Dark Matter and Dark Energy

For Prelims: **Dark Matter**, **Electromagnetic Force**, **Protons, Neutrons, Electrons**, **Weakly Interacting Massive Particles**, **Neutrino**, **Black Hole**, **White Dwarfs**, **Neutron Stars**, **Brown Dwarfs**, **Gravitational Lensing**, **IceCube Neutrino Observatory**, **Large Hadron Collider**, **James Webb Space Telescope**, **Dark Energy**.

For Mains: Dark Matter and Dark Energy

Source: TH

Why in News?

Recently, **physicists** revised the **minimum mass of** **dark matter** and pushed it up to **2.3 × 10-30 proton masses.**

- For decades scientists thought this minimum mass was about **10-31 times the mass of a proton.**

Note: In **1922, Dutch astronomer Jacobus Kapteyn** concluded the **density** of **"dark matter"** (using that term for one of the first times) must be **0.0003 solar masses per cubic light year.**

What is Dark Matter?

- **About:** Dark matter is a **form of matter** that is **entirely invisible**, emitting **no light or energy,** making it **undetectable** by conventional sensors and detectors.
  - Dark matter **doesn't interact with** **electromagnetic forces**, so it **neither absorbs, reflects, nor emits light,** making it hard to detect.
  - Dark matter makes up about **27% of the** **universe**, outweighing visible matter six to one, while **visible matter** accounts for **only 5%.**
  - **Visible matter (Baryonic matter)** consists of subatomic particles like **protons, neutrons, and electrons**.

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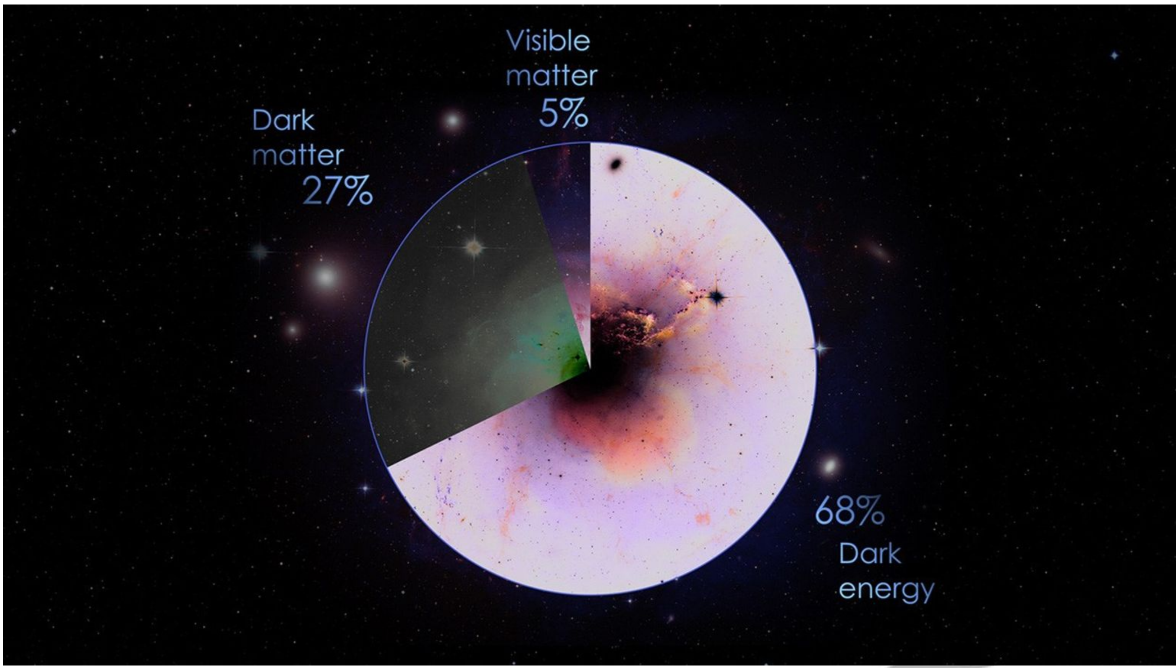

