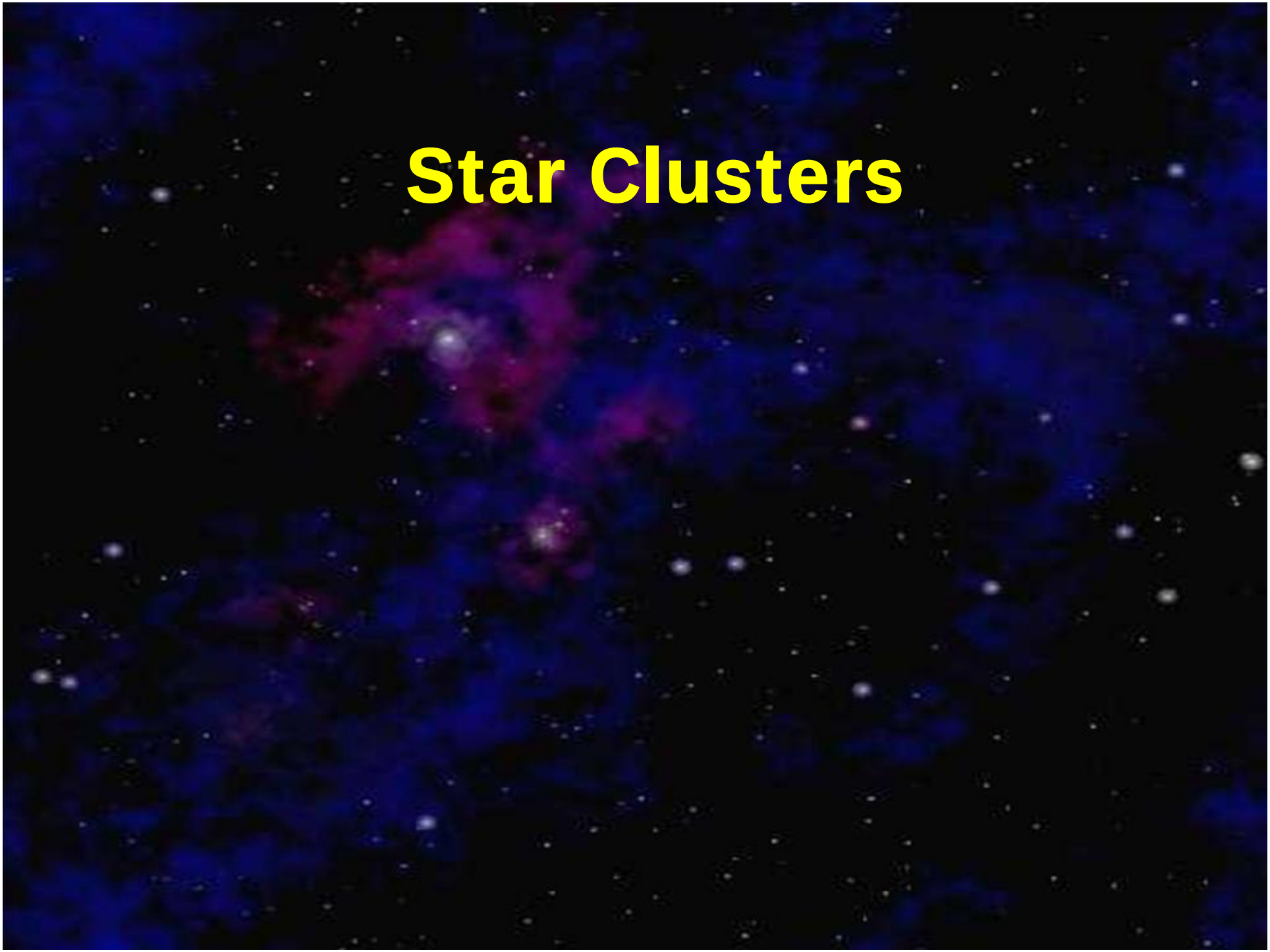
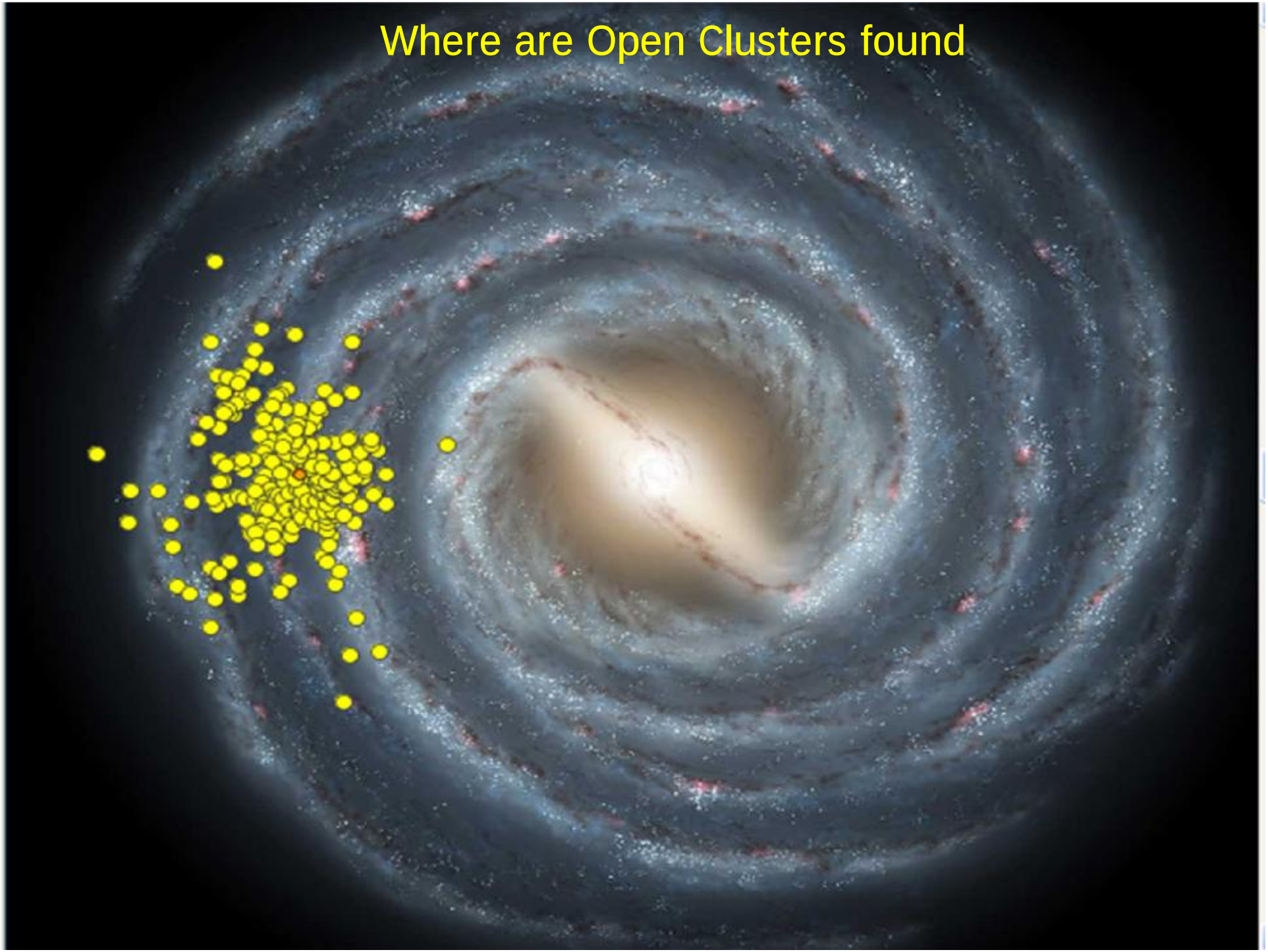

Star Clusters

Open Cluster M7

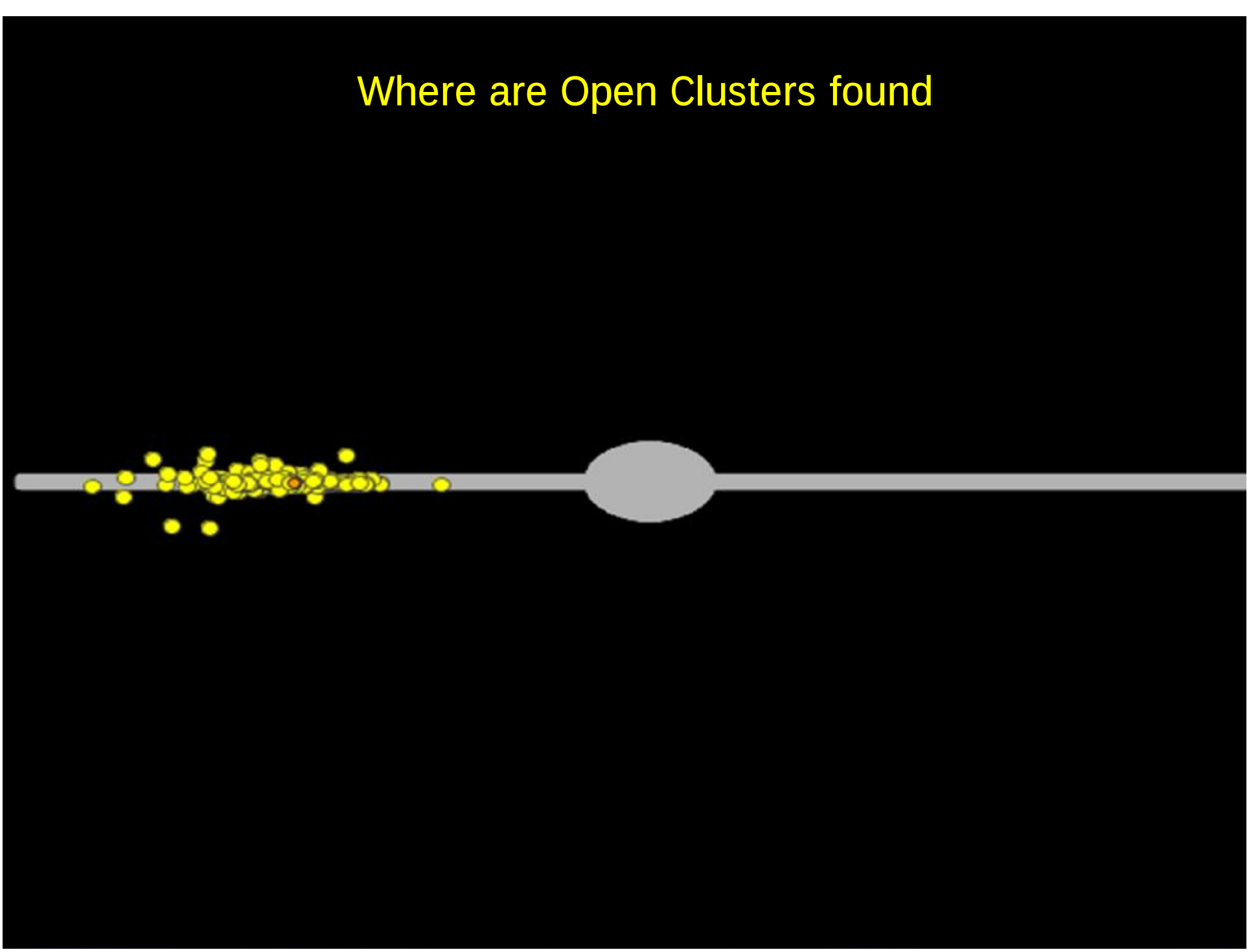
Globular Cluster M55

Globular Cluster M55

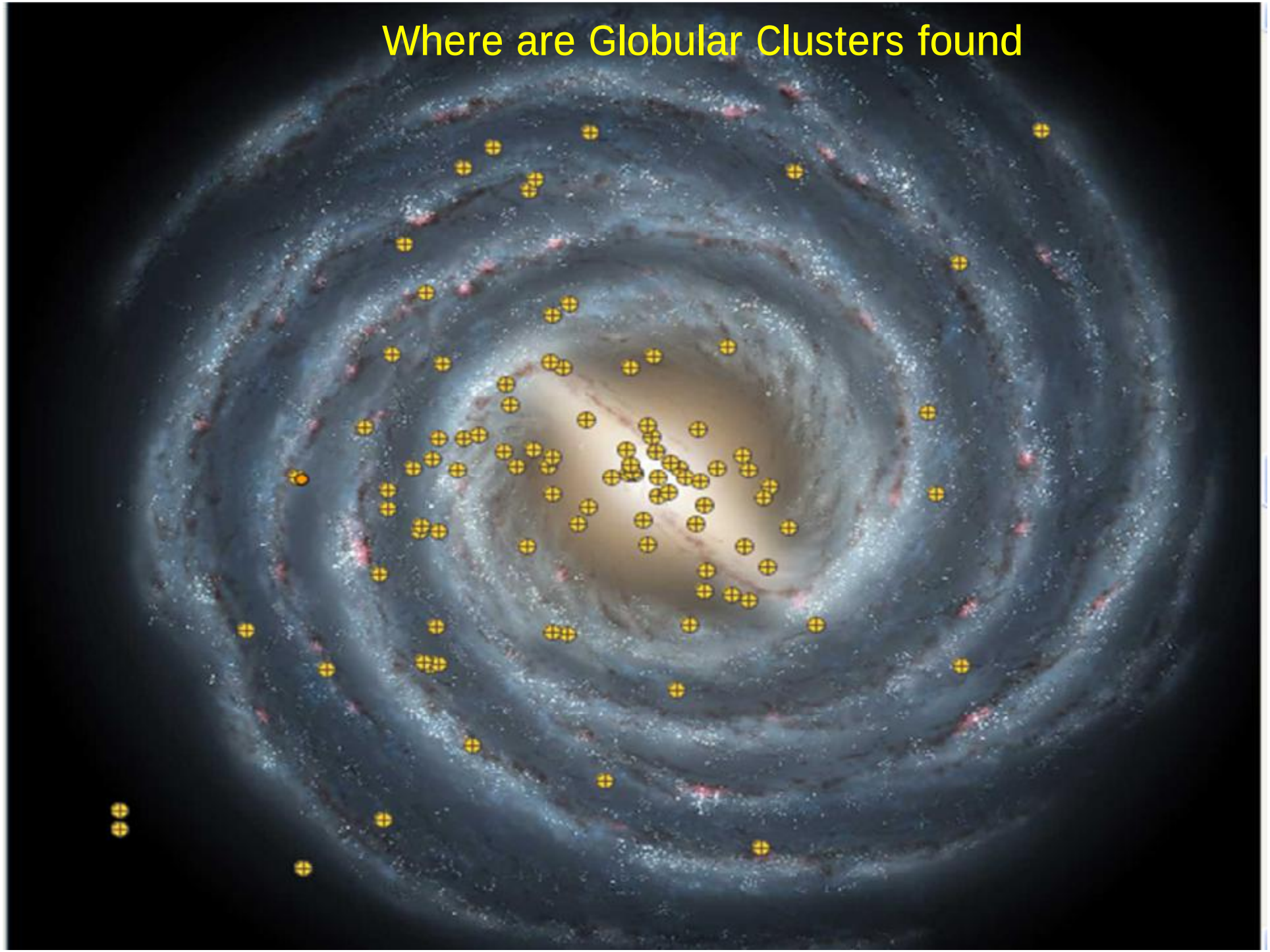
Where are Open Clusters found



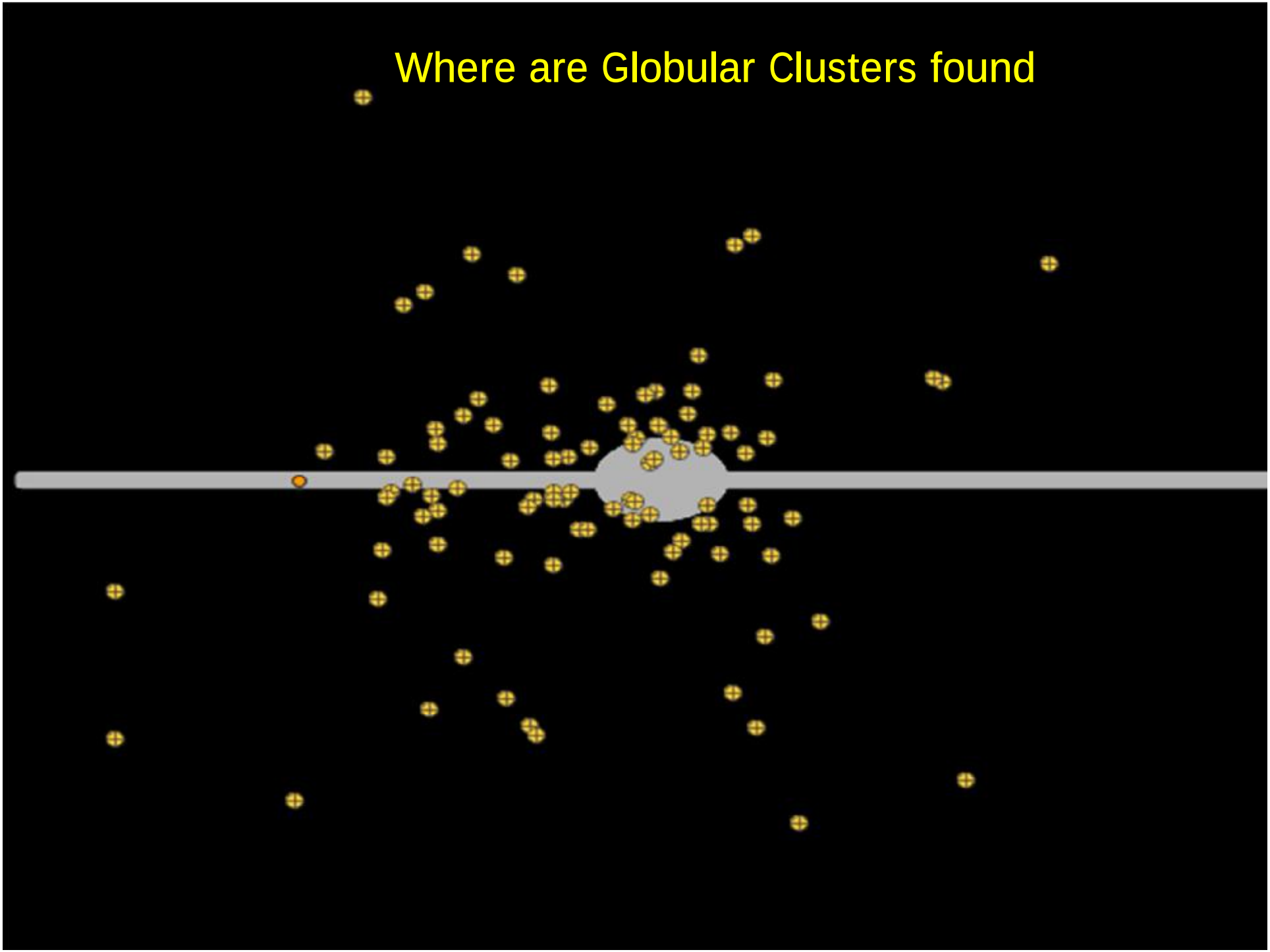
Where are Open Clusters found



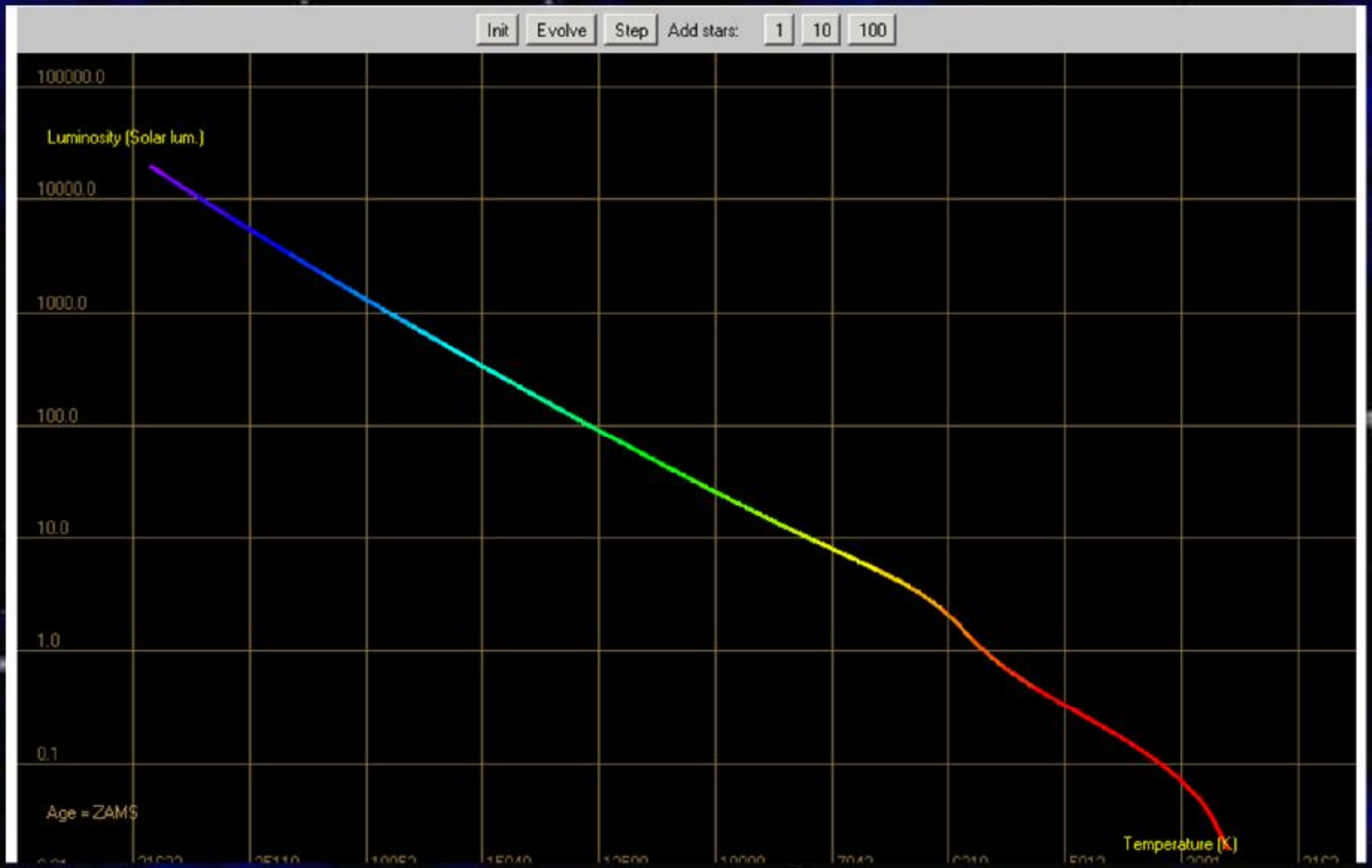
Where are Globular Clusters found



Where are Globular Clusters found



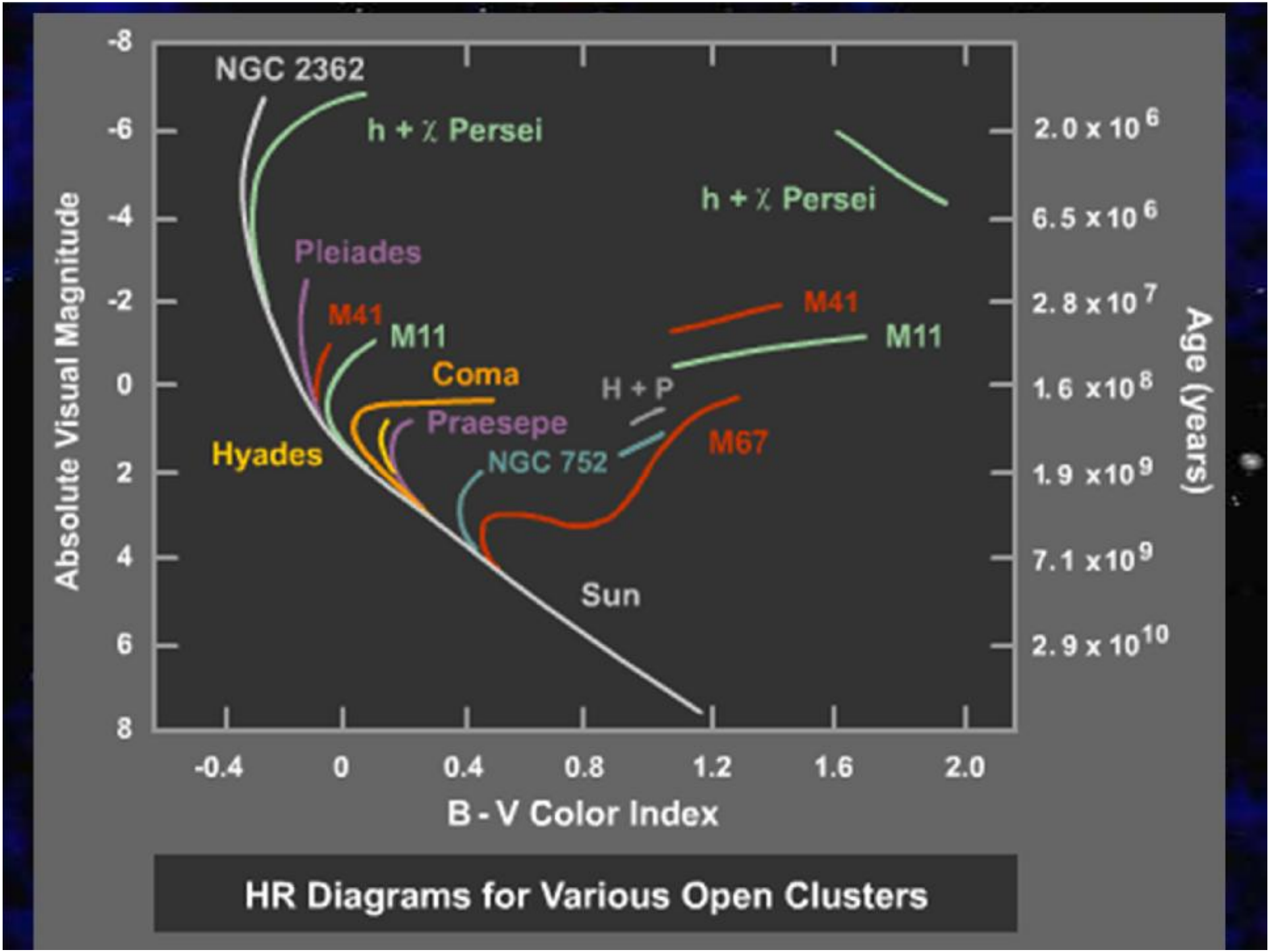
Recall the lifespan of a star depends on its Mass

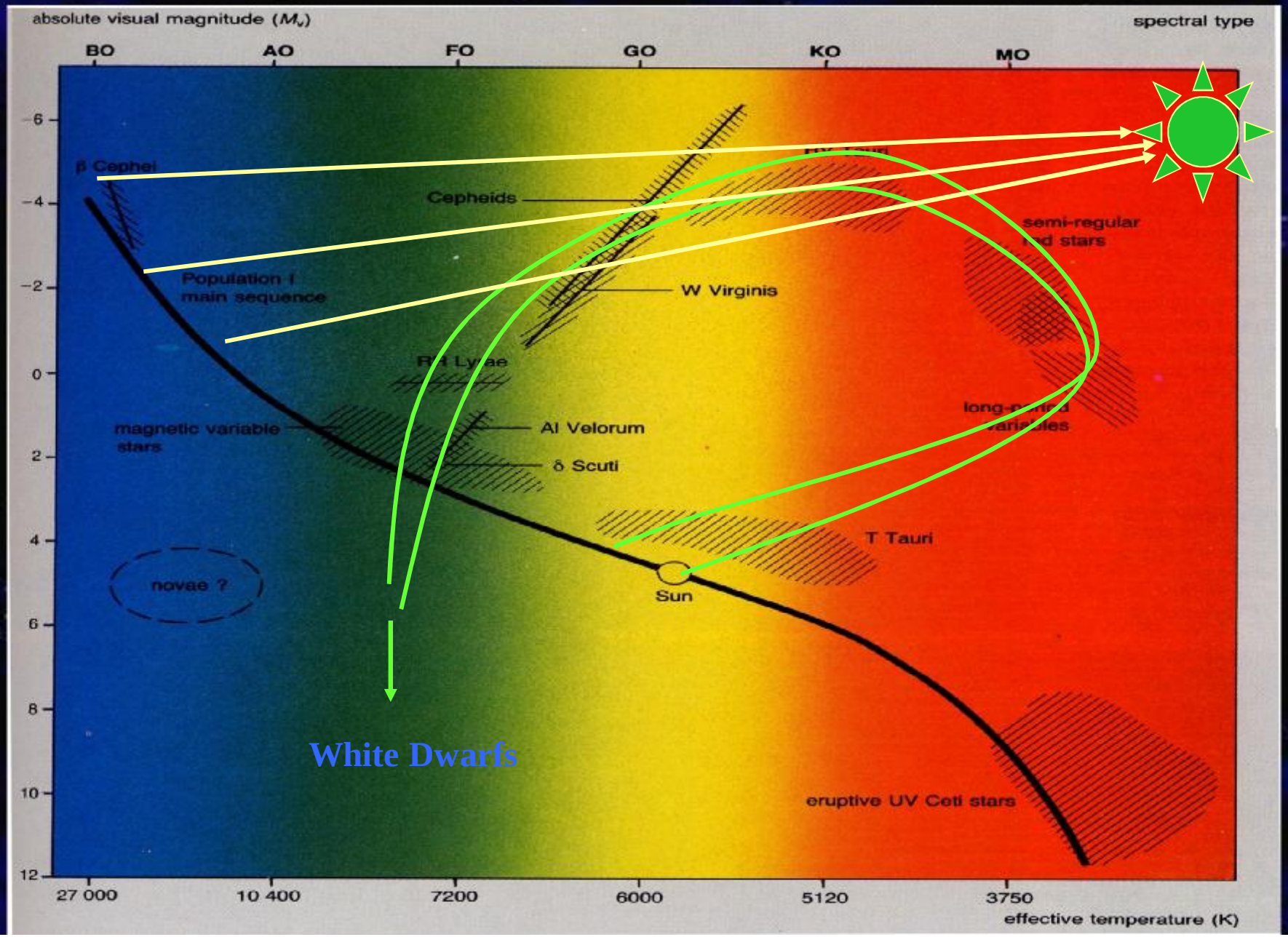


As Observed from the earth, the distance to all the stars within a cluster are ~ the same

Therefore the differences in brightness are directly related to the differences in Luminosity or energy output.

