An overview of close binary systems containing (massive) neutron stars: the intermittent accretion disc phenomenon

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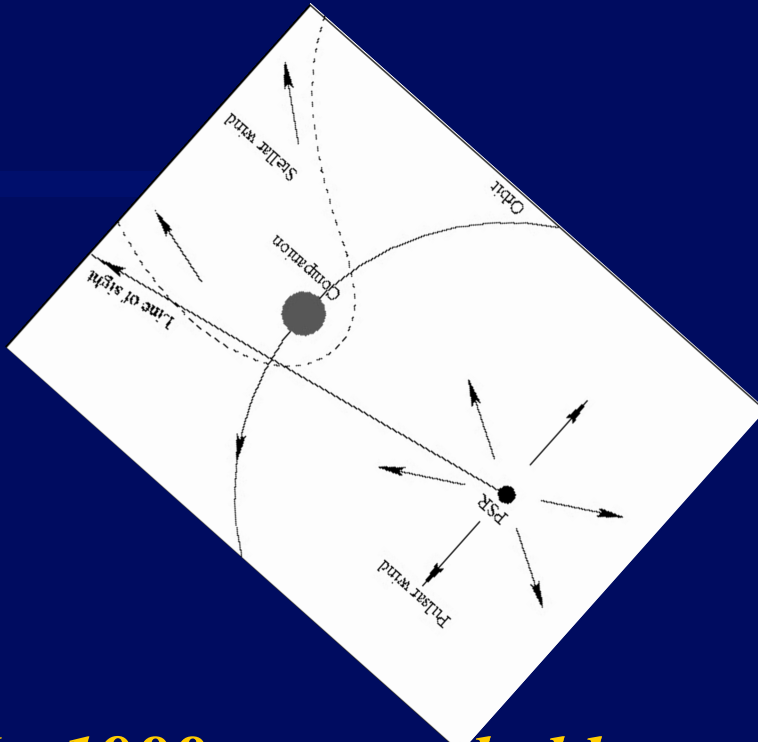
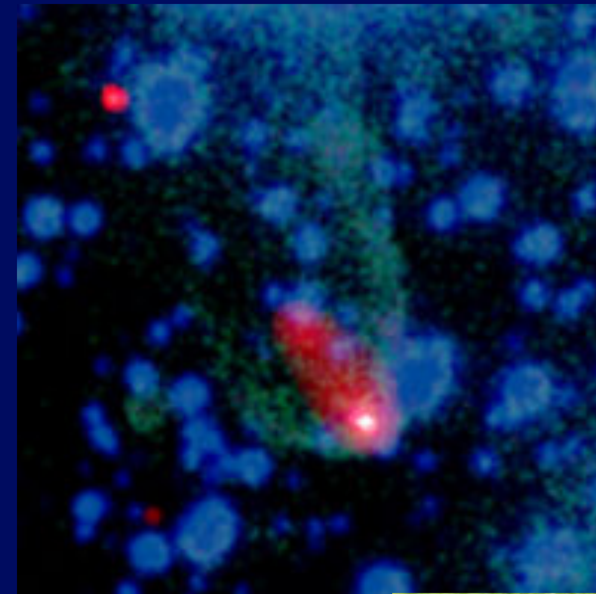
What are we talking about?



