

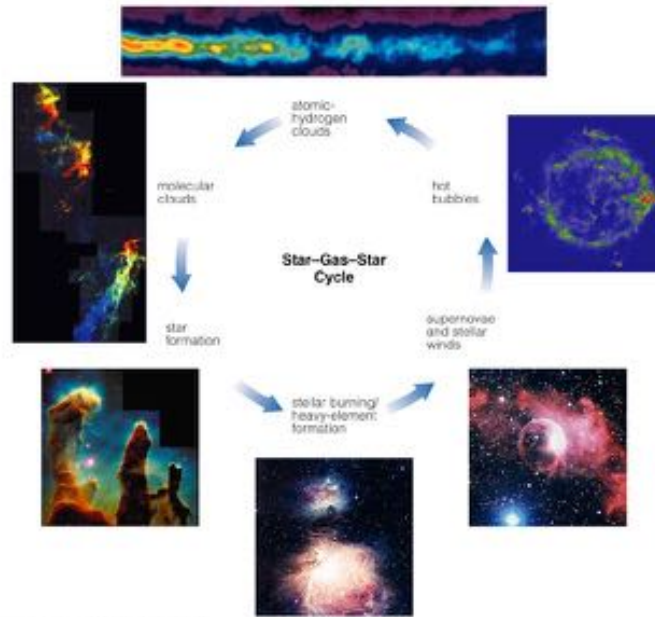
Last time: More bizarre endings - black holes etc.

- gravity's ultimate victory: black holes
- finding black holes by their influence on their surroundings
- black hole phenomenology and general relativity in action

Today: The Milky Way Galaxy

- Stars, gas, dust, cluster are all part of the Milky Way Galaxy
- The MW Galaxy has neighborhoods, populations, etc. that belie the history of its formation and evolution
- the structure of the Milky Way - nucleus, halo, and spiral arms
- we know the mass of the Milky Way by mapping the orbits of stars, clusters, and clouds around the galactic center
- ours is a 'spiral' galaxy with spiral arms that are shaped by complex dynamics



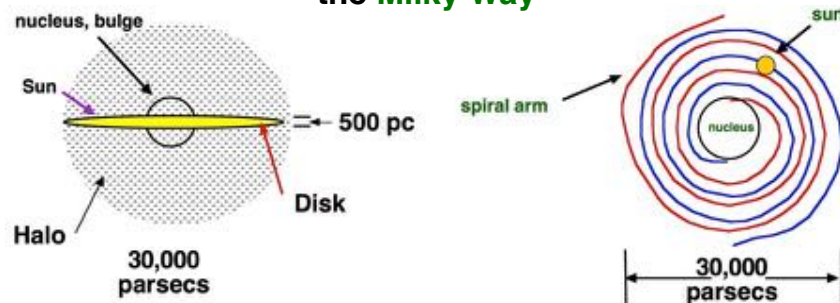


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We've now studied:

- stars
- star clusters
- molecular clouds (stellar nurseries...)
- interstellar gas (HI, HII, ...) and dust
- stellar corpses (white dwarfs, neutron stars, ...)

