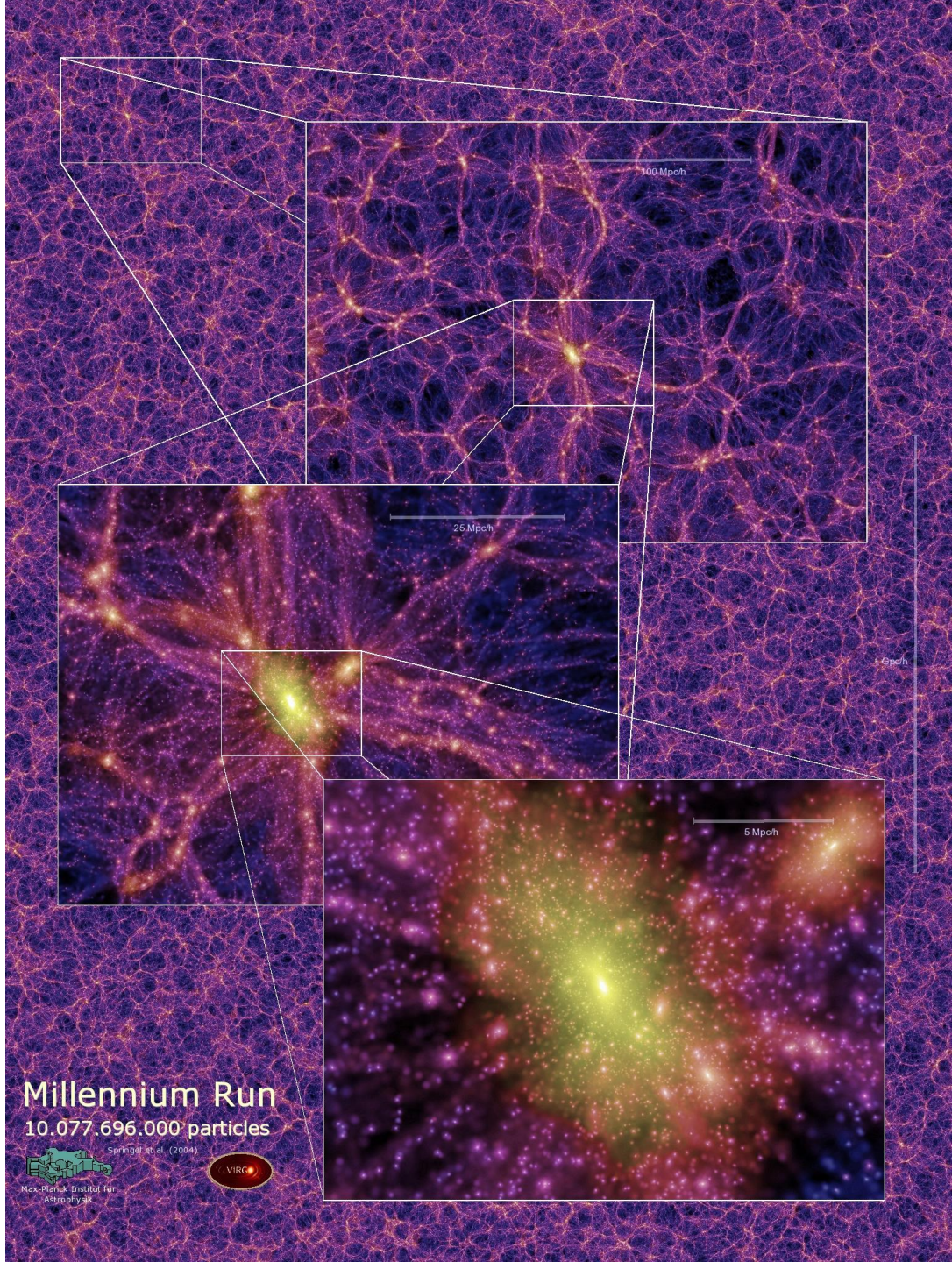
A Journey Through Cosmology: Mechanics, Gravity, and the Mysteries of the Universe



[Reference: Millennium]

The Cosmic Challenge:Is the Cosmos Predictable?