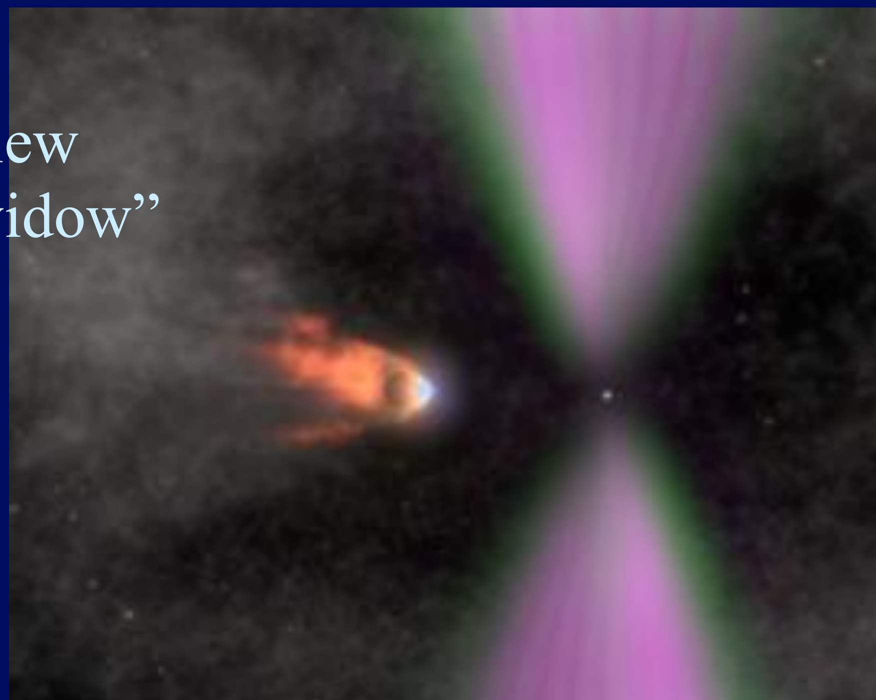


In 1988 a remarkable system was discovered, which seems to be evaporating

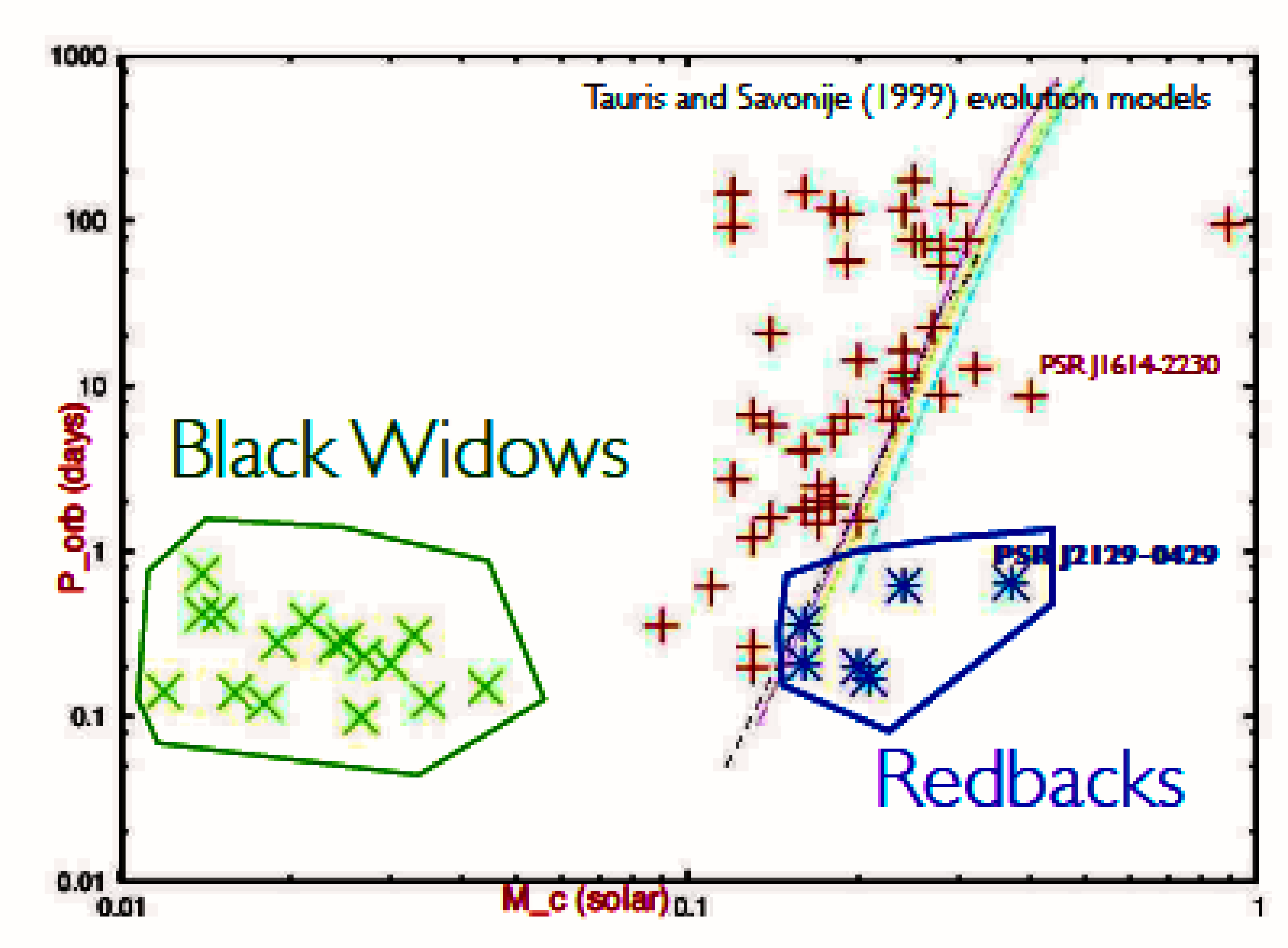
PSR 1957+20: irradiated surface by a recycled PSR, mass loss of the donor to the ISM (comet-like effect), termed "black widow" system, geometry expected in 1988 (left) and observed by Chandra and Hubble (2001)

