PROCEEDINGS OF SCIENCE

GRB observations with H.E.S.S.

Quentin Piel[*1], Cornelia Arcaro[3], Halim Ashkar[5], Elisabetta Bissaldi[10], Markus Böttcher[3], Kathrin Egbert[2], Alessandro Carosi[1], Clemens Hoischen[2], Markus Holler[7], Paul O'Brien[11], Robert Parsons[4], Heike Prokoph[9], Gerd Pühlhofer[13], Gavin Rowell[6], Edna Ruiz-Velasco[4], Fabian Schüssler[5], Monica Seglar-Arroyo[5], P.H. Thomas Tam[7], Stefan Wagner[12], for the H.E.S.S. Collaboration[†]

[1] *Laboratoire d'Annecy de Physique des Particules, 9 Chemin de Bellevue, 74941 Annecy, France*
[2]*Institut für Physik und Astronomie, Universität Potsdam, Karl-Liebknecht-Strasse 24/25, D 14476 Potsdam, Germany*
[3]*Centre for Space Research, North-West University, Potchefstroom 2520, South Africa*
[4]*Max-Planck-Institut für Kernphysik, P.O. Box 103980, D 69029 Heidelberg, Germany*
[5]*IRFU, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France*
[6]*School of Physical Sciences, University of Adelaide, Adelaide 5005, Australia*
[7]*Institute of Astronomy and Space Science, Sun Yat-Sen University, Guangzhou 510275, China*
[8]*Landessternwarte, Universität Heidelberg, Königstuhl, D 69117 Heidelberg, Germany*
[9]*DESY, D-15738 Zeuthen, Germany*
[10]*Instituto Nazionale di Fisica Nucleare*
[11]*Department of Physics and Astronomy, University of Leicester, University Road, Leicester, LE1 7RH, United Kingdom.*
[12]*Landessternwarte, Universität Heidelberg, Königstuhl, D 69117 Heidelberg, Germany*
[13]*Institut für Astronomie und Astrophysik, Universität Tübingen, Sand 1, D 72076 Tübingen, Germany*
E-mail: contact.hess@hess-experiment.eu

Fermi-LAT observations have proven that GeV γ-ray emission is a relatively common feature for many Gamma Ray Bursts (GRB). However the low effective area of space detectors implies low statistics for high-energy photons which prevent any physical interpretation at such energy range. The current generation of Imaging Atmospheric Cherenkov Telescopes (IACTs) arrays of $> 10^4$ m^2 effective area above a few tens of GeV is able to detect higher-energy photons.

The High Energy Stereoscopic System (H.E.S.S.) is one of the current generation of IACTs. The large light collection area of the largest telescope and its fast slewing make it perfectly suitable to observe γ rays below 100 GeV with an unprecedented sensitivity. Several tens of GRBs have been observed since 2007. This contribution is about the results of this large sample of observation above a few tens of GeV.

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*Speaker.
†for collaboration list see PoS(ICRC2019)1177

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PoS(ICRC2019)761

1. Introduction

Gamma ray bursts (GRBs) are brief and intense pulses of keV-MeV γ ray releasing as much as $10^{51}-10^{54}$ erg of isotropic equivalent energy. The duration of these transient events spans over milliseconds up to hundred of seconds. Since the first discovery in 1969 [1], GRBs have been target of several observational efforts at all wavelengths although a full comprehension of the physics of these outstanding events is still missing.

In the last decades, thanks to the improving follow-up capabilities of space- and ground-based observatories, the wealth of available multi-wavelength data has significantly improved revealing an unexpected richness and complexity of scenarios, in particular during the so-called *prompt* phase [2]. According to the relativistic-shock model known as *fireball* model [3, 4], GRB emission arises from the conversion of the kinetic energy of a relativistic outflow into electromagnetic emission. Although the details of this conversion remain poorly understood, a largely discussed possibility is that the observed photons are radiation from particles accelerated to ultra-relativistic energies by successive collisions within magnetised medium. More in detail, during the prompt phase, the GRB dynamic is thought to be governed by relativistic collisions between shells of plasma emitted by a central engine (internal shocks). Similarly, the emission during the afterglow seems to be connected to the shocks between these ejecta with the external medium (external shocks). The accelerated particles can emit the observed high-energy photons by several possible non-thermal mechanisms including both leptonic and hadronic processes [8, 9, 10]. Synchrotron emission is one of the longest-time discussed process and the most natural in explaining the GRB sub-MeV emission. Although alone it cannot fully explain the observed prompt spectrum for the majority of the GRB, it is supposed to play an important role in GRB emission. While the phenomenological Band function [12] is still widely used to fit the spectrum of the prompt emission, additional components may be present including possible thermal emission with distinct temporal evolution [11]. Furthermore, some particularly bright events show emission until tens-of-GeV [7] and more recently to sub-TeV energies[1].

