

# **Astr 102: Introduction to Astronomy**

Fall Quarter 2009, University of Washington, Željko Ivezić

## **Lecture 13:**

# **Our galaxy, the Milky Way**

# Outline

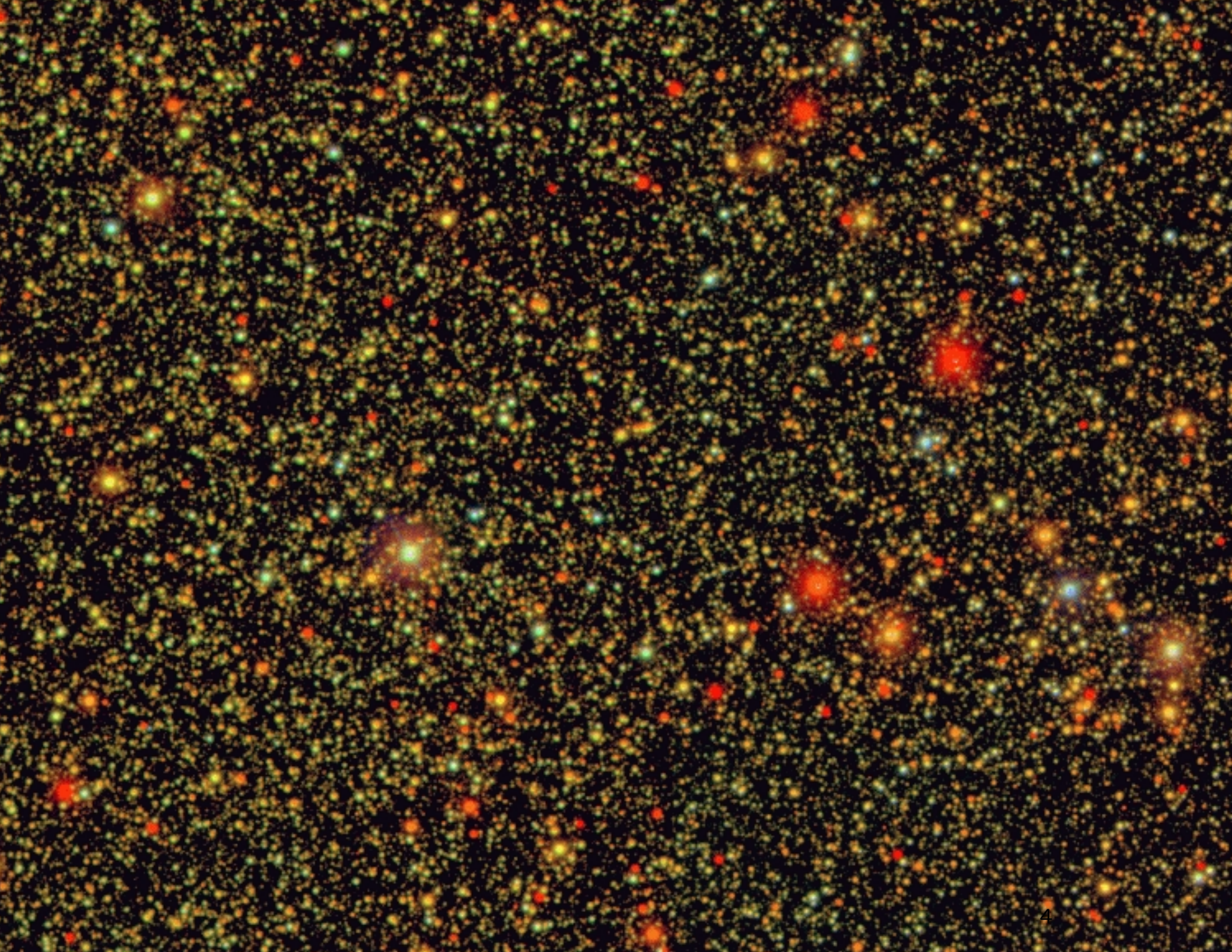
- **Spatial distribution of stars:** disk, halo, bulge
- **Interstellar medium:** gas and dust
- **Stellar kinematics:** rotation vs. random motions
- **Black hole in the center:** kinematic evidence

## **Good Milky Way sites:**

<http://seds.lpl.arizona.edu/messier/more/mw.html>

<http://www.space.com/milkyway>

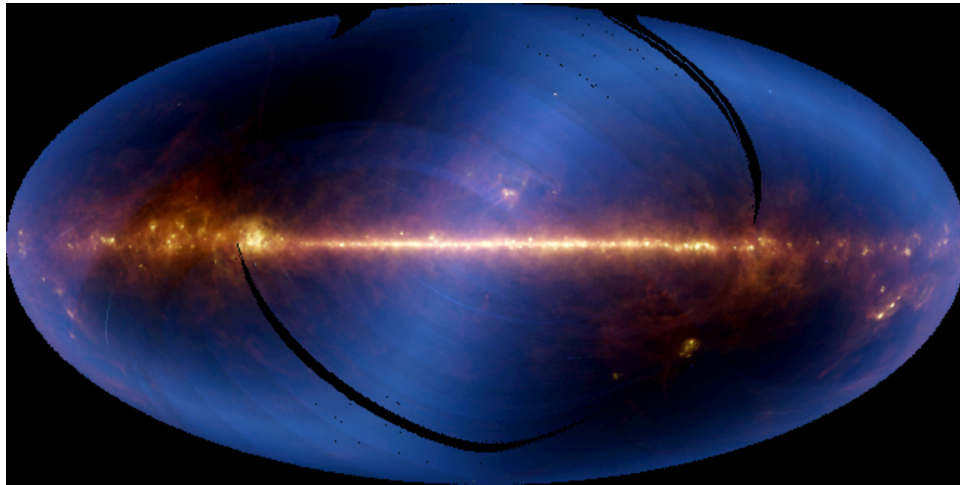
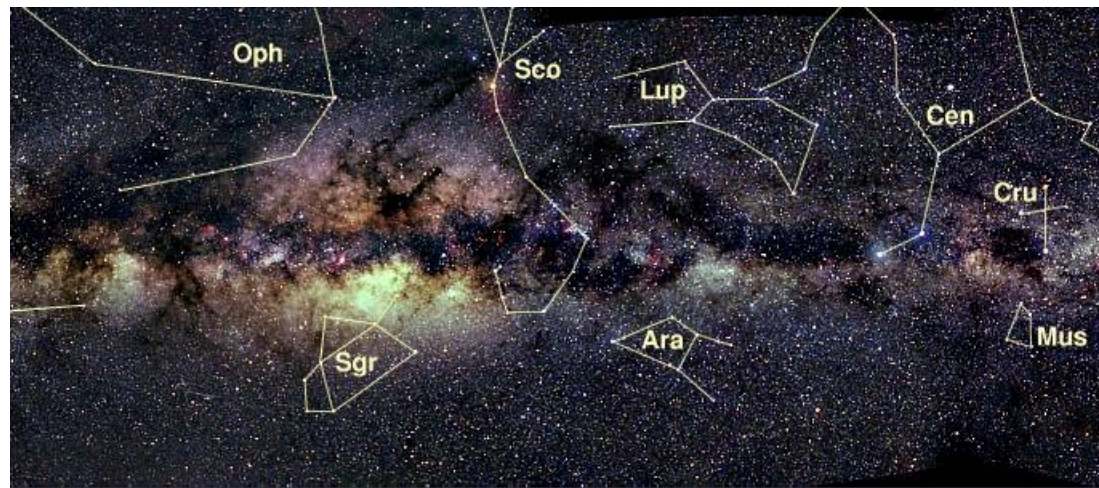


