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“Black widow”binary systems

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Once upon a time the idea of a single mass scale was firmly rooted in the community

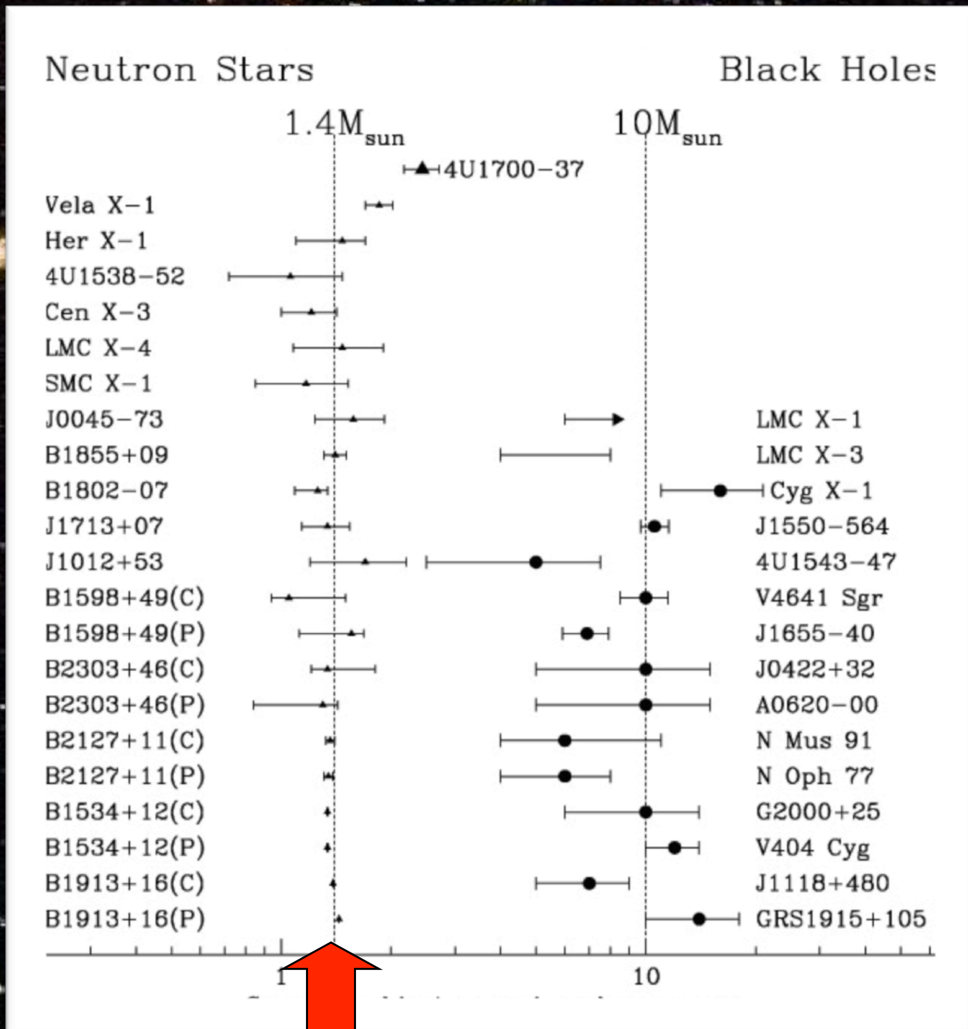

Figure from Clark et al. A&A 392, 909 (2002)

Consistent with 1.4 $M_\odot$

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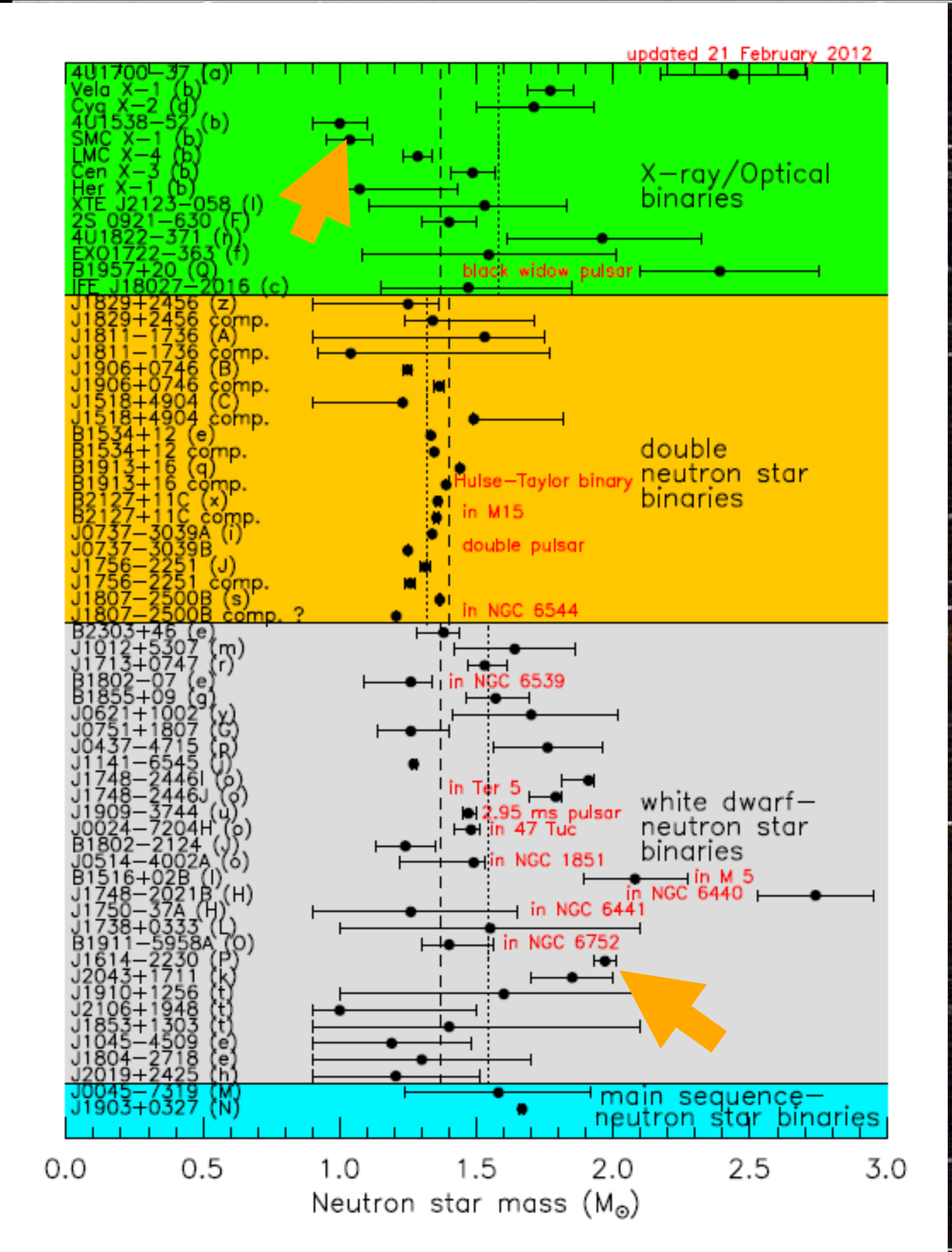

However, the newest evidence points towards a *much wider* range of masses

Sample compiled by Lattimer et al 2012, available at

http://www.stellarcollapse.org/nsmasses

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Bayesian analysis (Valentim, Rangel & Horvath, MNRAS 414, 1427, 2011) points out that one mass scale is unlikely, the distribution is more complex. Within a double gaussian scenario, two masses are present : 1.37 and 1.73 $M_{\odot}$

Is the high value related to the size of the Fe core? (jump @ 18 $M_{\odot}$)
Are some of them born as such, massive ?
Accretion role important? Stay tuned...

