
The Milky Way

If we could observe the Milky Way from a great distance, it might look a bit like this (edge-on and face-on).

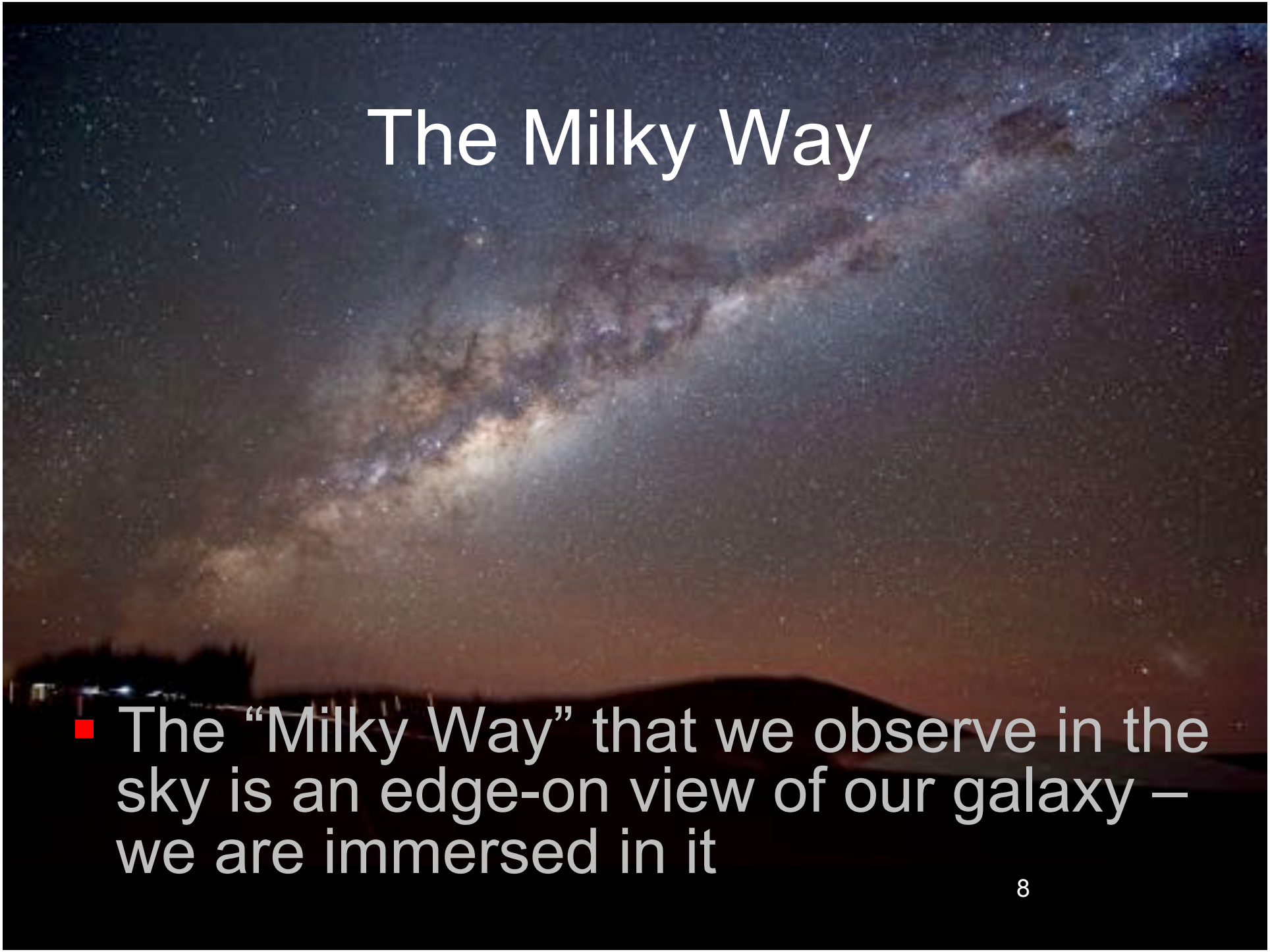
The Milky Way

- the Milky Way is a galaxy
- the sun is one of 10-100 billion stars in the Milky Way
- 10^{12} solar masses, mostly "dark matter"
- bright part about 30,000 pc = 100,000 light years across
- the sun is located 8,000 pc = 24,000 light years from the centre

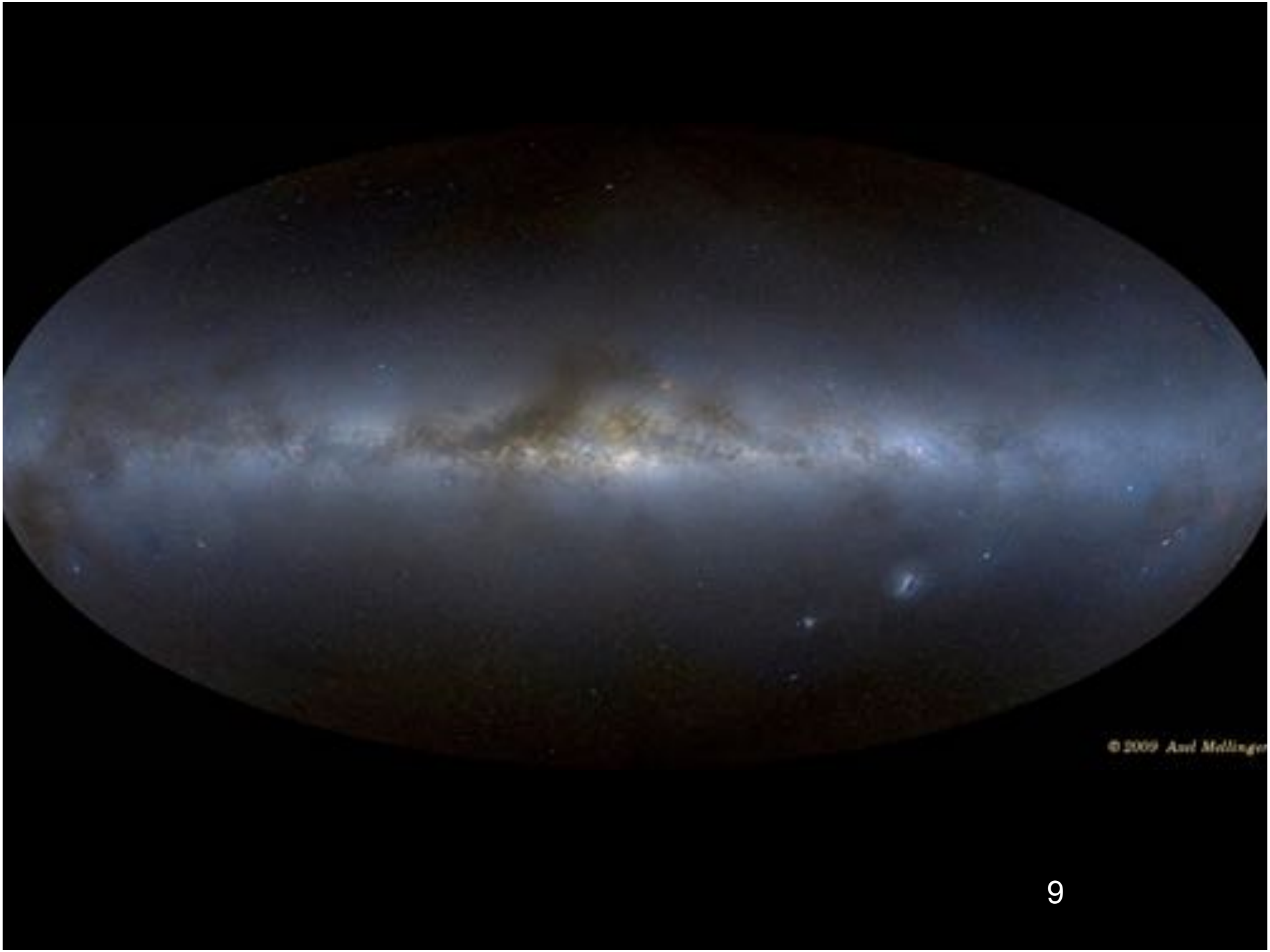
Galaxies Similar to the Milky Way

"Andromeda"

