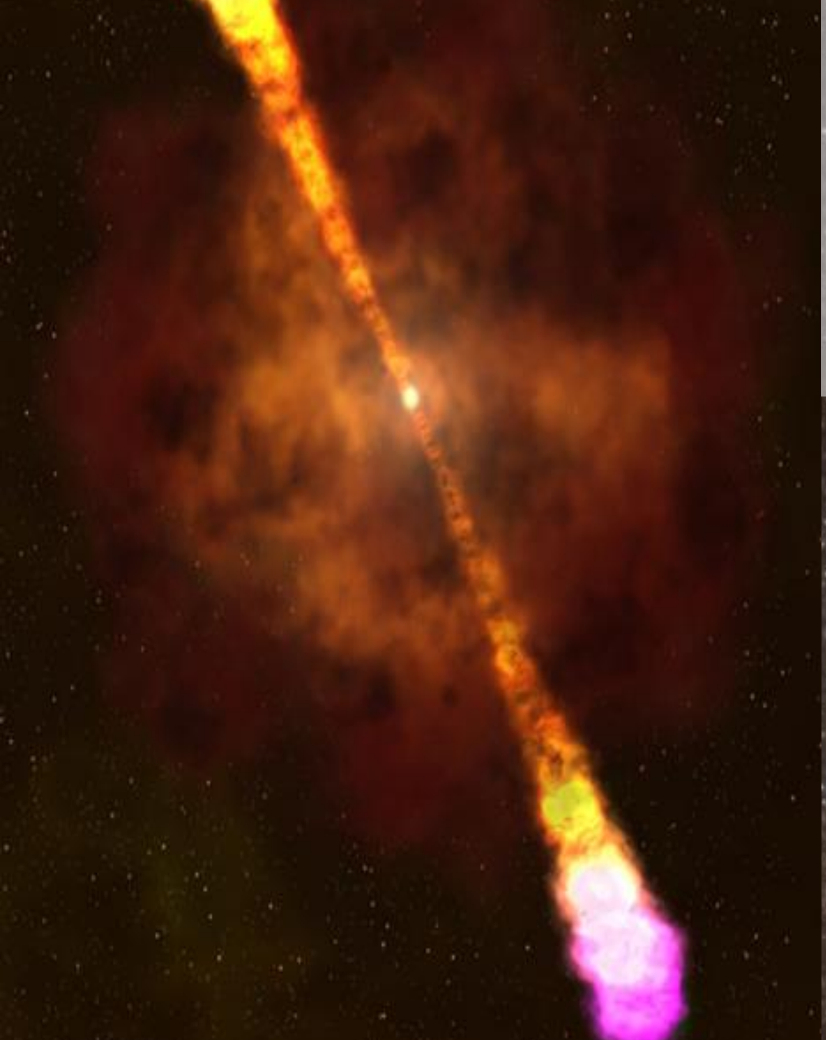
irap astrophysique & planétologie

Assemblée Générale du Gdr Ondes Gravitationnelles

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

Arcier et Atteia 2022, ApJ



B. Arcier – 3rd year PhD student

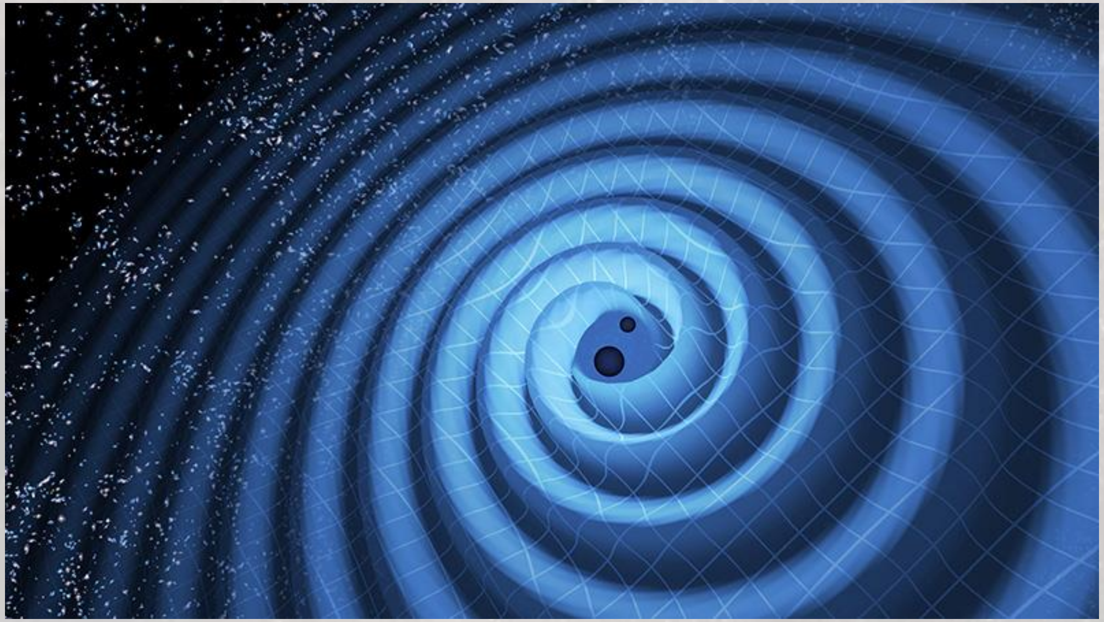
10/10/2022

Binary Black Hole Mergers

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 !



