INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

OSSERVATORIO ASTRONOMICO DI BRERA

Hermes Science meeting

Giancarlo Ghirlanda & Lara Nava

May 10 2021

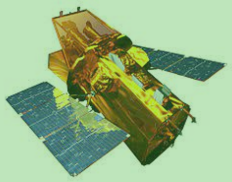
Objectives

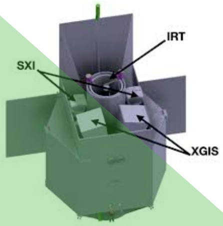
Gamma Ray Bursts:

Observed **samples**:

1. CGRO/Batse
2. Fermi/GBM (LAT)
3. Swift/BAT … …

Or a GRB **synthetic population**





How many GRBs? (detection rates)

What type of GRBs?

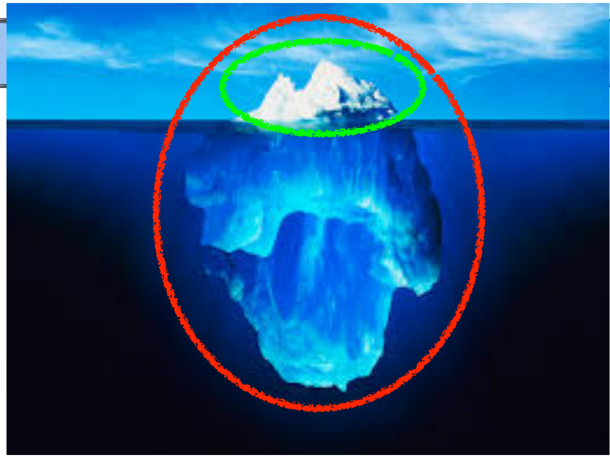
- Mission science objectives
- Optimise mission profile
- Explore synergies with other facilities (space/ground)

Part 1: G. Ghirlanda

Part 2: L. Nava

Population vs samples

Population



GRB detection rates

Encodes intrinsic properties of the sources

Maps the full parameter space

- Make predictions for new instruments/facilities with better control on selection biases
- Explore synergies/complementarity within instruments and among facilities

Detected Sample

$$F > F_{\mathrm{lim}}(\Delta E)$$

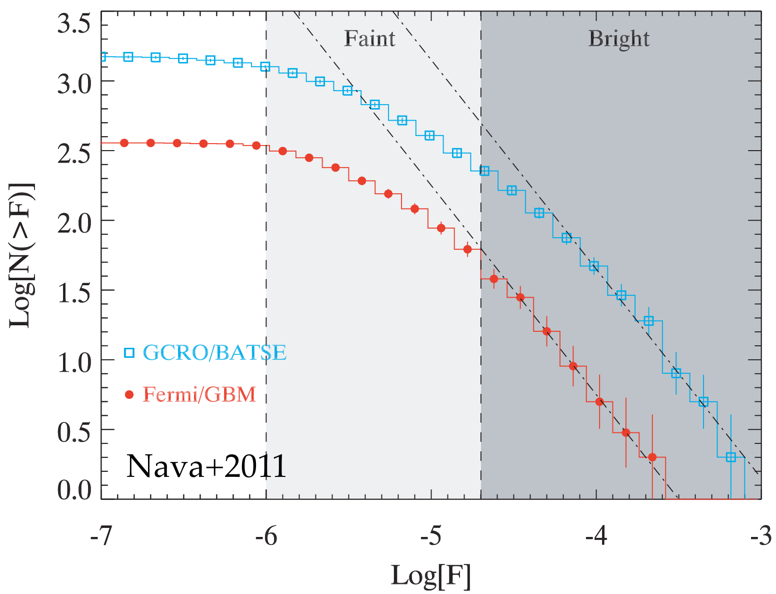
GCRO/Batse, Beppo-SAX, Hete-II, Fermi/GBM, Swift/BAT

… …

Result of instrumental selection of a portion of the population.

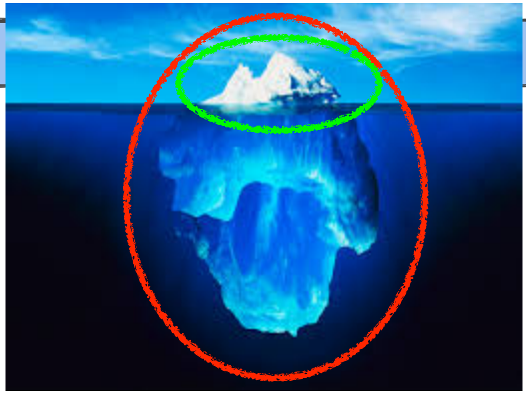
Maps a portion of the parameter space

Observed GRB samples extrapolation → GRB detection rates



Population based approach

Population



GRB detection rates

Population intrinsic properties:

1.**Luminosity/energy function** $\phi(L)$

2.**Cosmic rate distribution** $\Psi(z)$

$$N(P_1 < P < P_2) \propto A \int_0^\infty dz \frac{dV(z)}{dz} \frac{\Psi(z)}{1+z} \int_{L(P_1|z,P_{min})}^{L(P_2|z)} \phi(L) dL$$

Instrumental parameters

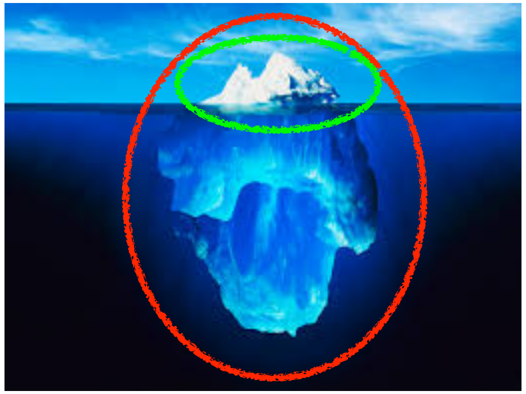
Building a population: Direct Inversion method

Population

Population intrinsic properties:

1.Luminosity/energy function $\phi(L)$

2.Cosmic rate distribution $\Psi(z)$



Collect a sufficiently large **sample** of sources with measured:

- Redshift
- Luminosity

Infer the luminosity function and source cosmic rate by **direct inversion** (2D binned method - Lynden-Bell 1971)

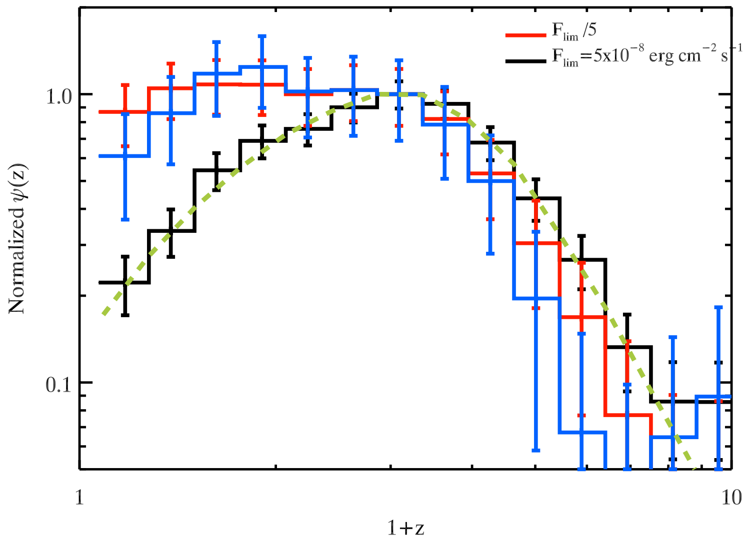
Strongly affected by samples' incompleteness (Pescalli+2016)

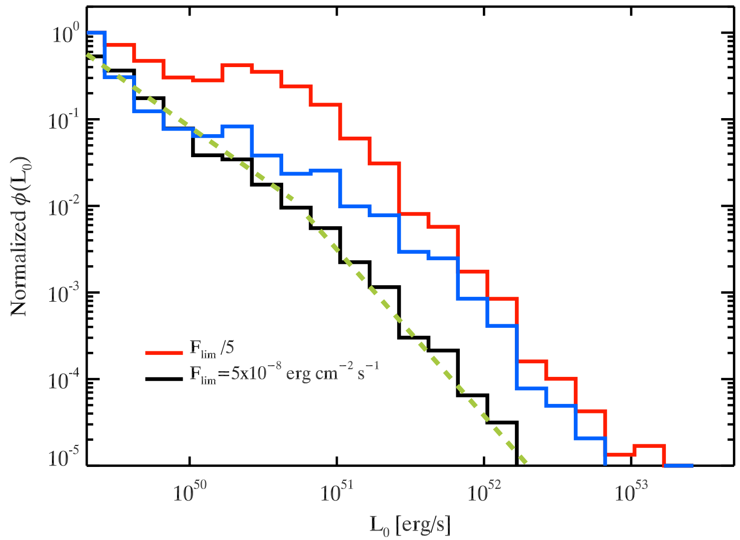
Input population

Complete sample flux limited

Randomly incomplete sample (I)

Randomly incomplete sample (II)





