Rosetta Mission

Pedagogical invitations

Charles Sol for @eduMediaTweets- 2014/11/8

After 10 years and 5.000.000.000 km travelling through space, Rosetta is about to land on a 5 km comet with 100 m precision. It is similar to launch a 1 mm diameter ball from the Earth on a 20 cm wide target placed on the moon within a 0.5 cm tolerance. #GoodLuckRosetta

This incredible performance deserves pedagogical investigations (light, wave, gravitation, math, energy…)

Glossary :

Comet : Icy small Solar System body. Some of them with a highly elliptical orbit pass close to the Sun. As the comet warms, parts of it sublimate displaying a visible atmosphere or coma. The word comet comes from old greek *komêtês* (« Head with long hair »).

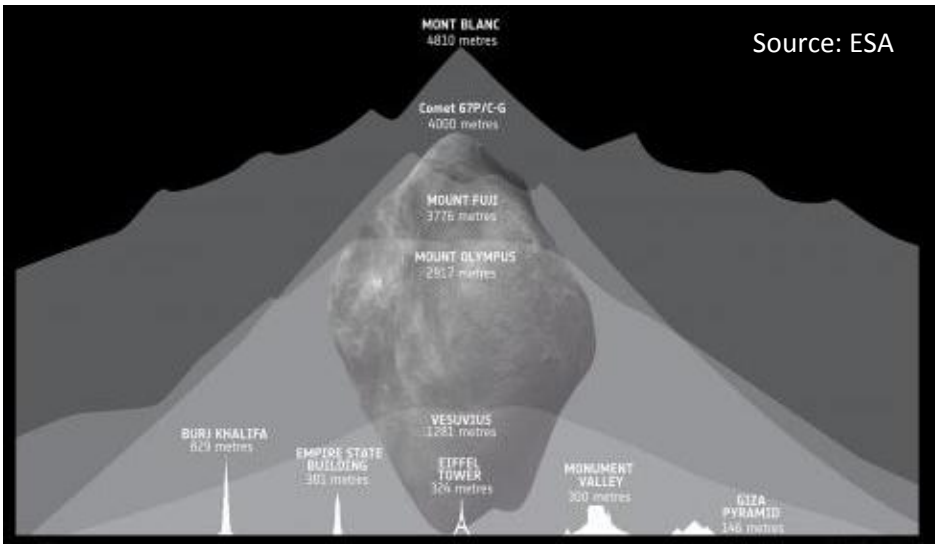
67P/Churyumov–Gerasimenko : Name of the comet visited by Rosetta. Let's call it « Chury ». Chury has been discovered by Klim Churyumov and Svetlana Guerasimenko in september 1969.

Rosetta : ESA (European Space Agency) spacecraft launched in march 2004 by Ariane 5 rocket. Mission : asteroid flyby (Šteins and Lutetia), detailed study of comet 67P/Churyumov-Gerasimenko with both an orbiter and a landing module.

Philae : 100 kg Landing module which will seperate from Rosetta probe the 12th of november 2014. Philae is designed to land on 67P/Churyumov-Gerasimenko with 10 instruments.

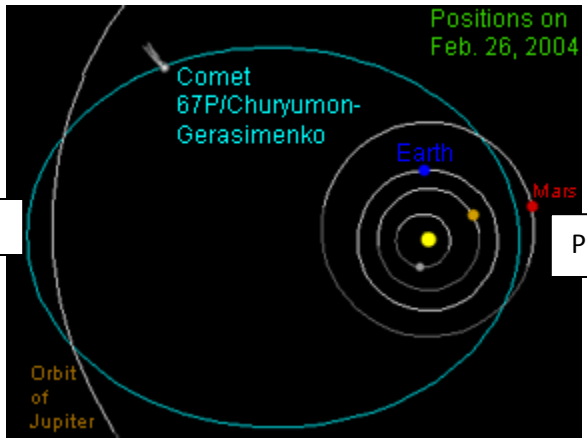
a.u. : Astronomic Unit = Earth – Sun distance – 150 million km ($1.5 .10^{11}$ m)

Comet 67P/Churyumov-Gerasimenko



Chury compared to Mahattan – Non spherical shape at all

Trajectory between Jupiter and Mars



Aphelion

Perihelion

67P/Churyumov-Gerasimenko in numbers

- 2 km - 5 km non spherical object
- 1.10^{13} kg (Mass of the Earth : 6.10^{24} kg)
- 400 kg/m^3 (density is 0.4) Chury floats in water !
- 6.5 years period
- Velocity at perihelion : 34 km/s
- Velocity at aphelion : 7.5 km/s
- Velocity at rendezvous with Rosetta : 18 km/s
- Temperature: -70°C
- 4 % Albedo. Very dark. Charcoal like. Moon's albedo is 7 %

