

# Galaxies and the Universe

Our Galaxy - The Milky Way  
The Interstellar Medium

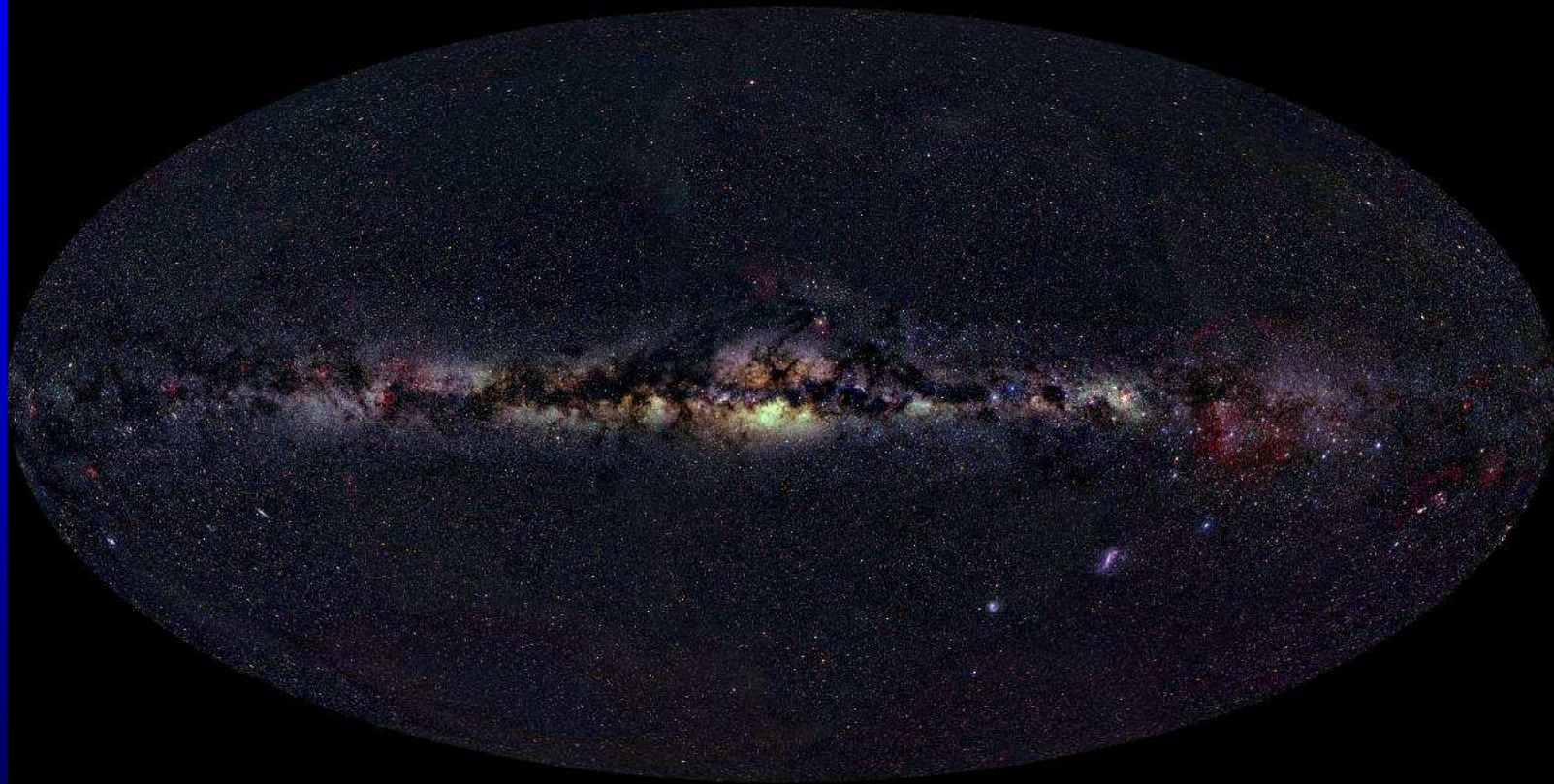




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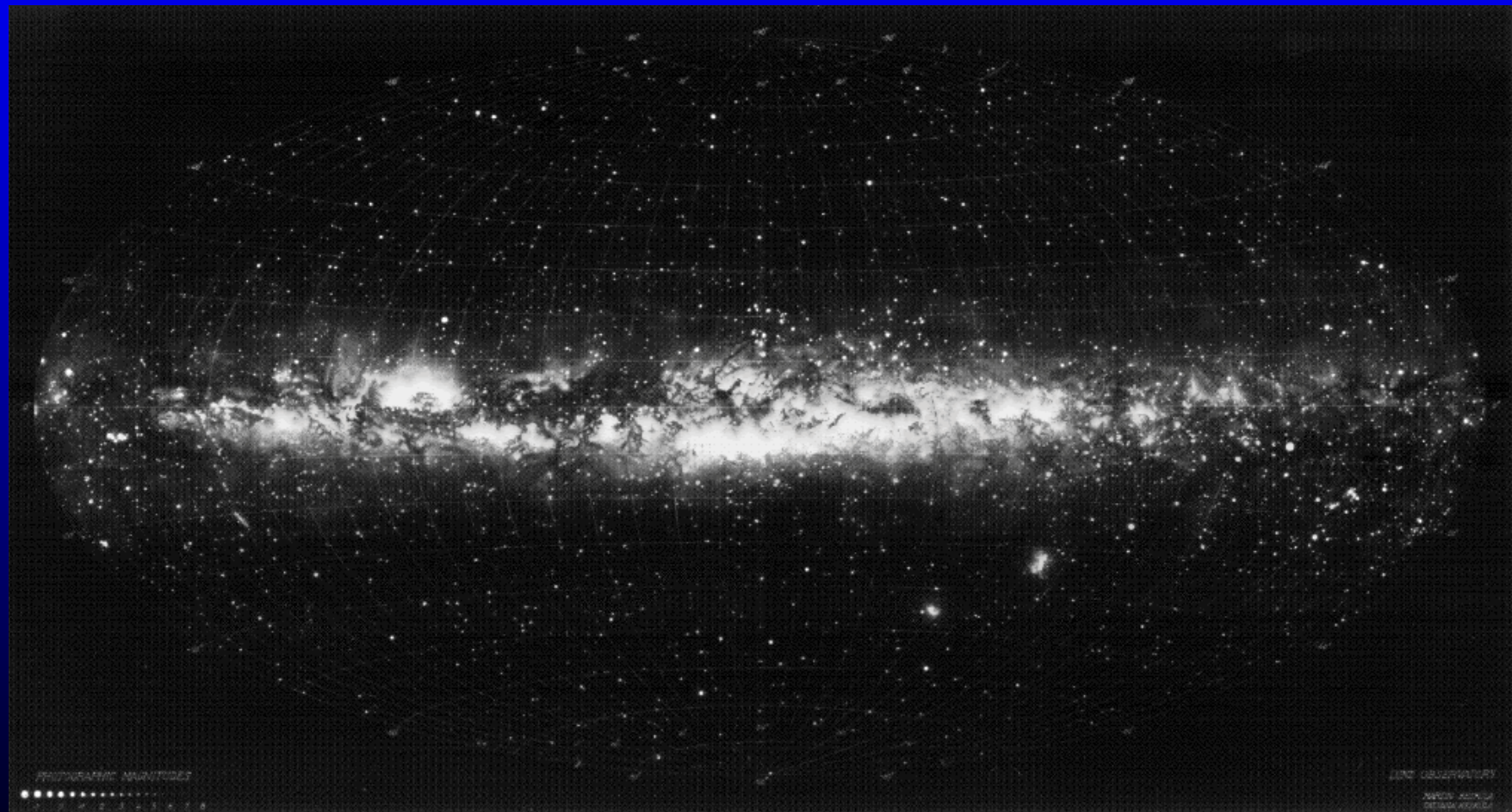
# *The Deep Sky*