Building a population: INDirect (parametric) method

Population intrinsic pr

1.Luminosity/en ion $\phi(L)$

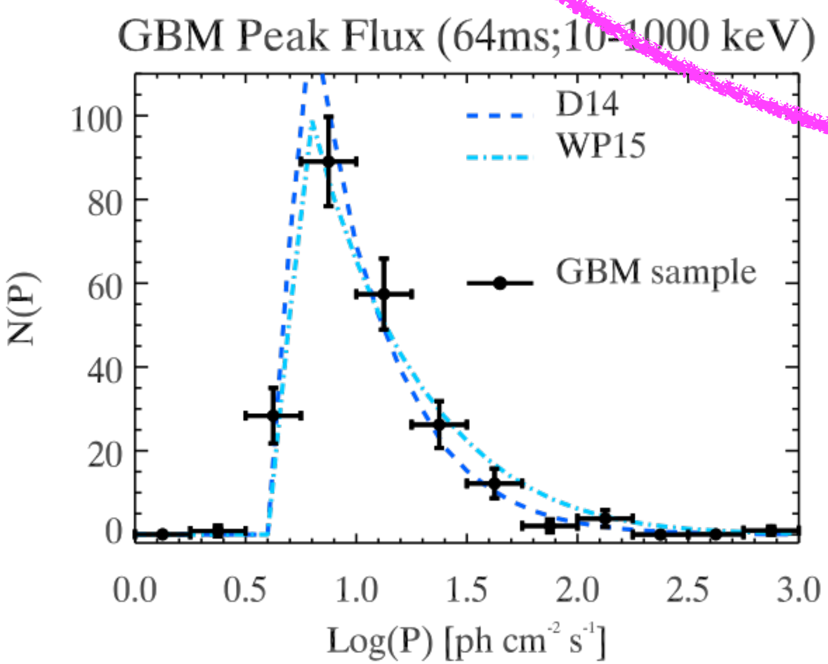
2.Cosmic ra ation $\Psi(z)$

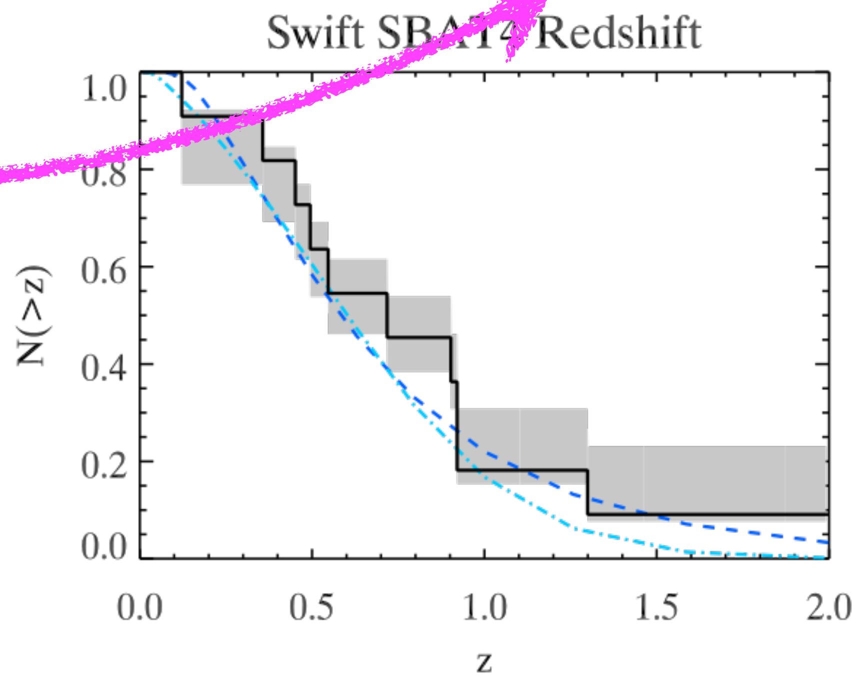
Free Parameter Space

Past and Present Instrumental parameters CGRO, Fermi, Swift)

Observational constraints: CGRO/Batse Fermi/GBM Swift/BAT …

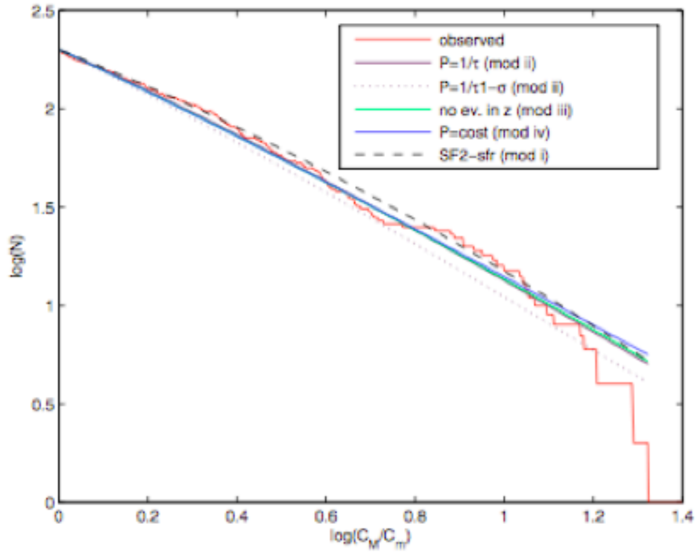
$$N(P_1 < P < P_2) \propto A \int_0^\infty dz \frac{dV(z)}{dz} \frac{\Psi(z)}{1+z} \int_{L(P_1|z,P_{min})}^{L(P_2|z)} \phi(L) dL$$

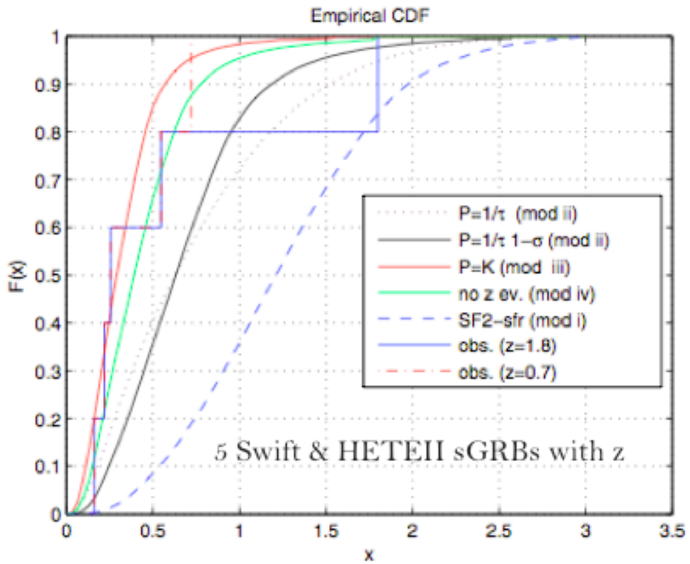




Adapted from
Ghirlanda et al 2016

Observational constraints: how many & which constraints





[Guetta & Piran 2006; .... Wanderman+2015; D'Avanzo+2014]

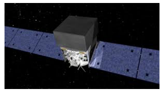
Steep LF for short GRBs (-2,-3 with 10^{50} erg/s break and large uncertainties)
Non unique delay time distribution (either power law with min 40 Myr or log-normal with 3 Gyr)

Break degeneracy?

