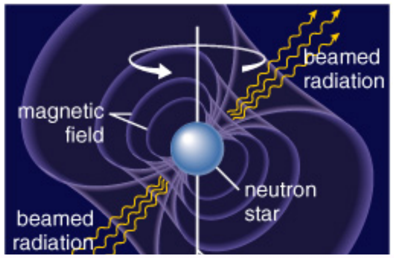
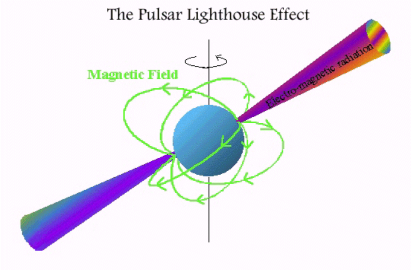
Agenda for Ast 309N, Nov. 1

- Quiz 7
- Card 10/30 feedback
- More on pulsars and other neutron stars
- Begin: the saga of interacting binary systems
- Card: questions for review
- Reading: - Kaler, ch. 7
  - Wheeler, chs. 3, 4, 5, and ch. 6.6 (Type Ia SNe)

The Nature of Pulsars





- A pulsar is a neutron star that beams radiation along a magnetic axis *not* aligned with its rotation axis.
- The radiation beams sweep around like lighthouse beams, as the neutron star rotates on its axis.
- The star rotates extremely fast because its angular momentum was conserved when the core collapsed.

To See or Not to See … (a Pulsar)

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 (yet) have lost most of its initial rotational and magnetic energy

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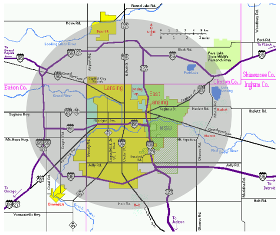
The Slowing & Fading of Pulsars

Kaler, p. 165: "A pulsar's energy is derived from its magnetic field and ultimately from its spin."

- A pulsar is "born" from a core-collapse supernova, spinning rapidly (P = 10^{-2} to 10^{-3} seconds).
- It starts with a huge amount of rotational energy; its rapid spin induces a strong magnetic field via a "dynamo" effect.
- The magnetic field causes synchrotron emission, which carries energy away (an energy "drain").
- As the star spins more slowly, the magnetic field weakens.

Kaler, p. 165: "As a neutron star slows, it loses its ability to radiate… By the time the period is up to 4 seconds or so, it is too old and weak to radiate much, and it disappears from view."

The Structure of Neutron Stars



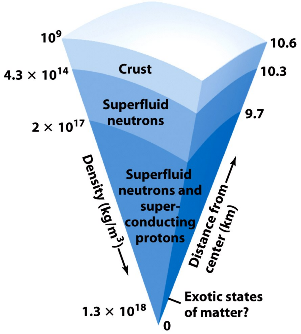


Figure 21-9
Universe, Eighth Edition
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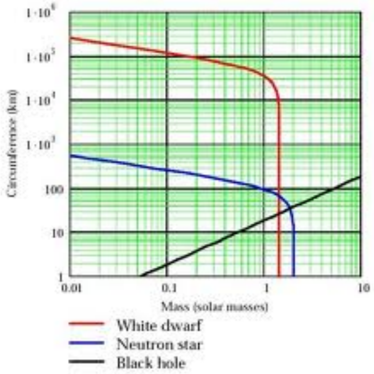
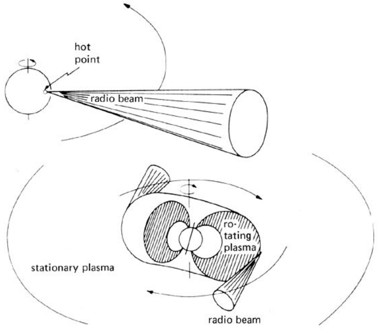
A neutron star is about the size as a small city:
it has a radius of about 10-12 km.

