INTEGRAL

"How does the continuous gamma-ray observation by the INTEGRAL satellite help to improve our understanding of distant galaxies and our solar system?"

1. Introduction:

INTEGRAL: INTErnational **G**amma-**R**ay **A**strophysics **L**aboratory

- Mission launch: 2002
- Planned mission end with re-entry into Earth's atmosphere: 2029
- Total mass of the satellite: 4.000 kilograms (4 tons)
- Located in a high elliptical orbit
- 4 instruments:
  - **IBIS** (imaging sensor)
  - **SPI** (spectrometer)
  - **JEM-X** (x-ray monitor)
  - **OMC** (optical camera)

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The INTEGRAL satellite is a gamma-ray observatory operated by the ESA (European Space Agency) that has been operating in Earth orbit since 2002. Its main task is to explore the most energetic and violent phenomena in the universe that are revealed by gamma radiation. INTEGRAL is equipped with the four highly specialized scientific instruments mentioned above, which enable it to detect and analyze gamma radiation.

The **IBIS** and **SPI** instruments are used for observation and analysis in the gamma range of the electromagnetic spectrum. **JEM-X** is used to observe and analyze X-rays, while **OMC** is used to observe and analyze visible light. These instruments enable scientists to study and understand extreme cosmic events such as supernovae, black holes, and gamma-ray bursts. INTEGRAL's mission thus contributes significantly to our understanding of the most energetic processes in the universe and opens up new insights into astrophysics.

- **Black holes:**

  Black holes are among the most fascinating and powerful objects in the universe. They are regions of space with an extremely strong gravitational force from which not even light can escape. This is why they are called black holes. They are so powerful that they can destroy stars like our sun down to the smallest atomic level. Important properties of black holes are:

  - They usually form when massive stars collapse at the end of their life cycle.
  - Black holes have what is known as an event horizon, a boundary beyond which nothing can escape, not even light.
  - The gravity near a black hole is so strong that it distorts space and time.
  - Although black holes themselves are invisible, we can detect their existence through their effects on surrounding matter and radiation.

  Black holes play an important role in modern astrophysics and help us to better understand the structure and evolution of the universe.

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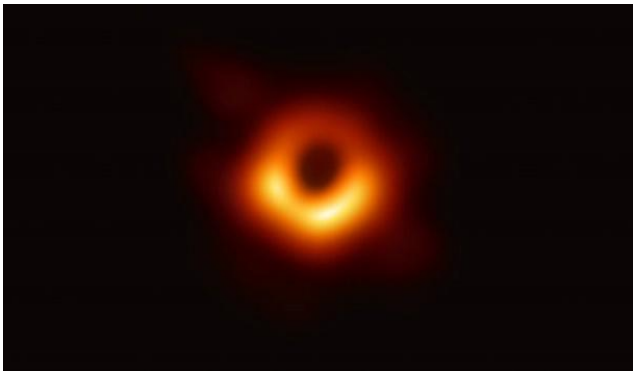
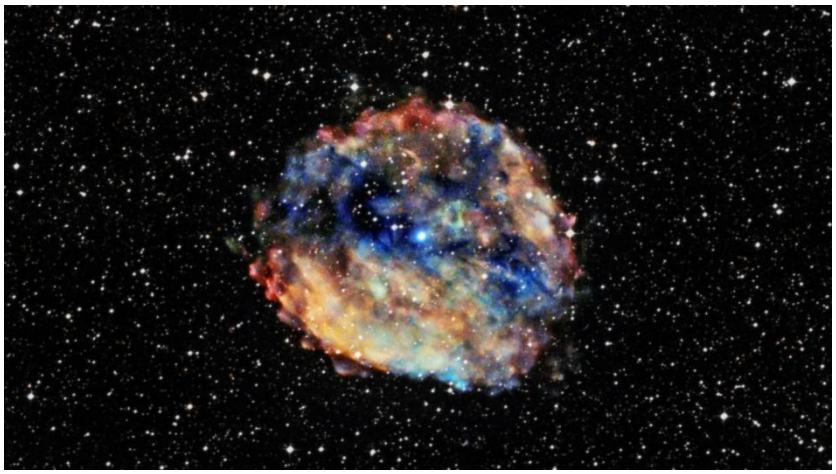


Black hole in the galaxy „Messier 87“

- **Supernovae:**

  A supernova is a massive explosion at the end of a star's life. These explosions are among the most energetic events in the universe and are so bright for a short time that they can outshine entire galaxies. Studying supernovae helps us understand the chemical evolution of the cosmos. There are two different mechanisms by which stars become supernovae:

  1. Massive stars with an initial mass of more than eight solar masses, whose core collapses at the end of their evolution. This collapse or hydrodynamic supernova results in a neutron star or a black hole.
  2. Low-mass stars that, in their preliminary final stage as white dwarfs, absorb material from a companion star (accretion). This leads to gravitational collapse—since white dwarfs can only exist up to a certain mass — and is followed by a thermonuclear supernova (1a). Density and temperature rise sharply in the center of the star.



