Neutron Star Merger Afterglows: Population Prospects for the Gravitational Wave Era

R. Duque, F. Daigne & R. Mochkovitch

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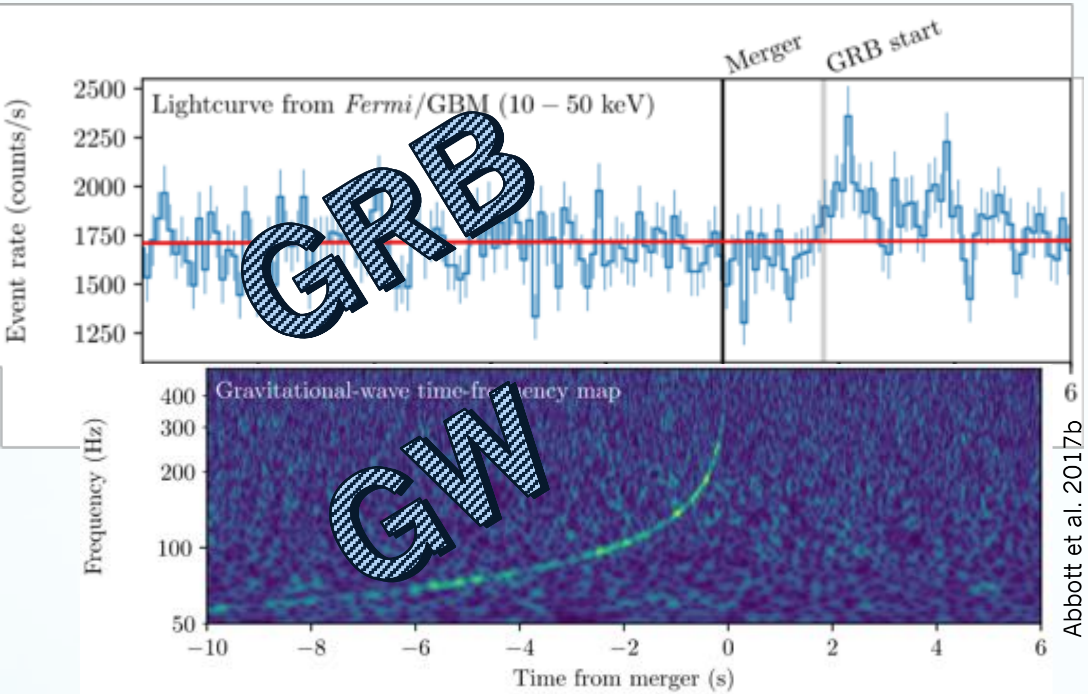
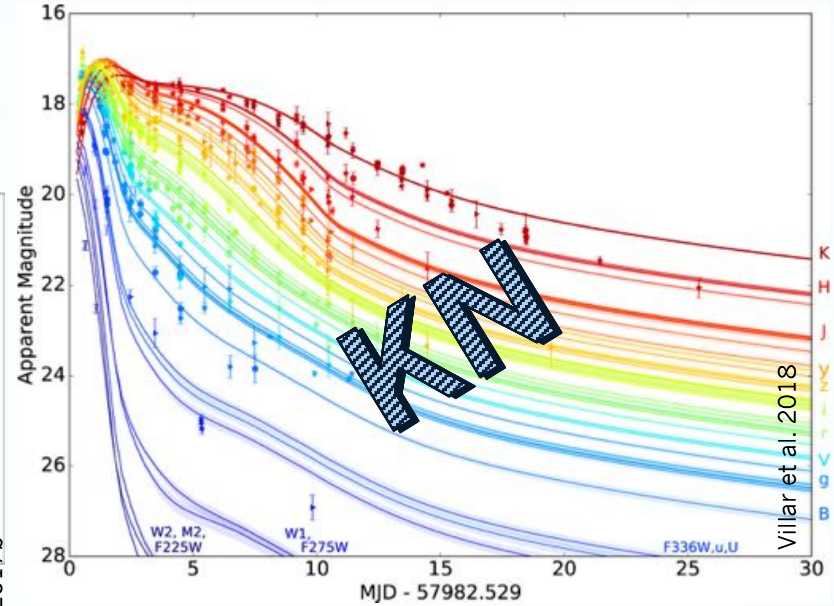
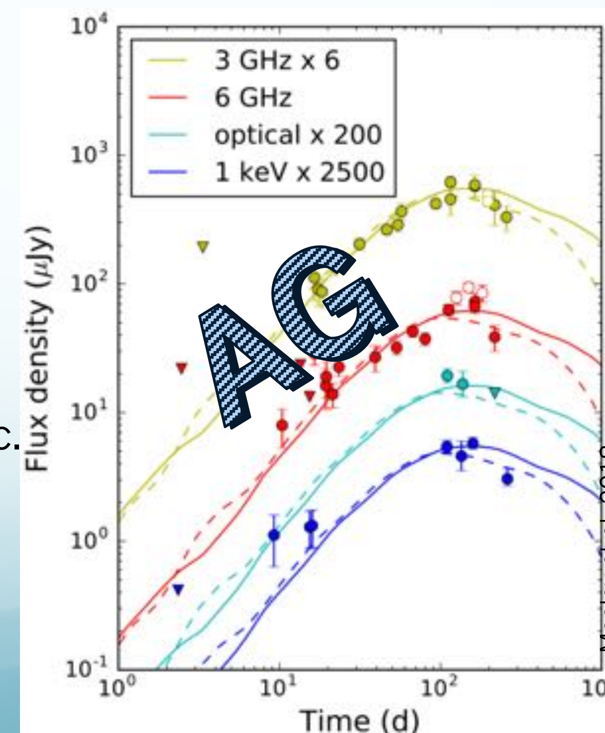
New Era of Multi-Messenger Astrophysics,
Groningen, The Netherlands

On August 17th 2017…





- Confirmed NS-NS mergers as **progenitors for short GRBs**
- Inauguration of the **era of multi-messenger astronomy with GW**
- Other fundamental (astro-)physics: GR, NS EOS, Hubble constant measurement, r-process nucleosynthesis, etc.

