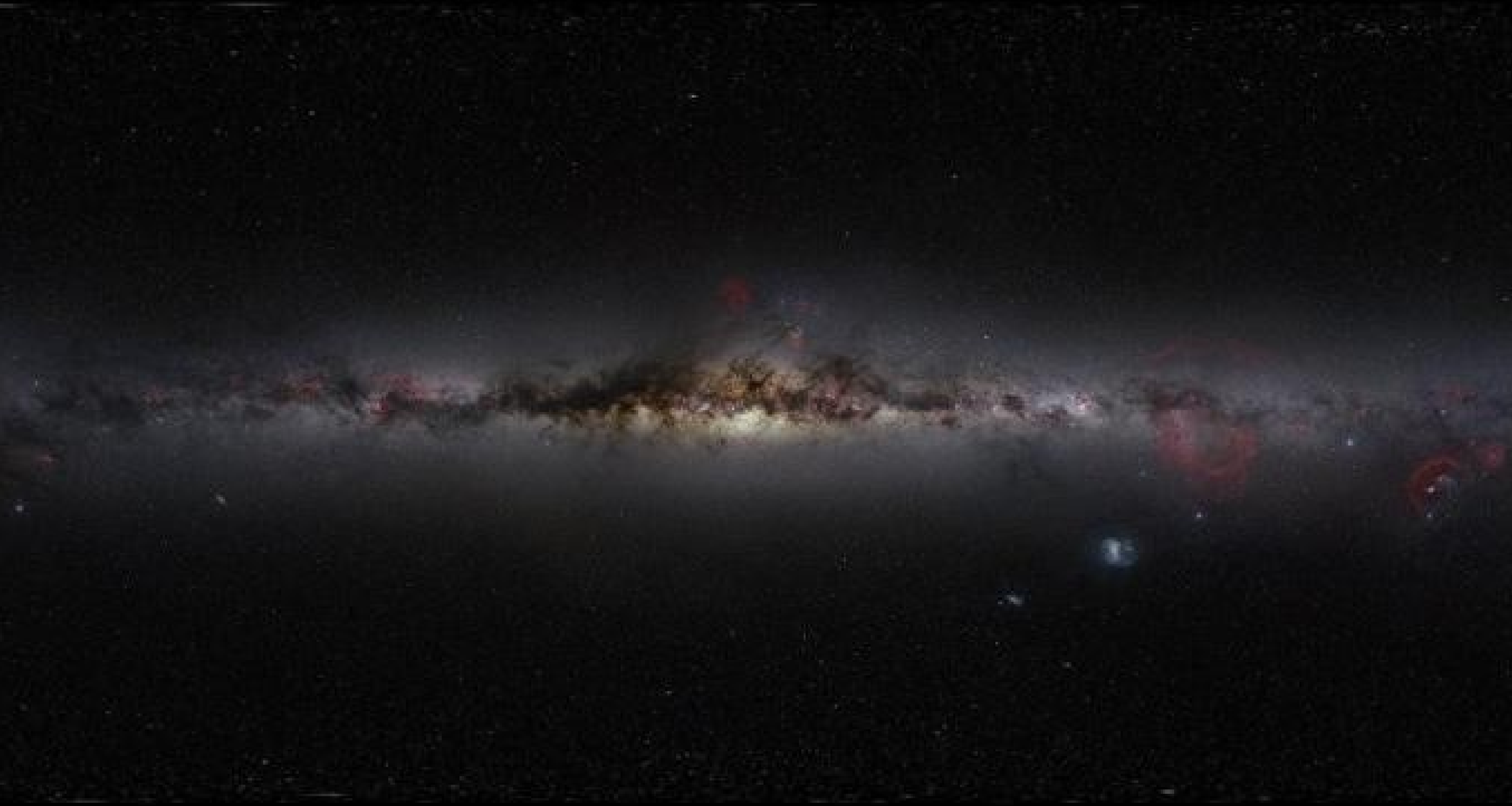

Galaxies 1
The Milky Way
Our local City!

The Milky Way

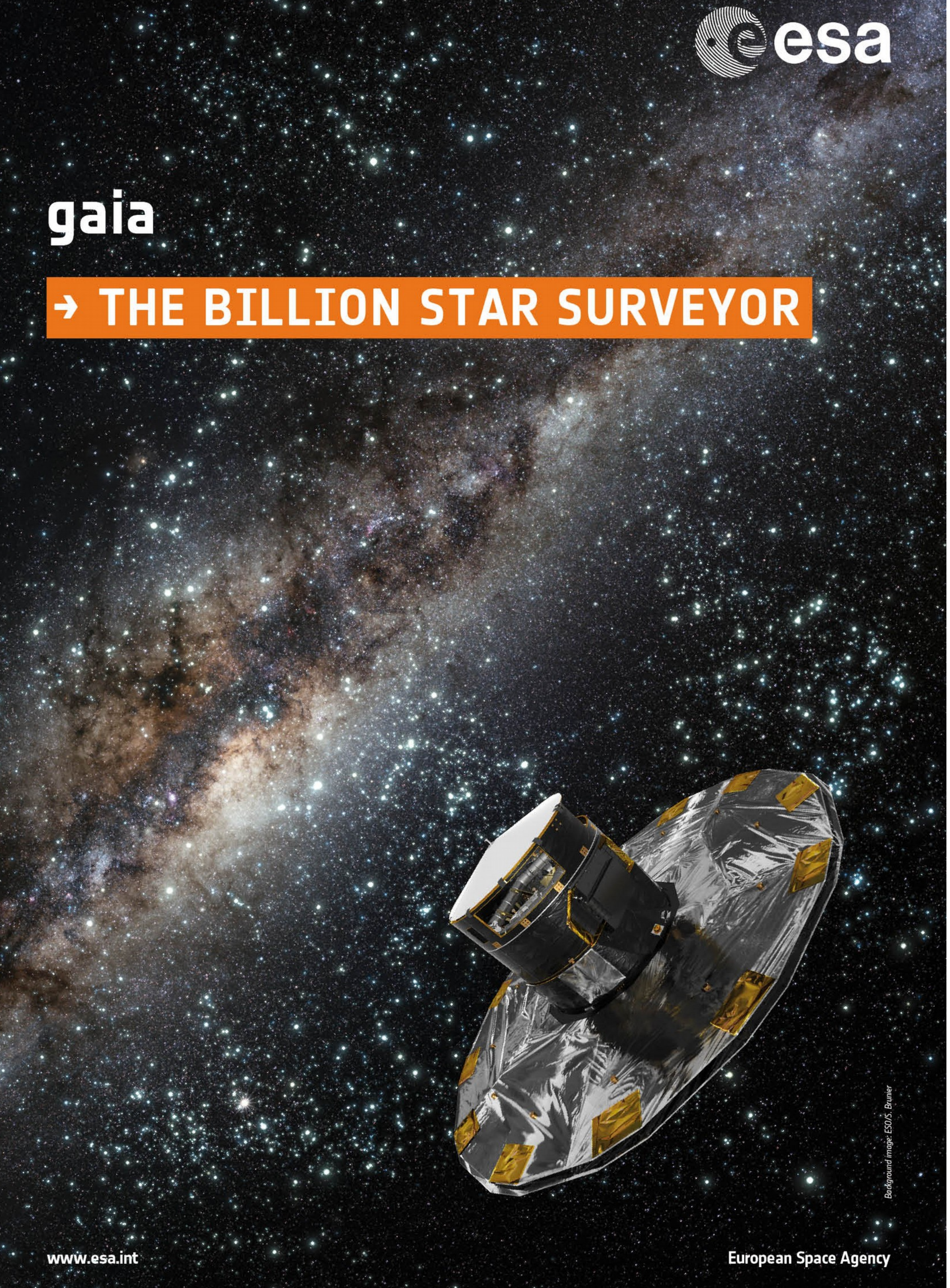
- Milky Way – milky glow in sky, not resolved
- We see ~6000+ stars , but are many more (Galileo)
- Counting stars – flattened system
- Brightest and thickest towards galactic centre in Sagittarius

- Telescopes can see many thousands of stars plus dust, which obscures most of galaxy

Whole galaxy optical composite (37,000 images)



https://apod.nasa.gov/apod/ap110520.html

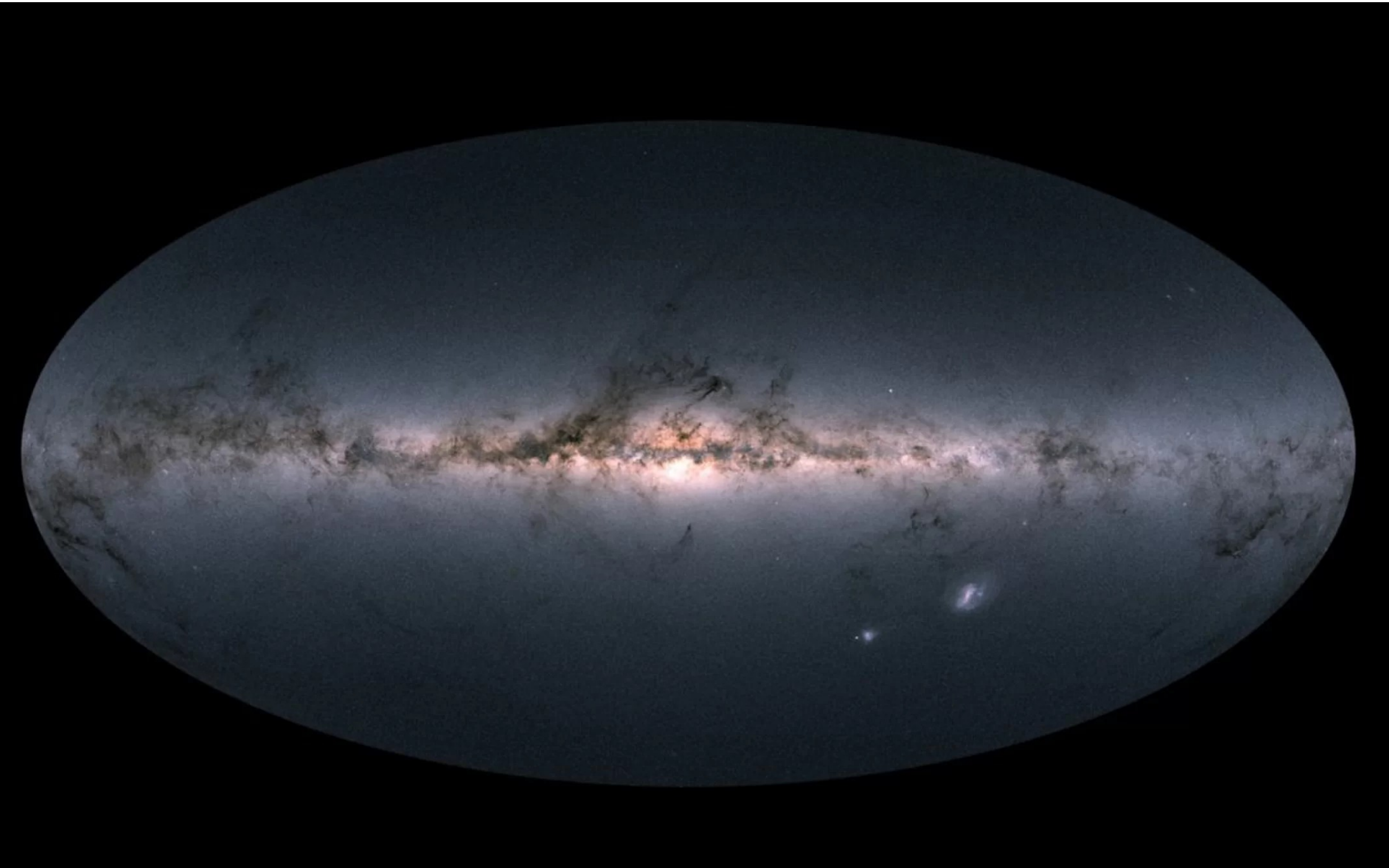


Gaia

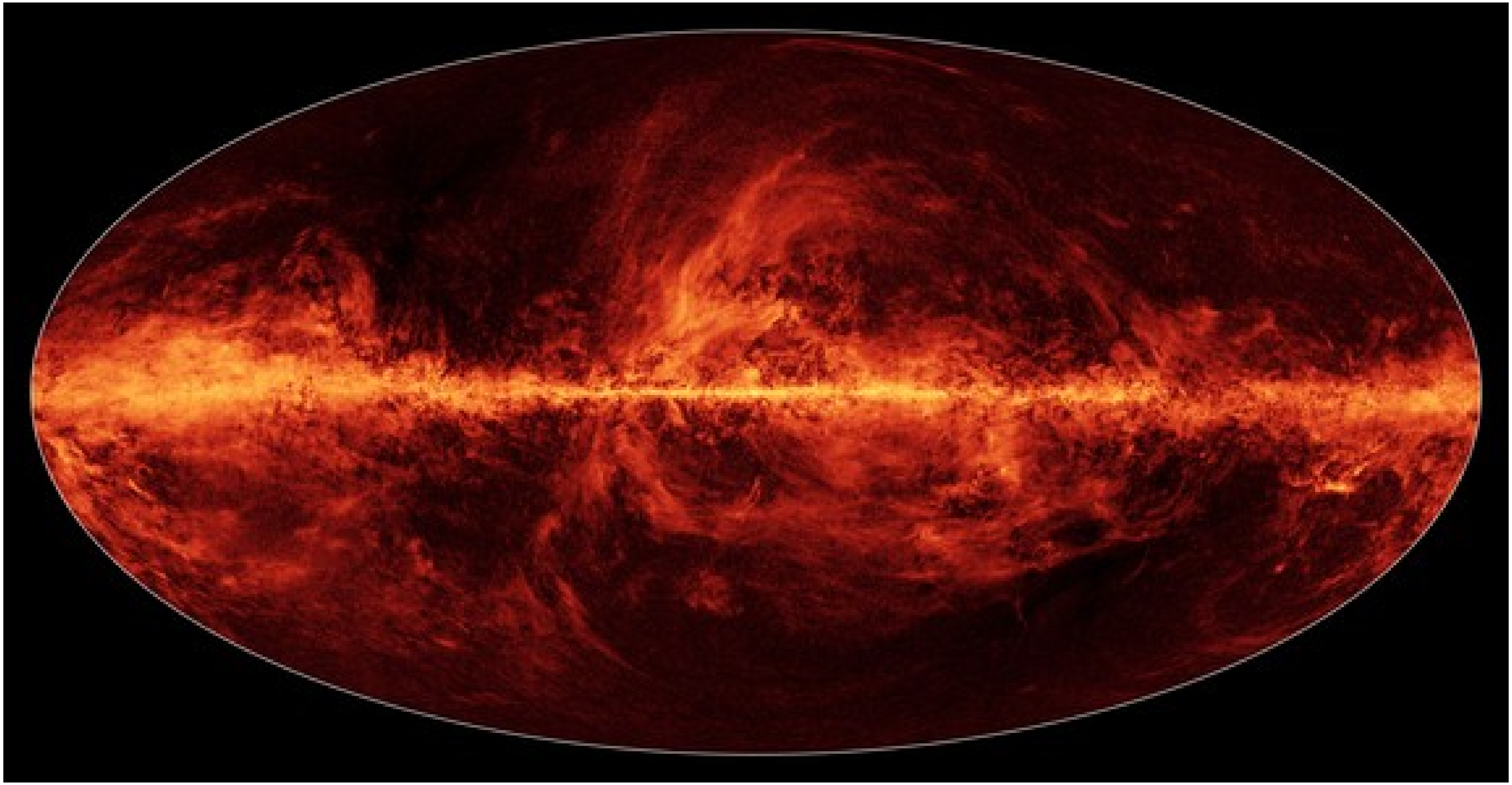
- 3-D map of our Galaxy
- Position and radial velocity measurements
- Stereoscopic and kinematic census of ~1% of stars in galaxy

