Neutron Stars

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Outline

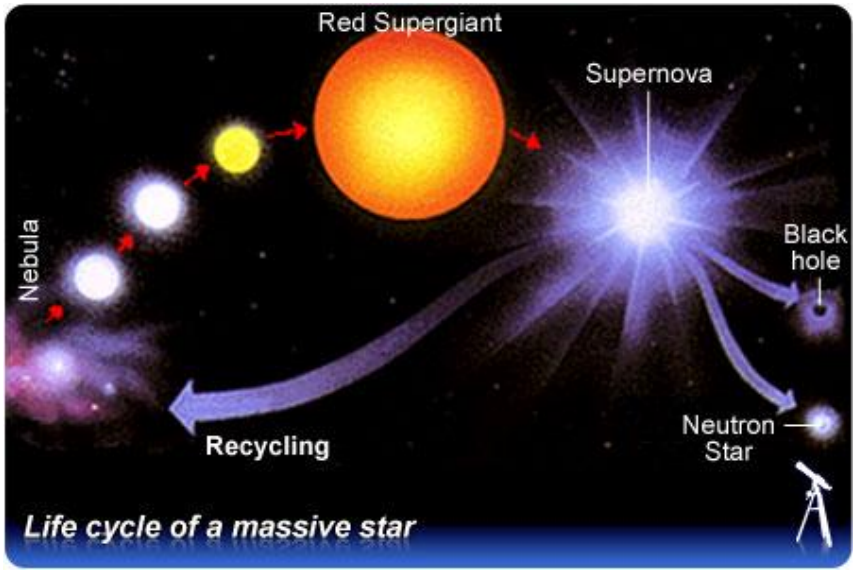
- History, Formation, Properties
- Detection
- Pulsars
  - Crab Nebula Pulsar
  - Pulsar Timing
  - Pulsars in Binary Systems
- Isolated Neutron Stars
  - J185635-3754
- Summary

The Neutron and the Neutron Star

- In 1932 Chadwick discovered the neutron
- Baade & Zwickly (1934) suggested a compact core contain only neutrons
- Many incorrect calculations about Neutron Stars until accounting for the Nuclear Force in the late 1950's
- Finally lead to the conclusion that a star consisting of only neutron could and should exist in nature.

Neutron Stars

- In larger stars, heavy elements begin to fuse in the core of large stars
- Iron cores of large stars collapse
- Protons and electrons fuse to neutrons and neutrinos
- Gravitational collapse is stopped by degenerate-neutron pressure, if not the core would pass the Schwarzschild radius



Properties of Neutron Stars (NS)

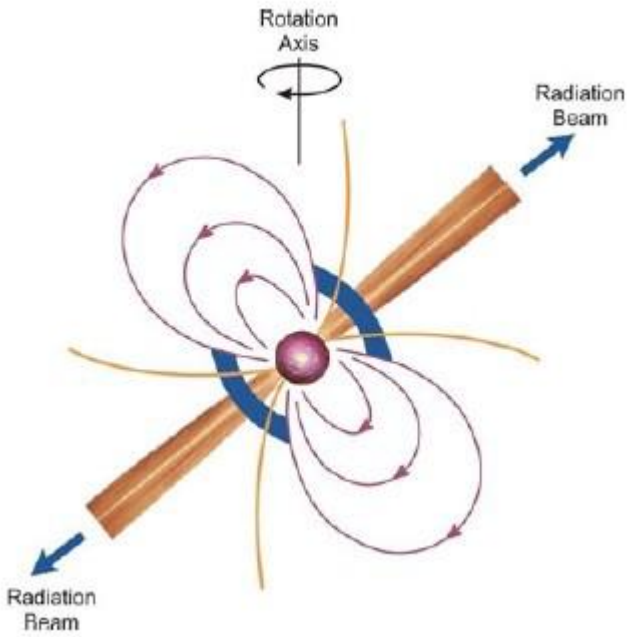
- Small
  - Radii of 5 - 20km
- Dense
  - 10^{57} neutrons
  - 400 million tons per cubic centimeter
- Rotate Rapidly
  - Can rotate hundreds of times per second
- Strongly Magnetized
- Temperatures up to thousands of millions degrees Kelvin

