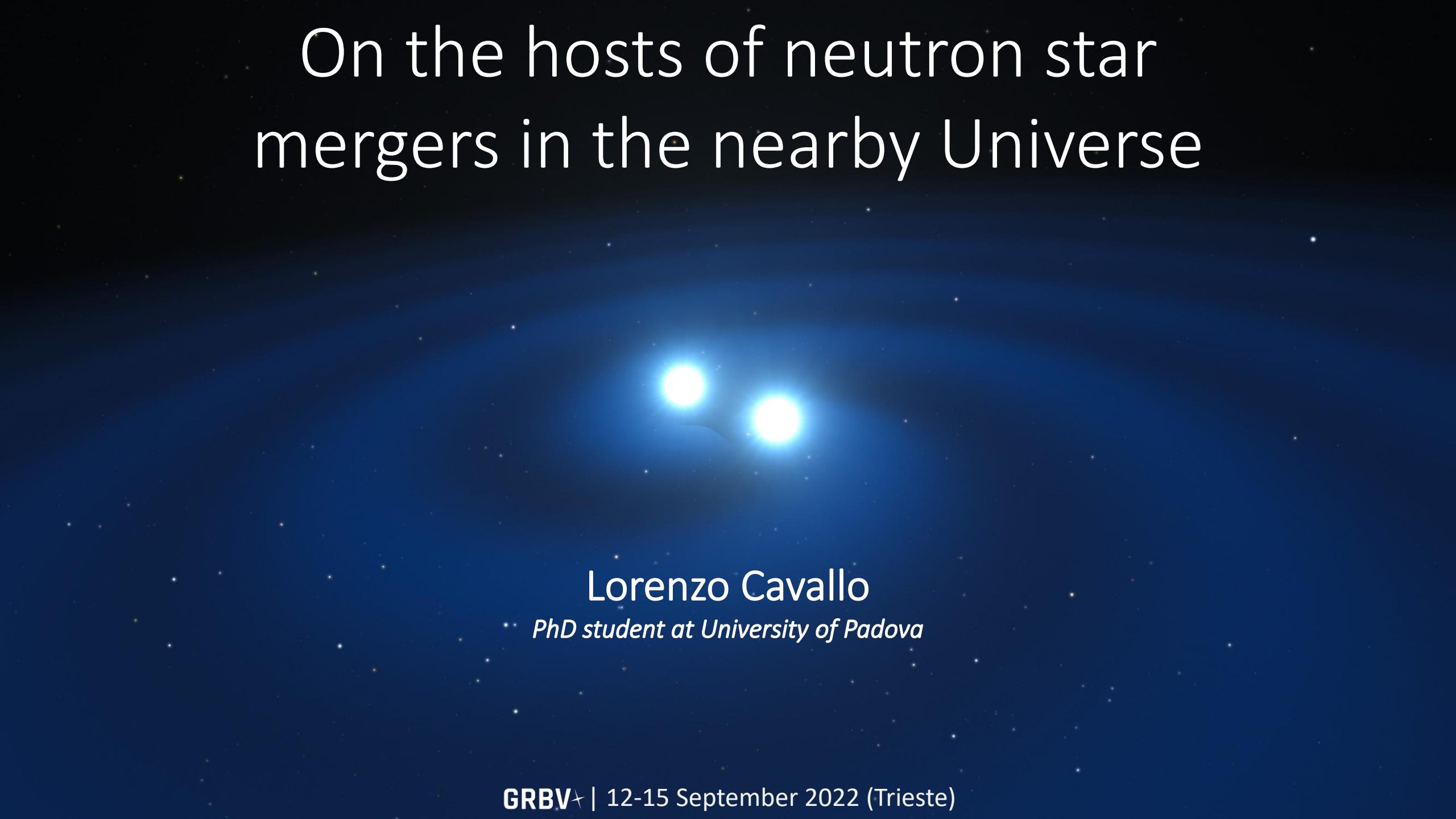
On the hosts of neutron star mergers in the nearby Universe

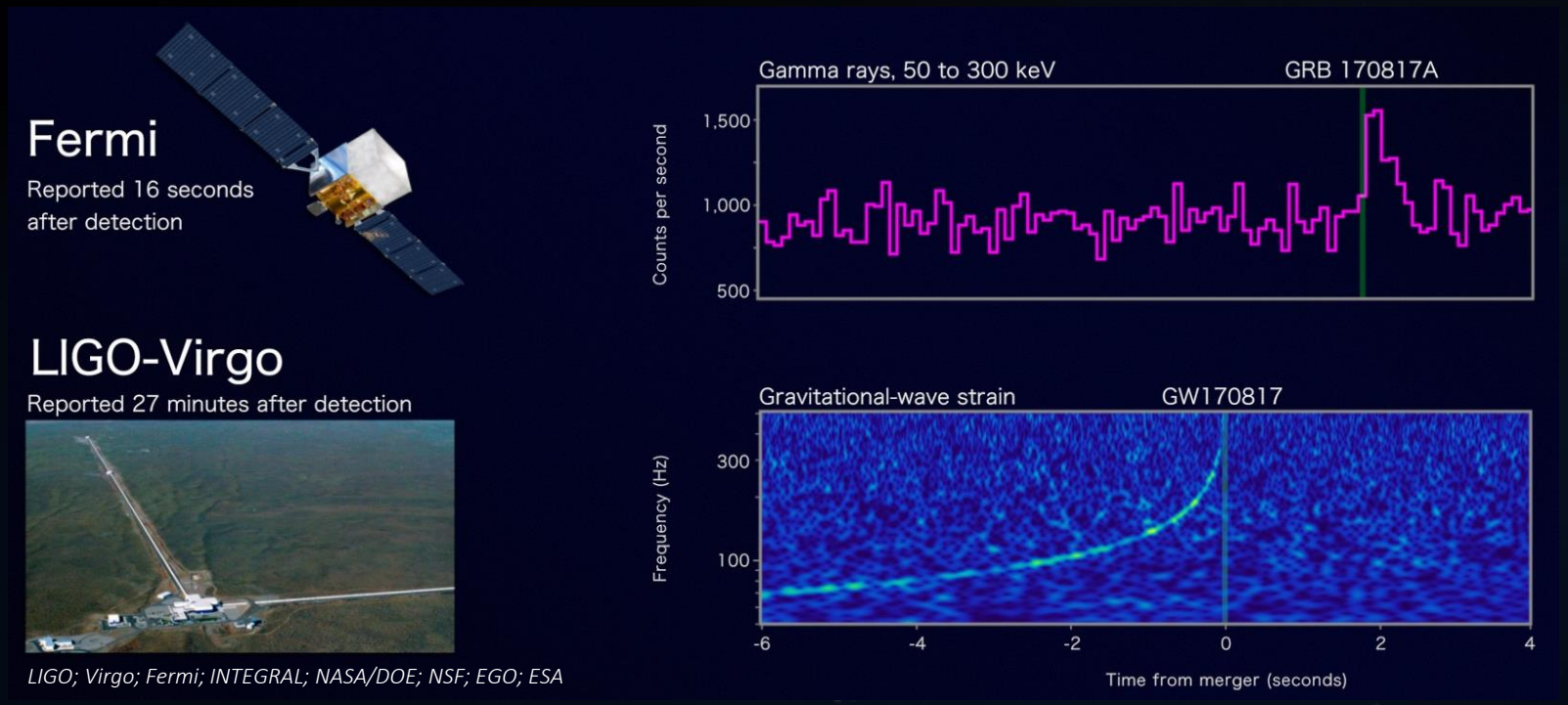


Lorenzo Cavallo

PhD student at University of Padova

GRBV✦ | 12-15 September 2022 (Trieste)

