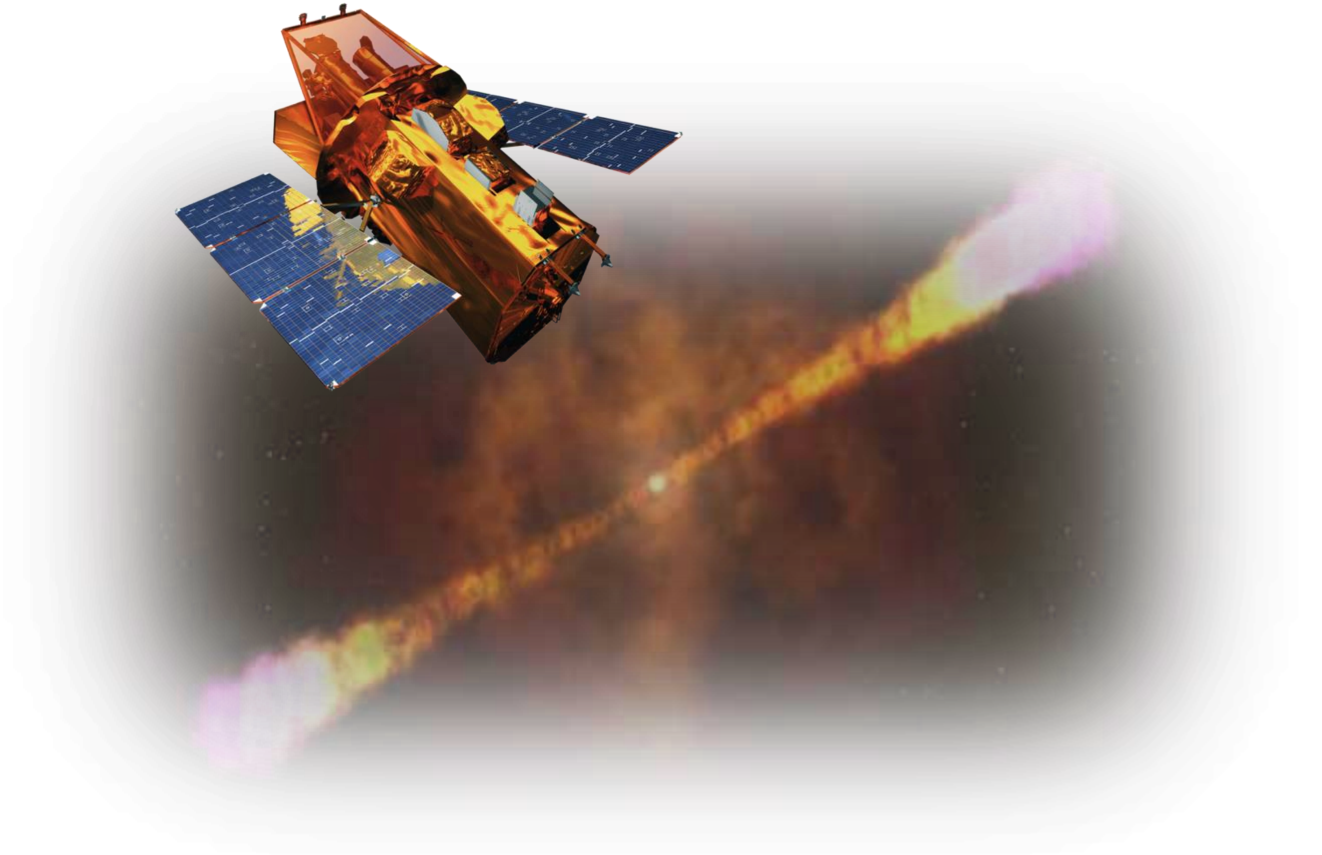
S-BAT4

A COMPLETE SAMPLE OF SGRBs

Environmental and host galaxy properties



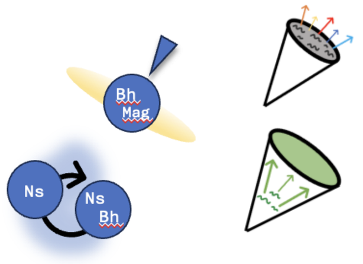
***Matteo Ferro*, INAF OAB-Merate**

In collaboration with the INAF-OAB *Swift* team

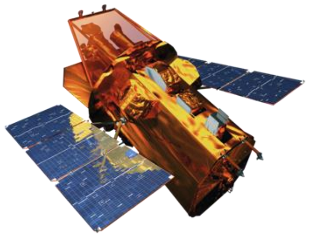
Celebrating 20 years of Swift Discoveries - 25/03/2025, Florence

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

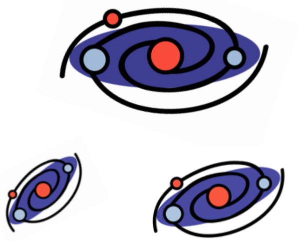
1 SGRB Intro



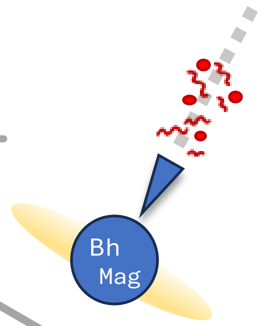
2 The sample



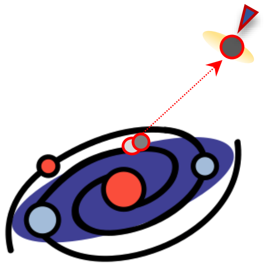
3 Host galaxies



4 NH



5 Offsets



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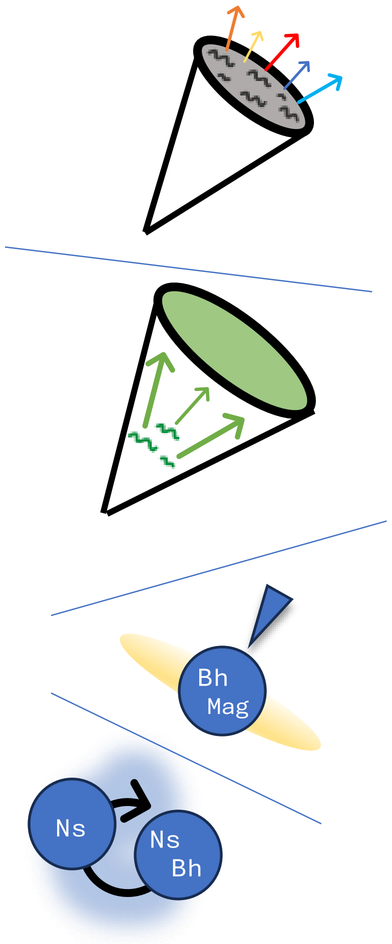
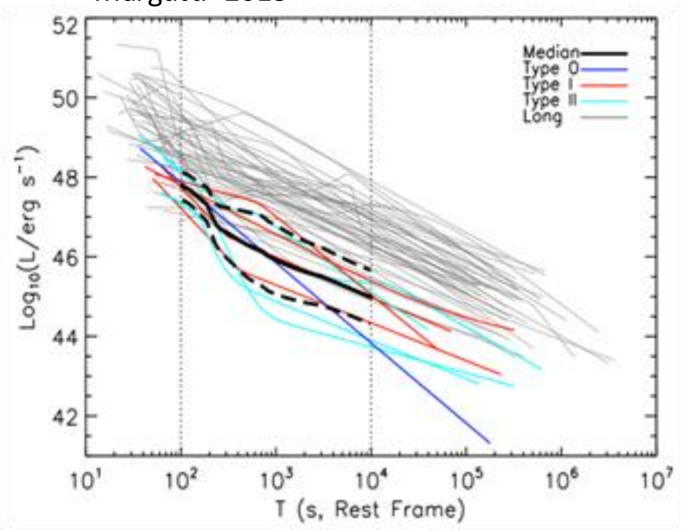


- Less energetic prompt emission than long GRBs
  ($E_{iso,S}$ ~10^{51} erg vs $E_{iso,L}$ ~10^{53} erg)

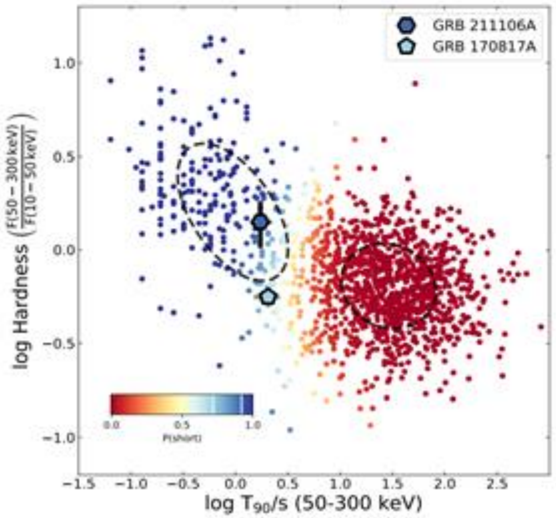
- Harder spectra with negligible spectral lag

- Fainter afterglow emission, from X-rays to Optical and NIR

Margutti+2013



Laskar+2022



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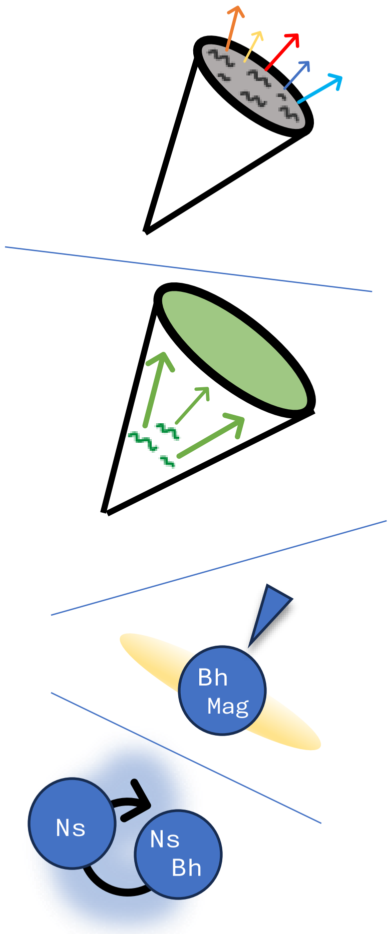

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  ($E_{iso,S}$ ~10^{51} erg vs $E_{iso,L}$ ~10^{53} erg)

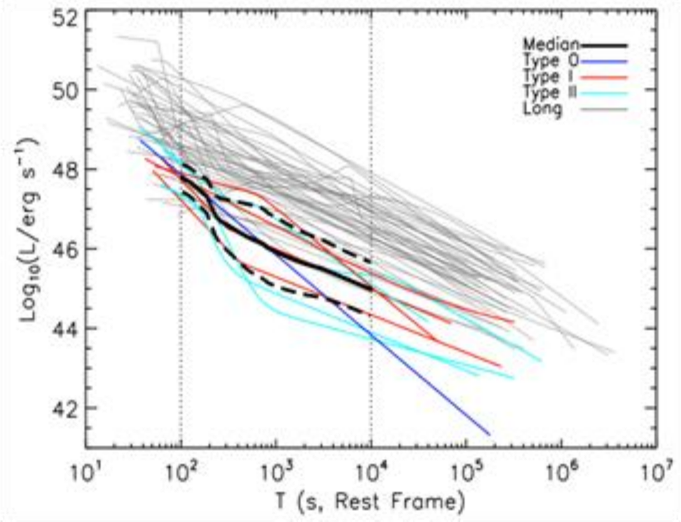
- Harder spectra with negligible spectral lag

- Fainter afterglow emission, from X-rays to Optical and NIR

→ difficult to determine redshift from the afterglow

→ important to select a sample of reliable bursts with redshift determined in order to frame the rest frame properties of sGRBs

Margutti+2013



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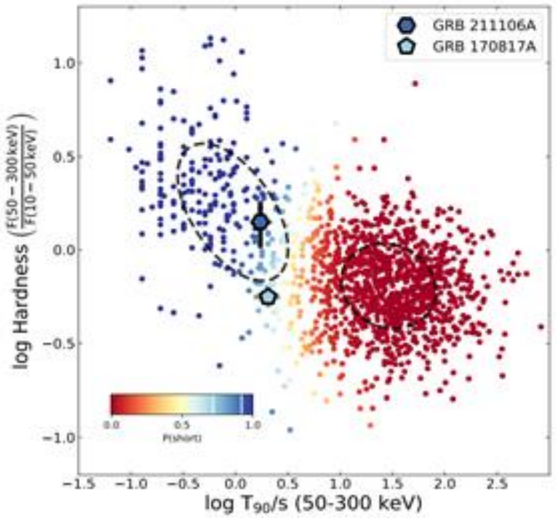

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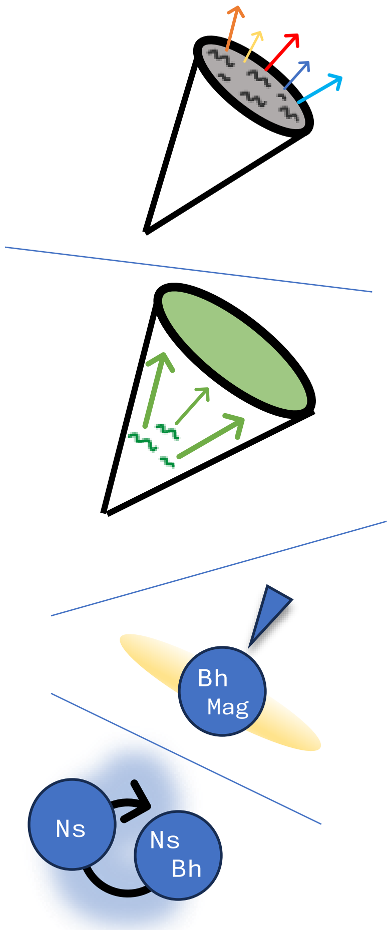


Since 2005, with the advent of the *Swift* satellite, the discovery of sGRB afterglows and the identification of their host galaxies made it possible to measure their distances and study their energy scales and environments.

