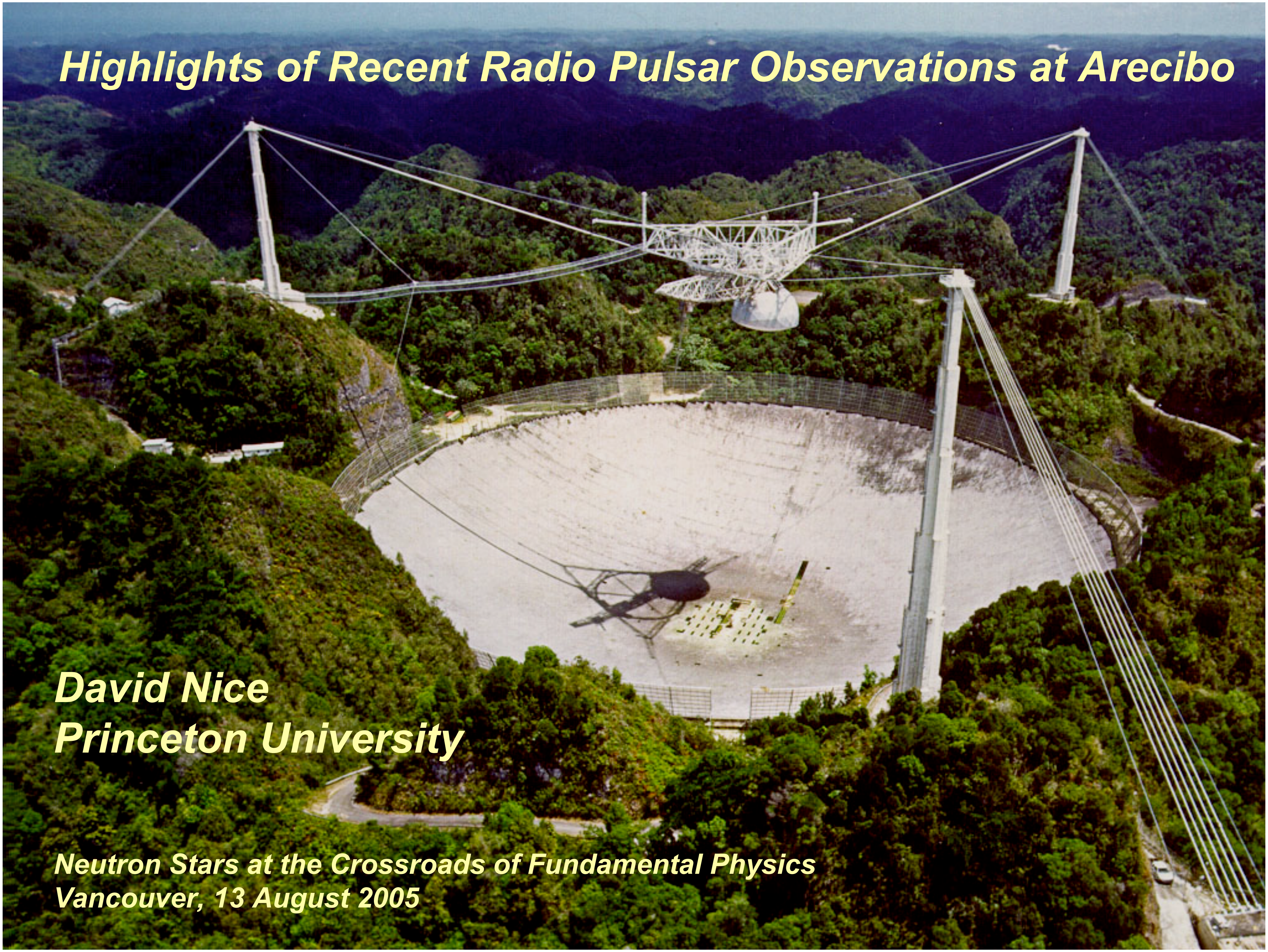

Highlights of Recent Radio Pulsar Observations at Arecibo

David Nice
Princeton University

Neutron Stars at the Crossroads of Fundamental Physics
Vancouver, 13 August 2005

1. The mass of PSR J0751+1807, a recycled pulsar in a binary with a Helium white dwarf
2. The Proper motion of the Hulse-Taylor double neutron star binary, B1913+16
3. The PALFA survey (Pulsar - Arecibo L-band feed Array)

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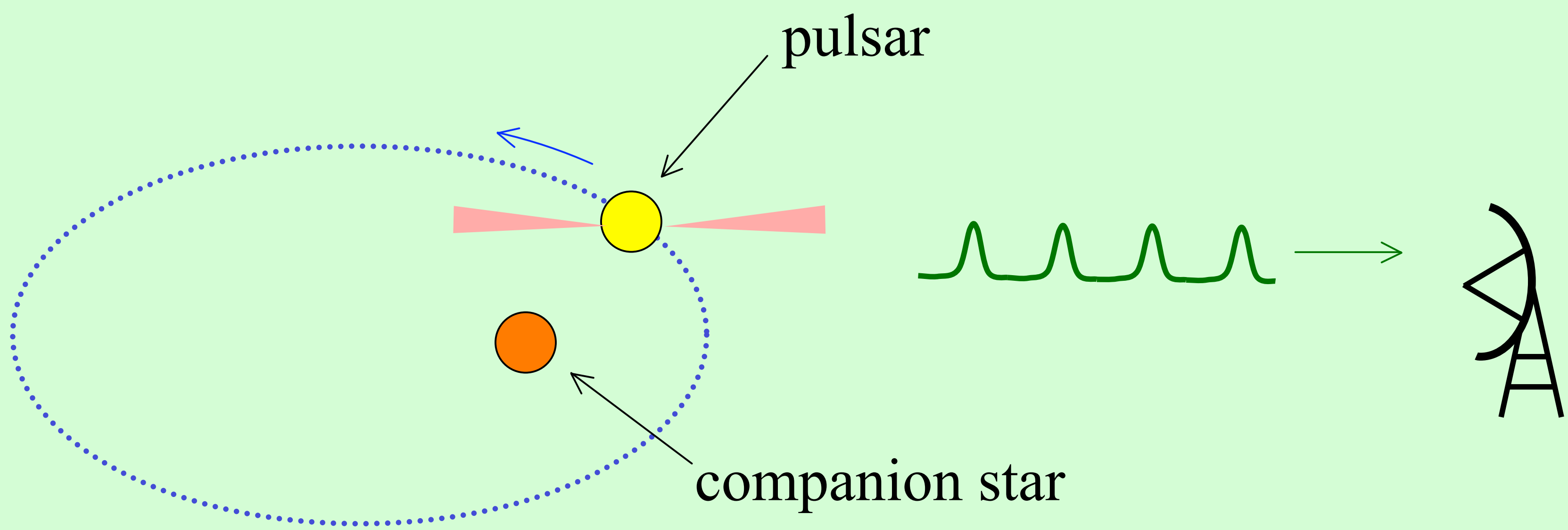
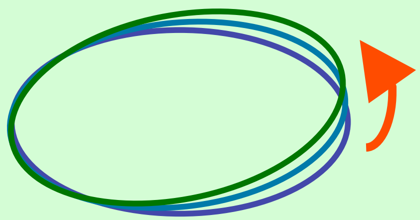
Nice et al., ApJ, in press; astro-ph/0508050

