Exploring CTA Science with Ted and Friends - Activities

Introduction: The animated series “Exploring CTA Science with Ted and Friends,” available on CTA’s YouTube Channel, presents different astronomical concepts, such as light, pulsars, black holes, why observatories are located in dark places, etc.

Activity: This handbook proposes questions and exercises of different levels related to each episode of the animated series (~ 3 min/episode). The handbook is designed for educators, including the answers, as given in the video, as well as extra annotations. The questions are divided according to each episode - we recommend educators to perform the activities with the students right after watching each episode in order to consolidate new ideas before starting the next episode.

Goal: The goal is to introduce the students to astronomy - particularly to high-energy astrophysics that the future gamma-ray observatory, the Cherenkov Telescope Array (CTA), will study - and especially to develop their scientific thinking and logic, and to improve attention and retention of information.

Age range: 5-11 years
Supplementary material: https://www.cta-observatory.org/outreach-education/
Questions? Contact CTAO Outreach and Education Coordinator, Alba Fernández-Barral (alba.fernandezbarral@cta-observatory.org)
EPISODE 1: “CTA: Searching the Skies”

How many CTA telescopes will be located around the world?
More than 100 (Note for educators: CTA means Cherenkov Telescope Array. CTA will host up to 118 – 19 in La Palma, Spain, and 99 near Paranal, Chile).

Where are they going to be located?
One group will be in Chile (South America) while the other will be in La Palma (a Spanish island in the Canary Islands, off the coast of west Africa).

What do CTA telescopes search for?
They search the sky for gamma rays.

What are gamma rays?
Gamma rays are like X-rays, which are used to see human bones in the hospitals, but much more energetic (Note for educators: gamma rays are the most energetic light-electromagnetic radiation- that exists in the Universe. Light can be classified according to its energy, which is known as the electromagnetic spectrum. Thus, within the electromagnetic spectrum the light spans as follows: radio waves, microwaves, infrared, visible light, ultraviolet light, X-rays and, finally, gamma rays. Highest-energy gamma rays can only be found in outer space, because there is nothing here on Earth that is powerful enough to emit them).

What examples of objects that emit gamma rays from space has Ted mentioned in this episode?
Pulsars (stars that spin around very fast) and supernovae (cosmic explosions).

Why do Ted and his friends from CTA want to observe gamma rays?
To understand what happens inside those sources and in the Universe.
**EPISODE 2: “CTA: Detecting Gamma Rays”**

Can we see all the colours of light that exist in the Universe?
No, we can only see a tiny fraction called visible light, which is formed by the colours of the rainbow (Note for educators: explain that white is when an object reflects all colours and that black is when an object absorbs all colors).

What color of light do Ted and friends observe?
They observe gamma rays (which we cannot see with our eyes).

Where do these gamma rays come from?
From space (Note for educators: emitted by very energetic sources in space).

What are particles?
Particles are tiny little blobs that, when put all together, make up all the matter we can see, including us!

What is the fastest thing in the Universe, and what is its speed?
The fastest thing in the Universe is light traveling through empty space. It goes so fast that it could go around the Earth seven and a half times in just one second (Note for educators: light speed is ~300,000 km/s).

Does light move at the same speed in any medium?
No, it travels at its maximum speed through empty space, but when light goes through other mediums like air, it travels a bit slower because those mediums slow it down.

Is there anything that can travel faster than light in empty space? And faster than the speed of light in other mediums like air?
No, there is nothing in the Universe that can travel faster than the speed of light in empty space. Yes, in other mediums, since the light can be slowed down, there are super-fast particles that can move even faster than light.

Can you explain how Ted and friends observe the gamma rays that arrive from space? What is Cherenkov light?
When a gamma ray arrives from space, it interacts with the sky (Note for educators: it interacts with the atmosphere to be exact), producing super-fast particles. These mega-fast particles move faster than light in air (but not in empty space, that would be impossible!), giving rise to a blue light called Cherenkov light (this light moves with a V-shape along the particle’s track, like a shock wave). This Cherenkov light is the one that Ted and friends capture (Note for educators: another example of a medium where light slows down and particles can produce Cherenkov light is water).

So, do Ted and friends take pictures of gamma rays directly?
No, they take pictures of Cherenkov light, produced as a consequence of gamma rays interacting with the sky (Note for educators: by studying the pictures of the Cherenkov light,
scientists can obtain information about the gamma ray that produced it, as well as about gamma ray's cosmic source. Thus, Cherenkov telescopes study gamma rays indirectly. Video to show this concept).
EPISODE 3: “CTA: The Life of a Star”
Are all the stars in the Universe the same?
No, there are many types of stars, they can be big, small, hot or not so hot. Moreover, they change over time, just like we do as we grow up.

