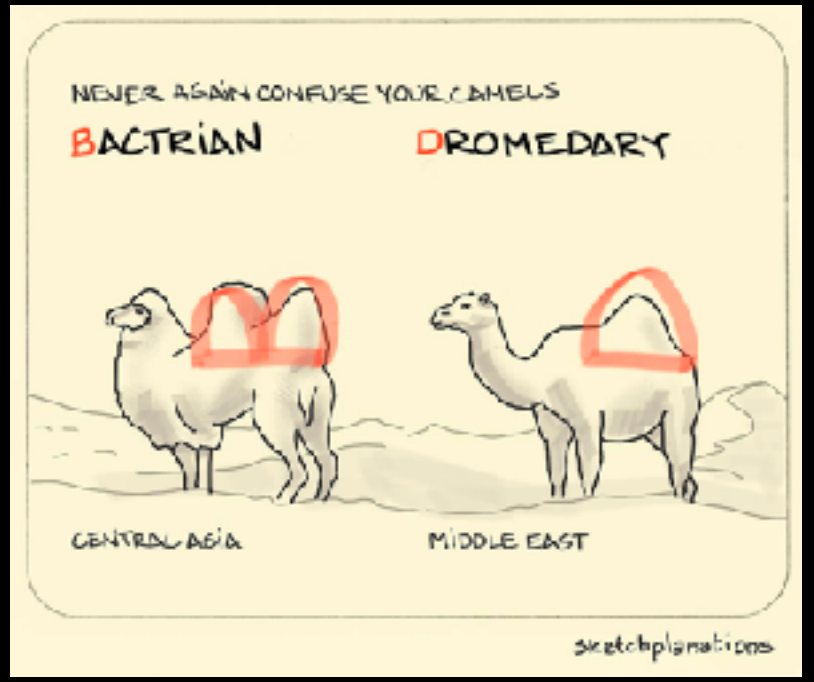
# Very-High-Energy gamma rays from gamma-ray bursts

## A tale of two camels

Very High Energy (VHE): >100 GeV




**Sylvia J. Zhu, DESY**
sylvia.zhu@desy.de

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

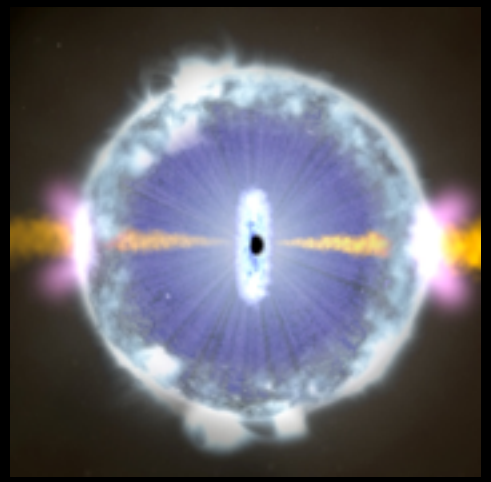
# disclaimer

I’m going to focus on the papers from the collaborations (sorry)
but there are plenty of other papers on these GRBs that you should look at
and plenty of people at this very conference that you should talk to

# don’t worry I’ll talk about GRB 221009A later

aka the one all your GRB colleagues are talking about

# so what the heck is a gamma-ray burst



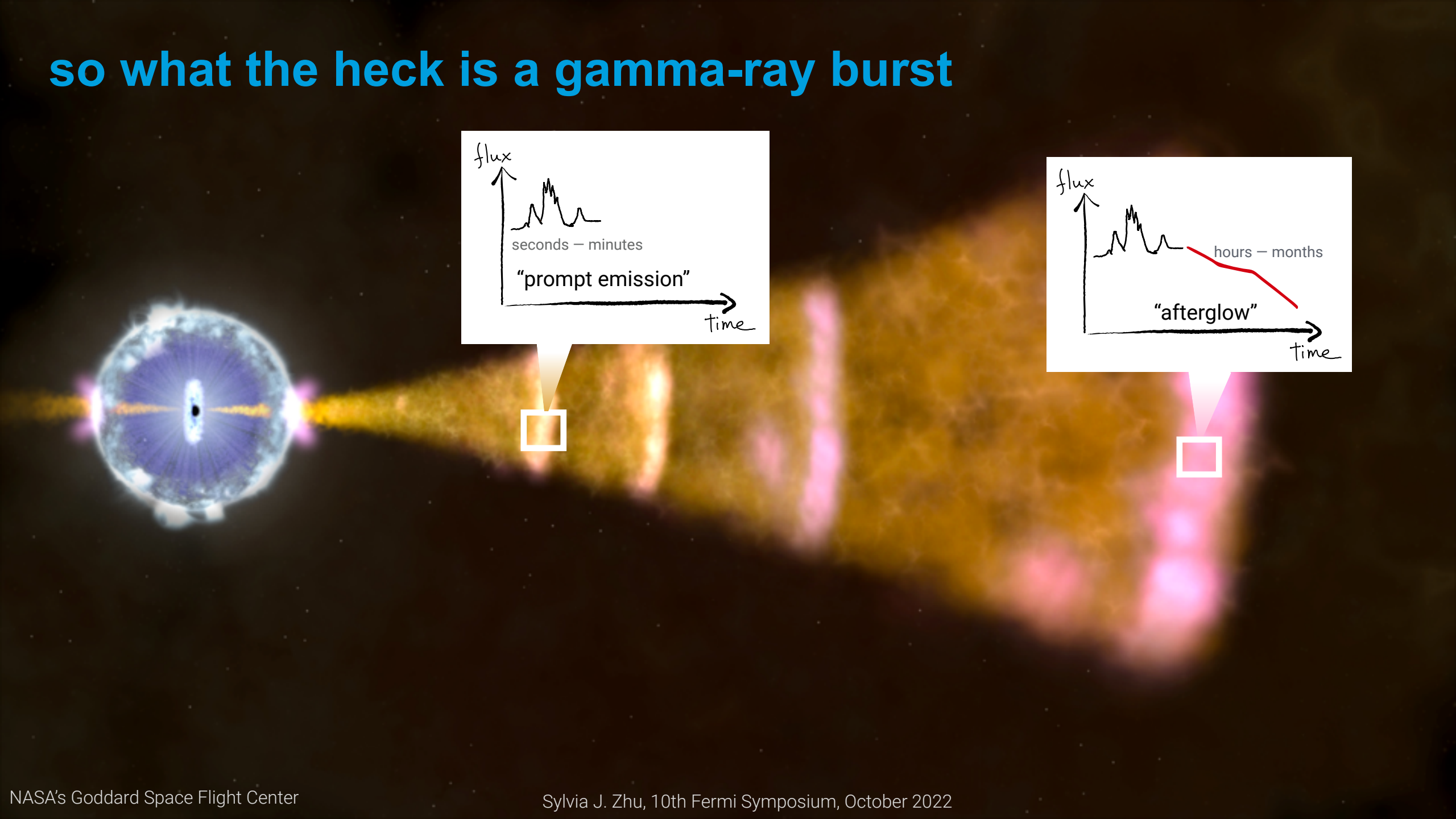
NASA's Goddard Space Flight Center/CI Lab

two compact objects merge

ESO/L Calçada

a massive star collapses

# so what the heck is a gamma-ray burst



# so what the heck is a gamma-ray burst

DESY, Science Communication Lab

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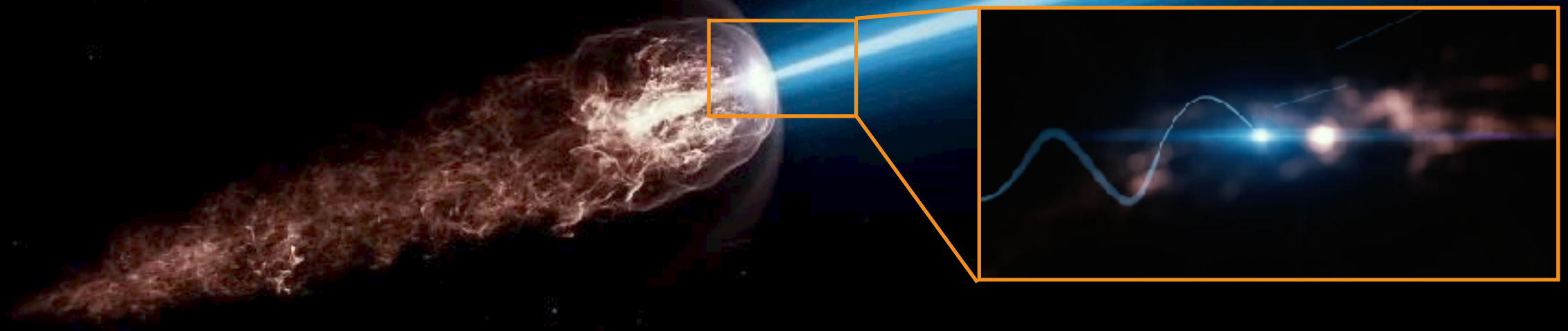

DESY, Science Communication Lab

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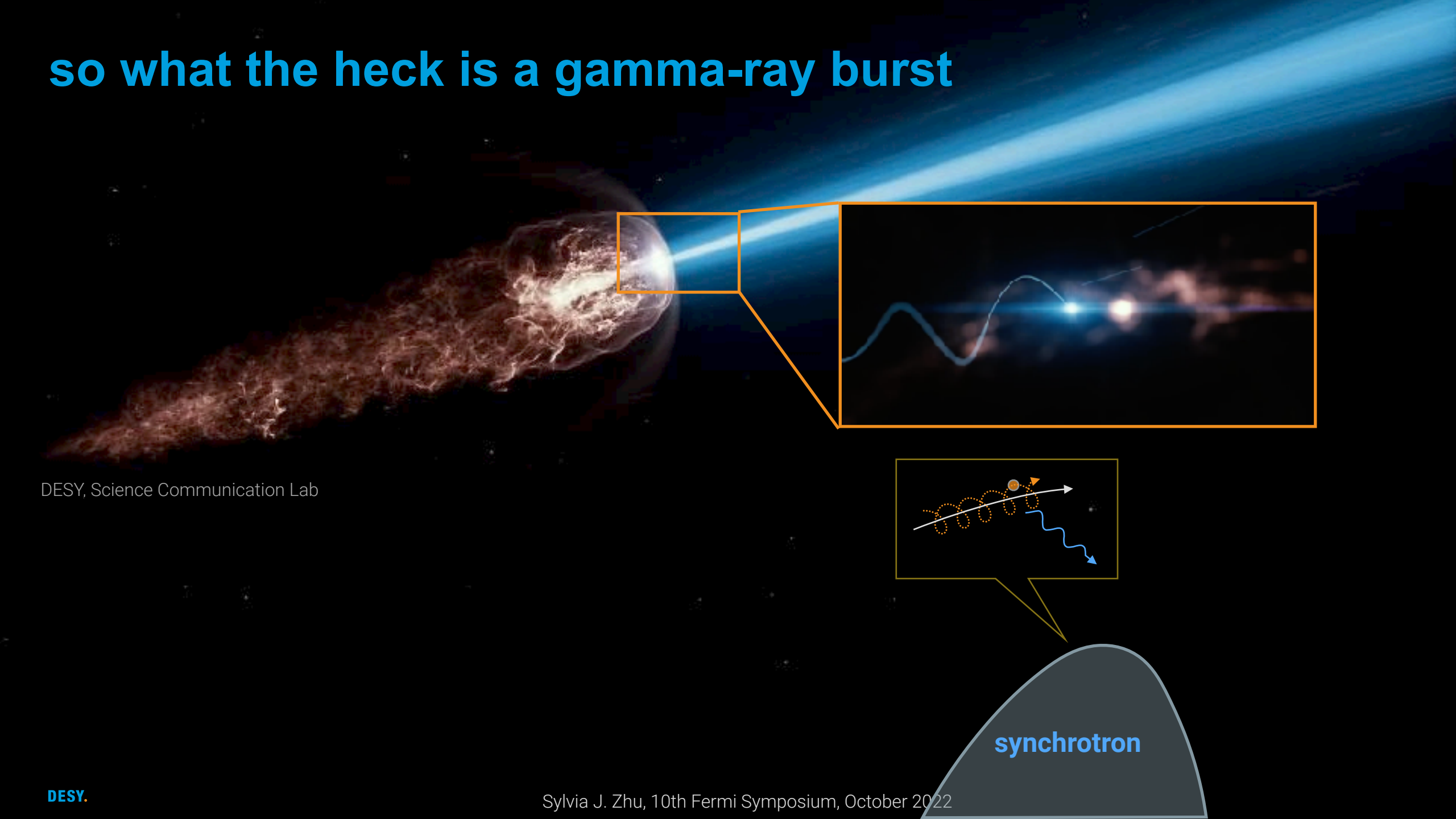


