Evolution of relativistic binary systems

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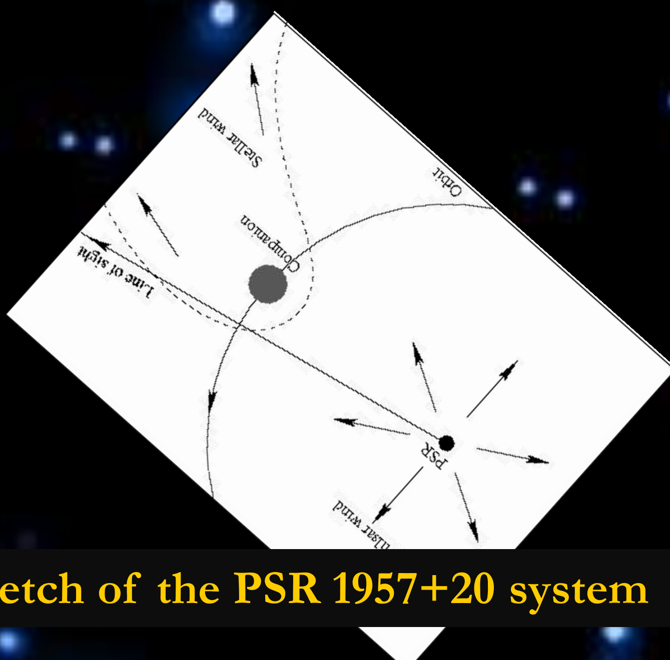
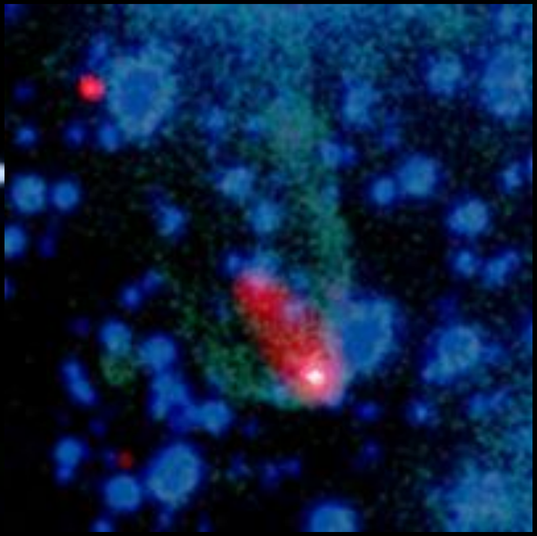
1982: Backer et al. discovered the first member of the *ms* pulsar class recycling scenarios

1988: Fruchter, Stinebring & Taylor (Nature 333, 237, 1988) found an eclipsing pulsar with a very low mass companion, the hypothesis of ablation wind quickly followed

Black widow



Original sketch of the PSR 1957+20 system



Composite Image from *Chandra* (2012)

Latest members of the spider family:

PSR J1719-1438 (Bailes et al., Science 333, 1717, 2011)
Extremely low mass companion, yet high mean density
$\rho > 23$ g cm^{-3} for it
(Benvenuto, De Vito & Horvath ApJLett 753, L33, 2012)

