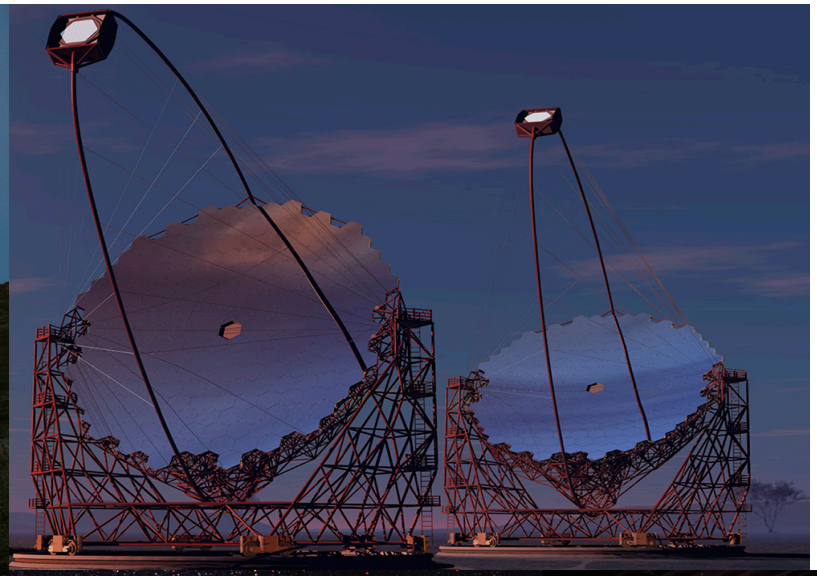
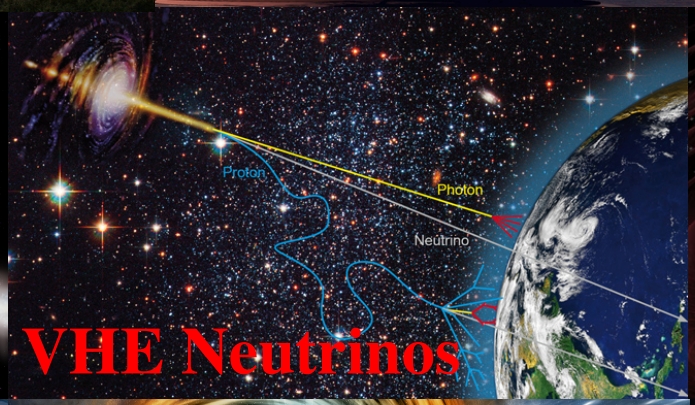
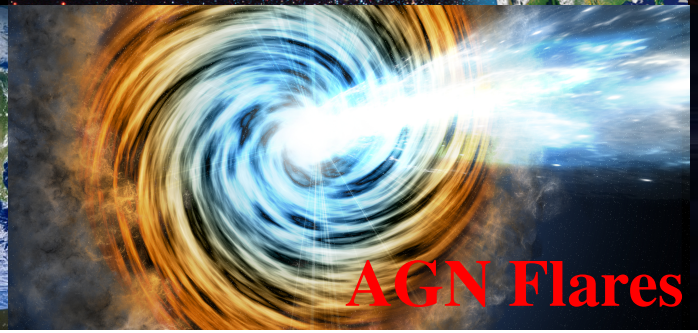
Multimessenger Transient Observations with MAGIC and Prospects for CTA

Susumu Inoue (RIKEN)







outline

1. introduction
2. gamma-ray burst follow-up
   - prospects for short GRBs
   - short GRB 160821B and implications
3. gravitational wave follow-up
4. neutrino follow-up
5. fast radio bursts

NB: various plots already shown at previous meetings
but still in preparation for publication

Transients with MAGIC, CTA

MAGIC: GRB Physics WG -> Transients PWG

convenors: Susumu Inoue, Francesco Longo, Konstancja Satalecka

Motto: "Expect the unexpected."

CTA: Transients Science WG

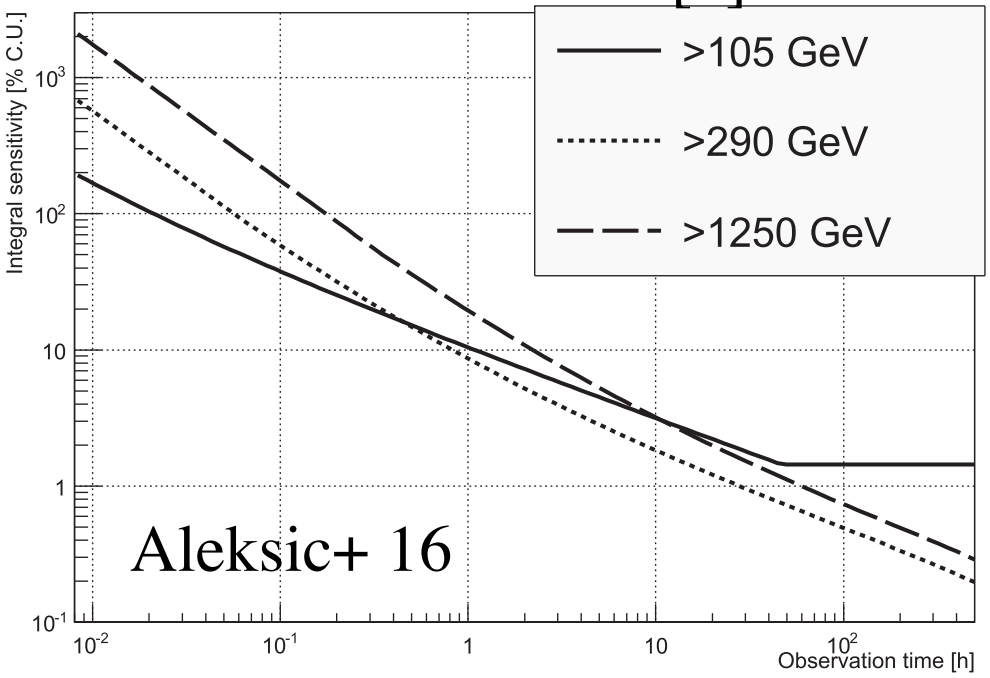
coordinator: Susumu Inoue; deputy: Catherine Boisson
-> coordinator: Catherine Boisson; deputy: Daniela Hadasch

References on CTA science prospects:
GRBs: SI+ for CTA 2013, Astropart. Phys. 43, 252
Transients: SI+ Chap. 9, "Science for CTA",
World Scientific, in press (arXiv:1709.07997)

MAGIC telescopes

- 2 × 17m IACTs
  La Palma, Canary Is.
  altitude 2200m
- Field of view: ~3.5°
- Angular resolution: ~0.1°
- Sensitivity:
  ~ 10% Crab in 1 h >100 GeV
- Threshold energy:
  ~50 GeV at zenith angle <20°
- Repointing speed:
  ~30 s for 180°
- Key observing program
  dedicated to GRB follow-up
  mono from Apr. 2005
  stereo from July 2009

Integral sensitivity [% Crab units]
vs Observation time [h]



Gamma-Ray Bursts

Most luminous explosions
in the Universe,
largely unexplored at VHE

via VHE observations:

Clarify physics of GRBs

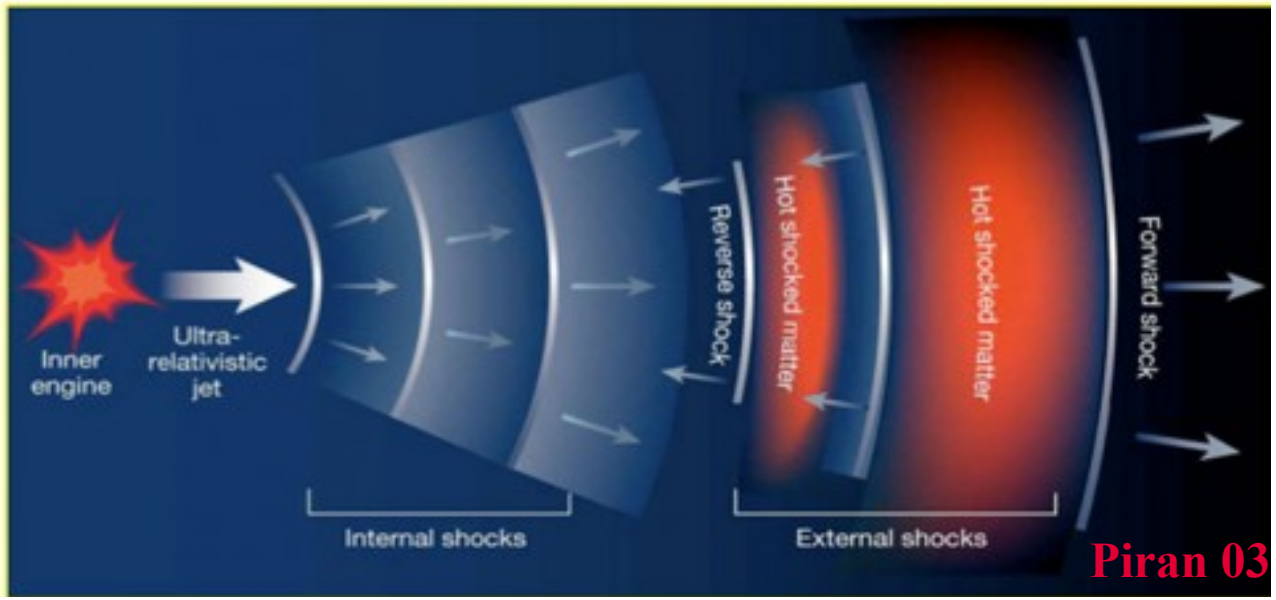
- prompt: mechanism, jet properties (central engine: NS/BH?)
- early afterglow: mechanism (plateau phase),
  particle acceleration, B field generation

Probe the Universe

- extragalactic background light (deeper than AGN)
- intergalactic magnetic fields

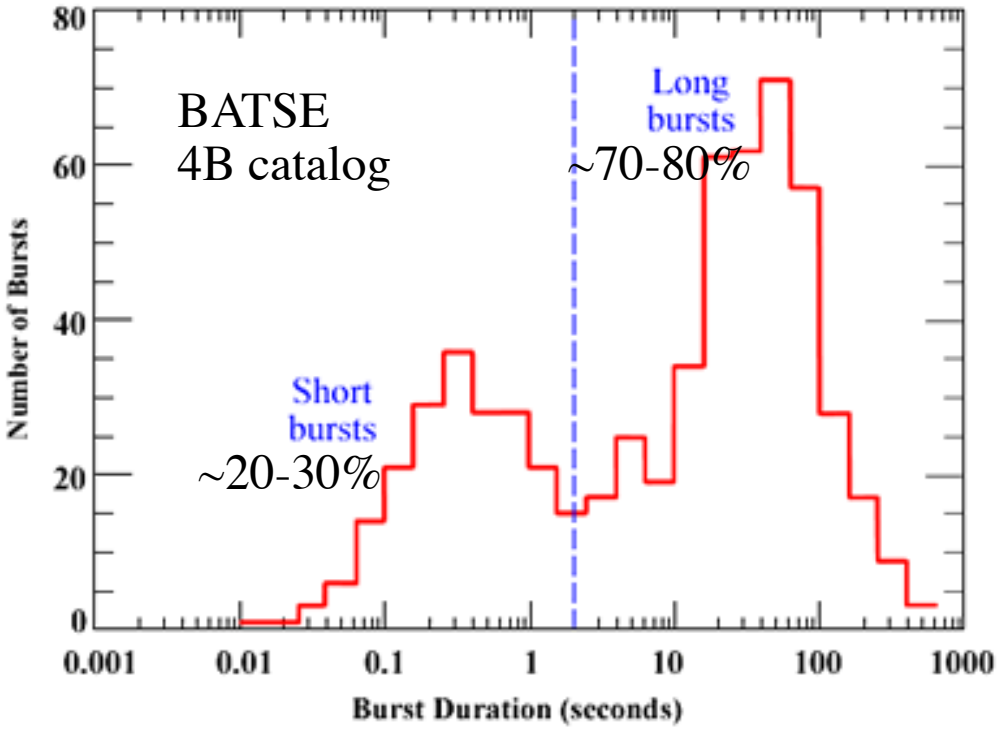
Test UHECR origin, fundamental physics
search for
signatures of:

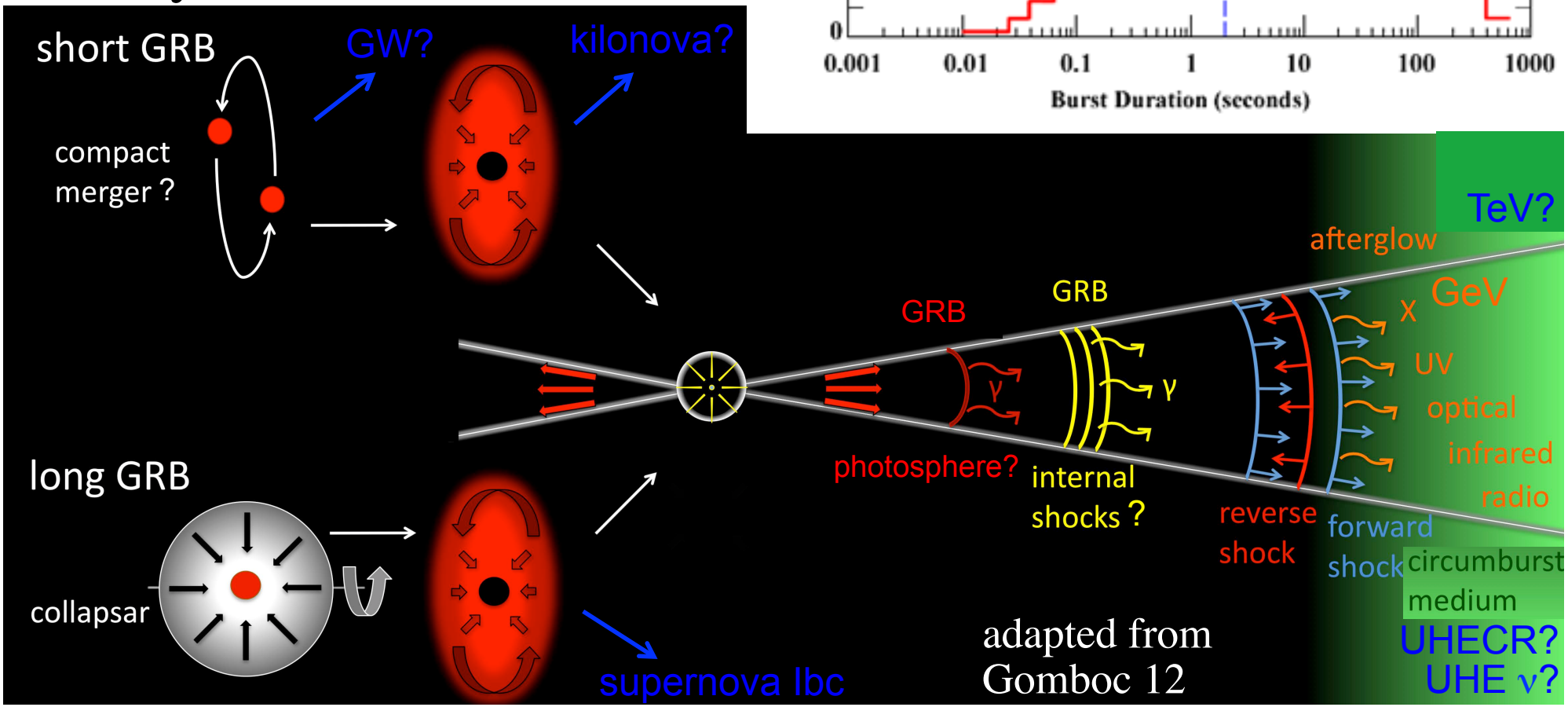
- accelerated hadrons
- Lorentz invariance violation



