Università degli studi di Trieste

Astrofisica Nucleare e Subnucleare

Analysis of a long GRB afterglow emission

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Journal Club 4

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GRB190829A

Long GRB - Core collapsing rapidly rotating star, with a associated Supernova

- Prompt: ~ 10^2 s
- Afterglow: ~ 10^7 s (slowly fading afterglow)

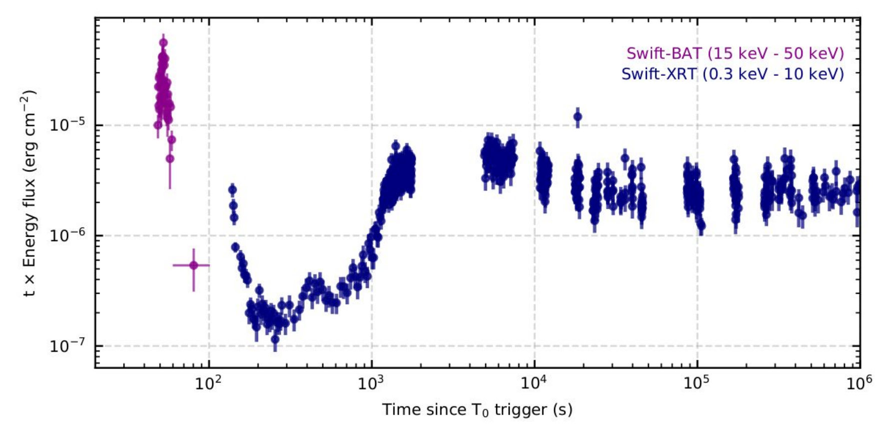
Observations

- Detection by FERMI GBM
- Swift BAT at T_0+ 51s
- Swift XRT at T_0+ 97.3s
- Swift Ultraviolet/Optical Telescope at T_0+ 158s
- Ground based telescope (NIR) at T_0+ 1318s
- HESS (γ) from T_0+ 4.3h to T_0+ 7.9h; from T_0+ 27.2h to T_0+ 31.9h; from T_0+ 51.2h to T_0+ 58.9h
- ATCA (radio) at T_0+ 20.2h
- NOEMA (radio) at T_0+ 29.48h
- VLBA, EVN (radio) from T_0+ 9d to T_0+ 117d
- MeerKAT, AMI-LA (radio) till T_0+ 143d

Prompt emission

3 main events:

- 1st prompt peak T_0 - T_0+4s (Fermi GBM)
- 2nd prompt peak T_0+50s - T_0+60s (Swift BAT)
- 3rd prompt peak T_0+10^3s - $T_0+3 \cdot 10^3$s (Swift XRT) that goes into the afterglow decay



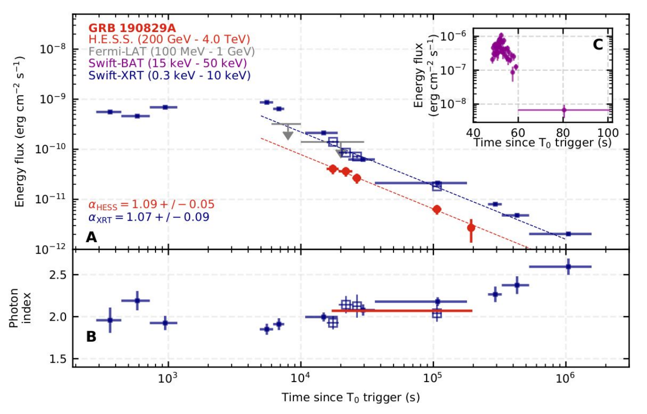
Afterglow emission

High energy photons emission (detected with HESS)

The third night of observation with HESS had not enough photon rilevations

Radio emission was detectable for almost 150 days

Both luminosity and photon energy decrease with time



Why GRB190829A?

Low host galaxy redshift $z=0.0785$	reduced external absorption
Low luminosity	reduced internal absorption

