

# Studying Galactic Compact Binaries with LISA

Gijs Nelemans

*Institute of Astronomy, Cambridge*

# Outline

- Introduction: compact binaries
- Formation of compact binaries in the Galactic disc
- A model for the Galactic population: uncertainties
- Current observational tests
- Expected results from LISA
- Gravitational wave astronomy: testing the models with LISA
- Conclusions

# Introduction: compact binaries

Ultra-compact binaries:  $P < 1$  hr: compact stars

$$R \leq R_L = 0.46a \left( \frac{M}{(M + m)} \right)^{1/3}$$

$$a^3 = P^2 G(M + m) / 2\pi$$

$$\Rightarrow R_L \sim P^{2/3} M^{1/3}$$

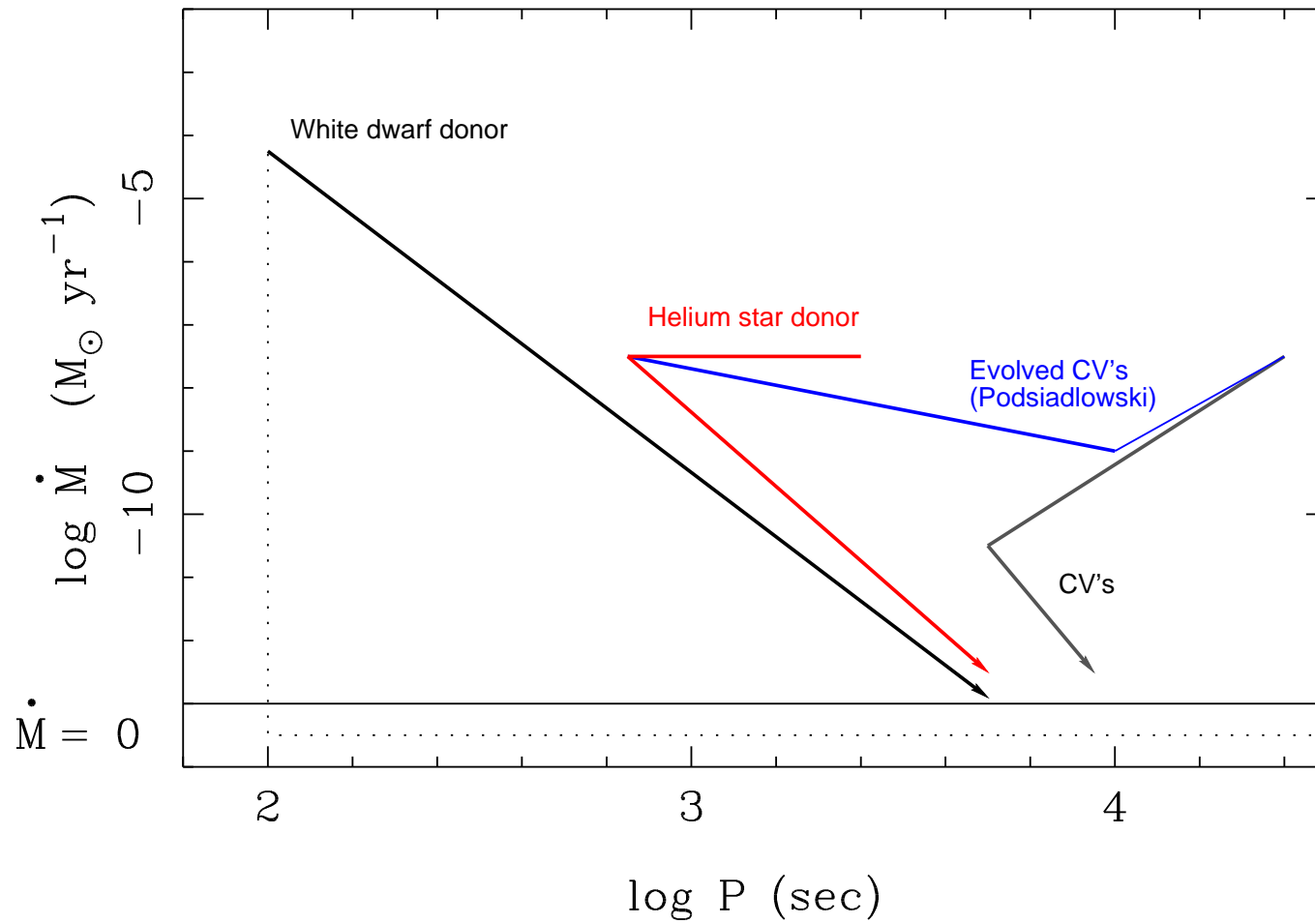
$$\bar{\rho} = M / (4/3\pi R^3) \geq M / (4/3\pi R_L^3)$$

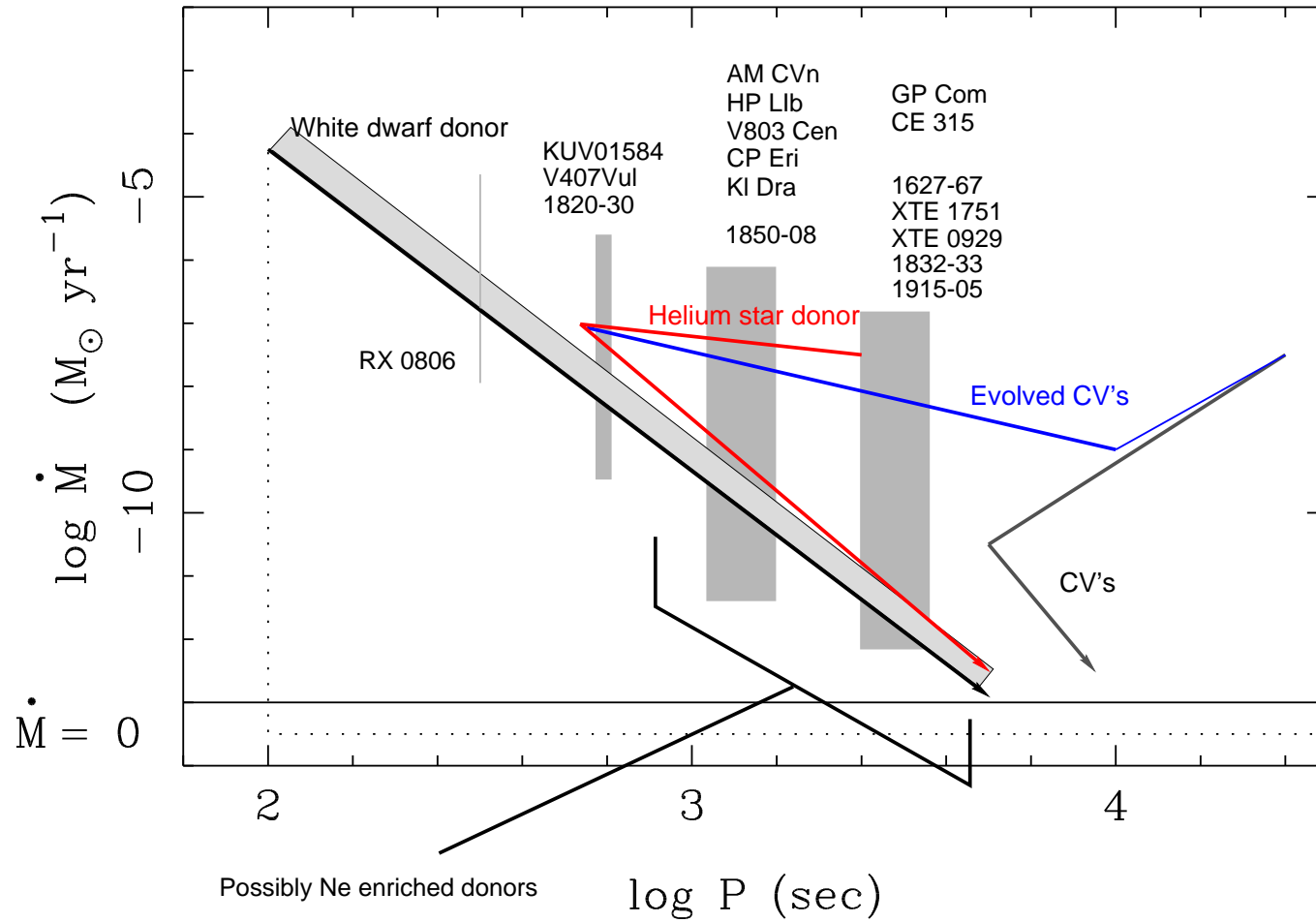
$$= 1.45 \cdot 10^3 (P/1000)^{-2} \text{gr/cm}^3$$

