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Atelier GAHEC-L2IT

Are binary black hole mergers and long γ-ray bursts drawn from the same black hole population?

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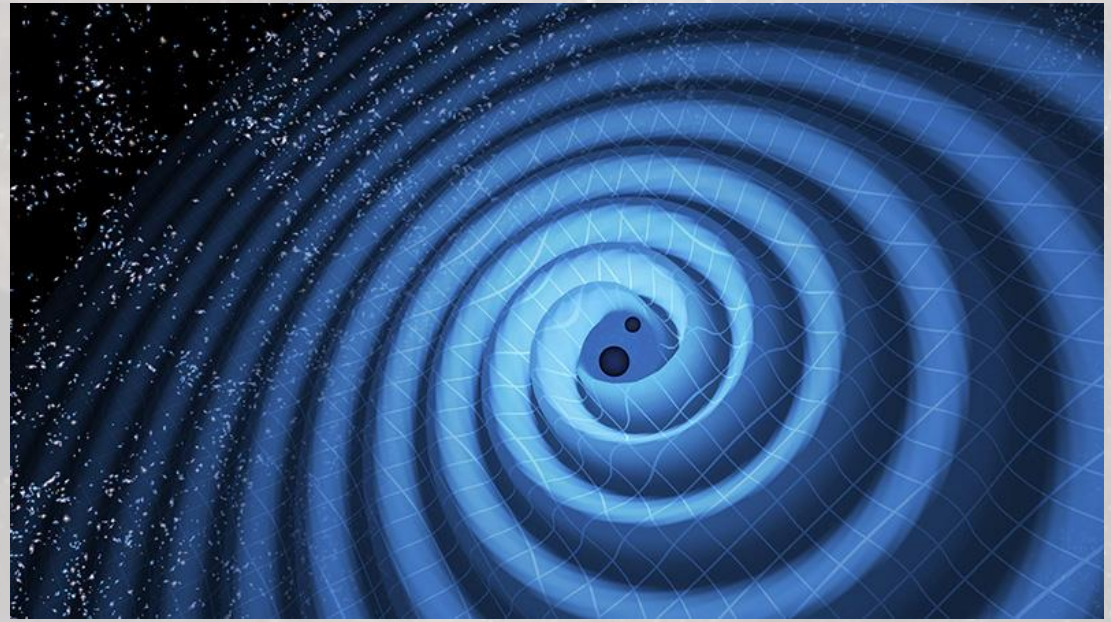
Binary Black-Holes mergers observed by advanced LIGO and advanced VIRGO:

O1, O2, O3a&b runs:
GWTC-1, GWTC-2, GWTC-2.1 & GWTC-3

74 BBH mergers with:

- Redshift z
- SNR
- Masses m_1 and m_2 and M_f

Characterization of population possible !



