Galactic Binaries as Sources of Gravitational Waves

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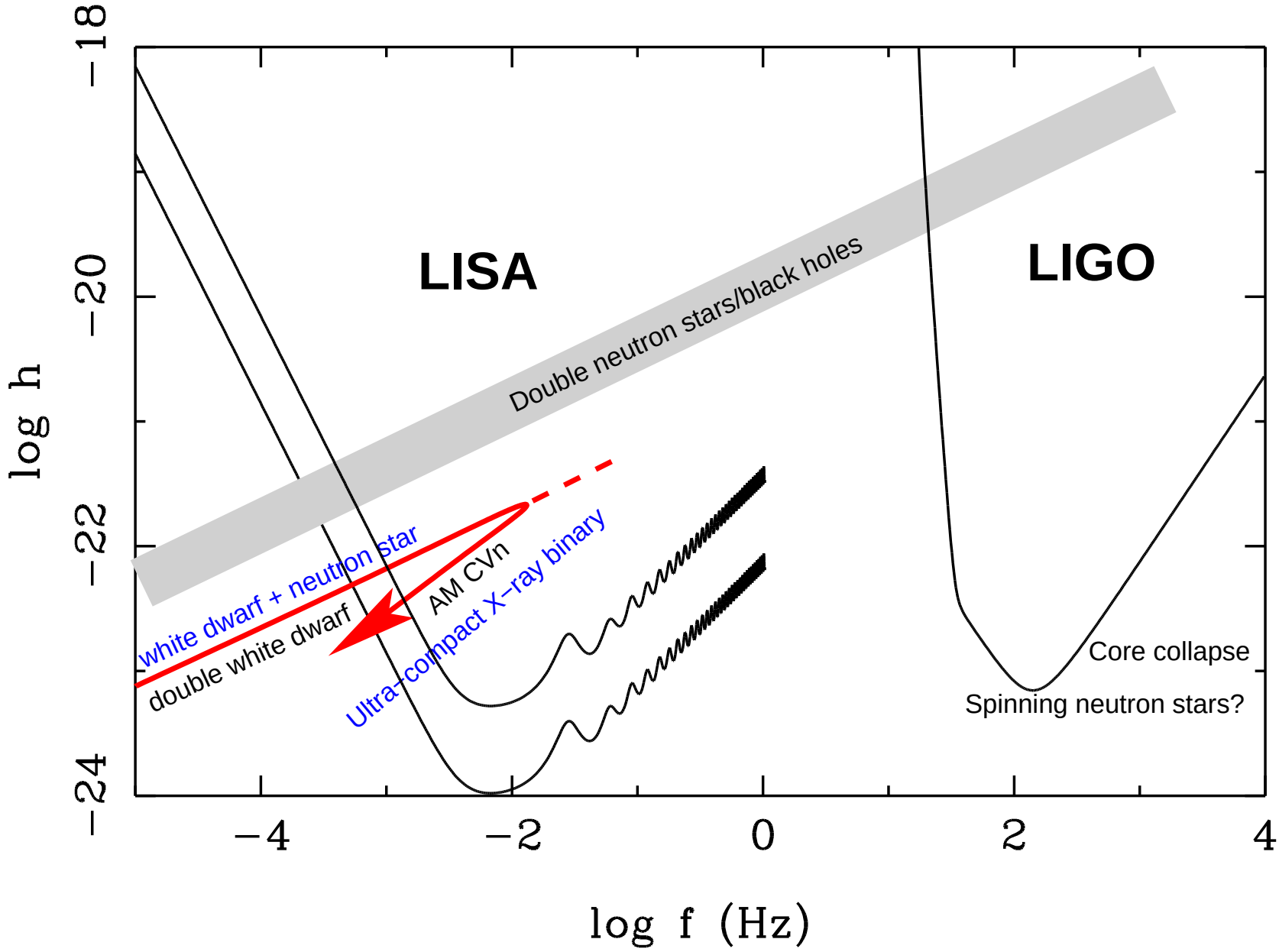
Outline

- Introduction: Galactic sources of GWR
- Summary of current observational knowledge
- A model for the Galactic population
- Expected results from LISA
- Complementary electro-magnetic observations
- Gravitational wave astronomy: testing the models with LISA
- Conclusions