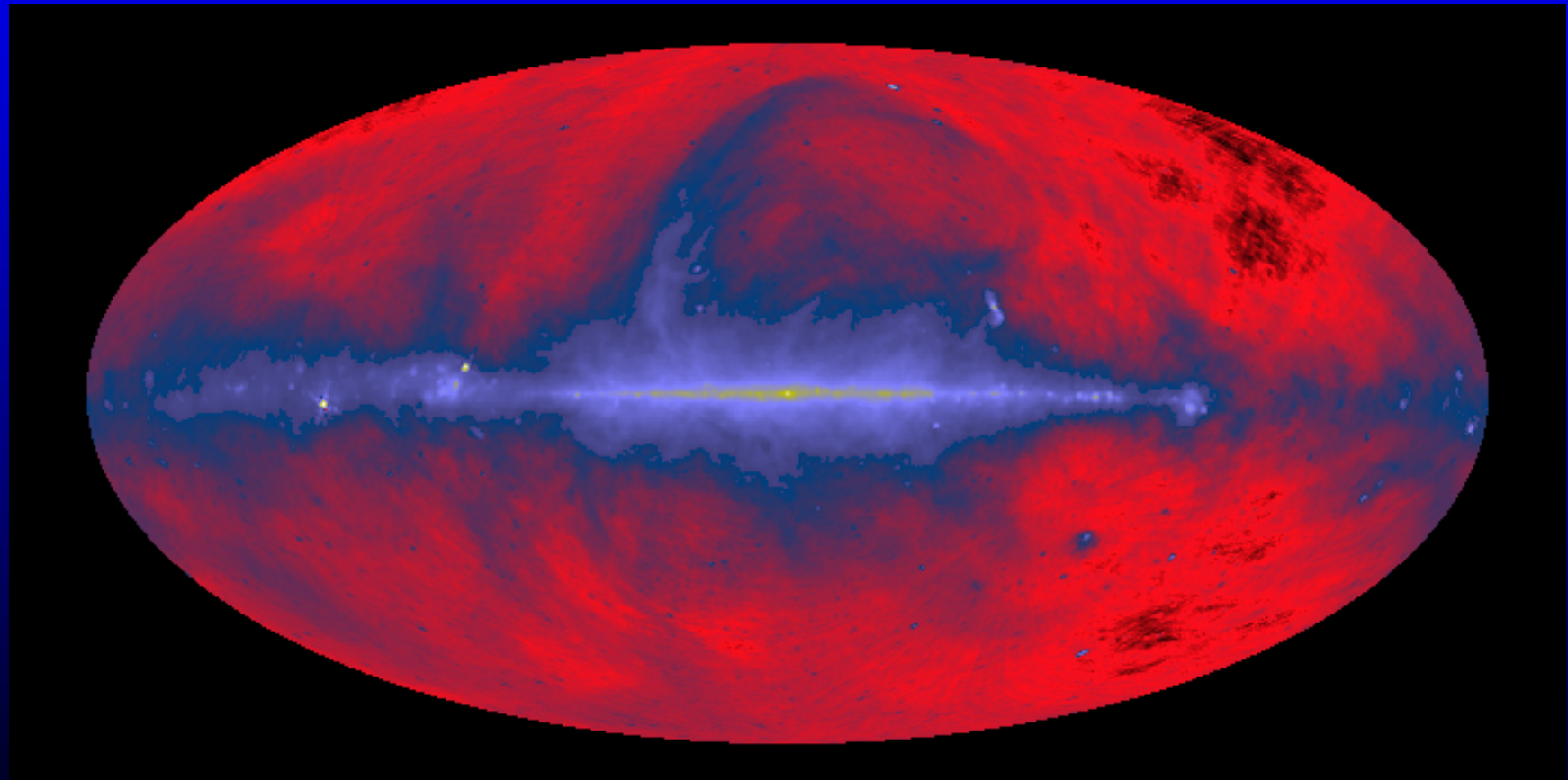
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# Our view of the Milky Way



# The Radio Sky



# COBE Image of our Galaxy



# The Milky Way Galaxy

## - The Galaxy

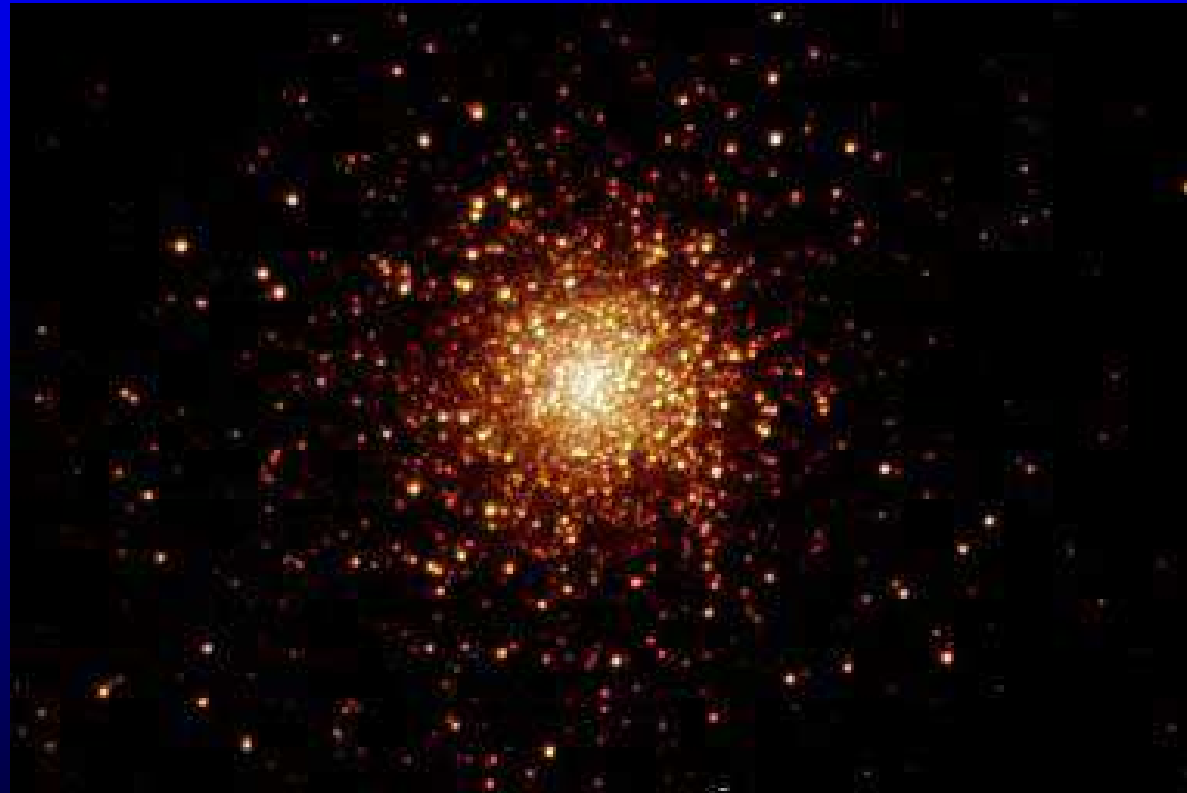
- By Visual Observation – a flat disc called the Galactic disc – mass  $\sim 10^{11} M_{\text{sun}}$ .
- From Far Infra-red and radio – a central Bulge mass  $10^{10} M_{\text{sun}}$ .
- This lies in the centre of a Halo composed of old main sequence stars, neutron stars, and, we believe, dark matter.



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  $\sim 8.5$  kpc or 27.3 thousand light years from the galactic Centre.

