Pulsars as Astrophysical Tools

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• Introduction to pulsars
  - Extreme properties
  - Pulsar searching
  - Pulsar timing

• Current projects
  - Transient sources
  - The double pulsar
  - A pulsar timing array

• Future plans
  - Next-generation telescopes...
The discovery of pulsars

Observation of a Rapidly Pulsating Radio Source

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Unusual signals from pulsating radio sources have been recorded at the Mullard Radio Astronomy Observatory. The radiation seems to come from local objects within the galaxy, and may be associated with oscillations of white dwarf or neutron stars.

Today over 1700 pulsars are known. It is now established that they are neutron stars.
Neutron stars are really extreme objects...

- **Extremely dense objects**
  - 100,000,000,000,000,000 kg m^{-3}
- **Extremely rapid rotators**
  - Spin rates up to 719 Hz known
- **Extremely high magnetic fields**
  - <10,000,000,000,000 x Earth’s field
- **Extremely fast moving stars**
  - Up to and beyond 1000 km/s
...in a variety of environments
Basic pulse properties
Individual pulses are very erratic

22 s time series

140 ms zoom in on individual pulses
...but average behavior is stable
The profile is the pulsar’s fingerprint.
The distances to pulsars
The pulsar sky distribution

Solid points: PSR/SNR; Points + circles: MSPs
Pulsars are dispersed in frequency by free electrons in the interstellar medium.

Photons with higher frequencies travel faster through space and arrive earlier than lower frequency ones.

The total delay is proportional to the distance to the pulsar.

Using a model for the interstellar medium, we can use this property to estimate distances to pulsars.
Distribution in our Galaxy

Black points: 0.4 GHz; Yellow points: 1.4 GHz
Searching for pulsars

Number of known radio pulsars

- approx. one per cent of total population
- PSR#1!
- 1913+18
- 2nd Molonglo
- 1937+21
- MSP#1!
- GCPSR1!
- 1821-24
- All-Sky
- 1257+12 ... planets!
- 1534+12 ... NS-NS!
- Parkes Multibeam
Standard pulsar searching

Multi-Channel Search Data → De-dispersed Time Series → Amplitude Spectrum

Radio Frequency

Telescope Time → yes! → Another DM? → Save Candidates

Fold best candidates → no! → once in a while you’ll see...

a pulsar!!
Pulsar timing
Timing pulsars

We compare the pulse arrival times with those predicted by a simple model.

we effectively count each neutron star rotation!
Timing pulsars

The pulse period may be Doppler shifted if it is in a binary system.

an additional Doppler shift occurs due to Earth–Sun motion!
Evolution

Strong links to

supernovae
stellar evolution
binary evolution
stellar winds
white dwarf cooling
magnetars
Some current projects

- The transient radio sky
  - New source classes

- The double pulsar
  - Testing strong-field gravity

- Pulsar timing array
  - Searching for gravitational waves
A new class of neutron star only detectable through bright radio bursts.

Detected with the Parkes Multibeam survey in Australia. Follow-up studies with the GBT.

Working on understanding how these relate to other classes of neutron stars.

Huge implications for number of neutron stars in Galaxy!!
The transient radio sky

We are always searching for new radio signals in our data.

A new radio transient:

- extragalactic origin
- frequency dispersion
- $D \sim 500$ Mpc ($1.7$ Gly)
- origin unknown (NS-NS?)

Lorimer, Bailes, McLaughlin, Narkevic & Crawford (2007)
The double pulsar: J0737-3039

Both neutron stars are visible as pulsars:

A: P=22.7 ms
B: P=2.7 s

Orbital period = 2.4 hr
Size of orbit = 3 lt sec
Speeds = 330 km/s

Two clocks in a compact, highly relativistic orbit!
The double pulsar: J0737-3039

Was Einstein Right???

Radio timing yields 5 Keplerian parameters

- $P_B$ - binary period
- $a \sin i$ - semi-major axis
- $e$ - eccentricity
- $\omega$ - longitude of periastron
- $T_0$ - epoch of periastron

We have five measurable relativistic (Post-Keplerian) parameters and only 3 unknowns ($M_A$, $M_B$, $i$).

Can measure $M_A$, $M_B$, $i$ AND test GR.
The double pulsar: J0737-3039

A unique system for tests of general relativity in the strong-field regime:

We measure:
- periastron advance
- time dilation
- gravitational redshift
- Shapiro delay
- gravity wave damping

System currently verifies GR predictions to 99.95%
Double pulsar movies: formation and ultimate fate due to gravitational wave emission...
Astronomers are looking for these events in other Galaxies

http://www.einstein-online.info/en
A unique niche - GW detectors
Green Bank Drift Scan Survey

We carried out a large-scale survey during GBT track refurbishment.

Over 25% of sky was covered.

Most sensitive large-scale survey for pulsars...

Some of the data will be reduced by WV high-school students (PSC).
Next generation telescopes

www.skatelescope.org

www.lofar.org
A pulsar census with the SKA

Essentially complete census
- Galactic disk
- globular clusters
- Galactic center
- Magellanic clouds
Plus other Galaxies

>20,000 normal PSRs
several thousand MSPs

10s of DNS binaries
PSR-BH binary
MSP-MSP binary?
Concluding remarks - pulsar applications to phys/astro

- First measurement of galactic magnetic field
- First test of GR outside our solar system
- First proof of existence of gravitational waves
- First discovery of extra-solar planets
- First measurement of gas in a globular cluster

Holy grails for the not-too-distant future...
- First measurement of black hole spin?
- First direct detection of gravitational waves?