- Helium stars, white dwarfs, neutron stars black holes

# Formation of compact binaries

- Formation of two compact stars in close binaries: two common envelope phases
- Mass transferring systems:
  - With white dwarf donors: AM CVn systems
  - With neutron star (black hole) donors: ultra-compact X-ray binaries
- Three main formation scenarios
  - White dwarf donor + compact object  
*Paczynski 1967, Joss et al 1978*
  - Helium star + compact object  
*Savonije et al. 1986, Iben & Tutukov 1991*
  - From CV's with evolved donors  
*Tutukov et al 1987, Podsiadlowski et al 2002*





# A model for the Galactic population

- Description of stellar and binary evolution
  - $M, R, L, M_{\text{core}}$  as function  $M_i, t$
  - Recipe for effect of winds, mass transfer, supernova etc on orbit
- Initial parameter distributions
  - $M$  (IMF),  $m/M$ , separation  $a$ , eccentricity  $e$
- Normalization and space distribution
  - Star formation history
  - Binary fraction
  - Galactic distribution

# Our model

- Alternative description common envelope

*Nelemans, Verbunt, & Yungelson, 2000, A&A, 360, 1011*

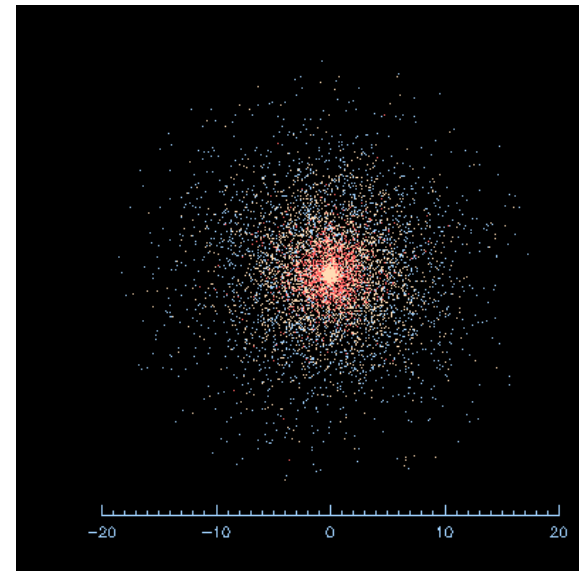
- IMF

*Kroupa, Tout & Gilmore, MNRAS, 262, 545*

- Galactic model

*Boissier & Prantzos, 1999, MNRAS, 307, 857*

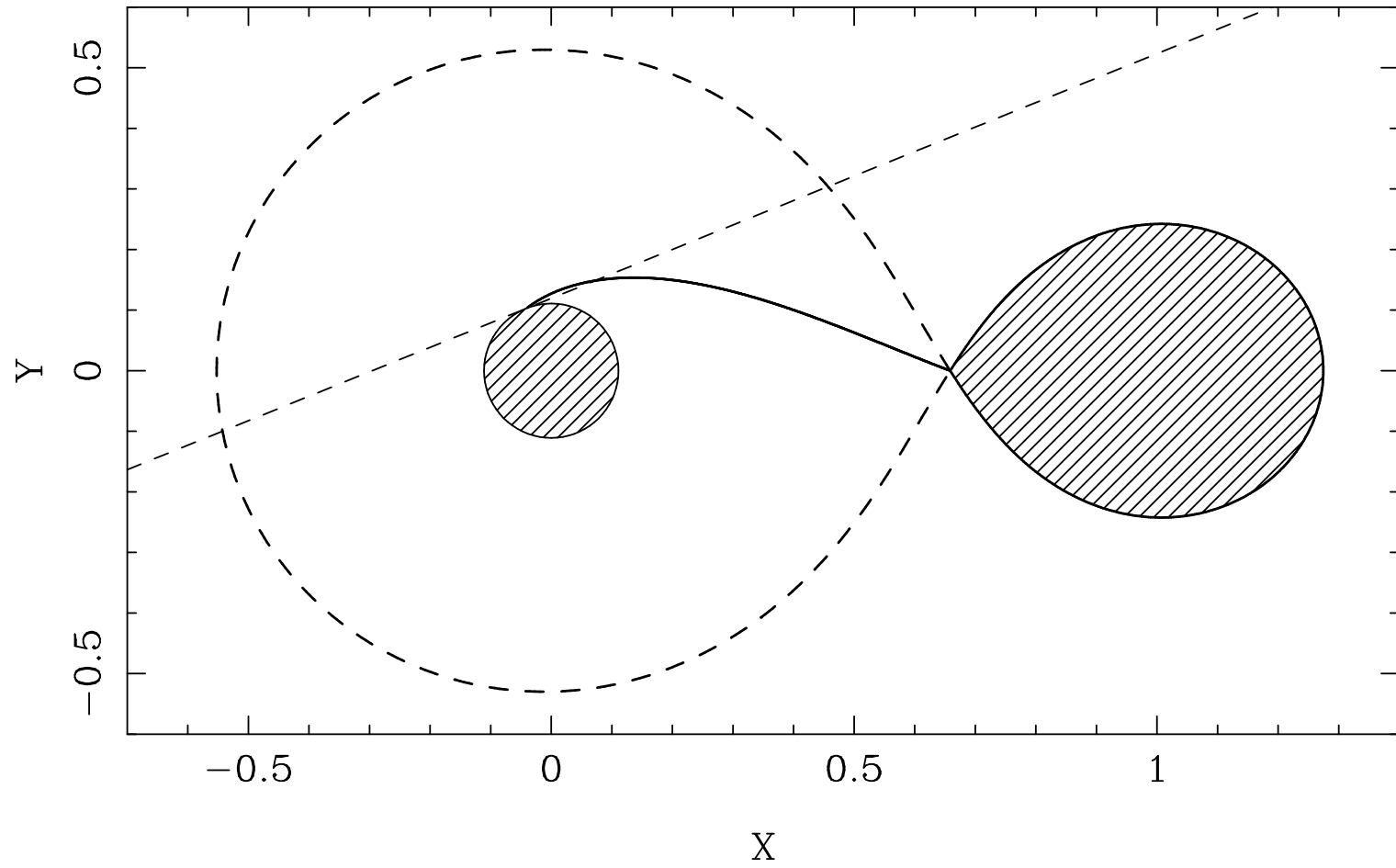
- Inside out disc formation
- $\text{SFR}(R, t) \propto \Sigma_G^{1.5} R^{-1}$
- Added bulge: mass consistent with dynamics and micro-lensing



