

Chapter 19: The Milky Way – A Classic Spiral Galaxy

Here's the mystery story we'll unfold...

- Fuzzy blobs in the sky – new solar systems, or “galaxies”?
- Observational tests
- Herschel's map of the “universe” (what we today know as just our Galaxy)
- Dust, globular clusters, and the discovery of the Milky Way as our Galaxy
- Structural components of our galaxy



Fuzzy Blobs – what were they?

- Ever since the 1700's, telescopes had shown these faint, oblong fuzzy blobs with central concentrations
- 1. Nearby solar systems in formation, with a sun at the center??
- 2. Or, giant pancake systems of stars (Galaxies – Greek for “milk”)??

Henrietta Leavitt – Harvard Observatory in Capetown

- She studied the Large Magellanic Cloud – what looked like a super star cluster of millions or billions of stars
- Found stars with the right color and light curves to be classified as Cepheids
- Like, Delta Cephei, Eta Aquilae, and other well known nearby examples
- But here, she found an interesting pattern...



Figure 14.2 Henrietta Swan Leavitt (1868–1921). (Courtesy of Harvard College Observatory.)

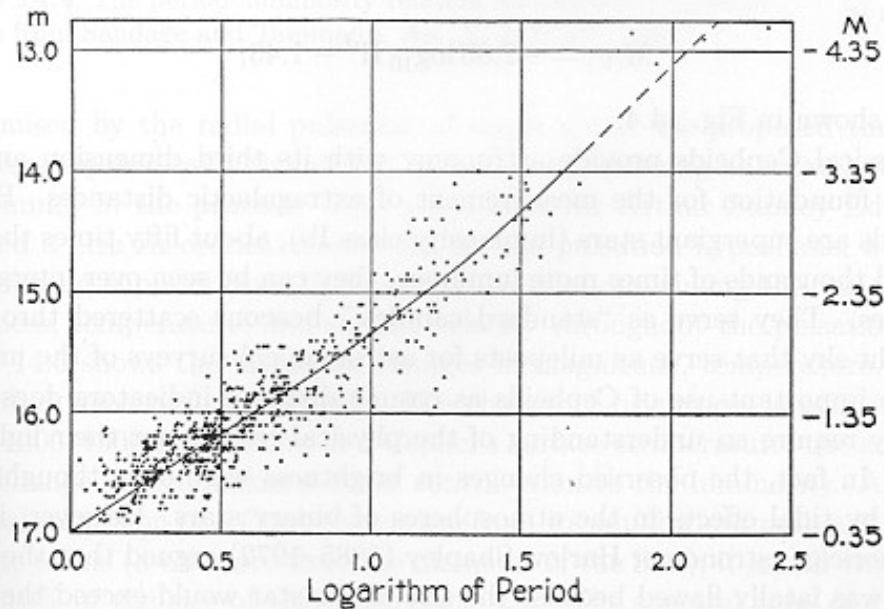
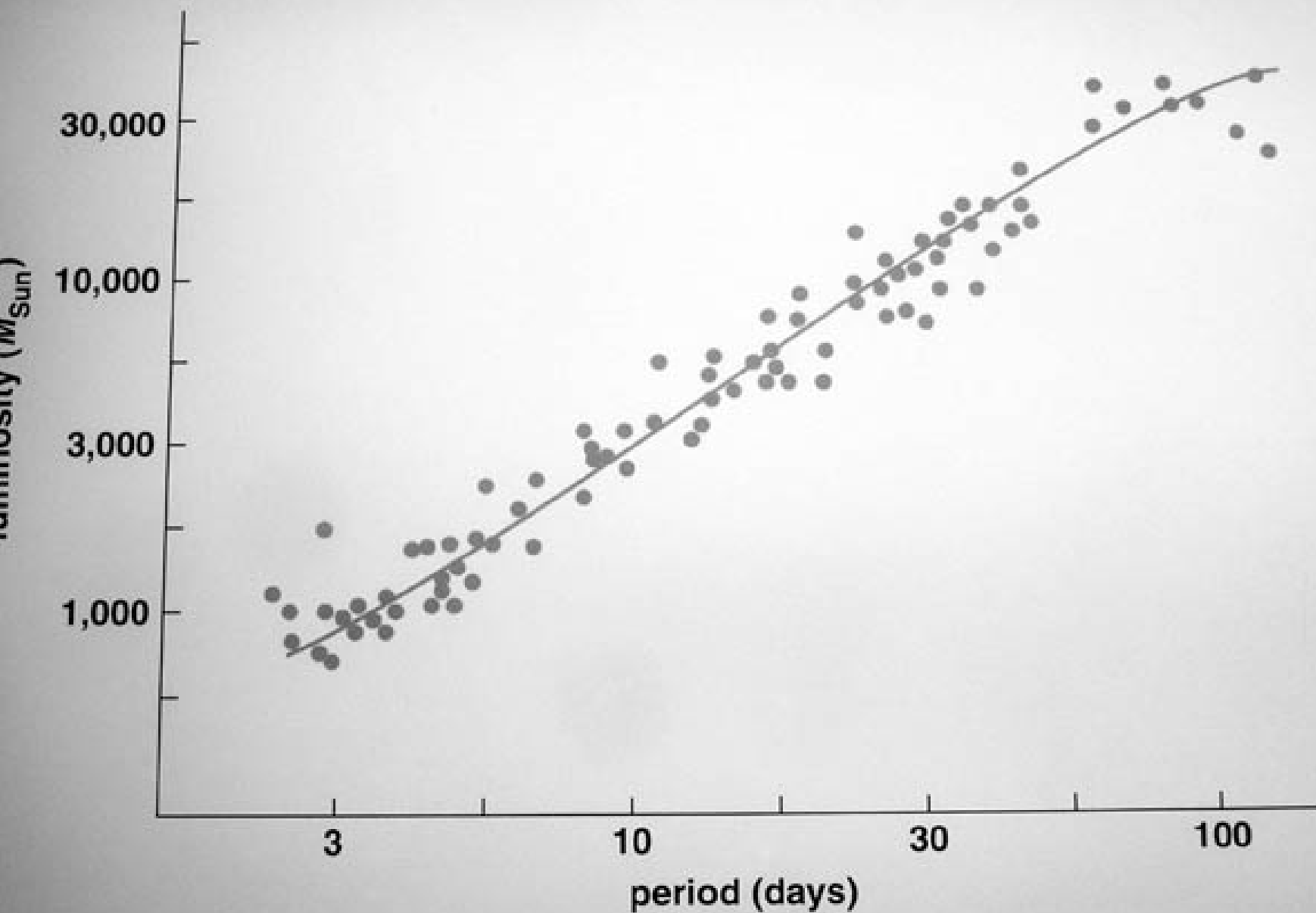


Figure 14.3 Classical Cepheids in the Small Magellanic Cloud, with the period in units of days. (Figure from Shapley, *Galaxies*, Harvard University Press, Cambridge, MA, 1961.)

Even the
early, lower-
accuracy
data showed
a clear
Period/Lumi-
nosity
relation

Figure 17.10 Cepheid period-luminosity relation



This Makes Cepheids Excellent Distance Indicators!

- Take a bunch of photos and measure the changing brightness, construct the light curve
- Measure the period of pulsation
- Pick off the Luminosity from the Cepheid P-L Relation
- Calculate how far away the star must be to have that luminosity look like the apparent brightness we see here from Earth
- (Doing it right is a bit more complex, see next purple slide for details beyond scope of this course)

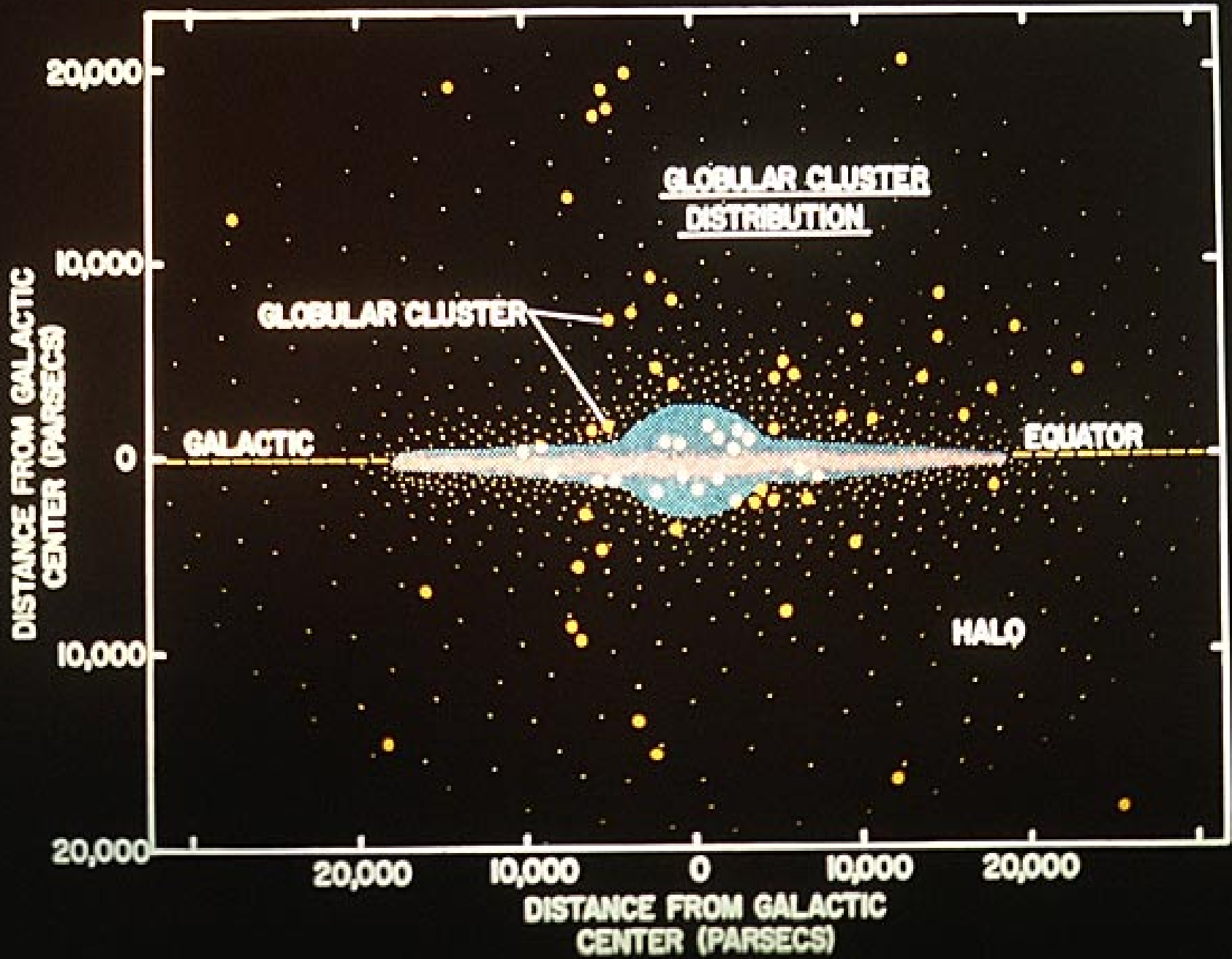
Caveats to Cepheid PL Relation

- Calibration has been hard; Cepheids too far away for ground-based parallaxes in order to measure distances. Space-based more successful, but still squishy.
- Calibrated using some complex methods and also using Main Sequence Fitting for those in star clusters. First and best example: bright open cluster M23 has a Cepheid. As of 1999, 29 more clusters now known to have Cepheids.
- Cepheid PL relation has much less noise if brightnesses measured in the Infrared, which is what is always done these days.
- By “Cepheids” I mean “Classical Cepheids”. There are also “Type II Cepheids” which are better classified as W Virginis stars etc., and they have PL relations too, which is dimmer.
- Theoretical PL relations using different assumptions of the internal structure do, or do not, show a metallicity effect).
- Observationally, old “metal poor” Cepheids may have a slightly different PL relation than young “metal rich” Cepheids but it is slight. The Cepheid PL relation is essentially independent of metallicity, according to largest samples and most recent data (e.g. [Mottini 2006](#), [Udalski et al. 2001](#)), as long as one uses infrared luminosities. This is what modern astronomers do. (in the old days, before IR technology, this issue caused a lot of confusion in using Cepheids as distance indicators!)