- distance effects are removed


NGC 2362
h + χ Persei
h + χ Persei
Pleiades
M41
M11
Coma
Praesepe
Hyades
NGC 752
H + P
M41
M11
M67
Sun
Absolute Visual Magnitude
-8
-6
-4
-2
0
2
4
6
8
-0.4
0
0.4
0.8
1.2
1.6
2.0
B - V Color Index
Age (years)
2.0 x 10 6
6.5 x 10 6
2.8 x 10 7
1.6 x10 8
1.9 x10 9
7.1 x10 9
2.9 x 10 10
HR Diagrams for Various Open Clusters

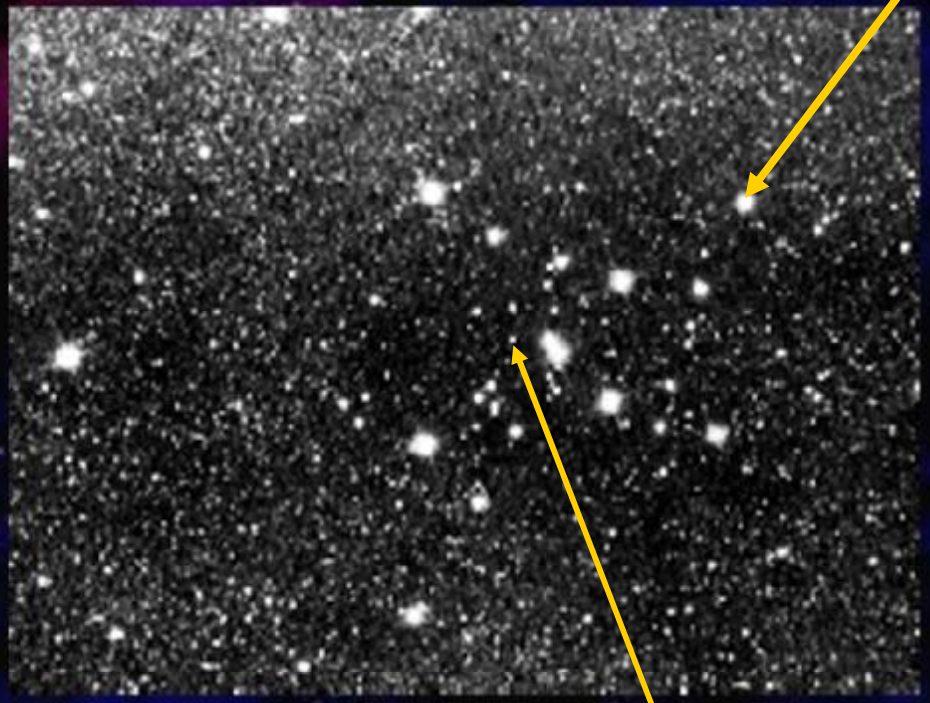

absolute visual magnitude (M_v)
spectral type
BO
AO
FO
GO
KO
MO
-6
-4
-2
0
2
4
6
8
10
12
β Cephei
Cepheids
Population I
main sequence
W Virginis
RR Lyrae
magnetic variable
stars
Al Velorum
δ Scuti
T Tauri
Sun
novae ?
White Dwarfs
eruptive UV Ceti stars
27 000
10 400
7200
6000
5120
3750
effective temperature (K)

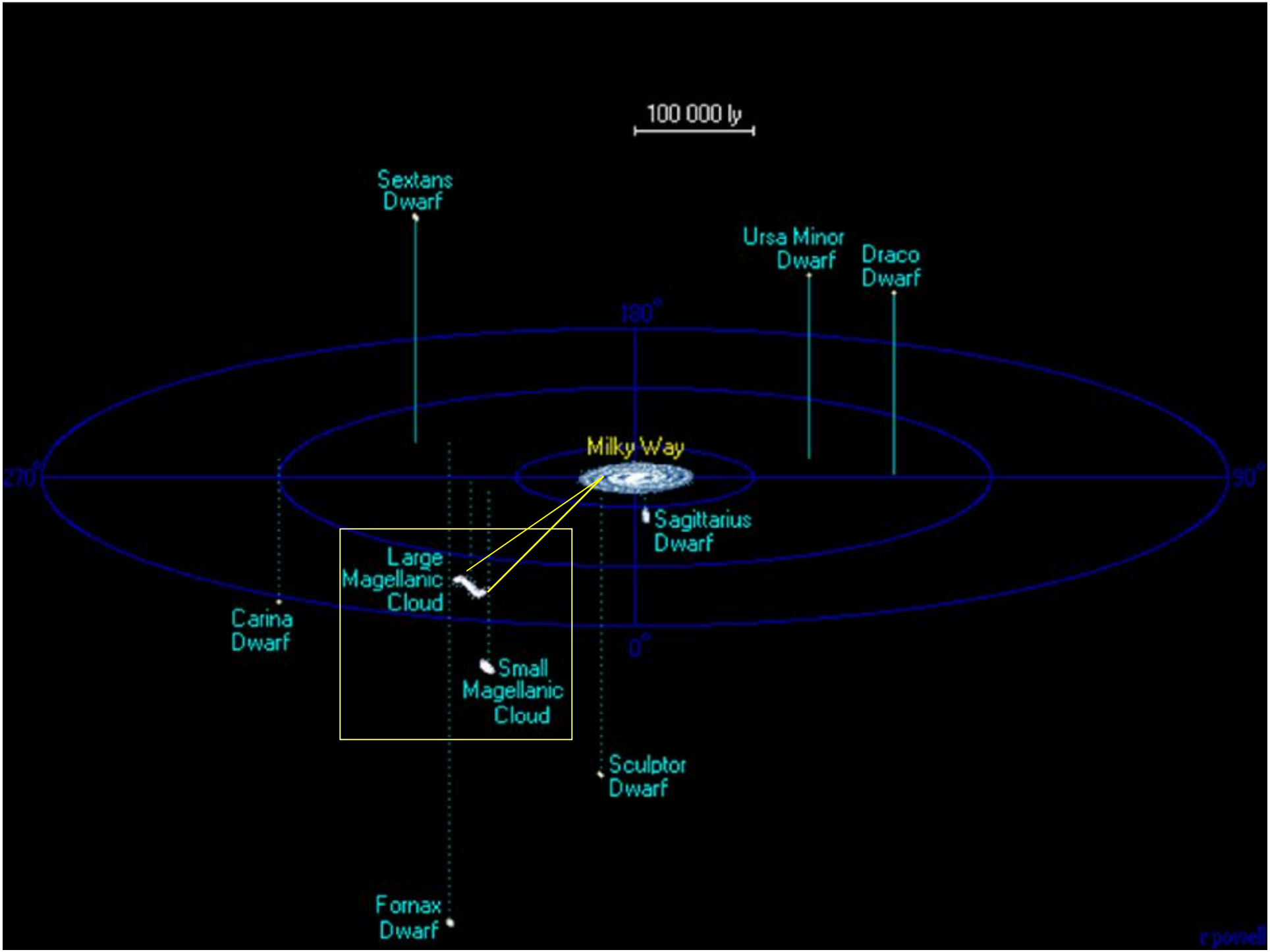
As Observed from the earth, the distance to all the stars within a cluster are ~ the same

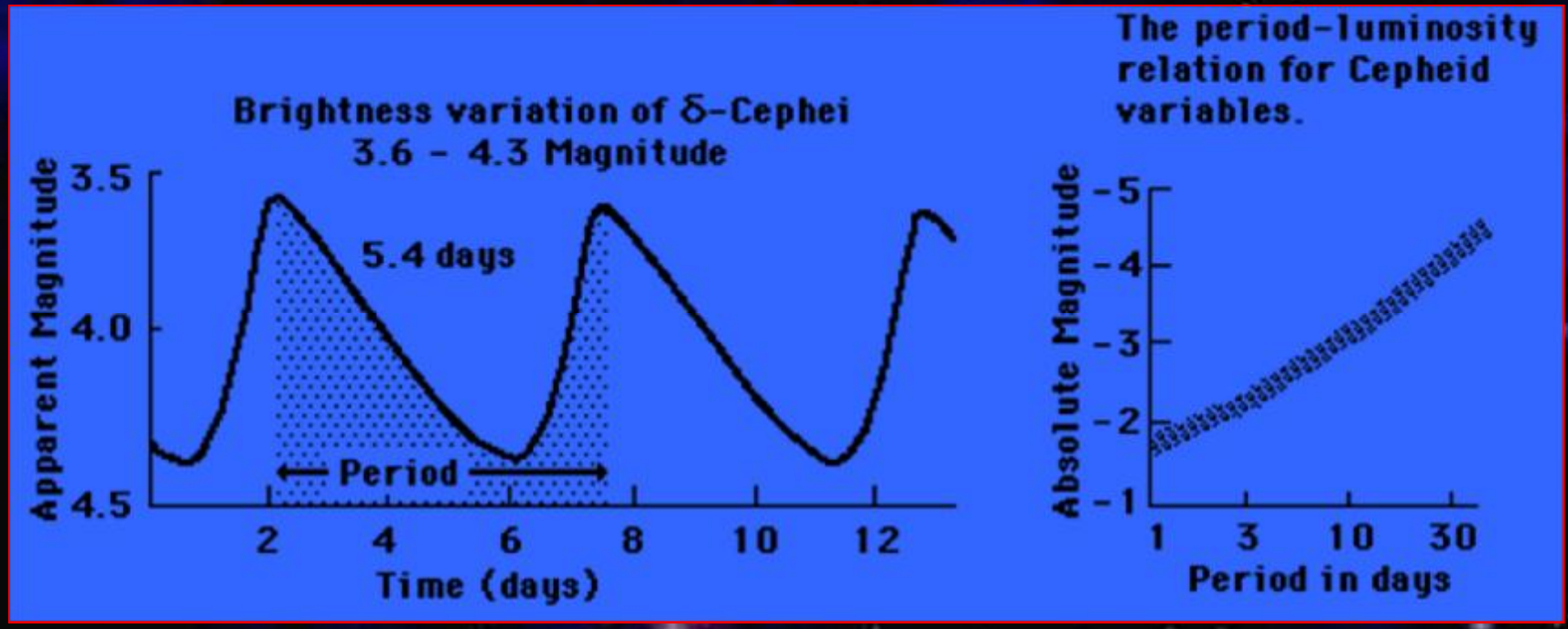
Therefore the differences in brightness are directly related to the differences in Luminosity or energy output.

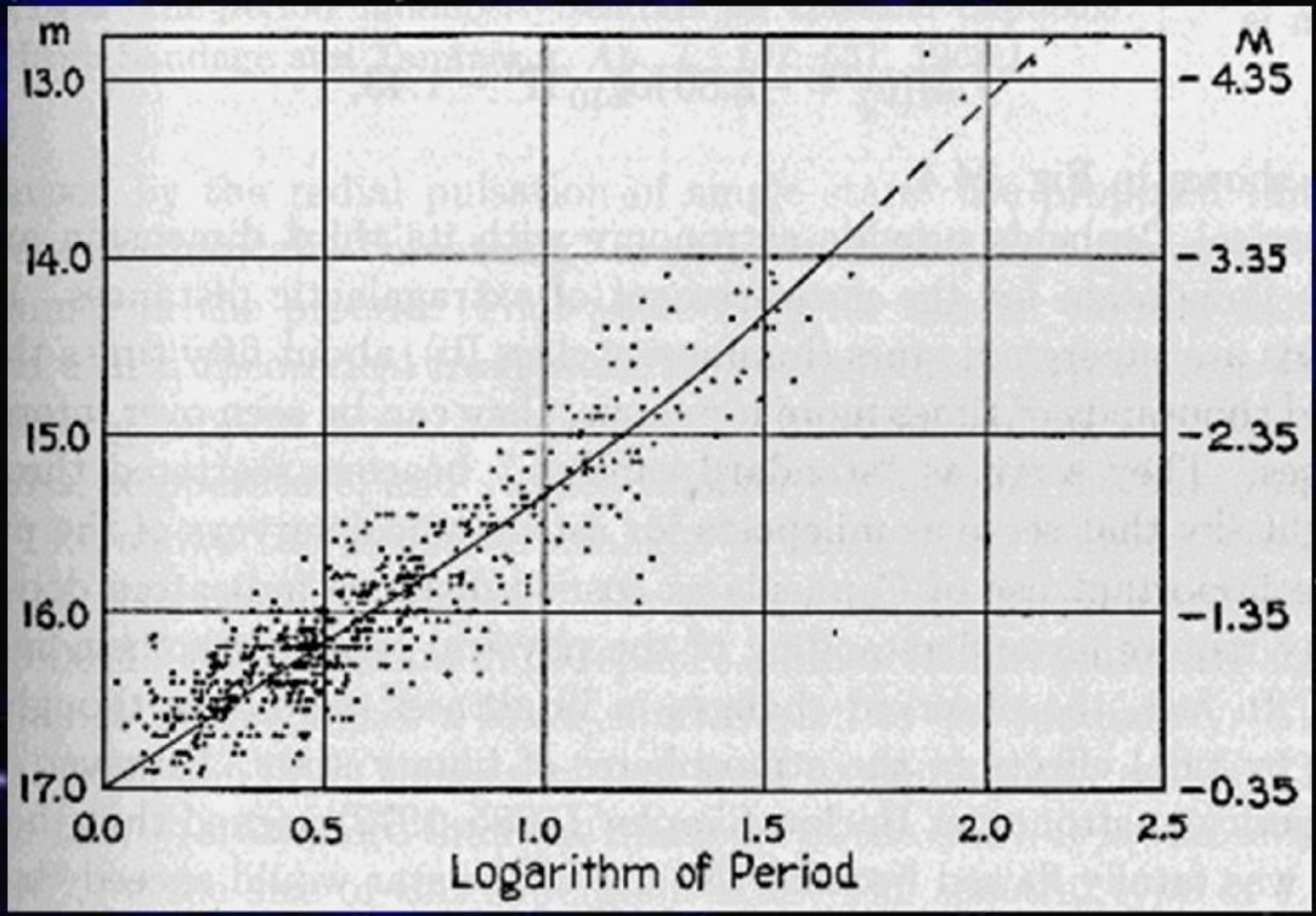
- distance effects are removed

Open Cluster M7



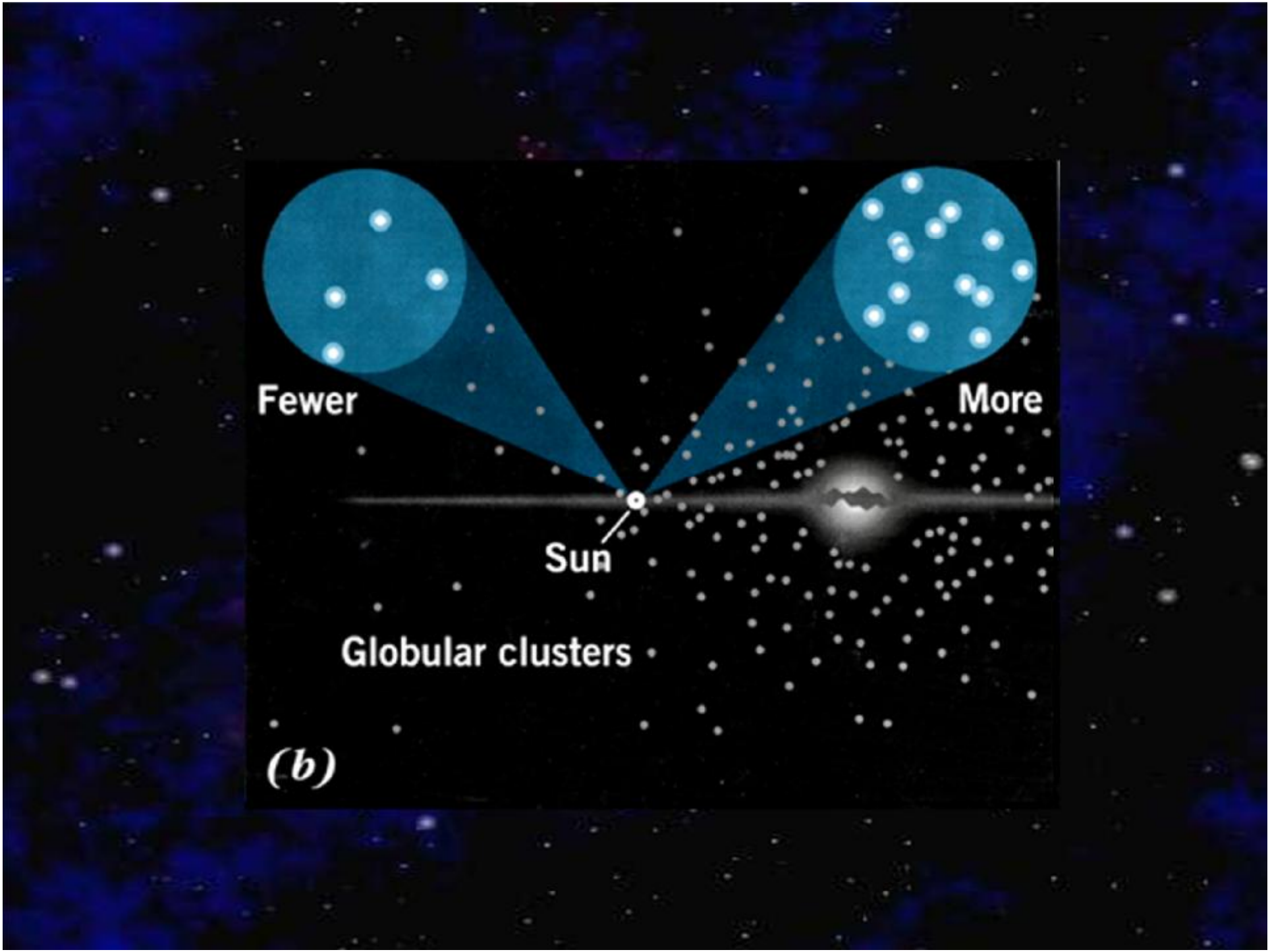

100 000 ly
Sextans Dwarf
Ursa Minor Dwarf
Draco Dwarf
180°
Milky Way
270°
90°
Sagittarius Dwarf
Large Magellanic Cloud
Carina Dwarf
0°
Small Magellanic Cloud
Sculptor Dwarf
Fornax Dwarf
r powell


Brightness variation of δ-Cephei
3.6 - 4.3 Magnitude
Apparent Magnitude
3.5
4.0
4.5
5.4 days
Period
2
4
6
8
10
12
Time (days)
The period-luminosity relation for Cepheid variables.
Absolute Magnitude
-5
-4
-3
-2
-1
1
3
10
30
Period in days


m
M
13.0
14.0
15.0
16.0
17.0
-4.35
-3.35
-2.35
-1.35
-0.35
0.0
0.5
1.0
1.5
2.0
2.5
Logarithm of Period

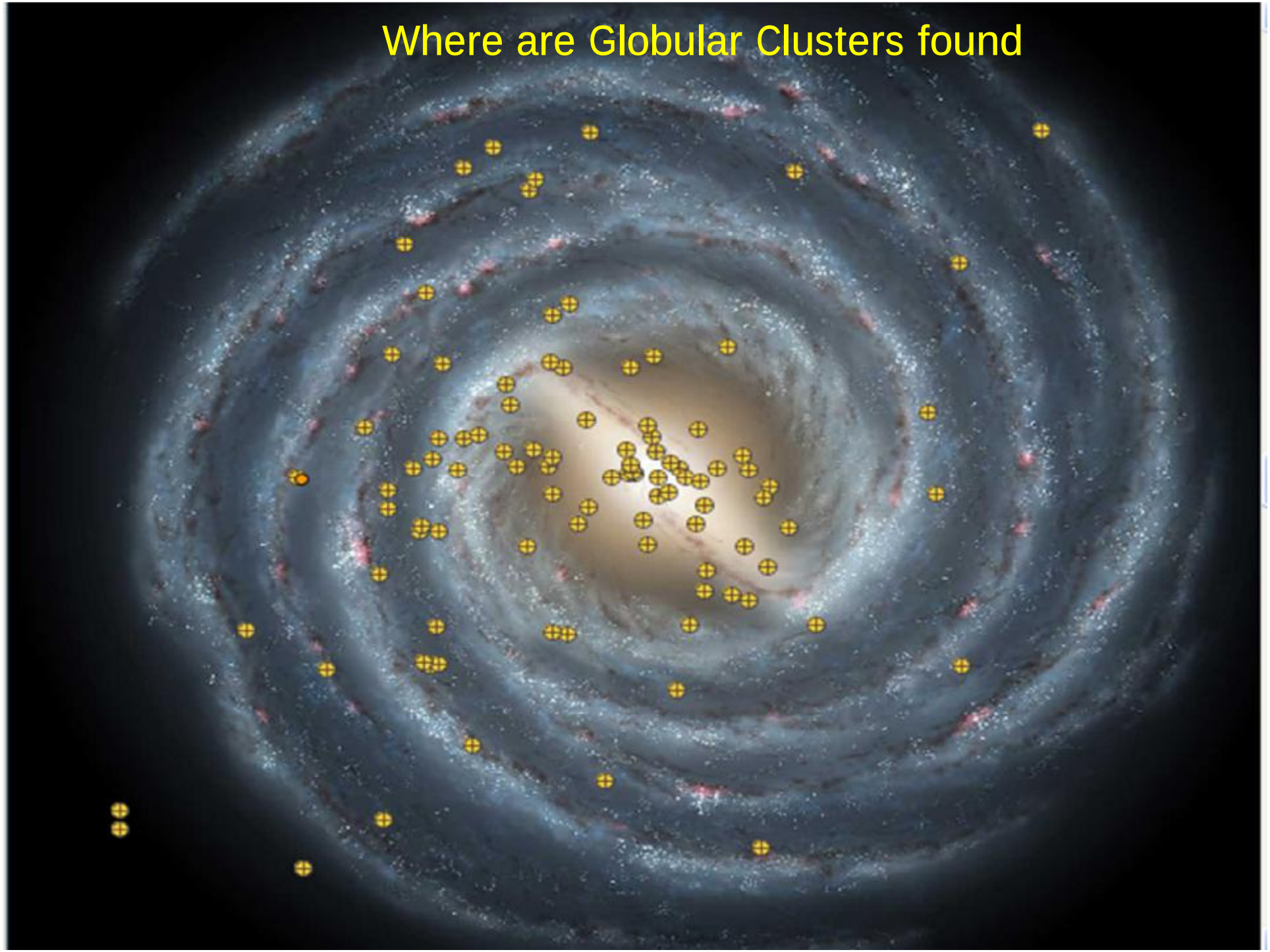
Where is the Sun located in the Milky Way?

- Harlow Shapley (1915)
- Globular Clusters

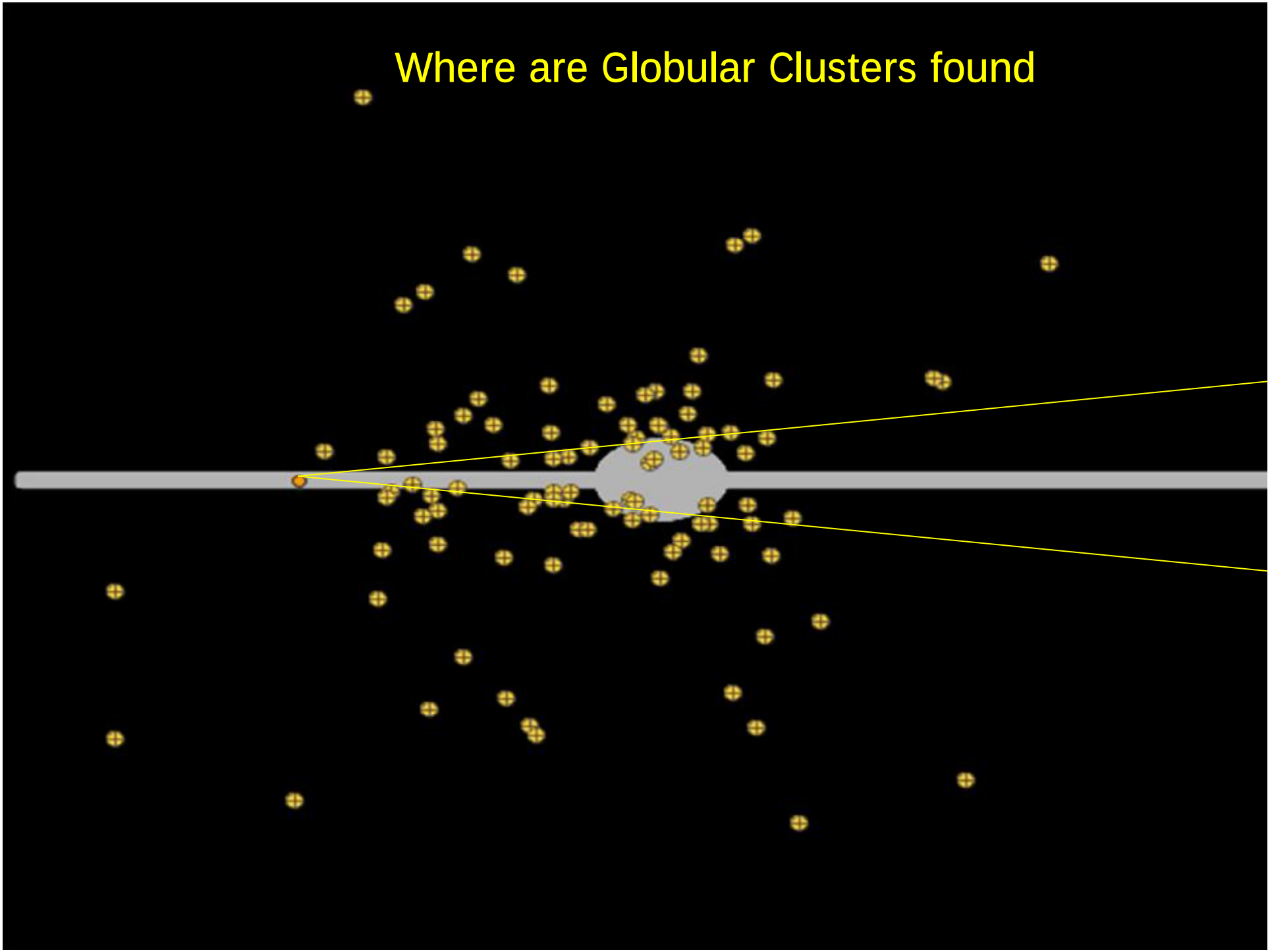

Fewer
More
Sun
Globular clusters
(b)

Harlow Shapley made the bold leap to assume that the globulars would be evenly distributed around the central core of the galaxy

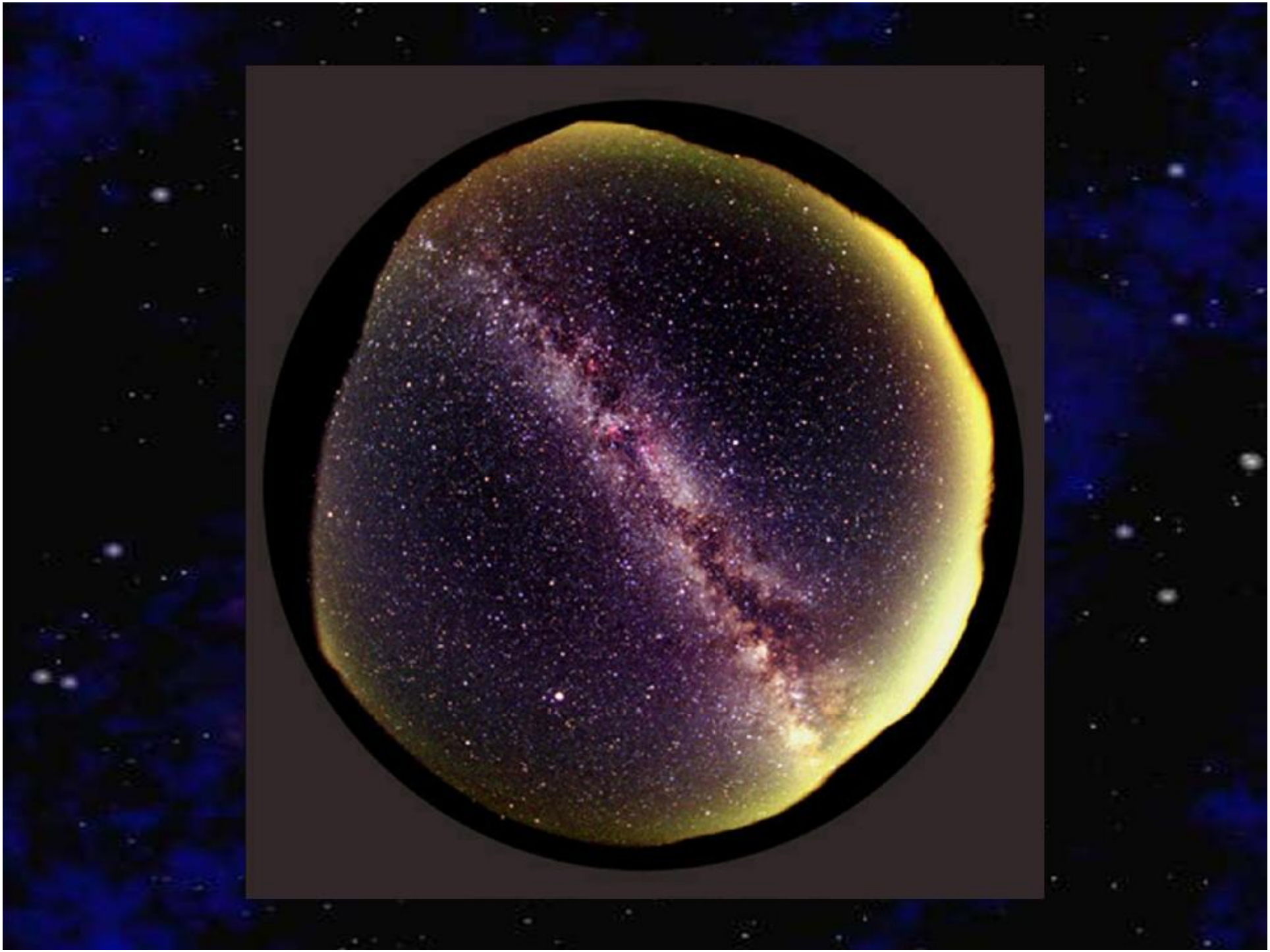
Where are Globular Clusters found



Where are Globular Clusters found

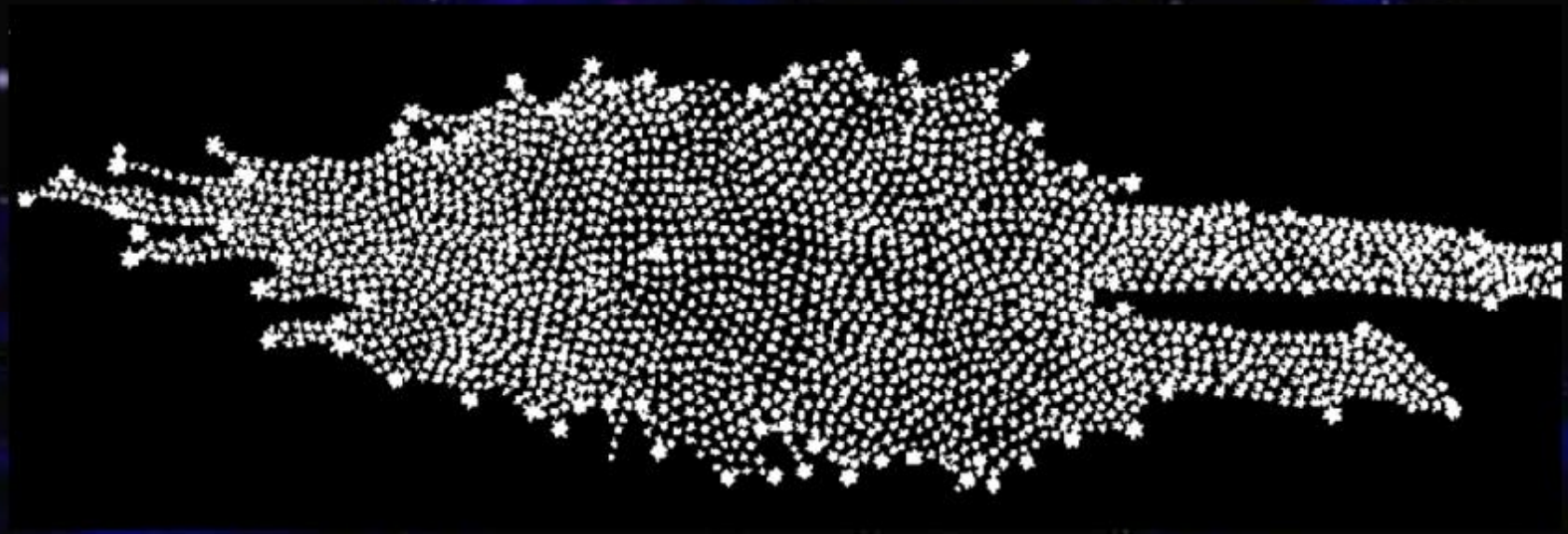


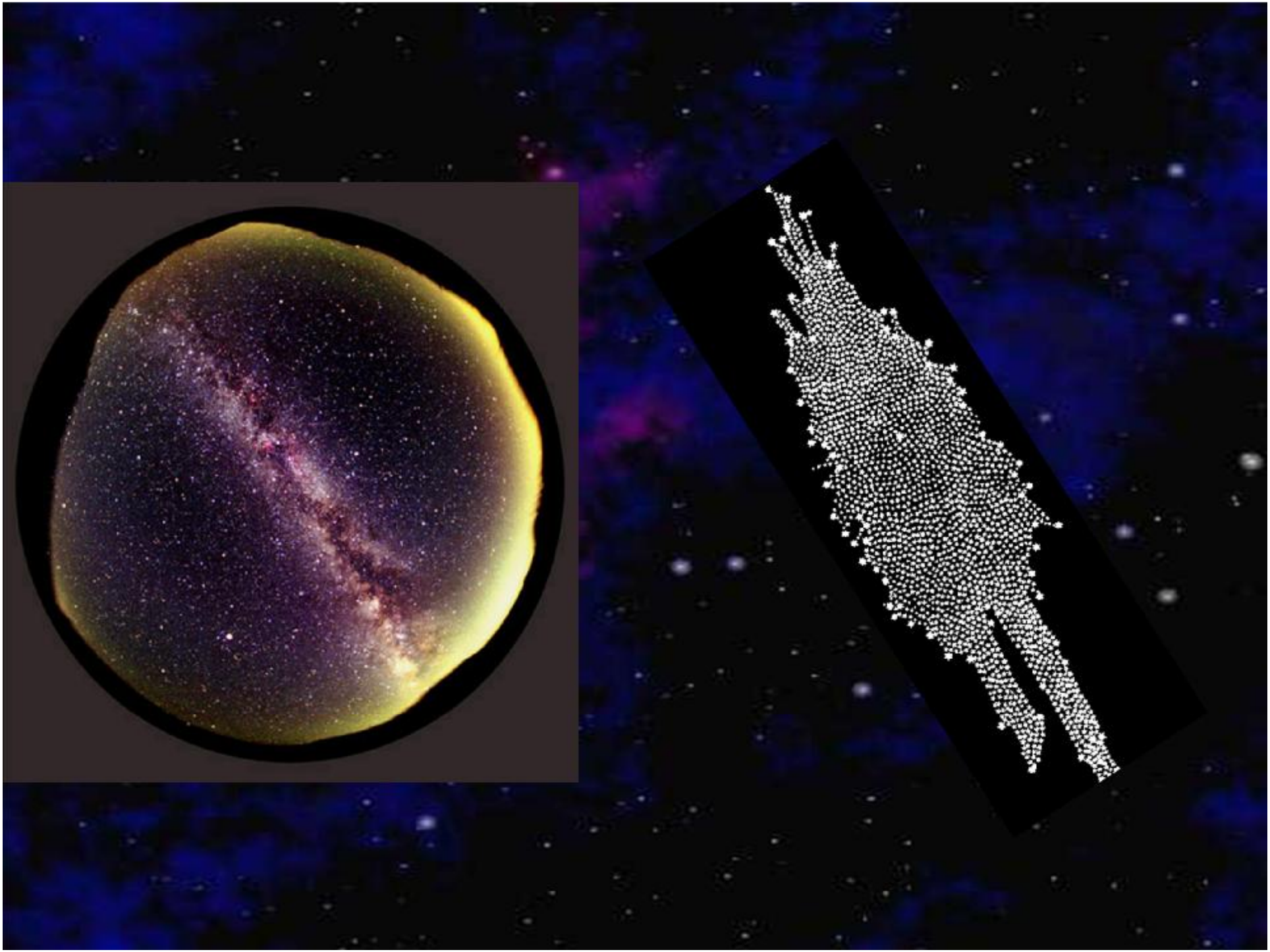
GALAXIES



What is the shape of the Milky Way Galaxy?