The Gaia Map

1.7 billion stars



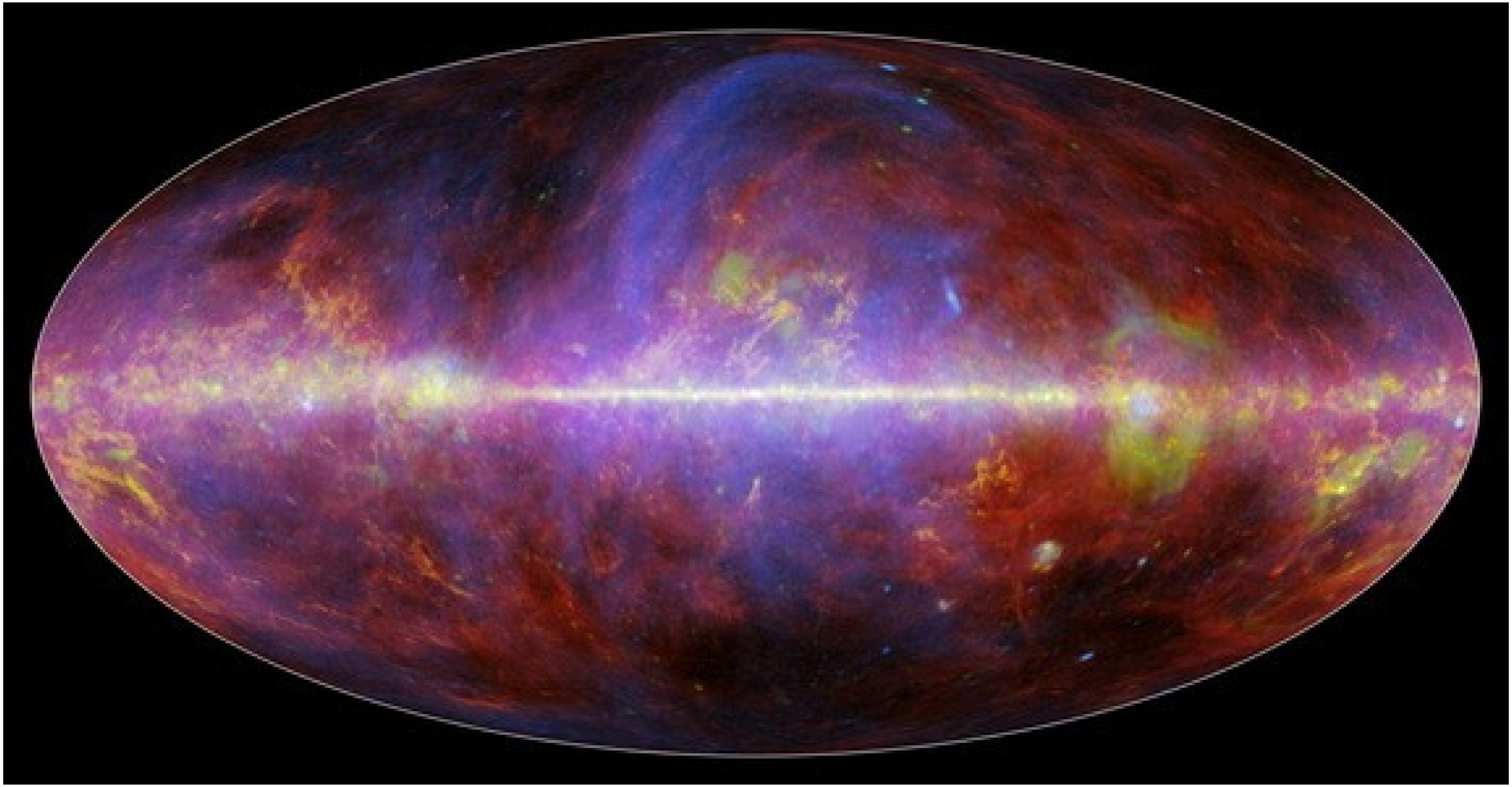
Distribution of interstellar dust through the Galaxy as seen by ESA Planck satellite



http://www.space.com/14254-photos-planck-spacecraft-big-bang-images.html

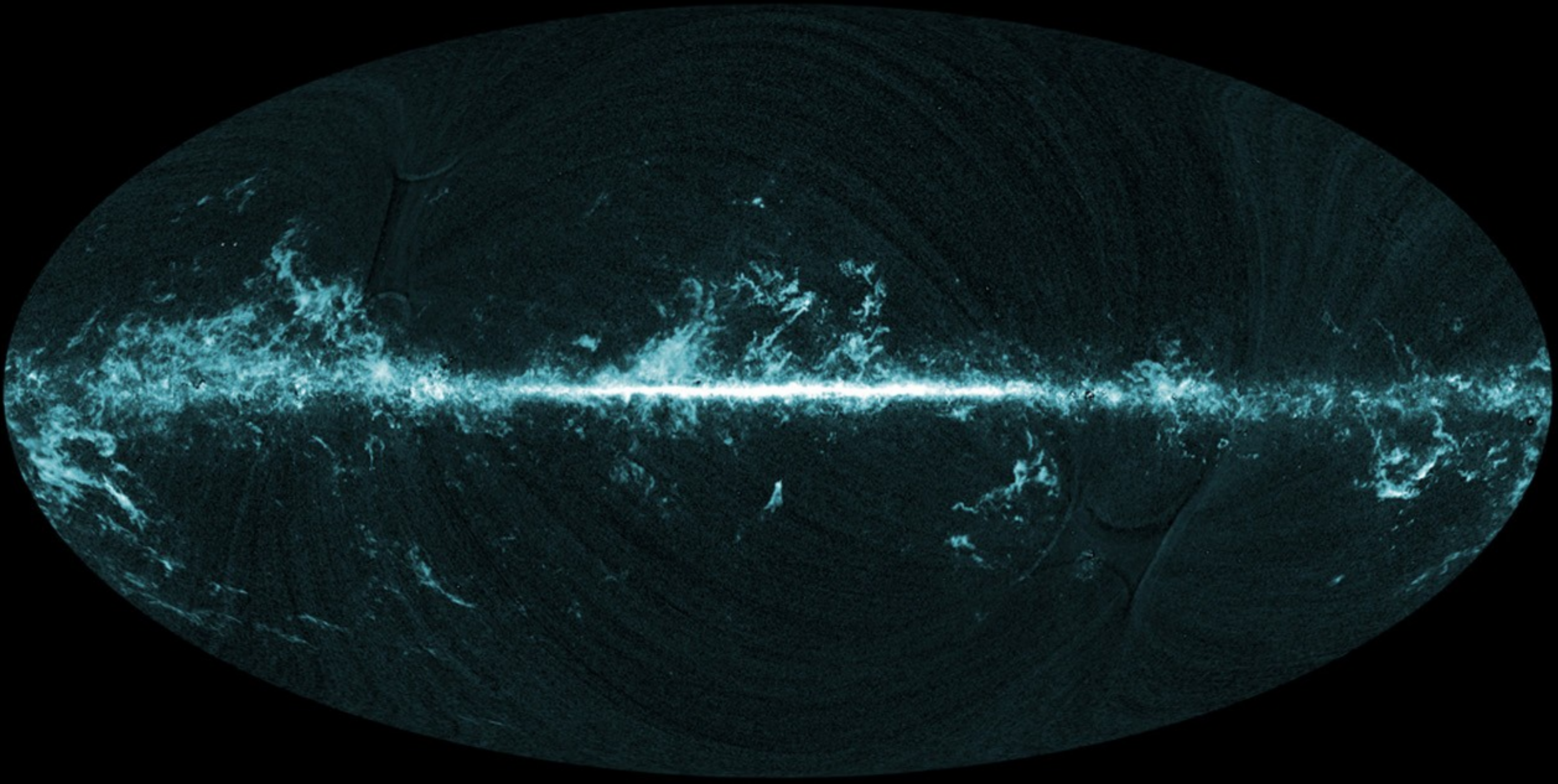
Planck Foreground emission

Composite of Synchrotron, Free-free, Spinning Dust, CO, and Thermal Dust components [Feb 2015]

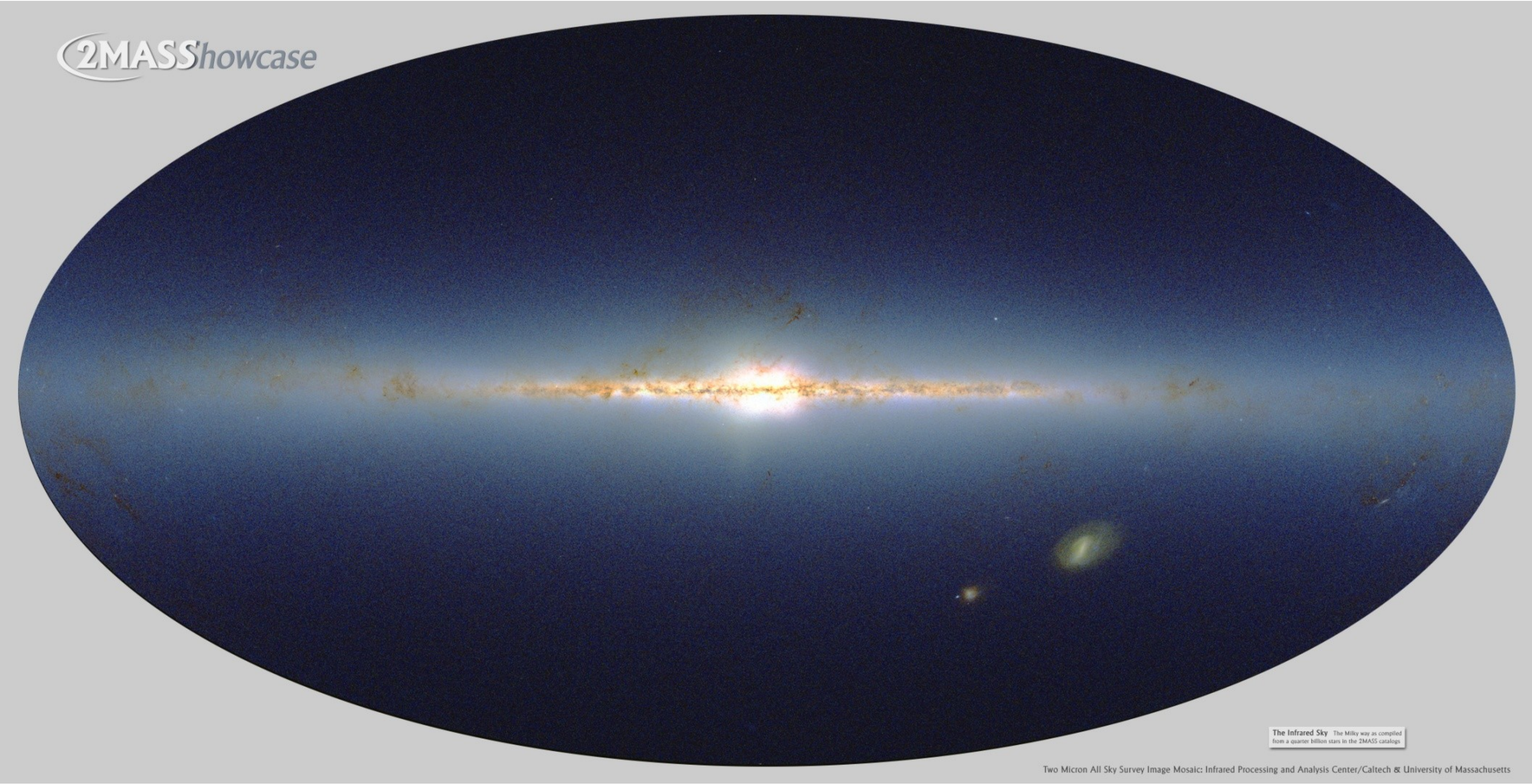


http://www.cosmos.esa.int/web/planck/picture-gallery

Planck CO map of Galaxy



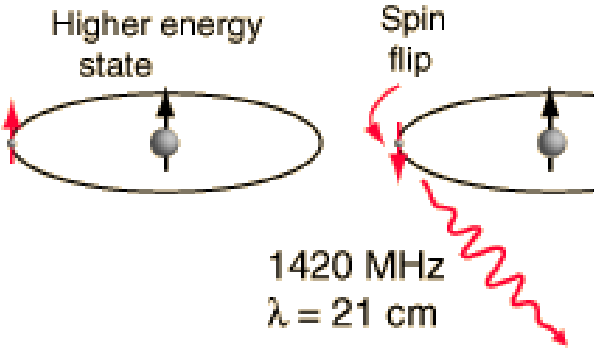
Near-infrared: 1-2 μm



Atlas Image obtained as part of the Two Micron All Sky Survey (2MASS), a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation.

Interstellar medium

- Many gas clouds – nebulae
- HI emits in radio
  spectrum



- Hydrogen gas HI – formed into hot young stars under gravity, start emitting ultraviolet light, which ionises surrounding gas – HII region
- HII (ionised gas) emits as electrons fall back to lower energy states – red (6563A) emission