Supernova detected by NASA’s Chandra X-Ray Observatory

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- **Gamma radiation:**

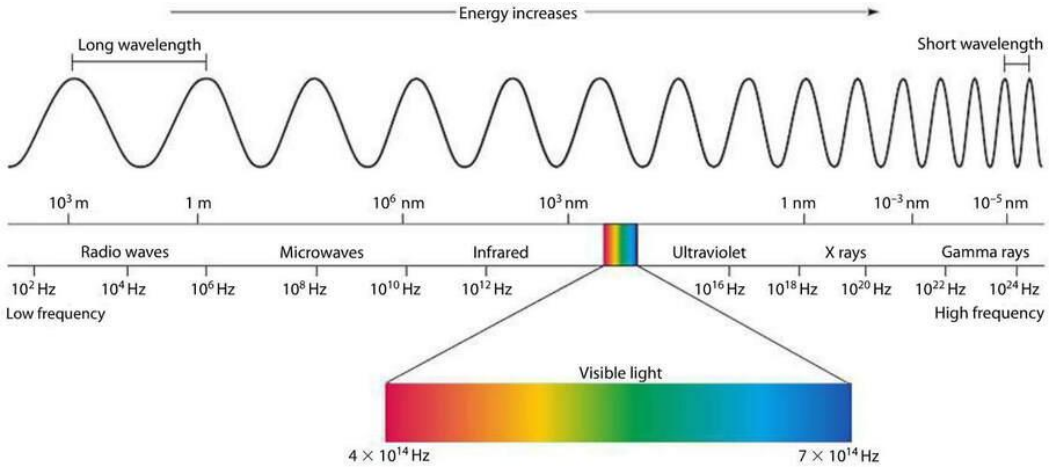
Gamma radiation is a form of electromagnetic radiation with extremely high energy. It forms the most energetic part of the electromagnetic spectrum (see figure). Possible formation process:

1. After radioactive decay, an atomic nucleus is in an excited state.
2. To return to its ground state, the nucleus releases excess energy in the form of high-energy photons (known as gamma quanta).
3. This process is called a gamma transition.

Gamma-ray bursts are short but extremely energetic bursts of gamma radiation that are observed in space.

- Duration: Usually only a few seconds.
- Energy: Extremely high, up to several million electron volts per photon.
- Origin: In connection with a supernova; during the merger of compact objects such as neutron stars

The formation of gamma-ray bursts is associated with catastrophic cosmic events such as collisions of neutron stars or explosions of particularly massive stars. The energy released during these events is so enormous that it is comparable to the complete conversion of Jupiter's mass into energy.



Gamma radiation in the electromagnetic spectrum

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1.1 *Summarize in your own words what makes the INTEGRAL satellite unique and what instruments it has.*

1.2 *Summarize in your own words what black holes, supernovae, gamma radiation, and gamma-ray bursts are.*

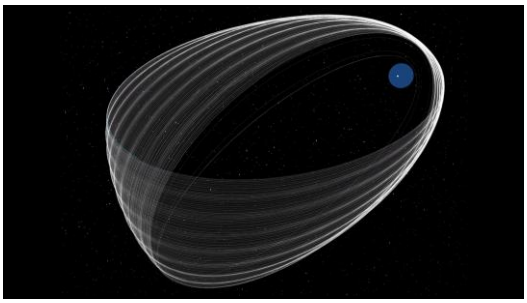
2. Orbit

Read the following info text about the orbit of the INTEGRAL satellite and assess why this particular orbit was chosen for the satellite, especially in relation to the large distance from Earth on its highly elliptical orbit. You can also see the orbit visually in the video below via the QR code.

The INTEGRAL satellite is a scientific observatory that studies gamma radiation from space. A special orbit was chosen for it to successfully carry out its mission. This orbit is elliptical, which means that the distance between the satellite and Earth varies greatly: It moves between a minimum distance of about 3,300 kilometers and a maximum distance of about 159,000 kilometers from Earth. The orbital period is about 72 hours, or three days.

