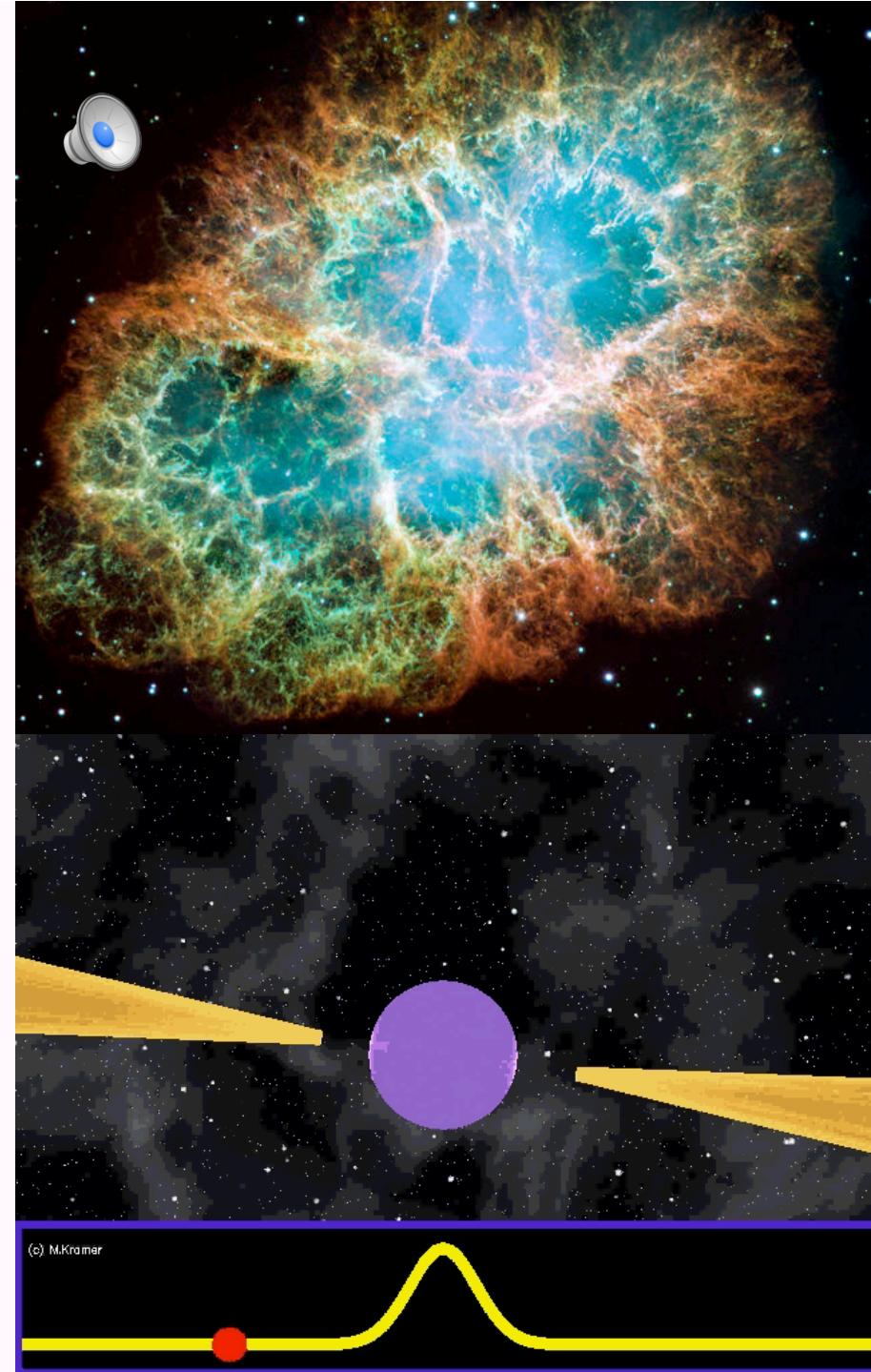


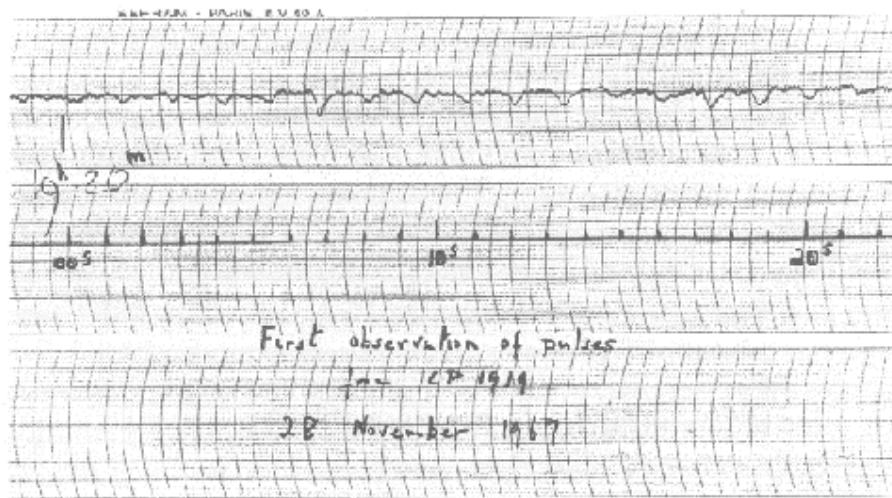
Pulsars as Astrophysical Tools

Duncan Lorimer
(West Virginia University)

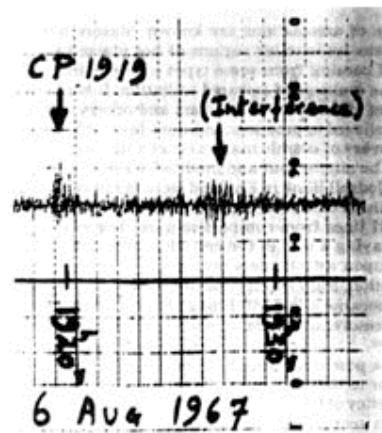
- Introduction to pulsars
 - Extreme properties
 - Pulsar searching
 - Pulsar timing
- Current projects
 - Transient sources
 - The double pulsar
 - A pulsar timing array
- Future plans
 - Next-generation telescopes...



The discovery of pulsars



Observation of a Rapidly Pulsating Radio Source



by

A. HEWISH
S. J. BELL
J. D. H. PILKINGTON
P. F. SCOTT
R. A. COLLINS

Mullard Radio Astronomy Observatory,
Cavendish Laboratory,
University of Cambridge

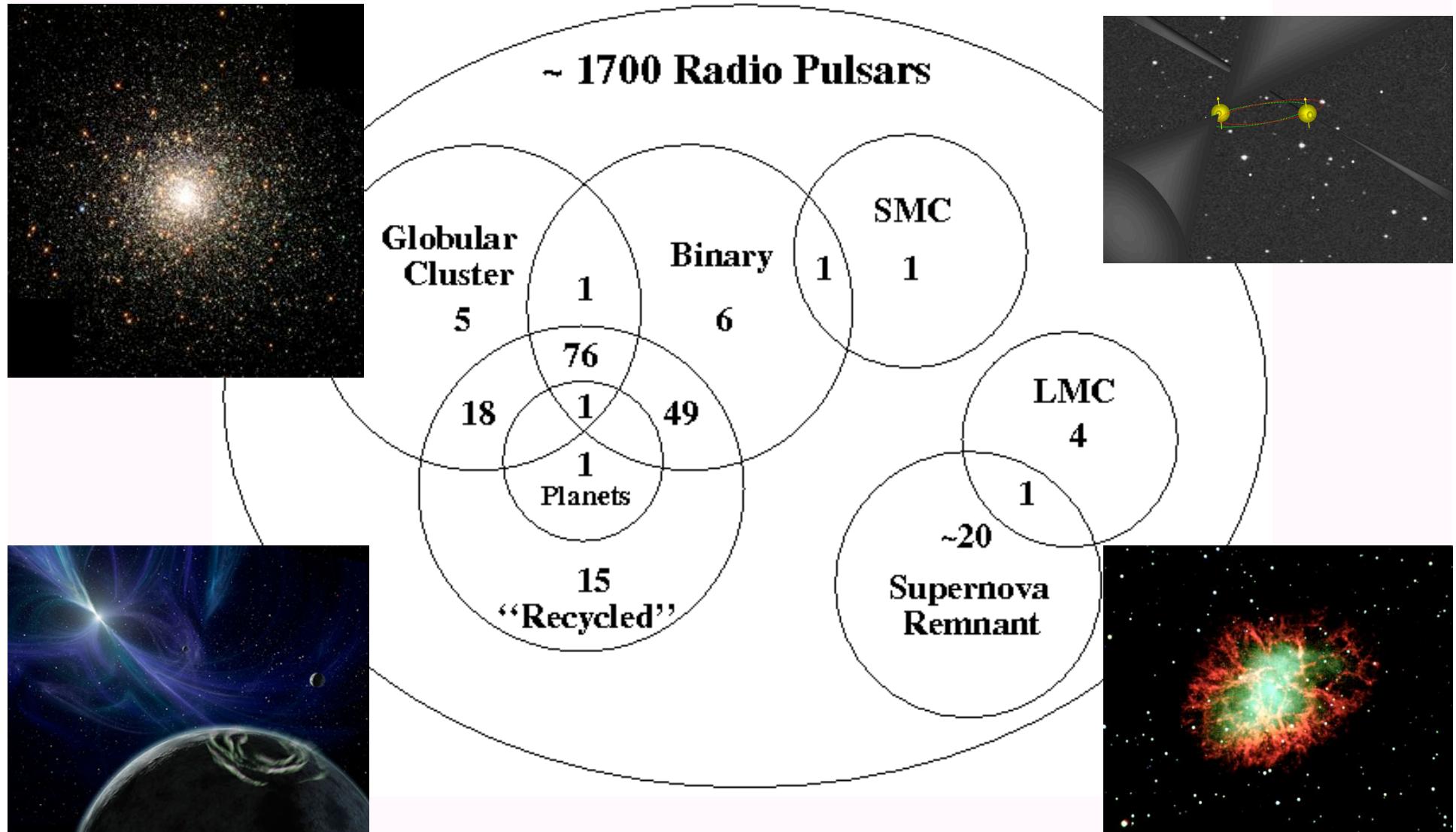
Unusual signals from pulsating radio sources have been recorded at the Mullard Radio Astronomy Observatory. The radiation seems to come from local objects within the galaxy, and may be associated with oscillations of white dwarf or neutron stars.

Today over 1700 pulsars are known. It is now established that they are neutron stars

Neutron stars are really extreme objects...

