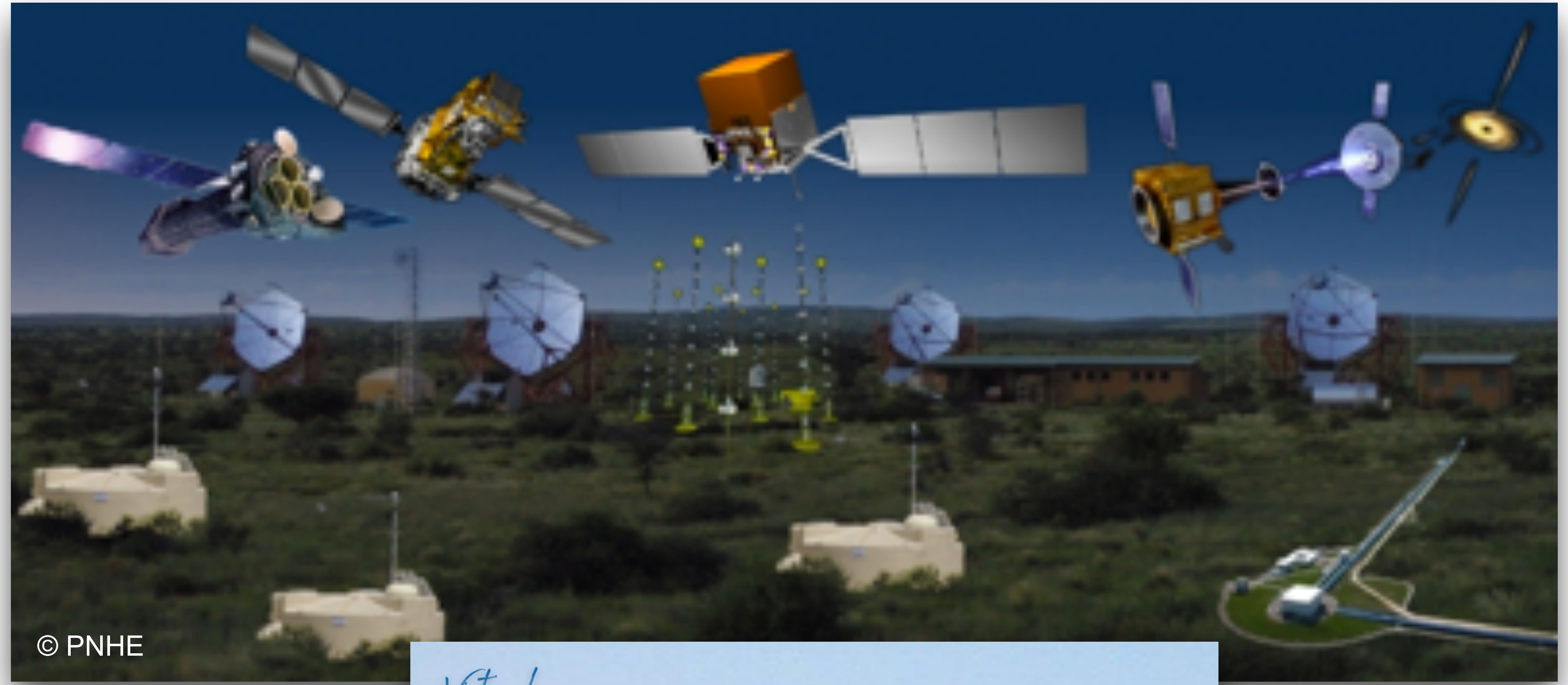
The Transient High Energy Sky (seen with H.E.S.S.)



Virtual

HEASA 2021

13 - 17 September

Fabian Schüssler

September 13, 2021

SA-GAMMA
THE SOUTH AFRICAN GAMMA-RAY ASTRONOMY PROGRAMME

Irfu - CEA Saclay
Institut de recherche sur les lois fondamentales de l'Univers

université PARIS-SACLAY

The H.E.S.S. Transient program

Flaring stars

CVs / Novae

Supernovae

Gamma-ray Bursts

Gravitational Waves

Gamma-ray Binaries

Microquasars

Unknowns

Active Galactic nuclei

Tidal Disruption Events

Neutrinos

Fast Radio Bursts

Soft Gamma-ray Repeaters

The H.E.S.S. Transient program

Flaring stars

CVs / Novae

Supernovae

Gamma-ray Bursts

Gravitational Waves

Gamma-ray Binaries

Microquasars

Unknowns

Active Galactic nuclei

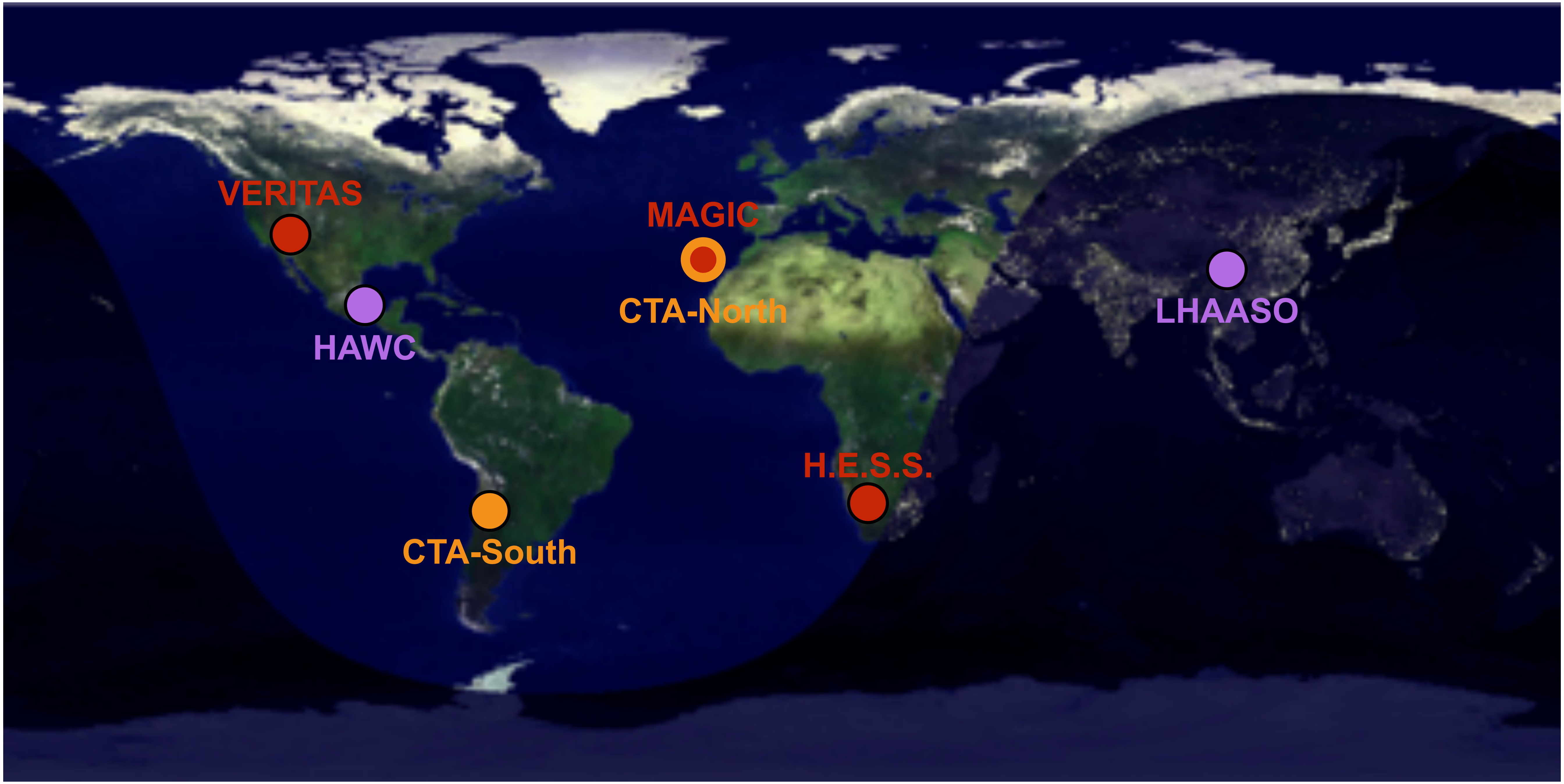
Tidal Disruption Events

Neutrinos

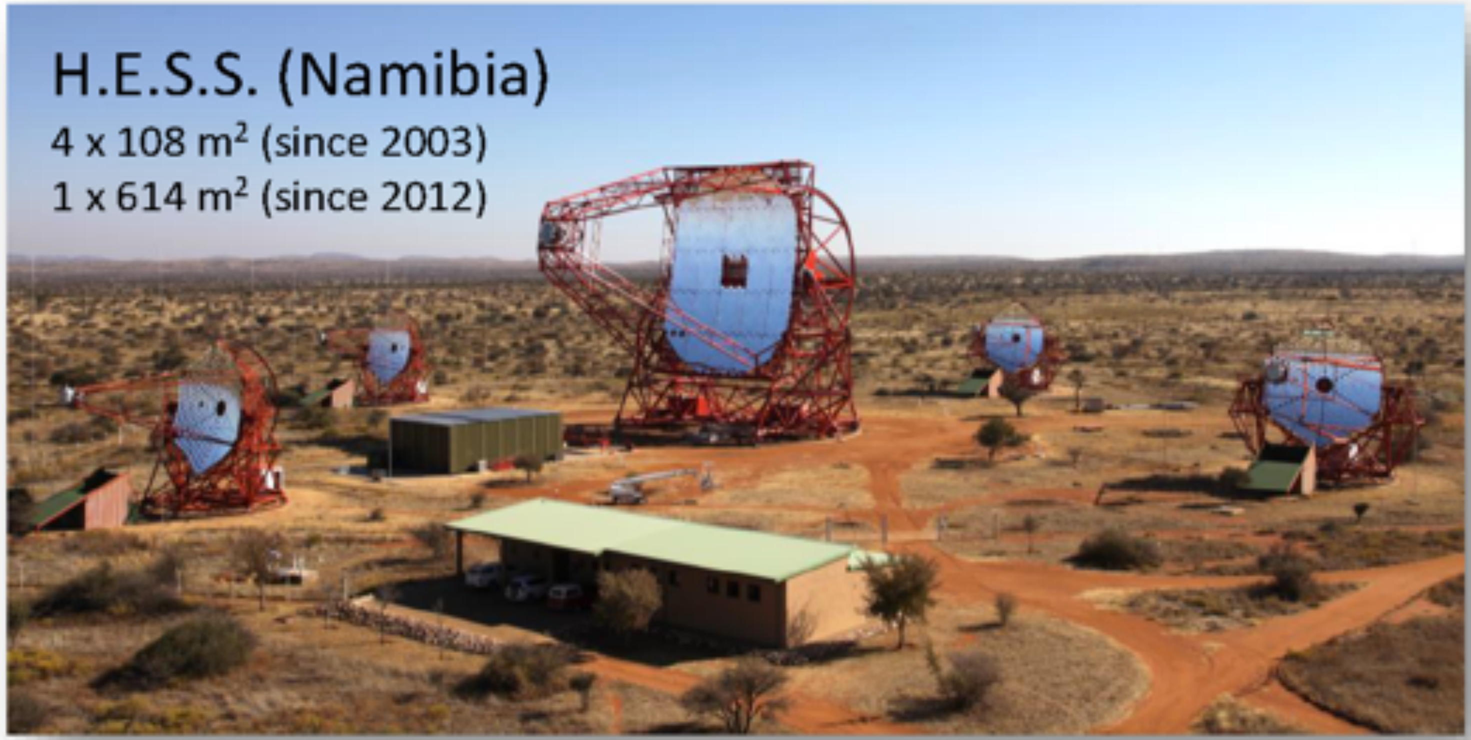
Fast Radio Bursts

Soft Gamma-ray Repeaters

VHE gamma-ray astronomy



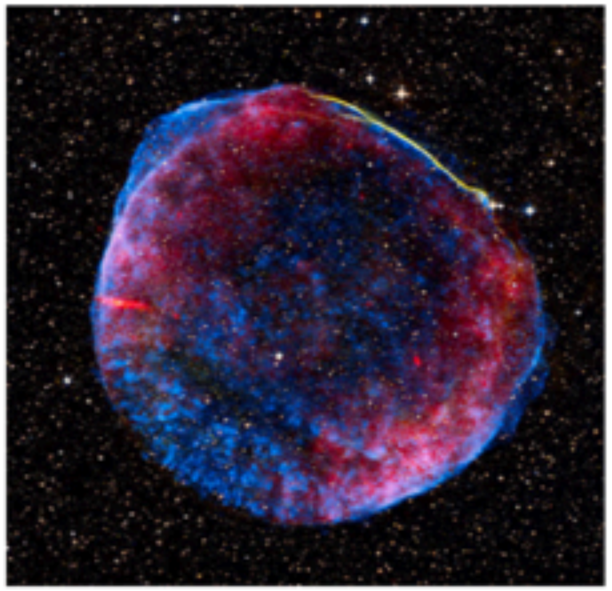
Current IACTs: high resolution follow-up observatories



Irfu

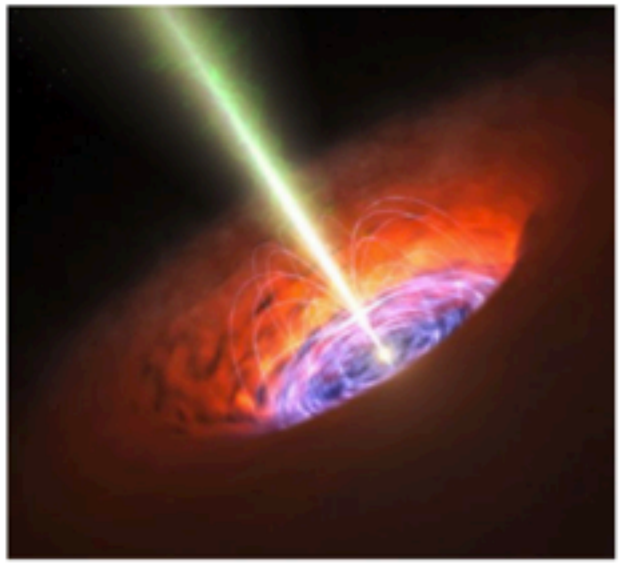
COSMIC PARTICLE ACCELERATION

- How and where are particles accelerated?
- How do they propagate?
- What is their impact on the environment?



PROBING EXTREME ENVIRONMENTS

- Close to neutron stars and black holes
- Relativistic jets, winds and explosions
- Cosmic voids

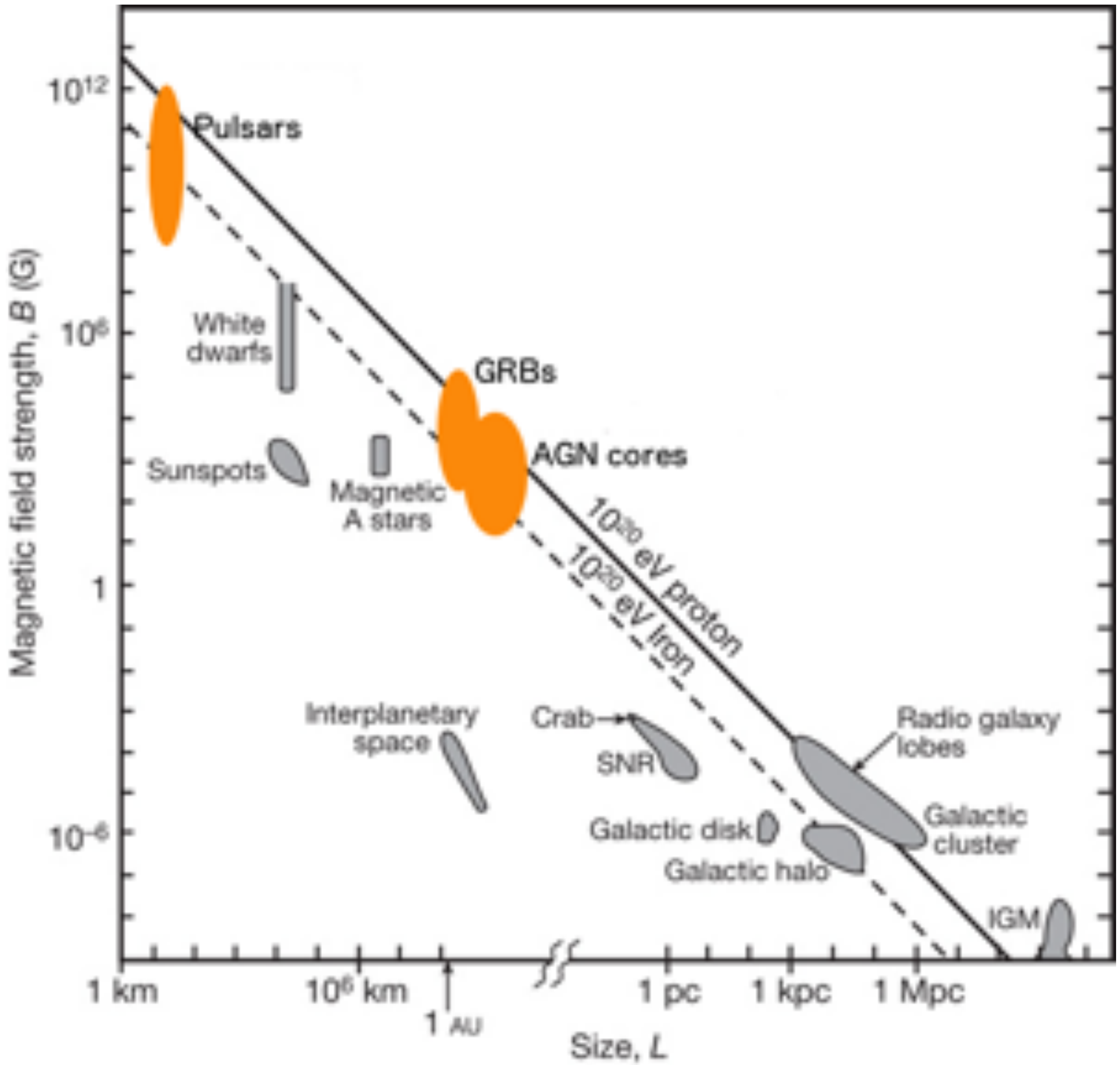


PHYSICS FRONTIERS

- What is the nature of Dark Matter?
- Is the speed of light a constant?
- Do axion-like particles exist?

W. Hofmann, TeVPA2018

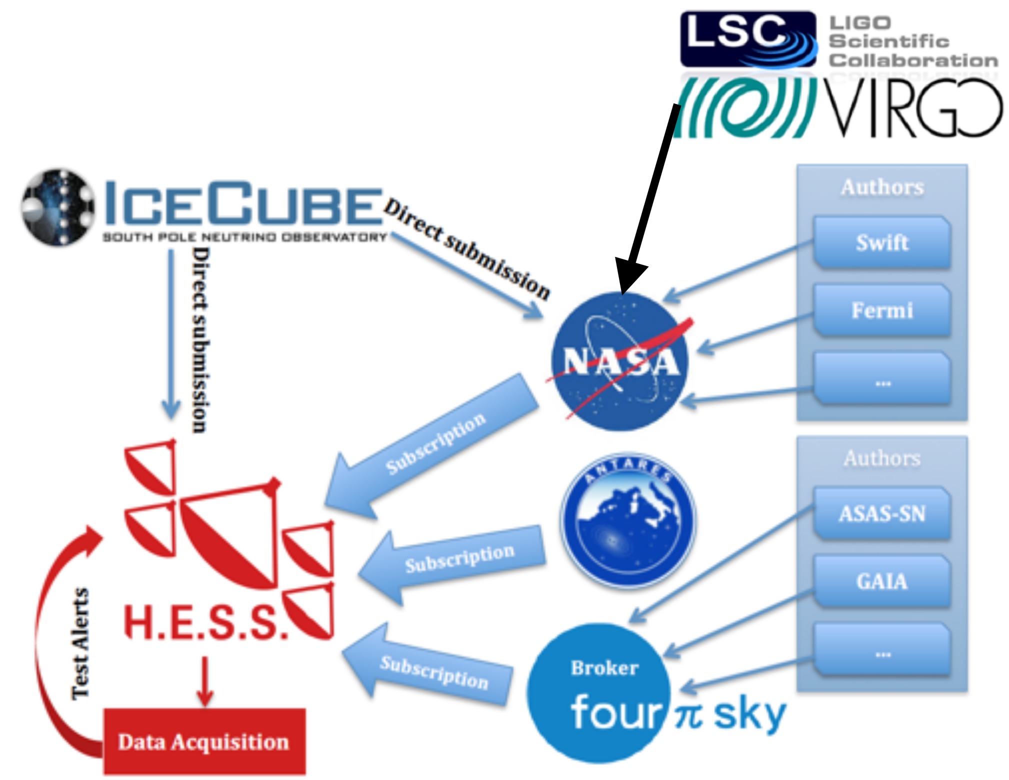
Transient sources

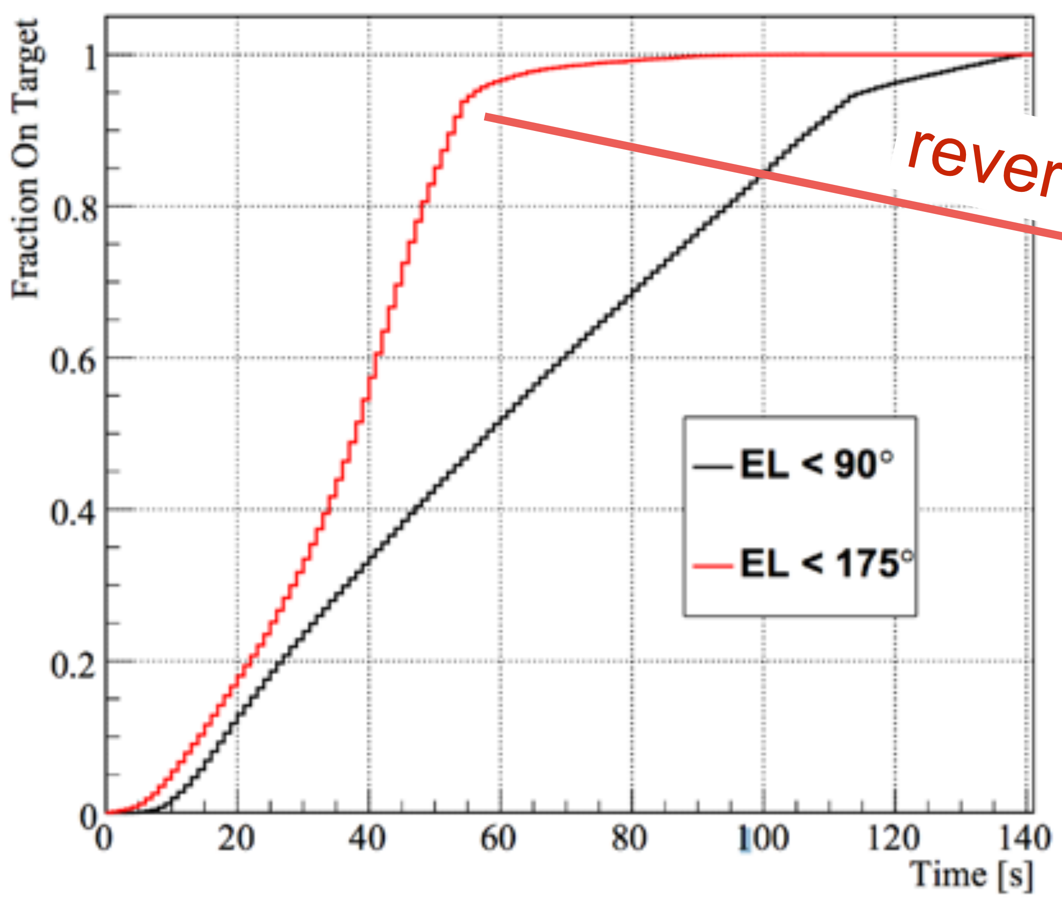


Modified from P.M. Bauleo and J.R. Martino. Nature 458 (2009)

The H.E.S.S.-II response to ToOs

- main design principles of the H.E.S.S. 28m telescope
  - large photon collection area (614 m^2 mirror area; largest IACT worldwide)
  - **rapid response time**
  - **flexible + fully automatized alert system**



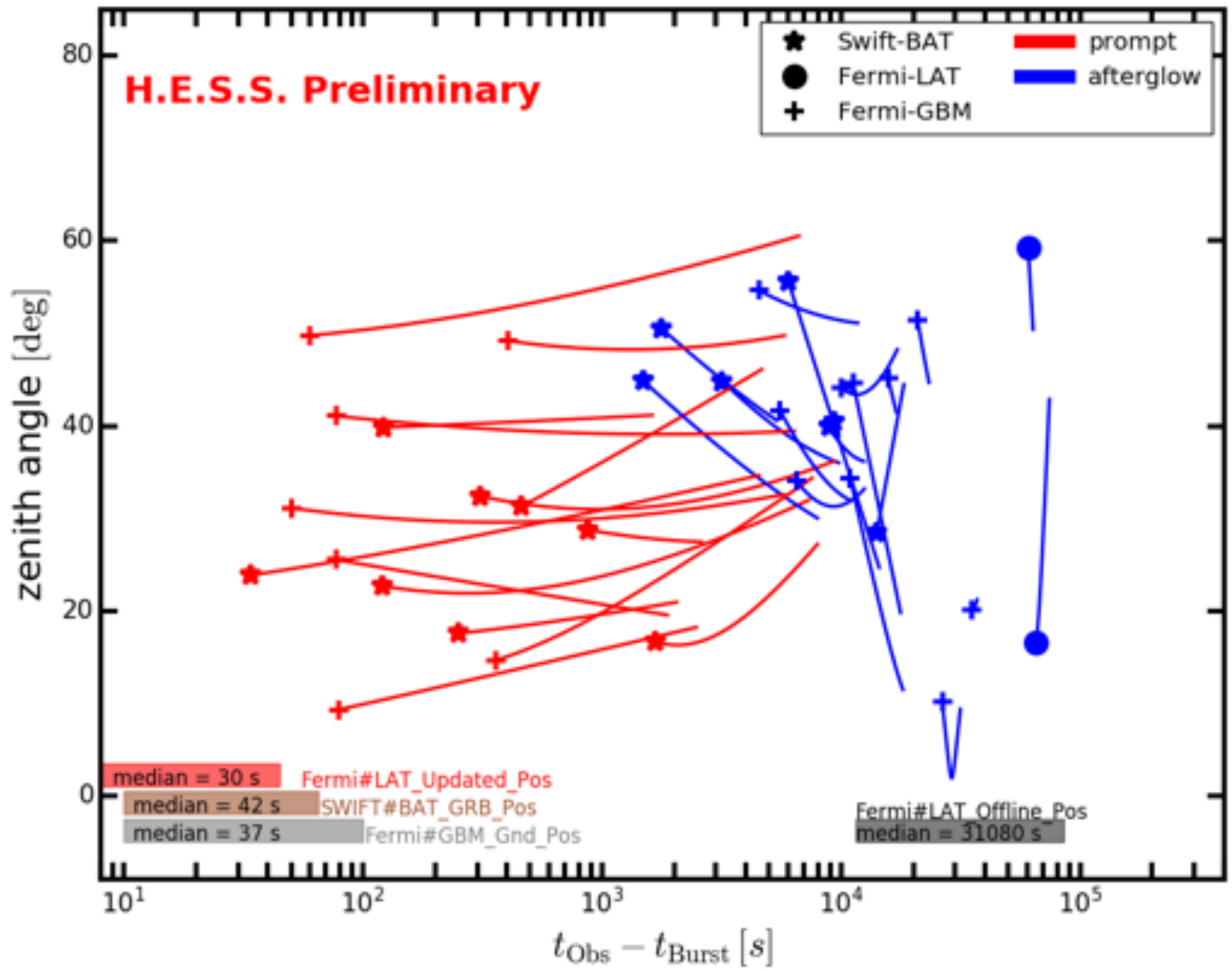


reverse tracking

Hofverberg et al., ICRC 2013

Hunting GRBs with IACTs

- The H.E.S.S. GRB program (< 2018)



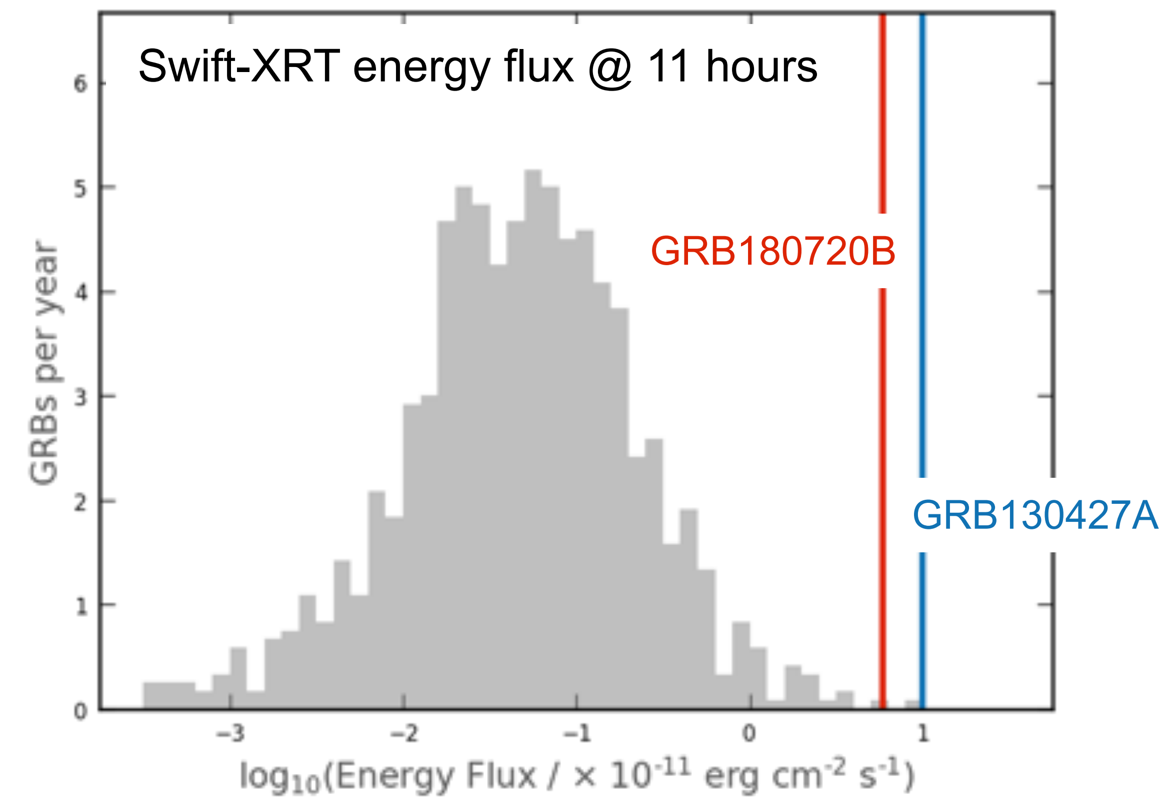
C. Hoischen et al., PoS(ICRC2017)636

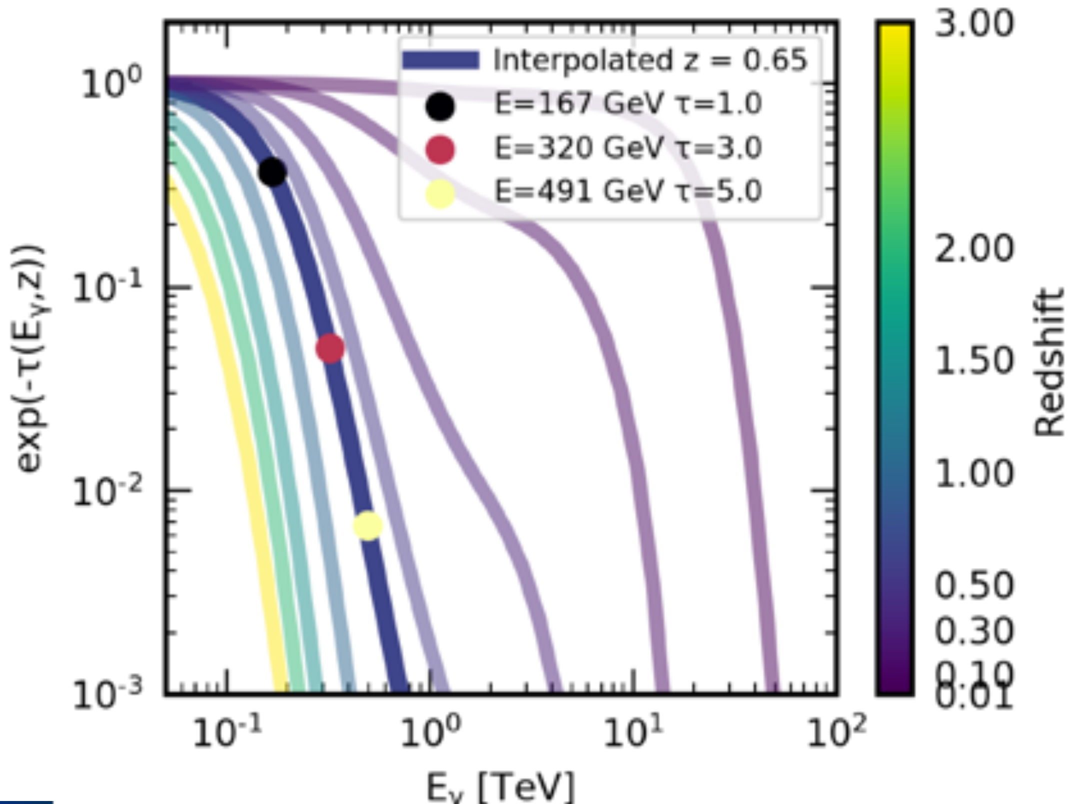
Recent news on Gamma Ray Bursts @ IACTs

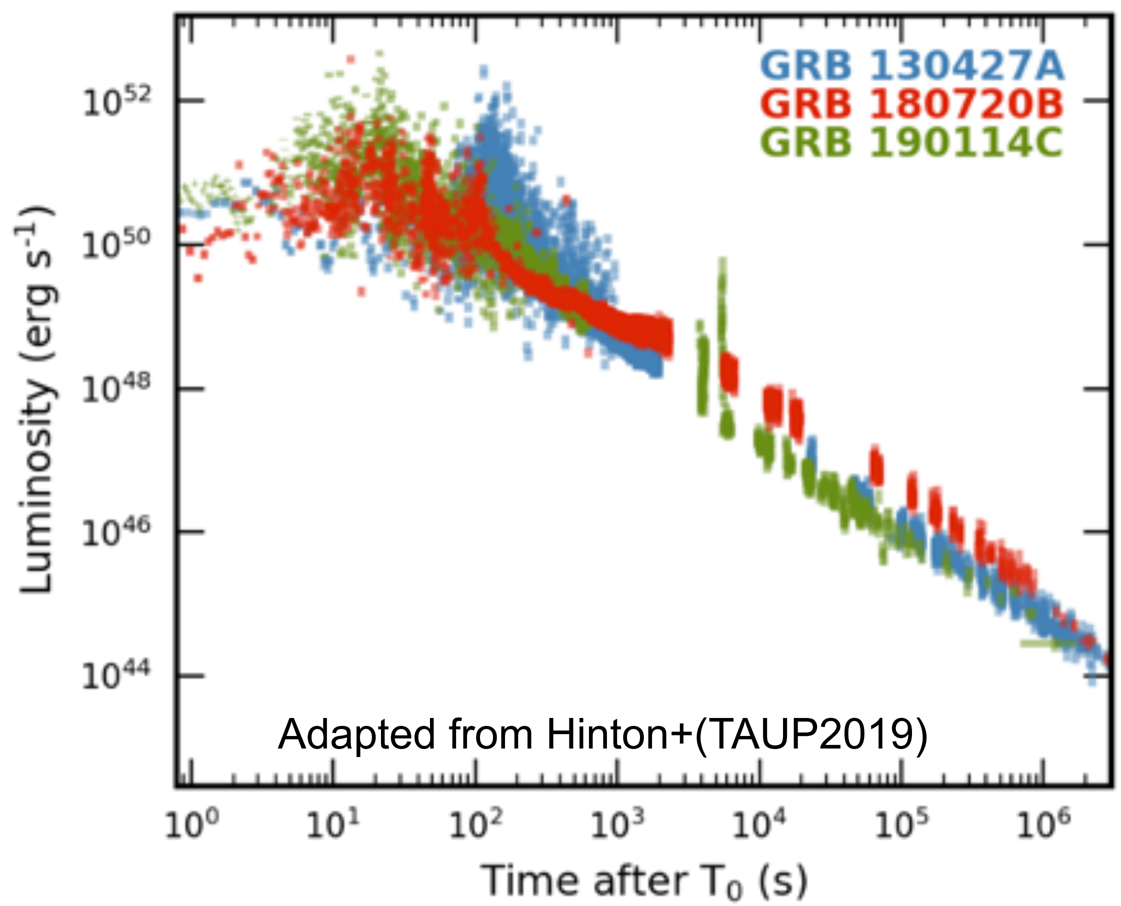
- short-GRB 160821B @ MAGIC: hint for detection (arXiv:2012.07193), later associated with a kilonova (Lamb et al. 2019 arXiV:1905.02159)
- GRB 180720B @ H.E.S.S.: >100GeV emission 10h after the burst (Nature 575, 464–467 (2019))
- GRB 190114C @ MAGIC: >300GeV emission 50s after the burst (Nature 575, 459 (2019))
- GRB 190829A @ H.E.S.S.: >180GeV during 56h; striking similarity between VHE and X-rays (Science 372, 6546 (2021))
- GRB 201216C @ MAGIC: >5sigma, observations >57s (ATEL #14275)

H.E.S.S.: GRB180720B

- Triggered by Fermi-GBM and Swift-BAT
- Fermi-LAT detection until T_0+700s (E_{max} ≈5 GeV)
- Extremely bright burst (e.g. 2nd brightest XRT afterglow)
- Redshift: z = 0.653 (>99% absorption at ~500 GeV)

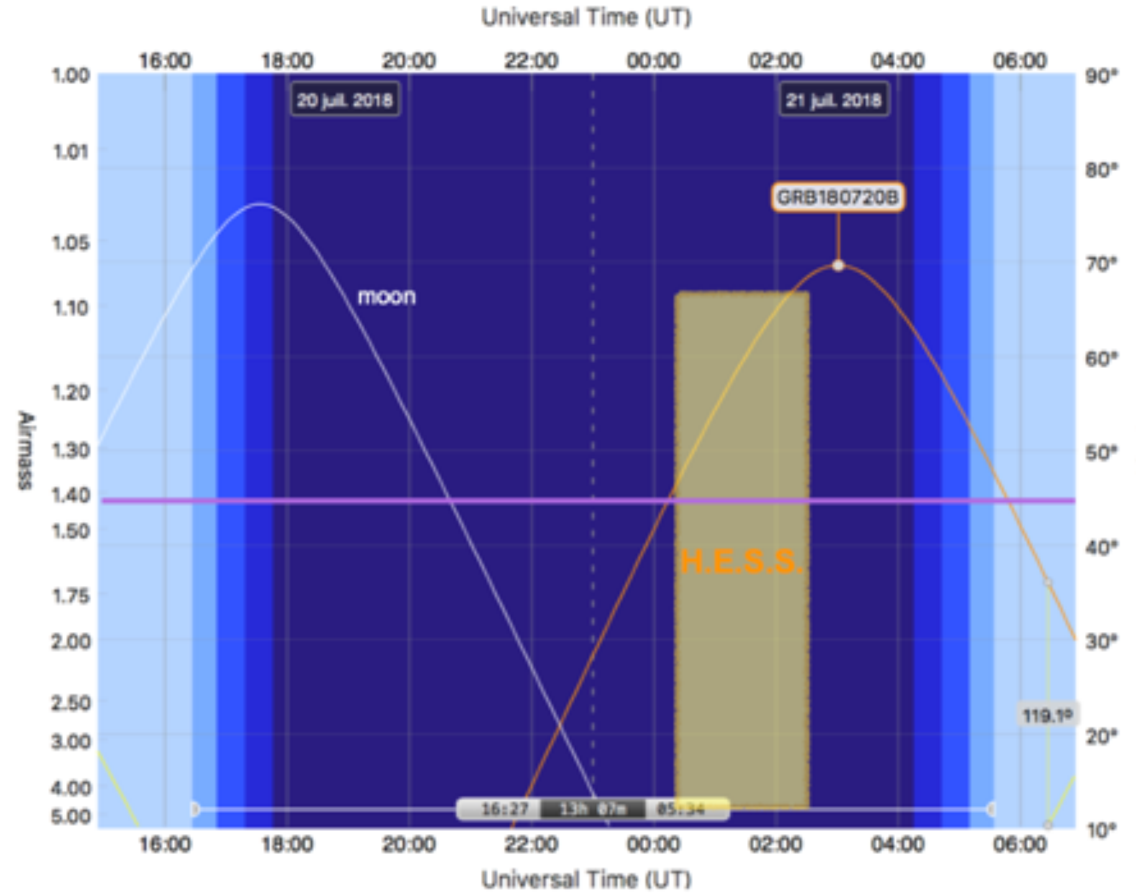


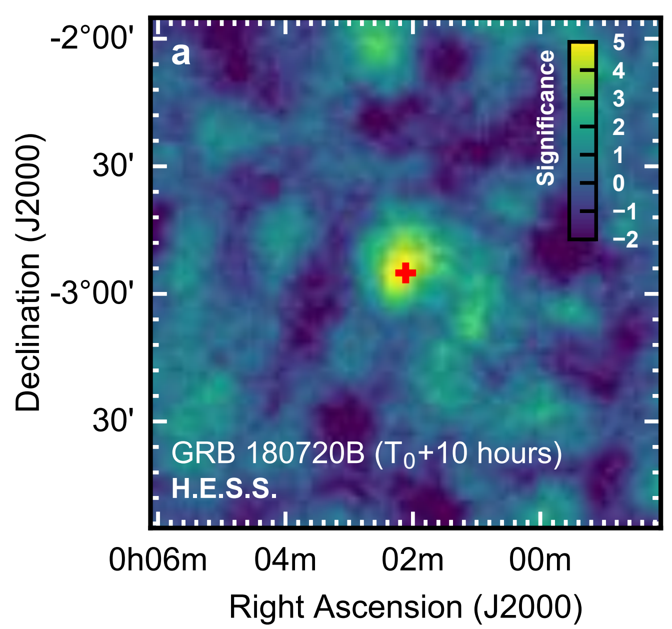


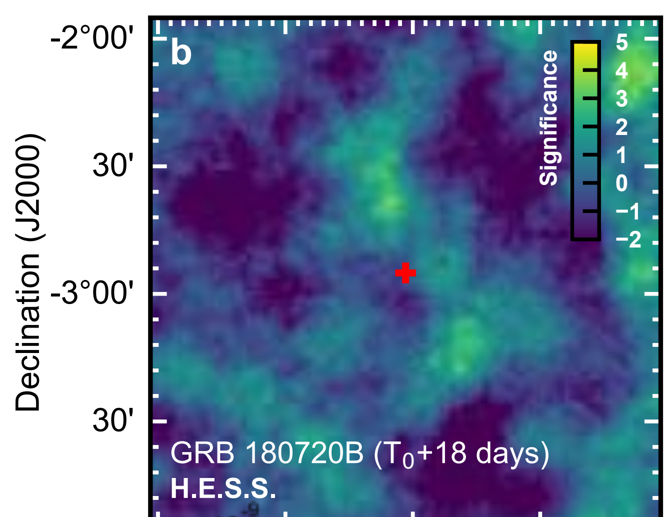


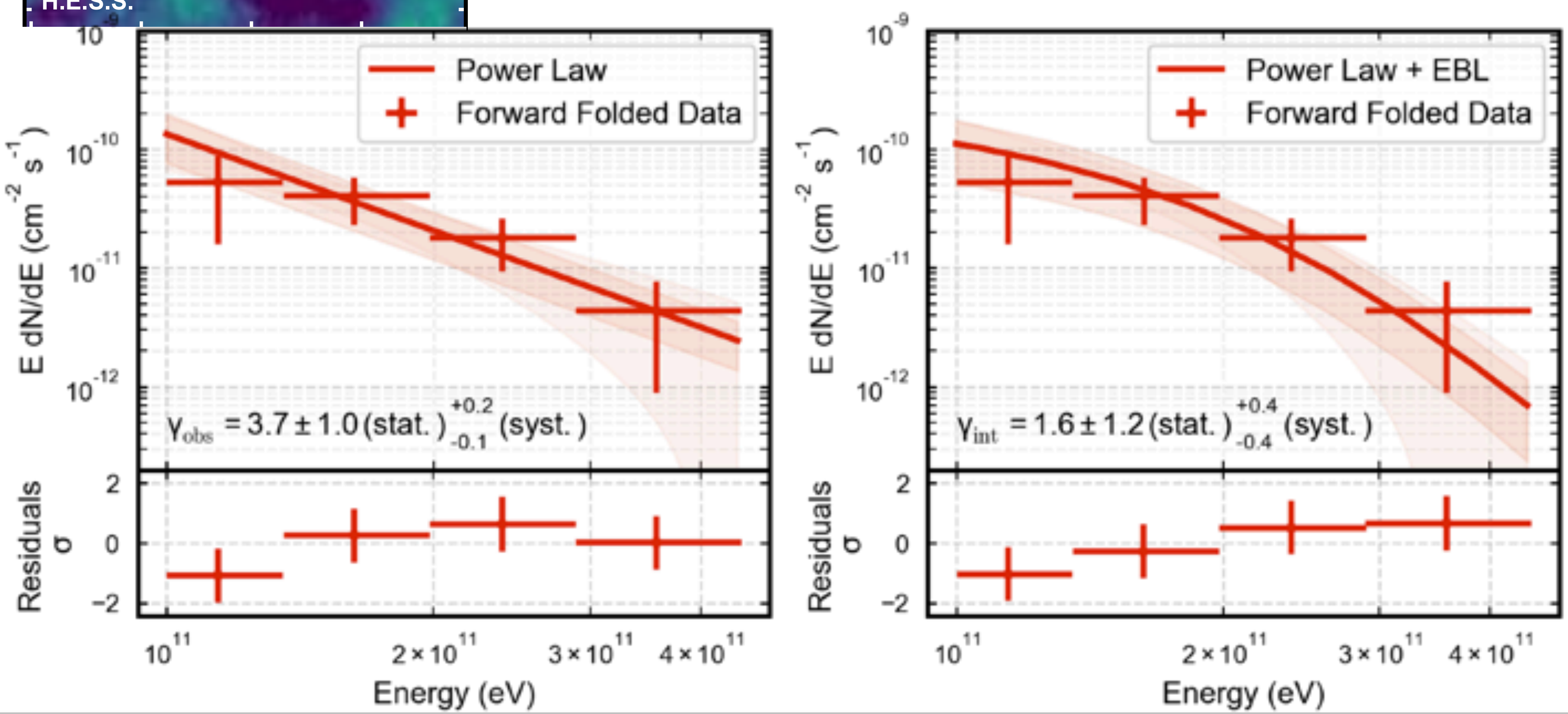
H.E.S.S.: GRB180720B

- Visibility constrains: observations starting ~10h after the burst !!
- 2h of data (zenith >45deg)





