Physics 343 Lecture # 4:
gas dynamics (and more statistics)

This week's schedule

Tonight 11:59pm: report for lab # 1 due by email (PDF please)

Monday – Thursday: hands-on sessions for lab # 2 (using archival SRT data in Excel format)
+ attendance mandatory; active participation (this week = getting a head start on your analysis) counts towards your course grade

Monday (Baker) & Thursday (Wu): regular office hours

Next week: "on call" office hours for lab # 2

Velocities in astronomy

Observed frequency and wavelength are related to rest (emitted) frequency and wavelength by a velocity (or redshift).

Exact relation = Doppler shift:

$\nu_0/\nu = \lambda/\lambda_0 = 1 + z = \gamma\,(1+ v/c)$ **for** $\gamma = (1-v^2/c^2)^{-1/2}$

and for relative velocities, $\Delta\nu/\nu = \Delta\lambda/\lambda = \Delta z/(1 + z) = \Delta v/c$.

However, astronomers also make different approximations...

radio: $\nu \simeq \nu_0\,(1- v_{rad}/c)$

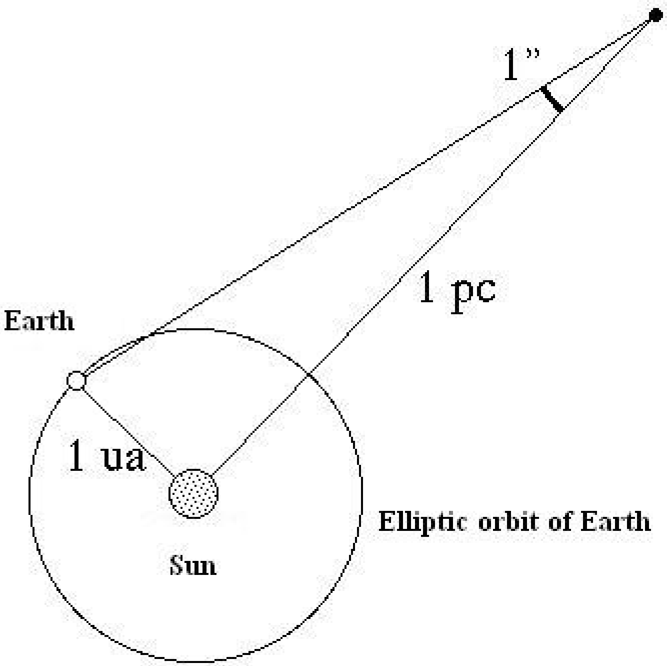
optical: $\lambda \simeq \lambda_0\,(1+ v_{opt}/c)$

Distances in astronomy

Nearest stars can have distances measured by parallax:
the apparent shift in position relative to the background pattern of more distant stars caused by the earth's motion around the Sun.

1 parsec = 1 pc:
3.089×10^{18} cm
~ 3.3 light years

Distances inside galaxies ~ kpc.
Distance between galaxies ~ Mpc.