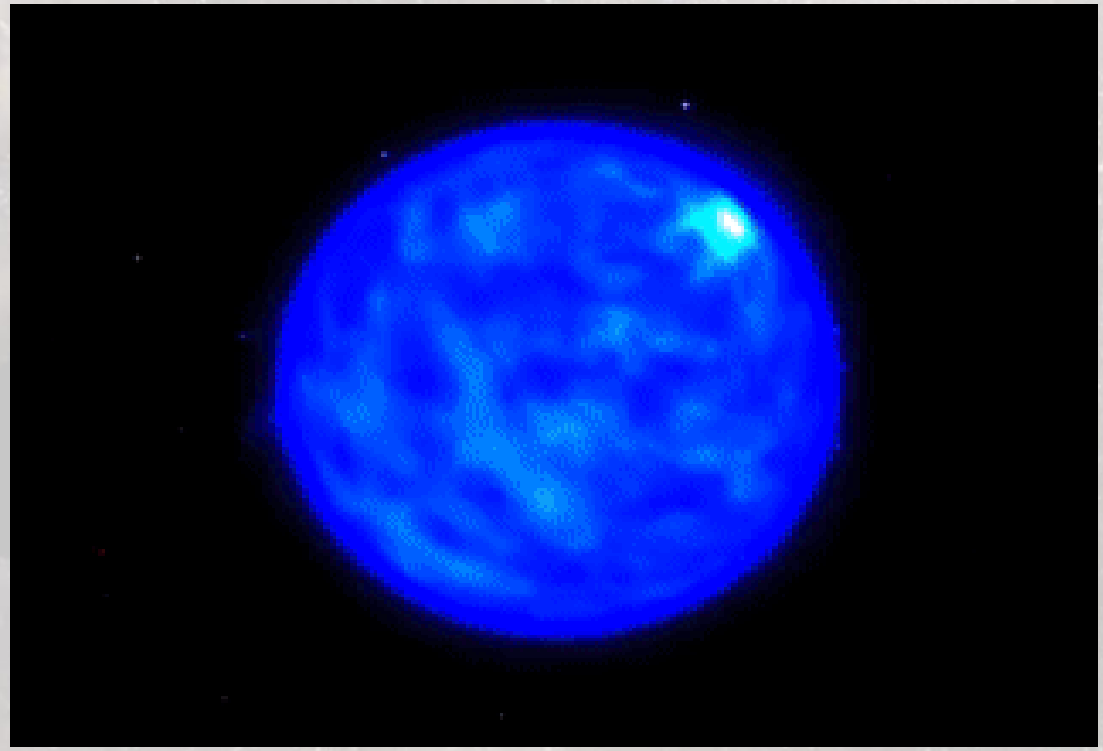
Binary Black Hole merger
Source: LVC

Long Gamma-Ray Bursts originate from collapsars

Common mechanism of formation:

- Massive stars evolve in binarity
- Low metallicity
- Rotational speed

The population might be linked ?



Collapsar artistic view
Source: INAF

Long Gamma-Ray Bursts Density Rate

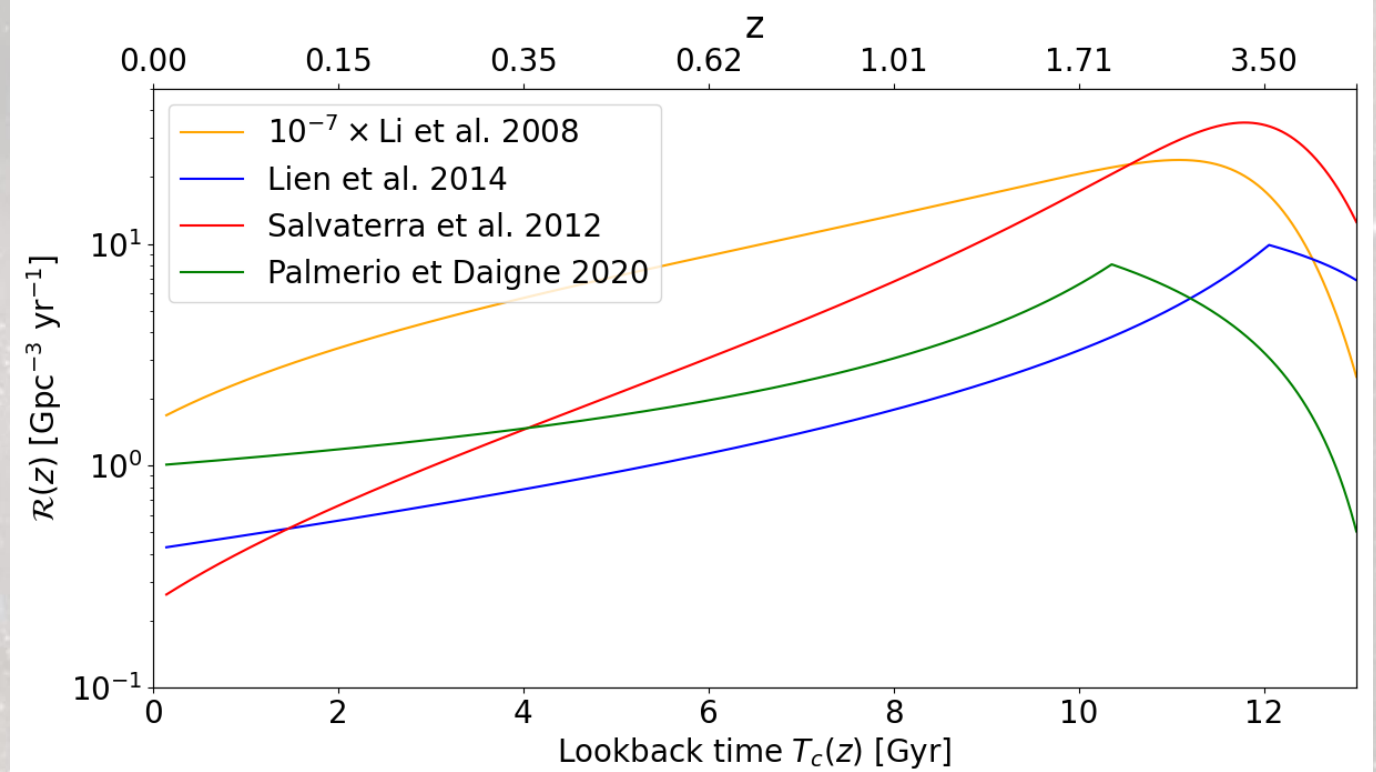
(based on Swift/BAT & Fermi/GBM observations):

