Weighing a galaxy / Black holes / Quasars —16 Nov

- Dark matter
  - Interpret rotation curve of galaxy NGC3672
  - Find that mass is much more than that of stars & gas.
  - The dominant mass is called "dark matter."
- Black holes & quasars
- Our dusty Universe: Astronomical Horizons Lecture
  - Heather Jacobson
  - Thurs, 7:30 at Planetarium
- Hwk 9 is due Fri, 20th.
  - Questions about measuring the mass of galaxies.
  - No late papers. Answers will be put on angel after class.
  - Missouri Club on Wed.
- Observing on Wed & Thurs, 18th & 19th. Extra credit.
- Test 3 is on Mon, 23rd.
  - Covers material through "dark matter" today.
- No class on Wed, 25th.

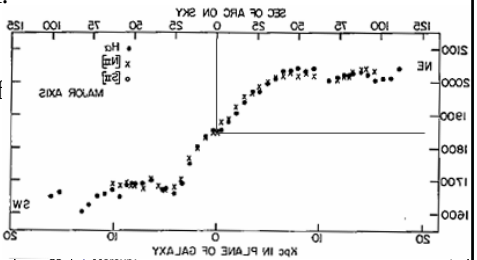
Where is the mass? Ask the rotation curve

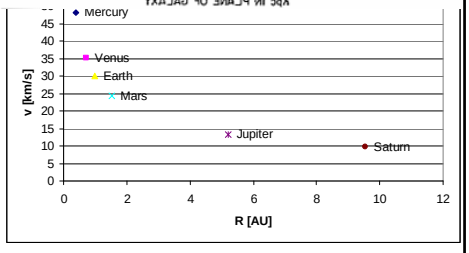
- M(R) is mass enclosed within radius R.
- K's 3rd Law
  $M(R) \propto v^2 R$
- We disproved the hypothesis that all of the mass is at the center.

2. From Earth's orbit (R=1AU) to Saturn's orbit (R=9.5AU), M(R) changes by ___. ($M_{Jupiter}=0.001M_{Sun}$)
   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.

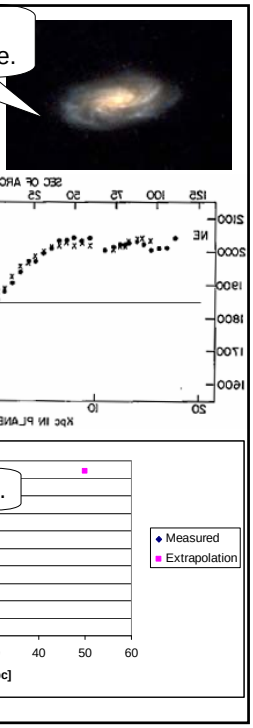
3. From R=9 to 18kpc, M(R) for NGC3672 changes by ___.
   A. a minuscule amount
   B. a factor of 2
   C. a factor of 4.





Dark Matter

- 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.
- Where v is constant, M(R) ∝ R.
  - Between 7 & 16 kpc, M(R) rises linearly.
- There is not much light between 7 & 16 kpc.
- There is little light beyond 7 kpc, but the amount of mass doubles.
- ***Where there is mass there is not necessarily light from stars & gas***



