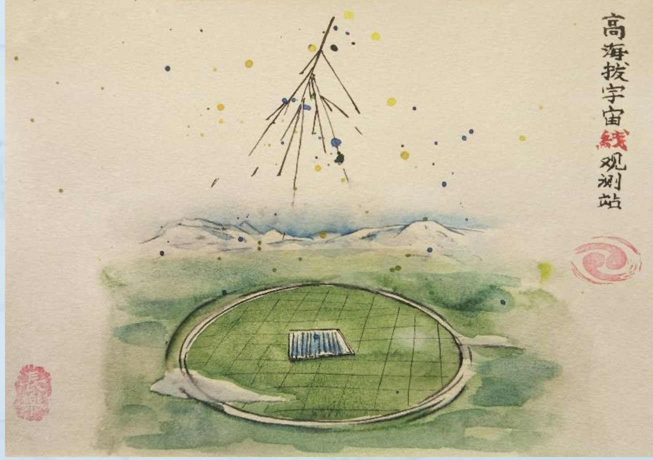
LHAASO
高海拔宇宙线观测站



LHAASO and the BOAT GRB

Zhen Cao
on behalf of
LHAASO Collaboration

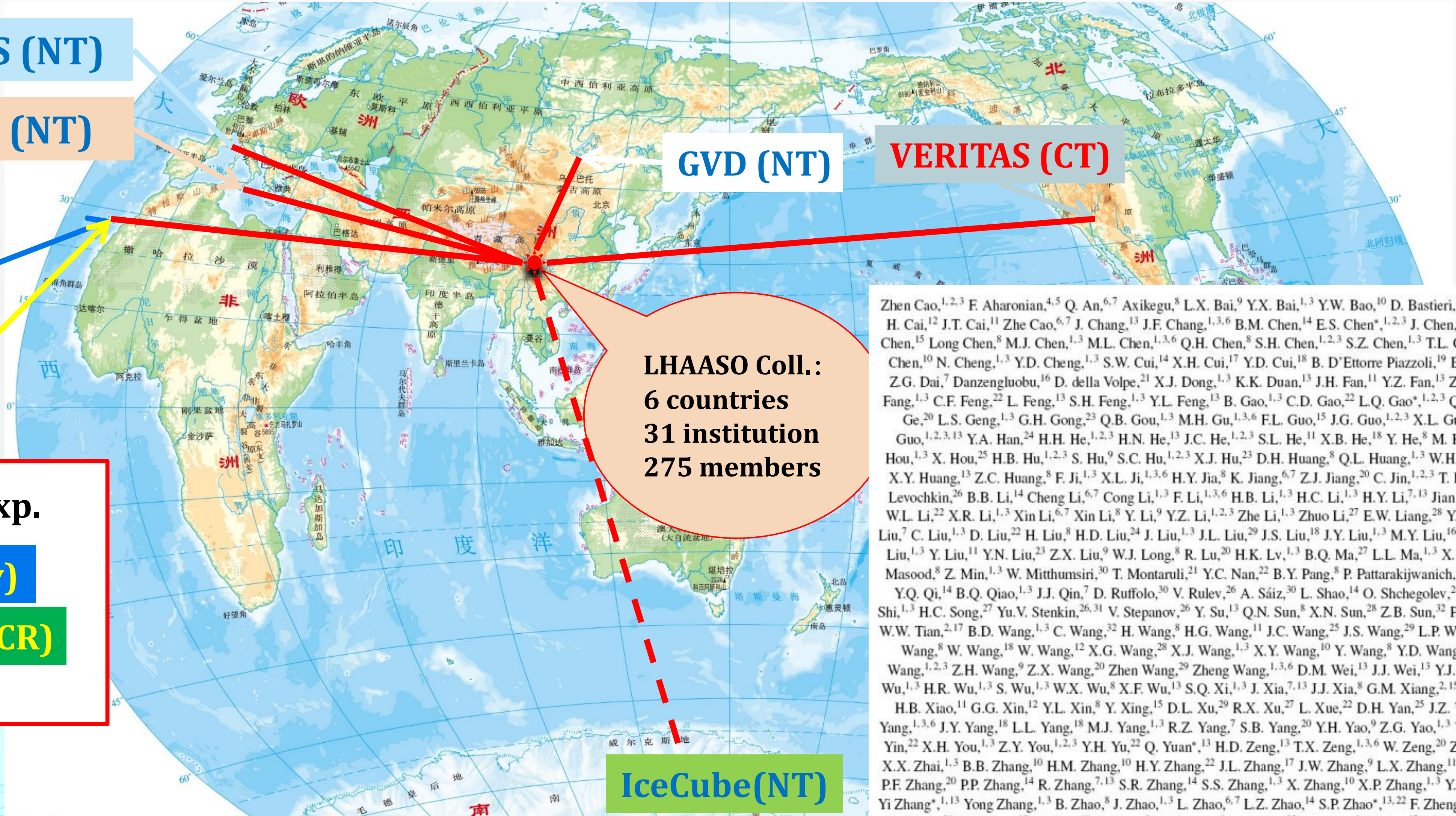
Astrophysical Black Holes, U. of HK, June, 2023

Bird’s eye view of LHAASO， 2021-08

- Location： 29º21’ 27.6” N , 100º08’19.6” E
- Altitude: 4410 m
- 2021-07 completed built and in operation

LHAASO
高海拔宇宙线观测站

Multi-Messenger Collaboration Network

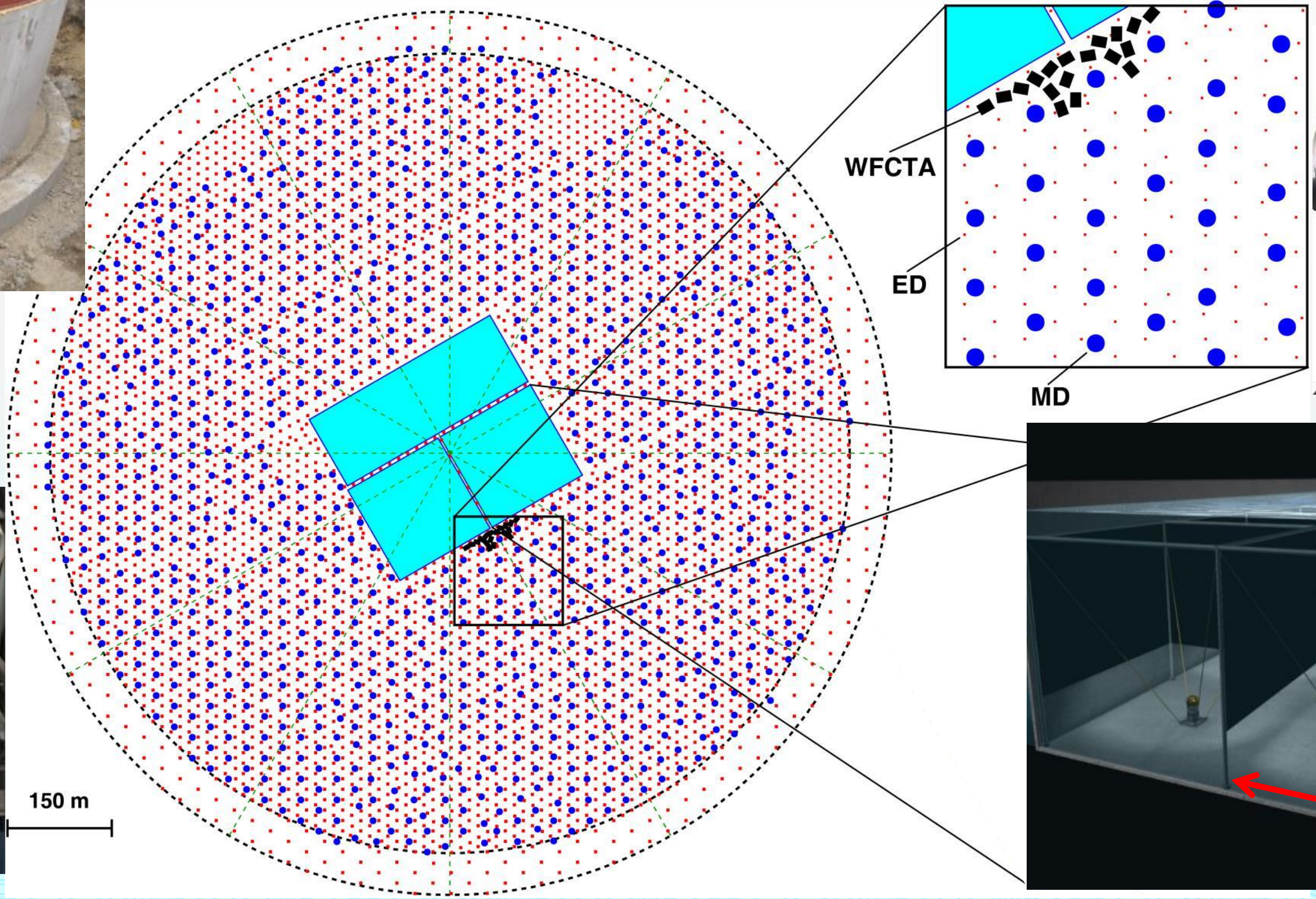


Space borne Exp.

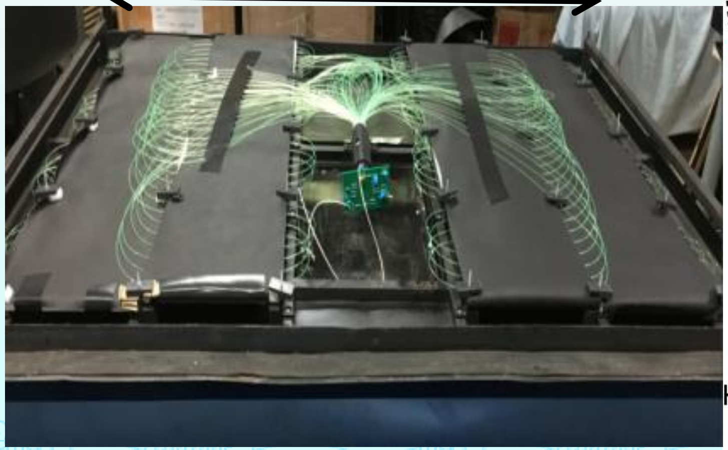
- eROSITA(X-ray)
- DAMPE(γ-ray, CR)

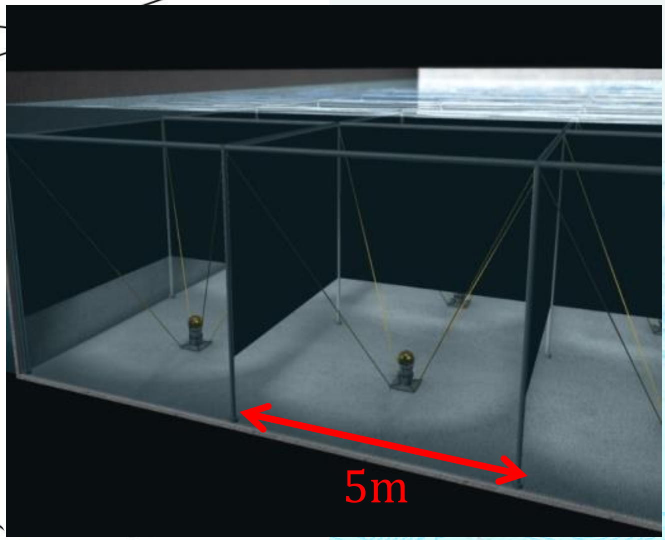
Zhen Cao,[1,2,3] F. Aharonian,[4,5] Q. An,[6,7] Axikegu,[8] L.X. Bai,[9] Y.X. Bai,[1,3] Y.W. Bao,[10] D. Bastieri,[11] X.J. Bi*,[1,2,3] Y.J. Bi,[1,3] H. Cai,[12] J.T. Cai,[11] Zhe Cao,[6,7] J. Chang,[13] J.F. Chang,[1,3,6] B.M. Chen,[14] E.S. Chen*,[1,2,3] J. Chen,[9] Liang Chen,[1,2,3] Liang Chen,[15] Long Chen,[8] M.J. Chen,[1,3] M.L. Chen,[1,3,6] Q.H. Chen,[8] S.H. Chen,[1,2,3] S.Z. Chen,[1,3] T.L. Chen,[16] X.L. Chen,[1,2,3] Y. Chen,[10] N. Cheng,[1,3] Y.D. Cheng,[1,3] S.W. Cui,[14] X.H. Cui,[17] Y.D. Cui,[18] B. D'Ettorre Piazzoli,[19] B.Z. Dai,[20] H.L. Dai,[1,3,6] Z.G. Dai,[7] Danzengluobu,[16] D. della Volpe,[21] X.J. Dong,[1,3] K.K. Duan,[13] J.H. Fan,[11] Y.Z. Fan,[13] Z.X. Fan,[1,3] J. Fang,[20] K. Fang,[1,3] C.F. Feng,[22] L. Feng,[13] S.H. Feng,[1,3] Y.L. Feng,[13] B. Gao,[1,3] C.D. Gao,[22] L.Q. Gao*,[1,2,3] Q. Gao,[16] W. Gao,[22] M.M. Ge,[20] L.S. Geng,[1,3] G.H. Gong,[23] Q.B. Gou,[1,3] M.H. Gu,[1,3,6] F.L. Guo,[15] J.G. Guo,[1,2,3] X.L. Guo,[8] Y.Q. Guo,[1,3] Y.Y. Guo,[1,2,3,13] Y.A. Han,[24] H.H. He,[1,2,3] H.N. He,[13] J.C. He,[1,2,3] S.L. He,[11] X.B. He,[18] Y. He,[8] M. Heller,[21] Y.K. Hor,[18] C. Hou,[1,3] X. Hou,[25] H.B. Hu,[1,2,3] S. Hu,[9] S.C. Hu,[1,2,3] X.J. Hu,[23] D.H. Huang,[8] Q.L. Huang,[1,3] W.H. Huang,[22] X.T. Huang,[22] X.Y. Huang,[13] Z.C. Huang,[8] F. Ji,[1,3] X.L. Ji,[1,3,6] H.Y. Jia,[8] K. Jiang,[6,7] Z.J. Jiang,[20] C. Jin,[1,2,3] T. Ke,[1,3] D. Kuleshov,[26] K. Levochkin,[26] B.B. Li,[14] Cheng Li,[6,7] Cong Li,[1,3] F. Li,[1,3,6] H.B. Li,[1,3] H.C. Li,[1,3] H.Y. Li,[7,13] Jian Li,[7] Jie Li,[1,3,6] K. Li,[1,3] W.L. Li,[22] X.R. Li,[1,3] Xin Li,[6,7] Xin Li,[8] Y. Li,[9] Y.Z. Li,[1,2,3] Zhe Li,[1,3] Zhuo Li,[27] E.W. Liang,[28] Y.F. Liang,[28] S.J. Lin,[18] B. Liu,[7] C. Liu,[1,3] D. Liu,[22] H. Liu,[8] H.D. Liu,[24] J. Liu,[1,3] J.L. Liu,[29] J.S. Liu,[18] J.Y. Liu,[1,3] M.Y. Liu,[16] R.Y. Liu,[10] S.M. Liu,[8] W. Liu,[1,3] Y. Liu,[11] Y.N. Liu,[23] Z.X. Liu,[9] W.J. Long,[8] R. Lu,[20] H.K. Lv,[1,3] B.Q. Ma,[27] L.L. Ma,[1,3] X.H. Ma,[1,3] J.R. Mao,[25] A. Masood,[8] Z. Min,[1,3] W. Mitthumsiri,[30] T. Montaruli,[21] Y.C. Nan,[22] B.Y. Pang,[8] P. Pattarakijwanich,[30] Z.Y. Pei,[11] M.Y. Qi,[1,3] Y.Q. Qi,[14] B.Q. Qiao,[1,3] J.J. Qin,[7] D. Ruffolo,[30] V. Rulev,[26] A. Sáiz,[30] L. Shao,[14] O. Shchegolev,[26,31] X.D. Sheng,[1,3] J.R. Shi,[1,3] H.C. Song,[27] Yu.V. Stenkin,[26,31] V. Stepanov,[26] Y. Su,[13] Q.N. Sun,[8] X.N. Sun,[28] Z.B. Sun,[32] P.H.T. Tam,[18] Z.B. Tang,[6,7] W.W. Tian,[2,17] B.D. Wang,[1,3] C. Wang,[32] H. Wang,[8] H.G. Wang,[11] J.C. Wang,[25] J.S. Wang,[29] L.P. Wang,[22] L.Y. Wang,[1,3] R.N. Wang,[8] W. Wang,[18] W. Wang,[12] X.G. Wang,[28] X.J. Wang,[1,3] X.Y. Wang,[10] Y. Wang,[8] Y.D. Wang,[1,3] Y.J. Wang,[1,3] Y.P. Wang,[1,2,3] Z.H. Wang,[9] Z.X. Wang,[20] Zhen Wang,[29] Zheng Wang,[1,3,6] D.M. Wei,[13] J.J. Wei,[13] Y.J. Wei,[1,2,3] T. Wen,[20] C.Y. Wu,[1,3] H.R. Wu,[1,3] S. Wu,[1,3] W.X. Wu,[8] X.F. Wu,[13] S.Q. Xi,[1,3] J. Xia,[7,13] J.J. Xia,[8] G.M. Xiang,[2,15] D.X. Xiao,[16] G. Xiao,[1,3] H.B. Xiao,[11] G.G. Xin,[12] Y.L. Xin,[8] Y. Xing,[15] D.L. Xu,[29] R.X. Xu,[27] L. Xue,[22] D.H. Yan,[25] J.Z. Yan,[13] C.W. Yang,[9] F.F. Yang,[1,3,6] J.Y. Yang,[18] L.L. Yang,[18] M.J. Yang,[1,3] R.Z. Yang,[7] S.B. Yang,[20] Y.H. Yao,[9] Z.G. Yao,[1,3] Y.M. Ye,[23] L.Q. Yin,[1,3] N. Yin,[22] X.H. You,[1,3] Z.Y. You,[1,2,3] Y.H. Yu,[22] Q. Yuan*,[13] H.D. Zeng,[13] T.X. Zeng,[1,3,6] W. Zeng,[20] Z.K. Zeng,[1,2,3] M. Zha,[1,3] X.X. Zhai,[1,3] B.B. Zhang,[10] H.M. Zhang,[10] H.Y. Zhang,[22] J.L. Zhang,[17] J.W. Zhang,[9] L.X. Zhang,[11] Li Zhang,[20] Lu Zhang,[14] P.F. Zhang,[20] P.P. Zhang,[14] R. Zhang,[7,13] S.R. Zhang,[14] S.S. Zhang,[1,3] X. Zhang,[10] X.P. Zhang,[1,3] Y.F. Zhang,[8] Y.L. Zhang,[1,3] Yi Zhang*,[1,13] Yong Zhang,[1,3] B. Zhao,[8] J. Zhao,[1,3] L. Zhao,[6,7] L.Z. Zhao,[14] S.P. Zhao*,[13,22] F. Zheng,[32] Y. Zheng,[8] B. Zhou,[1,3] H. Zhou,[29] J.N. Zhou,[15] P. Zhou,[10] R. Zhou,[9] X.X. Zhou,[8] C.G. Zhu,[22] F.R. Zhu,[8] H. Zhu,[17] K.J. Zhu,[1,2,3,6] and X. Zuo[1,3]