Collaborators: Ingrid Stairs, Eric Splaver, Oliver Löhmer, Axel Jessner, Michael Kramer, Jim Cordes

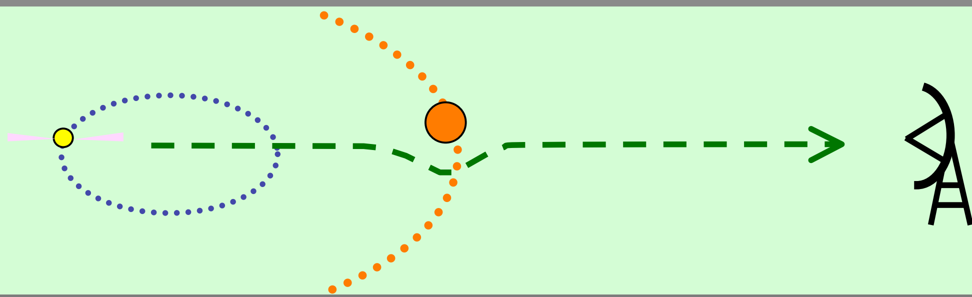
Mapping a Binary Orbit





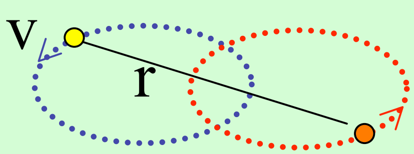
Precession

$$\dot{\omega} = 3\frac{G^{2/3}}{c^2}\left(\frac{P_b}{2\pi}\right)^{-5/3}\frac{1}{1-e^2}\left[(m_1+m_2)\right]^{2/3}$$



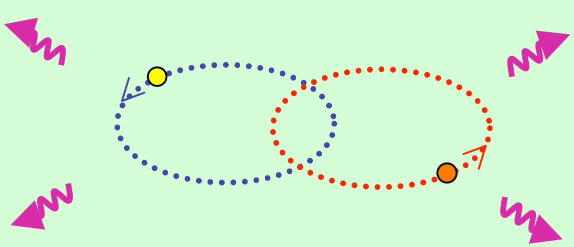
Shapiro Delay

$$\Delta t = 2\frac{G}{c^3}m_2 \ln\left[1-\sin i \sin(\varphi-\varphi_0)\right]$$



Grav Redshift/Time Dilation

$$\gamma = \frac{G^{2/3}}{c^2}\left(\frac{P_b}{2\pi}\right)^{1/3} e \frac{m_2(m_1+2m_2)}{(m_1+m_2)^{4/3}}$$



Gravitational Radiation

$$\dot{P}_b = -\left(\frac{192\pi}{5}\right)\frac{G^{5/3}}{c^5}\left(\frac{P_b}{2\pi}\right)^{-5/3}\left(1+\frac{73}{24}e^2+\frac{37}{96}e^4\right)\frac{1}{(1-e^2)^{7/2}}\frac{m_1m_2}{(m_1+m_2)^{1/3}}$$

Neutron Star-Neutron Star Binaries

Pulsar	Pulsar Mass ($M_\odot$)	Companion Mass ($M_\odot$)
PSR B1913+16	1.4408±0.0003	1.3873±0.0003
PSR B2127+11C	1.349 ±0.040	1.363 ±0.040
PSR B1534+12	1.3332±0.0010	1.3452±0.0010
PSR J0737–3039	1.337 ±0.005	1.250 ±0.005
PSR J1756–2251	1.40 ±0.03	1.18 ±0.03
PSR J1518+4904	$\frac{\text{PSR+Companion}}{2} = 1.352 \pm 0.003$	
PSR J1811–1736	$\frac{\text{PSR+Companion}}{2} = 1.300 \pm 0.450$	
PSR J1829+2456	$\frac{\text{PSR+Companion}}{2} = 1.250 \pm 0.010$	

In neutron star-neutron star binaries, all pulsars and companions fall in a narrow range of masses, 1.18-1.44 $M_\odot$.

Where to look for heavier neutron stars?

