Search for nearby short gamma-ray bursts with the Neil Gehrels Swift observatory

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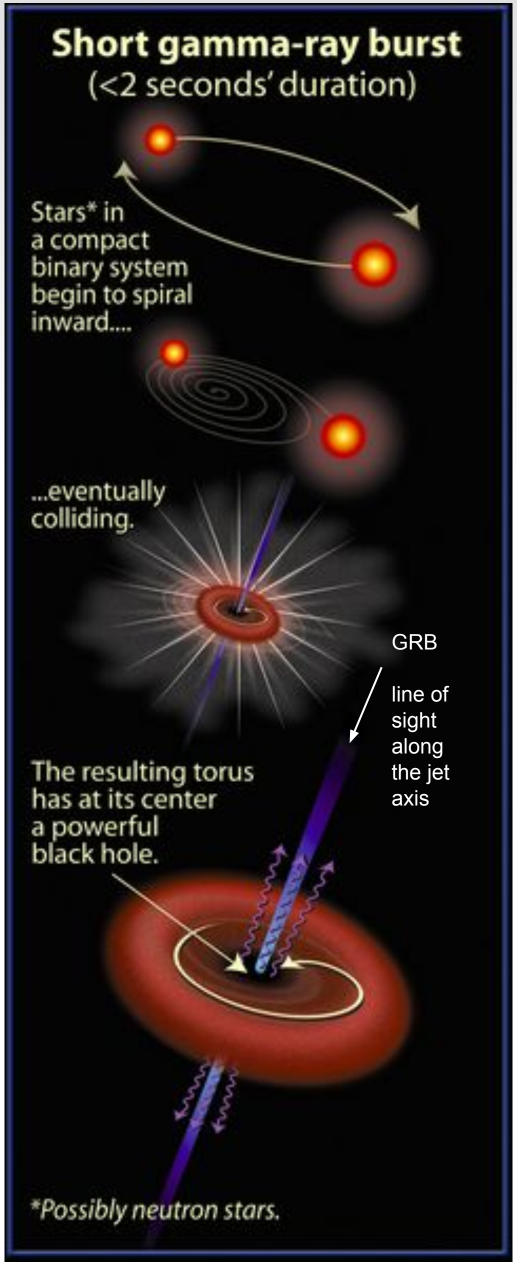


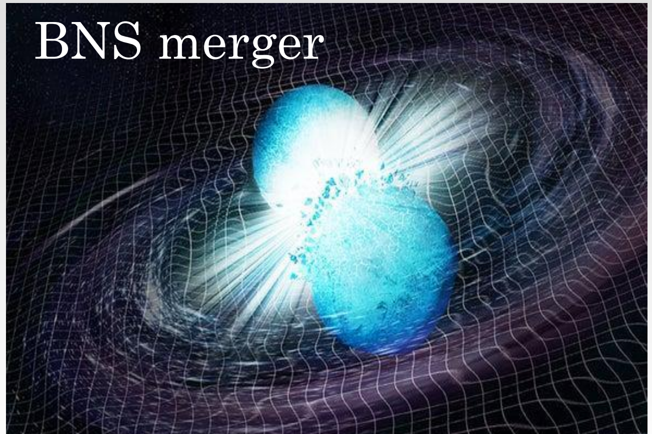
Short GRBs are brief flashes of gamma-rays radiation detected by low orbit satellites with a rate of about 1-2 per week