Lagoon nebula
Image credit Michael Miller, Jimmy Walker

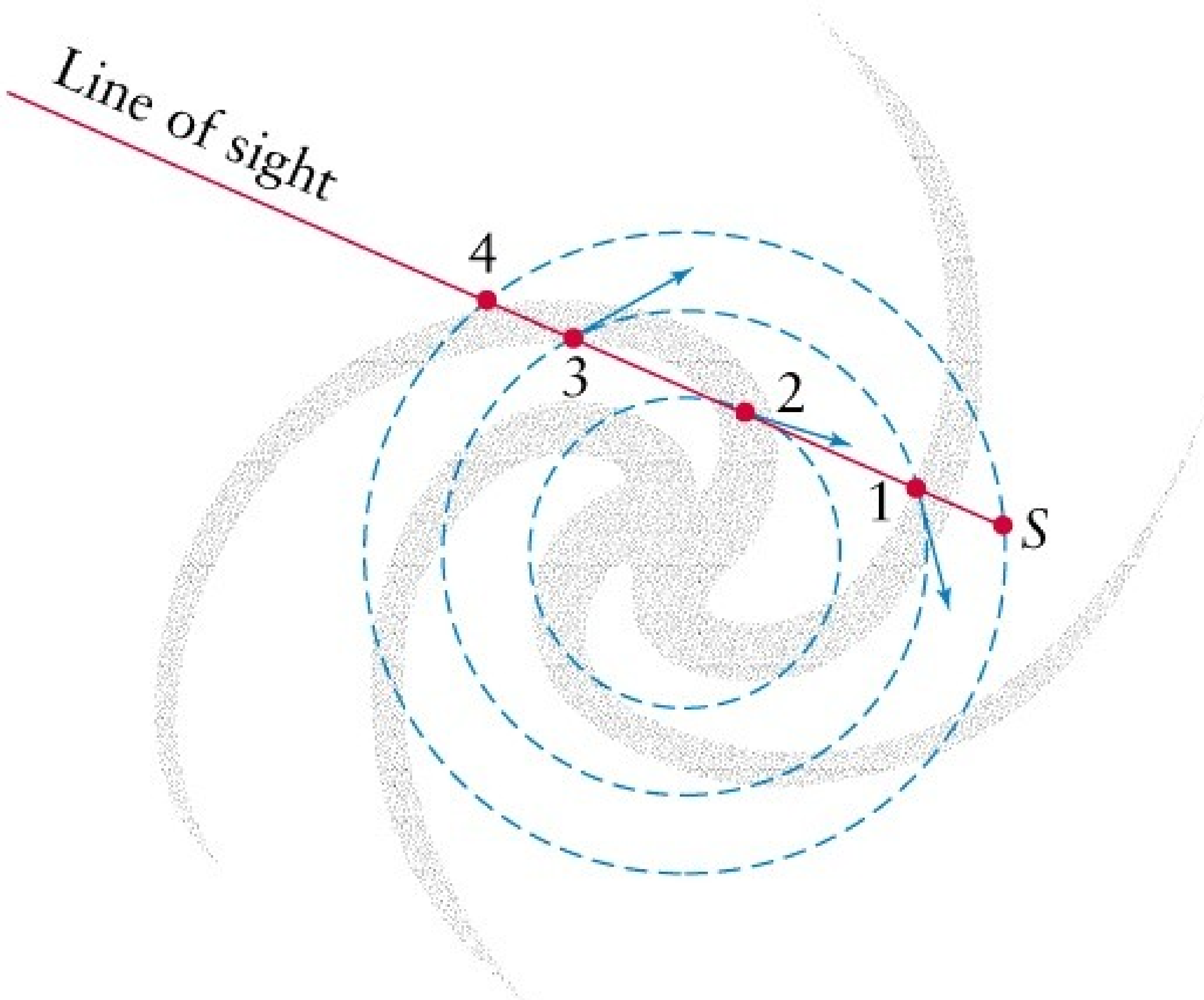
Radio astronomy

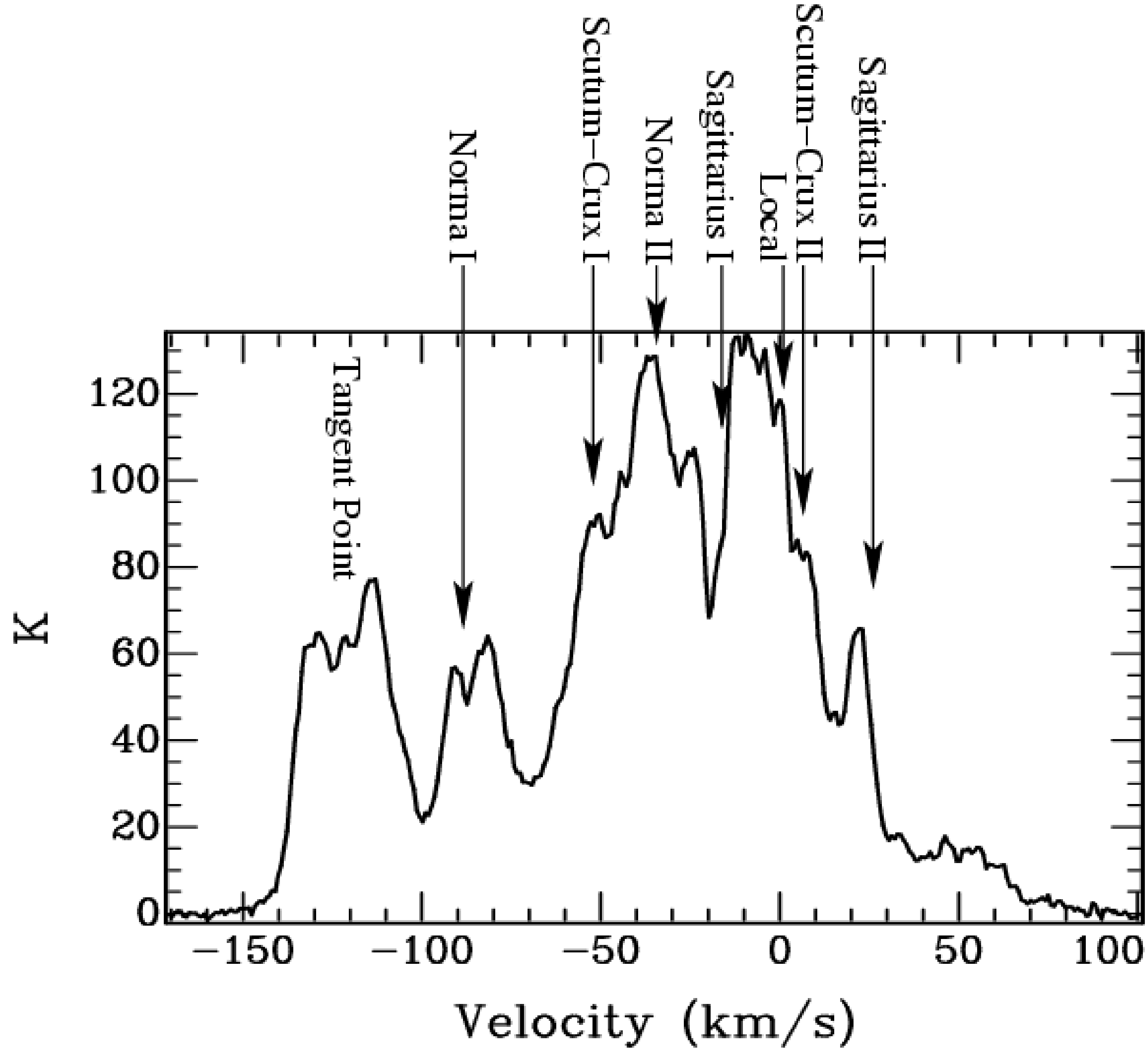
- Disk structure? Dust restricts – can only see 1000 light years away
- Hence need to use radio astronomy to penetrate dust
- Doppler shift of H1 (neutral hydrogen , emission line with wavelength of 21 cm)
- Reveals spiral arms (4 +side spurs)
- Young massive bright stars in spiral arms

Spiral Arms

- Spiral arm structure determined using tracers of massive star formation with known distances – usually via Doppler shift and a rotation model
- HI, massive stars, H II regions and CO clouds are used
- Our galaxy has 4 star-forming gaseous arms and 2 stellar arms originating at each end of a bar

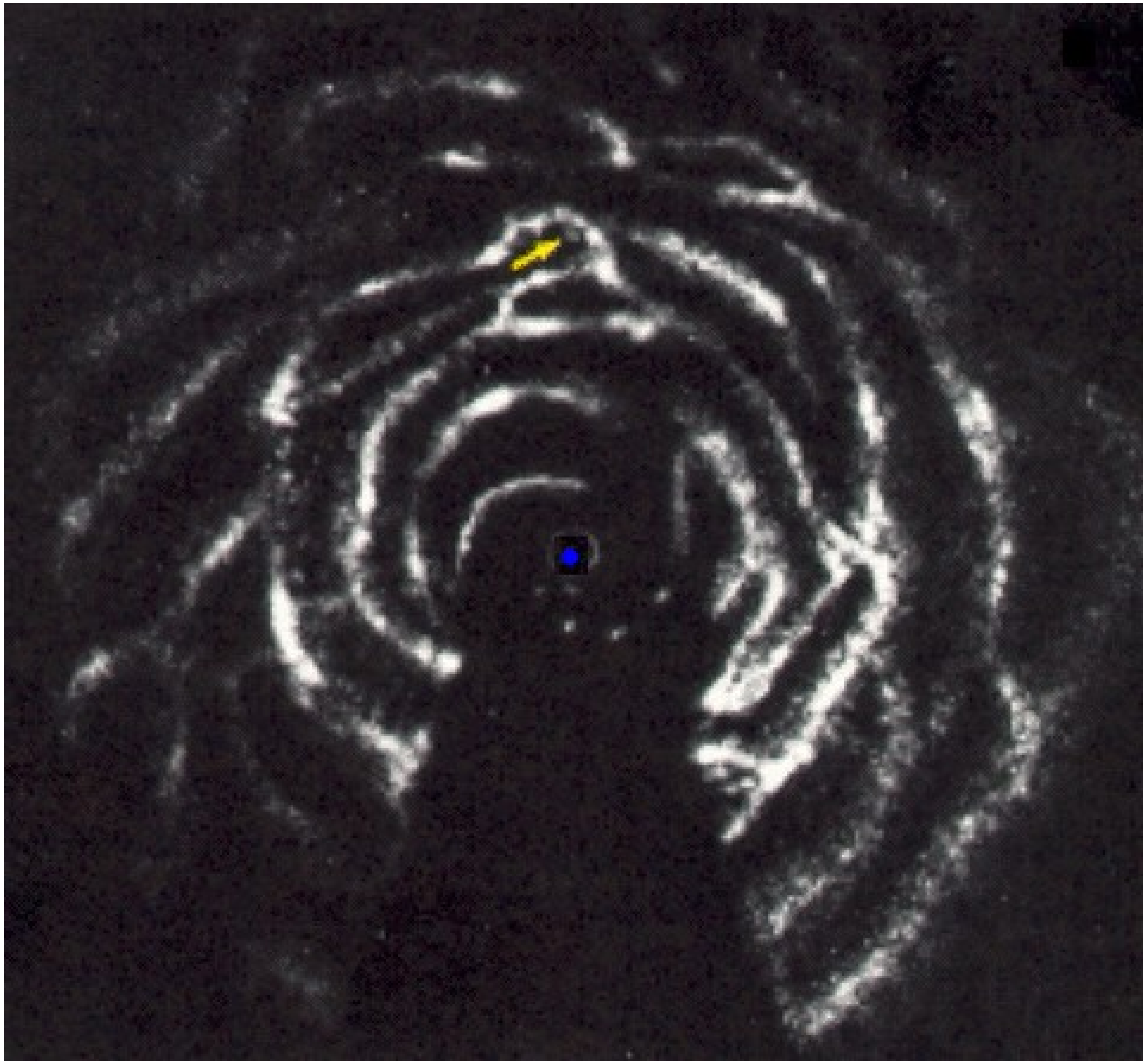
Differential rotation with respect to the Sun



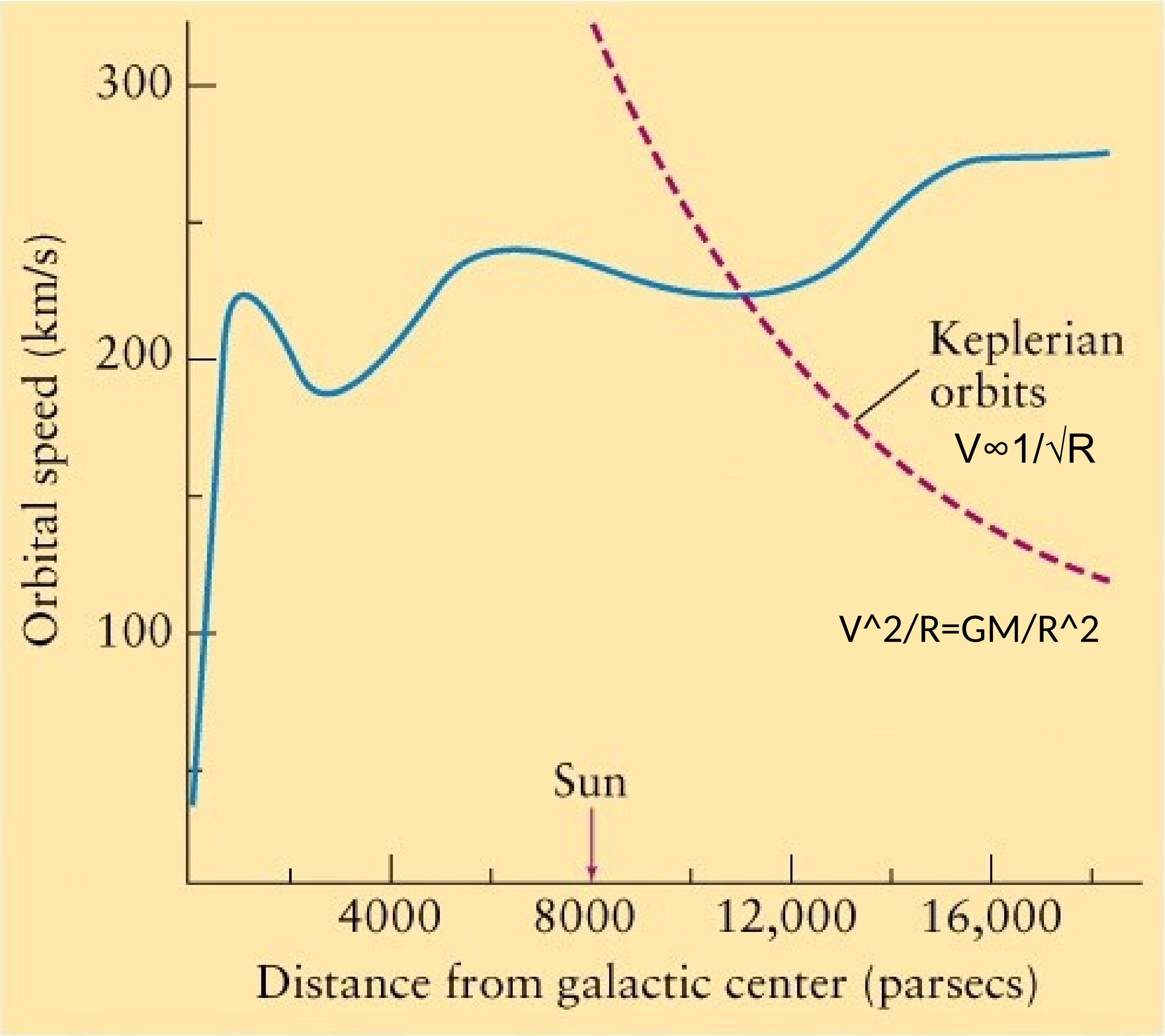


Norma I
Scutum–Crux I
Norma II
Sagittarius I
Local
Scutum–Crux II
Sagittarius II
Tangent Point
K
Velocity (km/s)
0
20
40
60
80
100
120
−150
−100
−50
0
50
100

Spiral arm map from HI



We think we live in a spiral galaxy like this one

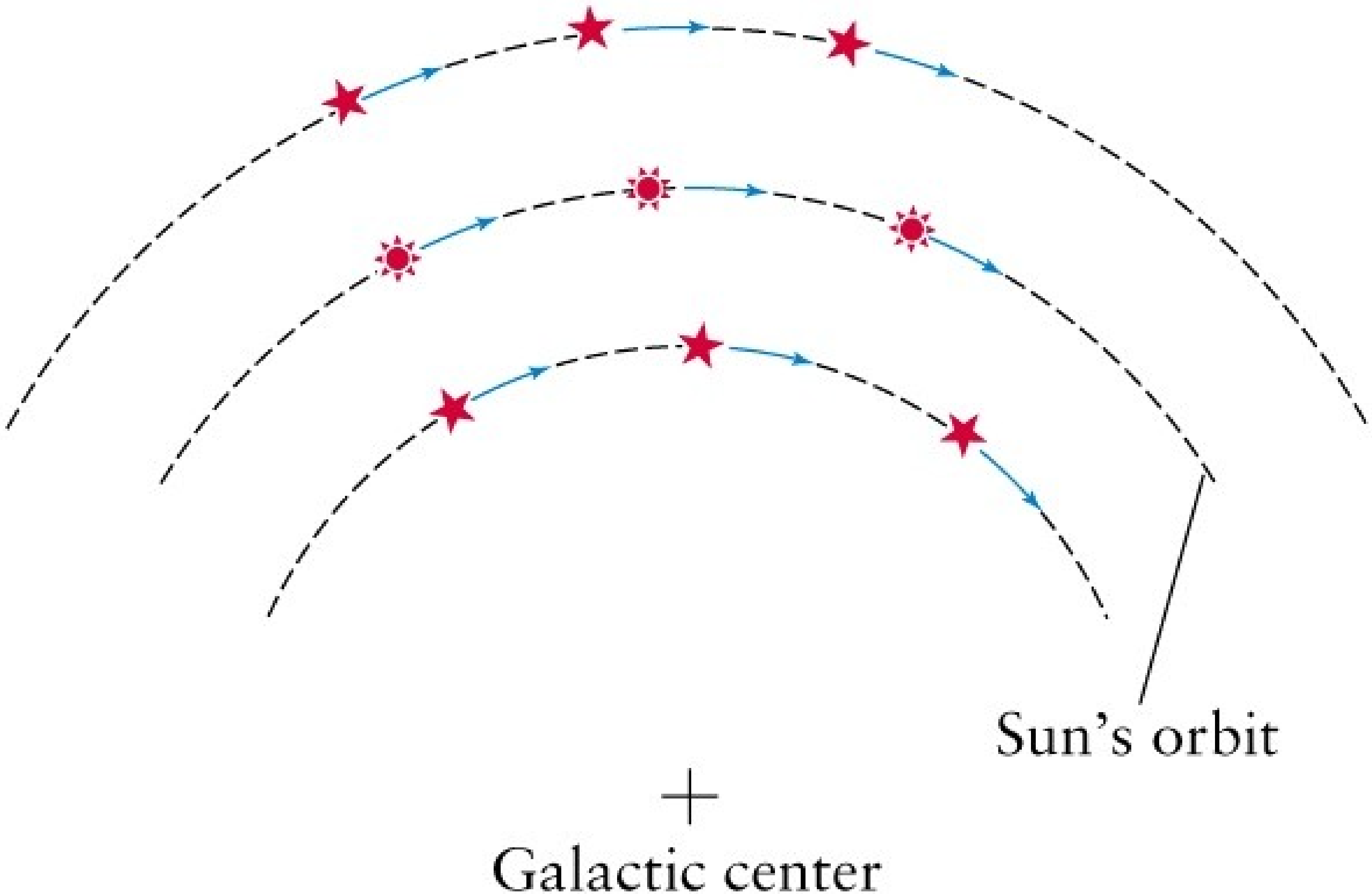

300
200
100
Orbital speed (km/s)
Keplerian
orbits
V∞1/√R
V^2/R=GM/R^2
Sun
4000
8000
12,000
16,000
Distance from galactic center (parsecs)

