Astronomy 162, Week 9
Properties and Distribution of Galaxies

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Review Properties of galaxies

- Review Table 26-1
  - galaxies have a large range of masses, luminosities and sizes
  - dwarf ellipticals very small, giant ellipticals can be very massive
  - the Milky Way is bigger, brighter, and more massive than a typical galaxy

Distribution of Galaxies in Space

- How is matter distributed in universe?
  - So far, we have studied
  - single stars
  - binary, multiple stars
  - star clusters
  - galaxies
  - non-uniform distribution on every scale
  - What about galaxies?

Galaxy Clusters

- On small scales, galaxies cluster together strongly.
- Consider the following examples:
  - Local Group
  - Virgo cluster
  - Coma cluster

Local Group

- Our Milky Way has numerous companions
  - M31 (Andromeda)
  - M33
  - Magellanic Clouds
  - intermediate and smaller galaxies
  - definitely is self-contained group

Fig. 26-00, M31 & Neighbors

Local Group

Fig. 26-17, The Local Group

Virgo Cluster

- Prominent cluster of galaxies
  - about 15-20 million parsecs distant from us
  - has thousands of galaxies
  - also has subgroups
  - includes M87

Virgo cluster

Coma Cluster

- Nearest rich cluster
  - mass about 4 x 10^{15} solar masses
  - X-rays from hot gas
  - iron present in gas
  - gas must have been processed through supernovae
  - few spirals in center, mostly ellipticals, S0s

Fig. 26-16, Coma Cluster

What about distribution on larger scales?

- Hubble counted galaxies in 1283 fields spread over sky
- (note use of sampling approach. He was not able to cover whole sky)
- He noted the zone of avoidance (dust in plane of Milky Way blocks view of distant galaxies)
- Otherwise he found a reasonably uniform distribution

- This was a very important result
  - Evidence that matter in universe is distributed uniformly on large scales
  - Essential for study of cosmology (will discuss this point more at that time)

Peculiar and Interacting Galaxies

- Some galaxies don't look like normal spirals, ellipticals, or irregulars
  - may have streaming tails
  - or look like double, distorted galaxies
  - or have unusual luminous rings
- What are they?

Galaxy collisions

- What happens if galaxies collide?
  - Actual collisions of stars are rare
  - Galaxies are big, loosely bound by their own gravity
  - When they collide, the result may be
  - a merger (if galaxies are comparable in size)
  - or cannibalism (larger galaxy absorbs smaller)
  - outer parts may be torn away

- Then we see long, tidal tails
- But the nuclear regions merge together, eventually leaving one nucleus
- Note Fig. 26-26, 26-27
- Today, computer simulations provide good explanations of collisions
  - Note that collision trigger bursts of star formation

Astronomy 162, Week 9
Expansion of the Universe

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Expansion of the universe

- Slipher - Lowell Observatory - 1912 and following years
  - found spectra of galaxies showed mainly red shifts (receding from us),
  - although M31 is approaching
  - as so often happens, his observations gave main clues, but it took years to sort out the puzzle

Hubble's work

- He and Humason used 100-in telescope
  - measured spectra and brightnesses of fainter galaxies
  - determines magnitudes and redshifts
  - in 1929, presented the velocity-distance relation
  - This was evidence for expansion of the universe!!!
  - see Fig. 26-15

Fig. 26-15, The Hubble Law today

Hubble law

- Result had profound consequences - universe was not static
  - Furthermore, the velocity of recession and the distance of the galaxies were proportional
  - velocity = H_0 x distance (H_0 is Hubble's constant)
  - velocity gives distance and vice versa
  - See box 26-2

- Additional consequence of Hubble law
  - universe appears everywhere the same
  - we are NOT at the center of expansion
  - if we see the same expansion law in all directions
  - then the universe is isotropic (same in all directions)
  - homogeneous (same structure everywhere)

What is expanding?

- Space is expanding
- Galaxies are (more or less) at rest in the universe
- They appear to move outward as space expands

Expansion and the redshift

- Redshift (z) - shift of spectral lines to red caused by expansion of universe
- at small values, like Doppler shift (but it isn't)
- at large distances from us, redshift can exceed the value of 1
- (1+z) tells us how much universe has expanded since light was emitted
- z=1 means universe is now twice as large as it was when light was emitted

How fast does space expand?

