New Insights from the Optical Study of 'Spiders'

Rene Breton
University of Manchester

with many collaborators
(V. Dhillon, J. Hessels, M. van Kerkwijk,
M. Roberts, ...)

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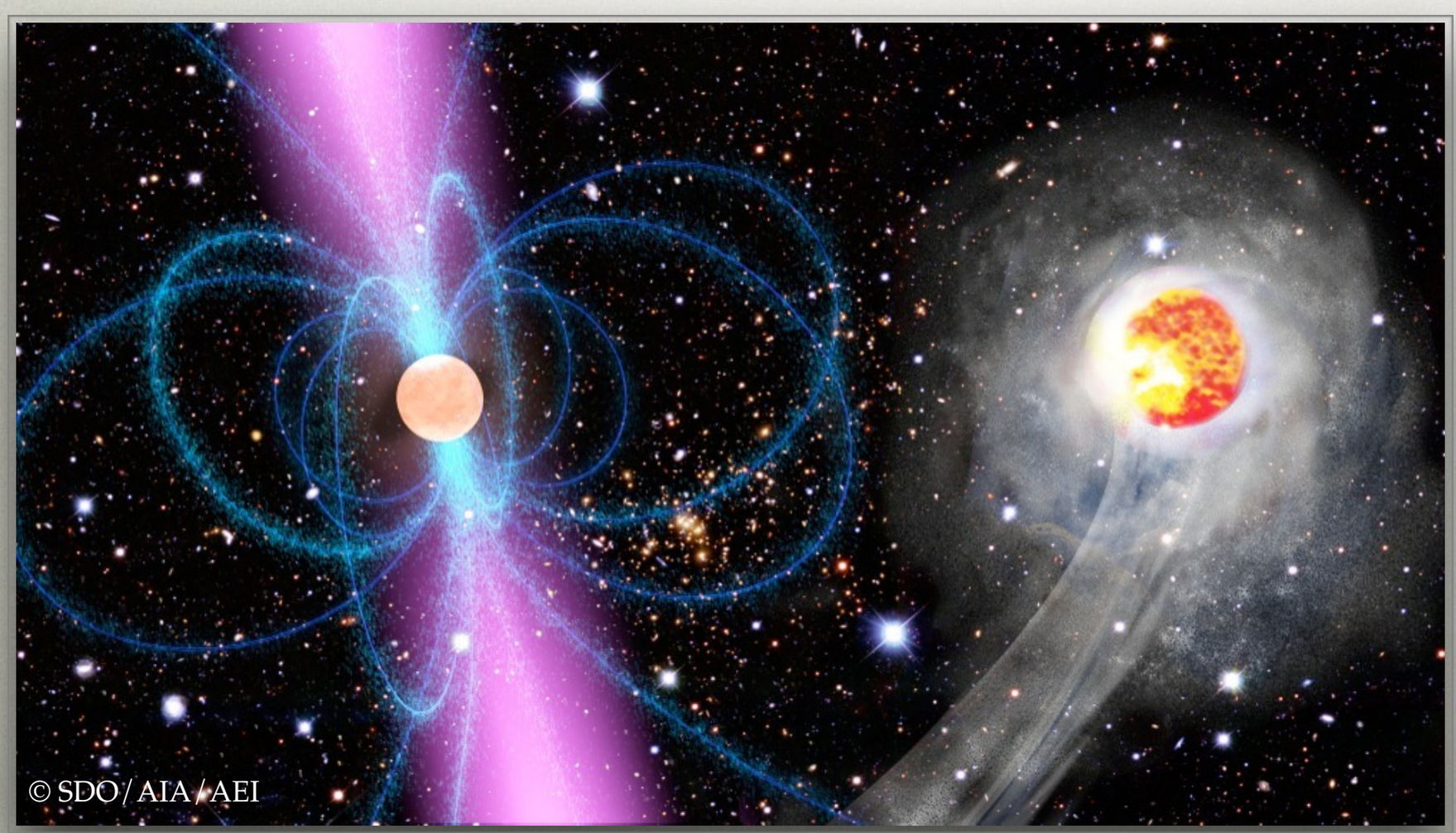
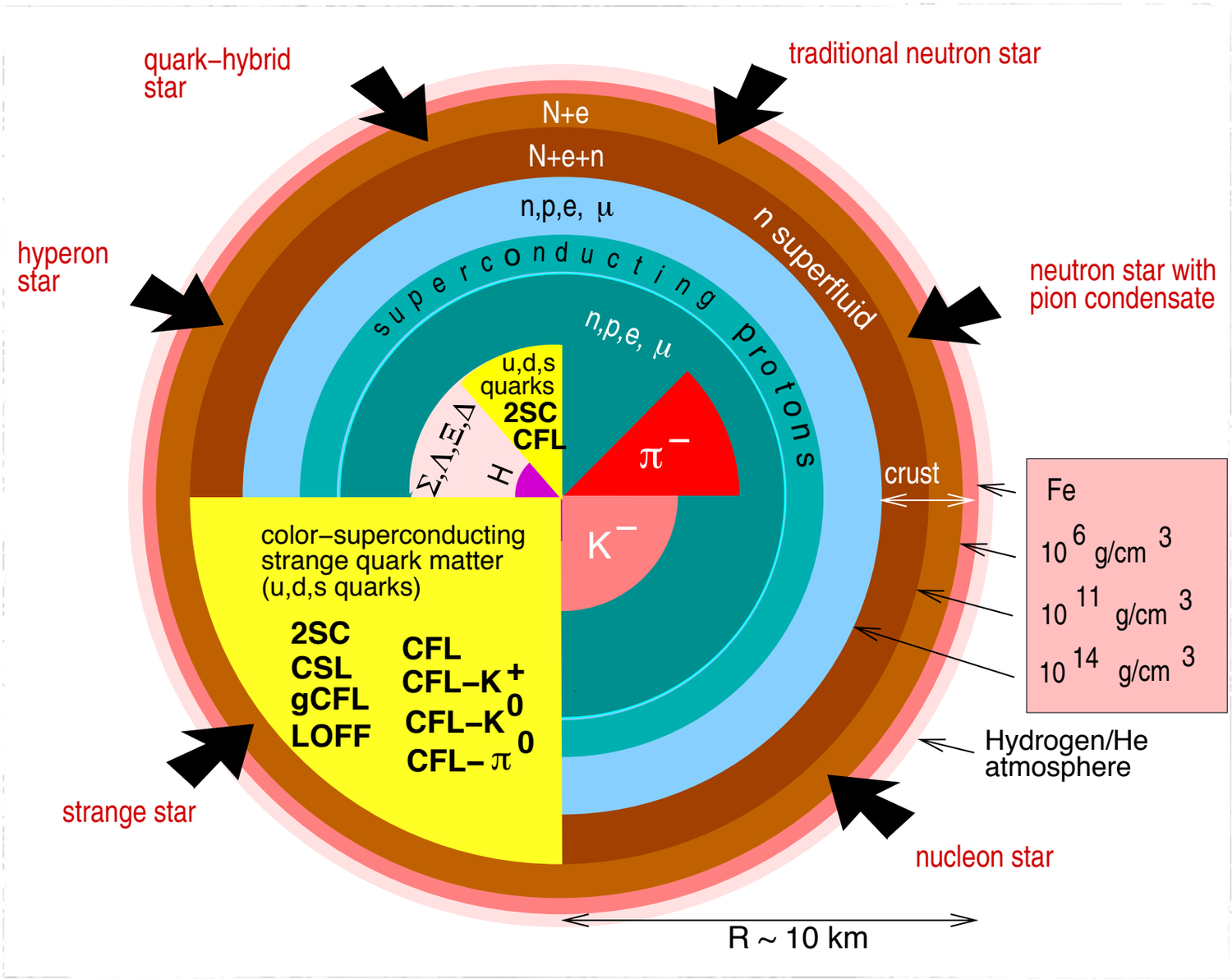
25 June 2015



Why Do Pulsar Masses Matter?

Our understanding of fundamental physics in the regime of a neutron star's centre is rather poor.

