Agenda for Ast 309N, Nov. 6

- Exam 2 information
- Quiz 7 feedback
- Some responses to 11/1 index card
- Magnetars & millisecond pulsars
- Video clip on above
- Card question
- Reading for next week:
  - Wheeler, chs. 3, 4, 5, and ch. 6.6 (Type Ia SNe)

Exam 2

- "Will it be cumulative?" No. Exam 2 will address the new material covered since Exam 1.
- Can you clarify what the make-up exam on Nov. 15 is?" Exam 2.5, to be given on 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. 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, but will cover only the last 4 weeks of the class. However, there is ***no make-up*** for Exam 3. (**No** exceptions.)

Exam 2

- The format will be the same as for Exam 1, with some multiple-choice questions to be answered on a bubble sheet, and 3 short essays to be chosen from 5 options.
- As with Exam 1, you must arrive by 9:45 AM in order to take this test for credit, and no one may leave until at least 9:50 AM.
- You must bring your **UT Photo ID**, and this time you must place it on the table in front of you during the test. There have been instances of unusual similarities between test/quiz papers in this class, and students have been warned. Those students must not sit next to each other during this exam – we'll check!

Index Card, 11/1

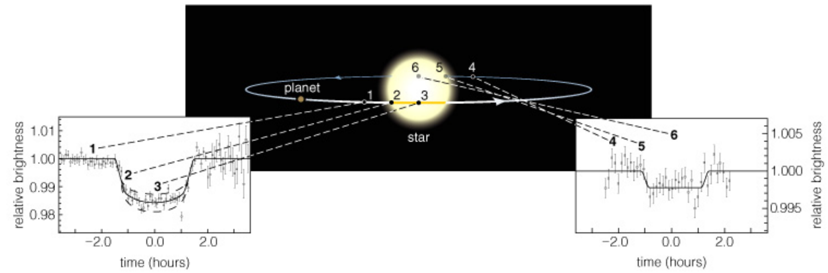
Take this opportunity to ask one or two specific questions on points that you don't understand, that will be included on the exam (see Study Guide 2).

A number of students simply repeated the questions on today's quiz (not very imaginative), or that have appeared on earlier cards & quizzes. Answers to these can be find on the respective feedback files. Others asked extremely broad, hence not useful questions. If you missed a week of class, you should find out about stellar aging by consulting the class slides.

Queries about Exoplanets

- "Which method for detecting exoplanets helps you find the planet's mass?" To measure mass you need to detect the gravity of the planet, by seeing its tugs on its parent star, usually via the Doppler method. If you don't know the orbital tilt, however, this gives only the minimum planet mass. (See slides & card from 10/11.)
- "Do interactions between multiple planets cause them to speed up or slow down?" Both. The planets attract each other through gravity, so they accelerate as they approach each other, then slow down as they try to move apart. But their gravity is too weak to pull them out of their orbits around the parent star.