**All are components of our GALAXY:
the Milky Way**





Views of Spiral Galaxies



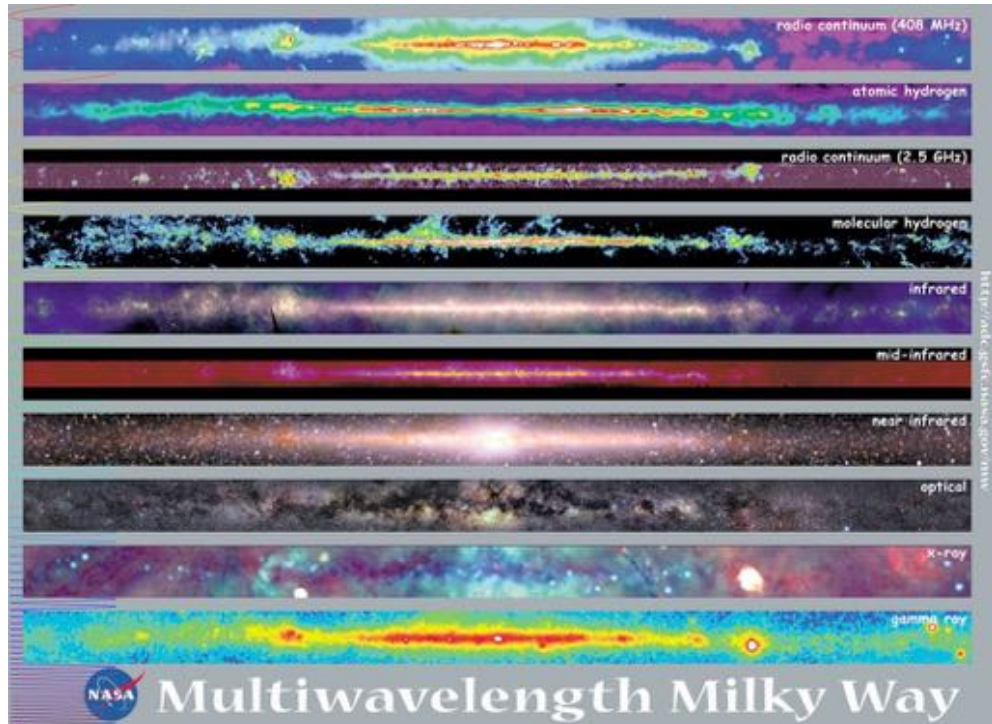
Views of our Milky Way

Optical



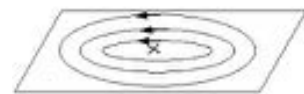
Infrared
(COBE)





Stellar Populations in the Milky Way

- **Population I - Stars in the Disk**
 - massive stars (open clusters)
 - orbit within disk of galaxy
 - “metal” abundance same as Sun or more
- **Population II - Stars in the Halo**
 - very low metal abundances
 - orbits way out of galactic plane
 - low mass stars (globular cluster)
- **Populations as clues to the formation of the Milky Way**
 - **Pop II stars: relics of earliest star formation in the M.W.**
MOTION: initial collapse of the Galaxy
LOW METALS: primordial (uncooked) material
 - **Pop I Stars: more recently formed**
HIGH METALS: stars formed from debris of older stars



Population I stars: ordered motion
Circular orbits in the disk plane;
younger, more metal-rich.

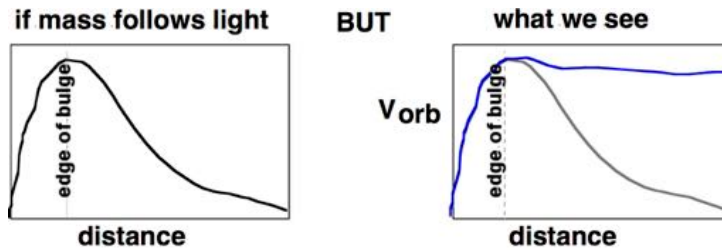


Population II stars: random motion
Eccentric orbits passing through disk
plane; older, more metal-poor.

Probing the structure of the Galaxy:

Galactic Rotation

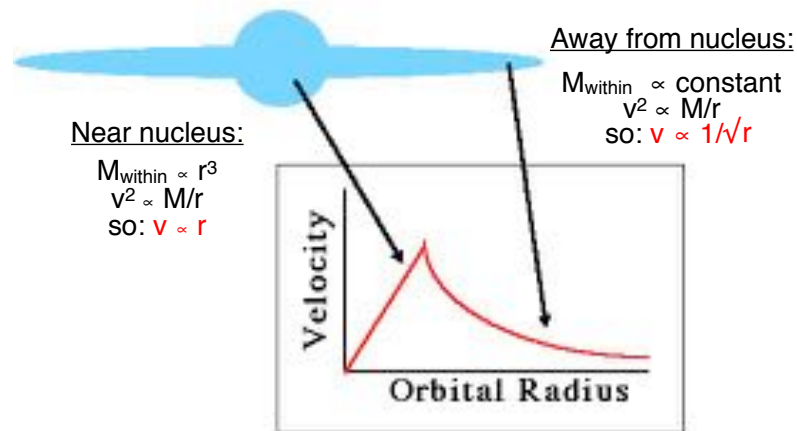
- **differential rotation**
 - inner parts rotate faster than outer parts
- orbital period of Sun: 230,000,000 years
 - the Sun is 20 galactic years old
- distance to MW center: 8,500 pc
- **Mass of Milky Way (via Kepler's Laws): $10^{11} M_{\text{sun}}$**



the 'dark matter' issue

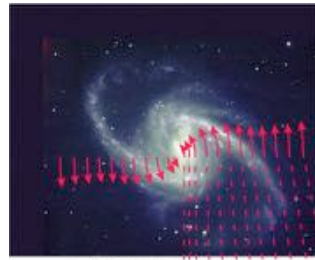
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"Expected" Galactic Rotation Speeds