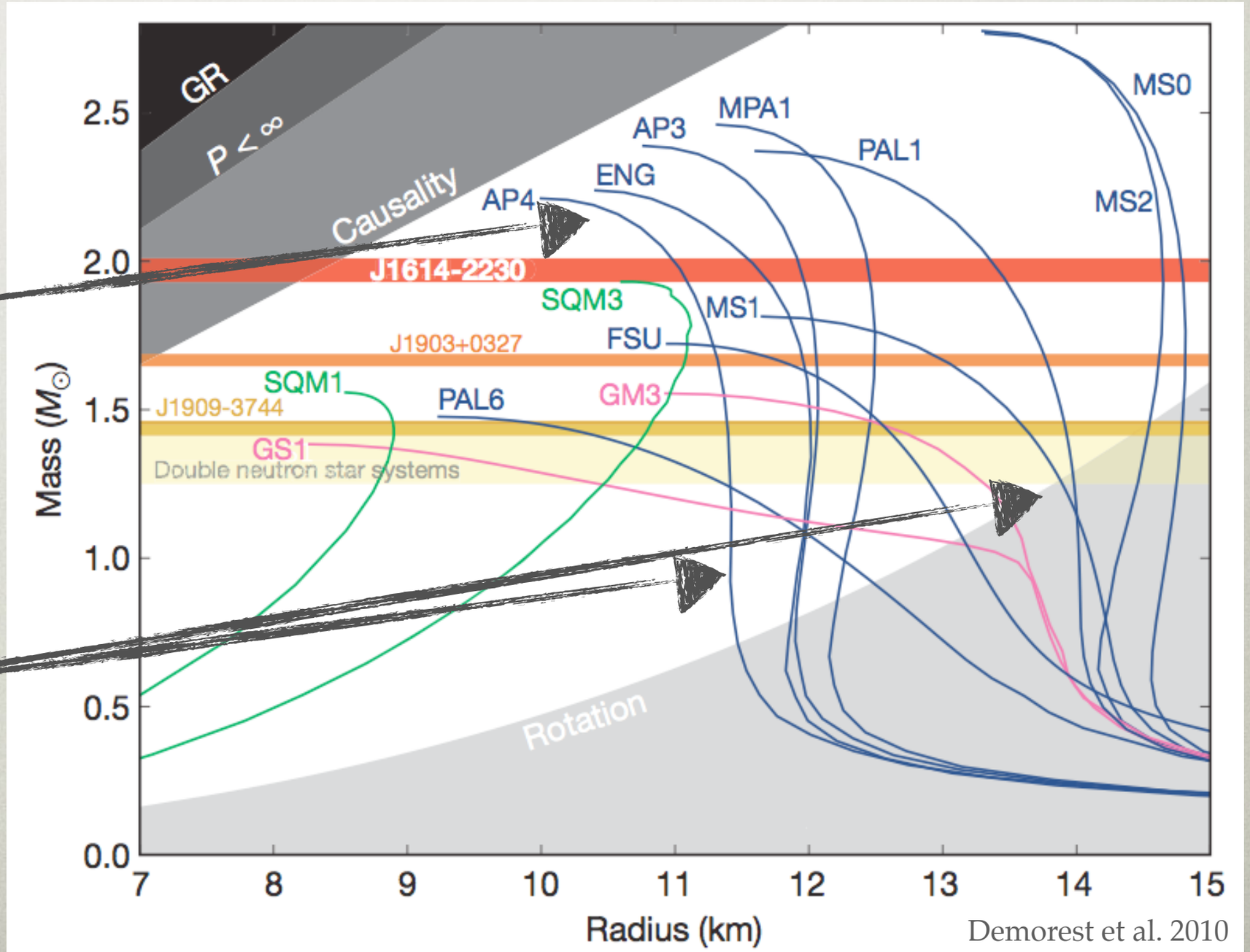


The Equation of State

- Measuring both mass and radius in a given neutron star is experimentally difficult.
- Statistical properties of radii and masses can independently restrain the phase space.

Maximum mass

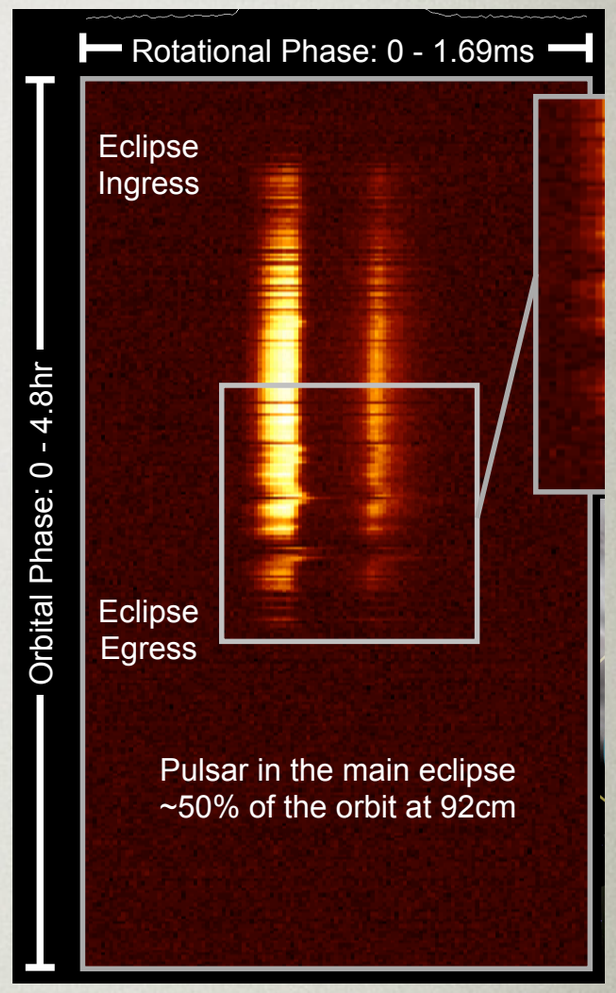
Range of radii



Demorest et al. 2010

Spiders: Black Widows and Redbacks

- Fast millisecond pulsars (≲5 ms)
- Short, circular orbits (75 minutes - 15 hours)
- Large spin-down luminosity (E_{dot} = few 10^{34} erg/s)
- Radio eclipses (0 - 70% of the orbit)
- Optical flux/colour modulation



(See J. Hessels' talk)

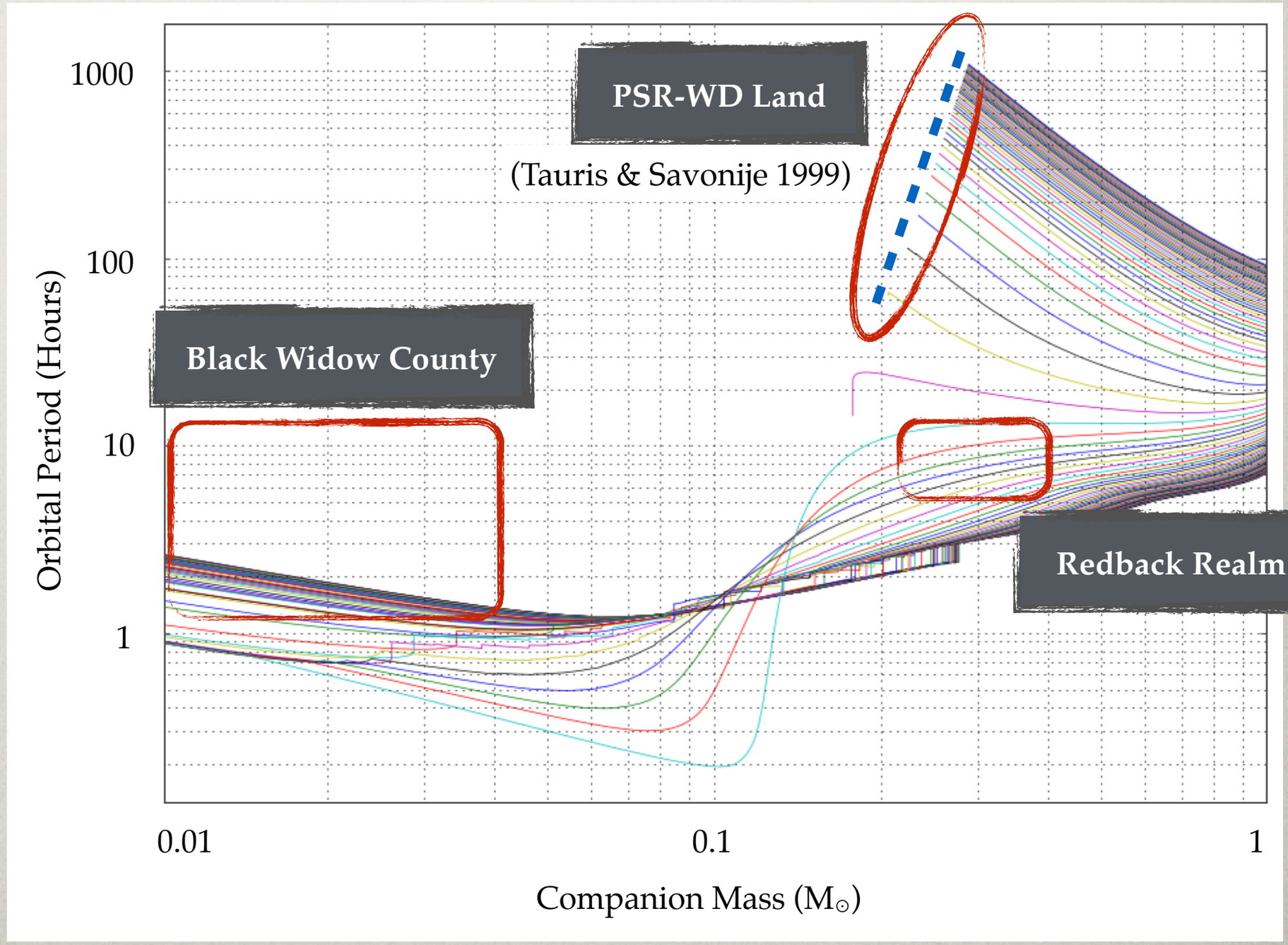
Black Widows

- Very low companion mass (~0.02 $M_\odot$)
- ?