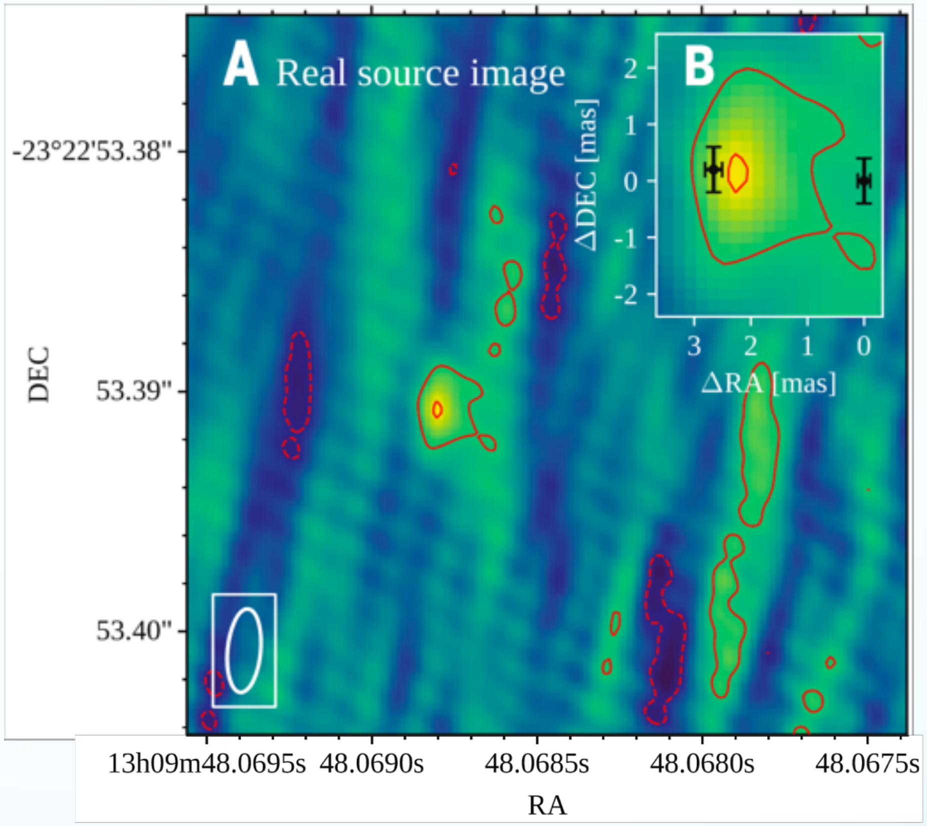


Afterglows and kilonovae: What should we expect for O3?

Context

Afterglow, kilonova
= great wealth of information!

- ✓ Localization
- ✓ External medium density
- ✓ Jet kinetic energy
- ✓ Jet geometry
- ✓ Viewing angle
- ✓ Magnetic field
- ✓ And more!



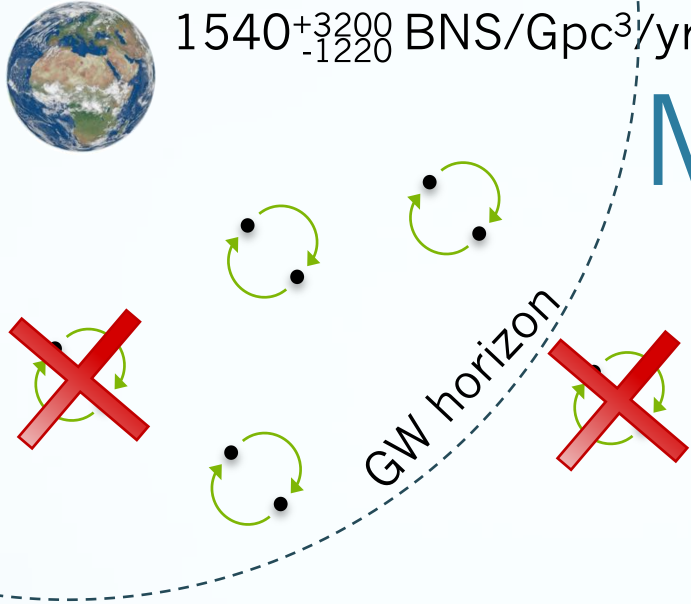
Ghirlanda et al. 2018

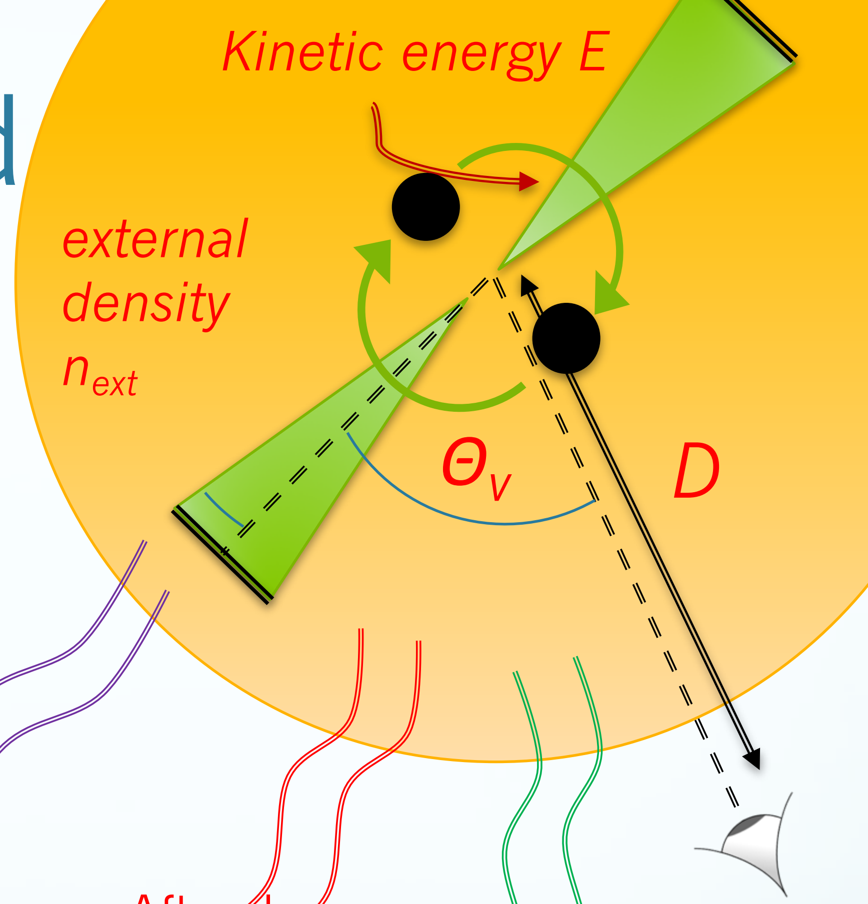
O3 is coming (April 2019)
→ More GW with afterglow and kilonova!