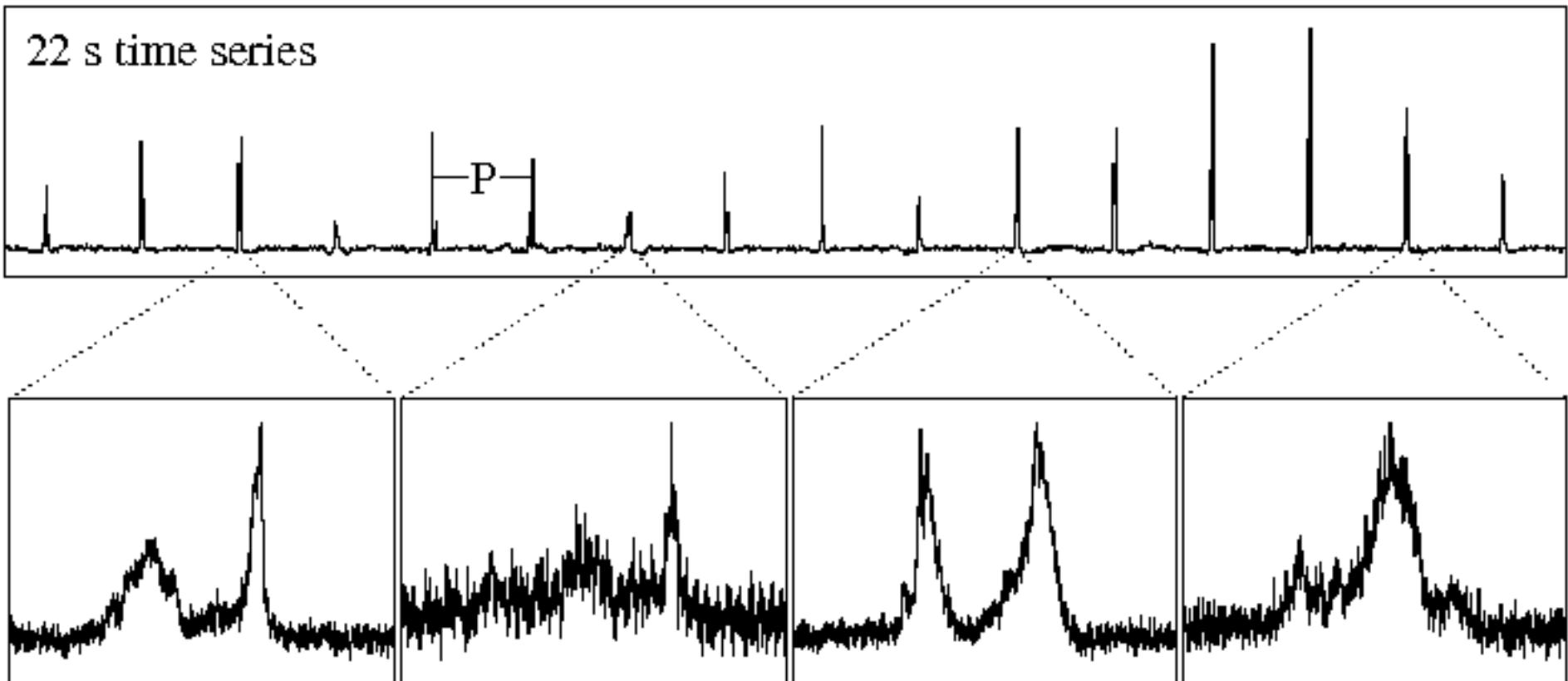
- Extremely dense objects
 - $100,000,000,000,000,000 \text{ kg m}^{-3}$
- Extremely rapid rotators
 - Spin rates up to 719 Hz known
- Extremely high magnetic fields
 - $<10,000,000,000,000 \times$ Earth's field
- Extremely fast moving stars
 - Up to and beyond 1000 km/s