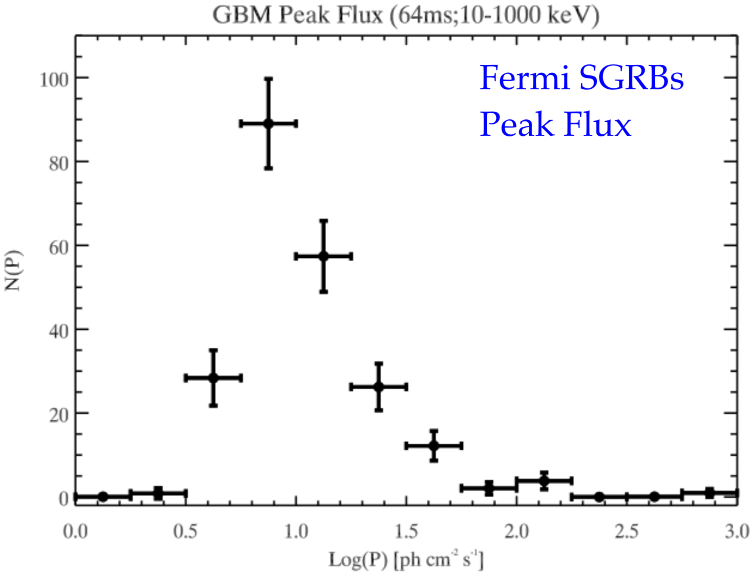
Additional constraints

Complete samples limit the effects of complexly-interlaced selection biases

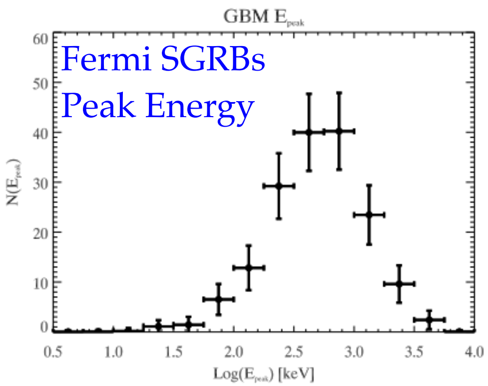
Short GRB population: constraints

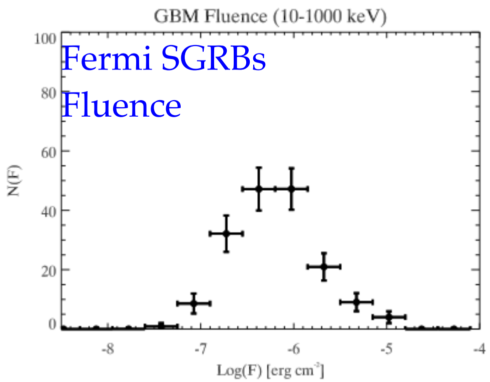
 +  = **7 Constraints**

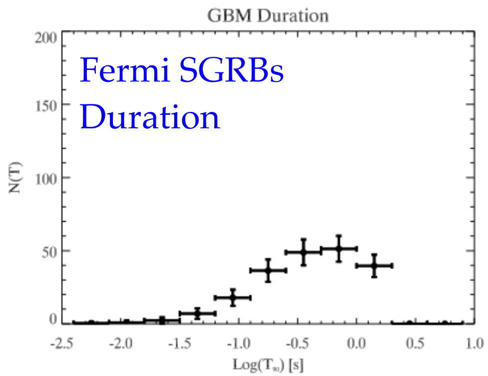
Short GRB population: Ghirlanda+2016



Fermi:
Large samples
Prompt emission
Observer frame properties







Complete samples

>1000 GRBs detected by Swift (since early 2005)

Definition of samples with favourable observing conditions for ground-based observations (then redshift measure)

> 60% of Swift GRBs are missing a redshift measure.

BAT6 sample

Salvaterra+12

- 58 **long** GRB (up to May 2011)
- peak flux > 2.6 photons/s/cm^2
- 97% with redshift (wrt 35% whole Swift sample)

SBAT4 sample

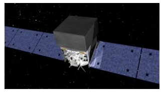
D'Avanzo+14

- 16 **short** GRB (up to June 2013)
- peak flux > 3.5 photons/s/cm^2
- 69% with redshift (wrt 25% whole Swift sample)

These samples are complete in flux (flux-limited) and have a high completeness in redshift

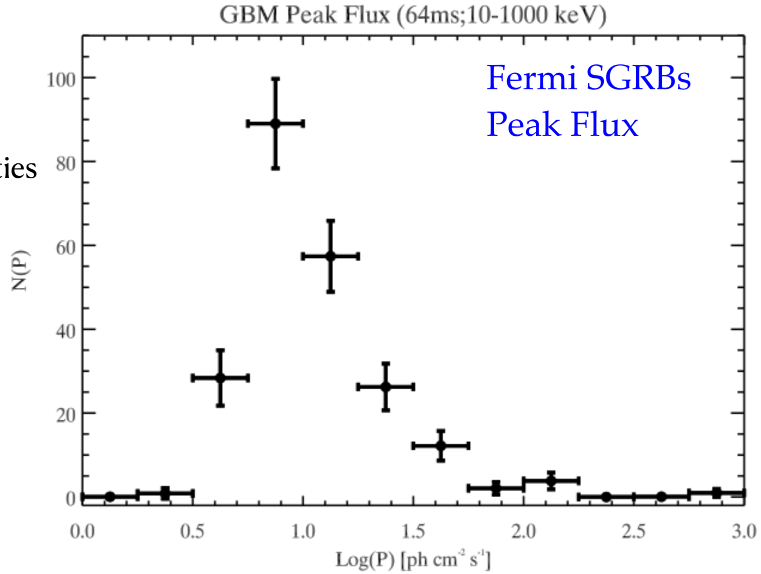
Provides L-z constraints

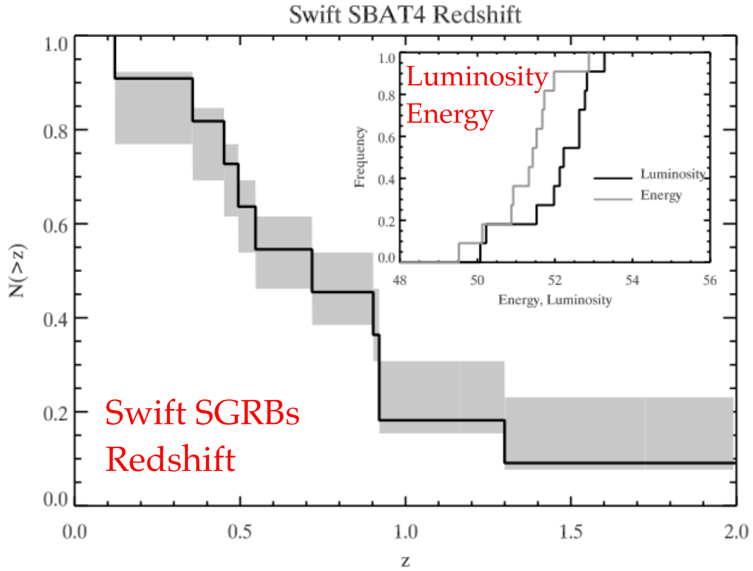
Short GRB population: constraints

 +  = **7 Constraints**

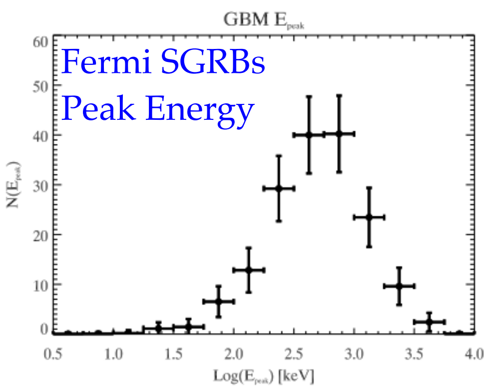
Short GRB population: Ghirlanda+2016

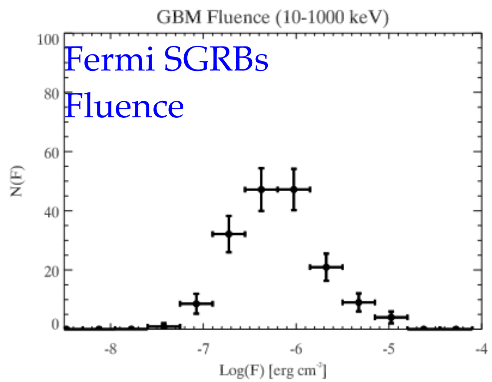
Fermi:
Large samples
Prompt emission
Observer frame properties

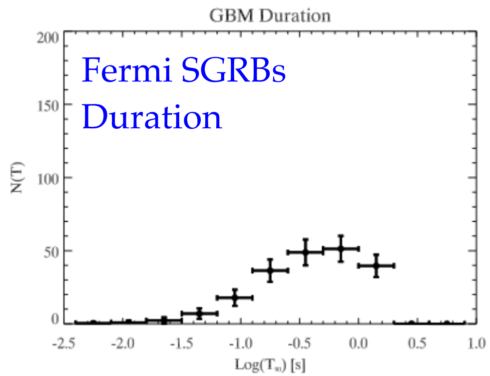




Swift+GB:
Small samples
Redshift
Rest frame prop.





