Announcements

Exam #4 is on Thursday, covering Chapters 12–15.

Bonus round of observing: Next Week, Dec. 6-9th, 6:30pm.

Don’t like your grade? Think about going back and completing overdue homeworks for >50% credit.

Homework this week — Ungraded/Exam Review: Complete “Study Area” quizzes for Chapters 12–15 (Remember: I don’t see any of your work there).
Galaxies have flat disks, and spheroidal (round or football-shaped) bulges and haloes.

Galaxies come in different types: spirals, barred spirals, ellipticals, and irregulars.

Different types have different proportion of spheroidal vs. disk.
In addition to stars, galaxies contain gas and dust ("Interstellar medium").

They also contain lots of "dark matter" which causes them to rotate fast, but is invisible... still not sure what it is.

Spirals have most gas/dust and forming stars in their spiral arms, which are bright thanks to all the young, hot, luminous stars.
Last Time: Galaxies

Disk is where gas and dust is, where stars form, were molecular clouds live. Bulge is old stars, little gas or dust. Halo is much larger and has old stars and globular clusters.

Milky Way in a quiet region: two dwarf neighbor galaxies, one big one nearby (Andromeda). Many very small dwarfs in the “local group”

Galaxies often occur in clusters of 10’s to hundreds of galaxies.
Southern Sky

SMC

LMC

Milky Way

Credit: R. Smith/CTIO

Tuesday, November 30, 2010
Last Time: Galaxies

Distances to galaxies is a fundamental problem: you don’t know how bright or how big they are by just looking!

Need to use a “distance ladder” working our way up from very nearby stars (parallax) to clusters of stars (main sequence fitting) to bright variable stars (cepheids) to galaxies at greater distances.

Distant galaxies (or any object) are seen not as they are now, but as they were millions or billions of years ago when the light we currently see was emitted.
Distance Ladder

- Distances are like a ladder.
- To get Parallax distance, we need distance to Sun (radar ranging).
- To get star cluster (main sequence) distances, we use parallax to the closest one of them (Hyades).
- To find Cepheid (variable star) distance, we use ones in clusters.
- Using cepheid distances to nearby galaxies, we can find out how bright white dwarf supernovae are, and use them.
- Distances measured with White Dwarf Supernovae let us measure Hubble’s Constant.
UNIVERSE IS FILLED WITH GALAXIES.

LIGHT IS FAST, BUT NOT INFINITELY FAST: THE FAR AND AWAY YOU LOOK, THE FURTHER BACK IN TIME YOU SEE.

GALAXIES IN THE VERY DISTANT UNIVERSE APPEAR AS THEY WERE SHORTLY AFTER THE UNIVERSE FORMED!
Our place in the universe: Historical Context

The Shapley-Curtis “Great” Debate of 1920. At issue: What is a “Spiral Nebulae”

The Galaxy is large, much larger than previously thought, and the sun is not at its center. It is the whole universe.

The “Spiral Nebulae” are island universes, each as large as the galaxy, and at great distance from the galaxy (which has the sun at its center)
Edwin Hubble

An astronomer in the early 1900’s who settled the debate on the “Spiral Nebulae” by observing Cepheid stars in the Andromeda galaxy.

Showed convincingly it was much too far away to be in the Milky Way.

He began to study the distances to other galaxies in the same way.
Locating the Spiral Nebulae

To measure the distance to nearby galaxies in the 1920’s, E. Hubble used Cepheid variable stars as “standard candles”.

He found something very surprising...
Galaxy Motion

- Galaxy spectra:
  - Absorption lines redshifted
  - More distant galaxies always have larger redshift

- How can they all be moving away from “us”??
Hubble's Law

Hubble's Law:

-The more distant the galaxy, the faster it is moving away!

\[ v = H \cdot d \]

\((H \text{ is the Hubble constant, } d \text{ is distance})\)
Hubble’s Law

- All galaxies are moving away.
- The farther away, the faster they move.

Conclusion: The Universe is Expanding!

Predicted by Einstein’s Theory of General Relativity.

