

Transient Science with CTA

Susumu Inoue (RIKEN)

on behalf of the CTA Transients SWG / CTA Consortium



星風の GRBを散らすと見る夢は 覚めても胸のさわぐなりけり
GRBに 銀河の光をさしそへて これや宇宙のにしきなるらん

S. Inoue

outline: transient science with CTA

1. introduction
2. GRBs (afterglows)
3. FRBs
4. GW follow-up
5. transient survey

skip:

neutrino follow-up

Galactic transients

others (TDEs, etc)

...

CTA Key Science Projects (KSPs)

Dark Matter Programme

Galactic Centre

Galactic Plane Survey

Large Magellanic Cloud Survey

Extragalactic Survey

Transients

Cosmic Ray PeVatrons

Star Forming Systems

Active Galactic Nuclei

Clusters of Galaxies

Non-Gamma-ray Science

dark observing time:
40% consortium KSPs
60% open observatory

Details in document
“Science with CTA”
to be published on
arXiv very soon

CTA Science Working Groups (SWGs)

overall coordinator: Stefano Vercellone; deputy: Stefan Funk

Galactic SWG

coordinator: Jamie Holder; deputy: Roberta Zanin

Cosmic-ray SWG

coordinator: Stefan Ohm; deputy: Sabrina Casanova

Extragalactic SWG

coordinator: Elna Lindfors; deputy: Fabrizio Tavecchio

Transients SWG

coordinator: **Susumu Inoue**; deputy: Catherine Boisson

Dark Matter and Exotic Physics SWG

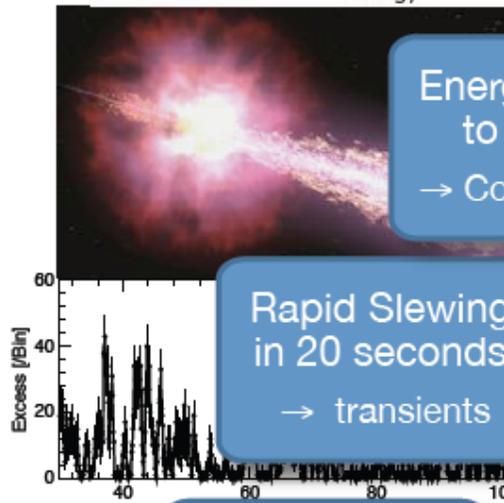
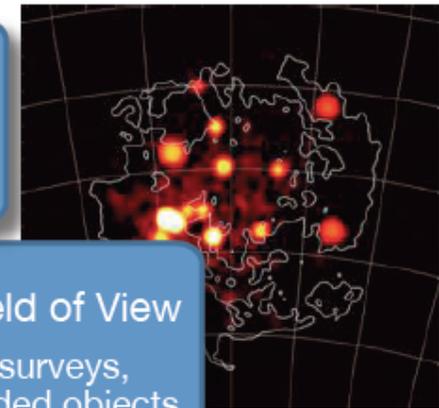
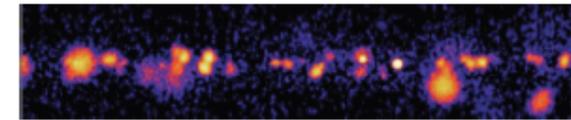
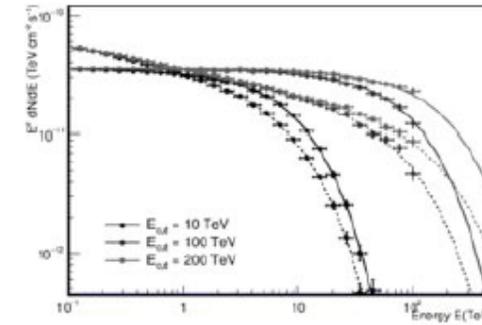
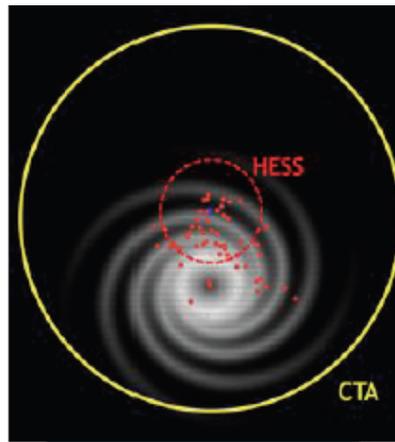
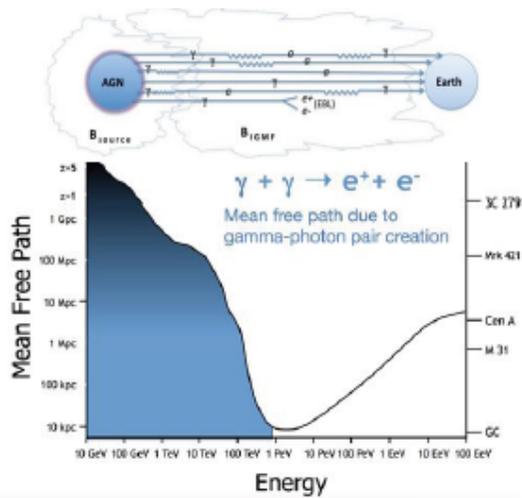
coordinator: Fabio Zandanel; deputy: Aldo Morselli

Intensity Interferometry SWG

coordinator: Dainis Dravins; deputy: Michael Daniel

Multiwavelength WG

coordinator: Sera Markoff; deputy: Emma de Oña-Wilhelmi



Energies down to 20 GeV
→ Cosmology++

10 x Sensitivity, Large Collection Area
→ all topics

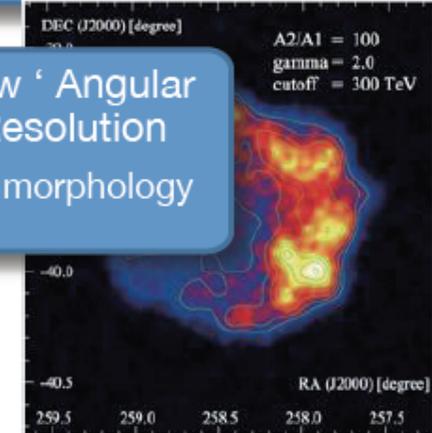
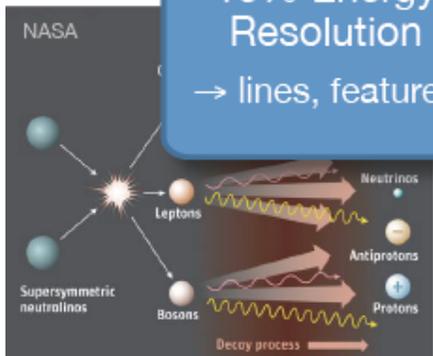
Energies up to 300 TeV
→ Pevatrons

Rapid Slewing in 20 seconds
→ transients

8° Field of View
→ surveys, extended objects

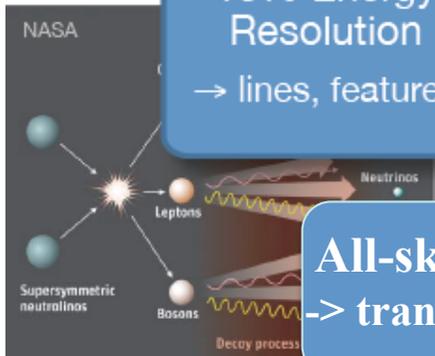
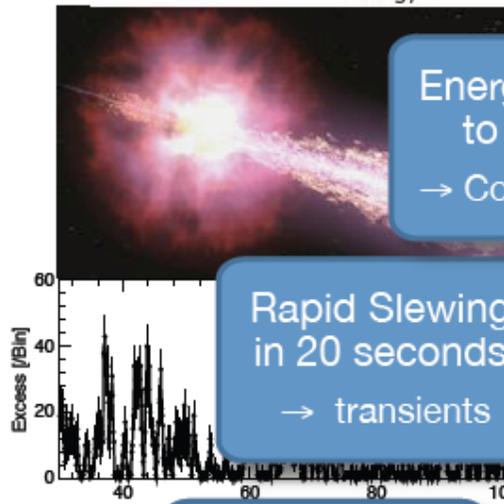
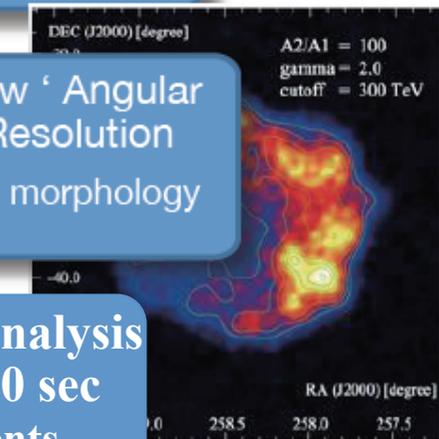
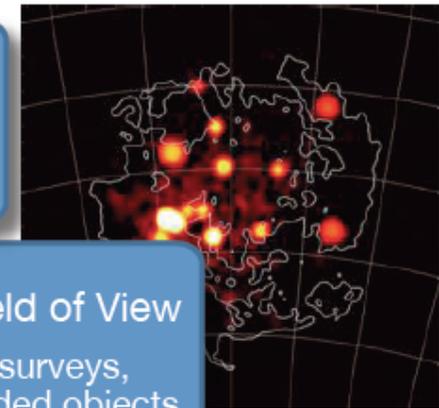
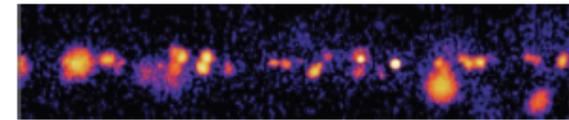
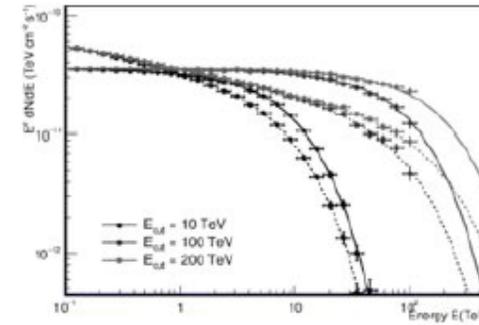
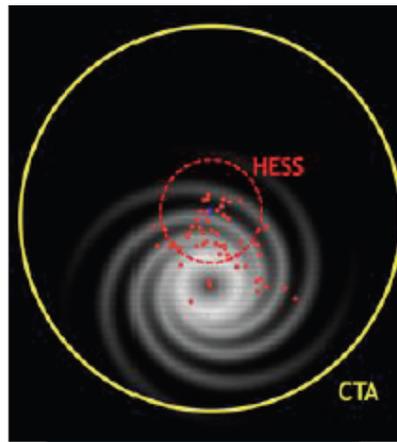
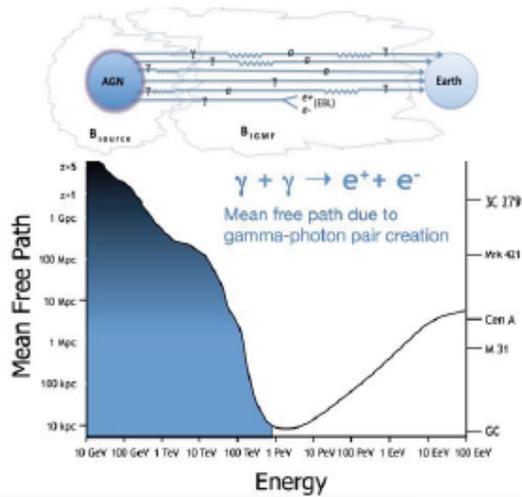
10% Energy Resolution
→ lines, features

