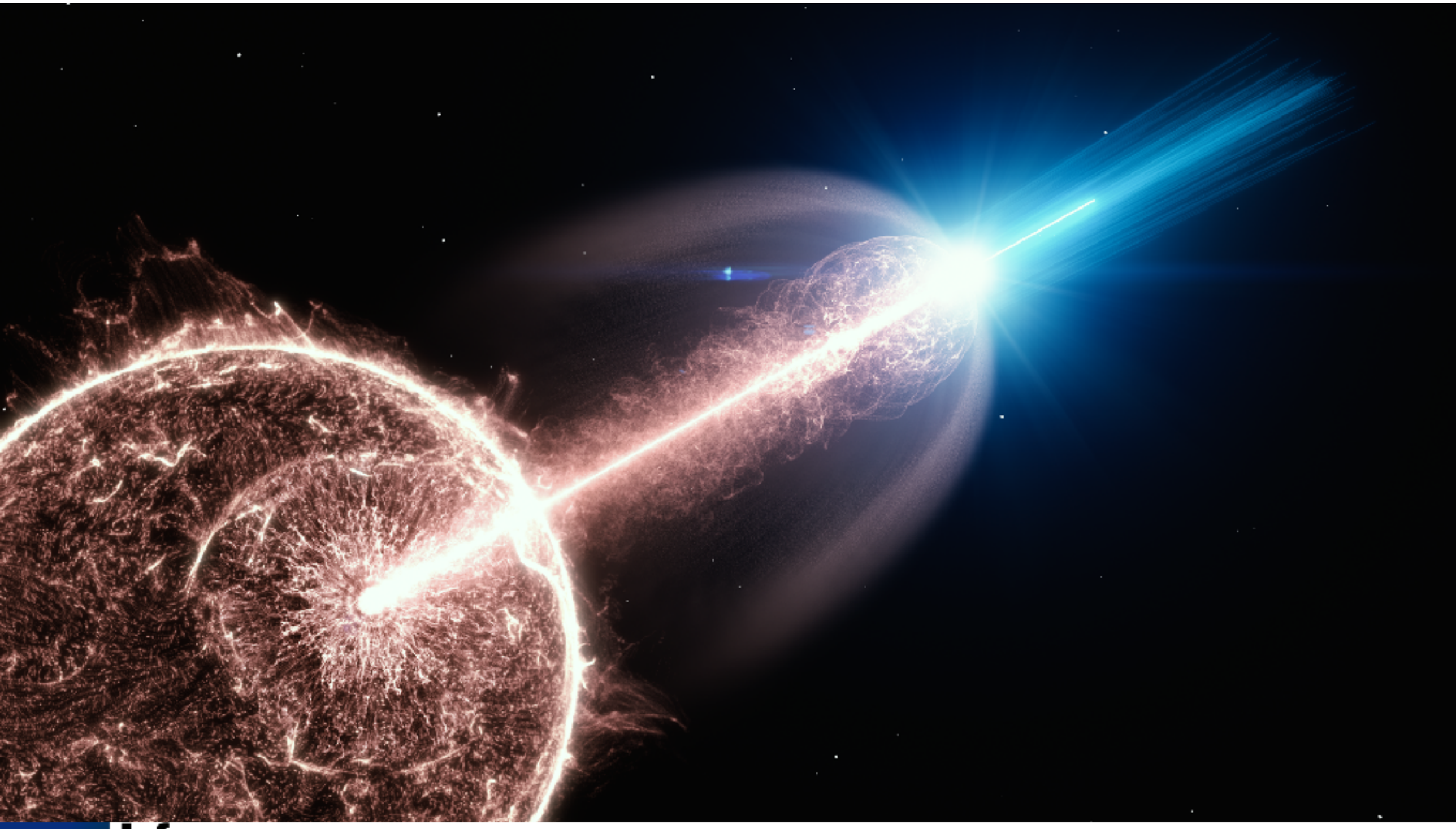
Gamma Ray Bursts and Gravitational Waves at VHE energy



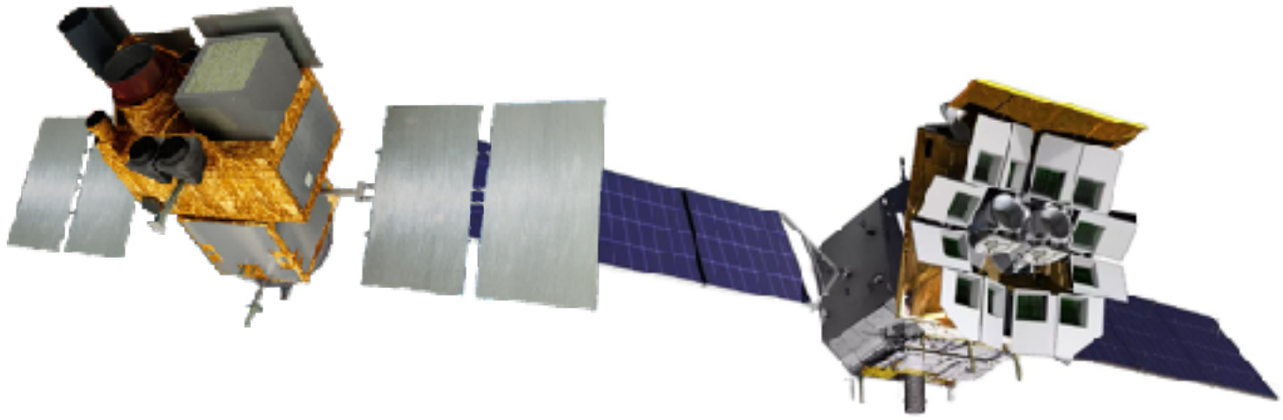
Irfu
Institut de recherche sur les lois fondamentales de l'Univers

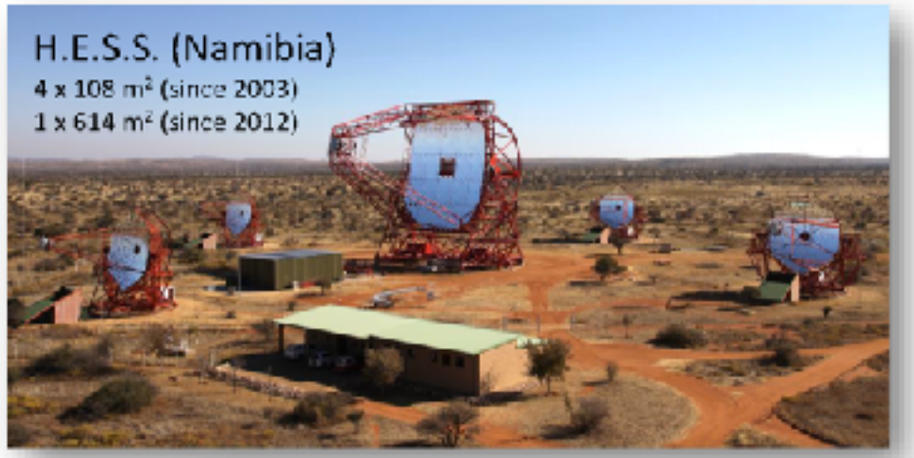
Fabian Schüssler

November 20, 2025

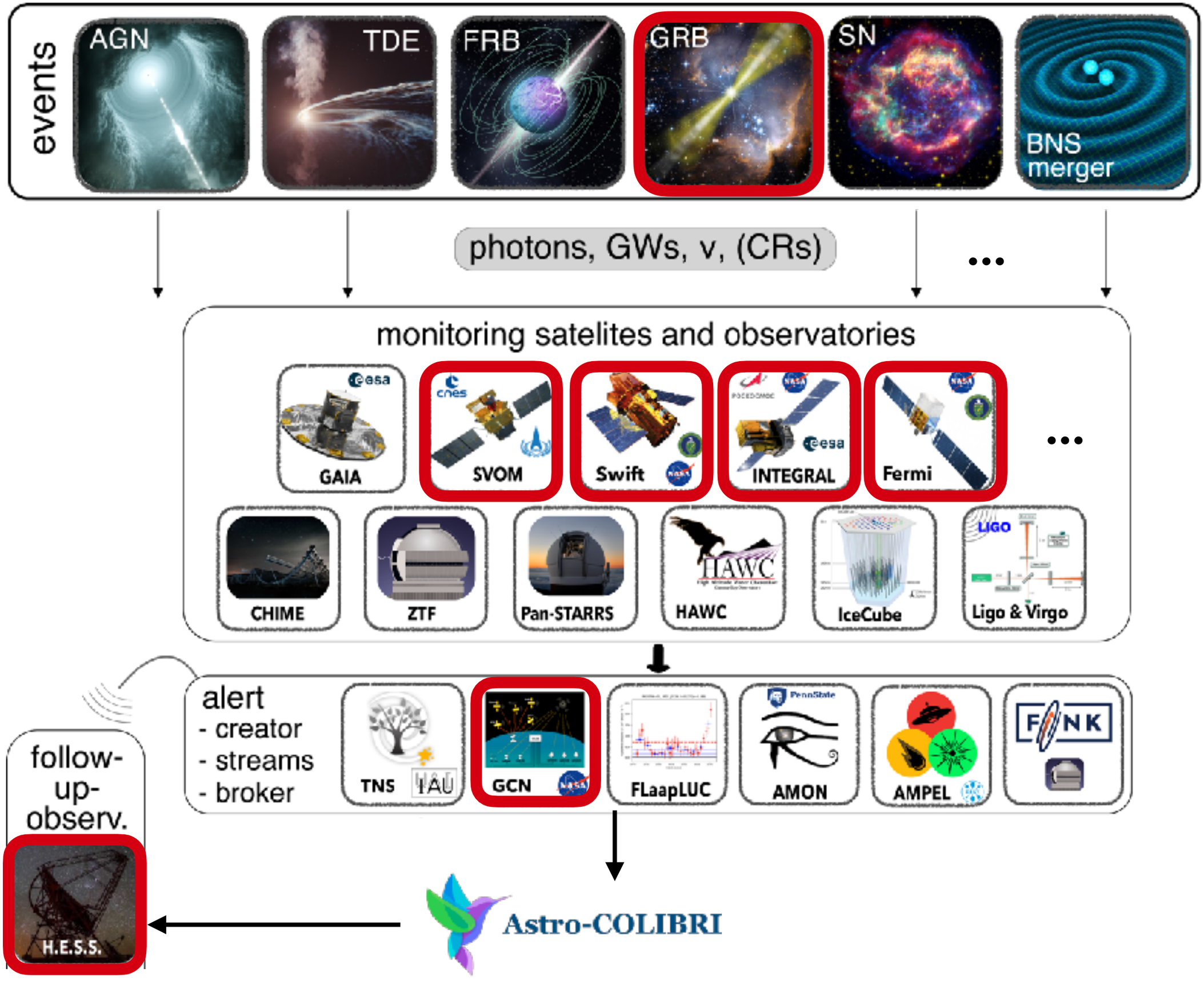
MOTS anr ACME

GRB detections and follow-up observations at TeV energies





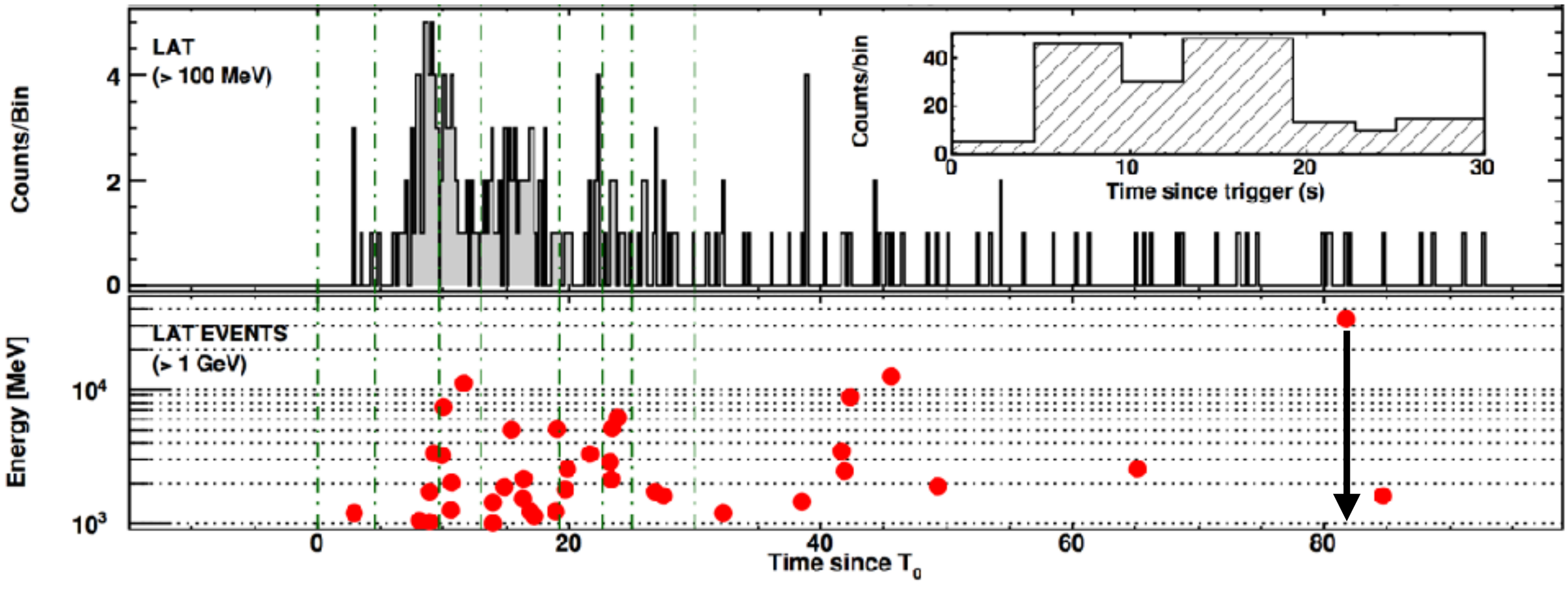
Transient detection and follow-up observations



Gamma Ray Bursts @ high-energies (~10 years ago)

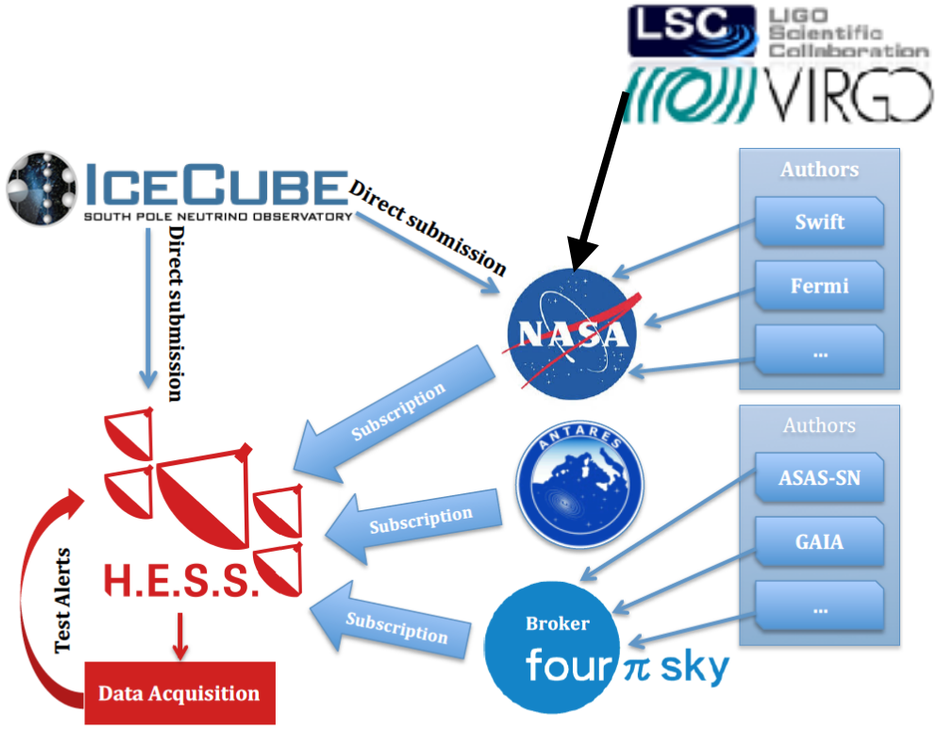
- detections mainly by Swift-BAT + Fermi-GBM + INTEGRAL (until early 2025)
- afterglow seen across the EM spectrum
  - ~100 GeV photon(s) seen by Fermi-LAT up to ~1min after T_0
- rapid reaction + low energy threshold crucial
  - e.g. MAGIC + H.E.S.S. phase II

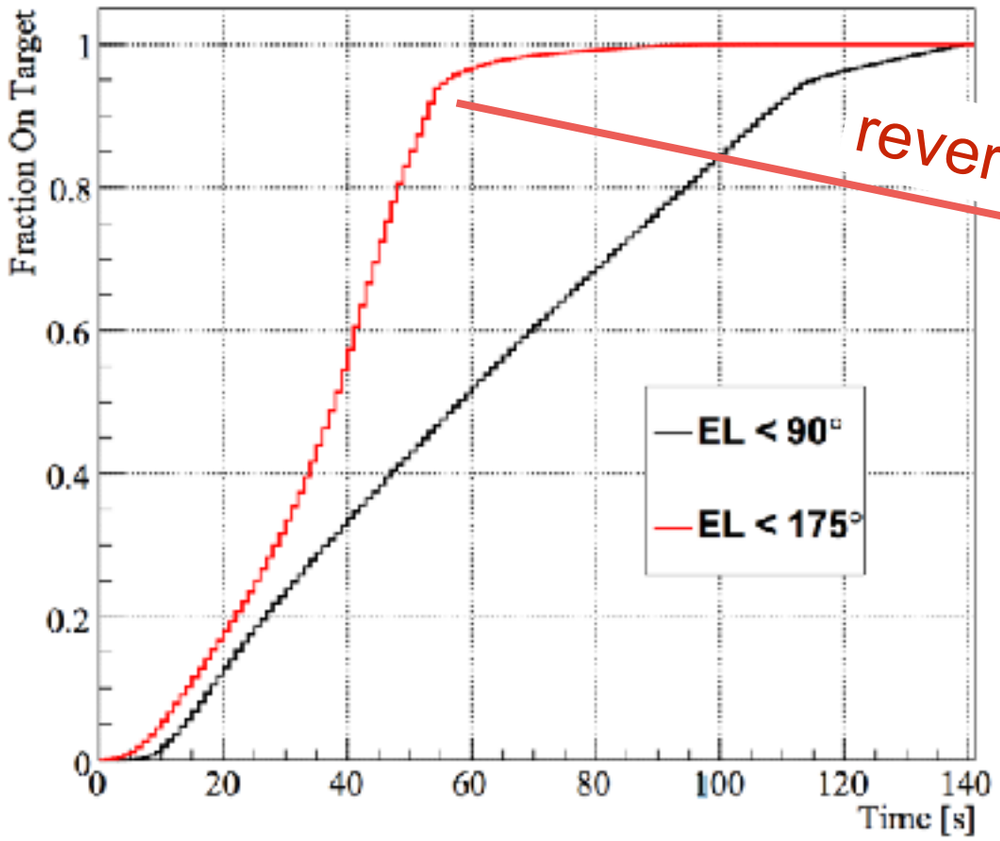
GRB 090902B (Abdo et al. APJ 706 (2009) 138)



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 m² mirror area; largest IACT worldwide)
  - **rapid response time**
  - **flexible + fully automatized alert system**



