ASTR 1010–004: significant dates

Now: Quiz 6 is available to pick up, as are the observing and planetarium reports, along with four papers that were misfiled last time. (Sorry about that!)

Wednesday, Nov. 21: no class.

Wednesday, Nov. 28: Quiz 7; Homework 7 distributed

Wednesday, Dec. 5: Homework 7 due

Wednesday, Dec. 12: final exam 7:30 PM, here
Additional Brooks Observatory opportunities

Possible additional Comet Holmes viewing sessions. Stay tuned for more information, but don’t count on this.

Regular public observing after planetarium shows (weather permitting) Fridays: Show 7:30, observing around 8:15 to 8:30

- Nov. 23
- Nov. 30
- Dec. 7
- Dec. 14
Troublesome questions on Quiz 6

Why fusion of helium to carbon requires a higher temperature than fusion of hydrogen to helium

- High temperature is required in the first place to overcome the mutual repulsion of protons.
- Helium nuclei (2 protons + 2 neutrons) repel each other more strongly.
- So it takes a higher temperature, that is, faster particle motions, to overcome the mutual repulsion of helium nuclei.
What stars have in common

- Gas spheres bound by gravity that shine by nuclear fusion at some time in their lives
- Formed out of 90% hydrogen, 10% helium, traces of other elements

Some ways in which they differ intrinsically

- Mass
- Luminosity
- Radius
- Surface temperature
Life history of a massive star

For stars with masses greater than about 8 solar masses, the star’s development is basically the same through the end of helium fusion and then through the second red giant stage.

Then, something fundamentally different happens: the star’s core does not become degenerate.

Instead, fusion of carbon and oxygen into heavier elements takes place.

- Silicon (Si)
- Neon (Ne)
- Magnesium (Mg)
- Iron (Fe)

The more massive a star is, the more rapid its development and the shorter each stage of its life.
Cross-sectional view of the interior of a massive star in an advanced stage of its development

Should be:

O → Ne
Ne → Mg
Mg → Si
Si → Fe
Seen from the outside, the star appears as a very luminous star, very large in diameter, either a red or a blue *supergiant*.

Betelgeuse, the bright red star in *Orion*, is thought to be in this stage (with an estimated mass of about 10 Suns).

But iron is the heaviest element that can be built up from lighter elements by nuclear fusion with the release of energy.

Therefore, when a large iron core develops, the star reaches the ultimate limit on its fuel supply.
The core can no longer resist the tremendous pull of gravity, and it collapses. The resulting explosion blows the rest of the star apart.
Two possible fates for the collapsed core

• Collapse to an extremely dense ball only about 10 miles across but with a mass a bit less than 1.4 solar masses: a *neutron star*

• Collapse to an even denser object called a *black hole*
Examples of the stages in the old age of a high-mass star

- Supergiant stars: Betelgeuse (red), the stars in Orion’s Belt (blue)

They are candidates to explode - sometime within the next few hundred thousand years. It's impossible to say when.
*Supernovae* — the explosions that accompany the sudden core collapse

- Star gets billions of times brighter than before, remains bright for months
- Rare events, most often observed in other galaxies, about 3 per galaxy per century
- Historical records of stars, once invisible to the naked eye, becoming bright for a period of weeks or months, even bright enough to see in the daytime, probably refer to supernovae in our galaxy. Most recent: 1620.

*Nova = nova stella* ("new star" in Latin). Most stellar explosions are novae, less-catastrophic events that happen to white dwarfs in binary systems.
Supernova remnants

- Rapidly expanding clouds of gas
  (Example shows 2 pictures taken 30 years apart)
- Famous example: Crab Nebula
- At location in sky where Chinese astronomers observed a bright new star in 1054 AD
- Another famous example, much older: Veil Nebula
Overview of the stellar life cycle

Formation or birth by gravitational contraction from interstellar gas clouds

Main-sequence stage: fusion of hydrogen to helium in core, exterior unchanged

Exhaustion of hydrogen, brief existence as red giant

Fusion of helium to carbon and oxygen
Low-mass stars (less than 8 Suns)
- Formation of electron-degenerate core
- Gentle shedding of outer layers
- Carbon-oxygen white dwarf remnant; cooling, no further change

High-mass stars (more than 8 Suns)
- Continue nuclear fusion, making heavier elements up to iron
- Explosion as supernova, dispersing nuclear fusion products into surroundings
- Neutron star or black hole left as remnant
• Some time later, formation of next generation of stars from “enriched” interstellar gas

Over billions of years, the interstellar gas has become more and more enriched with heavy elements. When they form, stars have the same composition as their birth clouds. As they age, their interiors change, but their exteriors do not.

If all this is true, older stars should have an even lower concentration of heavy elements than younger stars. In general, this is what is observed.

Without the heavy elements, there wouldn’t be planets — or people.
Stars and the origin of the elements

Hydrogen: primordial. Protons and electrons came into being a split second after the universe itself did.

Helium: originated before any of the stars. We’ll discuss this more thoroughly later.

Lithium, beryllium, boron: rare, special cases, another origin.
“We are star stuff” — Carl Sagan

All other elements: made in and by stars.

- Thermonuclear fusion in the core makes the most common elements up to and including iron.

- Other processes occurring in supernova explosions, etc., make the other elements, including the ones heavier than iron.

- Some of the heavy elements made in a massive star’s core are thrown out into space during the supernova explosion.

- There, they form part of the interstellar material.

- Later, may be incorporated into a star or planet
Are stars the only thing that could have made the heavy elements?

- Elements including carbon and heavier: the only known process is nuclear fusion in stars.
- Thousands of generations of massive stars have lived and died, enough to produce the heavy elements existing today.
- Stars make helium, but they also destroy it, so they can account for only a small fraction of the helium in the universe. We’ll account for it by nuclear fusion, but in another setting.
Evolution of Binary Stars

Star pairs can be close or wide

The two stars form at the same time

The more massive one completes the main sequence first, turns into a red giant

If it swells beyond a certain point, material will travel from it to the other star: mass transfer

It may never become a full-fledged red giant, but turns into a white dwarf instead.

Or it may survive to the red giant stage and explode as a supernova (if a massive star) leaving behind a neutron star.
Stellar Corpses

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
- If limit is ever exceeded, star explodes
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.

- Difficult because the gravitational pull at the surface is very strong.
- 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.
• For example, 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.
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.

To see graphic, scroll down linked page.
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.
Scores on Quiz 6

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