Later, the australians discovered similar systems but in which there is no evaporation: because of their parenthood they named them "redbacks" (an australian spider…)

Artistic view of a "black widow" system



How a "black widow" system should look like: the companion is being evaporated after the PSR was recycled by accretion in the (redback) stage. These may give rise to isolated ms PSR if the evaporation is complete.



M. Roberts, arXiv:1210.6903

Evolution models

Simultaneous solving of orbit + stellar structure equations (Henyey)

Accretion from donor M_1 captured by the neutron star M_2 → $\dot{M}_1 = -\beta \dot{M}_2$ **a fraction** β

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

Evaporating wind

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

1st ingredient (Stevens et al., MNRAS 254, 19, 1992)

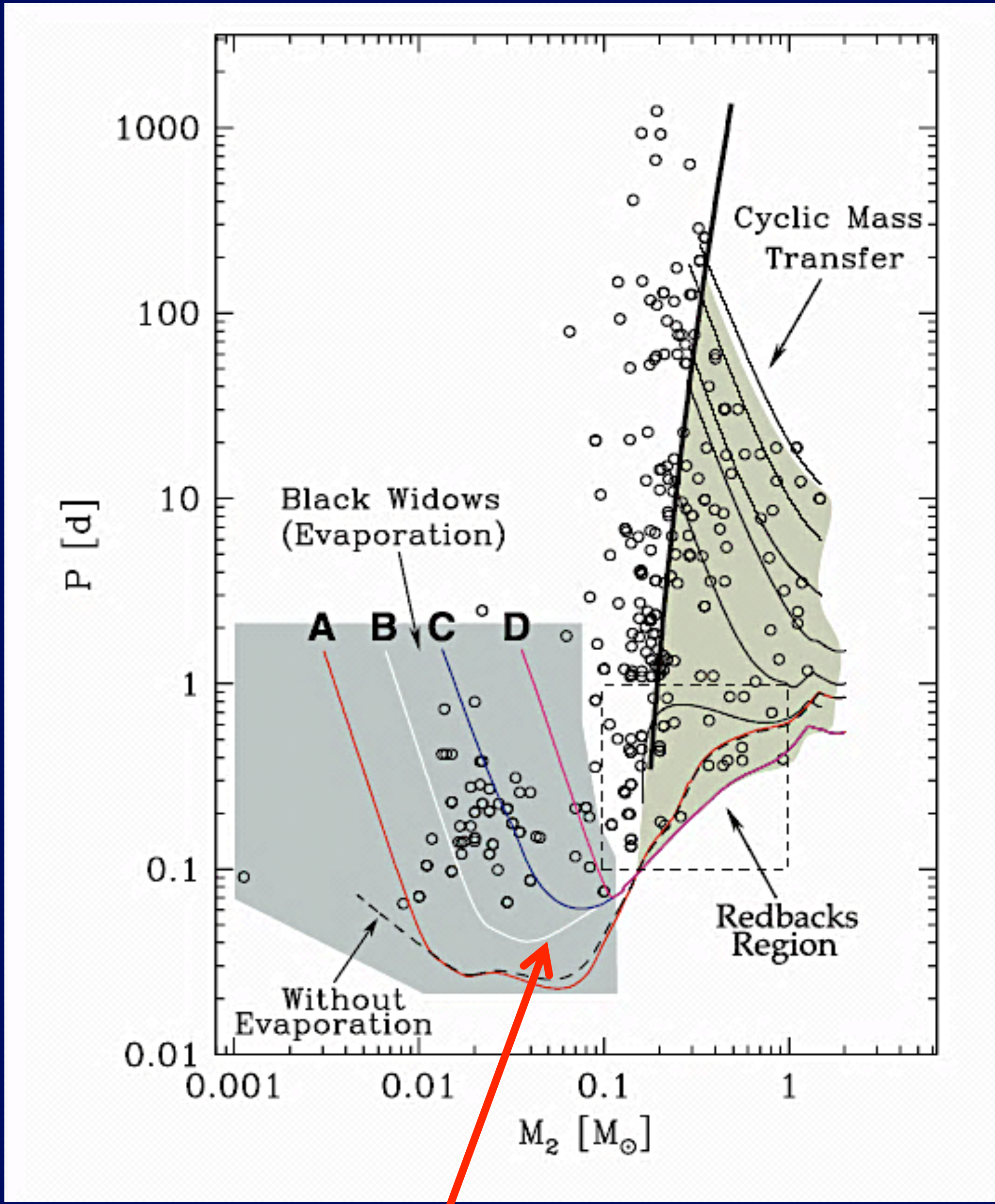
with $L_P = 4\pi^2 I_1 P_1 \dot{P}_1$

Irradiation feedback

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

2nd ingredient (Bunning & Ritter, A&A 423, 281, 2004 Hameury)

Calculations



Donors become degenerate here

Evolutionary tracks starting at short periods, giving rise to "redbacks" and later to "black widow" systems

Track A: $P_i = 0.85$ days, $\alpha_{evap} L_{PSR} = 0.04 L_\odot$

Track B: $P_i = 0.55$ days, $\alpha_{evap} L_{PSR} = 0.04 L_\odot$

Track C: $P_i = 0.55$ days, $\alpha_{evap} L_{PSR} = 0.20 L_\odot$

Track D: $P_i = 0.55$ days, $\alpha_{evap} L_{PSR} = 1.00 L_\odot$

If the starting period is longer, the system detaches and goes up

The quasi-RLOF state in redbacks

X-ray irradiation feedback from the accretion is seldom considered in stellar binaries, but it is important for these systems. The flow of energy from the interior is partially blocked and produces a cyclic mass transfer behavior. The usual expression for the luminosity of the donor

