Transient observations in the VHE gamma-ray band by MAGIC/CTA and Cherenkov Telescopes
(MAGIC/CTAなどのチェレンコフ望遠鏡による突発天体の高エネルギーガンマ線観測)

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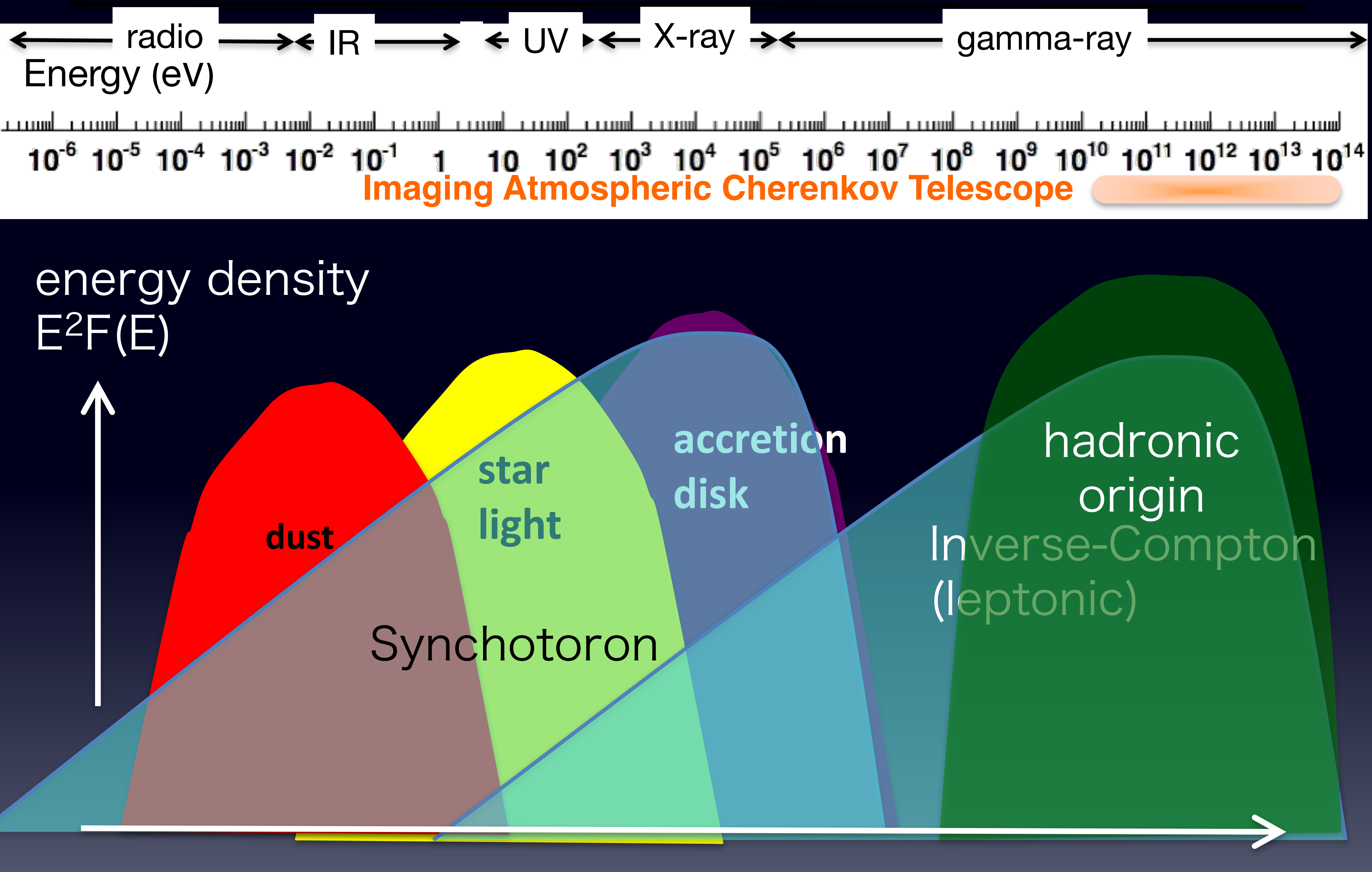
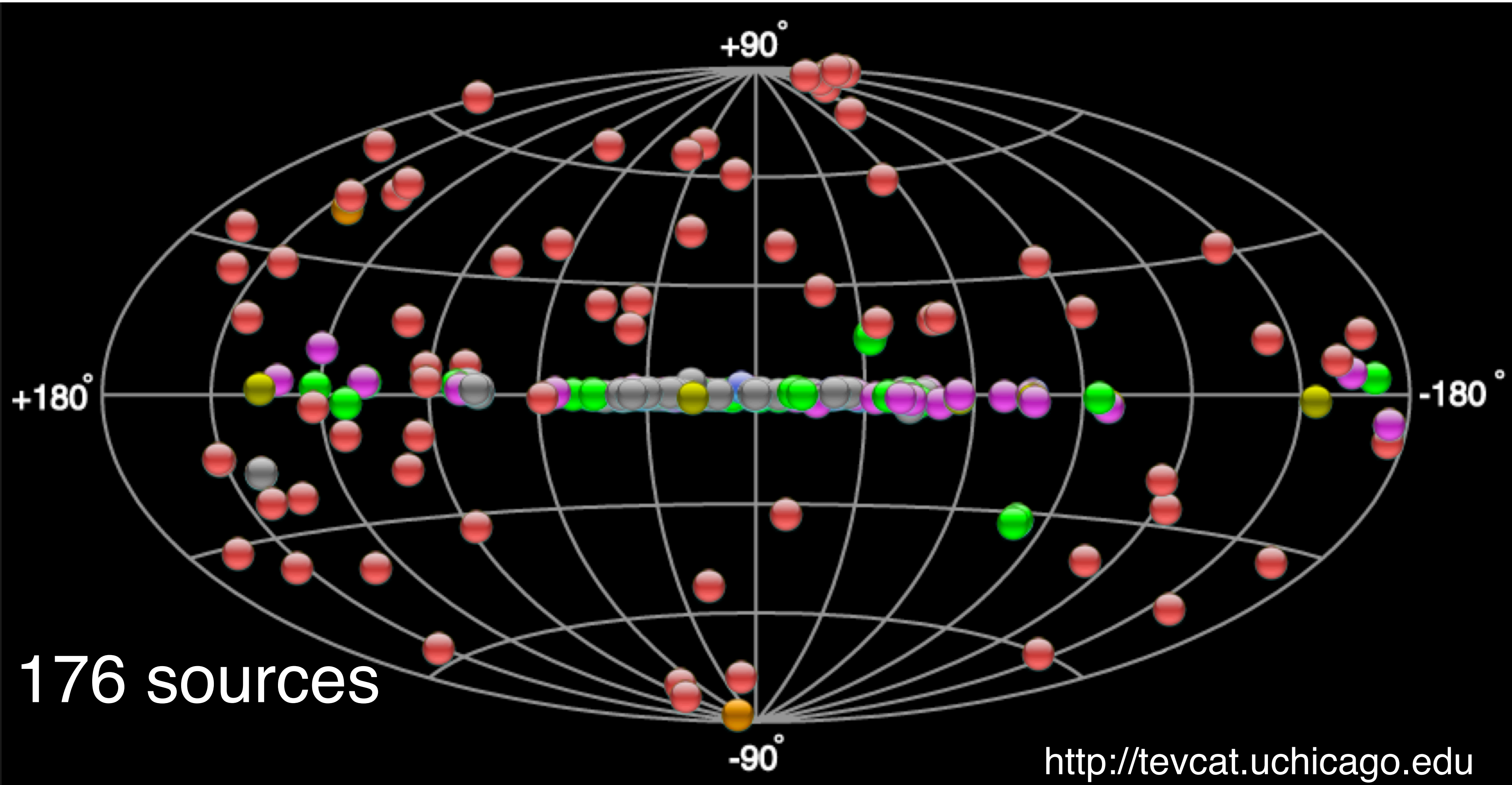
Outline of this talk

1. Very-high-energy gamma-ray band
   – Imaging Atmospheric Cherenkov Telescope
2. Neutrino event follow-up (all IACTs)
3. GRB observations (MAGIC)
4. AGN flare observations (MAGIC)
5. CTA status and plan for transient observations

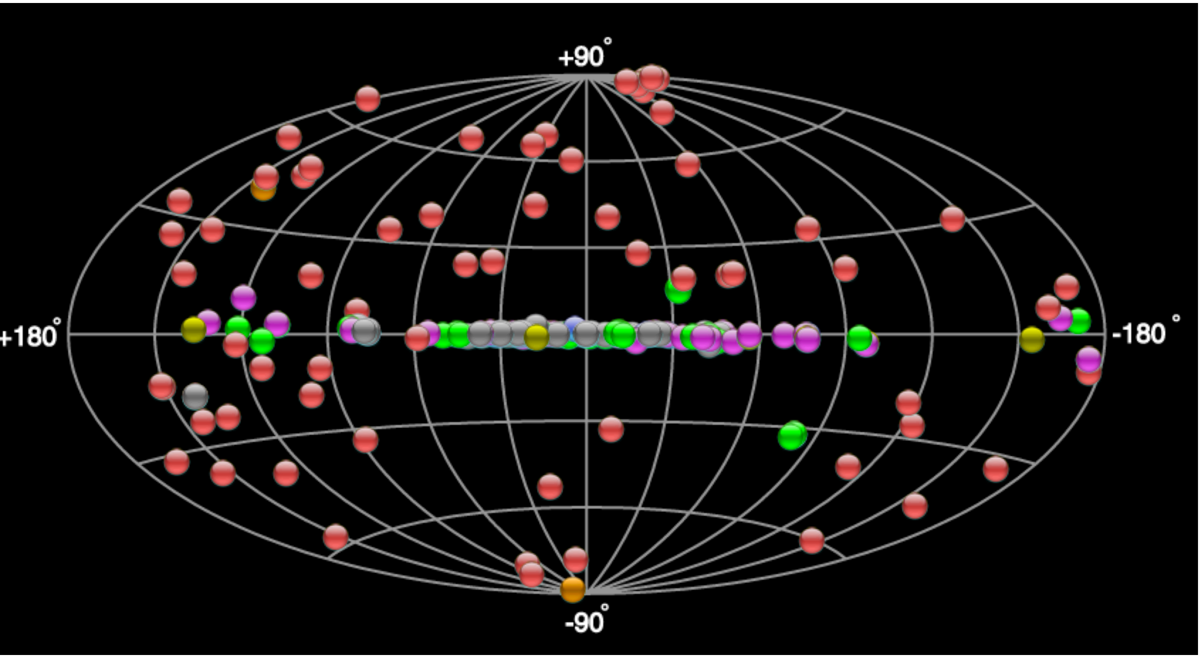
Very-high-energy gamma-ray band



TeV (>100 GeV) gamma-ray sky

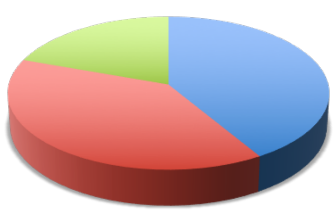


TeV (>100 GeV) gamma-ray sky

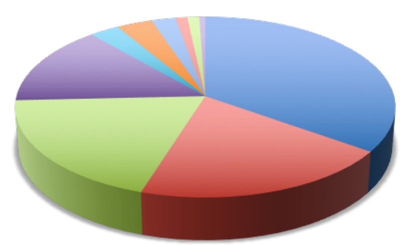


Galactic	**69**	
- SNR		23
- PWN		33
- PSR		2
- Binary		6
- Clusters		5
Extragal.	**72**	
- LMC		3
- Blazer		63
- FRI		4
- Starburst gal.		2
UNID	**35**	
Total	**176**	

Gal/Extragal.

