The April Brooks Observatory sessions

Because of our poor weather this semester, additional observing sessions have been scheduled for ASTR 1010, beginning at 8:45 PM each evening:

- Sunday, April 13 through Wednesday, April 16, including this evening
- Sunday, April 20 and Thursday, April 24 (newly scheduled)

Not required if you have already been to Brooks this semester & written a report.

If you attend this week, report due Wednesday, April 23.

If next week, report due at final exam (April 30).

As before, take elevator to 5th floor of this building, walk up to 6th floor. Bring your *blue* ticket with your name and my name (Nancy Morrison) written on it. Extra blue tickets are available.

Quiz 6 is graded and available for pickup in back

Homework 6 is due Wednesday; copies of assignment sheet are still available.

Planetarium and observing reports are also checked and available for pickup.

If you have sent in a report by email and have not received a response, please check with me.

Stellar Corpses

Possible end points of stars:

Initial mass of star	End point
Less than 8 Suns	White dwarf
More than 8 Suns	Neutron star or black hole

White dwarfs

- Mass: usually 0.5 to 1.3 solar mass
- Radius: similar to Earth (10,000 kilometers approx.)
- Density: 10,000 to 100,000 grams per cubic centimeter

Structure and origin of white dwarfs

- Carbon & oxygen with degenerate free electrons
- Exposed core of former red giant
- Remnant of stars up to 8 solar masses

Maximum mass of a white dwarf (Chandrasekhar Limit)

- Set by maximum gravitational pull that degenerate electrons can resist
- Corresponds to white dwarf mass 1.4 Suns
- Stars with larger initial masses must *lose* mass before becoming a white dwarf; this happens in the planetary nebula stage.

- If limit is ever exceeded, star explodes as a supernova

Thus, there are two kinds of supernova explosions.

1. Core collapse supernova: collapse of the iron core of a high-mass star at the end of its life
2. White dwarf supernova
   - A white dwarf collects mass through mass transfer from a binary companion, exceeds Chadrasekhar limit.
   - The explosion produces an expanding cloud of gas with no collapsed remnant.
   - While the explosion is bright, these can be recognized by their spectra: they contain no hydrogen.

- Because the exploding star has a uniform mass and composition — carbon-oxygen white dwarf with 1.4 solar masses — these explosions are good *standard candles.*

Nova explosions

- White dwarf collects matter from close companion star
- Hydrogen-rich material on surface of white dwarf reaches ignition point for fusion
- Explosion, material thrown off
- Star brightens by thousands of times
- Returns to previous state after a few days or weeks
- Explosion will recur
- Events are not unusual

Summary: stellar explosions

Nova White dwarf in binary system, minor explosion, doesn't destroy star, can recur; brightens thousands of times. Relatively frequent, seen mainly in the Galaxy & neighbors

White dwarf supernova White dwarf in binary system, total destruction of white dwarf, leaves no remnant, brightens billions of times. Rare, seen mainly in other galaxies.

Core collapse supernova Implosion of massive star (single or binary), remnant is black hole or neutron star + expanding cloud, brightens billions of times. Rare, seen mainly in other galaxies.

Neutron stars

Born in the collapse of the core of a massive star at the end of its life.

In the collapse, the nuclei get squeezed together and lose their identities, then the protons and the free electrons get squeezed together and form neutrons.

Finally, the neutrons reach a density where they can't be squeezed together any more—they become degenerate. This halts the collapse.

The resulting object is about 10 miles across—a *neutron star*.

Its density is about 100 trillion (10^{14}) grams per cubic centimeter (100 million Jeeps in a teaspoon).

Imagine landing on a neutron star.

- If you simply fell onto the neutron star, your speed would reach 1/3 of the speed of light before you hit.
- This is the escape speed from the neutron star.
- If you dropped a marshmallow onto the surface of a neutron star, the energy released would be equivalent to a thousand hydrogen bombs.

- All objects on the surface, no matter how rigid, would be crushed to a height of 1/2 inch or less.

Observing neutron stars

- We can observe thermal radiation from them, but it is weak because of their extremely small size.
- But in some special situations, neutron stars radiate far more energy than would be possible by thermal radiation alone.

