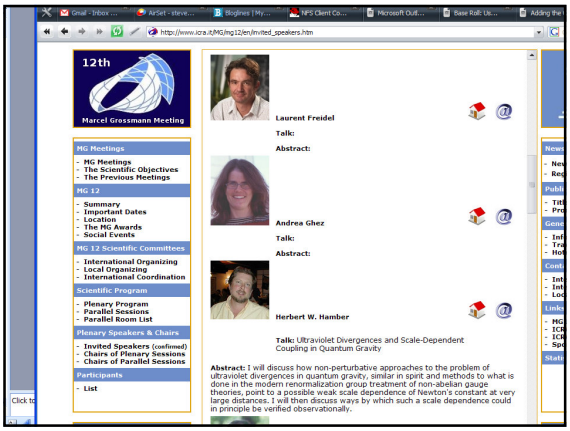
Chapter 16

Galaxies

Agenda

- Discuss Tuesday's movie
- Sample Project
  - Present Issue
  - Present Controversy (and the various sides)
  - Present Your Opinion
  - Backup Your Opinion
- Review Ch. 16
- Solar Altitude measurement
- Exercise: measuring galactic distances

- Role of SMBHs in galactic life cycle:
  - may limit runaway growth of galaxies
    - Fling stars in a collision out of galaxy
    - Propel matter out of galaxy along jets
  - Which comes first, the SMBH or the galaxy?
- Jets/SMBH/Magnetic field powers engine
- Even quiescent SMBH can have flare-ups
- What were the astronomers looking at…telescopes or computers?



Evolution vs Intelligent Design

- Explanations for the origin of species:
  - Evolution: natural selection combined with random genetic mutations provide a bias towards beneficial novel characteristics which carry-on through reproduction
  - Intelligent Design: wings, eyes could not have evolved and instead provide evidence of design. Sure evolution happens, but it's minor.

The Controversy

- ID proponents want it taught in science classes alongside criticism of evolution
  - Assert that ID is competing scientific theory (Source…)
  - Assert various criticisms of evolution:
    - Gaps in fossil record (Source…)
    - No way to "evolve an eye" (Source…)
- Critics say:
  - ID is not science
  - Many criticisms of evolution not scientifically valid
  - Some gaps in fossil records, but doesn't mean evolution is wrong

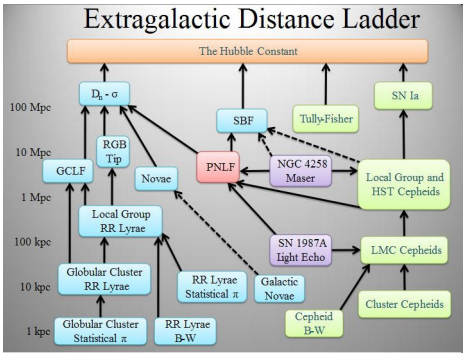
My Position

- ID should not be taught in science classes

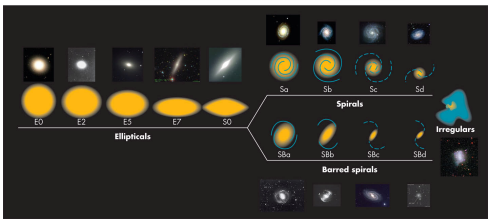
Reasoning…

- Why not teach ID:
  - Nothing wrong with seeing a designer behind the Universe, but that is not science which looks for natural explanations
  - If this universe were designed, science would not be able to address it (or disprove) it so no conflict
  - Similar, if not identical to, religion and doesn't belong in science class
- Defense of evolution:
  - Never failed a test…sure, not every fossil of every intermediate step has been found, but many gaps have since been filled in (Source: blahblah)
  - Various criticism have been answered:
    - Wing evolution (Source….)
    - Eye evolution (Source…)
  - Examples of co-evolution further attest to robustness of mechanism
    - Examples (Sources…)

Extragalactic Distance Ladder



The Hubble "Tuning Fork"