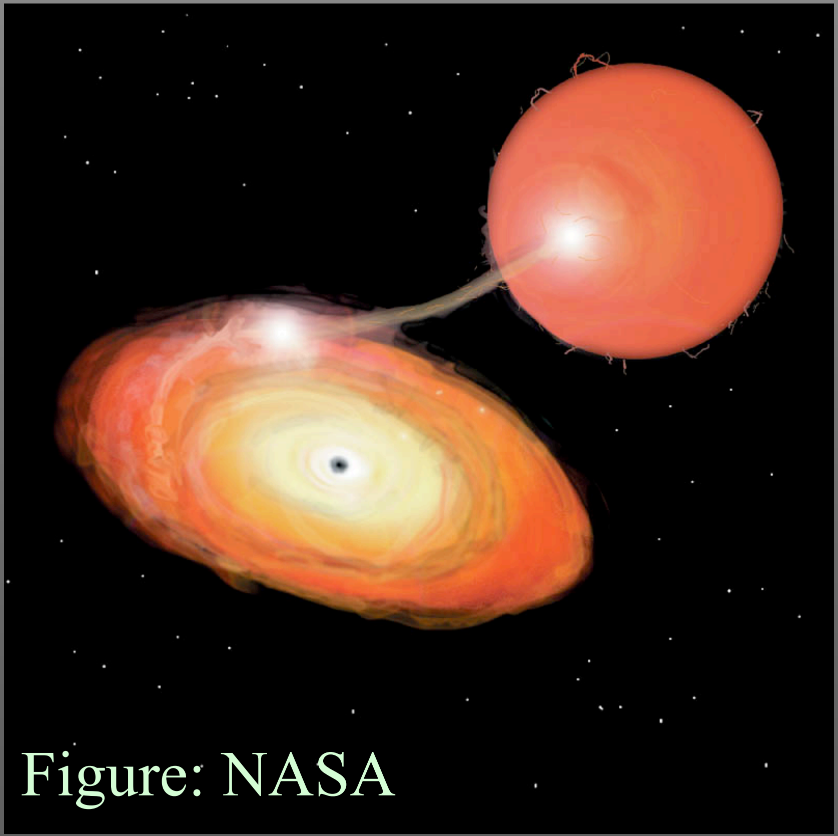
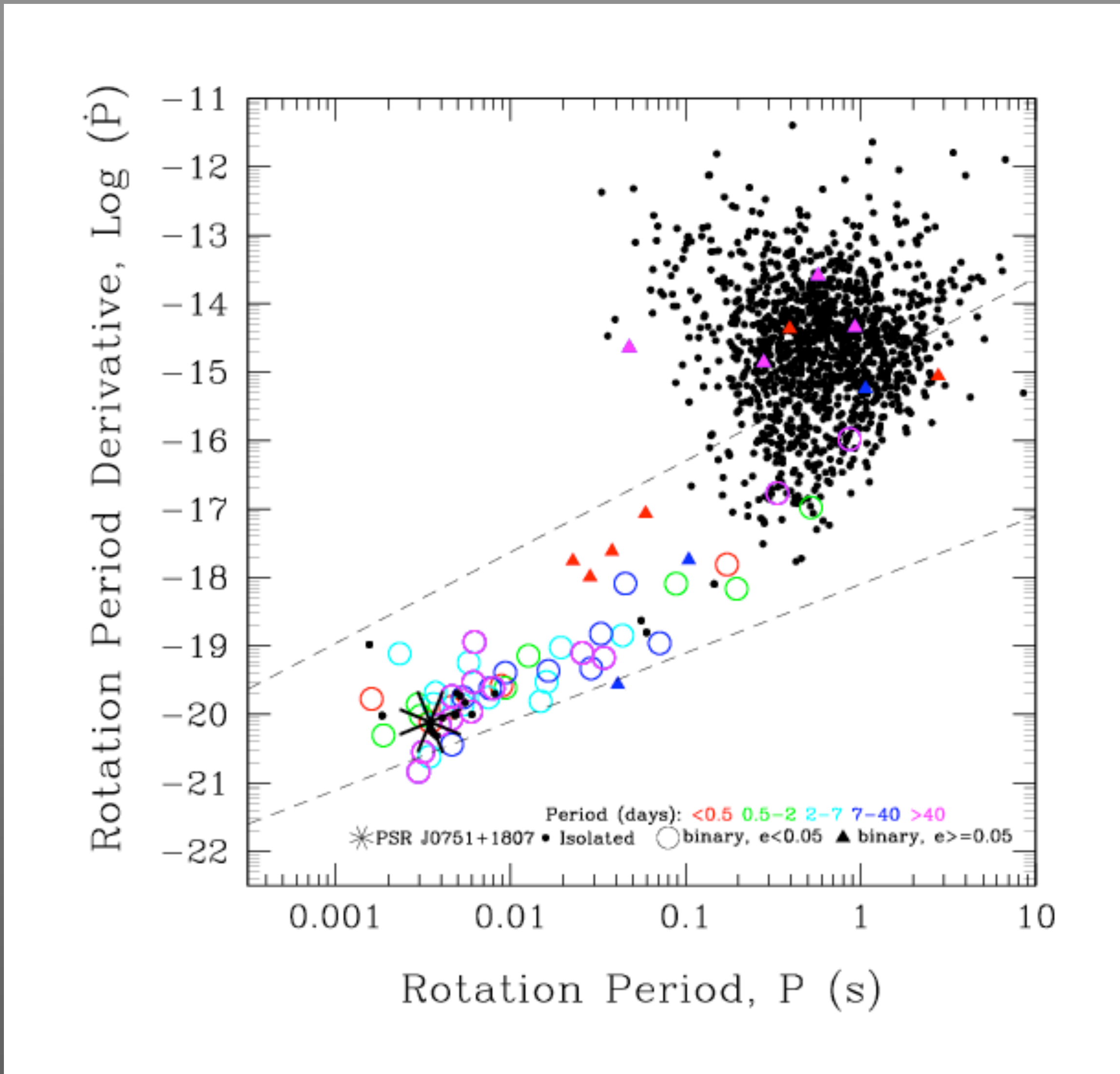


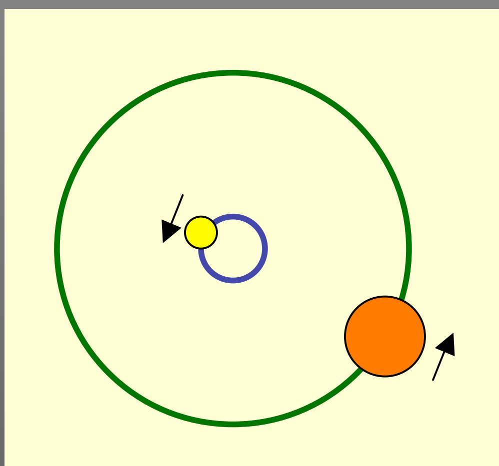
Figure: NASA

Pulsar-White Dwarf binaries

Descendents of LMXBs

Accretion onto the NS:
- Increases pulsar mass
- Increases pulsar spin rate
- Decreases pulsar magnetic field


Rotation Period Derivative, Log (Ṗ)
−11
−12
−13
−14
−15
−16
−17
−18
−19
−20
−21
−22
0.001
0.01
0.1
1
10
Rotation Period, P (s)
Period (days): <0.5 0.5−2 2−7 7−40 >40
PSR J0751+1807
Isolated
binary, e<0.05
binary, e>=0.05



Pulsar + White Dwarf in 6.3 <u>hour</u> orbit

Very Circular, $e < 10^{-5}$

Discovered in 1993.

