Pulsars in globular clusters: the view from Parkes

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Collaborators:

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P. Edmonds, J. Grindlay, C. Heinke (Optical/X-ray 47 Tuc)

- 1st MSP discovery (1982) +
- LMXB / MSP "recycling" model +
- High incidence of LMXBs in GCs,

→ 1st GC pulsar (1987) (MSP in M28)

Q1: what kind of pulsar systems form in GCs? (cf. binaries, stellar interaction)

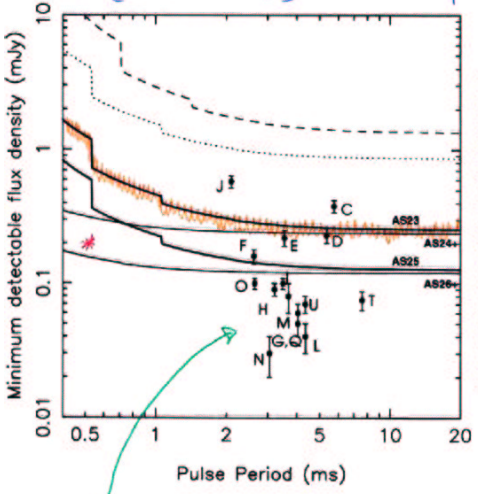
Q2: how are pulsars distributed in GCs? (cf. formation, dynamics)

Q3: what kind of clusters have pulsars, & how many? (cf. IMF, retention, cluster evolution, ...)

Selection effects, alas ...

- Distance ($\frac{1}{d^2}$), of course (MSPs are weak radio sources)
- Dispersion measure ($DM = \int_0^d n_e \, dl$) & Period (DM/P)
- Scintillation in ISM
- Processing / "acceleration searches"

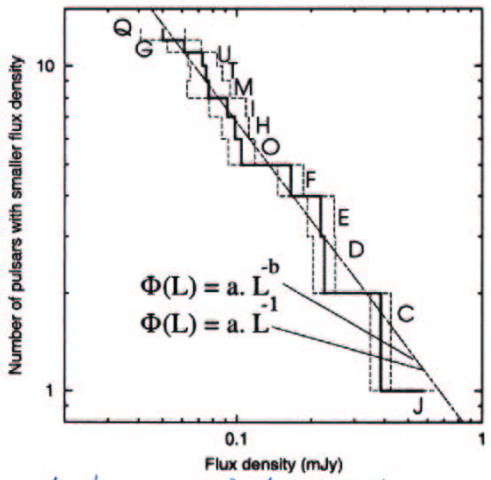
47 Tuc : $d \approx 5$ kpc , DM = 25 cm^{-3} pc
(@ 1400 MHz) 22 pulsars (MSPs) known



Average fluxes

* Faster sampled data (still being reduced)

Several MSPs found due to acceleration searches



$dN/dL \propto L^{-2}$ (as in disk, MS)

$1 \lesssim L_{1400} \lesssim 10$ mJy kpc^2

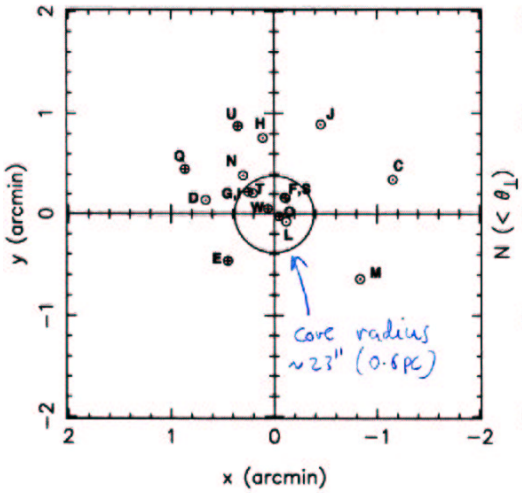
IF $L_{min} \lesssim 0.1$ (as in disk), might expect $\approx 10 \times 22 \approx 200$ pulsars