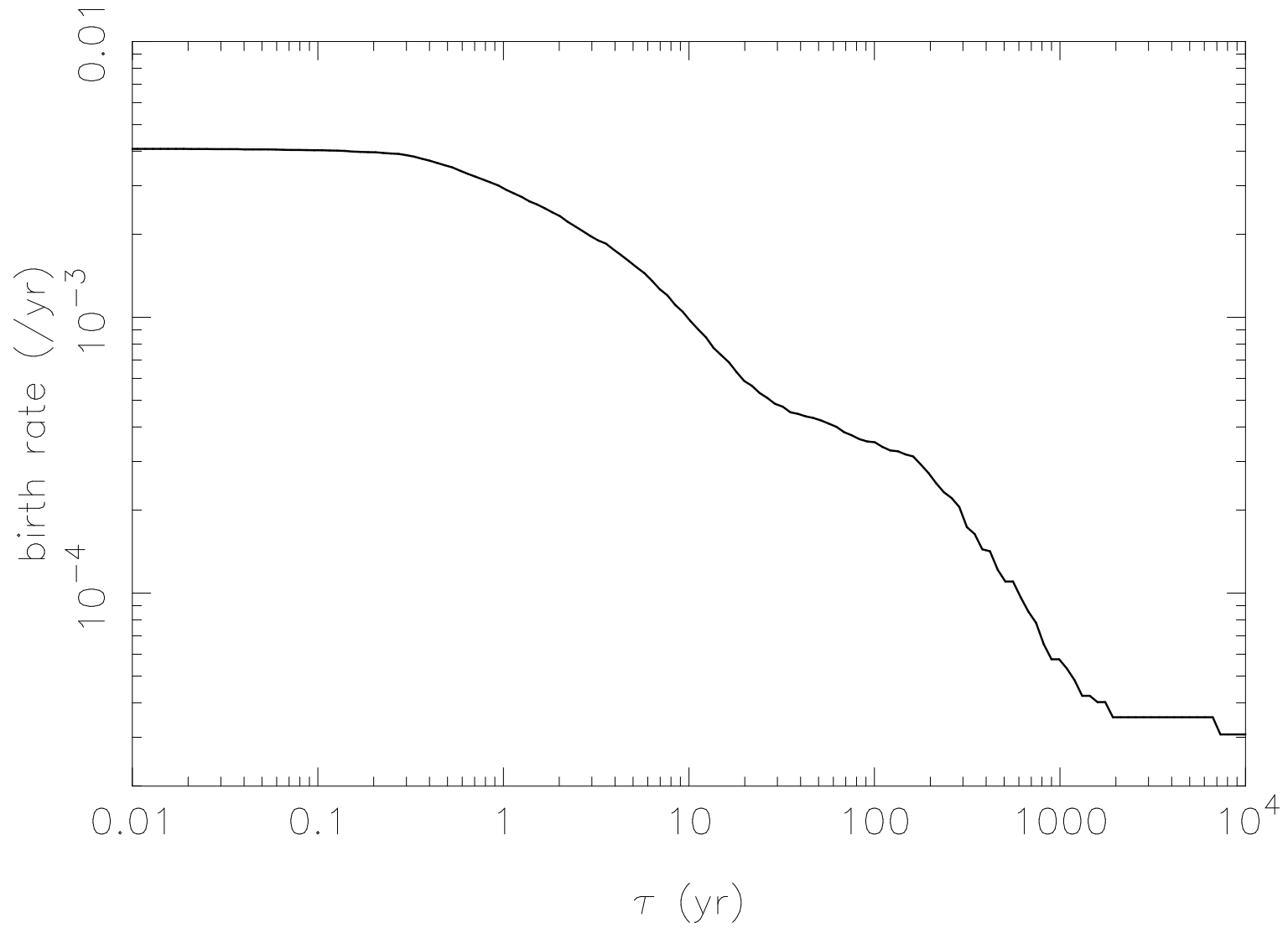
# Galactic model – uncertainties

- Uncertainties in binary evolution: common envelope, stellar wind from helium star, neutron star kick
- Uncertainty in formation AM CVn systems: direct impact and edge-lit detonation
- Uncertainties in “normalization”: IMF, star formation history, Galactic structure
- Result in rather large uncertainties: we have to test models with observations

$M1 = 0.5, M2 = 0.1$



*Nelemans et al 2001, Mash & Steeghs 2002*



*Marsh, Nelemans & Steeghs, submitted*

# Current observational tests

## Double white dwarfs

- In 1990's: 15 (low-mass) double white dwarfs

*Marsh, 2000, NewAR, 44, 119*

- Periods: 1.5 hr - 30 days
- New double white dwarf observations, the SPY project  
ESO VLT survey of  $\sim 1500$  white dwarfs for radial velocity variations (PI Napiwotzki)
- Current status:
  - Surveyed 497 white dwarfs
  - 94 with radial velocity variations (80 double white dwarfs)
  - 5 period determinations (between 0.3 and 1.5 d)