Other works finding the same pattern:

Zhang et al. A&A 527, A83, 2011
Özel et al., ApJ 757, 55, 2012 (1.33 and 1.48 $M_{\odot}$)
Kiziltan, Kottas & Thorsett, arXiv:1011.4291 (1.35 and 1.5 $M_{\odot}$)

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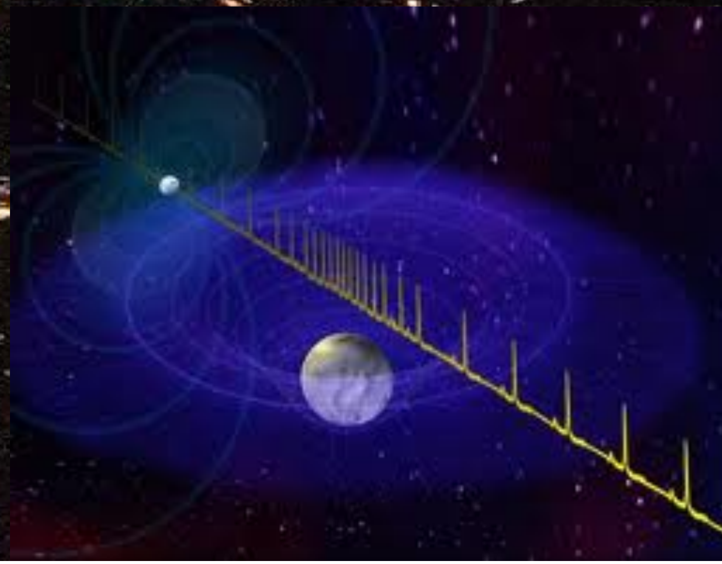
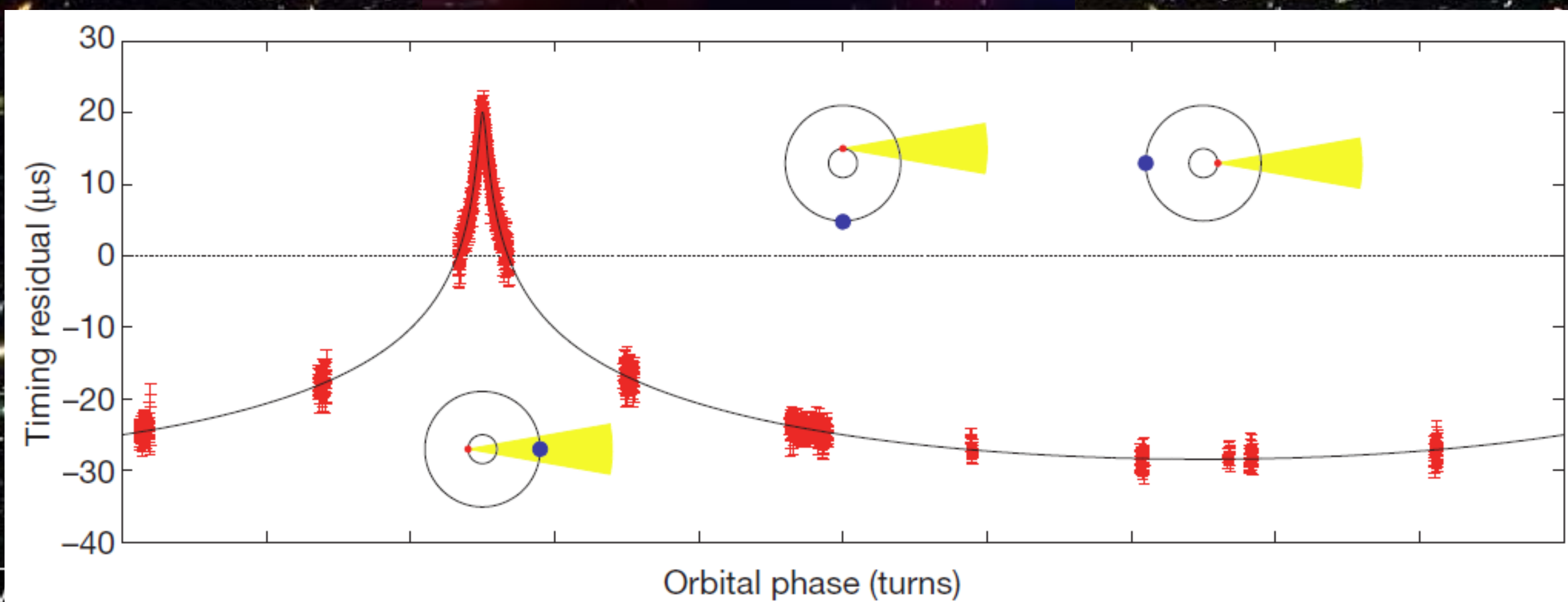
Demorest et al 2010: a NS with M~ 2 M_O measuring the Shapiro delay