- Are we at the center? No.

Universe Same in all directions, so there is no center! How can this be?

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Sidenote: Einstein’s Greatest Blunder

Albert Einstein’s theory of general relativity predicts that the universe must expand.

He thought the universe was unchanging, so he modified his law, adding a term to keep the universe static.

When Hubble proved the universe is expanding...

[Einstein] remarked that the introduction of the cosmological term was the biggest blunder of his life. — George Gamow, 1970
The Expanding Universe

- A uniformly expanding universe explains Hubble law
- Example: Expanding loaf of raisin bread
- Galaxies (like raisins) not moving, not expanding
- Space itself is expanding!
What can be said about the location of the center of our expanding universe?

A) Earth is at the center.
B) The Sun is at the center.
C) The Milky Way Galaxy is at the center.
D) The universe does not have a center.
WHAT CAN BE SAID ABOUT THE LOCATION OF THE CENTER OF OUR EXPANDING UNIVERSE?

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Structure in the Universe

Hubble’s law is very powerful.

By measuring the spectrum of a galaxy, you get its redshift. Using Hubble’s law, you get its distance.

Hubble’s law allow you to locate galaxies 3 dimensionally, and see how the universe is organized.
Structure in the universe
Structure in the Universe

- Galaxy surveys show structure
- Voids
- Filaments/sheets
- Galaxy clusters
  - Found within the filaments/sheets
- Superclusters
  - Found at intersections of several filaments/sheets
Cosmological Principle

- **Cosmological principle**

  on large scales, Universe is:

  - **Isotropic**

    looks the same in all directions

  - **Homogeneous**

    any region of space is about the same as any other
**Age of the Universe**

- **Hubble: Universe is expanding**

- “Run movie backward”. In the beginning, all matter within small region (single point)

- **Subsequent expansion called Big Bang.**

- **Not an explosion**

- Galaxies are not moving (flying apart). Instead, space is expanding!

- **Age of the Universe**

  \[ T_0 = \sim 1/H \]  
  (Hubble time)

  \[ = 13.7 \text{ billion years} \]
Your friend leaves your house. She later calls you on her cell phone, saying that she’s been driving at exactly 30 miles an hour directly away from you the whole time and is now 60 miles away. How long has she been gone?

A) 1 minute
B) 30 minutes
C) 60 minutes
D) 120 minutes
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Your observe a galaxy moving away from you at 0.1 light-years per year, and it is now 1.4 billion light-years away from you. How long has it taken to get there?

A) 1 million years
B) 14 million years
C) 10 billion years
D) 14 billion years
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Evolution of Galaxies

- We observe the history of galaxy not by watching one galaxy evolve, but by looking at galaxies at greater and greater distances, to observe them when they were young.

- The universe acts like a time machine in this respect.
Brief history of Galaxy Formation

- Universe is ~13.7 billion years old.
- Stars formed much more actively in the past.
- Galaxies formed from coalescing gas left over from the “Big Bang”.
- Galaxies evolved as a result of Star Formation, Stellar Evolution, Galaxy Collisions and mergers.
First Galaxies

Best models for galaxy formation assume:

- Matter originally filled all space almost uniformly
- Slightly denser regions began pulling in surrounding matter.
Galaxies Forming

- Denser regions contracted, forming protogalactic clouds of mostly Hydrogen and Helium.

- First stars form, and supernova explosions prevent all the gas from coalescing.

- Leftover gas settles into a spinning disk (conserving angular momentum).
Caught in the Act

Galaxy collisions are common, but "major" ones are less common in recent times.

Many such collisions have been "caught in the act".
Galaxy collisions are common, but "major" ones are less common in recent times.

Many such collisions have been "caught in the act".
Simulation by John Dubinski

Tuesday, November 30, 2010
Mergers

- Mergers and collisions can change the shape of a galaxy, and mix-up all the stars.
- Two spiral galaxies with large disks can merge into one larger elliptical without a disk!
- Such giant elliptical galaxies are much more common in huge galaxy clusters, because collisions happen more frequently there!
Galaxy Evolution

- Controlled in many ways by history of collisions with other galaxies, big and small.

