Modeling the population of Galactic BNSs

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Supervisors:

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SISSA

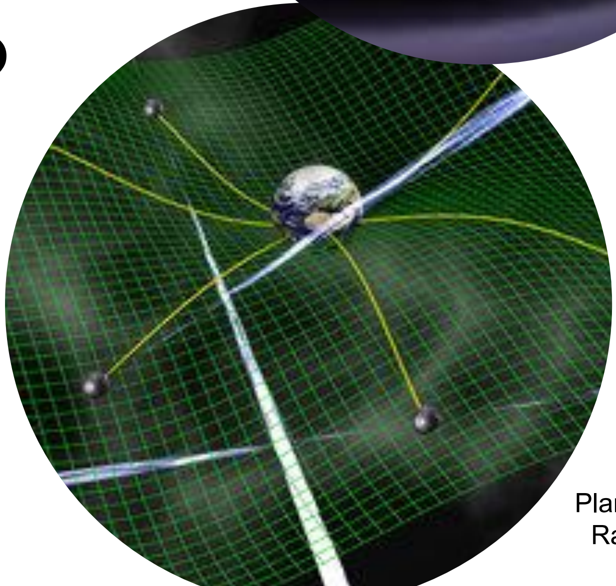
Credit: X-ray: NASA/CXC/SAO; Optical: NASA/STScI; Infrared: NASA-JPL-Caltech

Credits: Soubrette/iStock/ Getty Images Plus

Credits: NASA/Goddard Space Flight Center

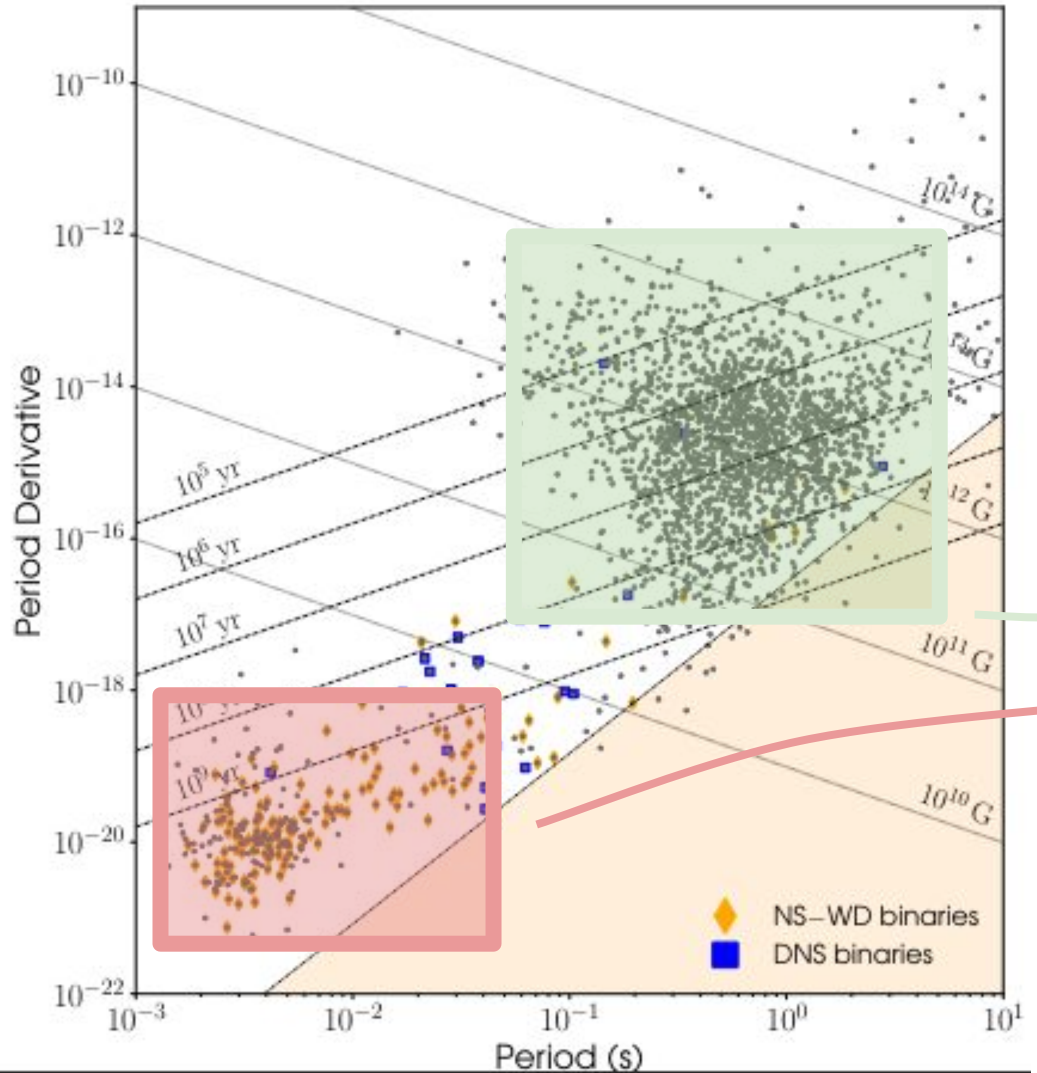
Why study the BNSs?