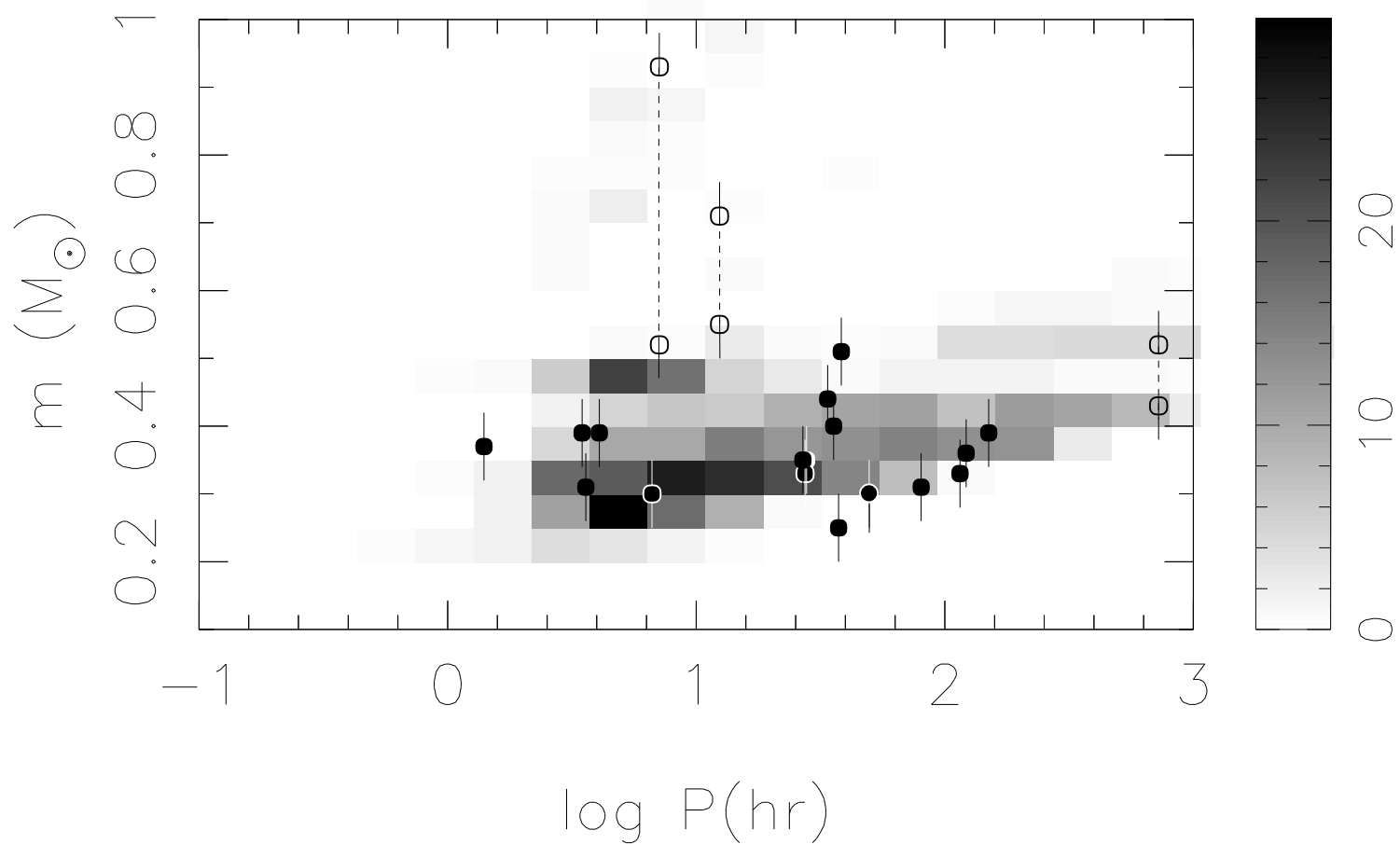
## AM CVn systems

- Up to 1990's: 8 systems
- Periods: 17 - 65 minutes
- Three new (possible) ultra-compact AM CVn systems
  - V407 Vul (RX J1914.4+2456)  
P = 9.5 min, X-ray source  
*Cropper et al. 1998, Ramsay et al. 2002, Mash & Steeghs 2002*
  - KUV 01584-0939  
P = 10.3 min  
*Warner & Woudt, 2002*
  - RX J0806.3+1527  
P = 5.3 min, X-ray source  
*Israel et al. 2002, Ramsay et al. 2002*

# Ultra-compact X-ray binaries

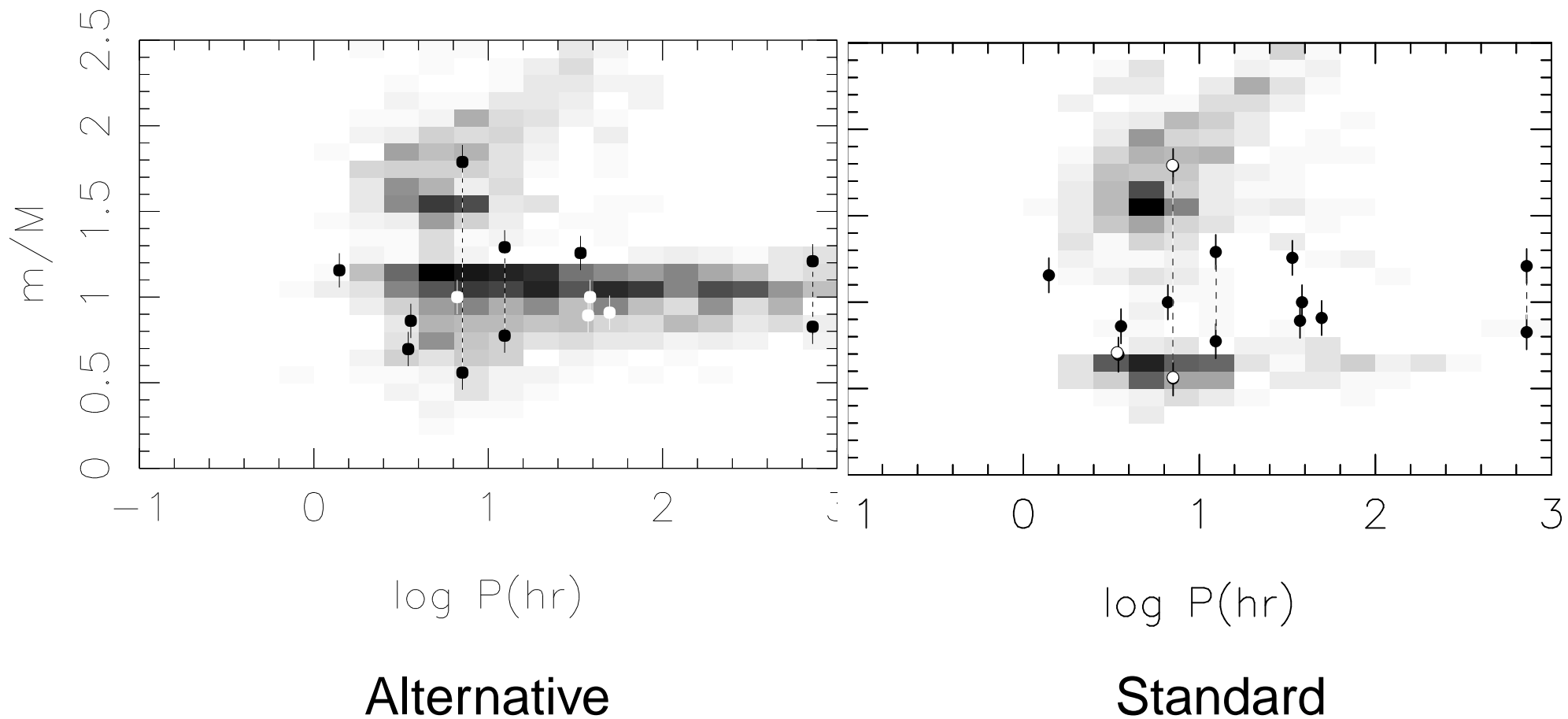
- Up to 1990's: 5 systems
- Periods: 11 - 50 minutes
- Two new systems
  - XTE J1751-305,  $P = 42.4$  min  
*Markwardt et al., 2002, ApJ, 575, L21*
  - XTE J0929-314,  $P = 43.6$  min  
*Galloway et al., 2002, ApJ, 576, L137*
- Another four candidate systems on basis X-ray spectra  
*Juett et al., 2001, ApJ, 560, 59*

## Comparison: double white dwarfs



*Nelemans, Yungelson, Portegies Zwart & Verbunt, 2001, A&A, 365, 491, with updates*