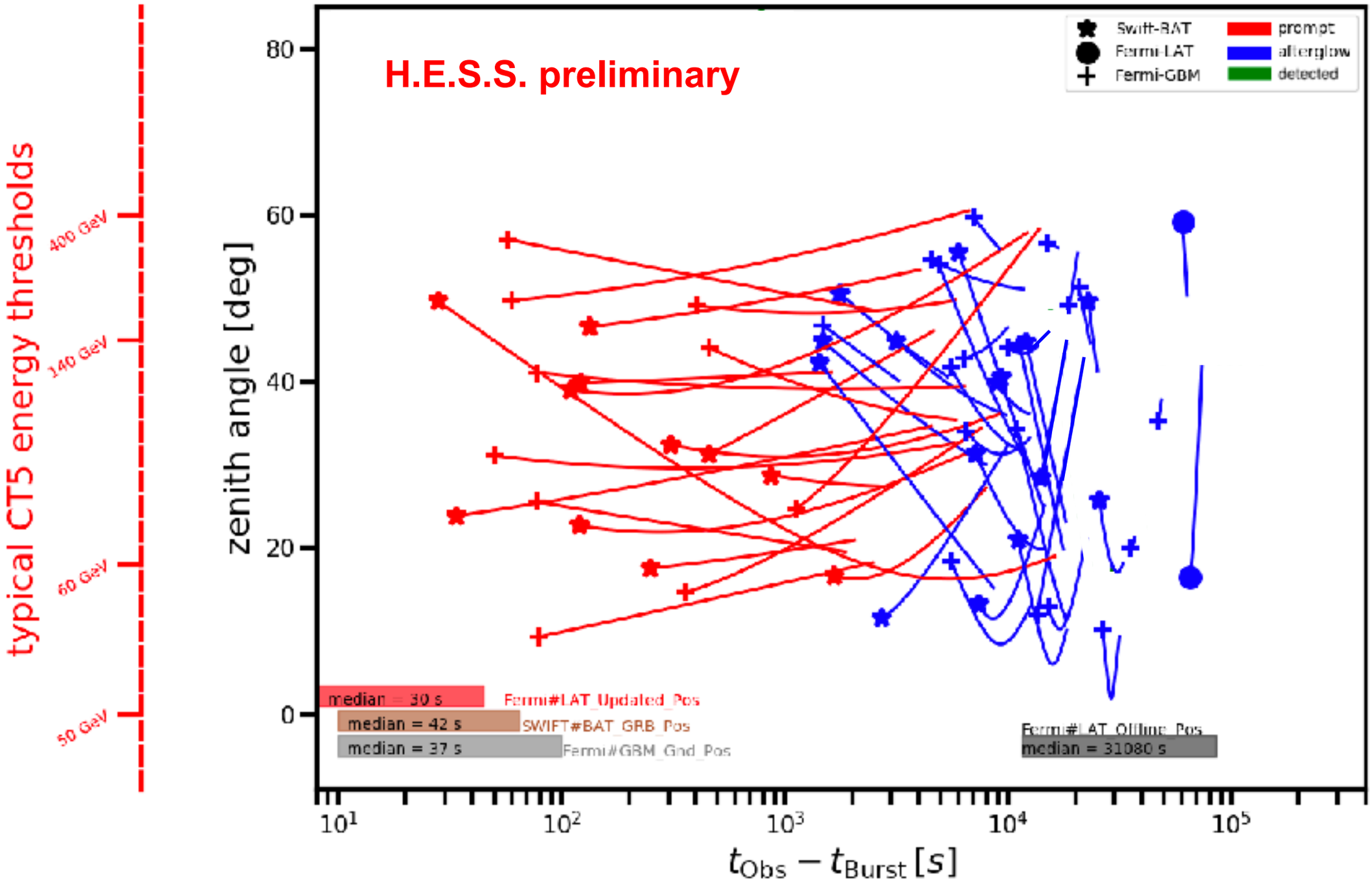


reverse tracking

Hofverberg et al., ICRC 2013

Hunting GRBs with IACTs

- Example: the H.E.S.S. GRB program



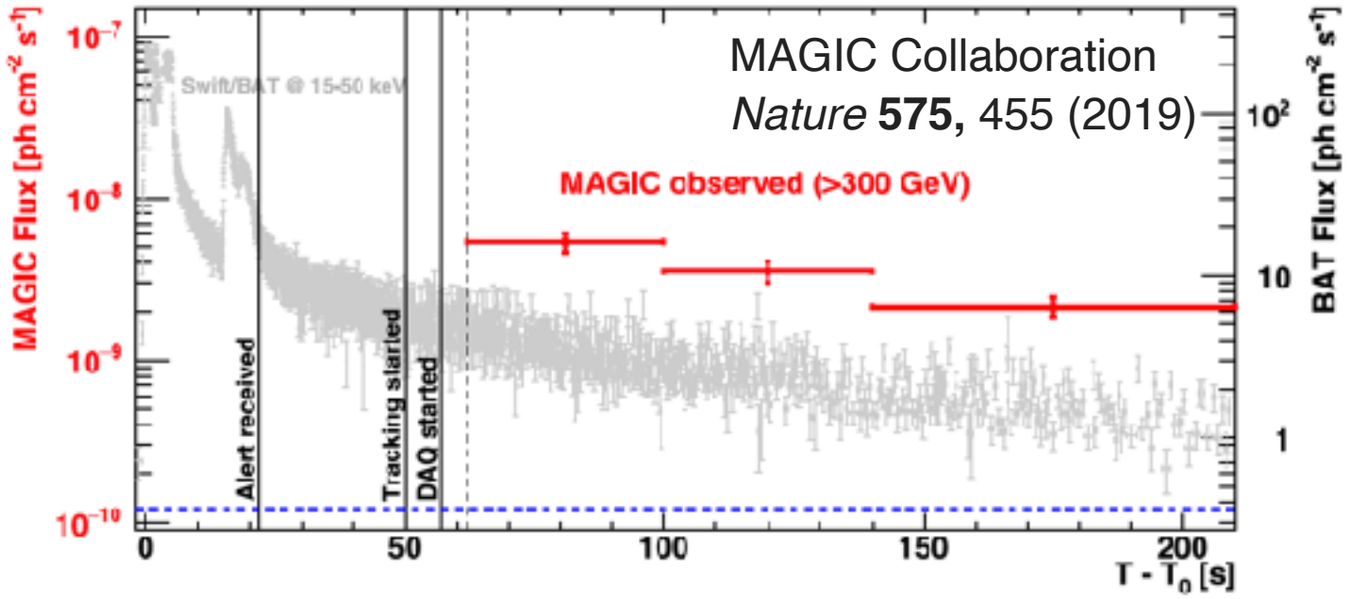
C. Hoischen et al., PoS(ICRC2017)636

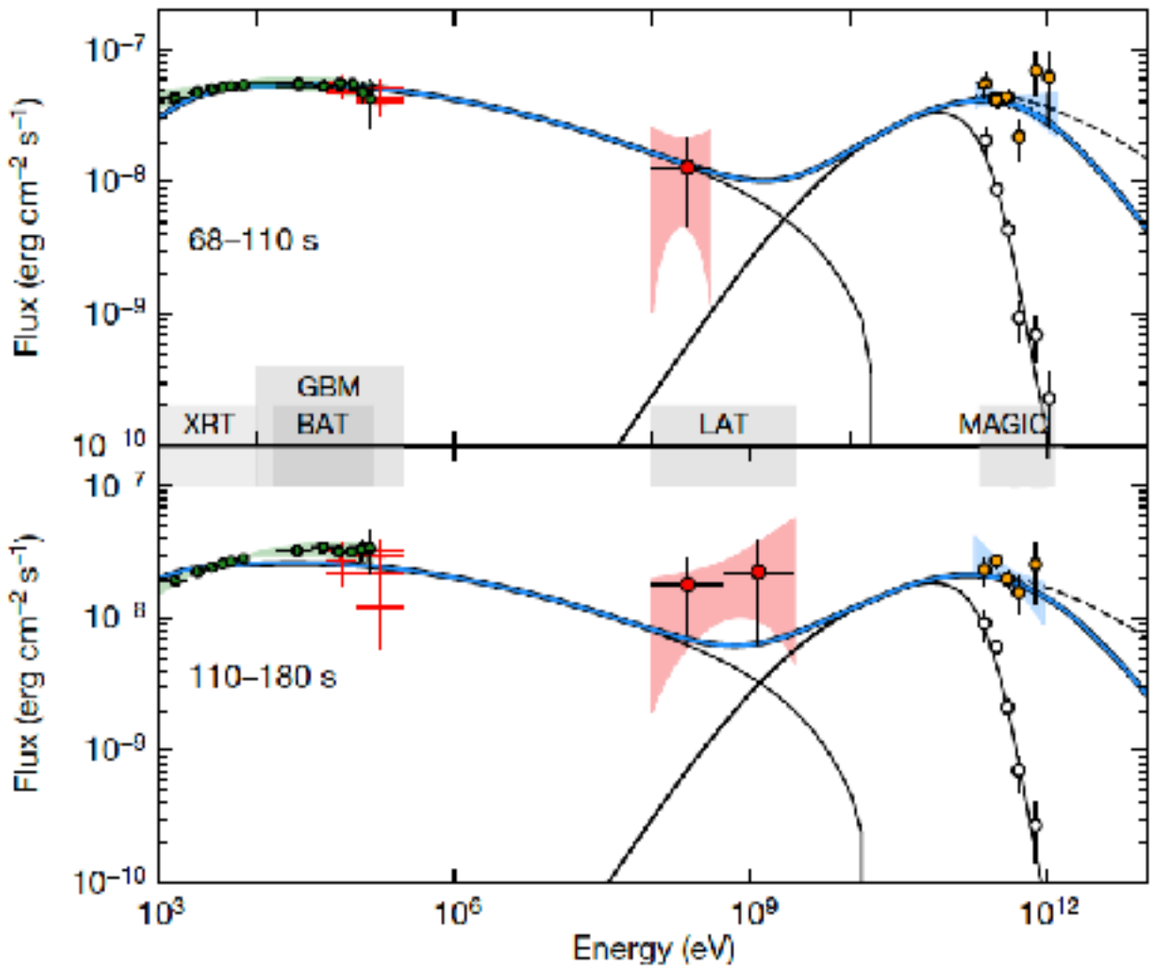
Finally: Gamma Ray Bursts @ IACTs

- 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: observations >57s, z=1.1 (MNRAS 527, 3 (2024))
- GRB 221009A @ LHAASO: TeV photons delayed by a 226s, rising within 10s (Science 380, 6652 (2023))

MAGIC: GRB190114C

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

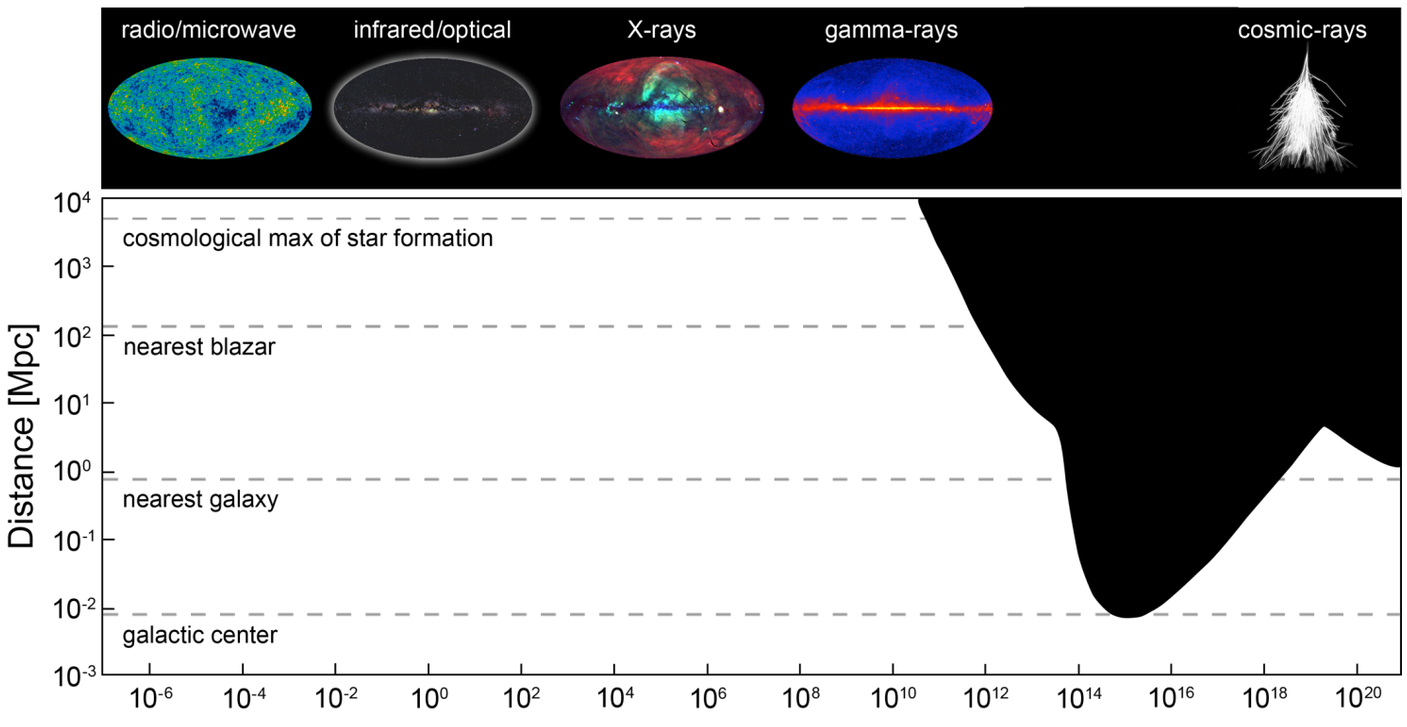


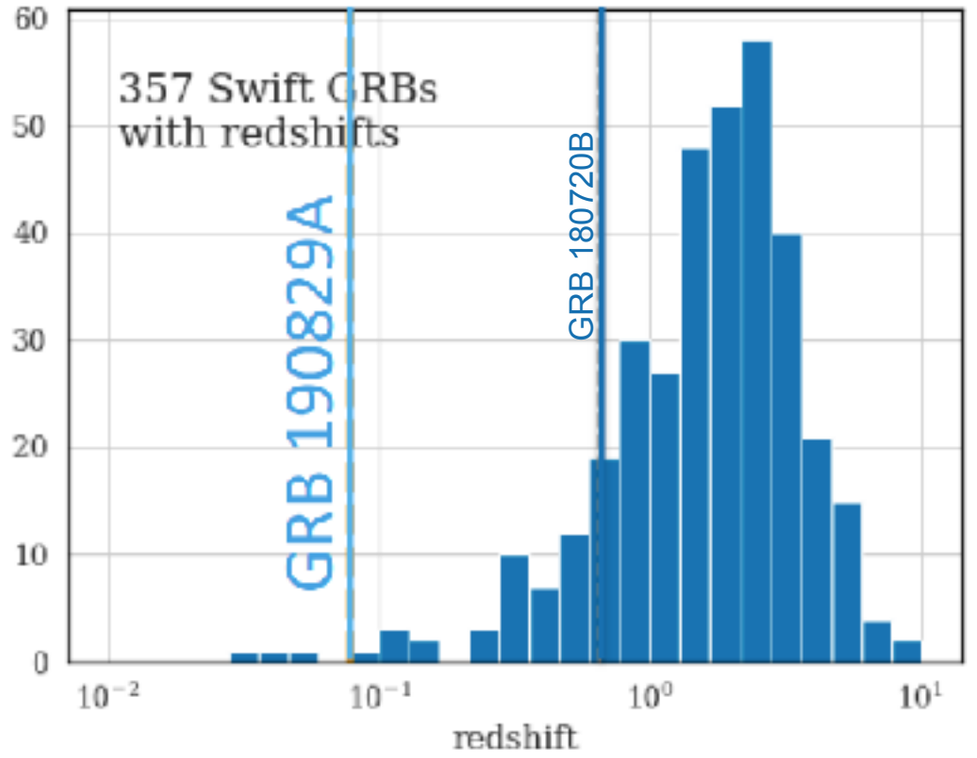


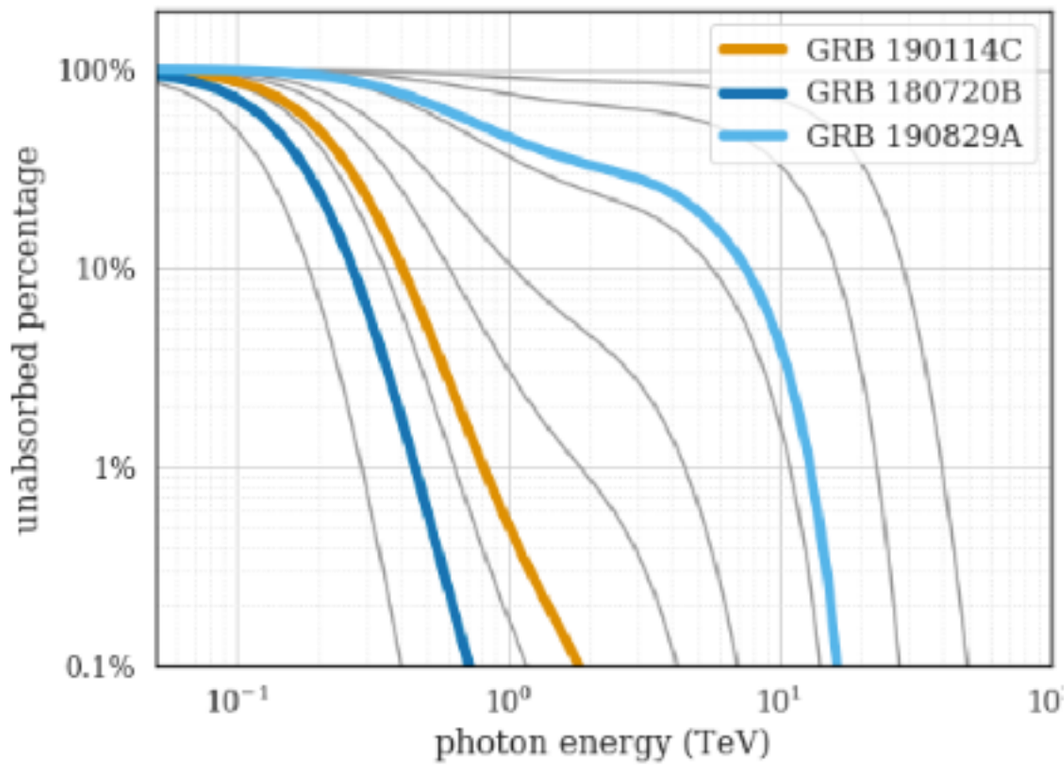
MAGIC et al., *Nature* **575,** 459 (2019)