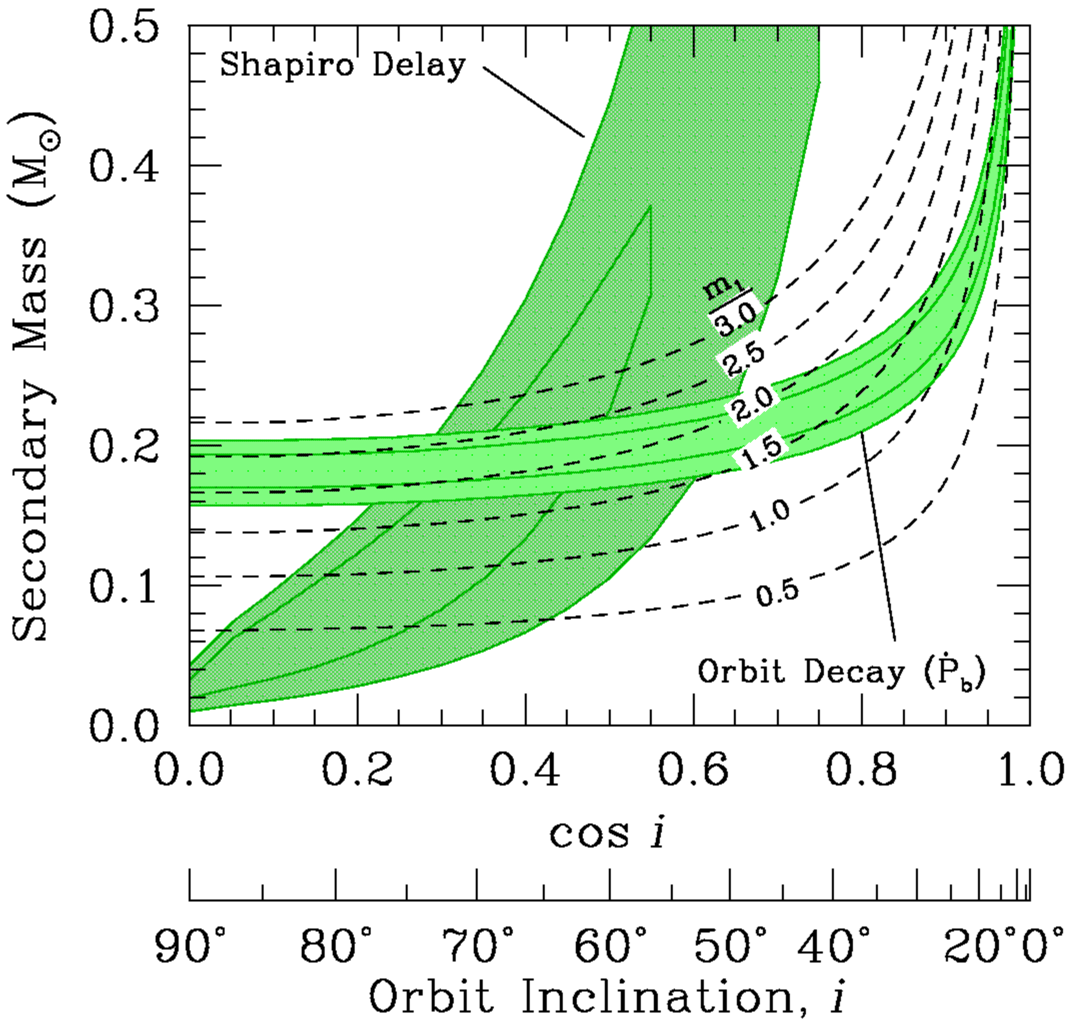
Intense ~annual campaigns since 1999.

Most recent data January 2004.

- Relativistic Orbit Decay Detected:

  $dP_b/dt = -(6.4 \pm 0.9) \times 10^{-14}$ s/s. = $-2.0 \pm 0.3\mu$sec /year

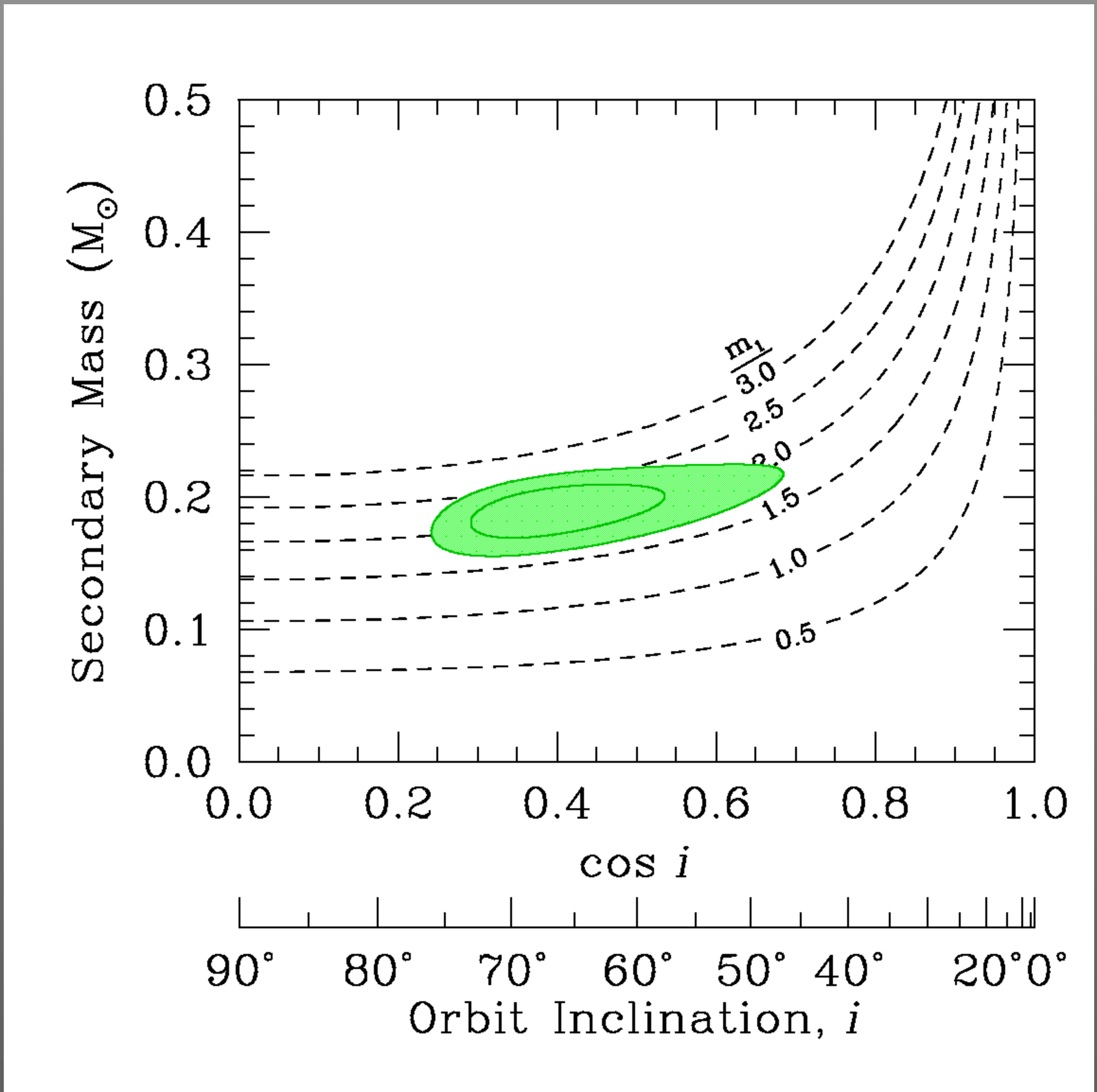
- First Measurement of Gravitational Radiation in a circular binary.