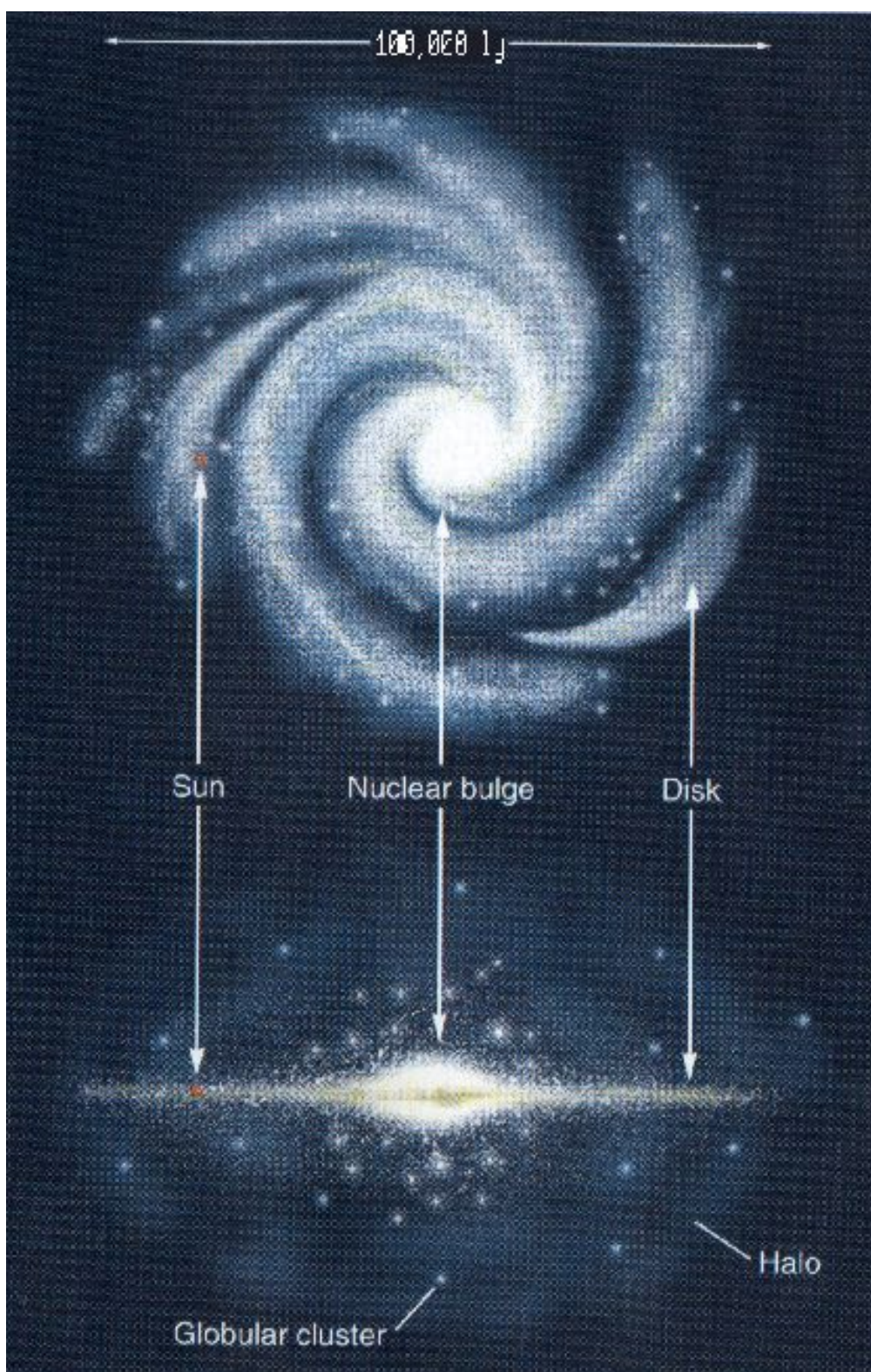




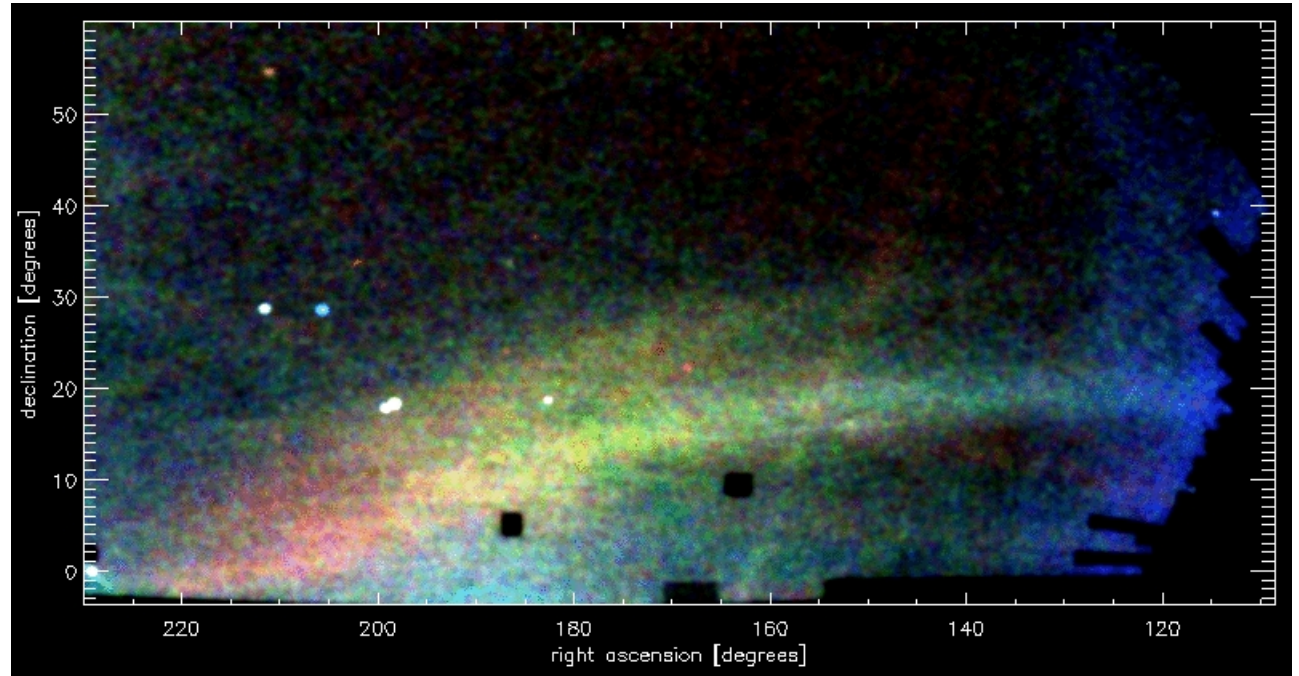
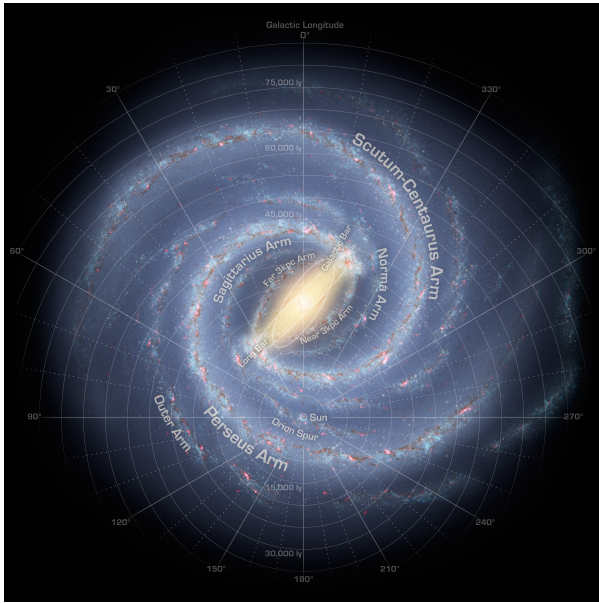
## Introduction

- **Top left:**  $30^\circ$  by  $10^\circ$  (optical) view towards the Galactic center (from Axel Mellinger)
- **Middle left:** The all-sky view by the Infrared Astronomical Satellite
- **Bottom left:** a spiral galaxy (NGC 7331) similar to the Milky Way
- **Conclusion:** the density of stars on the sky varies greatly because we are observing from inside a disk of stars
- **We live in a spiral galaxy** the same conclusion supported by the motions of stars and the presence of abundant interstellar medium (more later)





GALACTIC DISK	GALACTIC HALO	GALACTIC BULGE
Highly flattened	Roughly spherical—mildly flattened	Somewhat flattened and elongated in the plane of the disk ("football shaped")
Contains both young and old stars	Contains old stars only	Contains both young and old stars; more old stars at greater distances from the center
Contains gas and dust	Contains no gas and dust	Contains gas and dust, especially in the inner regions
Site of ongoing star formation	No star formation during the last 10 billion years	Ongoing star formation in the inner regions
Gas and stars move in circular orbits in the Galactic plane	Stars have random orbits in three dimensions	Stars have largely random orbits but with some net rotation about the Galactic center
Spiral arms	No obvious substructure	Ring of gas and dust near center; Galactic

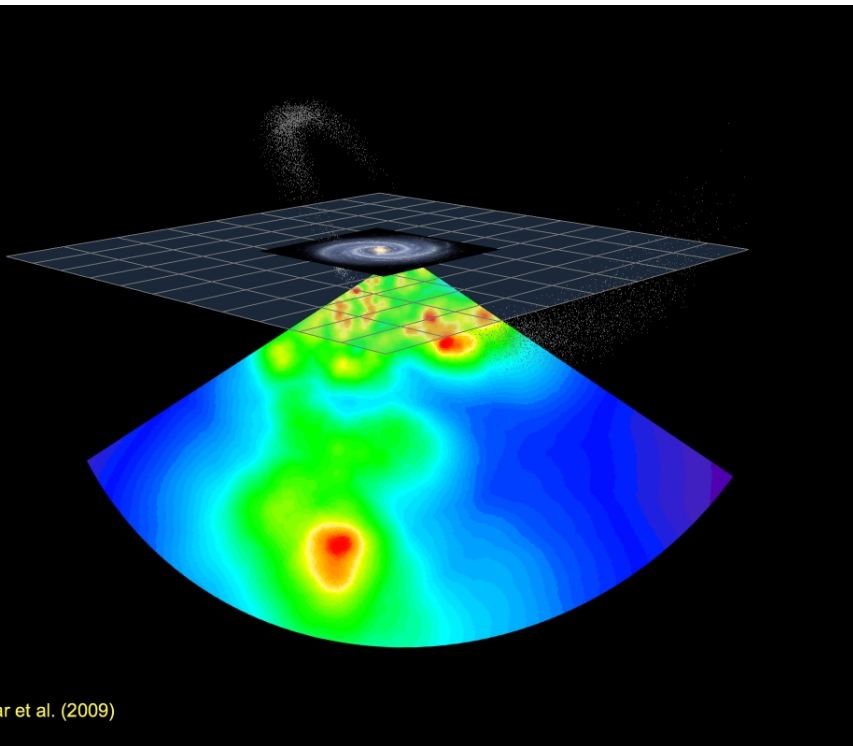


## Halo Substructure

The table on the previous page is wrong: most recent data clearly show that **halo has rich substructure**