Few ' Angular Resolution
→ morphology



CTA vs current IACTs

from W. Hofmann



Energies down to 20 GeV
→ Cosmology++

10 x Sensitivity, Large Collection Area
→ all topics

Energies up to 300 TeV
→ Pevatrons

Rapid Slewing in 20 seconds
→ transients

8° Field of View
→ surveys, extended objects

10% Energy Resolution
→ lines, features

Few ' Angular Resolution
→ morphology

All-sky Coverage
→ transients, survey

Versatile Pointing (subarrays, divergent)
→ transients, surveys

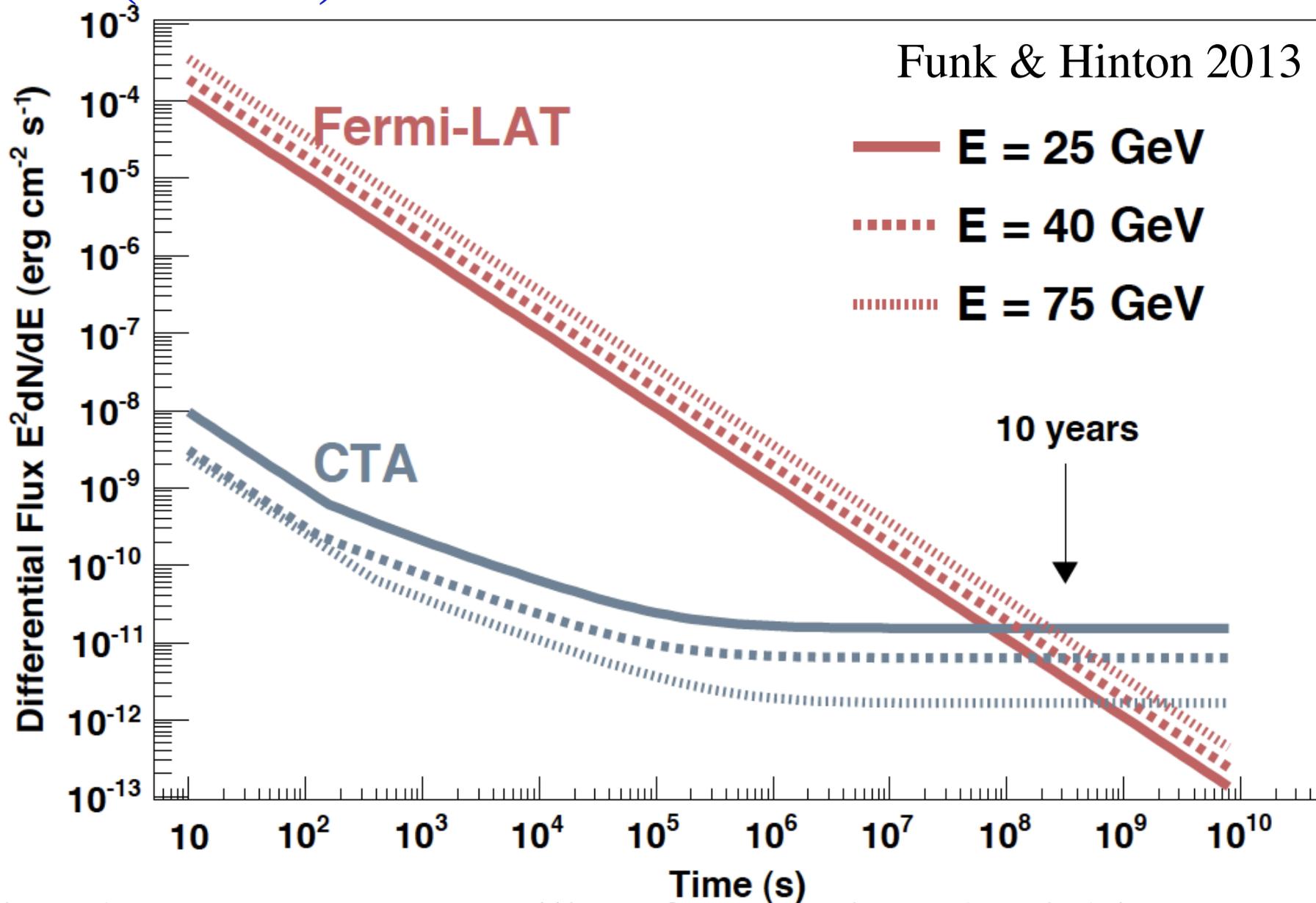
Real Time Analysis Alerts in 30 sec
→ transients



CTA vs current IACTs

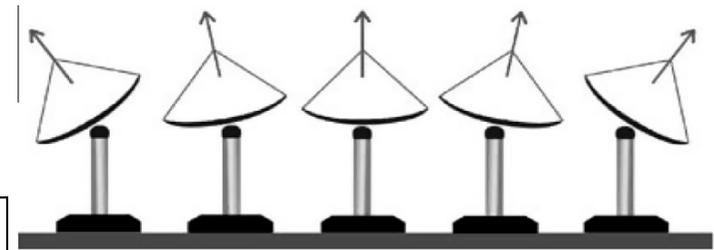
adapted from W. Hofmann

CTA (IACTs) vs Fermi



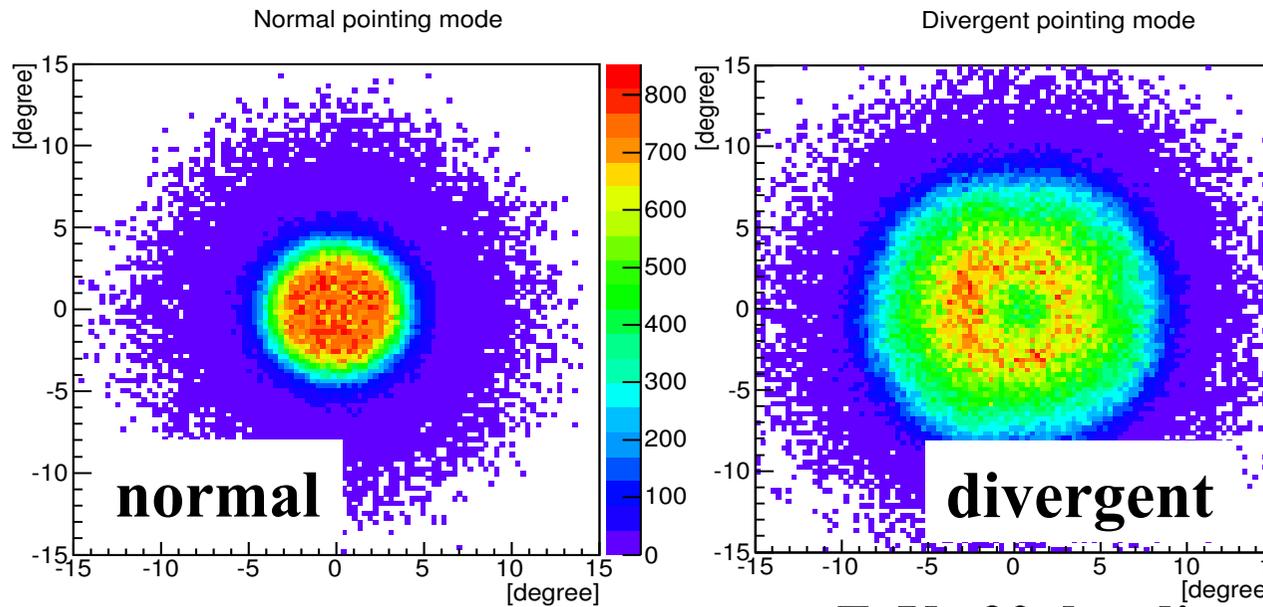
big advantage over satellites for transients/variables:
effec. area $\sim 10^4 \times \text{LAT@30 GeV}$