Orbit decay rate:

$$\dot{P}_b = -(6.4\pm0.9)\times10^{-14}$$

Timing fit is influenced by both orbit decay and Shapiro delay.



Orbit decay rate:

$$\dot{P}_b = -(6.4 \pm 0.9) \times 10^{-14}$$

Timing fit is influenced by both orbit decay and Shapiro delay.

Distribution for m_1 alone:

$$m_1 = 2.1 \pm 0.2\ M_\odot$$

What about biases from Galactic Acceleration and Proper Motion?

Quantity	$\dot{P}_b$
Measurement ...	
	-6.2×10^{-14}
Uncertainty	$\pm 0.8 \times 10^{-14}$
Acceleration biases ...	
z-acceleration	-0.1×10^{-14}
Galactic rotation	0.1×10^{-14}
Proper motion	0.2×10^{-14}
Intrinsic value ...	
Measurement−Bias	-6.4×10^{-14}
Uncertainty	$\pm 0.9 \times 10^{-14}$

No Problem ... for now.

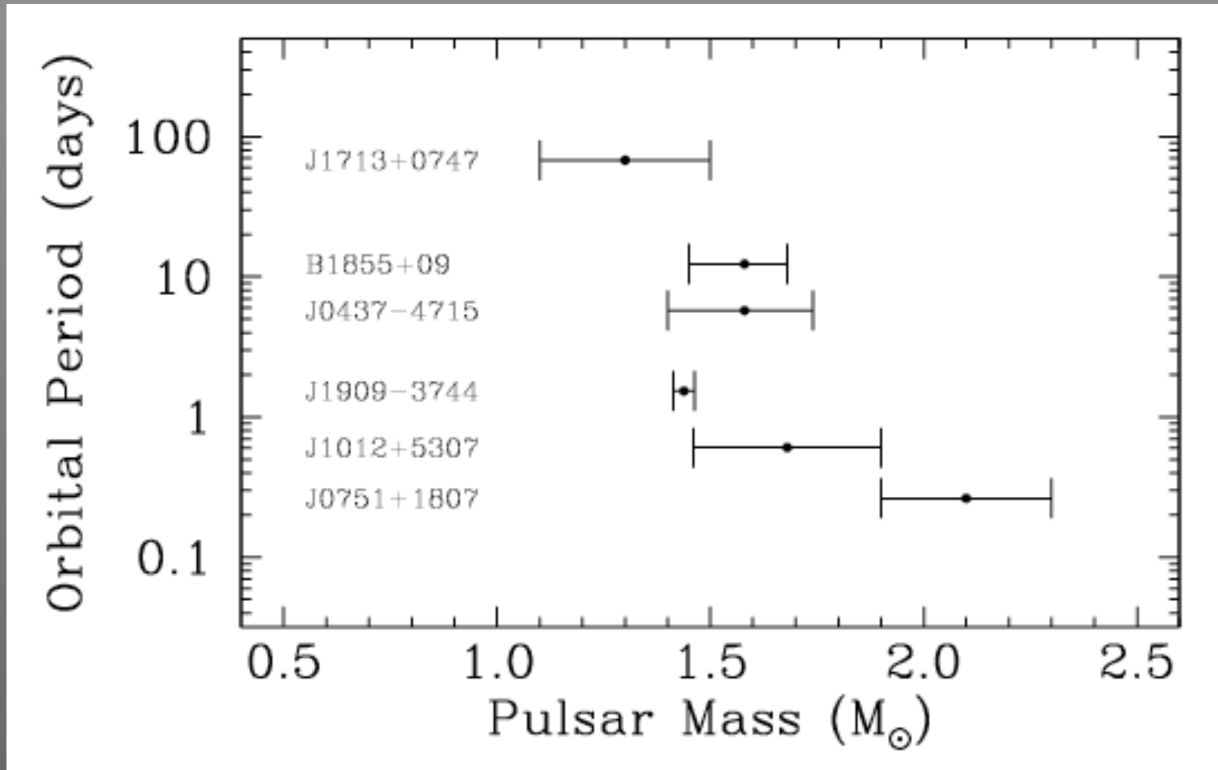
Any Evidence for an Interacting Binary?

Dispersion measure: there is no variability in dispersion measure at $\Delta DM < 4 \times 10^{-4}$ pc cm^{-3} .

Optical observations: Bassa, van Kerkwijk, & Kulkrani (in prep) see no evidence of variability. The secondary star is unusually cool and lacks a hydrogen atmosphere.

⇒Interaction not an issue.
⇒The orbit decay may safely be attributed to Graviatational radiation

An anti-correlation between pulsar mass and orbital period?