To date, *Swift* detected ~**180** short GRBs (~10/yr), ~**10%** all *Swift* GRBs:

- ~**75%** with an **X-rays** afterglow detected

- ~15% with no X-rays afterglow detection despite prompt XRT slew

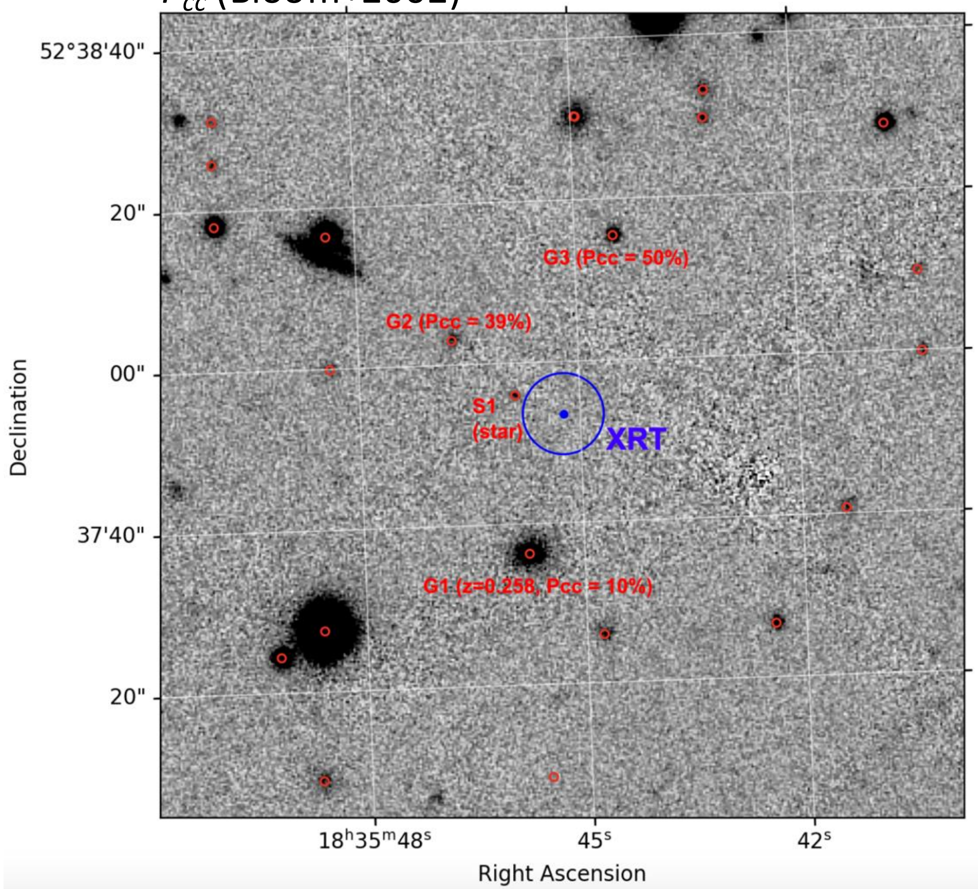
- ~**35%** with an **optical** afterglow detected

- ~**5%** with a **radio** afterglow detected

- ~50% with a redshift measurement (mainly from host galaxy spectroscopy importance of precise – arcsec – position for host galaxy association)

Based on probabilistic arguments:

P_{cc} (Bloom+2002)



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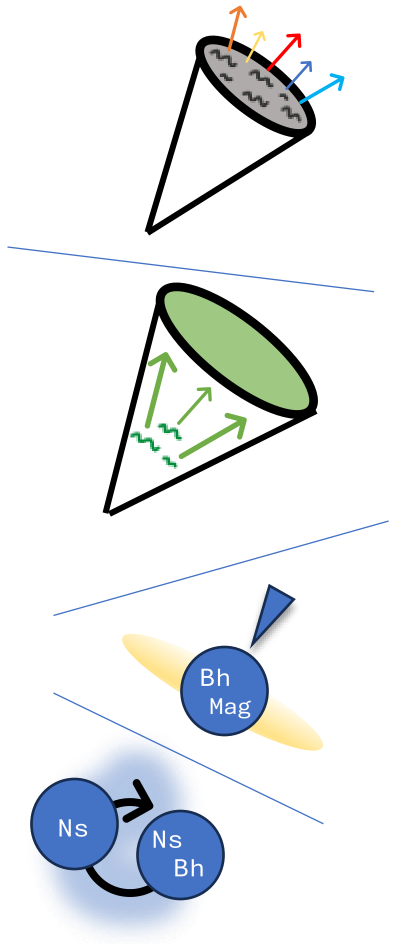

Precise identification and investigation of the candidate host galaxy to secure the association → we can analyze the rest frame properties of the burst, but also:

- ❑ Nature of the **central engine** for sGRBs (i.e. magnetar, prompt BH) & **evolutionary channels** of the compact objects system
- ❑ **Birth sites**, **environment**, **offsets** with respect to the underlying host galaxy
- ❑ Characterization of the **local environment** of compact object binary mergers
- ❑ Shedding light on **different classes** of compact object GRBs

The sample

- 51 sGRBs selected from Nov 2004 to Dec 2022
- 31 spectroscopic redshift (61 %)
- 9 photometric redshift: 40 in total (78 %)

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Host galaxy properties retrieved from **BRIGHT** catalogue (Fong+2022; Nugent+2022)

XRT afterglow spectra retrieved from the **XRT Repository** (Evans+2009)

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- 51 sGRBs selected from Nov 2004 to Dec 2022
- 31 spectroscopic redshift (61 %)
- 9 photometric redshift: 40 in total (78 %)

- 35 Host galaxy SEDs (68 %)
- 39 XRT Spectra analyzed (76 %) + 13 A_V retrieved from optical afterglows
- 38 normalized offsets (74 %)

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Optical/NIR imaging data + photometry + spectra

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The sample

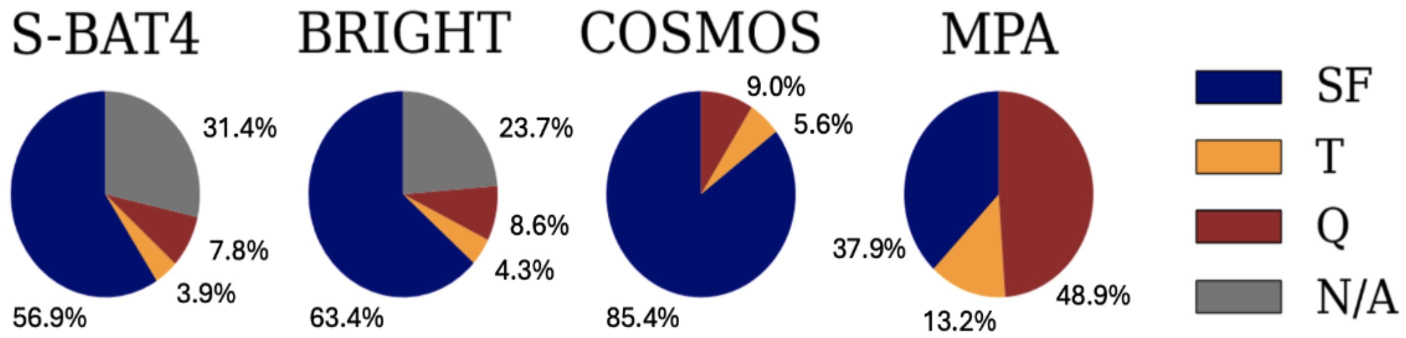
Three comparative samples to frame SGRB host galaxy properties:

(1) **BAT6:**
long GRBs host galaxies (Vergani+2015; Japelj+2016; Palmerio+2019), all star forming galaxies + N_H (Arcodia+2016)

(2) **COSMOS 2020:**
catalog for overall properties (Weaver+2022)

(3) **MPA/JHU:**
SDSS catalog (z<0.3), for mass, SFR and gas-phase metallicities (Kauffmann+2003; Brinchmann+2004; Tremonti+2004)

Star formation classification (Tacchella+2022 & Nugent+2022)



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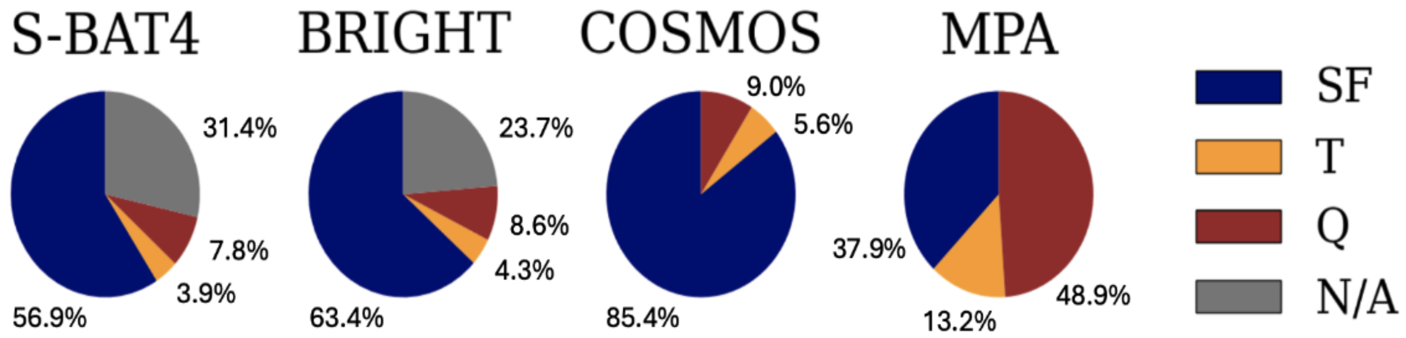
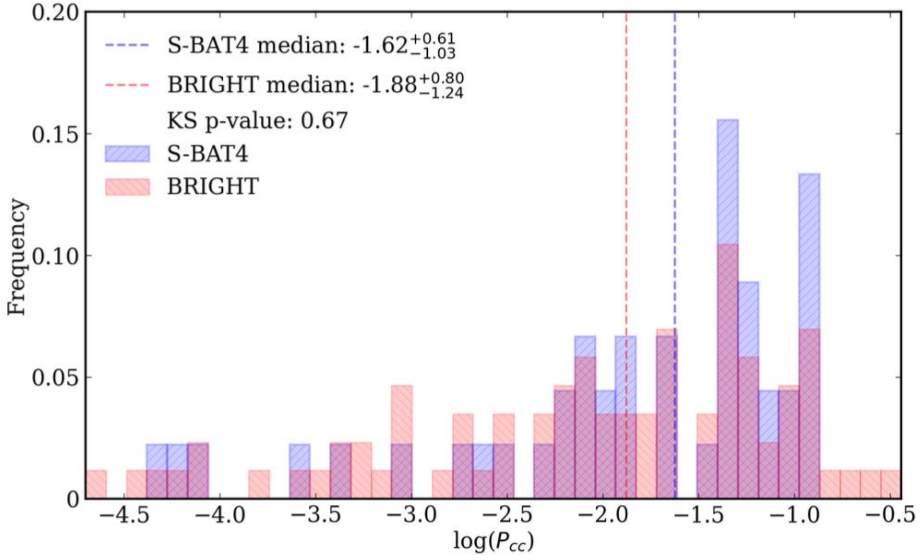
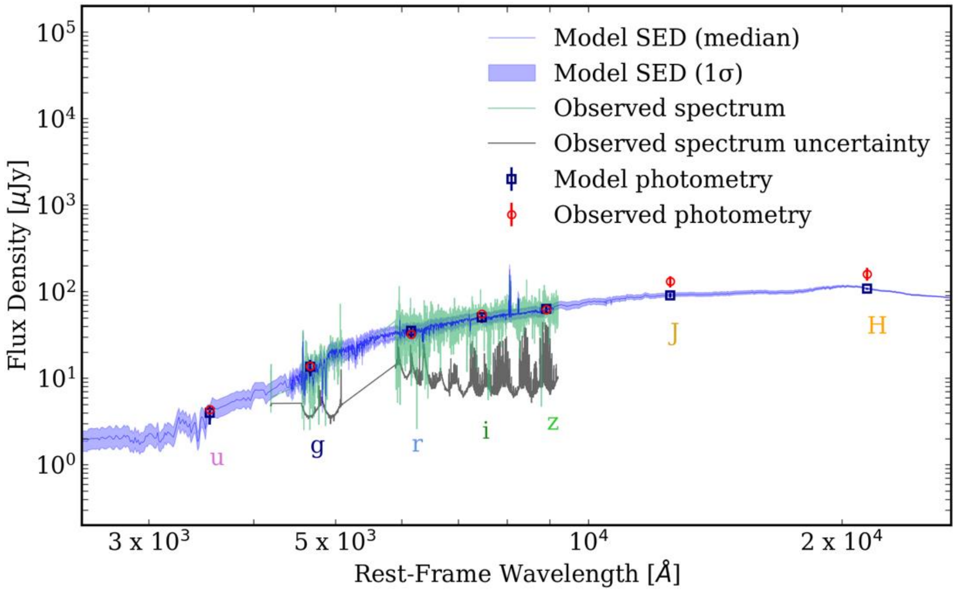


