Index Card, 11/29

Take this opportunity to ask one or two specific questions on points covered since the last Exam, that you don't understand. I will use the most commonly asked questions as the basis for some review slides next Tuesday, to help you prepare for Exam 3. As was the case last time, broad or vague questions are less likely to be answered than narrow, targeted queries.

No more than the 3 questions per card, please!

"Roche Lobes" in a Binary

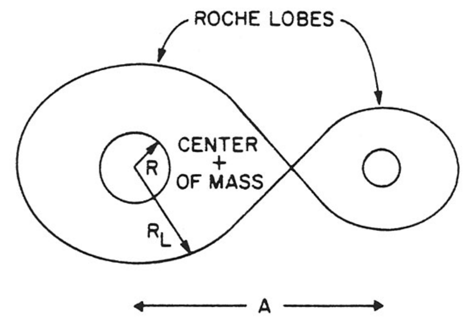


Fig. 8 of Iben, Astrophysical Journal Supplements, Vol. 76, page 64.

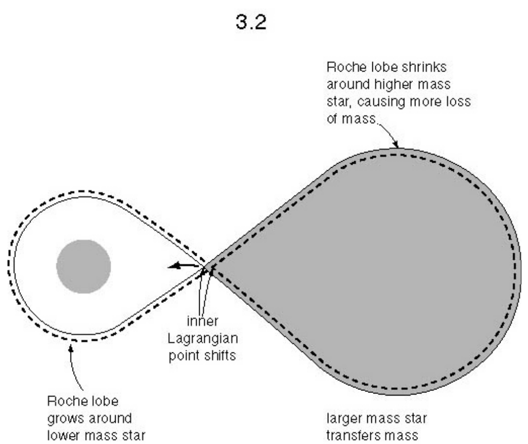
The "Roche lobes" can be thought of as the gravity domains of the two stars. They represent positions where the gravity effects of the two stars balance. "A" is the separation of the stars (semi-major axis of the orbit). The star on the left is more massive.

Interacting Binary Systems - I

- "What determines the size of a Roche lobe?" The star's mass. A Roche lobe represents the gravitational sphere of influence. The more massive the star, the larger the Roche lobe (see p. 45 – 46 in Wheeler).
- "How/why do Roche lobes shrink?" When a star loses mass, its Roche lobe gets smaller in proportion.
- "What is the Algol paradox?" Algol consists of a red giant and a Main Sequence star, but the red giant is less massive than the MS star. This contradicts the rule that higher-mass stars have shorter MS lifetimes. The resolution to the "paradox" is mass transfer took place in the past (read pages 46 – 50 in Wheeler).

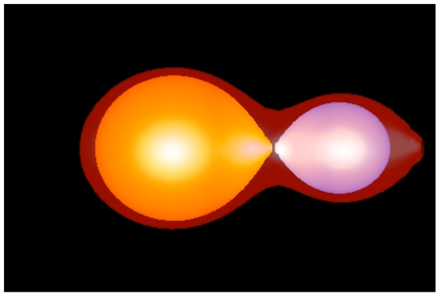
Consequences of Mass Transfer

As the higher-mass star loses mass to its companion, its Roche lobe shrinks; but the star is moving up the red giant branch, so it swells up even more. The process can get out of hand and undergo a *runaway* (things keep getting worse, more and more mass is transferred)



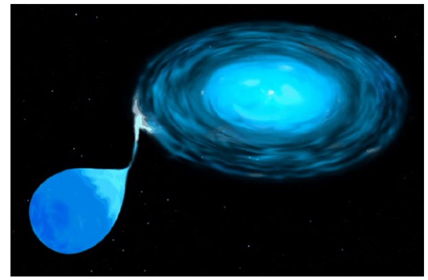
More Roche Lobe Questions

"What would happen if two binary stars filled their Roche lobes at the same time?" There are some binary systems like this; they are called "contact binaries." It is possible that sometimes the stars merge, creating a "blue straggler." Or one star might become a giant and swallow the other, in a "common envelope" system.



Interacting Binary Systems - 2

- "How do you detect that there is mass transfer in a binary system if we cannot see it?" We can't see a detailed picture like the artist's conception below, but we *can* see emission from the disk and hot spot. It may show up in the spectrum and perhaps the light curve. The picture is an interpretation of what objects are present.



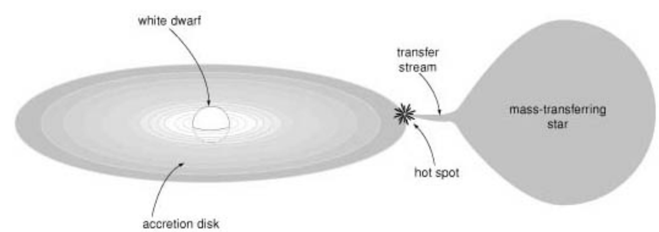
The companion star turns first a cool, then a hot face towards us as it orbits, and the "hot spot" where the mass stream hits the disk goes in and out of view as the disk turns.