Credits: Pablo Carlos Budassi



Credits: David Champion/Max Planck Institute for Radio Astronomy

Pulsars in the Milky Way

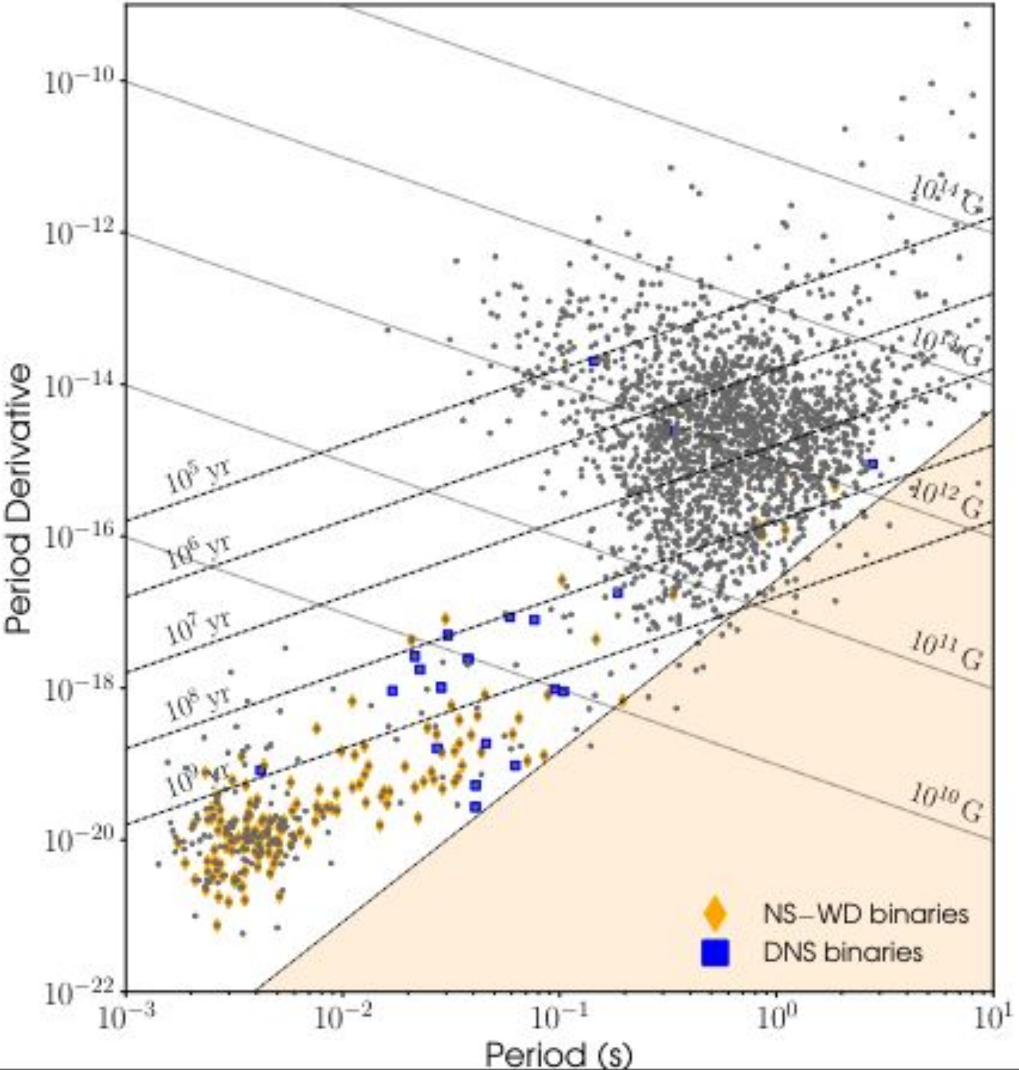


Mostly isolated pulsars
- young pulsars
- high magnetic field

Mostly pulsars in binaries
- old/recycled pulsars
- low magnetic fields

Pol et al. 2019,
data from the ATNF catalog,
Manchester et al. 2005

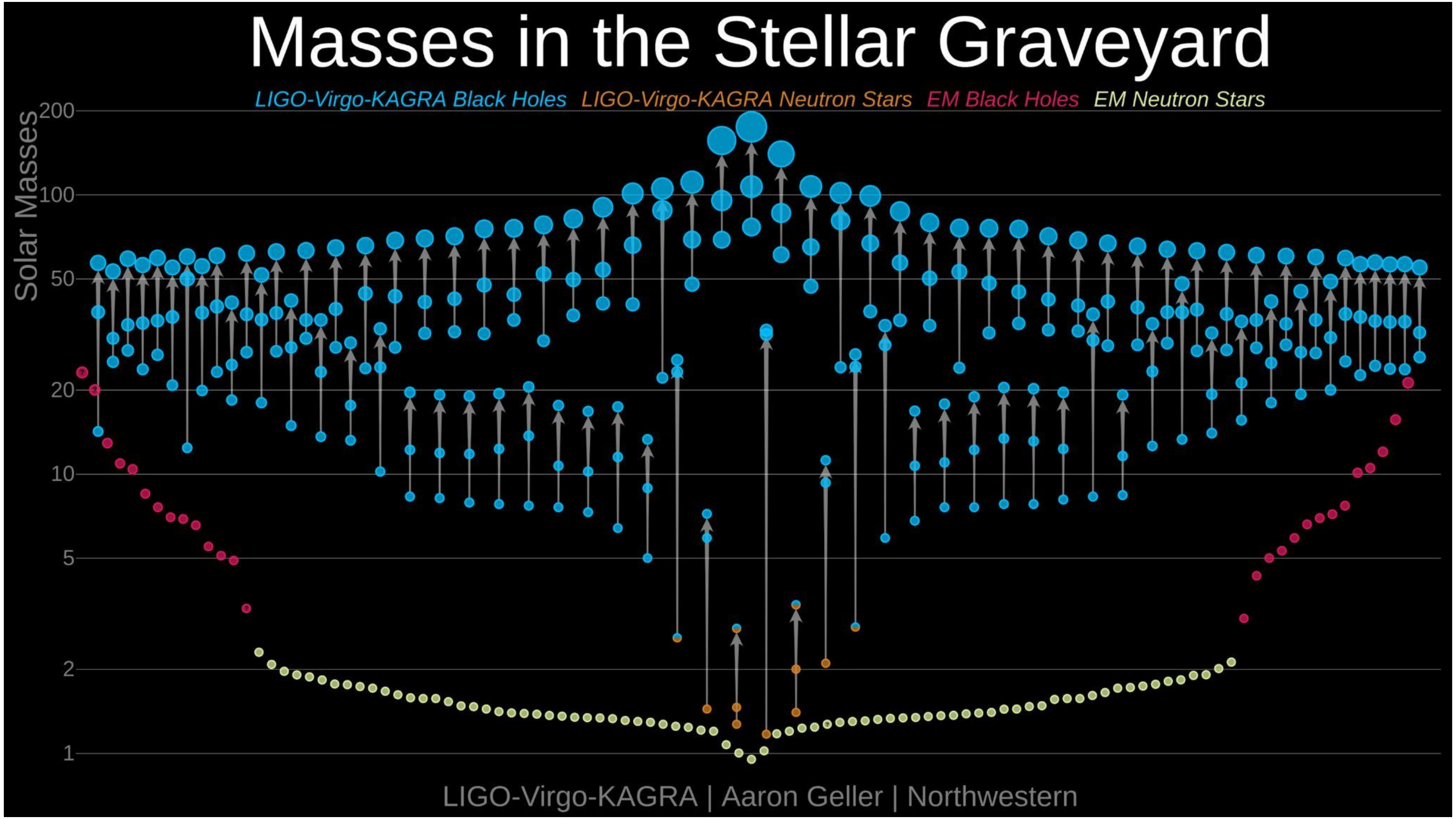
Pulsars in the Milky Way



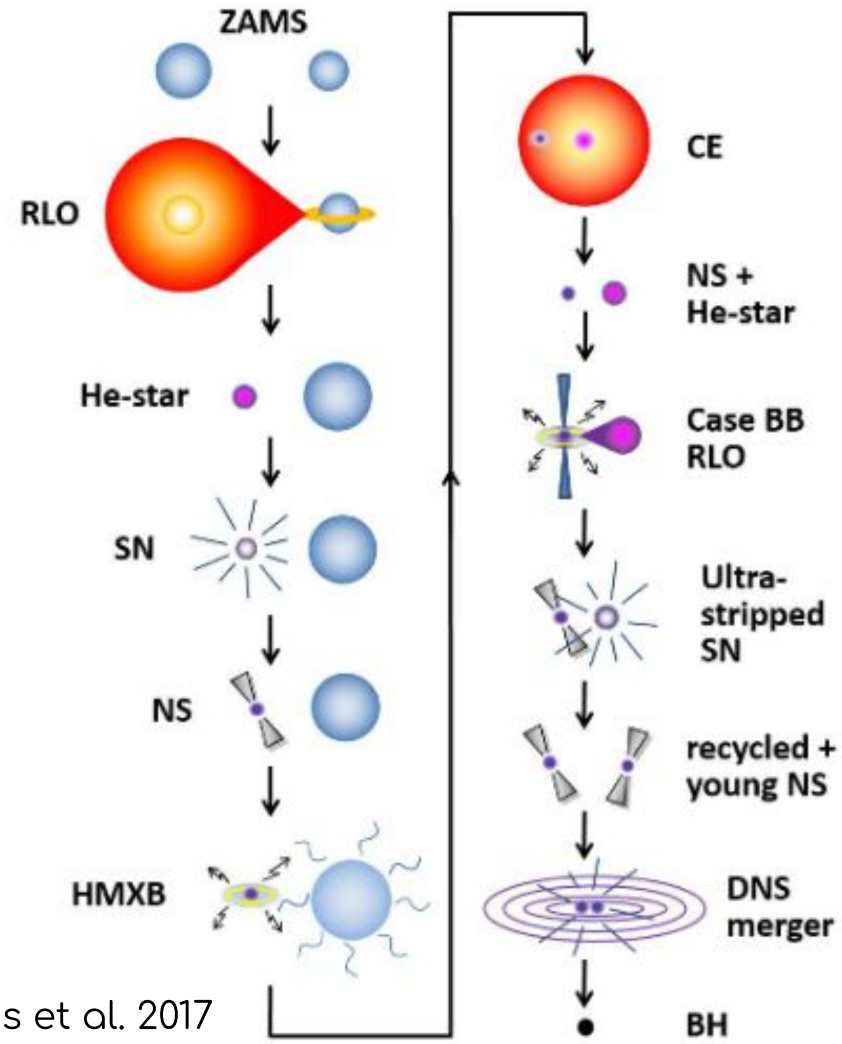
- What are the birth magnetic fields and spin periods?
- How do they evolve?