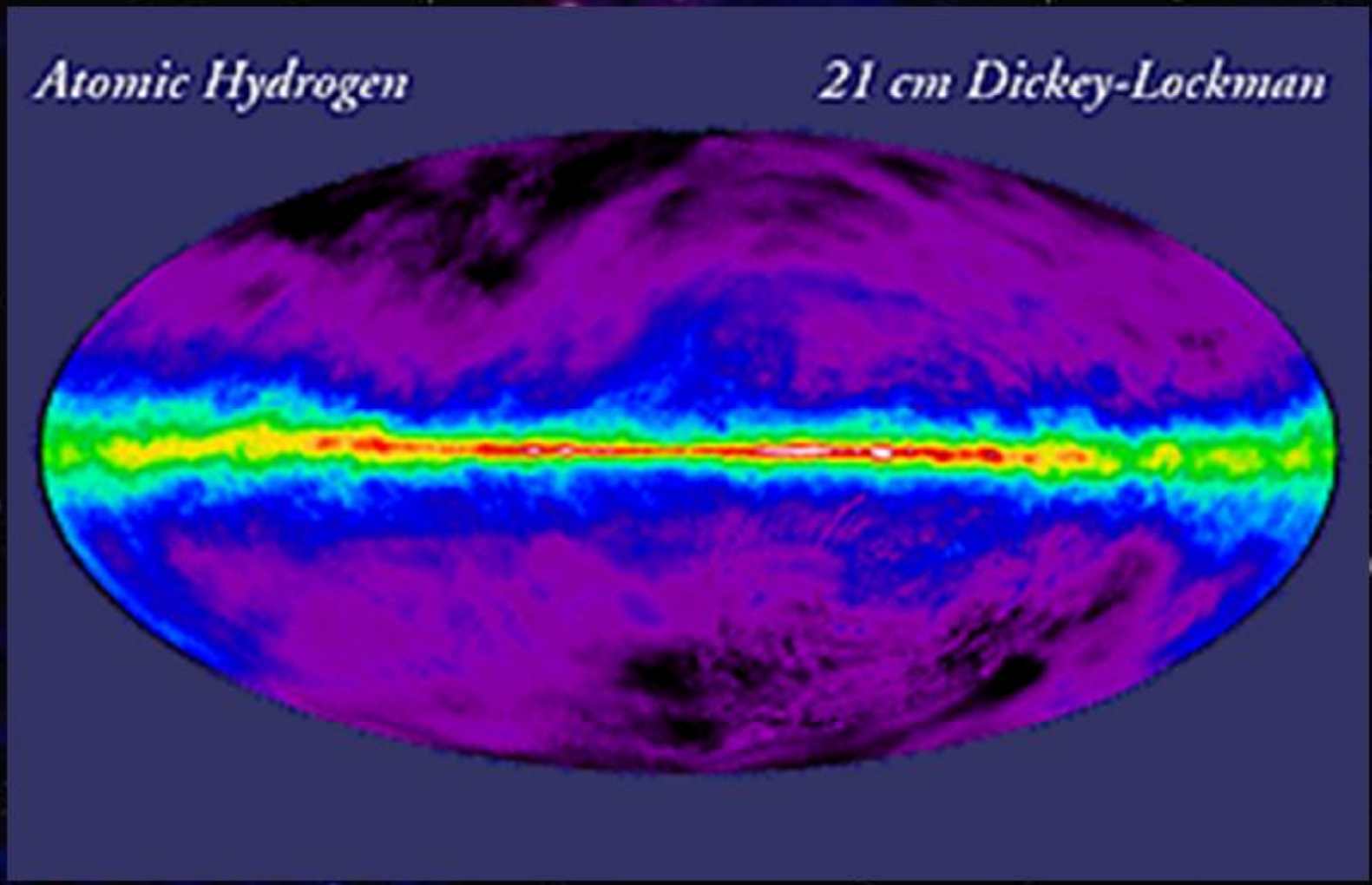
William Herschel



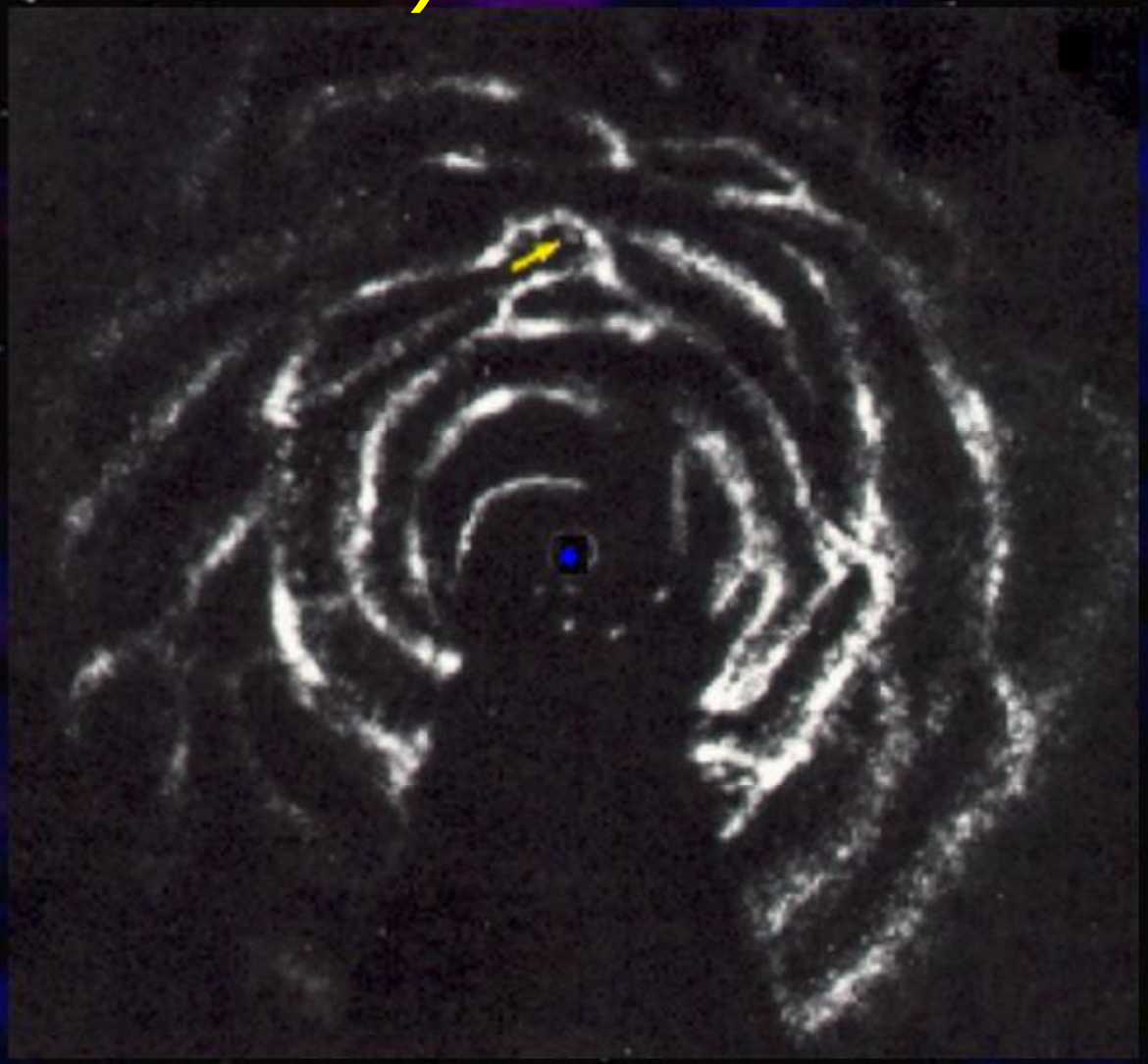


Near-infrared all-sky (cool stars)

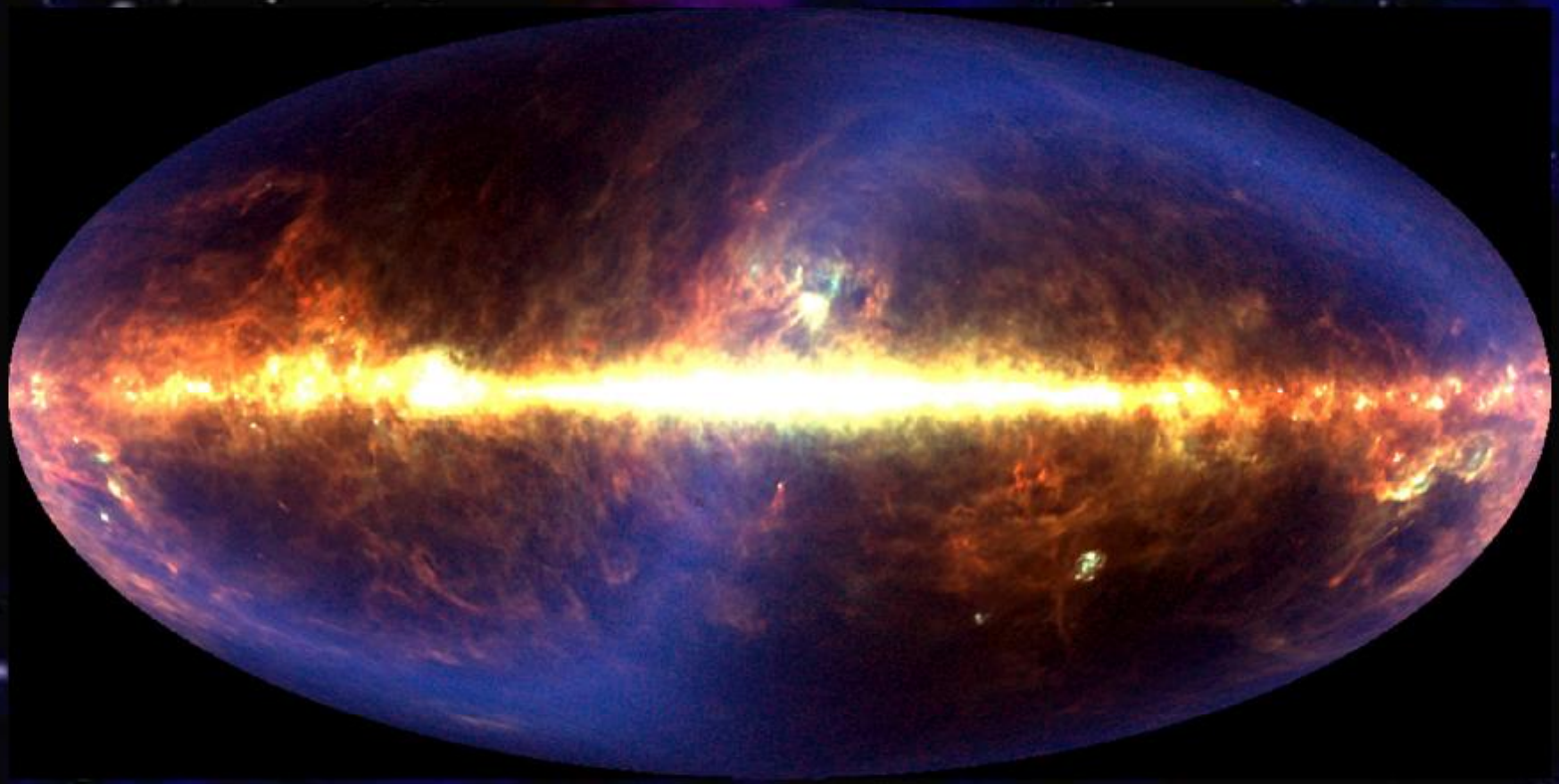
Atomic Hydrogen (all sky)



Location of hydrogen
(top-down view)

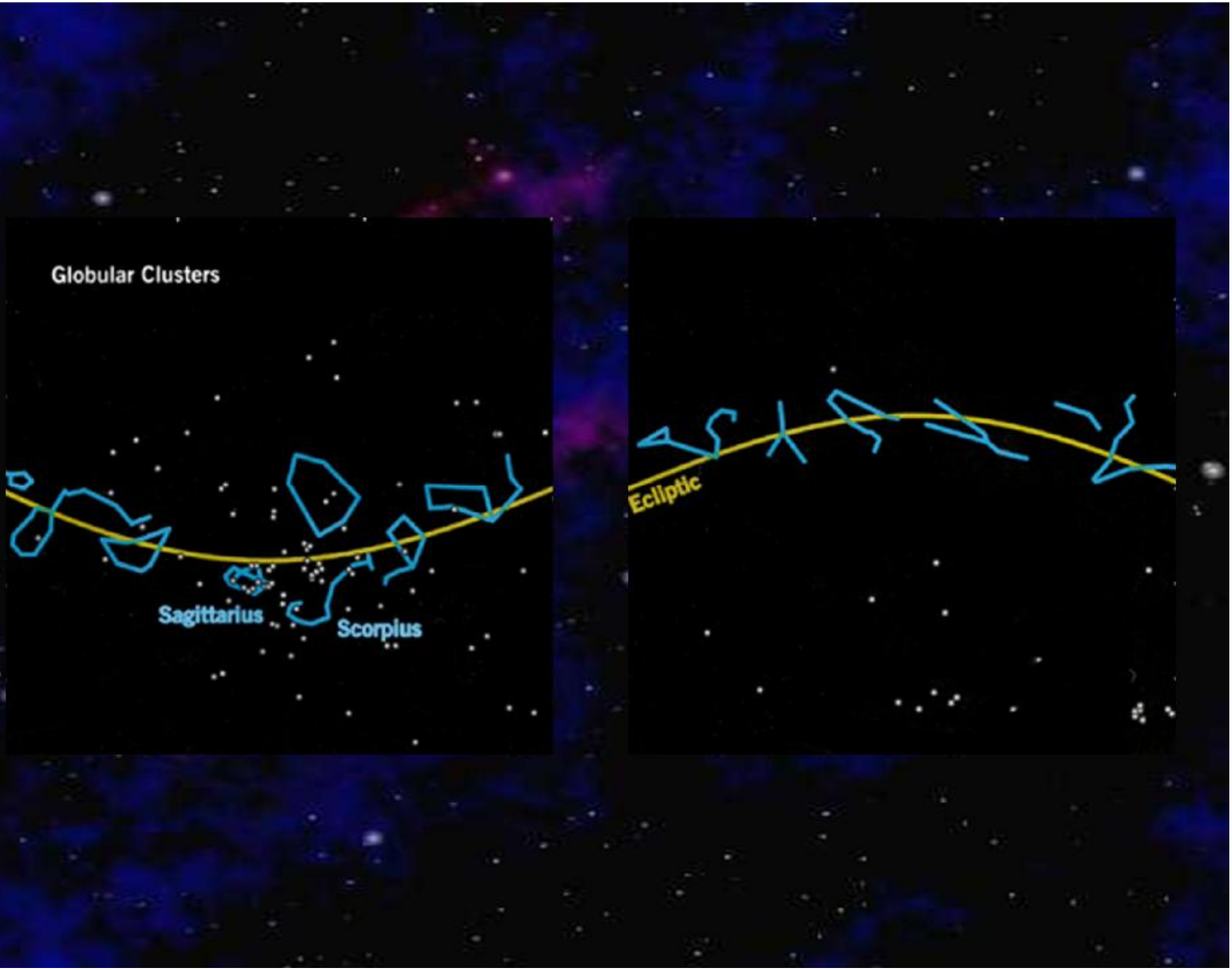


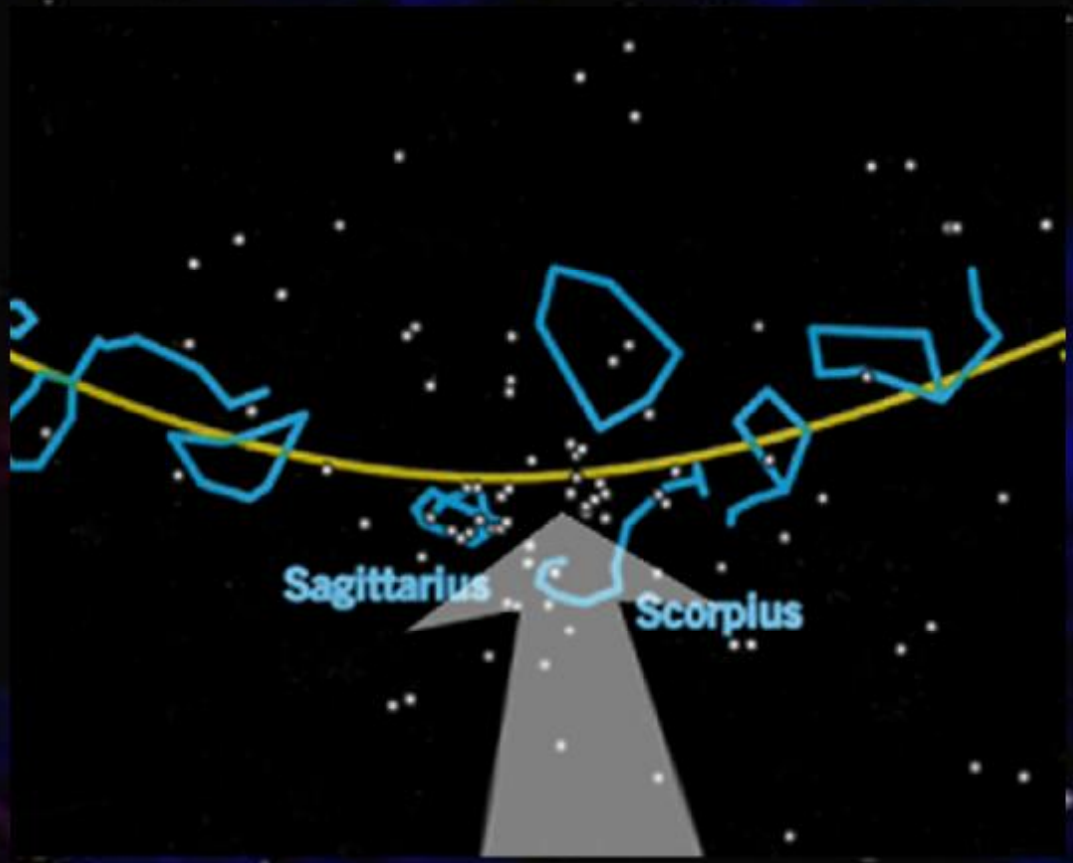
Far-infrared all-sky (interstellar dust)



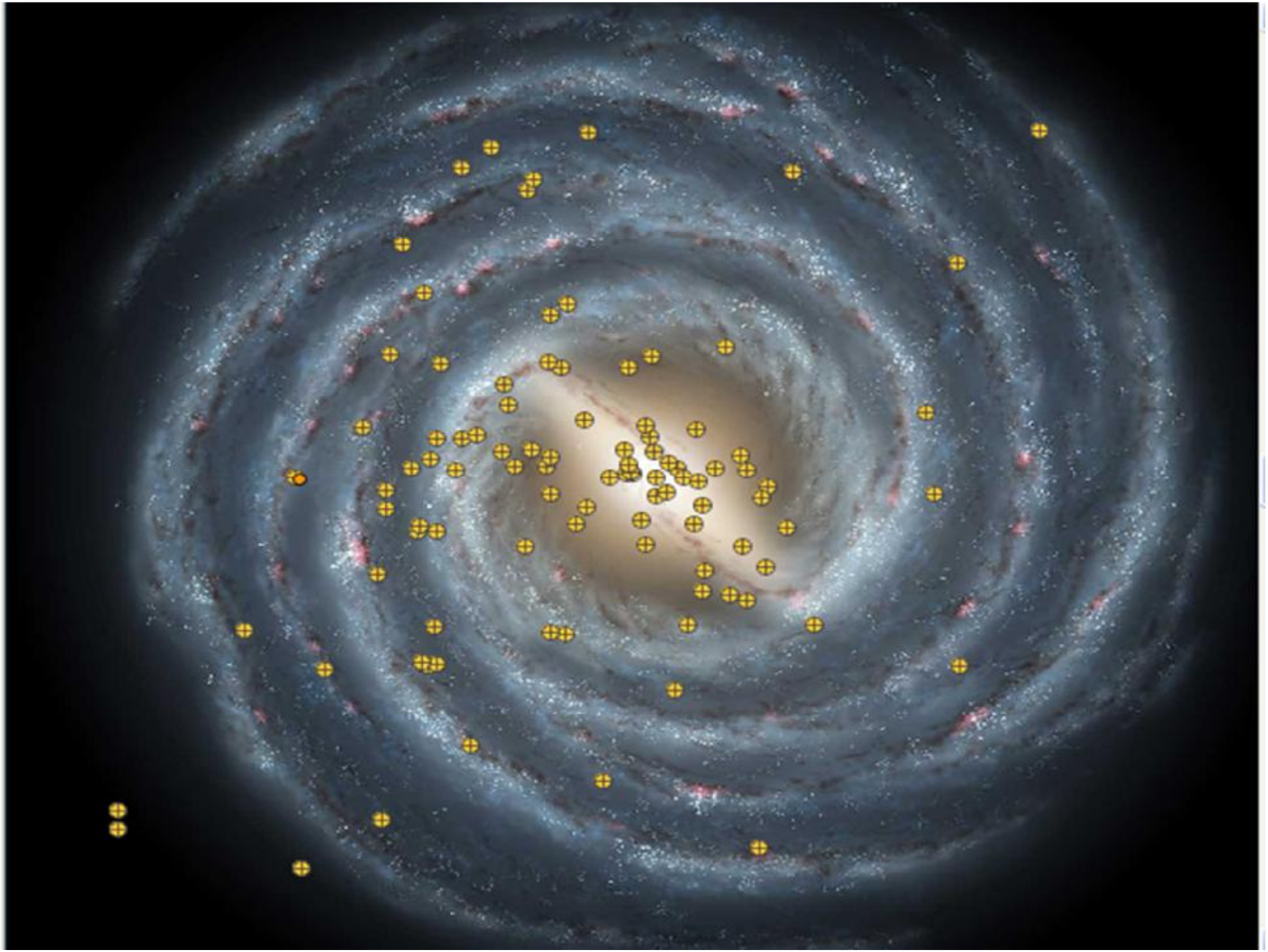
NGC 891

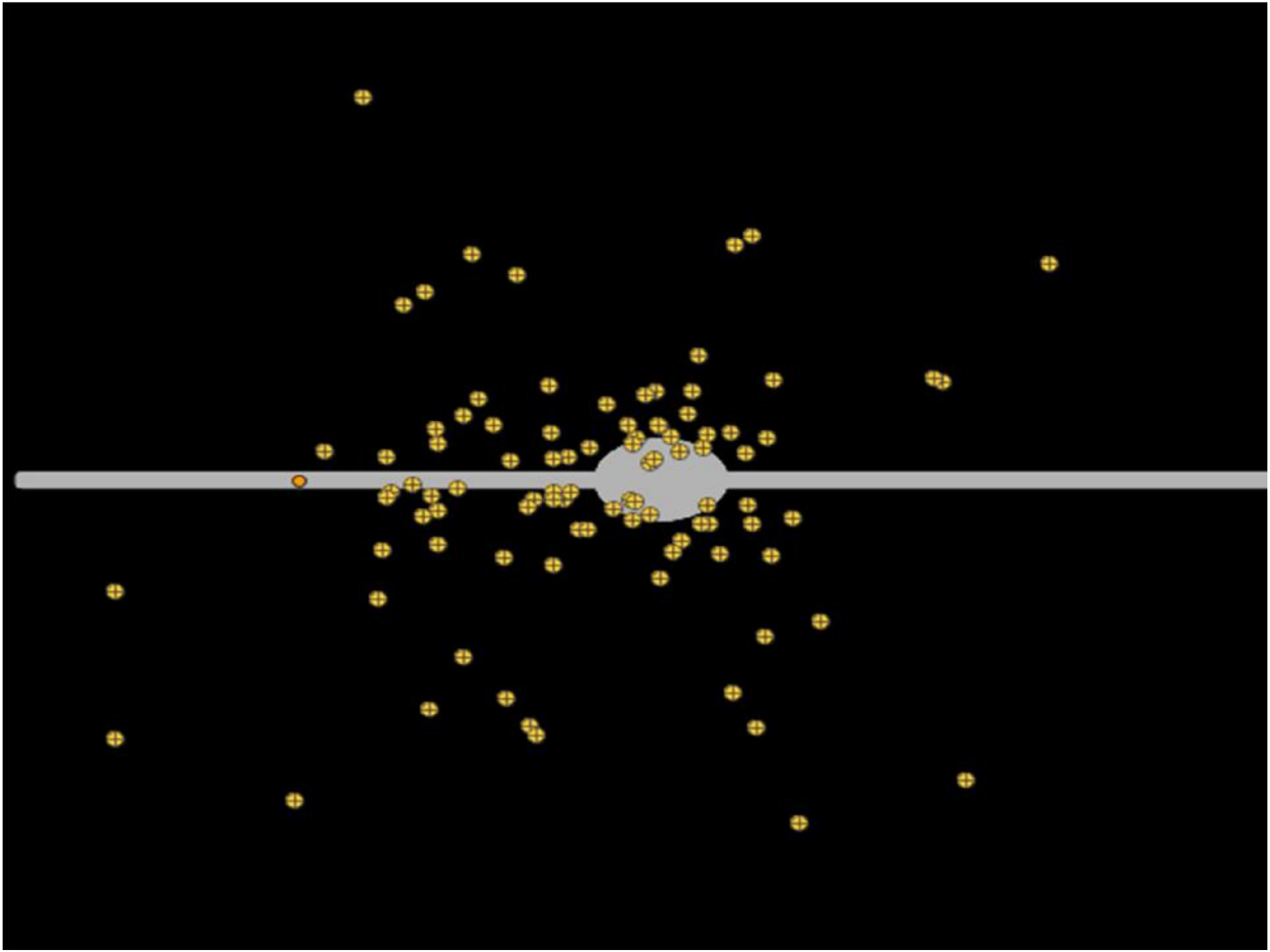
...the Milky Way is a
“spiral” galaxy

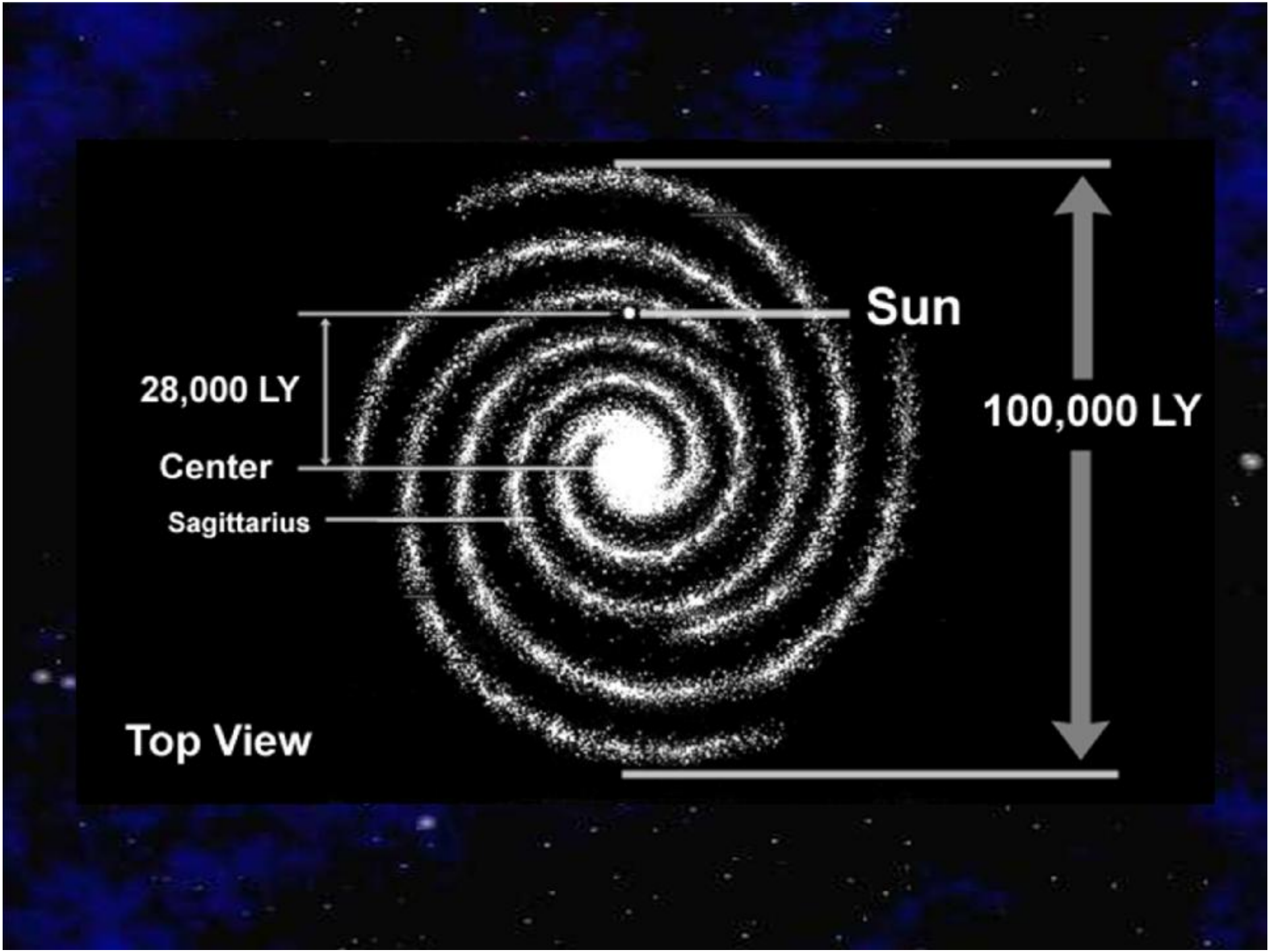

Globular Clusters
Sagittarius
Scorpius
Ecliptic

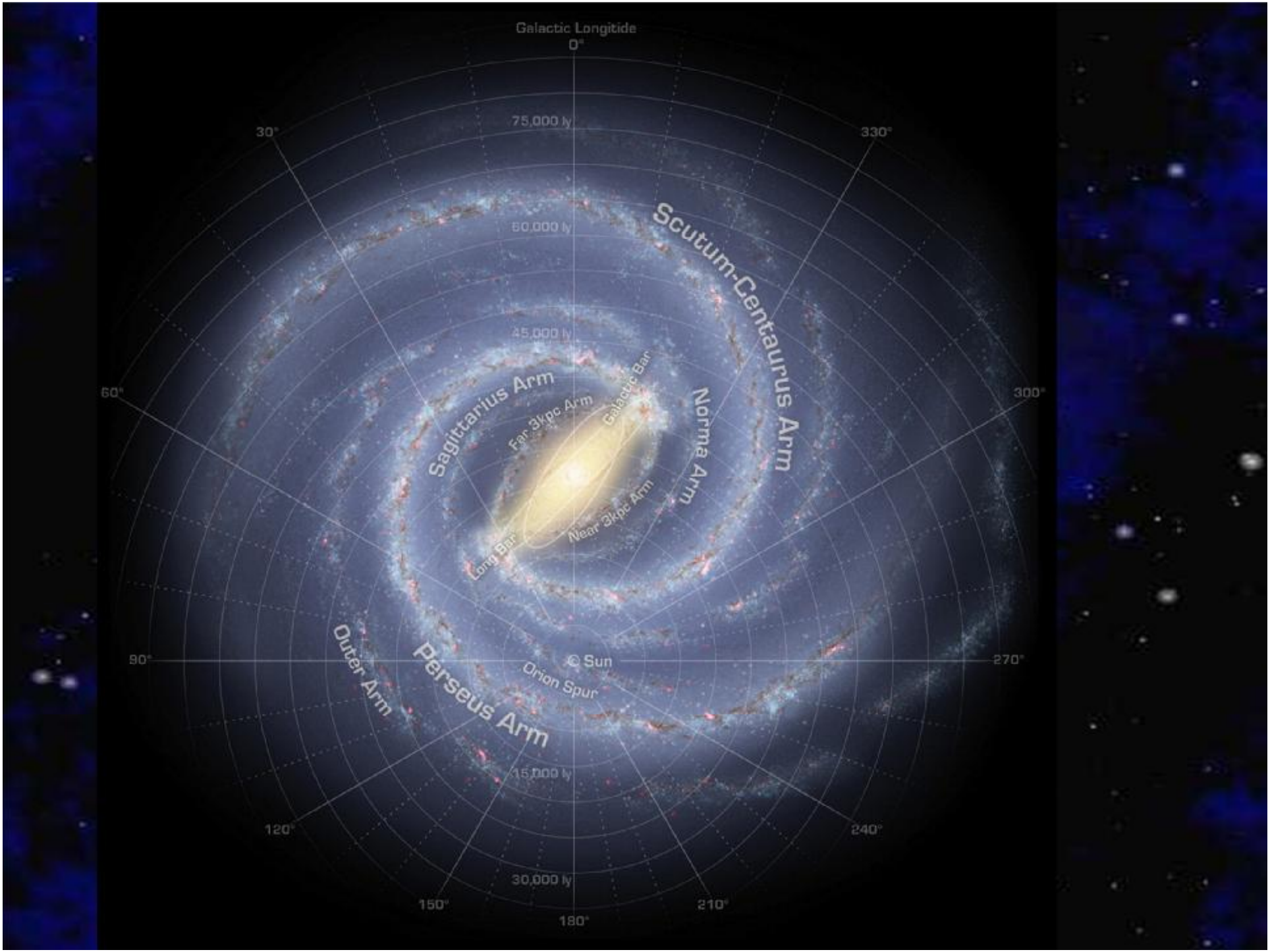


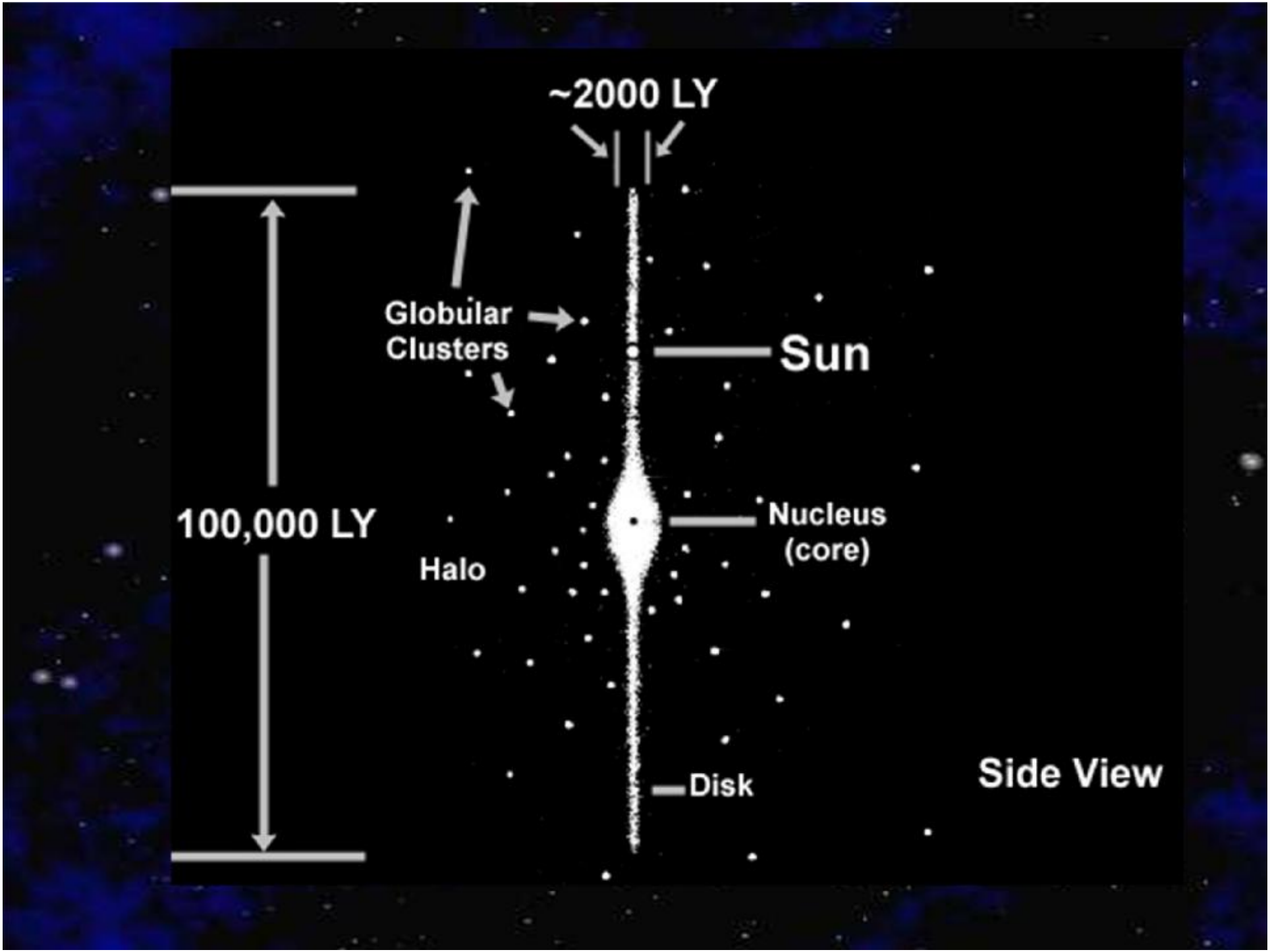
- Center of the Milky Way is in Sagittarius
- The distance from the Sun to the center is ~ **28,000 light years**