Redbacks

- Low companion mass (~0.2 $M_\odot$)
- Some show state transitions 'MSP ↔ LMXB' (see A. Archibald's talk)

Origin and Fate of Spiders

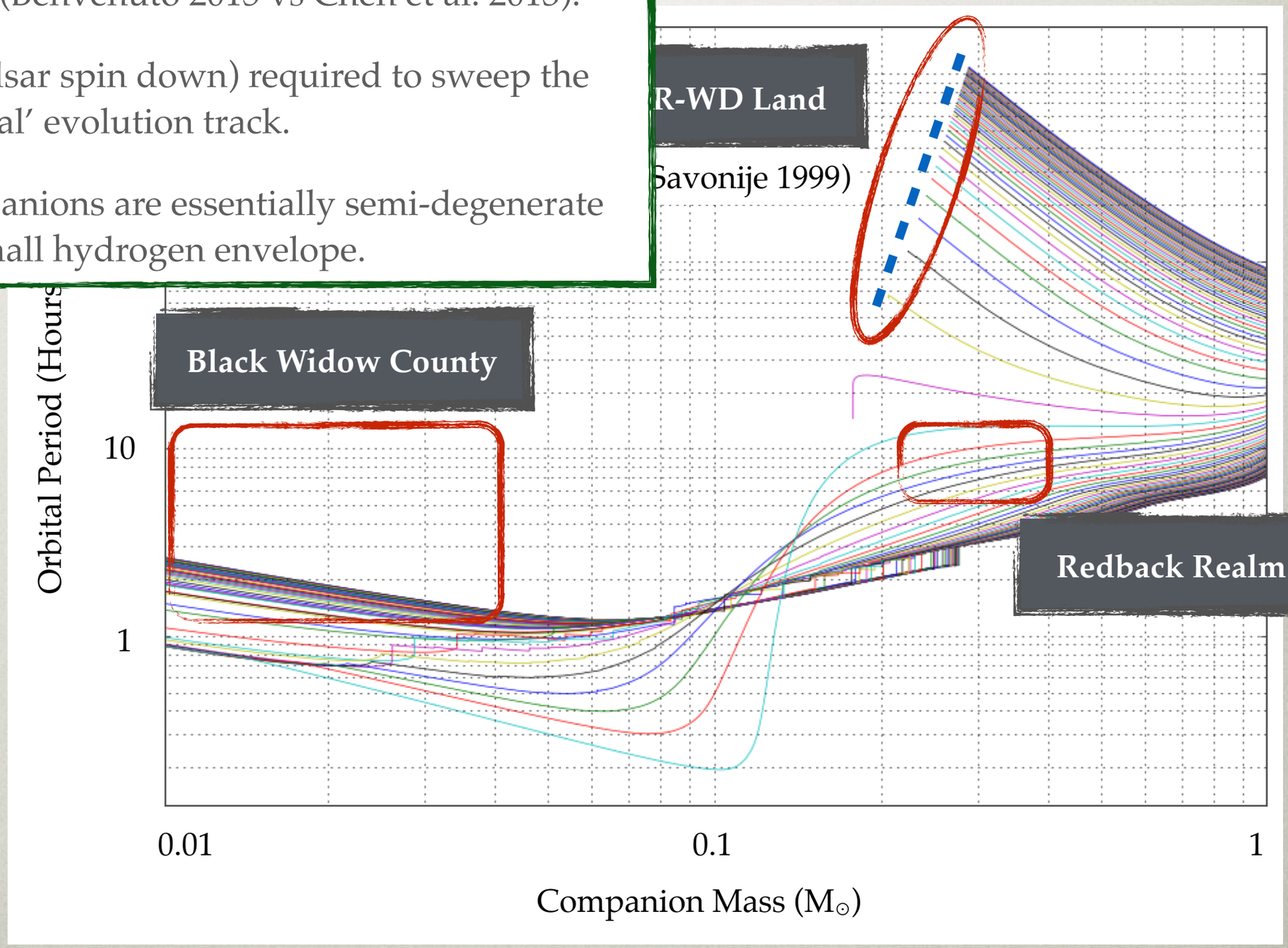


(see e.g. Istrate et al. 2014)

(More in T. Tauris' talk)

Origin and Fate of Spiders

- **Redbacks** unlikely to turn **black widows** because of evolution timescale. (Benvenuto 2015 vs Chen et al. 2013).
- Irradiation (from pulsar spin down) required to sweep the companion of 'normal' evolution track.
- (Black widow) companions are essentially semi-degenerate helium stars with small hydrogen envelope.

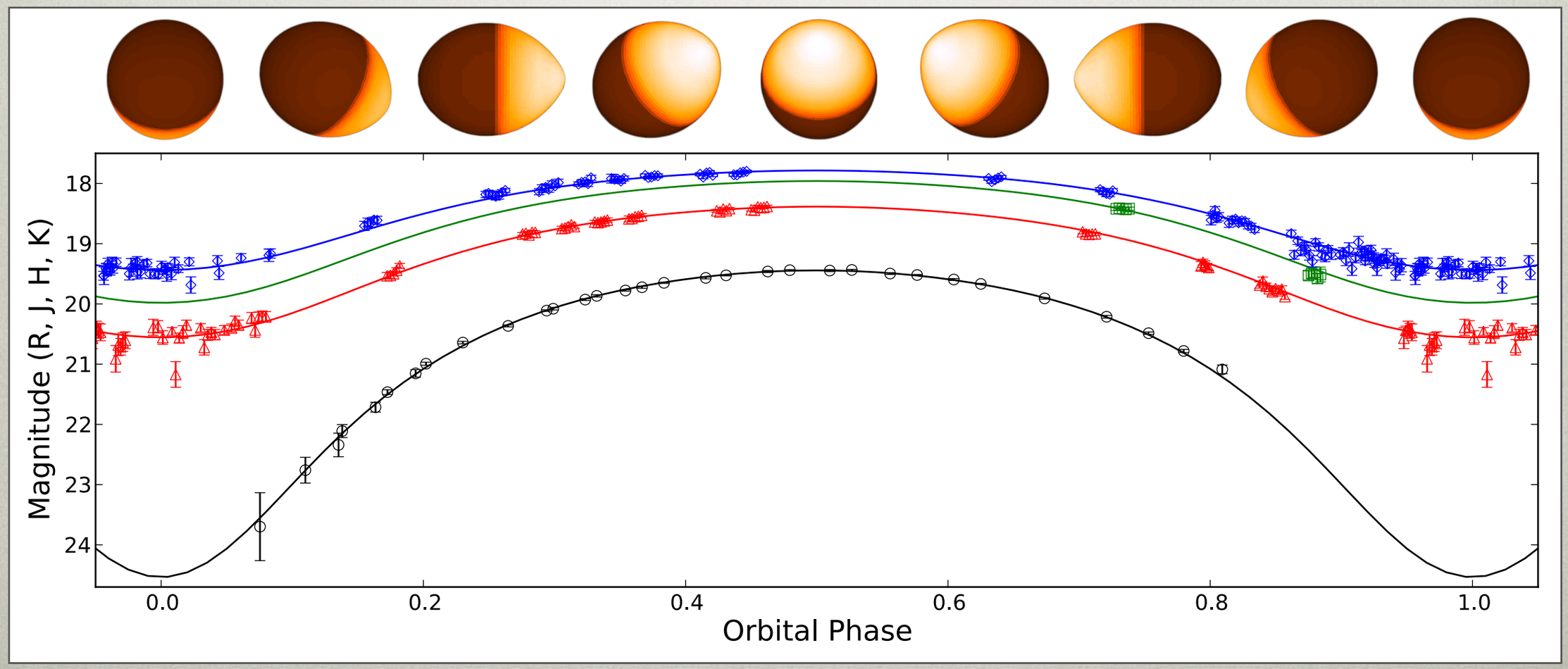


(see e.g. Istrate et al. 2014)

(More in T. Tauris' talk)