Question time

If you could travel at 100 km/h, how long would it take to reach our nearest galaxy, Andromeda?

The answer reveals the **immense scale of cosmic distances**.

Universe explorer

Universe scales



Reference: NASA

Question time

If the gravity of a single body is the only force acting on an object, how will that object move?

This principle perfectly describes basic orbital mechanics, governing the behavior of our **Solar System.**

Solar system

But does it also apply to billions of stars?

From Earth to Infinity: A Universe of Galaxies and Clusters

Cosmology

The science that studies the origin, evolution, and large-scale structure of the Universe.

Cosmic Scales

Distances in the Universe are immense, with measurements in light-years, parsecs, and kiloparsecs. For instance, our own Milky Way galaxy spans approximately 100,000 light-years across.

Galaxies

Vast systems bound by gravity, containing billions of stars, gas, dust. They come in diverse types: spiral (like our Milky Way, which contains 200-400 billion stars), elliptical and irregular.

Clusters and Groups

Groupings of hundreds or thousands of galaxies, representing one of the largest known structures in the observable Universe. Our own Local Group contains the Milky Way and Andromeda galaxies.



Reference:Milky Way galaxy

Question time

What holds a galaxy together and determines its rotation speed?

Classical Mechanics & Gravitation

Newton

Newtonian mechanics and the law of universal gravitation represent fundamental pillars of classical physics.
The Law of Universal Gravitation describes the attraction between two bodies based on their mass and distance.

$$F_g = \frac{Gm1m2}{r^2}$$

Circular Motion

In our Solar System, **gravitational force** (Fg) acts as **centripetal force** (Fc), keeping bodies in stable orbits. In circular motion, the centripetal force is:

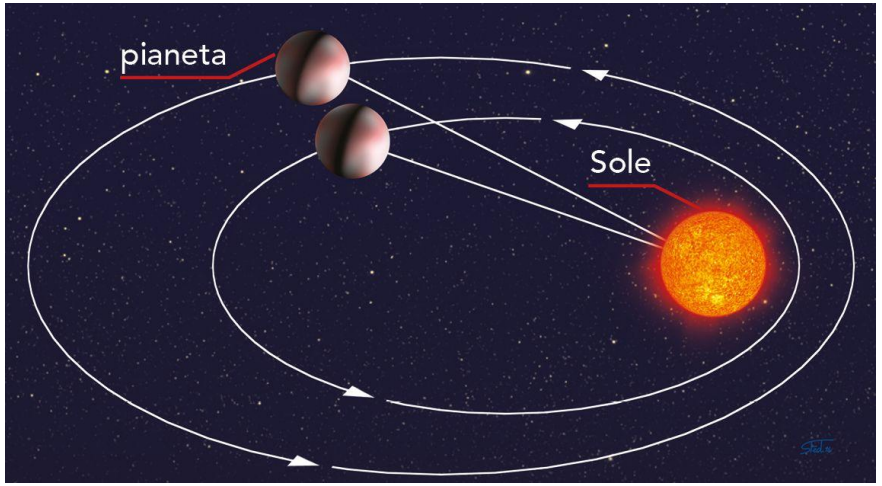
$$F_c = \frac{mv^2}{r}$$

Kepler

Defines planetary motion around the Sun. The 3rd law connects period and distance, assuming mass is centralized.

$$T^2 \propto r^3$$

For example, if Earth takes 365 days, Venus (closer to the Sun) takes 225 days, and Mars (further from the Sun) takes 687 days.