...in a variety of environments



Basic pulse properties

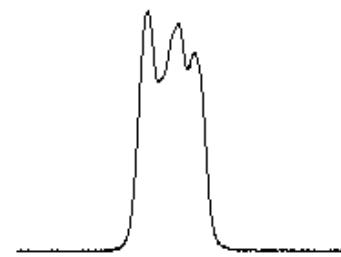
Individual pulses are very erratic



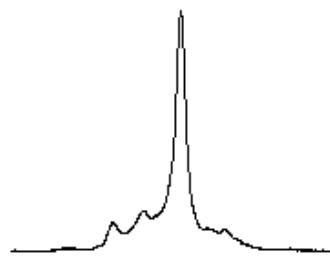
140 ms zoom in on individual pulses

...but average behavior is stable

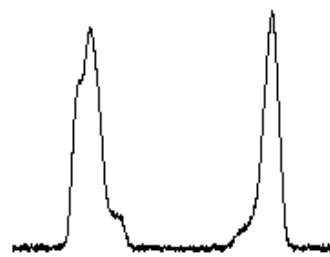
(a) J0407+1607



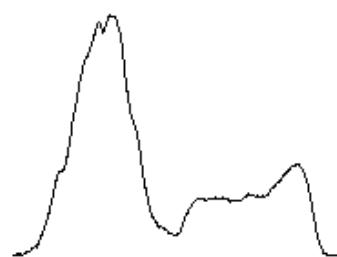
(b) J0437-4715



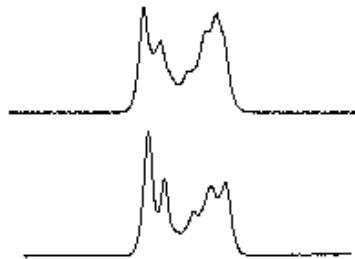
(c) J0737-3039A



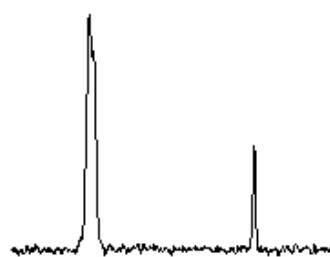
(d) B0826-34



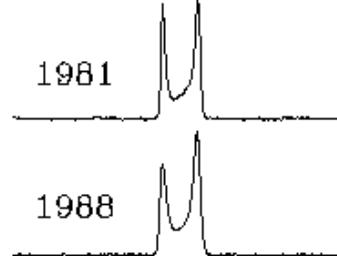
(e) B1237+25



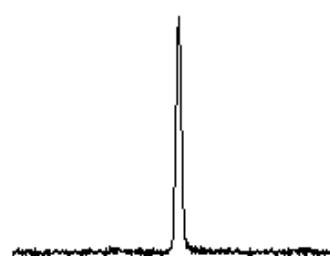
(f) B1702-19



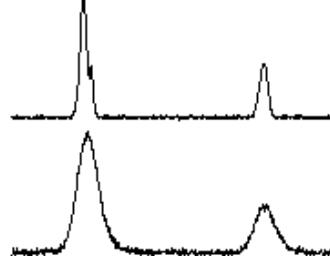
(g) B1913+16



(h) B1933+16

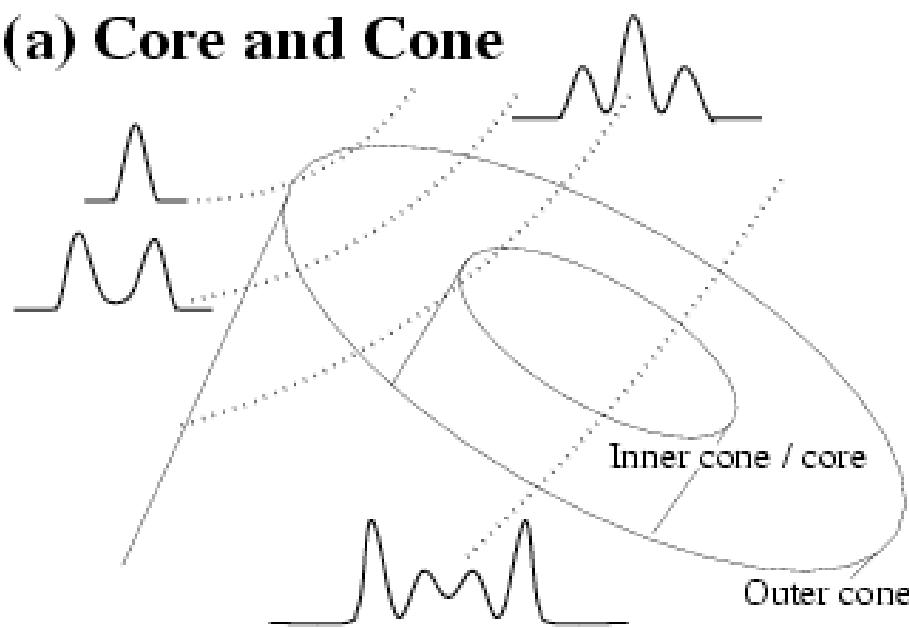


(i) B1937+21

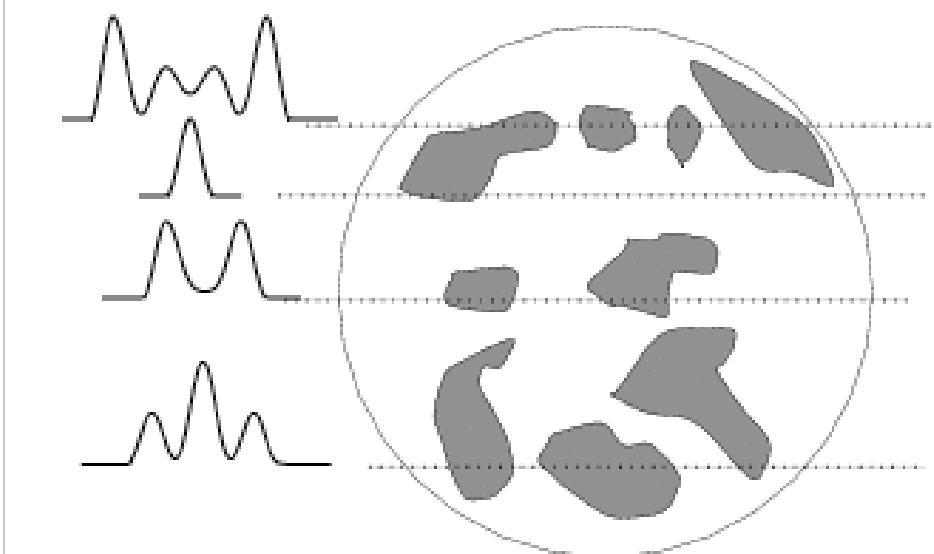


The profile is the pulsar's fingerprint

(a) Core and Cone

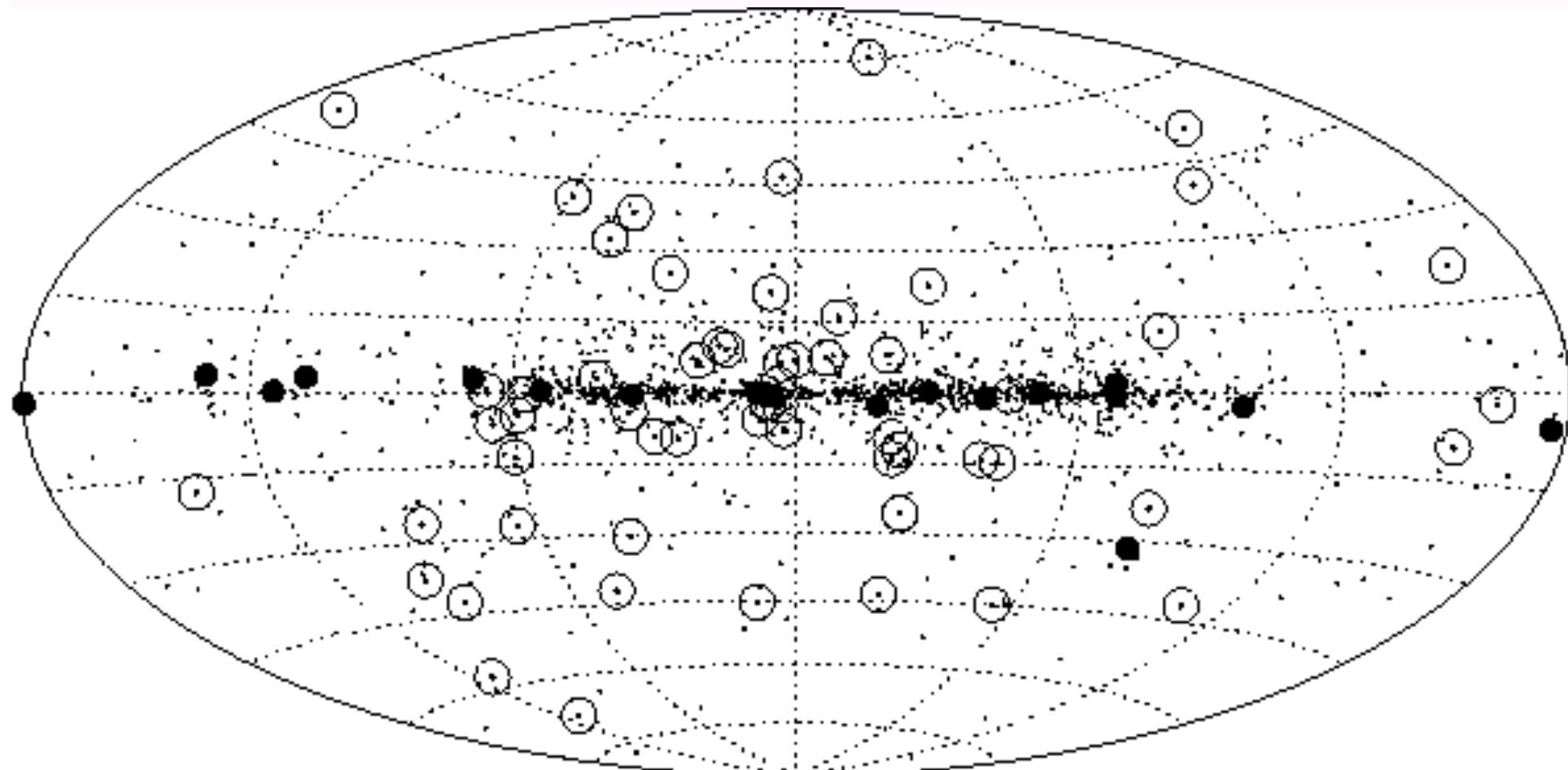


(b) Patchy Beams



The distances to pulsars

The pulsar sky distribution



Solid points: PSR/SNR; Points + circles: MSPs

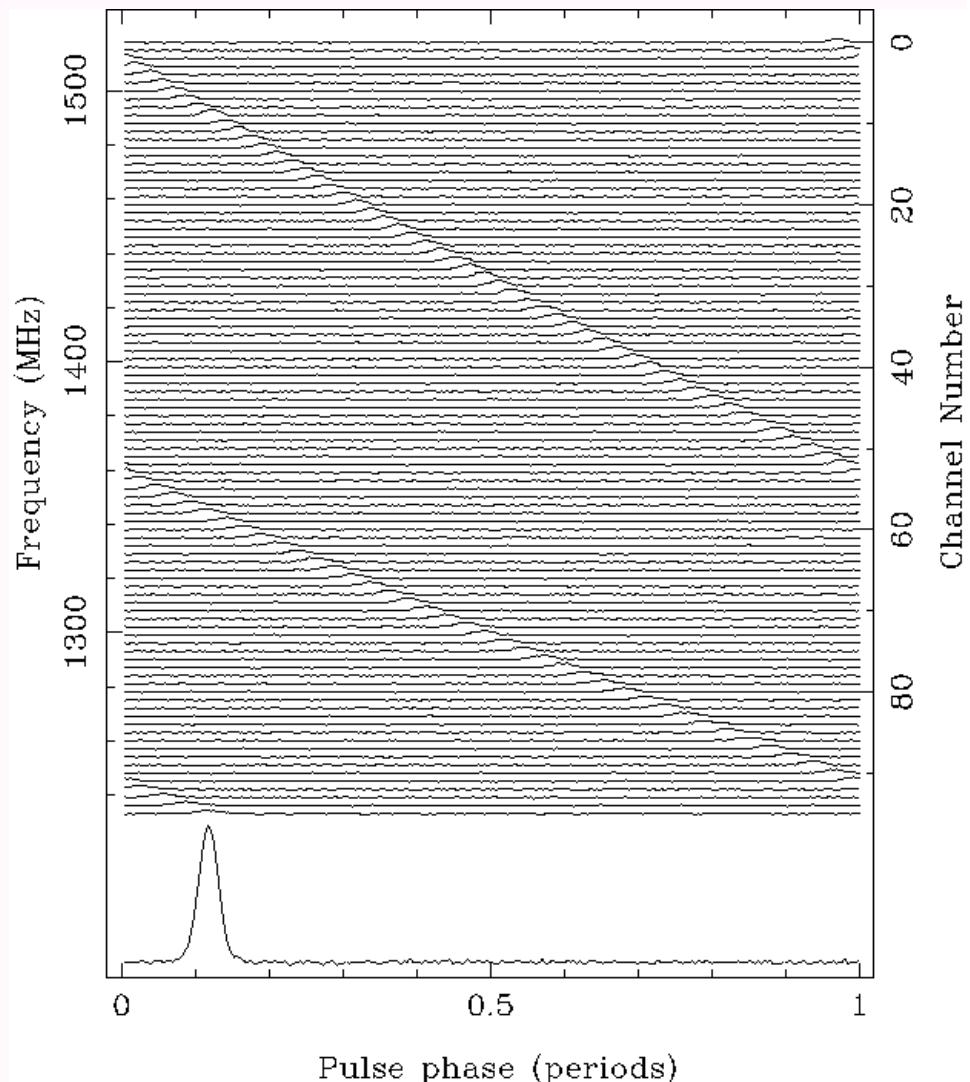
The effect of pulse dispersion

Pulsars are dispersed in frequency by free electrons in the interstellar medium.

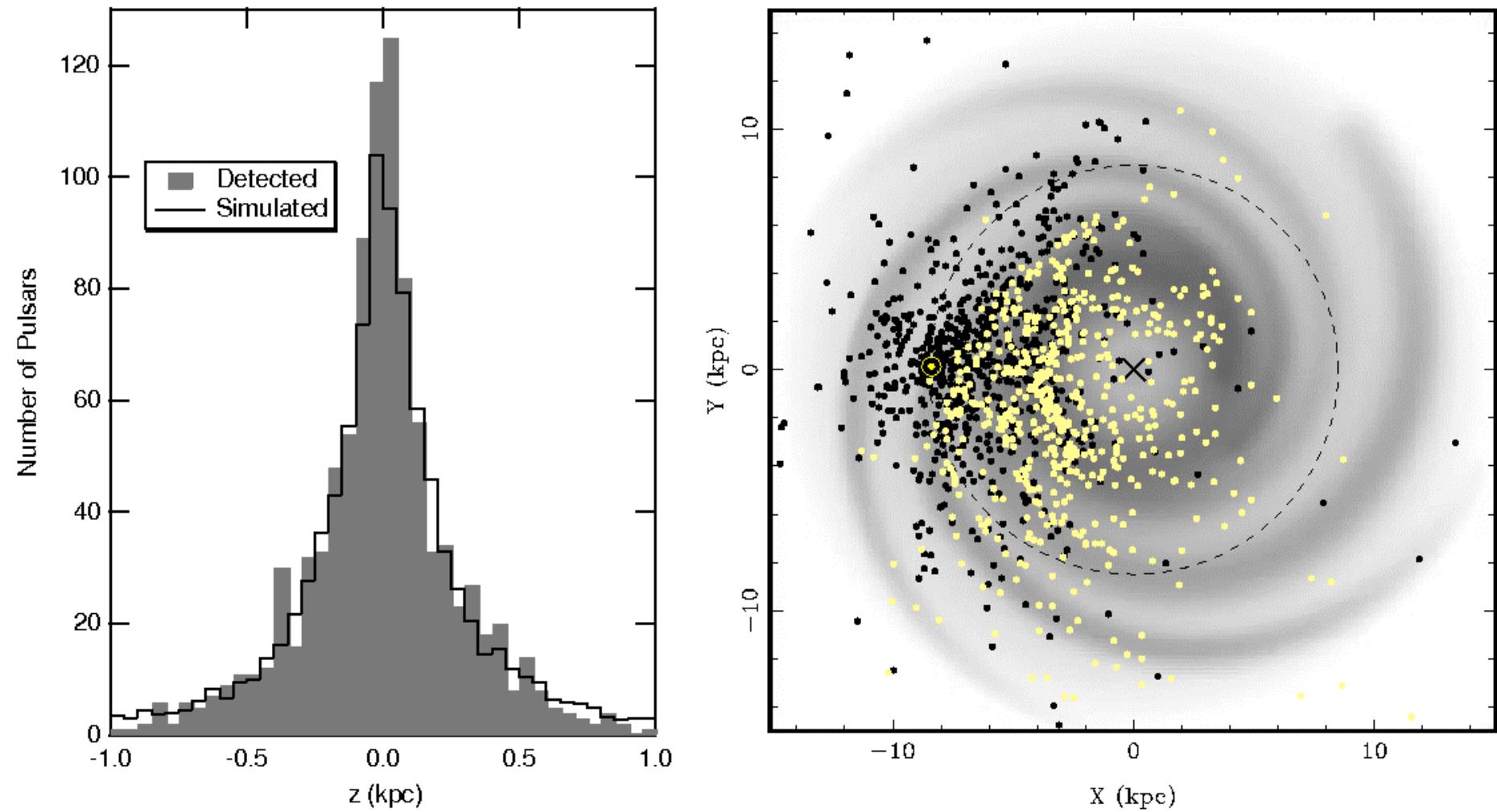
Photons with higher frequencies travel faster through space and arrive earlier than lower frequency ones.

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.

