An investigation into the absence of detected VHE emission from GRBs prior to 2018

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The VHE GRB spectrum - From 2002 to 2018

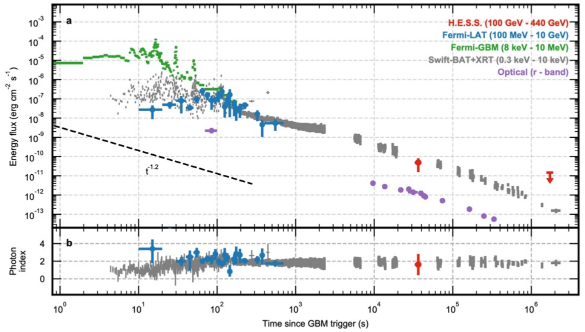
- H.E.S.S. I: 2002-2012
- H.E.S.S. II: 2012- present
- MAGIC I: 2009 – 2012
- MAGIC II: 2012- Present
- VERITAS I: 2007-2012
- VERITAS II : 2012 - Present

Hundreds of observations

Detections > 100 GeV:

- GRB130427A: 90 GeV photon Fermi-LAT
- Nothing else during 16 years

The VHE GRB spectrum - From 2018 to 2019

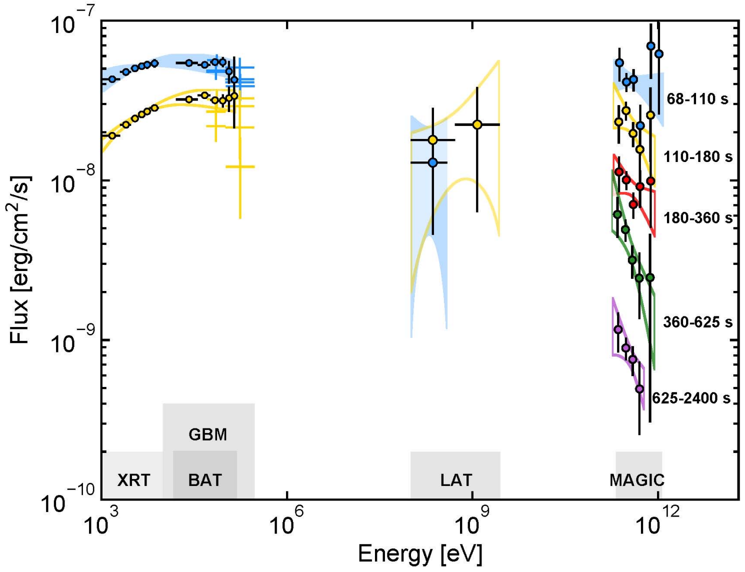


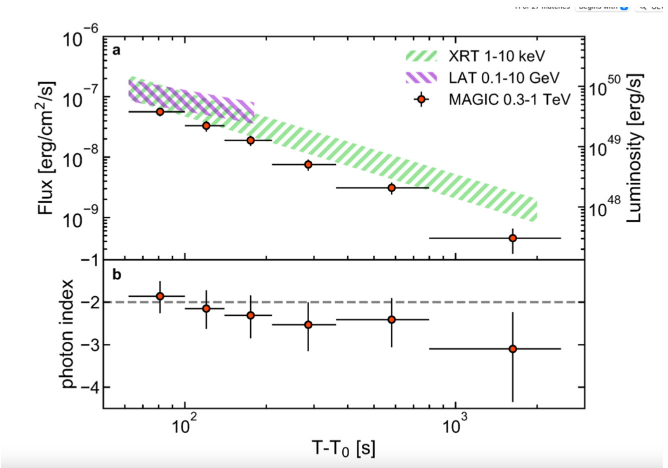
From 2018 to 2019

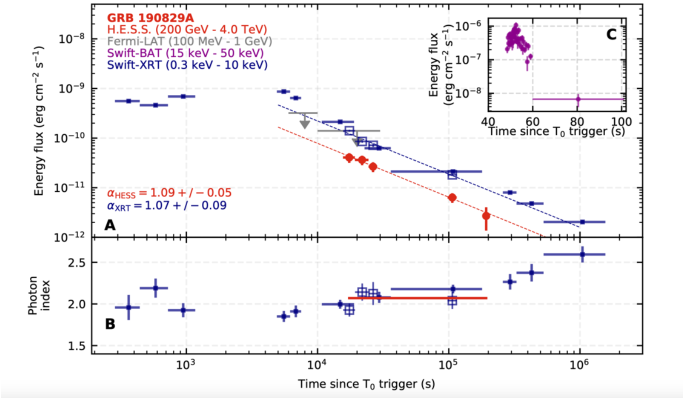
GRB 180720B: 100 GeV – 440 GeV

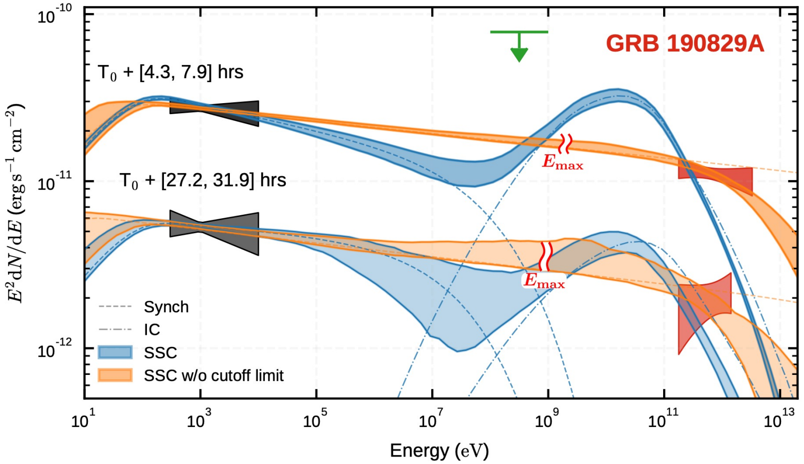
GRB 190114C: 300 Gev – 100 TeV

GRB 190829A: 200 GeV – 3 TeV





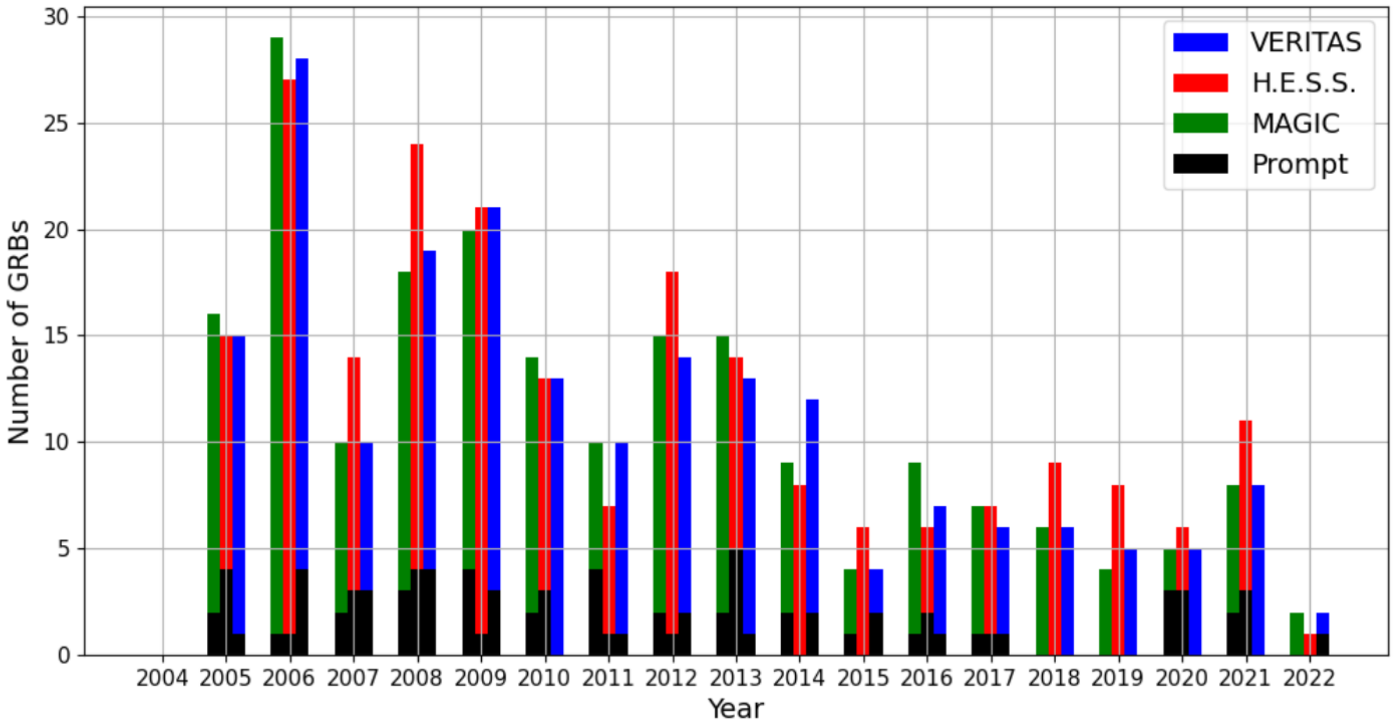




A retrospective study of Swift gamma-ray bursts visibility for IACTs 2004 - 2022

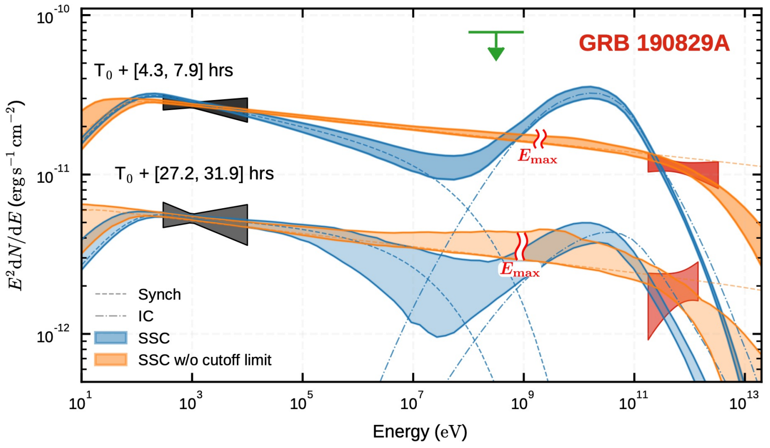
Maximum allowed zenith angle	60 deg
Field of view	2 deg
Maximum allowed observation delay	24 hours