Discovery of the Milky Way as a Galaxy...

- Edwin Hubble used the new 100" Mt. Wilson telescope in the 1920's to image The Andromeda Nebula
- Could see the brightest individual stars. Among them, variables of the right color and light variation to show them as ***Cepheids***
- Therefore, this was not a nearby nebula around a new star, it was an entire galaxy.
- Herschel's map then could be seen as a map of our own Milky Way Galaxy





But... where are WE in this huge star system?

- Globular Clusters are the clue
- So first... what ARE globular clusters (globulars, as we say in the business)
- Tight spherical cluster of a hundred thousand to a million stars, like this one...

Globular Cluster NGC 6093



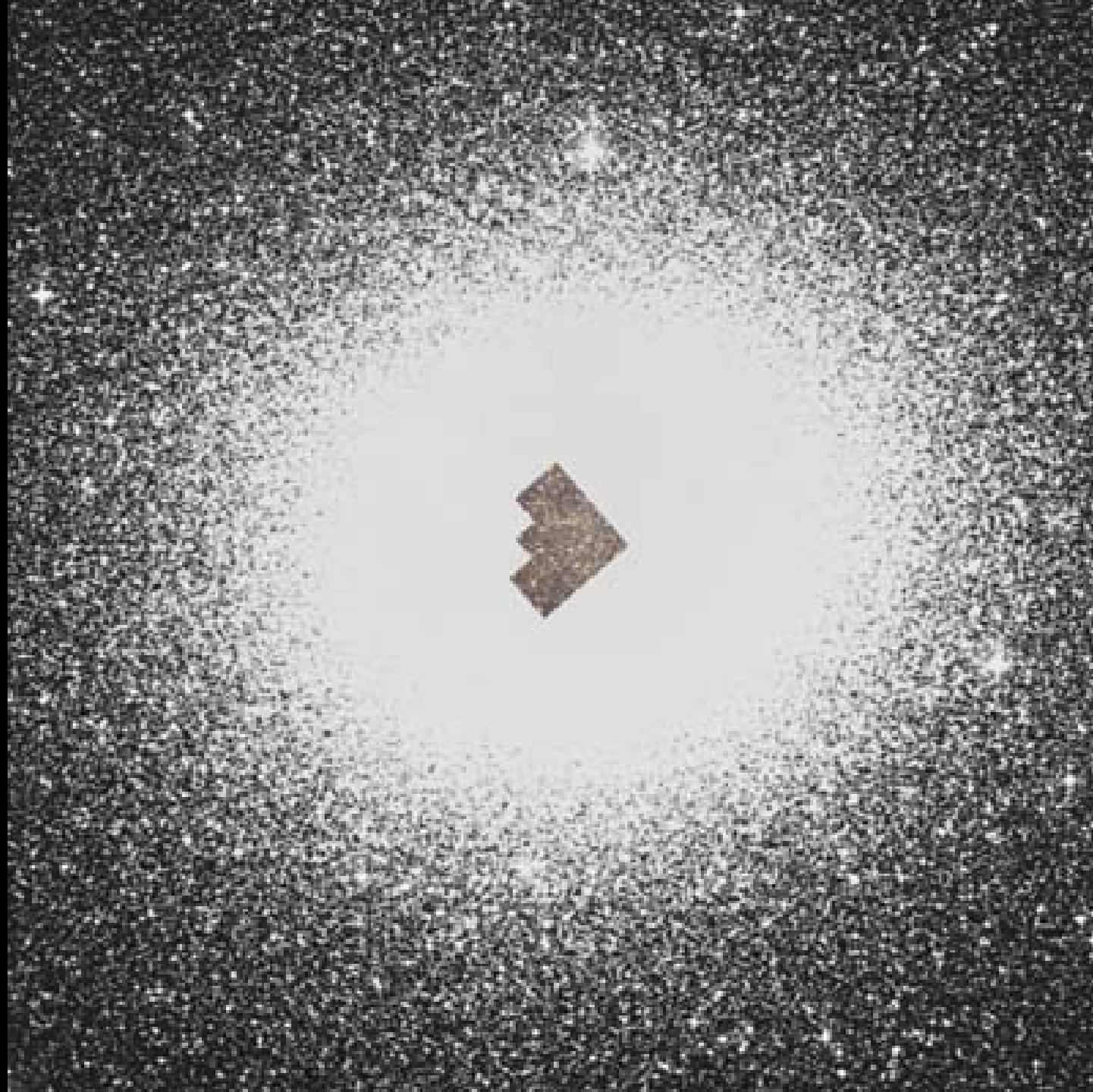
Hubble