GRB population models:

- *Palmerio et Daigne 2020*
- *Lien et al. 2014*
- *Salvaterra et al. 2012*

SFH models:

- *Li et al. 2008*



Density rate evolution for GRB and SFH models
Source: Arcier et Atteia 2021

Delayed models to get a $\rho(z_0)$:

$$\rho(z_0) \propto \int_{z_0}^{\infty} \mathcal{R}_{\rm GRB}(z)\, f(T_c(z) - T_c(z_0))\, \frac{{\rm d}T_c}{{\rm d}z}\, {\rm d}z$$

- Log-Normal

$$f(\tau) = \frac{1}{\tau\sigma_{\rm t}\sqrt{2\pi}} \exp\left(-\frac{\ln(\tau/t_{\rm d})^2}{2\sigma_{\rm t}^2}\right)$$

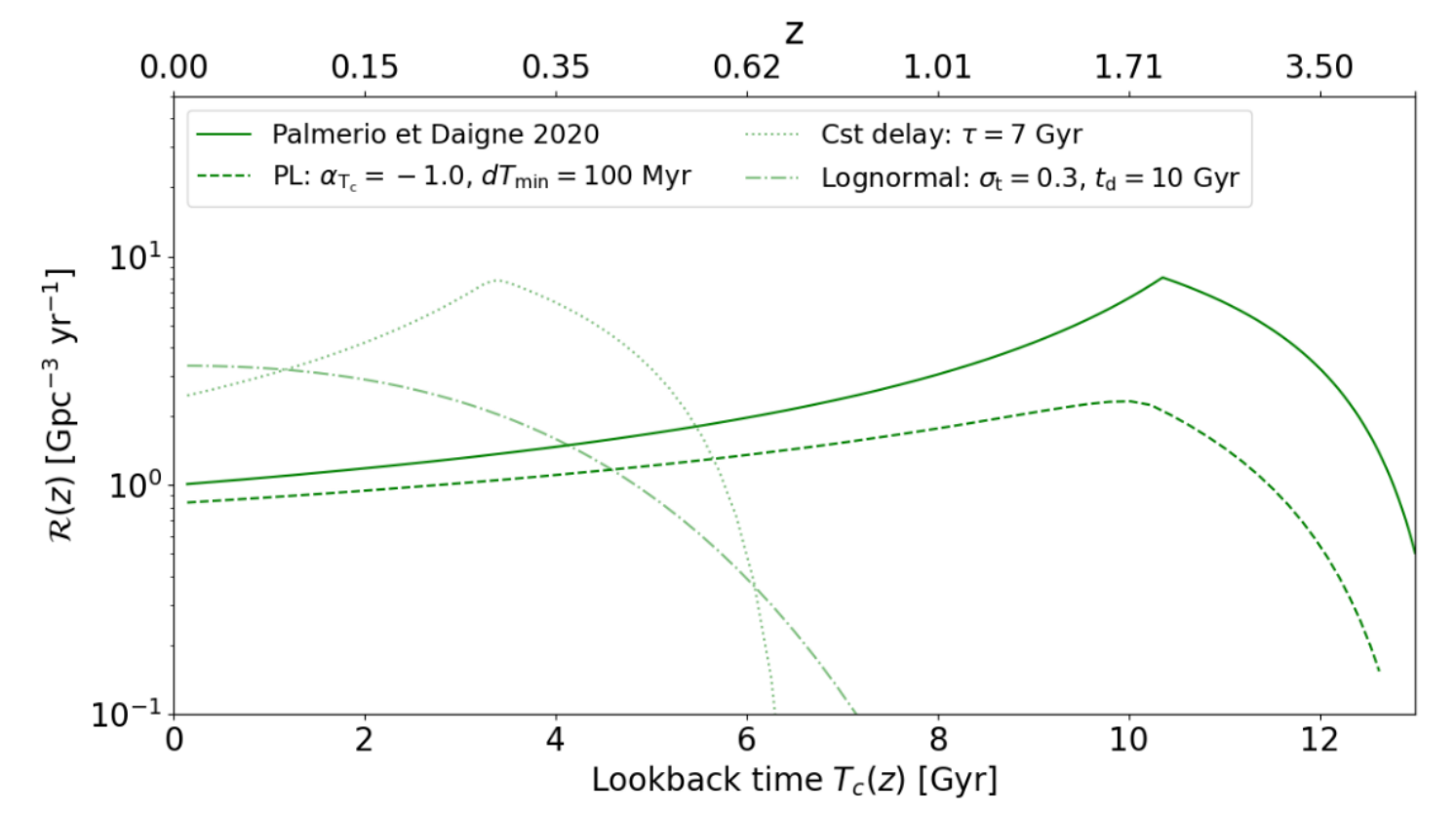
- Power-law

$$f(\tau) = \begin{cases} 0 & \tau \leq dT_{\rm min} \\ \tau^{\alpha} & \tau > dT_{\rm min} \end{cases}$$