- Which **kilonovae and afterglows** to expect and **what will they look like**?
- How will they help to study **the environments of NS binaries**?
- What insight will they bring on the **origin of the jet structure**?
- What will they tell us on **GRBs** and their **dissipation mechanisms**?

1540^{+3200}_{-1220} BNS/Gpc^3/yr (Abbott+2018)

Method





Population model with ingredients: *D*, Θ_v, *E*, n_{ext}, ...
+ **Detection criterion**
→ Deduce **GW+AG observed** population of mergers

Gravitational wave

Afterglow

Kilonova

Detection depends on *D*, Θ_v
*... and **GW horizon***

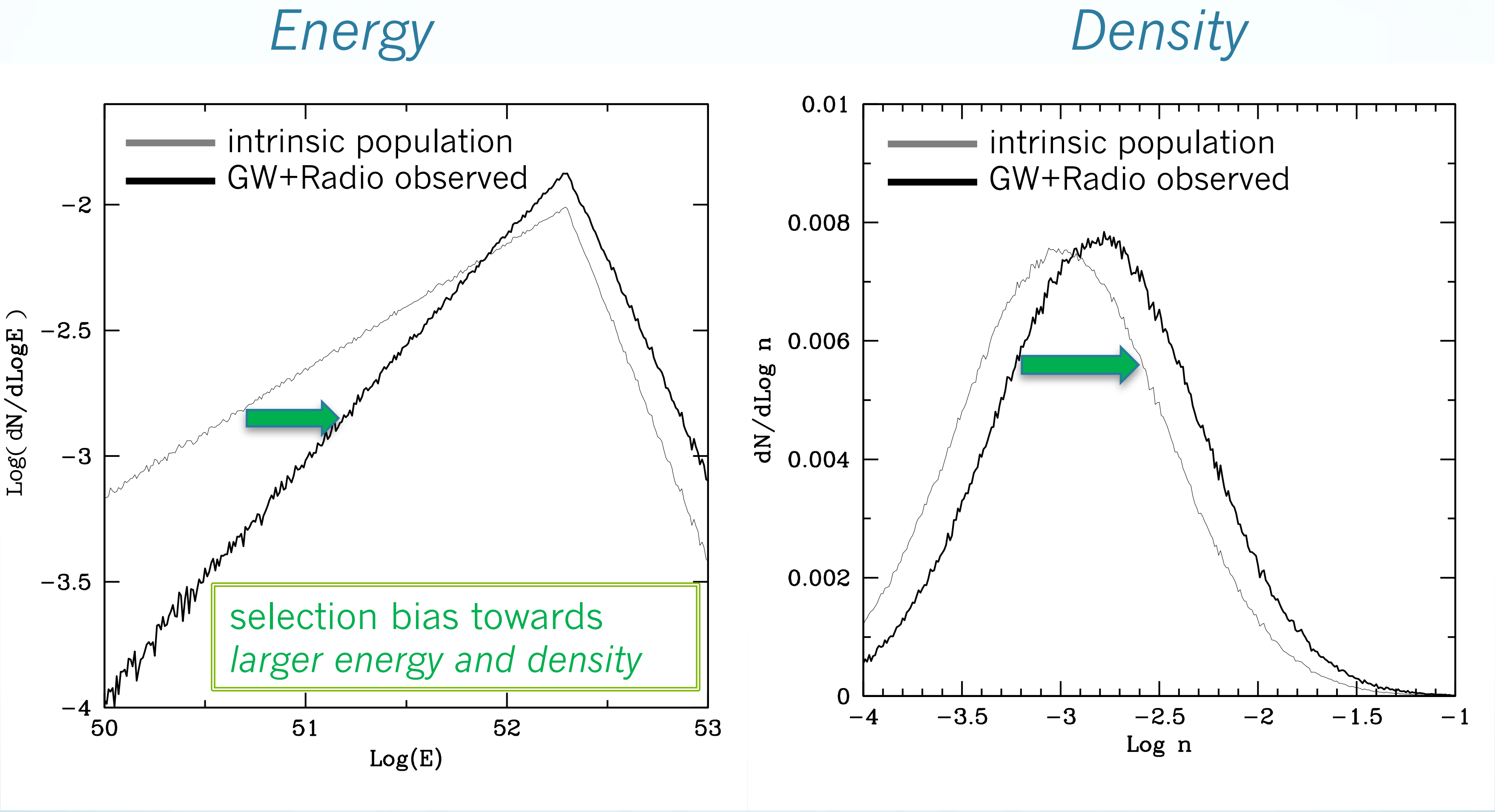
O3: 380 Mpc
Design: 430 Mpc

Detection depends on *D*, Θ_v, *E*, n_{ext},
*... and **radio sensitivity***

VLA: 15 μJy @ 3GHz
SKA1-Mid: 3 μJy

Detection depends on *D*, Θ_v
*... and **Vis.-IR follow-up depth***

Population model distributions:



Reference model:

- *Energy*: BPL, break energy 2.10^{52} erg, slopes +0.5 and -2 (Ghirlanda et al. 2016)
- *Density*: Log-normal centered on 10^{-3} cm^{-3}

(Detectable) Event rates for NS-NS

Detector conf.	#GW	#(GW+AG)	#(GW+KN)
O3 + VLA	9	2	**100%**
Design + VLA	21	4	
Design + SKA	21	6	
700 Mpc Horizon + SKA	92	20	**?**

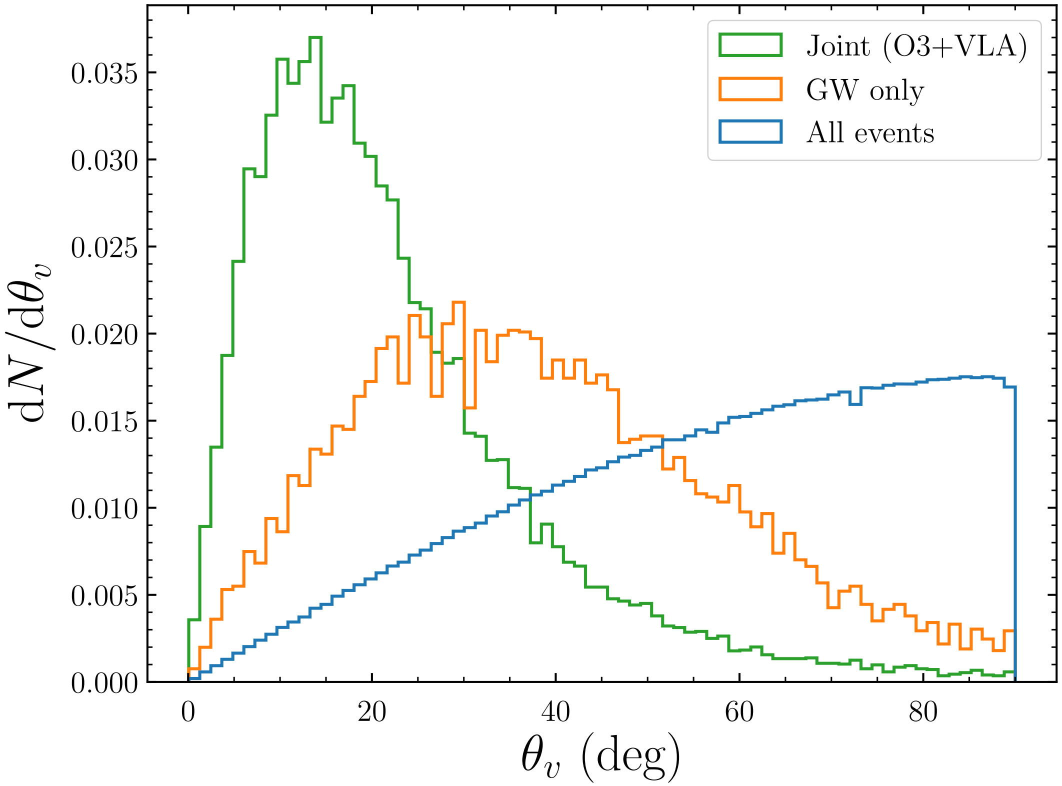
Can we **detect** all **detectable** events?

Uncertainties: $^{+200\%}_{-73\%}$ (intrinsic rate from LIGO-Virgo O2/O3)
+ uncertainty on population model

- In general: **10-20% events have detectable AG** (depending on energy distribution)
- Large deviation from this **= constraints on population!**

GW+GRB ~ 1-10% (O3)
(Beniamini et al. 2018)

Properties of joint events: viewing angle

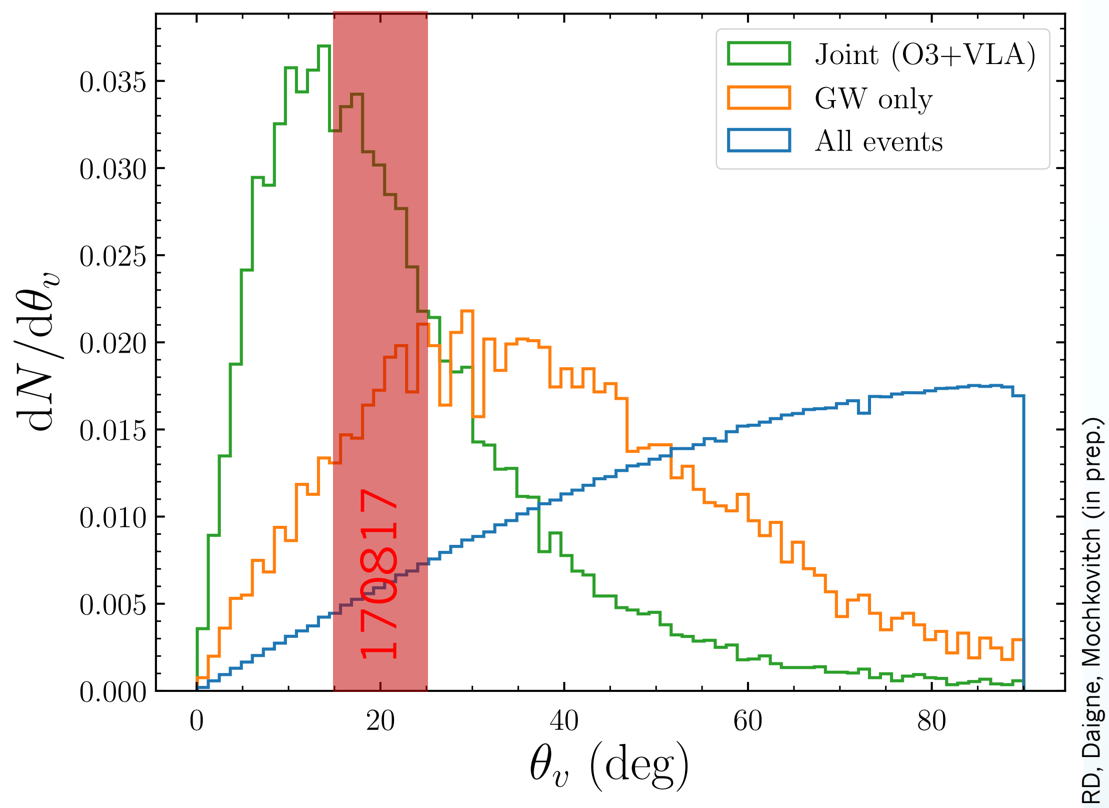


RD, Daigne, Mochkovitch (in prep.)