M13





M92

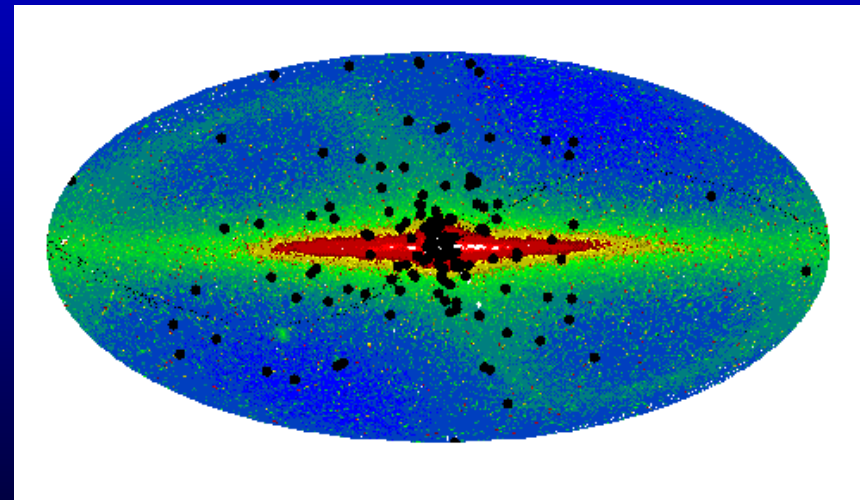
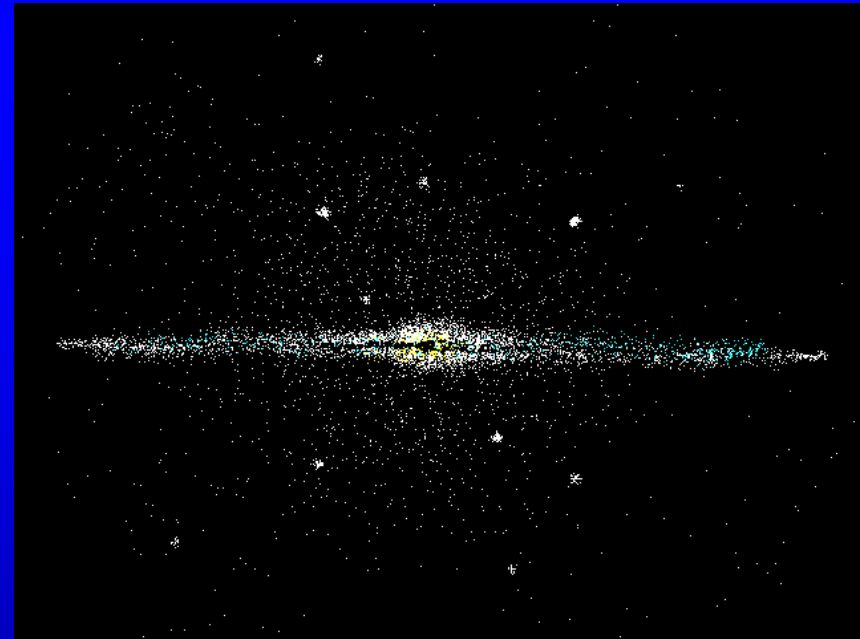
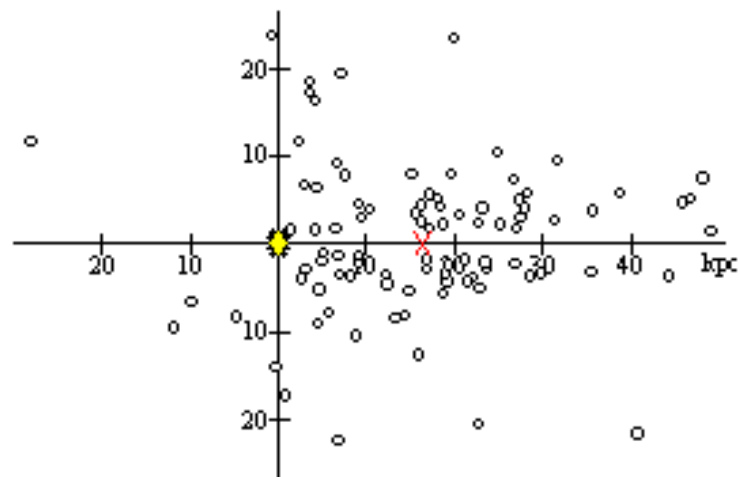