The dawn of a new era

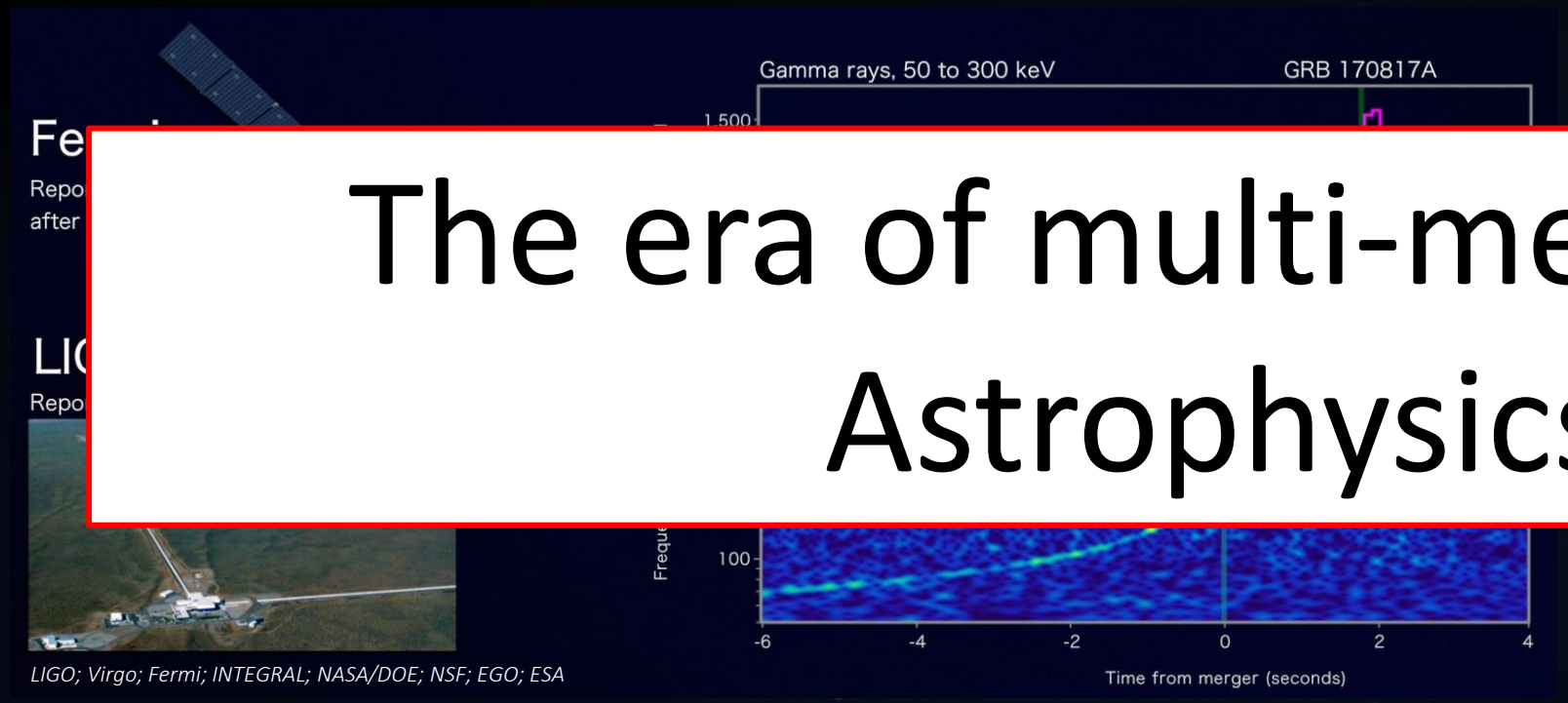


LIGO; Virgo; Fermi; INTEGRAL; NASA/DOE; NSF; EGO; ESA

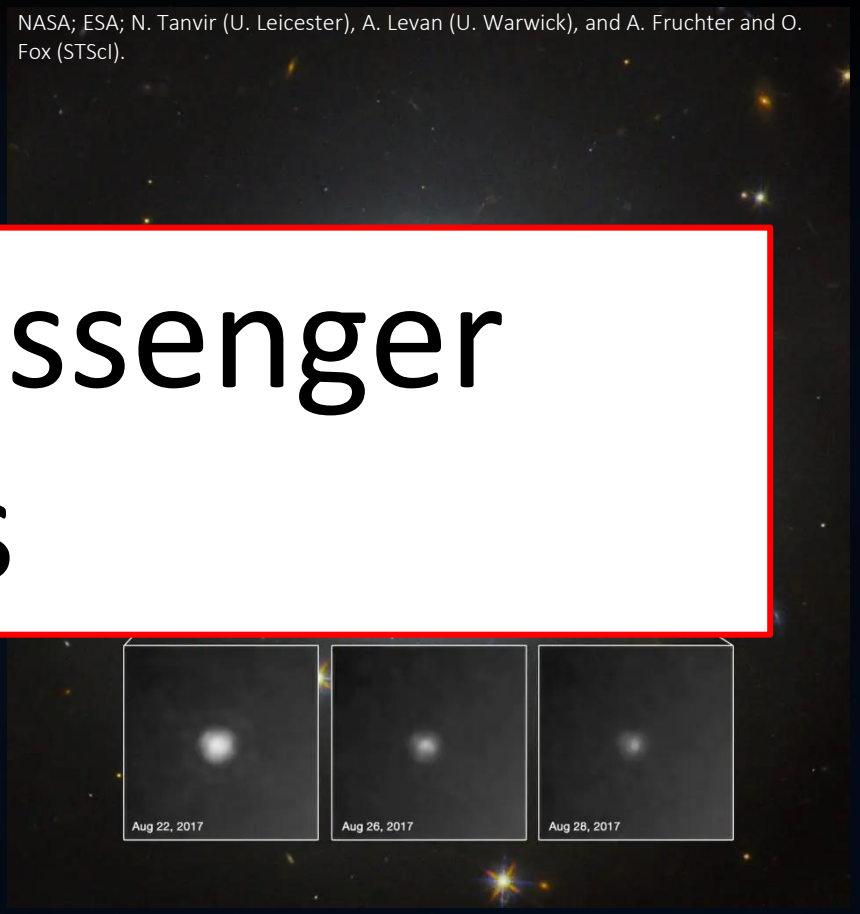
NASA; ESA; N. Tanvir (U. Leicester), A. Levan (U. Warwick), and A. Fruchter and O. Fox (STScI).

The dawn of a new era

The era of multi-messenger Astrophysics



LIGO; Virgo; Fermi; INTEGRAL; NASA/DOE; NSF; EGO; ESA



NASA; ESA; N. Tanvir (U. Leicester), A. Levan (U. Warwick), and A. Fruchter and O. Fox (STScI).