LHAASO Layout



1.2m





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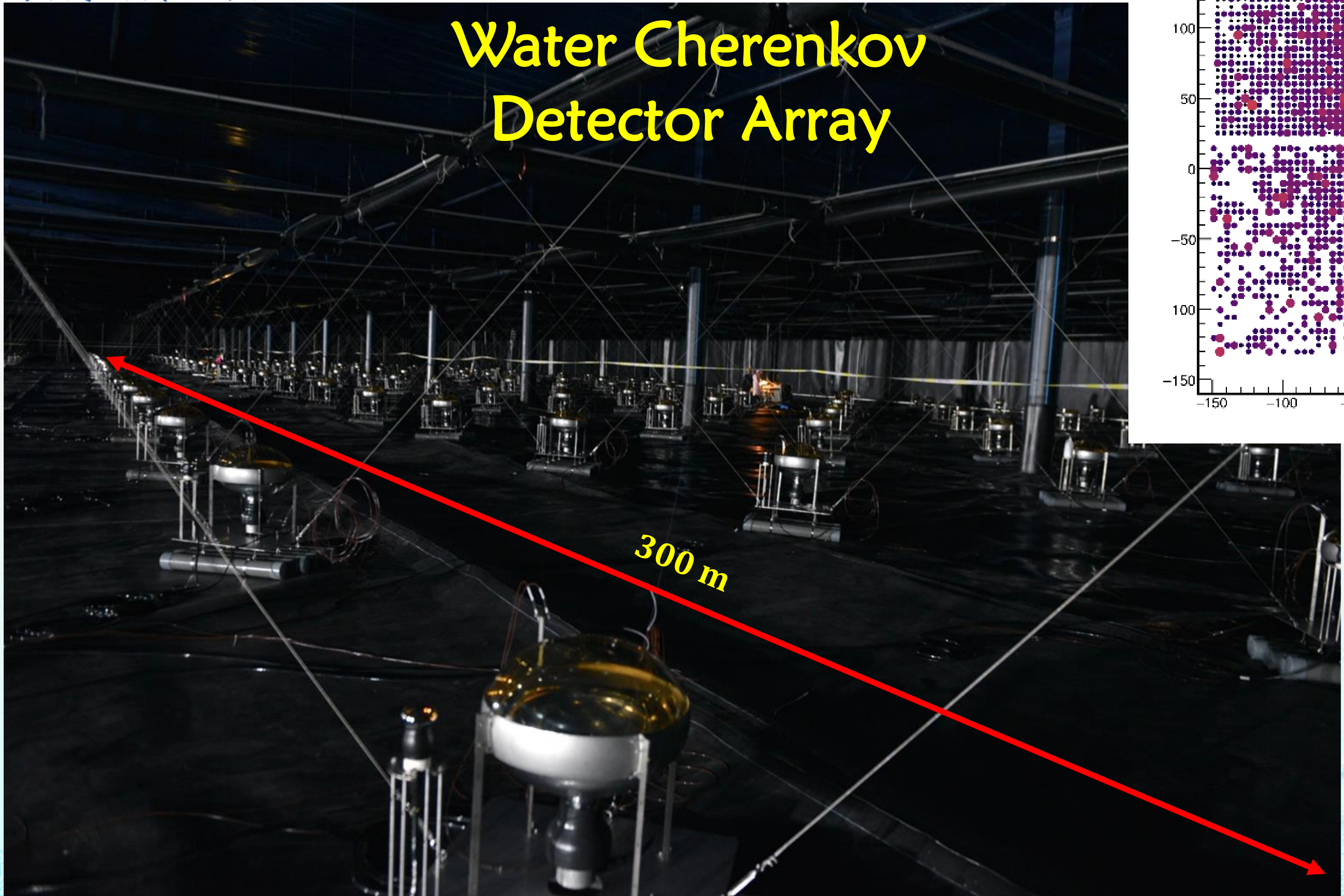
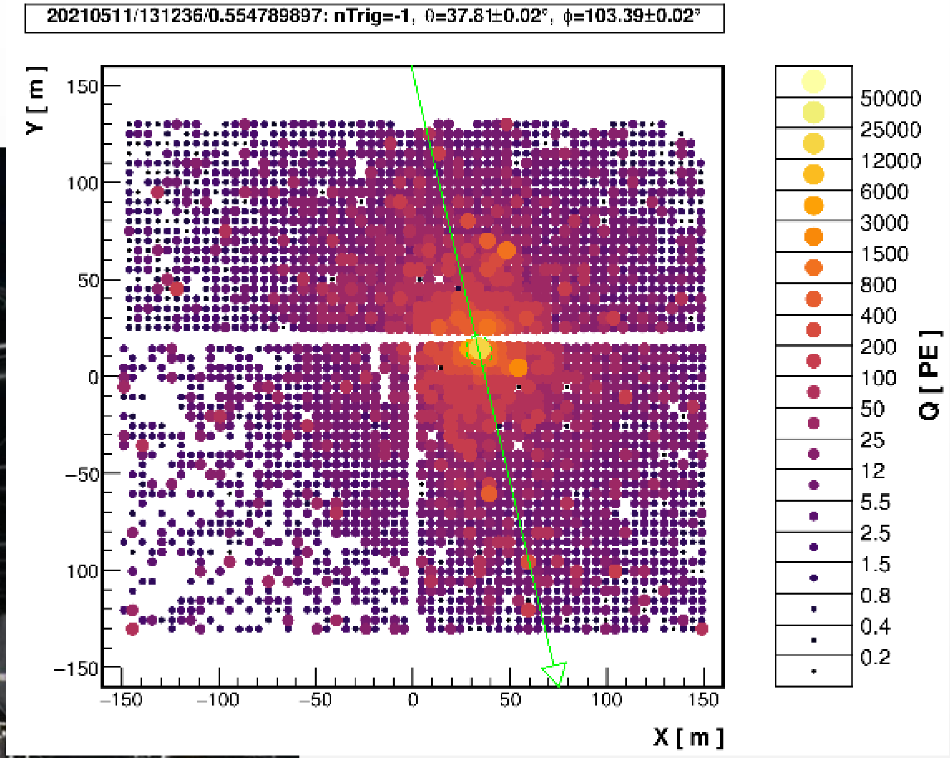
LHAASO-WCDA

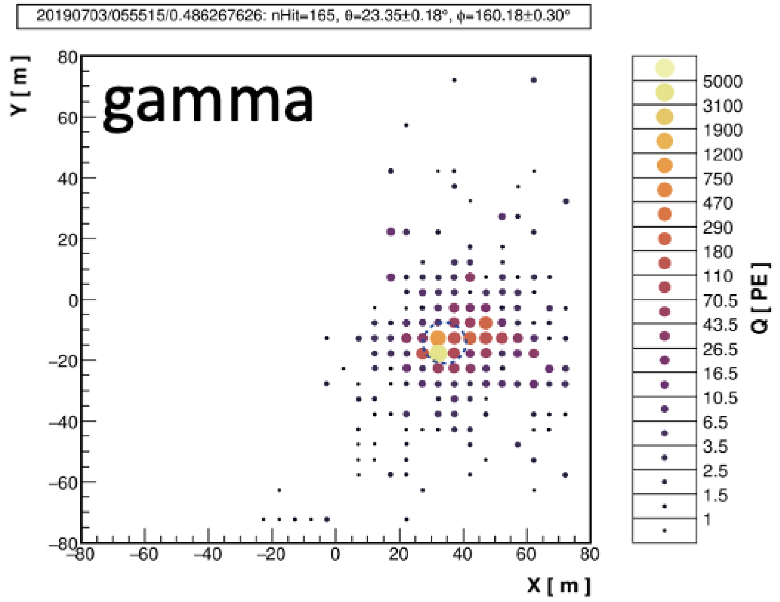
Water Cherenkov Detector Array

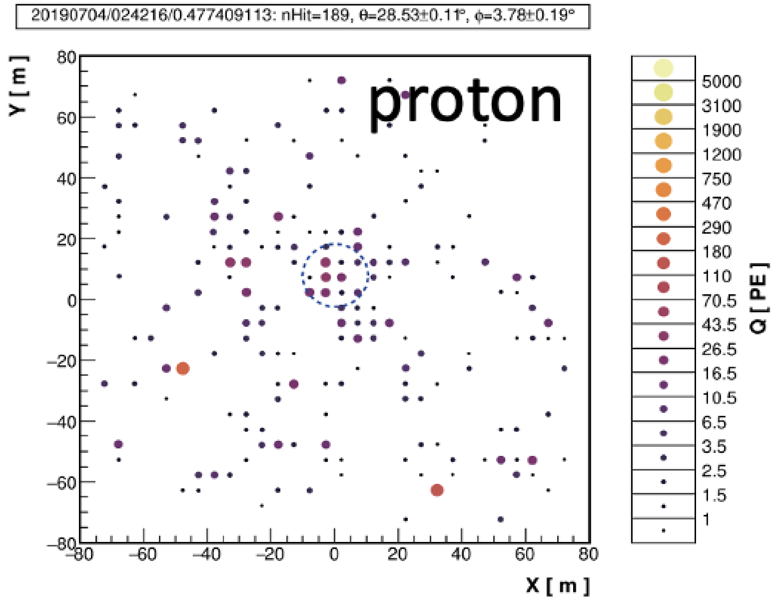


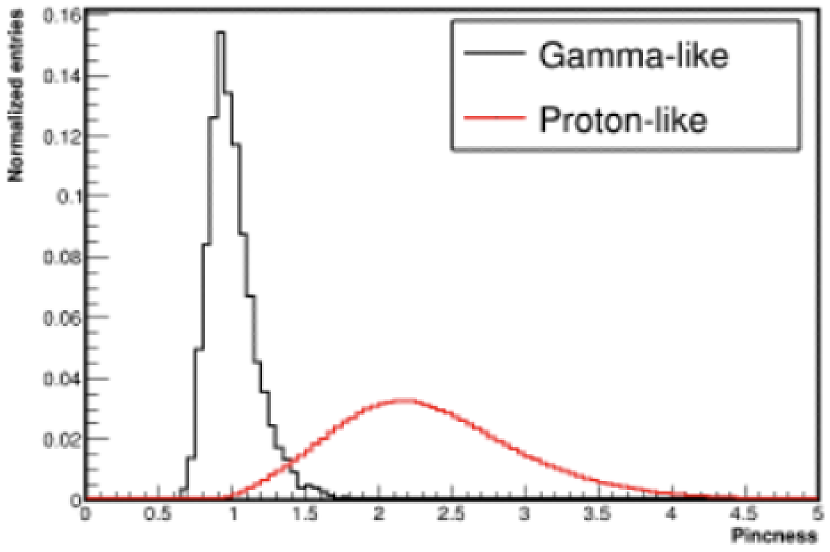


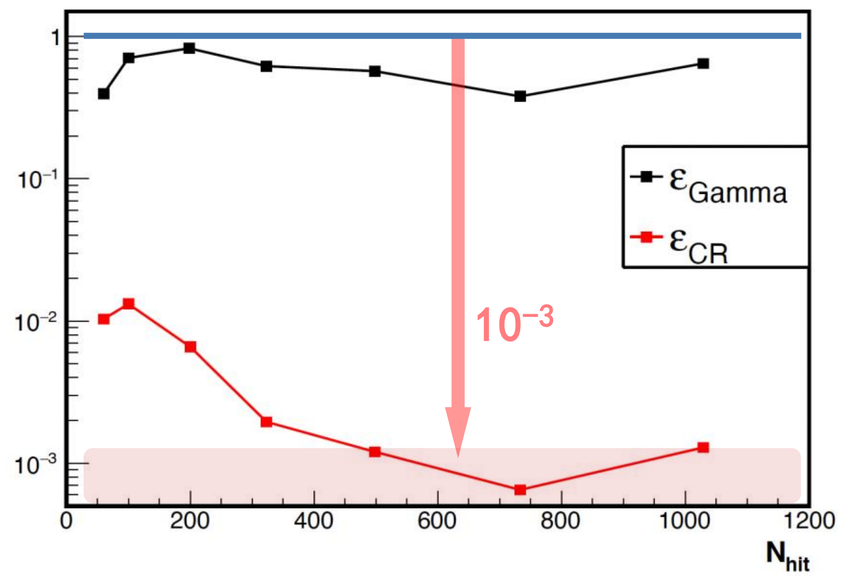
- **Area:**
  78,000 m²
- **Detector units:**
  3120
- **Energy Range:**
  0.1-10 TeV

CR Background rejection in WCDA

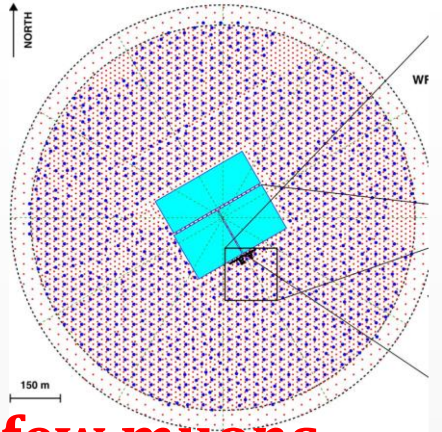








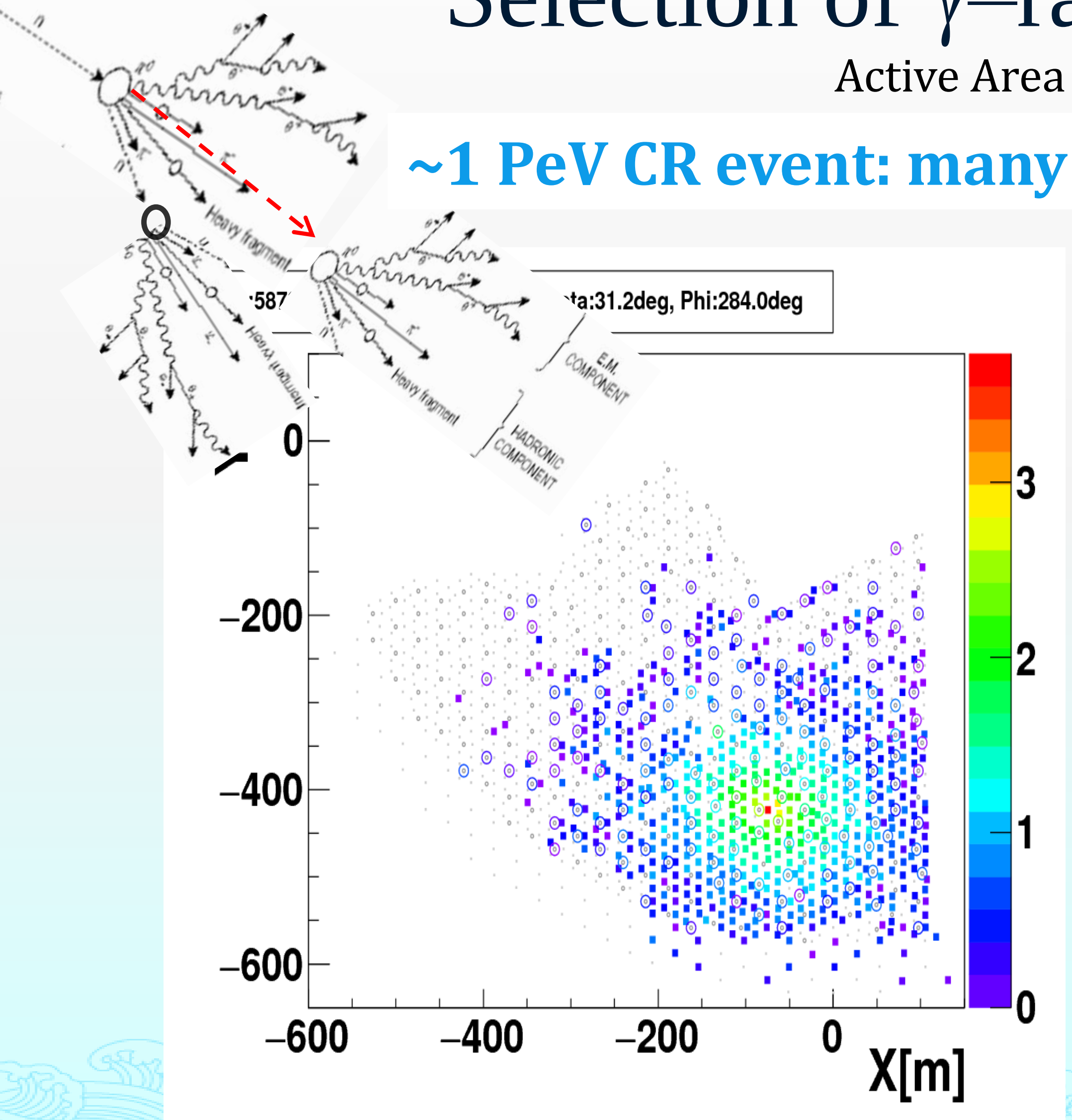
LHAASO-KM2A



Selection of γ–rays out of CR background

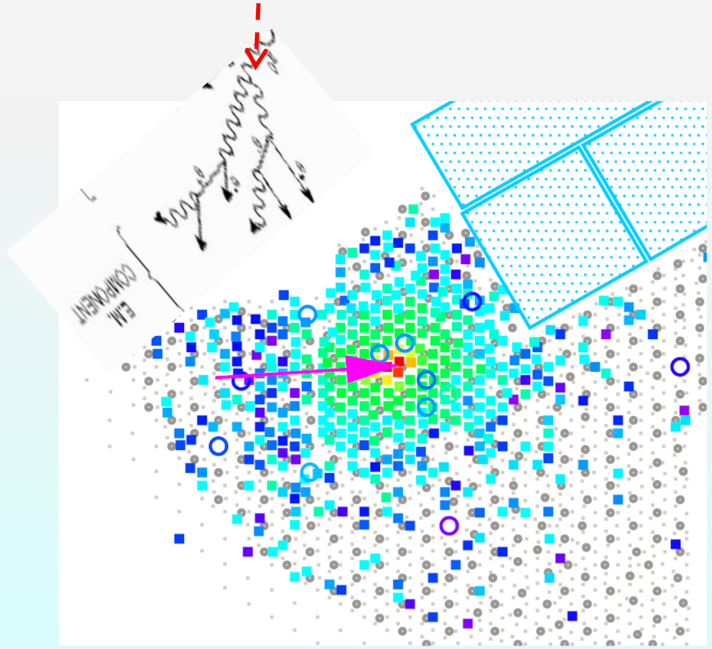
Active Area for Muons vs. Array Area: 4%

~1 PeV CR event: many muons



~ 1 PeV γ–ray event： very few muons

~1 PeV from the Crab

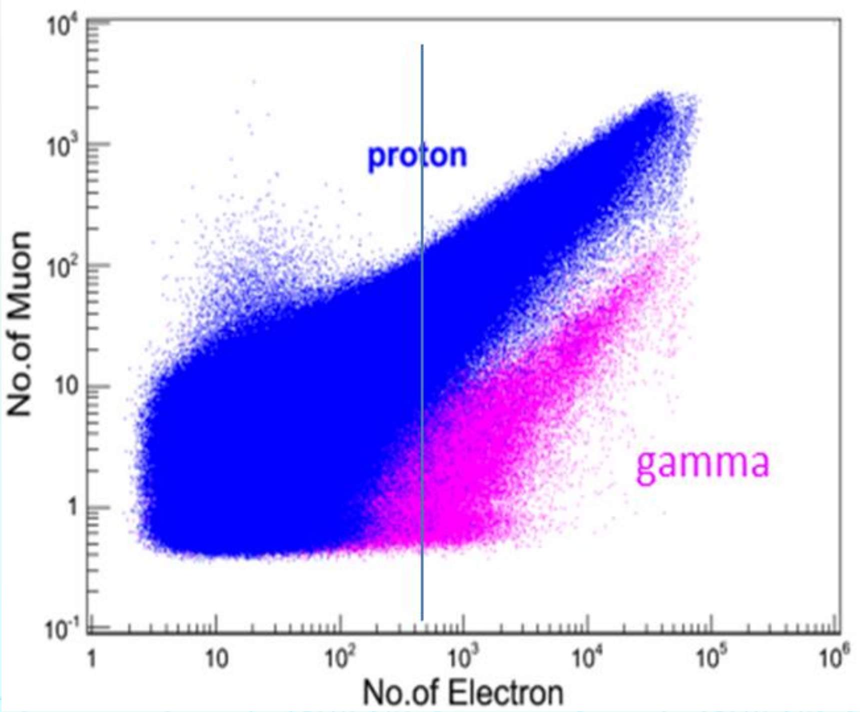


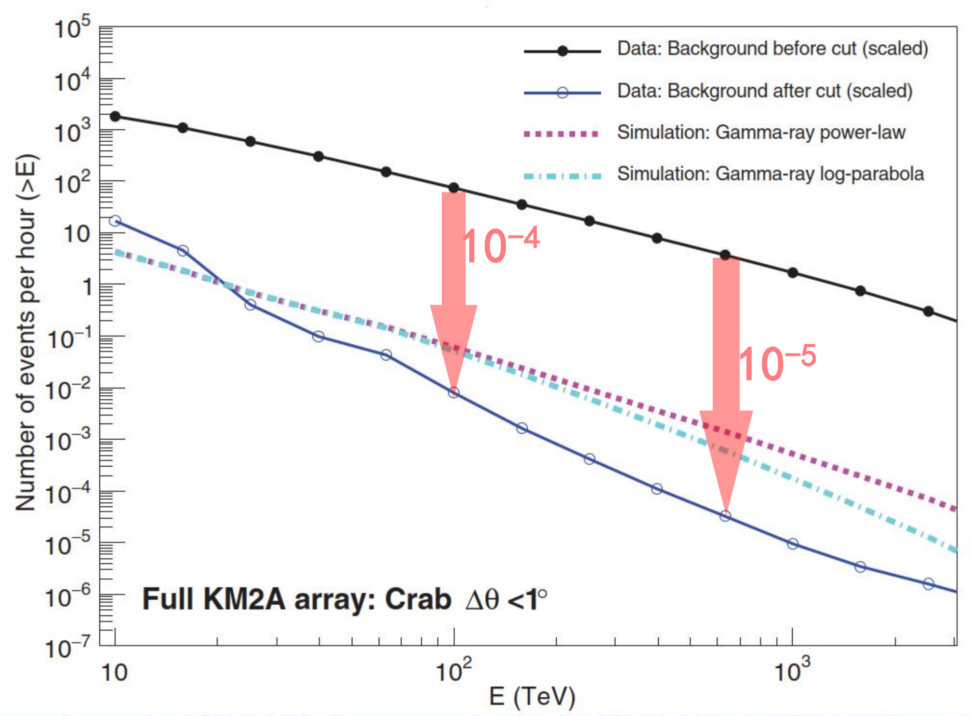
- **Area：**
  1.3 km²
- **Detectors：**
  5216 ED
  1188 MD
- **Energy Range：**
  0.01-10 PeV