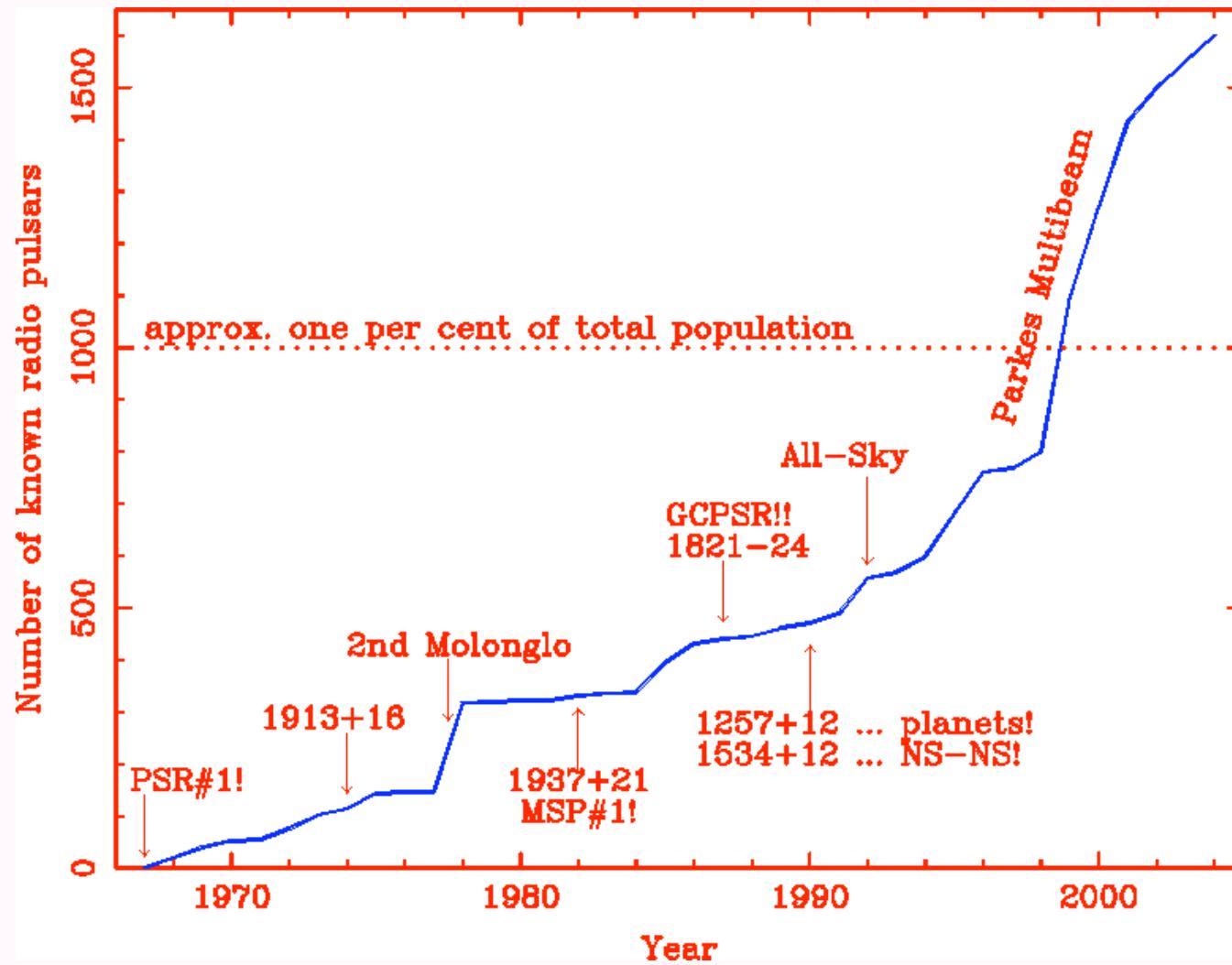


Distribution in our Galaxy

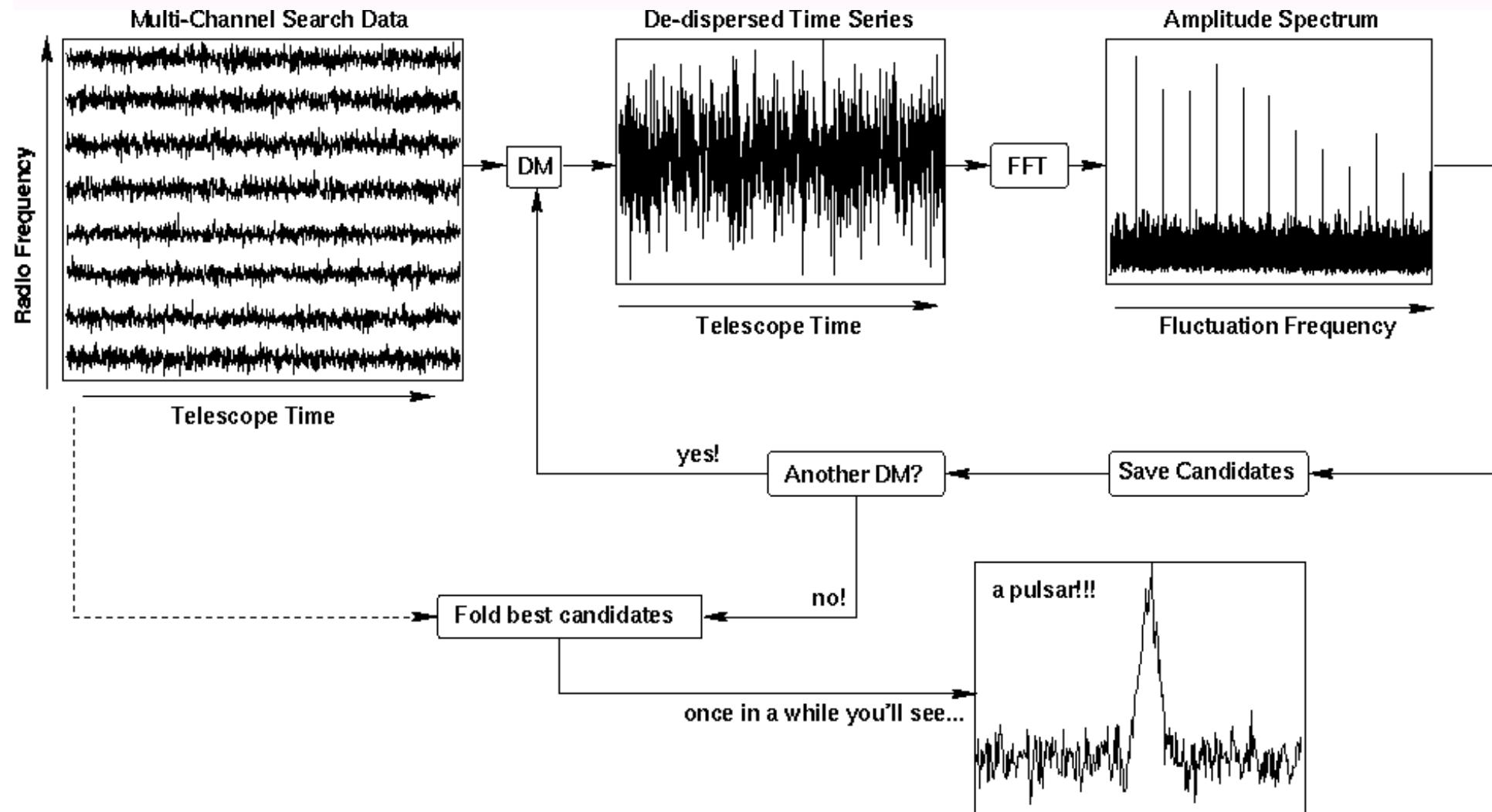


Black points: 0.4 GHz; Yellow points: 1.4 GHz

Searching for pulsars



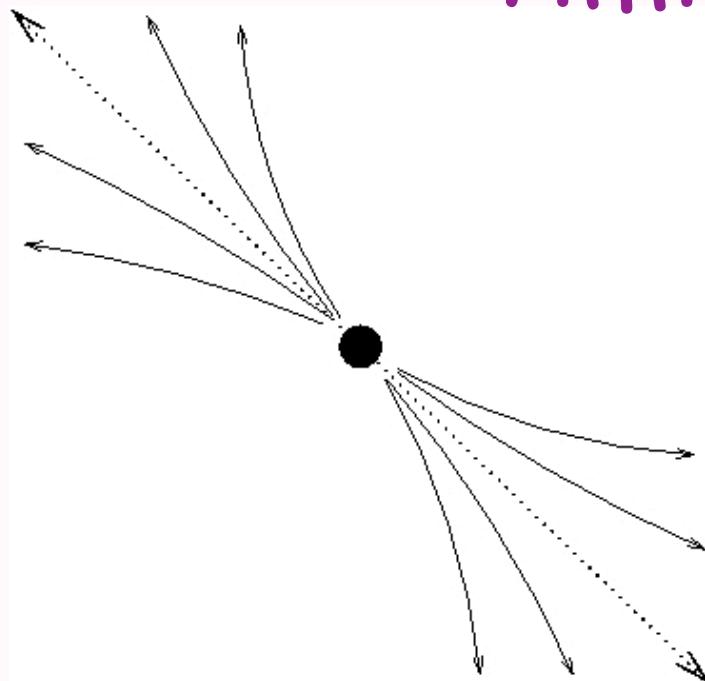
Standard pulsar searching



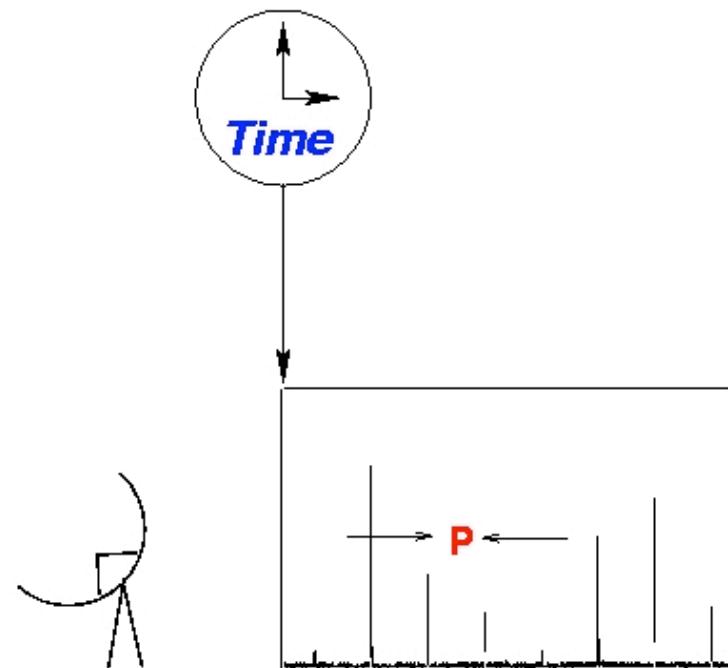
Pulsar timing

Timing pulsars

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

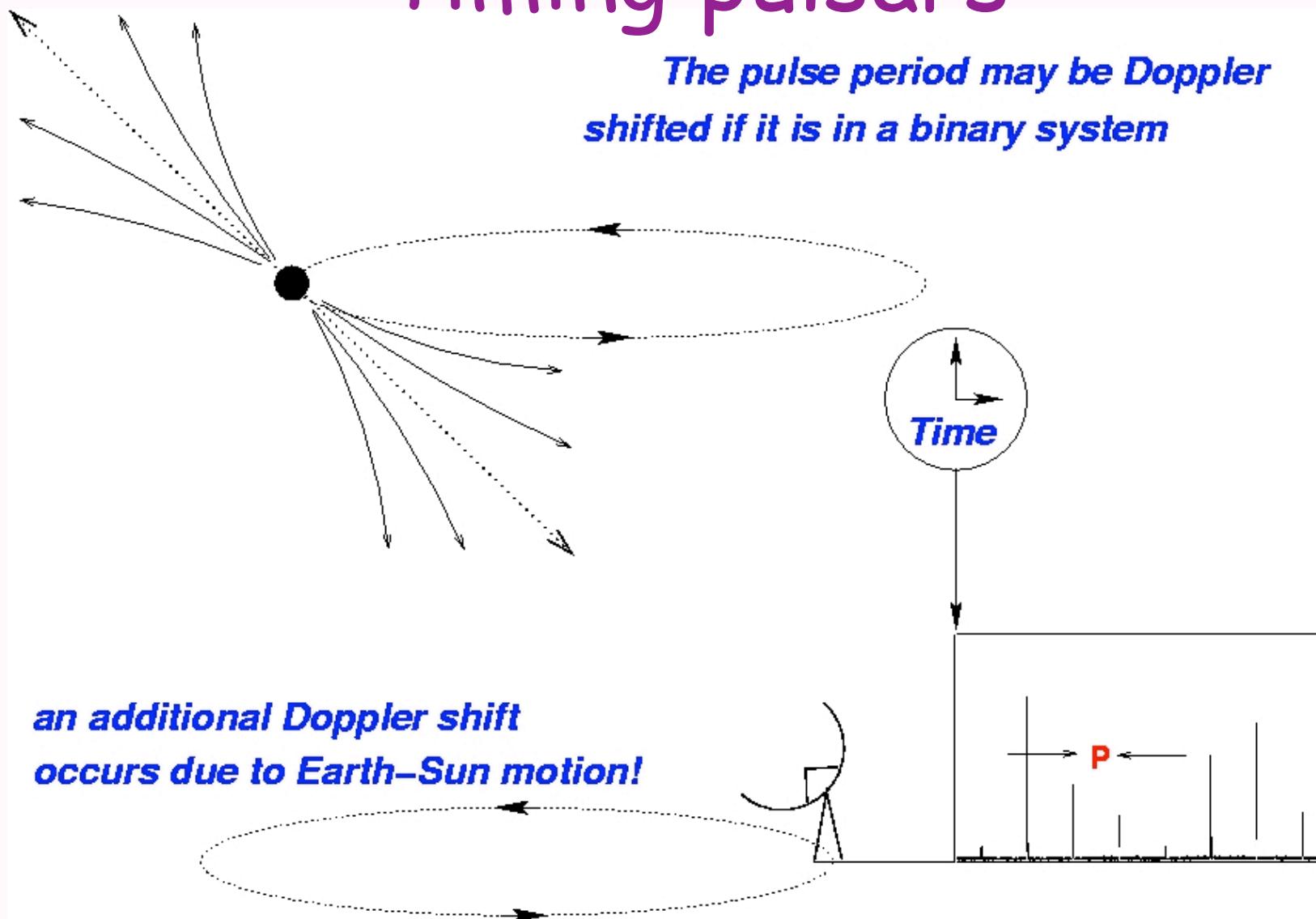


*we effectively count each
neutron star rotation!*



Timing pulsars

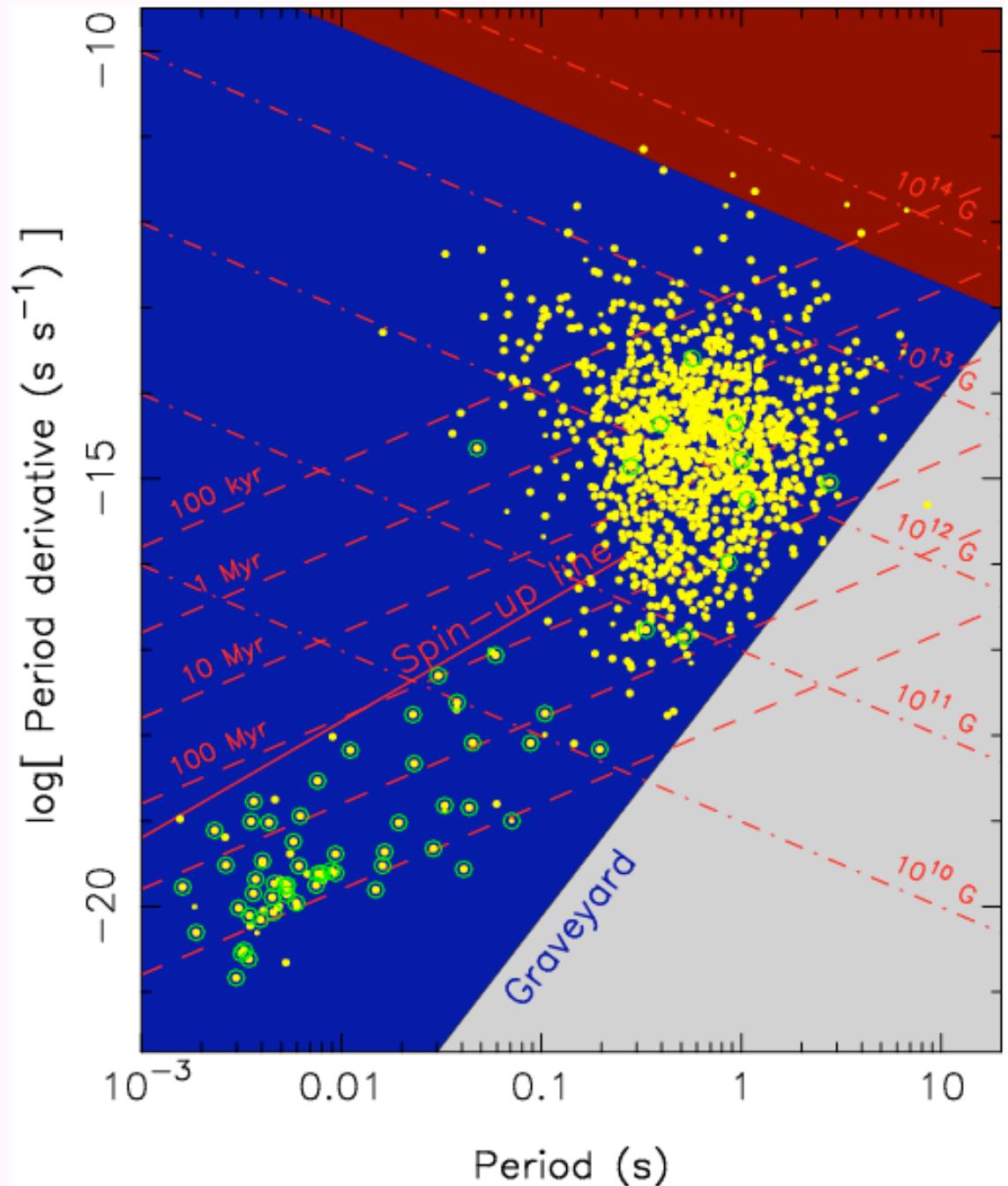
The pulse period may be Doppler shifted if it is in a binary system



Evolution

Strong links to

- supernovae
- stellar evolution
- binary evolution