Low luminosity?
This can lead us to
some problems

It is easier to analyse and determine the proper spectrum of this kind of GRBs

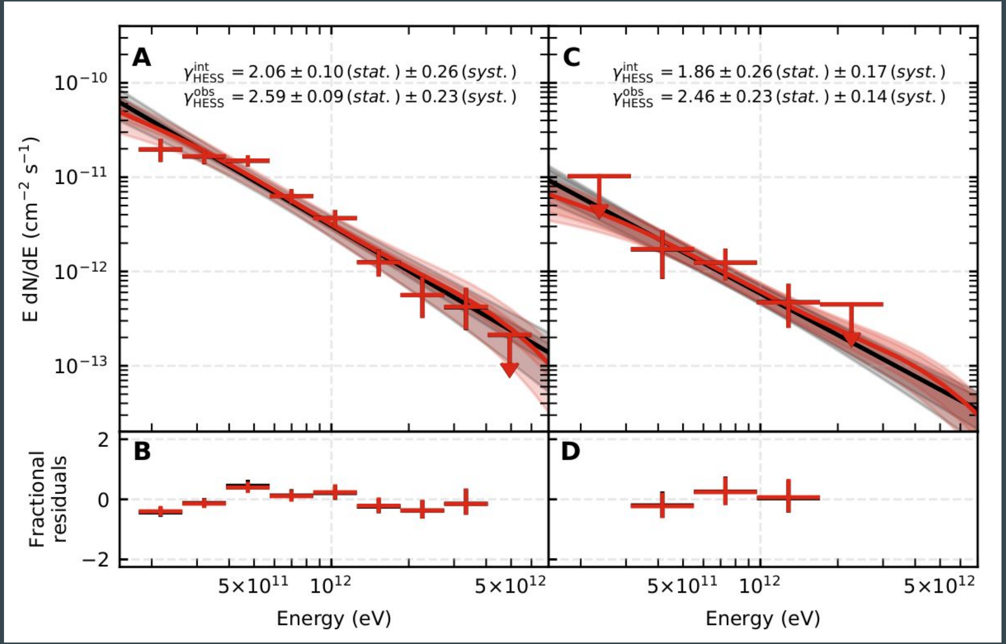
HESS Collaboration - Spectral Analysis

Spectral analysis for first and second night
Consistent results

Result: γ_{VHE}=2.07±0.09(stat)±0.23(syst)
γ_{th}~2

The results are consistent with the Power-law fitted in the X-ray emission with Swift-XRT datas

Attenuated Power-law fit $dE/dN = N_0(E/E_0)^{-\gamma}\, e^{-\tau(E,z)}$
Attenuated Power-law fit for all three nights



HESS Collaboration - Time-dependent decay analysis

Time dependent analysis

Result: $\alpha_{VHE}=1.09\pm0.05$ (0.2 - 4.0 TeV)
$\alpha_{XRT}=1.07\pm0.09$ (0.3 - 10 keV)
$\alpha_{th}\sim1.4$

Power-law fit $F_{VHE} \propto t^{-\alpha}$

There is no time-dependent variability in the shape of the spectrum in the X-ray band

Trying to compute the energy emitted during the prompt and during the afterglow
$E_{prompt} = E_{GBM} + E_{BAT} = 2 \cdot 10^{50} + 1 \cdot 10^{50} = 3 \cdot 10^{50}$ erg
$E_{afterglow} = E_{XRT} = 5 \cdot 10^{50}$ erg
$E_{prompt} < E_{afterglow}$ unusual

HESS Collaboration - Energy problem

Why $E_{prompt} < E_{afterglow}$?

- A non-negligible fraction of the shock energy is transferred into magnetic field enhancement and particle acceleration
- Hadrons and Electrons are accelerated
    - Hadrons cooling time is very long
    - Leptons can lose energy with Synchrotron emission and inverse Compton radiation

Decays of this form suggest that the Magnetisation level, the fraction of energy transferred to non-thermal electrons, and radiative efficiency are constant in time

HESS Collaboration - Multiwavelength model

The emission region has a bulk Lorentz factor $\Gamma=4.7$ (first night) $\Gamma=2.6$ (second night)

- If $\Gamma<10$ accelerated electrons produce very high energy emission
- Get recoiled when up-scattering the synchrotron photons
- This lead to the inverse Compton spectrum shape

It is difficult to reproduce the X-ray and the very high energy spectra with a Self Scattering Compton

