SOAR 2018: Galaxies

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Photo by Marc Staves 2011

Galaxies

- 9/4/18
  - Milky Way Galaxy Contents & Motions
- 9/11/18
  - Milky Way Environment & the Local Group
- 9/18/18
  - Other Galaxies & Clusters of Galaxies
- 9/25/18
  - Expansion, History & Evolution of the Universe

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SOAR: Galaxies

The Milky Way Galaxy: Contents & Motion

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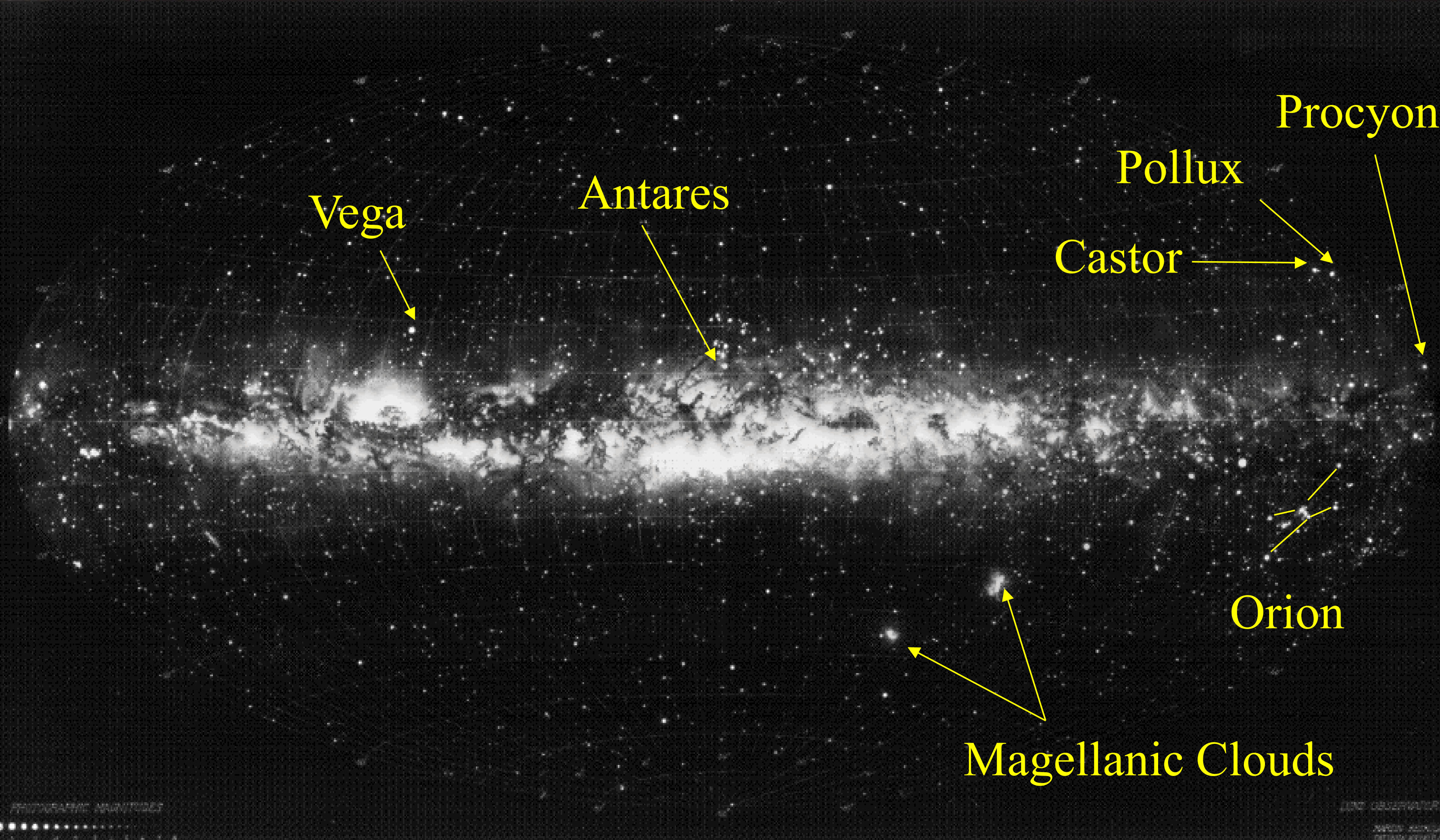
The Milky Way

- ☆ The optical sky: stars, gas & dust



The Milky Way

- ☆Disk with nuclear bulge and halo 100 kly

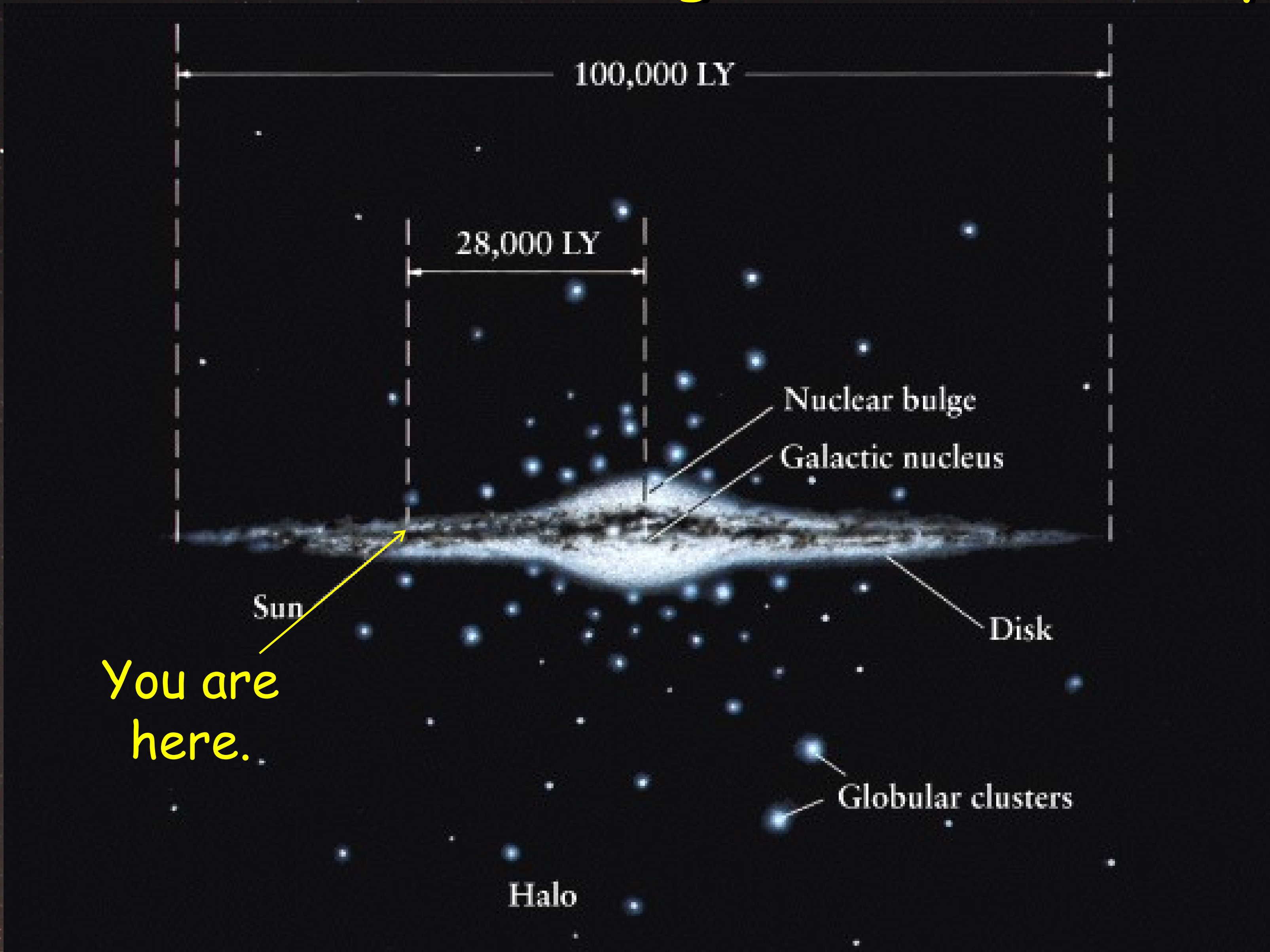
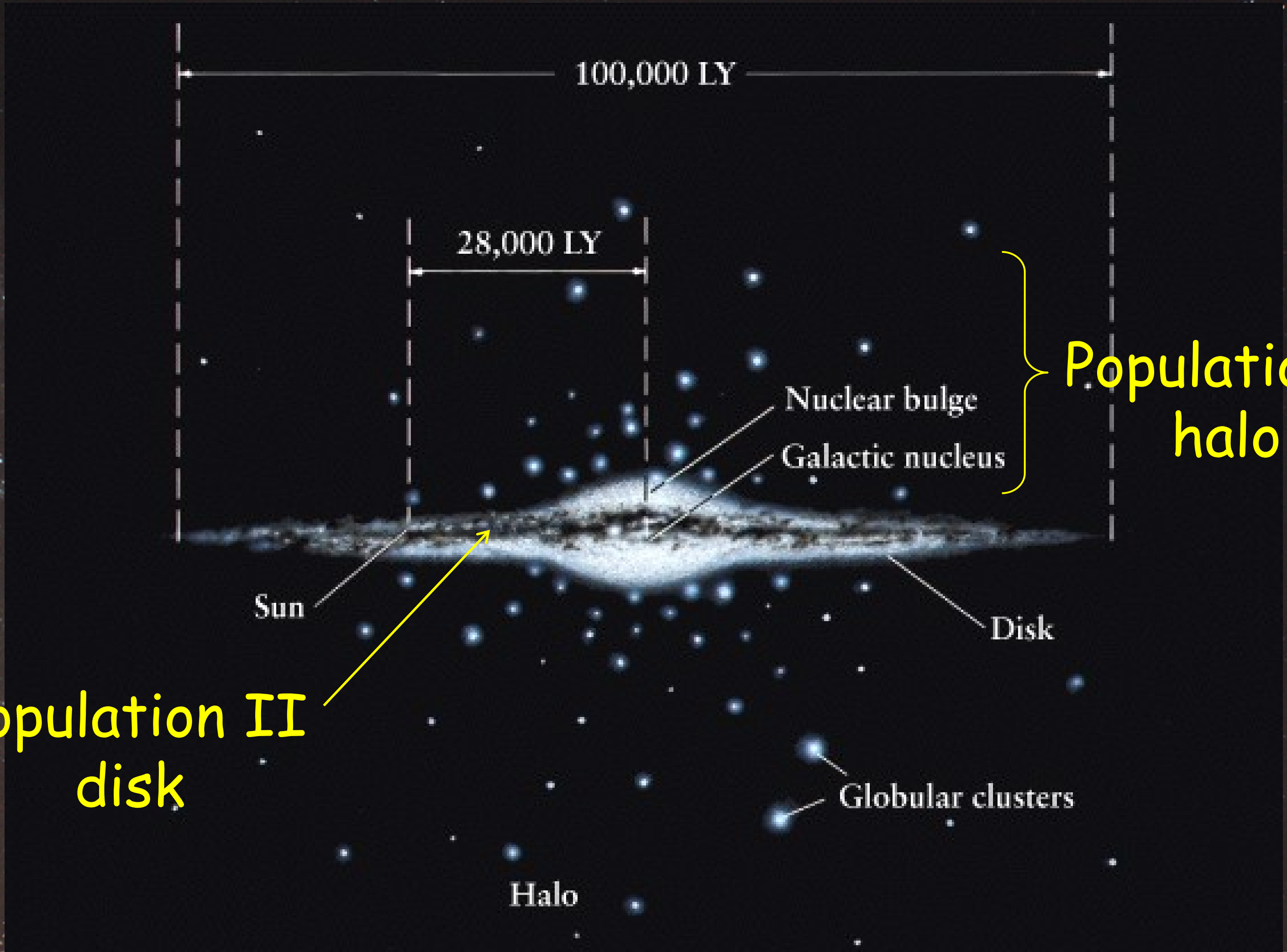


Photo by Marc

Milky Way Stellar Populations

- ☆Population I - Stars in halo (most old)
- ☆Poplulation II - Stars in disk (many young)