DESY, Science Communication Lab

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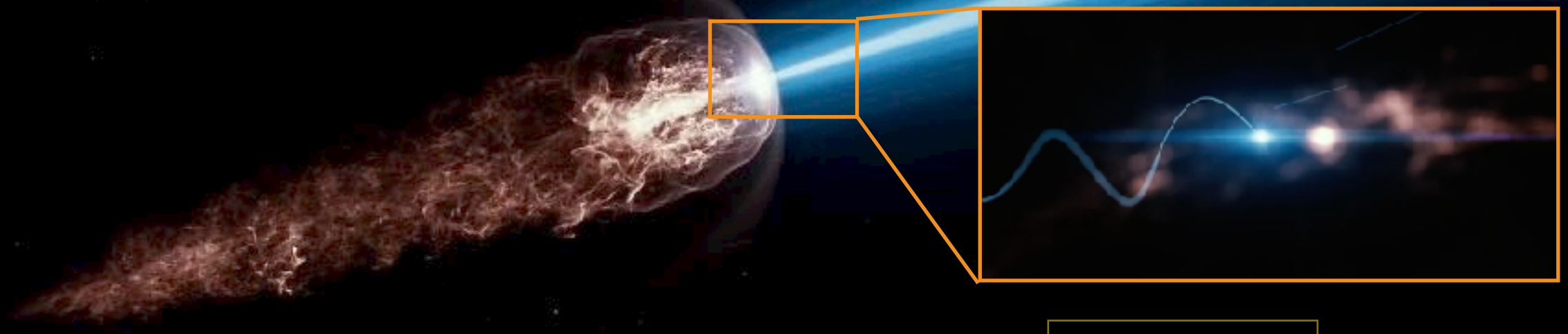
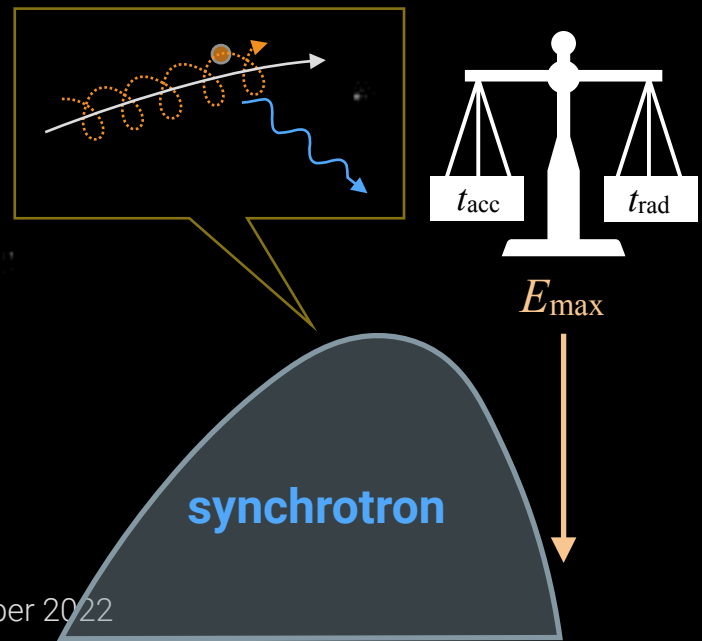


DESY, Science Communication Lab



# so what the heck is a gamma-ray burst

DESY, Science Communication Lab

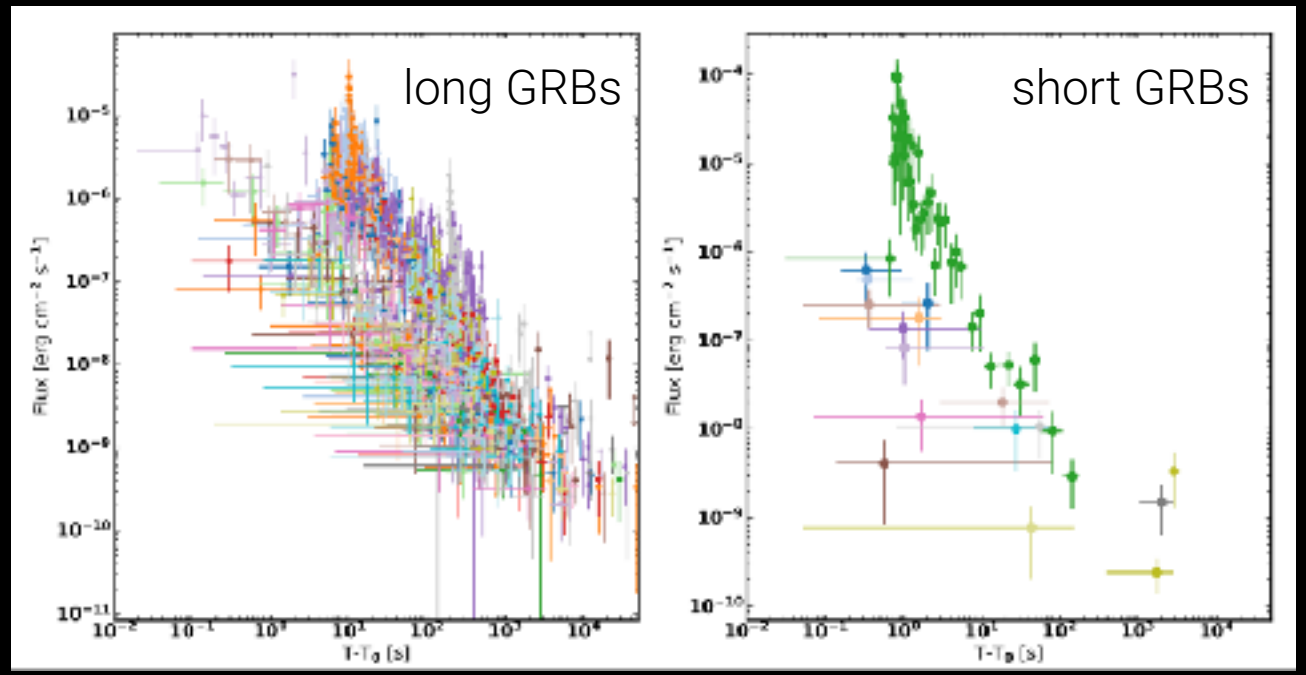
synchrotron

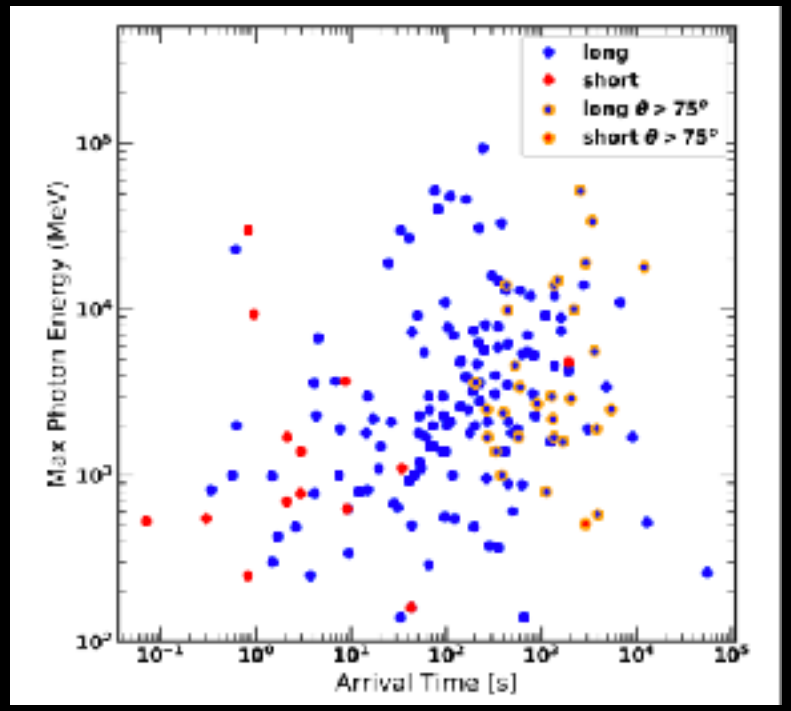
synchrotron self-Compton

# Things we learned from LAT

The GeV emission can last for >hours after GRB onset, and high-energy photons still arrive at late times

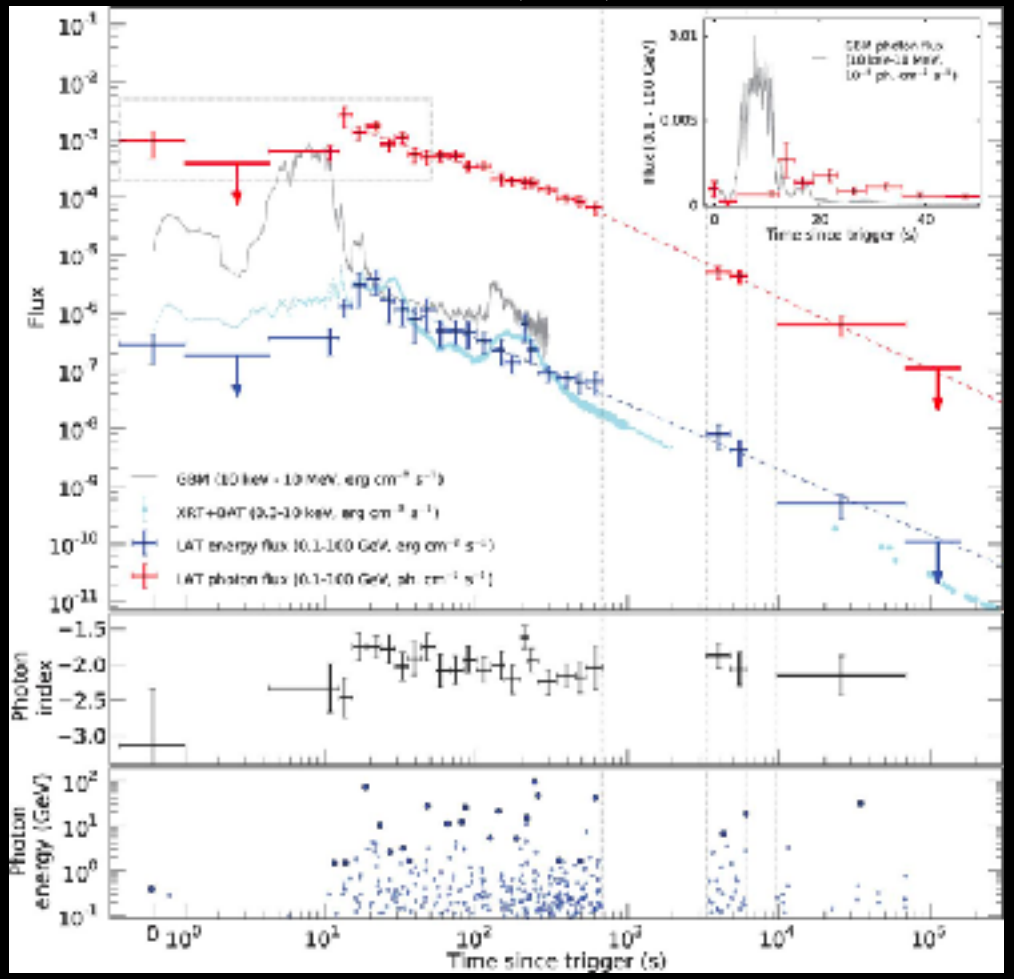
Ajello et al., ApJ 878 (2019)



# Things we learned from LAT: GRB 130427A

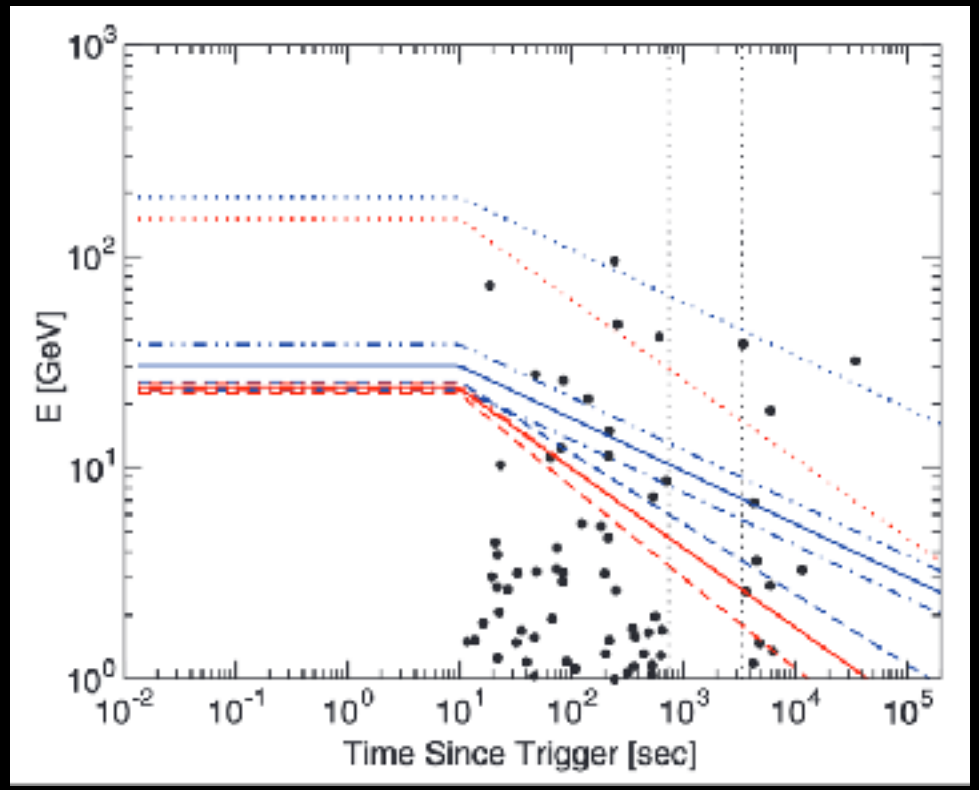
Ackermann et al., Science 343 (2014)




(almost a VHE GRB!)

