Exploring progenitor pathways for long duration gamma-ray bursts from compact object mergers

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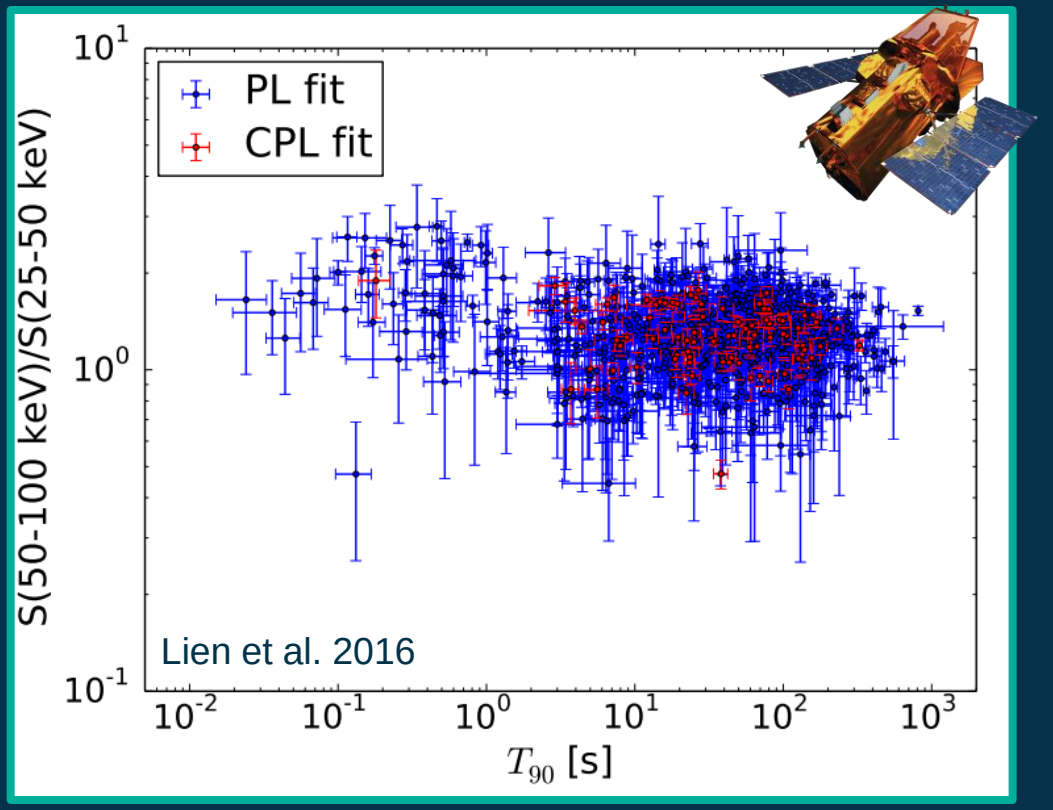
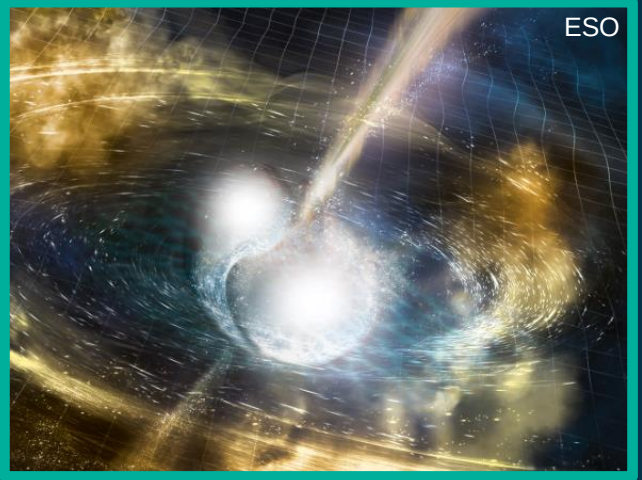
The GRB dichotomy