divergent pointing for MSTs/SSTs



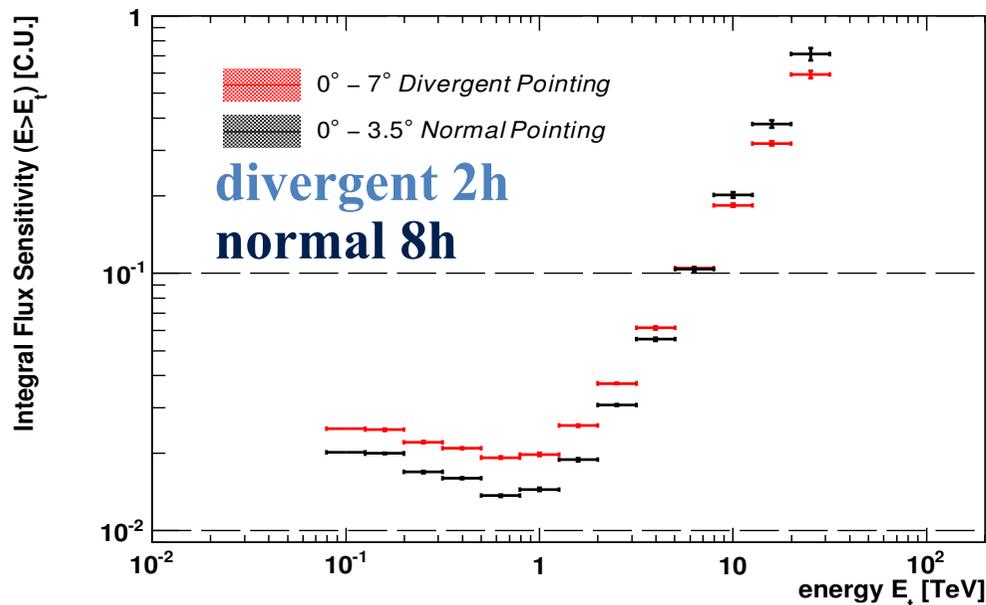
Szanecki+ 2015

Wider FoV at expense of angular/energy resolution



Gérard+ 2015

FoV ~20 deg dia.



fast scanning of large regions, e.g. GW follow-up

Preliminary studies:

point source survey

efficiency comparable?

-> possibly interesting

for commensal unbiased

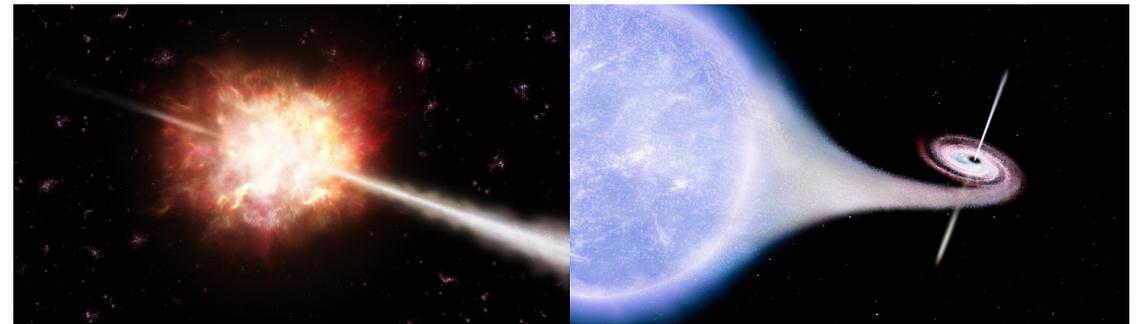
transient survey

Transients KSP

- GRBs -> Tam
- Galactic transients
(microquasars, PWN flares, novae, etc) -> Saito
- X-ray/optical/radio transients
(TDEs, SN shock breakout events, FRBs, new transients)
- HE neutrino transients -> Yoshida -> Aoki, Totani
- gravitational wave transients -> Kisaka
- serendipitous VHE transients
- VHE transient survey via divergent pointing

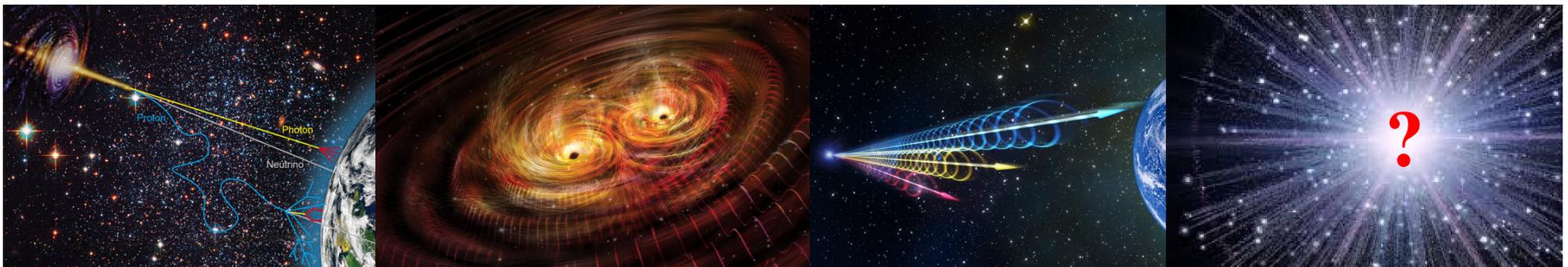
Related KSPs:

- AGN (flares), LIV studies



Wanted:

- ***gamblers***
- ***fortune seekers***
- ***thrill hounds***



2. Gamma-Ray Bursts

high photon statistics
>tens of GeV

Physics of GRBs

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

Tools to probe the Universe

- Extragalactic background light (deeper than AGN)
- Intergalactic magnetic fields

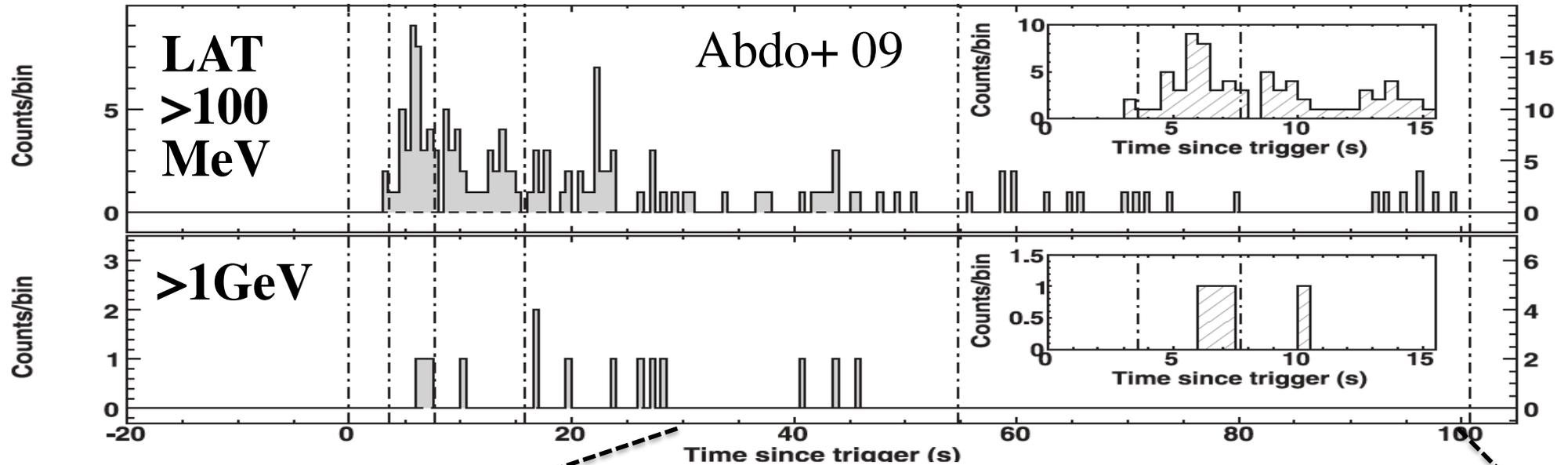
Tests of UHECR origin, fundamental physics

- Search for signatures of:
- Accelerated hadrons
 - Lorentz invariance violation