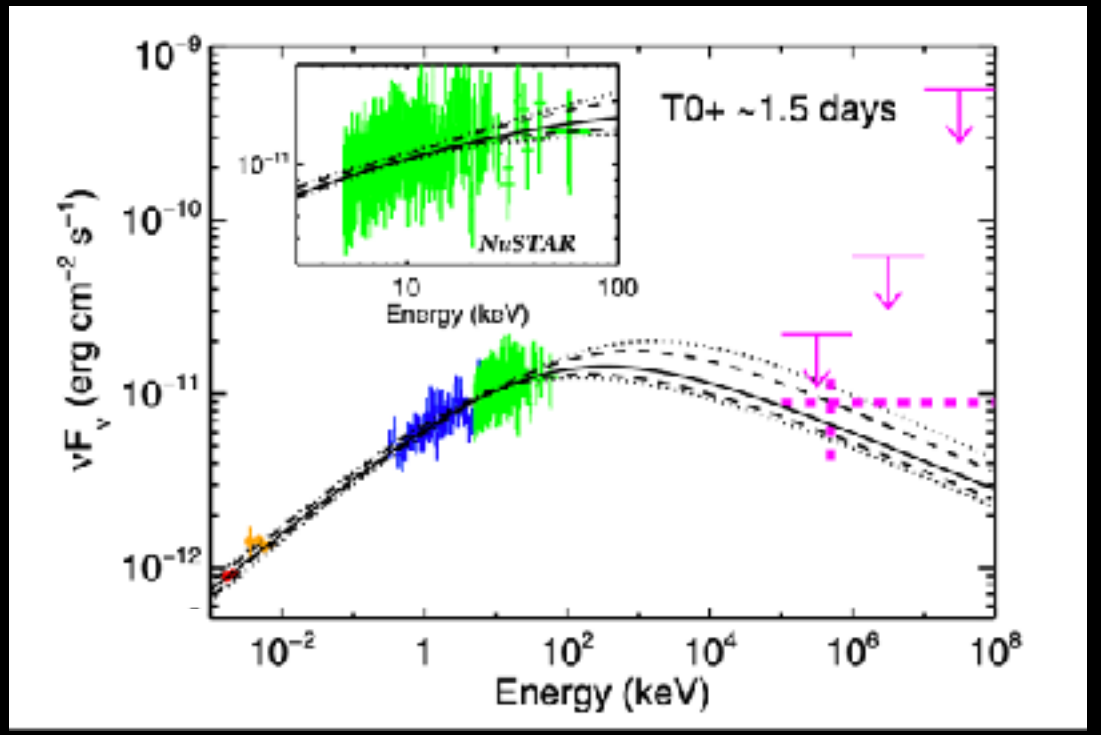
# Things we learned from LAT: GRB 130427A

Ackermann et al., Science 343 (2014)




The highest energy photons are hard to explain as synchrotron in the standard scenario (one-zone)

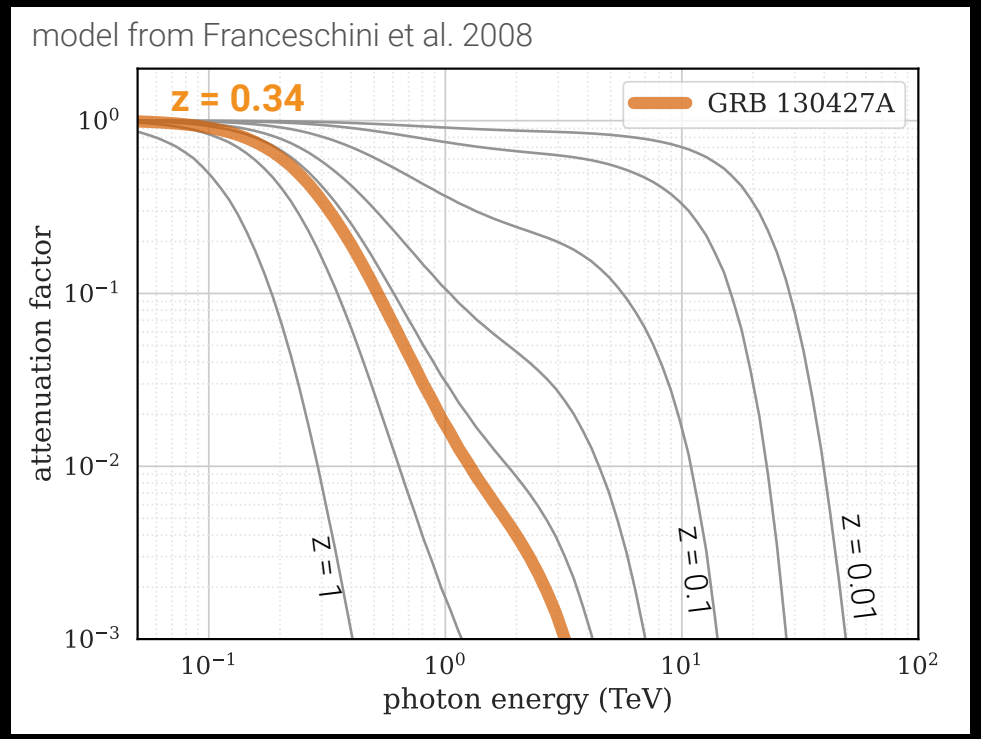
Kouveliotou et al., ApJL 779 (2013)

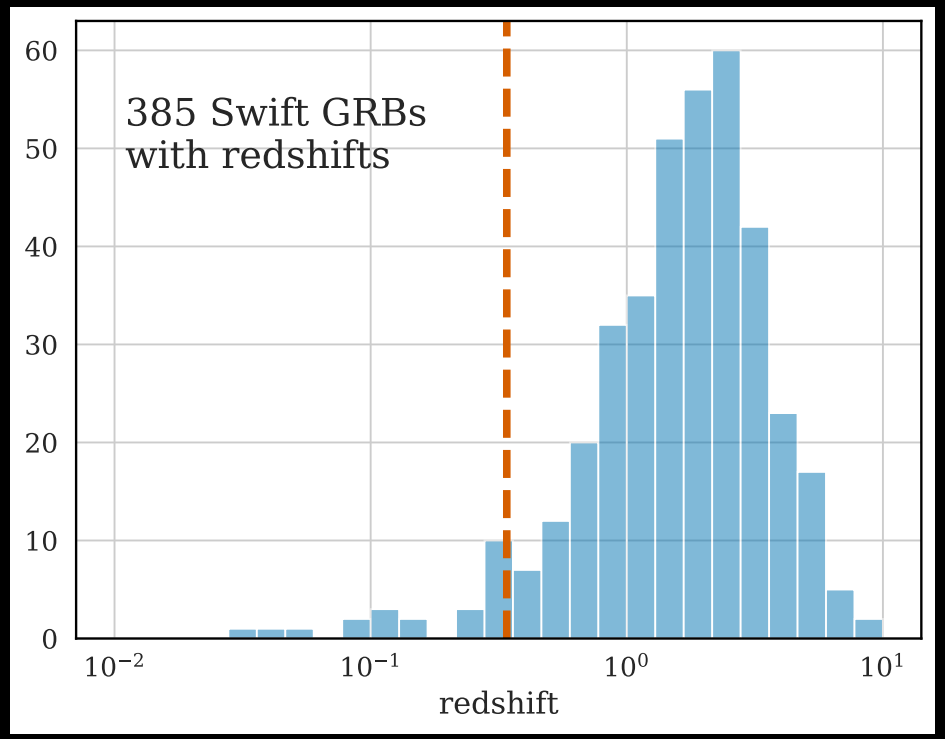



But there is no sign of an extra component in the LAT energy range

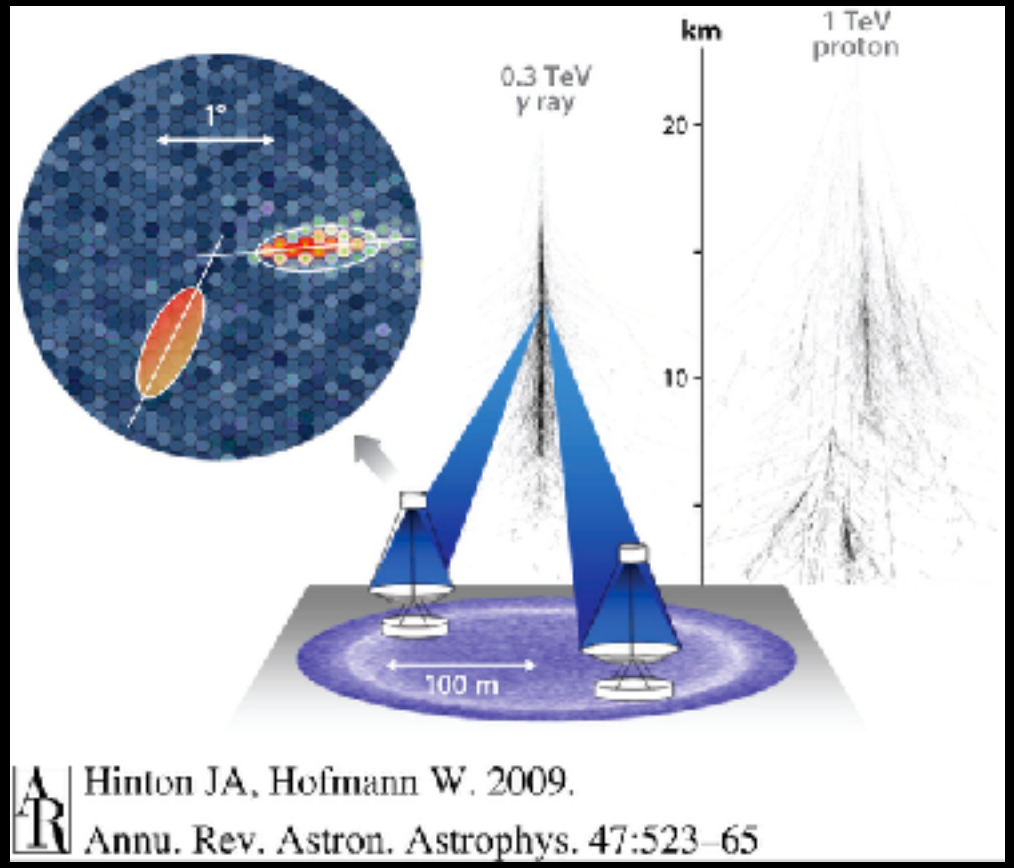
# The highest energy gamma rays are preferentially absorbed

To explore the highest energies, we need to examine the closest GRBs



# Imaging Atmospheric Cherenkov Telescopes (IACTs)

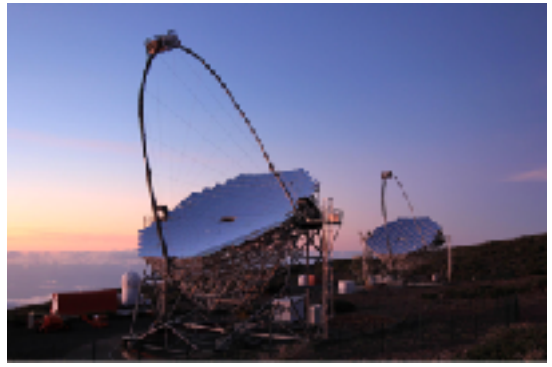


# The current set of IACTs

Derek Strom, Giovanni Ceribella and the MAGIC Collaboration

## MAGIC

3.5° field of view
can slew 180° in 25 s
>50 GeV
two 17m



Otger Ballester (IFAE)

## LST-1

4.5° field of view
can slew 380° in 25 s
>20 GeV
23m



## VERITAS



VERITAS Collaboration



## H.E.S.S.

3° field of view at 50 GeV
can slew 100°/min
>50 GeV
28m + four 12m

H.E.S.S., MPIK/Christian Foehr

Wikimedia Commons

# VHE observations of GRBs so far

**(GRB 130427A *Fermi*-LAT)**

(GRB 160821B MAGIC)

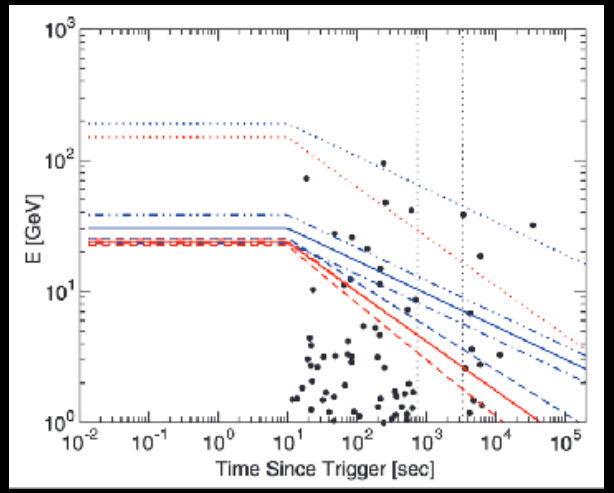
GRB 180720B H.E.S.S.

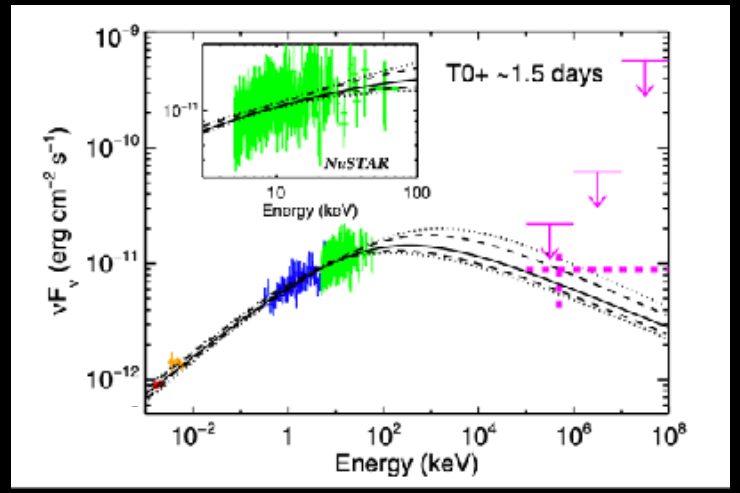
GRB 190114C MAGIC

GRB 190829A H.E.S.S.

GRB 201015A MAGIC

GRB 201216C MAGIC




Highest-energy photons difficult to explain as synchrotron in the single-zone scenario

But, no indication of extra component between X-rays and GeV

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GRB 180720B H.E.S.S.

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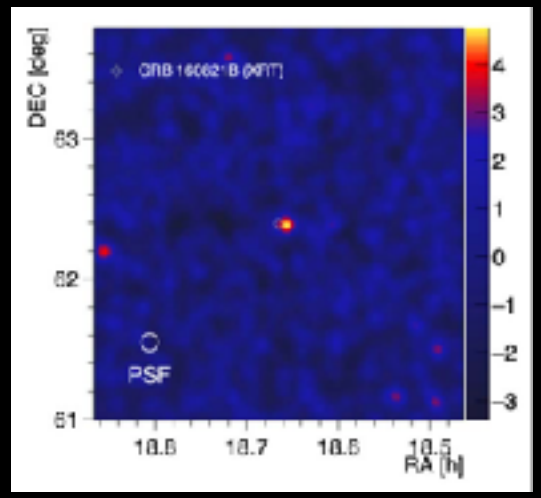
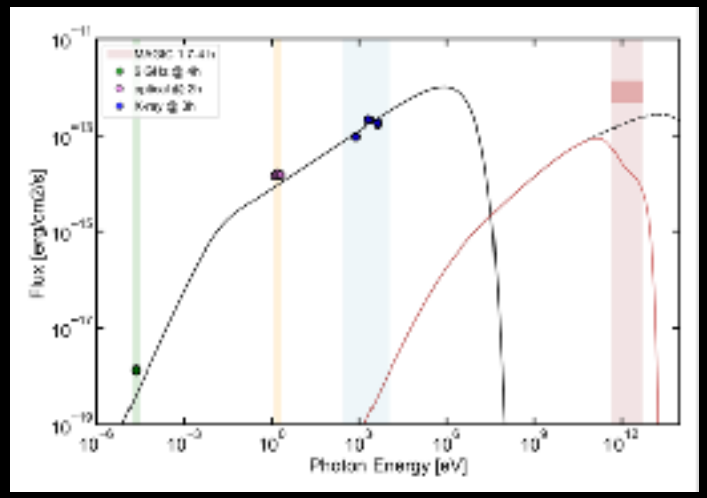
GRB 190829A H.E.S.S.