Consensus from 50 years of observations



Binary neutron star mergers

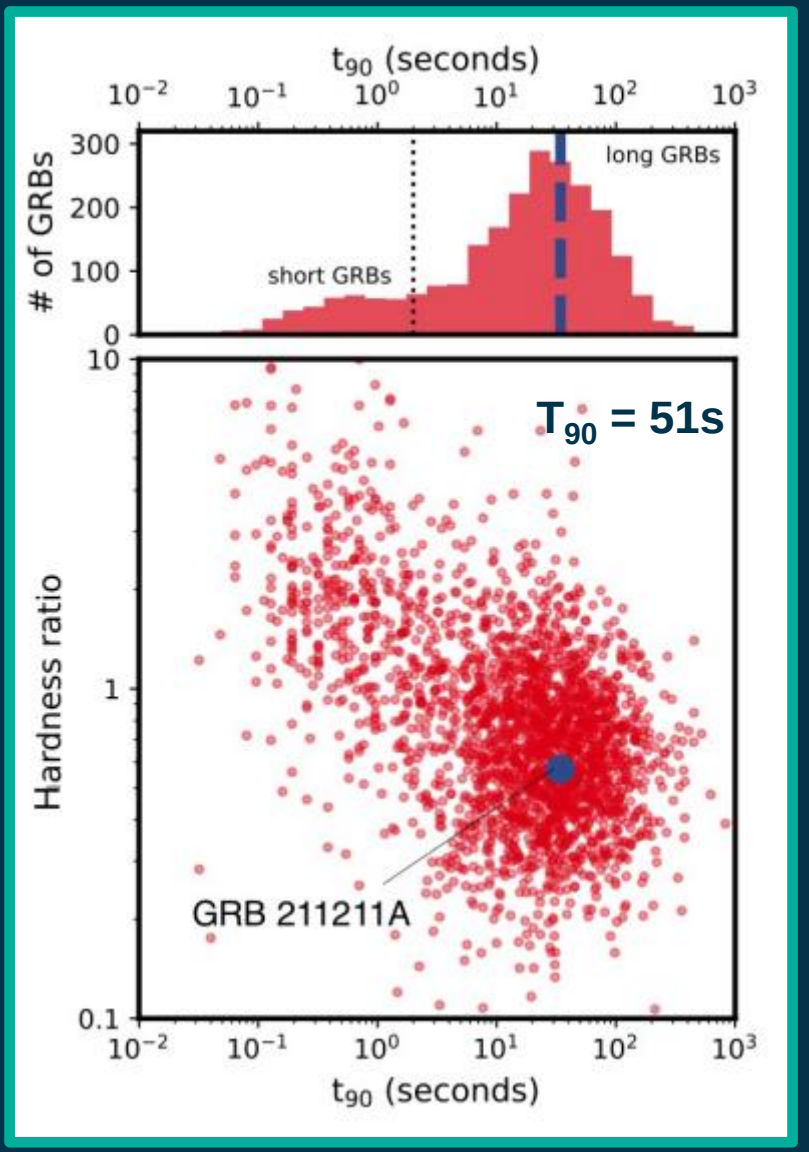


Short GRB + kilonovae

Massive star core-collapse

Long GRB + supernova

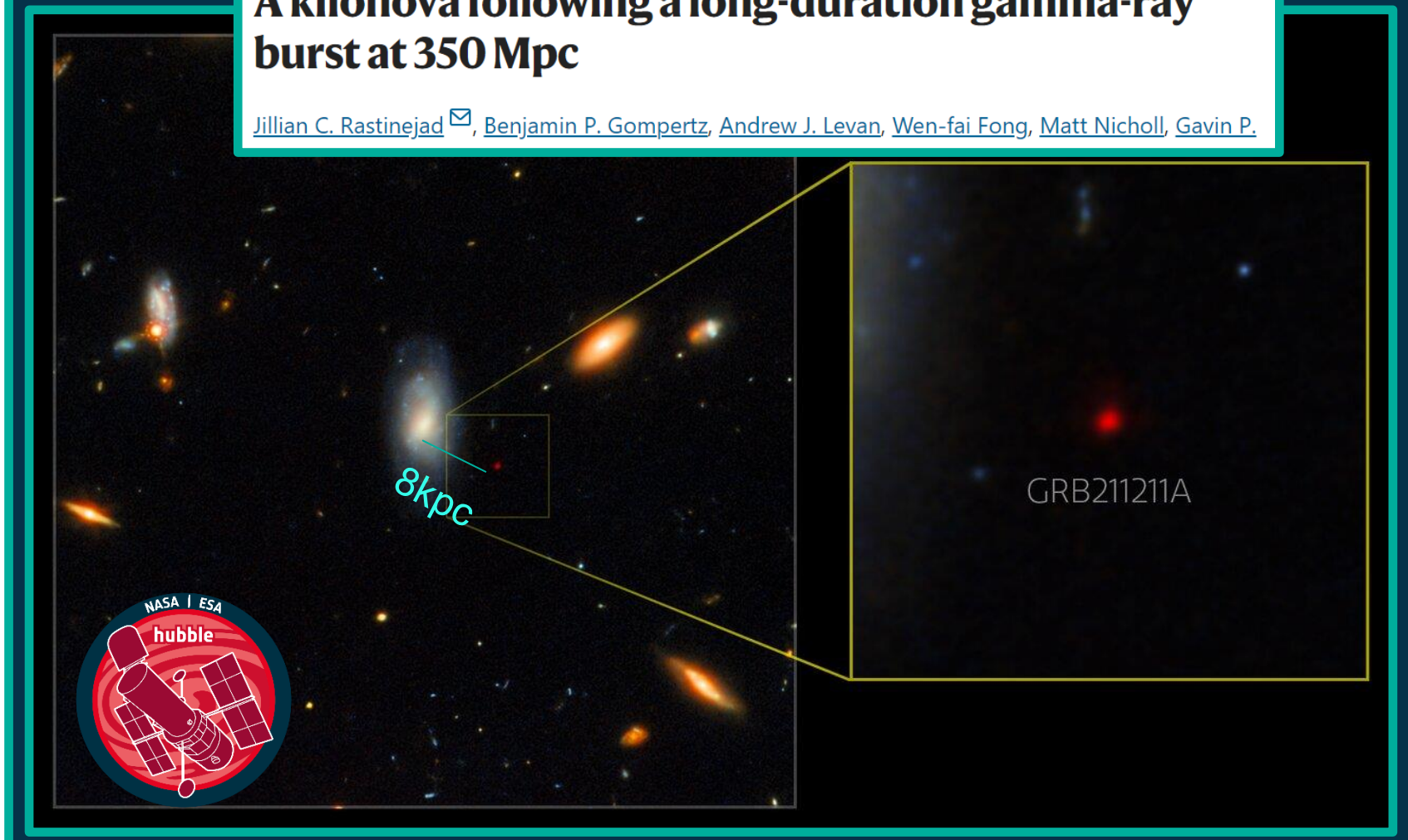
GRB211211A



Article | Published: 07 December 2022

A kilonova following a long-duration gamma-ray burst at 350 Mpc

Jillian C. Rastinejad, Benjamin P. Gompertz, Andrew J. Levan, Wen-fai Fong, Matt Nicholl, Gavin P.