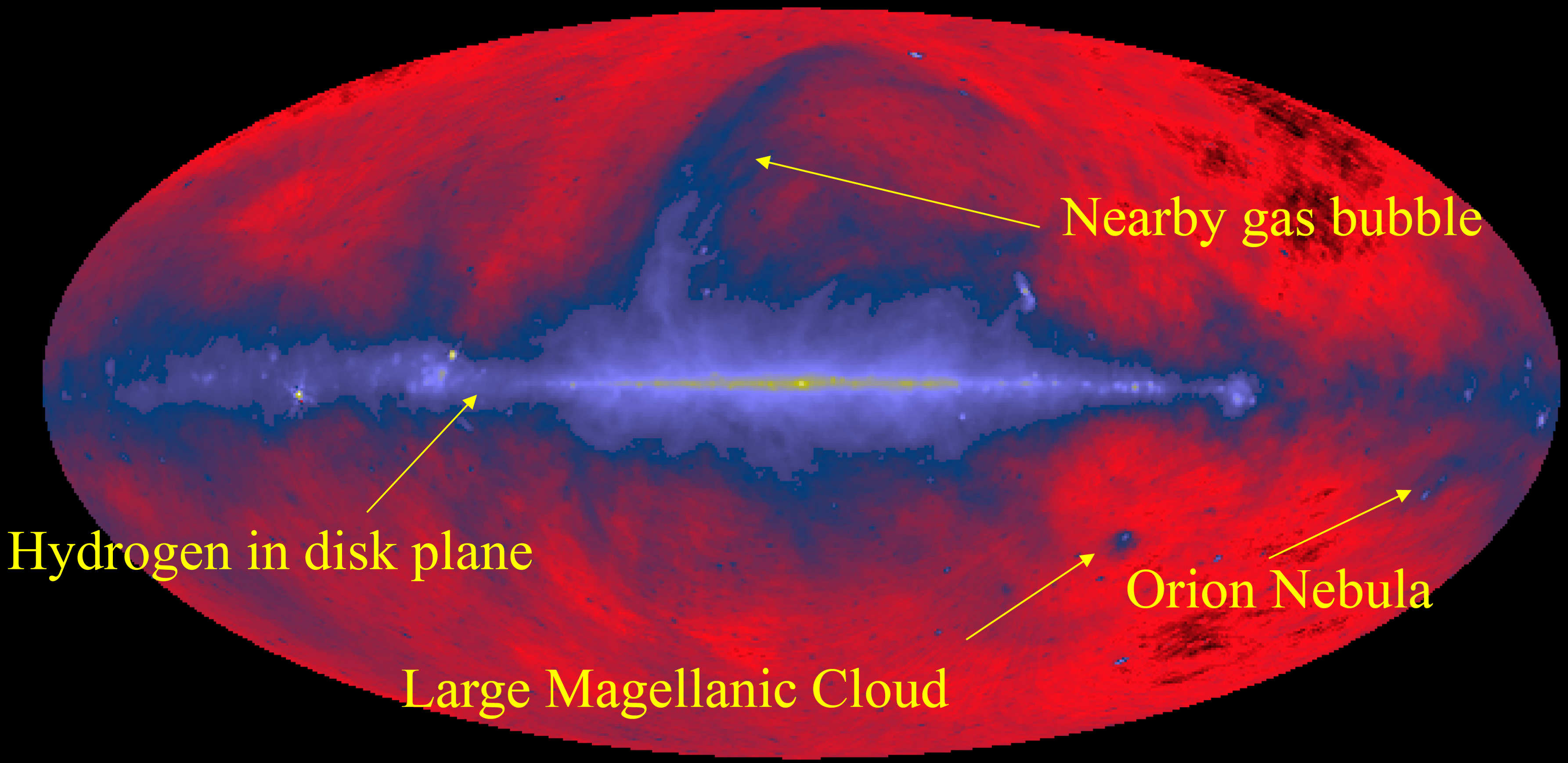
Population I
halo

Population II
disk

Photo by Marc Staves

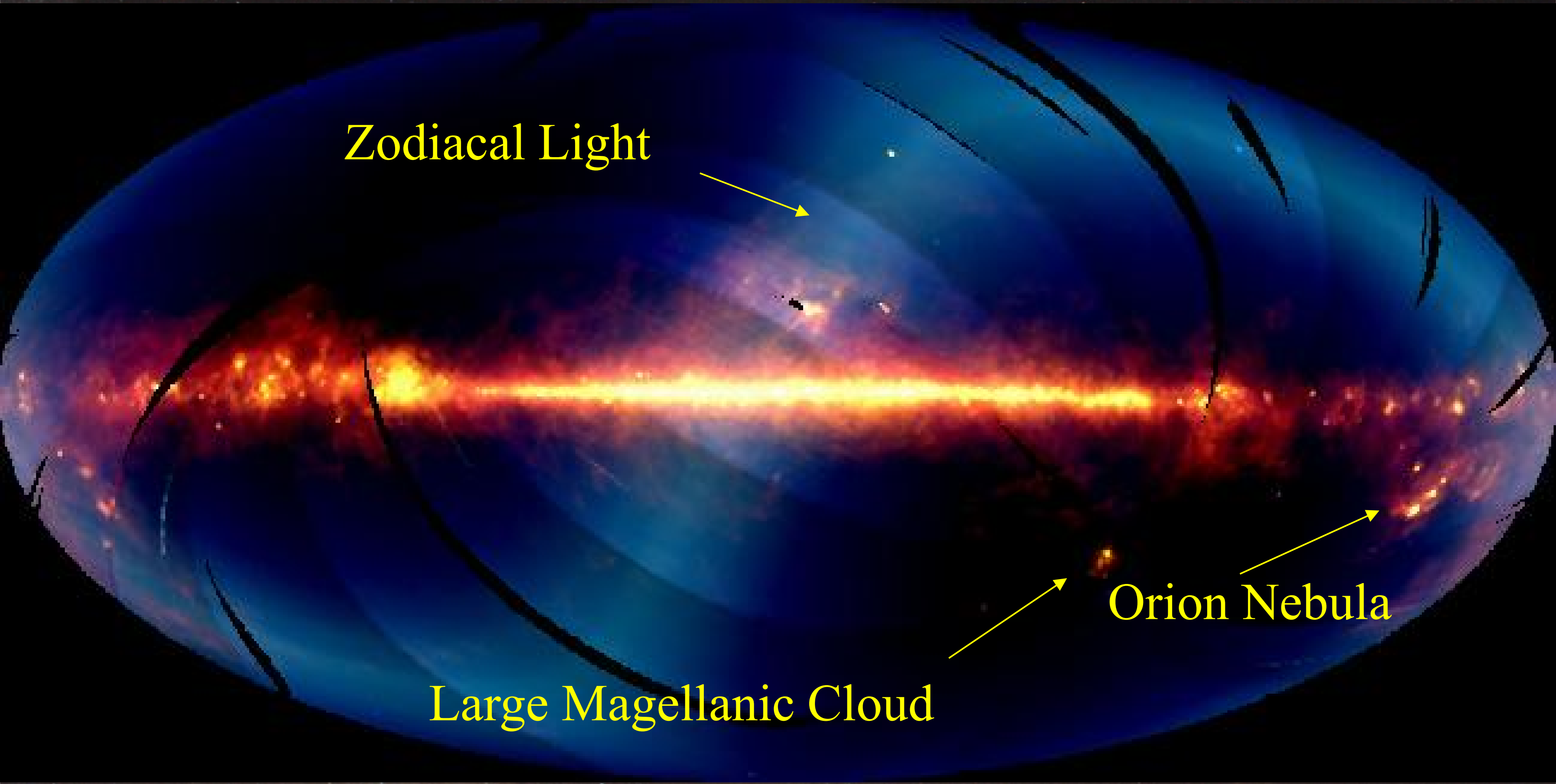
The Milky Way

- ☆ The radio broadband sky: warm gas



The Milky Way

- ☆ The IR sky: warm gas & glowing dust



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The Milky Way

- ☆ The X-ray sky: HOT gas & black holes

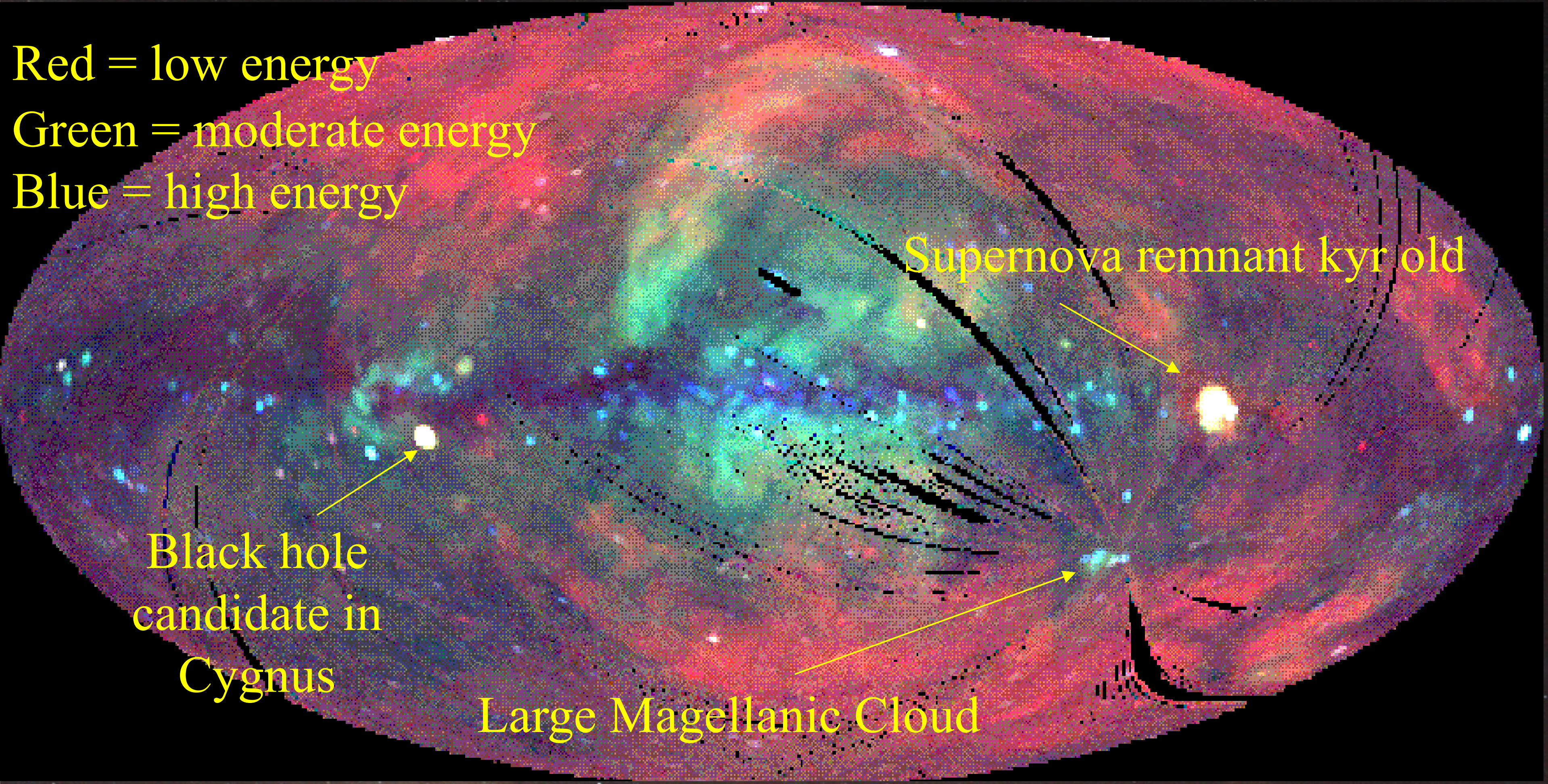
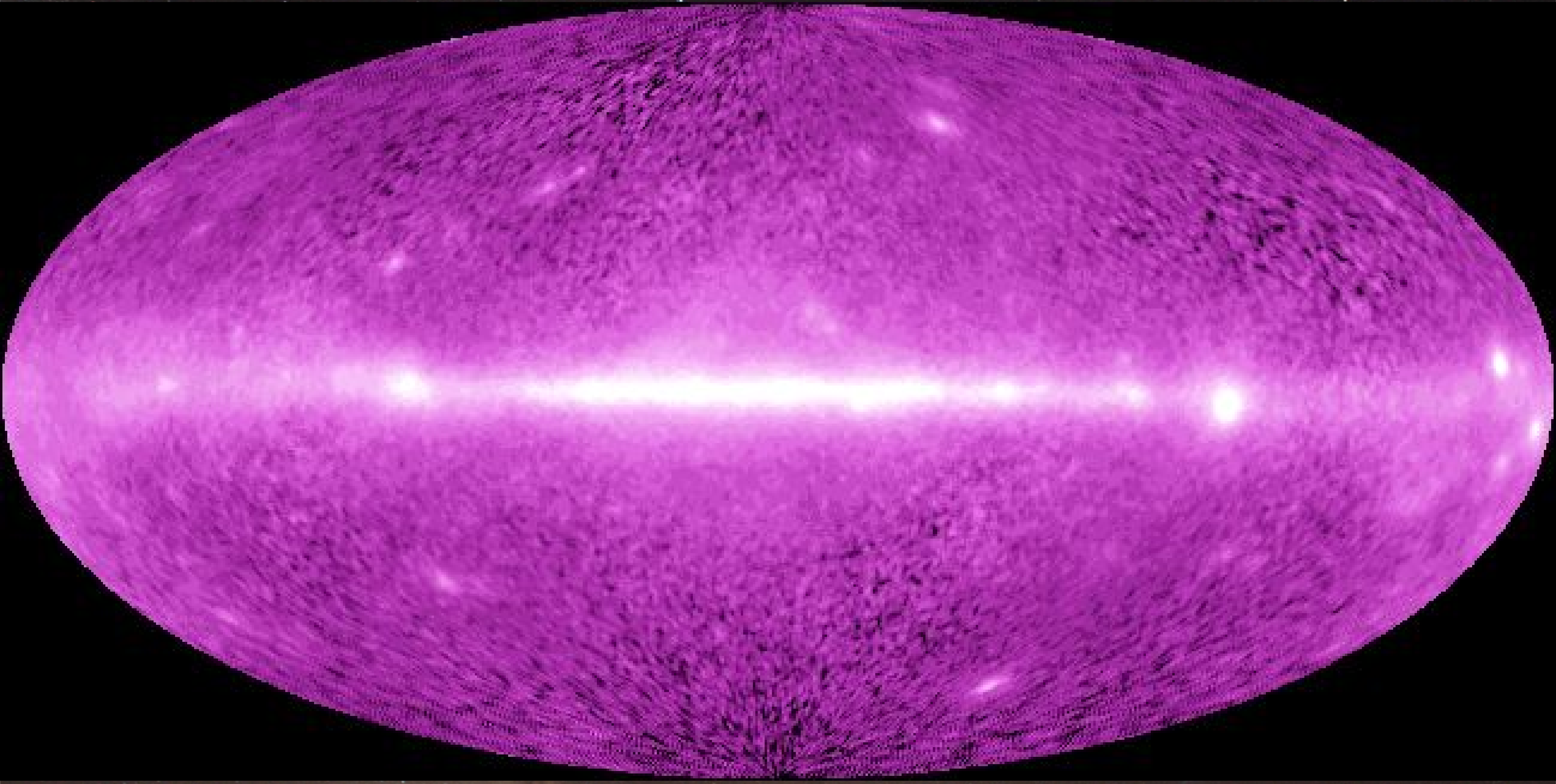


Photo by Marc Staves 2011

The Milky Way

- The γ-ray sky: Extreme energy events
  - Stars colliding, falling into black holes, exploding



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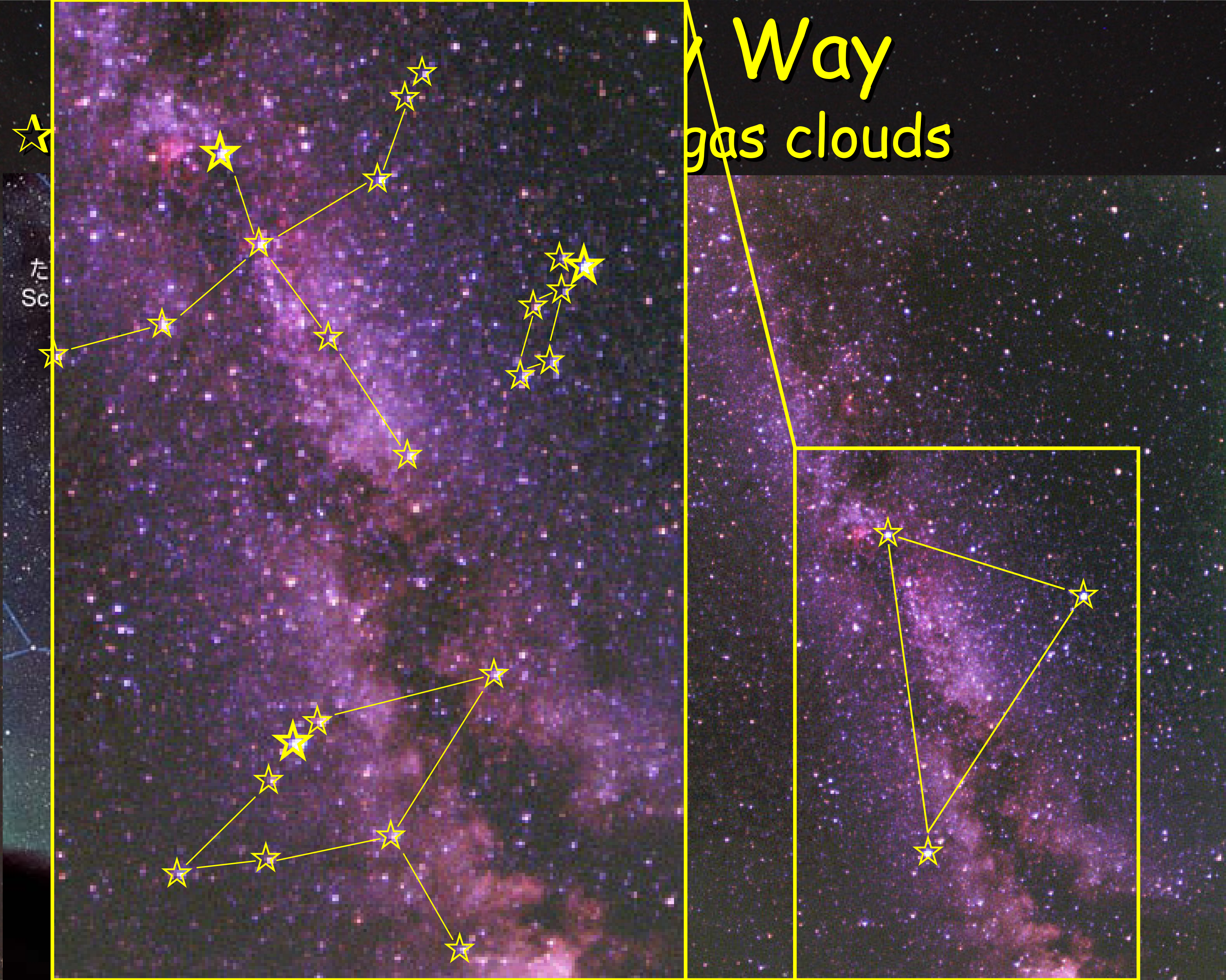
Contents of the Milky Way

- Stars ~ 100 billion – 500 billion
- Nebulae
  - Clouds of gas and dust
  - Emission Nebulae (eg, Lagoon, Trifid, Eagle, Orion)
    - Heated, glowing gas,
    - RED due to Balmer α
  - Reflection Nebulae (eg. Trifid)
    - Dust & cool gas
    - Blue for same reason sky is blue
  - Dark Nebulae (eg. Horsehead, Coalsack)
    - Dust & cold gas
    - Black because it blocks light from nebulae & stars beyond
  - Stellar Remnants
    - Planetary Nebulae and Supernova Remnants