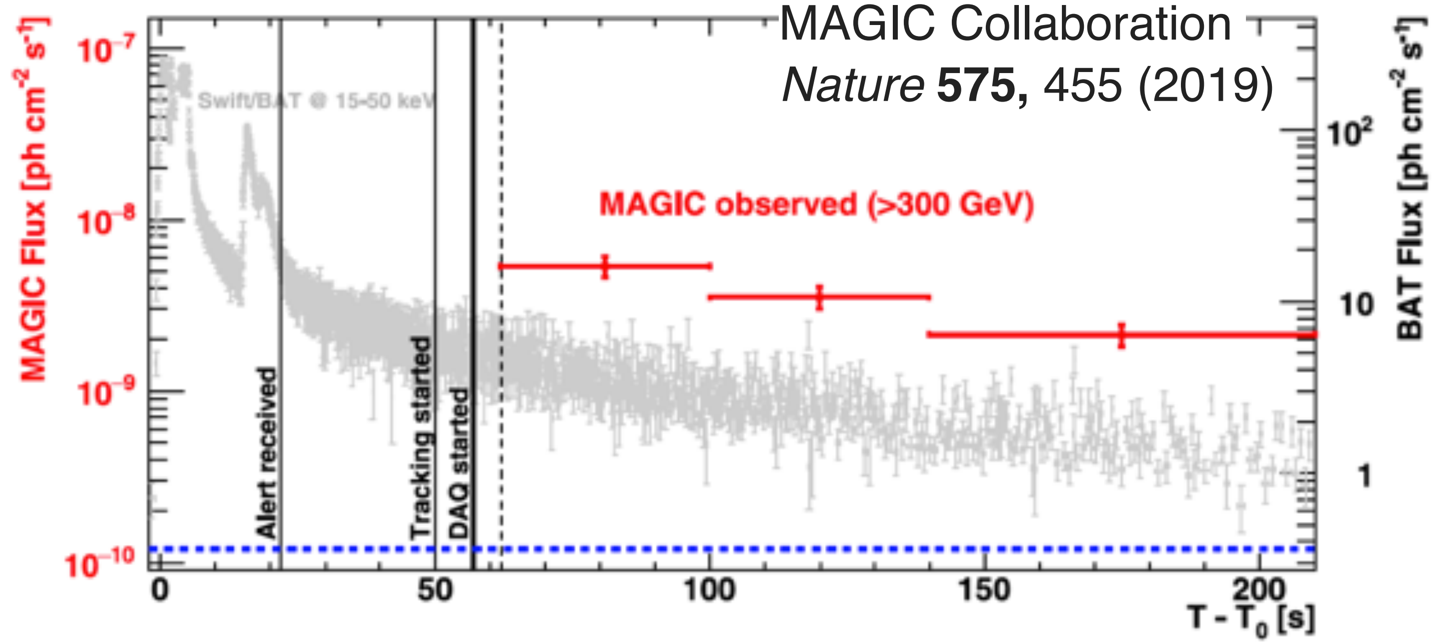


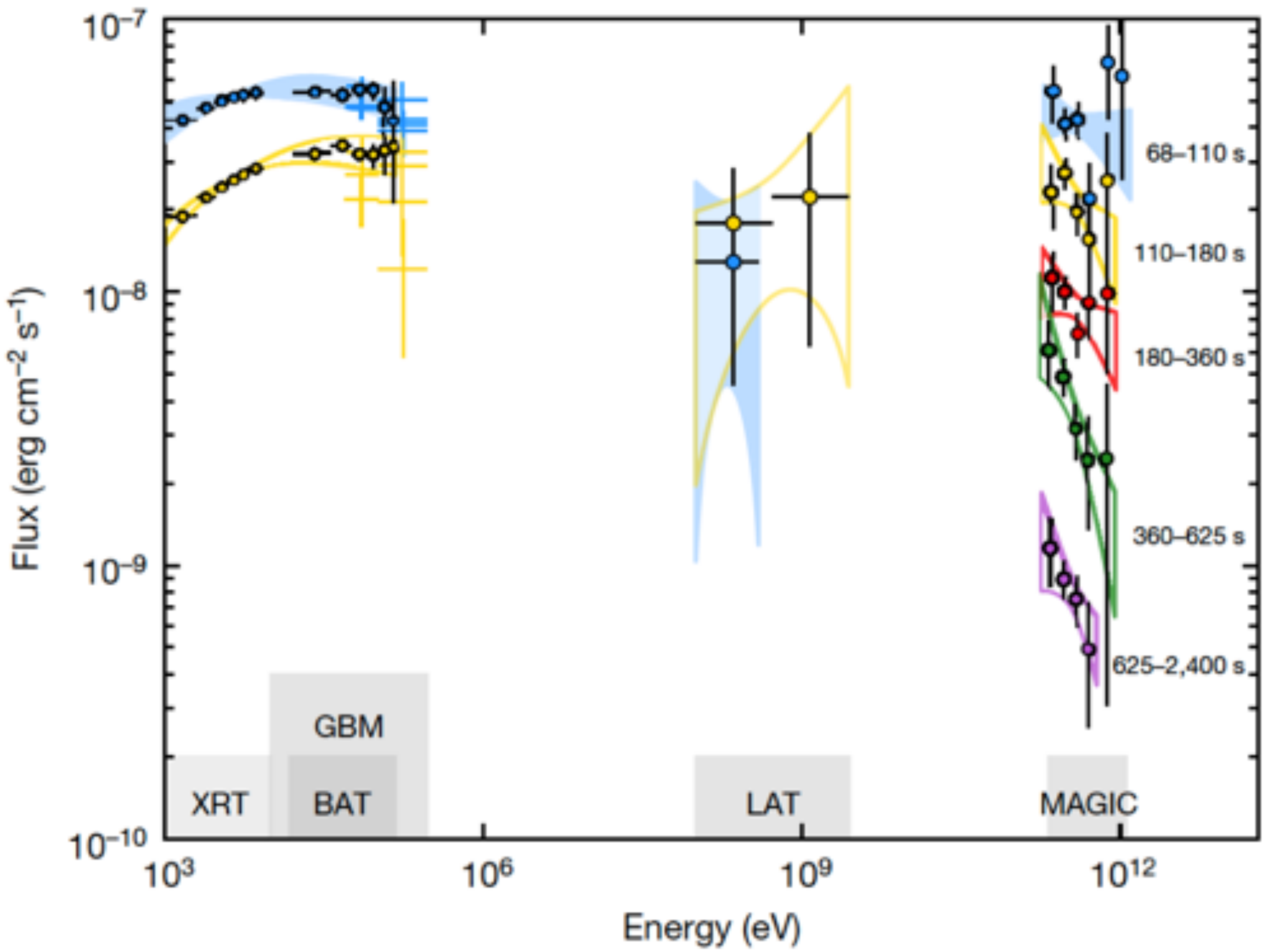


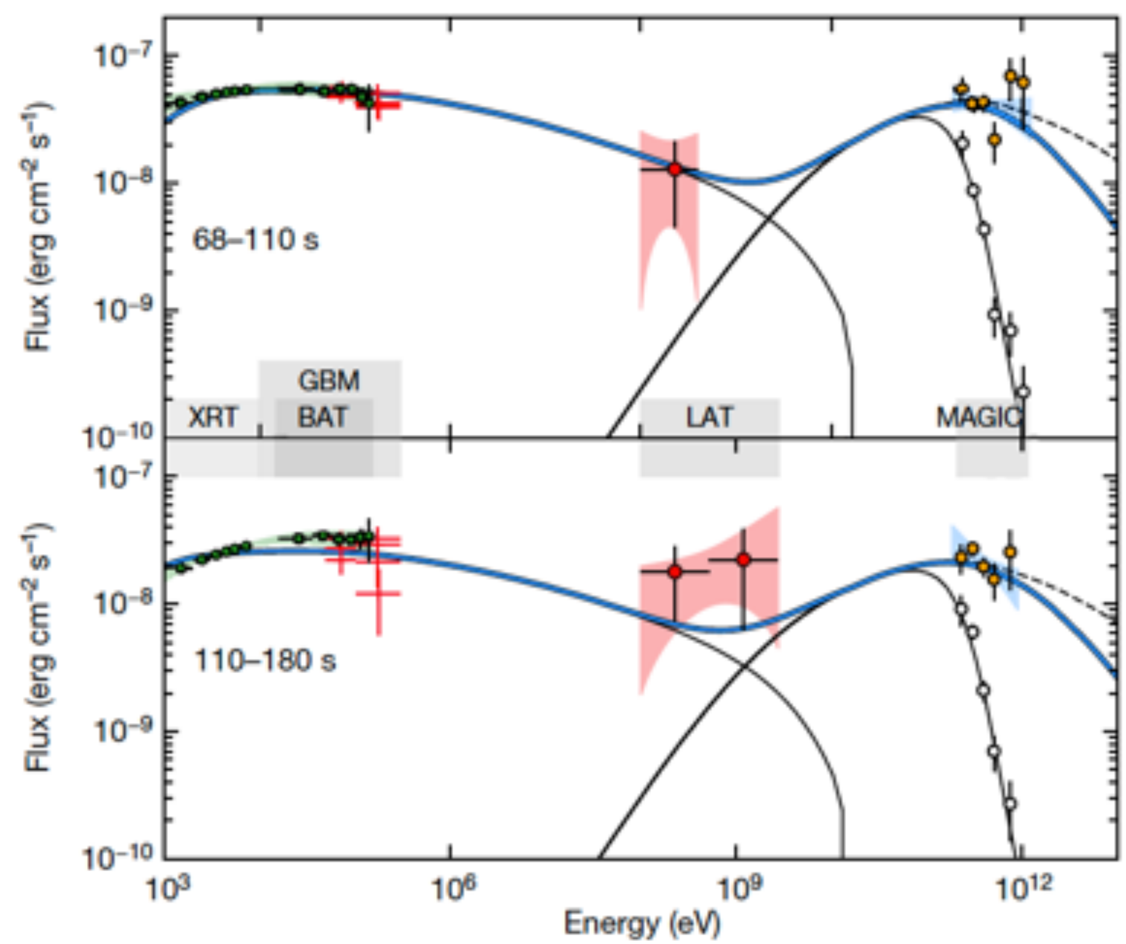
HESS Collaboration
Nature **575,** 464–467 (2019)

MAGIC: GRB190114C

- Redshift z = 0.42
- Large zenith angles + moonlight => relatively high energy threshold (~300GeV)

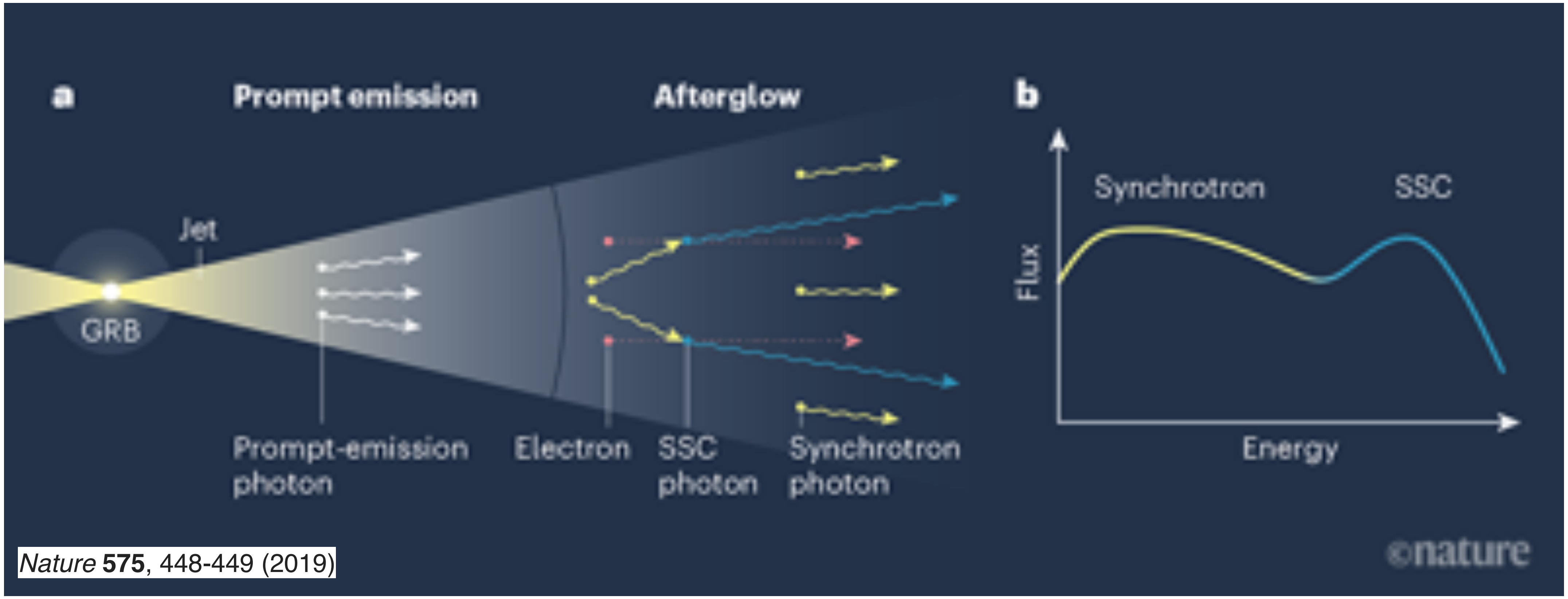






MAGIC et al., *Nature* **575,** 459 (2019)

A second high-energy component

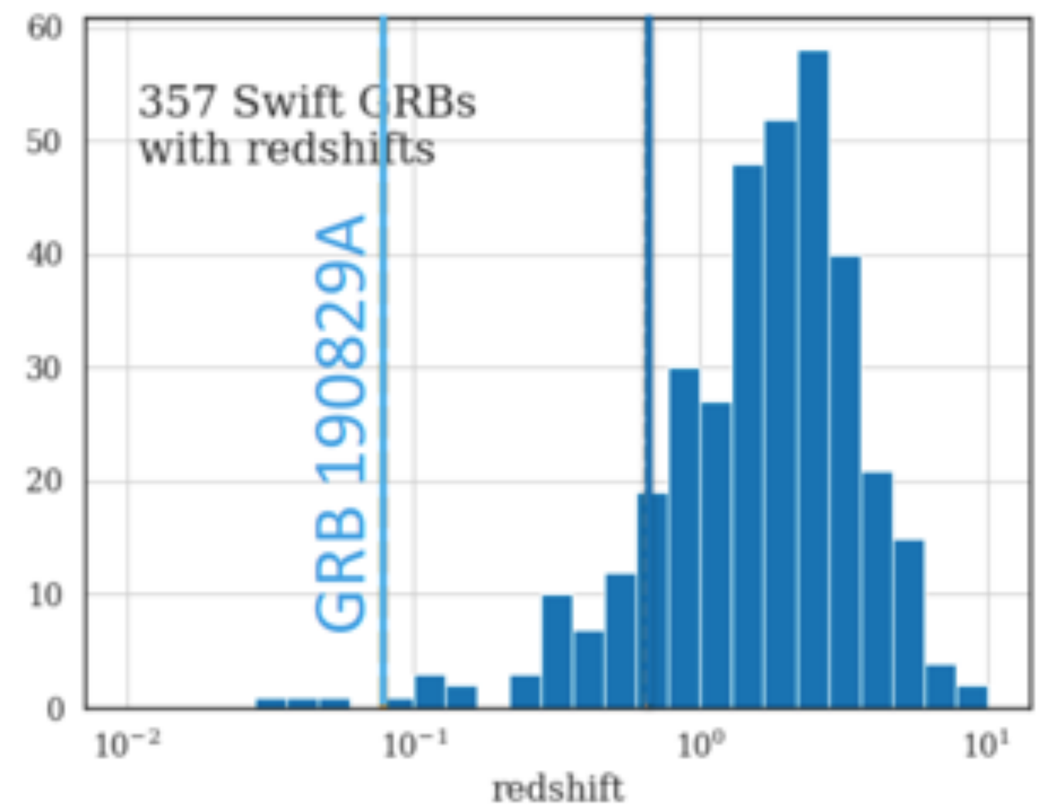


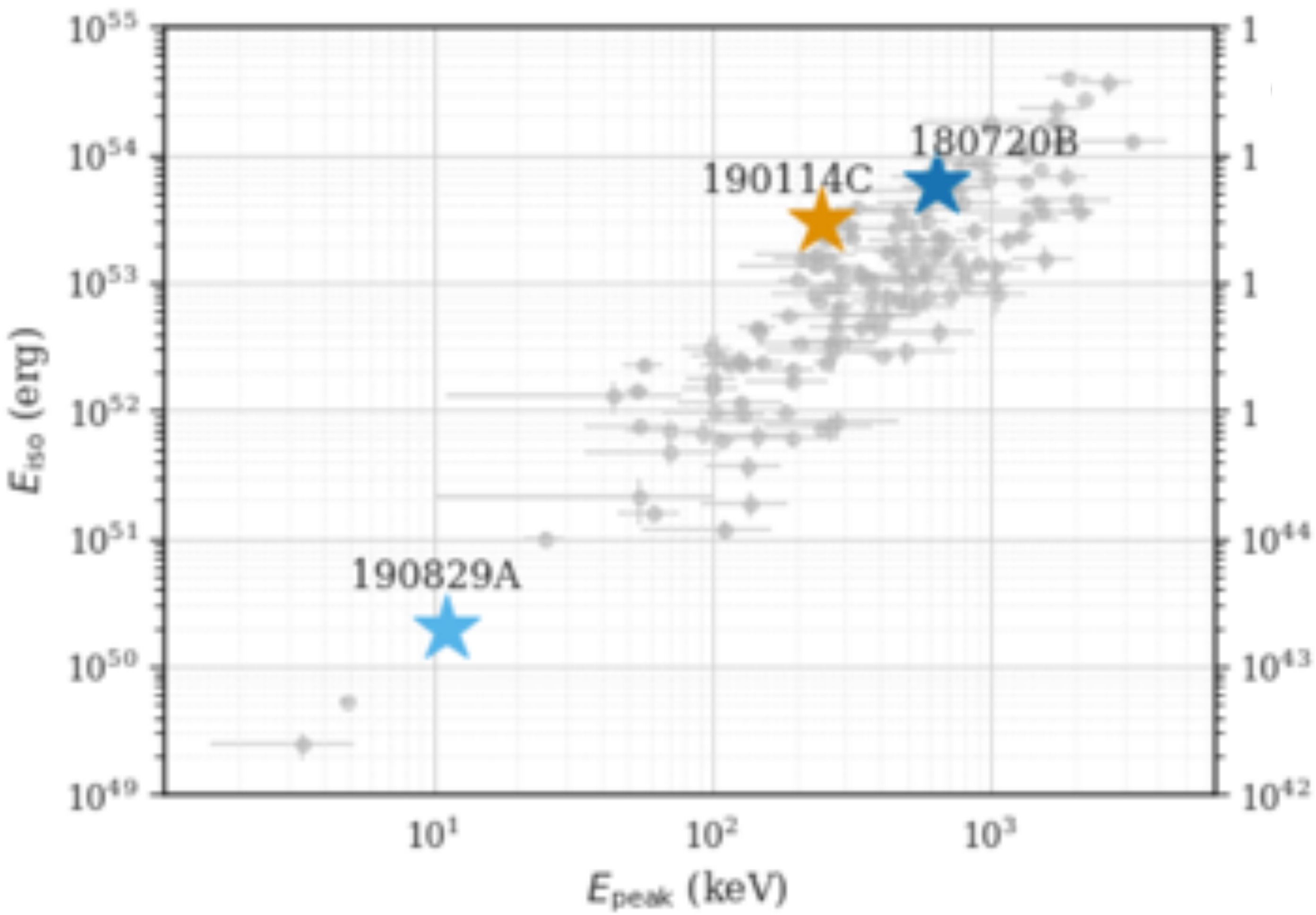
Nature **575**, 448-449 (2019)

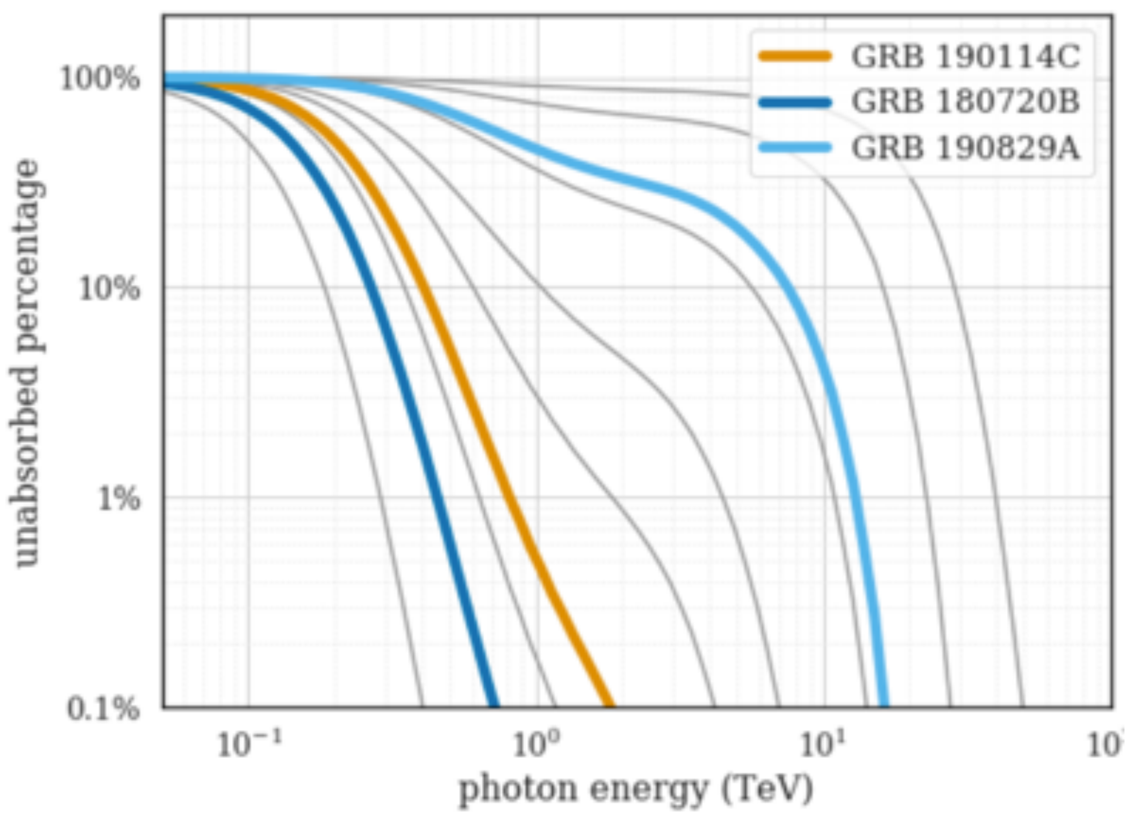
- Observation of the SSC component in GRBs
- X-rays and gamma-ray fluxes are of the same level
  - We were missing ~half of the emission in all previous GRB observations
- New questions
  - Is this true for all GRBs? What are the necessary conditions? …
  - How long does the VHE emission last? What is the maximum energy/efficiency/… ?
- Can we verify this with further observations (?)

GRB 190829A in a nutshell

- Extremely close burst: redshifts z = 0.0785
- Another very X-ray bright burst
- A special burst: low E_{iso} + low E_{peak}



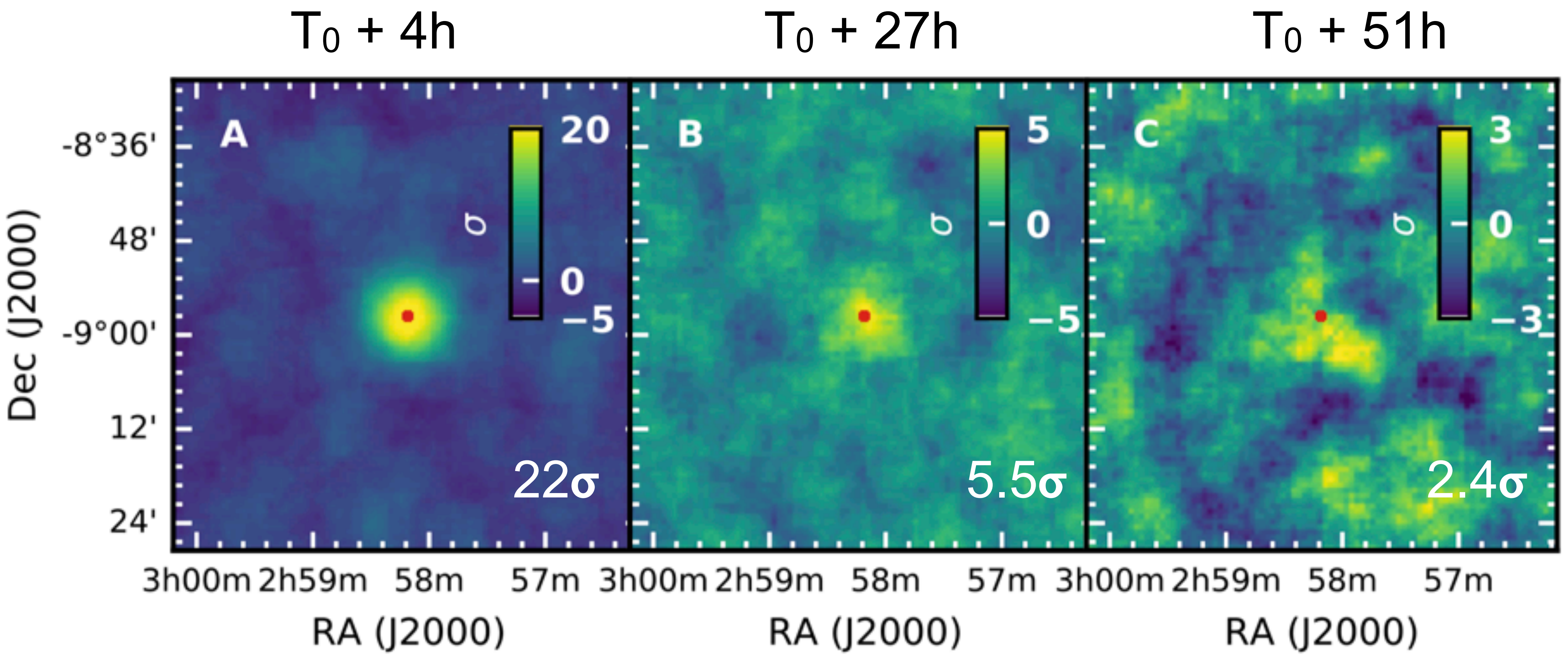




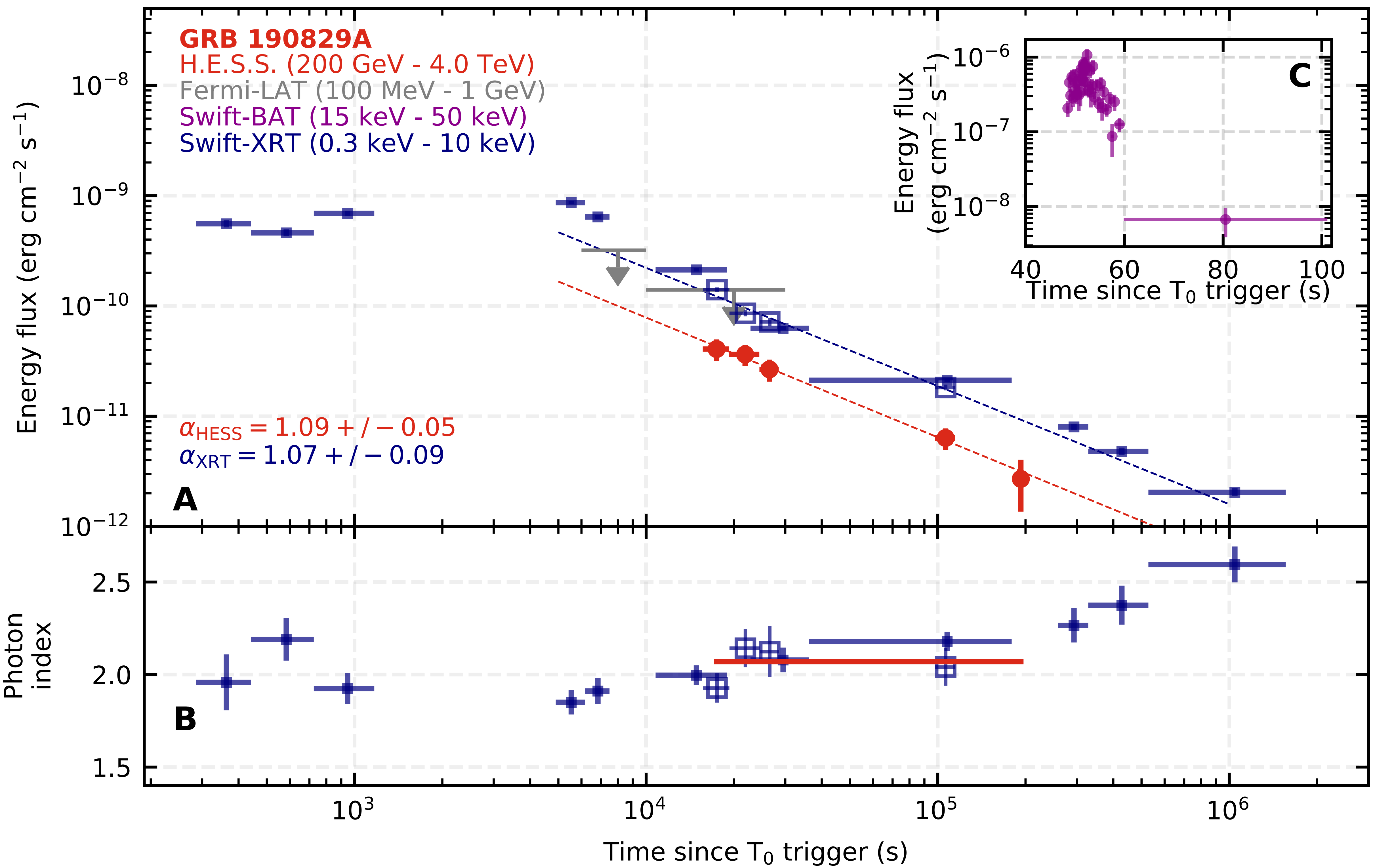
Irfu

GRB 190829A: the longest VHE afterglow

- Detection over 3 nights

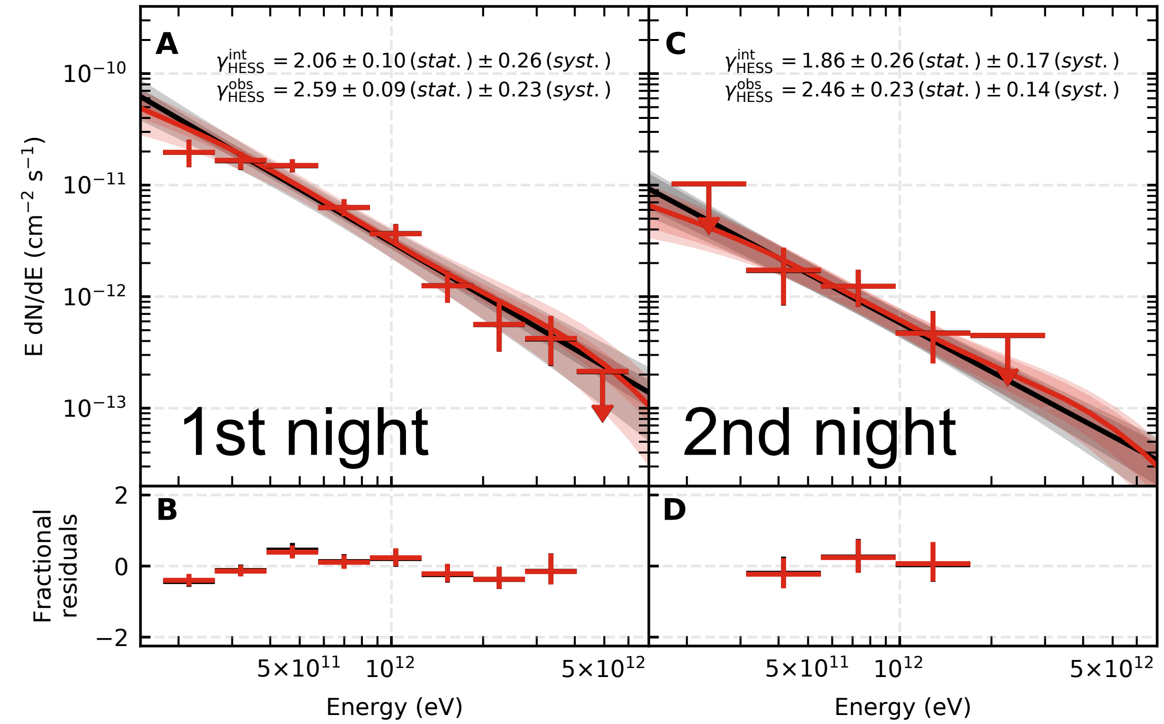


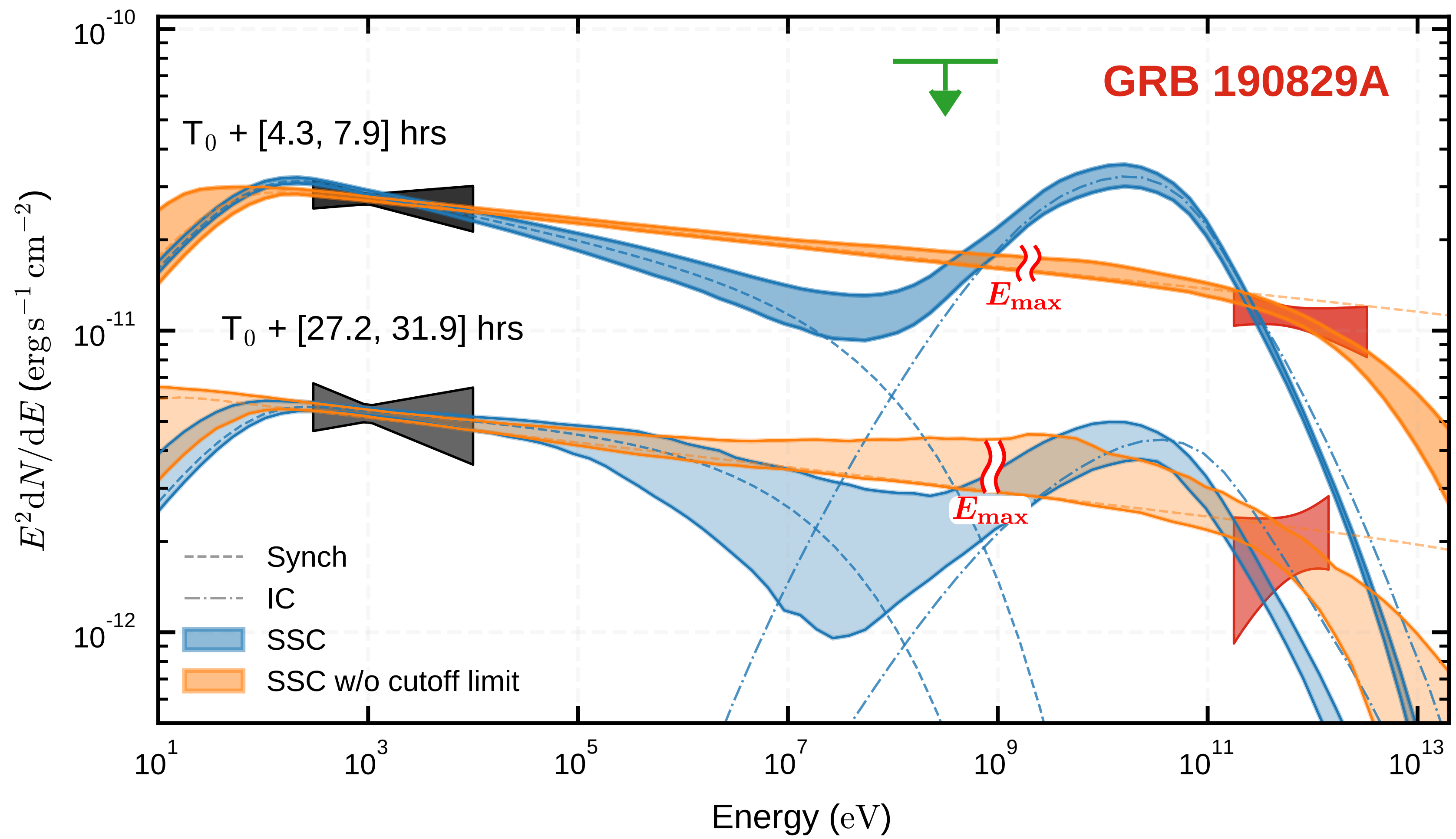
GRB 190829A: temporal evolution



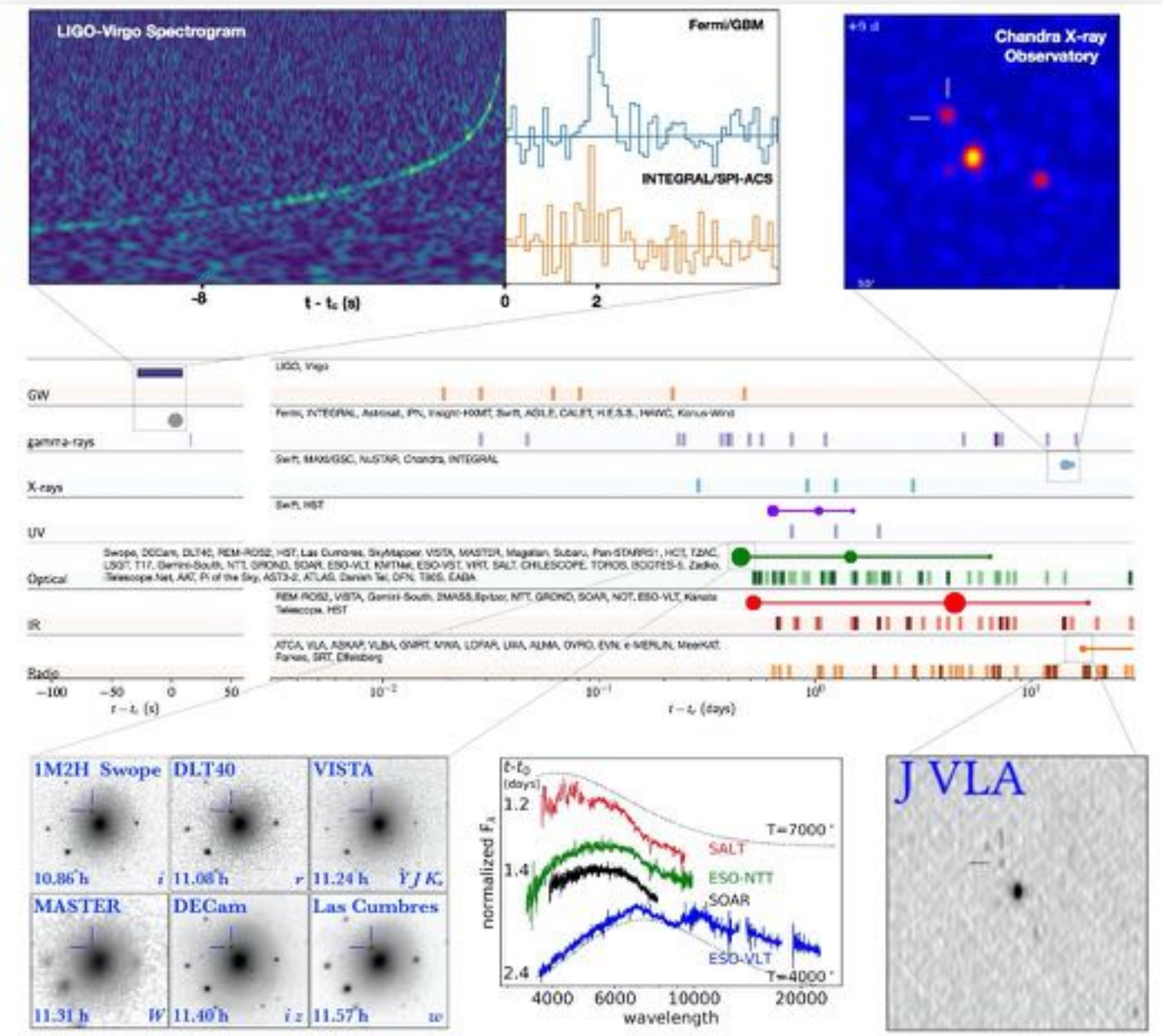
GRB 190829A: spectrum

- Problems for SSC model
  - Parameters outside the *standard* range (e.g. 10^3 doppler boosting; electron spectral break in the GeV-TeV range, leading to B-field and densities outside the typical range, …)
  - Synchrotron emission beyond the burn-off limit ? Need to separate acceleration and emission regions (e.g. decreasing downstream B-field, magnetic blobs, etc.)





Gravitational waves and Gamma-Ray Bursts

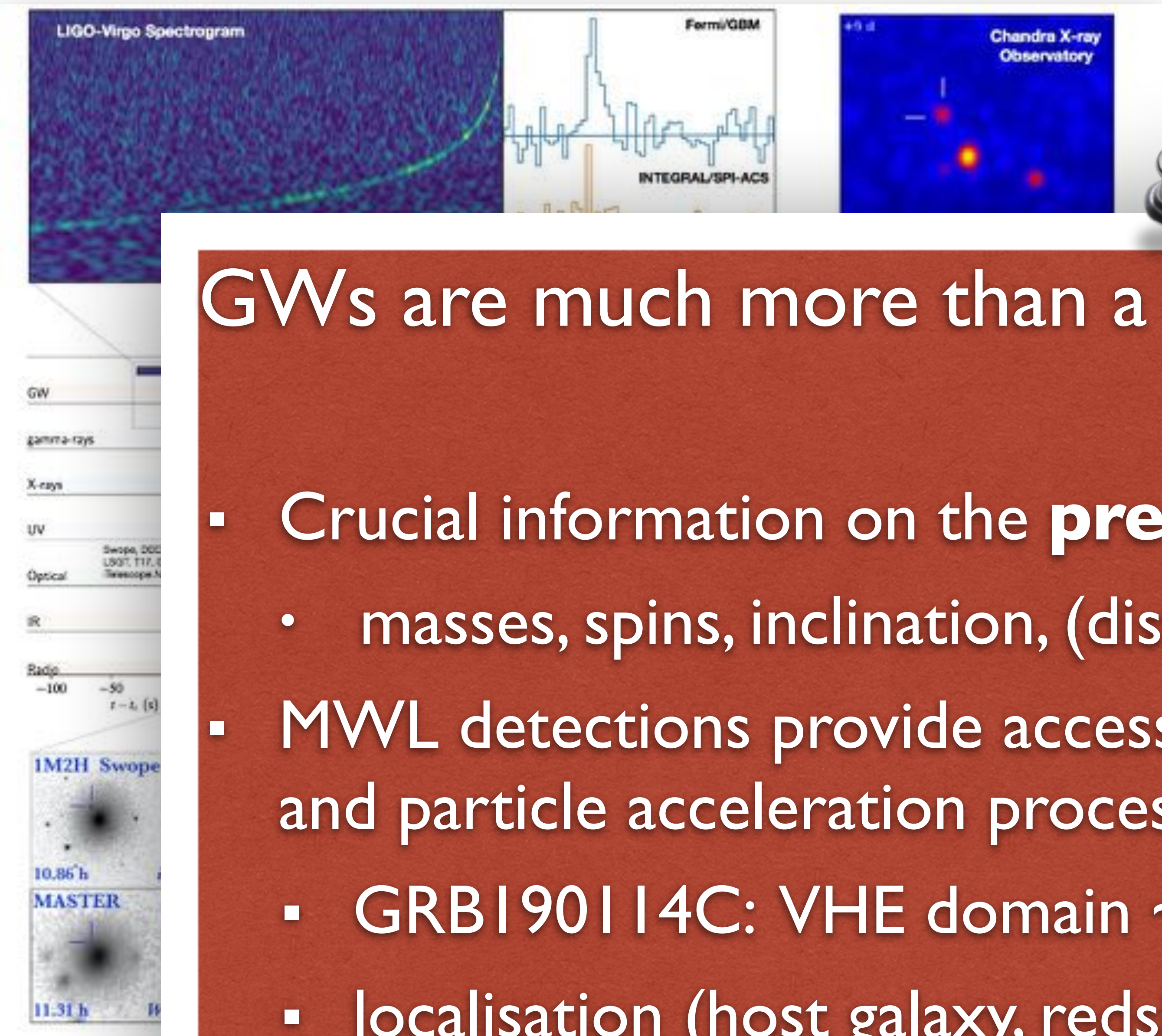


Abbott, B.P. et al 2017 ApJL 848 L12

- GW170817: NS-NS mergers are sources of (short) GRBs
- GRB160821B (!?!)
- GRB180720B
- GRB190114C
- GRB190829A
- GRBs emit at VHE energies
- VHE emission is strong enough for current IACTs
- VHE emission is long-lasting (GRB190829A: >56h)
- Let's detect VHE emission from NS-NS (and NS-BH) mergers…

Links to Gamma-Ray Bursts

- GW170817: NS-NS mergers are sources of (short) GRBs
- GRB160821B (?)