The choice of this orbit is closely linked to the requirements of the scientific measurements. A decisive factor is the Earth's environment, which is characterized by various radiation zones. These zones can affect sensitive instruments and impair the quality of the measured data. Due to the shape of its orbit, the satellite spends most of its time far away from these zones.

In addition, the long orbital period enables regular communication with ground stations and efficient organization of workflows for ground personnel.



Elliptical orbit of the INTEGRAL satellite

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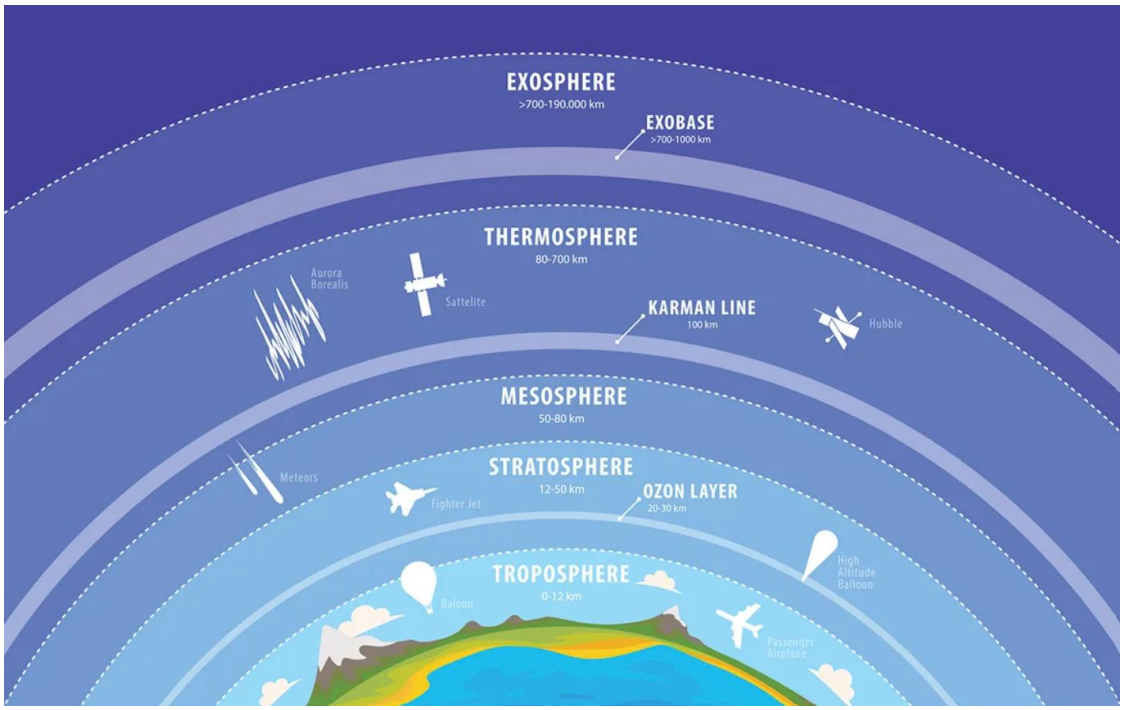
3. Structure of the Earth's atmosphere

Look at the diagram showing the structure of our Earth's atmosphere, read the info text, and decide whether the measurements of gamma radiation and the analysis of supernovae and black holes out of the Earth's atmosphere make sense.



Structure of the Earth's atmosphere

The Earth's atmosphere is divided into several layers, which differ in their physical and chemical properties. This stratification plays an important role for life on Earth and influences various atmospheric phenomena.

Troposphere: Weather occurs in the troposphere, as it contains almost all of the water vapor in the atmosphere. The temperature here decreases with altitude, by about 6.5°C per kilometer.

Stratosphere: This layer contains the ozone layer, which absorbs UV radiation and converts it into heat. As a result, the temperature in the stratosphere rises with increasing altitude.

Mesosphere: Here, the temperature drops sharply again to around -90°C, as there is hardly any ozone left most of the meteors that we see as shooting stars burn up in the mesosphere.

Thermosphere: In this layer, the temperature rises sharply due to the absorption of high-energy solar radiation and can reach 1500°C. This is where polar lights occur and the International Space Station (ISS) orbits the Earth. The thermosphere also contains the "boundary" to space, at an altitude of approximately 70-100 km (known as the Karman line).