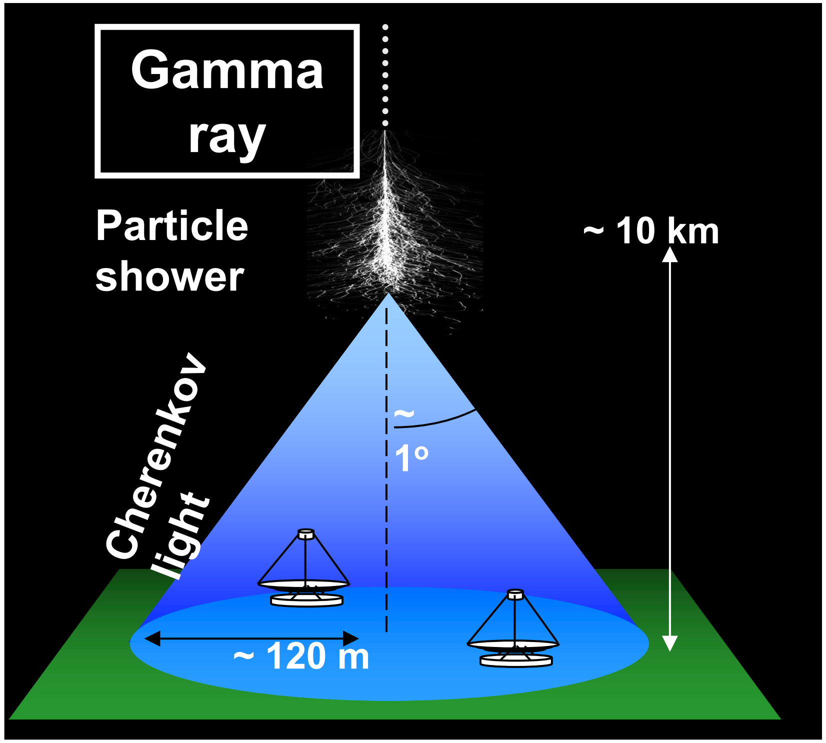


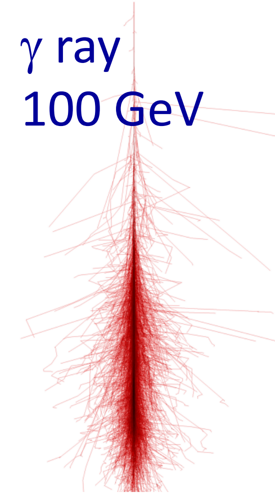
Source Class

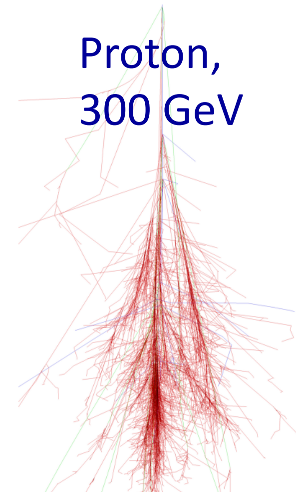


40% Extragal. 40% Galactic + 20% UNID

Detection of E>100 GeV γ-rays







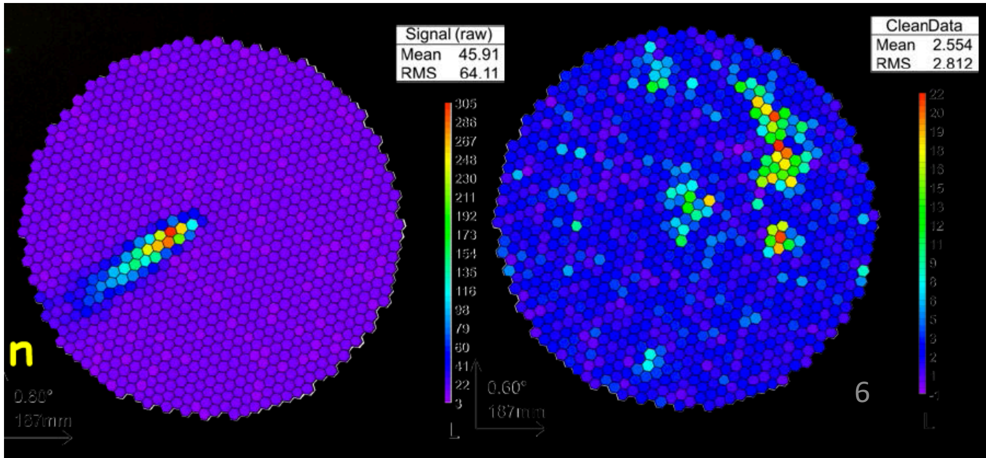
γ showers

- Narrow images
- Aligned towards source direction

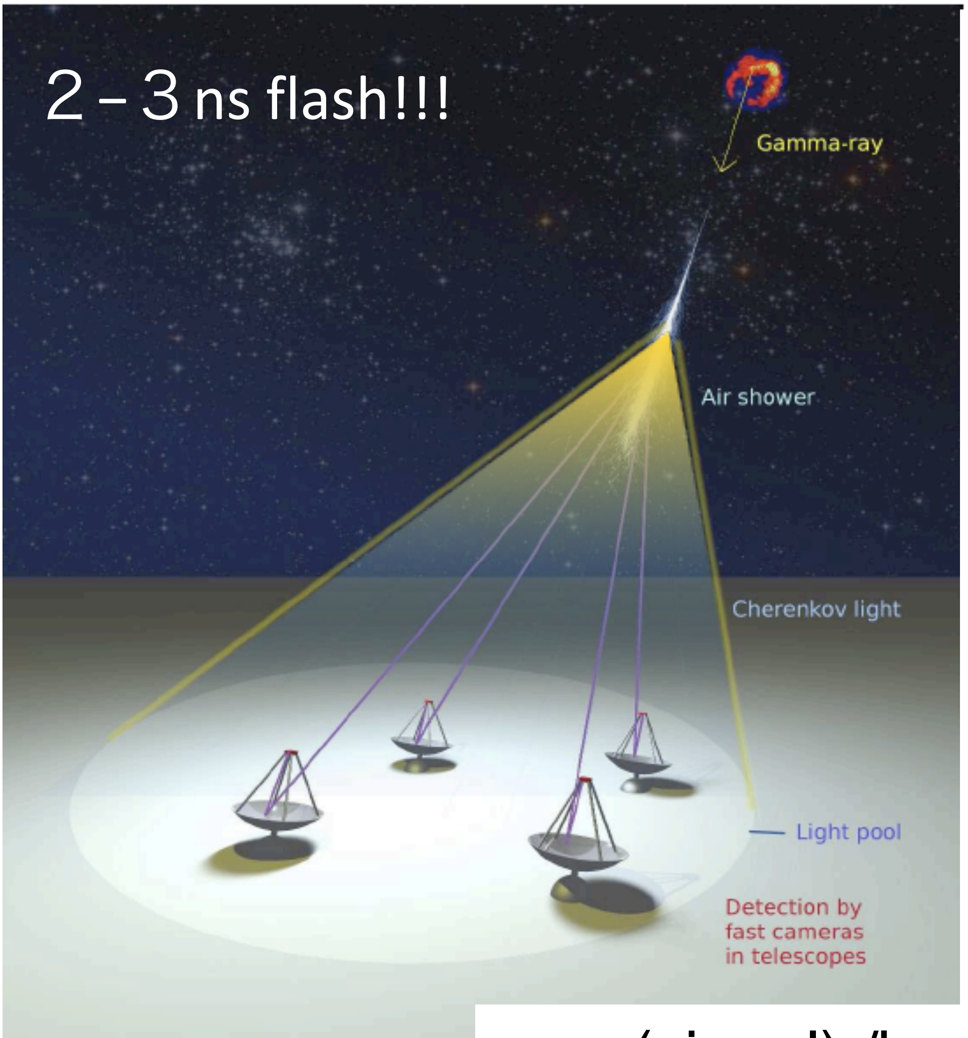
hadronic showers

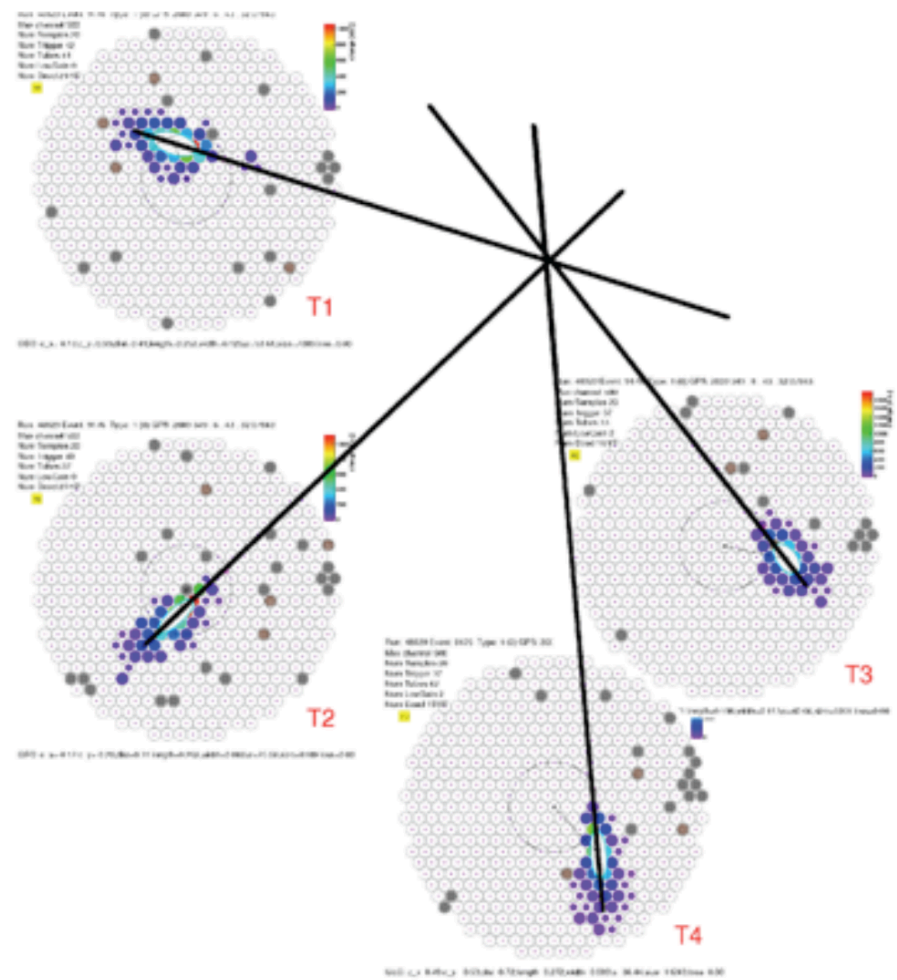
- Spread images
- Isotropic arrival direction

- **Cherenkov light** is emitted by relativistic particles in the shower
- **number of hadron/gamma more than 1000 times**
  -> need to reject hadron events



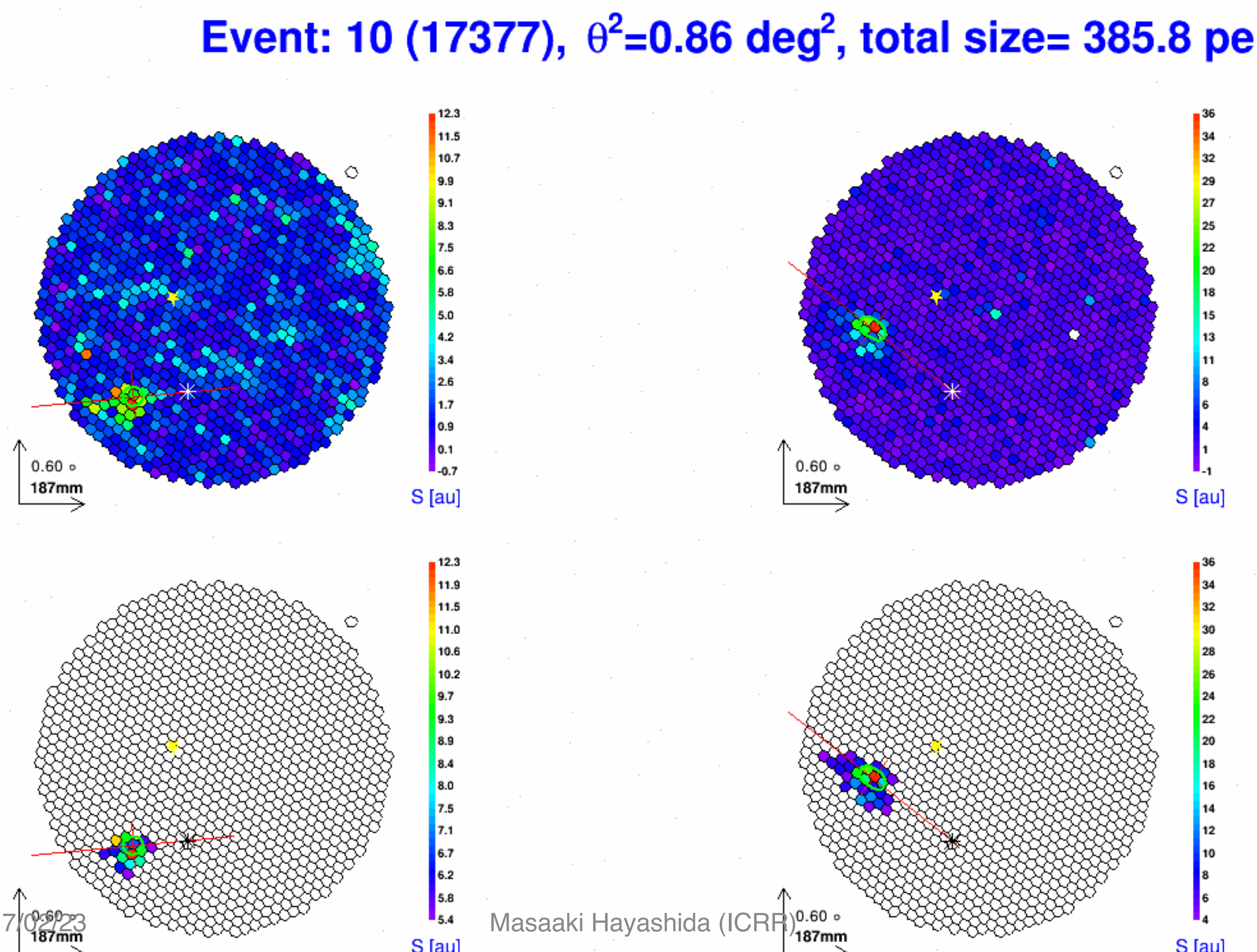
Stereo observations



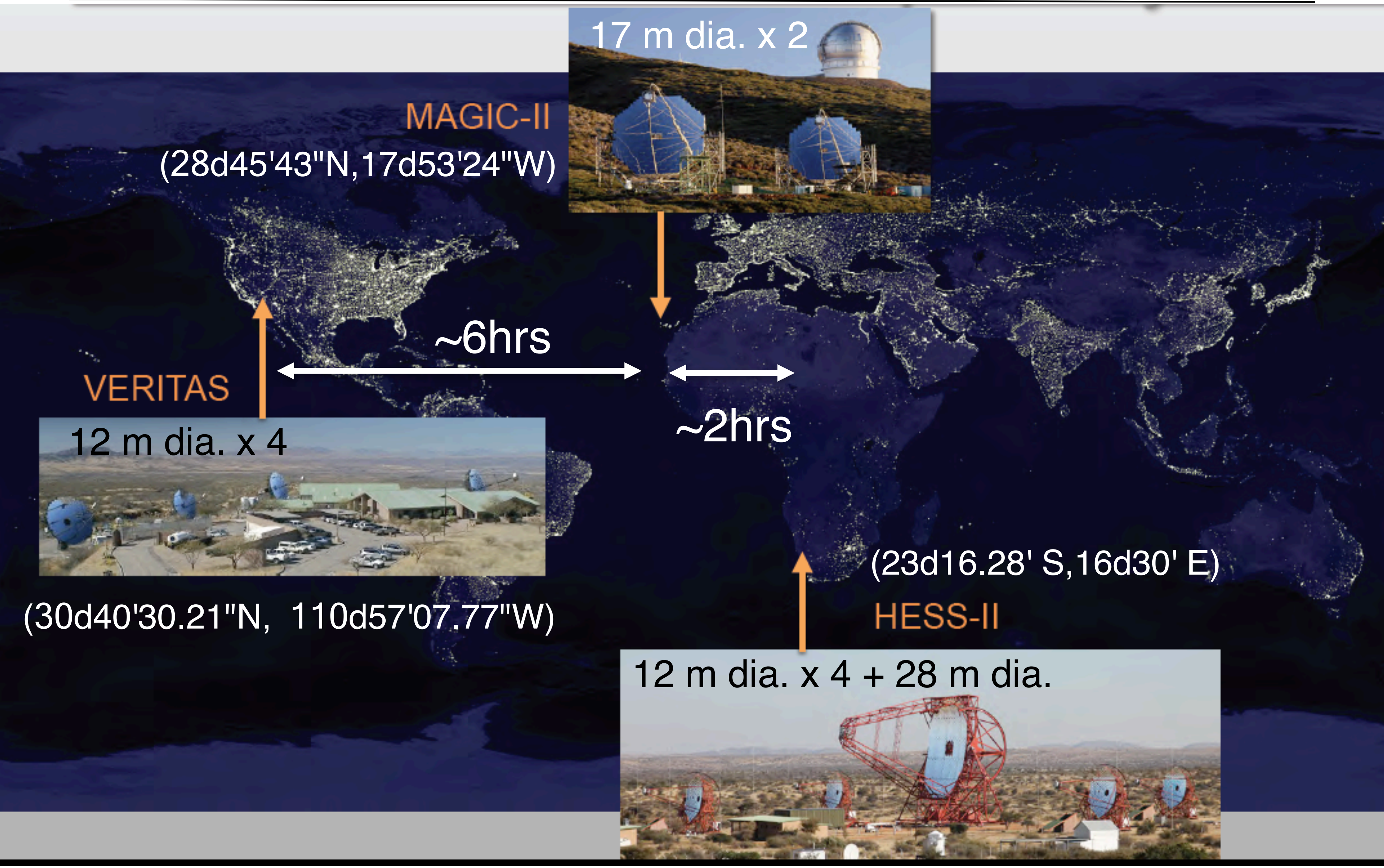


γ-ray(signal) /hadron (background) > 1000

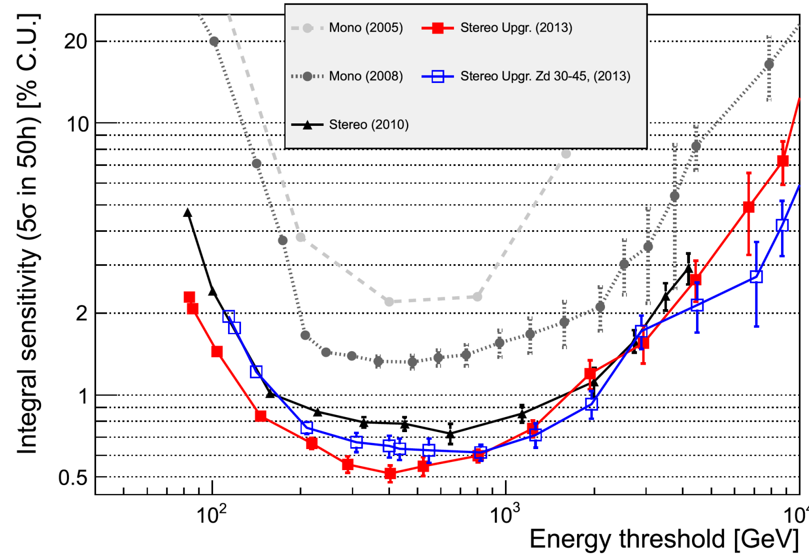
event (real) display (MAGIC)



IACTs in currently operation



The MAGIC telescopes



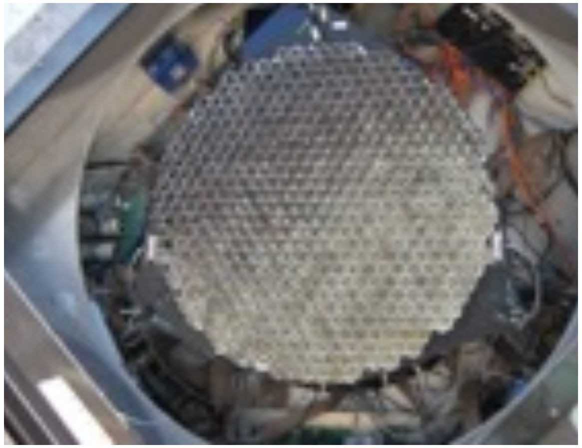
- **observational performance:** (Aleksic+16, APh)
  - Energy threshold (trigger): 50 GeV (LZA), 100 GeV (at 40°)
  - Energy resolution: 15% - 23 % (LZA: low zenith angle)
  - Angular resolution: 0.05° (>1 TeV), 0.09° (> 90 GeV)
  - Sensitivity : 0.67±0.04% C.U. (at 290 GeV LZA) [50 hr obs.]

Crab. Unit (@290GeV) ~10^{-10} cm^{-2} s^{-1}

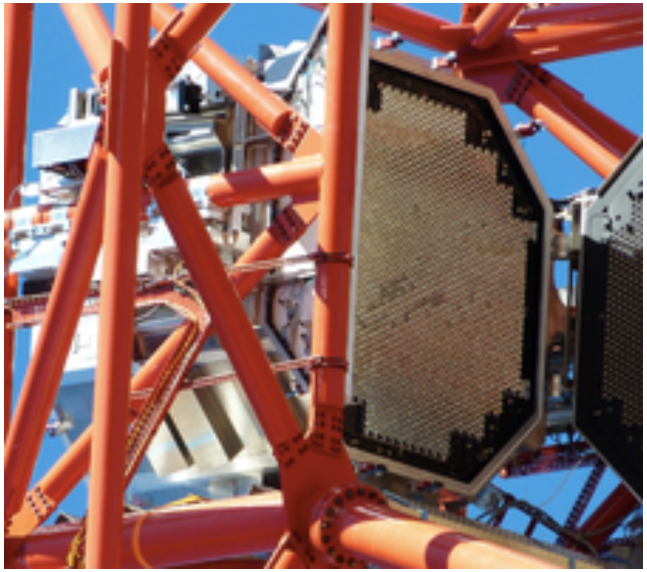
Camera Field of View (FoV)

MAGIC: ~3.5deg

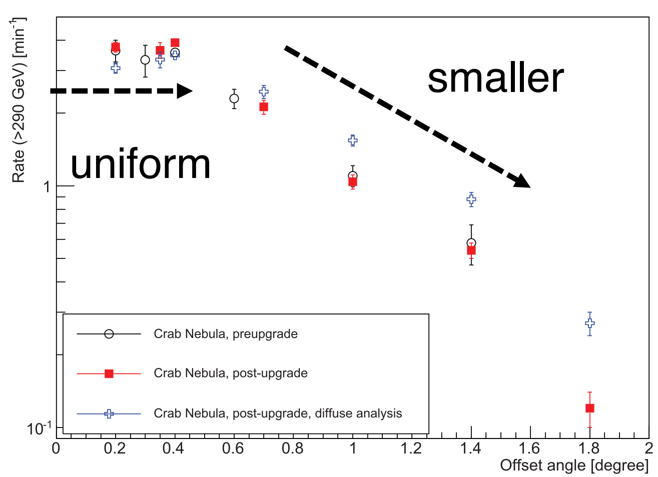
VERITAS: ~ 3.5deg



HESS: ~5deg



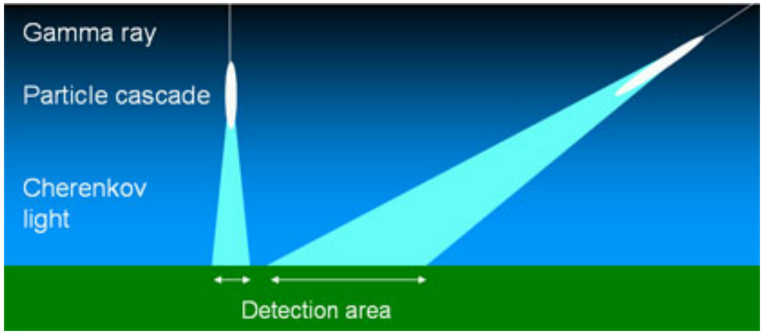
Acceptance on camera (MAGIC)