Photo by Marc Staves 2011

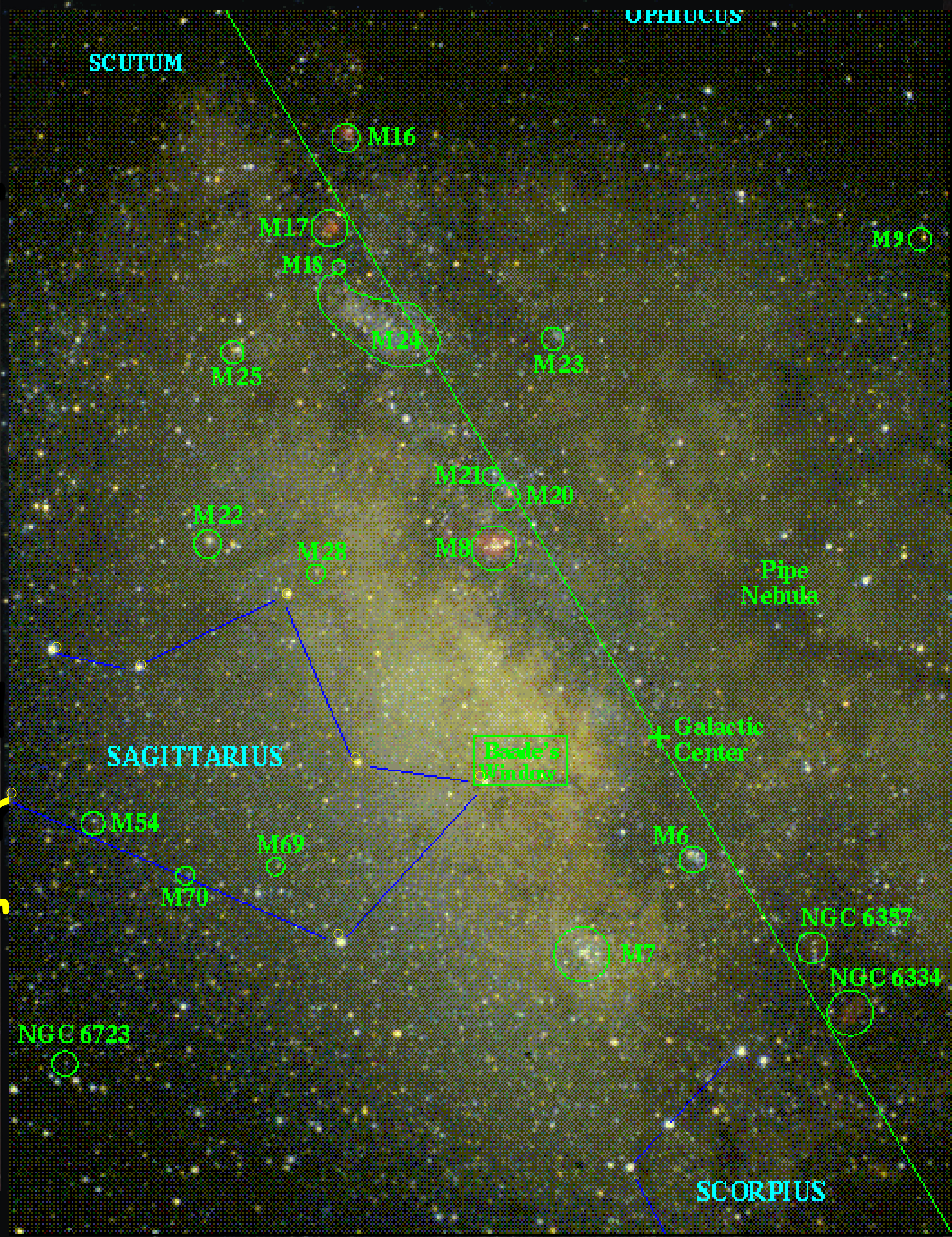
y Way

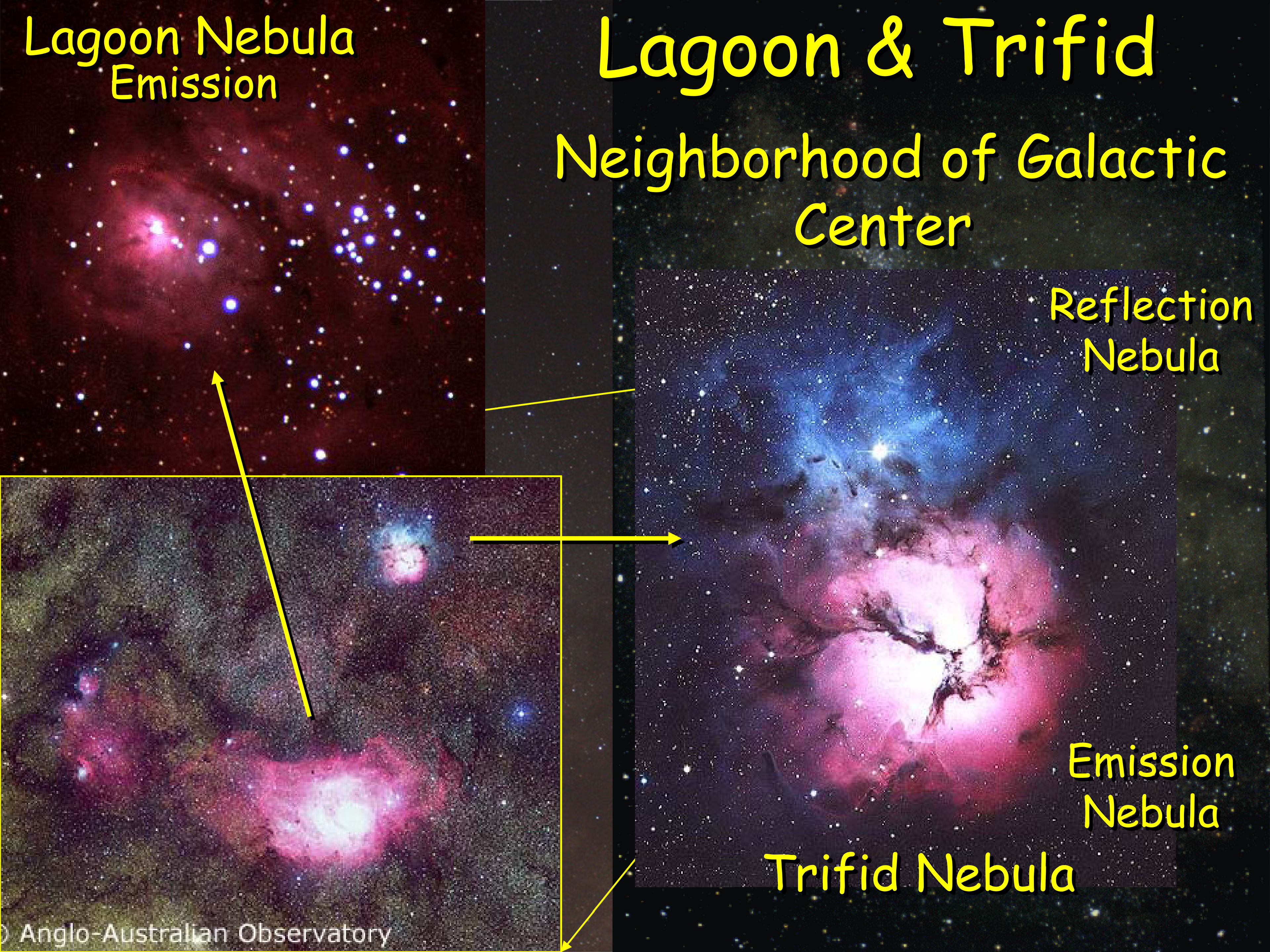
gas clouds



Bright Nebulae

- ☆ The Galactic Center
  - M8: Lagoon Nebula
  - M20: Trifid Nebula
  - M16: Eagle Nebula
  - M17: Omega Nebula
  - M24: Sag. Star Cloud
  - M6: Butterfly Cluster
  - M7: Ptolemy's Cluster
    Mentioned in 138 BCE




Lagoon & Trifid
Neighborhood of Galactic Center
Lagoon Nebula
Emission
Reflection
Nebula
Emission
Nebula
Trifid Nebula
© Anglo-Australian Observatory

Dark Nebulae

- ☆ Horsehead & Barnard's Nebula
- ☆ Dust & cool gas blocking background light

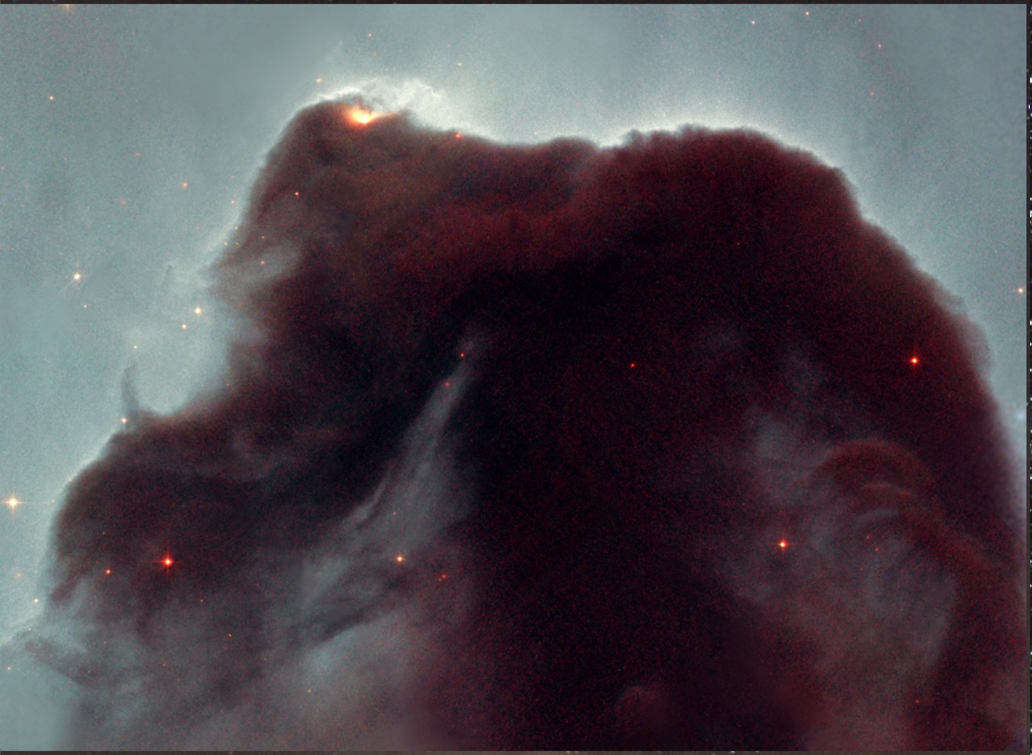
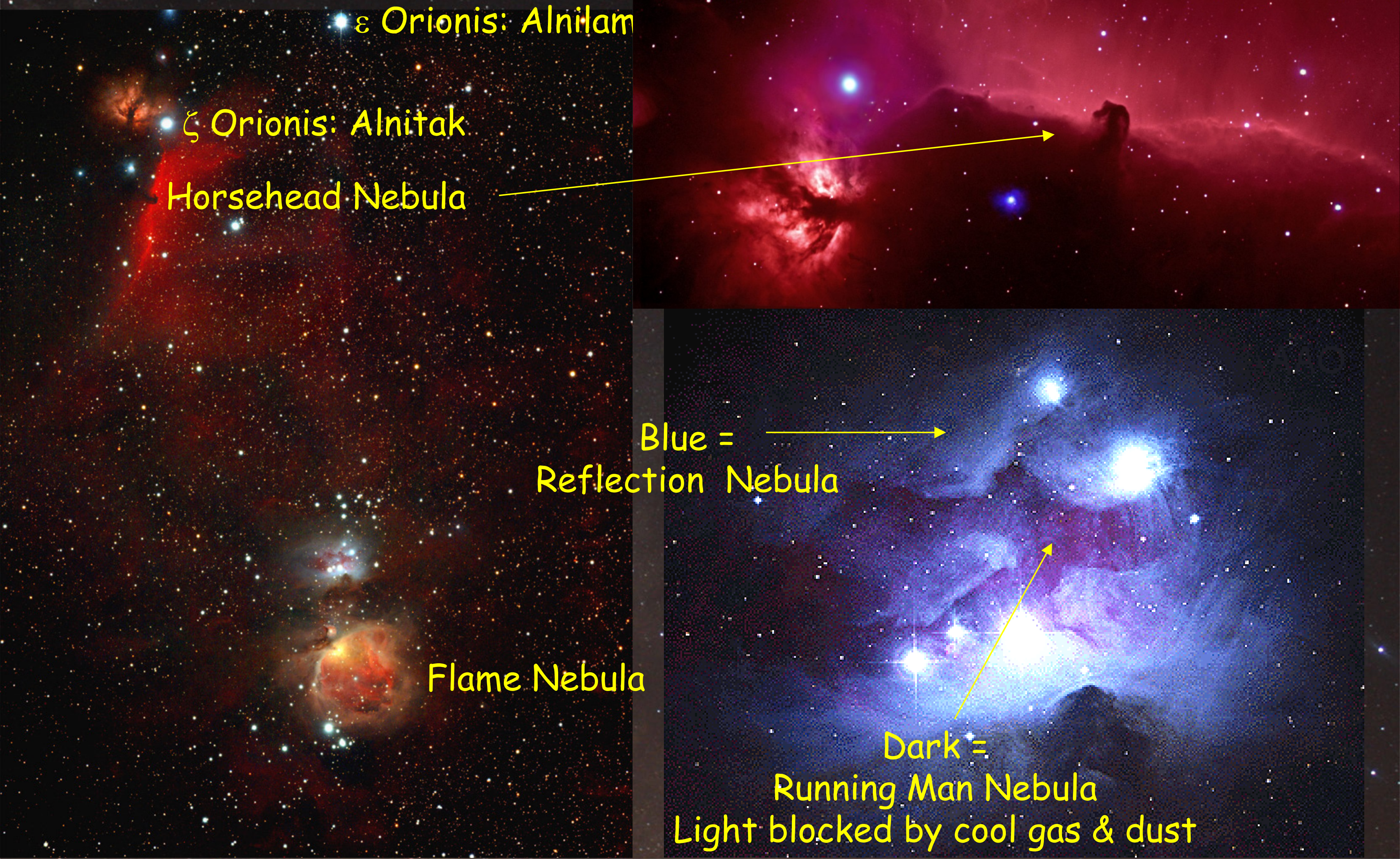


Photo by Marc Staves 2011

Orion Nebulae … 1300 ly away



Reflection Nebulae

- ☆ Dust reflecting light from stars
  - Blue due to not scattering red light

Nebulosity and the Pleiades

Star Clusters

- ☆ Open (Galactic Clusters)
  - Mostly blue stars ⇒ young population
  - Stars born in "litters" from cloud complexes
    - ☽ Open clusters become less dense in time
  - 10's to 1000's of stars

Photo by Marc Staves 2011

Open Clusters

Star Clusters

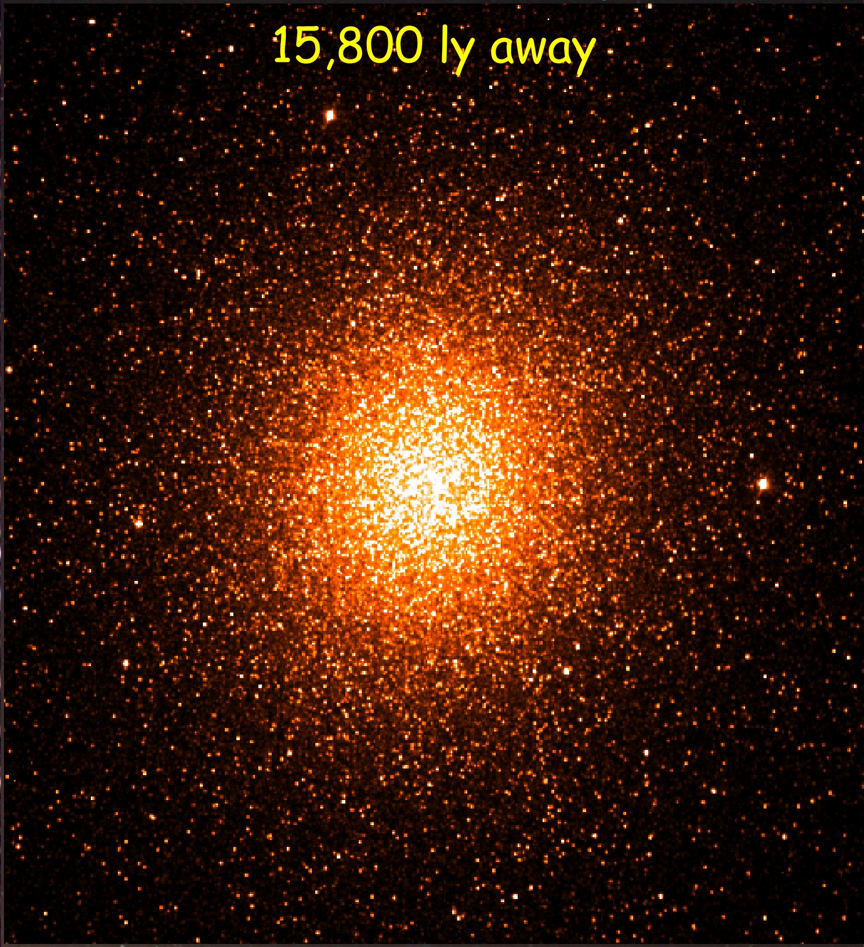
- ☆ Globular Clusters
  - Mostly red stars ⇒ old population
  - Spherical orbits about MW center
  - Thousands to millions of stars

Photo by Marc Staves 2011

Globular Star Clusters

M3 Canis Venatici
≈ ½ million stars

Omega Centauri
≈ millions of stars



Globular Clusters

- ☆ M15 in Pegasus
  - Stars falling into a black hole?