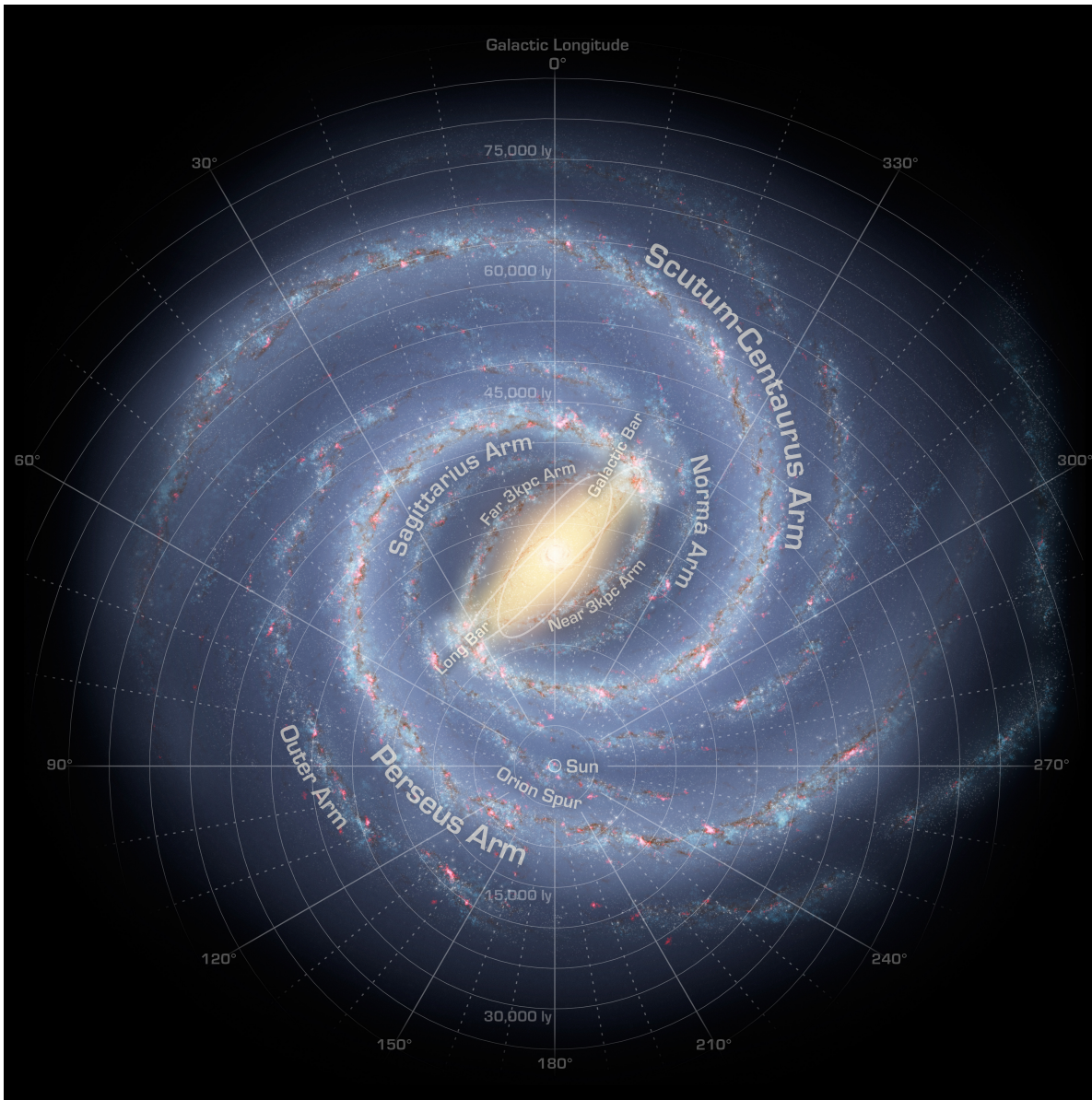
**Top right:** the counts of SDSS stars color-coded by distance (red:  $\sim 10$  kpc, blue: several kpc) from Belokurov et al. (2007)

**Bottom left:** the distribution of distant SDSS RR Lyrae stars (Sesar et al. 2009)





## Revised Spiral Arms



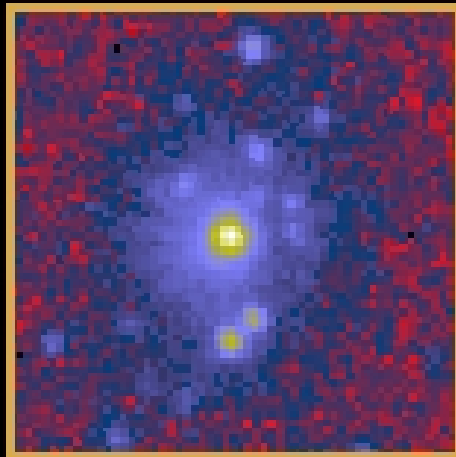
- The stellar bar was discovered in 1990s based on IRAS data
- It was believed that the Galaxy has four spiral arms: the Scutum-Centaurus, Perseus, Sagittarius and Norma
- The stellar counts from Spitzer galactic plane survey (Benjamin et al. 2008) strongly suggest that there are only two major arms, the Scutum-Centaurus and Perseus arms, as is common for barred galaxies

# M81 – Spiral Galaxy (Type Sb)

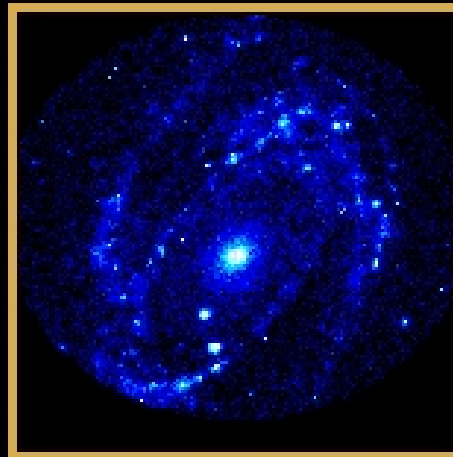
Distance: 12,000,000 light-years (3.7 Mpc)