GRB 201015A MAGIC

GRB 201216C MAGIC

Acciari et al., ApJ 908 (2021)




3σ signal from a **short** GRB at z = 0.16
"Simplest emission model (synchrotron + SSC at external forward shock) is intension with the TeV predicted flux"

- A. Berti's presentation (pdf)

# VHE observations of GRBs so far

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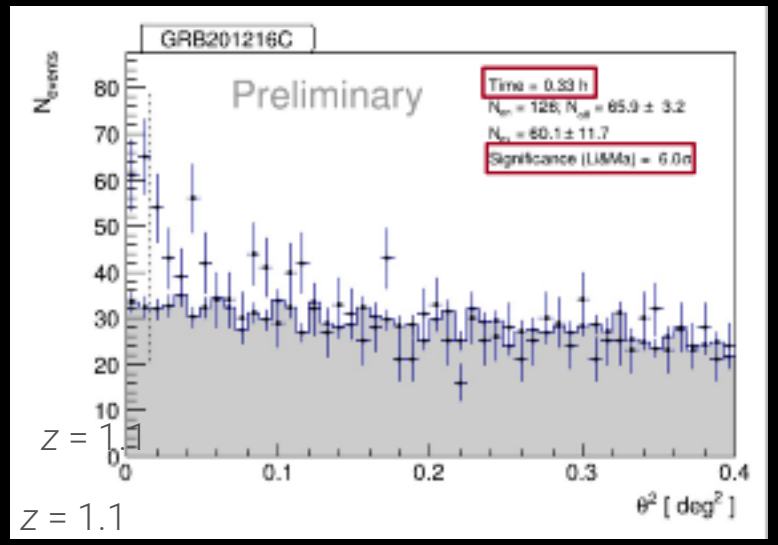
GRB 190114C MAGIC

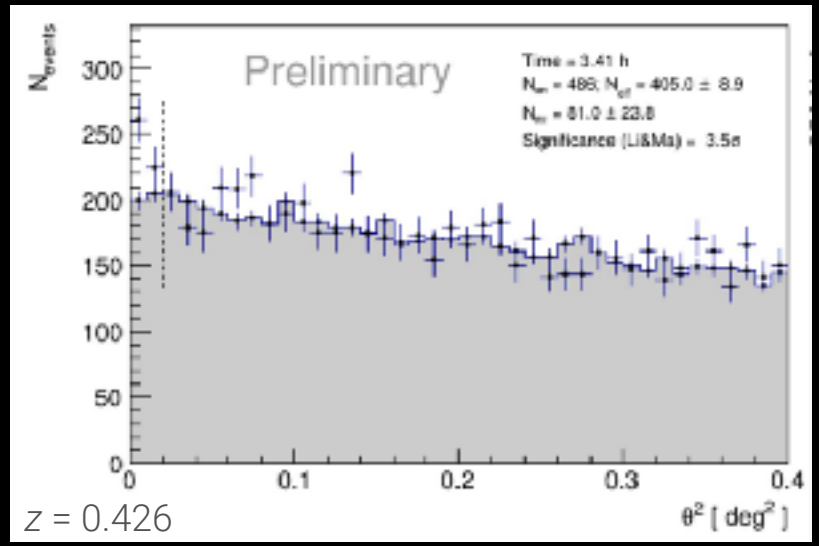
GRB 190829A H.E.S.S.

**GRB 201015A MAGIC**

**GRB 201216C MAGIC**

From A. Berti's presentation at TeVPA 2022 (pdf)




Two as-yet unpublished but interesting GRBs
Paper on 201216C by MAGIC collaboration expected soon

# VHE observations of GRBs so far

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GRB 190114C MAGIC

GRB 190829A H.E.S.S.

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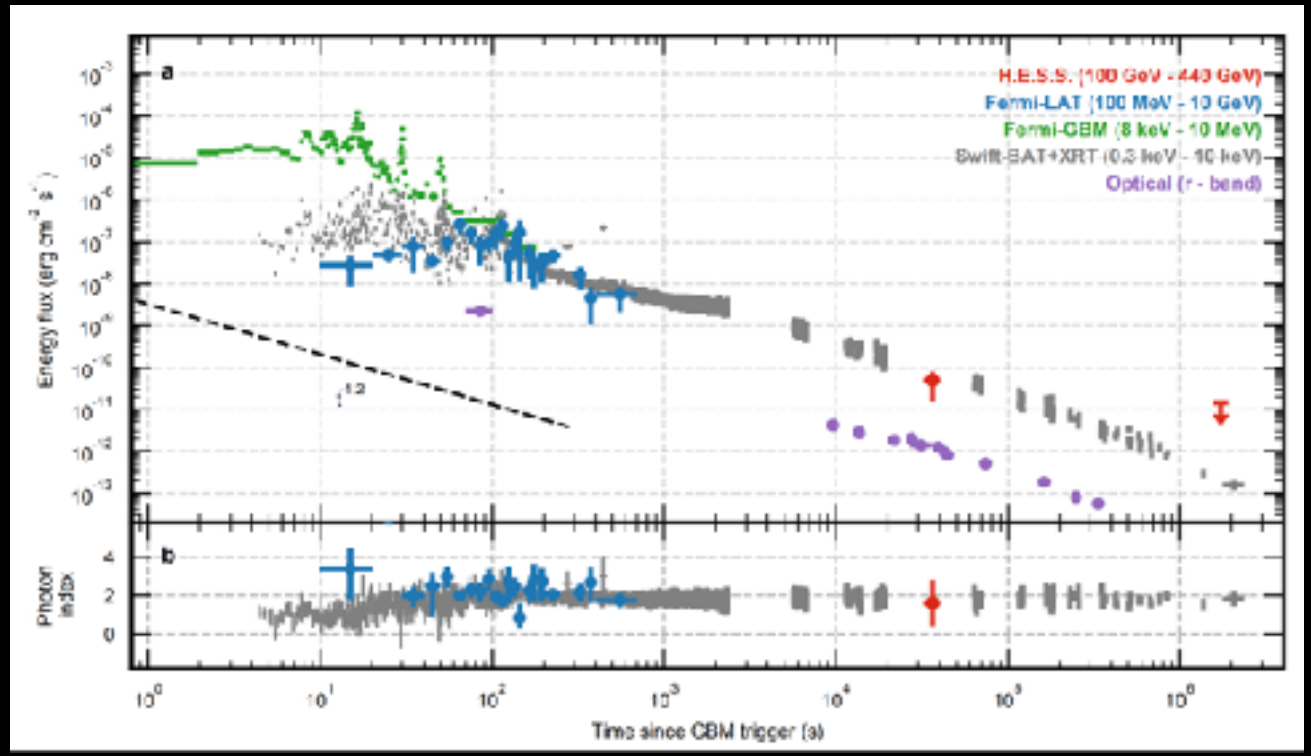
Abdalla et al., Nature 575 (2019)




H.E.S.S. reported a 5σ detection 8 hours after the GRB onset
The VHE and X-ray energy fluxes at this time are around the same level

# VHE observations of GRBs so far

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GRB 190829A H.E.S.S.

GRB 201015A MAGIC

GRB 201216C MAGIC

Article | Published: 22 November 2019

**Teraelectronvolt emission from the γ-ray burst GRB 190114C**

MAGIC Collaboration

Nature 575, 455–458 (2019) | Cite this article

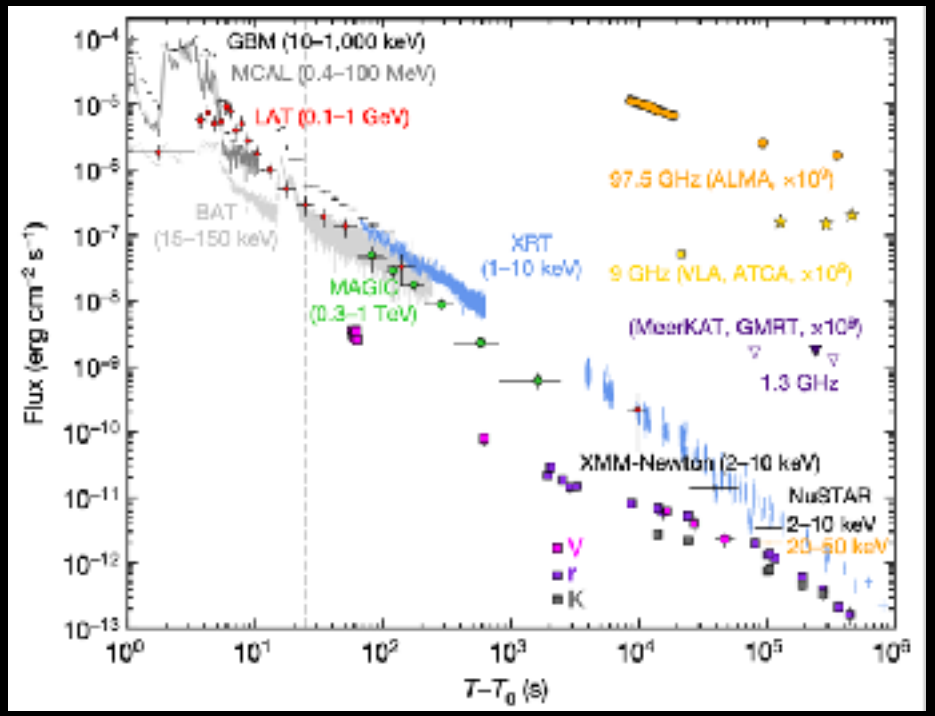
Article | Published: 22 November 2019

**Observation of inverse Compton emission from a long γ-ray burst**

MAGIC Collaboration, P. Veres, P. N. Bhat, M. S. Briggs, V. H. Cleveland, K. Hamburg, C. M. Hui, B. Mailyan, S. C. Pierce, D. J. Roberts, A. von Kienlin, C. A. Wilson-Hodge, E. Bissaldi, M. Arimoto, D. Tak, K. Asano, M. Axelsson, C. Baldini, E. Bissaldi, F. Fana Dirirsa, Y. Gill, J. Granot, J. Hoffmann, W. ...

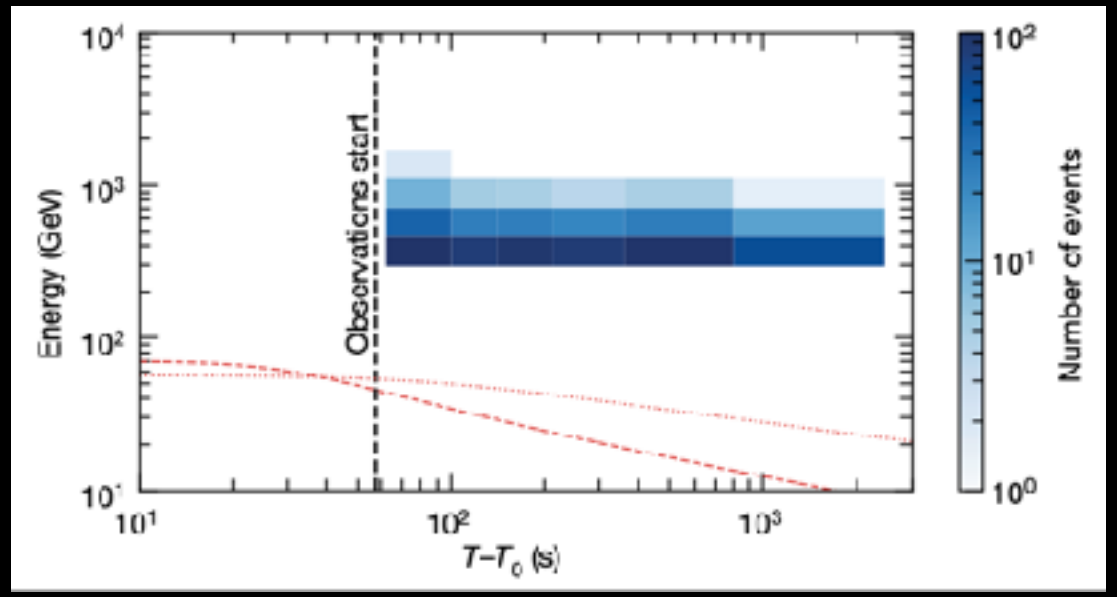
Nature 575, 459–463 (2019) | Cite this article

Acciari et al., Nature 575, p. 459 (2019)

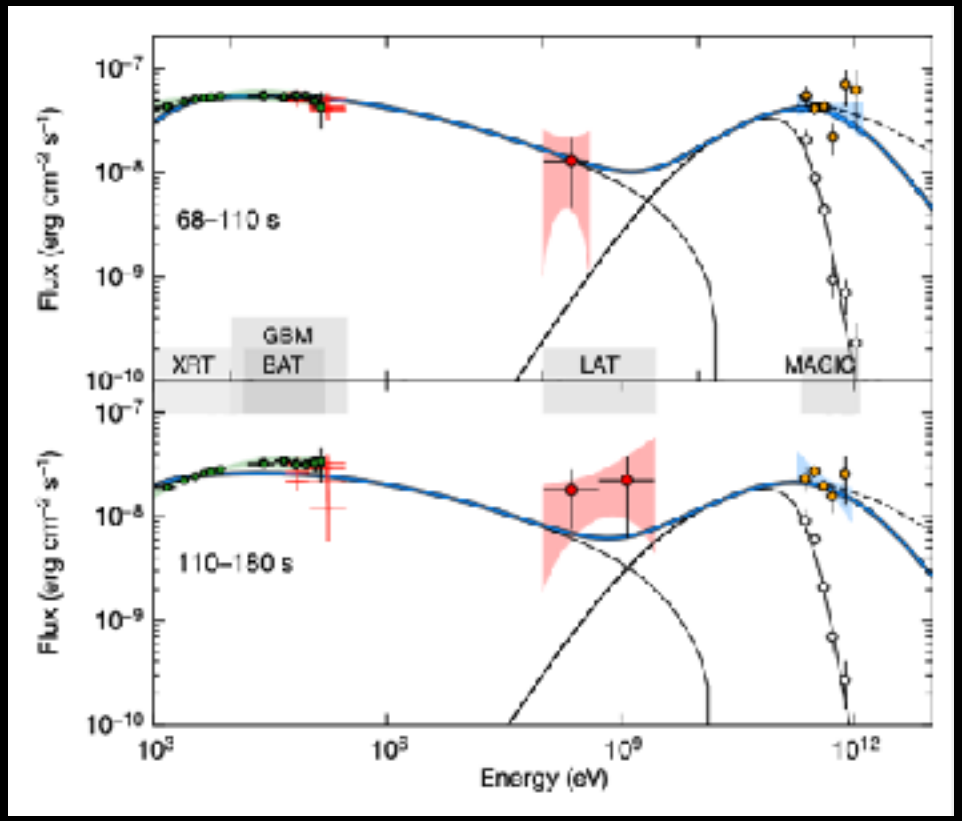


# GRB 190114C: Extremely bright in VHE gamma rays

Acciari et al., Nature 575, p. 455 (2019)




Acciari et al., Nature 575, p. 459 (2019)




but see arXiv:2206.11148
(disclaimer: I'm involved in this study)

# VHE observations of GRBs so far

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(GRB 160821B MAGIC)

GRB 180720B H.E.S.S.