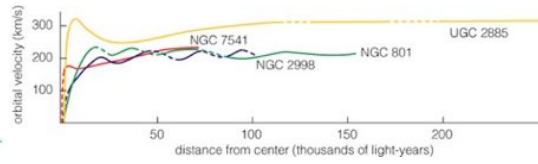
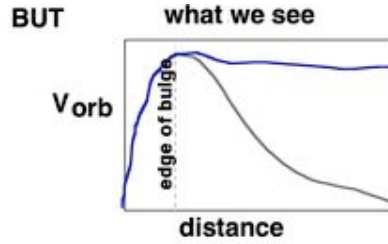
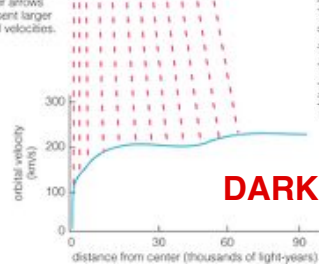


the 'dark matter' issue

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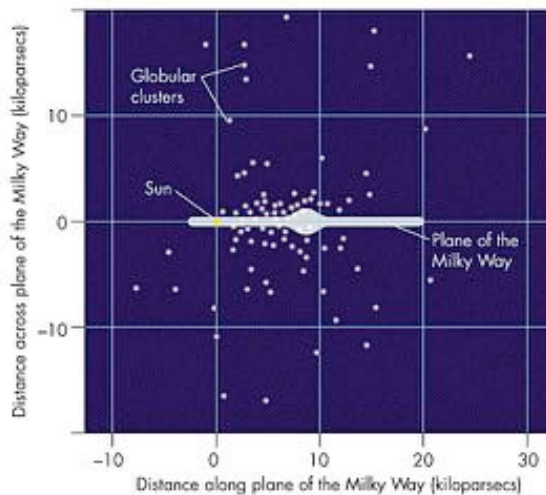
Longer arrows represent larger orbital velocities.