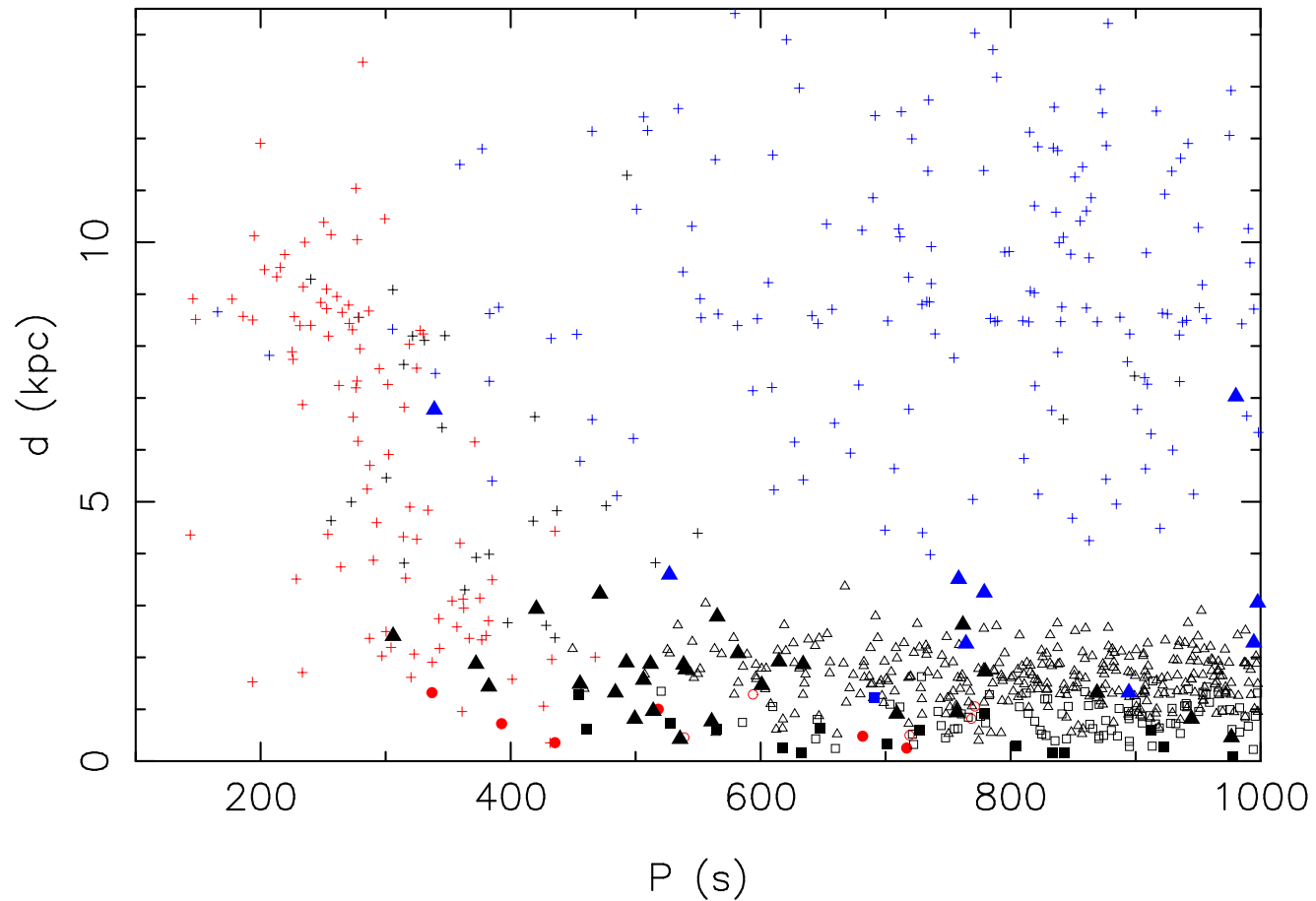
- Alternative common envelope description



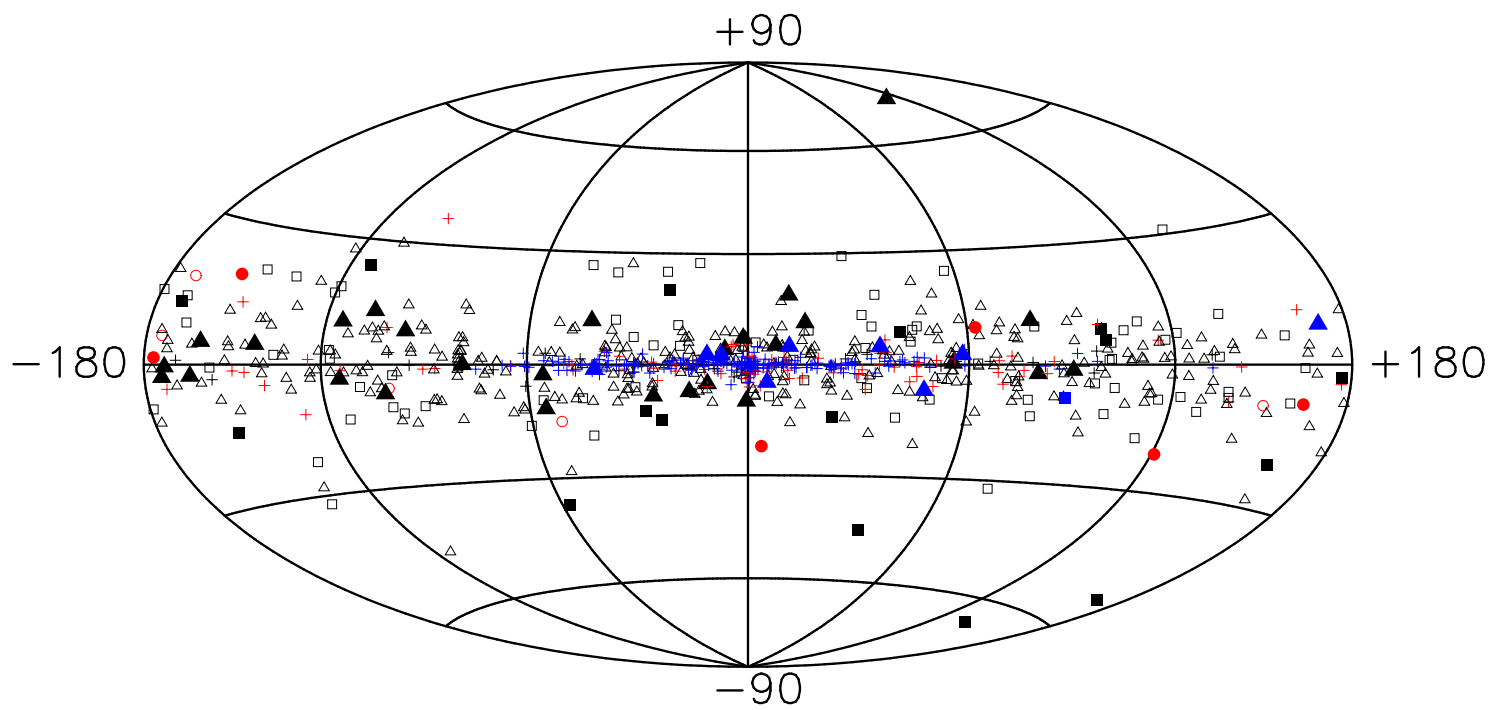
*Nelemans, Yungelson, Portegies Zwart & Verbunt, 2001, A&A, 365, 491, with updates*

# Removing uncertainties with observations?

- Stability of mass transfer in double white dwarfs
  - From observed possible short period systems
- Overall numbers
  - Distances with HST
  - Survey for emission line systems
- New systems from X-ray surveys?
- Chemical abundances from accretion disc spectral modelling



birth rate	( $\text{yr}^{-1}$ )
AM CVn (direct impact)	$1.8 \times 10^{-3}$
UCXB's	$1.9 \times 10^{-5}$