CR background Rejection Power

- Counting number of measured muons in a shower
- Cutting on ratio N_{μ}/N_e<**1/230**
- BG-free (N_{γ}>10N_{CR}) Photon Counting

for showers with E>100 TeV from the Crab





LHAASO Coll., *Science*, 373, 425 (2021)

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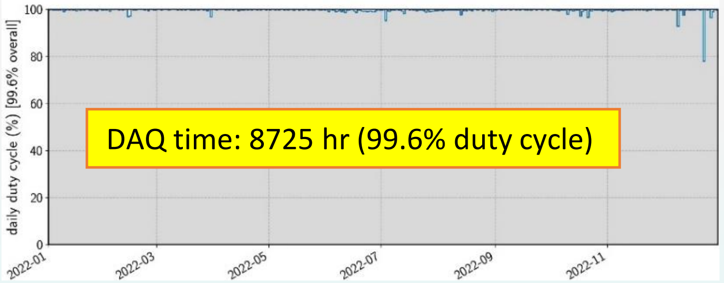
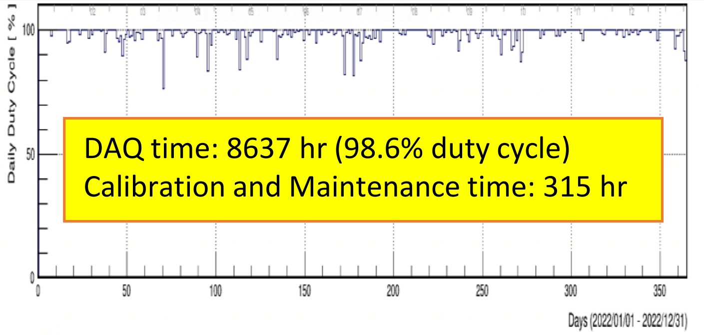
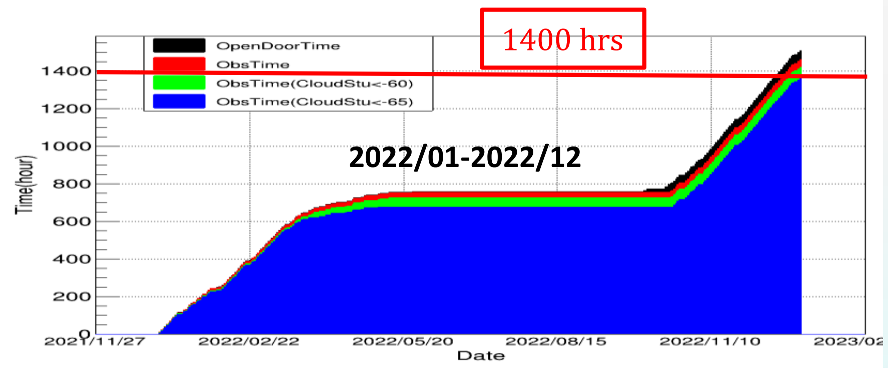
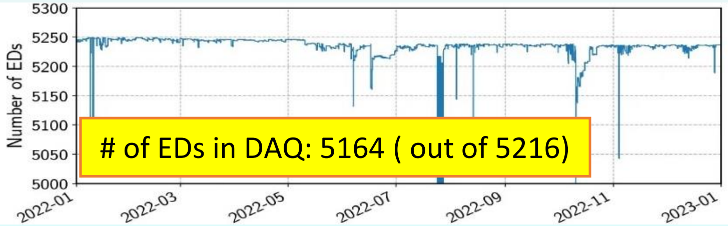
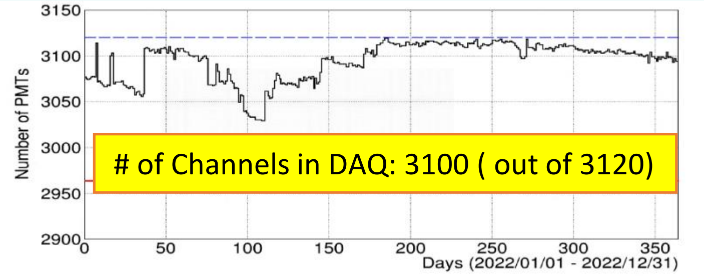
Supper Stable & Fruitful Operation

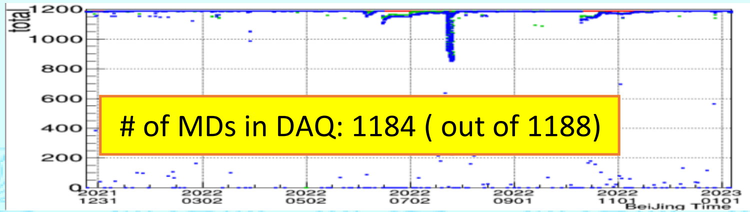










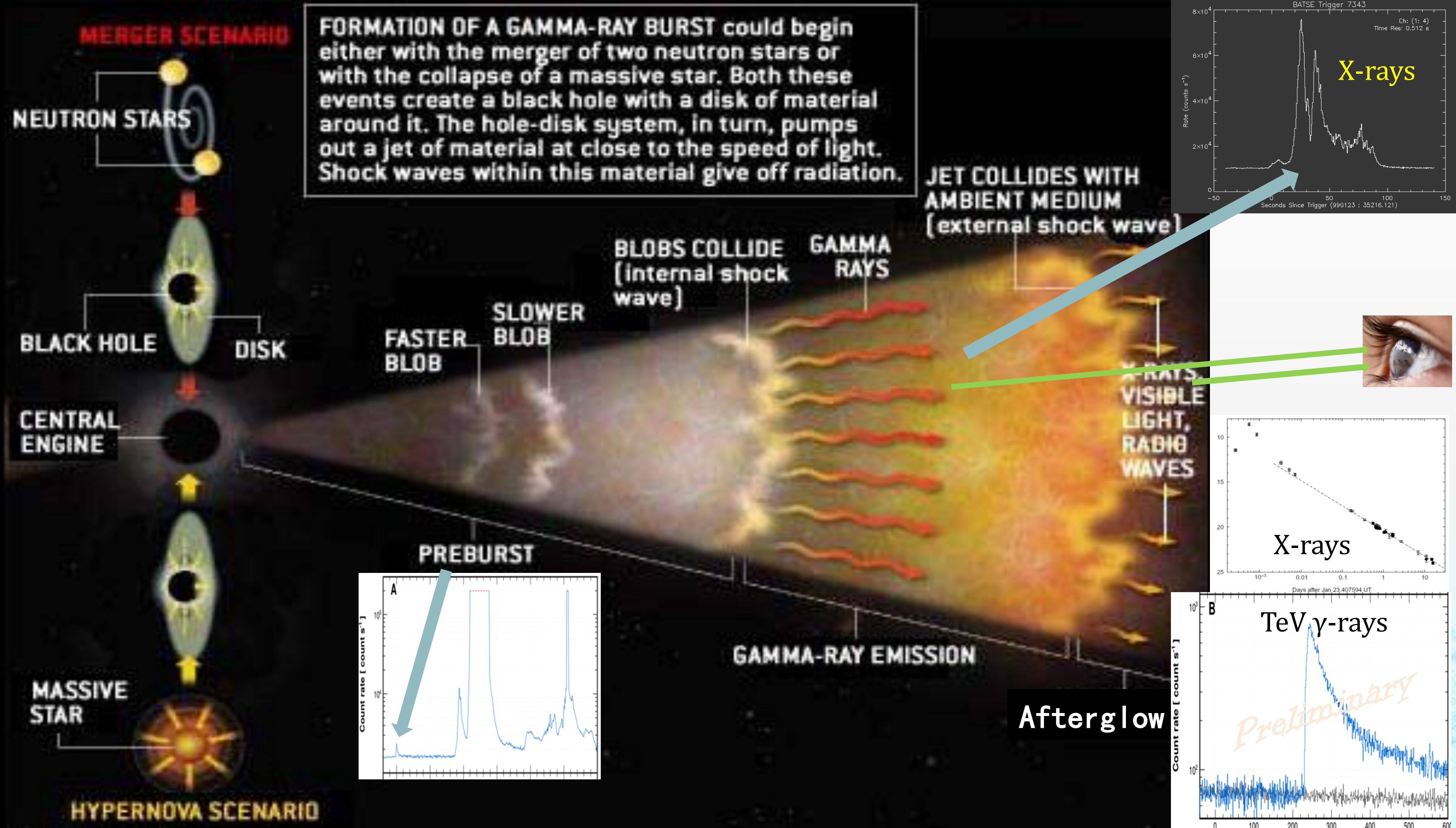


< 2% failure rate

Reconstruction and Analysis

- Data procession
  - # of events: 1 trillion LE、70 billion HE、70 million hybrid
  - Amount: 11 PB
- Simulation
  - # of events: 1 billion LE、0.7 billion HE、150 million hybrid
  - Amount: 4 PB
- # of jobs: 10M for data, 50M for simulation

GRB model



Gehrels, Piro & Leonard 2002, Scientific American

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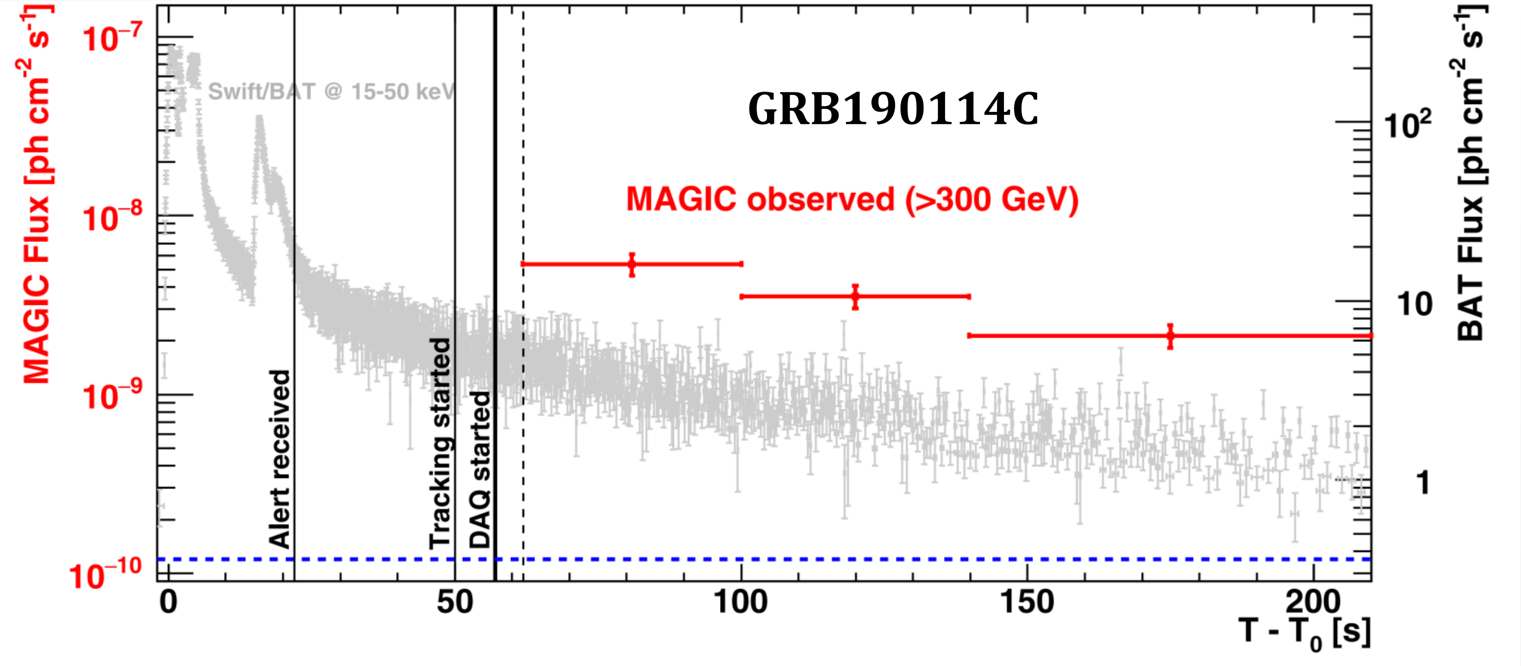
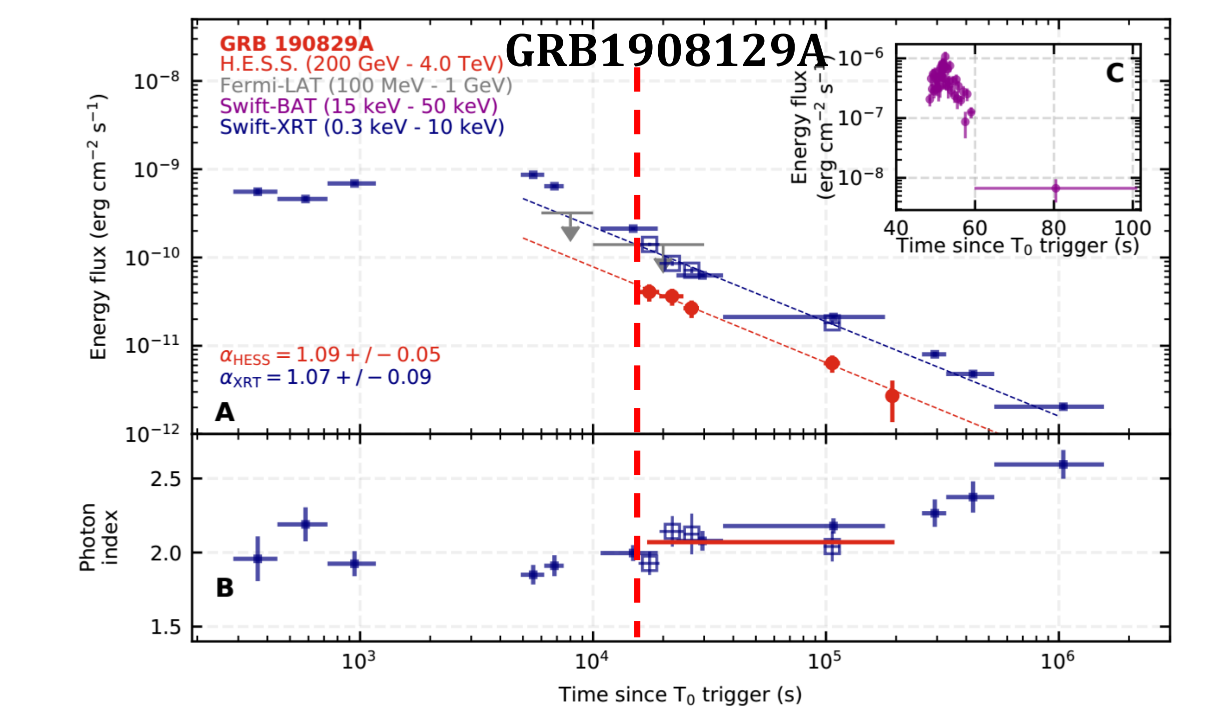
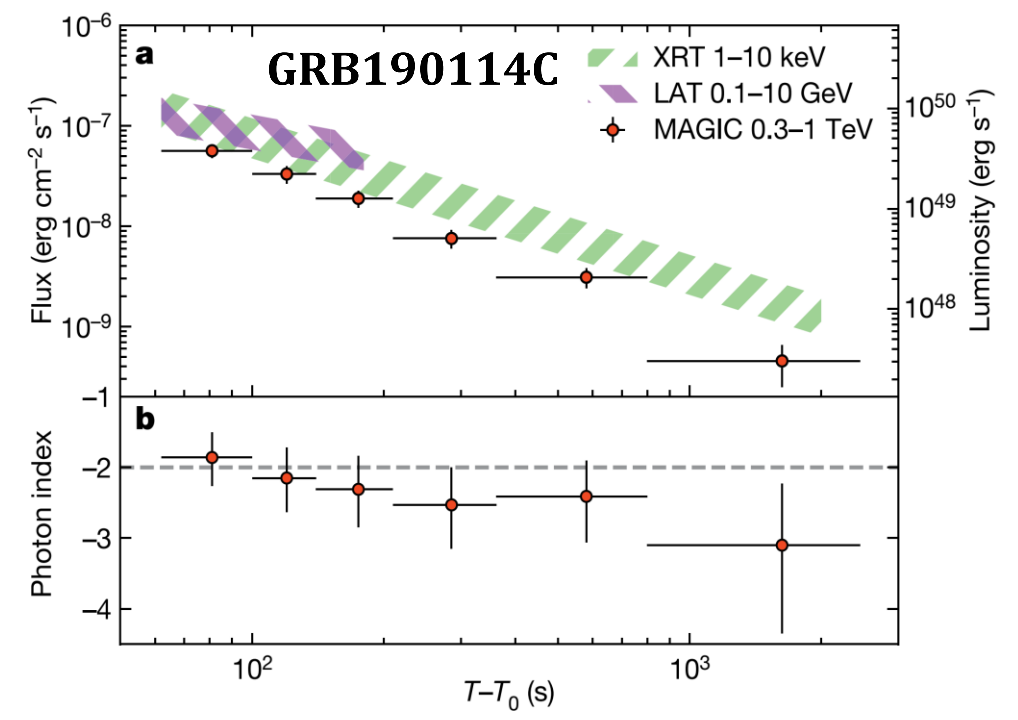
TeV afterglow

