# ASTROPHYSICAL COMPACT OBJECTS AND THEIR PROPERTIES

**Musurmonova Shahnoza Dilshod qizi**

**Abstract** *This article analyzes the main theoretical concepts and physical properties of compact objects in astrophysics — neutron stars, white dwarfs, and black holes. It discusses the formation processes and internal structures of these objects, as well as the methods of their detection through electromagnetic and gravitational radiation. Furthermore, the role of compact objects in high-energy astrophysics and cosmic evolution is highlighted. The article is based on modern scientific research and observations, and it also explores their practical significance.*

**Keywords:** *compact objects, neutron star, white dwarf, black hole, gravitational waves, electromagnetic radiation, astrophysics, stellar evolution*

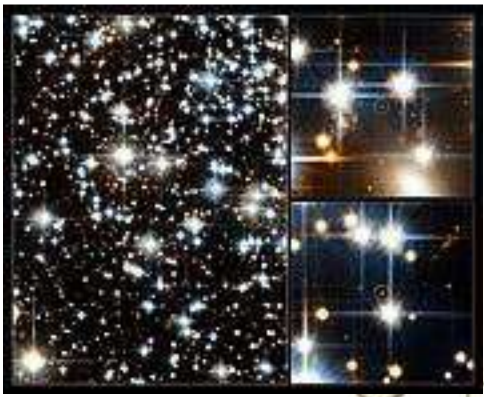
## Astrophysical Compact Objects

Astrophysical compact objects are celestial bodies characterized by extremely high densities. They include white dwarfs, neutron stars, and black holes — all of which are formed during the final stages of stellar evolution.

### White Dwarfs

These objects represent the dense cores of stars that have exhausted their nuclear fuel. They are supported against further collapse by electron degeneracy pressure. Although their mass is comparable to that of the Sun, their volume is similar to that of Earth. The ultimate fate of a star depends on its initial mass. Stars with initial masses ranging from approximately 80% up to 10 times the mass of the Sun can end their lives as white dwarfs. Typically, a white dwarf forms when a star sheds its outer layers during the late stages of its evolution, creating a planetary nebula, and leaving behind a compact core roughly Earth-sized.Some white dwarfs exist in binary star systems and can undergo explosive events known as novae. However, such explosions do not result in their transformation into neutron stars or black holes. In contrast, stars with greater masses may end their lives in supernova explosions, leading to the formation of other compact objects.

White dwarfs no longer undergo nuclear fusion processes, meaning they do not generate energy. However, they remain at very high temperatures and gradually cool down over time. Theoretically, they can eventually become black dwarfs, but the universe has not yet aged enough for this stage to be reached, so no black dwarfs currently exist.The luminosity of white dwarfs is an important tool for astronomers to determine when star formation began in a particular region. They serve as remnants that provide valuable information about previous generations of stars and play a significant role in cosmological studies.



1-rasm. White dwarfs

**Neutron Stars**

Neutron stars are remnants of very massive stars that have avoided complete collapse due to neutron degeneracy pressure. They are extremely dense, with masses comparable to that of the Sun but with radii of only a few kilometers. Neutron stars form as a result of a supernova explosion. During the supernova, under the influence of gravity, the stellar core compresses beyond the density of a white dwarf to nuclear densities. Neutron stars are the smallest and densest stellar objects in the universe after black holes. After their formation, neutron stars no longer produce internal heat and gradually cool over time. Despite cooling, their state can change due to collisions or accretion of matter:

1. Collision with a companion star
2. Accretion of surrounding matter

Neutron stars are believed to be composed almost entirely of neutrons. This is because under extremely high pressure, protons and electrons combine to form neutrons. To prevent gravitational collapse under their own weight, neutron stars are supported by neutron degeneracy pressure, similar to how white dwarfs are supported by electron degeneracy pressure. However, neutron degeneracy pressure alone cannot support neutron stars above approximately 0.7 solar masses. To stabilize neutron stars with higher masses, repulsive nuclear forces between particles are also required.

**Tolman–Oppenheimer–Volkoff (TOV) Limit**

This limit defines the maximum mass a neutron star can have before collapsing into a black hole. The estimated TOV limit ranges from about 2.2 to 2.9 solar masses (M⊙). If a neutron star exceeds this limit, not even nuclear forces and degeneracy pressure can prevent collapse.

The most massive neutron star observed to date is PSR J0952-0607, with an estimated mass of approximately 2.35 ± 0.17 M⊙.

**2-rasm**. Neutron stars

**Black Holes**

Black holes are among the most mysterious and extraordinary objects in the universe. Although they are called “holes,” they are not empty space. Rather, these objects are forms of matter compressed into an extremely small volume with an enormous mass. Because of this, their gravitational pull is so strong that not even light can escape from them. This boundary is known as the event horizon. The event horizon is not a physical surface like the Earth’s or the Sun’s surface; it is simply a boundary beyond which nothing can return.

What lies inside the event horizon remains largely unknown, but scientists have gathered considerable knowledge about black holes. For example, the formation of black holes, their effects on surrounding matter, and methods of detecting them — such as through gravitational waves or X-ray emissions — have been extensively studied. However, some questions remain unanswered: for instance, the state of matter inside the event horizon or what exists at the very center of a black hole are still open issues in physics.

**3-rasm. Black Holes**

This artist’s concept depicts Sagittarius A* (Sgr A*), an ultramassive black hole located at the center of the Milky Way galaxy. It is surrounded by a swirling accretion disk composed of hot gas. The strong gravitational pull of the black hole bends the light coming from the far side of the disk, creating the appearance that the light curves around the black hole both above and below it.

Within the disk, several bright, hot spots (flares) are observed, which are similar to solar flares but significantly more powerful. NASA’s James Webb Space Telescope has detected bright flares and much fainter but extremely rapid flickering coming from this black hole. These flickers are so fast that they must originate from regions very close to the black hole itself.

Illustration credits: NASA, ESA, CSA, Ralph Crawford (STScI)

Black holes neither emit nor reflect light, making them essentially invisible to telescopes. Scientists identify and study black holes mainly through their effects on the surrounding environment:Black holes may be surrounded by rings of gas and dust called accretion disks. These disks emit light at various wavelengths, including X-rays.Ultramassive black holes cause stars near them to move in specific orbits due to their powerful gravity. By tracking the orbits of several stars near the Milky Way's center, astronomers have confirmed the presence of an ultramassive black hole there. This discovery was awarded the Nobel Prize in 2020.

Massive objects such as black holes generate ripples in the fabric of spacetime — gravitational waves — when they move through space. Scientists can detect these waves by measuring their effects on specialized detectors.

Heavy objects like black holes can also bend and distort light from distant sources, a phenomenon known as gravitational lensing. This effect allows astronomers to detect otherwise invisible and isolated black holes.

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