Rotation of the disc

- The observed rotational velocity of the Galactic disc is approximately constant with radius

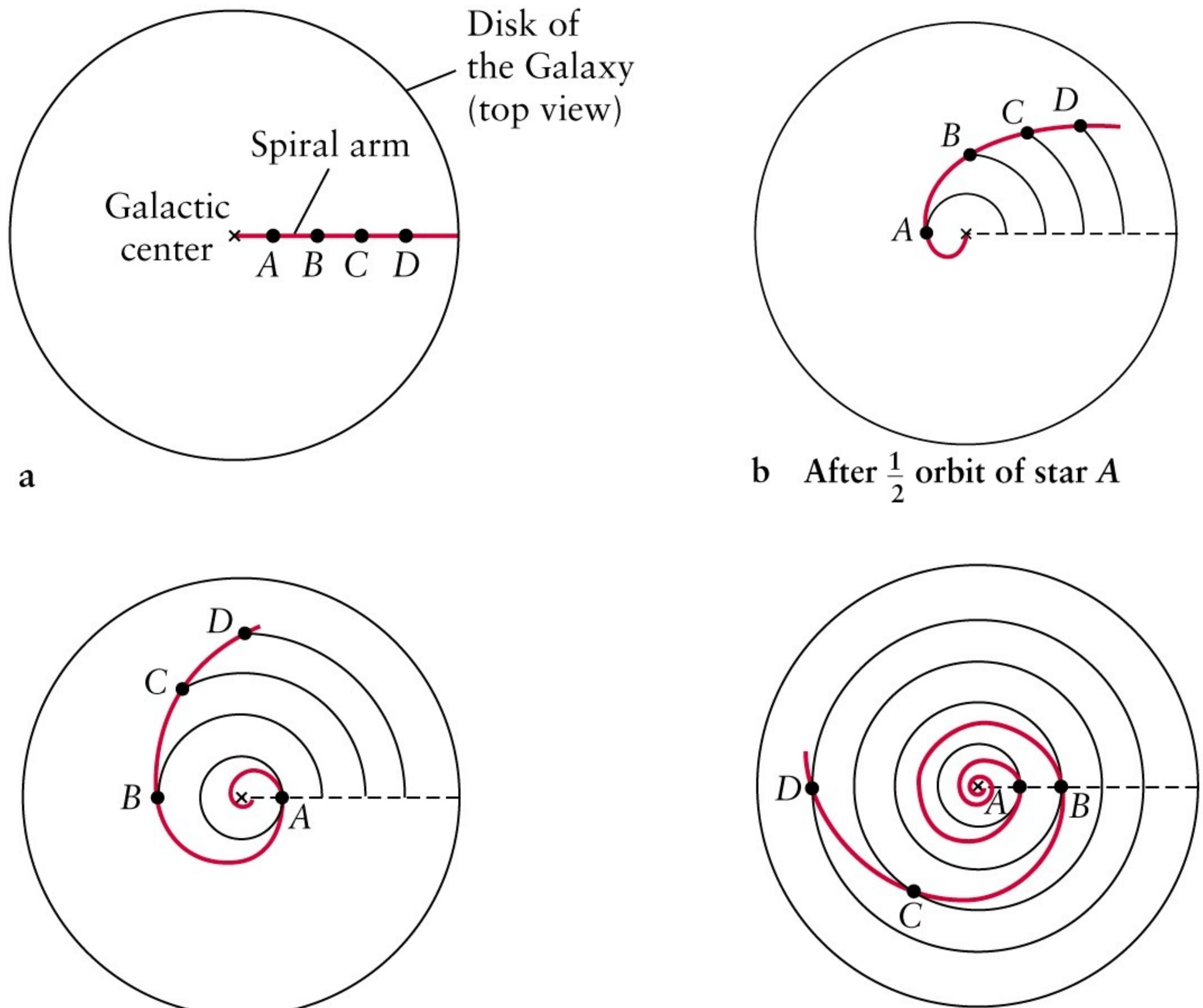
$$v \approx \text{constant} \approx 220\ \text{km s}^{-1}$$

- This requires **differential rotation**: stars closer to the centre of the galaxy orbit in a shorter time (period $P \propto r$) and overtake us, whilst we overtake stars further out


Sun's orbit
Galactic center

The Wind-up Problem

- Differential rotation suggests lines in the galaxy would get stretched out
- If the spiral arms were a fixed pattern in the stars and gas the differential rotation would cause them to ‘wind-up’ in a few revolutions



a

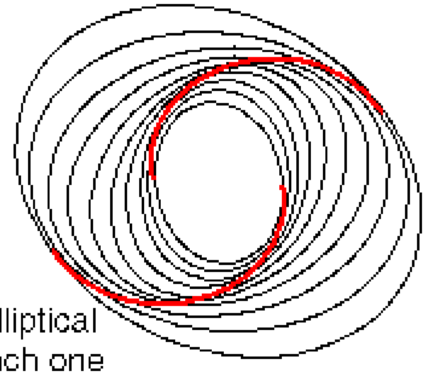
b After $\frac{1}{2}$ orbit of star *A*

c After one orbit of star *A*

d After two orbits of star *A*

Spiral arms

- Don’t wind up like solid structures
- “Traffic jams”
- Long lasting, stars move through arms on ~circular or elliptical orbits
- Jam started by over dense region – ripple gets sheered by motion of disk
- Stars take ~250 million years to orbit galaxy, so move in and out of spiral arms, say 20 times for the Sun (moving at 220km/sec).

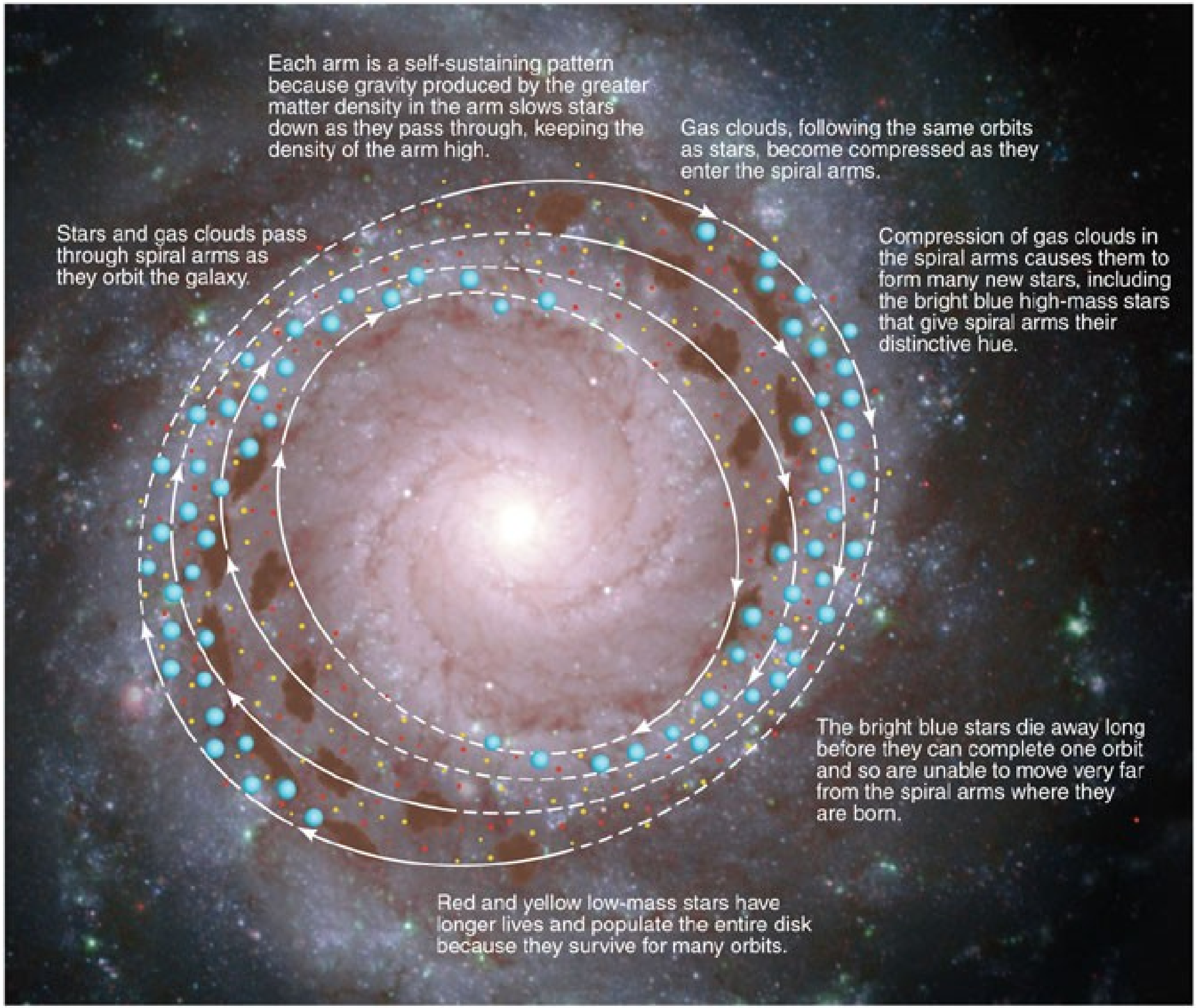


Nested Elliptical Orbits, each one slightly rotated.

Density Waves

Lin & Shu

- The current model for spiral arms is that they are a density wave pattern that rotates at a slower speed than the galaxy
- Stars and gas pass in and out of the arm
- As gas gets compressed in the arm molecular clouds form with subsequent star formation
- Spiral arms usually trail the rotation


Each arm is a self-sustaining pattern because gravity produced by the greater matter density in the arm slows stars down as they pass through, keeping the density of the arm high.
Gas clouds, following the same orbits as stars, become compressed as they enter the spiral arms.
Stars and gas clouds pass through spiral arms as they orbit the galaxy.
Compression of gas clouds in the spiral arms causes them to form many new stars, including the bright blue high-mass stars that give spiral arms their distinctive hue.
The bright blue stars die away long before they can complete one orbit and so are unable to move very far from the spiral arms where they are born.
Red and yellow low-mass stars have longer lives and populate the entire disk because they survive for many orbits.

- Dust lane where material enters spiral arm, then H II regions, then blue stars

Credit: NASA and The Hubble Heritage Team (STScI/AURA)