Pol et al. 2019,
data from the ATNF catalog,
Manchester et al. 2005

Gravitational Waves



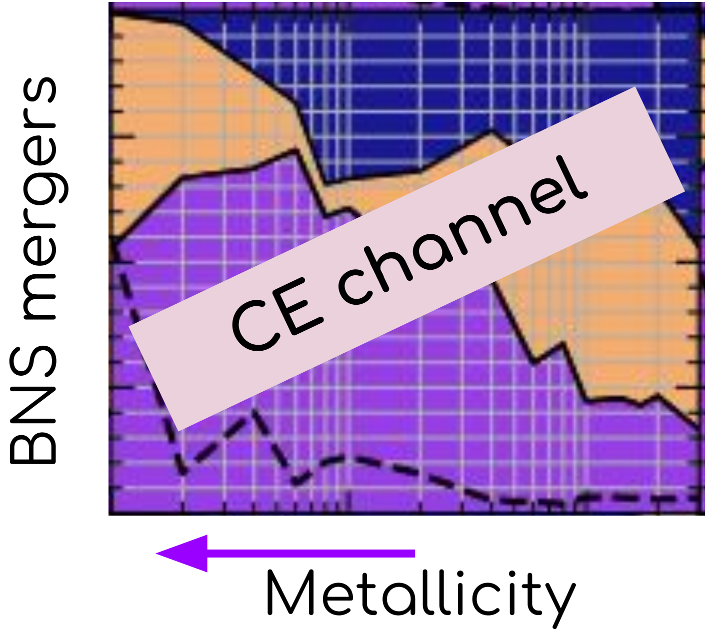
BNS formation

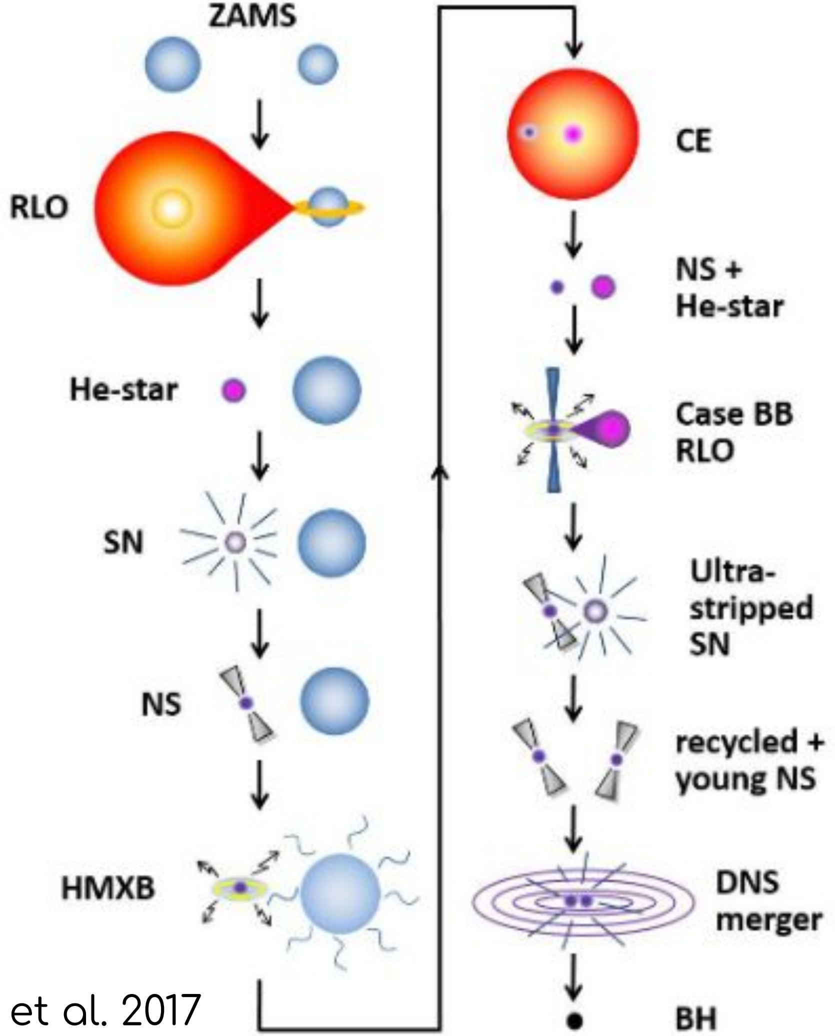


Tauris et al. 2017

BNS formation

Iorio et al. 2023

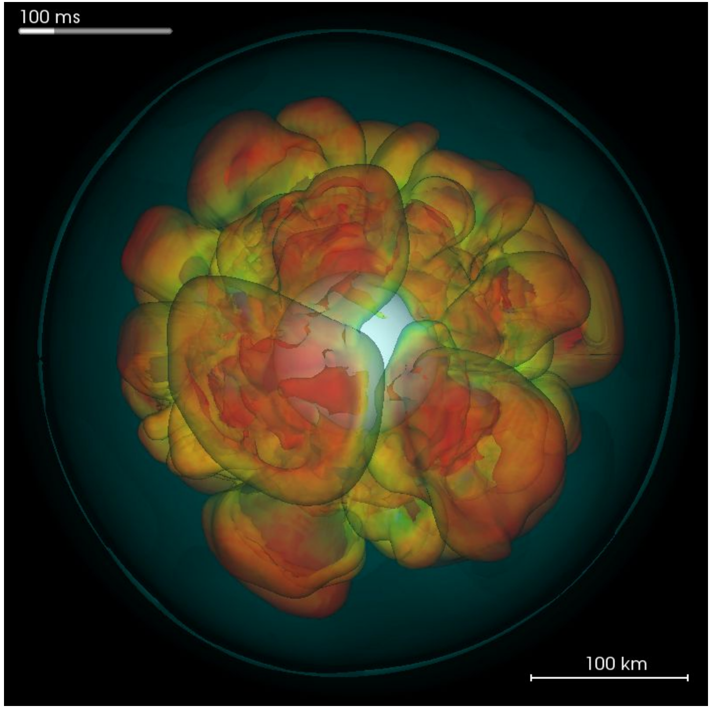




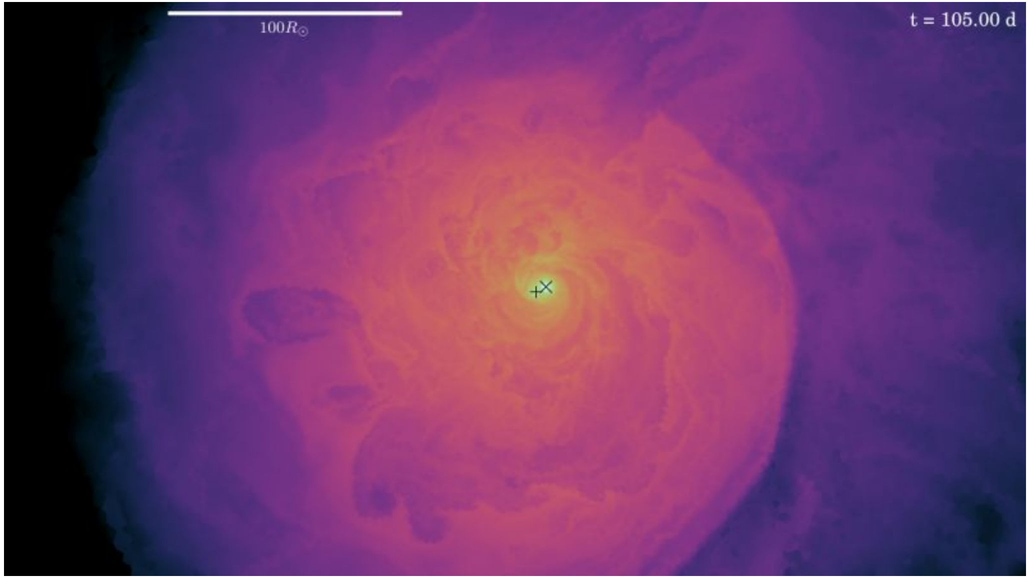
Tauris et al. 2017

What are the major uncertainties?

Supernova kicks



Common Envelope



Credit: Sebastian Ohlmann / HITS

Credits: Janka, Hans-Thomas, MPA

- What can we say about the common envelope?
- What are the birth magnetic fields and spin periods?
- Does the magnetic field evolve with time?

3 main ingredients …

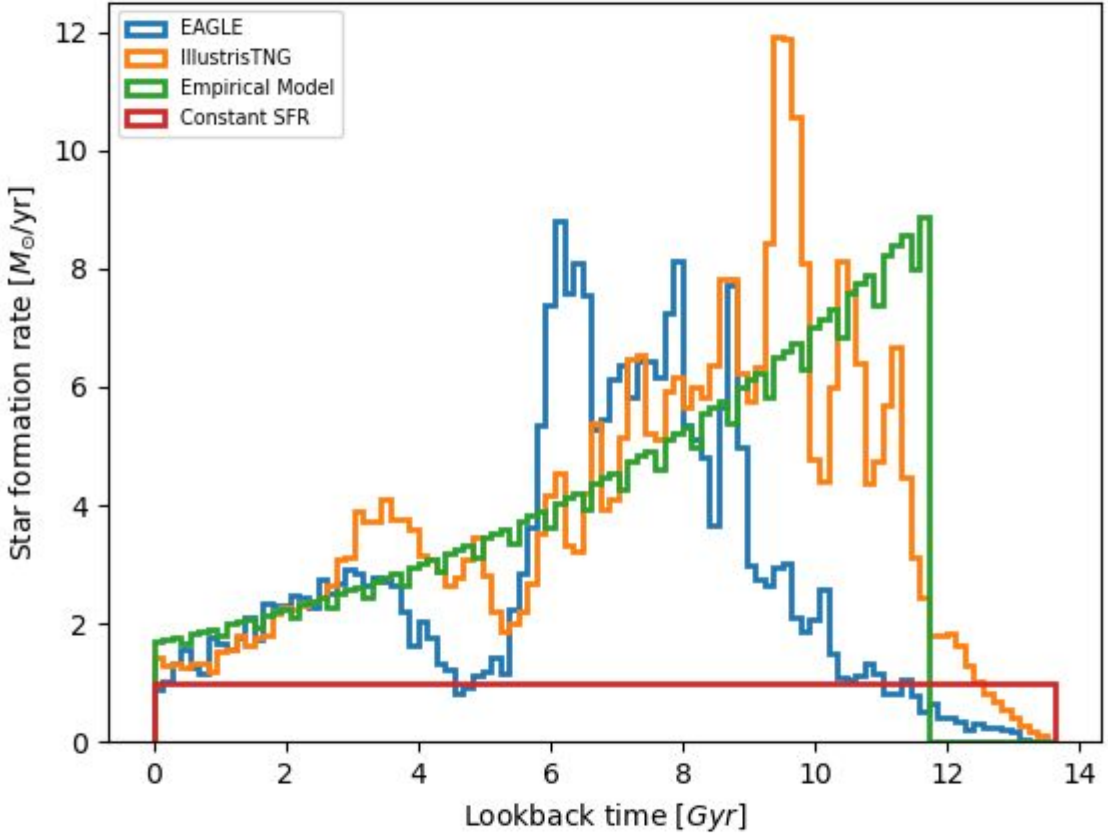
Milky-Way model

Stellar evolution

Neutron Star evolution

Credits: Cecilia Sgalletta

Milky Way model



1. $SFR(z=0) \sim 1.65 \mathrm{M}_\odot \mathrm{yr}^{-1}$

2. $M_* \sim 5 \times 10^{10} M_\odot$

EAGLE Schaye et al. 2015
IllustrisTNG Nelson et al. 2019

SEvN

Stellar EVolution N-body

Population synthesis code written in C++

https://gitlab.com/sevncodes/sevn

STELLAR EVOLUTION

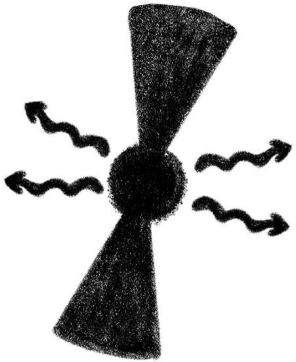
Interpolation of precomputed stellar tracks