Introduction: Galactic sources of GWR

- Strongest GWR sources have shortest periods
- GWR detection probes unique aspects of compact binaries
- Short period binaries: compact stars
  - Double white dwarfs
  - AM CVn systems
  - White dwarf + neutron stars
  - Ultra-compact X-ray binaries
  - Double neutron star/black holes binaries
- Other Galactic GWR sources
  - Spinning/oscillating neutron stars (in binaries)
  - Collapsing stars (in binaries)


LISA
LIGO
Double neutron stars/black holes
white dwarf + neutron star
double white dwarf
AM CVn
Ultra-compact X-ray binary
Core collapse
Spinning neutron stars?
log h
log f (Hz)
−18
−20
−22
−24
−4
−2
0
2
4

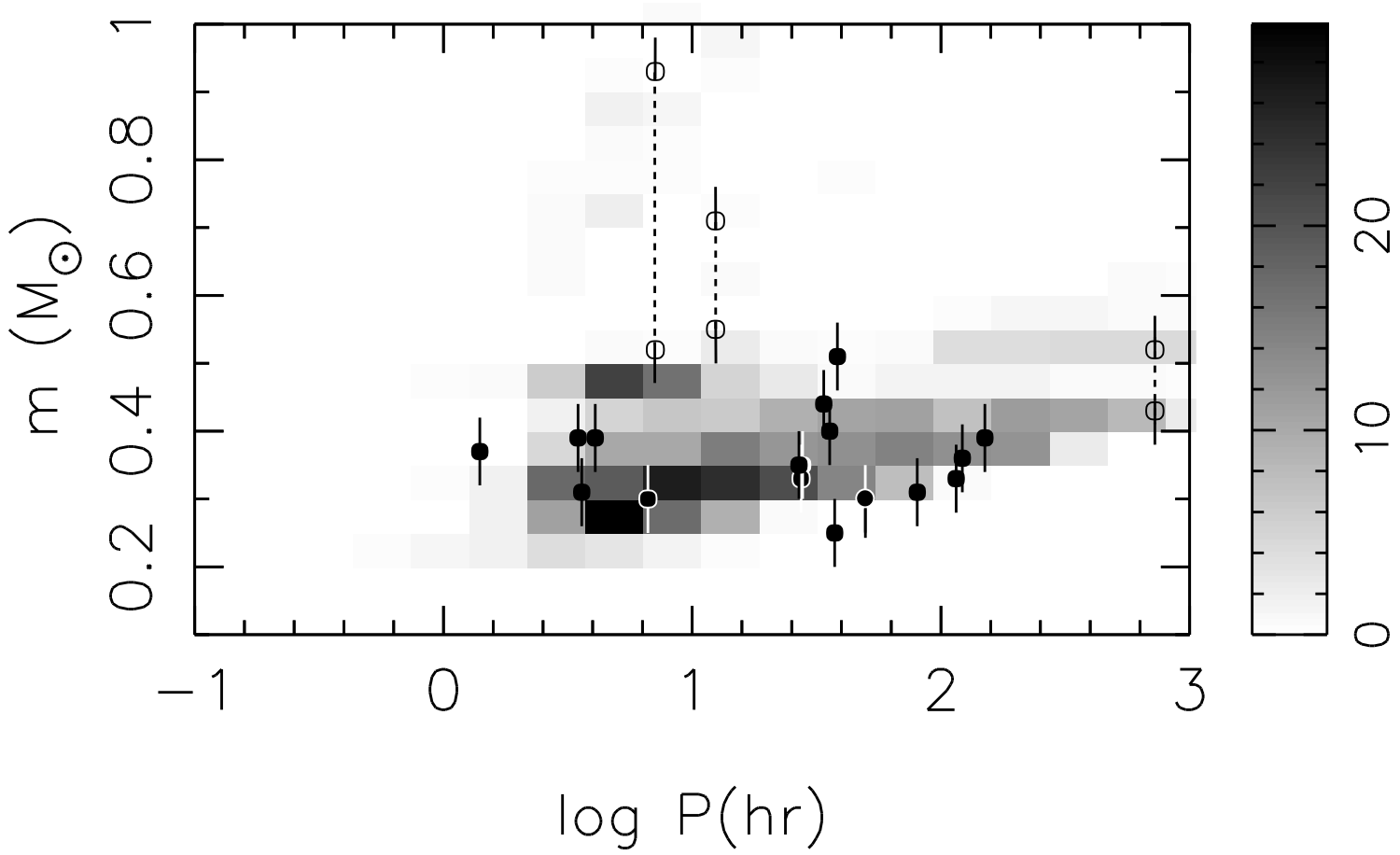
Current observational knowledge

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 577 white dwarfs
  - 123 with radial velocity variations (109 double white dwarfs)
  - 10 period determinations (between 0.3 and 5 d)