- Cst Delay

29 models in total !

Delayed models to get a $\rho(z_0)$:



Density rate evolution for delayed GRB and SFH models
Source: Arcier et Atteia 2021

METHOD
N/N_{max} test using $\rho(z)$

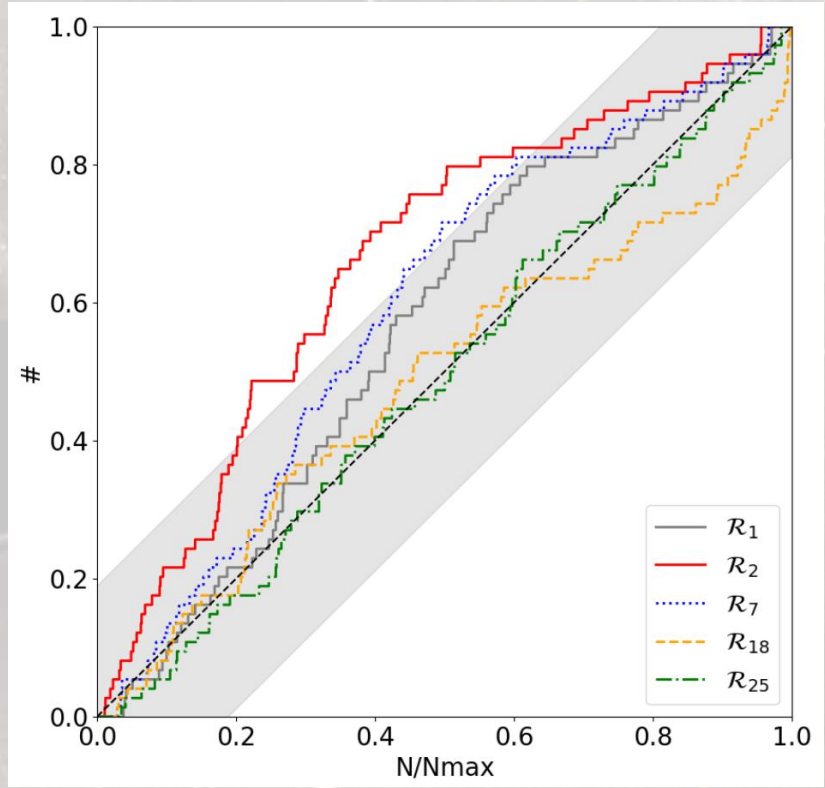
$$N_i = \int_0^{z_i} \rho(z) \frac{dV(z)}{dz} \frac{1}{1+z} dz$$

for i in 74 BBHs mergers:

- Compute horizon redshift $z_{h,i}$
- Compute N_i and $N_{max,i}$ using a model

With N/N_{max} distribution:

- Perform a KS-test vs $\mathcal{U}(0,1)$
- Reject based on p-value (1% - 10%)



Cumulative distribution for different tested models
Source: Arcier et Atteia 2021