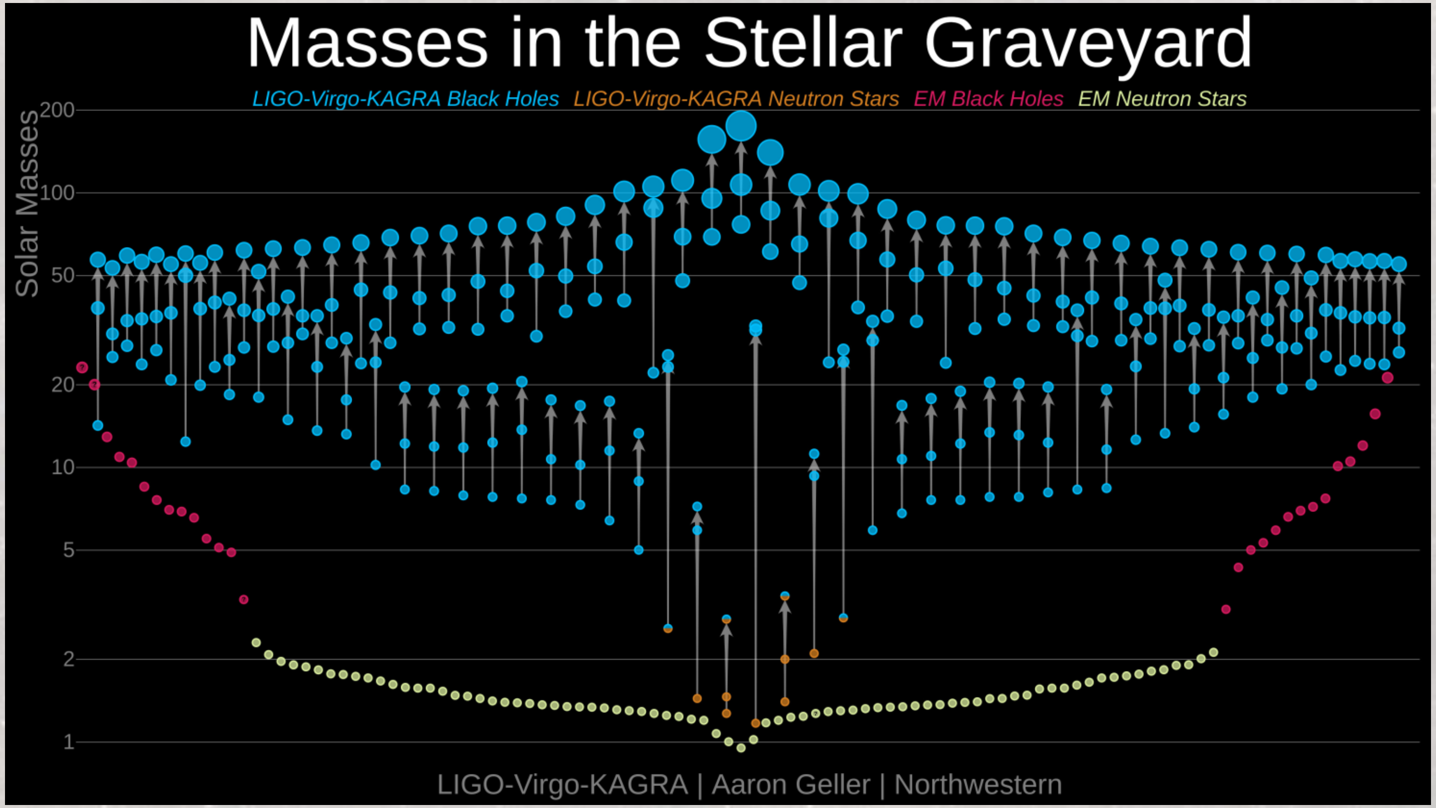
Binary Black Hole merger
Source: LVC

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

Characterization of population(s) possible !

→ High masses:
De Luca 2021,
Volonteri 2021

→ $\chi_{eff} \approx 0$:
LVK Collaboration 2021



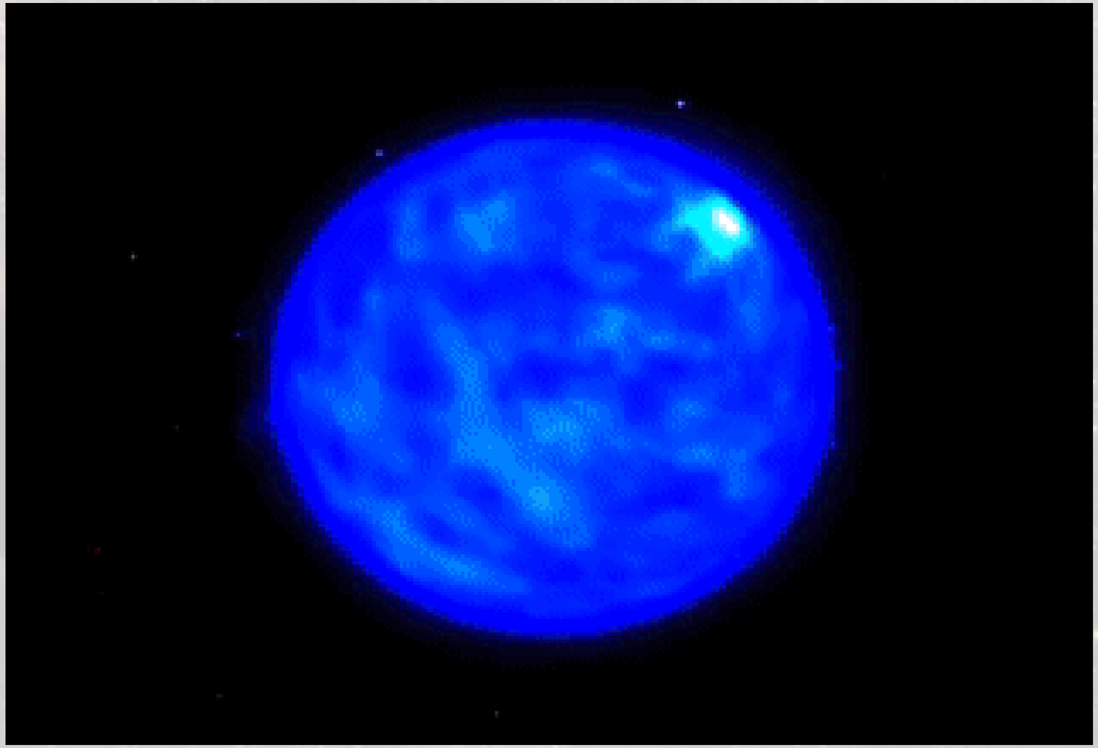
Credit: LVC

Long Gamma-Ray Bursts

Long Gamma-Ray Bursts originate from collapsars

Common mechanism of formation:

- Created by massive stars (evolving in binary systems)
- Black Hole birth



Collapsar artistic view
Source: INAF

Long Gamma-Ray Bursts originate from collapsars

BUT Angular Momentum:

- Required to create LGRBs (Metallicity dependence, …)

- **However:** aLIGO / aVirgo → efficient AM transport
  → **Not enough** for long GRBs
  (*Olejak & Belczynski 2021, Bavera et al. 2022*)

- Tidal spin-up in compact systems **OR** different populations
  (*Piran & Piran 2020, Belczynski et al. 2020, Marchant et al. 2021*)

Long Gamma-Ray Bursts originate from collapsars

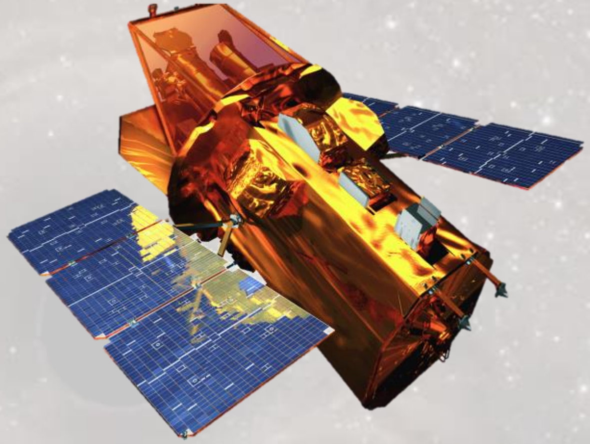
Populations linked? (e.g. *Bavera et al. 2022*)

BHs seen with **GW emissions**

&

BHs seen with **LGRBs emissions**

Long Gamma-Ray Bursts Density Rate



Swift mission
Credit: NASA

Fermi mission
Credit: NASA

CGRO/BATSE mission
Credit: NASA

→ **Density rate evolution with redshift**
(e.g. *Palmerio & Daigne 2020*)

Long Gamma-Ray Bursts Density Rate

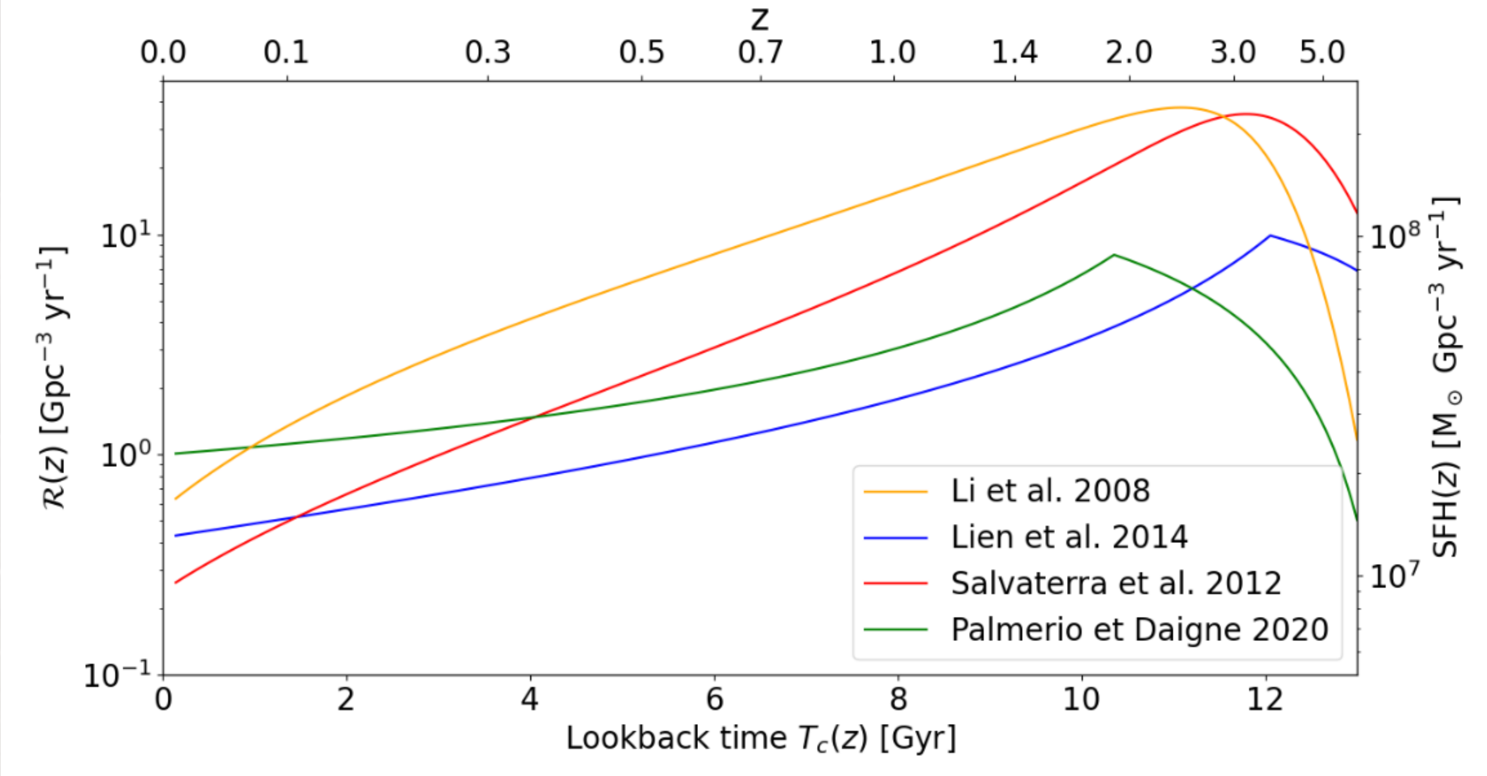
(based on CGRO/BATSE, Swift/BAT, Fermi/GBM observations):

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 $\rho(z_0)$:

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

- Log-Normal

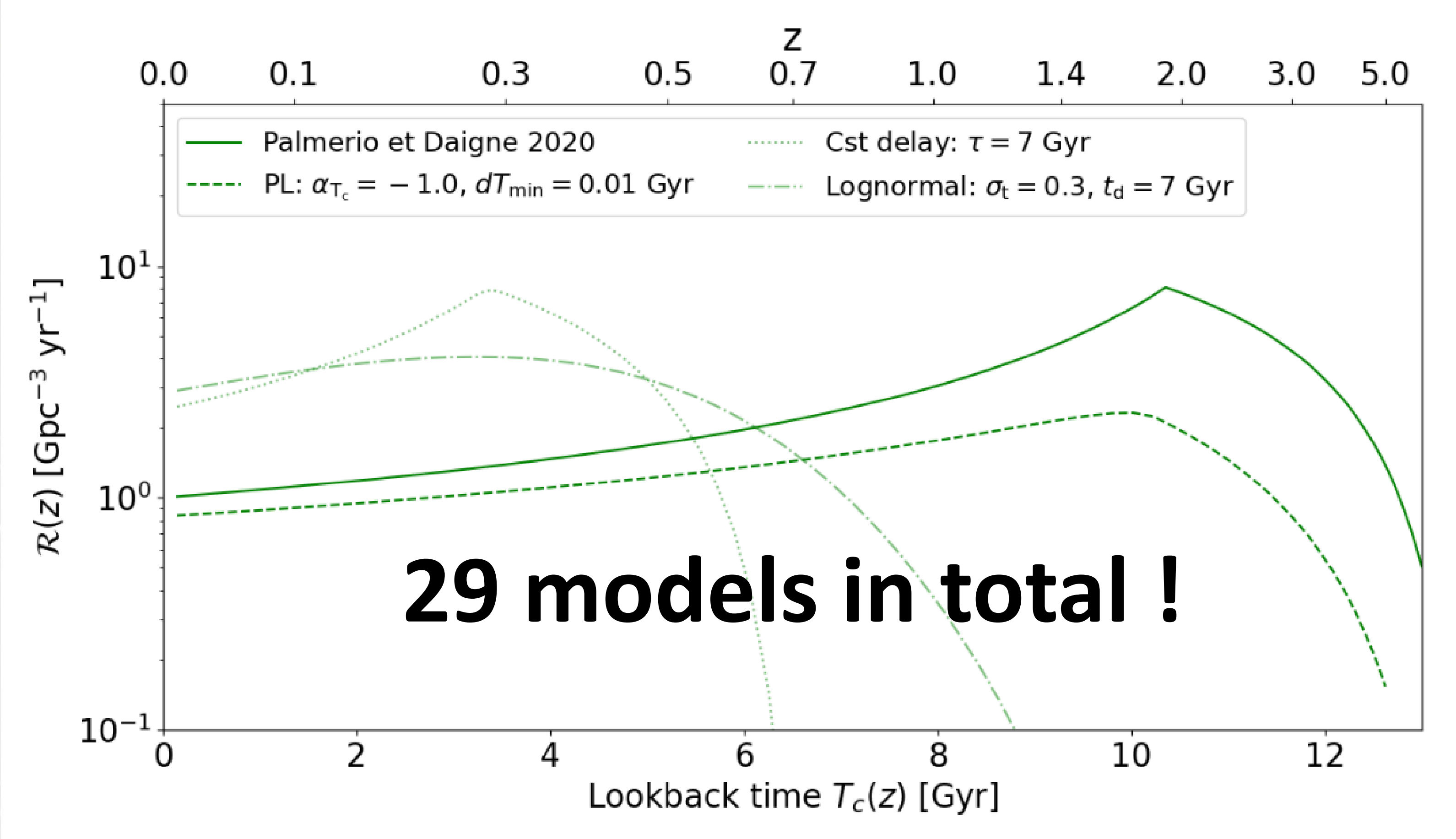
$$f(\tau) = \frac{1}{\tau\sigma_{\mathrm{t}}\sqrt{2\pi}} \exp\left(-\frac{\ln(\tau/t_{\mathrm{d}})^2}{2\sigma_{\mathrm{t}}^2}\right)$$

