Exploring Dark Matter Freeze-Out

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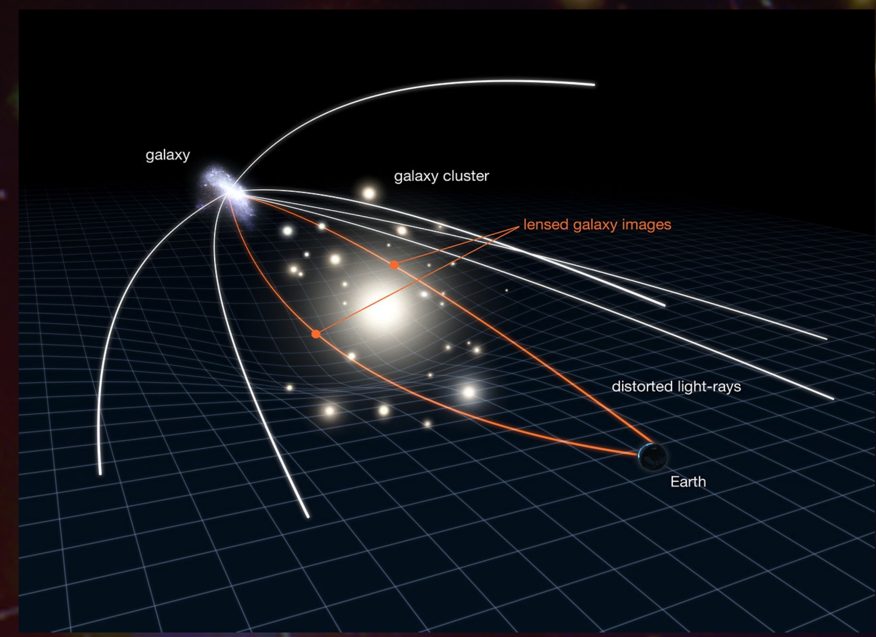
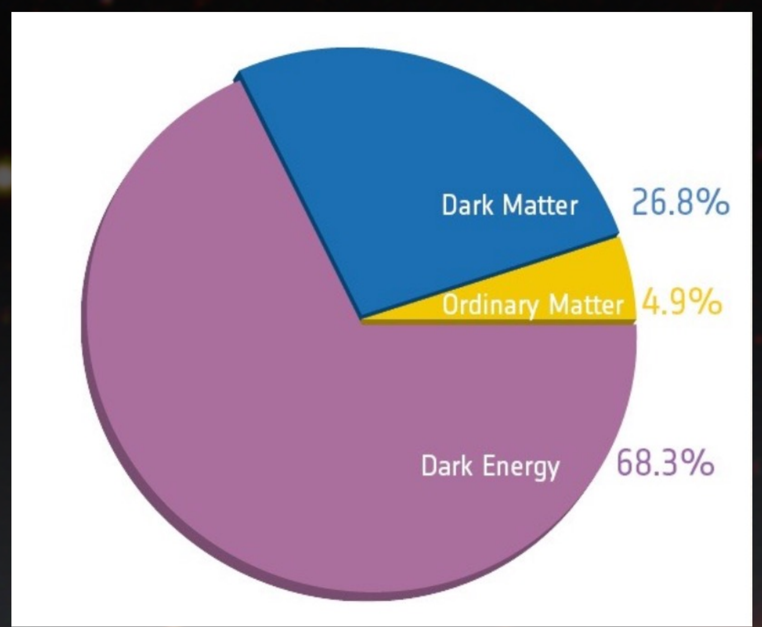
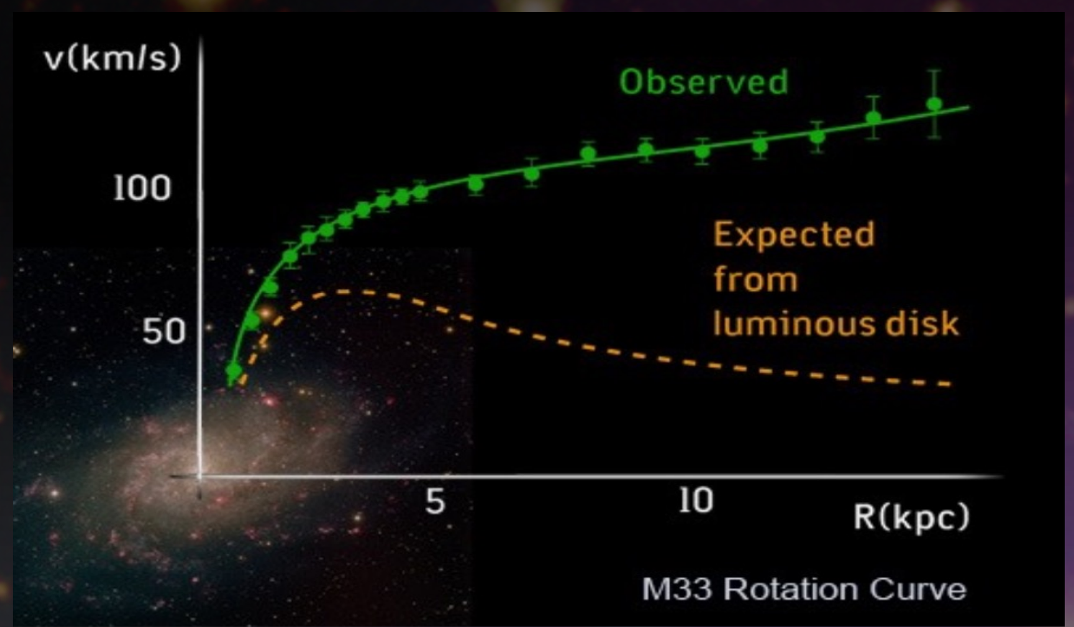
Background