Maximum Sun altitude	-16 deg
Maximum Moon Phase	40%
Maximum Moon altitude	65 deg
Minimum Moon-source separation	45 deg
Maximum Moon-source separation	145 deg
Minimum observation duration	6 minutes

- Redshift measurement
- > 2 X-ray points with Swift-XRT

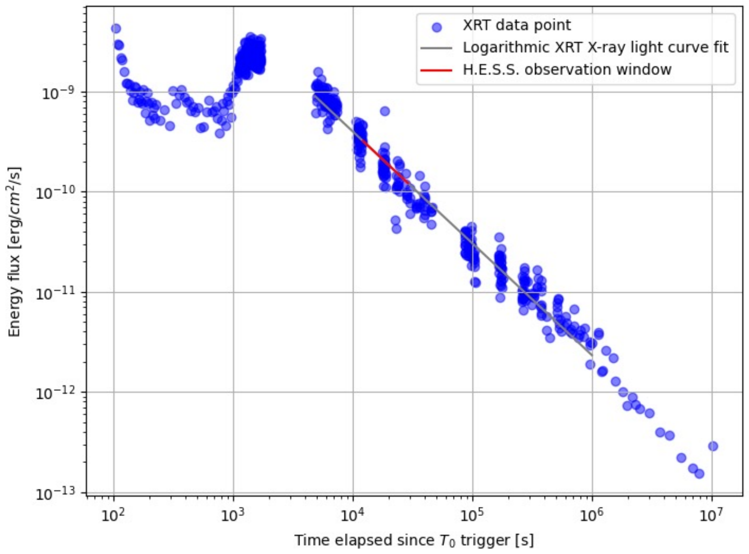


Methodology: assumptions

We want to **INDEPENDENTLY** predict the VHE gamma-ray emission of all these GRBs and check if this VHE gamma-ray emission is detectable by IACTs using real-time observation conditions.