Transit plus Doppler Method

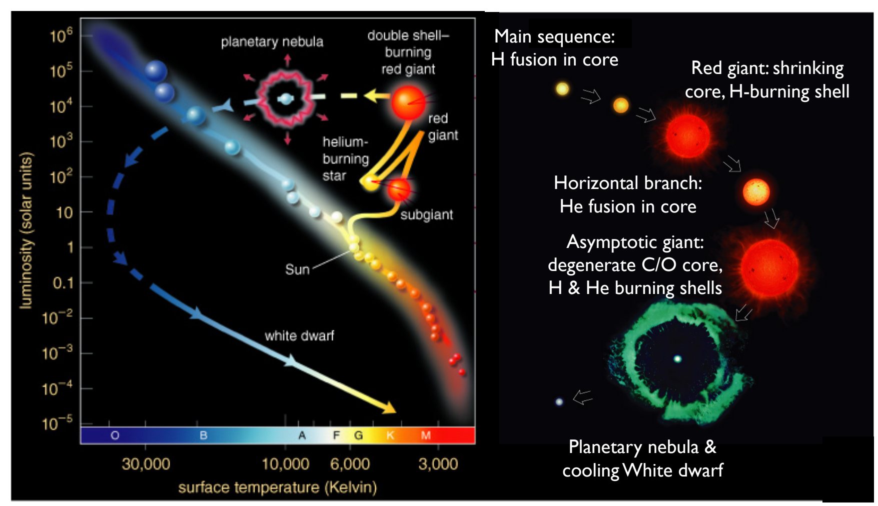


- A **transit** is when a planet crosses in front of a star
- The resulting (partial) eclipse reduces the star' s apparent brightness and tells us planet' s radius
- If you see transits, the orbit must be nearly edge-on; therefore the Doppler measurements of the system give you the actual planet mass, not just a minimum value.

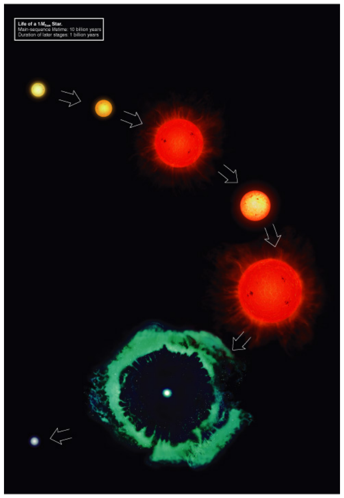
Queries about Low-Mass Stars

- "Differences between horizontal branch & asymptotic giant stars?" The horizontal branch phase is when He is fusing in the star's *core*. It is sort of like a rerun of the Main Sequence, when H fuses in the core. The asymptotic giant stage follows the horizontal branch. AGB stars have a dense C/O core, that becomes degenerate, with a He-burning shell around it, and an H-burning shell above it. See the Quiz 6 feedback file.
- "Difference between a red giant and red supergiant?" Red giants are evolved lower-mass stars; the term red supergiant usually means an evolved high-mass star. Only the lower-mass stars become AGB stars.

Life Stages of a Low-Mass Star

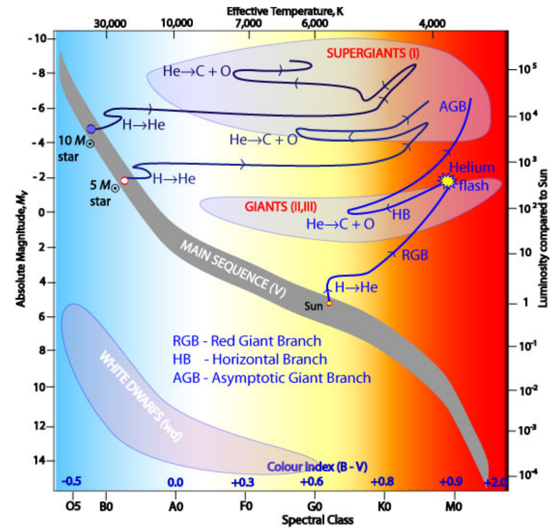


Overview: Life Story of a Low-Mass Star

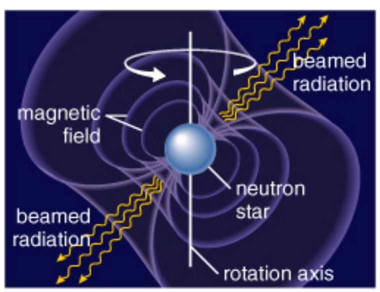


1. Main Sequence: H core-burning: H → He in core
2. Red Giant: H shell-burning: H → He outside the He core
3. Horizontal Branch: He → C in the core, H → He in shell
7. AGB or Double Shell Burning: H and He both fuse in shells, CO core becomes degenerate
5. Planetary Nebula lifts off, leaves white dwarf behind

Evolutionary Tracks for Various Masses

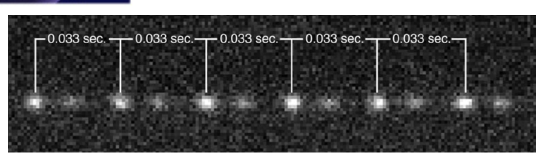


The Lighthouse Model for Pulsars



When the beam is briefly pointed at us, the observers, we see a brighter star image than when it has swept past and points in a different direction. A time sequence of pictures looks like this:

For an animation, see the link below.



http://relativity.livingreviews.org/open?pubNo=lrr-1998-10&page=node3.html

Queries about Nucleosynthesis

- "What is nucleosynthesis?" The creation of new elements from other, usually lighter ones.
- "What are the major nuclear reactions?"
  All Main Sequence stars fuse H to He, via the p-p chain or CNO cycle. Lower-mass stars continue to He fusion, the "triple-alpha" process, making C, O. Only the higher-mass stars continue with heavier even-numbered elements, up to Fe. The elements heavier than Fe are made by adding neutrons to pre-existing Fe nuclei. This happens in AGB stars via the slow or "s" process, or in supernovae via the rapid or "r" process. This was covered on Oct. 23.

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.

Pulsars in a Nutshell

Pulsars are spinning neutron stars, formed by the core-collapse of a high-mass star going supernova.

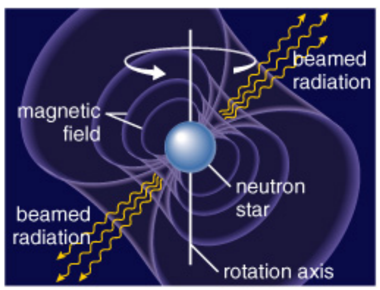
What conditions must be met, in order for us to actually see pulses from a pulsar?

- It must be emitting in our direction at least some of the time (its beam must "cross" our direction)

–the spin axis must be different from the magnetic axis (that's true for the Earth!)

- It must not have lost most of its initial rotational and magnetic energy

The Lighthouse Model for Pulsars



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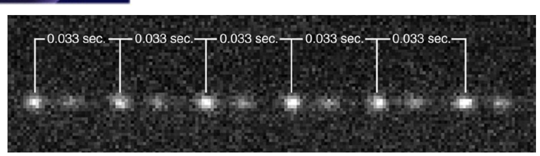

http://relativity.livingreviews.org/open?pubNo=lrr-1998-10&page=node3.html

Synchrotron Radiation is **Non-Thermal**

The electromagnetic radiation in the pulsar beams is ***not** thermal emission*. It has a different spectral shape from a blackbody, being very strong at radio wavelengths.

It *does* weaken with time, but not because of thermal cooling.

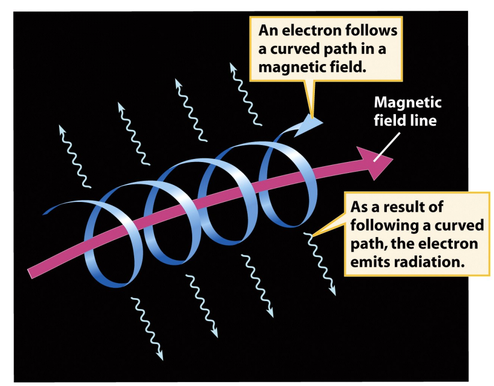

Figure 21-6a
Universe, Eighth Edition
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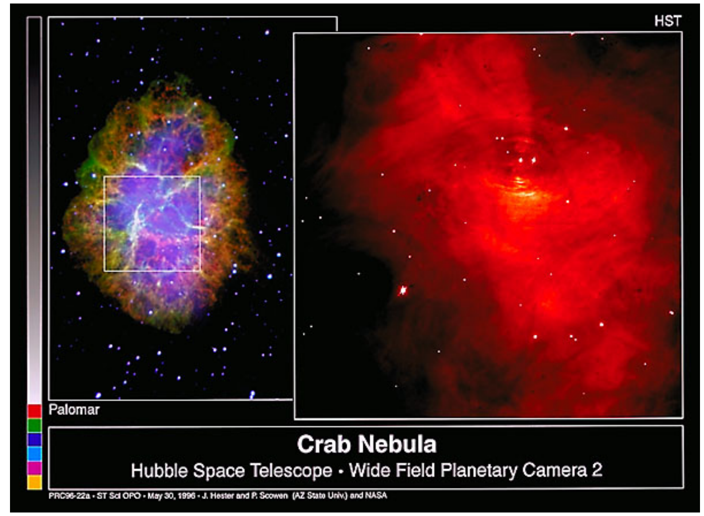
Neutron Star "Hall of Fame"