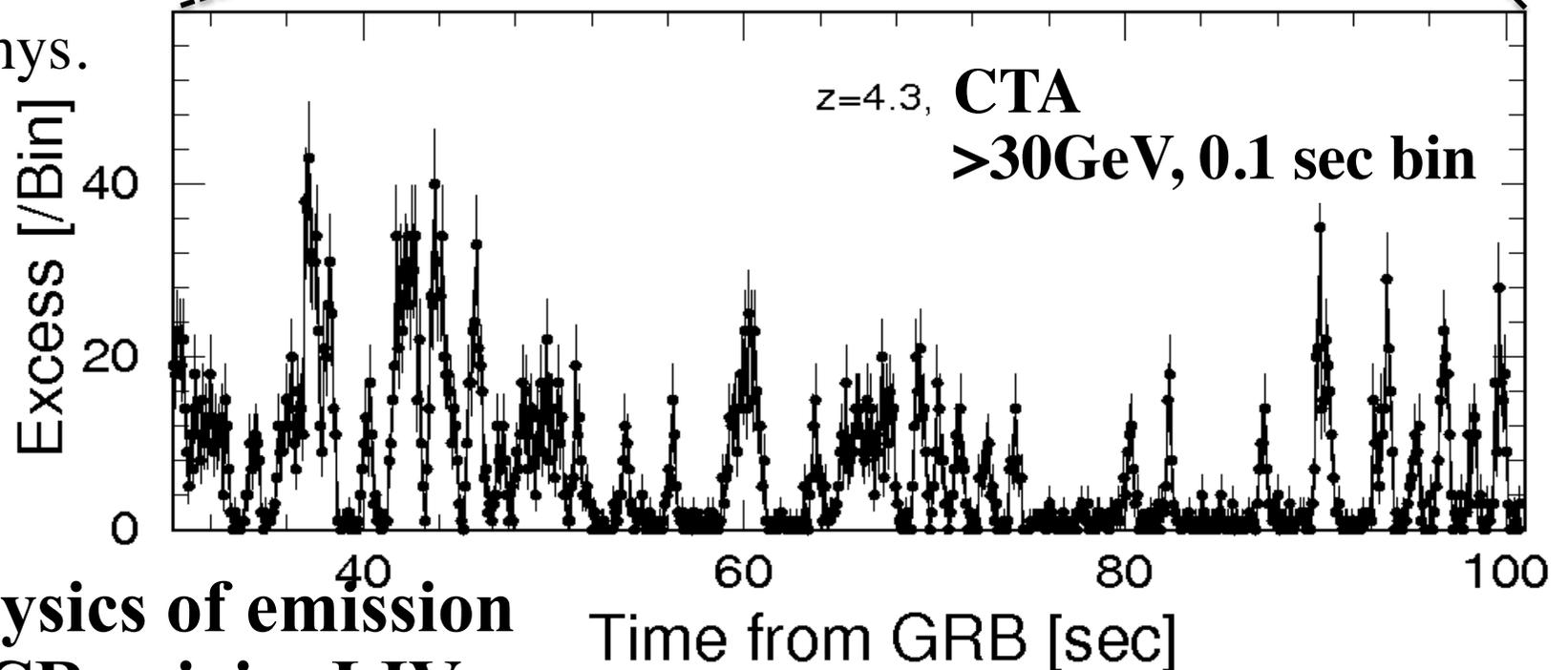


GRB light curve: Fermi vs CTA

GRB 080916C

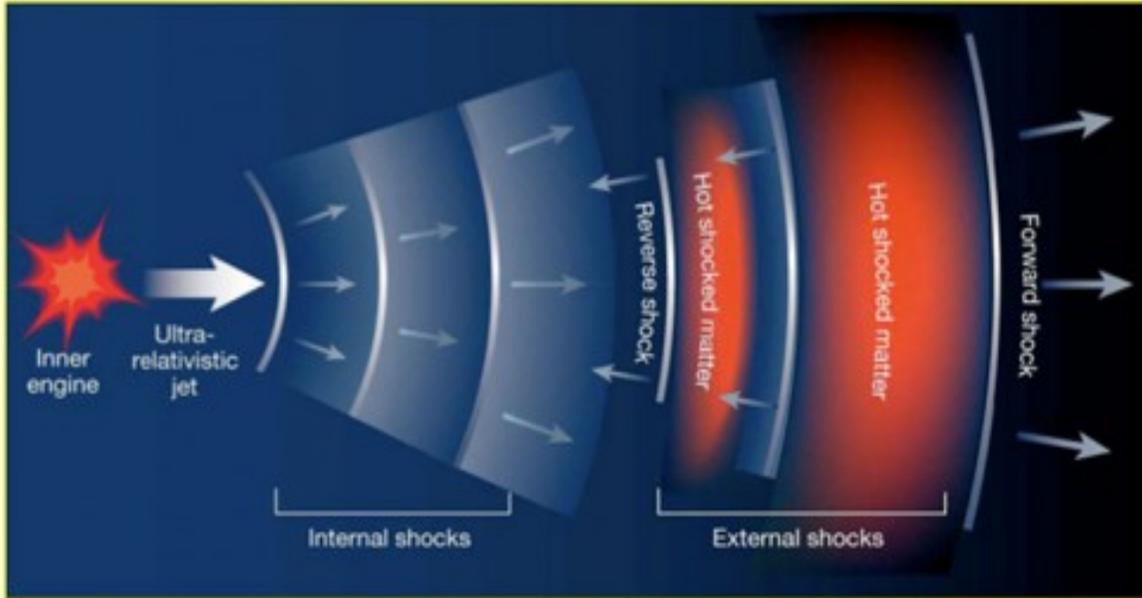


SI+ 2013
Astropart. Phys.
43, 252



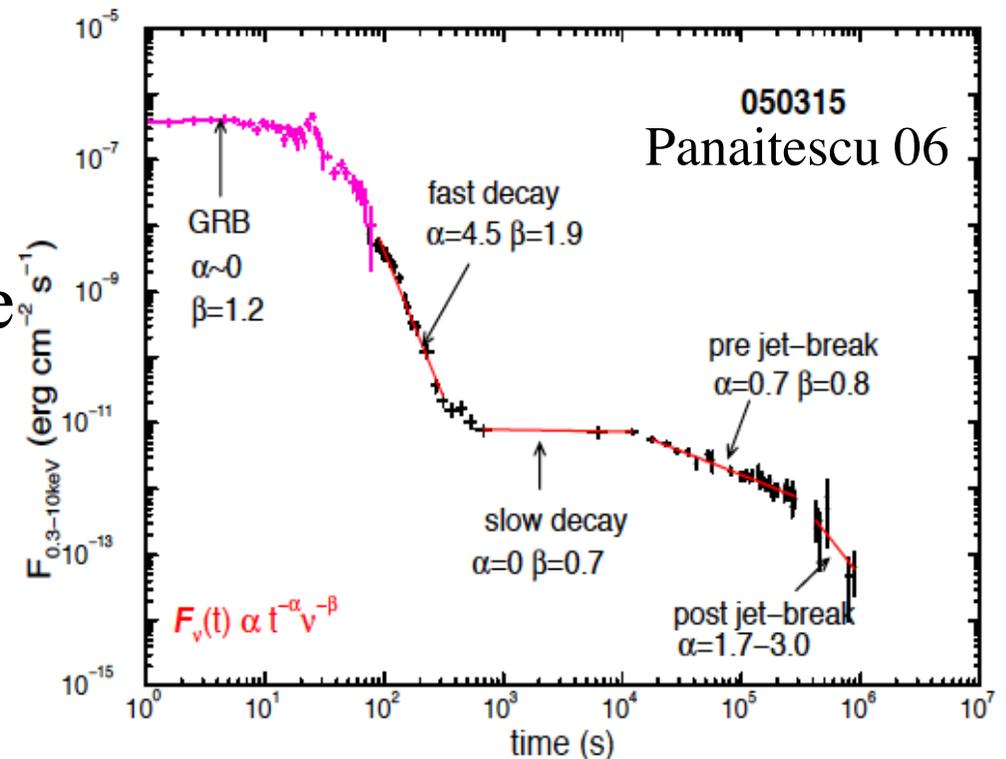
Clarify physics of emission
Test UHECR origin, LIV

GRB afterglows



ultrarelativistic outflow
+ ext. medium interaction
-> relativistic blastwave
+ electron acceleration
-> synchrotron emission
radio - opt. - X - ~GeV

- open questions:
mechanisms of
- X-ray plateau (shallow) phase
 - chromatic light curve breaks
 - B field generation
 - particle acceleration
- ...



afterglows at VHE: beyond the synchrotron burnoff

maximum synchrotron photon energy for electrons
dominated by synchrotron cooling

$$\tau_{\text{accel}} \propto \gamma_e B^{-1}, \tau_{\text{syn}} \propto \gamma_e^{-1} B^{-1}$$

$$\tau_{\text{accel}} = \tau_{\text{syn}} \rightarrow \gamma_{e,\text{max}} \propto B^{-1/2}$$

$$v_{\text{syn,max}} \propto B \gamma_{e,\text{max}}^2$$

$$E_{\text{syn,max}} \sim 2^{3/2} [27 / (16\pi\alpha_f)] m_e c^2 \\ \times \Gamma(t)(1+z)^{-1} \\ \sim 106 \Gamma(t)(1+z)^{-1} \text{ MeV}$$

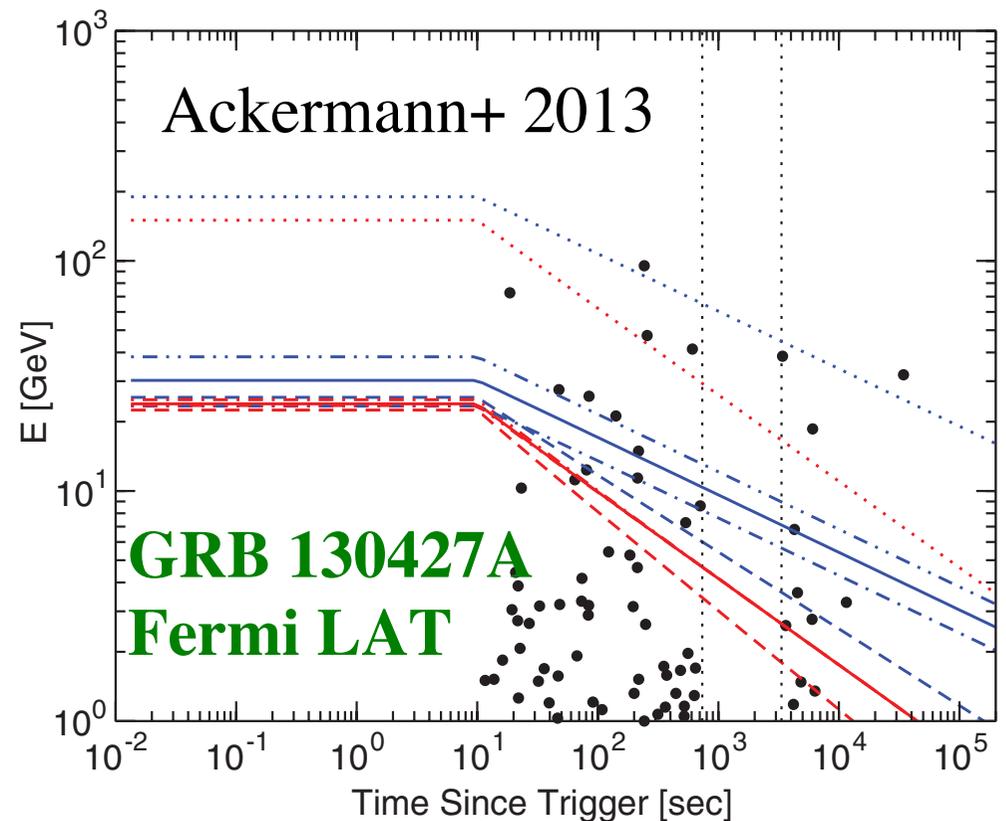
GRB afterglows

$$\Gamma < \Gamma_{\text{max}} \sim 1000 \quad (\Gamma \sim 10 \text{ at } t \sim 1\text{d})$$

$\rightarrow E > 100 \text{ GeV}$ surely

beyond synchrotron

(SSC, EC, hadronic...)