H.E.S.S.: GRB 190829A

- Extremely close burst: redshift z = 0.0785
- Another very X-ray bright burst

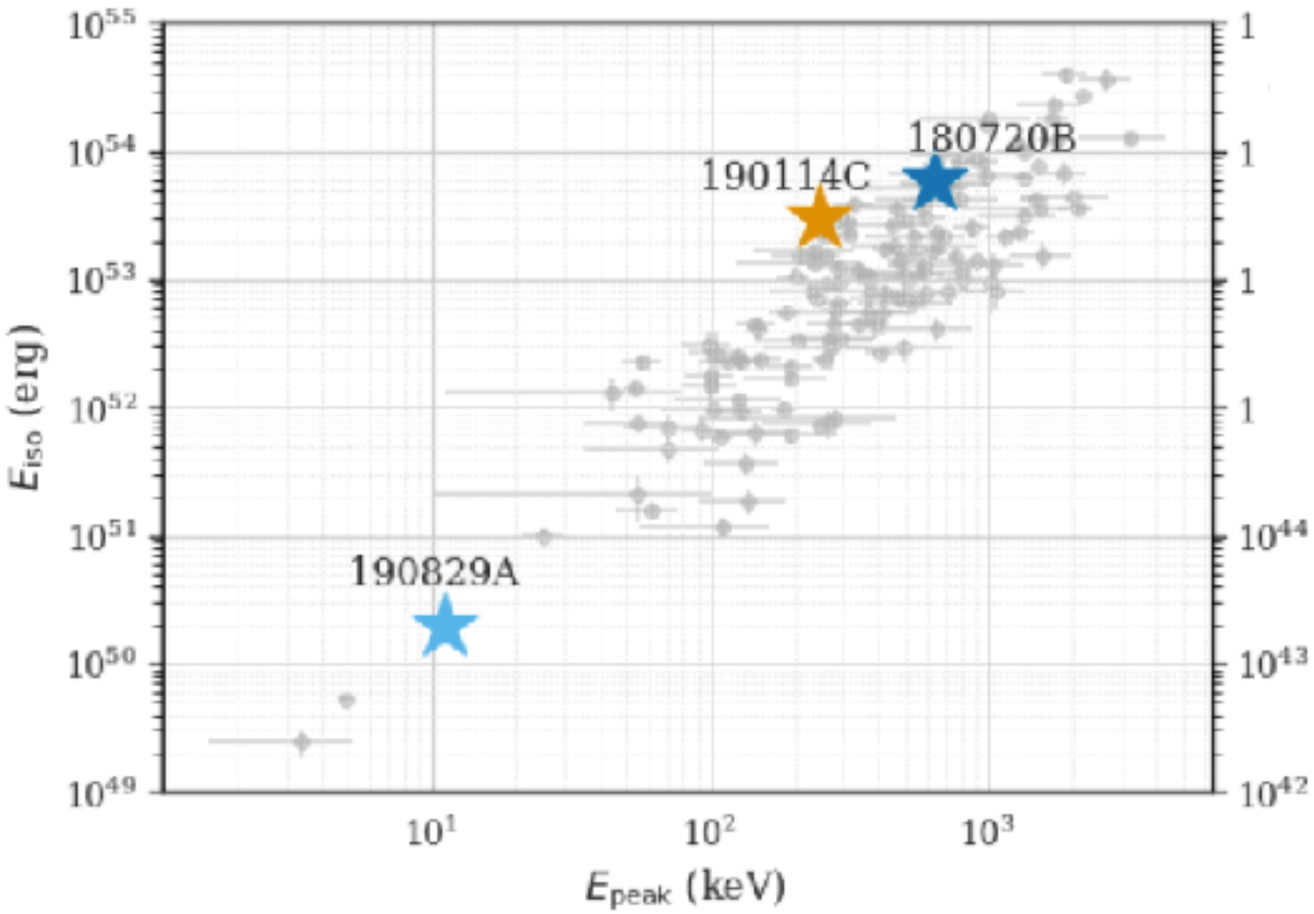


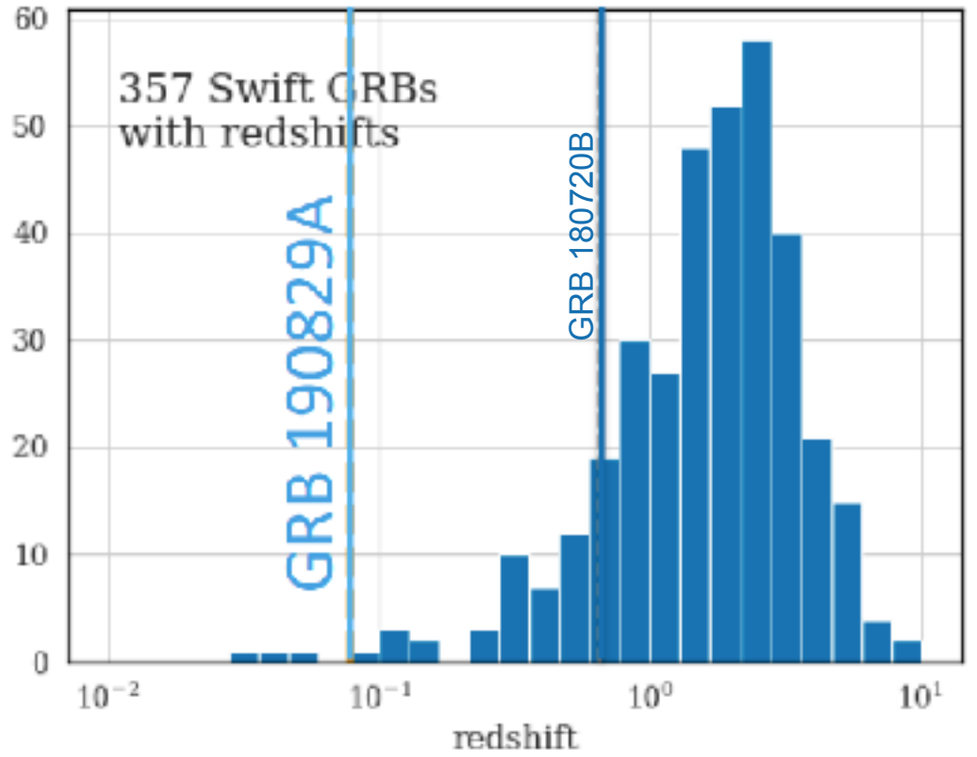


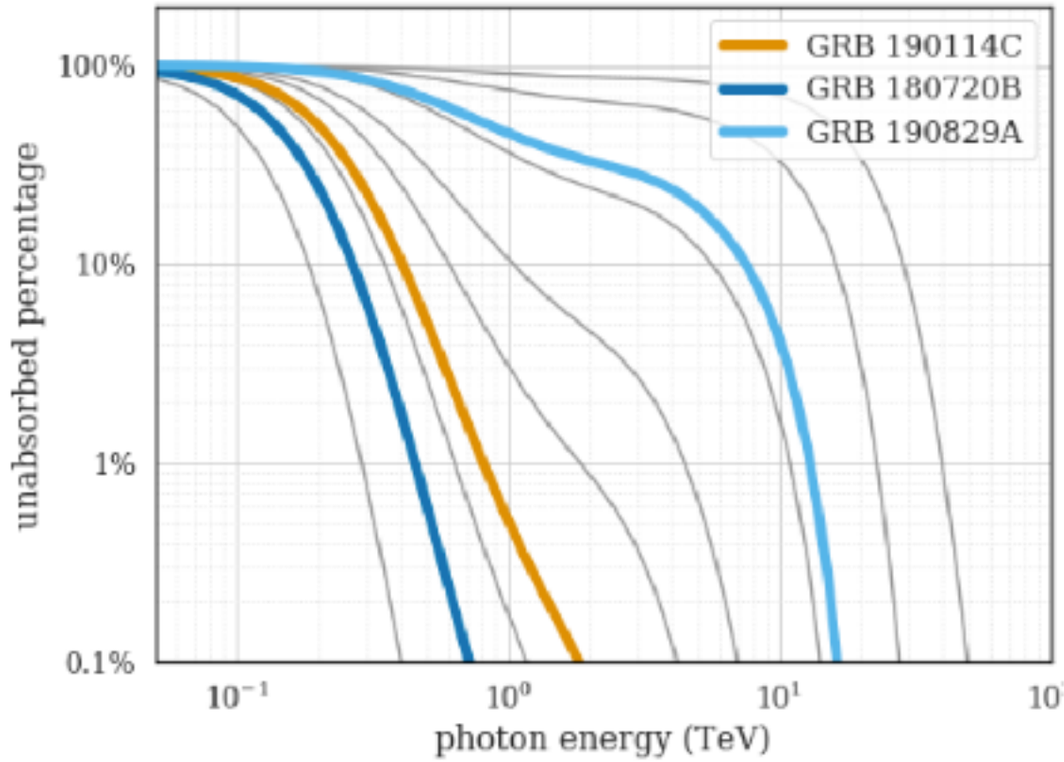


H.E.S.S.: GRB 190829A

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

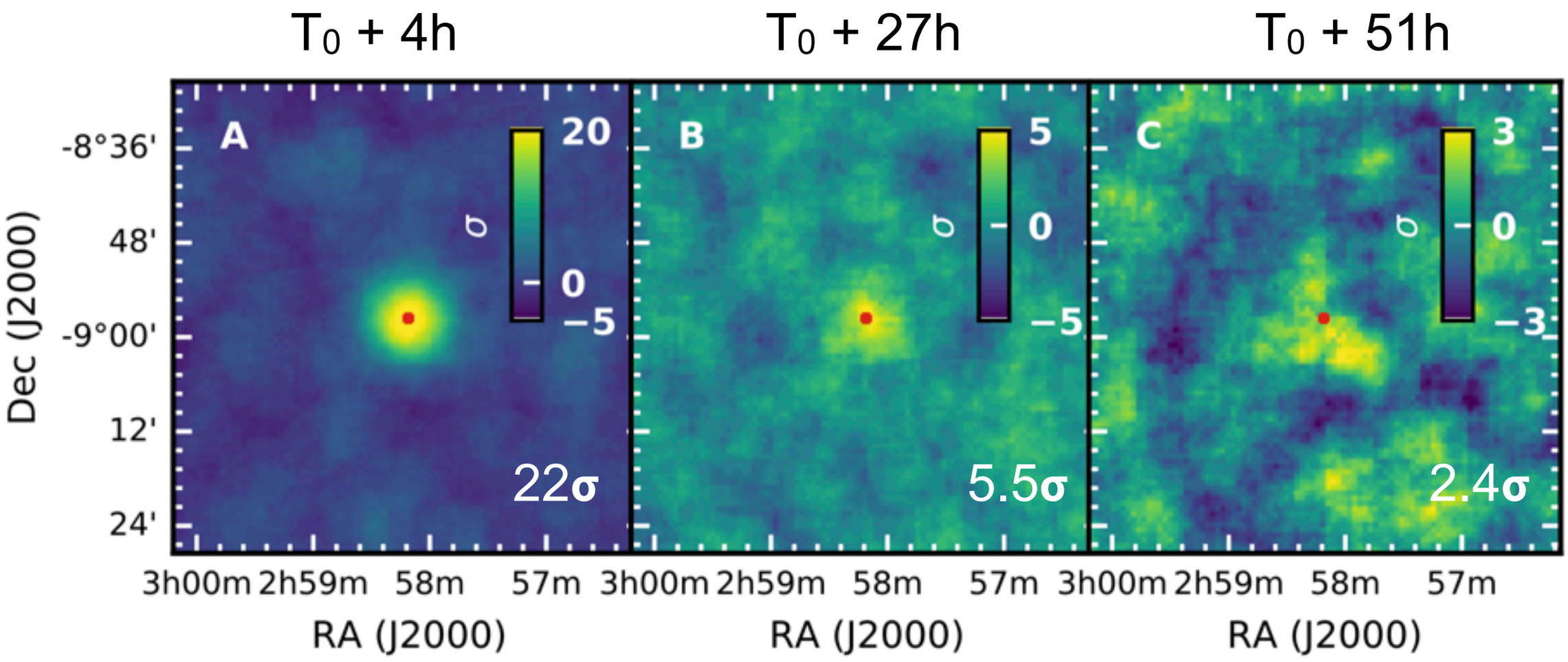






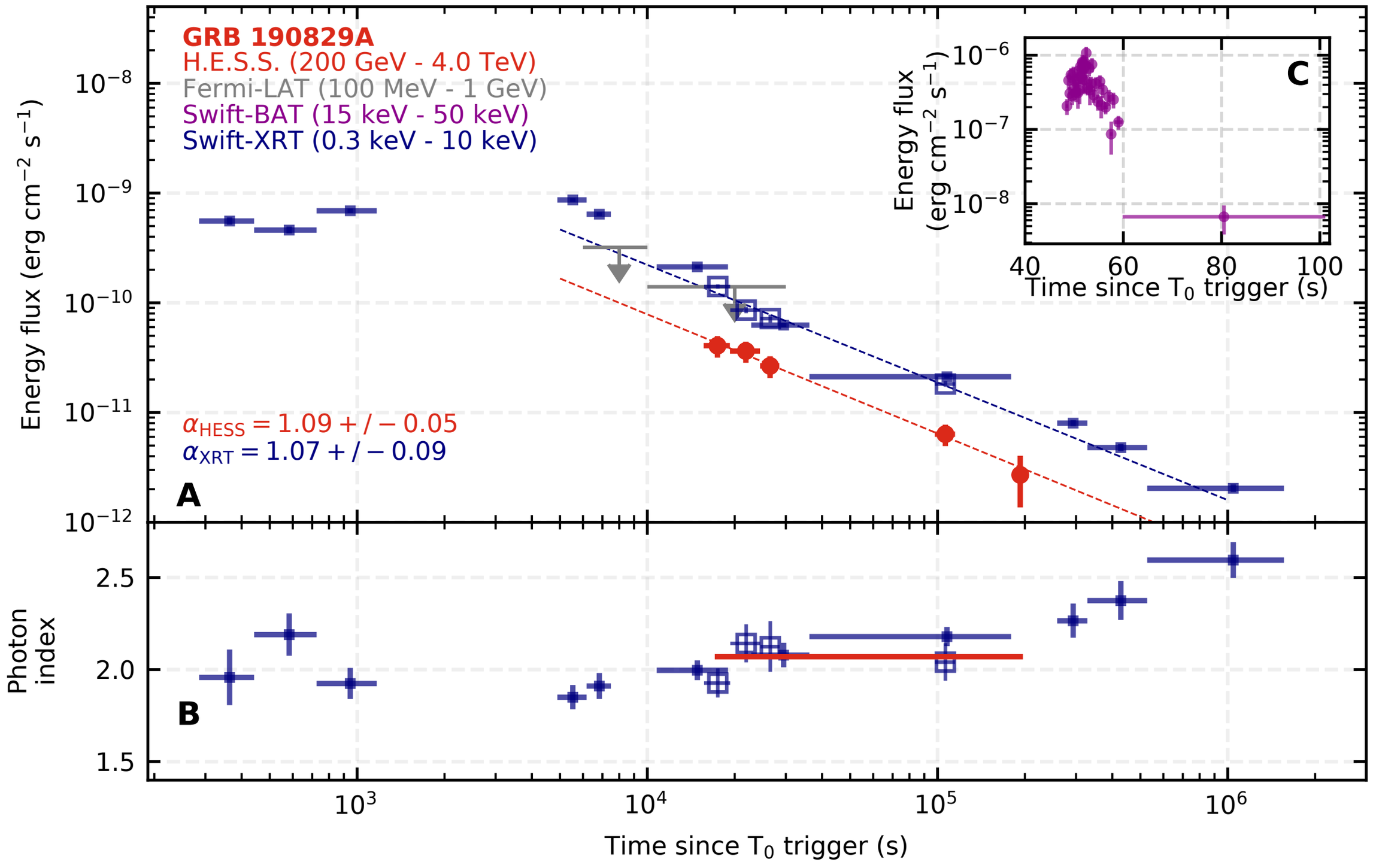
GRB 190829A: the longest VHE afterglow

- Detection over multiple nights



H.E.S.S. Collaboration, Science 372, 6546 (2021)

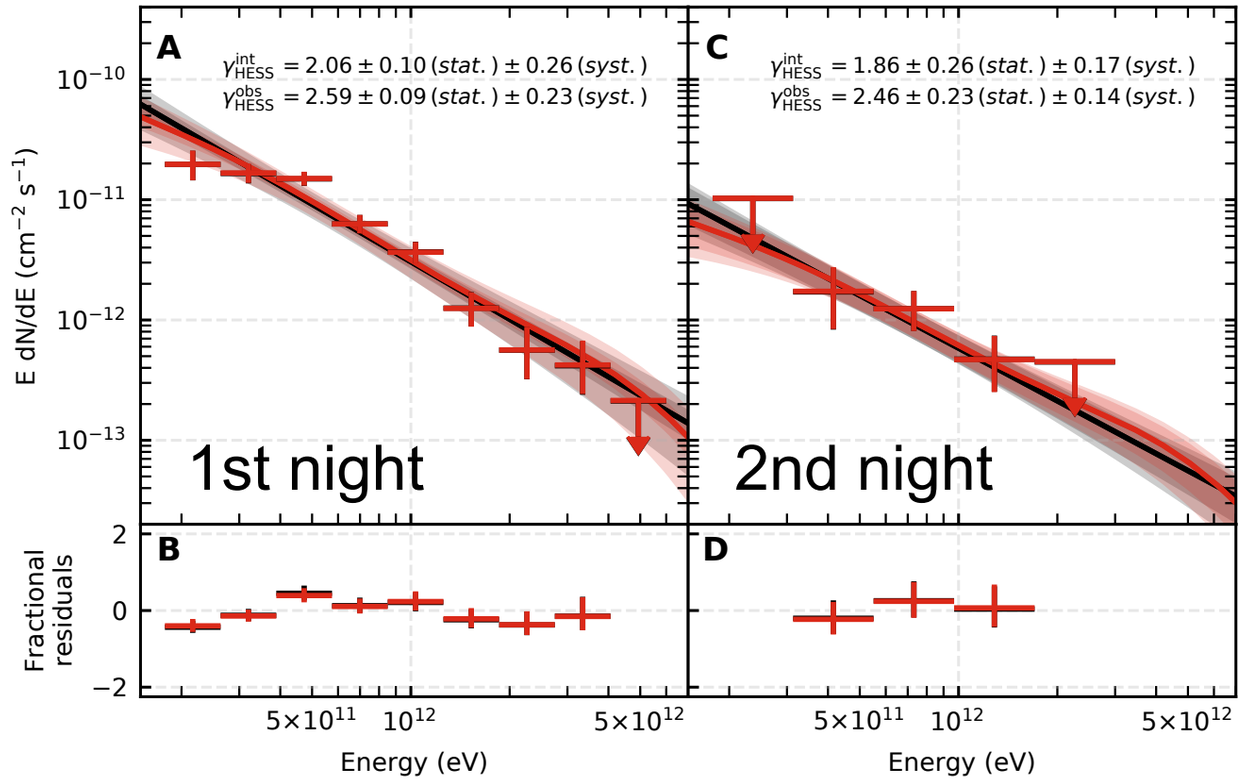
GRB 190829A: temporal evolution

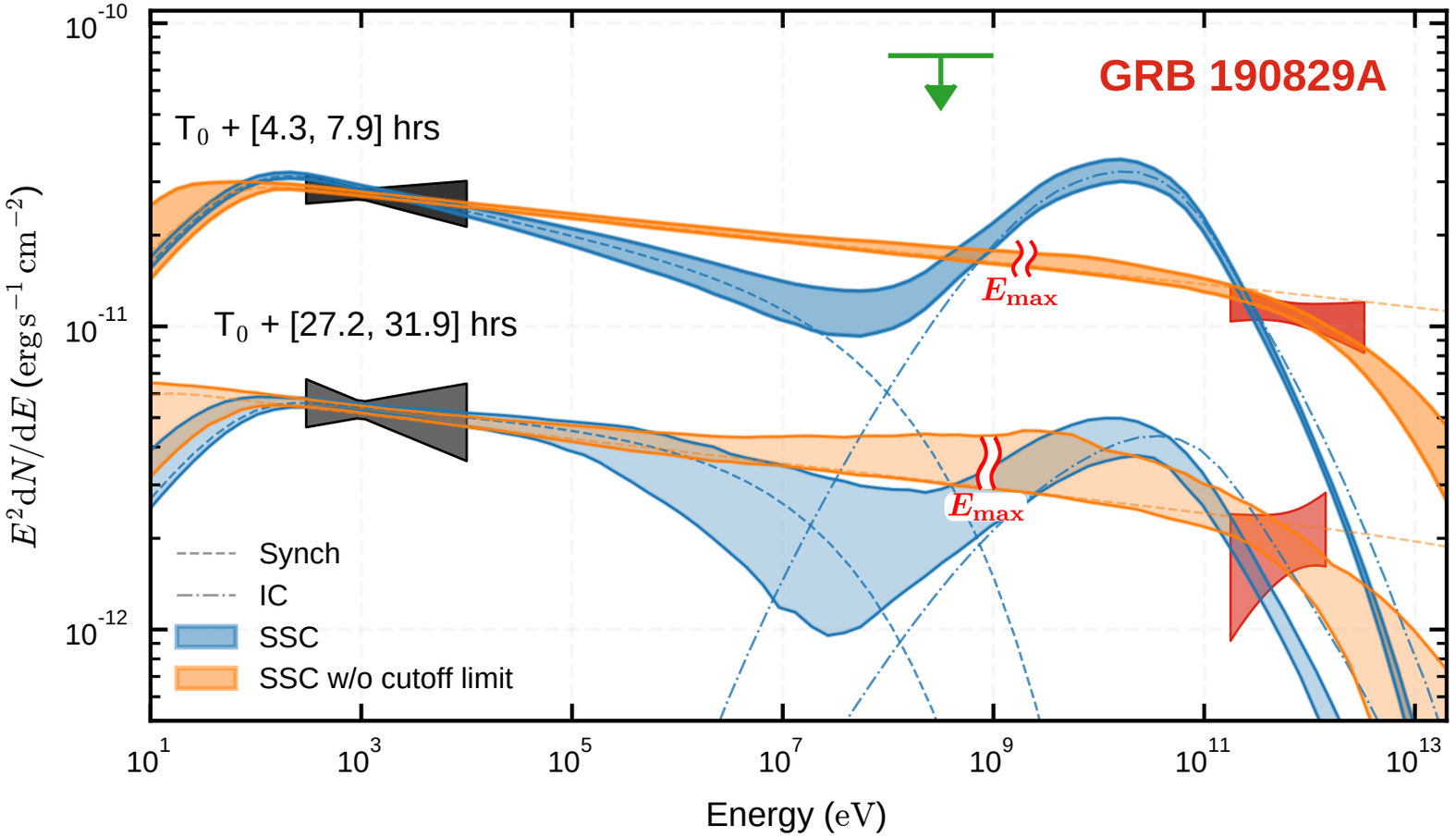


H.E.S.S. Collaboration, Science 372, 6546 (2021)

GRB 190829A: spectrum

- High statistics over >30h
- Harder spectrum than expected from simple SSC model

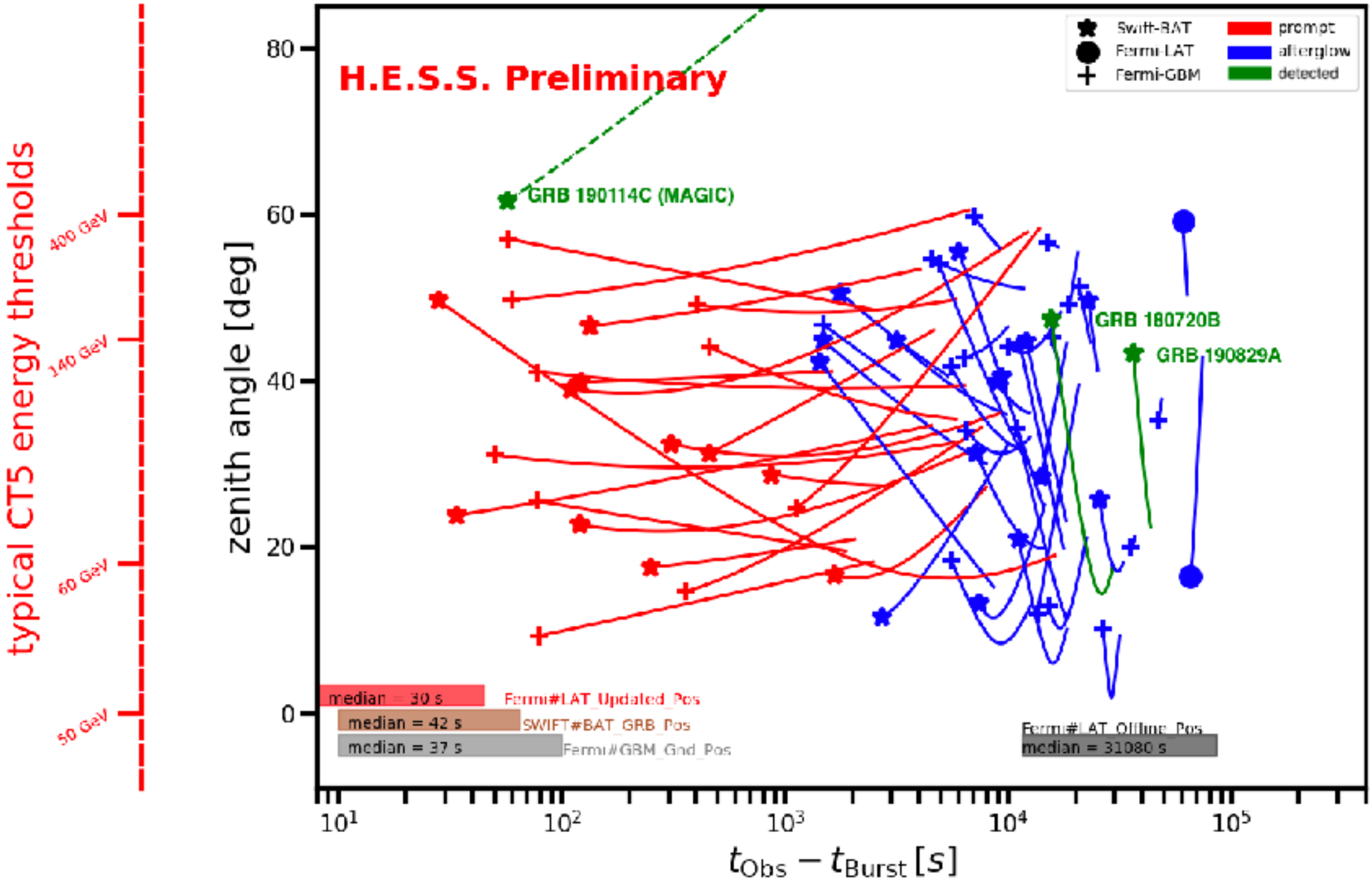




H.E.S.S. Collaboration, Science 372, 6546 (2021)