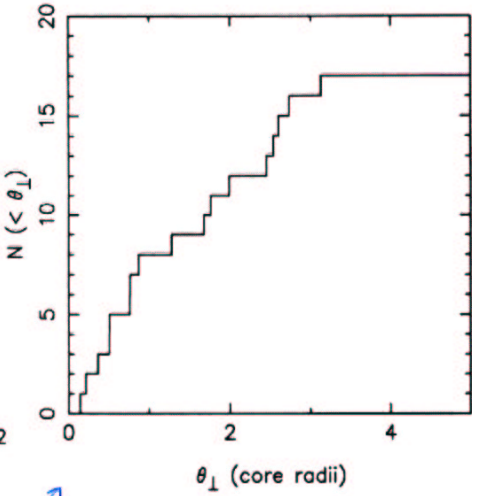
Chandra ($\lesssim 100$?)
(Jack)

ATCA (? a good idea, in principle ...)

Radio Luminosities + Chandra : way to estimate pulsar populations ...

Spatial distribution in GC:





All (17) pulsars with precisely determined positions ($\sigma_\Theta \lesssim 10$ mas) within $r \sim 1.'2$

Deprojected spatial density $n(r) \propto r^{-2}$
(but none at $r \gtrsim 3 r_c$)
(not so for Chandra sources)

(Area of Parkes beam $\approx 100 \times$ larger than this!)

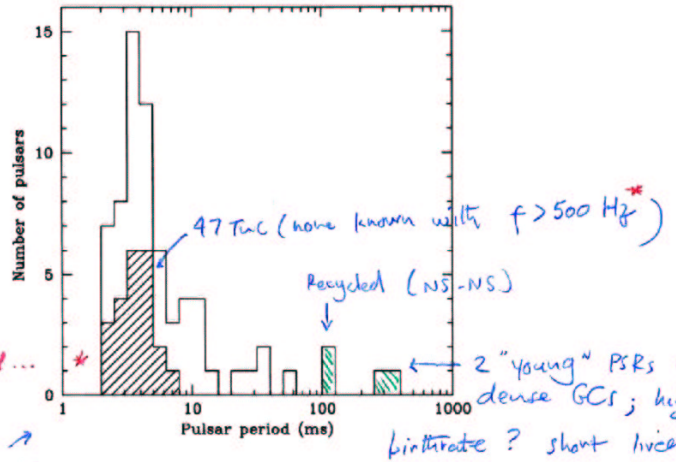
Is this as expected? ($h_p \propto r^{-2}$ in MS, dominant species $\sim 0.9\ M_\odot$ WDs ...)

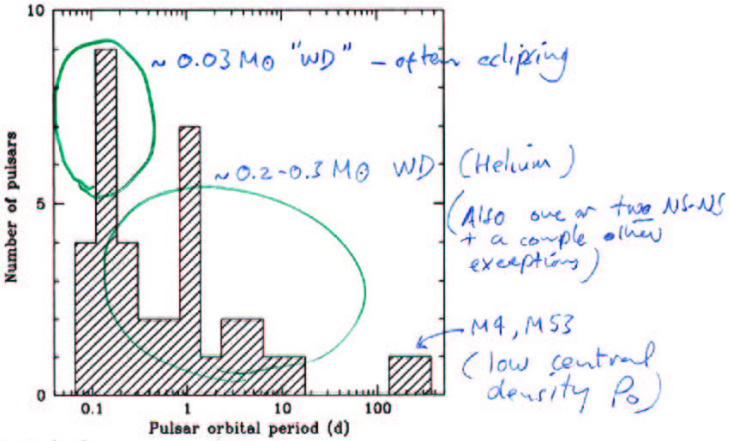
47 Tuc : isothermal equilibrium ... dominant mass species $\sim 1.5\ M_\odot$?

(however, notice that all MSPs within $2 r_c$ ... even if you might expect a more compact core for NSs ...)

(Fred ???)