Reference:Kepler

Theoretical Prediction

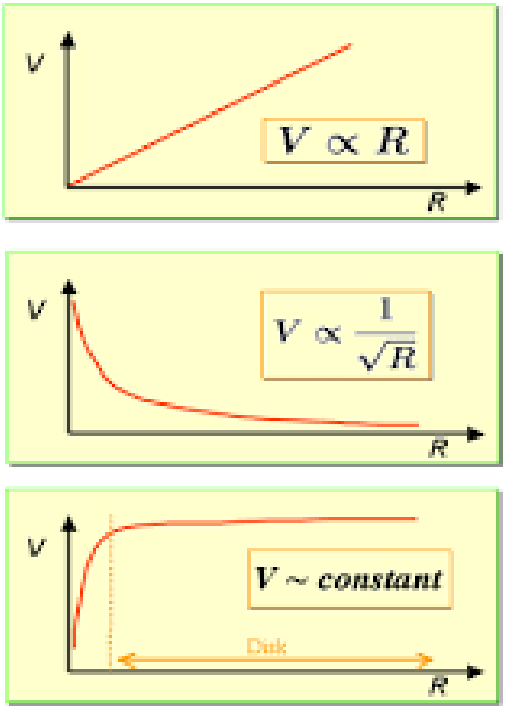
Question time

Based on these principles of classical physics, how is the speed of planets moving around the Sun determined?

$$v(r) = ???$$

Galaxy Kepler Prediction

Based on these classical principles, we predict that a galaxy whose mass decreases beyond the disk should show a rotation velocity curve that **drops rapidly** in the peripheral regions.



Reference: Velocity

Will the physics we study in class, which works perfectly for planets, be sufficient to understand cosmic systems comprising billions of stars?

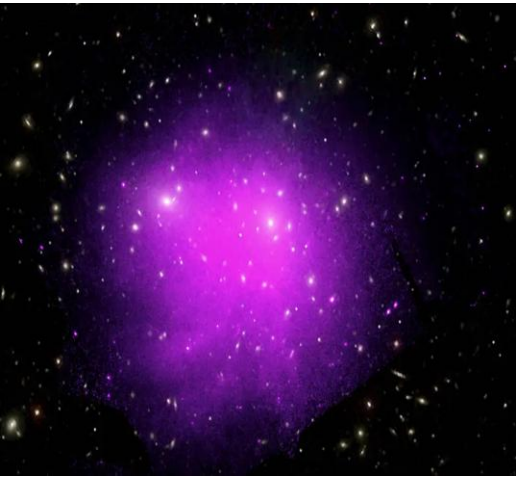
The Plot Twist: when the Observations challenge the Theory

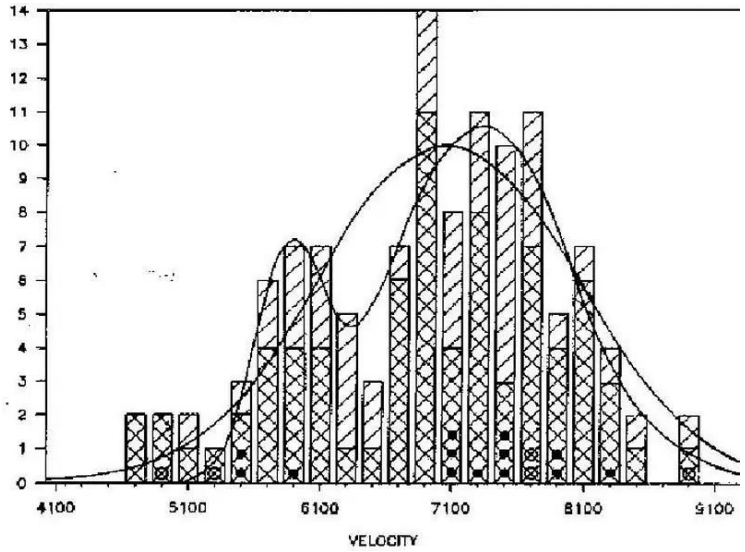
1

Anni ‘30: **Fritz Zwicky**

He studied galaxy clusters (Coma cluster), applying the **Virial Theorem** (2K + U = 0) to estimate the total mass required to hold the clusters together

The Discrepancy: He calculated a total mass tens of times greater than the sum of the masses of all the galaxies