Detection

- Small radius makes hard to detect optically
- Temperatures produce blackbody radiation that peaks in X-Ray
- Estimated that there should be 100,000,00 NS
- Need to use other methods to find NS:
  - Neutron stars should be near supernova remnants
  - Radio Observations
  - X-Ray and Gamma Ray Observations

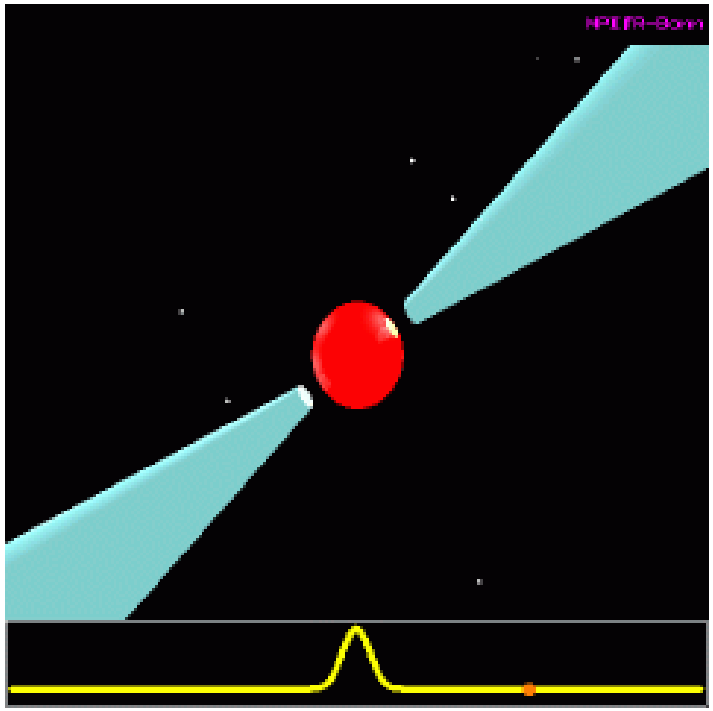
Pulsars

- Pulsars
  - First evidence that NS actually exist
  - B Fields pull particles off surface and accelerates them down beams along magnetic poles
  - Magnetic poles and the rotational axes are not aligned



Margueron, Compstar School 2009, Slide #25

Pulsars



http://pulsar.ca.astro.it/pulsar/Figs/smallmodpulsar.gif

First Pulsar Discoveries

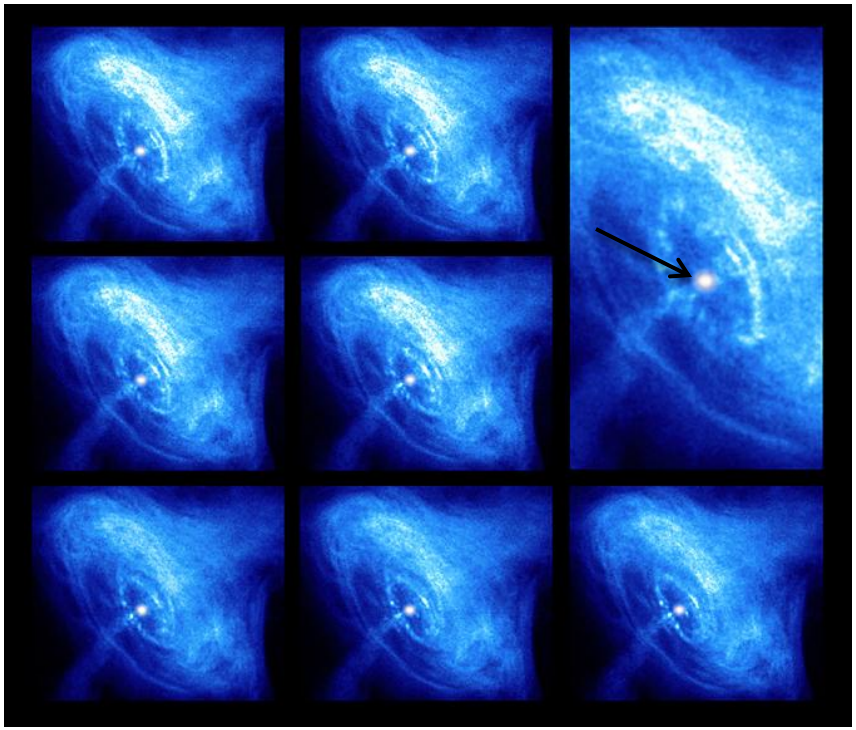
- First Pulsar was discovered by Bell and Hewish in 1967
  - Radio pulses of every 1.4 seconds
- 1968, Pulsars were discovered in SNR
  - Crab SNR
  - Vela SNR
  - Confirmed Baade and Zwickly (1934)