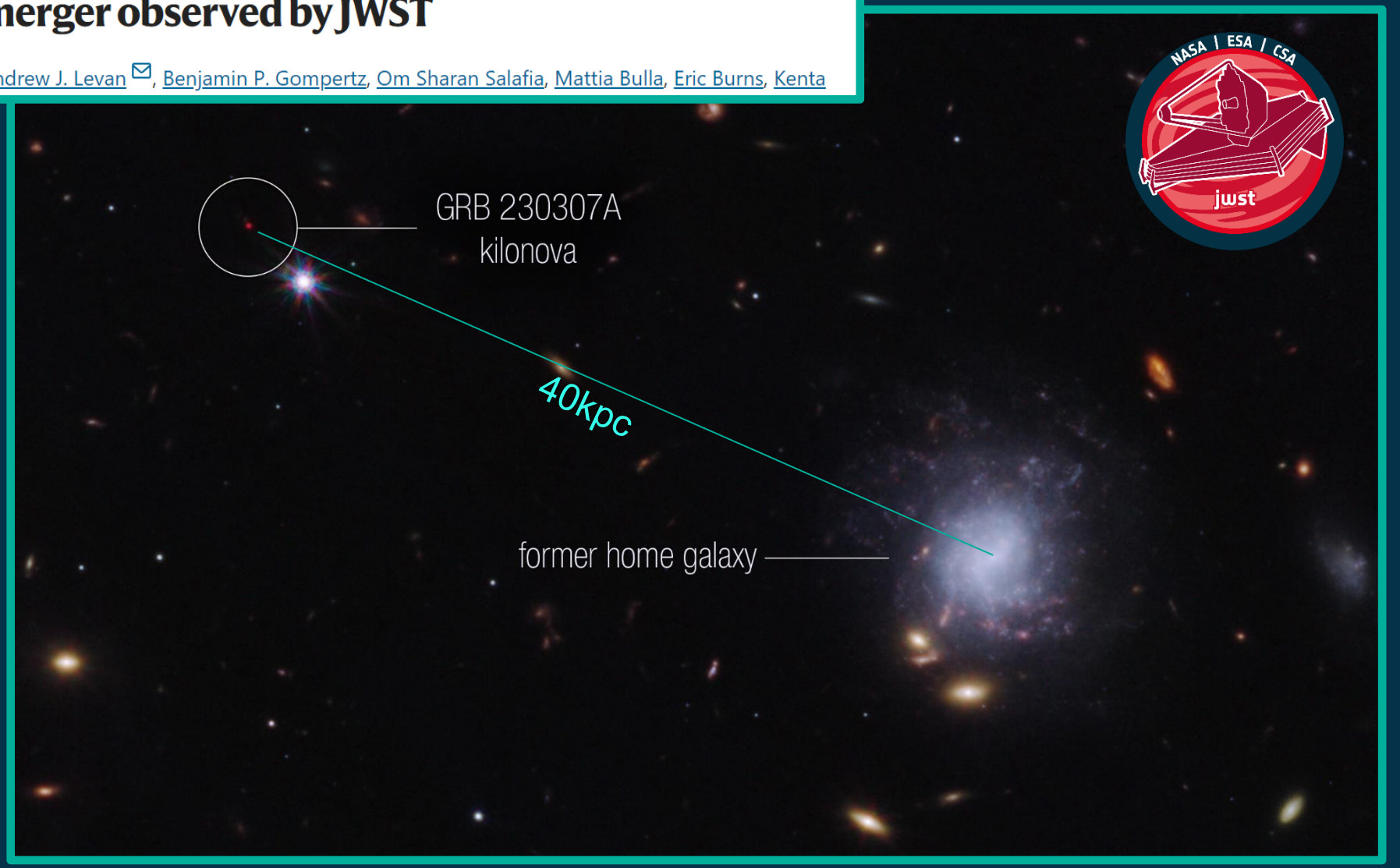
GRB230307A

T_{90} = 35s

Article | Open access | Published: 25 October 2023

Heavy-element production in a compact object merger observed by JWST

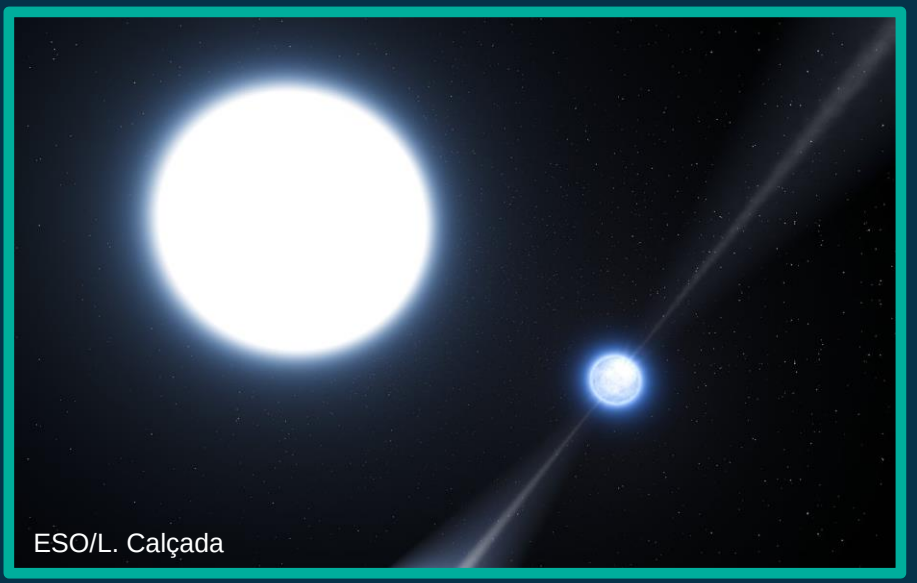
Andrew J. Levan, Benjamin P. Gompertz, Om Sharan Salafia, Mattia Bulla, Eric Burns, Kenta



Explaining long-merger GRBs

Hypothesis:

- White dwarf (WD) - neutron star (NS) / black hole (BH) mergers?
- Less dense (~6000km versus 10km), dynamical timescale is longer, longer lasting accretion / magnetar central engine?
- E.g. Fryer et al. (1999), King et al. (2007), Yang et al. (2022), Kaltenborn et al. (2023), Morán-Fraile et al. (2024), Ai et al. (2025), Zhang (2025)



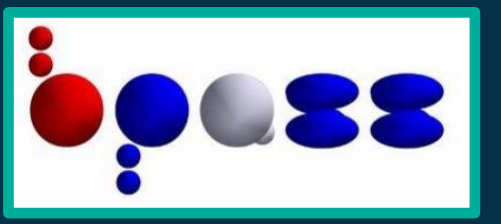
Our test (Chrimes et al. in prep):

Simulate populations of compact binaries & their kinematics

in models for the host galaxies of GRBs **211211A** and **230307A**

Binary population synthesis

- Grid of thousands of binary stellar evolution models, weighted according to observed Galactic systems (Moe & di Stefano 2017)
- Binary dynamics with model of Tauris et al. (1998, 1999)
- NS kicks: Verbunt et al. (2017), Hobbs et al. (2005) and Bray et al. (2016)
- GW in-spiral time (Mandel 2021)