The Milky Way



- The “Milky Way” that we observe in the sky is an edge-on view of our galaxy – we are immersed in it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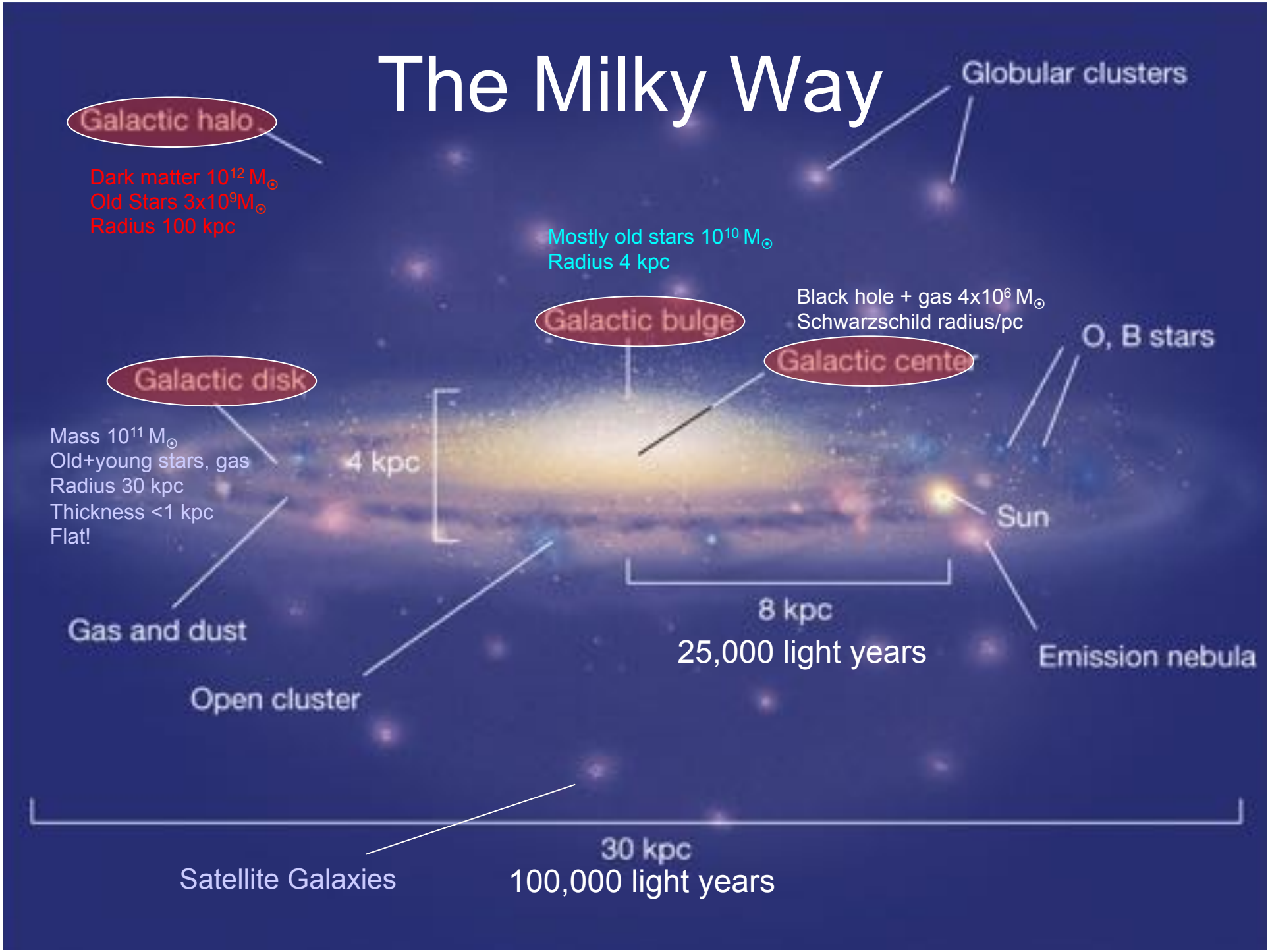
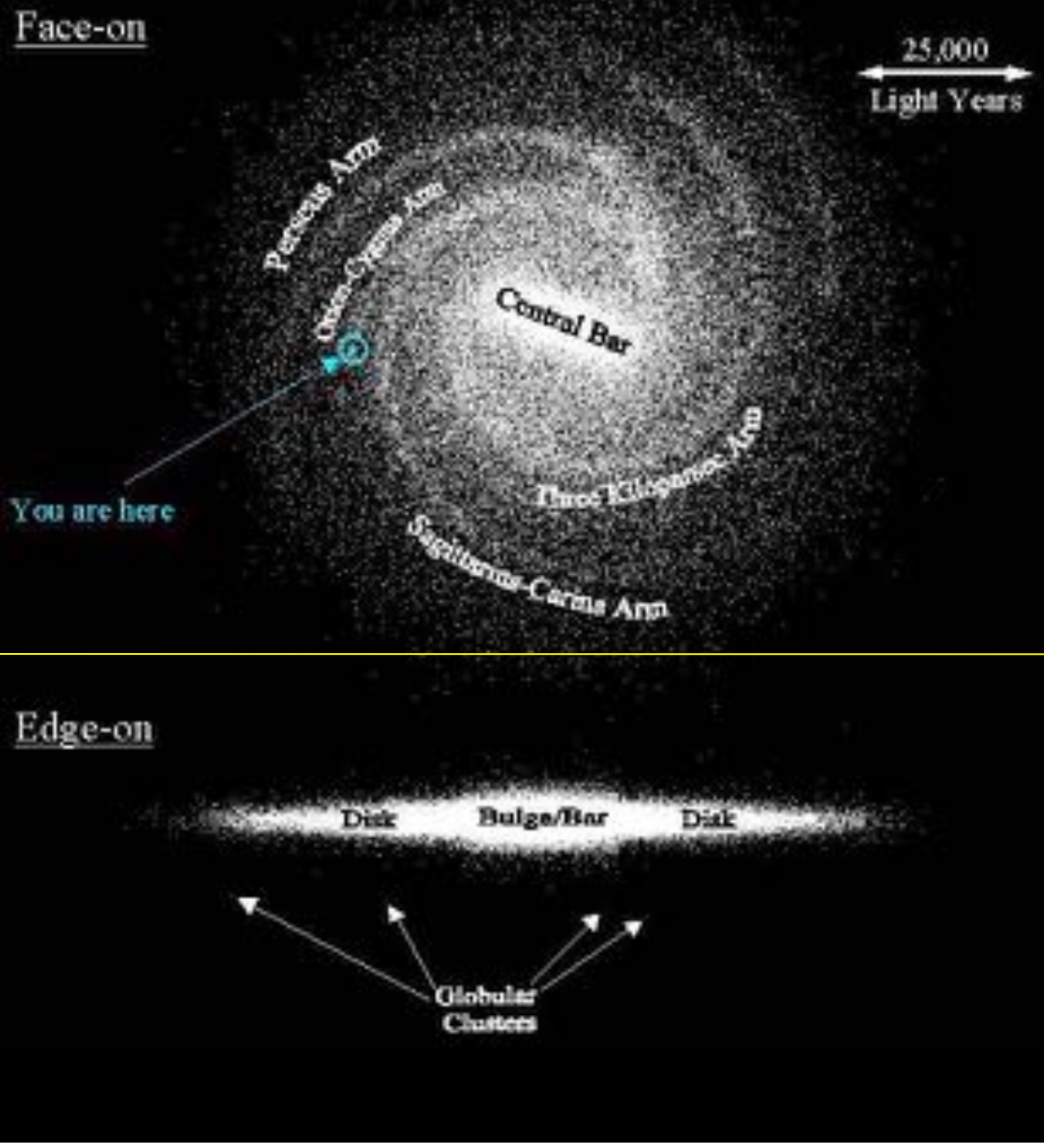
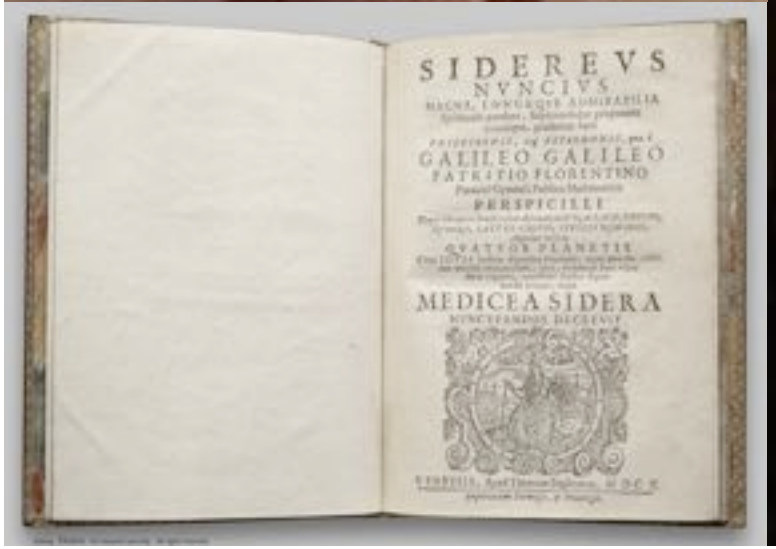

The Milky Way
Globular clusters
Galactic halo
Dark matter 10^{12} $M_\odot$
Old Stars $3x10^9 M_\odot$
Radius 100 kpc
Mostly old stars 10^{10} $M_\odot$
Radius 4 kpc
Black hole + gas $4x10^6$ $M_\odot$
Schwarzschild radius/pc
Galactic bulge
Galactic center
O, B stars
Galactic disk
Mass 10^{11} $M_\odot$
Old+young stars, gas
Radius 30 kpc
Thickness <1 kpc
Flat!
4 kpc
Sun
8 kpc
25,000 light years
Gas and dust
Emission nebula
Open cluster
30 kpc
100,000 light years
Satellite Galaxies

The Milky Way Galaxy



Historical Introduction to the Milky Way



- Galileo 1609
  - Milky Way is a blur of unresolved stars
  - telescopic confirmation of Democritus (460-370BC)

Nature of Milky Way from Star Counts

- William Herschel c. 1800, Kapteyn c.1900
  - Star counts show MW to be roughly centred on sun (wrong!)

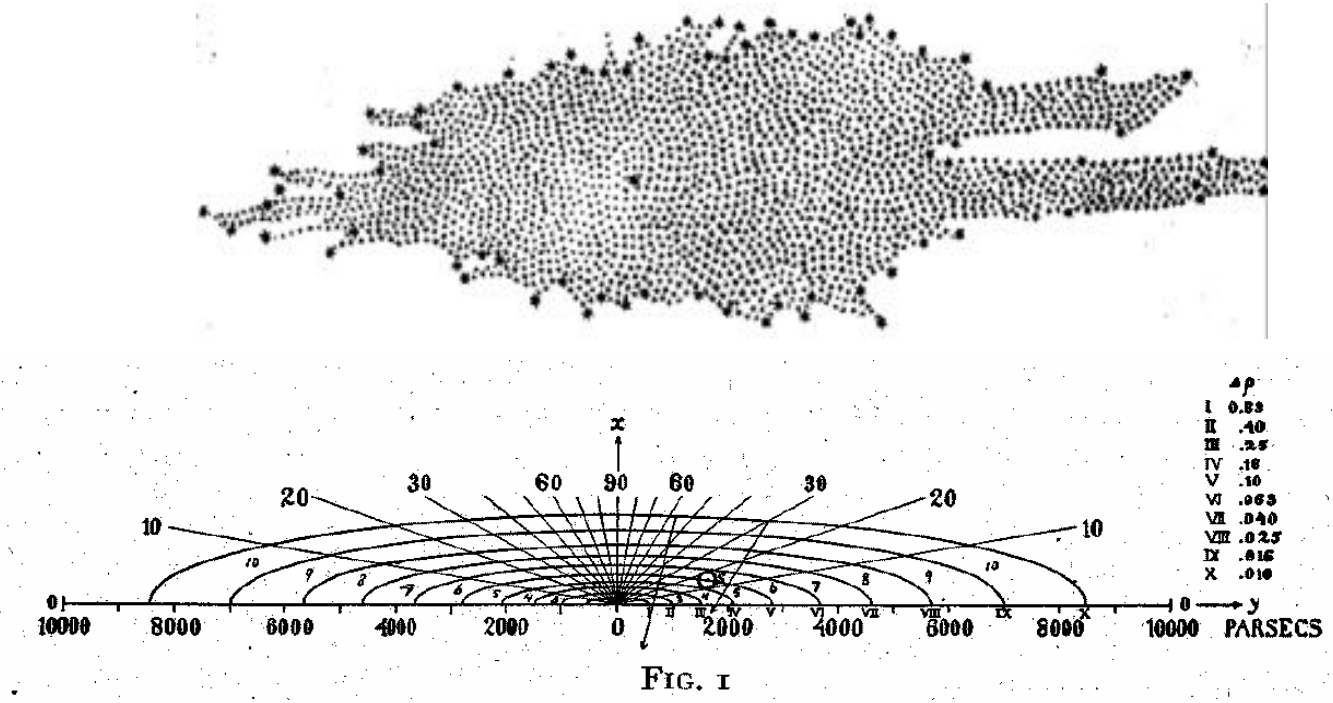
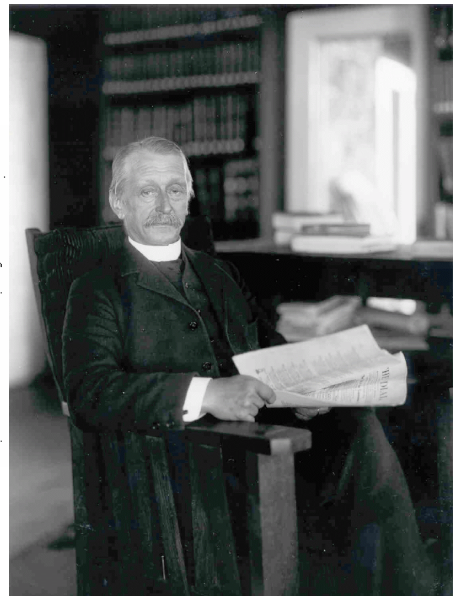


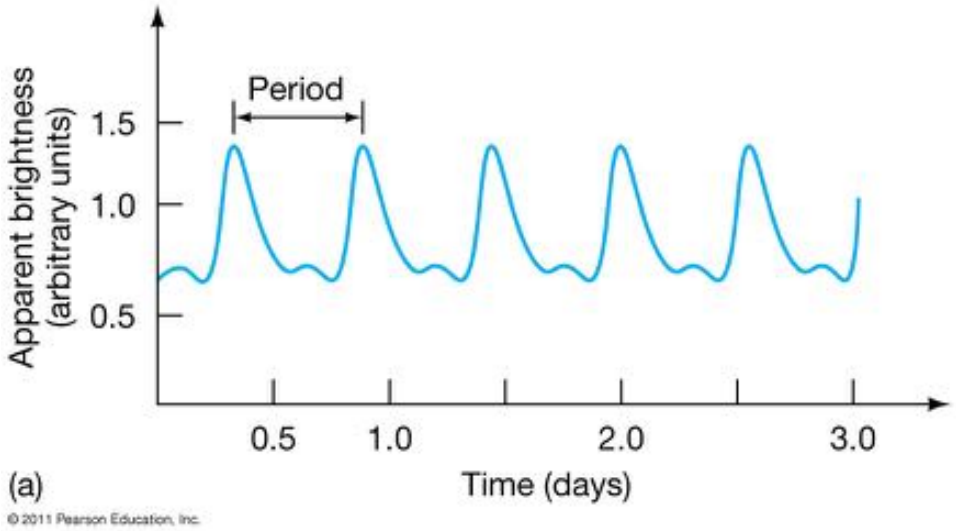
FIG. 1



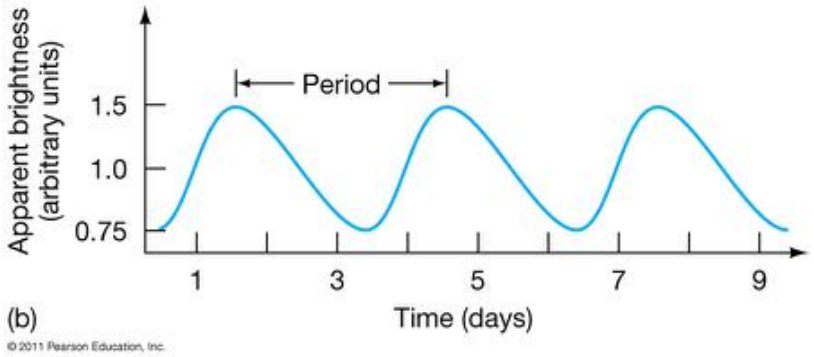
Kapteyn, c. 1900

Quick Aside: Pulsating Variables

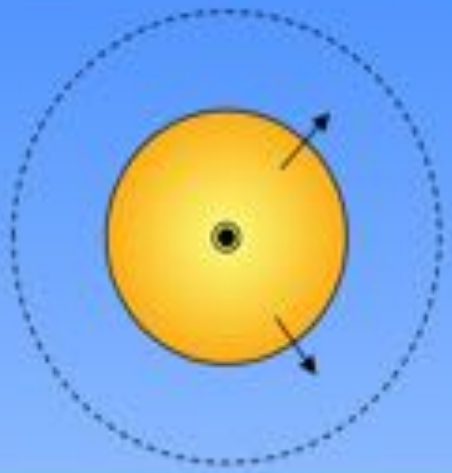
RR Lyrae star - periods from 0.5 to 1 day.

