IAU Symposium 291
Neutron Stars & Pulsars: Challenges and Opportunities after 80 years
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Binary Pulsars evolution: unveiled links and new species

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INAF Istituto Nazionale di Astrofisica National Institute for Astrophysics

Thanks to the organizers for inviting me to introduce this session

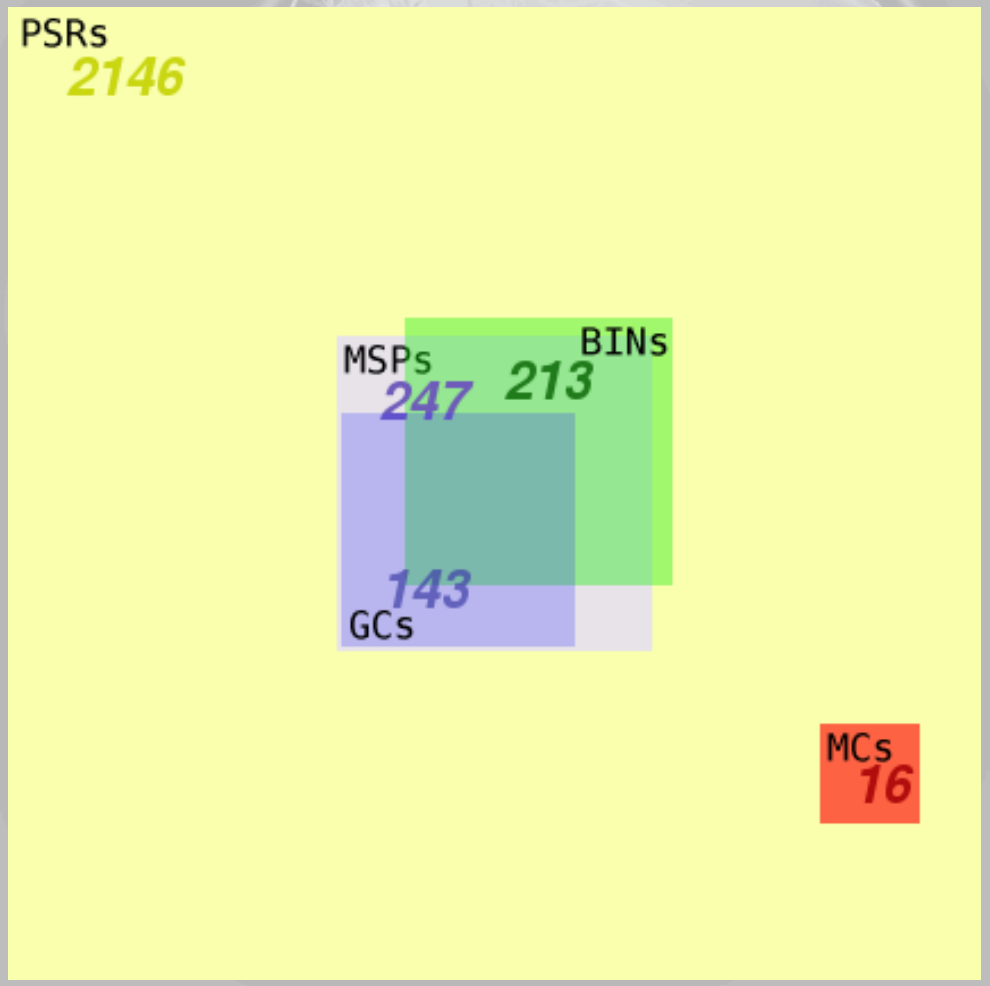
Not a canonical review...

...a "FIL ROUGE" going across recent evolutions in binary pulsar evolution...

...from the (biased) perspective of an observer...

so let's start with the census of the available targets

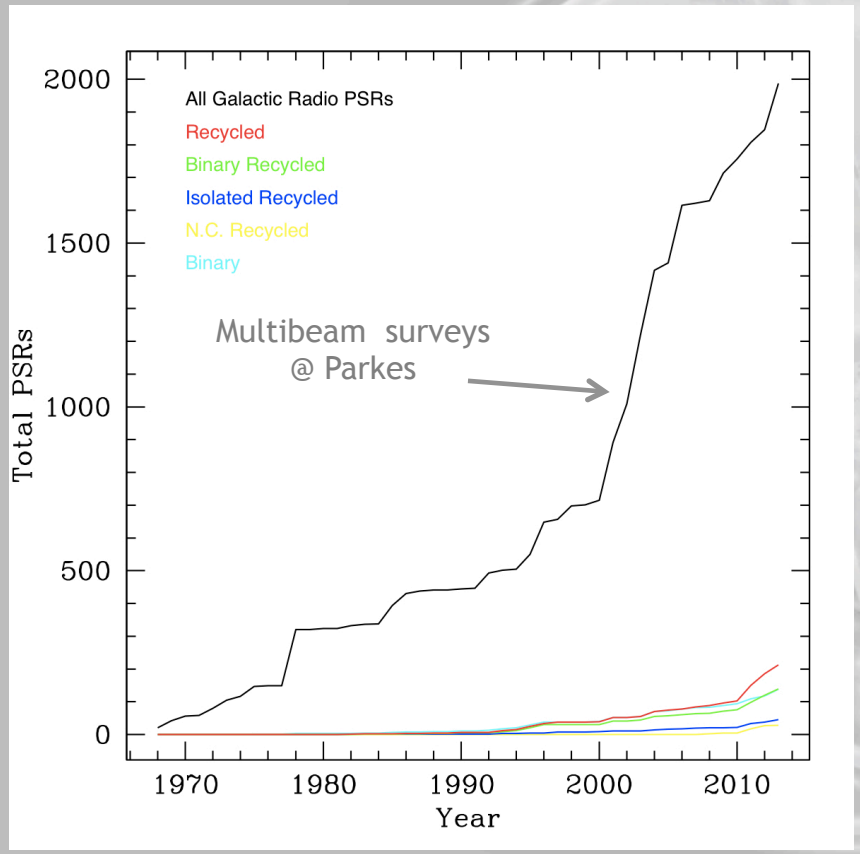
The current (almost) complete demography of radio pulsars

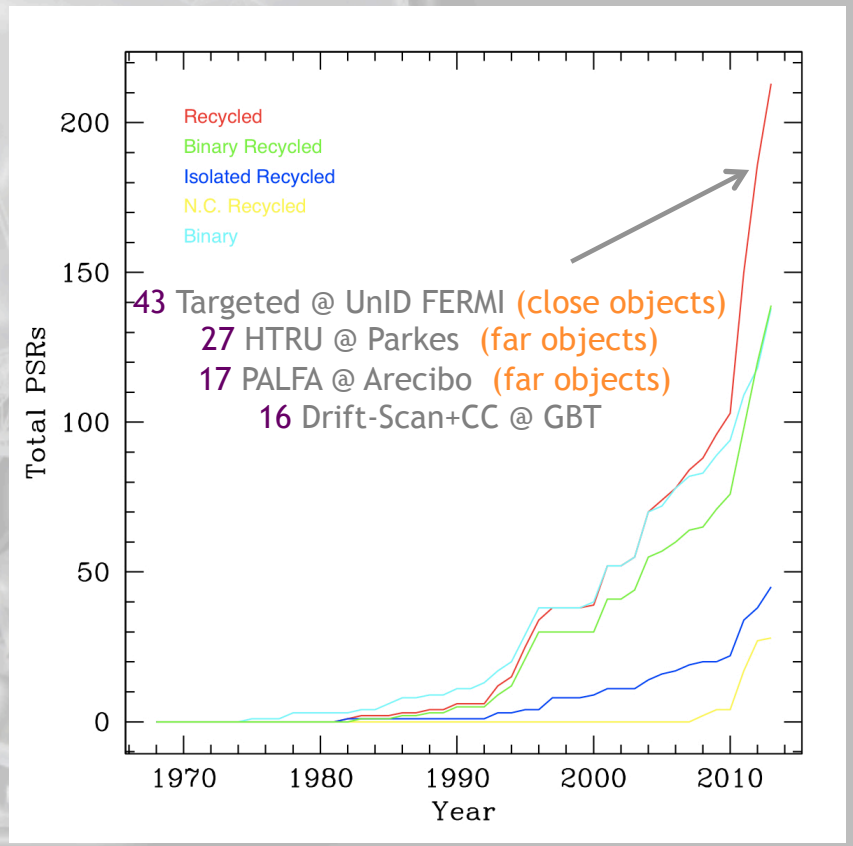


[Possenti & Burgay 2012, in prep]