GRBs: short vs long

Many systematic differences:
MeV spectra, z distribution,
host galaxy type, environment
-> likely distinct progenitors
-> high-energy properties
may well be different





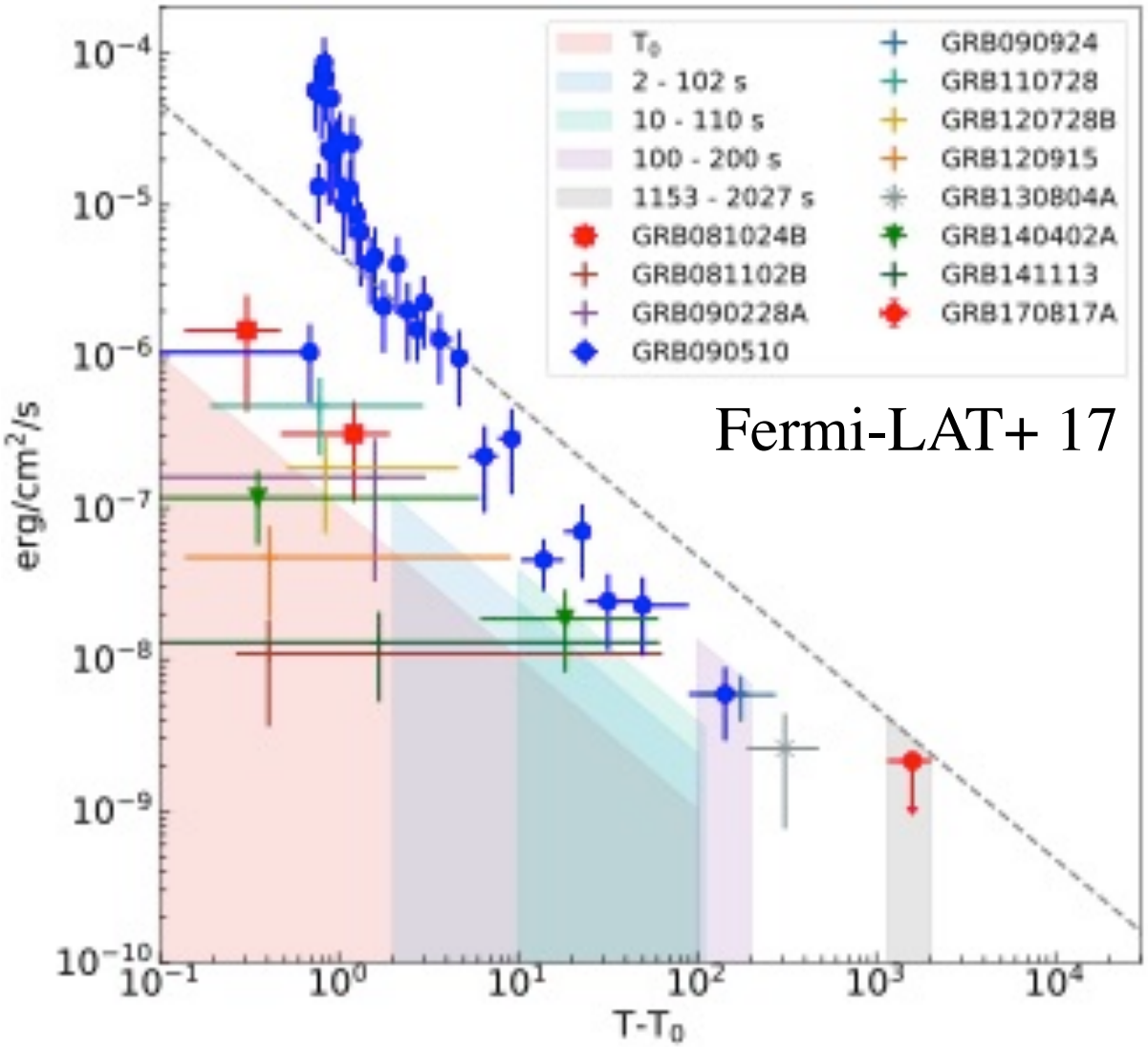
short GRBs: GeV

LAT detections, as of July 2017

~120 long GRBs vs.

~11 short GRBs,

only 1 with z



GRB 090510

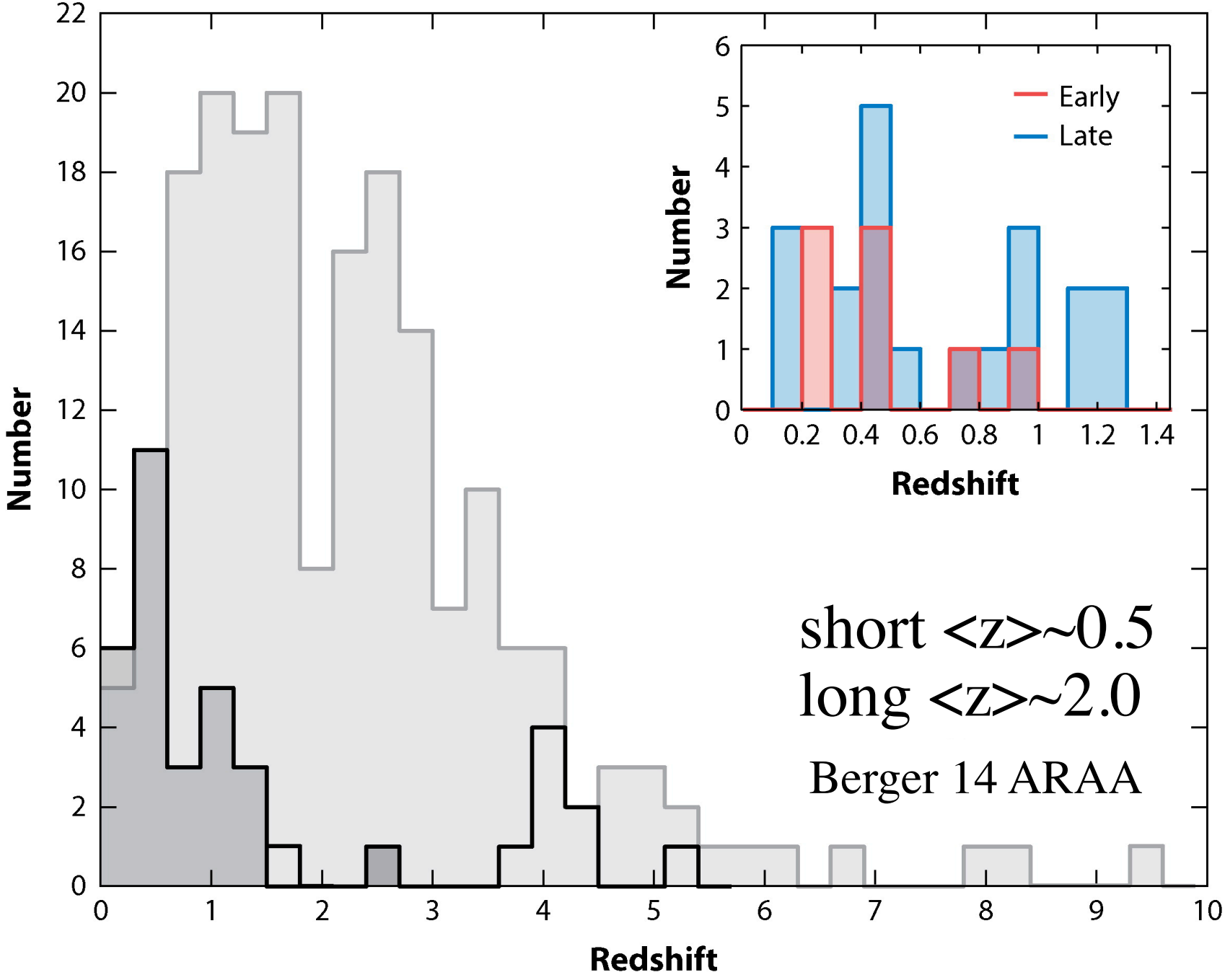
z=0.903 (D_L~6 Gpc)