- Most events seen off axis!
- Mean angle ~20-30°

+ Other distributions:
distance, peak flux, proper motion, ...

Properties of joint events: viewing angle



- Most events seen off axis!
- Mean angle ~20-30°
- New insight on GRB physics

→ ***Jet geometry? Origin of lateral structure?***

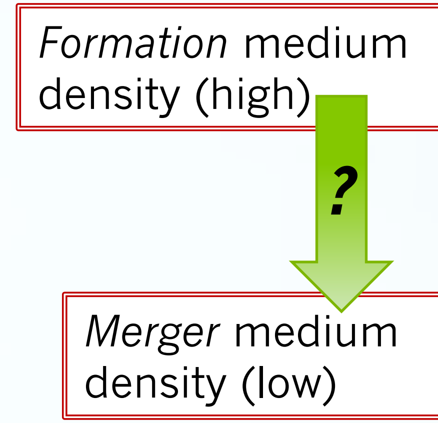
→ **GRB dissipation mechanisms** (thermal tail?)

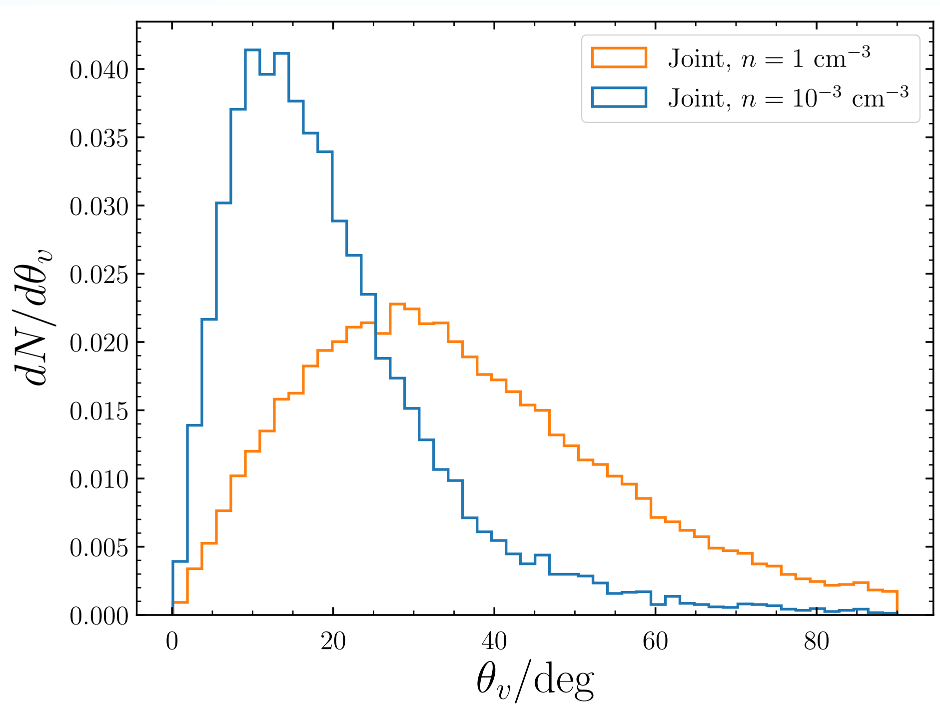
+ Other distributions:
distance, peak flux, proper motion, ...

Binaries in high density media

- NS binaries with high **eccentricity** or efficient **common envelope** phase merge in high density media after **short delay time** (Beniamini+2016)
- Mergers occurring in dense media produce **brighter AG** and are **more likely detected** ($F \sim n^{4/5}$)

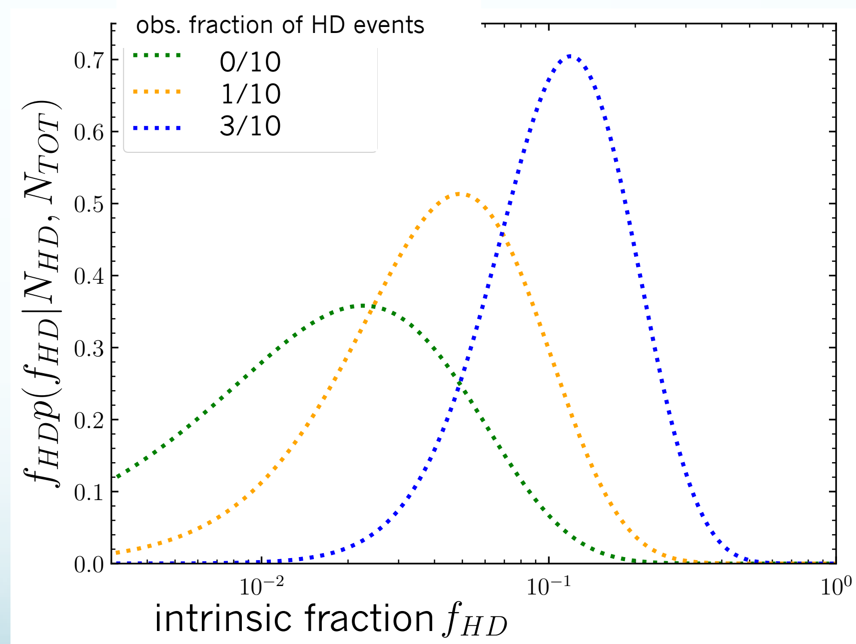
→ **Tight constraints** on binary environment **from only a few events**





Beniamini, RD, Mochkovitch, Daigne (in prep.)