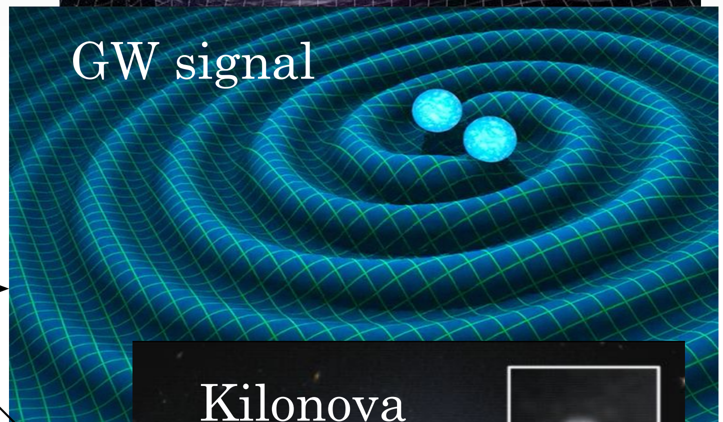
Typical duration: less than 2 seconds

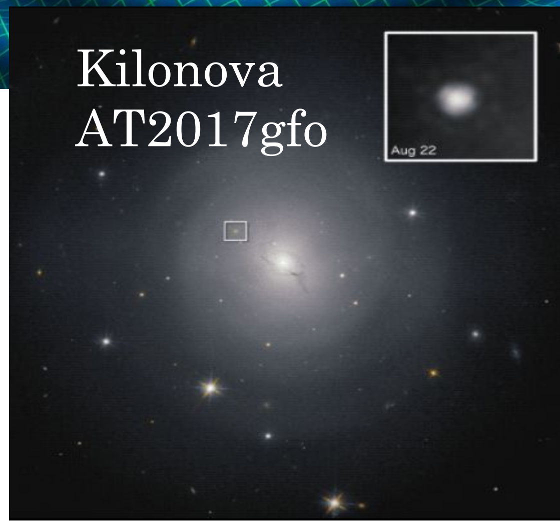
Spectrum: typically hard (e.g. high peak energy)

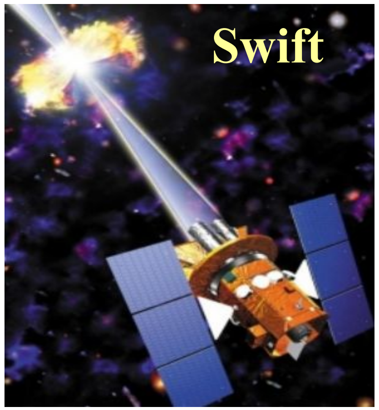
Possible progenitor: merger of compact objects (e.g. **binary neutron stars** or **black hole-neutron star merger**)

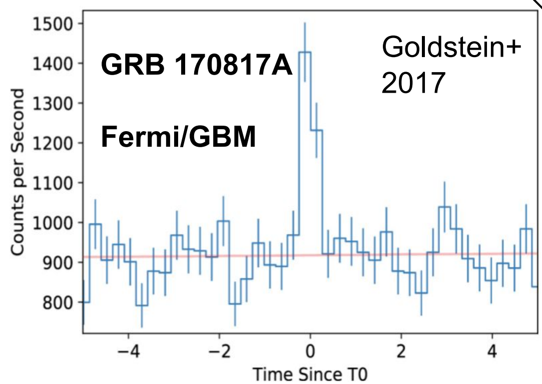
Associated signals: **Gravitational waves** & **Kilonovas.**
GW signals are detectable for nearby events (e.g. <200 Mpc)