detected by LAT up to

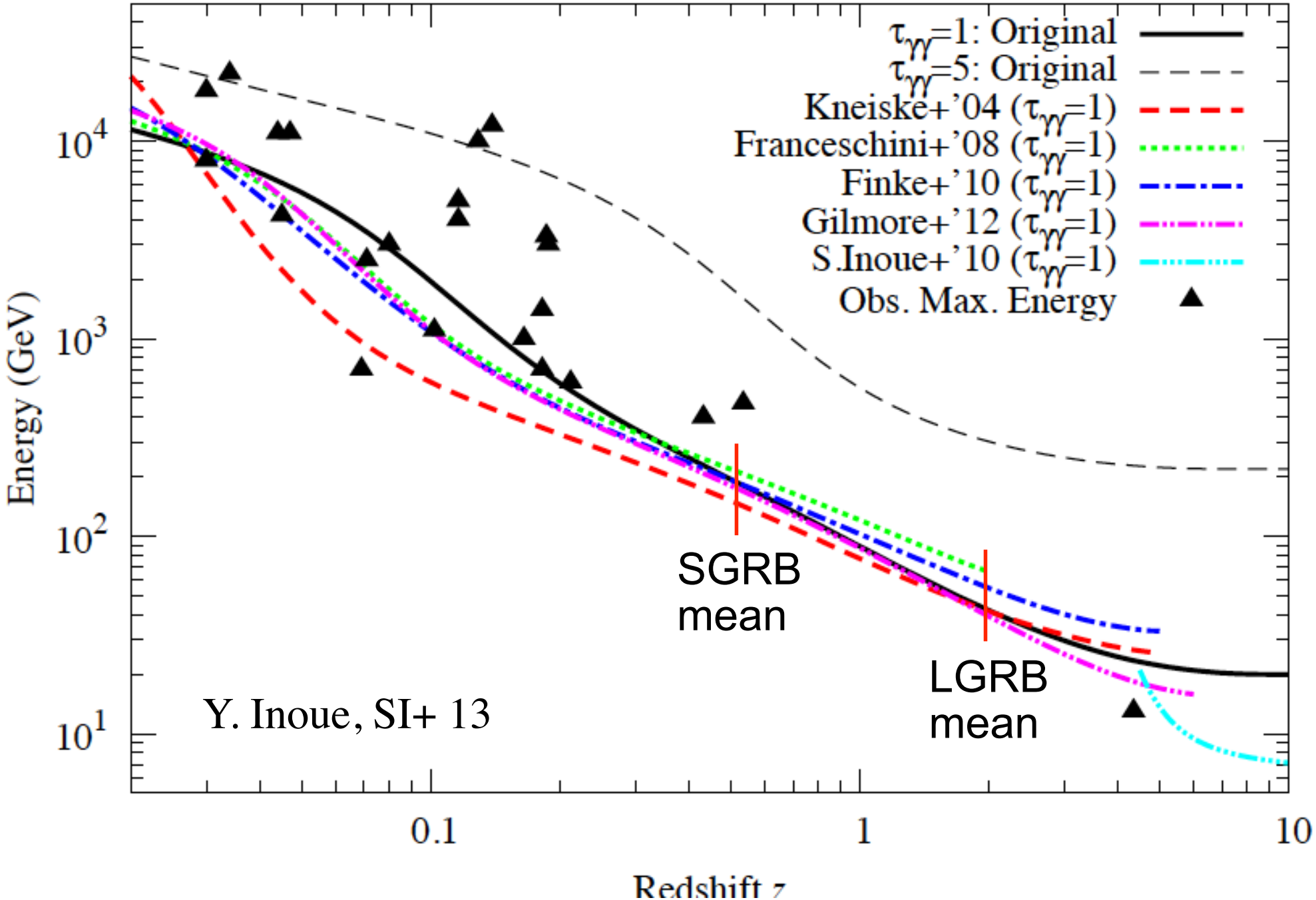
E_γ~31 GeV, t~178 s

Human knowledge on high-energy properties of short GRBs is sorely lacking

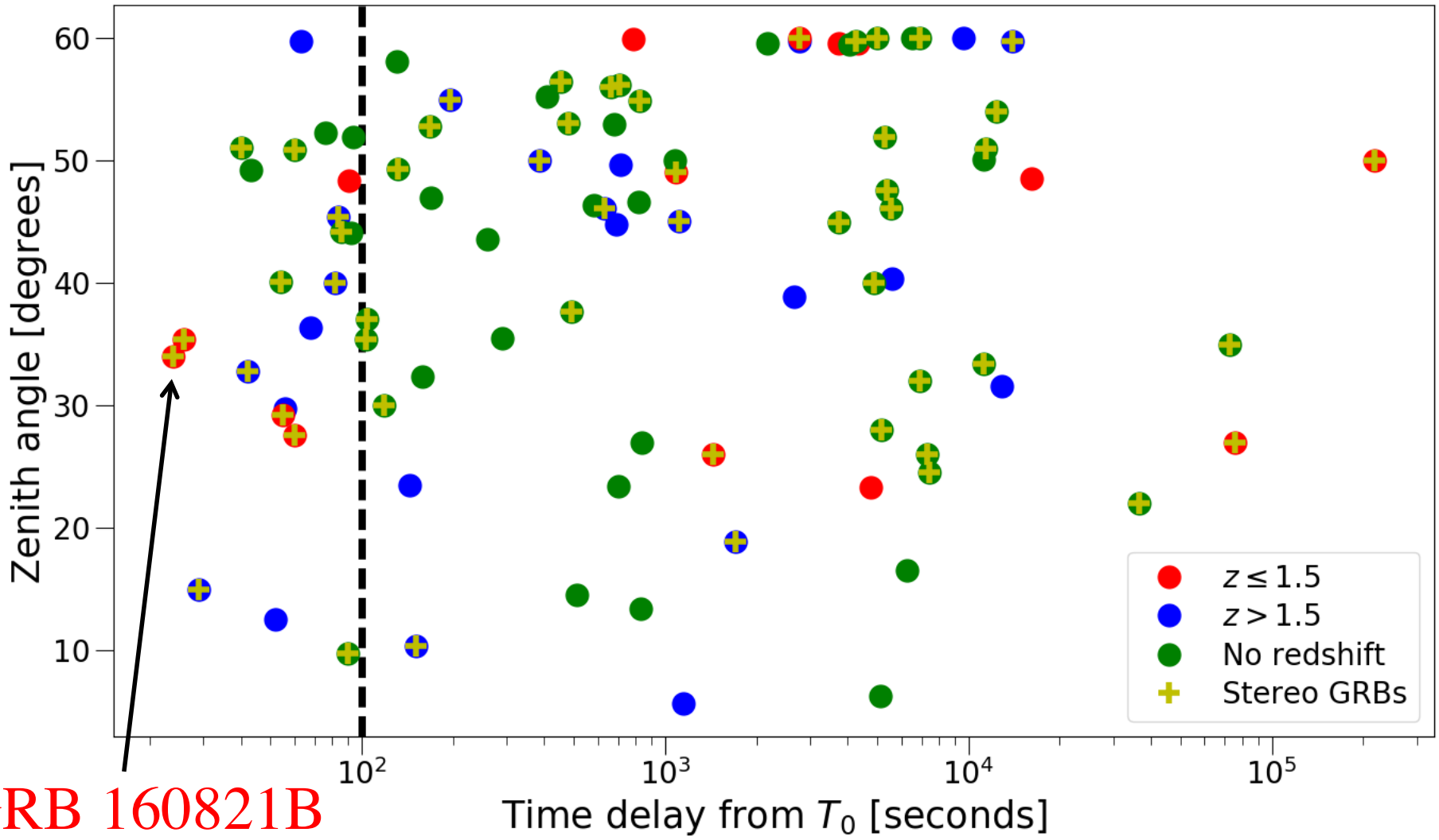
short GRBs: z distribution



gamma-ray horizon $E(\tau_{\gamma\gamma}=1)$ vs z due to EBL

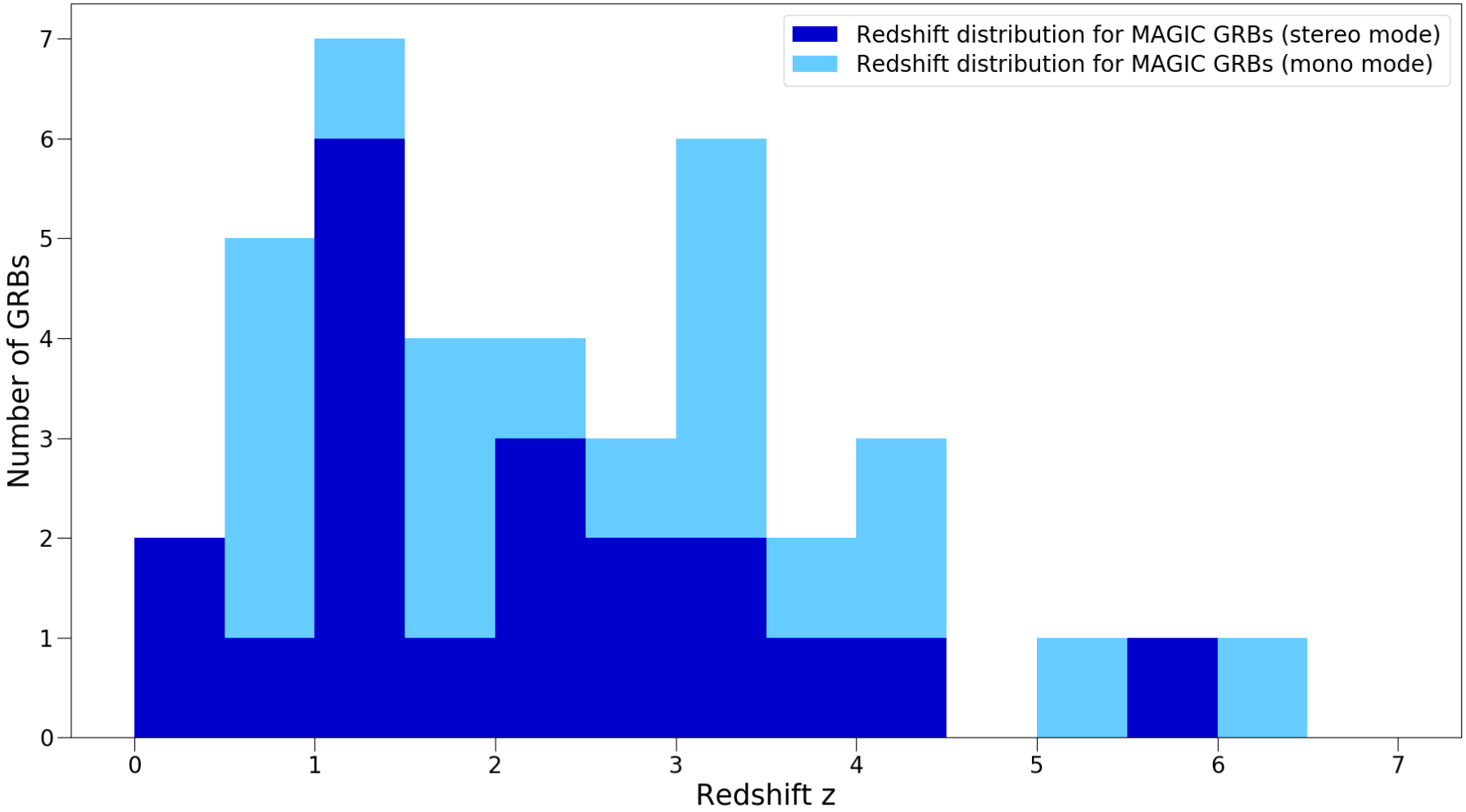


MAGIC GRB observations: time delay, zenith angle



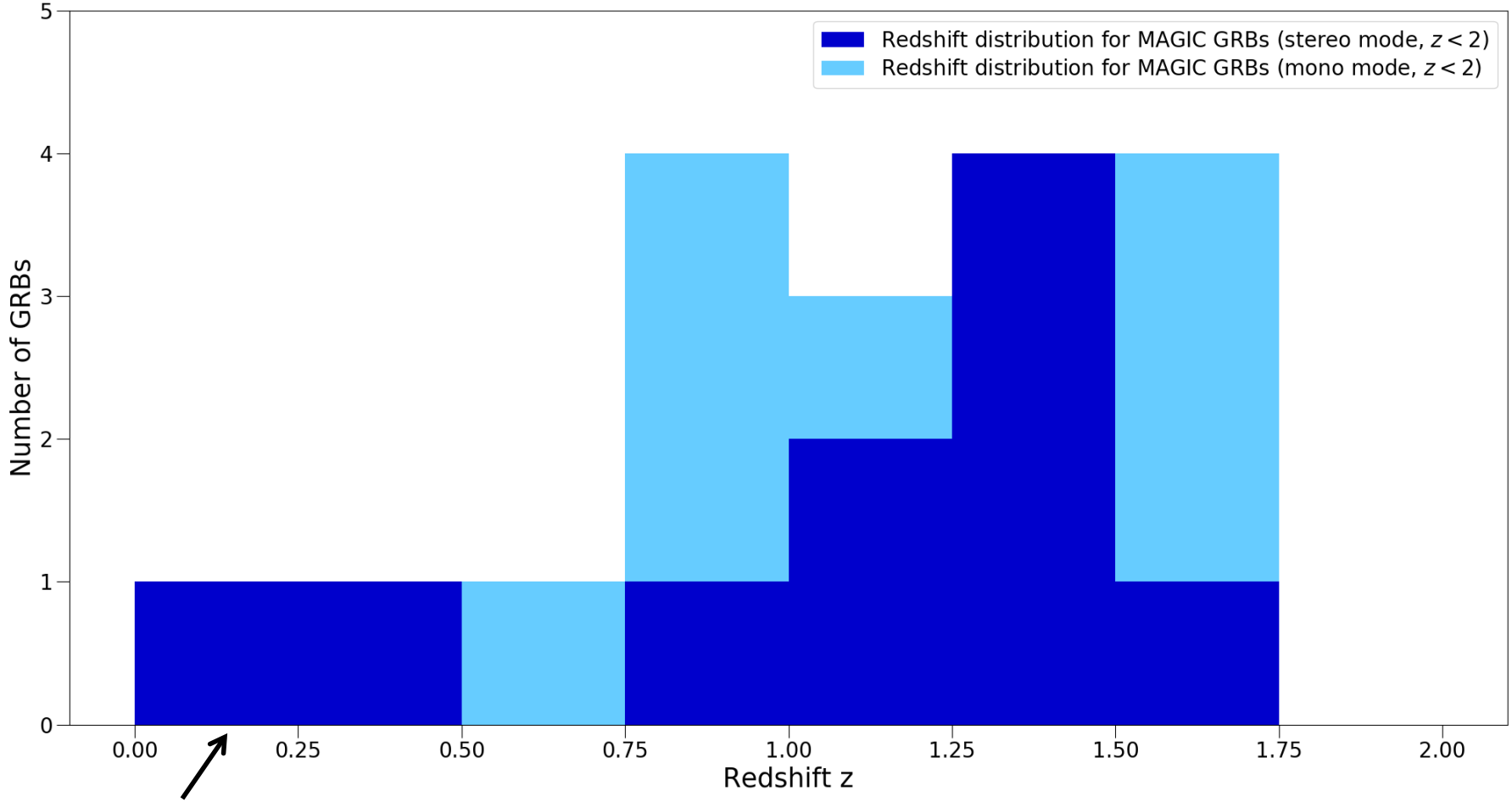
As of July 2017:
96 GRBs observed without hardware issues
43 mono, 53 stereo

MAGIC GRB observations: redshift distribution



As of July 2017:
39 (of 96) GRBs with z; 19 mono, 20 stereo

MAGIC GRB observations: redshift distribution z<2



GRB 160821B

As of July 2017:
39 (of 96) GRBs with z; 19 mono, 20 stereo
(18 with z<2; 8 mono, 10 stereo)

short GRB 160821B

z=0.16 one of nearest ever

GBM: T_{90}~1s, E_p~84 keV, S~1.7×10^{-6} erg cm^{-2} -> E_{iso}~1.2×10^{50} erg

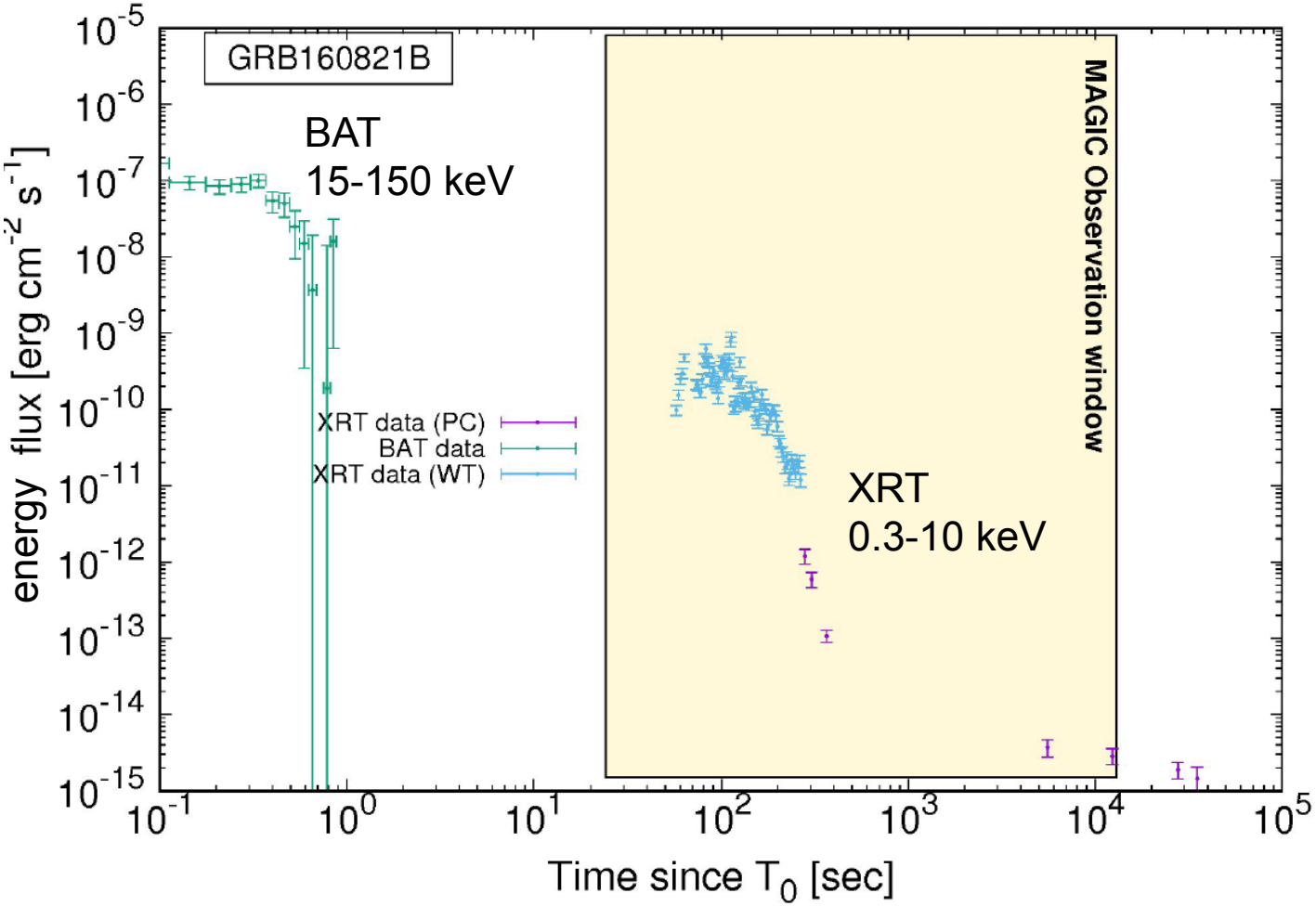
c.f. 090510: E_{iso}~10^{53} erg , 130427A (long): >10^{54} erg

