An Off-axis Jet Model for Multi-wavelength Afterglow Emission of GRB 190829A detected by H.E.S.S.

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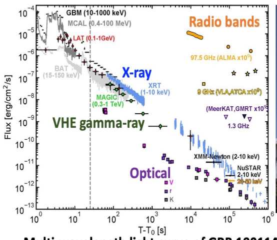
VHE Gamma-ray Afterglows



Multi-wavelength light curve of GRB 190114C (MAGIC collaboration 2019).

Photo of CTA (LST). Credit : Daniel Lopez (IAC)

VHE gamma-rays from some GRBs were detected by MAGIC and H.E.S.S. (GRB 180720B, 190114C, 190829A, 201216C).

It is expected that the number of events will increase in CTA era.

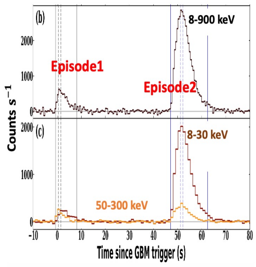
VHE GRB 190829A

Features of GRB 190829A
H.E.S.S. detection with ~20 σ at about 2×10^4 s.
Low redshift of z = 0.0785. (ex ; GRB 180720B : z = 0.654 , GRB 190114C : z = 0.425)
Prompt emission (2 episodes) : smaller $E_{\rm iso}$ and $E_{\rm peak}$ than typical long GRBs.
Early X-ray and optical/IR afterglow : rising part and achromatic peak at about 2×10^3 s.

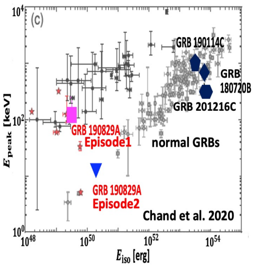
We consider off-axis jet model to explain those unusual observed properties of GRB 190829A.

GRB 190829A : Prompt Emission

Light curves of prompt emission of GRB 190829A



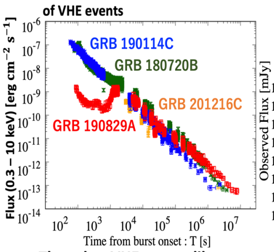
GRB 190829A in $E_{\rm iso}$-$E_{\rm peak}$



GRB 190829A has smaller $E_{\rm iso}$ and $E_{\rm peak}$ than typical long GRBs and the other VHE gamma-ray events.

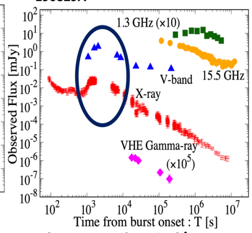
GRB 190829A : Afterglow

Light curves of X-ray afterglow of VHE events



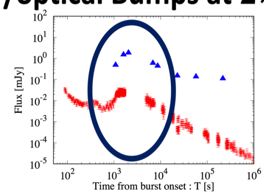
The other VHE events like GRB 190114C and 180720B, showed monotonically decaying X-ray afterglow emission.

Multiwavelength light curves of GRB 190829A



Early X-ray and optical/IR afterglow emission showed a rising part and had achromatic peaks at about 1.4×10^3 s.

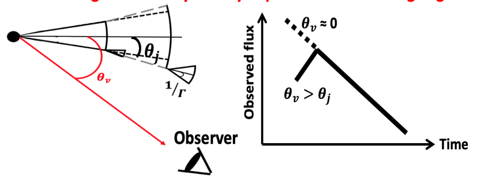
X-ray/optical Bumps at 2×10^3 s



Theoretical models of bumps at 2×10^3 s	
An X-ray flare	Chand et al. 2020, BT Zhang et al. 2021
Baryon loaded outflow	Fraija et al. 2020
e^+e^- dust shell	LL Zhang et al. 2021
Reverse shock	Salafia et al. 2021, Dichiara et al. 2022
Off-axis afterglow	This work (Sato et al. 2021)

Off-axis Jet Model

- If the jet is viewed off-axis ($\theta_v > \theta_j$), the relativistic beaming effects cause the prompt emission to be dimmer and softer than on-axis ($\theta_v \approx 0$) viewing case.
- The bulk Lorentz factor of the jet is initially so high that the afterglow emission is very dim because of the relativistic effect.
- As the jet decelerates, the beaming effect becomes weak, resulting in the emergence of a rising part in afterglow light curves.
- After the peak of the emission, the jet has smaller Lorentz factors so that the light curve only weakly depends on the viewing angle.

