Stars, Galaxies & the Universe Announcements

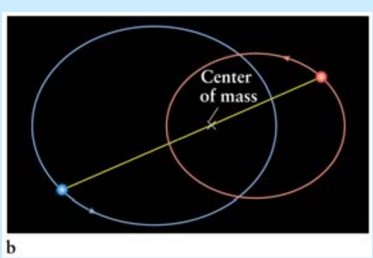
- Reading Quiz #9 – today in class
- HW#8 in ICON – due Friday (10/29) by 5 pm
  - available after class today

Stars, Galaxies & the Universe Lecture Outline

1. Binary Systems
   - Detecting that a system is a binary (3 methods)
   - Close binary systems (Roche lobe overflow)
2. Binary Systems with compact objects
   - Supernova Type 1a (important later on in course!)
   - X-ray bursters

Use lecture notes for this material as the book goes into too much detail!

Binary stars orbit around a common CENTER OF MASS



binary periods: a few hours (close stars) to 100’s of years
→ can find masses if you know periods (using Kepler/Newton’s laws)
binary separations: a few AU (!!) to 100’s of AU

Types of Binary Stars

- (1) Visual Binaries
  - Visible as two distinct stars
  - Most binaries are not visual binaries!
- (2) Spectroscopic Binaries
  - Detectable in the stellar spectral lines
- (3) Eclipsing Binaries
  - Detectable by changes in brightness (light curves)

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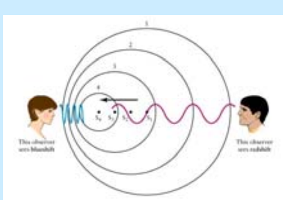
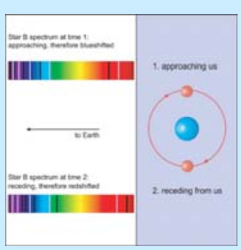
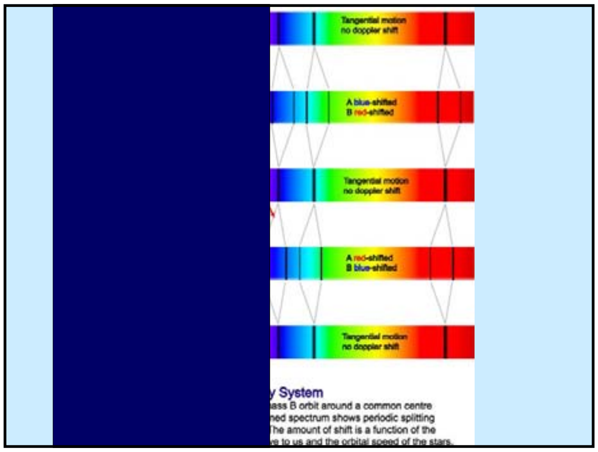
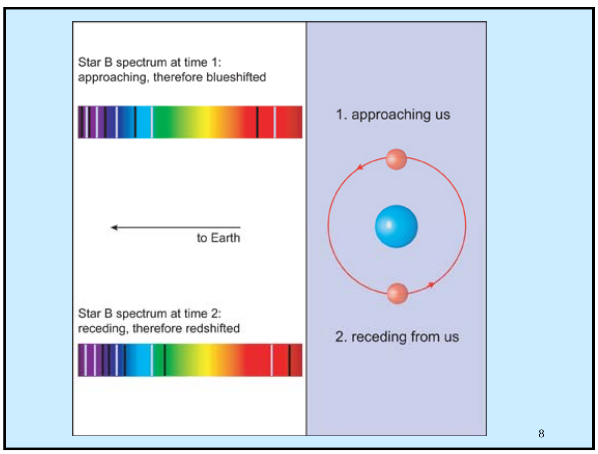
(1) Visual Binary Star System in the Big Dipper