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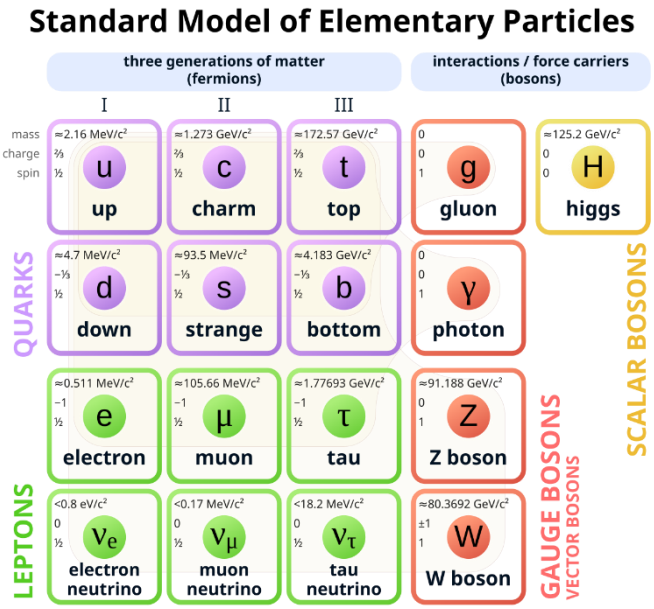
Exosphere: This is the outermost layer of the atmosphere. It consists mainly of very light particles such as hydrogen. This layering of the atmosphere is crucial for protecting life on Earth by filtering harmful radiation, regulating temperatures, and enabling various atmospheric processes.

4. Particle physics

There are many different particles that combine to form larger particles, which in turn make up all the matter in the universe. The best-known particles are probably electrons, neutrons, and protons, as well as photons (the "light particles"). Neutrons and protons consist of so-called quarks. Like electrons, these are elementary particles, which means that they themselves do not consist of even smaller particles. Since this can quickly become confusing, physicists have created the particle zoo. This provides a clearer overview of the different types of particles that exist.



Particle zoo of elementary particles

As can be seen in the figure, there are different subgroups in the zoo. The green group are the leptons (the "light particles"). The purple group are the quarks, which combine in various ways to form, for example, neutrons (N) or protons (p). A third, orange group are the gauge bosons, which include the photon, for example. The last, very abstract yellow group of scalar bosons consists only of the Higgs particle. This gives all particles their mass.

However, there is another subdivision. Depending on how the quarks are combined, there are mesons

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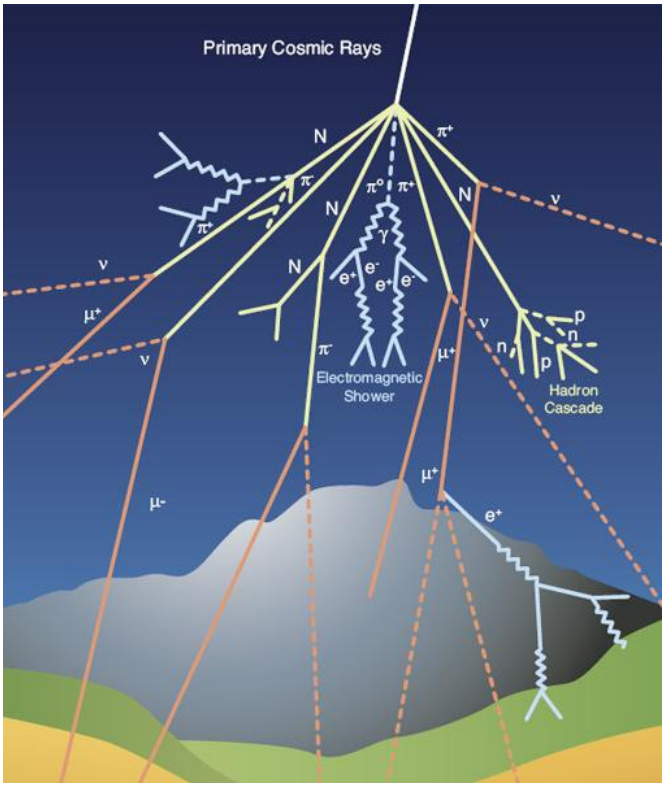
(the "medium-heavy particles") and baryons (the "heavy particles"). Mesons include pions and K mesons, while baryons include neutrons and protons. Mesons and baryons together form hadrons.

Decay of cosmic radiation in the atmosphere



Primary cosmic radiation hits the Earth's atmosphere and "breaks down" into secondary cosmic radiation.

4.1. *Read the text and highlight important terms*

4.2. *Which particles can you identify in the adjacent illustration based on the abbreviations (see particle zoo)?*

4.3. *Do you think the particle shower has an impact on Earth and humans? If so, what kind?*

5. **Answer the key question:** "How does the continuous gamma ray observation by the INTEGRAL satellite help to improve our understanding of distant galaxies and our solar system?"

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