≈10 % of known pulsars are in binaries

Cumulative discoveries plots for pulsars in the Galactic field

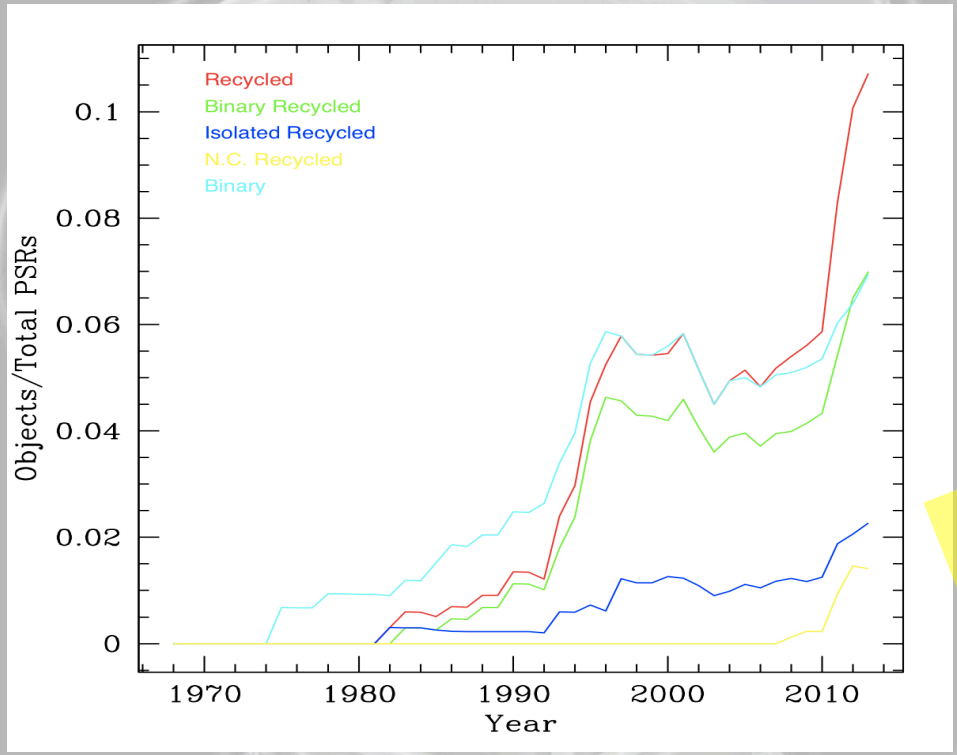




[thanks to M. Burgay]

almost doubled the population of recycled psrs in last ≈2 yrs

The increasing efficiency in discovering binary or recycled vs ordinary pulsars

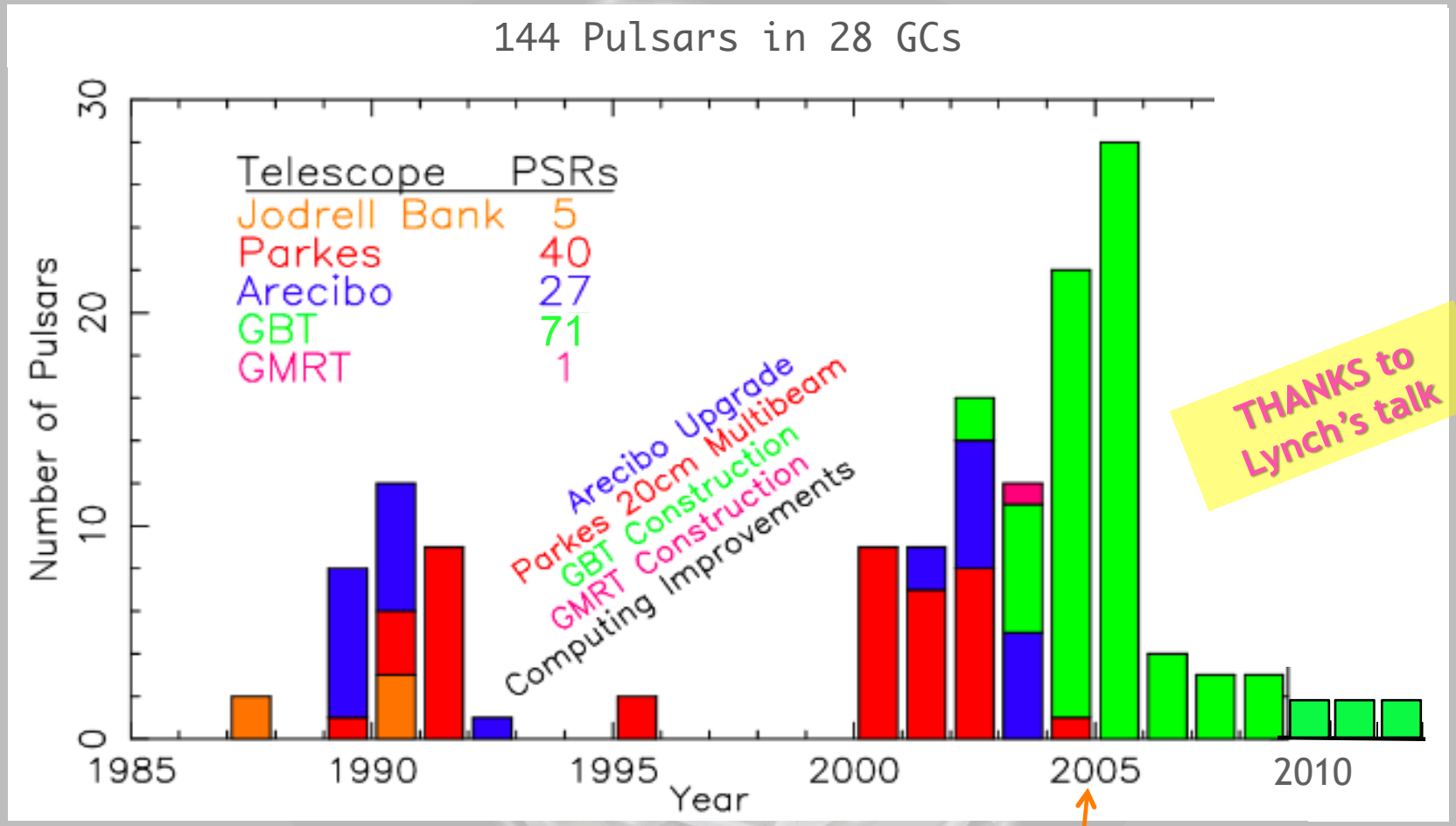


[thanks to M. Burgay]

THANKS to
Keith's talk
Lazarus' talk
Lynch's talk
Guillemot's talk

The fraction of discovered recycled pulsars reaches
≈15% (PALFA) / ≈20% (GBTs') / ≈25% (HTRU) in recent blind surveys
- Even larger % in targeted surveys on γ-ray candidates

The population of binaries in Globular Clusters



[adapted from Ransom 2012]

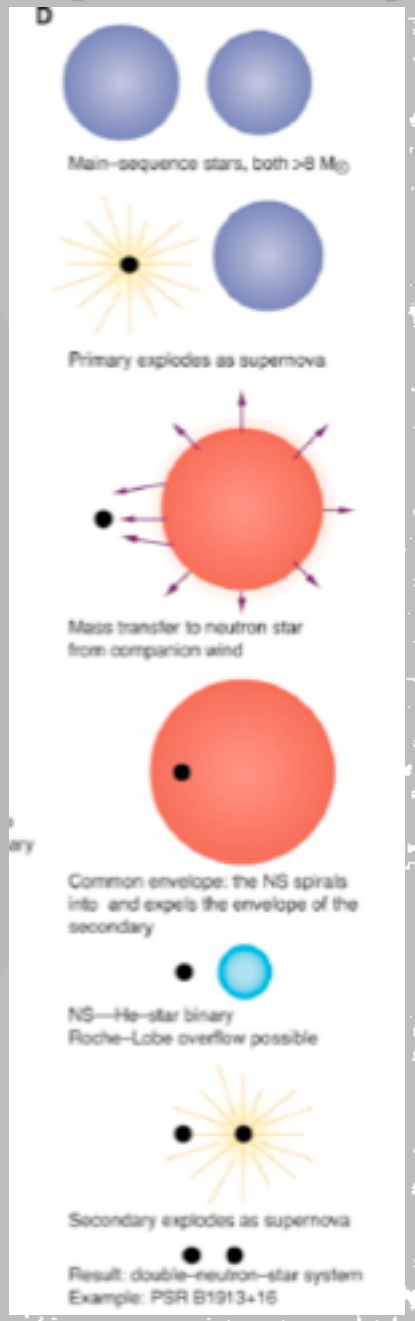
THANKS to Lynch's talk

72 recycled in binaries
60 recycled isolated
6 recycled unclassified
6 not (?) or very mildly recycled

The big burst btw 2000-2005

The power of a larger sample:
CONSTRAINS proposed MODELS
UNVEILS previously missing LINKS
FACES with NEW SPECIES

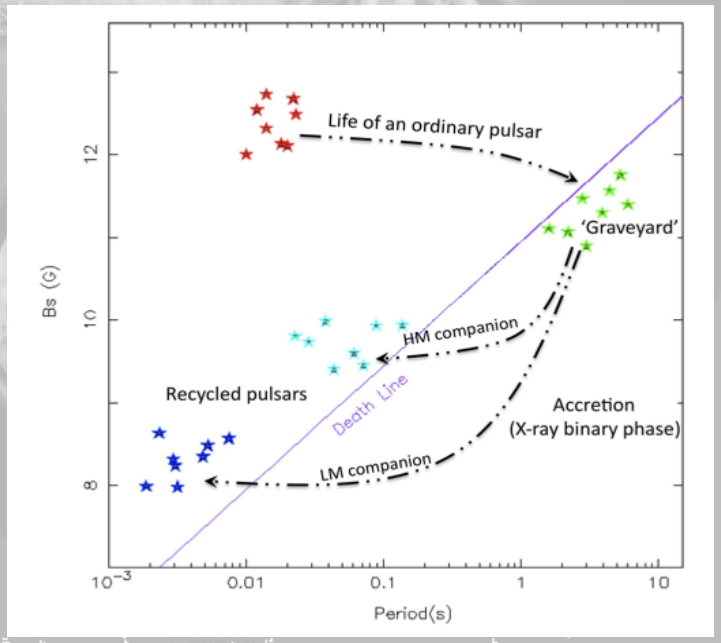
[@ Stairs 2004]



E.g. that happened during past decade - after discoveries of few Double Neutron Stars, e.g. the Double Pulsar [Burgay et al 2003; Lyne et al 2004] and J1906+0746 [Lorimer et al 2005] - for the class of the HIGH MASS BINARY PULSARs (HMBPs)