How to Measure Masses

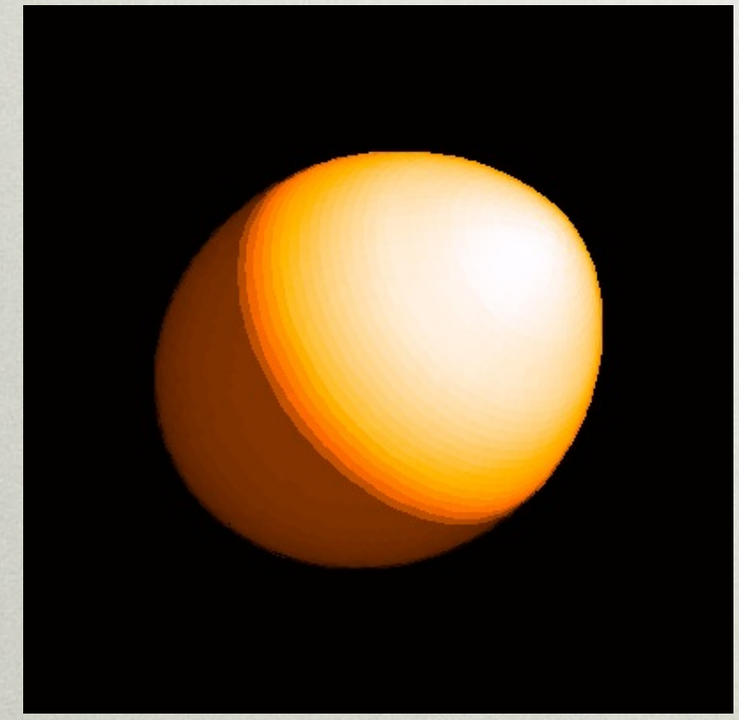
- Pulsar radio timing
  - 5 Keplerian parameters
  - Unknown masses and orbital inclination
- Optical follow-up of the companion
  - Light curves ➔ orbital inclination
  - Spectroscopy ➔ mass ratio (from projected velocity)

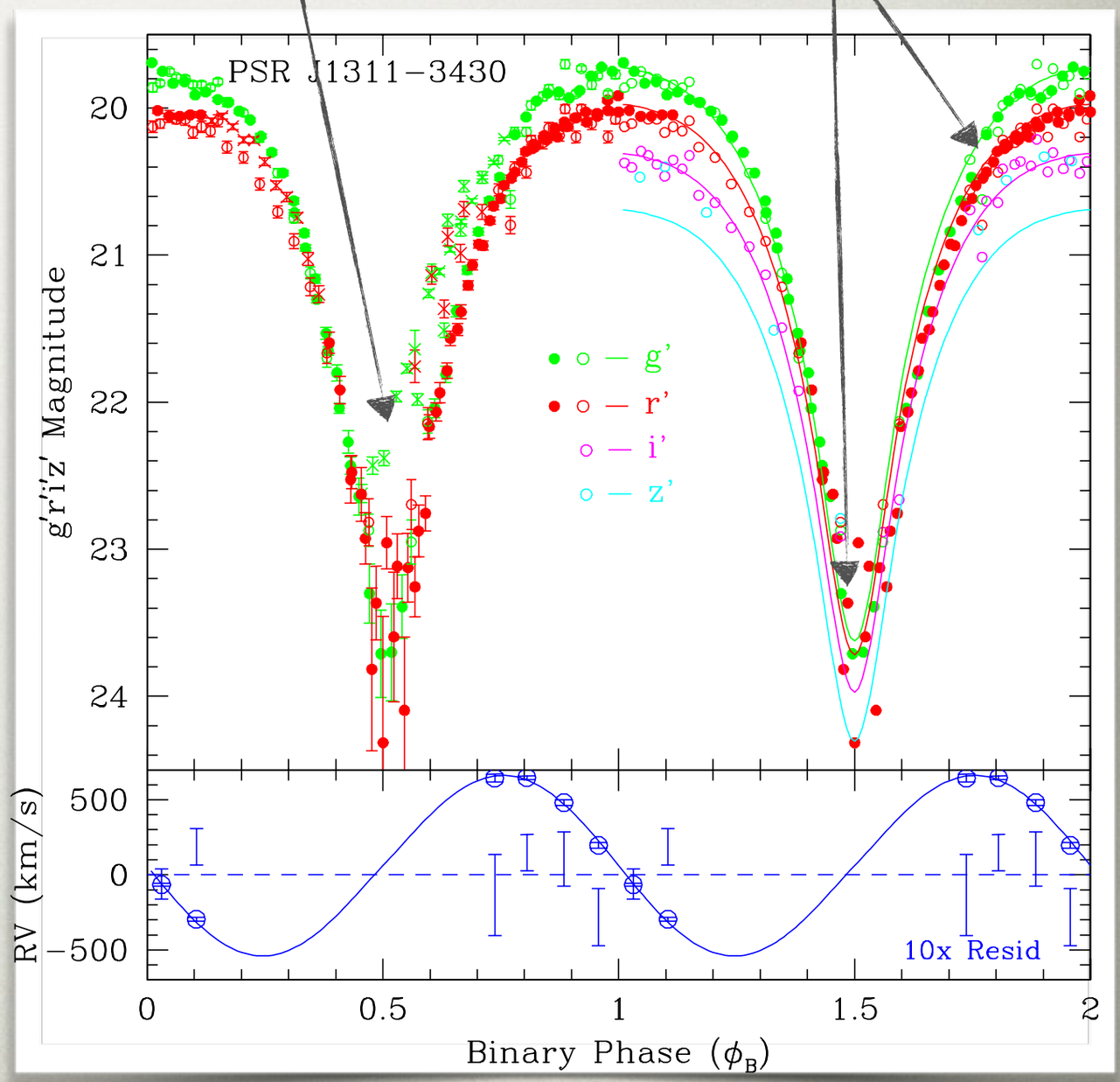


Difficulty #1: Light Curve Modelling

- Irradiated model works well to first order but…
  - Short timescale variability
  - Spotty surface
  - Asymmetric light curve

∴ Hinders orbital inclination measurement





PSR J1311-3430

Romani et al. (2012)
(see also Romani al. 2015)

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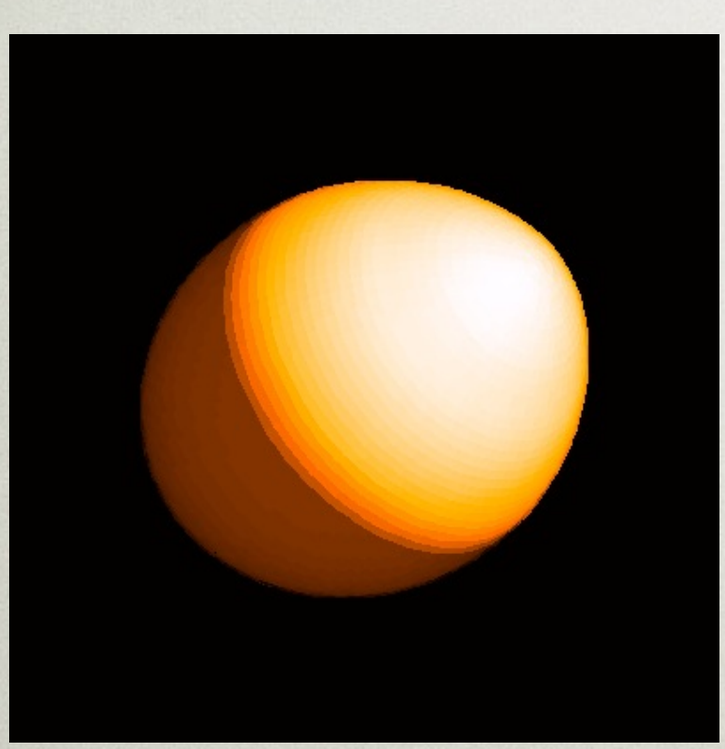
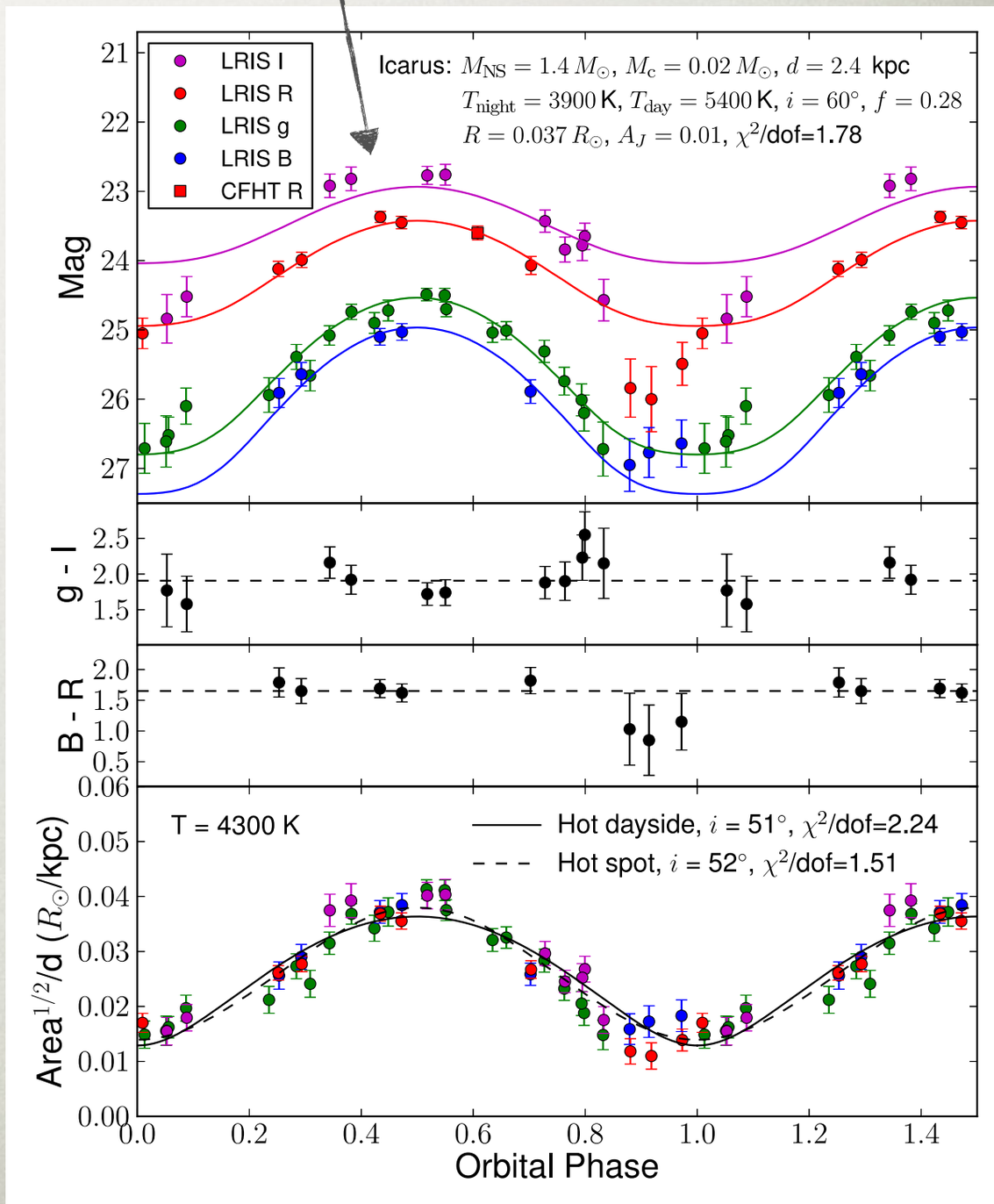