Spin and orbital period dist. for PSRs in GCs





47 Tuc: (22 MSPs)
- ~ 1/3 isolated
- ~ 1/3 0.5-2.5 d 0.2 M⊙ He WD (accent ≈ 1-4 x 10^-9 - large! one with e = 0.07!!)
- ~ 1/3 1.5-5 hr 0.03 M⊙

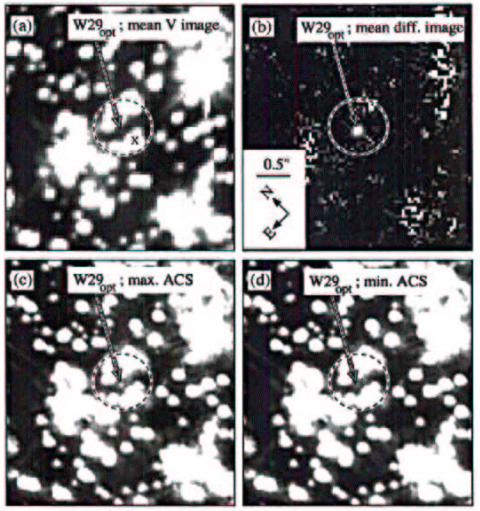
+ 1 MS...

47 Tuc W : MSP + MS binary

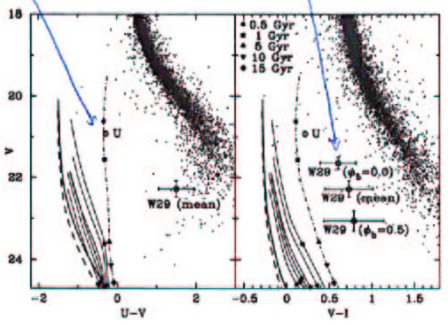
P = 2 ms
P_b = 3.19 hr
m_c > 0.13 M⊙

eclipsing in radio

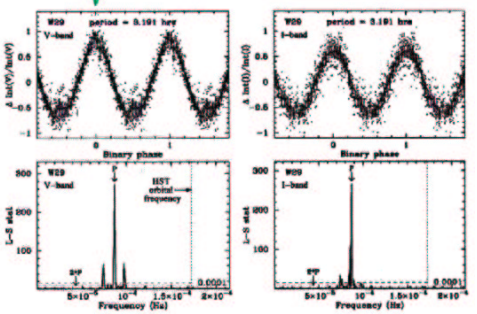
(no "timing" position!)



← HST (also Chandra)



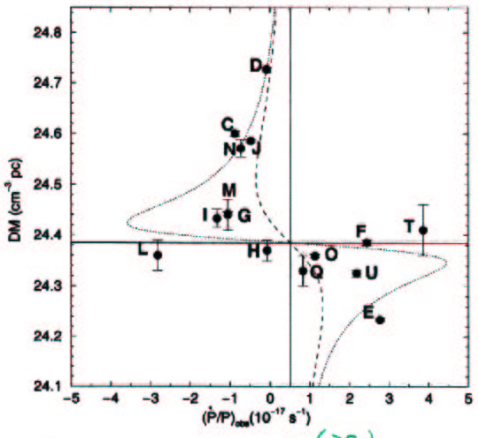
* Maximum light (heated by MSP); matching phase (within 1.2 min!!)

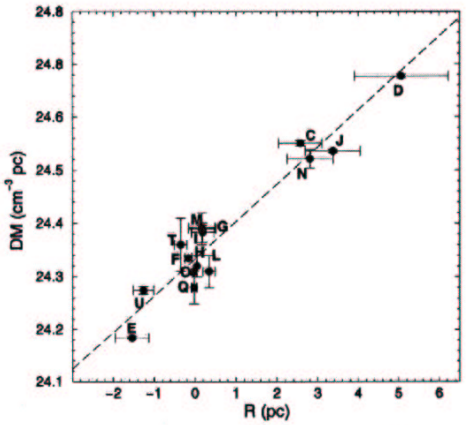


* Same binary period (within 0.5 sec!)

* W29 is 47 Tuc W!