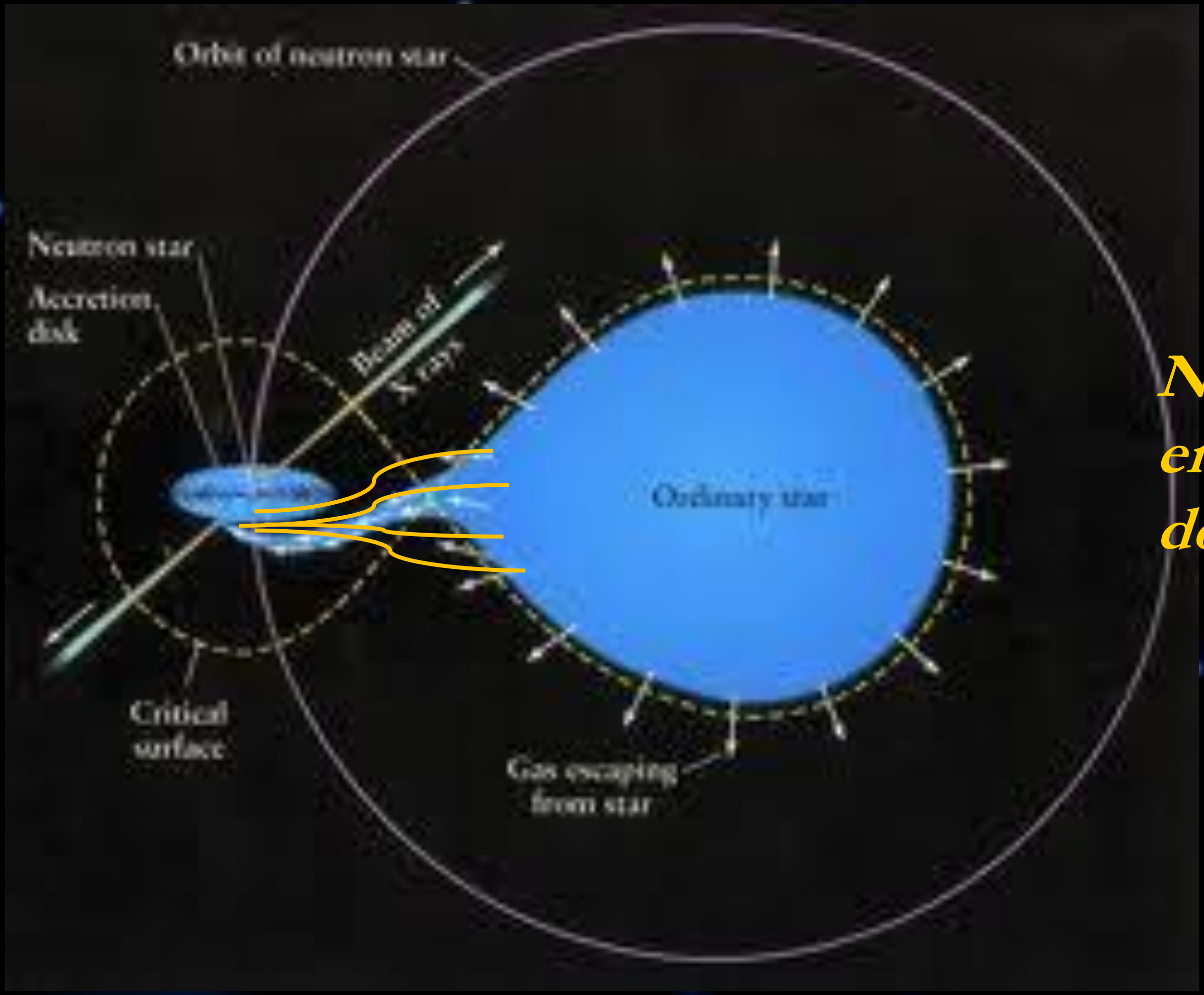
PSR J1311-3430 (Romani et al. , ApJ 760, L36, 2012)
similar system, but with extremely low hydrogen
abundance for the donor $n_H < 10^{-5}$

(Benvenuto, De Vito & Horvath MNRASLett 433, L11, 2013)