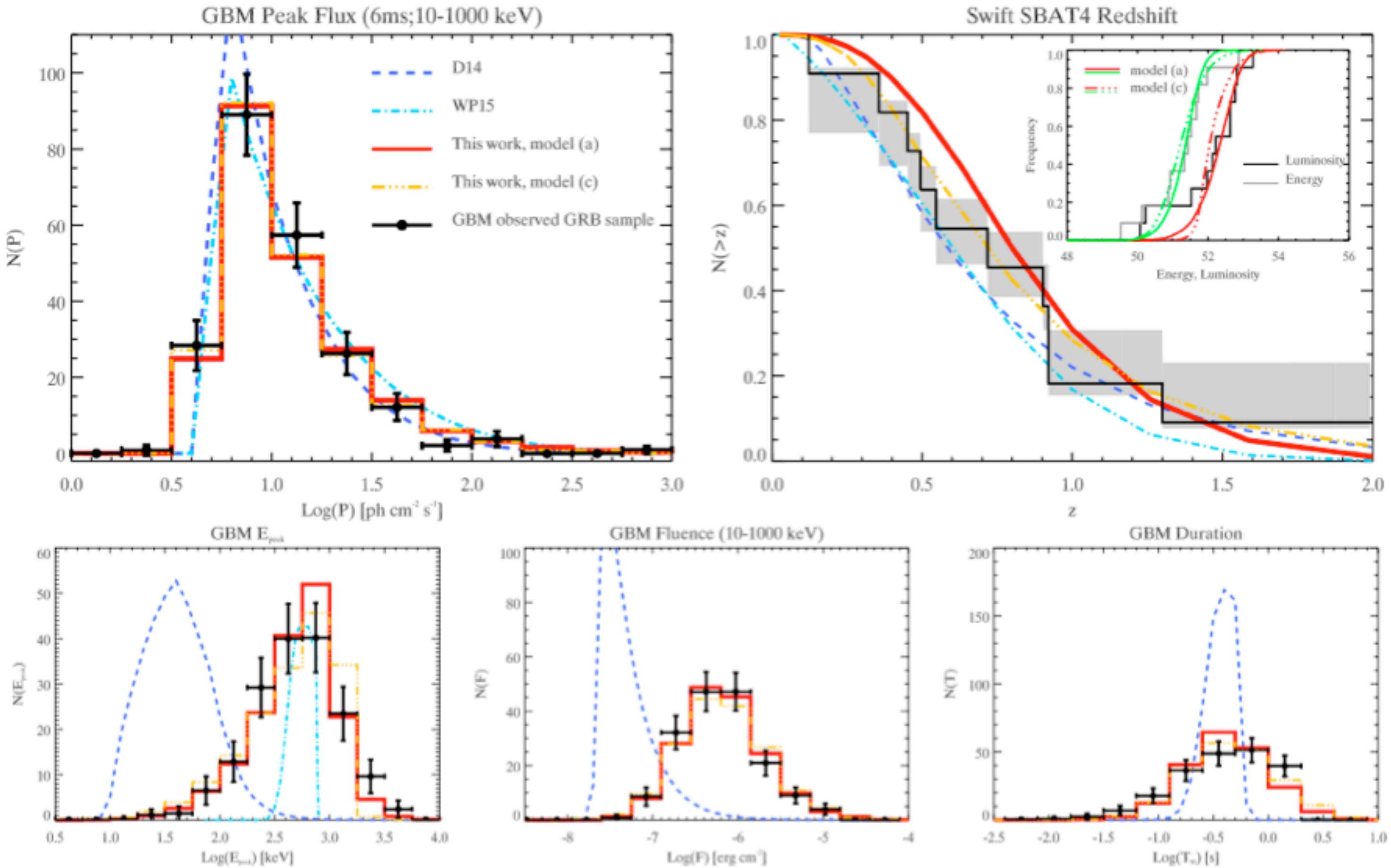


Short GRB population

(1) Delay independent constraints on z-dependent event rate

(2) Luminosity function

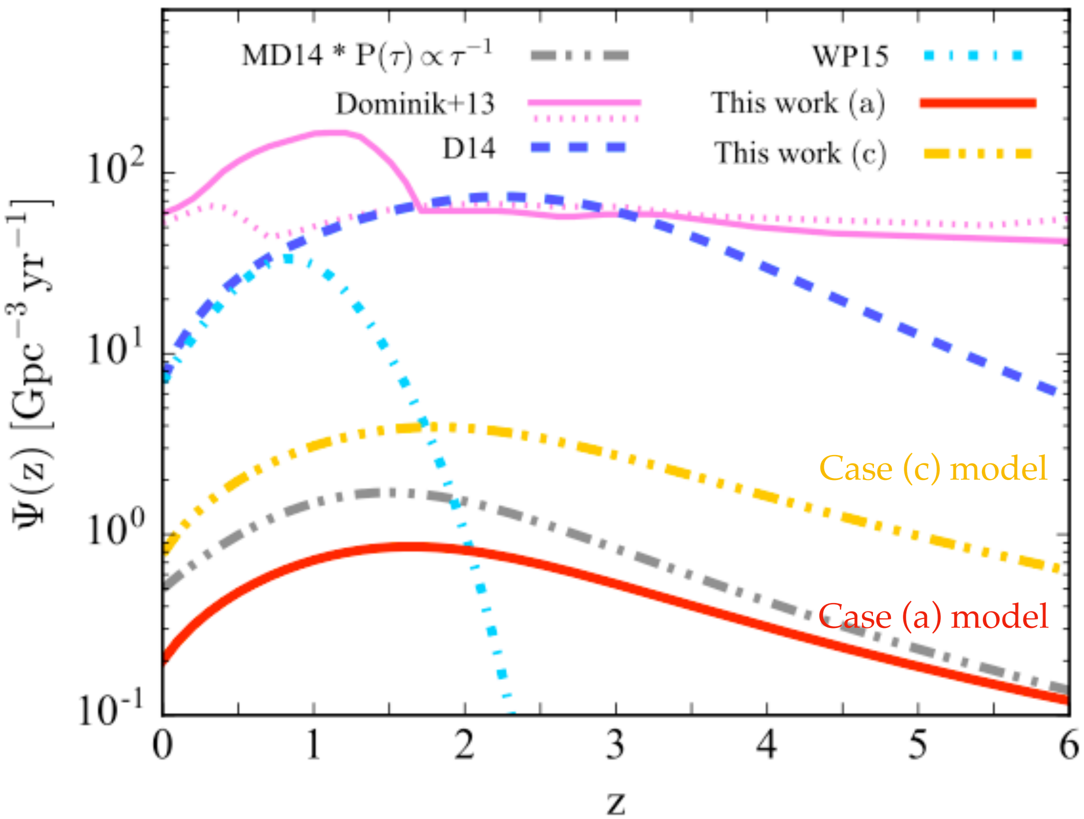
α_1	0.53	0.88	(0.39, 1.0)
α_2	3.4	2.2	(1.7, 3.7)
L_b	2.8	2.1	(0.91, 3.4)



Ghirlanda et al. 2016

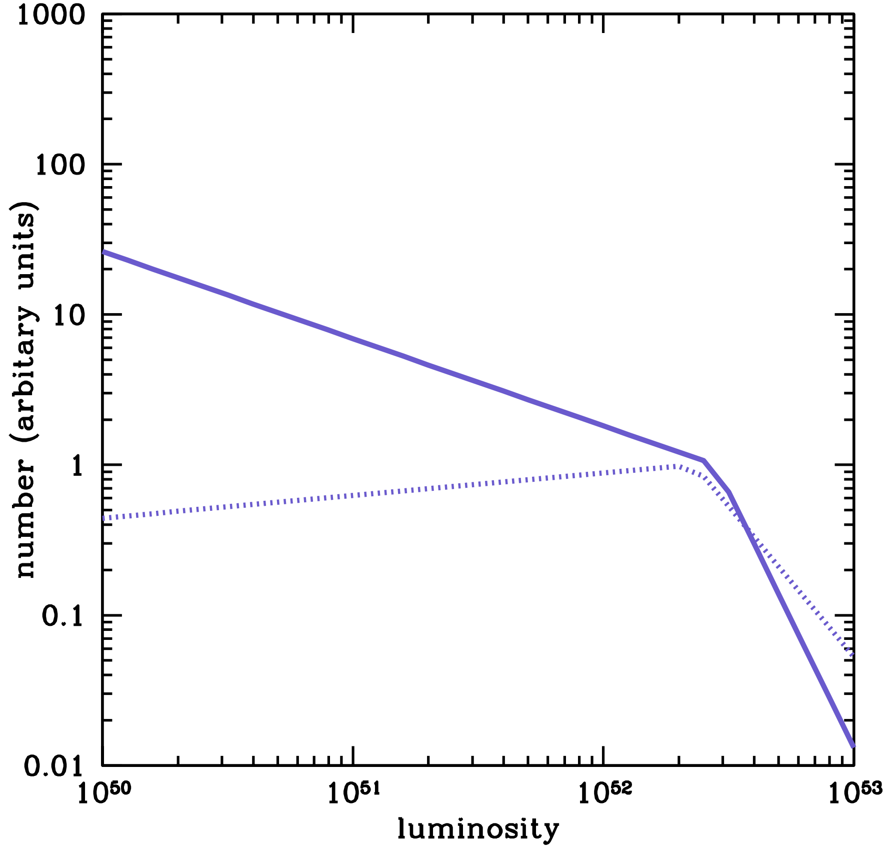
Short GRB population: results

$\Psi(z)$



Primordial NS-NS binary merger distributions provides a good description of the sGRB population