- stellar winds
- white dwarf cooling
- magnetars



Some current projects

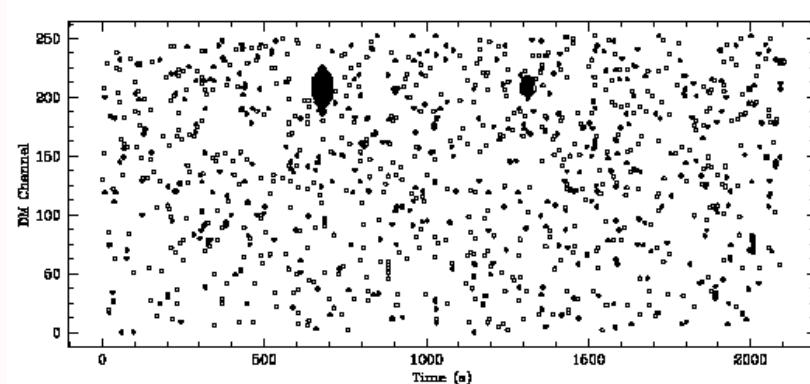
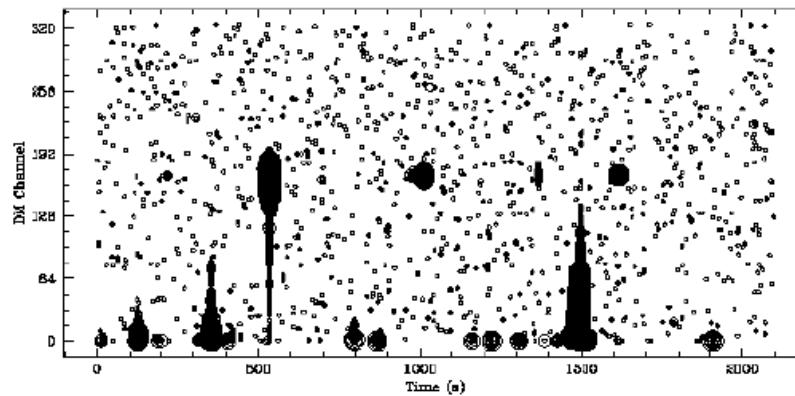
- The transient radio sky
 - New source classes
- The double pulsar
 - Testing strong-field gravity
- Pulsar timing array
 - Searching for gravitational waves

The transient radio sky

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!!

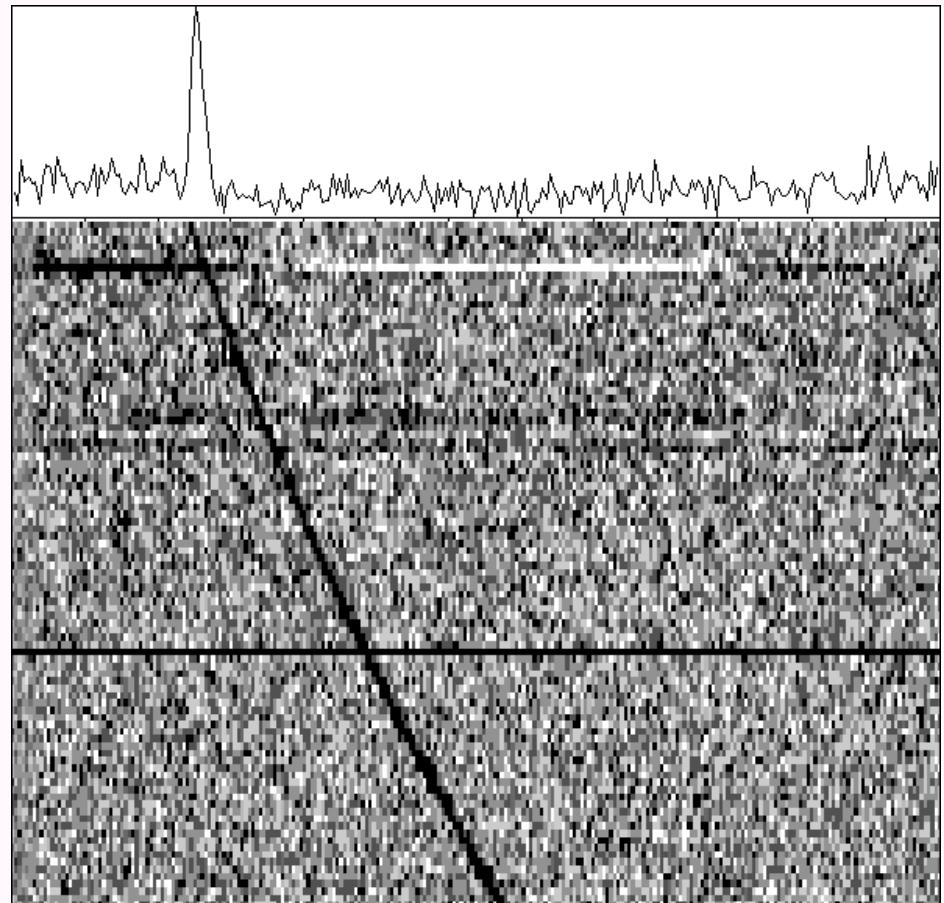
The transient radio sky

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

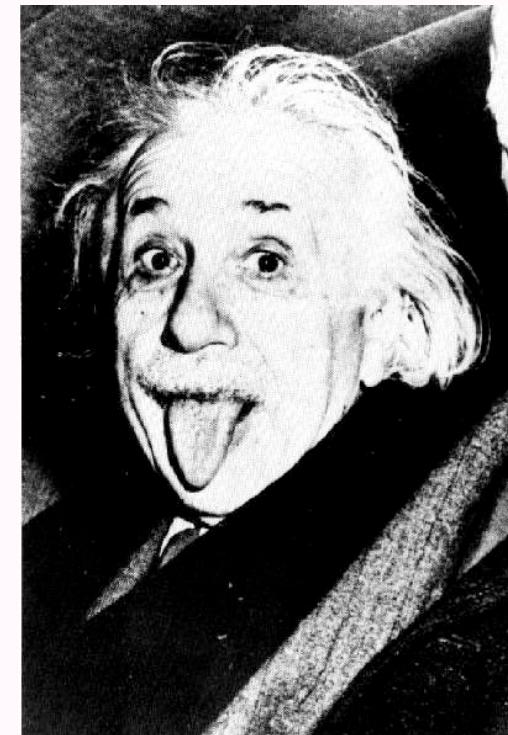
P_B - binary period

$a \sin i$ - semi-major axis

e - eccentricity

ω - 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.