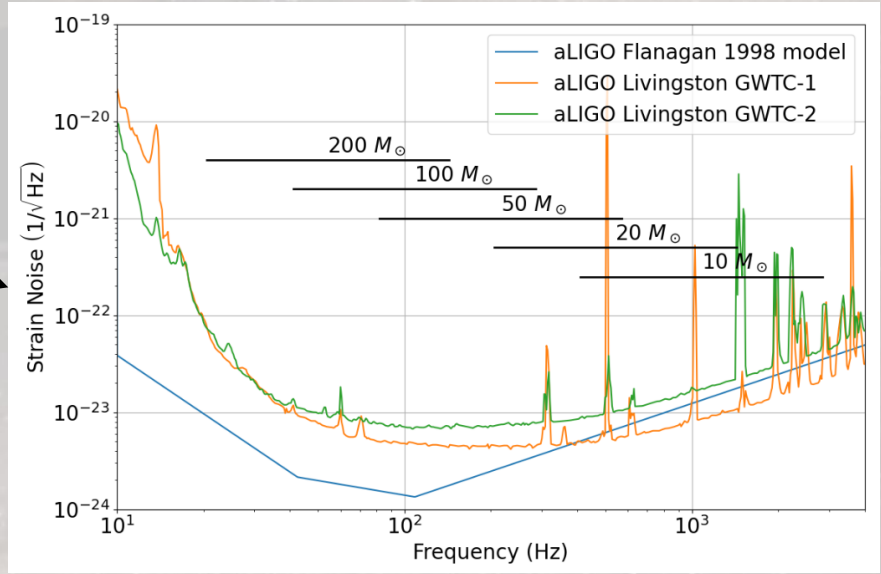
METHOD: Computation of $z_{h,i}$

LALSimulation

m_1, m_2, z *with IMRPhenomD*

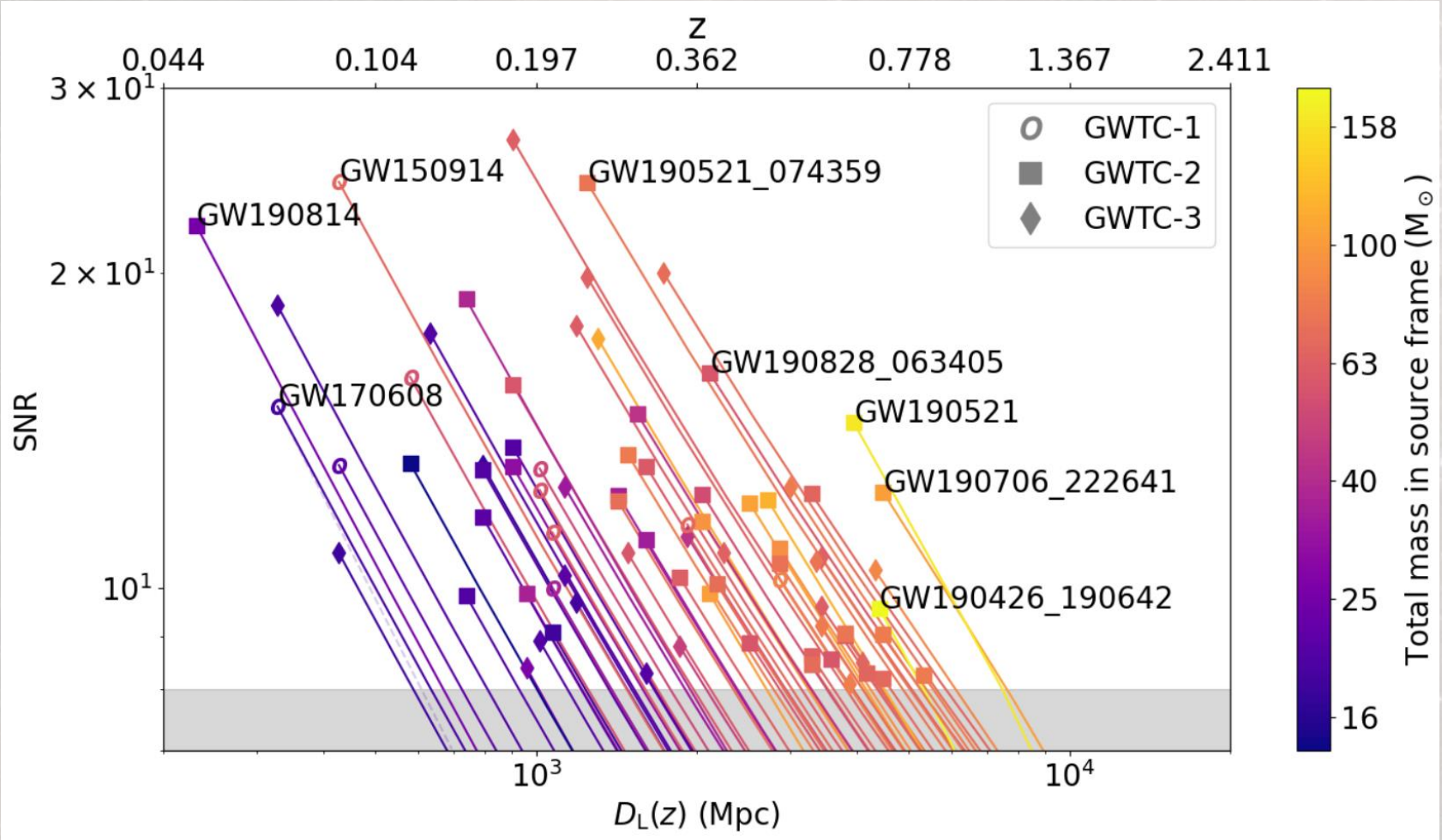
$$\mathrm{SNR}_{\mathrm{Ch21}} = \sqrt{4 \int_{f_{\min}}^{f_{\max}} \frac{|h^{+}(f)|^2}{S_h(f)} \mathrm{d}f}$$