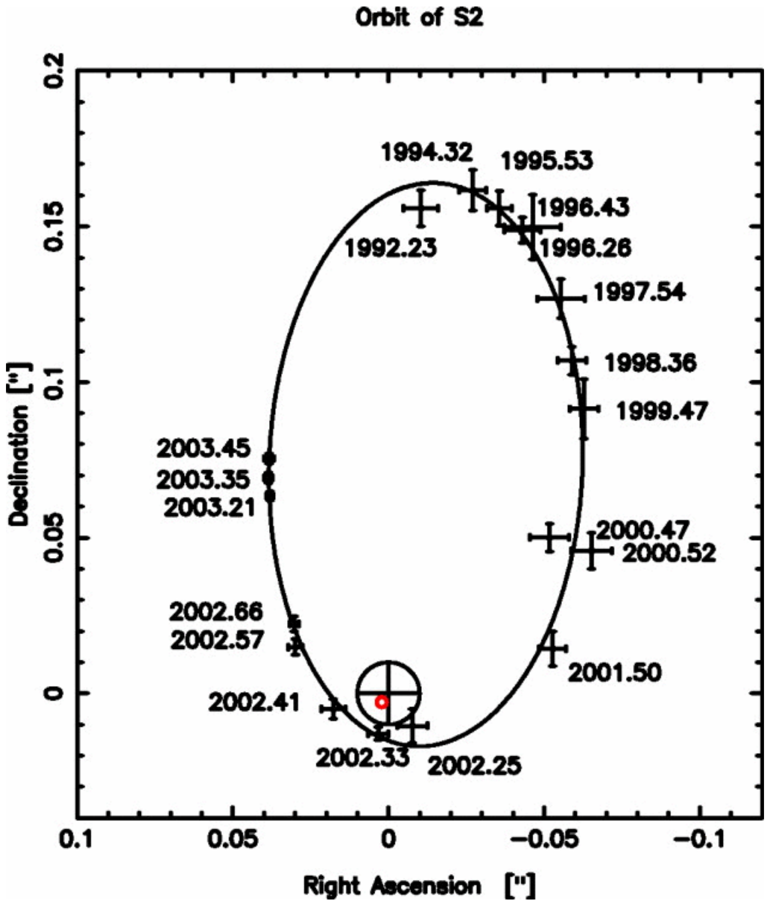
Stellar components of spiral galaxies

Spiral galaxies have two principal components: disk and bulge.

Where is the Sun within the Galaxy?

Note on terminology: Milky Way = "the Galaxy"; other "galaxies" are not capitalized.

Sun and solar system lie at a distance of 8 kpc from the Galactic Center, where a supermassive black hole lies.



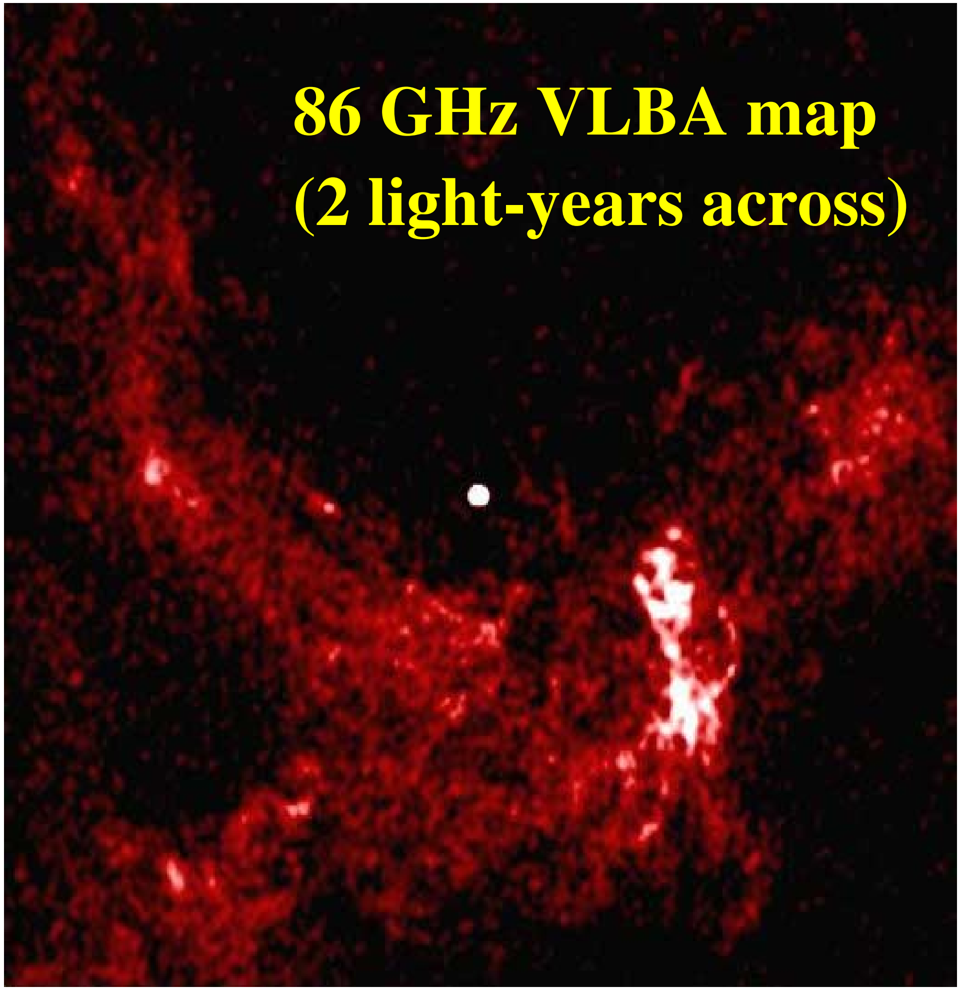
Eisenhauer et al. (2003)