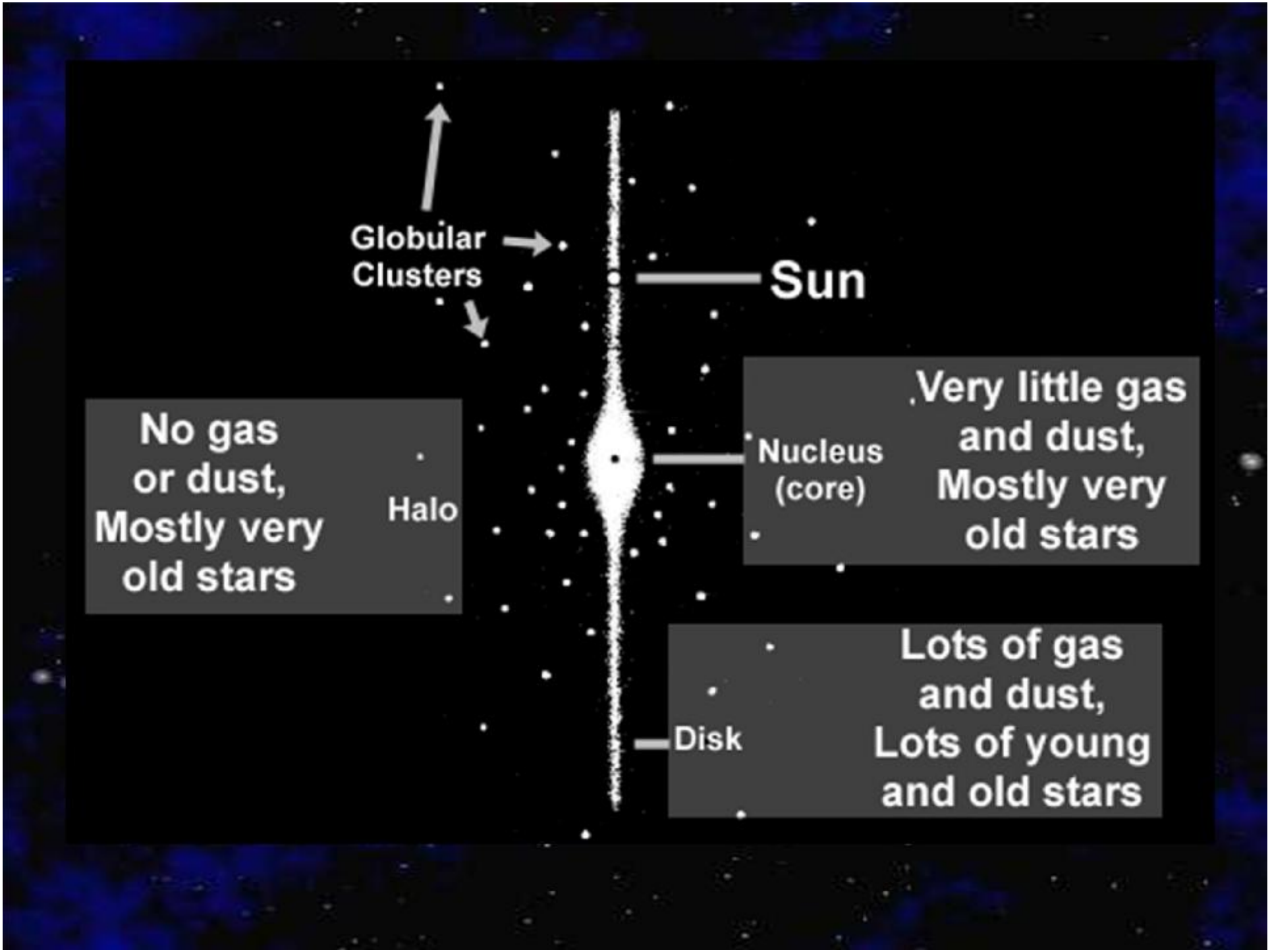




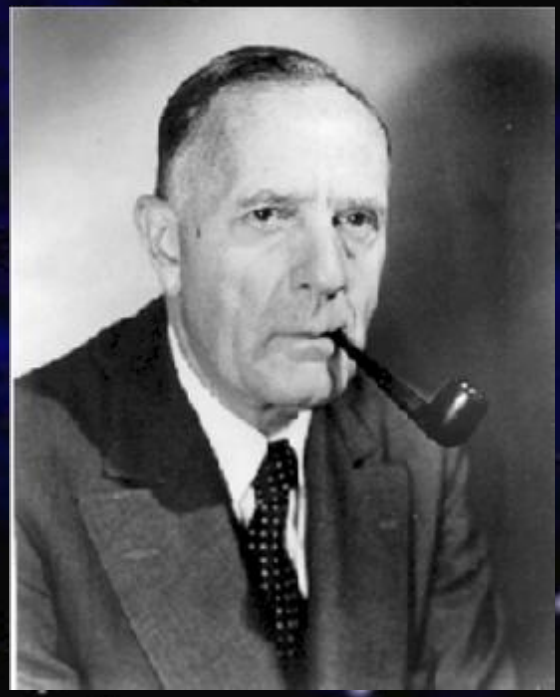

Sun
28,000 LY
100,000 LY
Center
Sagittarius
Top View


Galactic Longitide
0°
30°
330°
75,000 ly
60,000 ly
45,000 ly
60°
300°
Scutum-Centaurus Arm
Sagittarius Arm
Far 3kpc Arm
Galactic Bar
Norma Arm
Near 3kpc Arm
Long Bar
90°
270°
Outer Arm
Perseus Arm
Sun
Orion Spur
15,000 ly
120°
240°
30,000 ly
150°
210°
180°

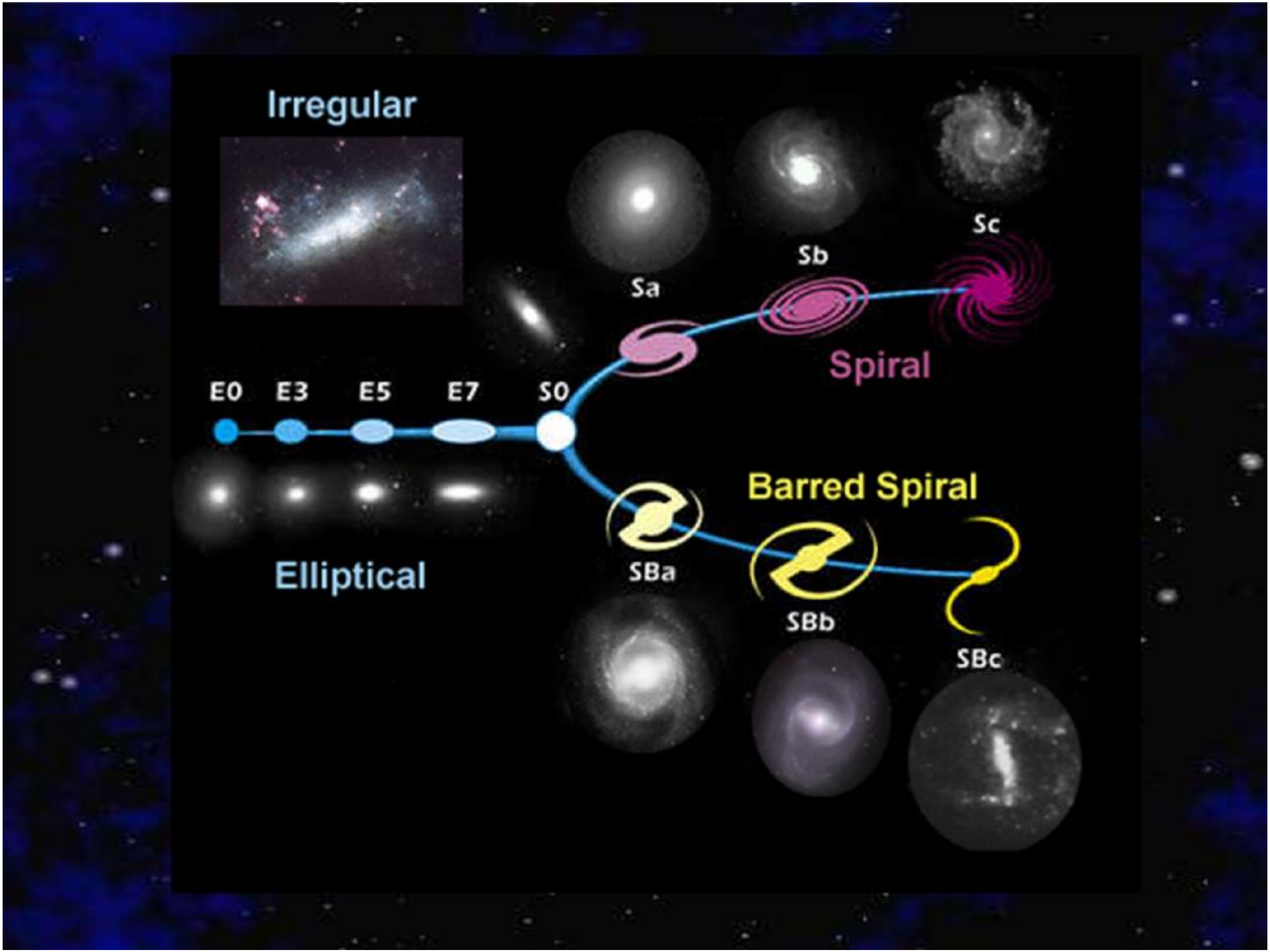

~2000 LY
Globular
Clusters
Sun
100,000 LY
Nucleus
(core)
Halo
Disk
Side View


Globular Clusters
Sun
No gas or dust, Mostly very old stars
Halo
Nucleus (core)
Very little gas and dust, Mostly very old stars
Disk
Lots of gas and dust, Lots of young and old stars

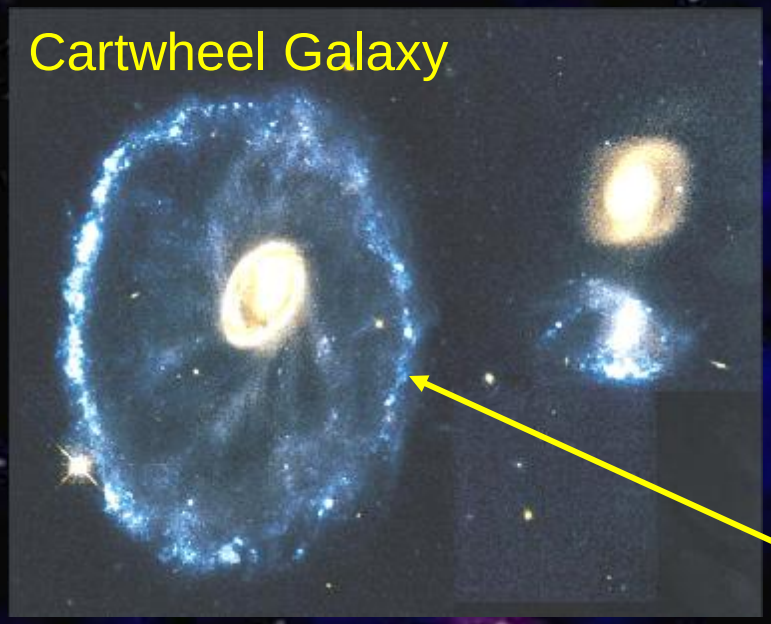
Hubble Galaxy Classification Sequence



- Edwin Hubble (1920's-1940's)
- Classified galaxies based upon SIZE, SHAPE, etc...


Irregular
Sa
Sb
Sc
Spiral
E0
E3
E5
E7
S0
Elliptical
Barred Spiral
SBa
SBb
SBc

Interacting Galaxies



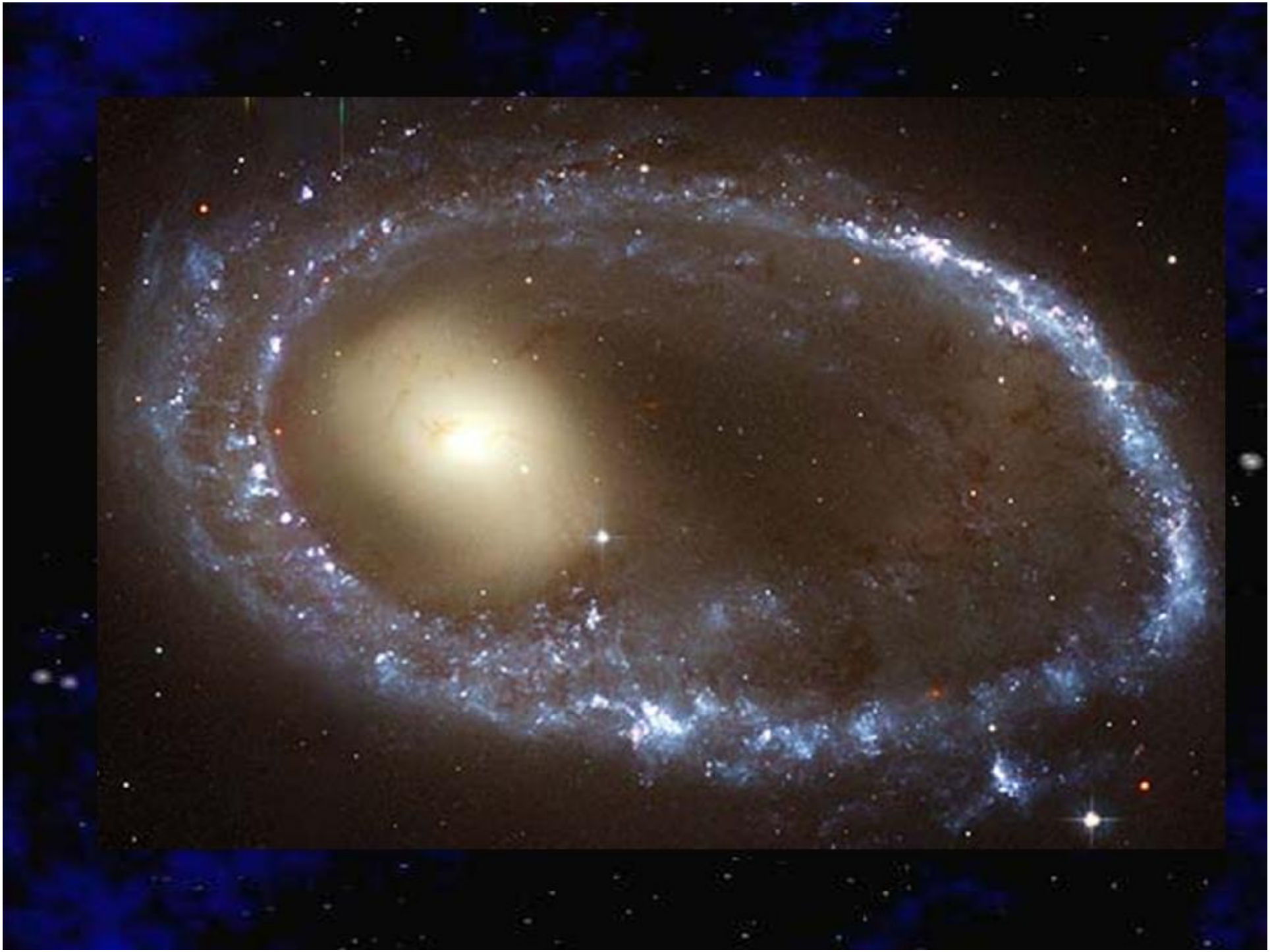
Particularly in rich clusters, galaxies can collide and interact.

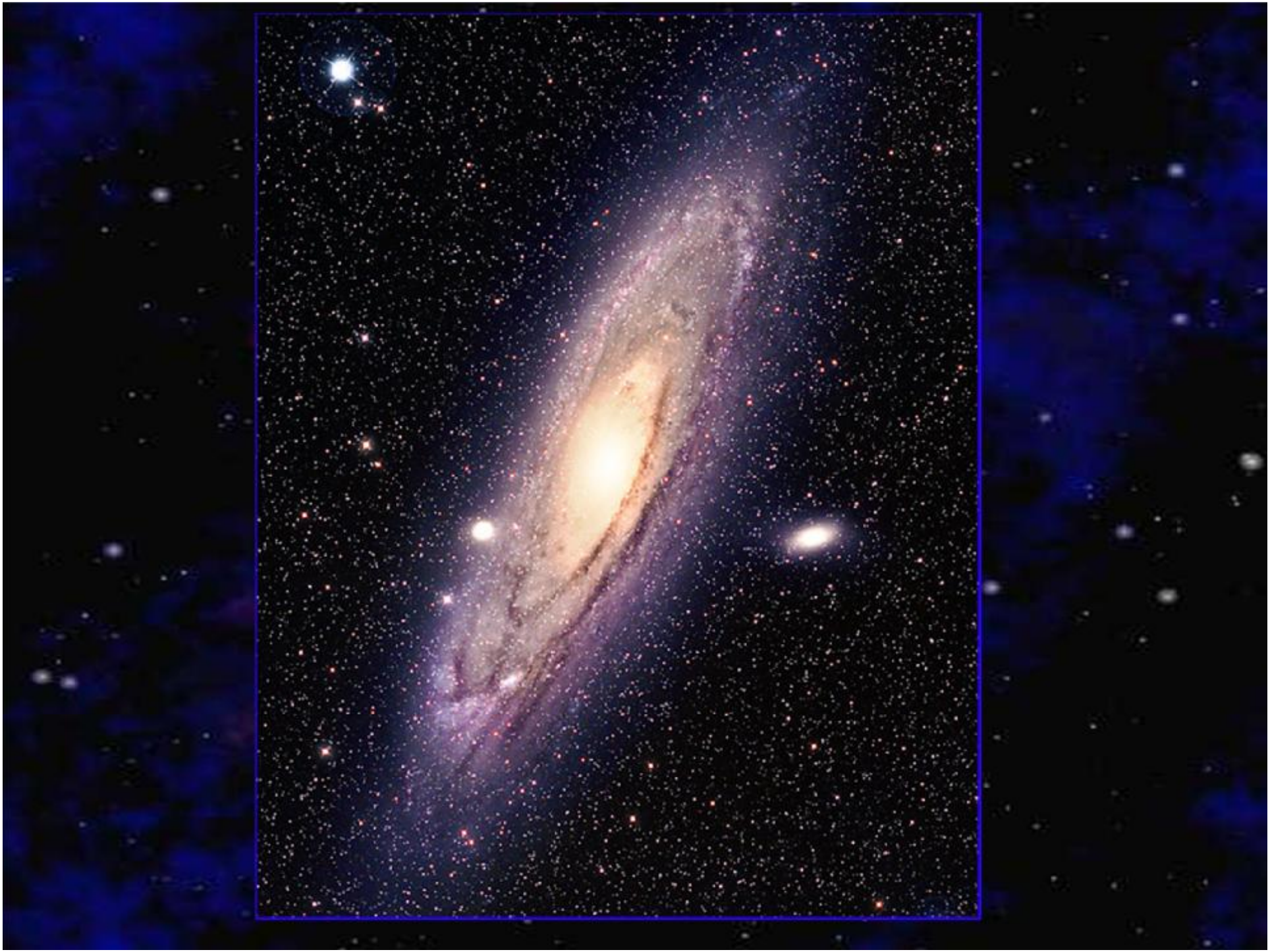
Galaxy collisions can produce

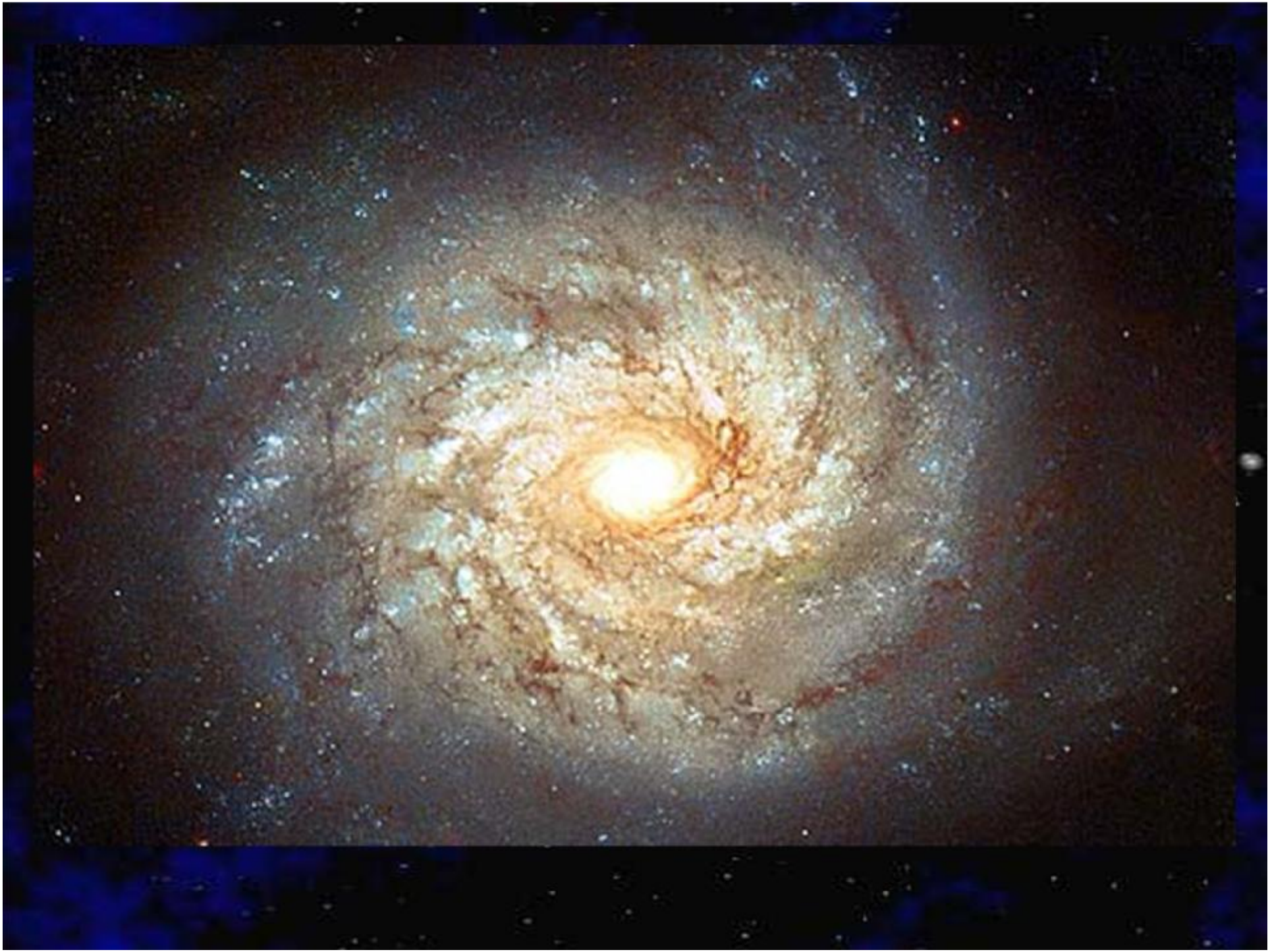
ring galaxies and

tidal tails.

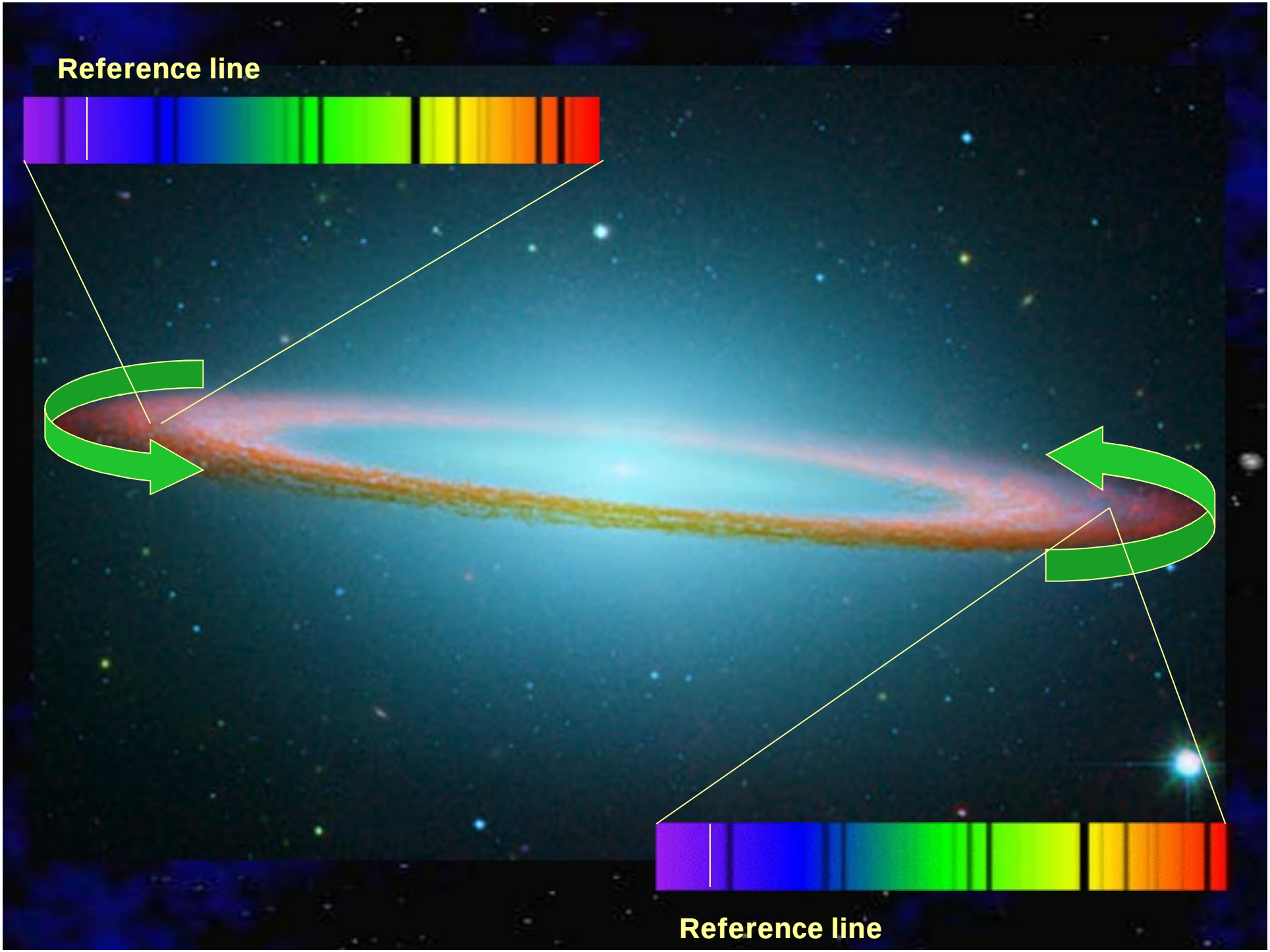
Often triggering active star formation: Starburst galaxies