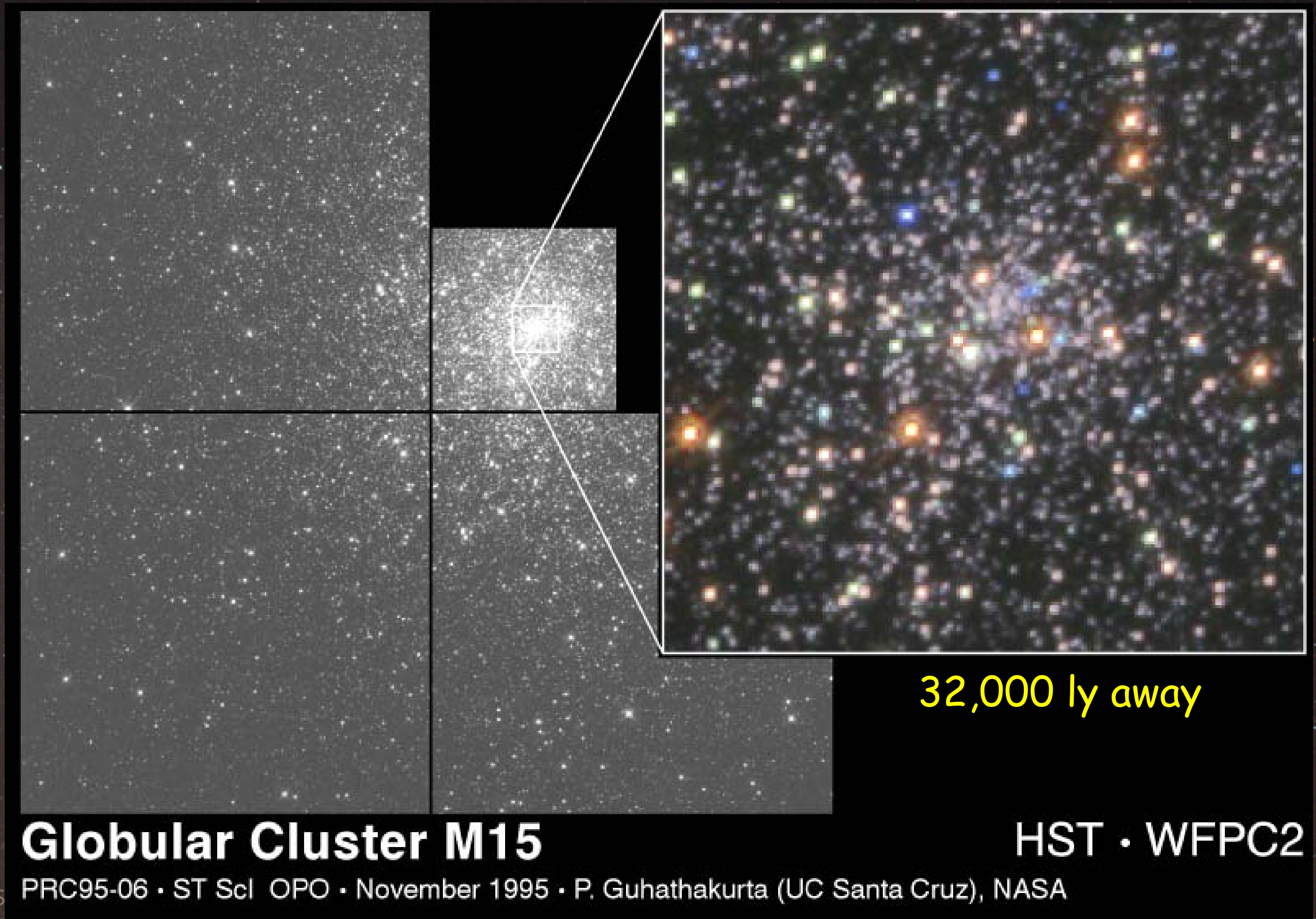


Photo by Marc S

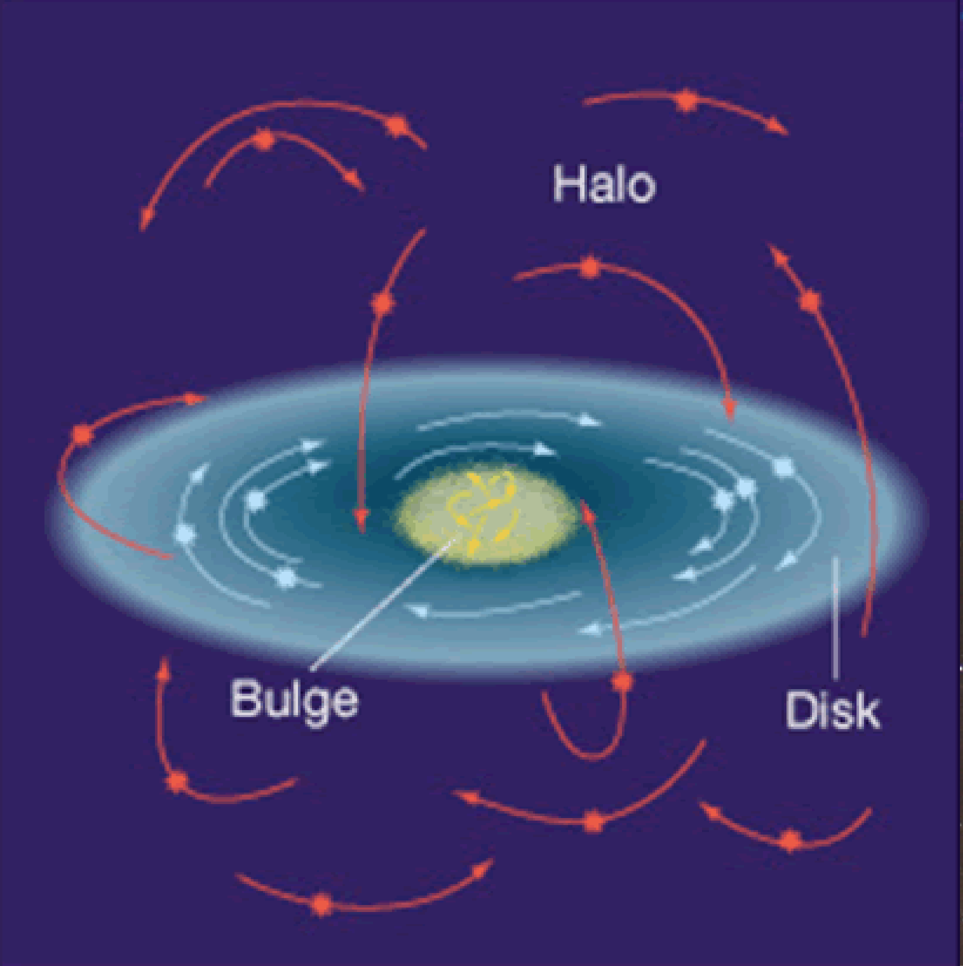
Age of the Milky Way

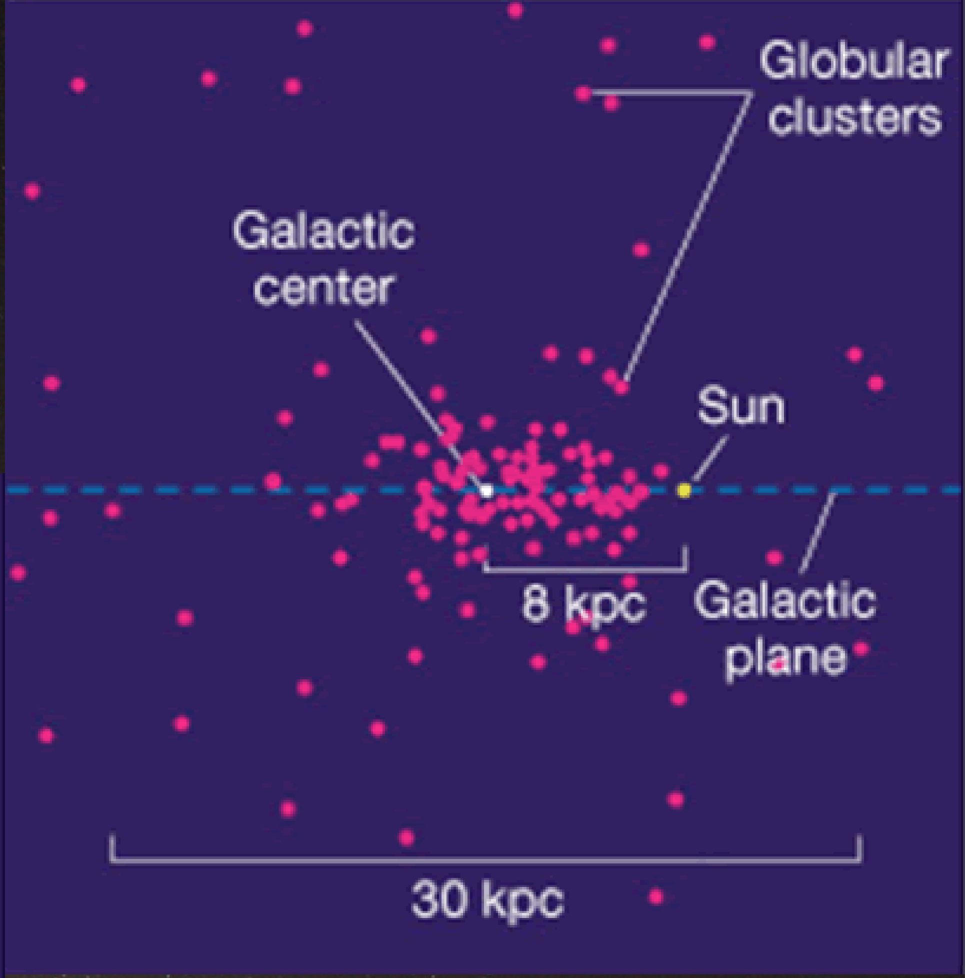
- Oldest stars in NGC 6397 ~ 13.4 ± 0.8 by
  - But the galaxy is older than the stars!
- Berillium Age
  - ^{4}Be only made in supernovae
    - presence of ^{4}Be in stars indicates >2nd generation
    - amount of ^{4}Be in stars determines generation
    - amount of ^{4}Be in oldest stars gives age of galaxy when stars were formed
  - Oldest stars in NGC 6797
    - formed 200-300 million years after 1st stars
- Total age of MW = 13.6 ± 0.8 by

Photo by Marc Staves 2011

The Milky Way

Globular clusters give sun's position & motion





Galactic year ~ 225 million years (Sol is 22)

Sol crosses galactic plane every 33 Myr

The Milky Way

Cold hydrogen "spin flip" transition gives 21-cm line

(radio band)

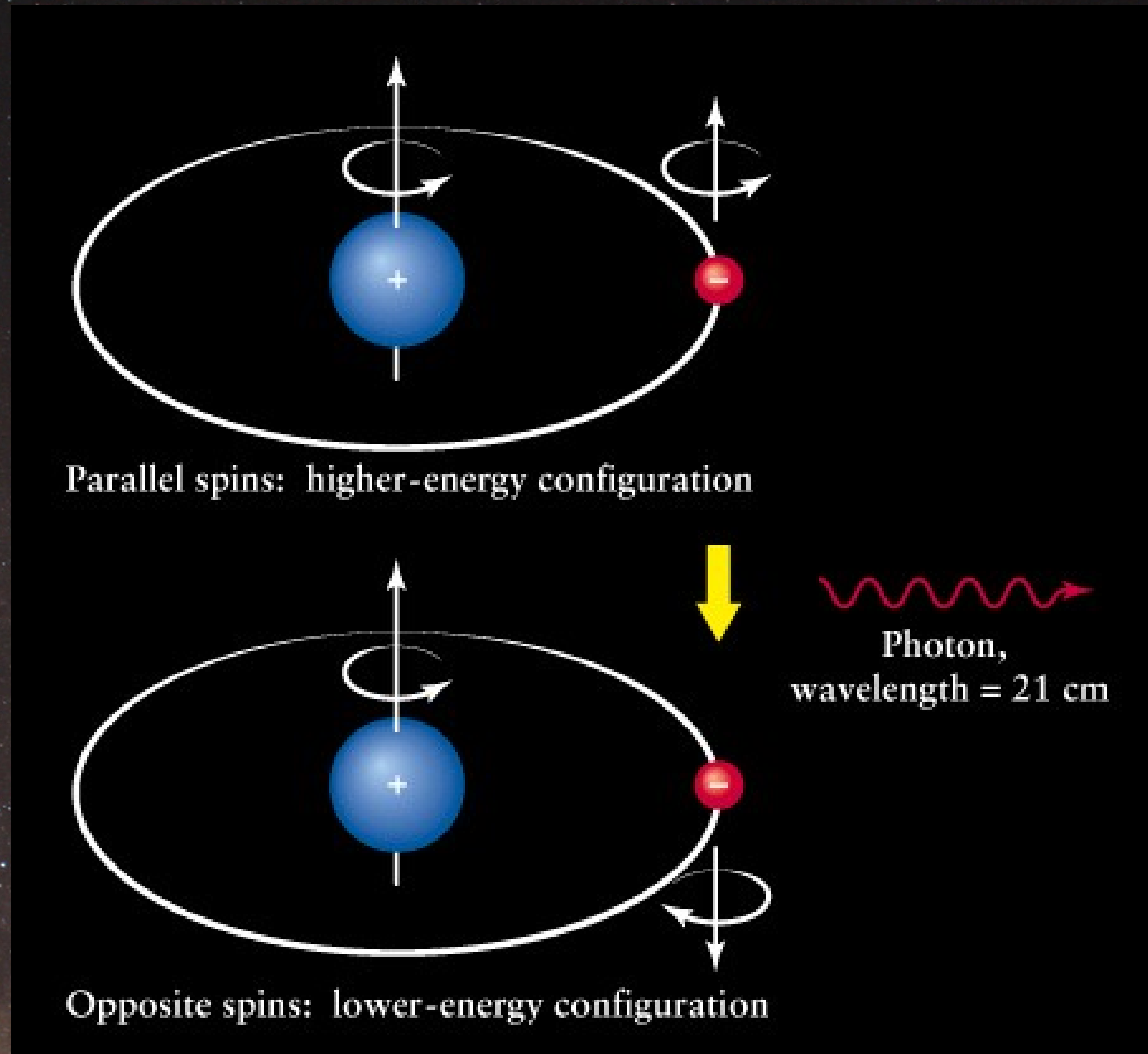
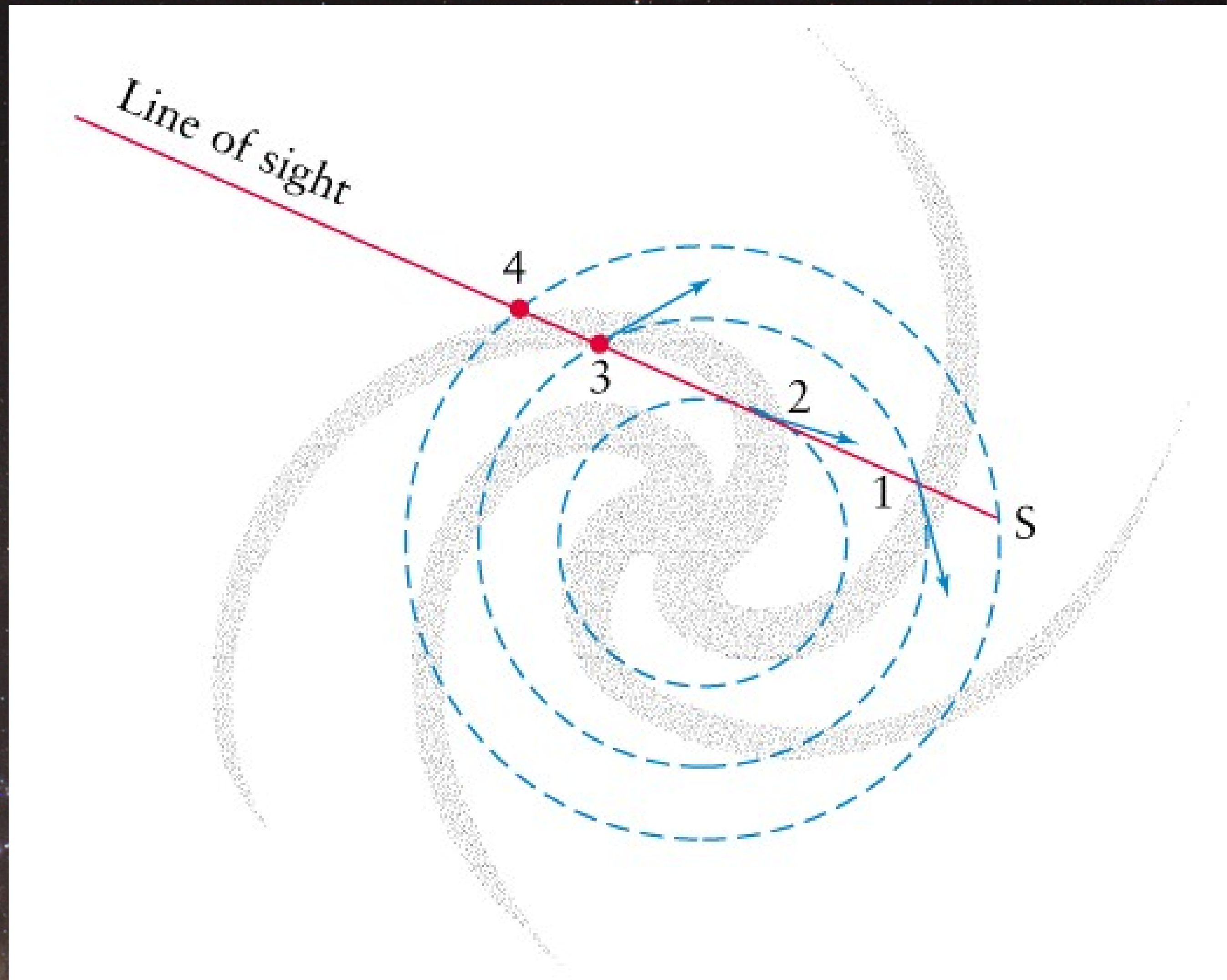