XRT: "extended emission"+ steep decay t~<500s, "plateau" t~<30ks

Lü+ 17

optical, IR: afterglow, constraints on kilonova

Kasliwal+ 17, Tanvir+ in prep



MAGIC:

automatic follow-up

t~24 s - 1.5 h

Z_d~34-40°

poor weather

NSB ~3-5 ×dark

t~1.5 - 4 h

Z_d~40-55°

good weather

NSB ~5-9 ×dark

(higher Moon)

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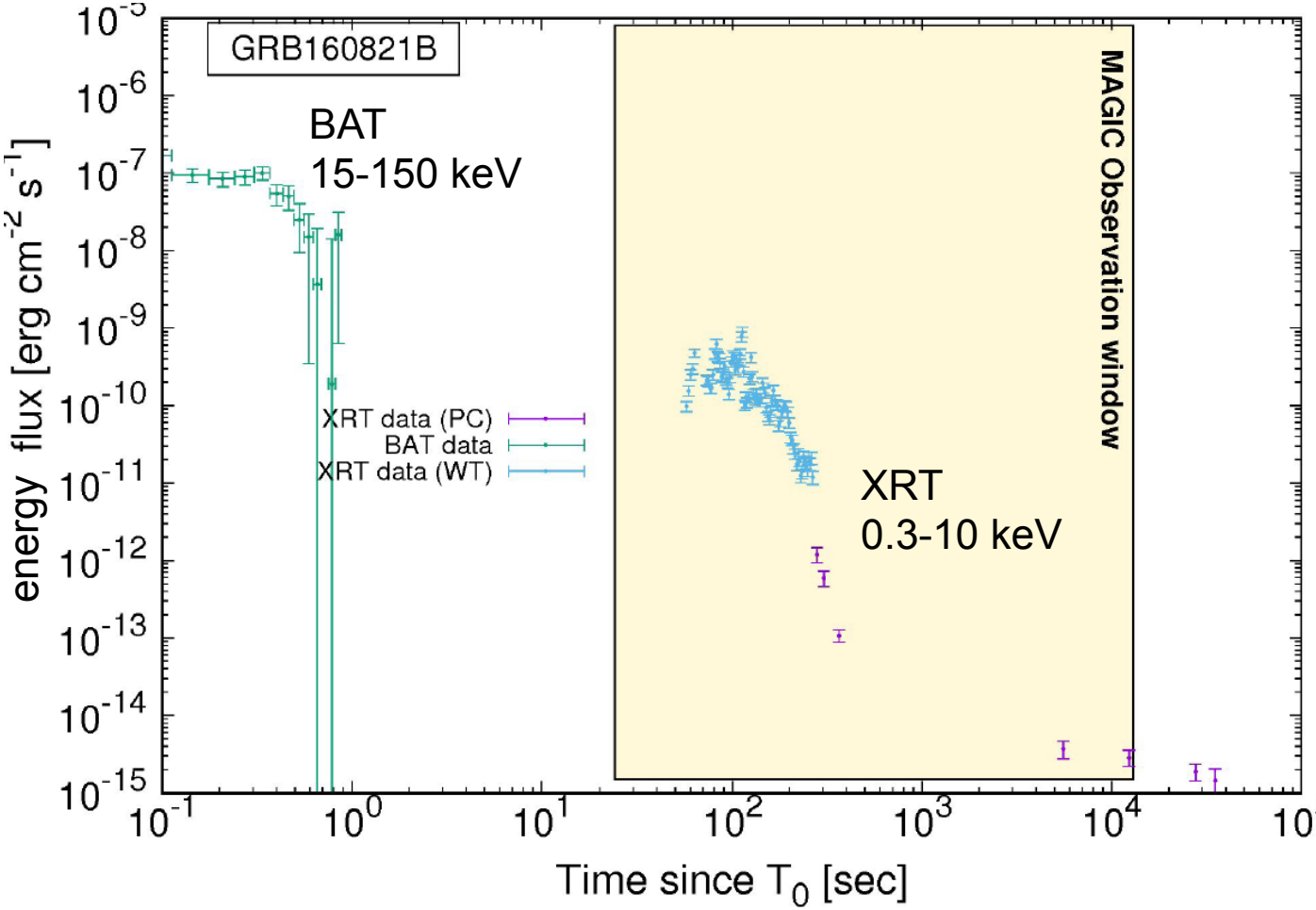
Lü+ 17

LAT: no detection reported, but likely not strong limit
(outside FoV at t<5 ks, around edge of FoV at t~5-9 ks) Tanvir+ in prep



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t~24 s - 1.5 h
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poor weather
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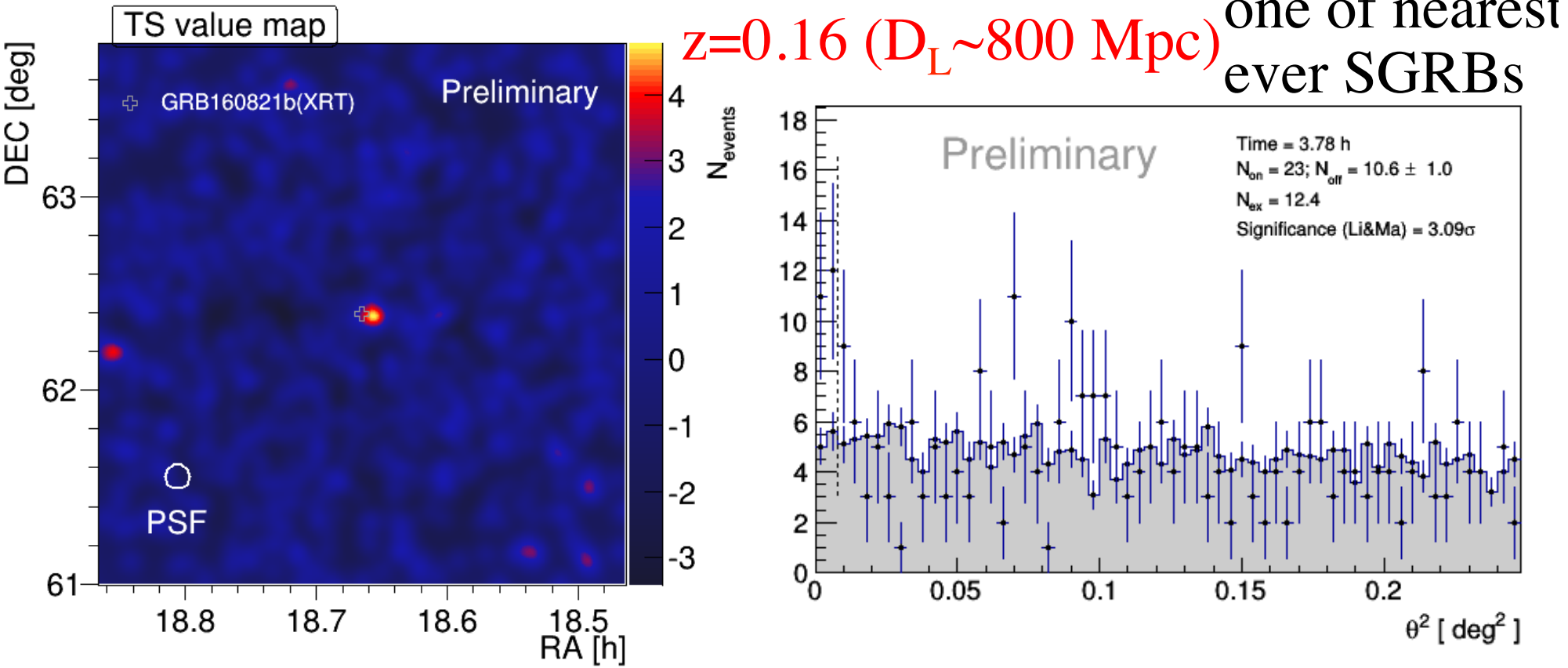
Z_d~40-55°
good weather
NSB ~5-9 ×dark
(higher Moon)

MAGIC observations of low-z short GRB 160821B

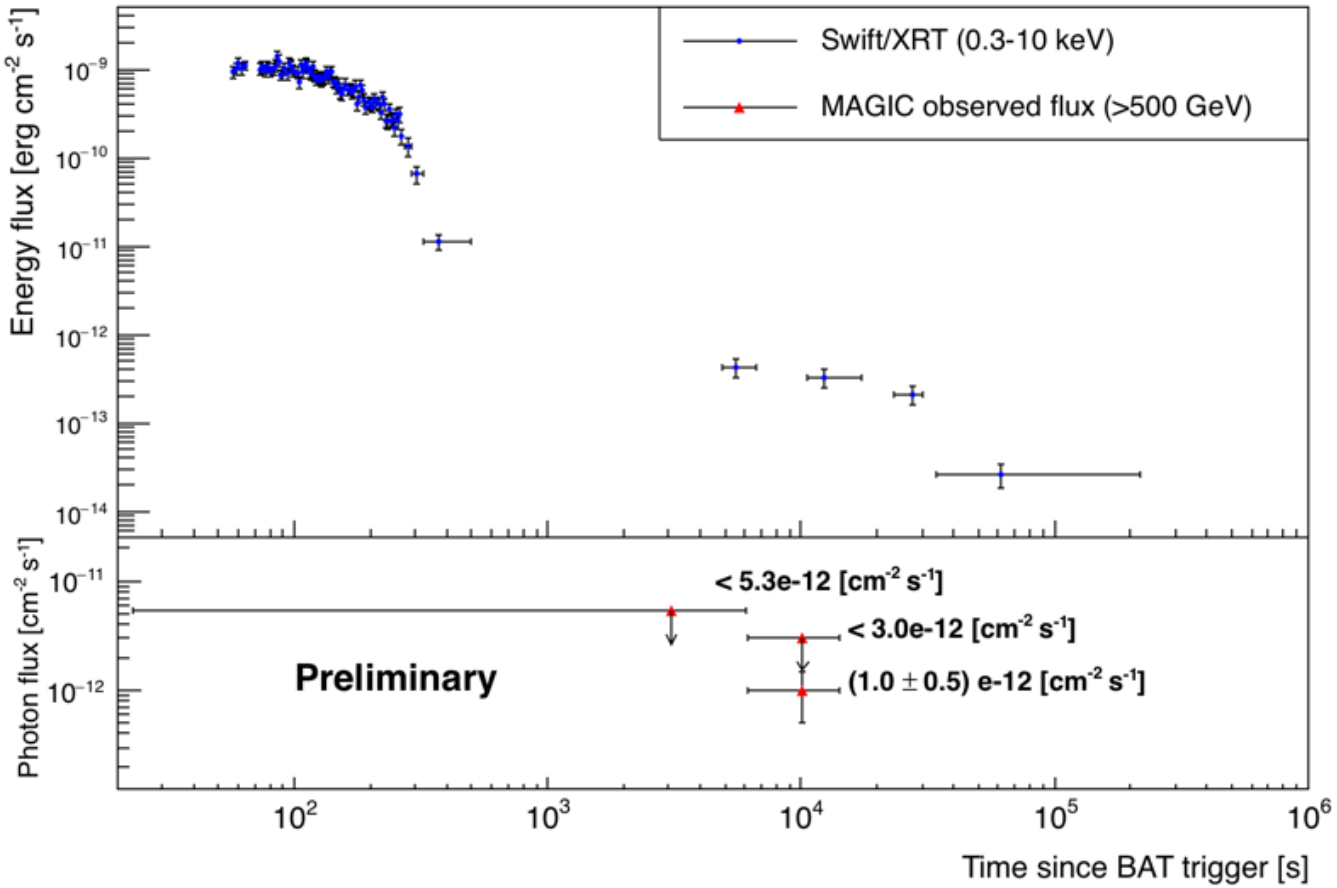
z=0.16 (D_L~800 Mpc) one of nearest ever SGRBs



- Followed up from t~24 s to t~4 h. Fastest ever, nearest ever for MAGIC, but under non-ideal weather, high Moon.

- Dedicated analysis yields >4 sigma (pre-trial), ~3.1 sigma (post-trial) at >600-800 GeV at GRB position.
  Possible evidence of gamma-ray signal, but not firm detection.

