Agenda for Ast 309N, Nov. 13

- Announcements: Exam 2.5 on Thursday, HW 3 (due Nov. 27), start Black Holes on Tues. Nov. 20
- Exam 2 feedback
- Interacting binaries: mass transfer, accretion disks
- White dwarfs in interacting binary systems and some explosive situations that may develop
- Card question
- Reading his week: Wheeler, chs. 3, 4, 5, 6.6, 8
- Reading for next week: chs. 9, 10

Exam 2.5

- Exam 2.5, given during class time on Thurs., Nov. 15, is a make-up exam for *either* Exam 1 or Exam 2, so it will cover all material in the course up that point. See Study Guides for Exams 1 & 2 for details.
- No special permission is required to take Exam 2.5. It cannot lower your grade, so we recommend that you take it, in case a last-minute problem arises with Exam 3. Exam 3, given on Dec. 6, is *not* cumulative: it will cover only the last 4 weeks of the class. If you miss Exam 3, you *must* have a documented, acceptable (to the professor) reason, but there will be no make-up for it. In that case, Exam 2.5 will replace Exam 3.

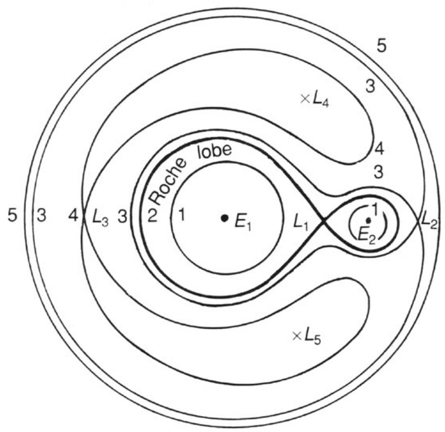
Exam 2.5

- The format will be the same as for Exams 1 & 2; you're probably getting used to it by now.
- As usual, you must arrive by 9:45 AM, and no one may leave until at least 9:50 AM. *No one may leave the room during the exam and return to continue taking it.*
- You must bring your **UT Photo ID**, and this time you must place it in front of you during the test. Last time there was a remarkable coincidence: no fewer than **three** students in this class of 165 (2% of the class!) managed to lose their wallets the night before the exam. I trust that history will not repeat itself!

New Topic: Interacting Binary Stars

- When two stars are in a close binary system, they can potentially interfere with each other's evolution.
- Any matter in the vicinity feels gravitational effects from both stars.
- If one constructs surfaces of constant gravitational potential, there is one surface where any mass has equal gravitational gravitational potential energy with respect to both stars. This is called the Roche lobe.
- The point where the lobes "touch" is called the inner Lagrangian point, or "L_1".

Surfaces of Equal Gravity



Surfaces of equal gravitational energy in a binary system. The "Roche lobes" are the surfaces where the effects of the two stars balance. Anything at the "inner Lagrangian point," L_1, feels equal effects from both stars.

(Luminet, Fig. 59)

"Roche Lobes" in a Binary

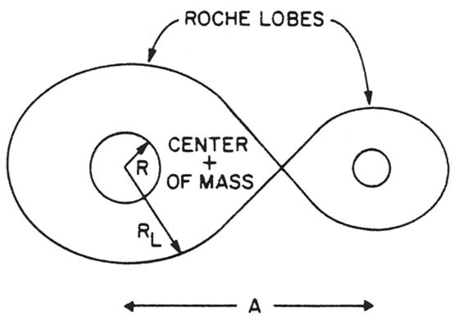
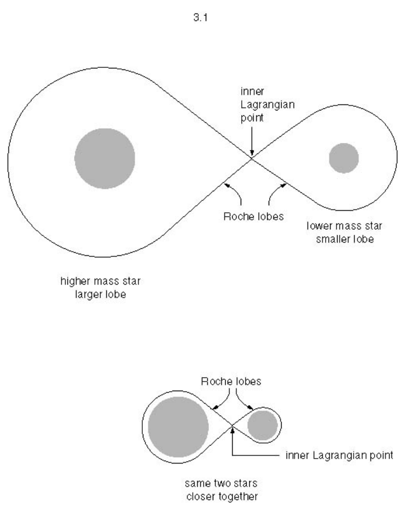


Fig. 8 of Iben, Astrophysical Journal Supplements, Vol. 76, page 64.