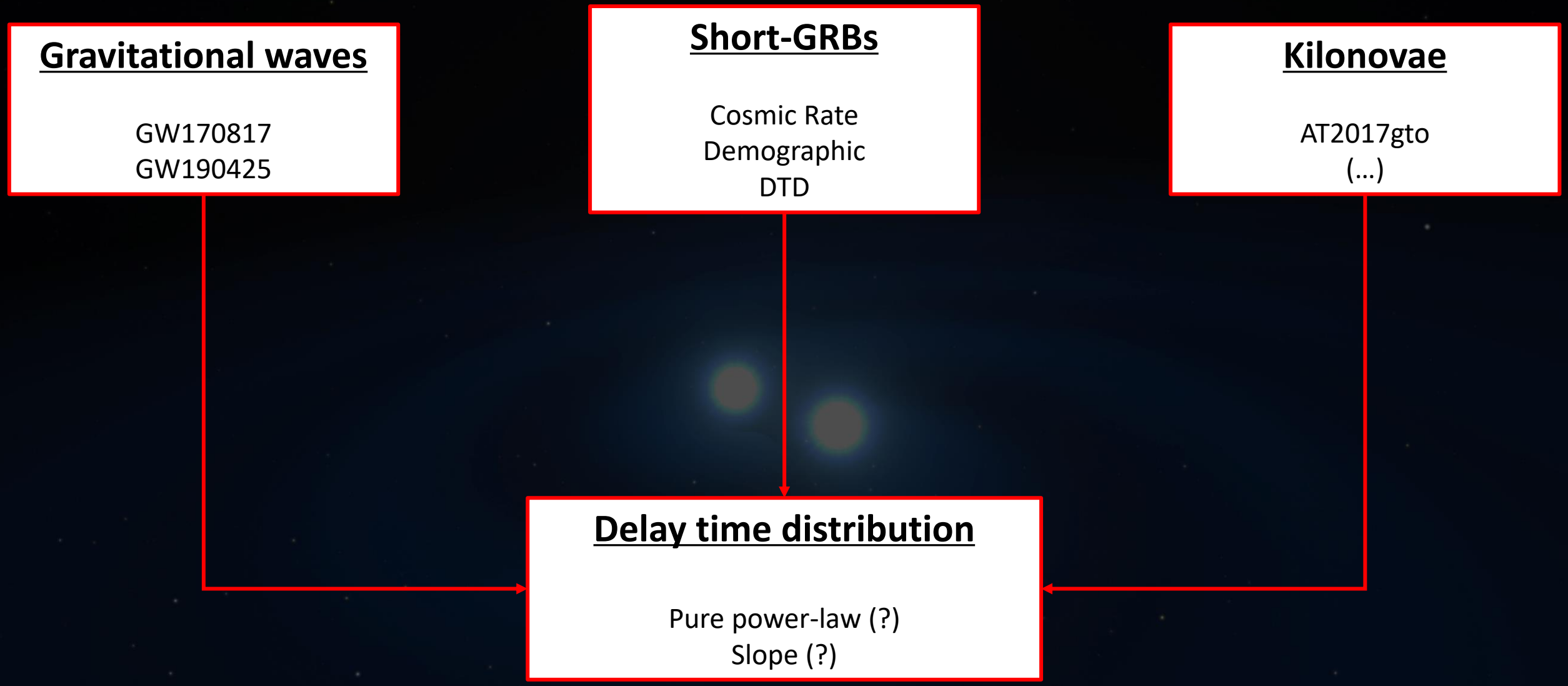
Chemical evolution of heavy elements

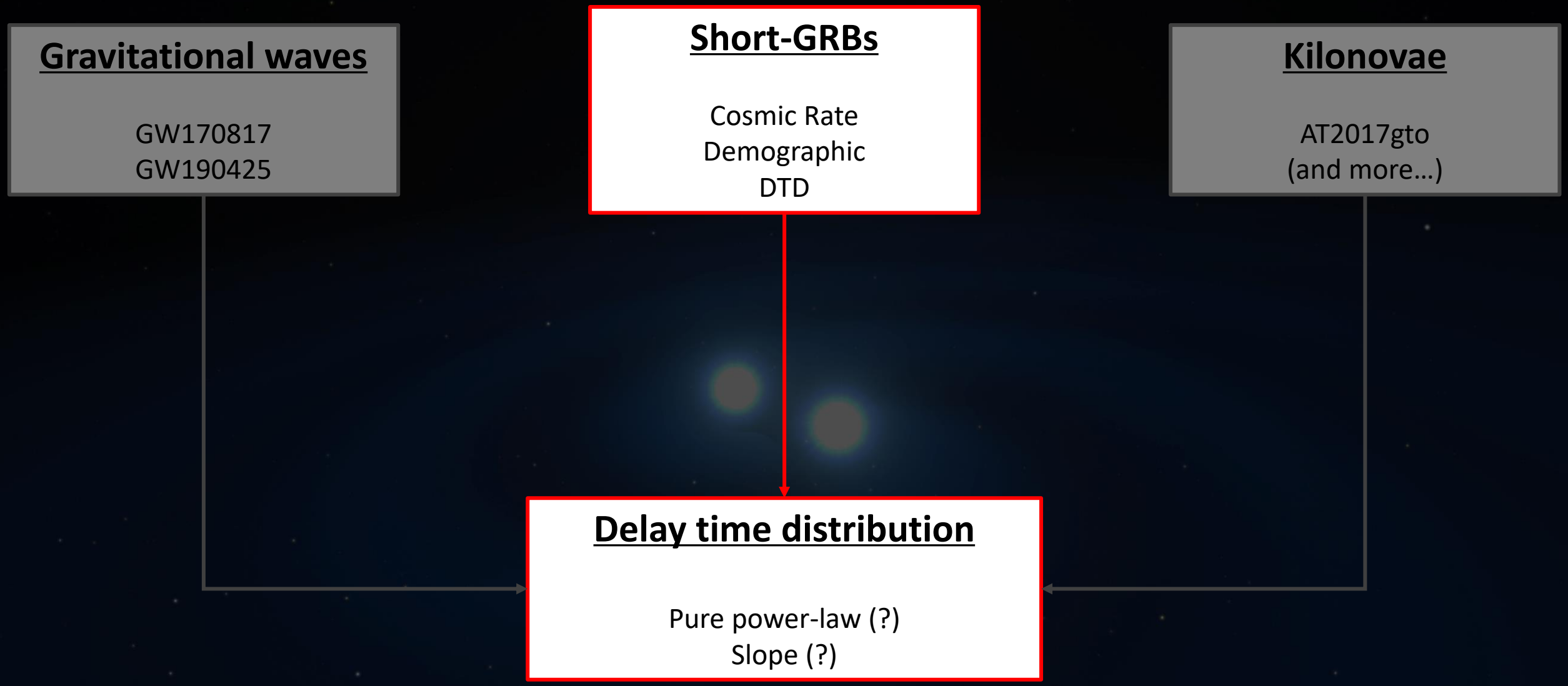
- **Delay time**

Matteucci et al. 2014, Cescutti et al. 2015, Côté et al. 2019; Simonetti et al. 2019; Cavallo et al. 2021

- **Environment**

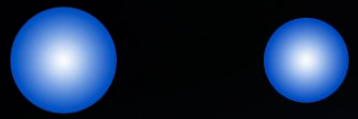
Bonetti et al. 2019, Cavallo et al. (2022a) [submitted]


Gravitational waves
GW170817
GW190425
Short-GRBs
Cosmic Rate
Demographic
DTD
Kilonovae
AT2017gto
(…)
Delay time distribution
Pure power-law (?)
Slope (?)


Gravitational waves
GW170817
GW190425
Short-GRBs
Cosmic Rate
Demographic
DTD
Kilonovae
AT2017gto
(and more…)
Delay time distribution
Pure power-law (?)
Slope (?)