# Globular Cluster 47 Tucanae

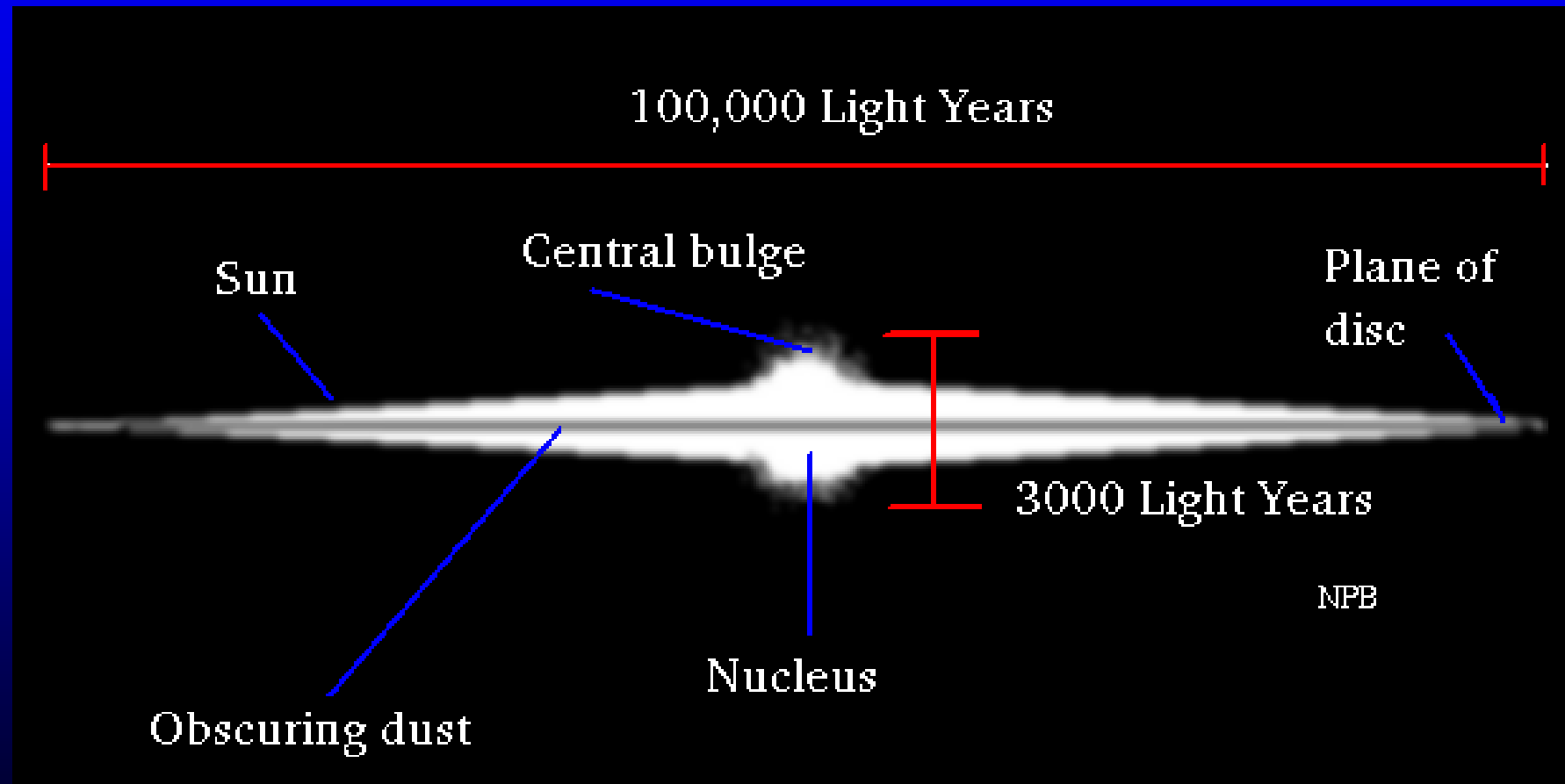


# Globular Clusters

Shapley's Globular Cluster Distribution



# Light takes 100,000 years to travel across the Galaxy

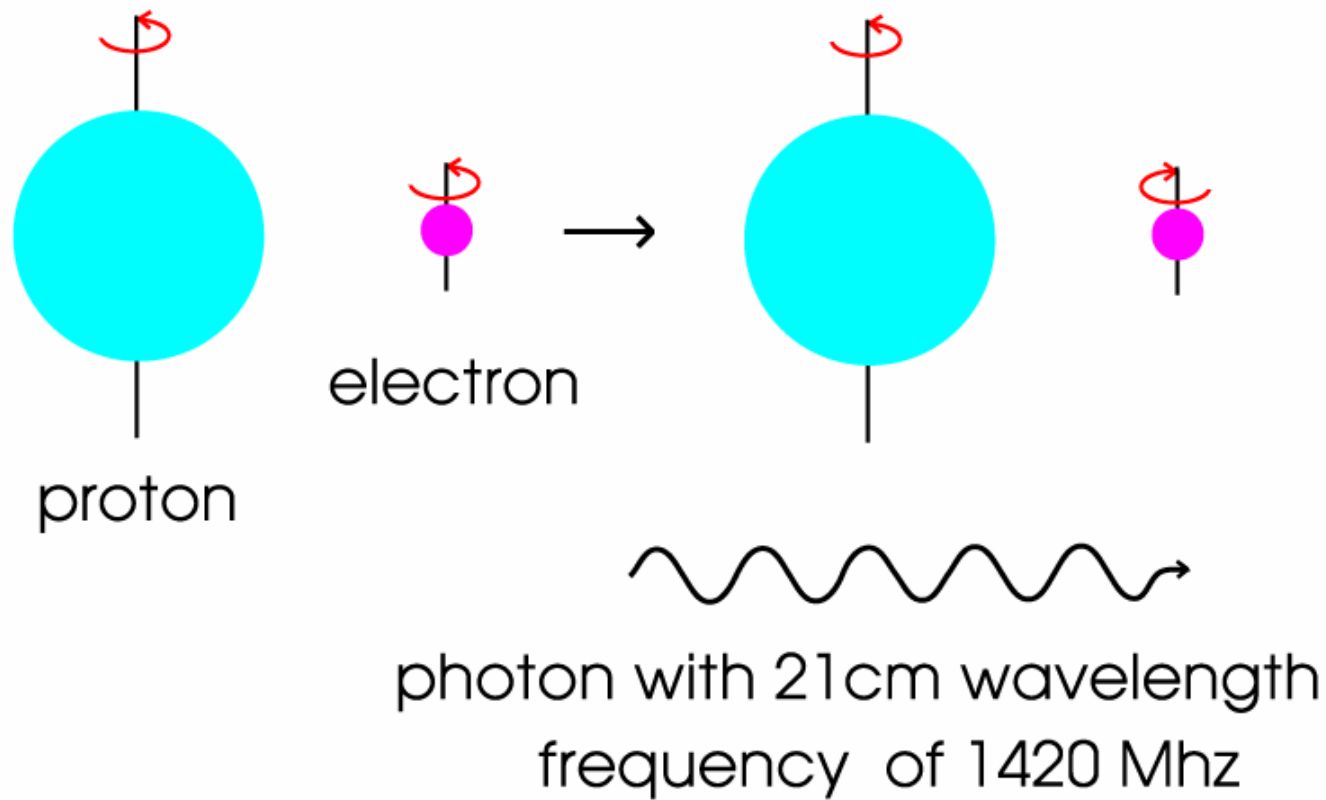




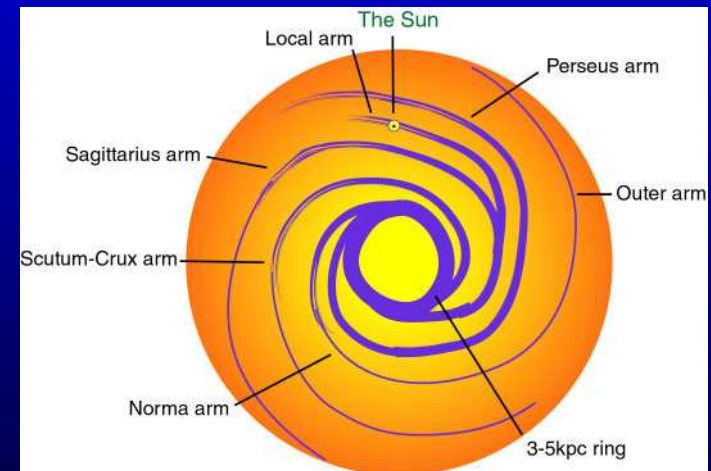
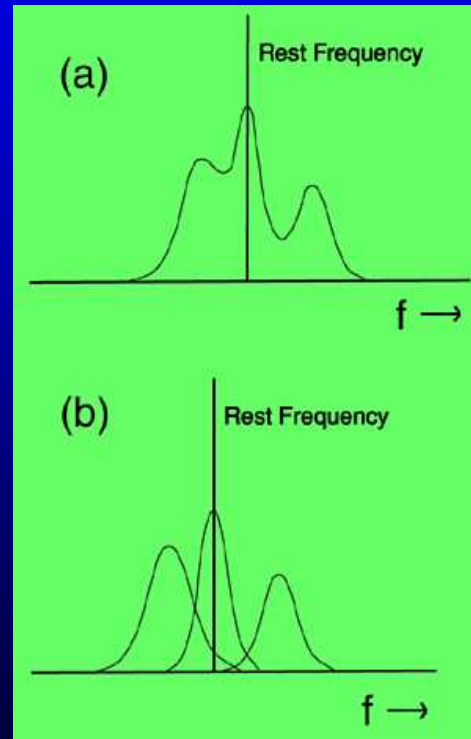
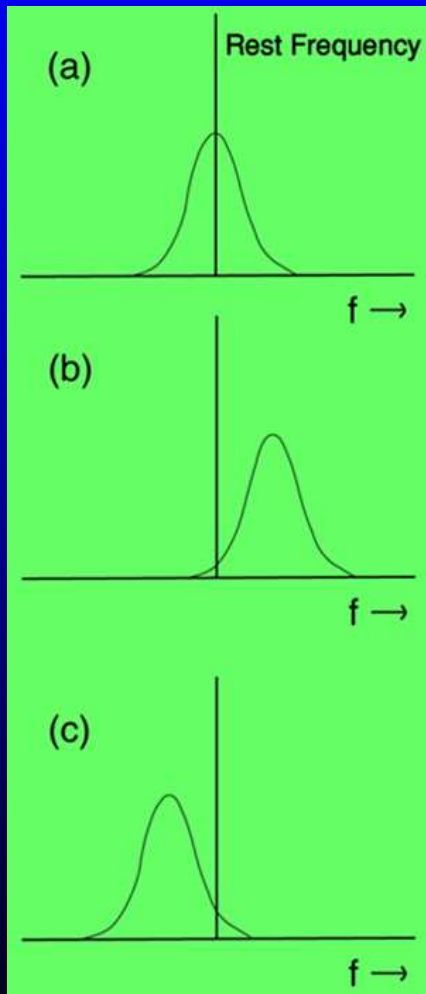
# The Spiral Structure of the Galaxy