DARK MATTER = 90% of galaxy mass

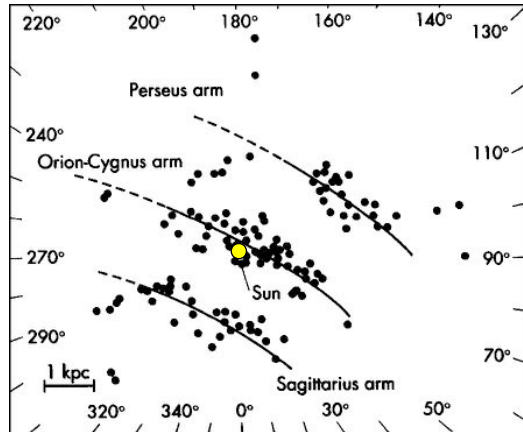
Tracing the structure of the Milky Way

- **Globular clusters**: spherical halo of old stars



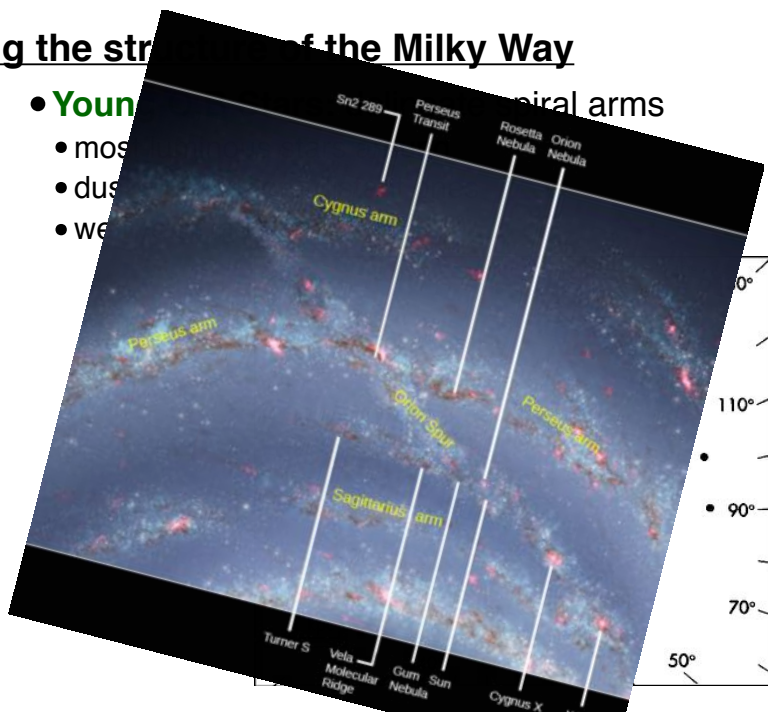
Tracing the structure of the Milky Way

- **Young O,B Stars:** delineate spiral arms
 - most luminous stars around
 - dust blocks more distant ones
 - we live in the “Orion Arm”



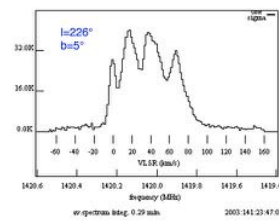
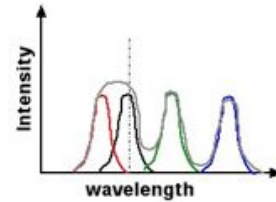
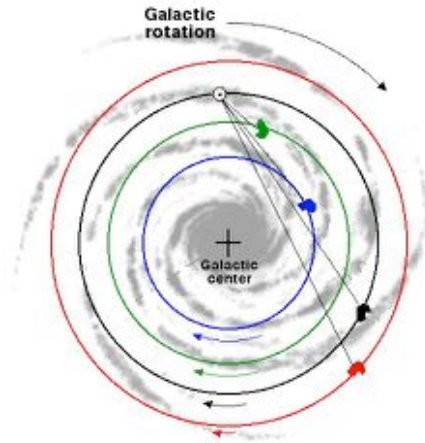
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Tracing the structure of the Milky Way