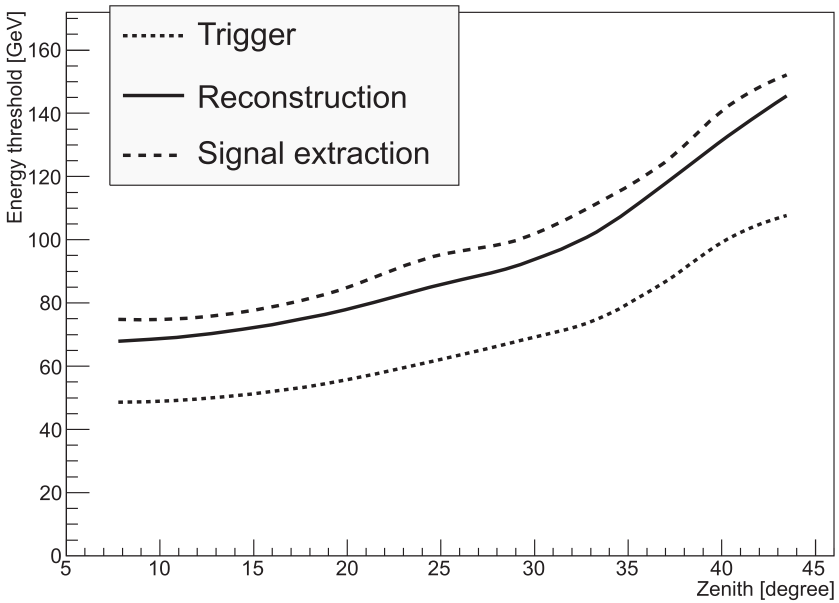
off-axis

Zenith angle dependences

- observing energy range (energy threshold: E_{th}) has dependency on zenith angle (zd)

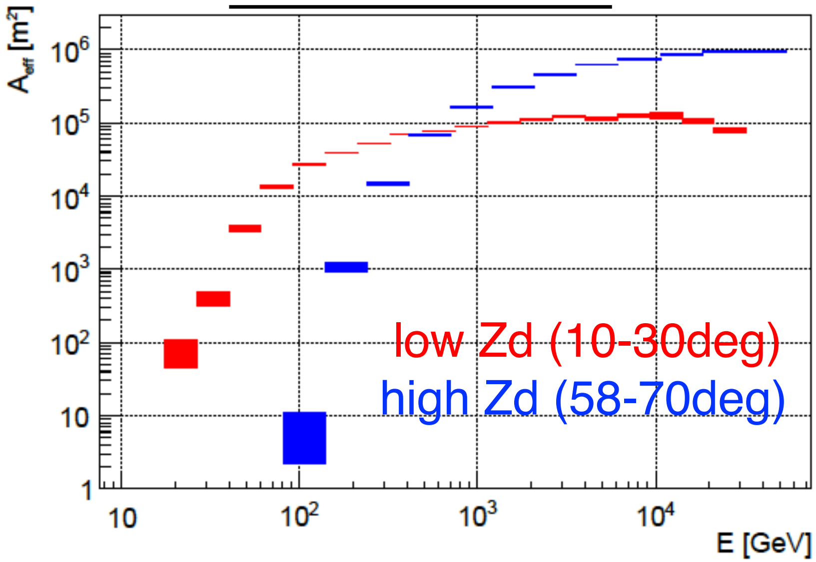


higher E_{th}

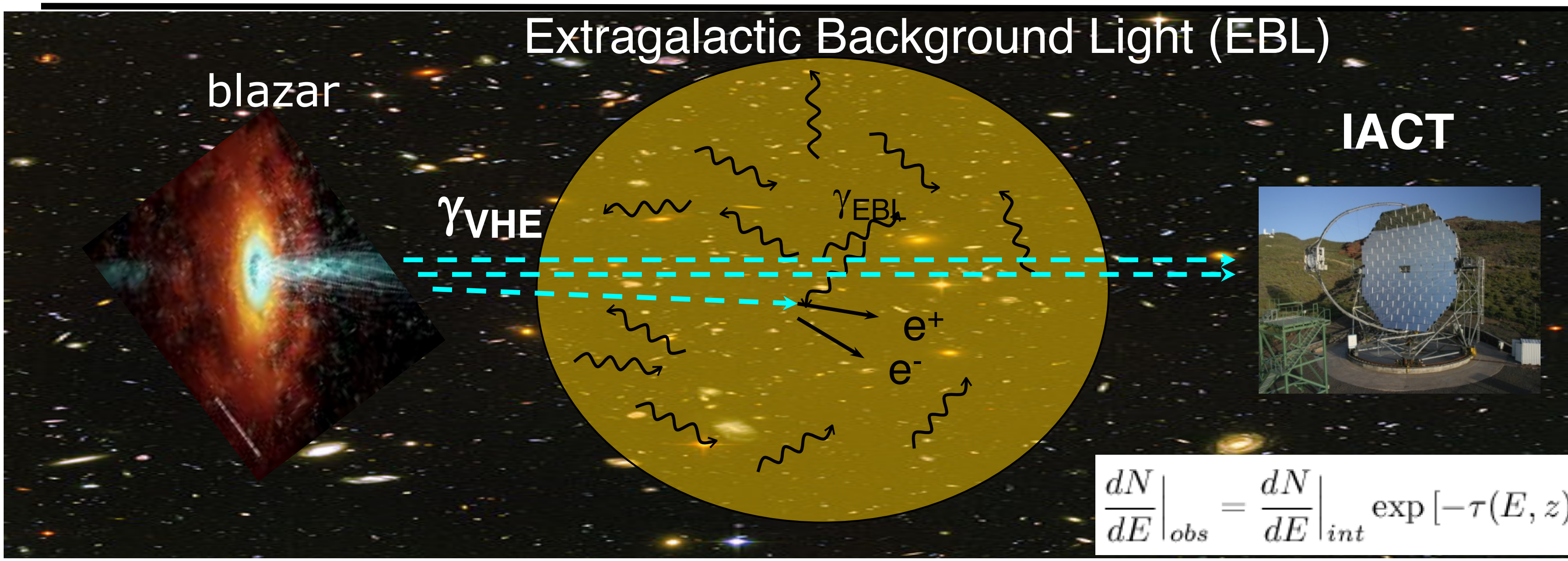


higher zenith angle

effective area



Gamma rays absorbed by EBL



$\gamma + \gamma_{EBL} \rightarrow e^+ + e^-$

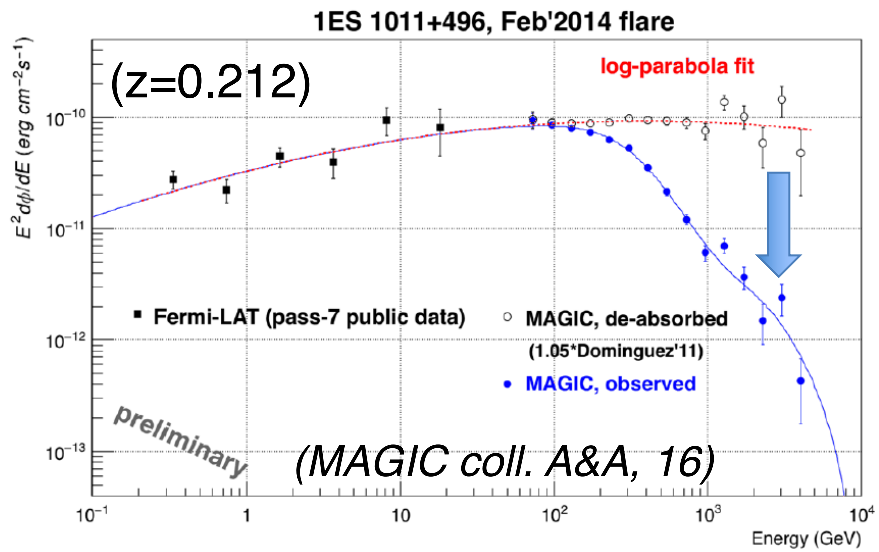
threshold condition: $E\,\varepsilon\,(1-\cos\theta) > 2\,m_e^2 c^4$

Max cross-section:

$\lambda \sim 1.24(E_\gamma/\mathrm{TeV})\ \mu m$ (at 90° interaction)

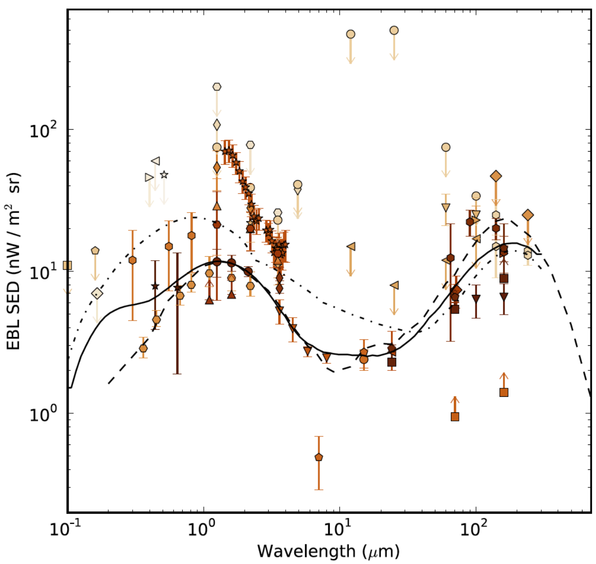
e.g. TeV + IR

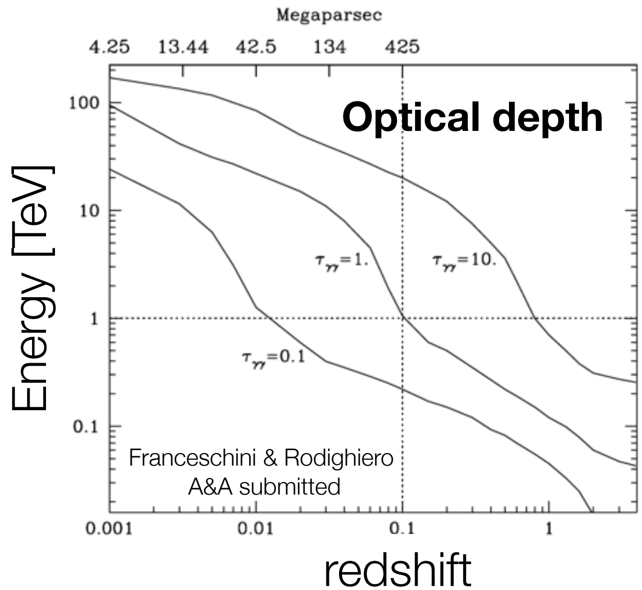
100 GeV + UV



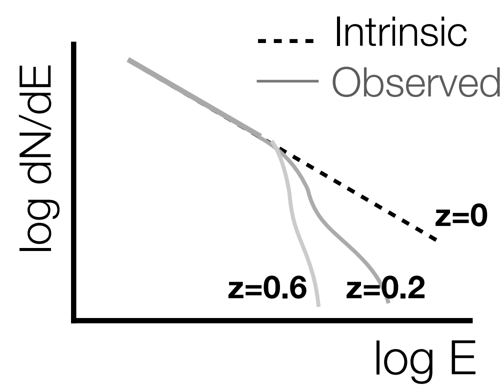
γ-ray attenuation

EBL spectrum





$$dN/dF_{obs} = dN/dF_{int}\ e^{-\tau(z,E)}$$



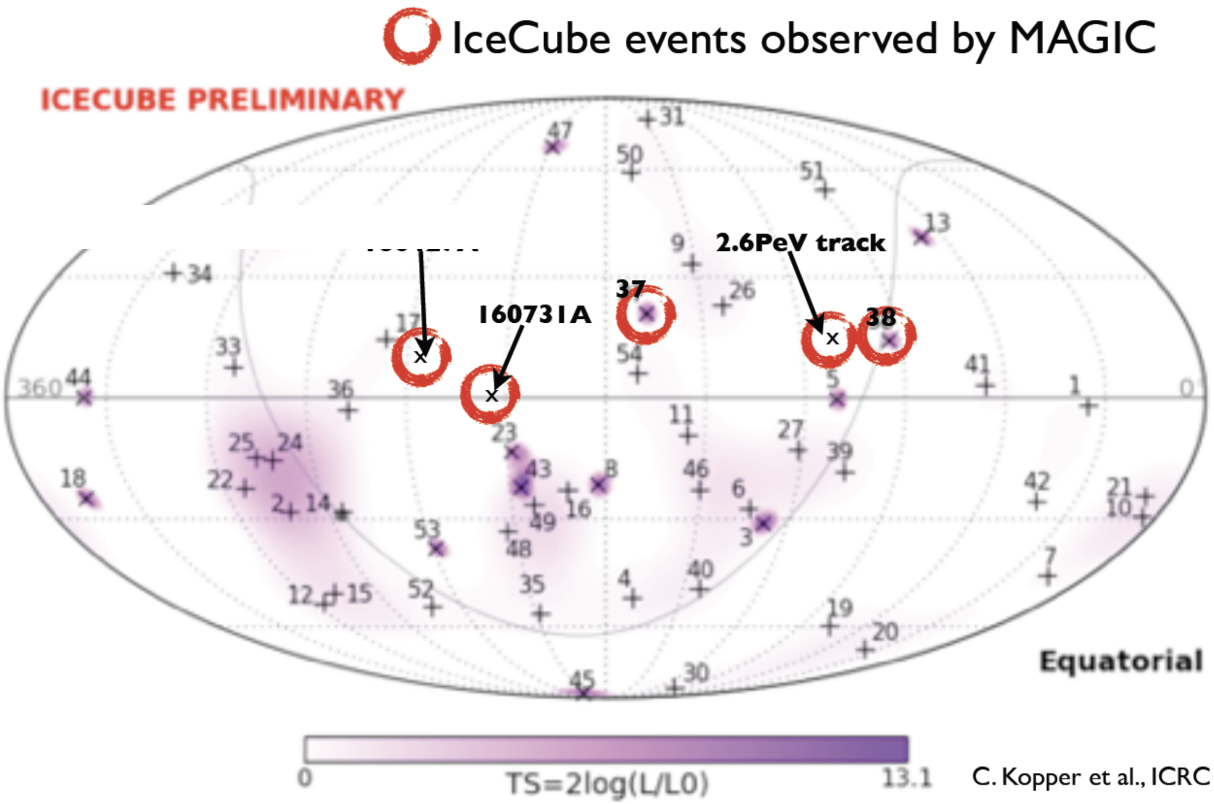
Observation strategy

- Fixed (normal) observations
  - scheduled in period by period
  - time allocation (source selection) once a year
  - time critical observations (MWL campaign, phase)

- ToO observations
  - multi-messenger (ν, GW) alerts
  - GRB alerts
  - multi-wavelength alerts (known sources)

ν event observations by MAGIC

3 ”archival” events + 2 real time alters

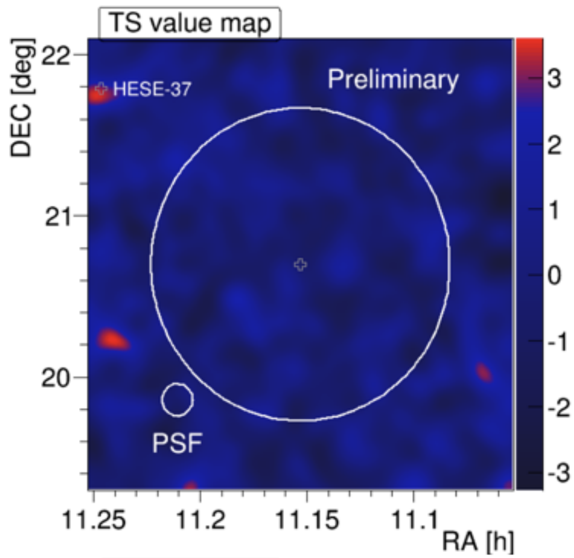


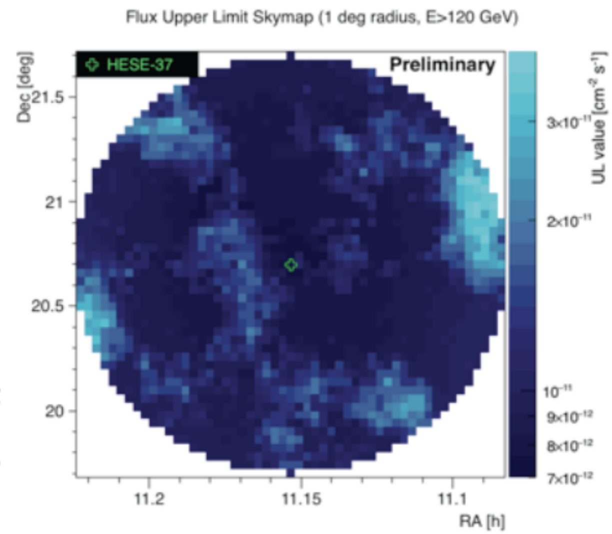
C. Kopper et al., ICRC 2015

Archival HESE events by MAGIC

HESE-37

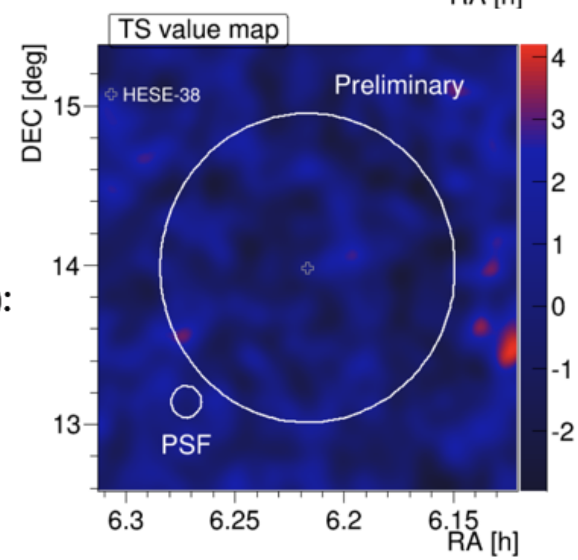
★7.5 h in Jan/Feb 2016
★ zenith 8 -30 deg
★ E > 120 GeV
★ Flux UL (95% C.L., a=2.3):
(0.7- 4.0) x 10^{-11} $cm^{-2}s^{-1}$
(~1-10% C.U.)