Flux variability but no/little colour change
(difficult to reconcile with eclipses)



PSR J1544+4937 Tang et al. (2014)

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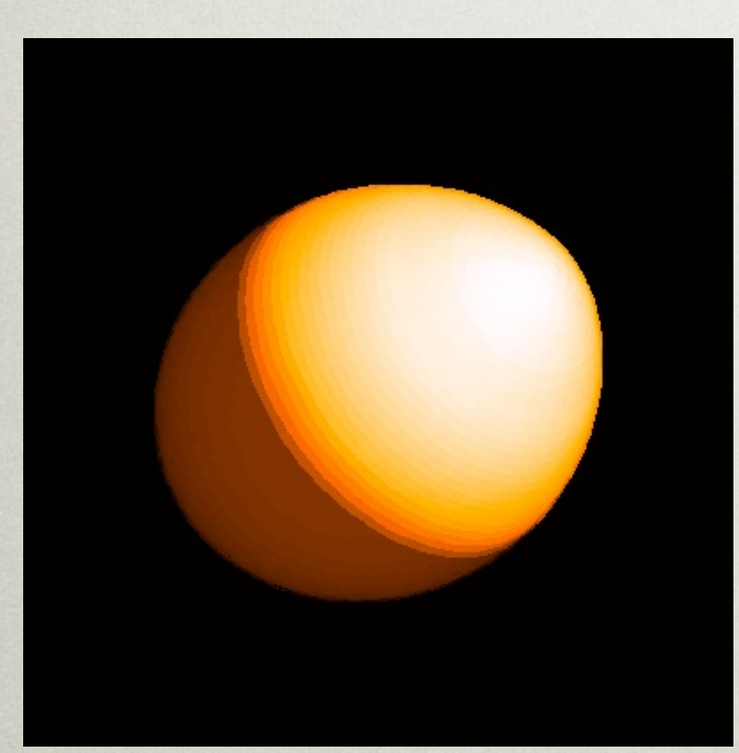
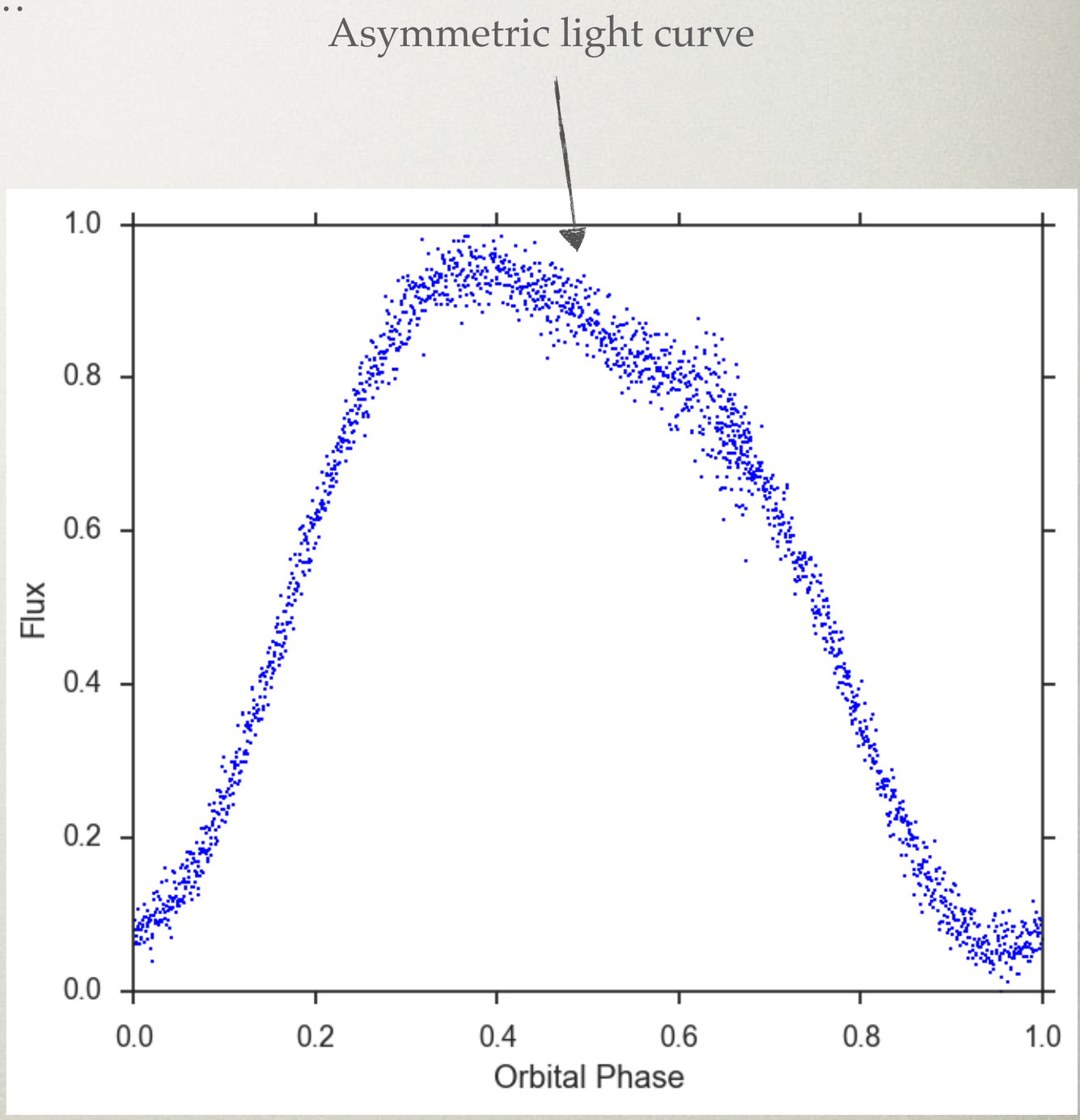