What is the evolution of a star?
A star is born from a clump of gas and dust, which comes together to create a baby star called protostar. This star starts growing until it becomes a normal star, a period in which it will spend most of its life. If it is a big star it will become a red giant and if it is a very big star, it will turn into a red supergiant. After a while, red giants end their life as white dwarfs. However, red supergiants, really big stars, have a much more spectacular end: they die in a big cosmic explosion called supernova, where the star expels most of its material into space in just a few seconds at millions of miles per hour. The material thrown into space will also create another object called a “supernova remnant.” Not all material from the initial star is expelled into space: its core remains there as a new type of star (neutron star) or as a black hole (Note for educators: As mentioned before, when a cloud of gas and dust collapses, it creates a protostar. If it has enough mass and temperature, it can trigger nuclear fusion in its core (the source of the star’s energy). It will fuse, for example, hydrogen to form helium. However, there are protostars that do not get enough mass to start that nuclear fusion and remain as “failed stars”, as is the case of brown dwarfs. That is why in the text we talk directly about giant and supergiant stars).

What kind of star is our Sun?
Our Sun right now is a normal star that will become a red giant. Therefore, it will end up its life as a white dwarf (Note for educators: When the Sun becomes a red giant, it will increase its size so much that its outer layers will consume Mercury and Venus. Whether our planet will be engulfed or not is still under debate, although considering the extremely proximity, life as we know it will cease to exist. Oh, no, are we going to see that happen? You can play a guessing game with students asking when they think the Sun will turn into a red giant. They will be amazed, as well as relieved, to know that it will take around 5000 million years until the Sun initiates the transition to its next evolutionary phase).
Draw the different phases of a star's life. Show the steps of how a clump of gas and dust ends up as a white dwarf, neutron star or black hole.

- Clump of gas and dust
- Protostar
- Big normal star
- Red supergiant (if the exploding star is very big)
- Supernova (after the explosion, another object is created in the Universe: Supernova Remnant)
- Neutron star (if the exploding star is very big)
- Black hole (if the exploding star is very big)
EPISODE 4: “CTA: Exploding Stars”

What are supernova remnants?
Supernova remnants are the material that was ejected into space when a big star exploded in a supernova, producing shock fronts (Note for educators: shock fronts are created when the expelled material interacts with the interstellar medium).

What colours of light do supernova remnants emit?
All colours of light, those we can see (visible light) and even those we cannot (including gamma rays).

Why are supernova remnants and supernovae that important?
Supernovae are extremely energetic cosmic explosions that are able to join together heavy metals, like lead or uranium, allowing them to travel as supernova remnants through space and to exist in the Universe, including on Earth. Moreover, in supernova remnants, particles can get accelerated up to really high speeds.

What are cosmic rays?
Cosmic rays are super-fast particles, which come from very energetic sources in space.

Where can cosmic rays be produced? Do they reach high speeds?
They are produced in cosmic objects, like supernova remnants. There, they are accelerated up to super-fast speeds much higher than any particle accelerator made by people here on Earth can reach (Note for educators: particle accelerators are human-made machines that use electric and magnetic fields to accelerate beams of particles and make them collide to study their interactions and even find new particles. Those that reach highest energies have ring-like shapes. Currently, the most powerful accelerator on Earth is the CERN’s Large Hadron Collider (LHC), mentioned in the video, which is located underground in Geneva, Switzerland.)

Why are cosmic rays interesting?
Because they play a role in the making of stars.

So, do we understand everything about these cosmic rays?
No, we still aren’t sure where they come from (Note for educators: we are investigating the sources in the Universe that produce and accelerate them at different energies. Supernova remnants are just one of the types of sources that can produce them) and what it is that they do in space (Note for educators: it means how cosmic rays affect their environment, for example, how they affect the evolution of galaxies).

How will CTA help us to better understand the mystery of cosmic rays?
CTA will study cosmic rays through its study of gamma rays, finding out how they can be accelerated up to such high speeds and how they affect the surrounding space (Note for educators: cosmic rays emit gamma rays while interacting within the most extreme cosmic sources. Studying gamma rays, we can obtain information about those cosmic rays).
EPISODE 5: “CTA: Black Holes”

What are black holes?
Black holes are what is left after a very big star explodes into a supernova. The supernova leaves behind the core of the star, which falls in on itself due to its own gravity, creating the black hole.