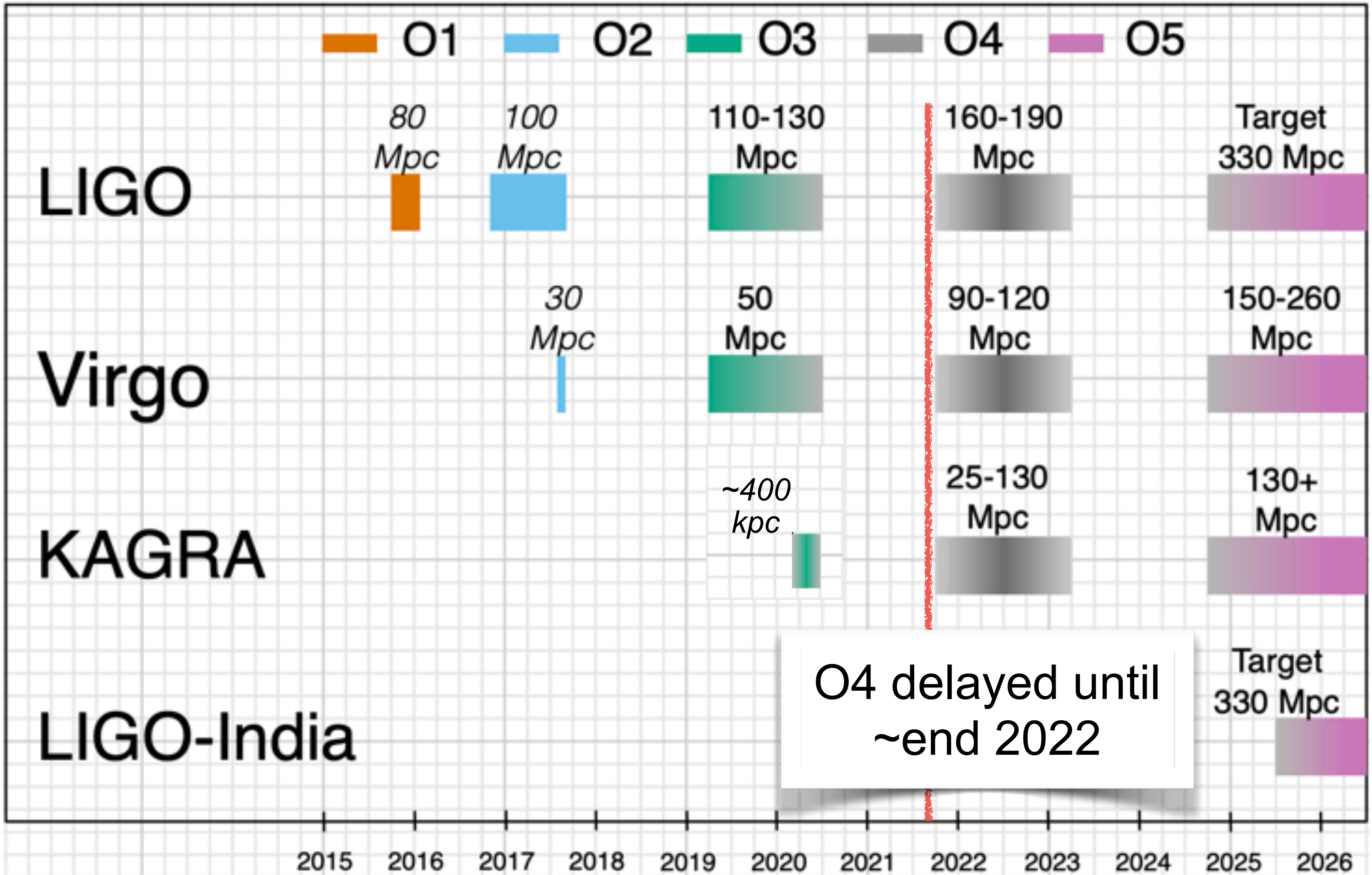


GWs are much more than a new way to detect GRBs

- Crucial information on the **pre-merger** system
  - masses, spins, inclination, (distance), …
- MWL detections provide access to **post-merger** energetics and particle acceleration processes
  - GRB190114C: VHE domain ~50% of L_{tot}
  - localisation (host galaxy, redshift, etc.), local environment, …

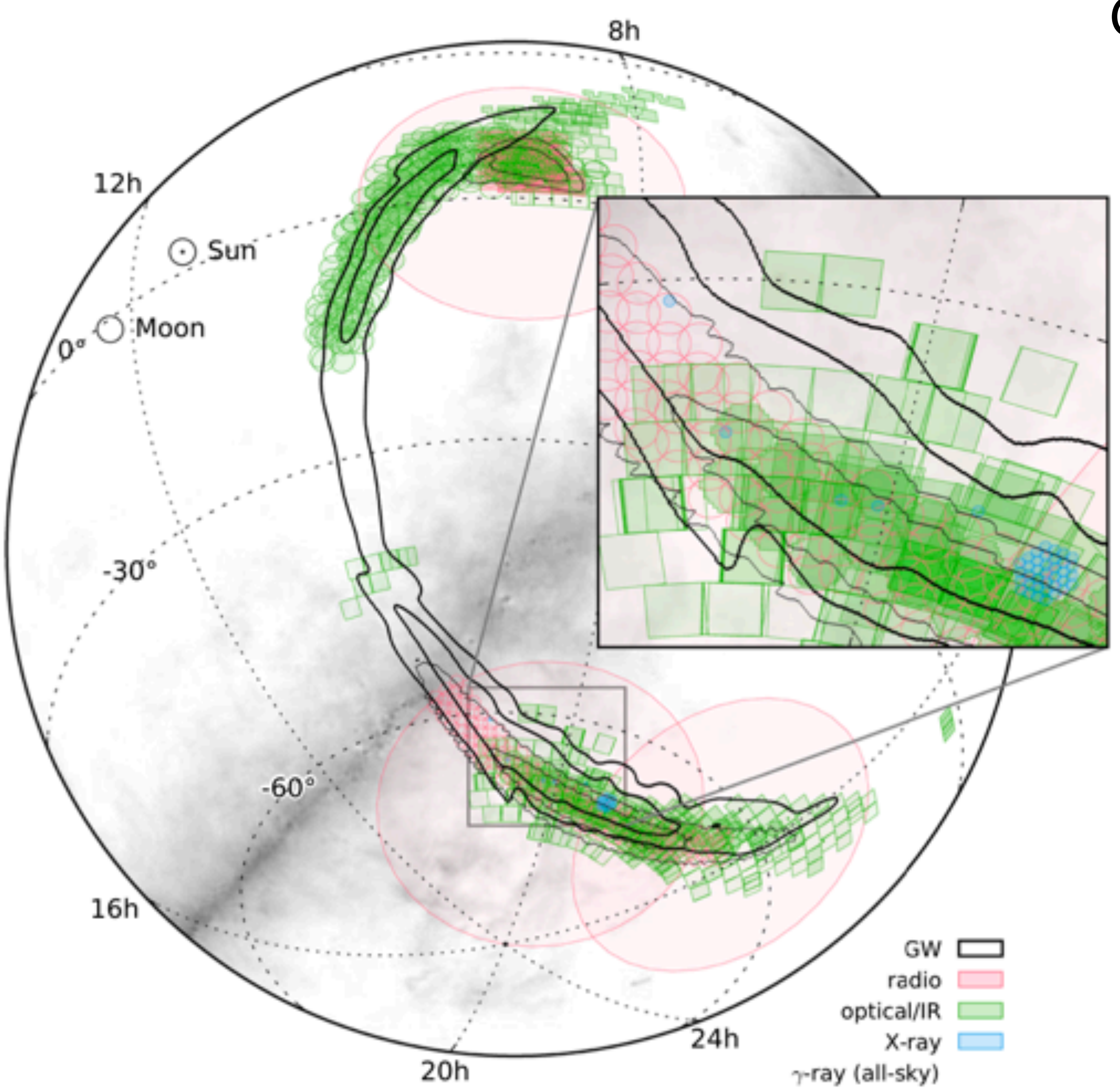
- Let's detect VHE emission from NS-NS (and NS-BH) mergers…

Overview: O1 + O2 + O3 + …



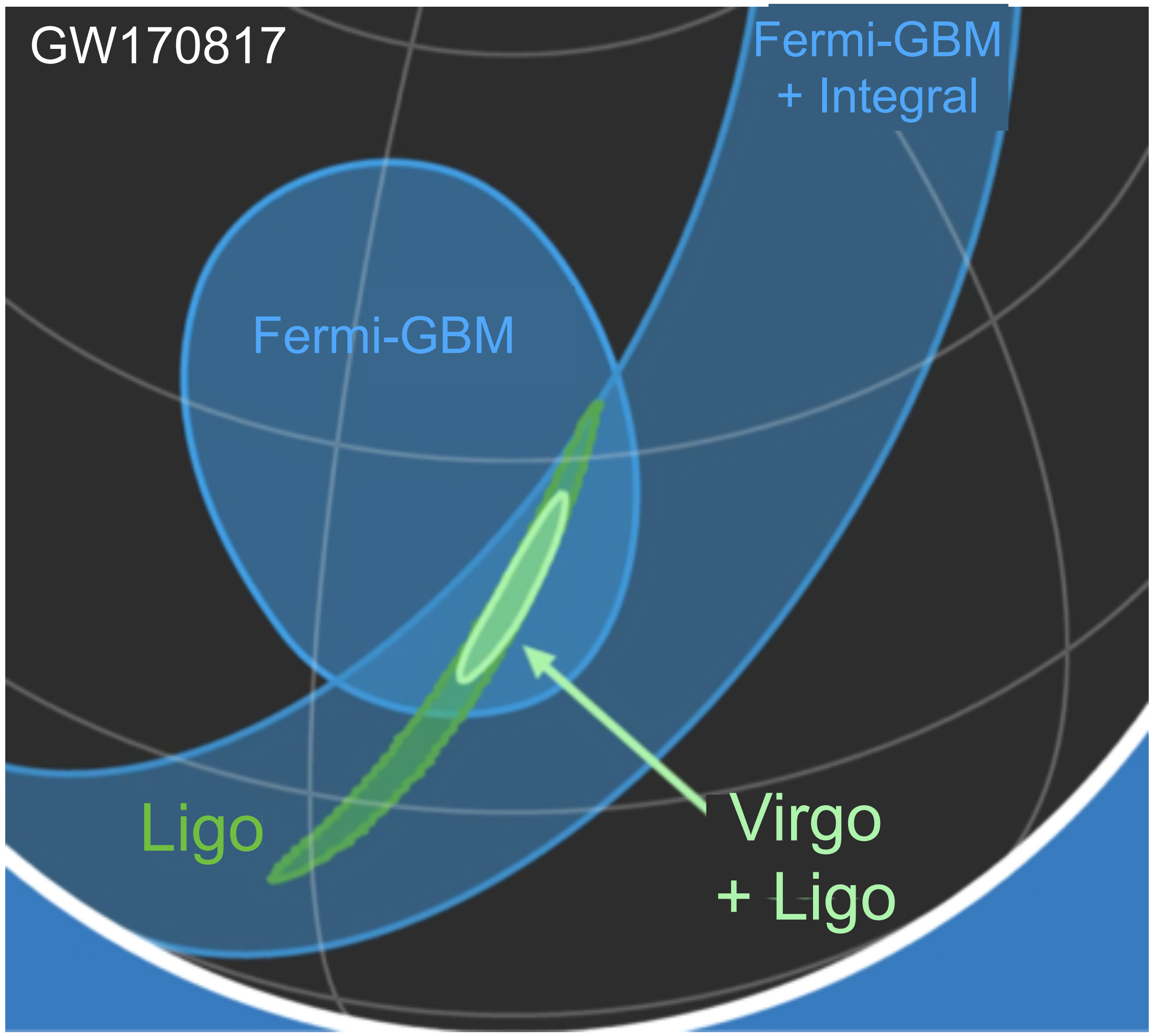
Modified from B.P. Abbott et al., arXiv:1304.0670 (v11, 2020-11-24)

GW150914

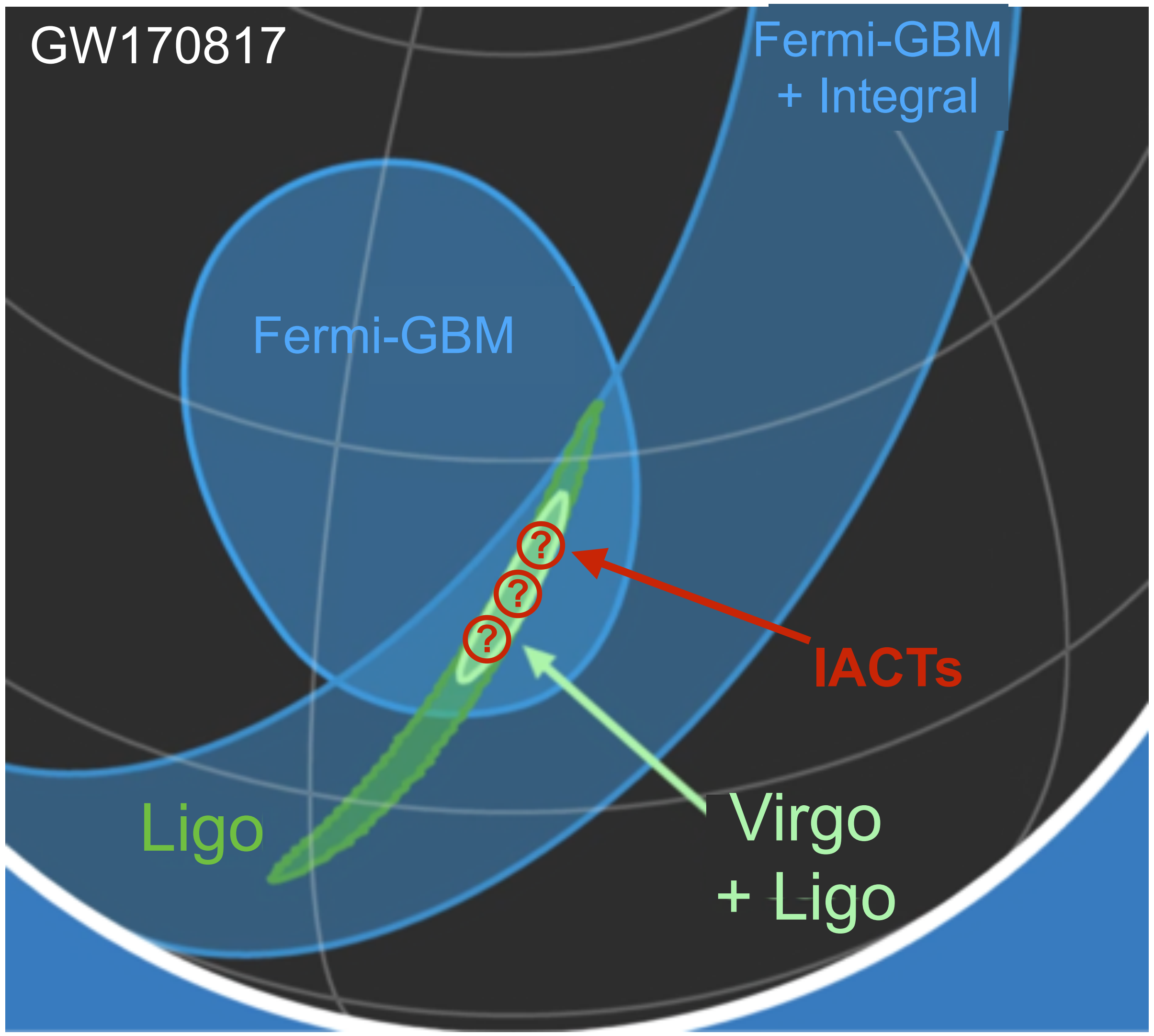


Virgo+Ligo+et al., ApJL 826:L13 (2016)

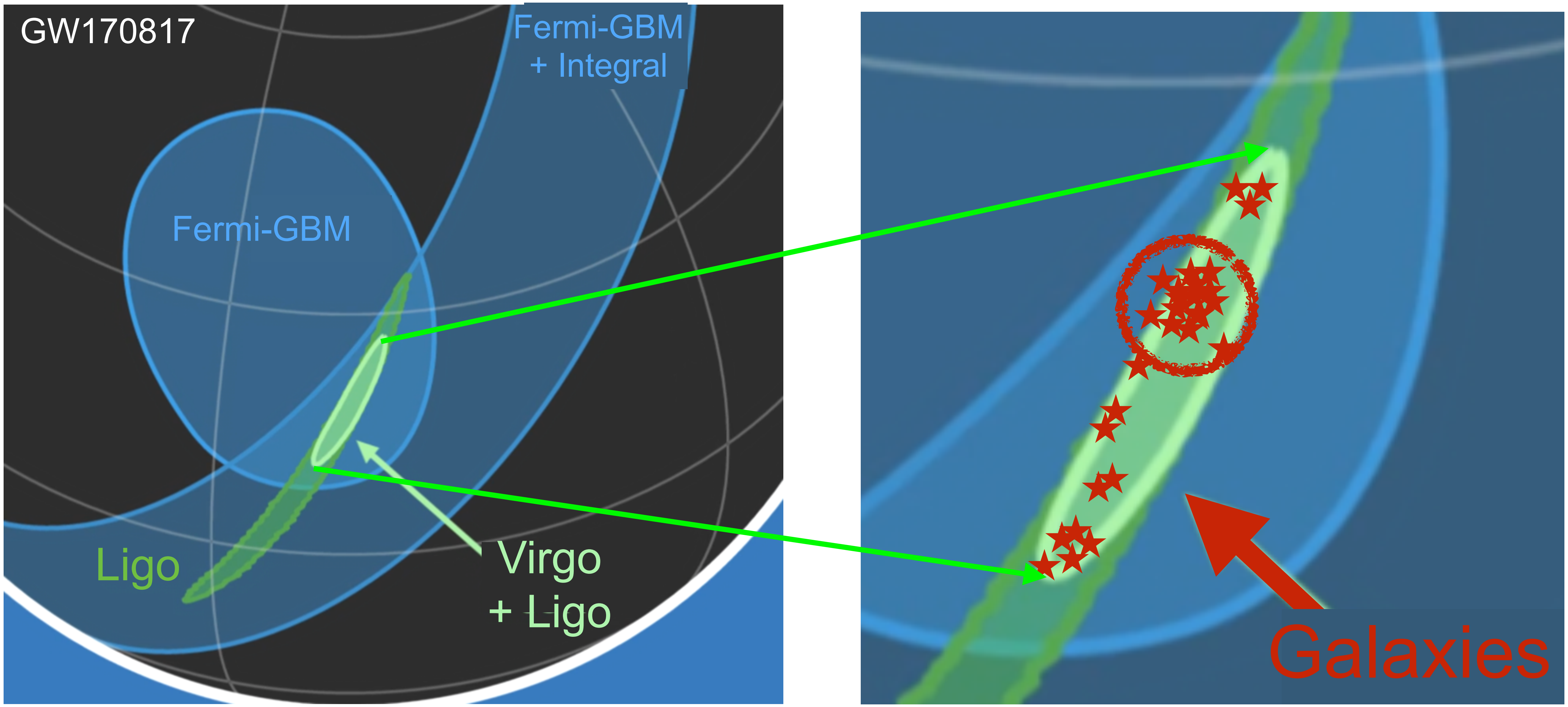
Scheduling and pointing strategy



Scheduling and pointing strategy



Scheduling and pointing strategy

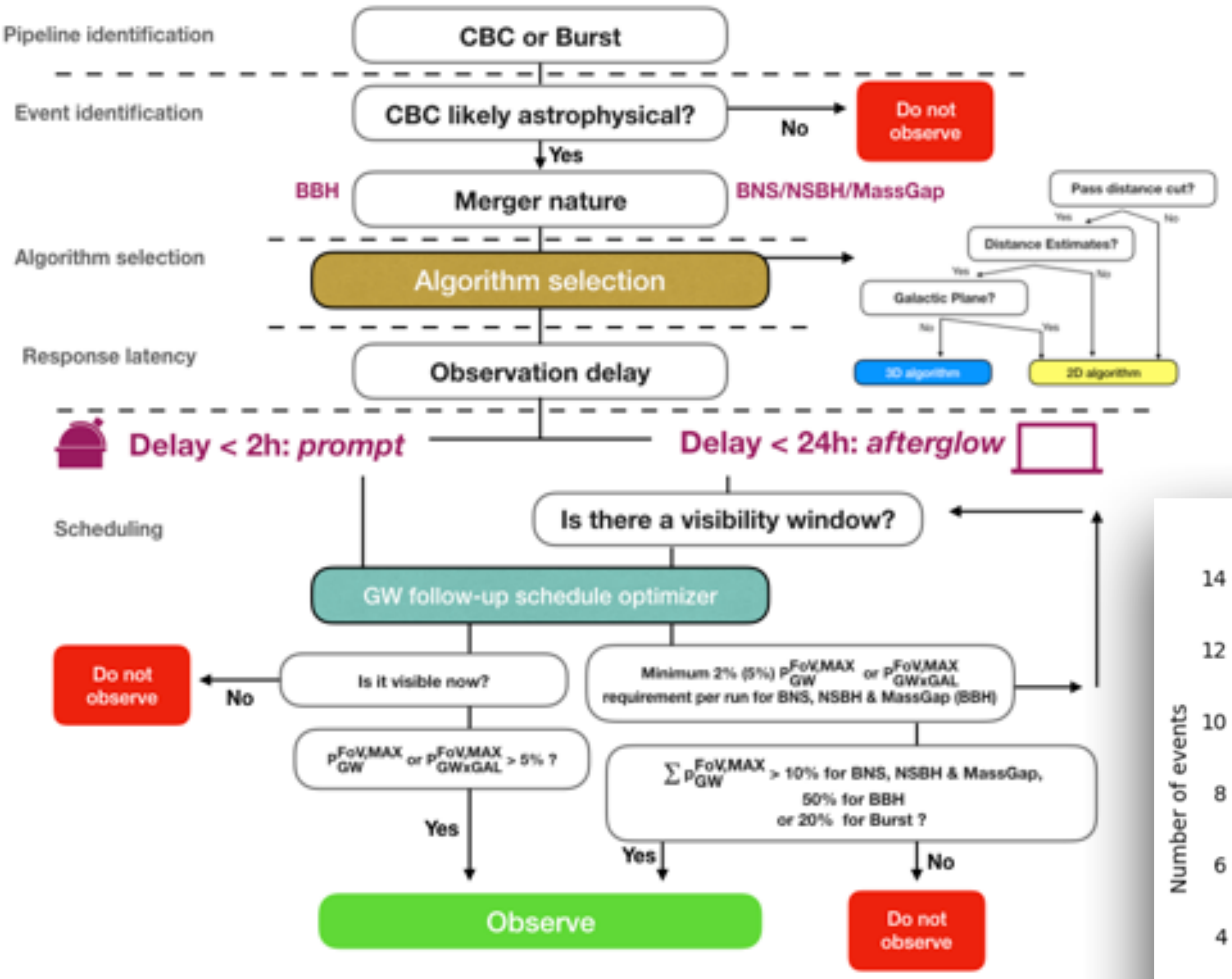


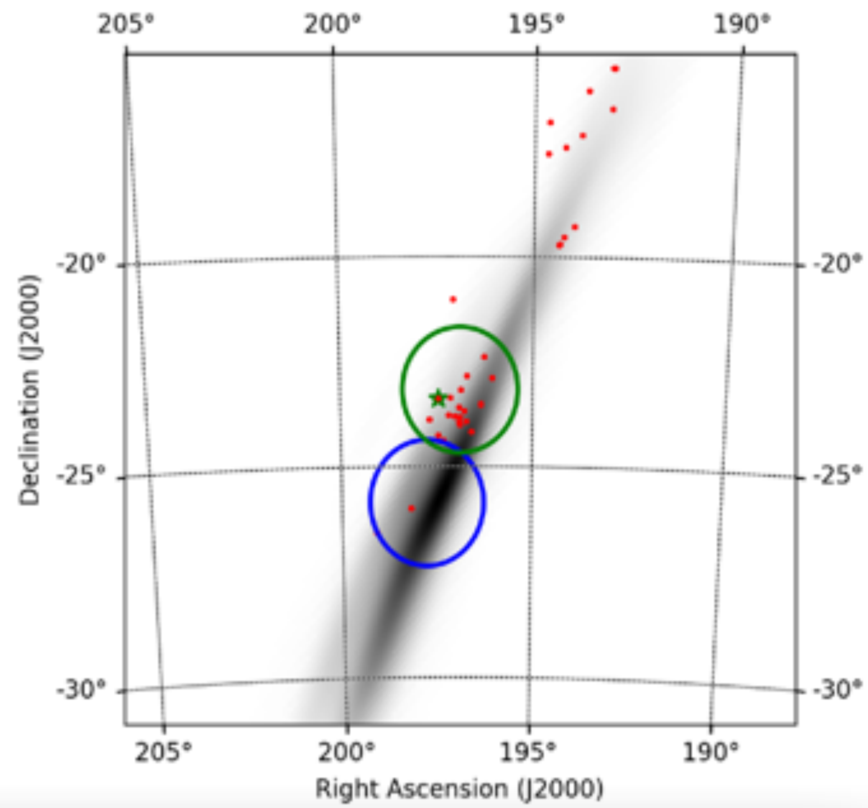
- automatic selection of regions of interest
  - correlation with galaxy catalog(s) in 3 dimensions
  - dedicated algorithms for the different possibilities (e.g. BNS, BBH, bursts, etc.)

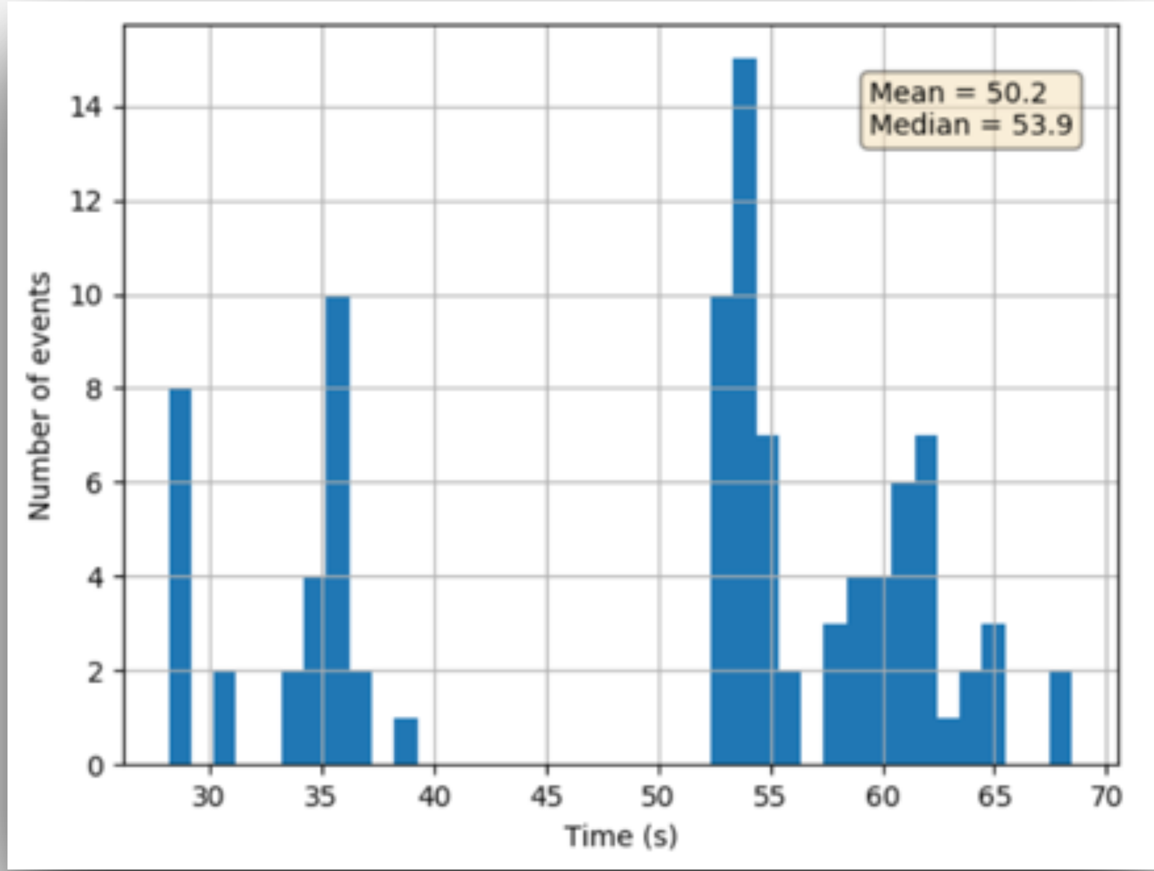
M. Seglar-Arroyo + FS (H.E.S.S.), Moriond VHEPU 2017, arXiv: 1705.10138

Irfu

Scheduling and pointing strategy

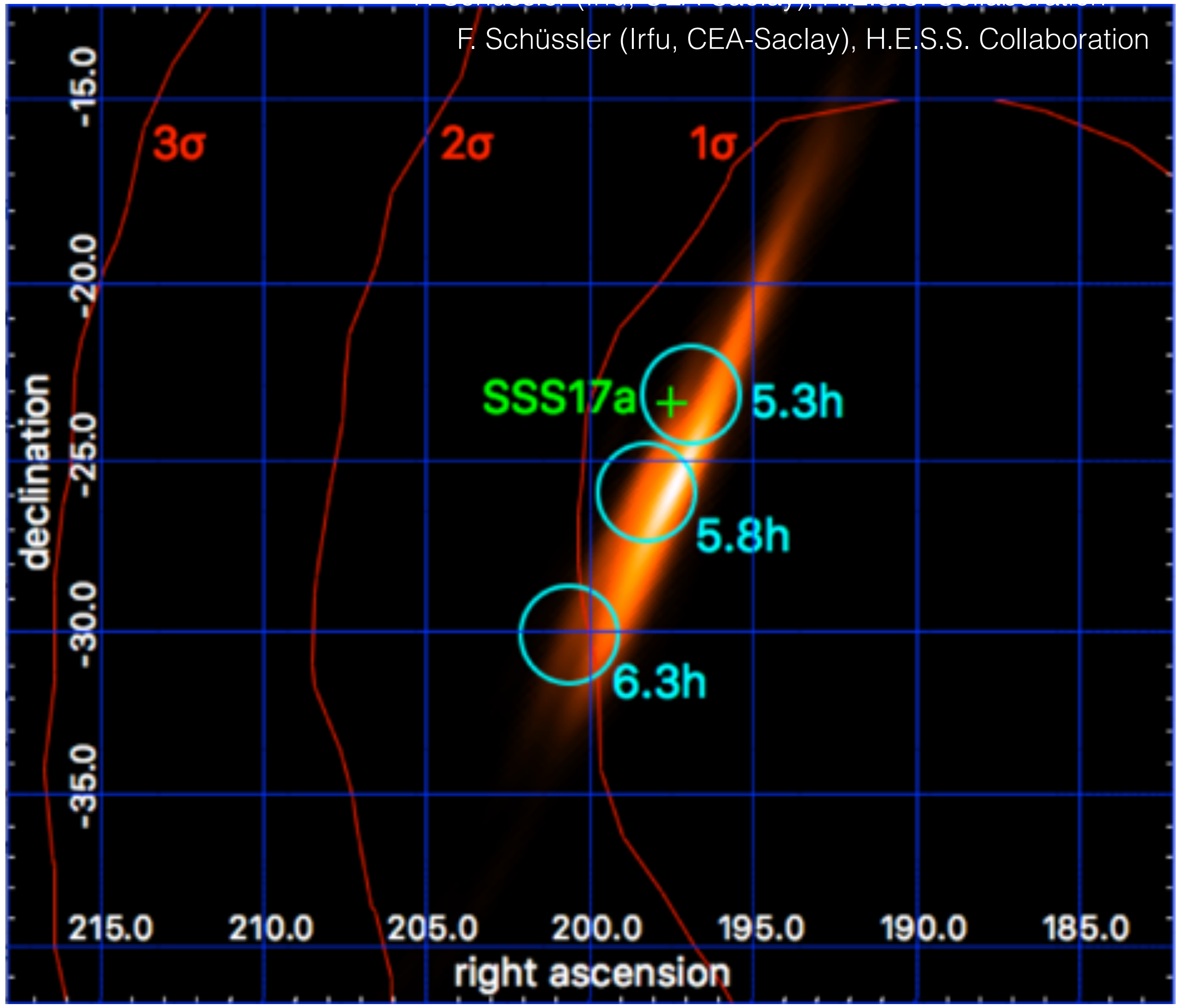






H. Ashkar et al., "The H.E.S.S. Gravitational Wave Rapid Follow-up Program", JCAP03(2021)045, arXiv: 2010.16172

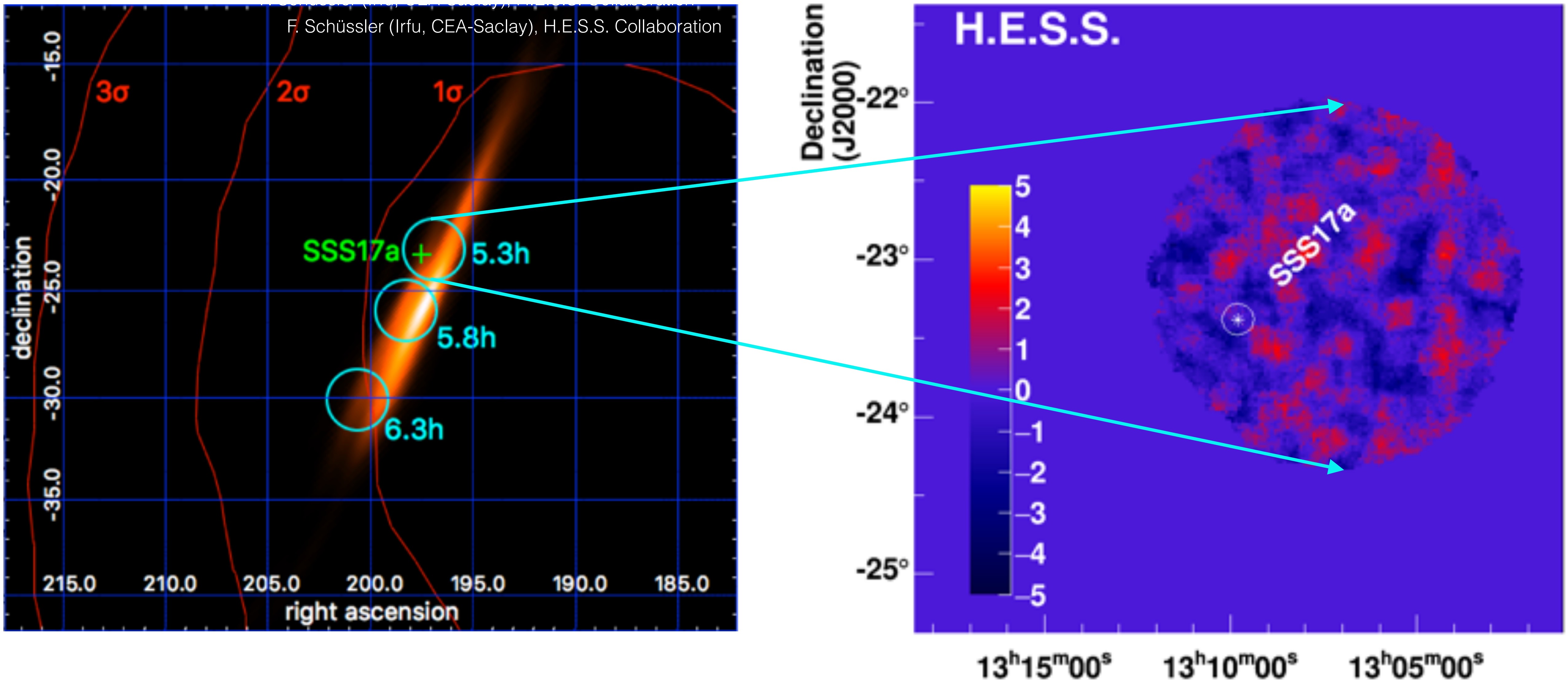
H.E.S.S. rapid follow-up of GW170817



H. Abdalla et al. (H.E.S.S.), ApJL 855:L22 (2017)

- First observations of a ground-based pointing instrument
  - 5.3 hours after GW170817 (5 minutes after GCN circular with Ligo+Virgo analysis)
  - first pointing containing SSS17a (AT 2017gfo)

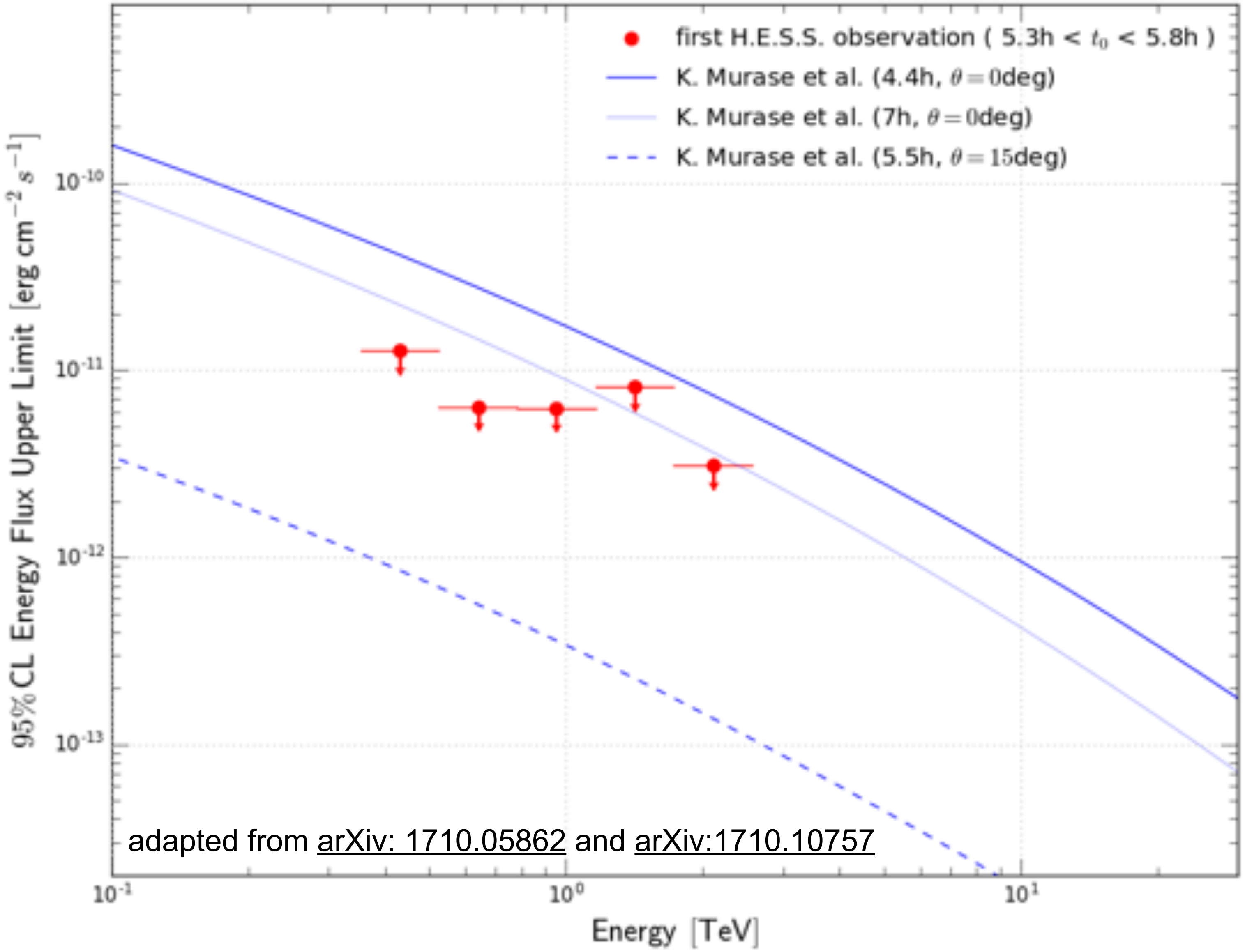
H.E.S.S. rapid follow-up of GW170817



- First observations of a ground-based pointing instrument
  - 5.3 hours after GW170817
  - 5 minutes after the GCN circular announcing the Ligo+Virgo analysis
  - no significant signal: Φ (0.28 < E [TeV] < 2.31) < 3.9 x 10^{-12} erg cm^{-2} s^{-1}
  - monitoring campaign over 5 nights

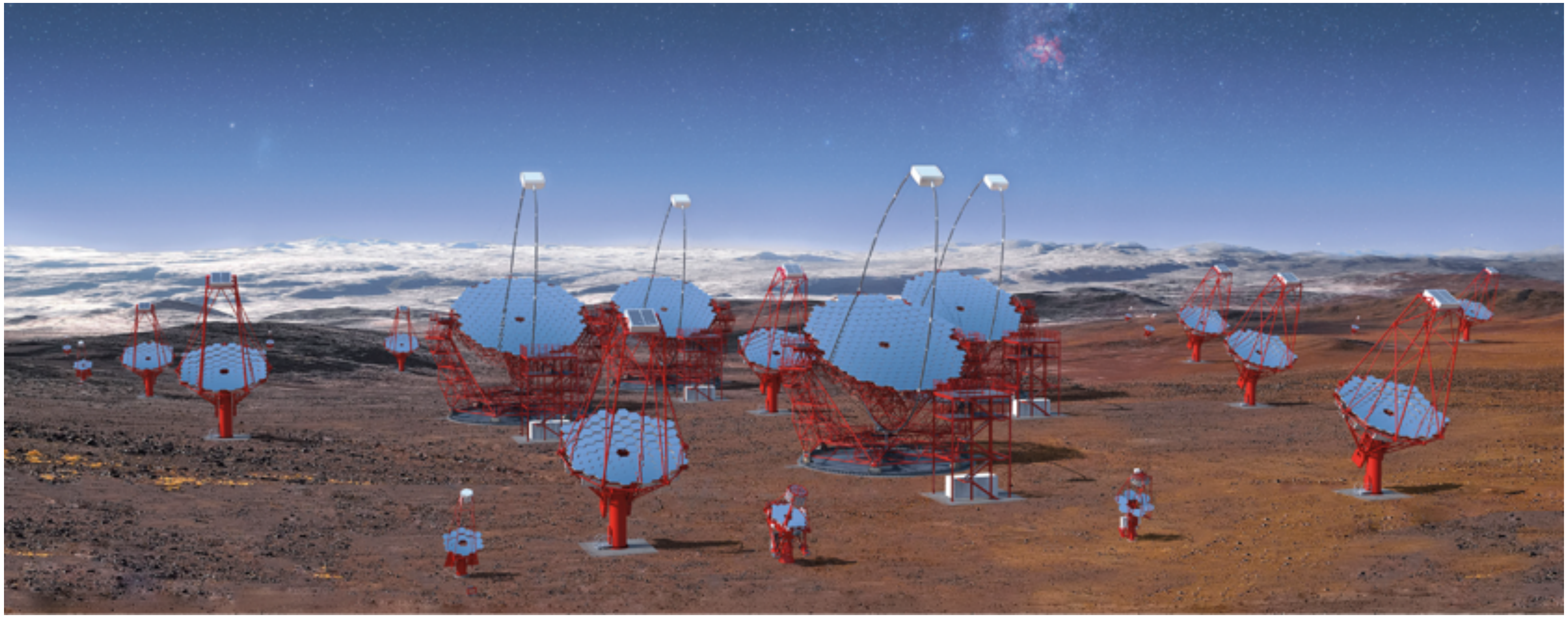
H. Abdalla et al. (H.E.S.S.), ApJL 855:L22 (2017)

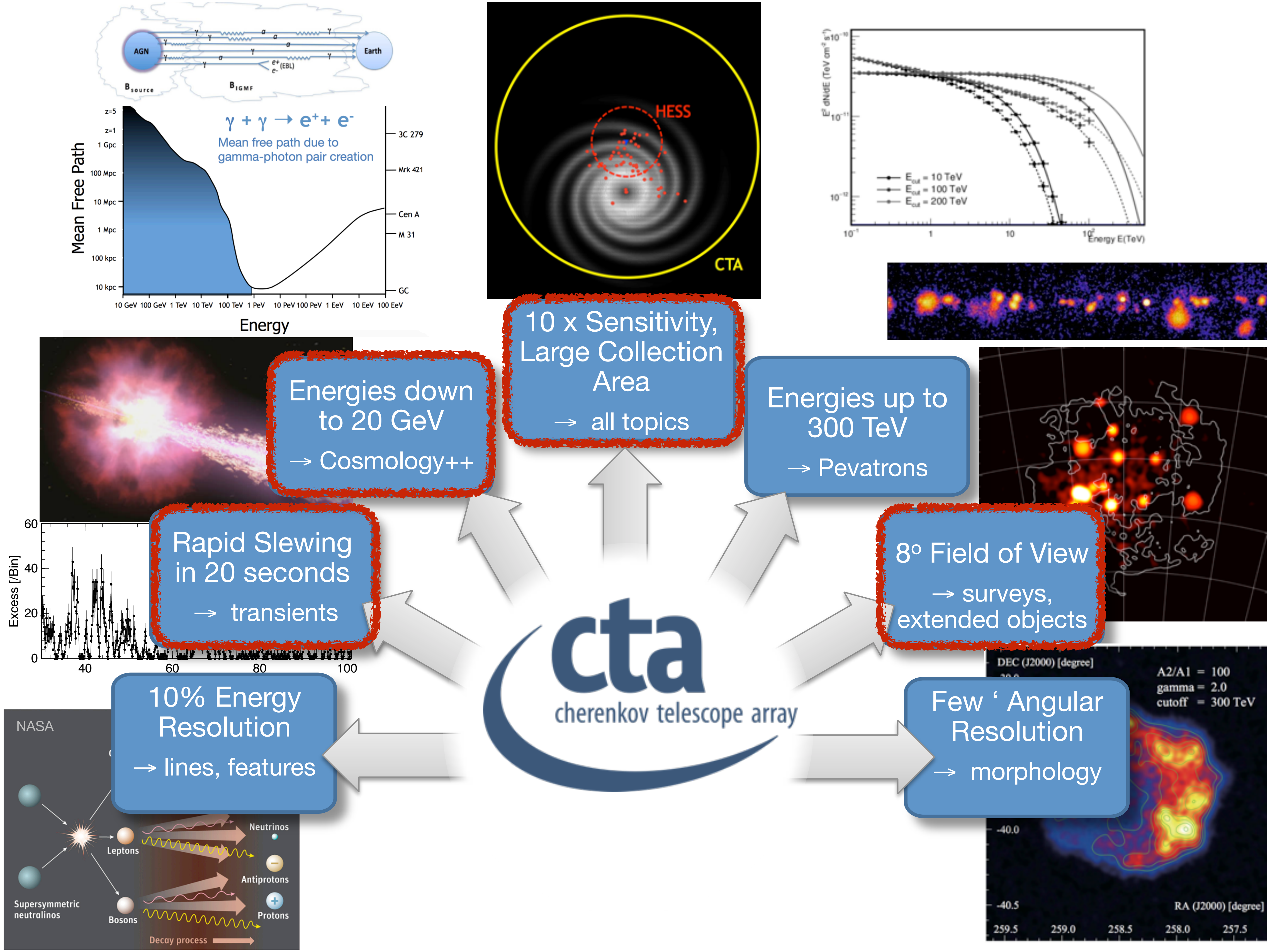
H.E.S.S. observations of GW170817: prompt observations