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

AM CVn systems

- 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

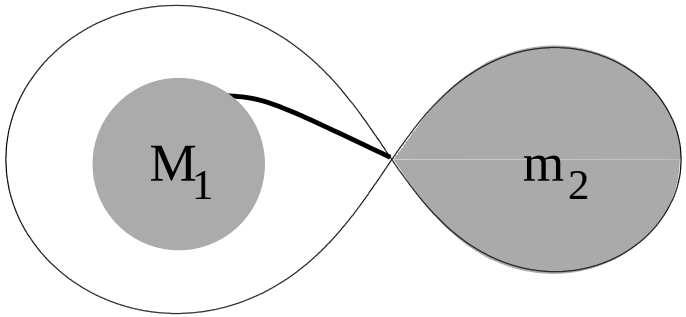
    Cropper et al. 1998, Ramsay et al. 2002,

    Mash & Steeghs 2002
  - ES Cet (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

Direct impact



Nelemans et al 2001, Webbink 1984

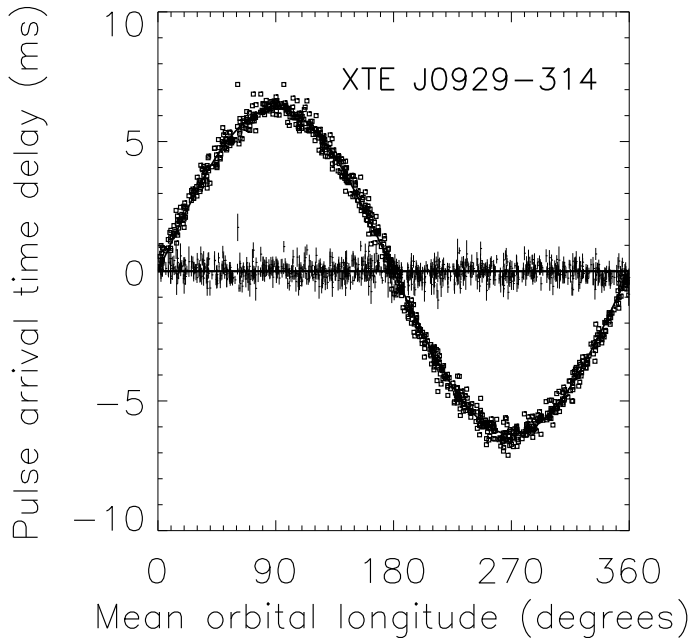
Ultra-compact X-ray binaries

- 7 systems
  (2 in globular cluster)
- Periods 11 - 50 minutes
- Three millisecond pulsars
  - XTE J1751-305, 42.4 min

    Markwardt et al., 2002, ApJ, 575, L21
  - XTE J0929-314, 43.6 min

    Galloway et al., 2002, ApJ, 576, L137
  - XTE J1807-294, 40.1 min

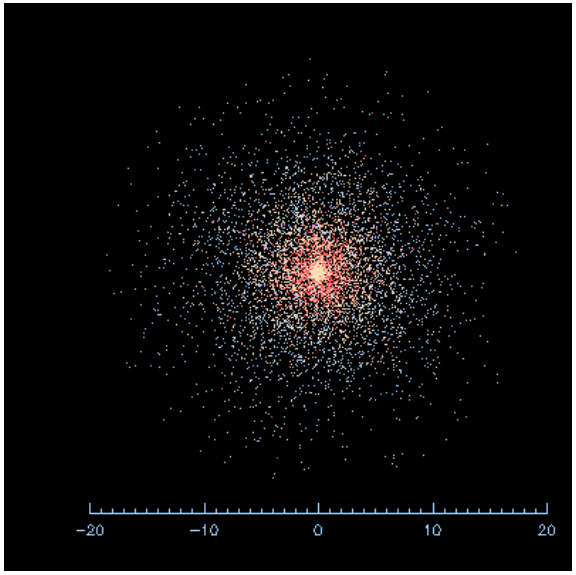
    Markwardt et al., 2003, IAUCirc., 8095
- 6 candidates