Central black hole is a radio source!

Motions of stars imply a large central mass – but from low proper motion of Sgr A* ("Sagittarius A–star"), we know that *it* must be massive.

Observations with the Very Long Baseline Array reveal a proper motion only due to the Sun's motion around the Galaxy.

Shen et al. (2005)



Galactic coordinates

The Sun is located in the disk.

***b* = Galactic latitude**

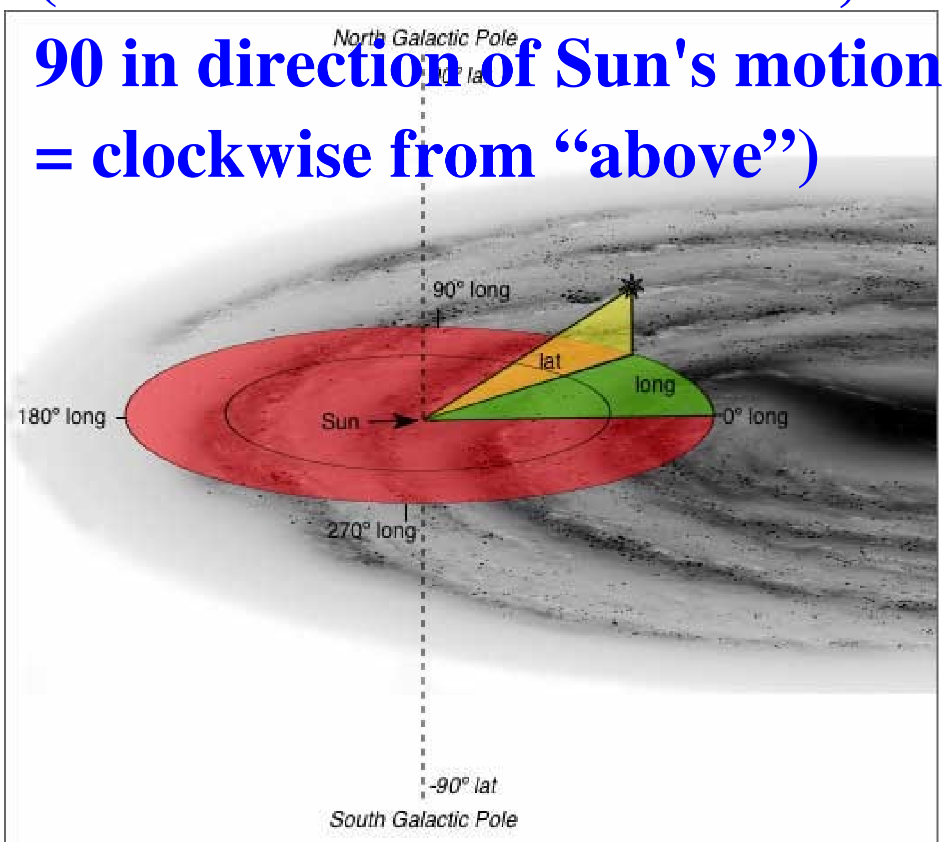
(above/below plane)

