Pulsar Mass Measurements

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Radio Pulsars

The number of radio pulsars in binary systems has increased appreciably with the Parkes Multibeam and Arecibo sky surveys in the last 5 years. There are more than 60 known pulsars in binary systems, including at least 7 in double neutron star systems (table 1). Measurements of pulsar masses as well as radii, cooling histories and rotational instabilities, provide a unique parameter space in which extreme physics can be tested. Observations of neutron stars also provide our only current probe of general relativity in the "strong field" regime, where gravitational self-energy contributes significantly to the stellar mass.

The mass of most neutron stars can be determined via a detailed analysis of the binary motion. The common *methods used for pulsar mass estimates* are:

1) Pulsar Timing

1) Masses of Companion Stars:
- i) Optical Observations of White Dwarf Companions
- ii) Optical Observations of Main Sequence Companions
- iii) The Binary Period-Core Mass Relation (P_b-m_2)

3) Orbital Inclination:
- i) Polarization
- ii) Interstellar Scintillation
- iii) Secular Variation of $x= a_1 \sin i$
- iv) Random Distribution of Orbital Inclination

X-ray Binaries

The recent successful X-ray missions (Chandra & XMM) helped increase the number of pulsars with well defined orbits. Even though these mass estimates are less constrained than radio pulsars, the X-ray pulsar masses are complimentary to the the radio pulsar mass estimates. The apparent wider distribution of masses (table 2) might not only point out evolutionary differences between these two populations, but also between different classes of X-ray binaries (IMXBs, LMXBs & HMXBs).

The methods for estimating pulsar masses in X-ray binaries are:

1) X-ray Timing

2) Masses of Companion Star: i) Radial Velocity Measurements

3) Spectral Modeling

Radio Pulsars

Double Neutron Star Systems	Mass ($M_\odot$)
J1518+4904	1.56 +0.13/-0.44
Companion of J1518+4904	1.05 +0.45/-0.11
B1534+12	1.339 $\pm$ 0.003
Companion of B1534+12	1.339 $\pm$ 0.003
B1913+16	1.4411 $\pm$ 0.00035
Companion of B1913+16	1.3874 $\pm$ 0.00035
B2127+11C	1.349 $\pm$ 0.040
Companion of B2127+11C	1.363 $\pm$ 0.040
J1811-1736	1.3 $\pm$ 0.45
Companion of J1811-1736	1.3 $\pm$ 0.45
J0737-3039A	1.337 $\pm$ 0.001
Companion of J0737-3039A	1.250 $\pm$ 0.001
Neutron Star - White Dwarf Systems	
B2303+46	1.30 +0.13/-0.46
J0437-4715	< 1.51
J1012+5307	1.7 $\pm$ 0.5
J1045-4509	< 1.48
J1713+0747	1.45 $\pm$ 0.31
B1802-07	1.26 +0.08/-0.17
J1804-2718	< 1.73
B1855+09	1.41 $\pm$ 0.10
J2019+2425	< 1.68
J2145-0750	1.5 $\pm$ 0.3
J0621+1002	1.7 +0.32/-0.29
J0751+1807	2.1 $\pm$ 0.2
J1909-3744	1.438 $\pm$ 0.024
J1141-6545	1.30 $\pm$ 0.02
Neutron Star - Main Sequence Binaries	
J0045-7319	1.58 $\pm$ 0.34

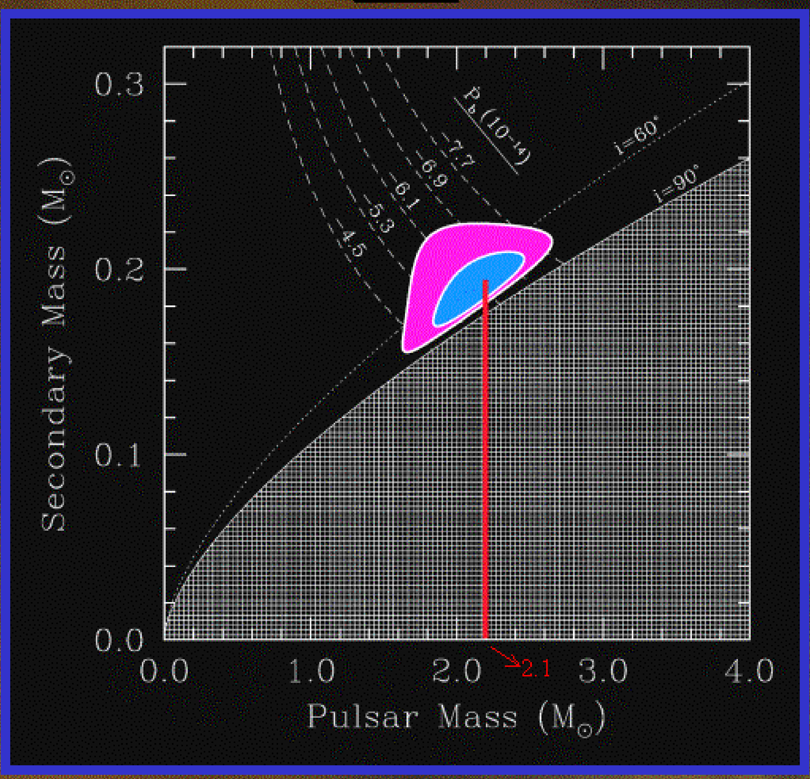
Table 1.