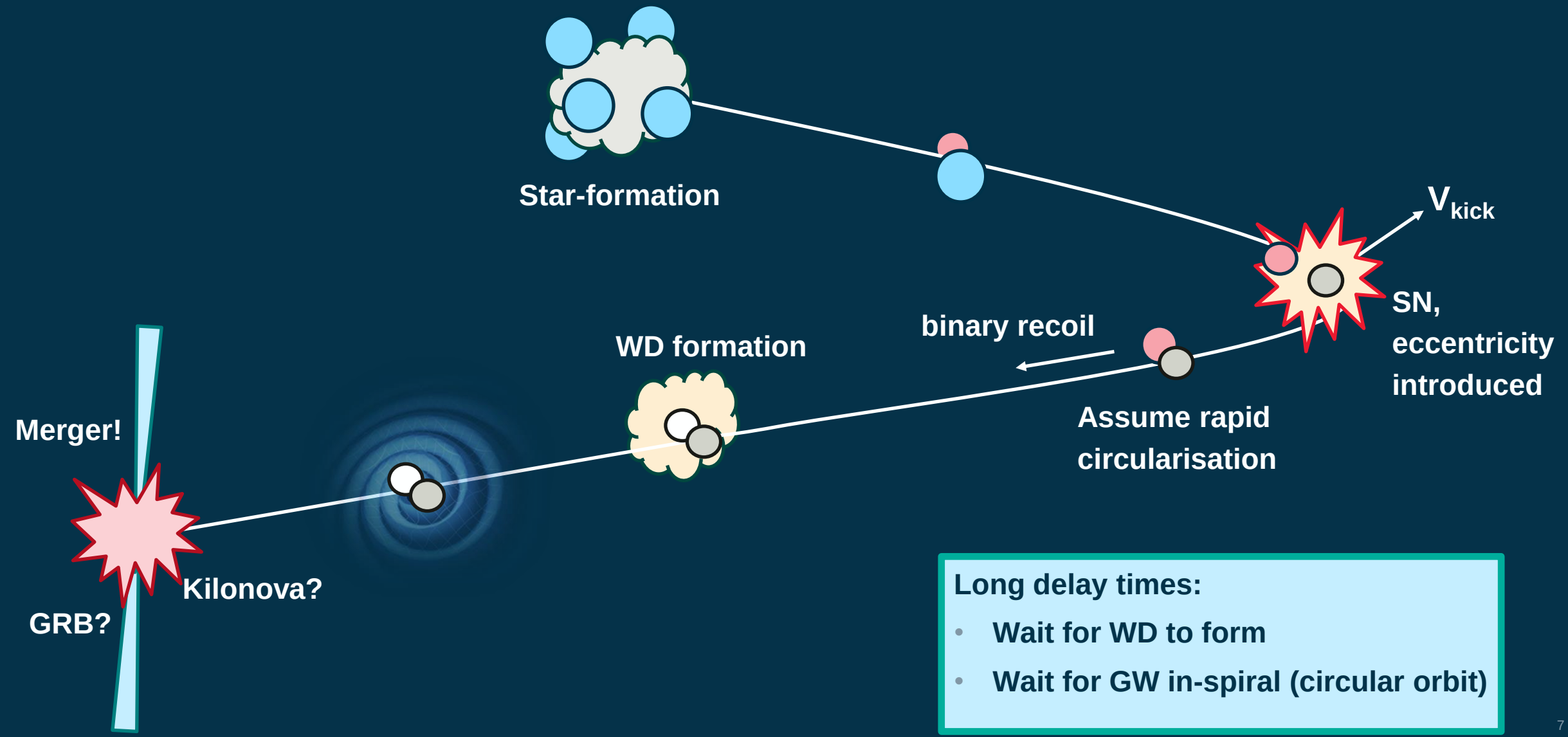
Binary population synthesis and spectral synthesis
(Eldridge et al. 2017)

$$T_c = \frac{5c^5 a_0^4}{256 G^3 M_1 M_2 (M_1 + M_2)}$$ circular

$$T \approx T_c \left(1 + 0.27 e_0^{10} + 0.33 e_0^{20} + 0.2 e_0^{1000}\right) \left(1 - e_0^2\right)^{7/2}$$ eccentric

See also Toonen et al. 2018 for WDNS demographics with SeBa!

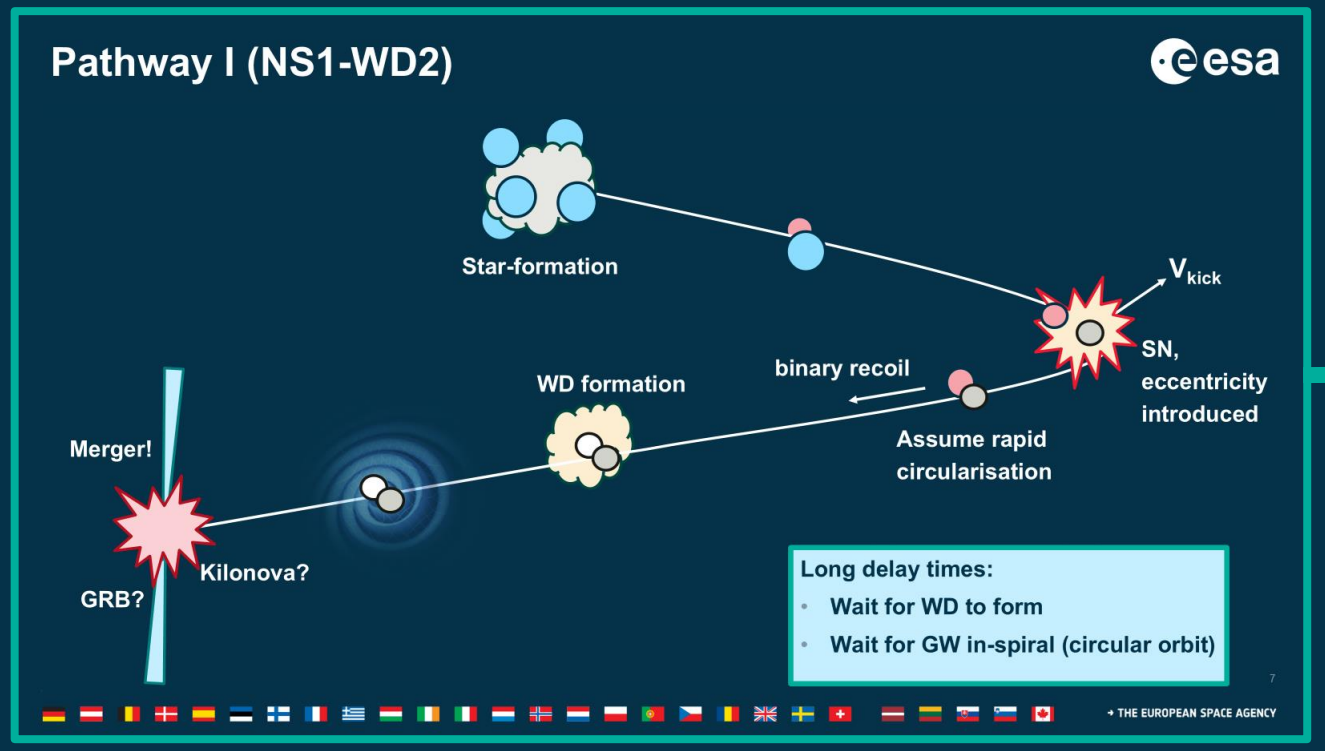
Pathway I (NS1-WD2)

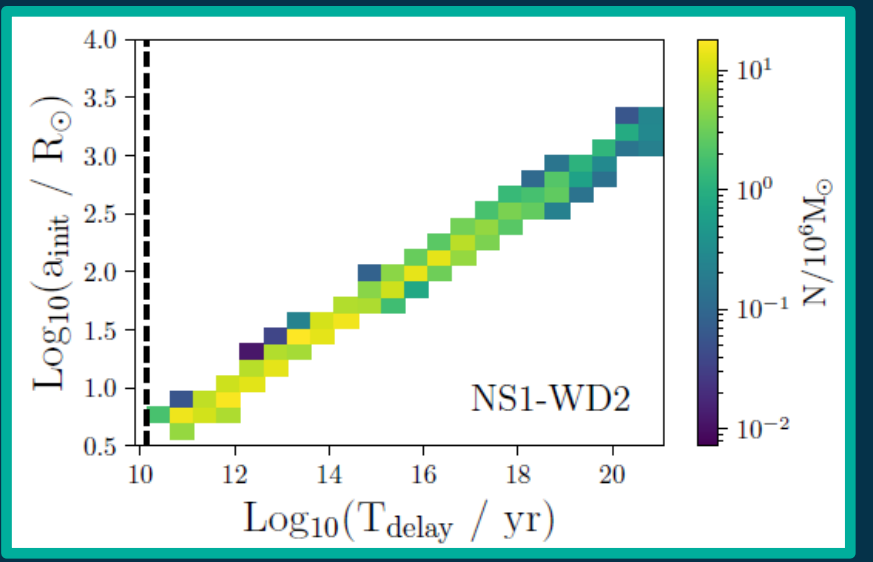


Long delay times:

- Wait for WD to form
- Wait for GW in-spiral (circular orbit)

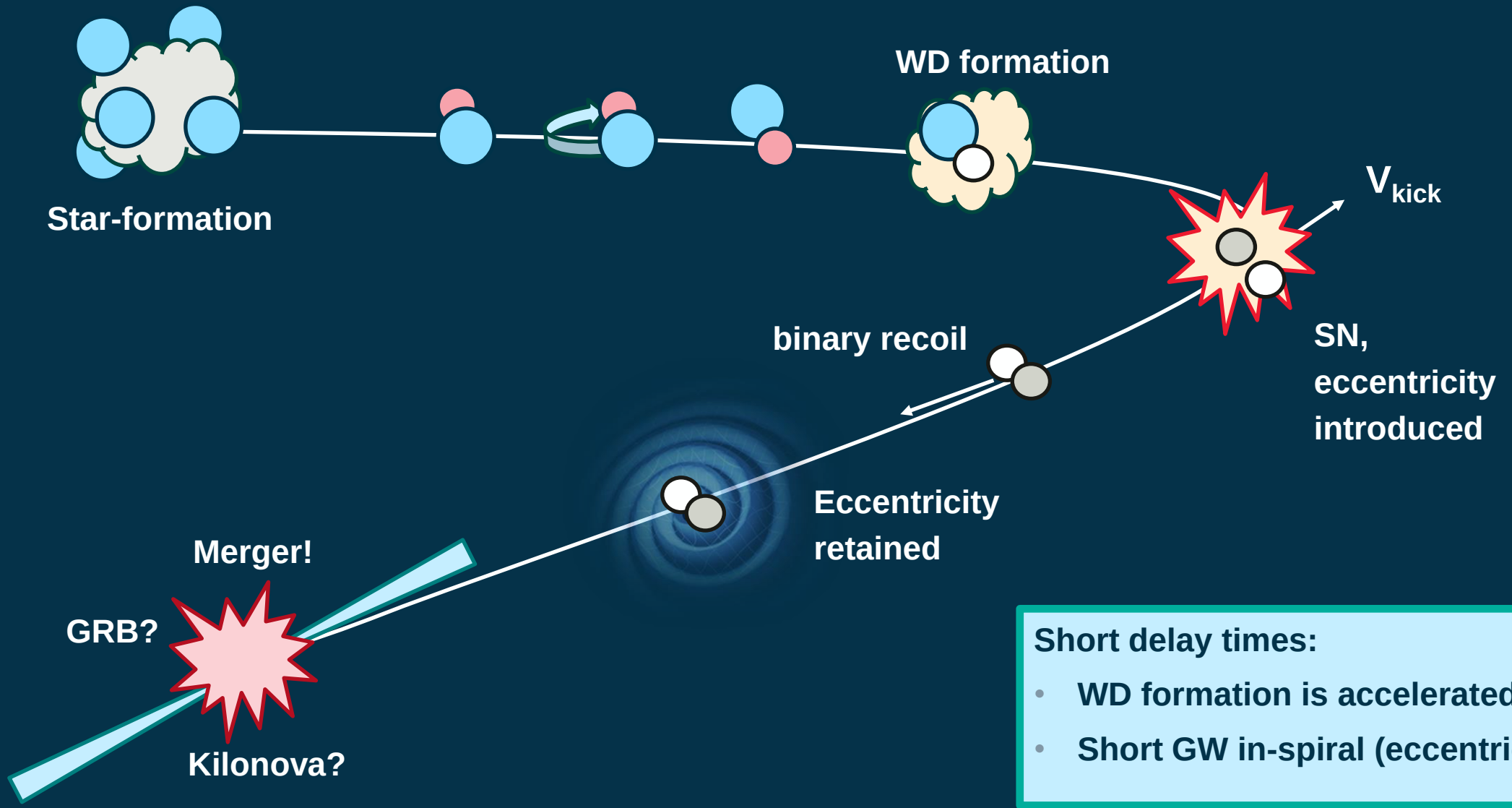
Pathway I (NS1-WD2)





(also find analogous WDBH systems, but ~x10 rarer)

Pathway II (WD1-NS2)