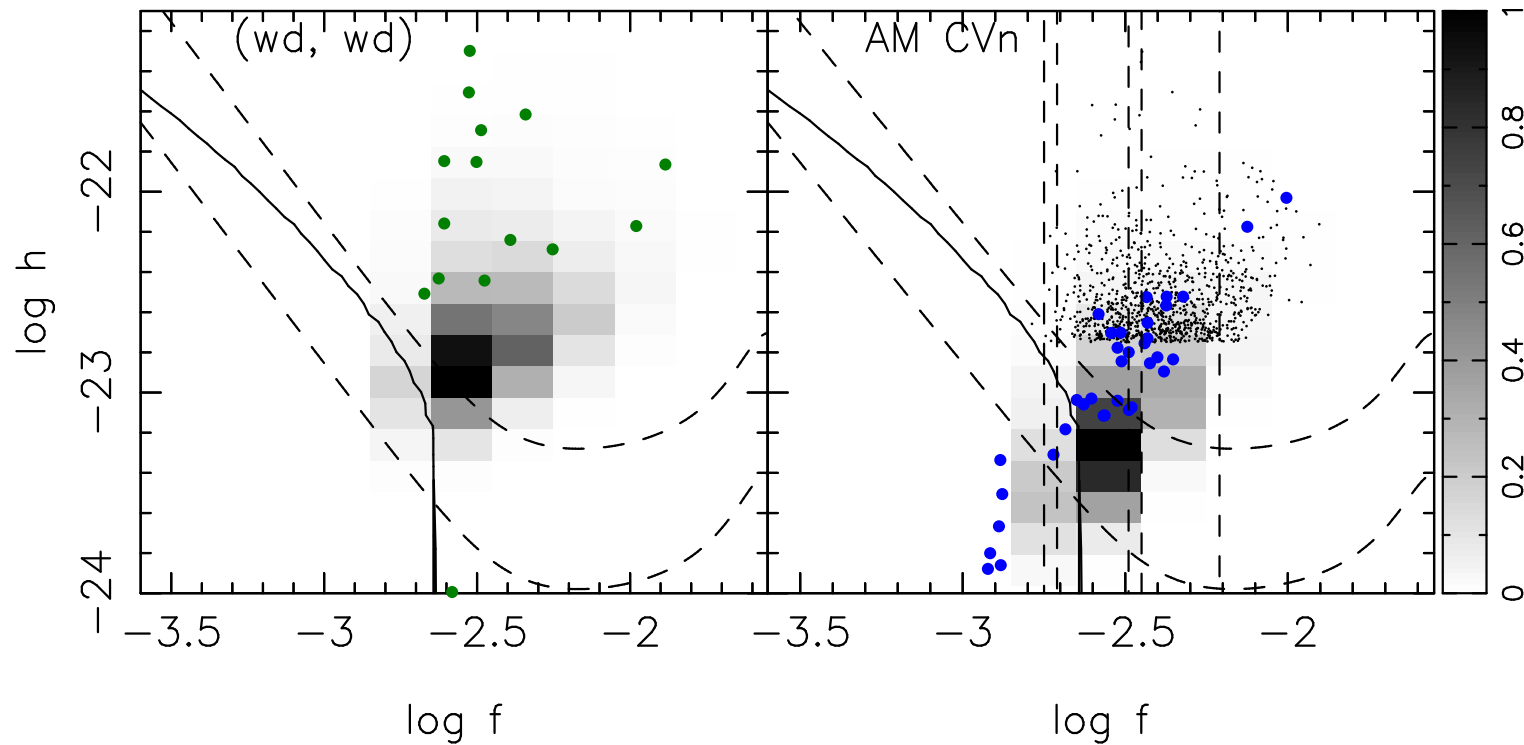


# Expected results from LISA

- Population synthesis including all binaries with compact objects
- Gravitational waves from (all) compact binaries

*Nelemans et al. 2001, A&A, 375, 890*

- No angular resolution included
- Double white dwarf noise background
- Many resolved binaries
- Quite a few with measurable frequency change (all?)



- resolved systems:  $\sim 12000$  (wd, wd),  $\sim 10000$  AM CVn, few tens neutron star binaries

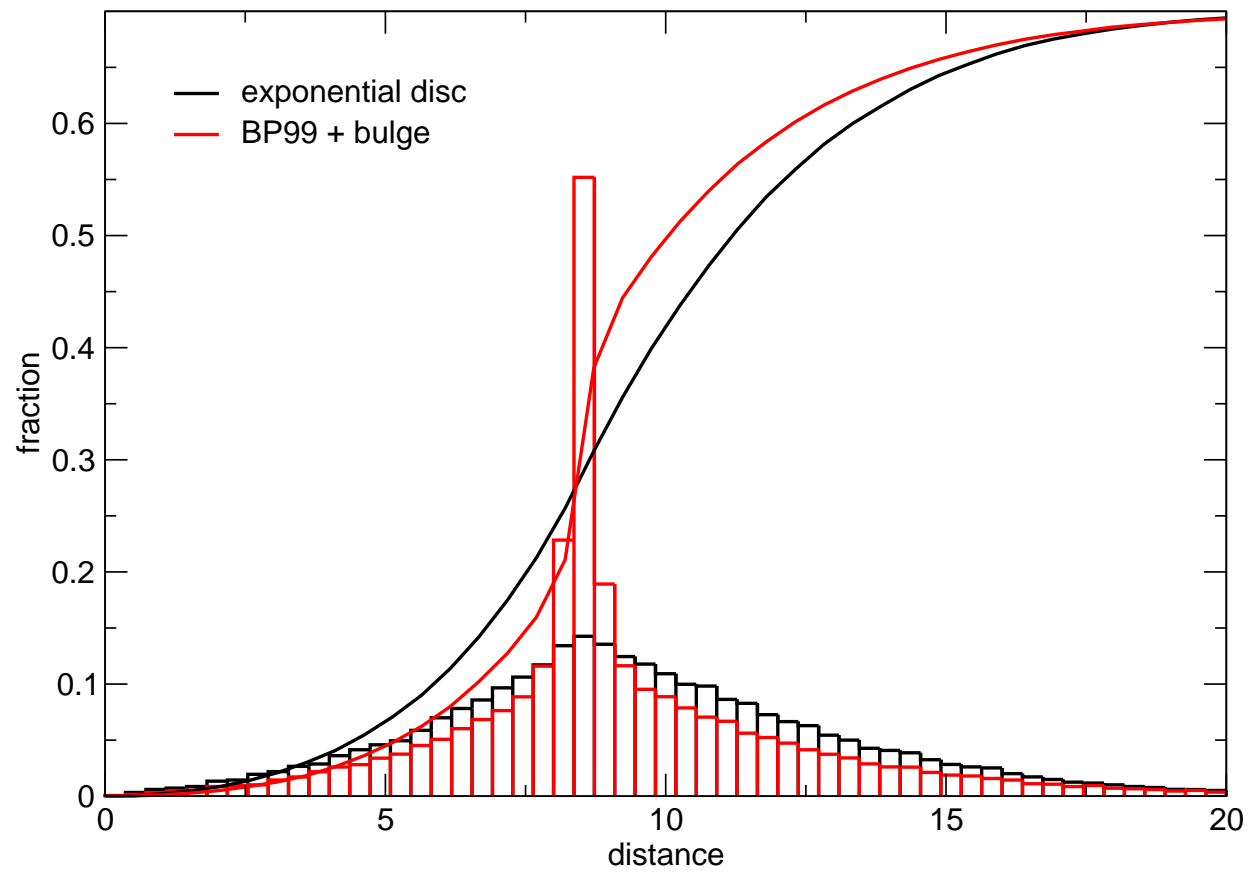
*Nelemans, 2002, LISA symposium proceedings*