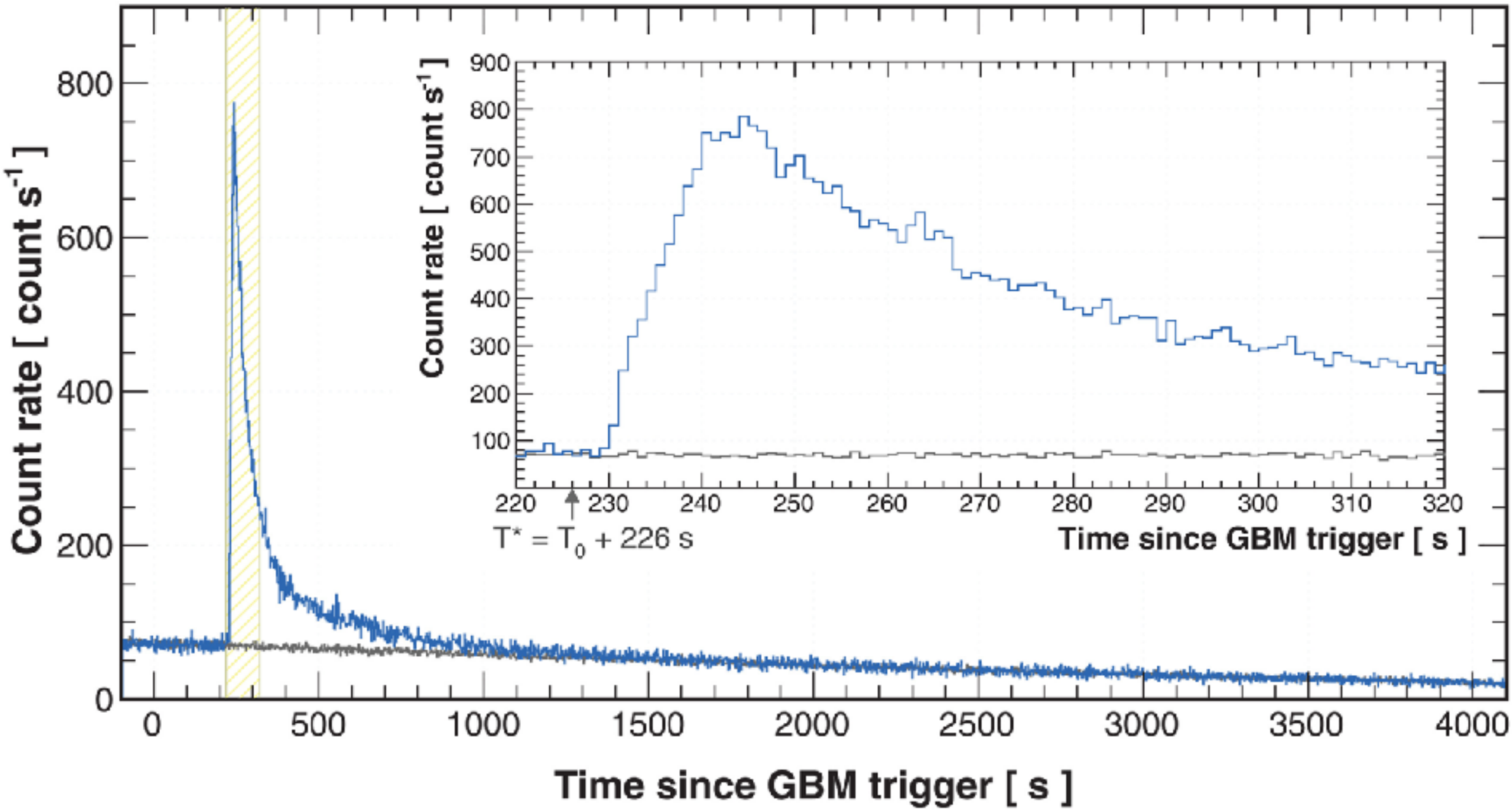
First detections of GRBs with IACTs

update on poster by Bernardo Cornejo



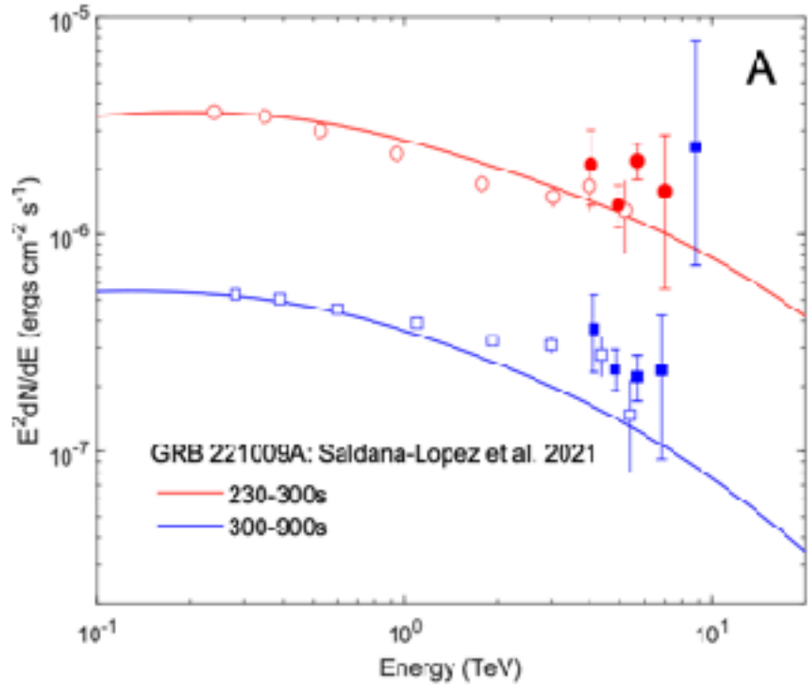
Updated from C. Hoischen et al., PoS(ICRC2017)636

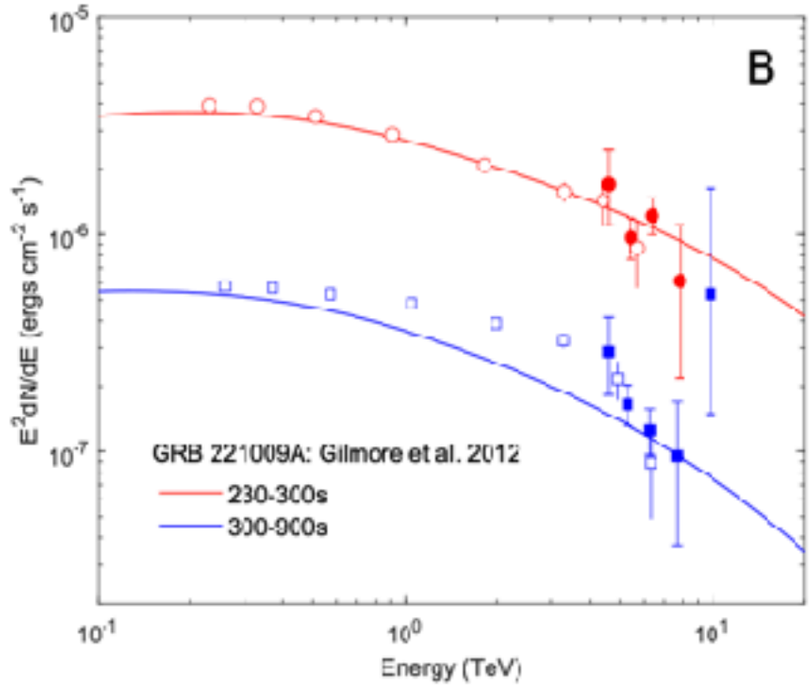
GRB 221009A @ LHAASO

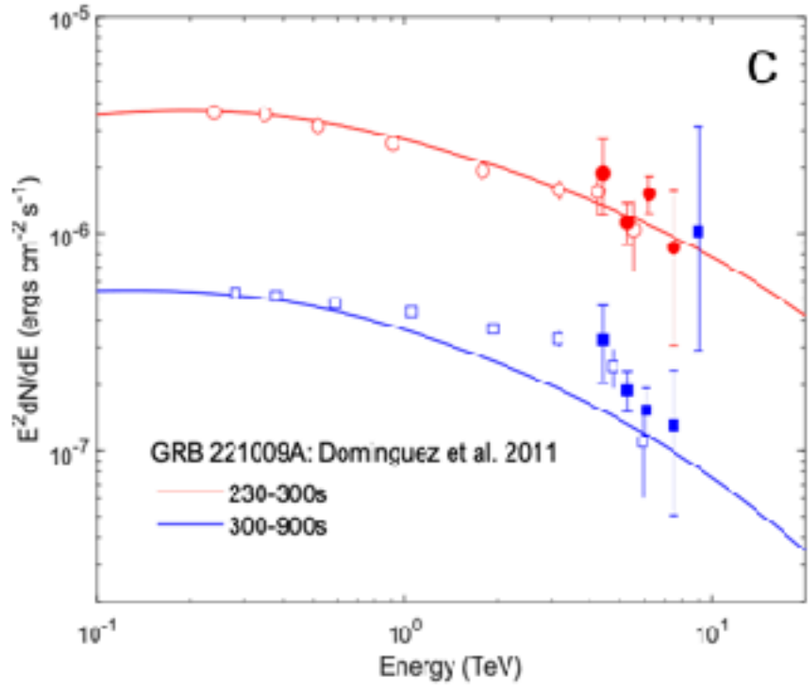


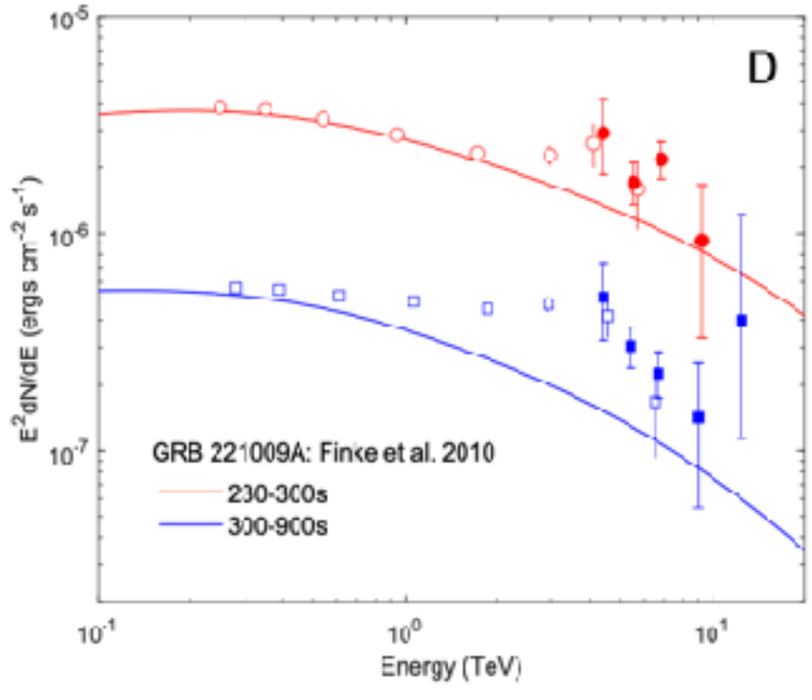
LHAASO Collaboration, Science 380, 6652 (2023)

GRB 221009A @ LHAASO





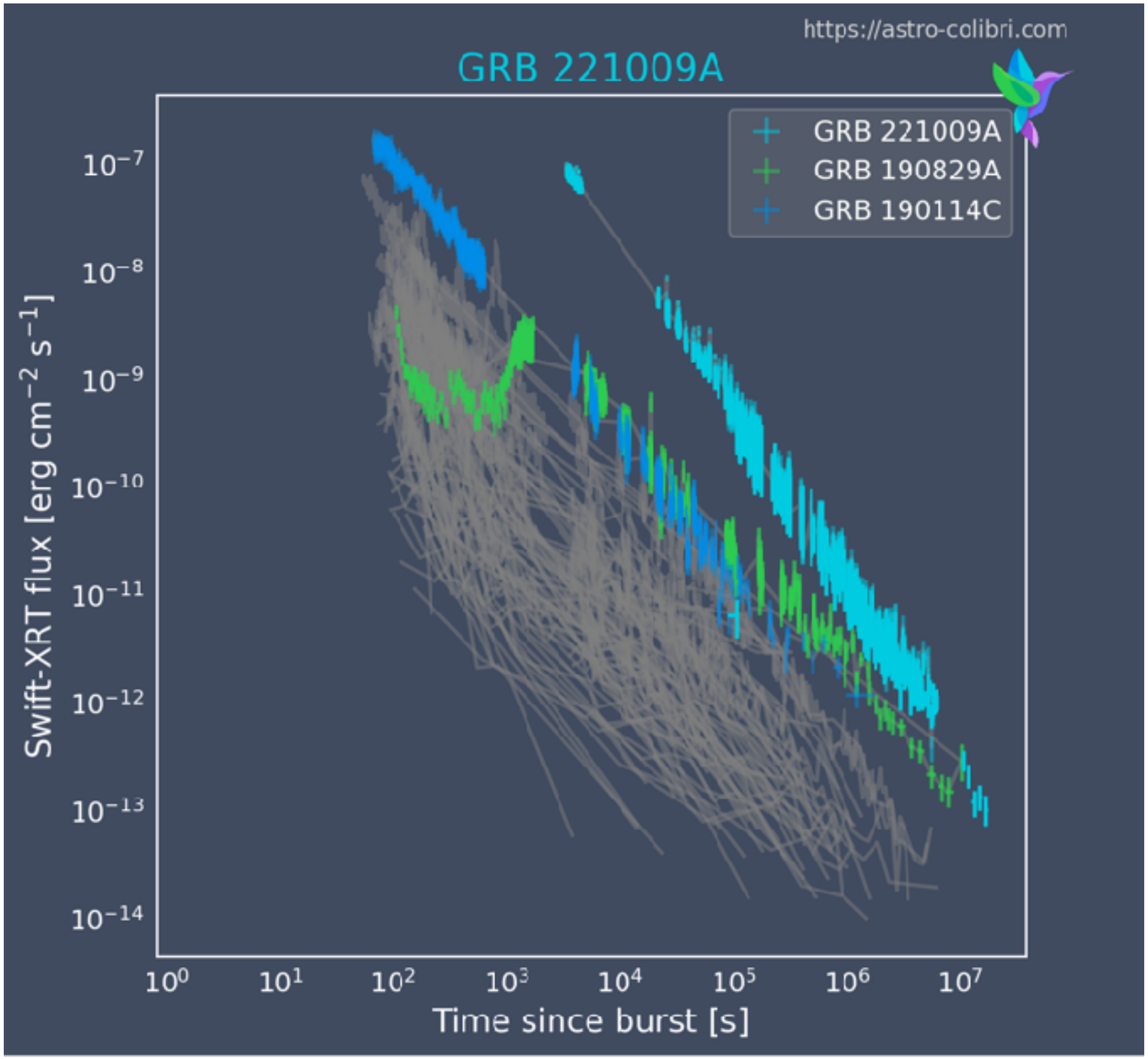




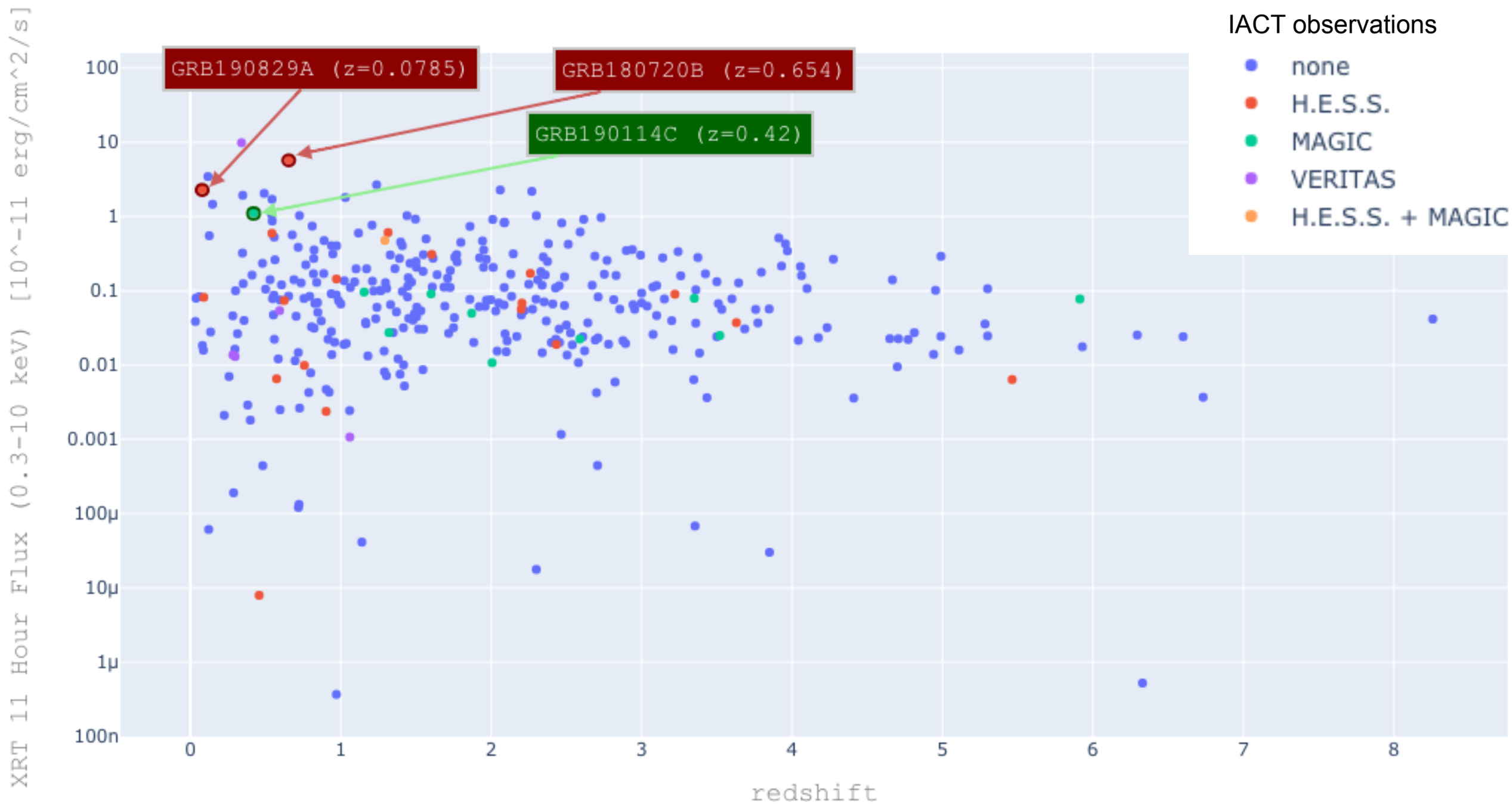
SSC model; A-D: different EBL models

LHAASO Collaboration, Science Advances 9, 46 (2023)

VHE detected GRBs are X-ray bright



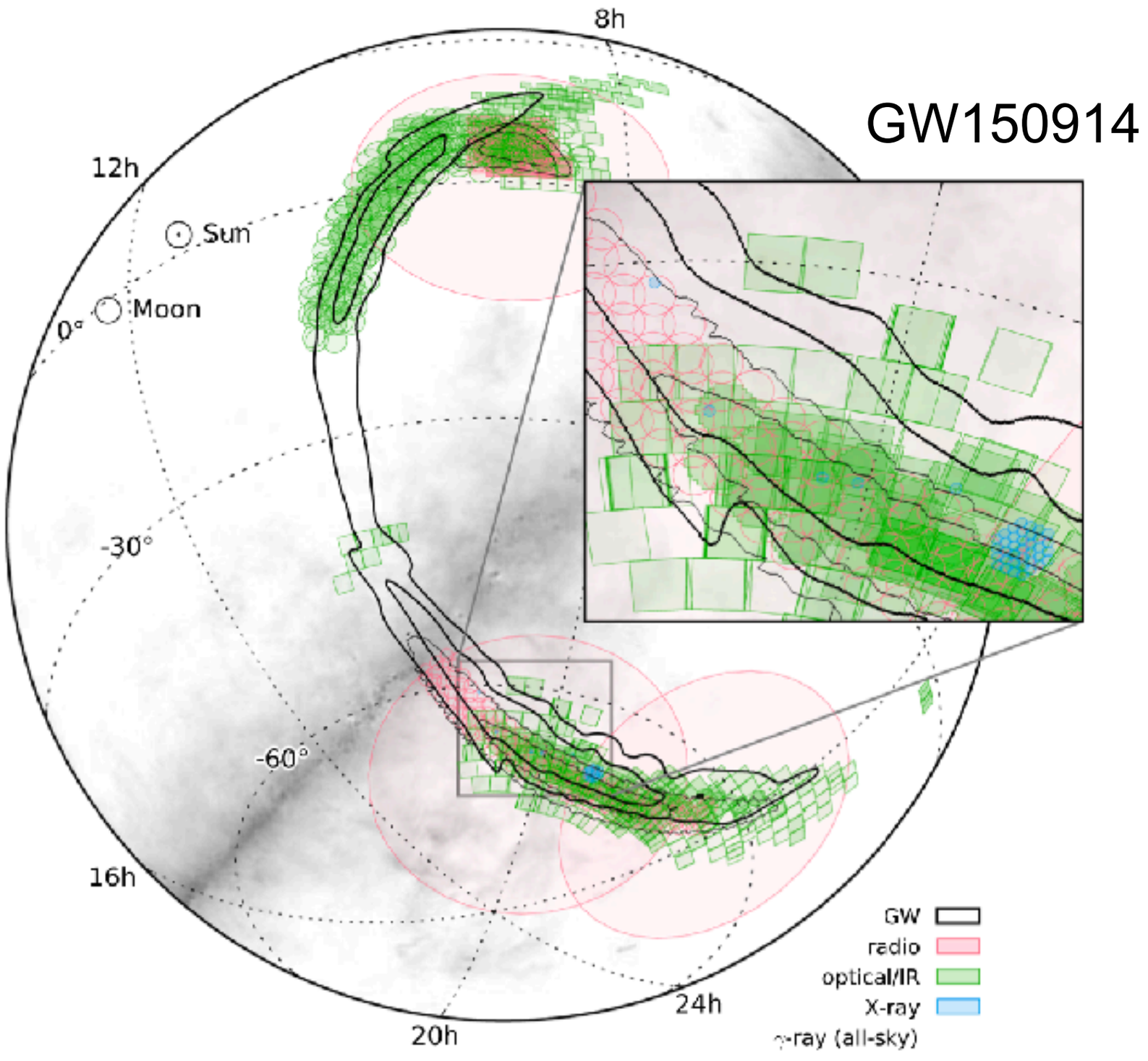
VHE detected GRBs are X-ray bright and nearby