+

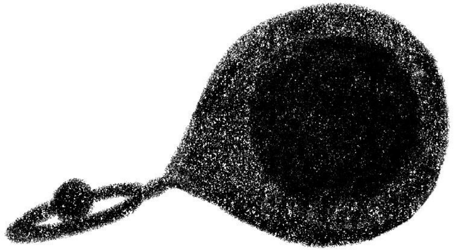
BINARY PROCESSES

Analytical and semi-analytical models

Spera and Mapelli 2017, Spera et al. 2015, Spera et al. 2019, **Iorio et al. 2023**



Spin-down

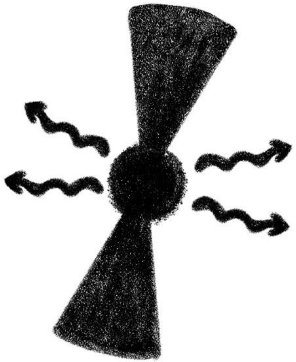


Spin-up

Radio Selection Effects

PSRPOPPY
Lorimer et al. 2011

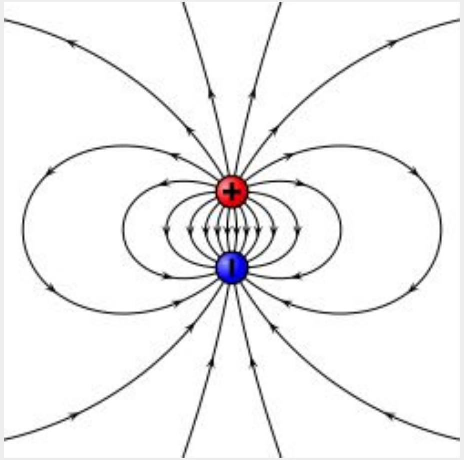
Credits: Cecilia Sgalletta

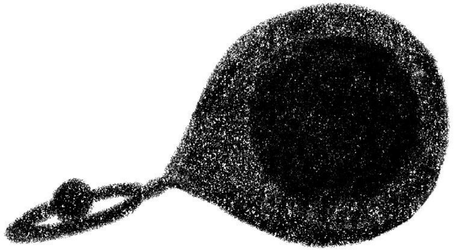


Spin-down

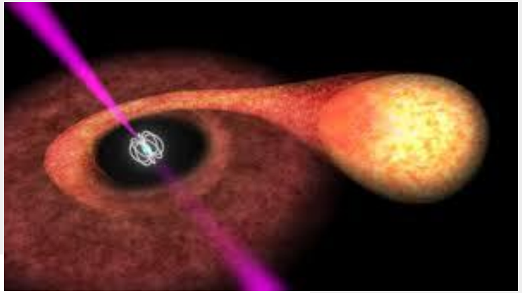
$$\dot{\Omega} \propto B^2 \Omega^3$$

$$B \propto e^{-\Delta t/\tau}$$





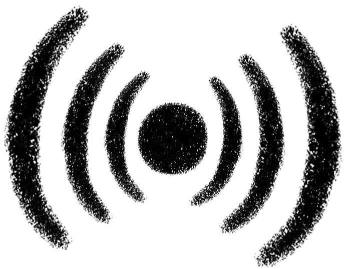
Spin-up



$$\dot{J} = V_{diff} R_A^2 \dot{M}_{NS}$$

$$V_{diff} = \Omega_K - \Omega_{NS}$$

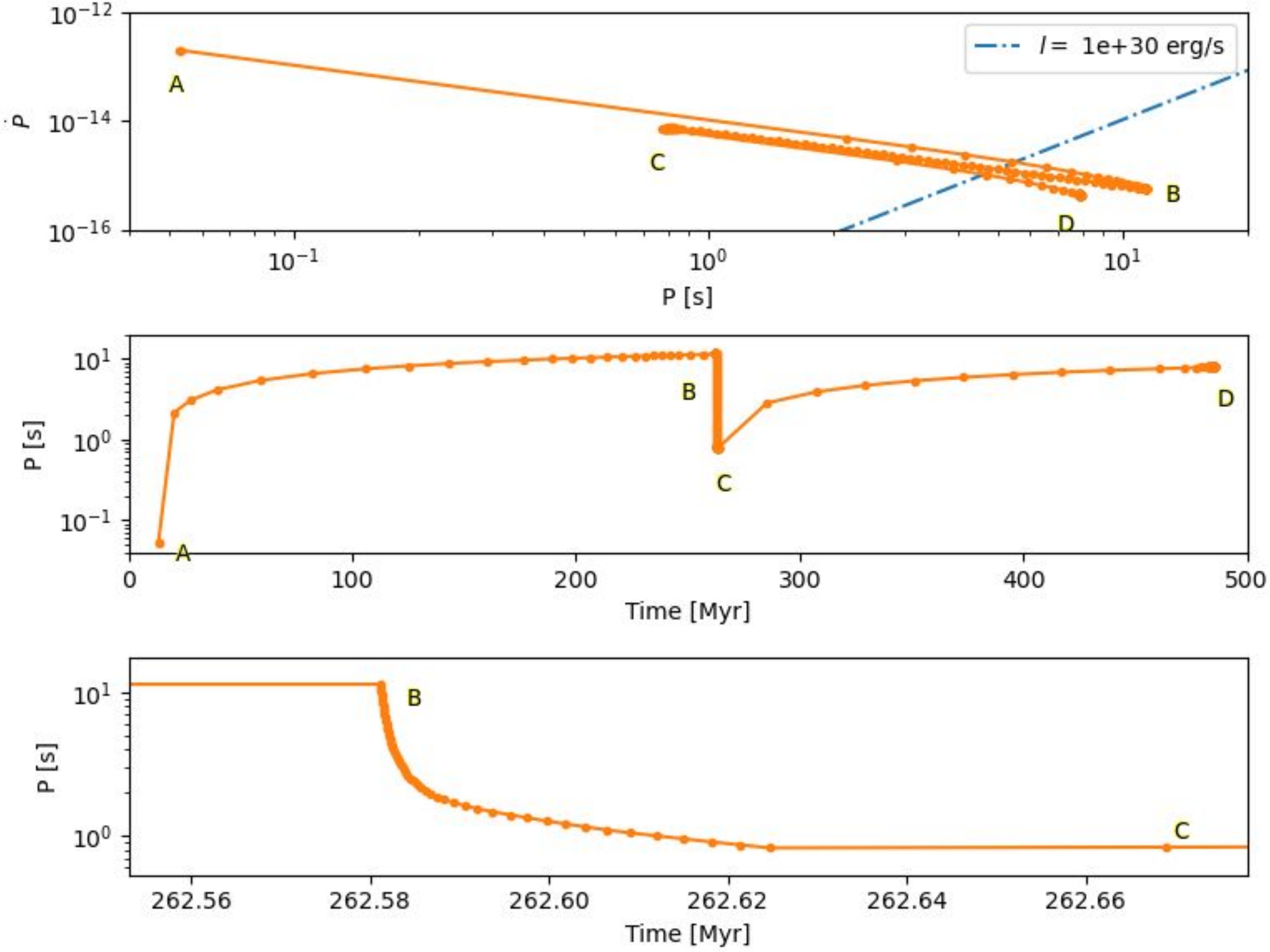
$$B \propto e^{-\Delta M_{NS} / \Delta M_d}$$