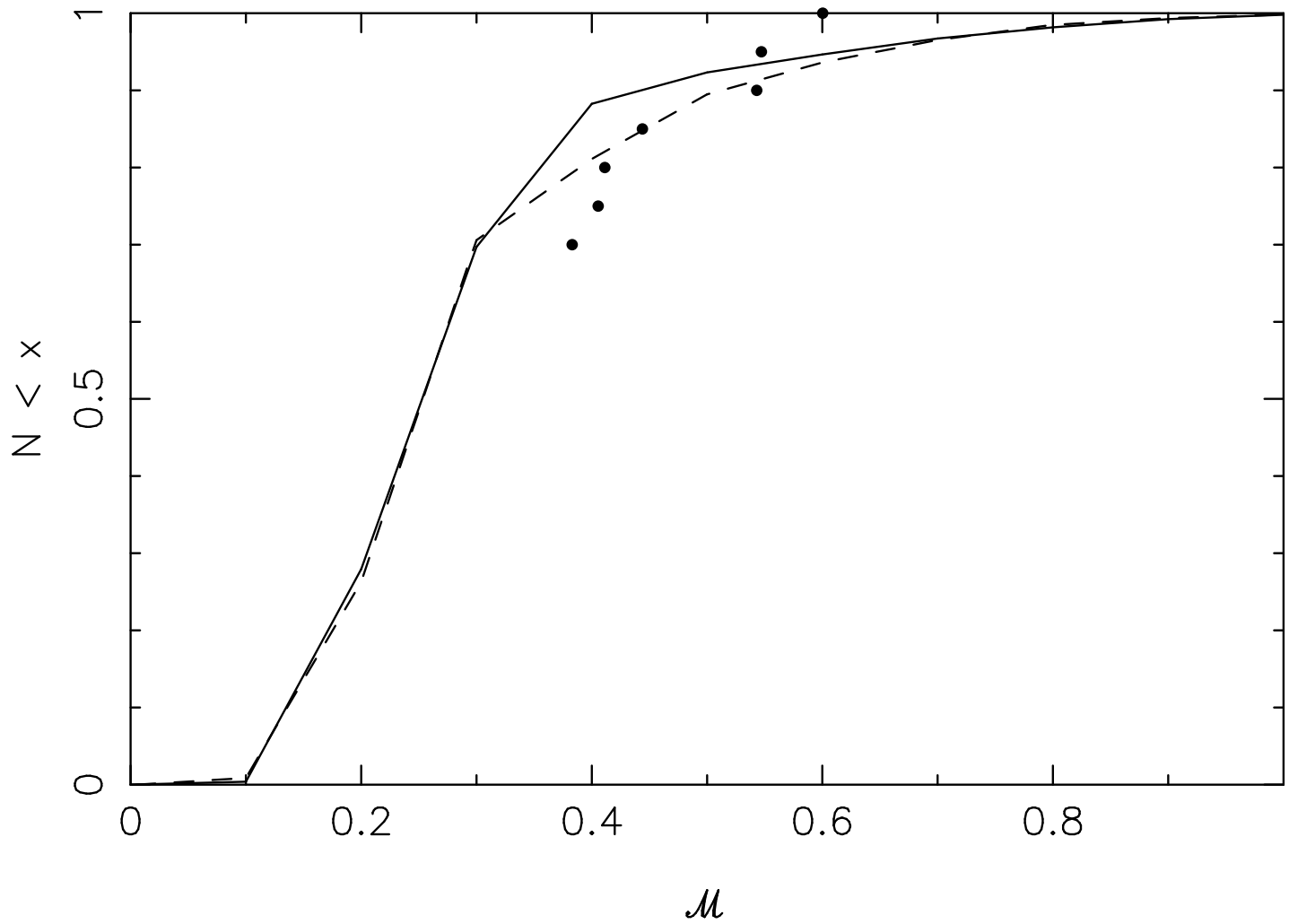
- resolved systems

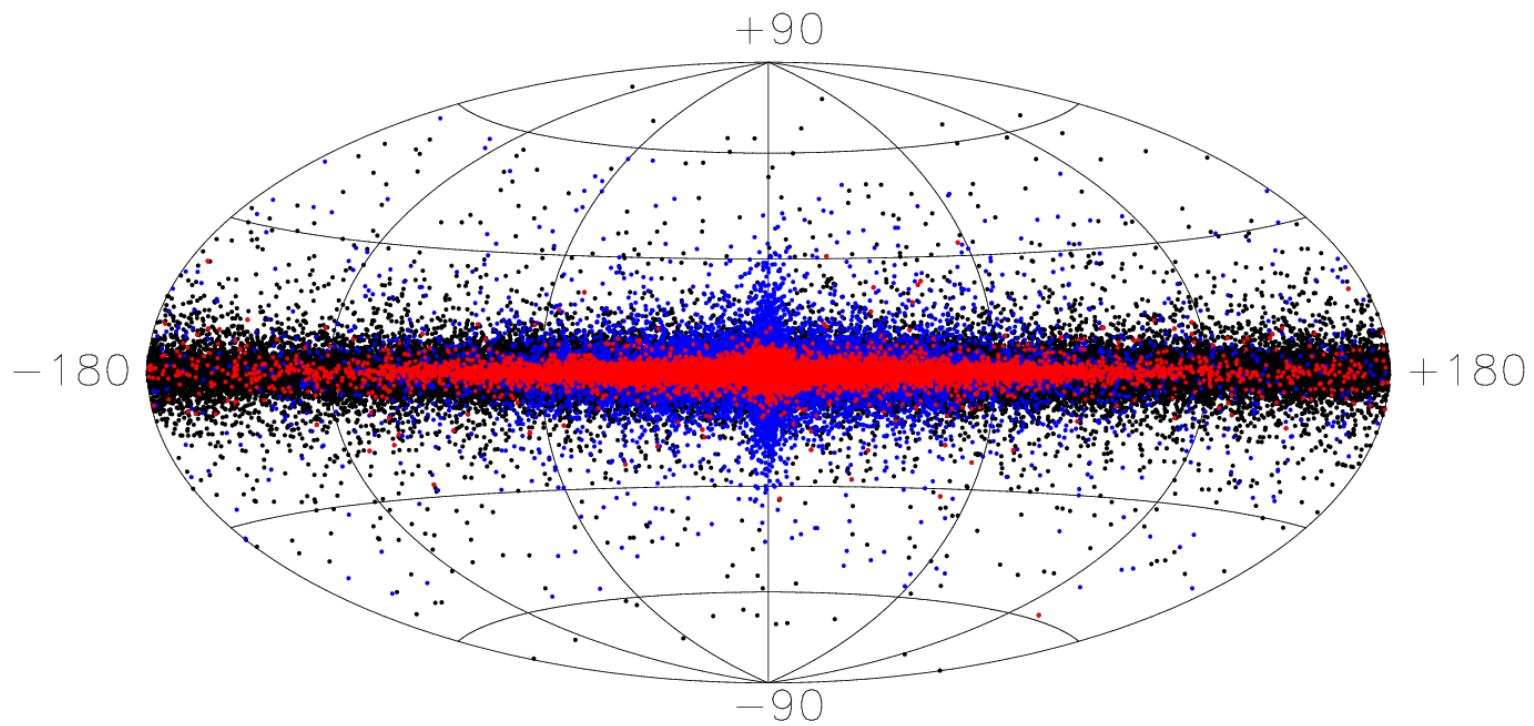
Type	birth rate ( $\text{yr}^{-1}$ )	resolved systems	with frequency change
(wd, wd)	$2.9 \times 10^{-2}$	12163	560
AM CVn	$1.8 \times 10^{-3}$	10117	49
UCXB	$9.0 \times 10^{-5}$	37	0
(ns, wd)	$1.4 \times 10^{-4}$	21	3
(ns, ns)	$3.2 \times 10^{-5}$	1	0
(bh, wd)	$3.8 \times 10^{-5}$	1	0
(bh, ns)	$1.0 \times 10^{-5}$	0	0
total		22340	614