Masses of pulsars in Pulsar–Helium White Dwarf binaries measured by detection of relativistic phenomena in pulsar timing. (Exception: J1012+5307, mass is based on optical luminosity and spectroscopy of secondary.)

astro-ph/0508050

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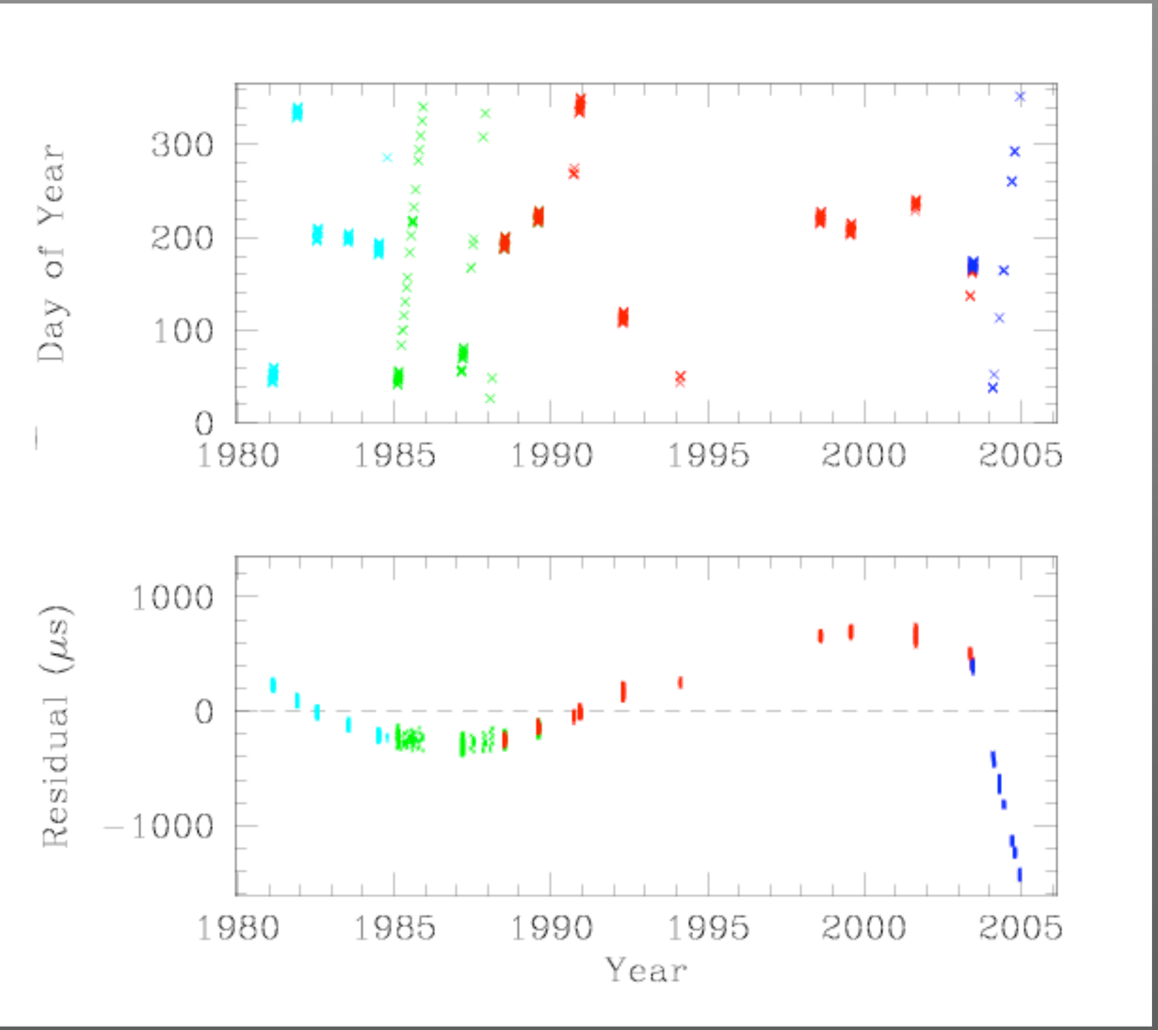
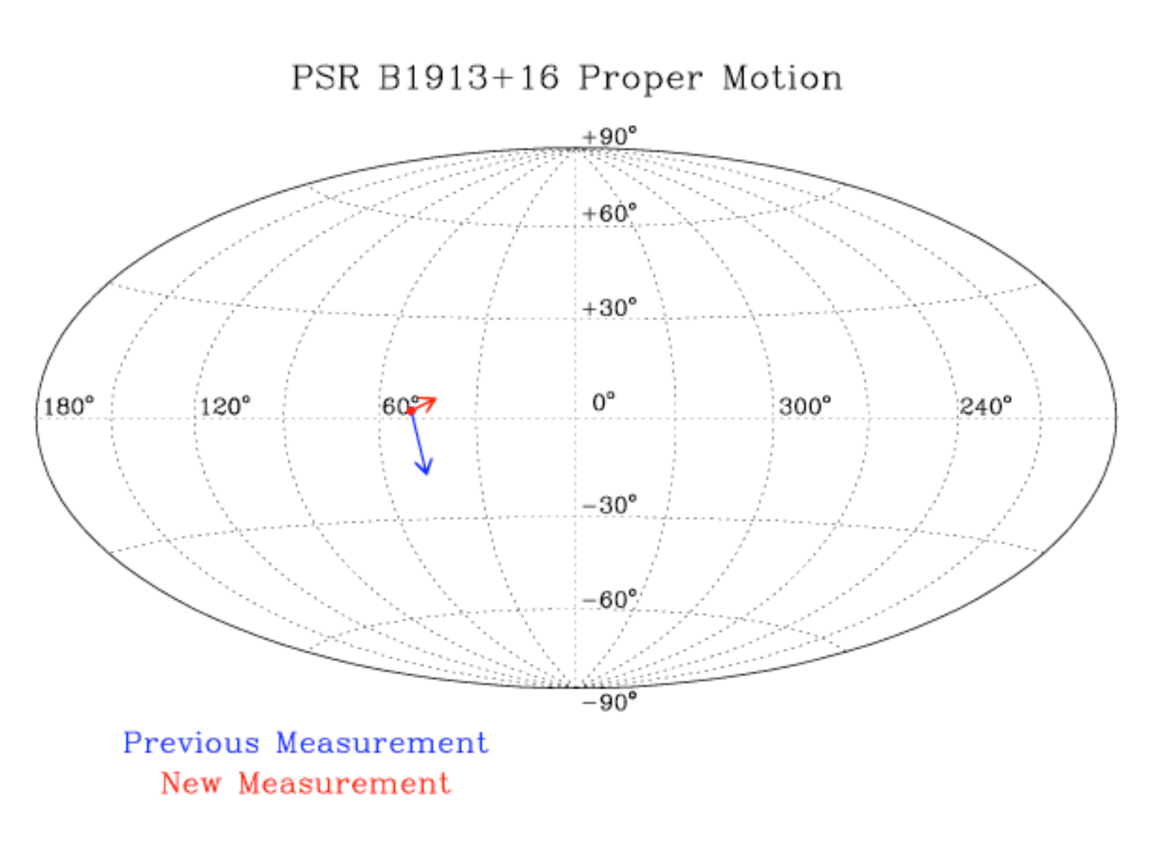
Work in Progress....