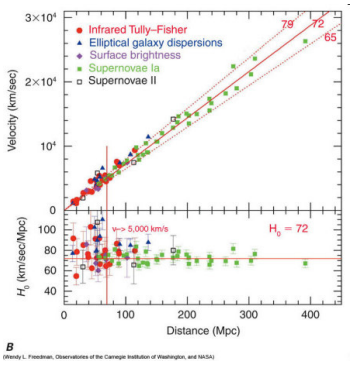


- Hubble proposed the "tuning fork" diagram as a hypothesis for galactic *evolution* – today it is believed this interpretation is incorrect. However, we still use his classification scheme.

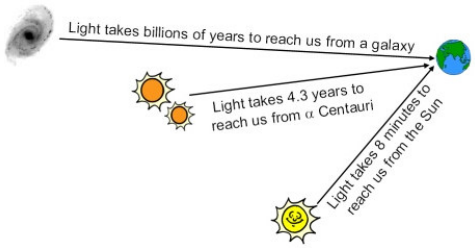
Stellar and Gas Content of Galaxies

- Spirals
  - Star types: Mix of Pop I and Pop II
  - Interstellar content: 15% by mass in disk
- Ellipticals
  - Star types: Only Pop II, blue stars rare
  - Interstellar content: Very low density, very hot gas
- Irregulars
  - Star types: blue stars common
  - Interstellar content: As much as 50% by mass

Hubble's Law



Lookback Time



Hubble's Law

- Can use Law in reverse to deduce distance from redshift
- Often distance is just quoted in terms of redshift

Galactic Evolution

- Birth: Collapse of massive clouds
  - Probably only produces small galaxies
  - Such young galaxies have been observed at large distances (therefore early times in the Universe)
- Questions:
  - Where does variety of galaxies (e.g. size, composition) come from?
  - Though spiral arms rotate rel. fast, bulges and halos don't…how to square with presumed birth?

Galactic Collisions

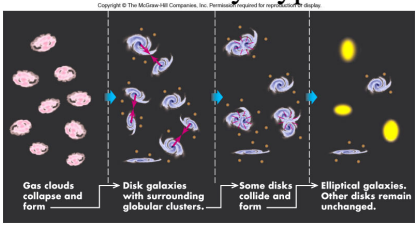
- Suspect Mergers play large role:
  - If lots of gas results: spiral
  - If not, then elliptical
- Ellipticals could get incorporated as a bulge
- Explains wide ranging ages of stars in our bulge
- Explains distorted galaxies observed

Stellar and Gas Content of Galaxies

- Other items of note:
  - Ellipticals have a large range of sizes from globular cluster sizes to 100 times the mass of the Milky Way
  - Census of galaxies nearby: Most are dim dwarf E and dwarf Irr sparsely populated with stars
  - Census of distant galaxies: In clusters, 60% of members are spirals and S0, while in sparsely populated regions it is 80%
  - Early (very young) galaxies are much smaller than Milky Way – merging of these small galaxies is thought to have resulted in the larger galaxies of today

Approx. 700,000 light-years

The Cause of Galaxy Types

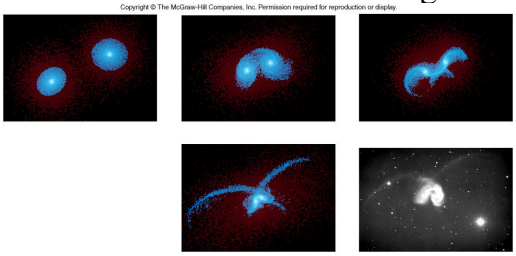


- Rotation?
  - Spirals in general rotate relatively faster than ellipticals
  - Rotation speed of ellipticals of different flattening shows little or no relation to rotational speed
  - Consequence: Rotation plays a role in galaxy types, but other factors probably do so too