- 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



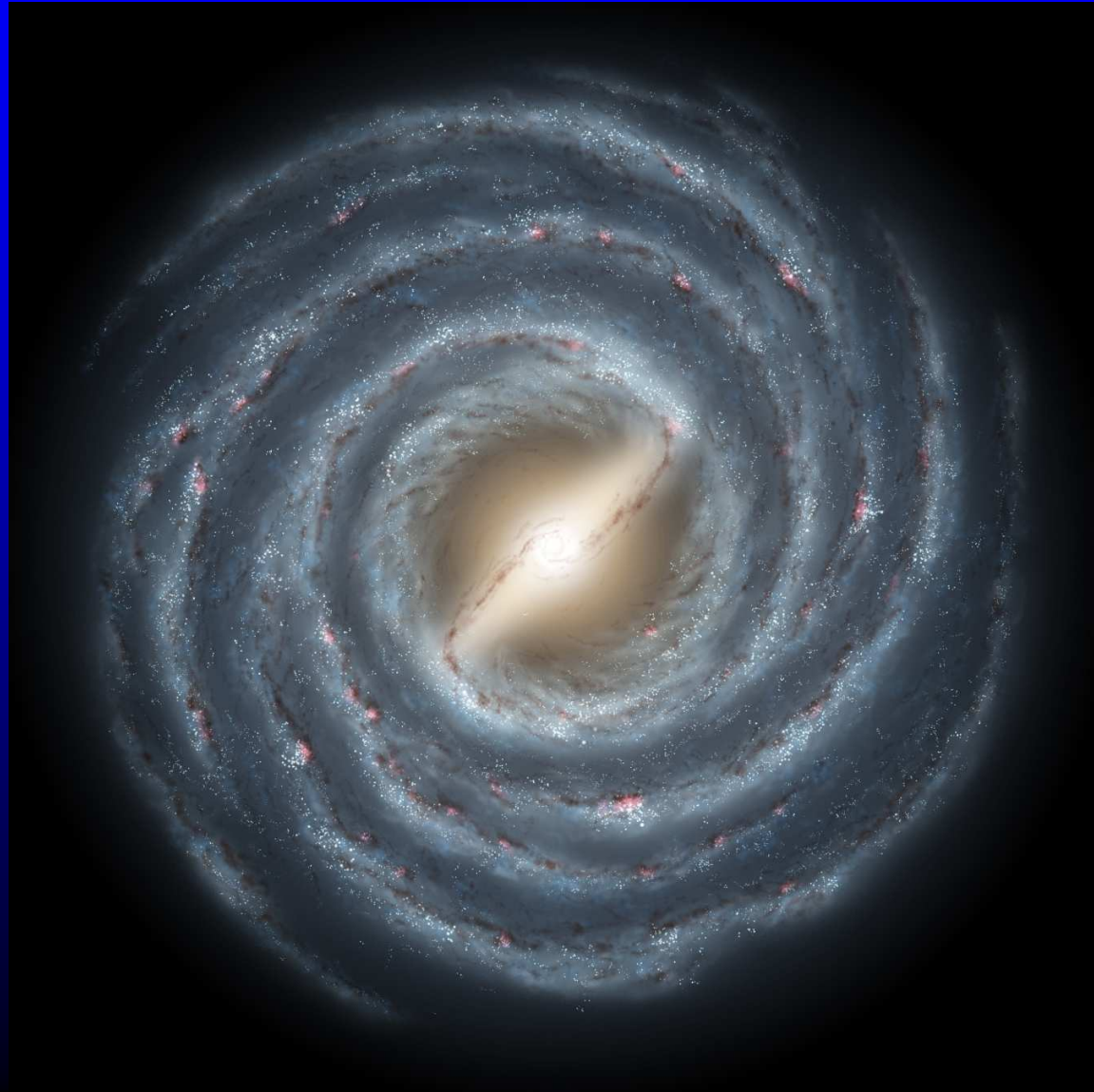
# Using the 21cm Hydrogen Line







# 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.
  - $Z = \text{Mass of elements heavier than Helium} / \text{Mass of all elements}$

# 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  $\sim$  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



## THE ORION NEBULA

This beautiful three-colour infrared image of the Orion Nebula and Trapezium Cluster was obtained on December 20<sup>th</sup> 1999 with the ISAAC near-infrared camera/spectrometer at the Nasmyth focus of the 8.2 m VLT telescope at the ESO Paranal Observatory.

Over the Hunter is perhaps the best known constellation in the sky. It contains one of the nearest and most active stellar nurseries in the Milky Way, where some of thousands of new stars have formed within just the past ten million years or so.

Just below Orion's belt, the belt of the sword holds a great jewel, the Orion Nebula. Within the arms of just a few light-years, there are about one thousand very young stars, only a million years old, the so-called Trapezium Cluster. It is very

hard to observe in visible light due to the bright nebula, the obscuring effects of dust, and the intrinsic redness of the young stars. At near-infrared wavelengths however these problems are nicely circumvented, allowing us to view stars

In addition to stars and brown dwarfs in the cluster, powerful outflows and winds from the most massive stars are evident, as well as the presence of jets studied by these stars, and more finely focused jets of gas flowing from the smaller stars.

Images like these and the follow-up studies will help to solve some of the fascinating and perplexing questions about the birth and early lives of stars and their planetary systems.

### Technical information

The image is a near-infrared mosaic (2 x 3 grid) of ISAAC pointings. In each pointing, three images were taken through each of the  $J_1$ ,  $H$  and  $K_1$  filters (1.25 microns, 1.65 microns and 2.1 microns) with a total exposure time of 170 seconds in total. The pointing size between  $J_1$  and  $K_1$  is 20 arcsec, during the observations, in total. In individual ISAAC images were needed to cover the mosaic. The final field of view spans approximately 7.7 arcmin, covering roughly 2 x 1 light years (i.e. a 2.4 pc) at the distance of the nebula (around 1,500 light years). The field of view is at the top and end of the belt. The data were obtained by Mark McCaughy of the Astrophysics and Space Science Department as part of a broader study of the young stars in the region.

More information about ESO can be found at URL: <http://www.eso.org>













# 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

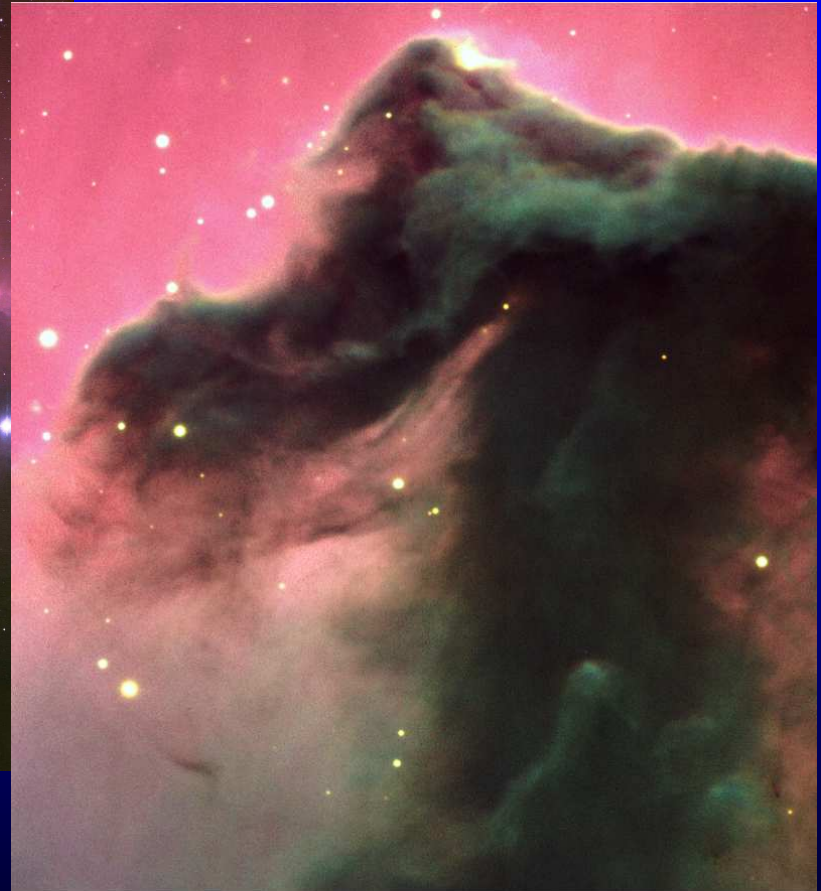
- Dust – comprises Carbon, Silicon and Iron etc produced in stars.
- Tiny lumps of solid compounds of C, O, Si and other “metals”.
  - Major part composed of graphite or silicon compounds, often coated with a coating of more volatile compounds such as water ice, ammonia and carbon monoxide.
  - Total mass  $\sim 0.1\%$  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