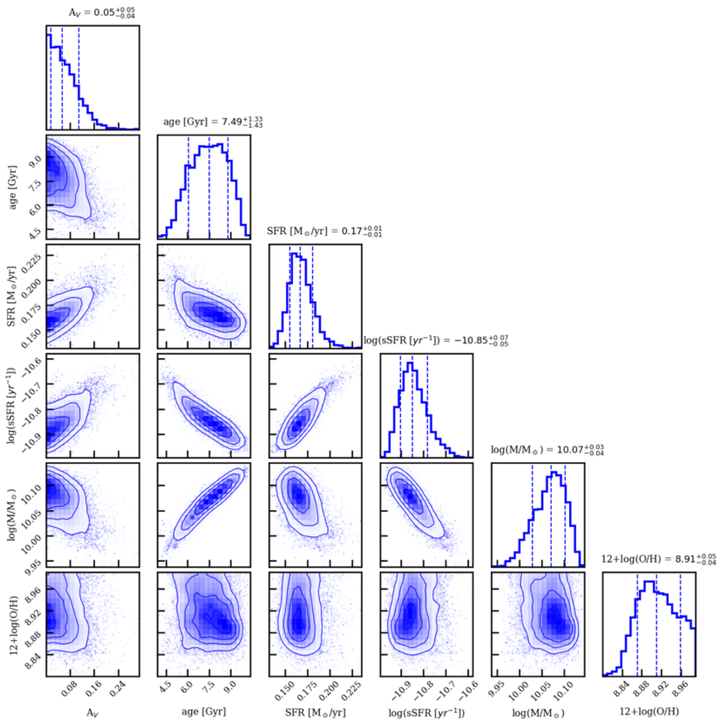
P_{cc} S-BAT4 < 12%



Host galaxies

SED fit of photometry + spectrum (when available) with **`Prospector`** (Johnson+2021), following Nugent+22

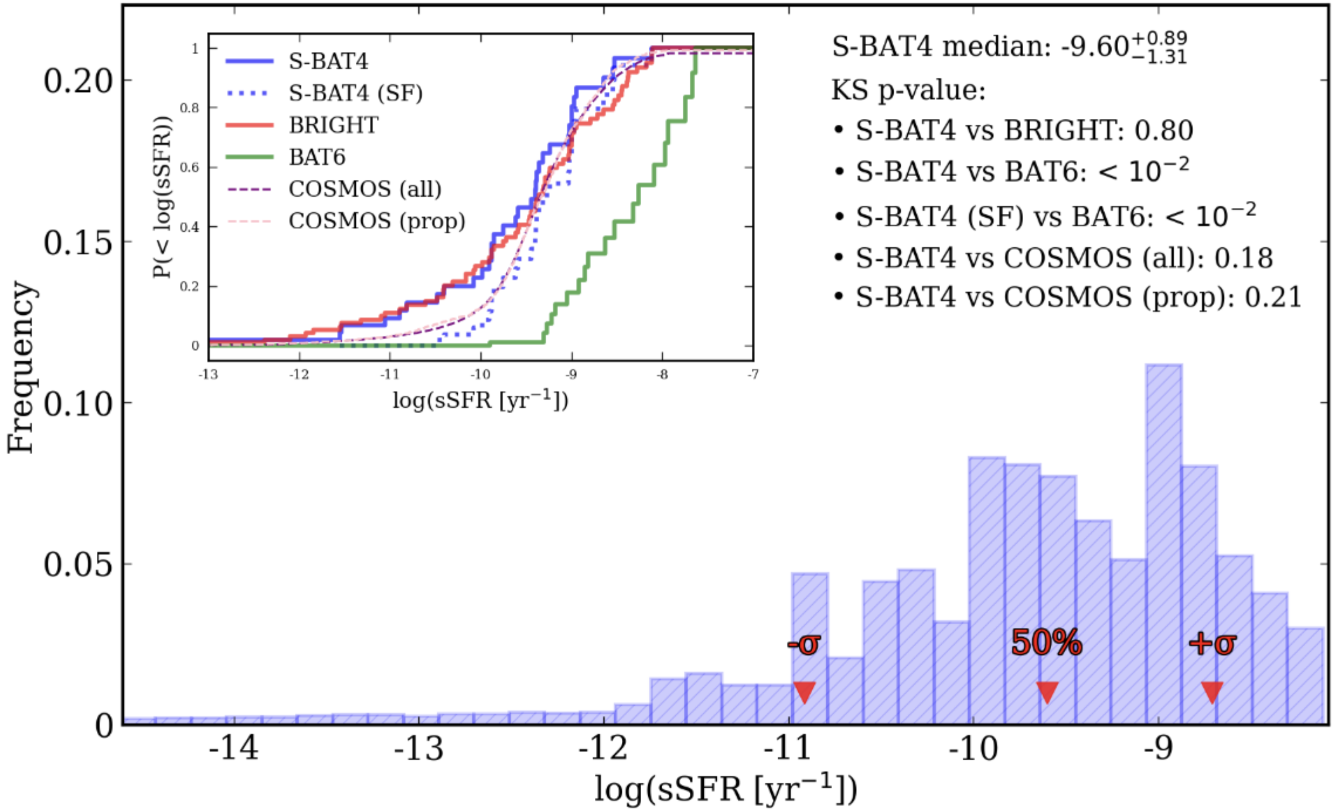




A total of **35** host galaxies with:
Mass, ***SFR***, ***sSFR***,
AV, *age*, and ***redshift***
*(+ **gas phase metallicity**)*

Host galaxies

Joint distribution for every parameter of interest



- sGRB host galaxies are fully consistent COSMOS field galaxies for all properties
- Consistent with MPA sample for the gas-phase met. at z < 0.3

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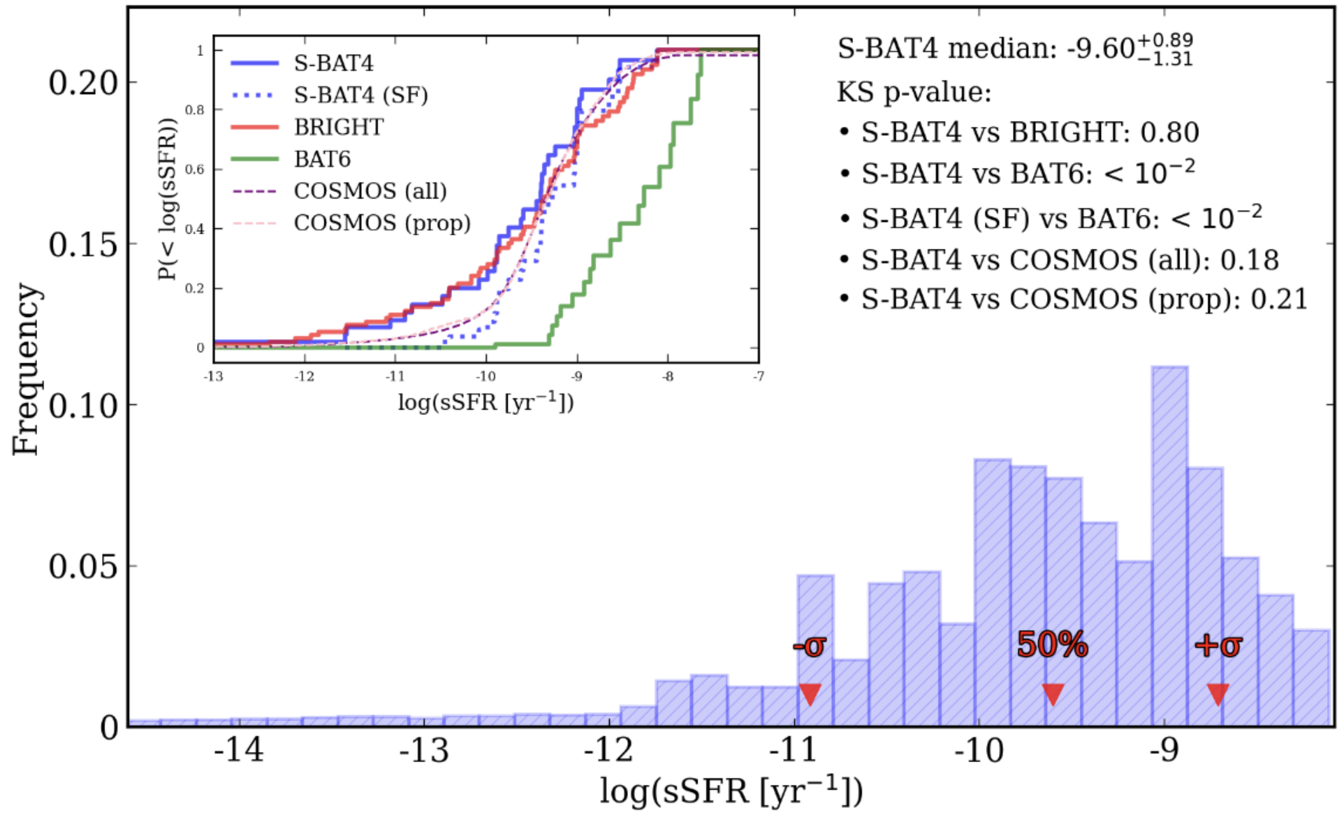
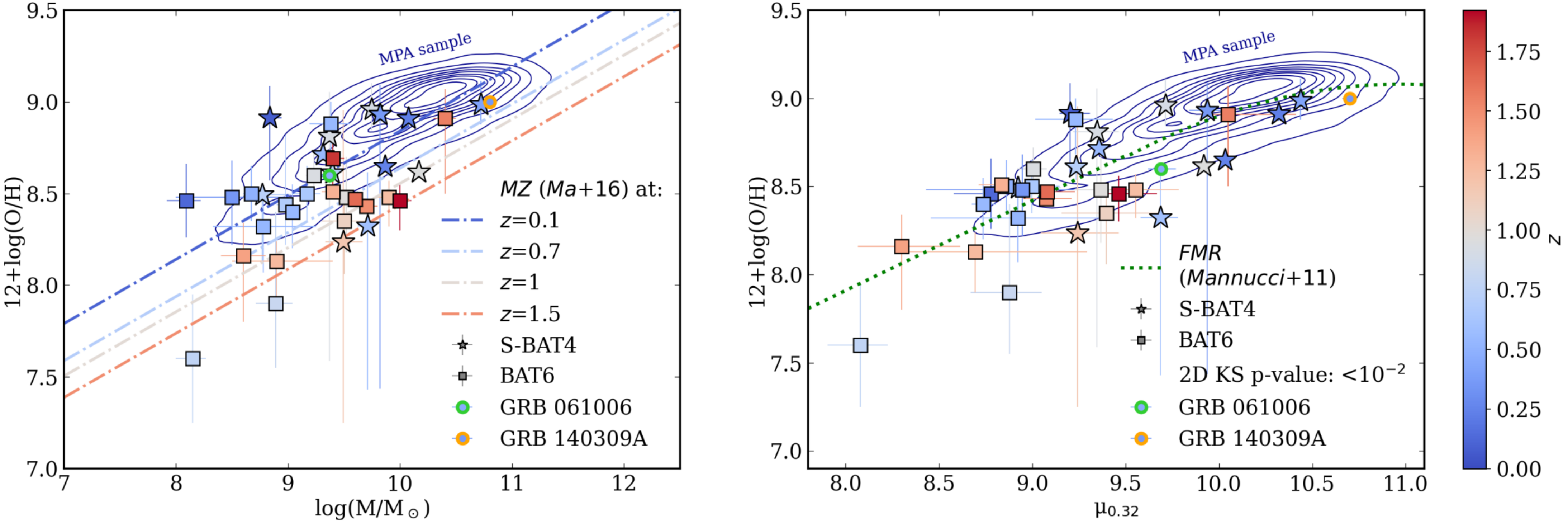