Astronomical orders

- 5.000.000.000 km : Distance travelled by Rosetta before rendezvous (5.10^9 km = 30 a.u. = 15 Earth – Sun go back)
- 750.000.000 km : Distance to the Sun in november 2014 = 5 a.u.
- 10 years : Mission duration since launch.
- 1 Billion € : Mission price.
- Gravity on Chury ≈ 10^{-4} $m.s^{-2}$ (Earth : 9.8 $m.s^{-2}$ is 100.000 times more)
- 7h : Duration of the free fall of Philae when separated from Rosetta at 20 km of altitude. Such a free fall would be 3 minutes long on the Earth (friction neglected)
- 65.000 km/h (18 km/s) : Chury and Rosetta speed at rendezvous compared to a gun bullet which is about 3000 km/h)
- Escape velocity ≈ 1 $m.s^{-1}$ (a mild jump could put you in orbit around the comet)

Timeline

- 1969 : Comet is doscovered by Klim Churyumov and Svetlana Guerasimenko
- 1993 : ESA decides Rosetta mission (initially with another comet)
- 2004 : Rosetta launch with Ariane 5 rocket
- 2008 : Steins asteroid flyby
- 2010 : Lutetia asteroid flyby
- 2011 : Rosetta probe is put in hibernation mode for 31 months
- January 2014 : Rosetta is taken out of hibernation mode.
- March 2014 : Philae lander is taken out of hibernation mode
- November 2014 : Philae landing on the 67P/Churyumov-Gerasimenko

- August 2015 : Comet at perihelion (near point to the sun = maximum outgas)
- December 2015 : end of mission

Pedagogical scenario

Level : Middle School – High School
Few details are provided since a lot of documentation exists on the web for each subject
Thank you for contacting me @eduMediaTweets for corrections or suggestions.

<u>Spped of light</u> :

- How to send and receive information and orders to/from Rosetta from ground control? Radio waves. #eduMedia : http://www.edumedia-sciences.com/en/a189-electromagnetic-spectrum
- Can we pilot Rosetta and Philae from the Earth to control the landing pf Philae for example? No, electromagnetic signals travel at the speed of light. 30 minutes delay will apply as a result of a 600.000.000 km distance between Rosetta and the Earth. No immediate/real time communications are possible.

<u>Mass, density :</u>

- How dow we find out the mass of a comet? Good question. It seems gravitation law make this easy but it is not. Kepler third law $\frac{a^3}{T^2} = \frac{GM}{4\pi^2}$ links period *T* and semi-major axis *a* of the ellipse of the comet with mass *M* of the Sun. We do not have information of the orbiting object, and engineers didn't really know this mass before arriving close to it. Kepler third law would help if Chury had a satellite orbiting around. Trajectory of this satellite (a_s, T_s) would reveal Chury's mass according to $\frac{a_s^3}{T_s^2} = \frac{Gm}{4\pi^2}$, but Chury has no satellite … well … now it has Rosetta. Observations of Rosetta's motion indicate now a 10^{13} kg mass and a gravity between 10^{-4} and 10^{-3} $m.s^{-2}$.
- What about Density? Volume is easily computed from tele-detection and density is found out: 0.47 ($tons/m^3$) which is 10 times weaker than density of Earth or Moon. It is half the density of water so 67P would float in water. Floating or sinking is just a question of density. #eduMedia: http://www.edumedia-sciences.com/en/a459-sink-or-float

Gravitation :

Do not confuse weight and mass ! #eduMedia http://www.edumedia-sciences.com/en/v41-weight-and-mass

- Gravity field on the comet is 100.000 times weaker than on the Earth. Does it matter? Such a weak gravitation field makes it difficult to remain in orbit around 67P. Rosetta speed has to be accurate to remain in orbit or it would escape the attraction of Chury. As a result, it is also very difficult to land. No one knows what a comet's surface is like. Too soft or fudgy, and Philae will sink. Too hard and Philae could rebound. This is why engineers have designed harpoons to prevent the lander from rebounding into space.
- Find out the escape velocity on 67P/Churyumov–Gerasimenko. Let's consider the comet as a perfect 2 km radius sphere, with 10^{13} kg mass. The following formula is easy to determine :

$$V_e = \sqrt{\frac{2GM}{R}} = 0.7\ m.s^{-1}$$

  Value is close to 1 $m.s^{-1}$. It is 11 $km.s^{-1}$ on the Earth. This is why you need a powerful rocket to escape the Earth gravitational attraction. But on Chury, a good flexion/extension of your knees could be enough!
- Considering that gravity g = 10^{-4} $m.s^{-2}$ is constant within 20 km surrounding 67P (which is completely false!) how long does it take for Philae (100 kg) to reach the ground once released with no initial velocity by Rosetta? Applying the Newton's law of motion, we find $z = \frac{1}{2}gt^2$, which lead to a 5h30 free fall. More accurate computation is easy to do in a case of a spherical object, keeping in mind that g depends on altitude z. Integral calculus is therefore requested. The real value is about 7h long including a 0.7 $m.s^{-1}$ initial velocity.