INTRACLUSTER MEDIUM





$\left(\frac{\dot{P}}{P}\right)_{obs} = \frac{a_l}{c} + \left(\frac{\dot{P}}{P}\right)_{int}^{(>0)}$

$\dot{P}_{obs} < 0 \Rightarrow$ location on "far side" of GC

PSRs with $\dot{P}<0$ have higher DMs $\Rightarrow$ Gas!

$n_e = 0.067\,(15)$ cm^{-3}

$M_{gas,\,<2.5pc} \sim 0.1\,M_\odot$

$C \ll 100\,M_\odot$ expected to accumulate in 10^7–10^8 yr)

CE of MSPs expels gas?)

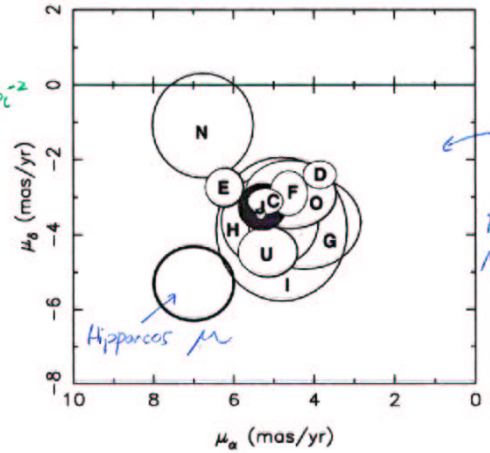
(A. Possenti on Friday)

Also, a_l bound

$\Rightarrow \Sigma$ bound

$\therefore \sum_{s(<12'')} > 8.4\times10^{4} M_\odot\,pc^{-2}$

$M/L > 1.4\,M_\odot/L_\odot$



$\delta\mu_{\odot} \sim 0.1$ mas yr^{-1}

Future: measure MSP μ wrt GC center!

Recent Parkes searches

- 60 GCs with DM expected < 300 cm^{-3}pc (+ a few more)
- 2 hr integrations at f = 1.4 GHz
- 45 GCs processed (but not yet with uniform acceleration searches)

(Computationally, this problem is still HARD!)
(~ 100 Mpt FFTs – and many of them – with acceleration!)

Pulsars discovered in the Parkes GC search

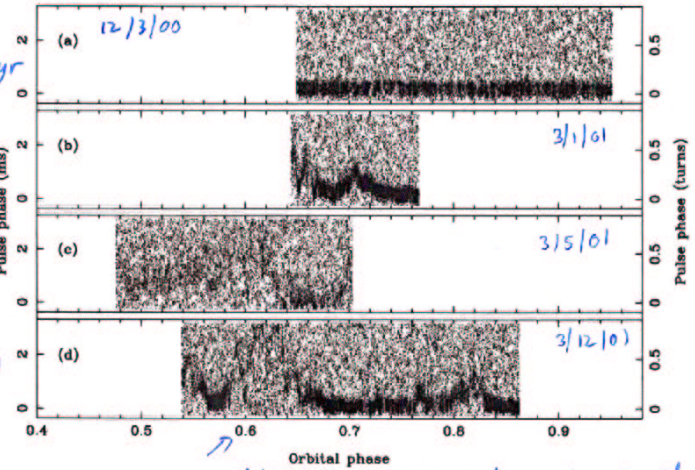
Cluster	Pulsar	Period (ms)	DM (cm^{-3} pc)	P_{orb} (days)	$a_p \sin i$ (l-s)	$m_{c\,min}$ ($M_\odot$)	
NGC6752	J1910-5958A	3.266	34	0.837	1.206	0.19	WD
	J1910-5958B	8.357	33	single			
	J1910-5958C	5.277	33	single			
	J1910-5958D	9.035	33	single			
	J1910-5958E	4.571	33	single			
NGC6397	J1740-5340	3.650	72	1.354	1.652	0.18	
NGC6266	J1701-3006A	5.241	115	3.805	3.483	0.19	WD
	J1701-3006B	3.593	113	0.144	0.252	0.12	(eclipsing)
	J1701-3006C	3.806	115	0.215	0.192	0.07	?
NGC6544	J1807-2459	3.059	134	0.071	0.012	0.009	
NGC6522	J1803-3002	7.101	193	single			
NGC6441	J1750-3703	111.60	233	17.334	24.392	0.58	(e=0.71)

PSR J1740-5340 in NGC 6397 ($L_{1400} \sim 5$ mJy kpc^2; not many MSPs - Chandra - $\lesssim 5$?)