MAGIC observations of low-z short GRB 160821B



IF signal is real:

- energy flux >500 GeV ~ 2 × energy flux in X-rays at t~10^4 s
- First SGRB seen >500 GeV

  First SGRB seen >GeV to t~10^4s

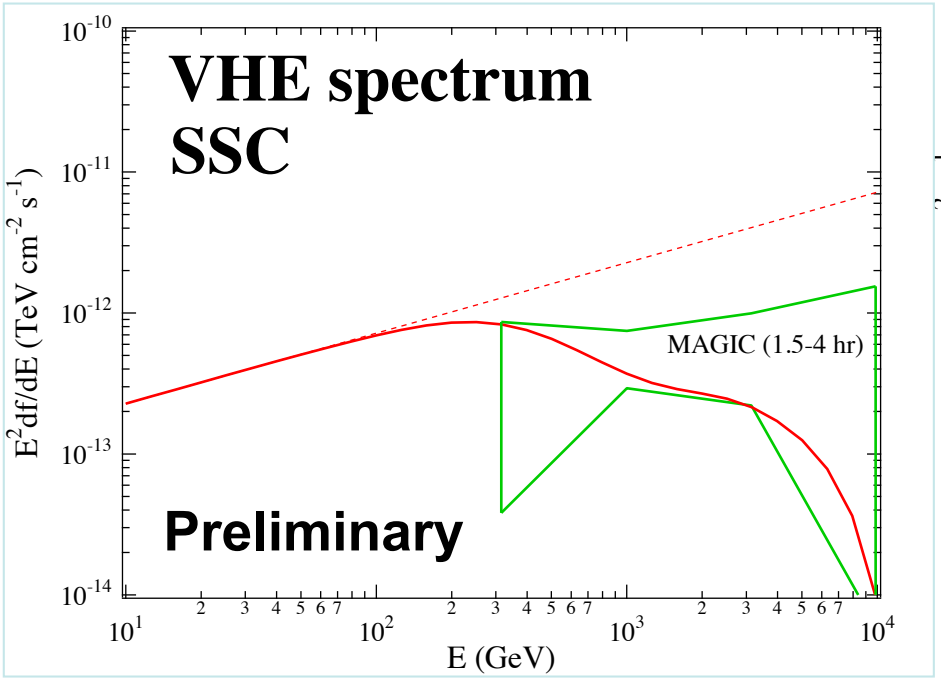
  Only second SGRB with known z seen >GeV

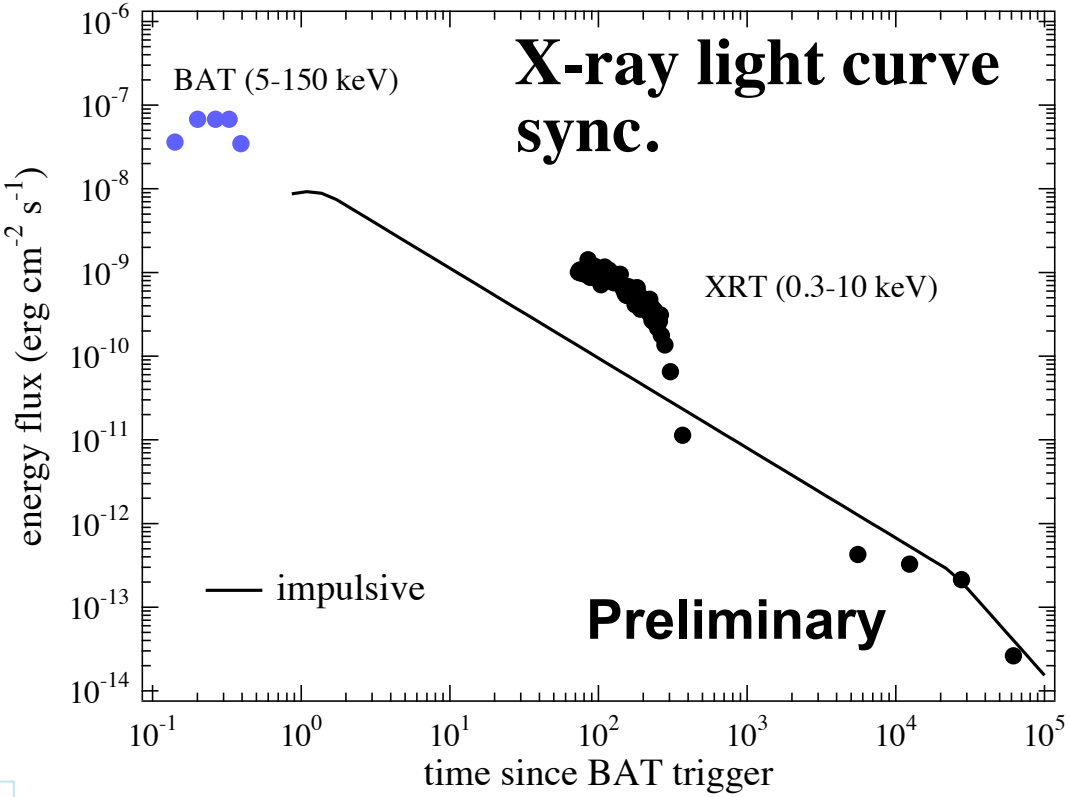
  -> Advances our knowledge of HE properties of sGRBs

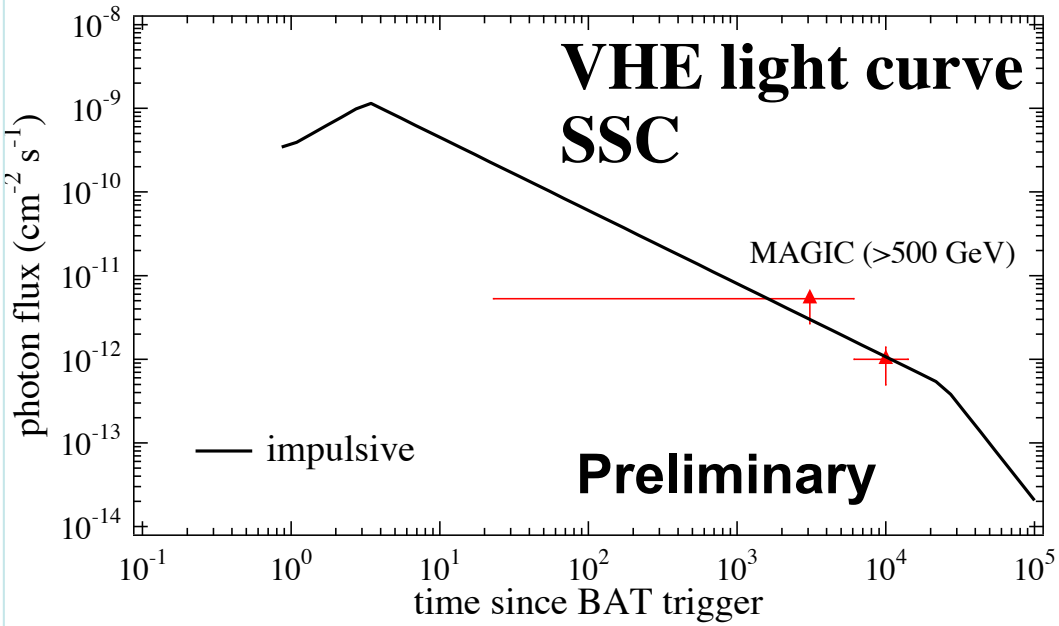
short GRB 160821B interpretation

simple impulsive blastwave
uniform ISM
$E_{kin}=10^{51}$ erg, n=0.1 cm^{-3}
$\varepsilon_e=0.1$, $\varepsilon_B=0.01$, p=2.1, $\theta_{jet}=0.1$
EBL Dominguez+ 11

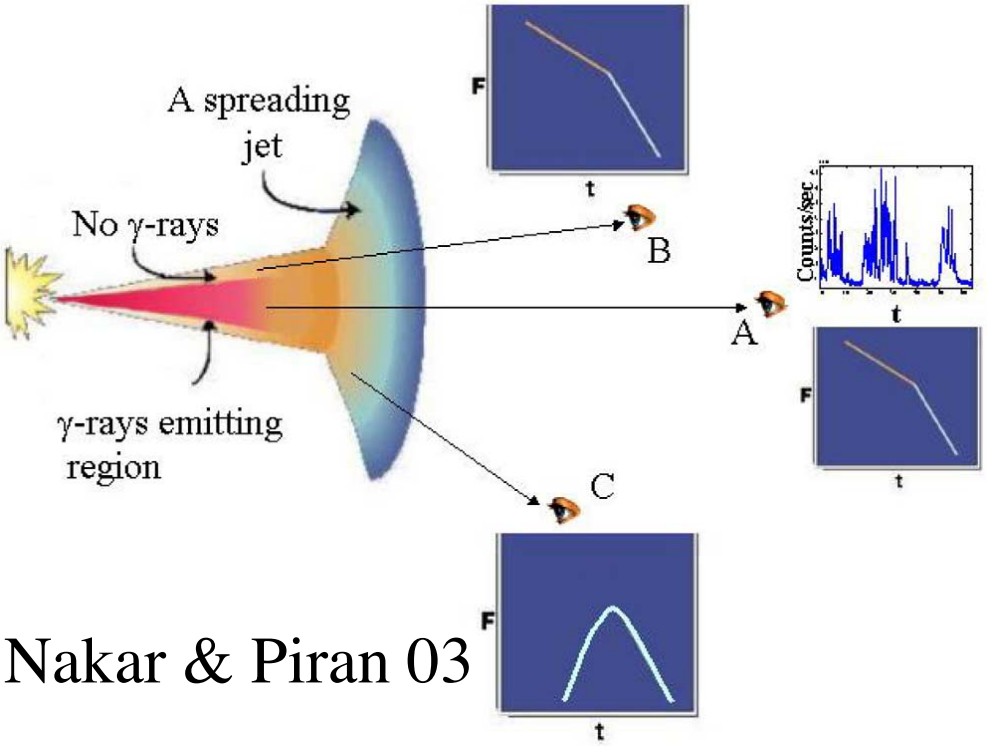
interesting implications
for GW follow-up