- van den Heuvel & DeLoore 1975
- Piran & Shaviv 2005
- Podsiadlowski et al 2005
- Willems et al 2005
- van den Heuvel
- Willems et al 2006
- Stairs 2006
- Dewi 201
- ven den Heuvel 2010
- Oslowski et al 2011
- Farr et al 2011
- Belczynski et al 2010, 2011, 2012

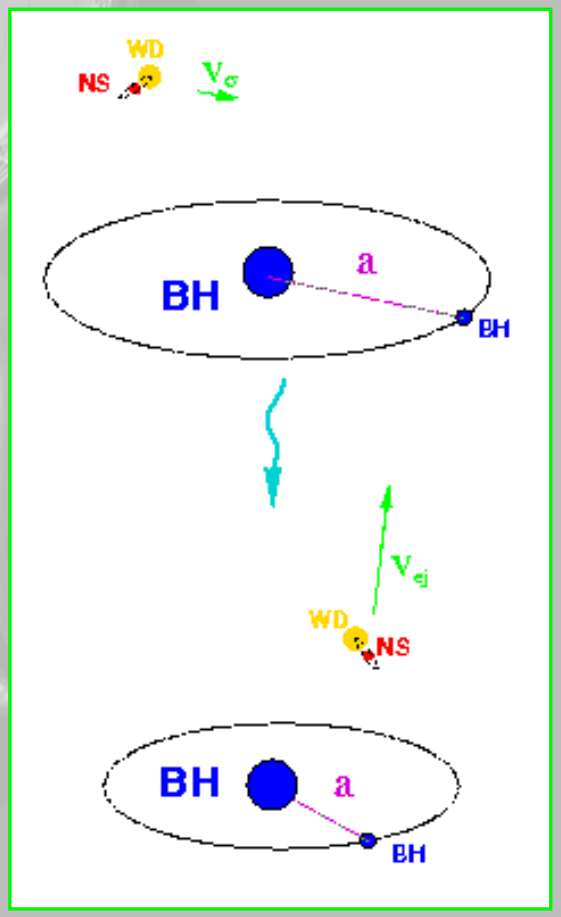
+ ...



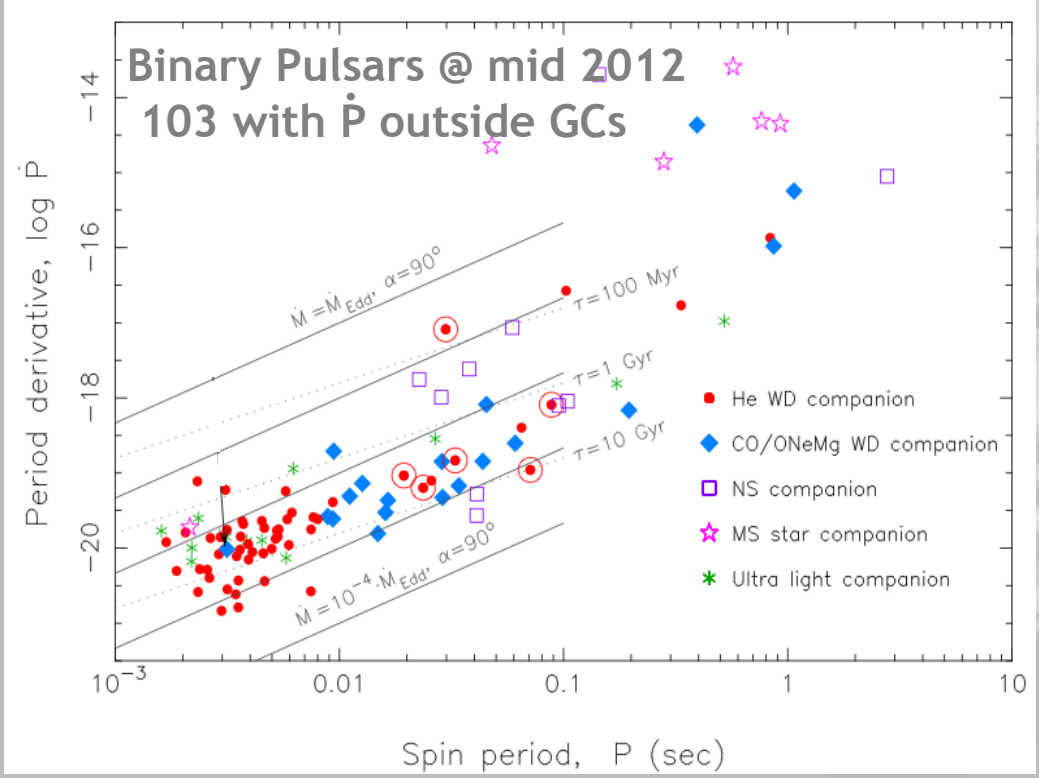
Similarly - in the past decade - for the class of the RECYCLED PULSARs in GLOBULAR CLUSTER characterized by a unique interplay between phases of evolution of the binaries in isolation and evolution driven (if not dominated) by dynamical encounters

- Rasio et al 2000
- Podsjadlowski et al 2002
- Sepinski et al 2002
- Fregeau et al 2003, 2004
- King, Davies & Beer 2003
- van der Sluys 2004
- Ivanova 2005
- Willems & Kolb 2005
- King at al 2005
- De Vecchi et al 2007
- Ivanova 2009
- Hui, Cheng, Taam 2010
- Lynch et al 2012
- + ...

SEE
Ransom's talk
Freire's talk



Expected a re-flourishing, in next years, of the studies about the
LOW MASS BINARY PULSARs (LMBPs)
INTERMEDIATE MASS BINARY PULSARs (IMBPs)
as well as the
VERY LOW MASS BINARY PULSARS (VLMBPs)
FULLY RECYCLED ISOLATED PULSARs
+ additional classes linked to those above



[from Tauris, Langer, Kramer 2012]

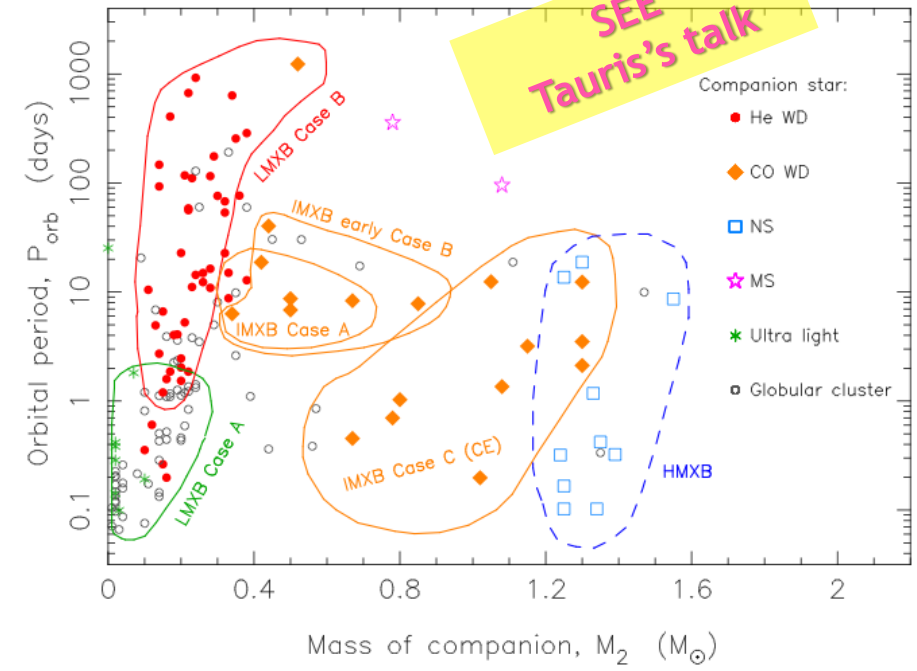
In this perspective - and also from the point of view of an observer - I have appreciated a lot the very recent attempt by Tauris et al. to systematize the current knowledge about evolution of LMBPs and IMBPs

Finding Charts for the nature of a pulsar companion

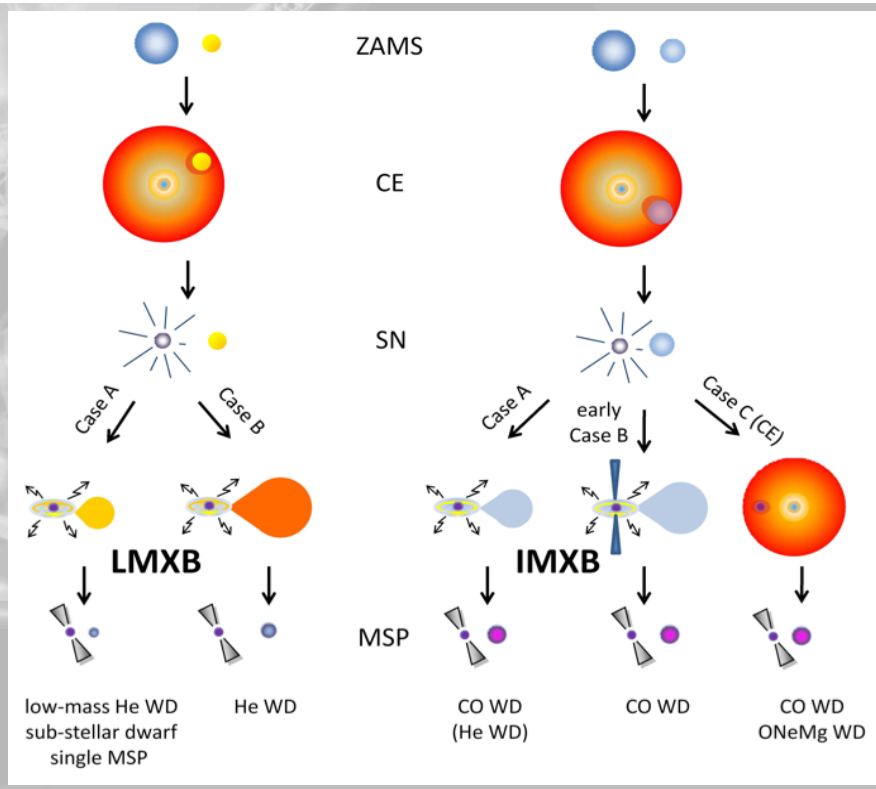
Companion type	Conditions								
MS	$M_2^\star > 0.5\ M_\odot$	and	$P_{\rm orb} > 50^{\rm d}$						
NS			$P_{\rm orb} < 50^{\rm d}$	and	$ecc > 0.05$				
CO	$M_2^\star > 0.335\ M_\odot$	and	$P_{\rm orb} < 75^{\rm d}$	and	$ecc < 0.05$	and	$P > 8$ ms		
He	$M_2^\star > 0.08\ M_\odot$	and	$\{(P_{\rm orb} < 75^{\rm d}$	and	$M_2^\star < 0.335\ M_\odot)$	or	$(P_{\rm orb} > 75^{\rm d}$	and	$M_2^\star < 0.46\ M_\odot)\}$
*UL***	$M_2^\star < 0.08\ M_\odot$								