Image Size = 14 x 14 arcmin

Visual Magnitude = 6



X-Ray: ROSAT



Ultraviolet: ASTRO-1



Visible: DSS



Visible: R. Gendler



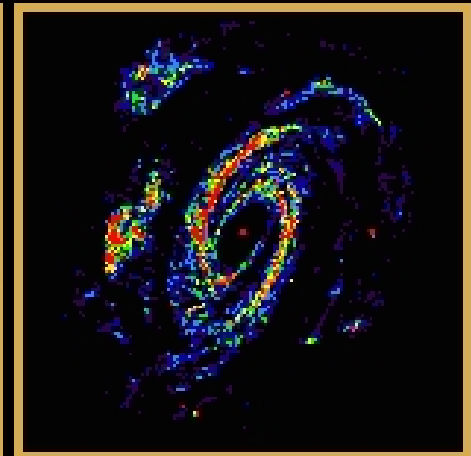
Near-Infrared: Spitzer



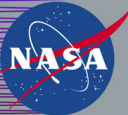
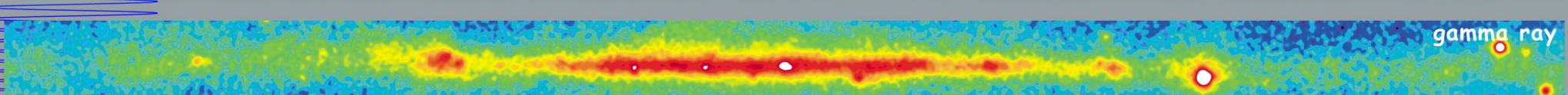
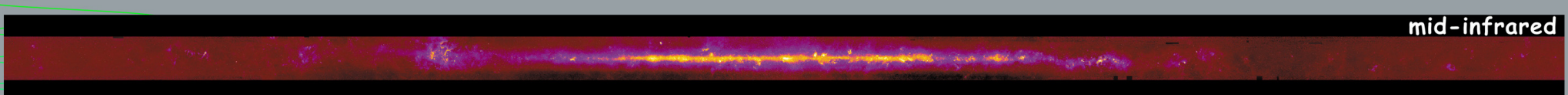
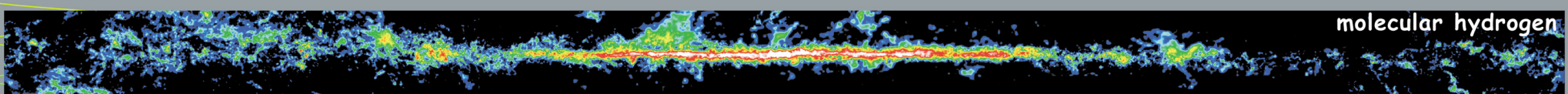
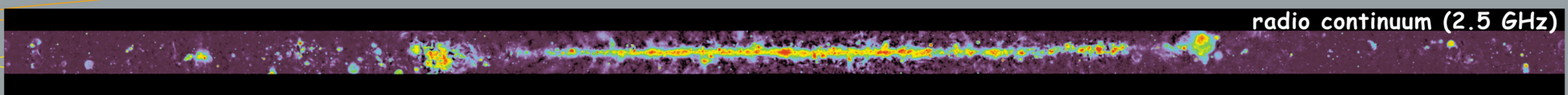
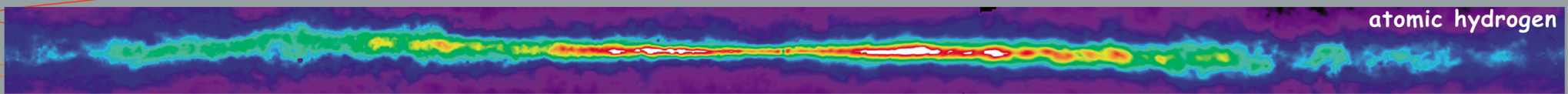
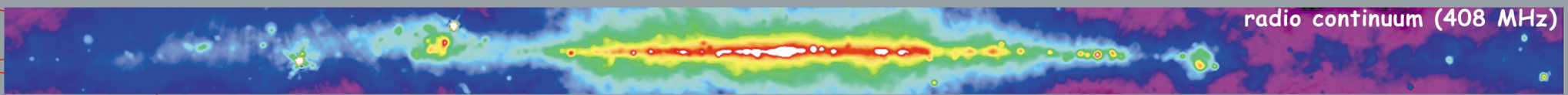
Mid-Infrared: Spitzer



Far-Infrared: Spitzer



Radio: VLA



# Multiwavelength Milky Way

# Stars form from gas in galaxies

“Interstellar Medium” = “ISM”

- Hot ionized Gas
- Neutral Atomic Gas
- Cold Molecular Gas
- Dust

# What these phases are called:

- Hot ionized Gas
- Neutral Atomic Gas
- Cold Molecular Gas
- Dust

"HII" = "H two"

"HI" = "H one"

"H<sub>2</sub>"

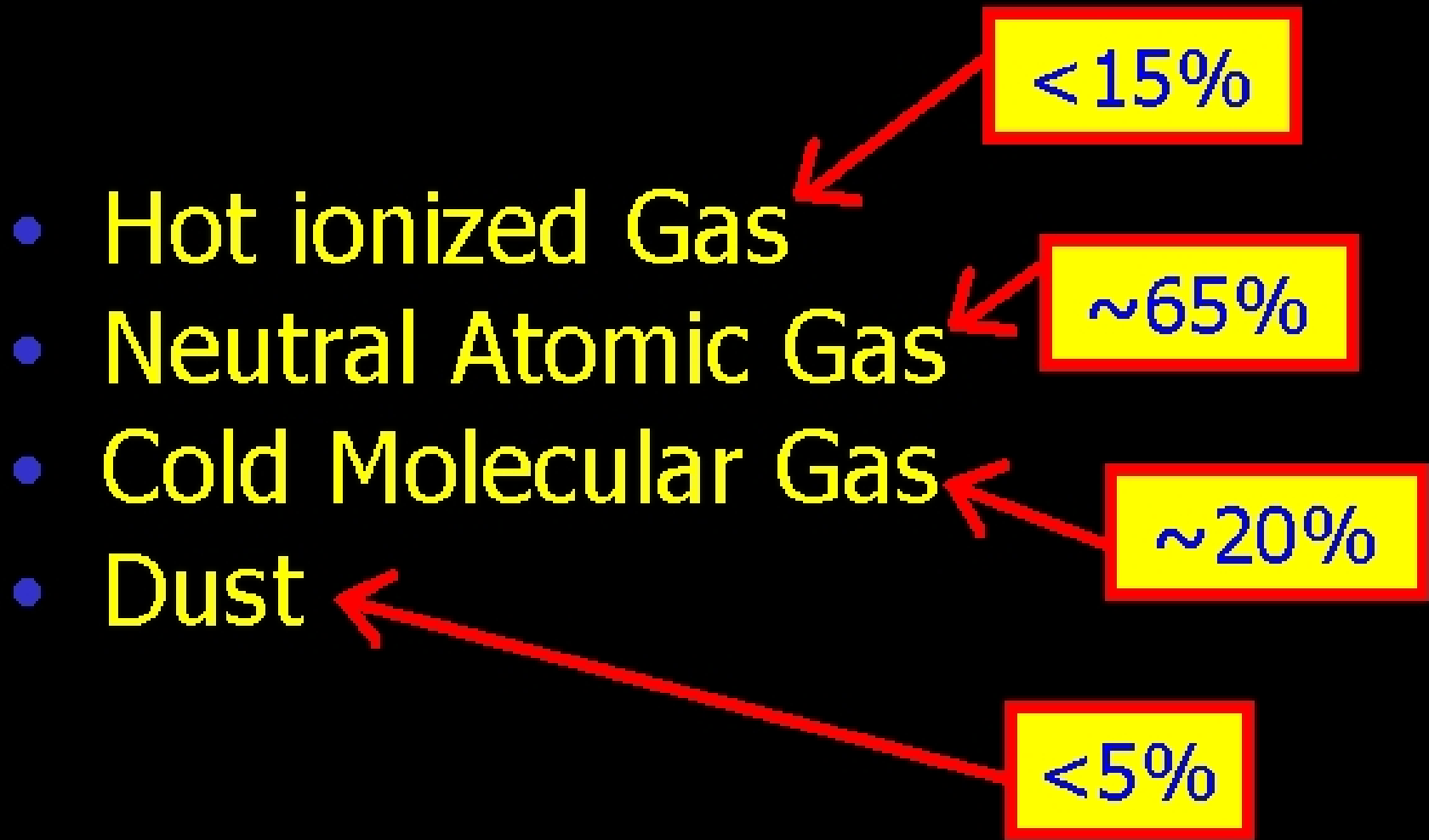
"Dust"

Nomenclature: "ElementI" = unionized Element

"ElementII" = singly ionized Element

"ElementIII" = doubly ionized Element...etc

# What fraction is in each phase?



# Typical Densities

- Hot ionized Gas
- Neutral Atomic Gas
- Cold Molecular Gas
- Dust

Low  
( $<0.5$  atoms/cm<sup>3</sup>)

Medium  
(1-10 atoms/cm<sup>3</sup>)

High  
( $10^2$ - $10^5$  atoms/cm<sup>3</sup>)

Very High  
(solid)

# Typical Temperatures

Hot  
( $>10^4$ - $10^7$  K)

Medium  
(100 - $10^4$  K)

Cold  
( $<50$ K)

Medium-cold  
( $<100$ K)

- Hot ionized Gas
- Neutral Atomic Gas
- Cold Molecular Gas
- Dust



## Detected How?

H $\alpha$  emission line (6563Å)  
X-Rays (if  $T > 10^6\text{K}$ )

- Hot ionized Gas
- Neutral Atomic Gas
- Cold Molecular Gas
- Dust

21cm emission line

(hyperfine splitting of H ground state)

CO rotational emission line  
(mm wavelengths)