GRB 190114C MAGIC

**GRB 190829A H.E.S.S.**

GRB 201015A MAGIC

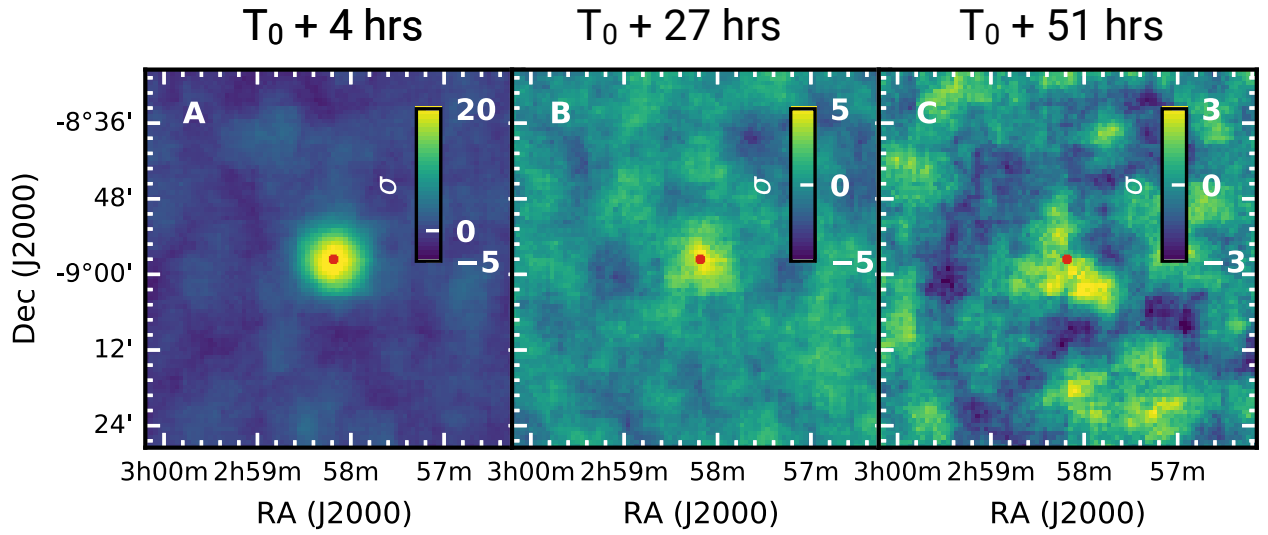
GRB 201216C MAGIC

**Revealing x-ray and gamma ray temporal and spectral similarities in the GRB 190829A afterglow**

H.E.S.S. COLLABORATION, H. ABDALLA, F. AHARONIAN, F. AIT BENKHALI, E. O. ANGÜNER, D. ARCARO, C. ARMAND, T. ARMSTRONG, H. ASHKAR, [...] K. PAGE

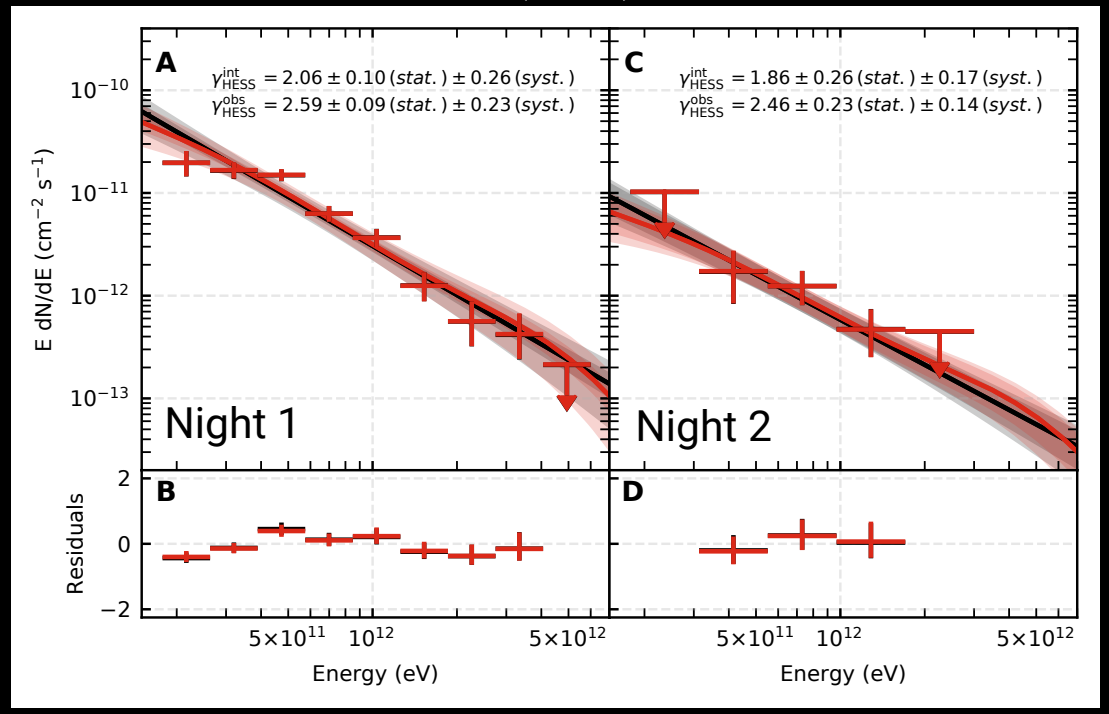
+230 authors Authors Info & Affiliations

SCIENCE · 4 Jun 2021 · Vol 372, Issue 6545 · pp. 1081-1085 · DOI: 10.1126/science.abe8560

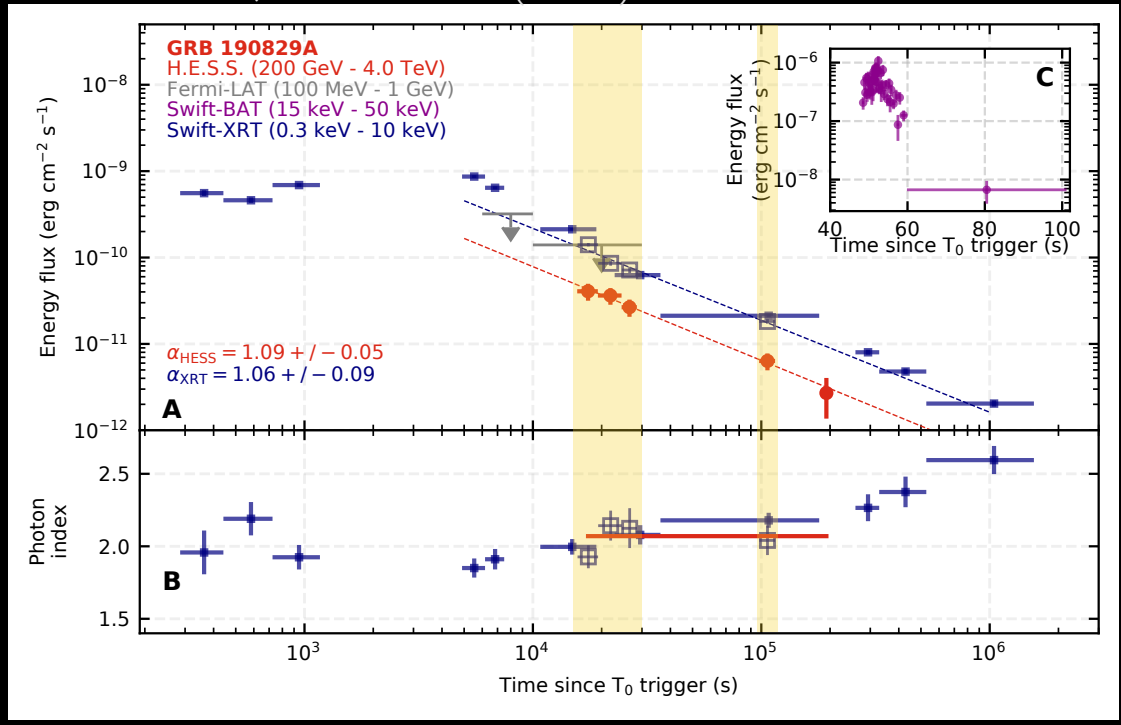


# GRB 190829A: Extremely long-lasting in VHE gamma rays

Abdalla et al., Science 372 (2021)




Abdalla et al., Science 372 (2021)



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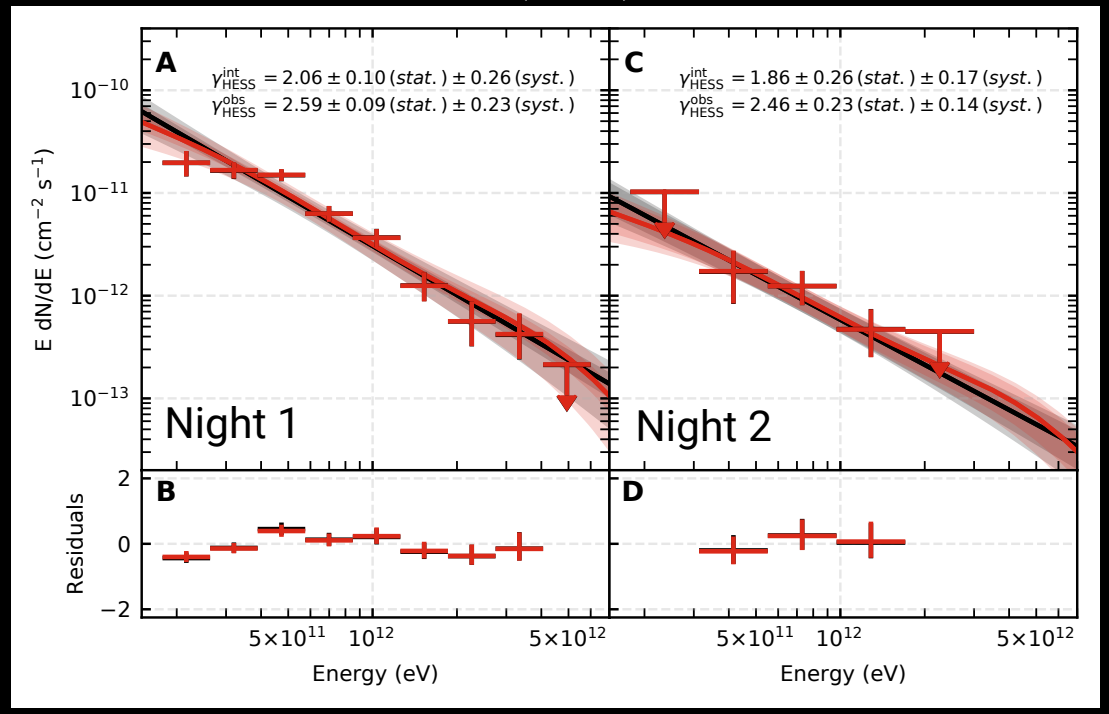
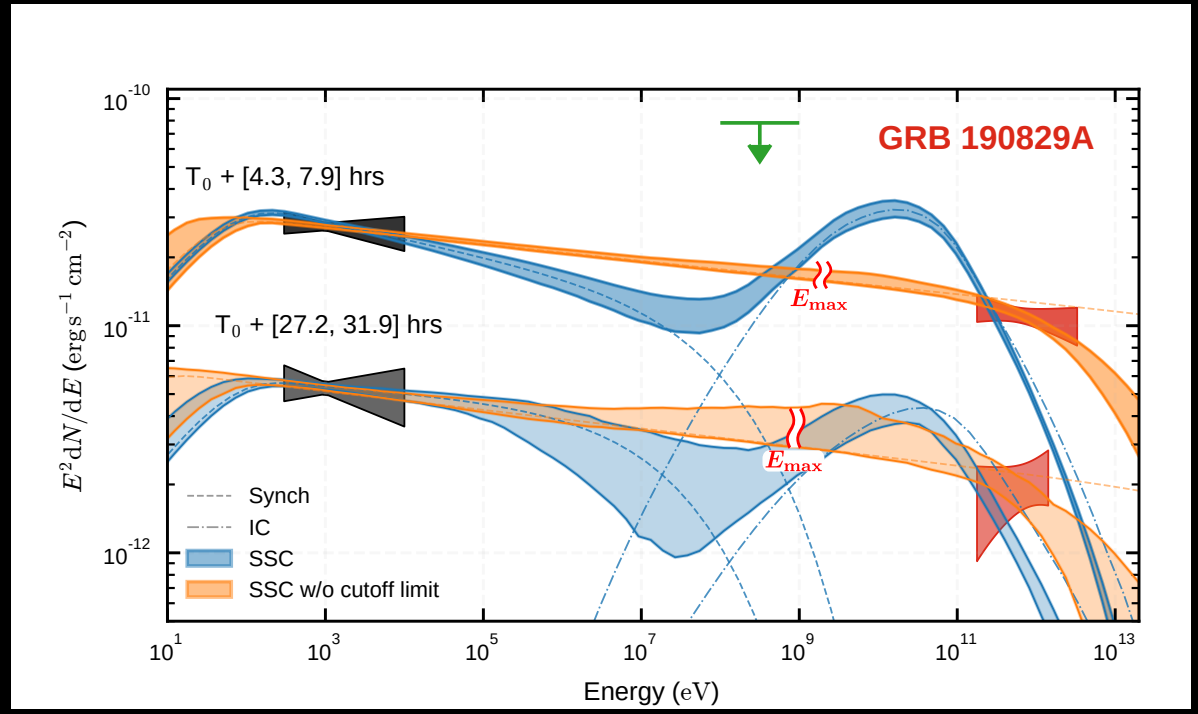
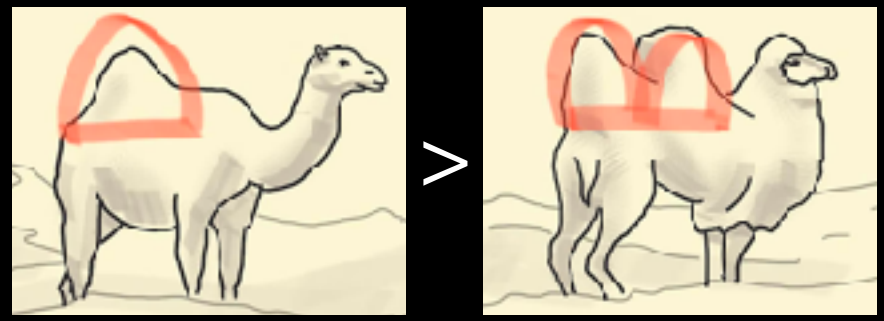
Abdalla et al., Science 372 (2021)