$$L = 4\pi R_2^2 \, \sigma \, T_{\rm eff}^4$$

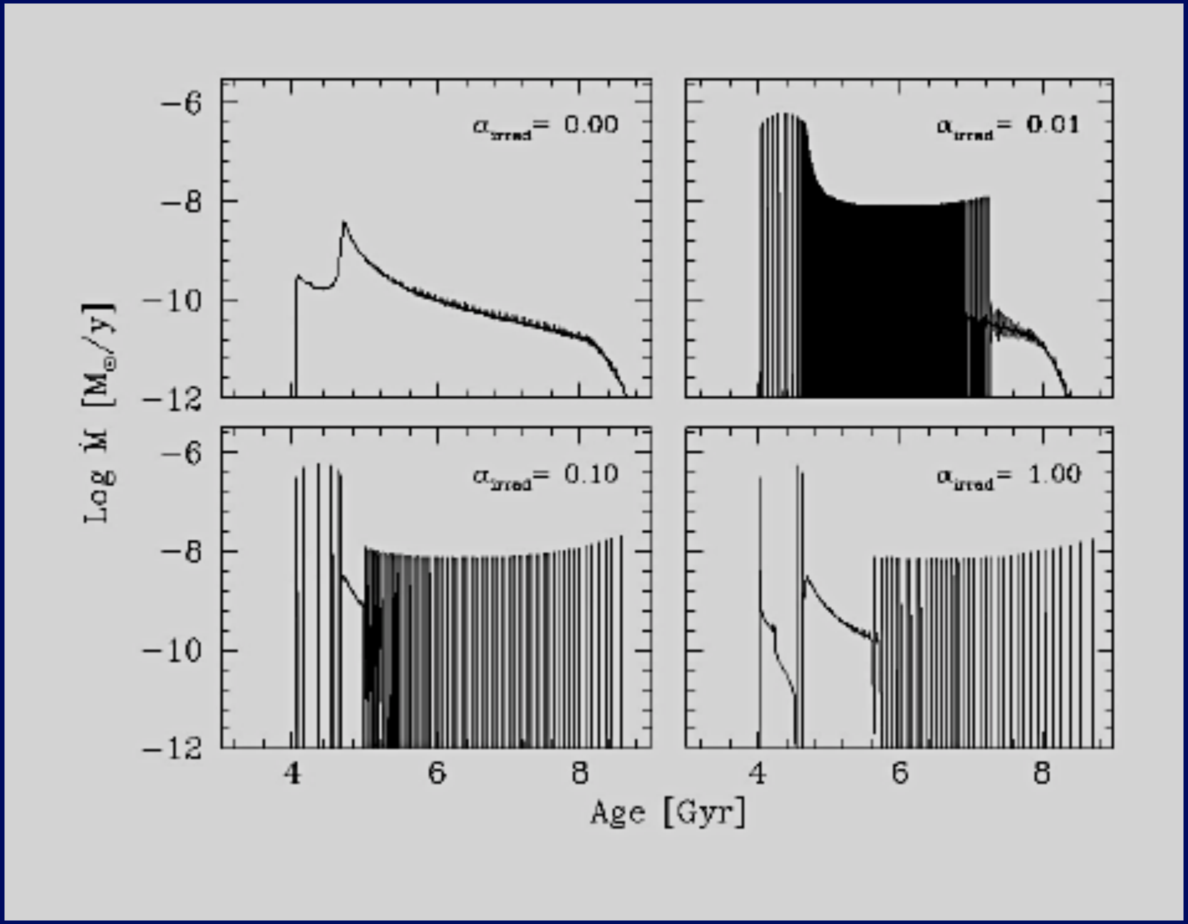
has to be replaced by

$$L = R_2^2 \, \sigma \, T_{\rm eff,0}^4 \int_0^{2\pi} \int_0^{\pi} G(x(\theta, \phi)) \, \sin\theta \, d\theta \, d\phi,$$

with

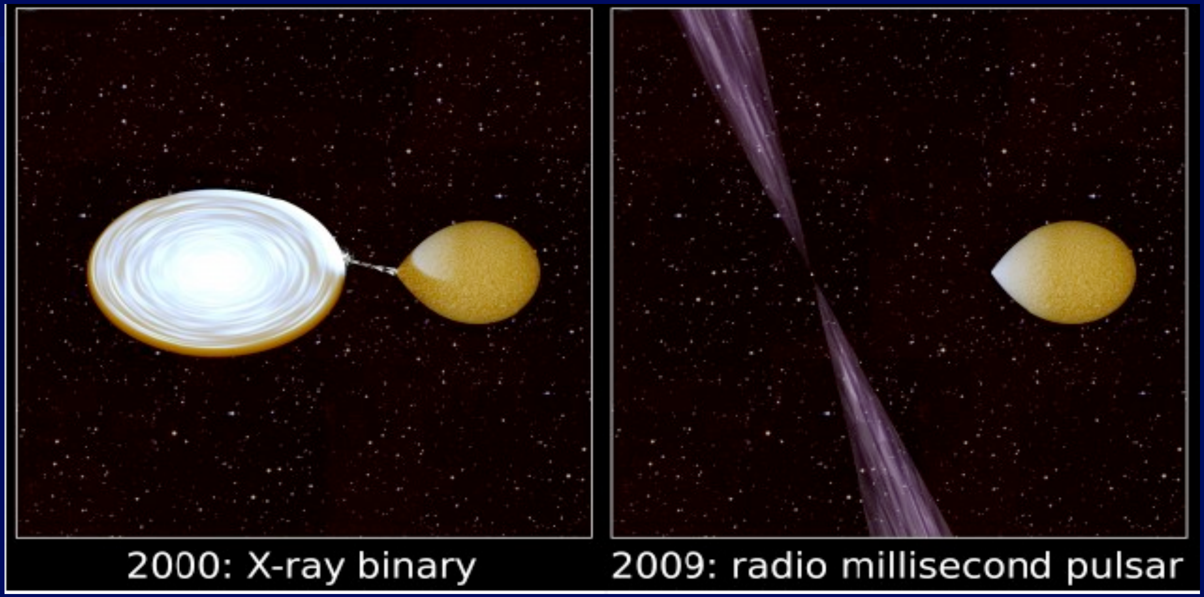
$$G(x) = (T_{\rm eff}(x)/T_{\rm eff,0})^4 - F_{\rm irr}/(\sigma \, T_{\rm eff,0}^4)$$