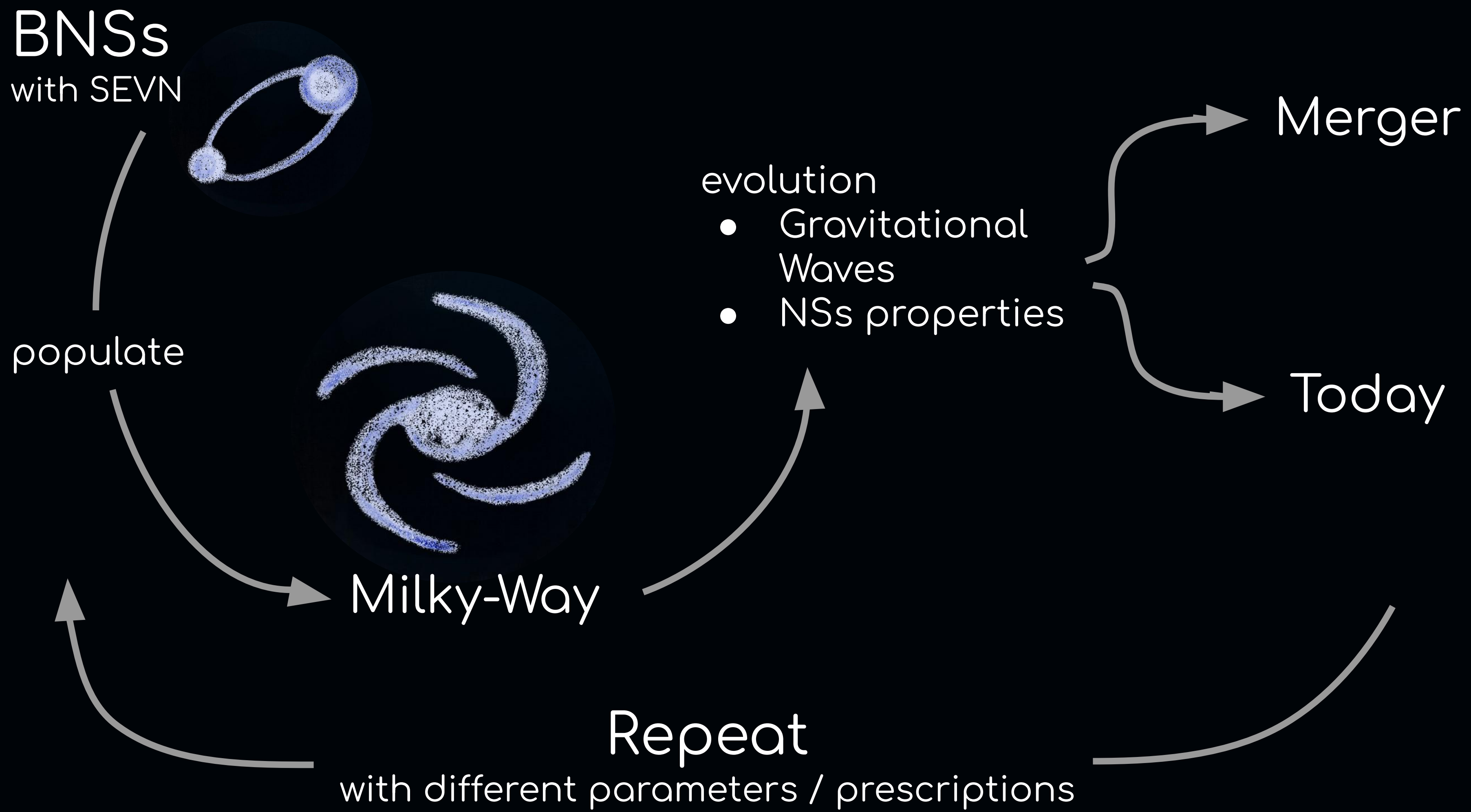
Radio selection effects

PSRPOPPY
Lorimer et al. 2011

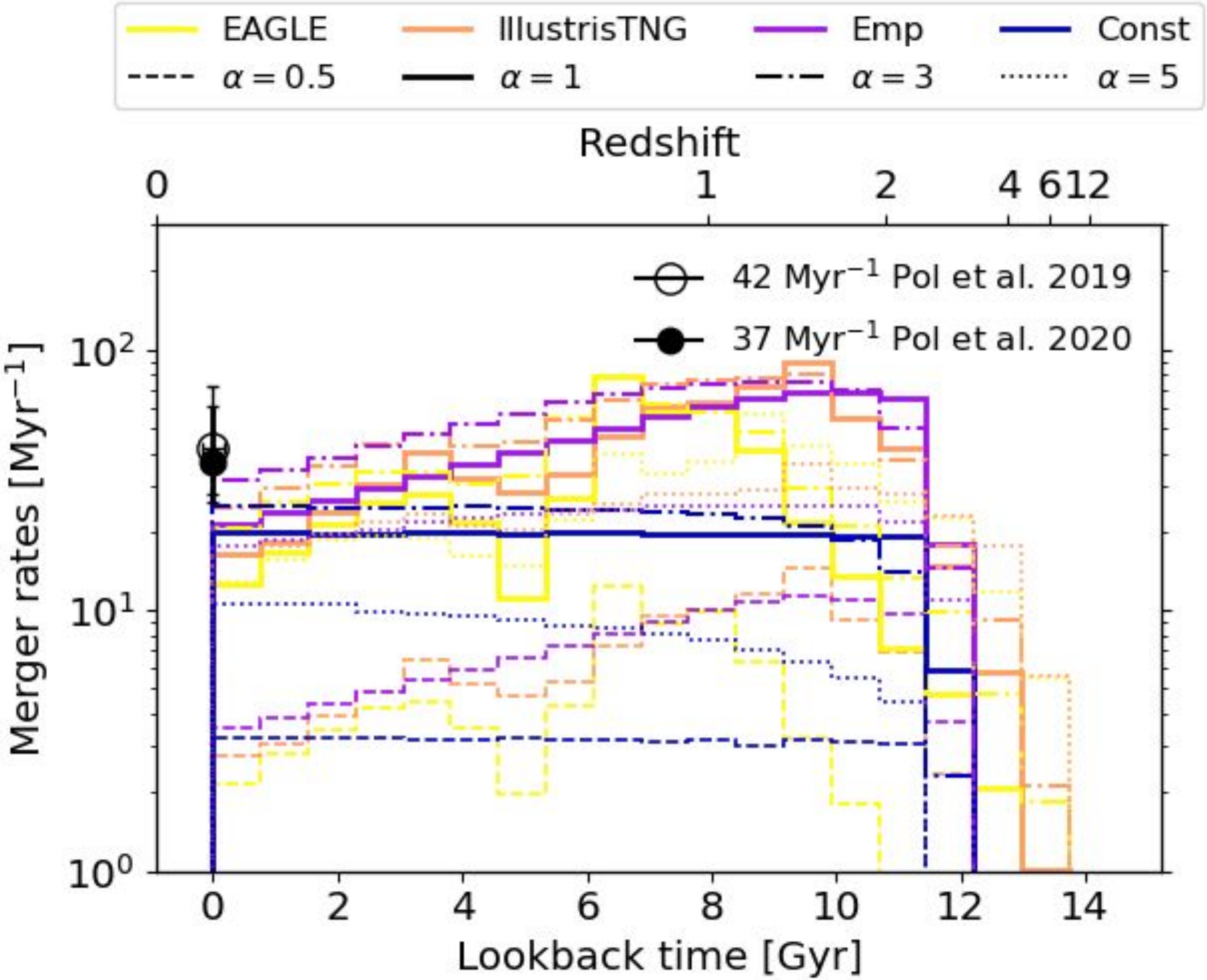
- Death lines
- Observational selection biases
- Binarity effects



- A. First NS
- B. Roche Lobe Overflow
- C. End of Roche Lobe Overflow
- D. Second Compact object

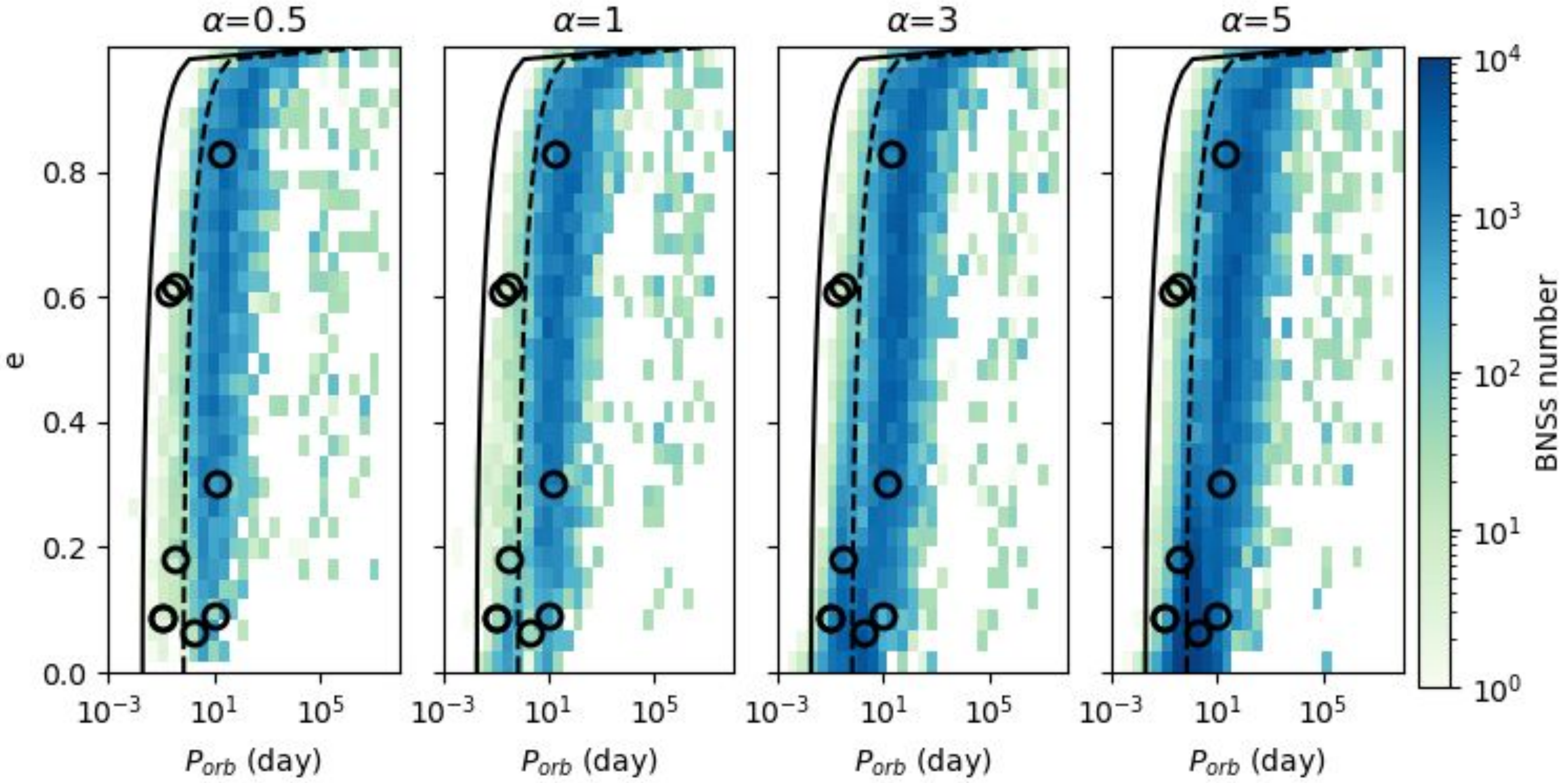

BNSs
with SEVN
populate
Milky-Way
evolution
Gravitational Waves
NSs properties
Merger
Today
Repeat
with different parameters / prescriptions