Collaborators: Joel Weisberg, Joe Taylor


Day of Year
300
200
100
0
1980
1985
1990
1995
2000
2005
Residual (μs)
1000
0
−1000
1980
1985
1990
1995
2000
2005
Year


PSR B1913+16 Proper Motion
+90°
+60°
+30°
180°
120°
60°
0°
300°
240°
−30°
−60°
−90°
Previous Measurement
New Measurement

Stay Tuned....

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(Pulsar - Arecibo L-band feed Array)

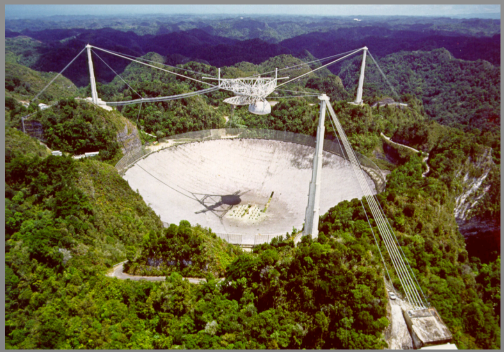
The collaboration...

ARECIBO PULSAR SURVEY USING ALFA. I. SURVEY STRATEGY AND FIRST DISCOVERIES

J. M. Cordes,[1] P. C. C. Freire,[2] D. R. Lorimer,[3] F. Camilo,[4] D. J. Champion,[3] D. J. Nice,[5] R. Ramachandran,[6] J. W. T. Hessels,[7] W. Vlemmings,[1] J. van Leeuwen,[8] S. M. Ransom,[9] N. D. R. Bhat,[10] Z. Arzoumanian,[11] M. A. McLaughlin,[3] V. M. Kaspi,[7] L. Kasian,[8] J. S. Deneva,[1] B. Reid,[5] S. Chatterjee,[12] J. L. Han,[13] D. C. Backer,[6] I. H. Stairs,[8] A. A. Deshpande[2] and C.-A. Faucher-Giguère[7]

...and more

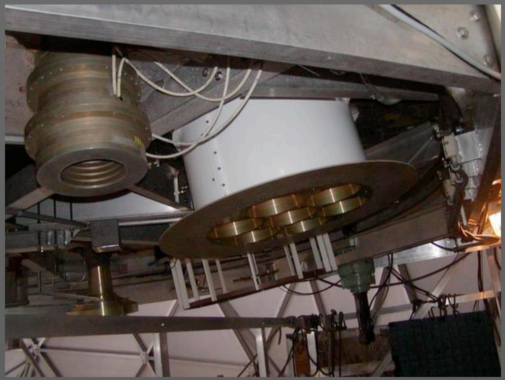
What Next? Find More Pulsars!



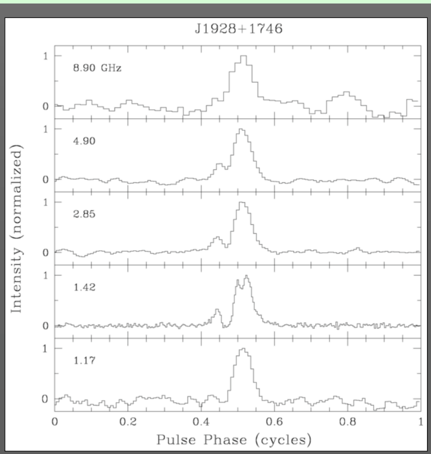
ALFA

Arecibo L-Band Feed Array

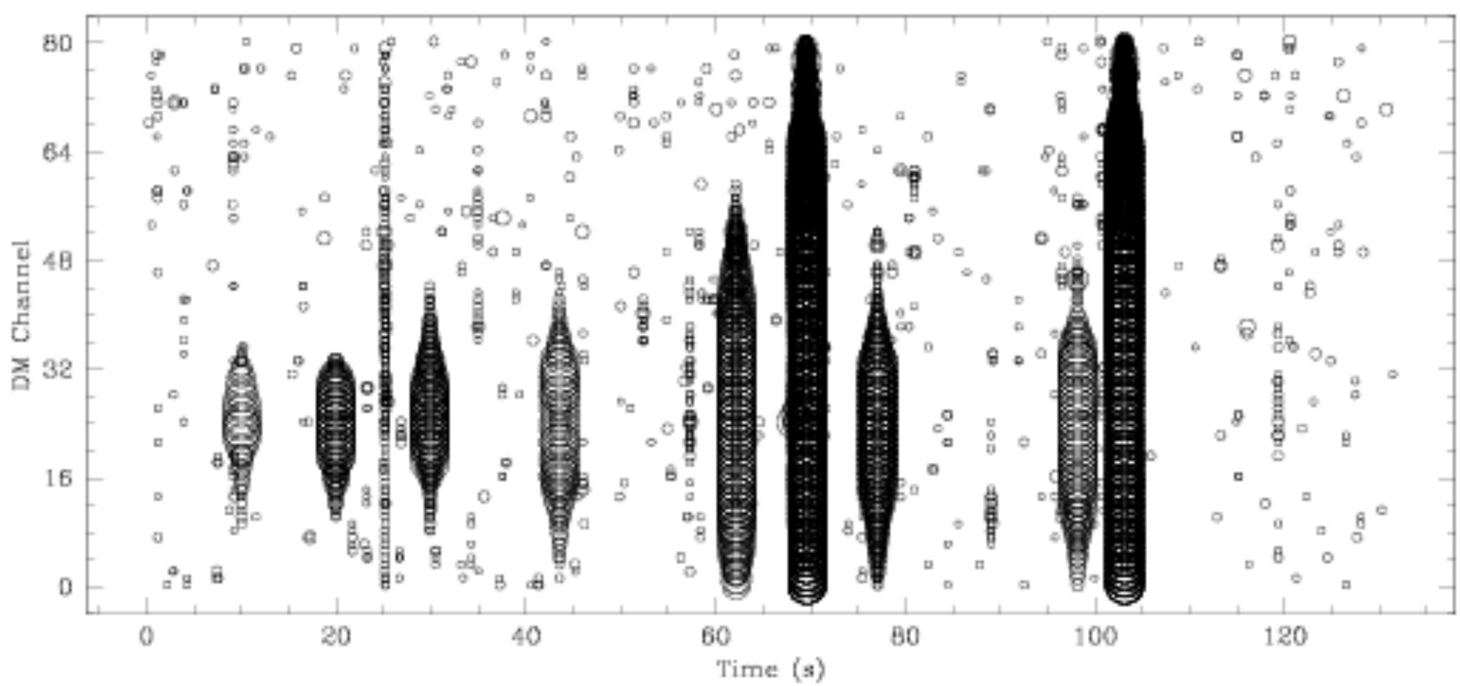
- 7-Beam receiver at 1225-1525 MHz.
- Limited precursor observations began August 2004:
  100 MHz bandwidth, 256 channels, 64 μs samples,
  67 and 134 second integration times
- New spectrometer in winter 2005-6:
  300 MHz banwidth, 1024 channels, 64 μs samples,
- Twelve pulsars discovered to date in low-resolution analysis
- Several hunderd new pulsars expected in full survey.