The Cause of Galaxy Types

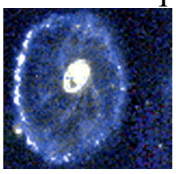
- Other factors:
  - Computer simulations show galaxies formed from gas clouds with large random motions becoming ellipticals, whereas small random motions become spirals
  - Ellipticals had a high star formation rate in a brief period after their birth, while spirals produce stars over a longer period – did the rate cause the type of the reverse?
  - Dark matter halo spin rate – fast for spirals, slow for ellipticals
  - Density wave or SSF model for creating spiral arms

Galactic Collisions and Mergers



- Could galaxy's type change with time?
  - Computer simulations show a galaxy's shape can change dramatically during a close encounter with another galaxy

Consequences of a Collision



- Individual stars are left unharmed
- Gas/dust clouds collide triggering a burst of star formation
- A small galaxy may alter the stellar orbits of a large spiral to create a "ring galaxy"
- Evidence (faint shell-like rings and dense clumps of stars) of spirals colliding and merging into ellipticals

Galactic Collisions and Mergers

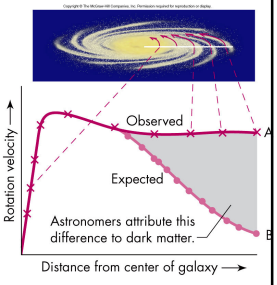
- Evidence for galaxy type change via collisions/mergers over time
  - On a large scale, small galaxies may be captured and absorbed by a large galaxy in a process called ***galactic cannibalism***
    - Explains abnormally large ellipticals in center of some galaxy clusters
    - Milky Way appears to be "swallowing" the Magellanic Clouds, while Andromeda shows rings and star clumps of "swallowed" galaxies

Galactic Collisions and Mergers

- Evidence for galaxy change type via collisions/mergers over time
  - Very distant clusters have a higher proportion of spirals than near clusters
  - Distant clusters contain more galaxies within a given volume
  - Distant galaxies show more signs of disturbance by neighboring galaxies (odd shapes, bent arms, twisted disks), what astronomers call "harassment"

Dark Matter

- The amount of matter needed to resolve this discrepancy is as much as 10× the visible mass
- The strongest evidence that dark matter exists comes from galaxy rotation curves, which do not show diminishing speeds at large distances from the galaxy's center



Dark Matter Candidates

- Dark matter cannot be:
  - Ordinary dim stars because they would show up in infrared images
  - Cold gas because this gas would be detectable at radio wavelengths
  - Hot gas would be detectable in the optical, radio, and x-ray regions of the spectrum
- Objects that cannot be ruled out:
  - Tiny planetesimal-sized bodies, extremely low-mass cool stars, dead white dwarfs, neutron stars, and black holes
  - Subatomic particles like neutrinos
  - Theoretically predicted, but not yet observed, particles referred to as WIMPS (weakly interacting massive particles)

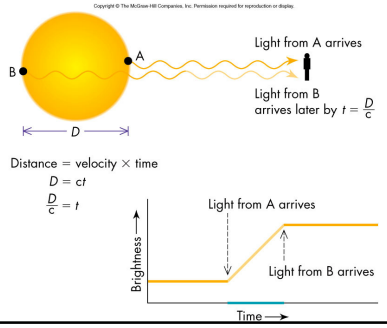
Active Galaxies

- Centers (nuclei) emit abnormally large amounts of energy from a tiny region in their core
- Emitted radiation usually fluctuates
- In many instances intense radio emission and other activity exists well outside the galaxy
- Centers of active galaxies referred to as AGNs – active galactic nuclei
- 10% of all galaxies are active
- Three overlapping classes: radio galaxies, Seyfert galaxies, and quasars

Types of AGN

- Radio
  - Associated w/ elliptical galaxies
  - Jets interact w/ IGM
- Seyfert
  - Associated w/ spiral galaxies
- Quasars
  - Most distant, visible objects (ala 10 GYrs)