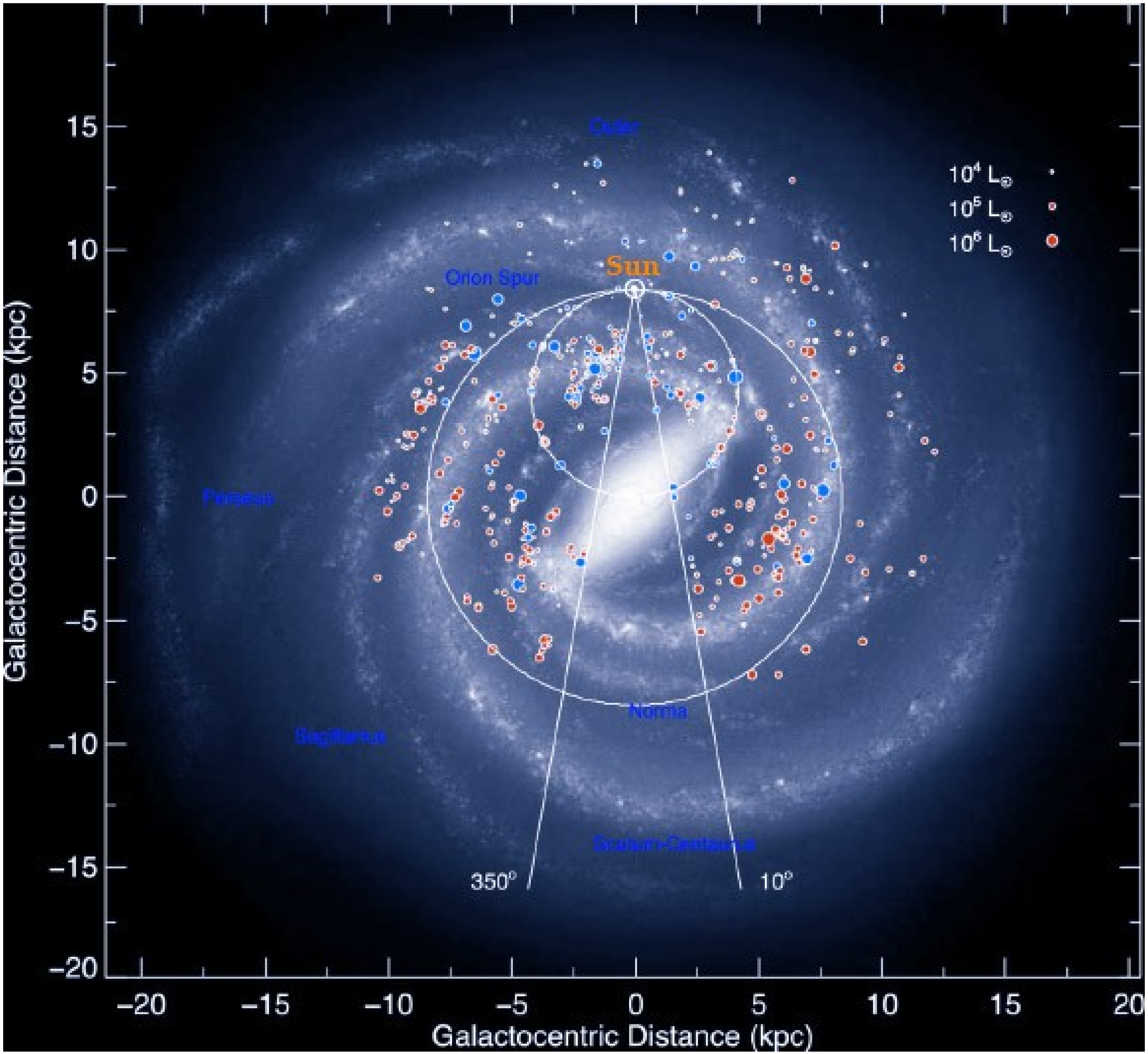
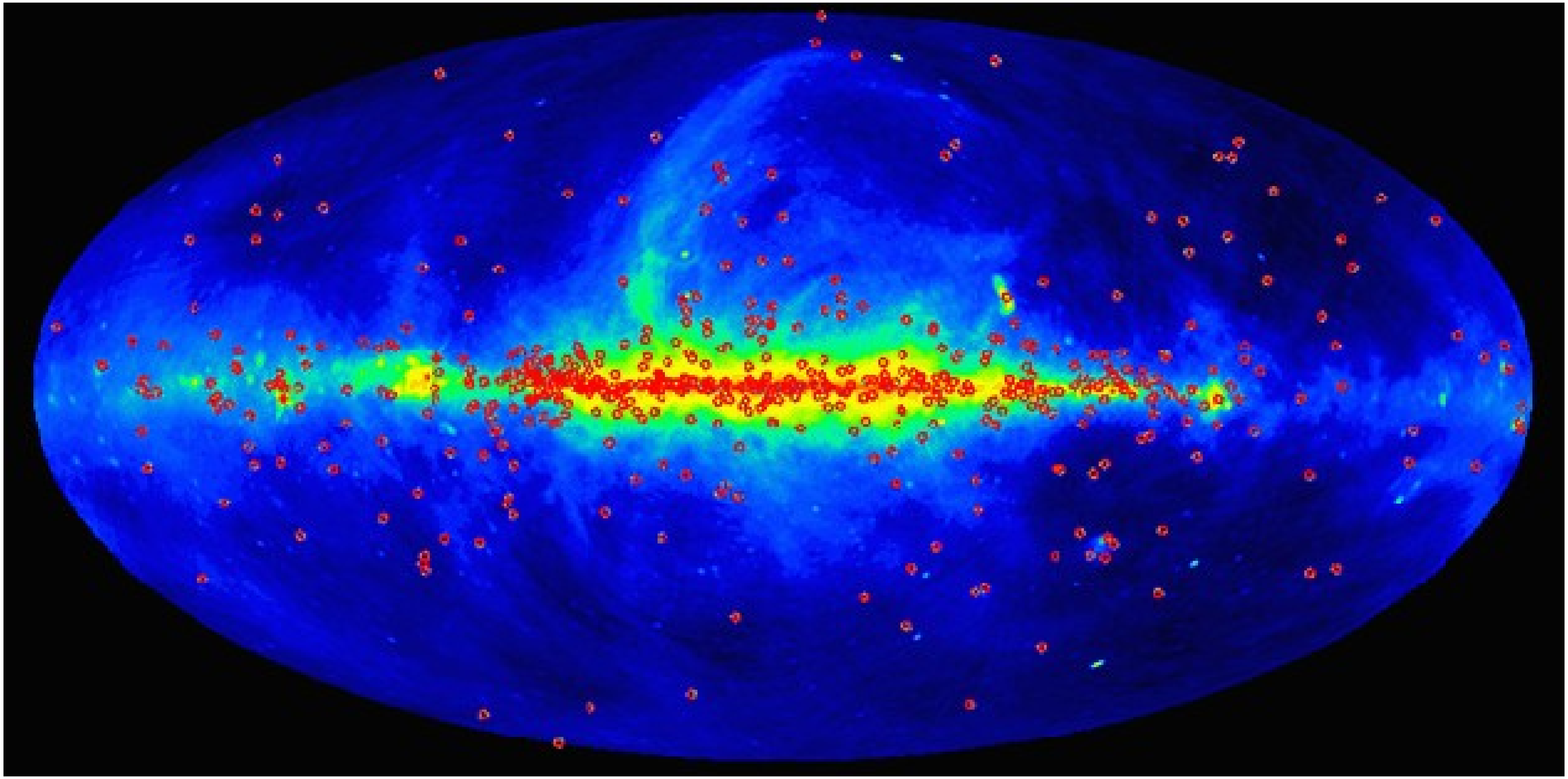


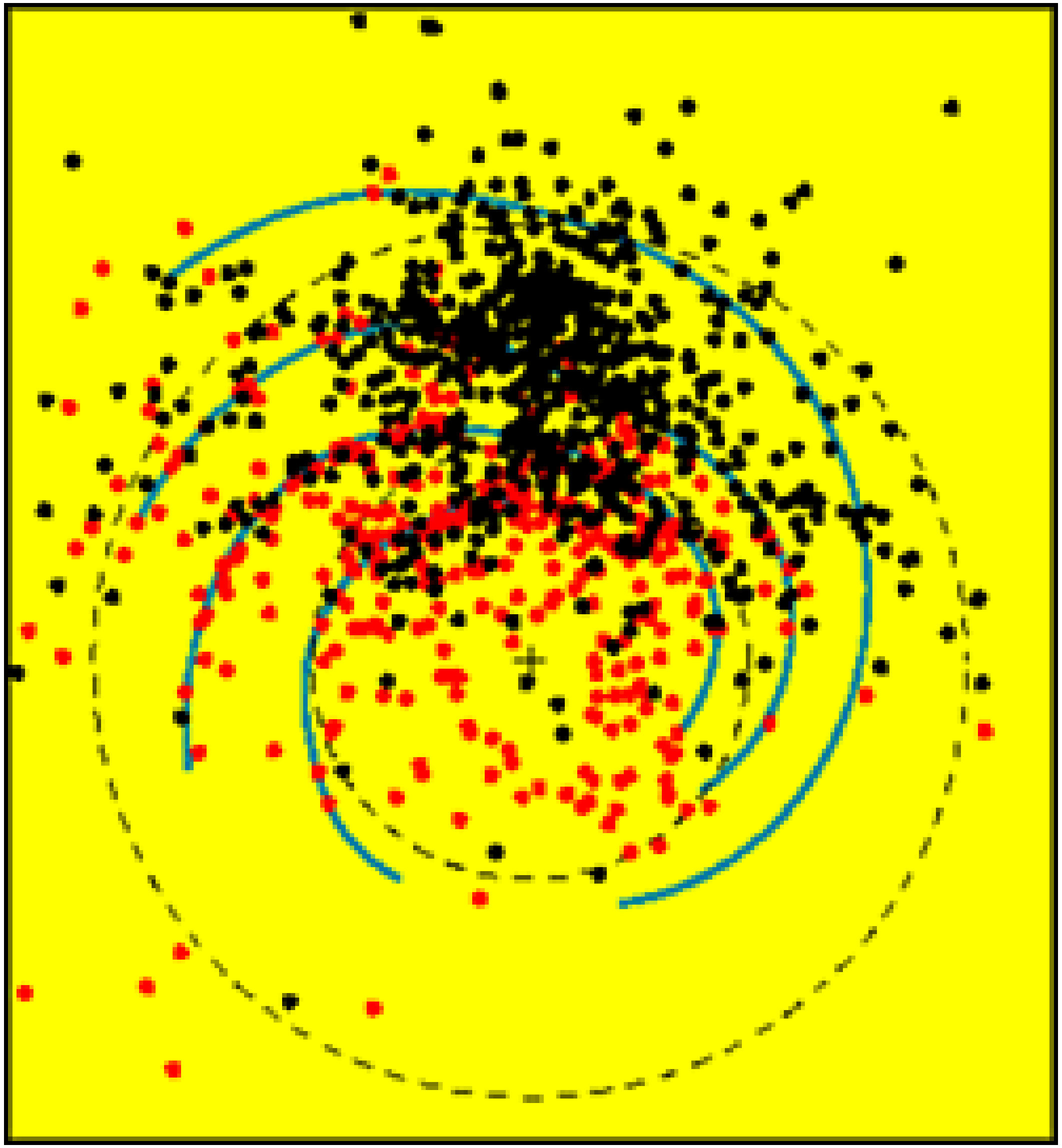
Image credit: Urquhart JS et al / Robert Hurt, the Spitzer Science Center / Robert Benjamin

408 MHZ survey with pulsars



http://www.jb.man.ac.uk/distance/frontiers/pulsars/section6.html

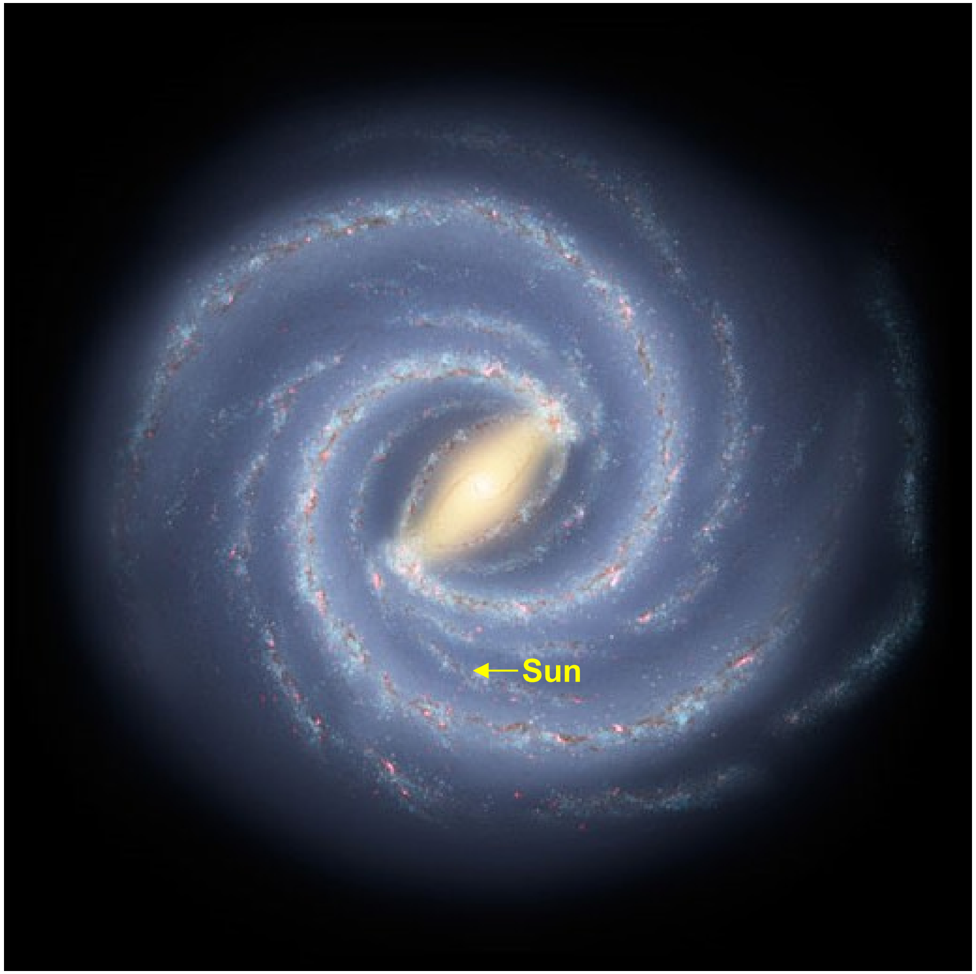
Pulsars as spiral arm markers



- The positions of the known pulsars in the galactic plane before (black) and after the Parkes Multibeam Survey (red). Positions of spiral arms are indicated by blue lines and the galactic centre by a cross.

The Bulge and Bar

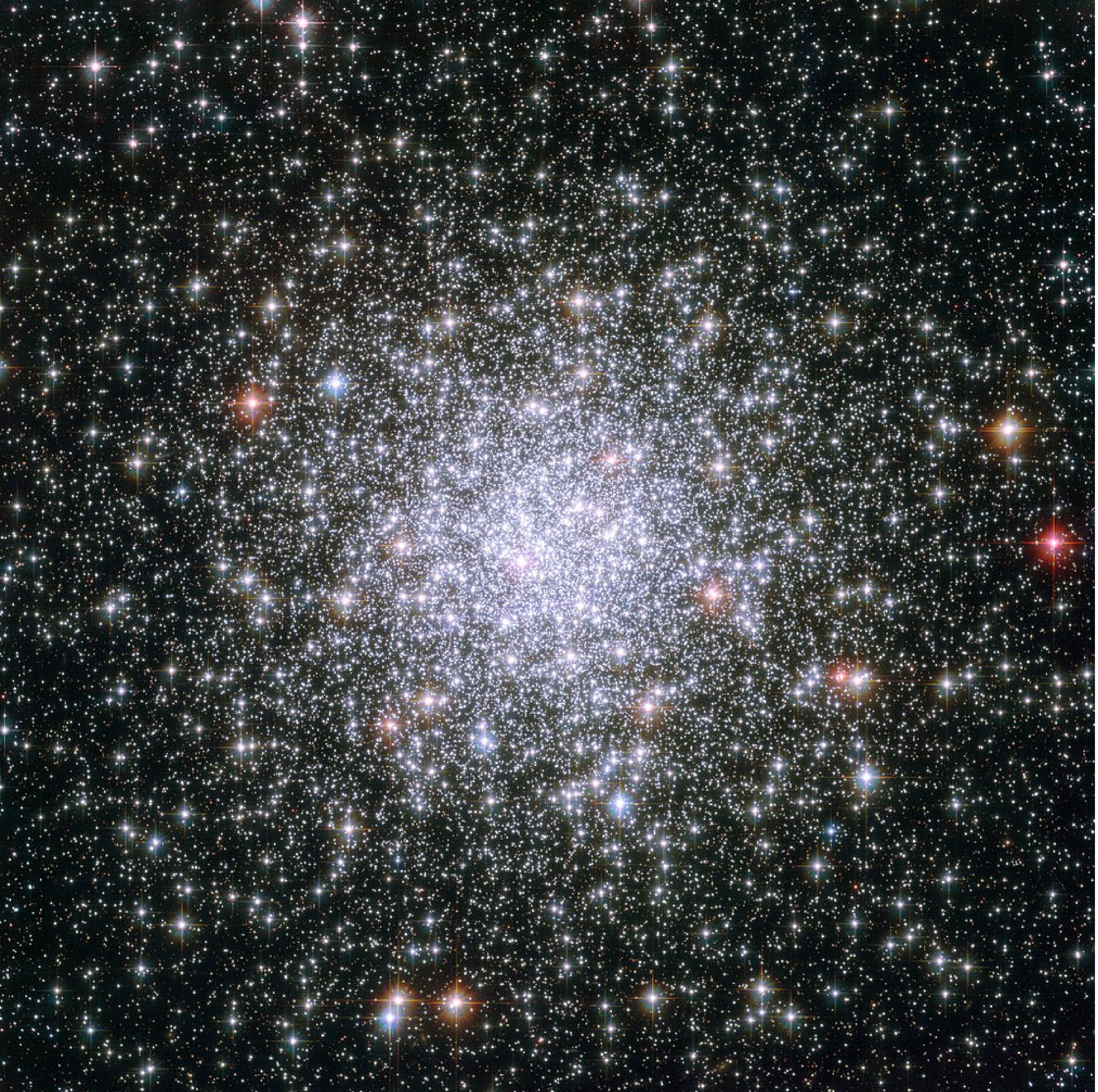
- Bulge is about 1 kpc in radius
- Bar is about 4 kpc in length, and rotates as a solid body



credit: NASA/JPL-Caltech

The Galactic Halo

- The plane of our galaxy is surrounded by a more spherical halo of objects
- Consists of globular clusters and halo stars
- Total radius of the halo is ~ 100 kpc