- Hubble constant, H_0, is crucial number
  - units are km/s per Mpc
  - current value is near 71 km/s/Mpc
  - thus, speed is 710 km/s at 10 Mpc,
    7100 km/s at 100 Mpc

Age of universe

- Inverse of Hubble constant is a time
  - Let t_0 be age since expansion began
  - $t_0 = 1/H_0$
  - If H_0= 75 km/s/Mpc, this implies t_0 = 13 billion years, that is, the expansion age of universe
  - There is still uncertainty in the exact value

Difficulties in measuring H_0

- Main problem is getting accurate distances to galaxies
  - but Hubble Space Telescope has made much progress by measuring cepheids in galaxies in Virgo Cluster
  - Another problem is motion of galaxies relative to each other (e.g. Virgo and Local Group)
  - Need to reach even greater distances

Large Scale Structure

- Consider distribution of galaxies on largest observable scales
  - clusters of galaxies may be 5 Mpc across, 100s of Mpc distant
  - How is matter distributed on large scales?
  - On what scale does distribution become uniform?

Methods

- Use redshift as indicator of distance
  - OK in a relative sense (uncertainty in H_0 only produces change in scale)
  - galaxy motions can be a problem, but can be corrected for

Local Supercluster

- Galaxies cluster to form clusters of galaxies
- Clusters group together to form superclusters
- Local Group is but one member of great collection of clusters, including Virgo
- Our supercluster is expanding, however

Larger scales

- Filamentary structure (see Figs. 26-20, 26-21 and 26-22)
- Voids - regions empty of galaxies
- Great wall - mapped by redshift surveys, about 200 Mpc across
  - largest structure observed to date

How to observe still larger scales?

- Need to cover a good part of entire sky to faint magnitudes, great distances
- Sloan Digital Sky Survey is mapping the entire north polar cap (www.sdss.org)
- Goal is to find at least 1 million galaxies, obtain redshifts

When does it become uniform?

- The universe finally appears uniform on scale of about a billion parsecs

The most distant galaxies: The deepest views of the universe

- The Hubble Deep Field, GOODS, UDF
  - Deepest images of sky ever taken
  - For example, 10 days of observation with Hubble on a single field, over 300 exposures
  - Implies we could see 40 billion galaxies over entire sky
  - Reaches to such large distances, we see galaxies as they were over 10 billion years ago

- See www.stsci.edu/resources/
  - Look for links on
  - HDF (Hubble Deep Field)
  - GOODS (Great Observatories Origins Deep Surveys)
  - UDF (Ultra Deep Field)

- Large telescopes act as time machines
  - allow to look back to when galaxies were forming
  - Hubble Deep Field shows galaxies over wide range of evolutionary states

Astronomy 162
Active Galaxies and Quasars

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Background

- Recall main properties of galaxies
  - composed of stars, gas, dust, molecular clouds
  - may be 100,000 light yrs across
  - may have 100 to 1000 billion solar masses
  - 100 billion or more solar luminosities
  - they're big collections of stars and matter, held together by gravity, understandable in many ways

Active Galaxies
Ch. 27

- Some galaxies have very bright nuclei
  - We'll see the nuclear activity is not due to stars
- Will discuss three main types:
  - Seyfert galaxies
  - Radio galaxies
  - Quasars
- Quasars are the most luminous objects in the universe

Seyfert Galaxies

- 1943 - Carl Seyfert - study of spiral galaxies with strong emission lines
- Common properties include:
  - bright, starlike nuclei
  - broad emission lines (rapid motions of gas)
  - continuous emission (including X-rays), not from stars
  - variable in light in days to weeks

Radio galaxies

- Elliptical galaxies with strong radio emission
- bright starlike nuclei with X-ray emission
- nuclear light not produced by stars
- optical jet seen in M87
- radio jets commonly seen, may extend to millions of parsecs
- often have extended radio emission on both sides

Quasars

- story begins with radio astronomy
  - 1st radio source discovered is at center of Milky Way
  - later, other radio galaxies were discovered, some very powerful
  - how to produce so much radio emission? Not by ordinary stars
  - irony - radio waves have very low energy

- but some radio sources have very large amounts of total energy
- Radio galaxies are mysterious enough
- When radio "stars" were discovered, they were really mysterious
- Were they stars in our galaxy?
- Establishing their distance was crucial

Quasar History

- 1st positions of radio sources not accurate
- As they improved, some peculiar radio galaxies were identified
  - Cygnus A (Fig. 27-1)
  - To Baade and Minkowski, looked like colliding galaxies
  - What are they?