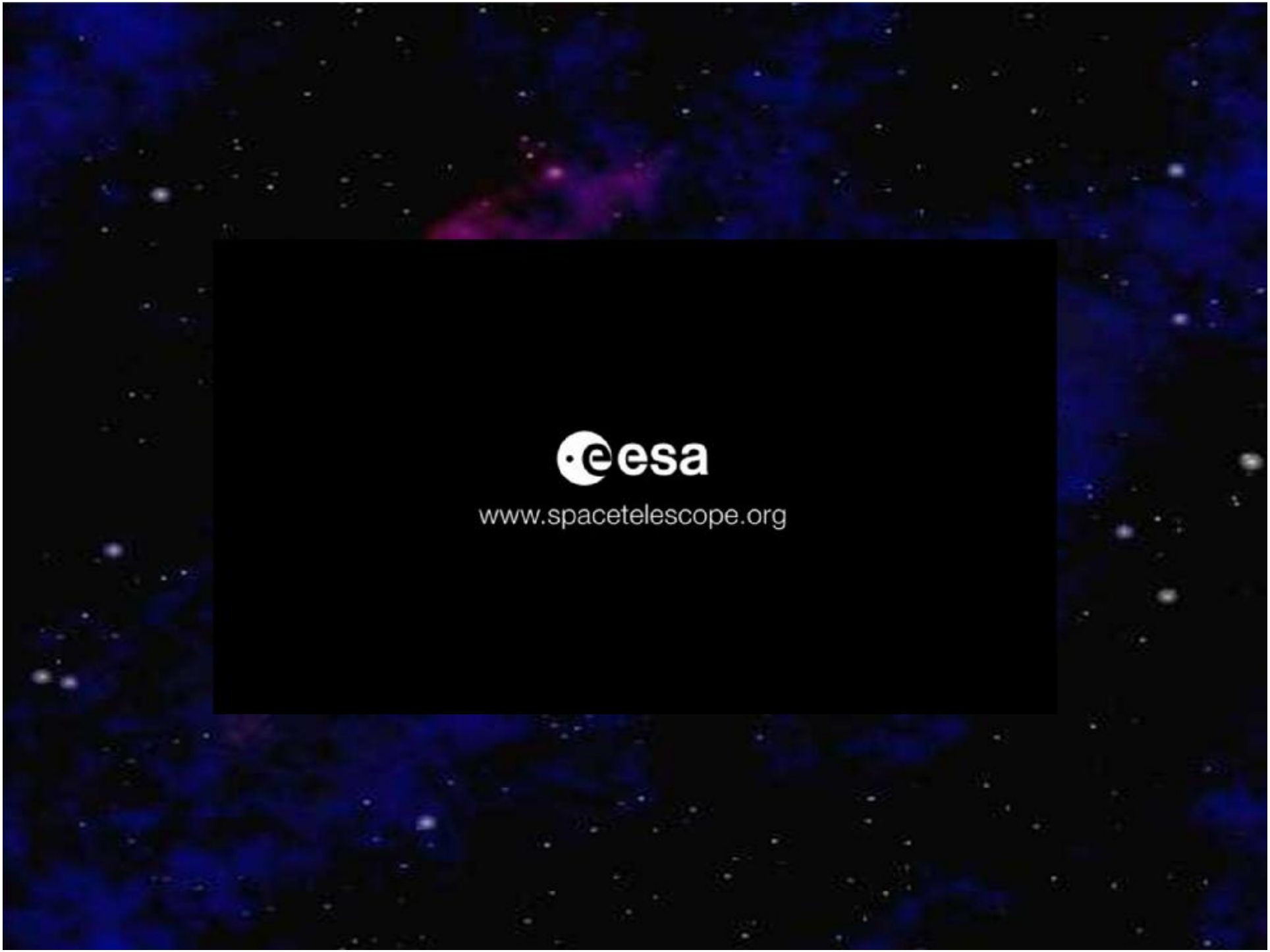


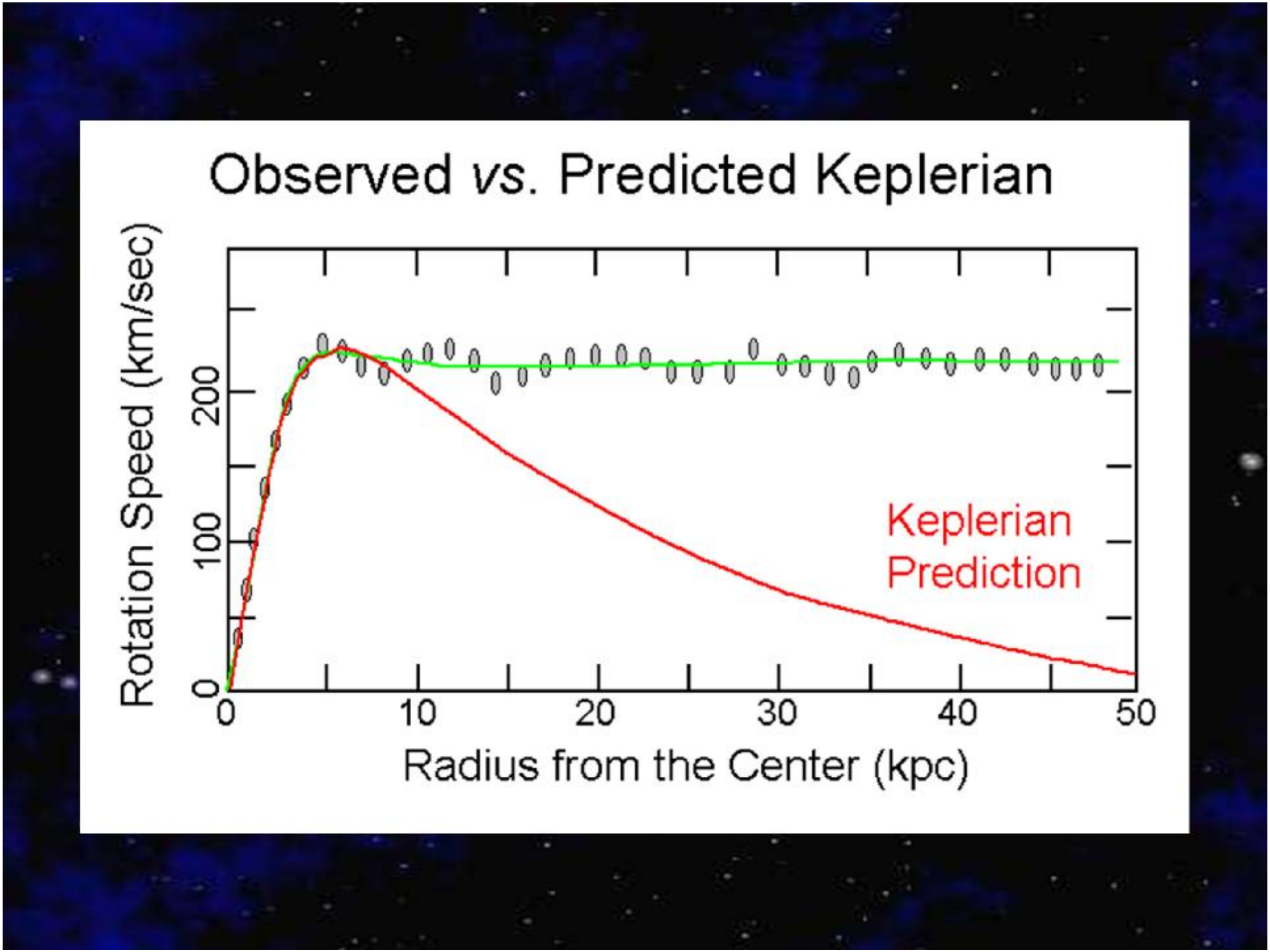


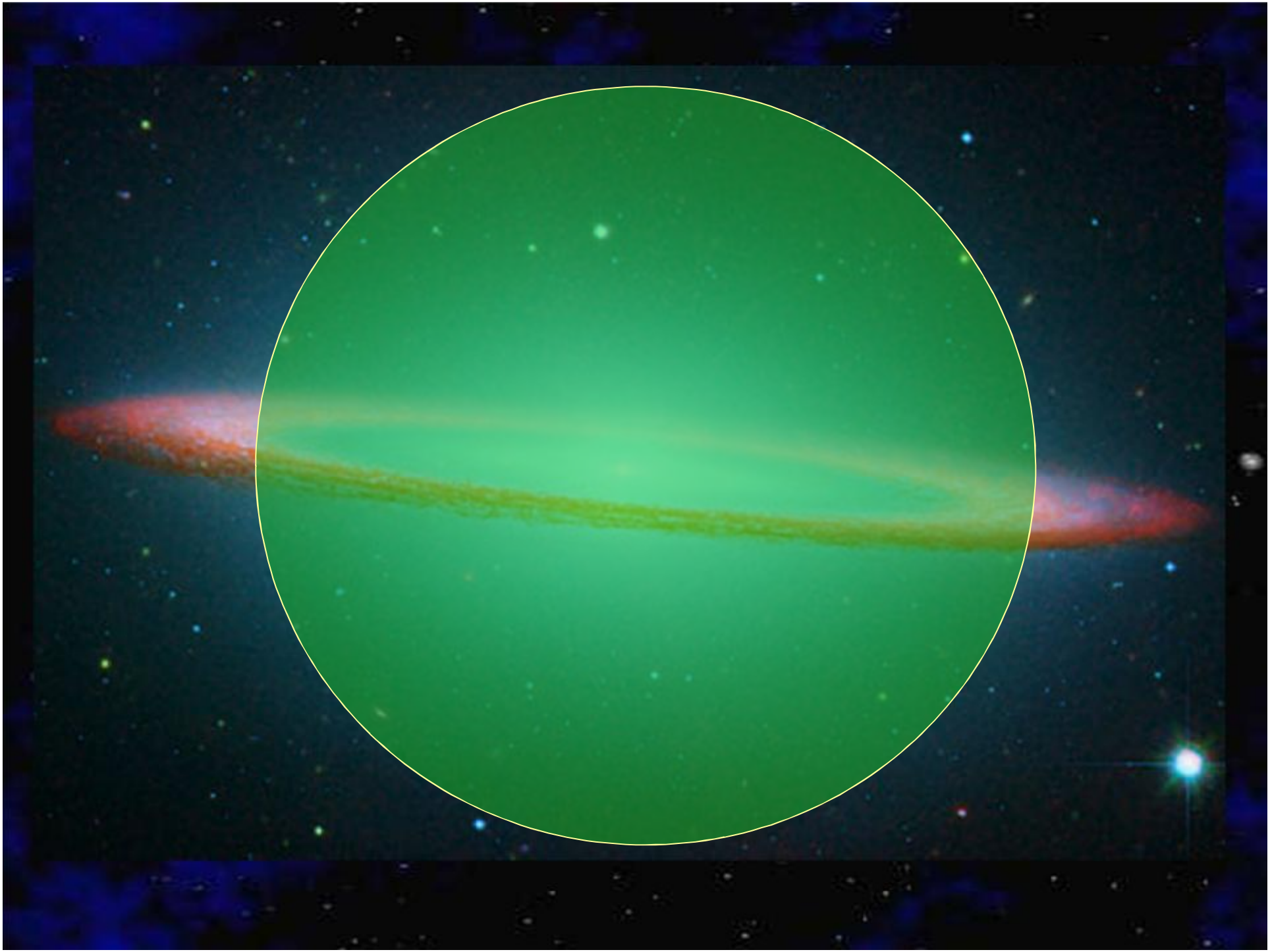


What we see is NOT what we may get!!
Great enigmas still exist


Reference line
Reference line


esa
www.spacetelescope.org


Observed vs. Predicted Keplerian
Rotation Speed (km/sec)
0
100
200
0
10
20
30
40
50
Radius from the Center (kpc)
Keplerian
Prediction



The only explanation for this curve is that a large Fraction of the matter in a galaxy exists as a vast halo around the core of the galaxy

First observed and predicted by Fritz Zwicky...1930's

Since the matter is not visible, called dark matter!

~90% of all the matter in a galaxy is dark matter

What are the scales we have learned about?

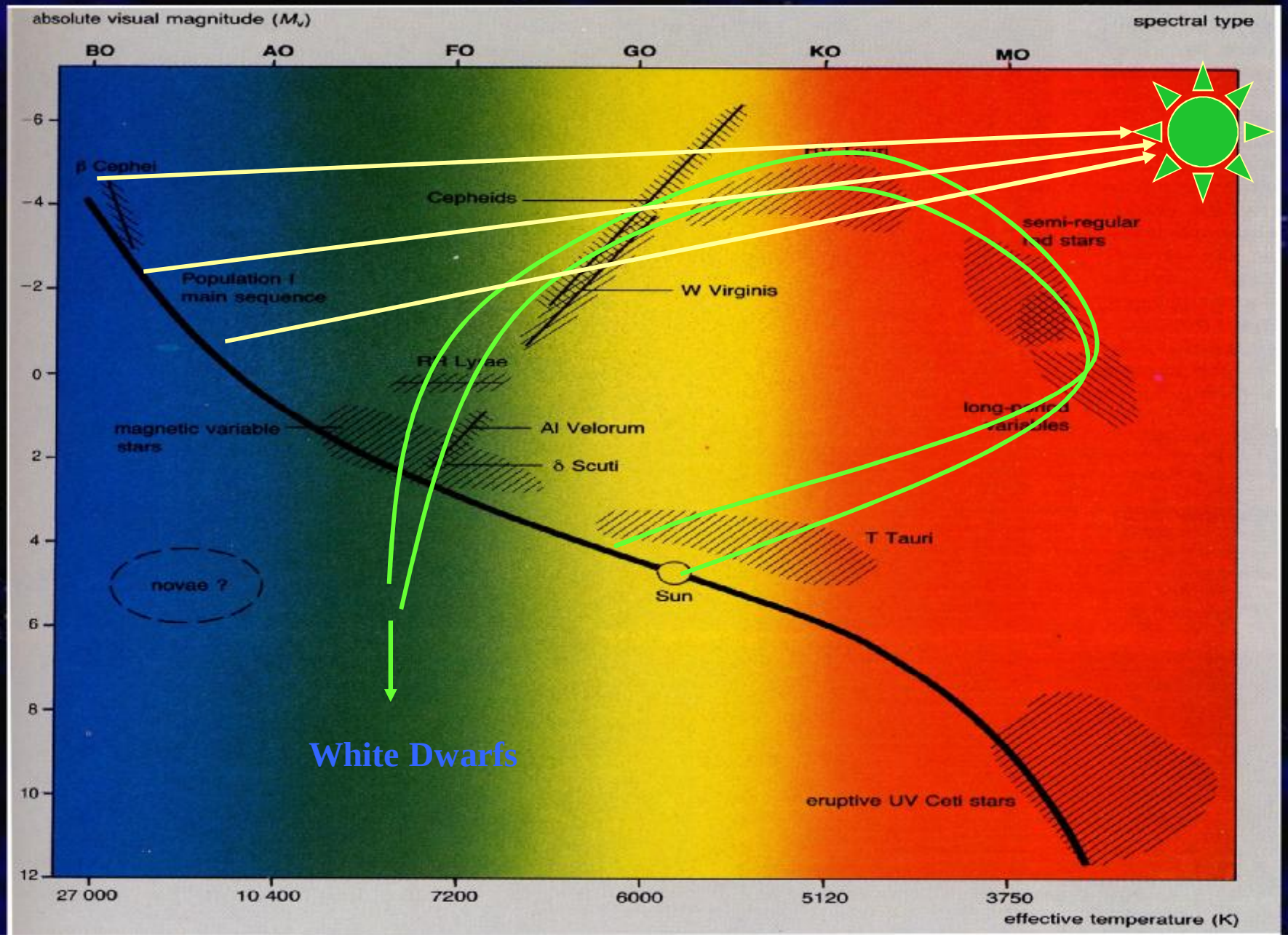
1. The Earth-Moon	~200,000 miles
2. The Solar System	~1,000,000,000 miles
3. The local stellar neighbor	~1,000,000,000,000,000 miles
4. The galaxy, globular clusters	~1,000,000,000,000,000,000 miles
5. The local galactic neighbor	~100,000,000,000,000,000,000 miles
6. Our neighborly galaxy cluster	~10,000,000,000,000,000,000,000 miles
7. SuperClusters	~100,000,000,000,000,000,000,000 miles
8. The very edge....?	~100,000,000,000,000,000,000,000.... miles

What are the scales we have learned about?
How are their distances determined?

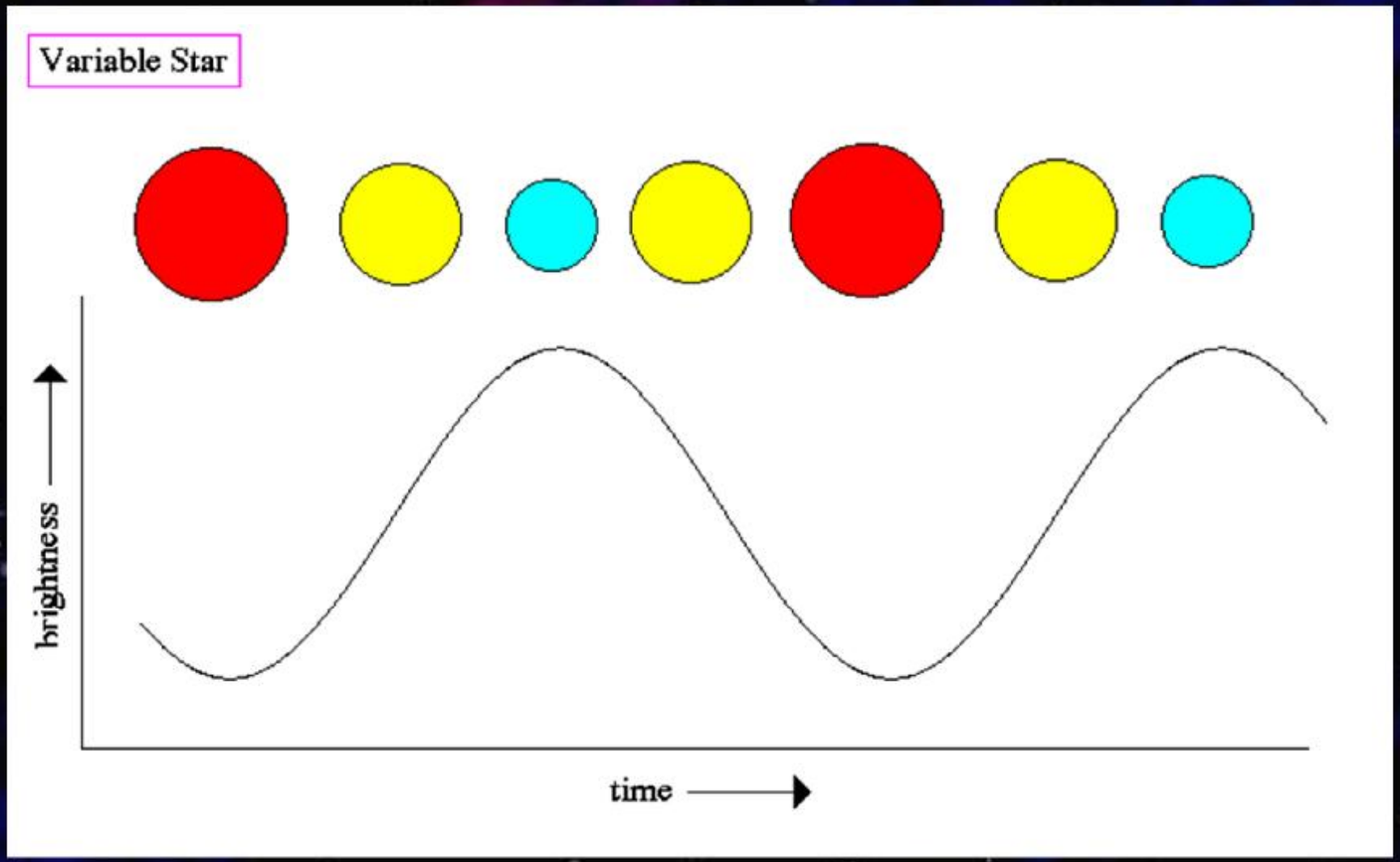
1. The Earth-Moon	Direct, parallax, radar, light
2. The Solar System	Direct, parallax, radar
3. The local stellar neighbor	Direct, parallax
4. The galaxy, globular clusters	Indirect, calibrated Period-Luminosity
5. The local galactic neighbor	Indirect, calibrated Period-Luminosity
6. Our neighborly galaxy cluster	Indirect, calibrated Period-Luminosity
7. SuperClusters	Hubble Expansion,
8. The very edge....?	~100,000,000,000,000,000,000,000,000.... miles

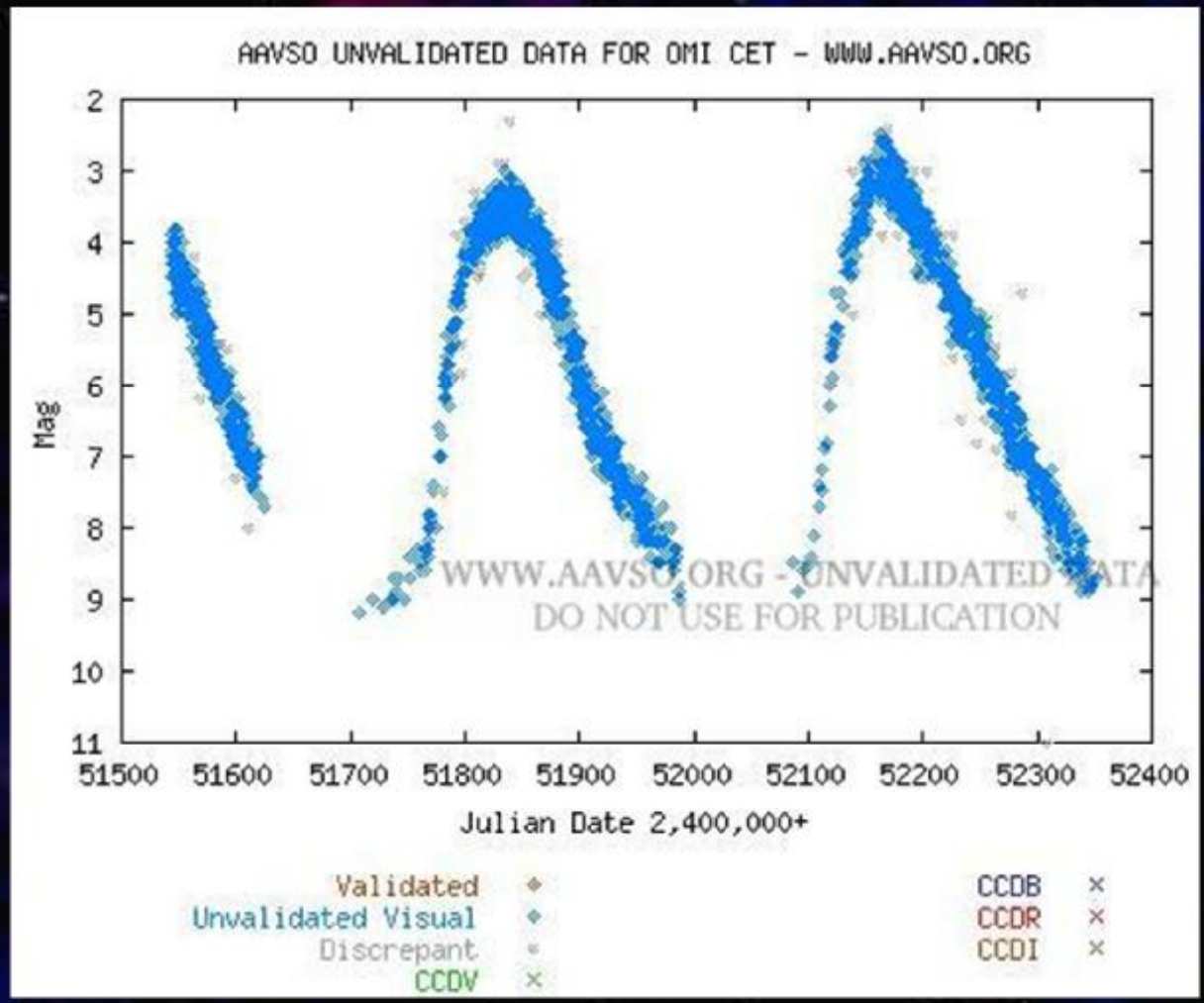
Distances to the galaxies

- Much to distant to use direct method (trig. Parallax)
- Some of the brighter stars on the MS can be used for spectroscopic parallax. Tough to get spectrum to type
- Period-Luminosity relationship Cepheid variables
  Extremely luminous (very large R)

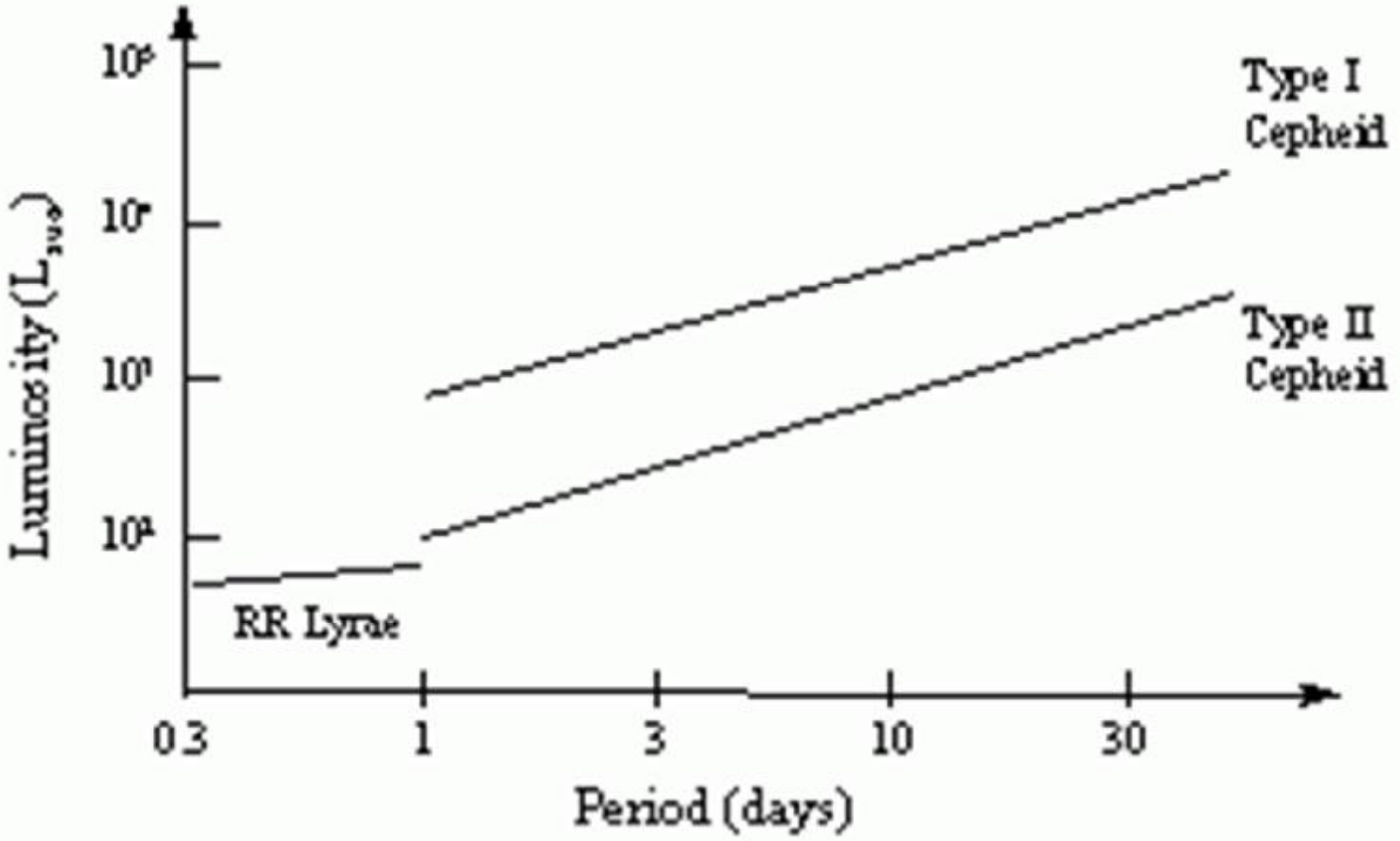

absolute visual magnitude (M_v)
spectral type
BO
AO
FO
GO
KO
MO
-6
-4
-2
0
2
4
6
8
10
12
β Cephei
Cepheids
Population I
main sequence
W Virginis
RR Lyrae
magnetic variable
stars
Al Velorum
δ Scuti
T Tauri
Sun
novae ?
White Dwarfs
eruptive UV Ceti stars
27 000
10 400
7200
6000
5120
3750
effective temperature (K)

RR Lyr and Cepheid Variables: a class of pulsating stars



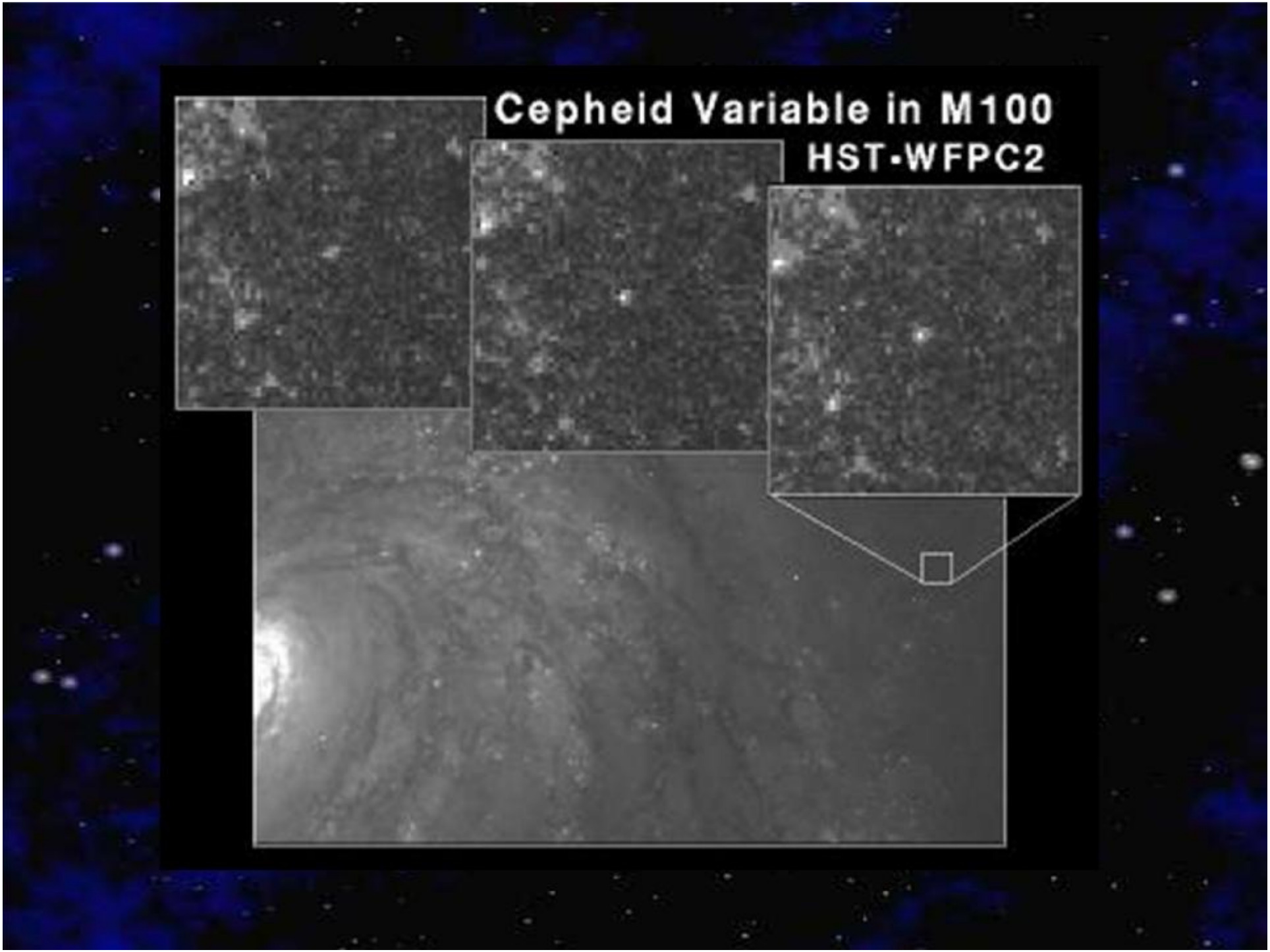

AAVSO UNVALIDATED DATA FOR OMI CET - WWW.AAVSO.ORG
Mag
2
3
4
5
6
7
8
9
10
11
51500
51600
51700
51800
51900
52000
52100
52200
52300
52400
Julian Date 2,400,000+
WWW.AAVSO.ORG - UNVALIDATED DATA
DO NOT USE FOR PUBLICATION
Validated
Unvalidated Visual
Discrepant
CCDV
CCDB
CCDR
CCDI

Period-Luminosity Relationship



Edwin Hubble accomplished 2 great things:

1. 1924 he was able to recognize Cepheids (variable stars) in nearby galaxies and once and for all showed that these were separate “island universes”.


Cepheid Variable in M100
HST•WFPC2

The History of Astronomy is a history of the displacement of man from being the Center of everything

Pre 1500's	Earth and man center of all there is (Universe)
After Copernicus (~1500)	OK, sun is at the center, but man is center of everything, center of galaxy, center of Universe
1910-1920	Oh no! we are not at center of galaxy but out toward the edge but at least our galaxy is at the center of everything!!
	-study of globular clusters, their distribution and variables contained in them
1925-1930	The Universe is full of galaxies, rushing away from each other we have no special place whatsoever!!
	-study of variable stars (pulsating) in distant galaxies

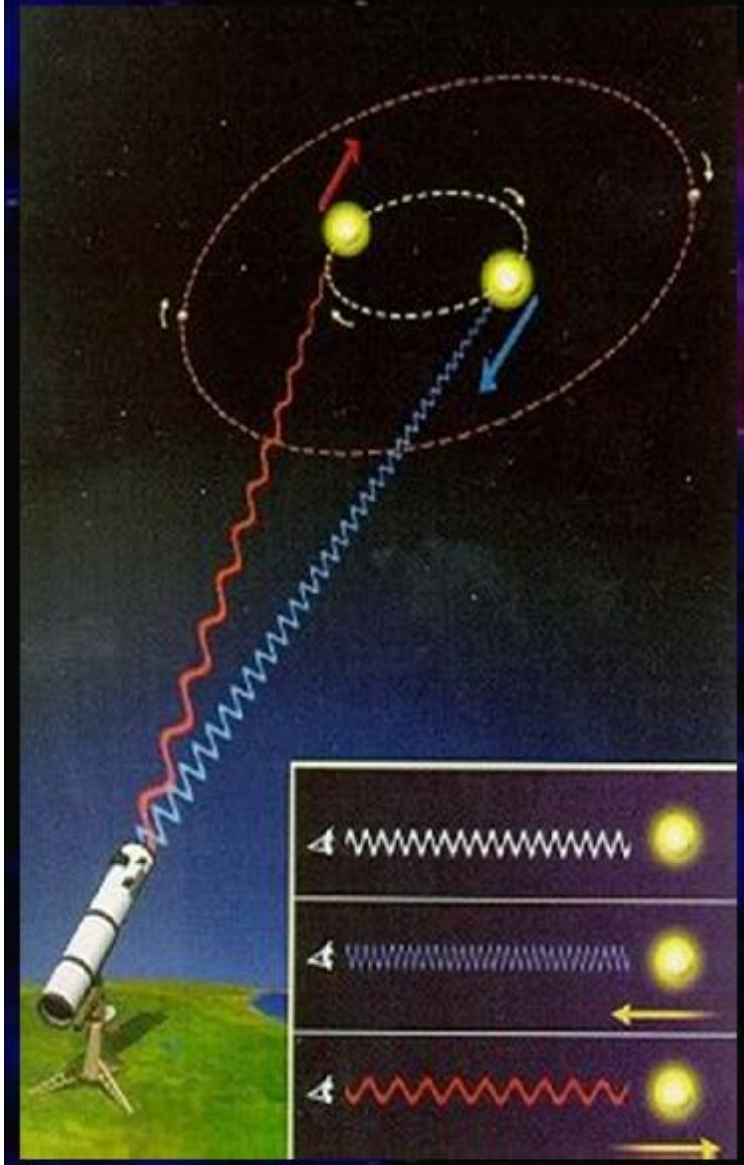
Edwin Hubble accomplished 2 great things:

1. 1924 he was able to recognize Cepheids (variable stars) in nearby galaxies and once and for all showed that these were separate “island universes”.

2. 1929 he showed through the analysis of red shifts of galaxies (spectroscopy) that the more distant a galaxy is the faster it is rushing away from us.

