The Binary Pulsar

Gravitational waves

Prediction of general relativity:

- perturbations to curvature of spacetime
- propagate at speed of light

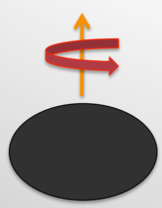
Analogy: dropping a stone (perturbation) in a pond (spacetime) produces waves (spacetime ripples) that propagate away from the source

Gravitational waves

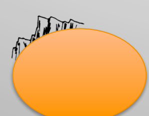
Sources:

- non-axisymmetric motions of…
- massive bodies…
- moving close to the speed of light

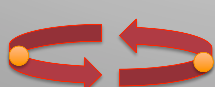
→ strong gravitational waves



Rotating black hole: NO
(axisymmetric)



Rotating neutron star with a
"mountain" on surface: YES



Binary stars: YES
…strong if the binary is so close
that v ~ c

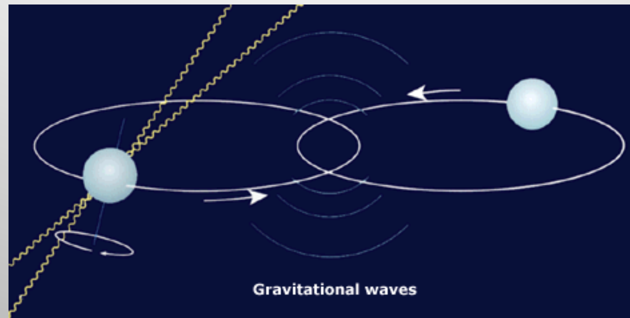
Strongest sources of gravitational waves:

- merging binaries of compact objects
- black hole – black hole (either stellar mass or supermassive)
- black hole – neutron star
- neutron star – neutron star

Ongoing experiments to detect gravitational waves from these sources directly on Earth

No direct detections yet: but there is strong *indirect* evidence that gravitational waves exist

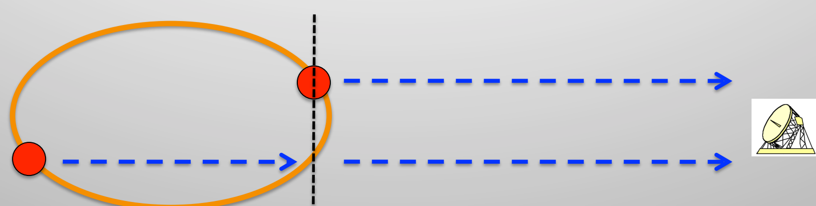
The "Binary Pulsar"



1974: Joe Taylor & Russell Hulse discover a binary pulsar

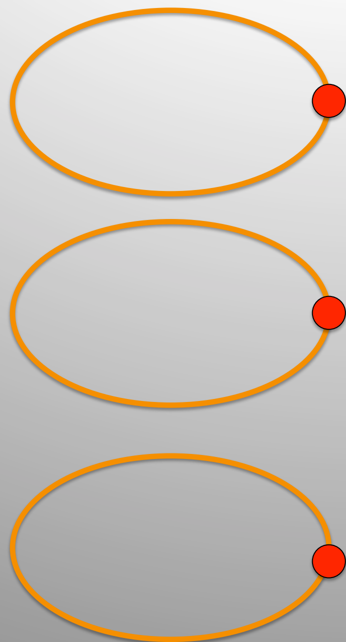
- two neutron stars in a binary
- one of them is observed as a radio pulsar
- Nobel Prize 1993

Why is this system exciting? Pulses from a rotating neutron star are very regular: a near-perfect clock



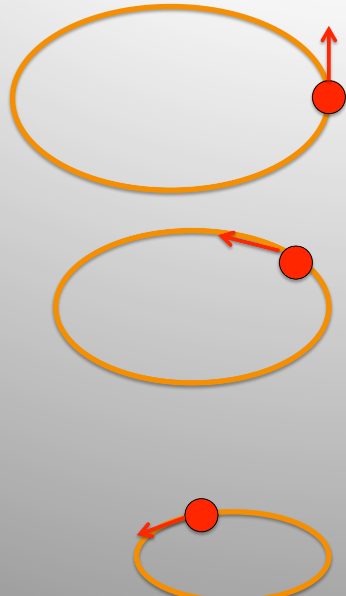
Radio pulses emitted when the neutron star is at the "far" side of orbit have further to travel: arrive "late"

