Exam #3 Buy-back: due today, right now!

Now that observing is over, don’t forget to fill out your M.A. reports (planetarium too!).

Homework #4: Available Now, Due Tue, Dec. 2nd (after the holiday), 11:30pm.
Exam #3

Average: 53%, Max: 96%

Adjusted grades so that 39% is minimum passing grade (60). Max: 96%.

Buy-back extra credit, and OBAFGKM(LT) extra credit will be added on top of this adjusted grade.

Grades available on the course website.

Don’t remember your class ID? See me after.
The Exam Distribution
The exam in review

Answer key with your grades available after class.

Let’s go over the exam questions.
Improving your grade

Only 54% of course grade “complete”. STILL room for improvement.

Go back and do any HW problems you skipped: you’ll still get points.

Don’t forget the out-of-class planetarium/observing events. These should be “freebies”, like getting 100% on an exam!
First Image of Extra-Solar Planet!

Fomalhaut
HST ACS/HRC

Location of Fomalhaut
Coronagraph mask
Dust ring
Scattered starlight "noise"

Background Star

100 AU 13"

No data

Fomalhaut b planet

2006
2004
And another, with 3 planets! A third was found even closer using Keck + AO.
LAST TIME: MILKY WAY

- A spiral disk galaxy, sun about 2/3rd the way out.

- Consists of Disk (100,000 LY diameter), Bulge, and halo. Stars in each component orbit the galaxy differently.

- Sun orbits in plane of disk, once every 230 million years!
LAST TIME: MILKY WAY

The gas is denser in some places than others, but on average, only 1 molecule every $1 \text{ cm}^3$! Dust: on grain per house sized region.

Gas and dust released from stars as they die is recycled into new stars by the Galaxy.

Galaxy arranged in spiral structure: spiral arms contain the gas, the star-formation.
**Last Time: Milky Way**

- Stars orbit too fast to be pulled around by only visible matter. Even counting gas and dust, there is not enough. We need **dark matter**. 5x more dark matter in universe than “normal” matter.

- Disk is filled with dust: Infrared Light penetrates through dust, to view the center. We see stars moving very fast, pulled by a 3 million solar mass object in a space the size of the solar system: **supermassive black hole!**
A Universe of Galaxies
Dwarf galaxies orbit Milky Way

Large Magellanic Cloud

Small Magellanic Cloud

Recently a third small galaxy was discovered

Collide with Milky Way

Stars and gas stripped during collision

Companions slowly being cannibalized
OTHER GALAXIES

- **EXTERNAL** to Milky Way
  - established by Edwin Hubble
  - used Cepheid variable stars to measure distance
  - M31 (Andromeda Galaxy) far outside Milky Way

**Three basic types:**
- **ELLIPITICAL**
- **SPIRAL**
- **IRREGULAR**
Galaxies come in different types
Spheroidal Component: Old Stars, little gas (bulge & Halo)

Disk Component: stars of all ages, gas, and dust
Andromeda Galaxy (M31)
Spiral Galaxies

Similar to Milky Way:
- Thin disk + nuclear bulge + halo

- Disk contains:
  - Dust and gas
  - H II regions, H I regions, molecular clouds
  - Spiral arms
  - Active star formation
  - Open clusters
  - Mixture of young & old stars

- Halo contains:
  - Old stars
  - Globular clusters

- Bulge contains:
  - Old stars
Barred Spiral Galaxies

Some spiral Galaxies have a bar in center
Elliptical Galaxies

**Shape ranges from:**
- Spherical to ellipsoidal

**Characteristics:**
- No disk or spiral arms
- Old reddish stars
- Similar to halo or bulge in spirals
- Little gas or dust
- Little star formation
Irregular Galaxies

- No specific shape
- Often appear chaotic
- Often have intense star formation
  - gravitational interaction with other galaxies?
- Mixture of old and new stars
The Local Group

- **The Local Group**
  - Group of galaxies
  - Milky Way is member
  - At least 30+ galaxies
  - 3 Large Spirals
    - Milky Way, Andromeda, M33
  - Remainder mostly dwarf ellipticals

Positions are approximate.
THE LOCAL GROUP

Galaxies stretch in every direction beyond the Milky Way, but gravity keeps a family of some 30 galaxies, including our own, loosely bound. This Local Group of galaxies extends some four million light-years across. Most galaxies in the group are considered dwarfs, but the two largest—our own Milky Way and the Andromeda galaxy—are giant spirals. Andromeda is at the center of a small subgroup, which includes two elliptical galaxies, M32 and NGC 205, where star formation has ceased. Even though it is more than two million light-years away from Earth, the Andromeda galaxy can be seen with binoculars.

It is possible that astronomers have not found some of our group’s smaller galaxies, which may be hidden behind dust clouds in the Milky Way. All three main types of galaxies are represented in the Local Group: spirals, ellipticals, and irregulars. Nevertheless, the group has relatively few members, a hundredth of that of some large galaxy clusters.

The galaxies of the Local Group are traveling together through space. Measurements show that the Milky Way is falling toward Andromeda. No collision is expected, however: Like race cars on opposite highways.
GALAXY CLUSTERS

Most galaxies found in "GALAXY CLUSTERS"

Examples: Virgo cluster, Coma cluster

Superclusters

Extremely rich galaxy clusters
Which Galaxy is Bigger?
Which Galaxy is Bigger?

Who Knows?
Distances to Galaxies

**Distance = Time:** The universe has its history encoded in images!

**Really hard!** (How big, how bright, we don’t know!). Too many different types/shapes of galaxies.

**Compare Apparent and Absolute Brightness using standard candles** (things we know the intrinsic luminosity of):

- Cepheid and RR Lyrae variable stars, brightest stars, supernovae, planetary nebulae.
Distances to Galaxies

- **Main sequence fitting.**
- **Other techniques:**
  - **For Spirals:** Rotation of rate galaxy gives mass, which depends on number of stars (roughly).
  - **For ellipticals:** Stellar velocities depend on mass, hence luminosity.
Looking at Distant Objects (page 131).
Announcements

Read sections 15.3–15.4 for next time.