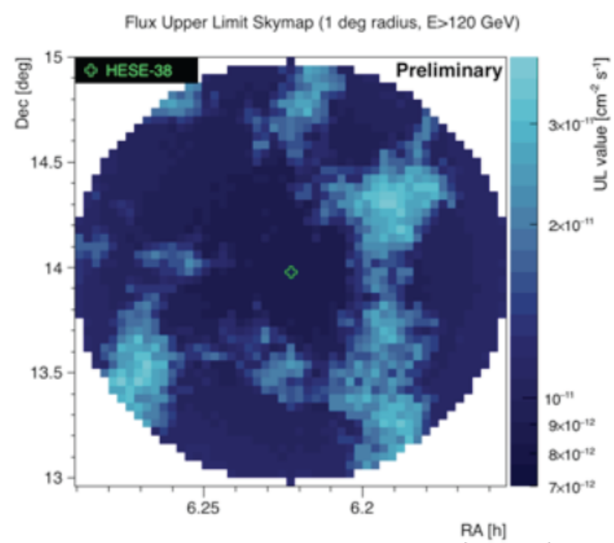




HESE-38

★ 5.7 h in Feb/Mar 2016
★ zenith 15 -50 deg
★ E > 120 GeV
★ Flux UL (95% C.L., a=2.3):
(0.9- 3.9) x 10^{-11} $cm^{-2}s^{-1}$
(~2-10% C.U.)



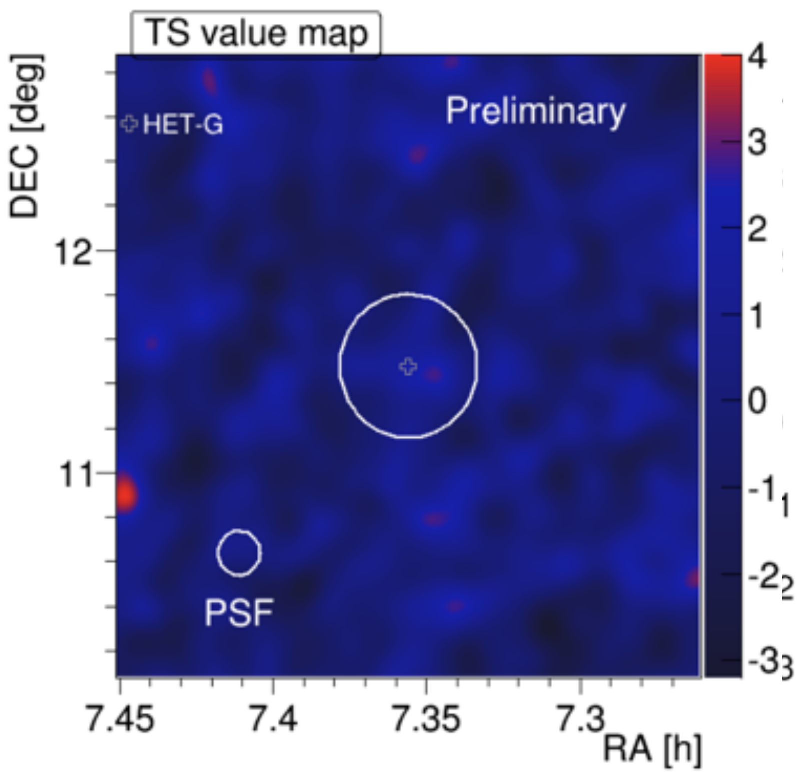


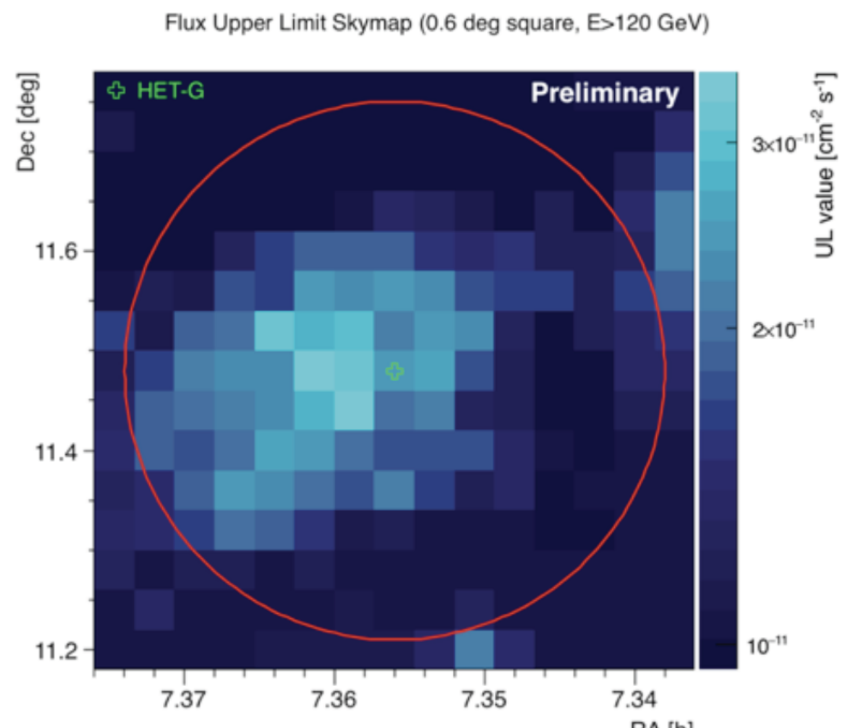
Satalecka@AMON16

(archival) multi-PeV track (Atel#7856)

detected on 2014 June 11
2.6+/-0.3 PeV
reported on 2015 July 29

- ★ 5 h observations in March 2016
- ★ zenith 21 -38 deg
- ★ E > 120 GeV
- ★ Flux UL (95% C.L., a=2.3): (0.9- 3.5) x 10^{-11} cm $^{-2}$s $^{-1}$ (~2-10% C.U.)



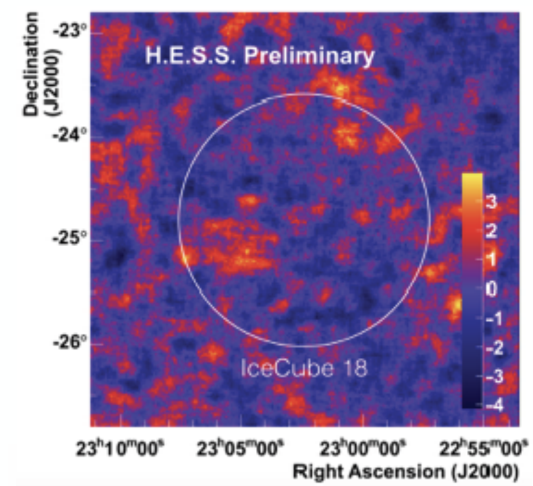


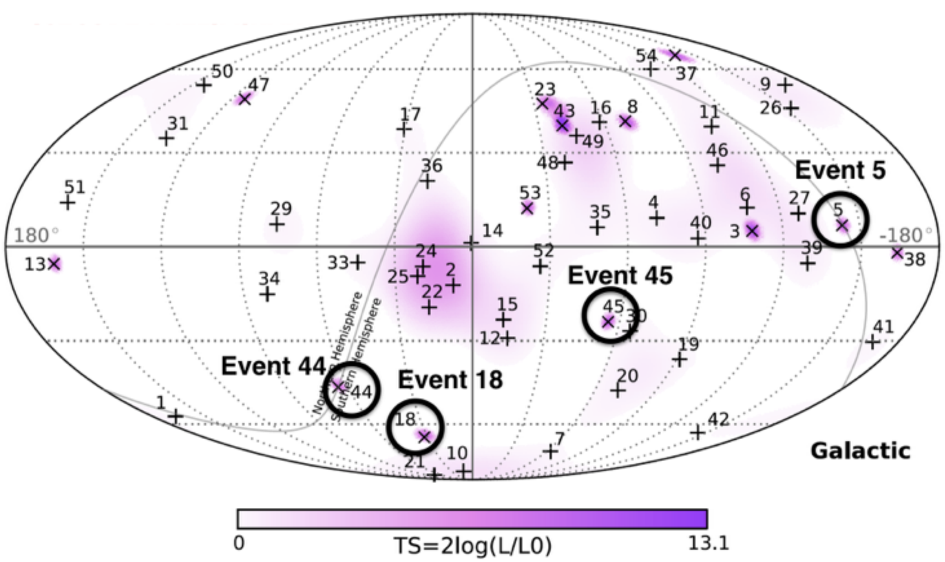
Satalecka@AMON16

Archival HESE events by H.E.S.S.

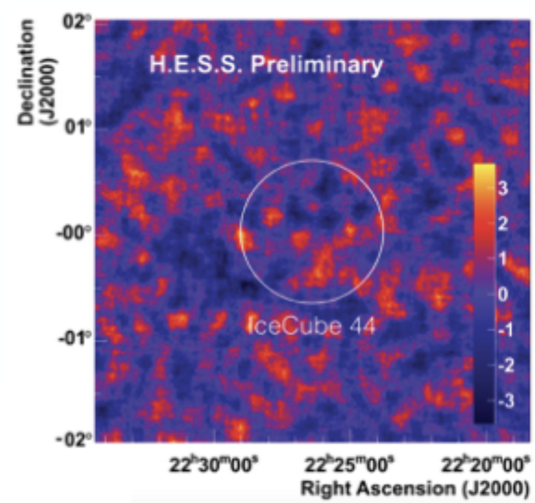
- Track like events
- angular uncertainty < FOV
- southern source

■ IceCube 18





■ IceCube 44



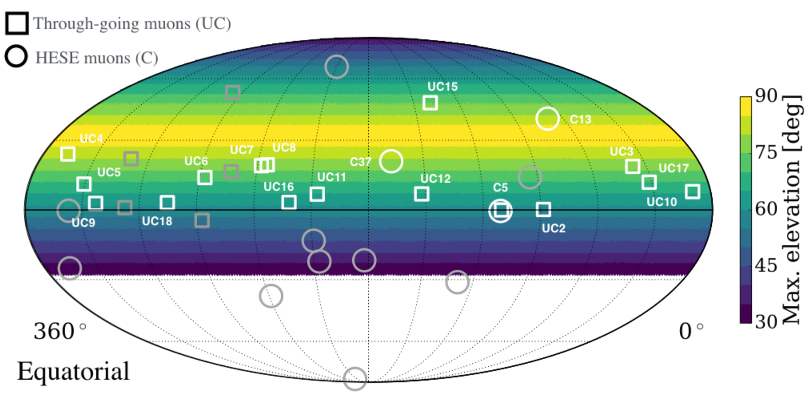
no significant excess

Schuessler@AMON16

Archival ν events by VERITAS

57 hours for 18 events
(3 HESE, 15 through-going track)

Santander+16 (arXIv:1612.0430)



ID	Observation time [min]	UL (99%) [$cm^{-2}\ s^{-1}$]	UL (99%) [C.U.]
C5	180	8.33×10^{-12}	2.3%
C13	574	4.01×10^{-12}	1.1%
C37	275	7.30×10^{-12}	2.0%
UC2	25	2.12×10^{-11}	5.8%
UC3	180	6.31×10^{-12}	1.7%
UC4	122	9.89×10^{-12}	2.7%
UC5	90	6.66×10^{-12}	1.8%
UC6	25	9.53×10^{-12}	2.6%
UC7	15	3.96×10^{-11}	10.9%
UC8	60	9.31×10^{-12}	2.6%
UC9	40	1.52×10^{-11}	4.2%
UC10	90	9.40×10^{-12}	2.6%
UC11	209	4.4×10^{-12}	1.2%
UC12	25	9.53×10^{-12}	2.6%
UC15	90	7.40×10^{-12}	2.0%
UC16	40	8.57×10^{-12}	2.4%
UC17	150	4.41×10^{-12}	1.2%
UC19	210	3.92×10^{-12}	1.1%

no significant excess

3-10 hours for each HESE (C) events
and UL of 1-2 % Crab (>100 GeV)

Alert-1 : 1st HESE

2016-04-27 05:52:32 UTC (the first GCN event: HESE)

1st notice: 05:53:53 UT

- RA=239.66deg, Dec=+6.85deg (8.9deg@90%, 1.6@deg50%)
- **VERITAS** observed it from 05:55:45 UTC for 71 min

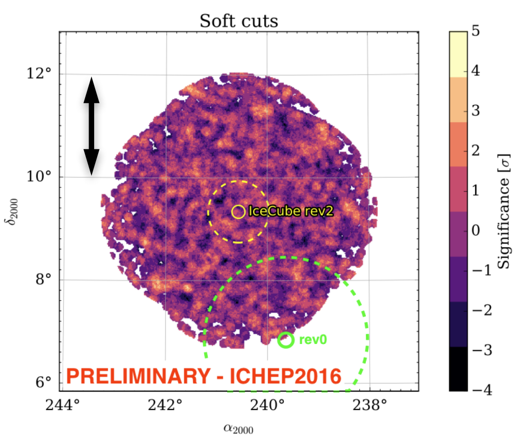
2nd notice: 23:24:24 UT, a refined position (offline analysis)

- RA=240.57deg, Dec=+9.34deg (0.6deg@90%)
- **VERITAS** observed it on the next night (28th) for 118 min
- **MAGIC** observed for ~2 h with ~42 hrs delay.

no excess..

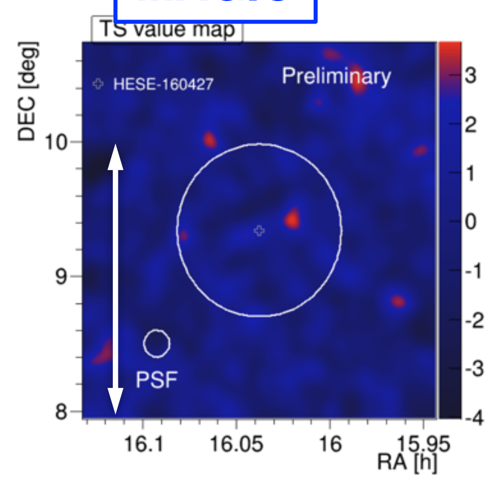
VERITAS

GCN#19377
Santander+16 (arXIv:1612.0430)



UL: 5.7e-11 (cm^{-2} s^{-1} TeV^{-1}) at 0.2- 0.28 TeV at position of the refined ν event

MAGIC



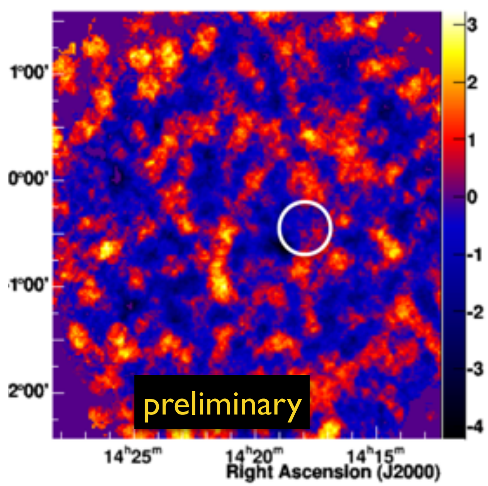
Zd: 18-26deg
Eth: ~ 120 GeV

Alert-2: 2nd HESE/1st EHE

2016-07-31: 01:55:58 UT (the 2nd GCN alert) from both HESE and EHE (the 1st EHE alert)

- Initial HESE pos. = 215.11deg, Dec = -0.46deg
- Initial EHE pos.   = 215.09deg, Dec = -0.42deg
- Not visible at the time of alert. Observed in the next night.
- **H.E.S.S.** for ~1 hr,   **MAGIC:** 1.3 hrs (started 21:25 UT.),
- Refined postion: RA=214.544deg, Dec:-0.335deg (@Aug 1, 02:35:54 UT)

H.E.S.S. Atel#9301
Schuessler@AMON16



Zd>45deg

MAGIC Atel#9315

- Zd:45-65deg
- E_{th}: ~ 600 GeV
- no significant excess

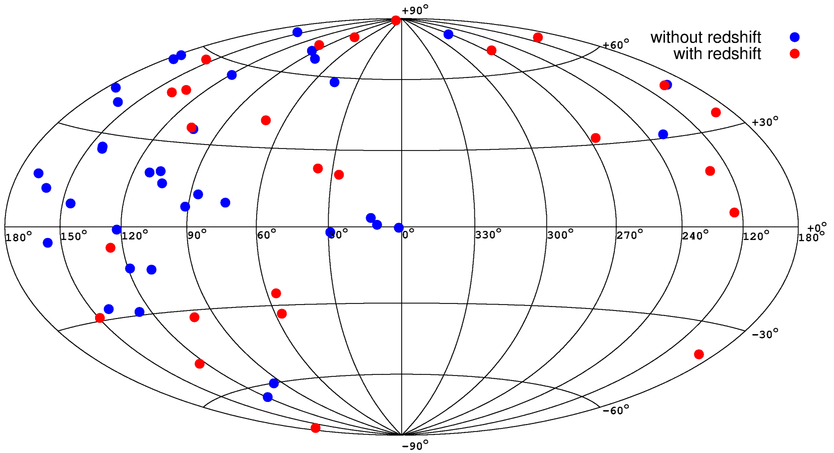
no excess..