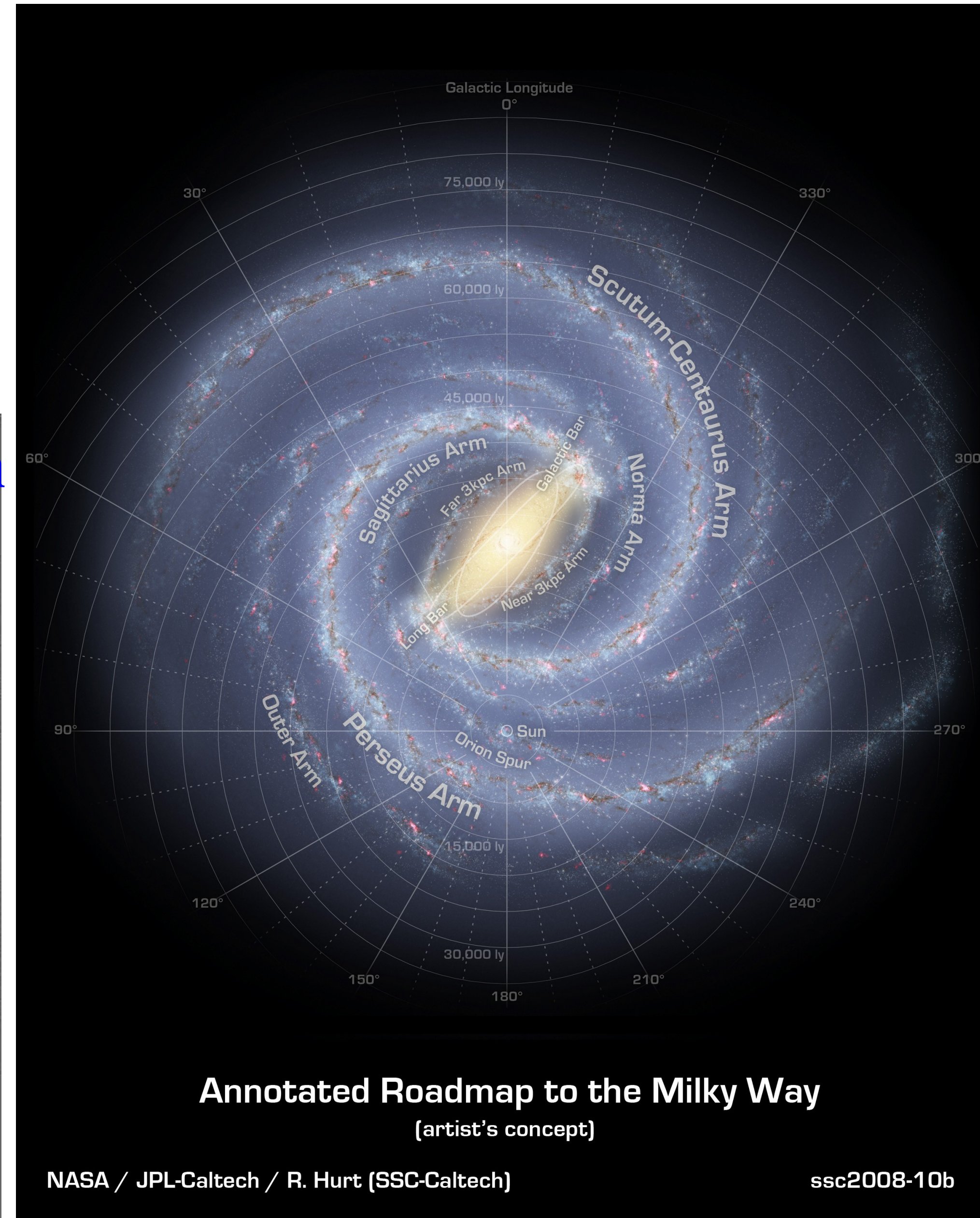
***l* = Galactic longitude**

(0 towards Galactic Center;