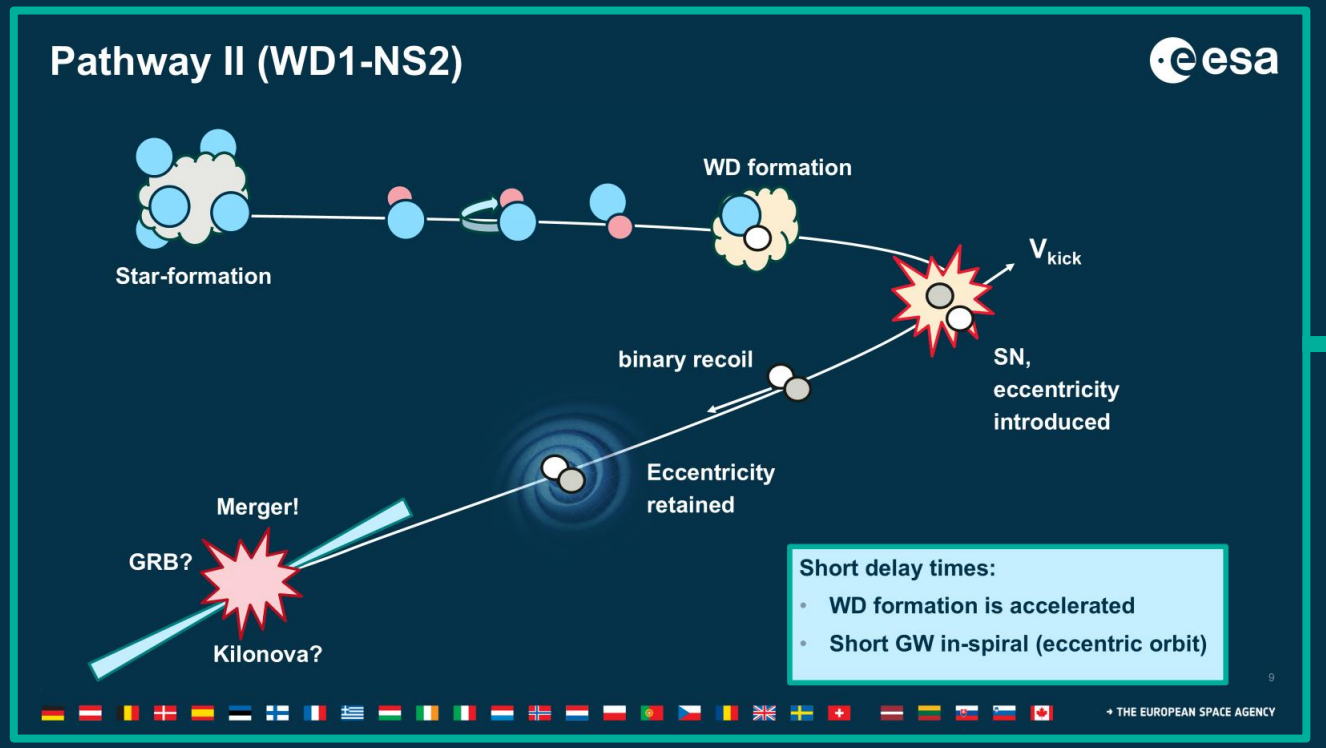


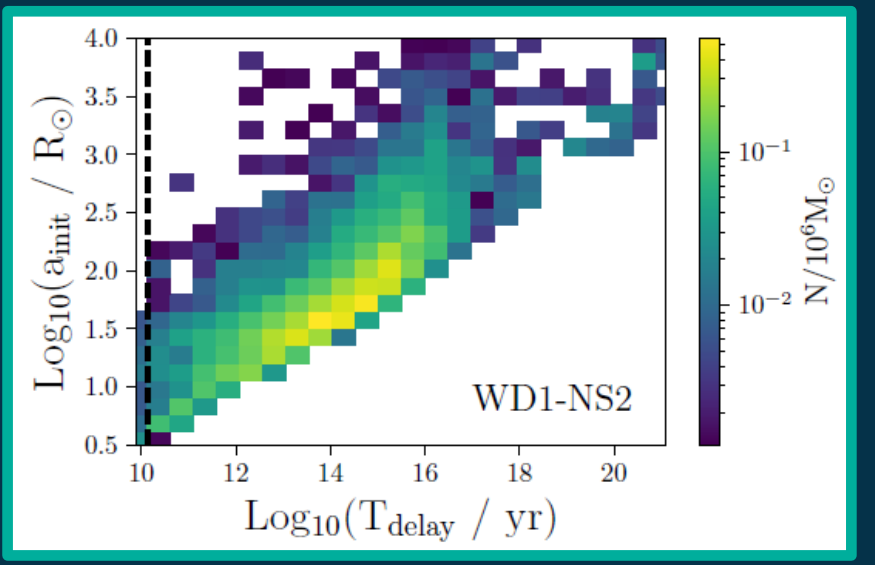
Short delay times:

- WD formation is accelerated
- Short GW in-spiral (eccentric orbit)

Pathway II (WD1-NS2)

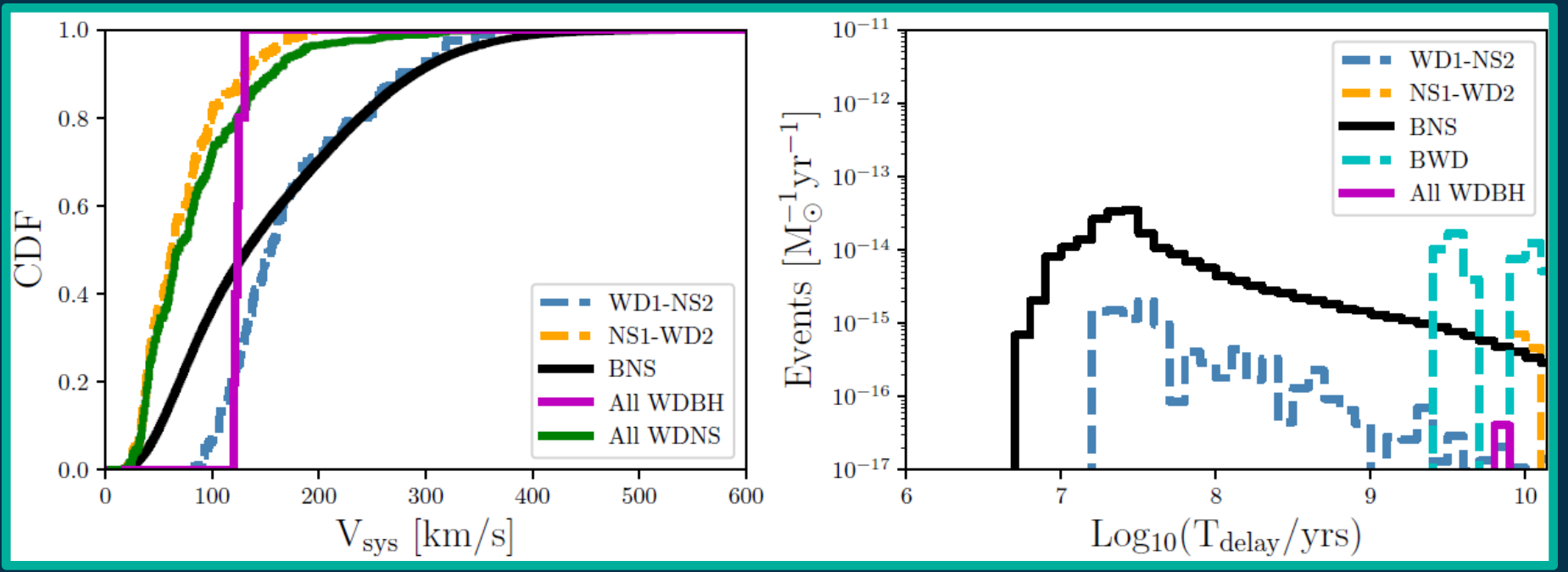
Dominates mergers within a Hubble time!