Since the quantity $F_{irr} = \alpha_{irr} L_{acc} / 4\pi a^2$ *depends on the irradiation strength* $\alpha_{irr} \leq 1$ *, we have calculated the mass transfer histories shown below for several values of this parameter*



Cycles last around ~1 Myr or more

Because of the X-ray irradiation, even when the systems detach, the radius of the solar-mass donor is never too different from the Roche Lobe Overflow value (donor swells)



PSR J1023+0038

(from Roberts 2013)

This quase-RLOF timescale (~ 10^6 yr) is not the timescale for the disc destruction/rebuilding, driven by disc instabilities and operating for ~ few years. The back-and-forth switching between a LMXB (accreting) and a radio pulsar (detached) has been confirmed recently.

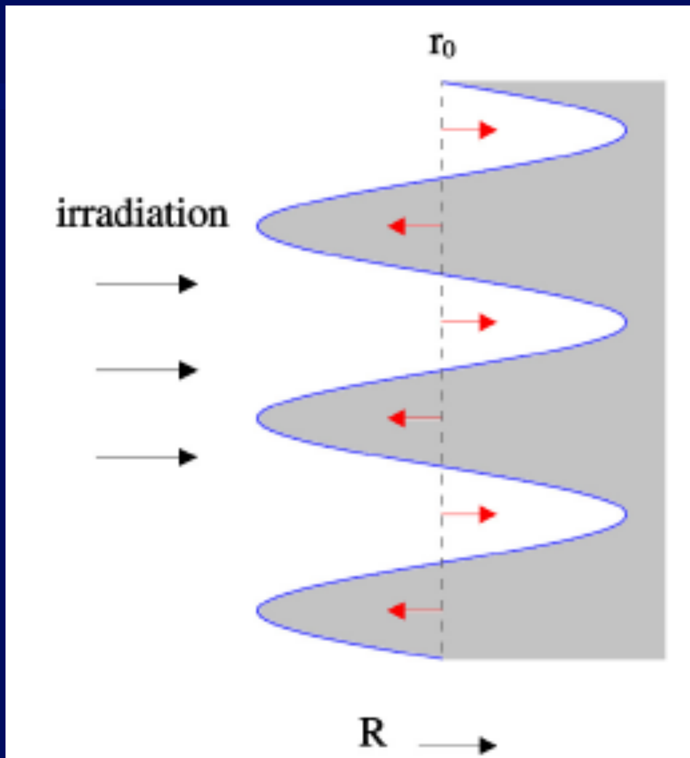
Evidence for the quasi-RLOF state : the filling factors

	Pulsar	P_s (ms)	T K	Filling Factor (kpc)	P_B (hrs)	M_{ns} (solar)
Old BWs	B1957+20[1] F	1.61	2500-5800	0.95	9.2	2.4
	J0610-2100[2] F	3.86	3500	High?	6.9	-
	J2051-0827[8]	4.51	2500-2800	0.43/0.95	2.4	
New BWs	J1311-3430[3] F	2.56	3440-12000	0.99	1.56	2.7
	J2241-5236 F	2.19			3.4	
	J2214+3000 F	3.12			10.0	
	J1745+1017 F	2.65			17.5	
	J2234+0944 F	3.63			10	
	J0023+0923[4] F	3.05	2900-4800	0.3	3.3	
	J1544+4937 F	2.16			2.8	
	J1446-4701 F	2.19			6.7	
	J1301+08 F	1.84			6.5	
	J1124-3653 F	2.41			5.4	
	J2256-1024[4] F	2.29	2450-4200	0.4	5.1	
	J2047+10 F	4.29			3.0	
	J1731-1847	2.34			7.5	
	J1810+1744[4] F	1.66	4600-8000	0.8	3.6	
New RBs	J1628-32 F	3.21			5.0	
	J1816+4510[5] F	3.19	15000	0.5	8.7	> 1.8
	J1023+0038[6] F	1.69	5600-6650	0.95	4.8	2.1
	J2215+5135[4] F	2.61	4800-6200	0.99	4.2	
	J1723-28	1.86			14.8	
	J2339-0533	2.88		high?	4.6	
	J2129-0429[7] F	7.61	5750	0.95	15.2	> 1.7

1. van Kerkwijk et al. 2011 2. Pallanca et al. 2012 3. Romani et ... ton et al. 2013 5. Kaplan et al. 2013
6. McConnell et al 2012 7. Bellm et al 2013 8. Stappers et al 2001