Interacting Binary Systems - 3

- "What is an accretion disk composed of?" It's composed of gas from the donor star, specifically from its outer layers. Usually the composition is essentially "normal," that is mostly H and He, with a little of everything else.
- "How do the properties of a black hole affect the classical novae?" I don't understand this question. These things are not related to each other.

Cataclysmic Variables - 1

- "What is a cataclysmic variable?" Wheeler, p. 69: "binary systems in which mass flows from one star first into an accretion disk and then onto a white dwarf… most of the light comes from the *hot spot* where the transfer stream collides with the outer edge of the accretion disk."



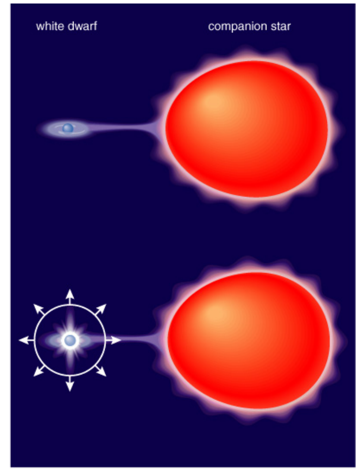
Cataclysmic Variables - 2

"Differences between different types?" These systems are capable of flare-ups – dramatic increases in brightness:

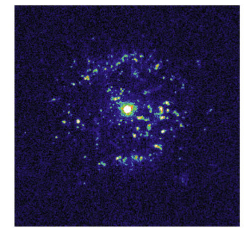
- "Dwarf novae" – the "gentlest" kind: "matter builds up into the accretion disk until some instability causes the matter to suddenly spiral down toward the white dwarf, leading to an increase in the light output."
- "Recurrent novae" – 1000 x brighter, cause is unclear
- "Classical novae" – much brighter still, these flare-ups are actually due to explosive nuclear fusion on the surface of the white dwarf, in a degenerate layer near the surface

(discussed in almost all of ch. 5 of Wheeler)

Classical Novae

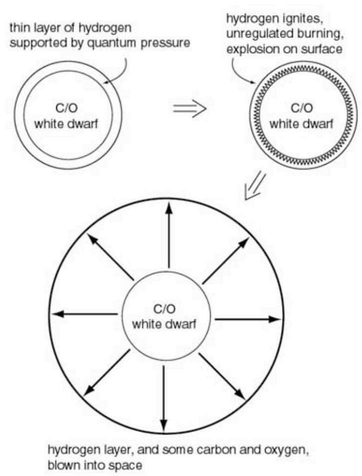


- Mass accumulates on the surface of the white dwarf until it gets hot enough for H fusion to begin.
- The nova star system appears much brighter, ***temporarily***.
- The explosion drives the accreted matter out into space



Classical Novae

- The classical novae reach much brighter flare-ups than the dwarf and recurrent novae.
- They can run nuclear fusion reactions up to the light even-numbered elements like Ne and Mg; they may also actually blast off some of the outer layers of the white dwarf.
- But they do not destroy the white dwarf, so after the system settles down, mass transfer can resume, and eventually another nova explosion can occur.



Recap: Kinds of Stellar Explosions

Nova: A modest amount of mass is transferred slowly onto a white dwarf from a binary companion. The surface heats up until it ignites in runaway H fusion reactions. The ensuing explosion blows the surface layers off the WD but does not destroy it.

White dwarf or "thermonuclear" supernova: A larger amount of mass is transferred onto a white dwarf so that its mass nears the WD limit of 1.4 $M_{\odot}$. The entire WD "goes up in flames," and is incinerated into heavier elements, including a good deal of Fe and Ni. This is a "Type Ia" supernova.

Massive-star or "core collapse" supernova: A high-mass star reaches the end of its life and forms an iron core. This core collapses, the layers above it "bounce off" and explode into a supernova remnant. This is a Type II supernova. (Types Ib and Ic are also thought to be core-collapse supernovae, from massive stars that lost their outer layers in a strong stellar wind.)

Gravity - 1

"Gravity, mass, and acceleration: confusing!"

Gravity is a force, at least according to Newton.

Acceleration is a change in velocity, change in motion.

The acceleration caused by a force, such as gravity, is inversely proportional to the force. You can say *F = m x a*, or

acceleration = (Force)/(mass)

In this course, we have described the "strength of gravity" as the ***acceleration*** felt by objects near a star. This is better than saying just "strength" because the latter is vague; it also uses a quantity that does not depend on the mass of the object feeling this gravity. In Einstein's picture, we replace the idea of acceleration by the steepness of the curvature.