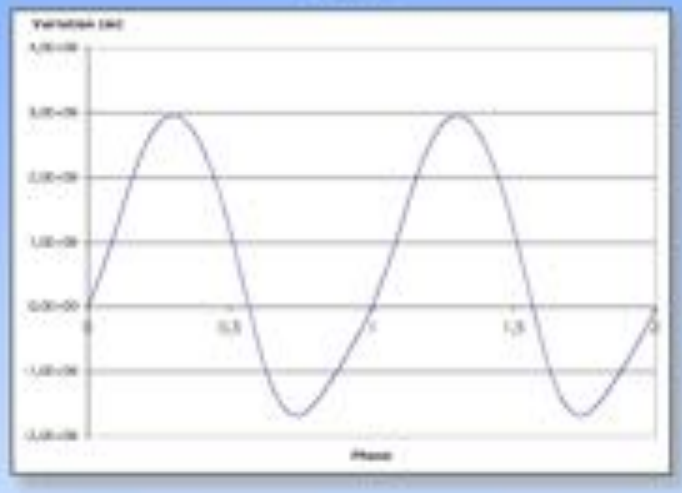


Cepheid variable - periods range from about 1 to 100 days.



- Vélocimétrie radiale

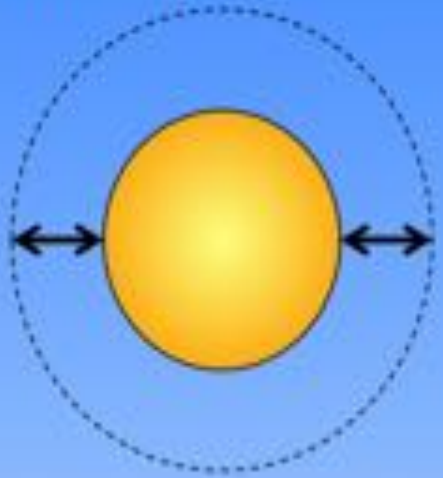


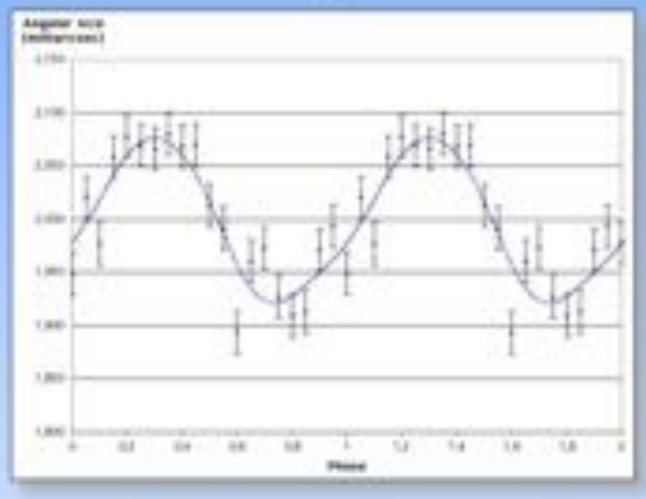


Perpendiculairement au plan du ciel

Distance

- Interférométrie

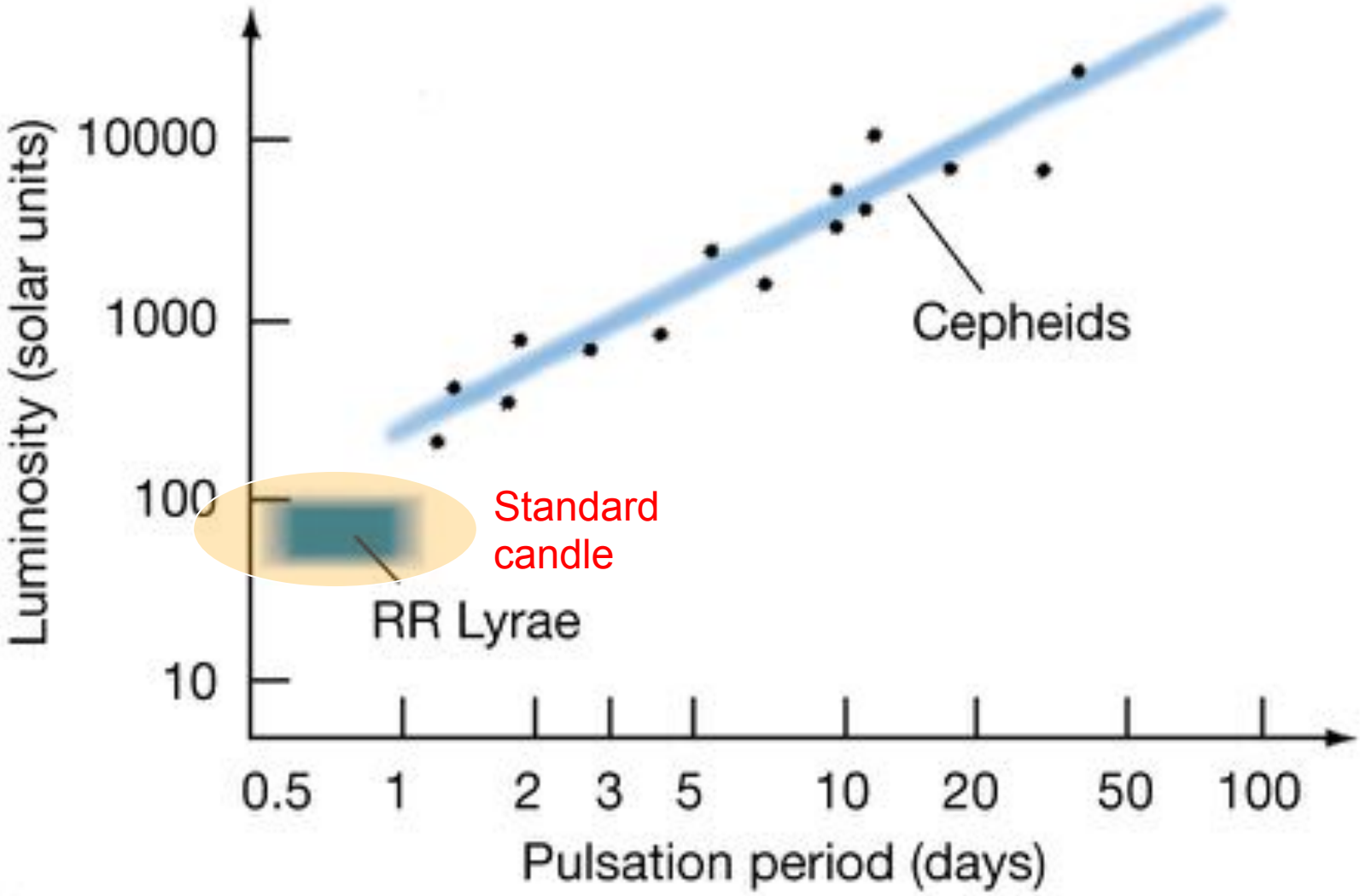




Dans le plan du ciel

http://www.obspm.fr/actual/nouvelle/dec01/kervella.en.shtml

Pulsating Variables



Quick aside: Globular Clusters

Millions of stars!
Outer regions of galaxies
Milky Way has around 150
Lots of pulsating RR Lyrae stars

Harlow Shapley 1918

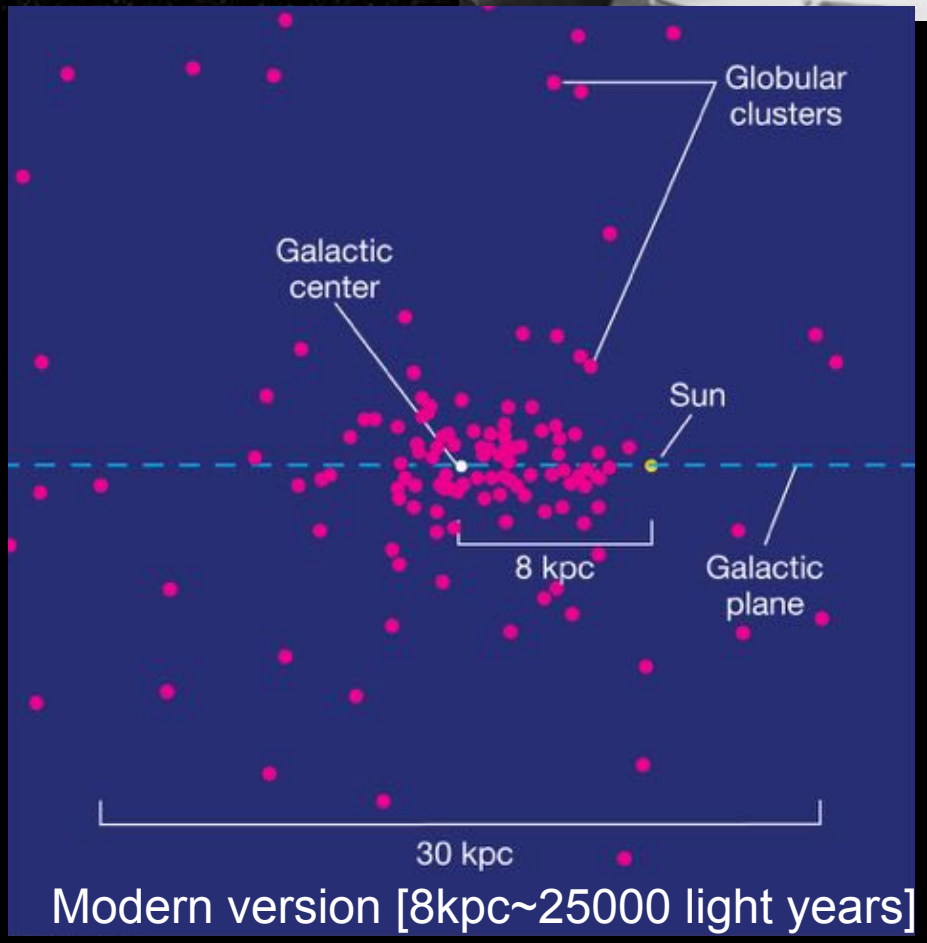
- Distances of pulsating variables (RR Lyrae stars) in globular clusters

Modern version [8 kpc ~ 25000 light years]