Open vs globular clusters

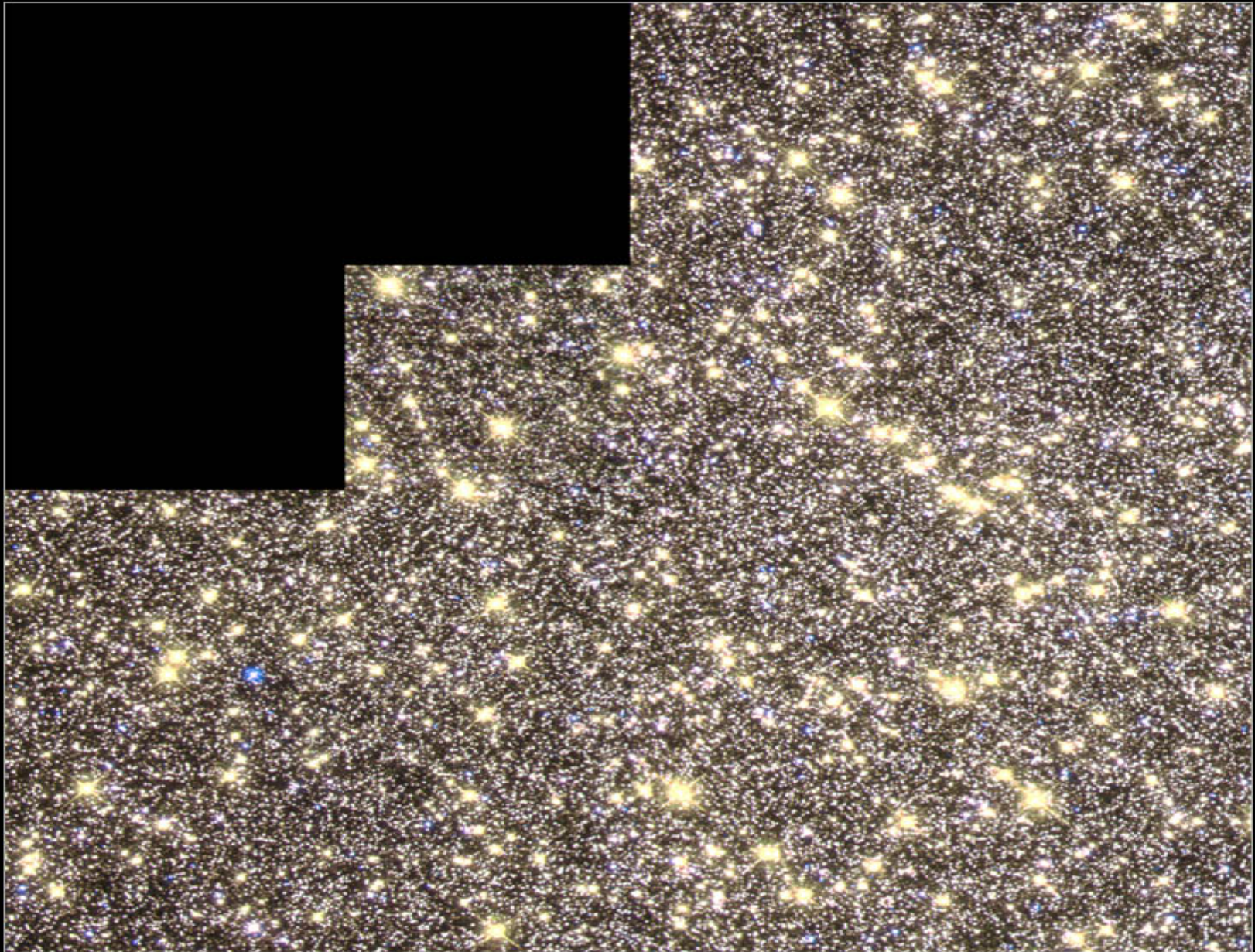








Globular Cluster Omega Centauri



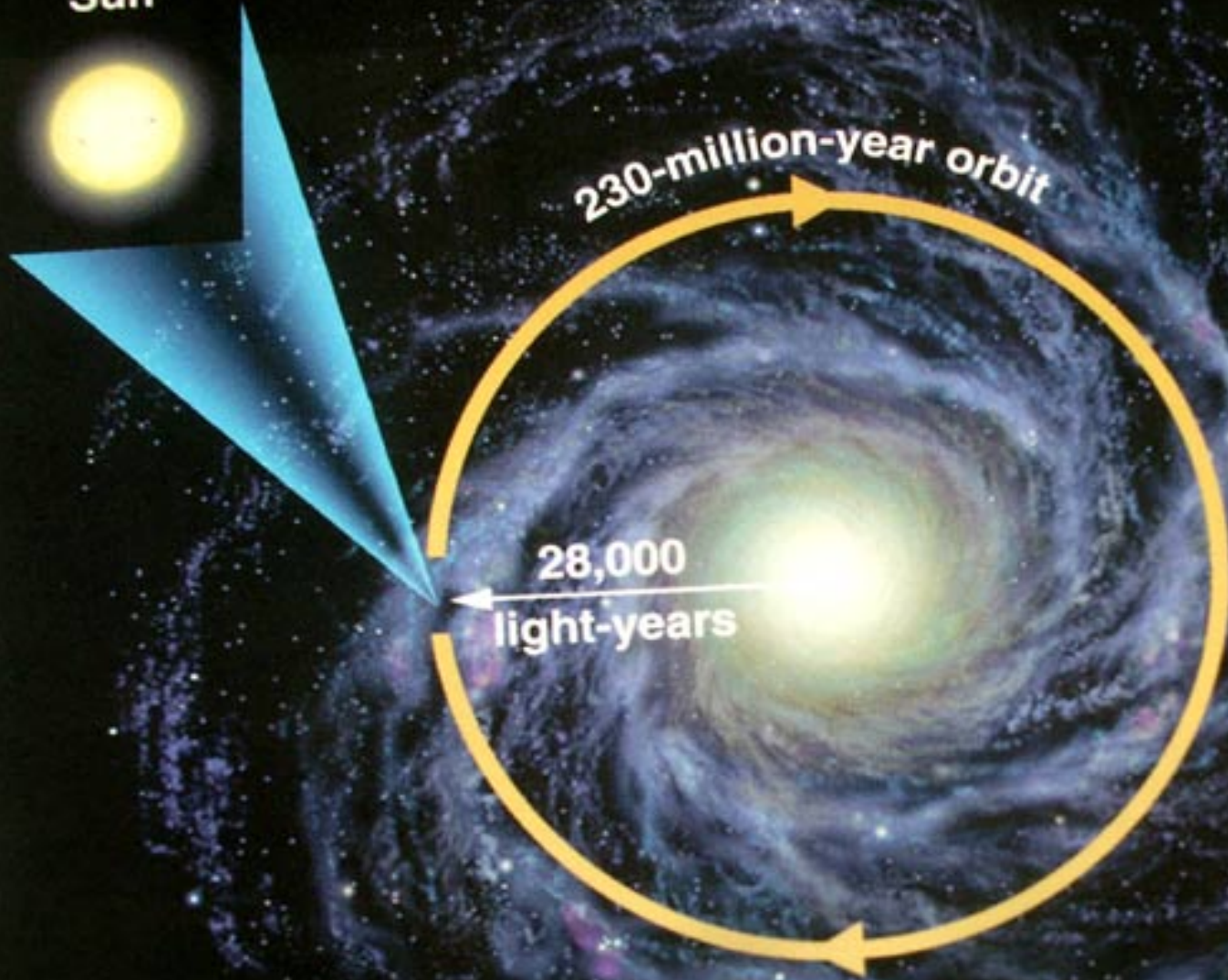
- Hubble found globulars in Andromeda; they were roughly spherically distributed, and centered on the center of the galaxy.
- In our own sky, we'd known for over a hundred years that **globulars are strongly concentrated in the summer sky**; hardly any in the winter sky. Ergo - We must be far from the center!

Sun



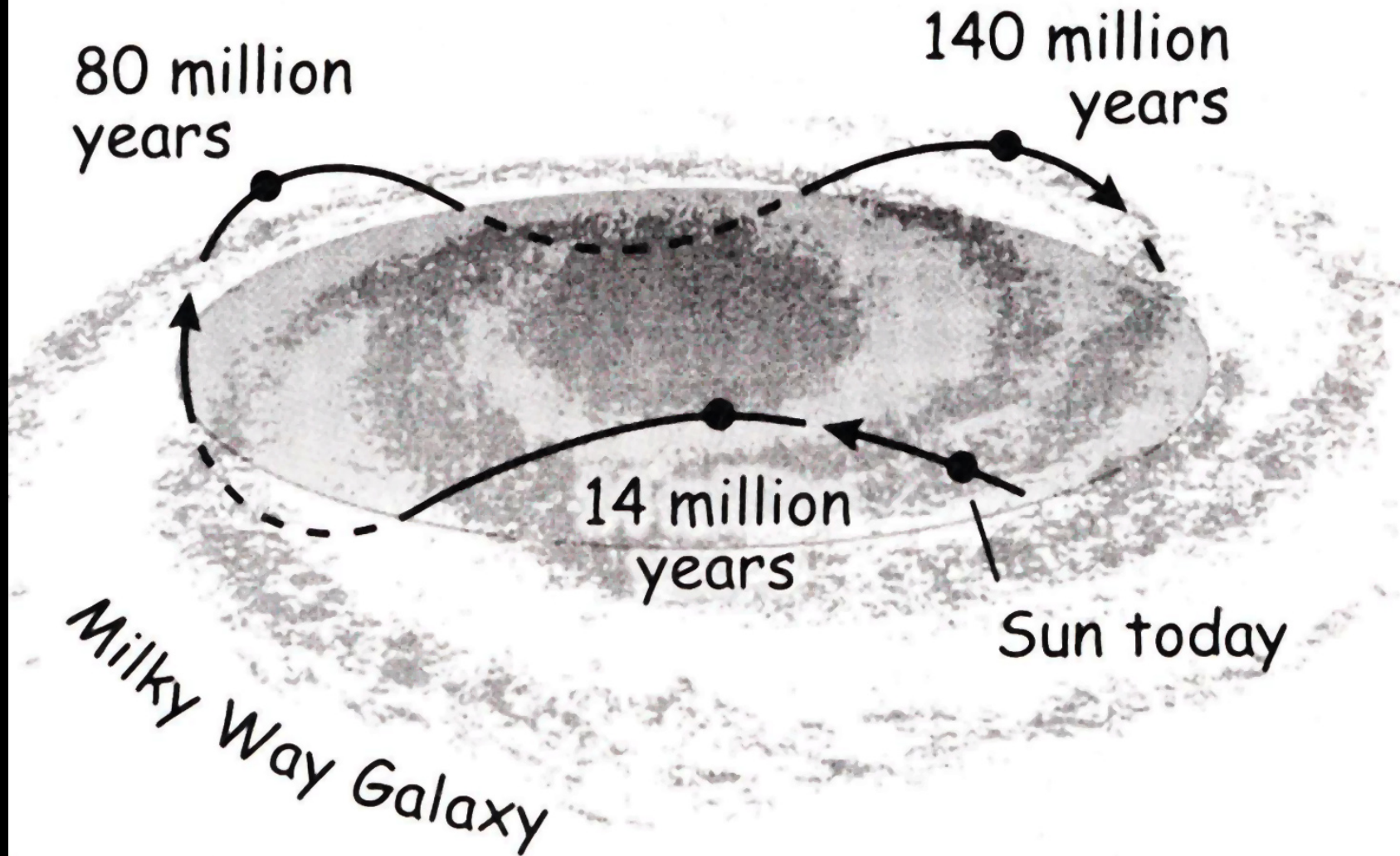
230-million-year orbit

28,000
light-years



The disk's gravity provides a restoring force, making the sun yo-yo as it orbits

Sun's Motion (Exaggerated)



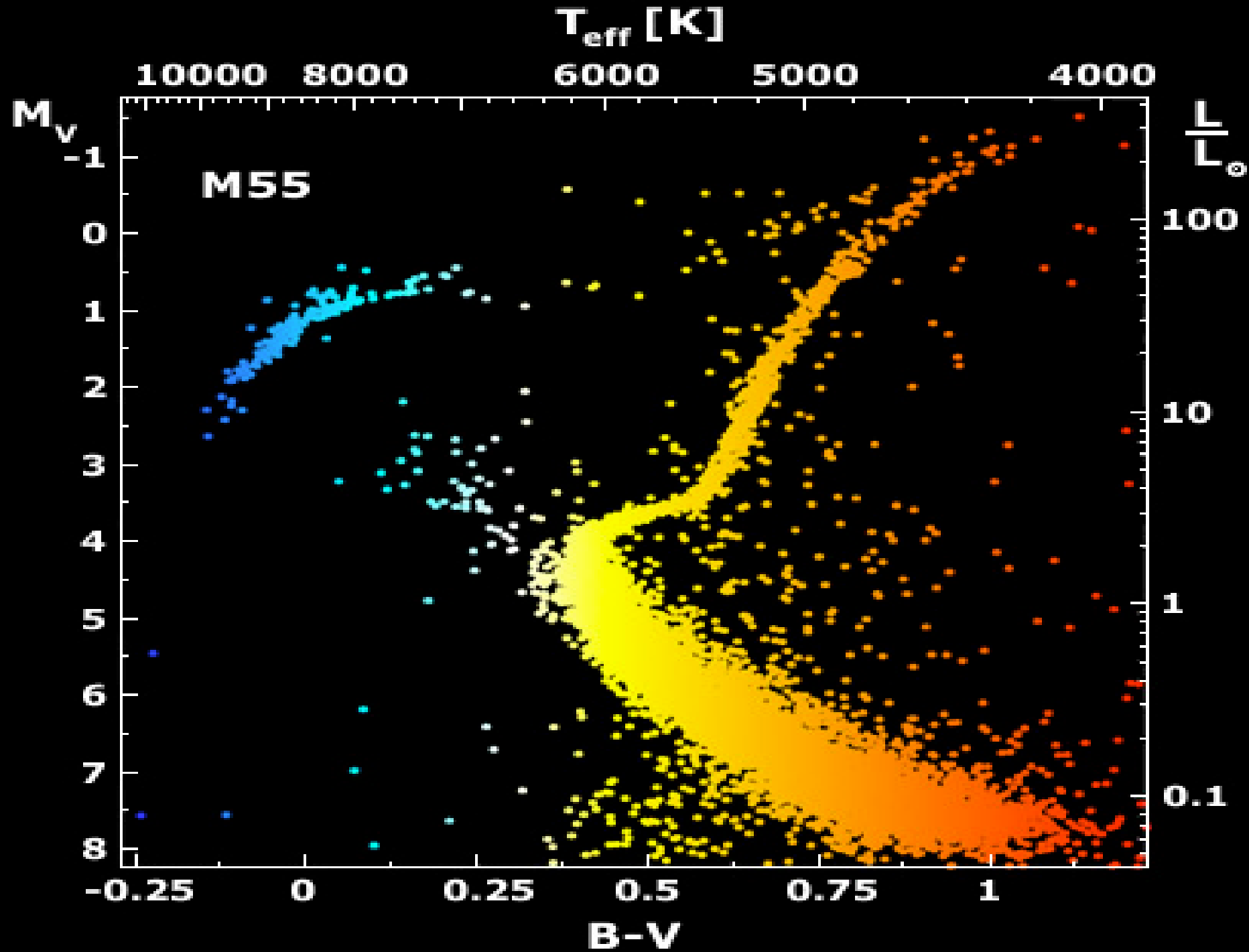
Why was it so hard to locate ourselves within the Milky Way?