Globular cluster M69

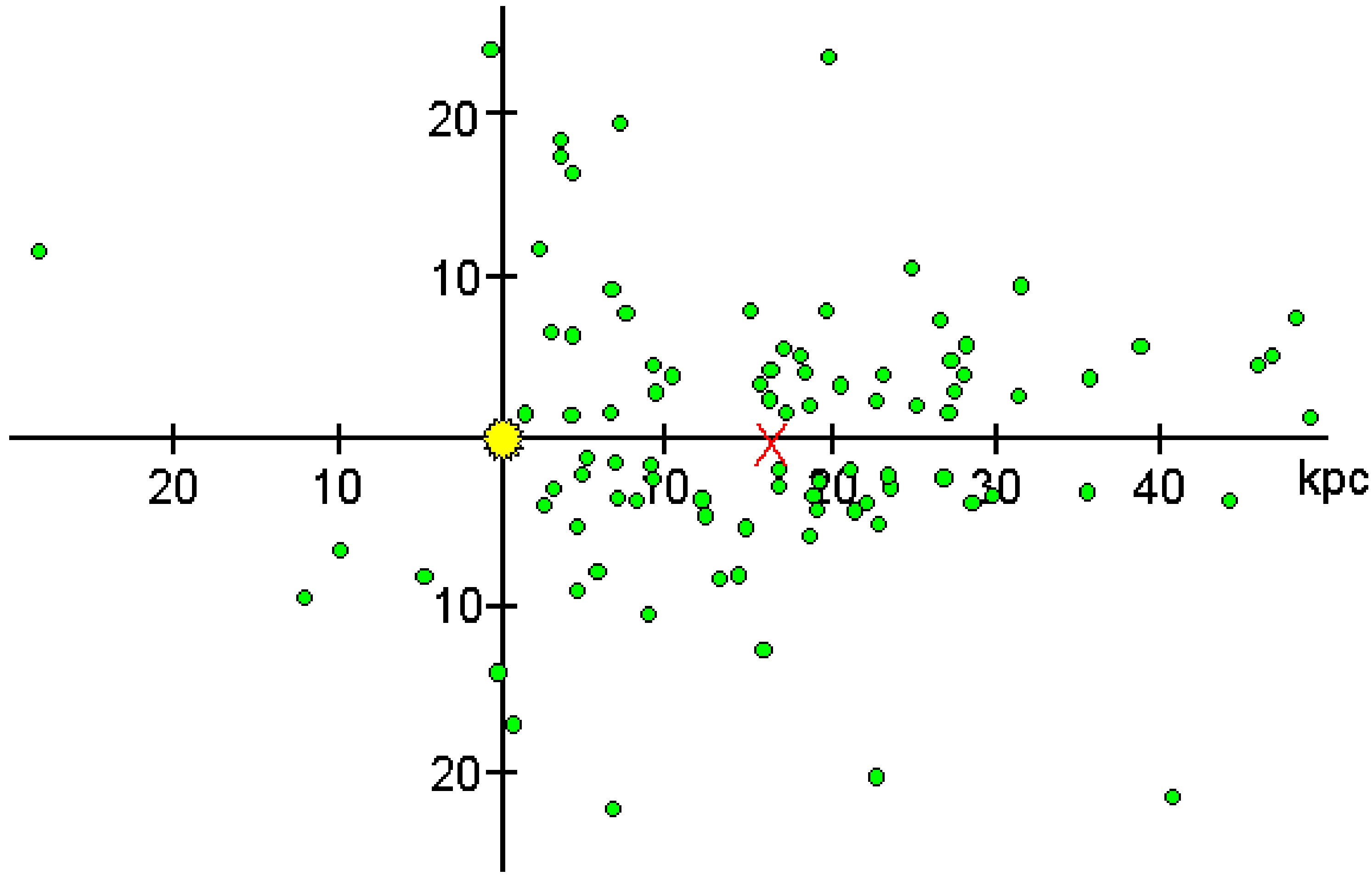
29,700 light years away

http://www.messier-objects.com/messier-69/

Globular clusters

- Globular clusters – very old stars, tight spherical concentrations ~200 light years across, 20,000 to 1 M stars. Old – all stars made together in original period of star formation in Galaxy
- Spherical distribution
- We see offset, more on one side, so we are not at centre
- 27,700 light years off centre Shapley picture (~8Kpc)

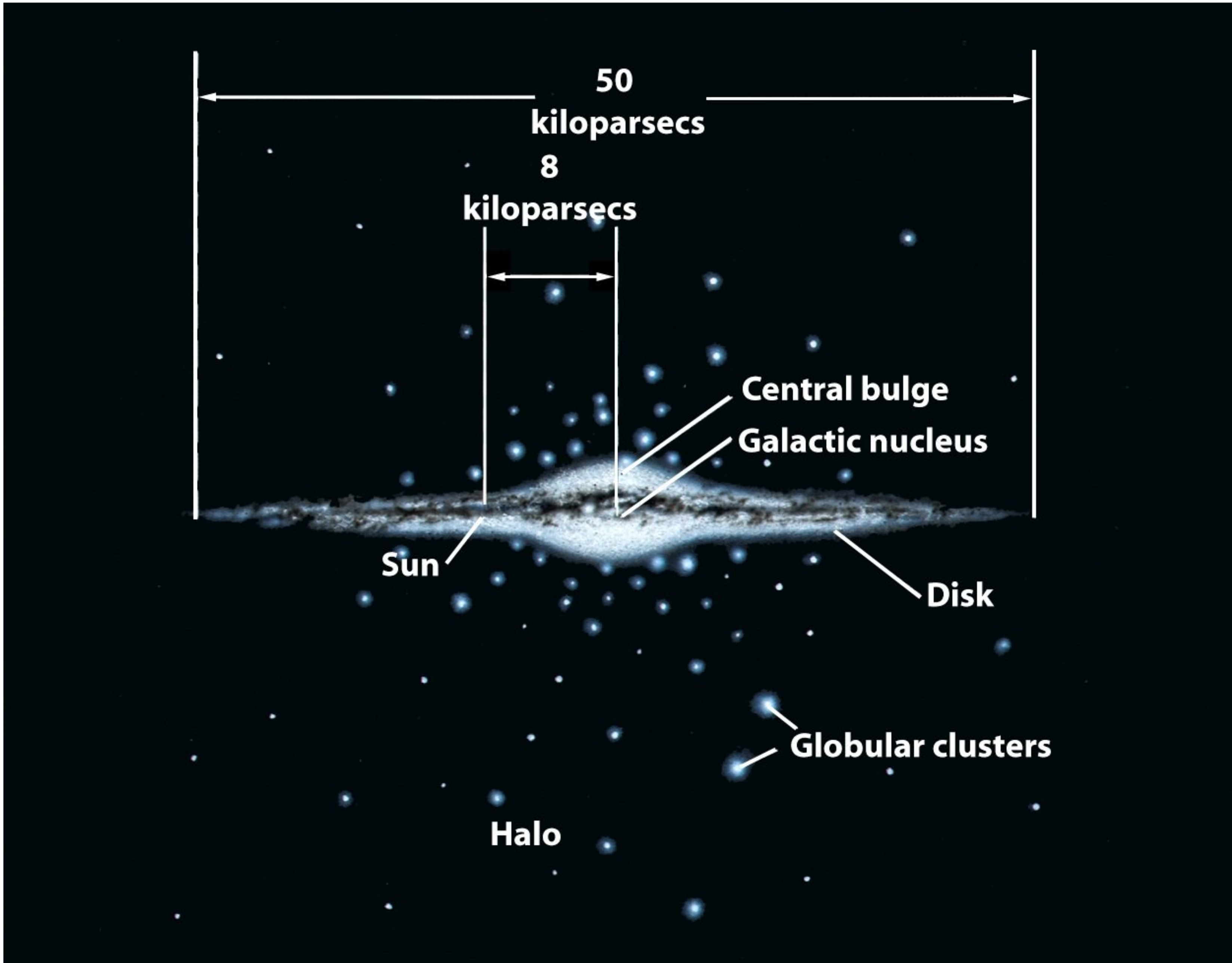
Shapley's Globular Cluster Distribution



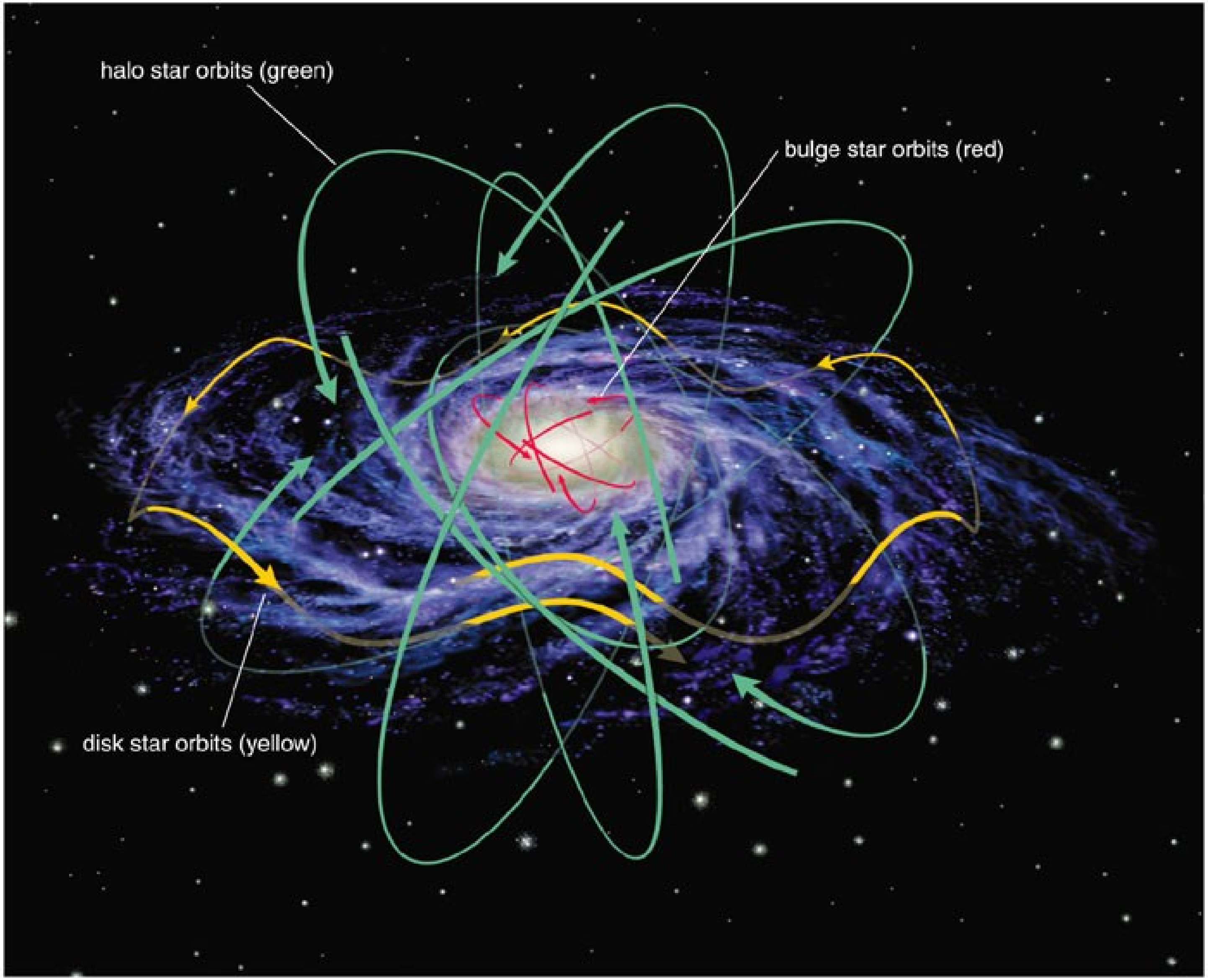
Central Black Hole Sgr A*

- Existence known by motion of stars round it.
- Mass about $4x10^6$ solar masses
- 10^{11} solar masses in galaxy
- Not currently “active” (luckily for us!)
- https://www.youtube.com/watch?v=u_gggKHvfGw

The Black Hole in the Galactic centre


50
kiloparsecs
8
kiloparsecs
Central bulge
Galactic nucleus
Sun
Disk
Globular clusters
Halo

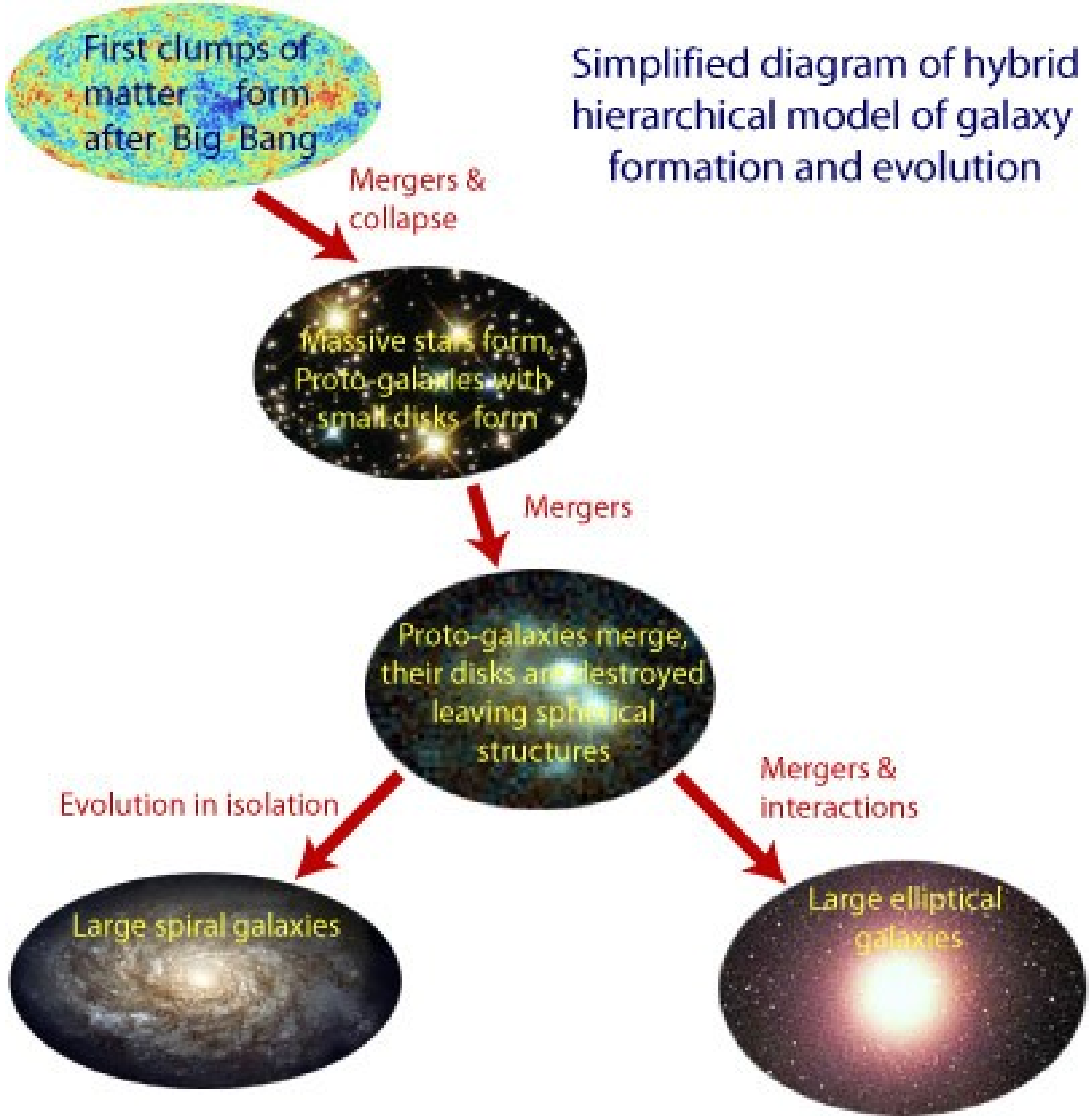
How the stars move



http://www.physast.uga.edu/~rls/1020/ch19/19-18.jpg

Formation of the Galaxy

- Spherical halo formed first out of metal-poor material
  - One initial burst of star formation and none since?
- Disc formed later
  - Continuous star formation leading to metal-rich population
- Bulge also has some metal-rich stars as a result of mergers with small galaxies



http://www.atnf.csiro.au/outreach//education/senior/cosmicengine/images/cosmoimg/galaxyformation.jpg



Galaxies definitely do merge!