- sGRB host galaxies are fully consistent COSMOS field galaxies for all properties
- Consistent with MPA sample for the gas-phase met. at $z < 0.3$
- BAT6 hosts are younger, less massive, and with substantially higher sSFR (p-value < 1%)

Host galaxies

FMR and **MZ** relations: S-BAT4 sample has scatter comparable to BAT6, overall consistent with relations



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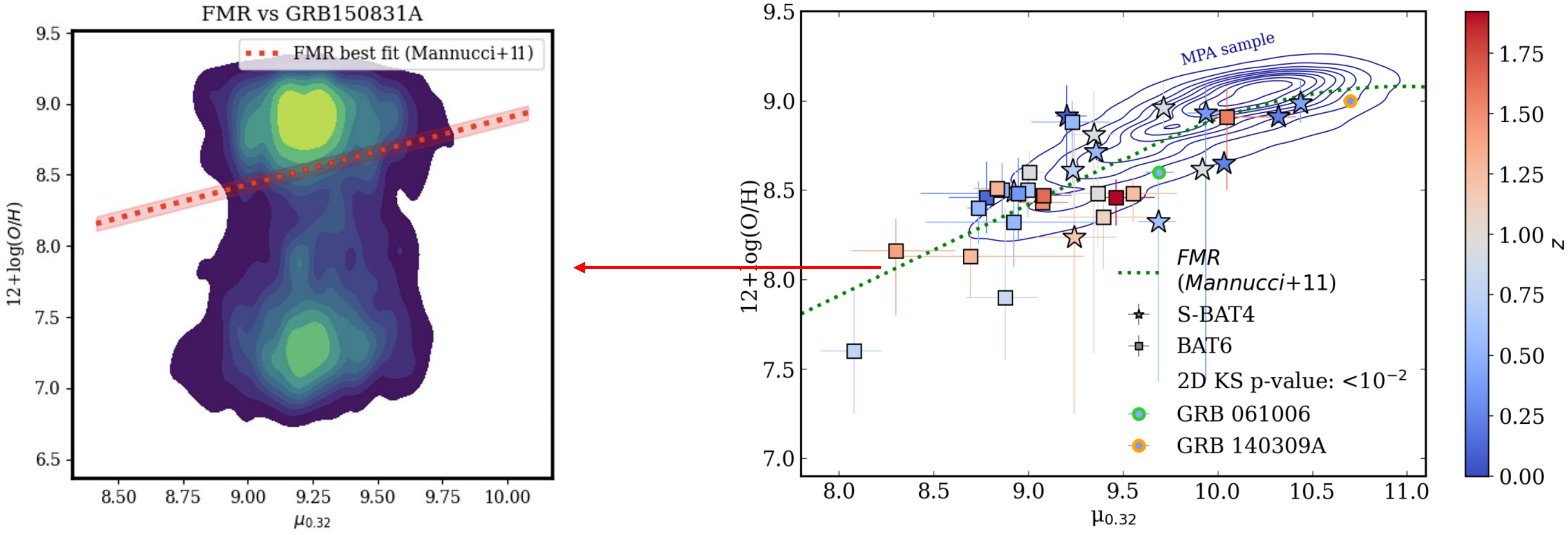

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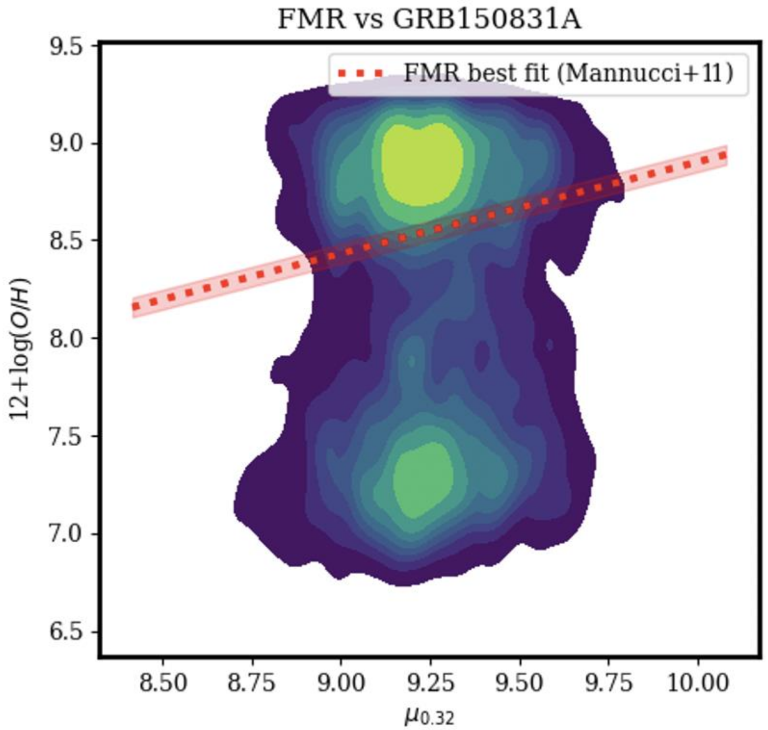
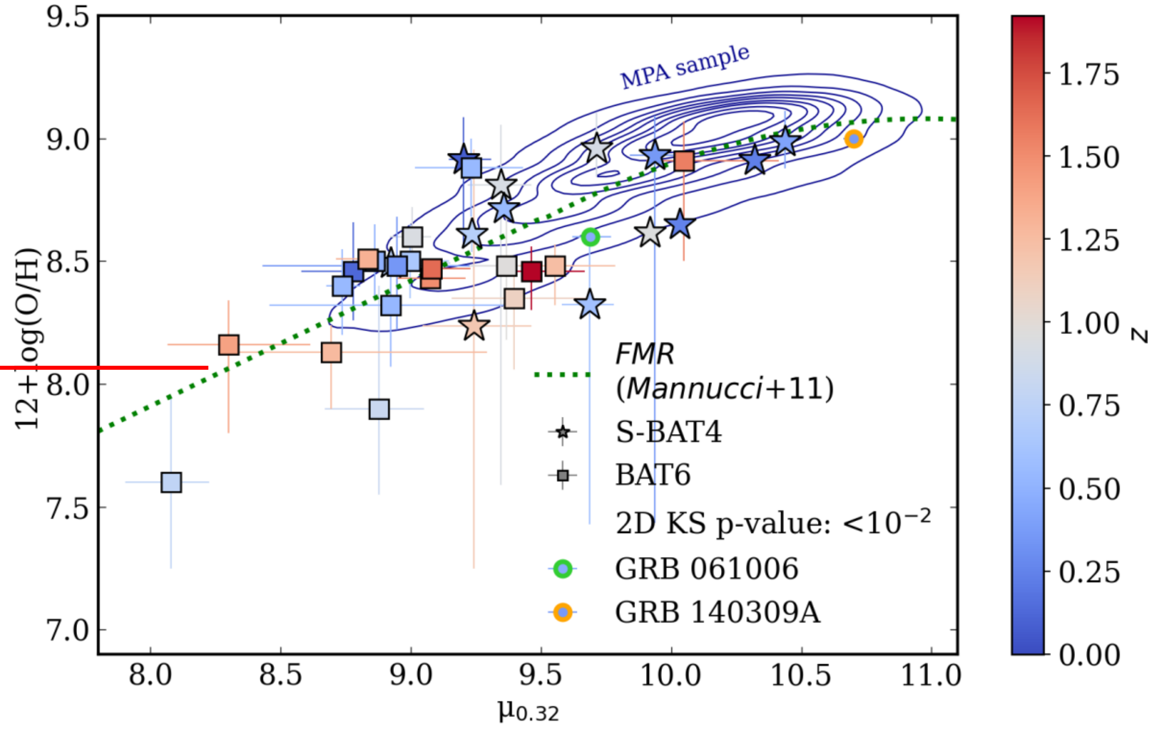
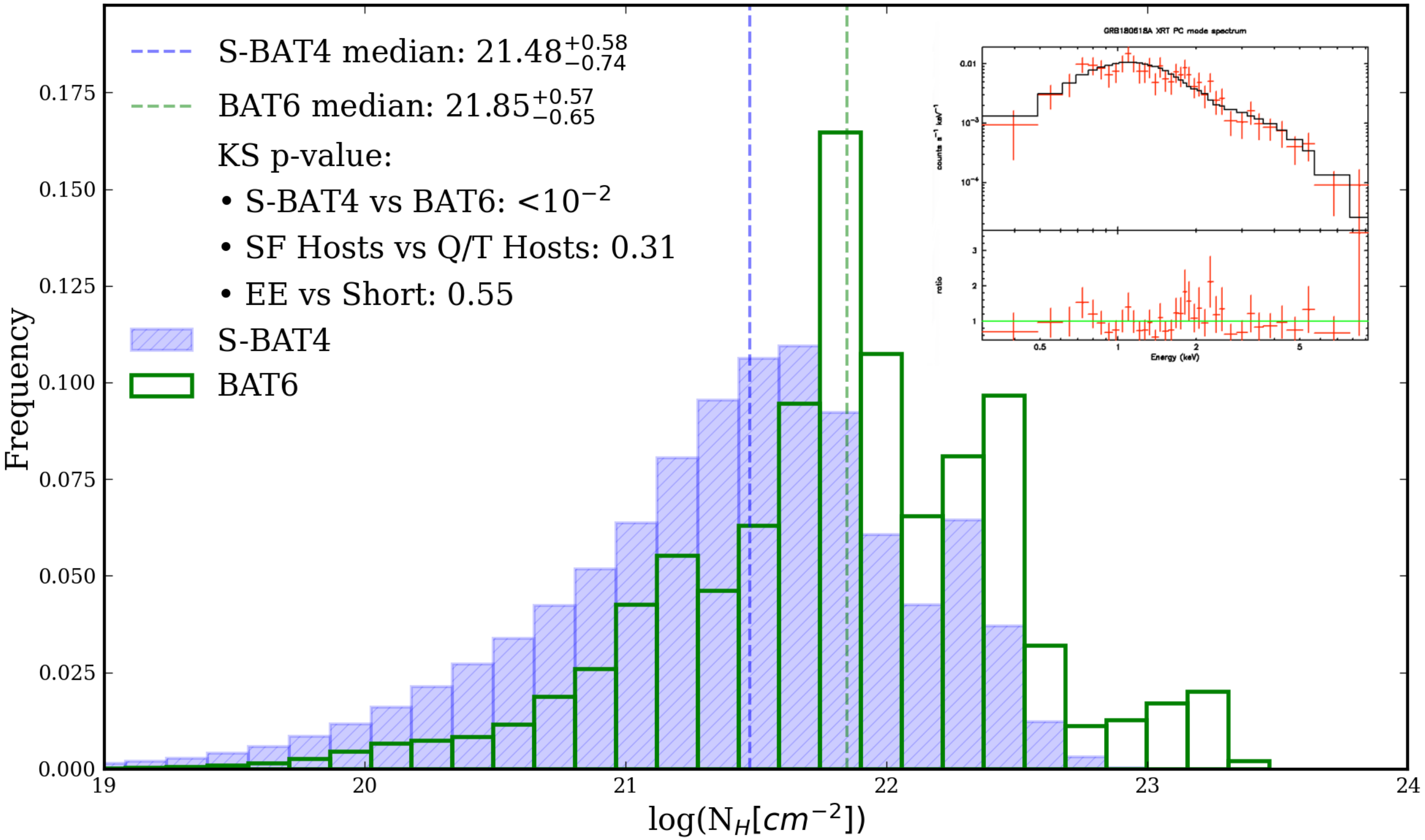