- Smooth **decaying** of TeV emission
- Low redshift







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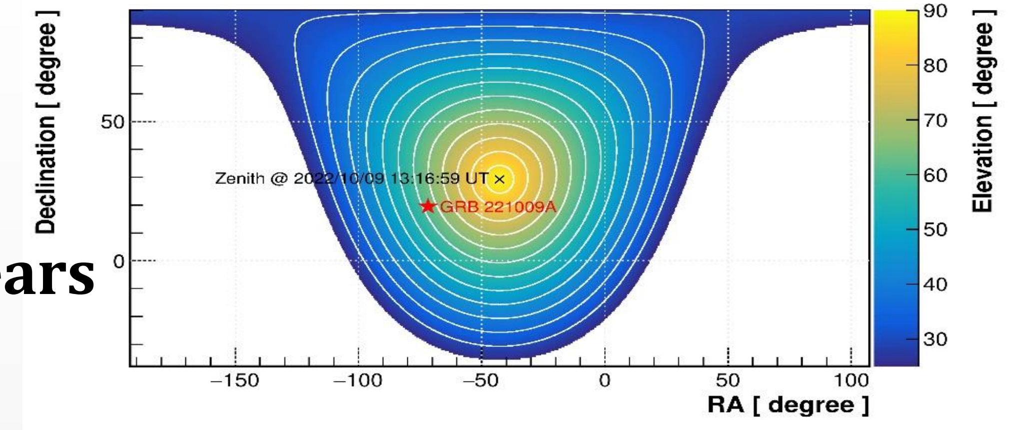
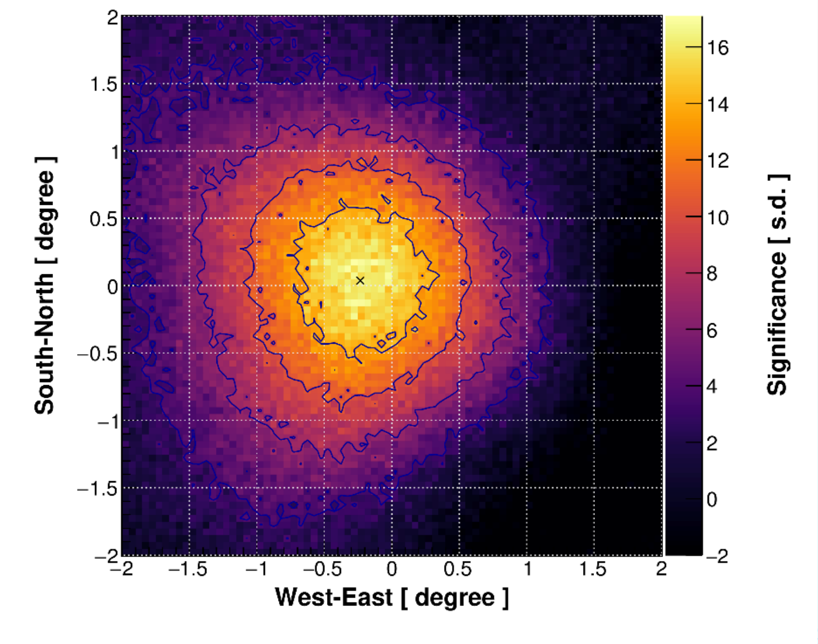


LHAASO observed the brightest GRB in last 60 years

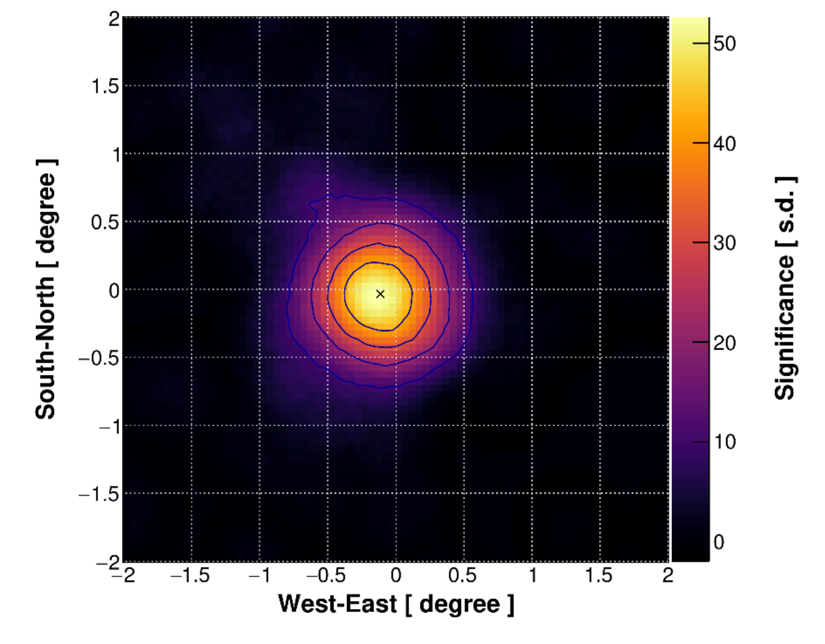
1. **>5,000 photons recorded above 200 GeV**
2. **Significance >131 σ**
3. **Photon energy: E_{max} ~ 18 TeV**

GCN 32677 on Oct. 10th, 2022

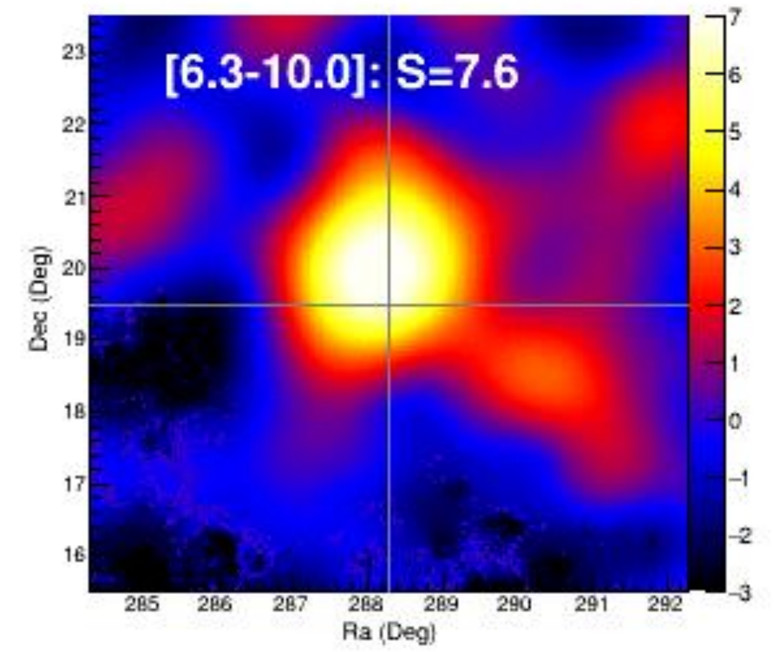
Photon energy E: 0.5 TeV



3 TeV



8 TeV



GRB 221009A: a very rare event

1. arXiv:2302.03642 [pdf, other] astro-ph.HE

GRB 221009A: Discovery of an Exceptionally Rare Nearby and Energetic Gamma-Ray Burst

Authors: Maia A. Williams, Jamie A. Kennea, S. Dichiara, Kohei Kobayashi, Wataru B. Iwakiri, Andrew P. Beardmore, P. A. Evans, Sebastian Heinz, Amy Lien, S. R. Oates, Hitoshi Negoro, S. Bradley Cenko, Douglas J. K. Buisson, Dieter H. Hartmann, Gaurava K. Jaisawal, N. P. M. Kuin, Stephen Lesage, Kim L. Page, Tyler Parsotan, Dheeraj R. Pasham, B. Sbarufatti, Michael H. Siegel, Satoshi Sugita, George Younes, Elena Ambrosi , et al. (31 additional authors not shown)

Abstract: We report the discovery of the unusually bright long-duration gamma-ray burst (GRB), GRB 221009A, as observed by the Neil Gehrels… ▽ More

Submitted 7 February, 2023; **originally announced** February 2023.

Comments: 30 pages, 13 figures, submitted to ApJL

Even more remarkable, we can use these results to derive the rate of GRB 221009A-like GRBs within the volume out to $z = 0.151$ ($1.1\,\mathrm{Gpc}^{-3}$). **This implies we would need to wait over $\approx 10^3$ years to detect another GRB 221009A-like event within this volume.** The combination of the large energy release and the small distance make GRB 221009A truly a once in a lifetime phenomenon.

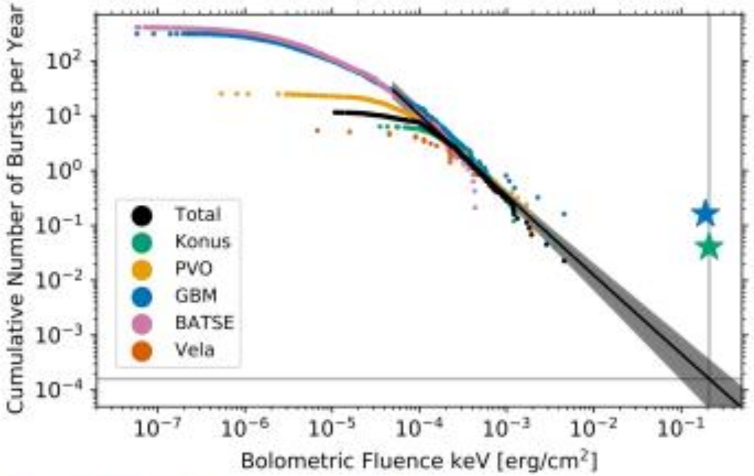
A song:
千年等一回！ …

Fluence: >5 × 10 $^{-2}$ erg/cm^2 at z=0.15 **$R_{GRB,comov}(z = 0) \leq 6.1 \times 10^{-4}\ \mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$**

GRB 221009A:

The brightest of all time

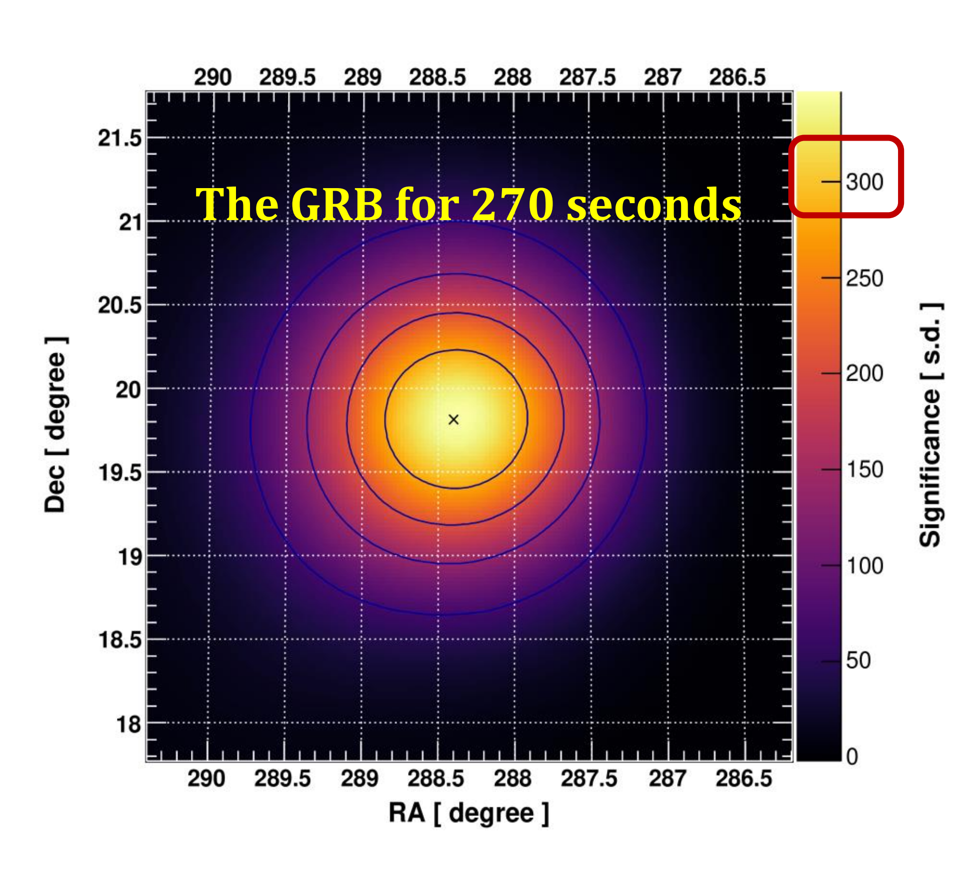
- Highest fluence / peak flux (An et al. 2023)
- Nearby
- Highest energy / peak luminosity (An et al. 2023)
- Once a 1,000/10,000 yr event (Burns et al. 2023)

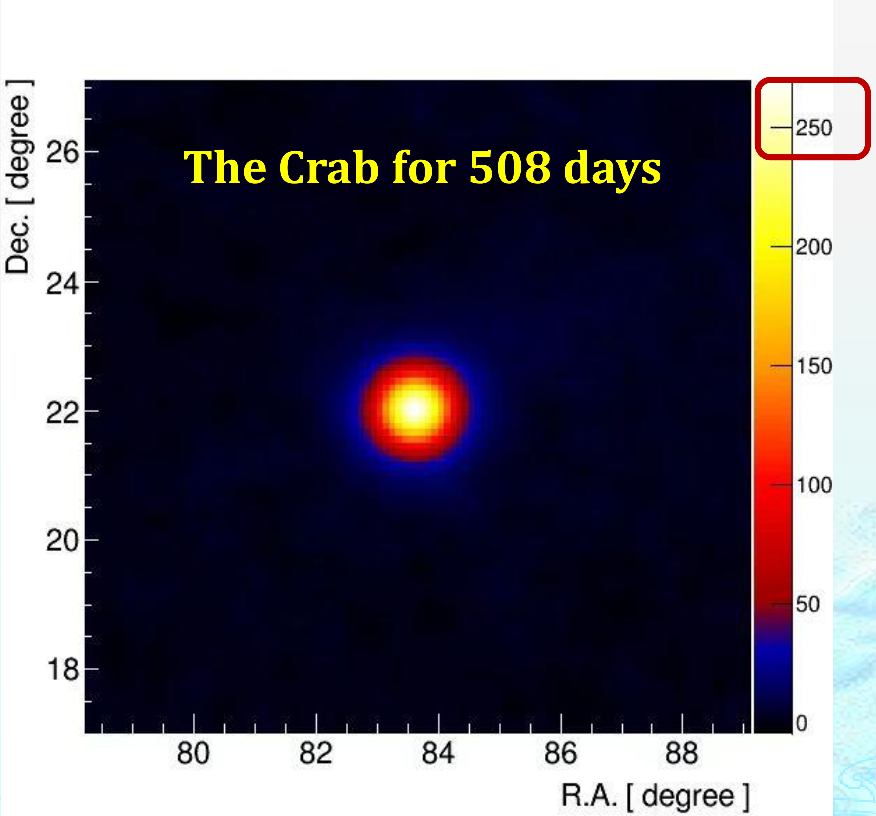


By Bing Zhang

Even much less chance for it in the middle of FoV of LHAASO

◈ The burst of 64k photons in **270 seconds** versus the exposure of the Crab for 508 days

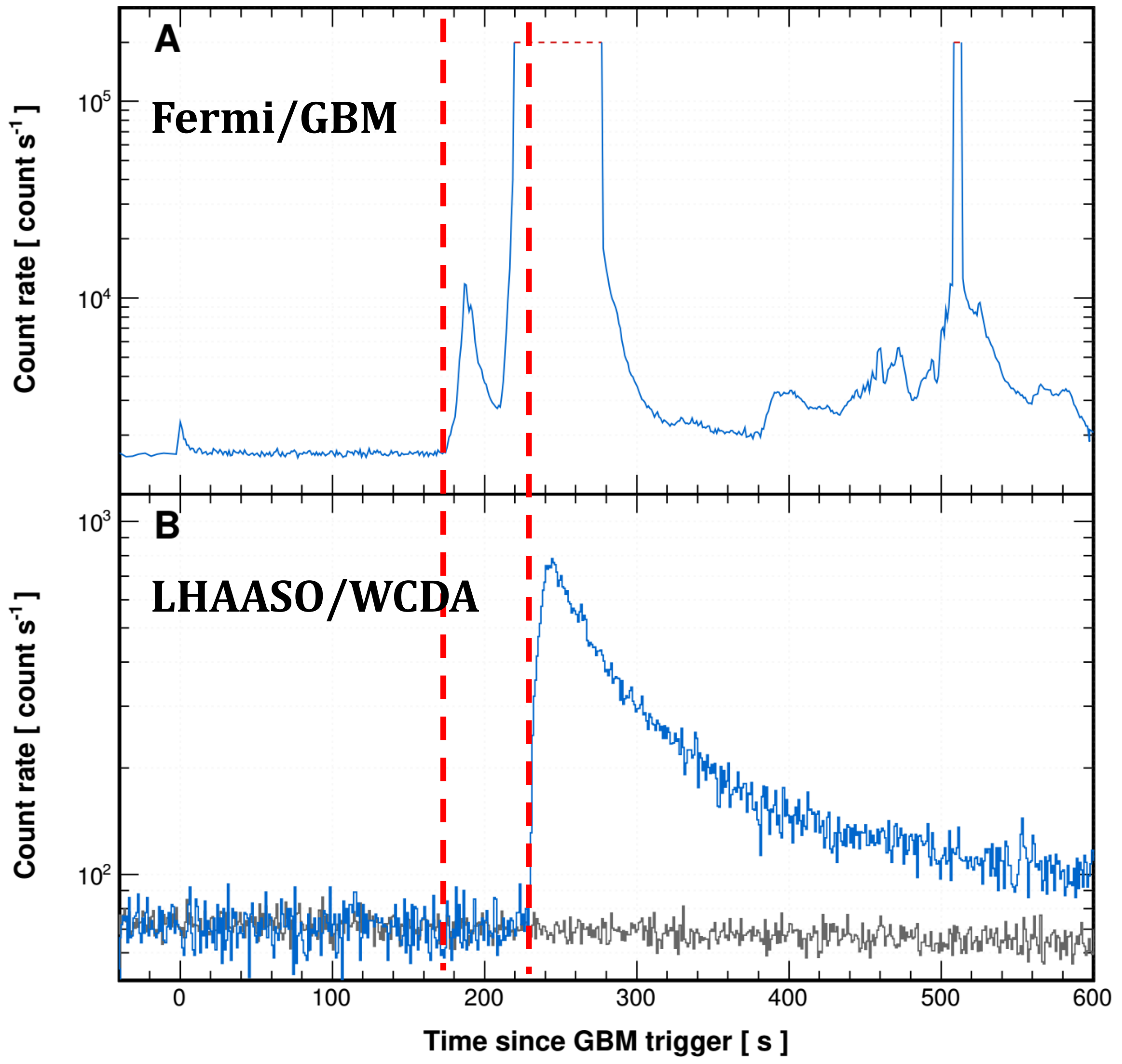




GRB 221009A: A Complete View of the Burst

- Triggered on a precursor at T_0
- Silent phase of ~170 s before the huge prompt emission of γ-rays
- The brightest-of-all-time (BOAT GRB) blinded GBM and LAT
- Fluence: **>5×10^{-2}** erg/cm^2

derives an enormous $E_{\gamma,iso}$~**10^{55}** erg
- Onset of the afterglow ~230 s
- Flares found in both prompt and afterglow phases