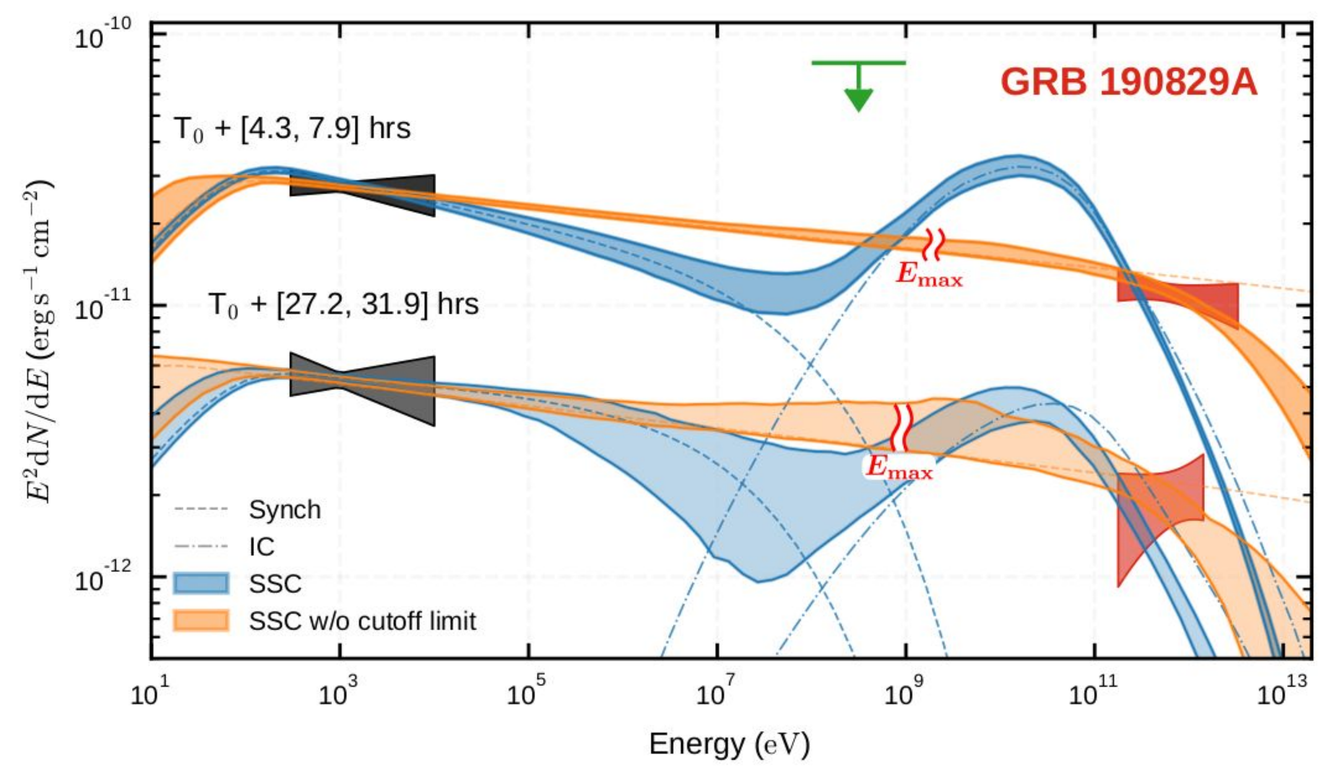
Important: it is set an electron maximum energy due to the energy loss limit

HESS Collaboration - Alternative leptonic scenario

Now remove every constrain on the electron energy (the synchrotron emission can extend to very high energies)

- Synchrotron and Self Scattering Compton explain Gamma-ray and X-ray spectra
- Fit with Markov Chain Monte Carlo with 5 parameters (magnetic field + 4 parameters for the Power-law)

HESS Collaboration - results



HESS Collaboration - Comments

Standard Model

The spectrum is softer then the observations

Spectrum steeped by the internal photon-photon absorption

Inconsistent with observations

Alternative Model

Theoretical spectrum dominated by Synchrotron component from 1 keV to 10 TeV

Self scattering compton and internal photon-photon absorption are negligible (in contrast with observations)

Synchrotron emission electrons accelerated to PeV need a high efficiency process

Inconsistent with observations

HESS Collaboration - New hypothesis suggestion

Higher bulk Lorentz factor

Compton scattering and photon-photon absorption are reduced
Γ too big and inconsistent with the standard hydrodynamic model

Higher electron energy

Additional high energy distribution for accelerated electrons
Extreme conditions on the circumburst medium

Off-axis jet

The bulk Lorentz factor could be underestimated
The low luminosity can be a sign of the off-axis jet
The bulk Lorentz factor decrease is not explained yet

