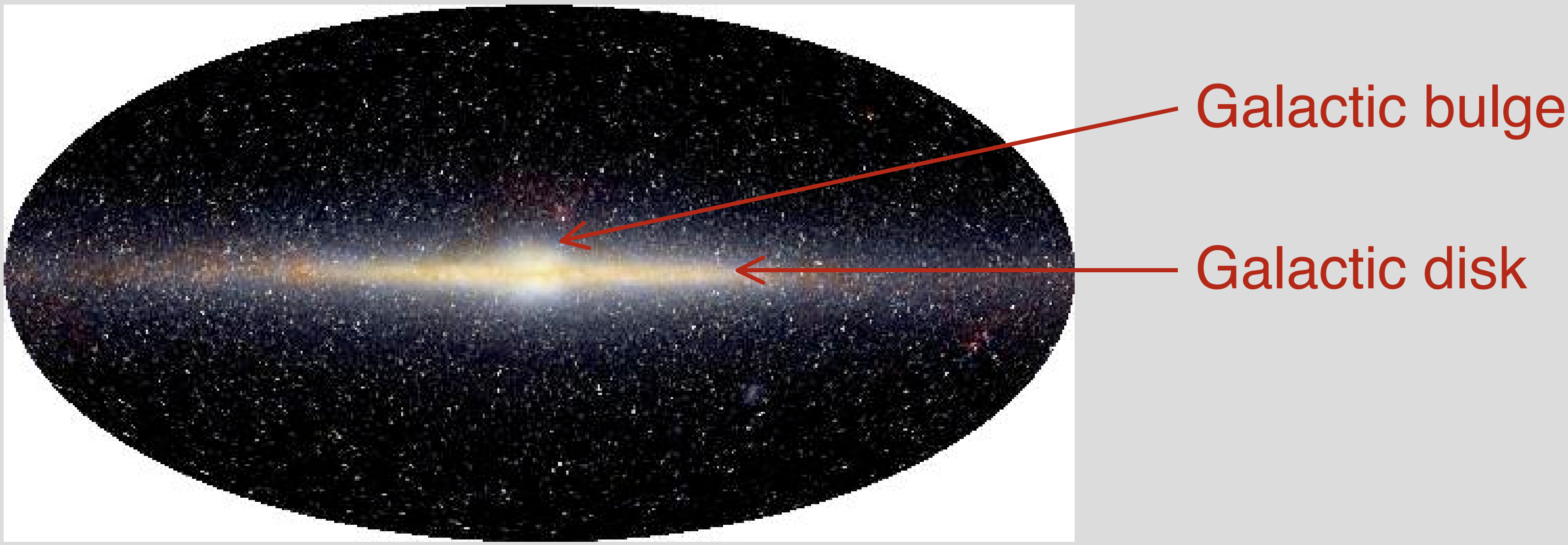
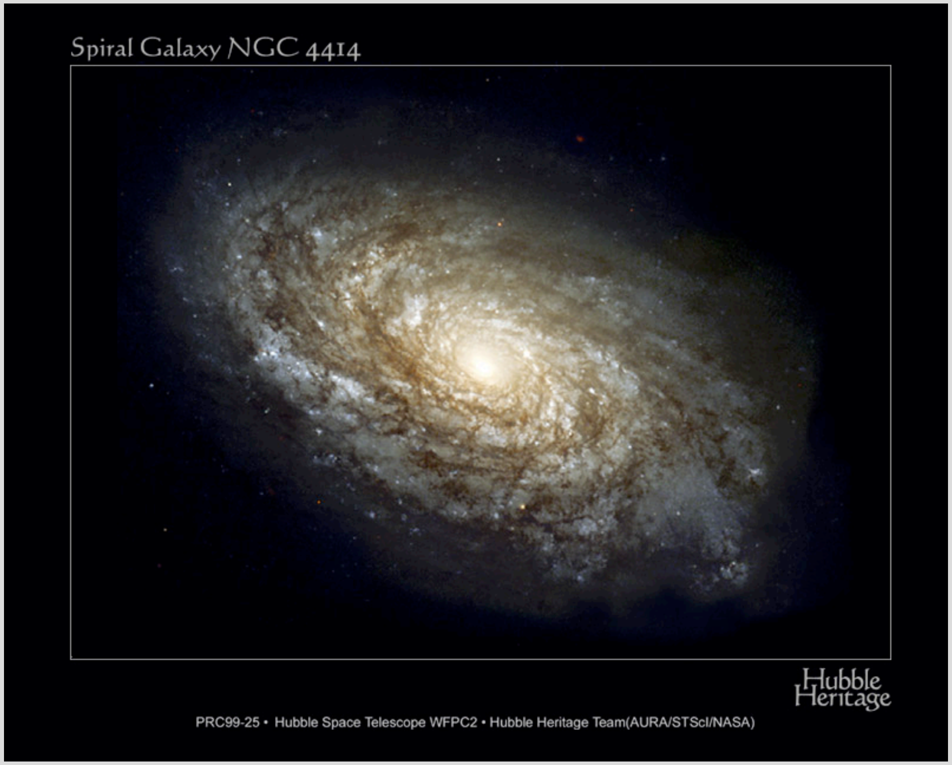
The Milky Way galaxy