P = 3.6 ms
$\tau = P/2\dot{P} = 350$ Myr
$P_b = 1.35$ d
$e < 10^{-4}$
$m_c > 0.19\ M_\odot$

$\dot{E} = \frac{d}{dt}(\frac{1}{2} I \omega^2) = 1.4 \times 10^{35}$ erg s^{-1}

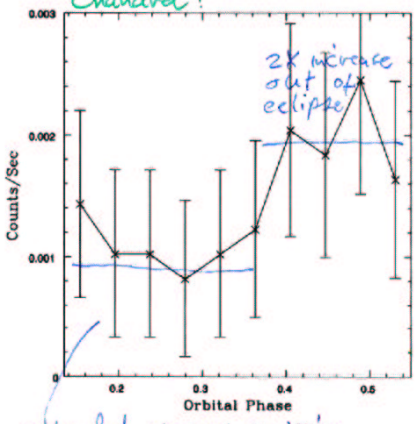
Always eclipsed at $0.1 < \phi_b < 0.4$



Variable (dispersive) delays at all phases

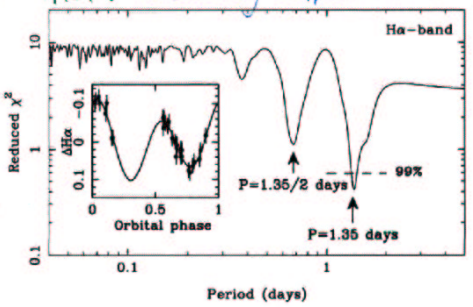
Most massive companion among all eclipsing pulsars...
Position in GC: $r \sim 0.'55 \sim 11\ r_c$ - ejected! (recently? probably in eccentric orbit about cluster center)

Chandra:



extended x-ray emission...

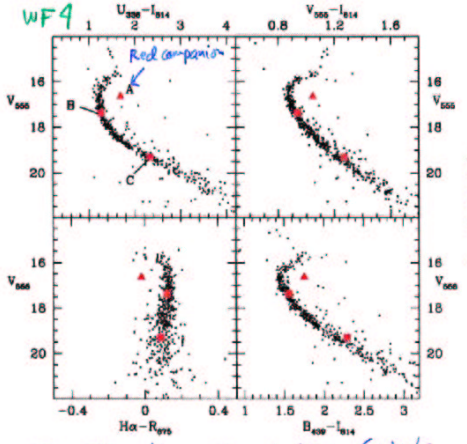
HST: ~0.2 mag ellipsoidal variations



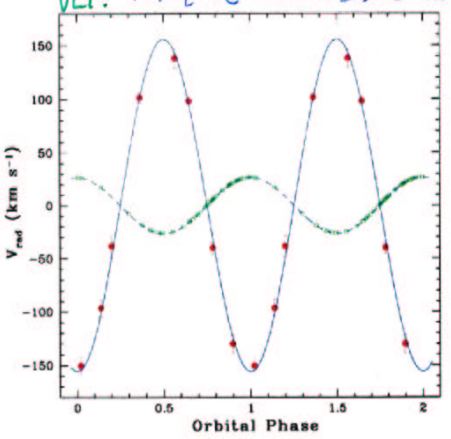
$i \sim 50°$

(see Sabi poster)

WF4



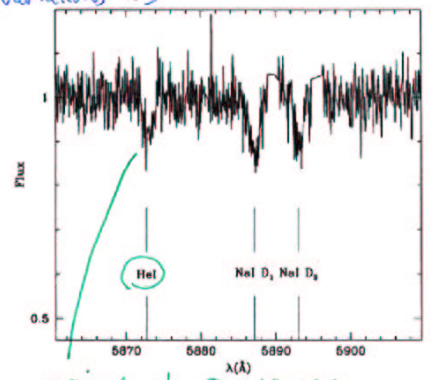
VLT: $M_{PSR}/M_c = 5.85(13)$; $M_c \approx 0.13 M_\odot$

