Galaxies and the Universe

Our Galaxy - The Milky Way

The Interstellar Medium


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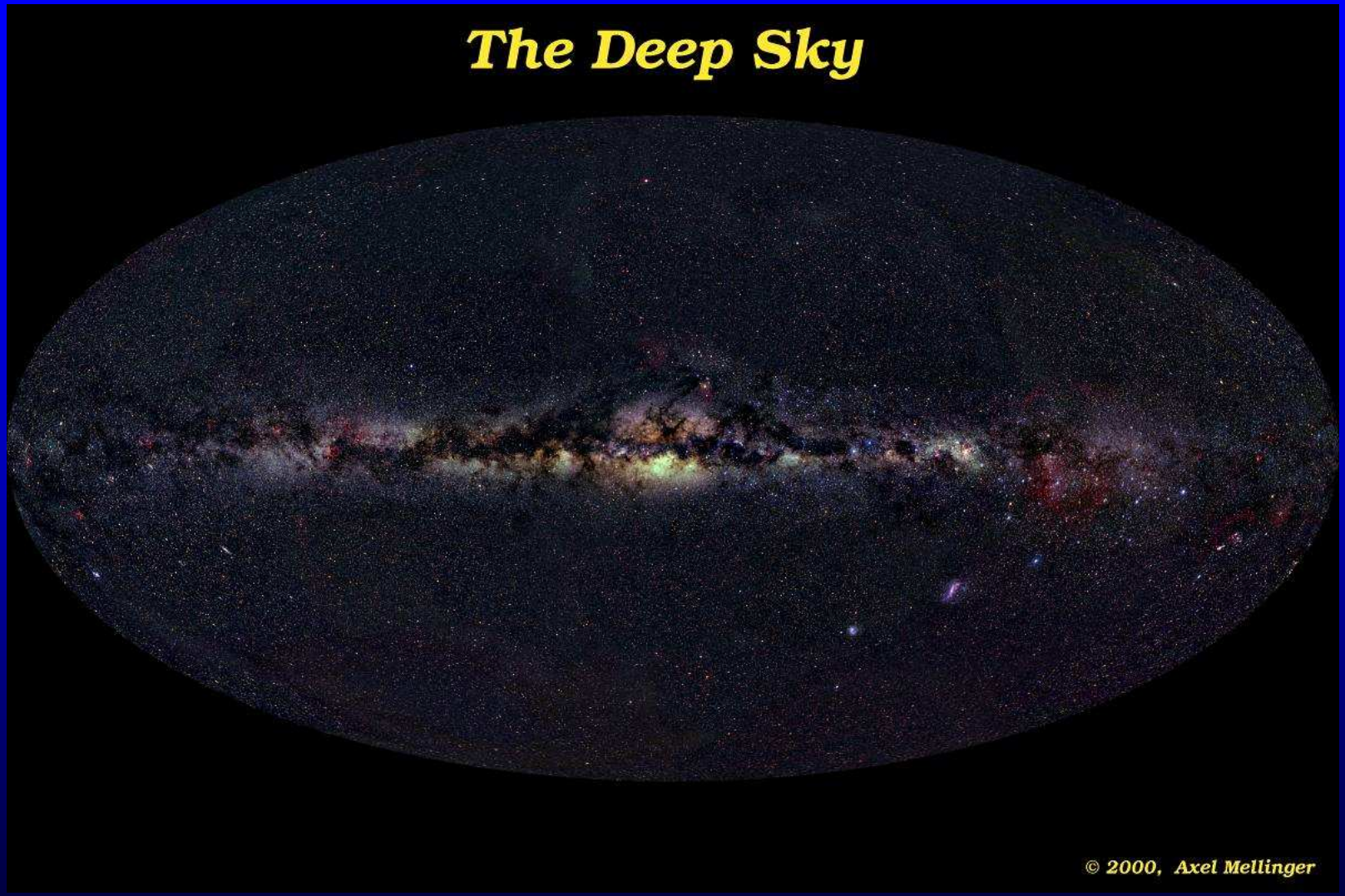
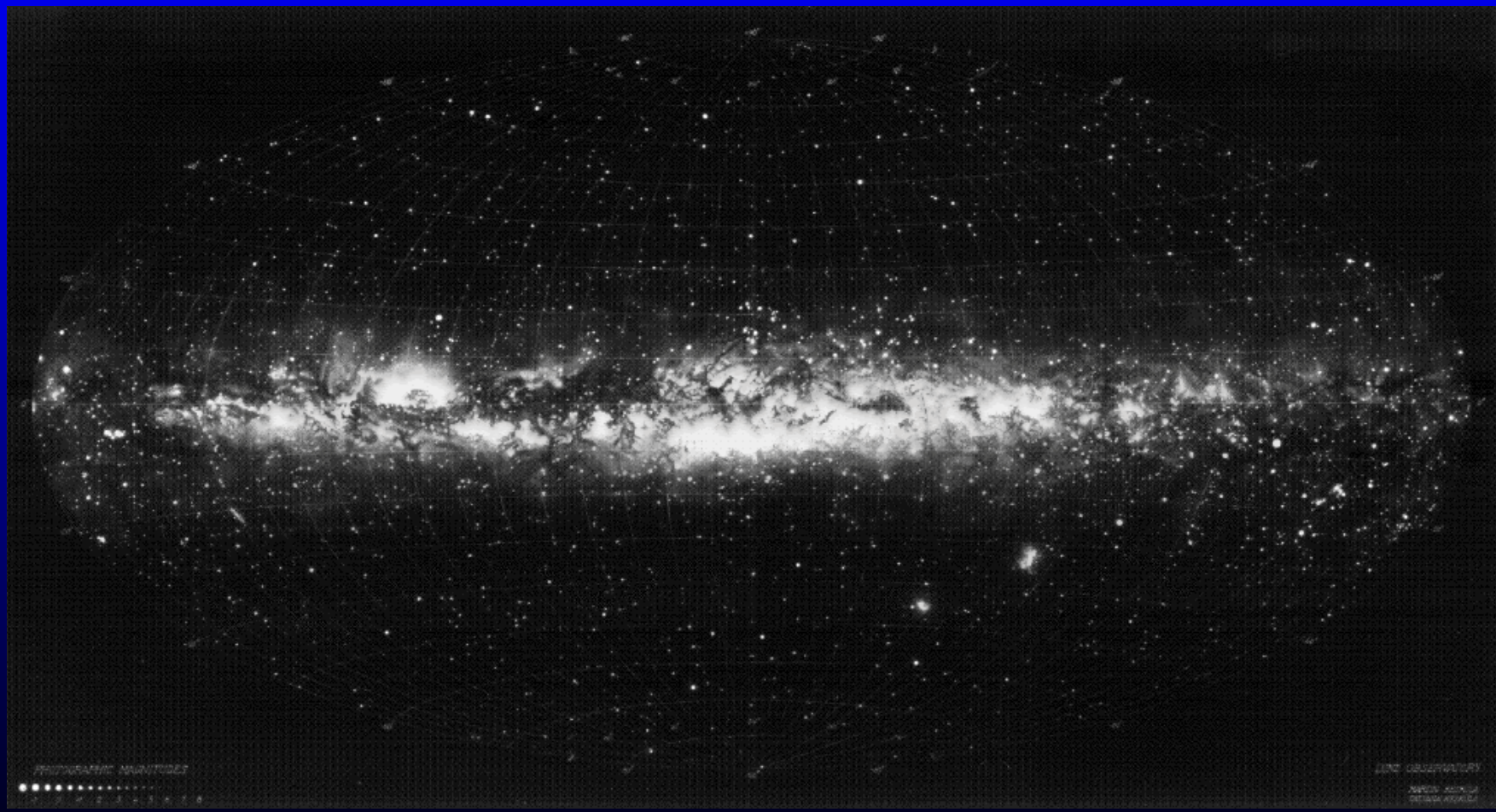
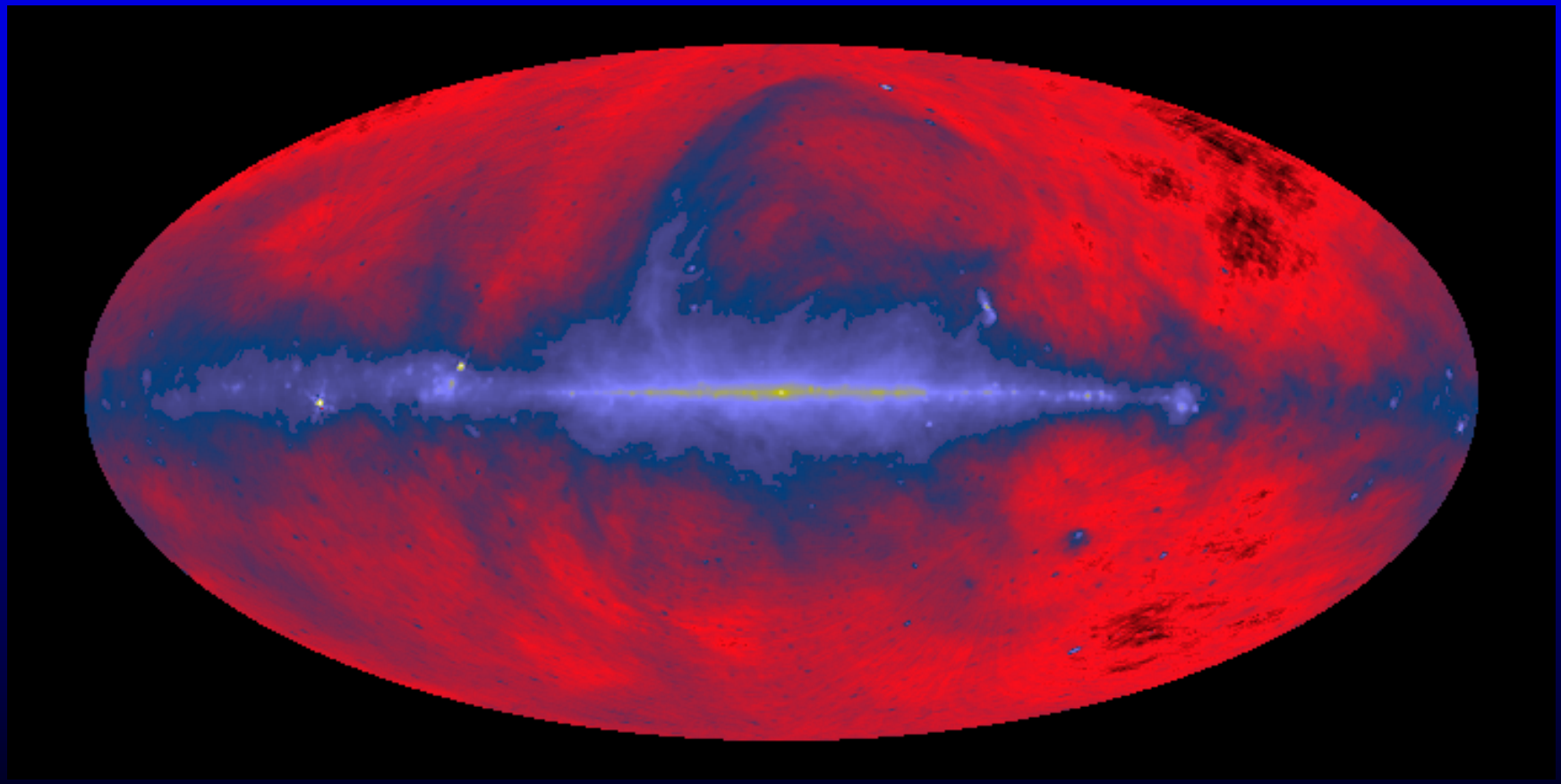
The Deep Sky