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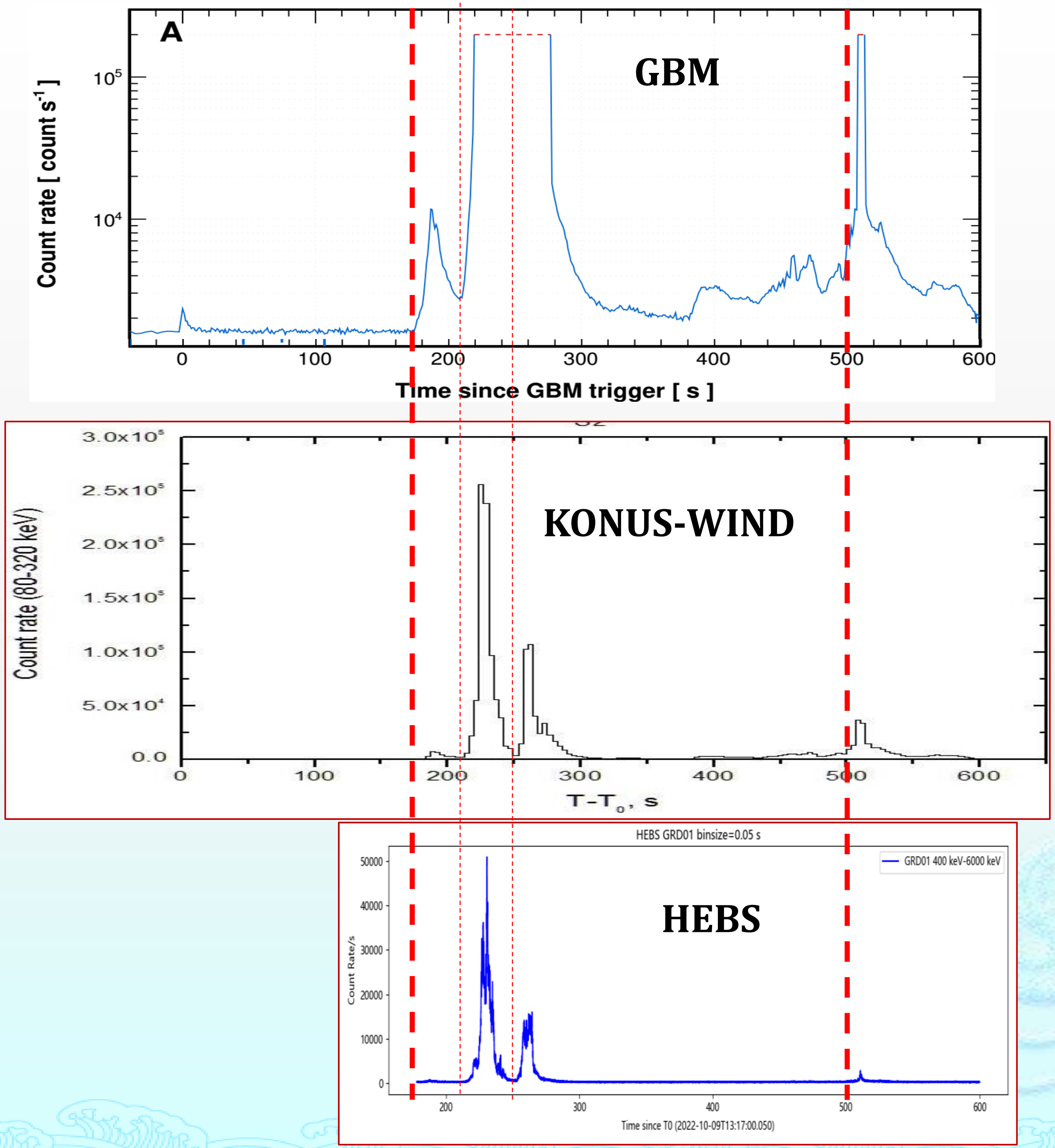
Prompt Emission

- By GBM and LAT (saturated)
- By KONUS-WIND
- By HEBS



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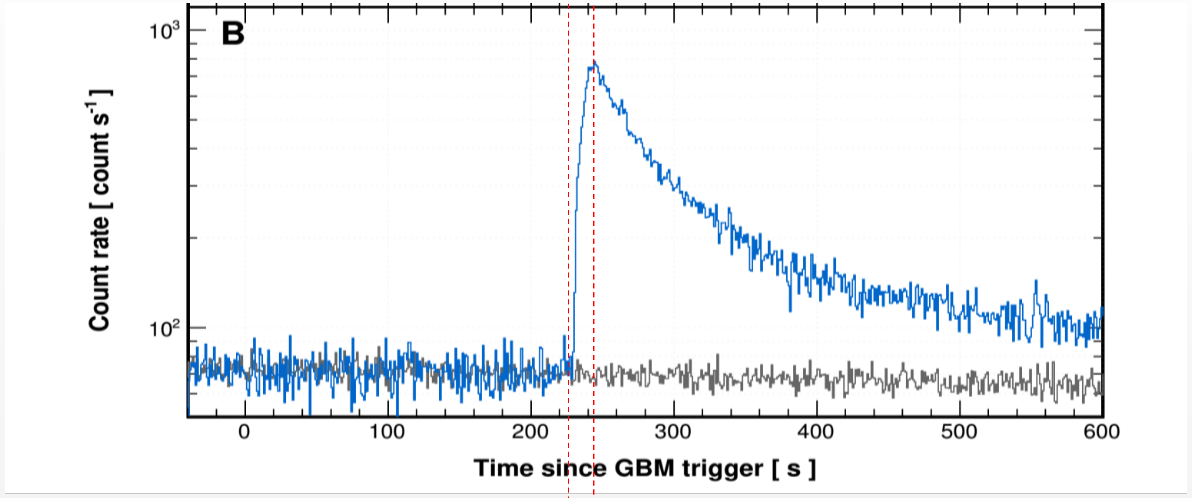
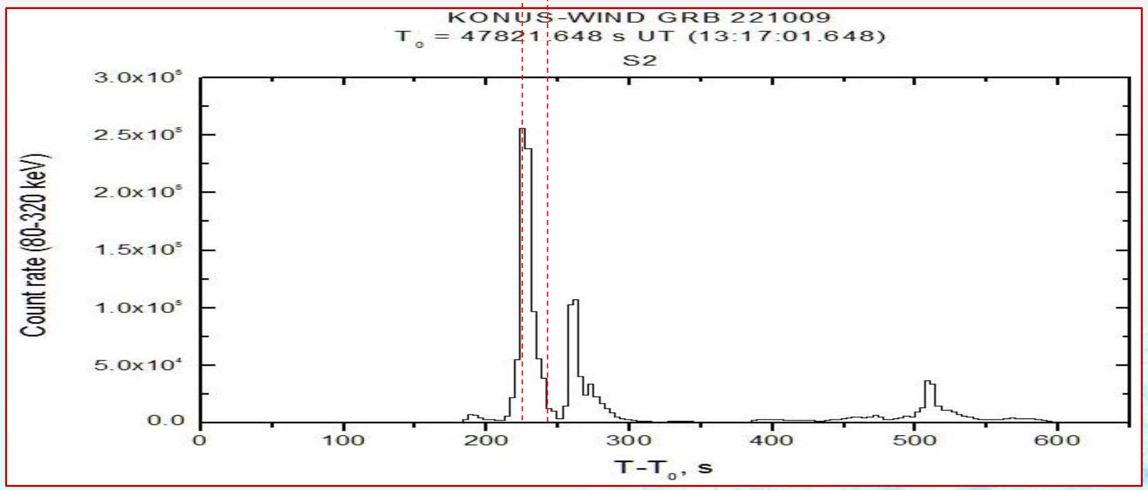
Onset of the afterglow

- LHAASO on GRB 221009A: the 1st GRB seen by EAS detector
- Light curve: complete temporal profile at TeV
  — **dominated by the external shock origin**

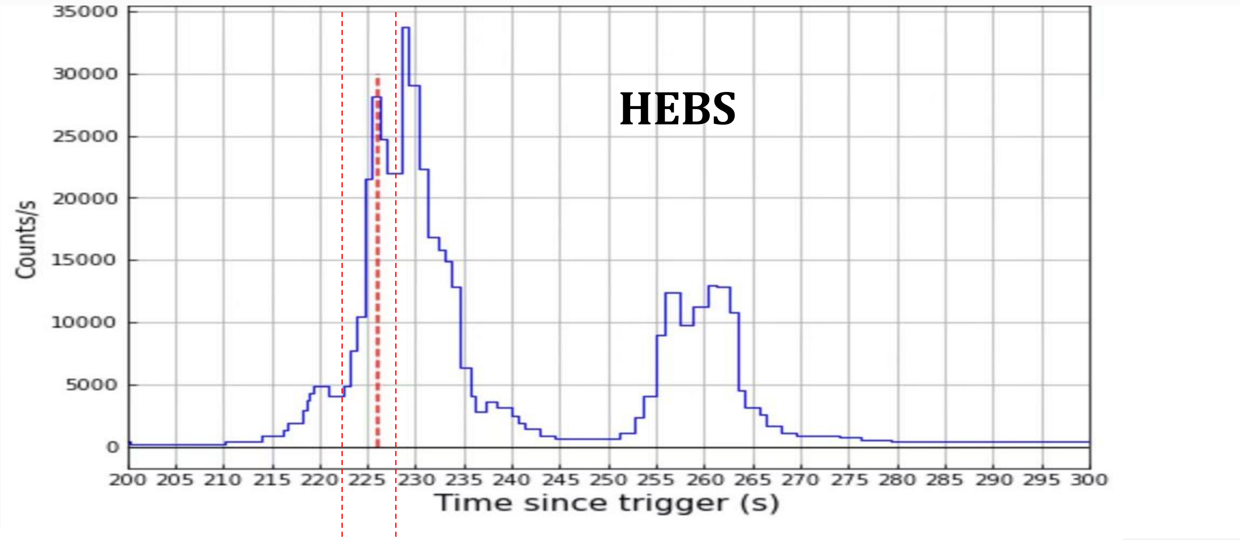


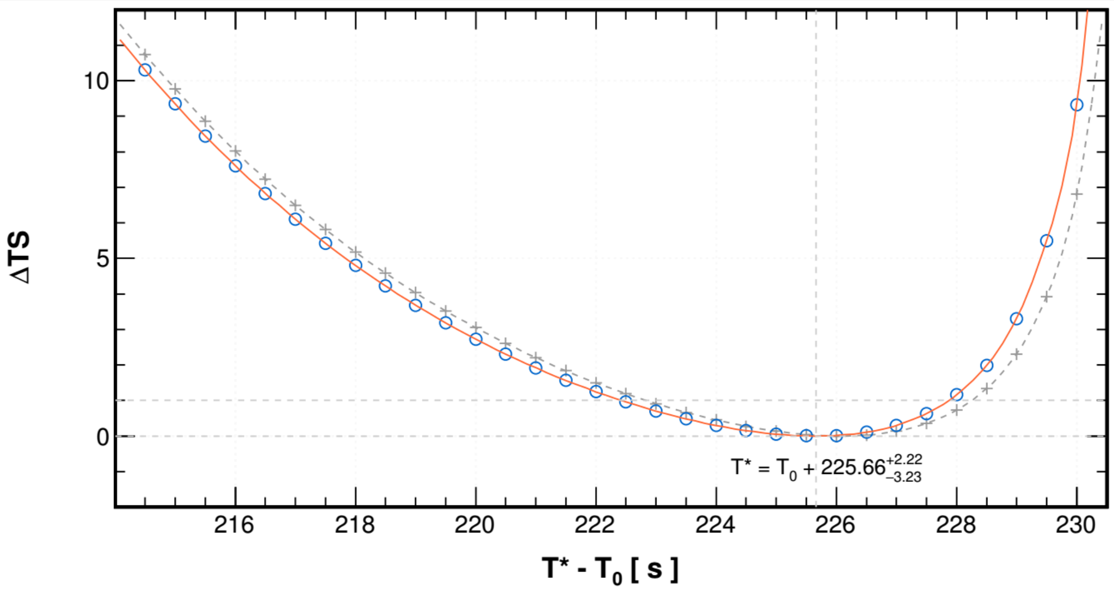


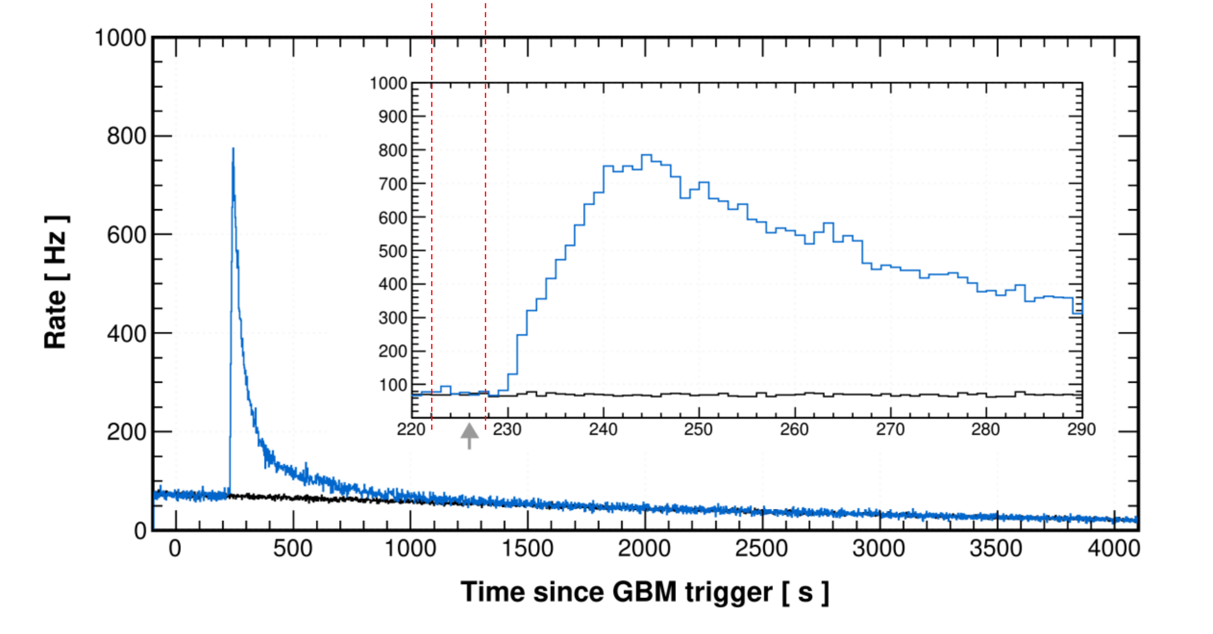
Reference time T*

- The reference time: $T^* \approx 225\text{–}228$ s
- A good approximation of T^* is the main burst in prompt phase (Lazzati, Zhang…)
- Fitting of LHAASO light curve:

$$T^* \approx 226_{-3}^{+2} \quad \text{s}$$







What we've learnt from the GRB 221009A

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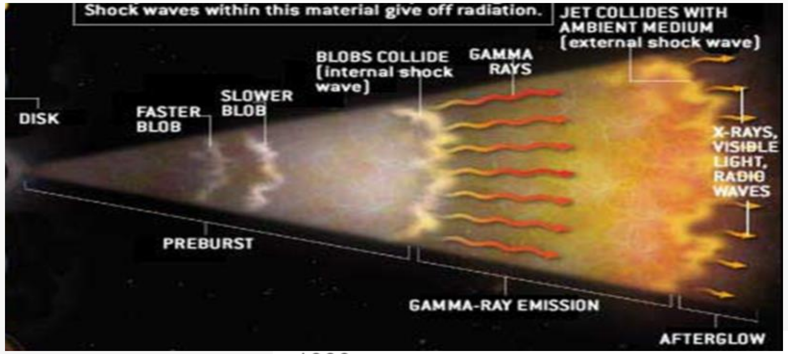
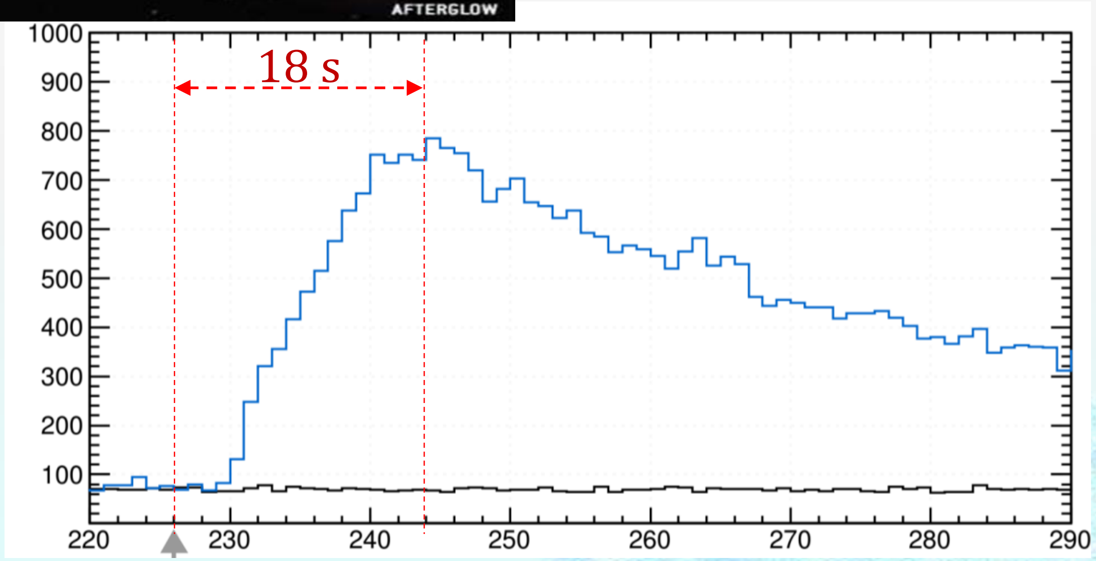
1. The initial bulk Lorentz Factor of the ejecta

R ~ 10^{15} cm 10^{18} cm





- From the time when the main prompt emission reaches the peak flux (~T*) to the moment when the afterglow reaches the peak, it takes **~18 s**
- The initial bulk Lorentz factor is estimated as

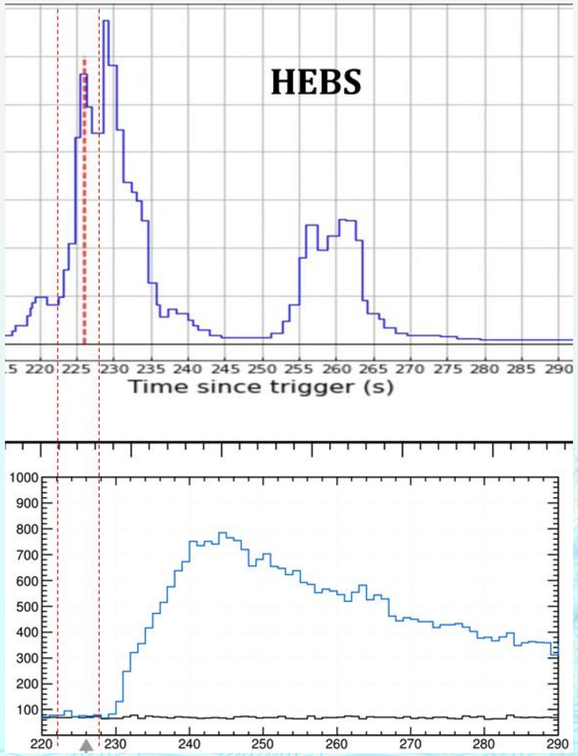
$$\Gamma_0 = \left(\frac{3E_k}{32\pi n m_p c^5 t_{\rm peak}^3}\right)^{1/8} = 440 E_{k,55}^{1/8} n_0^{-1/8} \left(\frac{t_{\rm peak}}{18\,{\rm s}}\right)^{-3/8}$$

2. Upper limit on emission in TeV band in prompt phase

- The most strict limit on the TeV prompt emission before T*

$$R = F_{TeV}/F_{MeV} < 3 \times 10^{-5}$$

- As a consequence, the jet might be highly magnetized



Implying a low Compton ratio

Assuming the internal dissipation radius ~10^{15} cm, according to the scale of variability of the prompt emission

$$Y \equiv L_{\rm SSC}/L_{\rm syn} \sim \bar{R}/(f_{\gamma\gamma} f_{\rm spec}) \leq 1.6 \times 10^{-3} R_{\rm in,15}^{-1} f_{\rm spec}^{-1}$$

$$\overline{Y} \approx Y(\gamma_m) \approx \frac{\epsilon_e}{\epsilon_B} \begin{cases} 1 & \frac{\gamma_m}{\widehat{\gamma_m}} < (p-2)^2 \\ (p-2)\left(\frac{\gamma_m}{\widehat{\gamma_m}}\right)^{-1/2} & \frac{\gamma_m}{\widehat{\gamma_m}} > (p-2)^2, \end{cases}$$

$\Rightarrow$ $f_{\rm KN} \sim 0.1$

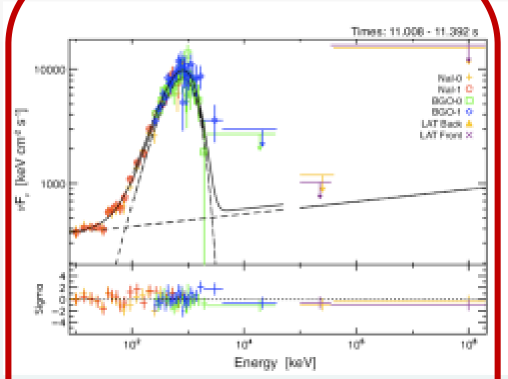
$$\boxed{\epsilon_{\rm B,in} \geq 30 \epsilon_{\rm e,in}}$$

magnetic field energy density is much larger than the energy of relativistic electrons