The Neutron Star Mass Limit

- Like electron degeneracy pressure, neutron degeneracy pressure increases with density, so neutron stars as well as white dwarfs also obey an "inverse" mass-radius relation.
- Also like electron degeneracy pressure, there is a maximum mass that can be supported by a degenerate neutrons: if the object exceeds 2 - 3 $M_{\odot}$, it will collapse to infinite density and zero radius (that is, it becomes a black hole)

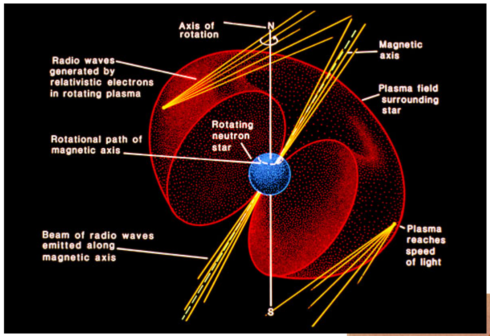


Aside: Oolar vs. Equatorial Models

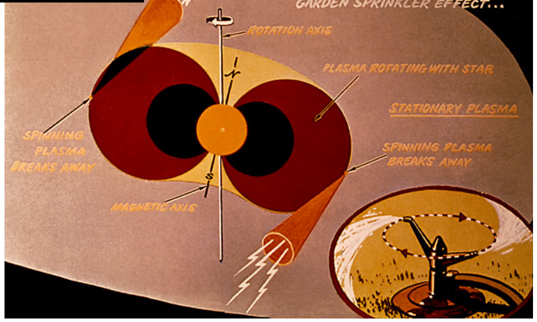


One idea is that the synchrotron emission is radiated as twin "beams" from the magnetic poles.

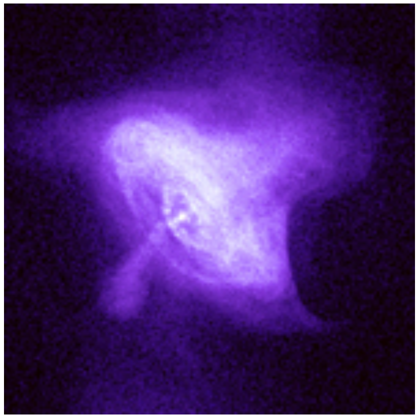
Another possibility is that the radiation comes from the co-rotating magnetic lobes, at the point where their speed approaches that of light, c. This is called the "speed of light cylinder" model.

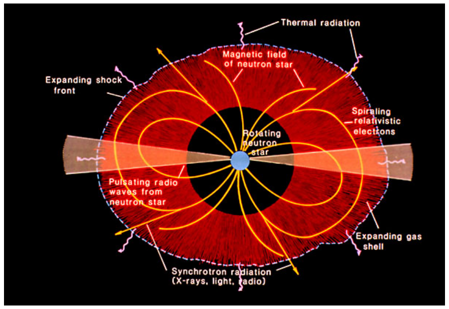


Analogies for pulsars: beacon or garden sprinkler



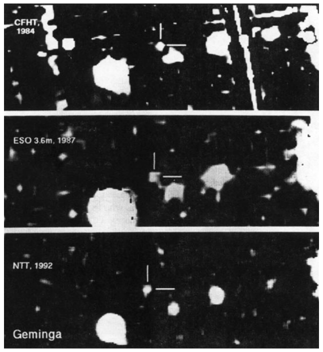
The Crab “Pulsar Wind” Nebula





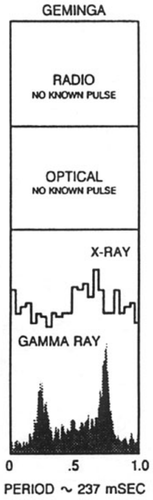
Geminga: A Nearby Neutron Star

Geminga is an isolated, nearby neutron star. First discovered as a gamma-ray source in 1970, it does not emit radio waves, but is seen to “pulse” in X-rays.