“Redback” pulsars

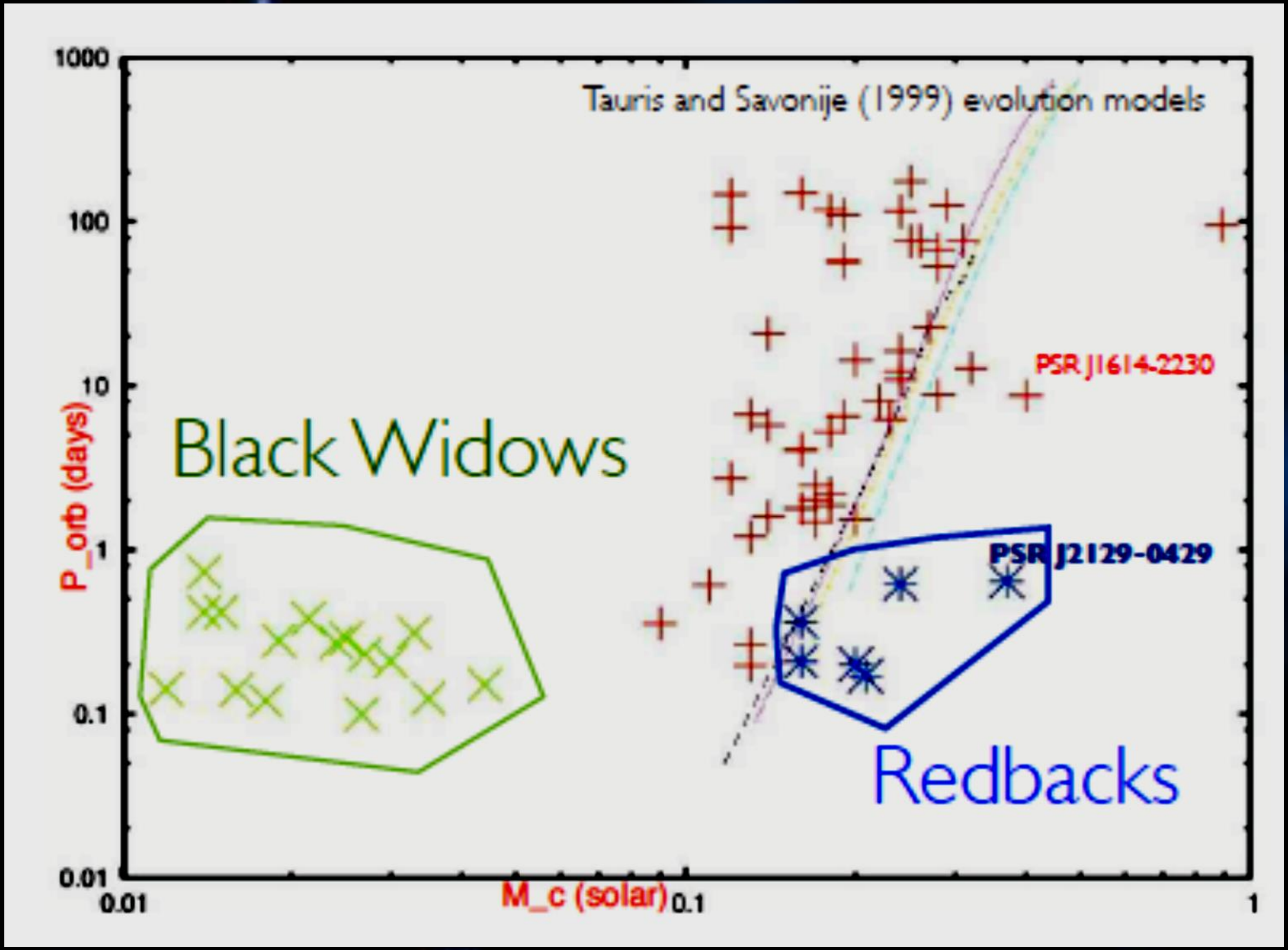
Australian redback

Eclipsing , $M_2 \sim 0.3\ M_o$, P ~hours



X-ray irradiated

Non-linear feedback energy flow from the donor interior



M. Roberts, arXiv:1210.6903

How are these ultra-compact systems formed?

(Benvenuto, De Vito & Horvath ApJL 753, L33, 2012, ApJLett 2014)

M_1 *primary (NS)* ; M_2 *secondary (donor)*

Onset of Roche Lobe Overflow (RLOF) , Paczynski

$$R_L = 0.46224\, a \left(\frac{M_2}{M_1 + M_2} \right)^{1/3}$$

$$\dot{M}_1 = -\beta \dot{M}_2$$

Accreted by the NS, always <

$$\dot{M}_{Edd} = 2 \times 10^{-8}\ M_{\odot}\ yr^{-1}$$

In general, $\beta < 1$ and angular momentum is lost from the system. The exact value of β is not critical

Important new ingredients incorporated

Irradiation feedback

$$F_{irr} = \frac{\alpha_{irr}}{4\pi a^2}\frac{GM_1}{R_1}\dot{M}_1$$

(Bunning & Ritter, A&A 423, 281, 2004 Hameury)

Evaporating wind

$$\dot{M}_{2,evap} = -\frac{f}{2v_{2,esc}^2}L_P\left(\frac{R_2}{a}\right)^2$$

(Stevens et al., MNRAS 254, 19, 1992)

with

$$L_P = 4\pi^2 I_1 P_1^{-3}\ \dot{P}_1$$

All new effects incorporated into an adaptative Henyey code, solving simultaneously structure and orbital evolution (Benvenuto & De Vito, 2003 ; De Vito & Benvenuto, 2012)

(M_1, M_2, P_i) *must be in the "right" range to explain the observed systems*

If P_i is too short (< 0.5 d), the mass transfer would start at ZAMS

If P_i is too long (> 0.9 d), the orbit widens and a ~0.3 Mo

not the observed state !