(**VERITAS** can not be operational during summer)

GRB observations with MAGIC

- Dedicated alert system from GCN
- Automatic response (upgraded in 2013)
  - Zenith < 60˚
  - Moon distance > 30˚
  - Sun zenith > 103˚
- up to 4h of observations after prompt emission
- Fast movement of the telescopes

<Galactic coordinate>



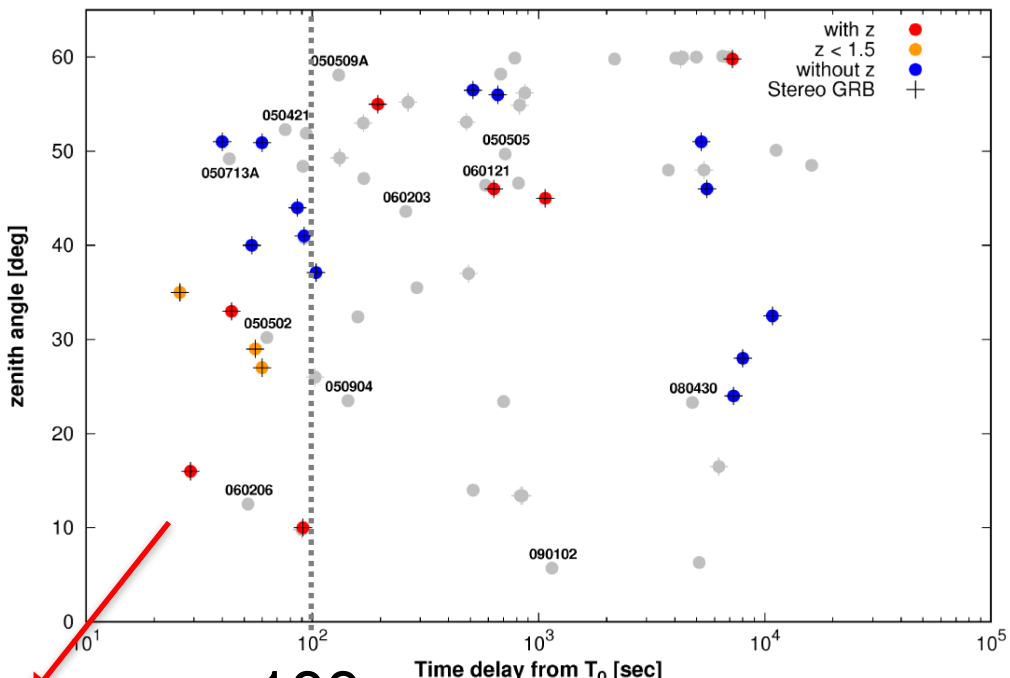
90 GRBs were observed

(since 2005)

GRBs observed with MAGIC

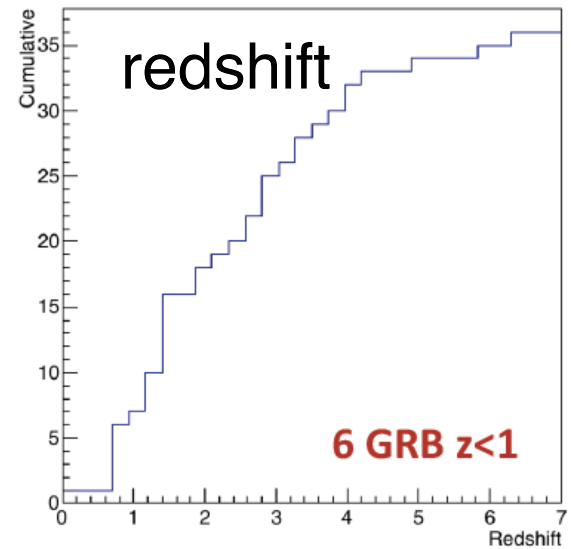
No significant detection until now,,,

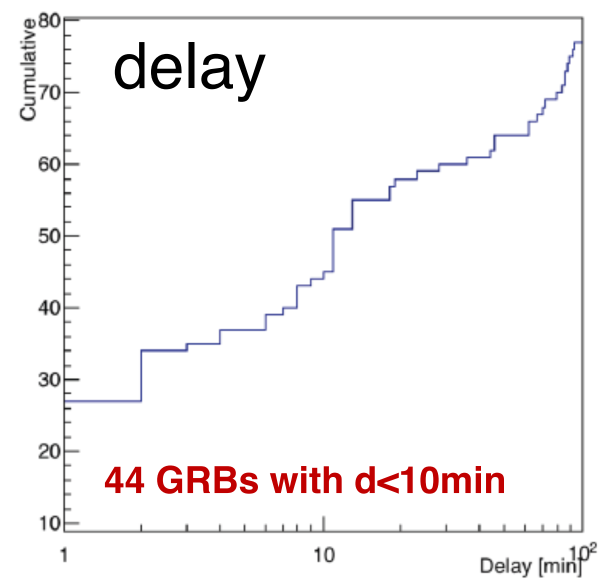
(color: after 2013)



100s

more desirable condition





GRB observation status

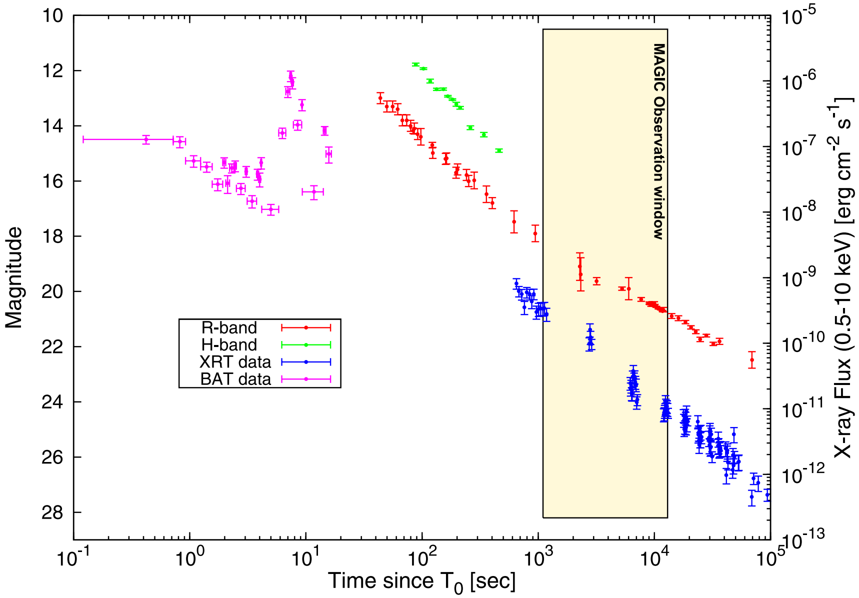
Moretti@Yachay16

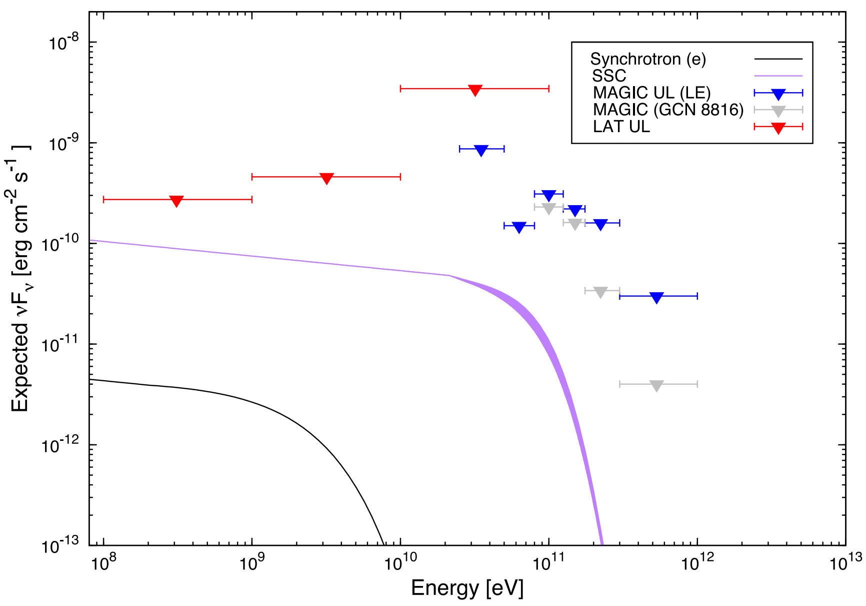
	T_0 [UTC]	T_{90} [sec]	Z	Alert [UTC]	Start [UTC]	Zenith [deg]	Delay [sec]
GRB131030	20:56:19	41	1.3	20:56:34	20:56:45	33-40	26
GRB140430	20:33:36	174	1.60	20:33:51	20:52:06	45-54	1110*
GRB140709	01:13:41	99	-	01:14:02	03:17:15	25-37	7414*
GRB140930	19:41:42	0.8	-	19:42:02	21:10:05	51-18	5243*
GRB141026	02:36:51	146	3.35	02:38:09	02:38:27	10-50	96
GRB141220	06:02:52	7	1.32	06:03:17	06:03:47	28-19	55
GRB150428A	01:30:40	53	-	01:31:43	01:32:10	37-54	90
GRB150428B	03:12:03	131	-	03:12:38	03:13:02	50-27	59
GRB151215	03:01:28	18	-	03:01:46	03:01:57	16-58	29
GRB160119	03:06:08	116	-	03:07:50	03:17:09	56-13	661
GRB160203	02:13:10	20	3.52	02:16:13	02:16:25	55-52	195
GRB160821B	22:29:13	0.5	0.16	22:29:28	22:29:37	34-55	24
GRB160910	17:19:39	-	-	17:20:19	20:21:53	45-70	3734*

GRB 090102 limits from MAGIC

GRB090102 (z=1.547), afterglow observations

ULs both LAT and MAGIC

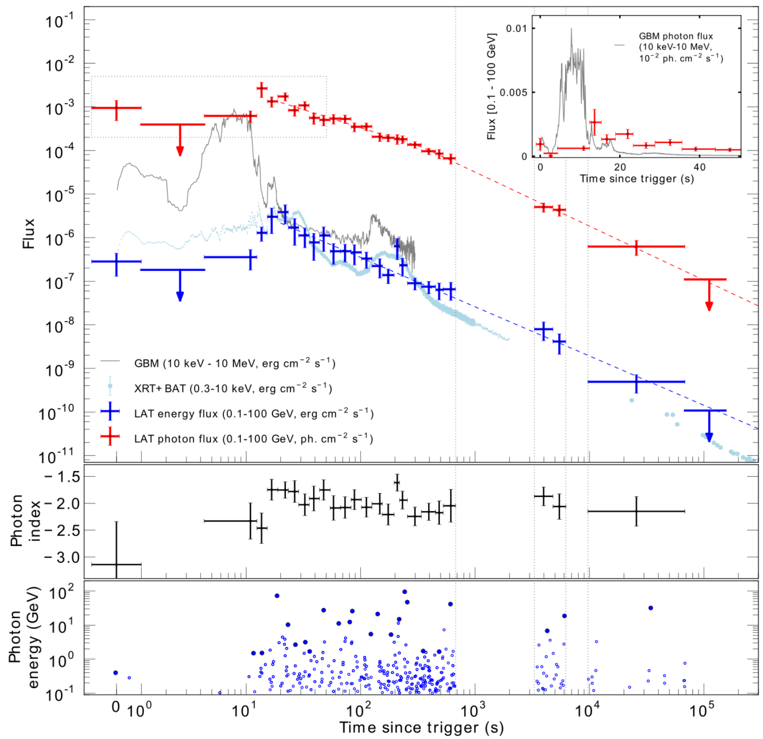




(J. Aleksic et al. (MAGIC Collaboration), 2014, MNRAS, 437, 3103)

GRB: Late time observations

GRB130427A (Ackerman+14)



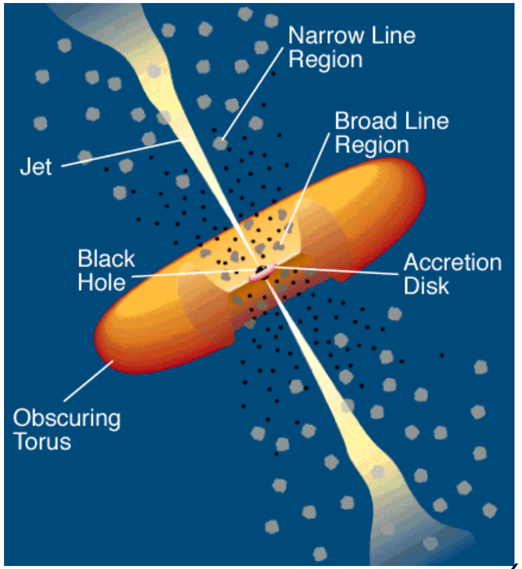
VERITAS observed the source +20h (70ks), +2 days, + 3 days (no detection)

Date	t_{start} (UTC)	t_{end} (UTC)	Exposure (s)	Significance[b] (σ)	Flux UL[c]
2013 Apr 28	03:32:35	04:31:16	2925	1.3	9.4×10^{-12}
2013 Apr 29	03:32:59	05:33:39	5746	1.1	6.6×10^{-12}
2013 Apr 30	03:22:02	06:05:40	7814	−0.5	2.7×10^{-12}
Total			16485	0.9	3.3×10^{-12}

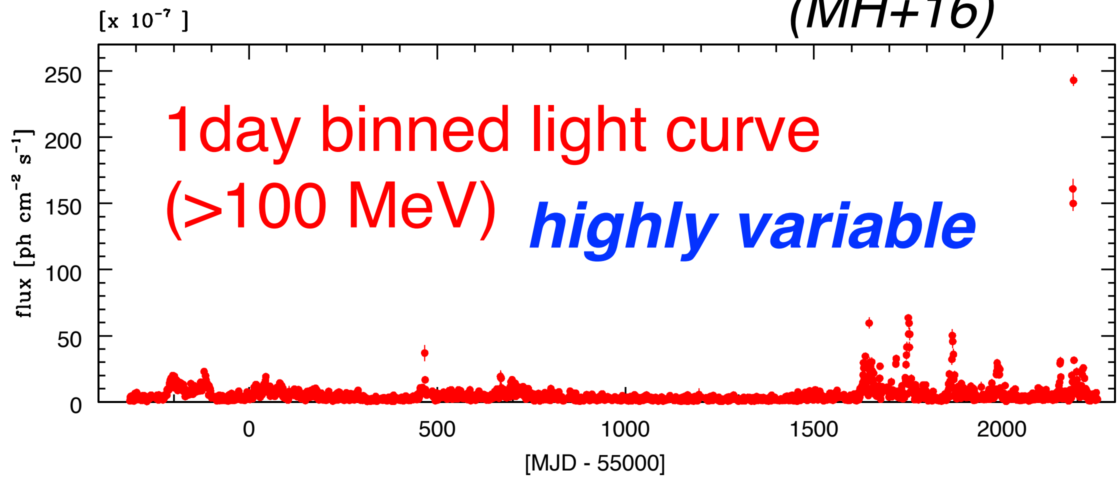
(Aliu+14)

- Many LAT GRBs show late time (delayed) emission in the (early) afterglow phase
- ***GRB observation strategy of MAGIC has been updated to observe events even +2-3 days.***

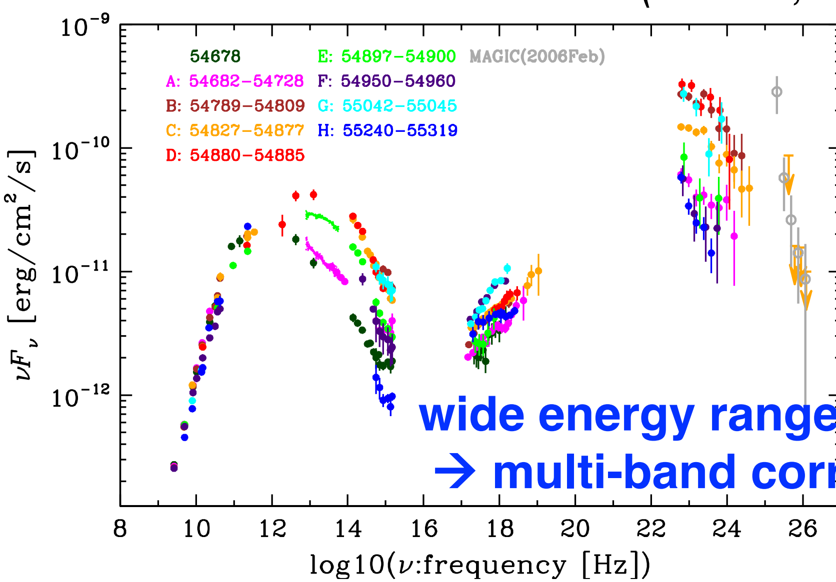
AGN (blazar) flare



(MH+16)



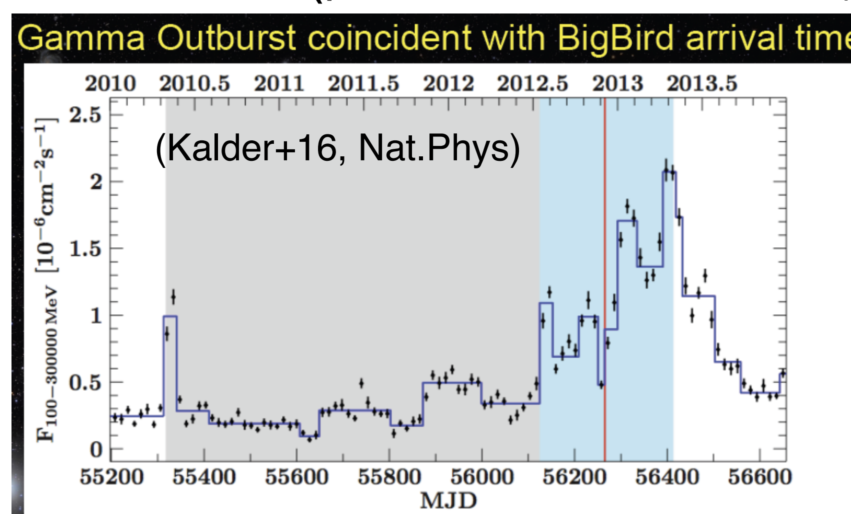
(MH+12, ApJ)



wide energy range

→ multi-band correction

PKS1424-418 (possible ν associations?)