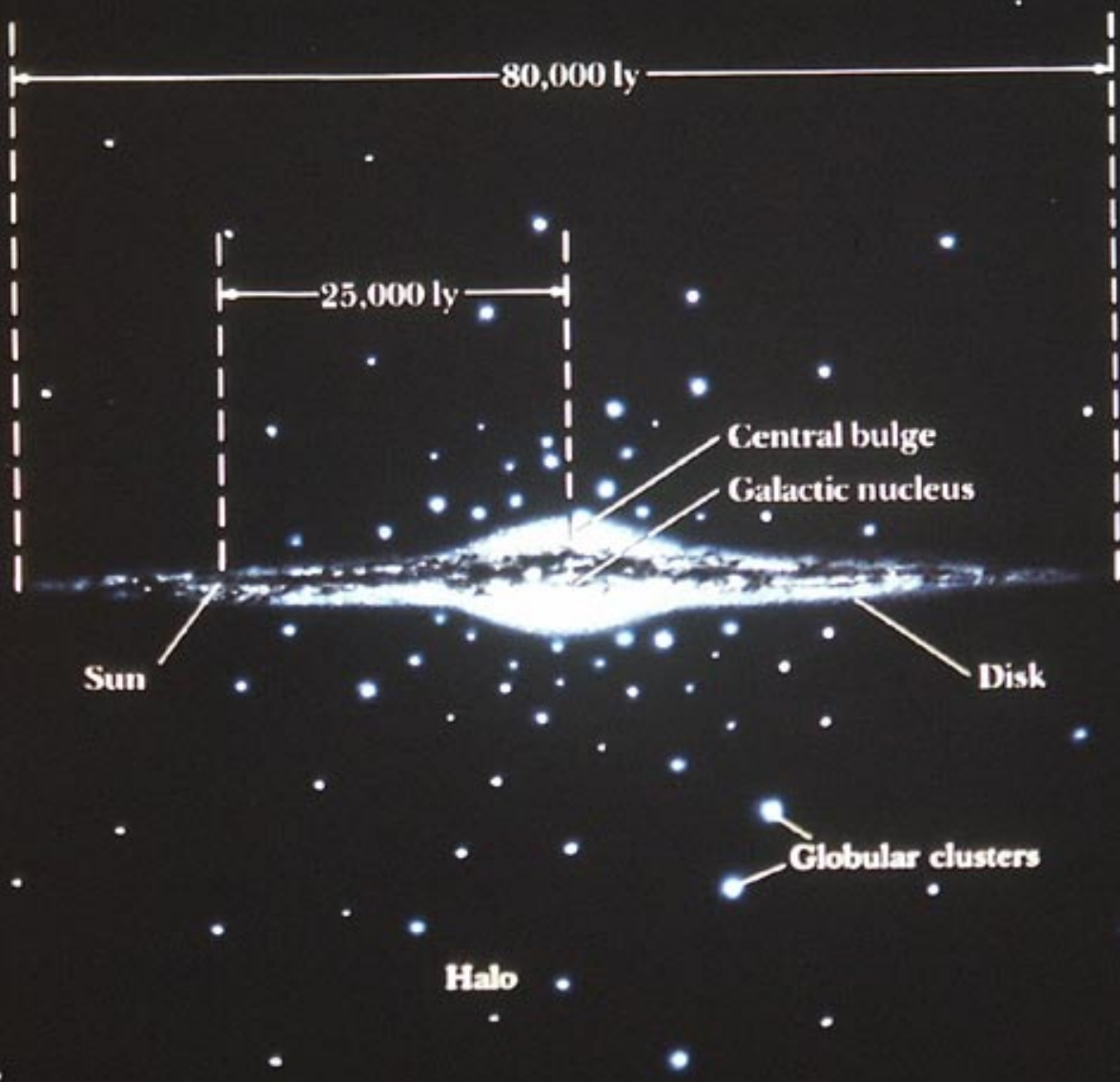
- Dust! We're right inside the dust layer which fills the center plane of the disk of our flat galaxy.
- Makes it tough to see very far into the galactic plane from here.
- Look again at a time exposure of the summer sky and see the dark blotchy “plane” of dust from lower right to upper left, right through the densest stars in the centerplane...



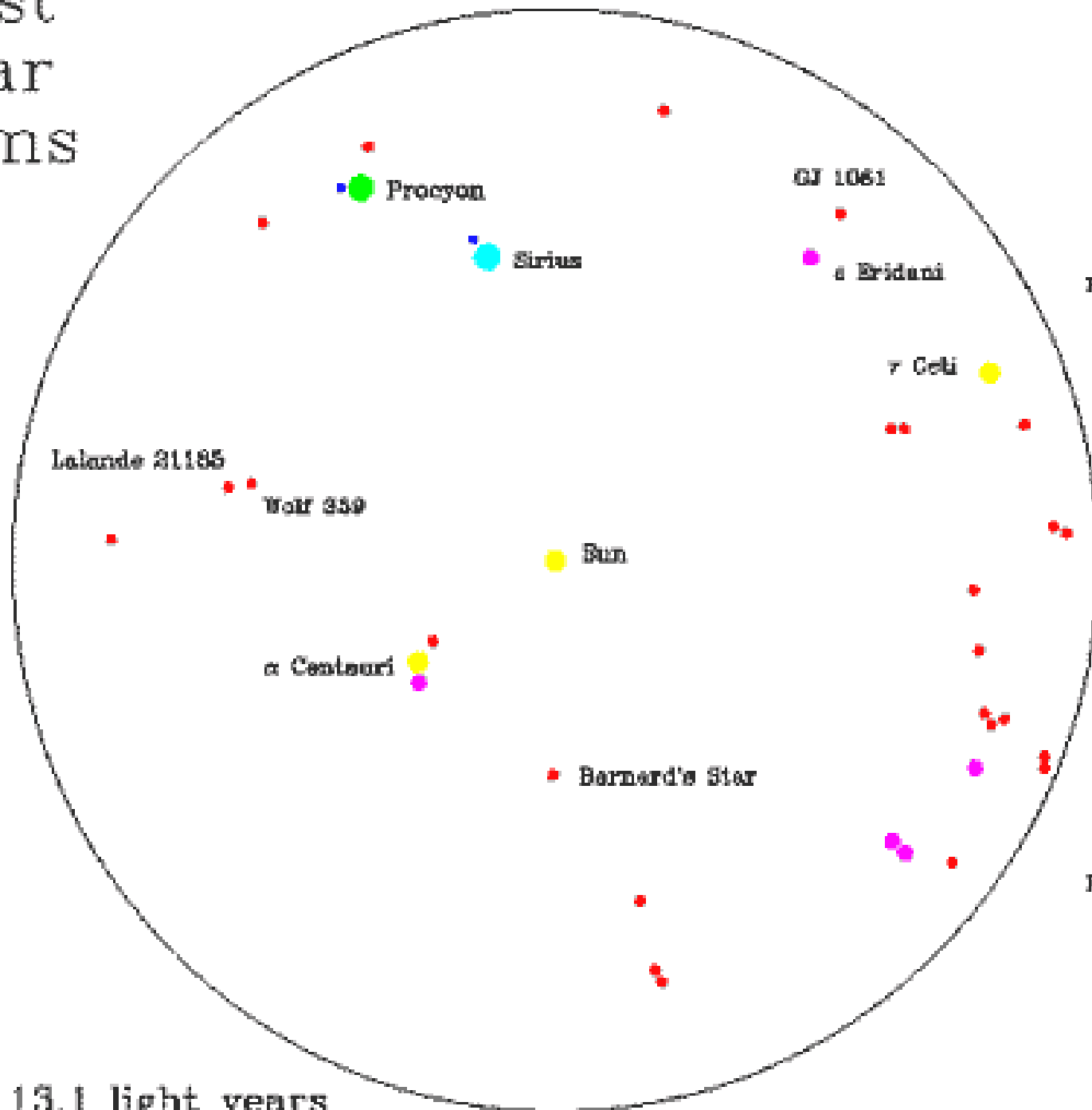
How old is the Milky Way?

- Globular clusters again are the clue...
- As we saw, we can age date any star cluster...
- The **main** sequence is a **mass** sequence; and higher mass stars live shorter lives.
- We use stellar evolution models and take advantage of the convenient fact that all stars in a cluster are born at essentially the same time
- So, the turnoff point tells you the age of the cluster...





Nearest 25 Star Systems



Five Nearest Systems

1. α Centauri
2. Barnard's Star
3. Wolf 359
4. Lalande 21185
5. Sirius

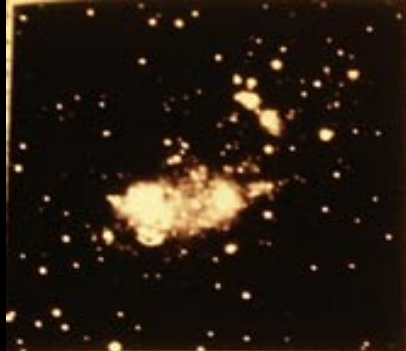
RECONS Discovery

23. GJ 1061
(11.9 light years)

Five Brightest Systems Among Nearest 25

1. Sirius
2. α Centauri
3. Procyon
4. γ Ceti
5. ϵ Eridani

horizon = 13.1 light years



Upper left: Star-formation rates are high in irregular galaxies like IC 10 (top), which are almost completely flat, disklike, and rich in gas. Photograph courtesy Hale Observatories. On the other hand, star formation is practically nonexistent in elliptical galaxies such as NGC 205 (above), which have no disk component and very little gas. Courtesy Martin C. Germano of The Woodlands, California. Spiral galaxies like the Milky Way fall between these two extremes, having both a gaseous disk where star-formation rates are high and a central bulge with little gas where stars ceased to form long ago.

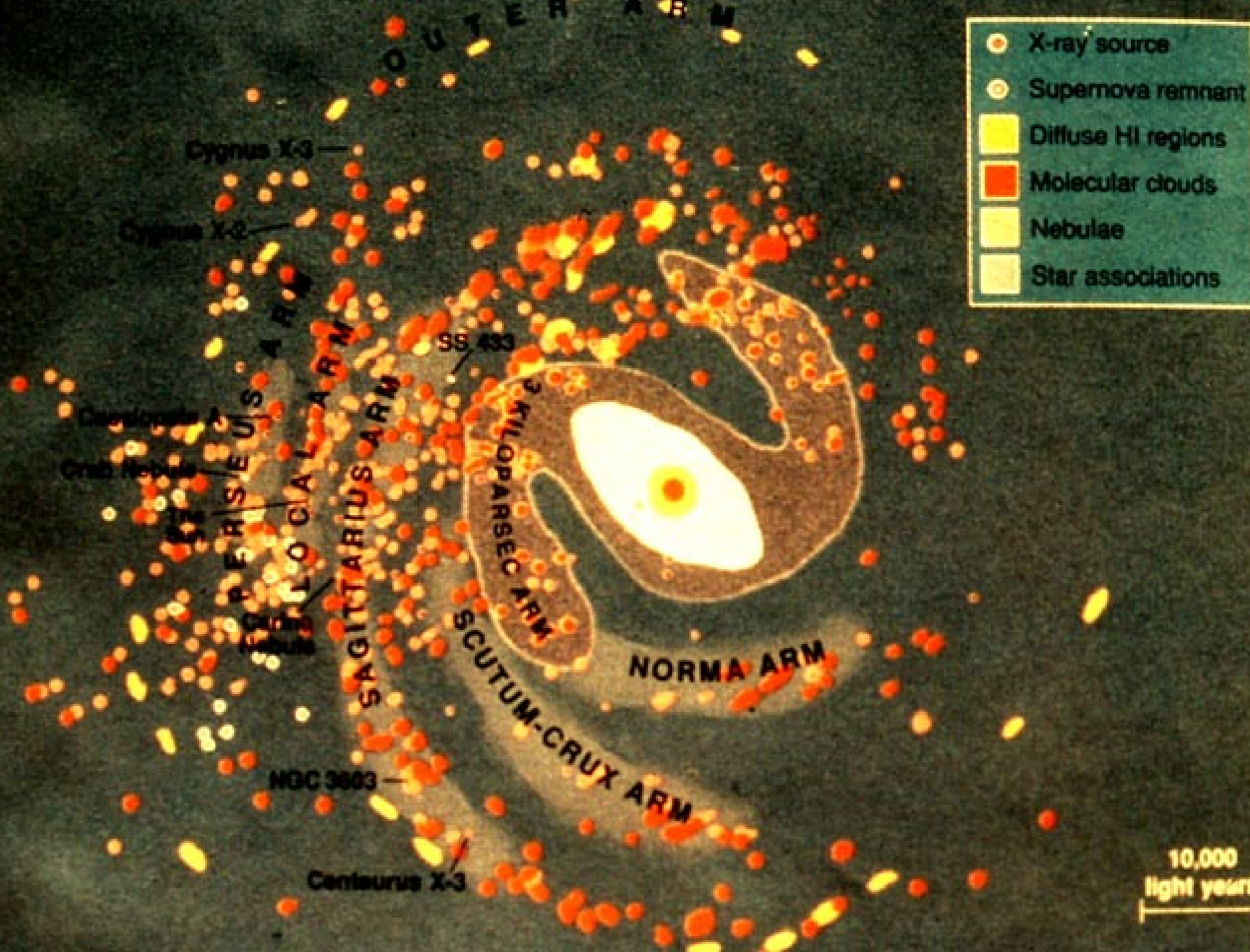
Above and left: The region of the galaxy immediately surrounding our solar system is rather dull — a few dozen stars and a ring of diffuse hydrogen gas are all that distinguish the local bubble. This transparent, low-density region defines the observable limit at some ultraviolet wavelengths. The local bubble is probably not quite as spherical as depicted here. Courtesy Julian Barson.