Timing of pulses can measure the size of the orbit (+special relativistic effects)



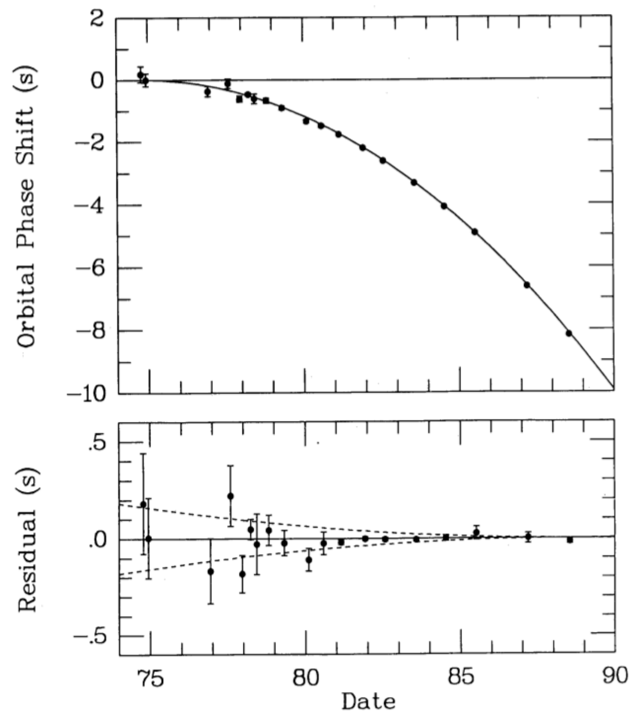
No gravitational waves:

Orbit is exactly periodic: time between closest approaches to Earth is fixed



Gravitational waves:

- orbit shrinks (loss of energy)
- smaller orbit has shorter period
- time between closest approaches gets less with time



Through 1988, binary pulsar moment of closest approach got less by 8 seconds

Matches the prediction of gravitational wave emission in general relativity

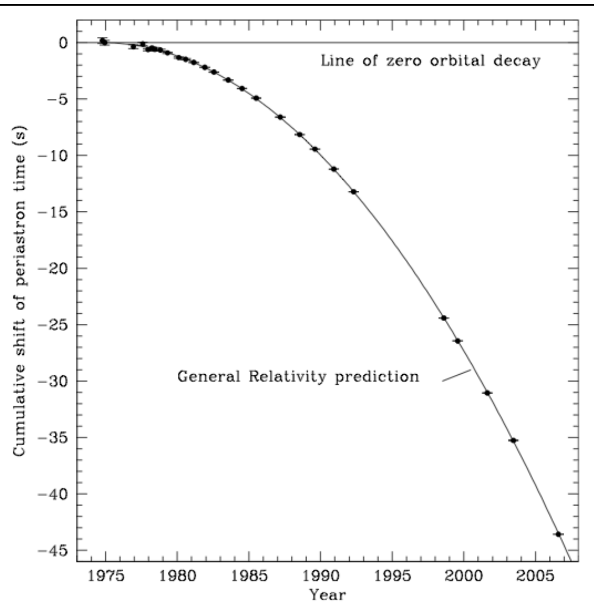
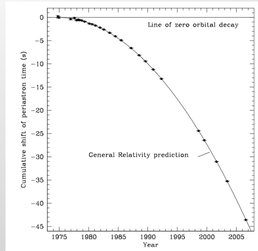


Figure 2. Orbital decay caused by the loss of energy by gravitational radiation. The parabola depicts the expected shift of periastron time relative to an unchanging orbit, according to general relativity. Data points represent our measurements, with error bars mostly too small to see.

Latest timing measurements

Weisberg et al. (2010)

Ratio between GR prediction and measurements for this system: 0.997 +/- 0.002



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This system, and others discovered subsequently, best tests of general relativity to date: agree with expectations to few tenths of a percent

Highly confident gravitational waves exist, even though we haven't detected them (yet!)