The origin of high energy photons in GRBs is still under discussion. In certain conditions, synchrotron emission can extend up to the GeV regime during the early afterglow phase [10]. However, other mechanisms such as synchrotron-self Compton [8, 9] and hadronic mechanisms could produce such emissions. Unfortunately, the poor effective area of *Fermi*-LAT allows to detect small quantities of photons in the $\sim$GeV range. Due to this lack of detections, theoretical modelling scenarios are still poorly understood. They could benefit of the follow-up observations at higher energies by instruments with better sensitivities above 100 GeV such as Imaging Air Cherenkov Telescope (IACTs). Several attempts to observe GRB emission have been already presented in the past by H.E.S.S. [14, 13, 15] as well as by the other Cherenkov collaborations [20, 16] and, recently, by the HAWC collaboration [17]. In all cases only upper limits have been derived. This study completes the previous GRB work by analysing the last 10 years of GRB observations.

[1] http://www.astronomerstelegram.org/?read=12390

PoS(ICRC2019)761

2. Gamma Ray Burst observations

2.1 The H.E.S.S. experiment

The H.E.S.S. array[2] is an instrument of four 12m-diameter and one 28m-diameter IACTs located at 1 800 m above sea level in the Khomas Highland of Namibia. Four telescopes are placed at a corner of a square with a side length of 120 m with the largest and fifth one in the center. This configuration was optimised for a maximum sensitivity to ≥ 100 GeV photons. The slew rate of the array is 100° per minute for the small telescopes and 200° per minute for the large one, enabling it to point to any sky position within 1 and 2 minutes, respectively. The H.E.S.S. array is currently the only IACT array in the Southern Hemisphere used for an active GRB observing programme.

2.2 The H.E.S.S. alert system and selection

Since GRBs are unpredictable and impulsive events uniformly distributed in the sky, observing their position at the relevant time is very unlikely. Narrow-field-of-view instruments ($\sim 5°$ diameter) such as H.E.S.S. need to join global alert networks composed of large-field-of-view satellites such as *Swift* and *Fermi*, but also neutrino and gravitational-waves instruments (IceCube, LIGO/VIRGO). For a few years, H.E.S.S. has been using the VoEvent protocol to receive alerts [18].

Around 1 GRB alert per day is received by H.E.S.S. However, the H.E.S.S. duty cycle of around 1000 h per year (up to now H.E.S.S. observed during nights without any moon) has to be shared by several science cases. Around 40 h of observation per year are expected for the GRB programme. Thus a relevant GRB filtering strategy was created and is currently applied. The alert follow-ups depend on several parameters such as the instruments sending alerts (*Swift*-BAT, *Fermi*-LAT or *Fermi*-GBM), the GRB's redshift and the delay of observation. Alerts received maximum 1 h before the night (called prompt observations) are always followed by H.E.S.S. (15% of the total amount of alerts). They represent the best chances to detect GRBs. Concerning other alerts called afterglow, follow-ups depend on a redshift/delay filter to focus on the most interesting events. In order to keep only the most promising ones, the maximum allowed delay decreases as the GRB distance increase. The maximum delay of H.E.S.S. follow-ups is given by:

- 24 h if $z < 0.1$
- 12 h if $z < 0.3$
- 6 h if $z < 1$
- 4 h if z is unknown

All the available telescopes are involved in the data taking. The standard observation time is 2 h. However, for special cases such as *Fermi*-LAT or very bright *Swift*-XRT detections, observation times can be longer (up to 20 h).

A real-time analysis is running while data is taken. If a hot spot is found, the observation of a source can be extended up to the end of dark time and more time can be requested for the following nights.

[2] http://www.mpi-hd.mpg.de/hfm/HESS/HESS.html

PoS(ICRC2019)761

2.3 The H.E.S.S. follow-up analysis

Since 2008, around 68 follow-ups have been performed, among them 39 with the large telescope CT5. However, the data taking condition strongly varies between GRBs, for example CT5 availability, weather conditions, and the delay of observation change the way GRBs are analysed. In order to take into account this variety of cases and avoiding to analyse several times each GRB (adding trials which should be taken to account for the calculation of the signal signficance), a stringent analysis procedure was applied to all of them. The aim of this procedure is to check very carefully the data quality. The first step concerns the low-level data quality. Due to calibration and objects in the field of view, artefacts can be created and lead to fake hot-spot appearance. To avoid this, the participation fractions of all camera pixels (e.g. the pixel pedestal values, and the distribution of events within the field of view), the night sky background light during data taking, and the presence of known TeV sources are checked. If data pass through all these checks, the high-level analysis are ran. Unfortunately, 19 follow-ups were removed by using this procedure due to bad weather or issues during the data taking.