Photo by Marc Staves 2011

The Milky Way

Different spiral arms give different red and blue shifts of 21-cm line



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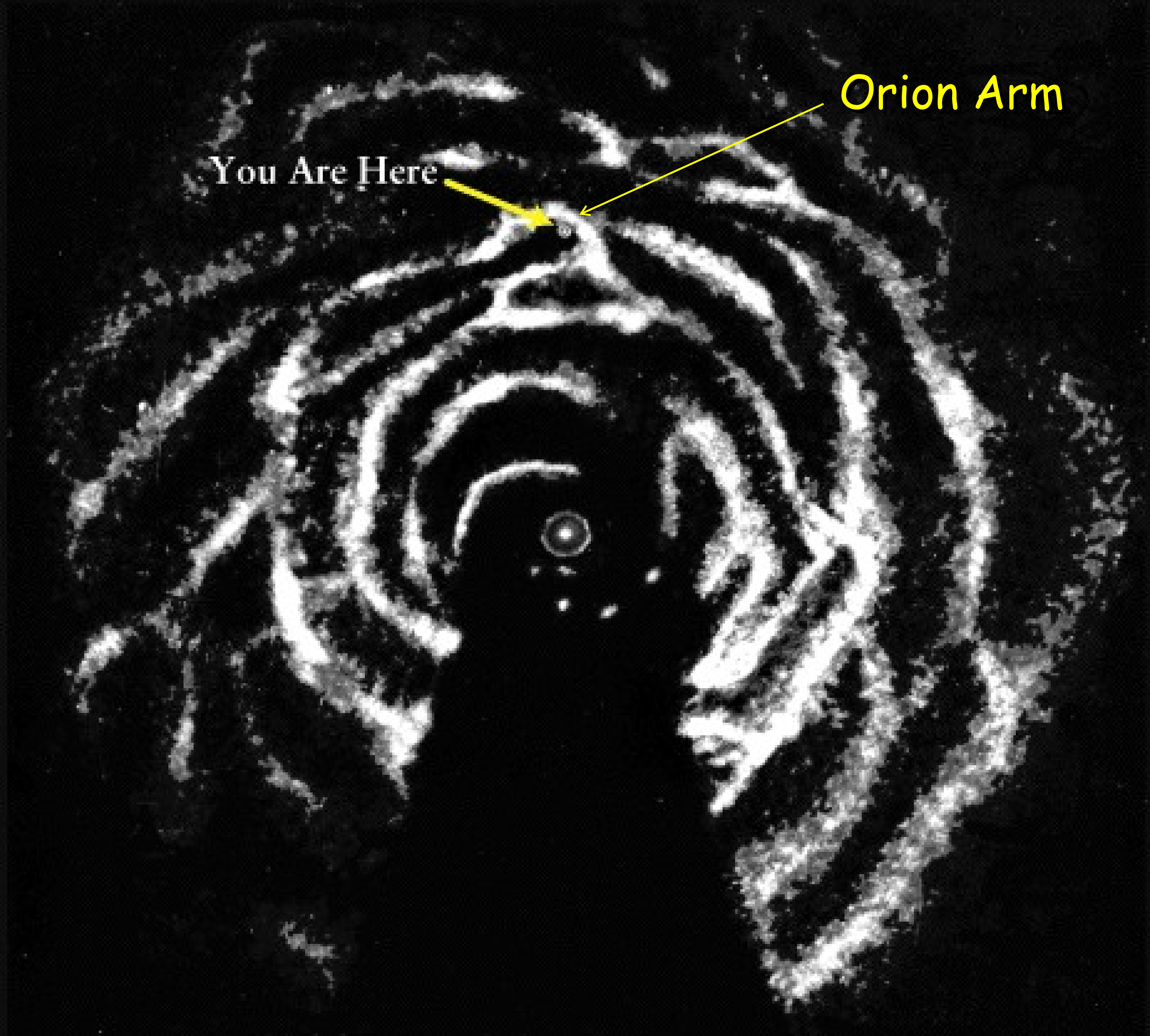
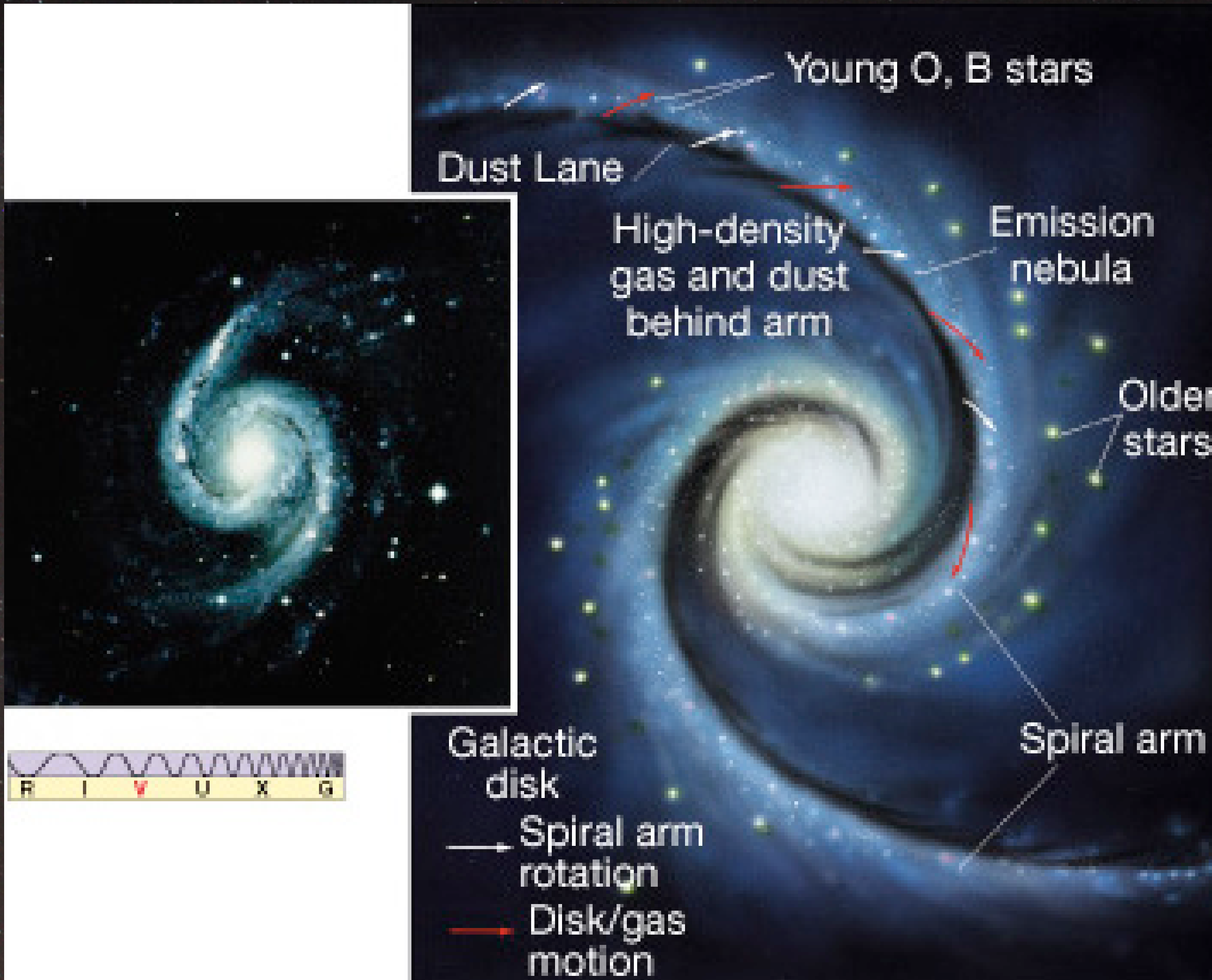
The Milky Way



The Milky Way



Spiral Arms are active!

Photo by Marc Staves 2011

Rotational Velocity of MW

- ☆ Stars not on "Keplerian" orbits
  - Kepler determined solar system orbits
- ☆ Indicates galactic mass in halo …
  - Glowing matter does not supply enough mass!
  - Dark Matter (what?) must be there
    - MACHOs? WIMPs?

Weakly Interacting Massive Particles

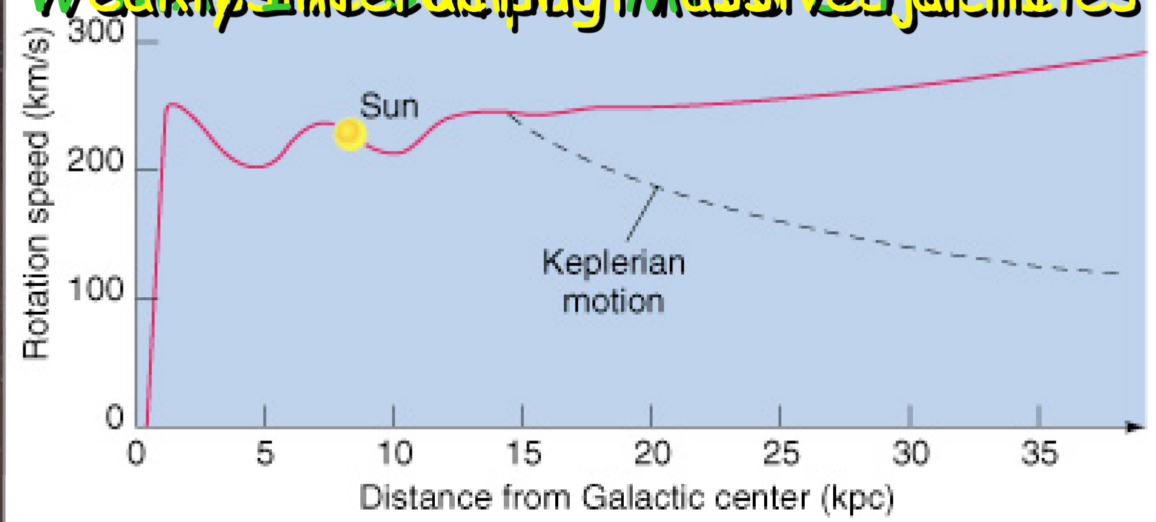
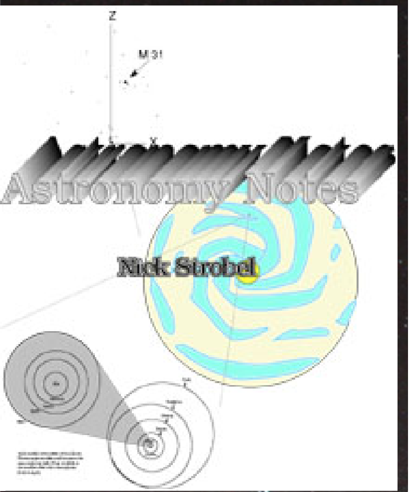


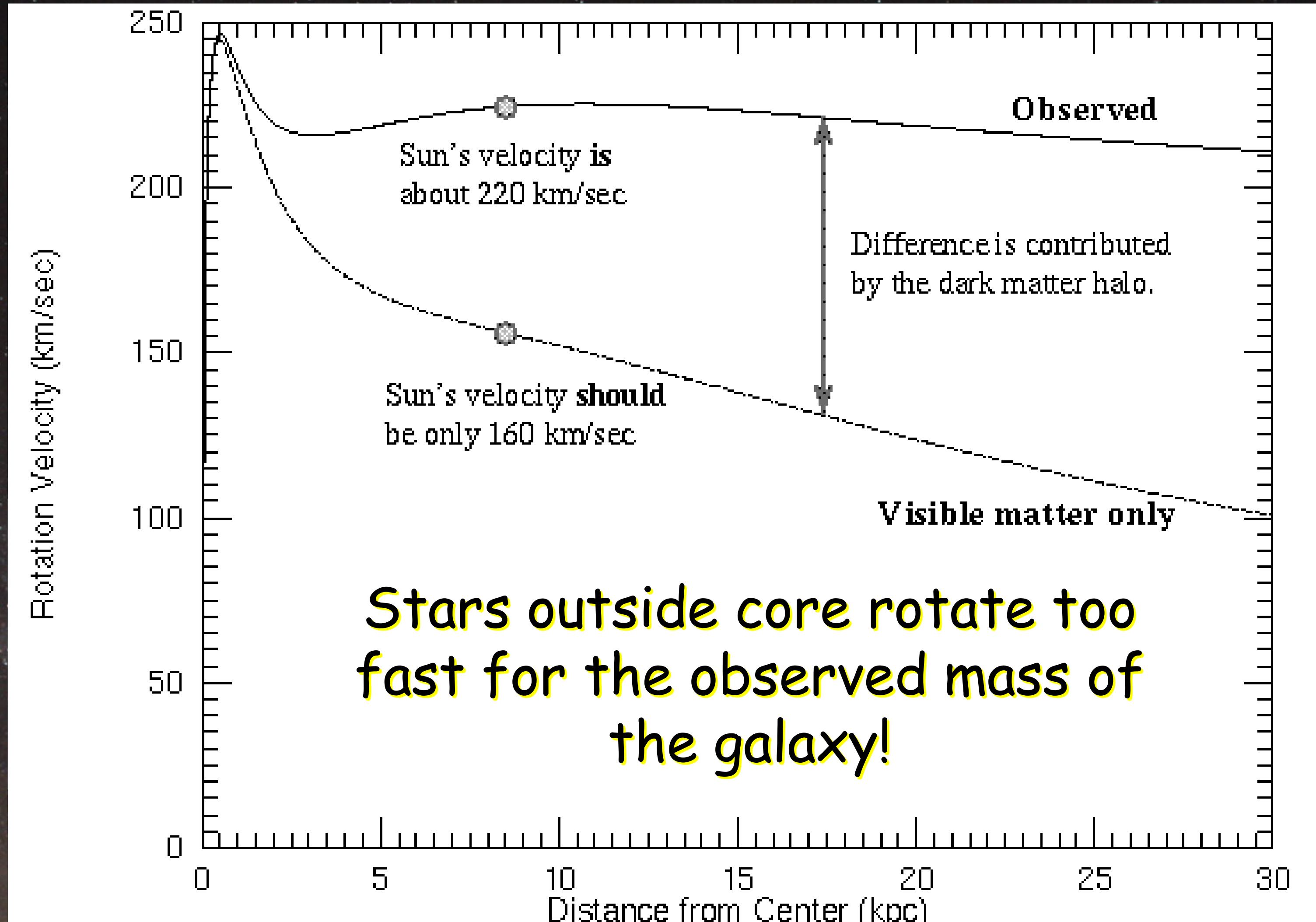
Photo by Marc Staves 2011

Rotational Velocity of MW



Rotation Curve Figures from Nick Strobel's Astronomy Notes at

www.astronomynotes.com



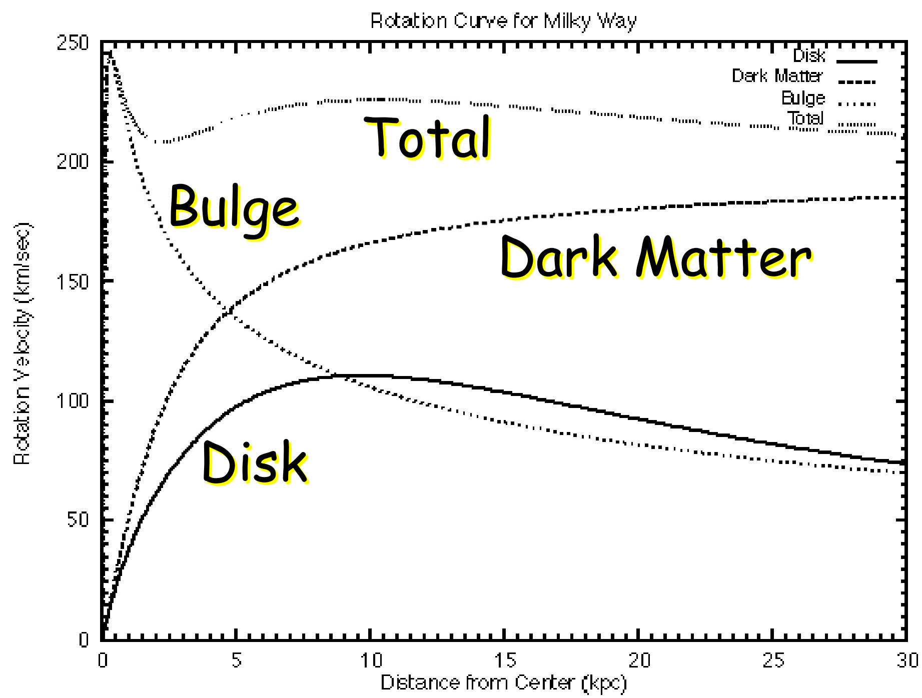
The gravity of the visible matter in the Galaxy is not enough to explain the high orbital speeds of stars in the Galaxy. For example, the Sun is moving about 60 km/sec too fast. The part of the rotation curve contributed by the visible matter only is the bottom curve. The discrepancy between the two curves is evidence for a **dark matter halo.**

