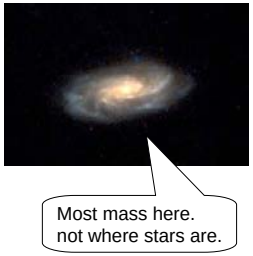
Dark Matter in NGC3762—5 Nov

- No class on Wed, Nov 26th
- To find mass of NGC3762 and the location of the mass.
- Where is the mass?
  - Answer: Mass is not where the stars are.
- Galaxies are made mostly of what we cannot see.



1. How fast is the galaxy moving from us?
   A. 2040 km/s
   B. 1850 km/s
   C. 1650 km/s
2. Why is the galaxy moving from us?
   A. It is rotating
   B. Big bang
   C. Supernova
3. If the mass of the galaxy were greater, would this speed be different?
   A. Yes
   B. No
4. What is the rotation speed of gas that is 16 kpc from the center?
   A. 2040 km/s
   B. 1850 km/s
   C. 190 km/s
5. If the mass of the galaxy were greater, would this speed be different?
   A. Yes
   B. No

NGC 3672, Vera Rubin, Norbert Thonnard, & Kent Ford, jr., 1977, Astrophys. Journal 217, L1.

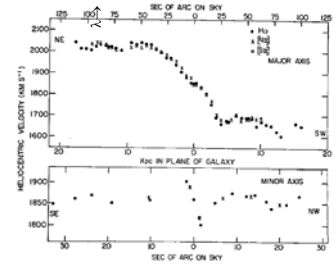


FIG. 3.—*Upper*, major axis heliocentric velocities on plane of sky, as a function of distance from the nucleus. *Lower*, minor axis velocities as a function of distance from the nucleus; note change in scale from upper plot. The steep velocity gradient in nuclear region along minor axis is prominent.

Calculating mass

- Astronomer's gravitational constant for use in $M=1/G\ R\ v^2$

  $1/G=232\ M_{sun}/parsec/(km/s)^2$.
- If an object orbits a big mass at a radius of 1 parsec with a speed of 1km/s, then the big mass has the same mass as 232 suns.
- The earth orbits the sun at a radius 1/200000pc with a speed 30km/s. The mass inside the orbit of the earth is

  $232 M_{sun}/parsec/(km/s)^2.(parsec/200000)(30km/s)^2 = 1\ M_{sun}$.

Mass within 16 kpc

- Gas at R=16 kpc orbits the galaxy at 180 km/s.
- The gas orbiting the galaxy at radius r feels the mass within the orbit. Ignore mass outside the orbit when applying K's 3rd law.
  - If galaxy is spherical,
    - Mass inside 16 kpc pulls on gas
    - Pull of mass outside 16 kpc cancels.
  - True if galaxy is spherical. Approximately true if galaxy is not spherical.
- K's 3rd Law: The mass inside of radius R is

  $M(R) = 232\ M_{sun}/parsec/(km/s)^2\ R\ v^2$
- Within a radius of 16 kpc, the mass is

  $232\ M_{sun}/pc/(km/s)^2 * 16{,}000pc\ *(180km/s)^2$
  $= 120 Billion\ M_{sun}$.
- Where is the mass? Is the mass all in the center of the galaxy?
  - Examine the rotation curve.

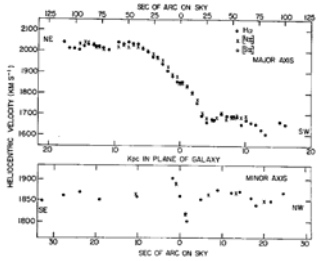
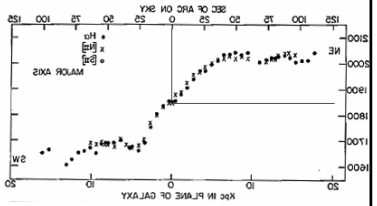


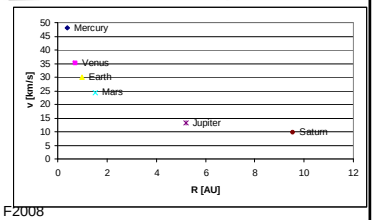
FIG. 3.—*Upper*, major axis heliocentric velocities on plane of sky, as a function of distance from the nucleus. *Lower*, minor axis velocities as a function of distance from the nucleus; note change in scale from upper plot. The steep velocity gradient in nuclear region along minor axis is prominent.