Monitoring the universe in Gravitational Waves

Penelope Cowley

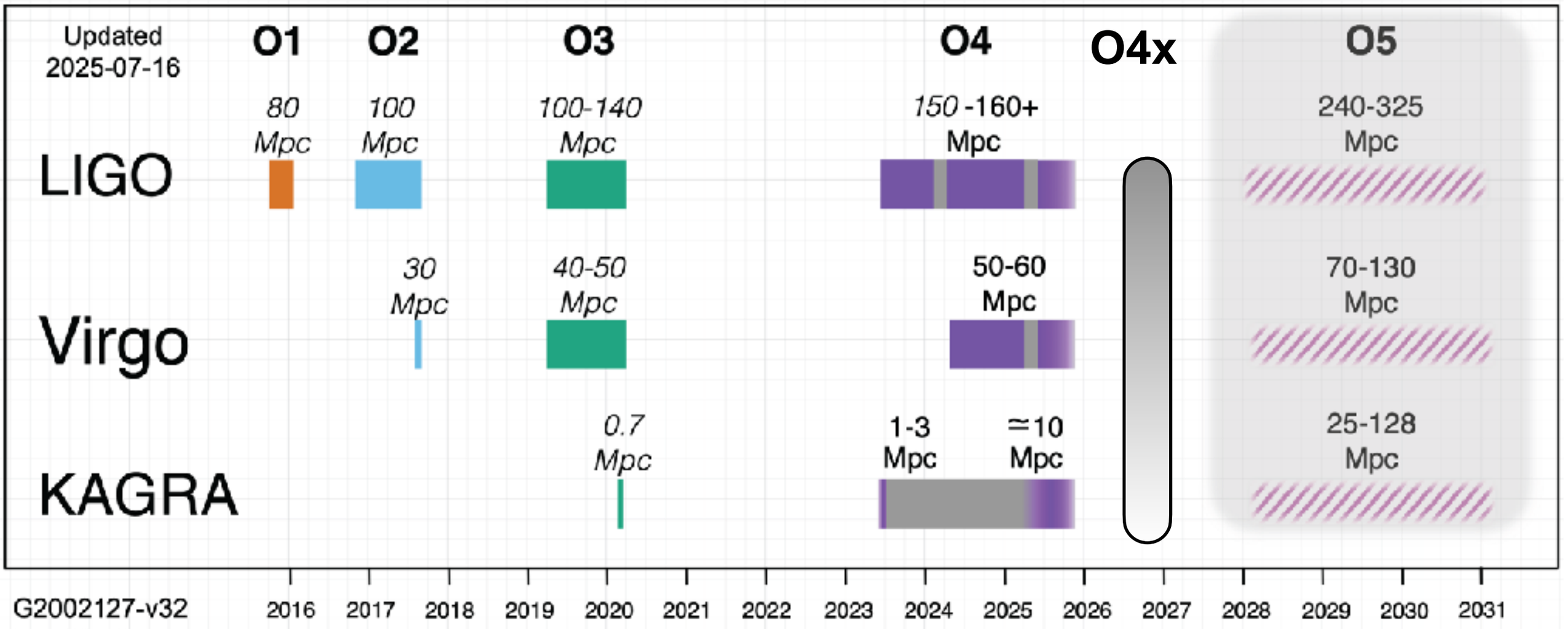
10 years of GW observations (+ multi-messenger searches)



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

Overview: O1 + … + O4 + …

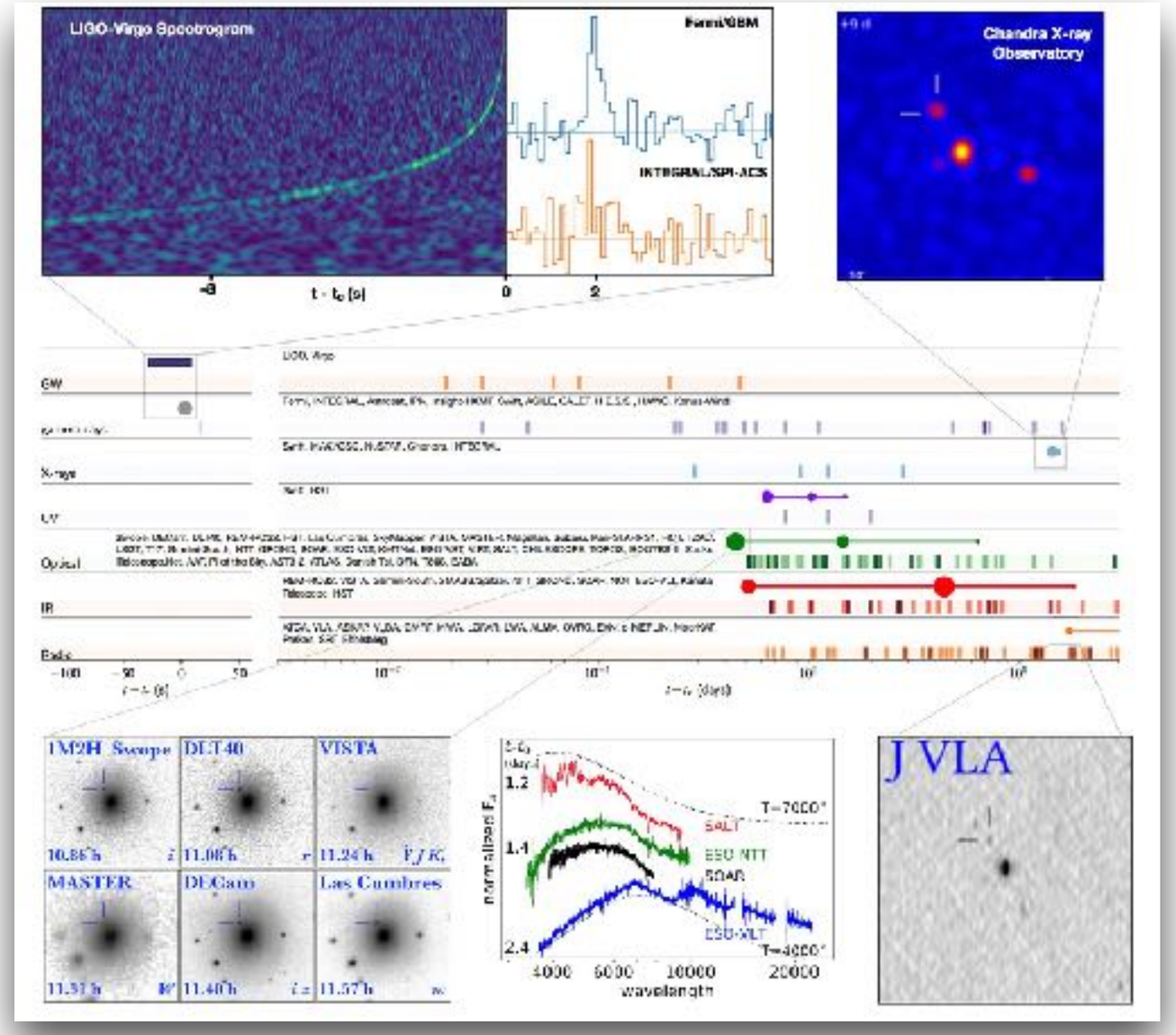
O4 ended on Tuesday, Nov 18 (without another BNS merger)



(modified)

We currently envision a six month observing run to begin in the late summer/early fall of 2026, with detectors participating as available.
From: https://observing.docs.ligo.org/plan/

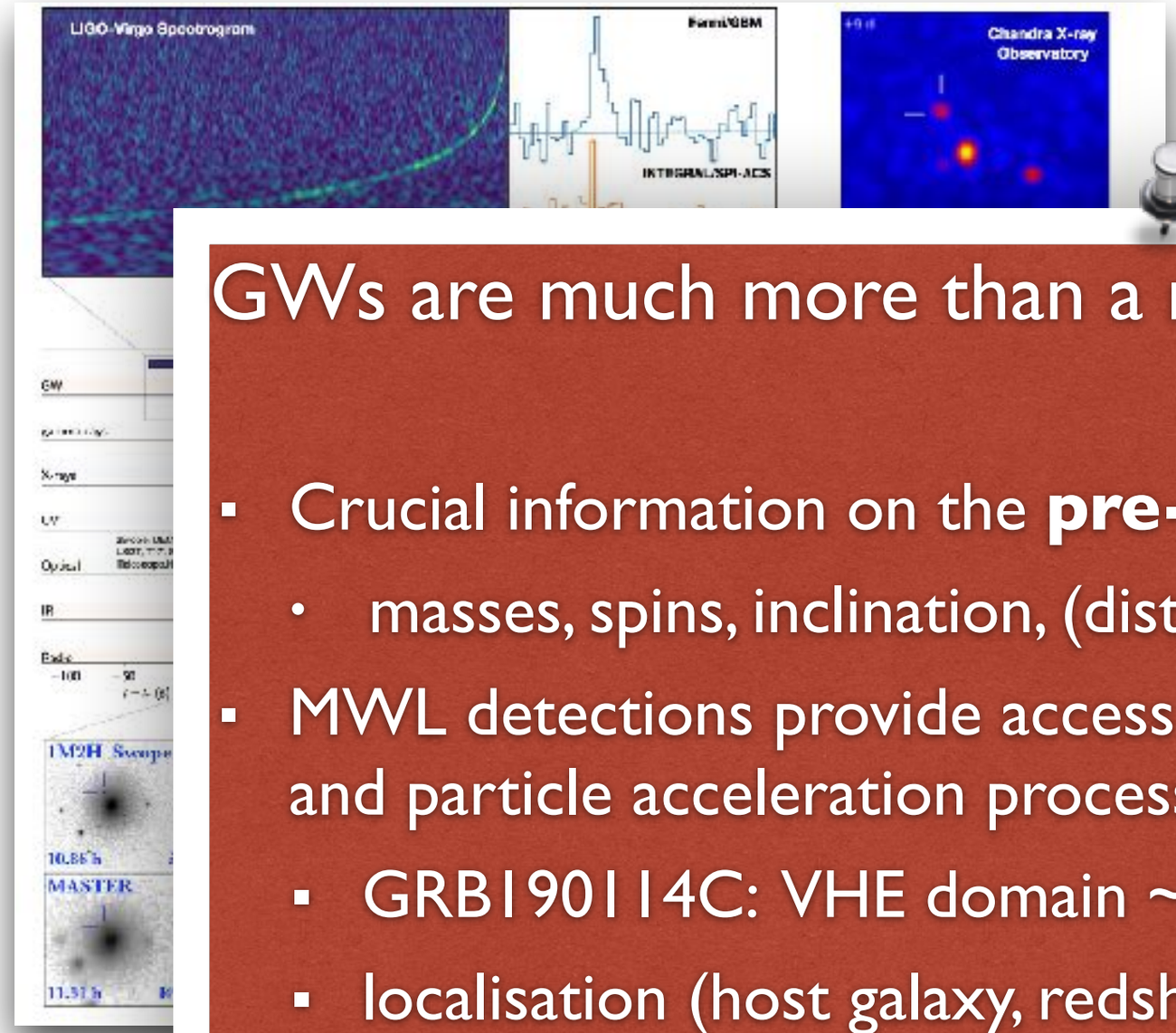
Gravitational waves and Gamma-Ray Bursts



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

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

Gravitational waves and Gamma-Ray Bursts



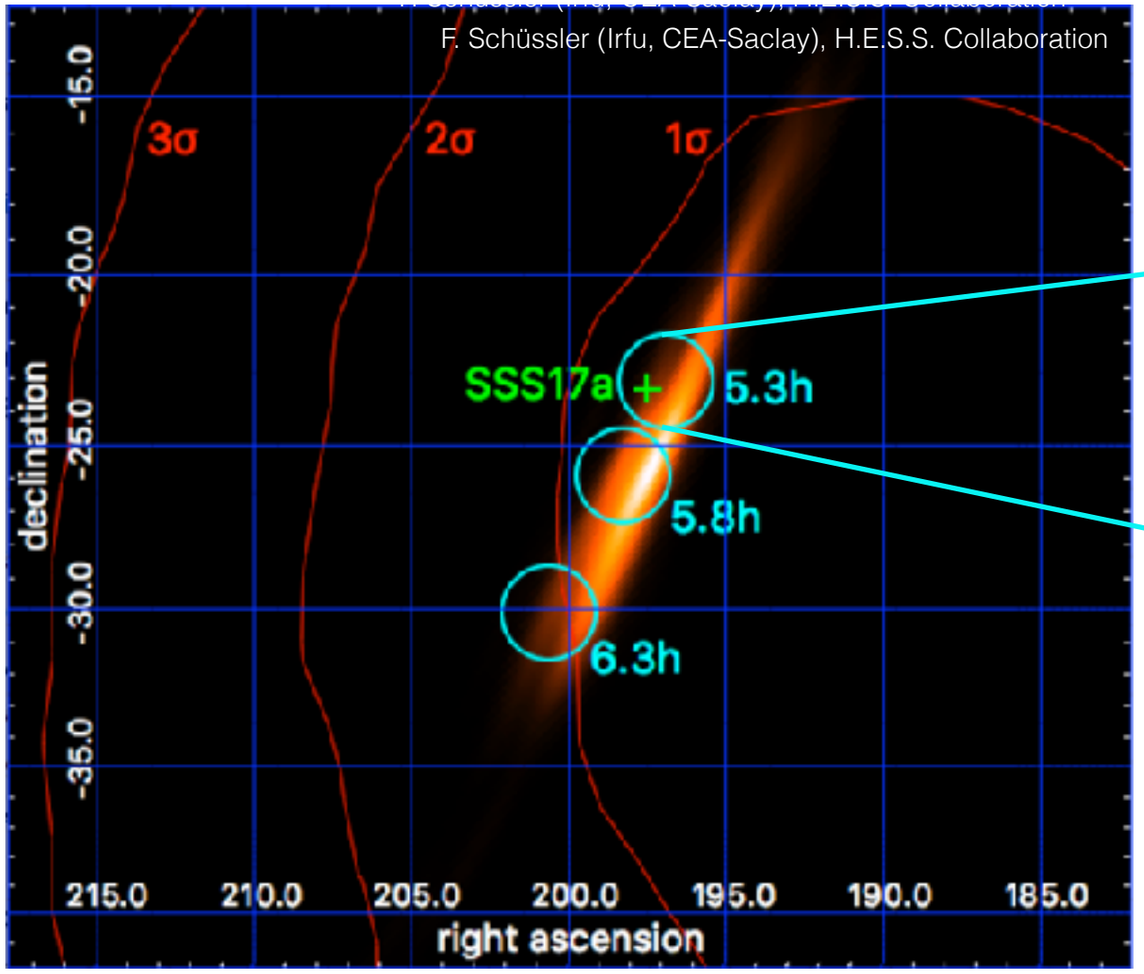
- GW170817: NS-NS mergers are sources of (short) GRBs

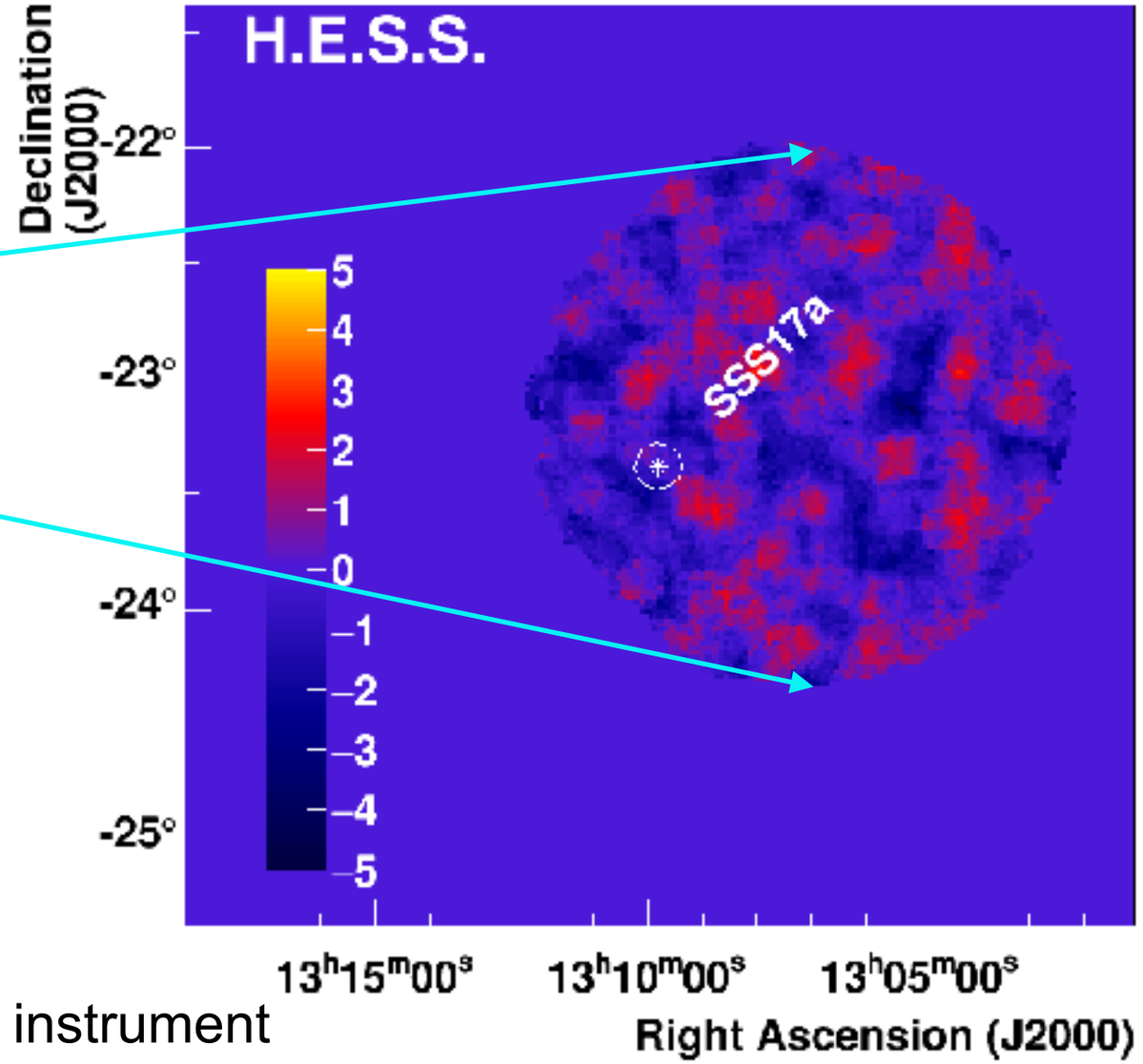
GWs are much more than a new way to detect GRBs