- The Crab Nebula pulsar: fastest among the first batch found (1/30th sec); the first one identified in optical light, associated with supernova in 1054 AD
- The (first) binary pulsar: indirect proof of one prediction of Einstein's theory of general relativity, namely gravitational radiation
- Geminga and other nearby neutron stars: faint, fading, cooling stellar cores
- Millisecond pulsars; "rejuvenated" by mass transfer
- Magnetars, found via repeating 'soft γ-ray' bursts

The Crab Nebula and its Pulsar

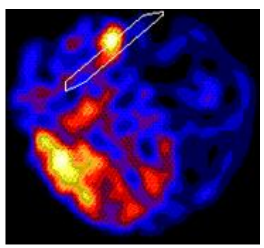


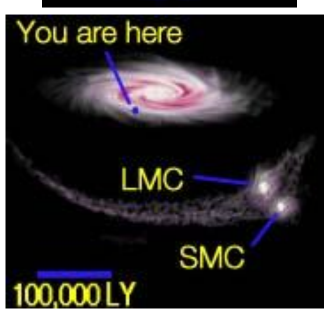
Soft Gamma-Ray Repeaters: Observations

The γ-ray burst of March 5, 1979 was found to be located in supernova remnant N49 in the Large Magellanic Cloud

What does this make you suspect about its nature?

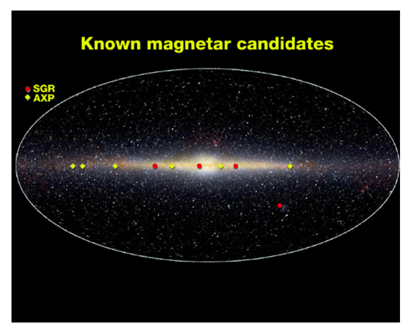
At such a large distance, it must have been enormously luminous!



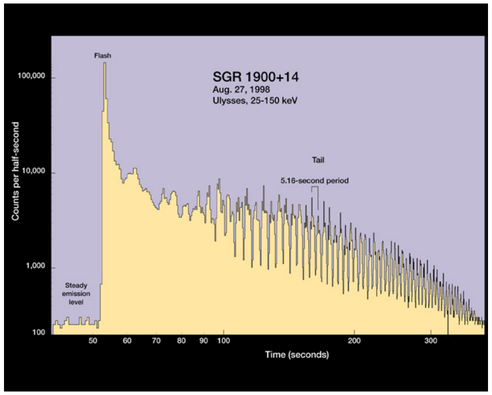


SGR in the Milky Way

The outburst of August 27, 1998 partially ionized the Earth's atmosphere for a few hours! However, because it was closer to us, despite the extreme apparent brightness, its intrinsic energy must have been lower.



Light Curve of a Soft-Gamma Repeater

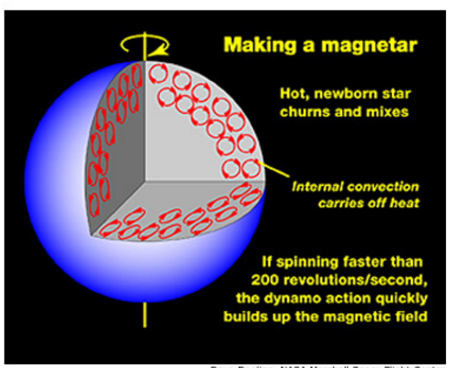


Seeing a light curve with regular peaks every 5 seconds reminds us of the "lighthouse" model of pulsars as spinning neutron stars