- e.g. K. Murase et al. (arXiv:1710.10575)
  - high-energy signatures from long-lasting central engines
  - inverse Compton: X-ray up-scattering by electrons in the jet
  - H.E.S.S. observations constrain on-axis emission
  - CTA will have access to off-axis emission

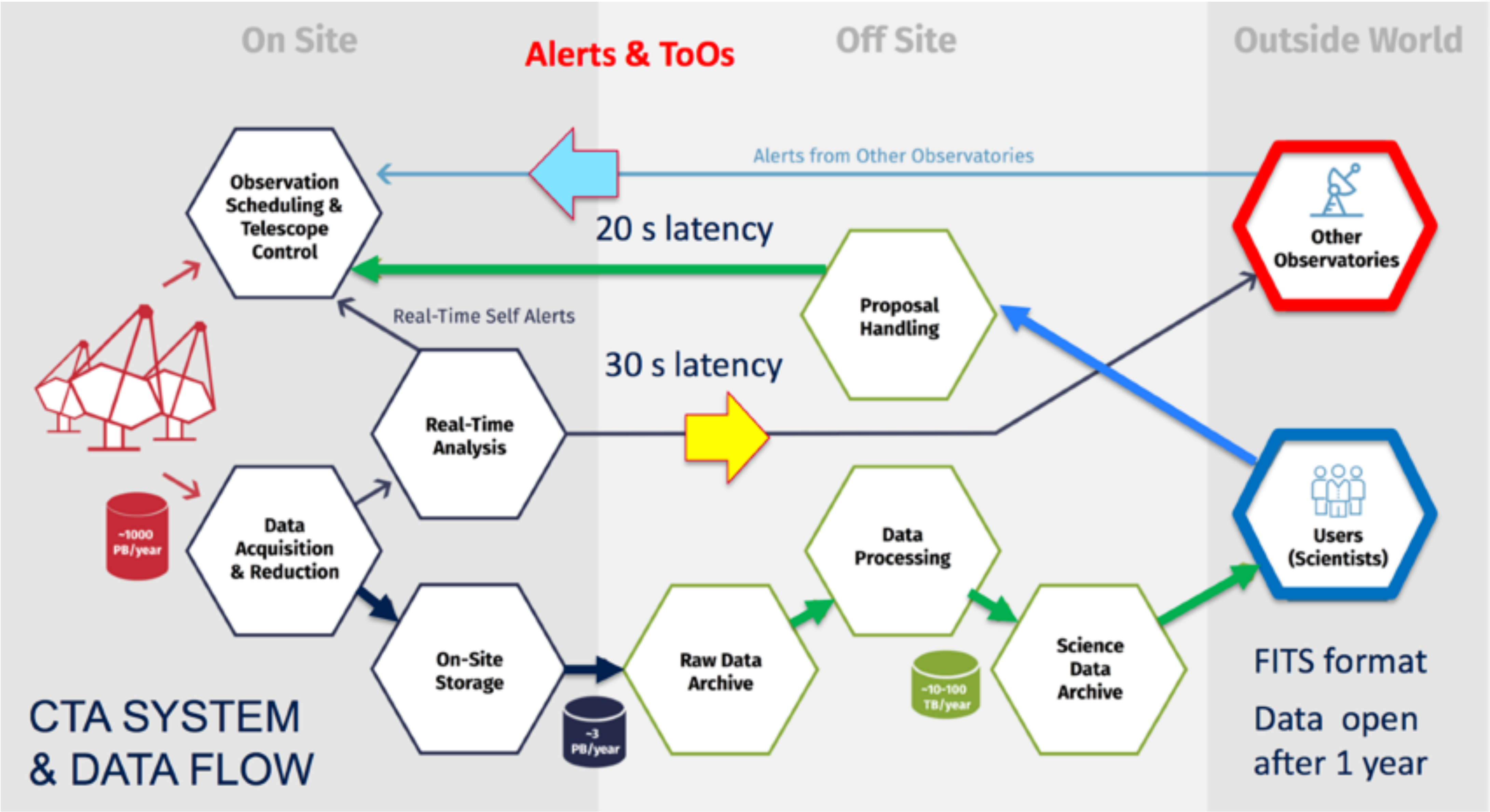
The Cherenkov Telescope Array




10 x Sensitivity, Large Collection Area
→ all topics
Energies down to 20 GeV
→ Cosmology++
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
cherenkov telescope array
γ + γ → e⁺+ e⁻
Mean free path due to gamma-photon pair creation
Mean Free Path
Energy
HESS
CTA
NASA
Neutrinos
Leptons
Antiprotons
Protons
Bosons
Supersymmetric neutralinos
Decay process
Excess [/Bin]
A2/A1 = 100
gamma = 2.0
cutoff = 300 TeV

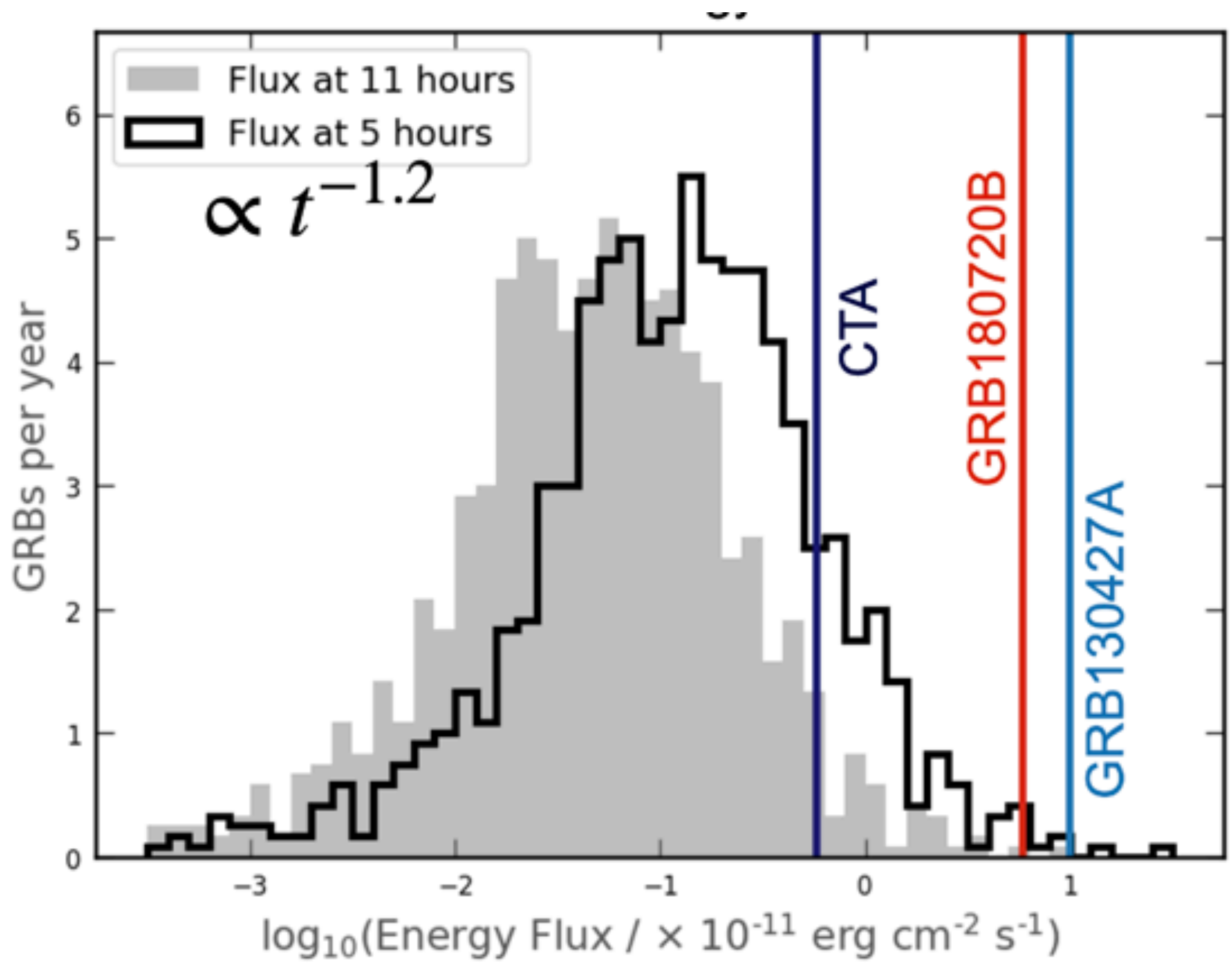
The CTA Transient program

- Transients are integral part of the CTA "Key Science Projects"
  - Observation time allocated to the CTA consortium
- dedicated Science Working Group "Transients and MWL"

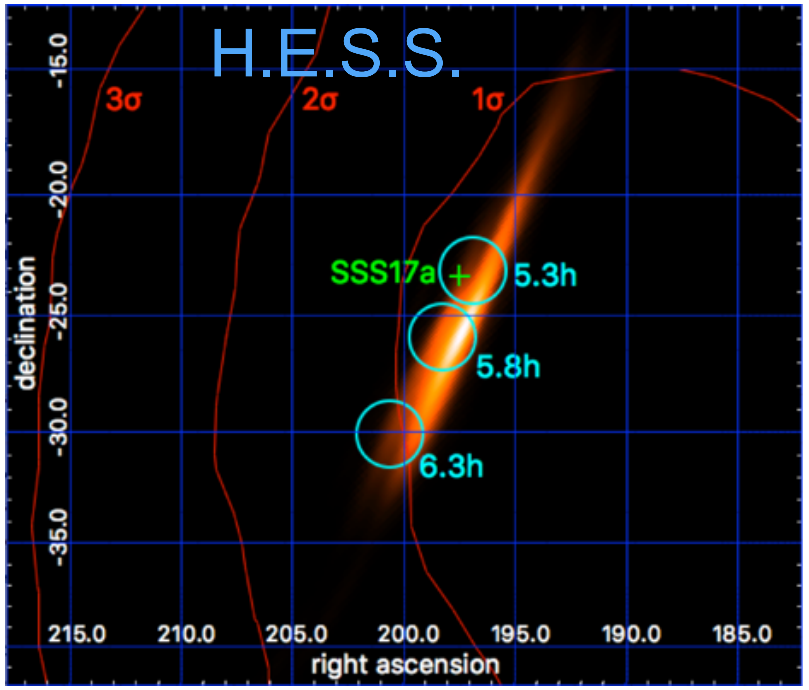


Outlook: GRB detections with CTA

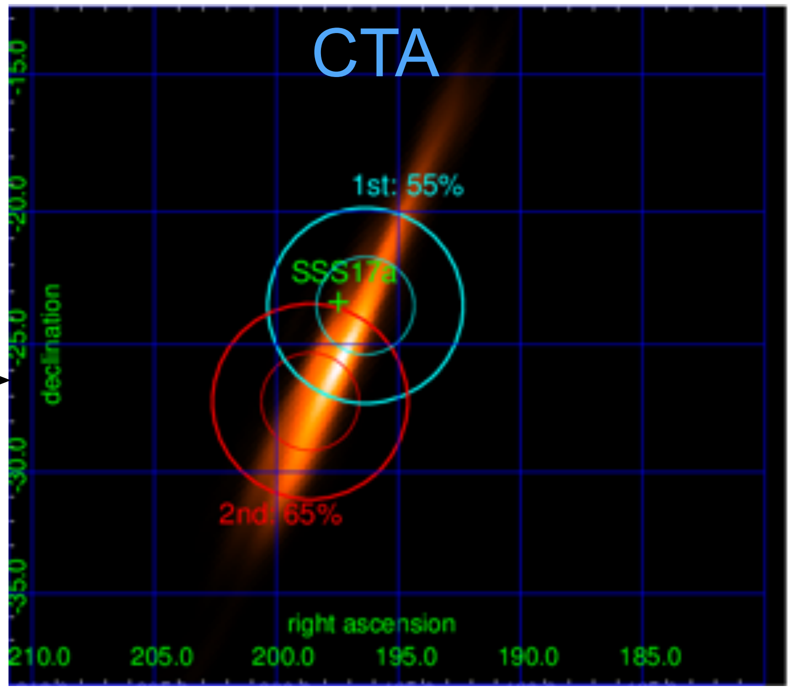
- ~10 times better sensitivity => increase detections + probe deeper into the afterglow
- Rapid slewing of the LSTs => catch parts of the prompt phase (?)



GW follow-up with CTA



H. Abdalla et al. (H.E.S.S.), ApJL 855:L22 (2017)

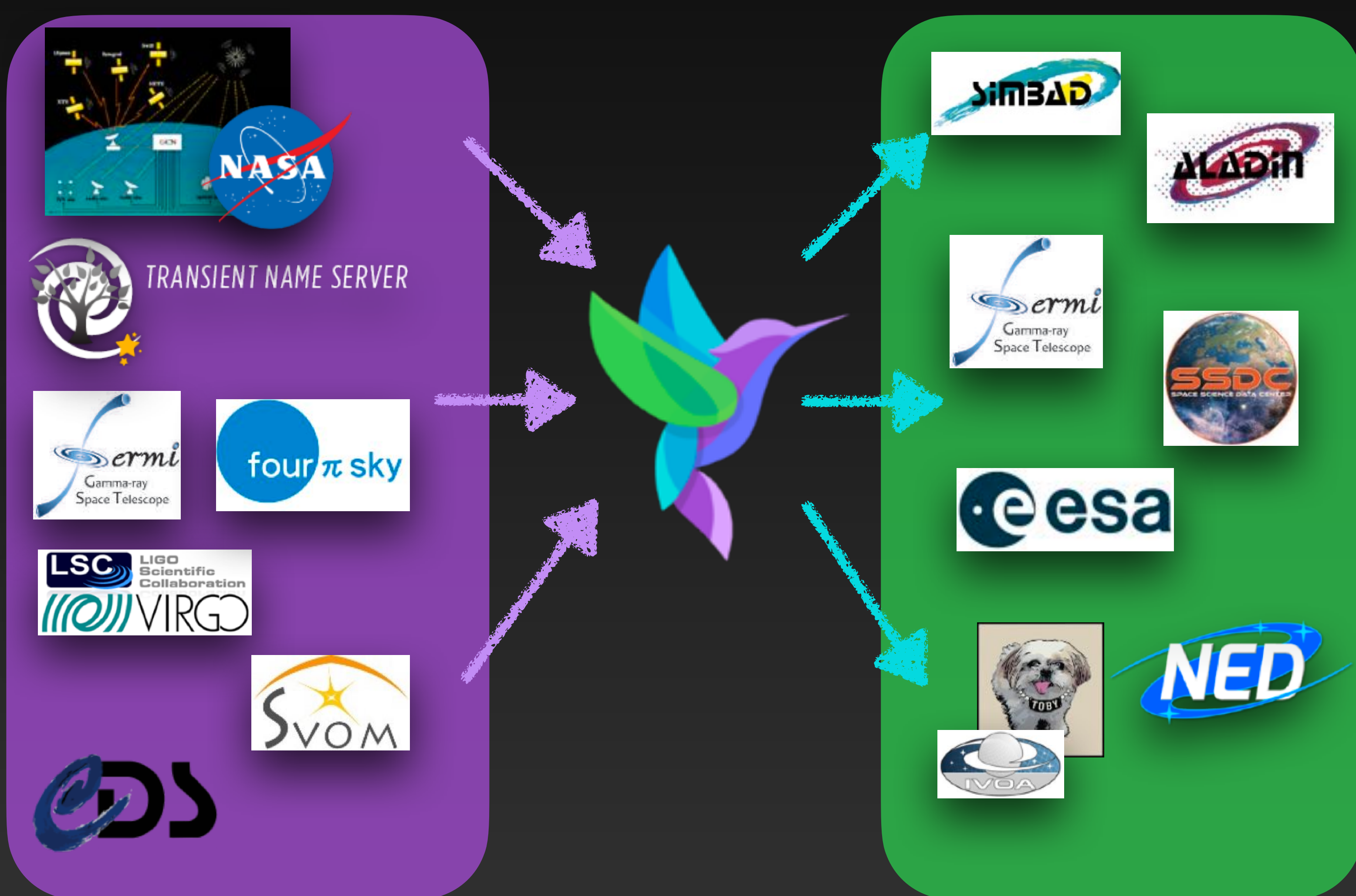


FS (CTA consortium), preliminary

- detailed studies ongoing
- extending work from
  - all current IACTs
  - I.Bartos et al., MNRAS 477 (2018) 639-647
  - B. Patricelli et al., JCAP 05 (2018) 056

Astro-COLIBRI

- Increasing number of multi-messenger transients + a large variety sources of information (alerts, catalogs, monitoring, etc.)
- Need for novel tools and platforms to keep track and make informed decisions



https://astro-colibri.com

GET IT ON Google Play

Download on the App Store

High-energy multi-messenger astrophysics in real-time

- **Several years of preparation coming to fruition**
  - automatic alert systems + dedicated data analysis tools + MoUs + …
- **Gravitational waves + Gamma Ray Bursts**
  - major breakthroughs over the last years (GW170817, GRB180720B, GRB190114C, etc.)
- Main future players: CTA + LHAASO (+ SWGO?)
- **High-energy neutrinos**
  - diffuse astrophysical flux detected (details lacking statistics)
  - transient sources promising (no point-source in IceCube + reduced chance prob.)
  - IceCube-170922A and TXS 0506+056: a first hint
- **Fast Radio Bursts**
  - rapidly evolving domain (# of bursts, dedicated analysis pipelines, joint MWL campaigns!!)
- **Galactic Novae: new class of VHE transients !**
- …

High-energy multi-messenger astrophysics in real-time

Detection of VHE gamma-ray emission from the recurrent nova RS Ophiuchi with H.E.S.S.

ATel #14844; *Stefan J. Wagner, for the H. E.S. S. collaboration*
on *10 Aug 2021; 18:34 UT*
Credential Certification: Stefan J. Wagner (swagner@lsw.uni-heidelberg.de)

Subjects: Gamma Ray, >GeV, TeV, VHE, Binary, Nova

Referred to by ATel #: 14845, 14846, 14848, 14849, 14851, 14855, 14857, 14858, 14860, 14882, 14885, 14886, 14894

The H.E.S.S. array of imaging atmospheric Cherenkov telescopes was used to carry out observations of the recurrent nova RS Ophiuchi currently in outburst and detected with Fermi/LAT (Cheung et al, ATel #14834). RS Ophiuchi is a high-mass WD/red giant binary with an orbital period of 455d that undergoes an outburst approximately every 15-20 years, with the previous one occurring in February 2006. The current outburst is associated with a high-velocity outflow (Taguchi et al., ATel #14838, Munari et al., ATel #14840).// H.E.S.S. Observations started on August 9 at 18:17 UTC , lasted until 22:41 UTC and were taken under good conditions. A preliminary onsite analysis of the obtained data shows a >6 sigma very-high-energy gamma-ray excess compatible with the direction of RS Ophiuchi. Further H.E.S.S. observations are planned. We strongly encourage follow-up at all wavelengths.// H.E.S.S. is an array of five imaging atmospheric Cherenkov telescopes for the detection of very-high-energy gamma-ray sources and is located in the Khomas Highlands in Namibia. It was constructed and is operated by researchers from Armenia, Australia, Austria, France, Germany, Ireland, Japan, the Netherlands, Poland, South Africa, Sweden, UK, and the host country, Namibia. For more details see https://www.mpi-hd.mpg.de/hfm/HESS/

H.E.S.S. observations of soft spectrum VHE gamma-ray emission from the recurrent nova RS Ophiuchi

ATel #14857; *Stefan J. Wagner, for the H. E.S. S. collaboration*
on *12 Aug 2021; 23:03 UT*
Credential Certification: Stefan J. Wagner (swagner@lsw.uni-heidelberg.de)

Subjects: Gamma Ray, >GeV, TeV, VHE, Nova

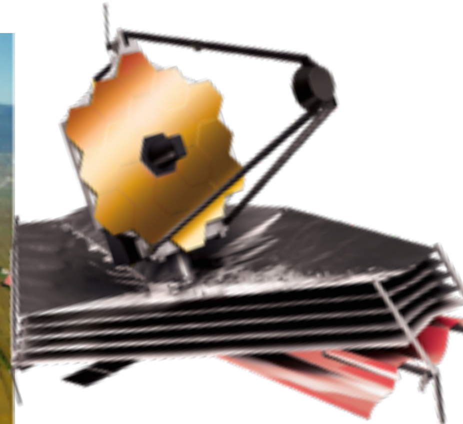
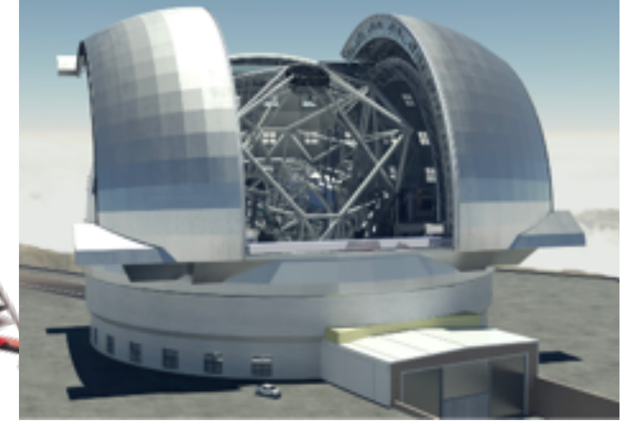
Referred to by ATel #: 14858, 14860, 14864, 14866, 14882, 14885, 14886, 14894

Following the detection of very-high-energy gamma-ray emission the recurrent nova RS Ophiuchi currently in outburst (ATel #14844), H.E.S.S. observations continued on August 10th and August 11th for about 5h each night. A continued VHE gamma-ray excess compatible with the direction of RS Ophiuchi is seen in these two nights, with comparable significance to the night of August 9 (ATel #14844). The Fermi/LAT collaboration (Cheung et al, ATel #14845) reports a brightening of the nova in >100 MeV gamma-rays with a hard spectrum (single power law spectral index 1.9 +/- 0.1) up to ~10 GeV. In the VHE energy band covered with the H.E.S.S. telescopes, for the three nights August 9-11, a preliminary onsite analysis shows a significantly softer power law spectral index (> 3) than that reported by Fermi-LAT. This implies that a spectral break occurs between the >100 MeV to ~13 GeV range of the Fermi-LAT data and the higher energy range of the H.E.S.S. data. Further H.E.S.S. observations are planned. We strongly encourage follow-up at all wavelengths (see also ATels #14834, #14838, #14840, #14845, #14846, #14848, #14849, #14850, #14851, #14852, #14855). H.E.S.S. is an array of five imaging atmospheric Cherenkov telescopes for the detection of very-high-energy gamma-ray sources and is located in the Khomas Highlands in Namibia. It was constructed and is operated by researchers from Armenia, Australia, Austria, France, Germany, Ireland, Japan, the Netherlands, Poland, South Africa, Sweden, UK, and the host country, Namibia. For more details see https://www.mpi-hd.mpg.de/hfm/HESS/

- **Galactic Novae: new class of VHE transients !**
- …

Irfu


Gravitational Waves
SGRs
Supernovae
Microquasars
AGN flares
Flaring stars
Novae
Neutrinos
Fast Radio Bursts
Gamma-ray Bursts

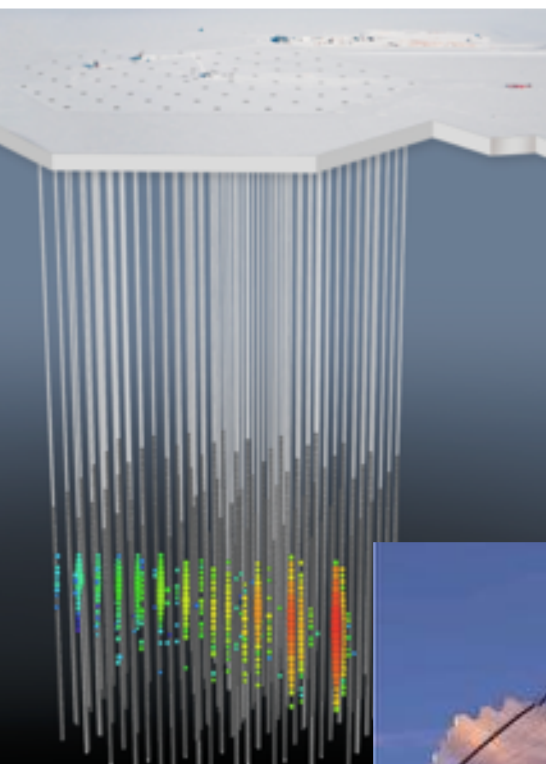




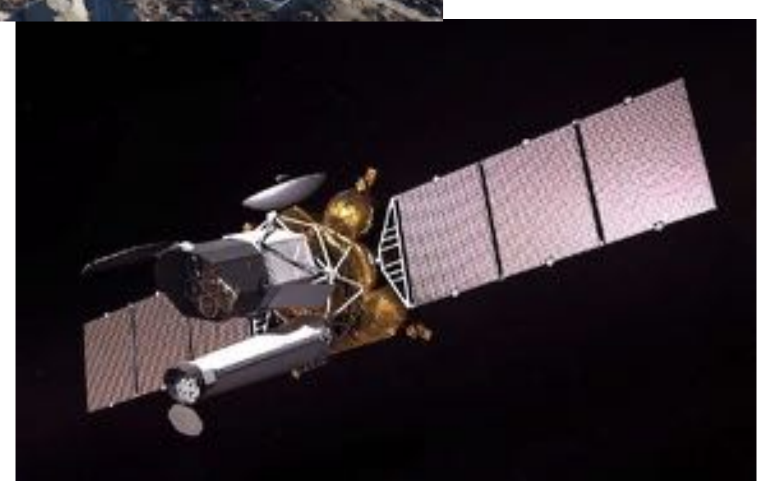
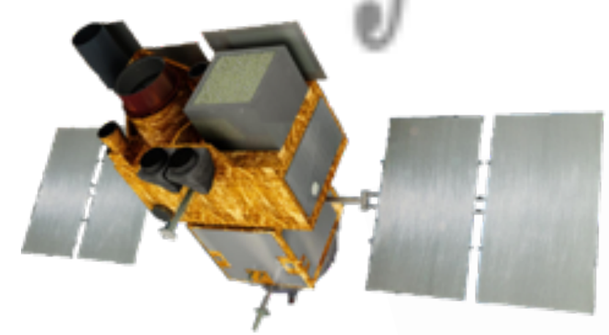
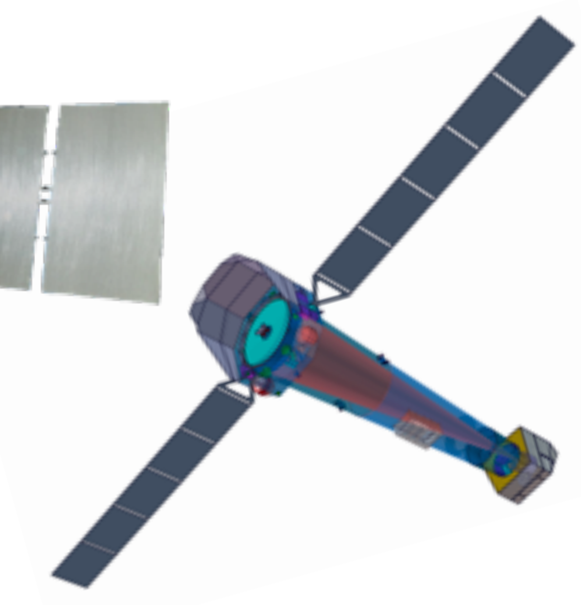
Gravitational Waves SGRs Supernovae Microquasars AGN flares Flaring stars Novae

Neutrinos

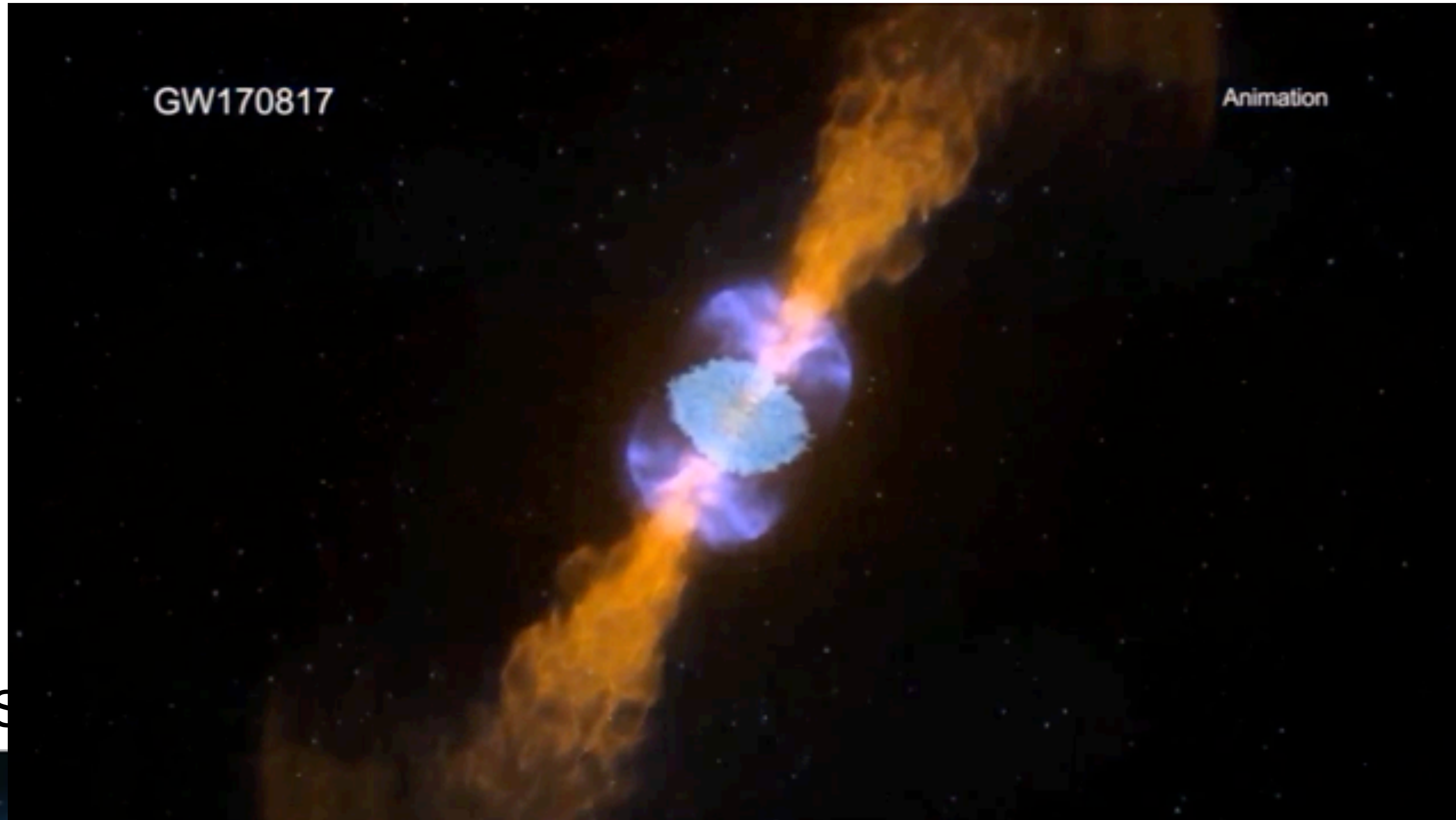
Fast Radio Bursts

Gamma-ray Bursts

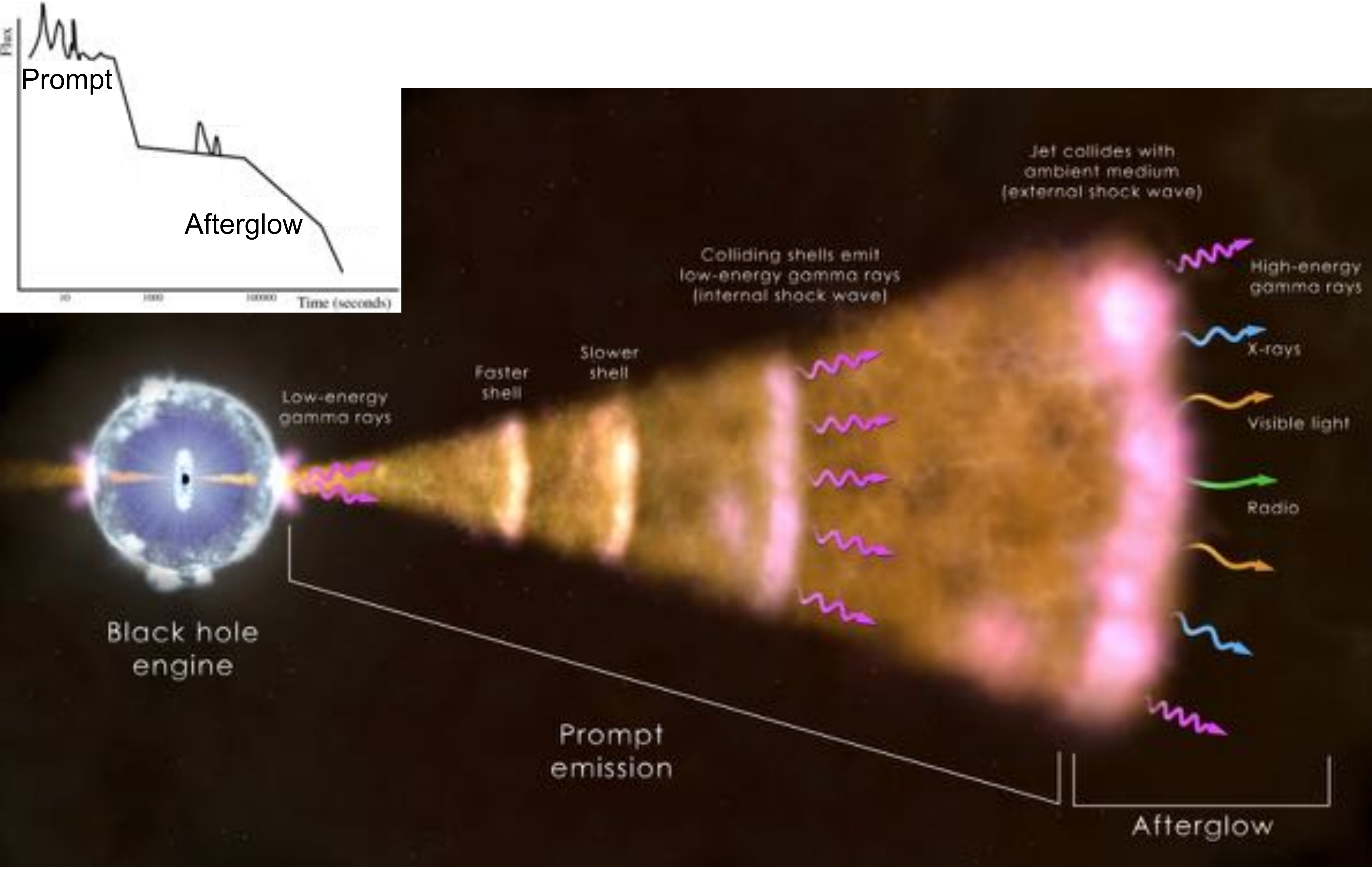


Short and long GRBs

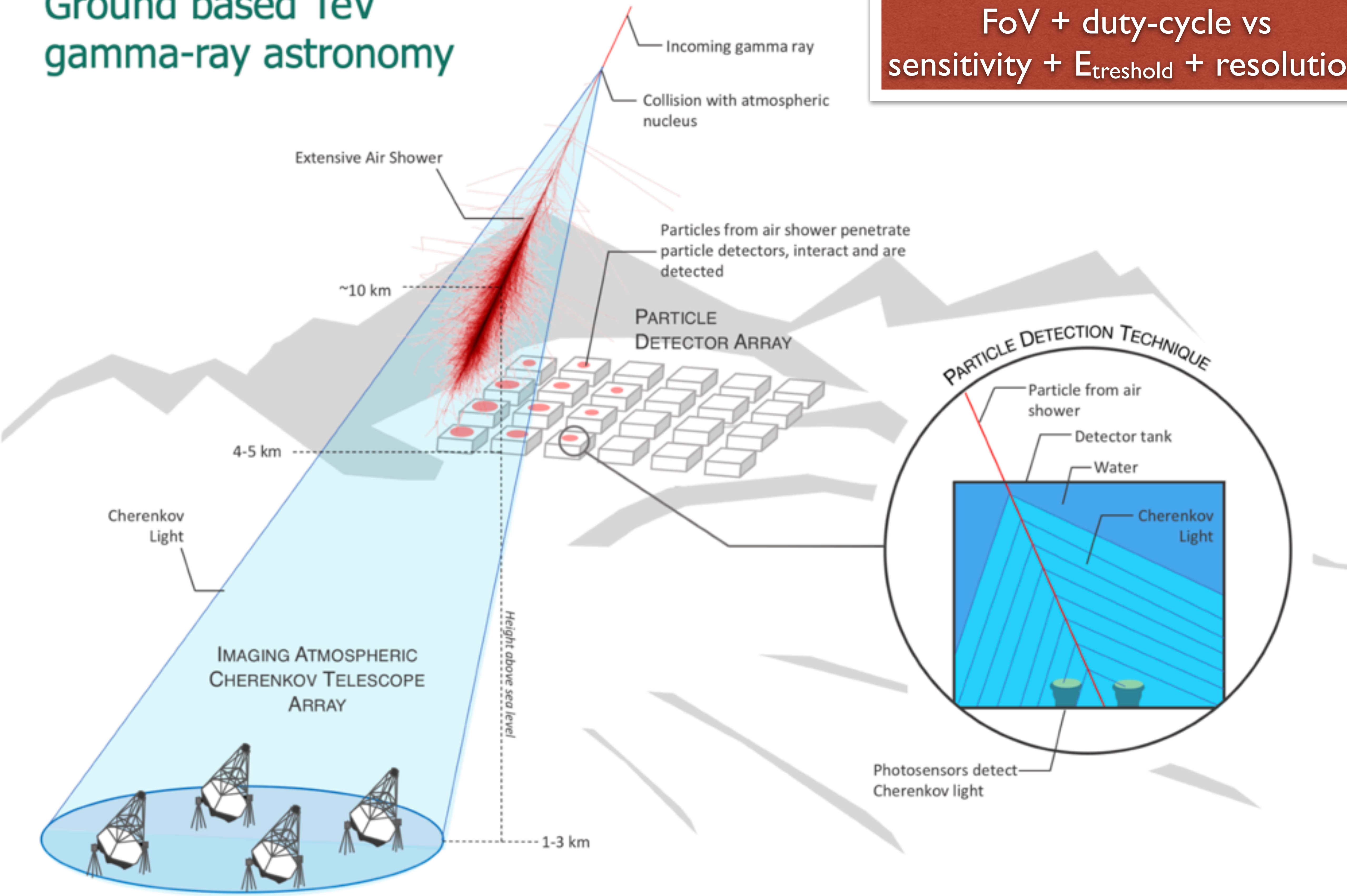


S Bs


Flux
Prompt
Afterglow
Time (seconds)
Jet collides with
ambient medium
(external shock wave)
Colliding shells emit
low-energy gamma rays
(internal shock wave)
High-energy
gamma rays
X-rays
Visible light
Radio
Slower
shell
Faster
shell
Low-energy
gamma rays
Black hole
engine
Prompt
emission
Afterglow

Ground based TeV gamma-ray astronomy

FoV + duty-cycle vs sensitivity + $E_{treshold}$ + resolution



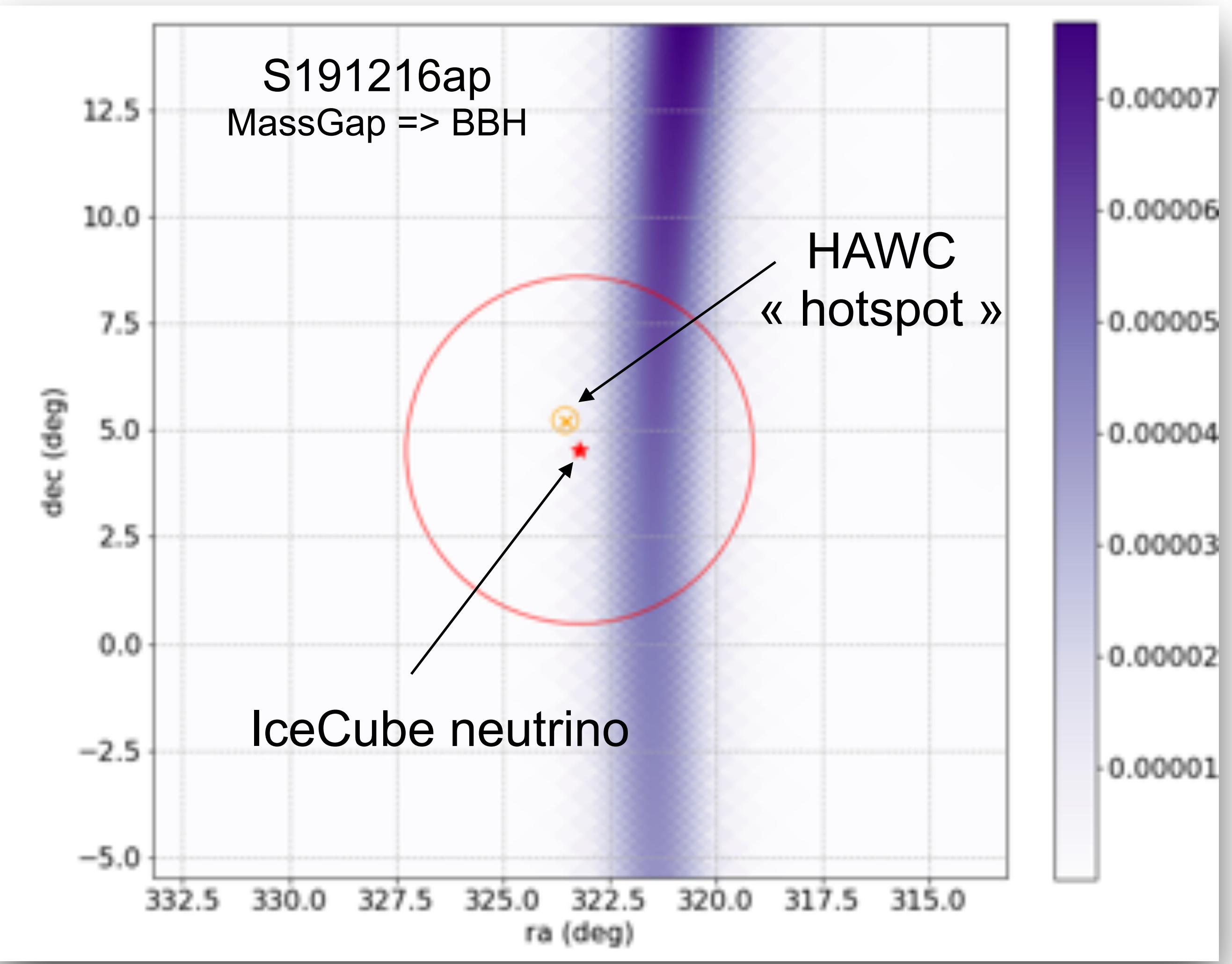
Shower image, 100 GeV γ-ray adapted from: F. Schmidt, J. Knapp, "CORSIKA Shower Images", 2005, https://www-zeuthen.desy.de/~jknapp/fs/showerimages.html

H. Schoorlemmer

High Altitude particle detector arrays

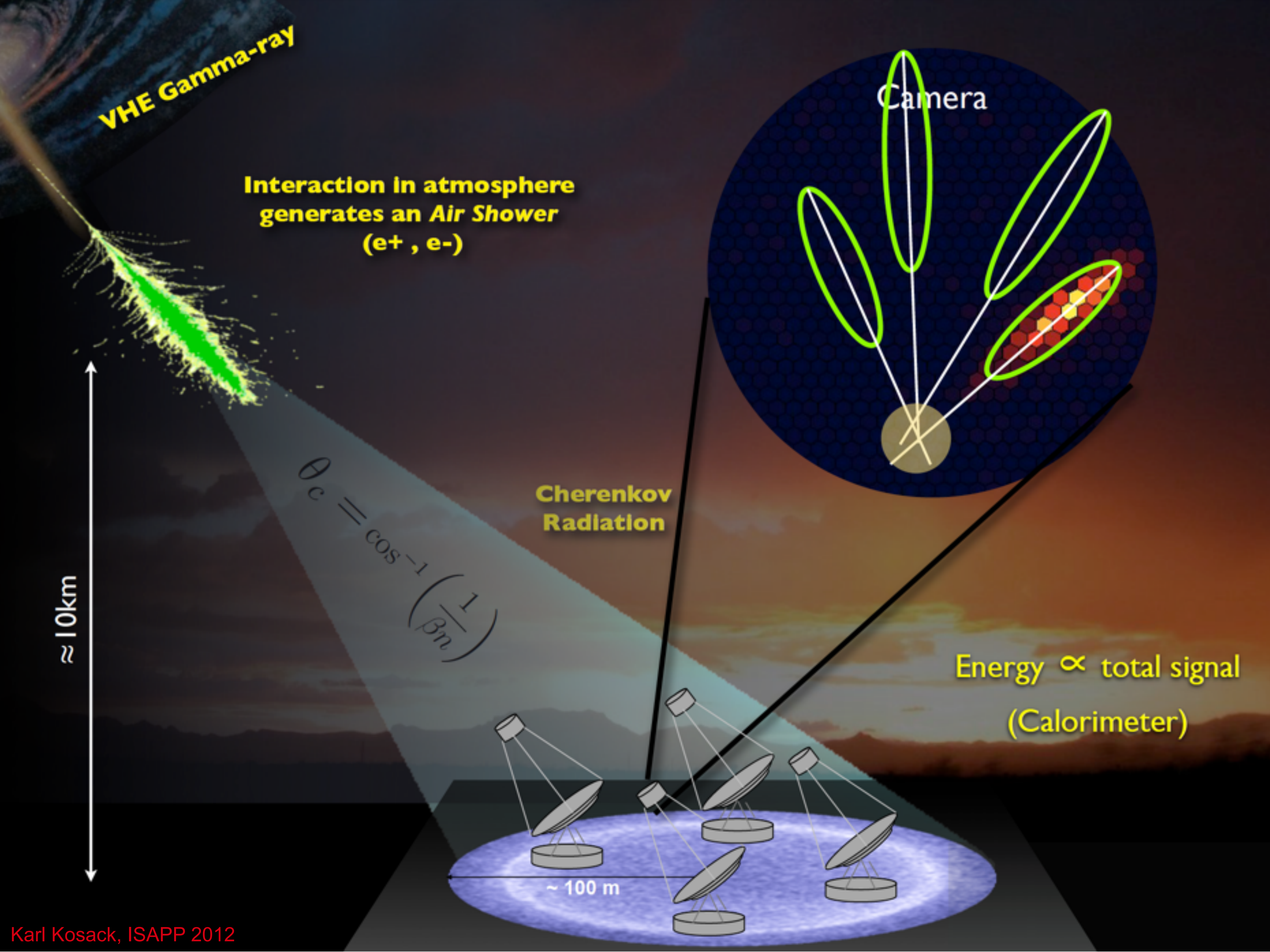
MM searches with air shower arrays

- Large FoV + high duty-cycle
  - Smaller instantaneous sensitivity + higher $E_{threshold}$
- HAWC: automatized searches for excess at several timescales (0.3s - 100s)