Harlow Shapley 1918

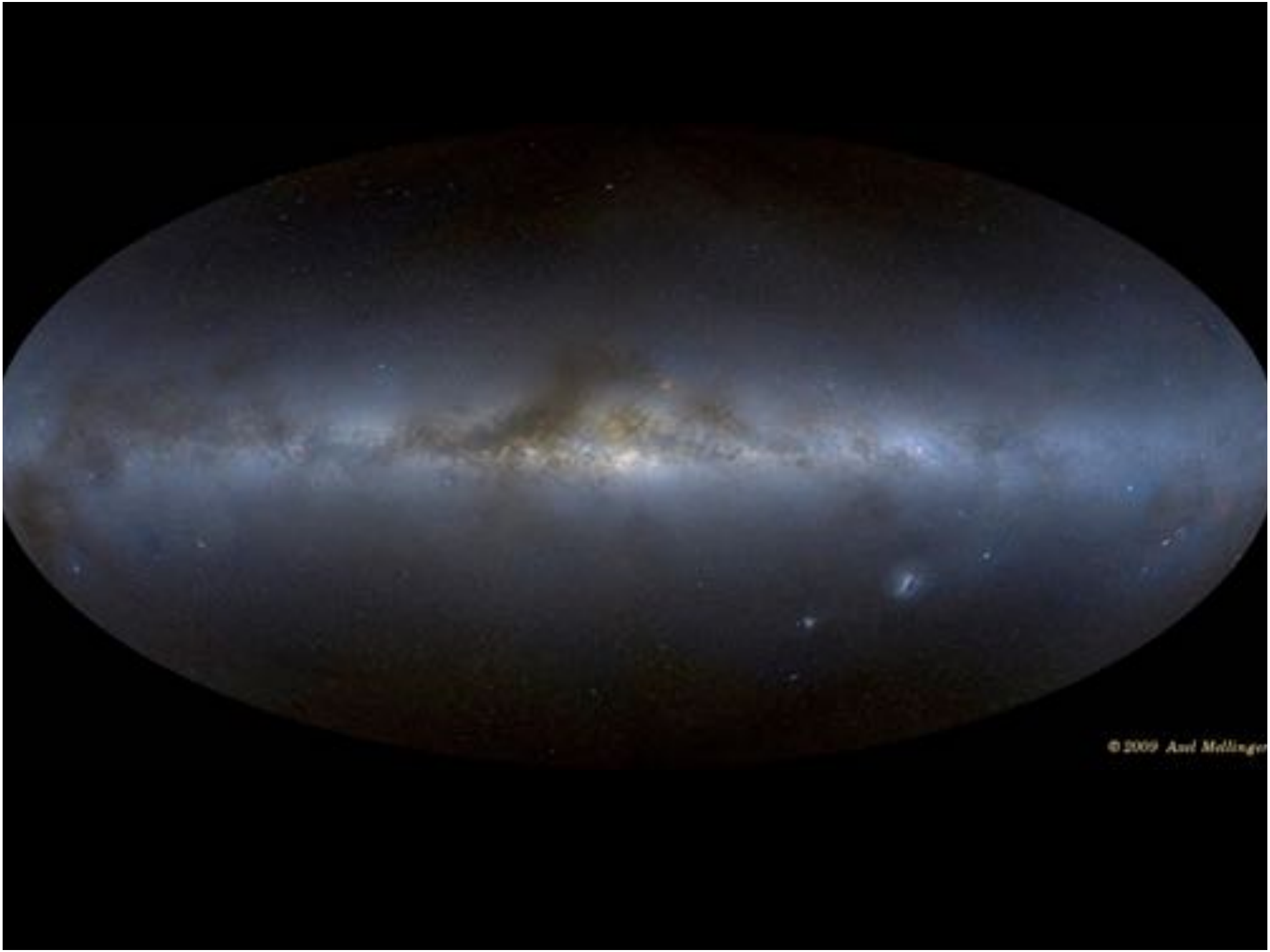
- Distances of pulsating variables (RR Lyrae stars) in globular clusters
- Globular clusters define a roughly circular system centred 8kpc [modern] from sun
- Sun is not at centre of Milky Way

- Final death of geocentricism!



Modern version [8kpc~25000 light years]

Dust – Trumpler 1930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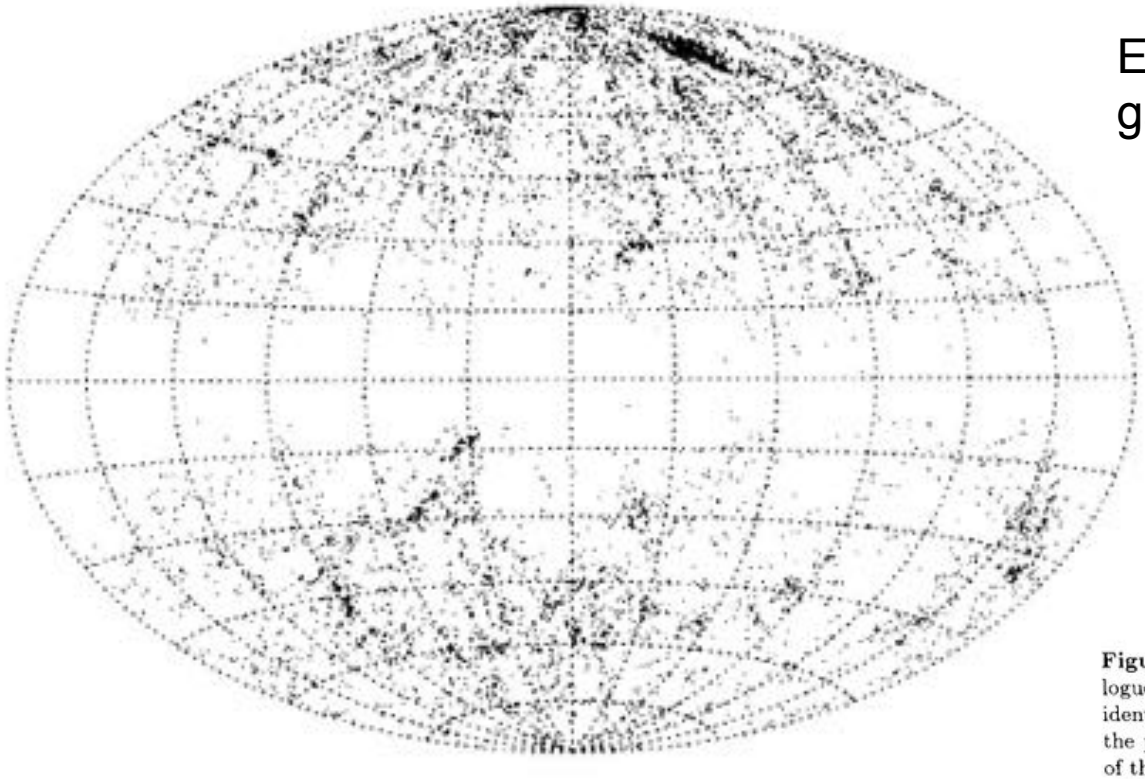
Dust – Trumpler 1930

- Explains Hubble's "zone of avoidance" of galaxies.



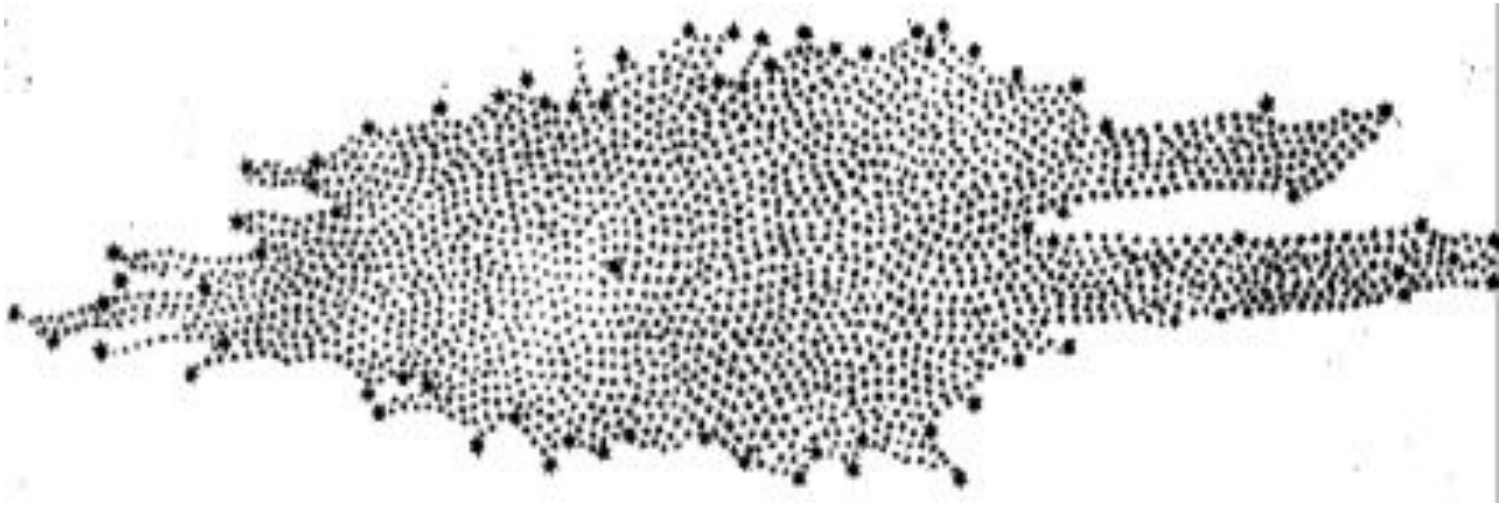
Each point is an NGC galaxy. Entire sky shown.

Plane of Milky Way

Figure 1.5 Map showing the distribution of New General Catalogue (NGC) and Index Catalogue (IC) objects which have been identified as spiral or elliptical nebulae. In this Aitoff projection, the plane of the Milky Way runs horizontally through the center of the map. Note the dearth of objects in the "zone of avoidance" within fifteen degrees of the plane.