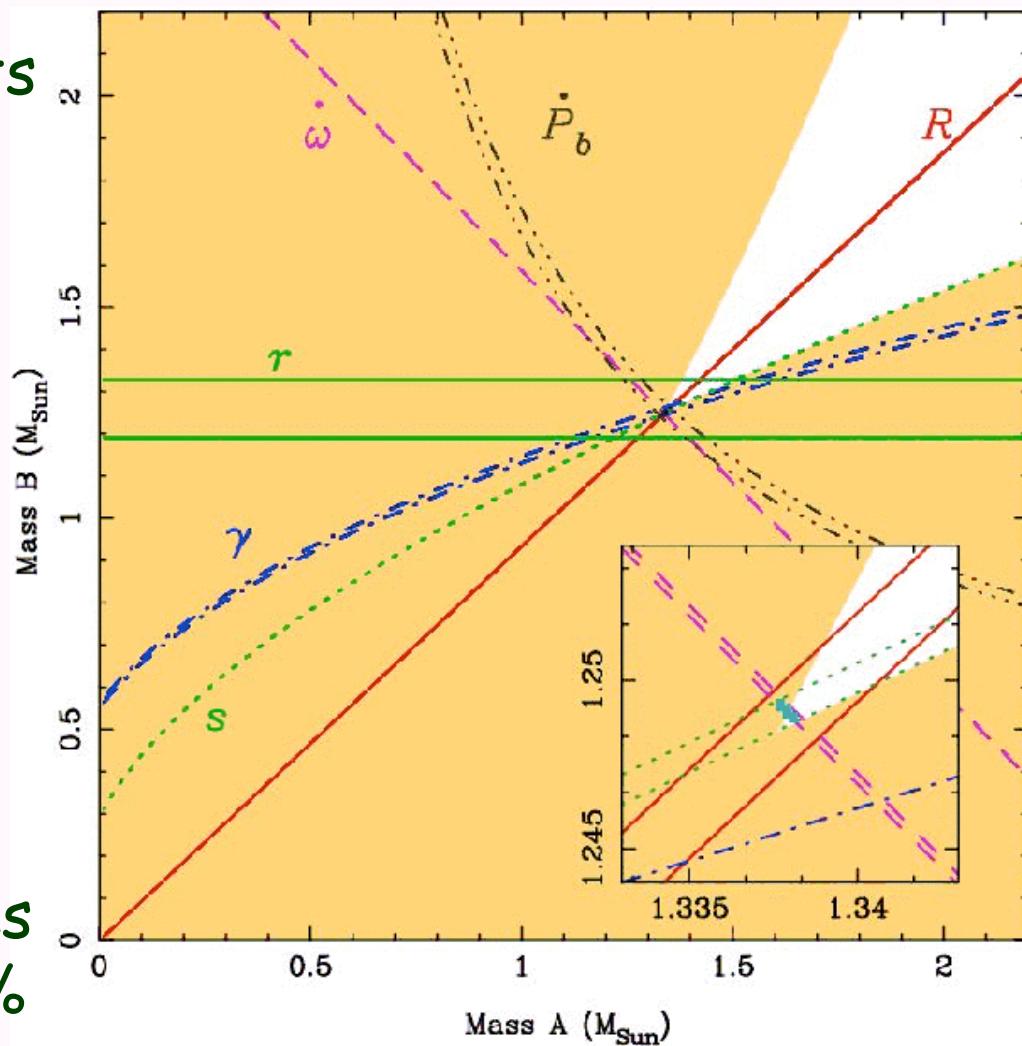
The double pulsar: J0737-3039

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

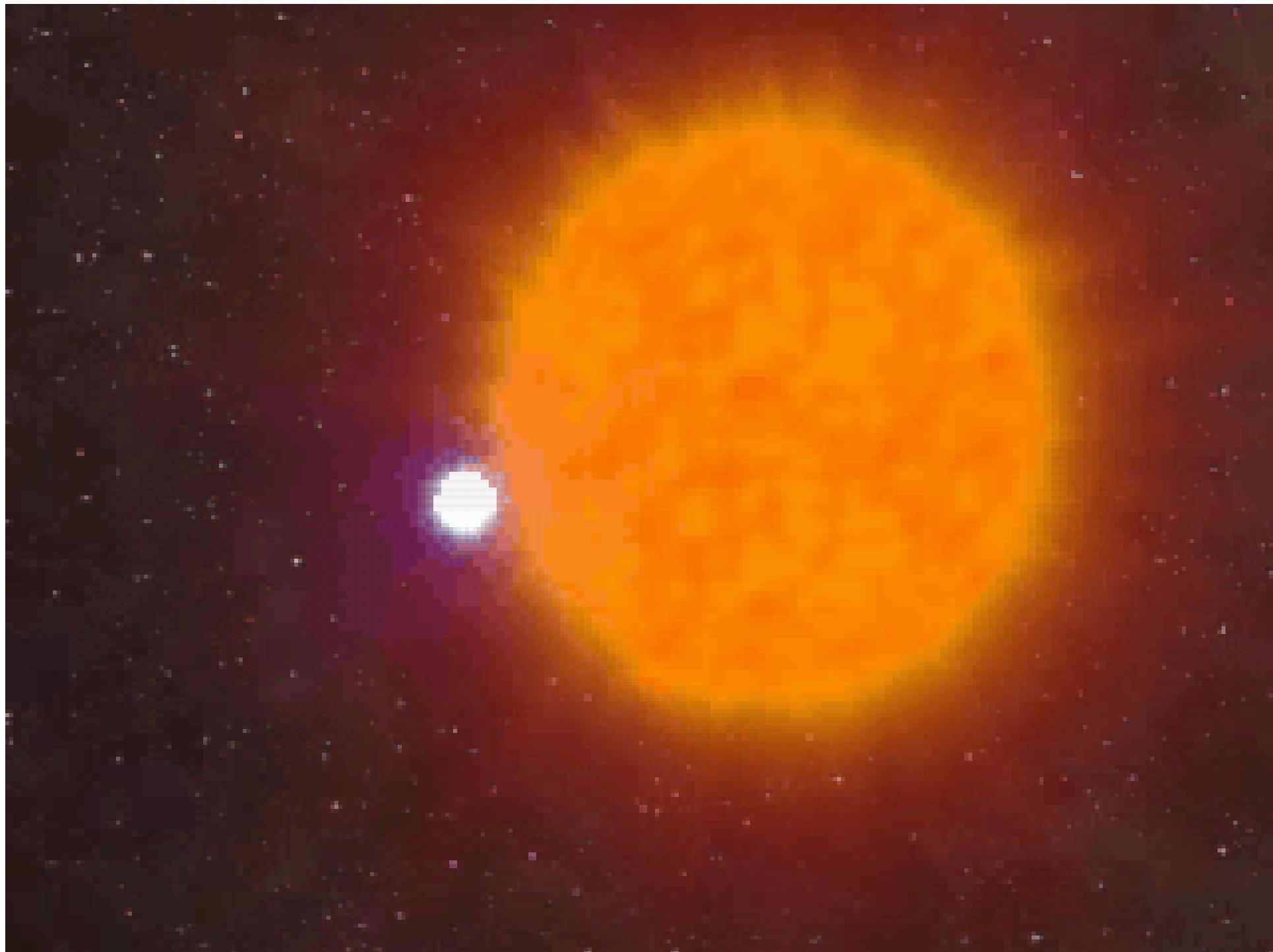
We measure:

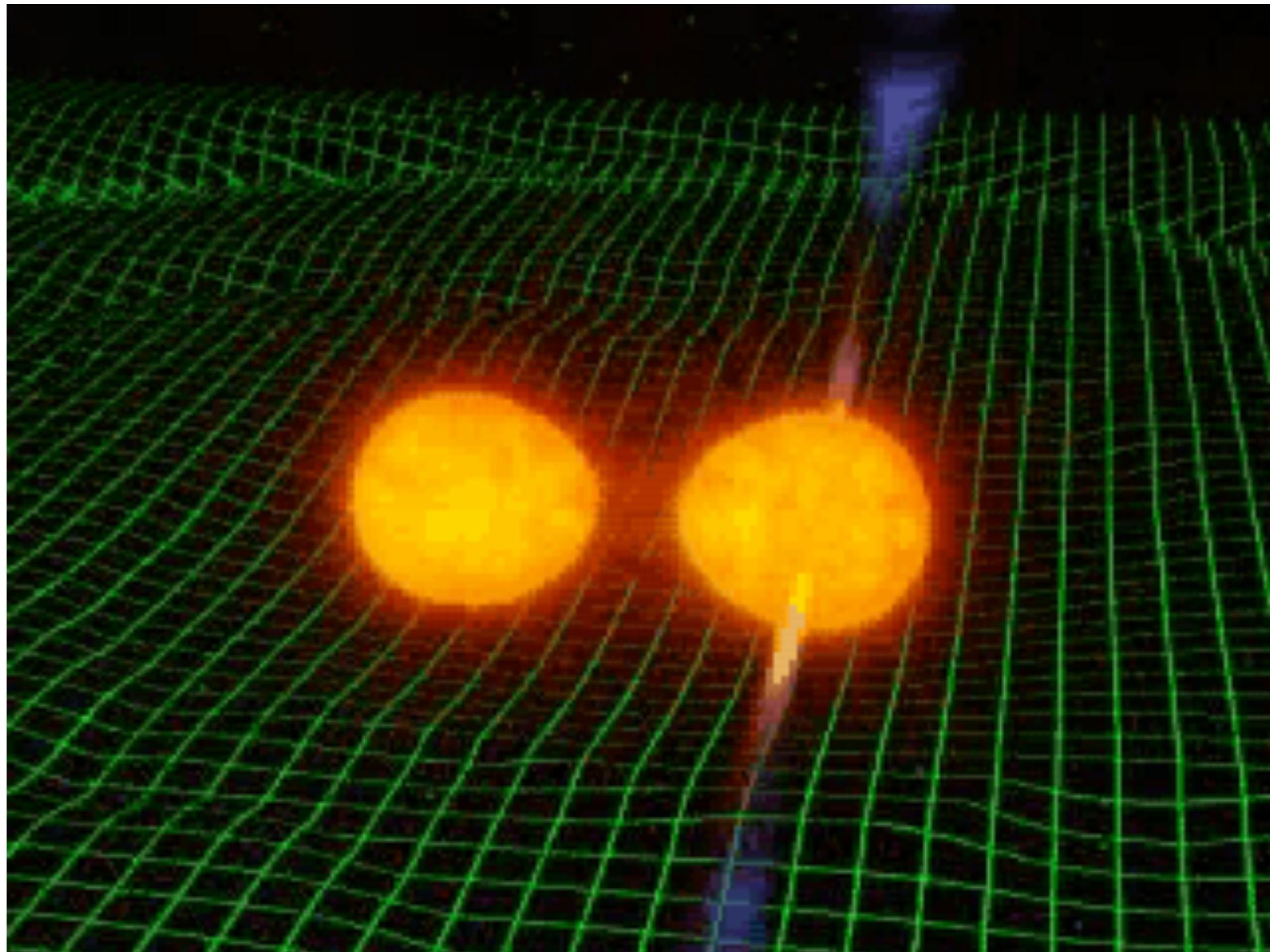
- periastron advance
- time dilation
- gravitational redshift
- Shapiro delay
- gravity wave damping