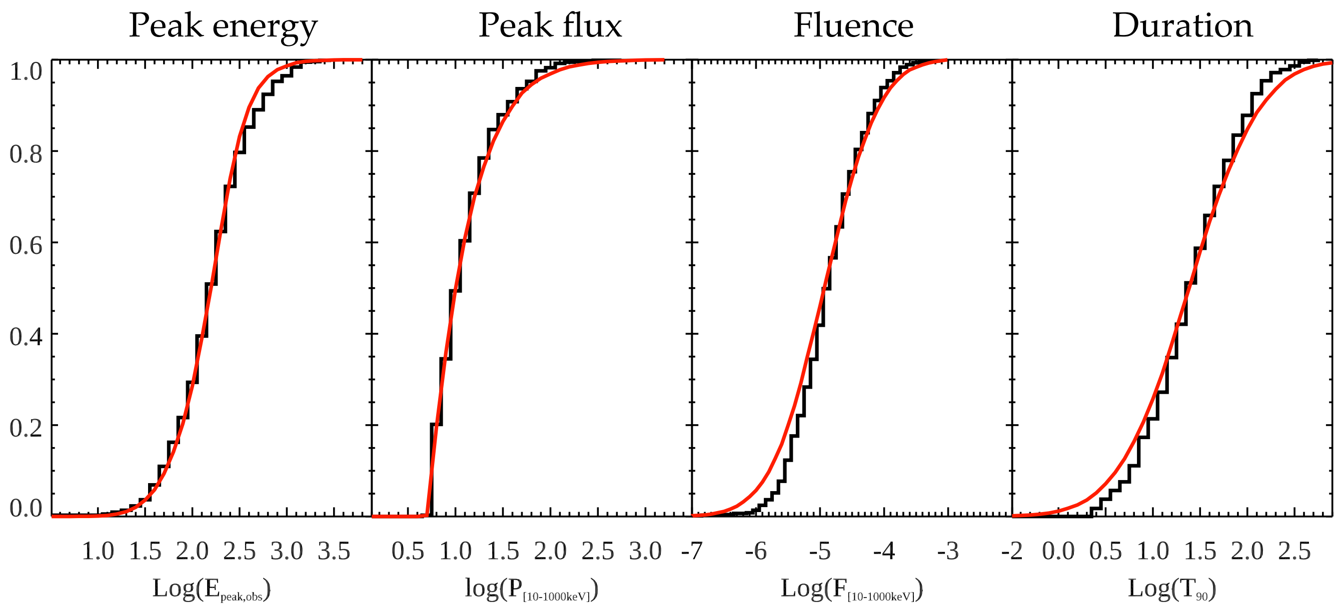
$\phi(L)$



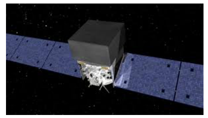
Relatively flat LF in the faint end

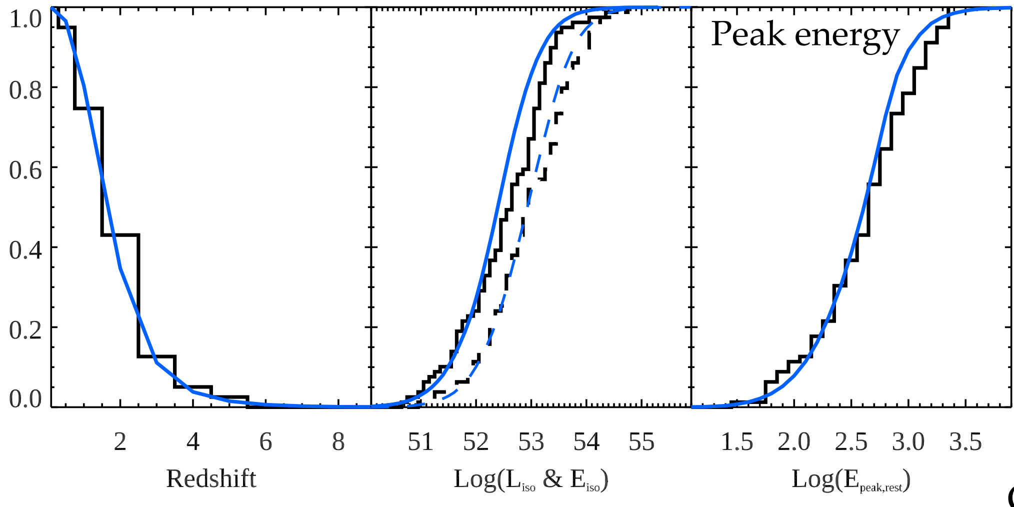
Ghirlanda et al. 2016

Long GRB population



Fermi / GBM
Constraints



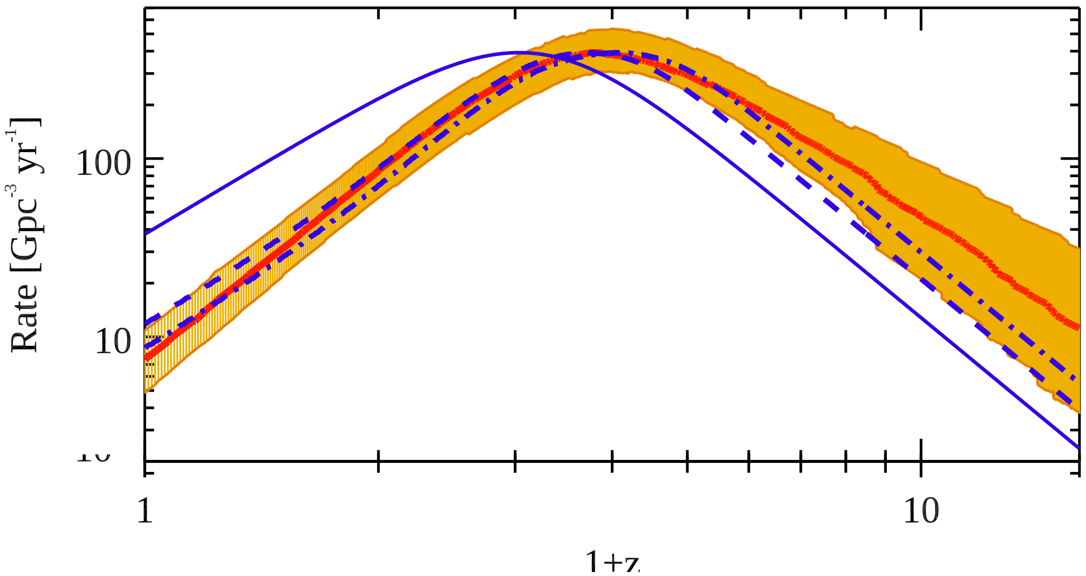


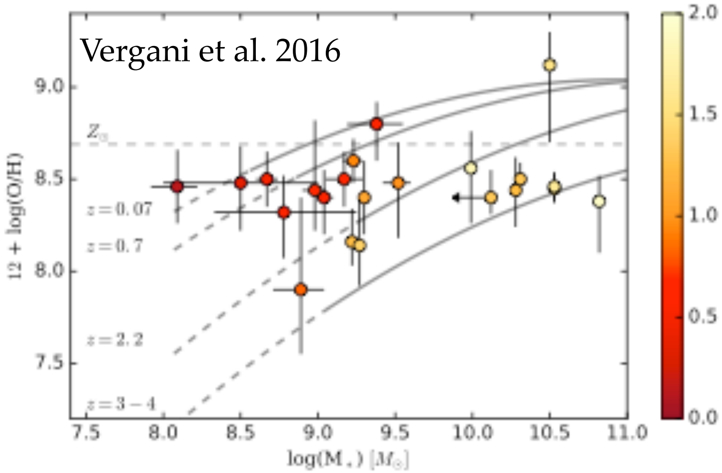
Swift constraints

GG et al., in preparation

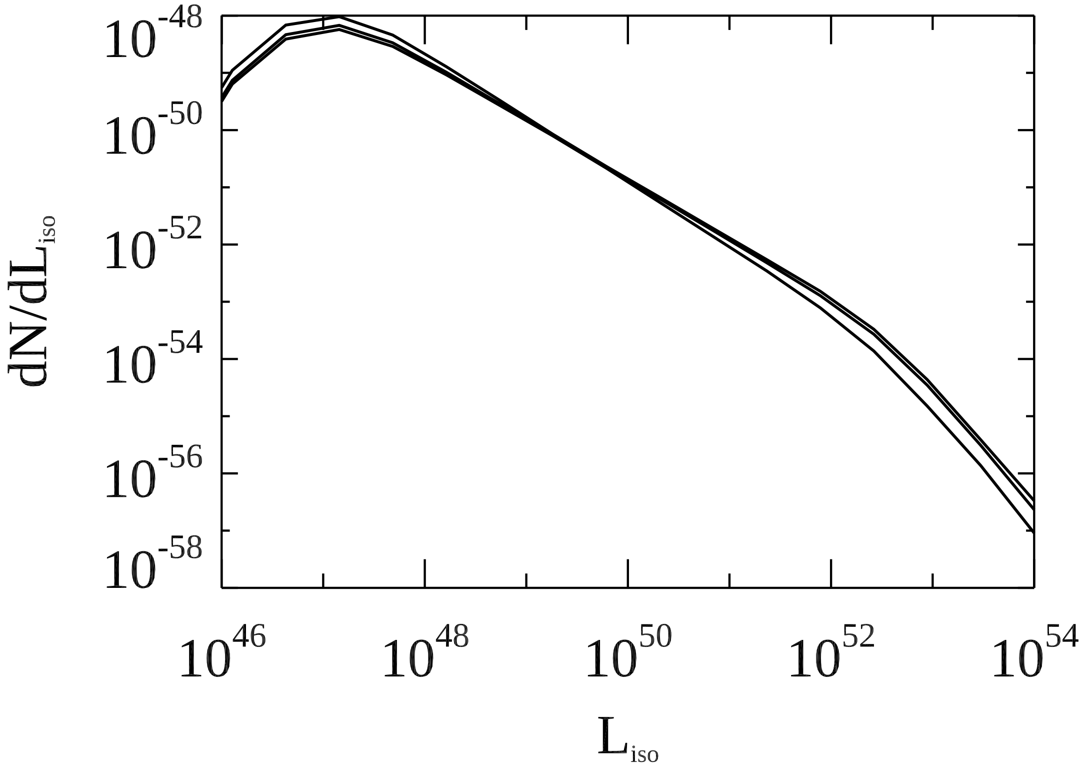
Long GRB population

$\Psi(z)$



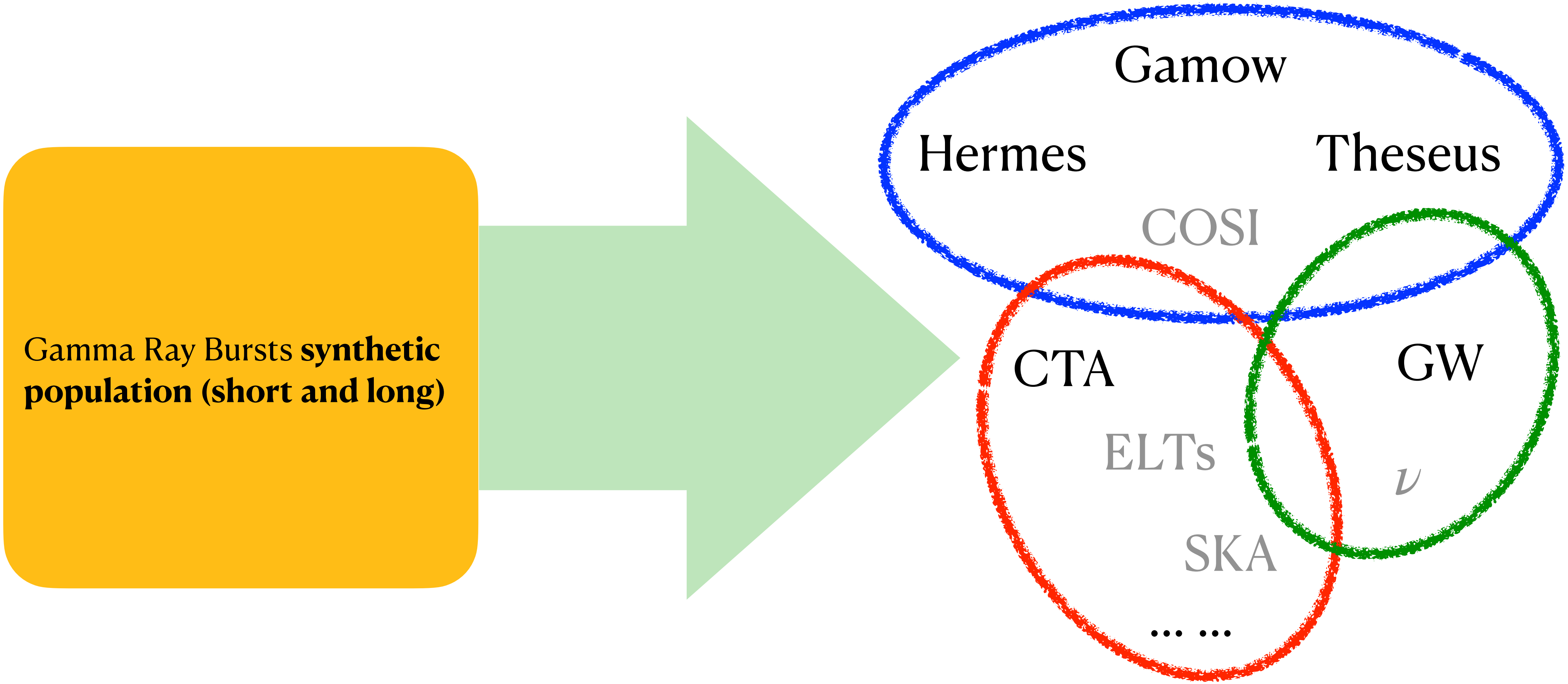


$\phi(L)$



GG et al., 2021 to be submitted

Exploring synergies



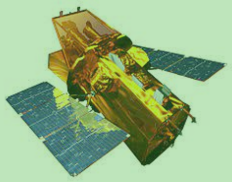
Advantage of using the same model population (short and long)

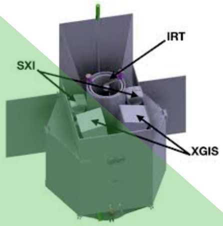
Objectives

Gamma Ray Bursts:

Observed **samples**:
1. CGRO/Batse
2. Fermi/GBM (LAT)
3. Swift/BAT … …

Or a GRB **synthetic population**





How many GRBs? (detection rates)

What type of GRBs?

- Mission science objectives
- Optimise mission profile
- Explore synergies with other facilities (space/ground)

Part 1: G. Ghirlanda

Part 2: L. Nava

PURPOSE OF THE STUDY