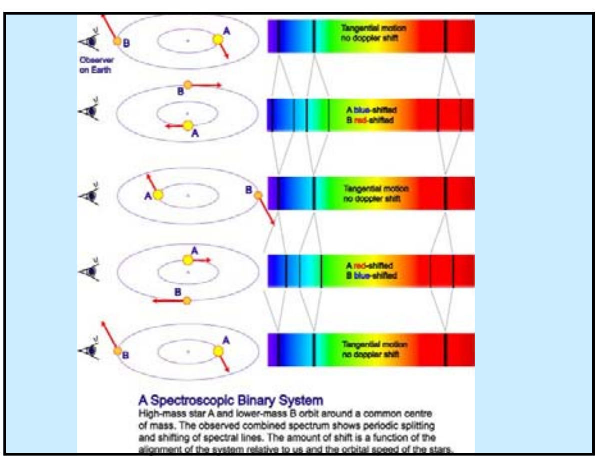
(2) Spectroscopic binaries – Doppler Shifting





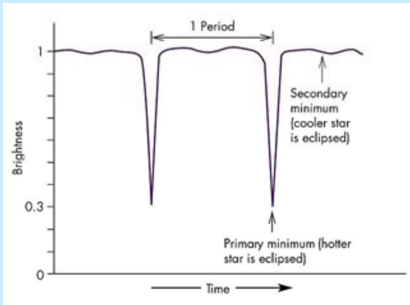

Tangential motion
no doppler shift
A blue-shifted
B red-shifted
Tangential motion
no doppler shift
A red-shifted
B blue-shifted
Tangential motion
no doppler shift


Star B spectrum at time 1:
approaching, therefore blueshifted
1. approaching us
to Earth
Star B spectrum at time 2:
receding, therefore redshifted
2. receding from us
8


Observer
on Earth
A
B
Tangential motion
no doppler shift
A blue-shifted
B red-shifted
Tangential motion
no doppler shift
A red-shifted
B blue-shifted
Tangential motion
no doppler shift
A Spectroscopic Binary System
High-mass star A and lower-mass B orbit around a common centre
of mass. The observed combined spectrum shows periodic splitting
and shifting of spectral lines. The amount of shift is a function of the
alignment of the system relative to us and the orbital speed of the stars.

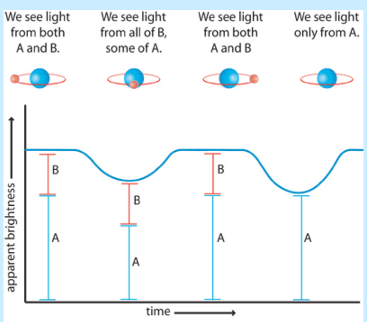
(3) Eclipsing Binaries:

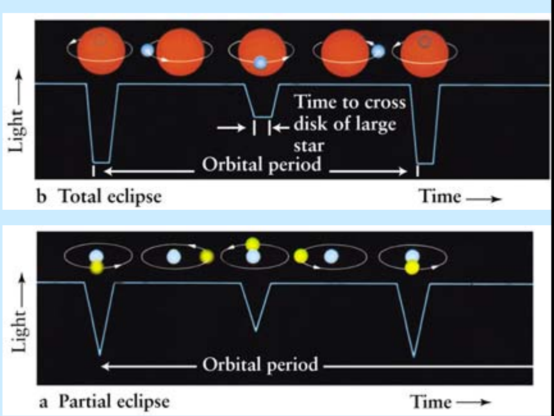
See a change in brightness of a star



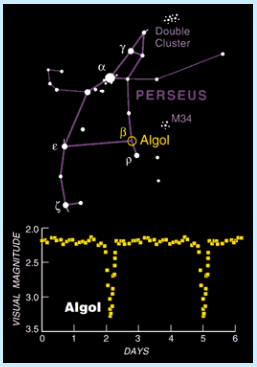
(3) Eclipsing Binaries:

See a change in brightness of a star





ALGOL: most famous eclipsing binary!



Beta (β) Persei

-first eclipsing binary star known

-every 2.9 days changes brightness by 6 x (minima)

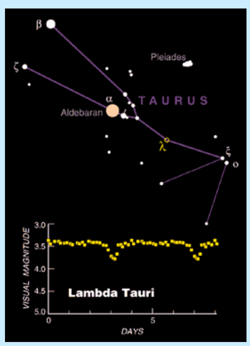
-lasts about 2 hrs as the star passes in front of it

- next minima:

10/26/2010 @ 07:58 pm

11/10/2010 @ 04:03 am

Lambda Tauri in the back of the Bull is another Algol-type eclipsing binary, less well known due to its smaller magnitude range of 3.4 to 3.9. The eclipses last 14 hours, too long to cover in a single night. But enough random observations will define the light curve well.