System currently verifies GR predictions to 99.95%

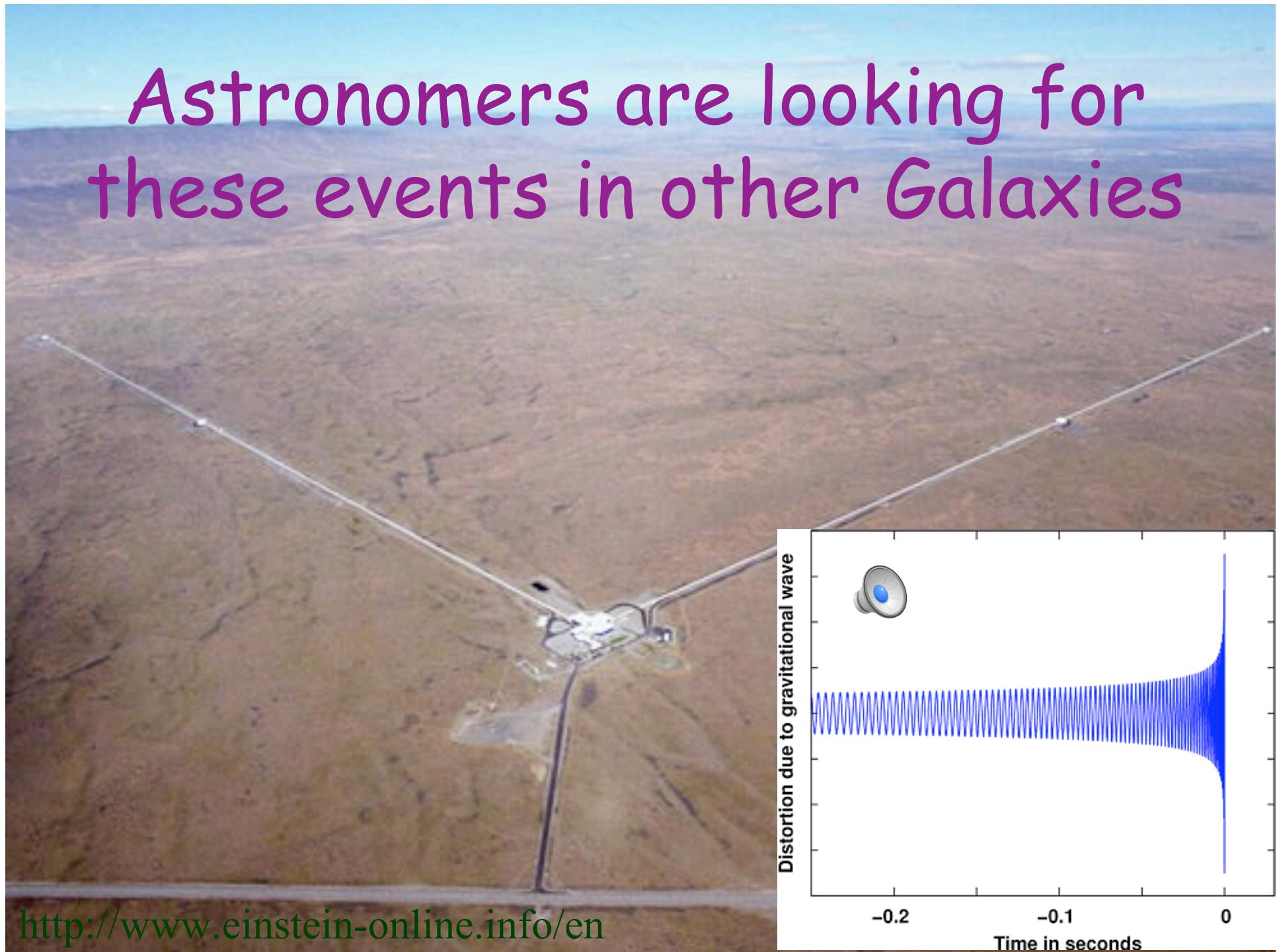


Double pulsar movies: formation
and ultimate fate due to
gravitational wave emission...

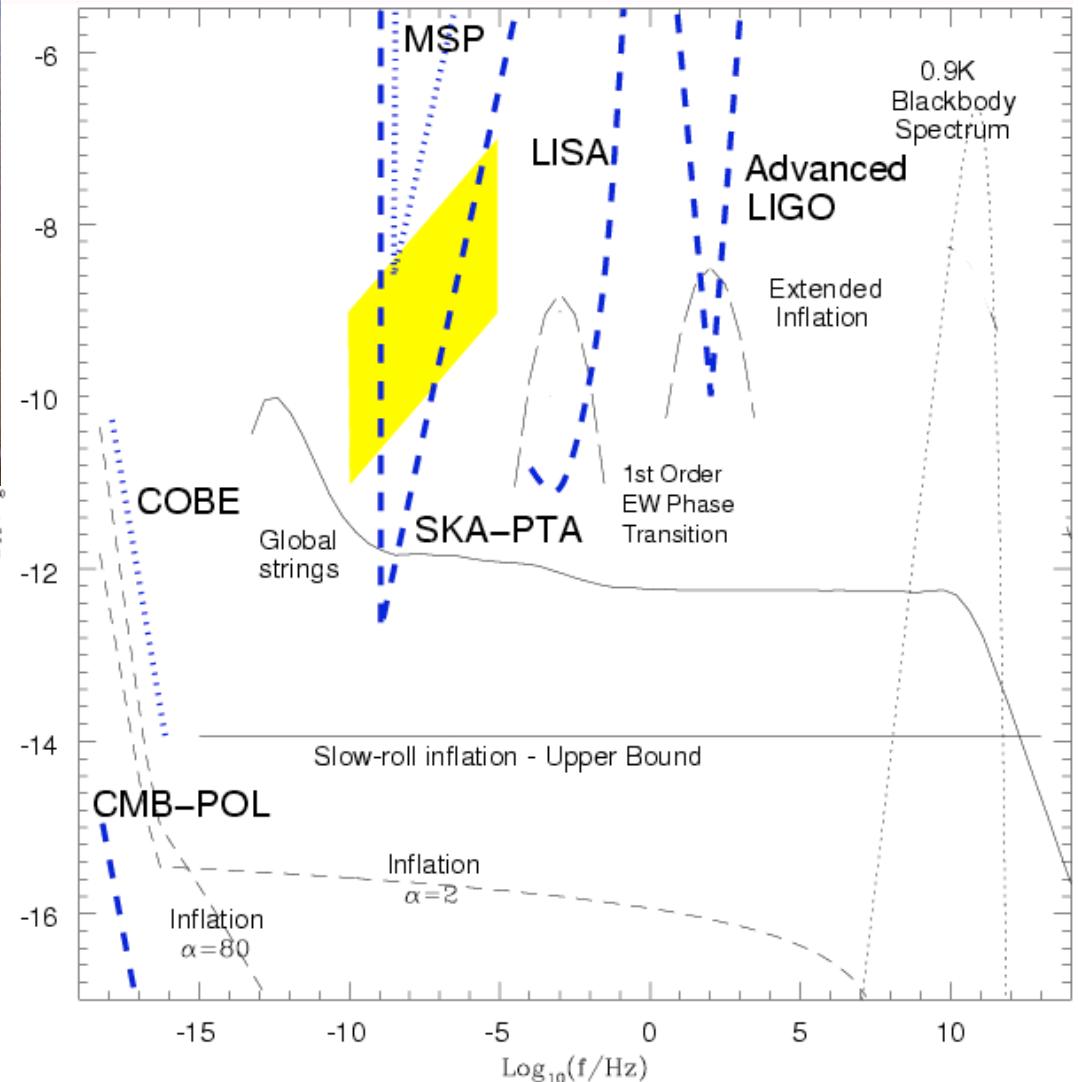
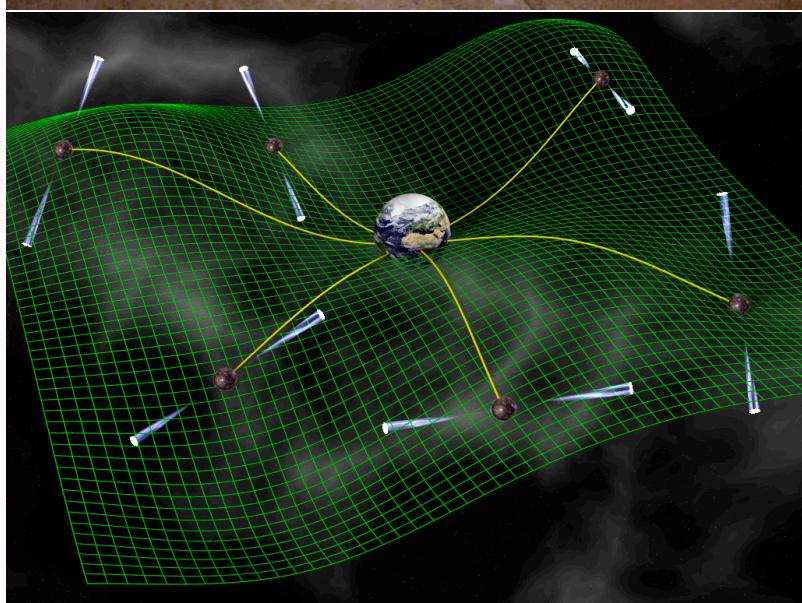