Favors a magnetically dominated jet

GRB 221009A: other constraints

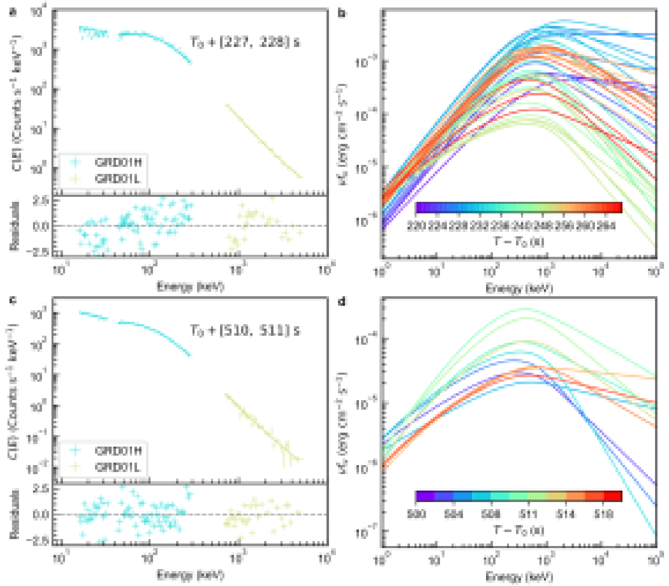
- Prompt emission: synchrotron only, no thermal component - consistent with a Poynting-flux-dominated jet (Yang et al. 2023)
- Afterglow:
  - Early LHAASO afterglow: consistent with a Poynting-flux-dominated jet
  - Late multi-wavelength afterglow: early radio emission requires reverse shock contribution (Gill & Granot 2023)

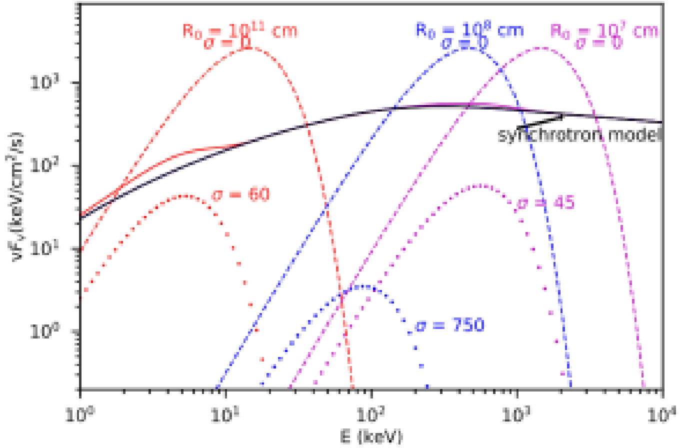


Strong thermal component indicate photosphere dominant jet

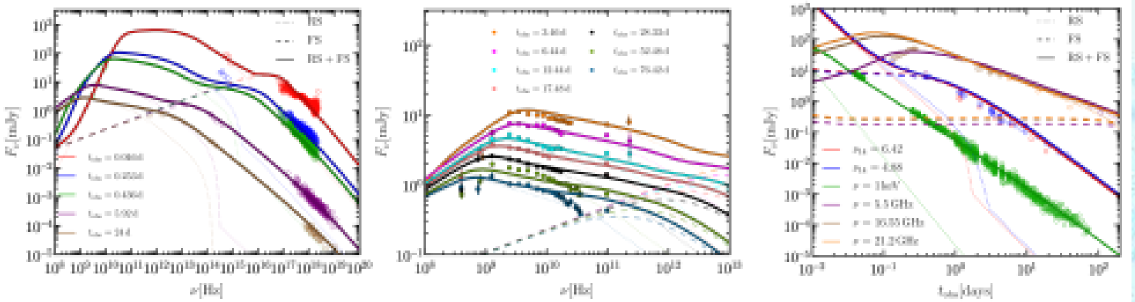
Rare case

GRB 090902B





Yang et al. 2023, ApJL



Gill & Granot 2023, arXiv

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3. Rising phase

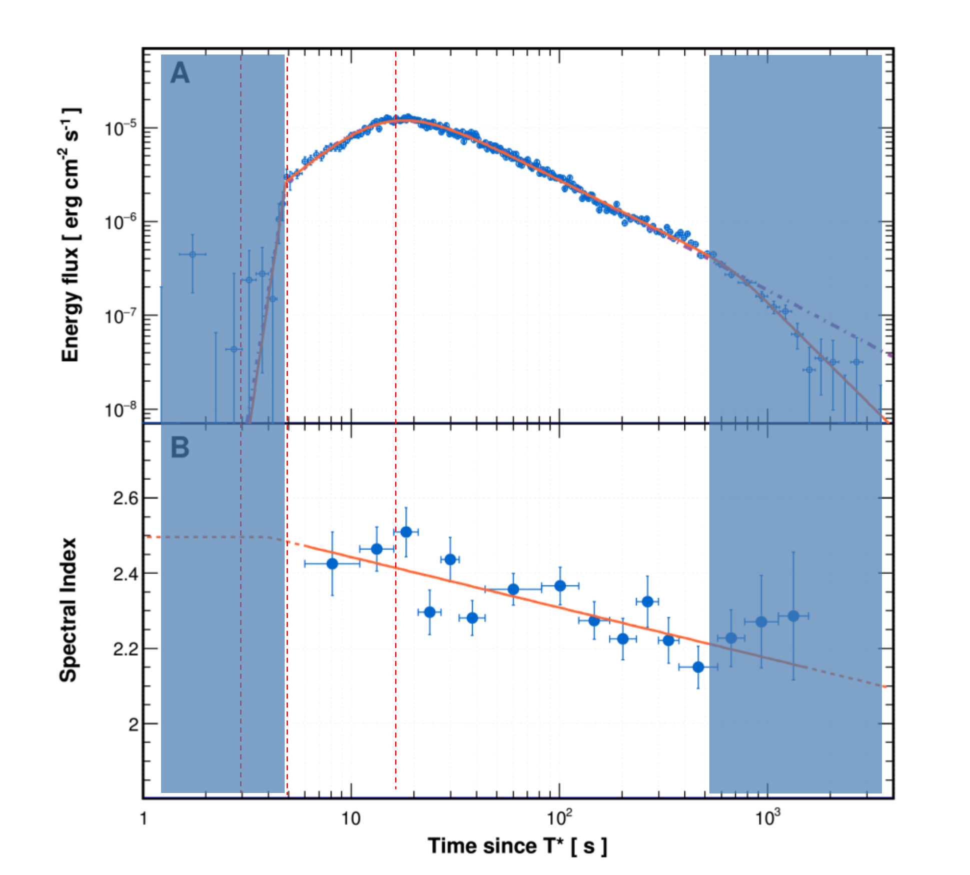
$$\alpha_1 = 1.82^{+0.21}_{-0.18}$$

- **Synchrotron Self-Compton mechanism** is implied by the broken power-law
- Light curve ~t^2 favors k=0 (ISM), and disfavors k=2 (stellar wind)

$$n \propto R^{-k}$$

$$F_\nu = \begin{cases} F_m^{\rm IC}\left(\frac{\nu}{\nu_m^{\rm IC}}\right)^{-\frac{p-1}{2}} \propto t^{\frac{16-(9+p)k}{4}} \nu^{-\frac{p-1}{2}}, & \nu_m^{\rm IC} < \nu < \nu_c^{\rm IC} \\ F_m^{\rm IC}\left(\frac{\nu}{\nu_c^{\rm IC}}\right)^{-\frac{1}{2}} \propto t^{\frac{8-3k}{4}} \nu^{-1/2}, & \nu_c^{\rm IC} < \nu < \nu_m^{\rm IC} \\ F_m^{\rm IC}(\nu_m^{\rm IC})^{\frac{p-1}{2}} (\nu_c^{\rm IC})^{\frac{1}{2}} \nu^{-\frac{p}{2}} \propto t^{\frac{8-(2+p)k}{4}} \nu^{-\frac{p}{2}}. & \nu > \max(\nu_m^{\rm IC}, \nu_c^{\rm IC}) \end{cases} \tag{12}$$

- **The fast rising**: implying a free expansion with an increase of number of electrons accelerated at the external shocks



Decay phase: SSC

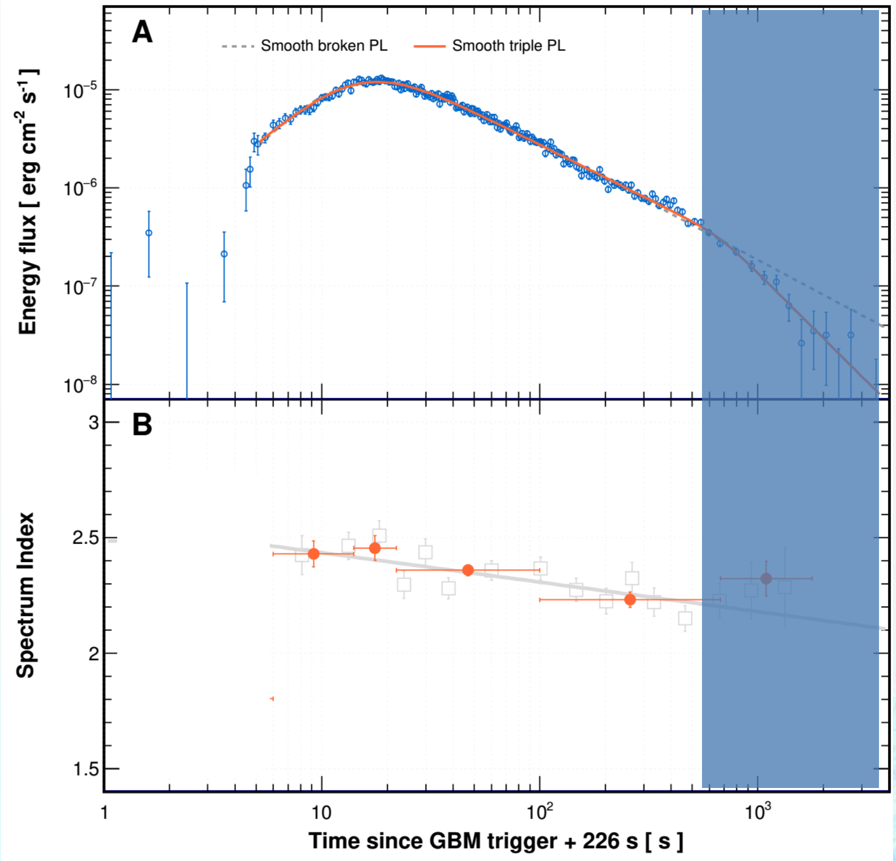
$$\alpha_2 = -1.115^{+0.012}_{-0.012}$$

- Standard decaying behavior

$$F_\nu = \begin{cases} F_m^{\mathrm{IC}} \left(\frac{\nu}{\nu_m^{\mathrm{IC}}}\right)^{-\frac{p-1}{2}} \propto t^{\frac{11-9p}{8}}, & \nu_m^{\mathrm{IC}} < \nu < \nu_c^{\mathrm{IC}} \\ F_m^{\mathrm{IC}} \left(\frac{\nu}{\nu_c^{\mathrm{IC}}}\right)^{-\frac{1}{2}} \propto t^{\frac{1}{8}}, & \nu_c^{\mathrm{IC}} < \nu < \nu_m^{\mathrm{IC}} \\ F_m^{\mathrm{IC}} (\nu_m^{\mathrm{IC}})^{\frac{p-1}{2}} (\nu_c^{\mathrm{IC}})^{\frac{1}{2}} \nu^{-\frac{p}{2}} \propto \boxed{t^{\frac{10-9p}{8}}}, & \nu > \max(\nu_m^{\mathrm{IC}}, \nu_c^{\mathrm{IC}}) \end{cases} \quad (13)$$

$$dN_e/dE \propto E_e^{-p}$$

$$p \sim 2.1$$



A fast component!

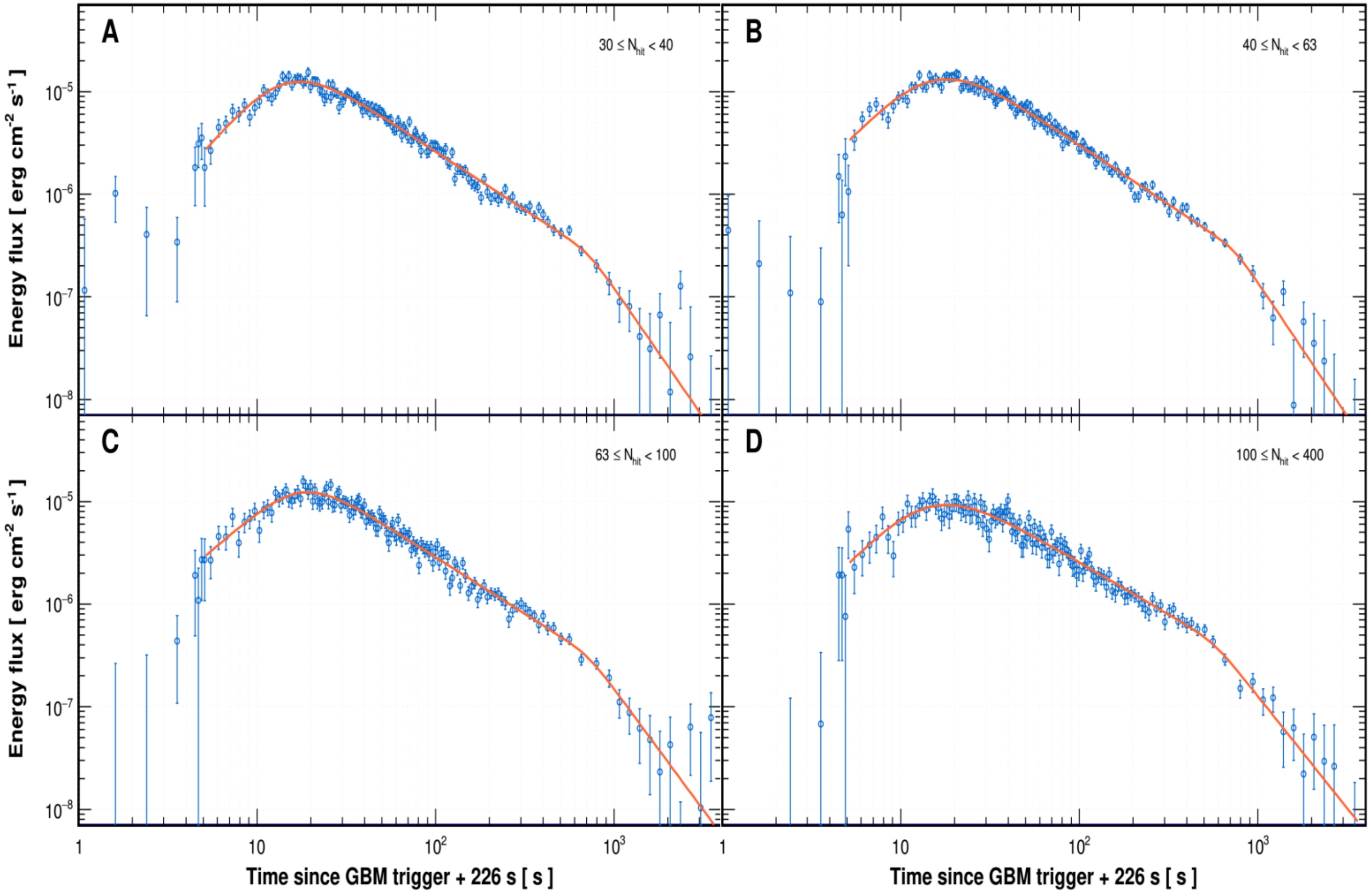
- **Very fine jet structure may be revealed at VHE ?**

4. A "jet break" : Observational evidence

- **Energy independence**

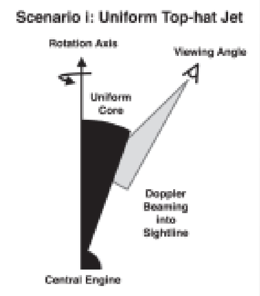
  As a pure kinematic and geometric effect, the time when the break appears should be energy independent

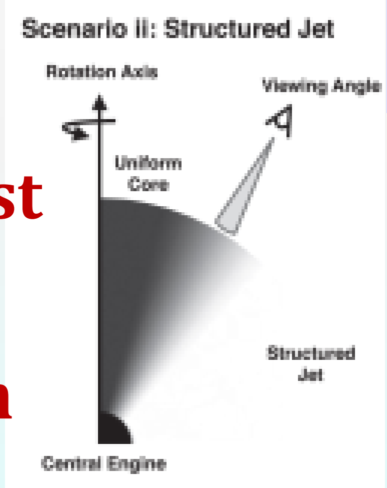
- **LHAASO observed the "break" in four energy bands**