Scroll down to see image shown.

Example: *pulsars*

- Rapidly spinning neutron star with magnetic field
- Sends out beams of radio waves (like a searchlight beam)
- We observe regular *pulses* of radio energy.
- The spin is so rapid — fractions of a second — that nothing but a neutron star could spin so fast.
- The Crab Nebula and its pulsar

Example: X-ray binary stars

- In a close binary, material from one star spills onto the other.
- The matter falling on to the neutron star is strongly heated and emits X-rays.
- From our point of view, detecting X-rays from a binary star is good evidence that one of the stars in the binary is a neutron star.
- In most cases, the other star is more or less normal.

For neutron stars, there is a maximum mass that can be held up against gravity by neutron degeneracy, about 3 solar masses.

In 3 well-substantiated cases, the mass of the X-ray source is more than 3 solar masses.

Black holes

The mass of a collapsing stellar core can become greater than about 3 solar masses if a lot of material from the surrounding layers of the star falls in on it.

In this case, there is no known way for the collapse ever to be halted.

Its density will grow without limit.

So will the strength of the gravitational attraction at its surface.

A spaceship falling freely toward it would reach the speed of light before striking the surface.

- In order to get out again, the spaceship would have to be launched at a speed above the speed of light.
- After this, no information about the spaceship could reach the universe outside, since nothing can travel faster than light.

The collapsing object has become a *black hole*.

The escape speed from its surface exceeds the speed of light.

After this, nothing can escape, not even light (radio waves, etc.)

But it still exerts a gravitational attraction on objects outside it, because it still has mass.

Black Holes (continued)

Definitions

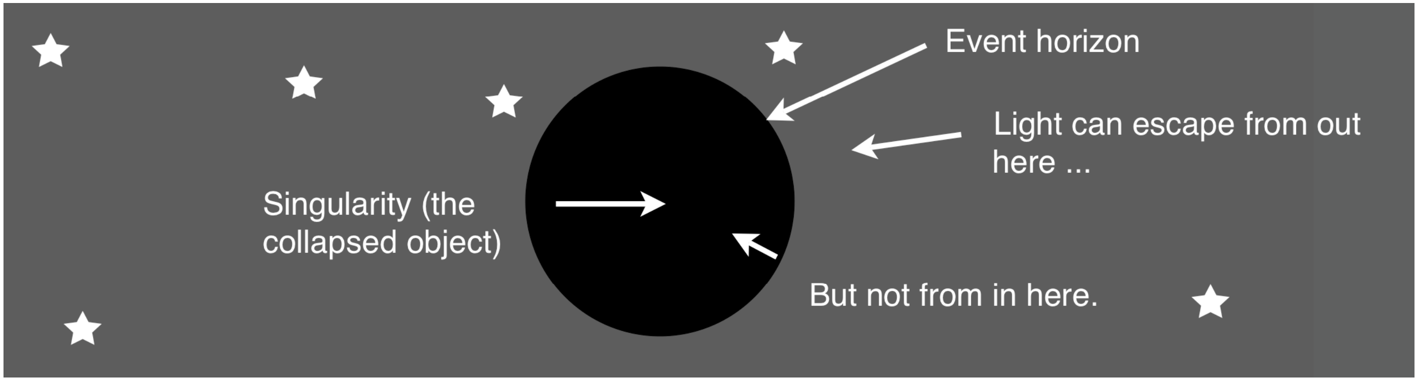
Event horizon An imaginary sphere, centered on a black hole, where the escape speed just equals the speed of light

Black hole An object at whose surface the escape speed exceeds the speed of light

- From anywhere outside the event horizon, light can escape from the pull of the black hole.
- Inside it, light cannot escape. Neither can anything else.

A 3-solar-mass black hole "seen" from 1 AU away

- Emits no light
- Same gravitational pull as a 3-solar mass star would have at the same distance, so it is safe to orbit the black hole.
- The event horizon is an intangible sphere 12 miles across.



Observe black holes from matter falling into them, as with neutron stars.