NASA

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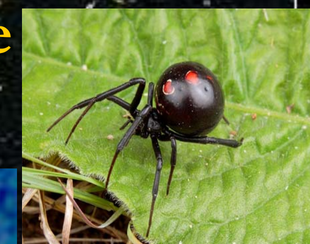
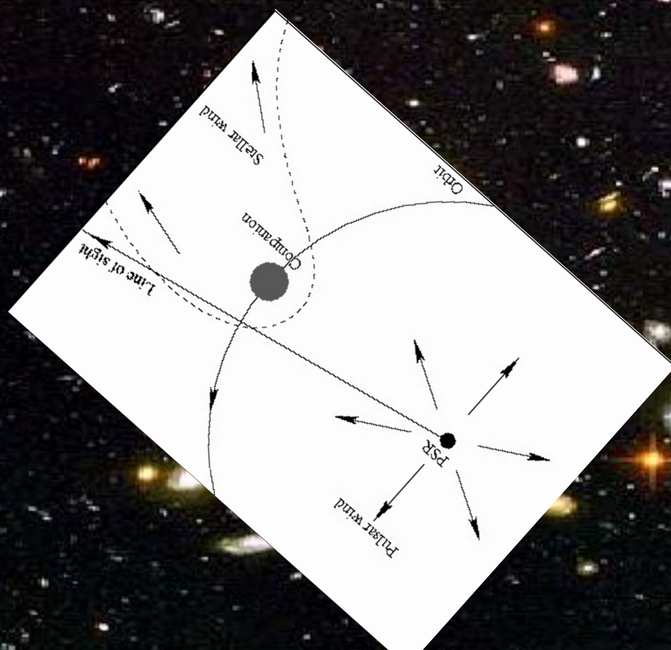
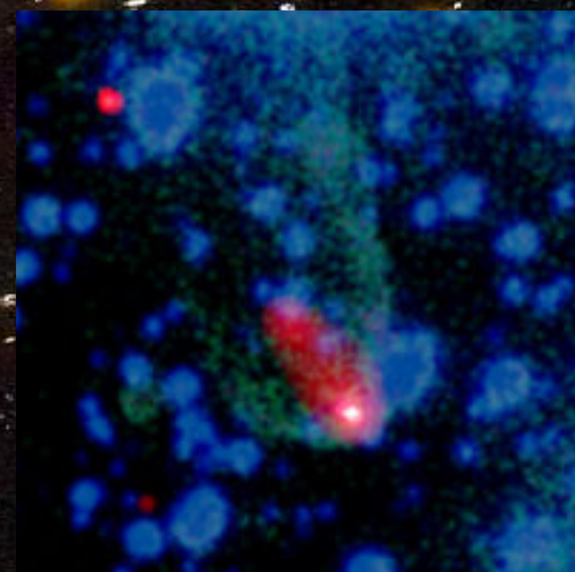
1982: Backer et al. discovered the first member of the *ms* pulsar class **RECYCLED BY ACCRETION?**

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





Original sketch of the PSR 1957+20 system



Composite Image from *Chandra* (2012)

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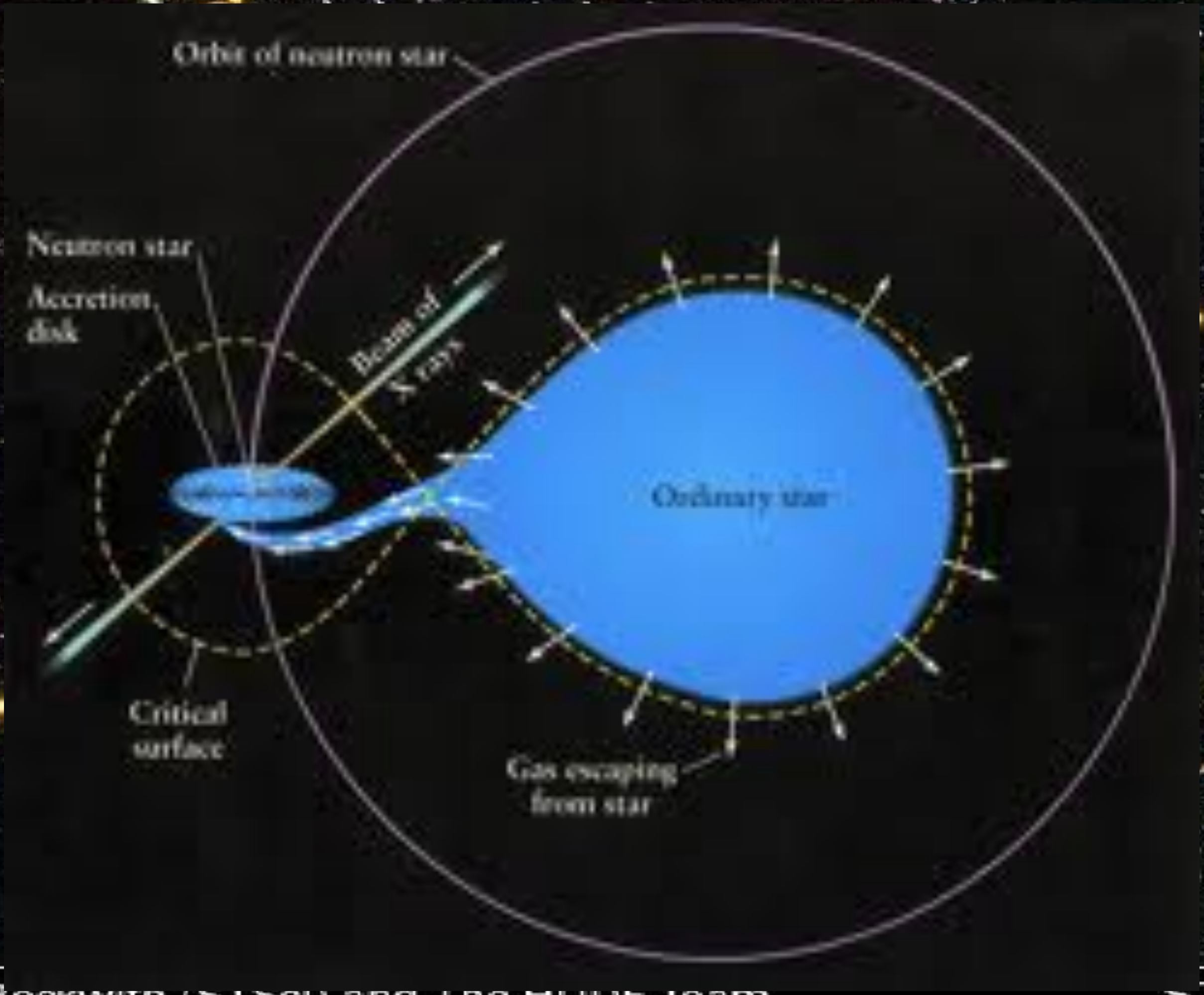
"Black widow" pulsars