X-ray Binaries

Intermediate Mass Binaries	Mass ($M_\odot$)	Companion
Her X-1	1.5 $\pm$ 0.3	HZ Her (A9-B)
Low mass X-ray Binaries		
Sco X-1	1.4 (?)	[M Class]
Cyg X-2	1.78 $\pm$ 0.23	V1341 Cygni
2A 1822-371	0.97 $\pm$ 0.24	V691 CrA
4U 1820-30	1.65 $\pm$ 0.35	Low mass helium rich WD
High Mass X-ray Binaries		
Vela X-1	1.86 $\pm$ 0.16	HD 77581-GP Vel [B0.5 Ib]
SMC X-1	1.1 $\pm$ 0.2	Sk 160 [B0 I]
Cen X-3	1.2 $\pm$ 0.21	V779 Cen [O6-8f]
LMC X-4	1.48 $\pm$ 0.23	Sk-Ph [O7 III-V]
4U 1538-52	1.3 $\pm$ 0.2	QV Nor [B0 Iab]
4U 1700-37	1.35 $\pm$ 0.04 (?)	HD 153919 [O6.5 Iaf]

Table 2.

Fig 4.



The constrains on the millisecond pulsar J0751+1807 and secondary mass. The shaded region is disallowed by the Keplerian mass function. 68% and 95% confidence limits are shown (Nice *et al.* '05).

Fig 3.