- **Composition of Dark Matter:** Dark matter is thought to consist of **non-baryonic WIMPs (weakly interacting massive particles),** 10-100 times the mass of a proton, but weakly interacts with normal matter, making detection difficult. Among WIMPs are:
  - **Neutralinos:** They are **hypothetical particles (not yet been observed)** that are heavier and slower than neutrinos.
  - **Sterile Neutrinos:** Sterile neutrino is proposed as a dark matter candidate as it **only interacts with regular matter through gravity**. Also, neutrinos are particles that don't form regular matter.
- **Origin of Dark Matter:**
  - **Big Bang Theory:** Dark matter may have formed during the Big Bang and concentrated into black holes, where their gravitational forces **trap dark matter** particles.
  - **Stellar Remnants:** Stellar remnants such as **white dwarfs and neutron stars** are also thought to contain high amounts of dark matter.
    - **Brown dwarfs (failed stars)** that didn't accumulate enough material to kick-start nuclear fusion in their cores can also be a source of **dark matters.**
- **Evidence of Dark Matter:**
  - **Galaxy Rotation Curves**: According to **Newtonian gravity**, objects at the **edge of galaxies** should be moving **slower** than those near the center.
    - Observations show **stars on galaxy edges move faster than expected**, suggesting **unseen mass**—attributed to dark matter—provides **extra gravitational pull.**
  - **Gravitational Lensing**: Gravitational lensing occurs when **light is bent by a massive object's gravity**, revealing more mass than visible, suggesting the presence of dark matter.
  - **Galaxy Formation: Galaxies' distribution and motion** over time suggest dark matter, as it enables galaxies to **clump together** and form current structures.
- **Projects to Study Dark Matter:** There are some key projects designed to shed light on dark matter.
  - **Alpha Magnetic Spectrometer (AMS):** The AMS is an experiment mounted on the **International Space Station** which has detected an **excess of positrons** (the antimatter counterpart to electrons), which may be a signature of dark matter.
  - **XENON1T:** The XENON1T experiment in the **Italian Gran Sasso Laboratory** aims to detect dark matter by observing the **interactions of WIMPs with xenon atoms.**
  - **IceCube Neutrino Observatory, Antarctica:** The IceCube Neutrino Observatory is investigating the possibility of **sterile neutrinos**—hypothetical particles that only interact with regular matter via gravity and could be a form of dark matter.
  - **Particle Colliders at CERN, Switzerland:** CERN's Large Hadron Collider (LHC)

conducts high-energy particle collisions to probe the fundamental particles of the universe. The LHC also looks for potential signs of **dark matter by analyzing the aftermath of particle collisions.**
  - **James Webb Space Telescope (JWST):** JWST is expected to provide valuable insights into how **galaxies and cosmic structures developed**, which could help us understand the role of dark matter in their formation.

Note: Antimatter consists of particles that are essentially the **same as visible matter** particles but with **opposite electrical charges.**

- These particles are called **antiprotons and positrons** (or antielectrons).
- **Antimatter** is **not** the same as **dark matter.**

What is Dark Energy?

- Dark energy is a **mysterious form of energy** that makes up about **68% of the universe.** It is thought to be responsible for the **accelerated expansion** of the universe.
- It is **distributed evenly** throughout the universe, not only in **space but also in time** i.e., its effect is **not diluted as the universe expands**.
- The even distribution means that dark energy does **not have any local gravitational effects,** but rather a **global effect** on the universe as a whole.
  - This leads to a **repulsive force**, which tends to accelerate the **expansion** of the universe.
- The **rate of expansion** and its **acceleration** can be measured by observations based on the **Hubble law.**
  - Hubble's Law states that **galaxies move faster away from Earth** as they are farther, implying the **universe is expanding**.

Conclusion

Dark matter, making up a significant portion of the universe, remains elusive yet crucial for understanding cosmic structures and evolution. Ongoing experiments and astronomical observations continue to explore its properties, origin, and impact, promising advancements in fundamental physics.

Drishti Mains Question:

Discuss the evidence supporting the existence of dark matter and its implications for our understanding of the universe.

UPSC Civil Services Examination Previous Year Question (PYQ)

Prelims

Q. In the context of modern scientific research, consider the following statements about 'IceCube', a particle detector located at South Pole, which was recently in the news: (2015)

1. It is the world's largest neutrino detector, encompassing a cubic kilometre of ice.
2. It is a powerful telescope to search for dark matter.
3. It is buried deep in the ice.

Which of the statements given above is/are correct?

(a) 1 only

(b) 2 and 3 only

(c) 1 and 3 only

(d) 1, 2 and 3

Ans: (d)