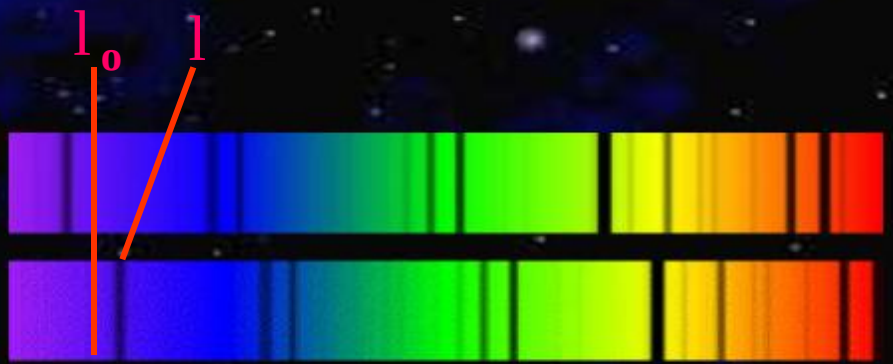
“Expanding Universe”

Doppler Shift of Light: measuring the speed of objects



$$z = v/c = (\lambda - \lambda_o)/\lambda_o$$

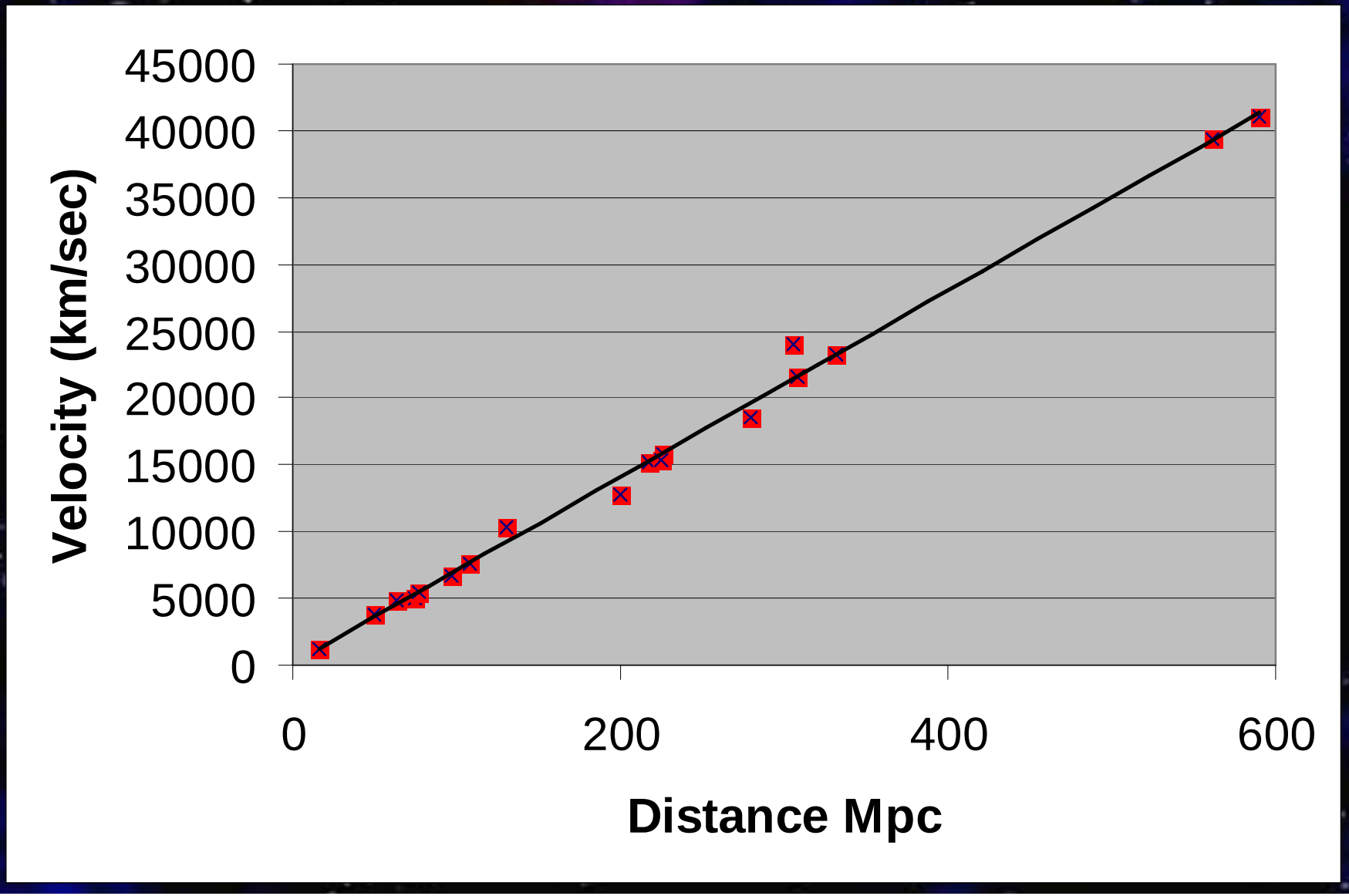
v = velocity of object
c = velocity of light (300,000 km/sec)
λ_o = rest wavelength
λ = measured wavelength



$V = H_o D$ or $H_o = V/D$

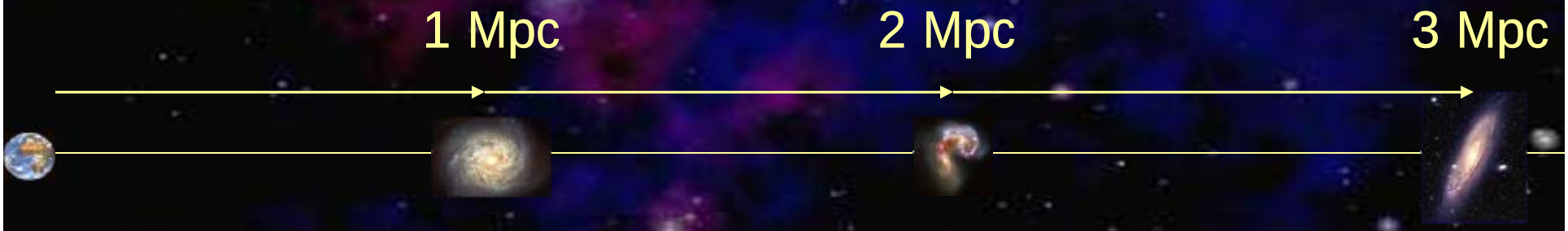
H_o is the Hubble Constant

H_o = ~70 km/sec/Mpc



H_o = ~70 km/sec/Mpc

1 Mpc = 1 million parsecs = 3.26 million light years



Velocity of recession = 70 km/sec

Velocity of recession = 140 km/sec

Velocity of recession = 210 km/sec

Edwin Hubble accomplished 2 great things:

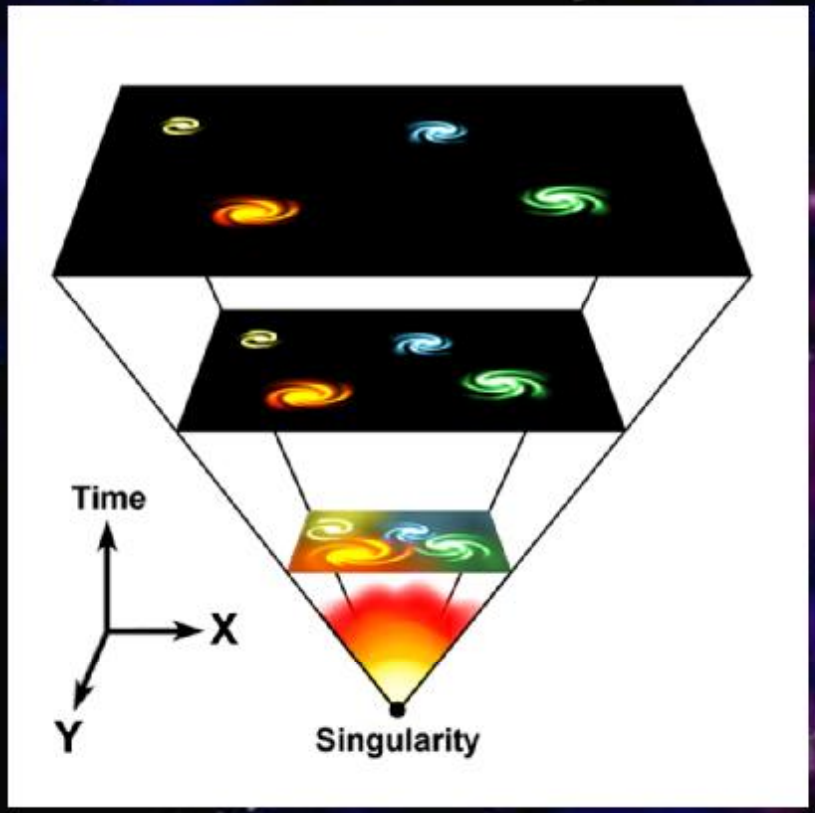
1. 1924 he was able to recognize Cepheids (variable stars) in nearby galaxies and once and for all showed that these were separate “island universes”.

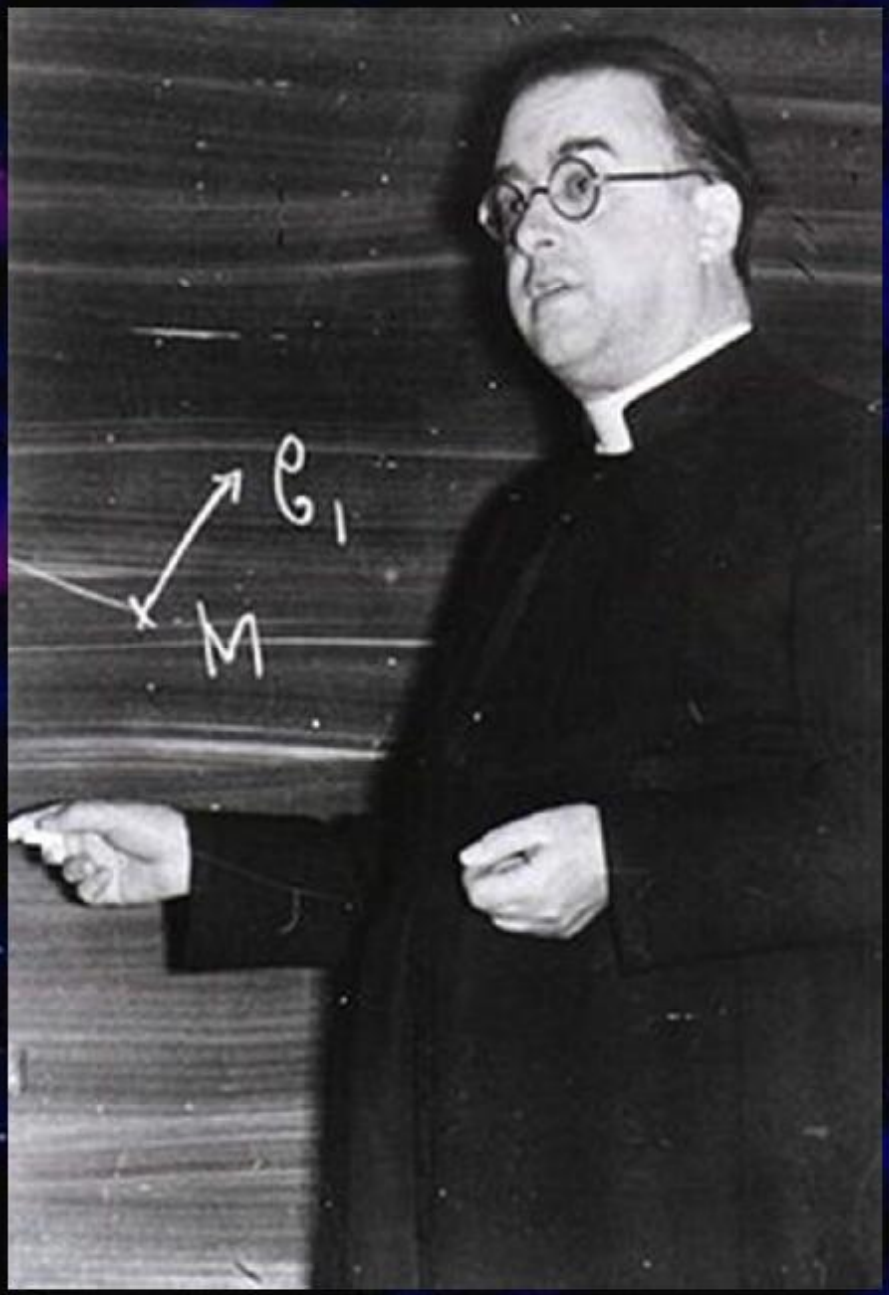
2. 1929 he showed through the analysis of red shifts of galaxies (spectroscopy) that the more distant a galaxy is the faster it is rushing away from us.

“Expanding Universe”

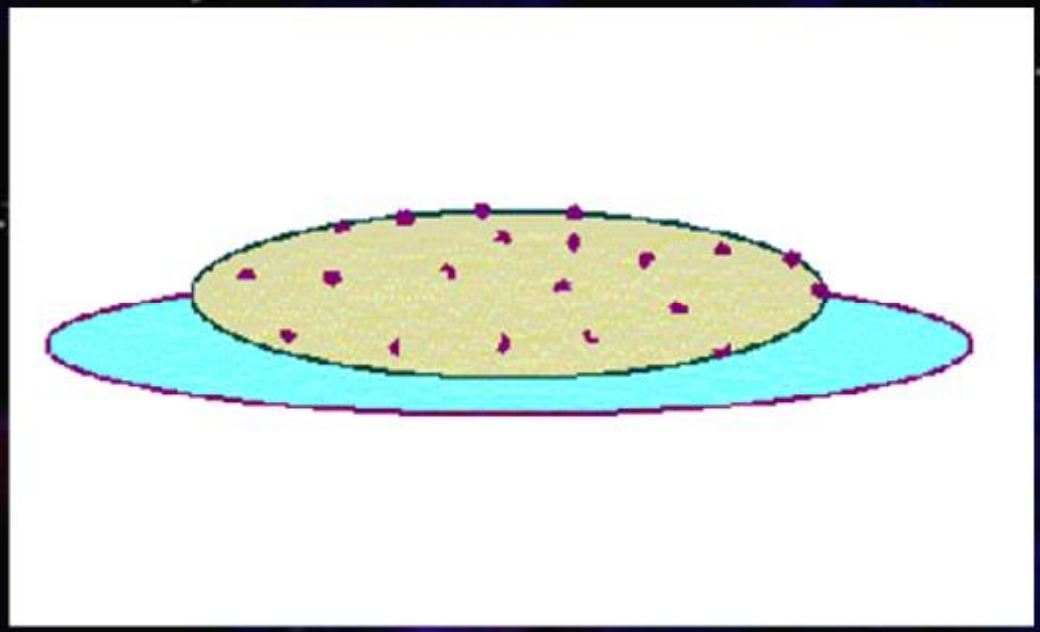
Sidebar: In 1916 Albert Einstein published his opus on General relativity. This theory *predicted* that the universe should be expanding!!! Since the prevailing thinking of the time was that the universe was static (not expanding or contracting), he added a term to his relativity equations that made the universe static.

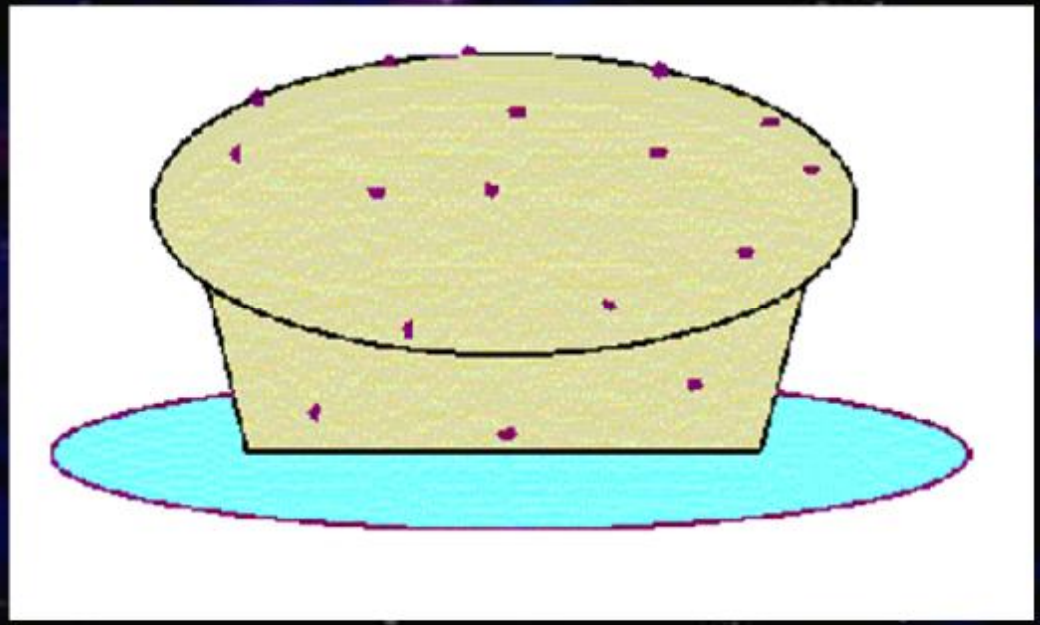
Einstein 14 years later called it was his greatest scientific blunder.





Georges Lemaitre

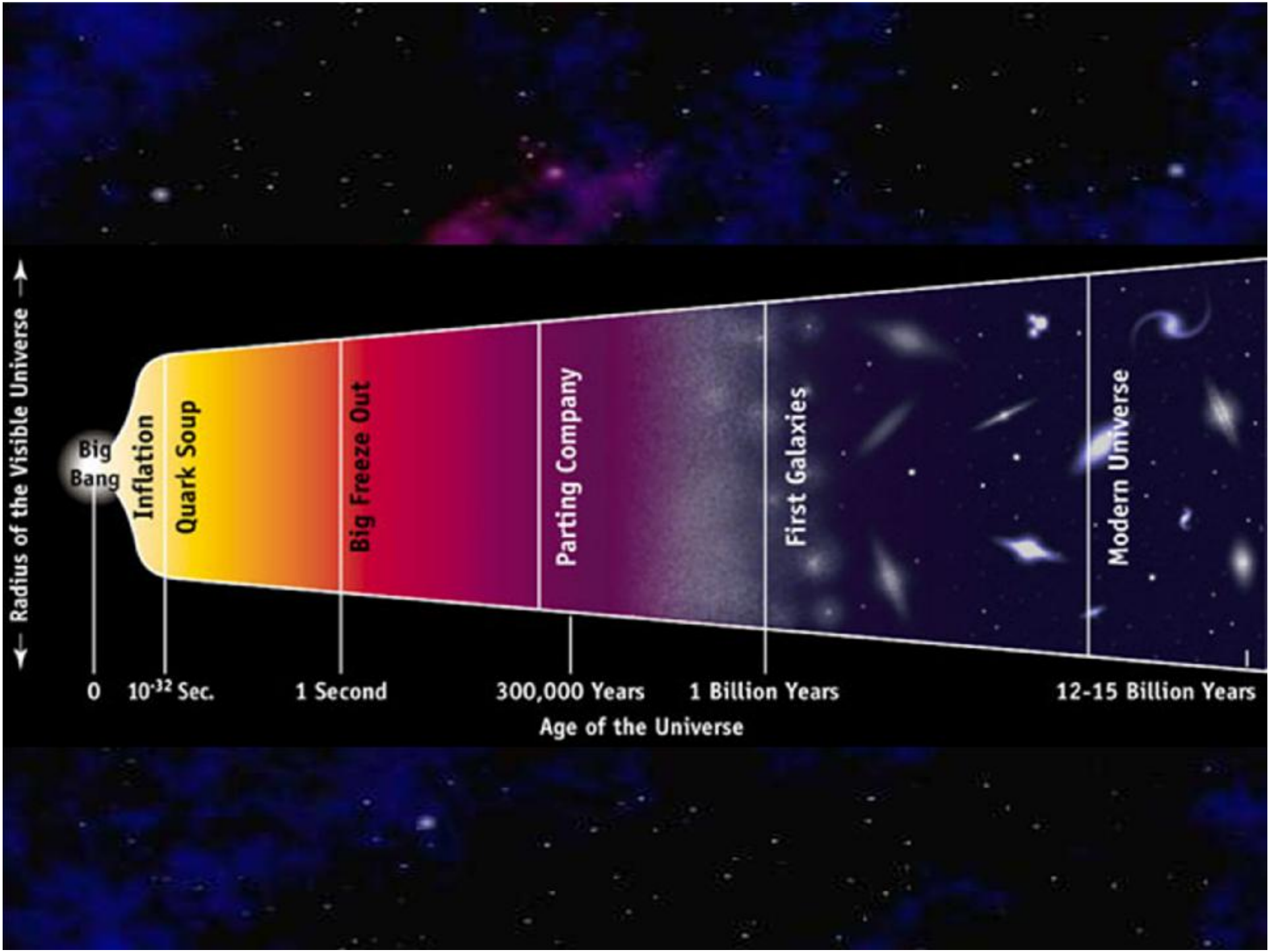


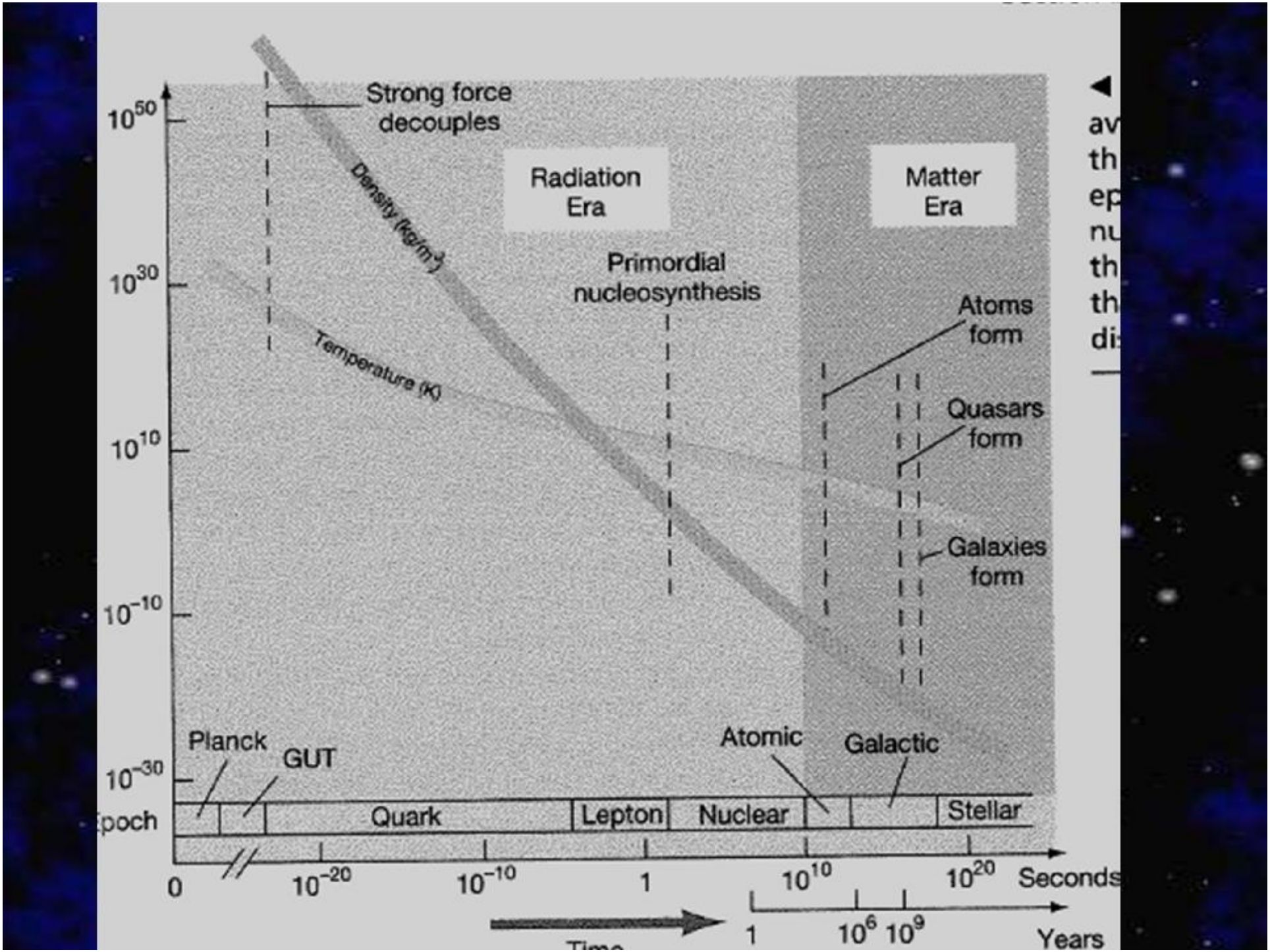


Origins of the Universe: two theories

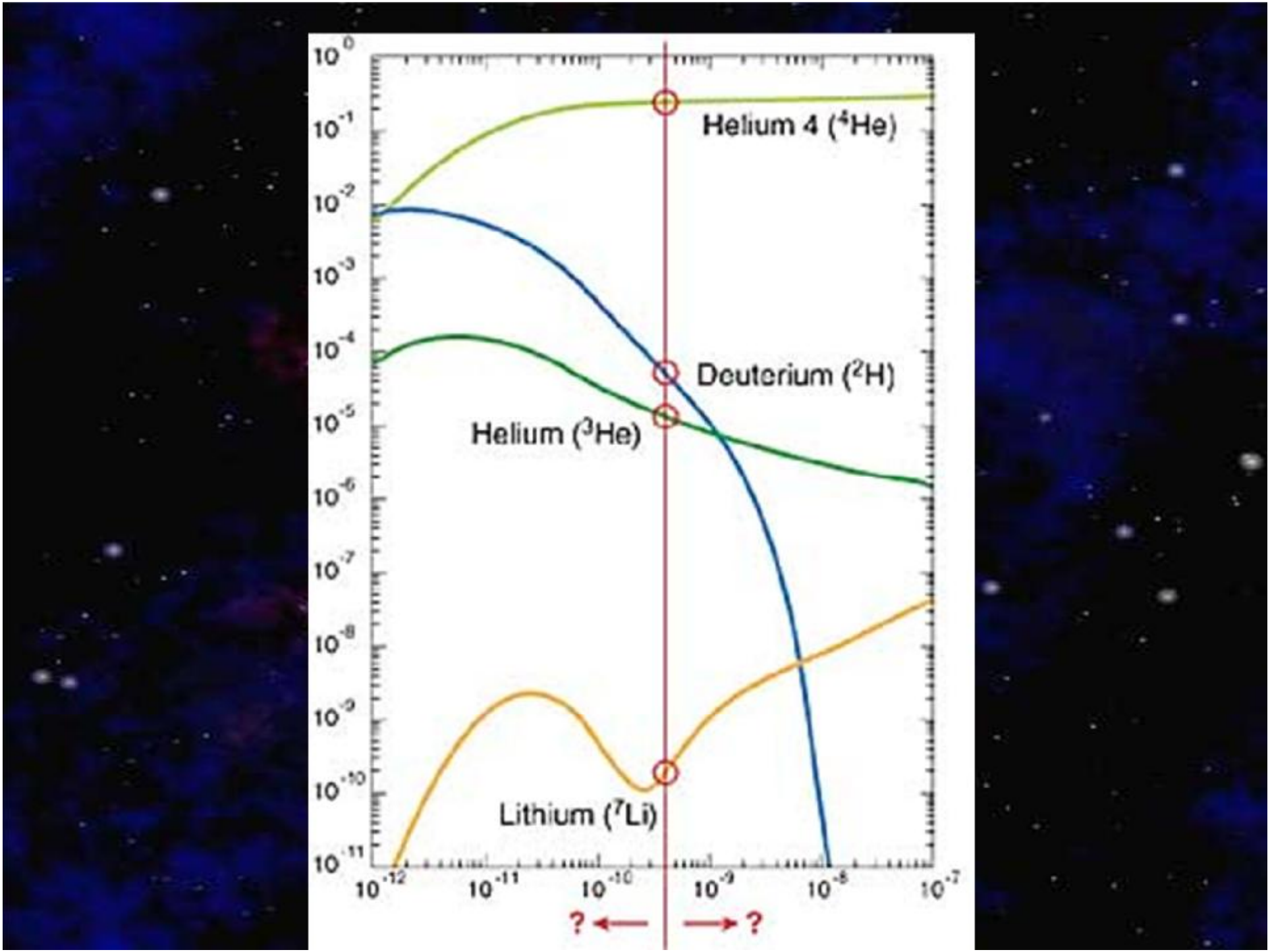
Steady State-1940's to present

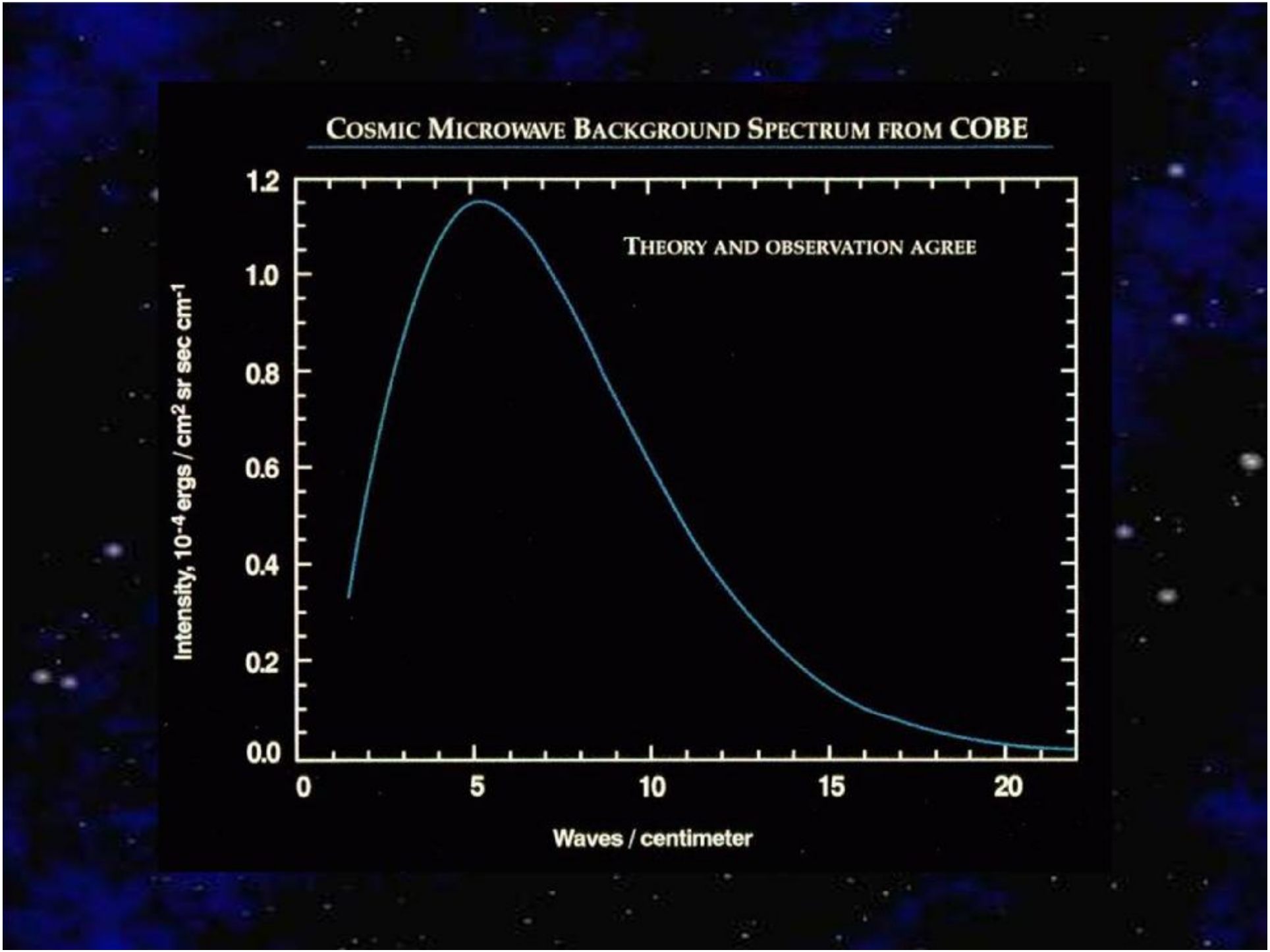
Big Bang

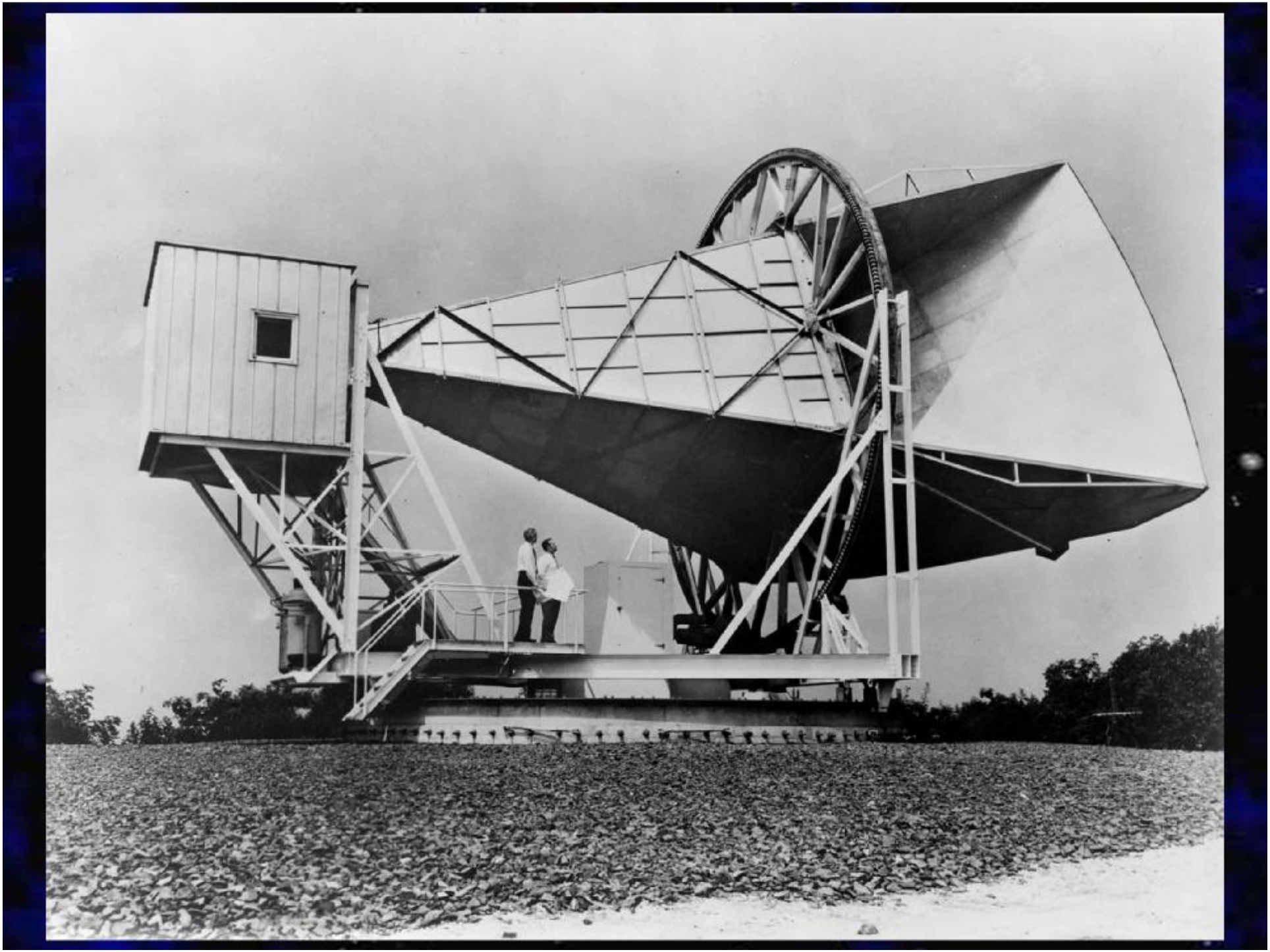

Radius of the Visible Universe
Big Bang
Inflation
Quark Soup
Big Freeze Out
Parting Company
First Galaxies
Modern Universe
0
10-32 Sec.
1 Second
300,000 Years
1 Billion Years
12-15 Billion Years
Age of the Universe