- <u>Spectral shape:</u> Power law with $\gamma = 2$
- <u>Emission level:</u> $\varphi(u)_{\gamma\ (0.2\text{-}3\ \mathrm{TeV})} \times F \equiv \varphi(u)_{X\ (0.2\text{-}10\ \mathrm{KeV})}$ **with F between 1-3**
- <u>Temporal decay</u>: Power law decay with $\alpha_\gamma = \alpha_X$



➢Get the VHE gamma-ray intrinsic emission $\varphi(u)_\gamma$

Methodology: Telescope response

EBL absorption: $\varphi(e)_\gamma = \varphi(u)_\gamma \, e^{-\tau\,(E,z)}$

➢Get the gamma-ray emission reaching Earth $\varphi(e)_\gamma$

Effective area | Energy bounds | Background rates ←→ zenith angle

IACT	E_1 (TeV)	E_2 (TeV)	Reference for eff. area	α	Bkg. rate (Hz)	Zenith (deg)
H.E.S.S. I	0.2	4	H.E.S.S. collaboration et al. (2006)	0.14	0.0865	45
H.E.S.S. II	0.1	4	Holler et al. (2015)	0.08278	0.1287	45
H.E.S.S. MONO	0.1	4	Holler et al. (2015)	0.102	0.0837	45
VERITAS I	0.2	4	https://veritas.sao.arizona.edu	0.14	0.07951	20
VERITAS II	0.2	4	https://veritas.sao.arizona.edu	0.14	0.1101	20
MAGIC I	0.1	4	Aleksić et al. (2012)	0.2	1.125	< 30
MAGIC II	0.1	4	Aleksić et al. (2016)	0.2	0.64	< 30

Methodology: Telescope signal

$$\phi_\gamma^{(u)} \times F = \int_{E_1^{(u)}}^{E_2^{(u)}} E \frac{dN}{dE} dE \equiv \phi_X^{(u)}$$