What is gravity?
Gravity is the force that attracts things together (like the Earth attracts us to the ground).

Does the black hole have mass?
Absolutely! The black hole is the result of the star’s core getting squashed together, so there is a large amount of mass, just gathered into a much smaller area.

Why do we call it black hole and not, for example, a blue hole?
Because the mass is so compressed into a small area that the pull of gravity becomes extremely strong. Therefore, nothing can escape from it, not even light. This is why we call it black hole (it does not emit light).

But if it is black and it does not emit light directly, how can we see it?
Because we can see stars and planets moving around an empty black space, like if they were attracted by something. For this reason, we can tell that in that region there is a black hole (Note for educators: in the video it is said that the black holes are very bright sources of gamma rays. This is meant to explain that they are very interesting objects for CTA and for gamma-ray astronomy, but actually gamma rays come from the vicinity of black holes, for example, from the particle jets that are mentioned afterwards, but never from inside of the black holes themselves).

Will the Sun become a black hole? (Extra question: how will the Sun end its life?)
No, the Sun will not become a black hole because it is not big enough to die into a supernova explosion. In a previous episode we saw that it will end its life (after going through a red giant phase) as a white dwarf.

What are supermassive black holes and where are they located?
A supermassive black hole is a gigantic black hole with a mass that is a million times the mass of our Sun. They are believed to be at the centre of every galaxy, like our own (the Milky Way).

How do supermassive black holes affect the stars, planets and other objects in the galaxies?
Black holes have a very strong gravitational pull so all objects, like planets and stars, orbit around them. Some galaxies with supermassive black holes eat so many of the stars and objects around them that they eject powerful jets where particles get accelerated and gamma rays are emitted.

What do we call the centre of the galaxies that make these jets with high-speed particles?
Active Galactic Nuclei or, for short, AGN.
**Why does Ted want to observe these AGNs?**
To learn more about black holes, to know how they emit gamma rays and how they speed up particles.
EPISODE 6: “CTA: Spinning Stars”

We have seen that, after a very big star explodes into a supernova it becomes a black hole. But, what other object can it turn into? When does this happen?

It can turn into a neutron star, and it happens when the exploding star is big, but not enough to become a black hole, so when it is between 8 to 20 times more massive than our Sun (Note for educators: the stars that become black holes after the supernovae are those whose initial mass ranges approximately between 20 and 40 times the solar mass).

Could you list three features of a neutron star?

1. They are very dense: they have a lot of mass (Note for educators: the mass of a neutron star can reach up to three times the mass the Sun), but they are very small, only about 20 km across. Really small if we compare them with the Earth, whose diameter is 12742 km or with the Sun, whose diameter is 1391 million km.

   Proposed exercise: Calculate the size proportion (ratio) between a neutron star and the Earth and draw them on a piece of paper or the chalkboard, in order to compare the different sizes in a reasonable scale for us. Start drawing a point of approximately 1 mm diameter, which simulates our neutron star in this new scale (dₙ) – we suggest the students such small scale to be able to draw the Earth afterwards (those who decide to use bigger diameter will not be able to finish their drawings¹). Let’s the students realize by themselves that, having the diameter of the neutron star in the new scale, dₙ, to obtain the diameter of the Earth in that scale (dₑ) we just need to know the ratio (proportion) of both objects in real life. This can be achieved by dividing the Earth’s real diameter by the neutron star’s real diameter²:
   
   \[ \text{Ratio} = \frac{d_{\text{E, Real}}}{d_{\text{n, Real}}} \]

   \[ \text{Ratio} = \frac{12742 \text{ km}}{20 \text{ km}} \]

   \[ \text{Ratio} = 637.1 \]

   With this ratio we can directly obtain the diameter of the Earth on our new scale (dₑ), so that we can draw it and compare it to the 1 mm diameter neutron star:

   \[ d_{\text{E}} = d_{\text{n}} \times \text{Ratio} \]

   \[ d_{\text{E}} = 1 \text{ mm} \times 637.1 \]

   \[ d_{\text{E}} = 637.1 \text{ mm} = 63.7 \text{ cm} \]

   What a difference! In our drawing, the neutron star is only 1 mm diameter while the Earth is almost 64 cm diameter. Can you realize now better the huge size difference that exists between them in real life with this comparison at smaller scale?