Strong force decouples
Radiation Era
Matter Era
Density (kg/m³)
Temperature (K)
Primordial nucleosynthesis
Atoms form
Quasars form
Galaxies form
10⁵⁰
10³⁰
10¹⁰
10⁻¹⁰
10⁻³⁰
Planck
GUT
Atomic
Galactic
Epoch
Quark
Lepton
Nuclear
Stellar
0
10⁻²⁰
10⁻¹⁰
1
10¹⁰
10²⁰
Seconds
Time
1
10⁶ 10⁹
Years

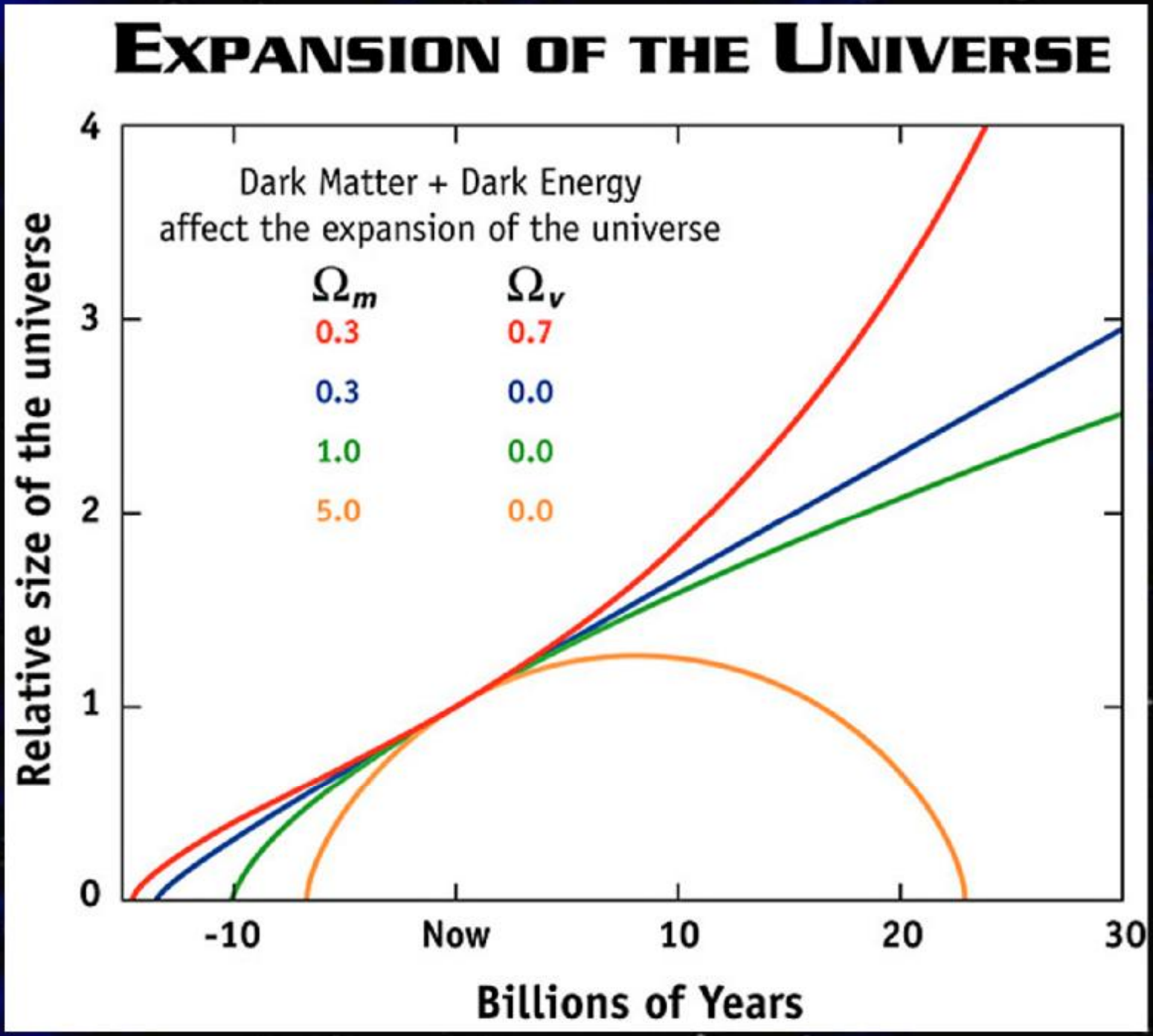
esa
www.spacetelescope.org

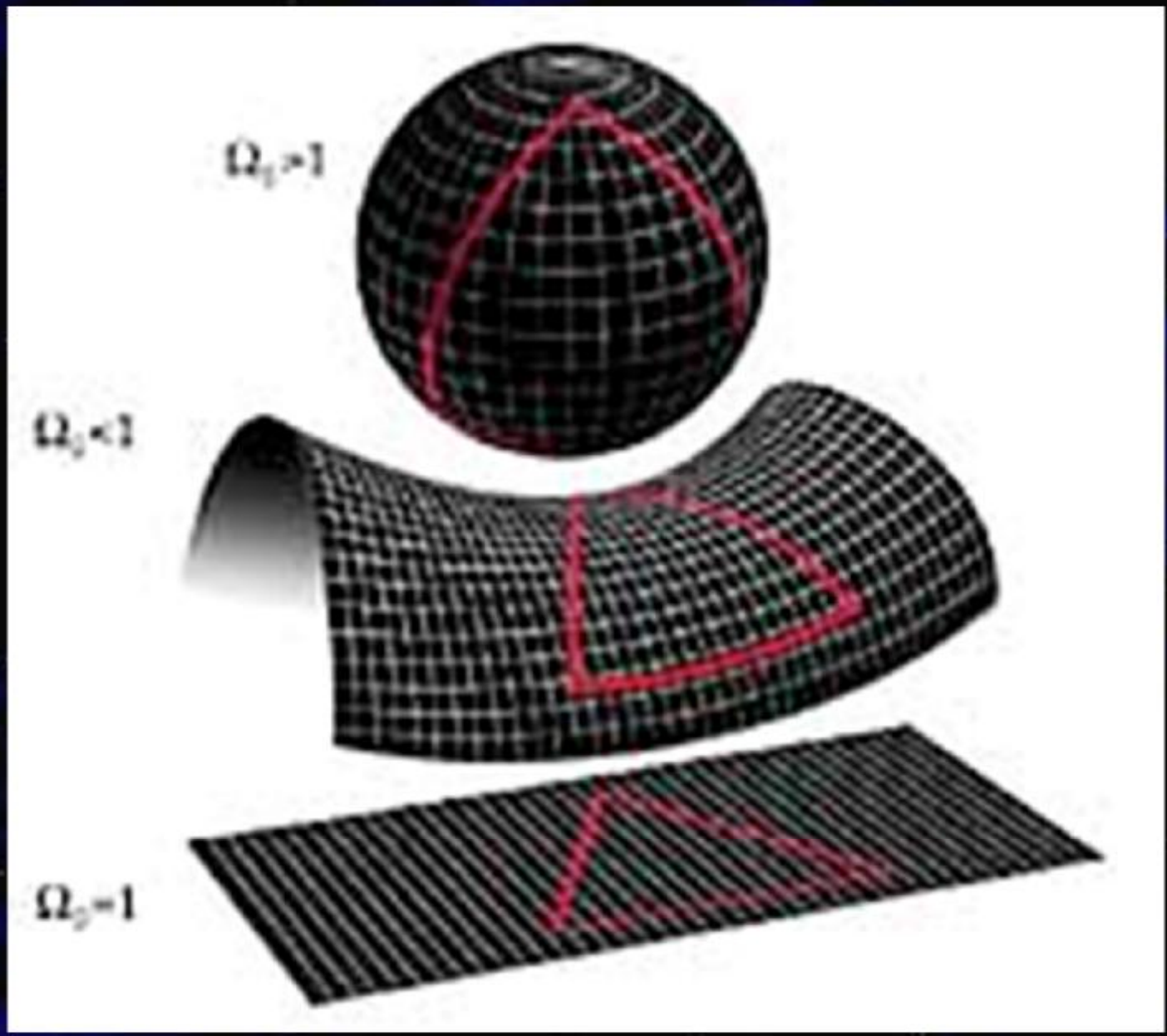

Helium 4 (^{4}He)
Deuterium (^{2}H)
Helium (^{3}He)
Lithium (^{7}Li)
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-11}
10^{-10}
10^{-9}
10^{-8}
10^{-7}
? ←
→ ?


COSMIC MICROWAVE BACKGROUND SPECTRUM FROM COBE
THEORY AND OBSERVATION AGREE
Intensity, 10-4 ergs / cm2 sr sec cm-1
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
Waves / centimeter

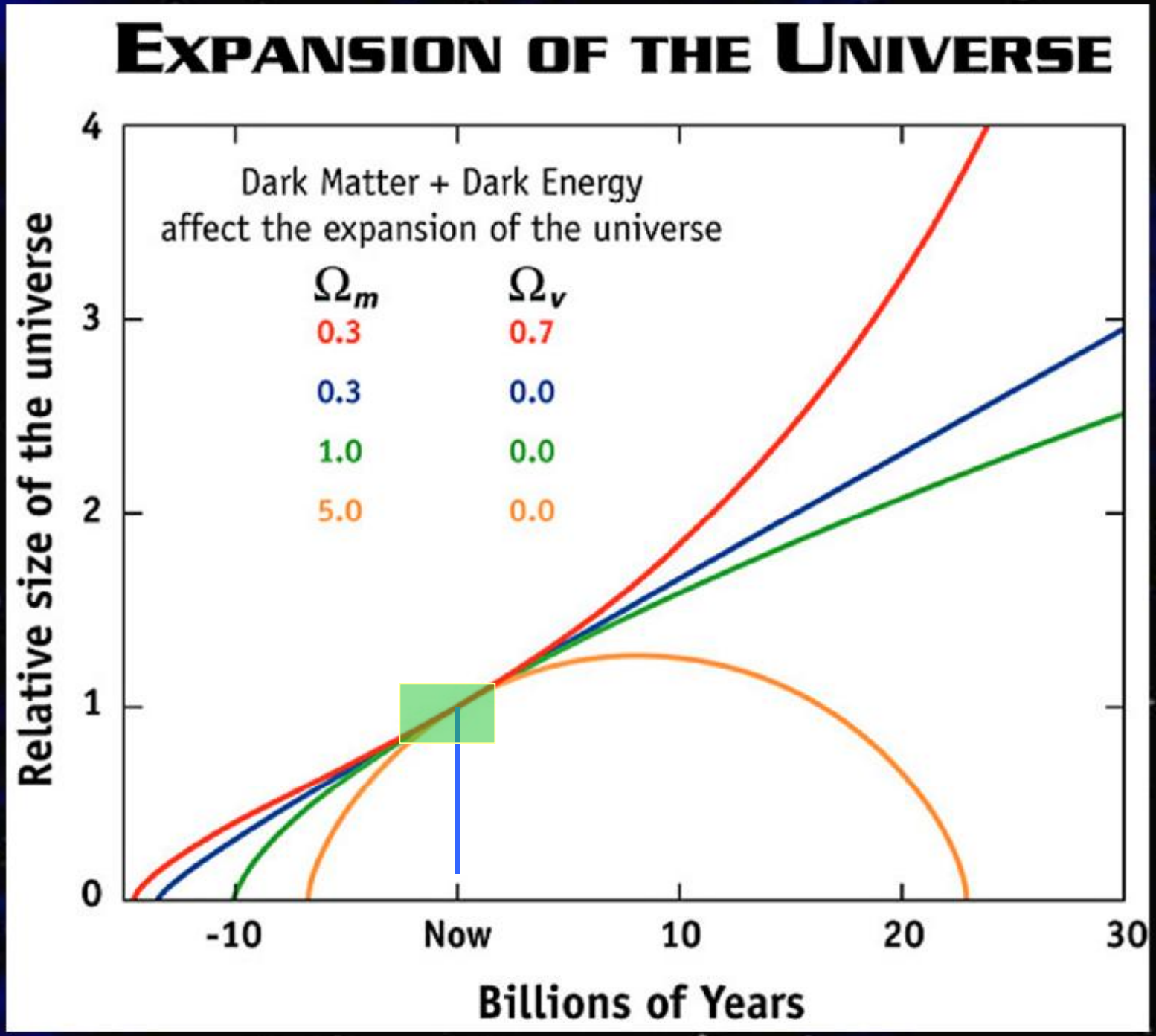


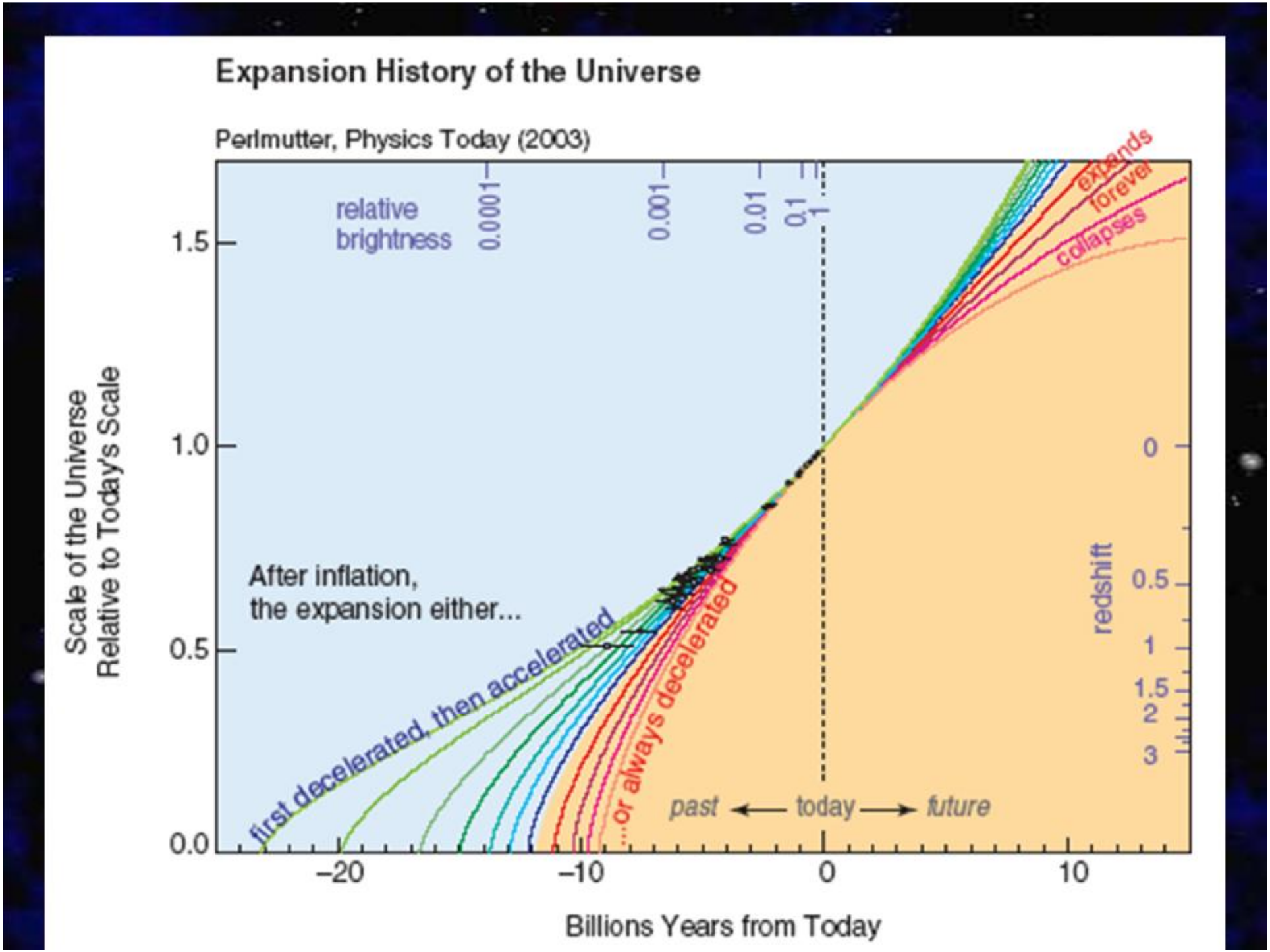
Expansion of the Universe



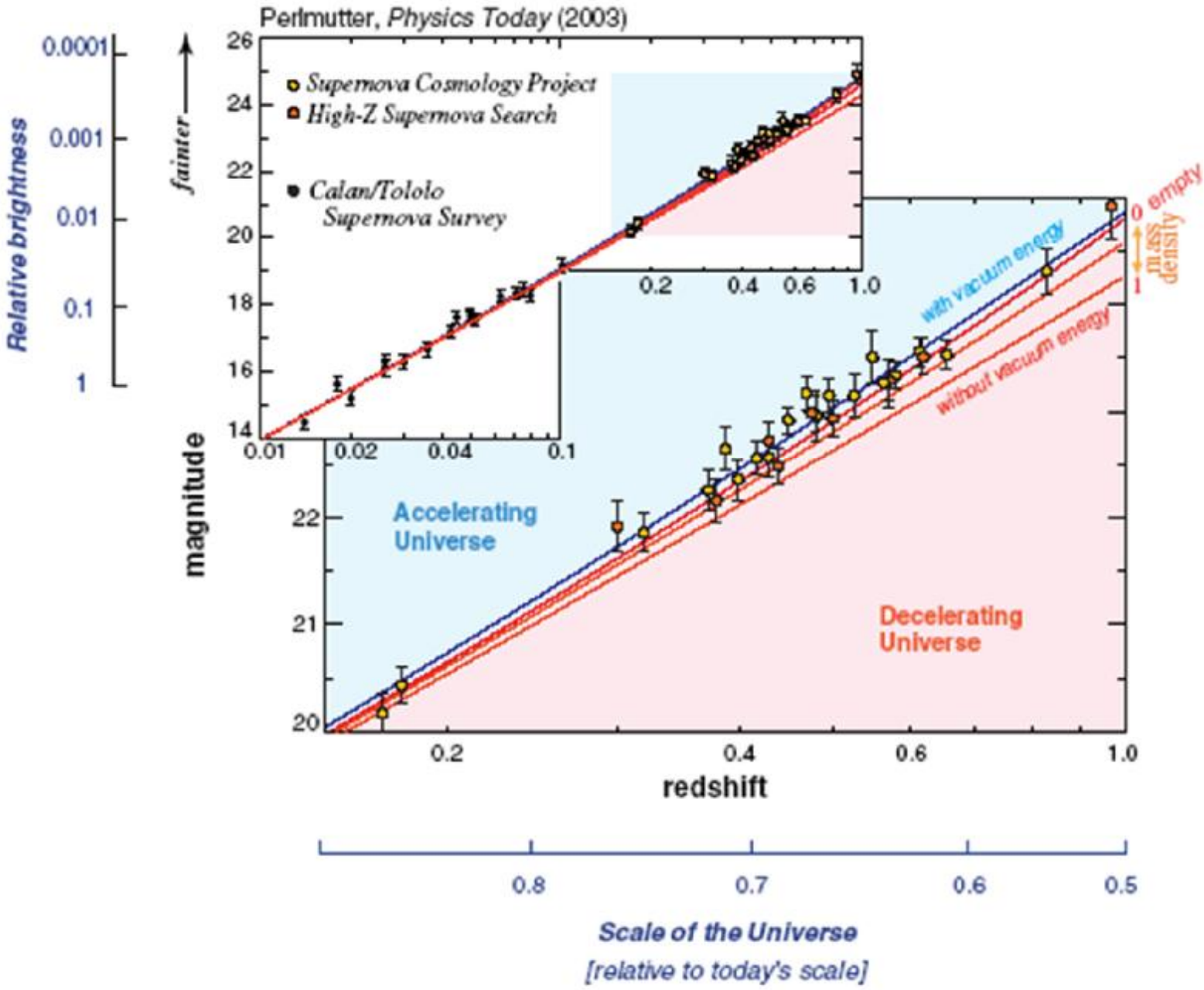

$\Omega_0>1$
$\Omega_0<1$
$\Omega_0=1$

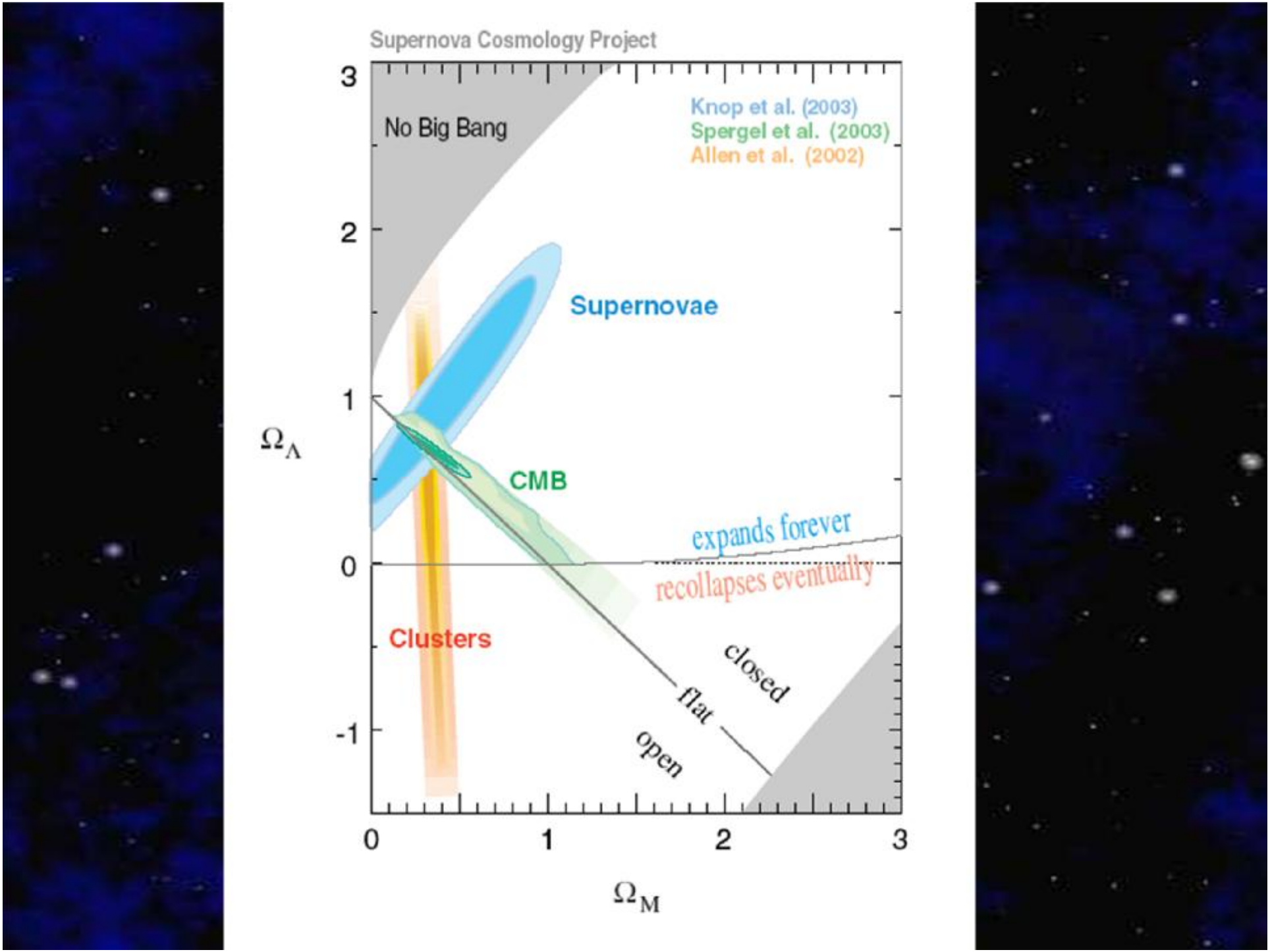
Expansion of the Universe

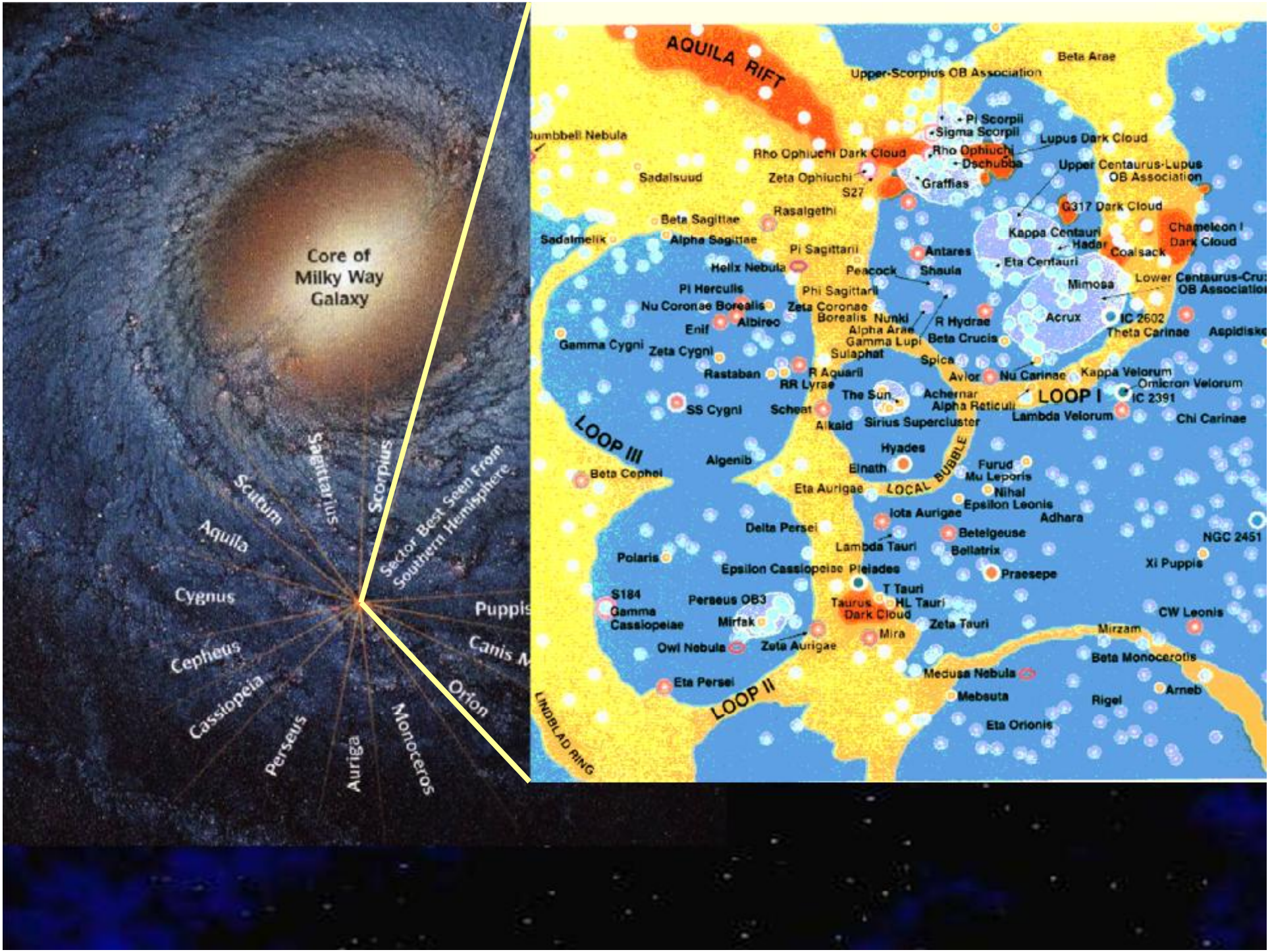


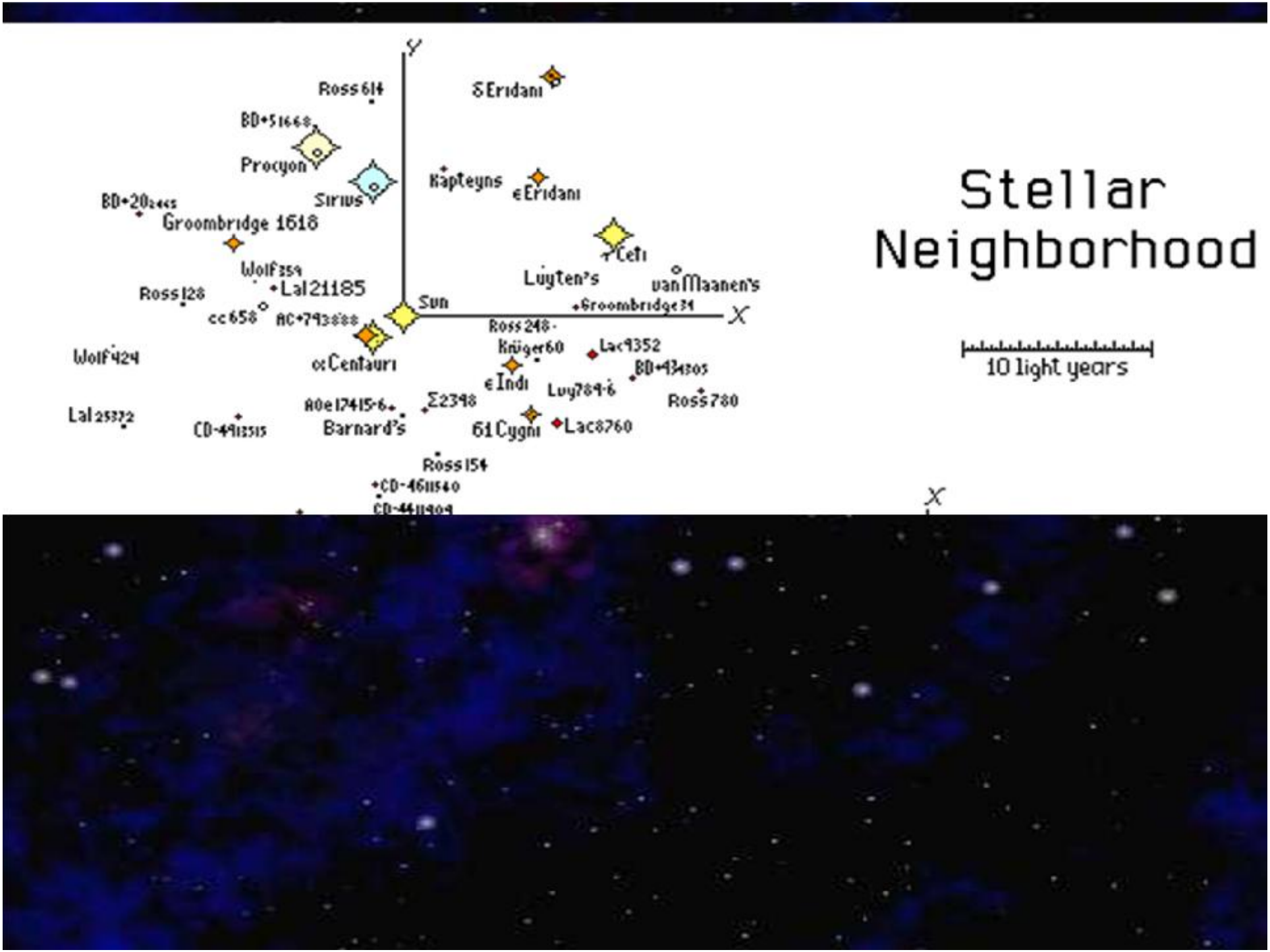

Expansion History of the Universe
Perlmutter, Physics Today (2003)
relative brightness
0.0001
0.001
0.01
0.1
1
expands forever
collapses
After inflation, the expansion either...
first decelerated, then accelerated
...or always decelerated
redshift
0
0.5
1
1.5
2
3
past
today
future
Scale of the Universe Relative to Today's Scale
0.0
0.5
1.0
1.5
–20
–10
0
10
Billions Years from Today