Merger Rates



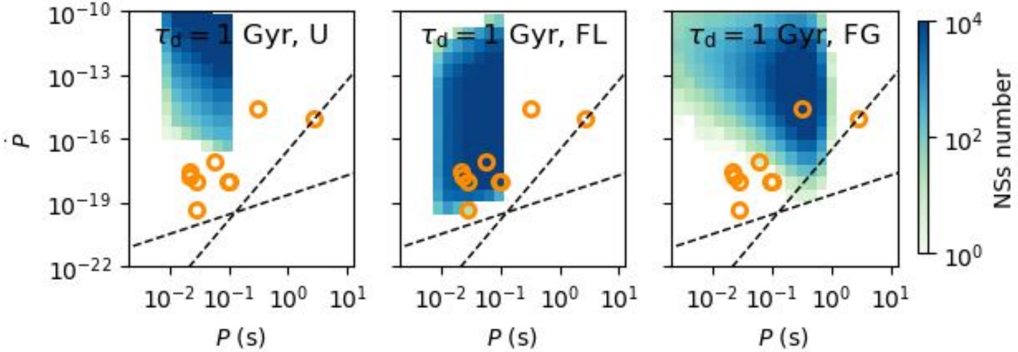
Sgalletta et al 2023: 10.1093/mnras/stad2768

BNSs population

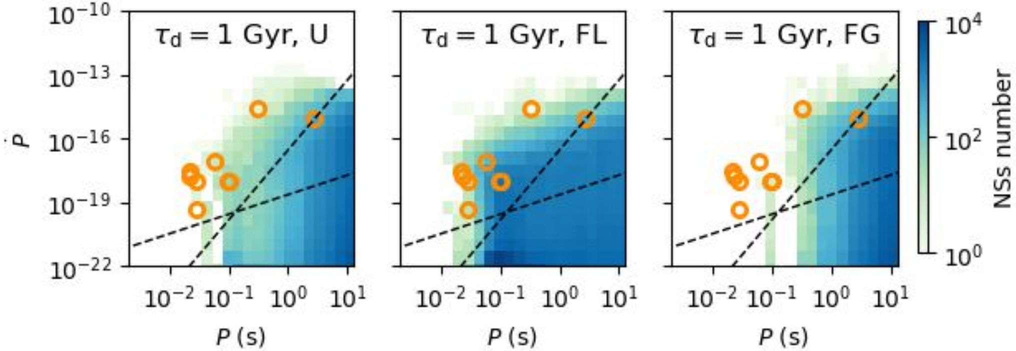


Sgalletta et al.2023

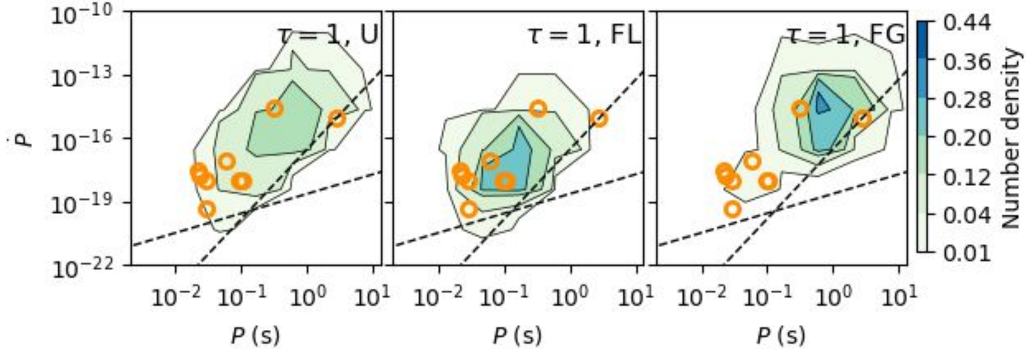
Initial distributions



Evolution in the MW

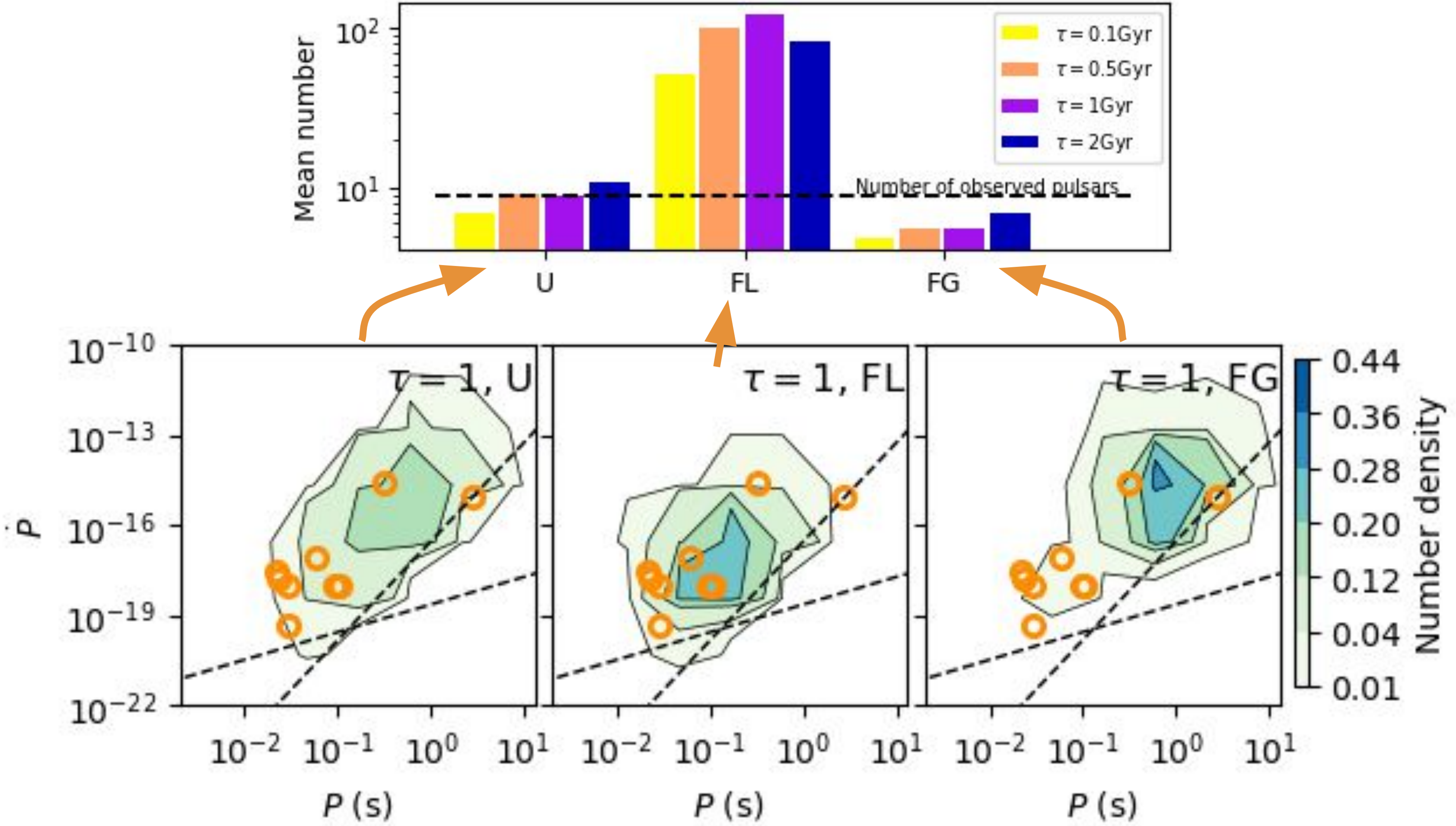


Radio selection effects



Radio selection effects

Sgalletta et al.2023



Conclusions

- Our model matches the merger rates, the orbital and the pulsar properties of the observed sample
- The CE parameter α has a large impact
- The distribution of magnetic field and spin period at pulsar formation play a critical role