Relatives of the accreting X-ray binaries…



LMXRB and others

Many ms pulsars in binaries

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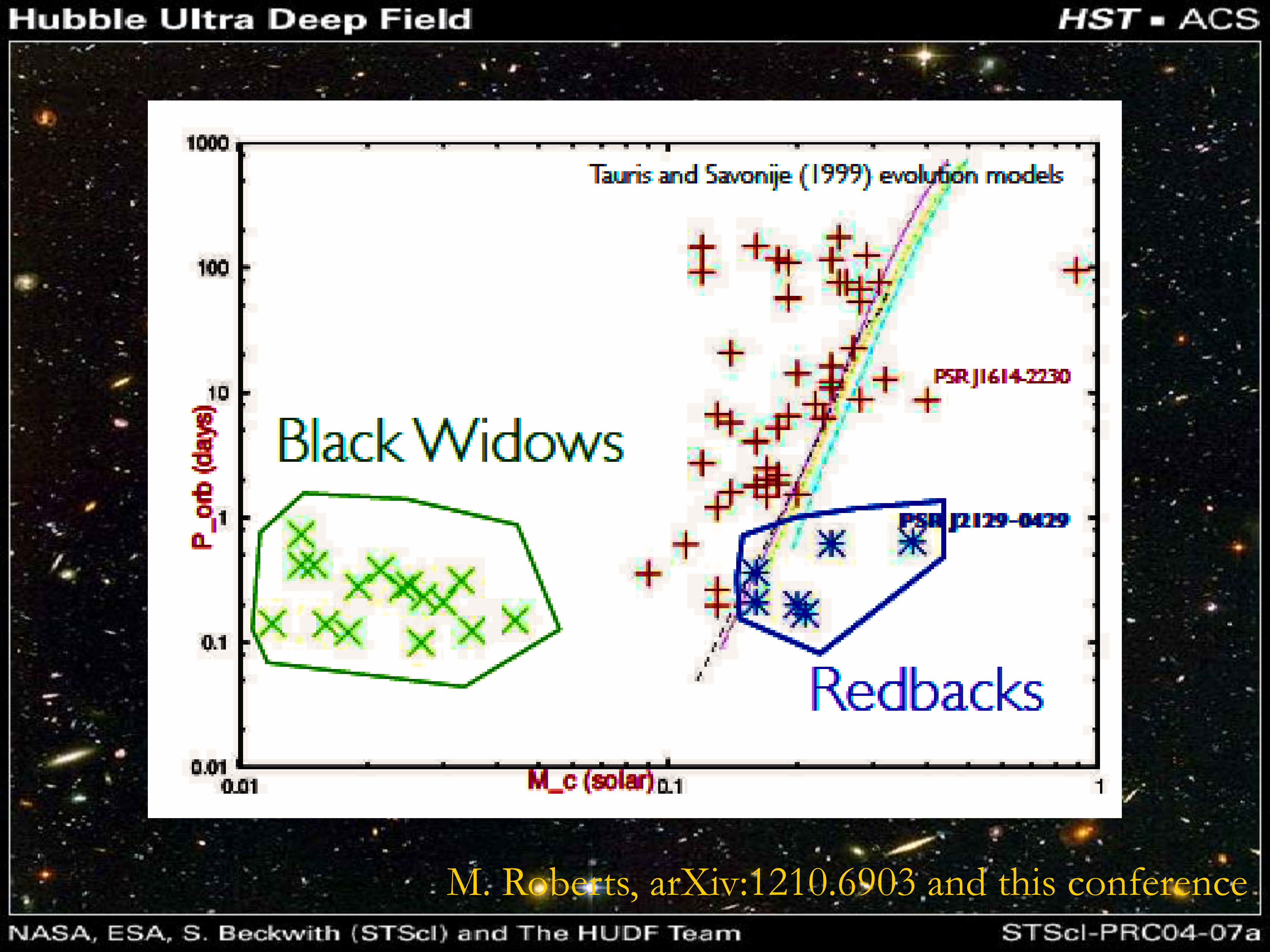
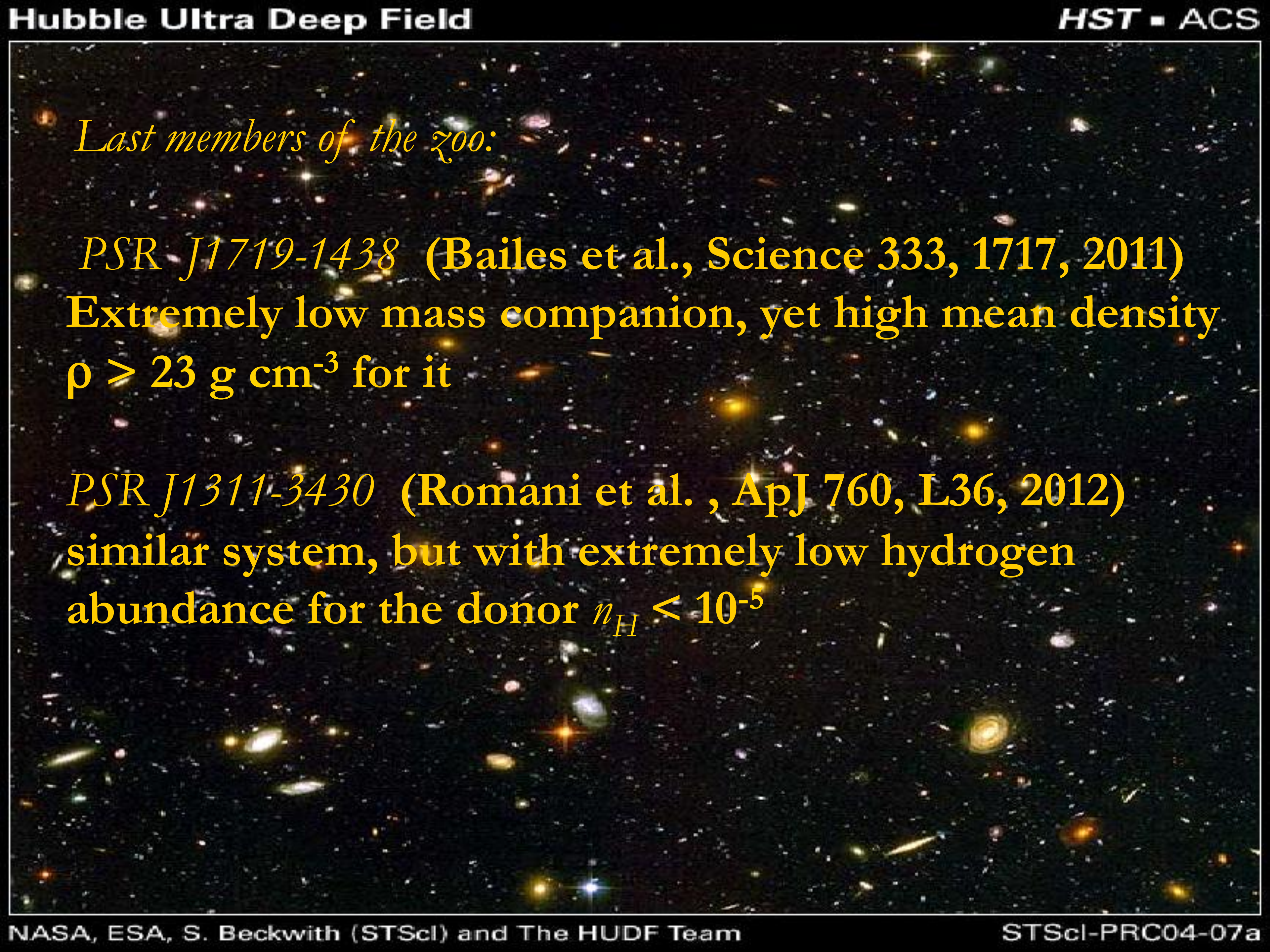


M. Roberts, arXiv:1210.6903 and this conference



Last members of the zoo:

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

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

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How are these ultra-compact systems formed?