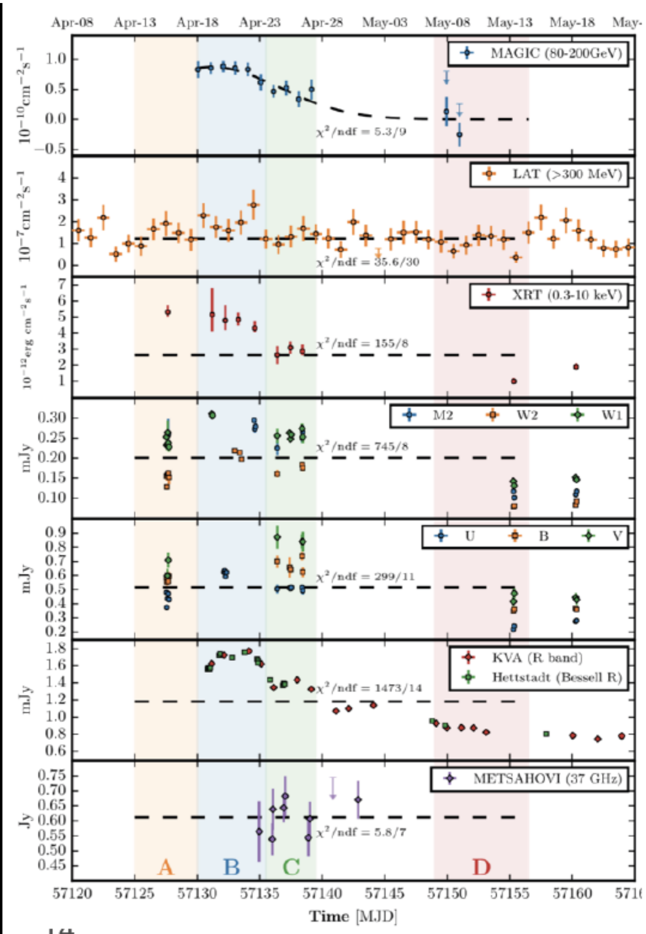


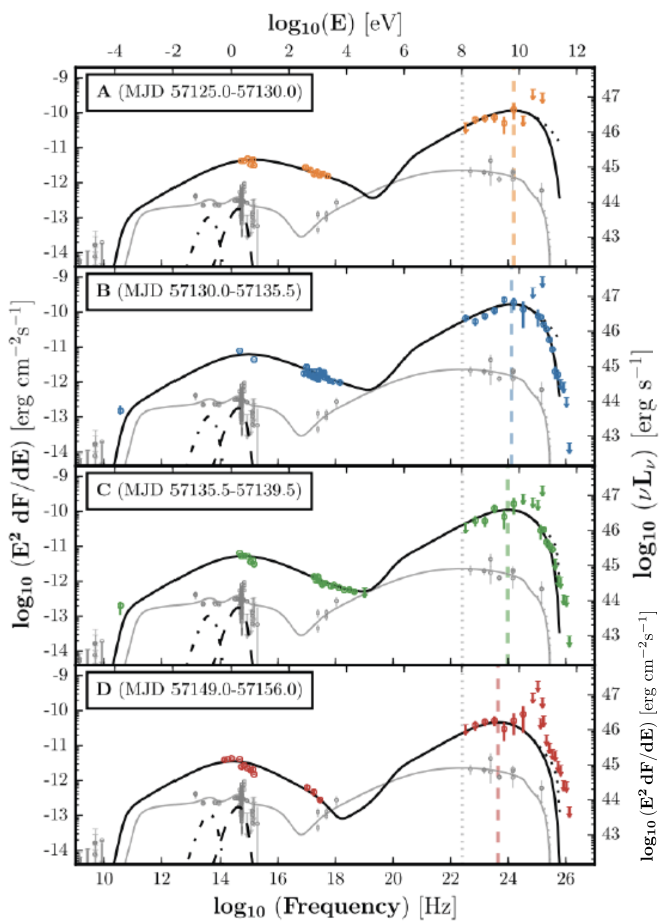
Flare alert system

1. VHE self-trigger
   – Under "MAGIC/HESS/VERITAS/HAWC/FACT flaring AGN agreement"
     • When one find a flare, one inform others by e-mail.
   – Usually, onsite analysis can shows a results in a few 10 minutes
2. HE (Fermi-LAT) trigger
   – Self monitoring. Communication between LAT and IACTs
   – About 6 - 8 hour delay at fastest (until LAT data becomes available)
3. X-ray/optical trigger
   – many "monitoring" programs are on going
     • On-site optical telescope in each group
   – The Astronomer's Telegram
   – informed by individuals

FSRQ PKS1441+25 (z=0.94)

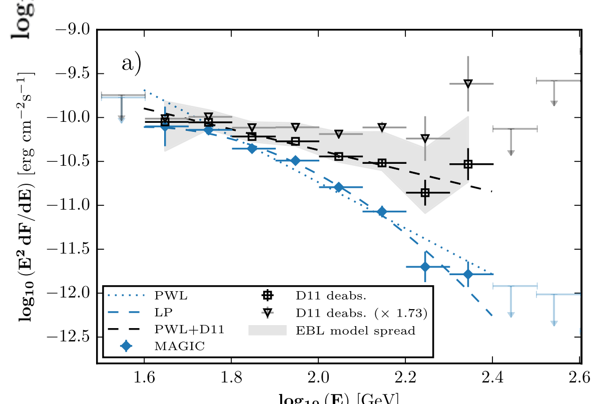
Initiated by high flux with a hard-index in Fermi-LAT (e.g., Atel7402)





- 25.5σ from periods A,B
- higher IC peak E during the flare.
- VHE flare from outside BLR. (while inside BLR in steady state?)

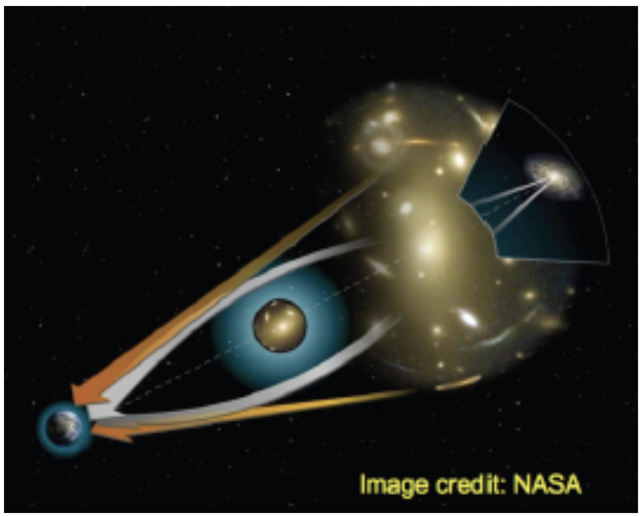
Γ_{obs}=4.62±0.11
Γ_{src}= 3.18±0.15



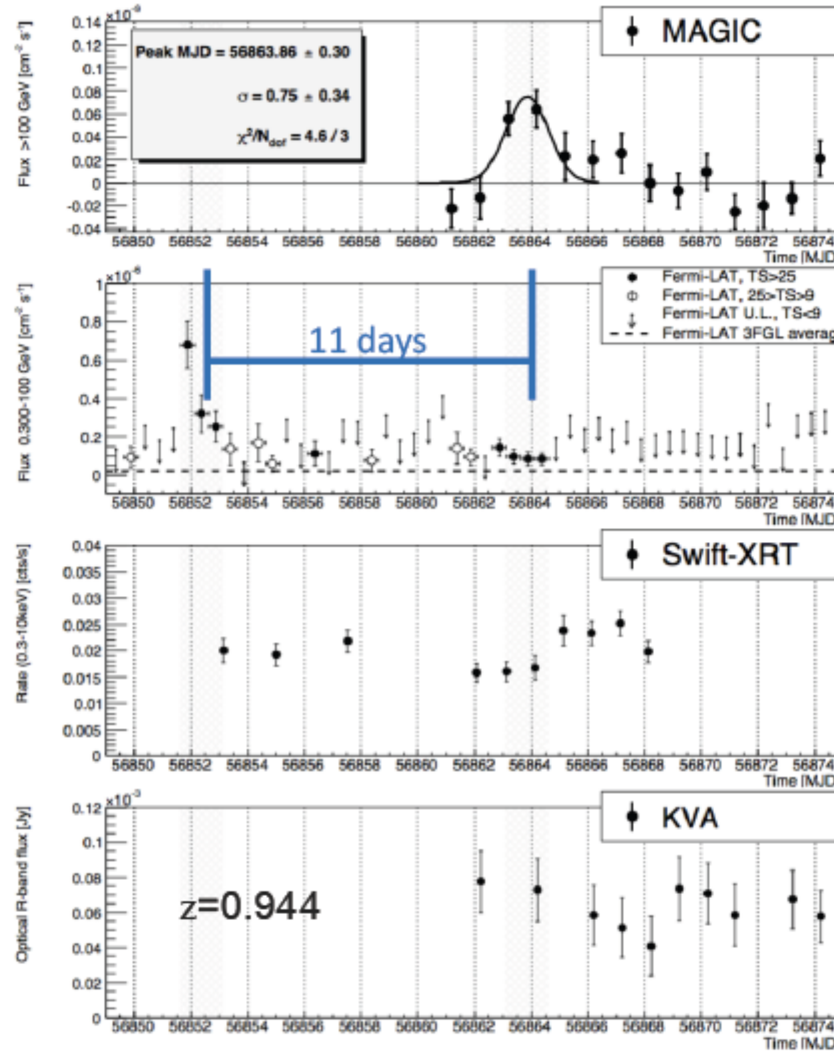
(Ahnen+15 ApJL)

QSO B0218+357 (z=0.944)

- **QSO B0218+357** is a gravitationally lensed blazar at z=0.944 with a spiral galaxy B0218+357G at z=0.68
- 11-days is the time-delay



(Ahnen+16, A&A)



- In 2014, Fermi got the first flare, and 11 days after, MAGIC detection
- First gravitationally lensed VHE γ rays ever observed
- – 2hours, 6 sigma significance

Hadronic origin γ-ray scenario: 3C 279

(Petropoulou, Nalewajko, MH+17, MNRAS)

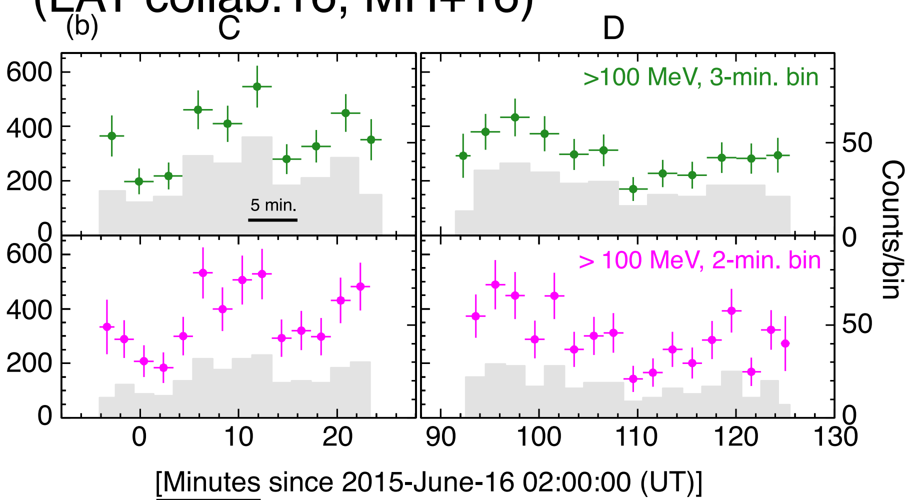
- Base code: Petropoulou & Dermer 16, ApJL
- GeV γ-ray origin: **proton synchrotron**
  (need less power but higher proton energies than photomeson (pγ) origin)

$\gamma'_{p,min}$	$\gamma'_{p,br}$	$\gamma'_{p,max}$	$s_{p,1}$	$s_{p,2}$
1	10^6	10^8	1.6	2.1

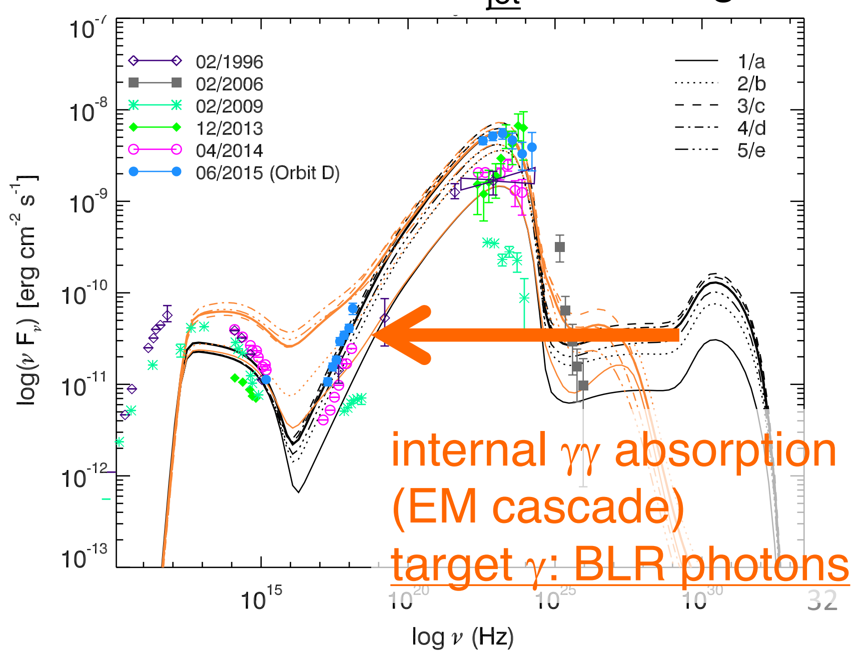
100PeV
(→ PeV ν)

- Data : Orbit-D (red: simultaneous UV, X-ray and γ-ray data)

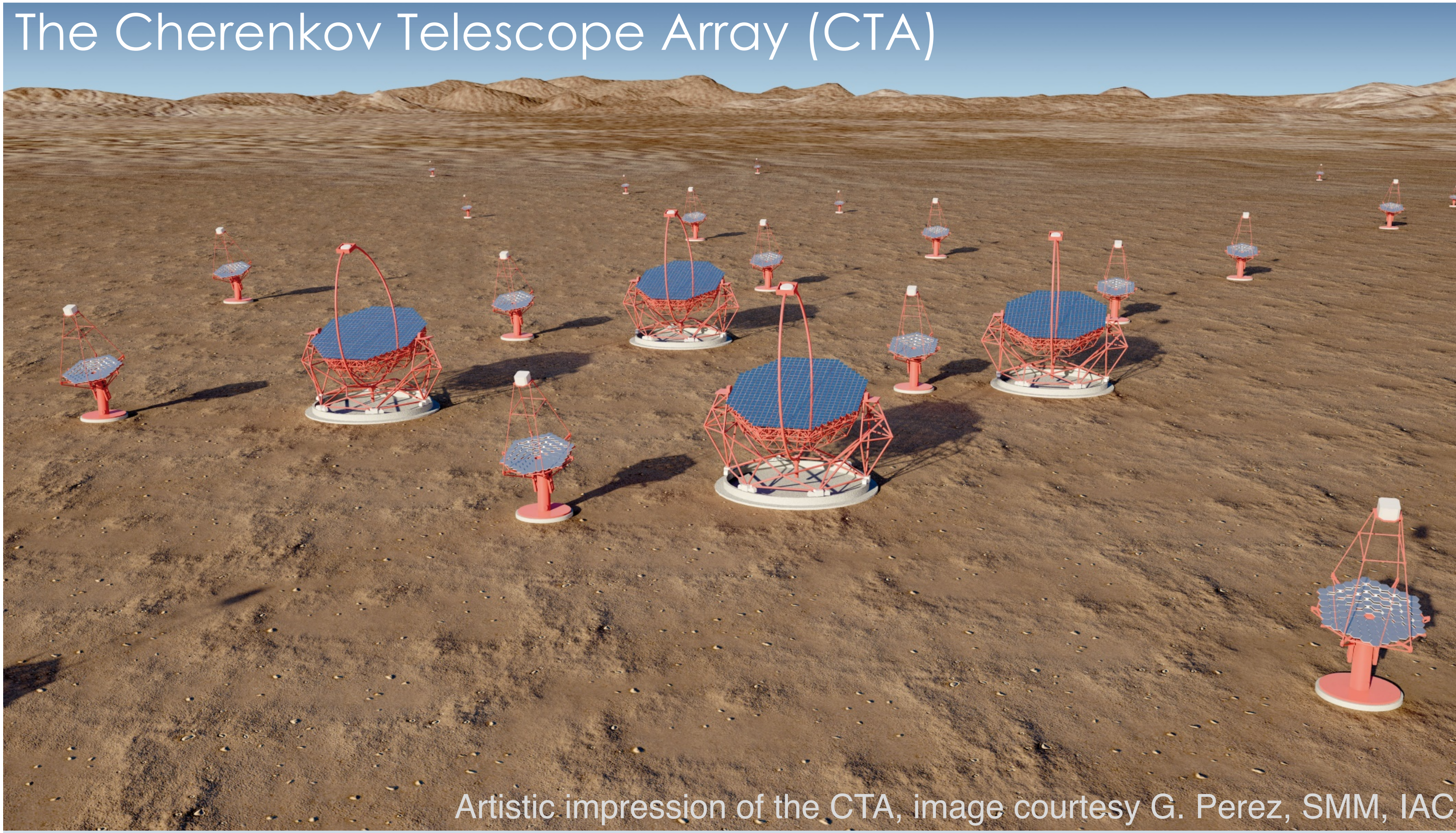
(LAT collab.16, MH+16)