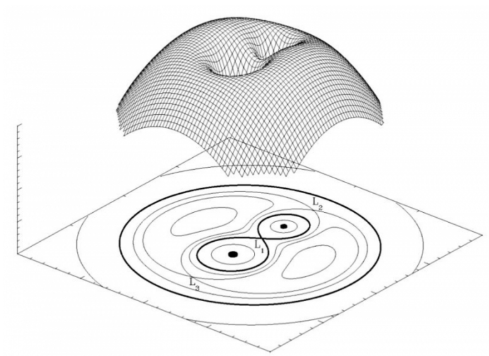
Gravity - 2

"Which is correct: Einstein's theory or Newton's theory?"

What scientists mean when they call a theory "correct" is that it successfully explains and predicts actual phenomena. Newton's theory is sufficiently correct to explain gravitational interactions among bodies like the Earth, Sun, and Moon, and most binary star systems. It does ***not*** correctly predict the gravitational bending of light, and other effects that show up in regions of strong gravity which ***are*** correctly predicted by Einstein's theory. But Einstein's theory may not be the last word either, as it has trouble explaining what happens on very small scales, near a singularity. So someday a more complete theory (string theory?) may explain more.

Gravity - 3

- "Do we have to know the difference between Newton's theory and Einstein's theory?" Yes, in terms of concepts.
- "What's the importance of embedding diagrams?" They offer a way to help visualize gravity according to Einstein.



Example: going from embedding diagram to Roche lobes – from Penn State website

Black Holes - 1

- "Is there a minimum mass for a black hole?" In principle, no. However, in practice we have not found any with less than about 5 $M_{\odot}$. The Sun will not become a black hole.
- "Is the event horizon an actual surface, or theoretical?" The event horizon is a theoretical construction, a location in space rather than an actual physical surface.
- "Is the event horizon technically the Roche lobe of a black hole in a binary system?" Not at all. The Roche lobes are where the two stars – the BH and the other star – have equal gravity (in terms of energy). The event horizon is likely to be tiny compared to the Roche lobe, but the latter depends on the mass and distance of the other star.

Types of "Compact Objects"

Object	Supported by	Comes from	Made of	Approx. Radius	Maximum Mass*
White Dwarf	electron degeneracy pressure	AGB giant	C & O; free electrons	R_{earth} = 0.01 $R_\odot$	1.4 $M_\odot$
Neutron Star	neutron degeneracy pressure	core-collapse supernova	neutrons	10 – 12 km (small city)	2 – 3 $M_\odot$
Black Hole	not supported!	Gamma-ray burst?	mass	3 km x M in $M_\odot$	no limit

*There are no minimum masses, though nature seems to like to make 0.5 $M_\odot$ white dwarfs and ≈1.5 $M_\odot$ neutron stars.

Black Holes - 2

- "I don't understand how black holes don't have mass." They ***do*** have mass! For an uncharged, non-rotating black hole, mass is its ***only*** characteristic!
- "How does a black hole develop?" The "stellar-mass" black holes in X-ray binaries form during the core-collapse supernova of a very high mass star, when the collapsing core exceeds the maximum mass for neutron stars.
- "Wouldn't the creation of a black hole destroy a companion star?" Apparently not, since we've found numerous binaries containing a black hole plus a normal star!
- "Life cycle of a black hole?" A BH is the ***end-state*** of a very high-mass star; it doesn't have its own life cycle.

Black Holes - 3

- "Properties of the event horizon?" See Quiz 8 feedback.
- "How do we observe spaghettification?" The stretching and squeezing effects of tidal force are not unique to black holes; they occur for any mass. Jupiter's moon Io has a molten interior and sulfur-spewing volcanos due to tidal forces. For most black holes, it is in-falling gas that is squeezed and heated, producing X-ray emission.
- "If a black hole exists without a companion, how can we detect the black hole?" We probably can't, unless the black hole passes in front of a background source of light and we can see the bending – distortion - of light.
- http://jila.colorado.edu/~ajsh/insidebh/schw.html

Recommended Websites on Black Holes

- Andrew Hamilton's site at U. Colorado:
  - http://jila.colorado.edu/~ajsh/insidebh/index.html
- Robert Nemiroff, author of the APOD, posted some simulations of relativity at
  - http://apod.nasa.gov/htmltest/rjn_bht.html
- An older site on General Relativity and Black Holes, hosted at the U. Illinois computer center:
  - http://archive.ncsa.illinois.edu/Cyberia/NumRel/GenRelativity.html or BlackHoles.html