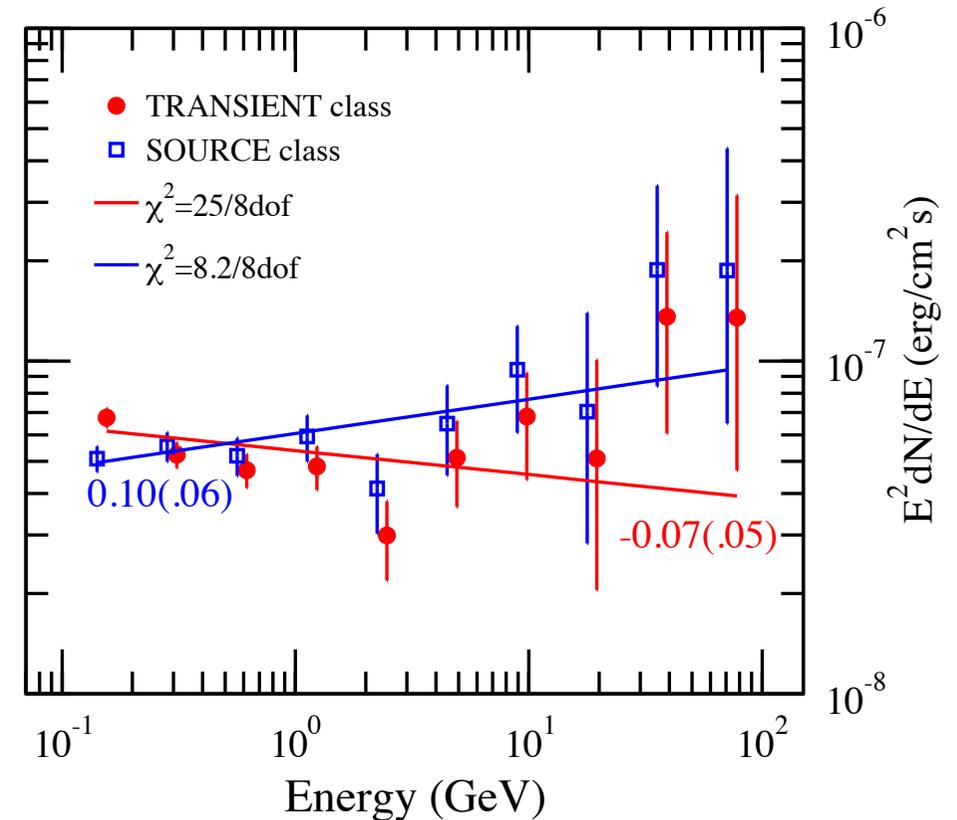
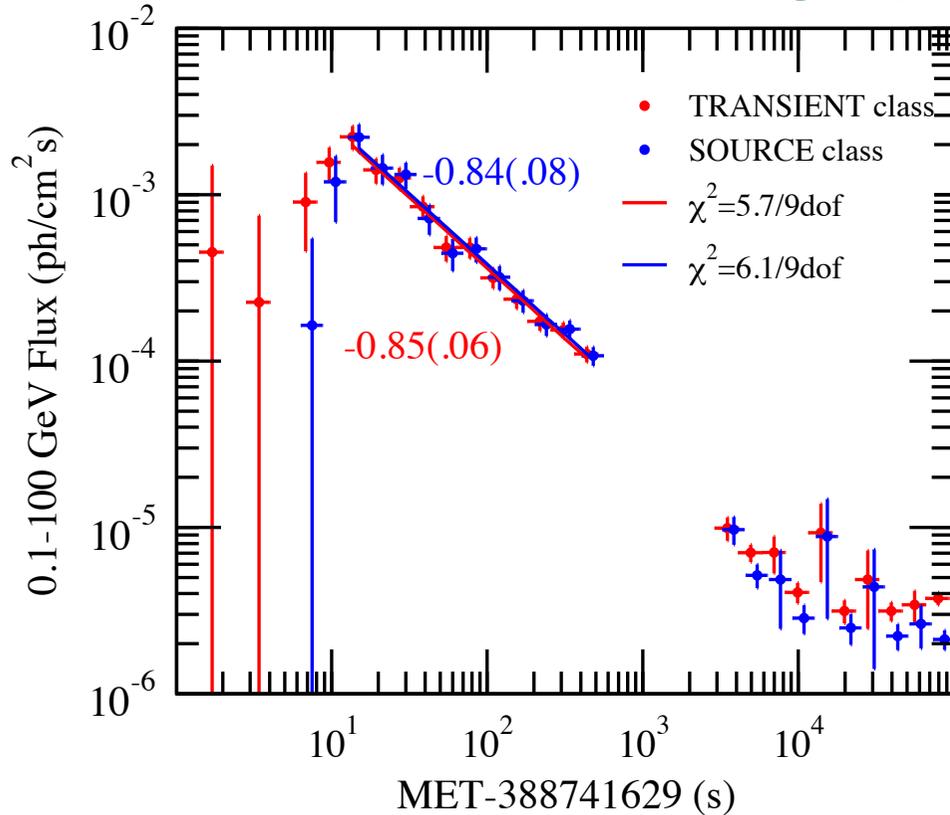