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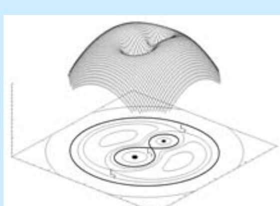
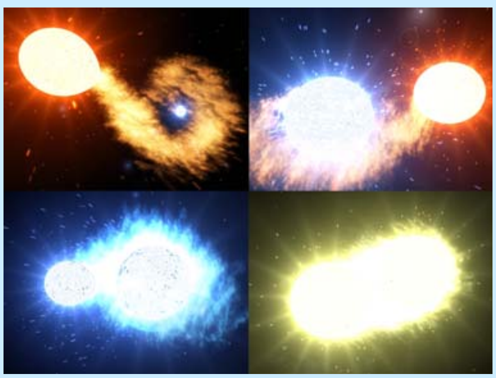
Roche Lobes & Overflow in Star Systems

- The **Roche lobe** is the region of space around a star in a binary system within which orbiting material is gravitationally bound to that star. If the star expands past its Roche lobe, then the material outside of the lobe will fall into the other star. It is an approximately tear-drop shaped region bounded by a critical gravitational equipotential, with the apex of the tear-drop pointing towards the other star

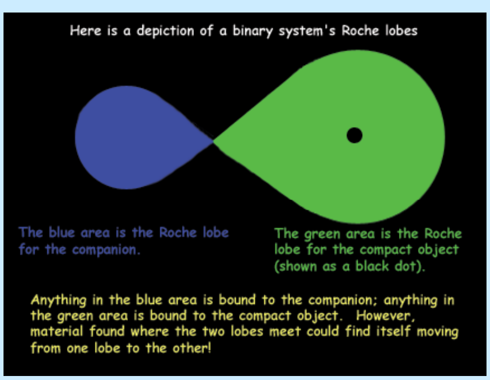


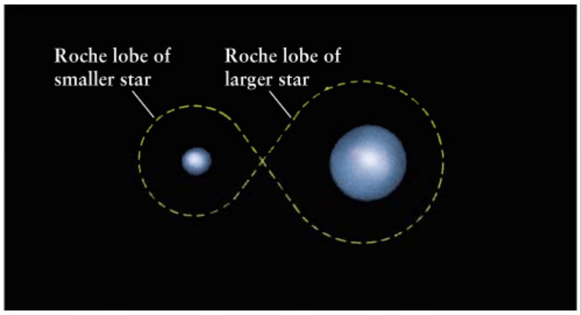
Different Types of Binary Systems

- **Detached binaries** – stars have no effect on one another; most binaries are this type
- **Semi-detached binaries** - one star fills the other's Roche Lobe, can affect star's evolution
  - → Cataclysmic variables (companion and white dwarf)
  - → X-ray binaries (companion and neutron star or black hole)
- **Contact binaries** – both stars fill their Roche Lobes and system ends up with one "common envelope"; eventually both stars are destroyed into a single star!