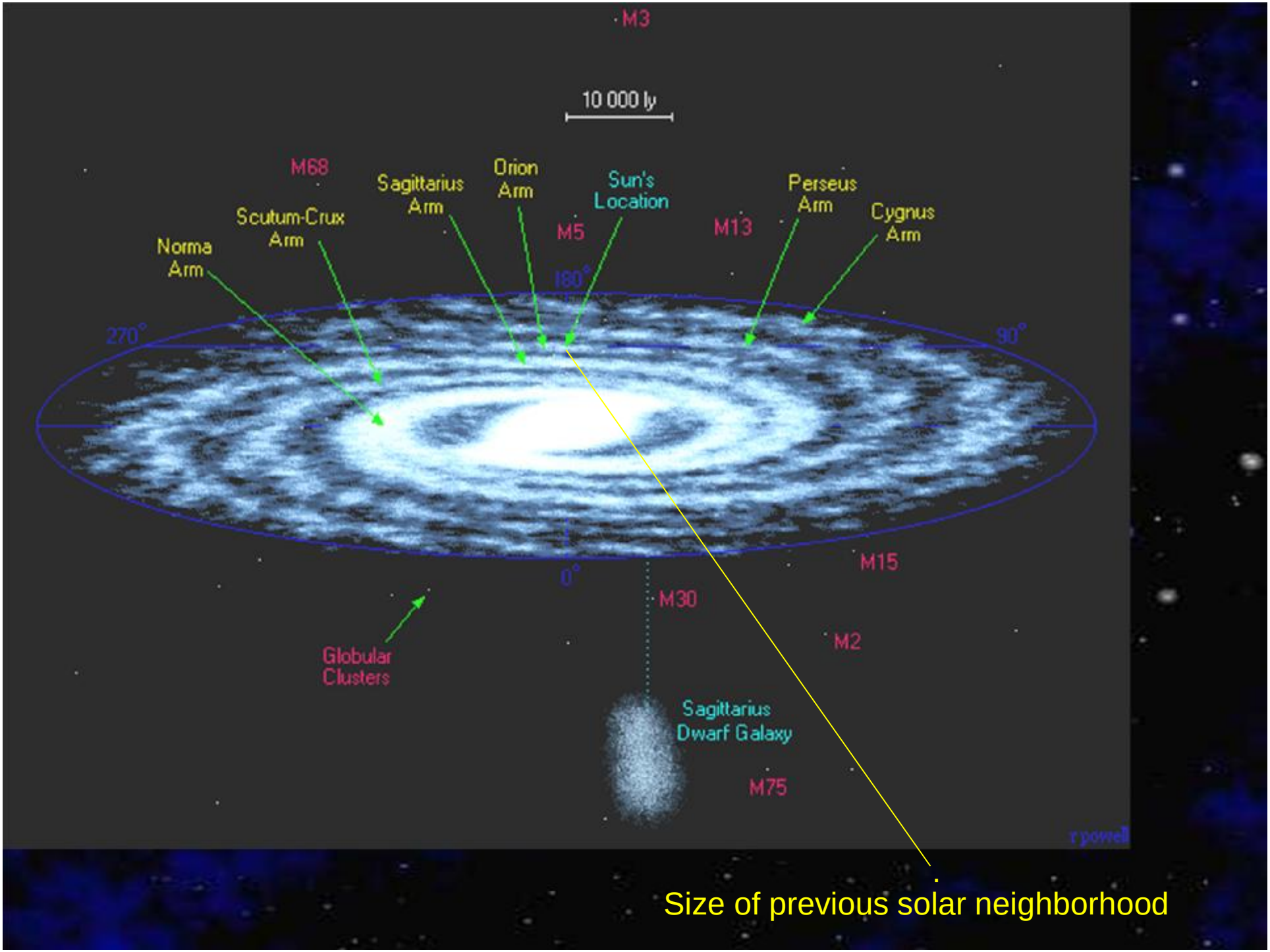
Type Ia Supernovae

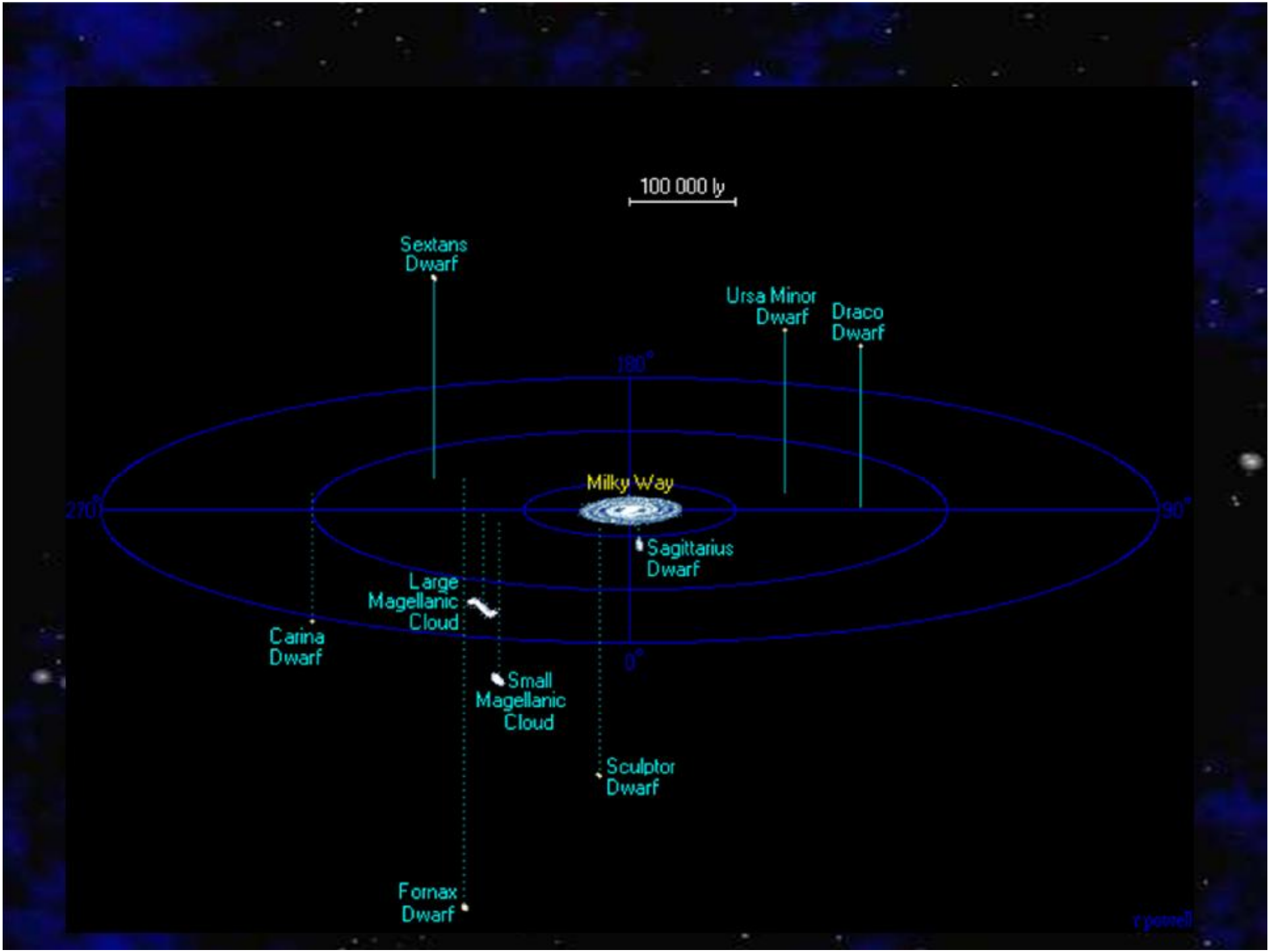


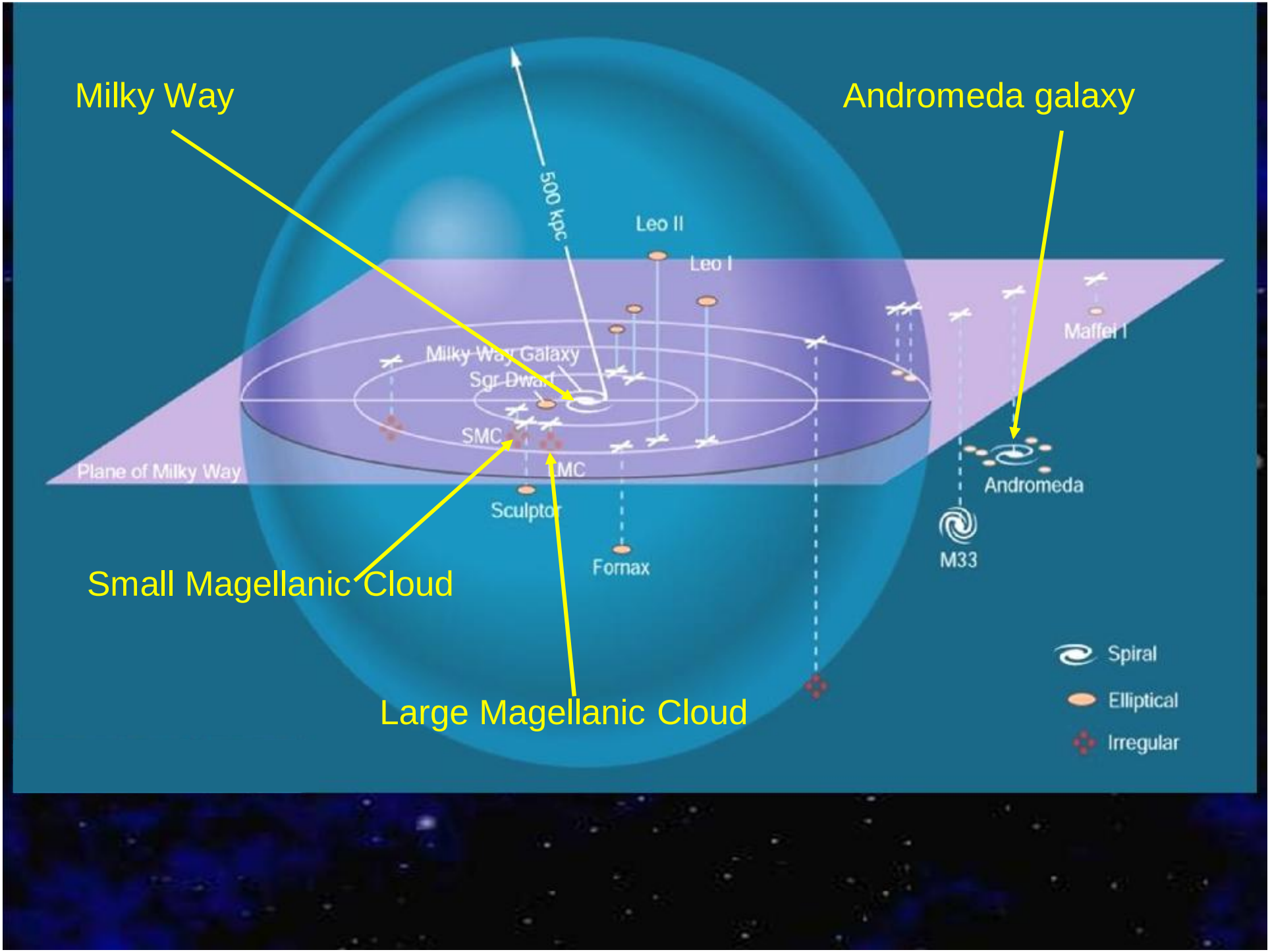

Supernova Cosmology Project
No Big Bang
Knop et al. (2003)
Spergel et al. (2003)
Allen et al. (2002)
Supernovae
CMB
Clusters
expands forever
recollapses eventually
closed
flat
open
3
2
1
0
-1
0
1
2
3
Ω_Λ
Ω_M

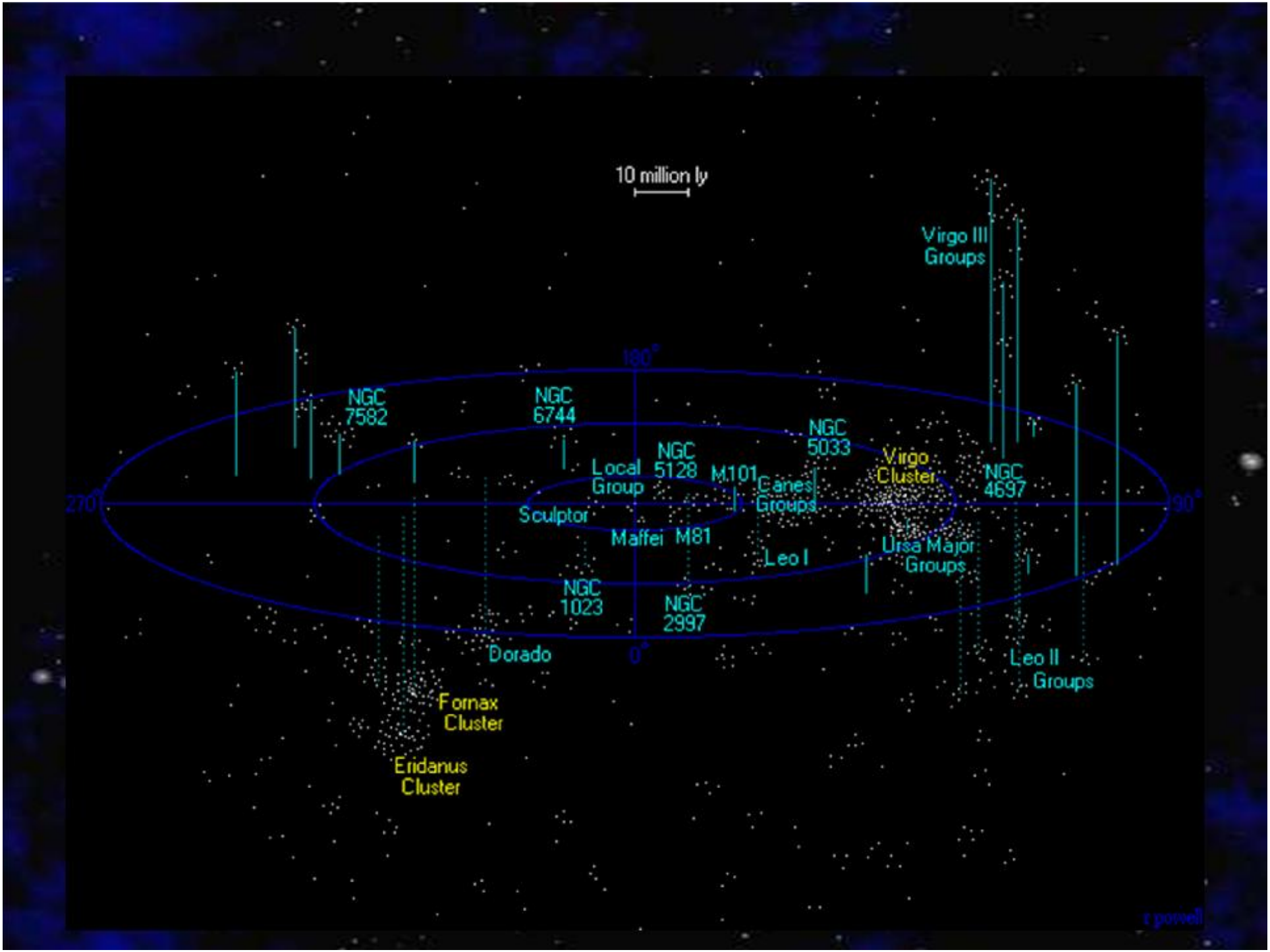

Core of Milky Way Galaxy
Sagittarius
Scorpius
Scutum
Aquila
Cygnus
Cepheus
Cassiopeia
Perseus
Auriga
Monoceros
Orion
Puppis
Canis M
Sector Best Seen From Southern Hemisphere
AQUILA RIFT
Beta Arae
Upper-Scorpius OB Association
Pi Scorpii
Sigma Scorpii
Lupus Dark Cloud
Rho Ophiuchi Dark Cloud
Rho Ophiuchi
Dschubba
Upper Centaurus-Lupus OB Association
Sadalsuud
Zeta Ophiuchi
S27
Graffias
G317 Dark Cloud
Rasalgethi
Beta Sagittae
Kappa Centauri
Hadar
Chameleon I Dark Cloud
Sadalmelik
Alpha Sagittae
Pi Sagittarii
Antares
Coalsack
Helix Nebula
Peacock
Shaula
Eta Centauri
Mimosa
Lower Centaurus-Crux OB Association
Pi Herculis
Phi Sagittarii
Nu Coronae Borealis
Zeta Coronae Borealis
Nunki
R Hydrae
Acrux
IC 2602
Albireo
Alpha Arae
Theta Carinae
Enif
Gamma Lupi
Beta Crucis
Gamma Cygni
Zeta Cygni
Sulaphat
Spica
Rastaban
R Aquarii
Avior
Nu Carinae
Kappa Velorum
RR Lyrae
Omicron Velorum
The Sun
Achernar
LOOP I
IC 2391
SS Cygni
Scheat
Alpha Reticuli
Lambda Velorum
Alkaid
Sirius Supercluster
Chi Carinae
LOOP III
Hyades
Algenib
Elnath
Furud
Beta Cephei
Mu Leporis
LOCAL BUBBLE
Eta Aurigae
Nihal
Epsilon Leonis
Iota Aurigae
Adhara
Delta Persei
Betelgeuse
NGC 2451
Lambda Tauri
Bellatrix
Polaris
Xi Puppis
Epsilon Cassiopeiae
Pleiades
Praesepe
T Tauri
S184
Perseus OB3
Taurus
HL Tauri
CW Leonis
Gamma Cassiopeiae
Dark Cloud
Mirfak
Zeta Tauri
Mira
Mirzam
Owl Nebula
Zeta Aurigae
Beta Monocerotis
Medusa Nebula
Eta Persei
LOOP II
Arneb
Mebsuta
Rigel
LINDBLAD RING
Eta Orionis

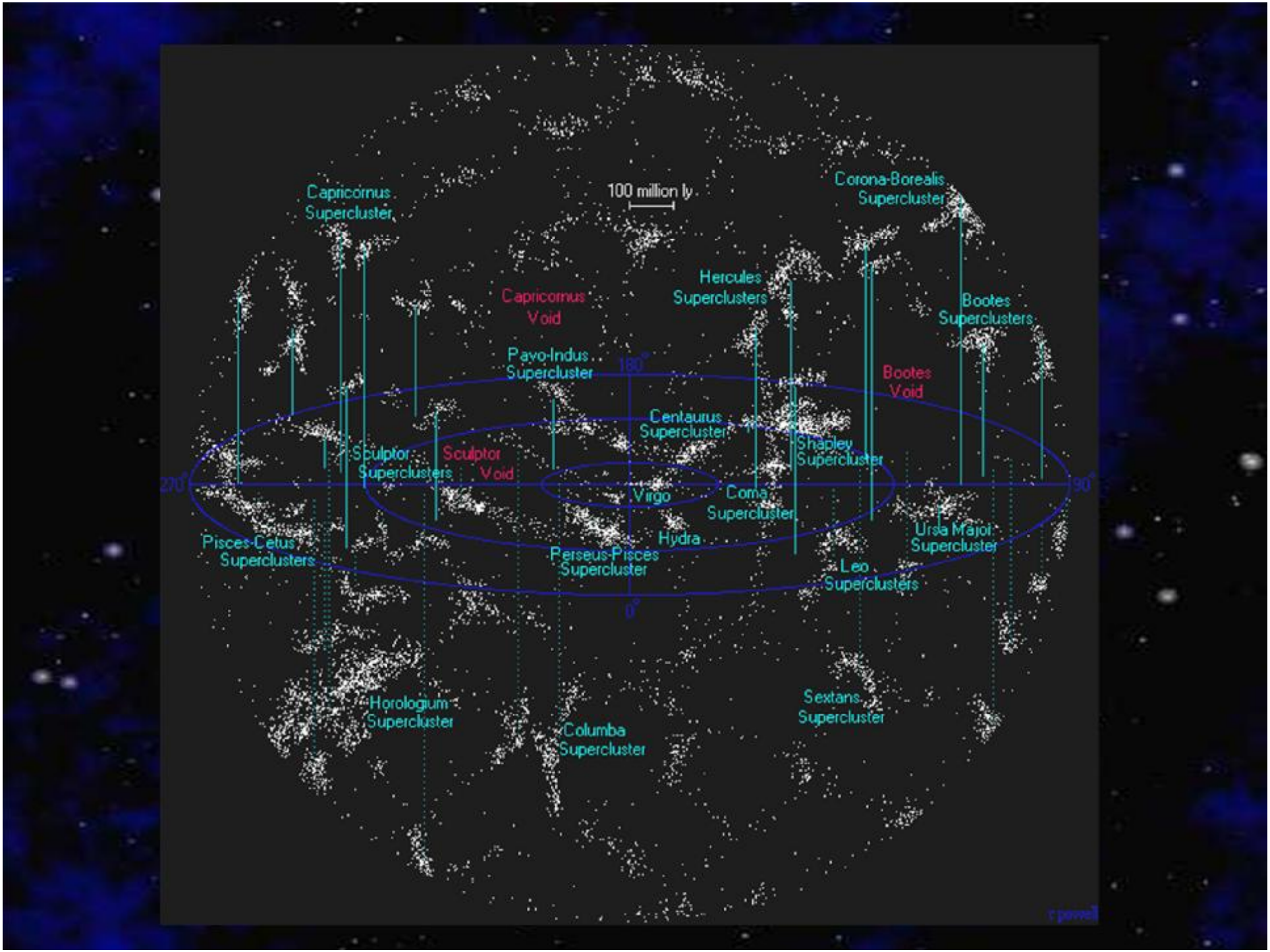

Stellar
Neighborhood
Y
X
Ross 614
δ Eridani
BD+51668
Procyon
Sirius
Kapteyns
εEridani
BD+20 2465
Groombridge 1618
τ Ceti
Wolf 359
Lal 21185
Luyten's
van Maanen's
Ross 128
Sun
Groombridge 34
cc 658
AC+79 3888
Ross 248
Wolf 424
α Centauri
Krüger 60
Lac 9352
BD+43 3305
εIndi
Luy 789-6
Ross 780
Lal 25372
CD-49 13515
Barnard's
Σ 2398
61 Cygni
Lac 8760
Ross 154
CD-46 11540
10 light years

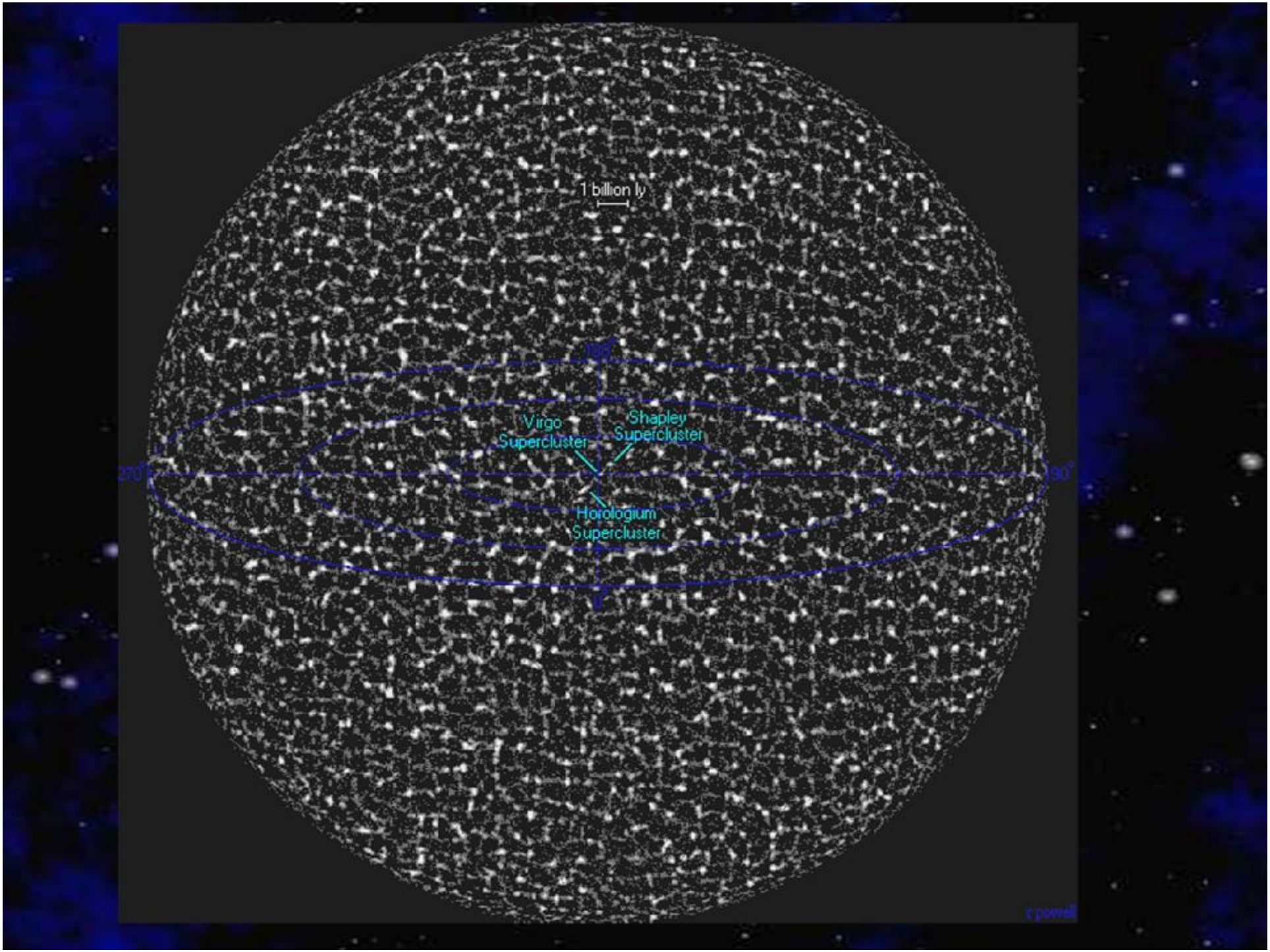

M3
10 000 ly
M68
Sagittarius Arm
Orion Arm
Sun's Location
Perseus Arm
Cygnus Arm
Scutum-Crux Arm
Norma Arm
M5
M13
180°
270°
90°
0°
M15
M30
M2
Globular Clusters
Sagittarius Dwarf Galaxy
M75
rpowell
Size of previous solar neighborhood

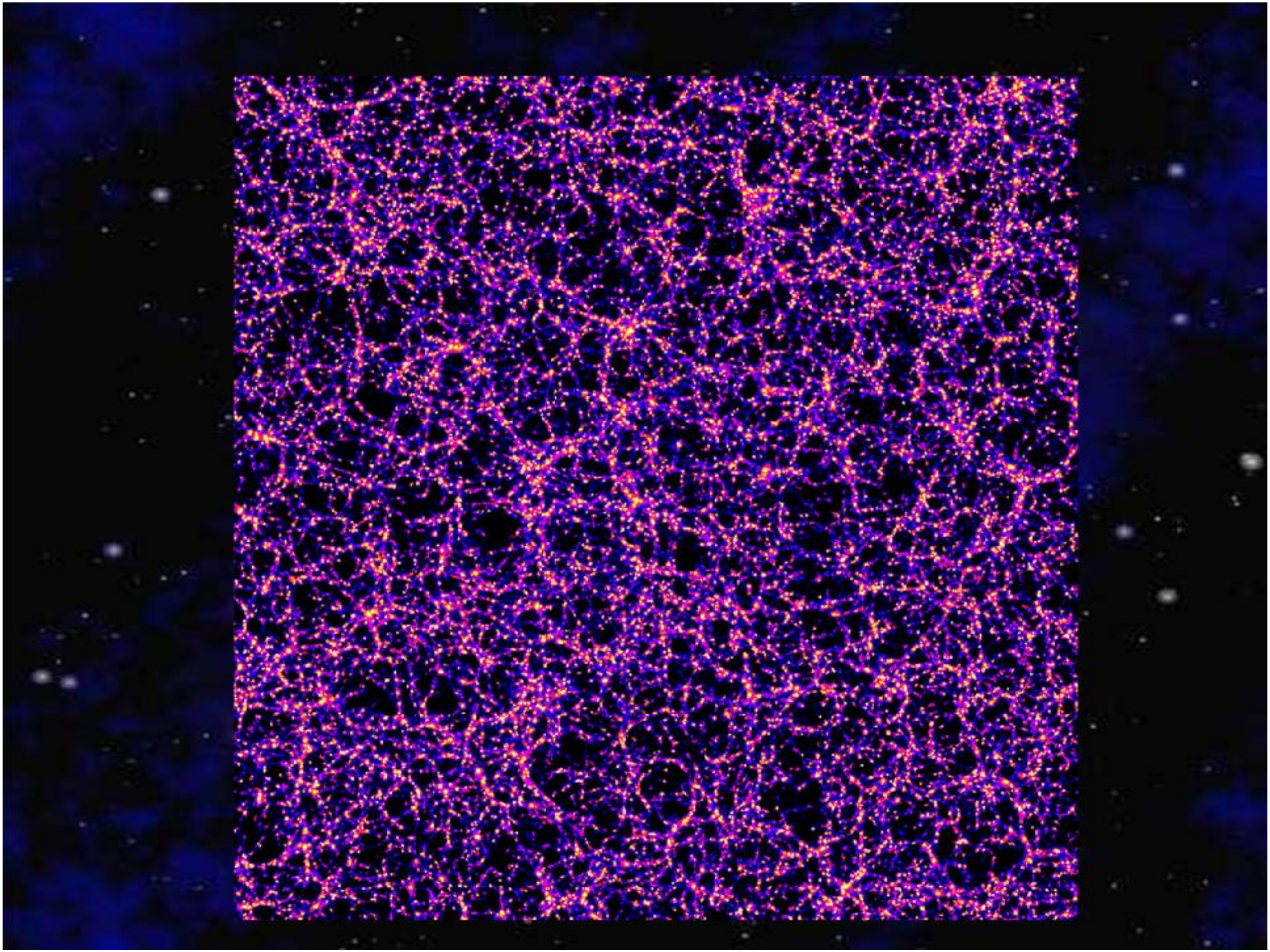

100 000 ly
Sextans Dwarf
Ursa Minor Dwarf
Draco Dwarf
180°
Milky Way
270°
90°
Sagittarius Dwarf
Large Magellanic Cloud
Carina Dwarf
0°
Small Magellanic Cloud
Sculptor Dwarf
Fornax Dwarf


Milky Way
Andromeda galaxy
500 kpc
Leo II
Leo I
Maffei I
Milky Way Galaxy
Sgr Dwarf
SMC
LMC
Plane of Milky Way
Sculptor
Fornax
Andromeda
M33
Small Magellanic Cloud
Large Magellanic Cloud
Spiral
Elliptical
Irregular

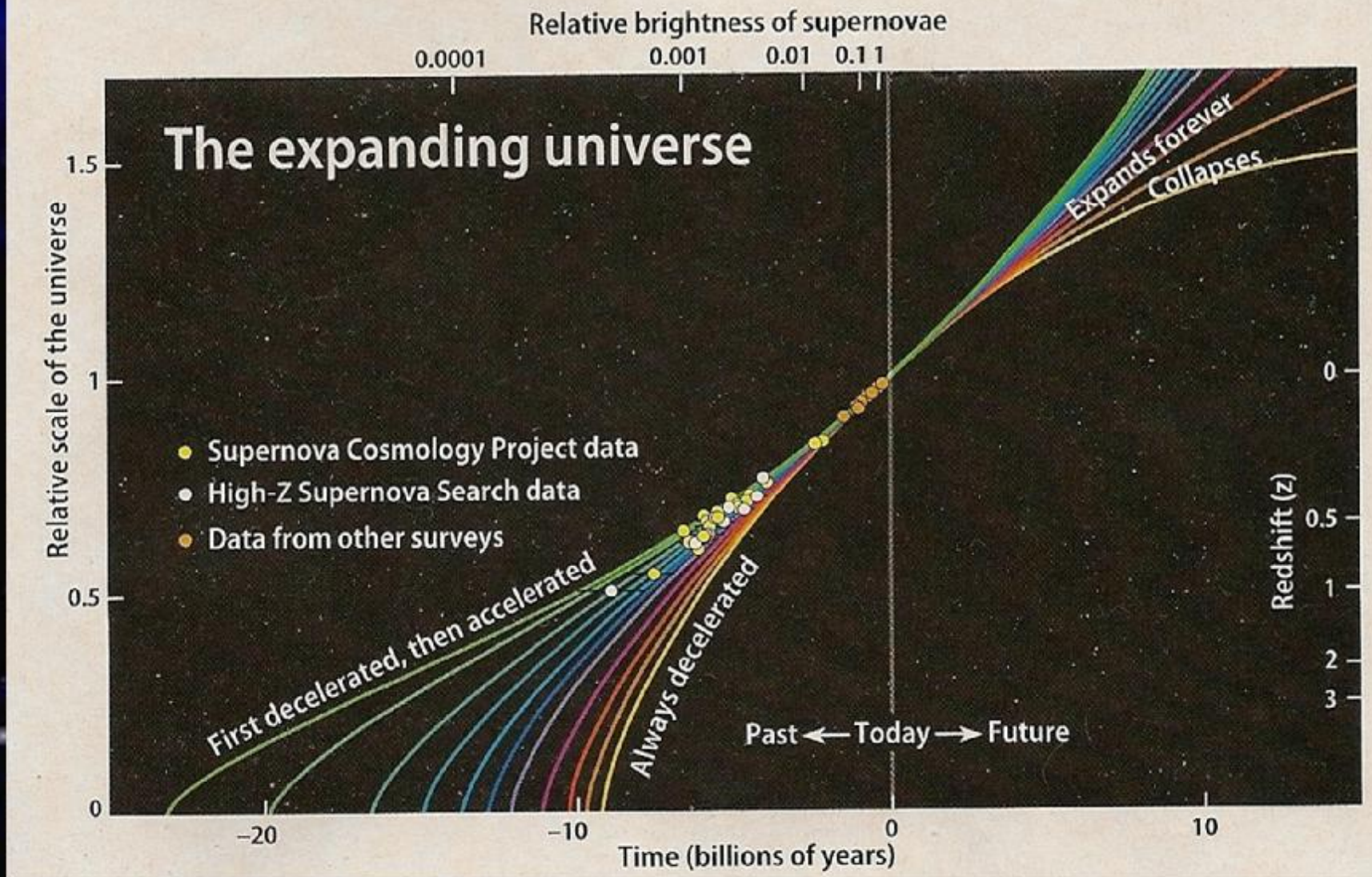

10 million ly
Virgo III Groups
180°
NGC 7582
NGC 6744
NGC 5033
NGC 5128
Local Group
M101
Canes Groups
Virgo Cluster
NGC 4697
270°
90°
Sculptor
Maffei
M81
Leo I
Ursa Major Groups
NGC 1023
NGC 2997
0°
Dorado
Leo II Groups
Fornax Cluster
Eridanus Cluster


100 million ly
Capricornus Supercluster
Corona-Borealis Supercluster
Hercules Superclusters
Capricornus Void
Bootes Superclusters
Pavo-Indus Supercluster
180°
Bootes Void
Centaurus Supercluster
Shapley Supercluster
Sculptor Supercluster
Sculptor Void
270°
90°
Virgo
Coma Supercluster
Hydra
Ursa Major Supercluster
Pisces-Cetus Superclusters
Perseus-Pisces Supercluster
Leo Superclusters
0°
Horologium Supercluster
Sextans Supercluster
Columba Supercluster


1 billion ly
Virgo
Supercluster
Shapley
Supercluster
Horologium
Supercluster



Deepest Image EVER


Relative brightness of supernovae
0.0001
0.001
0.01
0.1
1
The expanding universe
Relative scale of the universe
1.5
1
0.5
0
Supernova Cosmology Project data
High-Z Supernova Search data
Data from other surveys
First decelerated, then accelerated
Always decelerated
Expands forever
Collapses
Redshift (z)
0
0.5
1
2
3
Past ← Today → Future
−20
−10
0
10
Time (billions of years)