Pulsars: timekeepers of the cosmos

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- Radio astronomy history
- Introduction to pulsars
  - Extreme properties
  - Pulsar searching
  - Pulsar timing
- Current projects
  - Transient sources
  - The double pulsar
  - A pulsar timing array
- Future plans
Different colors of light are due to different wavelengths.

Different colors of light also have different energies.

\[ E = hf \quad f = \frac{c}{\lambda} \]

- \( E \) = energy
- \( f \) = frequency
- \( \lambda \) = wavelength

\[ 1 \text{ Hz} = 1/s \]
History of radio astronomy

• In 1888, Hertz built a machine which would receive and transmit radio waves (5 m).
• In 1901, Marconi sends first radio message across Atlantic Ocean from Chelmsford, UK to Newfoundland.
• In 1932, Jansky discovers radio waves (14m = 20 MHz) from the center of the Milky Way (Sgr A).
History of radio astronomy

• In 1937, Reber builds telescope in mother’s backyard and maps the radio sky for the first time.
How radio telescopes work

• Radio sources are weak

\[ 1 \text{ Jy} = 10^{-26} \text{ W/m}^2/\text{Hz} \]

• Radio telescopes act as light buckets. We need BIG dishes to collect as much light as possible.

• Big dishes also give better resolving power.

\[ \theta \approx \frac{\lambda}{D} \]

\[ \theta = \text{size of the radio beam} \quad D = \text{diameter of telescope} \]

\[ \lambda = \text{wavelength} \]
How radio telescopes work

- Radio waves are focused onto a receiver.
- Radio receivers work just like AM/FM radio. They sample the voltages carried by the radio waves.
- We like to take data over as wide a bandwidth as possible.

..... typically something like 100 MHz at 1 GHz
Telescopes we use...
The discovery of pulsars

Observation of a Rapidly Pulsating Radio Source

by

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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.
Mind’s-eye view
Sit back and enjoy the sounds of pulsars...
Basic pulsar properties

• Extremely dense objects
  - $100,000,000,000,000,000,000$ kg m$^{-3}$
  - Next thing down from a black hole
Basic pulsar properties

• Extremely rapid spin
  - Rotation rates in excess of 700 Hz
  - Speed at surface ~ significant fraction of c
Basic pulsar properties

- Extreme magnetic fields
  - $1,000,000,000,000 \times$ Earth's field
Formation of pulsars

A star on the main sequence

Equilibrium via H burning

Star collapses in on itself

Neutron core formed $p + e \rightarrow n$

A star in the giant phase

Equilibrium via heavy element burning

Expanding shell forms supernova remnant
Pulsars pop up all over the place

~ 1700 Radio Pulsars

Globular Cluster 5

Binary 6

SMC 1

LMC 4

Supernova Remnant

18

1

1

1

15 “Reycled”

1

1

49

76

1

1

~20
Individual pulses are very erratic

22 s time series

140 ms zoom in on individual pulses
...but average behavior is stable
Distribution in our Galaxy
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.
Searching for pulsars

- PSR#1!
- 1913+16
- 1937+21
- 2nd Molonglo
- 1257+12, 1534+12, and planets!
- All-Sky
- GCPSR!
- 1821-24
- Parkes Multibeam

Approximately one percent of the total population.
Standard pulsar searching

1. Multi-Channel Search Data
   - Radio Frequency
   - Telescope Time

   DM

2. De-dispersed Time Series
   - Telescope Time

   FFT

3. Amplitude Spectrum
   - Fluctuation Frequency

   yes!
   Another DM?
   Save Candidates

4. Fold best candidates
   - yes!
   - no!
   - once in a while you’ll see...

   a pulsar!!
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!
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