↓

$$\frac{dN}{dE} = N_0 \left(\frac{E}{E_0}\right)^{-\gamma}$$

↓

$$R_0 = \int_{E_1}^{E_2} \frac{dN}{dE}(t) e^{-\tau_{EBL}} A(E) dE$$

↓

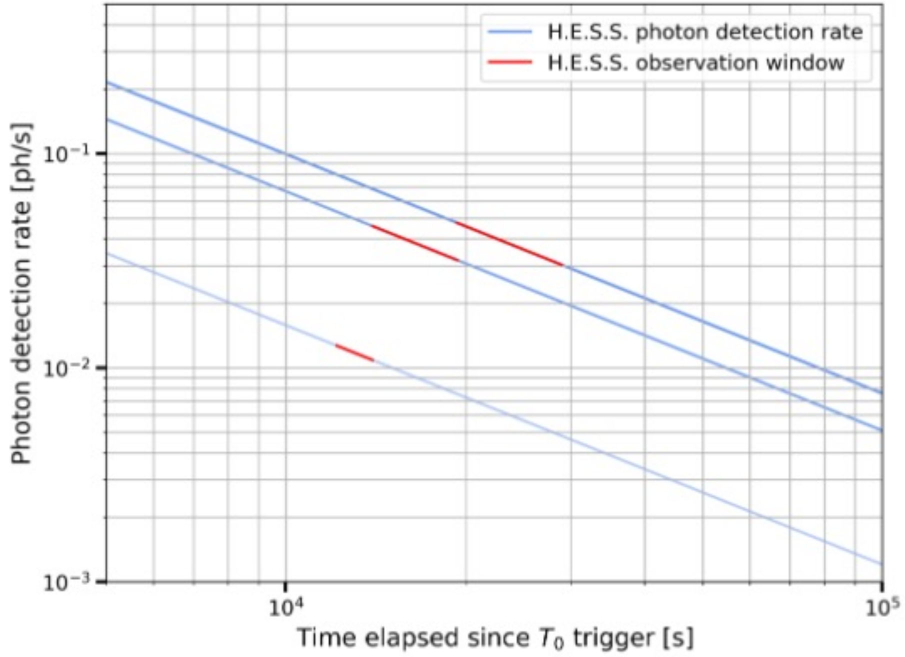
$$R(t) = R_0 t^{\alpha_X}$$

↓

$$S = \int_{t_1}^{t_2} R(t) dt \qquad B = \int_{t_1}^{t_2} R^B dt$$

↓

$$N_{ON} = S + \alpha B \qquad N_{OFF} = B$$



$$\sigma = \sqrt{-2 \ln \lambda} = \sqrt{2} \left\{ N_{on} \ln \left[\frac{1+\alpha}{\alpha} \left(\frac{N_{on}}{N_{on} + N_{off}} \right) \right] + N_{off} \ln \left[(1+\alpha) \left(\frac{N_{off}}{N_{on} + N_{off}} \right) \right] \right\}^{1/2}$$

Validation

- GRB 190829A
  - Using the time window as reported in the H.E.S.S. paper we get 20.9 σ for $N_{ON} = 682$ (reported value is 21.7σ)
  - $\gamma = 2.0 \rightarrow \gamma = 2.5$: 18.4$\sigma$ for $N_{ON} = 621$
  - Doubling the background rate lowers the significance to 16.5σ
  - Doubling the background rate for the $\gamma = 2.5$ case reduces the significance to 14.2σ

- GRB 180720B
  - 2.6 σ (reported value is 5.3σ)
  - *standard* vs. *loose* cuts

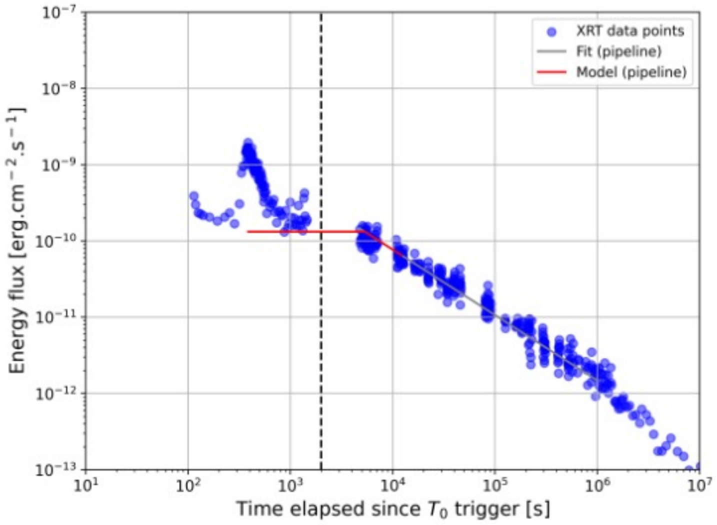
Preliminary results

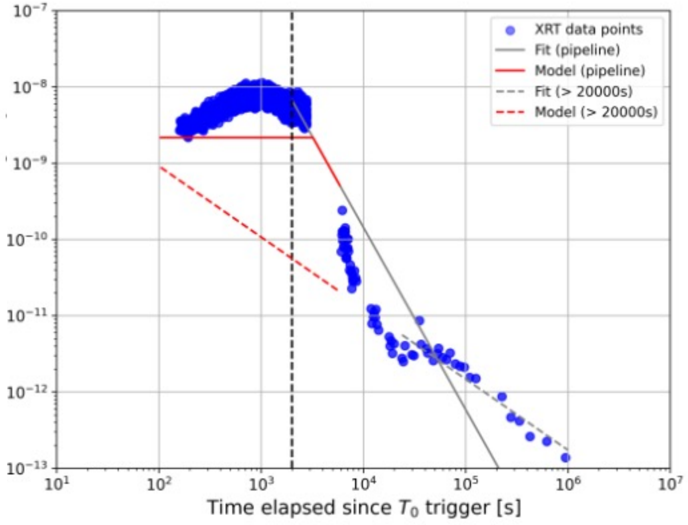
- Take a deeper look into the X-ray curve
- 1st case: > 2000 seconds
- 2nd case: entire observation window

For H.E.S.S.: GRB 060904B, 080605, 100621A, 100814A, 130925A, 131030A, 161219B, 180720B, 190829A and 210721A.