Kouveliotou+ 2013 still argue
for synchrotron extension

GRB afterglows at HE: emerging evidence of second hard component

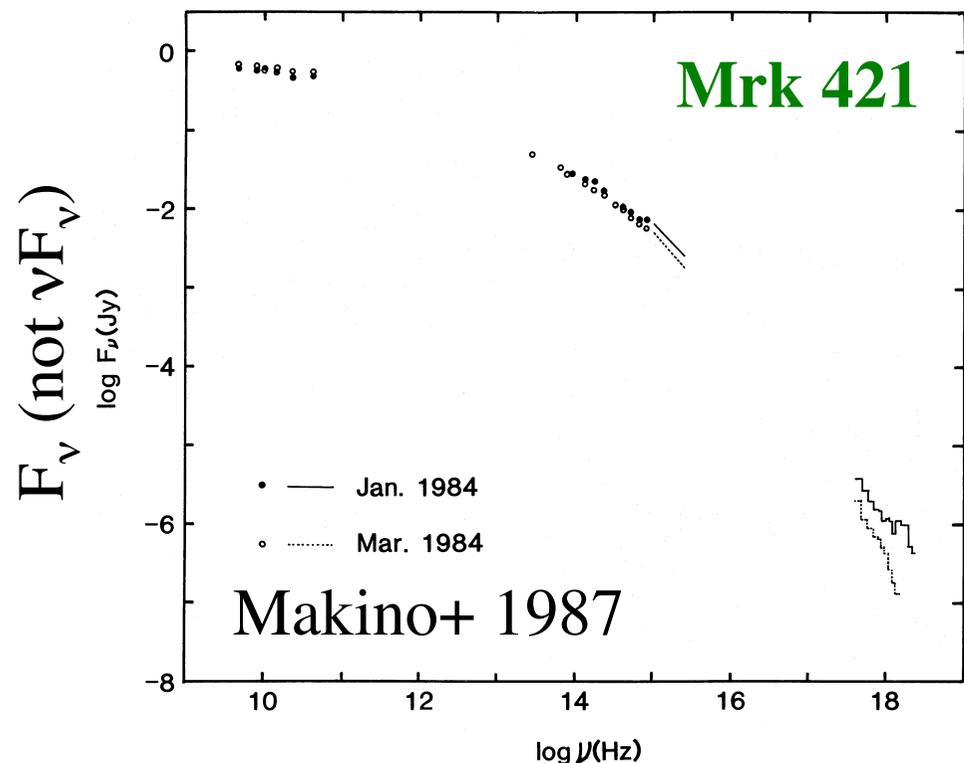
Panaitescu arXiv:1605.09367

Search Region = 10 deg **GRB 130427A** Search Region = 10 deg & t=20-500s



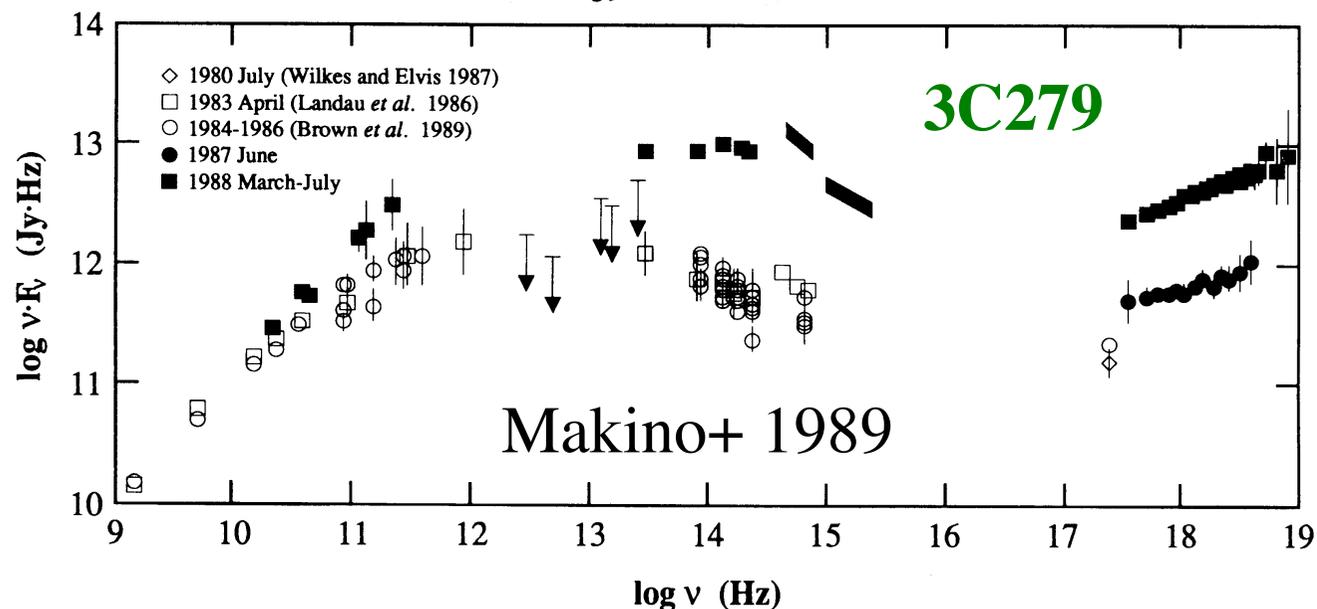
10/24 well-monitored LAT afterglows
better described by broken power-law at 1-3 σ CL ->
suggestive of hard component above ~0.5 GeV-5 GeV

blazars before EGRET (-1991)



prominent GeV-TeV components totally unknown and unexpected

for GRB afterglows,
analogous situation now:
- missing (possibly more than) half the picture
- possible surprises



3. Fast Radio Bursts

more from Aoki, Totani

FRBs:

- new class of radio transients
- ms duration, very frequent: $\sim < 10000/\text{sky}/\text{day}$
- likely extragalactic, extreme brightness temp. \rightarrow coherent
- multiple subclasses? 1 repeating, rest non-repeating (so far)
- origin mysterious! no. of models \gg no. of known FRBs
- new cosmological probe

Any multi-wavelength/messenger counterpart important!

VHE prospects:

IF magnetar flare-like, correlated VHE bursts?

- \rightarrow simultaneous campaign with radio of repeating FRBs
- \rightarrow search for serendipitous events

IF NS merger-like, short GRB-like prompt or afterglow, etc

- \rightarrow follow-up of FRB alerts

FRBs: new class of transients

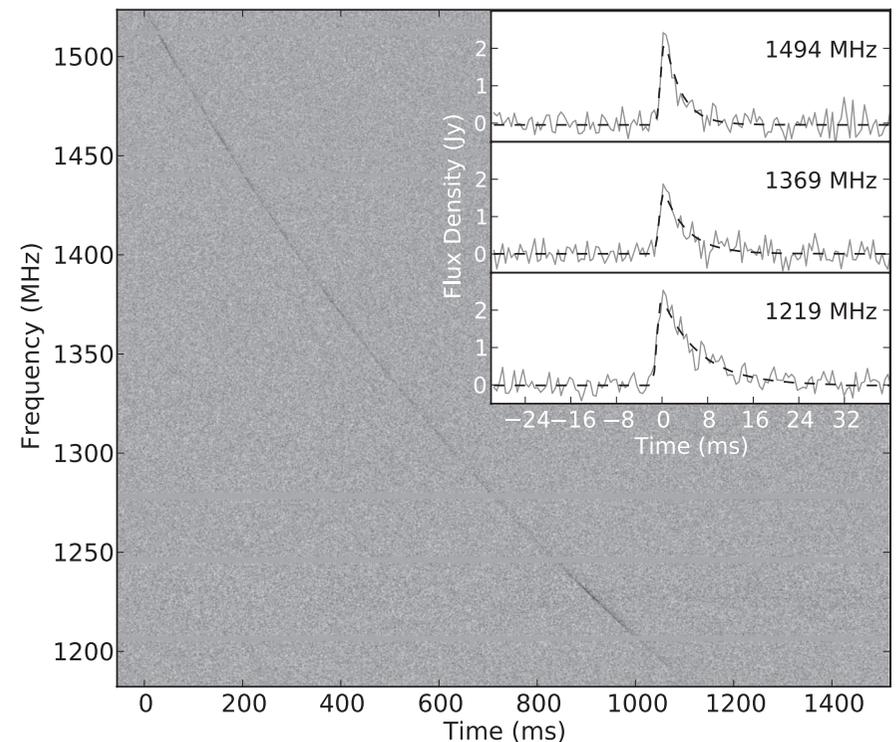
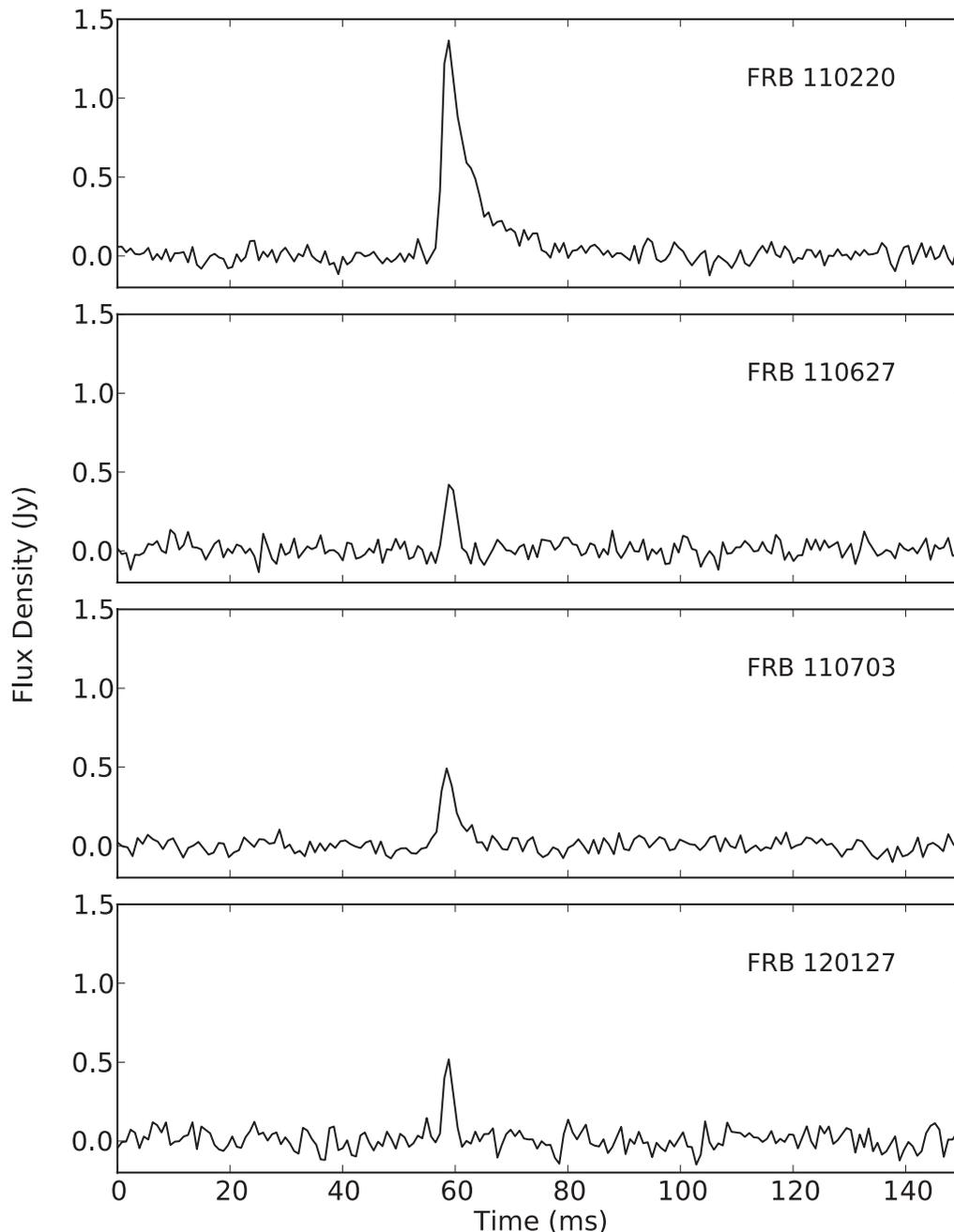
Thornton+ 13 Science

Parkes High Time Resolution Universe survey

$S_{\nu} \sim 0.4-1.3 \text{ Jy @ } 1.28-1.52 \text{ GHz}$
 $\Delta t \sim < 5 \text{ ms}$

$DM \sim 550-1100 \text{ pc cm}^{-3}$
 $\rightarrow D \sim 1.7-3.2 \text{ Gpc (} z \sim < 0.5-1.0)$
 $\rightarrow E_{\text{rad}} \sim 10^{37}-10^{39} \text{ erg}$
(E_{tot} possibly much higher, cf. pulsars)