- 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, …

for

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

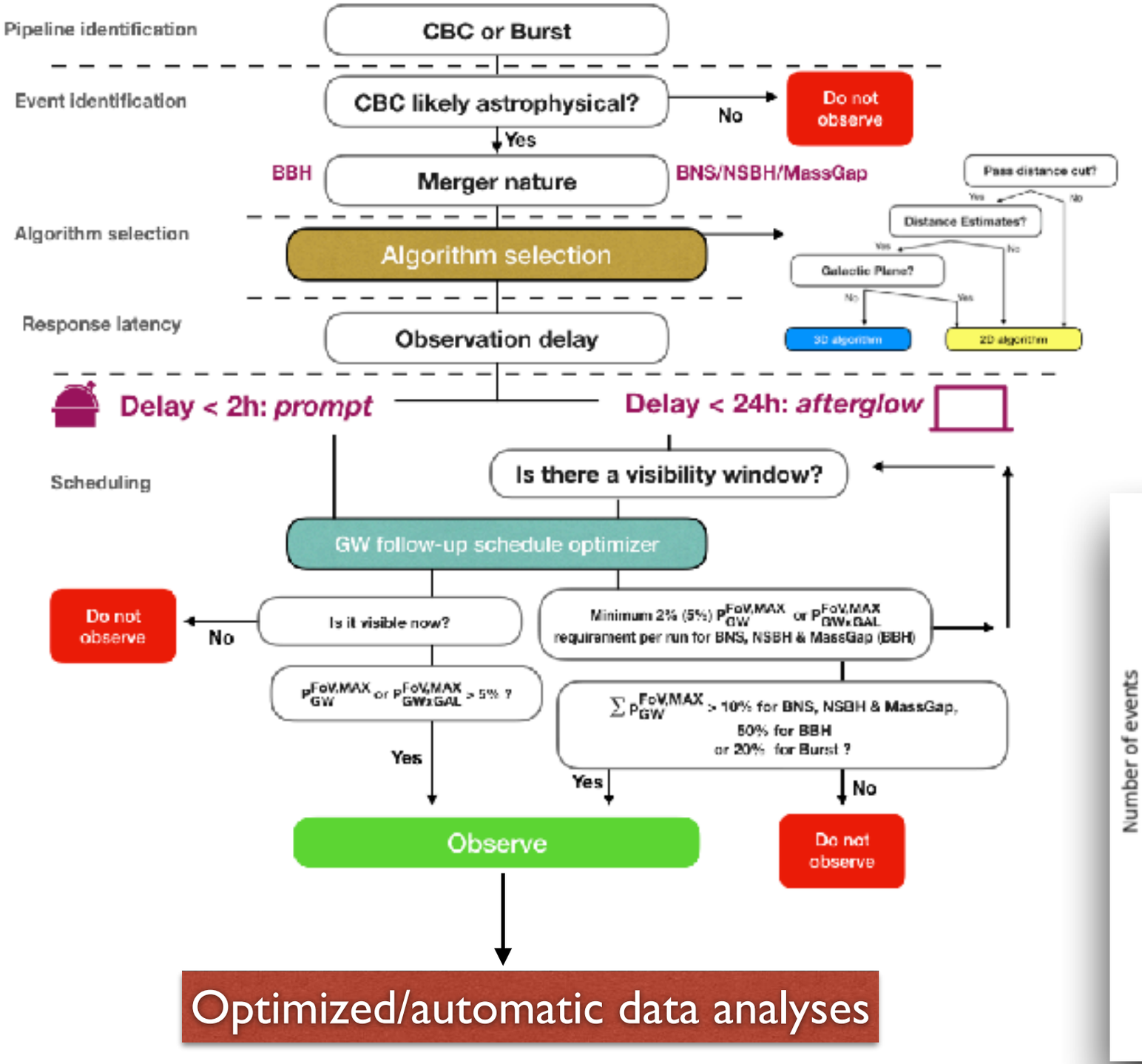


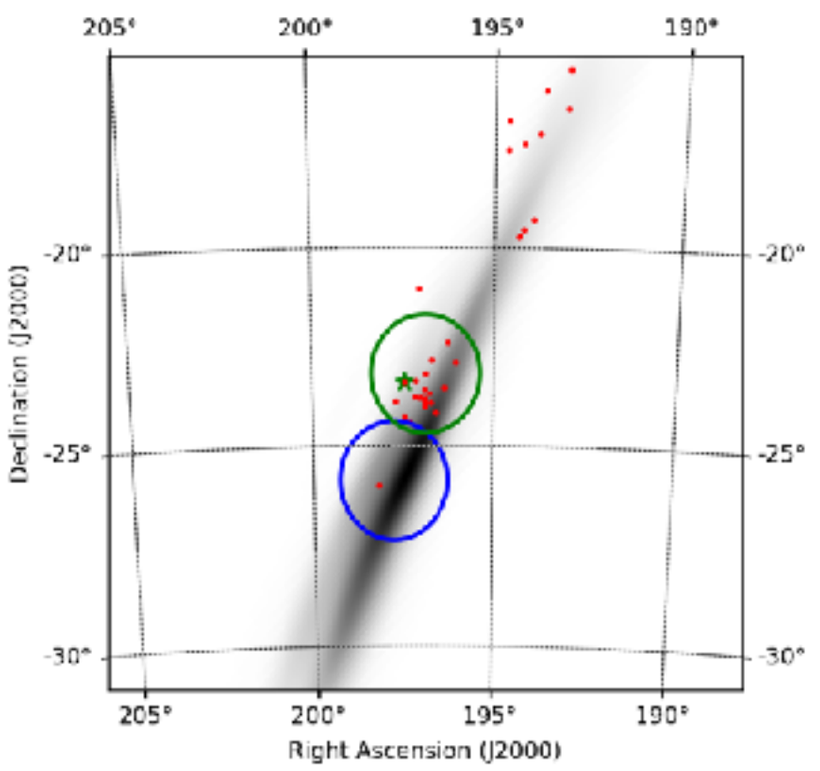


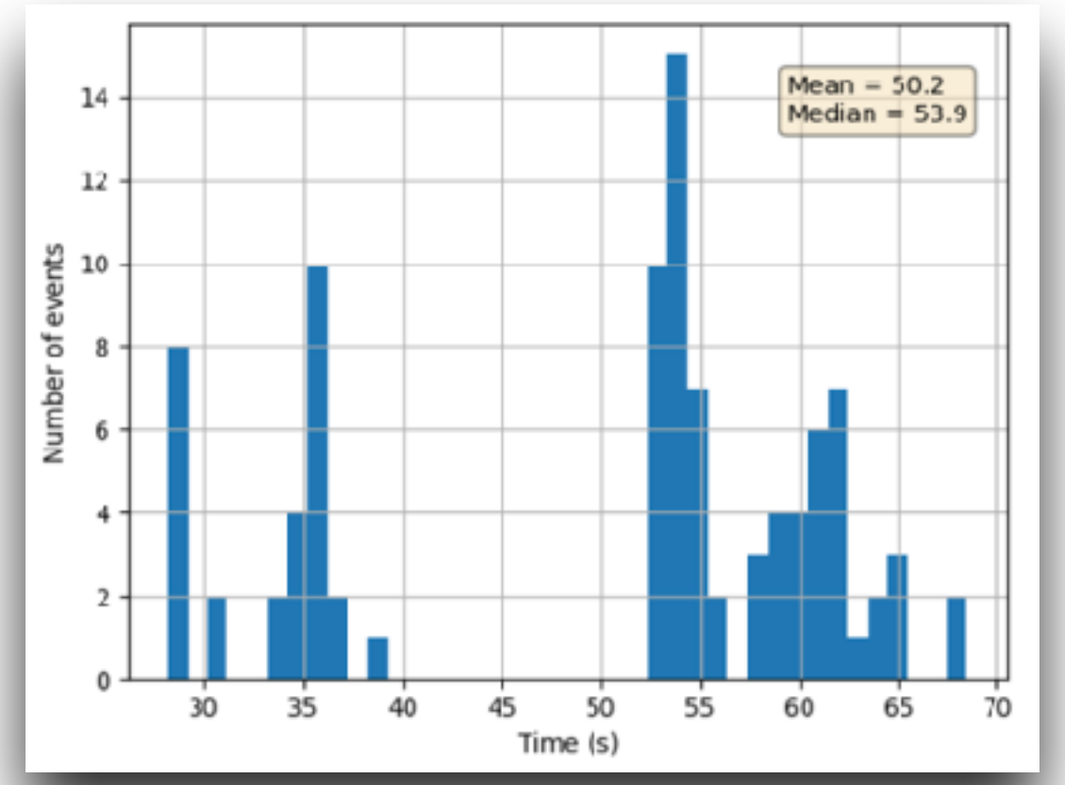
- First observations of a ground-based pointing instrument
  - 5.3 hours after GW170817
  - 5 minutes after the GCN circular announcing the LIGO+Virgo localisation
  - no significant signal: Φ (0.28 < E [TeV] < 2.31) < 3.9 x 10^{-12} erg cm^{-2} s^{-1}
  - monitoring campaign over 5 nights + extensive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

H. Abdalla et al. (H.E.S.S.), ApJL 855:L22 (2017) + ApJL 894:L16 (2020)

Scheduling and pointing strategies



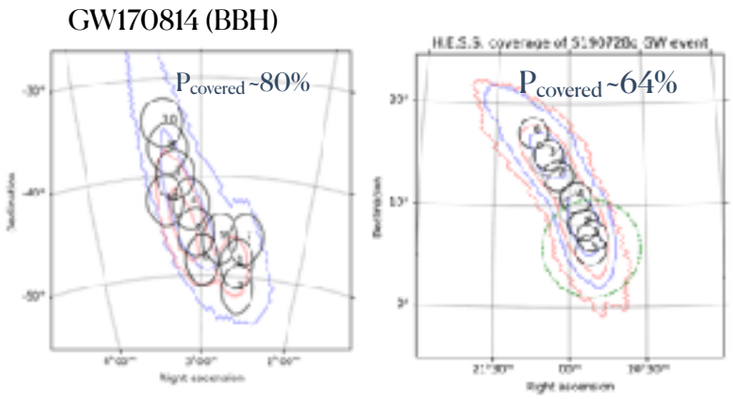




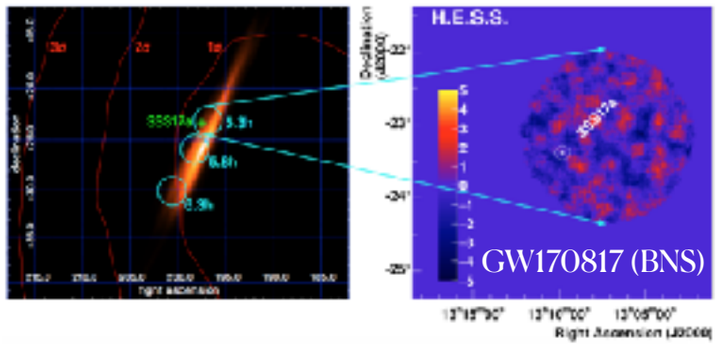
H. Ashkar et al., “The H.E.S.S. Gravitational Wave Rapid Follow-up Program”, JCAP03(2021), 45

tilepy

- Scheduling: **H.E.S.S**
-

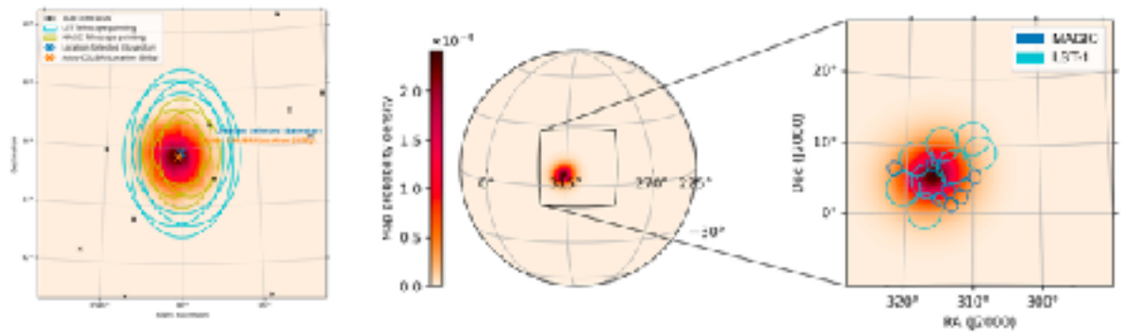


H.E.S.S. Collaboration, ApJ, 923, 109 (2021)



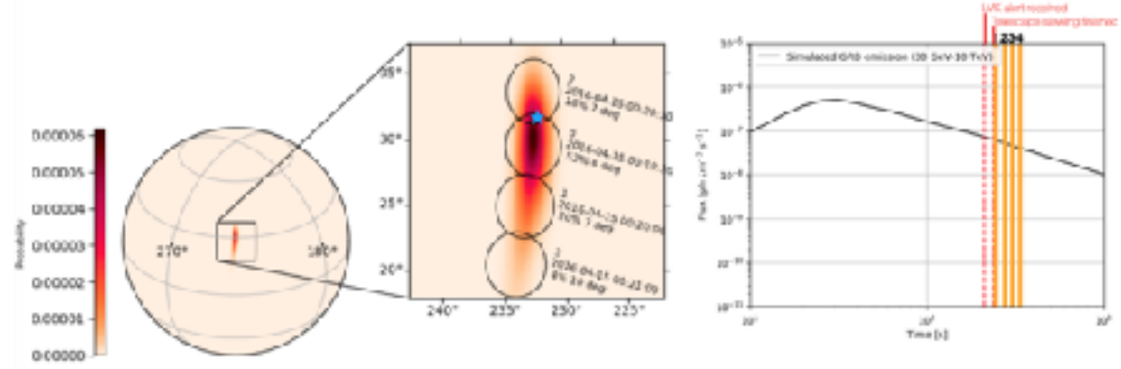
H.E.S.S. Collaboration, ApJL 850 (2017) L22

- Scheduling: CTAO/**Large Sized Telescope-1 + MAGIC**



M. Seglar-Arroyo, e*t al* [CTAO/LST Collaboration] (ICRC2025) 841

- Observation prospects: CTAO GW in Observing run O5



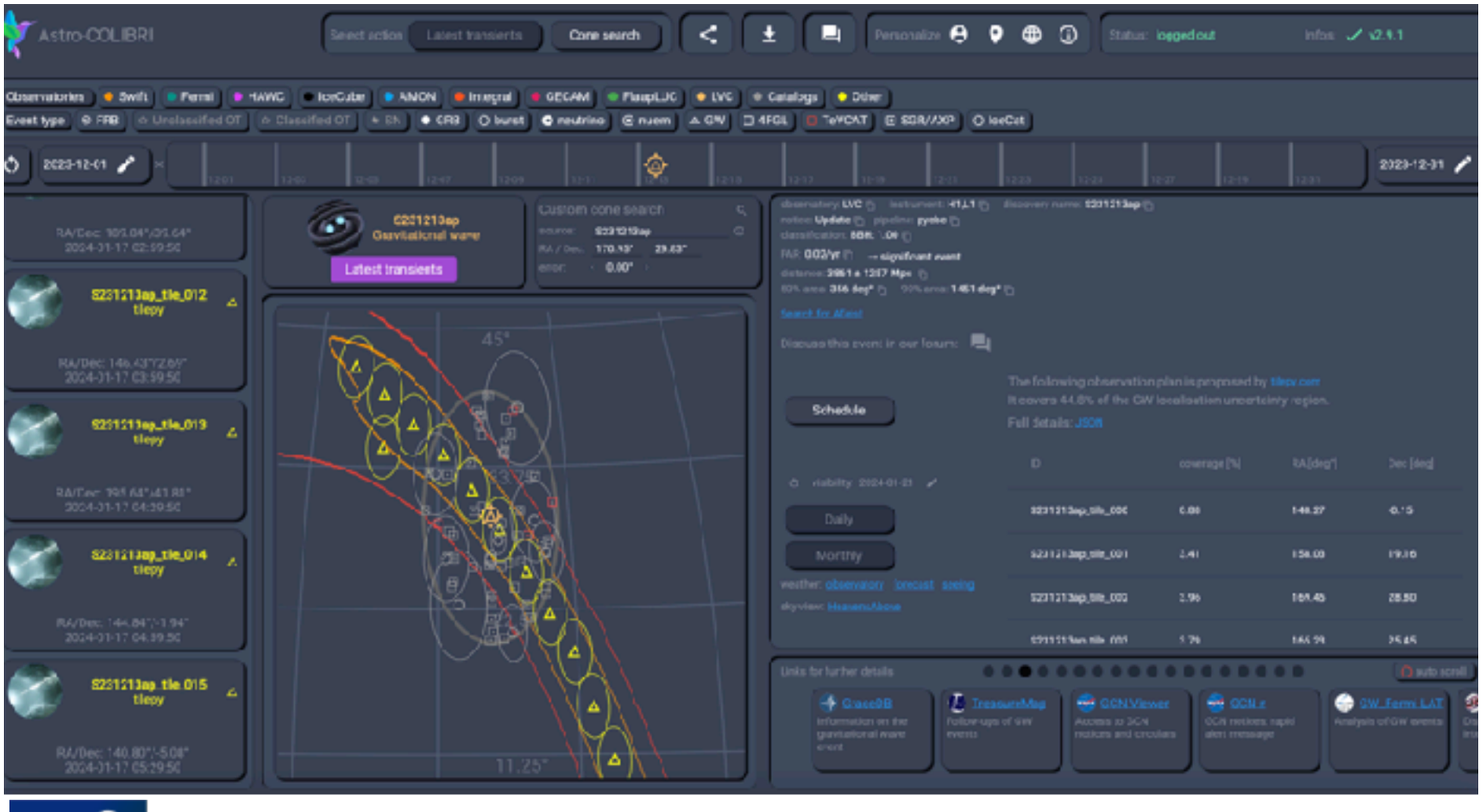
B. Patricelli, e*t al* [CTAO Collaboration] (ICRC2021) 998

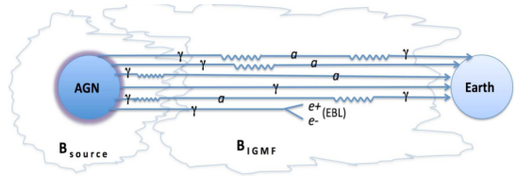
- **GitHub: github.com/astro-transients/tilepy**
- **PyPI: pypi.org/project/tilepy/**
- **Doc: tilepy.readthedocs.io**
- **API at tilepy.com**

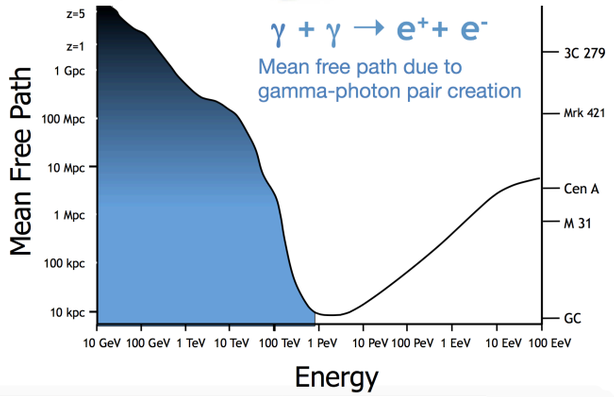
- Scheduling: CTAO (ACADA Transient-Handler)

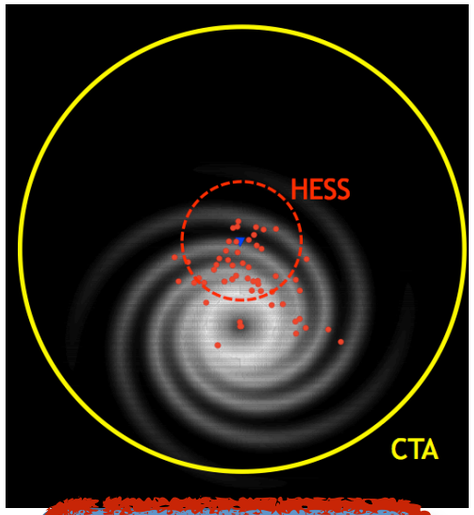
Tilepy integration in Astro-COLIBRI

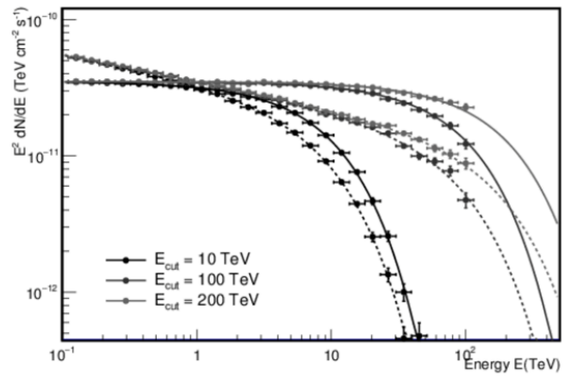
- Easy to use based on a default configuration:
  - Select the observatory
  - Select the gravitational wave
- Support for other poorly localised transients coming soon!

