Brooks observing

April 19 - 22: 9:00 PM to at least 10:15 PM

Tonight is a go!

April 26 - 29: 9:30 PM to at least 10:45 PM

Regular Friday evening public observing after planetarium shows also an option

- Begins about 8:45 PM through April
- Begins about 9:45 PM in May (planetarium starts 8:30 PM beginning May 7) *Emergencies only!

In all cases, your report due Wed. following

All planetarium, observatory reports due at final exam!
Quiz 6

Results better than Quiz 5, back to normal

Distribution not ready yet, sorry

Correct up to 4 questions, due Monday, Apr. 26

Final Exam

Wed., May 5, 7:30-9:30 PM, MH 1005

- Comprehensive but a little more emphasis on content after quiz 6
- Approx. 100 questions, best 90 (or more) to count
Study suggestions

Start from class notes

Find corresponding material in text

Study both versions

Test yourself

• Choose end of chapter questions that are relevant to class notes

• Make sure you can answer all quizzes (answer keys have been/will be posted)

• Reread text & notes with questions in mind
The Galaxy

A galaxy is a large grouping of up to a trillion stars that are bound together by their mutual gravitational attraction.

“The Galaxy” (capital G) refers to the one in which we live.

The Milky Way

• A dimly luminous, broad band of light encircling the sky and made of the light of thousands of stars too dim to be seen individually

• The Galaxy as seen from our point of view

• This name is also given to the Galaxy.
Contents

• Stars

• Star clusters, 2 types
  – Open clusters
    • No particular shape
    • Up to 1000 stars in a diameter of a few light years
Globular clusters (M13)

* Spherical in shape
* 100,000 or more stars in a diameter of about 300 light years
* Oldest dated objects, age typically about 13 billion years

- Interstellar matter
  - Very low-density material pervading nearly empty space between the stars
  - Gas: mostly hydrogen, helium
— Dust

* Small solid particles; like smoke
* Dims and reddens starlight by scattering or deflecting light from its path, short-wavelength light more than long-wavelength light
* Limits our ability to detect light from distant objects within the plane of the Galaxy
- Nebulae: denser concentrations or “clouds” some light years across; include gas and dust; often star forming
  - Dark nebulae: cold clouds. Dust blocks background light.
  - Emission or ionization nebulae: nearby hot stars ionize atoms, atoms recombine with electrons, producing emission-line spectra
  - Reflection nebulae: nearby star not hot enough to ionize gas, dust just reflects starlight. Blue in color.
  - Example shown — the *Trifid Nebula* — includes all three types
Structure of Galaxy: mapped out from studies of locations of thousands of stars and star clusters

- Within the Milky Way, young stars and ionization nebulae trace out arms

- As a group, globular clusters locate the center of the Galaxy at a distance of about 25,000 light years from us, beyond the constellation Sagittarius

But only a fraction of the Galaxy is observable to us in visible light; interstellar dust blocks out the rest.

Full-sky view of the Milky Way in infrared light

Artist’s concept of the structure of the Galaxy

(courtesy NASA)
Components of the Galaxy

**Thin disk:** includes the Sun & most nebulae; stars move in circular orbits in one plane

**Thick disk:** stars’ orbits more elliptical, inclined

**Spheroid:** more densely concentrated ball of older stars near the center

**Halo:** thinly populated, spherical volume
Rotation and mass of the Galaxy

- Picture built up from proper motions & radial velocities of thousands of stars, near and far (out to a few thousand light years)
- Near the Sun, stars move randomly at a few miles per second in relation to each other
- The Sun orbits the center of the Galaxy at a speed of about 150 miles per second. At that rate, it completes an orbit in 250 million years.
- From the Sun’s speed and distance from the center, the law of gravity says that the total mass inside the Sun’s orbit is about 100 billion solar masses.
Stars located far outside the Sun’s orbit move at about the same speed as the Sun.
This means: the stars’ motions in the Galaxy are not controlled by a dominant mass at the center.

Rather, by \textit{all} the stars’ masses together.

In fact, calculations show that most of the galaxy’s mass is not in the disk but in the halo.

This mass emits no light (there are few stars in the halo.)

Conclusion: the Galaxy has a massive \textit{dark matter halo}, which contains most of the Galaxy’s mass but emits no light.

What this \textit{dark matter} is made of is not known.
Central regions of the Galaxy

Zoom in . . . visible light views

Short wave infrared picture from *Hubble Space Telescope* emphasizes ionization nebulae, shows a surprising number of star forming regions

Infrared views of the central regions at longer and longer wavelengths penetrates obscuring dust that lies all along line of sight — the longer the wavelength, the more penetration

Longer wave infrared picture from *Spitzer* shows dust heated by young stars
Center of the Galaxy

- At the precise center of the Galaxy is a radio source called Sagittarius A*.
- **Infrared pictures** show a large cluster of stars, each star orbiting the center. Over the course of a decade, their motions have been measured with sensitive equipment.
- One star is on a **15-year elliptical orbit** plunging in to a distance of only 17 light *hours* from the center.
- From its orbit, calculations show it is orbiting an object with a mass of about 4 million Suns.
• From its small size, the object Sagittarius A* must be a supermassive black hole.

• But the relatively low luminosity from its vicinity shows that it currently doesn’t have an active accretion disk.

• As we’ll see, massive black holes are often found in the centers of galaxies.

X-ray picture from Chandra emphasizes X-ray binary stars and the central black hole.

Light echoes about 100 light years from the center suggest that Sgr A* had a luminosity outburst about 100 years ago.
Combined short-wave infrared, long-wave infrared, and X-ray picture of the Galactic center region
Fig. 2 — The space distribution of the associations, O, clusters, ., and H II regions, x, with supergiant members. H II regions with kinematic distances are designated by Δ and the arrow indicates the probable correction to the distance due to noncircular motions.
The Galactic Center (GC) is invisible at optical wavelengths (0.4-0.7 microns) from Earth even with the largest telescope imaginable! The interstellar dust in the plane of our Milky Way galaxy absorbs the light from the center, which is 26,000 light years away from us. Spitzer’s mid-infrared cameras see through the dust and can cover large areas efficiently.
90 degrees wide
4 degrees
0.4 degrees
Infrared Views of the Galactic Center

The GC is revealed at longer infrared wavelengths!
Schodel, R. et al. [22 other authors] 2002, Nature, 419, 694

Period 15.2 yr
Inclination 46°
Eccentricity 0.87
Semimajor axis 0.119"

Right ascension

Declination