/

https://www.nasa.gov/

**Acknowledge** This activity was inspired from the JPL Education Program & TeachEngineering