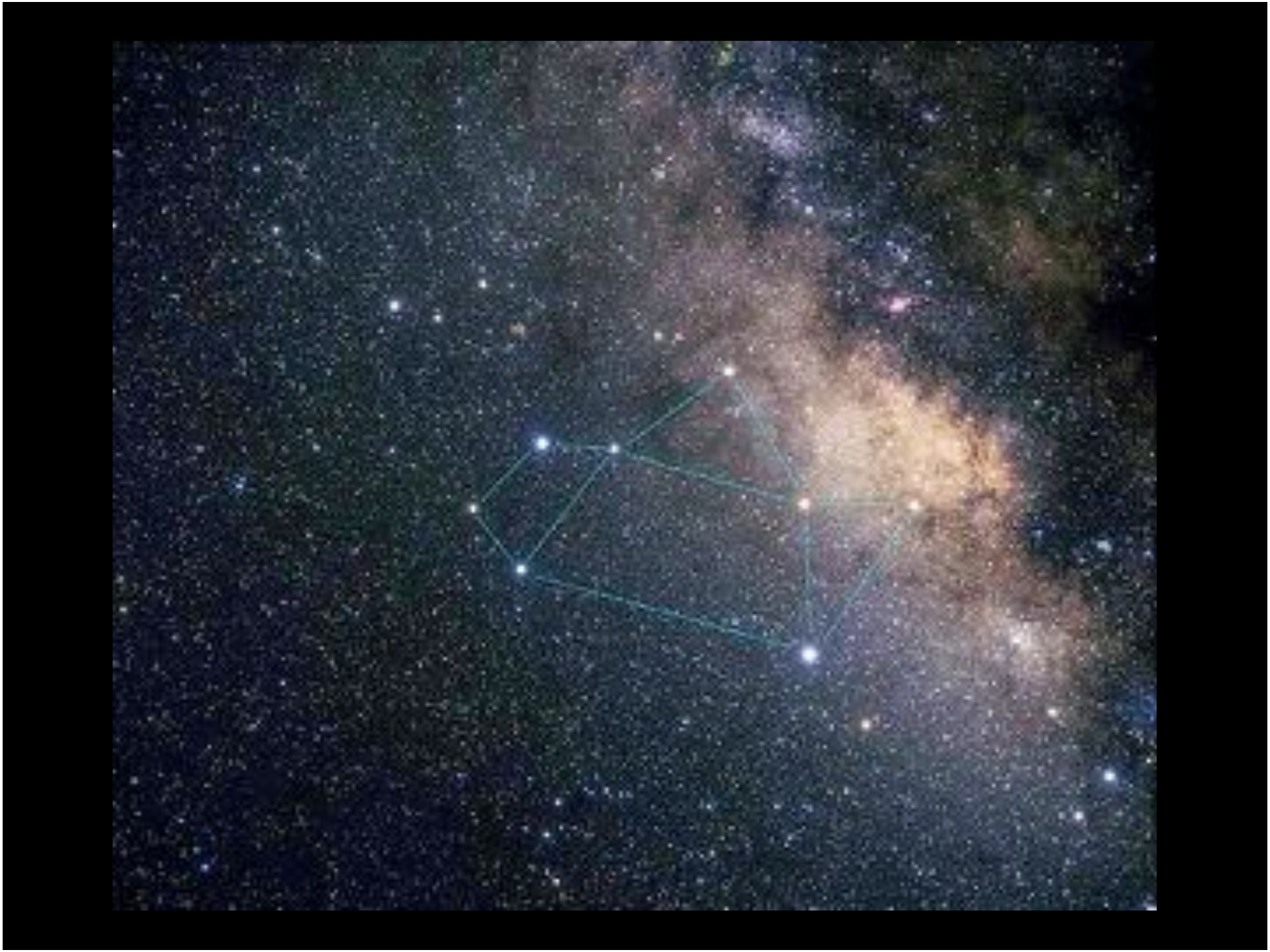
Dust – Trumpler 1930

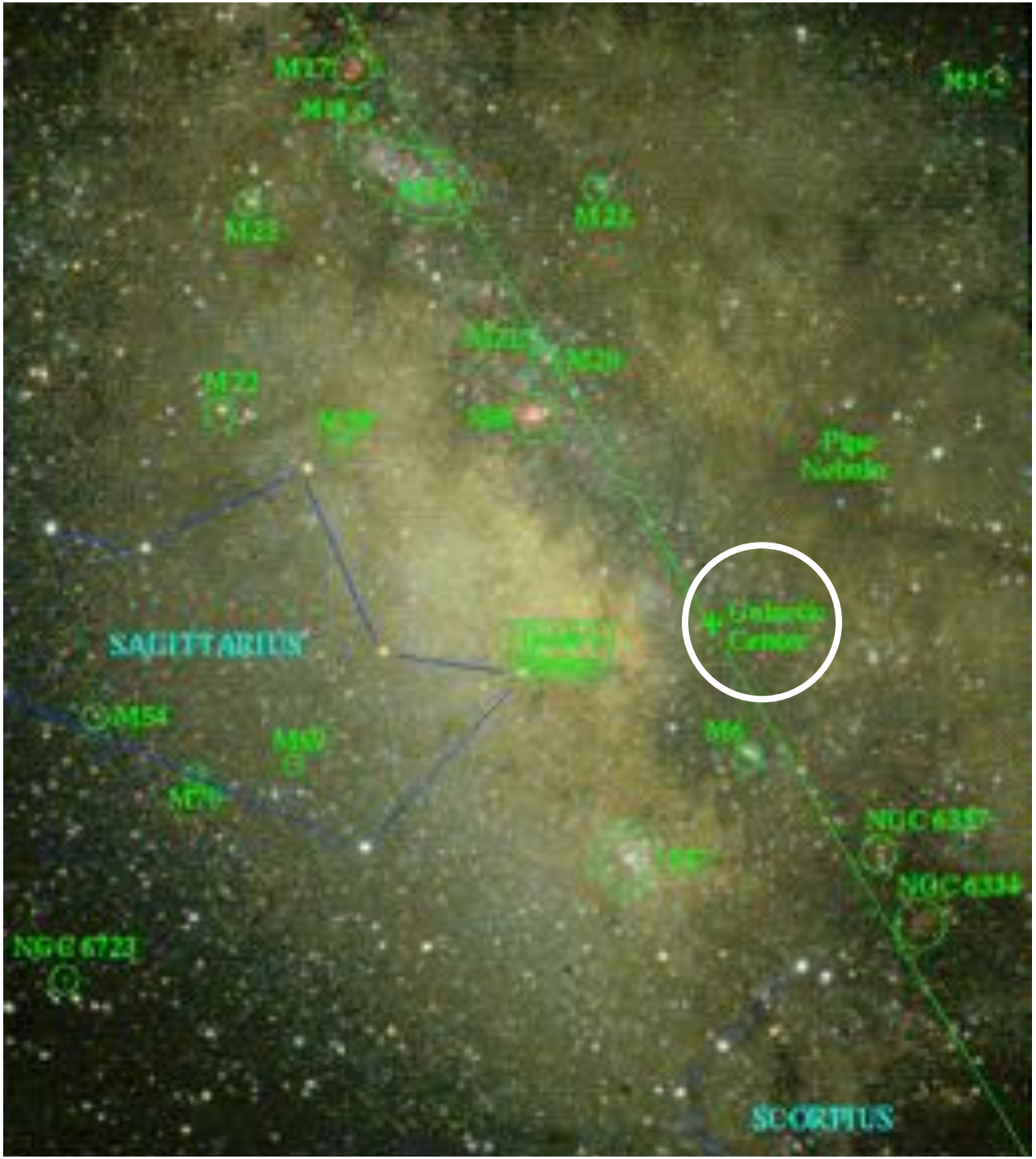
- Dust explains star count results (below) - how?



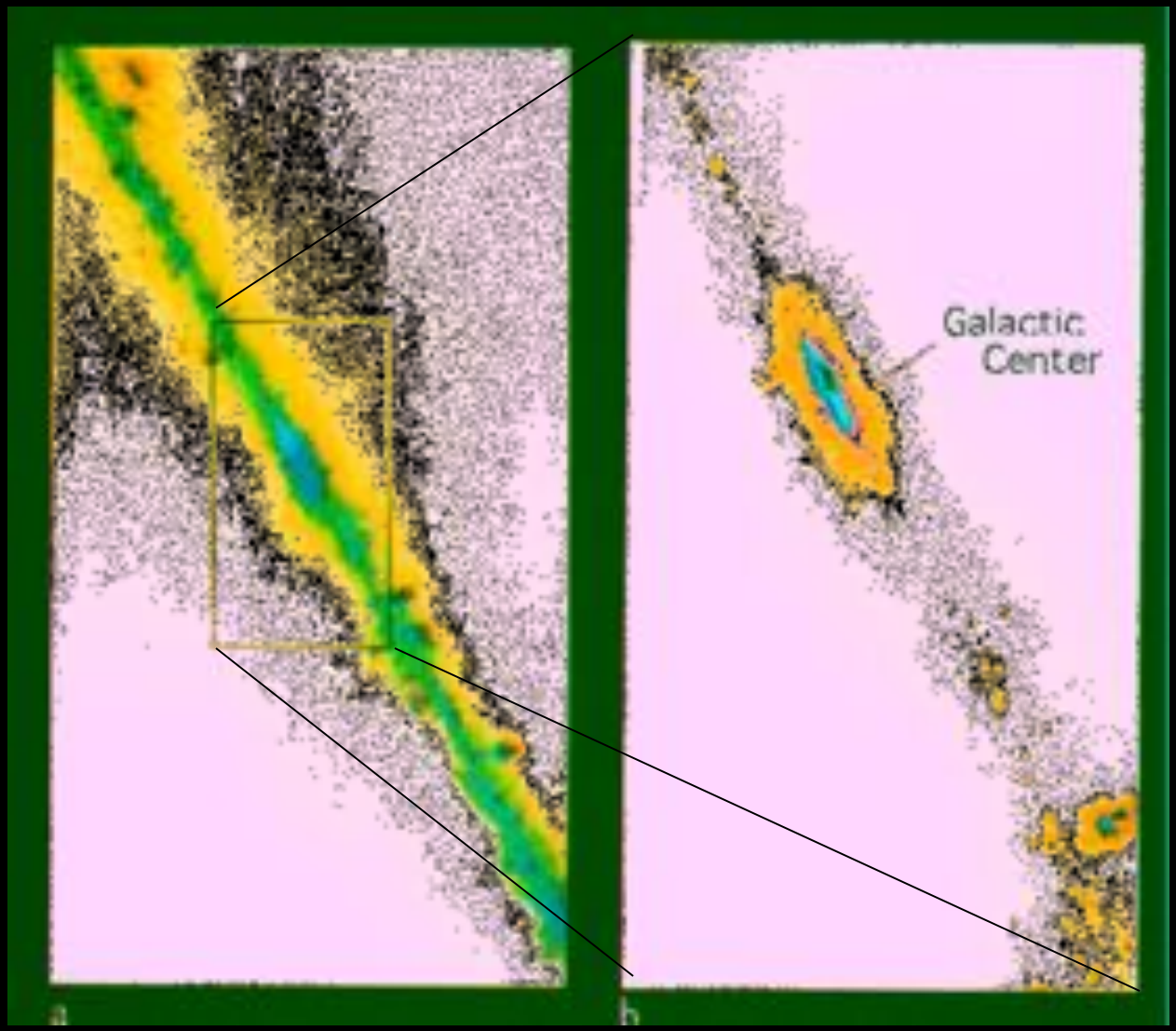
Herschel c.1800

Galactic Centre




M22
M23
M21
M20
M8
Pipe Nebula
SAGITTARIUS
M54
M69
M70
M6
NGC 6334
NGC 6723
SCORPIUS

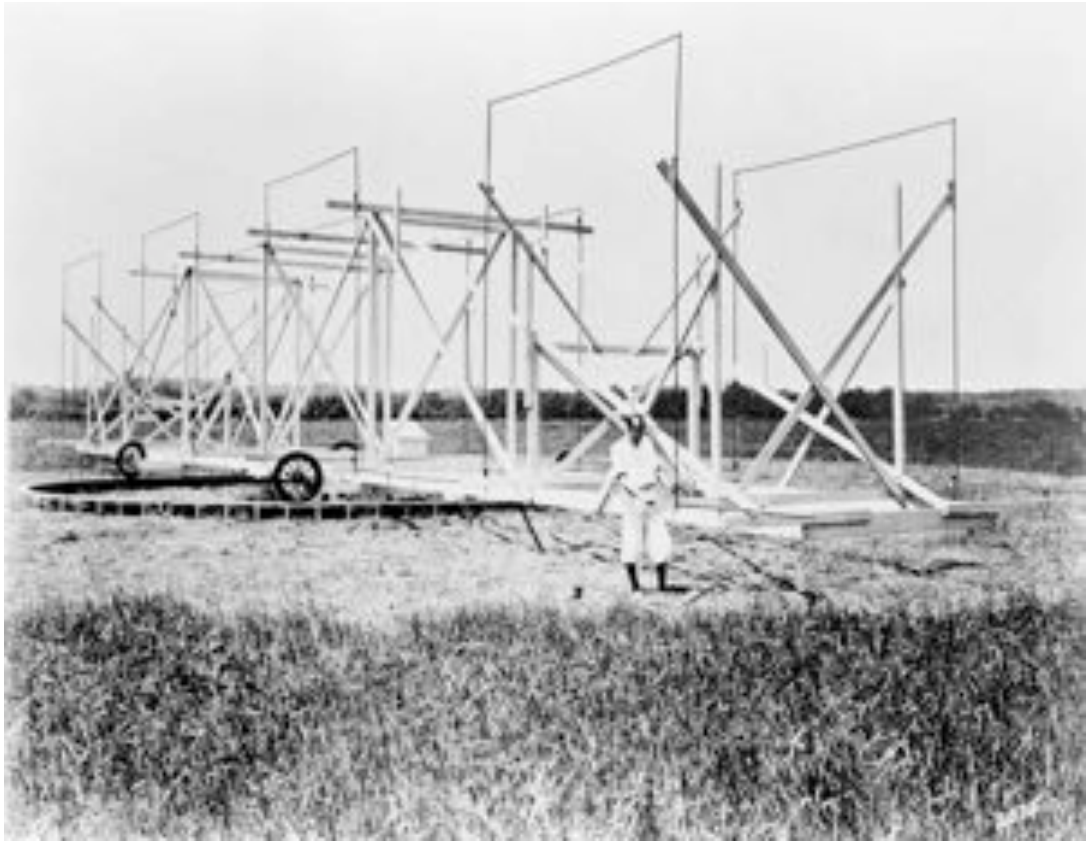
IRAS IR images: emission is due to warm dust, heated by nearby stars