90 in direction of Sun's motion

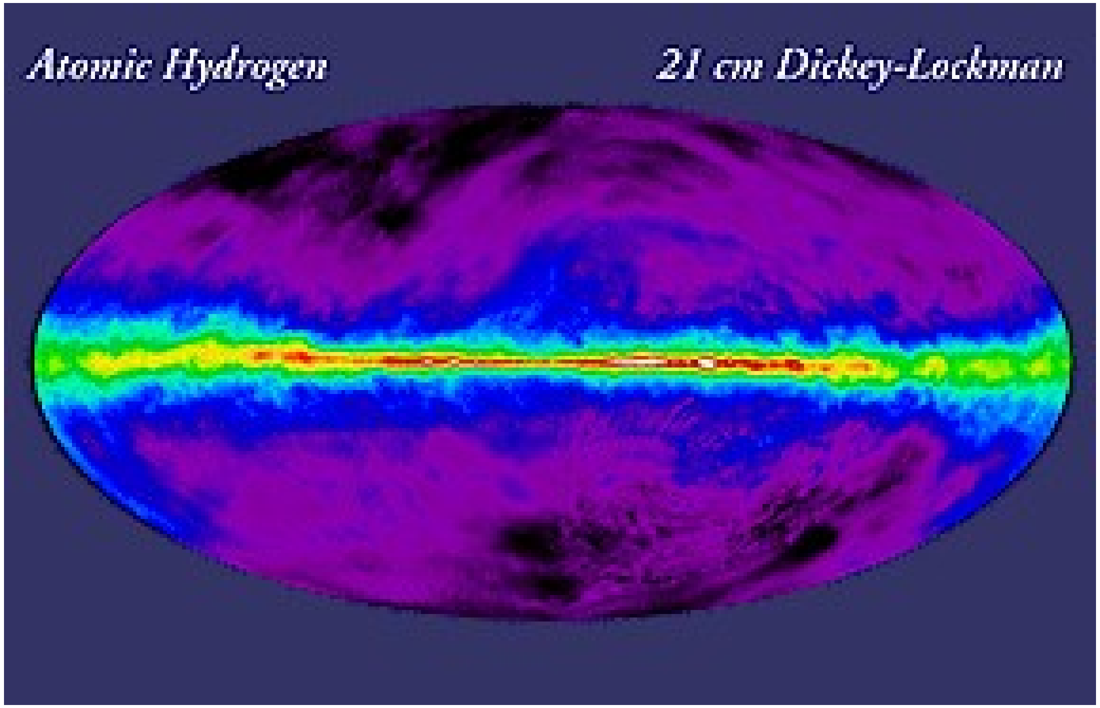
= clockwise from "above")





HI in the Milky Way

Nearly all the HI (neutral H) in the Galaxy is located in the disk.
Observed velocities governed by (a) rotation (b) random motions.



(plotted in Galactic coordinates)

Gas dynamics: the Keplerian case

If an ensemble of gas clouds, each with mass m, is distributed in a disk orbiting a single massive object with $M \gg m$, then for each cloud we can write