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

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<

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

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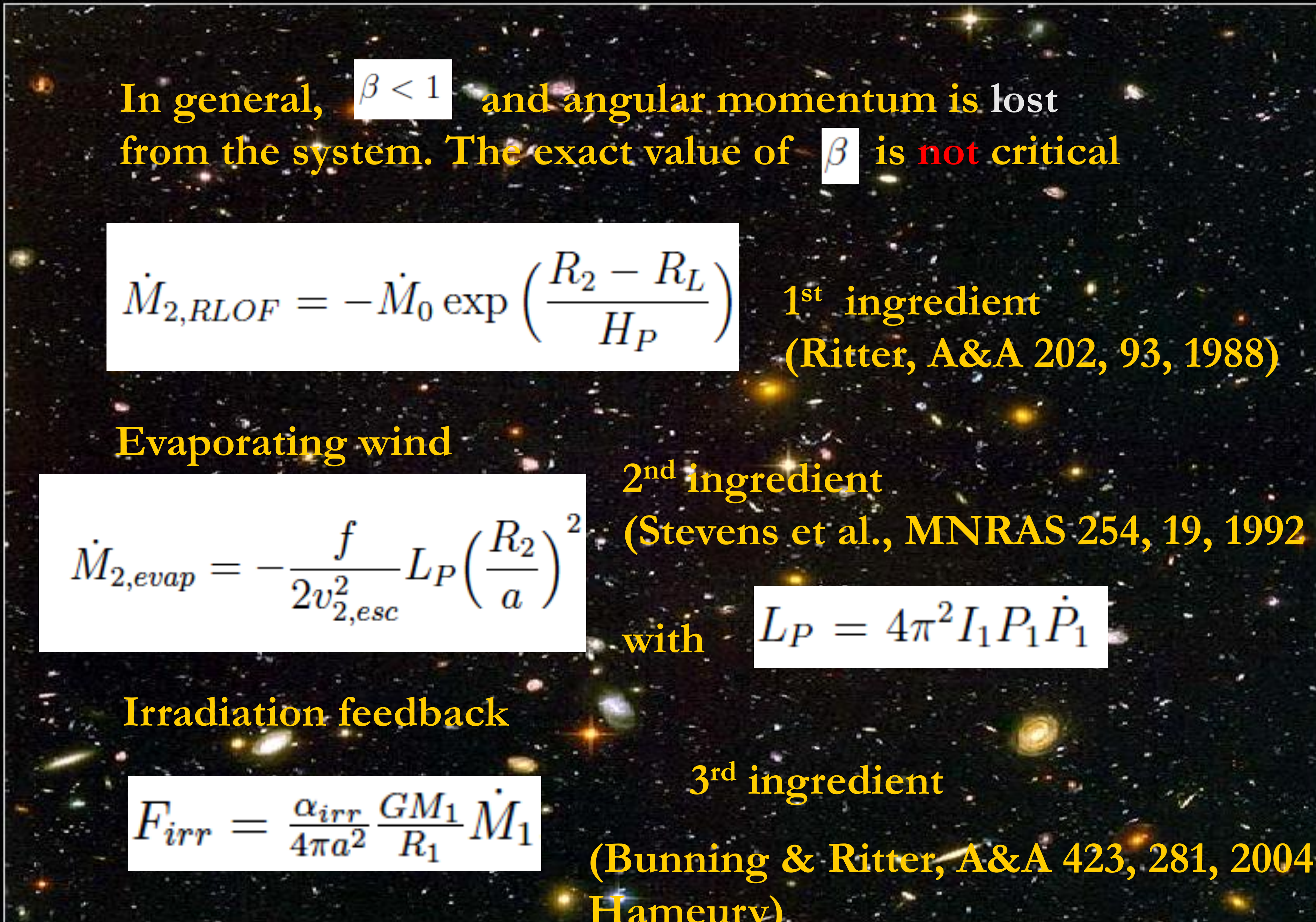

In general, $\beta < 1$ and angular momentum is lost from the system. The exact value of β is not critical

$$\dot{M}_{2,RLOF} = -\dot{M}_0 \exp\left(\frac{R_2 - R_L}{H_P}\right)$$

1st ingredient
(Ritter, A&A 202, 93, 1988)

Evaporating wind

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

2nd ingredient
(Stevens et al., MNRAS 254, 19, 1992)

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

Irradiation feedback

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

3rd ingredient

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

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All three 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 ➡ $M_1 = 1.4M_\odot$

