The Universe in my pocket

The high-energy universe

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No. 9

In the Cassiopeia Constellation, the five brightest stars form a 'W' shape. These stars are up to a thousand times more powerful than our Sun. But they do not emit in the high-energy domain.

Special instruments used for high-energy astrophysics are able to detect UV, X and gamma rays released by certain objects. Photometers measure the amount of light coming from these objects and provide us with an accurate measurement of the total energy they release.

Many objects emitting at high energies cannot be detected in visible light.

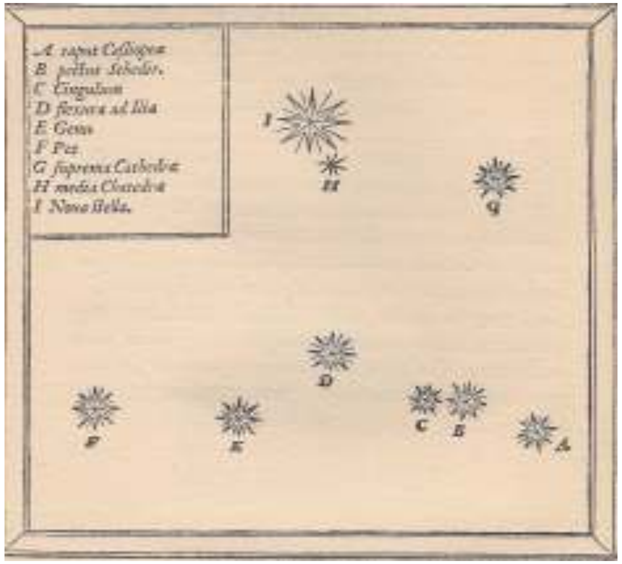
Even with the naked eye, we can see that some celestial objects are brighter than others. Are they closer to us and thus look brighter? Or do they release more energy?

Astronomers know how to measure the distances of many celestial bodies, so they can estimate the energy these emit in visible light.

Using special detectors working in the high-energy domain they can also gauge the energy that is invisible to the eye, being emitted by high-energy photons (UV, X and gamma-rays*), high-energy particles (neutrinos, cosmic rays) and gravitational waves.

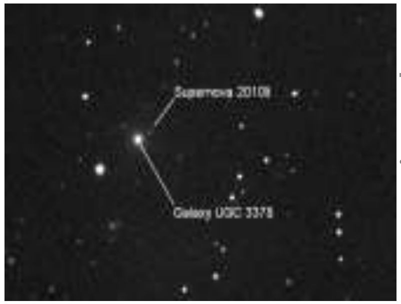
Some of the objects emitting in the high-energy domain, like Supernovae, Neutron Stars, Black Holes or Active Galactic Nuclei emit extreme amounts of energy. They radiate billions of times more energy than our Sun.

*see TUIMP 2



Left: In the star map of Cassiopeia, the astronomer Tycho Brahe marked by 'I' the 'new-born star', on 11 November 1572, later named Tycho's supernova. 'F', 'E', 'D', 'C', 'B', 'A', 'G' are long-lasting stars, and can be seen in the photo of Cassiopeia on page 2, but the 'I' star is no longer seen.

When it appeared, Tycho's supernova was as bright as Venus, although the burst occurred about 9 light-years away. It dimmed day after day and after about two years it could no longer be seen with the naked eye.



Left: The supernova 2010ltd, discovered by a ten-year old girl, Kathryn Gray. The burst happened 240million light-years away.

Supernovae

What a surprise if you watch the sky and suddenly observe a new star shining in a place that was empty before! Maybe you would cry: A new star is born! A nova, in Latin. Or, a supernova, if the new light is extremely powerful! The first such case was that of the guest-star seen by Chinese Astronomers in 1054*.

In fact this light does not signal the birth of a new star: A supernova is the explosion of an existing star. The burst is so tremendous that in a few minutes it releases as much energy as our Sun during its lifetime of10 billion years! Afterwards, the burst decays and the star becomes invisible again. What remains is a neutron star or a black hole. Telescopes show a large amount of matter moving away.

*see TUIMP 10

Left: A diagram demonstrating the collision between two black holes. The ripples propagating like waves in a pool represent gravitational waves.
The first gravitational wave detected by humans on 14 September 2015 informed us about such a collision, that happened 1.3 billion years ago between a pair of black holes of 36 and 29 solar masses. The power released during such a collision reached a level greater than that of the light radiated by all the stars in the Universe!

Right: A photo of the LIGO Hanford site, one of the observatories where gravitational waves are detected. The observed waveform matches the predictions of General Relativity developed by Albert Einstein.

Black holes

When a star with mass above 30 solar masses explodes as a supernova, a black hole of several solar masses forms in its center, inside a region of a few kilometers.

Why this unusual name? Because a black hole has such strong gravity that nothing can escape from it. No light, nor particles!

How then, can we observe them? By their influence on their surroundings!

Their gravitational energy is huge, because their mass is concentrated in a very small region. This energy can be released in the form of gravitational waves.

Gravitational waves were observed for the first time in September 2015. They were radiated by the collision of two black holes.