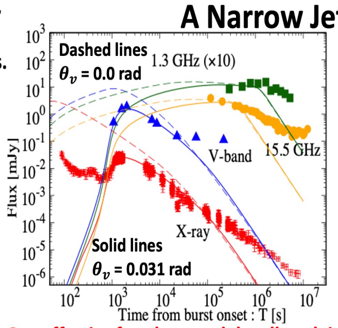


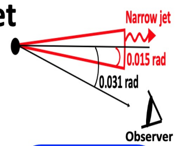
Model Description of Afterglow

- A relativistic jet interacts with ISM, forming external shock, radiating synchrotron emission in X-ray, optical(V-band) and radio bands(1.3 and 15.5 GHz) by accelerated electrons.
- We determined model parameters (shown below) to explain X-ray, optical and radio afterglows.

parameters of the present model	
θ_v	Viewing angle
θ_0	Initial jet opening half-angle
Γ_0	Initial Lorentz factor
E_K	Initial isotropic-equivalent kinetic energy
n_0	ISM density (uniform)
p	Electron power-law(PL) index
ε_e	The energy fractions of internal energy going into PL electrons
ε_B	The energy fractions of internal energy going into magnetic field
f_e	The number fraction of accelerated electrons

Off-axis Afterglow Emission from A Narrow Jet

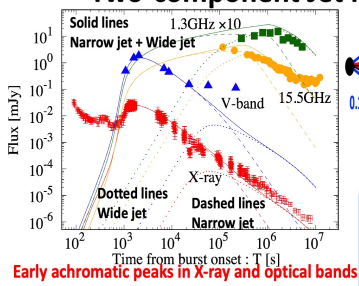


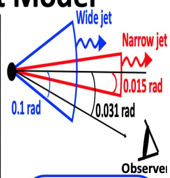


Narrow jet parameters
θ_v = 0.031 rad
θ_0 = 0.015 rad
Γ_0 = 350
E_K = 4.0×10^{53} erg
n_0 = 0.01 $\rm cm^{-3}$
p = 2.44
ε_B = 5.0×10^{-5}
ε_e = 0.2

Our off-axis afterglow model well explains the observational results of early X-ray and optical afterglow.

Two-component Jet Model





Wide jet parameters
θ_v = 0.031 rad
θ_0 = 0.1 rad
Γ_0 = 20
E_K = 2.0×10^{53} erg
n_0 = 0.01 $\rm cm^{-3}$
p = 2.2
ε_B = 1.0×10^{-5}
ε_e = 0.4

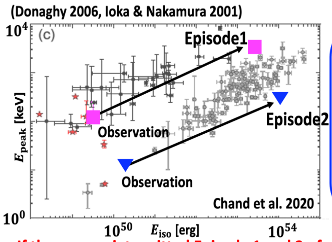
Early achromatic peaks in X-ray and optical bands → The off-axis narrow jet emission.

The late X-ray and radio afterglows → The wide jet emission.

The optical observation is brighter than our result later than 5×10^4 s → SN component (Hu et al. 2021).

Prompt Emission Properties of Narrow Jet

We discuss whether $E_{\rm iso}$ and $E_{\rm peak}$ from our narrow jet (Γ_0=350) were typical or not if it would have been viewed on-axis ($\theta_v \approx 0$). (Donaghy 2006, Ioka & Nakamura 2001)



Efficiency of prompt emission :

$$\eta_\gamma = \frac{E_{{\rm iso},\gamma}}{E_{{\rm iso},\gamma}+E_{{\rm iso},K}}$$

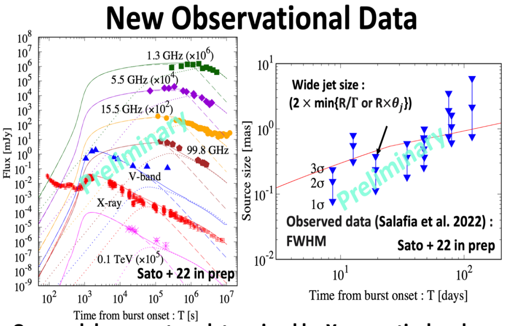
Episode 1 : η_γ = 0.4

Episode 2 : η_γ = 0.8

If the narrow jet emitted Episode 1 and 2 of observed prompt emission, on-axis quantities are similar to typical long GRBs.

It is uncertain whether the narrow jet causes both Episodes 1 and 2.

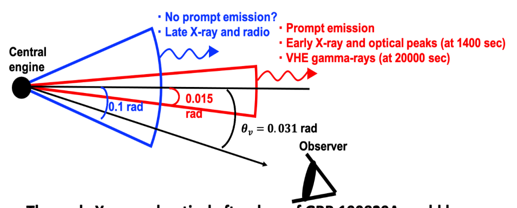
New Observational Data



Our model parameters determined by X-ray, optical and radio afterglows may roughly explain new observations.

VHE gamma-ray flux is consistent with SSC from large energy jet.

Conclusion



The early X-ray and optical afterglow of GRB 190829A could be off-axis emission from the narrow jet.

The late X-ray and radio afterglow came from the wide jet.

Our parameter may also explain VHE gamma-ray and and radio flux and radio size observation.

Some low-luminosity GRBs may be explained by off-axis jet model ??