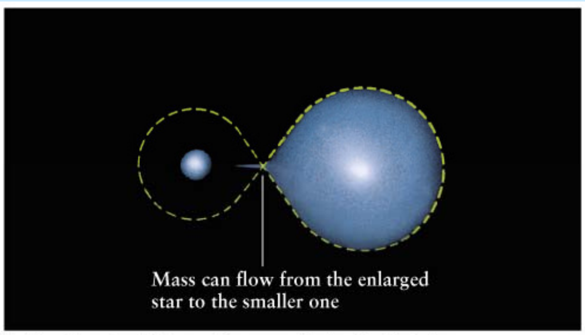


Illustrations of a contact binary system

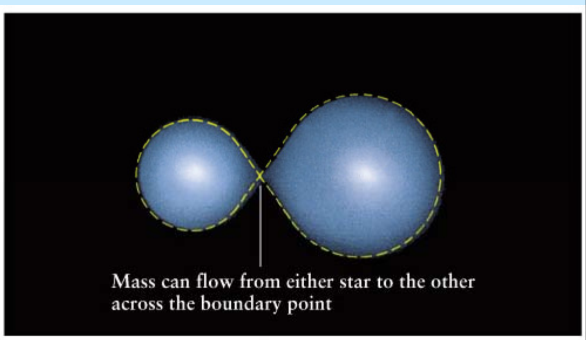




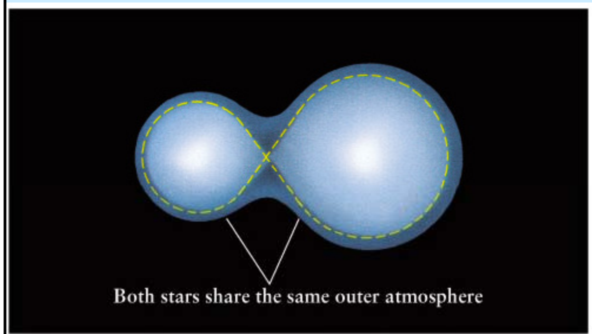
a Detached binary: Neither star fills its Roche lobe.



b Semidetached binary: One star fills its Roche lobe.



c Contact binary: Both stars fill their Roche lobes.



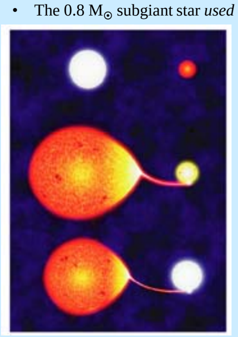
d Overcontact binary: Both stars overfill their Roche lobes.

The Algol Paradox

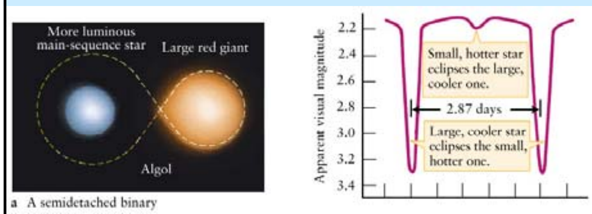
- For example, consider the star *Algol* in the constellation *Perseus.*
  - *Algol* is a close, eclipsing binary star consisting of…
  - a main sequence star with mass = 3.7 $M_{\odot}$ & a subgiant with mass = 0.8 $M_{\odot}$
  - since they are in a binary, both stars were born at the same time
  - yet the less massive star, which should have evolved more slowly, is in a more advanced stage of life

The *Algol Paradox* Explained

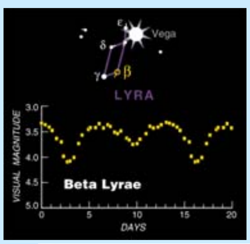
- This paradox can be explained by **mass exchange**.
- The 0.8 $M_{\odot}$ subgiant star *used to be* the more massive of the two stars.



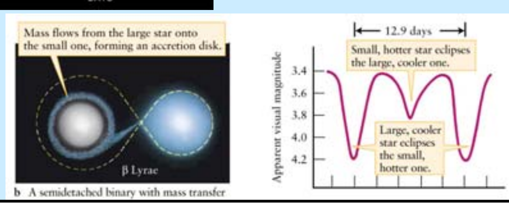
- When the *Algol* binary formed:
  - it was a 3 $M_{\odot}$ main sequence star…
  - with a 1.5 $M_{\odot}$ main sequence companion
- As the 3 $M_{\odot}$ star evolved into a red giant
  - tidal forces began to deform the star
  - the surface got close enough to the other star so that gravity…
  - pulled matter from it onto the other star
- As a result of mass exchange, today…
  - the giant lost 2.2 $M_{\odot}$ and shrunk into a subgiant star
  - the companion is now a 3.7 $M_{\odot}$ MS star



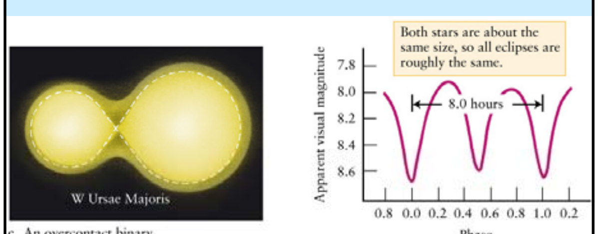
a A semidetached binary



Beta Lyrae is an eclipsing binary of a different type. Algol-type binaries appear nearly constant between eclipses, because the brighter star of the pair is approximately spherical. But Beta Lyrae's components are so close together that they are distorted into ellipsoids by each other's gravity. As the system revolves in its 12.94-day orbital period, we see continuous change at all phases of its light curve. The magnitude range is cataloged as 3.3 to 4.4.



