Dark Matter in Galaxies

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Outline of the talk

• What is Dark Matter?
• Existence of Dark Matter
• Rotation Curve
• Missing Mass Problem
• Observational evidence for Dark Matter
• Possible Candidate of Dark Matter
• Direct Detection of Dark Matter
• Content of the Universe
• Conclusion
What Dark Matter actually is?
Existence of Dark Matter
Existence of Dark Matter

Rotation Curve:
Existance of Dark Matter

Rotation Curve:

• A rotation curve is a graph of orbital speed vs orbital Radius.
Existance of Dark Matter

Rotation Curve:

- A rotation curve is a graph of orbital speed vs orbital Radius.
- A simple example is, compact disk
Existance of Dark Matter

Rotation Curve of a Compact Disk:
Existence of Dark Matter

Rotation Curve of a Compact Disk:
Rotation Curve of Orbits:

• Gravity holds the objects in orbit.
• Speed of the orbit depends on the amount of mass interior to the orbit.
• If mass is mainly concentrated at the center of the system, then the speed will decrease with distance.

--- Example: Our Solar System
Solar system Rotation Curve
But What about Galaxy?
But What about Galaxy?
But What about Galaxy?
But What about Galaxy?
But What about Galaxy?
But What about Galaxy?

**Figure 22.27** The rotation curve of the Milky Way Galaxy. The IAU standard values of $R_0 = 8.5$ kpc and $\Theta_0 = 220$ km s$^{-1}$ have been assumed. (Figure from Clemens, *Ap. J.*, 295, 422, 1985.)
What about Galaxy
What about Galaxy Cluster

Coma Galaxy Cluster
What about Galaxy Cluster
Where was the missing Mass?

- MOND (Modified Newtonian Dynamics)
- Cold Gases Between Stars?
- Black Holes?
- Massive Astrophysical Compact Halo Objects (MACHOs)?
- Weakly Interacting Massive Particles (WIMPs)?
MOND?
MOND?

Mordehai Milgrom
MOND? 

\[ F_N = \frac{ma^2}{a_0} \]
The dotted and dashed lines are the Newtonian rotation curves of the visible and gaseous components of the disk, and the solid line is the MOND rotation curve with $a_0 = 1.2 \times 10^{-8}$ cm/s$^2$ — the value derived from the rotation curves of 10 nearby galaxies (Begeman et al. 1991).

Begeman et al. 1991, annurev.astro.40.060401.093923
Not MOND

Real

Observed
Not MOND
Not Cold Gases

The Planck one-year all-sky survey (c) ESA, HFI and LFI consortia, July 2010
Not Black Holes

Fermi two-year all-sky map

Credit: NASA/DOE/Fermi/LAT Collaboration
Not MACHOs

SDSS–III Data Release 10

Special programs
Legacy
BOSS
SEGUE–1
SEGUE–2

Imaging (14555 deg²)
Once you eliminate the impossible, whatever remains, no matter how improbable, must be the truth.

Arthur Conan Doyle
WIMPs
WIMPs
WIMPs

- It is Probably Wimp (Weakly Interacting Massive Particle)
- Stable Heavy particle produced at the early Universe.
WIMP Wind
Listen to Faint Sound
Listen to Faint Sound

Cant Hear faint Sound
Listen to Faint Sound

Can't Hear faint Sound

Shout out the noise
Go Underground
Go Underground

Sanford Underground Laboratory (SURF)
Go Underground

http://lux.brown.edu/LUX_dark_matter/Home.html
Go Underground

http://lux.brown.edu/LUX_dark_matter/Home.html
Basic Idea

- Maximum Energy Transfer to Nucleus when there is a Direct Collision between DM and Nucleus.

- If a direct collision occur then there following possibilities
  
  Ionization
  Phonon
  Scintillation
Basic Idea

At LHC

http://www.atlas.ch/dark-matter.html
Program worldwide

- Telescope detection of Dark matter
- Direct Detection of Dark matter Particle in Underground Lab. LUX, LZ, DAMA, DRIFT, CODEX, CDMS, MIMIC etc.
- Production with Accelerators.
- If they Agree each other
  We will know What Dark matter is.
- We will understand the Universe back to $t = 10^{-10}$ sec
Expanding Universe
How do we measure the Expansion

Draw spots on a balloon to represent galaxies in the universe.

As you blow up the balloon, the "galaxies" move further apart.
How do we measure the Expansion

How do we measure the Expansion

Energy Content of the Universe

- Dark Energy: 73%
- Dark Matter: 23%
- Luminous Matter: 0.4%
- Nonluminous Matter: 3.6%

http://wmap.gsfc.nasa.gov/universe/uni_matter.html
Dark Energy
Dark Matter in Simulation

The Millennium Simulation Project
Luminous Objects in Simulation

The Millennium Simulation Project
Same Result

LUX  |  DAMA  |  MIMIC
DRIFT | CDMS   | CDEX
The identification of dark matter will most likely not be immediate, but will rather unfold gradually
References:

Thank You
Cosmological constant:
The Einstein field equations is

\[ R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R + g_{\mu\nu} \Lambda = \frac{8\pi G}{c^4} T_{\mu\nu} \]

\( R_{\mu\nu} \) is the Ricci curvature tensor
\( g_{\mu\nu} \) is the metric tensor
\( \Lambda \) is the cosmological constant
\( G \) is Newton's gravitational constant
\( R \) is the scalar curvature
\( T_{\mu\nu} \) is the stress–energy tensor.
<table>
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<th>Flavor</th>
<th>Mass (GeV/c²)</th>
<th>Elect. Charge</th>
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<tr>
<td>e⁻</td>
<td>&lt; 7 x 10⁻⁹</td>
<td>0</td>
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<tr>
<td>e⁻</td>
<td>.000511</td>
<td>-1</td>
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Case 1: 
\( k = 0 \) and \( \Omega_o = 1 \)

Einstein-deSitter universe

The Universe expands at an ever decreasing rate!

Borderline Universe or Marginally Bound

Case 2: 
\( k > 0 \) and \( \Omega_o > 1 \)

As scale factor increases, it eventually reaches a point where \( a_{\text{dot}} = 0 \). Expansion stops at \( a_{\text{max}} \).

\[
\frac{da}{dt} = H_0 a_0^{3/2} \frac{a}{a^{1/2}}, \\
a^{1/2}da = H_0 a_0^{3/2} dt \\
a \frac{a}{a_0} = \left(3H_0 t \right)^{2/3}.
\]

After \( a_{\text{max}} \) is reached, Universe starts to collapse!

Closed or Bound Universe

Case 3: 
\( k < 0 \) and \( \Omega_o < 1 \)

Energy term is now positive. Solution for \( a(t) \) is analogous to a rocket shot with velocity greater than escape velocity.

Expansion continues forever!

Open or Unbound Universe
The Fate of the Universe

Whether or not the universe continues to expand forever or eventually collapses depends on its **density**.

High density = lots of mass = enough matter to gravitationally halt expansion and cause gravitational collapse.

Low density = little mass = not enough gravitational attraction to stop expansion...it goes on forever.