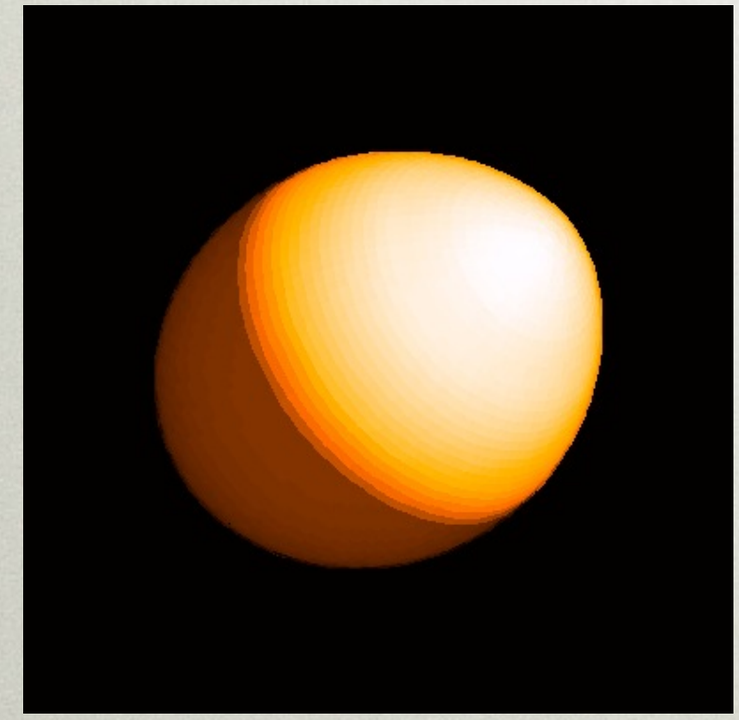


Breton et al. (in prep)

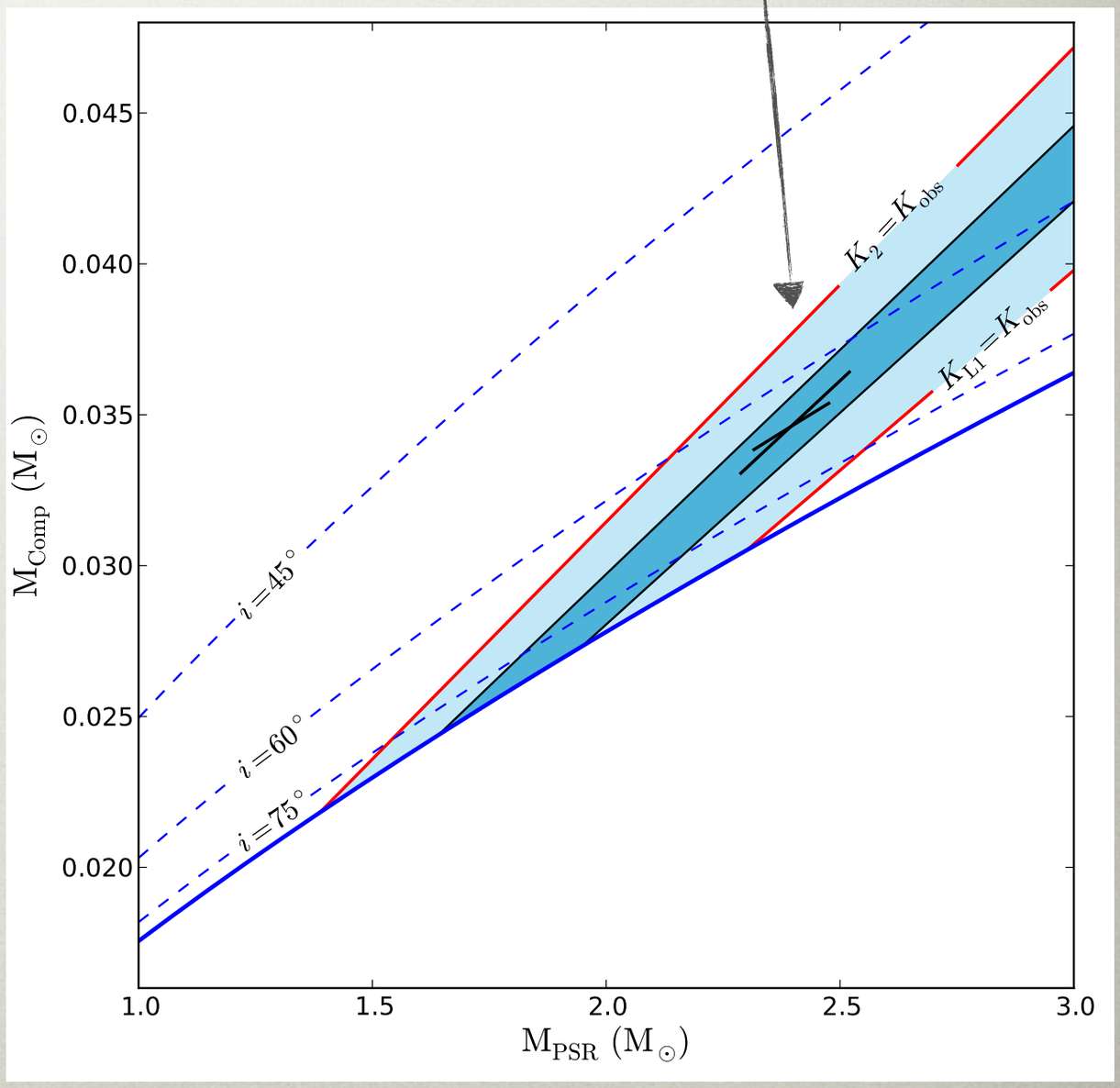
Difficulty #2: Spectroscopic Modelling

- The projected companion velocity doesn't track the centre of mass
  - Solution: use ICARUS to model spectrum directly
- Spectral 'features' departing from LTE

∴ Hinders mass ratio measurement



Where is the 'centre of light'?



van Kerkwijk et al. (2011)