Thermal (Black-body) radiation at far-infrared wavelengths

# Distributed How?

- Hot ionized Gas
- Neutral Atomic Gas
- Cold Molecular Gas
- Dust

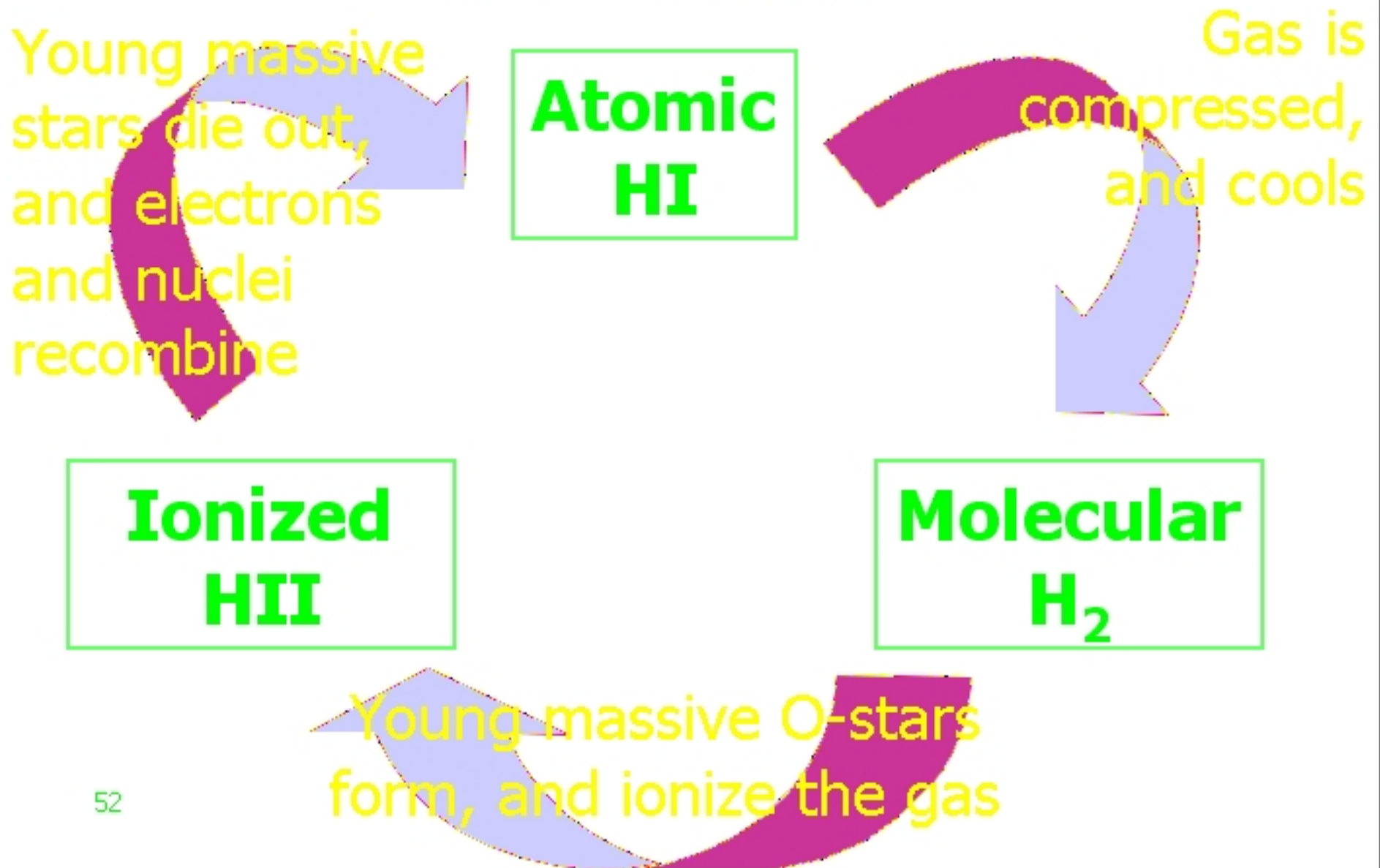
Halos of  
Galaxies

Galaxy  
Midplane, out to  
large radii  
beyond stars

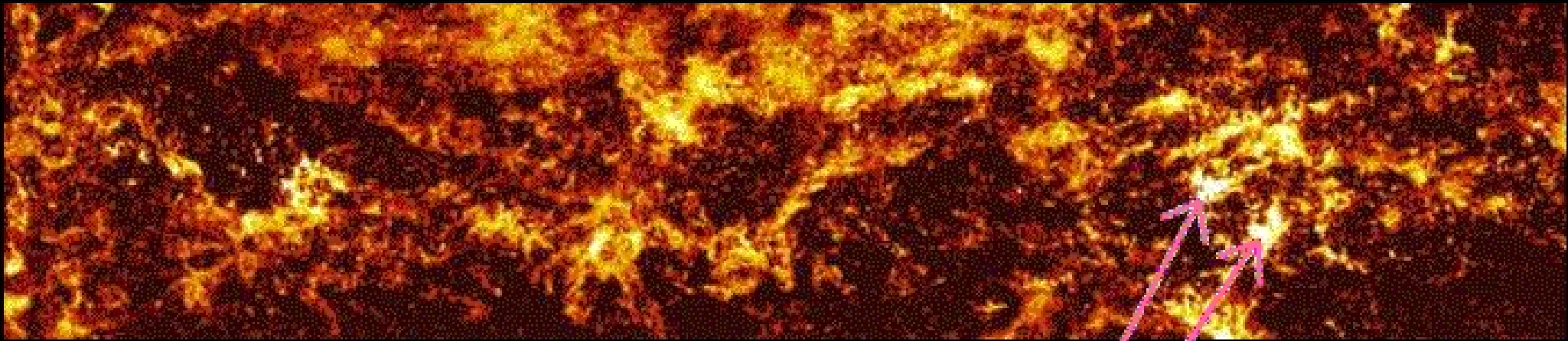
Galaxy Midplane,  
concentrated in  
spiral arms

Tracks the  
distribution of gas

# How are the three phases of gas inter-related?



Molecular gas is clumpy on small scales.

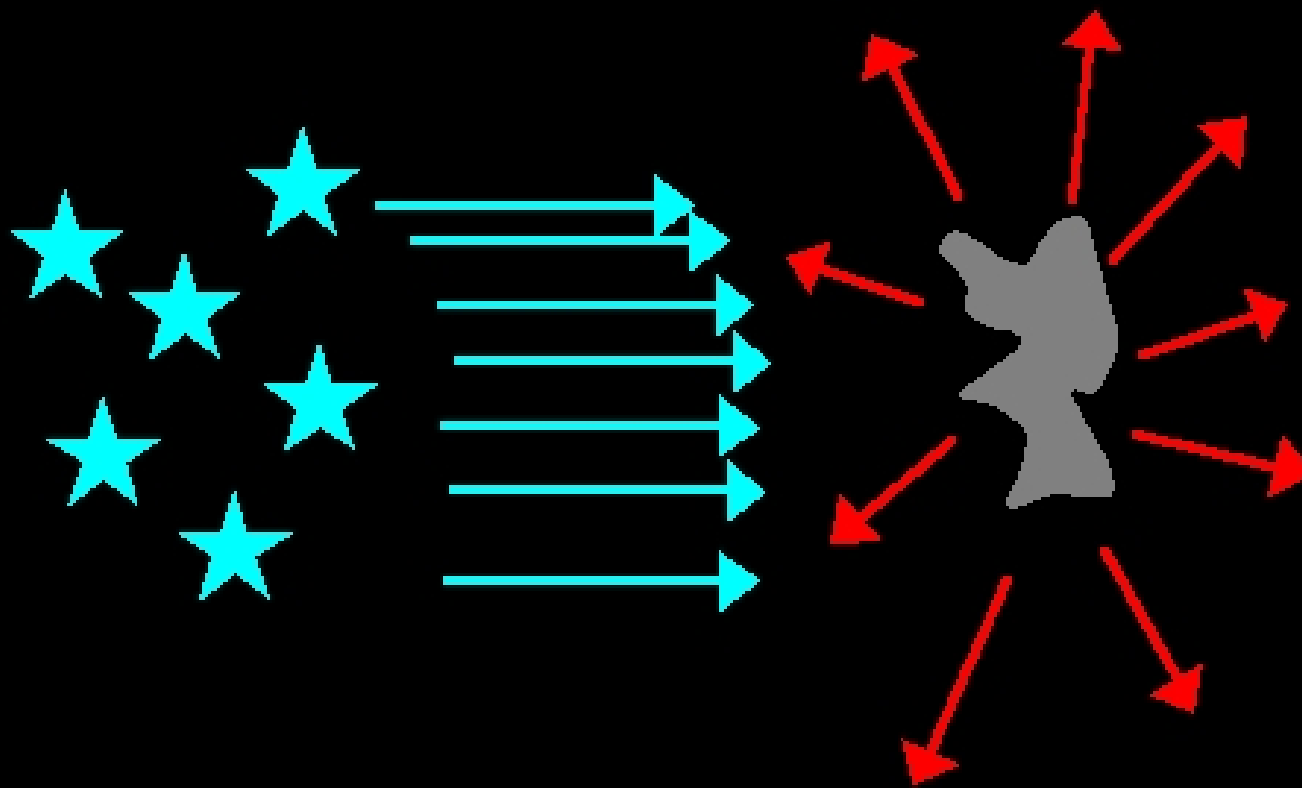


(View of the outskirts, away from the center)

“Molecular Clouds”

This is why stars form in clusters!

The amount of dust can be measured using light that has been **reprocessed** into the **infrared**.

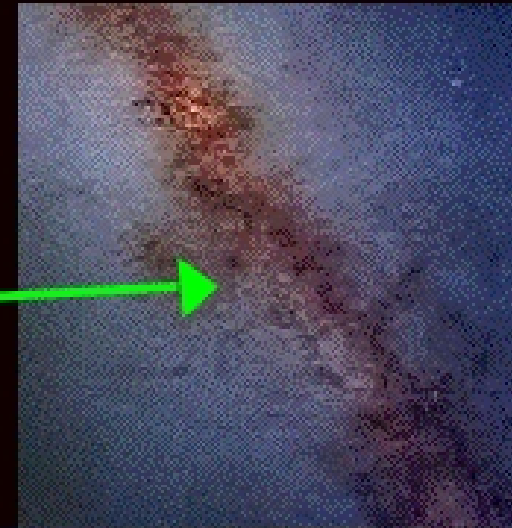
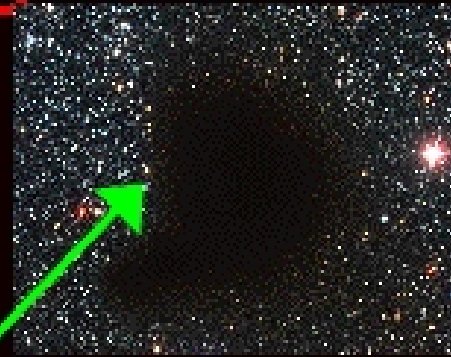


UV & optical light is absorbed by dust...