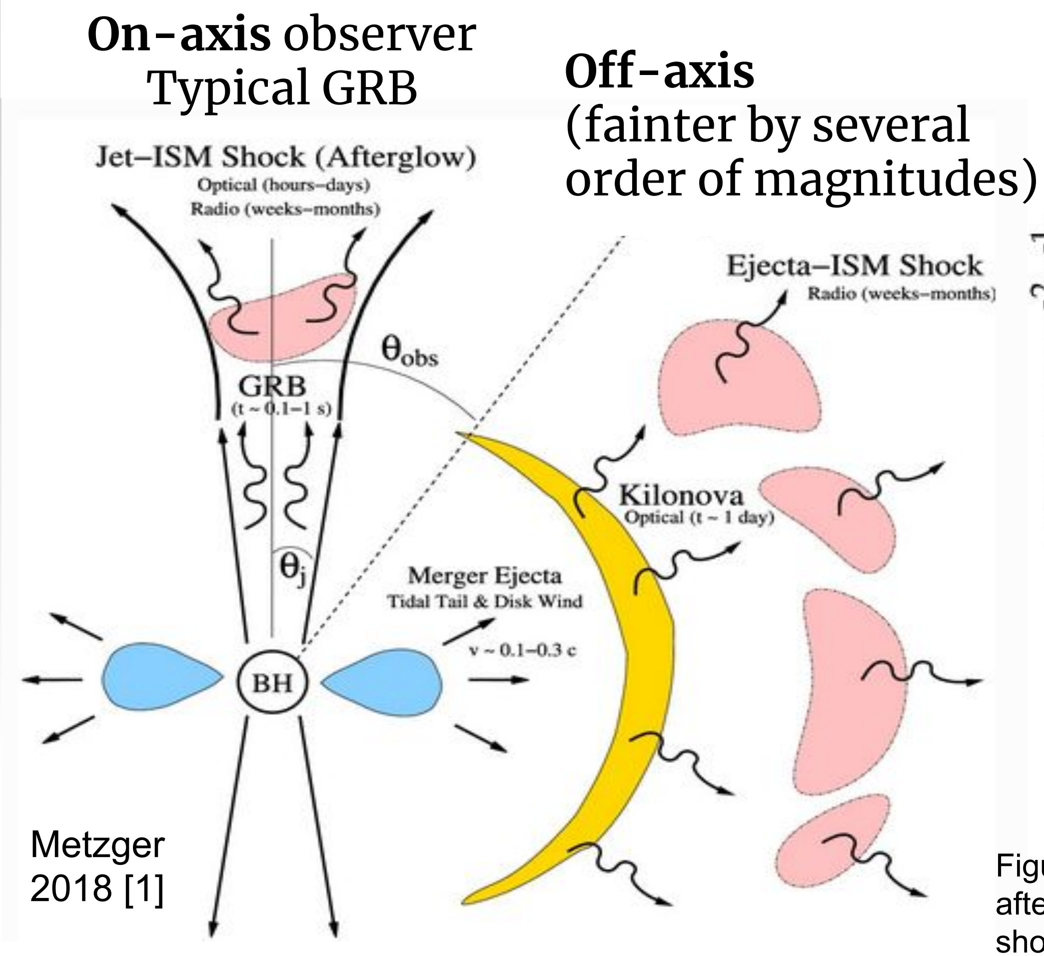












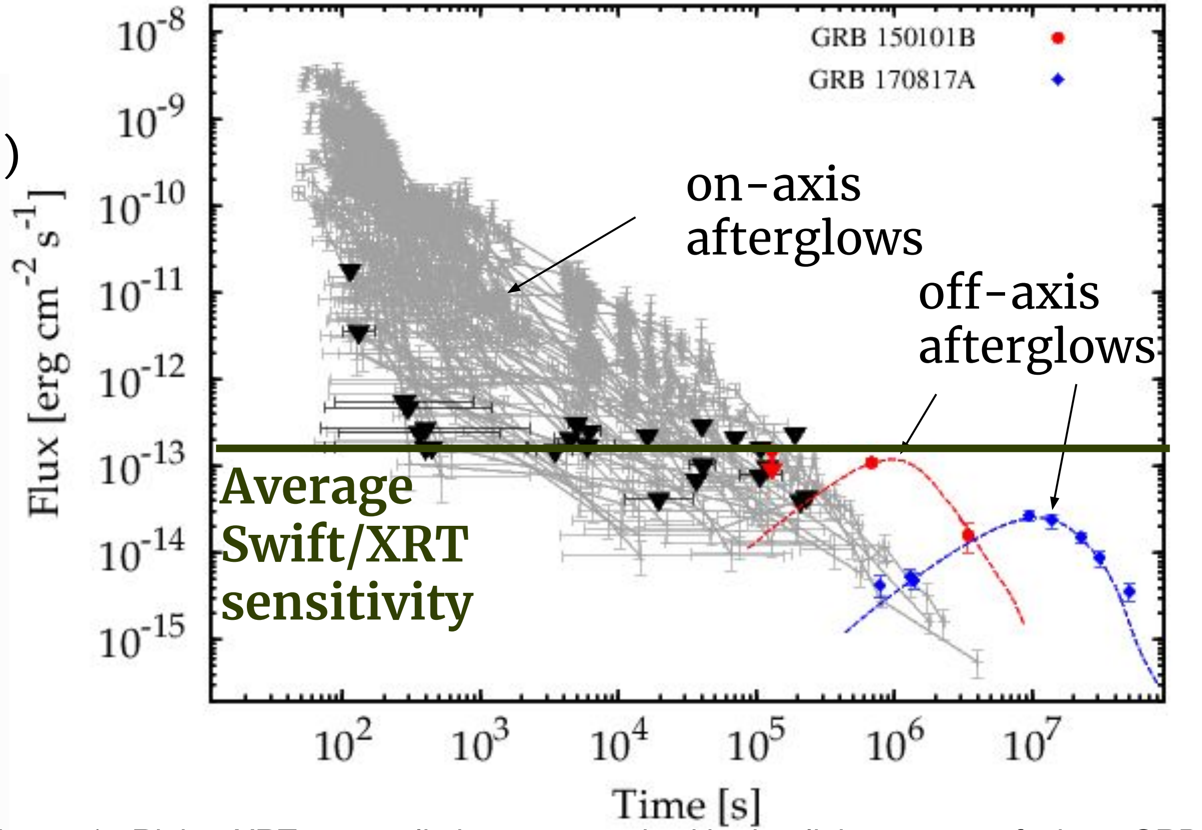


Figure 1: Right: XRT upper limits compared with the light curves of short GRB afterglows. GRB 150101B and GRB 170817A late time light curves (from [2][3]) are shown for comparison. Left: graphic description of the emission at different angles

The first common detection of a short GRB together with a gravitational wave signal (**GRB170817A/GW170817**) revealed the presence of a population of nearby events (< 200 Mpc) observed off-axis.

Search of off-axis short GRBs in the Swift sample

Total selected sample: 32 short GRBs

We select all the GRBs detected by Swift/BAT from January 1, 2005 to January 1, 2019 that satisfy the following criteria:

- **Short duration** (T90 < 1 second)
- **Lack of an afterglow detection** (as observed for off-axis short GRBs: faint afterglow and late onset)

The X-ray limits are fainter than the average population (Fig.1).

- **This is consistent with off-axis explosions or on-axis GRBs in a tenuous environment ($n < 4 \times 10^{-3}$ cm^{-3} for $\varepsilon_B > 10^{-4}$)**

Host galaxy search

The BAT GRB refined positions [4] (90% error region) were cross-correlated with the GLADE v2.3 galaxy catalogue [5]

four possible matches for distance ≤ 200 Mpc → higher than the rate expected from chance alignments (~3%)