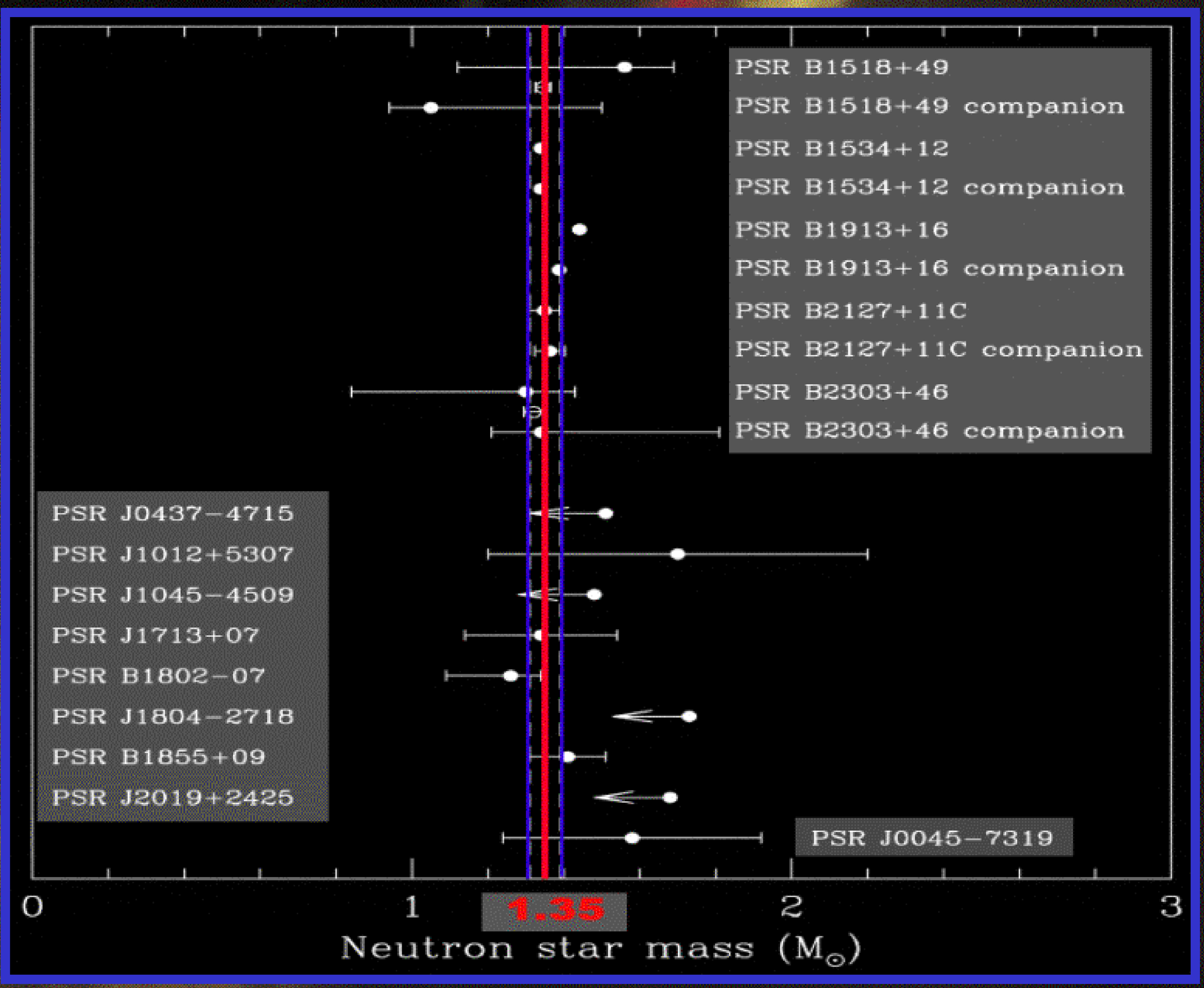
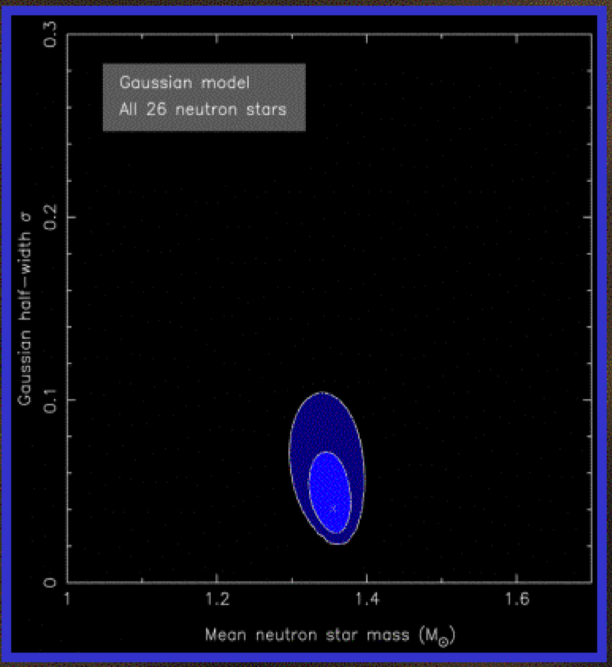


Fig 1.



Maximum likelihood estimates of the mean *m* and standard deviation σ for a Gaussian mass distribution

Thorsett & Chakrabarty '99 have investigated whether a single, simple distribution of neutron star masses would be consistent with all the observational constraints for radio pulsars. A Gaussian distribution of masses with mean *m* and a standard deviation σ (fig 1), and a uniform distribution of masses between m_l and m_u (fig 2) was used to demonstrate the statistical distribution of the pulsar masses. The resulting 68% and 95% confidence limits on *m* and σ are shown in figure 1, and on m_l and m_h in figure 2. The narrow distribution of masses have a maximum likelihood solution of $m= 1.35\ M_\odot$, $\sigma=0.04\ M_\odot$, $m_l=1.26\ M_\odot$ and $m_h=1.45\ M_\odot$ (fig 3).

Recently discovered high mass pulsars (J0621+1002, J0751+1807), especially in NS - WD binary systems, hint a higher neutron star mass for these populations than the canonical value. Nice *et al.* '05 have discovered a 2.1 $M_\odot$ pulsar around a helium white dwarf (fig 4) which is the pulsar with highest mass yet discovered.

Maximum likelihood estimates of min. & max. masses for a uniform mass distribution

Fig 2.