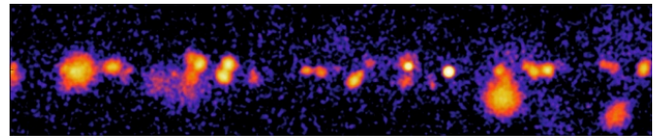


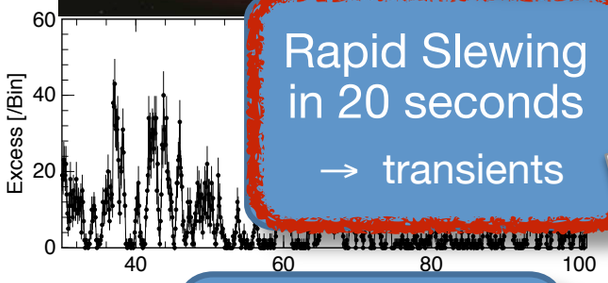


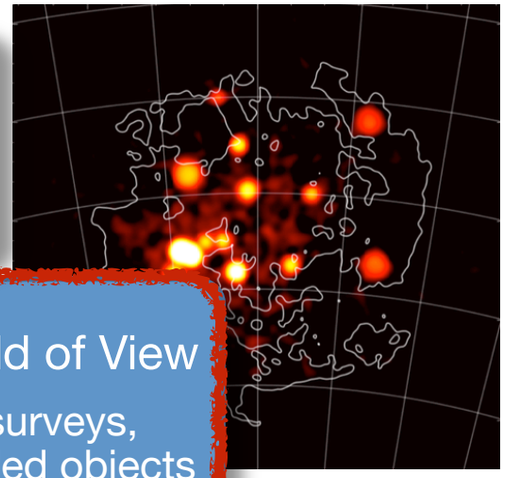


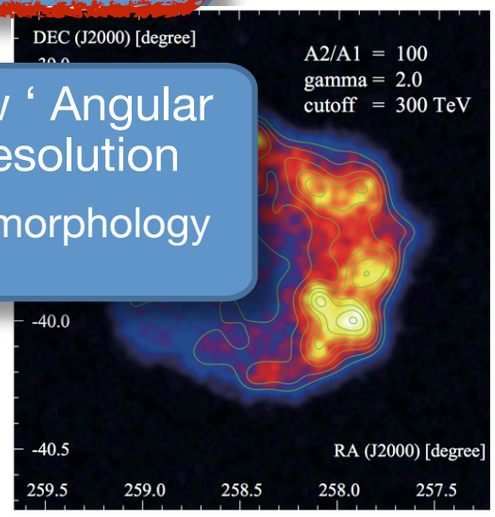


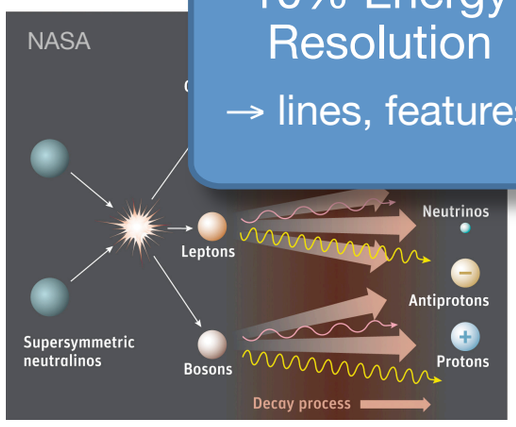












10 x Sensitivity, Large Collection Area → all topics

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

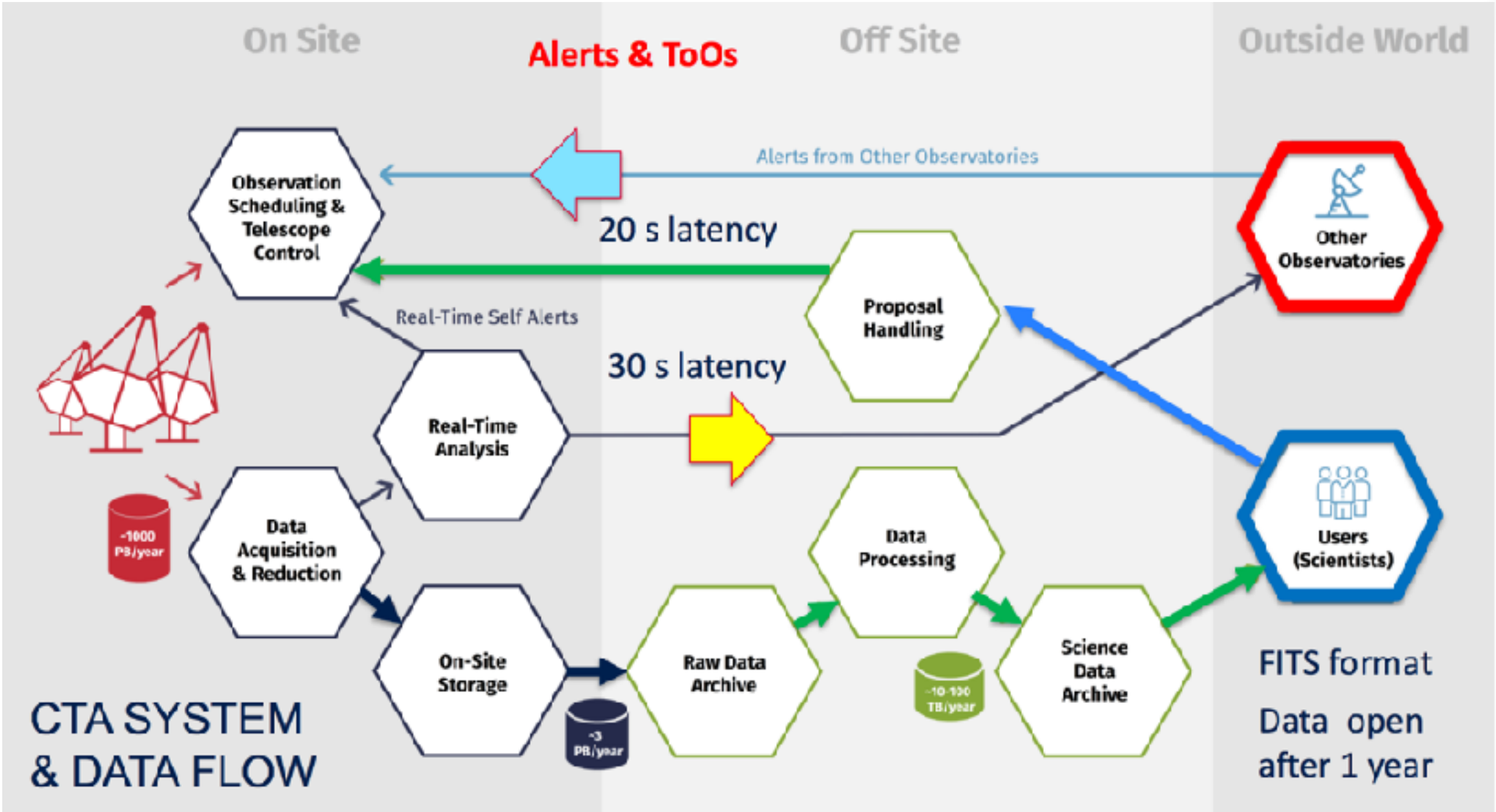
10% Energy Resolution → lines, features

Few ‘ Angular Resolution → morphology

CTAO

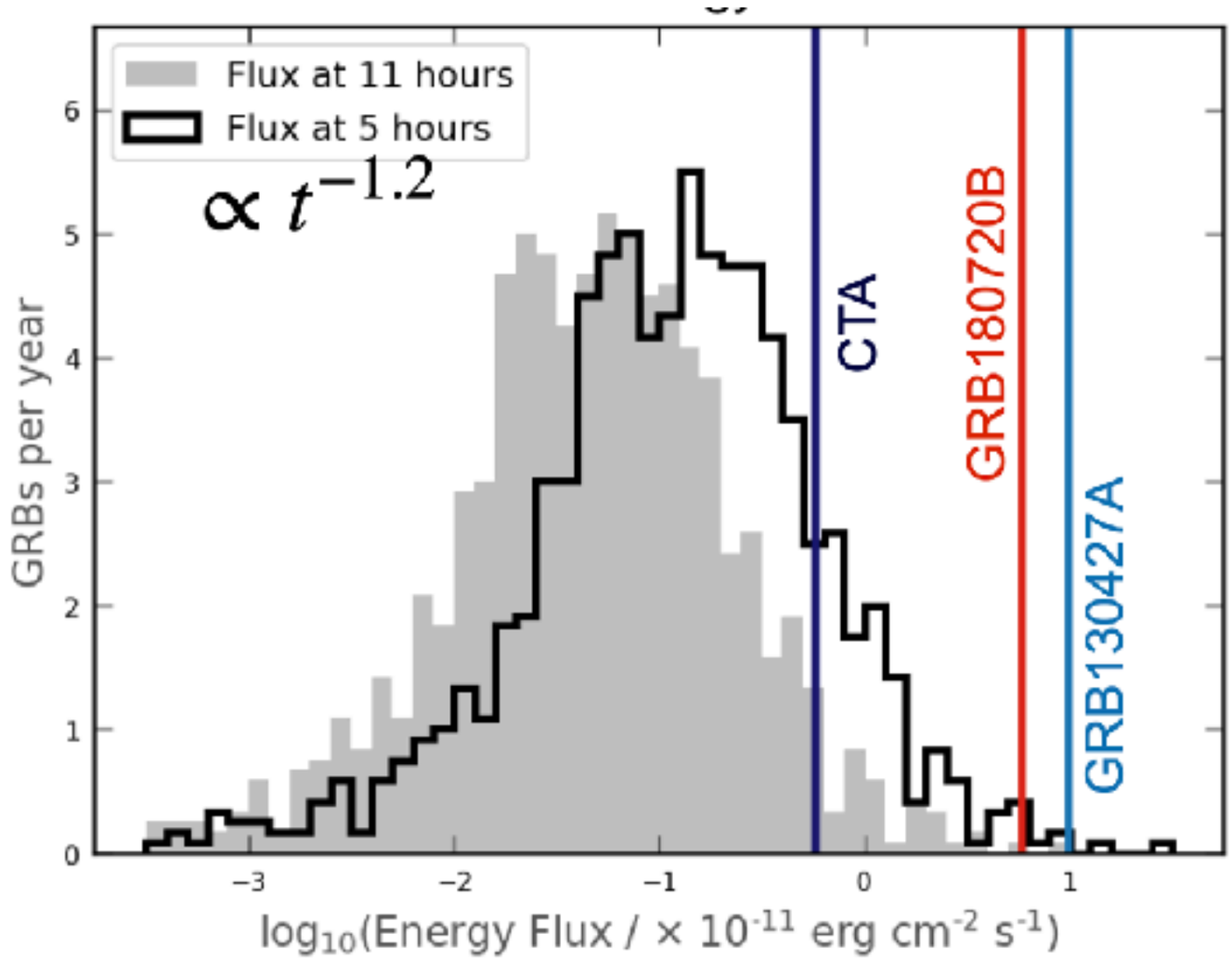
The CTA Transient program

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



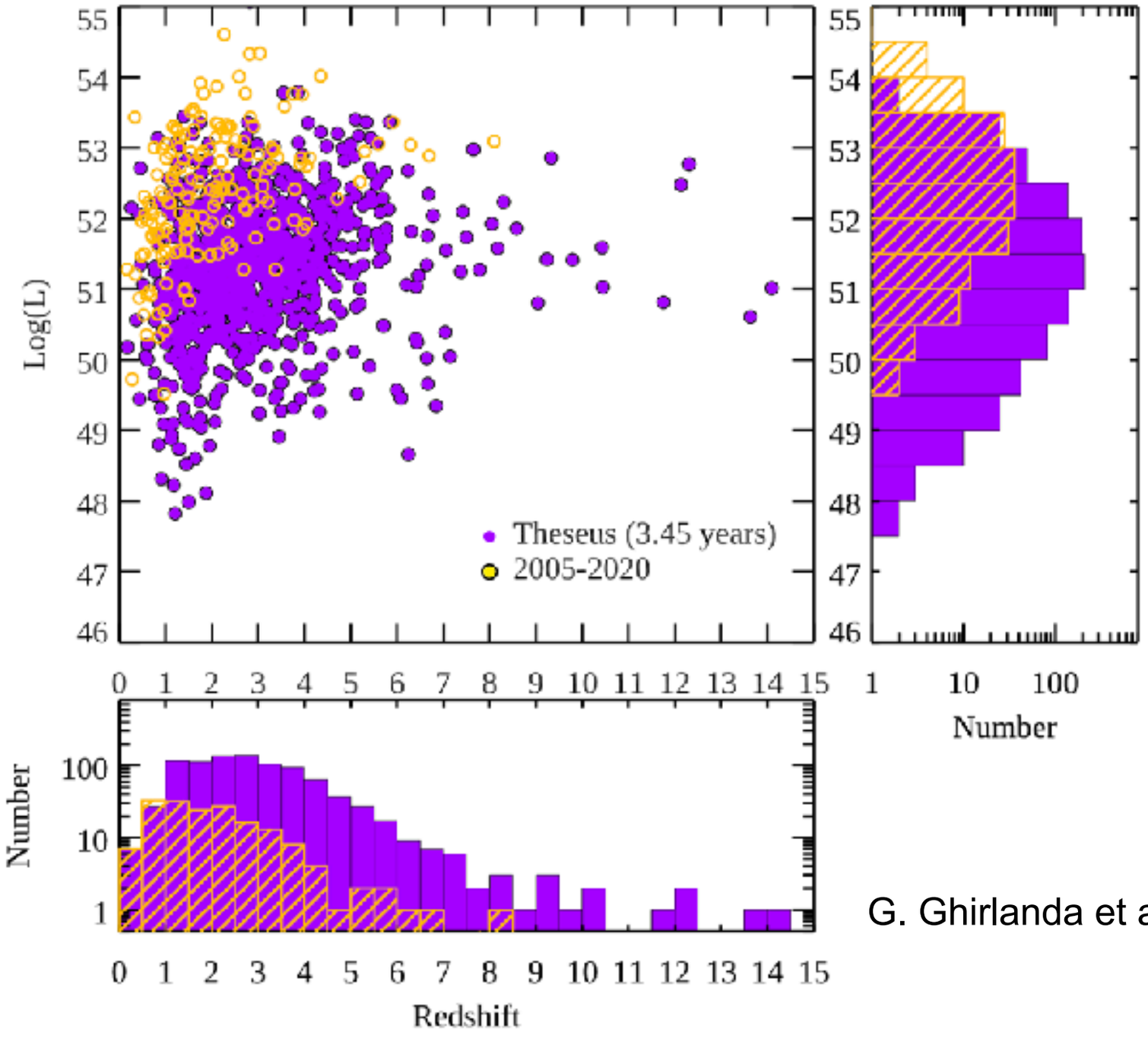
Outlook: GRB observations with CTA

- ~10 times better sensitivity => increase detections + probe deeper into the afterglow
- Rapid slewing of the LSTs => catch the early, very bright phase

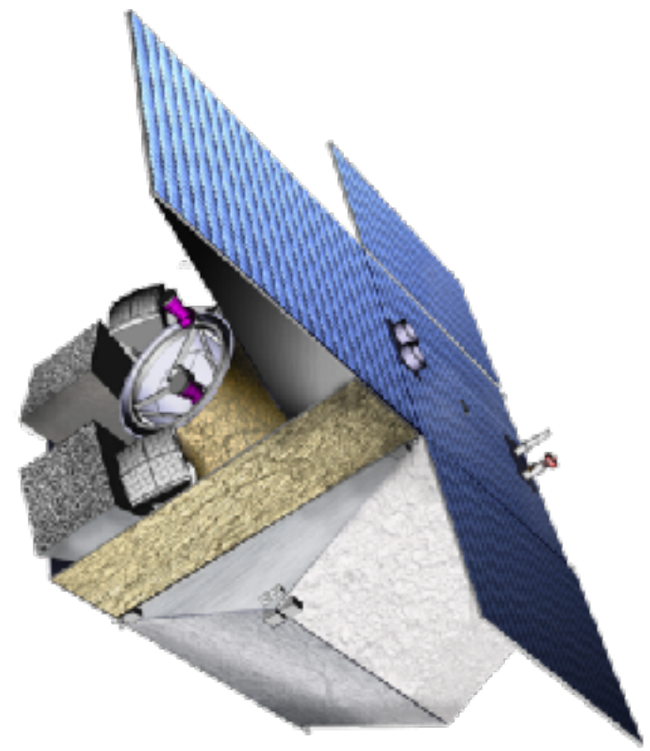


Outlook: GRB detections with SVOM +THESEUS

- SVOM: improved follow-up observations (night-sky pointing)
  - Rapid follow-up by the global community => rapid redshift measurements
- THESEUS (ESA phase-A study, possible launch in 2037)

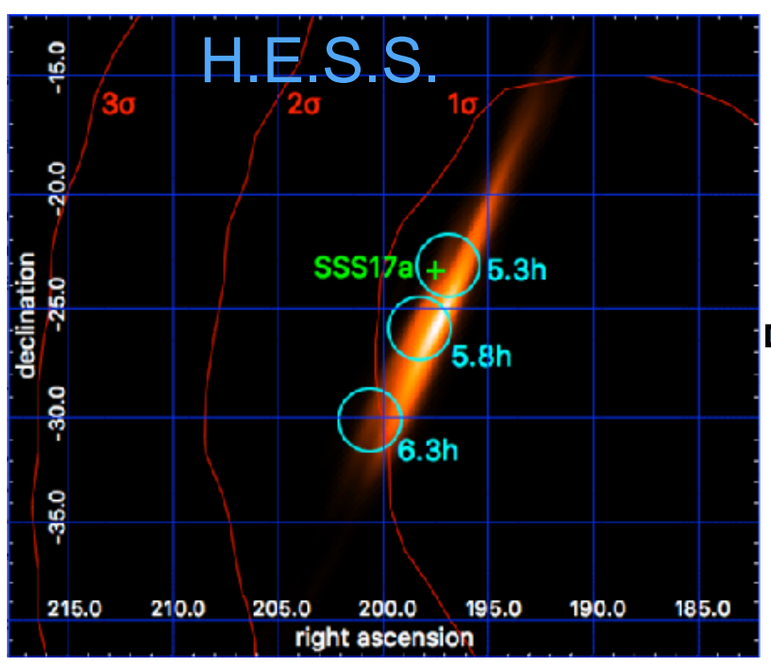


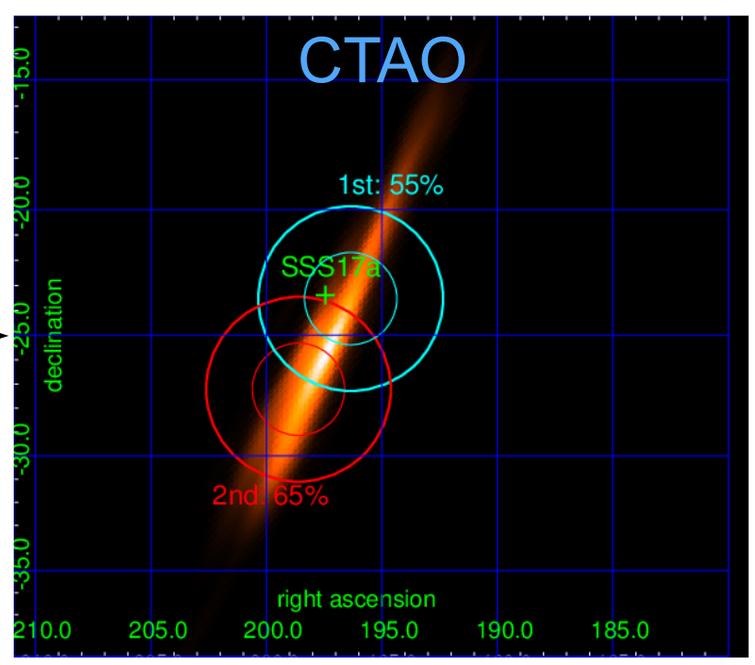
G. Ghirlanda et al.