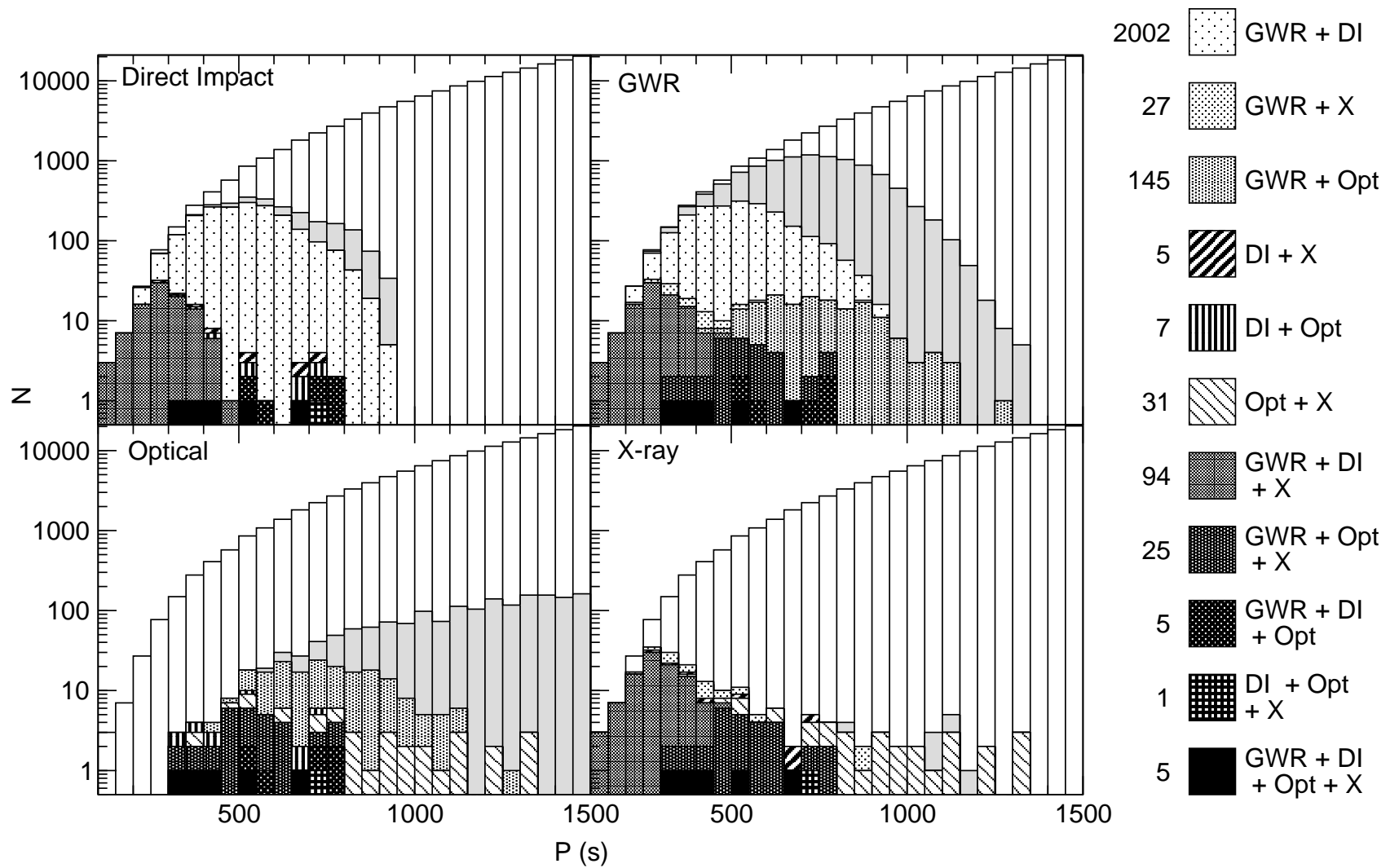
# Gravitational wave astronomy: testing the models with LISA

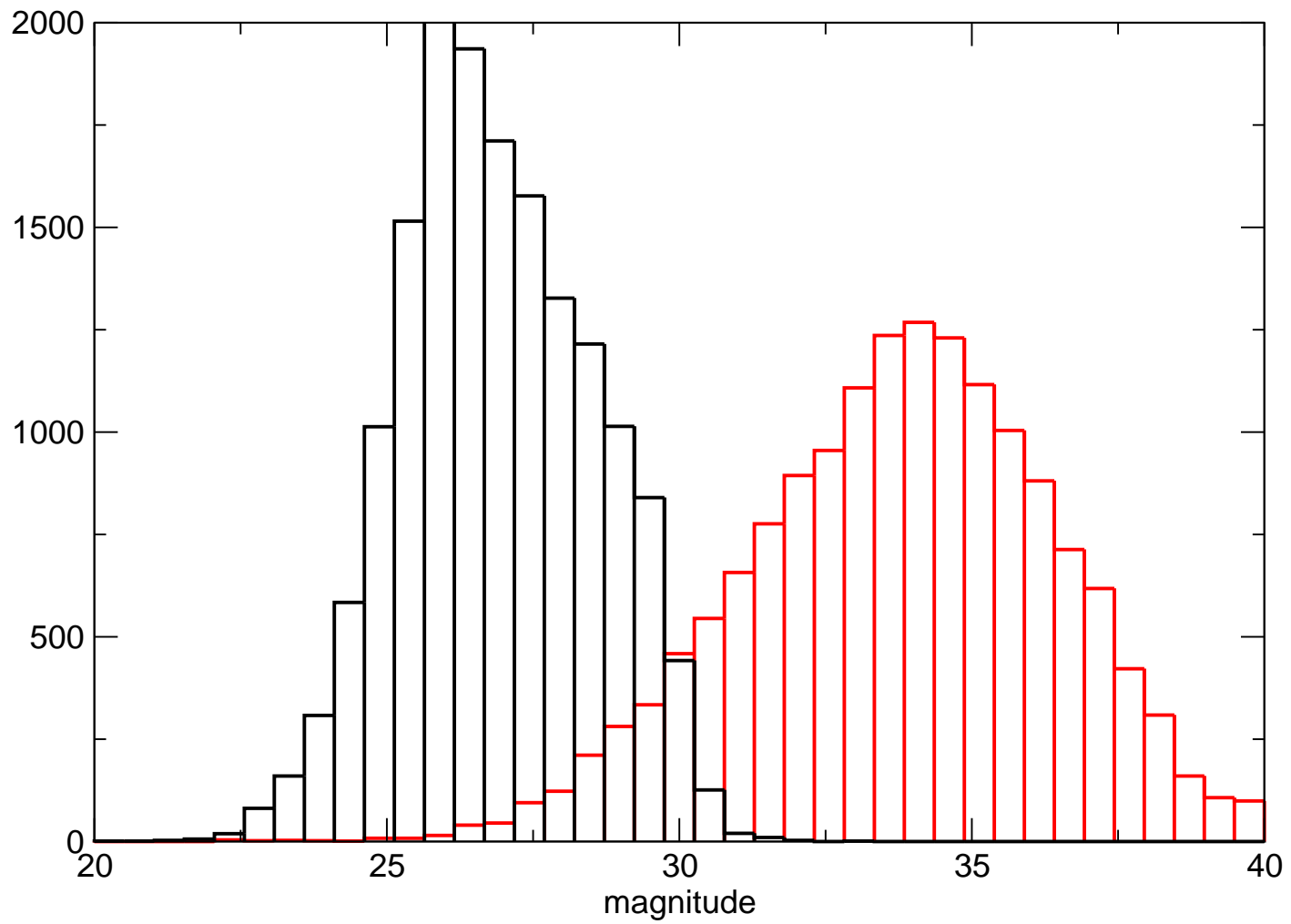
- Probe parameter space difficult to reach in other ways
- Sensitive to (rare) short period systems (direct impact)
- Overall Galactic distribution
- Systems with changing frequency: (chirp) masses
- Including angular resolution could increase number of detected (neutron star) binaries considerably
- Combined optical/IR, X-ray and GWR detections











# Conclusions

- Our knowledge of population of compact binaries is incomplete
- Observed samples increase: test of (some aspects) of the models
- Models imply lots of (resolved) compact binaries in the Galaxy
- Combining optical/IR, X-ray and GWR data might be useful
- To do: detailed modelling of detection of Galactic population