Continuing evolution

NGC 4911, surrounded by galactic friends in Coma Cluster. Simulations suggest galaxies trade large fraction of their gas with one another via star-driven gas outflows.
NASA / ESA / Hubble Heritage Team (STScI / AURA)

Galaxies also swap a lot of gas!

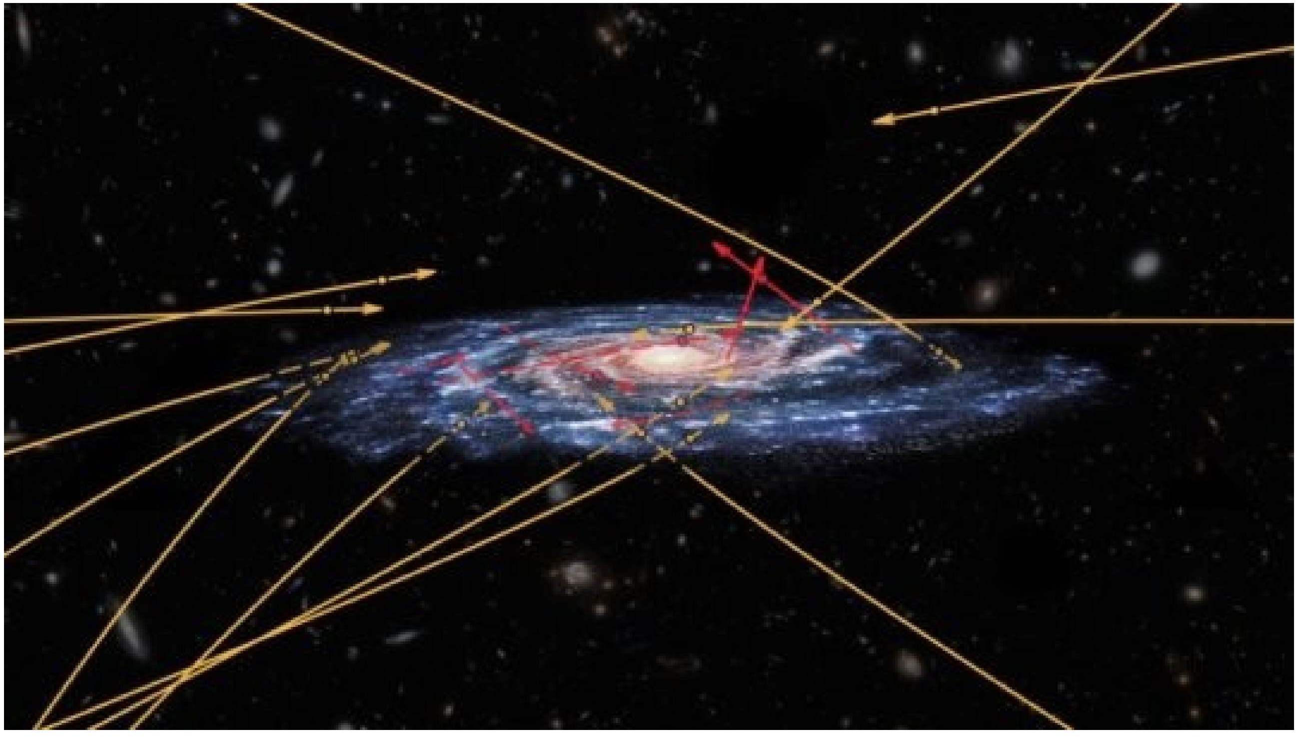
- Galaxies of all masses re-accrete $\gtrsim$50% of the gas ejected in winds and recurrent recycling is common.
- Exchange of gas between galaxies via *galactic winds* can dominate how a big galaxy acquires material.
- Recycling of the galaxy's own outflows more important for dwarf galaxies.

New for 2018 – Gaia result

Artist's impression - ripples in Galaxy

Caused by close encounter 300-900 M years ago

More from Gaia

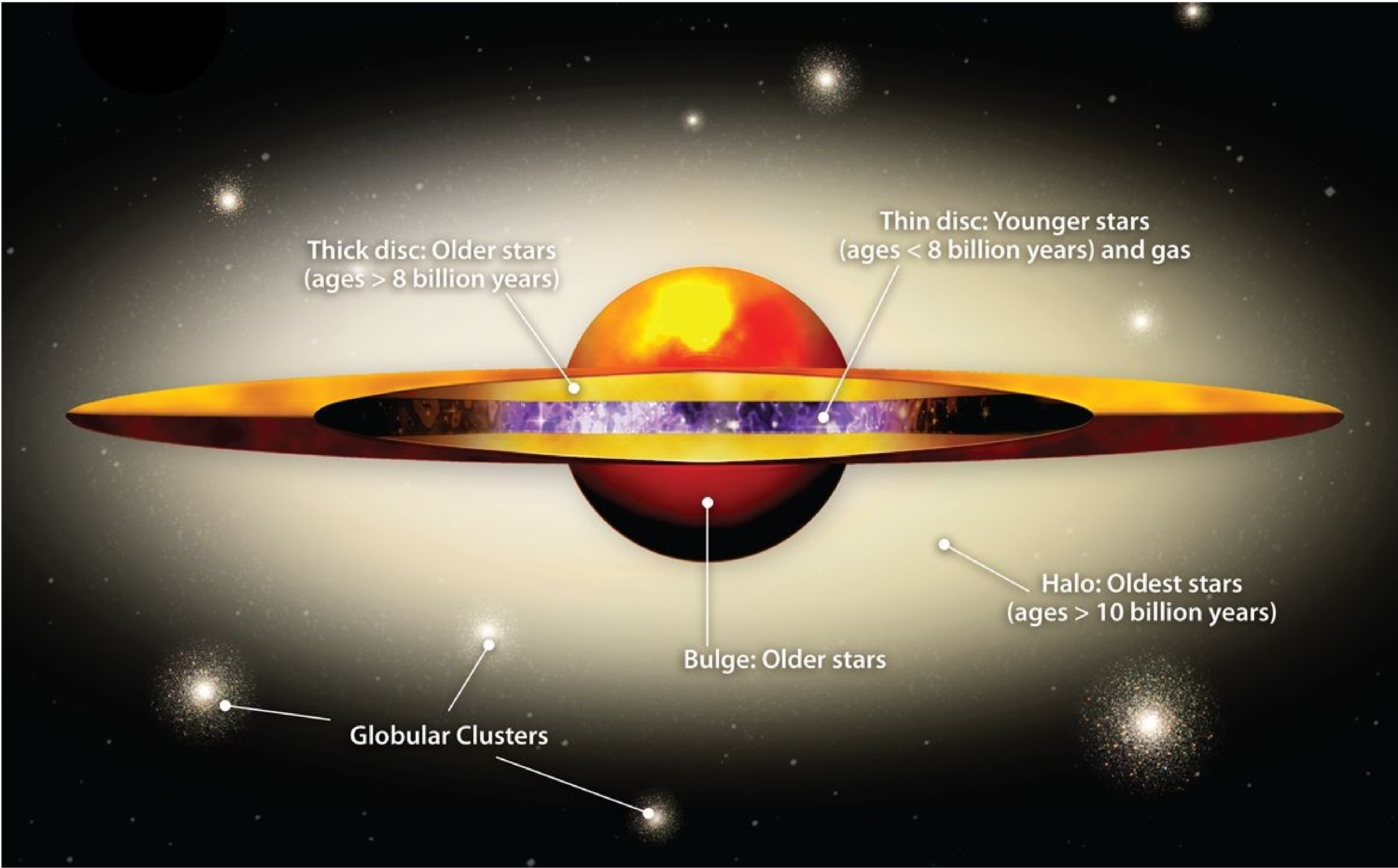


Artist’s impression – stars flying into and out of Galaxy at high velocity – galaxies exchange stars?

Summary

- Our Galaxy is SBb or SBc
- Rotation curve flat, indicating dark matter component
- Disc undergoes differential rotation
- Disc has multiple spiral arms
- Star formation going on in spiral arms
- Central massive black hole
- Disc surrounded by a spherical galactic halo
- Galactic halo is made up of Population II objects and was formed at earlier stage than disc

Portrait of our galaxy



The End

You Tube videos

- The Milky Way - Crash Course Astronomy #37

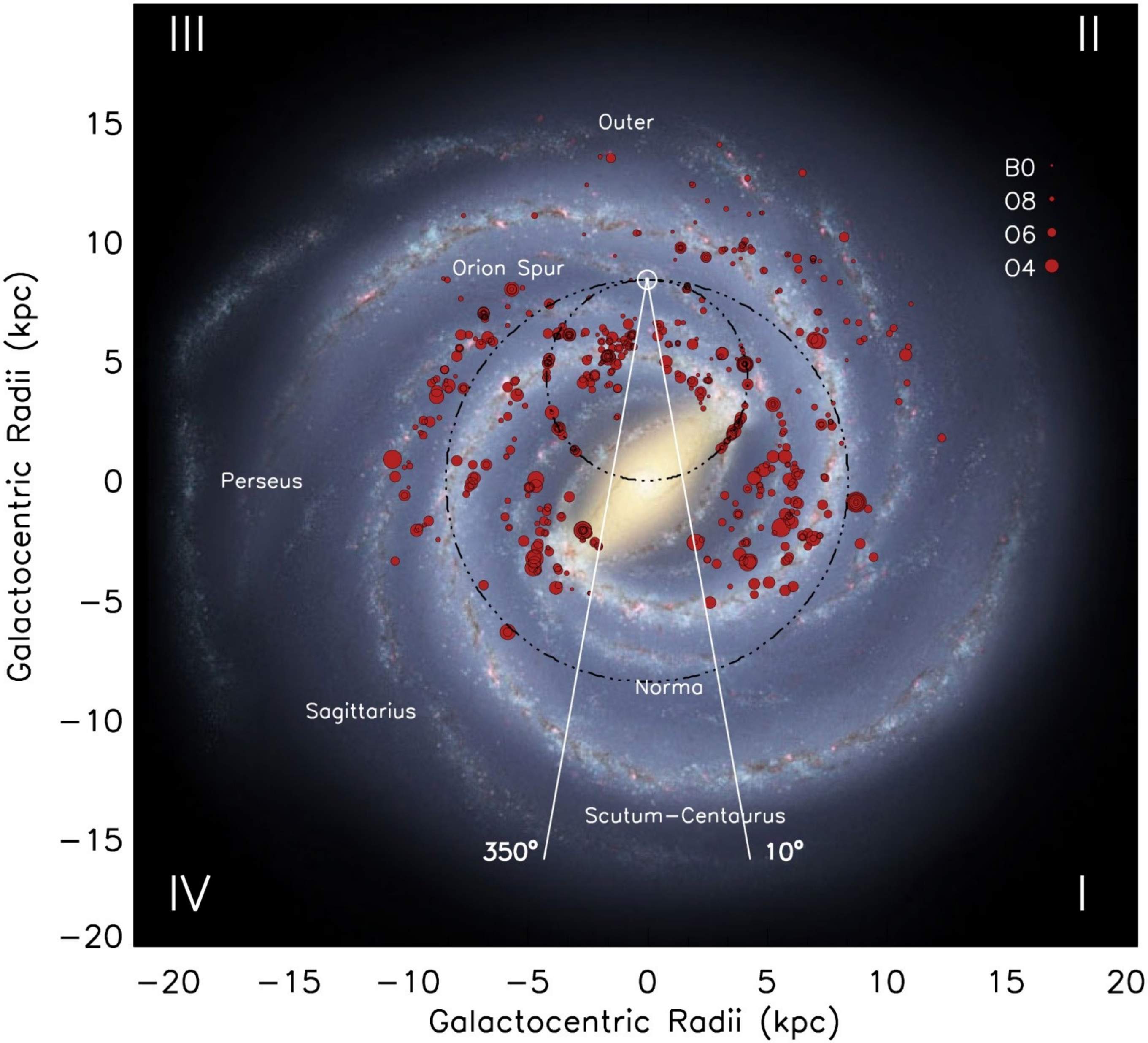
https://www.youtube.com/watch?v=MncUDWhPB_E

https://www.youtube.com/watch?v=y29RqyYdknw

Milky Way vs Andromeda as seen from Earth
https://www.youtube.com/watch?v=qnYCpQyRp-4

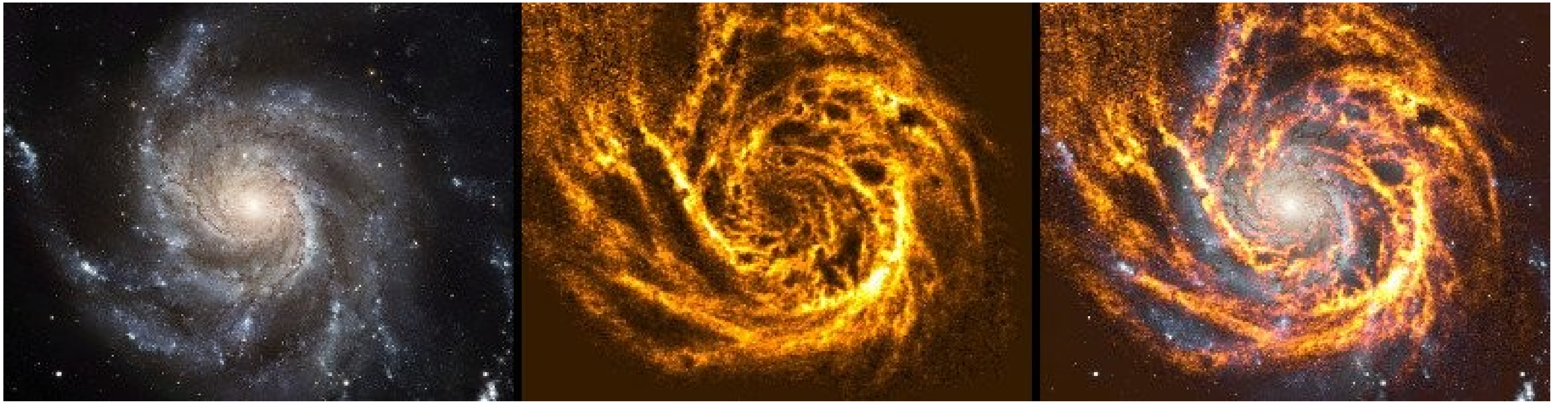
Galaxy collisions: Simulation vs observations
https://www.youtube.com/watch?v=C0XNyTp5brM