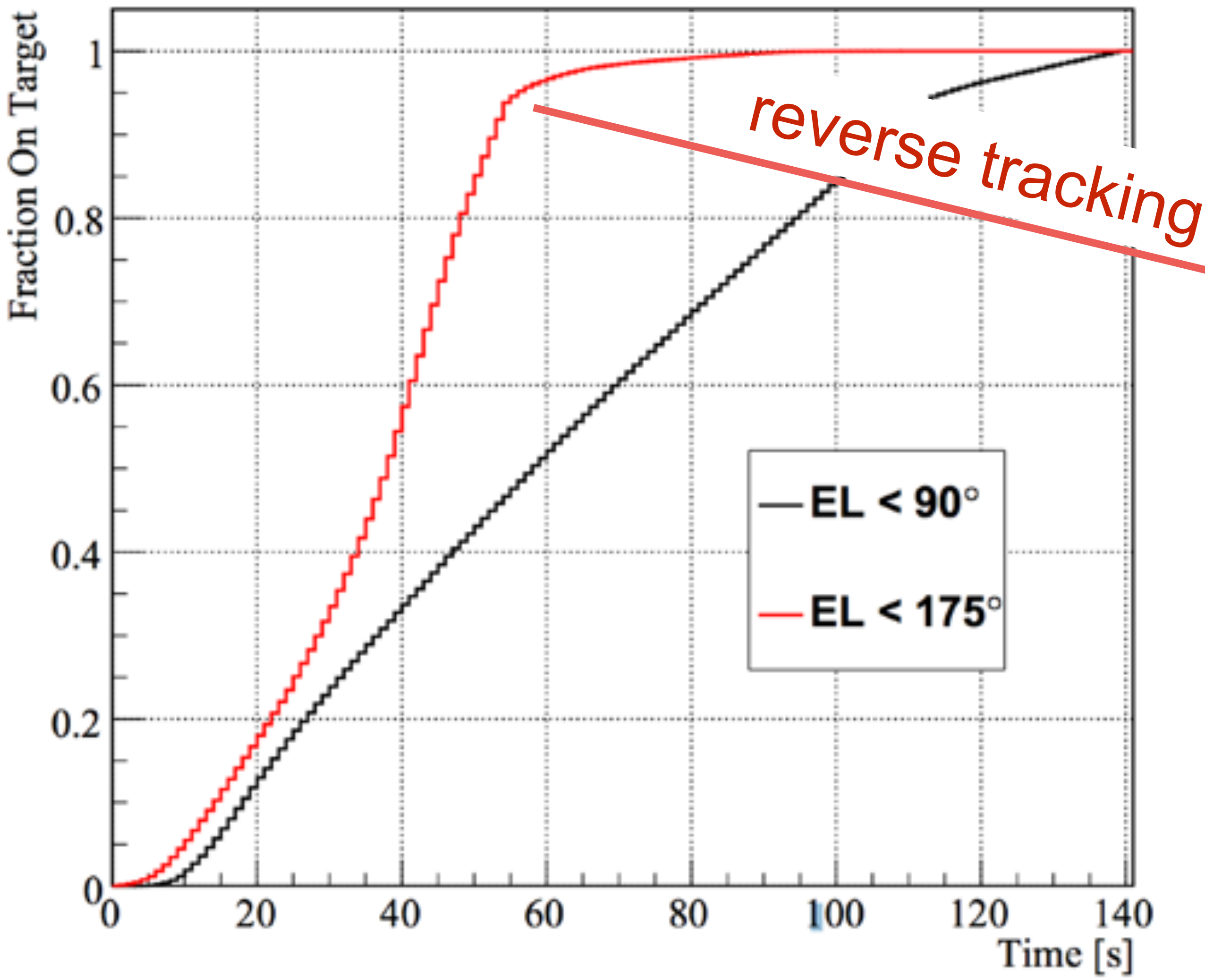
GCN #26455
GCN #26463
GCN #26472
…

I. Martinez + H. Schoorlemmer et al. (HAWC)


VHE Gamma-ray
Interaction in atmosphere generates an *Air Shower* (e+ , e-)
Camera
$\theta_c = \cos^{-1}\left(\frac{1}{\beta n}\right)$
Cherenkov Radiation
≈10km
Energy ∝ total signal
(Calorimeter)
~ 100 m
Karl Kosack, ISAPP 2012

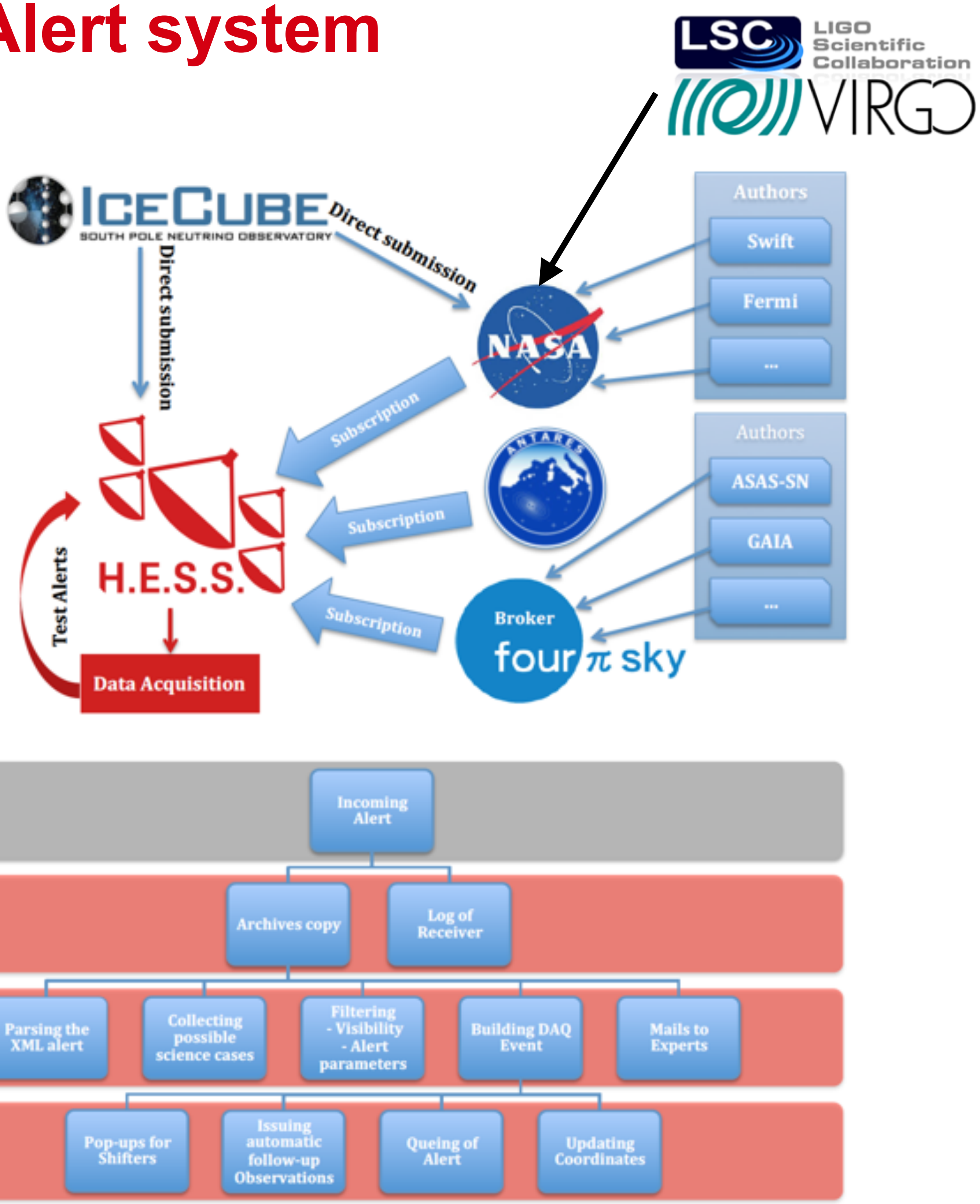
Time domain : searches for MM transients

- main design principles of the H.E.S.S. 28m telescope
  - large photon collection area ⟶ 614 m^2 mirror area (largest IACT worldwide)
  - **rapid response time**



Hofverberg et al., ICRC 2013

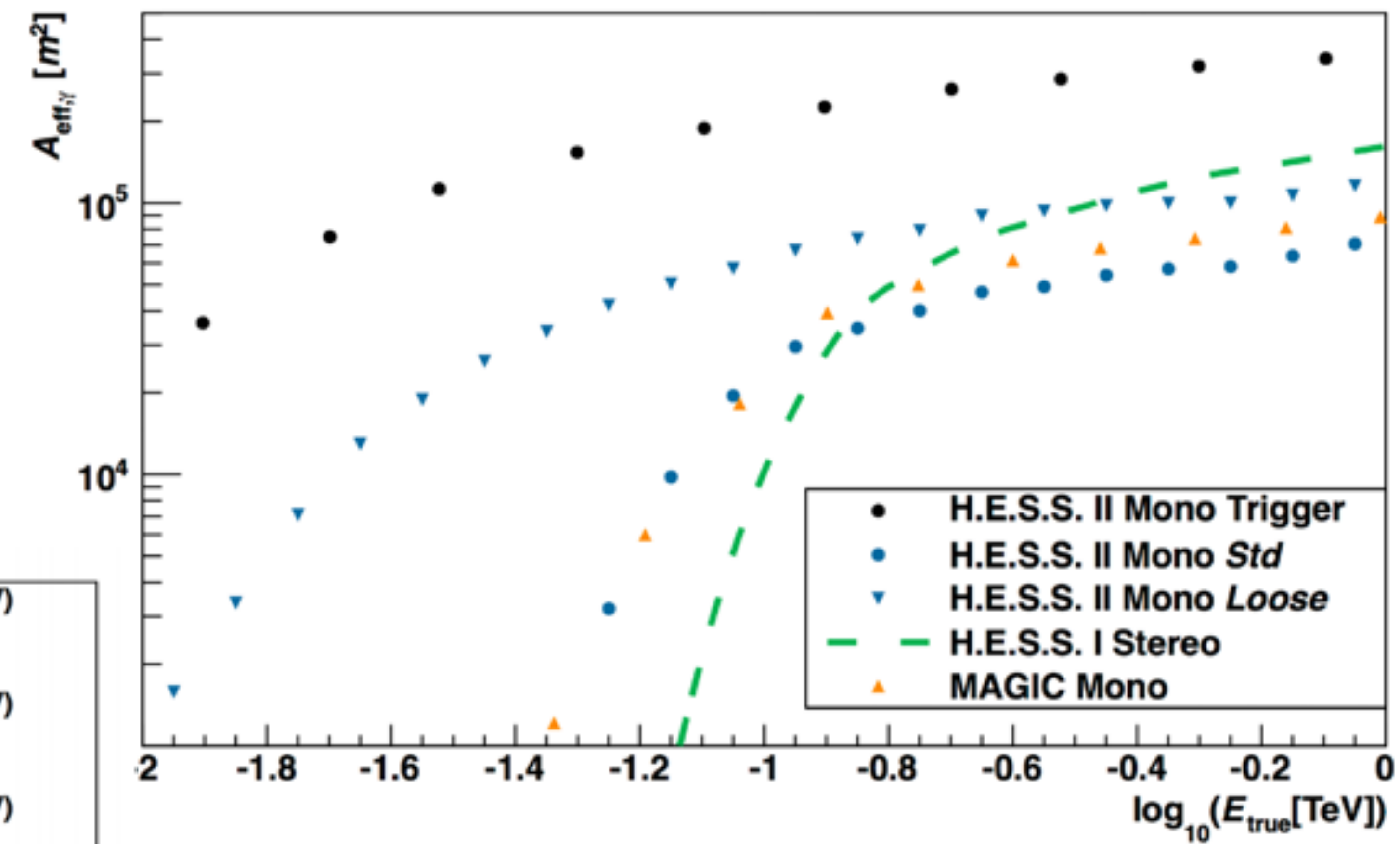
The H.E.S.S. VoAlert system

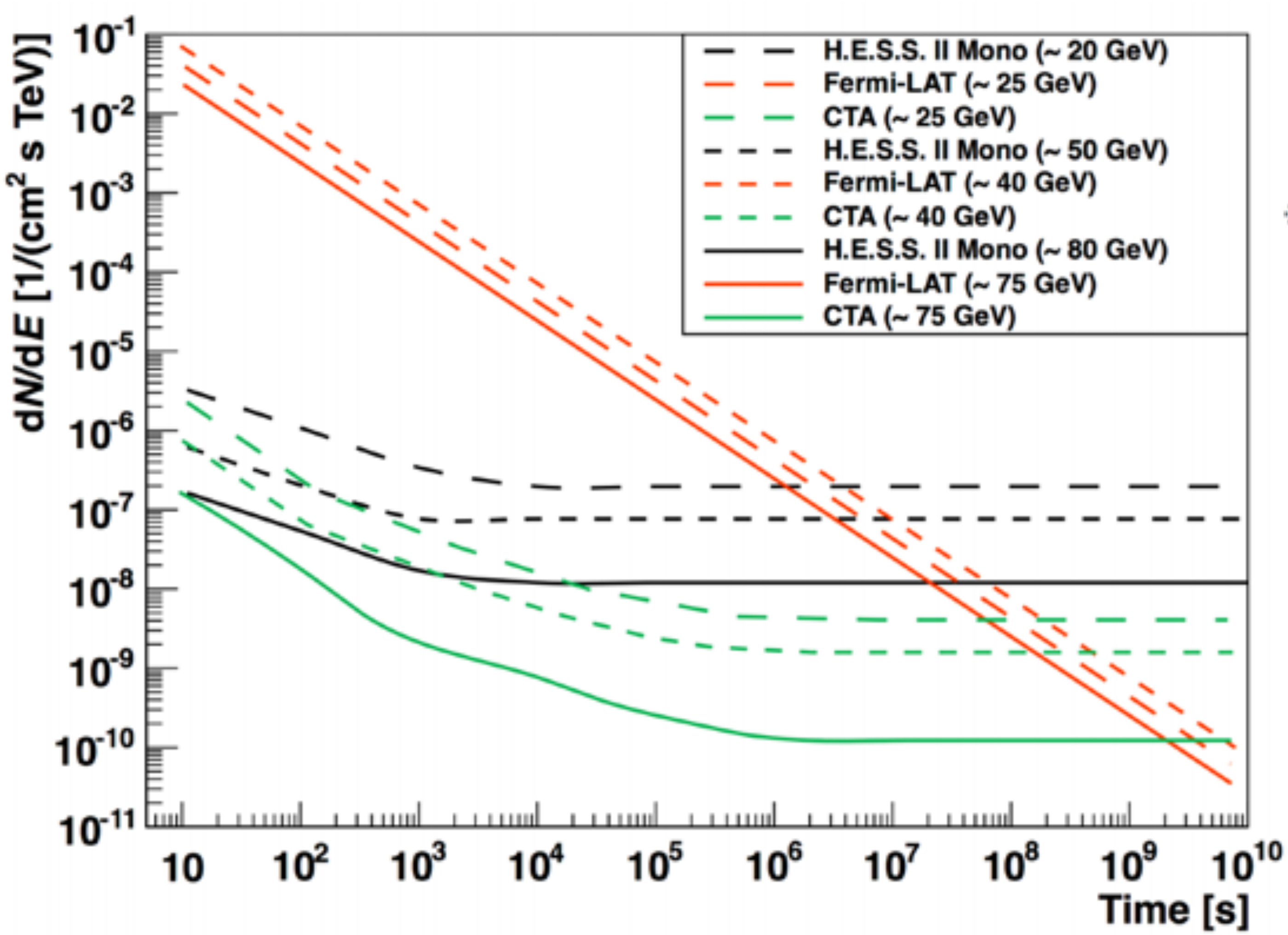


modified from C. Hoischen, Baikal 2016

GRB follow-up: sensitivity

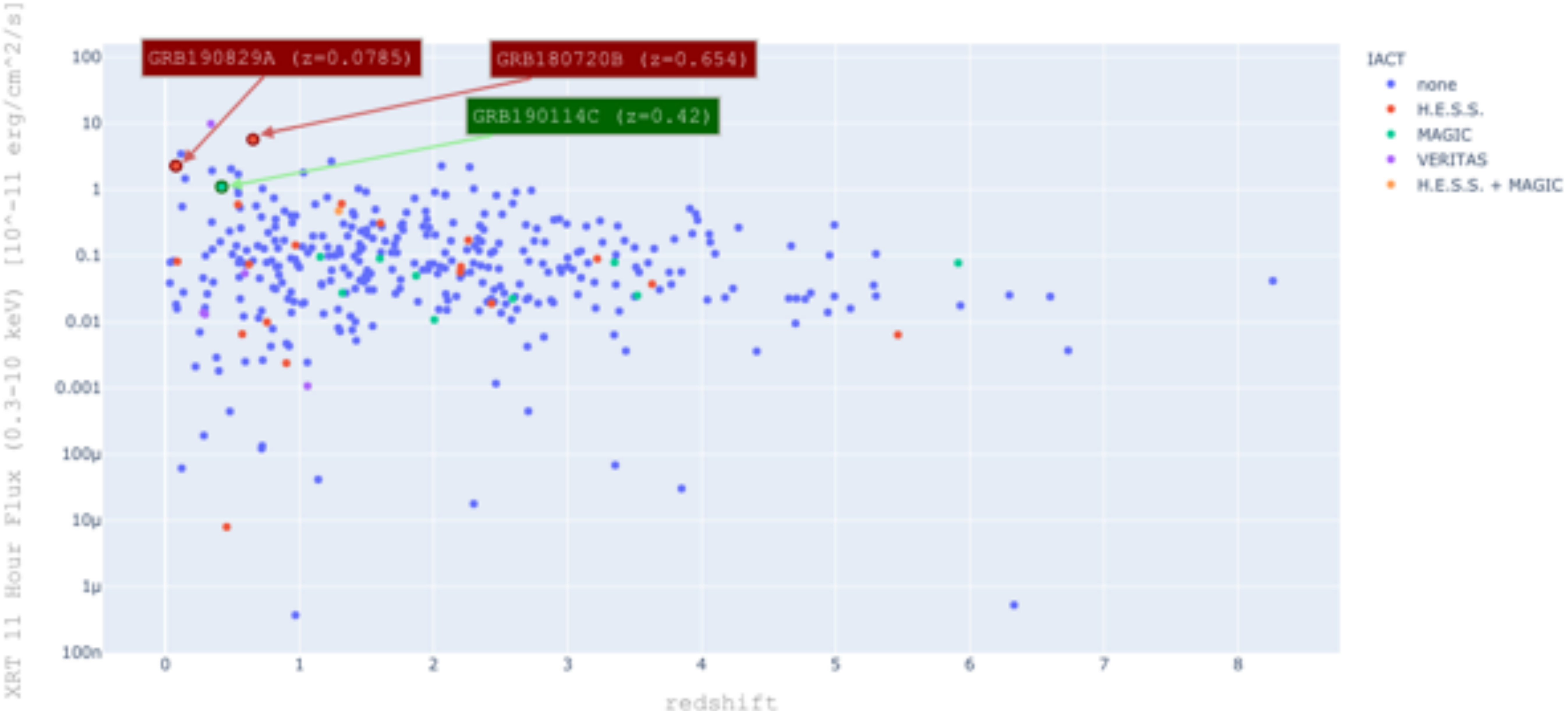
- rapid response + best sensitivity





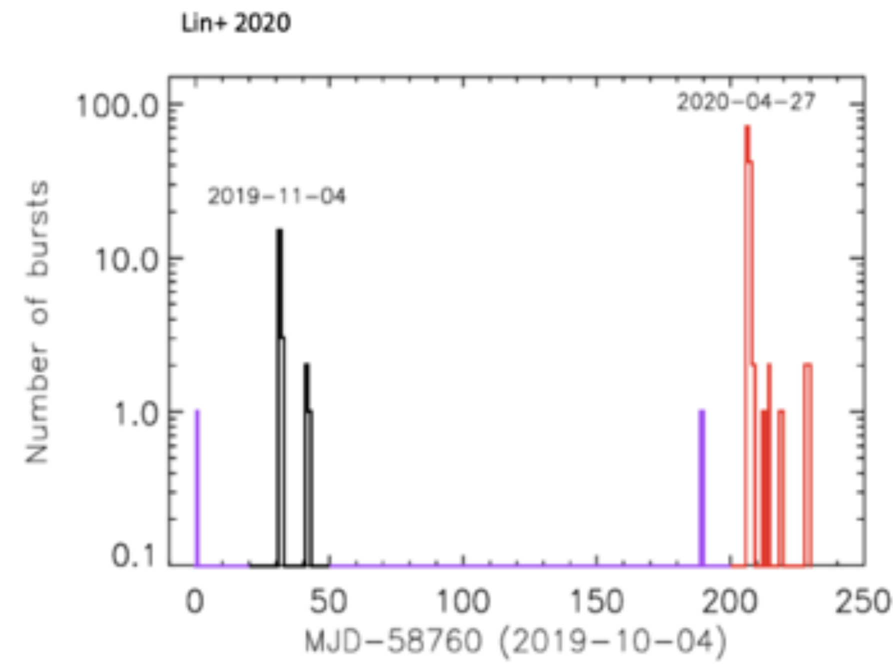
D. Parsons et al., ICRC 2015, arXiv: 1509.05191

GRB observations with IACTs

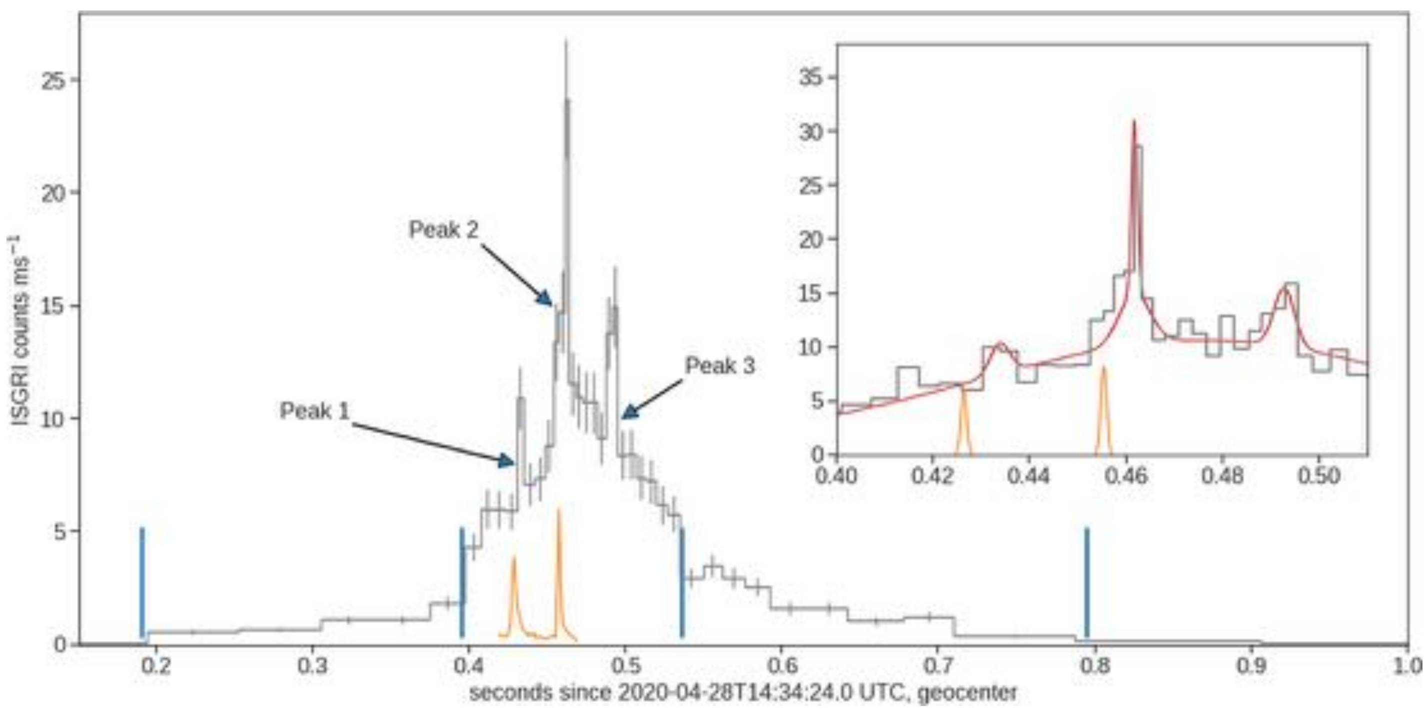


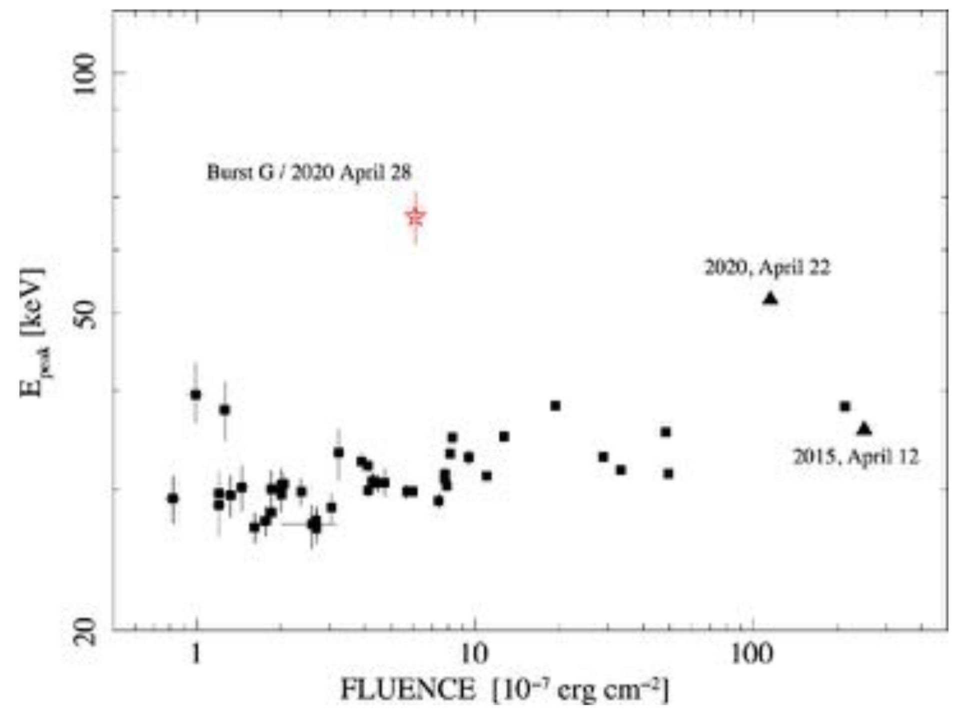
SGR1935+2154

- April 2020: renewed activity of a Galactic magnetar



- Coincidence between an X-ray burst (INTEGRAL) and a Fast Radio Burst like emission (CHIME) => magnetars can emit FRBs

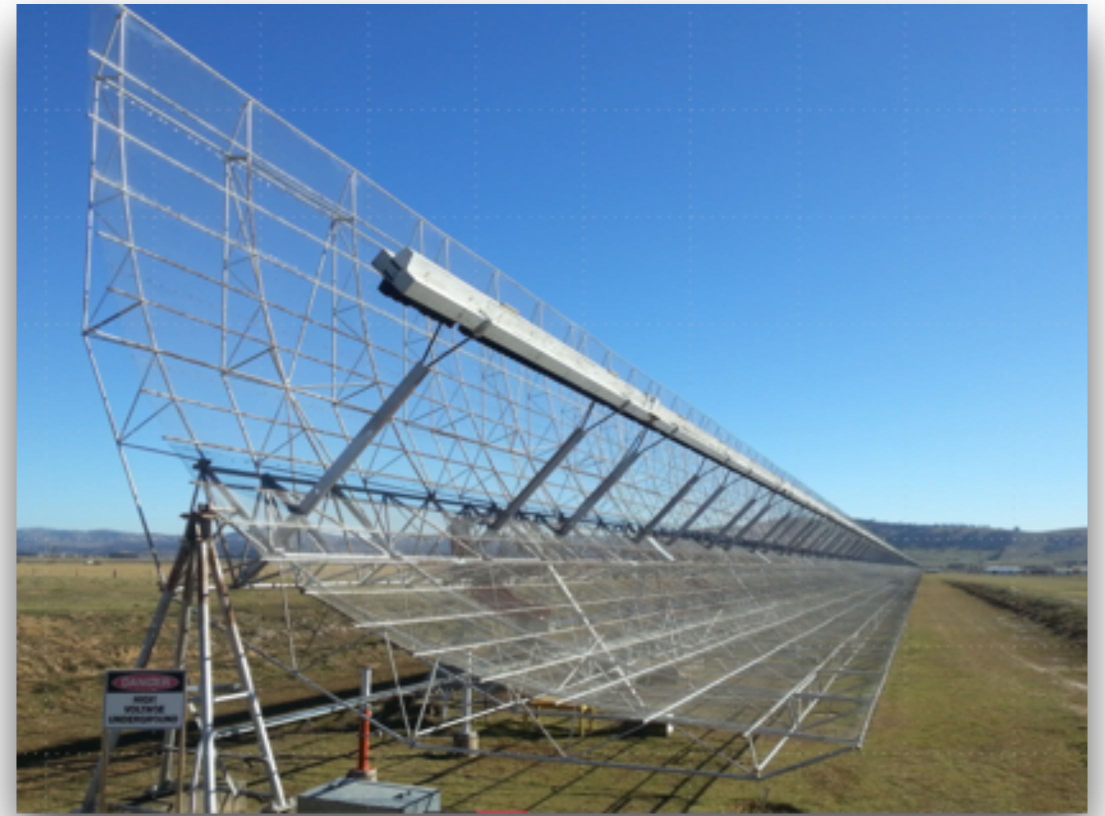




Mereghetti et al., ApJL 898 (2020)

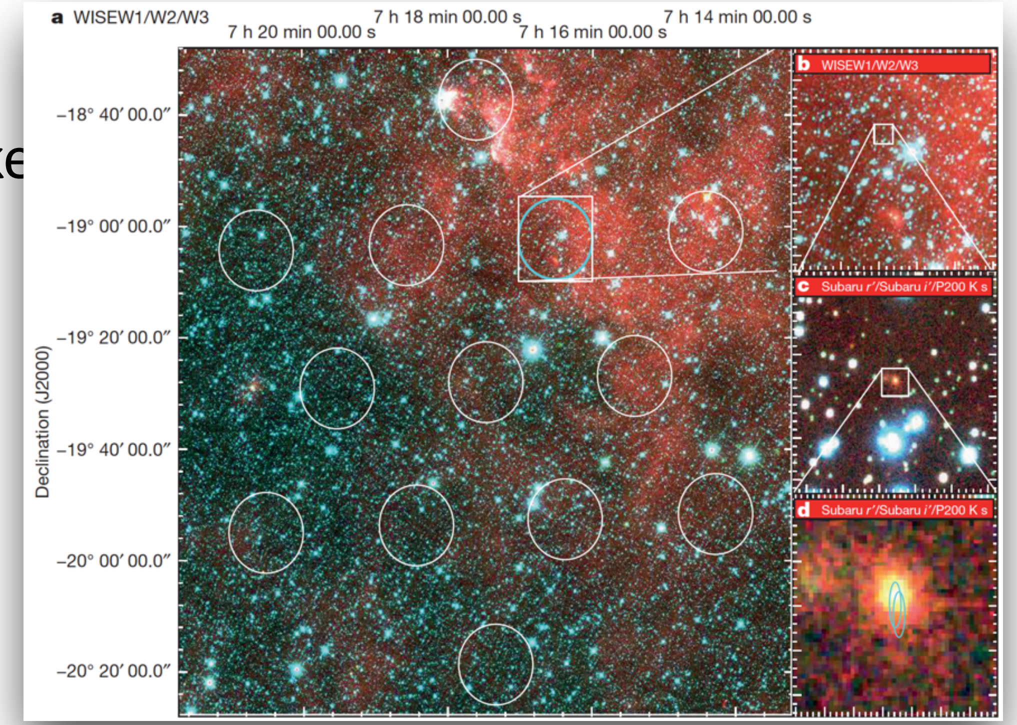
How to find a MWL counterpart?

- Follow-up observations
  - physics: sensitive to ”afterglow” emission only
  - technical: need rapid detection + alert emission + follow-up
    - e.g. SUPERB@Parkes -> H.E.S.S.
    - e.g. UTMOST -> H.E.S.S.

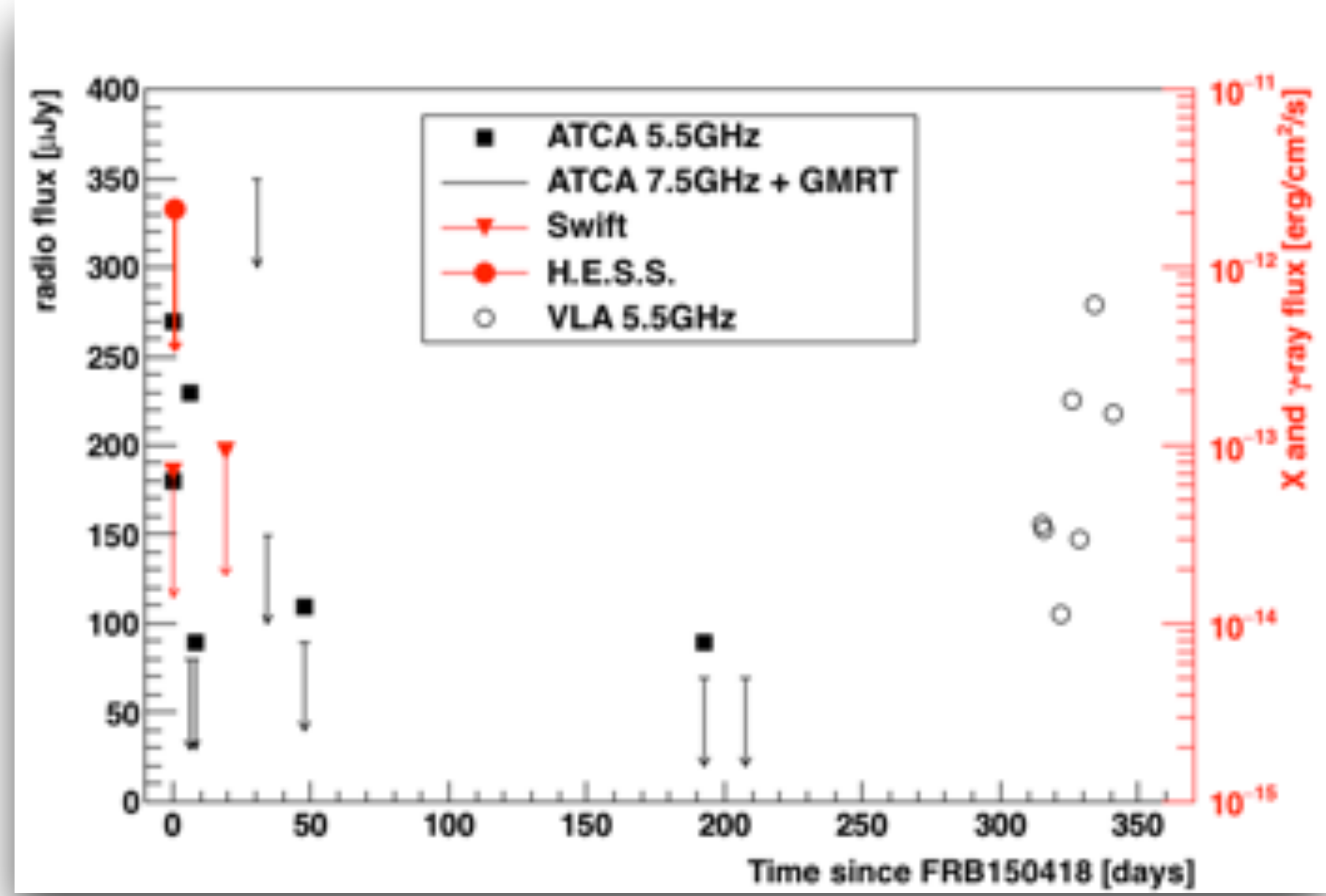


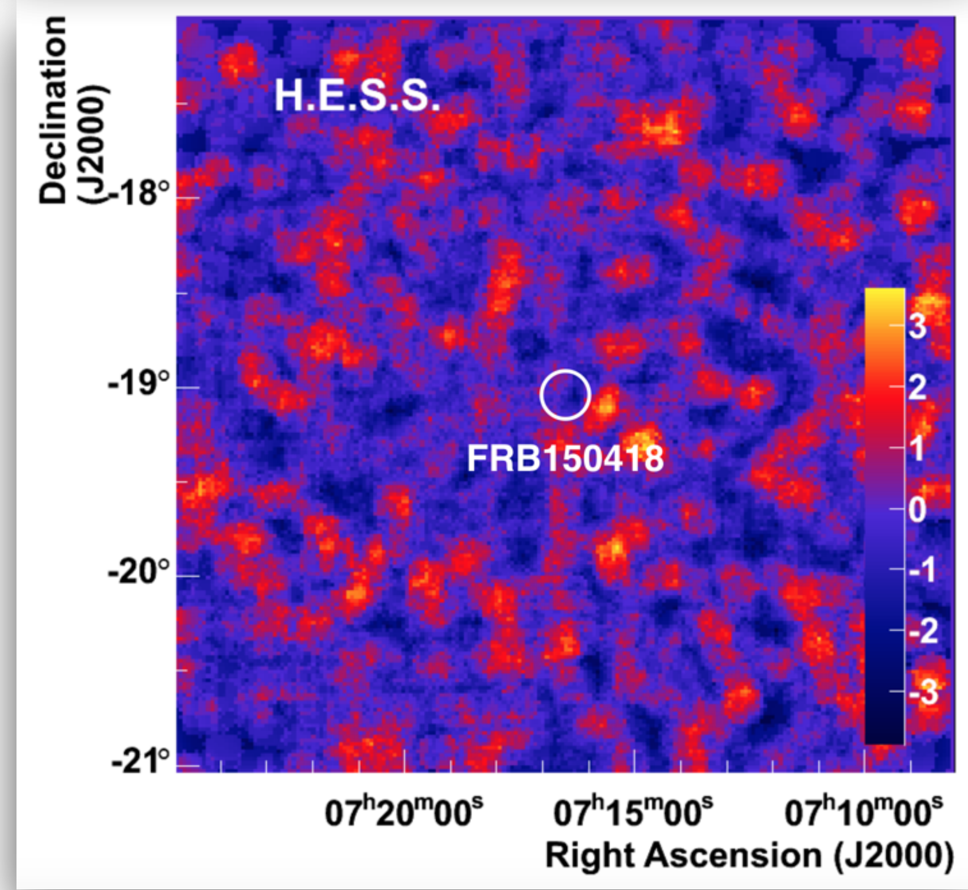
Alert follow-up: FRB150418

E. Keane et al., Nature 530 (2016)



- detected 2015 April 18 04:29:07.056 UTC at SUPERB@Parke
- ATCA: fading radio afterglow during ~6days
  - optical identification of galaxy at z=0.492
- H.E.S.S. observations the night after the burst
  - delay: ~14.5h
  - no VHE afterglow detected
  - $\Phi(E>350\text{GeV}) < 1.3 \times 10^{-8}\ m^{-1}\ s^{-1}$ (E^{-2}, 99% C.L.)



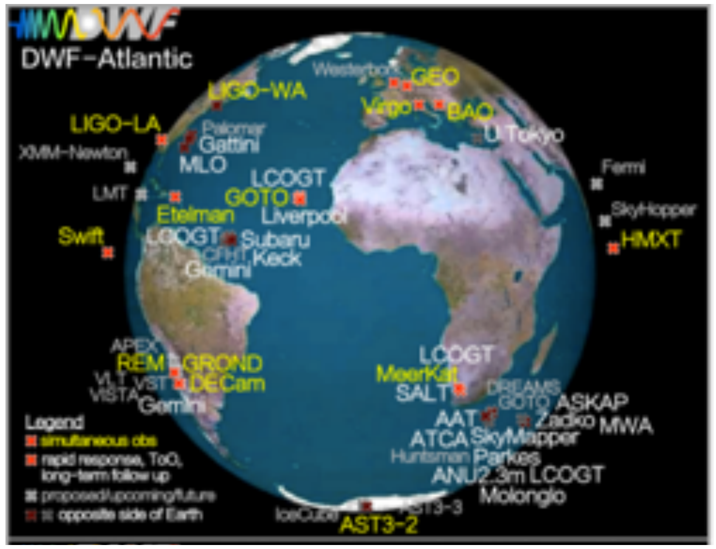


HESS+SUPERB, A&A 597 (2017)

How to find a MWL counterpart?

- Follow-up observations
  - physics: sensitive to ”afterglow” emission only
  - technical: need rapid detection + alert emission + follow-up
    - e.g. SUPERB@Parkes -> H.E.S.S.
    - e.g. UTMOST -> H.E.S.S.

- Contemporaneous observations
  - physics: sensitive to ”precursor” + ”prompt” + ”afterglow” emission
  - technical: joint, simultaneous observations
    - staring at the same field with several observatories
      - e.g. DeeperWiderFaster 2019 with H.E.S.S.



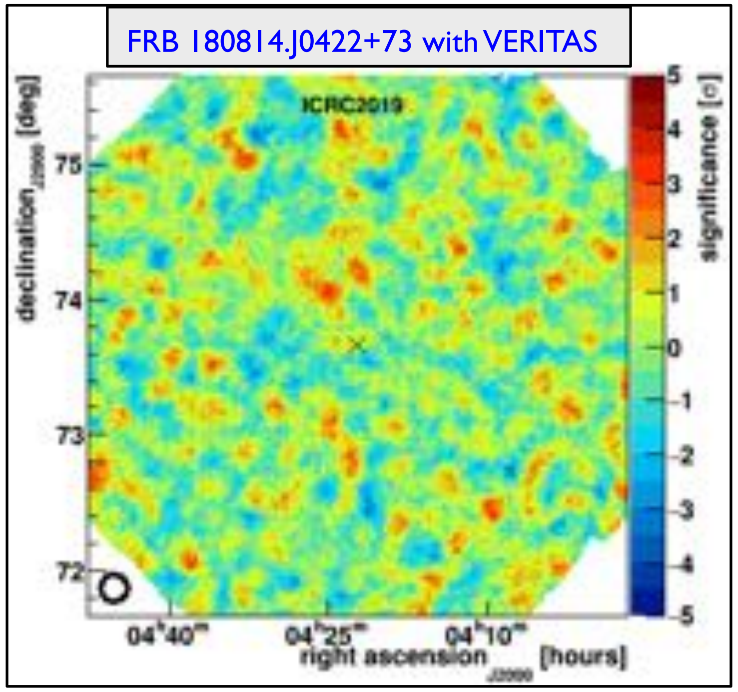
How to find a MWL counterpart?

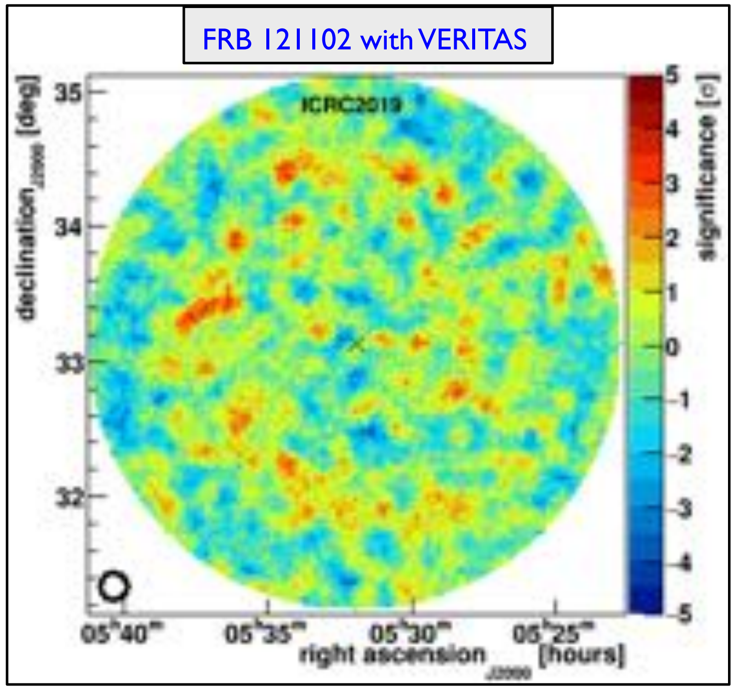
- Follow-up observations
  - physics: sensitive to ”afterglow” emission only
  - technical: need rapid detection + alert emission + follow-up
    - e.g. SUPERB@Parkes -> H.E.S.S.
    - e.g. UTMOST -> H.E.S.S.

- Contemporaneous observations
  - physics: sensitive to ”precursor” + ”prompt” + ”afterglow” emission
  - technical: joint, simultaneous observations
    - staring at the same field with several observatories
      - e.g. DeeperWiderFaster 2019 with H.E.S.S.
    - staring at a repeating FRB with several observatories
      - e.g. campaigns on FRB121102 with MAGIC, VERITAS (and H.E.S.S.)