$$F = mv^2/R = GMm/R^2$$

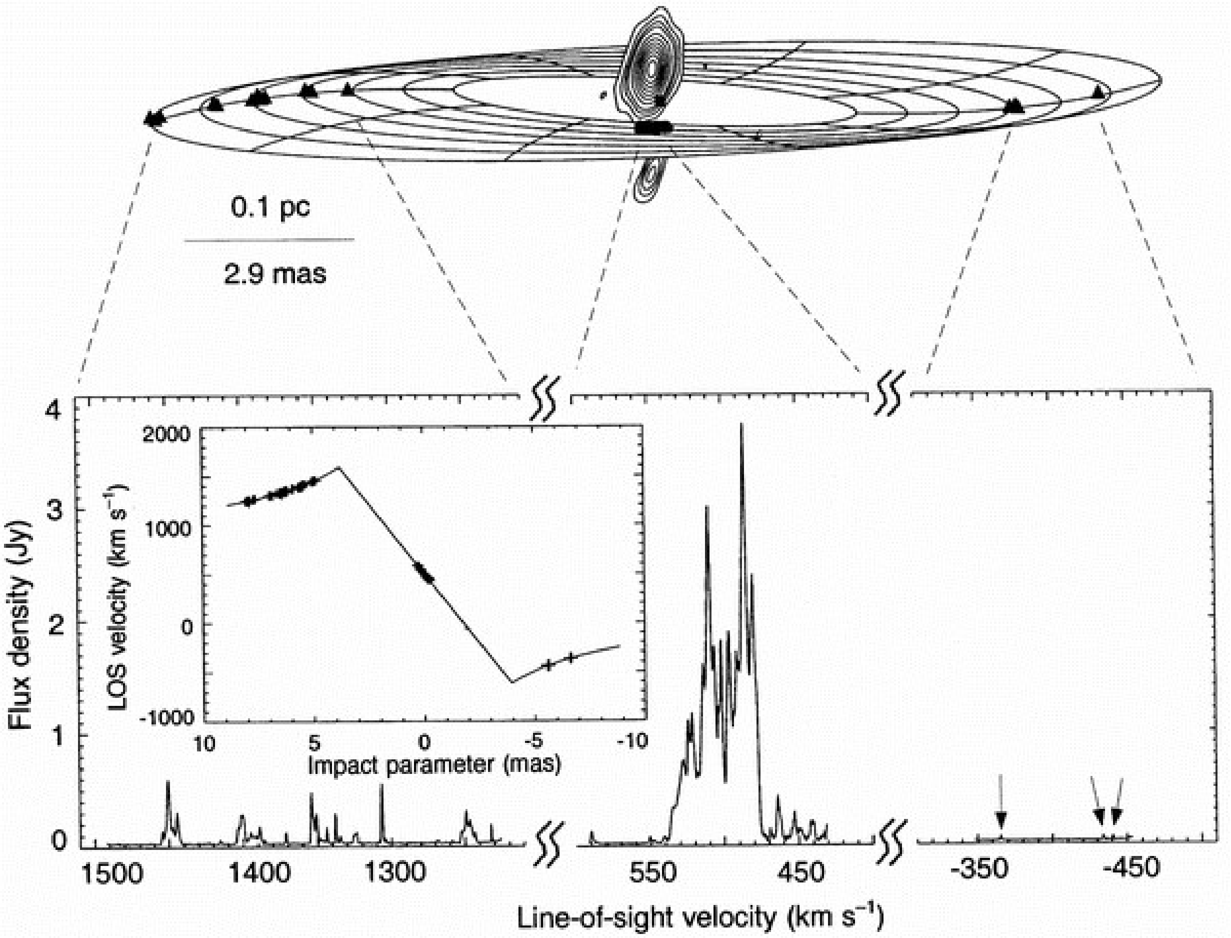
$$v^2R = GM$$

$$M = v^2R/G$$

which is equivalent to Kepler's third law for $v = 2\pi R/T$.