Galloway et al., 2002, ApJ, 576, 137

A model for the Galactic population

- Description of stellar and binary evolution
  - M, R, L, $M_{\rm core}$ as function $M_{\rm i}$, 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



Boissier & Prantzos, 1999, MNRAS, 307, 857

Expected results from LISA

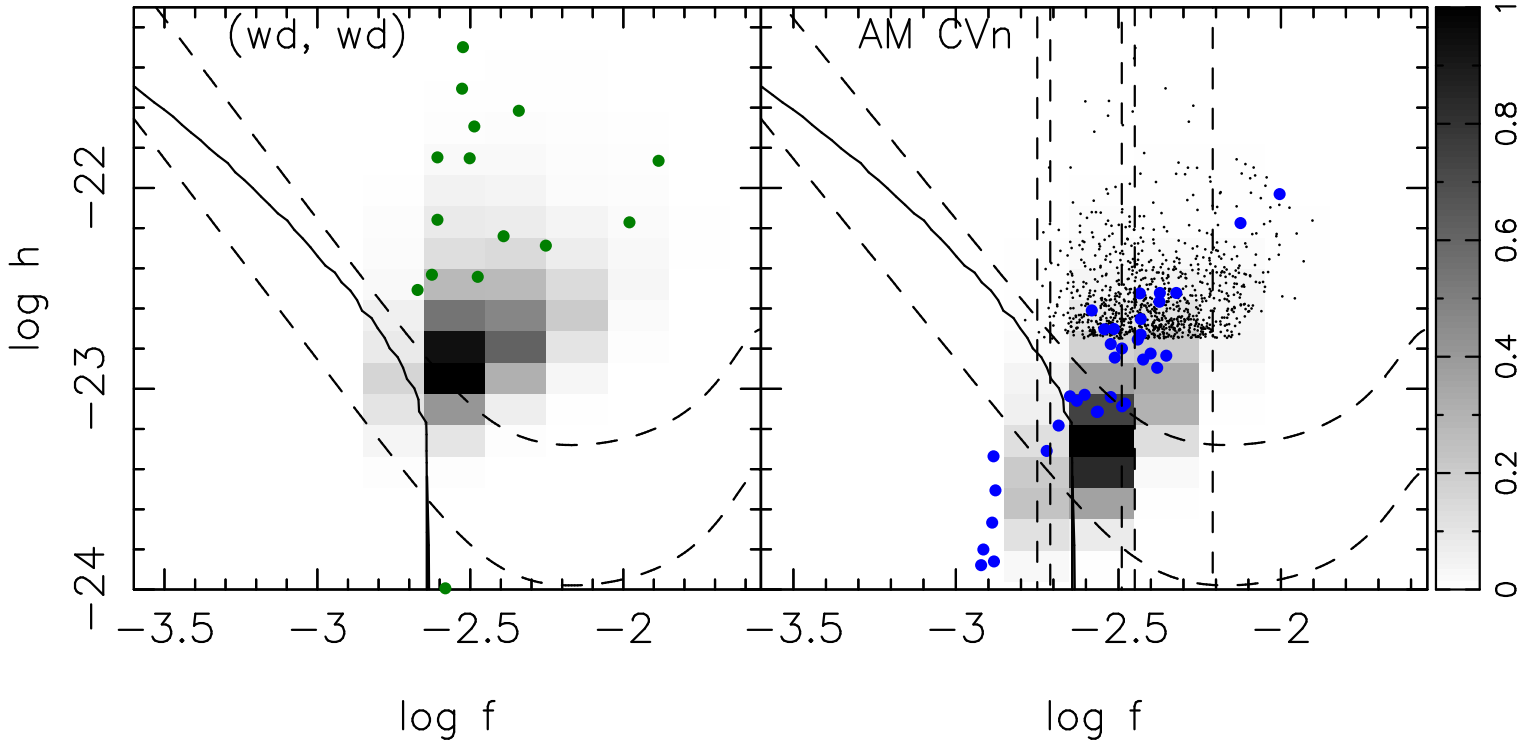
- Estimates of population of Galactic binaries

  e.g. Evans et al 1987, Hils et al 1990, Webbink & Han 1998, Postnov & Prokhorov 1998, Hils & Bender 2001

- Population synthesis for 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
- Many with measurable frequency change, i.e. measurement of distance