* The median companion mass M_2 is calculated for an orbital inclination angle $i = 60°$ and an assumed pulsar mass $M_{\rm NS} = 1.35\ M_\odot$.
** Many pulsars with unmeasured values of a_1 are also expected to host an ultra-light companion if $P_{\rm orb} < 2$ days and $P < 8$ ms.

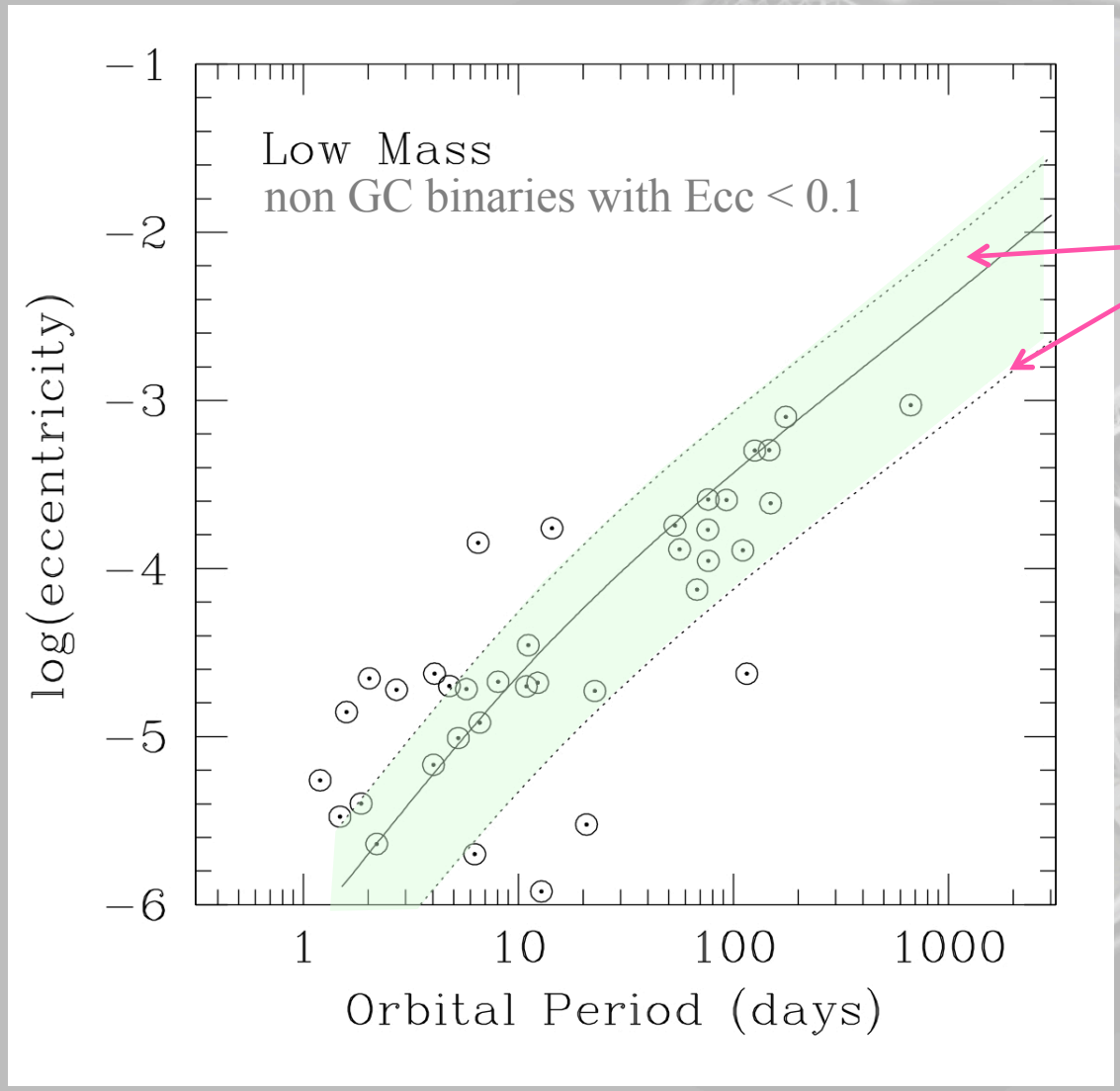
SEE Tauris's talk



[Tauris 2011; Tauris, Langer, Kramer 2012]



The “classic tests” of the evolutionary picture for LMBPs: Eccentricity vs Orbital Period



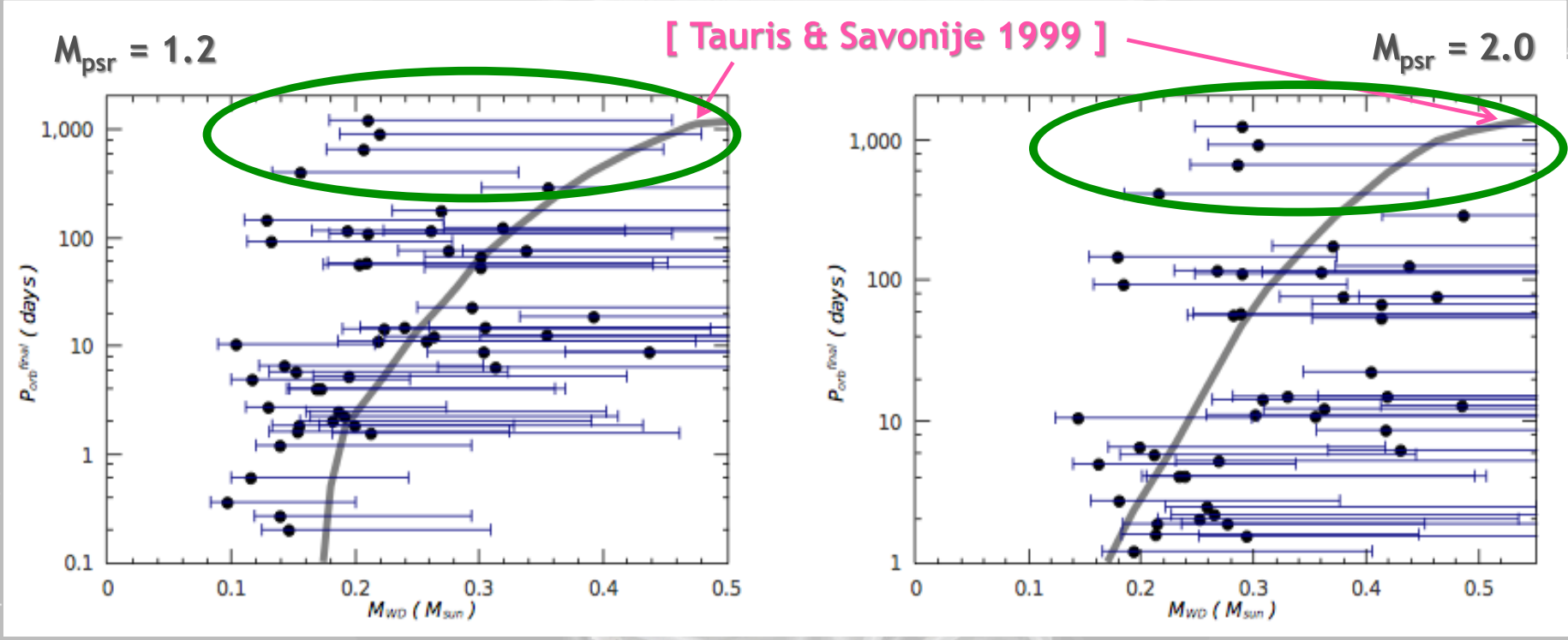
[Phinney & Kulkarni, 1994]

27 over 36 LMBPs ok with prediction

⊙ **LMBP with He-WD companion**

[adapted from Burgay et al, 2012, subm]

The “classic tests” of the evolutionary picture for LMBPs: Orbital Period vs Companion Mass for He-WD companions