b A semidetached binary with mass transfer



c An overcontact binary

Binary systems in which one member is a compact object

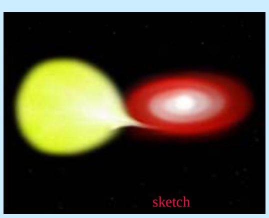
-White Dwarf
- Neutron Star
- Black Hole

How do we detect white dwarfs? → BINARY systems

Sirius A & B
Bright star in sky

Sometimes material from companion falls onto white dwarf

- hot gas from outer layers of giant star overflows
- gravity is strong near white dwarf
- gas is accelerated, heated, **fusion** starts!
- huge amounts of energy released – brighter

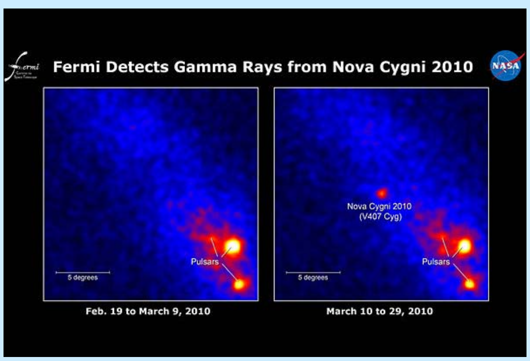


This brightness increase appears to observers: NOVA

"nova" means new in Latin

V1500 Cygni was discovered on August 29 in 1992 and reached magnitude 1.7 on the next day. It remained visible to the naked eye for about a week. 680 days after maximum the star had dimmed by 12.5 magnitudes.
It is an AM Herculis type star, consisting of a red dwarf secondary depositing a stream of material onto a highly magnetized white dwarf primary

HST image of Nova Cygni



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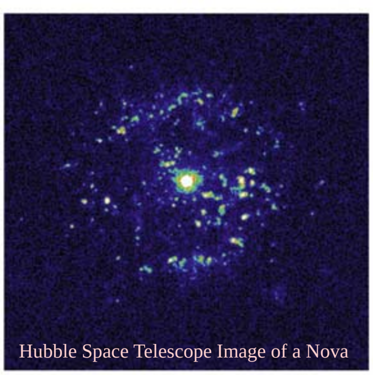
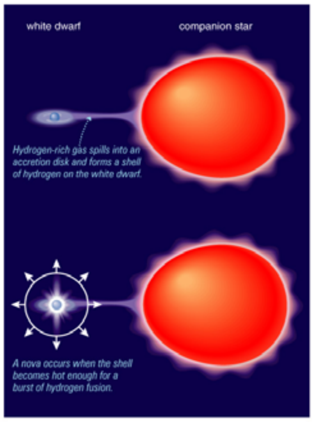
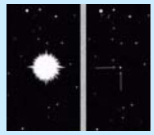


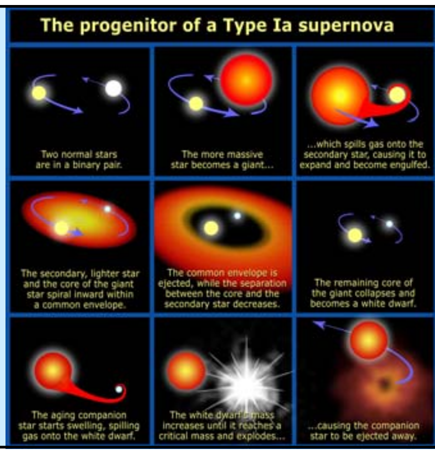
Hubble Space Telescope Image of a Nova



NOVA & SN Type 1a



- an extreme version of this: SUPERNOVA "Type I"
- thought to occur when core starts to fuse carbon/oxygen
- explosion actually blows the star apart, releases HUGE amounts of energy – *can outshine a galaxy*
- Luminosity in this explosion – Typically 10^9 solar luminosities!!