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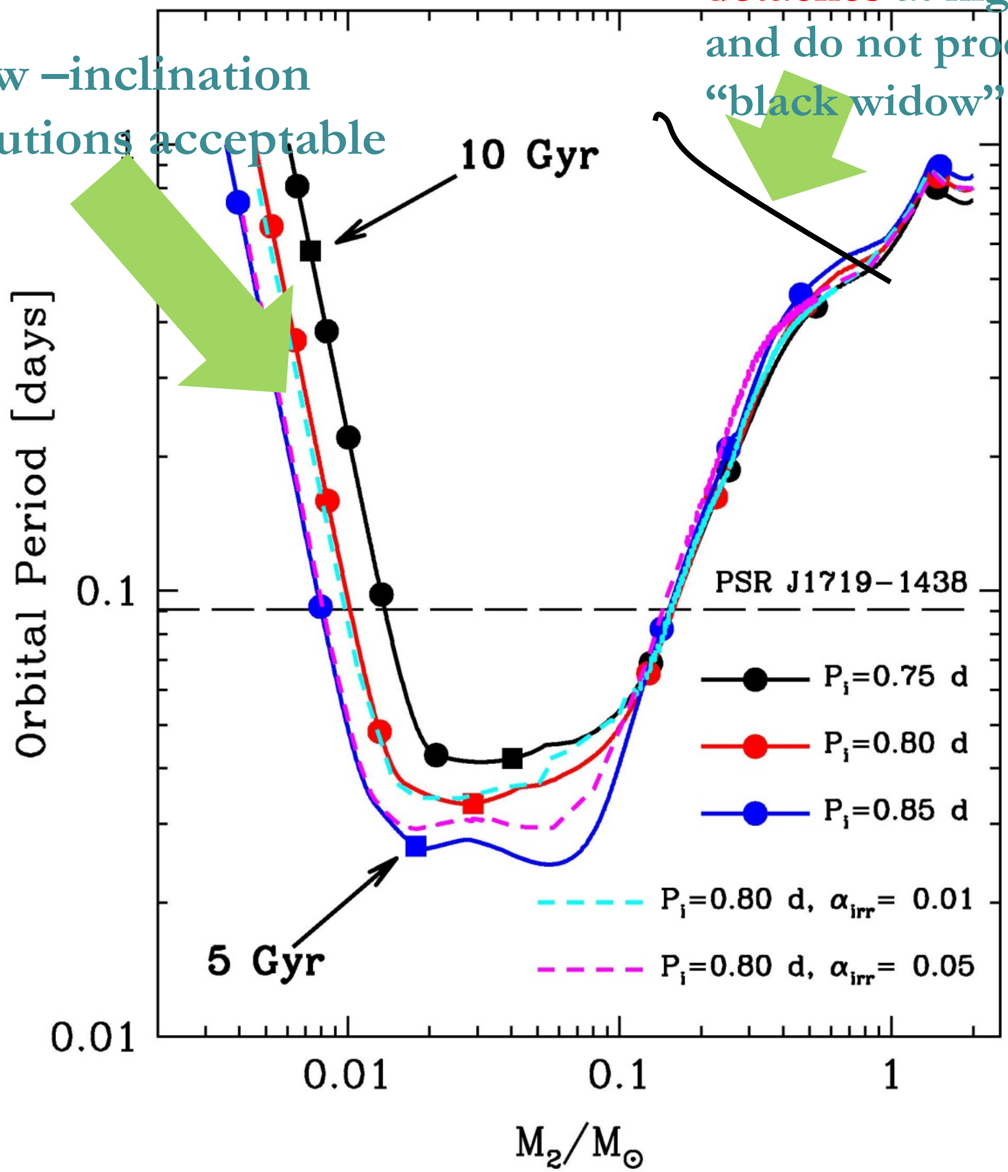
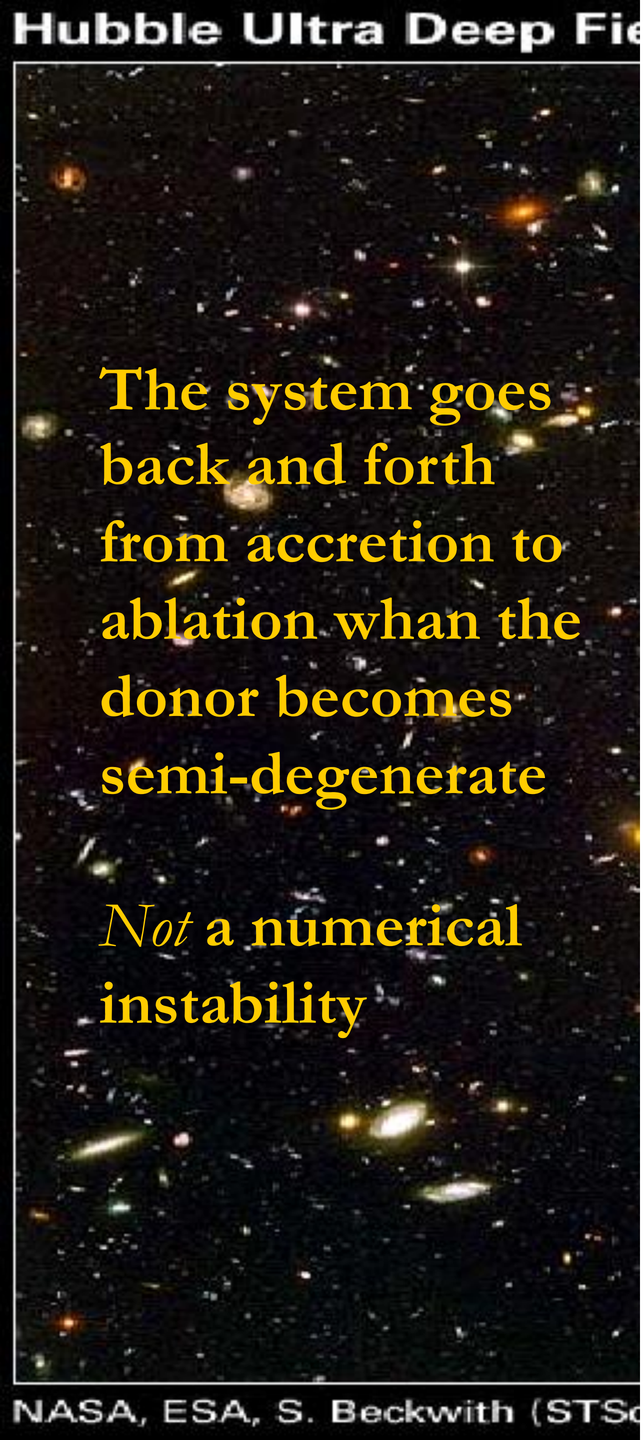
PSR J1719-1438

At slightly larger initial periods, the secondary detaches at high mass and do not produce "black widow" systems