- resolved systems: ∼12000 (wd, wd), ∼11000 AM CVn, few tens neutron star binaries

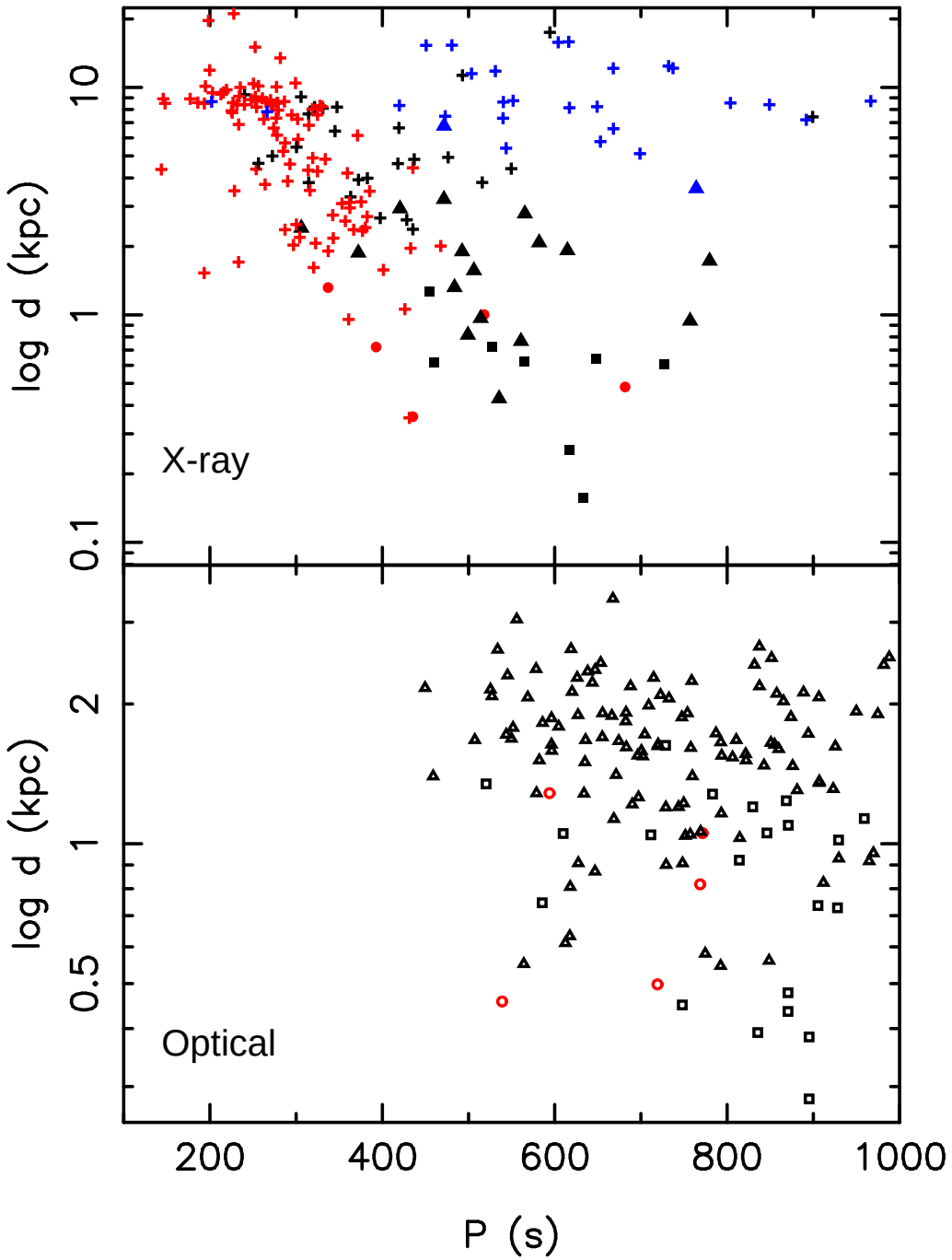
Nelemans, 2002, LISA symposium proceedings

Resolved systems

Type	birth rate (yr^{-1})	uncertainty factor	resolved systems
(wd, wd)	2.9×10^{-2}	5	12000
AM CVn	1.8×10^{-3}	50	11500
UCXB	1.9×10^{-5}	10	37
(ns, wd)	1.4×10^{-4}	50	21
(ns, ns)	3.2×10^{-5}	50	1
(bh, wd)	3.8×10^{-5}	50	1
(bh, ns)	1.0×10^{-5}	50	0