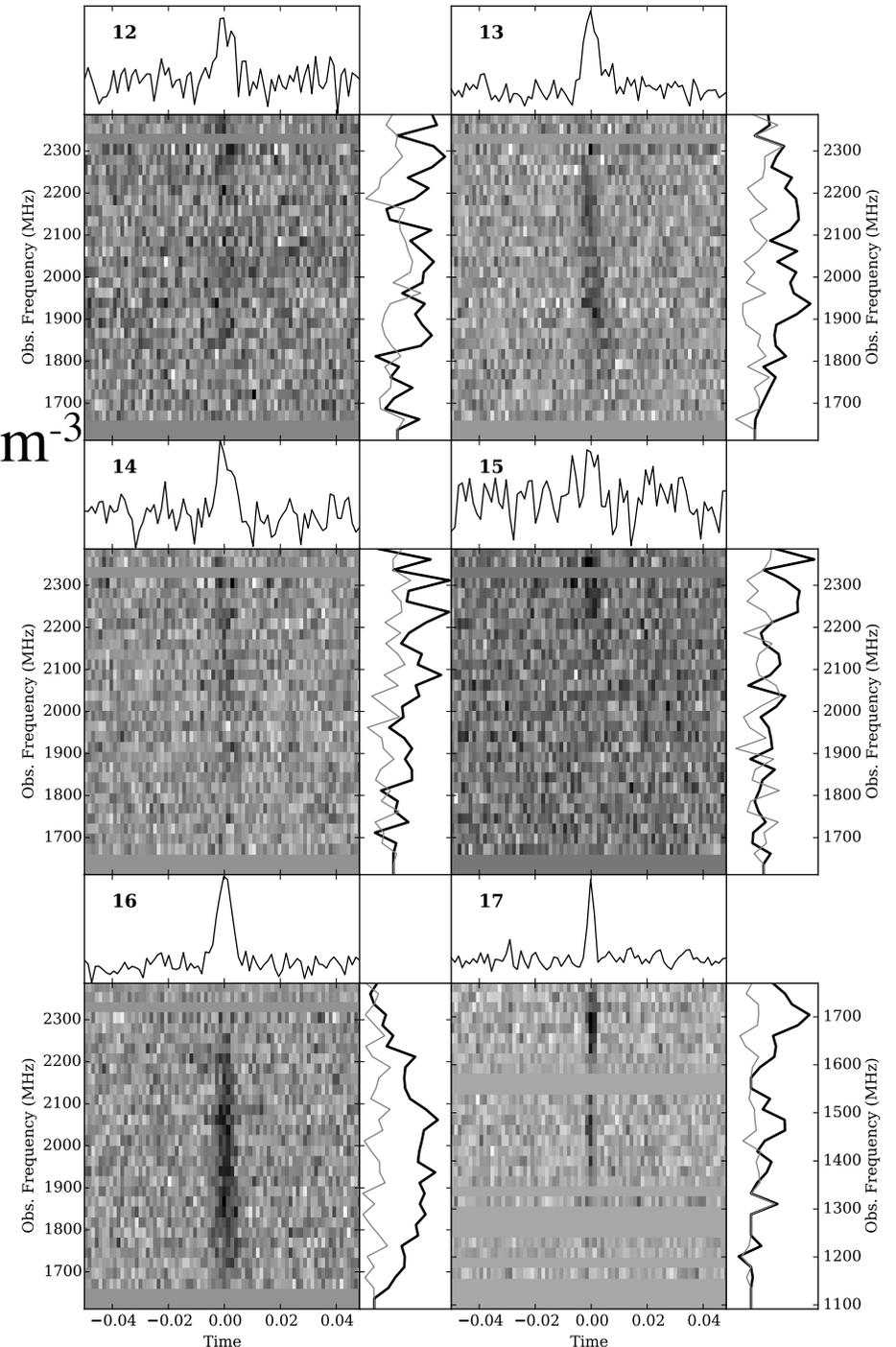
$R_{\text{FRB}} \sim 10^4 \text{ d}^{-1} \sim 0.1 R_{\text{SN}}, 1000 R_{\text{GRB}}!$



FRB 121102+: first (and so far only) repeater

Spitler+ 16, Nature; Scholz+ 1603.08880

- discovered by Arecibo in 2012
17 FRBs until June 2015,
inc. GBT, Effelsberg
- near Galactic anti-center
 $DM \sim 559 \text{ pc cm}^{-3} \gg DM_{MW} \sim 200 \text{ pc cm}^{-3}$
-> likely extragalactic, $z \sim 0.2$?
- average 3 FRBs/hr, but strongly
time-clustered, no periodicity
- large variations in profile, spectra
similar to Crab GRPs
-> extragalactic pulsar super-GRPs?
- comparison with other FRBs:
Arecibo sensitivity $> 10x$ Parkes
-> fainter repetition in other FRBs?
duration $\sim 3-9 \text{ ms}$, significantly longer
-> separate class?



VHE prospects for FRBs 1

- pulsar/magnetar-like progenitor
hyper-flare driven pulse/outflow
+ nebula interaction

e.g. model of Lyubarsky 14

FRB: synchrotron maser

VHE: shock synchrotron

(correlated ms duration)

$$\delta t = \frac{2}{c\Gamma_{\text{cd}}^2} \Delta r = 1.3 \times 10^{-4} l_6 \text{ s}$$

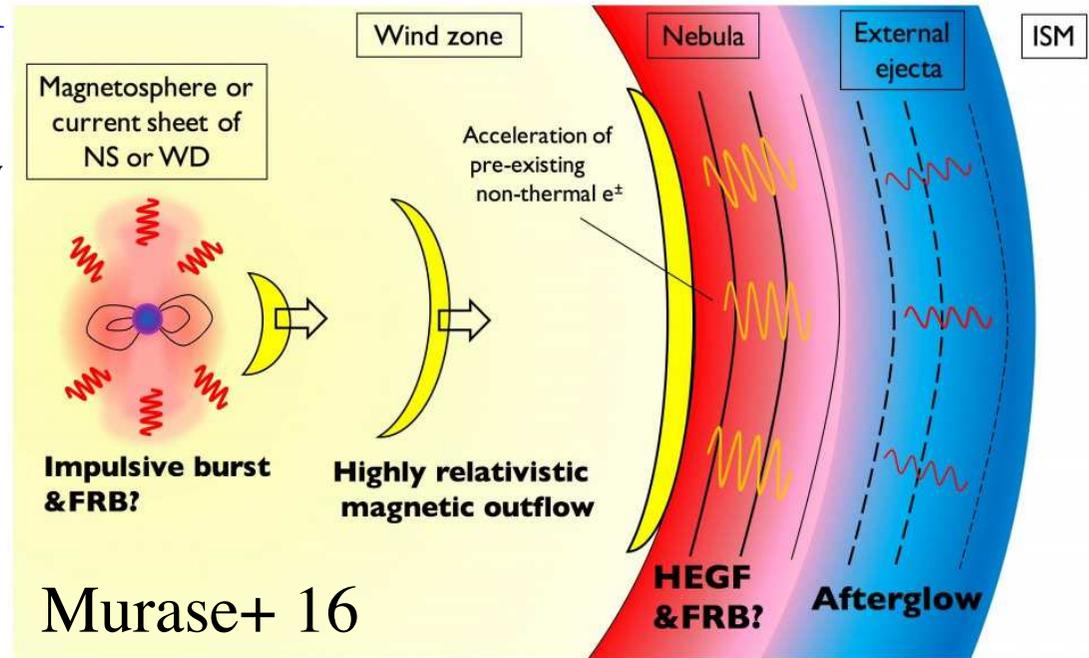
$$\varepsilon_1 \sim \frac{\hbar m_e c^3}{e^2} \Gamma_{\text{cd}} = 1.3 \frac{b^{1/2}}{\xi^{1/4} \Omega} \text{ TeV}$$

$$\mathcal{E}_{\text{total}} = B_{\text{pulse}}^2 r^2 l = 10^{48} b^2 B_{*15}^2 l_6$$

fluence $\sim 10^{-8} (D_{\text{Gpc}})^{-2} \text{ erg/cm}^2$

~ 10 photons $(D_{\text{Gpc}})^{-2}$ for $A_{\text{eff}} \sim 10^9 \text{ cm}^2$

(neglecting EBL; sets in $> \sim 0.4 \text{ TeV}$
for $D=1 \text{ Gpc}$ or $z=0.25$)



-> simultaneous radio + VHE
observation of FRB repeater(s)

-> search for serendipitous events
 ~ 1 FRB/4 days in 4.5 deg FOV

4. Gravitational Wave Follow-up

VHE prospects:

- short GRB on-beam (prompt or) afterglow cf. GRB 090510
- short GRB off-beam “orphan” afterglow?
- merger ejecta + CBM interaction?