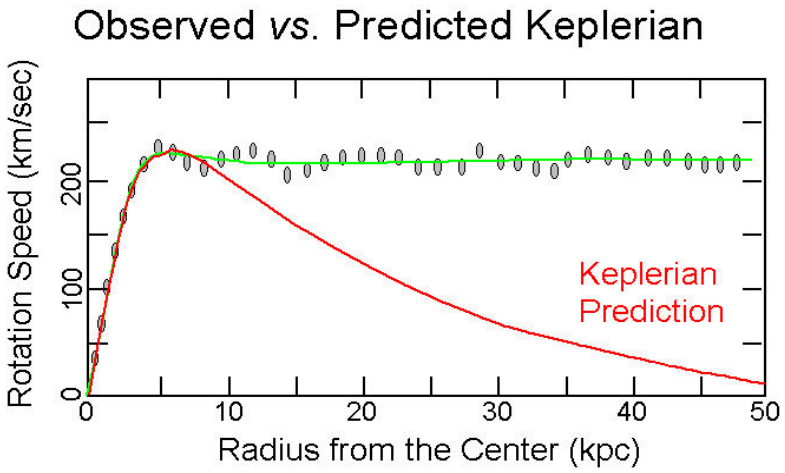
References: Coma cluster Histogram velocity dispersion

2

Anni '70: **Vera Rubin**

She analized the **rotational velocity curves** in spiral galaxies…

The result: The velocity did not decrease, but it still high also at larger radii.



Reference: Rotational velocity

Viral Theorem Easy

Considering a single light particle in circular orbit around a heavy one...
What is **gravitational potential energy**?

$U = ???$

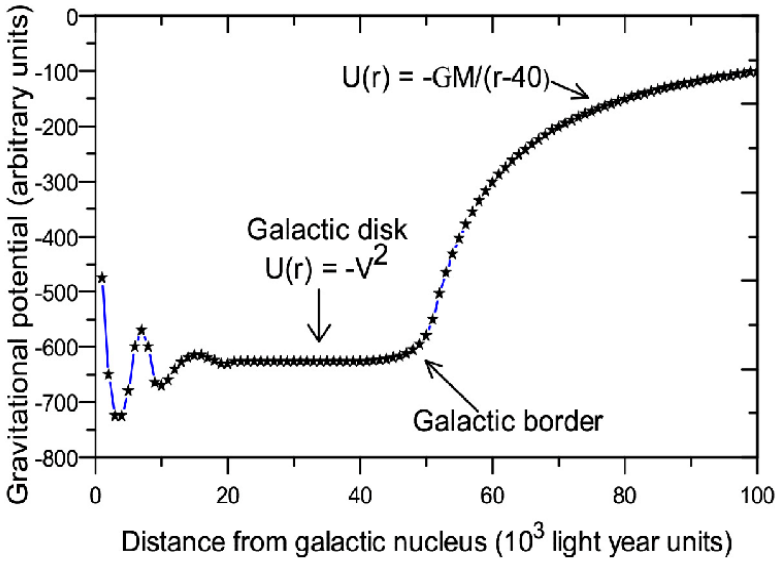
Gravitational force and centrifugal force, in a circular orbit, perfectly counteract each other..

$F_g = F_c$

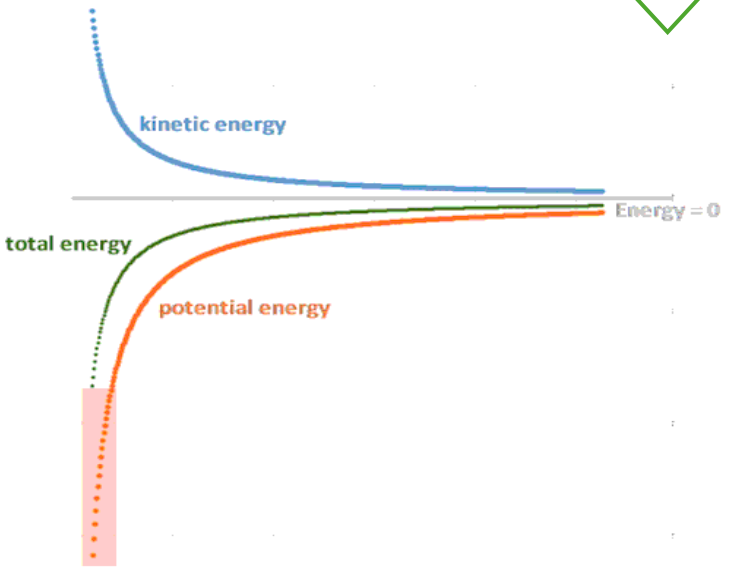
The kinetic energy of the heavy particle is negligible. What is the **kinetic energy** of the light particle?