→ **sGRB host galaxies appear to be a very good candidate for unbiased selection of field galaxies**

XRT spectral NH



- Lower neutral hydrogen column densities for S-BAT4 bursts vs BAT6
- No significant relation with the galaxy type or burst nature

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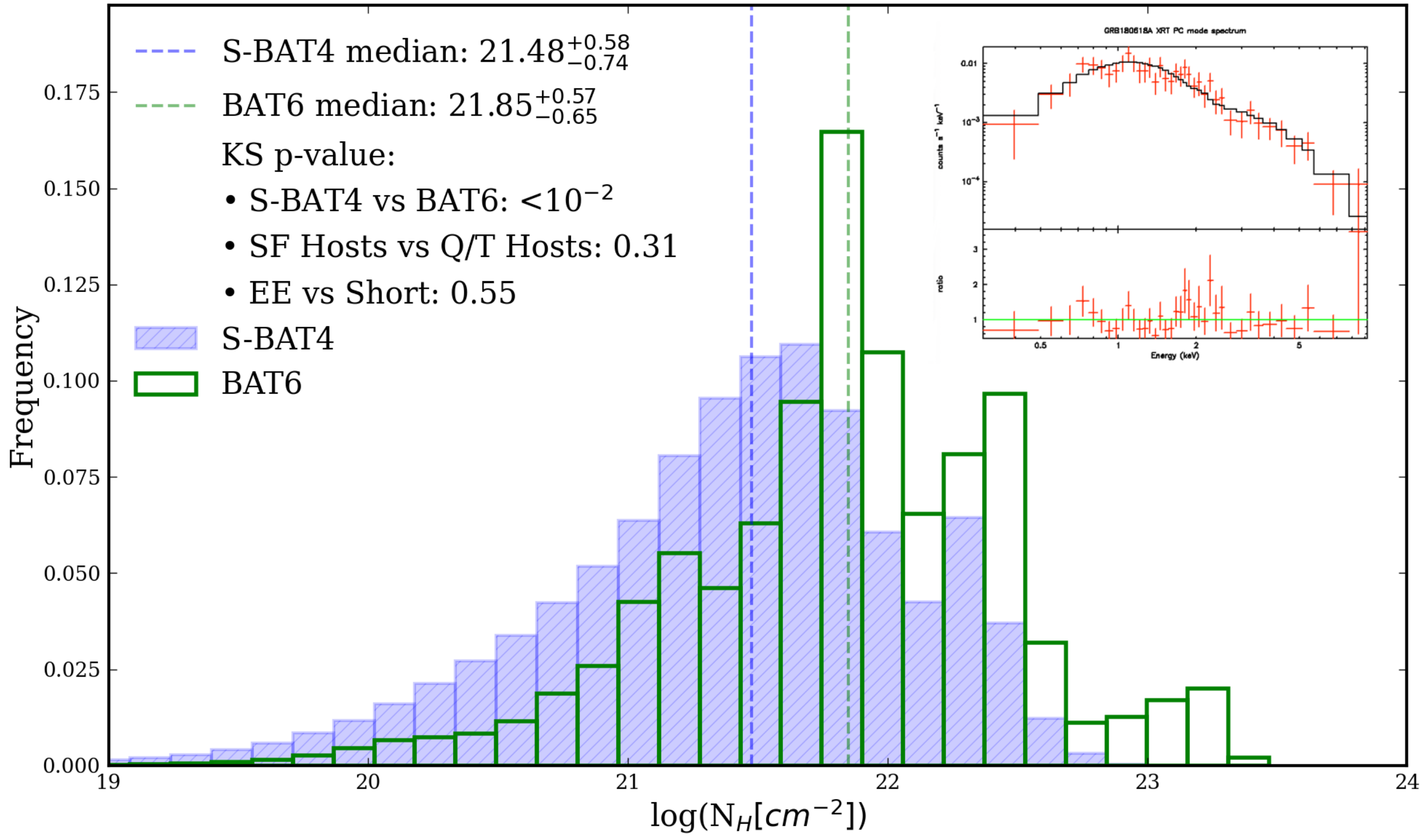

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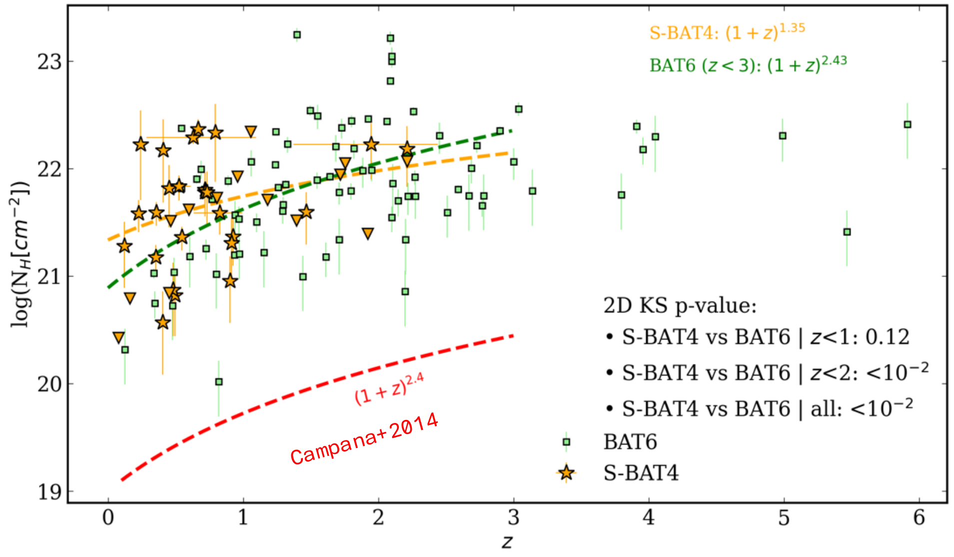
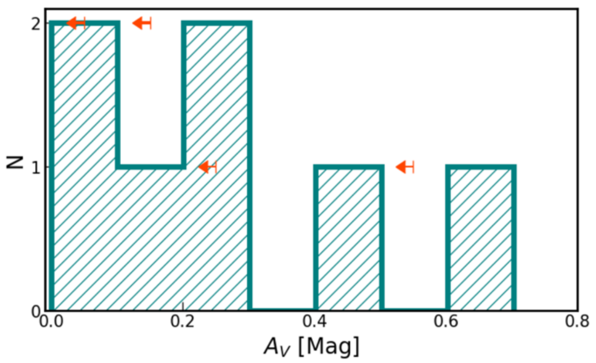
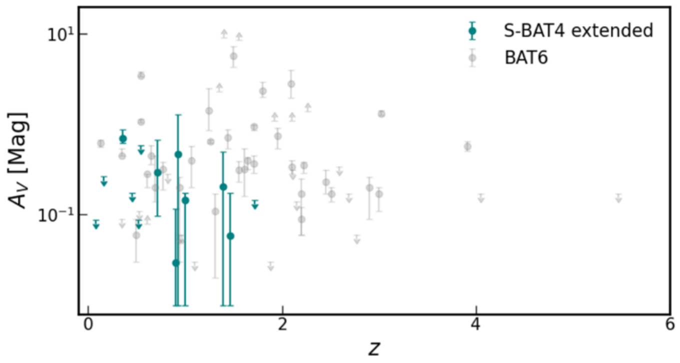
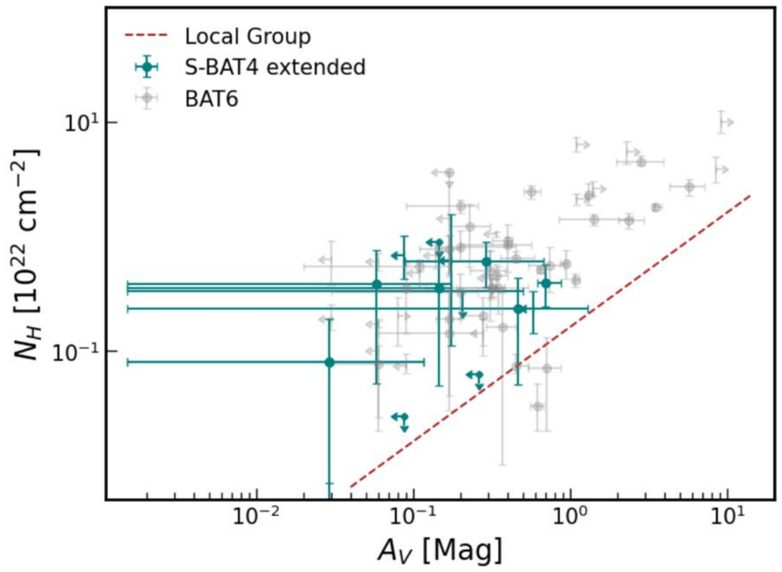


XRT spectral NH

- AV derived from AG SED analyses:





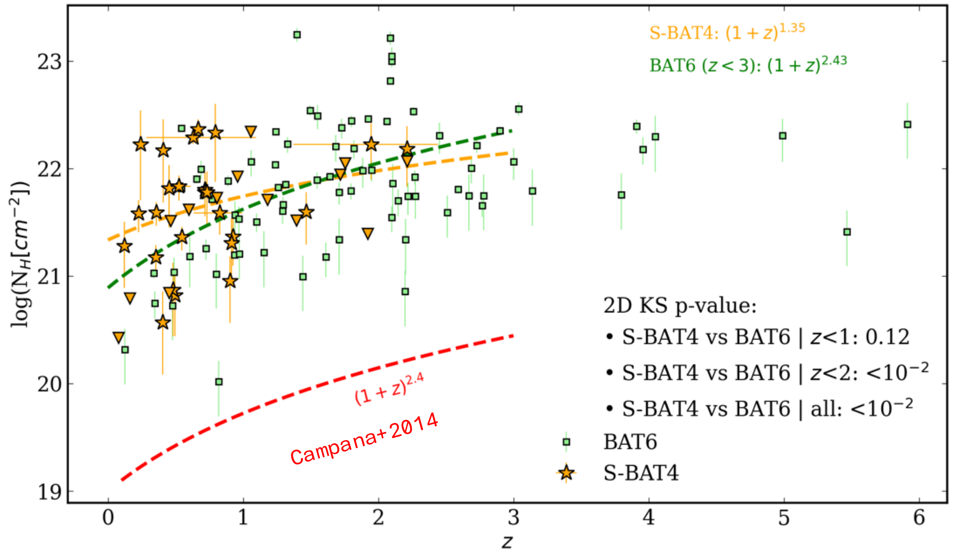


→ Two distinct populations of long GRBs

→ sGRBs consistent with the lower dust-to-gas ratio of BAT6 events (Covino+13) compared to LG values (Welty+2012)