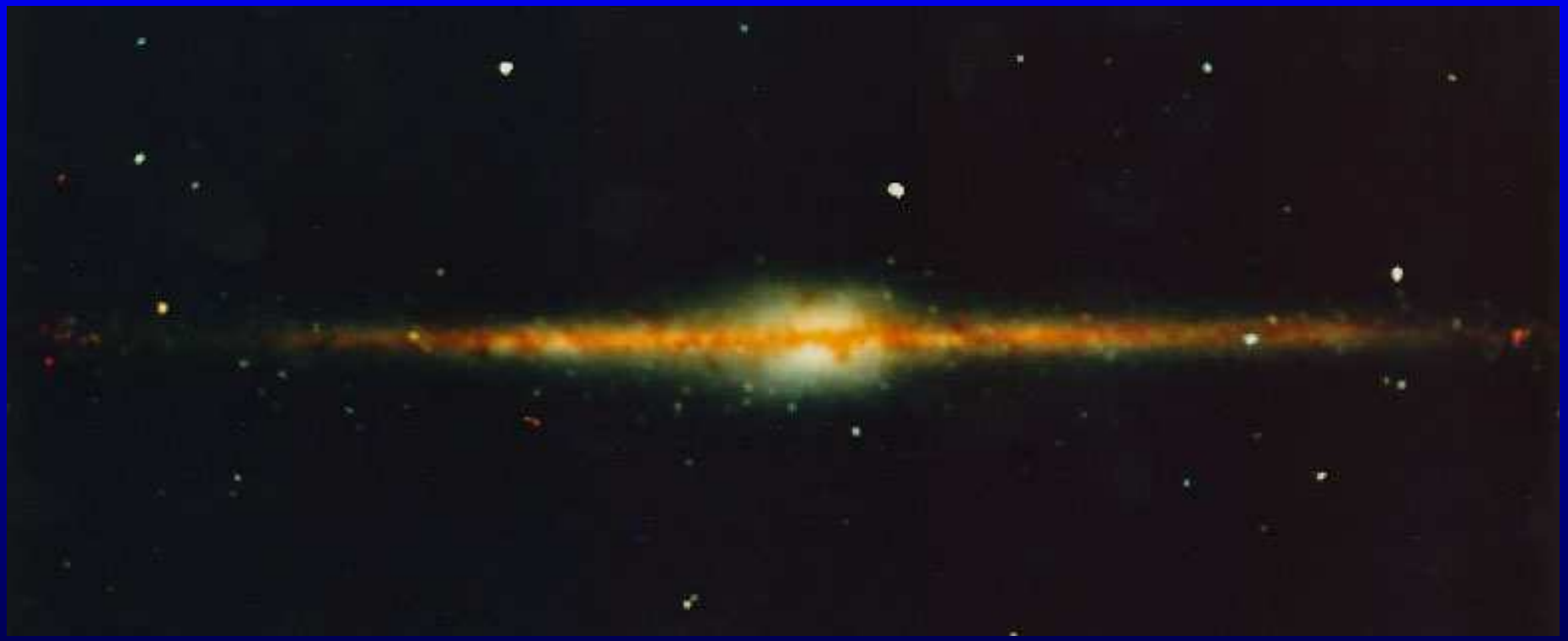
Our view of the Milky Way



The Radio Sky



COBE Image of our Galaxy



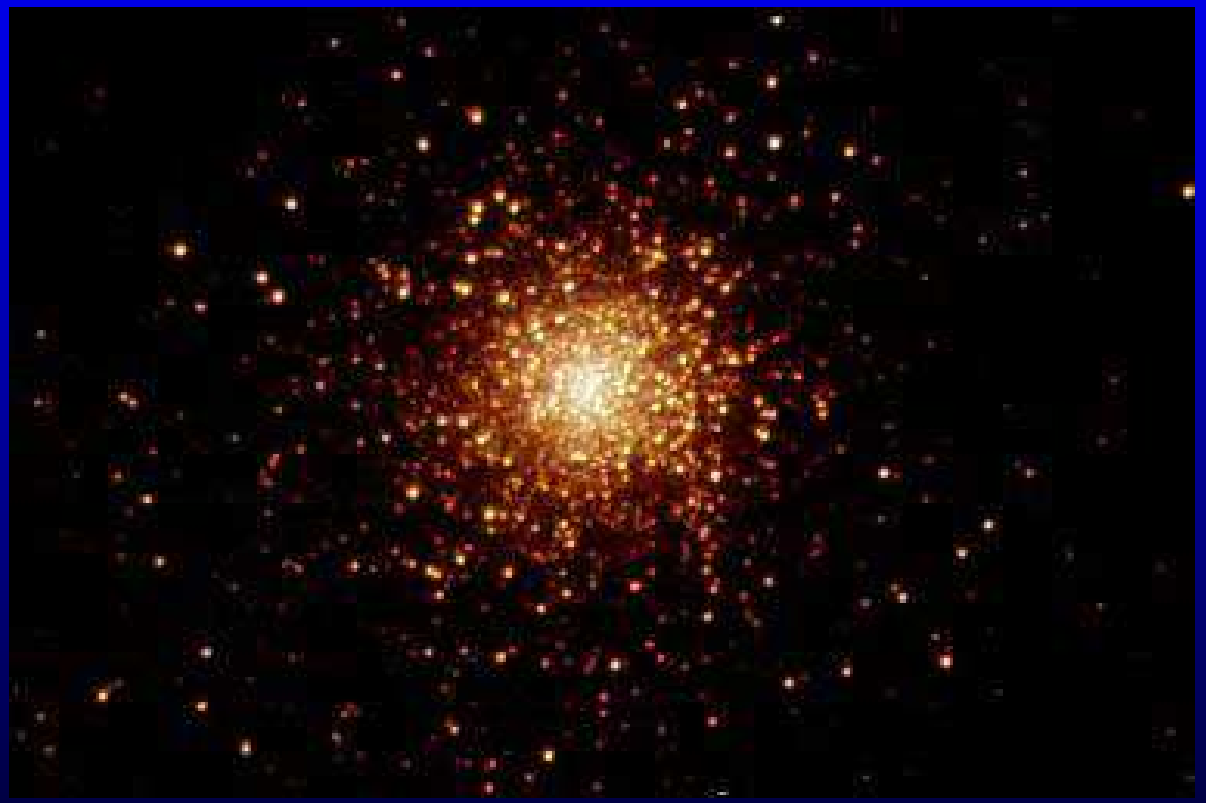
The Milky Way Galaxy - The Galaxy

- By Visual Observation – a flat disc called the Galactic disc – mass ~ 10^{11} M_{sun}.
- From Far Infra-red and radio – a central Bulge mass 10^{10} M_{sun}.
- This lies in the centre of a Halo composed of old main sequence stars, neutron stars, and, we believe, dark matter.

How do we know the size?

Distribution of Globular Clusters

Globular Cluster M15



Globular Clusters

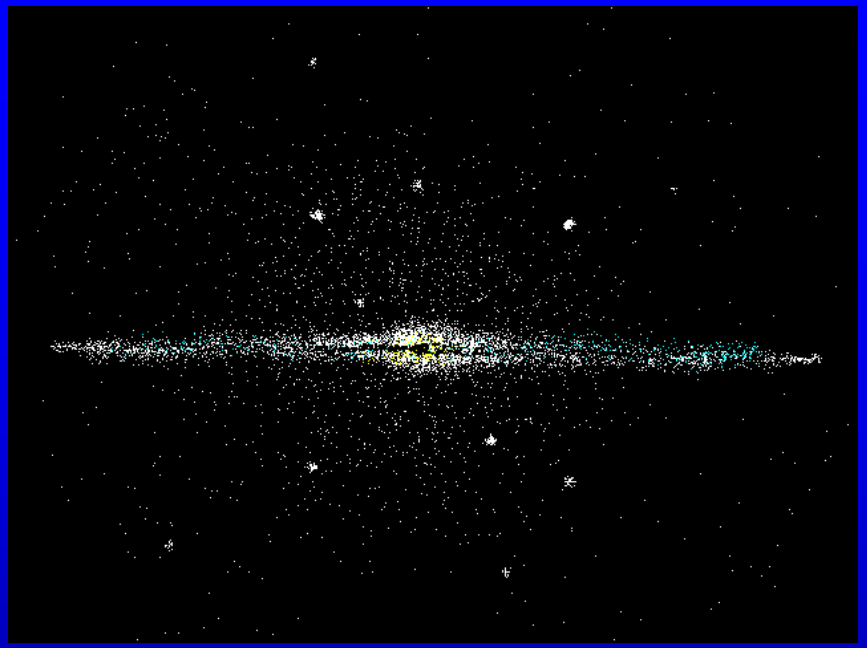
- Globular Clusters are compact dense spherical clusters of very old stars.
- They typically contain ten thousand to one million stars in a region about 50 pc in diameter.
- Globular Clusters lie in a spherical distribution.
- Howard Shapley deduced that the centre of this distribution would be the centre of the Galaxy.
- He thus deduced that our Sun lies ~ 8.5 kpc or 27.3 thousand light years from the galactic Centre.