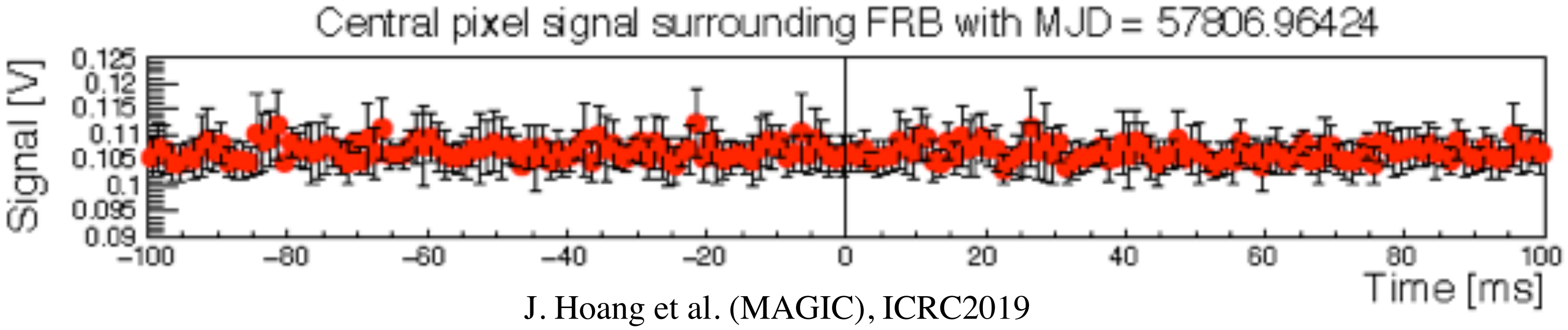
FRB 121102 and FRB 180814.J0422+73

- **VERITAS**: 12.7h + 8.2h of observations => no steady emission
- FRB 180814.J0422+73 observations overlapping with CHIME => no bursts found
  - $\Phi < 9.2 \times 10^{-13}$ ph cm^{-2} s^{-1} >300 GeV for *soft* cuts
- 115min of observations on FRB 121102 overlapping with GBT (Nov. 25, 2017) => 15 bursts found
  - dedicated analysis within 10ms around the bursts
  - $\Phi < 3.7 \times 10^{-8}$ ph cm^{-2} s^{-1} >200 GeV for all 15 bursts
- **MAGIC**: 23h of observations (8.9h overlapping with Arecibo) on FRB 121102 => 5 bursts found





J. Holder et al. (VERITAS), ICRC2019
arXiv: 1908.06471



J. Hoang et al. (MAGIC), ICRC2019
arXiv: 1908.07506

How to find a MWL counterpart?

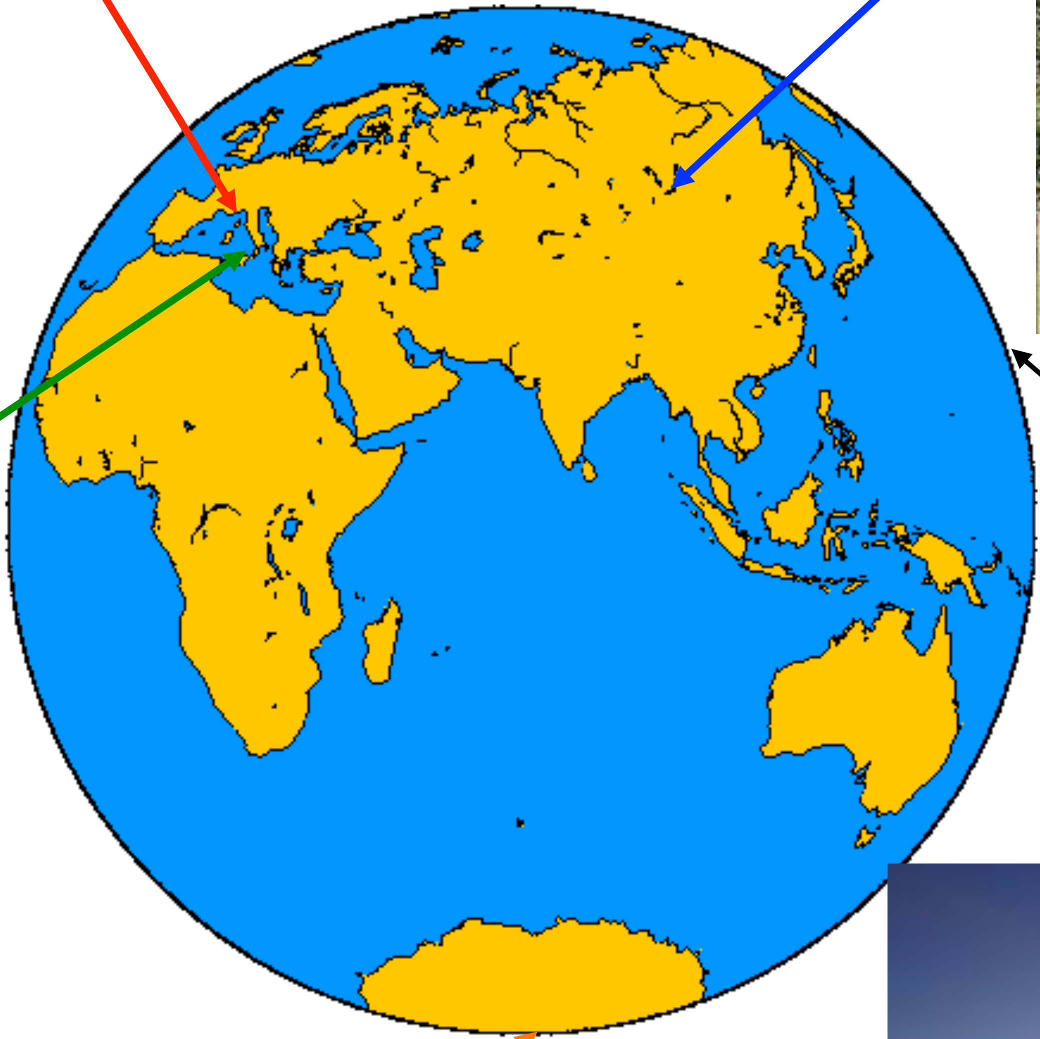
- Follow-up observations
  - physics: sensitive to ”afterglow” emission only
  - technical: need rapid detection + alert emission + follow-up
    - e.g. SUPERB@Parkes -> H.E.S.S.
    - e.g. UTMOST -> H.E.S.S.

- Contemporaneous observations
  - physics: sensitive to ”precursor” + ”prompt” + ”afterglow” emission
  - technical: joint, simultaneous observations
    - staring at the same field with several observatories
      - e.g. DeeperWiderFaster 2019 with H.E.S.S.
    - staring at a repeating FRB with several observatories
      - e.g. campaigns on FRB121102 with MAGIC, VERITAS (and H.E.S.S.)
      - **FRB171019** (ASKAP + GBT/CHIME): first repeating burst in the Southern hemisphere, stay tuned…

Neutrino telescopes: monitoring the neutrino sky

ANTARES: La-Seyne-sur-Mer, France

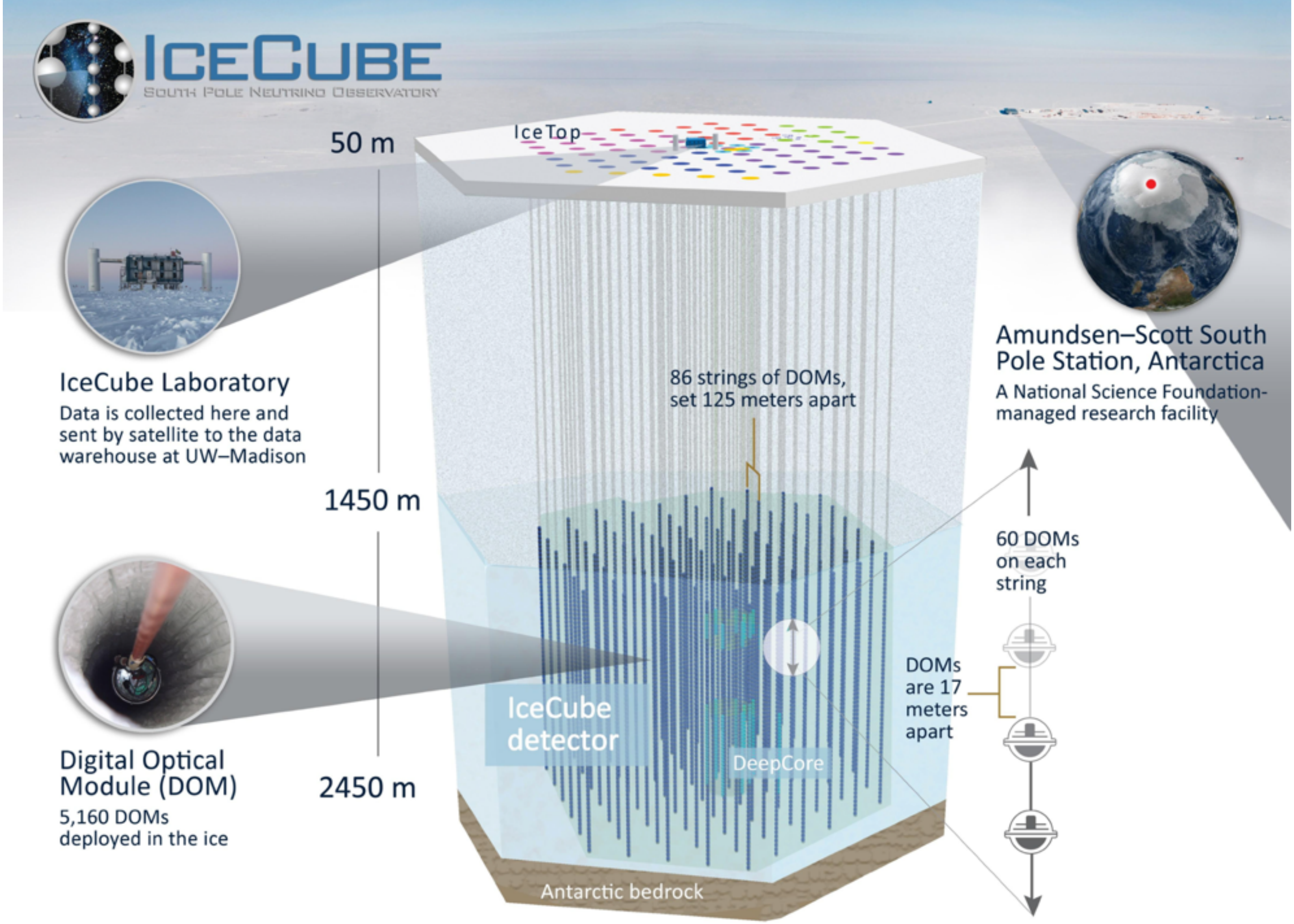
BAIKAL: Lake Baikal, Siberia



DUMAND, Hawaii
(cancelled 1995)

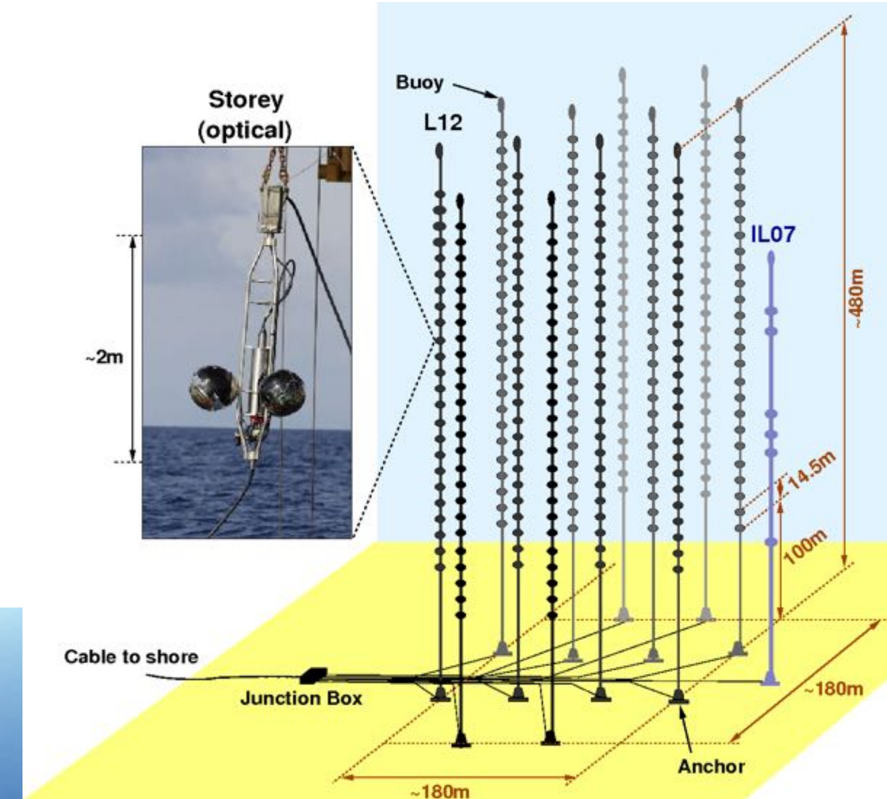
KM3NeT (Catania, Italy)

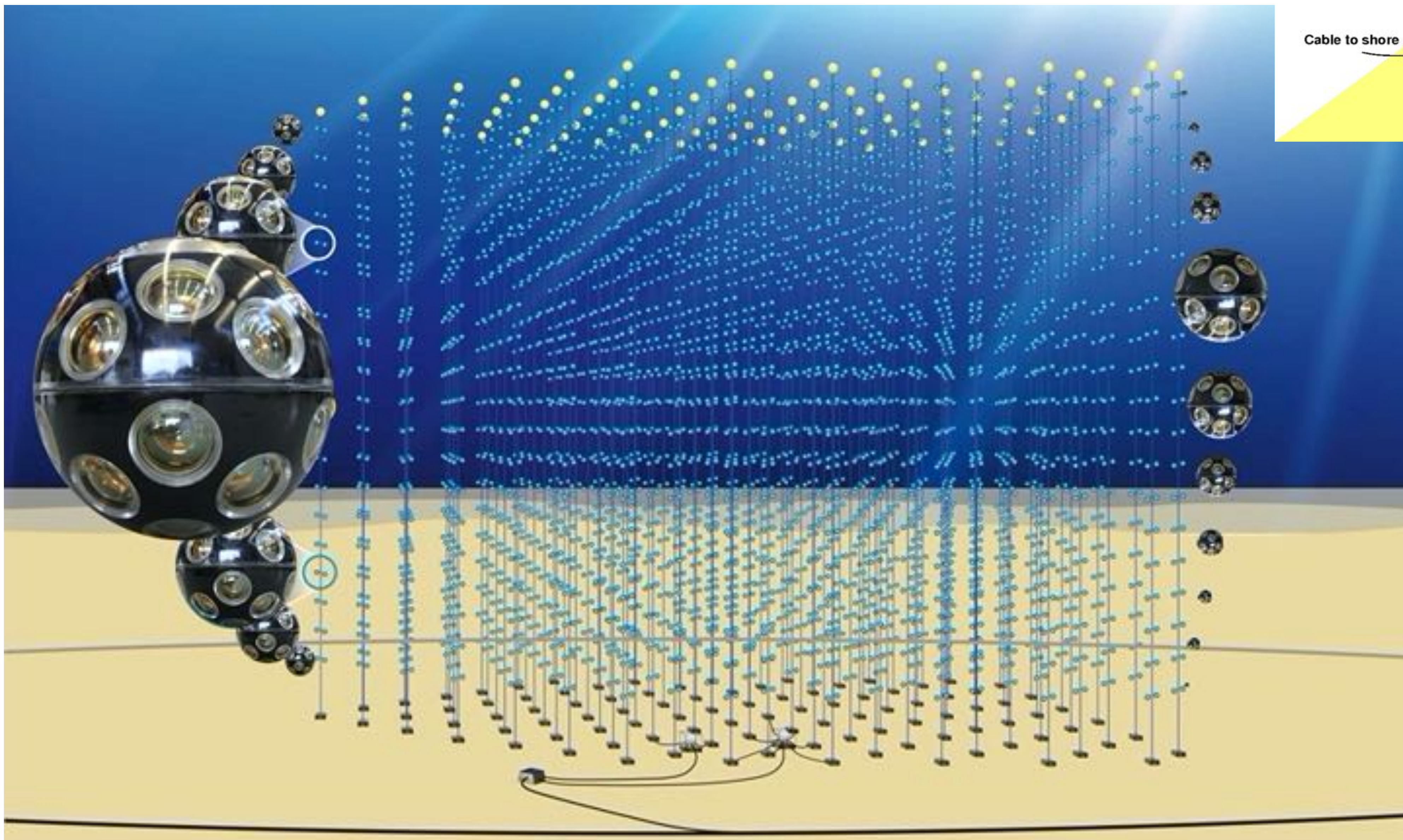
AMANDA/IceCube: Antarctica


ICECUBE
SOUTH POLE NEUTRINO OBSERVATORY
IceTop
50 m
IceCube Laboratory
Data is collected here and
sent by satellite to the data
warehouse at UW–Madison
1450 m
2450 m
Digital Optical
Module (DOM)
5,160 DOMs
deployed in the ice
86 strings of DOMs,
set 125 meters apart
IceCube
detector
DeepCore
Antarctic bedrock
Amundsen–Scott South
Pole Station, Antarctica
A National Science Foundation-
managed research facility
60 DOMs
on each
string
DOMs
are 17
meters
apart

ANTARES + KM3NeT

- Good visibility of the Southern Sky
- Water: low scattering => high angular resolution
- ^{40}K + bioluminescence



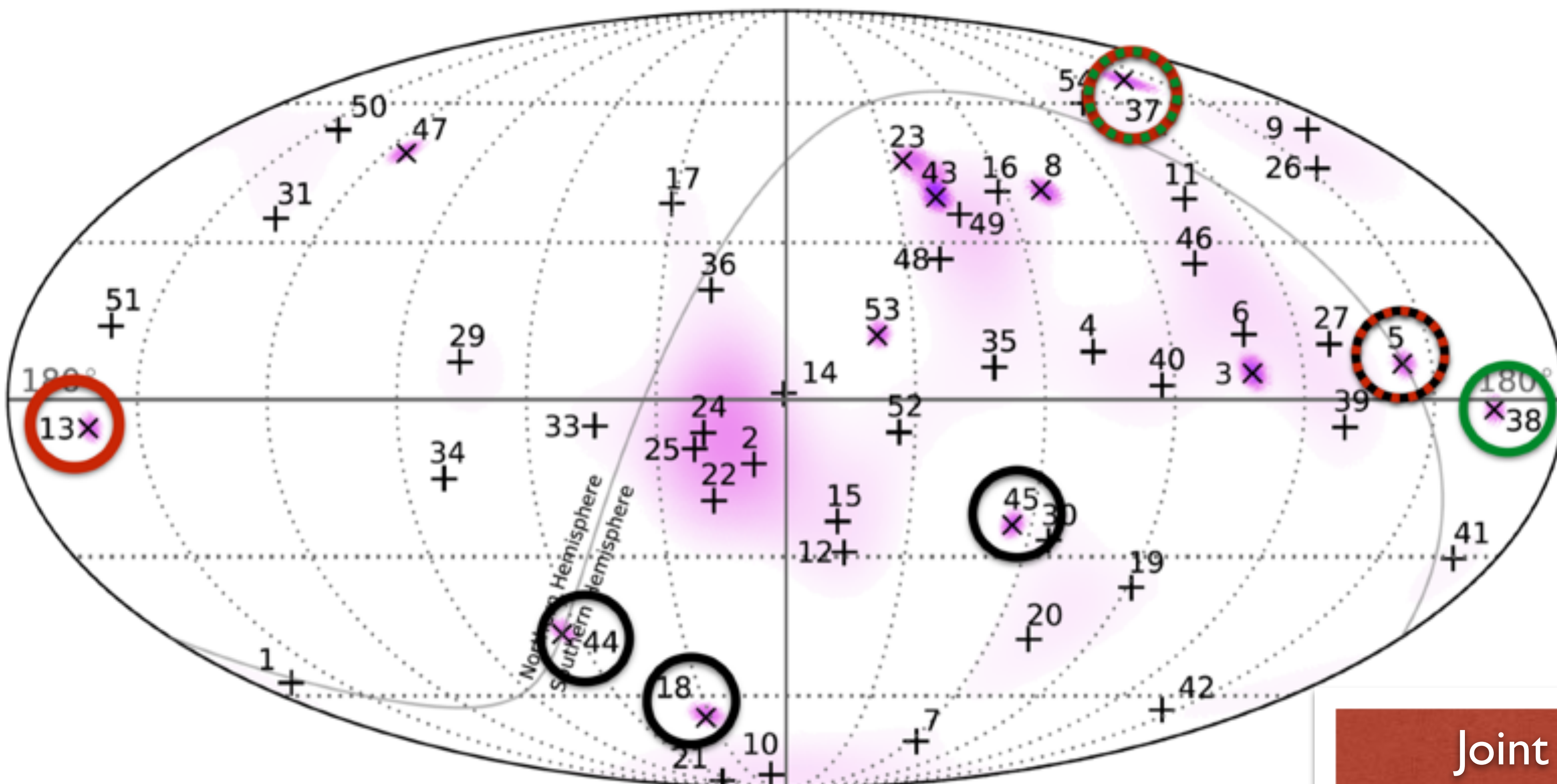


High-energy neutrino follow-ups with IACTs

FS et al., ICRC 2015
FS et al., Gamma 2016
FS et al., Moriond 2017

M. Santander et al., ICRC 2016
M. Santander et al., ICHEP 2016

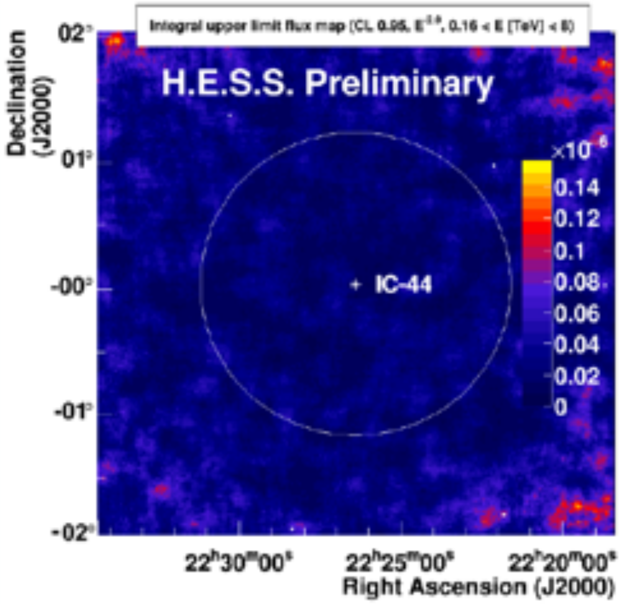
K. Satalecka, Gamma 2016

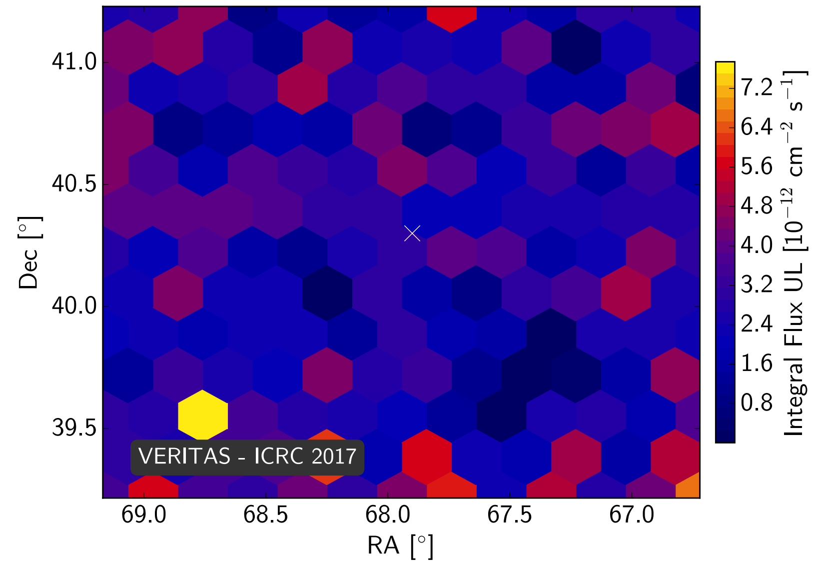


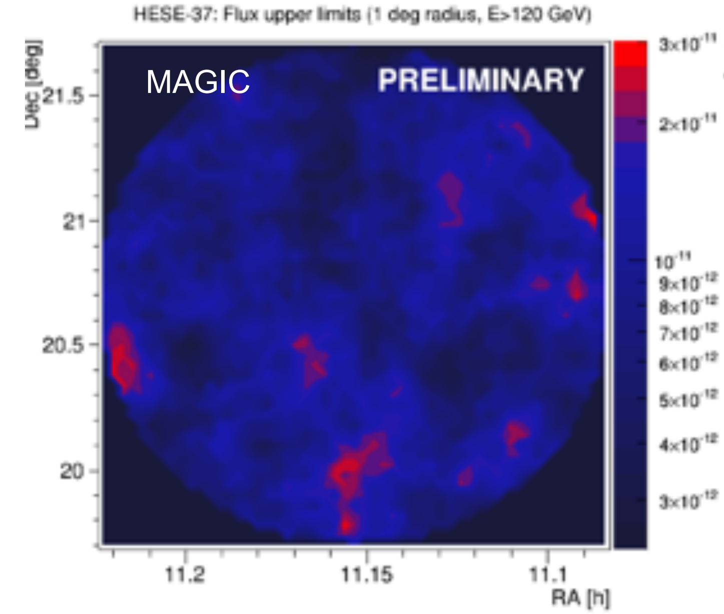
H.E.S.S. + MAGIC + VERITAS

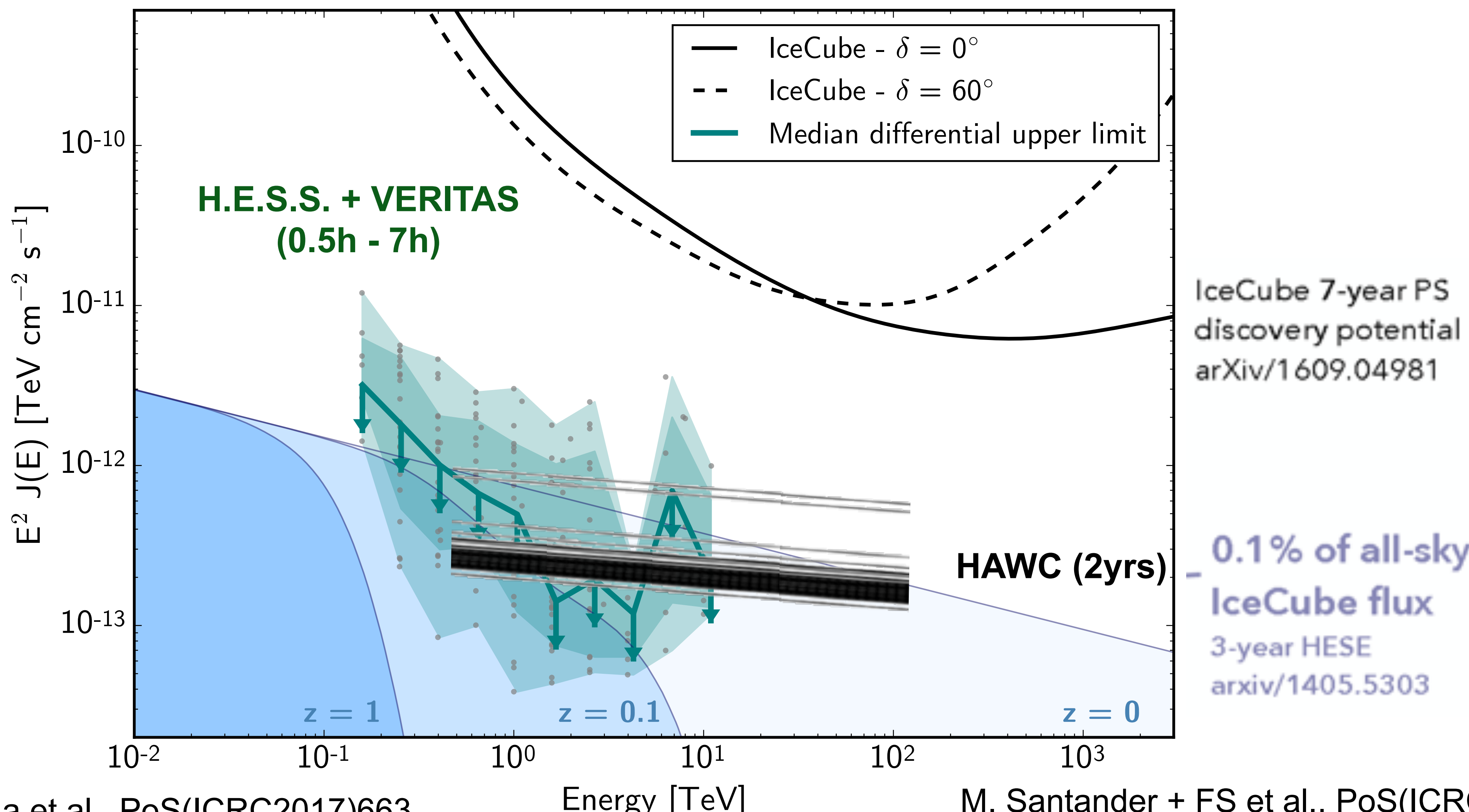
Joint analysis
M. Santander + FS et al.
PoS (ICRC2017) 618

Gamma-ray counterparts to IceCube events







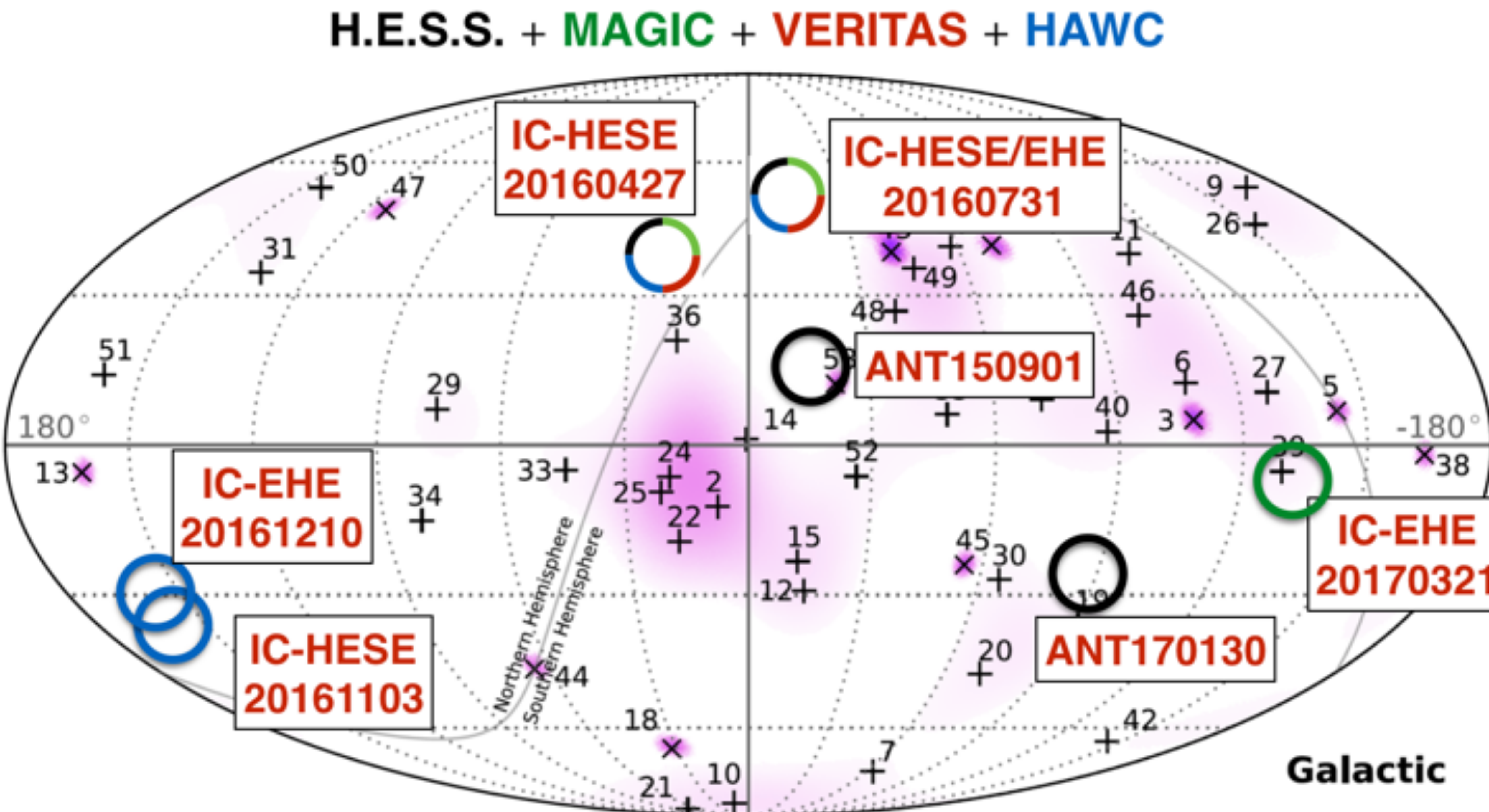


I. Taboada et al., PoS(ICRC2017)663

M. Santander + FS et al., PoS(ICRC2017)618

Gamma-ray follow-up of high-energy neutrino alerts

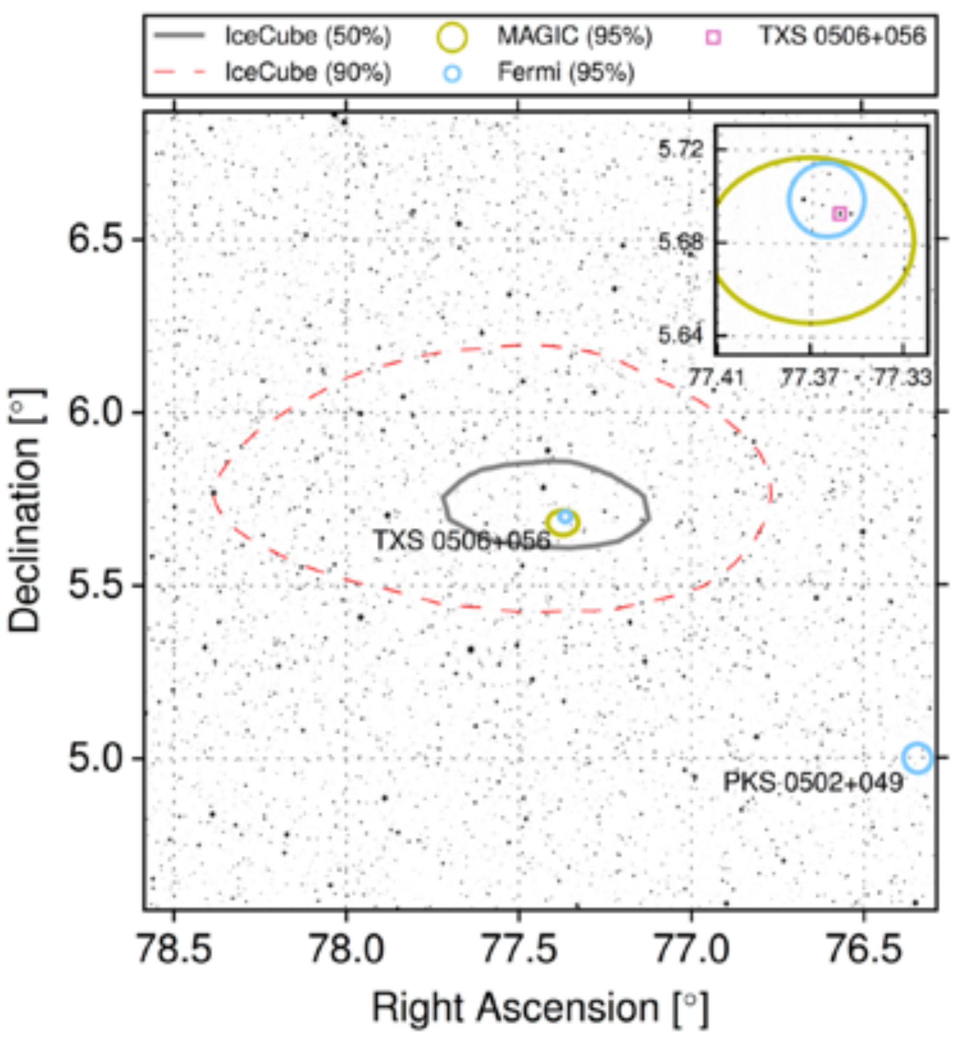
- **Space and time correlations** would provide ”smoking gun” signal for joint emission processes => CR interaction/acceleration

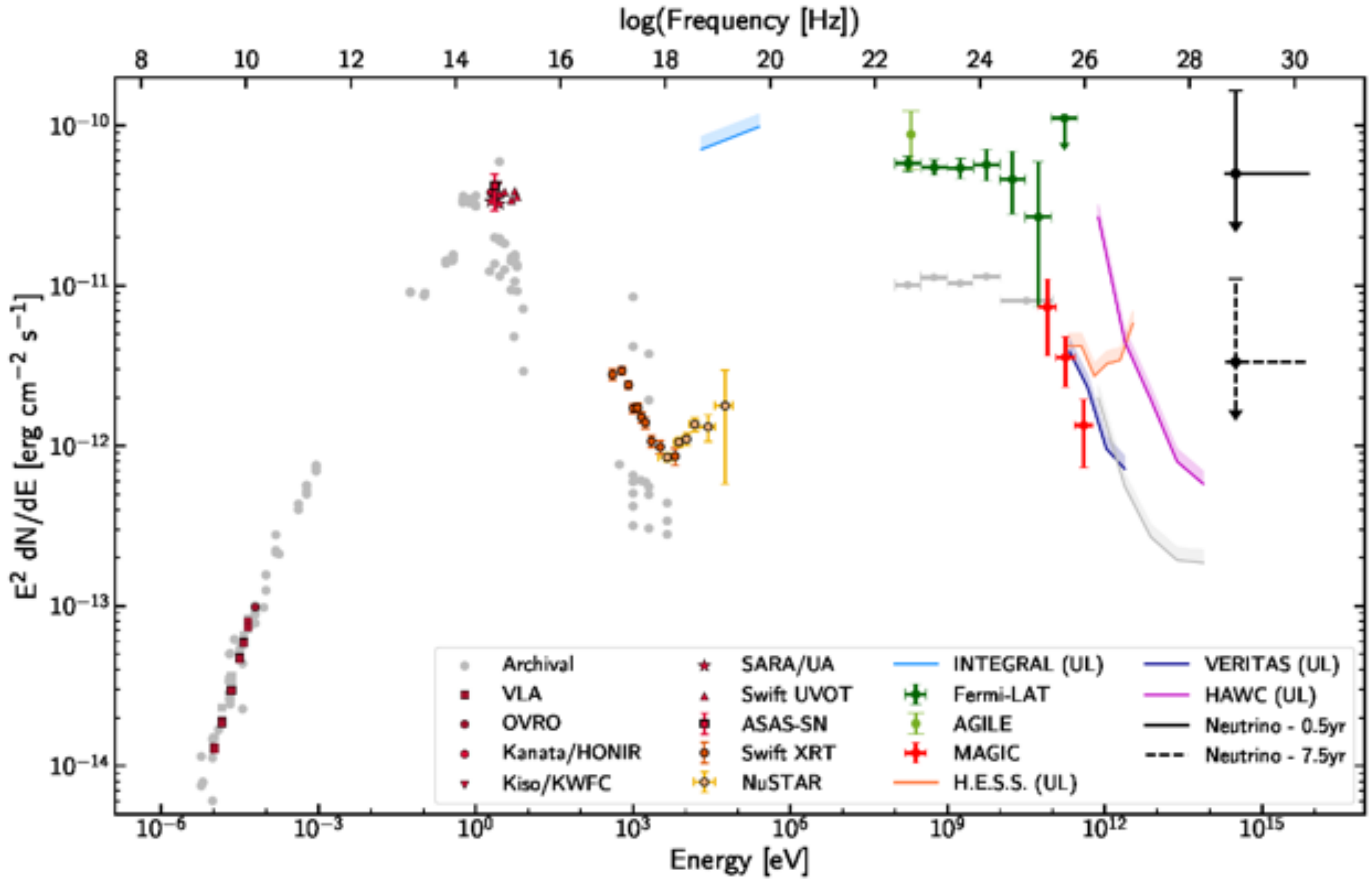


FS, ICRC 2017 highlight talk

IceCube-170922A and TXS 0506+056 : MWL campaign

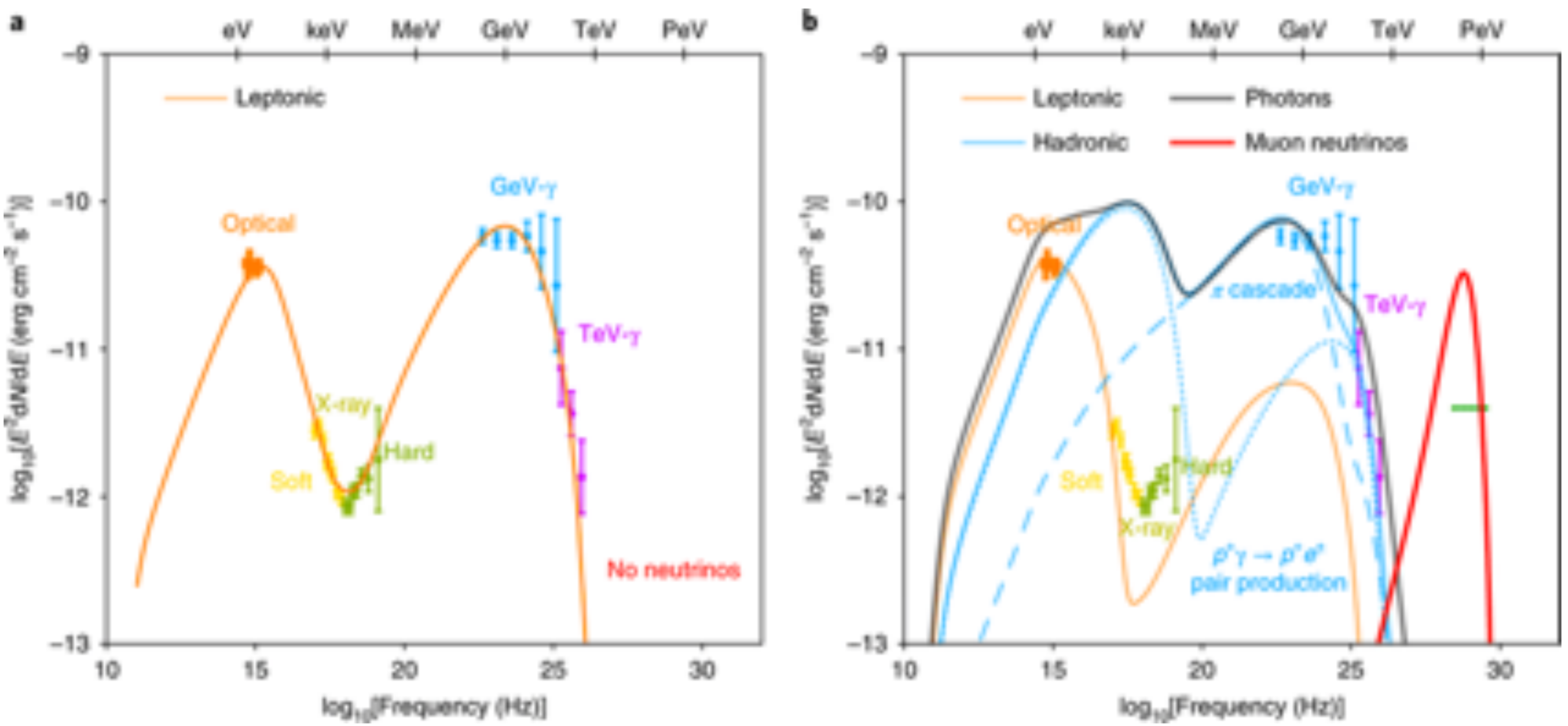
- the first extensive multi-wavelength and multi-messenger picture
- modeling not straight-forward (e.g. need for special jet models, etc.)