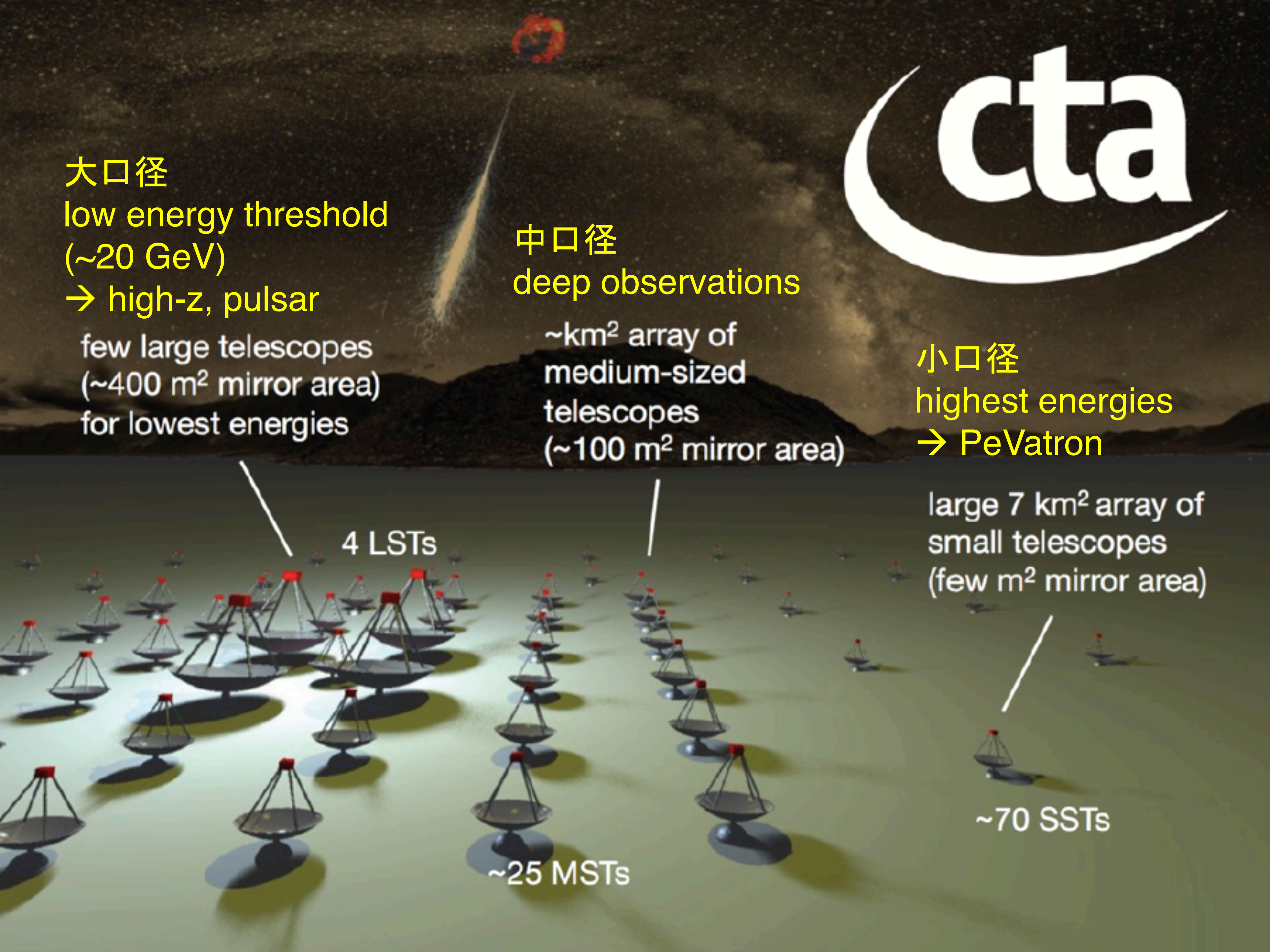


δ=50, B=0.8kG, P_{jet}=1e48 erg/s

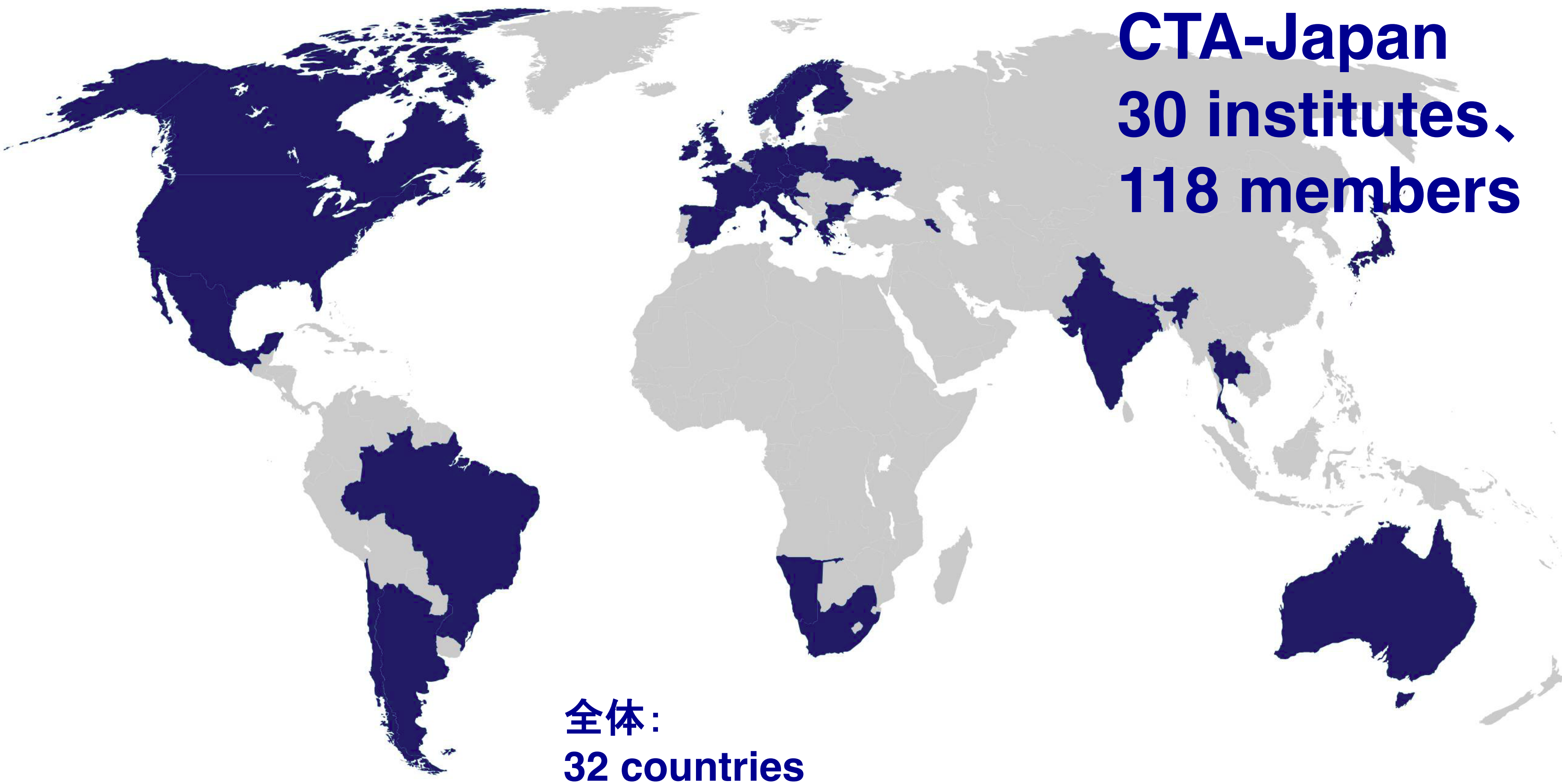


Towards the next generation IACTs




cta
大口径
low energy threshold
(~20 GeV)
→ high-z, pulsar
few large telescopes
(~400 m² mirror area)
for lowest energies
4 LSTs
中口径
deep observations
~km² array of
medium-sized
telescopes
(~100 m² mirror area)
~25 MSTs
小口径
highest energies
→ PeVatron
large 7 km² array of
small telescopes
(few m² mirror area)
~70 SSTs

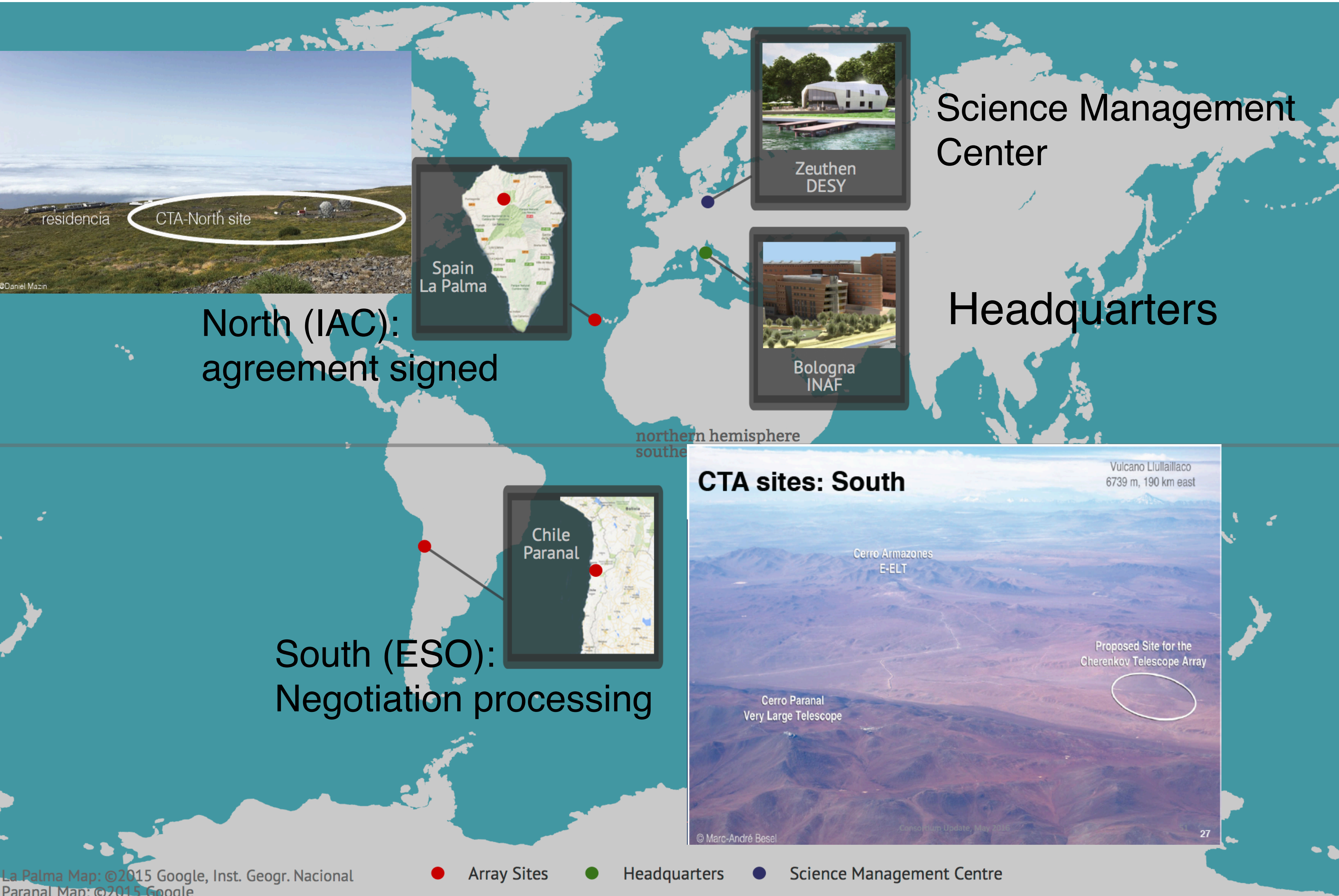
CTA Consortium



CTA-Japan
30 institutes、
118 members

全体:
32 countries
209 institutes
1346 members (456 FTE)

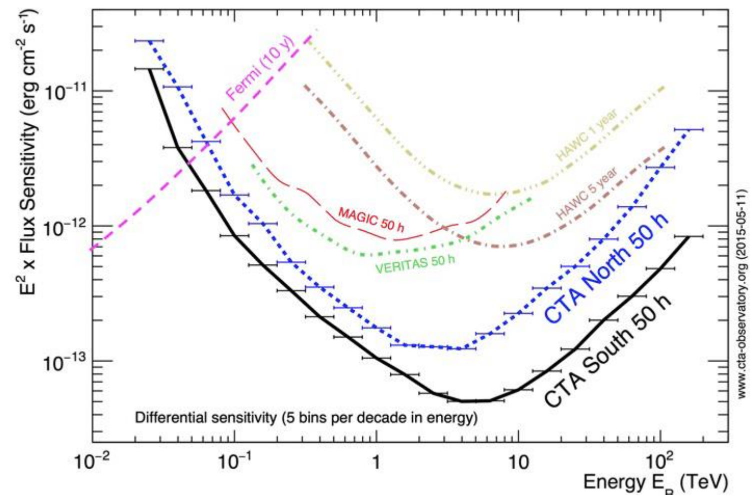
CTA : Two Array Sites



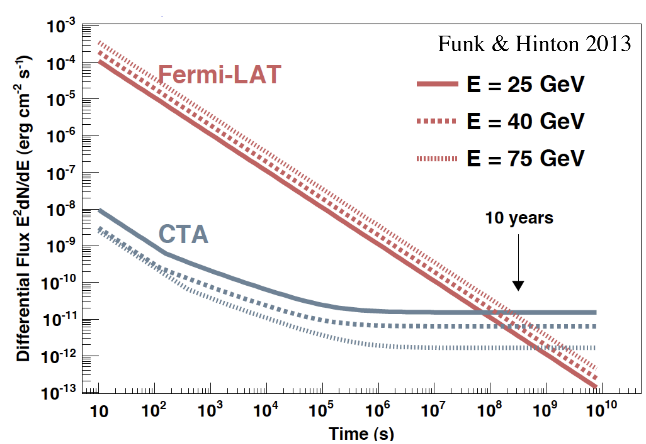
CTA performance

(compared to the current Cherenkov telescopes)

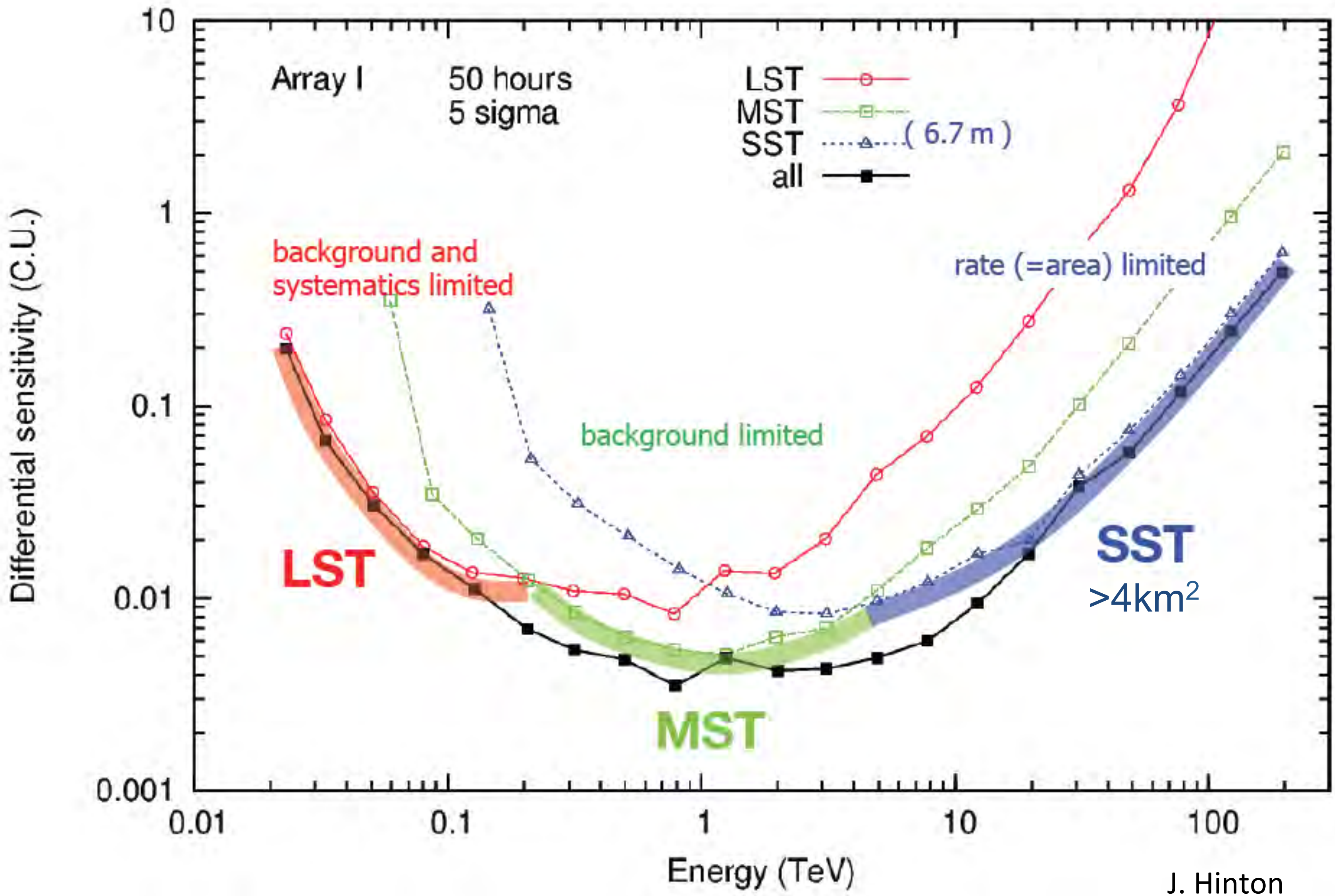
1. energy range is extended: 20 GeV to >100 TeV
2. increased FOV
   – (5°-8° [CTA] vs 3°-5°[now])
3. better angular resolution
   – (0.05° [CTA] vs 0.1° [now])
4. better energy resolution
   – (10-20 %[CTA] vs 15-30% [now])