Gas dynamics: a Keplerian example

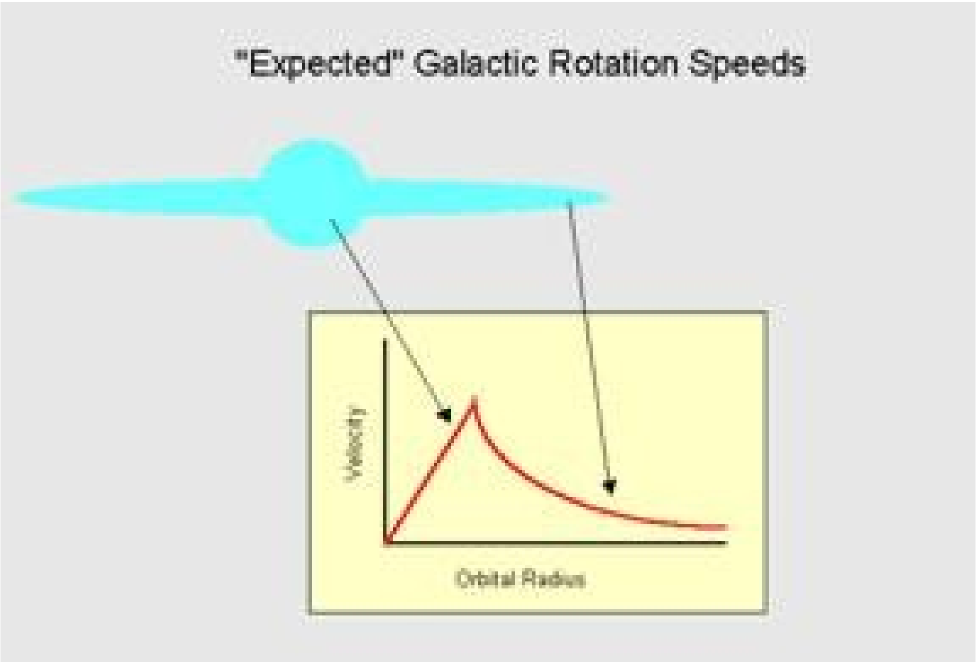
From Herrnstein et al. (1999): water masers tracing orbital motions around the central black hole in NGC4258.



Rotation curves in galaxies: expected

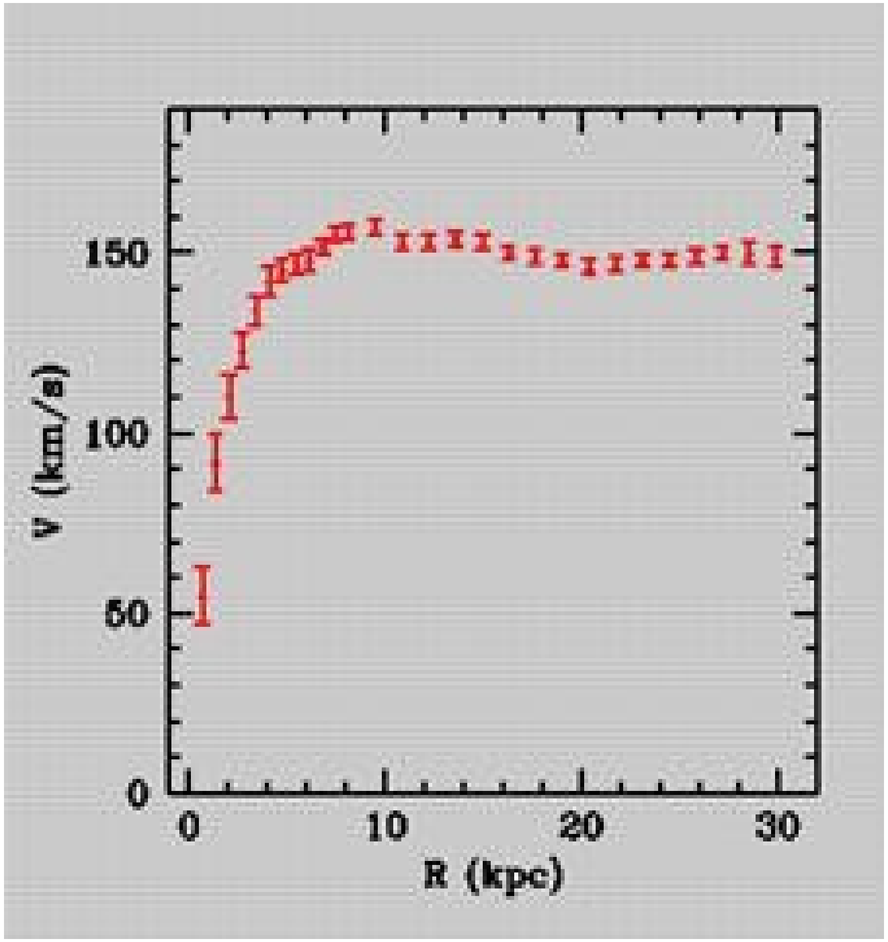
Rotation curves in galaxies are not Keplerian because we must replace *M* with the "interior mass" *M*(<*R*) in the force equation... and *M*(<*R*) is not constant as in the case of a central dominant mass.