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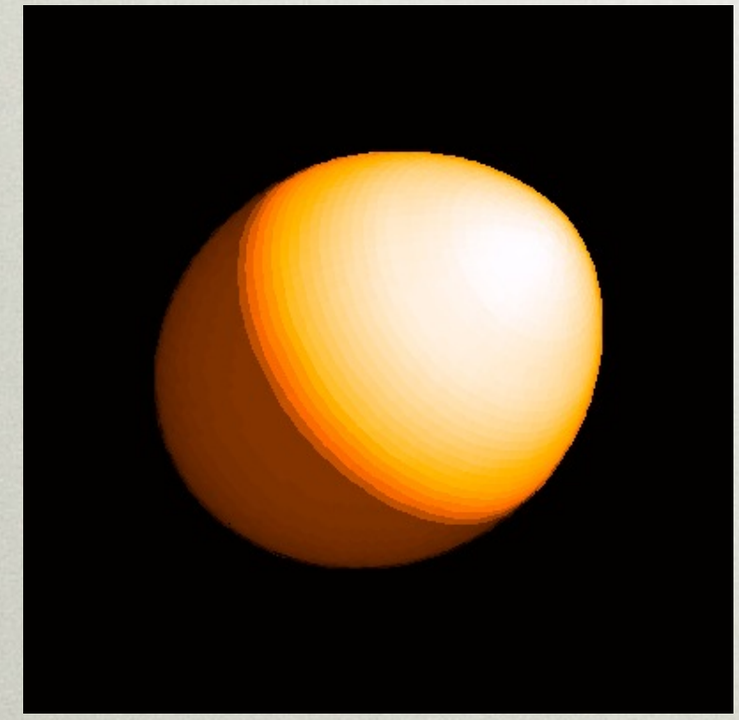
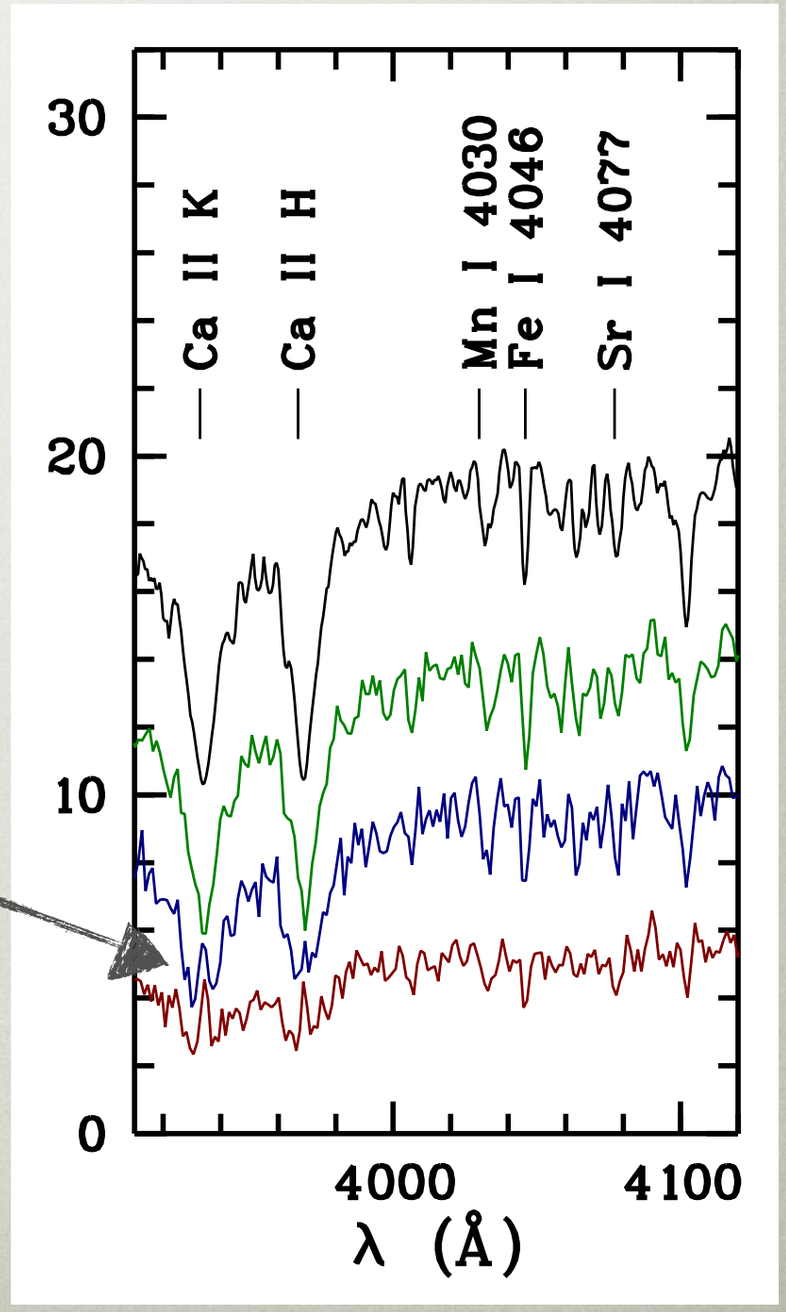
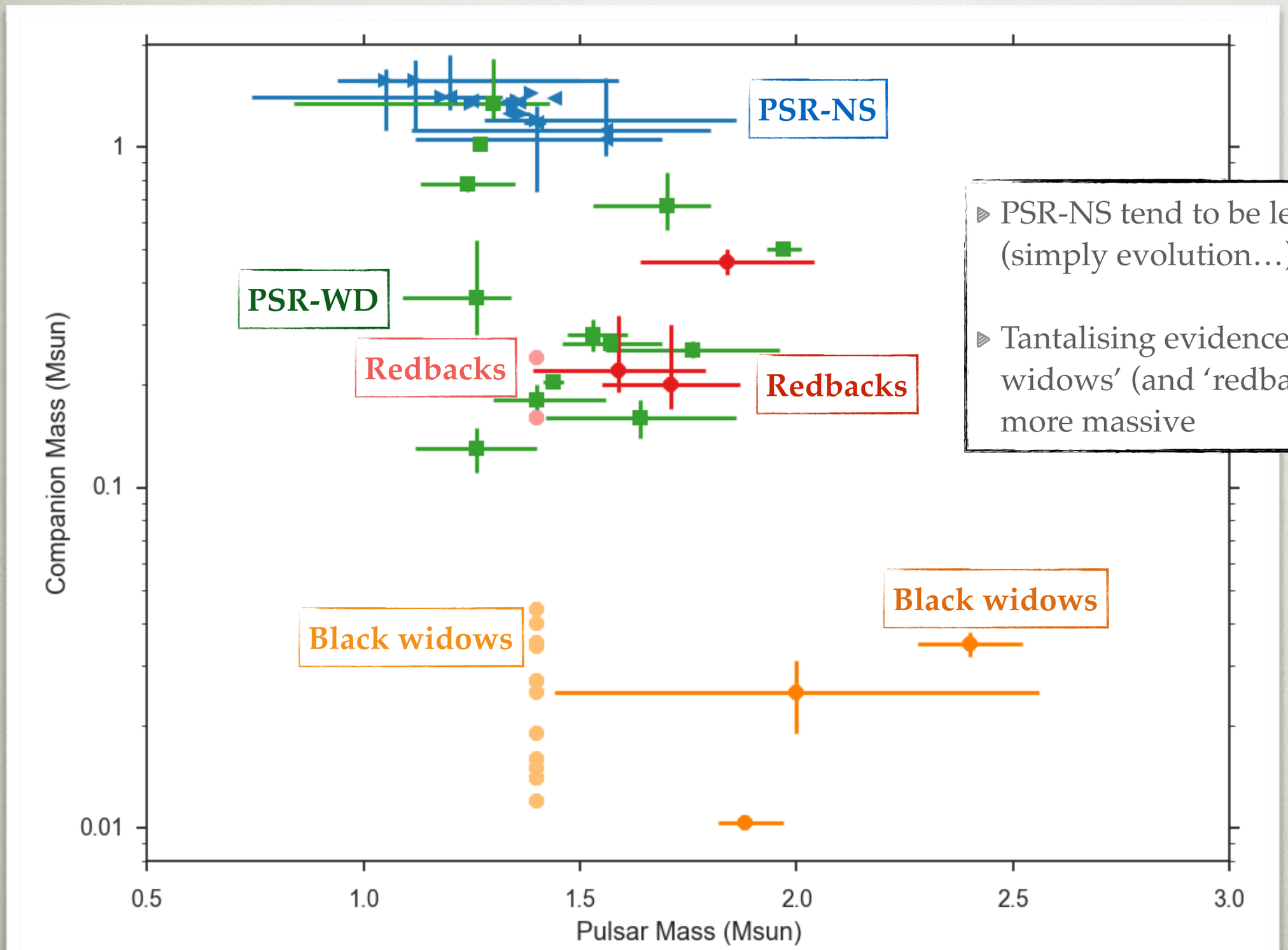


Emission cores



van Kerkwijk et al. (2011)

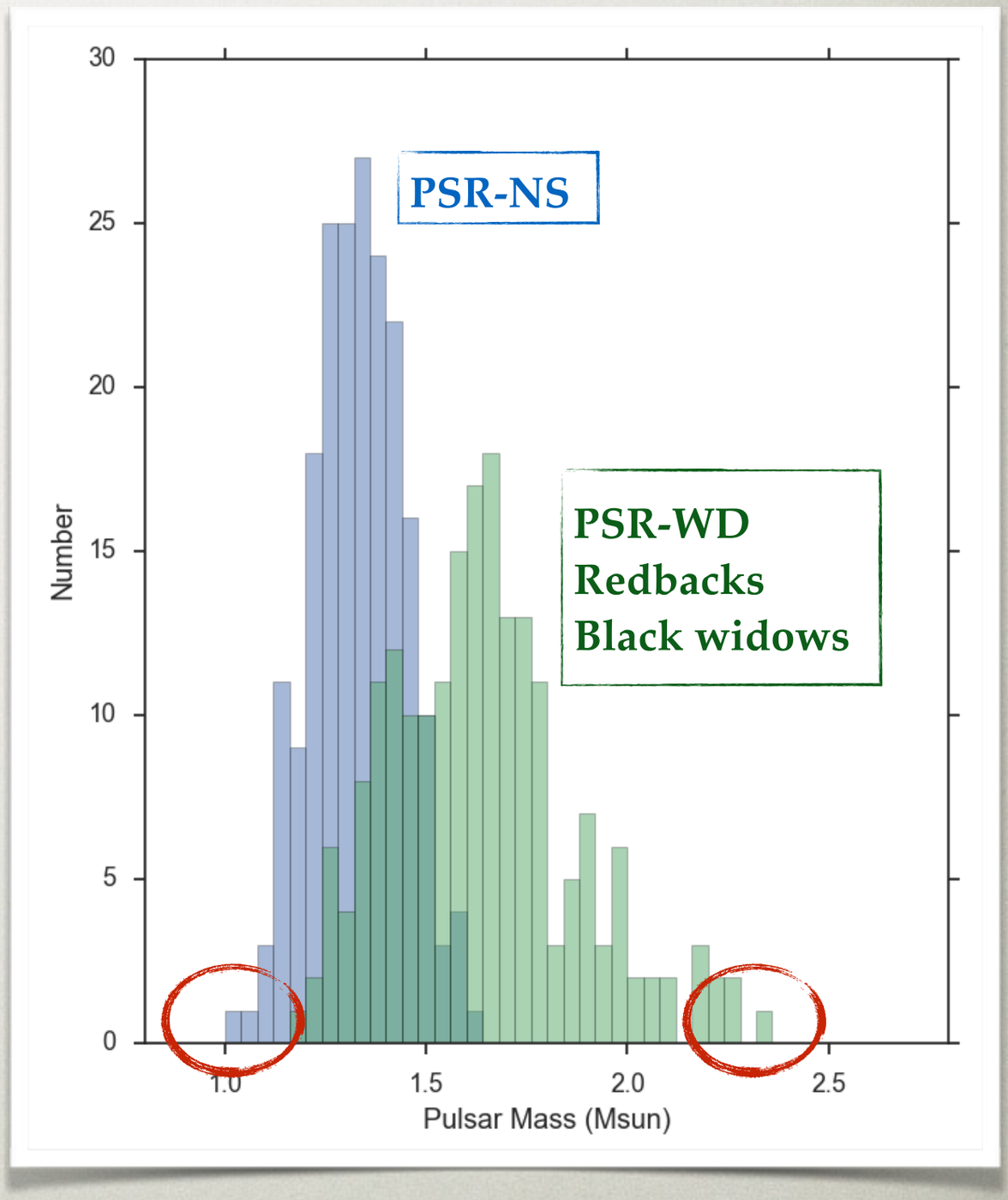
The Pulsar Mass Landscape



- PSR-NS tend to be less massive (simply evolution…)
- Tantalising evidence for 'black widows' (and 'redbacks') to be more massive

Future Prospects: How Light/Heavy?