~ 80 ly

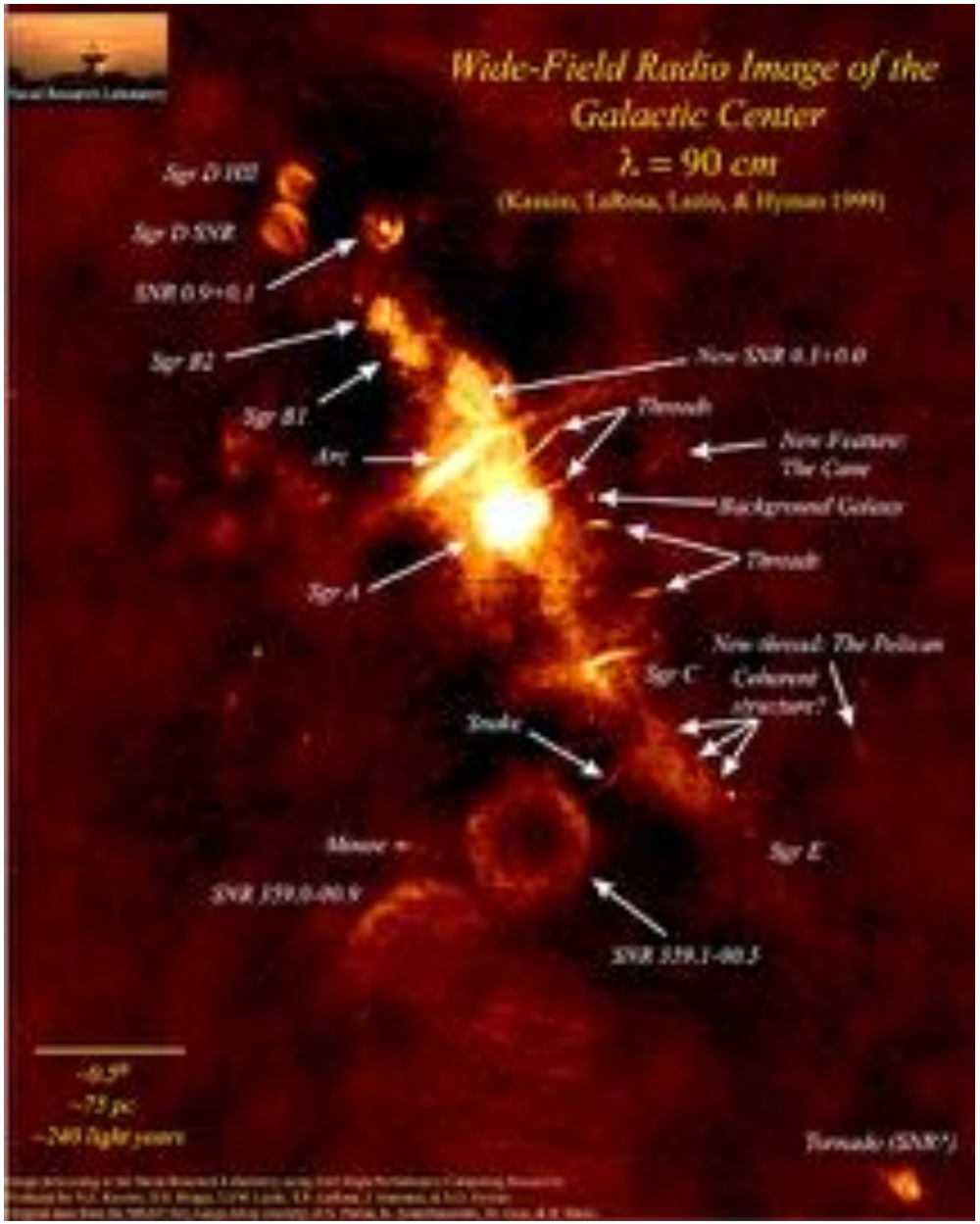
Radio Astronomy

Karl Jansky 1905-1950

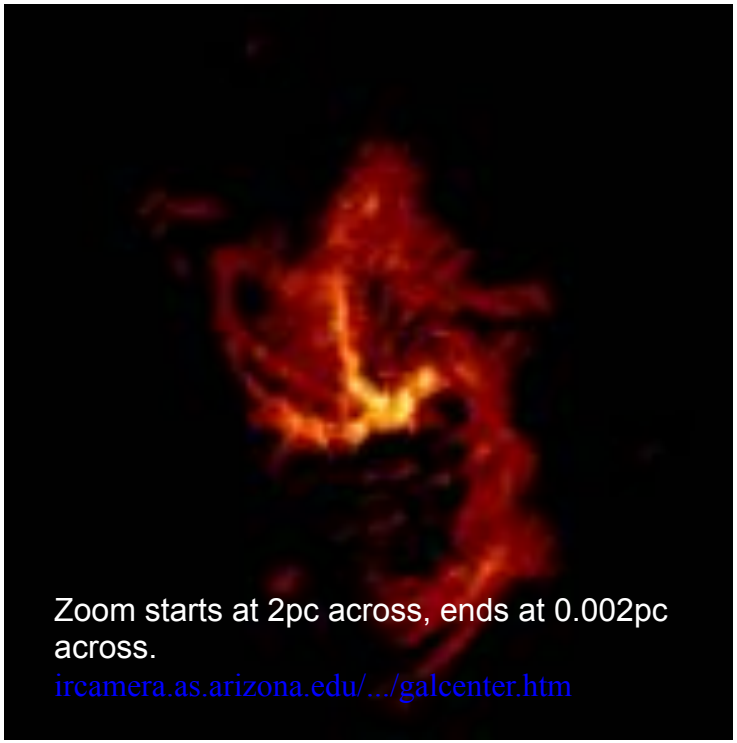


- discovered radio emission from the Milky Way in 1931

Galactic Centre – Radio - Sagittarius A

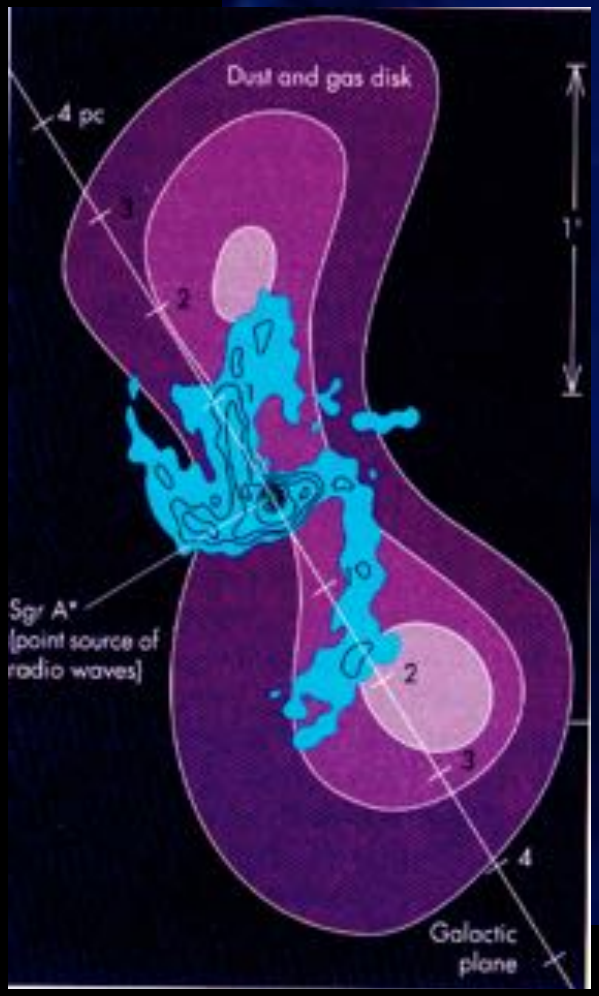


- ~10^7 L_{sun} in radio power (synchrotron, cm wavelength)
- Very complex
- Also X-rays, 511 keV



Sgr A* West: Observations at 6 cm taken at the VLA.

Synchrotron emission from relativistic charged particles in a magnetic field.

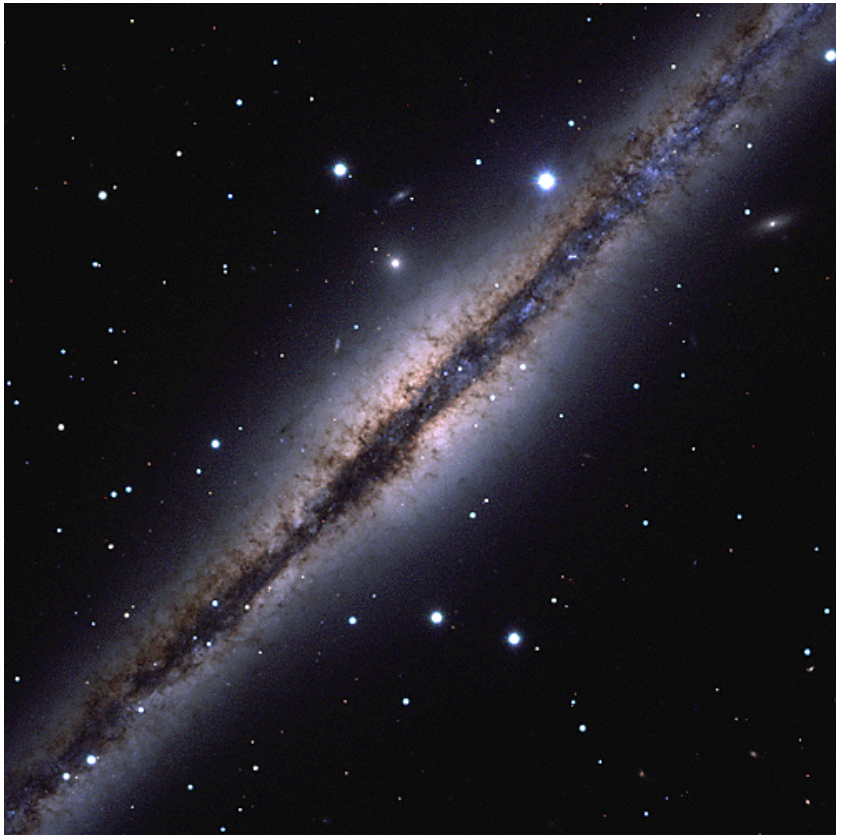


~30 ly

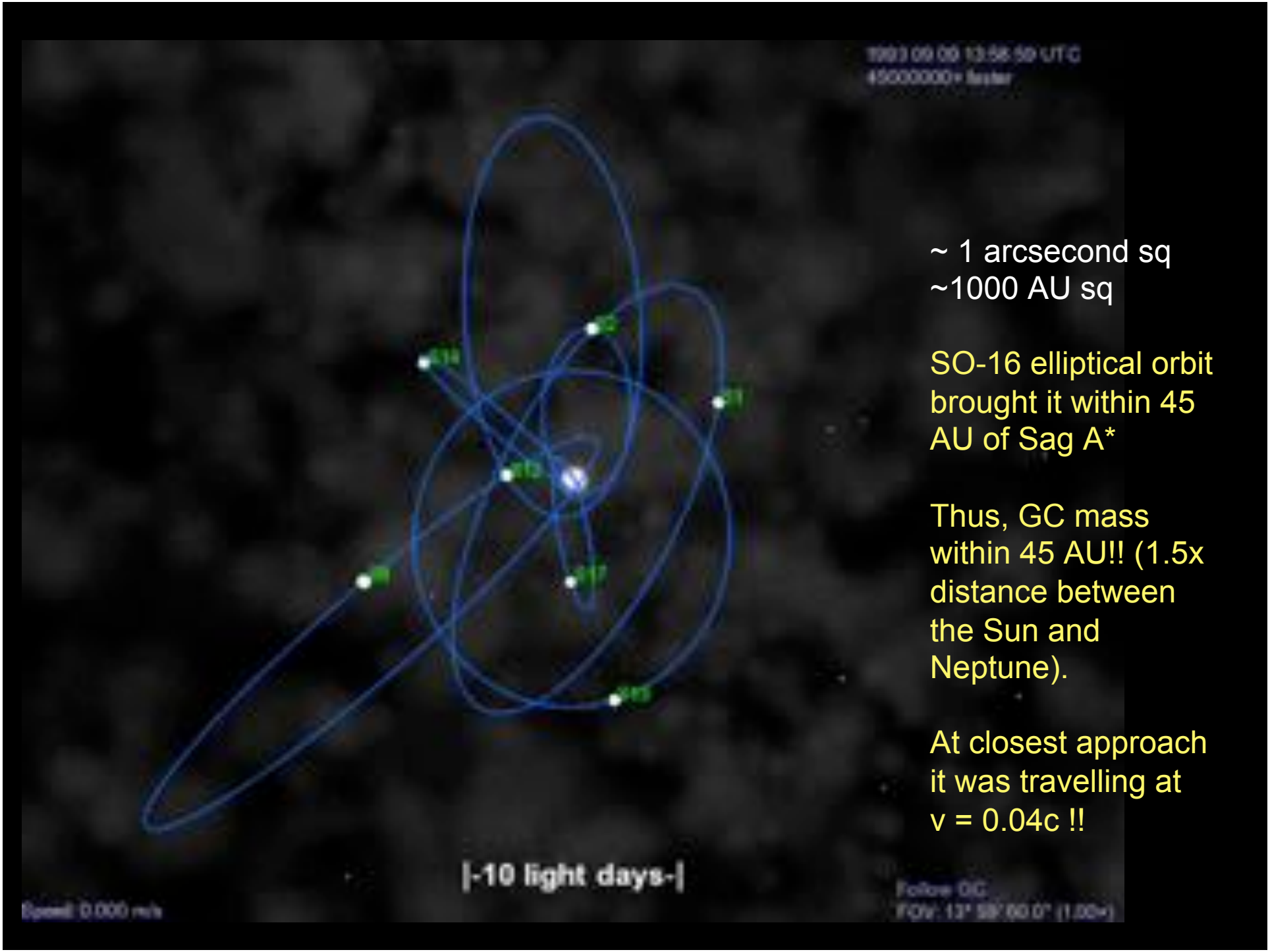
Cluster of OB stars (IRC 16): JHK imaging

Supermassive Black Holes

- Galactic Centre (Milky Way galaxy)
  - Distance ~ 8 kpc
  - edge on it looks a bit like this galaxy …



- Visible light: 30 mag of absorption due to dust
  - 30 mag = 10^{12} times!
- IR: only 3 mag!
- With IR + adaptive optics you can see individual stars!