Astronomers are looking for
these events in other Galaxies



A unique niche - GW detectors



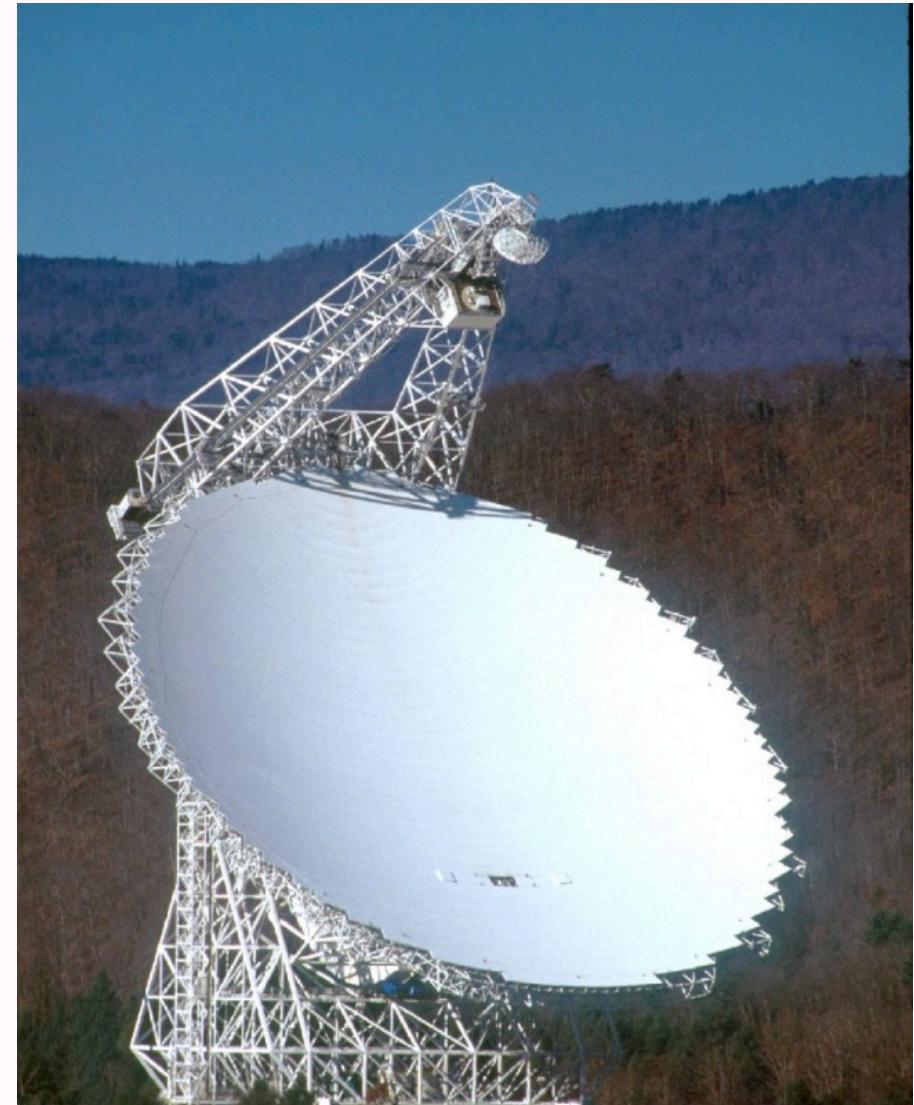
Green Bank Drift Scan Survey

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

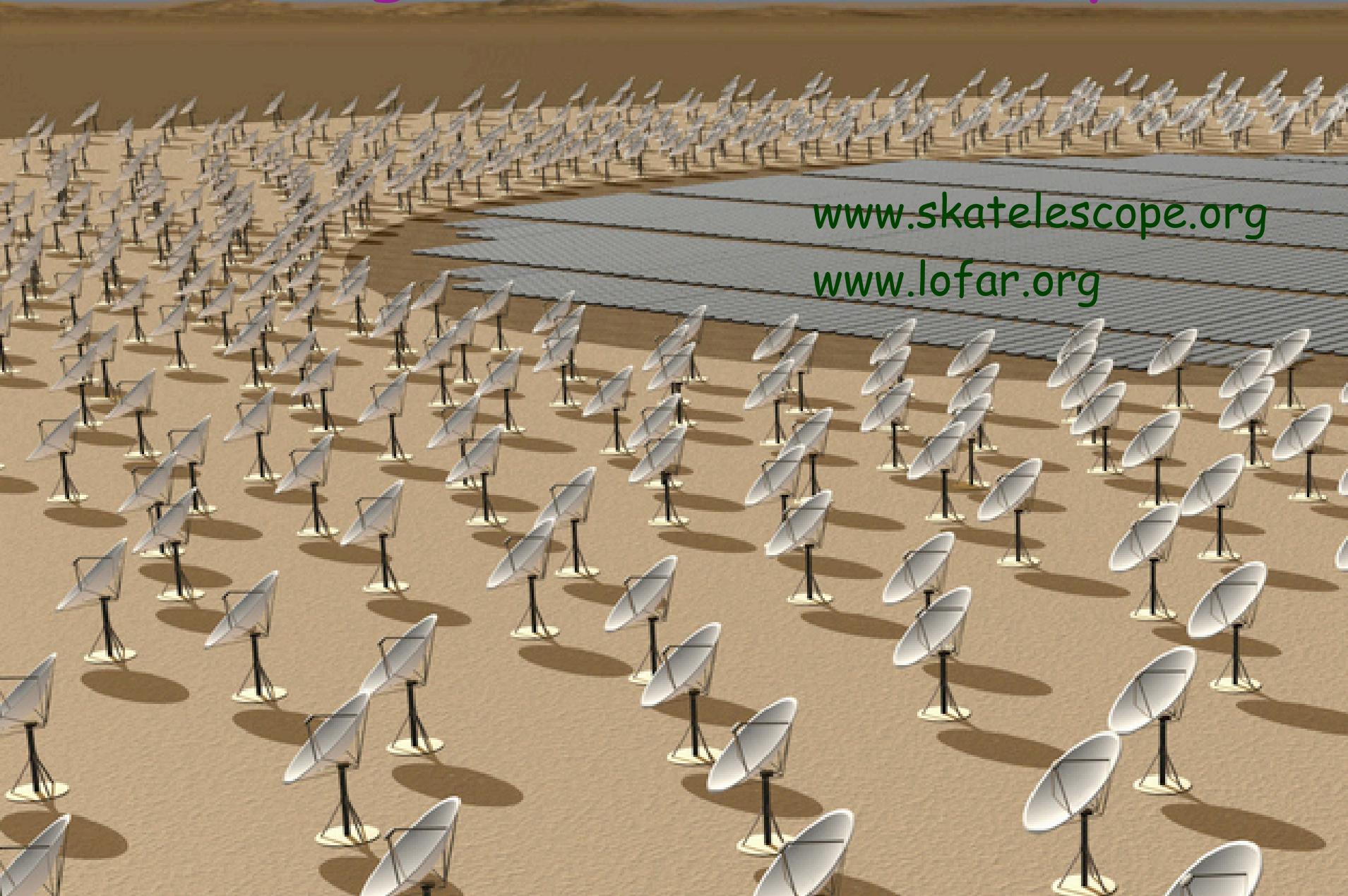
Over 25% of sky was covered.

Most sensitive large-scale survey for pulsars...

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



Next generation telescopes

A photograph of a vast array of satellite dishes or radio antennas, likely the Square Kilometer Array (SKA), spread across a dry, brown landscape under a clear blue sky. The dishes are arranged in a grid pattern, with many more in the background than in the foreground.

www.skatelescope.org
www.lofar.org

A pulsar census with the SKA

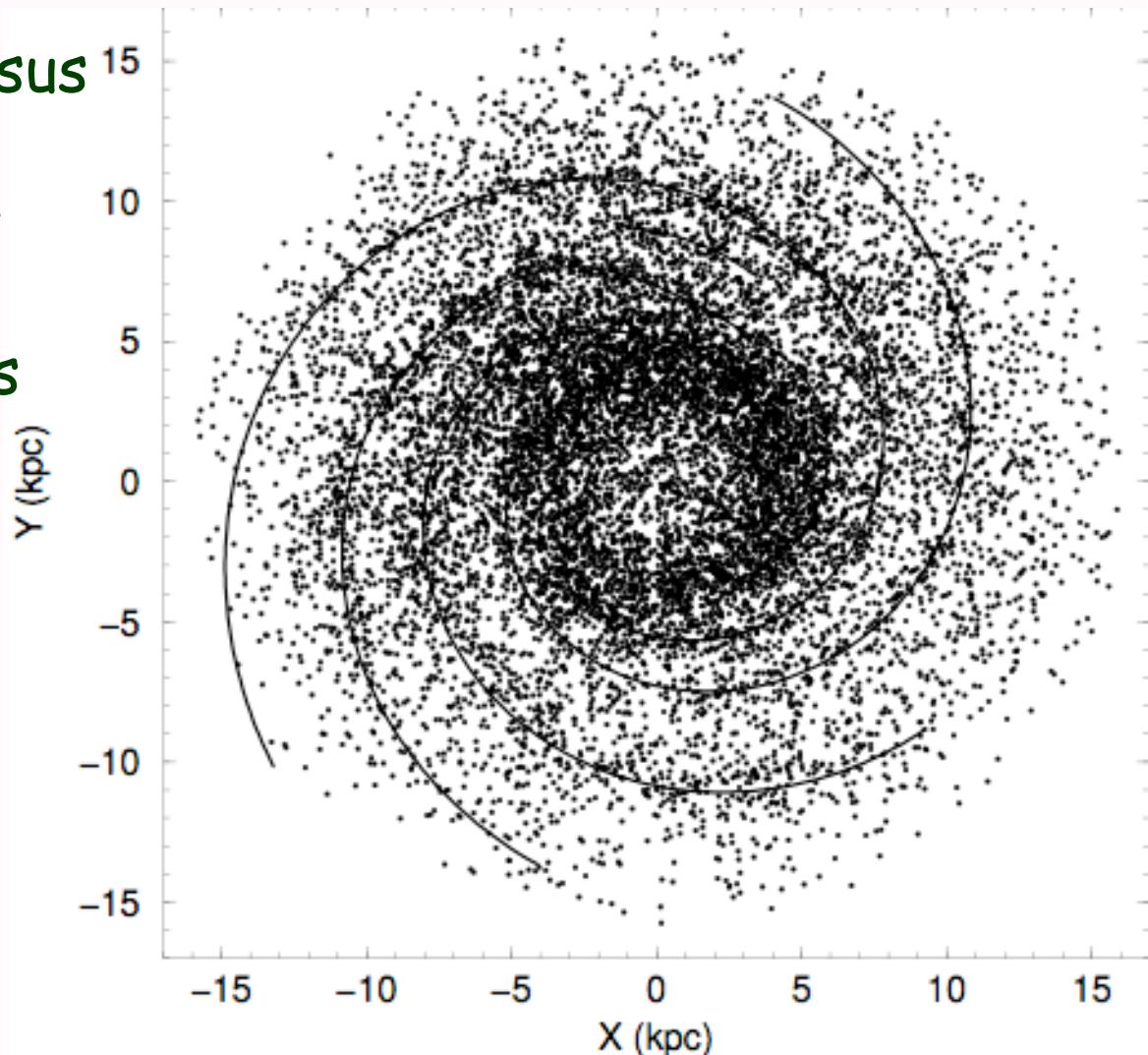
Essentially complete census¹⁵

- 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?