- Lower neutral hydrogen column densities for S-BAT4 bursts vs BAT6

- No significant relation with the galaxy type or burst nature

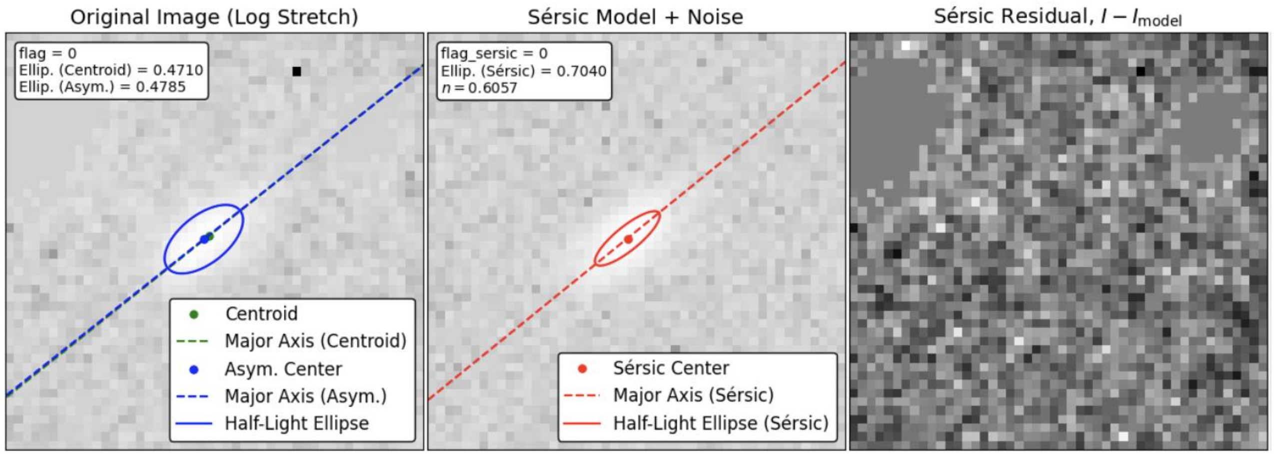


Normalized offsets

We computed/retrieved more than 30 normalized offsets for S-BAT4 events:

<u>PROS</u>:
- Avoid redshift bias
- Compare galaxies of different sizes

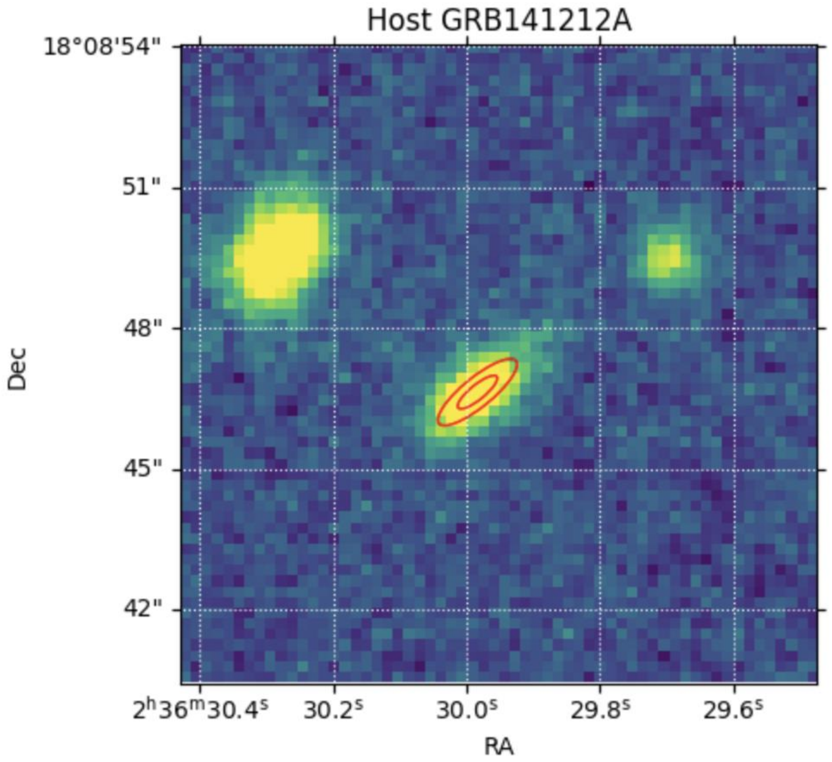
<u>CONS</u>:
- Galaxy profile has to be resolved



Computed with **`statmorph`** (Rodriguez-Gomez+2019)

Sersic fit of the galaxy profile:

$$\Sigma(r) = I_0 \exp\{-k_n[(r/r_e)^{1/n} - 1]\}$$



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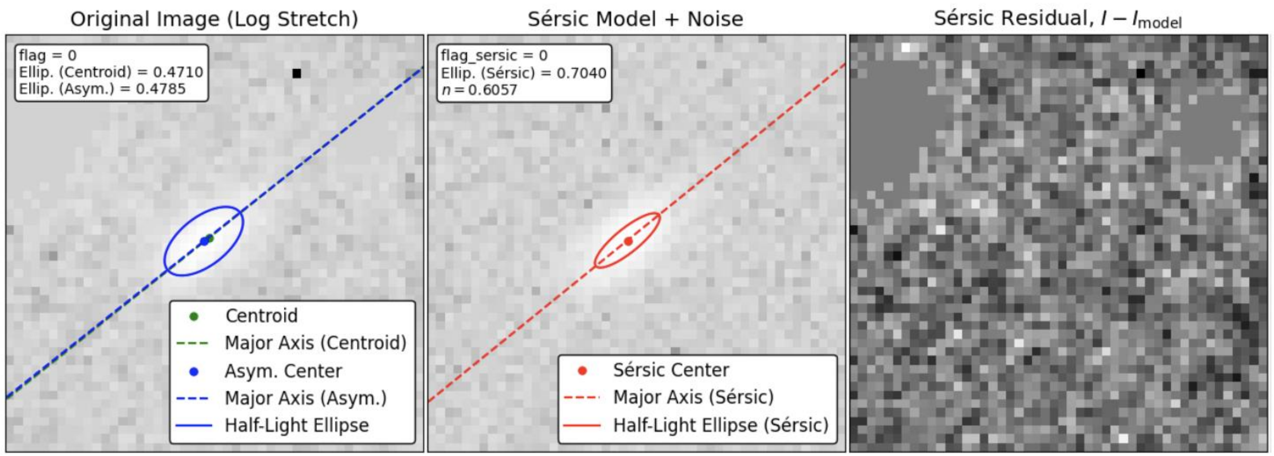

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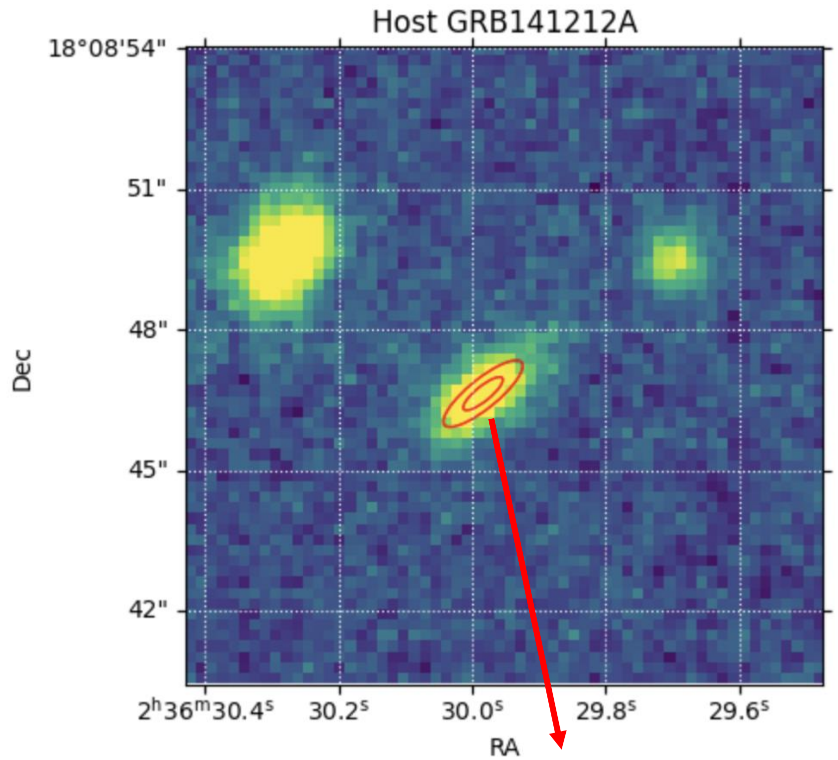
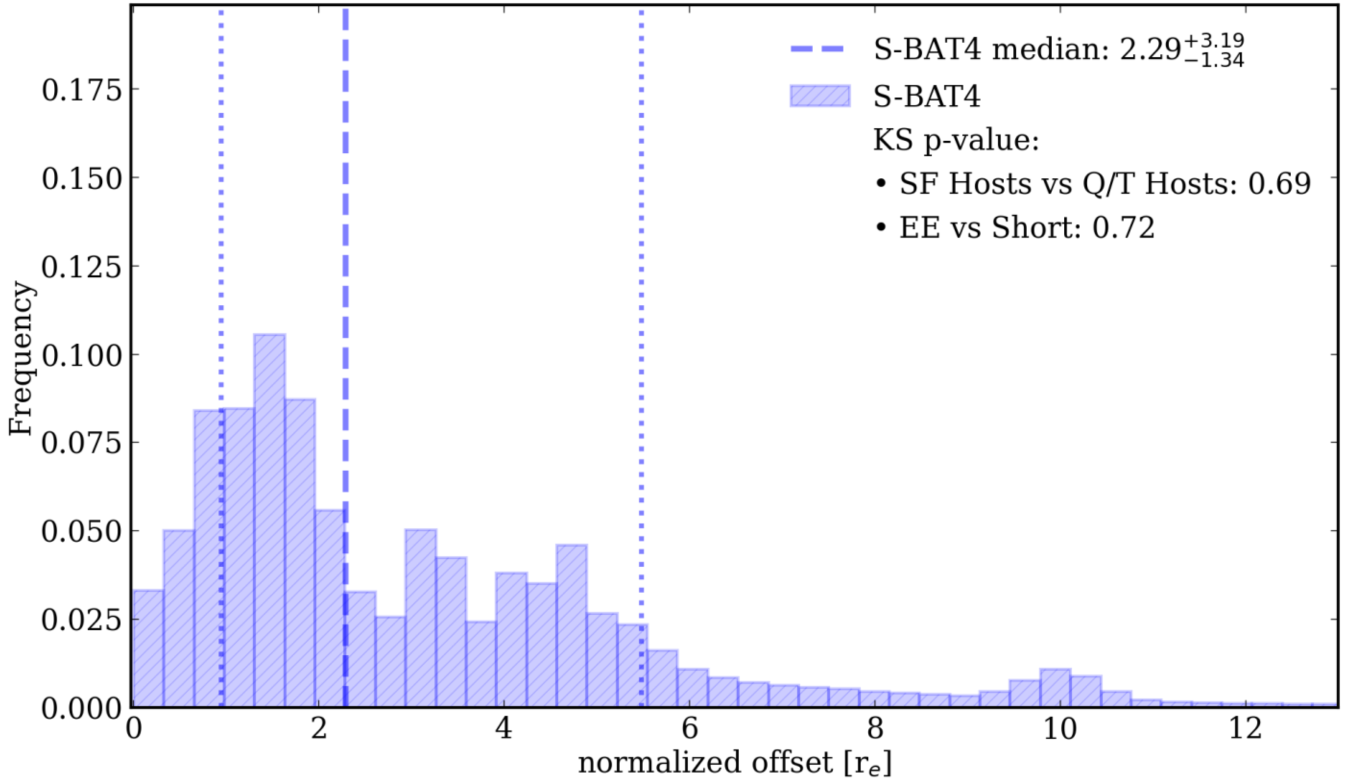


Important to estimate the PSF of the image and consider it for the fit

Normalized offsets

For every galaxy with determined effective radius → Rice distribution (following Fong+2022): distance from galaxy center to a Gaussian (XRT/optical error circle) position