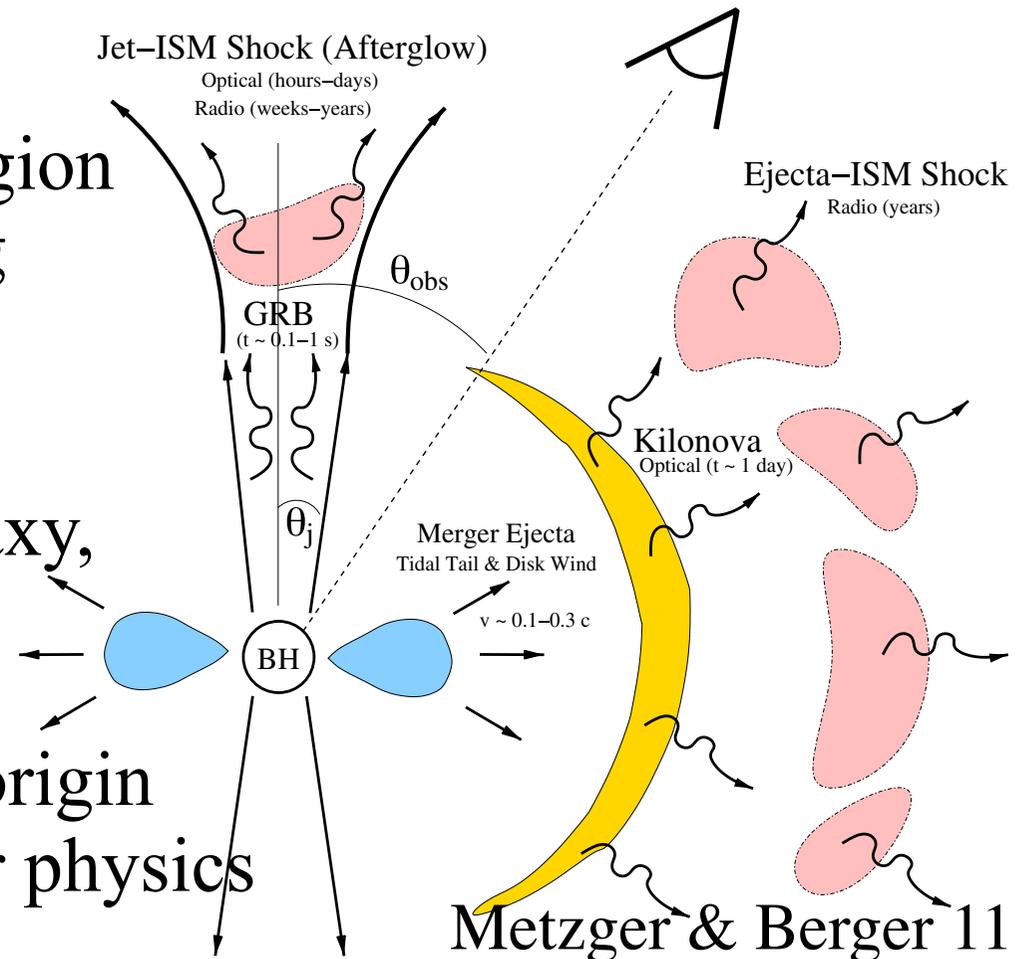
potential “prompt” component from fastest part of ejecta

c.f. Kyutoku+ 14

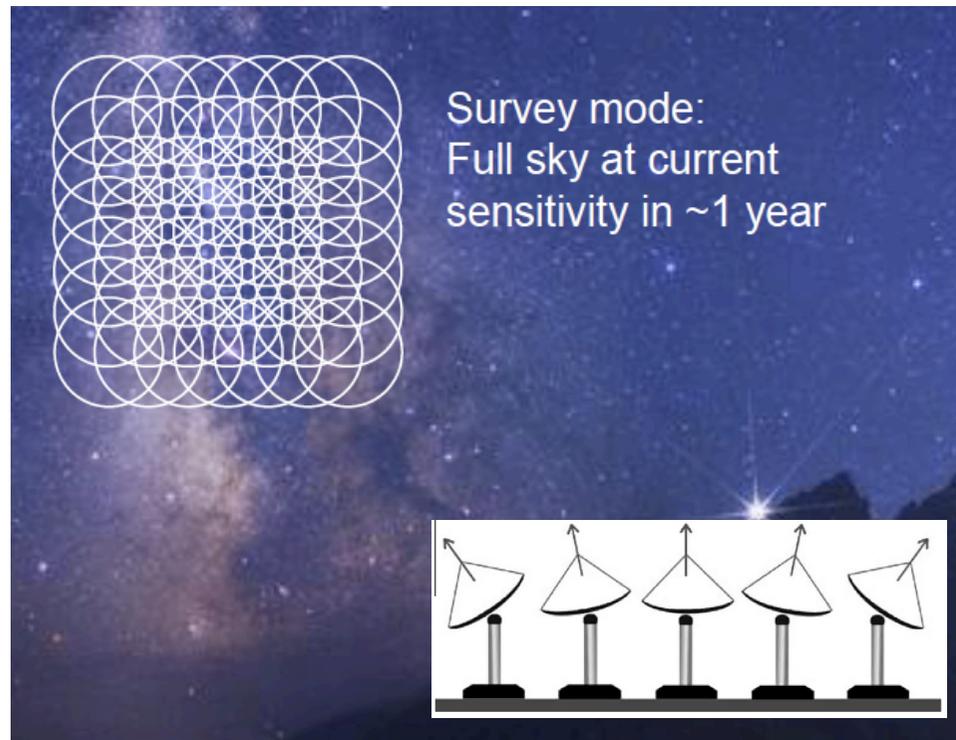
efficient scan of large error region
via tiling or divergent pointing
Bartos+ 13

detection of

- any emission: ID of host galaxy,
distance (less confusion
than other freq.)
- on-beam: test of short GRB origin
- off-beam: insight into merger physics



5. transient survey via divergent pointing



- 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 $\sim 1000/\text{yr}$ (BAT+GBM)

FRBs: all sky $\sim 6000/\text{dy}$

IF FoV $\sim 300 \text{ deg}^2 \rightarrow$

$\sim 8 \text{ GRBs}/\text{yr} \rightarrow \sim 1 \text{ GRBs} / 1000 \text{ hr}$

$\sim 45 \text{ FRBs}/\text{dy} \rightarrow \sim 2 \text{ FRBs} / 1 \text{ hr}$

summary Transients with CTA

crucial advantages over Fermi, current IACTs

- large effective area
- all sky coverage, versatile pointing, real-time analysis...

Exciting new prospects for:

- GRBs: prompt - detailed spectra, light curves...
afterglow - new components beyond sync.
- FRBs: test of origin(s)
- GW: localization, SGRB/FRB connection, merger physics...
- unbiased transient search via divergent pointing
- others: neutrinos, Galactic transients, etc...

Transients are most valuable for CTA Japan!

GRBの絶ゆ光 諸行無常の兆しあり...

VHE prospects for FRBs 2

- NS merger progenitor -> similar to prospects for GWs

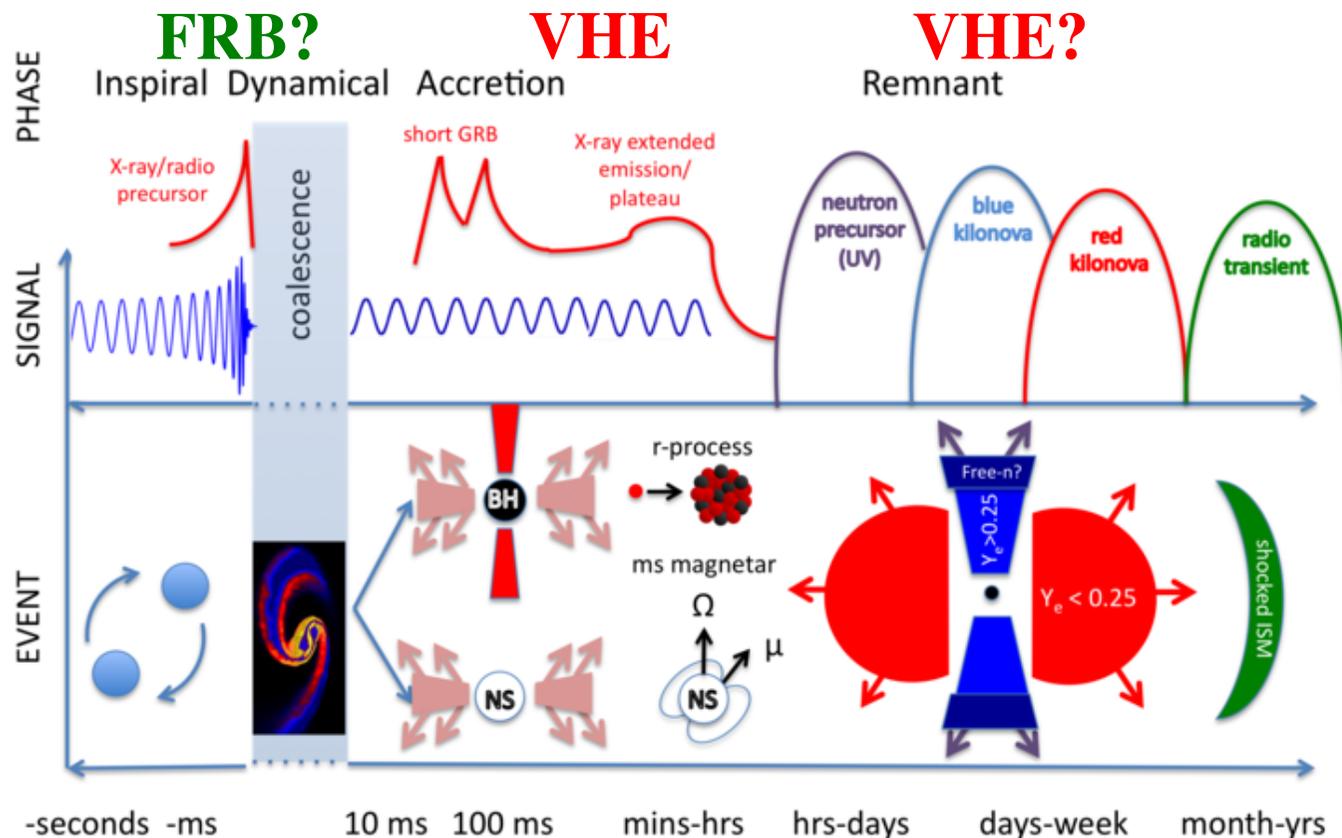
FRB: quasi-isotropic coherent emission from NS magnetosphere, etc
 e.g. Totani 13, Falcke & Rezzolla 13

VHE: short GRB on-beam prompt+afterglow cf. GRB 090510

short GRB off-beam “orphan” afterglow?

merger ejecta + ext. medium interaction?

-> follow-up of FRB alerts (currently Parkes, future CHIME, FAST...)



from
 Fernandez &
 Metzger 16