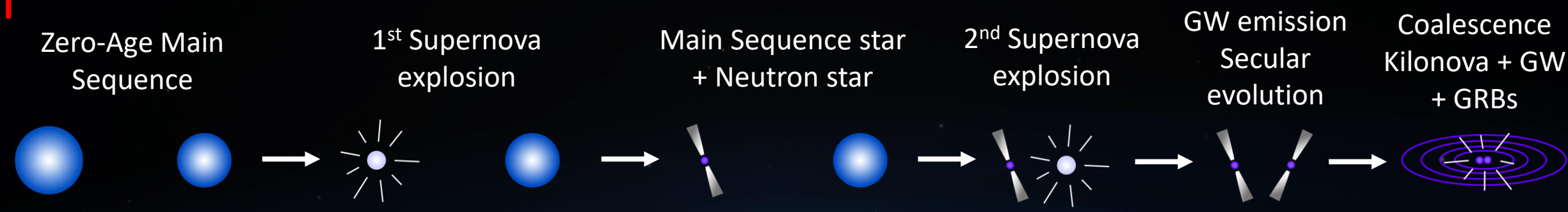
DELAY TIME

Zero-Age Main Sequence



Coalescence Kilonova + GW + GRBs

DELAY TIME



NUCLEAR TIME

GRAVITATIONAL TIME

DELAY TIME

Zero-Age Main Sequence

1st Supernova explosion

Main Sequence star + Neutron star

2nd Supernova explosion

GW emission Secular evolution

Coalescence Kilonova + GW + GRBs

NUCLEAR TIME

Depends on the assumption of the mass range of NS progenitors

GRAVITATIONAL TIME

Depends on the orbital parameters of the NS-NS system at formation

Separation, Total mass, and eccentricity

Greggio et al. 2021 have developed an analytical DTD for NSM

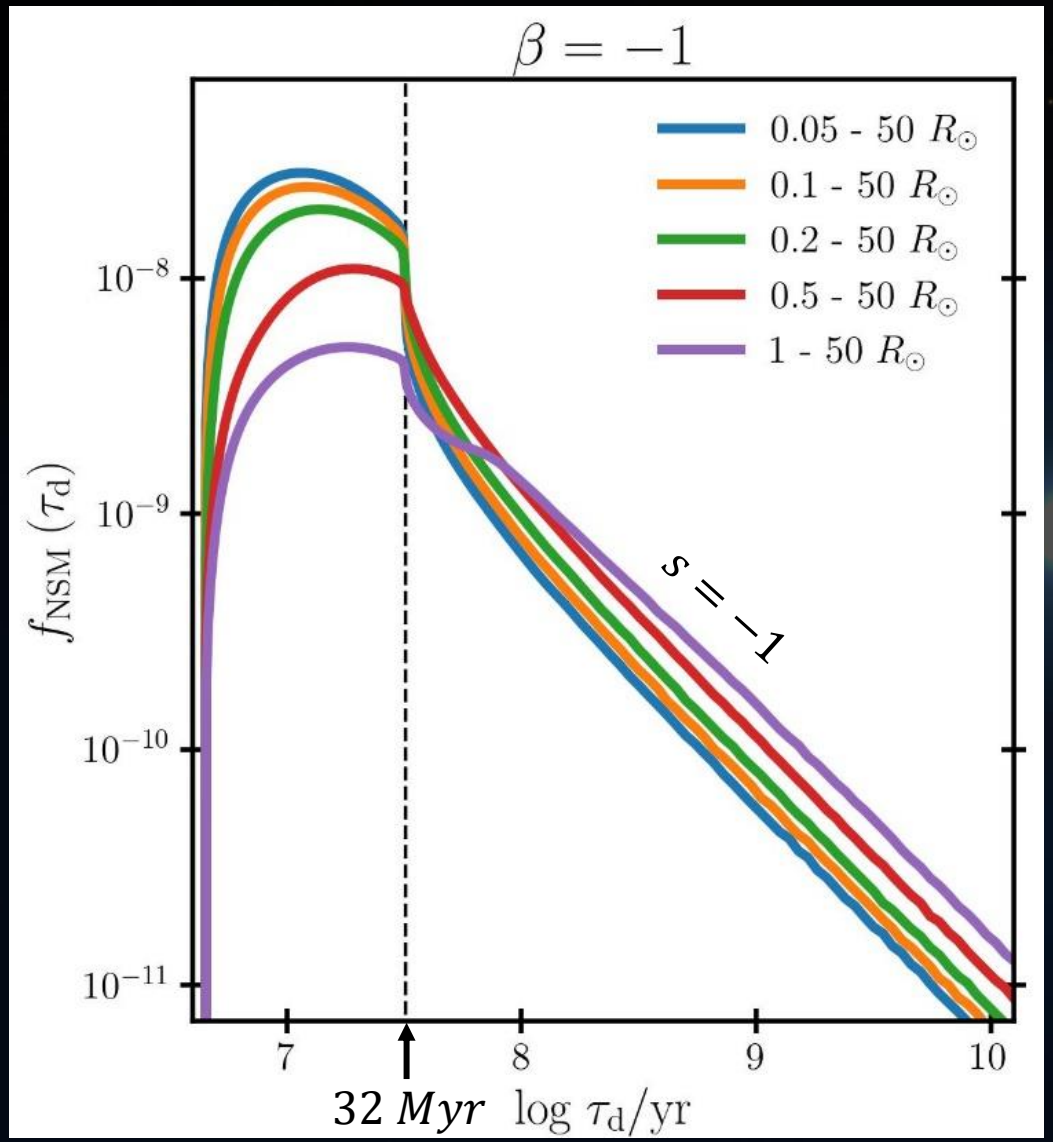
Slope of the power-law distribution:
$f(A) \propto A^{\beta}$