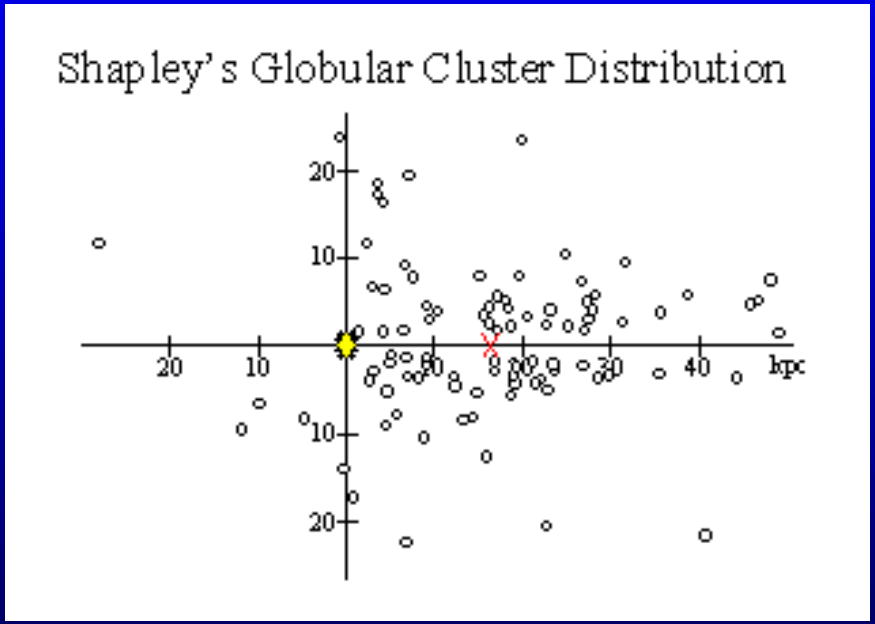
M13

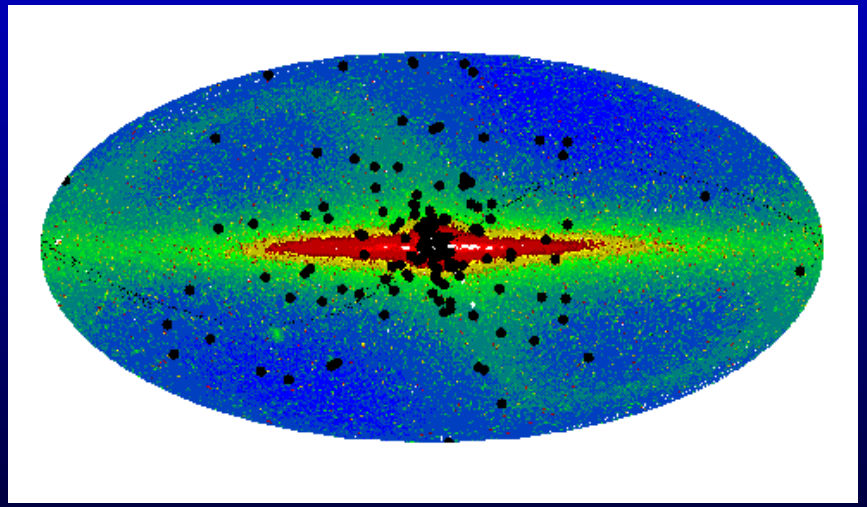
M92

Globular Cluster 47 Tucanae

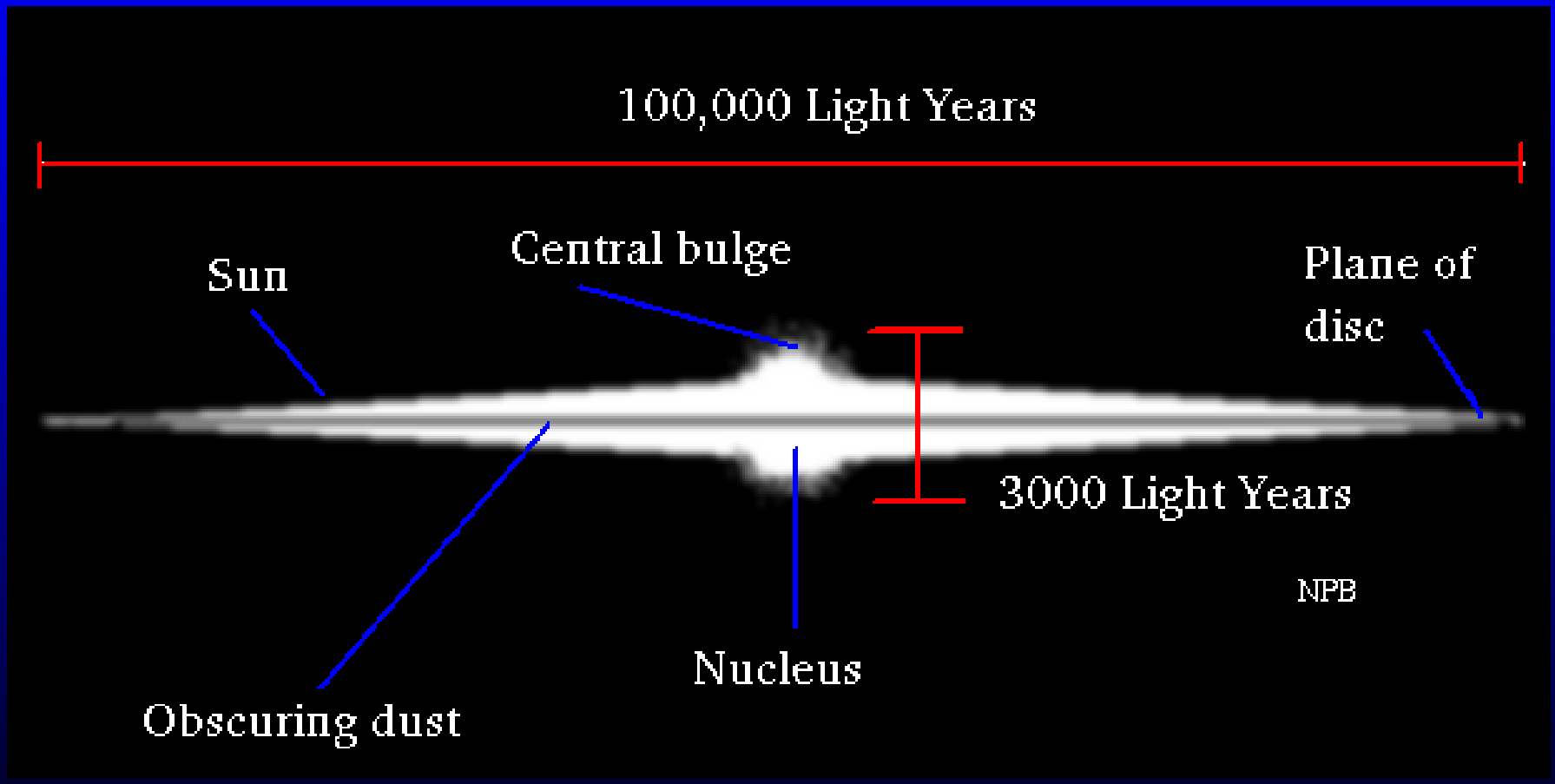
Globular Clusters







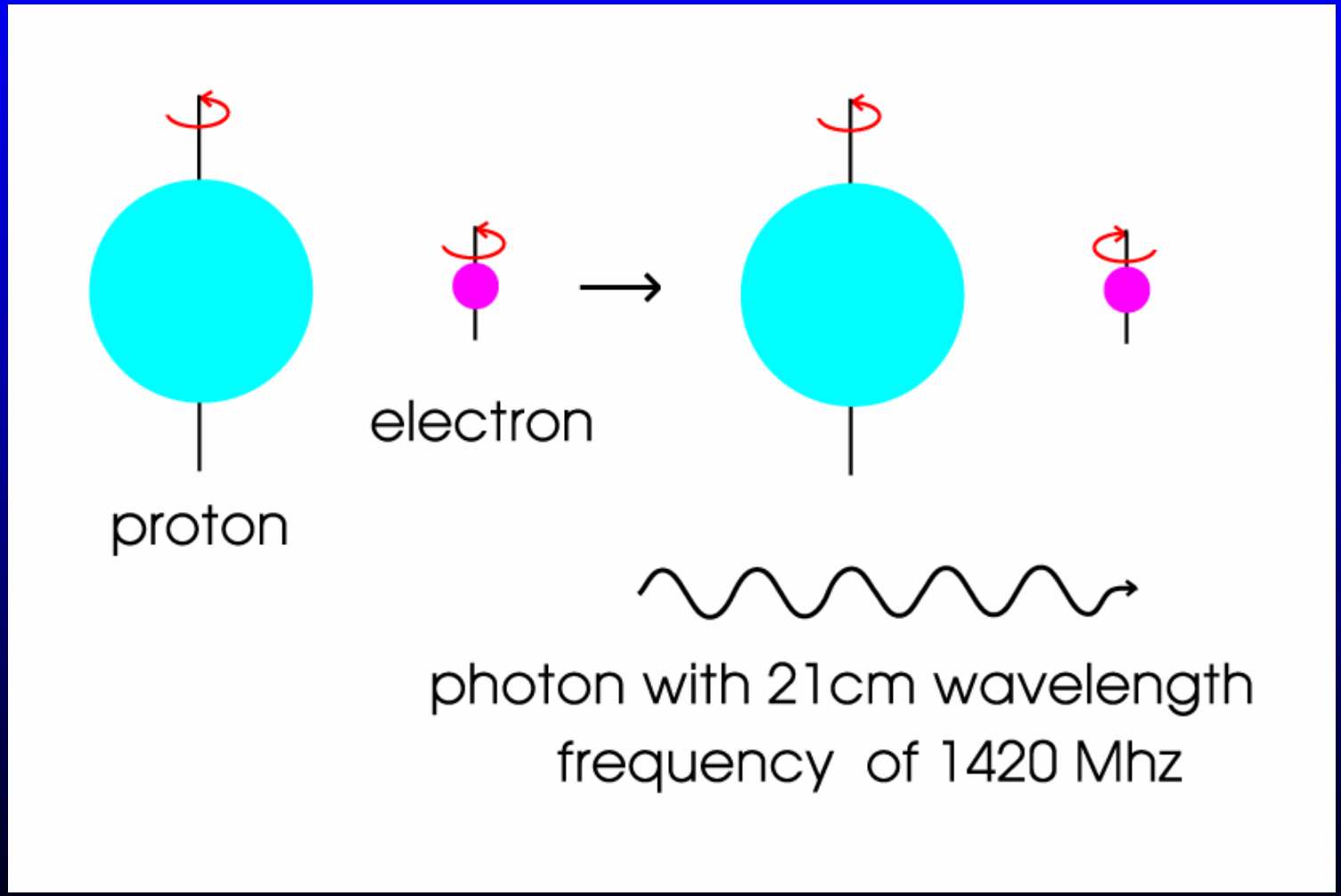
Light takes 100,000 years to travel across the Galaxy