Optical view of the Milky Way is restricted by absorption due to dust. Clearest view is obtained in infra-red:



map from the DIRBE instrument on COBE

At these wavelengths, primarily see emission from cool (hence low mass, typically old) stars. Maps presented in **Galactic co-ordinates**: at the center is the Galactic center, with the disk oriented along the `equator'.



Clear from the infra-red view that we live in a disk galaxy, very similar to local spiral galaxies.

Several different components in such systems.

1) The bulge: central spheroidal stellar component

Milky Way bulge:

$$L_{bulge} \approx 5 \times 10^{9} L_{sun}$$

$$M_{bulge} \approx 2 \times 10^{10} M_{sun}$$

($L_{sun} = 3.86 \times 10^{33}$ erg s^{-1}; $M_{sun} = 1.989 \times 10^{33}$ g)

Galactic center is about 8 kpc from the Sun, the bulge is a few kpc in radius (1 pc = 3.09×10^{18} cm).

<u>2) The disk</u>: thin, roughly circular disk of stars with organized sense of rotation about the Galactic center.

Milky Way disk:

$$L_{disk} \sim 15 - 20 \times 10^{9} L_{sun}$$

$$M_{disk} \sim 6 \times 10^{10} M_{sun}$$

Disk extends to at least 15 kpc from the Galactic center, and is centrally concentrated. Density of stars in the disk falls off exponentially:

$$n(R) \propto e^{-R/h_R}$$

← h_R is the *disk scale length*, which is about 2-4 kpc for the Milky Way.

Most of the stars (95%) lie in a **thin disk** - vertical scale height 300 - 400 pc. Rest form a **thick disk**.

Also a gas disk, which is thinner than either of the stellar disks.

<u>3) The halo</u>: the bulk of the Galaxy that is outside the bulge and well above the plane of the disk. Made up of:

(i) Stars - total mass in visible stars ~10^9 M_{sun}. Stars are all old, and have random motions. Very low density.

(ii) Globular clusters - dense compact clusters distributed in the Galactic halo.

Hubble image of the globular cluster M80. In the Milky Way, globular clusters are made up of old stars only.

(iii) Dark matter - mass in the visible components of the Galaxy is concentrated at $R < R_{sun}$.

- Bulge - only a few kpc in radius
- Disk - scale length is only a few kpc
- Halo stars and globular clusters - very small mass compared to the bulge and disk

If these visible components contained all the mass in the Galaxy, acceleration felt by the Sun toward the Galactic Center ought to be roughly the same as if all the mass were concentrated at the Galactic Center:

$$a \sim \frac{GM_{galaxy}}{R_{sun}^2}$$

R_{sun} is the Sun - Galactic Center distance (8 kpc)

For circular motion, Sun's velocity would have to be:

$$a = \frac{v^2}{R_{sun}}$$

Simple model predicts the rotation curve of the Milky Way ought to look like:

$$v \approx \sqrt{\frac{GM_{galaxy}}{R}} = 210 \left(\frac{M_{galaxy}}{8 \times 10^{10} M_{sun}} \right)^{1/2} \left(\frac{R}{8 \text{ kpc}} \right)^{-1/2} \text{ km s}^{-1}$$

This number is about right - Sun's rotation velocity is around 200 km s^{-1}.

Scaling of velocity with $R^{-1/2}$ is not right - actual rotation velocity is roughly constant with radius.

Implies:

- gravity of visible stars and gas largely explains the rotation velocity of the Sun about the Galactic center.
- Flat rotation curve requires extra matter at larger radii, over and above visible components.

Dark matter…