Low –inclination solutions acceptable

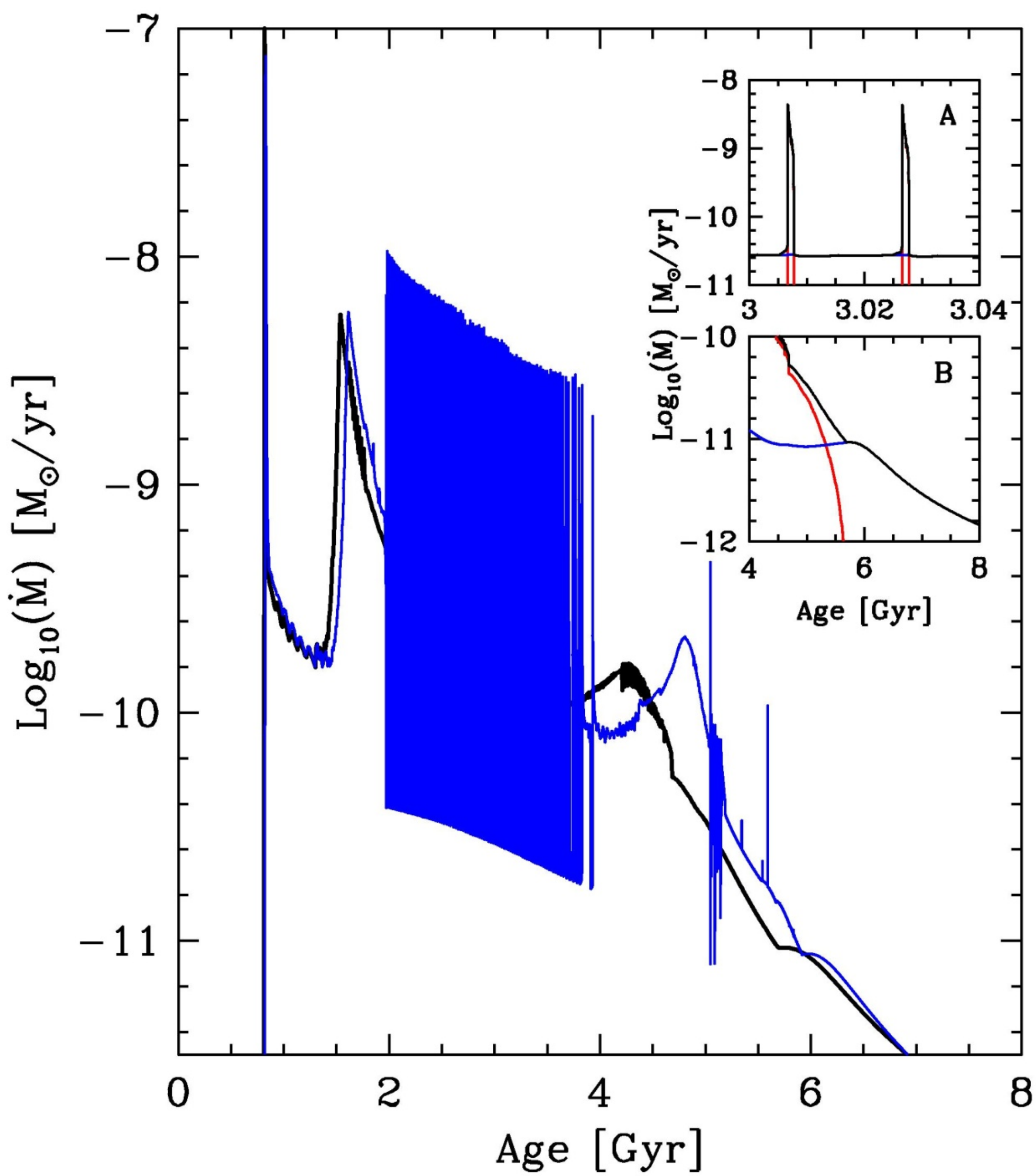


PSR J1719-1438



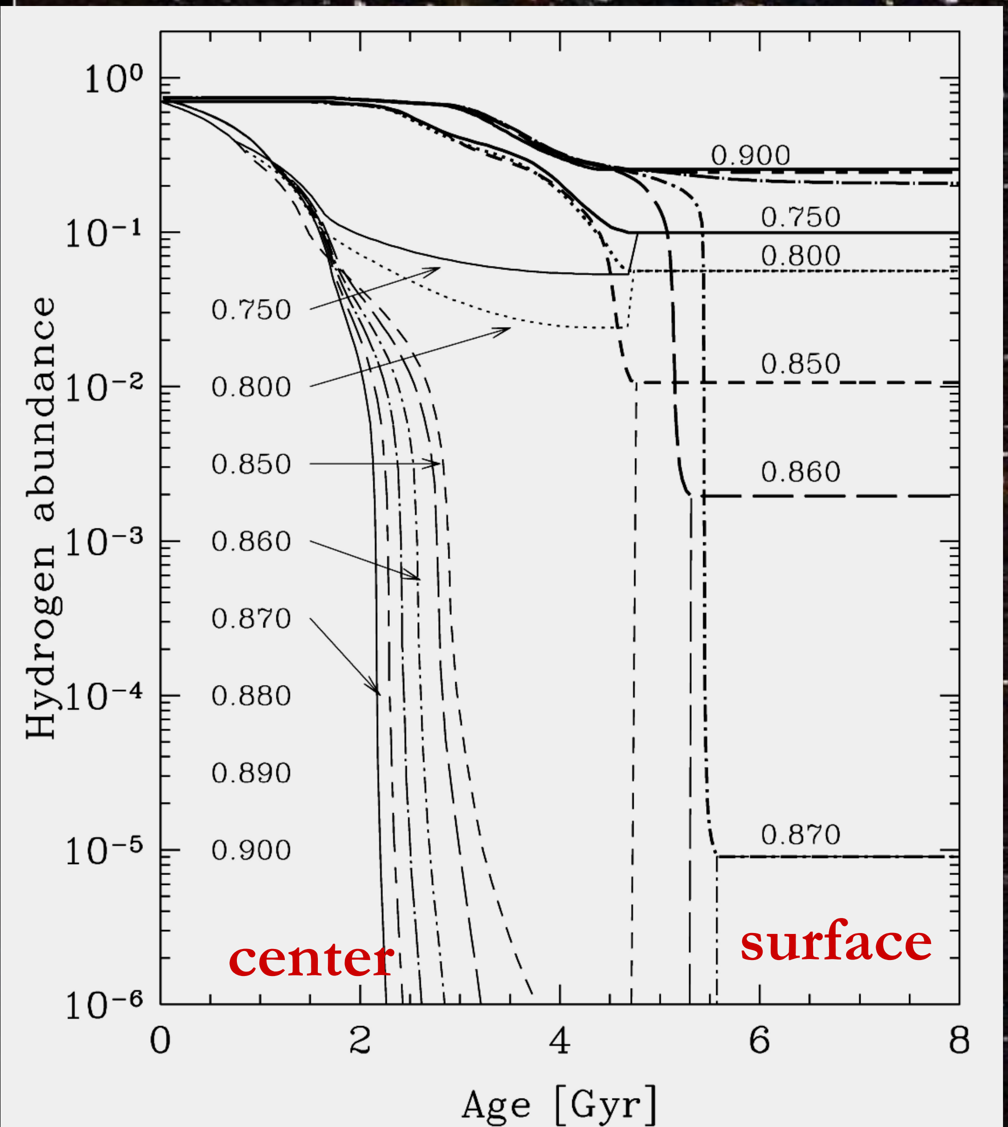
The system goes back and forth from accretion to ablation whan the donor becomes semi-degenerate

Not a numerical instability



PSR J1311-3430: similar but VERY hydrogen-free~ 10↑−5

Romani et al. ApJLett2012



When the donor star becomes fully convective, @ M_2=0.053M_O the central abundance can be zero (pure He star) provided P_i > 0.86 d

If P_i is shorter, it still produces a "black widow" but hydrogen is present

(Benvenuto, De Vito & Horvath MNRAS Letters, in the press)