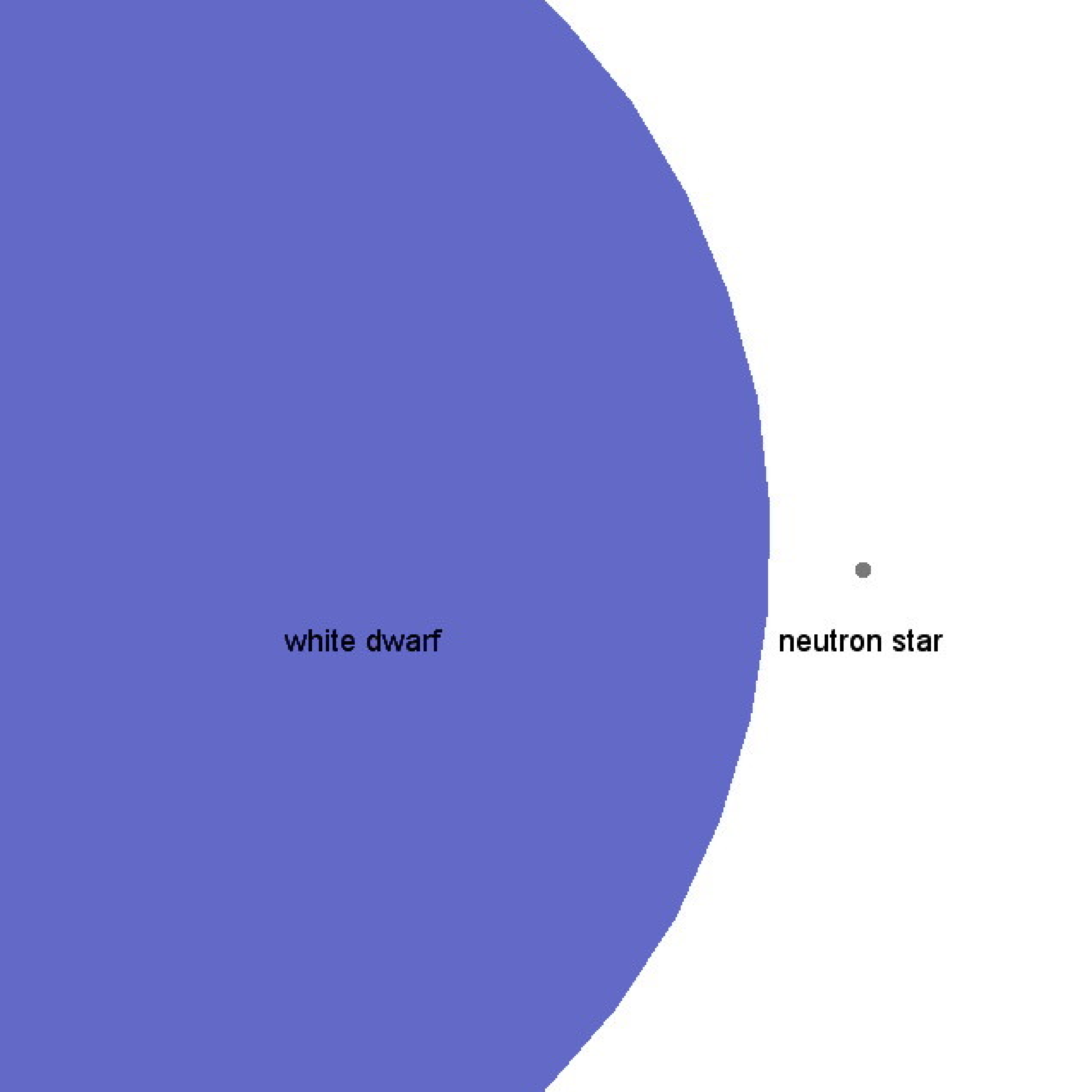
In a close binary star, the transferred matter forms a disk around the black hole.

The disk is strongly heated by friction within itself and emits X-rays.

Material at the inner edge of the disk falls in through the event horizon and disappears.

Summary: Sun/white dwarf/neutron star/ black hole comparison


Sun
white dwarf


white dwarf
neutron star

neutron star, 1 solar mass
(diameter about 10 miles)

black hole, 1 solar mass
(hypothetical, diameter
about 4 miles)