What we expect, based on the central concentration of luminous matter (stars and gas):



Rotation curves in galaxies: observed

What we observe: flat rotation curves, implying the existence of additional non-luminous matter (i.e., dark matter).

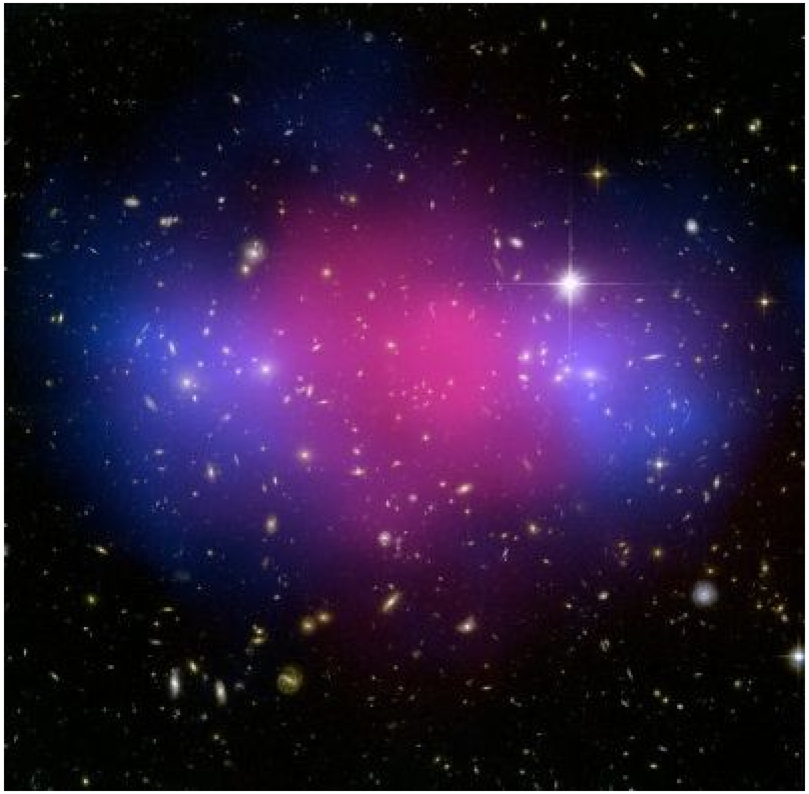


A heretical alternative?

A few bold souls have pointed out that once can just as easily relax the assumption of a universal law of gravitation as the assumption that all matter is luminous.

The idea that gravity might behave differently at low values of acceleration is known as Modified Newtonian Dynamics (MOND). It works well in the context of spiral galaxy rotation curves, but not so well elsewhere.

The "Bullet Cluster" vs. MOND



A collision between two clusters of galaxies: pink shows X-rays from hot gas, while blue shows mass based on weak lensing (apparently, mostly dark matter that is not "collisional").

Inclination and rotation curves

If a galaxy is inclined relative to our line of sight, where

$i = 90^o$ means edge-on
$i = 0^o$ means face on

then the observed line of sight velocity is related to the intrinsic rotation velocity by $v_{obs} = v_{rot} \sin i$ if we make the assumption of intrinsic axisymmetry (i.e., roundness).

Quiz