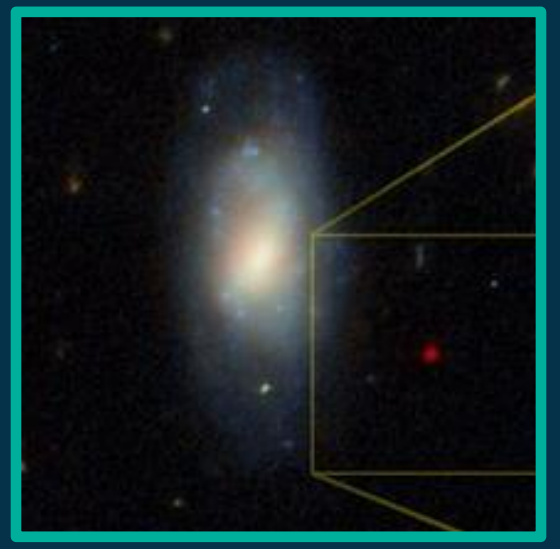


No WD1-BH2 systems found!

Systemic velocities & delay times



GRB211211A



Host galaxies

GRB230307A

Host galaxy models

Methodology of Gaspari et al. (in prep)

(see also e.g. Fryer+1999, Church+2011, Mandhai+2022, Wagg+2025)

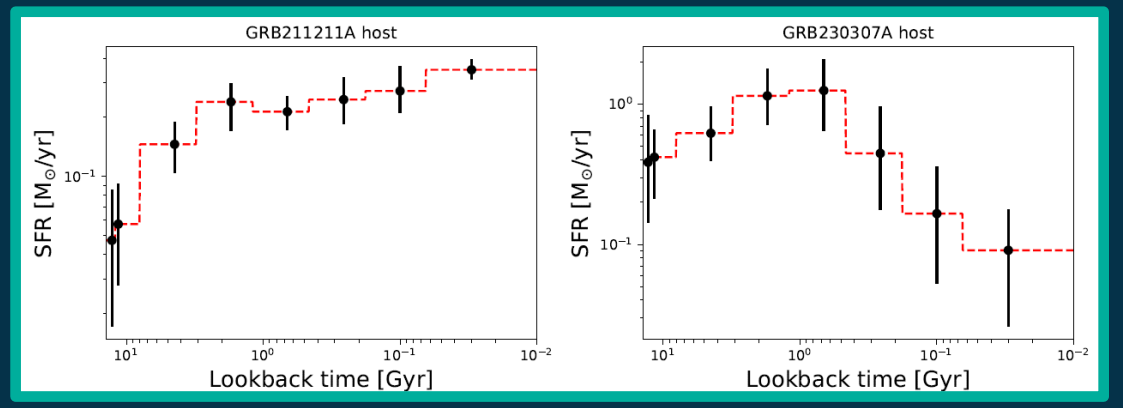
Seed the binary populations…

In space:

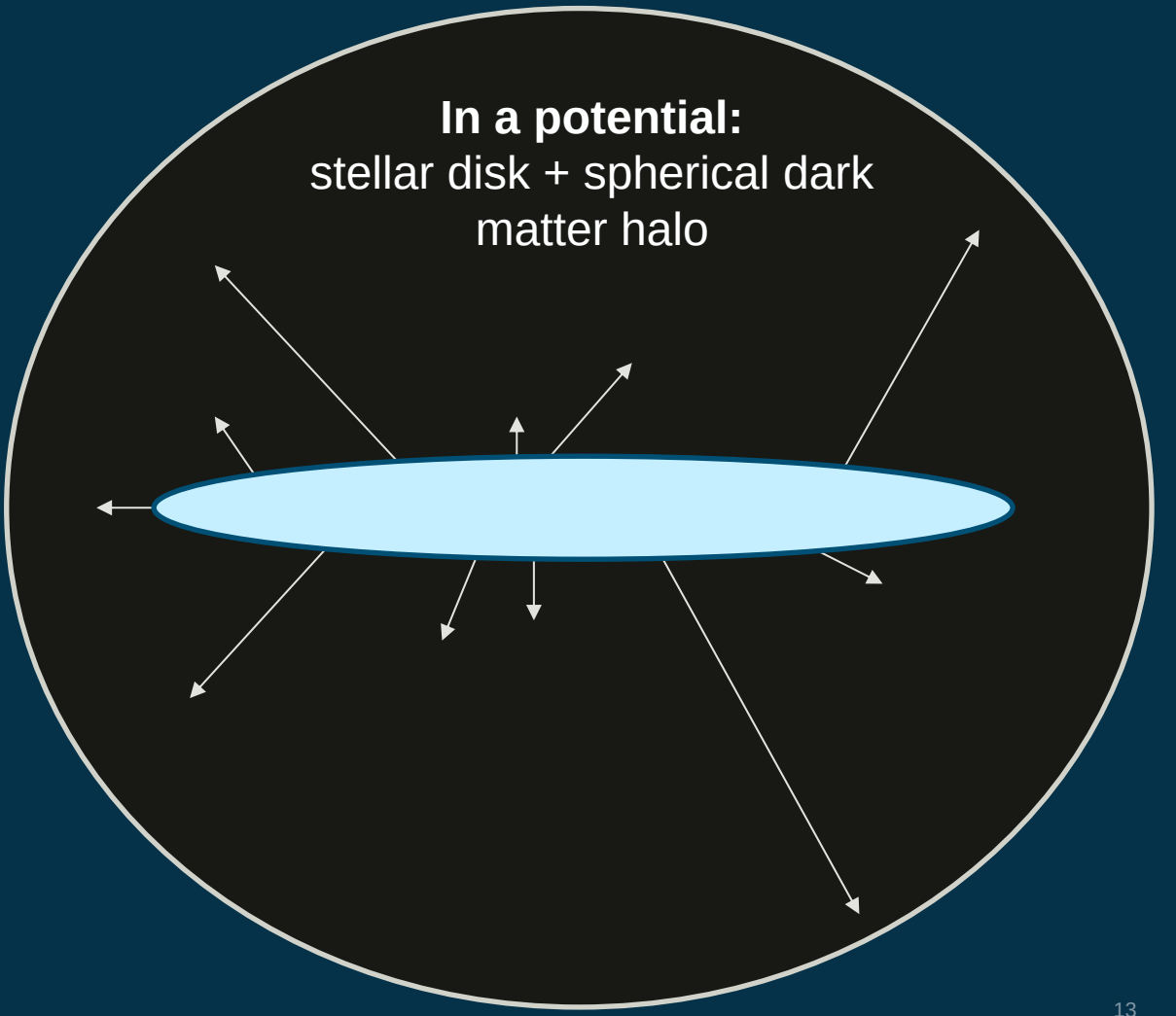
Assuming host galaxies are infinitely thin discs…

In time:

… with star-formation histories (SFHs)