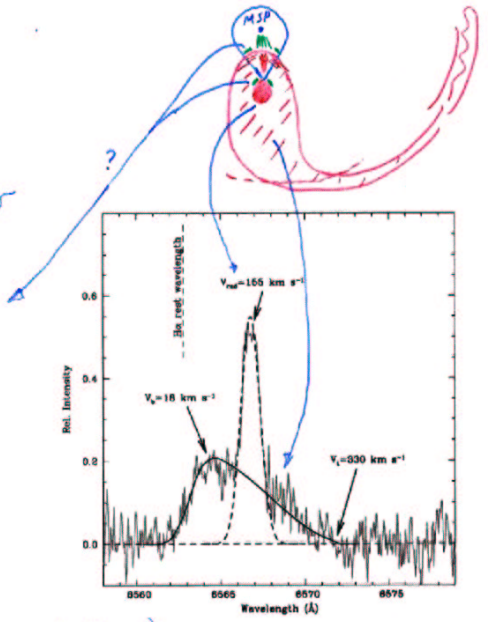


$T \sim 5500$ K ; $R \sim 1.6 R_\odot$ (just underfills Roche lobe) ; $L \sim 2 L_\odot$

Like 'sub-subgiants' in M67 (evolved subgiant) or 'red stragglers' in 47 Tuc

($\dot{E} \sim 20 \times L_{bol}$ companion - expect larger variations ?)





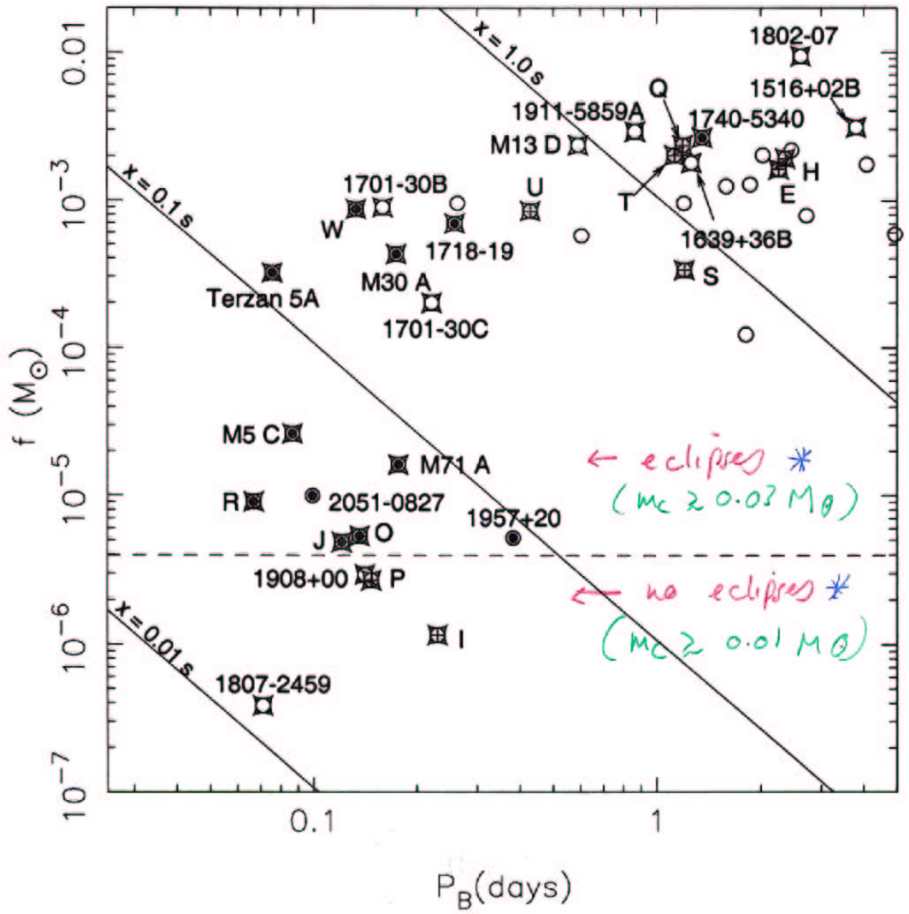
regions at $T > 10{,}000$ correlated with ϕ_b → heating in thin strip (anisotropic ? pulsar wind ?)