1. estimate the **detection rate** (number of GRBs per year)
   a. for long and short GRBs
   b. for pathfinder and constellation (one detector)
   c. by the Soft gamma-ray or/and the X-ray instrument
   d. for trigger on peak flux and on the fluence

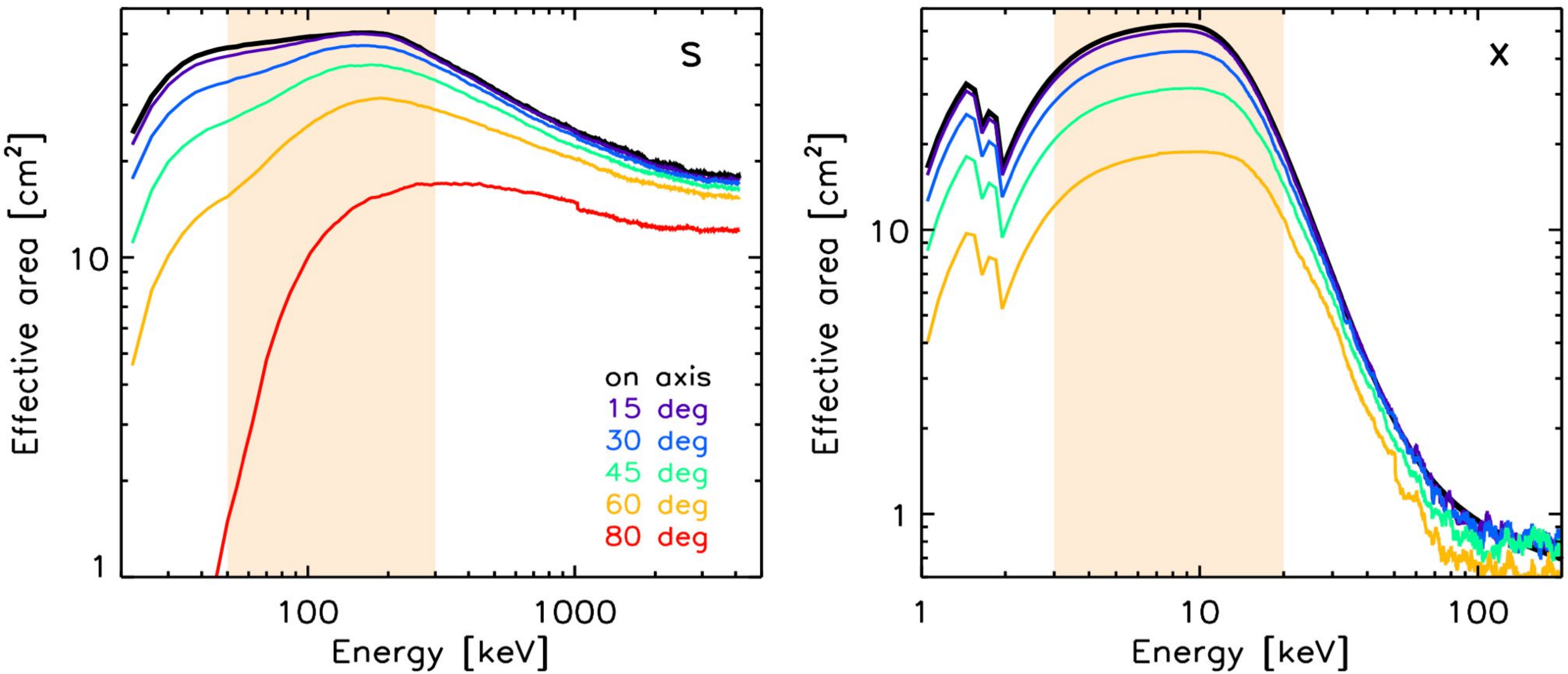
2. understand **which GRB population** will be observable by HERMES

PARAMETERS ADOPTED FOR THE TWO INSTRUMENTS

Instrument	FoV	energy range keV	back. rate counts/s	duty cycle
S	80°	50-300	72	0.5
X	60°	3-20	503	0.5

Parameters adopted for the two instruments. Background for low latitude, LEO orbits, version V5d1 (S detector), and V5 (X detector), produced by Riccardo Campana, February 2019

EFFECTIVE AREAS vs ENERGY

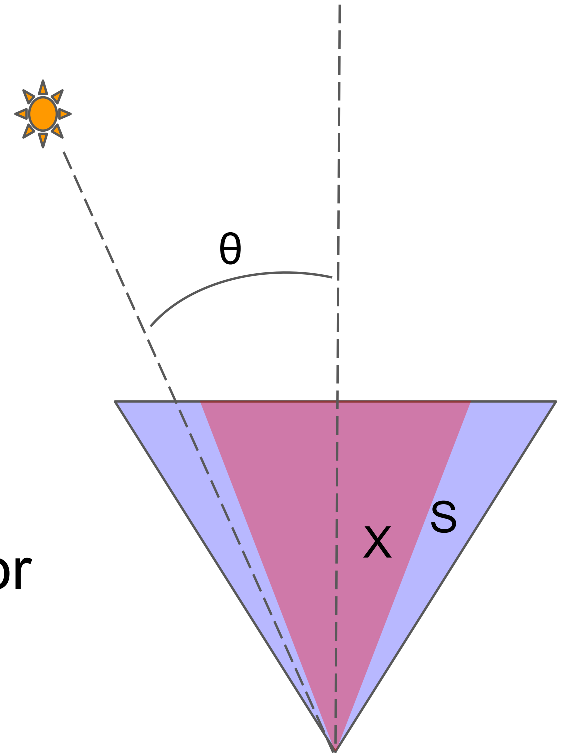


Effective areas for the S instrument (left-hand panel) and the X instrument (right-hand panel). Shaded vertical stripes show, for the two instruments, the energy range considered in this study to estimate the detection rates. Effective area files version V3d1, produced by Riccardo Campana February 2019.