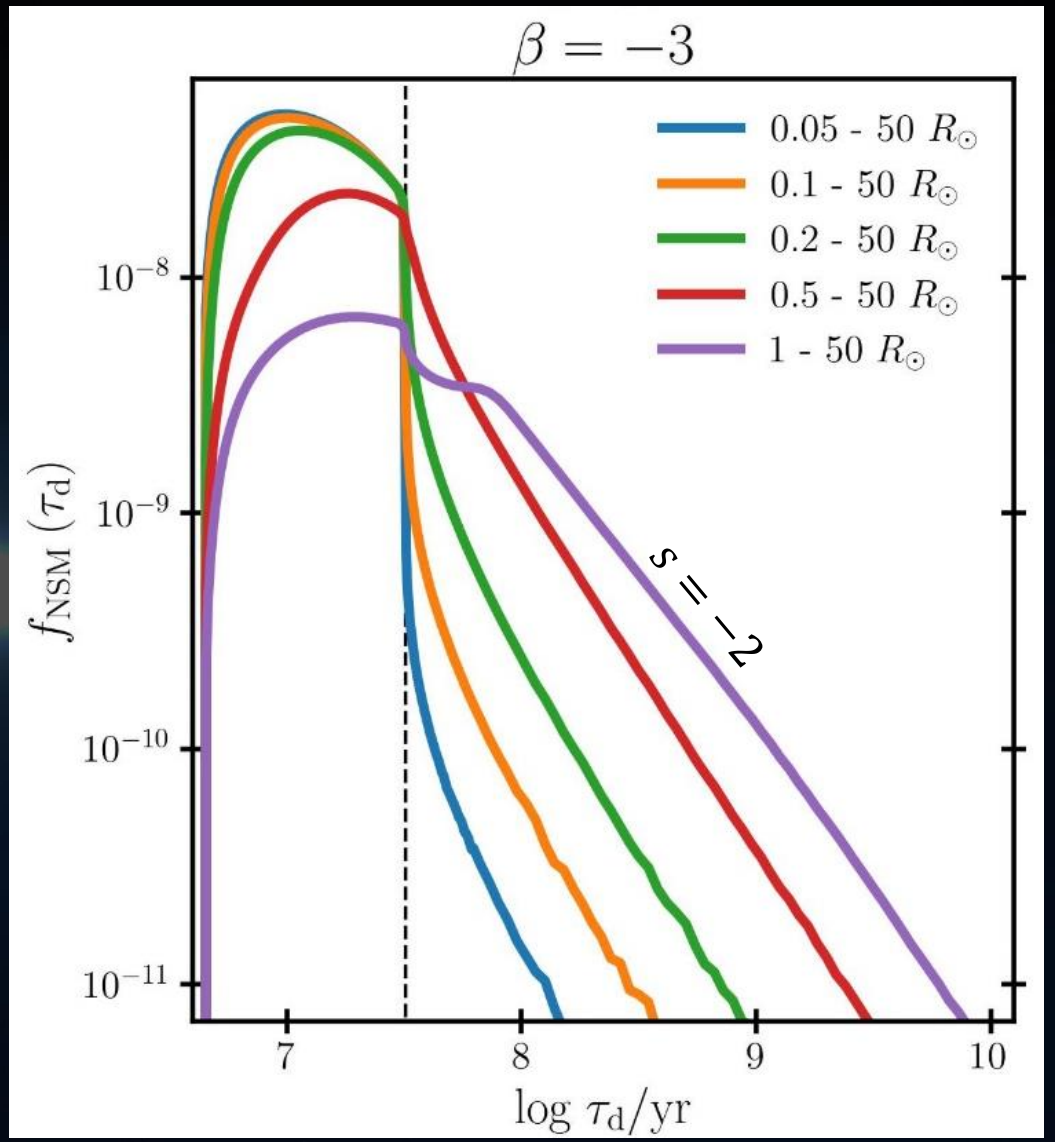
$\beta = -1$ $\beta = -2$ $\beta = -3$

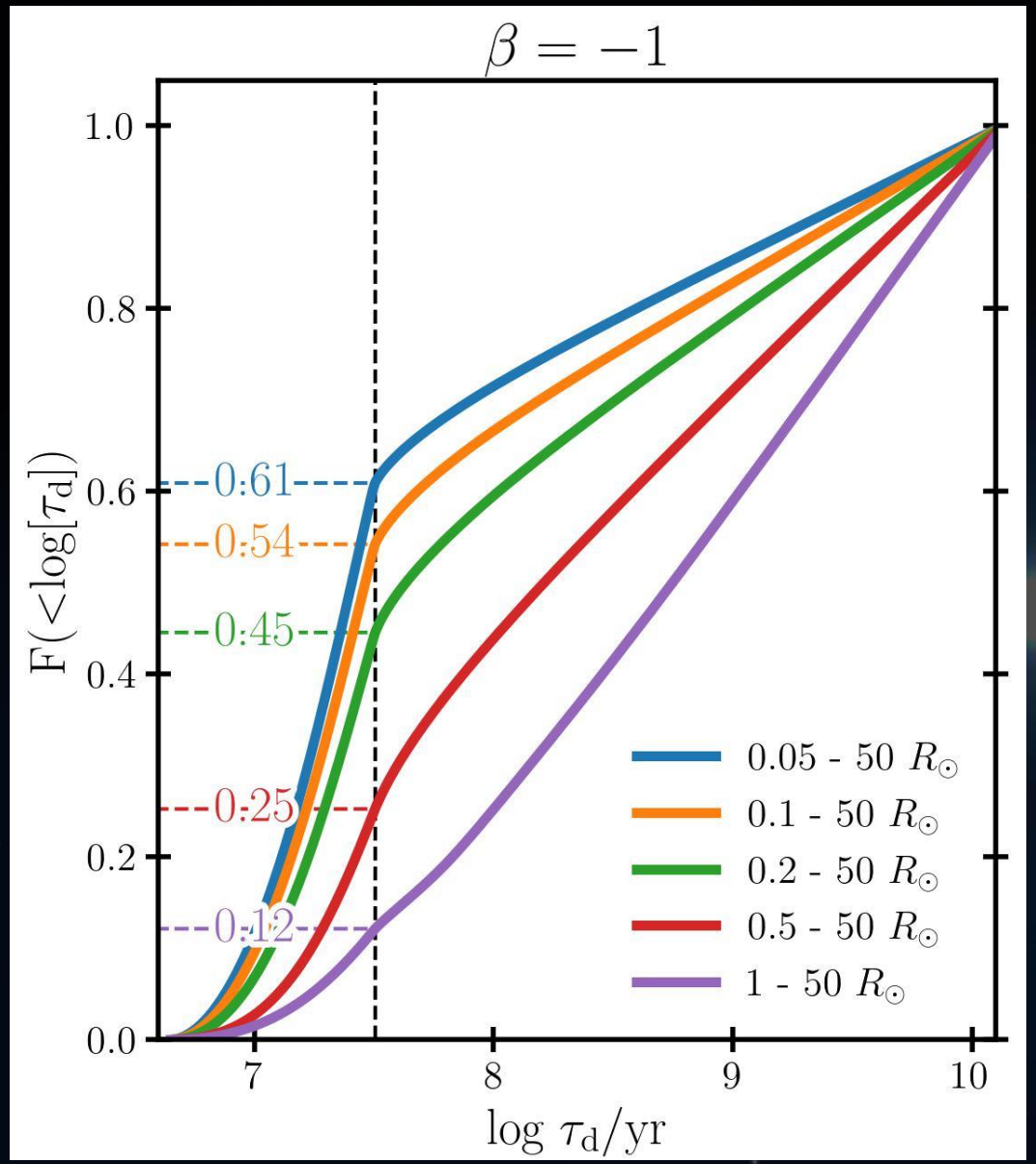
BPS models *Giacobbo & Mapelli 2018* *Belczynski et al. (2018)*

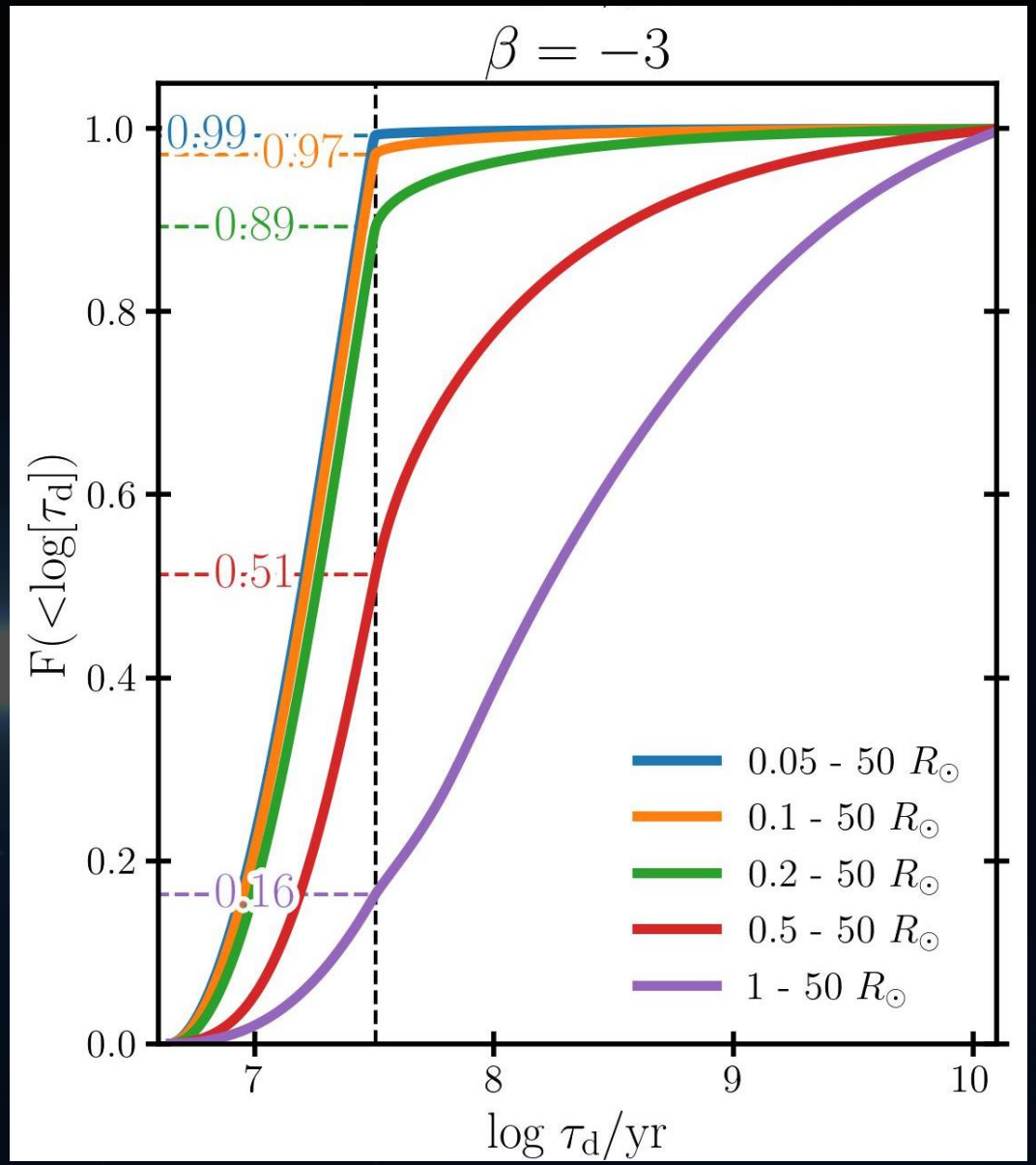
Range of separations:
$A_{min} - A_{max}$

$0.05\ R_{\odot}$ $0.2\ R_{\odot}$ $1\ R_{\odot}$


$\beta = -1$
0.05 - 50 $R_\odot$
0.1 - 50 $R_\odot$
0.2 - 50 $R_\odot$
0.5 - 50 $R_\odot$
1 - 50 $R_\odot$
$s = -1$
$f_{\rm NSM}\,(\tau_{\rm d})$
10^{-8}
10^{-9}
10^{-10}
10^{-11}
7
8
9
10
32 Myr
$\log\,\tau_{\rm d}/{\rm yr}$