44

...which heats up to 10-100K and radiates like a greybody at 10-300 $\mu$ m

# Dust plays many important roles in galaxies



1. Extinction/Attenuation
2. Reddening
3. Reprocessing UV/optical light into the infrared
4. Scatters light.
5. Locks up metals

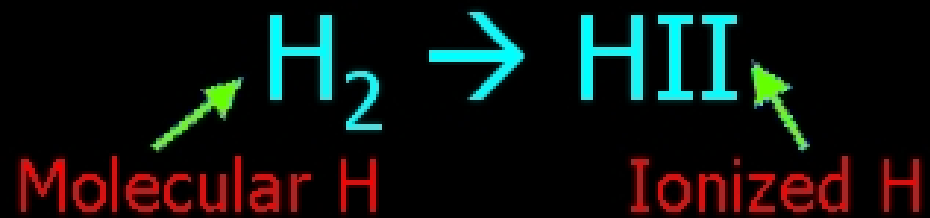
Dusty  
molecular  
gas

New stars

Ionized gas

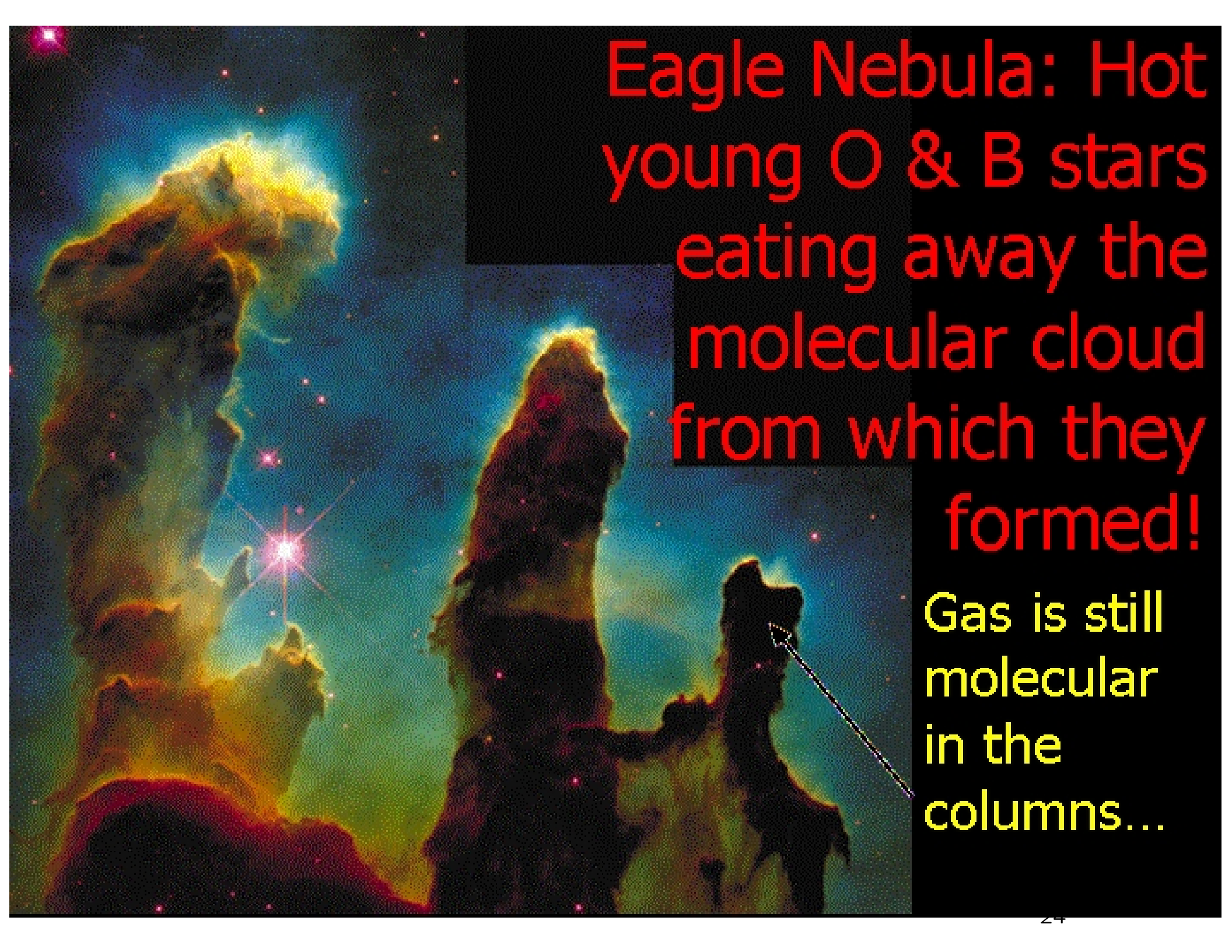
# The Orion Nebula

- Hot young O & B stars heat the surrounding gas, ionizing it.



Star formation transforms  
a molecular cloud into an

“HII Region”

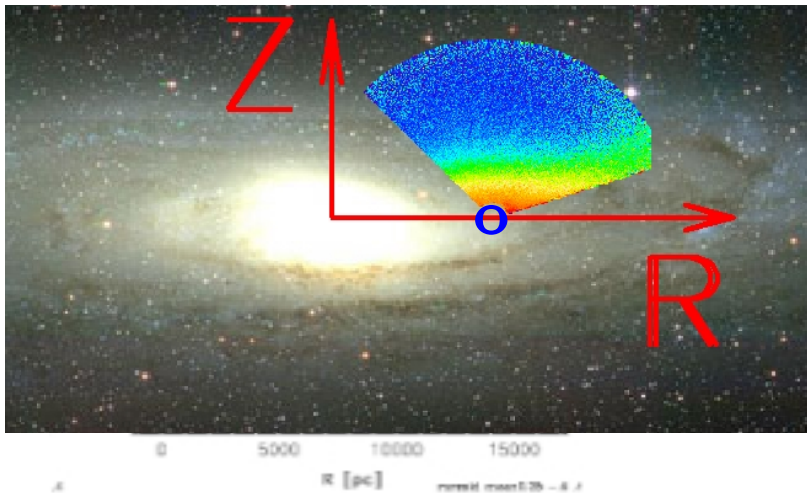
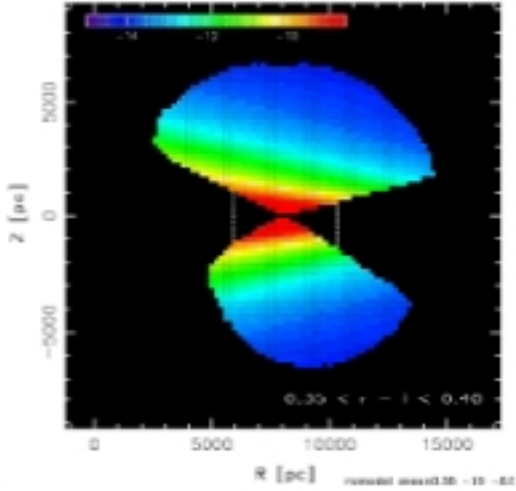
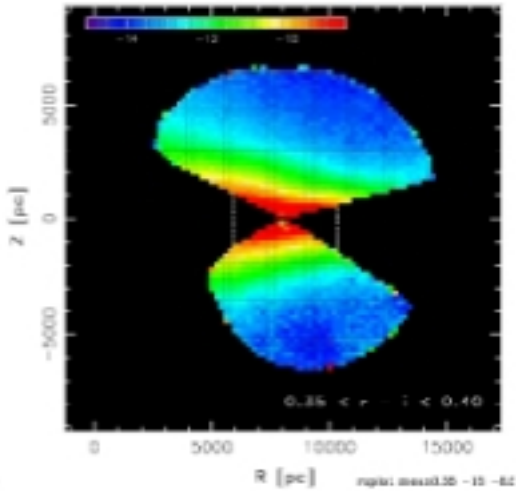
The image shows the Eagle Nebula, a stellar nursery. It features several prominent, dark, columnar structures of interstellar dust and gas, known as the 'Pillars of Creation'. The background is a vibrant blue and green, with numerous bright stars scattered throughout. A large, bright star with a prominent diffraction pattern is visible in the lower-left quadrant. The text 'Eagle Nebula: Hot young O & B stars eating away the molecular cloud from which they formed!' is overlaid in red on the right side of the image. A white arrow points from the text 'Gas is still molecular in the columns...' to one of the dark columns.

Eagle Nebula: Hot  
young O & B stars  
eating away the  
molecular cloud  
from which they  
formed!

Gas is still  
molecular  
in the  
columns...