(from Roberts 2013)

Irradiated disc instability



Because of the radiation coming from the central object, there is a transparent → opaque transition in the disc. The vertical structure at a fixed radius a is given by (Lasota 2001)

$$\frac{dP}{dz} = -\rho g_z = -\rho \Omega_K^2 z,$$

$$\frac{d\varsigma}{dz} = 2\rho,$$

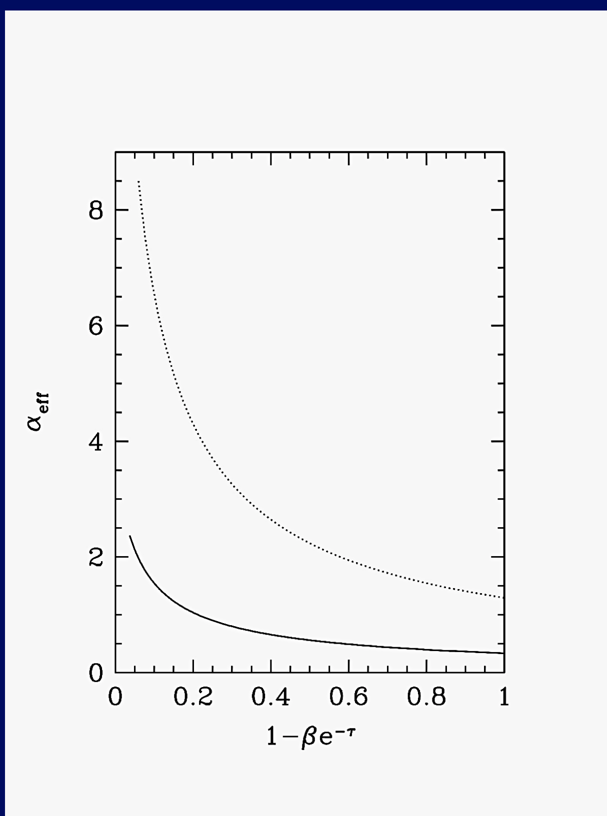
$$\frac{d \ln T}{dz} = \nabla \frac{d \ln P}{dz},$$

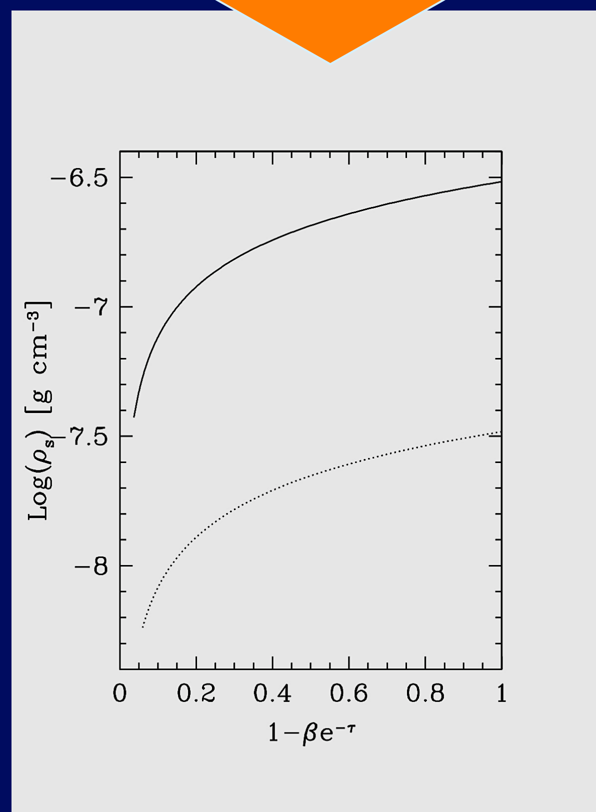
$$\frac{dF_z}{dz} = \frac{3}{2}\alpha \Omega_K P + \frac{dF_t}{dz},$$