NGC 6752: 1 binary, 4 single (large single incidence ?)
(odd radial distribution)
L_{1400} : 1-5 mJy kpc^2 (scintillation helps...)

NGC 6266: 3 binaries + 3 more binaries (at GBT, Bryan Jacoby)
"high" → (13-18 mJy kpc^2) (weaker)
(why so many binaries ?) (all – Pks ones – near core)
Not much scintillation, but for reasonable dN/dL, many MSPs should exist (à la 47 Tuc?! cf. Dave Pooley)

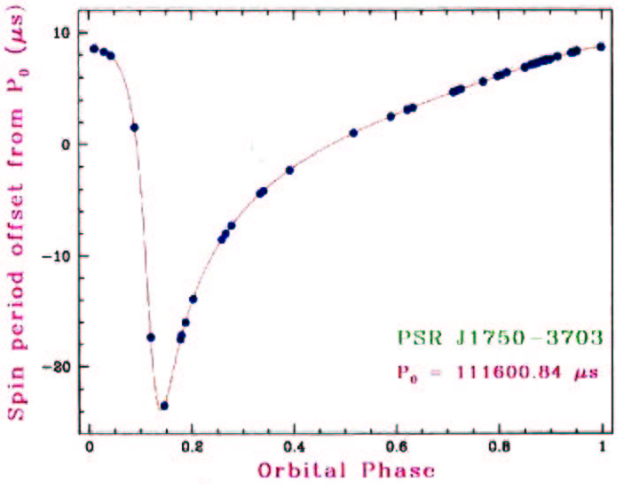
NGC 6522: 1 single, high DM, largish P, near core
L_{1400} = 24 mJy kpc^2 ← "high"
find others ? (DM a problem)

NGC 6544: 1 binary with very low mass companion
($\gtrsim 0.009\ M_\odot$), near core
1.3 mJy source first detected in continuum (VLA, Fruchter & Goss); any weaker ones ? (8 mJy kpc^2)



Perhaps ~all* these systems have $m_c \sim 0.03\ M_\odot$ and ones with higher mass function are more edge on ?!

NGC 6441: Unusual eccentric binary



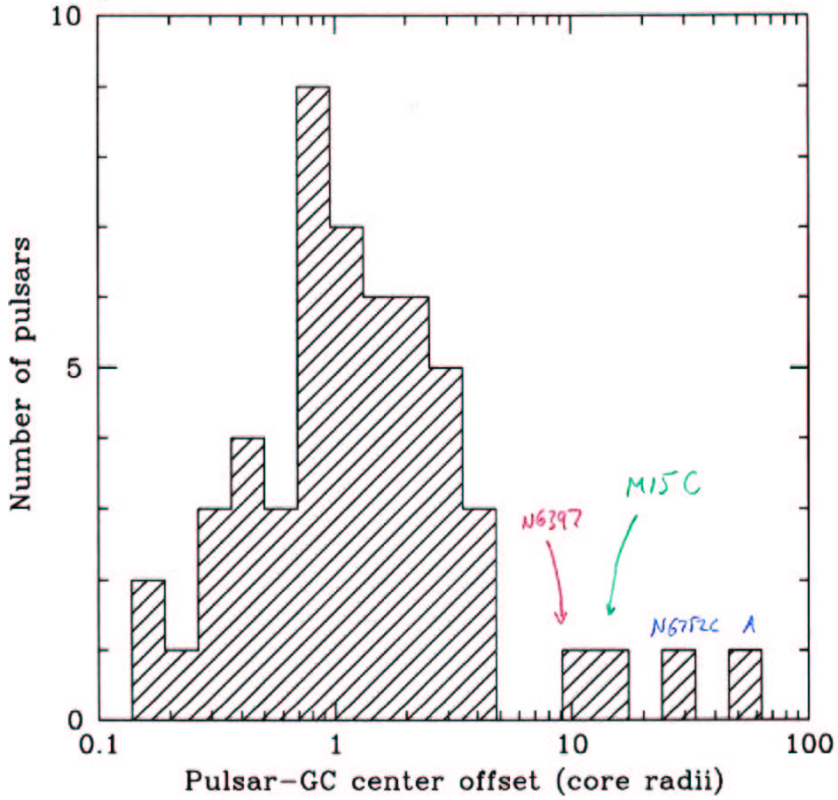
NS-NS? ($m_c > 0.6\,M_\odot$; $e = 0.7$)