- SKA should multiply the number of known binary pulsars by ~100
  - Catching light/heavy pulsars
  - Statistical analysis of the mass distribution



Tauris et al. (2015)

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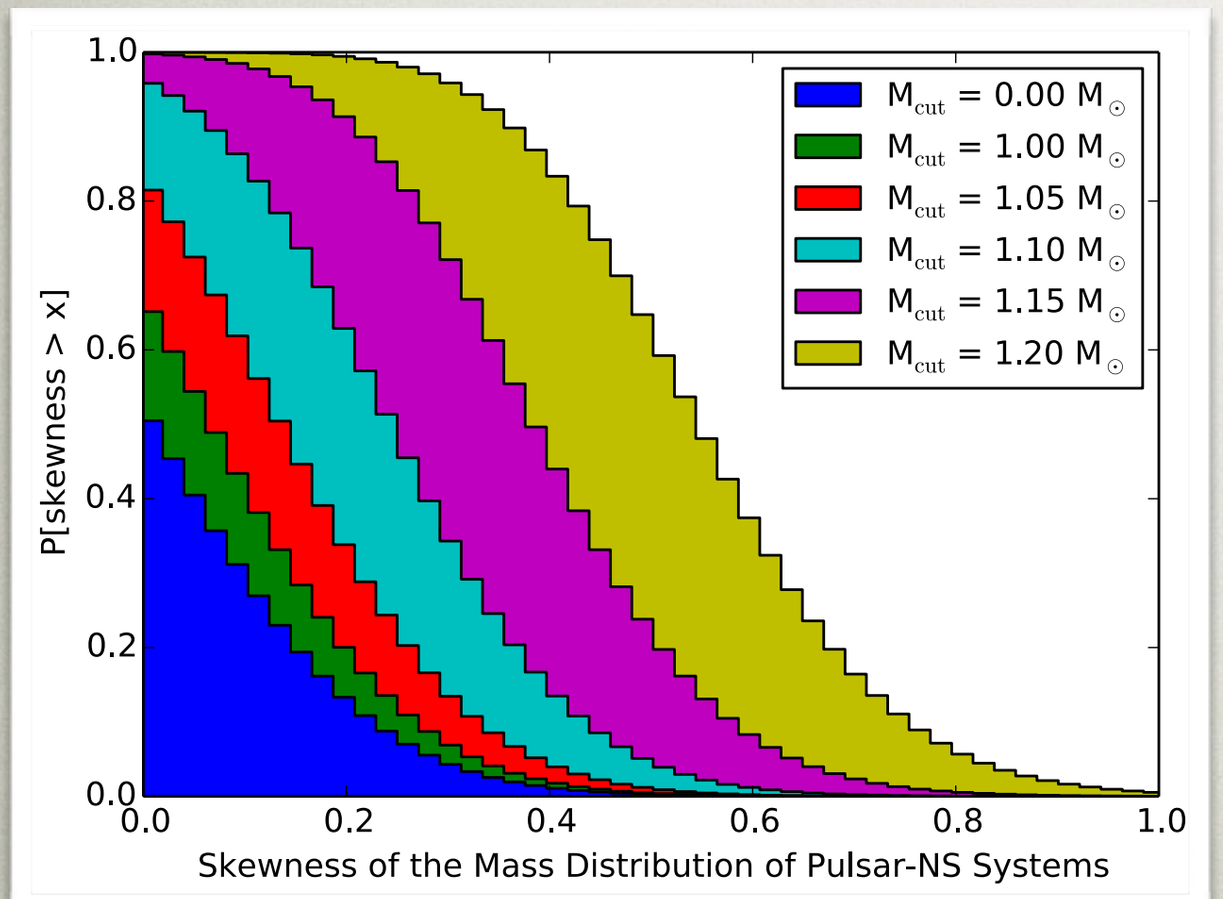

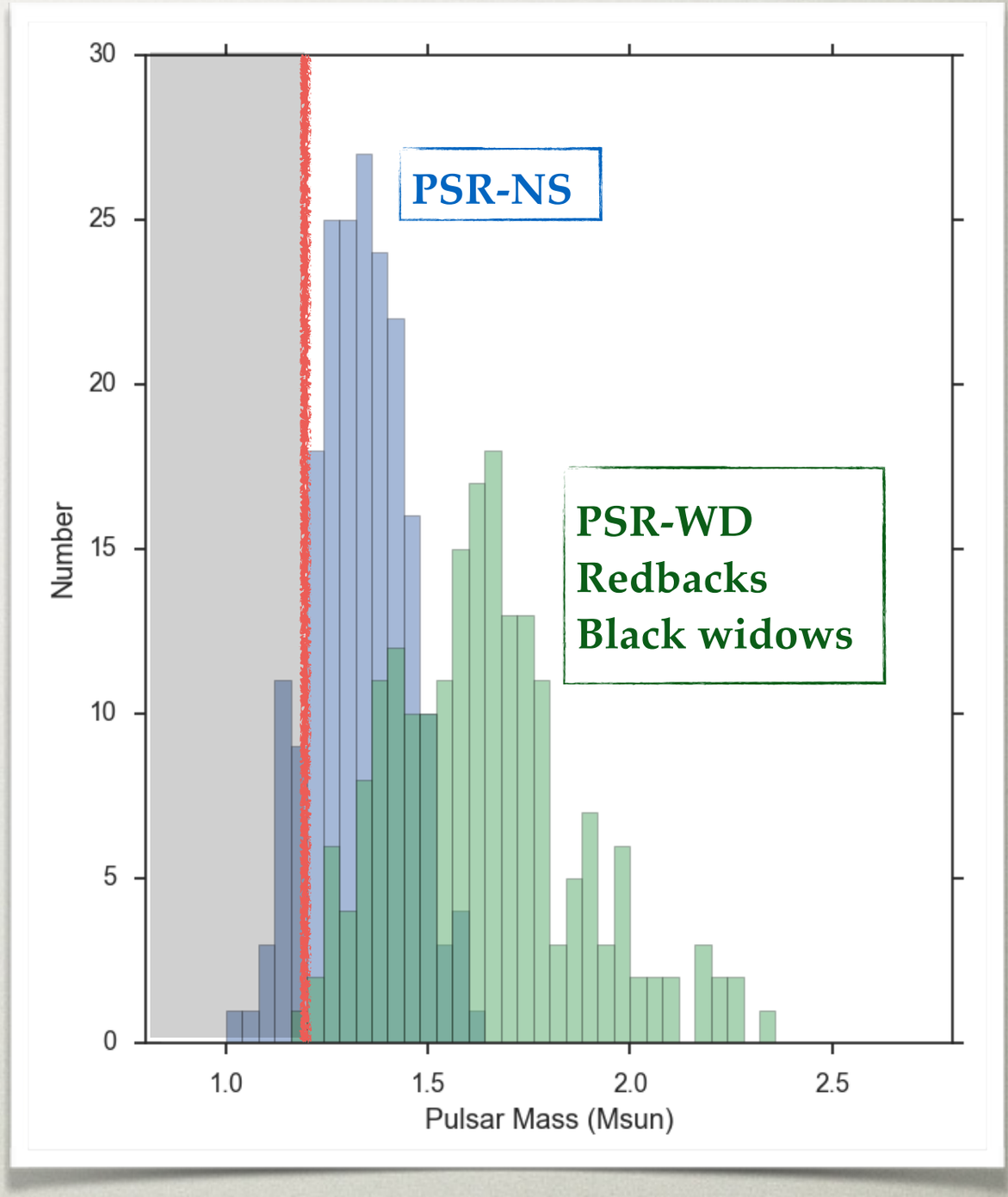

Tauris et al. (2015)

Conclusions & Open Questions

- 3(4) transitioning LMXB-pulsars systems so far
  - All are redback-type
    - Can black widows experience state transition?
- What does trigger the state transition?
- Is the radio pulsar still `on' but screened, or has it turned `off'
- What is happening in the accretion state?
  - Is the radio pulsar still `on' but screened, or has it turned `off'
  - Is the neutron star accreting?
  - Is a jet being launched?