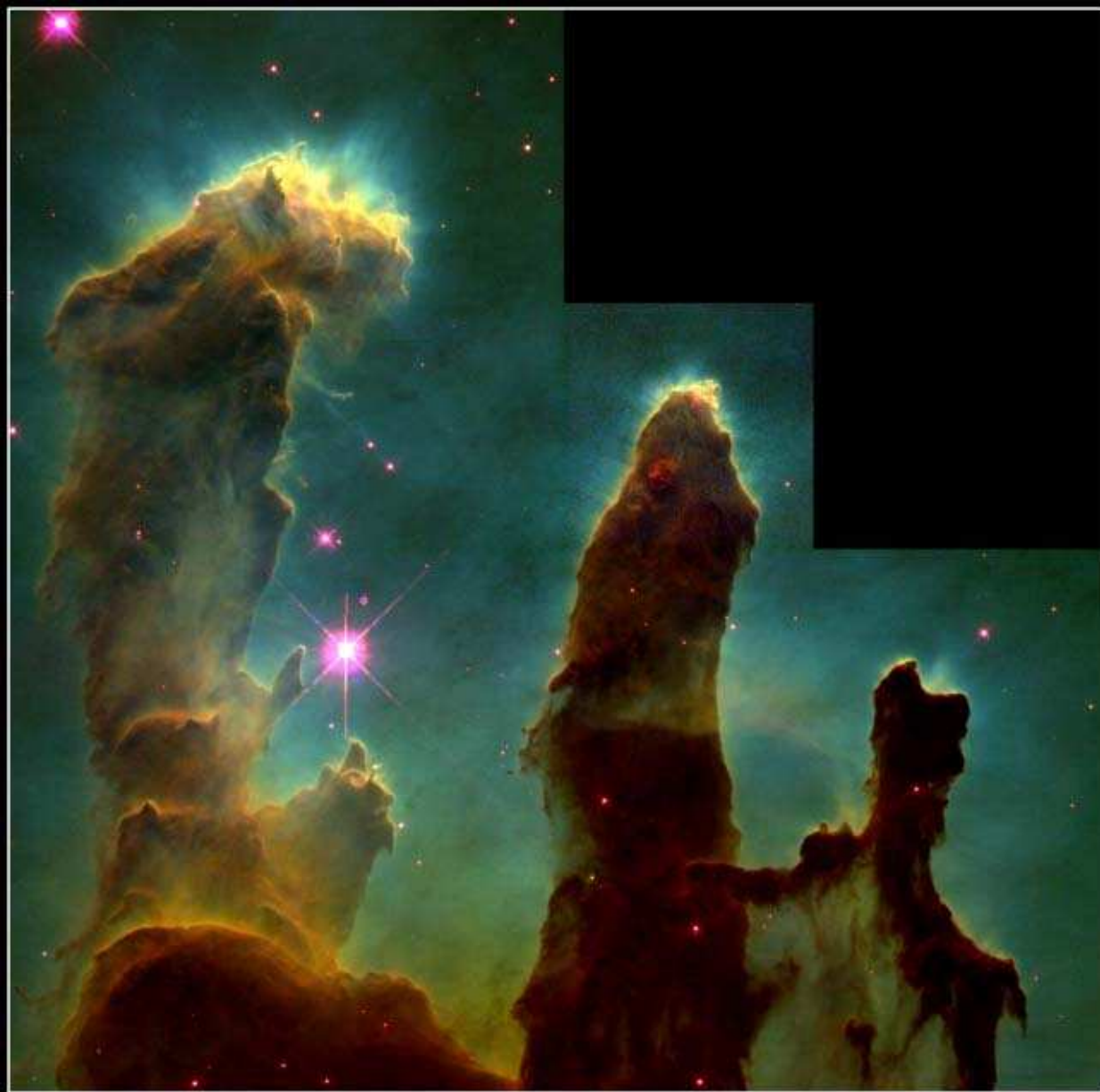


The Horsehead Nebula (detail)  
(VLT KUEYEN + FORS 2)