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.

Roche Lobes vs. Stellar Radii



In the upper panel, both stars are clearly smaller than their Roche lobes. However, if the stars were closer together, the surfaces might start to get dangerously close to their own Roche lobes!

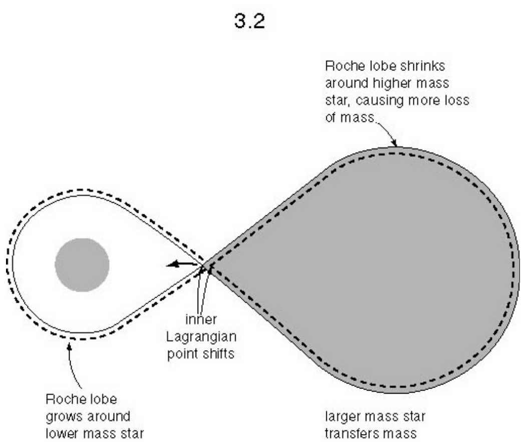
Wheeler, Fig. 3.1.

Mass Transfer in a Binary

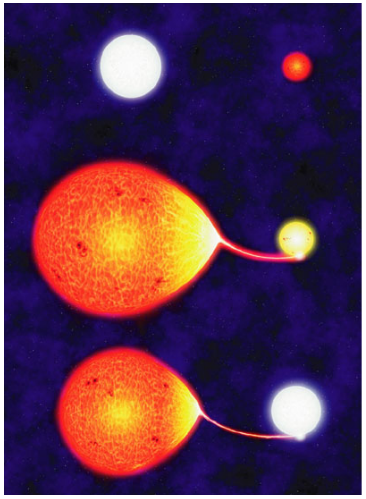
- Matter moving away from one star and passing through the point of equal gravity is captured by the other star, a process called "mass transfer."
- This flow can be caused by a stellar wind, or by evolution: as the star becomes a red giant, its surface swells up to "fill" the Roche lobe.
- Because it has (orbital) angular momentum, if the transferred mass lands on the companion star, it can cause it to spin (rotate) faster.

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!



The Algol Paradox



Something like this may have happened to Algol, which consists of a 0.5 $M_\odot$ red giant and a Main Sequence star of about 2 or 3 $M_\odot$. Why is this paradoxical?

The star that is now a red giant was originally the more massive star. When it started to become a red giant, it transferred so much mass to its companion that the latter is now the more massive star!

Index Card, 11/06

When an aging, evolving star (e.g. becomes a red giant and beyond) happens to have a close companion star, which of the following properties of the first star can be affected or changed by the second star?

What kinds of changes can occur, and why?

- mass
- rotation
- how long it can last as a red giant
- any other quantity you can think of; explain

Changes in Mass

- Key Point: **Which** star gains mass from the other?
- "As the [first] star becomes a red giant, the outskirts of the star may be more strongly ~~affected~~ [attracted] by the gravity of the companion, causing mass loss."
- "It will take mass away from the companion star… the red giant receives mass from the smaller star." Why? If the separation of the two stars remain the same (at first), and the second star hasn't expanded, its mass should stay bound to itself.
- The mass of the non-red giant will be absorbed." Only in the extreme case of a "common envelope.