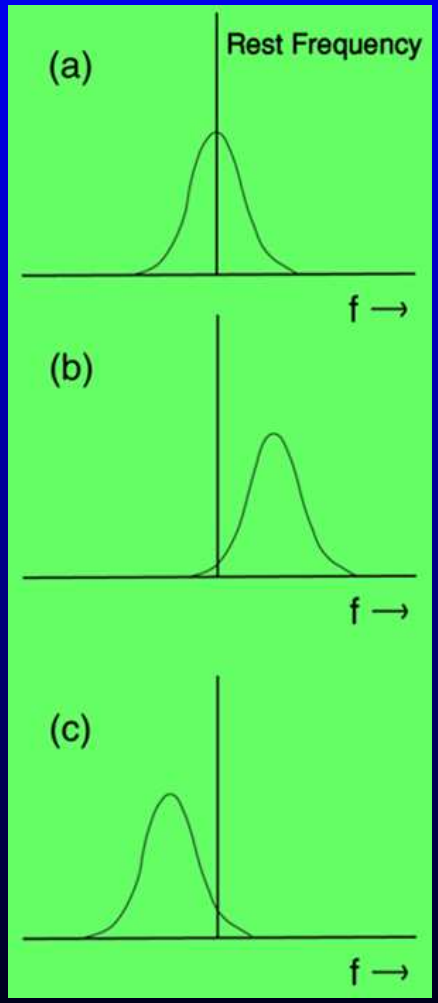
The Spiral Structure of the Galaxy

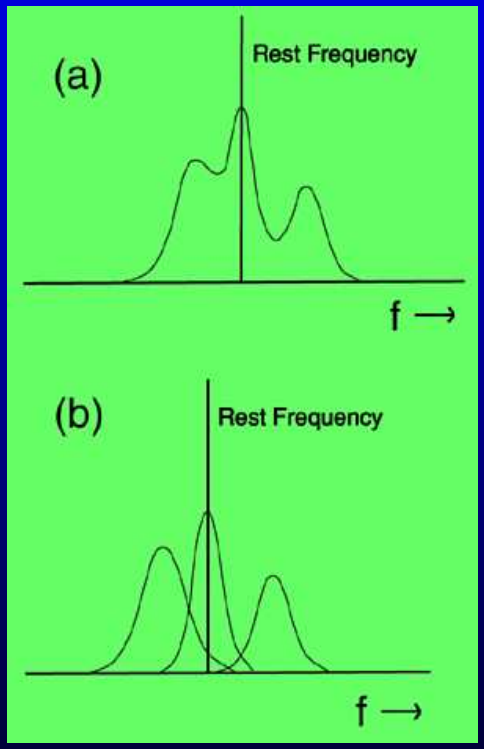
- Radio Observations of the 21cm (1400 MHz) Hydrogen Line enable us to show that the disk shows structure in the form of spiral arms.
- (The 21cm line photon is emitted when the electron changes its spin state with respect to the proton in the presence of a magnetic field - from parallel to anti-parallel.)
- The relative motion of the gas clouds that make up the spiral arms can be determined by from the Doppler shift in the received line frequency.