The “Local Bubble”

- Wallner (2016) and Breitschwerdt (2016) ([nice summary](#)), discovered Iron-60 in ocean sediments around the Earth. Iron-60 is ~only produced in supernovae and has a half-life of only 2.6 million years.
- Find layers at age 1.5Myrs and another at 2.3 Myrs ago,
- This indicates two SN blasts at these times, and roughly 300 light yrs away from the abundances.
- Agrees with Local Bubble size and expansion

The colorful region near red giant Antares (upper left) in Scorpio, showing both old globulars and young star birth





Spiral density waves sweep through the gas of the disk, compressing it, making new stars, and the most luminous are the most massive, and die in just a few million years, not long enough for the wave to have moved onward much. Hence, we get curvy spiral arms lit up by young hot (blue) massive stars and the arms are not very “thick”

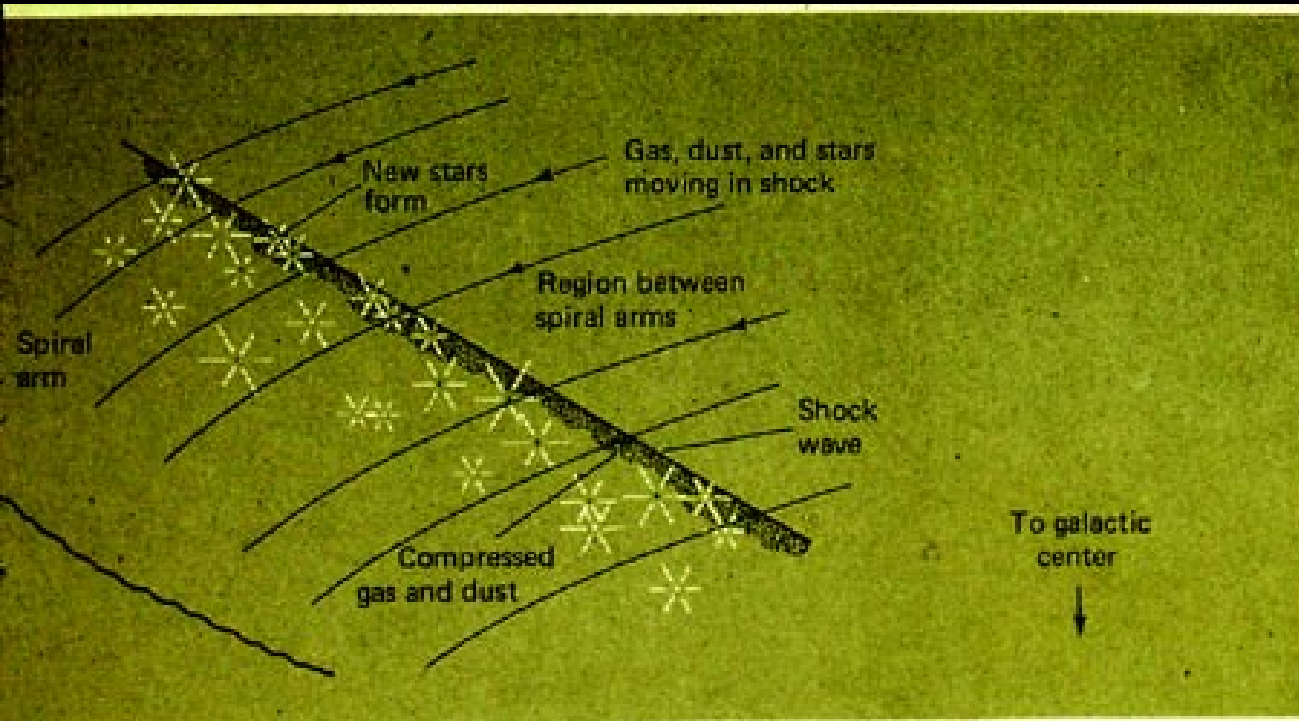
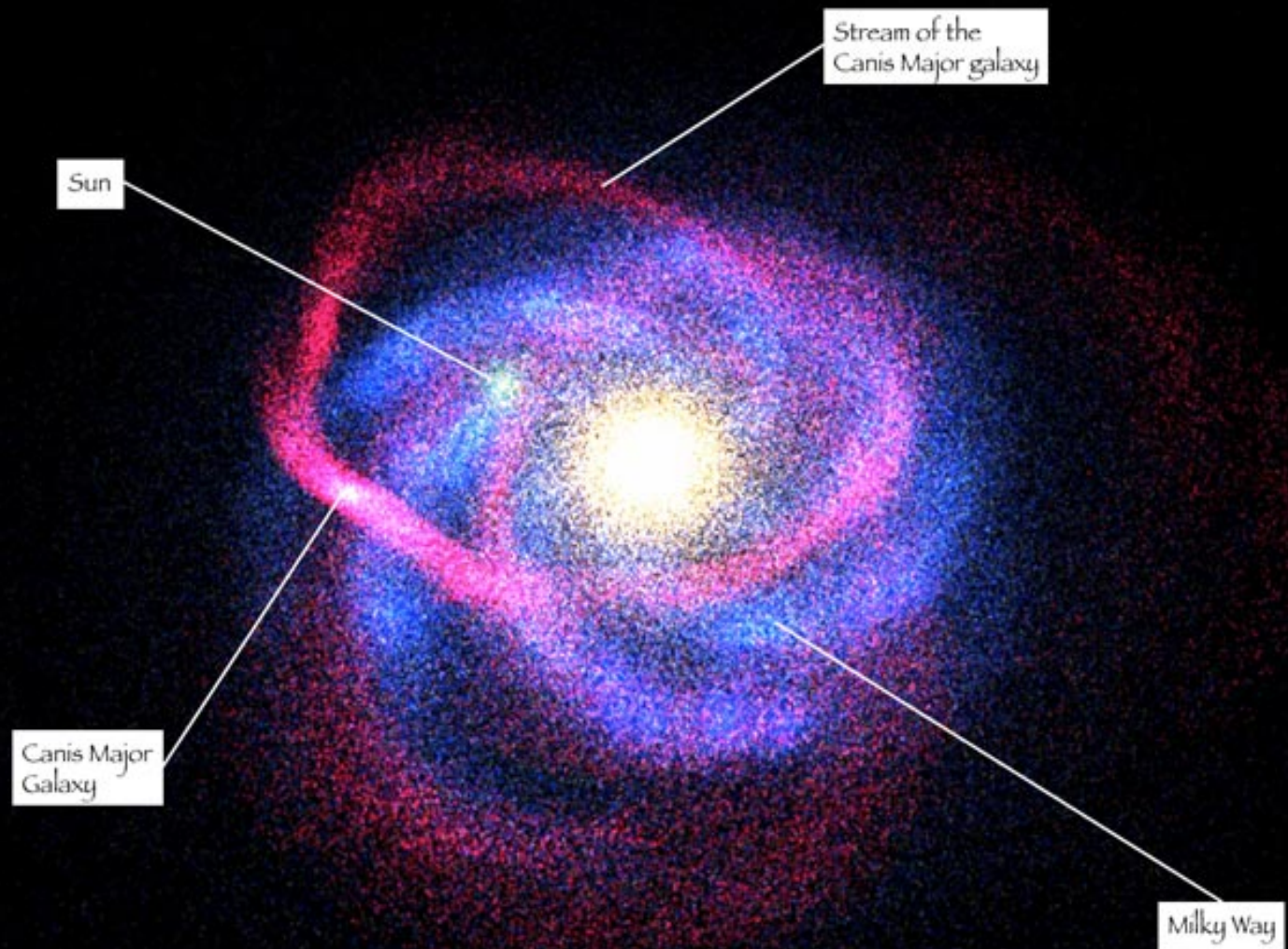


Figure 16.15 Formation of stars by a shock wave associated with a spiral density wave. The shock wave compresses the interstellar clouds and triggers star formation, especially of O- and B-stars that mark a spiral arm before they die out.

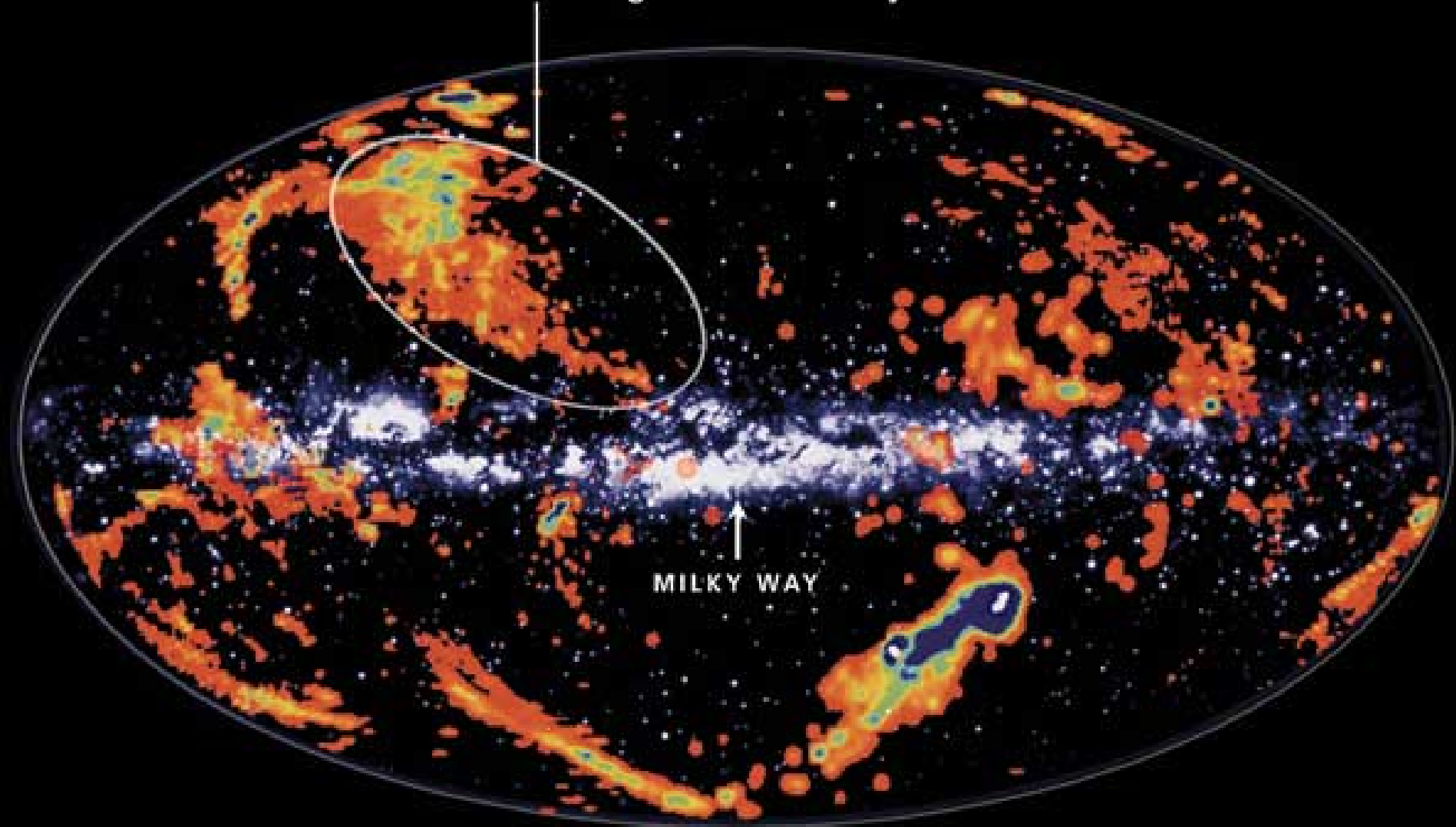
This dwarf galaxy (purple) is being tidally stretched into a “noodle” by the gravity of the Milky Way (blue spiral arms) as it falls inward and orbits. Much like the way they make cotton candy at a carnival. This is a plot reconstructed from data, not a photo!