Changes in Rotation

- Key Point: Does it **slow down** or **speed up**?
- "The second star's rotation becomes more rapid, as the matter from the red giant makes it spin faster."
- … many of you drew a [correct] analogy to milli-second pulsars: "pulsars which have mass transferred onto them increase in rotational speed." It's like the hand on the bicycle wheel (in the video), applying a sideways push and thus speeding up the rotation rate.
- "the companion star slows the other's angular momentum …" Why? And angular momentum is a quantity that can be larger or smaller, not "slower"

Changes in Red Giant Lifetime

- Key Point: Does it get **longer** or **shorter**? Opinions were fairly equally divided on this issue.
- "It will last as a red giant for a shorter time, because of the mass loss." Probably. The details will depend on the distance between the stars, but most likely the red giant phase will be truncated (cut short).
- "A red giant losing mass will last longer." Don't confuse this effect with the mass dependence of Main Sequence lifetimes; the red giant phase is a different phenomenon.
- "It will last longer … it takes longer for each step." ??
- "The period as a red giant would remain the same."

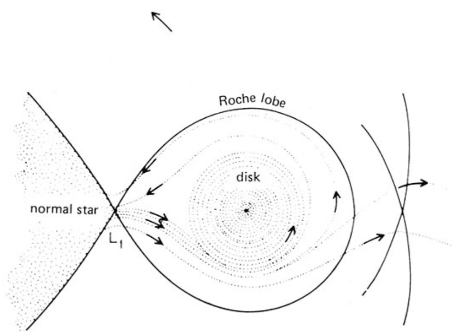
Other Properties?

- "Shape?" Yes, good idea! From the diagrams and videos you might notice that the stars can become almost teardrop-shaped as they fill a Roche lobe. Such distortions also can affect the brightness, because the star has a different cross-section (projected size) as seen from different angles.
- "Temperature?" Under some circumstances, the side of one star facing the other star will experience extra heating and might be hotter. This situation can develop when, for example, the second star is a white dwarf or some other hot type of star.

Mass Transfer in an Evolved Binary

- When the red giant finishes evolving, perhaps sooner than it would otherwise have done, a compact object, let's say a white dwarf, is left.
- Eventually the companion star becomes a red giant, initiating a second mass transfer phase.
- This is even more interesting, because the white dwarf is a smaller target, so instead of landing on it, the transferred mass can swing past it, but…
- … because it has (orbital) angular momentum, the it goes into orbit around the second star, forming an "accretion disk."

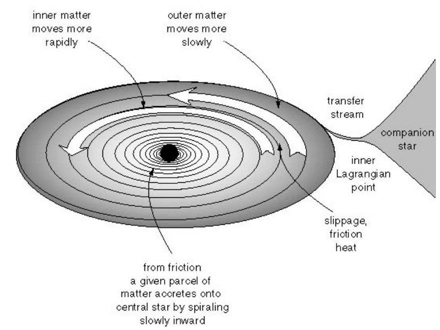
Accretion: Why a Disk?



Matter streaming from one Roche lobe to the other, passing through the L_1 point, carries a sideways (orbital) angular momentum, so it rotates *around* the other star instead of falling straight in.

(Looking down on the orbital plane)

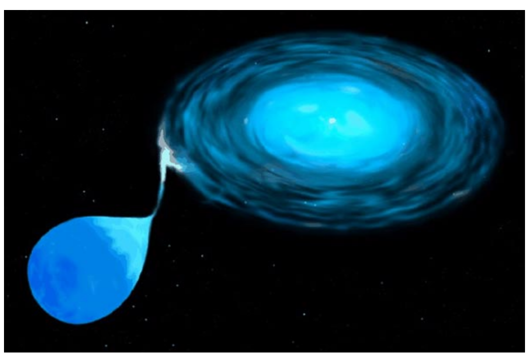
Accretion Disk around a White Dwarf



The accretion disk is like a "holding tank" or reservoir of material. Its radial layers "rub" against each other (the technical word is "viscosity") and heat up, so that they glow in visible and ultraviolet light. The disk slowly feeds mass to the white dwarf, a process called accretion.