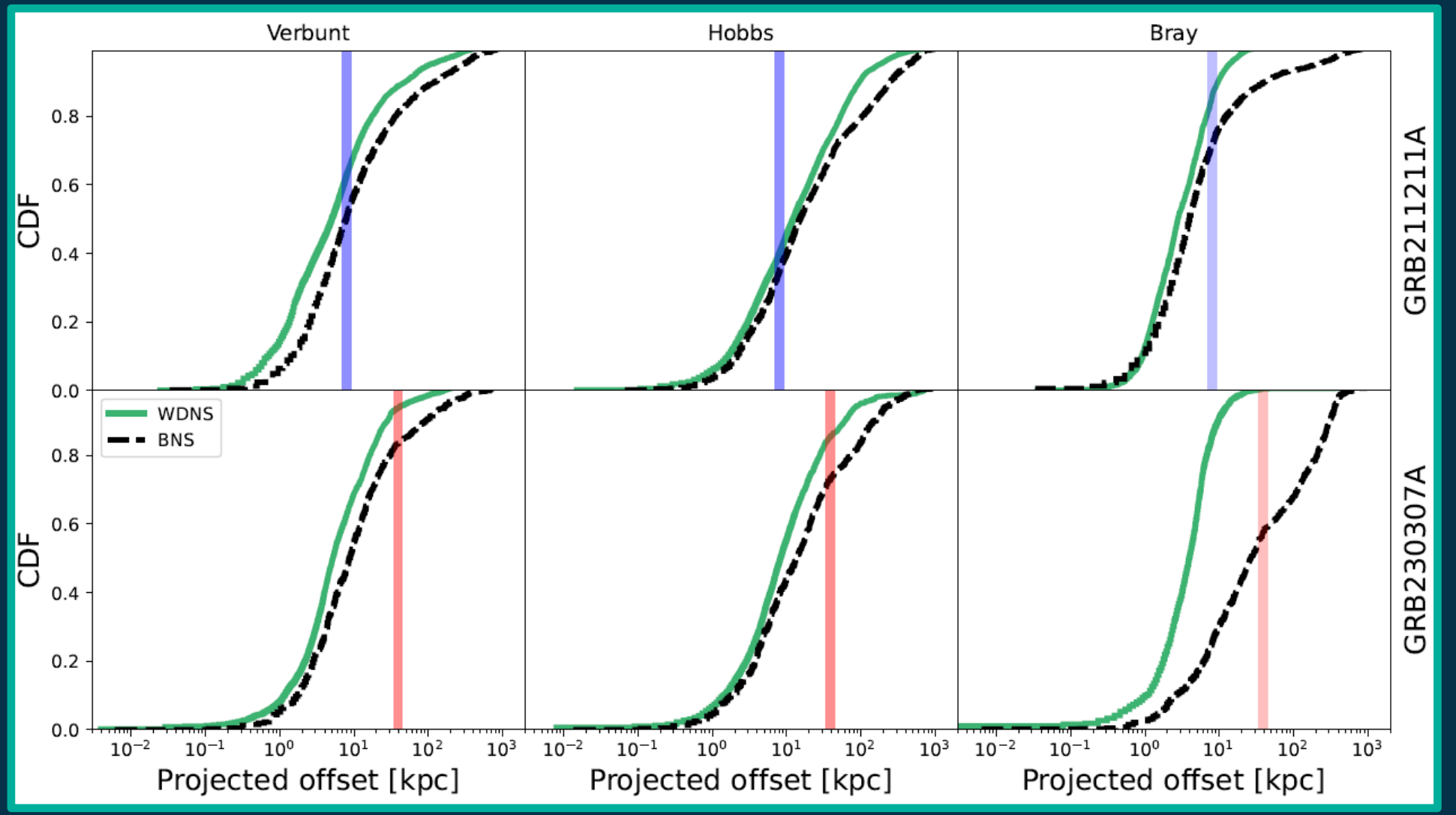
Nugent et al. 2024



Results: predictions vs observed offset

8kpc

40kpc



Conclusions & outlook

Gaspari et al. in prep, Chrimes et al. in prep

How to explain long-merger GRBs?

NSWD mergers:

- **Offsets:** plausible, need population statistics
- **Rates:** plausible. WDBH much rarer, consistent result across pop synth codes, e.g. Nelemans et al. 2001

Future tests:

- Kilonova variety? (e.g. Gompertz et al. 2018, Rastinejad et al. 2025)
- Best evidence: LIGO/VIRGO non-detection of a nearby event!

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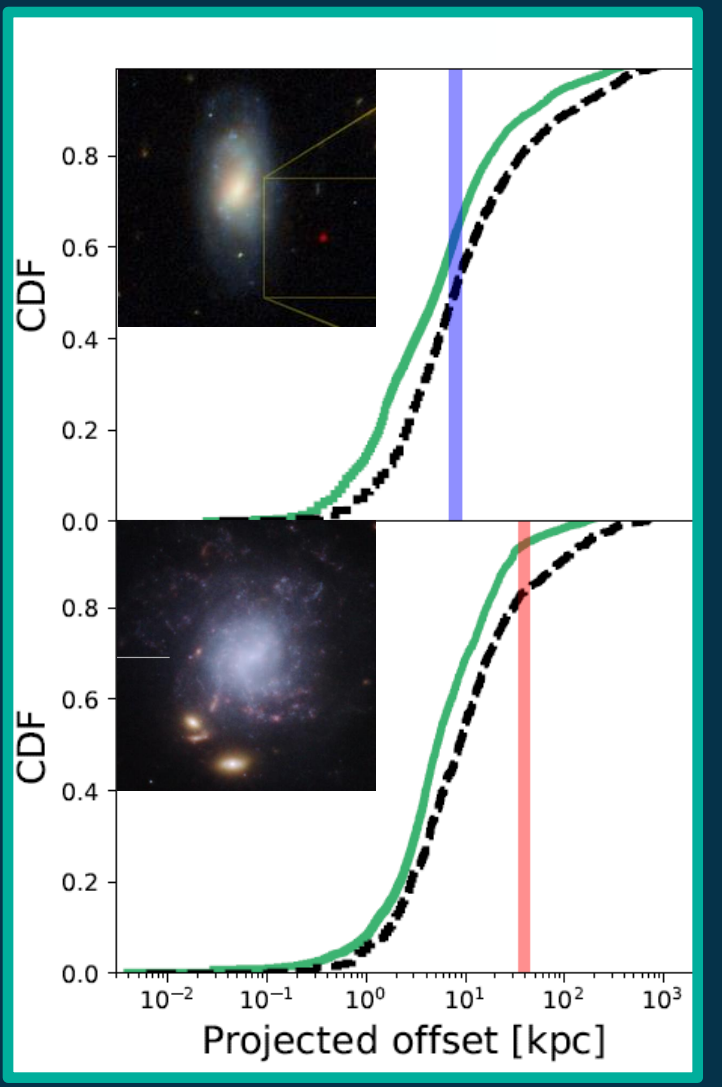

Results: volumetric rates