Crab Nebula

http://antwrp.gsfc.nasa.gov/apod/ap000711.html

Crab Nebula

- Supernova explosion in 1054 AD
- Good candidate for searching for a NS in a SNR
- Pulsar was discovered in 1968
- The lose of rotational energy should correspond with the luminosity of the nebula

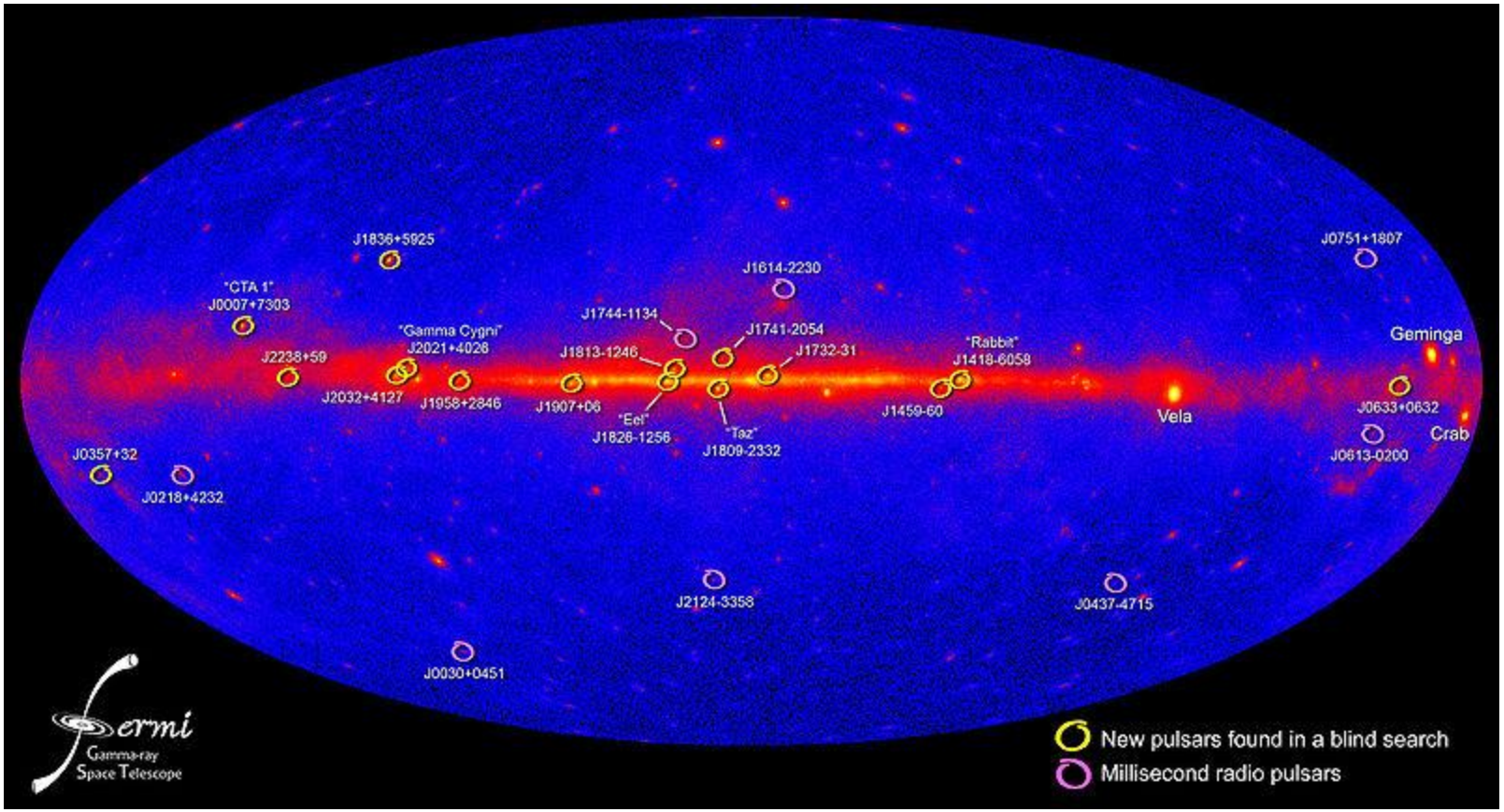


Chandrea Image of Crab Nebula Pulsar- NASA/CXC/ASU/J.Hester et al.

Pulsars Timing

- Pulsars have a very steady pulse