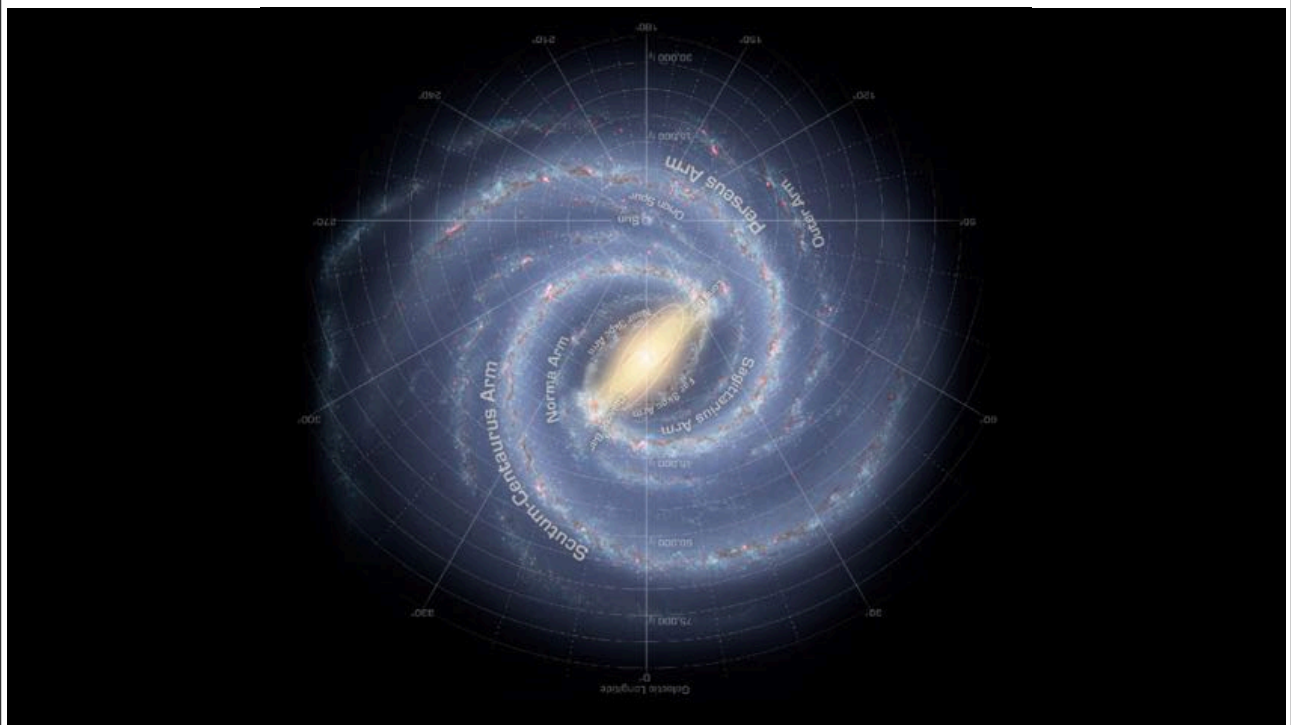
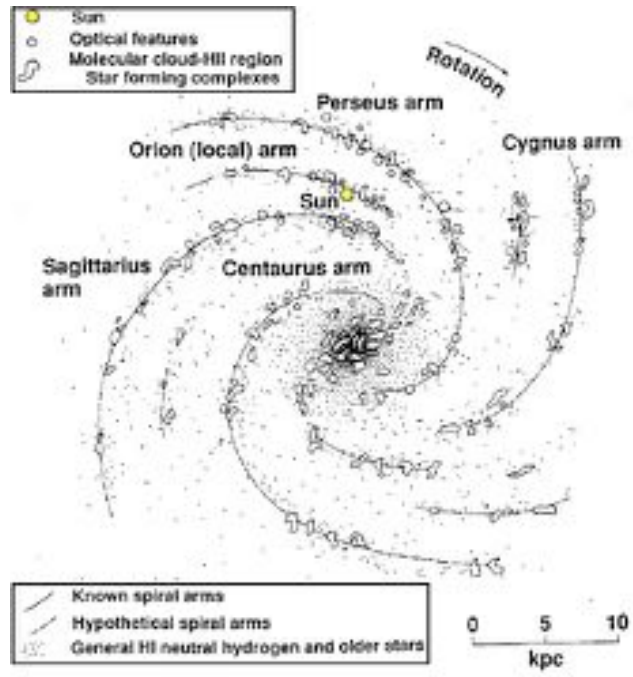
- HI 21cm and Molecular Cloud maps
- Each line-of-sight has many clouds at different distances
- Use differential rotation of galaxy to estimate:
 - cloud distance using radial velocity



Tracing the structure of the Milky Way

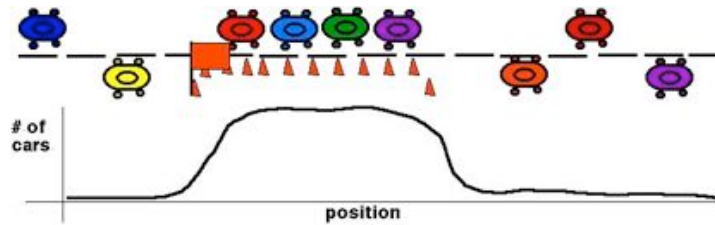
- HI 21cm and Molecular Cloud maps
- IR, Radio mapping
- differential rotation to get distances



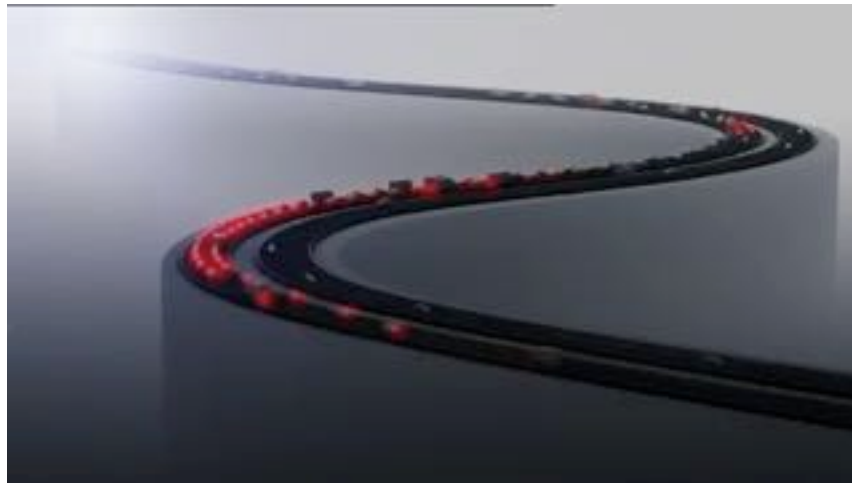


What keeps spiral galaxies spiral?