Measuring the Diameter of Astronomical Objects by Using Their Light Variability

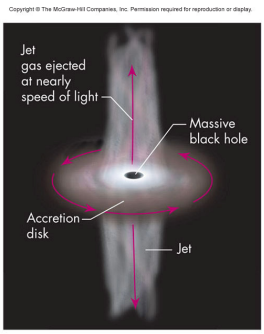


Cause of Activity in Galaxies

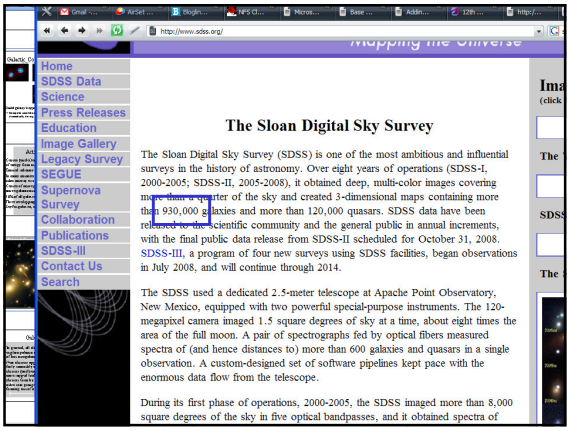
- All active galaxies have many features in common – this suggests a single model to explain all of them
  - Such a model must explain how a small region can emit an extreme amount of energy over a broad range of wavelengths
  - Model must be unusual since no ordinary star could be so luminous nor could enough ordinary stars be packed into such a small volume

Cause of Activity in Galaxies

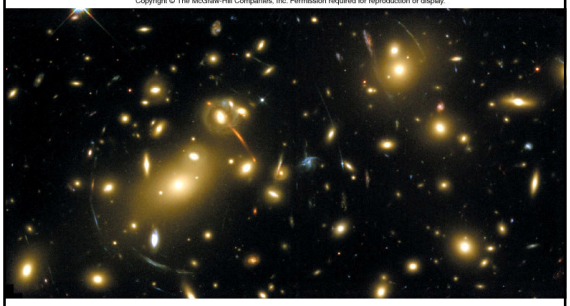
- Basic model
  - Black hole about the size of the Earth with a gas accretion disc tens to hundreds of AU across
  - Most gas drawn into black hole heats to millions K
  - Some gas channeled by magnetic fields into jets
  - Accretion gas replenished by nearby passing stars or material from collision with another galaxy