Horizon redshift computation
Source: Chen et al. 2021



Strain noise from LIGO
Source: Arcier et Atteia 2021

METHOD: Computation of $z_{h,i}$



Evolution of the expected SNR for the 74 BBH mergers
Source: Arcier et Atteia 2021

RESULTS

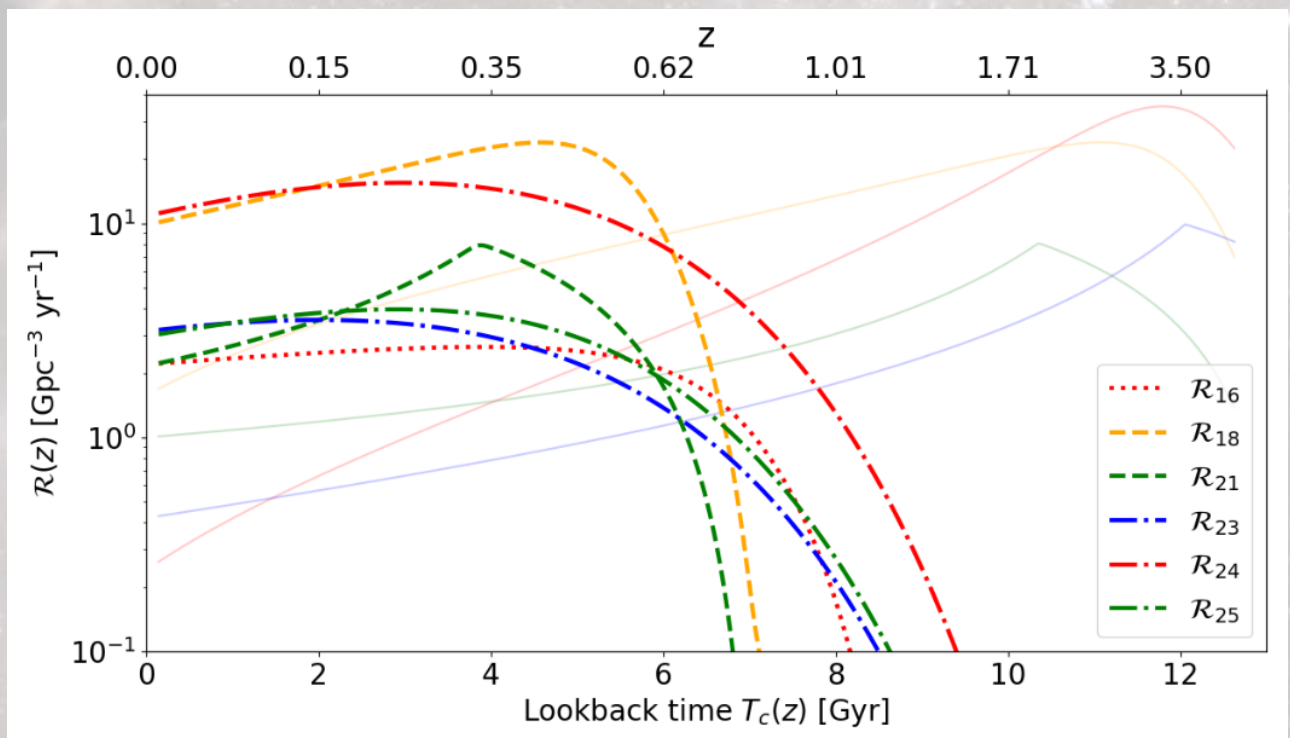
7 favored **GRB** models (p-value > 10%)

8 marginally accepted **GRB** models (1% < p-value < 10%)

- Without delay → not-favored
- Minimum delay $\sim 6\ Gyr$
- Dearth of BBHs mergers after $z \sim 1$?