Dark matter, unlike ordinary matter, doesn't interact with electromagnetic forces, making it invisible to light. Its presence is detected through gravitational effects, such as gravitational lensing. Although elusive, dark matter makes up about 85% of the universe's total mass and is essential for explaining the formation and structure of galaxies and other cosmic features. make these in points

The objective is to describe how the density of dark matter evolved after its interactions with other particles froze out in the early universe.







Evidence of Dark Matter

- **Rotation Curve**: The rotation curves of galaxies indicate that the orbital speed of stars and gas clouds remains constant at large distances from the centre. According to Kepler's laws, this speed should decrease if most of the mass were near the centre. However, observations show a flat rotation curve, suggesting additional unseen mass, or dark matter, affecting the galaxy's gravitational behaviour.

- **Bullet Cluster**: The Bullet Cluster, formed by the collision of two galaxy clusters, provides strong evidence for dark matter. Observations show ordinary matter (hot gas) slowed by the collision, while dark matter, unaffected by forces other than gravity, continued to move freely.

- **Gravitational Lensing**: Gravitational lensing occurs when massive objects, including dark matter, bend spacetime, distorting the light from distant sources. Although dark matter is invisible, its gravitational influence is detected through these distortions, revealing its presence and distribution.

Methodology

After the expansion of the early universe, particle decoupling occurs, and the relic density of these particles can be determined using the Boltzmann equation.

The focus was on the time evolution of the number density n_ψ for a particle species ψ, considering both cosmic expansion and particle interactions. We used the comoving number density, or yield Y, to account for particle dilution due to expansion, leading to the equation:

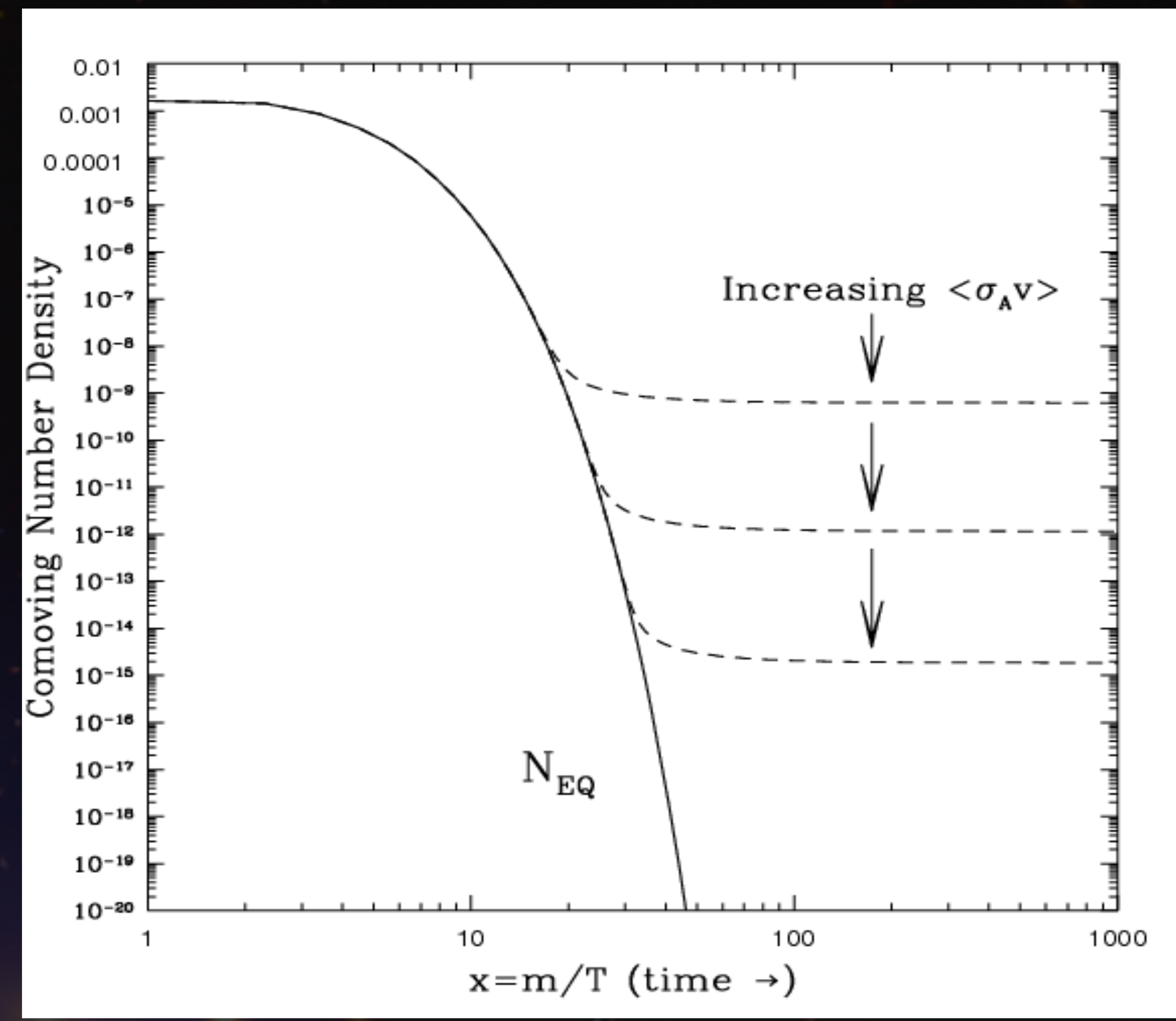
$$\dot{n}_\psi + 3Hn_\psi = s\dot{Y}$$

During the Radiation Dominated Epoch, the time evolution relation $t=0.301g^{-1/2} m_{pl} x^{-2}$ was used to track Y. Incorporating the thermal average cross-section and $\Gamma=n_\psi^{EQ}\langle\sigma v\rangle$, we derived a simplified differential equation for the yield:

$$\frac{dY}{dx} = -\frac{x\Gamma Y_{EQ}}{H}\left[\left(\frac{Y}{Y_{EQ}}\right)^2 - 1\right]$$

This describes how the number density evolves with expansion and interactions, covering the key processes of particle annihilation and creation.

Result and Conclusion



- The evolution of the yield Y was analysed.
- During early times, the difference between Y and Y_{EQ} is small, and the abundance tracks thermal equilibrium closely.
- As x increases, freeze-out occurs when interactions become inefficient, causing the yield to decouple from equilibrium and stabilize.
- Relic density is inversely proportional to DM annihilation cross section.
- Correct relic density indicates annihilation cross section to be of the order of weak interaction.
- Thus, they are called Weakly Interacting Massive Particle or WIMP.
- They are searched in direct, indirect and collider searches.

References

- E.W. Kolb, M.S. Turner, The Early Universe
- S. Profumo, "An Introduction to Particle Dark Matter," Santa Cruz Institute for Particle Physics

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