Abdalla et al., Science 372 (2021)

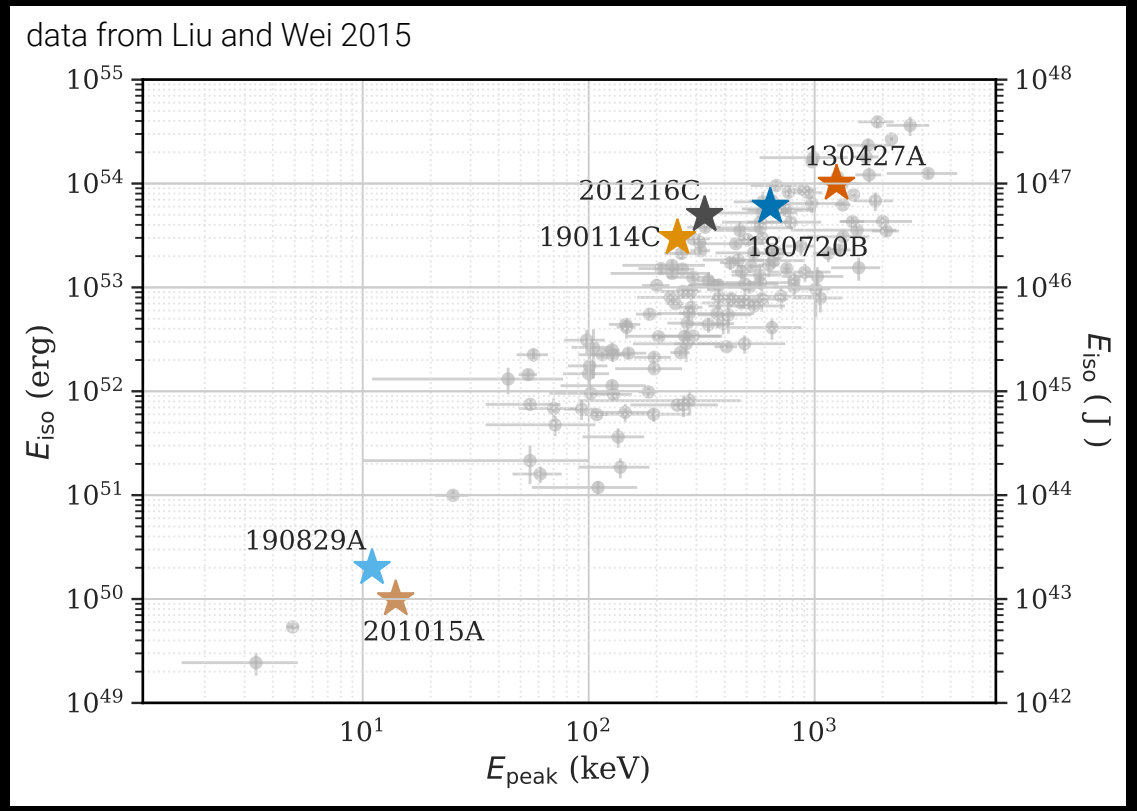


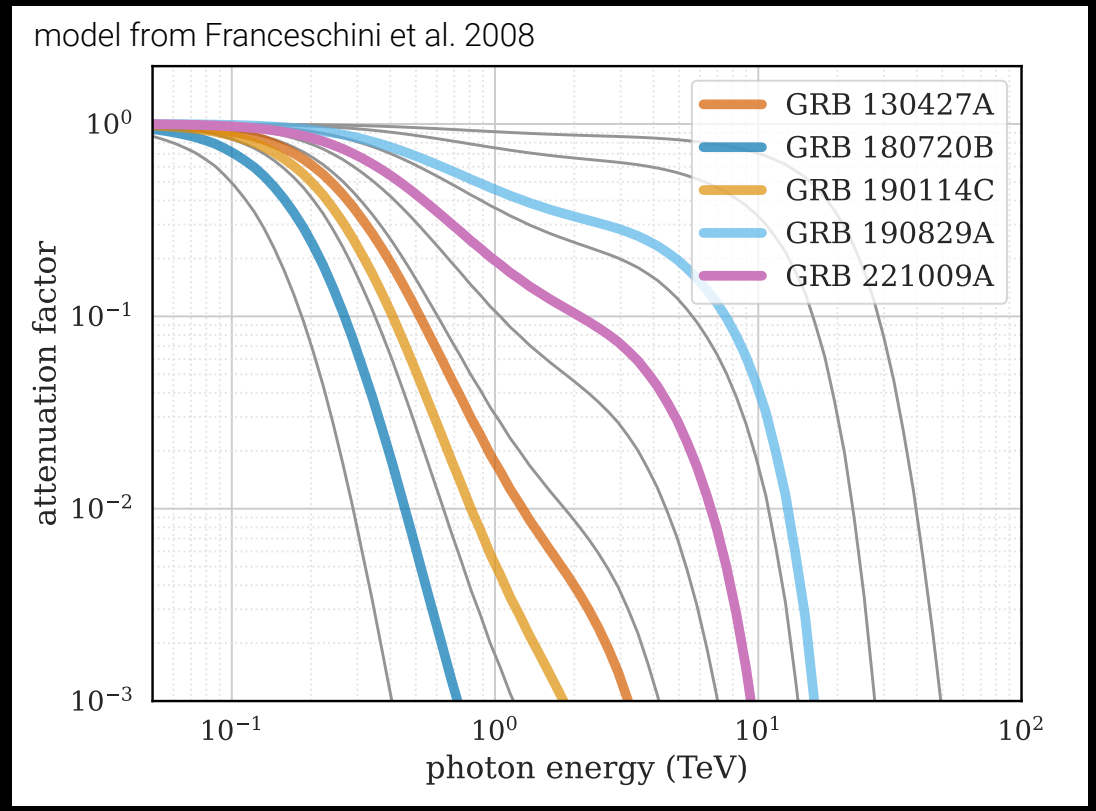

Maybe we should move beyond the one-zone assumption



# VHE GRBs as a "population" ($n$ < 10)

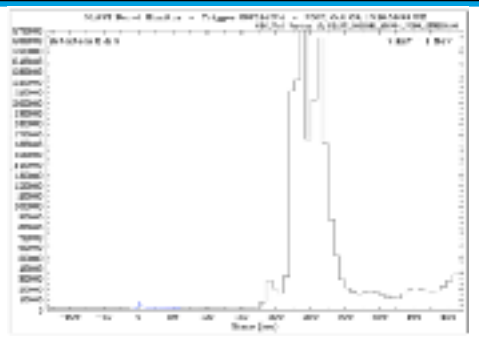
VHE GRBs span the range of GRB energetics properties



# ok fine let's briefly talk about GRB 221009A now

So what happened? — NOTE: Not an exhaustive list!!! Sorry if I missed your telescope!!!!! pls forgive me :(



**13:16:59 UTC, GBM triggers** (GCN 32636)
"the brightest among the GBM detected GRBs"
go find **Eric Burns** if you want more gossip about the GBM detection

At this time, the source is not visible to BAT

2022-10-09 2022-10-10 2022-10-11 2022-10-12

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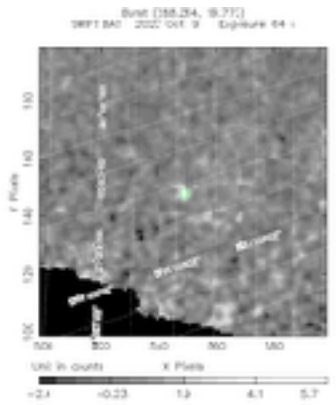

**14:10:17 UTC, BAT triggers** (GCN 32636), nearly an hour after the GBM trigger
-> Still bright enough for an image trigger

go find **Judy Racusin** if you want more gossip about the Swift observations

2022-10-09 — 2022-10-10 — 2022-10-11 — 2022-10-12

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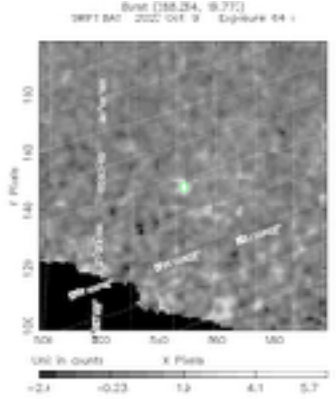
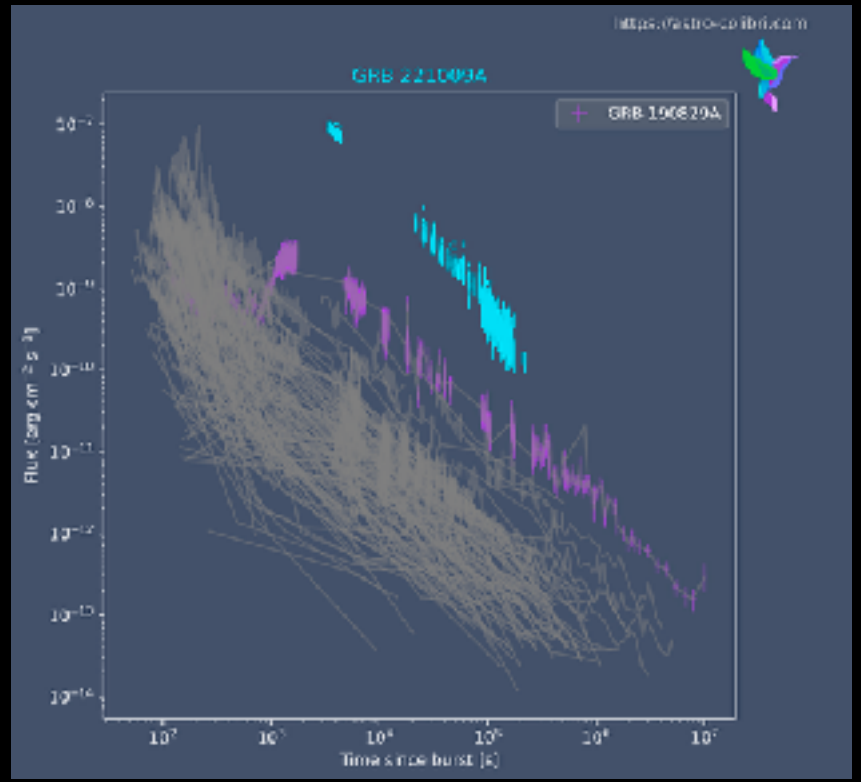


**14:10:17 UTC, BAT triggers** (GCN 32636), nearly an hour after the GBM trigger
-> Still bright enough for an image trigger

go find **Judy Racusin** if you want more gossip about the Swift observations

**brightest XRT afterglow by far**




2022-10-09 — 2022-10-10 — 2022-10-11 — 2022-10-12

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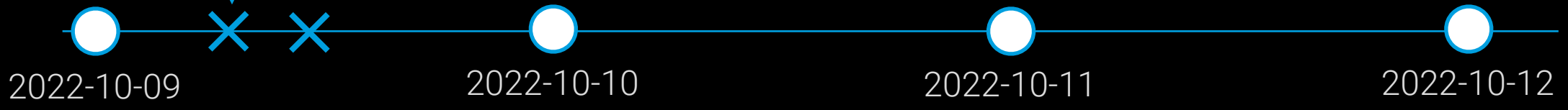
**LAT detected the prompt emission**
(GCNs 32637, 32658)

"bright structured emission episode … temporally coincident with the GBM main emission episode"
"extending for about 25ks post GBM trigger"
"The highest-energy photon is 99.3 GeV … 240 seconds after the GBM trigger."