To be taken with a grain of salt

→ hypothesis made



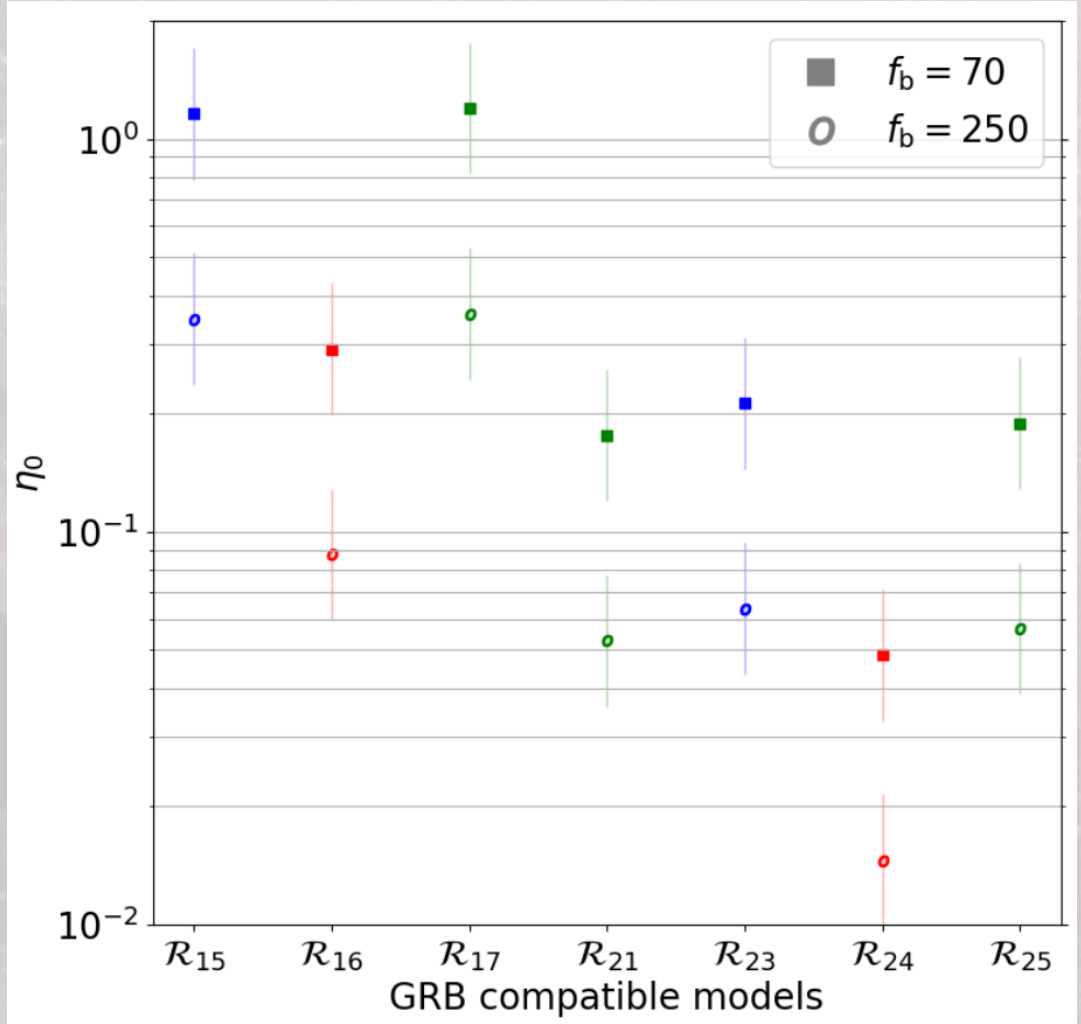
Density rate evolution for accepted models

Source: Arcier et Atteia 2021

RESULTS

7 favored **GRB** models (p-value > 10%)

- $\rho(z = 0.2) = 19 - 41\ \mathrm{Gpc^{-3}yr^{-1}}$ from GWTC-3
- η_0 is the ratio of BHs created during long GRBs that will eventually merge into a BBH
- $\eta_0 \sim 10\%$
- Assuming here all BBHs are LGRBs descendants, maybe only a fraction



Fraction of long GRBs with BBH mergers descendants, for two beaming factors f_b
Source: Arcier et Atteia 2021

ASTROPHYSICAL DISCUSSION

Are BBH mergers and LGRBs from the same BH parent population?