For MAGIC: GRB 060904B, 080605, 090112, 090417B, 101225A, 130430A,131030A, 190829A and 210619B.

For VERITAS: GRB 060218, 090618, 120729A and 190829A





Results

PRELIMINARY

GRB Name	z	Time (UTC)	Obs. delay (s)	Obs. duration (s)	σ > 2000s (full) H.E.S.S. II	σ > 2000s (full) H.E.S.S. I
GRB060904B	0.7029	2006-09-04T02:31:03	26.0	5045.0	<1 (1.8)	**<1** (**<1**)
GRB100621A	0.542	2010-06-21T03:03:32	40.0	4733.0	2.4 (19.6)	**<1** (**5.7**)
GRB130925A	0.348	2013-09-25T04:11:24	60115.0	5303.0	**2.4 (2.4)**	1.0 (1.0)
GRB131030A	1.293	2013-10-30T20:56:18	27.0	8313.0	**<1 (2.0)**	<1 (<1)
GRB161219B	0.1475	2016-12-19T18:48:39	388.0	11899.0	**11.5 12.1**	7.7 (8.0)
GRB180720B	0.654	2018-07-20T14:21:44	35209.0	15302.0	**2.5 (2.5)**	<1 (<1)
GRB190829A	0.0785	2019-08-29T19:56:44	12179.0	16817.0	**31.5 (31.5)**	24.6 (24.6)

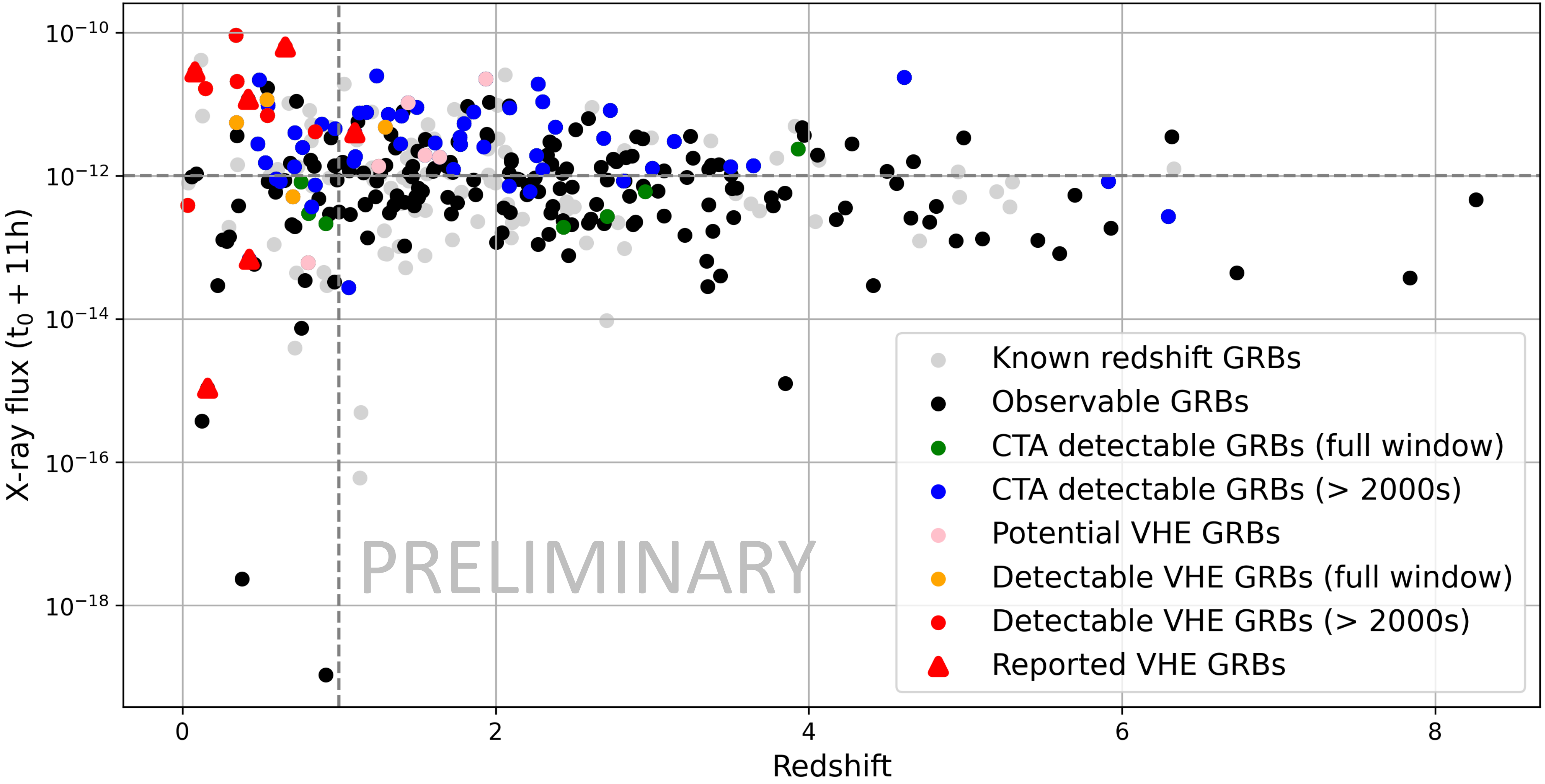
GRB Name	z	Time (UTC)	Obs. delay (s)	Obs. duration (s)	σ > 2000s (full) MAGIC II	σ > 2000s (full) MAGIC I
GRB090417B	0.345	2009-04-17T15:20:03	11456.0	20150.0	2.0 (2.0)	**1.2 (1.2)**
GRB101225A	0.847	2010-12-25T18:37:45	1124.0	5622.0	4.9 (5.4)	**3.9** (**4.9**)
GRB130427A	0.3399	2013-04-27T07:47:57	39056.0	2424.0	**2.0 (2.0)**	1.0 (1.0)
GRB190829A	0.0785	2019-08-29T19:56:44	14906.0	11363.0	**9.7 (9.7)**	6.5 (6.5)