The observations are analysed with two independent analysis and reconstruction chains [5] and [6] cross-checking each others. The CT5 monoscopic analysis is used to get the lowest energy threshold. If CT5 was not involved in the data taking, a stereoscopic CT1-CT4 analysis is performed.

Table 1 shows the results on the analysed GRBs. Unfortunately, no detection occurred but several upper limits were derived using [19] and assuming a power law with an index of 2. In order to avoid flooding the signal by background events for the most promising follow-ups (e.g. prompt observations), the first run is analysed separately.

The derived upper limits are are approximately of the order of 10^{-11}-10^{-12} cm^{-2} s^{-1} TeV^{-1}. These values can be used for the GRB modelling at VHE. Unfortunately only a few have known redshift making the modelling difficult. As expected the CT5 monoscopic analysis provide lower energy thresholds around 100 GeV which make them more interesting for modelling.

PoS(ICRC2019)761

	T_{start}	Exposition [h]	CT5 included	Mean zenith angle [°]	redshift	Significance [σ]	E_{th} [GeV]	Flux ULs [$\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{TeV}^{-1}$]
GRB 080413A	2008-04-13 03:02:20	0.3	No	16.4	2.433	0.98	220	6.00e-12
GRB 080804	2008-08-04 23:25:19	0.4	No	31.3	2.2045	0.05	320	1.80e-12
GRB 081028A	2008-10-28 01:05:30	0.1	No	55.7	3.038	0.82	-	[2]
GRB 081221	2008-12-21 19:08:02	0.9	No	26.3	0.7	-0.38	320	4.62e-12
GRB 081230	2008-12-30 20:54:44		No	42.0	-	0.55	320	4.63e-12
GRB 090201	2009-02-01 21:20:25	0.8	No	32.1	-	-0.27	220	3.63e-12
GRB 091018	2009-10-18 22:04:49	1.3	No	34.3	0.971	-0.09	320	1.50e-12
GRB 100418A	2010-04-18 23:22:19	0.8	No	48.8	0.6235	0.24	320	5.65e-12
GRB 120328A	2012-03-28 03:10:29	0.2	No	19.1	-	-1.62	190	2.68e-10
GRB 130206	2013-02-06 20:30:40	1.7	No	39.8	-	0.43	-	[1]
GRB 130502A	2013-05-02 19:24:05	0.4	No	45	-	-0.87	320	2.19e-11
GRB 130515	2013-0515 01:26:25	0.4	No	32.4	-	-0.12	-	[2]
GRB 131030A	2013-10-30 21:03:58	0.4	Yes	38.6	1.293	-0.11	150	3.05e-11
GRB 140818B	2014-08-18 18:46:53	1.6	Yes	24.9	-	-0.11	110	4.12e-11
GRB 141004A	2014-10-05 01:57:38	1.0	No	37.6	0.573	-1.41	320	3.38e-11
GRB 151205B	2015-12-05 21:43:48	0.2	No	28.9	-	-1.06	-	[2]
GRB 160310A	2016-03-10 18:29:42	0.6	Yes	27.8	-	-0.58	120	4.32e-12
GRB 161001	2016-10-01 01:07:16	1.2	Yes	35	-	-1.2	150	2.29e-11

Table 1: Results of the GRB analysis. [1] No upper limit due to clouds. [2] Not enough statistics to produce upper limits. Only alerts with small uncertainty positions are shown.

PoS(ICRC2019)761

3. Conclusion and outlooks

H.E.S.S. has performed several tens of follow-ups for the last 15 years. The feedback of all these observations provided a lot of information to constantly improve the GRB follow-up strategy. In spite of numerous follow-ups, only one GRB has been detected by H.E.S.S. (GRB180720B). Its detection and the GRB190114C detection made by MAGIC opened a new era in the GRB understanding at very high energy. The other follow-ups, concerning not detected GRB, provided a list of VHE GRB upper limits useful for modelling. The large collection area and fast slewing of H.E.S.S. make the instrument one of the best instruments to detect other GRBs at VHE.

4. Acknowledgements

The full H.E.S.S. ackwnowledgement list can be found at [3].

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PoS(ICRC2019)761

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PoS(ICRC2019)761