


AST1002




## *Galaxies and Beyond*

Chapter 18  
Dark Matter

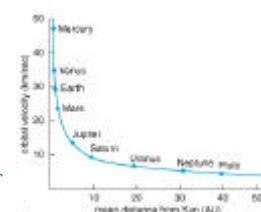
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## *Dark Matter*

- The rotation curve for the solar system
- Velocity drops rapidly outside center
  - Earth
    - $d=1$  AU
    - $v=30$  km/sec
    - $P=1$  year
- Newton's laws relate orbits to mass
- Mass highly concentrated at center



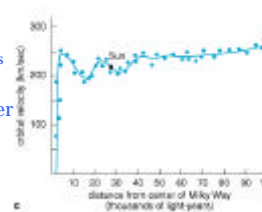
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## *Dark Matter*

- The rotation curve for the galaxy
- Velocity nearly constant outside center
  - Sun
    - $d=28,000$  LY
    - $v=220$  km/sec
    - $P=230$  million years
- Mass *not* concentrated at center
- Must be large amount of unseen mass (dark matter)



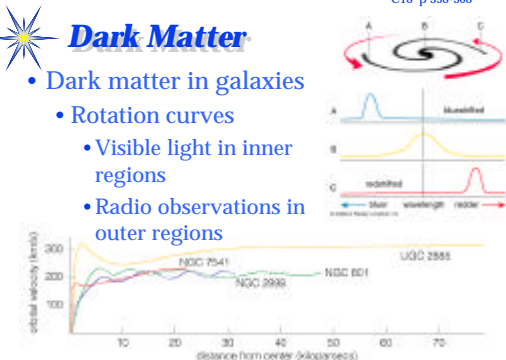
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## *Dark Matter*

- Dark matter in galaxies
- Rotation curves
  - Visible light in inner regions
  - Radio observations in outer regions



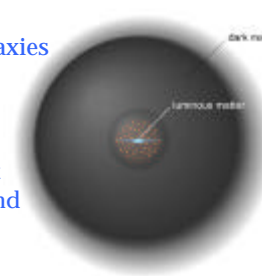
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## *Dark Matter*

- Dark matter in galaxies
- Only about 10% of matter is star light
- Dark matter must extend well beyond luminous matter



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## *Dark Matter*


- Mass-to-Light ratio of galaxies
- A way of estimating dark matter content
- Work in solar units ( $L_{\text{sun}}$ ,  $M_{\text{sun}}$ ) so the sun's  $M/L = 1$
- Inner regions of the Milky Way:  $M/L=6$  ( $M=9 \times 10^{10} L_{\text{sun}}$ ,  $L=1.5 \times 10^{10} M_{\text{sun}}$ )
  - Most stars are less luminous than the sun
- But ... entire spiral galaxies have  $M/L$  of 50 or even more

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**Dark Matter**

- Observed in clusters of galaxies
  - Galaxies orbit the center of a cluster
    - First done by Zwicky in the 1930's
    - Use Kepler's 3<sup>rd</sup> Law to get mass
    - Calculate mass-to-light ratios; many > 100
    - Result ... most of the matter must be dark


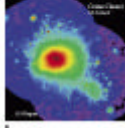


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**Dark Matter**

- Observed in clusters of galaxies
  - Intracluster gas
    - X-ray observations show large amounts of hot gas
    - Most of mass must be dark matter to keep this gas from escaping
    - Typical M/L calculated this way > 100

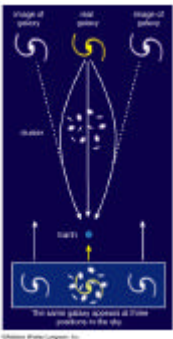



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**Dark Matter**

- Gravitational Lensing
  - not based on law of gravity (Newton)
  - Based on general relativity (Einstein)
  - Massive objects can act as lenses, forming images of distant object



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**Dark Matter**

- Observed in clusters of galaxies
  - Gravitational lensing
    - Masses calculated this way agree with other methods




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**Dark Matter**


- Dark Matter: What might it be?
  - MACHOs
    - Massive Compact Halo Objects
    - Jupiter mass objects
    - Brown dwarf stars
  - WIMPS
    - Weakly Interacting Massive Particles
    - Maybe an unknown particle otherwise similar to the neutrino

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**Dark Matter**

- Dark matter appears to be important in controlling the structure of the Universe
  - Clusters of Galaxies are not uniformly distributed
  - Sheets and voids appear common

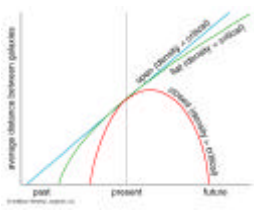


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 **Dark Matter**

- How will the Universe end?
  - Big Crunch?
  - Flat
  - Growing forever



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**Questions and/or Comments?**

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**or visit <http://www.astro.ufl.edu/~oliver/>**