- Power-law

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

- Cst Delay

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



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

Comparison of the populations

METHOD:
$\mathrm{N}/\mathrm{N}_{\mathrm{max}}$ test using $\rho(z)$

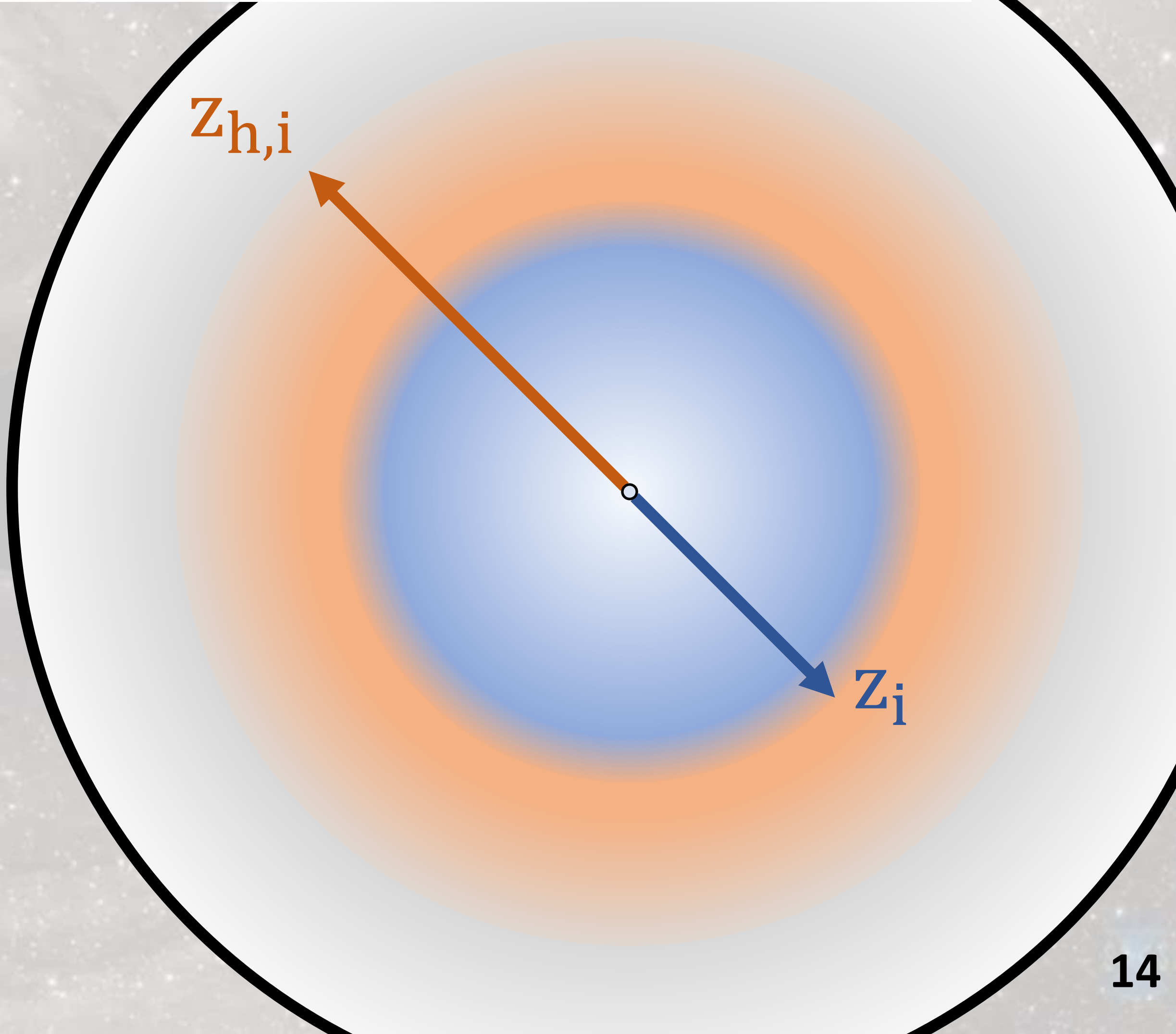
$$\mathrm{N_i} = \int_0^{z_i} \rho(z)\, \frac{\mathrm{d}V(z)}{\mathrm{d}z}\, \frac{1}{1+z}\, \mathrm{d}z$$

for i in 74 BBH mergers:

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

With $\mathrm{N}/\mathrm{N}_{\mathrm{max}}$ *distribution:*

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



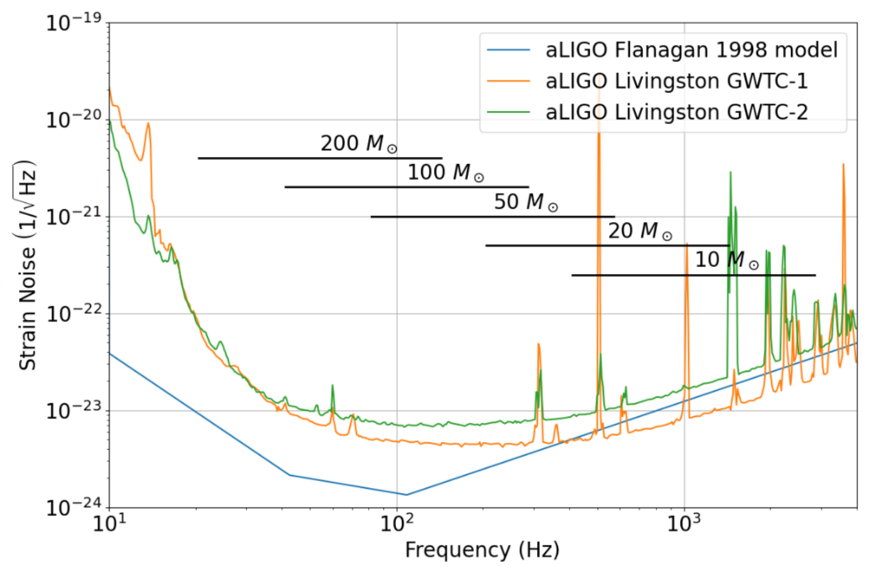
METHOD:
Computation of $z_{h,i}$

LALSimulation

m_1, m_2, z with IMRPhenomD

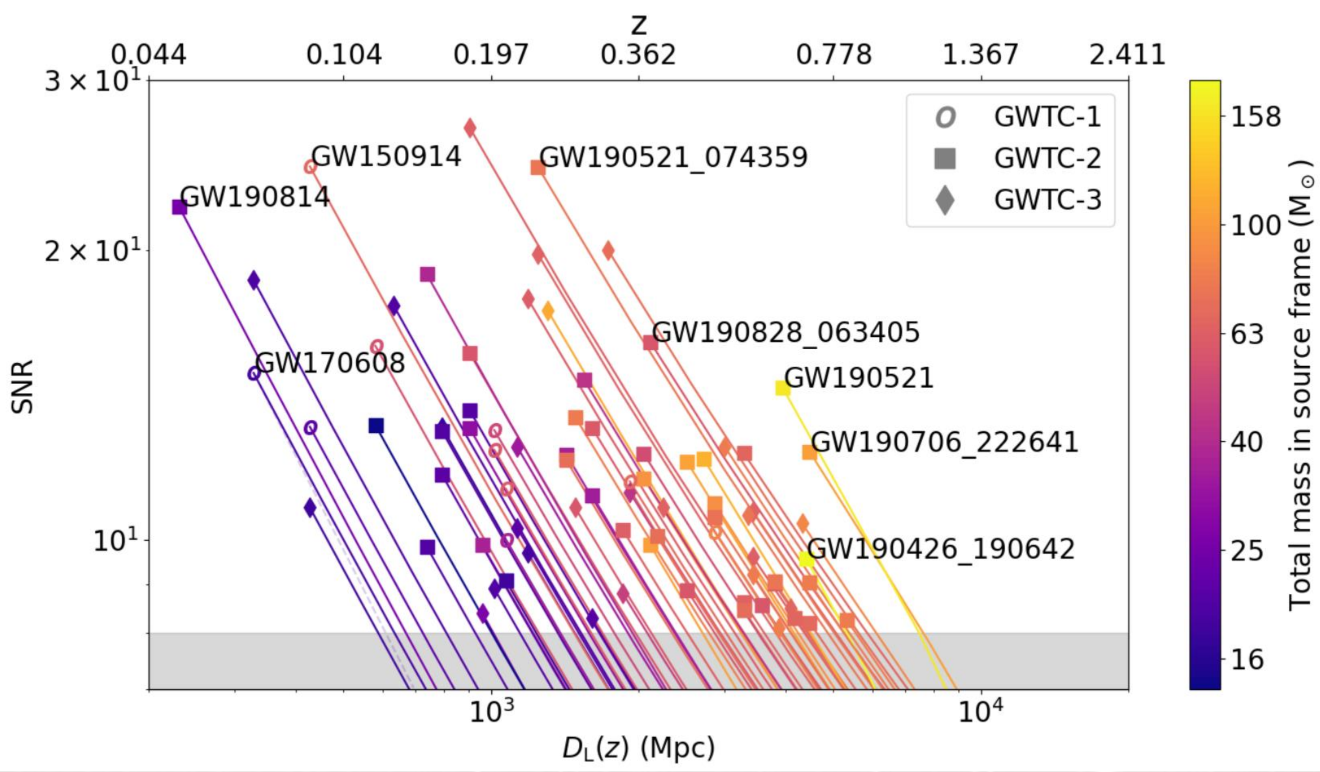
$$\mathrm{SNR}_{\mathrm{Ch21}} = \sqrt{4\int_{f_{\mathrm{min}}}^{f_{\mathrm{max}}} \frac{|h^{+}(f)|^2}{S_h(f)}\mathrm{d}f}$$

Horizon redshift computation
Source: Chen et al. 2021



Strain noise from aLIGO

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



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

METHOD:
Local rate comparison

$\boldsymbol{R_{\mathrm{GRB}}(z)}$ $[\mathrm{Gpc}^{-3}\mathrm{yr}^{-1}]$, $\boldsymbol{f(z)}$
→ GRB density rate model and delay

$$\eta_0 = \frac{\rho(z_0)}{f_\mathrm{b}} \times \left(\int_{z_0}^{\infty} \mathcal{R}_{\mathrm{GRB}}(z)\ f(z, z_0) \frac{\mathrm{d}T_c}{\mathrm{d}z} \mathrm{d}z \right)^{-1}$$

$\boldsymbol{f_\mathrm{b}}$
→ GRB beaming factor

$\boldsymbol{\rho(z_0)}$ $[\mathrm{Gpc}^{-3}\mathrm{yr}^{-1}]$
→ LIGO/Virgo local BBH rate estimation

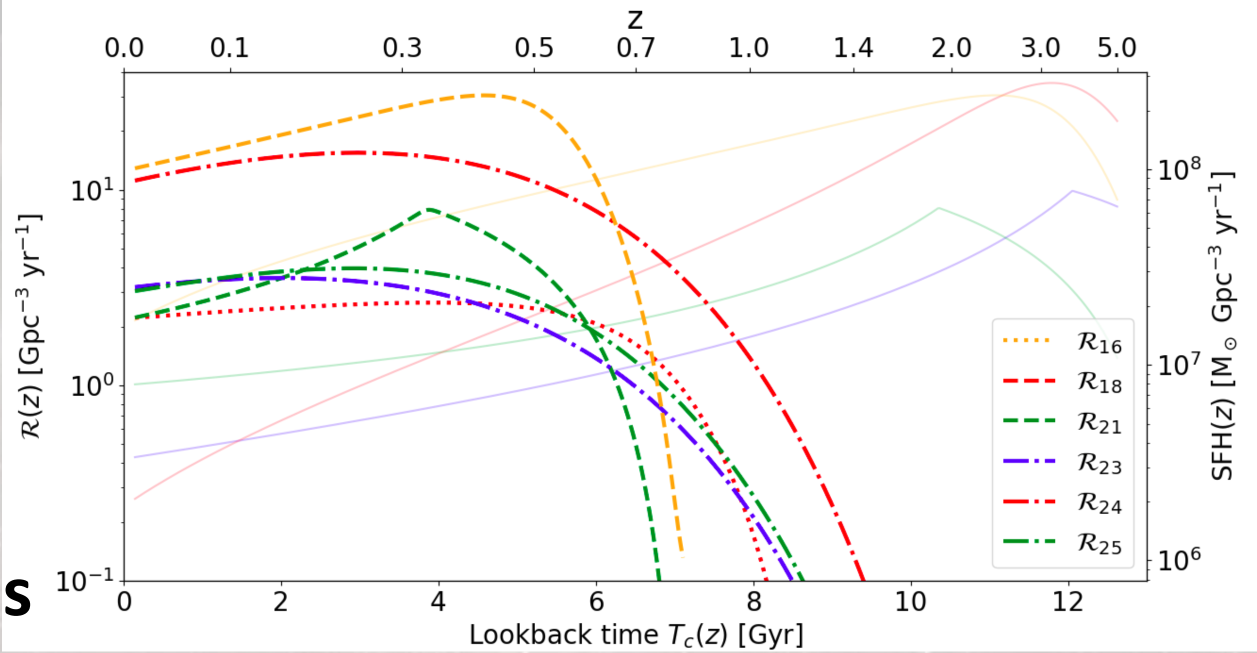
$$\eta_0 = \frac{\text{BBH mergers LIGO/Virgo}}{\text{BH descendants from LGRBs models}}$$

Results

RESULTS:

7 favored **GRB** models (p-value > 10%)
8 marginally accepted **GRB** models (1% < p-value < 10%)
14 rejected (p-value < 1%)

- Without delay → not-favored
- **Favored**: min delay $\sim 4\ Gyr$
  Dearth of BBHs mergers
  after $z \sim 1$
- **NOK with BBH formation models**
  (e.g. Dominik et al. 2012)