- Variations in pulse can be very useful in studying effects on surfaces and atmospheres of neutron stars
- About 1000 radio pulsars have been discovered
- Pulses can also be detected X-Ray and γ Rays

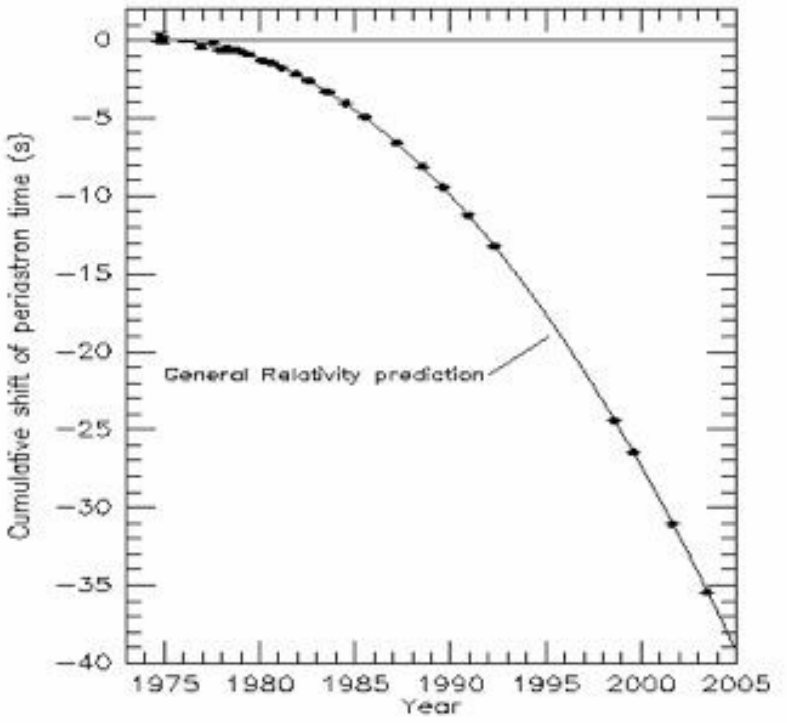
Recent Observations



http://www.phys.ncku.edu.tw/~astrolab/mirrors/apod_e/ap090709.html

Binary Systems

- P1913+16 - First Binary Pulsar System discovered in 1974 by Hulse and Taylor, lead to Nobel Prize in 1993
- Allowed for long term studies of GR prediction of Gravitational Waves