- When galaxies collide, their gas is ignited, and stars are formed very rapidly, in a phase called a Starburst Galaxy.

- The Milky Way forms about 1 sun’s mass worth of stars per year. A starburst galaxy might form stars at a rate 100x larger!
The formation of a Milky Way like galaxy

Galaxy formation simulations created at the

N-body shop
makers of quality galaxies

key: gas- green new stars- blue old stars- red

credits: Fabio Governato (University of Washington)
Chris Brook (University of Washington)
James Wadsely (McMaster University)

simulation run at the CINECA supercomputing center, (BO, Italy)
contact: fabio@astro.washington.edu
Milky Way vs. Andromeda

In 3 billion Years the MW and Andromeda will collide.

The sun will survive, but may get tossed out of the combined system!
What Lurks at the Heart of Galaxies?
Many galaxies contain “Active Galactic Nuclei” (AGN), fueled by super-massive black holes from millions to billions of times the mass of the sun.

Quasars are incredibly powerful AGN galaxies, no longer common in the universe, but up to 1000x as powerful as the milky way galaxy. They are among the most distant known objects in the universe.

A trillion solar luminosities all from a small region the size of our solar system in the center of a galaxy!
QUASARS AND AGN

Two Quasars with Their Host Galaxy (HST)

ESO PR Photo 28a/05 (September 14, 2005)
Quasar Jets

The supermassive black holes at the center of quasars shoot jets of material at nearly the speed of light, which can be seen at great distances.

These are seen in radio and other wavelengths.
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AGN Torus

- **AGN and Quasars contain a dusty torus of material which feeds the black hole.**

- **What we see depends on how we view this torus (along the jet, along the torus, etc.)**
The only power source which can launch jets to nearly light speed, and outshine thousands of galaxies is a supermassive black hole.

As matter falls onto a black hole, its gravitational potential is converted to heat, and the gas radiates in X-rays (among others).

This can convert from 10–40% of all the mass-energy into radiation (remember $E=mc^2$). By contrast, stars convert <1% of mass-energy. Burning coal: 1/10,000,000,000,000%.
Exam Review

- 4 Chapters, 12-15

- Same format as usual. Bring a pencil.

- Do the online study quizzes!!!

- Great chance to bump one of your lower mid-term grades.
Review

- Stellar birth, life, and evolution.
- Life of low and high mass stars.
- Evolution on the HR diagram.
- Degeneracy pressure as an alternative form of star’s support.
- Death of a star: high-mass vs. low-mass.
- Nova and Supernova
Review

- White Dwarfs, Neutron Stars and Black Holes.

- Nova: rejuvenating a white dwarf by dumping material on it/

- Visiting a black Hole.

- Gamma Ray Bursts.
**Review**

- Our Milky Way: normal spiral galaxy 100,000 light years in diameter.

- Bulge/Halo/Disk. Halo stars old (Globular clusters there), disk stars young and orbiting in a plane.

- Interstellar medium of gas and dust, continuously recycled through stars, increasing the amount of heavy elements (like us!).
Review

- Supermassive black hole at Galactic center, moving nearby stars in very fast orbits. 3-4 million solar masses!

- Bulge/Halo/Disk. Halo stars old (Globular clusters there), disk stars young and orbiting in a plane.

- Interstellar medium of gas and dust, continuously recycled through stars, increasing the amount of heavy elements (like us!).
Review

Today’s materials on galaxies, the expansion of the universe, galaxy collisions, quasars and “active galactic nuclei”.

Tuesday, November 30, 2010
Reminders

Exam #4 Thursday. Buy-Back online again, and due one week from Thursday.

Your (ungraded) Homework/Exam Review assignment: “Study Area” Quizzes on Chapters 12–15.

Bonus Observing week Next Dec 6-9th, 6:30 on the roof. Bring your Blue Tickets. Last Chance!!!

Last chance for Planetarium: next couple of weeks!