Complementary electro-magnetic observations

- Modelling optical and X-ray emission from AM CVn's and UCXB's
- Optical
  - Emission from direct impact
  - Disc emission
  - Emission from donor: white dwarf cooling (no irradiation yet)
- X-ray
  - Emission from direct impact
  - Emission from disc/boundary layer
- Reddening and interstellar absorption



Resolved systems also detectable in X-ray or optical

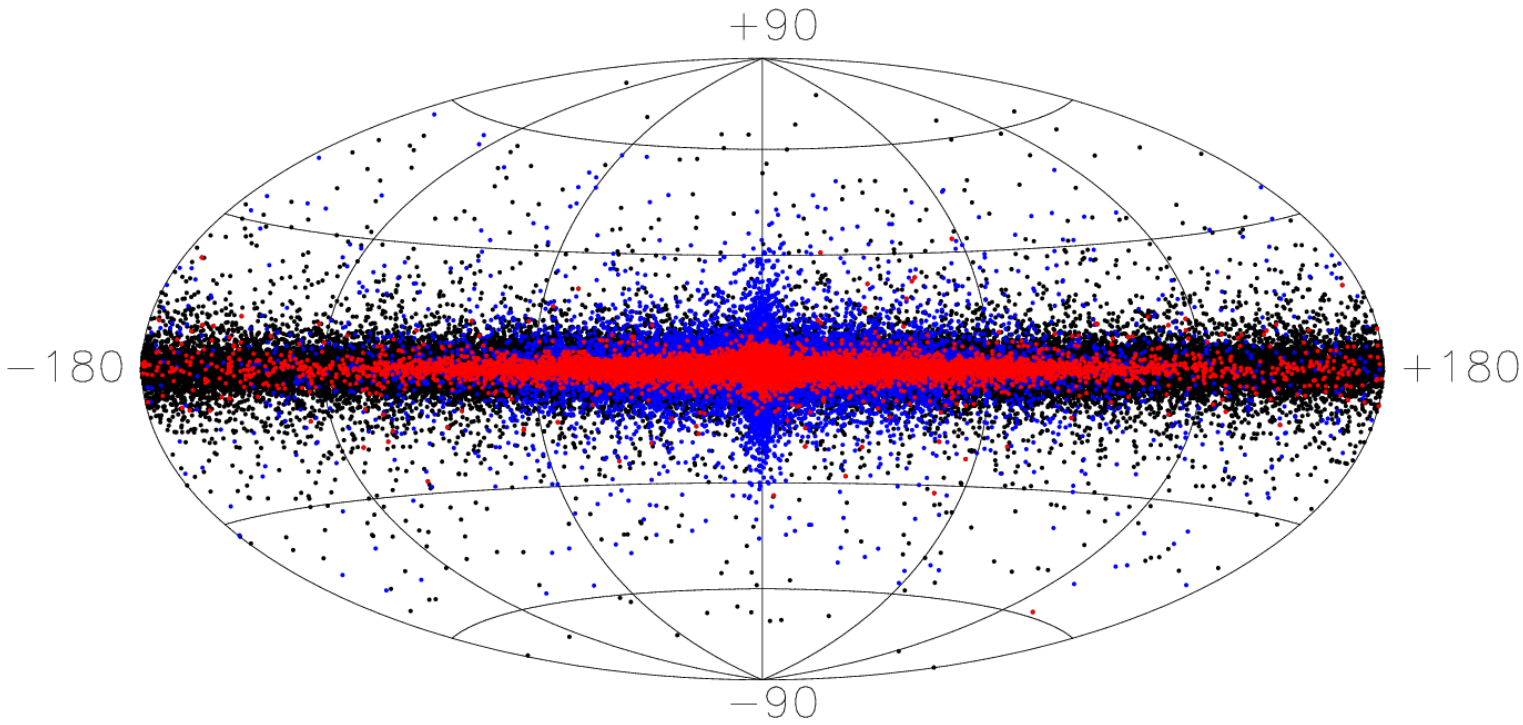
AM CVn
(direct impact)
UCXB's

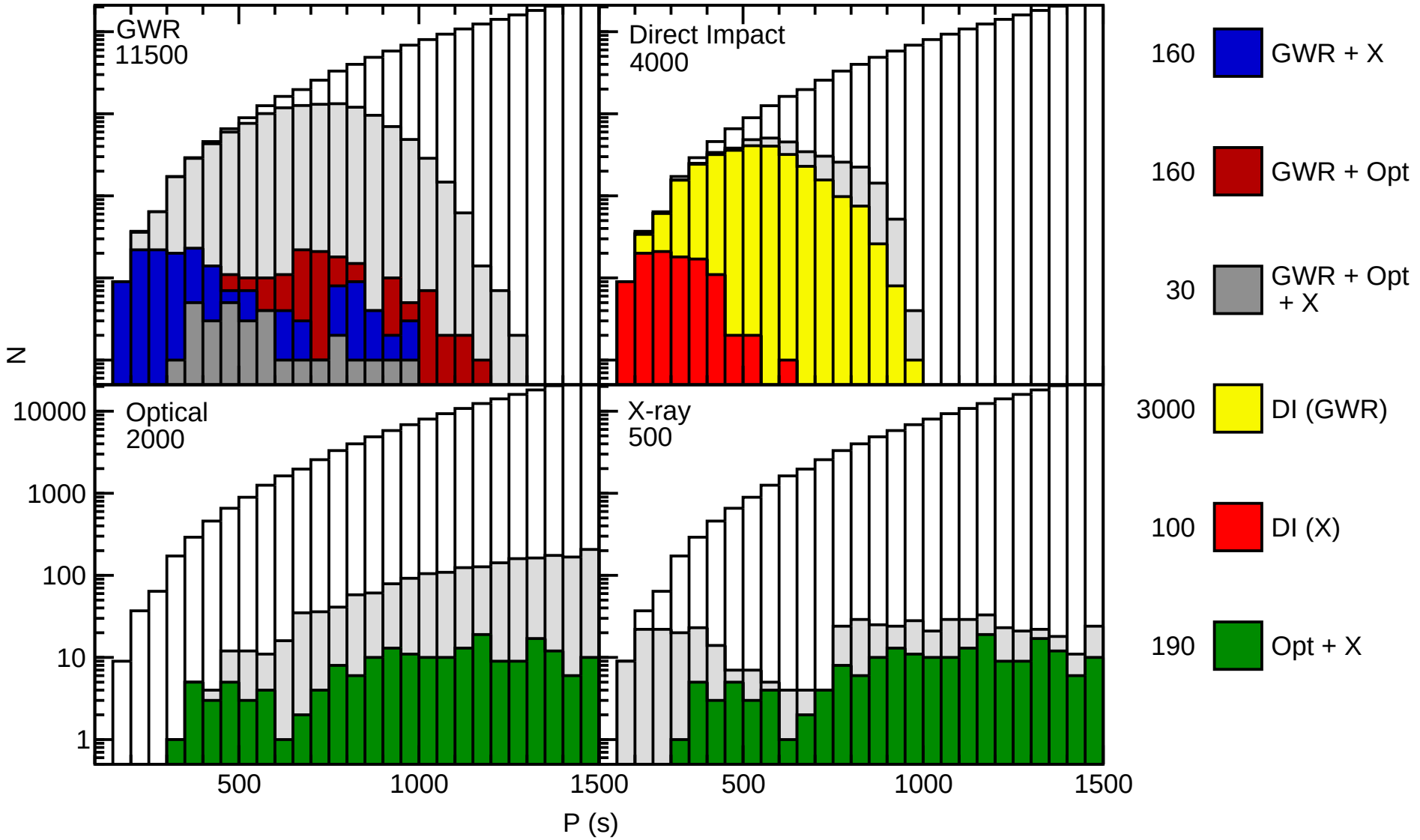
Optical		+X-ray
Disc	△	▲
Donor	○	●
Disc + donor	□	■
-		+

Nelemans, Yungelson, Portegies Zwart, in prep

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, inclinations
- Systems with changing frequency: (chirp) masses, distances
- Including angular resolution could increase number of detected (neutron star) binaries considerably
- Combined optical/IR, X-ray and GWR detections


+90
−180
+180
−90


GWR
11500
Direct Impact
4000
Optical
2000
X-ray
500
N
10000
1000
100
10
1
500
1000
1500
500
1000
1500
P (s)
160
GWR + X
160
GWR + Opt
30
GWR + Opt + X
3000
DI (GWR)
100
DI (X)
190
Opt + X

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

Resolved double white dwarfs