GRB Name	z	Time (UTC)	Obs. delay (s)	Obs. duration (s)	σ > 2000s (full) VERITAS II	σ > 2000s (full) VERITAS I
GRB060218	0.03342	2006-02-18T03:34:30	104.0	5766.0	63.7 (69)	**51.2** (**56**)
GRB090618	0.54	2009-06-18T08:28:29	31.0	8553.0	1.5 (1.6)	**<1** (**<1**)
GRB190829A	0.0785	2019-08-29T19:56:44	46116.0	10605.0	**6.0 (6.0)**	4.9 (4.9)

Discussion: Detectable VHE emission from GRBs

- Low redshift GRBs are favored.
- Early observation times are favored
- Improve IACT effective areas at low energies → ability to detect GRBs
- Some GRBs are flagged as interesting for more than one IACT
- Importance of publishing and updating telescope performance data
- We highly encourage the three IACT collaborations to look for any data that might have been collected on the reported GRB
- The study of these GRBs can constrain the relation between the X-ray and the VHE gamma-ray fluxes

Discussion: XZ diagram



Discussion and conclusion

- Interesting VHE GRBs: < 1 per year (0.6 - 0.8 per year) for all IACTs.
- <1 every 2 years for a single site.
- These numbers increase by ½ **order of magnitude** with CTA (2 vs. 3 sites).
- Comparing CTA North to MAGIC: **more than 1 order of magnitude** improvement.
- It is the effect of sensitivity at **low energy** that plays a role.
- IACT observation and visibility conditions and the availability of X-ray and redshift measurements are considered → **very low duty cycle.**
- Non-ideal observation conditions, like observations at high zenith angles, short observation periods, and long observation delays, affect these numbers.
- \+ weather and instrumental issues

→No surprise the rate is so low, especially with hard observation criteria.

\- GRB 221009A and GRB 230307A (BOAT & BOAT2)

- Taking GRBs with no redshift measurements might increase these numbers.

For the future

- Loosening criteria and quicker observations.
- After all 3 of the 5 VHE reported GRBs where observed either with large observation delay or under moonlight observations (outside hard criteria)
- Tests different hypothesis. GRB 221009A was not detected after 51 hours despite high X-ray emission

→ need to reconsider **F** for some cases?

- X-ray ←→ VHE relations constraints through stacked analysis