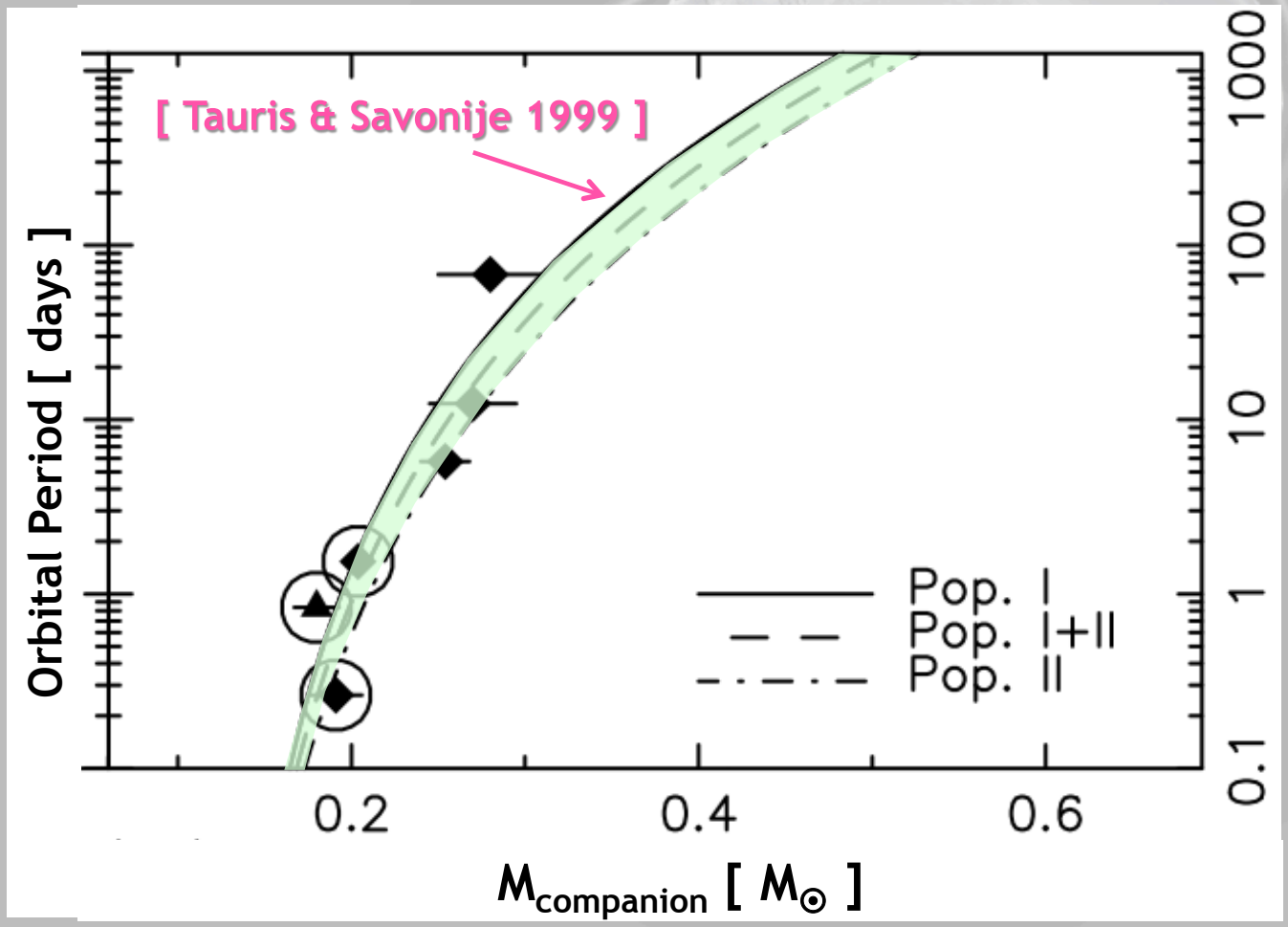


[Shao & Li 2012]

The effect of a high Pulsar mass might account for the very wide systems

However, the M_{wd} are estimated on a statistical basis, suffering of very large error bars

The "classic tests" of the evolutionary picture for LMBPs: Orbital Period vs Companion Mass for He-WD companions



[Corongiu, Possenti et al 2012, subm]

A more constraining test

The **6 LMBPs** for which the **Companion Mass** has been determined using the measurement of the **Shapiro delay**

Hottest targets, unveiled links, open questions & new ideas: a (personal) selection

1. J1023+0038 : the long sought link btw LMXPs and the largest family of LMBPs (those with a HeWD companion) ?

[Archibald et al 2009, Zhang et al 2009]

Parameter	Value
Right ascension (α; J2000)	$10^h23^m47.687(3)^s$
Declination (δ; J2000)	$00°38'41.15(7)''$
Proper motion in α (μ_α)	10(1) mas yr^{-1}
Proper motion in δ (μ_δ)	$-16(2)$ mas yr^{-1}
Epoch (MJD)	54802
Dispersion Measure	14.325(10) pc cm^{-3}
Pulsar period (P)	1.6879874440059(4) ms
Pulsar period derivative ($\dot{P}$)	$1.2(8) \times 10^{-20}$
Orbital period (P_b)	0.1980962019(6) d
Orbital period derivative ($\dot{P}_b$)	$2.5(4) \times 10^{-10}$
Orbital period second derivative ($\ddot{P}_b$)	$-5.21(14) \times 10^{-11}$ s^{-1}
Time of ascending node (MJD)	54801.97065348(9)
$a \sin i$	0.3433494(3) lt-s
Eccentricity	$\lesssim 2 \times 10^{-5}$

A 1.69-ms MSP in a 4.75-hr circular orbit with a ≈0.25 $M_\odot$ MS companion, displaying extended radio eclipses, X-ray orbital modulation and gamma-ray emission and showing to have had an accretion disk until around 2001

[Archibald et al 2010: Tam et al 2010; Bogdanov et al 2011]

VLBA parallax implies a distance of d = 1370±40 pc, whence a

M_{psr} = 1.71±0.16 $M_\odot$

a smaller dP/dt and so a revised

$dE_{rot}/dt = 4.3 \times 10^{34}$ erg/s

$B_{surf} = 9.6 \times 10^7$ G

$T_{sd} = 5.0 \times 10^9$ yrs

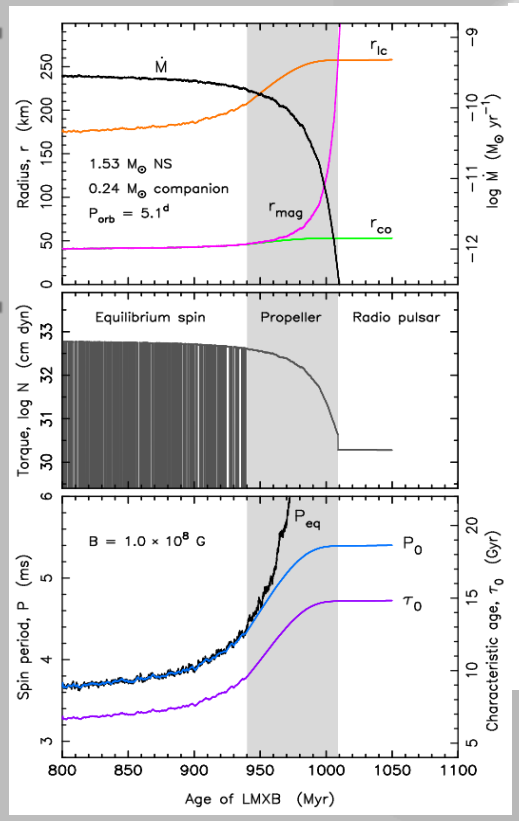
[Deller et al 2012]

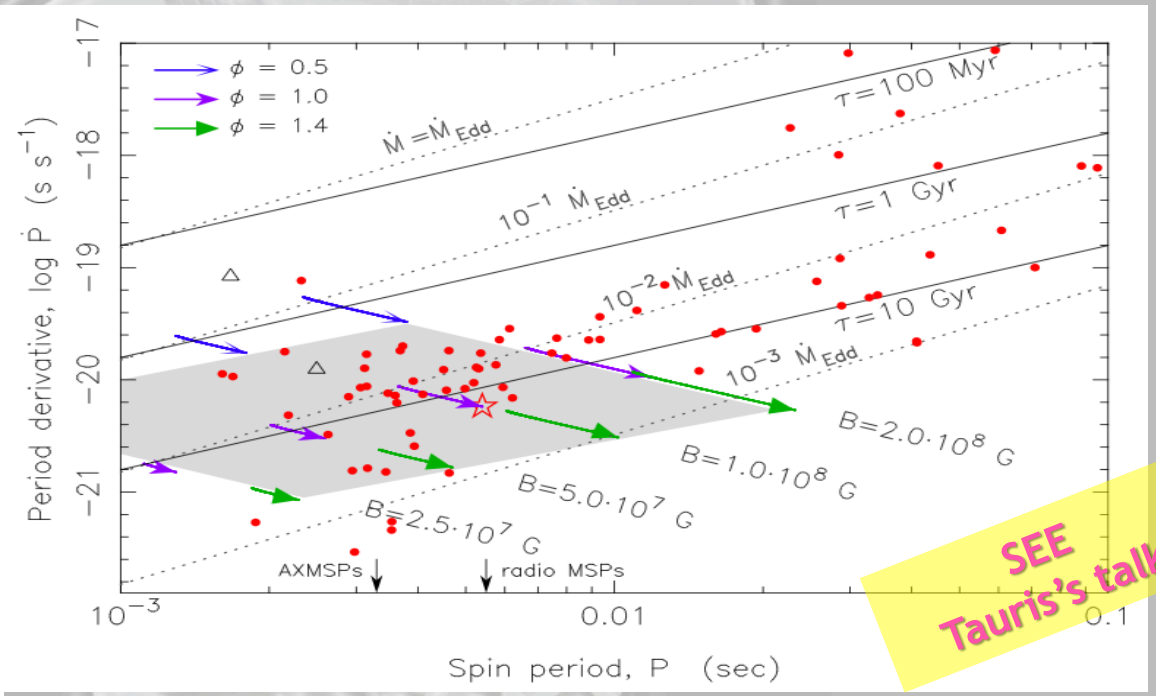
SEE Roberts's talk

IMPROVED MODELING of last stages of the recycling with emphasis on the interaction btw the pulsar wind and the matter lost by the companion

2. The spin discrepancy btw Accreting X-ray Millisecond Pulsars (AXMSPs) and MSPs: reconciled via Propeller effect (besides other options) ?