Advances in radio astronomy

- Use of interferometry (connected telescopes) and occultations (eclipses) of radio sources by moon
- led to better positions
- some "stars" were identified
- had mysterious spectra with unidentifiable emission lines

– 1963 - identification of radio source 3C273 with a 13th mag “star”
– Maarten Schmidt realized emission lines in spectrum were from hydrogen, but
– redshifted by 15.8%!!
– This was completely unexpected
– Was the discovery of quasars

Quasars

– Originally were called quasi-stellar radio sources (looked like stars, but were not)
– Later, many similar objects were discovered which did not emit (much) radio radiation
– Finally - all were regarded as members of same class
– Invention of word “quasar” - a starlike object of large redshift

Why the excitement?

– Schmidt made the cover of Time magazine
– quasars - obviously not stars
– if at distance indicated by the large redshifts (recall Hubble law)
– quasars had more luminosity than entire galaxies
– but were not much bigger than the solar system (because their light changes on time scales of days to months)

The big question

– How can quasars produce and emit so much energy in a volume not much bigger than solar system?
– nuclear reactions are not sufficient
– the problem brings us back to gravity
– and the concept of massive black holes

Quasars

- Some main points
  – starlike (compact) nuclei
  – redshifts from 0.1 to 6.3
  – variable in light from days to months
  – luminosities up to 10^{14} suns

Quasars, cont.

- Basic questions:
  - What are they?
  - What is their energy source?
  - How did they form and evolve?

Numbers and Evolution

- The number of quasars at different redshifts tells us about their evolution
  - Higher redshift means we see them as they were at earlier times
  - Recall Herschel & “star gauging” or counting
  - Use similar idea, but modified for cosmology
  - Difficulty is that quasars are rare, hard to find at large redshifts

Results

- Quasars are much more frequent at redshift 2 than at present time
  - universe was then 20% of its present age
  - at even earlier times, numbers decrease significantly
  - highest redshift known for a quasar is 6.4
  - See Fig. 27-5

- Have we seen back to the epoch of quasar formation?
  - Quite possibly
  - Light travel distance at redshift 5 is 14 billion light years, universe about 7% of its present age
  - Could dust be a problem (as it is for our galaxy)
  - Possibly - stay tuned for future results

Energy source for quasars

- How can so much energy be emitted from such a small volume?
  - Energy source must be even more powerful than nuclear reactions
  - Gravity is best bet
  - Matter falling onto a supermassive black hole can yield as much as 10% of its rest energy
    (10 times more than nuclear reactions)

Models for quasars

- Note the irony - gravity, the weakest force in nature, can yield the most energy, at least near a black hole
- General concept - accretion disk surrounding black hole
- Matter spirals in, gets very hot, radiates strongly
- Jets of matter are ejected from poles (same idea as in protostars)

Gravitational Lensing

- If light from distant quasar passes near galaxy or galaxy cluster on its way to us,
- gravitational lensing can occur
- Lensing can produce
  - double image of a quasar
  - a (Einstein) ring
  - a cross (four images)

Gravitational Lens Link

- CASTLES Survey (OSU Prof. Chris Kochanek)
- See, for example, the object at
  - http://cfa-www.harvard.edu/castles/Individual/MG0414.html

- Lensing can give
  - estimate of Hubble constant (from time delay of variation of both images)
  - estimate of amount of dark matter along line of sight

Summary

- Active galaxies, quasars believed to be powered by supermassive black holes in their centers
- Their appearance depends on viewing angle, how massive the black hole is, and how much mass is falling on it
- (Dead quasars would be galaxies with black holes but no mass falling in)

Quasars are the most luminous objects in the universe, are seen to great distances

- Quasars can tell us about the formation and evolution of galaxies

Fig. 27-6, Quasars and their Host Galaxies
Fig. 27-7, Seyfert Galaxy NGC 7742