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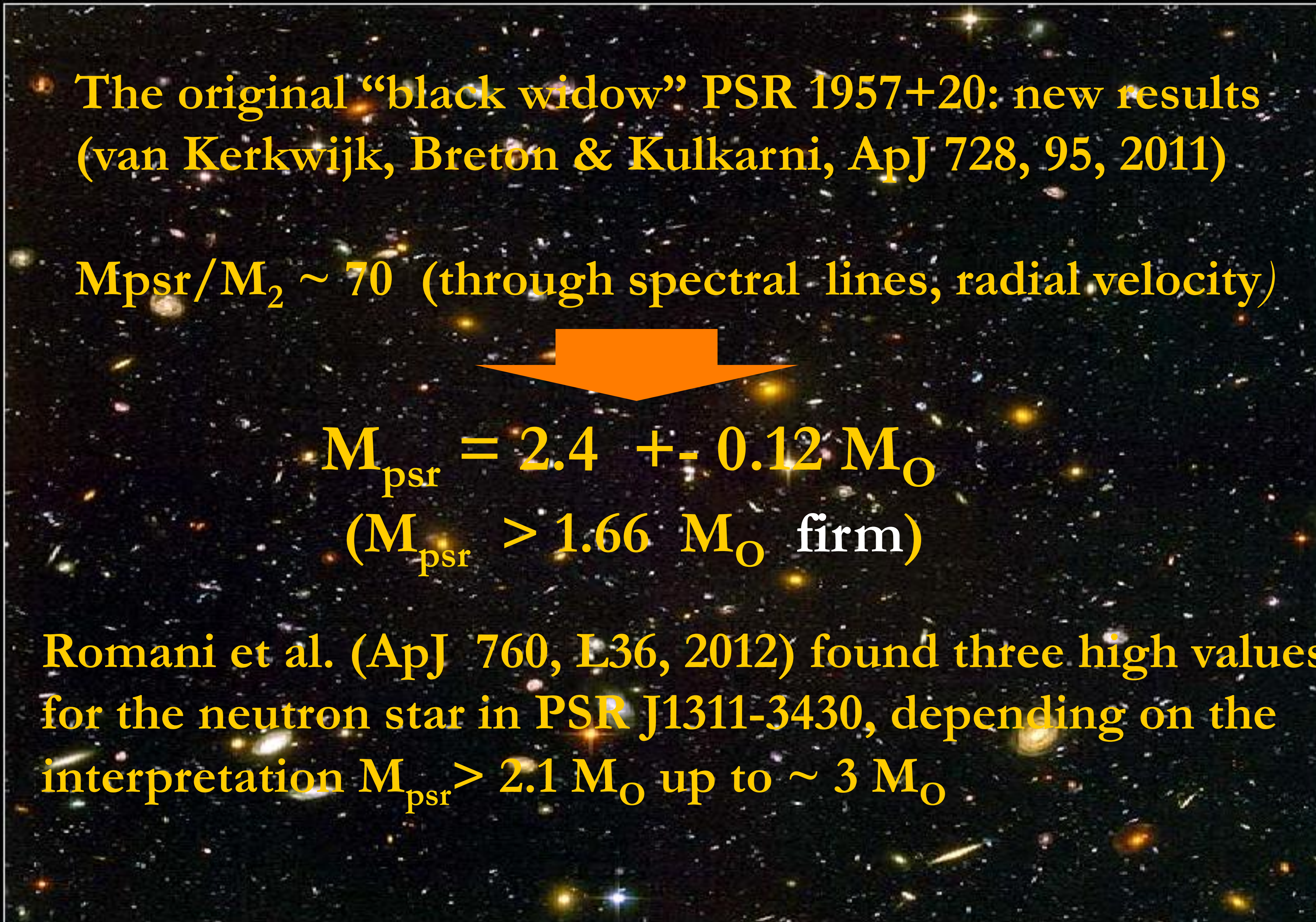

The original "black widow" PSR 1957+20: new results (van Kerkwijk, Breton & Kulkarni, ApJ 728, 95, 2011)

$M_{psr}/M_2 \sim 70$ (through spectral lines, radial velocity)

⬇

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

($M_{psr} > 1.66 \ M_O$ firm)

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 $\sim 3 \ M_O$

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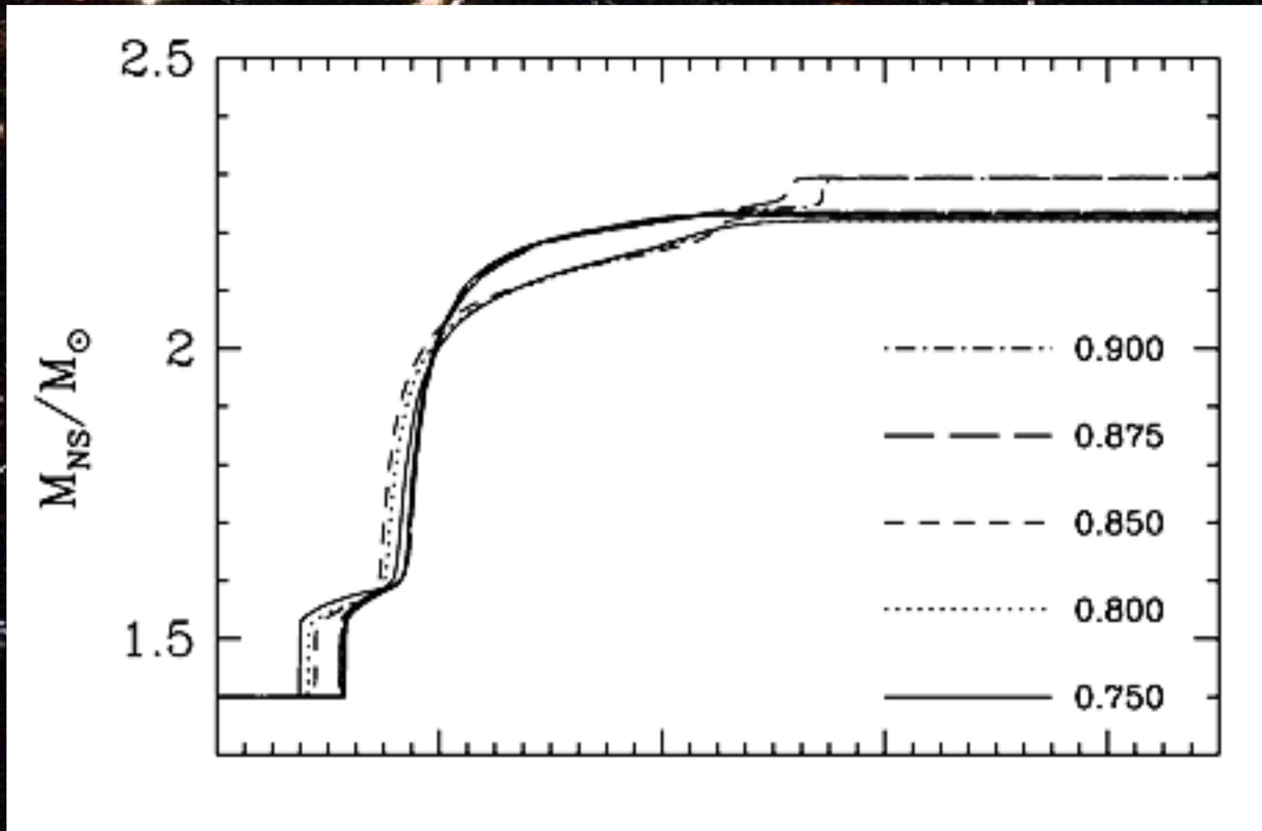
Self-consistent calculations of the PSR J1311-3430 system require such high values to reach the observed state



Calculations for several values of the initial period, and fixed accretion efficiency β of 50%

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Conclusions

* Ultra-compact "black widow" pulsar systems result from a bifurcation in parameter space, in this sense they are a new evolutionary path. Hydrogen-free companions result from very tight initial conditions

* The role of winds+irradiation is crucial : RLOF alone would not produce anything like PSR J1719-1438 or PSR J1311-3430 The full parameter space needs exploration, but we can state that PSR masses emerging are consistently very large

* We have results for the original black widow,just the radius comes out wrong, but the opacities were extrapolated and it should not be a surprise, meanwhile period, mass ratio, OK

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