Expanding towards the low-luminosity GRB population (+ XRFs)

GW follow-up with CTAO





- 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

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

FS (CTA consortium), preliminary

GRB and GW observations at TeV energies

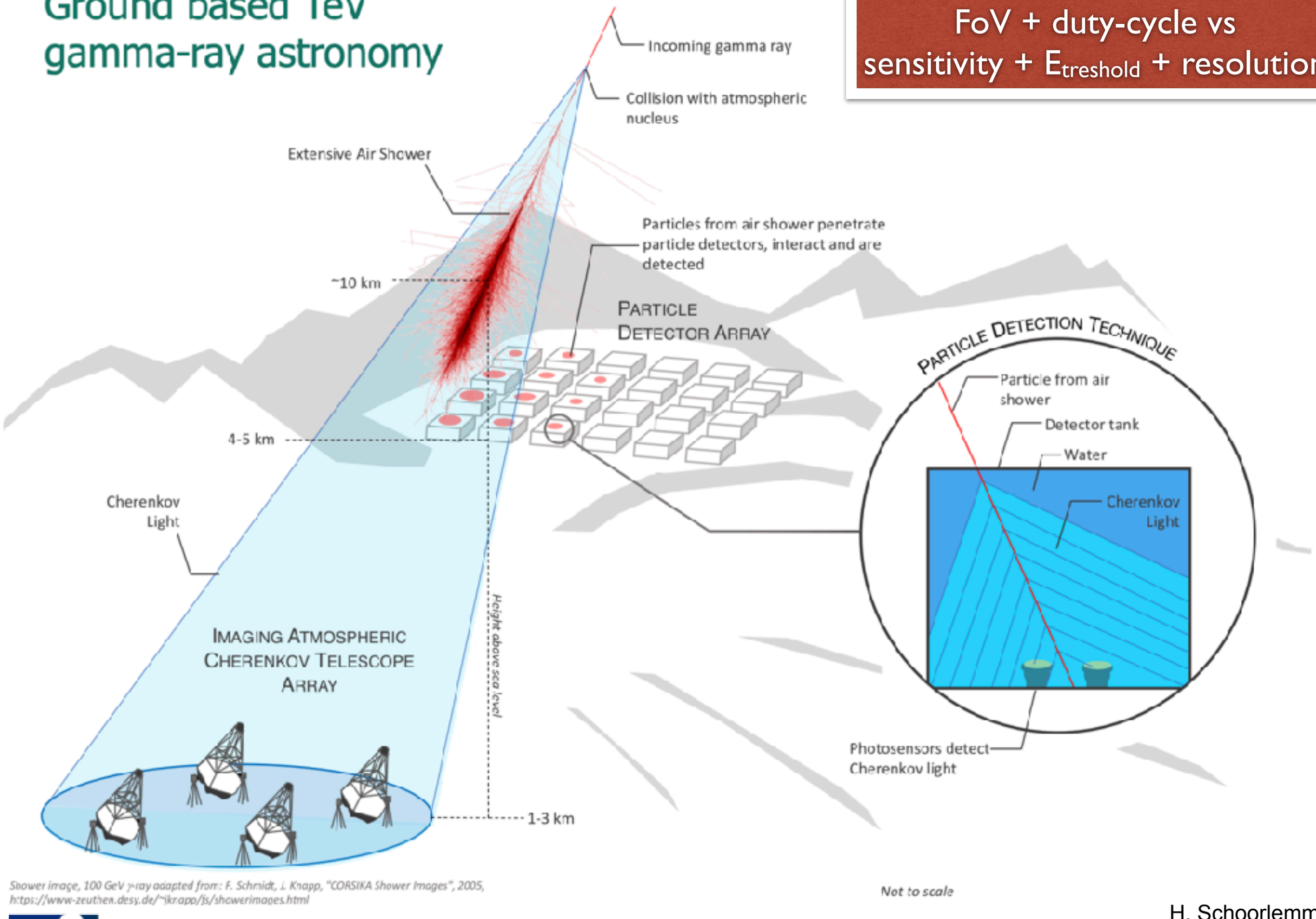
- **Many years of preparation coming to fruition**
  - automatic alert systems + dedicated data analysis tools + MoUs + …
  - multi-wavelength coverage crucial (H.E.S.S. GRB schedule: https://grbhess.github.io)

- **Gravitational waves + Gamma Ray Bursts**
  - major breakthroughs over the last years
  - GW170817, GRB190114C, GRB190829A, GRB 221009A, …

- Key role of monitoring X-ray instruments
  - Fermi-GBM, Swift, (INTEGRAL)
  - SVOM, Einstein Probe, …
  - THESEUS (tbc)

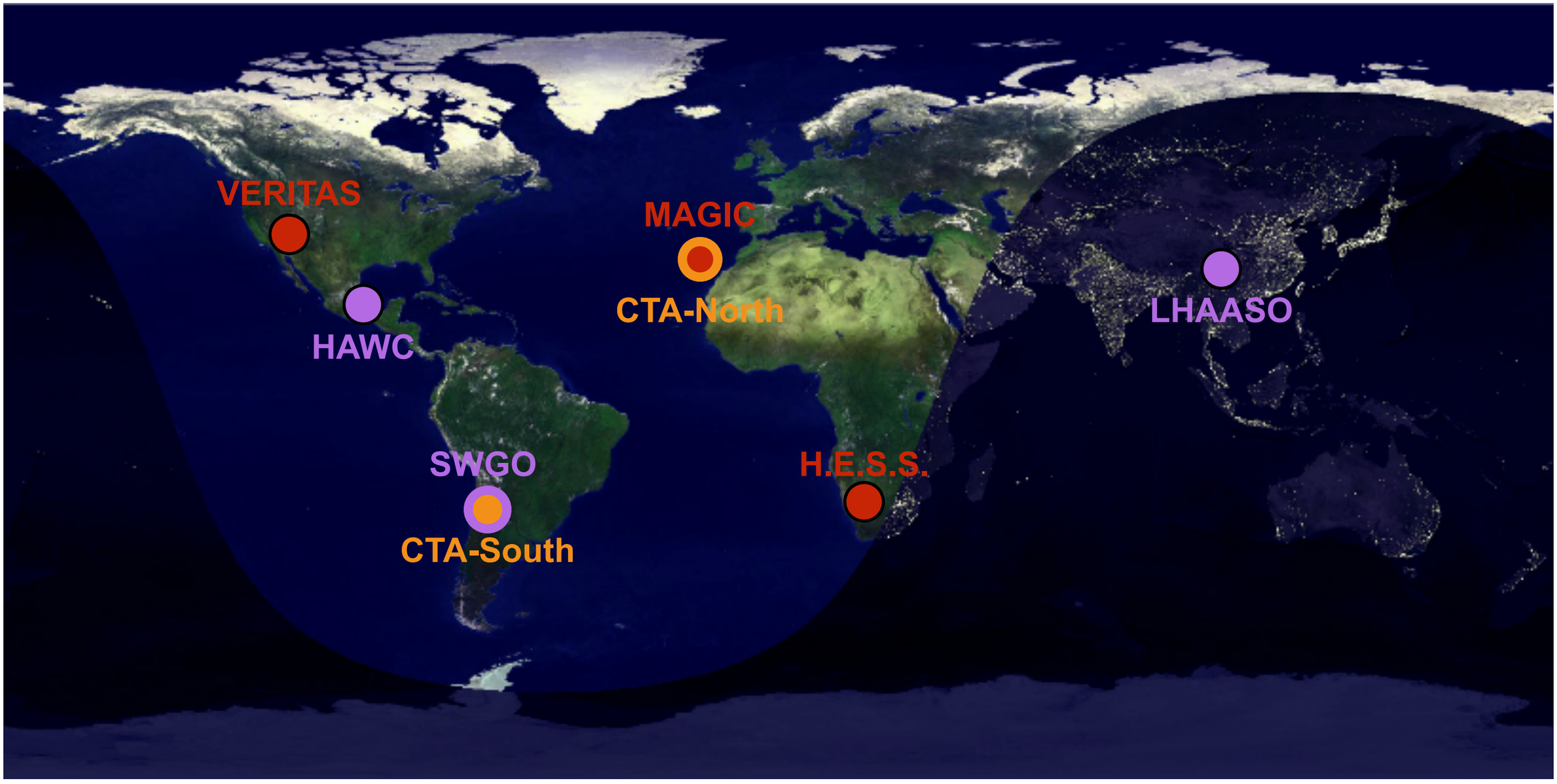
Ground based TeV gamma-ray astronomy

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

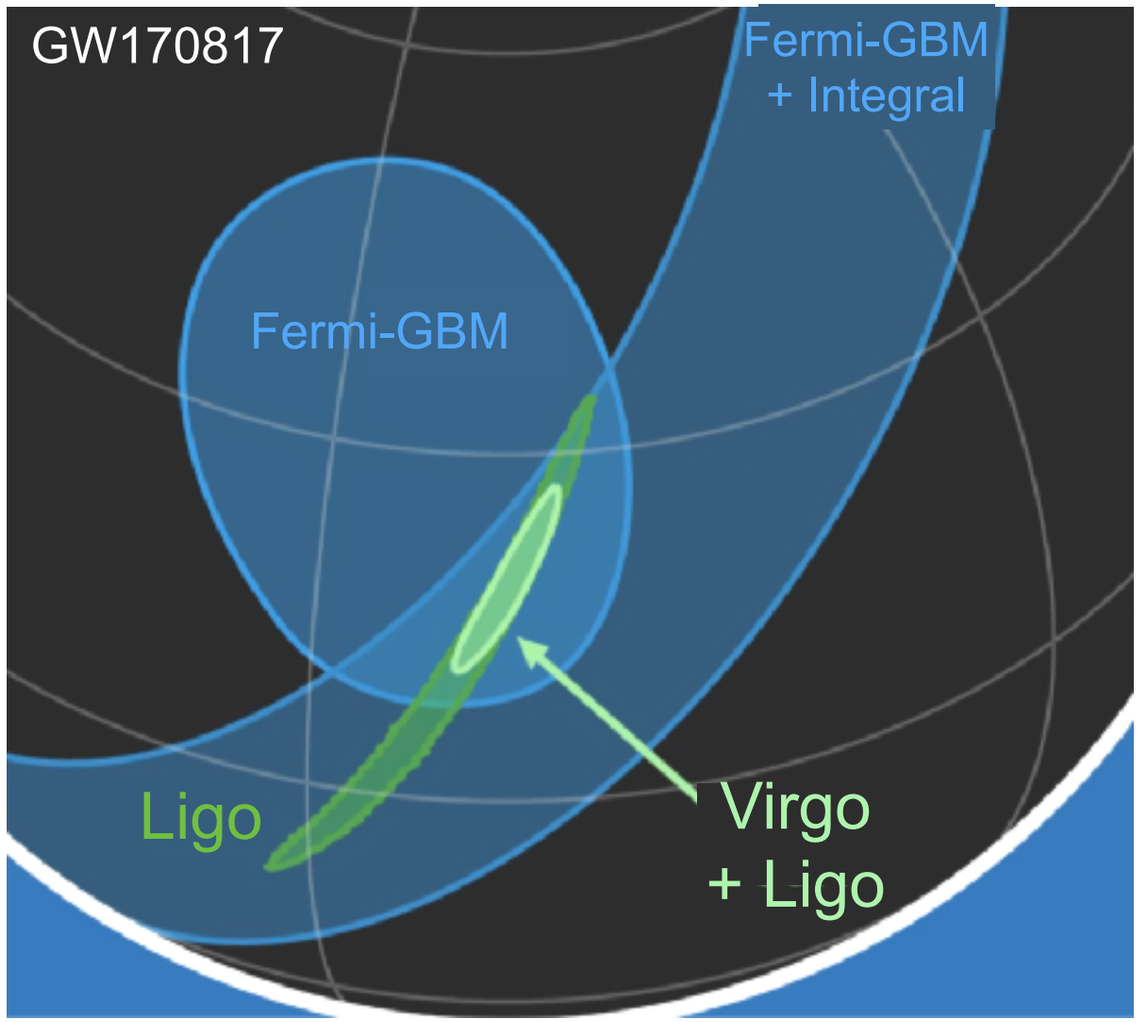


H. Schoorlemmer

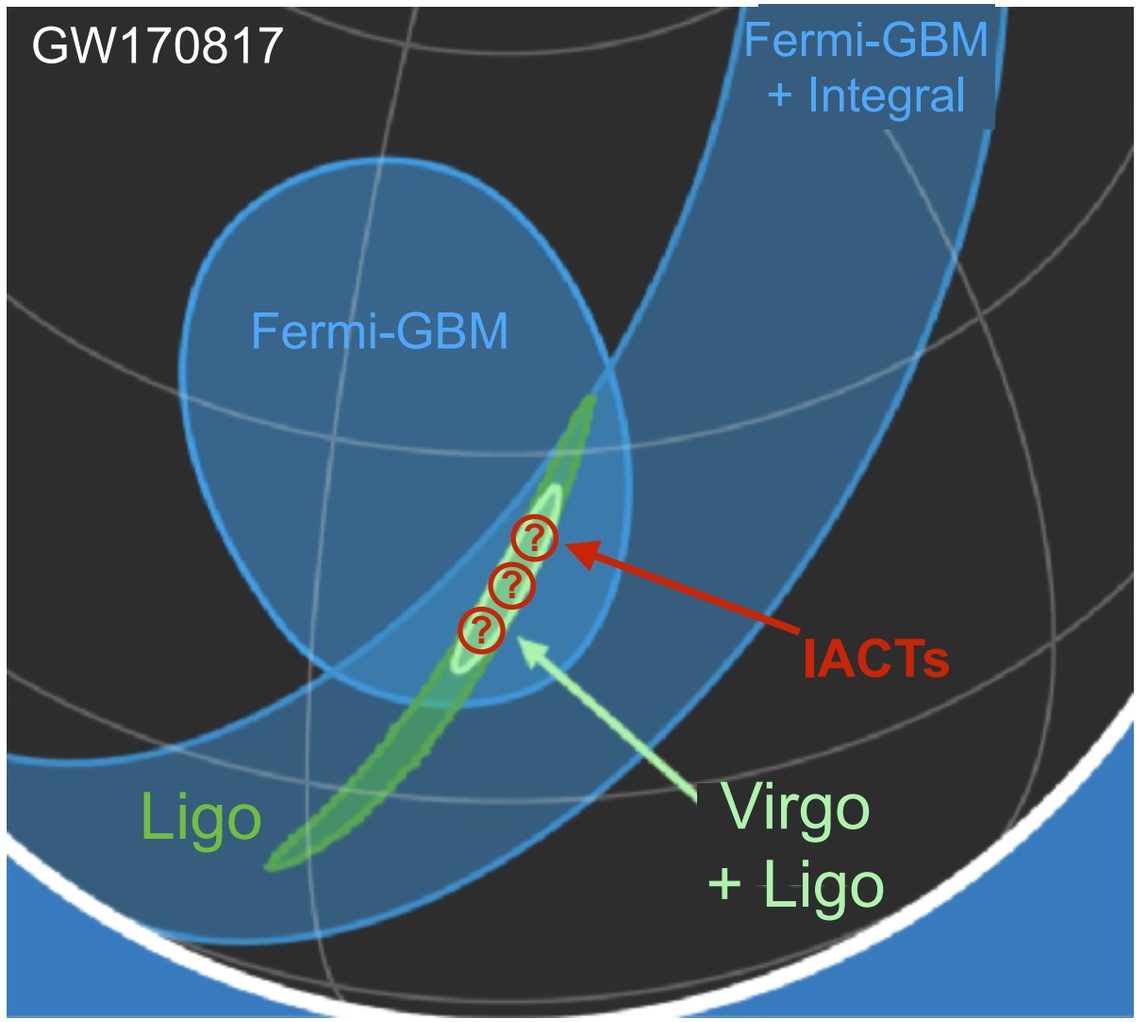
VHE gamma-ray astronomy



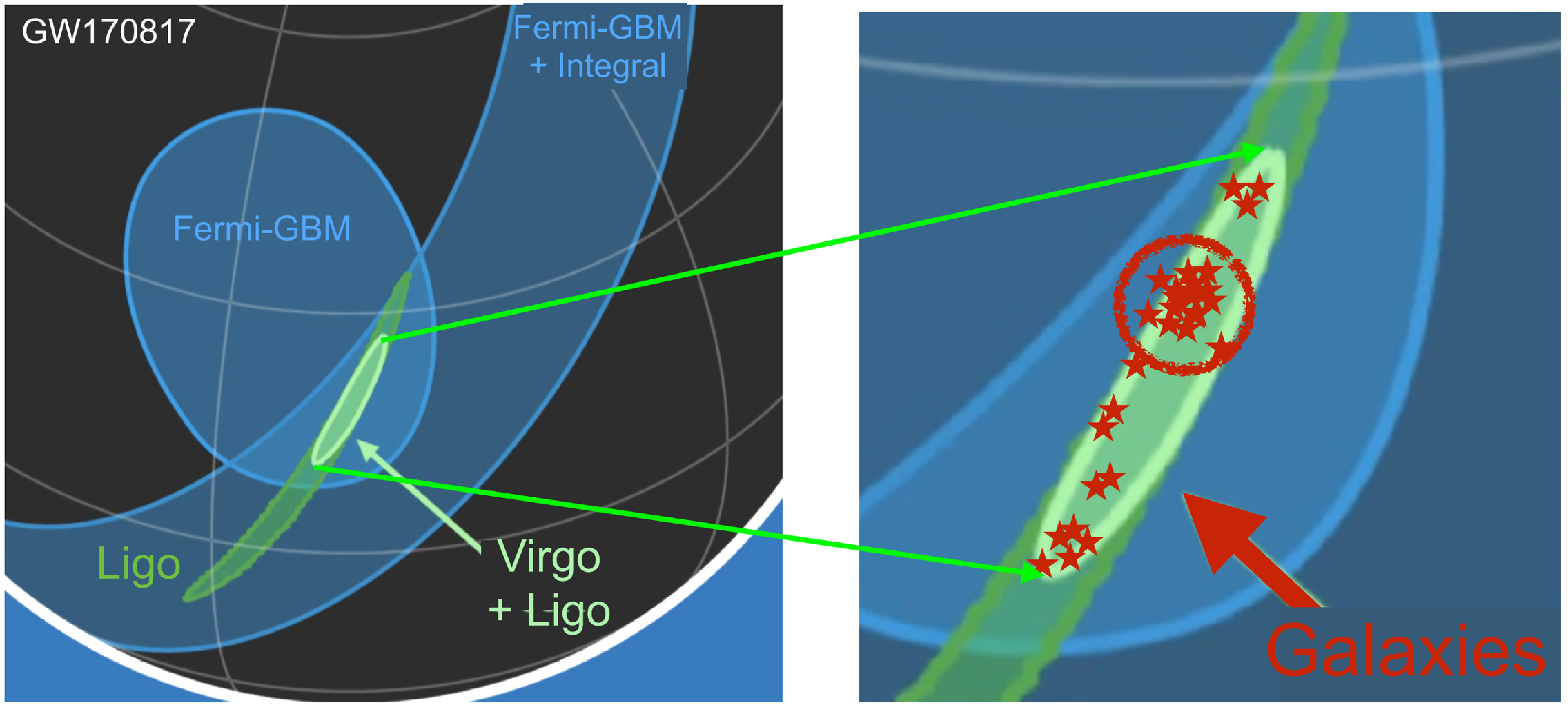
Scheduling and pointing strategy



Scheduling and pointing strategy



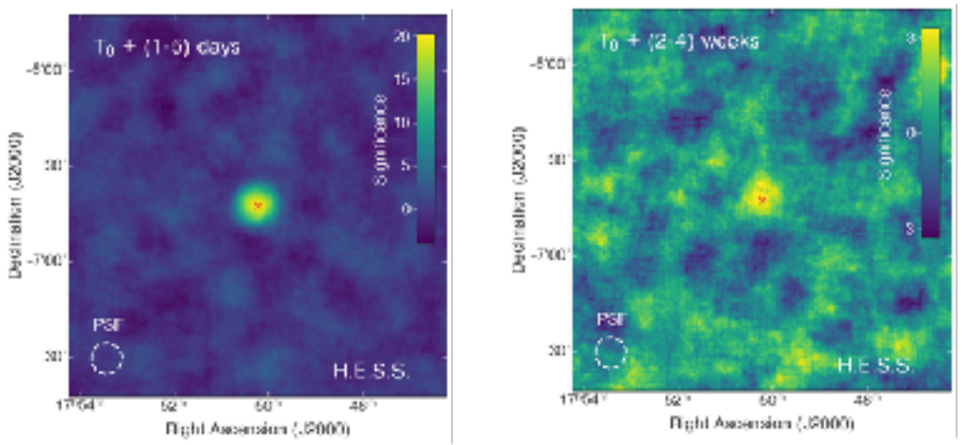
Scheduling and pointing strategy



- 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.)

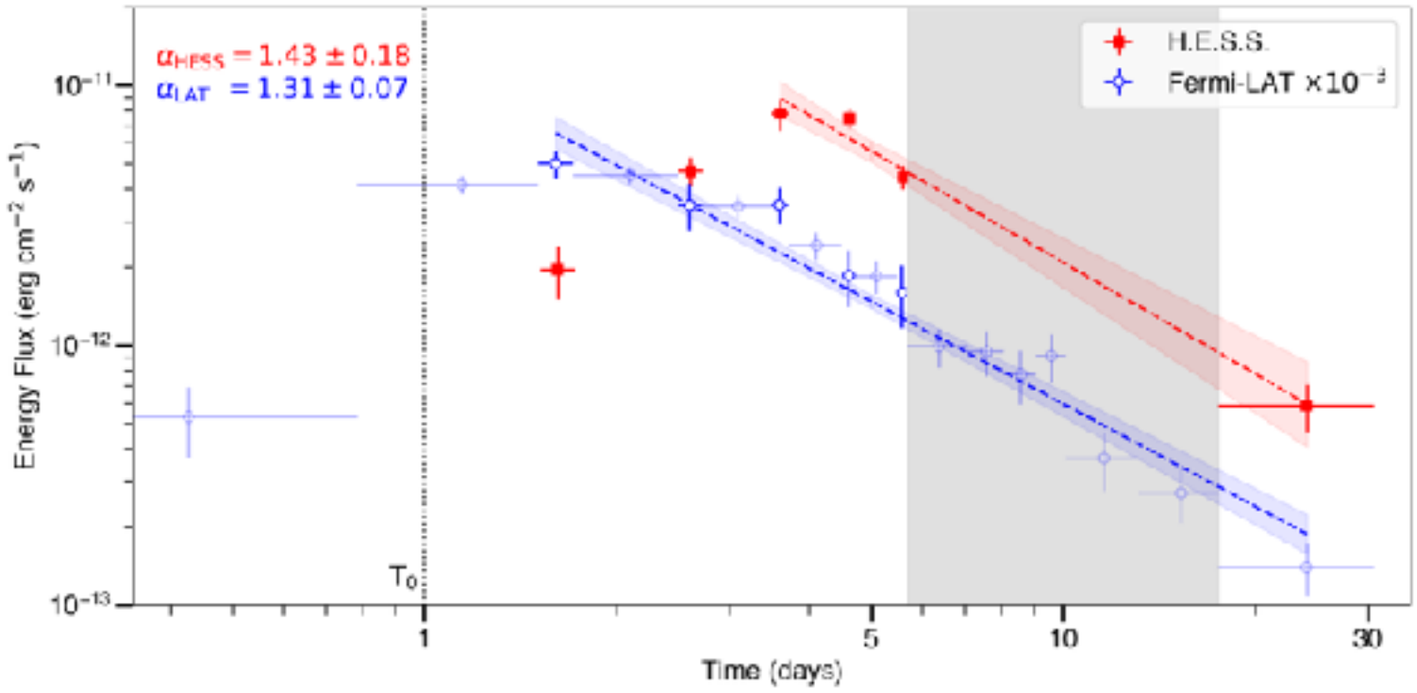
RS Ophiuchi: GeV -> TeV particles

- H.E.S.S. observations
  - Clear detection in each of the first nights (Aug. 9 - Aug
  - 3 sigma in cumulated long-term monitoring (Aug. 25 -
  - 250GeV to 2.5TeV



- Consistent observations by MAGIC

- Fermi-LAT
  - Detected in (sub)-daily bins



H.E.S.S. Collaboration, Science 2

RS Ophiuchi: GeV -> TeV particles

- Spectral results
  - Combined fit of Fermi-LAT and H.E.S.S data
  - GeV flux level decrease + parabola widens

- Interpretation
  - Shock expanding into the RG wind
  - Diffusive shock acceleration of protons reaching theoretical limits of the E_{max}
  - Total energy release ~10^{43} erg
  - Novae as sub-dominant contribution to the