High density ⇔ Large viewing angle

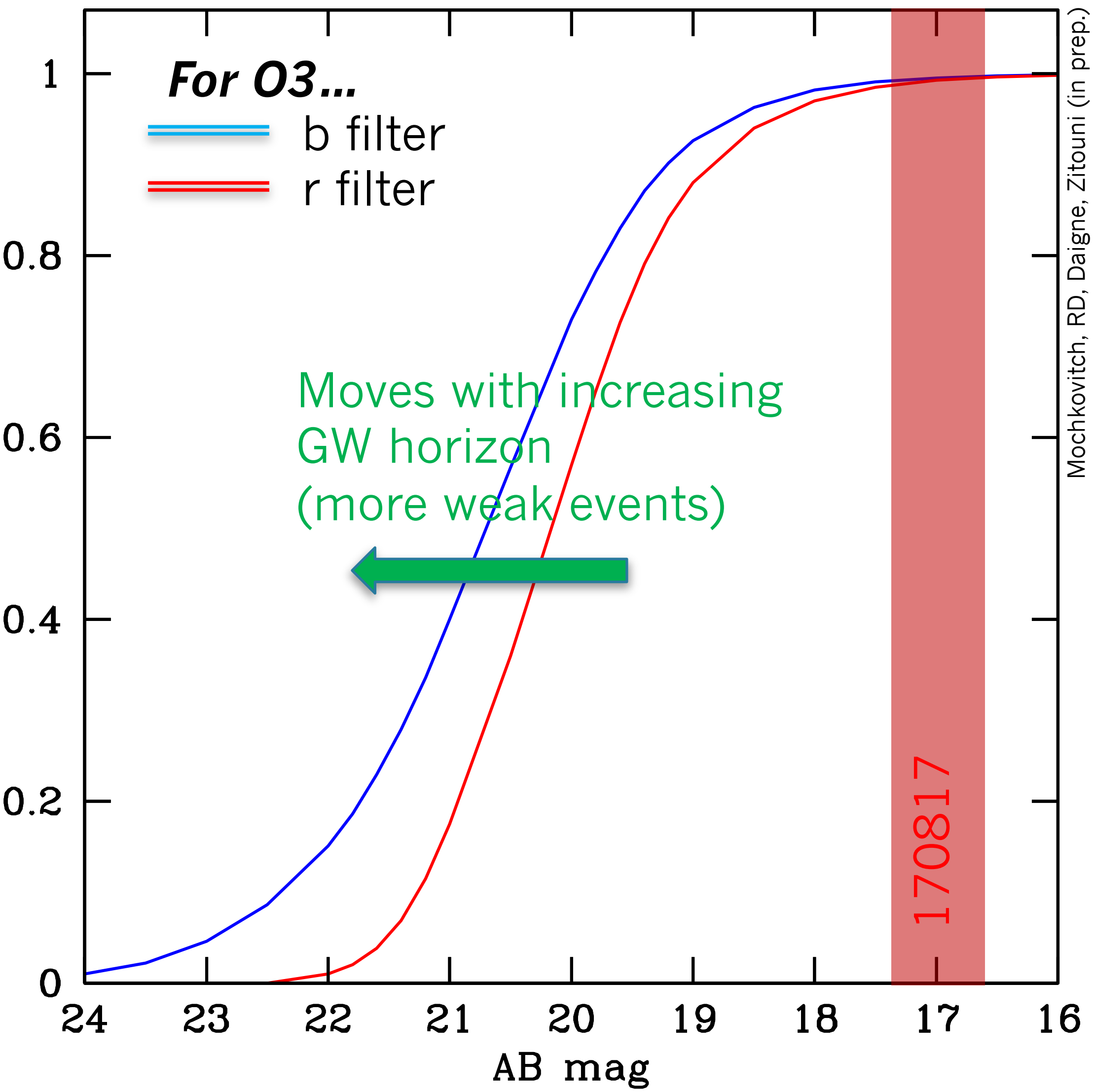


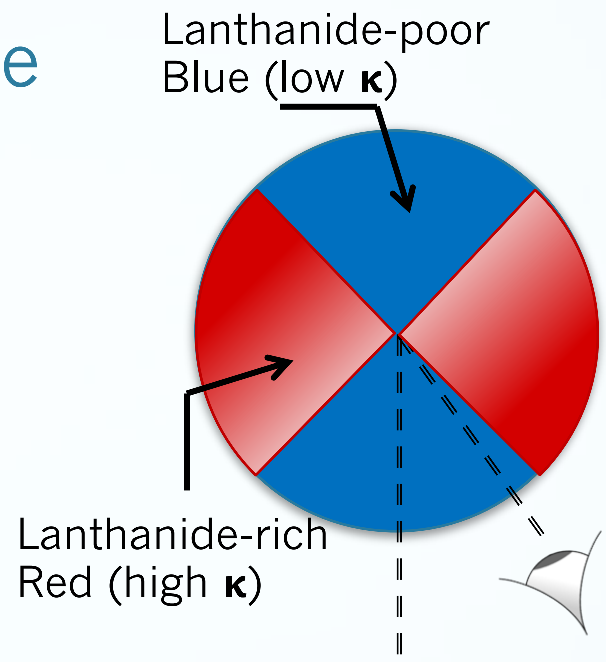
Beniamini, RD, Mochkovitch, Daigne (in prep.)