$K = ???$

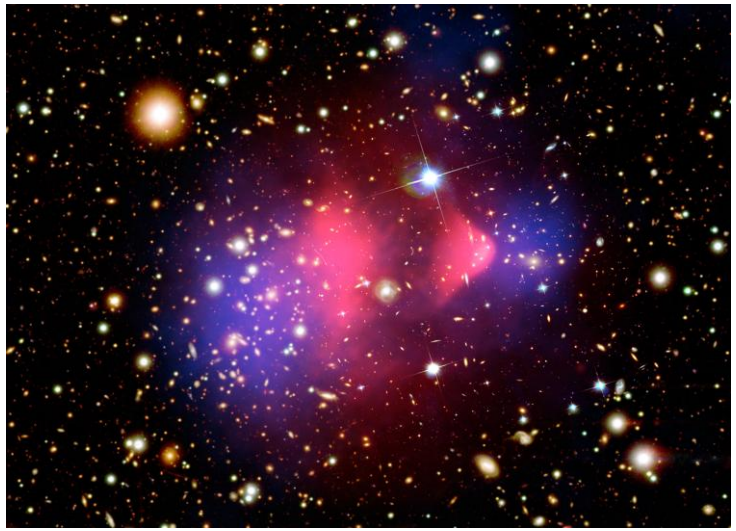
$2\langle K \rangle + \langle U \rangle = 0$



References: Gravitational potential



References: Energy

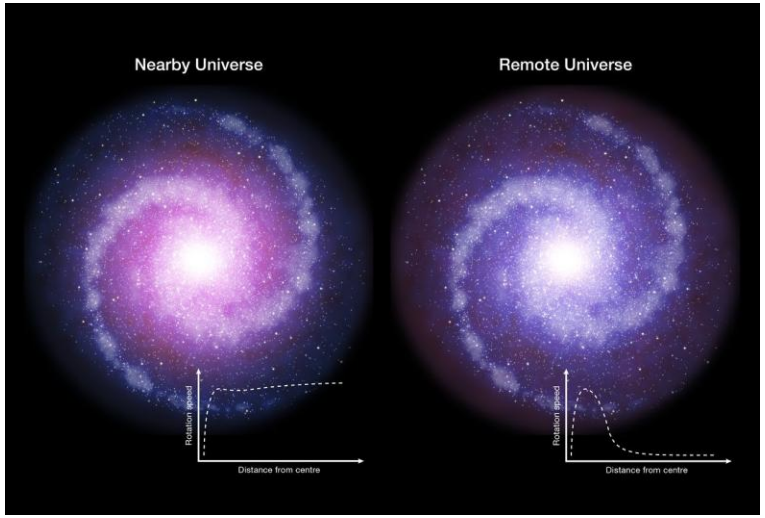


Reference:Bullet cluster

Cosmic Mission: Explore the Unknown!

The Persistent Enigma: Zwicky and Rubin's observations reveal a profound discrepancy!
This suggests that our understanding of gravity or the distribution of cosmic matter might be incomplete

Now that we have discovered these enigmas that challenge our understanding of the universe, it's time to act!
In our **Cosmo-Edu-Lab** app, you can become a true cosmic detective
Analyze **real data** from galactic observations, comparing them with your theoretical predictions



Reference: Galaxy rotation curve



Reference:Cluster composition

MIllennum simulation

Reference: Millennium

Illustris simulation

Reference: Illustris