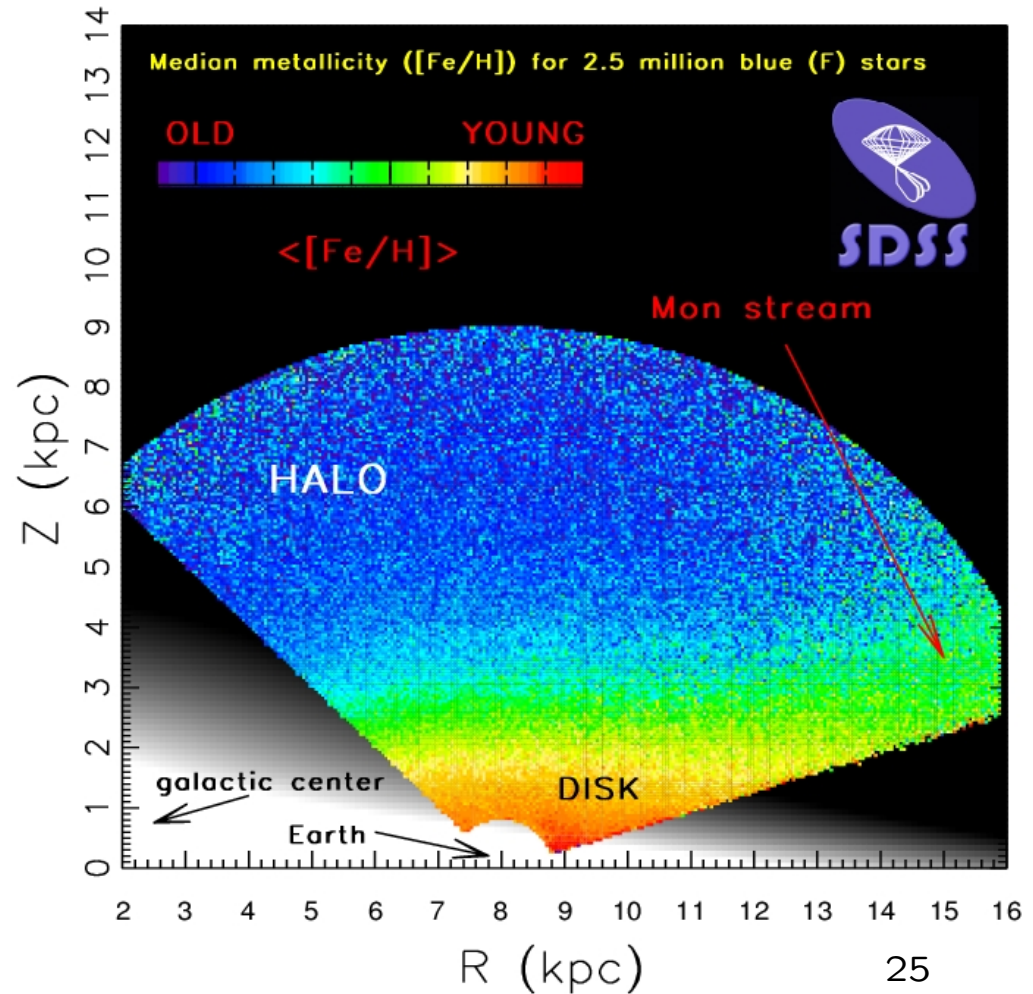


$0.35 < r-i < 0.40$

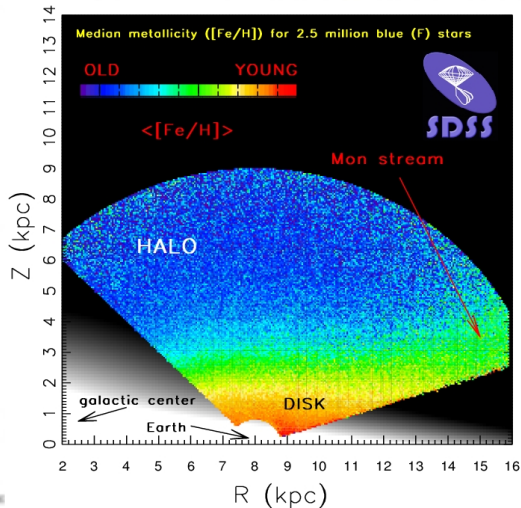
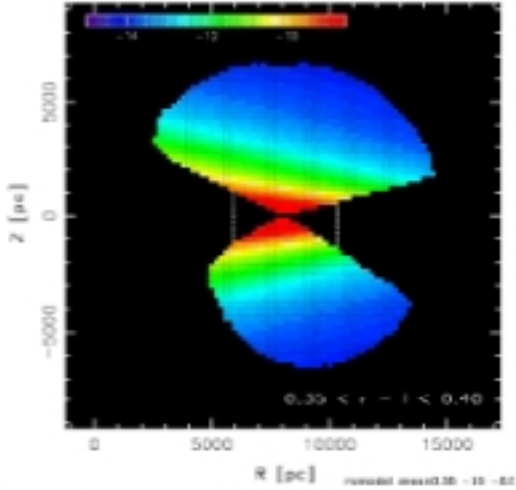
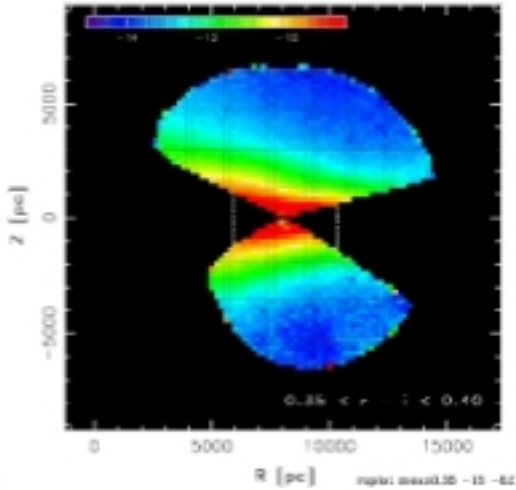


## Dissecting the Milky Way with SDSS

- Panoramic view of the Milky Way, akin to observations of external galaxies; good support for standard Galactic models
- Metallicity mapping (age is traced by chemical composition) supports components inferred from number counts mapping:

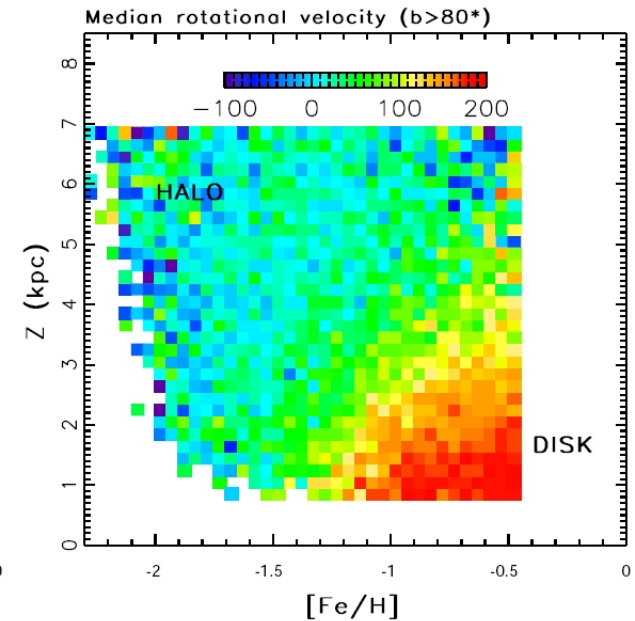
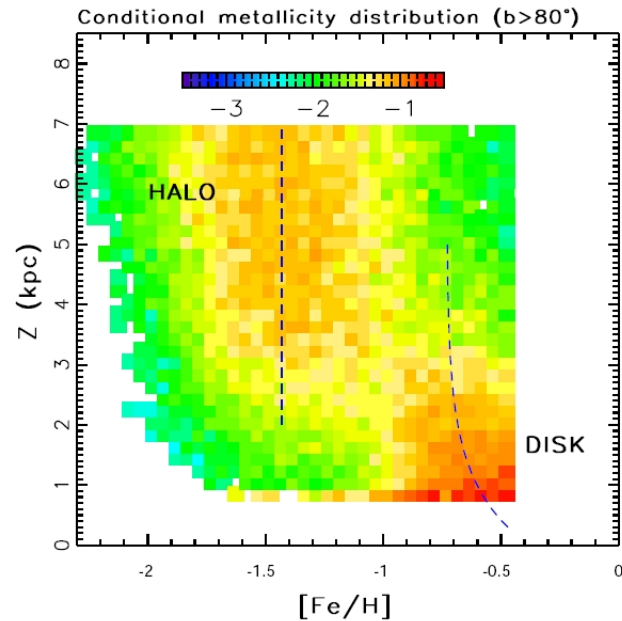