Neutrinos

Neutrinos are elementary particles with no charge and with a tiny, as yet undetermined, mass. They interact very weakly with other matter, so it is hard to detect them. Some giant experiments have been established on Earth to detect neutrinos.

Neutrinos are created by nuclear reactions, such as those taking place in the core of a star or in nuclear experiments. In supernova explosions, more than 99% of the energy can be released as neutrinos.

Despite their small mass, neutrinos are thought to be so numerous that they can influence the history of the Universe.

Right : The IceCube Neutrino Observatory. Thousands of sensors are placed under the Antarctic ice, distributed over a cubic kilometer for detecting neutrinos.

Neutron stars

When a star with mass between 8 and 30 solar masses explodes as a supernova, a neutron star forms. It is so dense that one teaspoonful would weigh a billion tons!

Neutron stars are composed of neutrons and rotate up to several hundred times per second, accelerating the particles in their atmosphere to near-light speed and generating a narrow radiating beam. In some cases, this beam sweeps across the Earth, making these stars detectable as pulsars*. The fastest pulsar, PSRJ1748-2446ad, rotates 716 times per second!

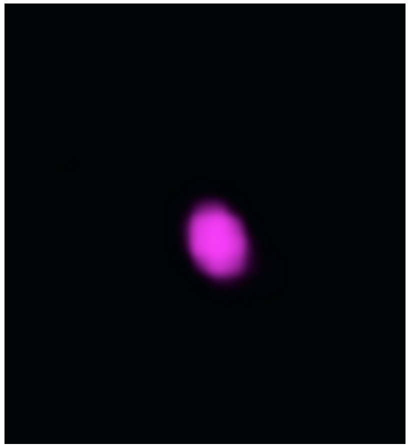
During the supernova burst leading to neutron star formation, apart from light, a huge stream of neutrinos leaves the star at nearly the speed of light. Some of these are observed on Earth.

* See TUIMP 10

Left: The Fermi Gamma-ray Space Telescope, which detects gamma-rays, the most energetic form of radiation, a million times more energetic than visible light.

On 17 August 2017, the Fermi telescope detected a short Gamma Ray Burst (GRB), just 1.7 seconds after a gravitational wave signal had reached Earth observatories. Both of these signals originated from the same event, two merging neutron stars, 130 million light-years away. Later, this event was observed in X-rays, ultraviolet light, and other bands of the electromagnetic spectrum.

Right: The same GRB seen in X-rays by the Chandra Space observatory, 9 days after the burst.



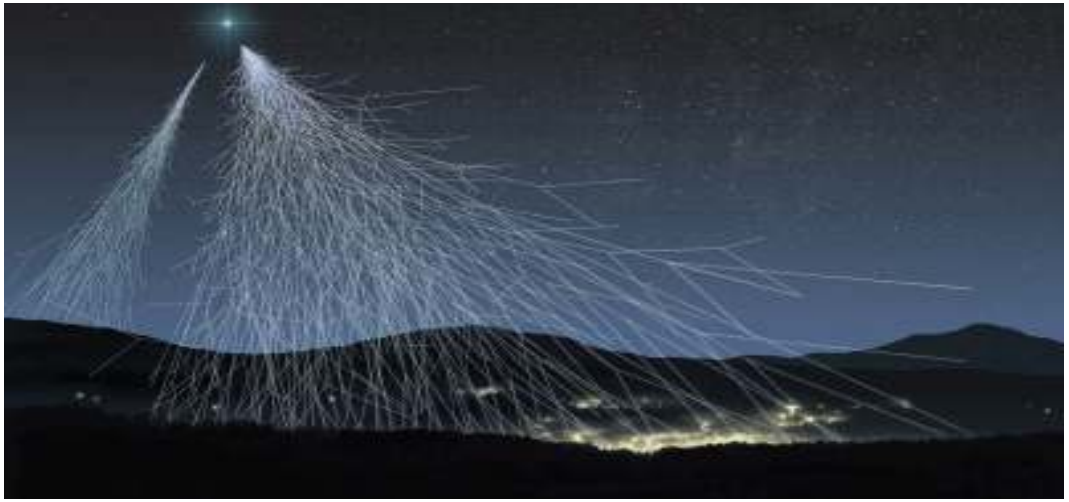
Gamma Ray Bursts

Gamma Ray Bursts (GRB) are the most powerful electromagnetic events known to happen in the Universe. Their energy, mostly released in the form of gamma photons*, can exceed one thousand times that of a supernova. Discovered fifty years ago, their physics is not yet fully understood.

GRB can be of short duration (from tens of milliseconds to few seconds) or long duration (from seconds up to hours). Long GRBs are linked with the burst of a star, during a supernova explosion. Short GRBs are thought to originate from the merging of two neutron stars or of a neutron star and a black hole.

Satellite telescopes discover about one GRB per day.

*see TUIMP 2



An artist's view of the impact of cosmic rays with the Earth's atmosphere. Upon interaction with the atmospheric molecules, a 'shower' of elementary particles is produced. Some of these particles may reach some of the thousands of detectors deployed by scientists in grids covering several thousand square kilometers.