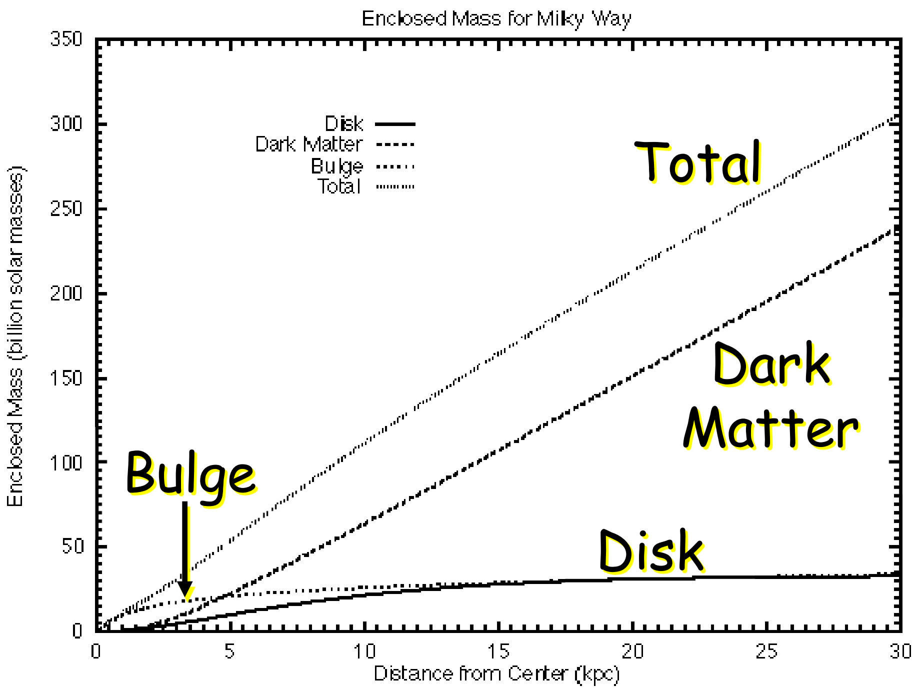
Photo by Marc Staves 2011

Rotational Velocity of MW

☆ Galactic Rotation Curve

- Due to all the matter … bright & dark





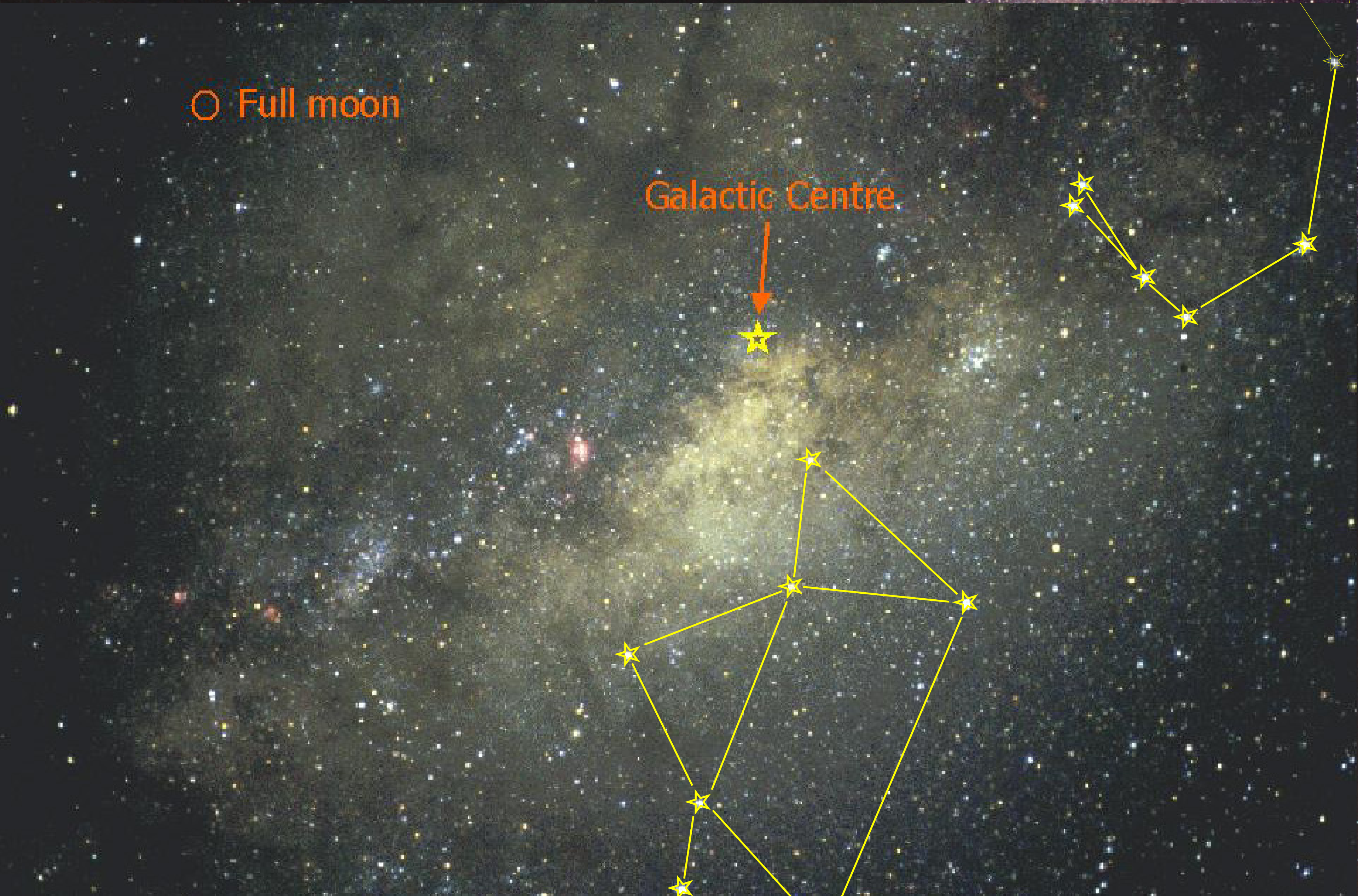
- 90% of galaxy's mass is DARK MATTER!
- 90% of UNIVERSE'S mass is DARK MATTER!

The Galactic Center

- ☆ What is everything orbiting?

Photo by Marc Staves 2011

The Galactic Center

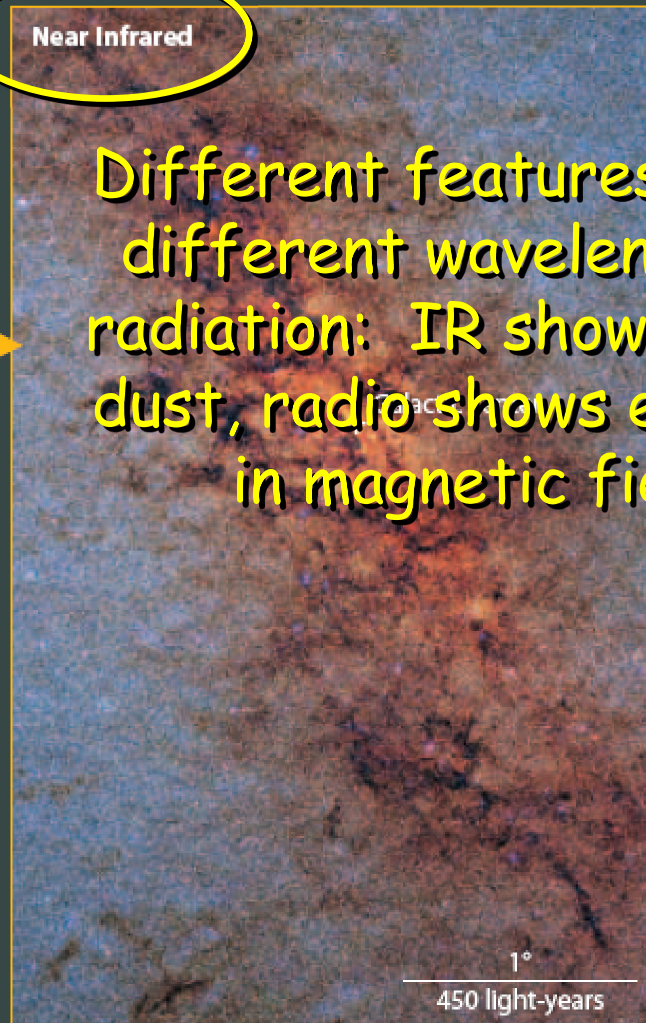


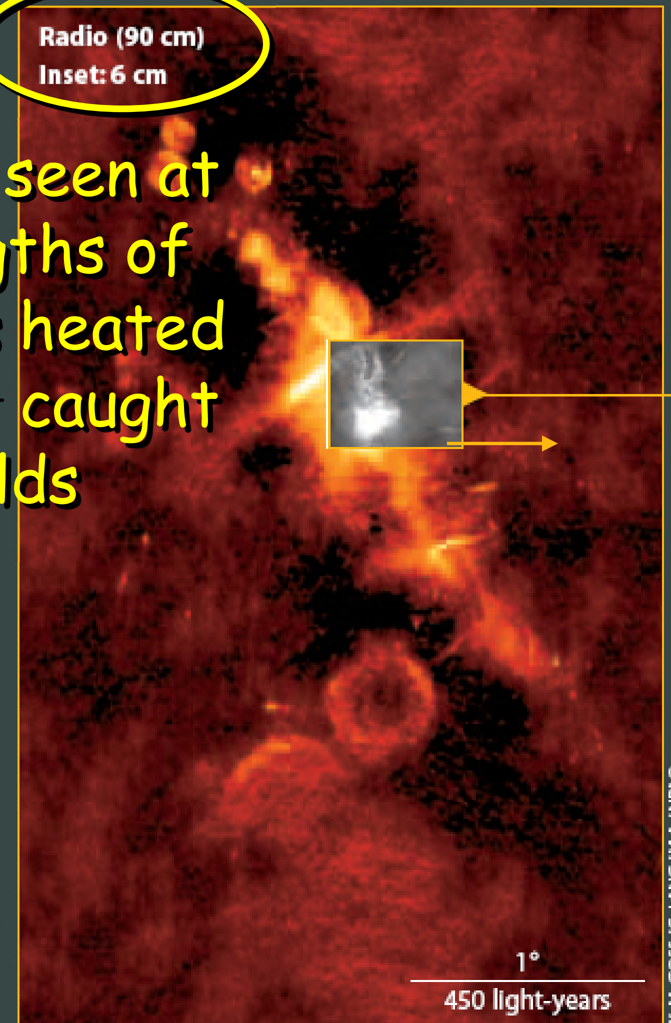
A Trip to the Galactic Center

- Angelle Tanner, Sky & Telescope, April 2003

Photo by M

A Trip to the Galactic Center

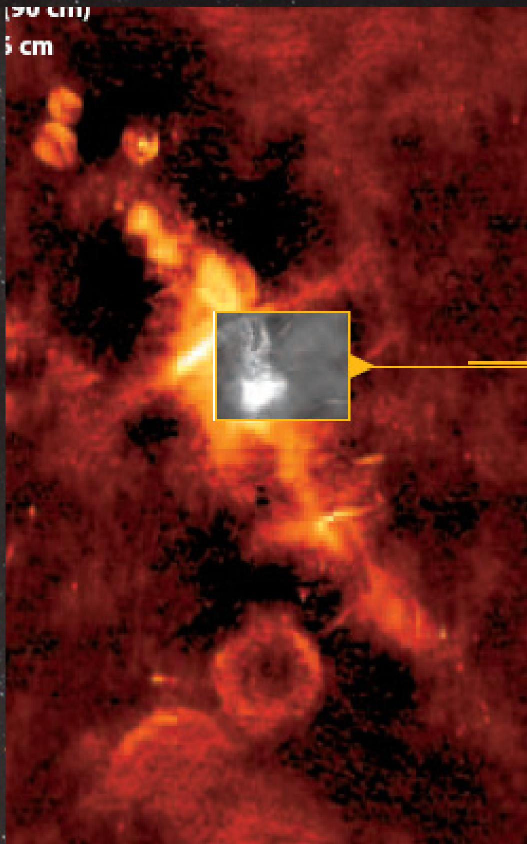


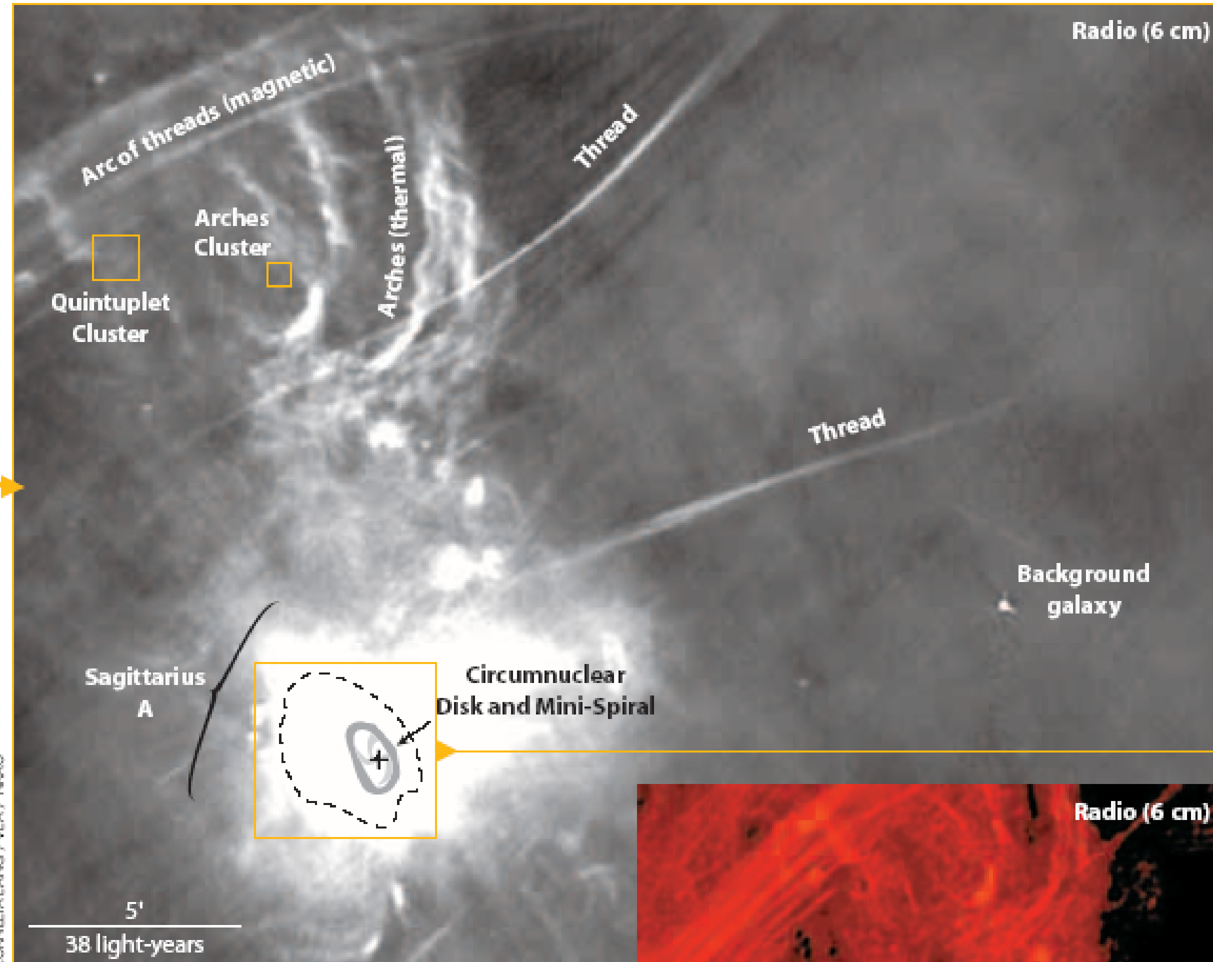


Different features seen at different wavelengths of radiation: IR shows heated dust, radio shows e^- caught in magnetic fields

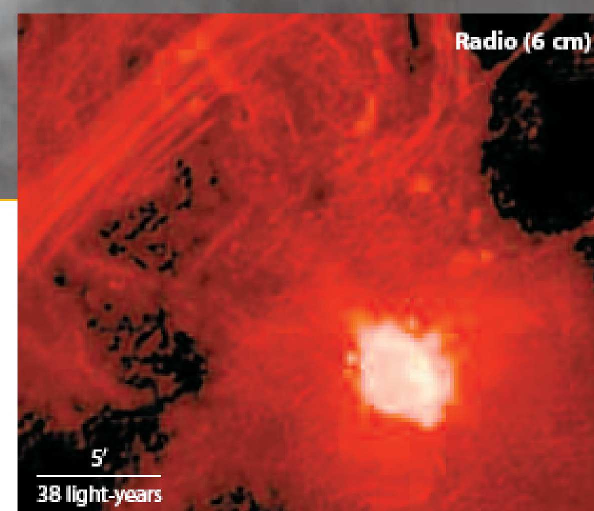
Above, left: Peering through the dust: an infrared view toward the galactic center. This image only hints at the tens of millions of stars filling this 2.8°-wide view. As in all near-infrared color images with this article, blue represents a waveband centered on 1.2 microns, green 1.6 microns, and red 2.2 microns — shifting our normal color vision toward longer wavelengths by a factor of 3. *Above, right:* The same field as at left, imaged at the radio wavelengths of 90 centimeters and *(inset)* 6 cm by the Very Large Array in New Mexico.