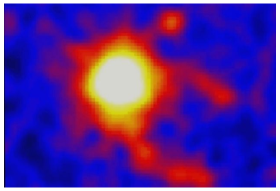


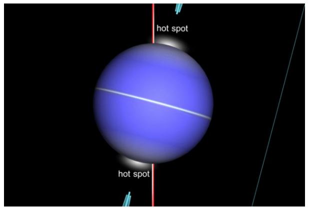
In 1995, it was identified with a faint, fast-moving blue star, and was measured (via parallax) to be 160 pc distant. It is moving across our line of sight at 120 km/sec (that’s fast!)

Geminga: A Nearby Neutron Star

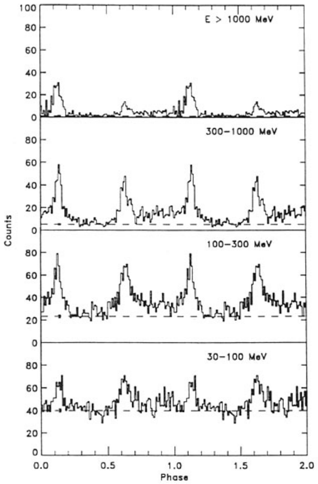


Most of its energy is emitted at energies of 30 MeV - 30 GeV per photon. “Tails” of energetic particles stream behind the neutron star as it moves through space.





Properties of Geminga



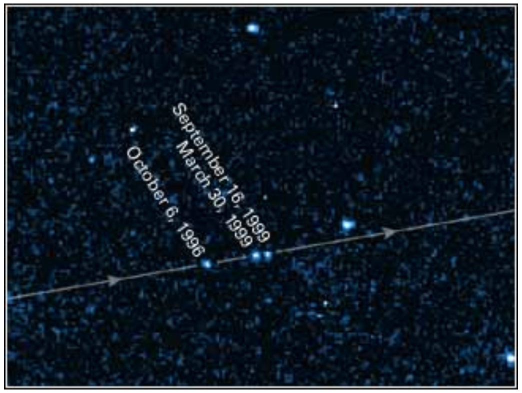
P = 235 millisec ≈ ¼ sec

Magnetic Field ≈ 10^{12} G

Age = 340, 000 years

T = 200,000 - 300,000 K

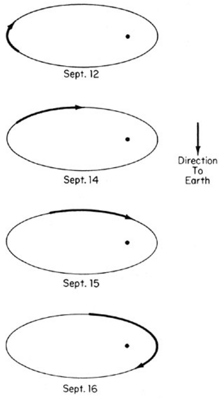
An Even Nearer Neutron Star?



Hubble Space Telescope has tracked another, even closer, neutron star streaking through space, a mere 200 light-years away (only about 60 pc).

RX J185635-3754

The (First) Binary Pulsar

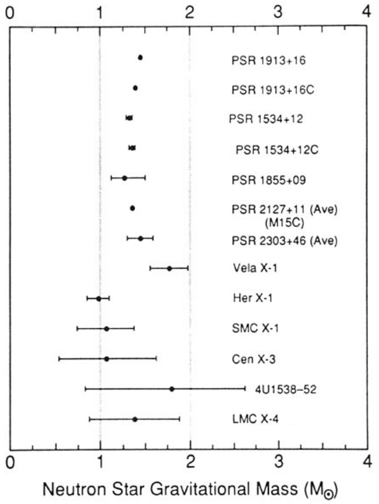


C. Will, Fig. 10-3.

The “Taylor-Hulse” pulsar was the first pulsar discovered to be in a binary system. We can tell that the pulsar is orbiting another object because there is a delay in the arrival time of the pulses when the star is on the “far” side of the orbit.

Astronomers were excited when this system was discovered. Why? What’s useful about finding a pulsar in a binary system?