Inverse Compton domination

Cooling electrons follow a harder distribution
Inconsistent with observations

Salafia et al. - Size evolution

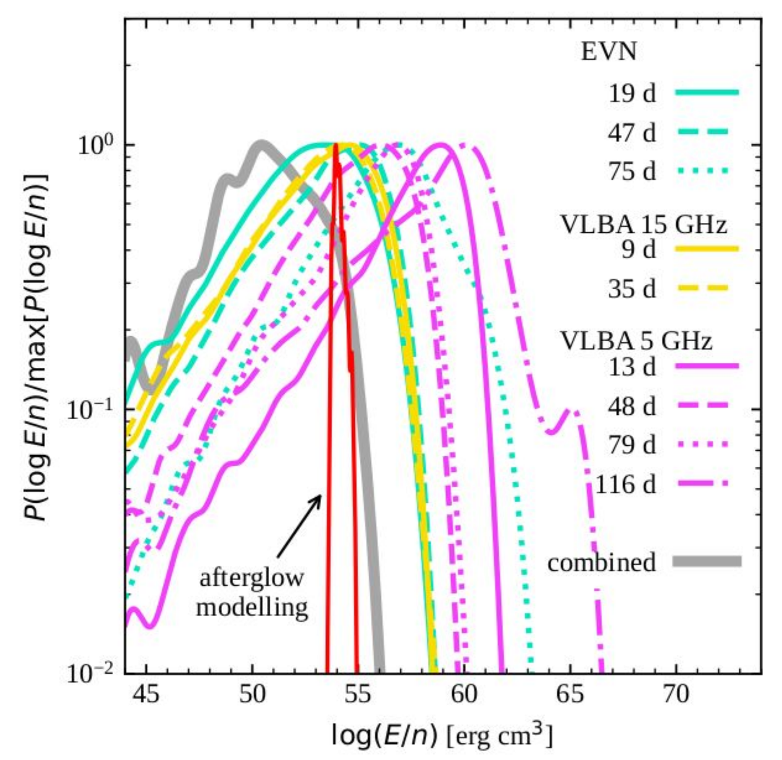
Assumption: $s \propto t^{5/8}$

Blandford-McKee solution for expansion of relativistic blastwave

Sedov length: $l_S = (3E/4\pi n m_p c^2)^{1/3}$

$s \propto l_s^{3/8} t^{5/8} \Rightarrow E/n \propto l_s^{3} \propto s^{8} t^{-5}$