Observation of 3 *high-density out of 10*

→ **log(f_{HD}) = - 1 ± 0.6**

Expectations for kilonovae





- Vis.-IR signal depends on **viewing angle** because of ejecta contrasts

For O3:

✓ **Magnitude OK** *a priori*

✗ Volume to explore potentially **100x larger** than for 170817

✗ Contrast with host galaxy

→ **Finding the OT challenging!**

KN model and population details in poster:
Prospects for KN signals in the GW era

Conclusion

- **Afterglows and KN are important** to understand the **local and viewing conditions** of **NS-NS mergers**
- O3 is coming: **several** NS-NS GW events, **a few** with afterglow, **all with detectable KN**
- Actual **fraction of AG/GW will constrain population** of NS-NS merger population (jet parameters, external density, etc.)
- Most events are seen **off-axis,** allowing to **probe the jet geometry** and **emission therein**
- **High-density mergers** will allow to study **fast-merging binaries**. Only a **few events** are necessary **to constrain this** particular binary **NS evolution channel**.
- What to expect from NS-BH mergers?

Long run

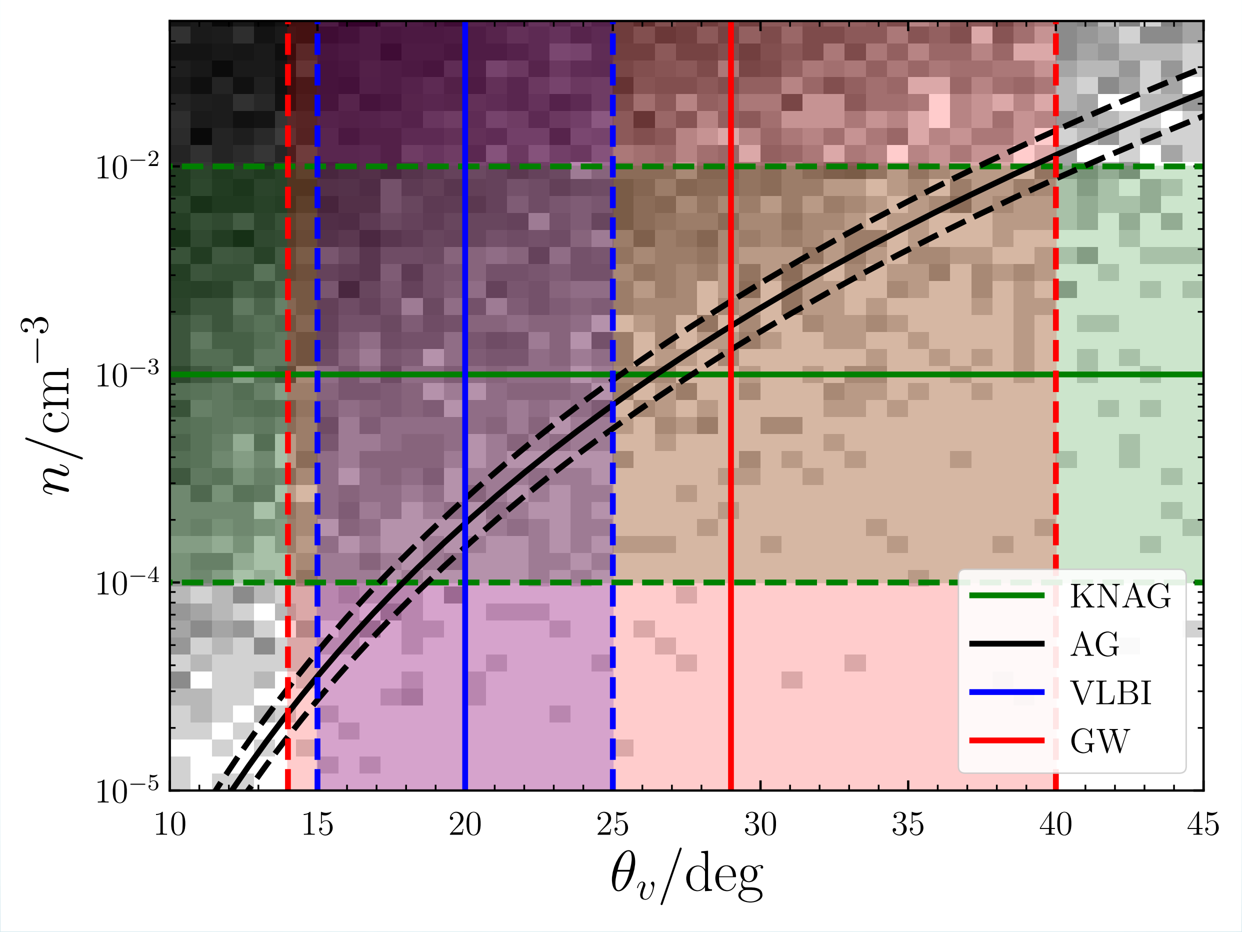
Link pop. coalescence — pop. sGRB

Interpretation tools for observations of GRBs in the multi-messenger context:

① Modeling of EM counterparts of CO fusions: sGRBs and afterglows
Context: observations by LIGO–Virgo (~2019)

② Modeling of the general population of GRBs and afterglows
Context: present and future observations: Swift, Fermi, INTEGRAL, **SVOM**

Determining viewing angle and density from multi-messenger observations



1: GRBs & CO fusions

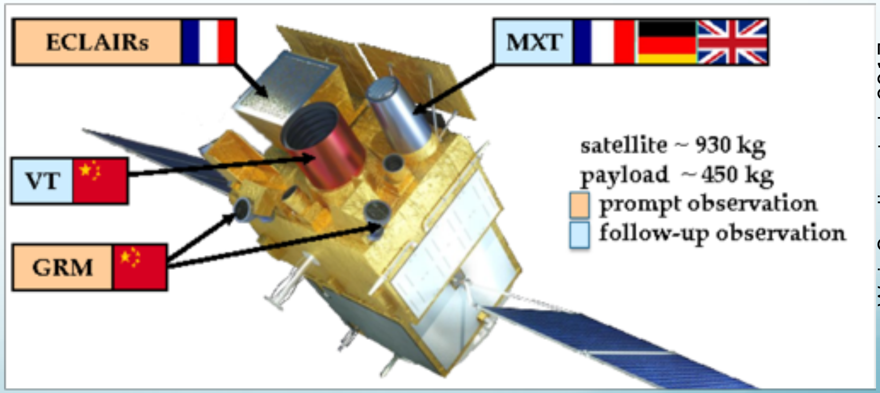
- Distinguish NS-NS and BH-NS?
- Nature of final object? Link with ring-down signal?
- **Systematic fusion/GW/sGRB/kilonova/afterglow association?**
- **GW/GRB delay?**