[Tauris 2012]





SEE Tauris's talk

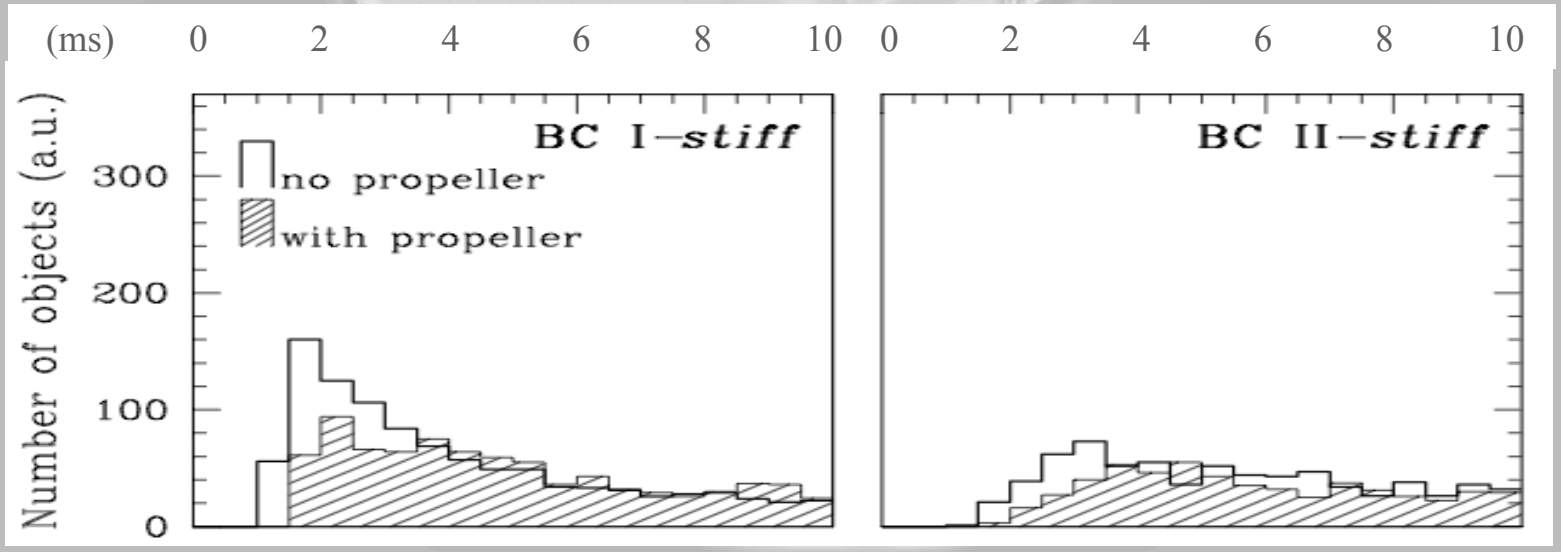
< P_{AXMSP} > = 3.3 ms < P_{MSP} > = 5.5 ms

P.S. Be careful - even more than before - when considering spin-down age of the MSPs

now needed full population simulations...

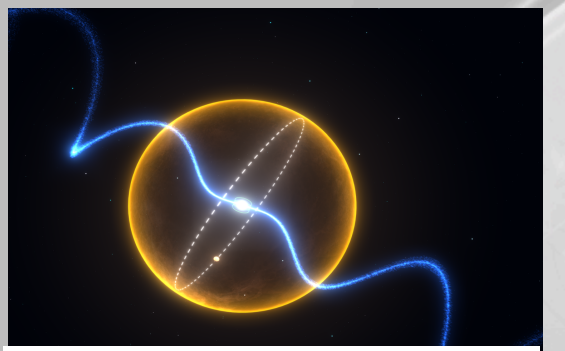
SEE Lorimer's talk

Old attempts - with much less physics than Tauris 2012 - indicate that propeller can really produce average slow down of one ➔few millisec over the population



[Possenti et al 1999]

3. J1719-1438 & the new population of the ULTRA LOW MASS BINARY PULSARs (ULMBPs): the previously missing descendants of the Ultra Compact Accreting X-ray Millisecond Pulsars (UC-AXMSPs) ?



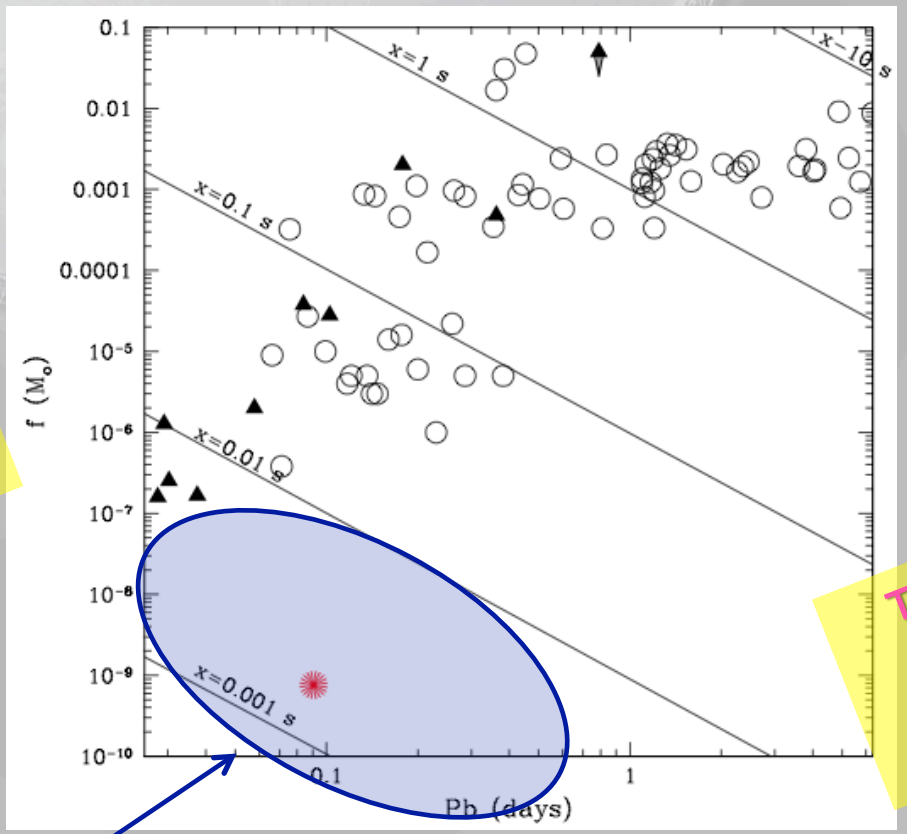
Parameter	Value
Right Ascension (J2000) (hh:mm:ss)	17:19:10.0730(1)
Declination (J2000) (dd:mm:ss)	−14:38:00.96(2)
ν (s^{-1})	172.70704459860(3) Hz
$\dot{\nu}$ (s^{-2})	$-2.2(2)\times10^{-16}$
Period Epoch (MJD)	55411.0
DM (pc cm^{-3})	36.766(2)
P_b (d)	0.09070623[illegible]
$a_p \sin i$ (lt-s)	0.[illegible]
T_0 (MJD)	55235.5165243[illegible]
e	< 0.0[illegible]
Data Span (MJD)	5[illegible]–55586
Weighted RMS residual (μs)	15
Points in fit	343
Mean 0.73 GHz Flux Density (mJy)	0.8*
Mean 1.4 GHz Flux Density (mJy)	0.2
Derived parameters	
Characteristic Age (Gyr)	>12.5
B (G)	$<2\times10^{8}$
Dispersion Measure Distance (kpc)	1.2 (3)
Spin-down Luminosity $L_\odot$	<0.40(4)

* Derived from a single observation.

$$\bar{\rho}(g\ cm^{-3})\ (\text{inferred}) \geq 23$$

REMEMBER Ng's talk

[Bailes et al 2011]