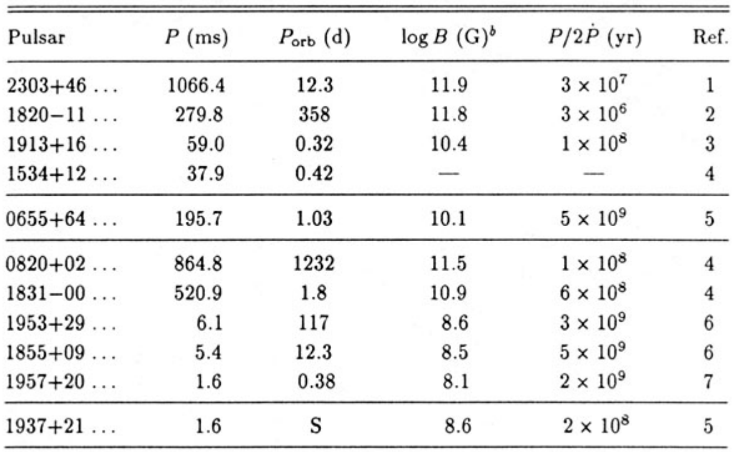
Pulsars in Binary Systems



It enables you to measure masses, which turn out to be typically 1 – 2 $M_\odot$

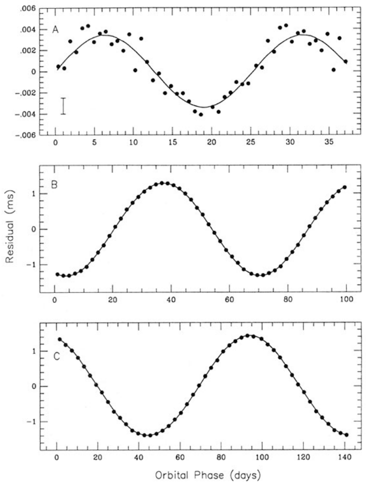
It also provides some tests of general relativity, Einstein’s theory of gravity.

Pulsars in Binary Systems



Pulsar	P (ms)	P_{orb} (d)	$\log B$ (G)^b	$P/2\dot{P}$ (yr)	Ref.
2303+46 ...	1066.4	12.3	11.9	3×10^7	1
1820−11 ...	279.8	358	11.8	3×10^6	2
1913+16 ...	59.0	0.32	10.4	1×10^8	3
1534+12 ...	37.9	0.42	—	—	4
0655+64 ...	195.7	1.03	10.1	5×10^9	5
0820+02 ...	864.8	1232	11.5	1×10^8	4
1831−00 ...	520.9	1.8	10.9	6×10^8	4
1953+29 ...	6.1	117	8.6	3×10^9	6
1855+09 ...	5.4	12.3	8.5	5×10^9	6
1957+20 ...	1.6	0.38	8.1	2×10^9	7
1937+21 ...	1.6	S	8.6	2×10^8	5

Pulsars and Planets (Really??)

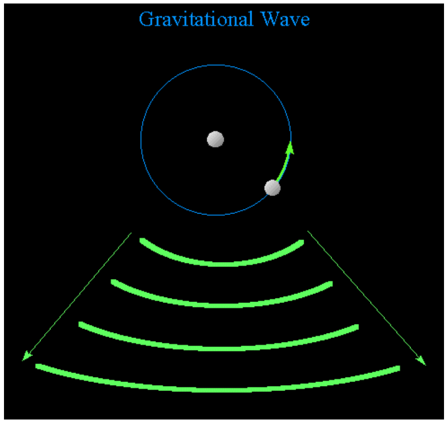


Periodic "delay times" were noted around PSR B1257+12 in the early 1990's. The inferred mass was too small for a stellar-mass companion. Instead, it seemed that there were planet-mass objects in mutual orbit with this pulsar.

How is that possible? It is speculated that the planets form in an accretion disk around the pulsar.

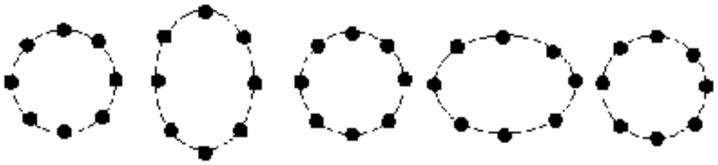
Gravitational Radiation (gravity waves)

Prediction of General Relativity: accelerating masses produce travelling waves of gravitational energy. These are analogous to the electromagnetic waves produced by accelerating charged particles.