After a century of numerous experiments, the scientific data up to now lead to the conclusion that a significant fraction of cosmic rays originate from outside our Galaxy, in supernova explosions or from Active Galactic Nuclei*.

*see TUIMP 6

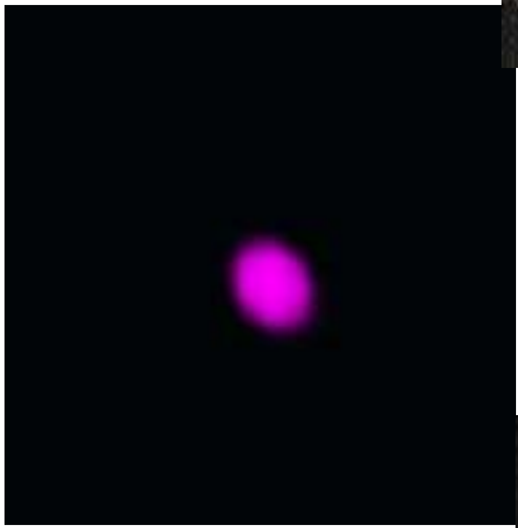
Cosmic rays

Not only photons, neutrinos and gravitational waves reach us from Space. The high-energy Universe also sends us charged particles, mostly protons, but also electrons and nuclei of atoms; these are called cosmic rays. Billions of billions of cosmic ray particles bombard Earth from Space every second.

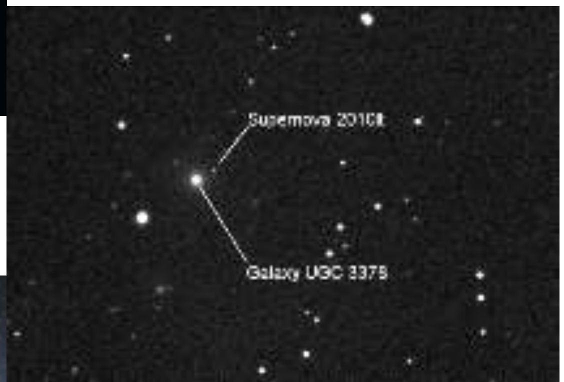
Discovered at the beginning of the 20th century, they are still of uncertain origin.

Cosmic ray particles can carry huge energies, and travel nearly at the speed of light. In extreme cases, their kinetic energy can be billions of billions of times greater than their rest-mass energy.

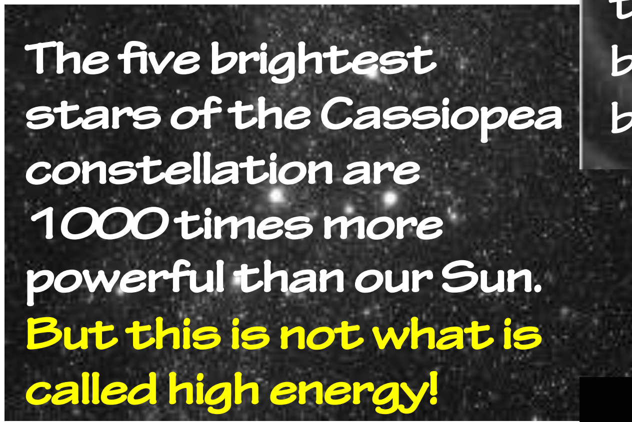
Quiz

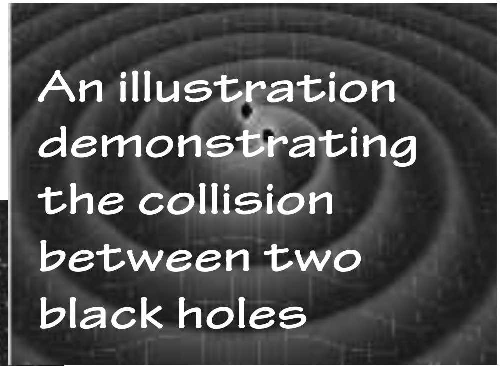


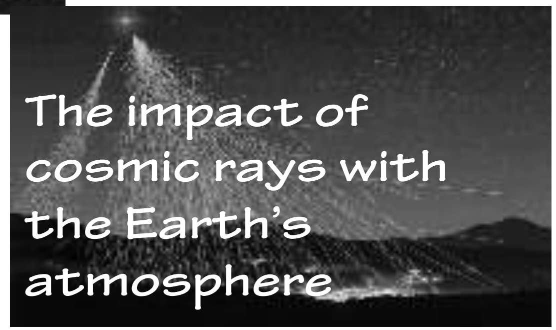
Which of these images is not related to high energy phenomena of the Universe?



Answers on overleaf







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This booklet was written in 2018 by Mimoza Hafizi from Tirana University (Albania) and revised by Stan Kurtz from the UNAM Radio Astronomy Institute in Morelia (Mexico).

Cover image: Artist's illustration of two merging neutron stars. [Credit: NSF/LIGO/Sonoma State University/A. Simonnet]

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