Dark Matter

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  - v(R) is constant beyond 7kpc.
- Where v is constant, M(R) ∝ R.
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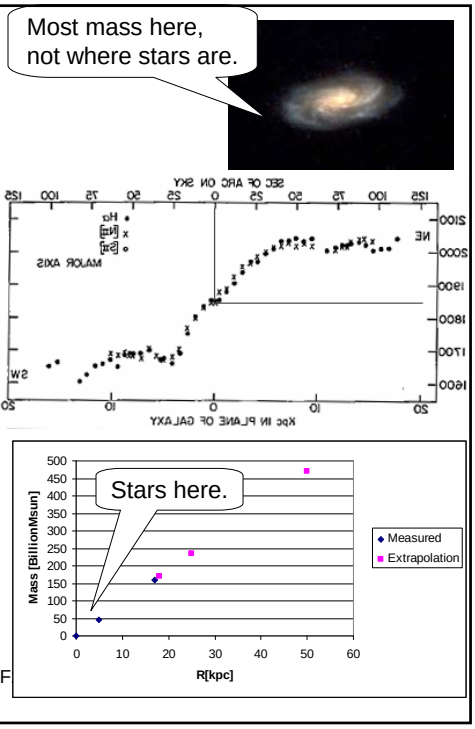
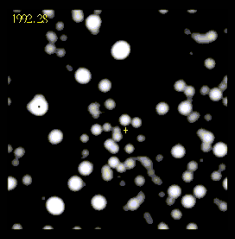
- *Where there is mass there is not necessarily light from stars & gas*
  - There is little light beyond 7 kpc, but the amount of mass doubles.
- What would you expect for M(R) beyond the visible parts of the galaxy?
- Hypothesis: M(R) is linear beyond visible part of galaxy.
- This hypothesis was tested with satellites of Milky Way Galaxy.
- Most of mass of galaxies is not in stars & gas. Most of mass is "dark matter."
- What is dark matter?
  - A candidate: A particle with significant mass that interacts very weakly with ordinary matter.
  - Experiments to detect dark matter have been in progress for 20 years.

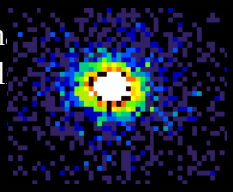


Black Holes & Quasars—16 Nov

- Black hole
  - Mass is so concentrated that nothing escapes
- Quasar
  - Black holes in the center of galaxies th is lit by material fall in toward the black hole.



BH in center of Milky Way



BH Cyg X1

Jet in galaxy M87

Black hole

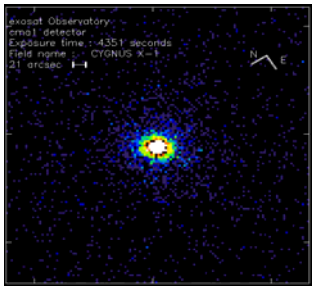
- Escape from earth
  - To escape from earth's gravity, a molecule must go faster than 11 km/s.
- Escape speed v depends on mass and radius

  v^2 = G mass / radius
- If mass is big enough or radius is small enough, escape speed is greater than speed of light: nothing can escape.
- If sun were squeezed to 3-km radius, light could not escape from it.
- If Earth were squeezed to 1-cm radius, light could not escape from it.
- Schwarzschild radius is boundary between inside & outside of a black hole.
  - Light can escape if outside Schwarzschild radius.

Comis & Kaufmann, Discovering the Universe

Black hole

- How can we detect a black hole if light cannot escape from it?
  - Look at something that orbits around it
  - Look at the mass that is falling into it.
- Objects that emit little or no light
  - Black hole
  - White dwarf
    - Degenerate electrons cause pressure.
    - Max mass is $1.4M_{\odot}$.
  - Neutron star
    - Degenerate neutrons cause pressure.
    - Max mass is $3M_{\odot}$.
- Cygnus X1
  - Bright source of X rays
  - In visible, star HD226868
  - HD226868 moves around something at 50km/s with 5 day period



heasarc.gsfc.nasa.gov/ Images/exosat/cygx1.gif

Cygnus X1

- HD226868, a giant, donates mass to BH
  - Mass falls toward BH, moves fast, gets hot.
  - Hot gas emits X rays
- Mass of companion
  - Kepler's 3rd law: Radius & period $\Rightarrow$ total mass of two stars.
    - P=5da
    - 5da & 50km/s $\Rightarrow$ R.
  - Speed $\Rightarrow$ mass of companion
  - Mass of companion is $10M_{\odot}$.
- Companion is compact
  - A $10\text{-}M_{\odot}$ star would be seen in visible.
- Cygnus X1 is a black hole