If M_2 is too small, mass transfer would be > age universe

If M_2 is too high, mass transfer is unstable (Podsiadlowski et al)

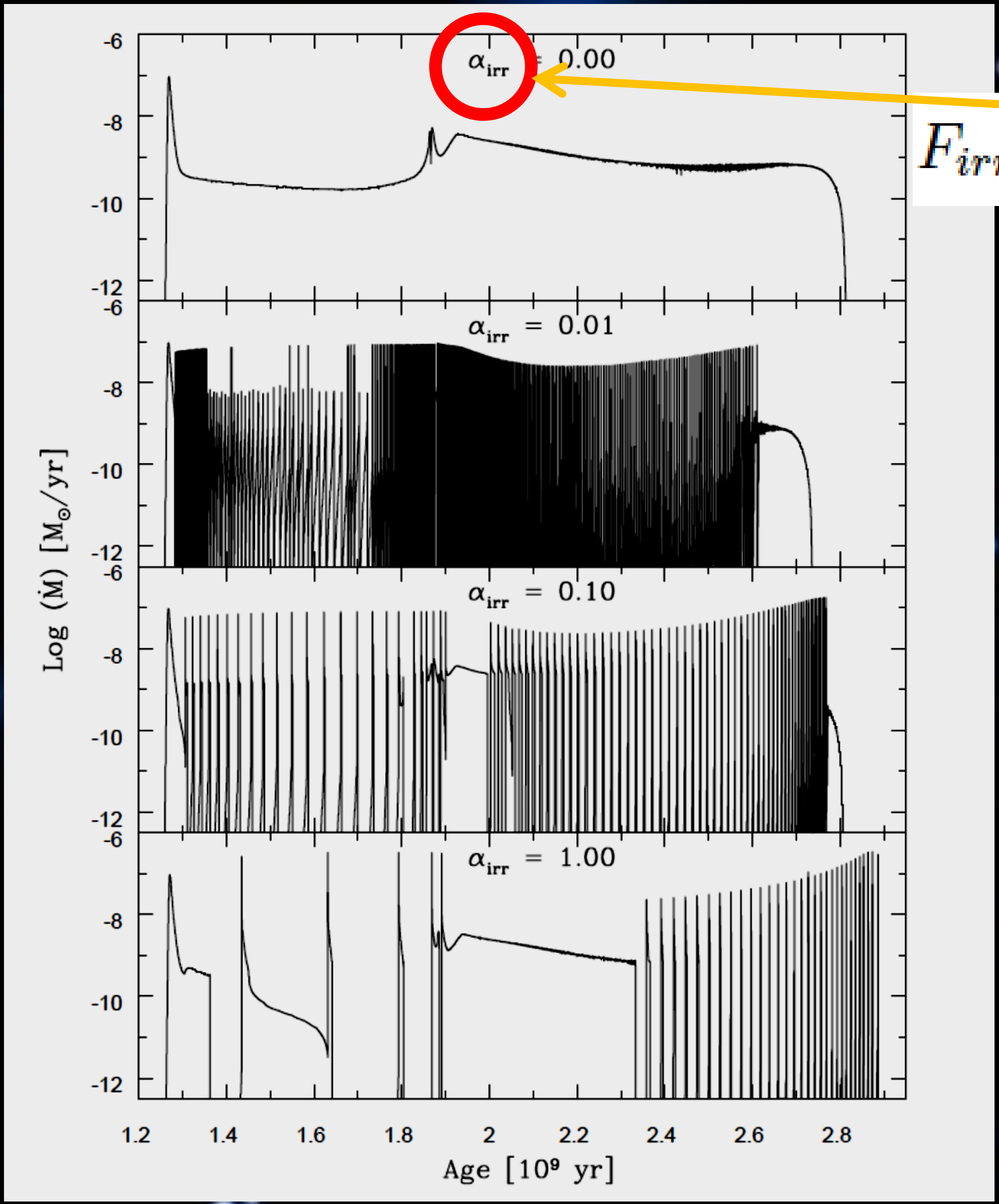
Started calculations right after the NS formation $M_2 = 2M_\odot$

CAVEAT !!!, just an hypothesis → $M_1 = 1.4M_\odot$

The system goes back and forth from accretion to detachment when the irradiation acts