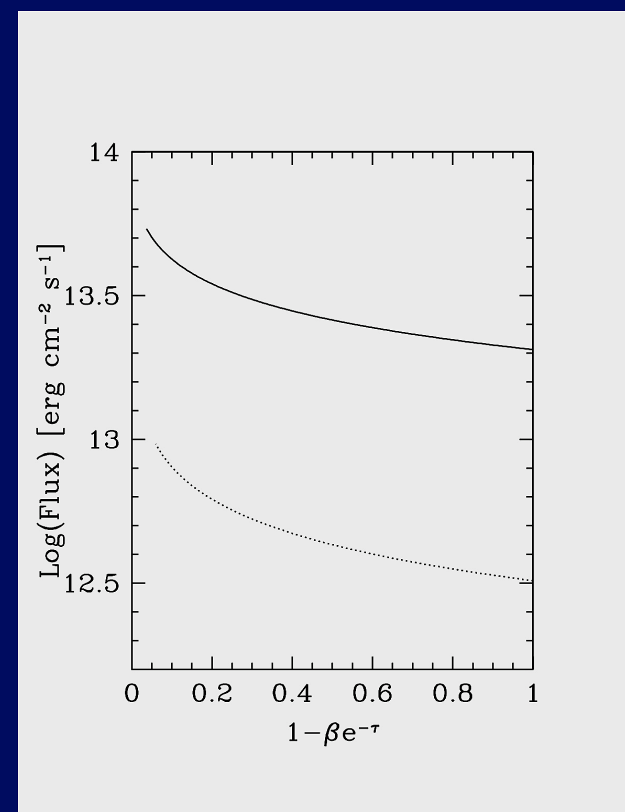
Geometrically thin discs, separation of radial and vertical components (Fung & Artymowicz 2014)

where Ω_k should be replaced by $\Omega = \sqrt{\Omega_k^2(1-\beta e^{-\tau})}$ which contains the effects of the inner irradiation and dilution and $\beta = \frac{\kappa_{\rm opa} L}{4\pi c G M}$ is the ratio of the radiation pressure to gravity

The results show that the disc is being swept by inner radiation, but only a coupled calculation including radial structure could confirm a ~ yr timescale (in progress...)

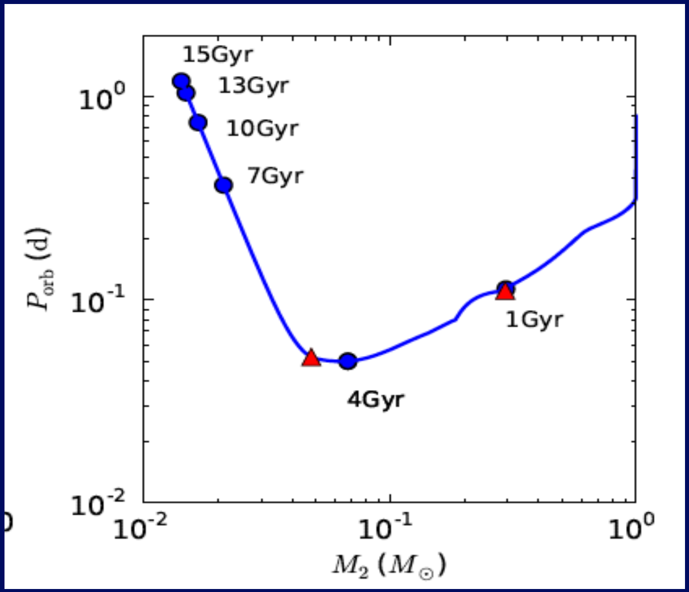






Conclusions

- ***Our evolution tracks show that some "redbacks" are progenitors of "black widows", the evolutionary times are very long (~ few Gyr)***



(Cheng, Cheng, Tauris & Han 2013)

- ***Because of these long accretion phase, it is expected that NS at the "black widow" stage are very massive. No way to put the systems into the "black widow" region with a small efficiency*** β ***(M > 2 Mo ??? i.e.*** **$M_{original} = 2.4 \pm 0.12\ M_\odot$** ***van Kwerkwijk, Breton & Kulkarni 2011)***

- *Redbacks are sometimes detached and sometimes accreting. The companion is irradiated and settles in a quasi-RLOF state. The disc is blown up and rebuilds on a ~ few years timescale (TBC) Caveat : the description of the disc structure has MANY uncertainties, starting with the very equations...*

- *Theory is being tested using the growing set of objects. There is no other known system for which irradiation (first) and evaporation (later) are so important.*

This work is based on

O.G.Benvenuto, M.A. De Vito and J.E. Horvath, ApJ 786, L7 (2014)
O.G.Benvenuto, M.A. De Vito and J.E. Horvath, ApJ 798, 44 (2015)

THANK YOU !