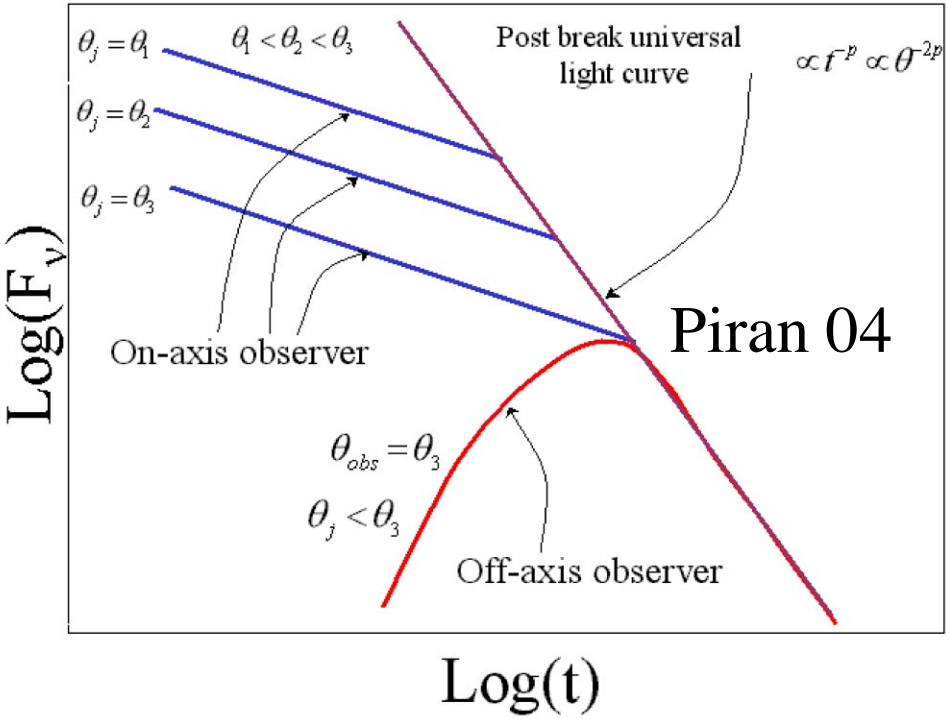




short GRB off-axis afterglow



Nakar & Piran 03



$$\Gamma(t) \simeq 4.4(E_{51}/n)^{1/8}(t_d/(1+z))^{-3/8}$$

assume top-hat jet structure

GRB 160821B-like event at D_L~40 Mpc, θ_v~30 deg

-> $\nu f_\nu \sim 10^{-13}$ erg/cm^2/s at t~25 day: possibly detectable by CTA

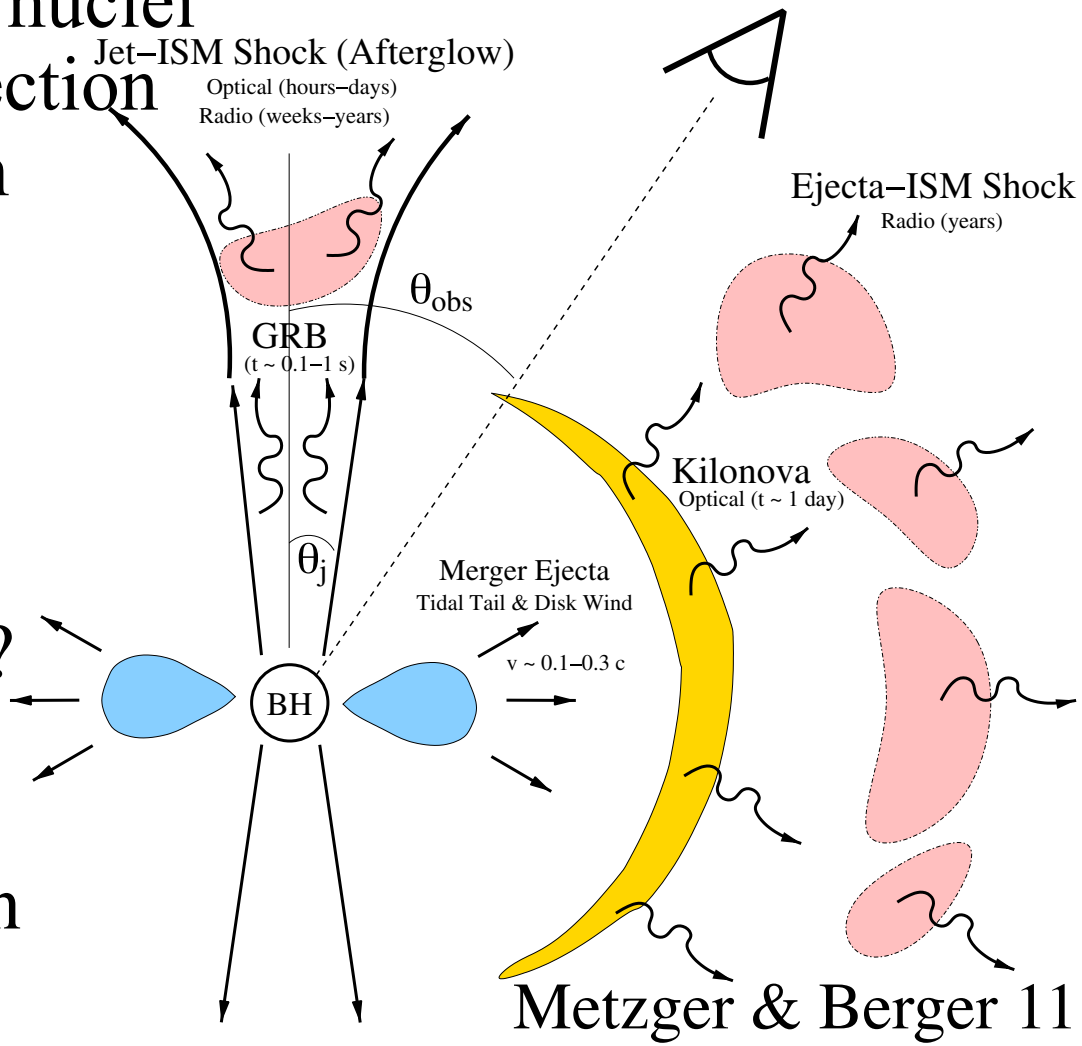
Gravitational Waves

Newest window onto the Universe, connection with GRBs, etc

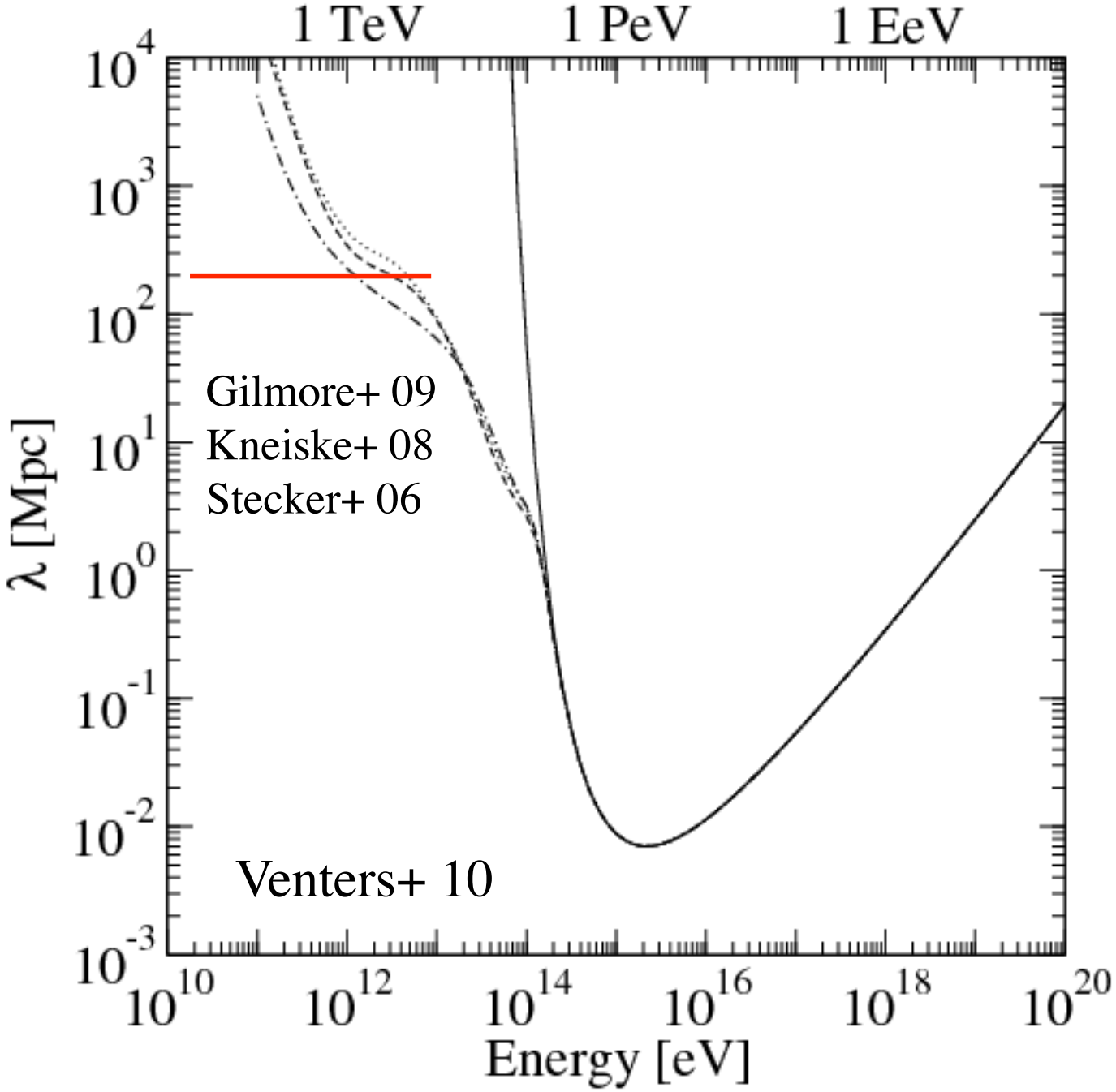
- powerful probe of relativistic dynamical phenomena, especially compact binary mergers
- NS-NS/BH mergers potential sources of short GRBs; fast ejecta rich in r-process nuclei
  -> coincident EM-GW detection provides new dimension

VHE γ follow-up

- test short GRB physics via:
  on-beam afterglow
  off-beam orphan afterglow?
- probe merger physics via emission due to ejecta + ambient medium interaction



local gamma absorption mean free path

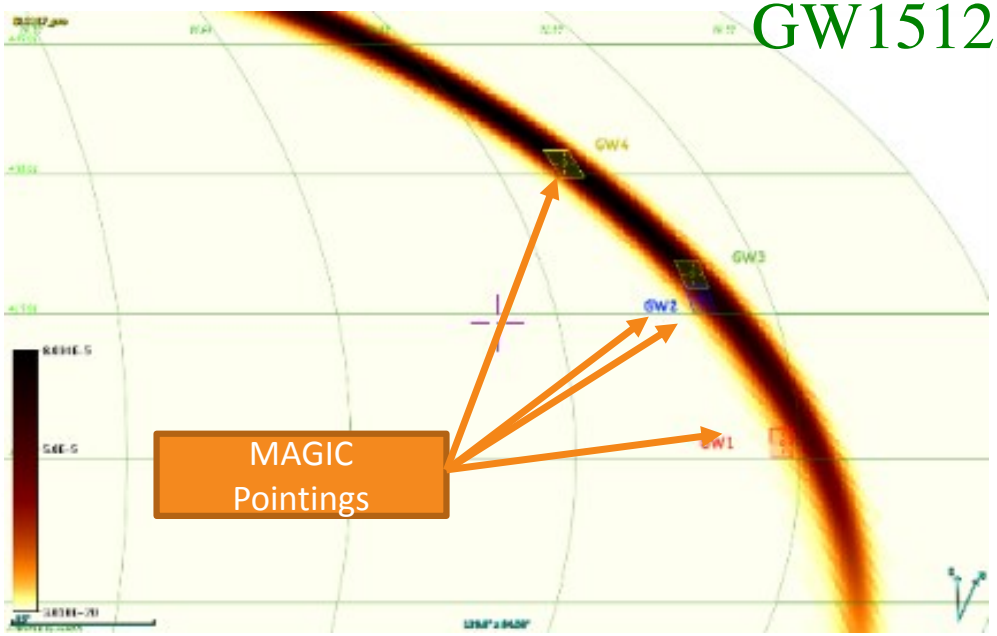


$\tau_{\gamma\gamma}<1$ at
~<10 TeV
~<200 Mpc

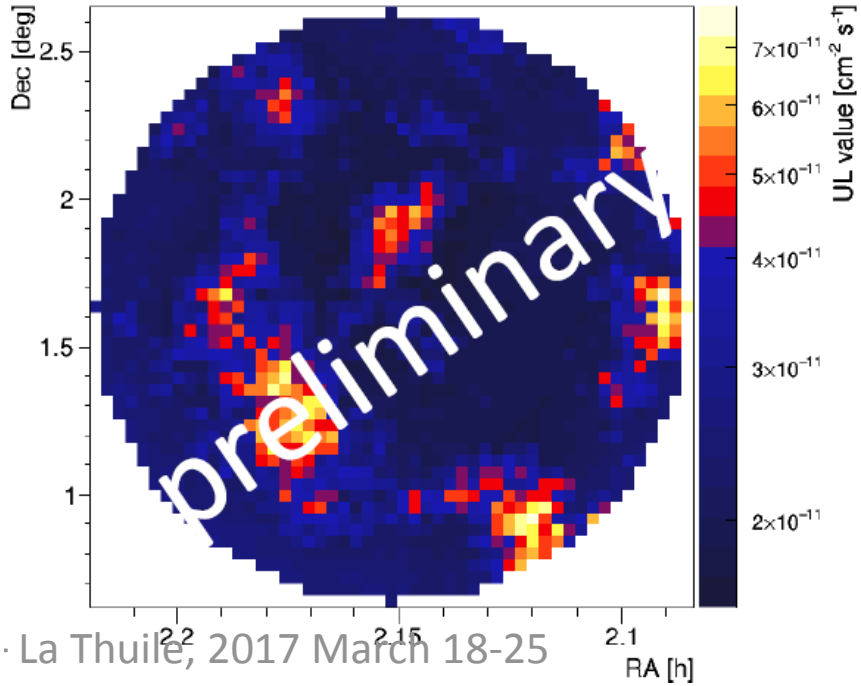
MAGIC gravitational wave follow-up

- GW151226: BH-BH
  upper limits for small part of error region
- GW1708__: potential binary with NS
  upper limits for optical transients (likely supernovae)

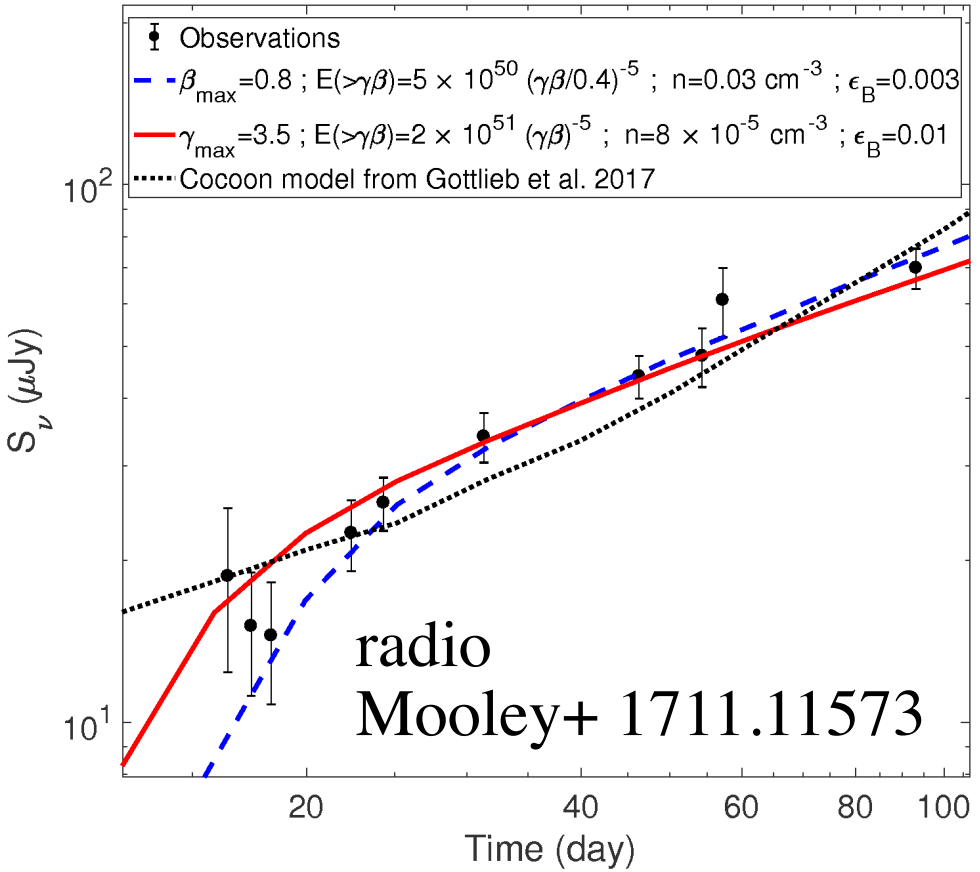
c.f. GW170817: NS-NS
  unobservable due to high ZA(~88 deg)

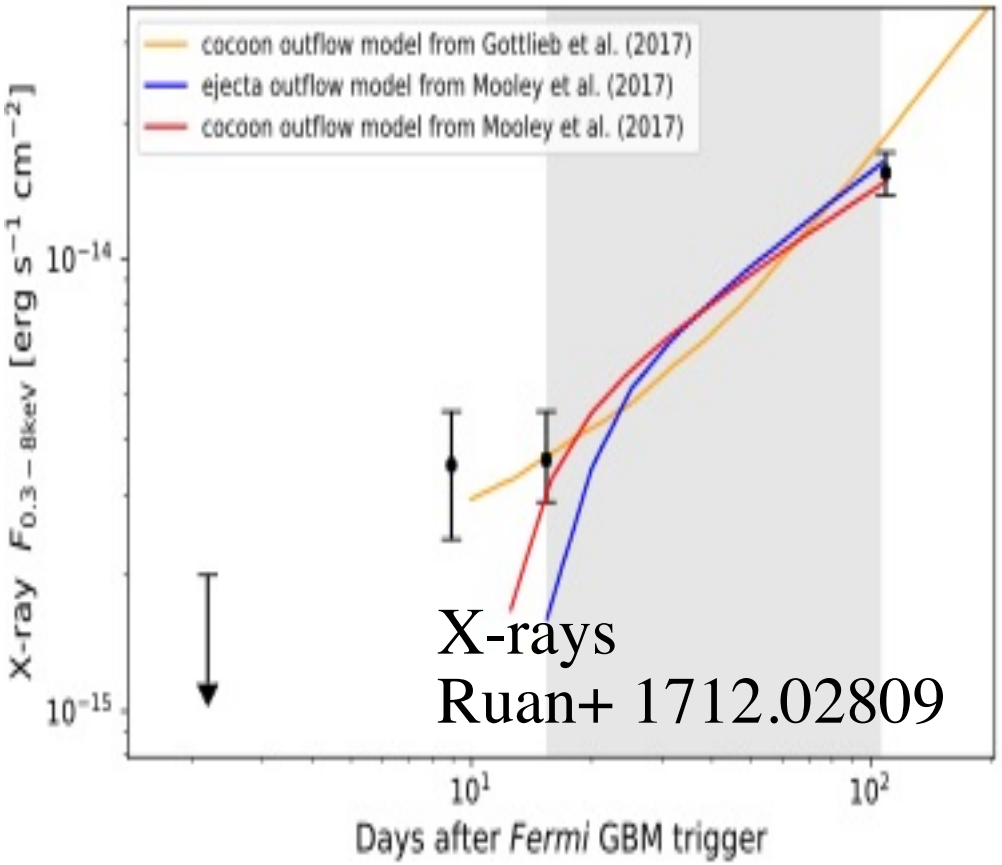


GW151226



GW170817 late-time X-ray, radio rising up to ~100 days





simple off-axis (uniform jet) disfavored
-> off-axis structured jet or cocoon / merger ejecta
(quasi-spherical, mildly relativistic outflow w. energy injection)

cocoon/merger ejecta: Y_{Comp}~3-6, $E_{e,max}$~1-100 TeV Hotokezaka priv. com.

associated HE/VHE emission?