**Gaseous Pillars · M16**

**HST · WFPC2**

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

# Coal Sack



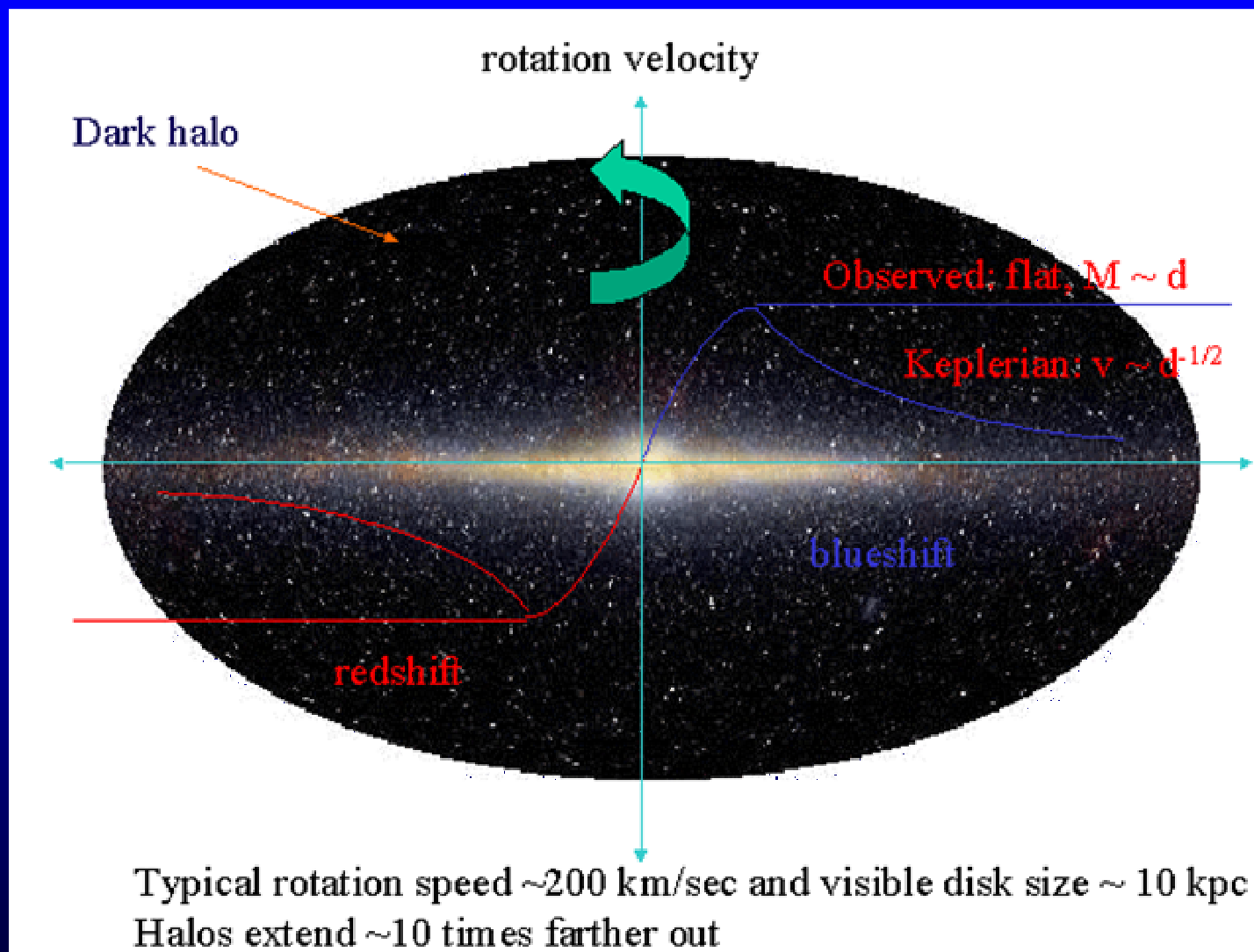


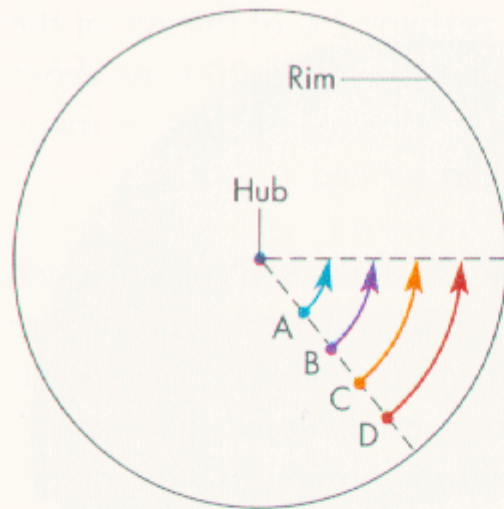
# Dark Matter

- 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  $\sim 10$  times that of the stars in the Galaxy.

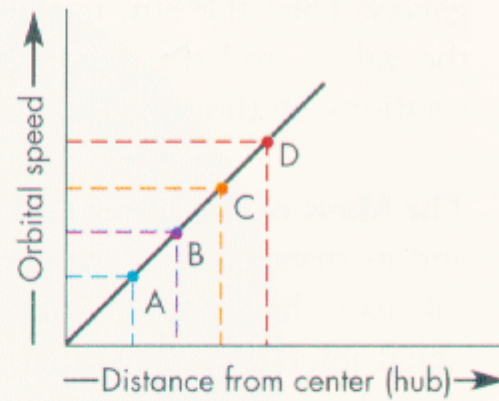
# Evidence for Dark Matter

- 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.

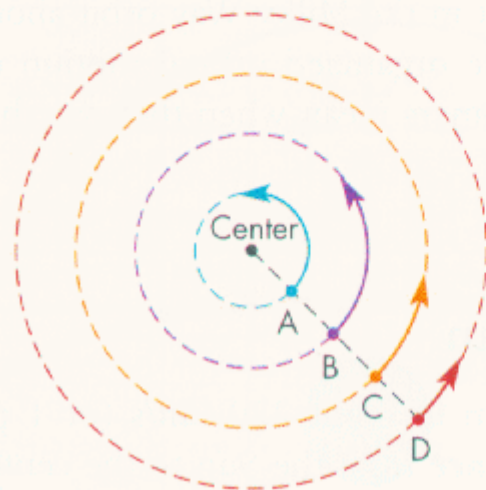




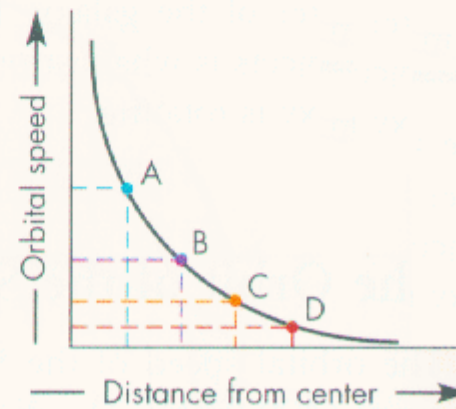
**Wheel-like rotation**



**Rotation curve for wheel-like rotation**

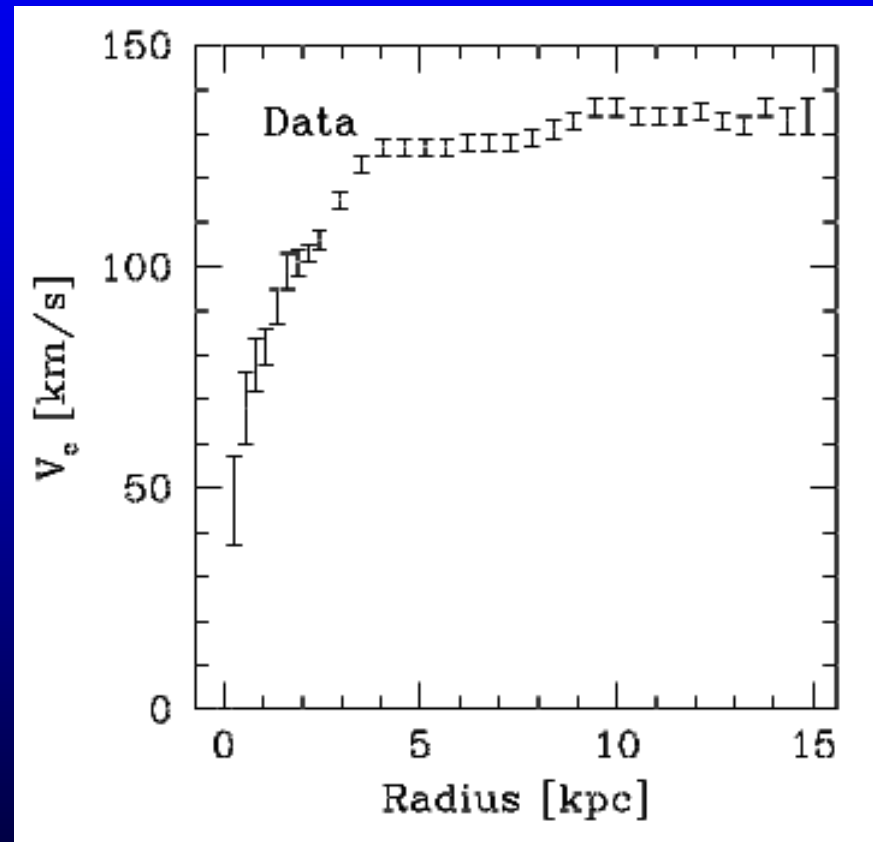
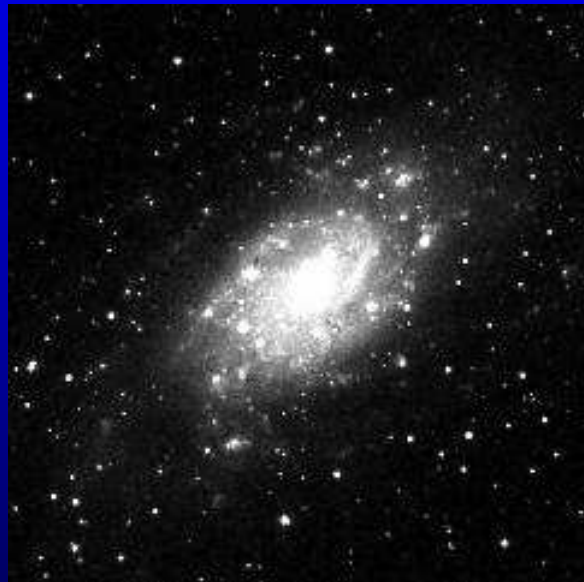