12.5% of Total sample

possible physical connection with these bursts

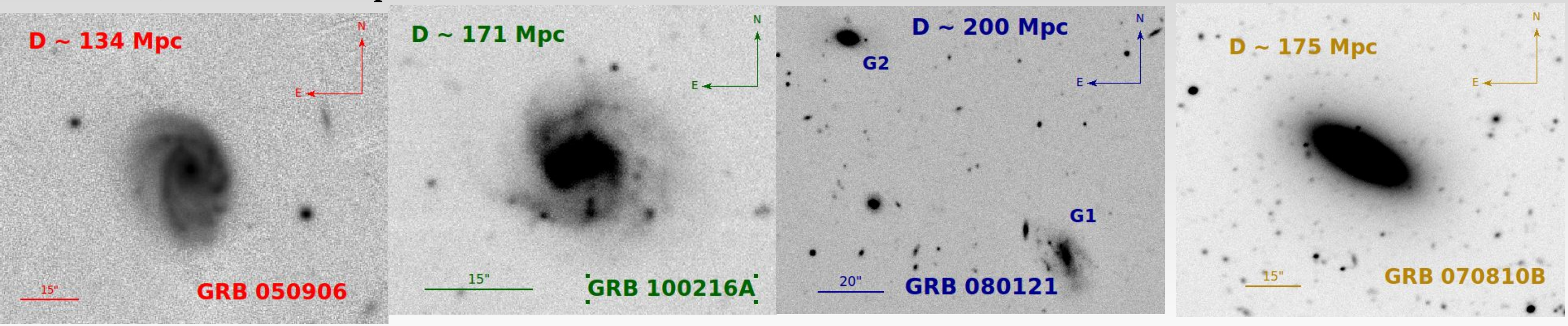
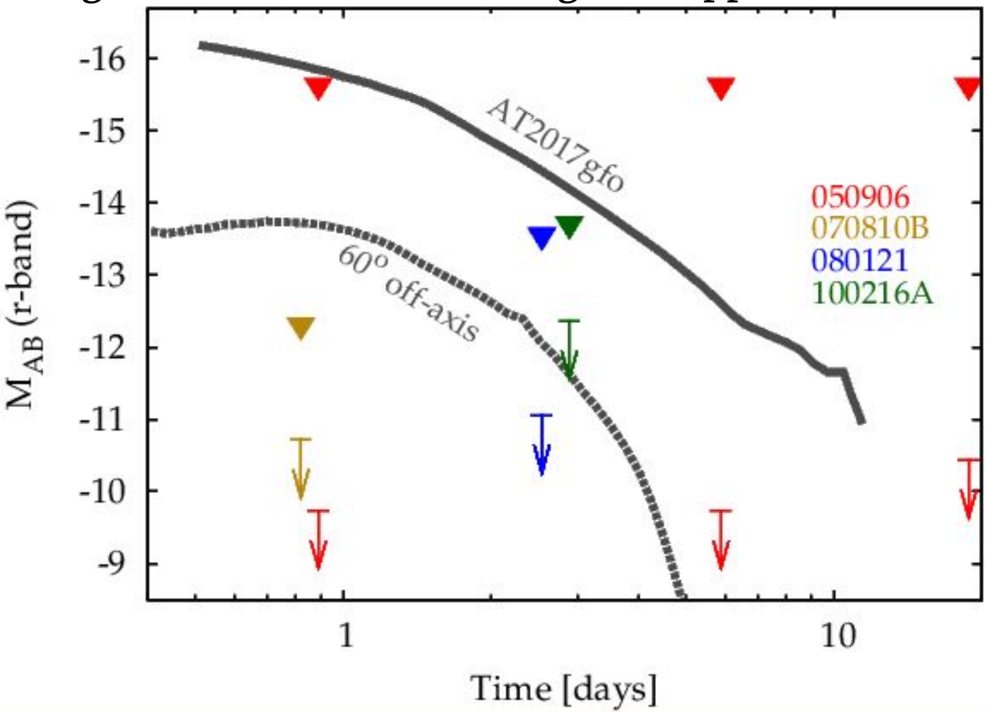


Figure 2: the four putative local host galaxies that match our sample. GRB 080121 has two possible associations (G1 and G2) at similar distance (~200 Mpc).

Optical limits

We analyzed archival afterglow observations deriving flux upper limits inside the galaxies and in the image fields

Figure 3: Upper limits derived in the r-band for the afterglow of the four possible local GRBs. Downward triangles and arrows show the limits derived in the internal and external region of the galaxy, respectively. GRB 050906 limits are retrieved from [6]. The AT2017gfo light curve is displayed by the solid line. Dotted line shows the emission expected for viewing angle of 60°



Assuming that they are the actual host galaxies of these short GRBs:

- **Kilonova constraints** for events viewed toward their polar regions (e.g. **lanthanide-poor ejecta**).
  Ejecta mass and velocity:

$$\boxed{M_{ej} \leq 10^{-3}\ M_\odot \quad \text{for} \quad v_{ej} \geq 0.2c}$$

- Our constraints are less tight in the internal region of the galaxies.
- We can not exclude emission observed at high latitude (e.g. lanthanide-rich)

Rate of local short GRBs

➢ **All sky rate** assuming a local origin :

$$R=160^{+200}_{-100}\ \mathrm{Gpc^{-3}\,y^{-1}}$$

rate of sGRBs within 200 Mpc detectable by *Swift* and *Fermi*:

$$R_{Swift}= 0.16^{+0.2}_{-0.1}\ \mathrm{yr^{-1}}$$
$$R_{Fermi}= 0.8^{+1.0}_{-0.5}\ \mathrm{yr^{-1}}$$