METHOD

Effective area $A_{eff}(\theta)$

- sources have isotropic distribution
- GRB position gives the angle theta wrt the detector normal
- GRBs outside the nominal FoV: not detected.
- GRBs inside the FoV: $A_{eff}(\theta)$ from interpolation



METHOD

Source counts

- intrinsic spectrum [ph/cm^2/s] is multiplied by:
  - the burst duration - *trigger on fluence*
  - the timescale over which the peak flux has been estimated - *trigger on peak flux*. For long GRBs we assume 1s, for short 64 ms and 1s

- the total spectrum [ph/cm^2] is convolved with $A_{eff}(\theta)$ to obtain the total counts

METHOD

Background counts

- average count rate [cts/s] is multiplied by:
  - the burst duration - *trigger on fluence*
  - the timescale over which the peak flux has been estimated - *trigger on peak flux*. For long GRBs we assume 1s, for short 64 ms and 1s

Significance of the detection

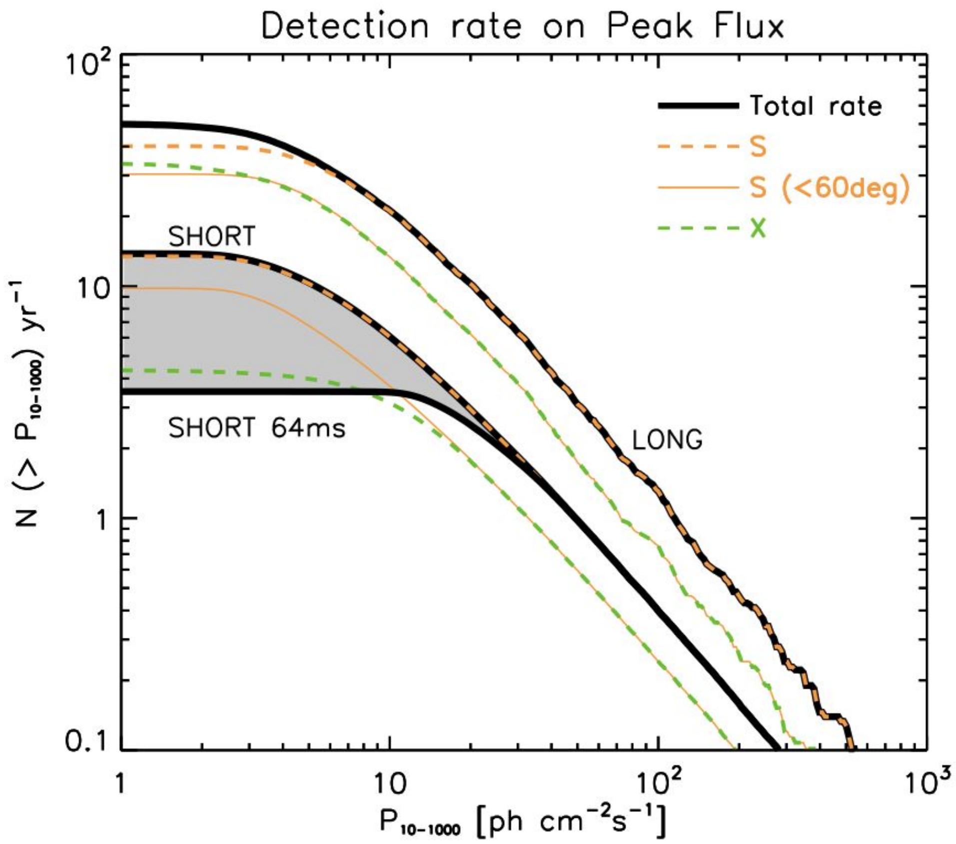
- source counts are compared with background counts
- GRB is detected if significance is at least 5σ

RESULTS

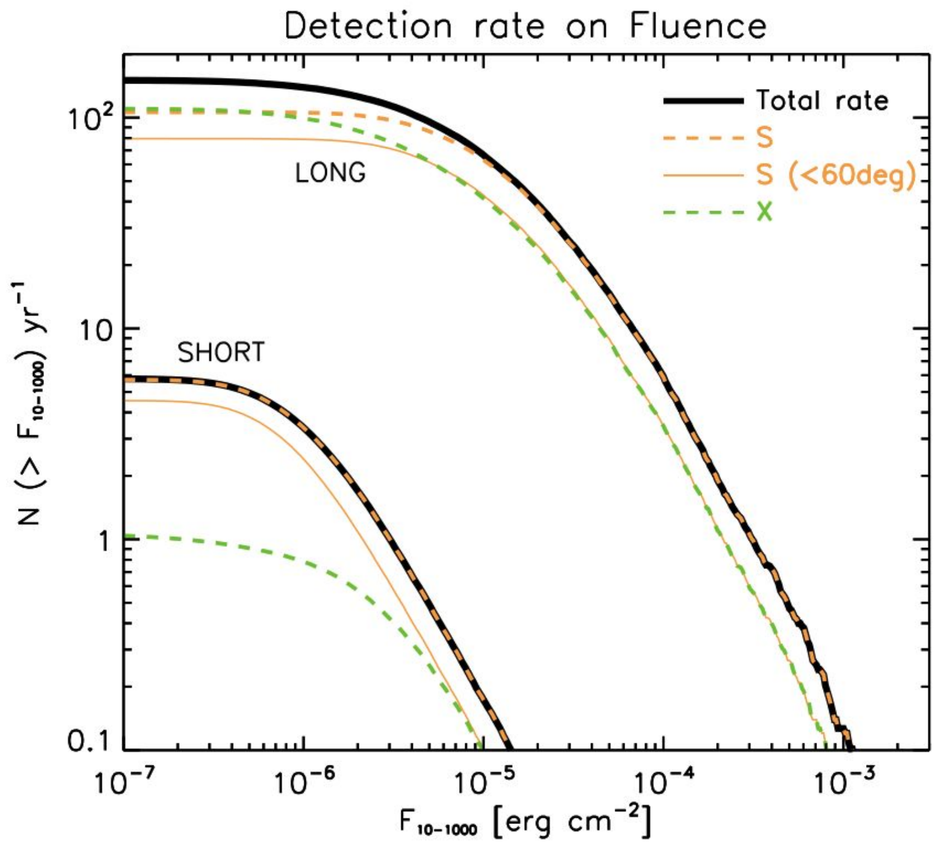
	Class	Total yr^{-1}	S yr^{-1}	X yr^{-1}	S-only yr^{-1}	X-only yr^{-1}	S and X yr^{-1}
LONG	Long (peak flux)	50 (40)	40 (30)	34	16 (6)	10	24
	Long (fluence)	150 (124)	106 (80)	110	40 (14)	45	65
SHORT	Short (peak flux 1s)	14 (10)	13 (10)	4	9 (6)	0.4	4
	Short (peak flux 64ms)	3.5 (2.7)	3.4 (2.7)	0.8	2.7 (2)	0.06	0.7
	Short (fluence)	5.8 (4.6)	4.7 (3.6)	1	4.7 (3.6)	0.1	1

Table 5.1: Detection rates for the short and long class of GRBs. The total rate is reported in column 2. Columns 3 to 7 refer to partial detection rates: 3) all events detected by S; 4) all event detected by X; 5) events detected only by S; 6) events detected only by X; 7) events detected by both detectors. The numbers in parenthesis in column 2 (3) refer to the number of events detected by S+X (by S) within an angle of 60°.