Gravitational Radiation (gravity waves)

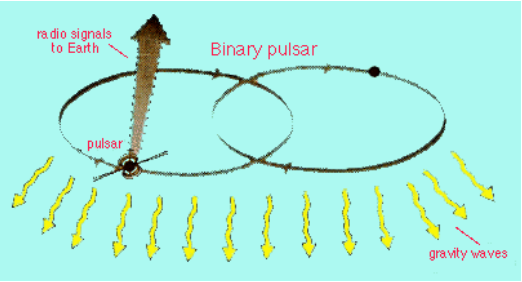
They are "quadrupole" waves that squeeze and stretch objects (in perpendicular dimensions) as they pass. They can be thought of as ripples in space-time.



Gravitational Radiation: Indirect Detection

- The strongest gravity waves will be produced by large masses experiencing high accelerations.
- Stars in short-period, "tight" orbits will radiate gravity waves that carry away orbital energy.
- This will cause their orbits to shrink, so their periods will get shorter.
- The ideal place to look for this effect is in close binary systems containing neutron stars, where quite massive objects can get very close to each other.

Discovery of the Binary Pulsar

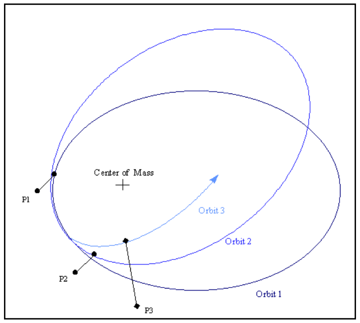


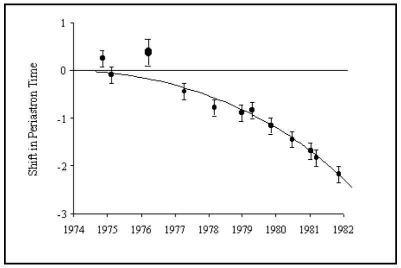
In 1974, J. Taylor & R. Hulse discovered that PSR 1913+16 was part of a binary system.

The orbital period is 7.75 *hours*, and the semi-major axis is 1 $R_\odot$! Both objects seem to be neutron stars of 1.4 $M_\odot$, but only one produces radio pulses that we can see. (Speculate on why?)

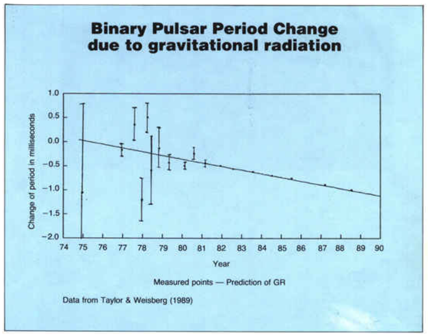
The Binary Pulsar 1913+16

Another general relativistic effect relates to how fast an object in an elliptical orbit will precess. The first example/proof of this was the motion of Mercury, but the binary pulsar's orbit also precesses at the rate predicted by general relativity.





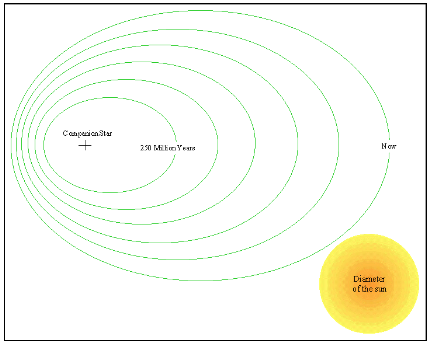
Binary Pulsar Period Change



More dramatically, the binary pulsar is losing energy via gravity waves, causing the period to shorten by 75 *micro*seconds (10^{-6} sec) per year. This rate of energy loss is exactly what is predicted by general relativity.

The 1993 Nobel Prize in physics was awarded to Taylor & Hulse for this work; it called the binary pulsar "a deep space proving ground for Einstein's general theory of relativity."

Eventual Fate of Binary Pulsar



Someday the two stars will collide, a truly catastrophic event! Gravitational wave emission will intensify during the last stages of this "in-spiral." At that point, it would be detectable by the new gravity-wave detectors such as LIGO.