Dark Matter in Galaxies

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Outline

• 1. Introduction
• 2. History of Dark Matter search
• 3. Evidences of DM existence
• 4. Observation(Rotation Curve Acquirements)
• 5. Recent discoveries and researches
• 6. Conclusion
Introduction

• What is Dark Matter:
  Defined as non-luminous matter with mass that is widely spread in universe.
• Dark Matter vs Dark Energy
• Baryonic and Non-Baryonic dark Matter
History

• 1844, Bessel. Measurements over Sirius and Procyon movements. Found “some mass missing”.
• 1932, Oort. By measuring the speed of stars in Milky Way, he provided the 1st evidence of DM in universe.
• 1974, Ostriker. Tabulated the M/R function and found out the galaxy mass is increasing linearly with radius in most Spiral Galaxies.
• 1979, D. Walsh. Discovered the 1st Gravitational Lens which is one of the most important evidences of DM.
Rotation Curve

- Rotation Curve is just a function of rotating velocity versus radius of galaxies. If there is no “invisible mass” in a galaxy, the velocity should follow the Keplar’s law:
  - \[ F = \frac{G(M \times m)}{r^2} = \frac{mV^2}{r} \]
- Truth is, most galaxies have a flat velocity dispersion once the radii reach a certain level. Which makes the mass of the galaxy rise linearly with the rotating velocity.
Rotation Curve

- Most galaxies have rotation curves that show solid body rotation in the very center, following by a slowly rising or constant velocity rotation in the outer parts.
Rotation Curve Acquisition
Rotation Curve Acquisition

Galaxy rotation curve

\[ \frac{V_s}{C} = \frac{\Delta \lambda}{\lambda_0} \]
Milky Way
Summary: Rotation Curve

- From the Velocity-Radius relation, we could derive the Mass-Radius relation, which indicates the galaxy mass will increase monotonically with radius in Spiral Galaxies:
  - \(GM/R^2 = V^2/R\) \(\rightarrow M \propto R\)
  - with \(V=\text{constant}\) as it is measured.
Velocity Distribution

• Acquired by measuring Doppler Width of spectral of the objects.
• Applied mainly to Elliptical Galaxies and clusters.

\[
\sigma_{ij}^2 \equiv \bar{v}_j\bar{v}_i - \bar{v}_j \bar{v}_i \quad \beta(r) \equiv 1 - \frac{\sigma_i^2}{\sigma_r^2},
\]

\[
M(r) = -\frac{\sigma_r^2 r}{G} \left( \frac{d \ln v}{d \ln r} + \frac{d \ln \sigma_r^2}{d \ln r} + 2\beta(r) \right)
\]

http://www.ifa.hawaii.edu/~barnes/ast626_05/dmeg.pdf
## Velocity Dispersion

<table>
<thead>
<tr>
<th>Object</th>
<th>$v$ (km s$^{-1}$)</th>
<th>$M_B$ (mag)</th>
<th>$M/L_B^*$ (solar units)</th>
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<tr>
<td>NGC 3379</td>
<td>240</td>
<td>-20.2</td>
<td>5.4</td>
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<td>11.5</td>
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<tr>
<td>NGC 5846</td>
<td>255</td>
<td>-21.2</td>
<td>8.3</td>
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</table>
Gravitational Lensing

1. A Distant Source
   Light leaves a young, star-forming blue galaxy near the edge of the visible universe.

2. A Lens of Dark Matter
   Some of the light passes through a large cluster of galaxies and surrounding dark matter, directly in the line of sight between Earth and the distant galaxy. The dark matter's gravity acts like a lens, bending the incoming light.

3. Focal Point: Earth
   Most of this light is scattered, but some is focused and directed toward Earth. Observers see multiple, distorted images of the background galaxy.
Virial Theorem

• For a stable, self-gravitating, spherical distribution of equal mass objects (stars, galaxies, etc), the total kinetic energy of the objects is equal to minus 1/2 times the total gravitational potential energy.
• The gravitational potential energy of the system can be written as:

\[ P.E.(\text{system}) \simeq -\frac{1}{2} G \frac{N^2 m^2}{R_{tot}} = -\frac{1}{2} G \frac{M_{tot}^2}{R_{tot}} \]

• We usually assume that all of the orbits travel on similar orbits that are isotropic, that is, are not flattened in any way and have no preferential direction.
Dark Matter Halo

• M 3 1 and other galaxies share the similar structure as Milky Way that widen at large radii. These galaxies have a round halo far from the galactic center.

• These are a dozen other SOs, seen edge on and ringed by annuli of gas more or less perpendicular to the main galactic disks. Both models for the formation and, more important, measured velocities of the gas rings require a roughly spherical mass distribution.
Baryonic & Non-Baryonic

• Dark Matter can be categorized as Baryonic and Non-Baryonic. Technically, we usually call non-dark matter which is just too dark to detect Baryonic Dark Matter. It is luminous after all because Baryons will absorb waves.