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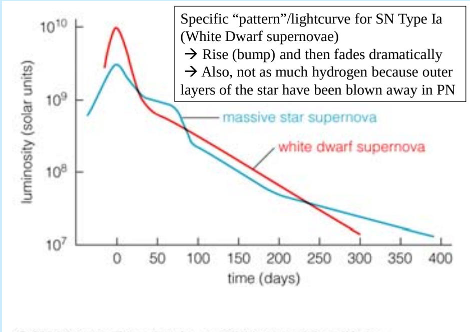
How might you be able to tell a Type I Supernova (WD star) from a Type II Supernova (Massive star)??

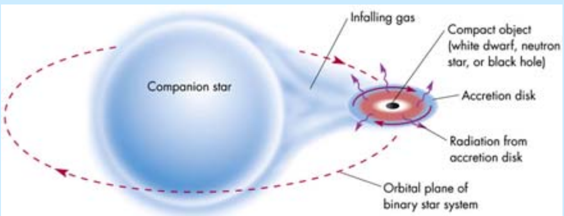


Specific "pattern"/lightcurve for SN Type Ia (White Dwarf supernovae)
→ Rise (bump) and then fades dramatically
→ Also, not as much hydrogen because outer layers of the star have been blown away in PN

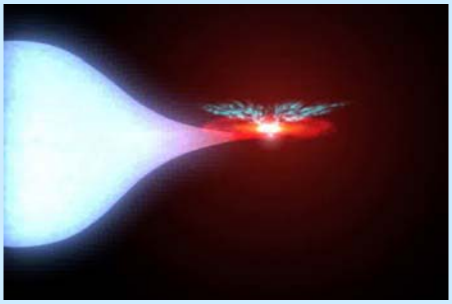
another way to detect neutron stars/pulsars/black holes:
in binary systems

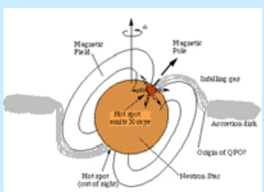
X-ray Binaries: a binary system with one neutron star or BH and one evolving star (lots of gas) main sequence, giant, supergiant

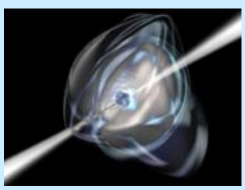
one compact star (neutron star or BH)



Detecting Black Holes: jets of material shoot off the disk







- Neutron star with a powerful magnetic field in an X-ray binary. Gas accreted from the companion star is channeled to the magnetic poles of the neutron star and forms X-ray emitting hot spots which move into and out of view as the neutron star spins, giving rise to regular X-ray pulses. The pulsation periods of X-ray pulsars range from 1.6 ms to >10 minutes in length. Long period X-ray pulsars have particularly strong magnetic fields that decrease their rotation rates through torques exerted on its magnetosphere

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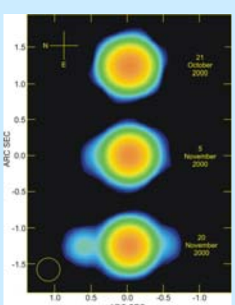
Cygnus X-3: A neutron star binary system in our Galaxy

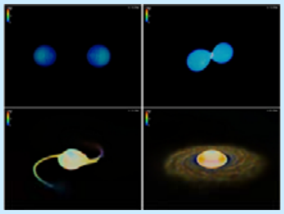


Cygnus X-3 has an orbital period about its companion of only 4.79 hours.

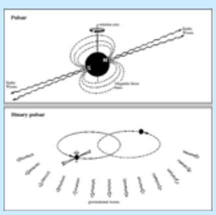
Cygnus X-3 has distinguished itself by its intense X-ray emissions and by ultrahigh energy cosmic rays.

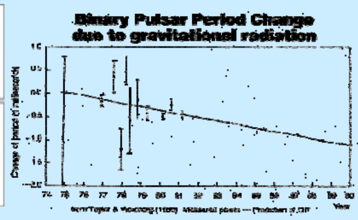
In 1972, a massive radio outburst (increased its lum. In radio by 1000x). Since then it has had periodic radio outbursts with a regular period of 367 days.

Very similar to Black Holes sources! (Friday's lecture…).



Two neutron stars in a binary system
- system will lose energy through gravitational waves
- eventually the neutron stars will merge





The “decay” of the neutron star (pulsar) binary orbit was observed
- in the late 1980s & early 1990s; using radio telescopes
- Joe Taylor & R. Hulse won Nobel Prize in 1993 for this discov