$0.35 < r-i < 0.40$



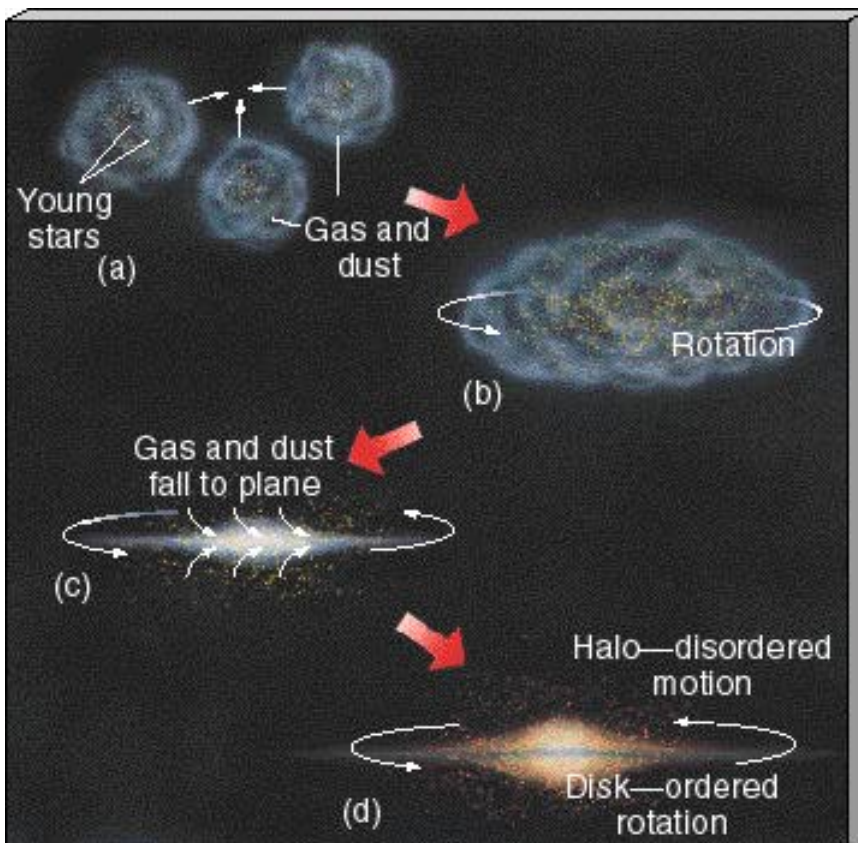
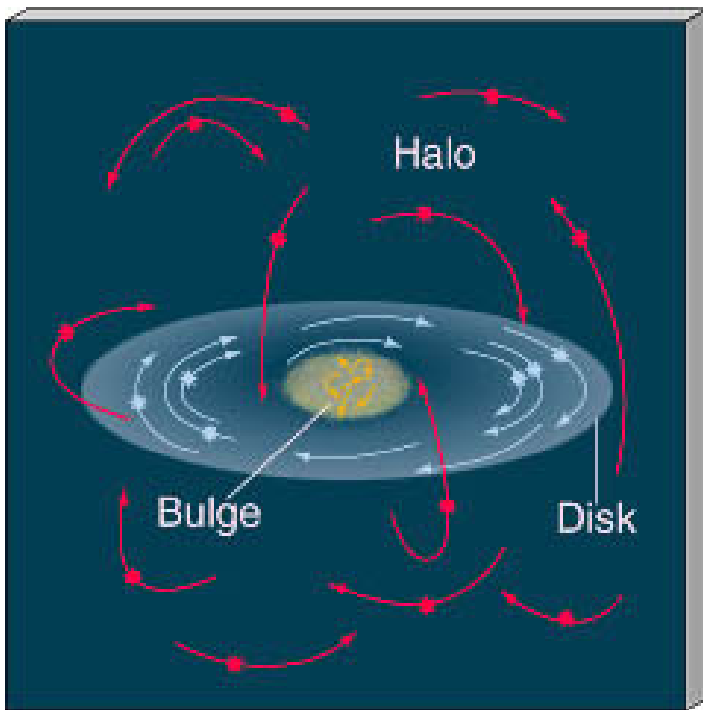
## Dissecting the Milky Way with SDSS

- Panoramic view of the Milky Way, akin to observations of external galaxies; good support for standard Galactic models
- Metallicity mapping supports components inferred from number counts mapping
- Kinematics correlated with metallicity: high-metallicity (disk) stars rotate, low-metallicity (halo) stars on random highly eccentric orbits



## Kinematics

- Stars move in a gravitational potential produced by all stars and dark matter
- Two types of motion: disk stars **rotate** around the center, while halo stars are on randomly distributed elliptical orbits
- The motion of stars was set during the formation period
- The details are governed by the laws of physics: conservation of energy and conservation of angular momentum!
- As the cloud collapses, its rotation speed must increase. As it spins faster, it must flatten.

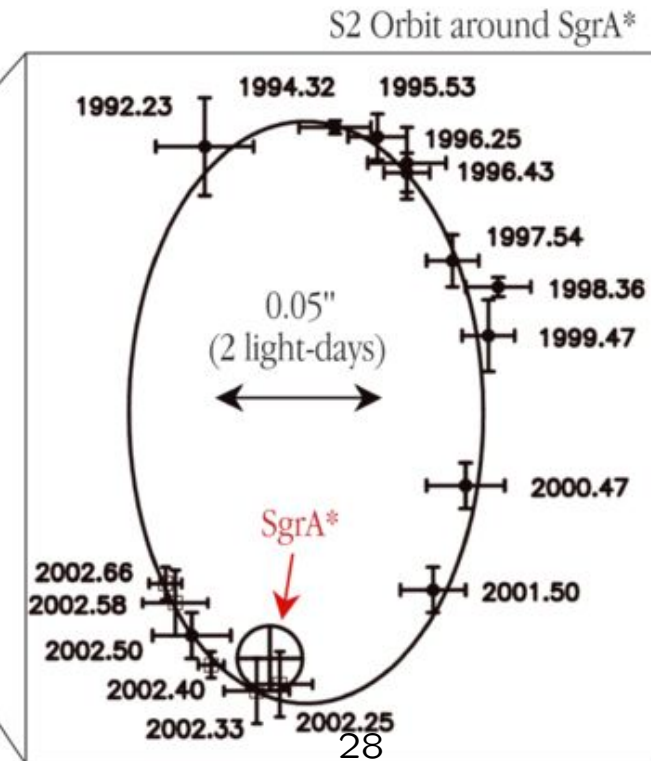
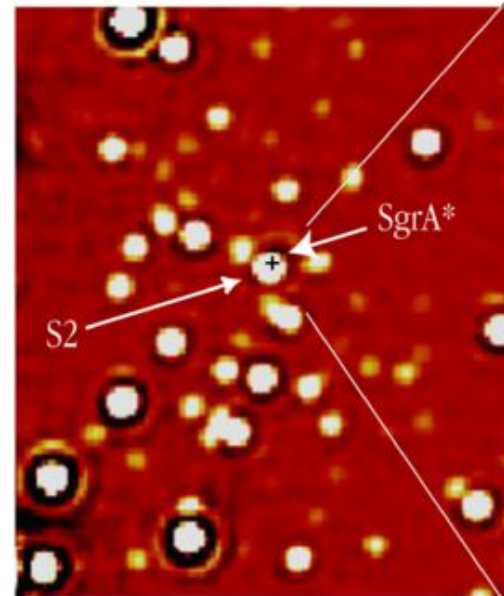
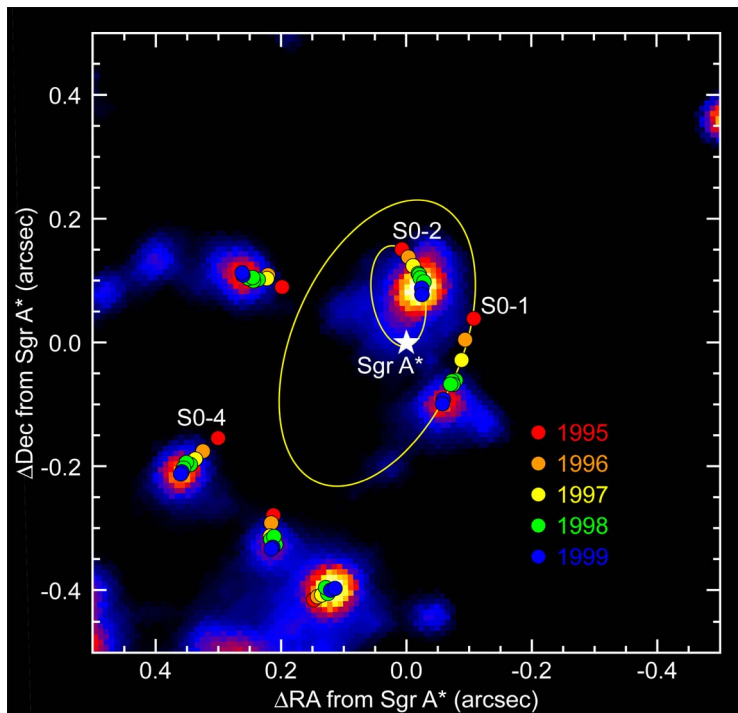


# Black Hole in the Galactic Center

- **Stars move** in a gravitational potential: the Galactic center is sufficiently close (“only” 25,000 light years) that we can trace the orbits of individual stars!
- **Observations:** a large mass (a few  $10^6 M_{\odot}$ ) confined to small space (0.1-0.2 AU) is required to explain about  $\sim 30$  **observed** orbits



NACO May 2002



## The Milky Way: Summary

Stars: Disk, Bulge and Halo

ISM: gas and dust

Halo: old stars with random orbits

Disk: young rotating stars

Black hole in the center!