Sgalletta et al. 2023: 10.1093/mnras/stad2768

Backup

Spin-down

$$\dot{\Omega} = \frac{8\pi B^2 R^6 \sin^2(\alpha)\Omega^3}{3\mu_0 c^3 I}$$

$$B = (B_0 - B_{min})e^{-\Delta t/\tau} + B_{min}$$

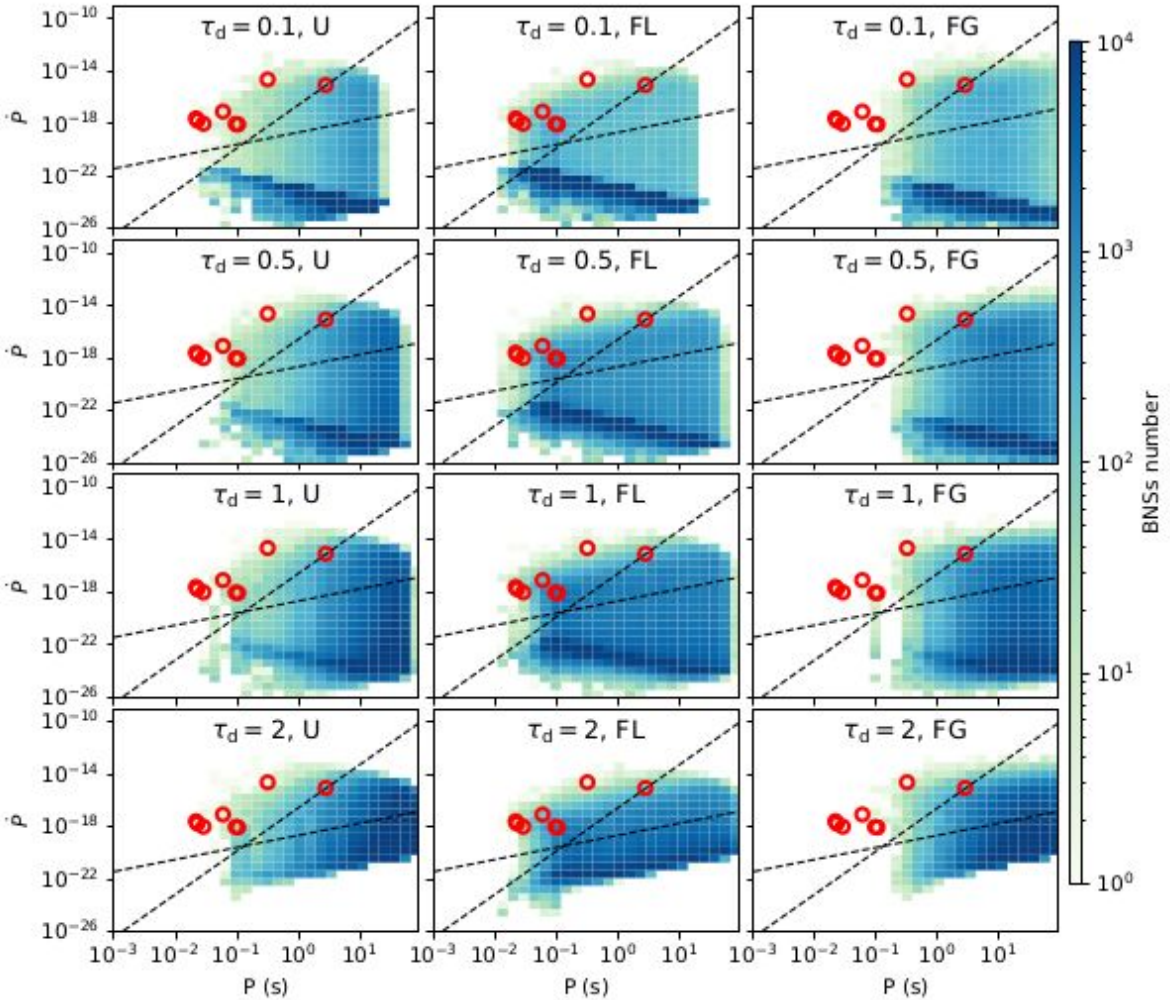
Spin-up

$$\dot{J} = V_{diff} R_A^2 \dot{M}_{NS}$$

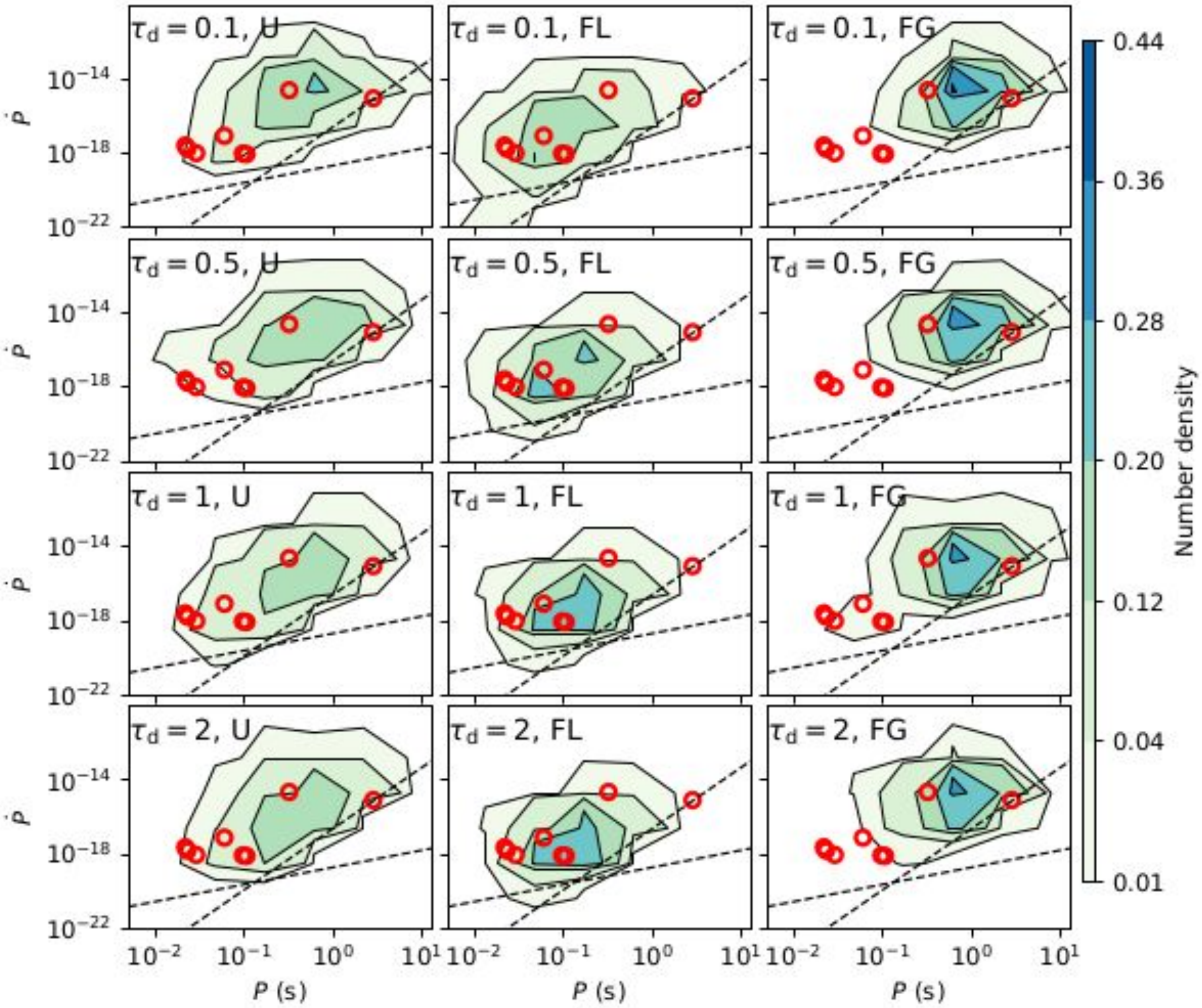
$$V_{diff} = \Omega_K - \Omega_{NS}$$

$$B = (B_0 - B_{min})e^{-\Delta M_{NS}/\Delta M_d} + B_{min}$$

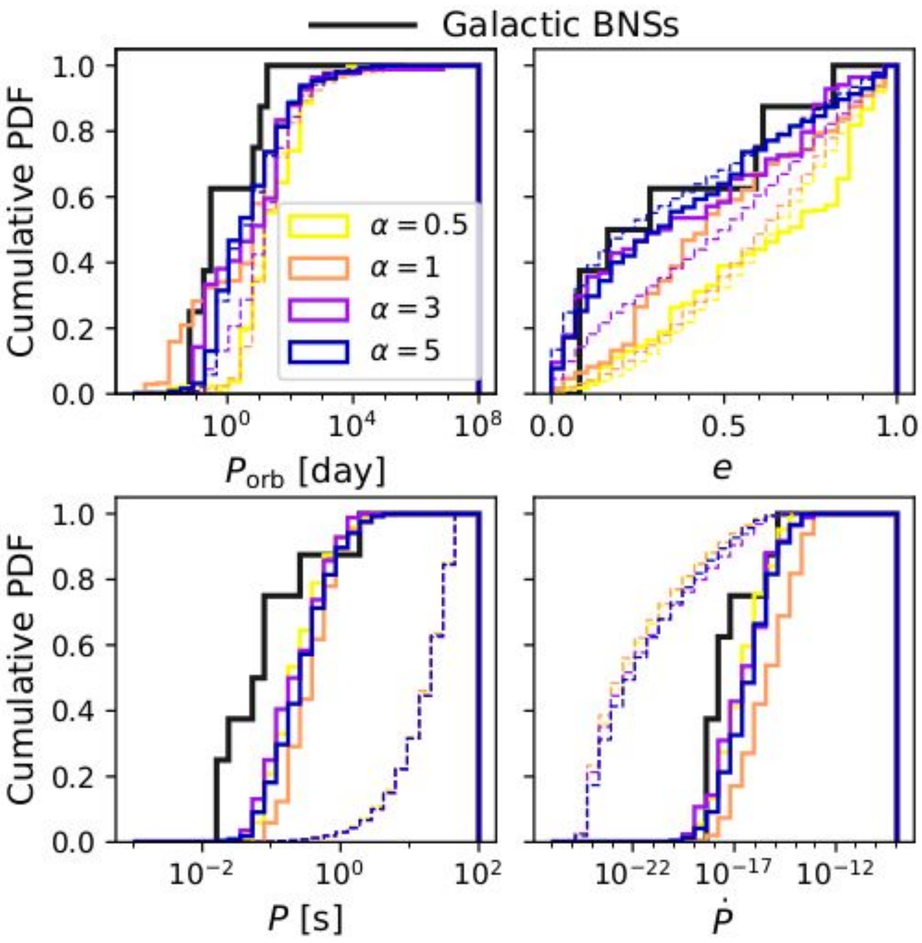
$$R_{Alfven} = \left(\frac{2\pi^2}{G\mu_0^2}\right)^{1/7} \left(\frac{R^6}{\dot{M}_{NS} M_{NS}^{1/2}}\right)^{1/7} B^{4/7}$$