go find **Nicola Omodei** if you want more gossip about the LAT detection



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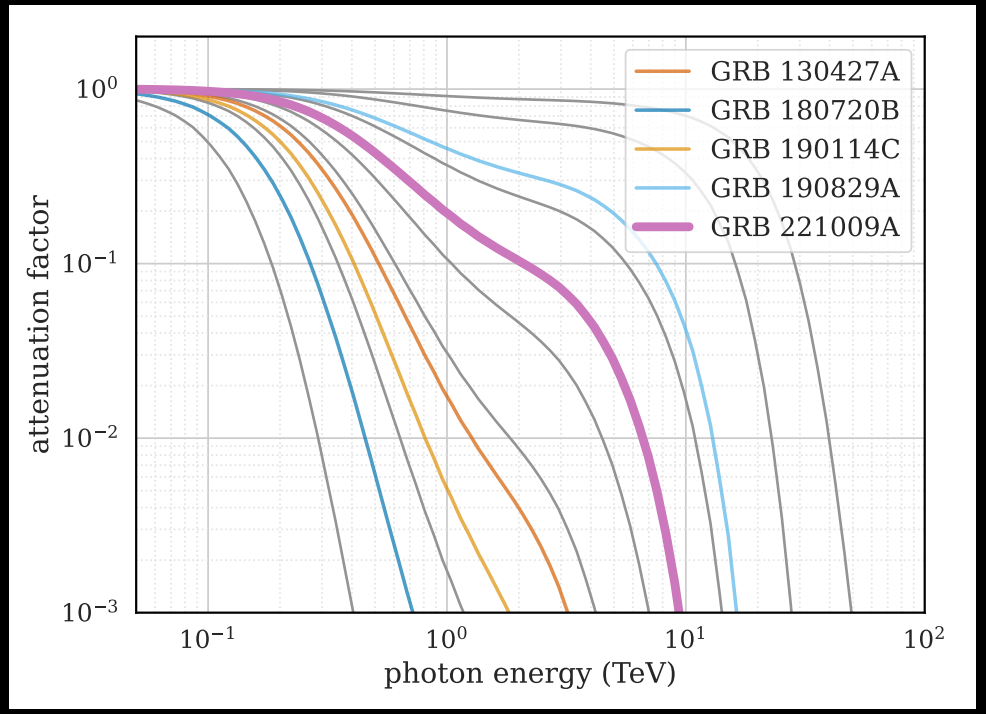
So what happened? — NOTE: Not an exhaustive list!!! Sorry if I missed your telescope!!!!! pls forgive me :(

**X-shooter/VLT: $z$ = 0.151**
(GCN 32648)

Eiso ~ 2e54 erg based on GBM fluence
but: GBM has strong systematic issues
because the burst was TOO BRIGHT

go find **Eric Burns** if you want more gossip about the GBM systematic issues




2022-10-09 — 2022-10-10 — 2022-10-11 — 2022-10-12

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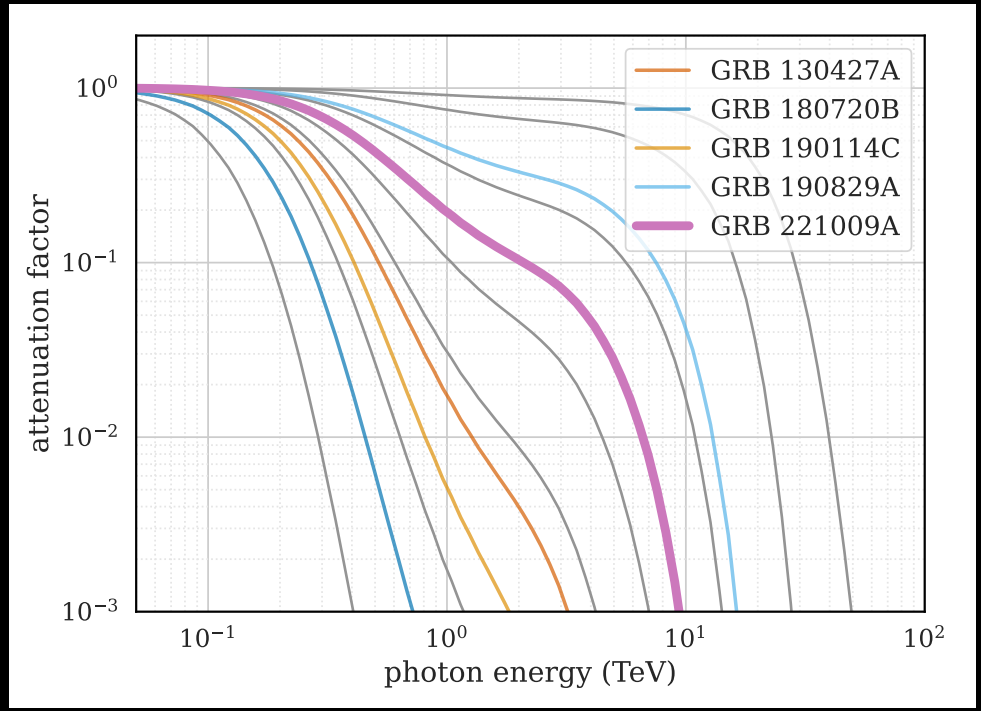
So what happened? — NOTE: Not an exhaustive list!!! Sorry if I missed your telescope!!!!! pls forgive me :(

**LHAASO** (GCN 32677)

"more than 5000 VHE photons up to around 18 TeV" !!!!
(previous record: 4 TeV)
"within 2000 seconds after T0"

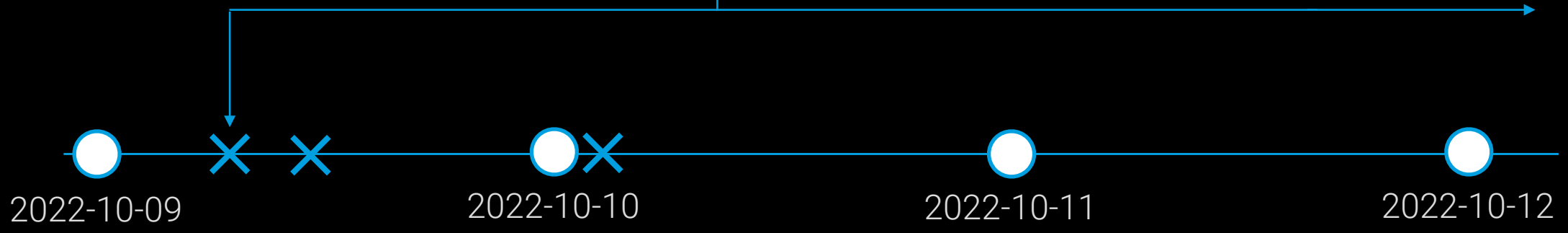



2022-10-09 — 2022-10-10 — 2022-10-11 — 2022-10-12

# ok fine let's briefly talk about GRB 221009A now

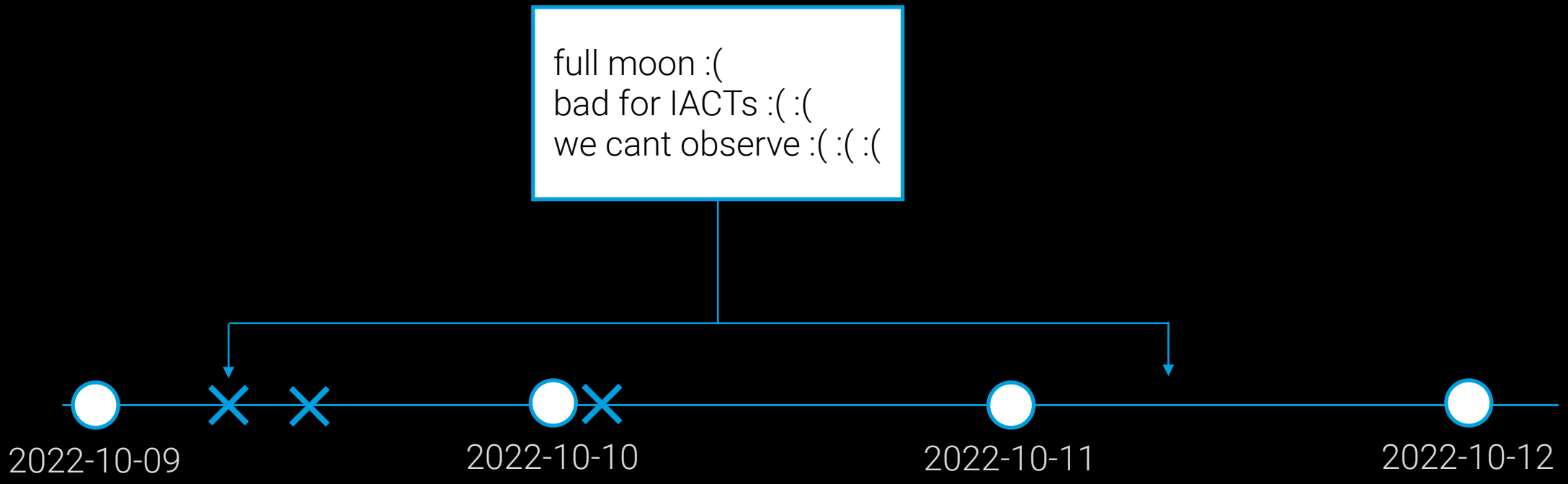
So what happened? — NOTE: Not an exhaustive list!!! Sorry if I missed your telescope!!!!! pls forgive me :(

**lots of other telescopes!!!**
BOOTES-2, Mondy, MeerLICHT, Nanshan, Xinglong, AGILE, REM, AMI-LA, PRIME, ATA, INTEGRAL, STIX, GIT, SRG, Burke-Gaffney, Lulin, Konus, Lick, Assy, Global MASTER-Net, CALET, NOEMA, BlackGEM, iTelescope, Sintez-Newton, GRBAlpha, GTC



# ok fine let's briefly talk about GRB 221009A now

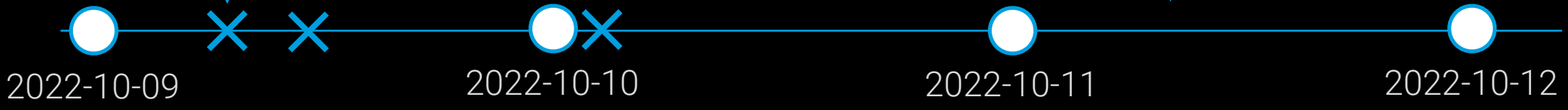
Why have IACTs been so quiet???



# ok fine let's briefly talk about GRB 221009A now

Why have IACTs been so quiet???

full moon :(
bad for IACTs :( :(
we cant observe :( :( :(



# So what do we know about VHE GRBs?

(GRB 130427A *Fermi*-LAT)

(GRB 160821B MAGIC)

GRB 180720B H.E.S.S.

GRB 190114C MAGIC

GRB 190829A H.E.S.S.

GRB 201015A MAGIC

GRB 201216C MAGIC

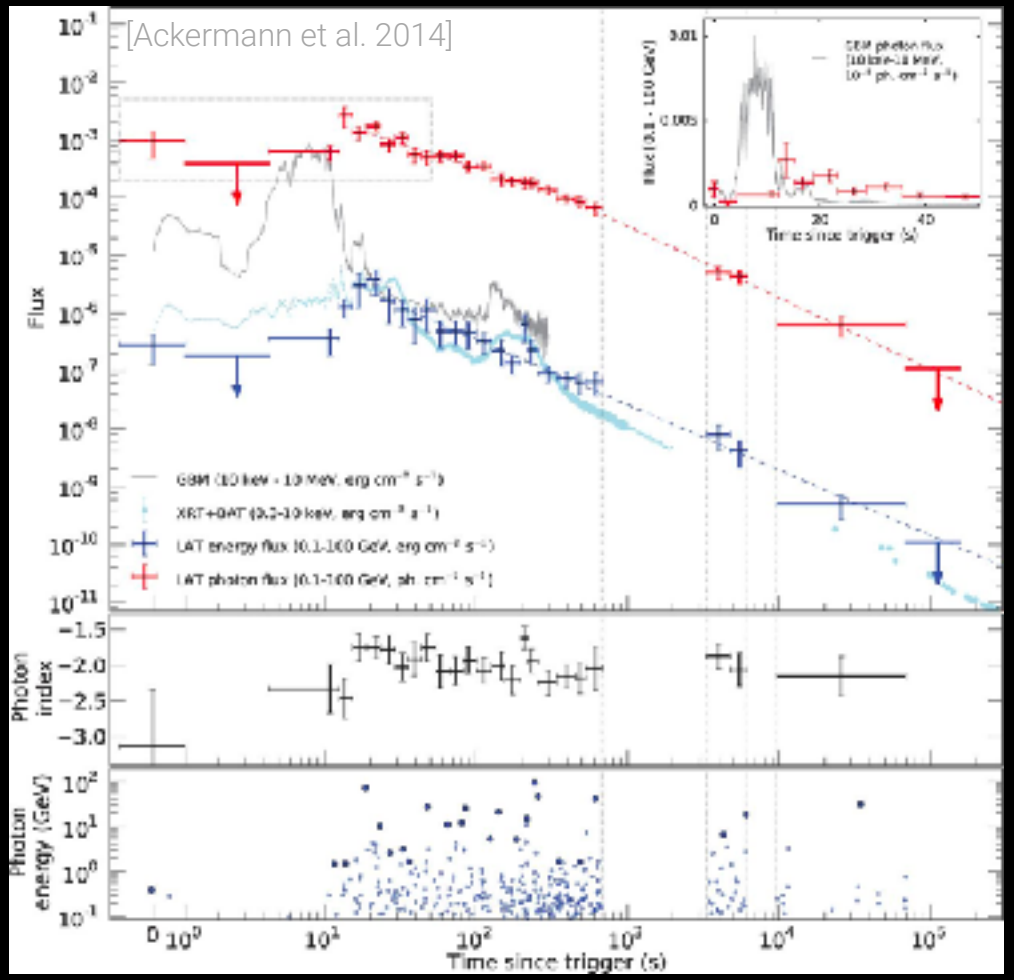
**GRB 221009A!!!!! LHAASO**

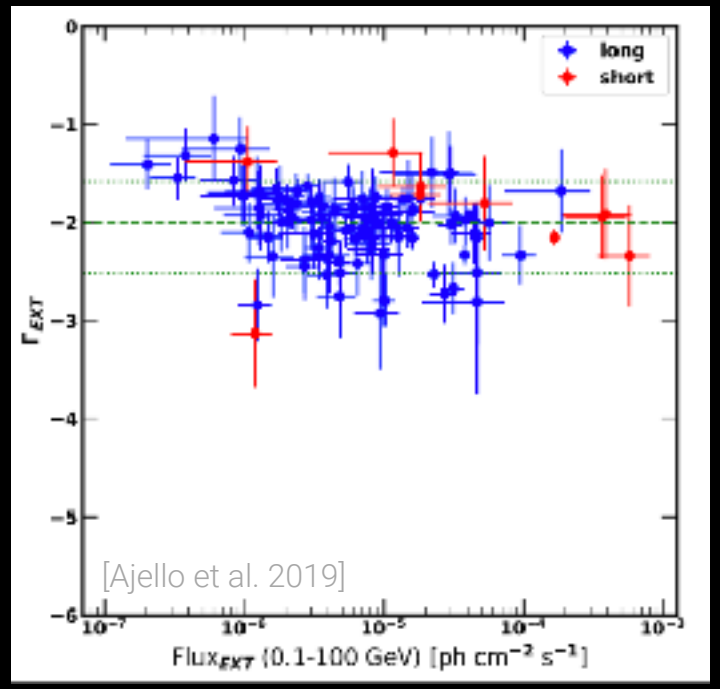
- So far, no smoking gun of an SSC component
- With better data, we can test more realistic models
- VHE GRBs span a wide range of properties