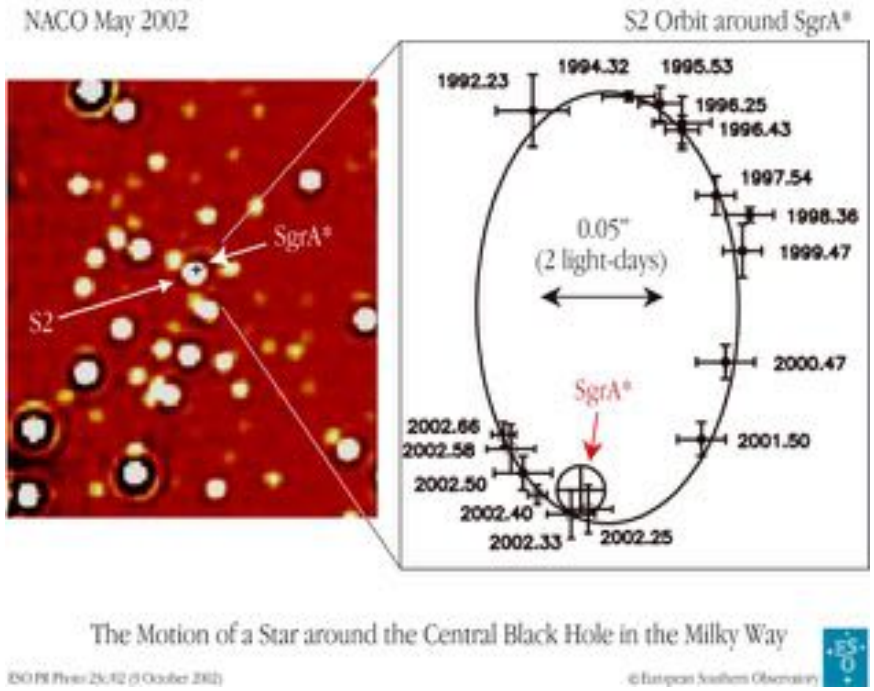
~ 1 arcsecond sq
~1000 AU sq

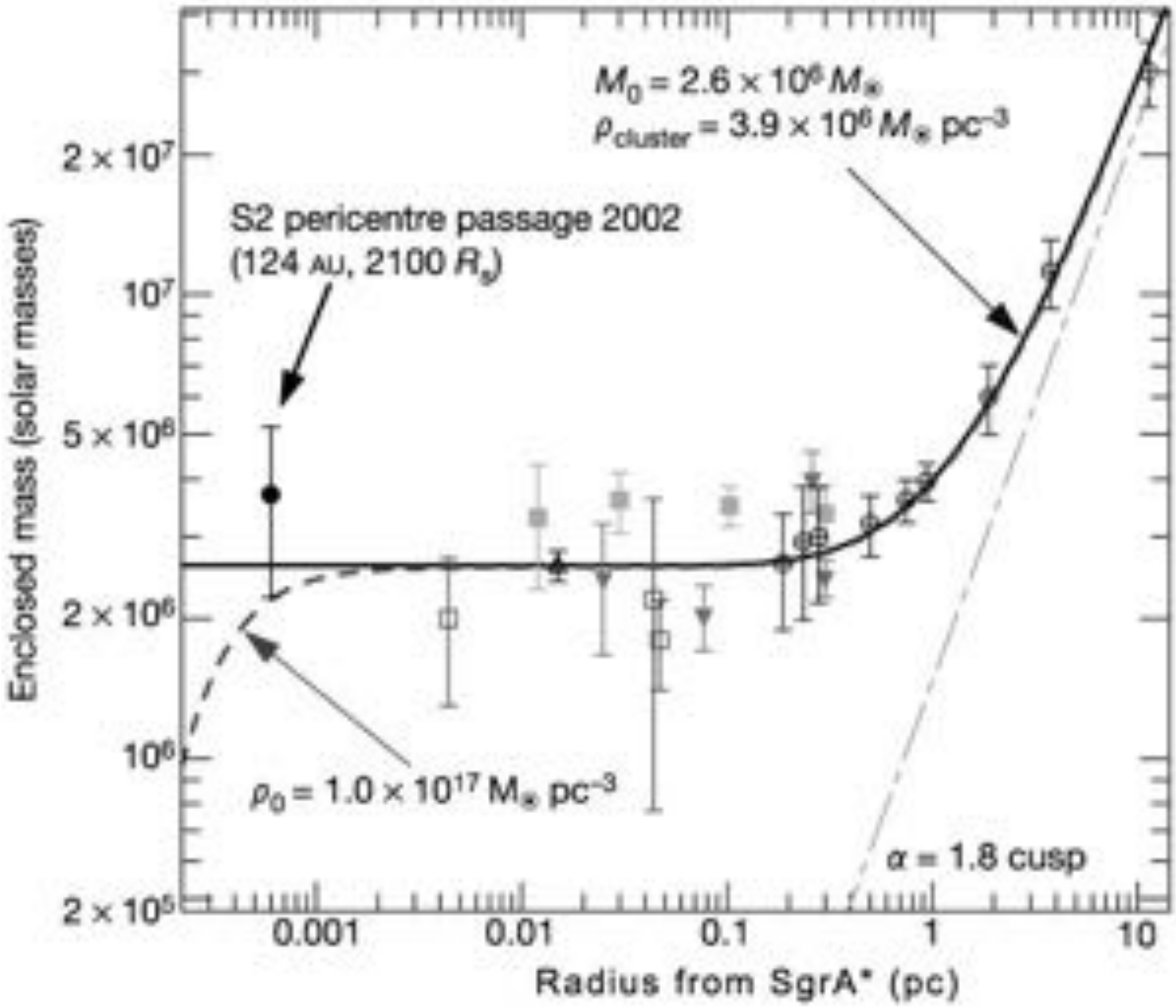
SO-16 elliptical orbit brought it within 45 AU of Sag A*

Thus, GC mass within 45 AU!! (1.5x distance between the Sun and Neptune).

At closest approach it was travelling at v = 0.04c !!

- E.g. star S2
-
  - P=15.2 yr, e=0.87, perigalacticon=120AU (17 light hours)!
  - Calculate mass interior to orbit …




$M_0 = 2.6 \times 10^6\, M_\odot$
$\rho_{cluster} = 3.9 \times 10^6\, M_\odot\ pc^{-3}$
S2 pericentre passage 2002
(124 AU, 2100 R_s)
$\rho_0 = 1.0 \times 10^{17}\, M_\odot\ pc^{-3}$
$\alpha = 1.8$ cusp
Enclosed mass (solar masses)
2×10^7
10^7
5×10^6
2×10^6
10^6
2×10^5
0.001
0.01
0.1
1
10
Radius from SgrA* (pc)

- Mass distribution - velocities rise in the core
- There is a star cluster within the inner parsec - but this cannot explain inner mass.
- Black hole!

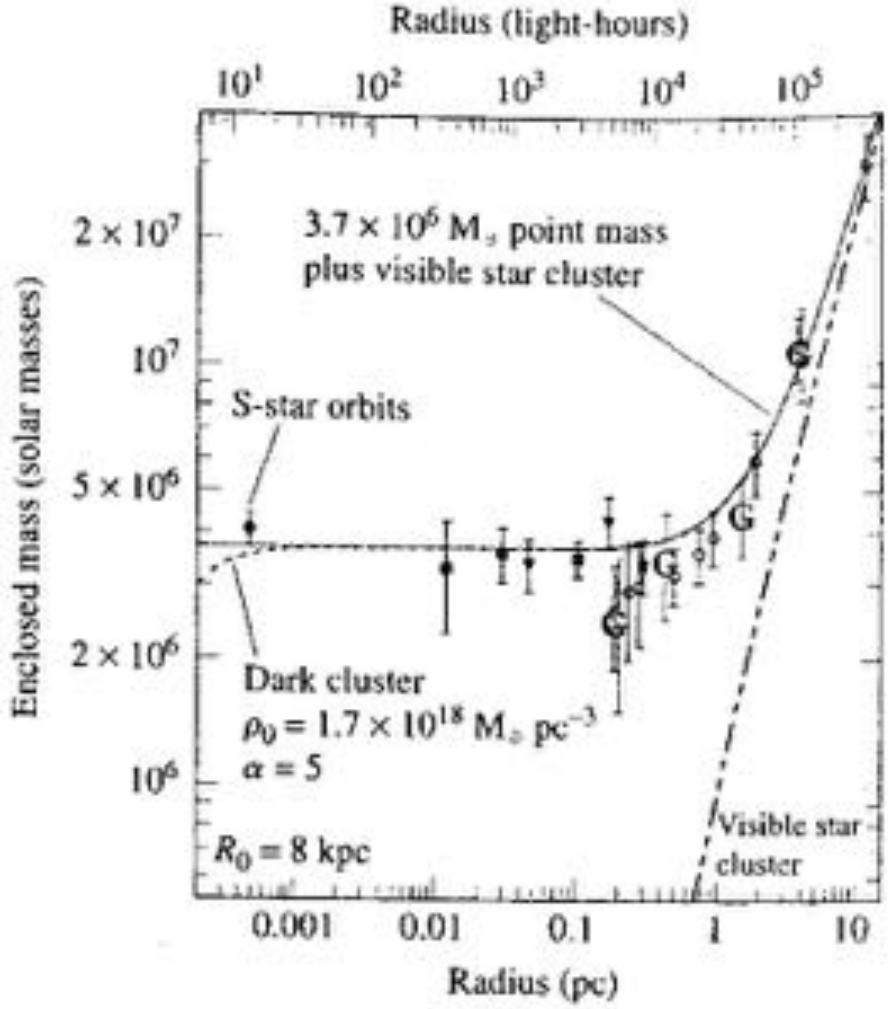


FIGURE 24.33 The interior mass function for the central 10 pc of the Galaxy. Note that the curve is consistent with a mass distribution $M_r \propto r$ beyond about 5 pc but that interior to 2 pc the distribution levels off, approaching a constant nonzero value of 3.7×10^6 $M_\odot$. "Dark cluster" refers to a hypothetical object. Note that the predictions of a dark cluster model at the center of the Galaxy do not agree with the observational data. (Adapted from a figure courtesy of Reinhard Genzel and Rainer Schödel. For a discussion of an earlier version of this diagram, see Schödel, et al., *Nature*, *419*, 694, 2002.)

What is Schwarzschild Radius for MW nucleus?

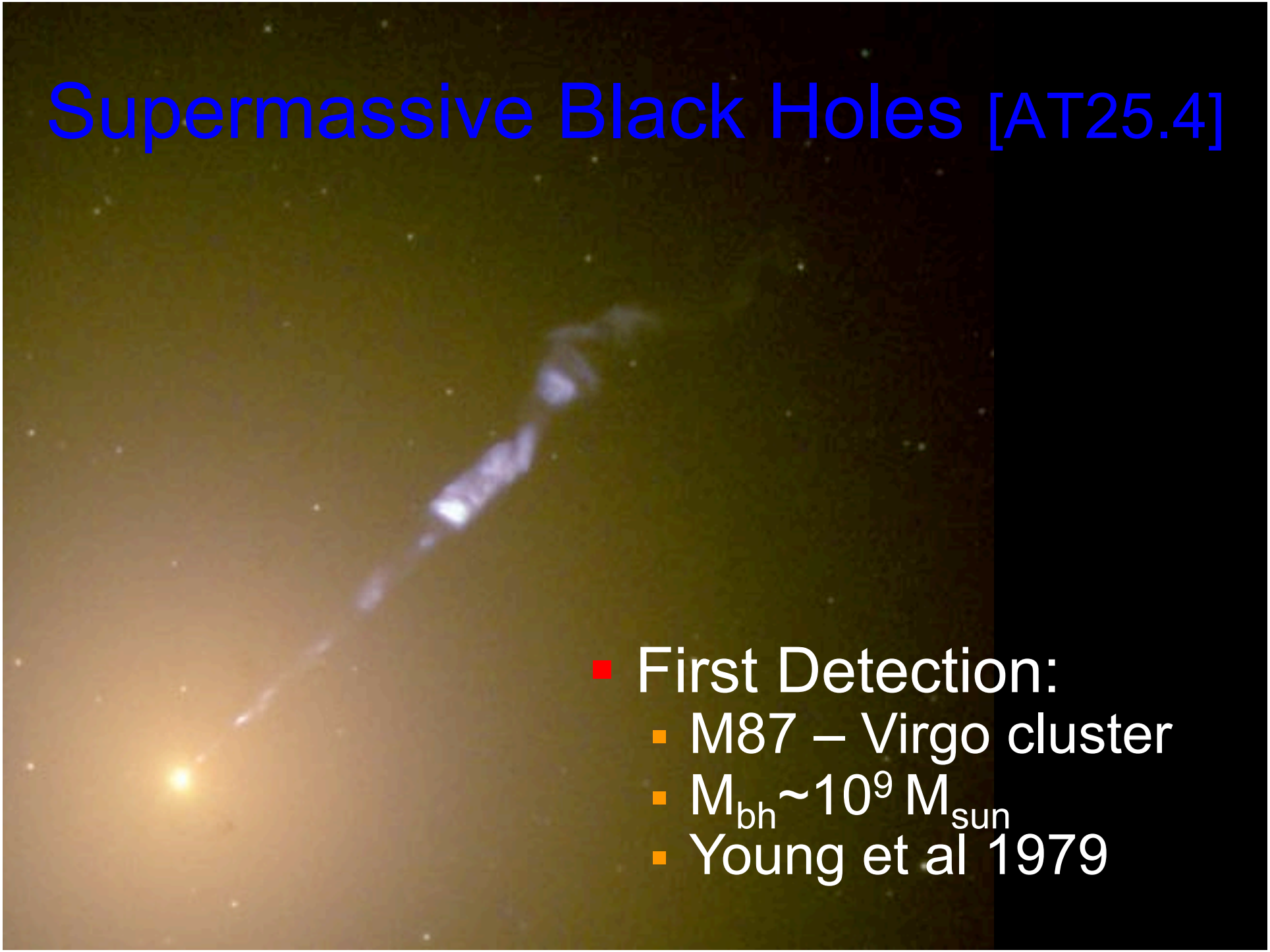
$$R_s = \frac{2GM}{c^2} = 3\left(\frac{M}{M_\odot}\right) \text{ km}$$