In-falling intergalactic clouds of gas here are also being tidally stretched. Most obvious is the Magallanic Stream

Accreting Low-Metallicity Gas

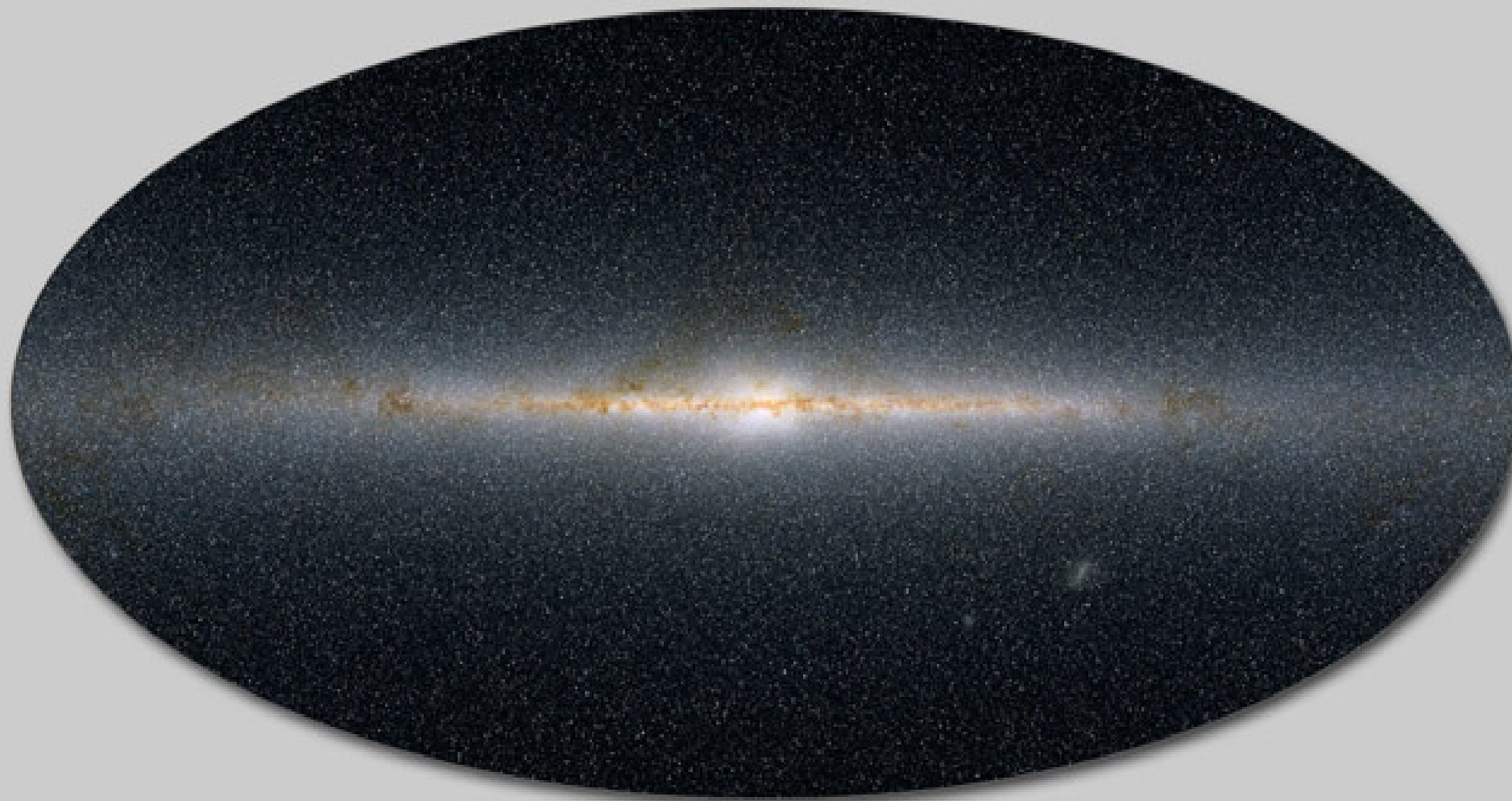
MILKY WAY



Let's take a trip to the center of the Milky Way Galaxy...

- We'll have to use pictures taken at long wavelengths, which can penetrate through the vast amounts of dust between here and there... Infrared, and radio wavelengths





The Infrared Milky Way This map of the infrared sky includes the light of a half billion stars