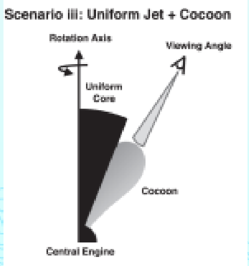


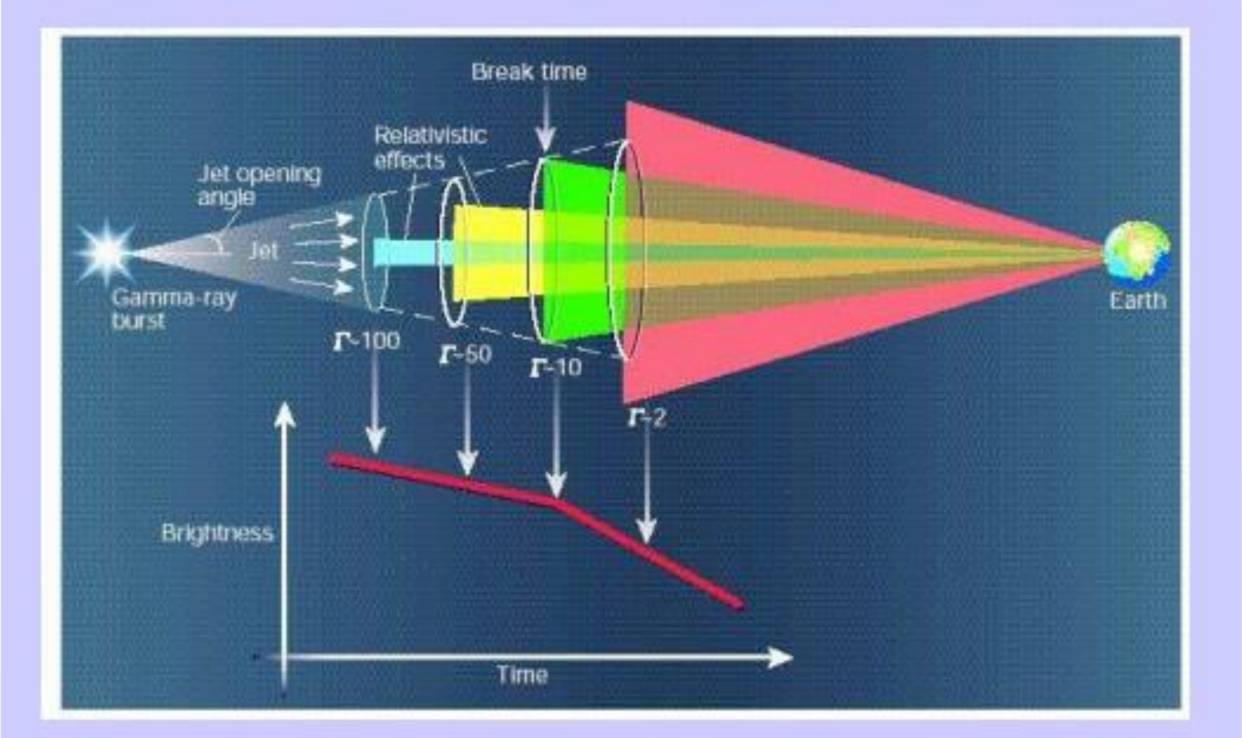
Jet Features

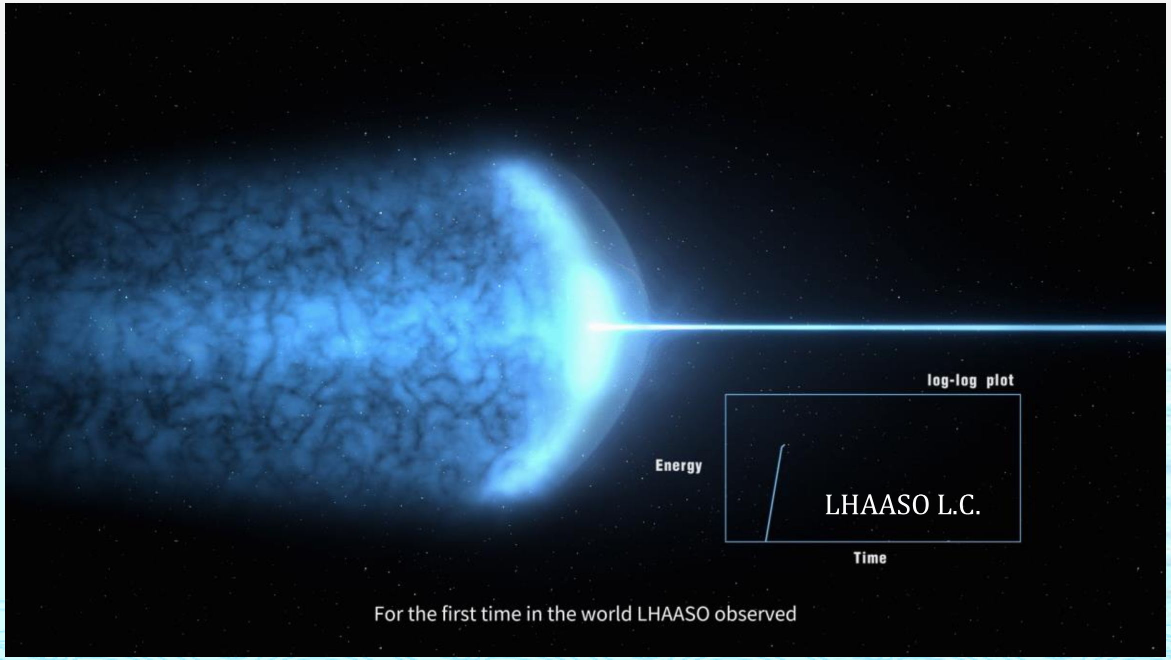
- Jet structure may be revealed at VHE band
- A "jet break" at high energy, indicated by the existence of the fast decay component, could be the evidence of the narrowest beam ~1°
- 1st time to see the HE "core" of the jet







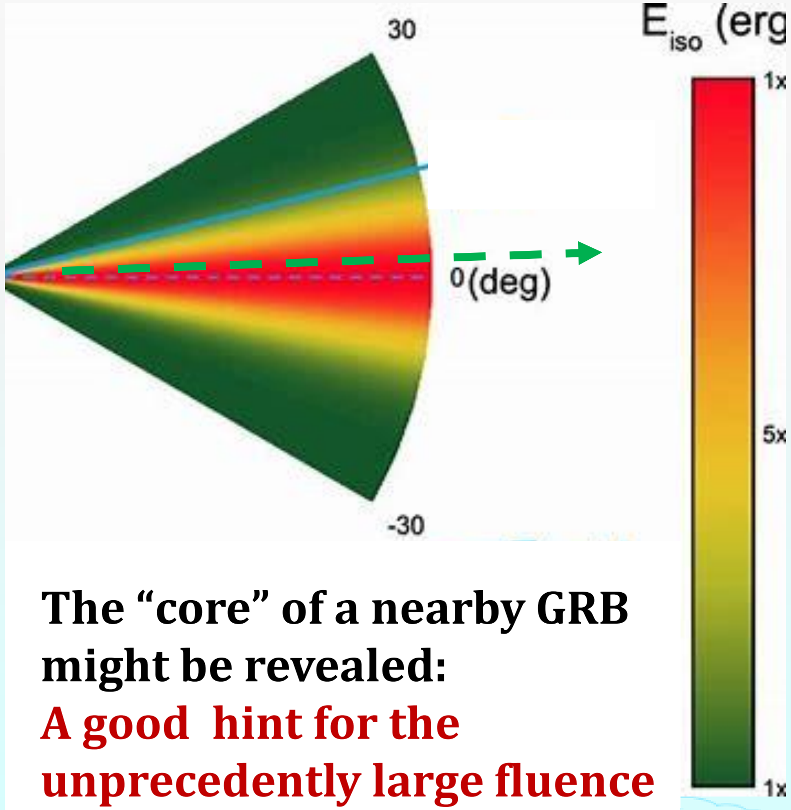




Very lucky? Sure it is!

Only in VHE band, the "core" has be revealed?

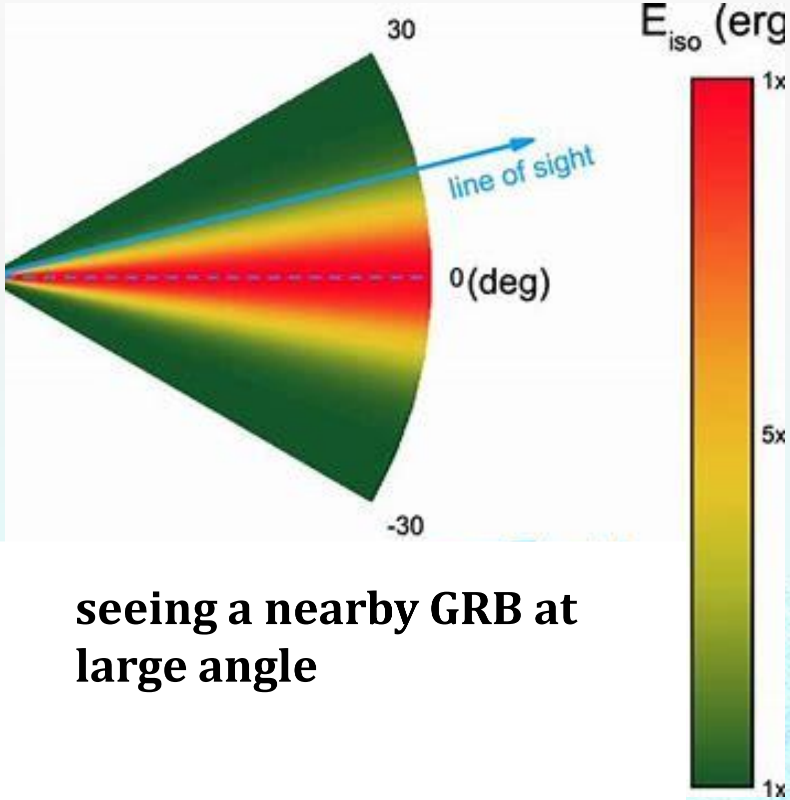
- GRB 221009A



The "core" of a nearby GRB might be revealed:
A good hint for the unprecedently large fluence

Versus

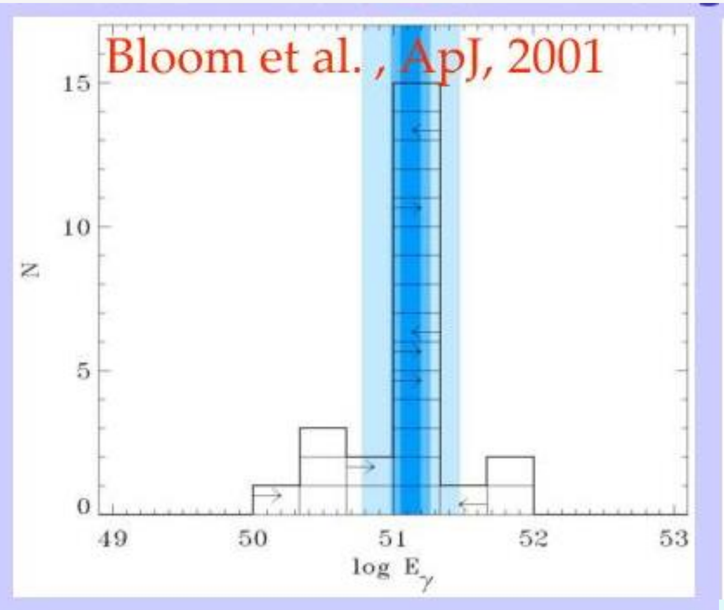
GRB 170817A (off-axis)

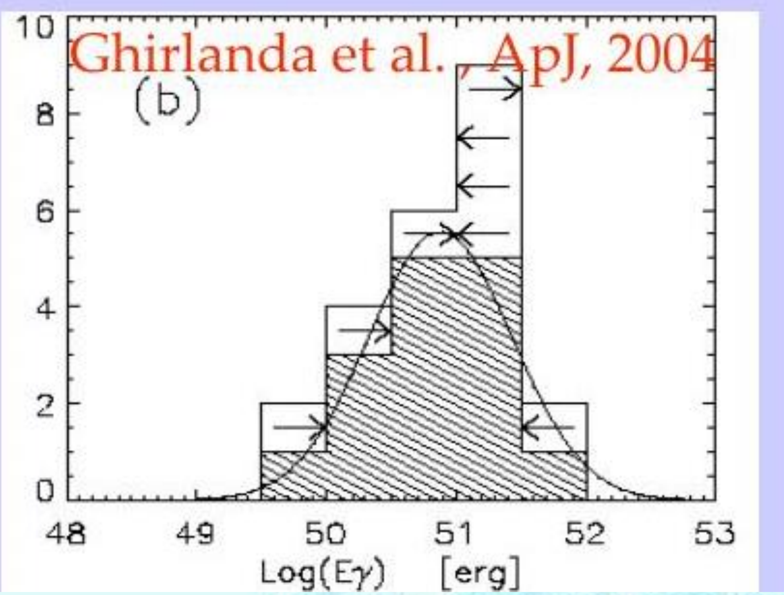


seeing a nearby GRB at large angle

Very narrow jet:
GRB 221009A an ordinary burst

- **First time seeing a jet break at TeV band**
- This helps to understand why it is the BAOT GRB
- The total energy of the GRB is normal

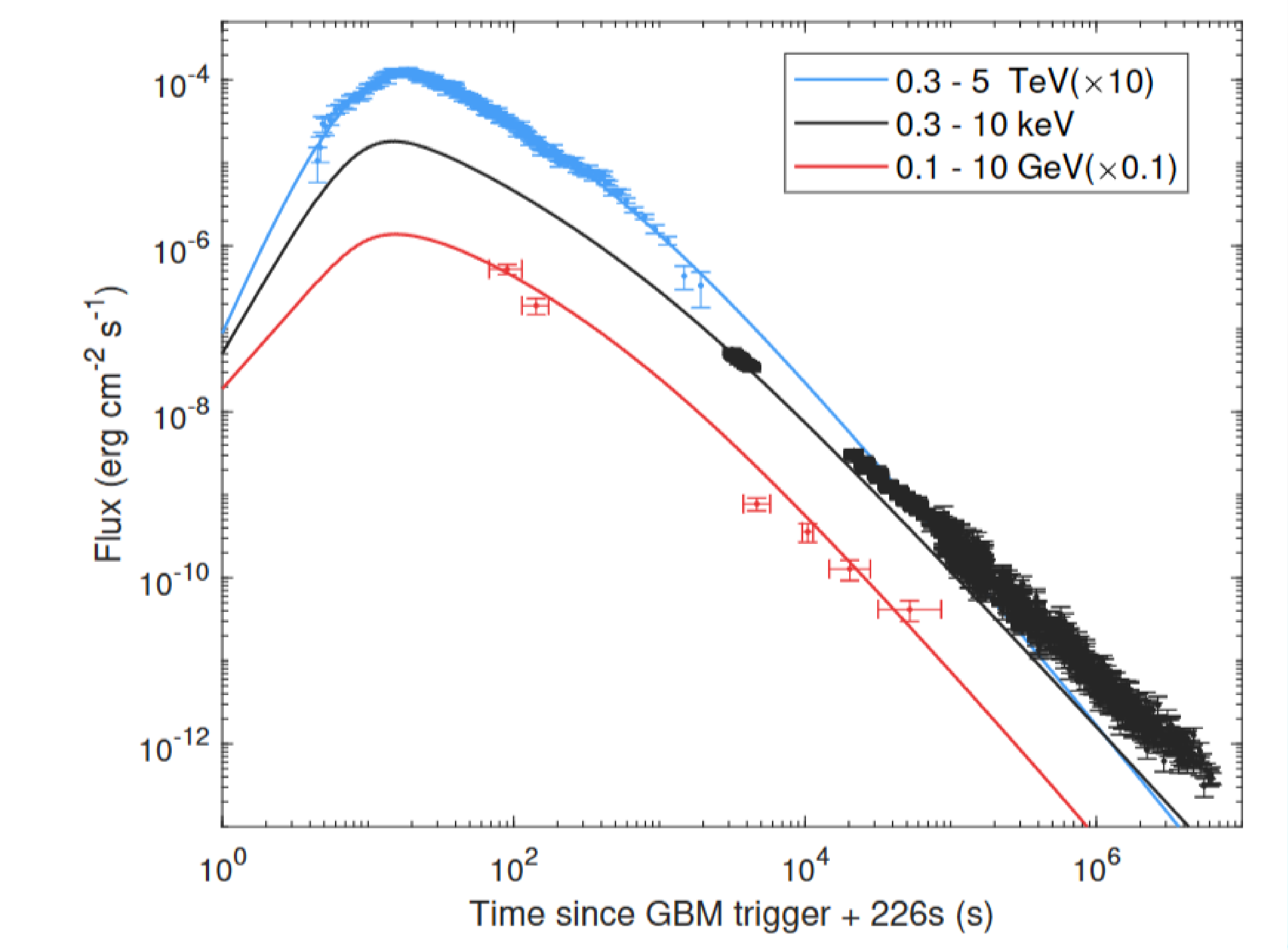




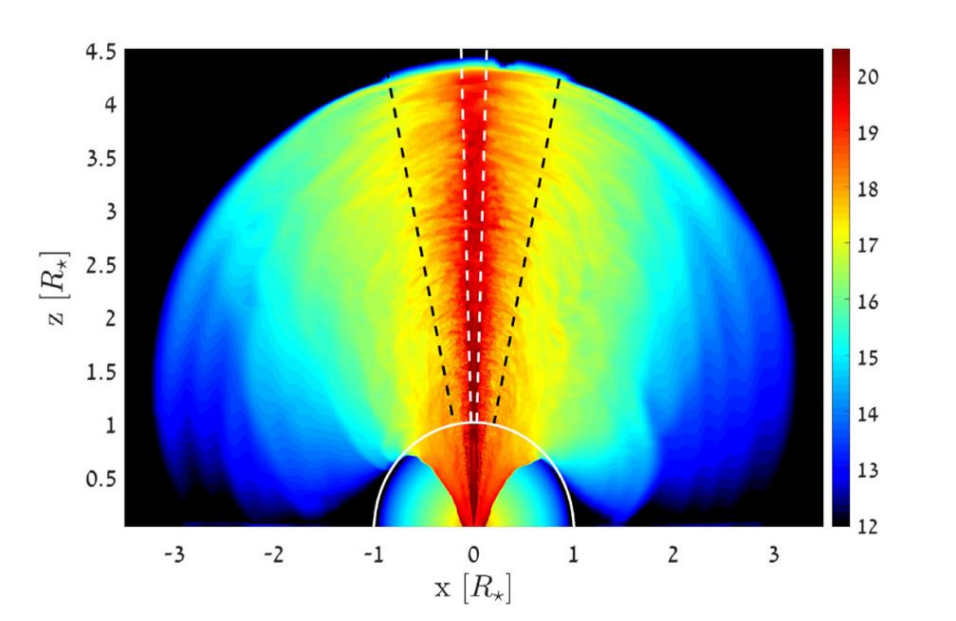
$$\theta_0 \sim 0.7^\circ E_{k,55}^{-1/8} n_0^{1/8} \left(\frac{t_{b,2}}{670\ \mathrm{s}}\right)^{3/8}$$

$$E_{\gamma,j} = E_{\gamma,\mathrm{iso}}\theta_0^2/2 \sim 7.5\times10^{50}\ \mathrm{erg} E_{\gamma,\mathrm{iso},55}(\theta_0/0.7^\circ)^2$$

Inner core is not sufficient… ?

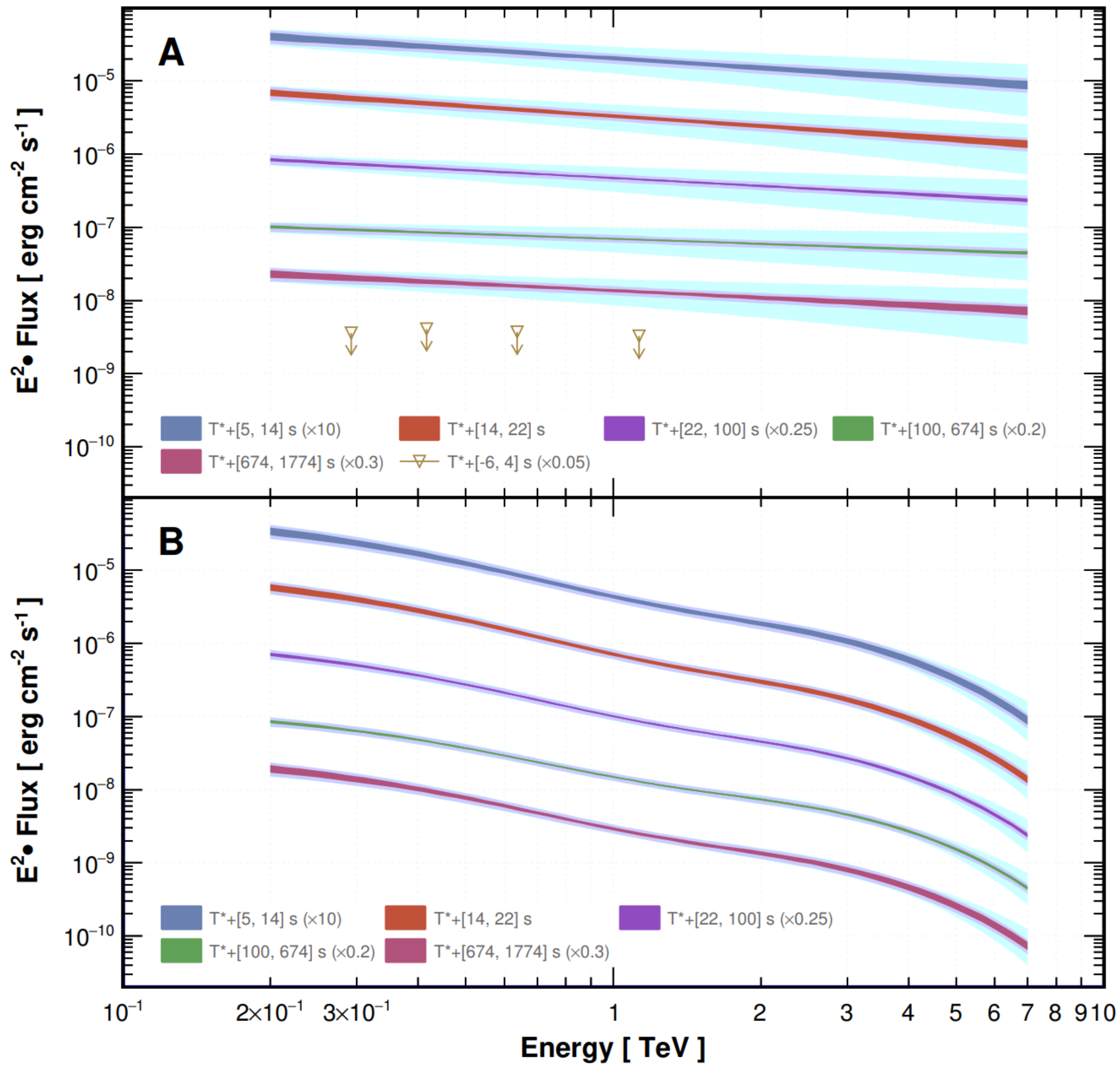


- **Some wider components are outside the core?**
- **Implying an "structured jet"**