<u>Joint distribution</u>



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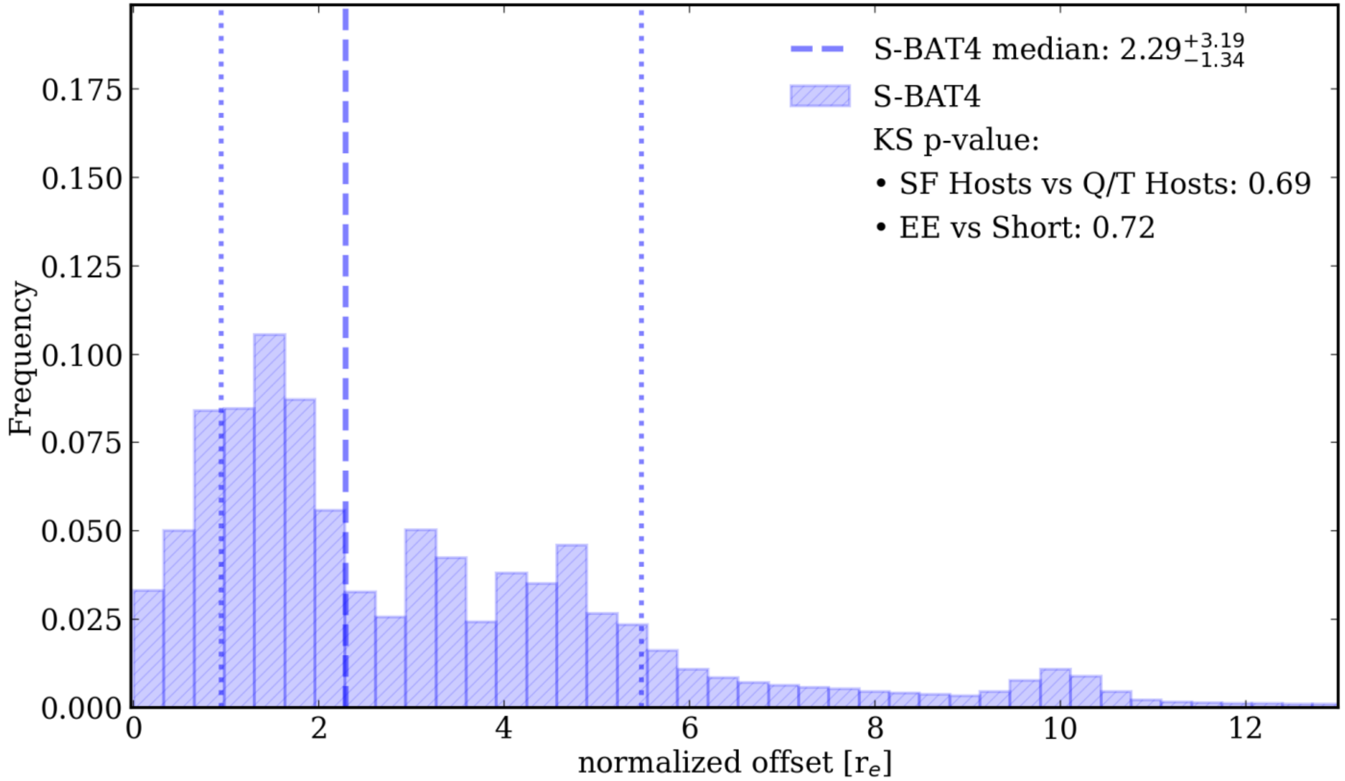


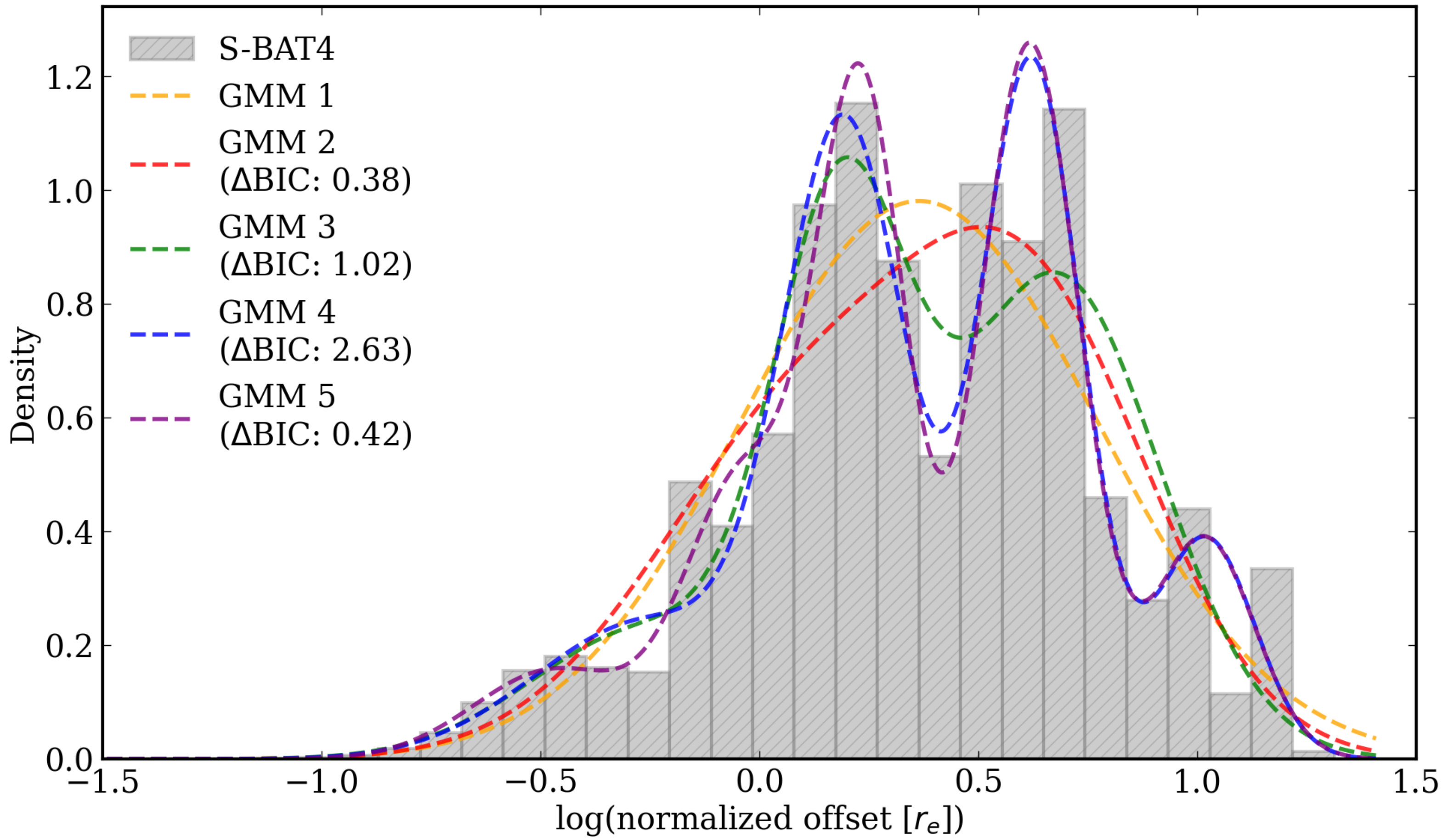
- Considerably farther away than lGRBS (0.6-0.8 r_e, Lyman+2017)
- Higher than BRIGHT catalogue values (1.5-1.8 r_e, Fong+2022)
- No difference between pure sGRBs and EE events (at variance with Troja+2008), consistent with Fong+2022

Normalized offsets

Hint of multiple birth sites or formation channels:

primordial origin in the galactic field (de Mink & Belczynski 2015; Vigna-Gómez+2018; Beniamini & Piran 2019)?

dynamical formation in dense environment, such as globular clusters (Salvaterra+2010; Ramirez-Ruiz+2015)?



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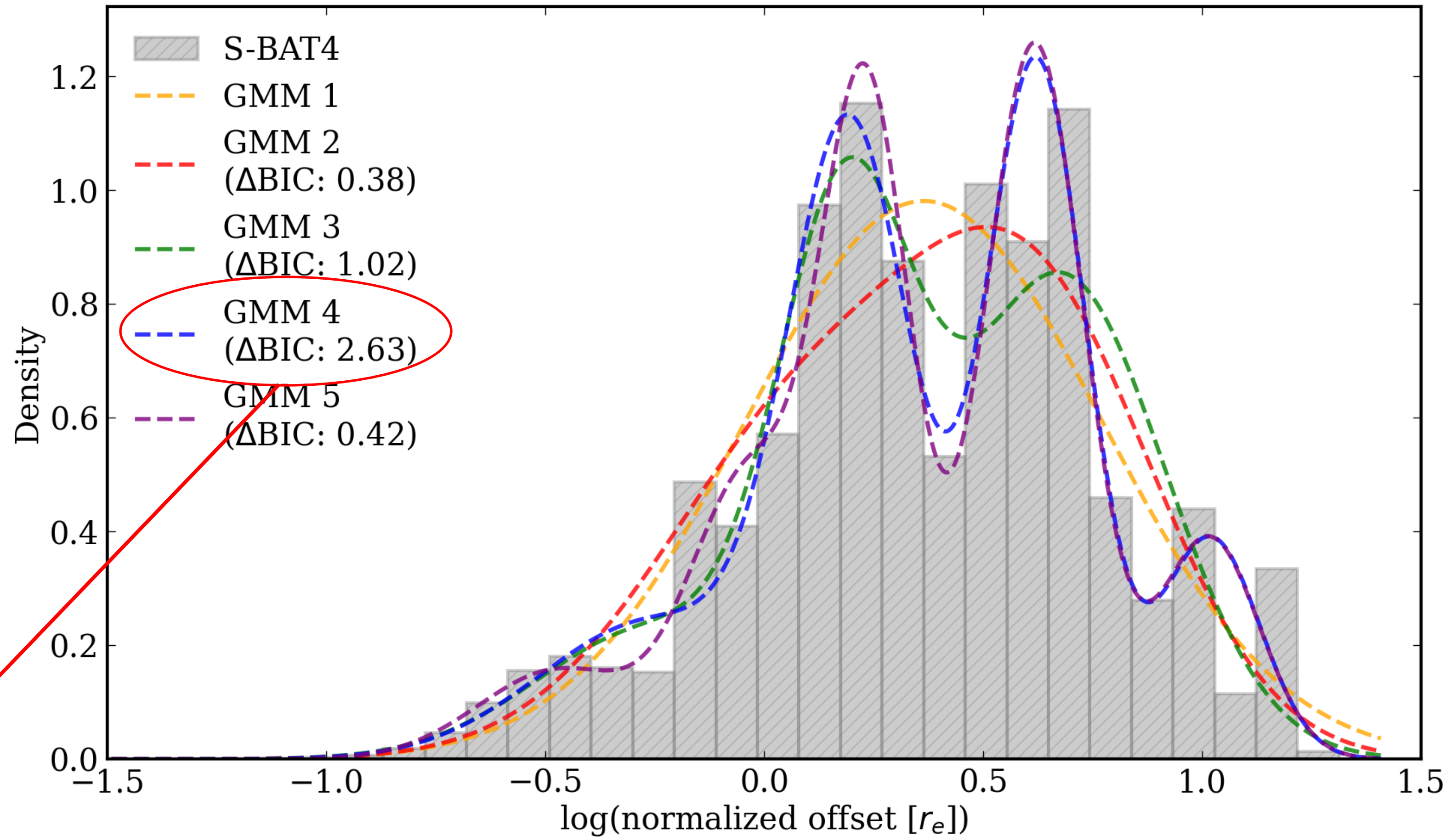


Biggest improvement from 3 to 4 components

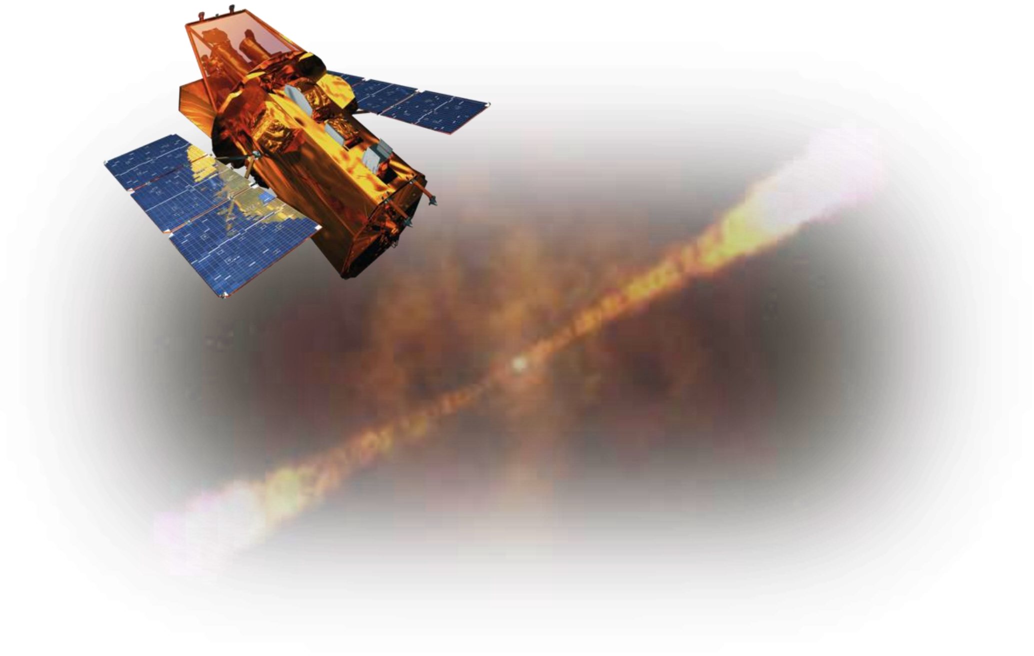
In agreement with simulations, multiple origin for sGRBs are expected (Church+2011)