A Trip to the Galactic Center





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.



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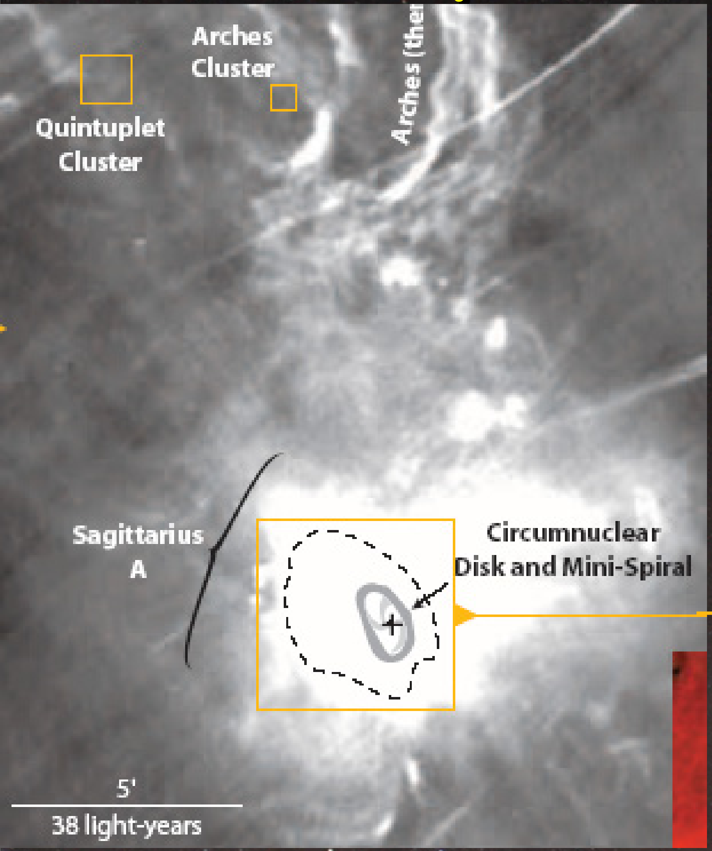
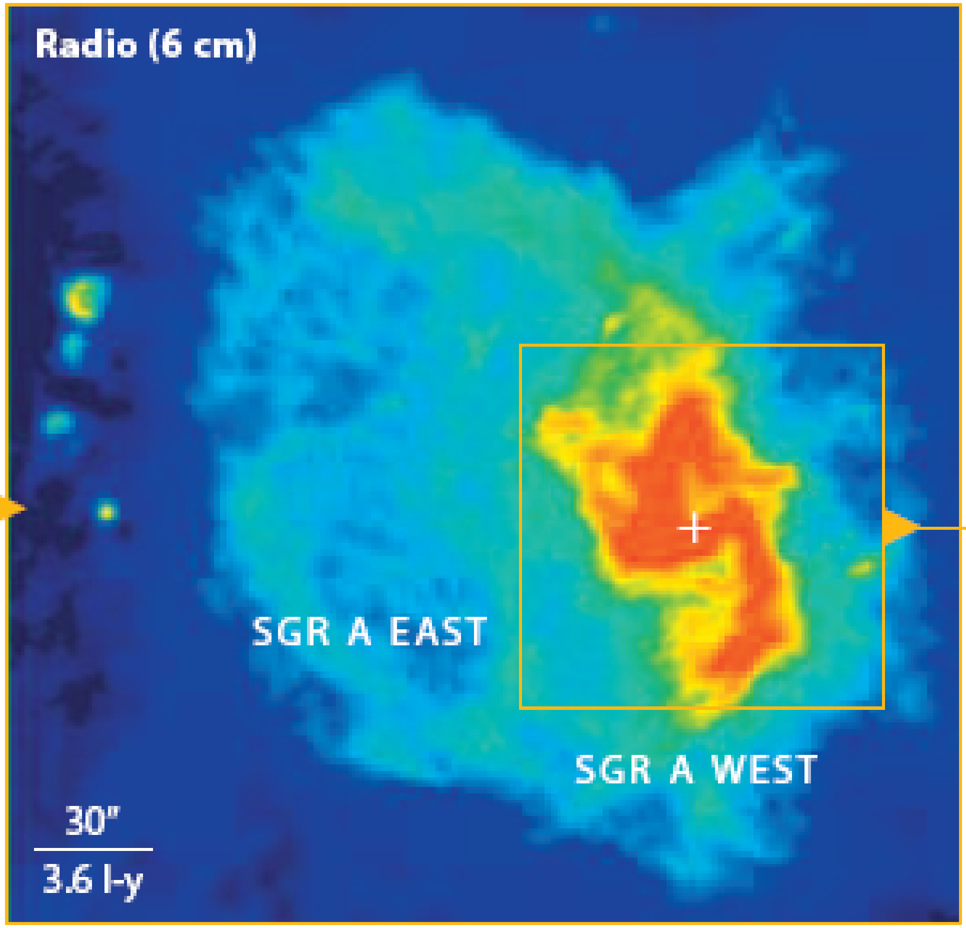
A Trip to the Galactic Center

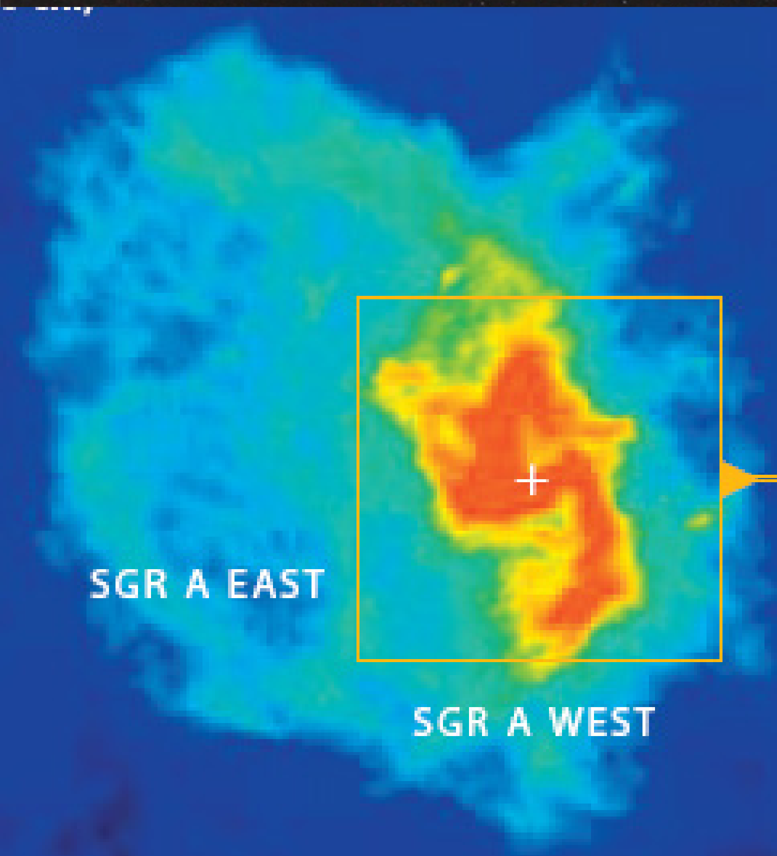


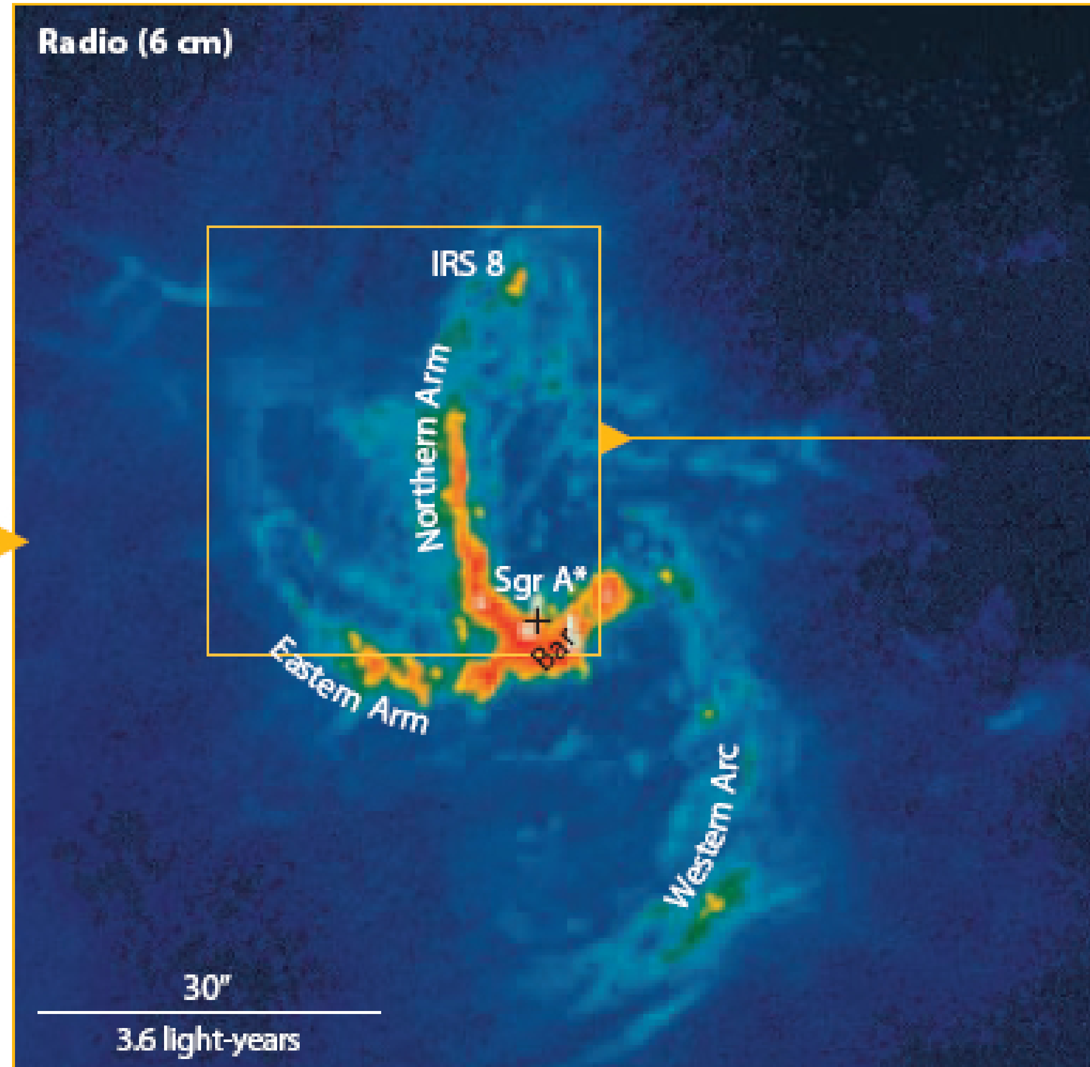


The Sagittarius A bright oval processed to bring out the Mini-Spiral: streams of gas falling the last few light-years toward the central black hole. Courtesy Farhad Yusef-Zadeh, VLA, and NRAO.

Photo by Marc Staves 2011

A Trip to the Galactic Center



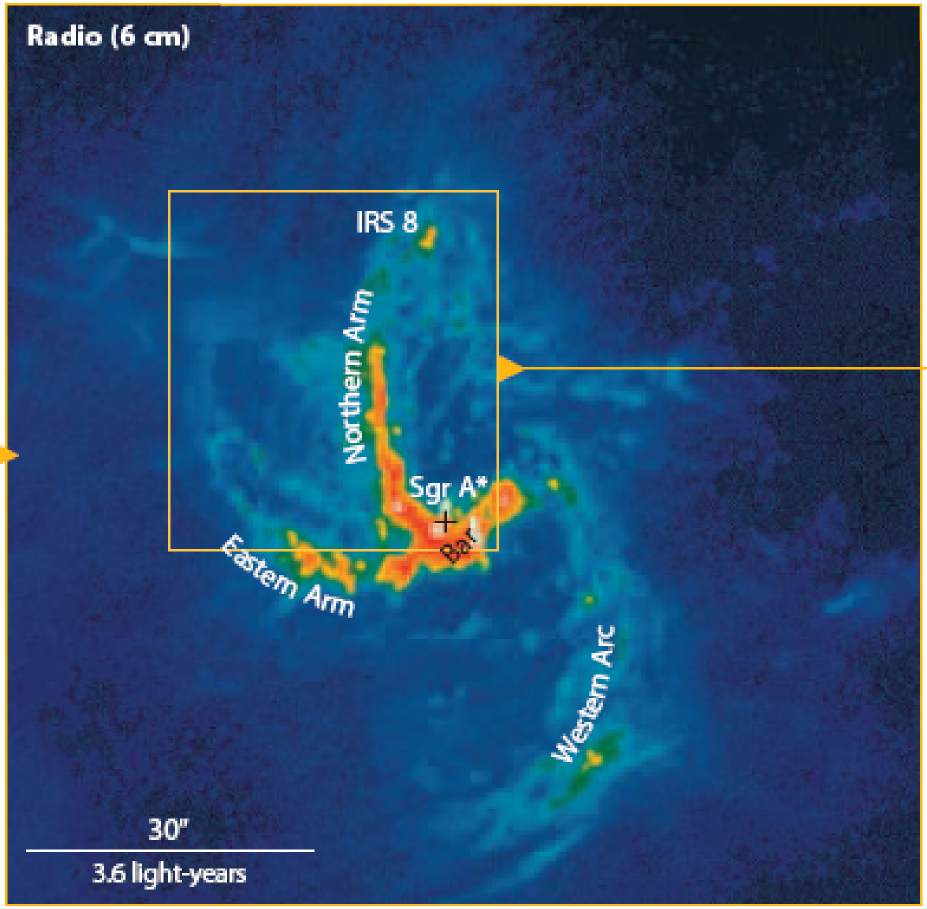


A higher-resolution radio view showing the main components of the Mini-Spiral. Courtesy W. M. Goss, VLA, and NRAO.

