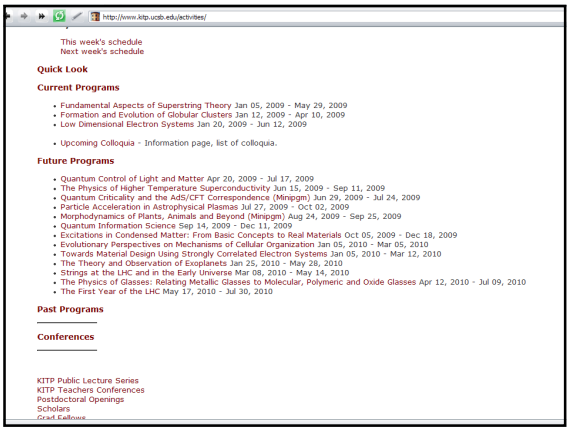
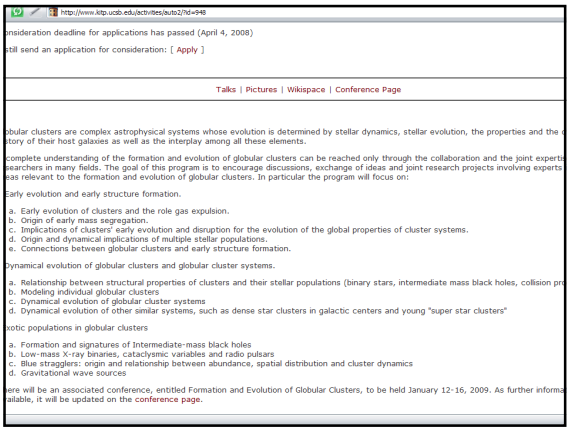
Chapter 15

The Milky Way Galaxy

KITP@UCSB





The Milky Way

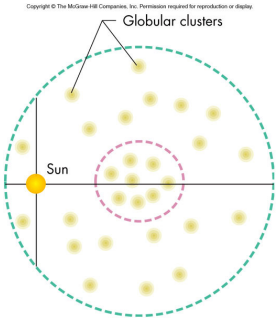
- Structure:
  - Disk
  - Bulge
  - Halo
  - ISM
- Stars:
  - Open vs. Globular Clusters
  - Pop I vs Pop II stars
- Age
- How do we study?
  - Distance maps of stars/clusters
  - Light:
    - Scattering
    - Reddening
    - Absorption lines
    - Dark nebular/obscuration
    - Ioniziation/emission lines HII

Diameter of the Milky Way

- All methods to determine the Milky Way's diameter depend on Sun's distance to center
- Red giant maser method
  - Red giant maser radio sources common in inner bulge
  - Stars near galactic center move in random directions
  - Assume in a given volume a star moving radially has the same speed as one moving across the line of sight
  - Use Doppler shift of radial maser source to determine speed and use this with transverse maser angular motion to determine distance
  - Geometric center of masers gives Sun distance of 7 kpc

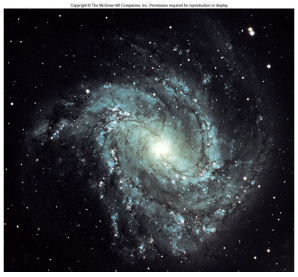
Diameter of the Milky Way

- Globular cluster method
  - Globular cluster distances and directions determined using period-luminosity relation for variable stars
  - Geometric center of globulars then marks the center
  - Distance to center from Sun is then found to be 8.5 kpc

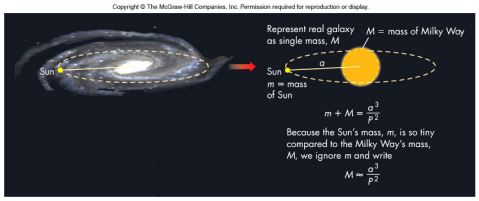


Diameter of the Milky Way

- Once distance to center from Sun found, this is added to distance to outer edge from Sun to arrive at the Milky Way's diameter – a value of about 40 kpc or more

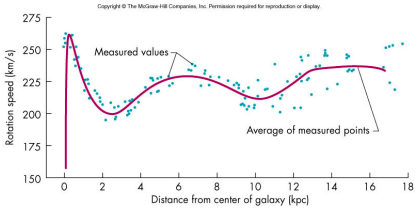


Mass of the Milky Way



- The mass of the Milky Way is determined by using Kepler's modified third law
- Using the Sun's distance to the center and its period of revolution, the mass interior to the Sun's orbit is at least $10^{11}\ M_{\odot}$

Mass of the Milky Way



- A more refined technique uses the rotation speeds of stars at a variety of distances from the center (the so-called ***rotation curve***)
- This technique can more accurately determine the mass of the entire galaxy – the Sun method only estimates the mass interior to its orbit

Mass of the Milky Way

- In either method, the speed of stars around the galaxy is crucial and there are many ways to do this – two of them are:
  - Use the Local Group of galaxies as a reference frame since the stars on the Milky Way move much faster
  - Use the distribution of randomly moving globular clusters as on average being at rest
- Analysis of the rotation curve also reveals a dark matter halo with a radius exceeding 100 kpc