VHE Neutrinos

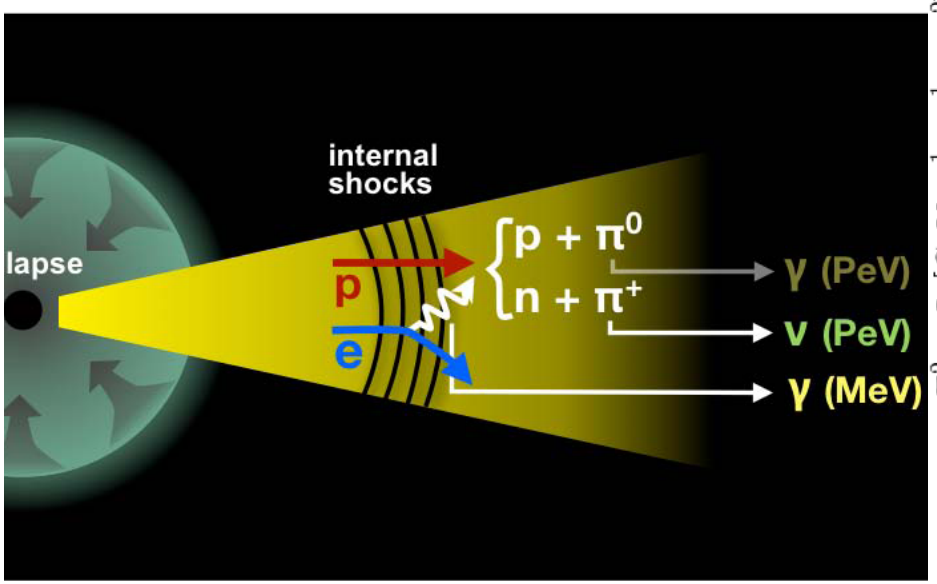
New window onto the Universe (UHECRs), turned new mystery?

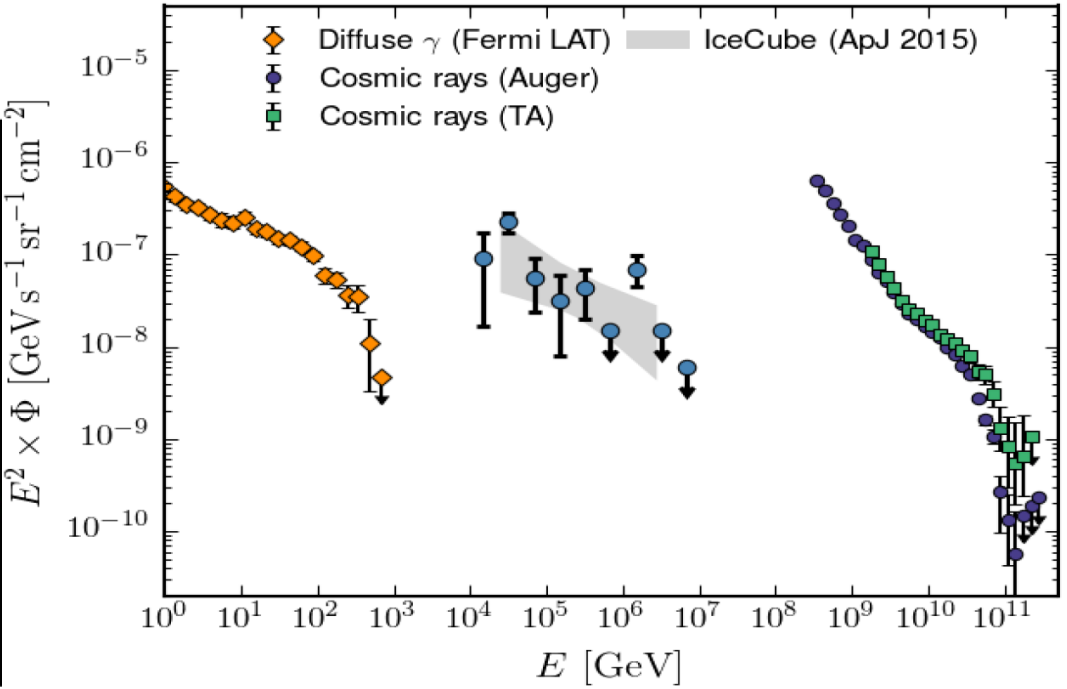
- clear indicators of VHE/UHE cosmic ray production
- being detected by IceCube, but no correlation with promising sources (bright GRBs, bright blazars) until recently

VHE γ follow-up

identify via co-produced γ rays:

- neutrino sources (if γ-rays escape + propagate)
- VHE/UHECR sources (if γ-rays + CRs escape+propagate)

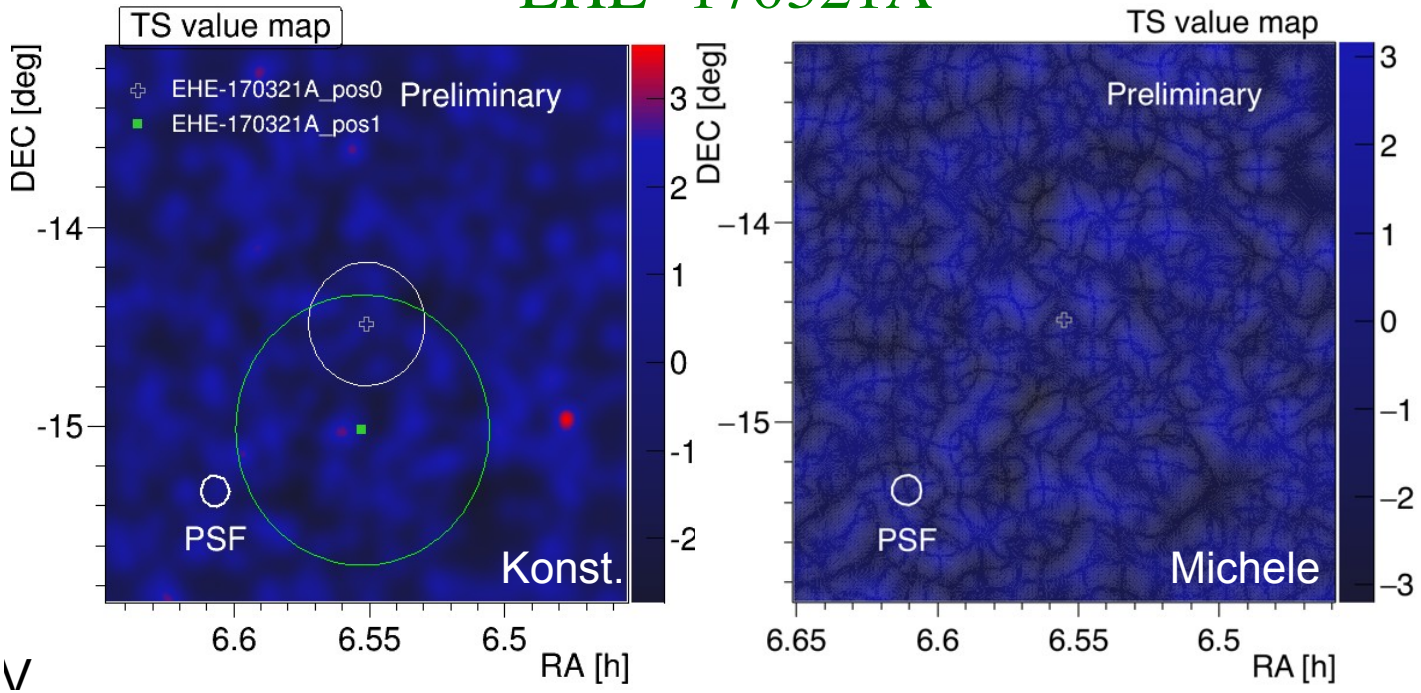




MAGIC high-energy neutrino follow-up

- IC-160427A HESE
- IC-160731A HESE/EHE
- IC-170321A EHE
- IC-170922A EHE -> TXS 0506+054 / 3FGL J0509.4+0541
- IC-171106A EHE (PeV)

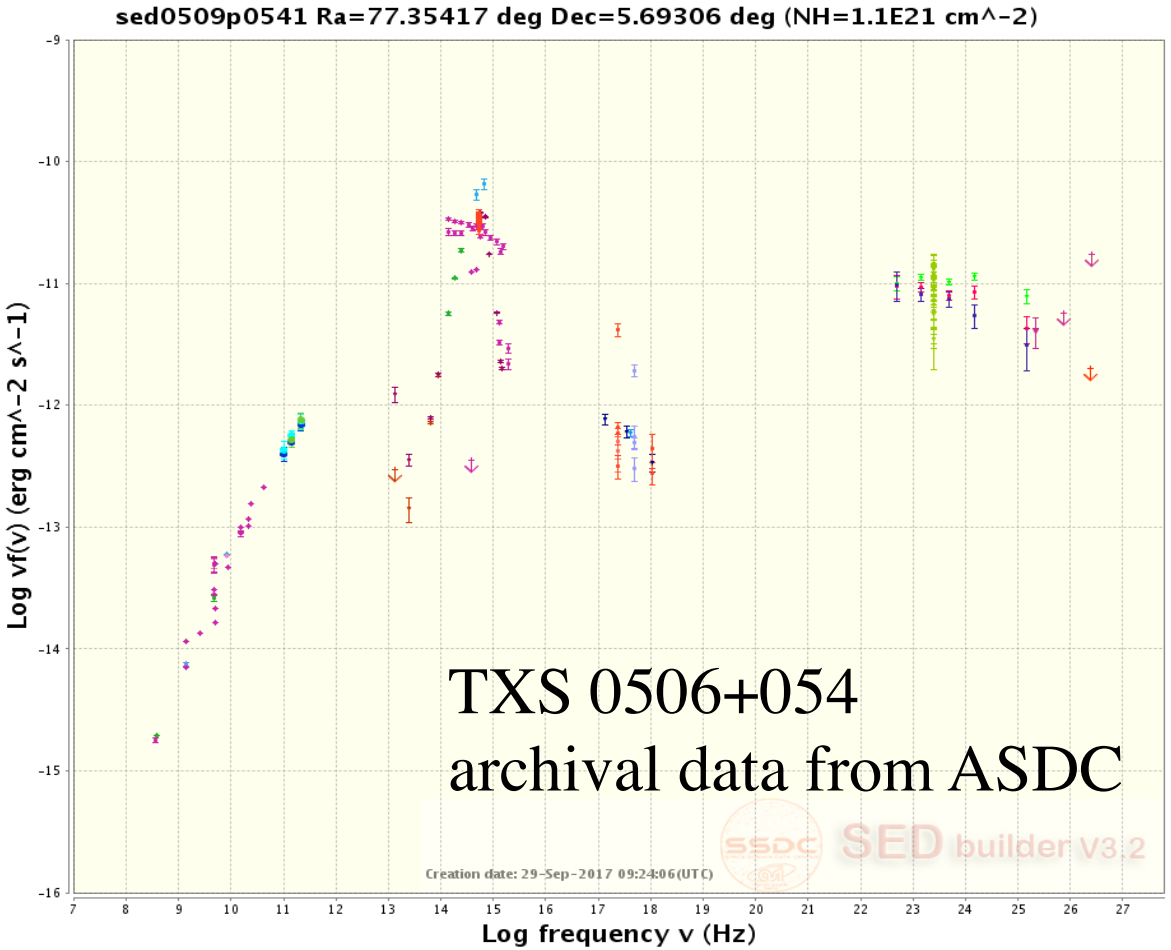
EHE -170321A



blazar TXS 0506+054: MAGIC observations

BL Lac (intermediate or low-frequency peaked)
unknown z (upper limit z<1.6)

clearly detected above 100 GeV
interpretation in terms of lepto-hadronic models in progress