- There is synergy between the different kinds of gamma-ray telescopes

# Extra slides

# Things we learned? from LAT



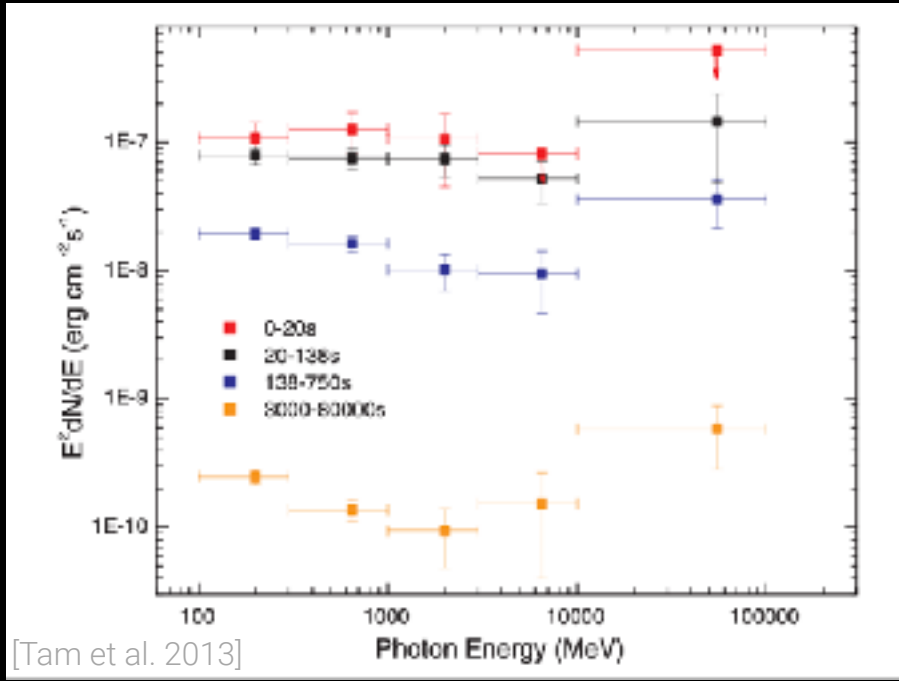




spectral index settles at 2,

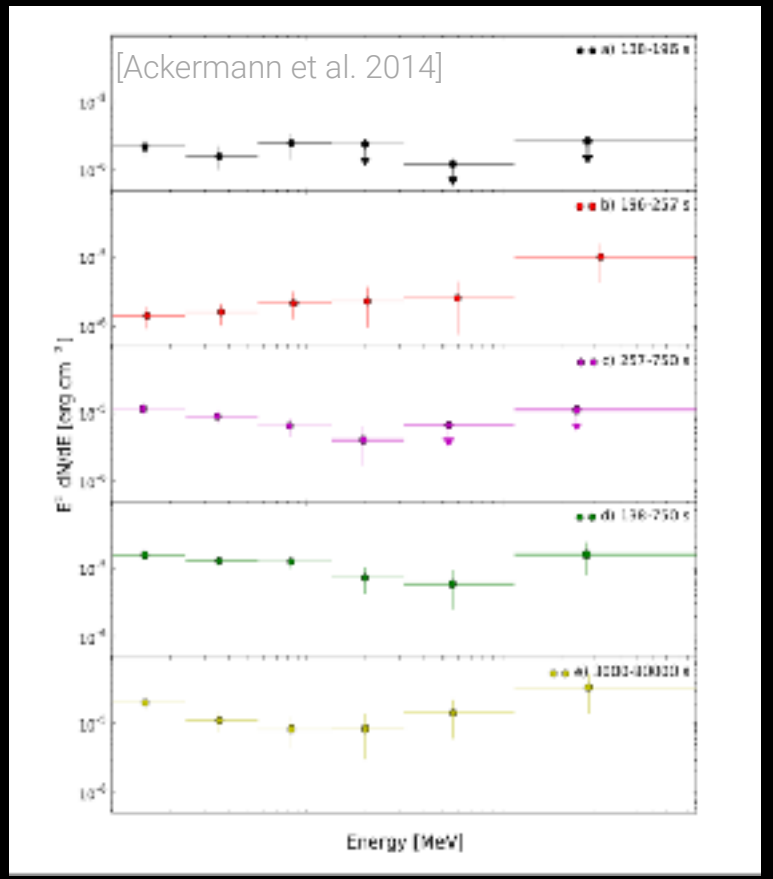
which is the average for LAT GBRs

# GRB 130427A

There were some reports of claims of an additional component *within* the LAT energy band
(i.e., broken power law > power law),
but no statistical preference was found, and spectral evolution can produce this effect too



[Tam et al. 2013]



# VHE observations of GRBs so far

(GRB 130427A *Fermi*-LAT)

(GRB 160821B MAGIC)

**GRB 180720B H.E.S.S.**

GRB 190114C MAGIC

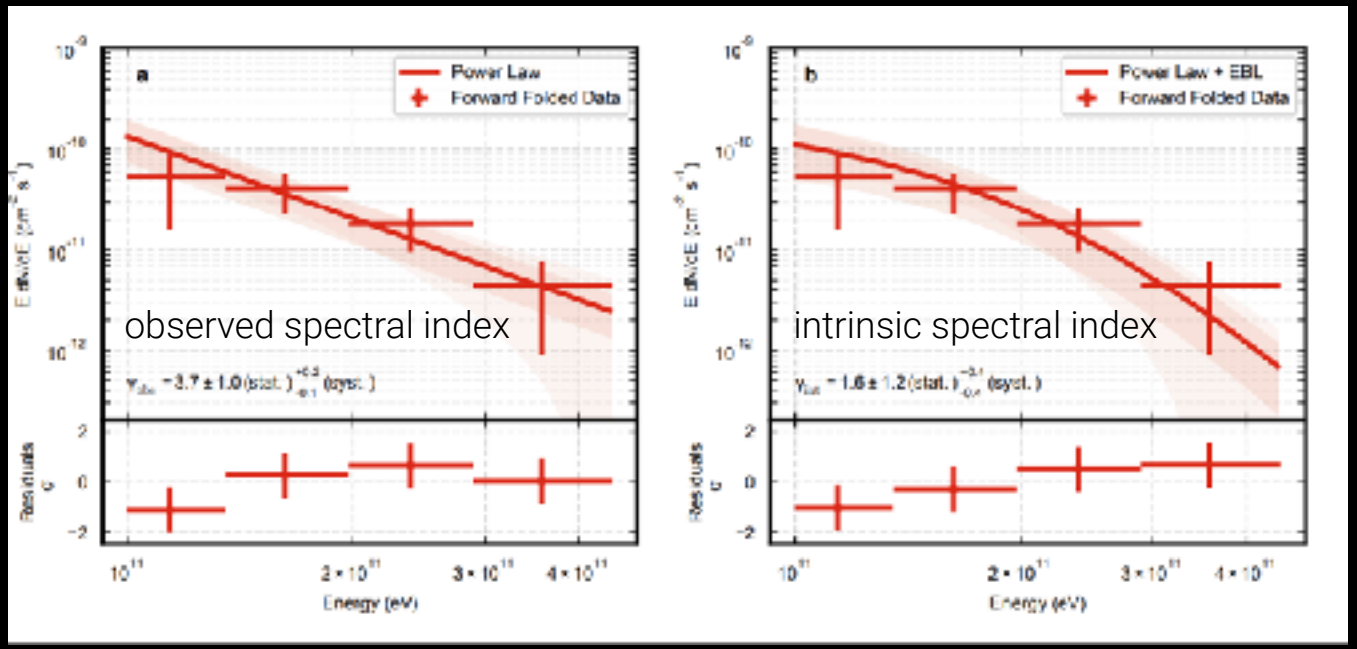
GRB 190829A H.E.S.S.

GRB 201015A MAGIC

GRB 201216C MAGIC

EBL plot?

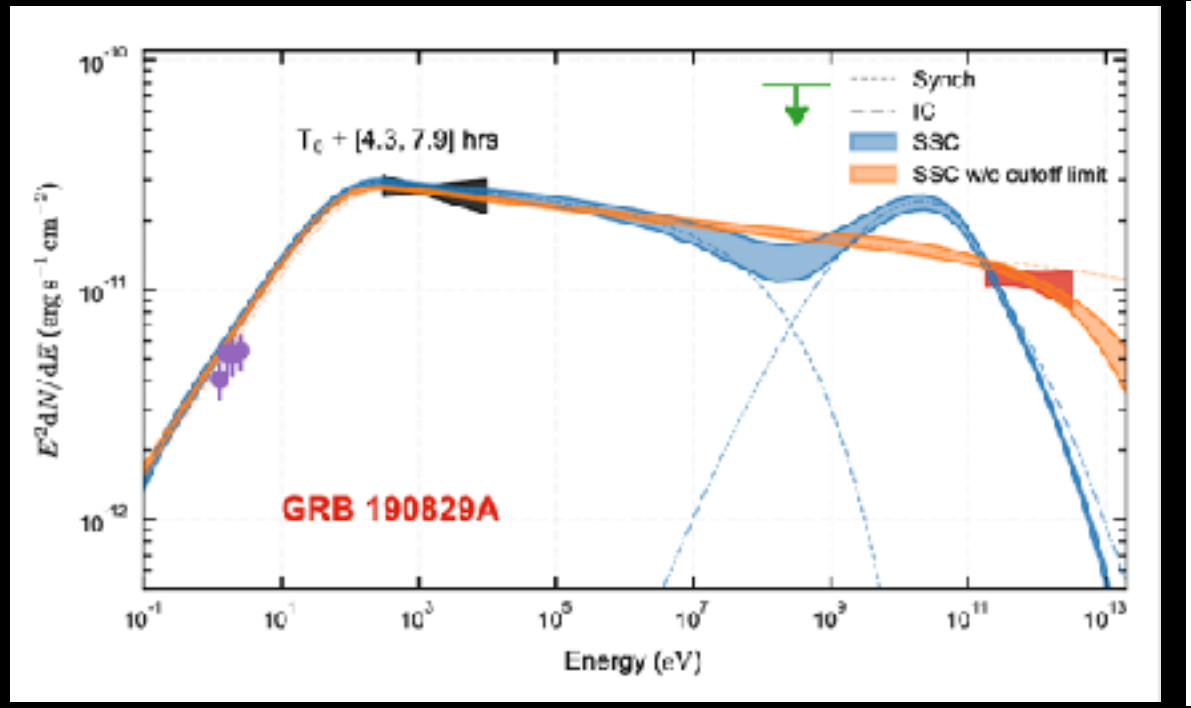
Abdalla et al., Nature 575 (2019)



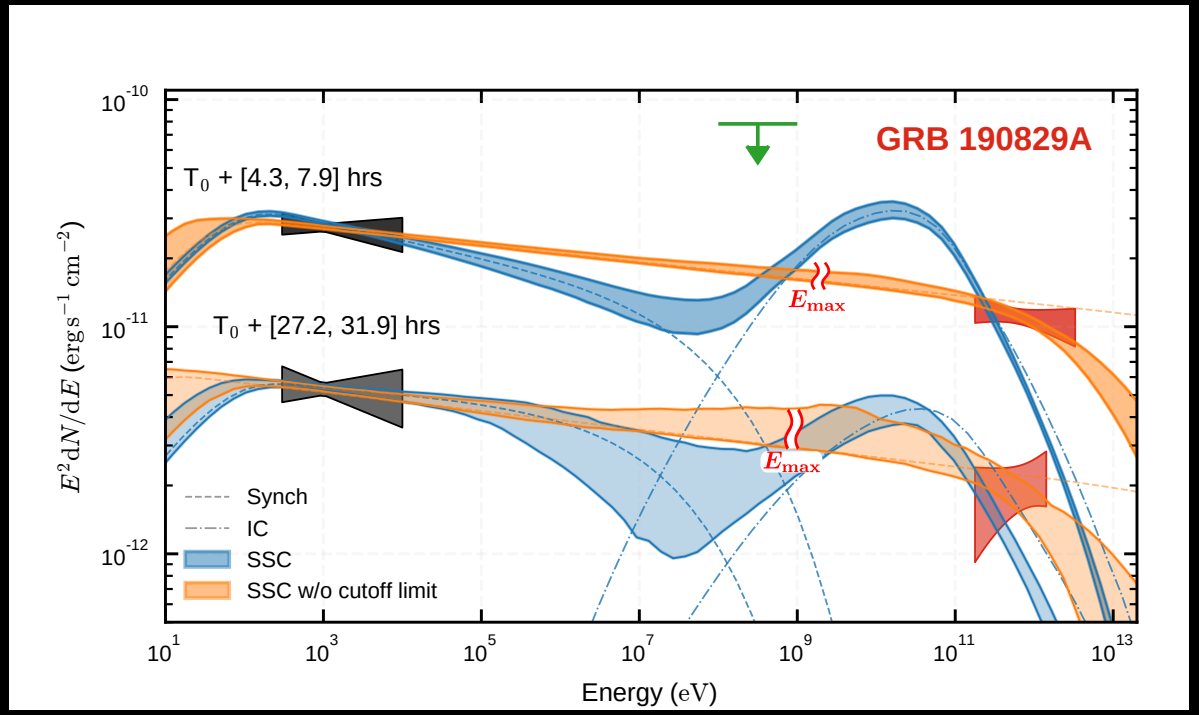

H.E.S.S. reported a 5σ detection 8 hours after the GRB onset
The VHE and X-ray energy fluxes at this time are around the same level
At $z$ = 0.653, the EBL had a large impact ($\gamma_{obs} \sim 3.7$, $\gamma_{int} \sim 1.6$)

# GRB 190829A: Extremely long-lasting in VHE gamma rays

Abdalla et al., Science 372 (2021)




Abdalla et al., Science 372 (2021)




Note: Optical and radio data during the H.E.S.S. observations are both tricky to deal with but including them (with reasonably estimated uncertainties) yields consistent fits