$\beta = -3$
0.05 - 50 $R_\odot$
0.1 - 50 $R_\odot$
0.2 - 50 $R_\odot$
0.5 - 50 $R_\odot$
1 - 50 $R_\odot$
$s = -2$
$f_{\rm NSM}\,(\tau_{\rm d})$
10^{-8}
10^{-9}
10^{-10}
10^{-11}
7
8
9
10
$\log\,\tau_{\rm d}/{\rm yr}$


$\beta = -1$
1.0
0.8
0.6
0.4
0.2
0.0
$F(<\log[\tau_d])$
0.61
0.54
0.45
0.25
0.12
0.05 - 50 $R_\odot$
0.1 - 50 $R_\odot$
0.2 - 50 $R_\odot$
0.5 - 50 $R_\odot$
1 - 50 $R_\odot$
7
8
9
10
log τ_d/yr


$\beta = -3$
1.0
0.8
0.6
0.4
0.2
0.0
$F(<\log[\tau_d])$
0.99
0.97
0.89
0.51
0.16
0.05 - 50 $R_\odot$
0.1 - 50 $R_\odot$
0.2 - 50 $R_\odot$
0.5 - 50 $R_\odot$
1 - 50 $R_\odot$
7
8
9
10
log τ_d/yr

With this work we aim to investigate if the **demographic of SGRBs** can be used to constrain the main characteristics of the **delay time distribution** (DTD) of neutron star mergers (NSMs).

To do that we first developed

↓

MOCK UNIVERSE

↓

composed of a sample of galaxies that fulfils major observational facts

To do that we first developed

↓

MOCK UNIVERSE

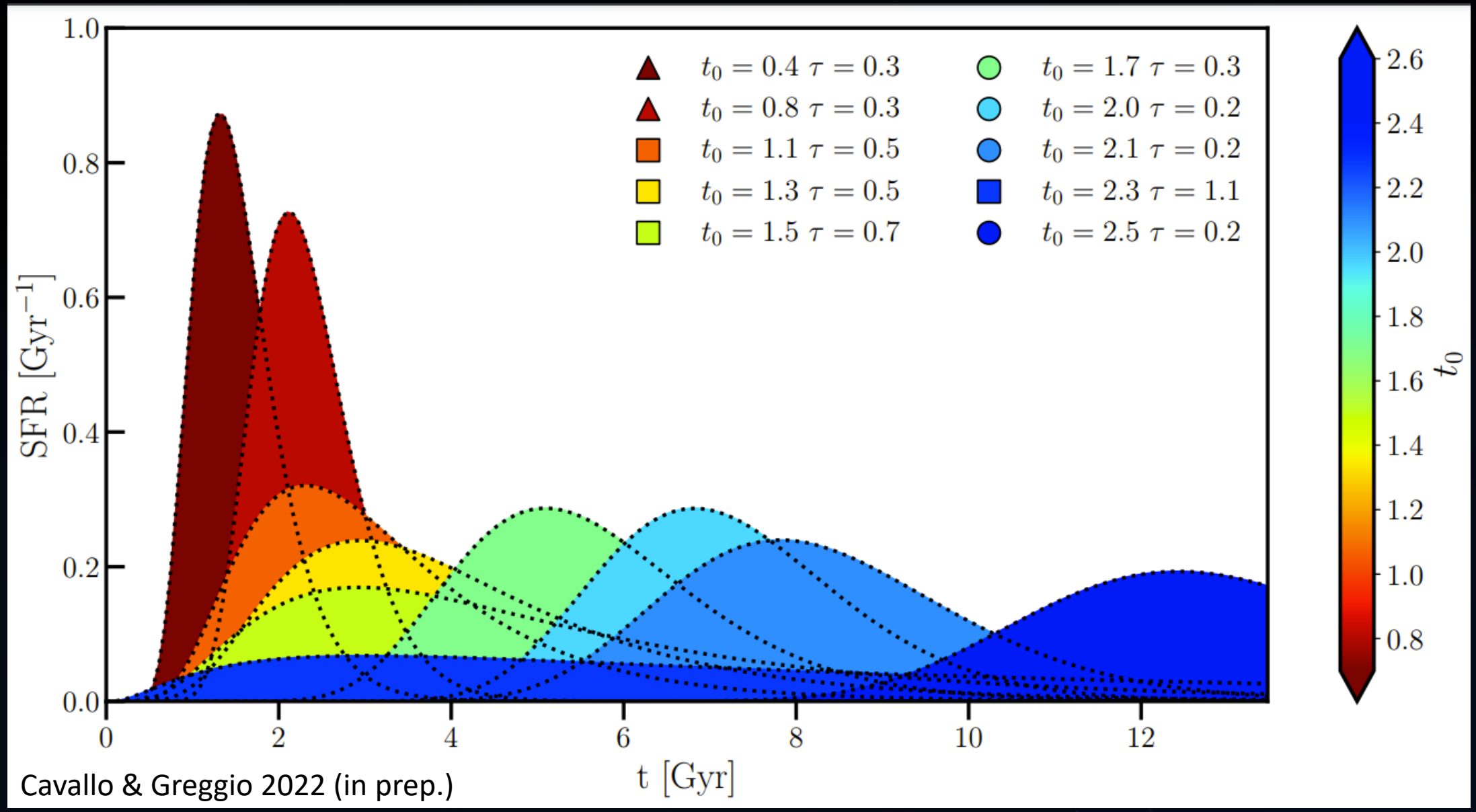
↓

composed of a sample of galaxies that fulfils major observational facts

Log-normal star formation history

$$\mathrm{SFR}(t, t_0, \tau) = \frac{1}{t\tau} e^{-\frac{(\ln t - t_0)^2}{2\tau^2}}$$

$[t_0, \tau]$ from *Abramson et al. (2016)*



Cavallo & Greggio 2022 (in prep.)

To do that we first developed

↓

MOCK UNIVERSE

↓

composed of a sample of galaxies that fulfils major observational facts

To do that we first developed

MOCK UNIVERSE

composed of a sample of galaxies that fulfils major observational facts

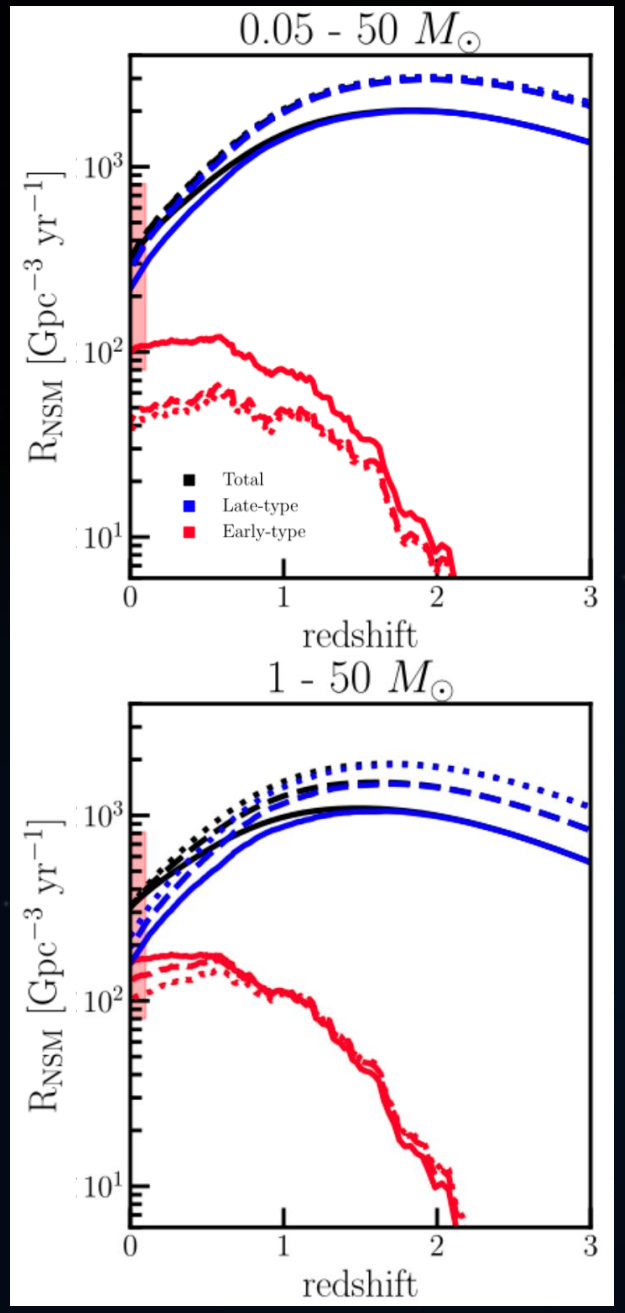
- Star formation rate density (SFRD) — *Madau & Dickinson (2014)*
- Mass distribution function (MDF) observed for nearby galaxies — *Peng et al. (2015)*
- Star-forming main sequence of galaxies — *Renzini & Peng (2015)*