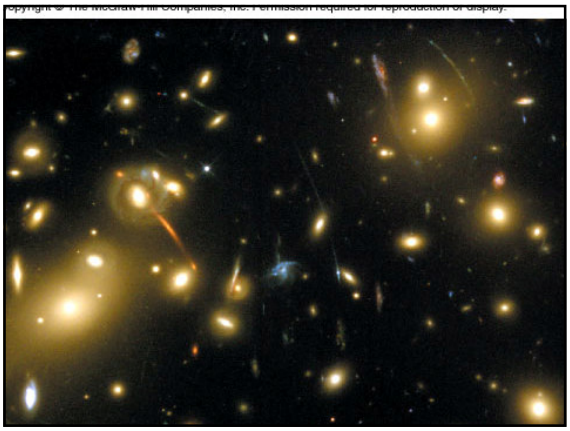


Galaxies as Structure

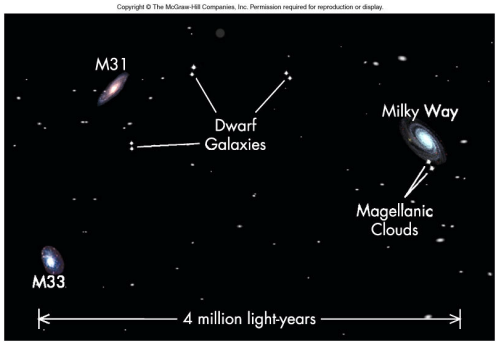


Galaxy Clusters





The Local Group



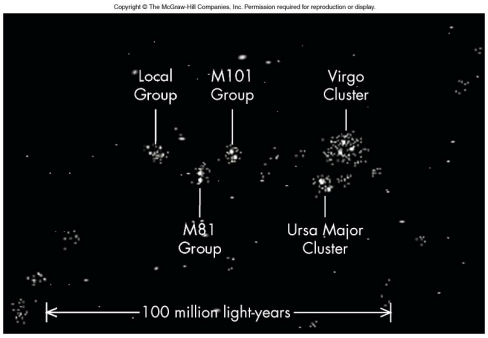
Galaxy Clusters

- In general, all clusters need dark matter to explain galactic motions and the confinement of hot intergalactic gas within cluster
- Near clusters appear to have their members fairly smoothly spread out, while far away clusters (and hence younger clusters) are more ragged looking – this suggests that clusters form by galaxies attracting each other into groups as opposed to clustering forming out of a giant gas cloud

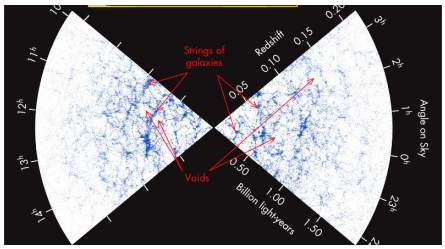
Superclusters

- A group of galaxy clusters may gravitationally attract each other into a larger structure called a ***supercluster*** – a cluster of clusters
  - A supercluster contains a half dozen to several dozen galaxy clusters spread over tens to hundreds of millions of light-years (The Local group belongs to the Local Supercluster)
  - Superclusters have irregular shapes and are themselves part of yet larger groups (e.g., the "Great Wall" and the "Great Attractor")