$$\simeq 10^7 \text{ km for MW nucleus}$$

$$\simeq \text{ solar diameter}$$

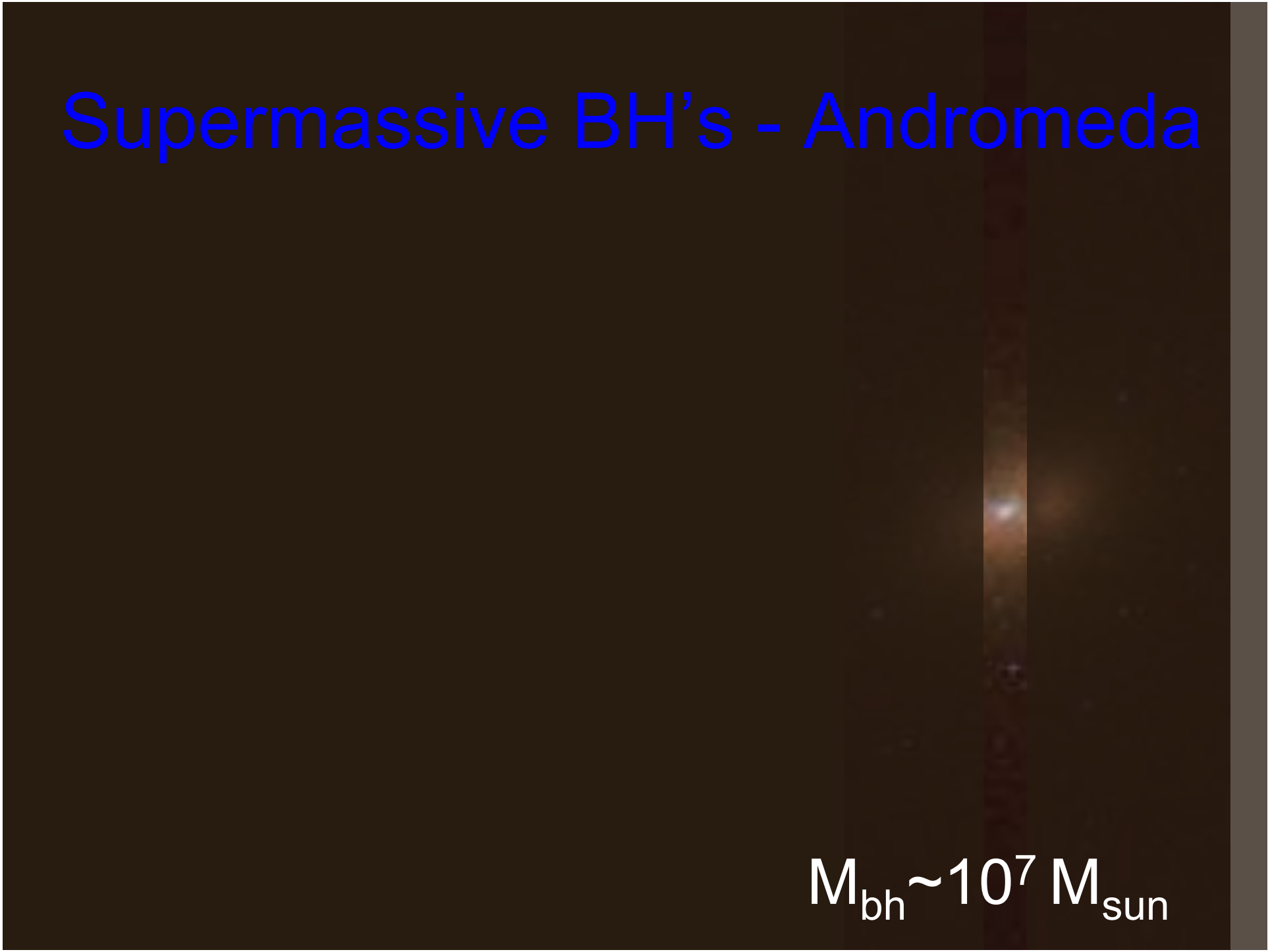
$$\simeq 3\times 10^{-7} \text{ pc}$$

Supermassive Black Holes [AT25.4]



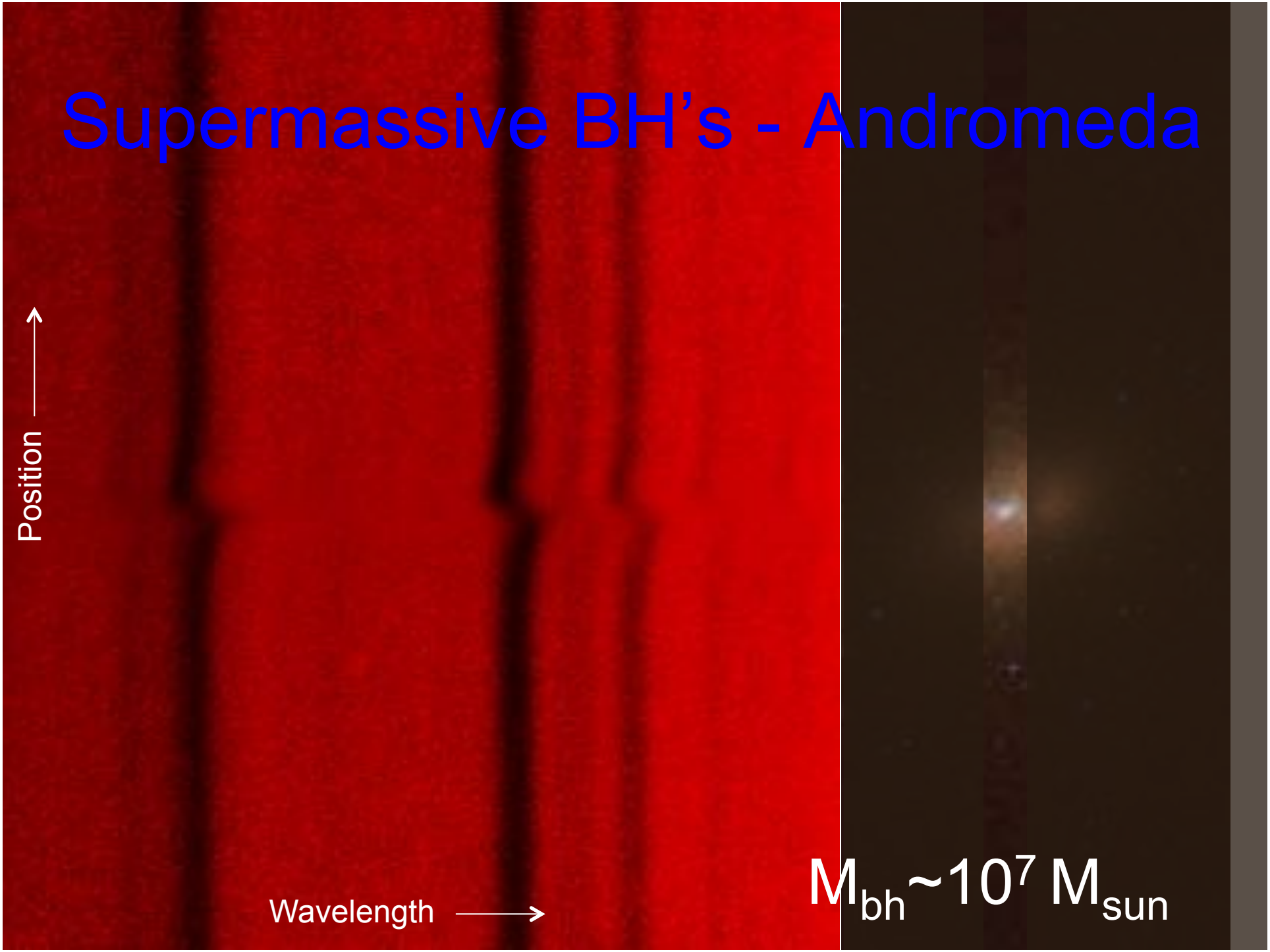
- First Detection:
  - M87 – Virgo cluster
  - $M_{bh} \sim 10^9 M_{sun}$
  - Young et al 1979

Supermassive BH's - Andromeda

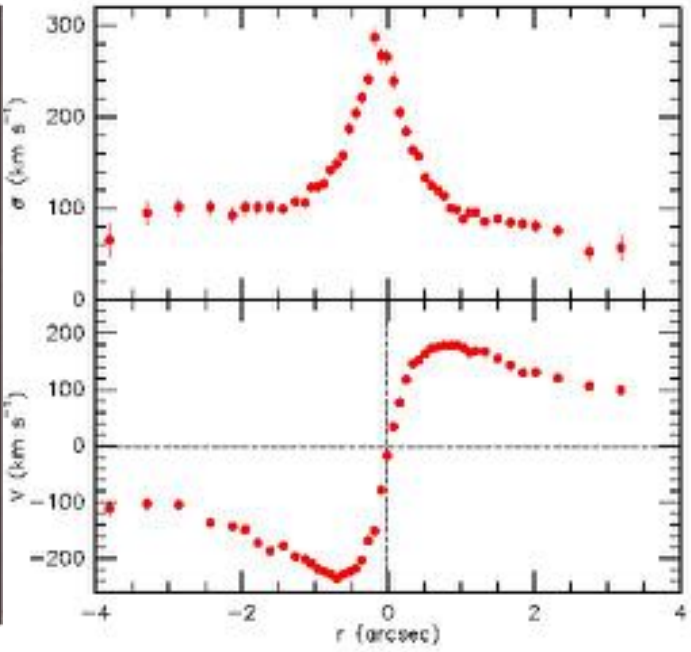


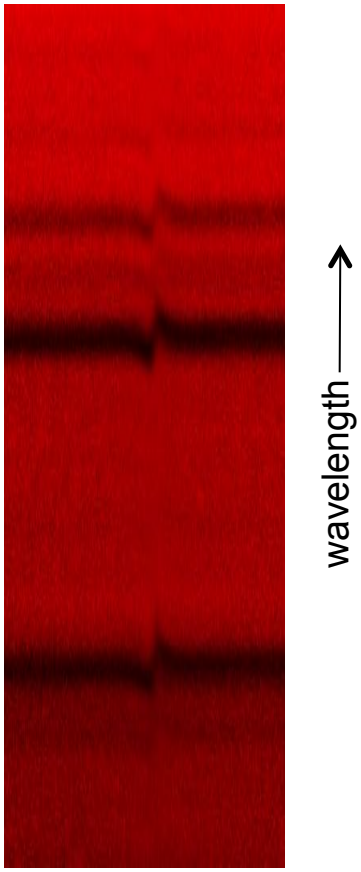
$M_{bh} \sim 10^7 M_{sun}$

Supermassive BH's - Andromeda



- M31 nucleus is blue cluster
- Black hole also centred on blue cluster
- Black hole mass = **~3 x 10^7 M_{sun}**





Supermassive Black Holes

The mass of the central black hole is well correlated with the mass of the galactic bulge, for those galaxies where both have been measured.

- $M_{bh} \sim 0.001\ M_{tot}$
- Note mass range!