• There are 3 separate evidences that proves the Dark Matter should be made of Non-Baryonic particles.

  1. Big Bang Theory predicts that Baryons only take a small portion of the matter in universe.
  2. Searches have shown that Dark Matter itself cannot hide in dark impact objects.
  3. Analysis shows that five-sixths of the total matter is in a form which does not interact significantly with ordinary matter or photons.
“Non-Luminous Galaxy

• In 2005, astronomers of Cardiff University discovered a galaxy which is almost pure dark. It is 50 million lightyear from Virgo Cluster. It is named “VIRGOHI21”. The mass of dark matter within is more than 100 times of its luminous matter, which is basically hydrogen.
Recent Researches

• **Dark Matter Mapping in Abell 383:**

Cluster 2.3 billion lightyears from earth. Dark matter within, which was mapped through gravitational lensing effects, looks like “a gigantic American Football”.

<table>
<thead>
<tr>
<th>Method</th>
<th>$M_{\text{vir}}$ $10^{14} M_\odot$</th>
<th>$c_{\text{vir}}$</th>
<th>$r_{\text{vir}}$ arcsec</th>
<th>$M_{200}$ $10^{14} M_\odot$</th>
<th>$\chi^2$/d.o.f.</th>
<th>$M_{2D}$ $10^{14} M_\odot$</th>
<th>Density gal/arcmin$^2$</th>
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<td>a</td>
<td>$7.78^{+3.34}_{-2.21}$</td>
<td>$4.73^{+0.09}_{-1.49}$</td>
<td>$698_{-73}^{+85}$</td>
<td>$6.44^{+5.94}_{-3.23}$</td>
<td>1.13</td>
<td>$12.3 \pm 2.98$</td>
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<td>$7.80^{+0.05}_{-1.52}$</td>
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<td>b</td>
<td>$7.61^{+2.94}_{-2.04}$</td>
<td>$5.77^{+0.36}_{-1.69}$</td>
<td>$693_{-89}^{+30}$</td>
<td>$6.42^{+6.85}_{-3.21}$</td>
<td>0.40</td>
<td>$8.14 \pm 3.15$</td>
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<td>$9.00^{+0.85}_{-1.69}$</td>
<td>$4.62^{+0.33}_{-0.11}$</td>
<td>$733_{-49}^{+7}$</td>
<td>$7.44^{+2.20}_{-1.85}$</td>
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<td>c</td>
<td>$7.51^{+2.00}_{-2.00}$</td>
<td>$5.40^{+0.13}_{-1.52}$</td>
<td>$690_{-88}^{+30}$</td>
<td>$6.30^{+6.15}_{-3.08}$</td>
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<td>$10.5 \pm 3.03$</td>
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<tr>
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<td>$8.38^{+0.69}_{-1.57}$</td>
<td>$4.67^{+0.11}_{-0.11}$</td>
<td>$716_{-48}^{+65}$</td>
<td>$6.94^{+2.01}_{-1.73}$</td>
<td>0.61</td>
<td>$7.82 \pm 2.26$</td>
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<td>d</td>
<td>$7.54^{+2.66}_{-1.91}$</td>
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<td>$7.59 \pm 2.19$</td>
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</table>
Recent Researches

- **Analyze Abell 520**
  Early in 2012, HST collected a series of data that indicates the dark matter in Abell 520 was mainly in the heart of the galaxy.

It was later proved wrong that the dark matter in A520 behaves as what we expect.
Recent Researches

• 1st Evidence of Big Bang Theory

• Big Bang Theory indicates that the universe was given birth in 14 billion years ago and it is still expanding outward. Researchers from the BICEP2 collaboration announced the first direct evidence for this cosmic inflation. Their data also represent the first images of gravitational waves, or ripples in space-time. These waves have been described as the "first tremors of the Big Bang." Finally, the data confirm a deep connection between quantum mechanics and general relativity.
Alternative theories

- **Modified Newtonian Dynamics (MOND):**
  - Proposed by *Mordehai Milgrom* in 1983
  - Newton's law for gravitational force has been verified only where gravitational acceleration is large
  - For extremely small accelerations the theory may not hold
Alternative theories

- Tensor–vector–scalar gravity (TeVeS):
  - Developed by Jacob Bekenstein.
  - Adjustments made to MoND theories.
  - TeVeS reproduces the MoND acceleration formula.
  - Accommodate gravitational lensing.
  - Respects conservation laws.
References

• Velocity Dispersions and Mass-to-light Ratios for Elliptical Galaxies. S.M.Faber, R.E.Jackson. Ast. Jo, 204, 668-683


• NASA Science Archieve..Sci.NASA.gov

• A weak lensing analysis of the Abell 383 cluster. Astronomy & Astrophysics manuscript no. a383

• ON DARK PEAKS AND MISSING MASS: A WEAK-LENSING MASS RECONSTRUCTION OF THE MERGING CLUSTER SYSTEM A520
Thank You