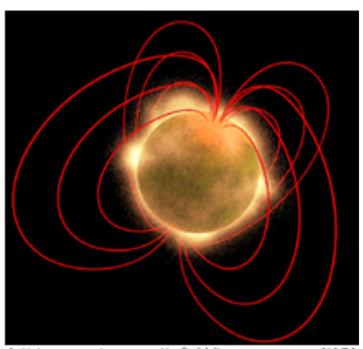
"Magnetars" – A New Class of Neutron Stars

- "Ordinary" pulsars have magnetic fields of "merely" $B = 10^{9-12}$ Gauss. What would happen if the fields were stronger, say 10^{14-16} Gauss?
- The theory of this idea was developed by Robert Duncan (of UT) and C. Thompson
- Then Christa Kouveliotou of NASA suggested that this was the origin of the "soft gamma repeaters" (SGRs).
- These astronomers jointly won the "Rossi Prize" for high-energy astrophysics in 2003.

Magnetars: NS with strong magnetic fields



Dave Dooling, NASA Marshall Space Flight Center

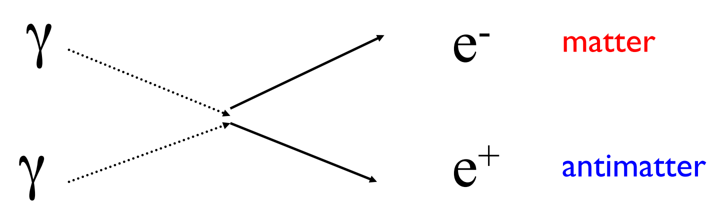


Artists concept: magnetic field lines NASA

The Creation of Matter from Energy

- We know that matter can be converted to energy, according to Einstein's formula $E = mc^2$.
- Einstein's equation is a two-way street: energy can be converted to matter (and anti-matter, in equal amounts); this is called *particle* ***pair production***.

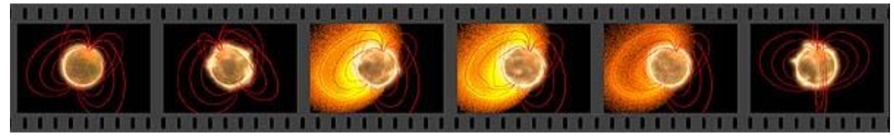
If T is very high,



Annhilation of Matter and Anti-matter

- When two identical particles of matter & antimatter collide, they annihilate (completely destroy each other) and revert to gamma rays
- This happens during H-fusion in the Sun! A positron is produced along with deuterium, but quickly meets a free electron, yielding two high-energy photons
- Conditions near a neutron star may be extreme enough to create and destroy particle/anti-particle pairs
- In particular, e^+ and e^- pairs create an emission "line" at 512 keV in the γ-ray spectral region

Outburst from a Magnetar



Imagine a cross between a pulsar and surface magnetic fields on the Sun: a magnetic "flare" creates a hot spot, which rotates in and out of view during the fading stage; field strong enough to create particle pairs (& 512 kev line)

New Topic: Interacting Binary Stars

- When two stars are in a close binary system, they interfere with each other's evolution.
- Any matter in the vicinity feels forces from both stars, in different directions.
- One can draw surfaces of constant gravitational potential energy with respect to the two stars.
- The surface where the two stars have equal effects (equal energy) is called the Roche lobe.

"Roche Lobes" in a Binary

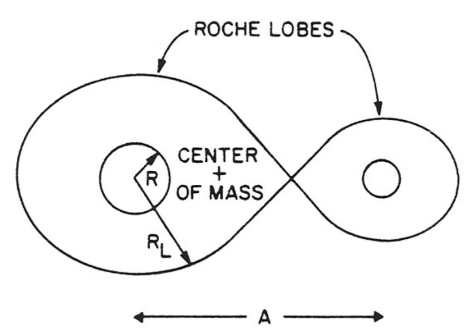


Fig. 8 of Iben, Astrophysical Journal Supplements, Vol. 76, page 64.

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.