Density rate evolution for accepted models
Source: Arcier et Atteia 2021

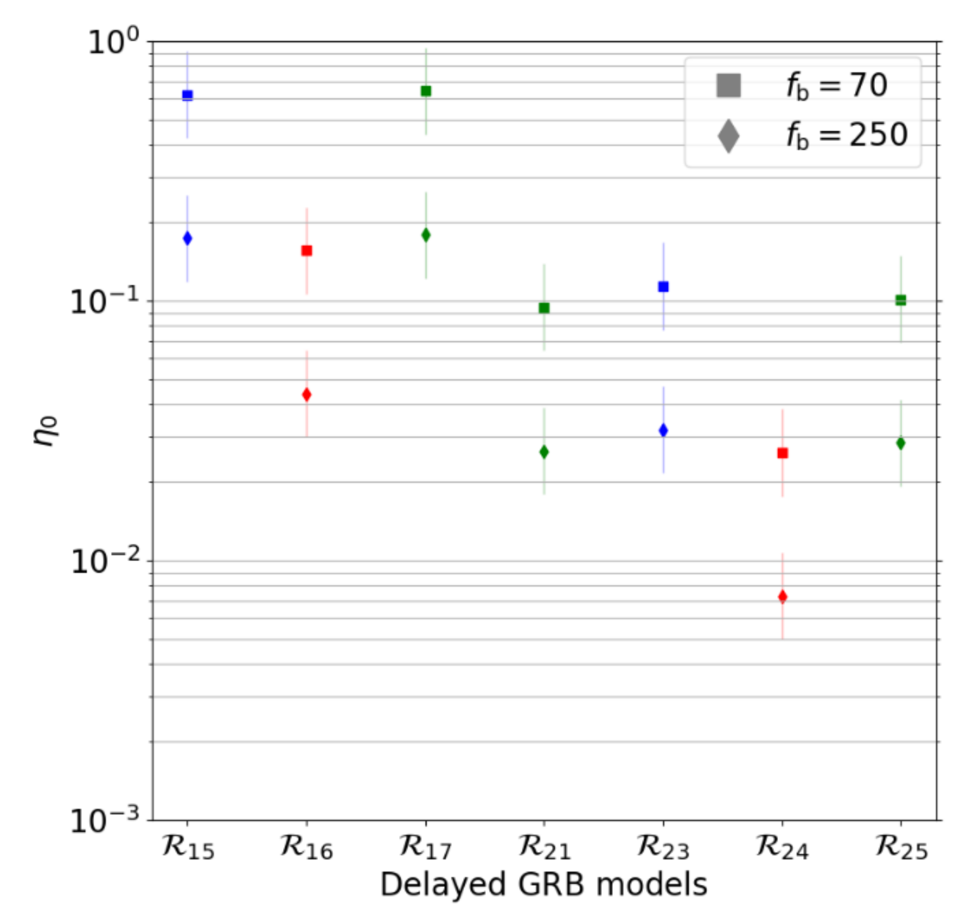
RESULTS:

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

$\eta_0 \sim 1 - 10\%$

BBH mergers are rare, even compared to LGRBs !

SN Ibc: $9{,}000\ \mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$
LGRBs: $250\ \mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$
BBH mergers: $30\ \mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$



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

Discussion

DISCUSSION

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

At least $\sim 90\ \%$ of LGRBs do not lead to BBH merger.

→ **Can all BBH mergers have LGRB ancestors?**

Possible, if long delay between LGRB emission and BBH merger

DISCUSSION

What are the descendants of the majority of LGRBs?

- Binarity of descendants?
- Mass range? Angular Momentum?
- Descendants similar to X-Ray Binaries?
  "Apples and Oranges" or "All Apples"?
  Fishback & Kalogera 2021, but also *Belczynski et al. 2021*…