Located at $\sim 2 r_c$, $\tau \sim 300$ Myr

Only one pulsar, but DM high (P large),
$L_{1400} \sim 13$ mJy kpc^2 ($S_{1400} \sim 0.1$ mJy)

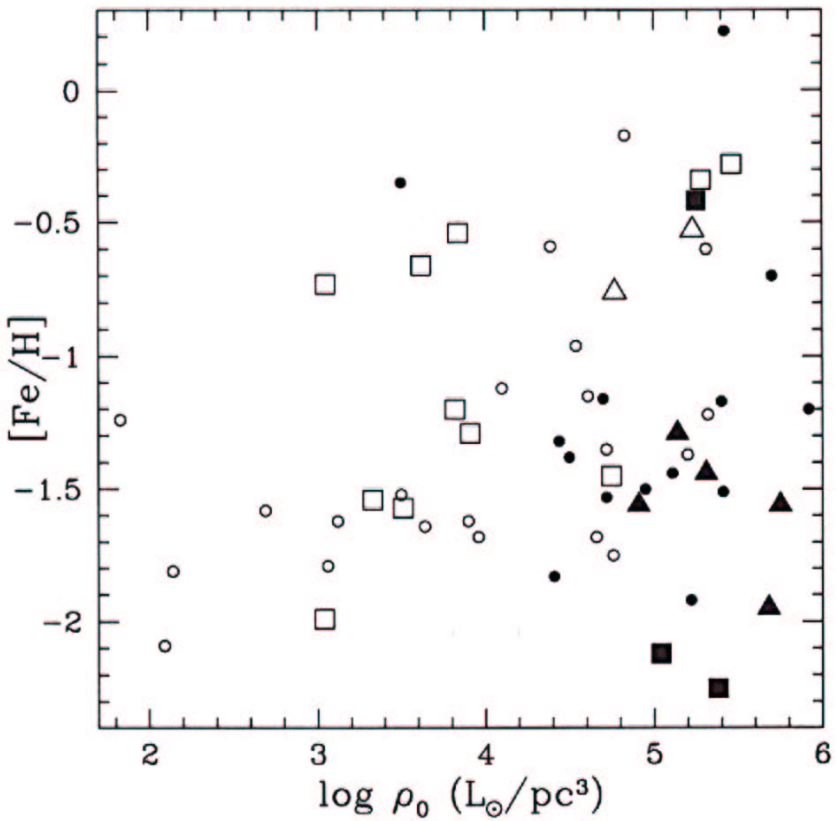
Others? Flux & DM a problem, especially for MSPs...

Radial distribution in GCs of pulsars
(69 PSRs in 22 GCs)



Vast majority at $\frac{1}{5} < \frac{r}{r_c} < 5$ (4 exceptions)

Clusters (searched, and with pulsars)



At Parkes: 25 non-core collapsed, 20 (possibly) core-collapsed } 5 of 6 GCs with PSRs are core-collapsed

(however elsewhere, low ρ_0 clusters found to have pulsars)

- Most luminous PSR in each GC has L_{1400} within a factor of 2 of 12 mJy kpc^2 – but at Parkes often (so for) $L_{min} \approx 18$ mJy kpc^2 ∴ Non-detection does not imply (or even suggest) non-existence (at Parkes ... go to AO/GBT)