Sgr A* is a bright, compact, so far unresolved radio source

Photo by Marc Staves 2011

A Trip to the Galactic Center
Model of the galactic Center



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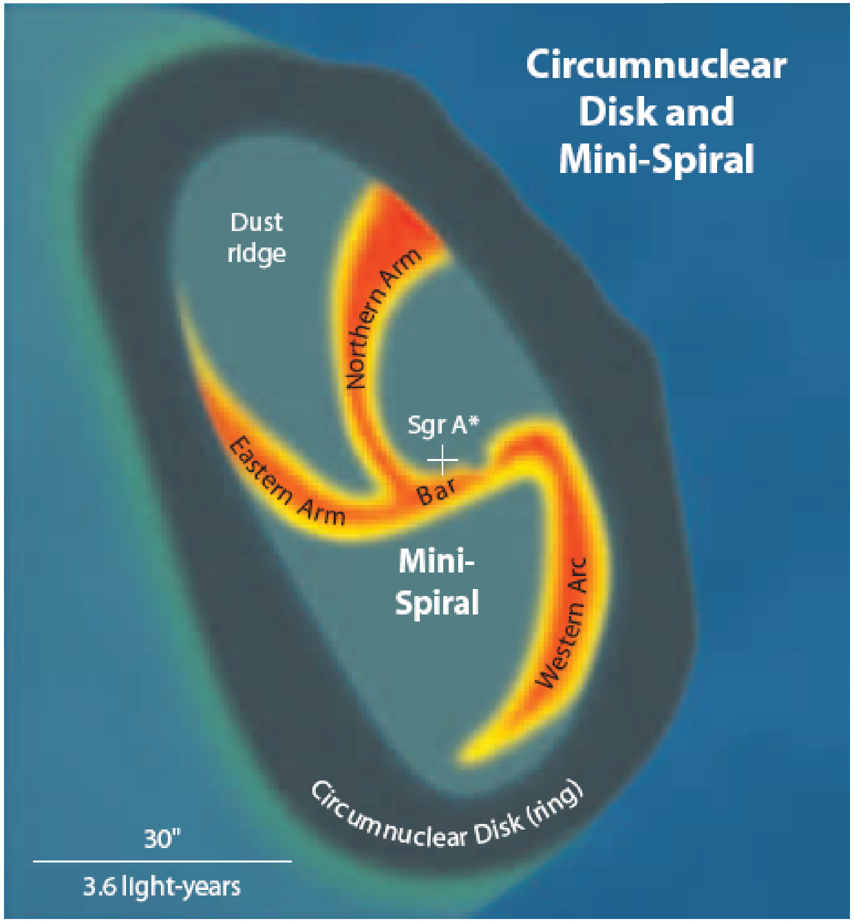
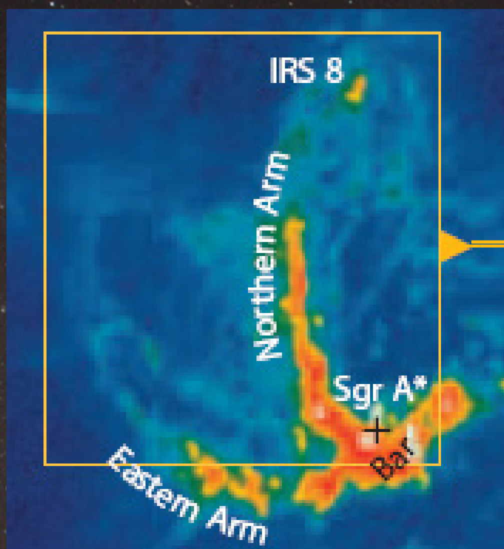


The Circumnuclear Disk, just a few light-years across, encloses and feeds the Mini-Spiral. Gas clouds that collide in the disk should lose orbital momentum, allowing parts of them to fall inward.

Photo by Marc Staves 2011

A Trip to the Galactic Center

Right: 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.



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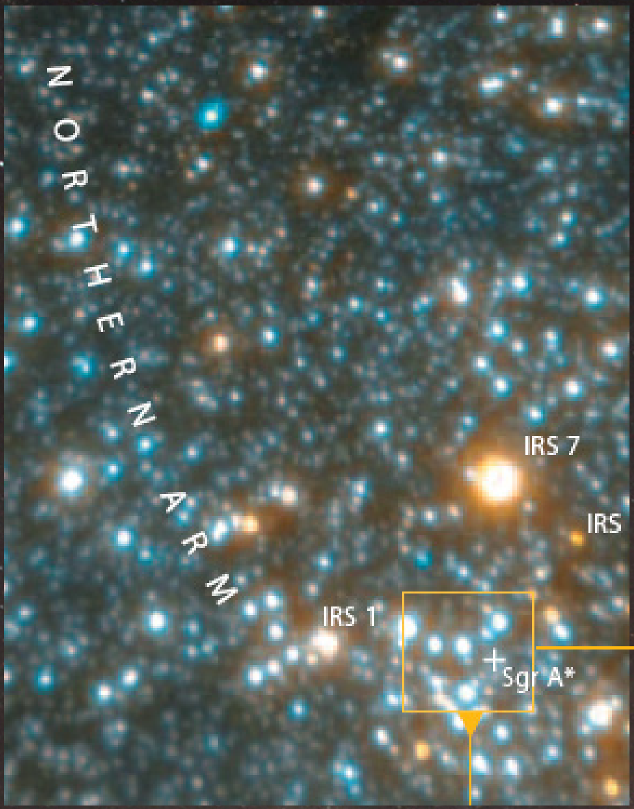
A Trip to the Galactic Center

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.



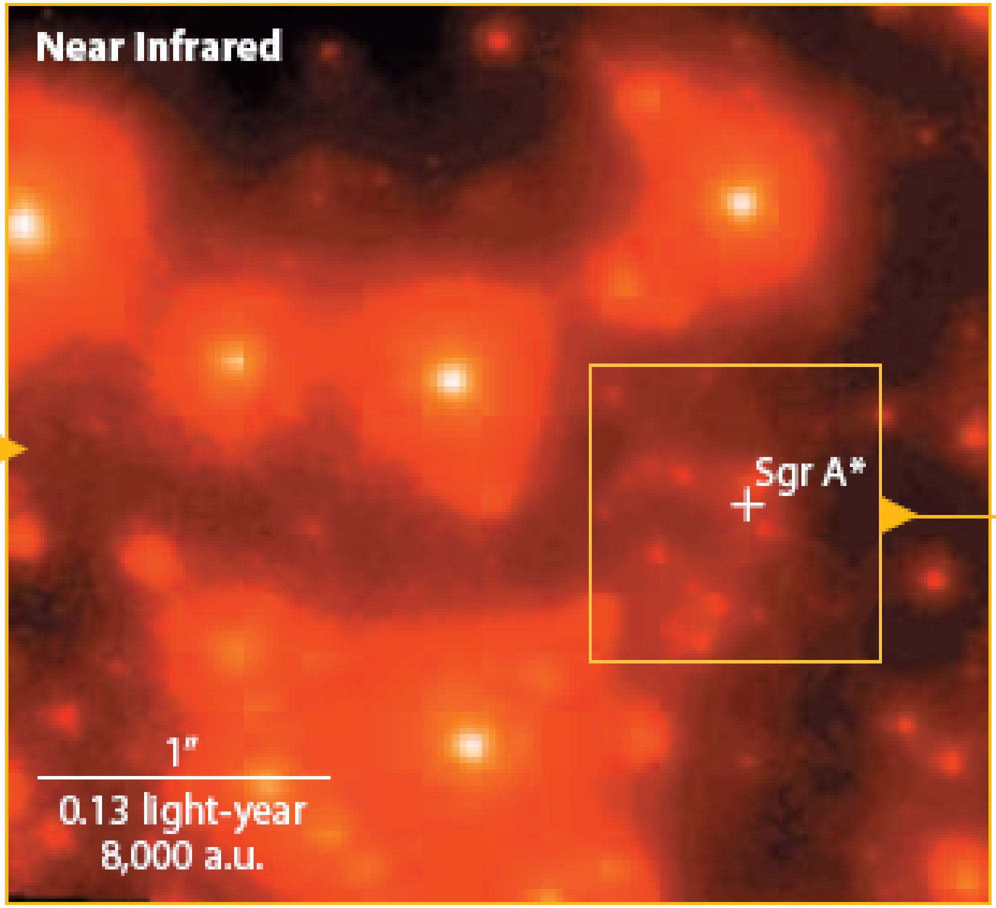
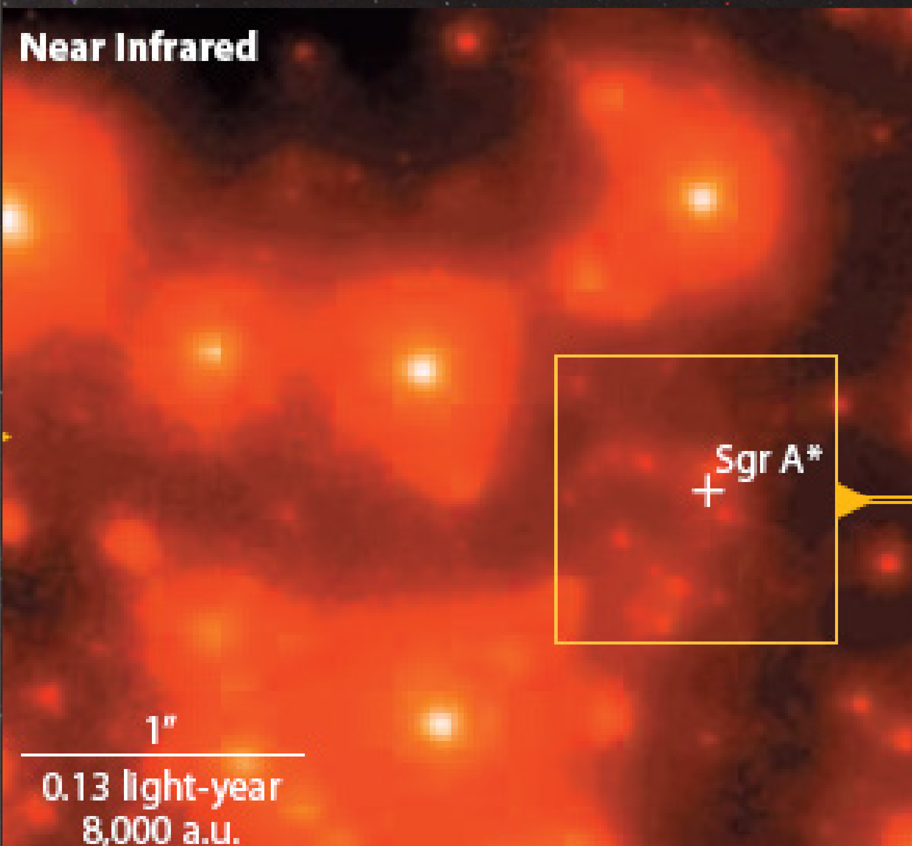


Photo by Marc Staves 2011

A Trip to the Galactic Center

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.



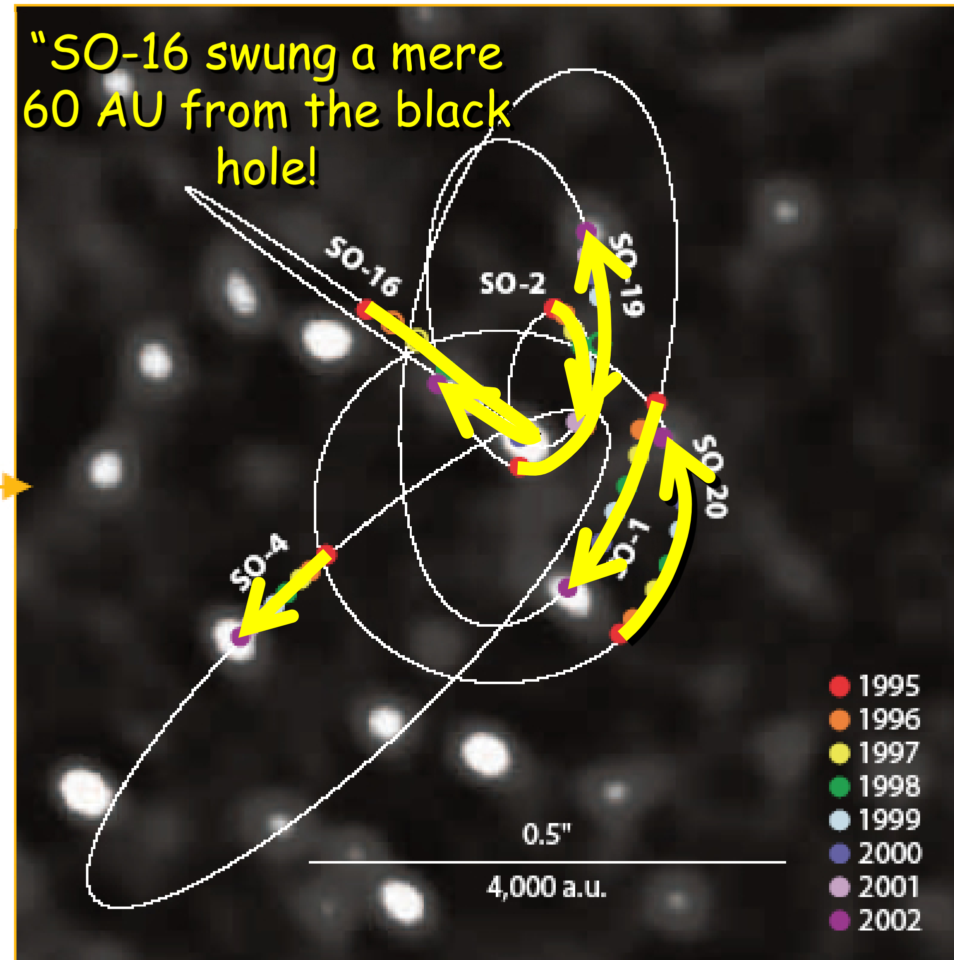
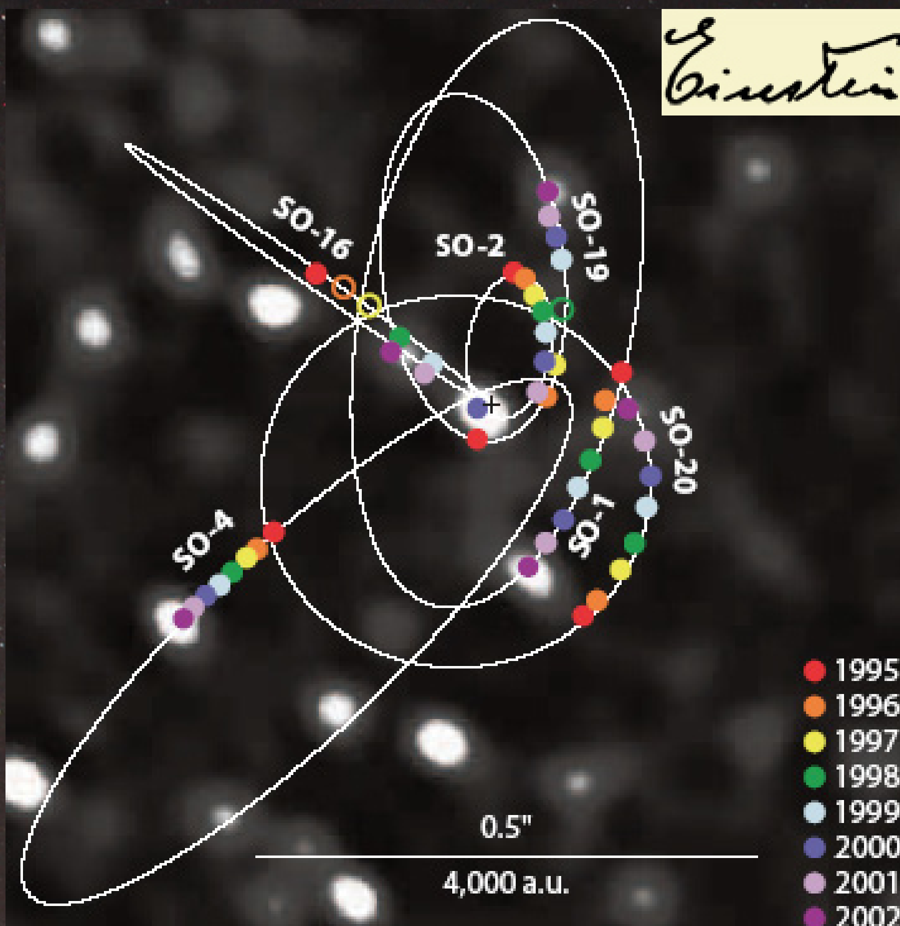
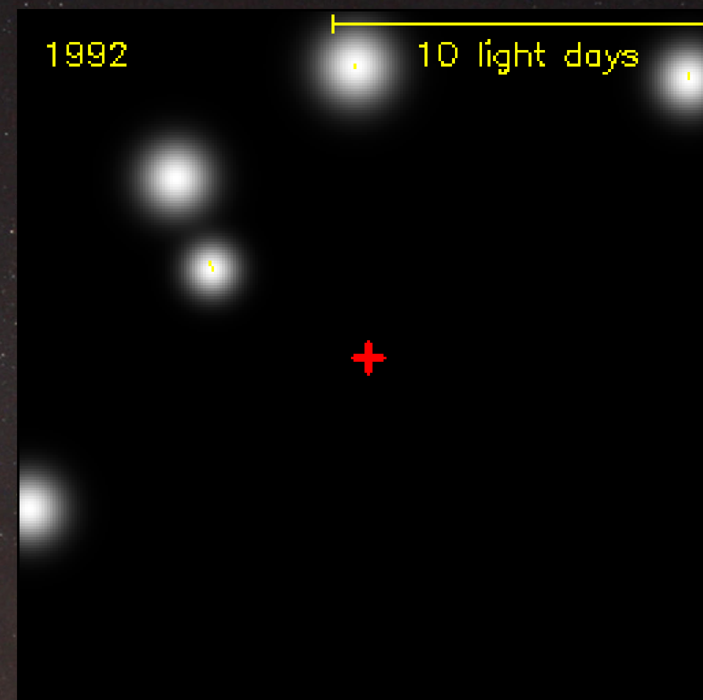


Photo by Marc Staves 2011

A Trip to the Galactic Center

Mass needed in center of orbits = 2.6 million times the mass of Sol!





https://phys.org/news/2017-08-stars-orbiting-supermassive-black-hole.html

A Trip to the Galactic Center

Mass needed in center of orbits = 2.6 million times the mass of Sol!

16-year-long study tracks stars orbiting Milky Way black hole

Photo by Marc Staves 2011

A Trip to the Galactic Center

Gas cloud ripped apart falling into black hole.

Position of cloud changing … shape can't be discerned