Neutrino - Gamma Ray emission scenarios

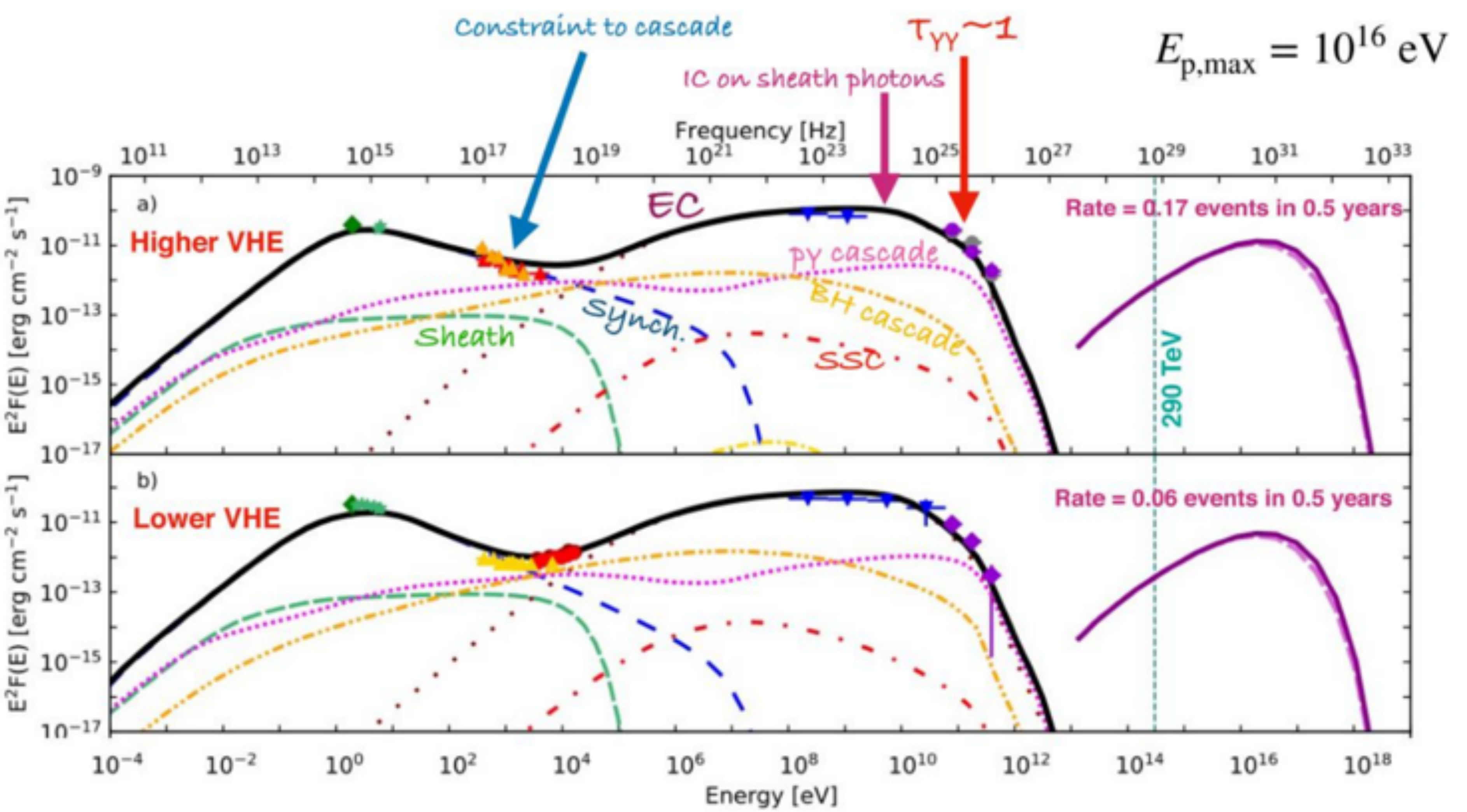
- TXS 0506+056 in 2017
  - purely hadronic models not able to describe the SED
  - leptonic models don't produce neutrinos

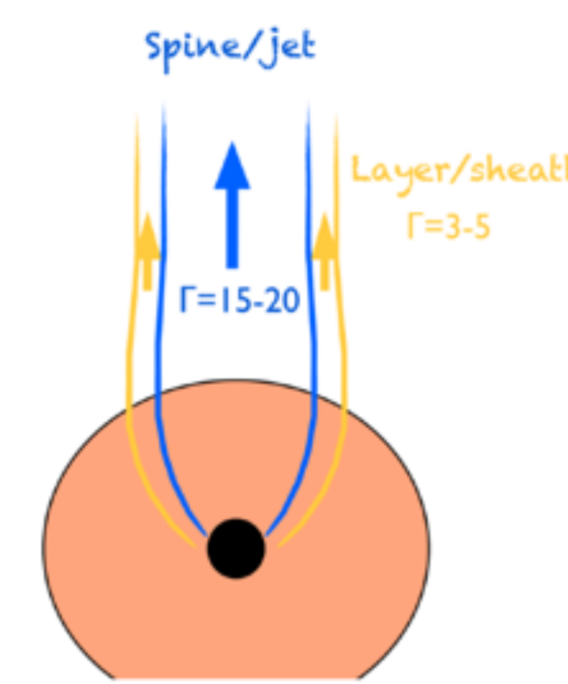


S. Gao, A.Fedynitch, W.Winter, M.Pohl, Nature Astronomy (2019) 3

Neutrino - Gamma Ray emission scenarios

- TXS 0506+056 in 2017
  - purely hadronic models not able to describe the SED
  - leptonic models don't produce neutrinos
  - hybrid models with specific parameters/assumptions necessary



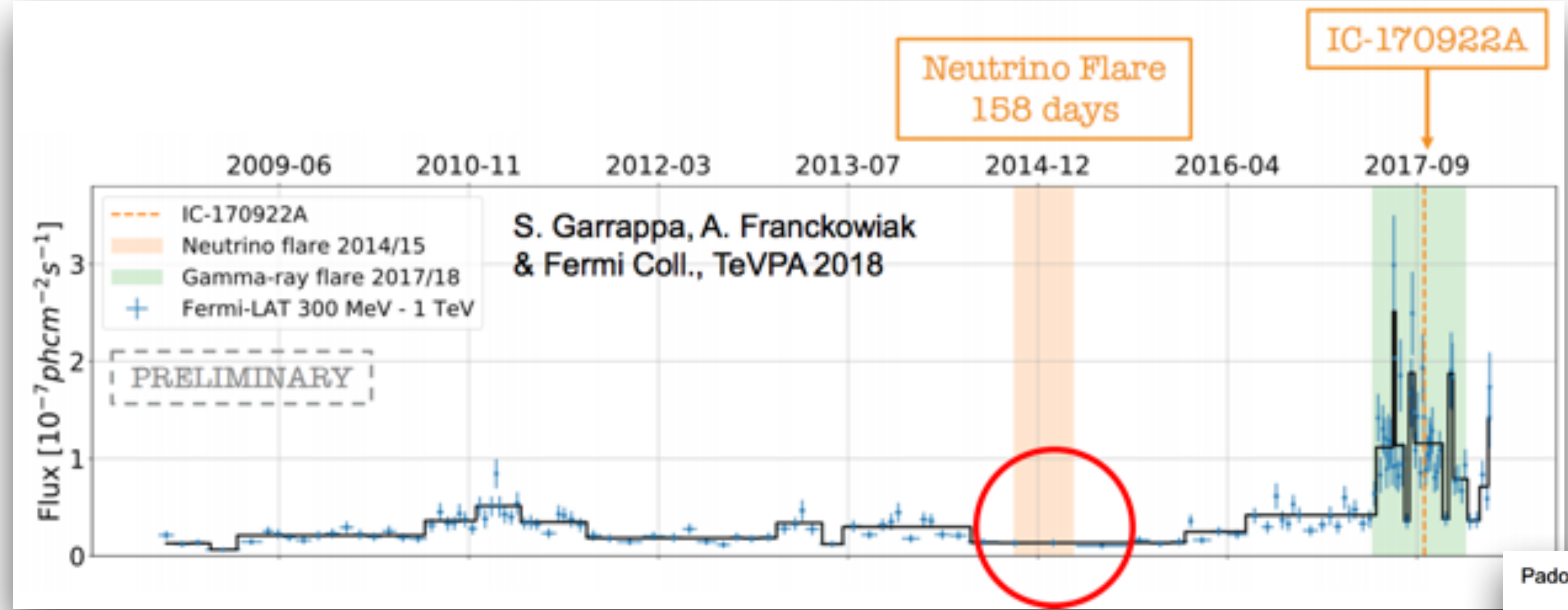


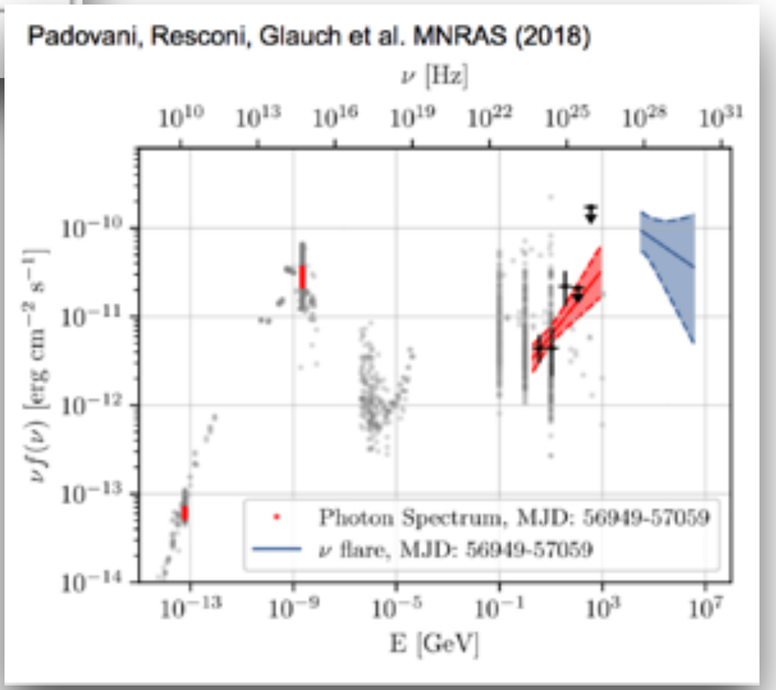
Ghisellini, Tavecchio, Chiaberge 2005
Tavecchio and Ghisellini, 2008

Ansoldi et al. (MAGIC) (arXiV: 1807.04300)

Neutrino - Gamma Ray emission scenarios

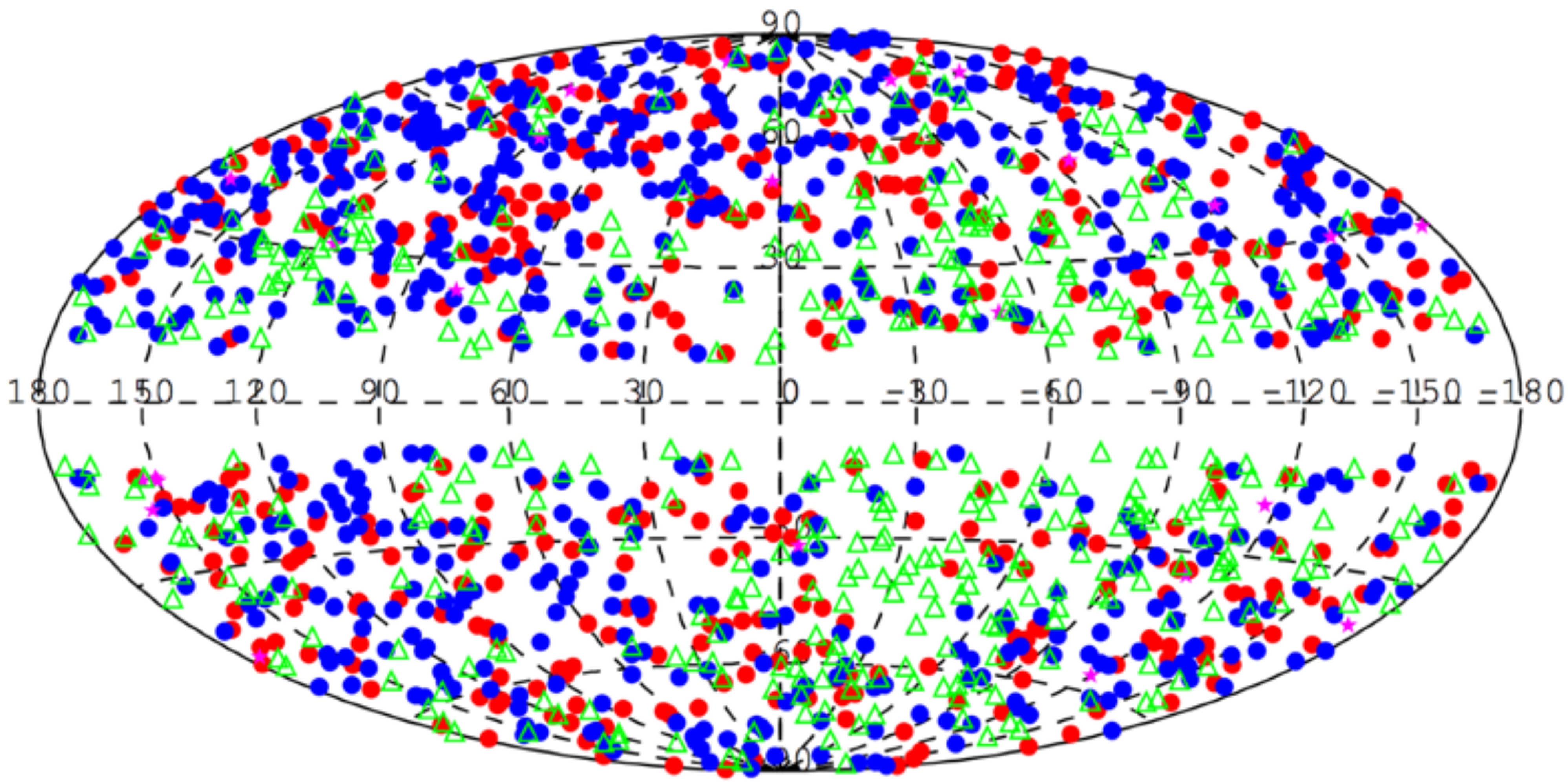
- TXS 0506+056 in 2014/2015
  - limited MWL data; no significant GeV flux increase; hint for spectral hardening





How significant is the correlation?

- 1591 AGNs in the Fermi-LAT catalog 3LAC
- about 5% chance to find a Fermi-LAT AGN in a neutrino error box (~1deg²)
- this is the 10th neutrino alert issued in real-time (+41 archival events)



Fermi 3LAC

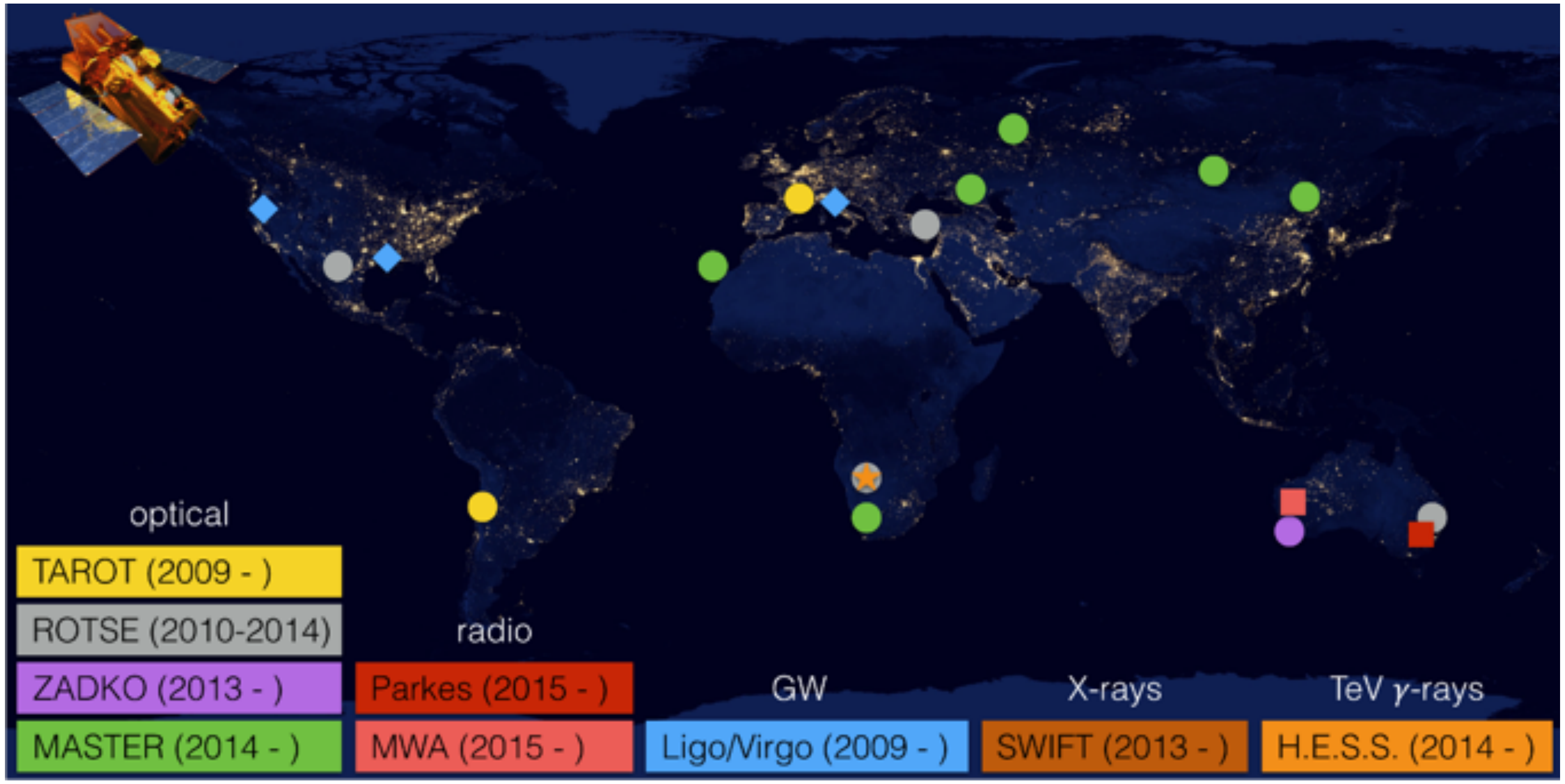
Multi-messenger observations of a flaring blazar

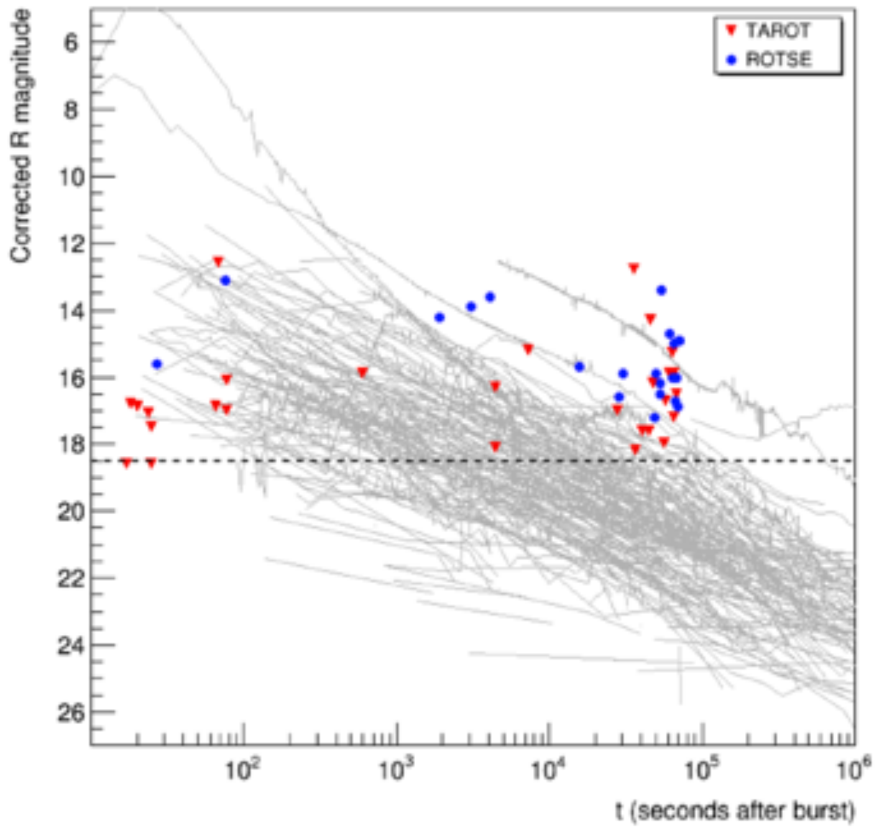
- Question asked in the paper: ”What is the chance probability to find a flaring blazar like TXS 0506+056 correlated with a high-energy neutrino like IC-170922A?”
- Answer: ~3σ

- Also, this question does not include the prior ”is the neutrino of astrophysical origin?”
  - probability of ~56%

TAToO: the ANTARES neutrino alert program

- online reconstruction of the ANTARES data within a few seconds
- filtering/detection of promising candidates
- alert emission to a list of MoU observatories (ANTARES) or via public announcements (IceCube)

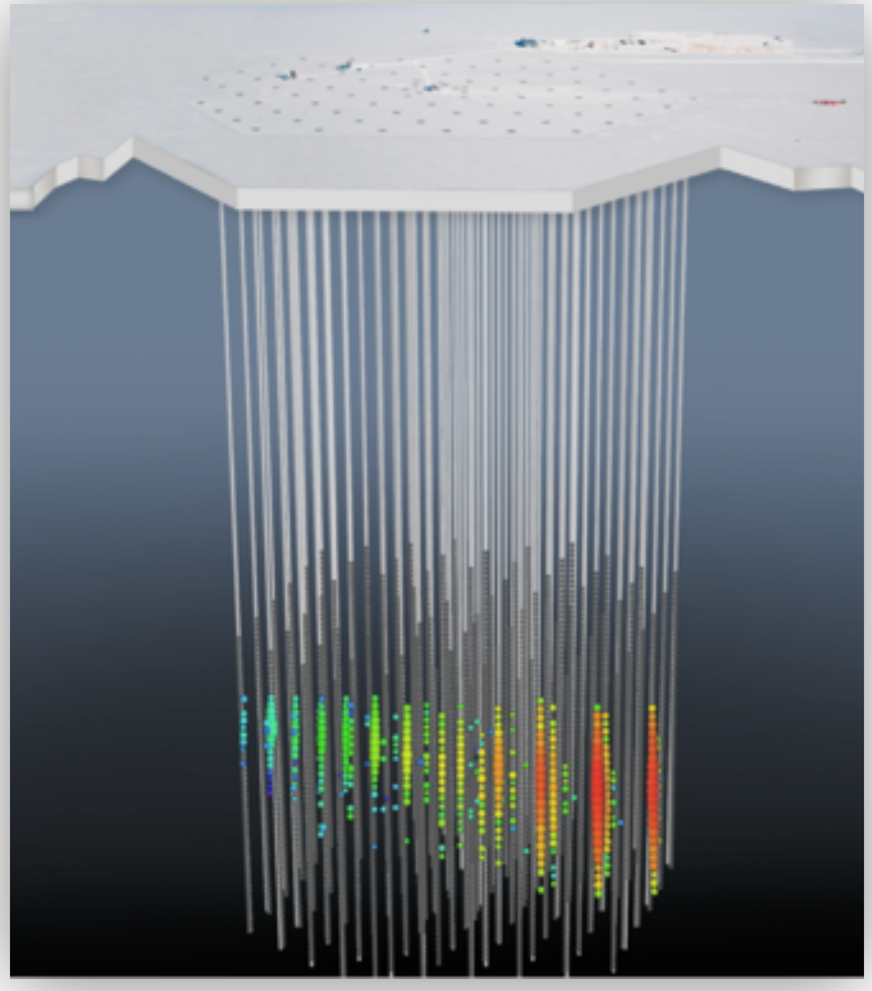


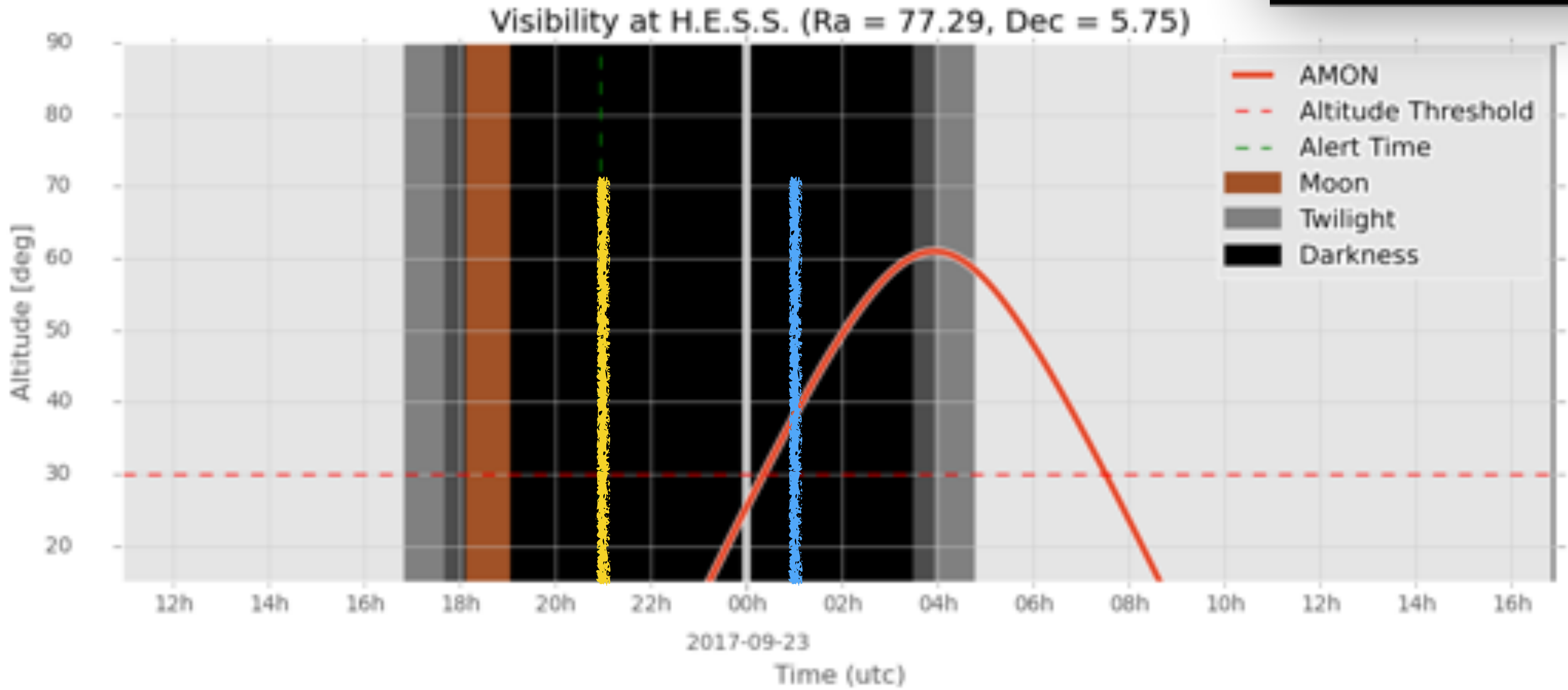


APP 35 (2012) 530–536

IceCube-170922A

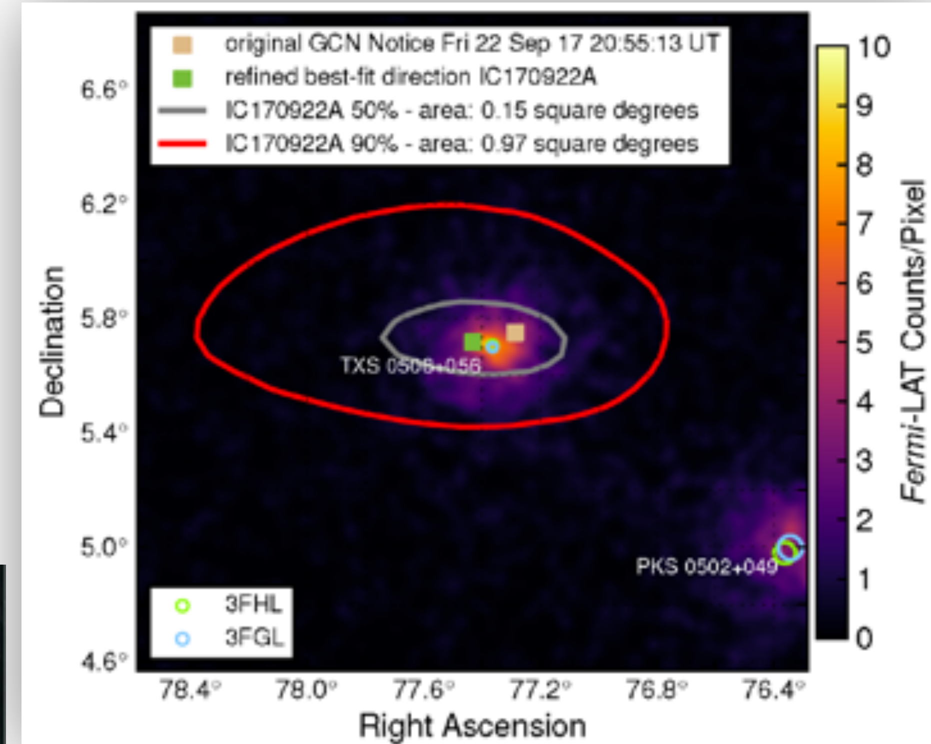
- 22/09/2017: Detection of another high-energy neutrino of about 300 TeV by IceCube: automatic and public alert distribution to follow-up observatories at all wavelengths
- Observations with H.E.S.S. started 4h later
- no gamma-ray signal found => ATEL #10787

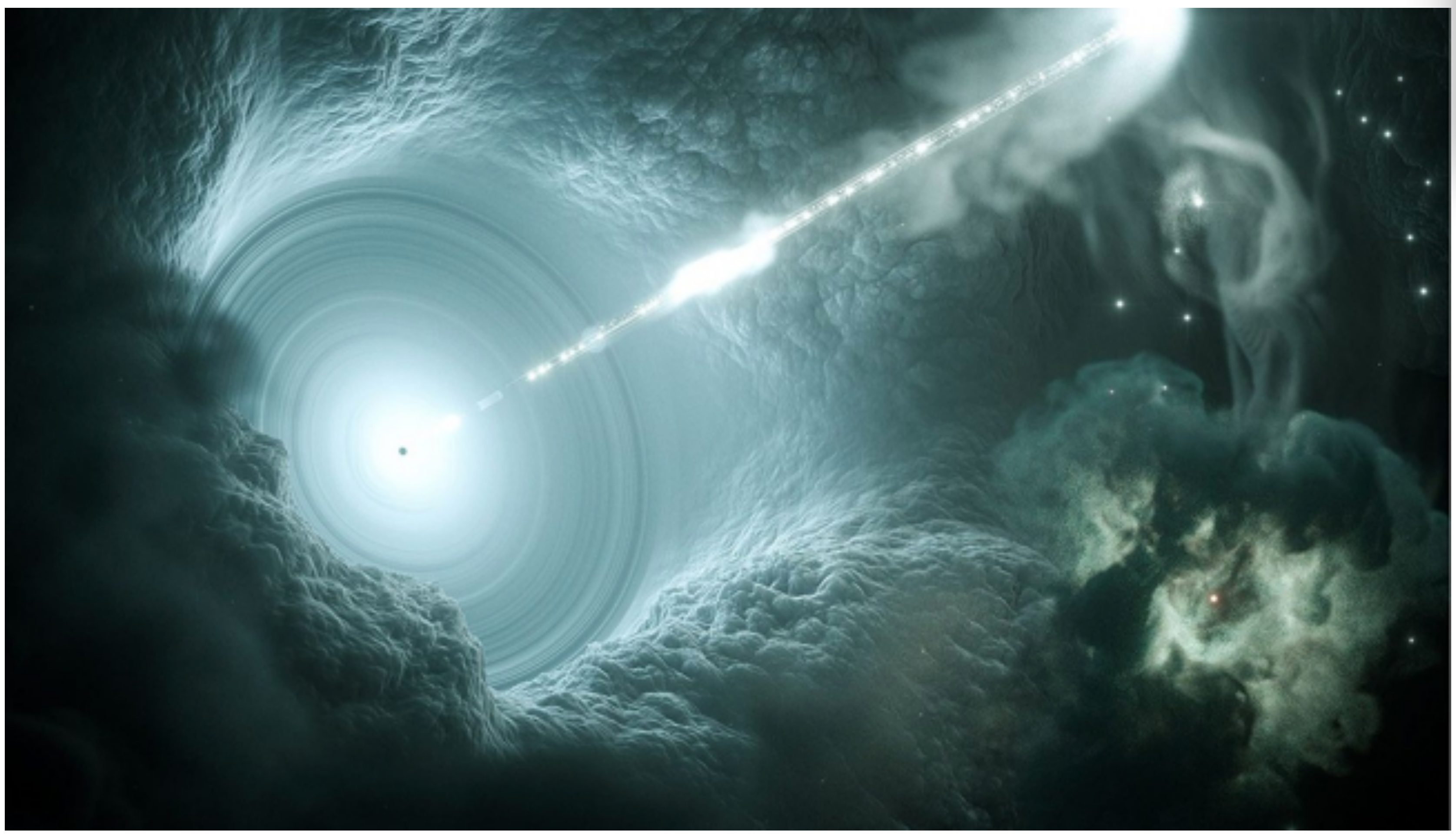




IceCube-170922A and TXS 0506+056

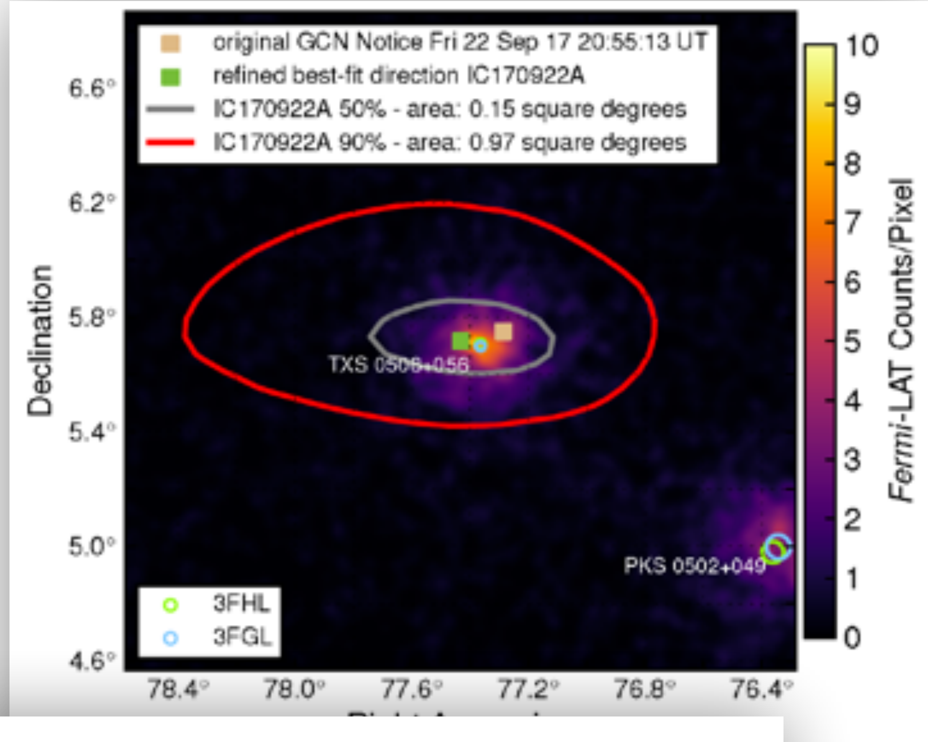
- 28/09/2017 Fermi-LAT: Detection of an active blazar (active galactic nuclei with the jet pointing towards Earth) within the neutrino uncertainty region ATEL #10791

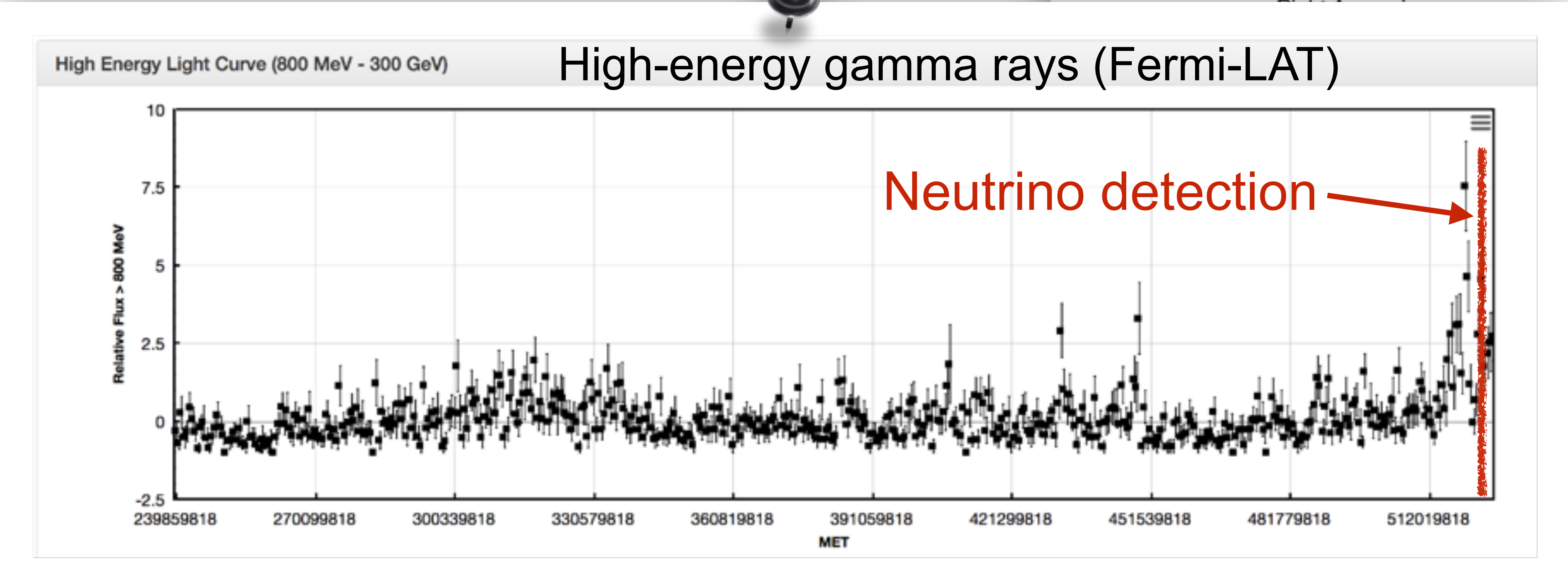




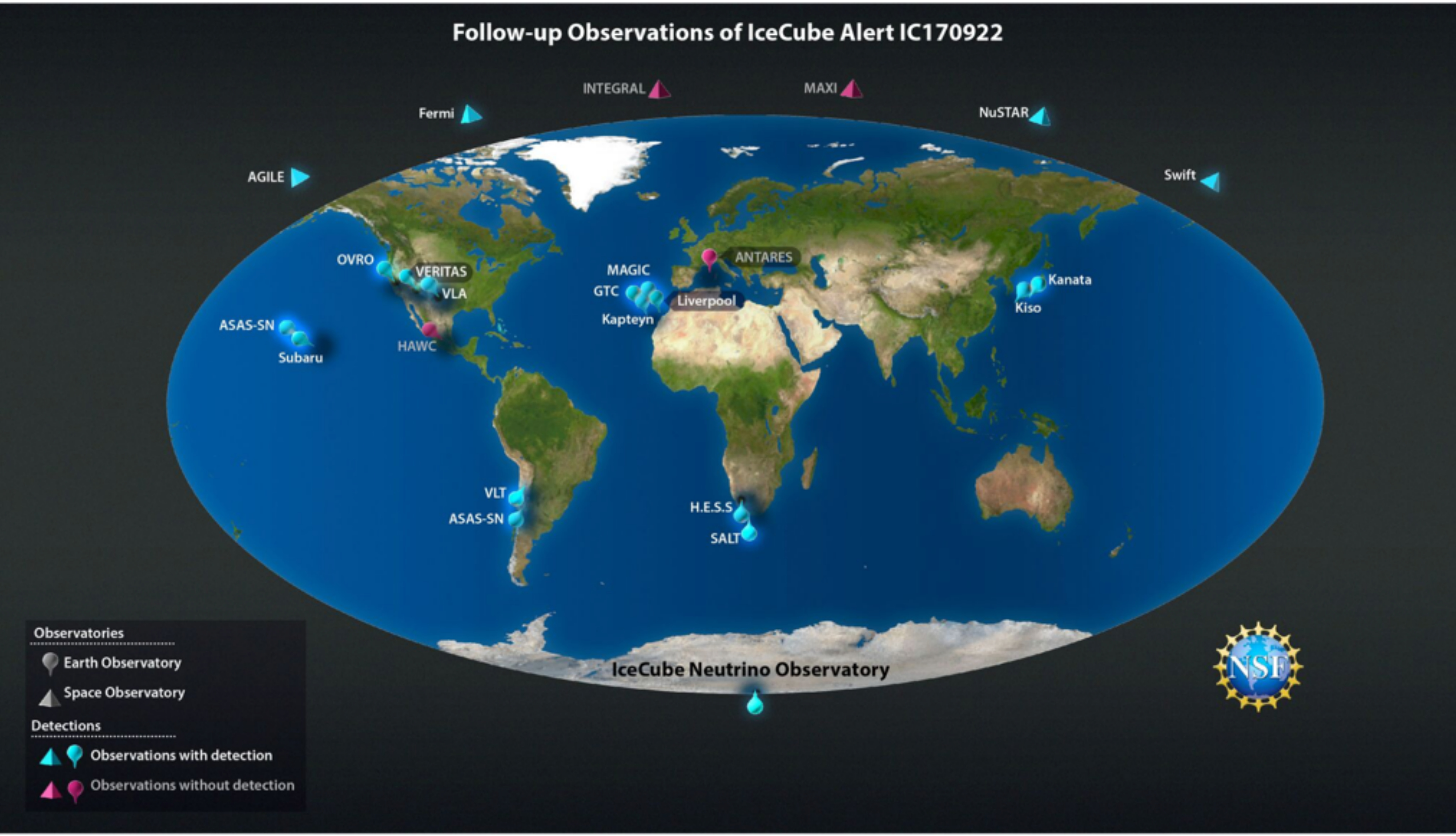
IceCube-170922A and TXS 0506+056

- 28/09/2017 Fermi-LAT: Detection of an active blazar (active galactic nuclei with the jet pointing towards Earth) within the neutrino uncertainty region ATEL #10791
- activity in all wavelengths (optical - X-rays - gamma rays) with unprecedented flux levels



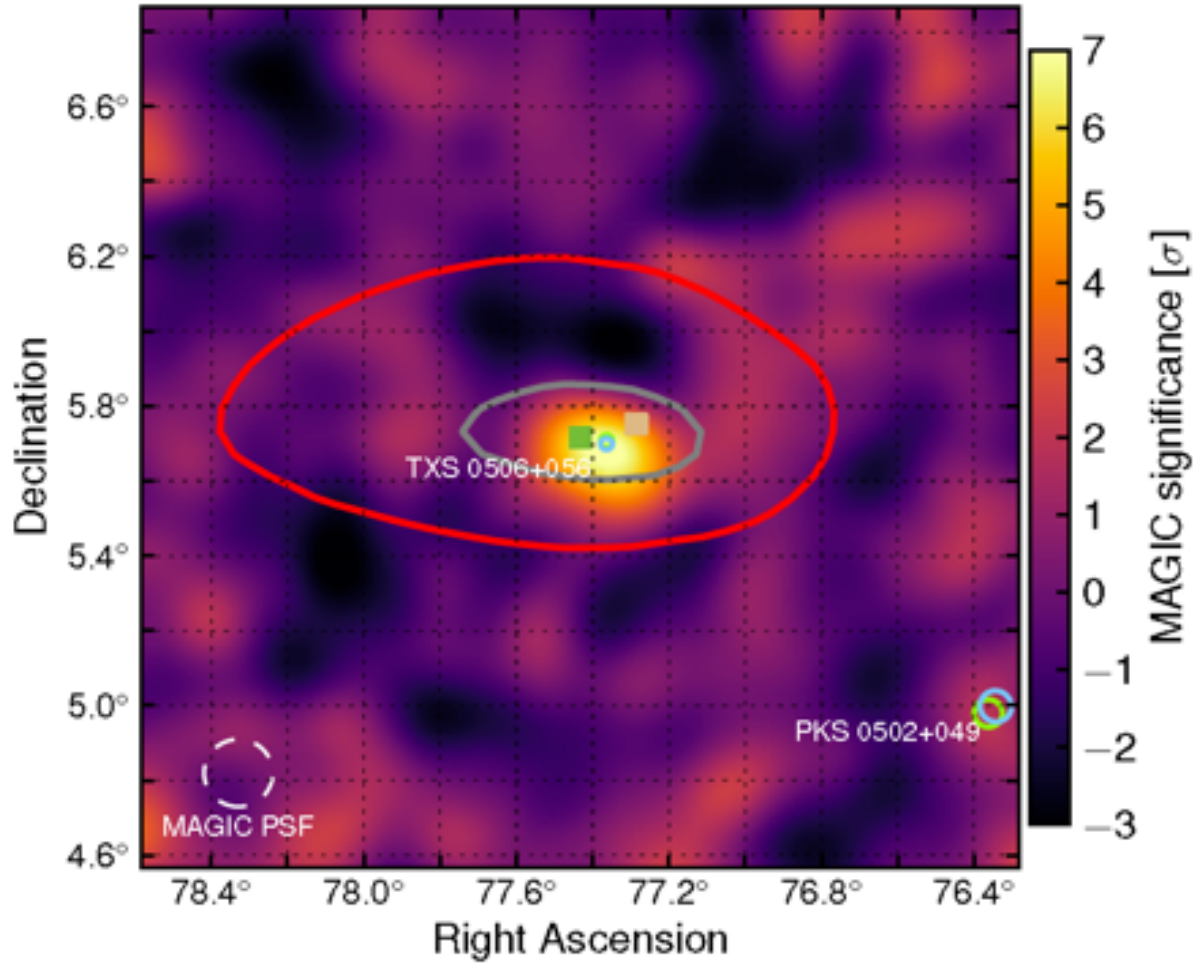


A worldwide observation campaign



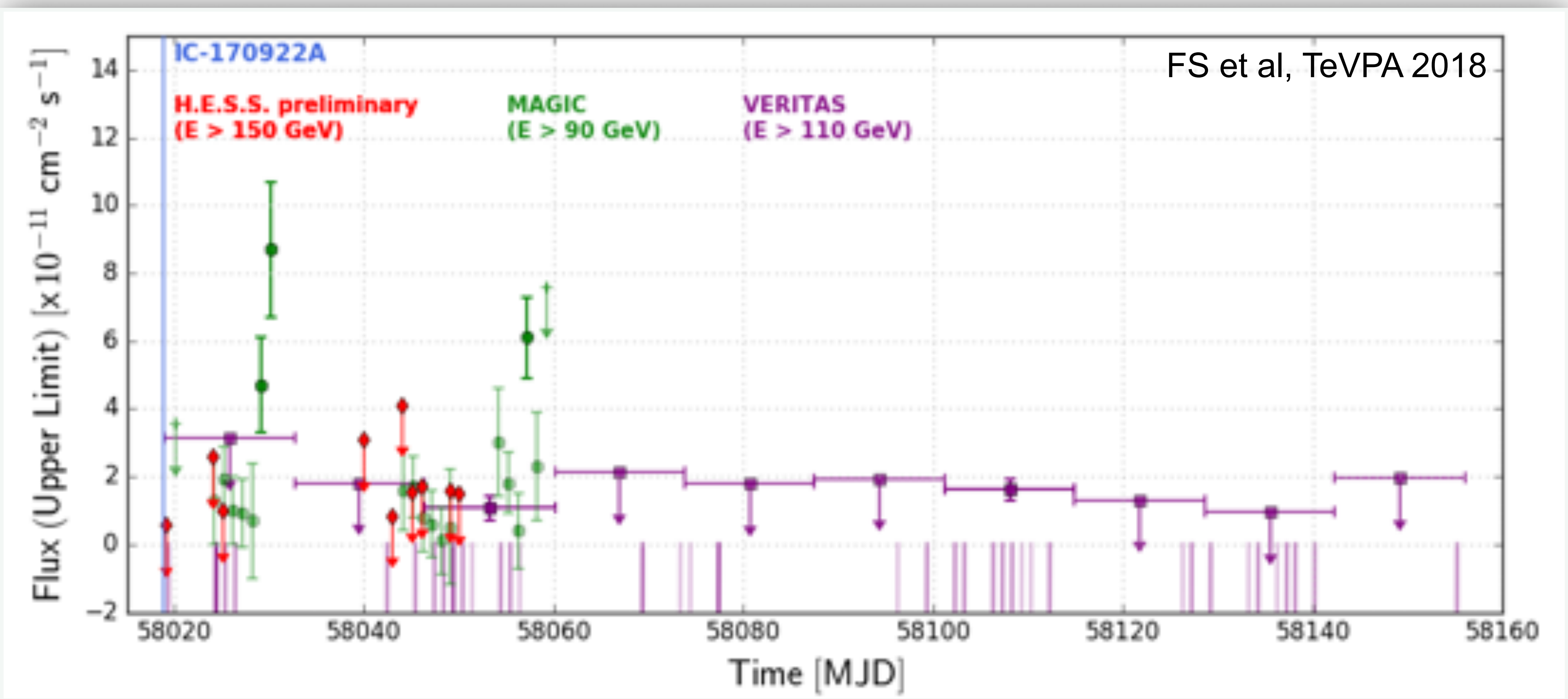
IceCube-170922A and TXS 0506+056 : MWL campaign