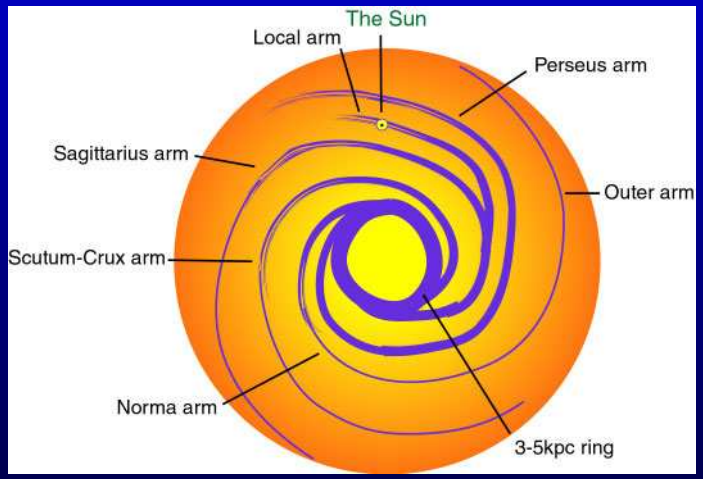
21cm Hydrogen Line

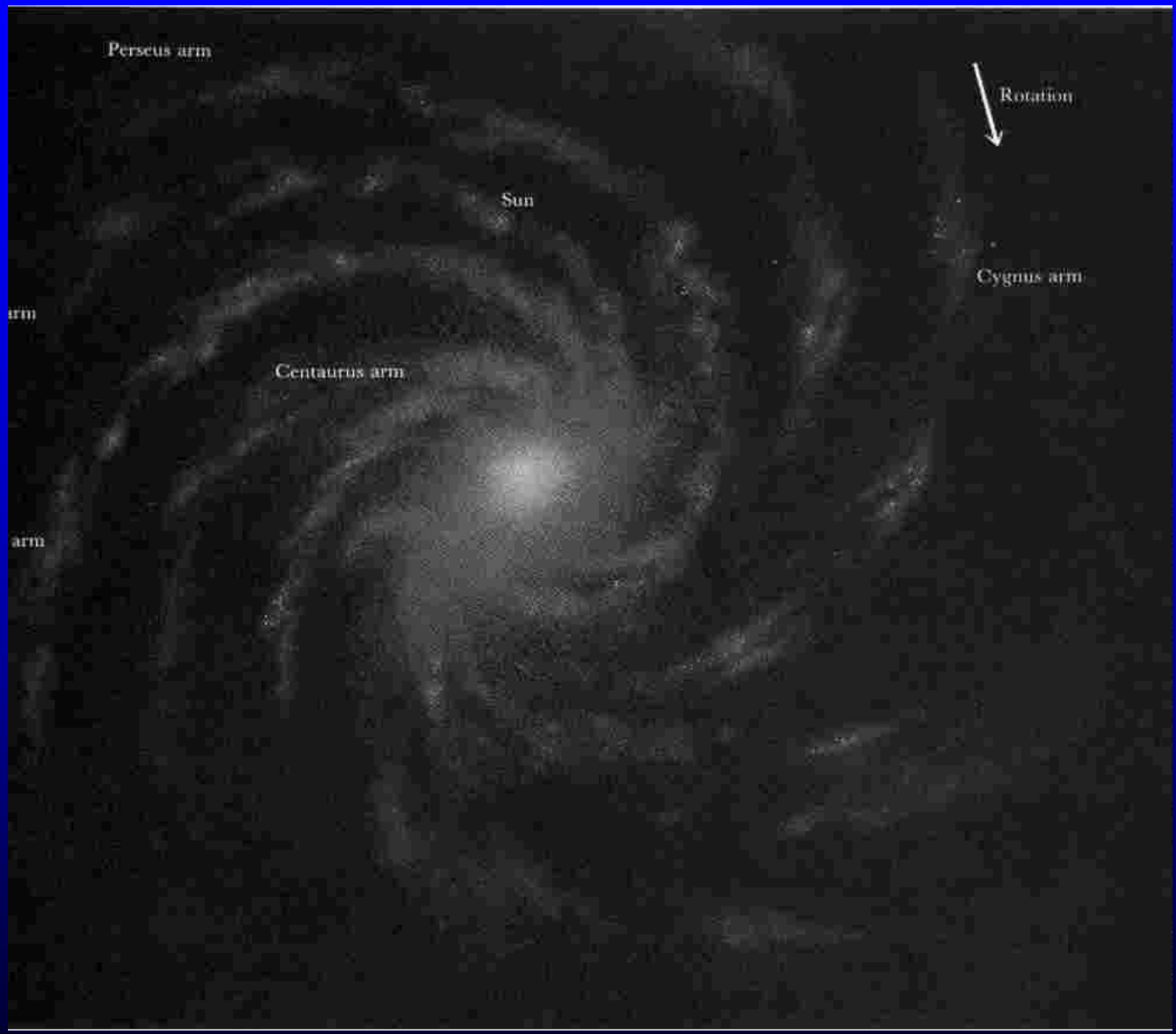


Using the 21cm Hydrogen Line

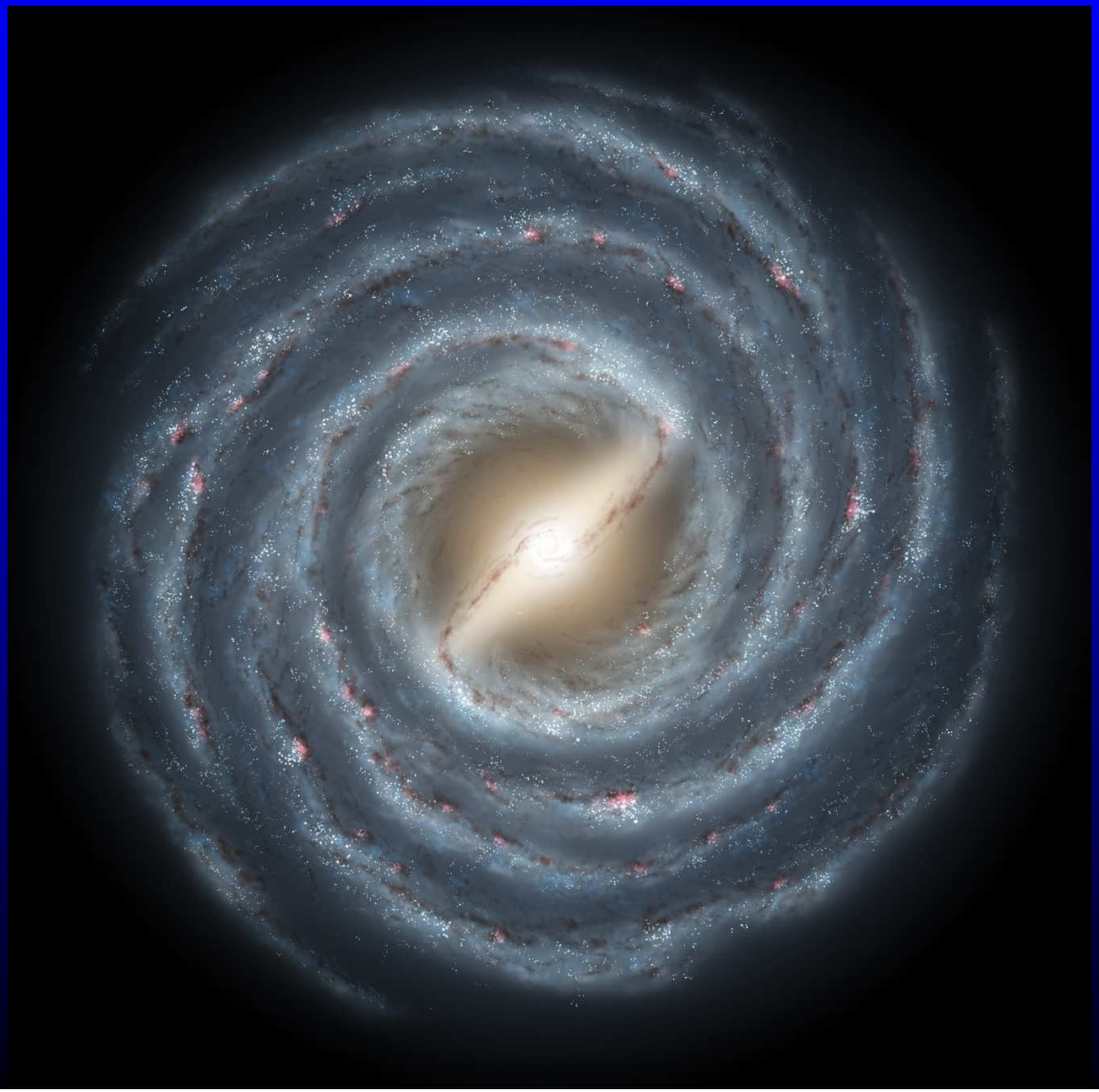







Perseus arm
Rotation
Sun
Cygnus arm
arm
Centaurus arm
arm

The Milky Way – a Barred Spiral



Formation of the Spiral Arms

- We believe that the spiral arm structure is a transient phenomena.
- A spiral density wave rotates round the centre of the Galaxy.
- This compresses the gas and triggers the formation of new stars.
- We see the spiral arms due to the light from the very hot blue stars that tends to dominate.
  - A blue star can be 50,000 times brighter than a yellow one.
- We also see regions of star formation – see later.

The components of the Galaxy – the Stars.

- Stars formed in the early Universe could only contain Hydrogen and Helium – there must be millions of low mass stars still around, but we haven't found any yet.
  - These are called Population III stars.
- As stars evolve and die they enrich the space between the stars with heavier elements.
- In astronomy ALL are referred to as METALS!
- So in stars formed later, the Metallicity, Z, gradually increases.
  - Z = Mass of elements heavier than Helium/ Mass of all elements

Population II stars

- The oldest stars we observe, they occupy the nuclear bulge and galactic halo.
- In the halo they have low metallicity.
  - $Z < 0.002$
- They move in eccentric orbits and are not confined to the plane of the Galaxy.
- They orbit with both senses of rotation
  - No net angular rotation.

Population I stars

- Associated with the disc.
- All rotate in same direction round nucleus in ~ circular orbits.
  - Sun takes 240 Million years to orbit nucleus.
- Many young stars
- Metallicities are higher, and in the range Z = 0.01 to 0.04.

The components of the Galaxy – the Interstellar Medium.

- Gas – Hydrogen and Helium.
  - Hydrogen from the Big Bang and Helium, both from Big Bang and ejected into space from stars.
  - Over time the percentage of Hydrogen reduces and Helium increases.
  - Now ~ 70% H, 28% He. (98% are H and He)
  - Was ~75% H, 25% He, after the Big Bang Origin of the Universe.

Hydrogen

- Hydrogen can exist in three forms:
  - Molecular Hydrogen H_2 in high density, low temperature regions.
  - Ionized Hydrogen, HII (“H-two”) ,found where UV light from young stars ionizes the atoms and the gas has low density so reducing the recombination of electrons and protons. HII regions are star forming regions like the Orion Nebula.
  - Atomic Hydrogen HI (“H-one”) in intermediate regions of density and temperature.

The Orion Nebula

The Trapezium

Other Gasses

The remaining 2% of the gas is made up of other elements such as Carbon and Oxygen and Nitrogen.

Many other molecules such as CO - Carbon Monoxide, CN - Cyanogen, and even large molecules such as alcohol!

Gases, in total, make up about 10% of the stellar mass.

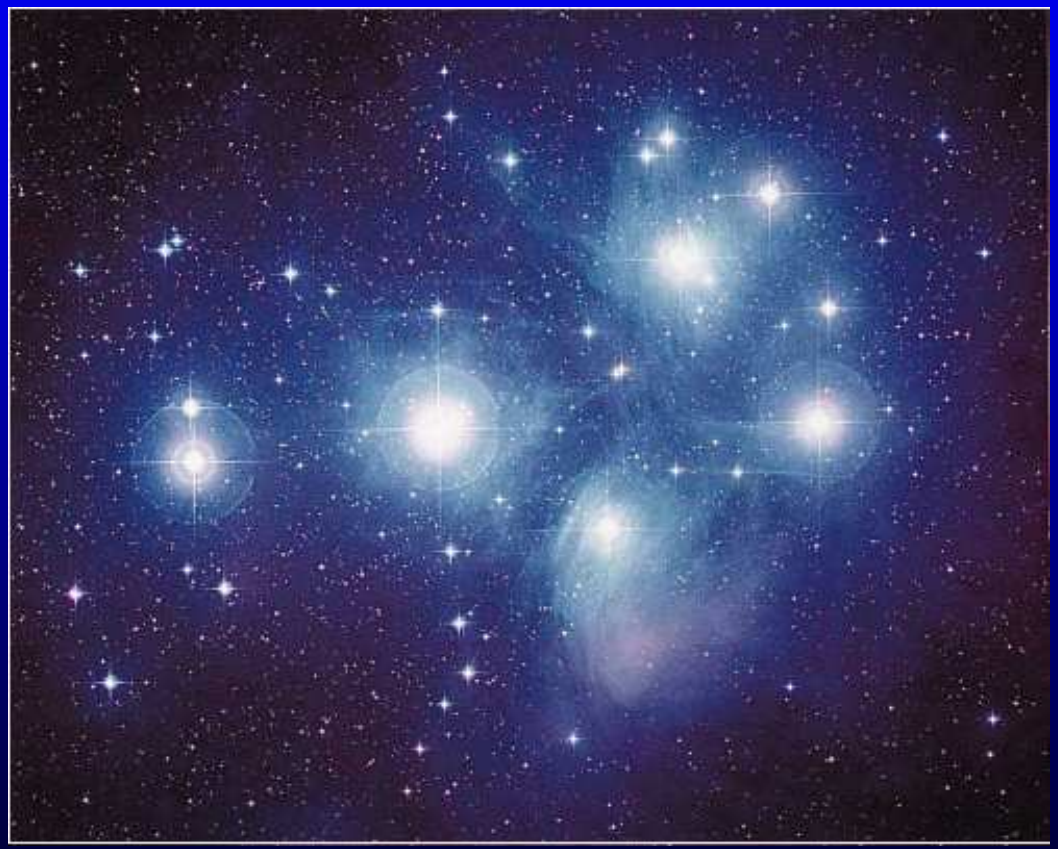
Much in the form of clouds – many thousands - with a range of temperatures and pressures.

Dust

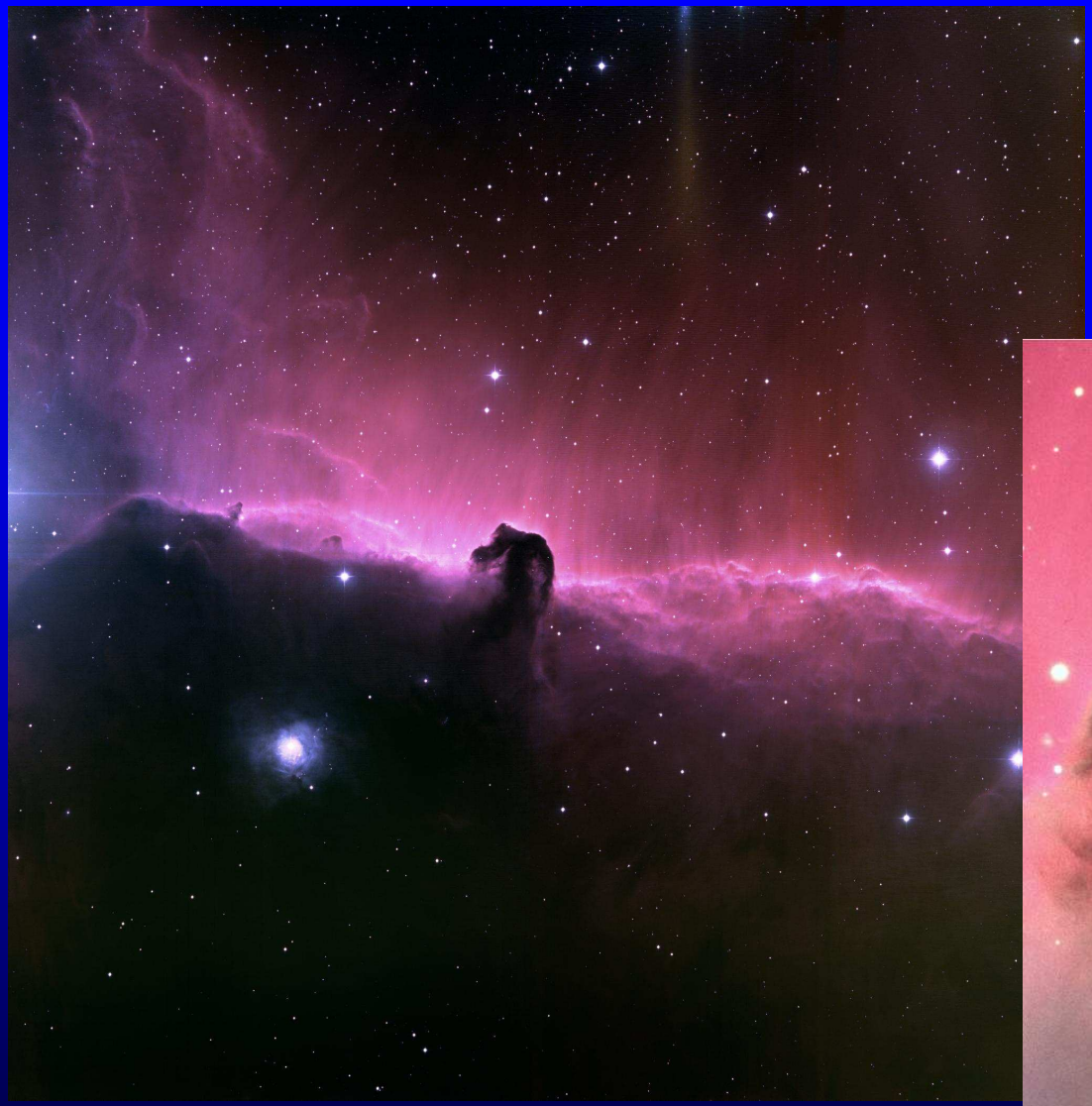
- Dust – comprises Carbon, Silicon and Iron etc produced in stars.
- Tiny lumps of solid compounds of C, O, Si and other “metals”.
  - Major part composed of graphite or silicon compounds, often coated with a coating of more volatile compounds such as water ice, ammonia and carbon monoxide.
  - Total mass ~ 0.1% of the mass of stars.
  - Found where the density is high and temperatures low.
  - These conditions occur in the disc.