Comparing it with BNS merger rate [8] we derive the beaming factor $f_b^{-1}>80$

➢ If none of the candidates are within 200 Mpc:

$$R<180\ \mathrm{Gpc^{-3}\,y^{-1}} \longrightarrow f_b^{-1}>10$$

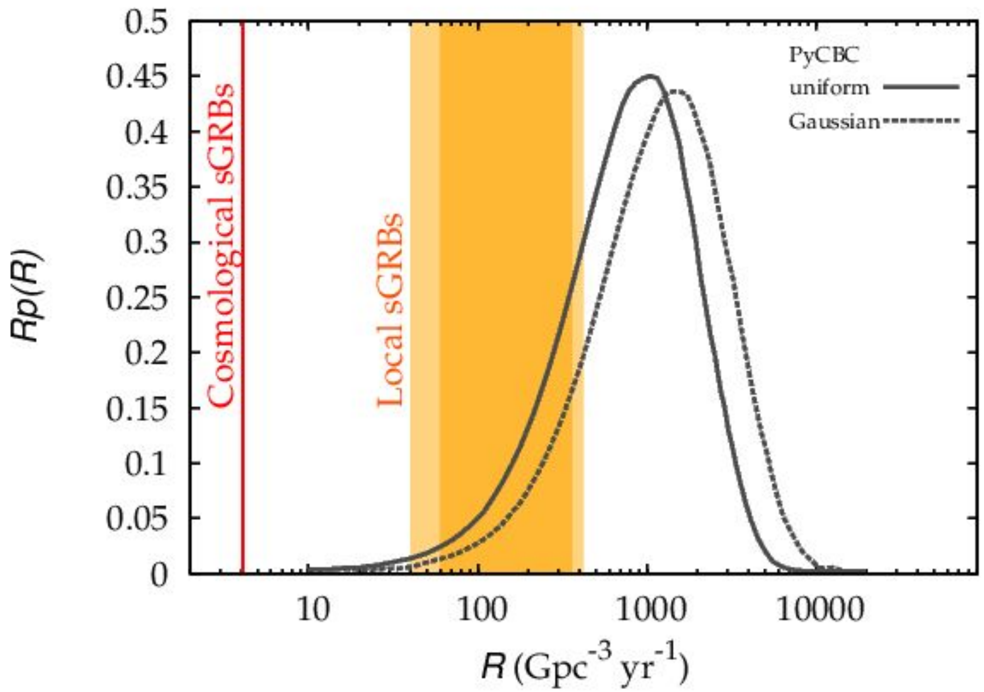


Figure 4: Our rate compared with the one derived from cosmological observations [7] and the BNS predictions presented by the LIGO/Virgo collaborations [8]. Dark (light) orange region shows the 68% (90%) confidence intervals

SUMMARY

- **We do not find evidence for a large population of sGRBs in the local universe (d<200 Mpc)**
- **4 candidates** (12.5% ot the total sample) with at least one local galaxy inside the 90% BAT error region.
- Assuming they are **local:**
  - ➢ the all-sky rate **R~160 Gpc^{-3} yr^{-1} (it is comparable with the population of BNS mergers [8])**
  - ➢ the rate of local sGRBs detectable by Swift and Fermi is:
    $R_{Swift}= 0.16^{+0.2}_{-0.1}$ yr^{-1} $R_{Fermi}= 0.8^{+1.0}_{-0.5}$ yr^{-1} (d<200 Mpc)

➢ **In no case we find evidence of a 170817-like kilonova** although we can not constrain the presence of a possible red kilonova (lanthanide-rich) due to the lack of IR limits

- if they are **cosmological:**
  - ➢ we derive an upper limit for the rate of **R<180 Gpc^{-3} yr^{-1}**
  - ➢ the lack of X-ray afterglow could be explained by **tenuous environment**

An optimization of the follow-up strategies and a systematic search for untriggered bursts could be crucial to increase the detection rate of local events.

References
[1] Metzger. 2018, LRR, 23, 1; [2] Troja, et al. 2018, Nature Com., 9, 4089; [3] Troja, et al. 2019, MNRAS, 489, 1919; [4] Lien et al. 2016, ApJ, 829, 7; [5] Dálya et al. 2018, MNRAS, 479, 2374; [6] Levan et al. 2008, MNRAS, 384, 541; [7] Wanderman & Piran 2015, MNRAS, 448, 3026; [8] Abbott et al. 2019, PRX, 9, 031040