Combined 2MASS-MSX View of the Galactic Center



Two Micron All Sky Survey
– Southern Facility –
2MASS Atlas Image Mosaic

Infrared Processing and Analysis Center & University of Massachusetts



Midcourse Space Experiment
SPIRIT III

SAGITTARIUS

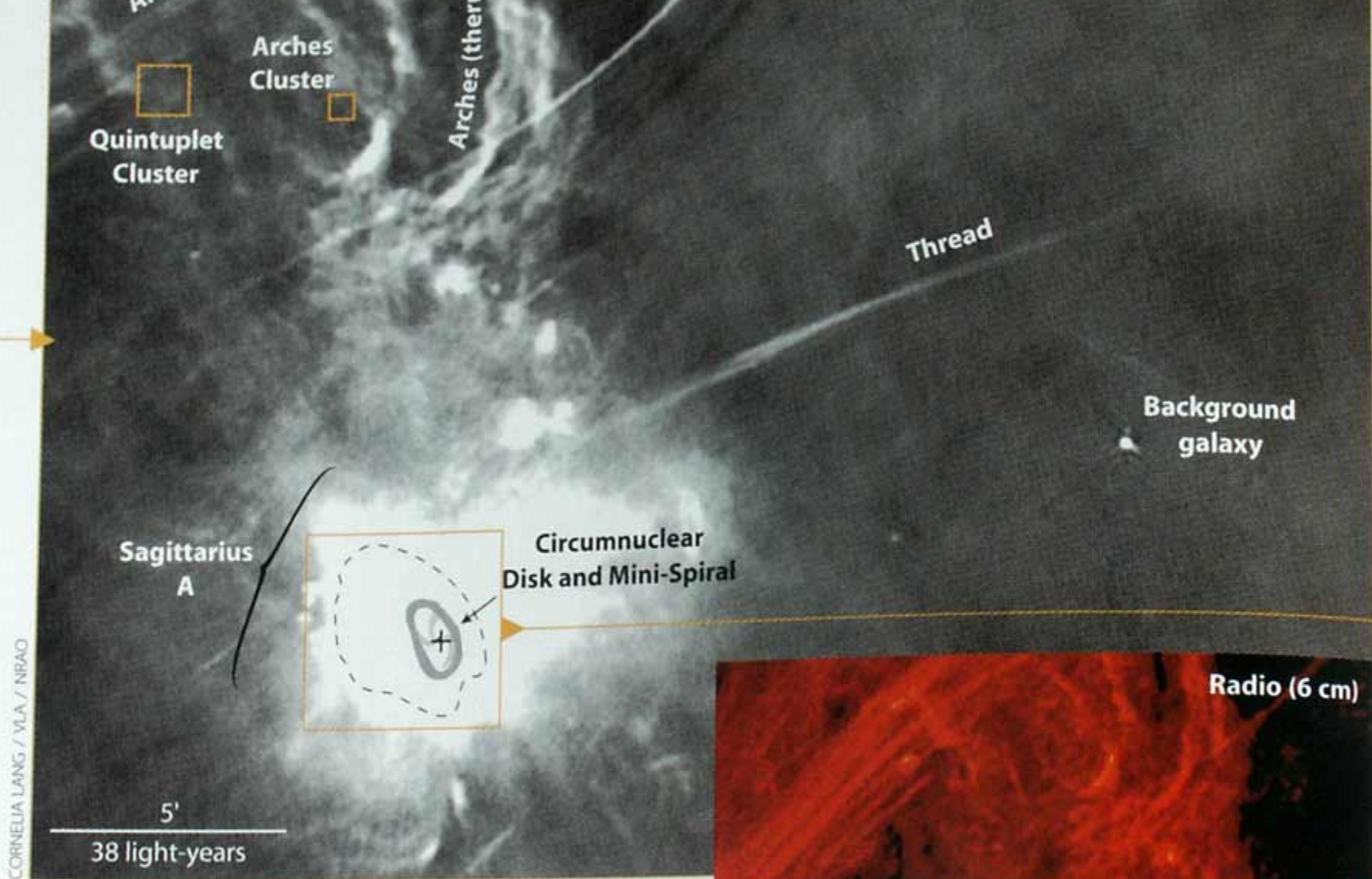


Galactic center





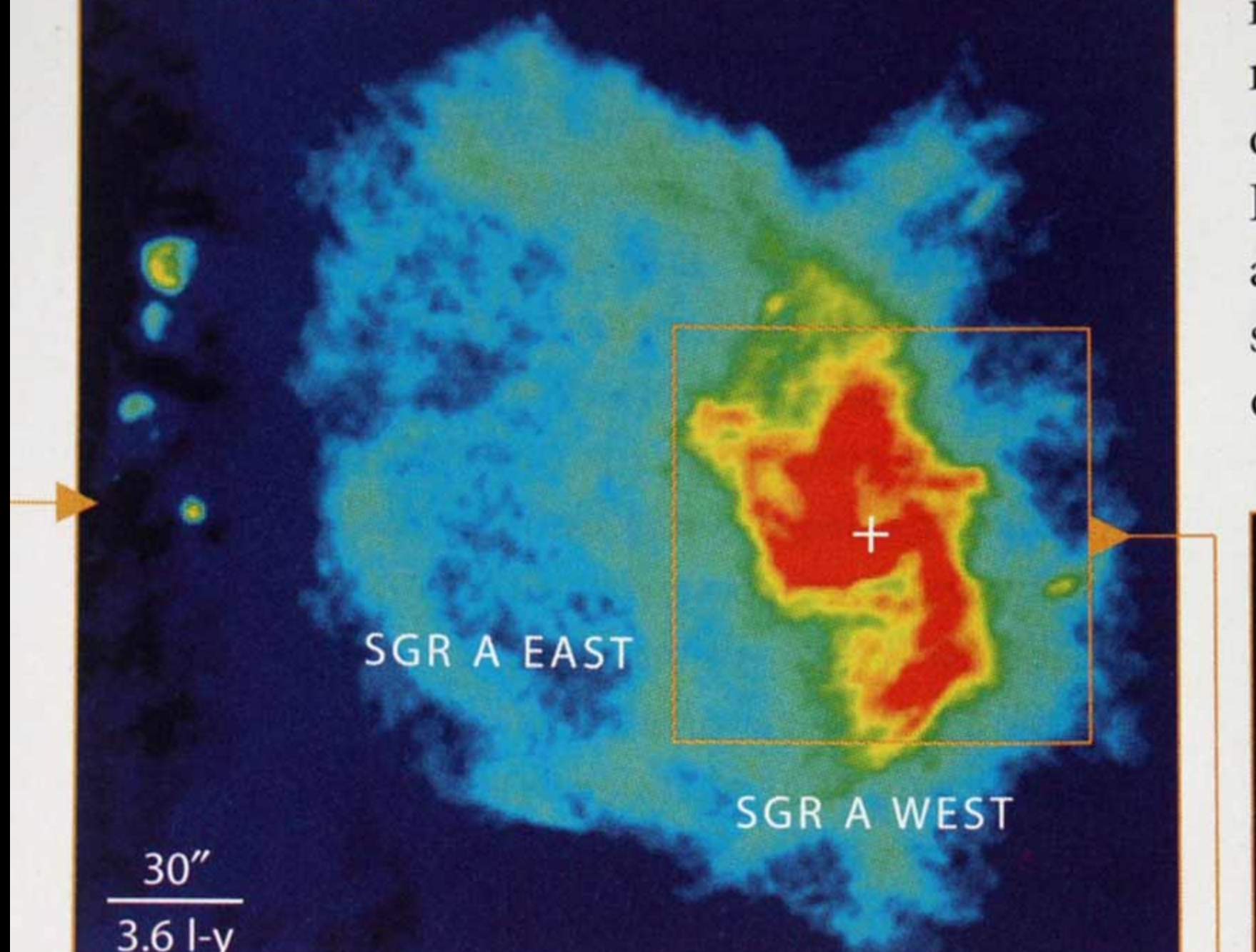
above, left: Peering through the dust: an infrared view toward the galactic center. This image only hints at the

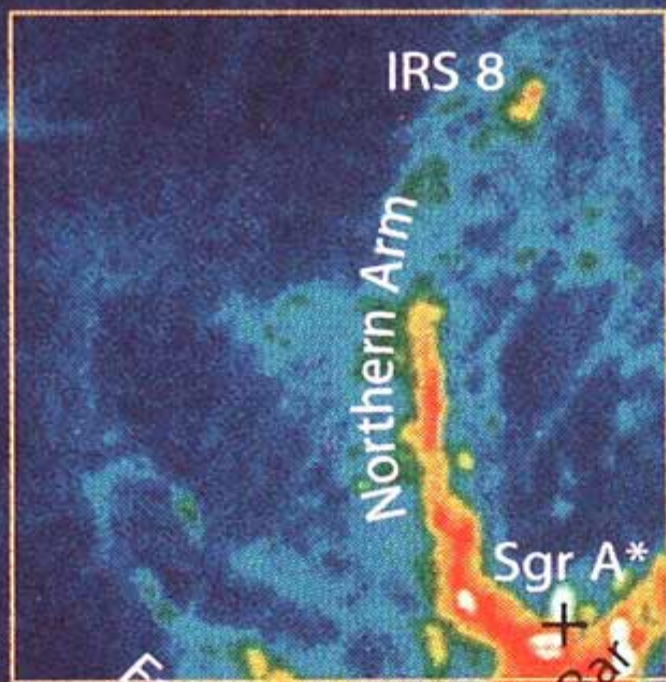


The most prominent gas features in the galaxy's central half degree, imaged here in radio, include the turbulent Arches, many thin magnetic threads, and large, powerful Sagittarius A, one of the first radio sources discovered in the early days of radio astronomy.



Radio (6 cm)






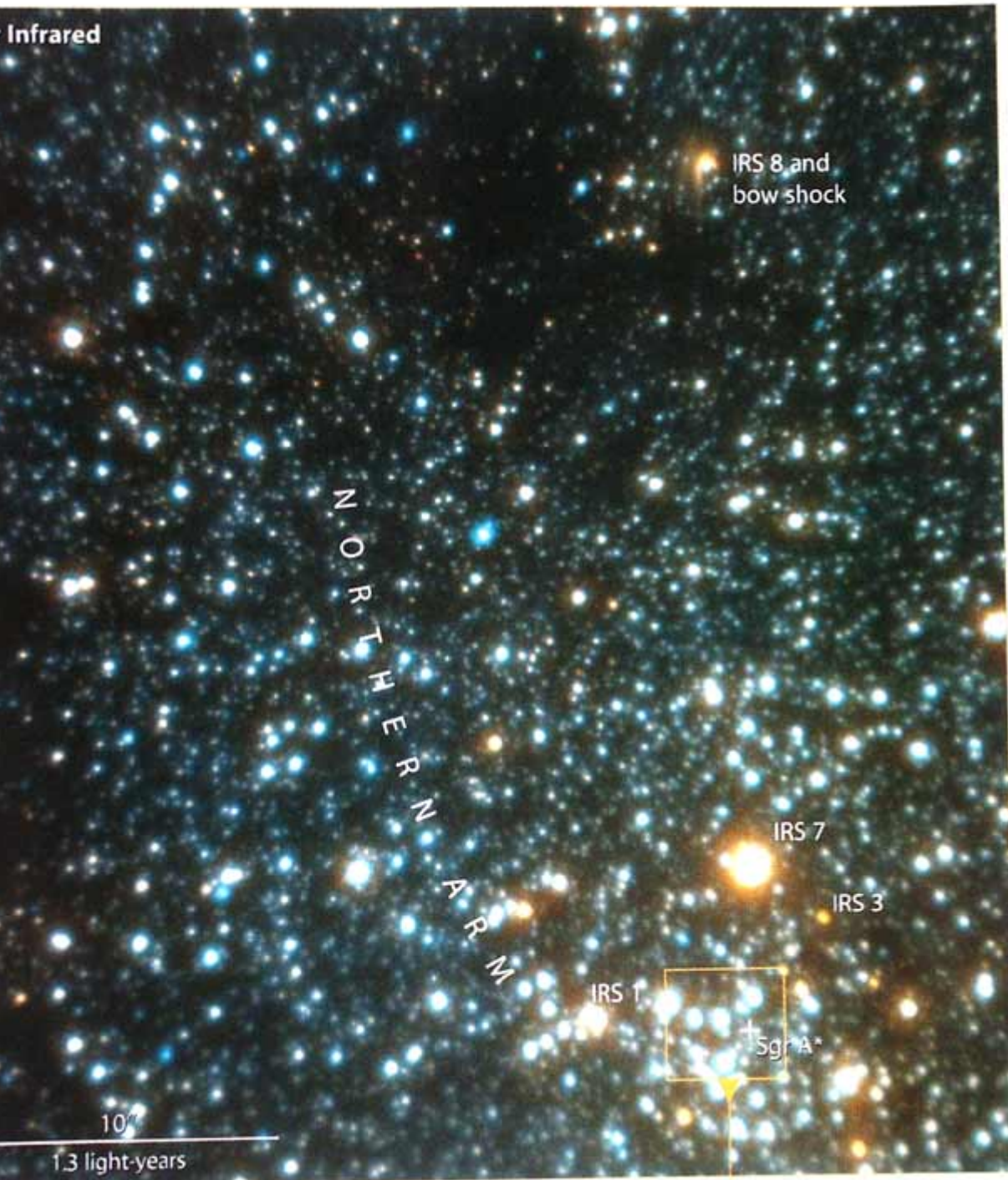
Eastern Arm

Western Arc

30''



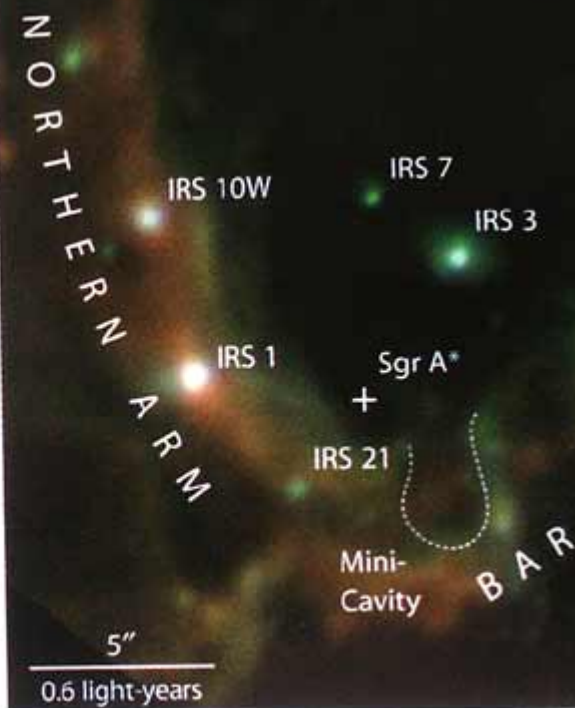
Infrared



Left: Great numbers of stars come back into view when we switch to near infrared. This high-resolution image was taken with the 8-meter Gemini North telescope. Courtesy F. Rigaut, Gemini Observatory, and NOAO.

Below: Zooming in on the Mini-Spiral's central portion at the mid-infrared wavelength of 12.5 microns, which reveals room-temperature dust. The pointlike infrared sources (IRS) in this false-color image are supergiant stars. The galactic-center black hole at Sagittarius A* is completely invisible.