Stellar motion round galactic centre
https://www.youtube.com/watch?v=u_gggKHvfGw

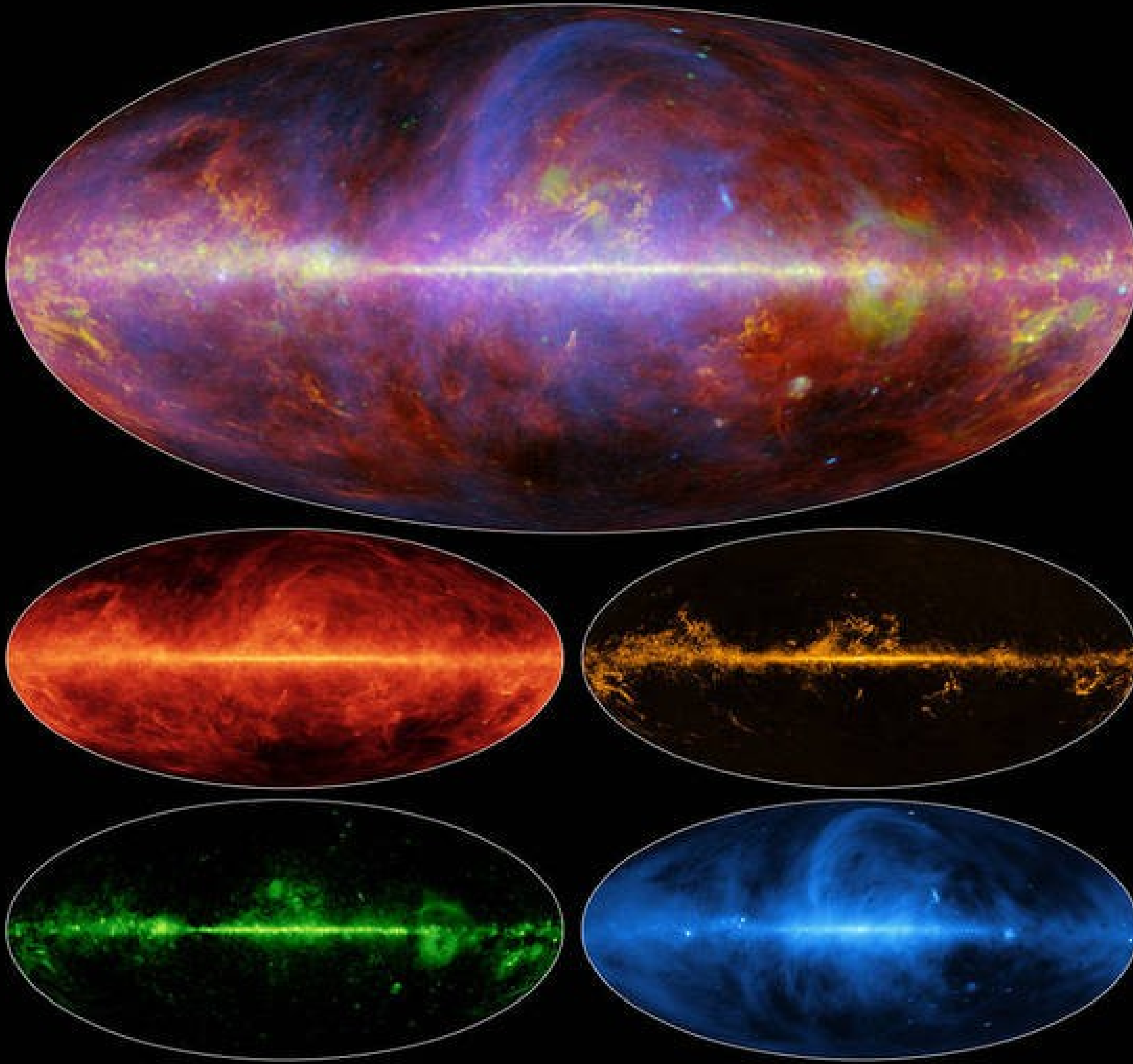


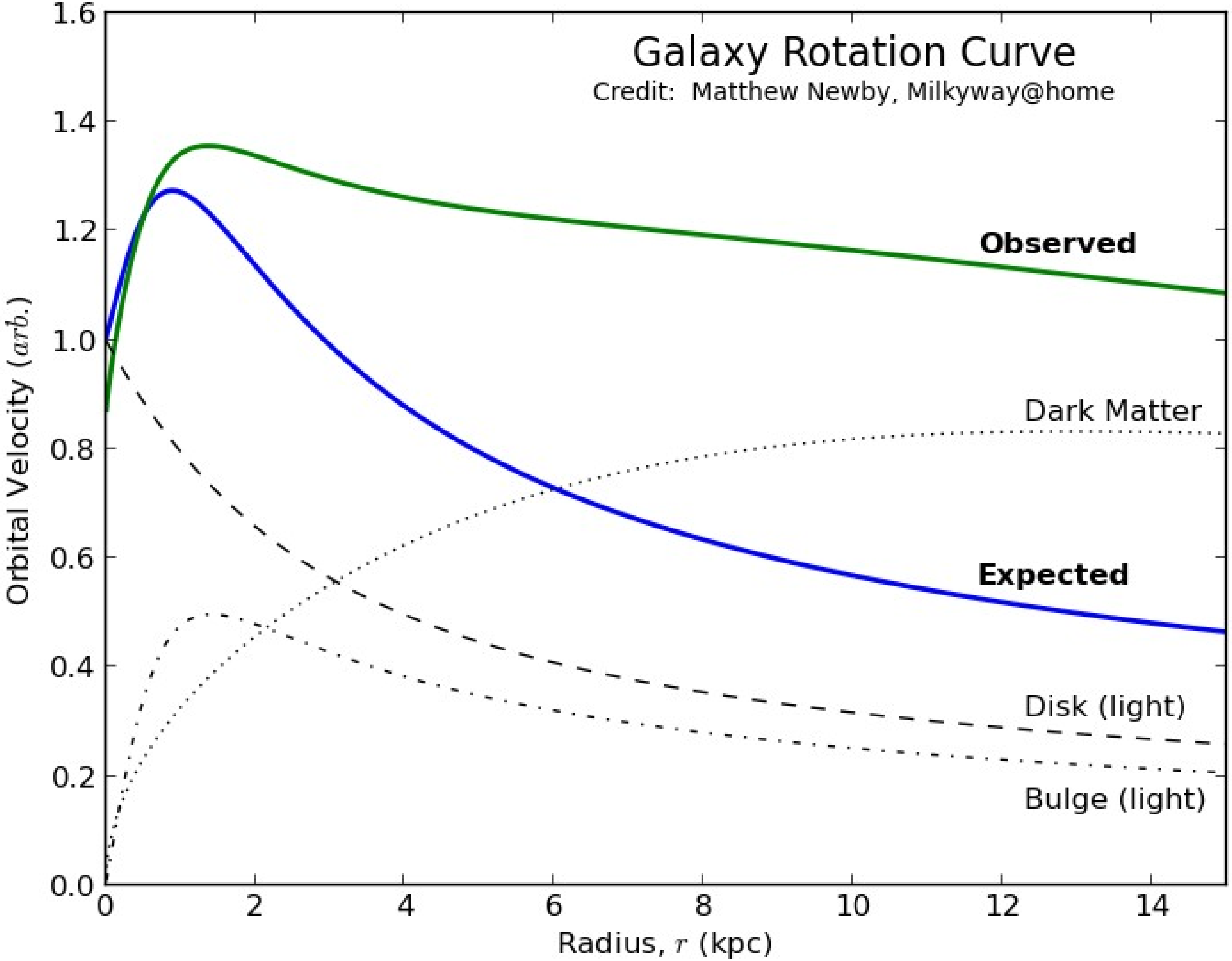
Distribution of massive star forming regions from the Red MSX Source Survey www.ast.leeds.ac.uk/RMS

M101 in visible and HI



http://galaxymap.org/drupal/node/202





Galaxy Rotation Curve
Credit: Matthew Newby, Milkyway@home
Observed
Expected
Dark Matter
Disk (light)
Bulge (light)
Orbital Velocity (arb.)
Radius, r (kpc)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
0
2
4
6
8
10
12
14

Milky way facts

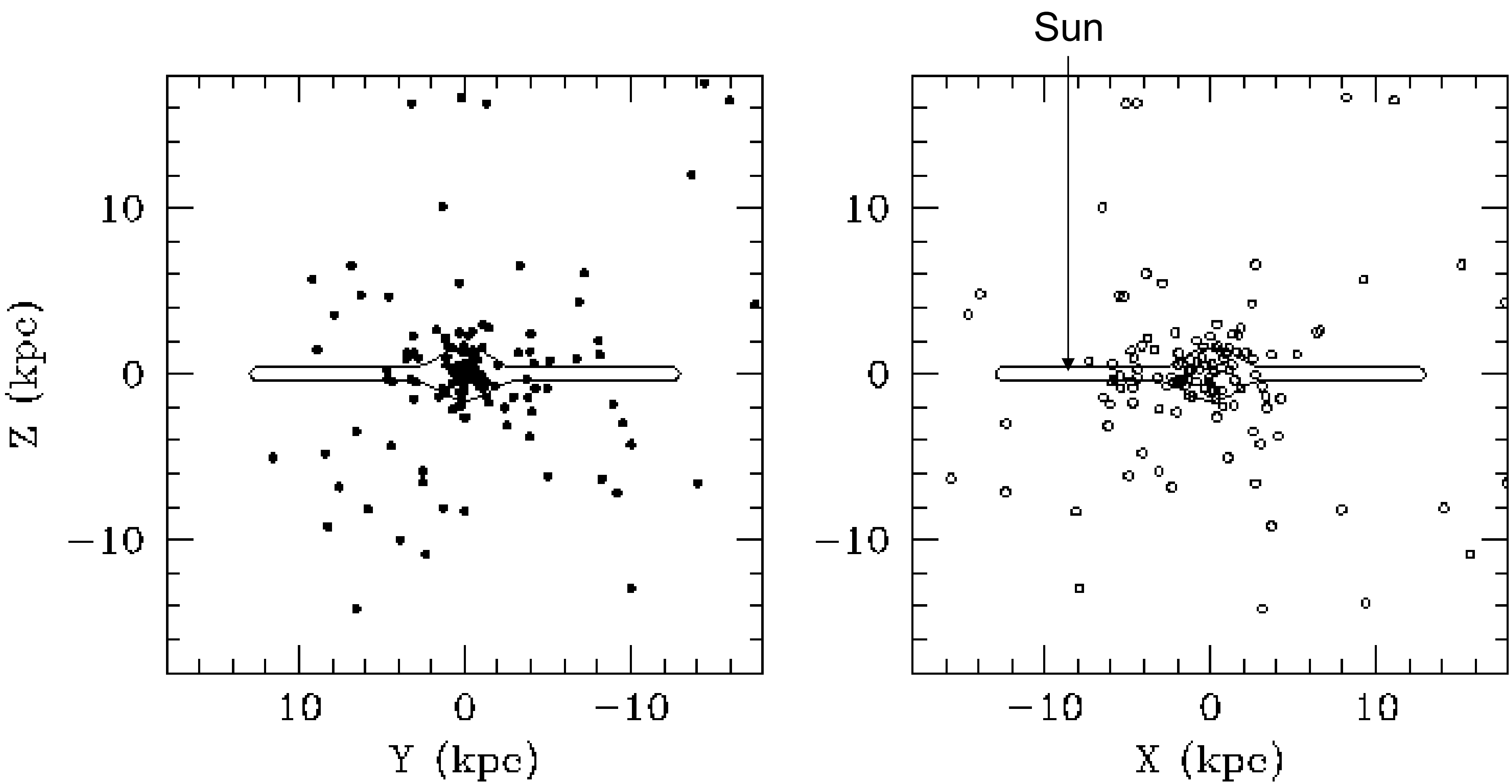
- Size – 100,000 light years in diameter
- 25,000 light years to galactic centre
- Flattened disk
- Sun inside thin disk, far from centre

Why spiral arms look blue

- Stars form in giant nebulae –short lived, nebulae in arms, so stars don't have time to move out of the arms before they explode (supernova)
- Hence arms outlined by bright young blue stars
- Different wavelengths reveal other components

The central Bar

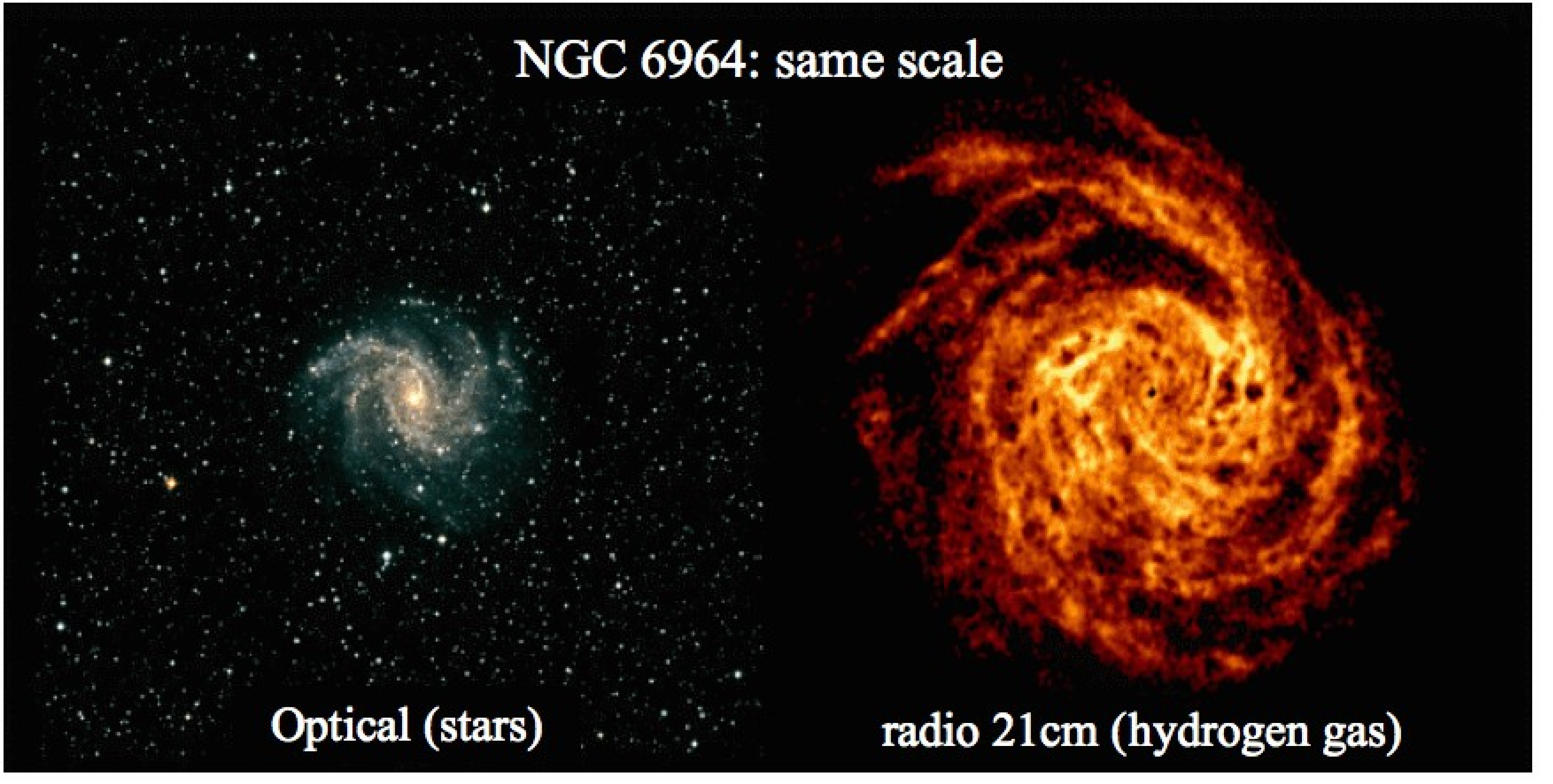
- Rotates like a solid body



Distribution of nearby globular clusters in the plane of the Galaxy

Harris, W. E. "Globular Clusters", 1999, Cambridge University Press

“Seeing” a galaxy in HI (21cm hydrogen line emission)



https://www.skatelescope.org/wp-content/uploads/2011/10/t5_HI_disks.gif