Conclusions

- We have built a flux-limited, complete sample with minimal selection effects. 51 short GRBs detected by *Swift* match our criteria, 78 % of which with a redshift measurement → thanks to a decade of **deep and extensive of host galaxies follow-up**

- Analysis of host galaxy features will allow us to characterize the intrinsic properties of the short GRBs and **investigate the progenitor features**

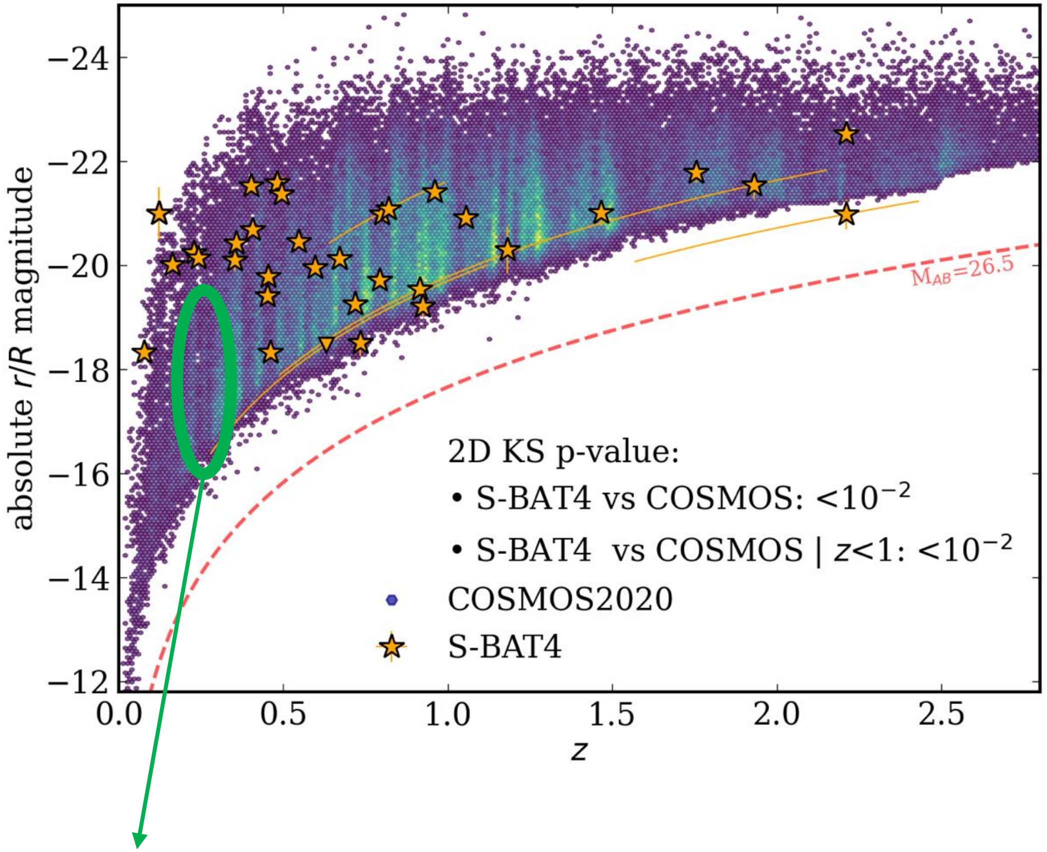
- Investigation of the offsets and N_H distributions could reveal different classes of compact object binary merger GRBs →
pure shorts vs. EE events, delay-time distributions of binary mergers, formation channels…

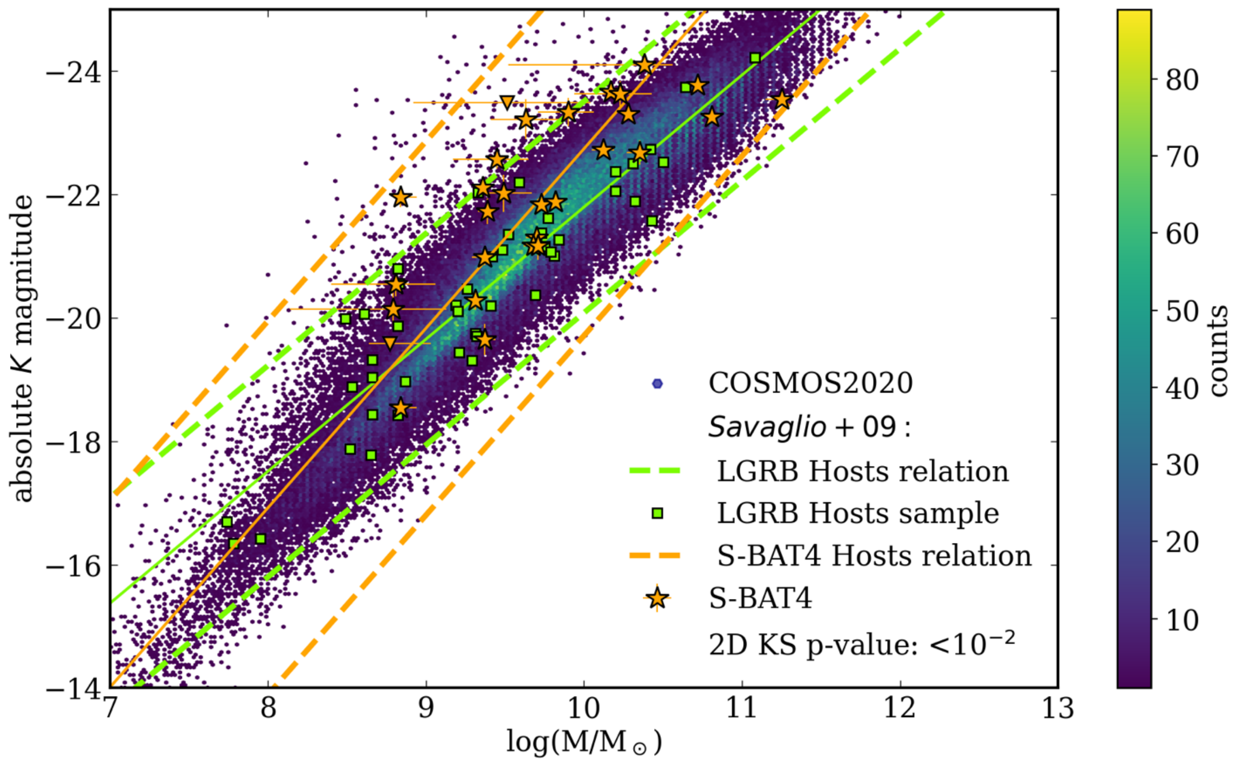


Thank you for the attention!

Luminosity correlations

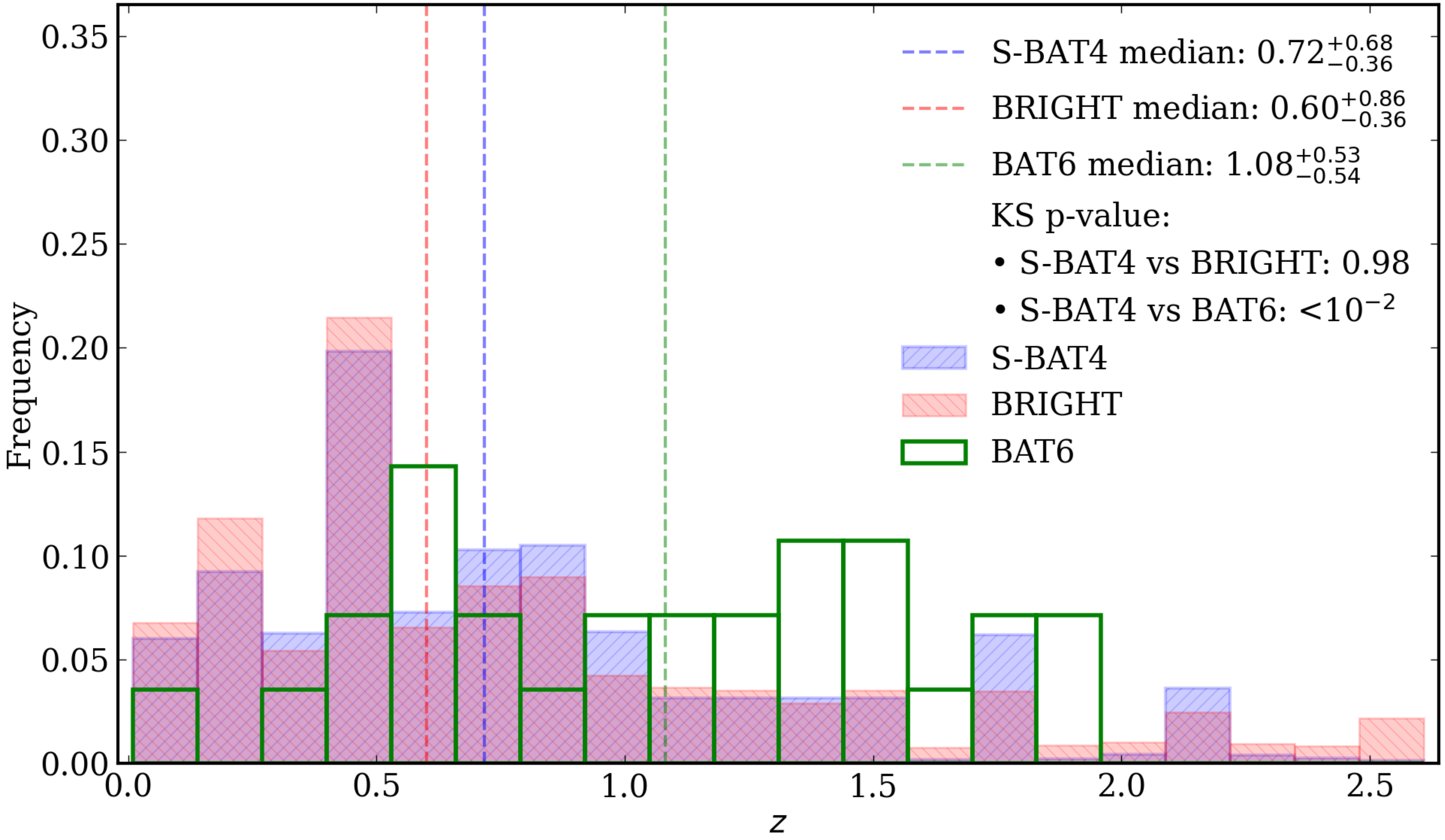
Optical and IR luminosities compared to redshift and mass





Possible population of red/dwarf galaxies (Nugent+2024)

Redshift distribution



Probability of Chance coincidence

$$P_{i,\mathrm{ch}} = 1 - \exp(-\eta_i)$$

where the subscript "ch" indicates "chance." Here

$$\eta_i = \pi r_i^2 \sigma(\leq m_i)$$

is the expected number of galaxies in a circle with effective radius r_i and

$$\sigma(\leq m_i) = \frac{1}{3600^2 \times 0.334 \log_e 10} \times 10^{0.334(m_i - 22.963) + 4.320} \text{ galaxy arcsec}^{-2}$$

is the mean surface density of galaxies brighter than R band magnitude of m_i

From **Bloom+02**

Assuming the surface distribution of galaxy is uniform

Using the result from **Hogg+1997**

Normalized offsets