RESULTS



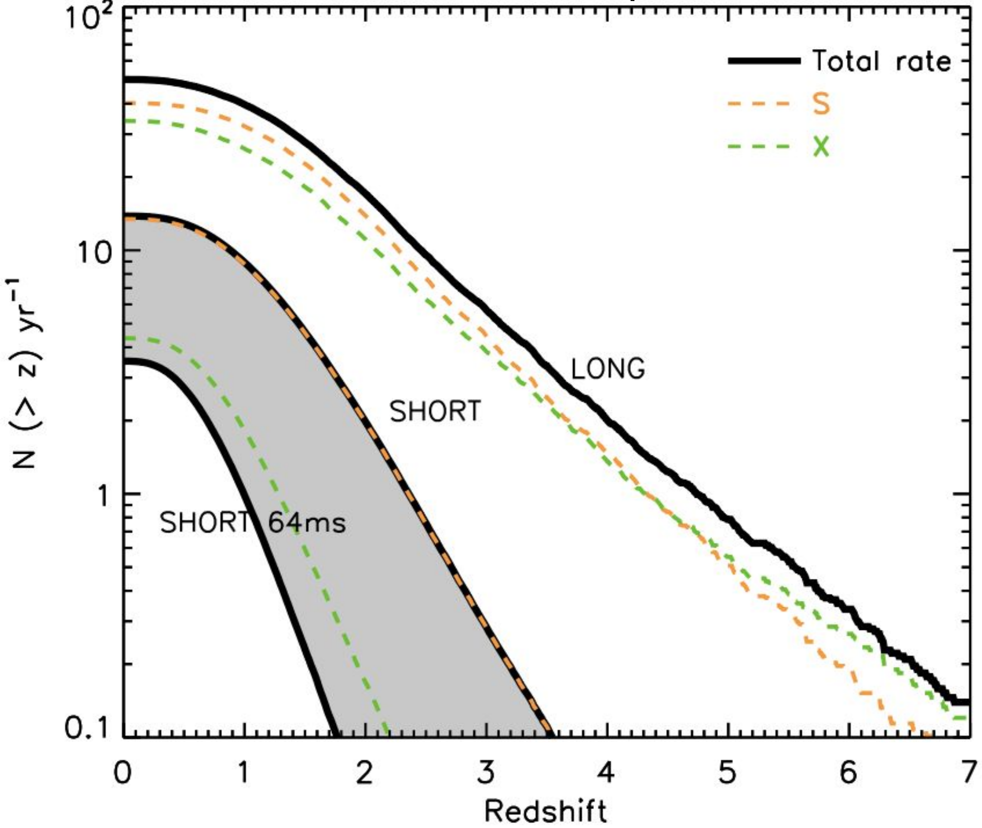
Detection rate on Peak Flux
Total rate
S
S (<60deg)
X
SHORT
SHORT 64ms
LONG
N (> P10-1000) yr^-1
P10-1000 [ph cm^-2s^-1]



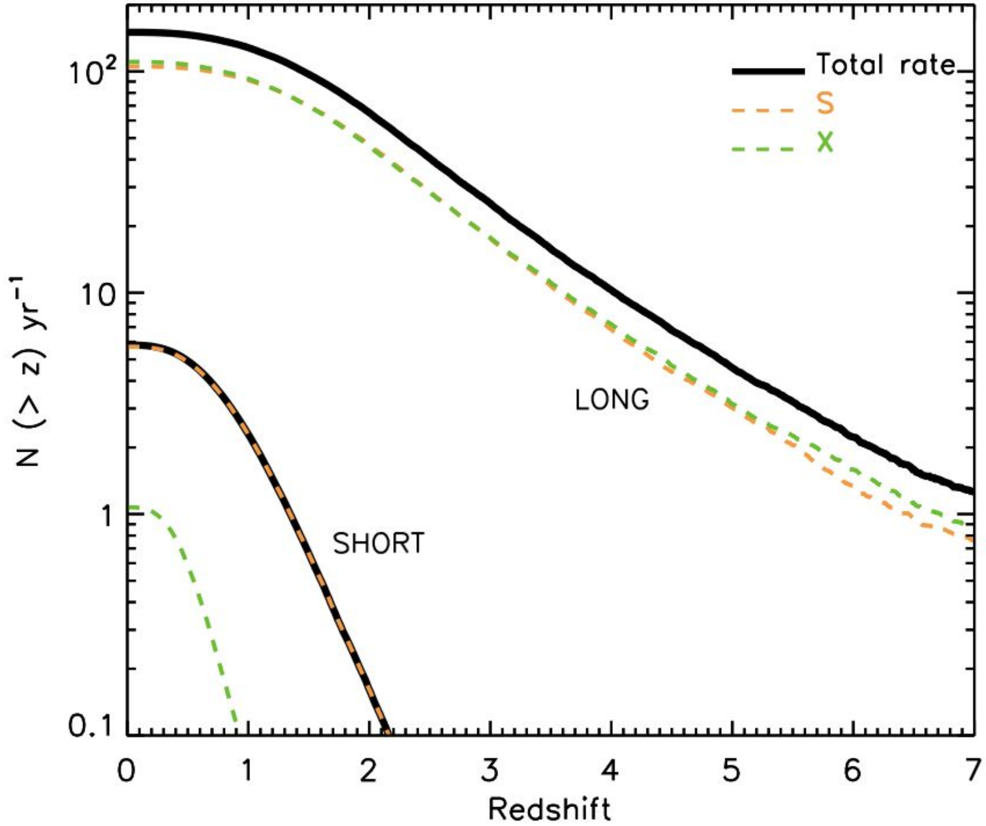
Detection rate on Fluence
Total rate
S
S (<60deg)
X
LONG
SHORT
N (> F10-1000) yr^-1
F10-1000 [erg cm^-2]

RESULTS

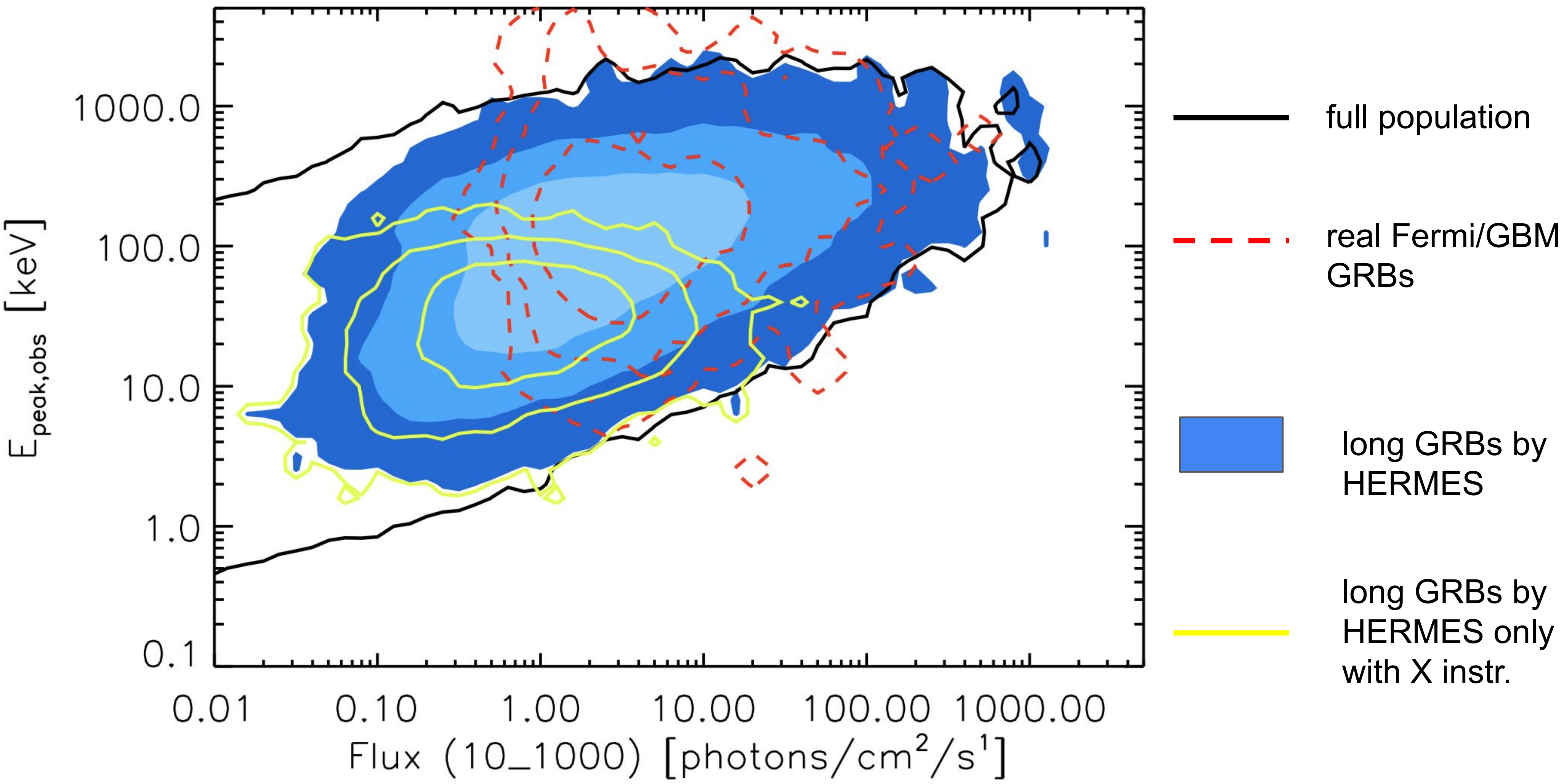
Detection rate on peak flux



Detection rate on fluence



RESULTS



1000.0
100.0
10.0
1.0
0.1
E_peak,obs [keV]
0.01
0.10
1.00
10.00
100.00
1000.00
Flux (10_1000) [photons/cm²/s¹]
full population
real Fermi/GBM GRBs
long GRBs by HERMES
long GRBs by HERMES only with X instr.

WORK in PROGRESS

Besides detection rates, we are performing / plan to perform studies on the following topics:

- detection rates of electromagnetic counterparts of GW events (from 3G to ET)
- GRB prompt emission spectral studies
- spectral breaks

- synergies studies I (Hermes ← → Ground based facilities)
- synergies studies II (Hermes ← → Skyhopper)