Mid-Infrared





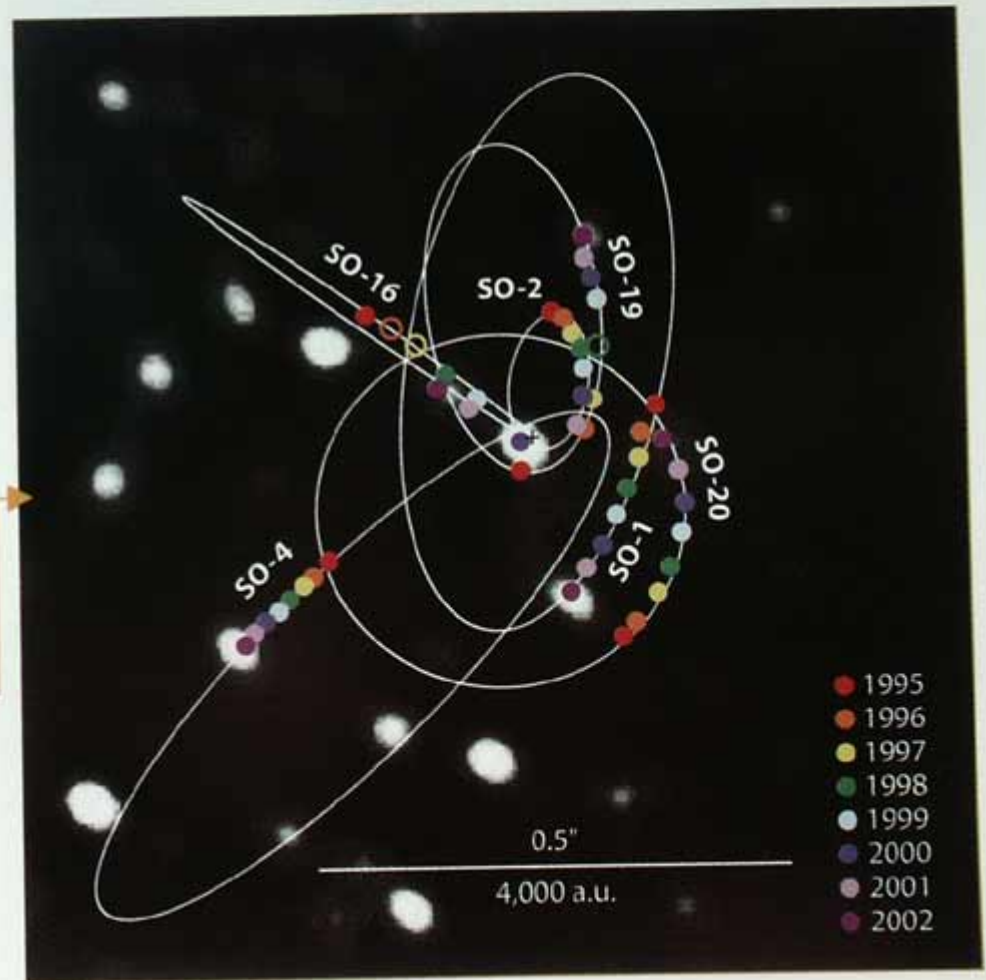
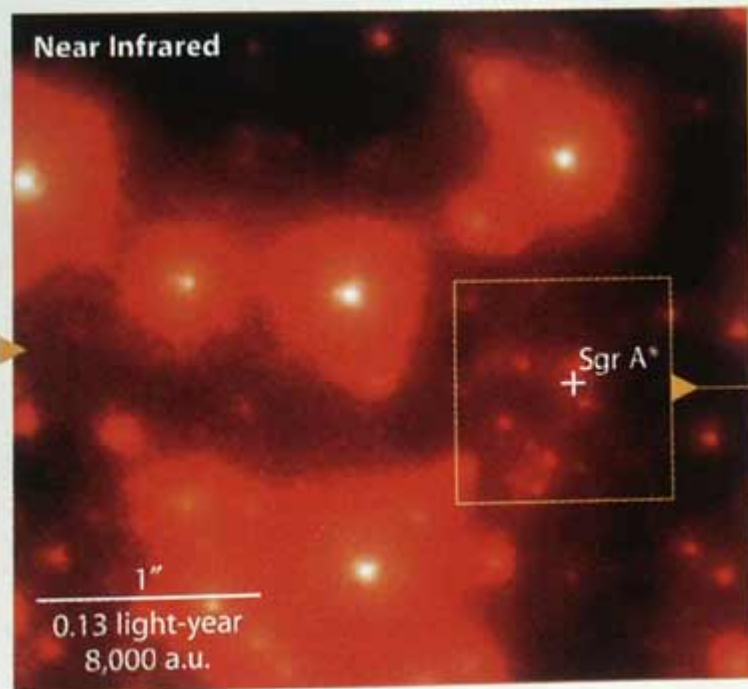
1 light-year

...that such a large mass in such a small volume cannot avoid ending up as a black hole. The hole's mass dictates that it is 16 million km across, yawning about 0.1 a.u (just under 1 light-minute) wide.

However, Sgr A* is remarkably quiet and dim as galaxy-center black holes go. Normally we see no infrared and only very weak, fitful X-ray emission at its position. Apparently, the hole is being "starved" of infalling matter. Geoffrey Bower (University of California, Berkeley) and

Below: Zooming deep into the central star cluster IRS 16 at a wavelength of 2.2 microns. This image was taken a few years before the one at right; note that several stars moved slightly during the intervening time. Courtesy A. Ghez and Keck Observatory.

Orbits of six stars around Sagittarius A*. This 2.2-micron adaptive-optics image, a mere 1 arcsecond square, was taken in 2002; symbols show the positions of the six stars for each of the previous 7 years as well. The white orbits are best fits to these positions. Four of the orbits have only short arcs of data and thus are very tentative, but the stars S0-2 and S0-16 have swung through half or more of their ellipses, allowing their orbits to be specified well. S0-16 swung a mere 60 astronomical units from the black hole. Courtesy A. Tanner, S. Hornstein, A. Ghez, and Keck Observatory.



How Did the Milky Way Form?

- More on galaxy formation later, but briefly...
- Gravity pulled together several, smaller “proto galaxies” which had already formed stars, and ***schmushed*** it all together into what is now the central bulge.
- Then, more slowly, gas fell in from farther out, had angular momentum, and so settled into a flat disk, and only gradually is forming itself into stars.
- Globular clusters formed during the proto-galaxy stage and during the time they collided to make us.
- All this happened within a billion or so years after the Big Bang. Same for most galaxies.

Evidence? Pop I and Pop II Stars!

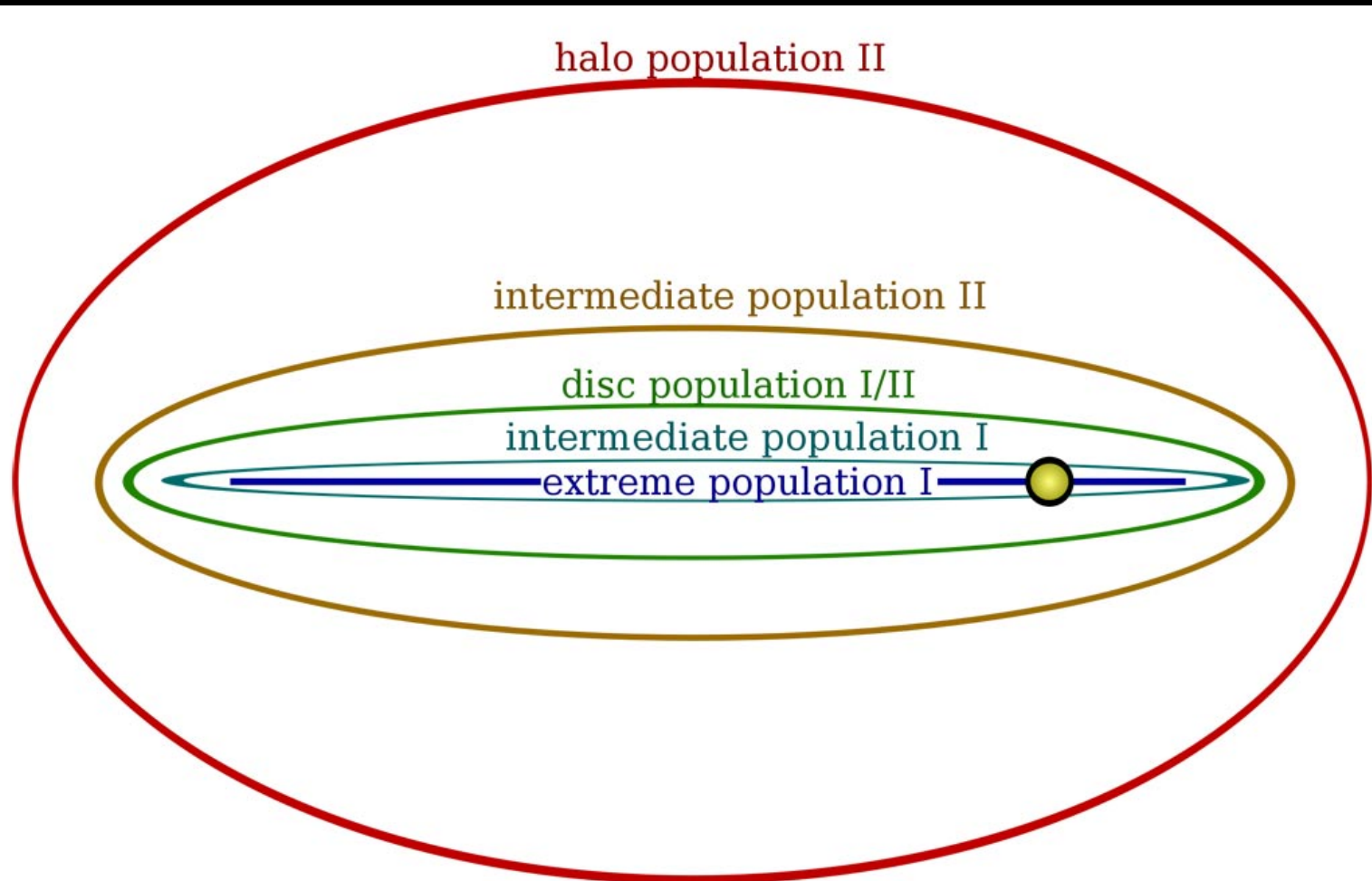
- Walter Baade in the 1950's discovered something interesting...
- Stars with “metals” (elements heavier than Helium) were all in the disk, while stars without metals were nearly all in the halo. He called them...
- **Stars with high metallicity stars = Population I**
Stars w/o metals = Population II
- Pop I, and Pop II; their distribution shows the bulge formed first, out of pristine material fresh from the Big Bang and thus had only hydrogen and helium (those are the only elements to emerge from the Big Bang). Then the evolution of stars and supernovae dirty'ed up the interstellar medium and so later forming stars in the disk inherited metals.

Age-dating 70,000 Red Giants across the Galaxy, (best sampling near the sun, of course) confirms this general picture. In the video link, notice how the

core “central bulge” is made up of very old stars (formed first), the fattened disk stars above and below us are intermediate age (they’ve had time for their originally flat disk orbits to acquire up/down motion by random near-encounters with massive objects), and the youngest stars are closest to the center plane of the disk.

- [18 sec video](#)

Data since the 1950's has improved, and we see there's a gradual transition from Pop I to Pop II



Distribution of Star Populations
in Milky Way

Ch19: The Milky Way – Key Pts

- Pop I: stars with metals, formed only after many supernovae enriched the interstellar medium and interstellar clouds with metals
- Pop II, metal-poor stars, all in the bulge and halo
- Pop I,II show MW formed spheroid first, then disk more gradually.
- Hubble discovered Cepheids in Andromeda Nebula, so it's a Galaxy, and we must be one too
- Star formation happening in disk right through today
- 10 million solar mass Giant black hole in nucleus of our Galaxy, evidence by rapid orbital motion of stars and gas light years away.
- Dust disk is dense and vertically thin, sun lives in this layer, near outskirts of Milky Way, as shown by globulars all being on one side of the sky
- Spiral arms: regions of recent star formation, light dominated by massive blue giant stars; they stand out against fainter background of the disk
- Globulars: oldest stellar systems we can reliably age-date, 13 billion years old, almost as old as the Universe.