(View from angle nearly in orbital plane)

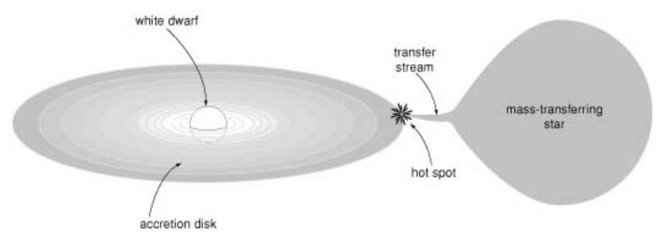
Accretion Disk & "Hot Spot"



Artist's conception of an accretion disk, showing the "hot spot" where the matter stream hits the disk.

http://antwrp.gsfc.nasa.gov/apod/binary_systems.html

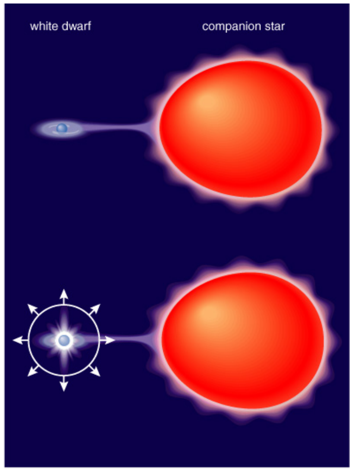
"Cataclysmic Variable" Stars



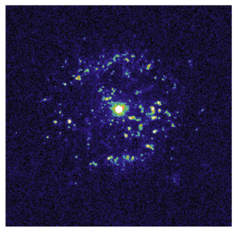
Mass is not always delivered steadily and slowly onto the white dwarf. The accretion disk can become unstable, and dump a large amount of mass all at once, causing a severe flare-up in brightness.

These are the dwarf novae, recurrent novae, and other CVs.

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



What Happens in a Classical Nova

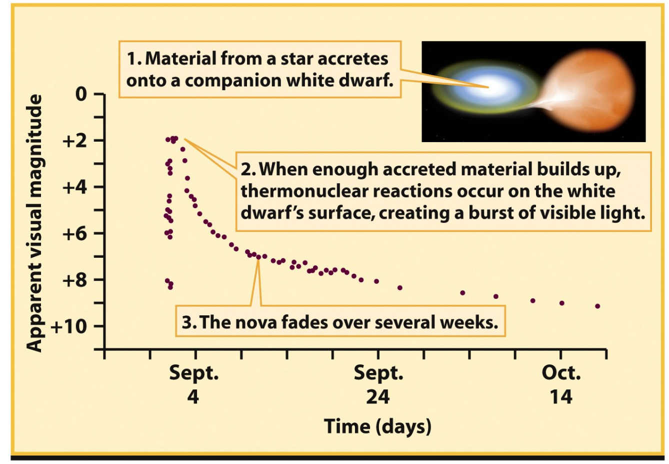
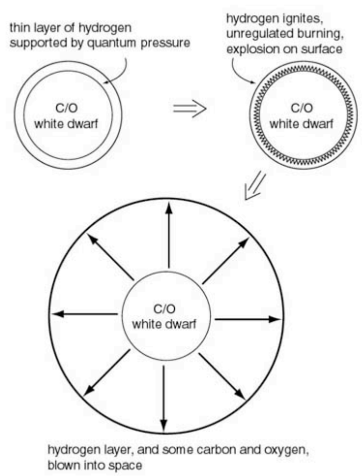


Figure 21-15
Universe, Eighth Edition

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.



What Happens in a Type Ia Supernova

If enough mass accumulates on the white dwarf, it can be heated to the point that its interior "goes up in flames" and explosive nuclear fusion blows the white dwarf apart. This takes place at nearly the white dwarf mass limit of 1.4 $M_\odot$. This is a "Type Ia" supernova, also called a "white dwarf" or "thermonuclear" supernova. (These are key to the discovery of the acceleration of the expansion of the universe.)