Astronomy Bizarre
309N Spring 2005
(46770)

Wheeler
April 4, 2005

Review for Test #3
SUPERNOVAE, NEUTRON STARS, BLACK HOLES

Type Ia - must generate explosion in old (1 to 10 billion years) stellar system. Most plausible mechanism mass transfer onto white dwarf.

Spectra of Type Ia reveal intermediate elements on outside (O, Mg, Si, S, Ca) and iron-like material on inside. Consistent with models of Chandrasekhar mass carbon-oxygen white dwarfs that begin with a subsonic *deflagration* and then ignite a supersonic *detonation*.

Identifying the binary evolution that makes Type Ia at the rate of 1 per 300 yrs. in a galaxy like ours has been difficult. Too much mass transfer will leave Hydrogen in the spectrum. Nova explosions will reduce the mass of the white dwarf, not grow it. There may be too few white dwarf pairs, too few recurrent novae, and too few supersoft x-ray sources.

Light curves - brightness versus time of supernova. Type Ia brightest, Type Ib, Type Ic, Type II dimmer.

Light curves - shock energy plus radioactive decay. Ejecta must be large before transparent enough for light to leak out. If too small originally (Ia, Ib, Ic) all shock energy goes into energy of motion, light curve must be from radioactive decay. Type Ia brighter, needs more nickel than Ib, Ic, hence different mechanism, a thermonuclear explosion of carbon/oxygen, not core collapse, produce ~1/2 $M_{\odot}$ of nickel.

Type II show shock energy in plateau, with evidence for radioactive decay at later time.

Explosion of carbon and oxygen or silicon - equal numbers of protons and neutrons, so first make nickel-56. Weak force causes radioactive decay in 6 days (half-life) to cobalt-56 and then in 77 days (half-life) to iron-56. Heat from decay provides delayed source of light.

In core collapse supernovae, Type Ib, Ic, Type II, radioactive nickel is produced by shock wave that induces rapid burning of silicon layer surrounding iron core. This produces ~ 0.1 $M_{\odot}$ of nickel.

Betelgeuse - 427 light years away, 15 to 20$M_{\odot}$, expected to explode within 10,000 years as core collapse Type II supernova.

Supernova 1987A

- The first supernova observable by the naked eye in about 400 years. It is directly observable only in the southern hemisphere.
- Large Magellanic Cloud—small irregular satellite galaxy about 150,000 light years from the Milky Way, the site of the explosion of Supernova 1987A.
- 30 Doradus or the Tarantula Nebula—the glowing region of new star formation near the site of the explosion of SN 1987A.
- SN 1987A was detected in radio, infrared, optical, ultraviolet, X-ray, and gamma ray bands of the electromagnetic spectrum.
- The star that exploded was a blue super giant. There was initial confusion over the identity of the star that exploded. Two stars are visible in photographs taken before the supernova, and two stars were still detected by satellite in the ultraviolet after the explosion. There originally were three stars in the same vicinity.

- Neutrinos were detected, proving that SN 1987A underwent iron core collapse to form a neutron star. No neutron star has been detected. Dim compact object in Cas A might be related. A black hole is still a possibility.
- Light Curve of SN 1987A
  Shock breakout in first day. Subsequent peak and tail of the curve are explained by energy of radioactive gamma rays from Nickle-56 and Cobalt-56 as they decay to form iron. Gamma rays, high-energy photons produced specifically by Colbalt-56, were also directly observed by satellite. SN 1987A ejected 0.07 $M_\odot$ of radioactive nickel.
- Rings
  The rings around SN 1987A were created by the star before it exploded, perhaps when it consumed a companion star. The ejecta of the supernova have begun to collide with the ring.
- Jets
  The shape and motion of the matter ejected by SN1987A are roughly consistent with the expanding "breadstick and bagel" configuration expected from the model of jet-induced supernovae. The "breadstick" is nearly perpendicular to the rings and the "bagel" is expanding in the plane of the inner ring.

Neutron stars – mass of sun, radius ~ 10km, density like atomic nucleus, huge gravity at surface.

Discovery of pulsars – pulsating radio sources

Interpretation of pulsars as rotating magnetized neutron stars

Role of magnetic field to cause radiation, misalignment of rotation axis, magnetic axis

Production of pulses – probably related to strong electric, magnetic fields at magnetic poles, ejection of electrons, annihilation of positrons

About 600 pulsars known, perhaps a billion neutron stars in the Galaxy.

Pressure support from quantum pressure of neutrons plus nuclear repulsion. Maximum mass of neutron star about 2 solar masses.

Neutron stars as binary X-rays sources.

X-ray pulsars – accreted gas channeled to magnetic poles, neutron star spins faster as it accretes.

X-ray transients – 4 or 5 in Galaxy. Outburst every few years for a month. Probably a disk instability like a dwarf nova, but with the white dwarf replaced by a neutron star.

X-ray Bursters – about 30 in the Galaxy. Burst every few hours for minutes. Probably the neutron star analog of a classical nova. Matter accretes on surface of neutron star. Hydrogen is supported by thermal pressure, burns to helium. Helium is supported by quantum pressure and is unregulated and explodes. Often found in globular clusters.

Black Hole History – Mitchell, Laplace, escape velocity.

Event Horizon —Since nothing with velocity less than or equal to the speed of light can pass backward through an event horizon, the information that an event occurred cannot pass through, so an event on the wrong side of an event horizon can never be known to an observer on the opposite side, hence the name.

Schwarzschild Radius—the distance of the event horizon from the center of a black hole. For a non-rotating, non-charged, black hole the size of the event horizon is 3 kilometers x (mass/solar mass) i.e. if the Sun were a black hole its event horizon would be 3 kilometers in radius (the Sun is actually about a million kilometers in radius).

Singularity—region in center of black hole where ordinary space and time cannot exist because of severe space time curvature and quantum uncertainty. The boundary of physics as we currently know it.

Tidal forces tend to draw any object into a "noodle" shape for two reasons: the force closer to the center is stronger and because two separated points the same distance from the hole tend to approach one another as they both try to fall directly toward the center.

Conceptual problems with Newton's Theory of Gravity

Einstein says there is no "force" of gravity. Matter curves space and curved space tells matter how to move.

Einstein says the space around a gravitating object (Earth, a star, a black hole) is curved in the same sense as a cone poked in a rubber sheet. The circumference of a circle drawn around such an object is less than 2π times the radius and "straight lines," the shortest distance between two points, curve around the object. One type of straight line in this kind of curved space follows the curved space and closes on itself. An orbit is interpreted as this kind of straight line.

Space versus Hyperspace

Far away from a gravitating object, space is "flat" and there is no gravity. Black holes are "safe" from a distance