$$R_{NSM}(t) = k_\alpha \, \alpha_{NS} \int_0^t SFR(t-\tau)\, f_{NSM}(\tau)\, d\tau$$

Fraction of massive stars with the right characteristics to lead to a NSM

R_{NSM} = R_{GW} by *Abbott et al. (2021)*

$$\mathcal{R} = 320^{+490}_{-240}\ Gpc^{-3} yr^{-1}$$



$$D(z) = sSFR(z) \times t_U(z)$$

Tacchella et al. (2022)

$D(z) \geq 1/3 \longrightarrow$ **Late-type**

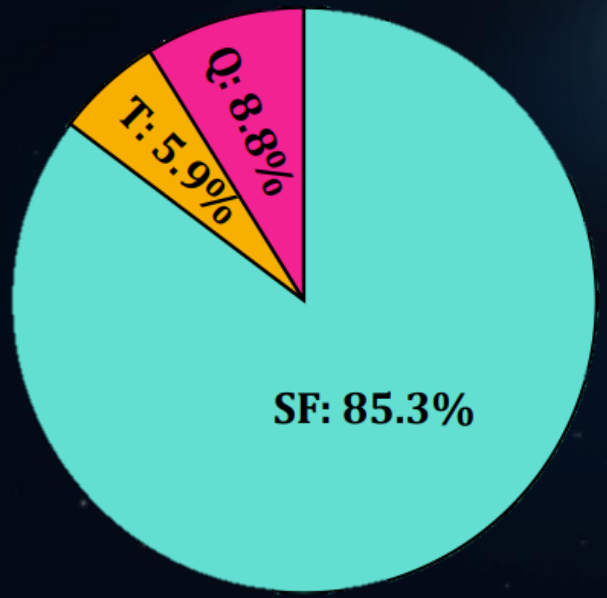
$D(z) < 1/3 \longrightarrow$ **Early-type**

Fraction of NSMs in late-type galaxies

$$\frac{\mathcal{R}_{LT}(z)}{\mathcal{R}_{TOT}(z)} = f_{LT}(z)$$

Demographic of SGRBs host-galaxies → constraint on the progenitors and their DTD

Fong et al. (2022) have presented a census of the 90 SGRBs observed from 2005 to 2021 that have an association with an host galaxy.

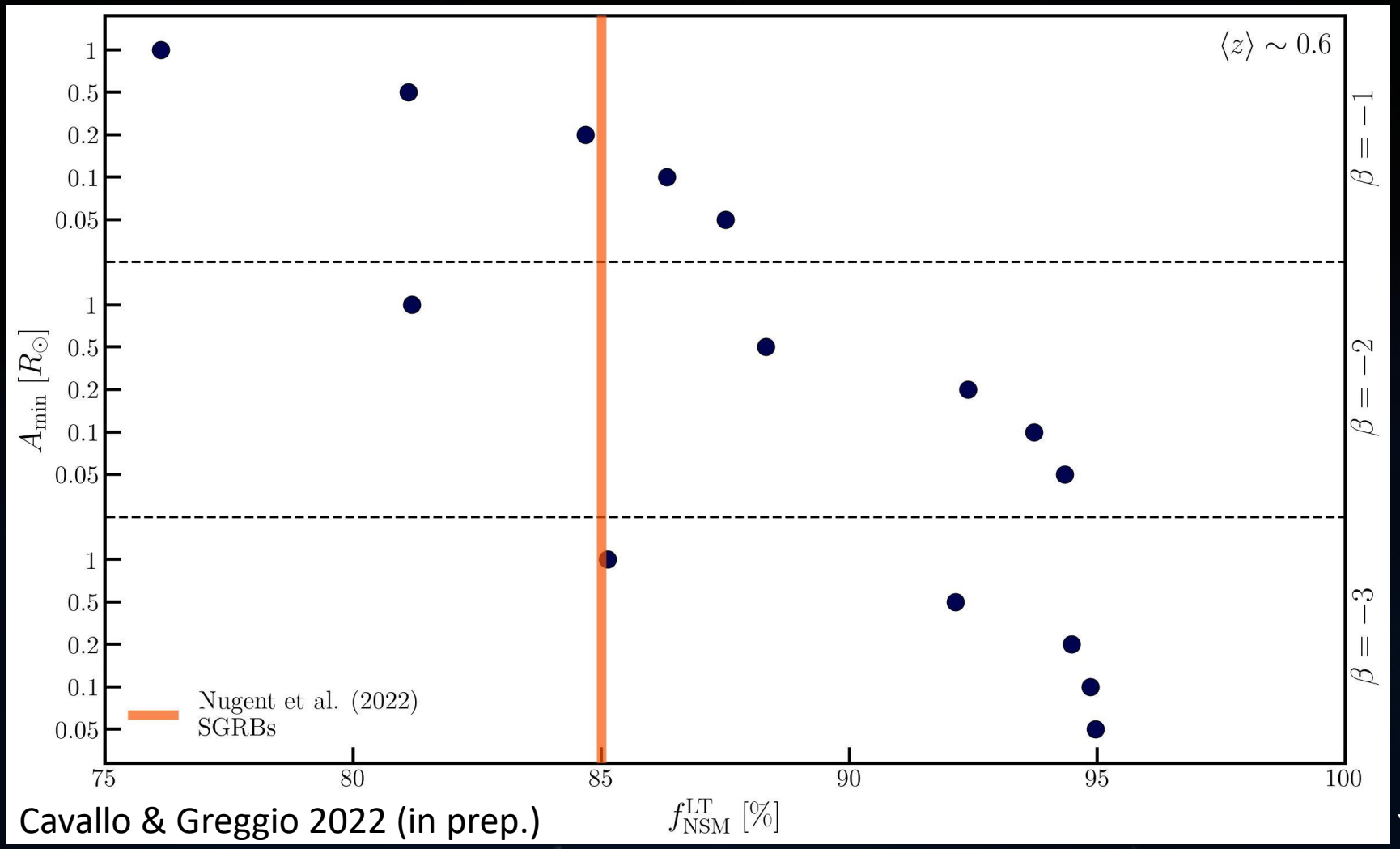


Nugent et al. (2022)