Where is the mass?

- Hypothesis: The mass is all in the center of the galaxy. Compare the rotation curve of the galaxy with that of the solar system, where the mass is all in the sun.
  - "Rotation curve" is a plot of distance from center *vs.* rotation speed.

5. In what way is the rotation curve different from that of the solar system?





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- Hypothesis: The mass is all in the center of the galaxy. Compare the rotation curve of the galaxy with that of the solar system, where the mass is all in the sun.
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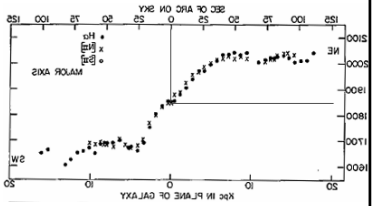
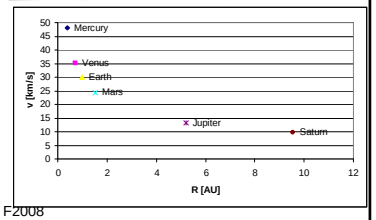
5. In what way is the rotation curve different from that of the solar system?

- Galaxy
  - Rot speed in center is low
  - Rot speed rises between 0 & 8 kpc
  - Rot speed is constant beyond 8 kpc.
- Solar system
  - Rot speed is highest near sun.
- Hypothesis is wrong. Mass of the galaxy is not all in the center. It is spread out.





Where is the mass?

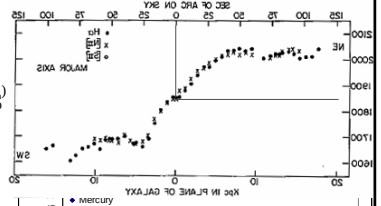
- M(R) is mass enclosed within radius R.
- K's 3rd Law
  $M(R) \propto v^2 R$

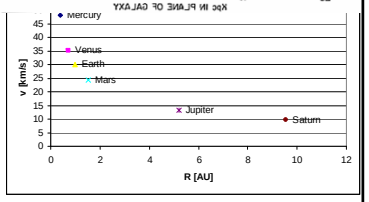
2. M(R) for the solar system.($M_{Jupiter}$=0.001M_{Sun}) changes by ___ from Earth's orbit (R=1AU) to Saturn's orbit (R=9.5AU).
   A. a minuscule amount
   B. a factor of 9.5
   C. a factor of about 90.

- NGC3672
  - v(R) rises from 0 to 7 kpc.
  - v(R) is constant beyond 7kpc.

3. M(R) for the for Galaxy NGC3672 changes by from R=9 to 18kpc.
   A. a minuscule amount
   B. a factor of 2
   C. a factor of 4.

4. What would you expect for M(R) beyond 20 kpc? Justify your guess.



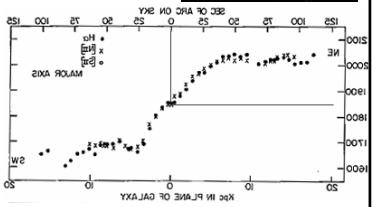


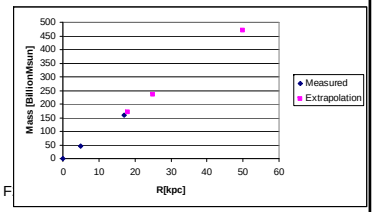
Dark Matter

- M(R) is mass enclosed within radius R.
- K's 3rd Law
  $M(R) \propto v^2 R$
- NGC3672
  - v(R) rises from 0 to 7 kpc.
  - v(R) is constant beyond 7kpc.

4. What would you expect for M(R) beyond 20 kpc? Justify your guess.
   - Between 7 & 16 kpc, M(R) rises linearly.
   - There is little light beyond 7 kpc.
   - Where there is mass there is not necessarily light from stars & gas.
   - Extrapolate M(R) is linear beyond visible part of galaxy.

- For the Milky Way Galaxy, this extrapolation was tested with satellites of Milky Way.
- Most of mass of galaxies is not in stars & gas.





Summarizing Question

5. Simplicio reasons, “The evidence for dark matter is really weak. How can you measure dark matter when you cannot see it.” Answer Simplicio.