- Highlights:
  - detection of VHE gamma-rays up to 400GeV by MAGIC (~10days after the neutrino event)



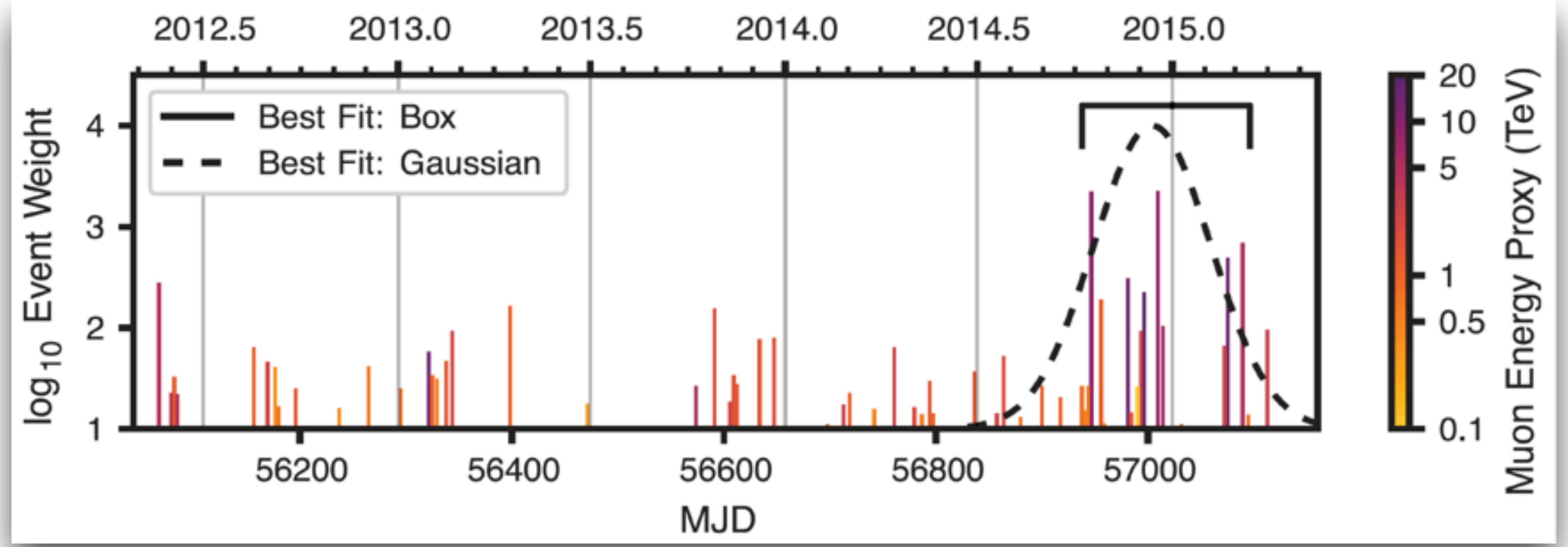
IceCube-170922A and TXS 0506+056 : MWL campaign

- Highlights:
  - detection of VHE gamma-rays up to 400GeV by MAGIC (~10days after the neutrino event) => variability at day-timescales
  - longterm monitoring campaign by VERITAS + MAGIC
  - ToO observations by H.E.S.S. (e.g. March 2018)



An orphan flare of neutrinos from the same direction

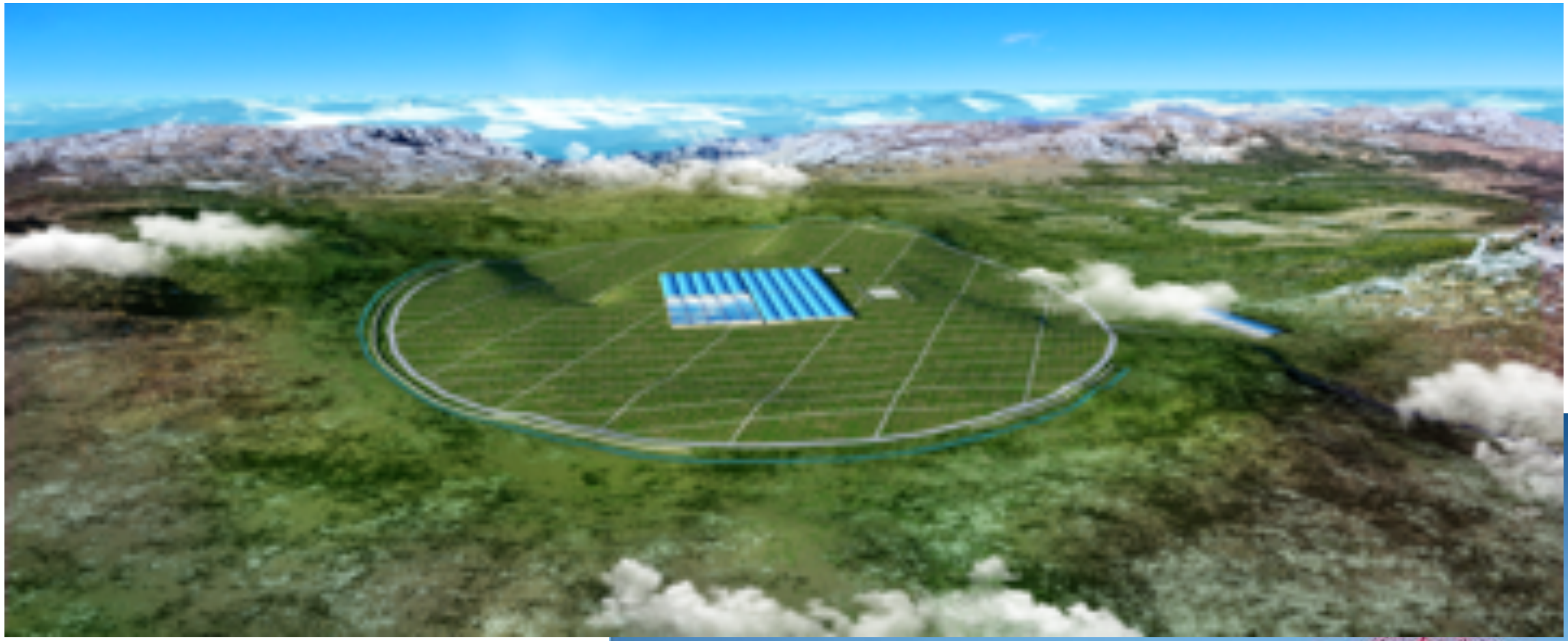
- dedicated searches in the IceCube (and ANTARES) neutrino data
- excess of 13 ± 5 neutrinos within ~100-150 days in 2014/2015
- spectrum following $E^{-2.1 \pm 0.3}$ (atmospheric: $E^{-3.7}$)
- significance : 3.5σ

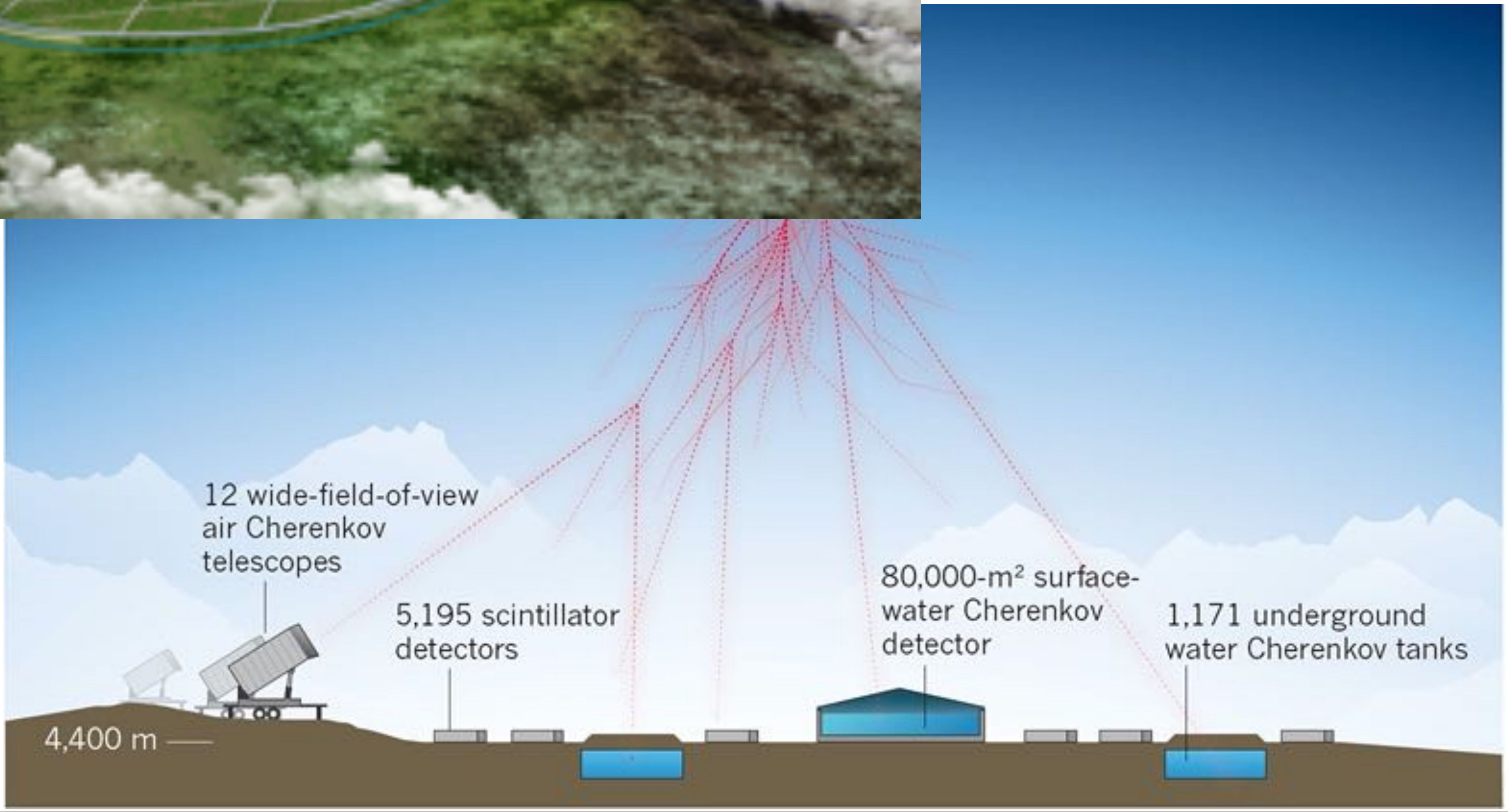


No associated MWL activity (no alert, i.e. few observations)
=> need for VHE monitoring observatories (see later)

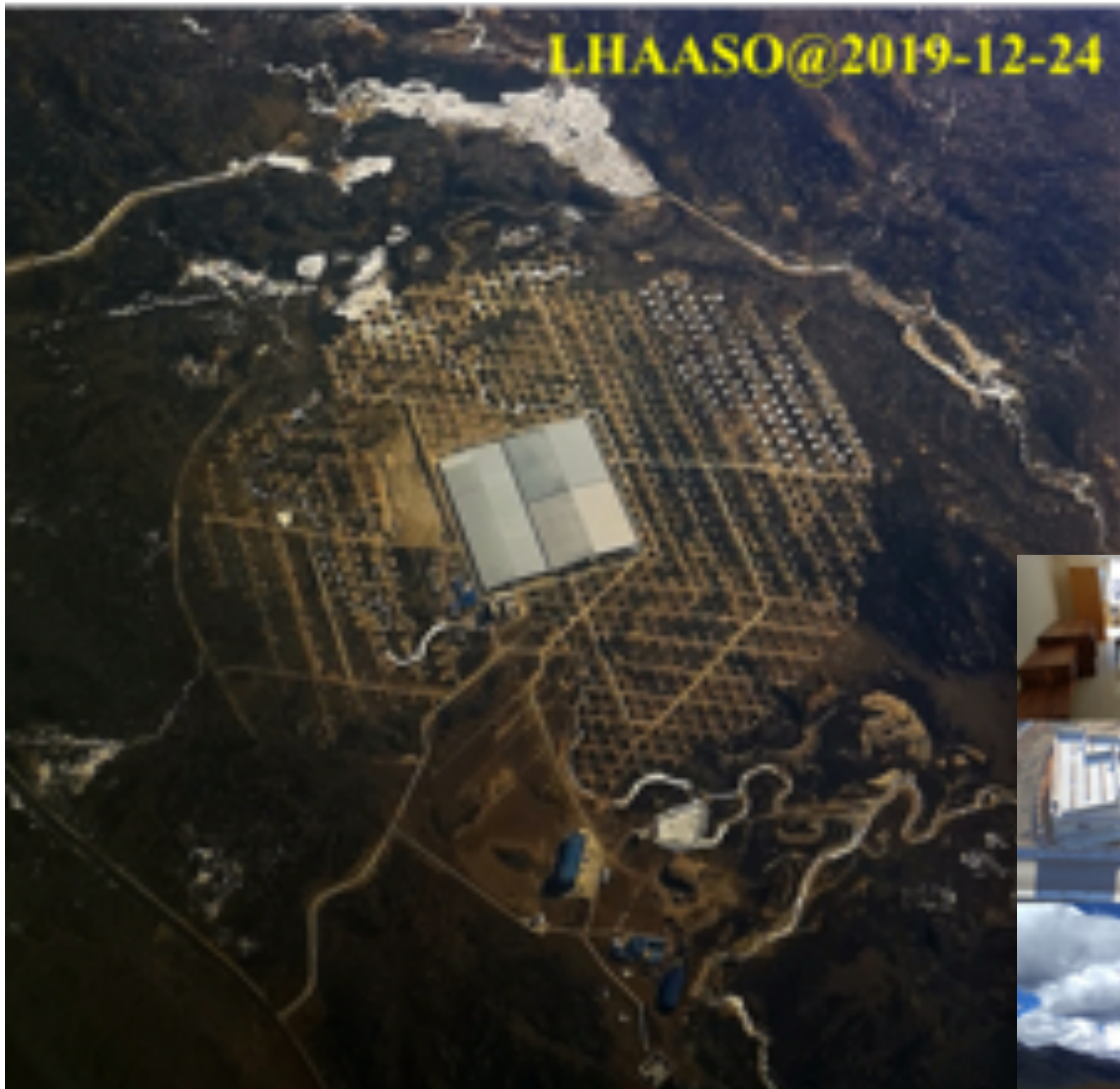
LHAASO

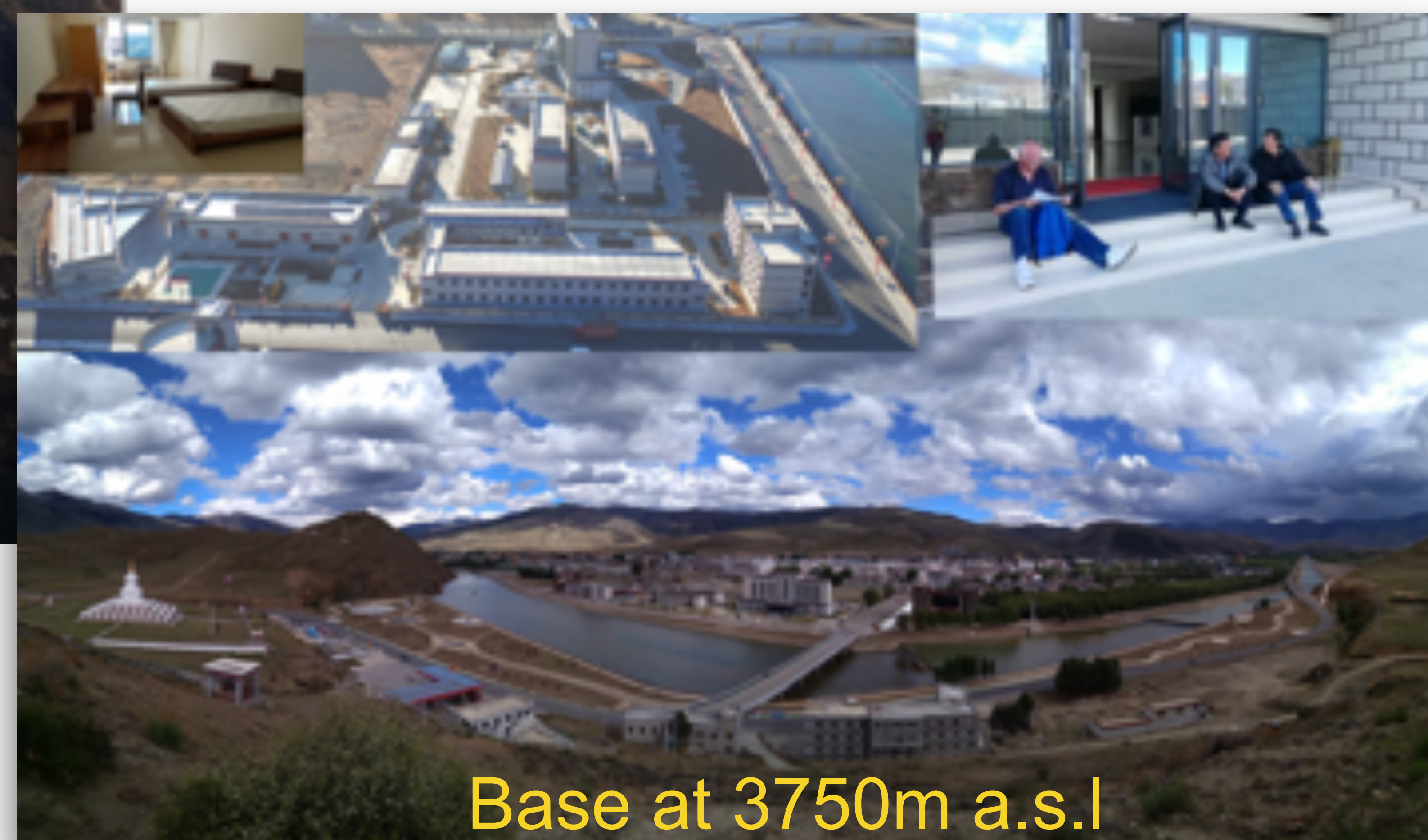
- Hybrid air-shower array at 4410m altitude in the Sichuan province of China





LHAASO: status



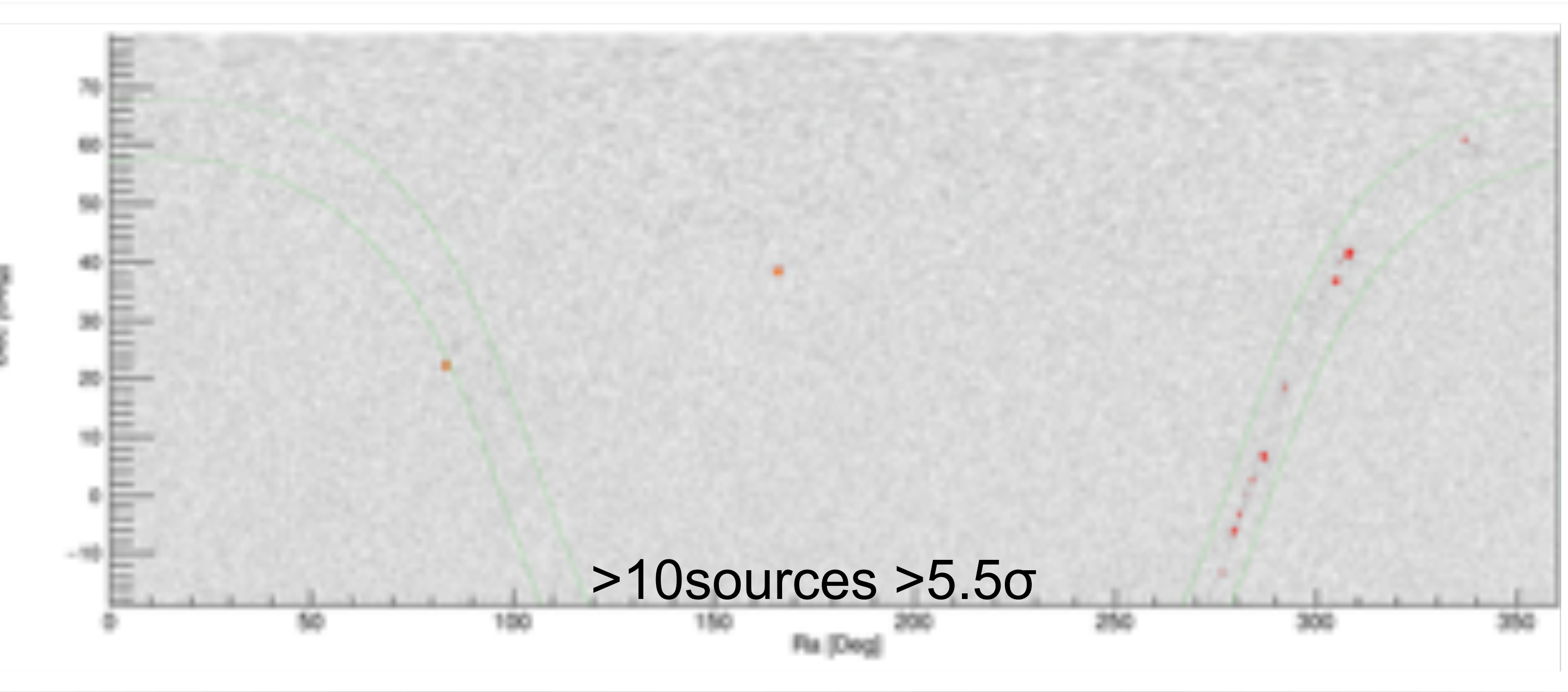


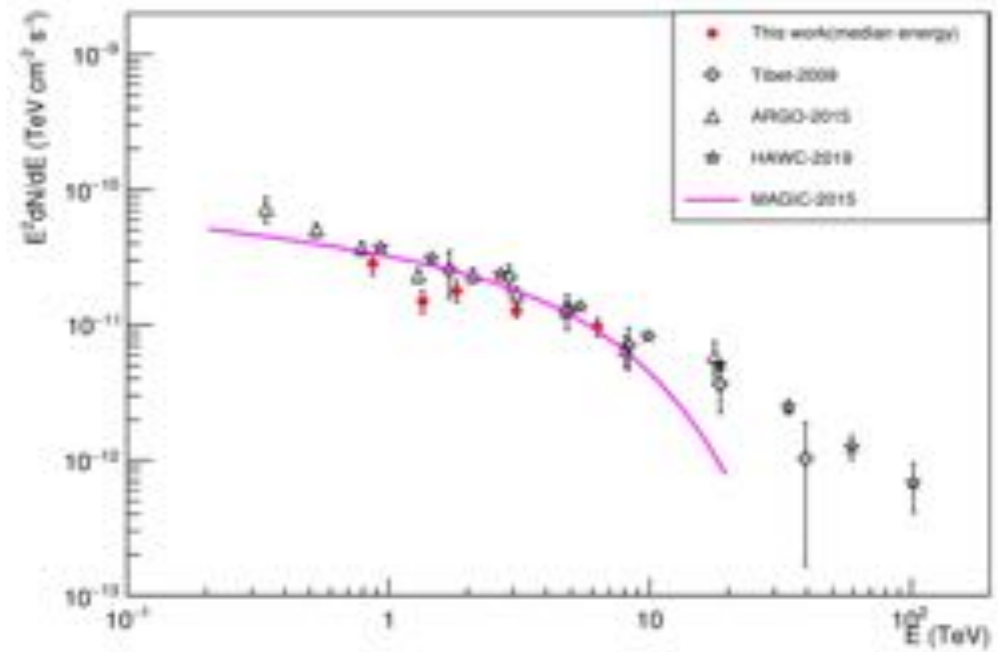
- >1/2 in operation
- Completion expected end 2020

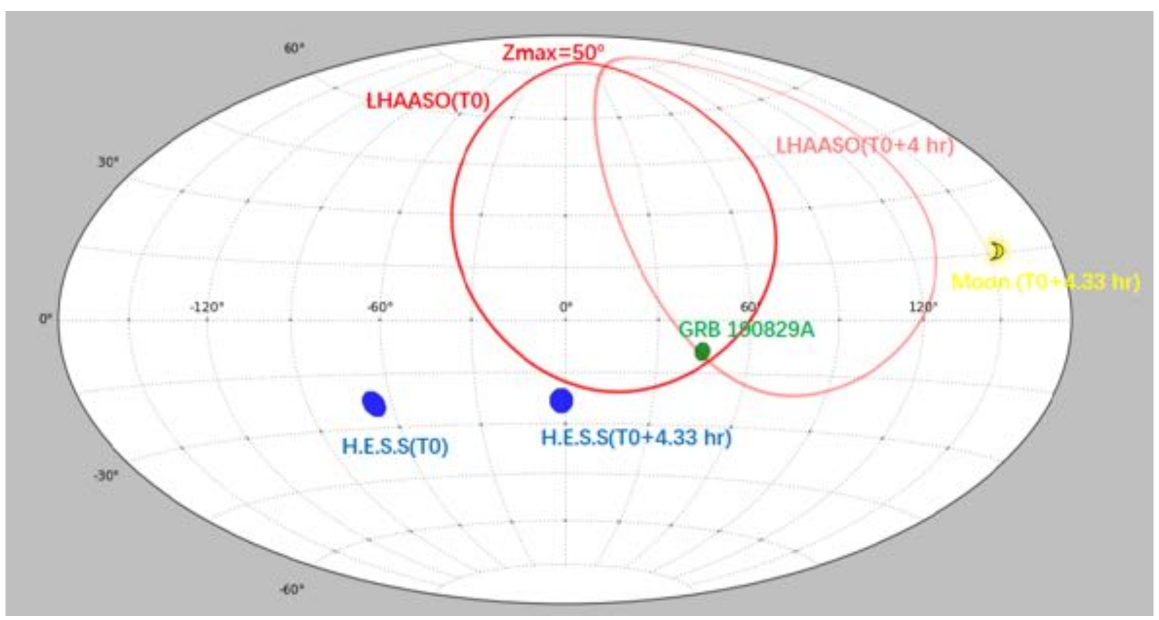
Huihai He, TMEX 2020

LHAASO: first results

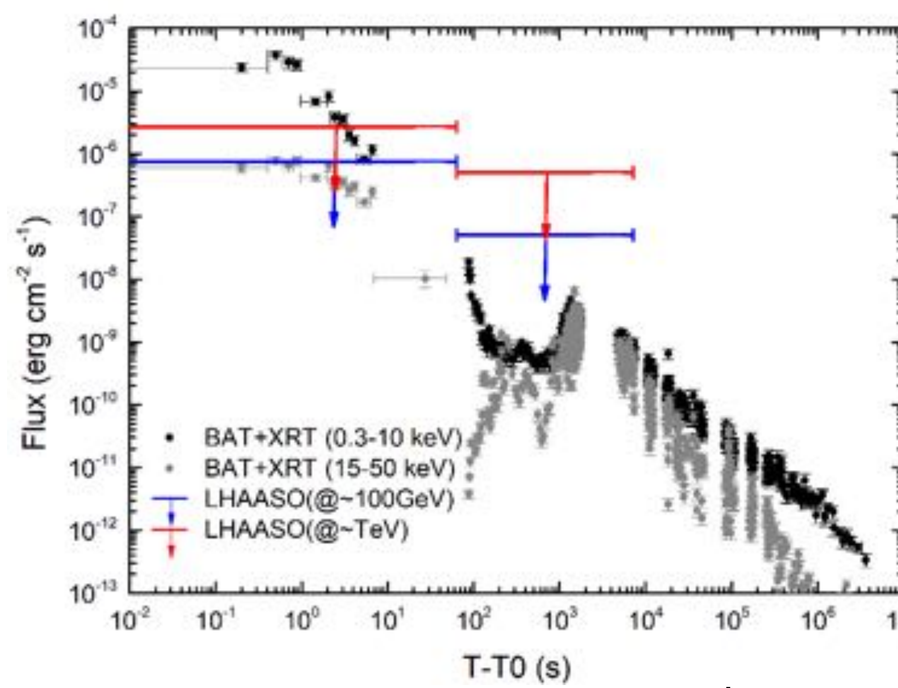
- 240days of data: Crab @ 63σ; pointing < 0.1°







GRB190829A @ LHAASO-WCDA1



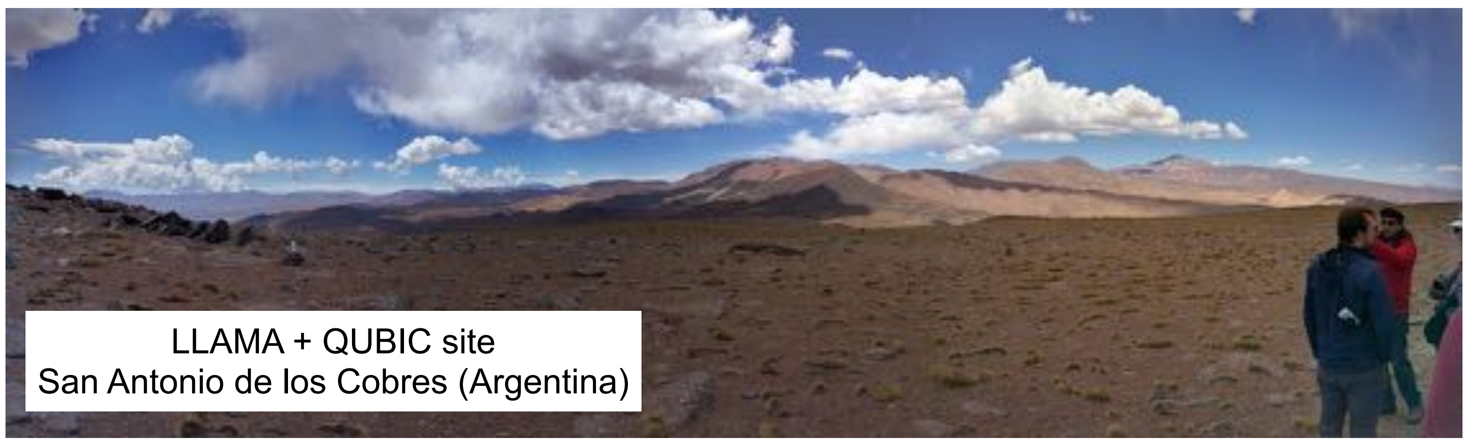
Huihai He, TMEX 2020

The Southern sky

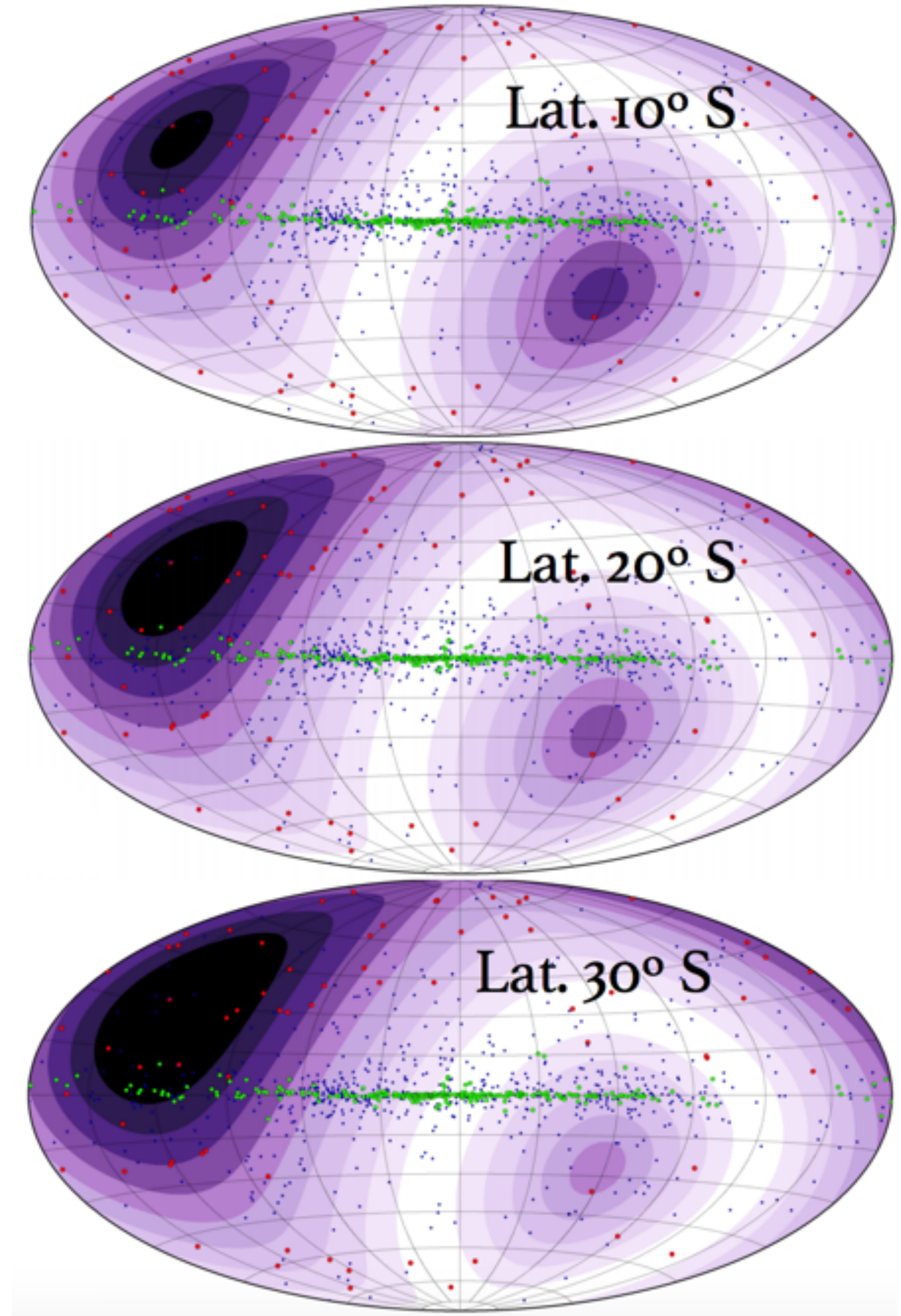
adapted from W. Hofmann (TeVPA2018)

Potential SGSO/SWGO sites

- altitude ~4xxx m
- reasonably flat area
- latitude around 30°S
- infrastructure (incl. access to water)



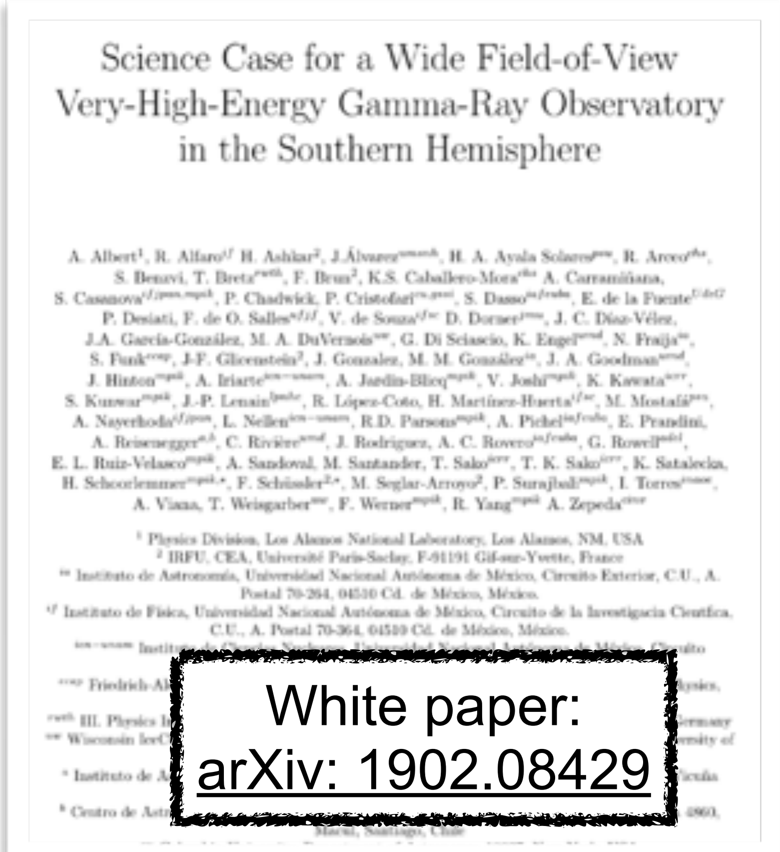
other potential sites in Bolivia, **Peru**, etc.



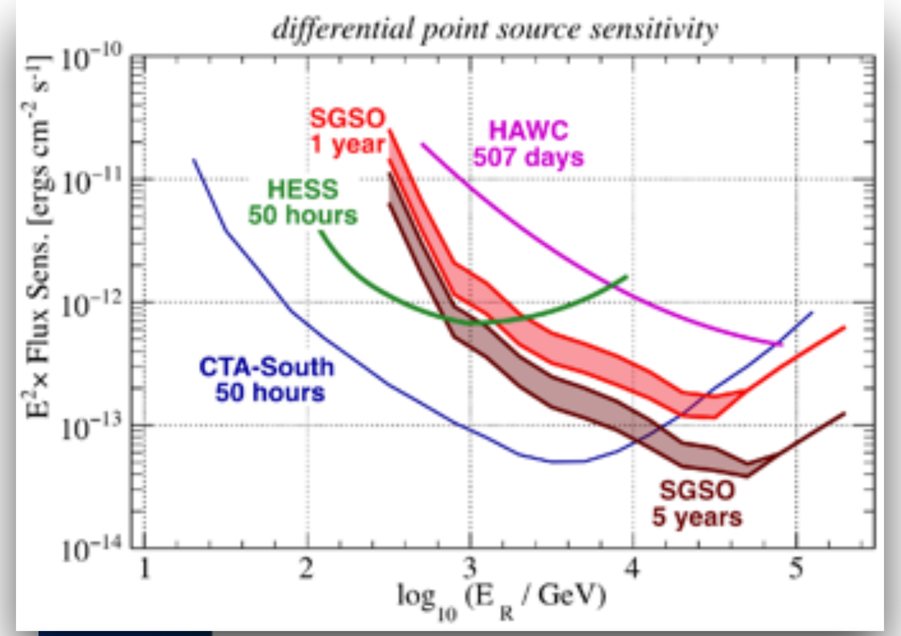
J. Hinton/H. Schoorlemmer

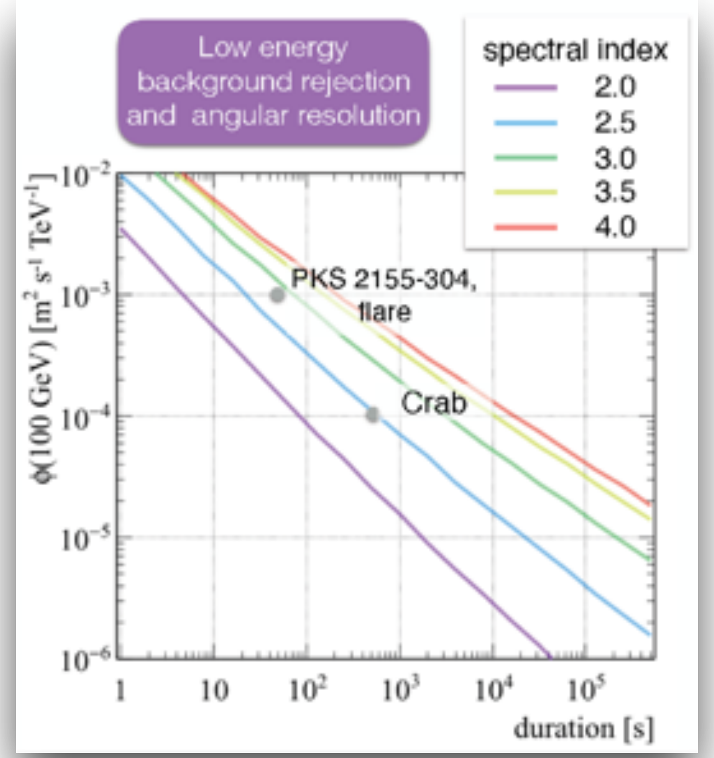
The main science drivers of SGSO/SWGO

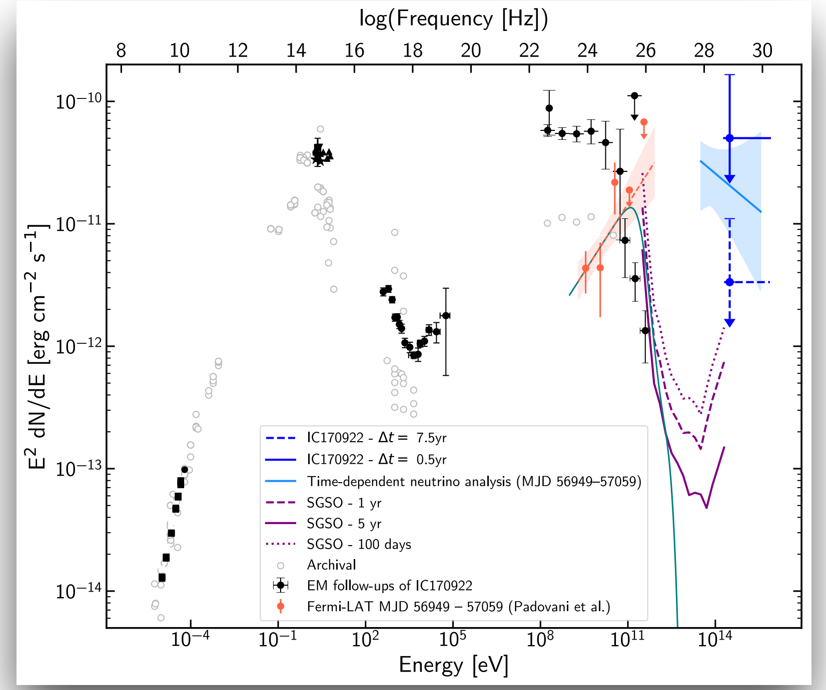
- Cosmic ray acceleration and transport
- **Monitoring the high-energy transient sky**
- Physics beyond the Standard Model of particle physics
- Cosmic ray observations


Science Case for a Wide Field-of-View Very-High-Energy Gamma-Ray Observatory in the Southern Hemisphere

Complementarity with CTA

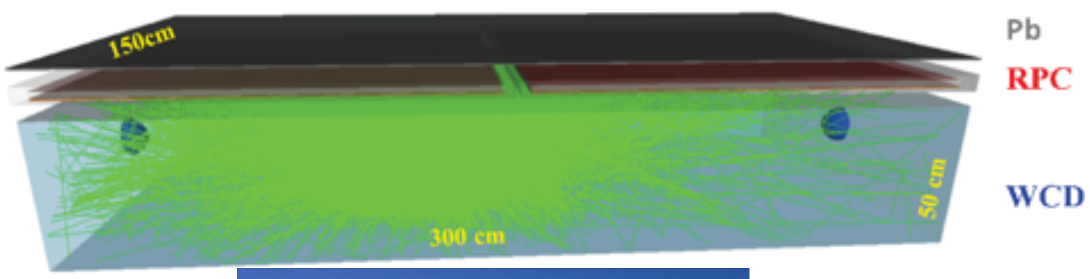


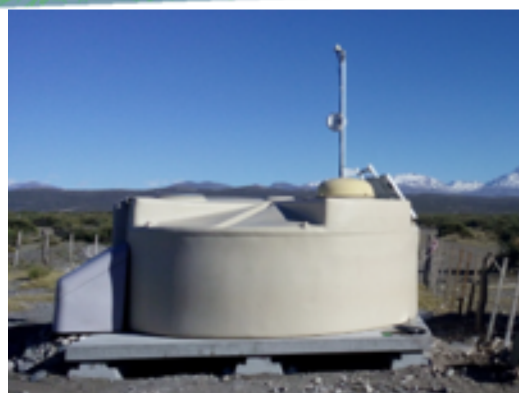




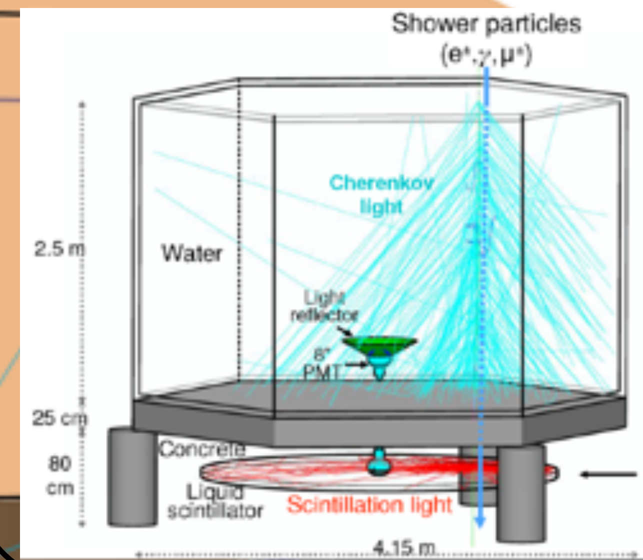
Different novel design ideas + prototypes

LATTES

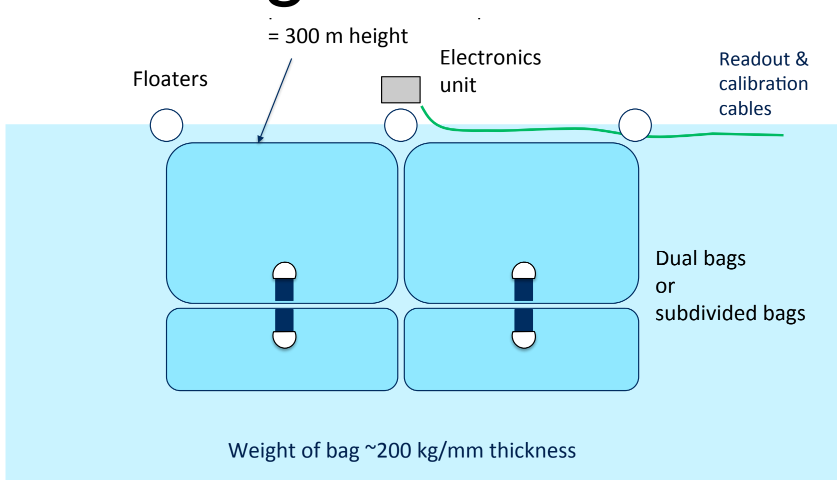




ALTO



"bags in a lake"



"layered WCD"

ALPACA