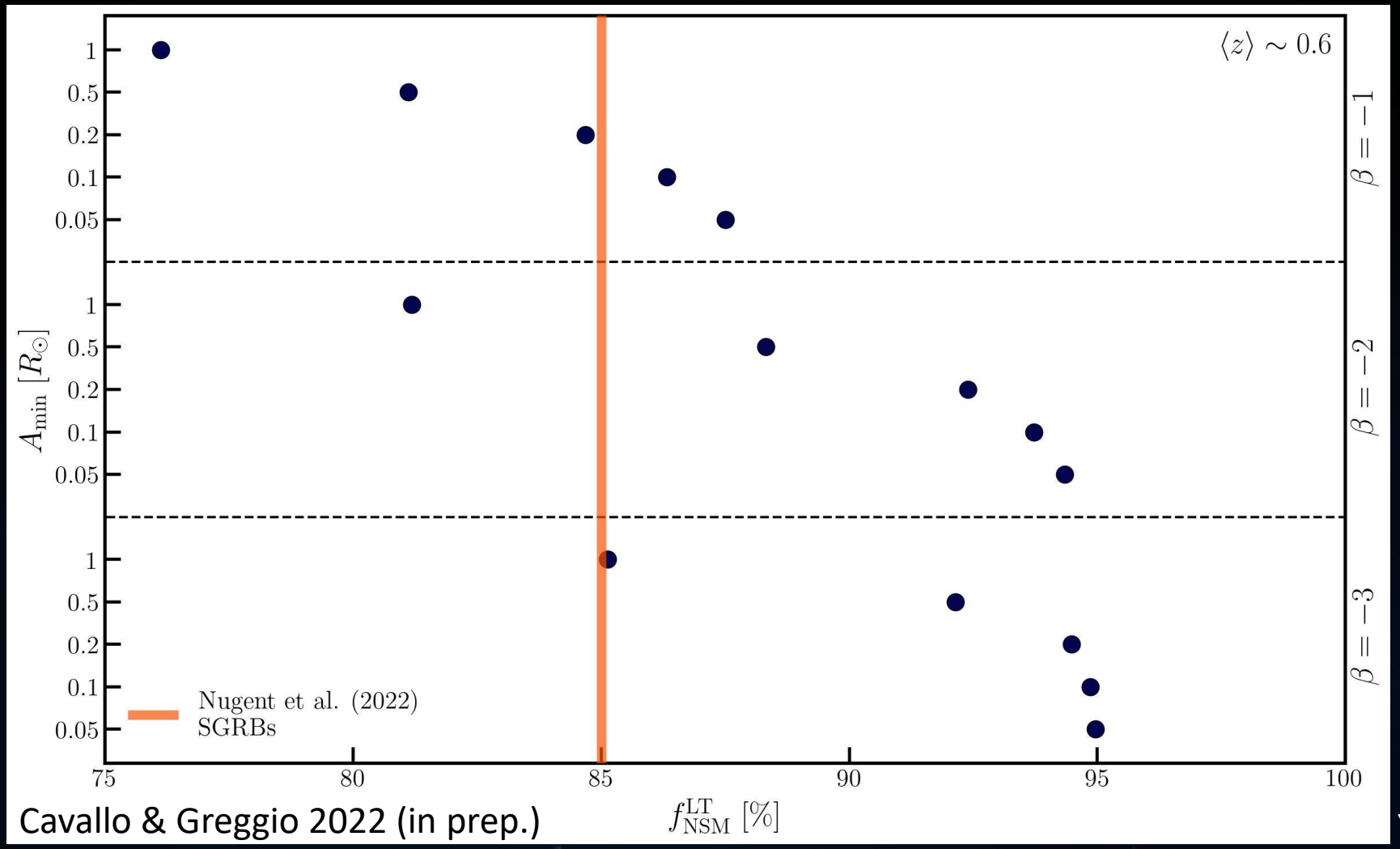
Nugent et al. (2022) used spectroscopy and optical and near-infrared photometry to characterize the stellar population properties of the host galaxies of SGRBs.

↓

~ 85% of the population of hosts are star forming galaxies

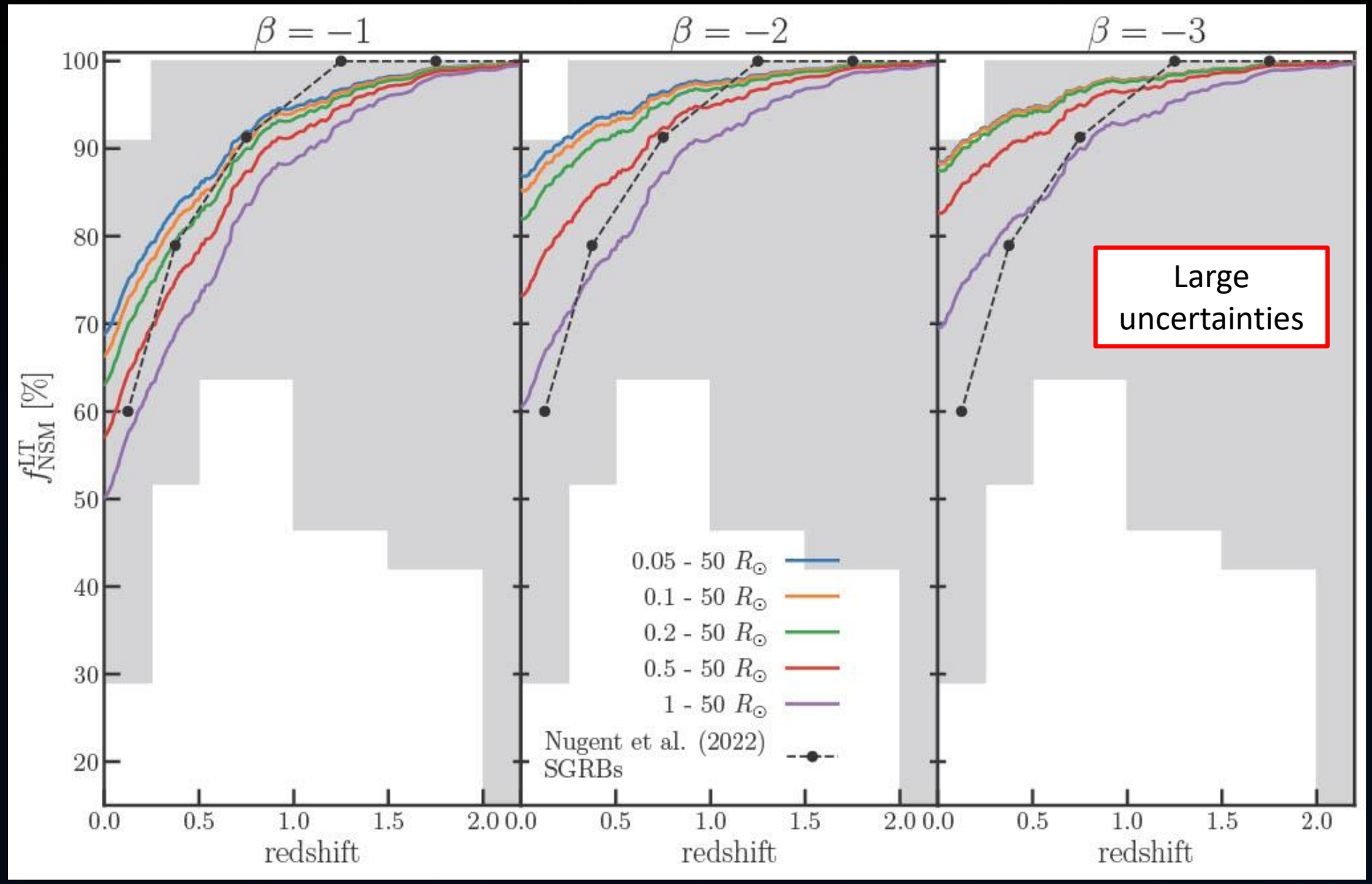


Cavallo & Greggio 2022 (in prep.)



The fraction of short-GRBs observed in late-type galaxies favors DTDs with a fair fraction of prompt events. This is supported by the relatively large fraction of short-GRBs occurring in galaxies with high star formation rate. We notice that a similar indication is obtained from chemical evolution models.

Future (?)


$\beta = -1$
$\beta = -2$
$\beta = -3$
$f^{\rm LT}_{\rm NSM}$ [%]
100
90
80
70
60
50
40
30
20
0.0
0.5
1.0
1.5
2.0
redshift
0.05 - 50 $R_\odot$
0.1 - 50 $R_\odot$
0.2 - 50 $R_\odot$
0.5 - 50 $R_\odot$
1 - 50 $R_\odot$
Nugent et al. (2022) SGRBs
Large uncertainties