Test 3 results

Grades posted in cabinet and Grades posted on-line

If you are not properly registered then come see me for your grade

Clicker Question:

What is the ultimate origin of the elements heavier than helium that make up your body?
(a) They were present when the Universe was created.
(b) They were created in low mass (< 8 solar mass) stars
(c) They were created in high mass (> 8 solar mass) stars
(d) They were created by neutron capture in interstellar space

Clicker Question:

A protostar that will eventually turn into a star like the Sun, is when compared to the Sun:
A: larger
B: fainter
C: hotter
D: less massive

Clicker Question:

What is the remnant left over from a Type Ia (carbon detonation) supernova:
A: a white dwarf + an expanding shell
B: a neutron star + an expanding shell
C: a black hole + an expanding shell
D: no remnant, just the expanding shell

Clicker Question:

A Type Ia supernova is the:
A: explosion of a massive star that has fused elements in its core all the way up to iron.
B: explosive burning of hydrogen on the surface of a white dwarf.
C: explosion of a white dwarf in a binary star system after mass has been transferred onto it from a companion star.
D: implosion of a blue supergiant to form a black hole.
The Milky Way Galaxy

Take a Giant Step Outside the Milky Way

Artist's Conception

Example (not to scale)

from above ("face-on")
see disk and bulge

from the side ("edge-on")

Another galaxy: NGC 4414. The Milky Way roughly resembles it.
The Three Main Structural Components of the Milky Way

1. Disk
   - 30,000 pc diameter (or 30 kpc)
   - contains young and old stars, gas, dust. Has spiral structure
   - vertical thickness roughly 100 pc - 2 kpc (depending on component. Most gas and dust in thinner layer, most stars in thicker layer)

2. Halo
   - at least 30 kpc across
   - contains globular clusters, old stars, little gas and dust, much "dark matter"
   - roughly spherical

3. Bulge
   - About 4 kpc across
   - old stars, some gas, dust
   - central black hole of $3 \times 10^6$ solar masses
   - spherical

Shapley (1917) found that Sun was not at center of Milky Way

Shapley used distances to variable “RR Lyrae” stars (a kind of Horizontal Branch star) in Globular Clusters to determine that Sun was 16 kpc from center of Milky Way. Modern value 8 kpc.

Stellar Orbits

Halo: stars and globular clusters swarm around center of Milky Way. Very elliptical orbits with random orientations. They also cross the disk.

Bulge: similar to halo.

Disk: rotates.

Precise Distance to Galactic Center

Distance = 7.94 +/- 0.42 kpc

Where is our solar system located?

A: near the center of the Milky Way Galaxy in the bulge.
B: 4 kpc from the center of the Milky Way in the halo.
C: 8 kpc from the center of the Milky Way in the disk.
D: 20 kpc from the center of the Milky Way in the disk.

Clicker Question:
Clicker Question:

What lurks at the center of our galaxy?
A: A giant star cluster.
B: A 30 solar mass black hole.
C: A 3 million solar mass black hole.
D: Darth Vader

Rotation of the Disk

Sun moves at 225 km/sec around center. An orbit takes 240 million years.
Stars closer to center take less time to orbit. Stars further from center take longer.

rotation not rigid like a phonograph record or a merry-go-round. Rather, "differential rotation".

Over most of disk, rotation velocity is roughly constant.

Spiral Structure of Disk

Spiral arms best traced by:
Young stars and clusters
Emission Nebulae
HI
Molecular Clouds
(old stars to a lesser extent)

Disk not empty between arms, just less material there.

Problem: How do spiral arms survive?

Given differential rotation, arms should be stretched and smeared out after a few revolutions (Sun has made 20 already):

The Winding Dilemma

The spiral should end up like this:

Real structure of Milky Way (and other spiral galaxies) is more loosely wrapped.
Proposed solution:

Arms are not material moving together, but mark peak of a compressional wave circling the disk:

_A Spiral Density Wave_

Traffic-jam analogy:

Molecular gas clouds pushed together in arms too => high density of clouds => high concentration of dust => dust lanes.
Also, squeezing of clouds initiates collapse within them => star formation. Bright young massive stars live and die in spiral arms. Emission nebulae mostly in spiral arms.
So arms always contain same types of objects, but individual objects come and go.

90% of Matter in Milky Way is Dark Matter

Gives off no detectable radiation. Evidence is from rotation curve:
- **Solar System Rotation Curve**: when almost all mass at center, velocity decreases with radius ("Keplerian")

**Milky Way Rotation Curve**

Not enough radiating matter at large R to explain rotation curve => "dark" matter!

Dark matter must be about 90% of the mass!
Composition unknown. Probably mostly exotic particles that don't interact with ordinary matter at all (except gravity).
Some may be brown dwarfs, dead white dwarfs …
Most likely it's a dark halo surrounding the Milky Way.

**Mass of Milky Way**

6 x 10^{11} solar masses within 40 kpc of center.

**Clicker Question:**

How long does it take our solar system to orbit once around the Milky Way?
A: 1 year
B: 2 million years
C: 250 million years
D: 250 billion years (longer than the age of the universe)
Clicker Question:

What makes up most of the mass (90%) of the Milky Way Galaxy?
A: hydrogen gas
B: stars
C: dead stars (white dwarfs, neutron stars, and black holes)
D: we don’t know

Seeing into the center of the Milky Way