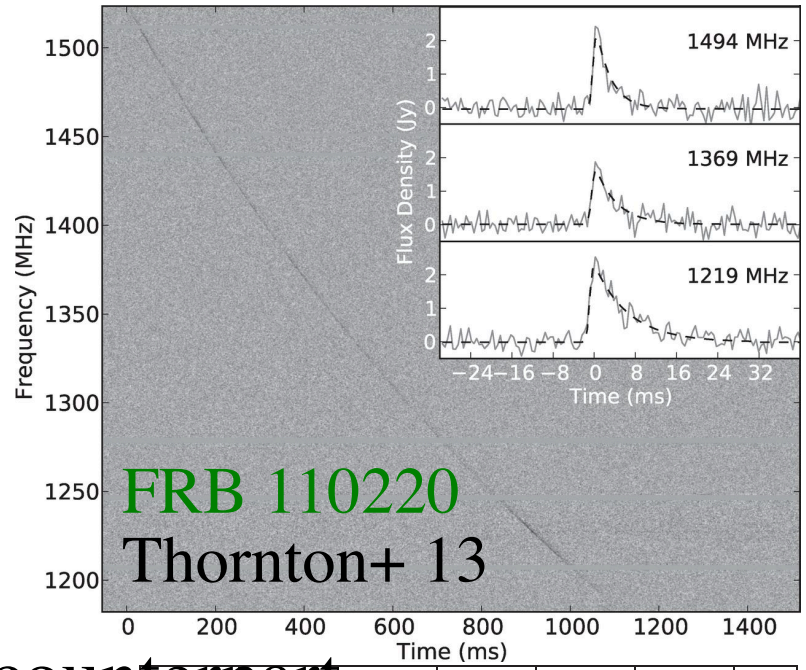


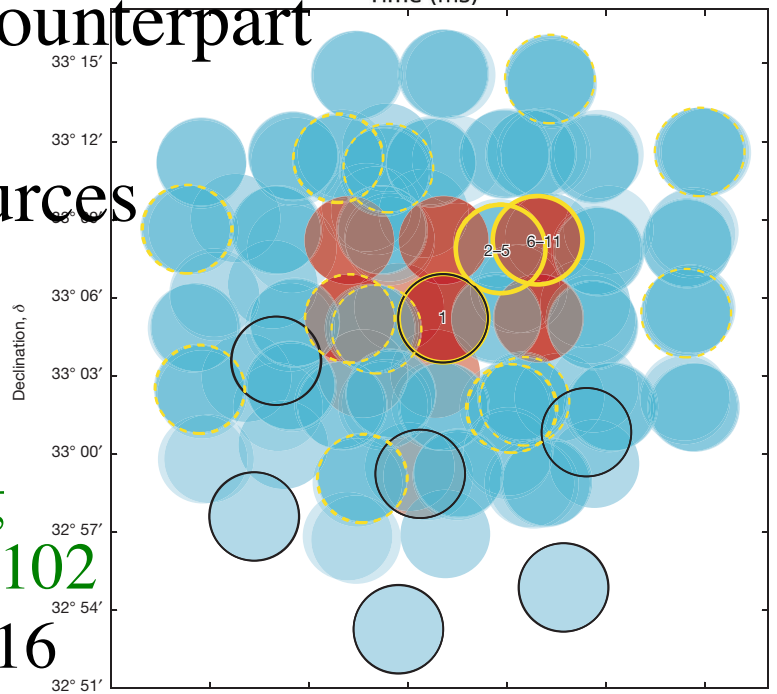
Fast Radio Bursts

- GHz band, ms duration, Jy flux, ~6000/sky/day
- likely extragalactic (z~<0.2-2.5), 1 confirmed
- extreme T_b-> coherent
- multiple subclasses? 1 repeating, rest non-repeat. (so far)
- repeating FRB 121102: z=0.19, dwarf host, persistent radio counterpart
- origin mysterious! no. of models >> no. known FRB sources
- some predictions for VHE correlated with FRBs in pulsar/magnetar models

search for multi-wavelength/ messenger counterparts!

Newest mystery objects in the Universe!



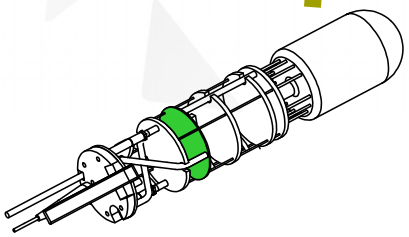


repeating FRB 121102
Spitler+ 16

FRB 121102: simultaneous MAGIC (VHE + optical) + radio campaign

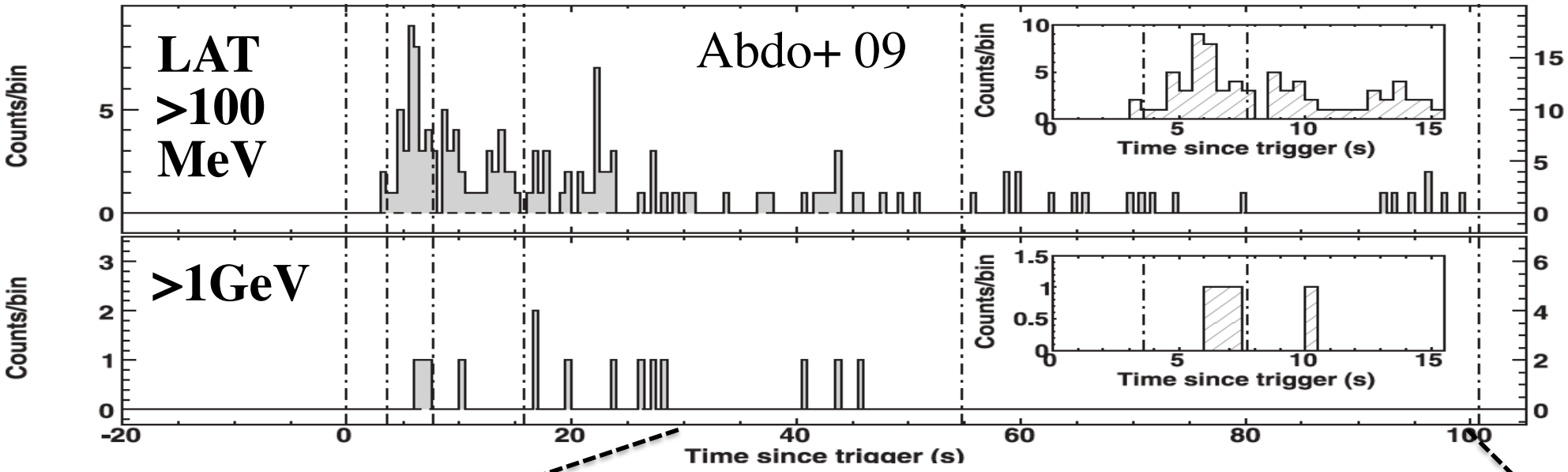
observations simultaneous with Arecibo in 2016-17
during epochs with few FRB detections
upper limits on persistent VHE emission
„ time-correlated VHE + optical emission
not yet sufficiently constraining for models
-> observations to be continued in 2018

optical: MAGIC central pixel
- ~300-450 nm (~U band), FoV >0.1 deg
- sensitive to signals with duration 0.1ms-1s
- observable simultaneously with VHE
- sensitivity for ~10ms Crab-like pulse ~3 mJy
-> comparable to recent dedicated studies, e.g. Hardy+ 17

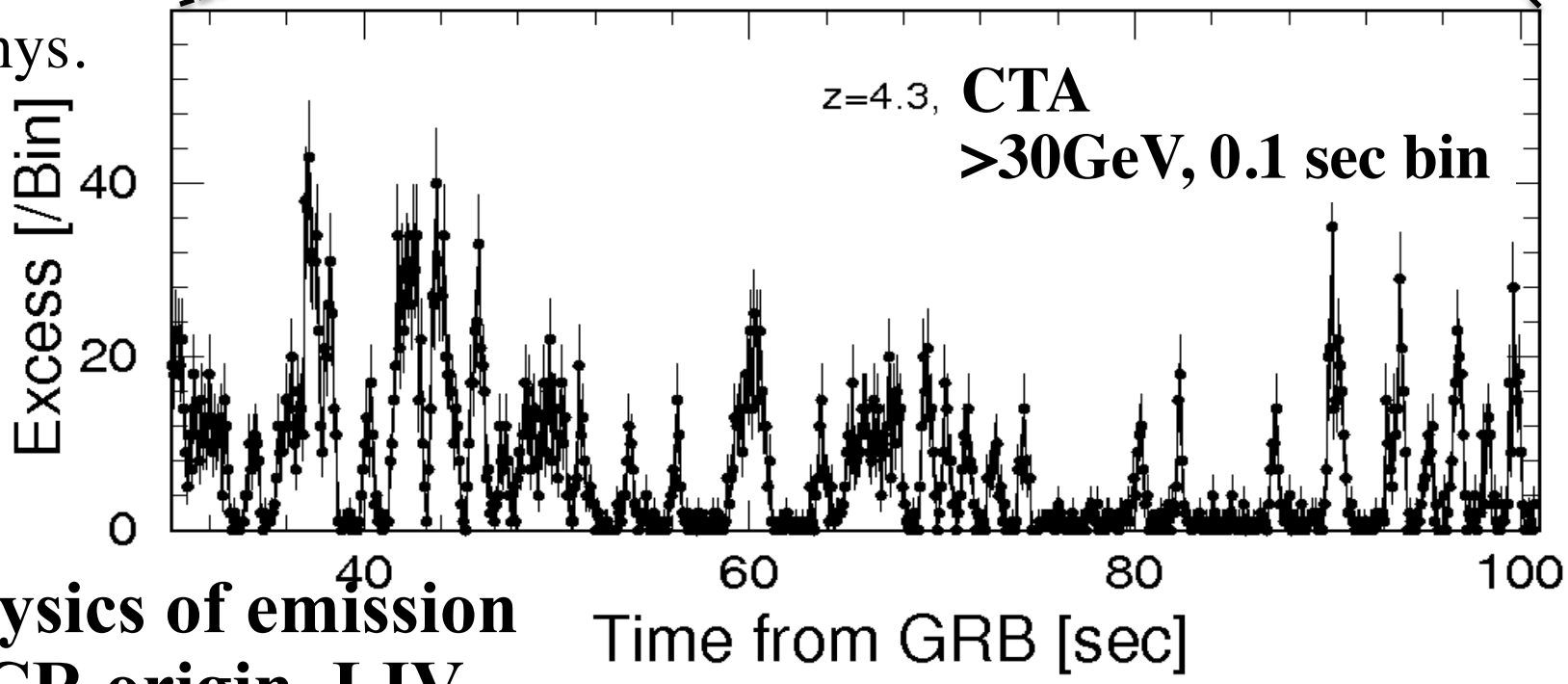


GRB light curve: Fermi vs CTA

GRB 080916C

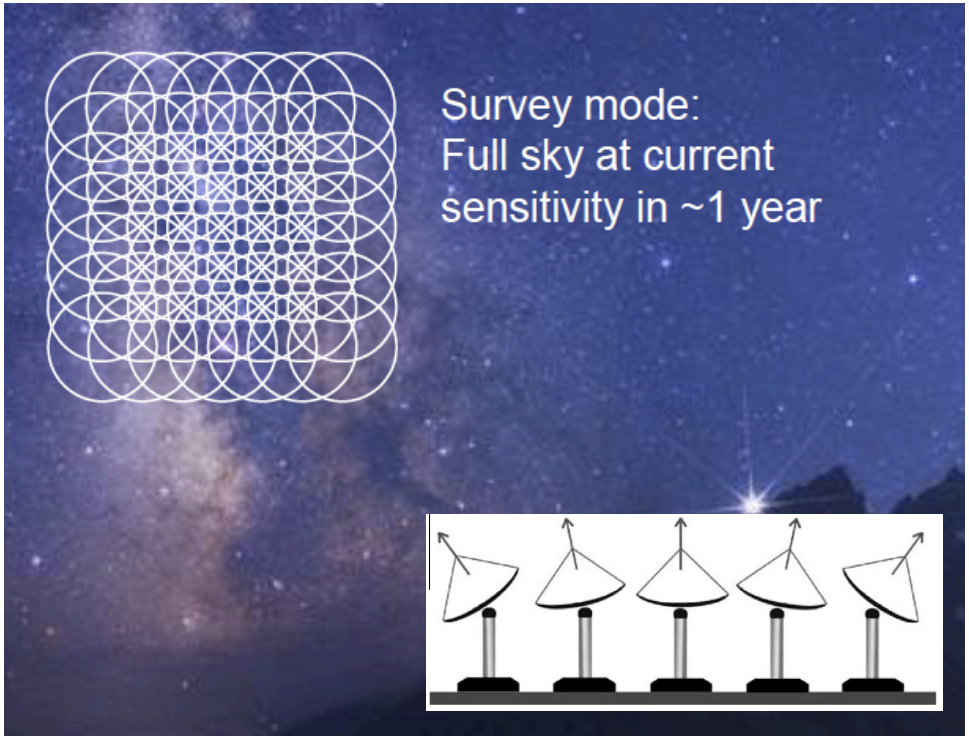


SI+ 2013
Astropart. Phys.
43, 252



Clarify physics of emission
Test UHECR origin, LIV

transient survey via divergent pointing with CTA



- possibly effective for surveys of persistent point sources

- GRBs from onset
  prompt emission physics
  (crucial but poorly understood)
- Lorentz invariance violation
  (big improvement over Fermi)
- unbiased transient survey
  e.g. FRBs

transients occurring in FoV (not necessarily detectable)
GRBs: all sky ~800/yr (BAT+GBM)
FRBs: all sky ~6000/dy
IF FoV~300 deg^2 ->
~8 GRBs/yr -> ~0.7 GRBs /1000 hr
~45 FRBs/dy -> ~2 FRBs / 1 hr

summary

MAGIC observations of multimessenger transients

GRBs

- intriguing hints for nearby short GRB 160821B
  - interesting implications for GW follow-up
- almost there; clearer detection imminent!

neutrinos

- first indications for BL Lac TXS 0506+054!
- more observations toward solving mystery of their origin

GWs, FRBs

- ongoing with interesting prospects

summary

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first indications for BL Lac TXS 0506+054!

more observations toward solving mystery of their origin

GWs, FRBs

ongoing with interesting prospects

CTA: new prospects for transients

advanced real-time analysis, survey via divergent pointing…

The fun has just begun!

The best is yet to come−let's look forward to CTA!