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¹ The exercise could be finished in that case simulating the distance with steps (1 step ~ 1 meter).
² Students should be aware about the units. You can try to give them one diameter in kilometers and one diameter in meters to make them work on unit conversion too as well as to realize that in equations is important to match units.
Some students might not see the relation of the ratio directly, but they can simply apply the rule of three between the real and the made-up scale:

<table>
<thead>
<tr>
<th>Real scale</th>
<th>Made-up scale</th>
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<tbody>
<tr>
<td>(d_n_{\text{Real}} = 20 \text{ km} )</td>
<td>(d_n = 1 \text{ mm} )</td>
</tr>
<tr>
<td>(d_E_{\text{Real}} = 12742 \text{ km} )</td>
<td>(d_E = X )</td>
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\[ X = \left( \frac{1 \text{ mm}}{12742 \text{ km}} \right) \times 20 \text{ km} \rightarrow \text{Equivalent to the aforementioned ratio. In any case, they have to be aware of the units.} \]

The ratios help us to change the scale. If the first point or circle we drew was the Earth instead of the neutron star and now we wanted to know how the neutron star would look like in the new scale, which value would the ratio have?

2. **They spin around very fast:** the star that exploded was rotating, and the laws of physics say that the spin cannot stop after the explosion (*Note for educators:* this is the Conservation of the Angular Momentum). However, we know that the exploding star was big, and that the neutron star is small, consequently the latter needs to rotate faster. Why? In the video, Ted explains it with the example of an ice skater who stretches her arms and spins slower, then she pulls them in and spins faster (*Note for educators:* neutron stars have rotational periods of a few seconds, up to 10 seconds and down to only milliseconds).

3. When they are spinning, neutron stars can speed up particles that give off beams of light, which we can see when they cross our line of sight (just like a lighthouse). Therefore, the star appears to flash on and off. This type of neutron star is called a pulsar.

**What are pulsars? Do they spin at the same speed all their life?**

**Pulsars** are neutron stars that emit beams of light that we can see when they cross our line of sight, like lighthouses. They do not spin at a constant speed all their life. Actually, the pulsar’s spinning starts to slow down as the spinning energy of the star is used to speed up the particles to very high energies.

**True or False? “All particles produced by pulsars rotate forever around the star.”**

False. Only nearby particles get trapped around the star and spin with it. At very far away distances, particles would have to travel faster than the speed of light to keep up with the spinning pulsar and, since that is impossible, they stream away from the pulsar.

**What do we call the region around the pulsar where particles are still spinning around with the star? What do we call the group of particles that stream away from the star?**

The region is called the light cylinder, and the group of particles that stream away (because they cannot move faster than the speed of light) are called the pulsar wind.
Why is pulsar wind important?
Because it bumps into the surrounding medium (*Note for educators: into the interstellar medium*) creating shock waves where particles are accelerated. This creates a new object called pulsar wind nebula.

Can you name of a very famous pulsar wind nebula?
The Crab Nebula.

Draw the Crab Nebula. You can draw it following the real image of the nebula or you can make a cartoon based on its name. Why do you think it is called the Crab Nebula?

Why does Ted want to observe pulsar wind nebulae?
To catch gamma rays from them and understand for example what happen with particles inside these nebulae. Moreover, Ted and his friends from CTA will be able to see more pulsar wind nebulae than even before so they will be able to understand how they grow and affect their environment.

After everything you learnt along the series, can you list some objects that Ted and his telescopes friends from CTA observe to catch gamma rays?
Supernova remnants, black holes (Active Galactic Nuclei or AGNs), neutron stars (pulsars) and pulsar wind nebulae.
EPISODE 7: “CTA: Where do telescopes live?”

Why are Ted and friends looking at the stars in La Palma and Chile? Because to make sure telescopes get the best pictures of the night sky, they need to be located in places with the best conditions.

And what makes it a good place for a telescope? Pick those right conditions from the following list (marked in light blue).

- The sky needs to be cloudy, gray looks good in pictures.
- Thunderstorms are great, they work as a flash in the photos.
- The sky needs to be clear, so that stars are visible.
- The weather should be rainy, because splashing is fun.
- Telescopes must be situated in places with low artificial light, far away from cities, so there is no light pollution and stars can be seen.
- It should not rain, so that it does not affect telescopes and they can work as much as possible.
- The weather needs to be windy, because it is very refreshing.
- Telescopes should be placed among cities, to see big buildings closer.
- The weather cannot be windy, so the telescopes do not wobble and ruin the picture.

You can find more information on our website, as well as more educational material and seminar options in the Section “CTA for Educators,” including more definitions in the Dictionary of the Extreme Universe.