AXMSP

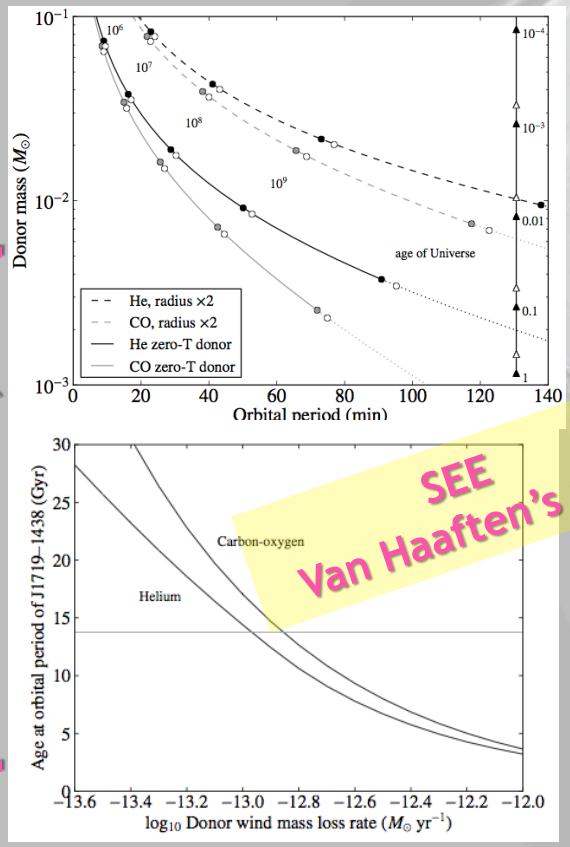
BIN-PSR

THANKS to Ng's talk Lynch's talk 2 new objects

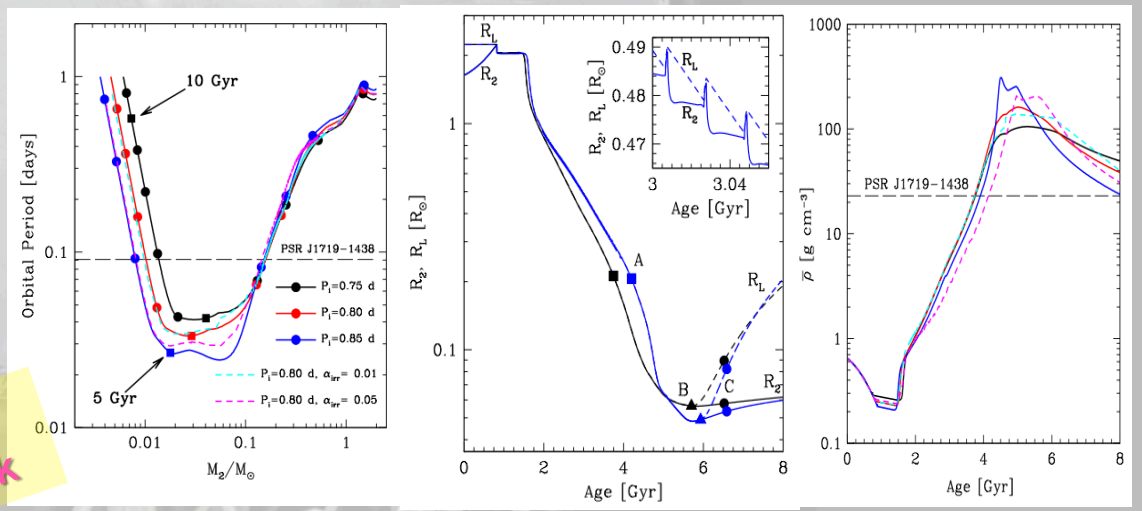
Jovian-like mass companions for ULMBPs

Indeed, detailed studies revealed that some additional ingredient (e.g. a combination of wind mass loss and expansion of the donor) is necessary, but confirm that the most likely evolutionary path is formation of the system from an UC-AXMSPs

[van Haaften et al, 2012]



SEE Van Haaften's talk

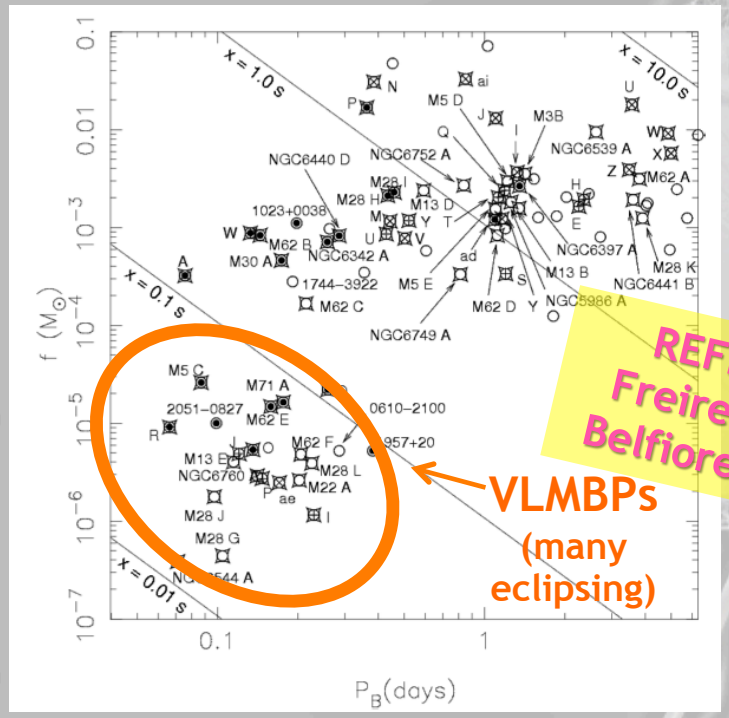


[Benvenuto & De Vito 2012, subm]

REMEMBER Weber's talk

Unless we want to speculate on a completely new species... a STRANGE QUARK MATTER NUGGETS orbiting a QUARK MATTER PULSAR [Horvath 2012]

4. ISOLATED RECYCLED PULSARs : are they descendants of Very Low Mass Binary Pulsars (VLMBPs) and ULMBPs ?

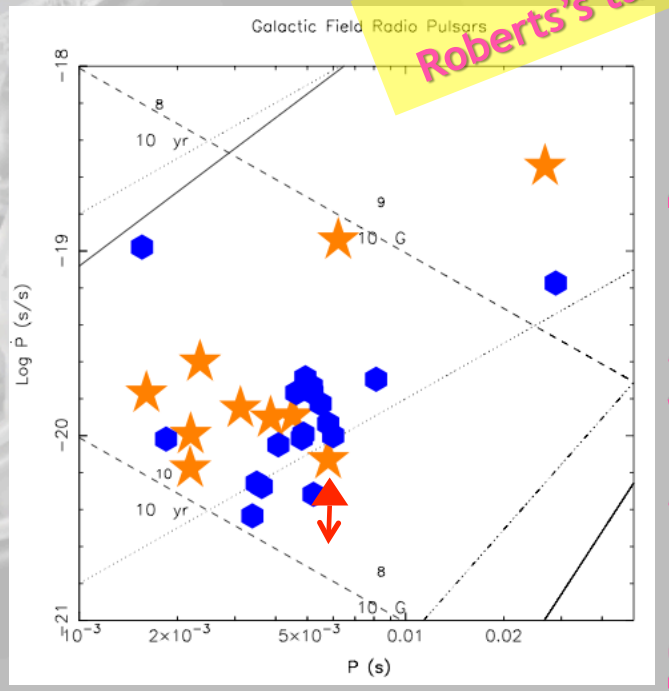


[© P. Freire]

Until recently, VLMBPs were mostly found in GCs, where the formation of Isolated Pulsars can easily occur via ionization of a binary following a dynamical encounter

REFER to Freire's talk Belfiore's talk

SEE Roberts's talk



[Possenti et al, in prep]

The blossom of discoveries of VLMBPs / ULMBPs and Isolated Recycled Pulsars in the Galactic field starts enabling a direct comparison of the two populations, searching for relationships

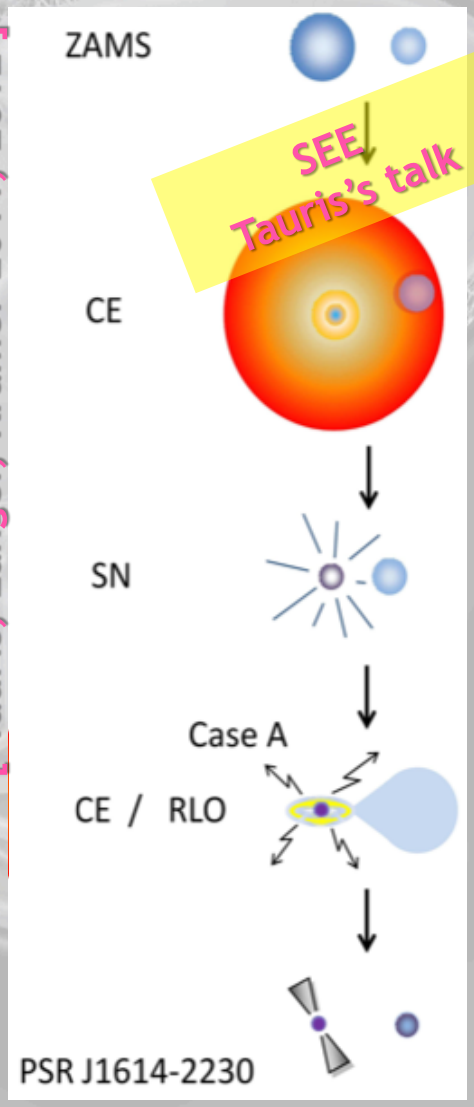
P.S. Also important to carefully check for Ultra light comp to claimed Isolated Recycled psrs

5. J1614-2230 : a new evolutionary path (case A RLO) for Intermediate Mass Binary Pulsars (IMBPs) ?

Parameter	value
Pulsar mass	$1.97 \pm 0.04\ M_\odot$
White dwarf mass	$0.500 \pm 0.006\ M_\odot$
Orbital period	8.6866194196(2) days
Projected pulsar semimajor axis	11.2911975 light sec
Orbital eccentricity	$1.30 \pm 0.04 \times 10^{-6}$
Inclination angle	89.17 ± 0.02 deg.
Dispersion-derived distance	1.2 kpc
Pulsar spin period	3.1508076534271 ms
Period derivative	9.6216×10^{-21}

[Demorest et al. 2010]

[Tauris, Langer, Kramer 2011, 2012]



The most likely pulsar mass at birth was $1.7 \pm 0.15\ M_\odot$

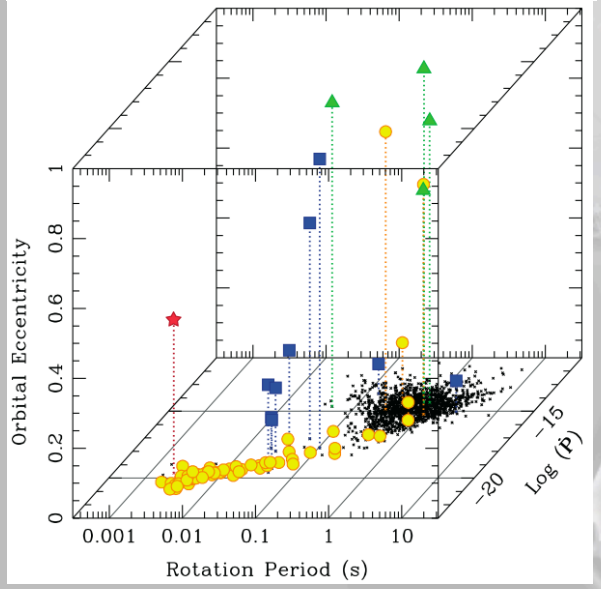
SEE Nice's talk

See also [Lin et al. 2011] and [Bhalerao & Kulkarni 2011] for alternate scenarios