more feasible than Fermi-LAT for short time observations



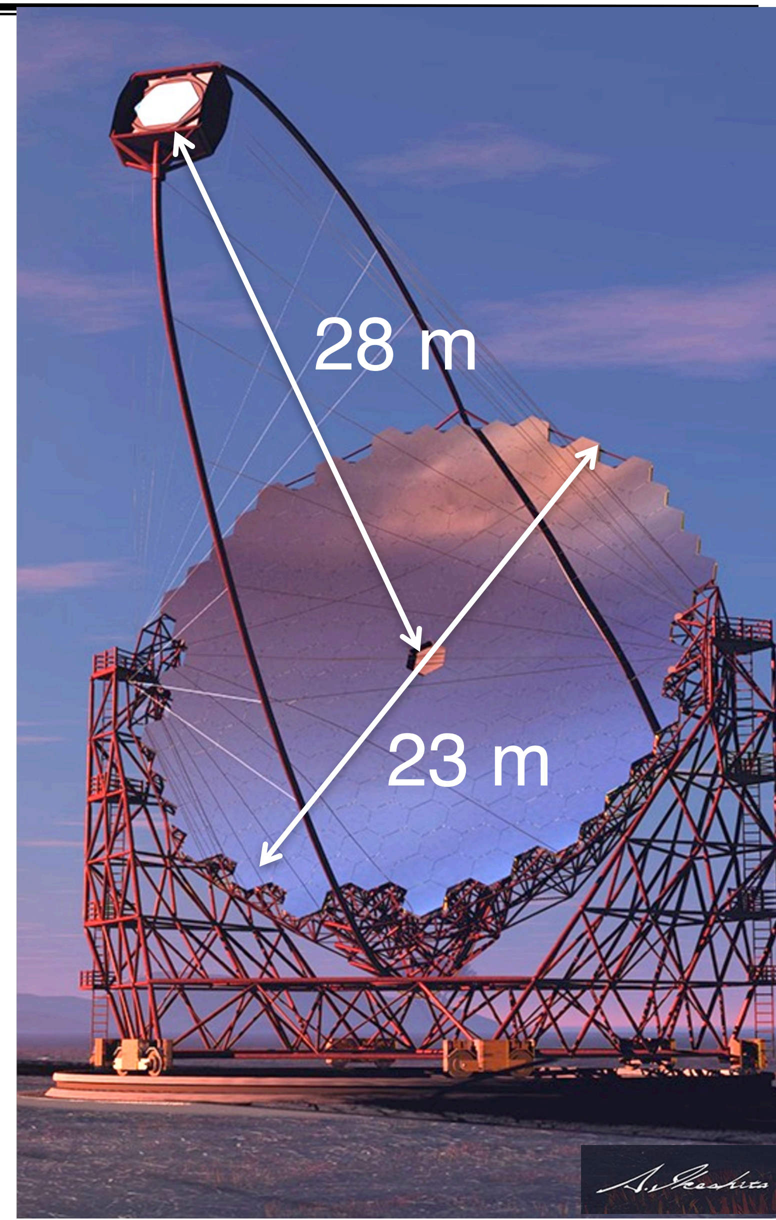
Sensitivity



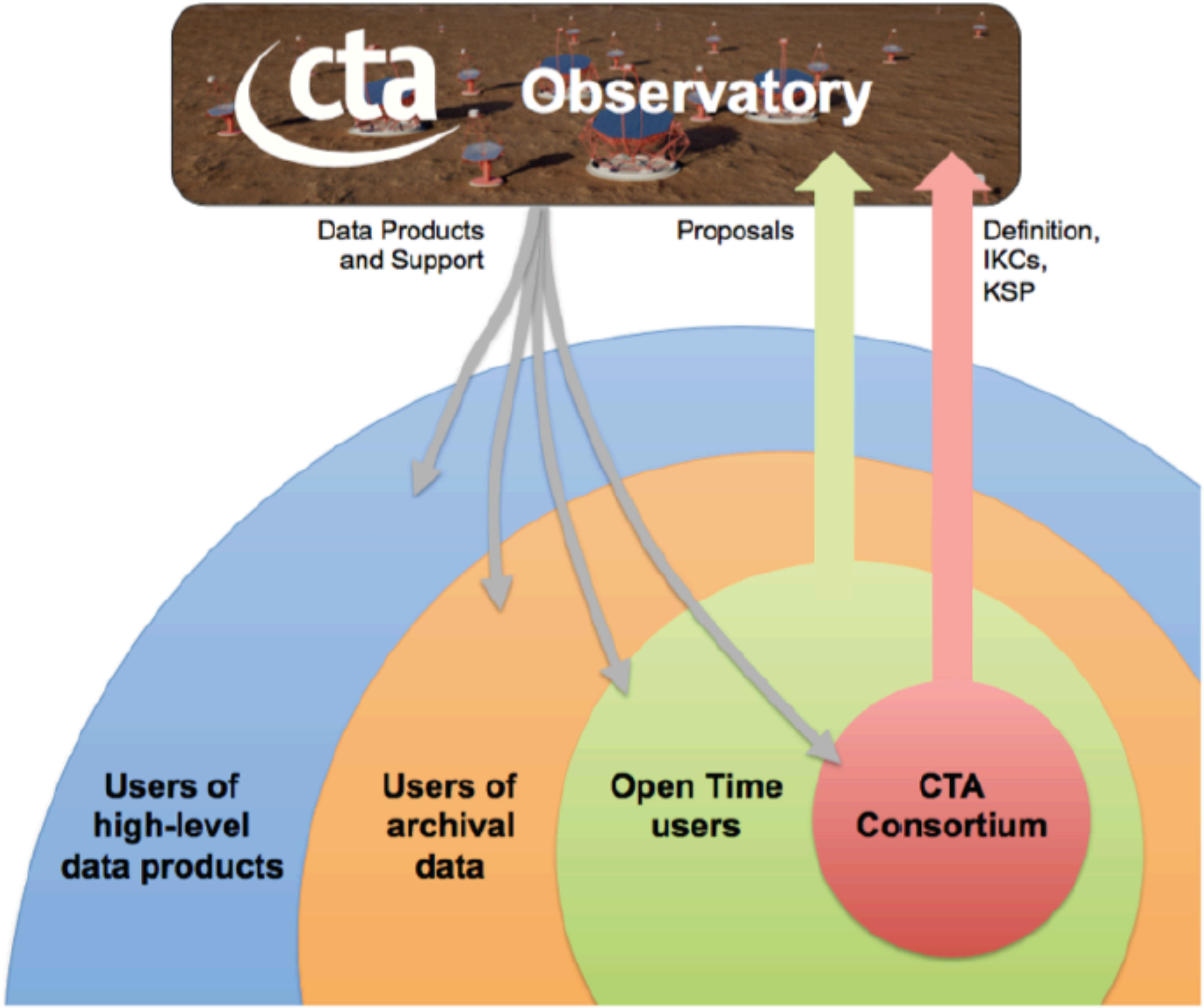
J. Hinton

LST (Large Size Telescope)

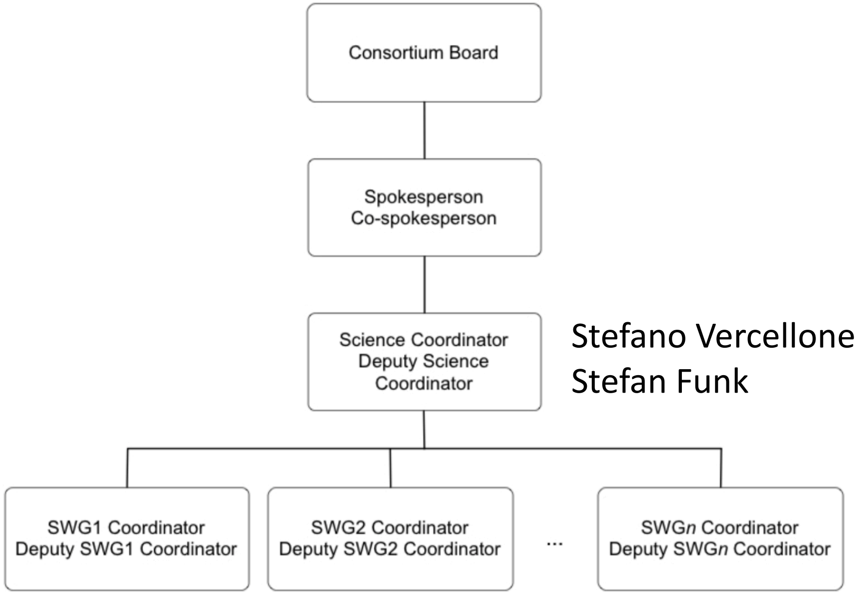
- Diameter : 23 m
- Dish Area: 368 m^2
- Focal Length : 28 m
- F/D :   1.2
- Dish profile : Parabolic
  (<0.6nsec)
- segmented mirror : 198
- **Camera FOV: 4.5°**
- 1855 pixel (0.1° /50mm/pix)
- dish structure : CFRP
- **total weight : ~ 120 ton**
- **re-pointing : < 20 sec**
- Active Mirror Control (<14")



Organization: observatory



Science Working Group coordinators



Stefano Vercellone
Stefan Funk

Six Science WG's

Galactic SWG
- Jamie Holder (Coordinator)
- Roberta Zanin (Deputy)

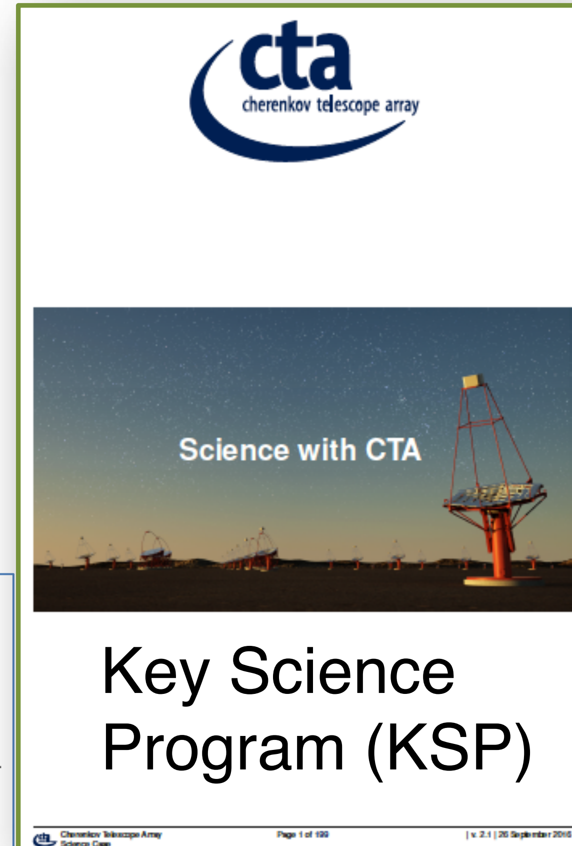
Cosmic-ray SWG
- Stefan Ohm (Coordinator)
- Sabrina Casanova (Deputy)

Extragalactic SWG
- Elina Lindfors (Coordinator)
- Fabrizio Tavecchio (Deputy)

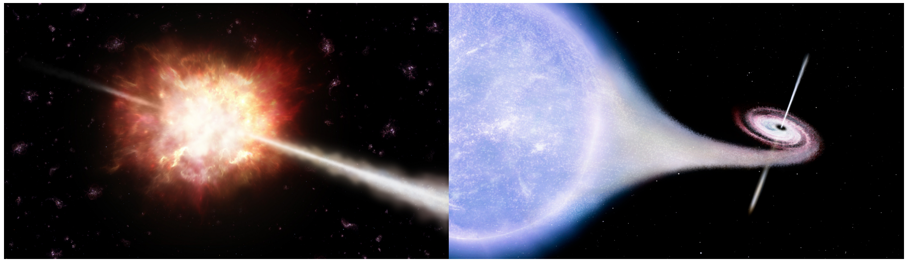
Transient SWG
- Susumu Inoue (Coordinator)
- Catherine Boisson (Deputy)

Dark Matter and exotic physics SWG
- Fabio Zandanel (Coordinator)
- Aldo Morselli (Deputy)

Intensity interferometry SWG
- Dainis Dravins (Coordinator)
- Michael Daniel (Deputy)



Transient KSP



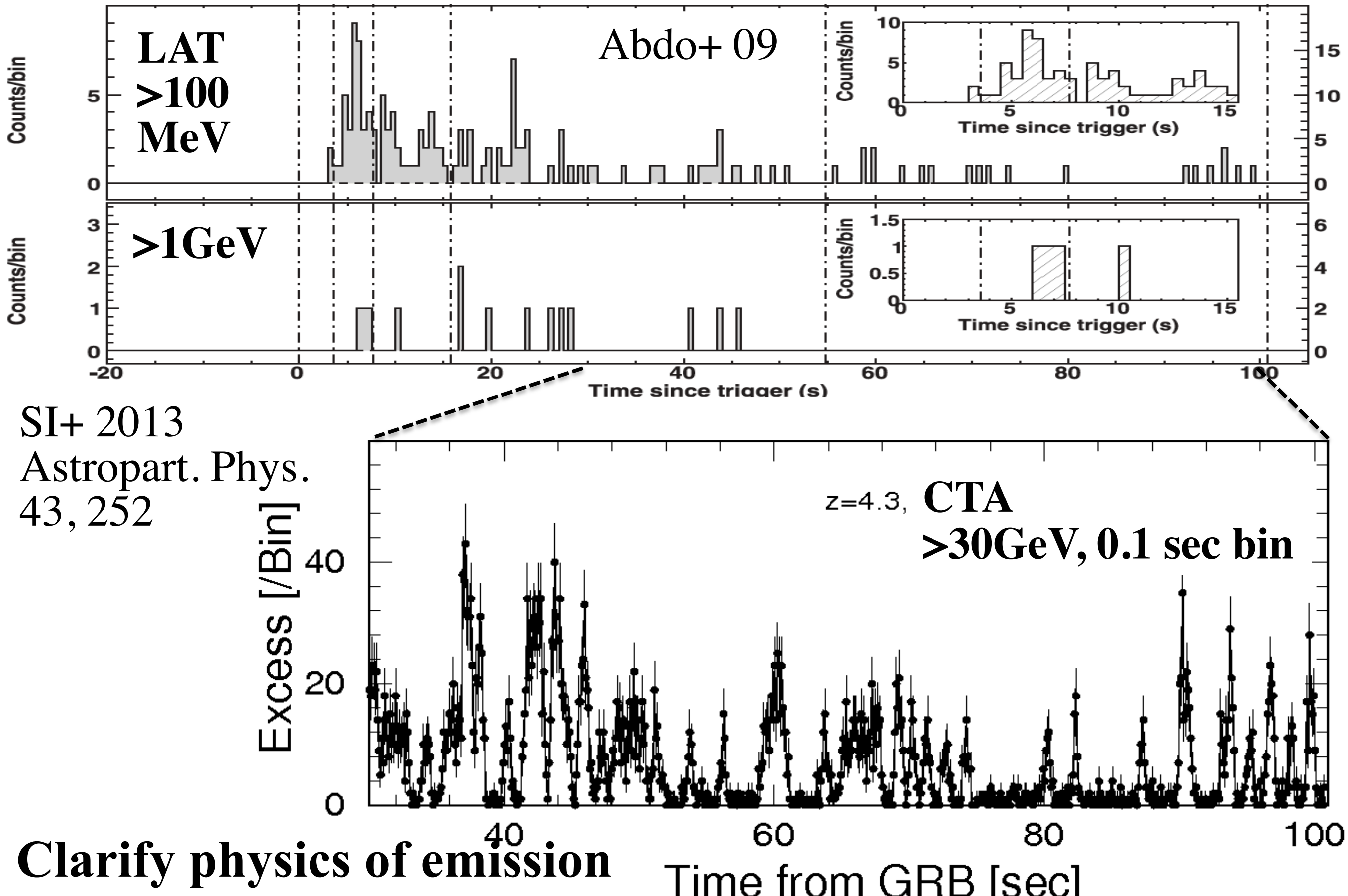
- **GRBs**
- **HE neutrino transients**
- Galactic transients
  - microquasars, PWN flares, novae, etc
- X-ray/optical/radio transients
  - TDEs, SN shock breakout events, **FRBs**, new transients
- **gravitational wave transients**
- serendipitous VHE transients
- VHE transient survey via divergent pointing

Related KSPs:

- **AGN (flares),** LIV studies

GRB light curve: Fermi vs. CTA

based on GRB 080916C

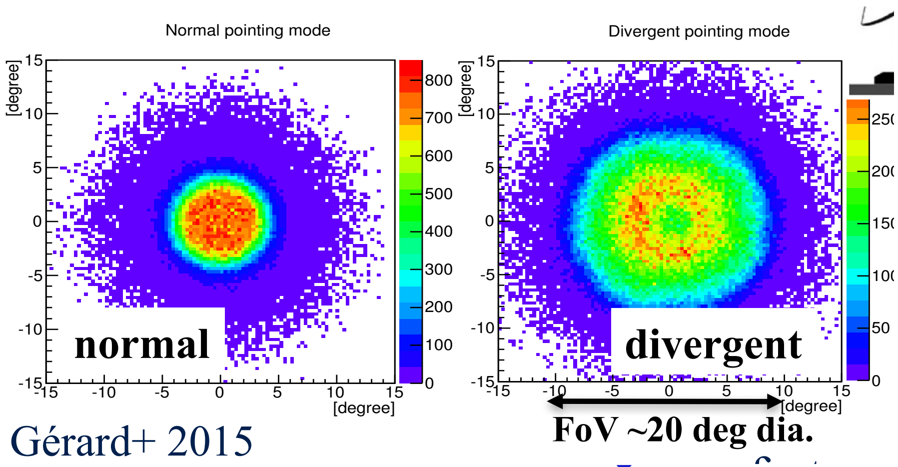


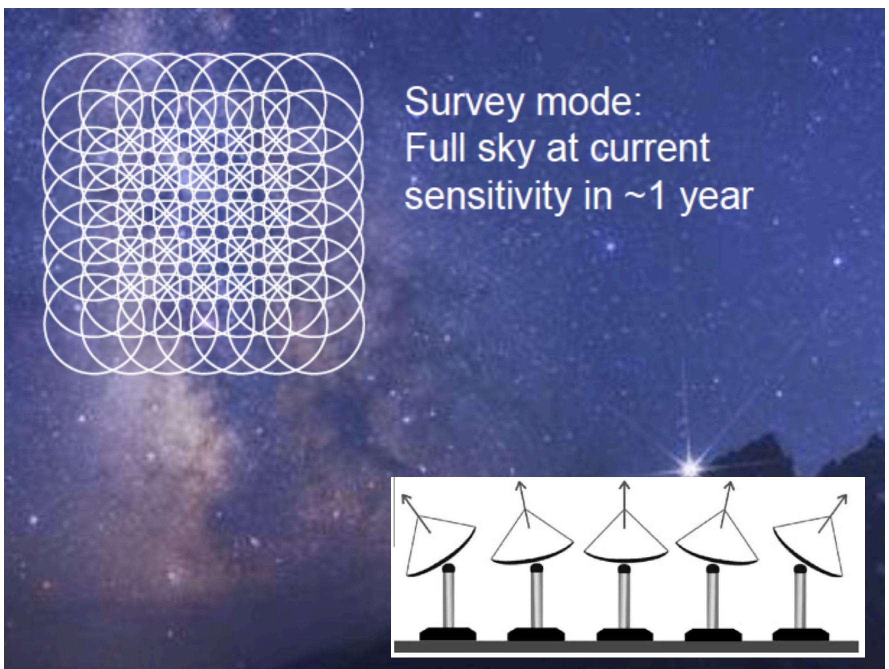
SI+ 2013
Astropart. Phys. 43, 252

Clarify physics of emission
Test UHECR origin, LIV

expected detection rate of GRB ~0.5 GRB yr^{-1}
(very model dependent, though,,)

Divergent pointing





Wide FoV at expense of sensitivity
(only MST/SST?)

ToO:

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

<u>Survey:</u>

- GRBs from onset prompt emission physics
  (crucial but poorly understood)
- unbiased transient survey
  e.g. FRBs

Summary

- IACT trainset follow-up programs (ToO program)
  - can start observation in real time (auto) and the next night (manual)
  - duty cycle ~15% (~1200 hr) including moderate moon time.
    - **multi-messenger (ν) alerts** (auto/manual) → ***no detection, yet***
      - archival HESE/track events, HESE/EHE alerts
    - **GRB alerts** (real time) → ***no detection, yet***
      - MAGIC observed 90 GRBs (and several within prompt)
    - **multi-wavelength alerts** (manual)
      - successful for blazars → extended the γ-ray horizon to z~1
- CTA: `transients' is one of the key sciences
  - pre-defined ToO program within the consortium
  - plan: 1st LST: 2017 Nov., Scientific operation starts: 2021?