Perspectives

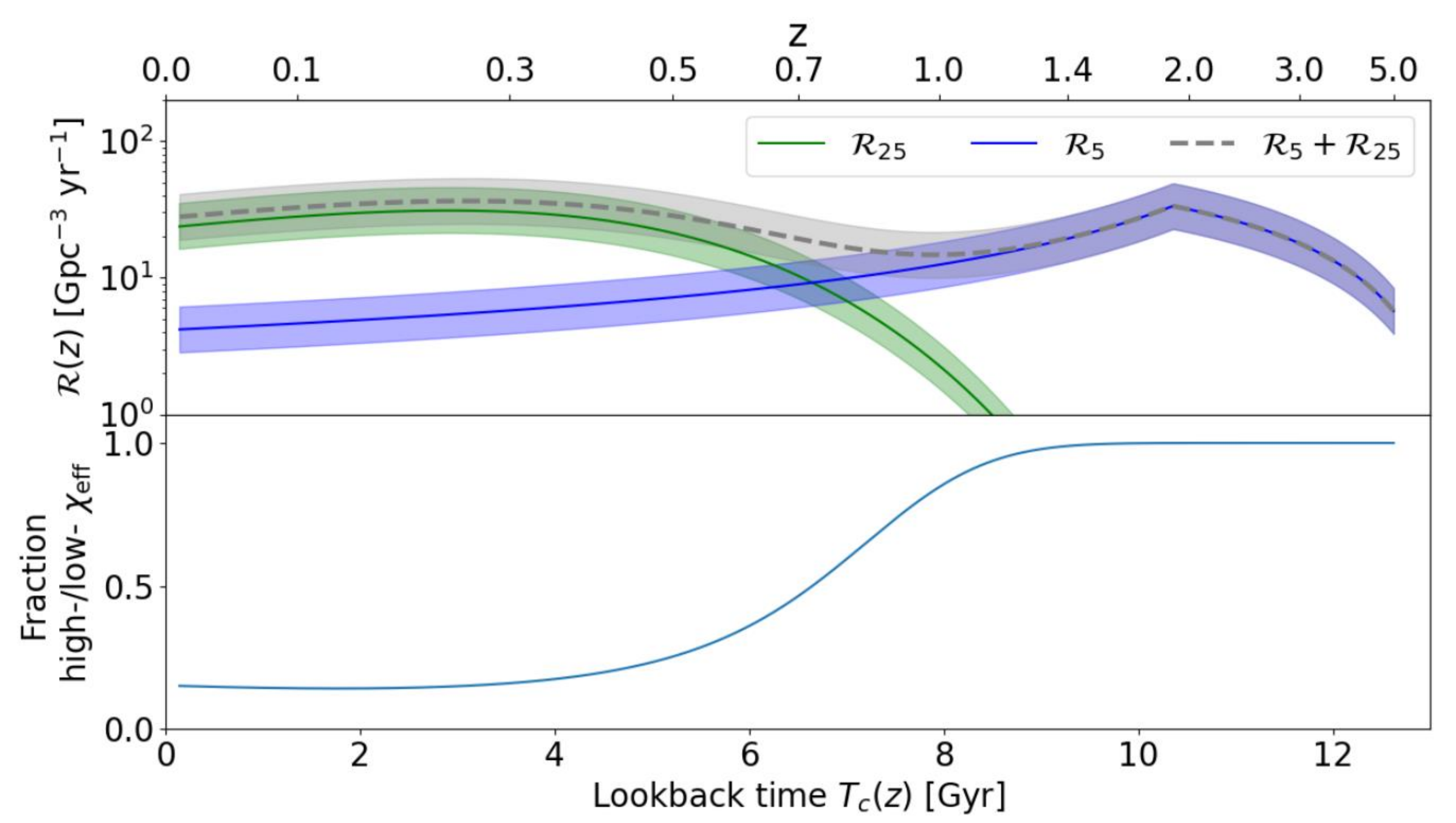
PERSPECTIVES

Insight from population models reproducing properties from both LGRBs and BBH mergers
e.g. *Bavera et al. 2022*

PERSPECTIVES

LVK Collaboration O4 / O5:

- More mergers (+100/yr at least)
- Higher redshift

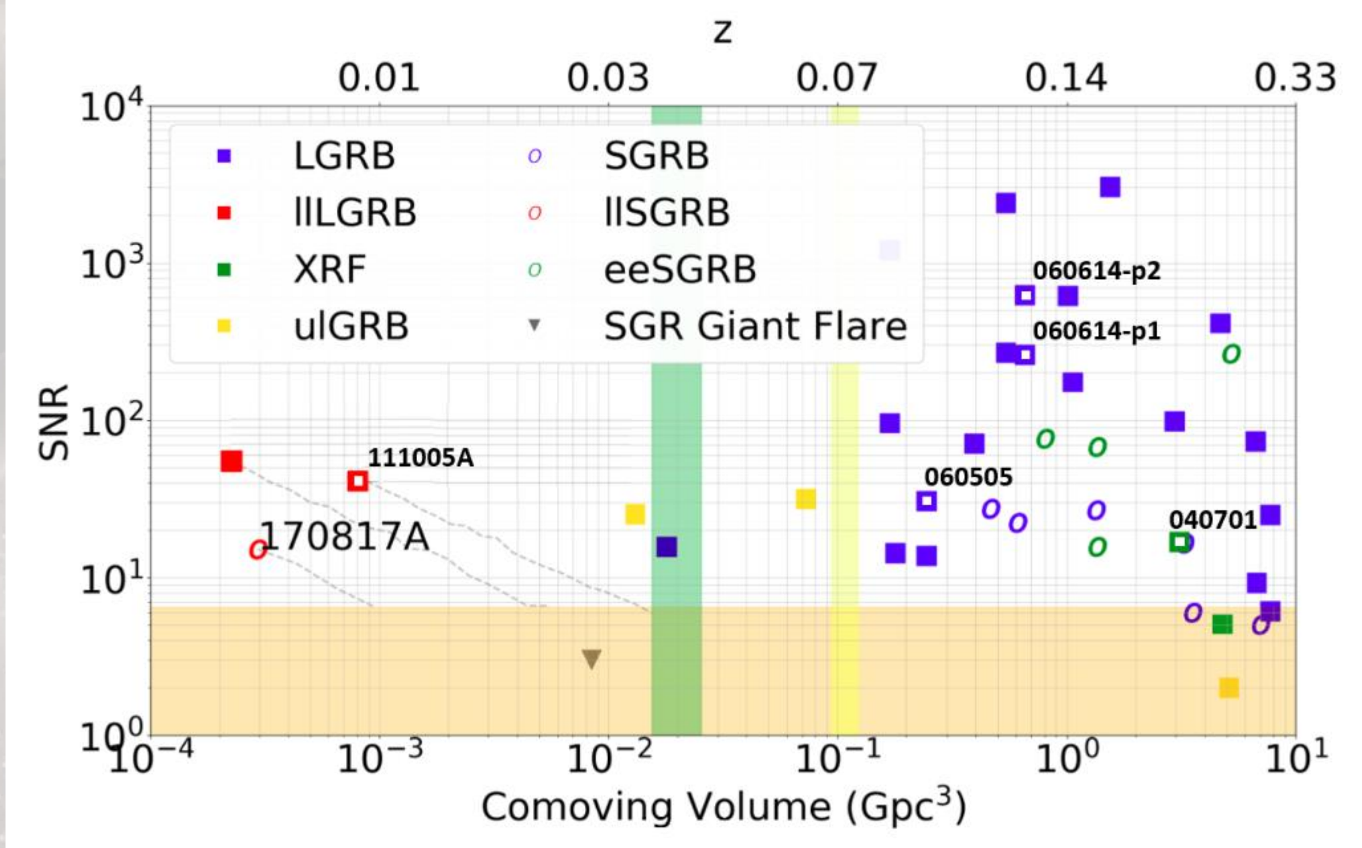


Two potential populations for BBH mergers
Source: Arcier et Atteia 2022

PERSPECTIVES

Sub-categories of LGRBs:

→ XRFs, XRRs
→ Choked jets
→ SN-less long GRBs



SVOM/ECLAIRs on-axis count SNR for GRBs in the local Universe
Source: Arcier et al. 2020

THANK YOU ! QUESTIONS ?