2: General population of GRBs

Rates: (Wei, Cordier et al. 2017a):

- SVOM: 60-70 yr^{-1}
- Swift, Fermi, INTEGRAL: ~100 yr^{-1}

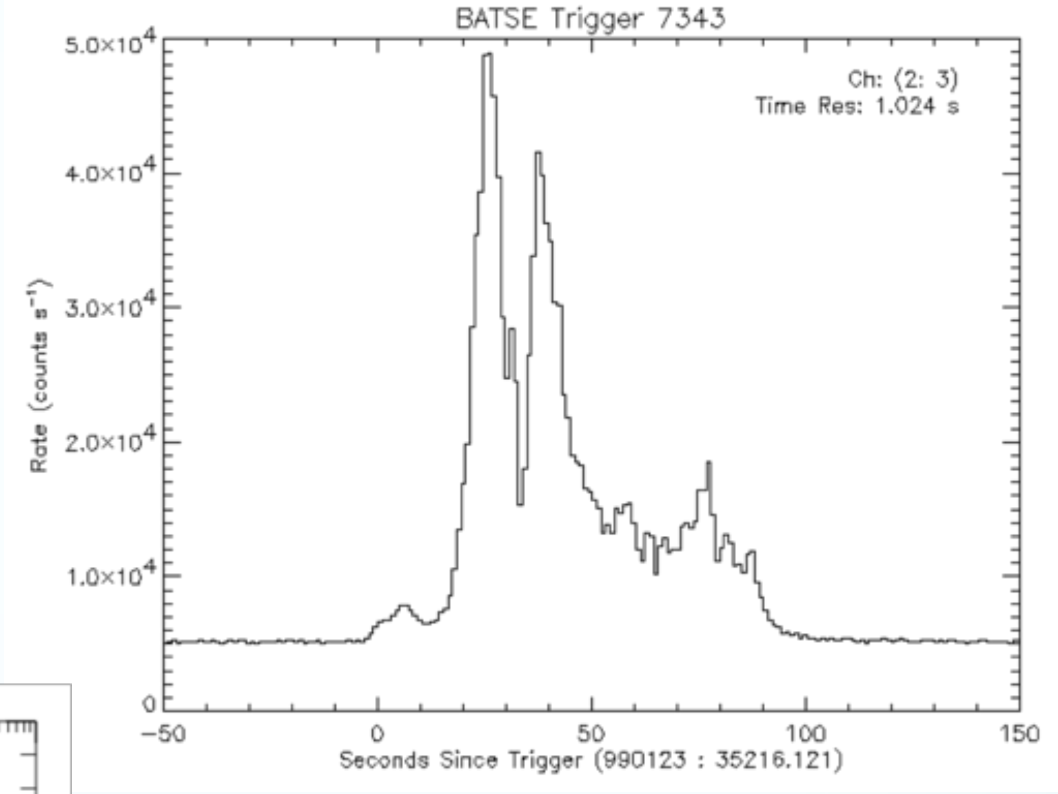
- **Radiative processes in GRB (shocks/magnetic reconnection)?**
- Ejecta magnetization?
- **Other afterglow observables (polarization, imaging)?**



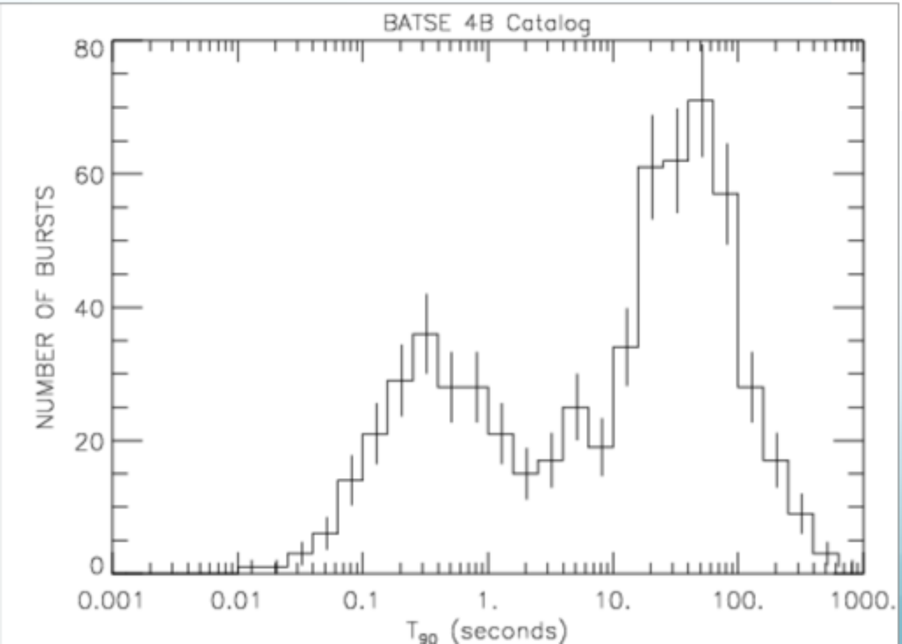
Wei, Cordier et al. 2017a

Gamma-ray bursts

Light curves:
- Strong variability
- Shape diversity
- Variation time-scale diversity



Paciesas et al. 1996



Paciesas et al. 1996

Duration

Longs (ccSNe):
- > 2s
- Soft
- High SFR galaxies

Short (compact object mergers):
- < 2s
- Hard
- Early-type galaxies

Gamma-ray bursts