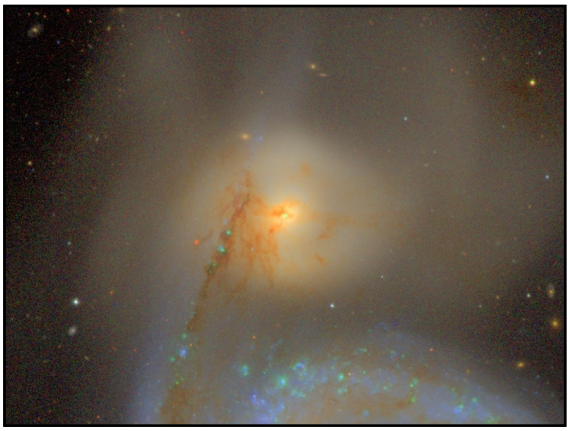
The Local Supercluster

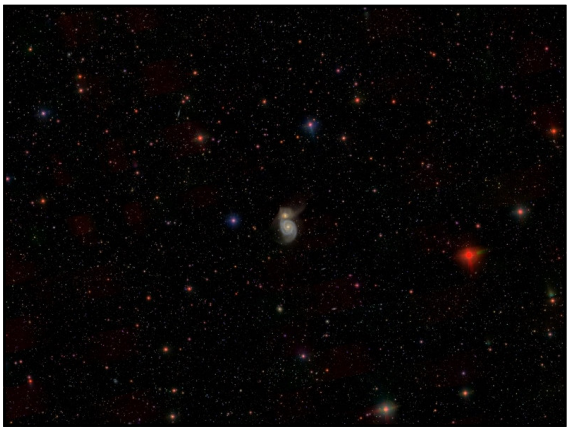


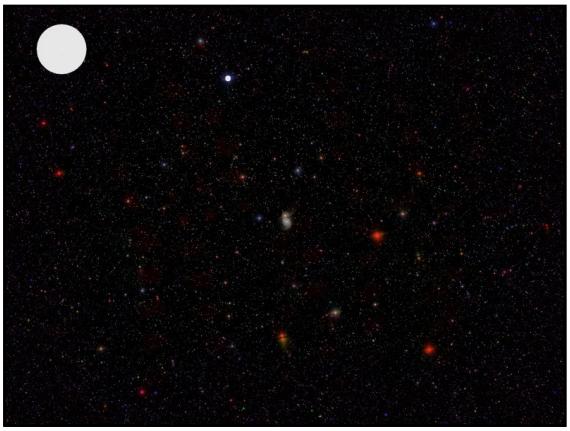
The Structure of the Universe

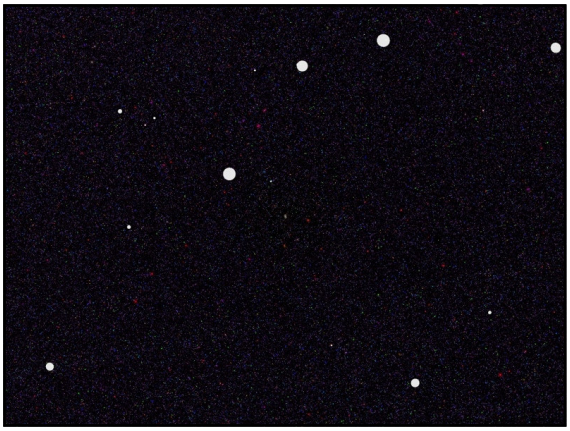


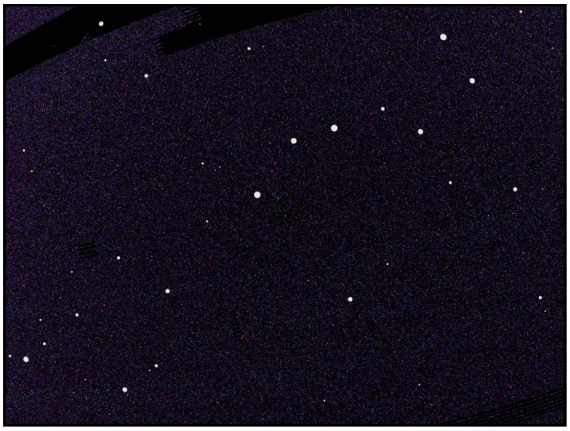
- Superclusters appear to form chains and shells surrounding regions nearly empty of galaxies – voids
- Clusters of superclusters and voids mark the end of the Universe's structure we currently see

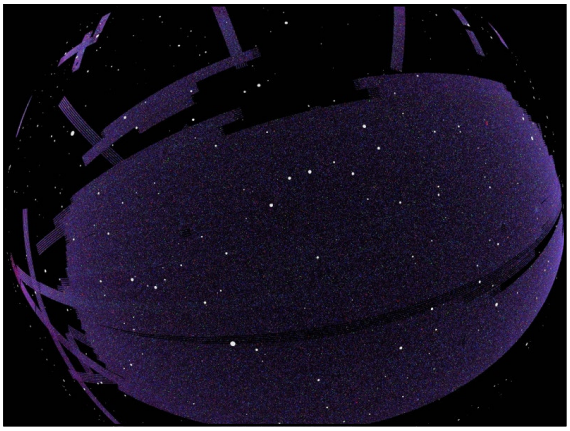


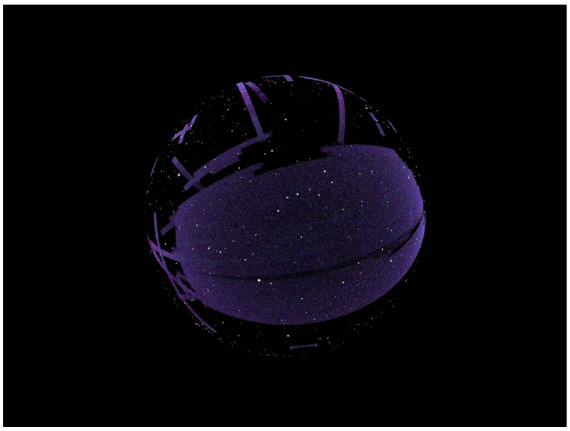












data: Sloan Digital Sky Survey
and the Bright Star Catalog

visualization: David W. Hogg (NYU)
with help from Blanton, Finkbeiner,
Padmanabhan, Schlegel, Wherry