Not a numerical instability, we called the ***quasi-RLOF state***

Radius of M_2 stays within 10% of the RLOF value

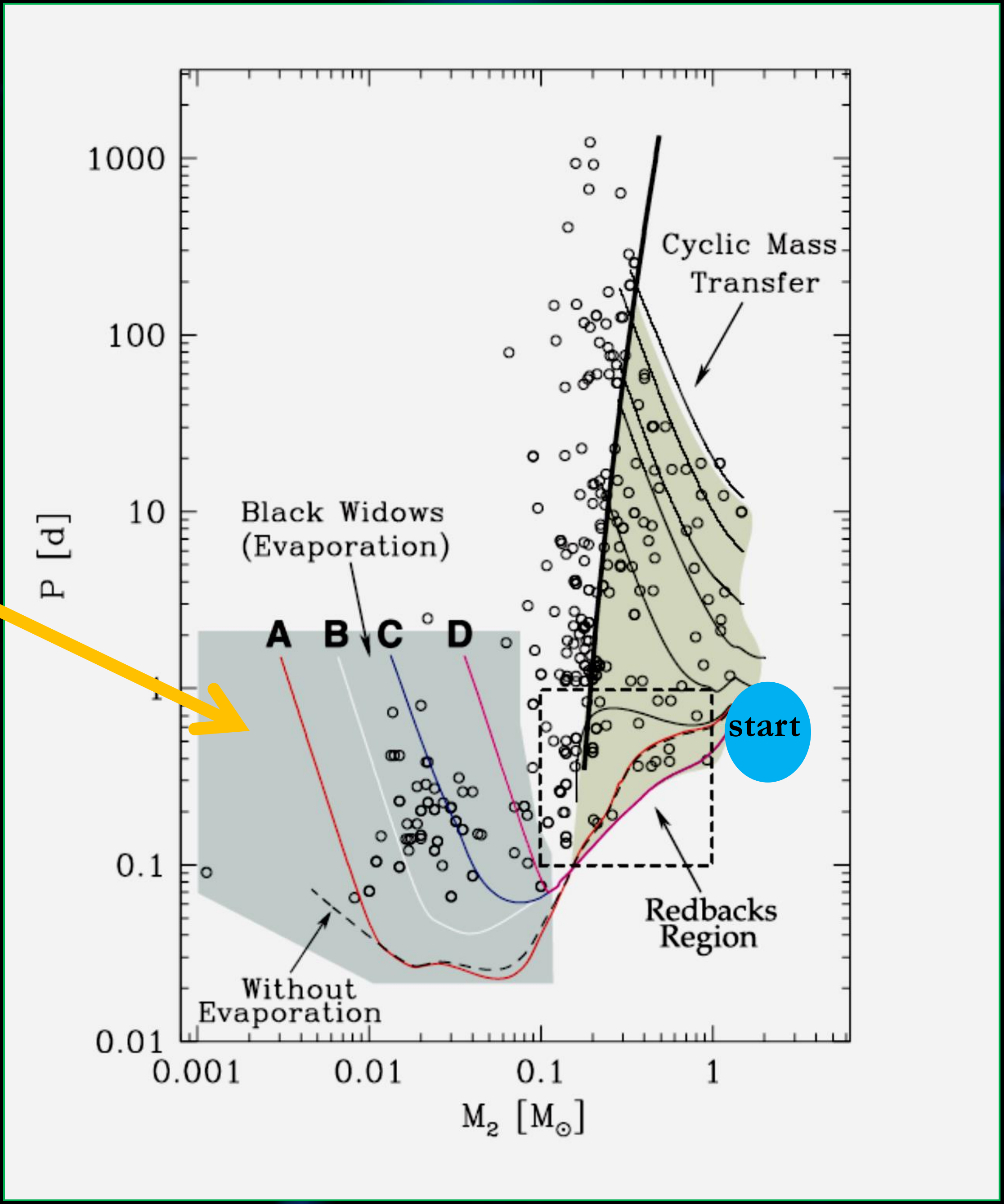


$$F_{irr} = \frac{\alpha_{irr}}{4\pi a^2} \frac{GM_1}{R_1} \dot{M}_1$$

Mass accretion as a function of time for several values of the illumination strength