- Age of Galaxy:
 - ~ 12 billion years
 - ~ 50 galaxy rotations
- differential rotation: arms would have **wound up** long ago
- youngest stars found in arms...
- **Arms must be *fixed patterns* through which stars move.**
- **Spiral Density Wave Theory:**

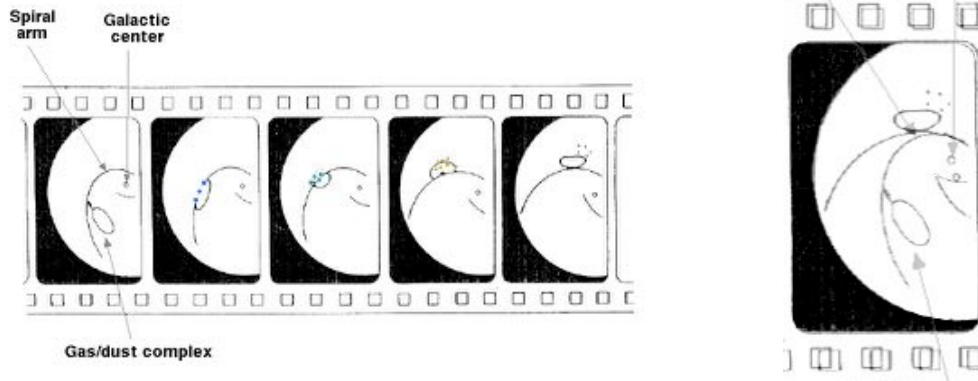


no obstruction needed...

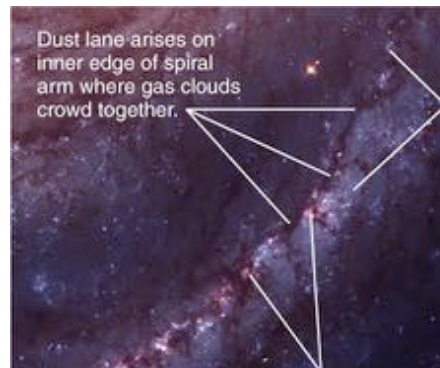
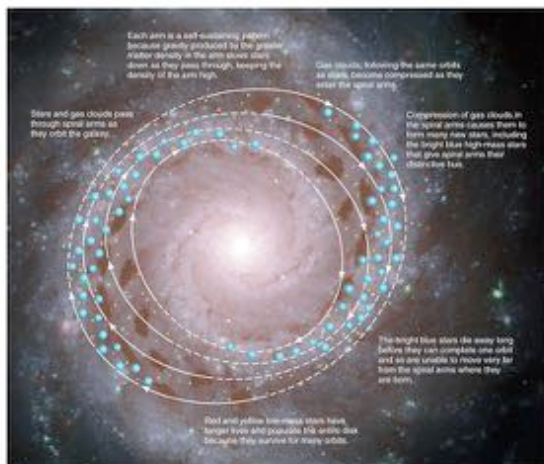


Spiral Density Waves

- Arms must be fixed patterns through which stars and gas move.
- Localized density increase → enhanced star formation