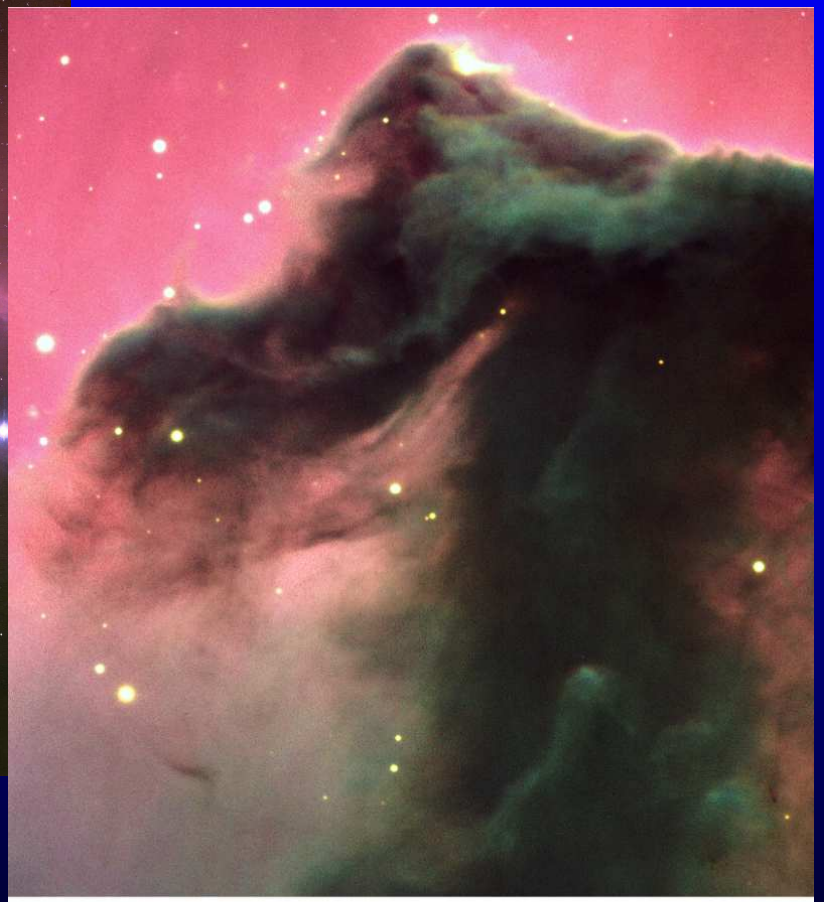
- Dust particles are typically 10^{-7} to 10^{-6} across – similar to smoke particles.
- This is comparable to the wavelength of light so scatter and absorb light!
- Concentrated toward the galactic centre.
  - So we cannot see far towards the centre in visible light!
- We can observe in reflection nebulae and dark clouds:

Reflection Nebula



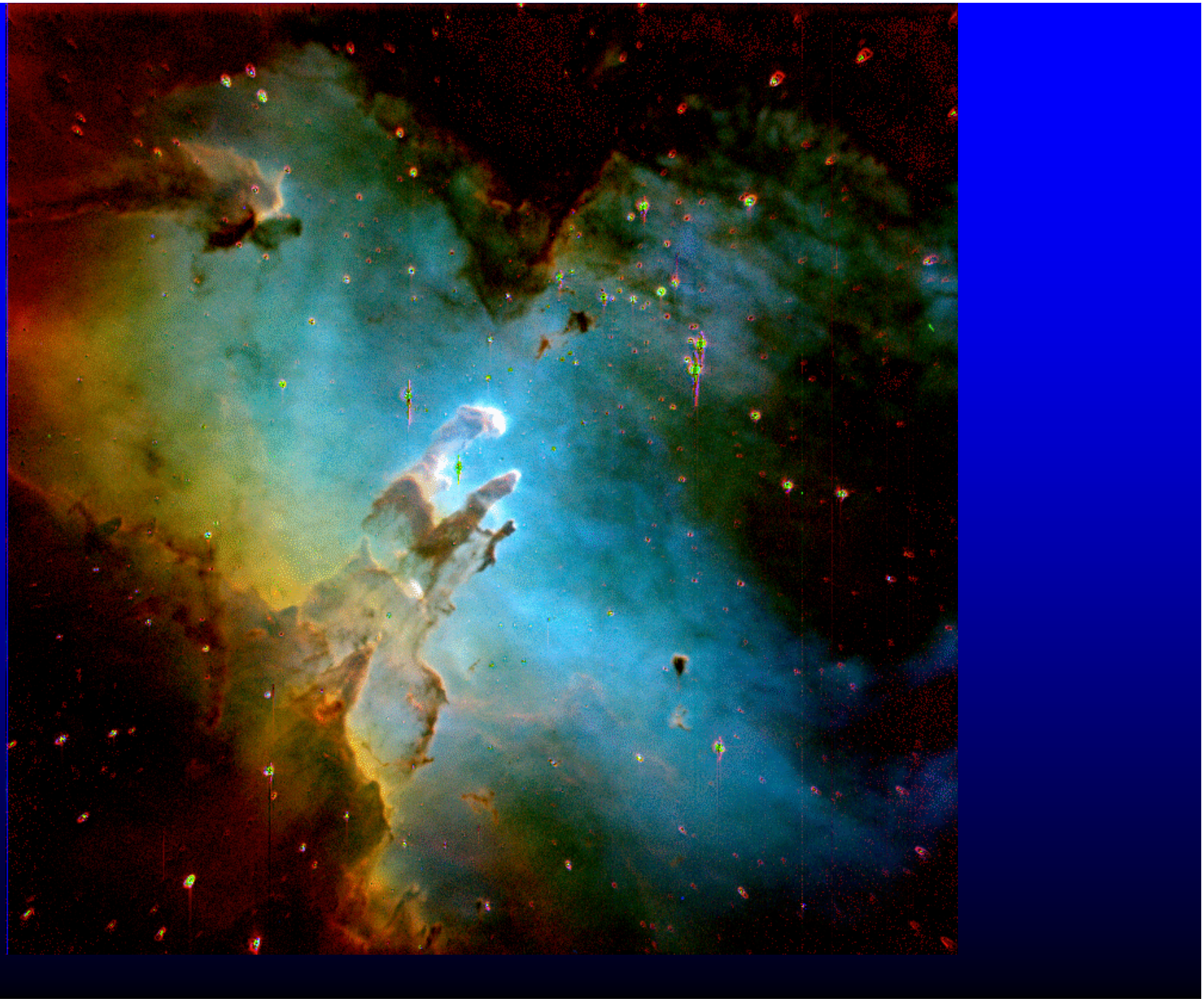
Dark Clouds

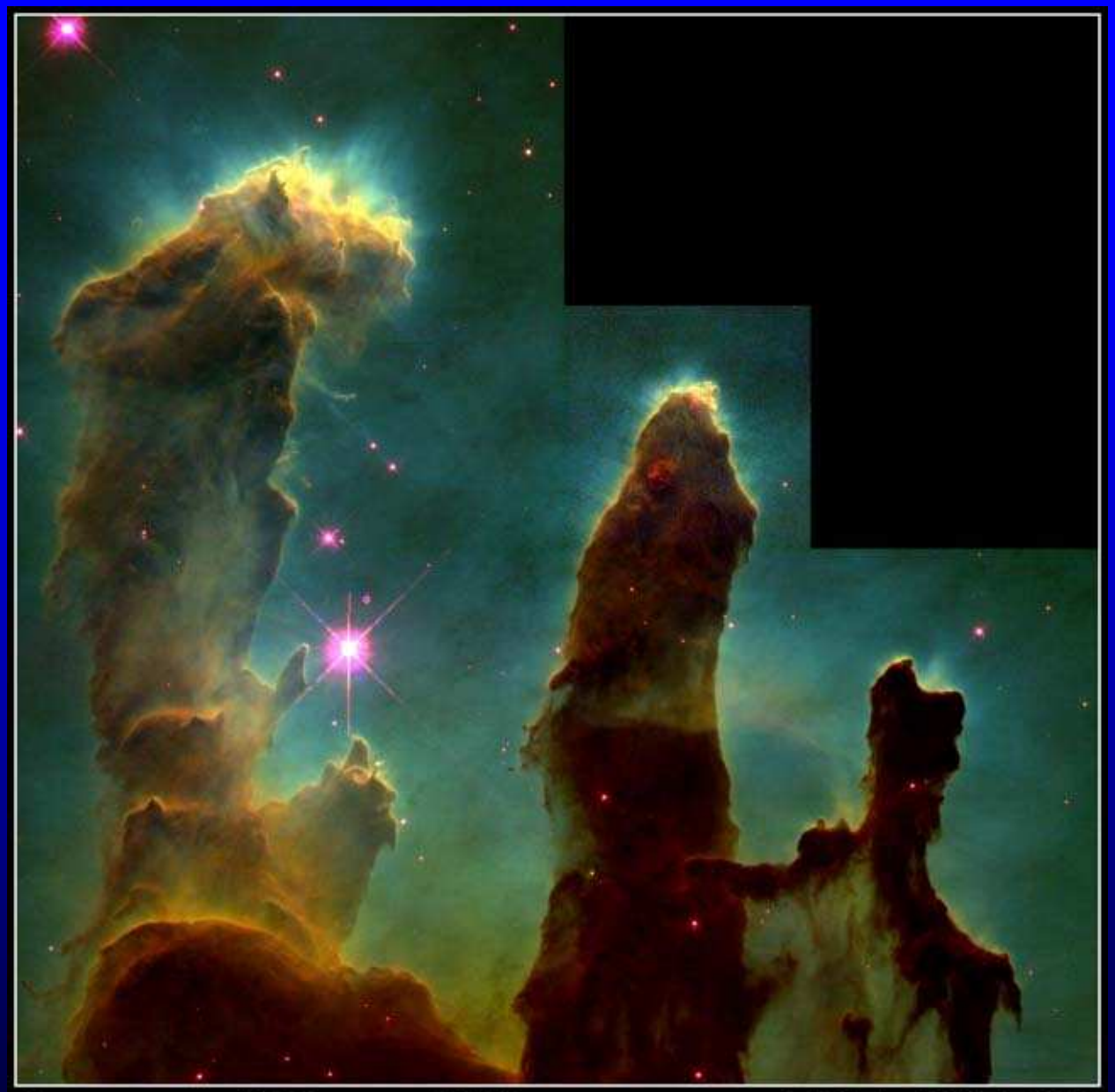




The Horsehead Nebula (detail)
(VLT KUEYEN + FORS 2)