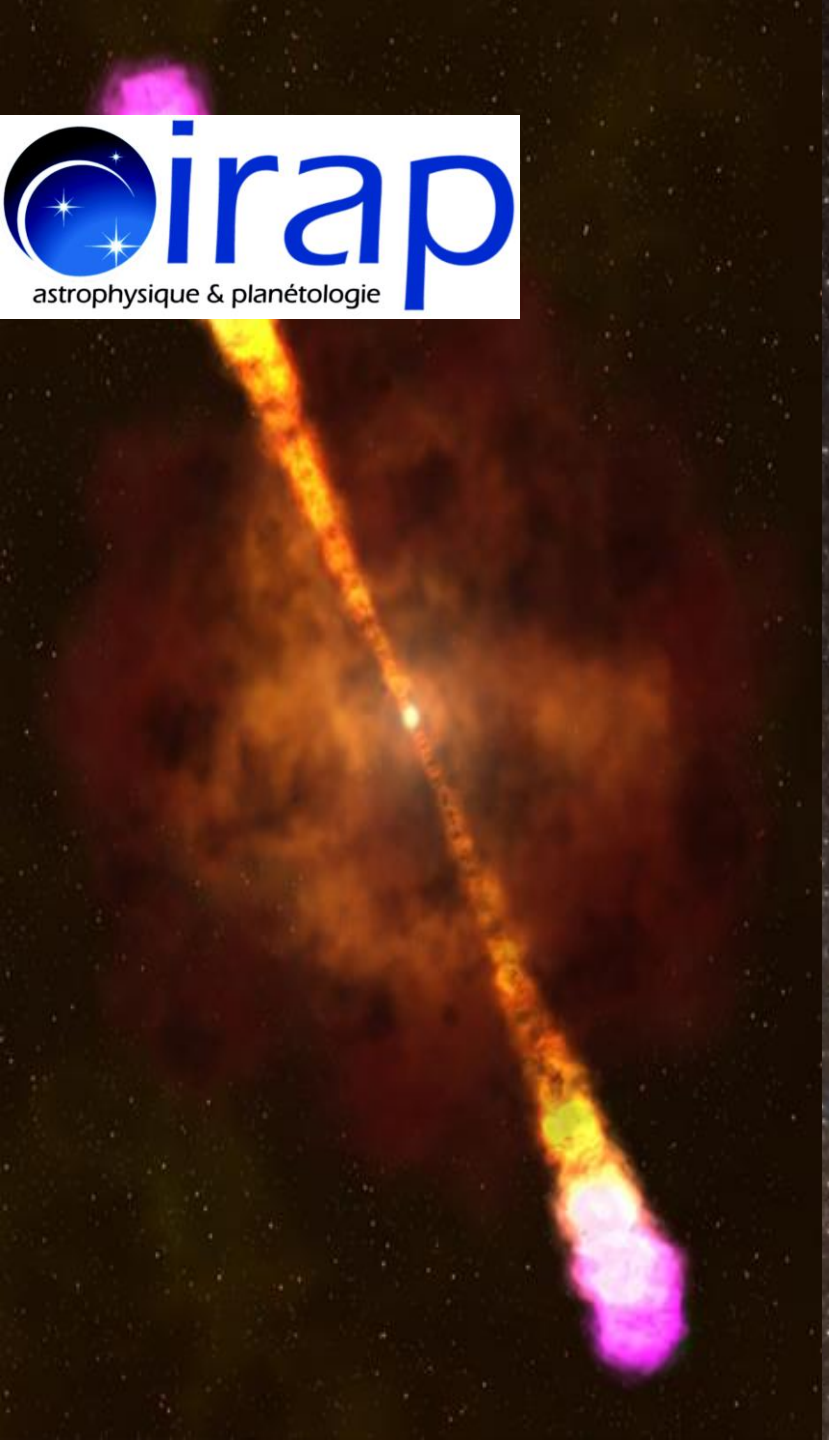
- Favored models have delay $\sim 5 - 6$ Gyr between formation and merger → A bit higher than simulations
- Lack of BBHs mergers after $z \sim 0.6$ → Stochastic background analysis (*Callister et al. 2020*)
- Maybe only a subsample ? High χ_{eff} ? Given mass range ? Same for GRBs with XRFs, uLGRBs, low-luminosity GRBs

ASTROPHYSICAL DISCUSSION

Consequences on the GRB phenomenology

- Similar mechanism for BBHs mergers and LGRBs formation: binarity
- Precessing BHs and GRB jets, with imprint on prompt emission and/or afterglow (*Fargion & Grossi 2006, Huang & Liu 2021*)
- Environment for first GRB: massive star occultation, possible occultation of the jet, afterglow in very dense environment (*Zou et al. 2021*)

→ ***SVOM*** (*Wei et al. 2016, Arcier et al. 2020*)



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THANK YOU ! QUESTIONS ?