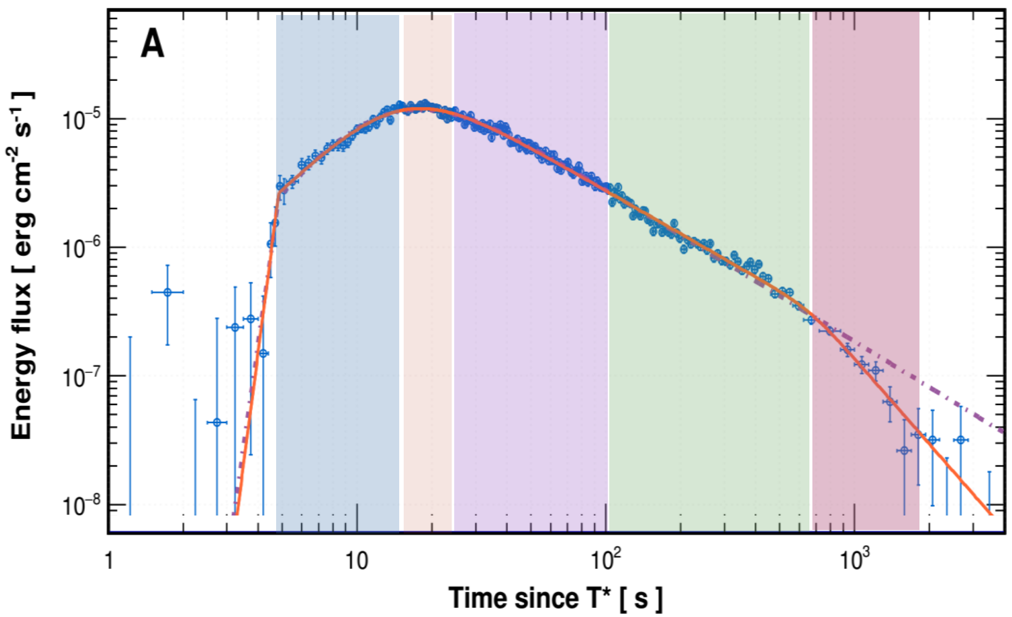


Gottlieb et al. 2021

5. Time-sliding SEDs :

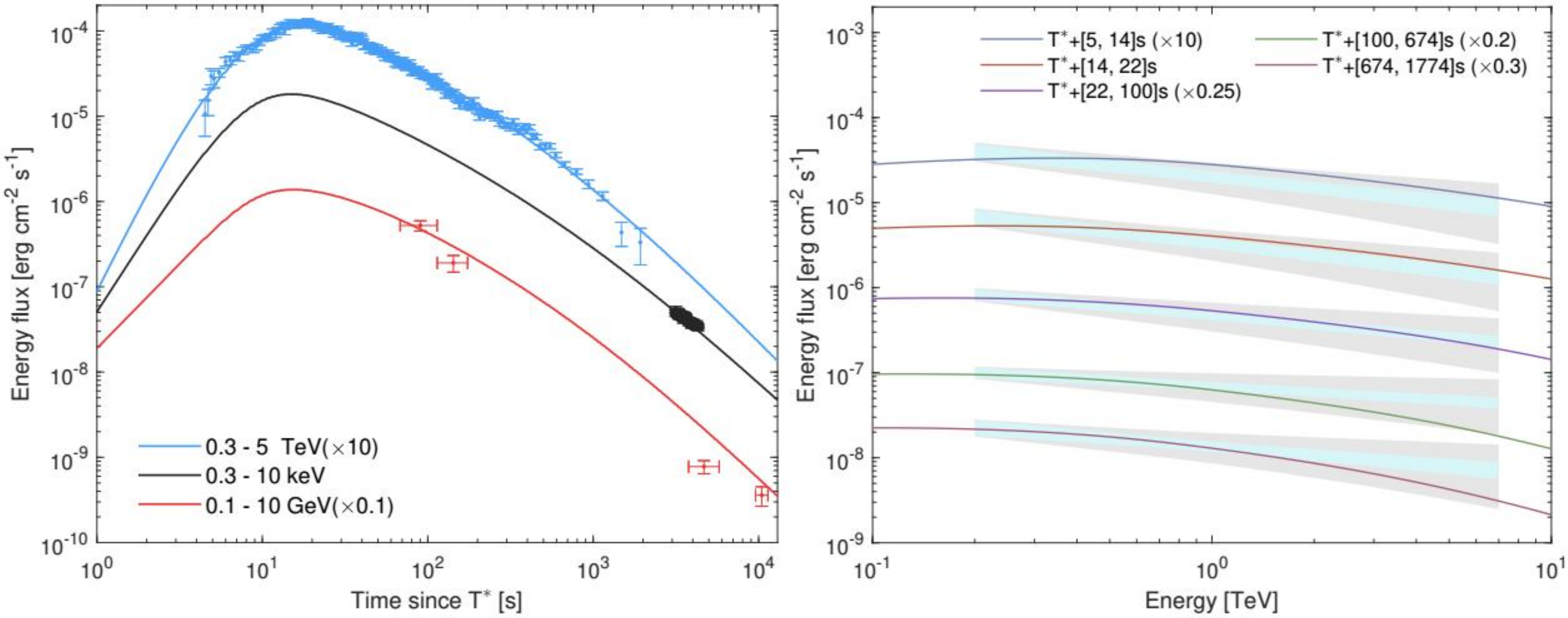


- z ~ 0.152, EBL absorption above 3 TeV
- EBL model: A. Saldana-Lopez et al., Mon. Not. R. Astron. Soc. 507, 5144-5160 (2021)
- Intrinsic SED:
  - Power law: $\sim E^{-2.3}$
  - No hint about cut-off below 10 TeV
  - Moderate spectral evolution is observed



Multi-wavelength modelling of afterglow synchrotron + SSC:

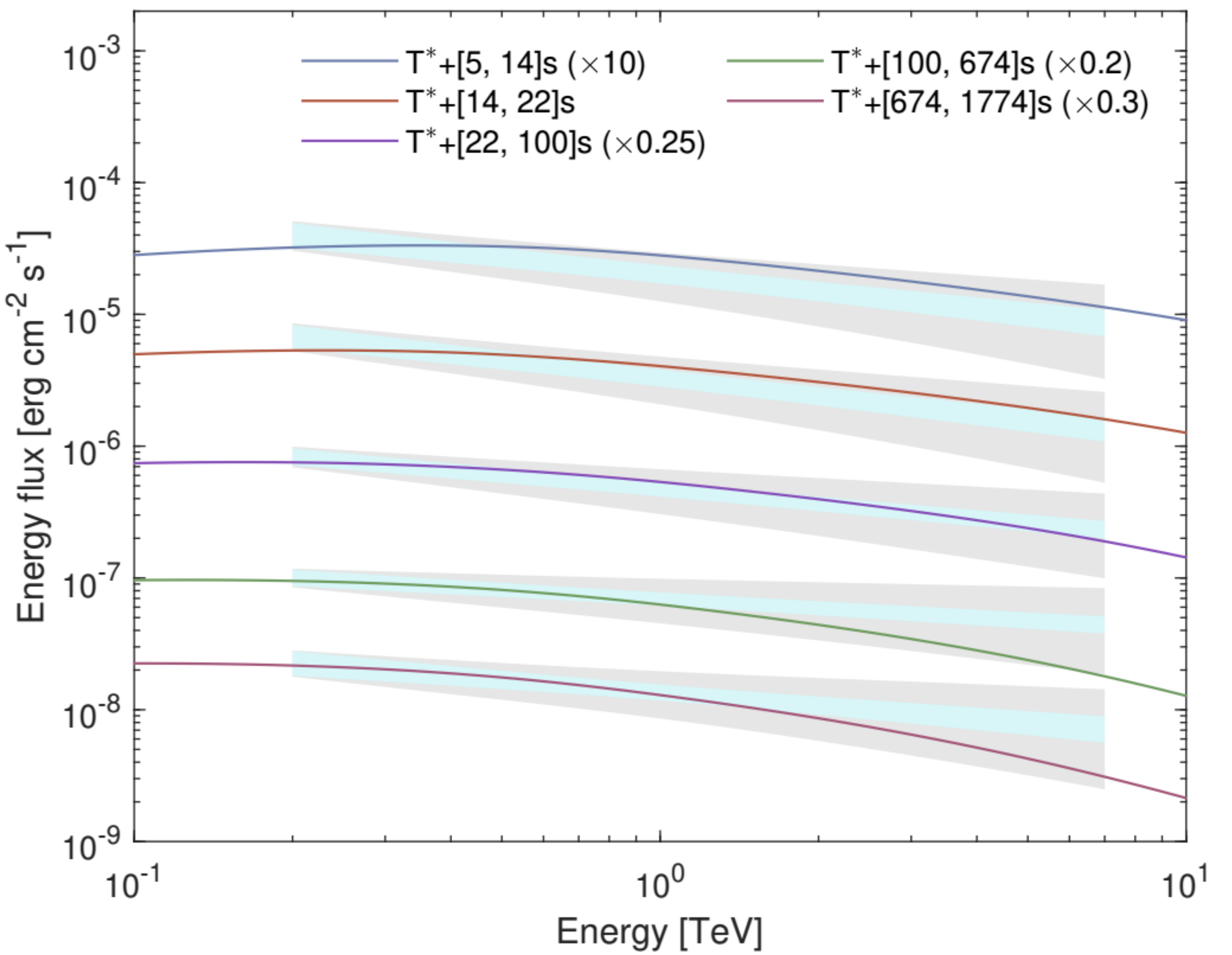
simultaneously fit light-curves in ΔE and time-sliding SEDs



$E_k = 1.5 \times 10^{55}$ erg, $\Gamma_0 = 560$, $\epsilon_e = 0.025$, $\epsilon_B = 6 \times 10^{-4}$, $p = 2.2$, $n = 0.4\,\mathrm{cm}^{-3}$ and $\theta_0 = 0.8°$.

SEDs at T > T* + 100 s :

indication of slight deviation from the one-zone SSC model



Time interval (seconds after T_0)	A (10^{-8} TeV^{-1} cm^{-2} s^{-1})	γ	$E_{\rm cut}$ TeV	χ^2/dof
		Observed spectrum		
231–240	42.9 ± 2.7	2.983 ± 0.061	3.14 (fixed)	4.6/6
240–248	70.1 ± 3.8	3.006 ± 0.052	3.14 (fixed)	8.0/6
248–326	39.9 ± 1.0	2.911 ± 0.028	3.14 (fixed)	14.8/6
326–900	7.35 ± 0.16	2.788 ± 0.026	3.14 (fixed)	8.9/6
900–2000	0.959 ± 0.043	2.880 ± 0.067	3.14 (fixed)	2.9/5
		Intrinsic spectrum, *standard* EBL		
231–240	127.3 ± 7.9	2.429 ± 0.062	\	3.1/6
240–248	208 ± 11	2.455 ± 0.054	\	6.5/6
248–326	117.8 ± 3.0	2.359 ± 0.028	\	8.7/6
326–900	21.77 ± 0.47	2.231 ± 0.026	\	3.4/6
900–2000	2.84 ± 0.13	2.324 ± 0.065	\	2.2/5

- EBL model: A. Saldana-Lopez et al., Mon. Not. R. Astron. Soc. 507, 5144-5160 (2021)
- statistical errors (the inner band) and
- systematic uncertainties (outer bands)

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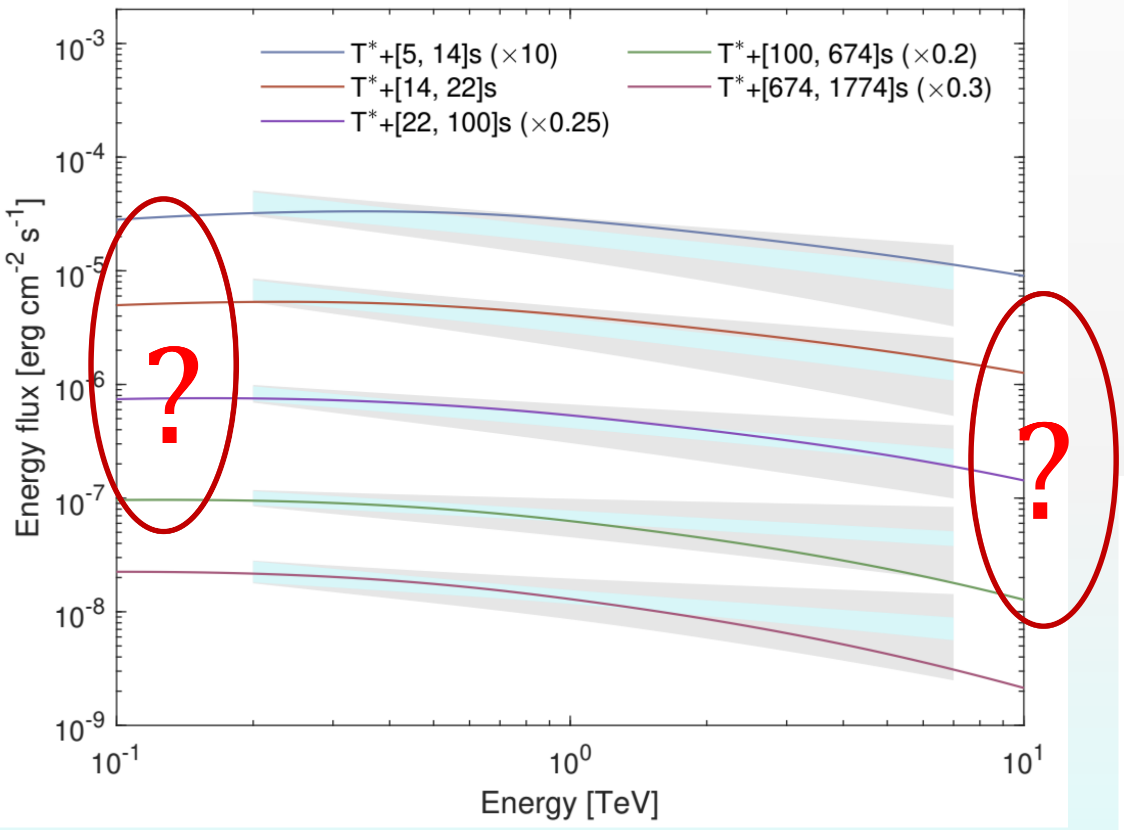
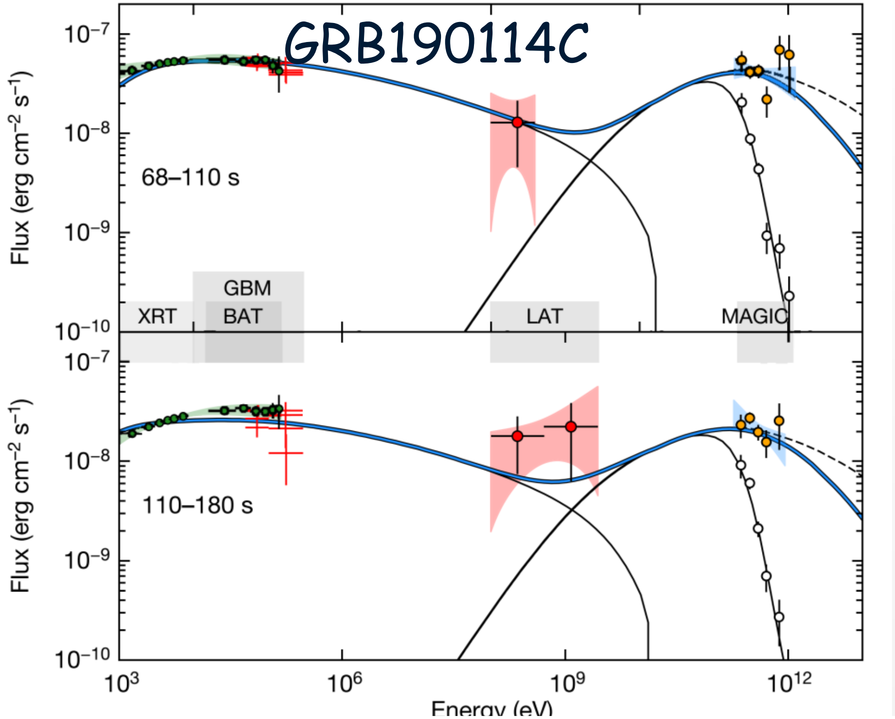
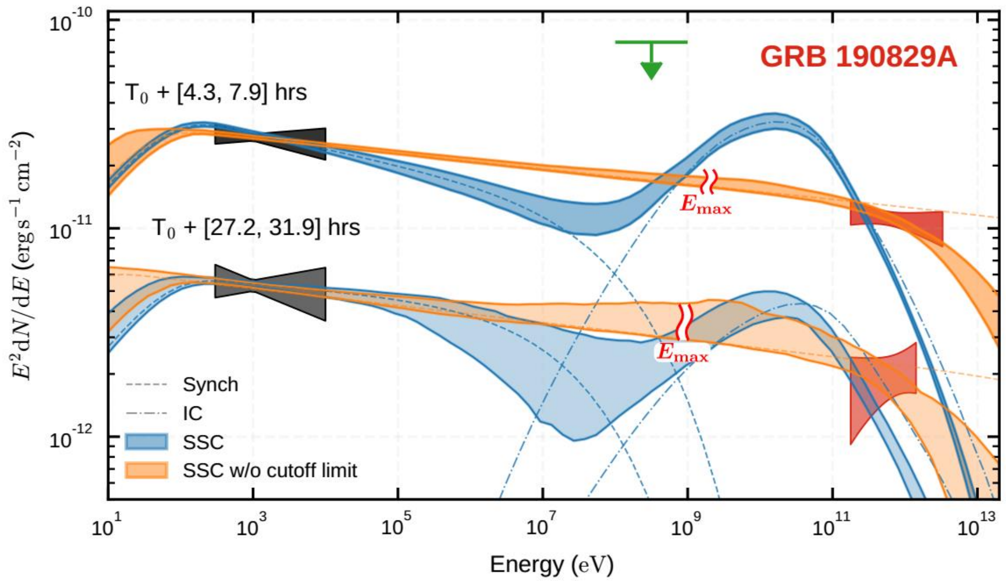
At lower energy<0.2TeV

Is there a SSC bump ?







At higher energy > 7 TeV

Very exciting events !?

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Many things we may learn......

6. IC peak observed ?
   - Combined analysis with HXMT and LAT(available only in a very limited time window)
7. The highest energy photons measured by LHAASO-KM2A
   - New physics frontier exploring
8. Fast variability of flux?
   - Should be highly unexpected at a scale of 10^{17} cm!

Conclusions

1. LHAASO operation is very stable since it was built in **July 2021**
2. LHAASO observed the BOAT **GRB221009A** in the middle of the FoV
3. **First time** observed the onset of the afterglow in TeV band by measuring the flux from the GRB since T_0 set by a precursor
4. This enables
    1. Determining the start time of the afterglow T* ~226 s after T_0
    2. Setting the **most strict limit** on the prompt emission in TeV band ~ 10^{-5}
    3. Indicating the jet **magnetized**, namely Poyting flux dominant jet
    4. Estimating the initial bulk Lorentz factor Γ_0 of the ejecta ~ **440**, one of the largest
    5. **First time** measuring the fast rising phase
    6. **First time** measuring the narrowest jet beaming angle, revealing the core of the jet
    7. **First time** measuring the time-sliding SEDs in VHE band, showing moderate evolution
    8. SSC model being tested: **generally supported** by the most complete measurement of the afterglow
5. Investigations are still on going, more items could be revealed soon

Thanks for your attention!