**Planet-like rotation**

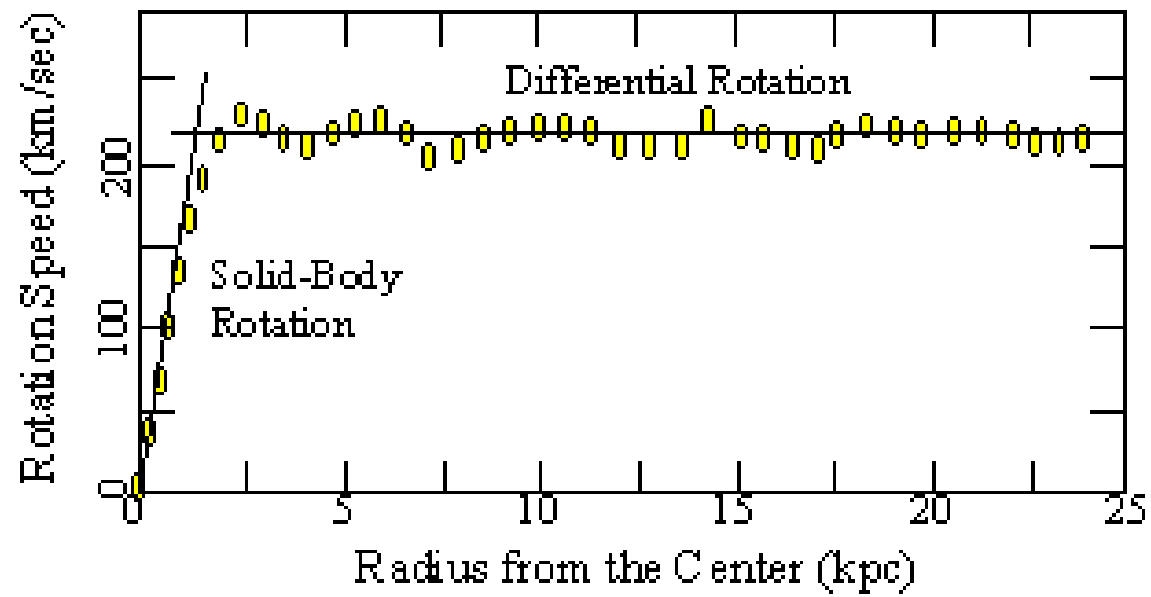


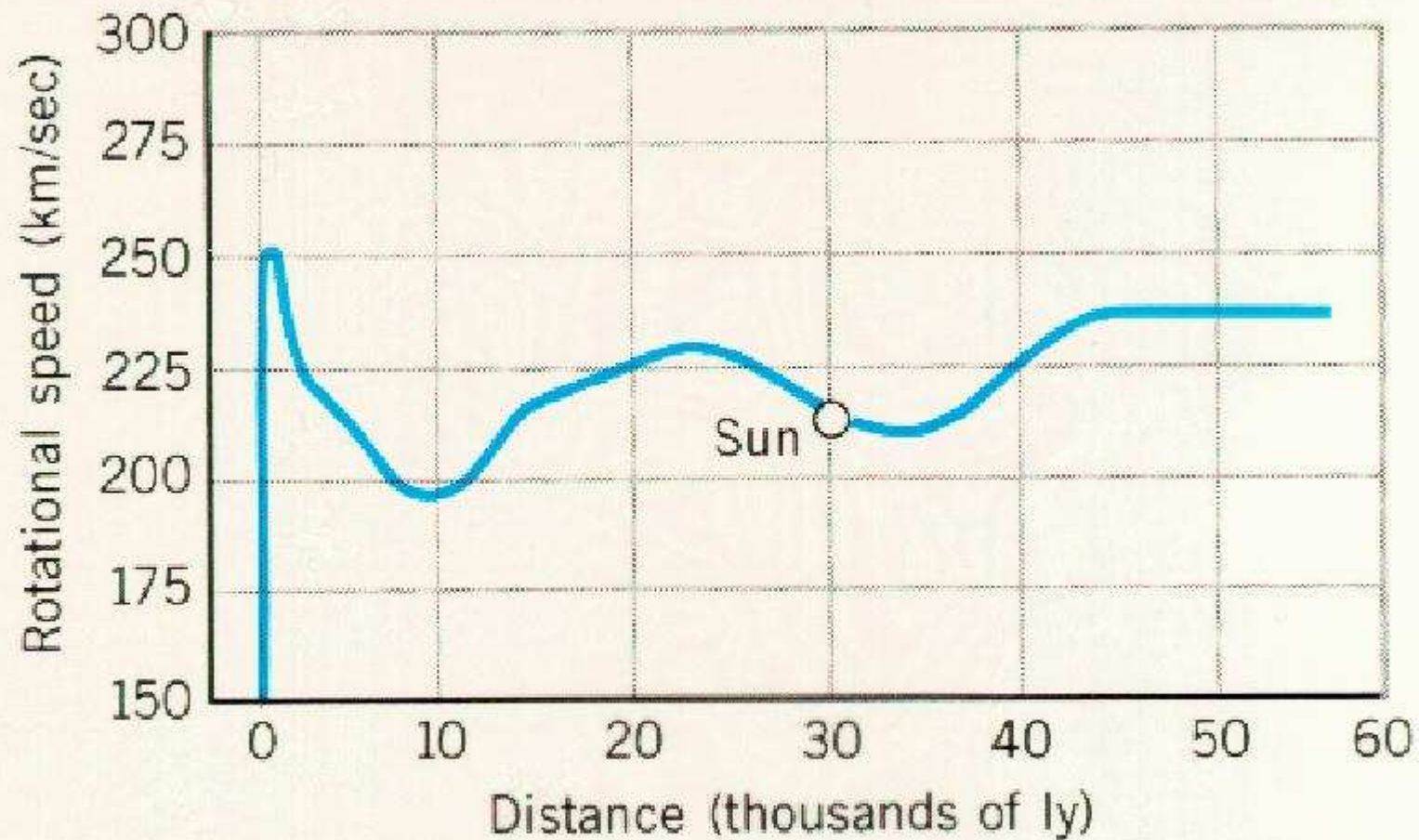
**Rotation curve for planet-like rotation**





## Typical Spiral Galaxy Rotation Curve

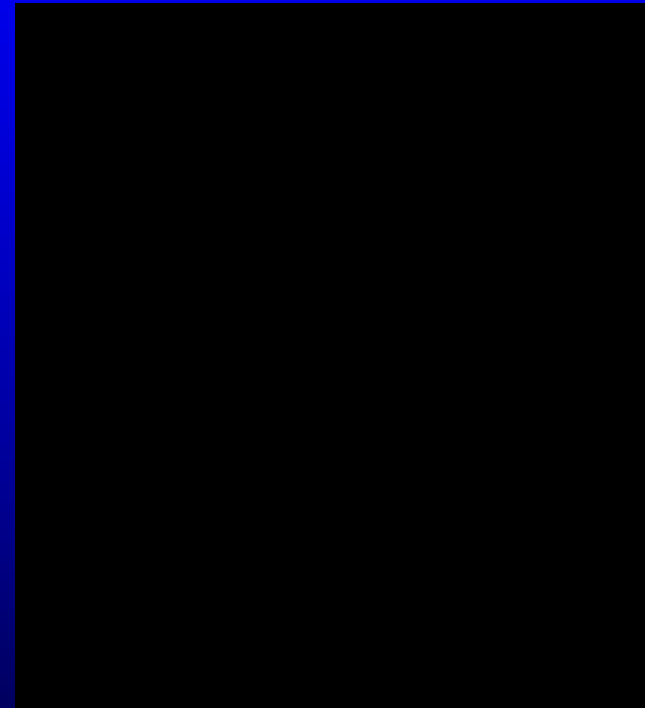




**Galactic rotation curve, based on carbon monoxide and hydrogen observations; the sun's speed is 220 km/s and its distance is 30,000 ly.**

# 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