ESO PR Photo 02b/02 (25 January 2002)





Gaseous Pillars · M16 HST · WFPC2

PRC95-44a · ST ScI OPO · November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA

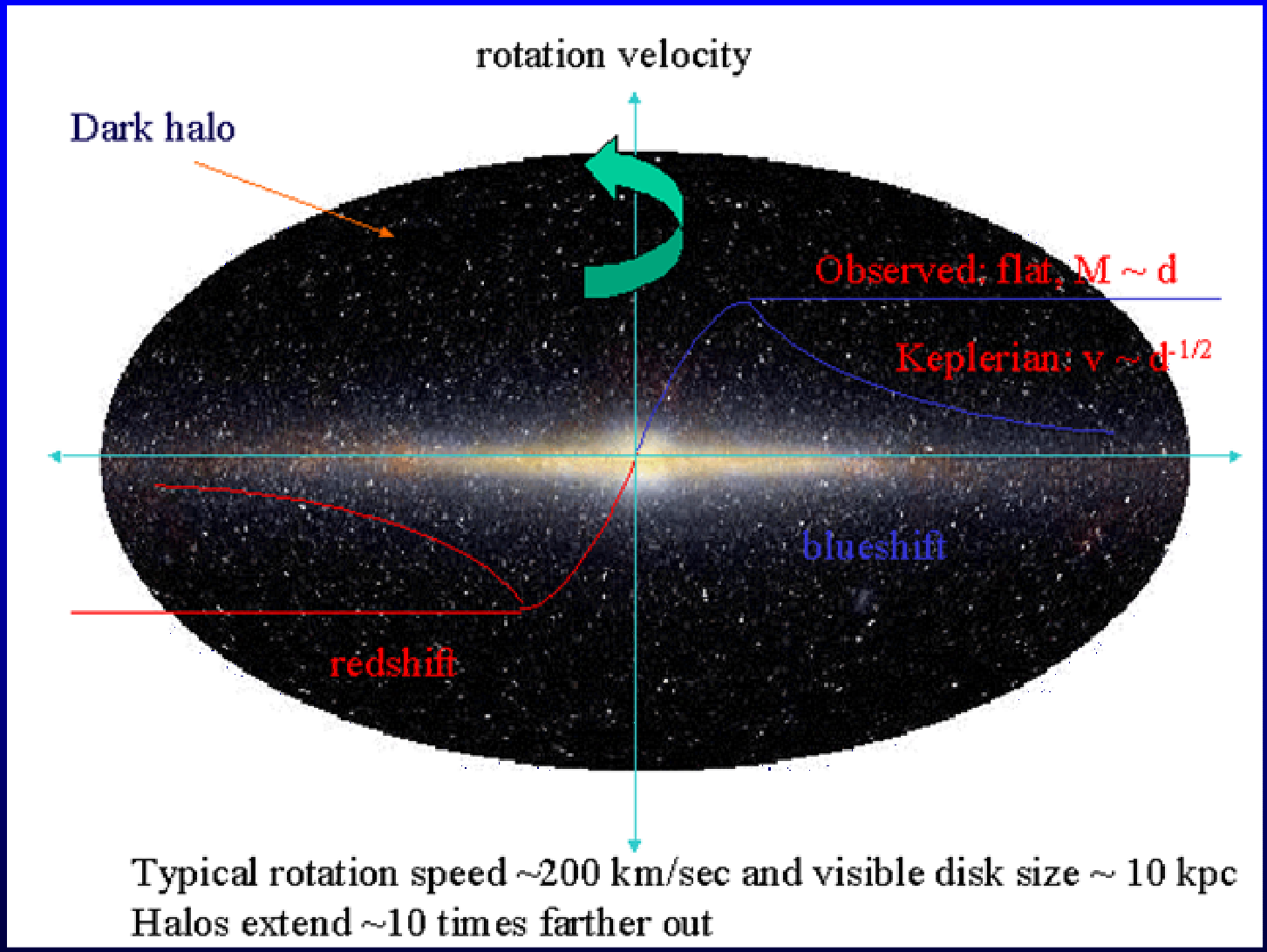
Coal Sack

Dark Matter

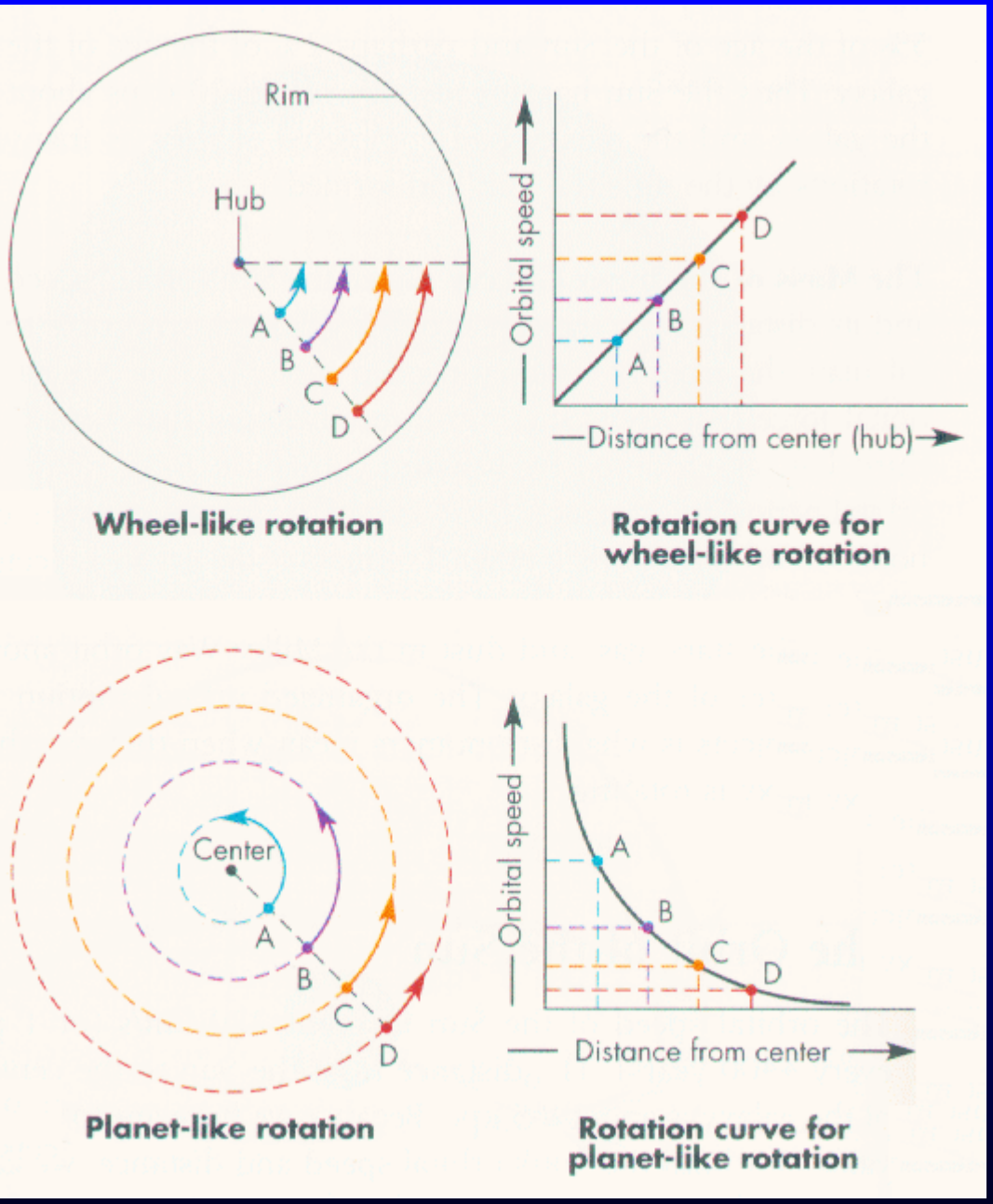
- It appears that there are several aspects of the Galaxy that we cannot understand without the existence of non-luminous matter that has never been directly detected.
- Its presence is revealed by its gravitational influence on the matter that we do see.
- Its mass is ~ 10 times that of the stars in the Galaxy.