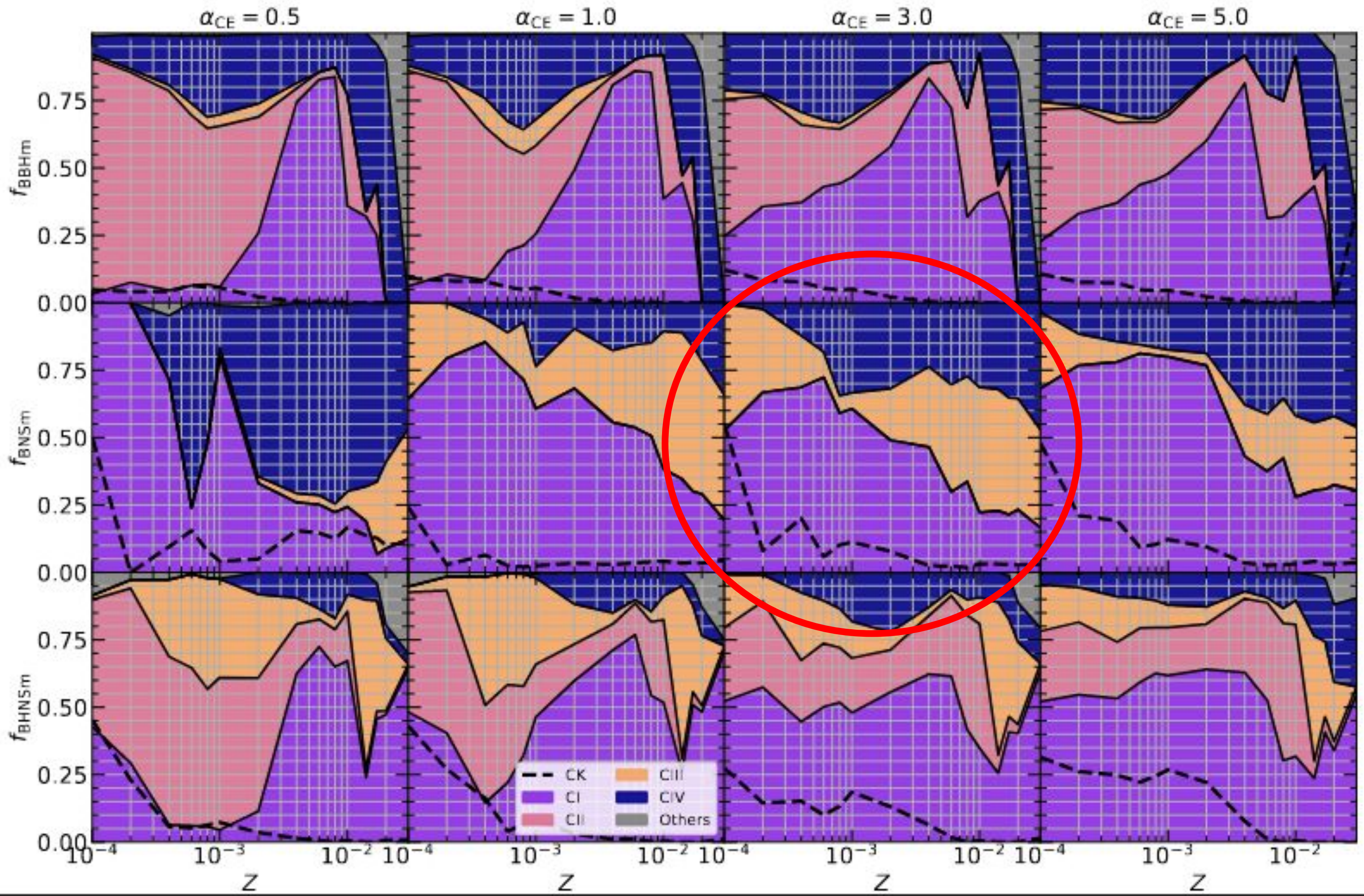
$\tau_d = 0.1$, U
$\tau_d = 0.1$, FL
$\tau_d = 0.1$, FG
$\tau_d = 0.5$, U
$\tau_d = 0.5$, FL
$\tau_d = 0.5$, FG
$\tau_d = 1$, U
$\tau_d = 1$, FL
$\tau_d = 1$, FG
$\tau_d = 2$, U
$\tau_d = 2$, FL
$\tau_d = 2$, FG
$\dot{P}$
P (s)
BNSs number



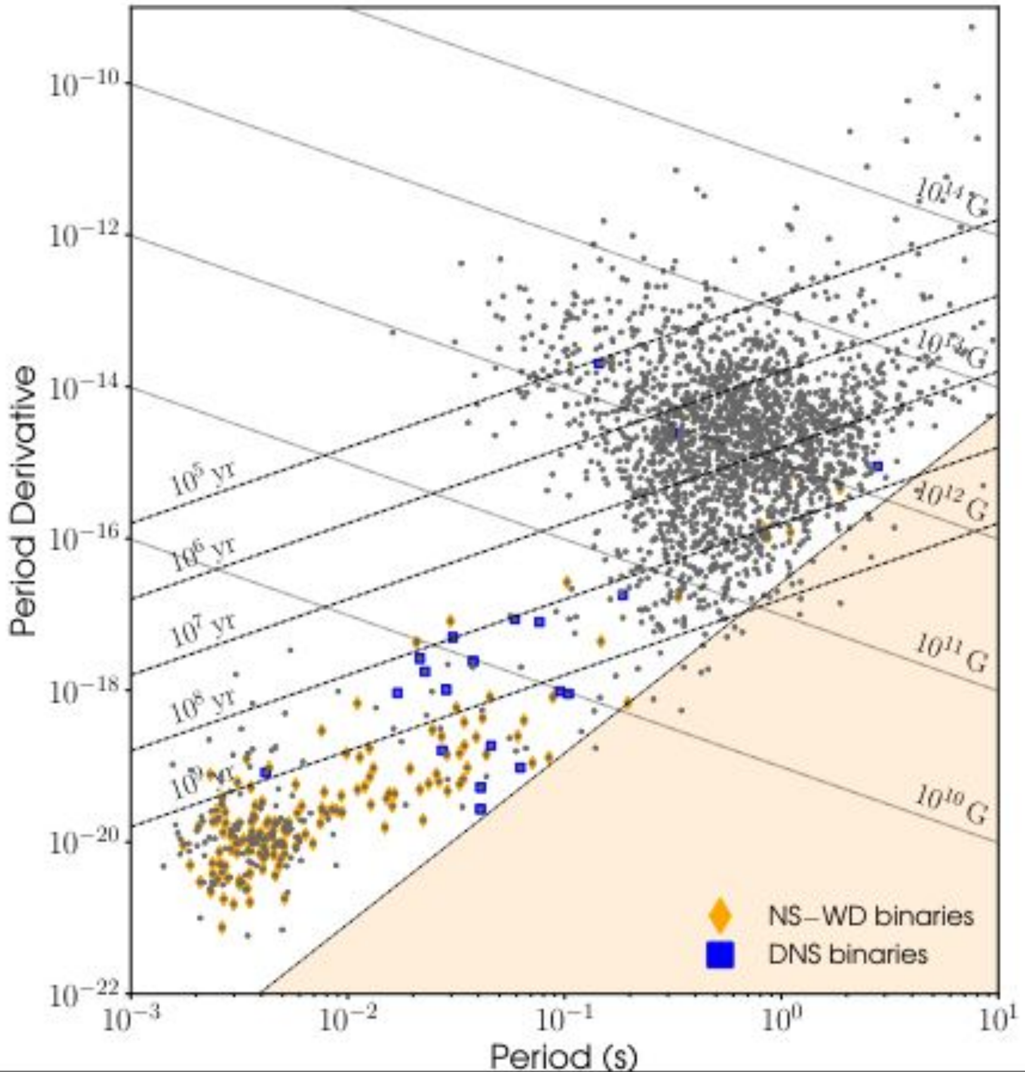
$\tau_d = 0.1$, U
$\tau_d = 0.1$, FL
$\tau_d = 0.1$, FG
$\tau_d = 0.5$, U
$\tau_d = 0.5$, FL
$\tau_d = 0.5$, FG
$\tau_d = 1$, U
$\tau_d = 1$, FL
$\tau_d = 1$, FG
$\tau_d = 2$, U
$\tau_d = 2$, FL
$\tau_d = 2$, FG
$\dot{P}$
10^{-14}
10^{-18}
10^{-22}
10^{-2}
10^{-1}
10^{0}
10^{1}
P (s)
Number density
0.44
0.36
0.28
0.20
0.12
0.04
0.01



Galactic BNSs
Cumulative PDF
$\alpha = 0.5$
$\alpha = 1$
$\alpha = 3$
$\alpha = 5$
P_{orb} [day]
e
Cumulative PDF
P [s]
$\dot{P}$



Iorio et al. 2023



Period Derivative
Period (s)
10^{-10}
10^{-12}
10^{-14}
10^{-16}
10^{-18}
10^{-20}
10^{-22}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{14} G
10^{13} G
10^{12} G
10^{11} G
10^{10} G
10^5 yr
10^6 yr
10^7 yr
10^8 yr
10^9 yr
NS−WD binaries
DNS binaries