The Big Picture

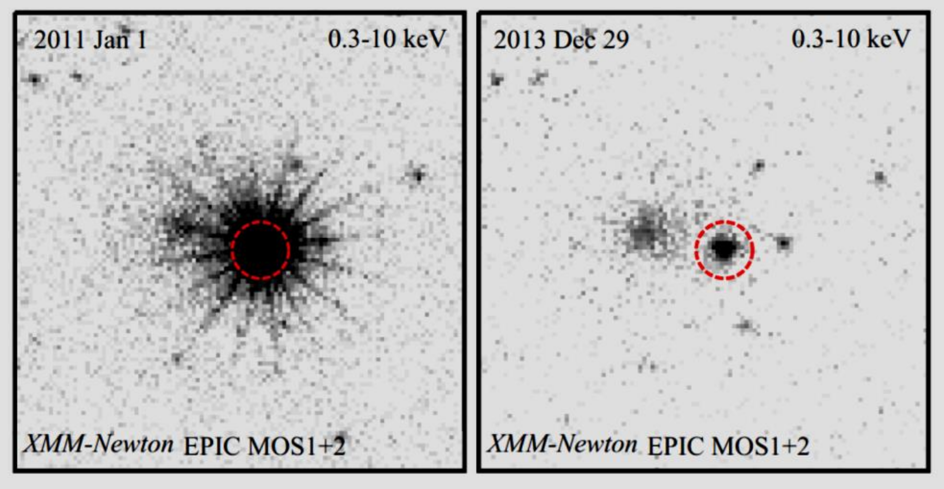
Trajectories bend upwards because the donor becomes degenerate and inflates when losing mass, orbit widens



Redbacks and the disappearance of the accretion disk

The case of IGR J18245–2452 (Papitto et al. Nature 501, 517 2013)

XSS J12270-4859 (Bogdanov et al. arXiv:1402.6324, submitted)



We suggest that this behavior is related to the oscillations driven by the quasi-RLOF state, although the specific disk instability remains to be identified

Redbacks are just the "low"state, eclipses are due to geometry related to the spatially extended quasi-RLOF state

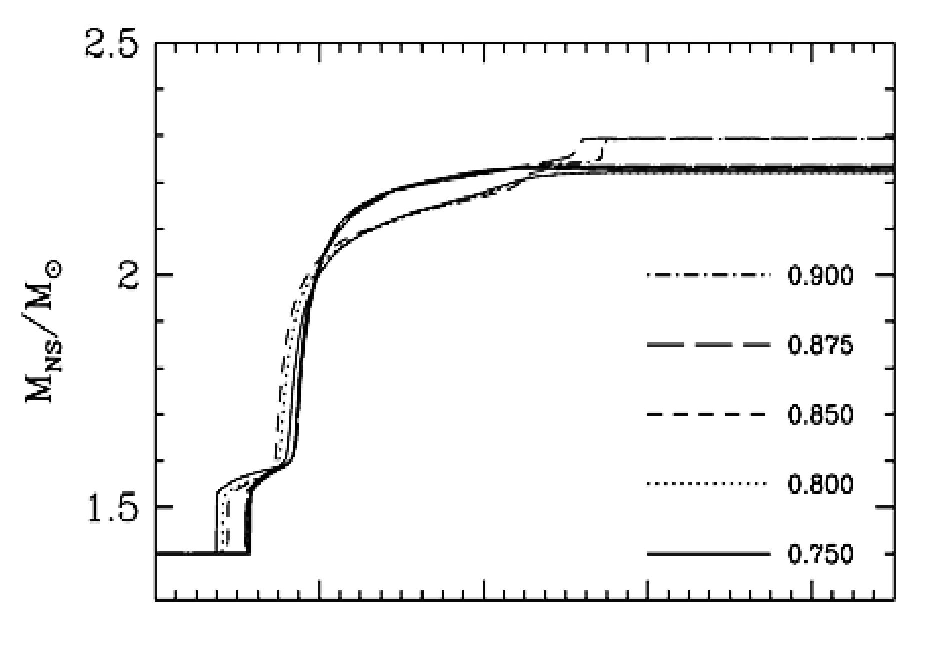
A last point about the masses…

The original "black widow" PSR 1957+20 (van Kerkwijk, Breton & Kulkarni, ApJ 728, 95, 2011)

$$M_{psr} = 2.4 \ \ +\text{-}\ 0.12\ M_O$$

Romani et al. (ApJ 760, L36, 2012) found three high values for the neutron star in PSR J1311-3430, depending on the interpretation

$M_{psr} > 2.1\ M_O$ up to ~ 3 M_O



- Self-consistent calculations of the PSR J1311-3430 system and related cases require such high mass values to reach the observed state

fixed accretion efficiency β of 50%

Conclusions

* Ultra-compact “black widow” pulsar systems result from a bifurcation in parameter space after a “redback” stage, in this sense they follow a new evolutionary path driven by irradiation+ evaporation

* The role of winds+irradiation is crucial : RLOF alone would not produce a black widow state. Because of their evolution, we can state that PSR masses emerging are consistently very large

* Redbacks are the progenitors of black widows, pop synthesis should reveal how many of them. The quasi-RLOF state should be related to the phenomenon of disk disappearance reported recently