6. J1903+0327: paving the way to play with triples ?

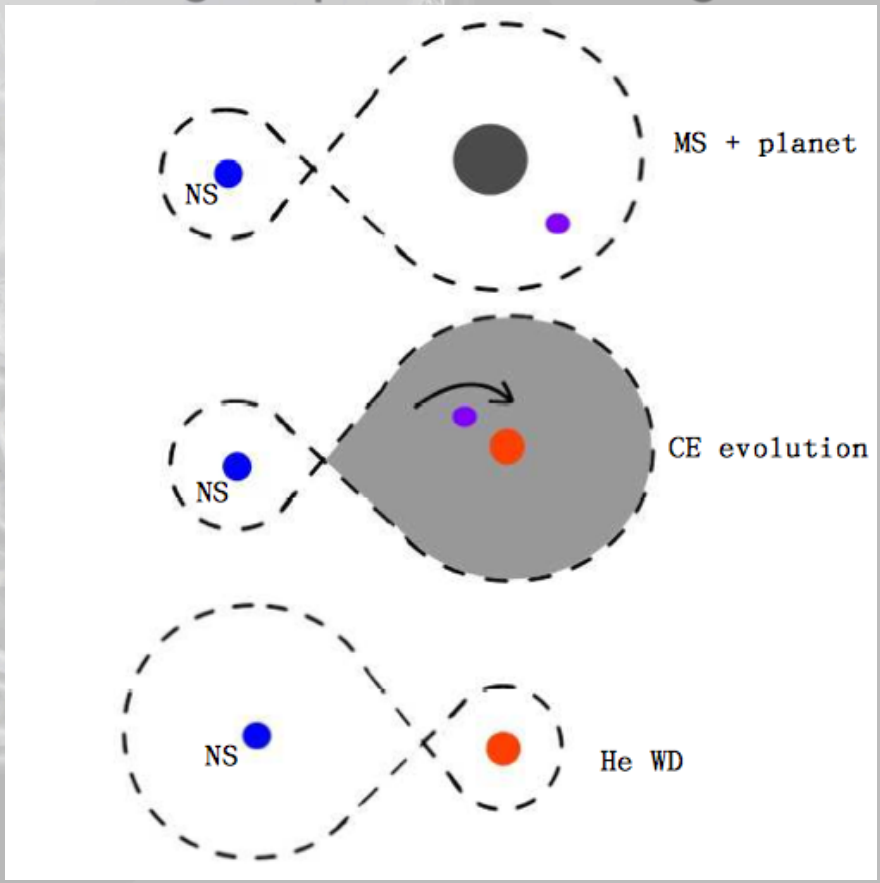
Derived Parameters

Spin Period, P (ms)	2.14991236434921(7)
First Derivative of Spin Period, $\dot{P}$ (10^{-20}ss^{-1})	1.88203(11)
Characteristic Age, τ_c (10^9 yr)	1.9
Dipolar Magnetic Flux Density at the Poles, B_0 (10^8G)	2.0
Galactic Longitude, l	37°.3363
Galactic Latitude, b	−1°.0136
Distance, D (kpc)	6.4 ± 1.0
Total Proper Motion, μ (mas yr^{-1})	5.60(11)
Galactic Position Angle of Proper Motion, Θ_μ	$263.9 \pm 0.8°$
Velocities, Solar System Barycentre Reference Frame	
Transverse velocity, V_T (km s^{-1})	168 ± 24
Radial velocity, γ (km s^{-1})	42.0 ± 4.4
Total 3-D velocity, V (km s^{-1})	174 ± 25
Velocities, Galactocentric Reference Frame (cylindrical)	
V_ρ (km s^{-1})	17 ± 13
V_ϕ (km s^{-1})	-189 ± 5
V_z (km s^{-1})	-11 ± 4
Total 3-D velocity, V (km s^{-1})	190 ± 5
Velocities, Relative to Pulsar Standard of Rest (cylindrical)	
V_ϕ (km s^{-1})	28 ± 5
Total 3-D velocity, V (km s^{-1})	37 ± 9
Derived Masses and Orbital Orientation	
Mass Function, f ($M_\odot$)	0.139558441(2)
Orbital Inclination, i (°)	77.47(15) or 102.53(15)
Total Mass of Binary, M_t ($M_\odot$)	2.697(29)[b]
Companion Mass, m_c ($M_\odot$)	1.029(8)[b]
Pulsar Mass, m_p ($M_\odot$)	1.667(21)[b]



[Champion et al 2008]

Maybe wrong, but nice idea: since planets seem ubiquitous, why not entering the pulsar evolution game...



[Shao & Li 2012]

See also [Freire et al 2011; Portegies-Zwart et al 2011; Khargaria et al 2012; Bejger et al 2012; Pijloo et al 2012]

7. The triple binary in the Galactic field: a wonderful gym for evolutionary and dynamical studies !

REMEMBER Lazarus's talk

8. The case of the RED BACKs: not anymore only in Globular Cluster ?

SEE Roberts's talk

9. The missing mass : is radio-ejection (see [Ruderman et al 1989, Burderi et al. 2001, 2002]) the primary responsible for getting rid of the excess transferred mass in a LMXB ?

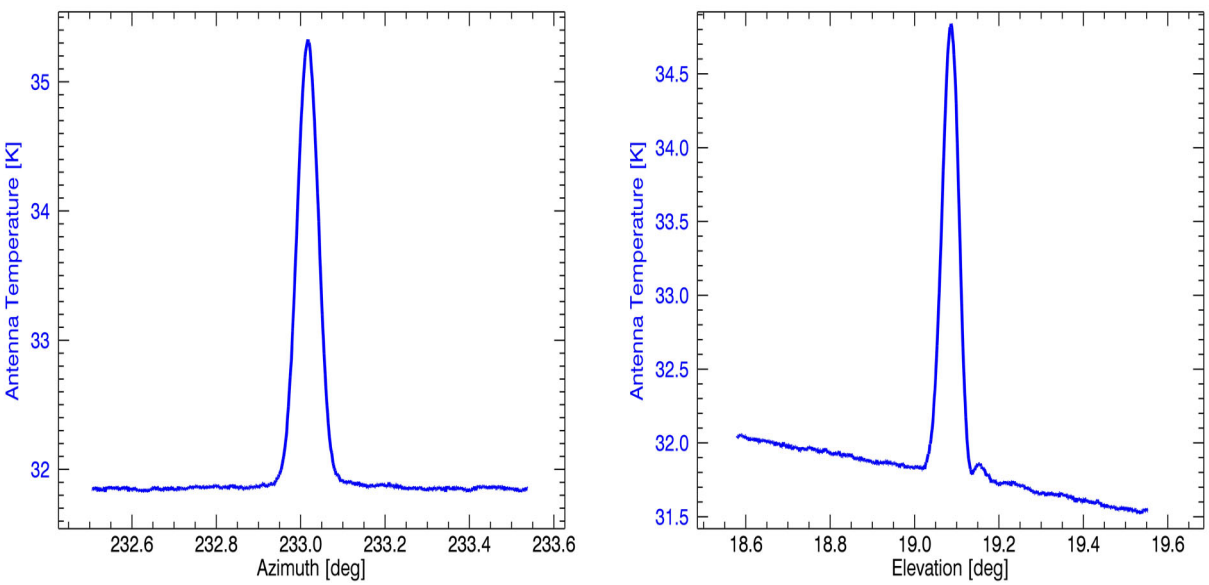
10. The missing AXMSPs : why no AXMSP with orbital period longer than 1 day ? Are they progenitor of only one specific subclass of the MSPs ?

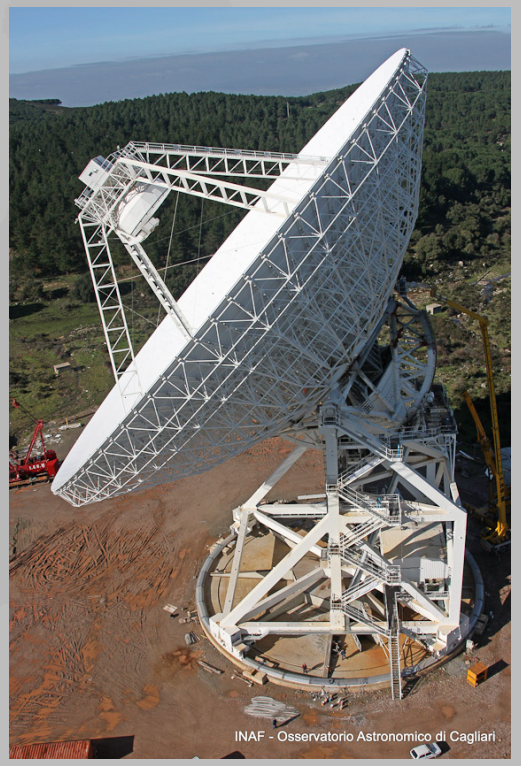
11. ...

Sorry for a last slide advertisement, about...

SRT - Sardinia Radio Telescope, 64m active-surface single-dish, operating from 0.3 GHz to 110 GHz

SRT had its “first wave” on 8 Aug 2012





Shared-risk open calls in ≈1 year ... Stay tuned !

Thank you !

Thank you !