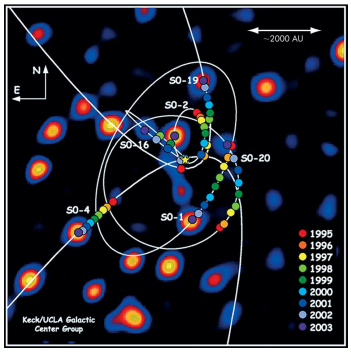
The Galactic Center

- Because the galactic center is not observable in the visible, astronomers must rely on radio, infrared, X-ray, and gamma-ray observations

The Galactic Center

- At a distance of 3 kpc, an arc of cold hydrogen sweeps outward at a speed exceeding 100 km/sec
- A giant swarm of stars, packed in at millions of stars per cubic light-year, are arranged in an elongated structure about 1000 light-years across
- Some energetic event, perhaps a supernova explosion, violently disturbed the center in the not-to-distant past
- Deep within the core lies an incredibly small (10 AU diameter) radio source known as Sgr A*
- A 10^6 $M_\odot$ black hole may occupy the very center of the galaxy, although other explanations have been given

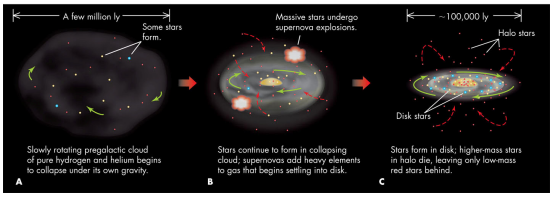
A Black Hole?



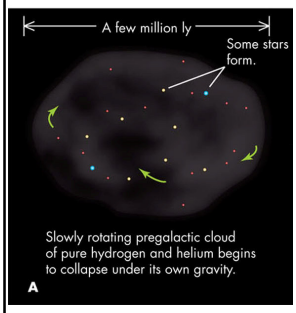
Formation of the Milky Way

- Forming galaxies is still a major unsolved problem
- Currently it is thought that galaxies form like stars, but only on a larger scale
  - Begin with a million-light-year cloud with 100 billion solar masses of material
  - The cloud gravitationally collapses and breaks up into stars
- Evidence for this galaxy formation process can be found in the Pop I and Pop II stars

Formation of the Milky Way

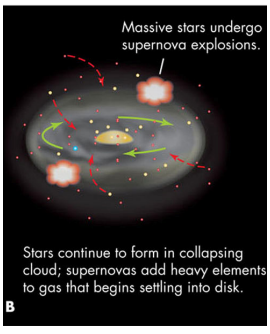


Formation of the Milky Way



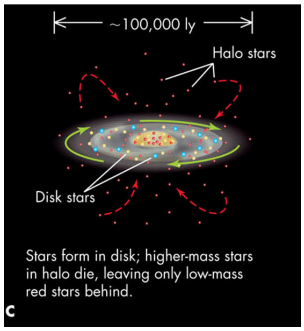
- The proto-Milky Way was a giant cloud of pure hydrogen and helium
- The existence of old Pop II stars with very little heavy elements suggests they formed at the onset of collapse and as they did so, they dropped out of the gas collapse

Formation of the Milky Way

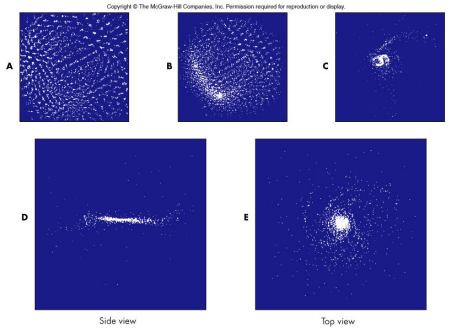


- The massive Pop II stars exploded early on, seeding the galactic cloud with heavy elements
- By the time the cloud collapsed into a disc it was rich enough in heavy elements to generate the Pop I stars we see there today

Formation of the Milky Way



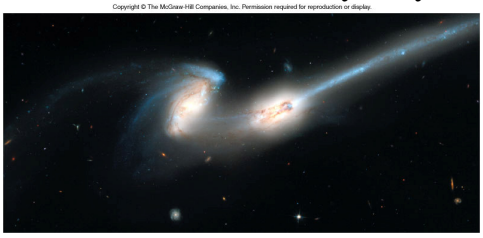
Computer Simulation of Galactic Formation



Formation of the Milky Way

- However, the collapse model fails to explain two important properties of stars
  - Pop II stars appear to have formed over a longer time scale than the collapse model allows
  - Some stars should have virtually no heavy elements, but no such stars have ever been observed

Formation of the Milky Way



- Today, astronomers also believe the collapse model fails to include the effects of galactic mergers on galactic and stellar evolution – merging appears to be the rule, not the exception

Population III Stars

- Despite uncertainties, the basic idea of the initial stars being made of pure hydrogen and helium is still true – so where are they
- These ***population III stars*** may not be observable for three reasons
  - Only short-lived massive population III stars can form – consequently none are left today
  - Population III stars exist, but are masquerading as Pop II since their atmospheres have been contaminated by gas ejected when a more massive star exploded
  - Pop II stars may be rare and hard to find

The Future of the Milky Way

- Eventually all gas finds its way into stars, which in turn will lock up material in stellar remnants
- Hundreds of billions of years from now the Milky Way will fade, slowly spinning in space, a dark disk of stellar cinders