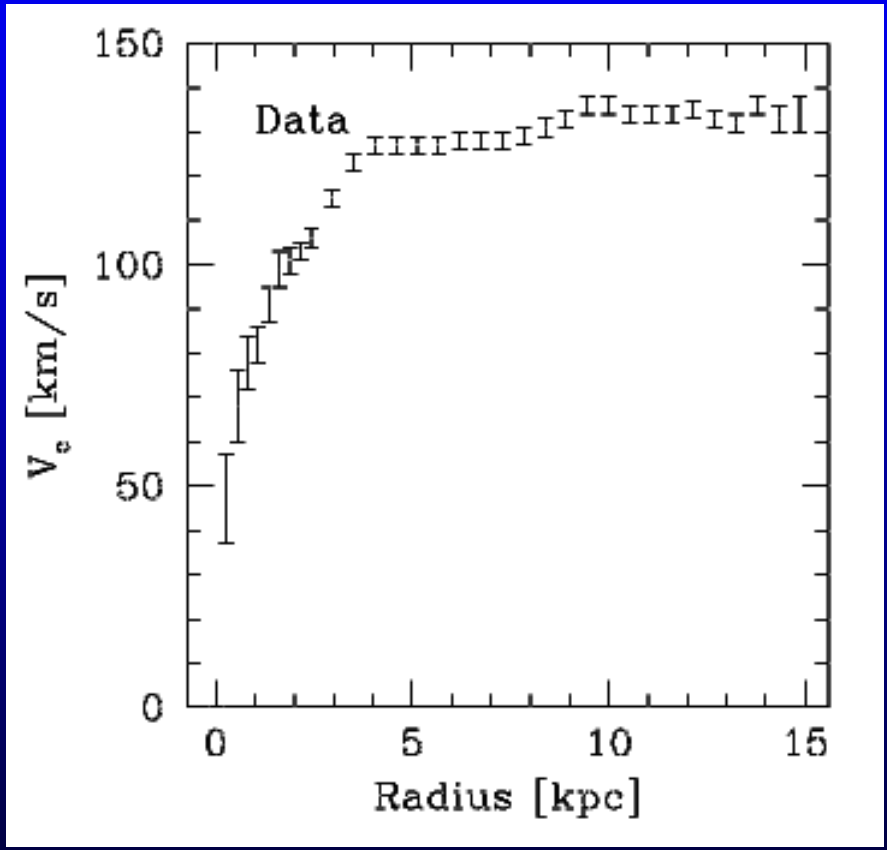
Evidence for Dark Matter

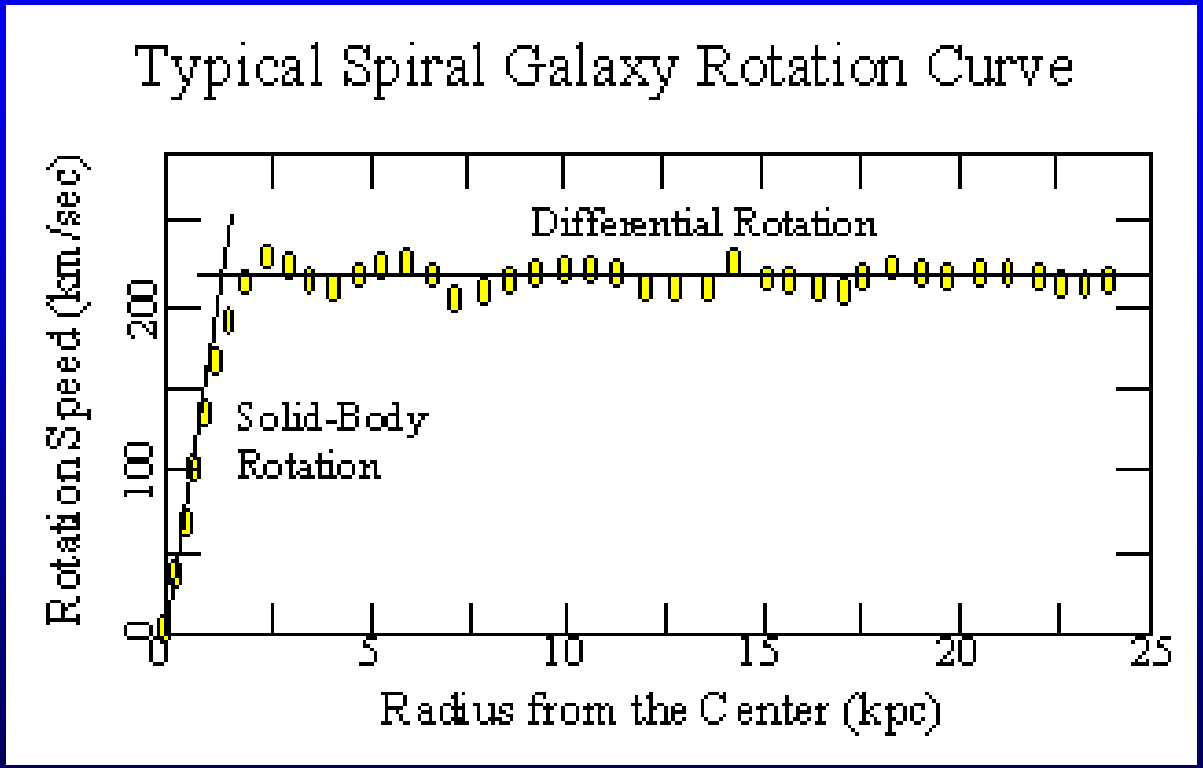
- The Galactic Rotation Curve
  - The speed at which stars in the outer part of the Galaxy rotate around its centre stays relatively constant - rather than falling off as would be expected if the matter distribution matches the distribution of stars, dust and gas.
  - It can only be explained if the galaxy lies in a massive halo of matter that we cannot detect except by its gravitational effects.
  - This is called the Dark Matter Halo.

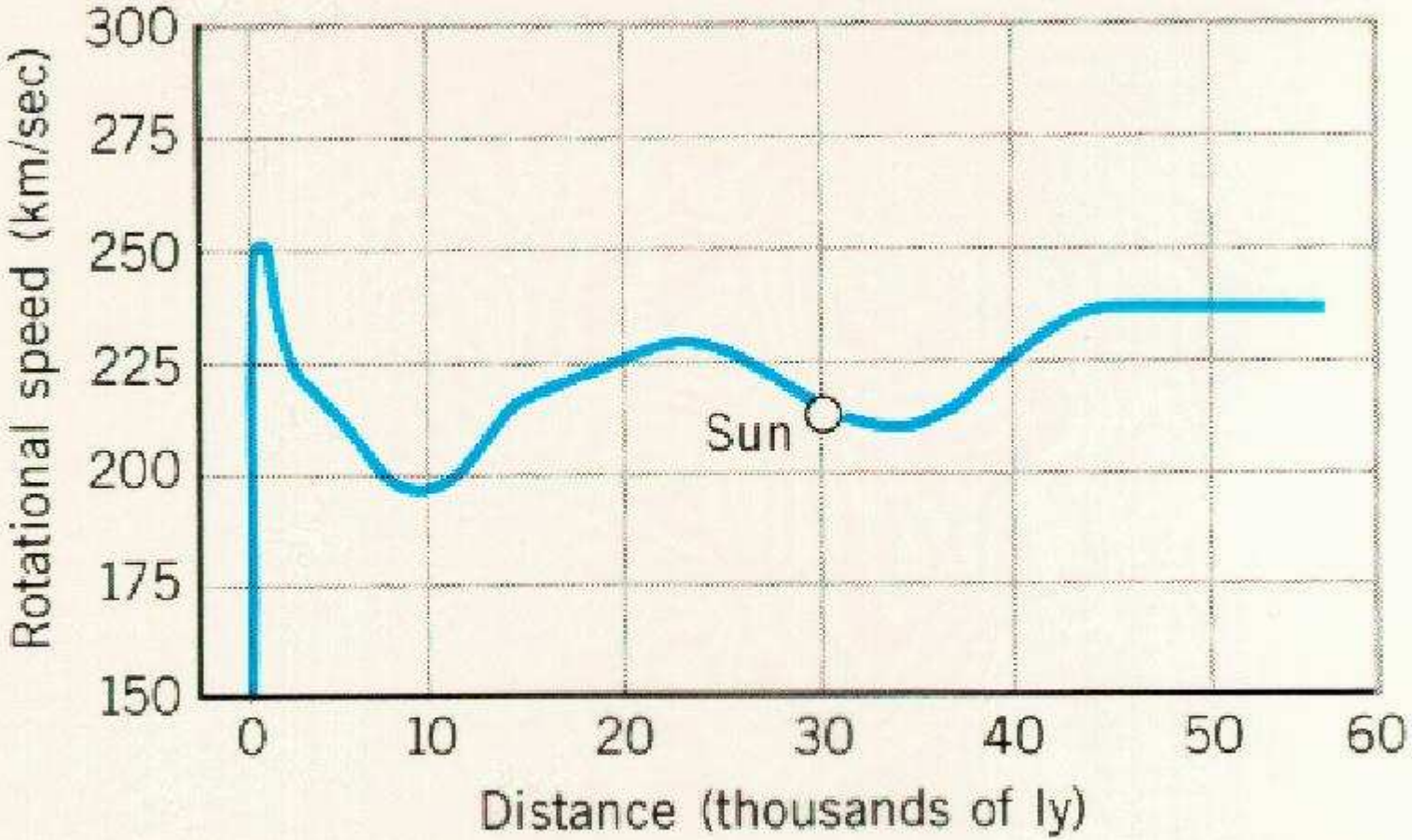


Typical rotation speed ~200 km/sec and visible disk size ~ 10 kpc
Halos extend ~10 times farther out


Rim
Hub
A
B
C
D
Wheel-like rotation
Orbital speed
Distance from center (hub)
Rotation curve for wheel-like rotation
Center
Planet-like rotation
Distance from center
Rotation curve for planet-like rotation


Data
150
100
50
0
0
5
10
15
V_c [km/s]
Radius [kpc]

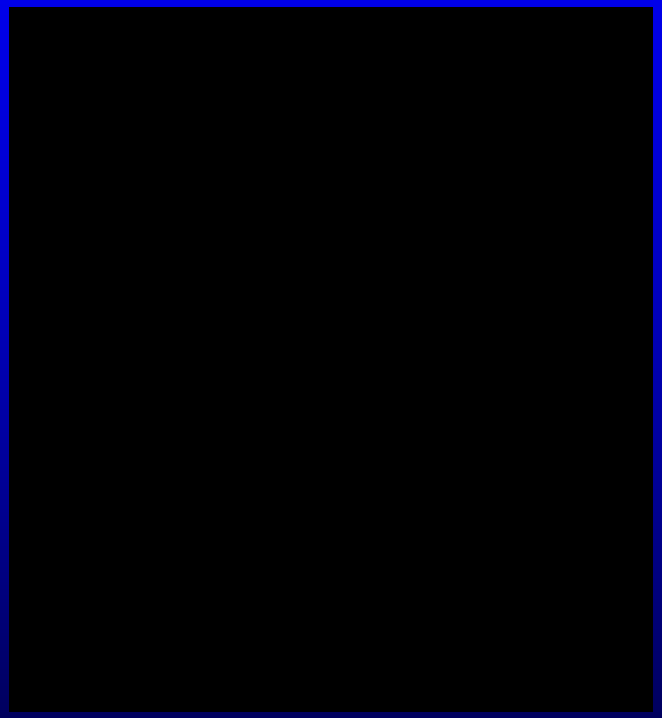

Typical Spiral Galaxy Rotation Curve
Rotation Speed (km/sec)
0
100
200
Differential Rotation
Solid-Body
Rotation
0
5
10
15
20
25
Radius from the Center (kpc)



Galactic rotation curve, based on carbon monoxide and hydrogen observations; the sun's speed is 220 km/s and its distance is 30,000 ly.

What is Dark Matter?

- As yet we do not know.
- Axions, WIMPs, Neutralinos and neutrinos are all candidates.
- Searches are actively taking place.



A high resolution image of Dark Matter