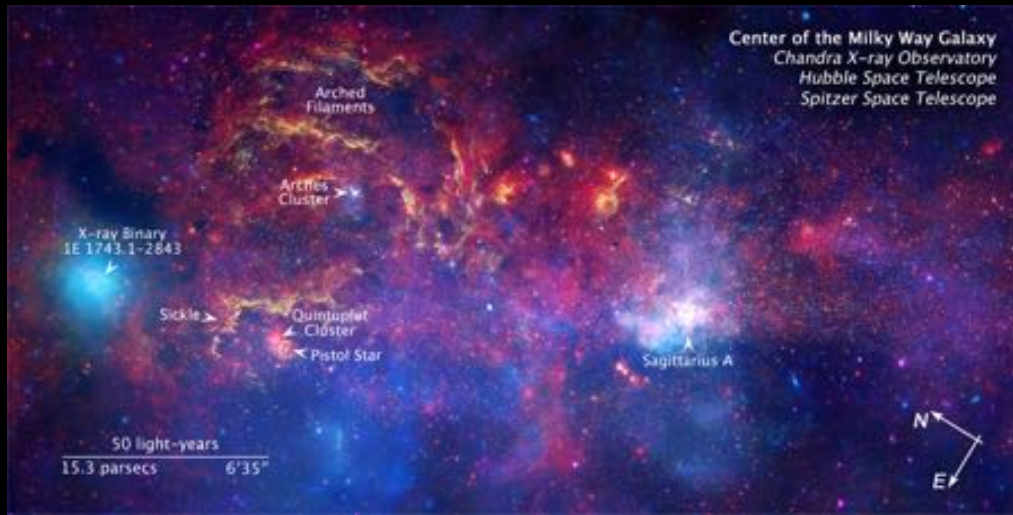


Spiral Density wave - close-up

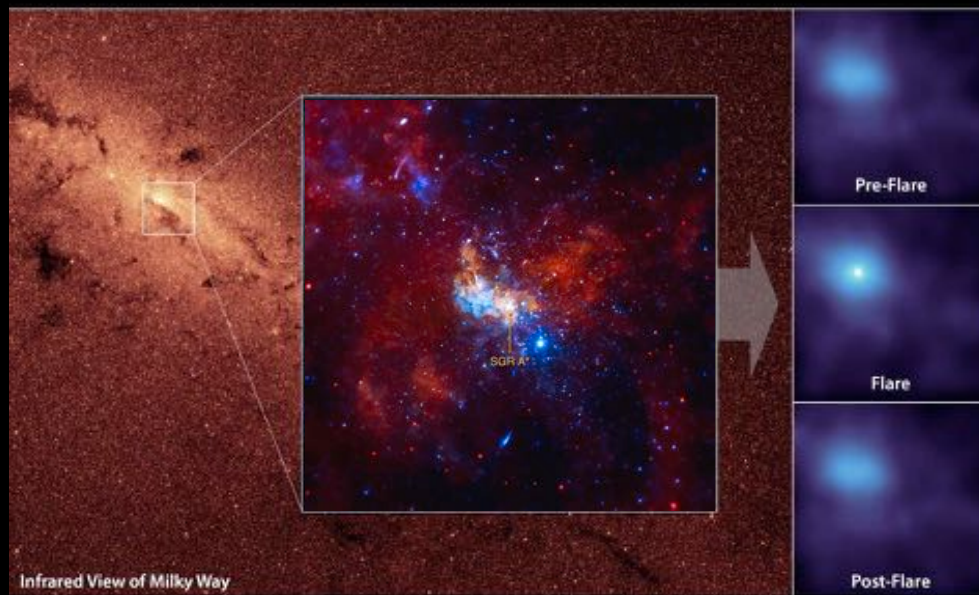


Ionization nebulae arise where newly forming blue stars are ionizing gas clouds.

Massive black hole in MW center



X-Ray, Optical, and IR
APOD - 11/11/09



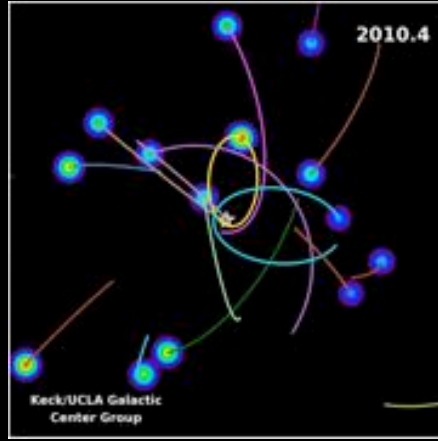
NuStar & Chandra- observations of a flare in the MW center

Massive black hole in MW center
 $3 \times 10^6 M_{\odot}$

2020 Nobel Prize
in Physics:
Andrea Ghez



IR view from ESO



IR -adaptive optics, Keck