Binary Systems

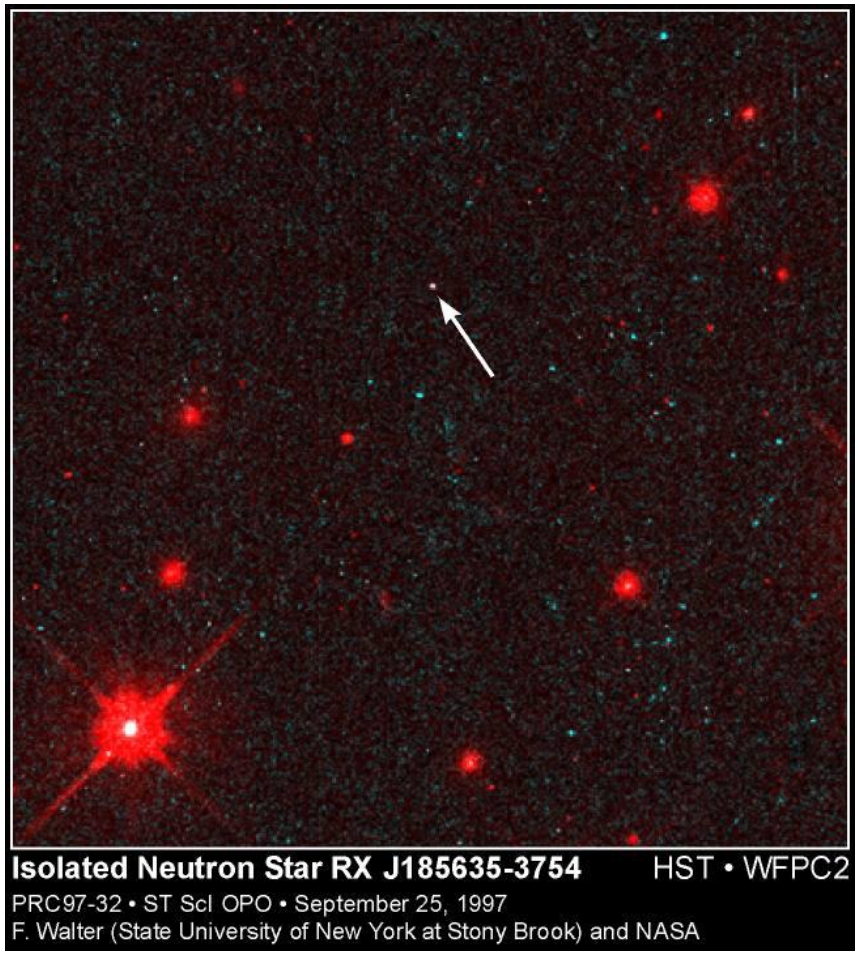
- Accretion Powered Pulsars
  - The binary component is accreting matter on to the pulsar
  - Pulses are caused by hot spots at the magnetic poles from mattering hitting of the star, that can be seen in X-Ray
  - Hundreds of accreting NS have been discovered
- Pulsar and Exoplanets
  - The first exoplanet was discovered around a pulsar
    - PSR B1257+12
  - Notice anomalies in pulsation

Isolated Old Neutron Stars (IONS)

- Over time NS move away from SNR
- Losing energy so pulsation stops and NS cools
- Observe only the neutron star
  - Help to determine composition and radius
  - Help put limits on equation of state
- Very few have been found, even though most NS are expected to be IONS

J185635-3754

- Bright X-Ray source
- Radius is less then 9km
  - Puts large constraints on equation of state
- Distance of 61 pc
- Not pulsing in radio or X-ray
  - Emission is directly from the surface of the NS!



Summary

- Studying NS have always stretches to various fields of physics
- NS have extreme conditions which can allow for research in QGP and Gravitational Radiation
- EOS for NS is still unknown but many different observations can and are putting constraints on models
- Observing different types of neutron stars is key to understand their complex structure and properties

References

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