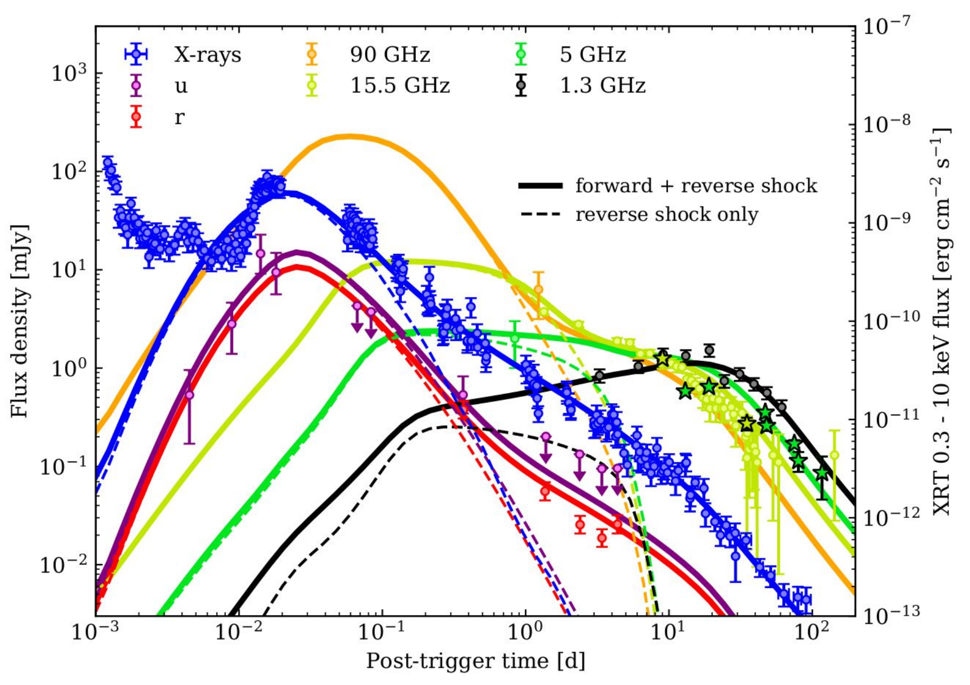
This give us an upper limit on E/n



Salafia et al. - Time evolution

Model used with both forward shock emission and reverse shock emission

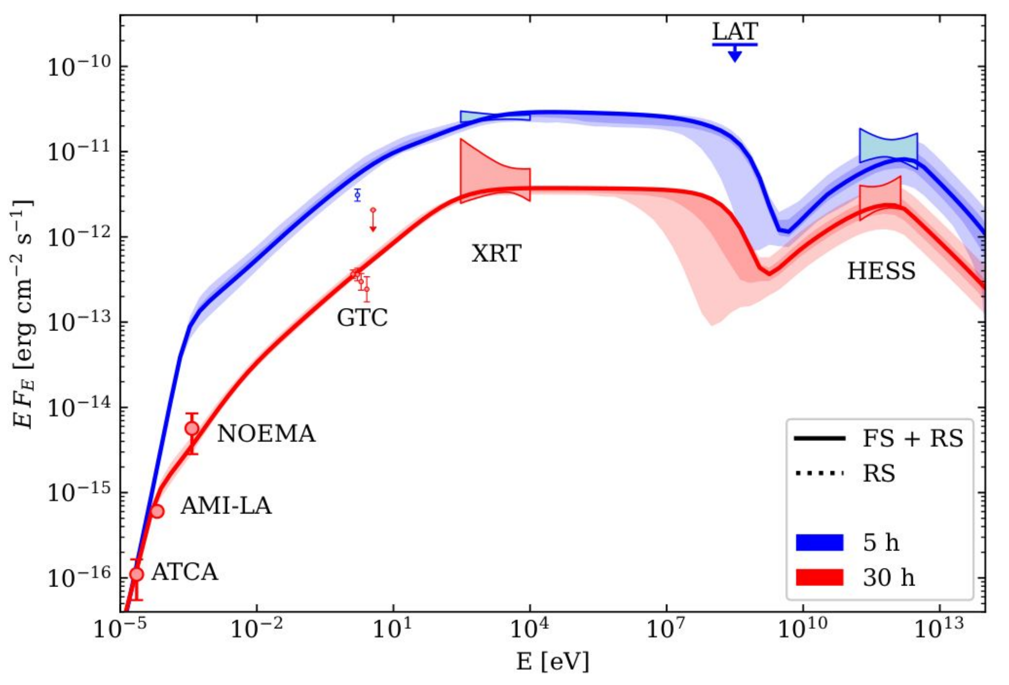
Includes Inverse Compton scattering on electron cooling, with ϵ_e relativistic electron energy density fraction, and ϵ_B isotropic magnetic field energy fraction



Salafia et al. - Spectral Analysis

Interpretation:

- HESS emission is Synchrotron Self-Compton
- Photon-photon absorption is negligible



Salafia et al. - Afterglow model

Usual assumption of χ_e=1 not considered (not all elecrons are accelerated to relativistic speed) ⇒ χ_e=0.04

$E_{afterglow}=2.5 \cdot 10^{53}$ erg
$\theta_{jet}= 15.4$ deg ⇒ $E_{\gamma,iso}=2.91 \cdot 10^{50}$ erg (low efficiency)
$E_{jet} = 9 \cdot 10^{51}$ erg

External medium: n=0.21 cm^{-3}, which is a very low value, in contrast with: the position in the host galaxy and the associated Supernova
It is possible that the progenitor is in a star forming region with a very low metallicity

Salafia et al. - Forward shock

Power-law fit: $\gamma=2.010\pm0.023$

Consistent with the Fermi acceleration in non-relativistic strong shocks

$\chi_{e,FS}=0.023\pm0.012$

$\epsilon_{e,FS}=0.030\pm0.023$

These are comparable with mildly relativistic and weakly magnetised shocks

$\epsilon_{B,FS}=(2.5\pm2.4)\bullet10^{-5}$

Consistent with the previous studies

Salafia et al. - Reverse shock

It is put $\chi_{e,PS}$=1 to reduce the number of parameters

The magnetic field must decay rapidly after the reverse shock crossed the jet
$\Rightarrow$ $\epsilon_{B,RS}$=const

These are the obtained values:

Power-law fit: γ=2.13±0.06
$\epsilon_{e,RS}$=0.28±0.24
$\epsilon_{B,RS}$=1.2±0.8

Salafia et al. - Conclusions

GRB190829A afterglow is produced by a relativistic blastwave

The model with both forward and reverse shocks is consistent with the observations, in the on-axis and uniform external medium assumptions

Not the totality of electrons are accelerated to relativistic energies

The stellar wind of the progenitor is very weak

Differences between the two publications

HESS COLLABORATION	SALAFIA ET AL.
Photon-photon absorption must be significant	HESS emission is synchrotron self-Compton from the forward shock Not significant photon-photon absorption
Size evolution not used (less information)	Size evolution used (more information)
Off-axis angle not taken into account	Off-axis angles analyzed and not considered