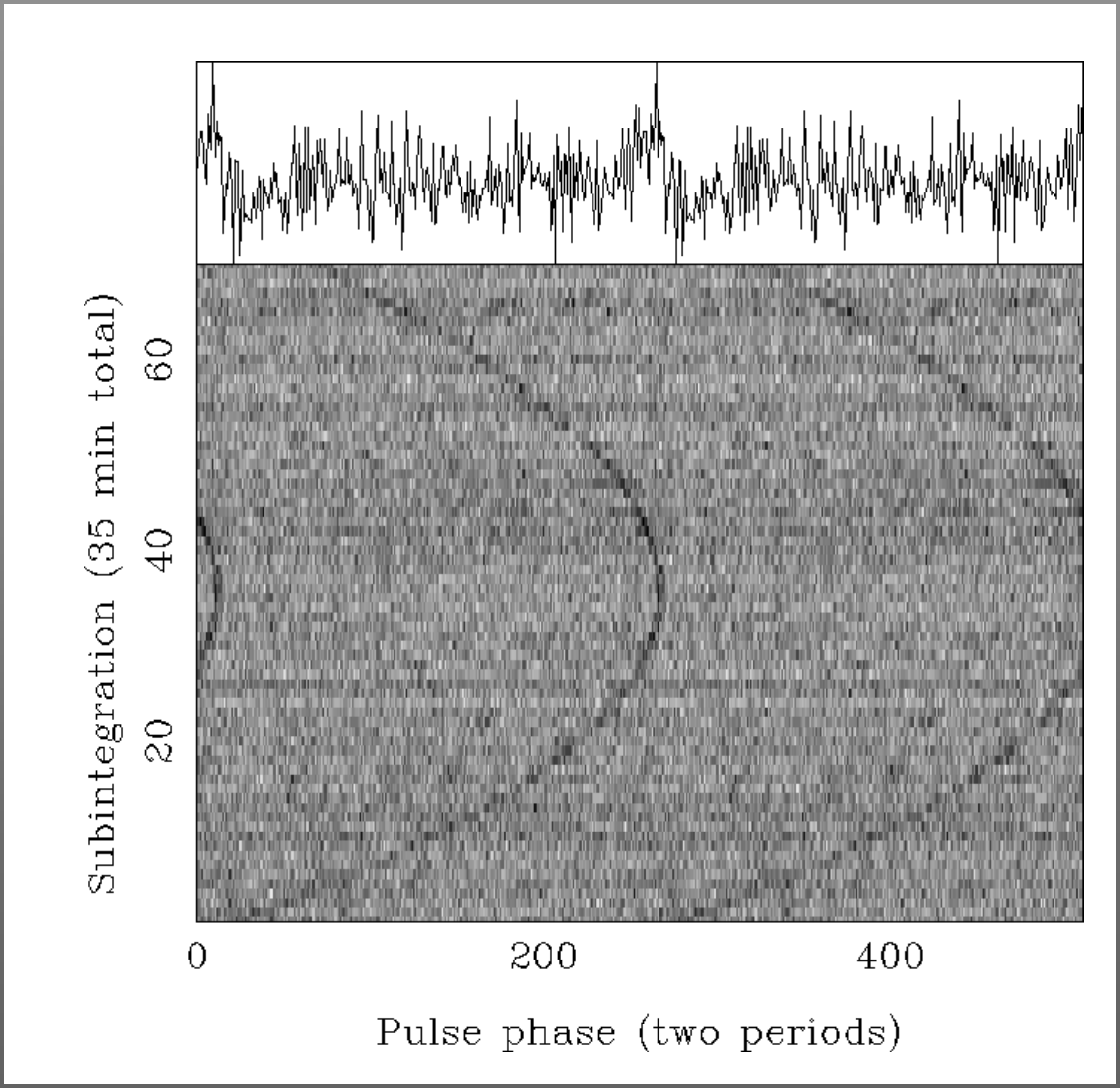
The first ALFA pulsar→



Single Pulse Searches



PSR J0628+09



J1906+0746
The first PALFA binary

Preliminary Parameters
(not ready for prime time -- please do not quote these results!)

Period	144 ms
Age	100 kyr
Orbital Period	3.98 hr
Eccentricity	0.085
Periastron Advance	7.5 deg/yr
Total Mass	2.59 Msun
Distance	5.5 kpc

Summary

1. The mass of PSR J0751+1807, a recycled pulsar in a binary with a Helium white dwarf

   It's heavy: $2.1 \pm 0.2 M_{\odot}$

2. The Proper motion of the Hulse-Taylor double neutron star binary, B1913+16

   It's slow: 100-150 km/s

3. The PALFA survey (Pulsar - Arecibo L-band feed Array)

   It's promising: 100s of new pulsars