Astronomy :

- What is a comet? So many documents on this subject.
- Why choosing to land on a comet? Comets likely remain largely unchanged since their formations 4.6 billion years ago. So studying their composition and behaviour should provide clues about the conditions that existed at the birth of the solar system.
- 67P/Churyumov–Gerasimenko is only 7° angle with the ecliptic. Are all comets like this? No. Comets comes mainly from two sources: Oort cloud which is a sphere surrounding the Solar System in all directions and, closer to us, the Kuiper

belt which is more like a disk aligned with the ecliptic. Scientists conclude that origin of 67P/Churyumov–Gerasimenko is likely to be in Kuiper belt rather than the Oort's cloud: http://www.solarviews.com/browse/comet/kuiper3.jpg

- What is the trajectory of a comet? Ellipse or parabola. #eduMedia https://www.edumedia-sciences.com/en/a243-kepler-s-laws
- Does all comets have a coma? Coma is formed when the comet passes close to the Sun. It warms, and parts of it sublimate. It is the reason why Rosetta rendezvous is so far away. Philae could not land on a active comet.
- Why comets are not spherical objects like stars or planets? The larger the object, the stronger its gravitational field. Mountains could become too heavy and cannot stand on the surface. Since gravity pulls toward the center of the planet or star, everything gets pulled down into a roughly spherical shape. Gravity os too low on tiny objects like comets or asteroids.

Space technology :

- How to launch a spacecraft or a satellite? It takes a rocket to escape Earth's gravity: #eduMedia Ariane5 : https://www.edumedia-sciences.com/en/a61-rocket
- How does the spacecraft fly to final destination? Spacecrafts have their own engines but for long distance mission, you need to save propellant and you may need gravitational assistance. The "assist" is provided by the motion of a planet as it pulls on the spacecraft. http://fr.wikipedia.org/wiki/Assistance_gravitationnelle#mediaviewer/File:Swingby_acc_anim.gif . Rosetta has done this 4 times as you can see on the video below summarizing the 10 years journey. Gravitational slingshots are visible at 4 s (Earth assist), 12s (Mars assist), 14s (Earth assist), 21s (Earth assist). http://www.esa.int/spaceinvideos/Videos/2014/01/Chasing_a_comet
- How to accelerate in empty space? Action/reaction principle. #eduMedia http://www.edumedia-sciences.com/en/a463-action-reaction-principle . Problem is that to eject mass, you need to take it with you first. The launching company may not appreciate this since extra mass is not so welcome aboard and you may prioritize scientific instruments because it is the main goal of the mission.
- Instruments? About 20 instruments including cameras (all wavelength), mass spectrometers, sismograph.
- What energy source for all these instruments? No refuel available. Spacecraft operating in the inner solar system usually rely on the use of photovoltaic solar panels to derive electricity from sunlight. Be aware that solar energy decrease

according to the square of the distance to the sun. Rosetta is 750.10^6 km away from the Sun which is 5 times the distance of the Earth. Therefore, solar energy received by a photovoltaic panel or Rosetta is 25 times lower than the similar panel placed on Earth (150.10^6 km to the Sun).

Other projects could be lead in Chemistry, math… but let's stop now. If you have time, you could approach all these subjects within a big classroom project : « Let's manage the landing of a spacecraft on a comet »:

- What is a comet?
- Why to go there?
- What not to forget before leaving Earth?
- How to escape Earth's gravitational attraction?
- How will you localize the spacecraft from ground-control?
- Adjust your trajectory into space.
- Save Energy.
- How to communicate within deep space?
- When do you land on the comet?
- What is a good landing spot? How do you find it when you discover only the real geography of the comet?
- Could you leave on a comet?

Evocating names : Rosetta, Philae, Agilkia ?

All these terms refer to ancient Egypt. Champollion (french) published the first translation of the Rosetta Stone hieroglyphs in 1822. Rosetta stone is a stele of Egyptian origin featuring a decree in three scripts. One of them was hieroglyphs. He also studied Egyptian inscriptions from the Obelisk of Philae (Island on the river Nile).

Wikipedia: "The probe is named after the Rosetta Stone, a stele of Egyptian origin featuring a decree in three scripts. The lander is named after the Nile island Philae, where an obelisk was discovered with Greek and Egyptian inscriptions. A comparison of the hieroglyphs on the Rosetta Stone and the obelisk catalysed the deciphering of the Egyptian writing system. Similarly, it is hoped that these spacecraft will result in better understanding of comets and the early Solar System. In a more direct analogy to its namesake the *Rosetta* spacecraft also carries a micro-etched nickel alloy Rosetta disc donated by the Long Now Foundation inscribed with 13,000 pages of text in 1200 different languages."

Rosetta is also a mineral symbol (stele) reminding the mineral nature of a comet.

Deciphering hieroglyphs opened a door to understand the Egyptian antique civilization. “Deciphering” cometary materials open a door to understand the formation of the solar system. Comets are supposed to be the “planetesimals” involved in Earth-like planets formation.

Philae landing site on comet 67P/Churyumov Gerasimenko has been named Agilkia after the Agilkia Island in the River Nile. Philae island has been flooded in the 70’s after the building of the Aswan Dam. The ancient temple complex of Philae was dismantled and relocated to Agilkia island.

Philae complex finally settle down on Argilkia island. In reference to this, Philae landing site is supposed to touchdown on Argilkia site.

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