H.E.S.S. multi-messenger and real-time follow-up observations

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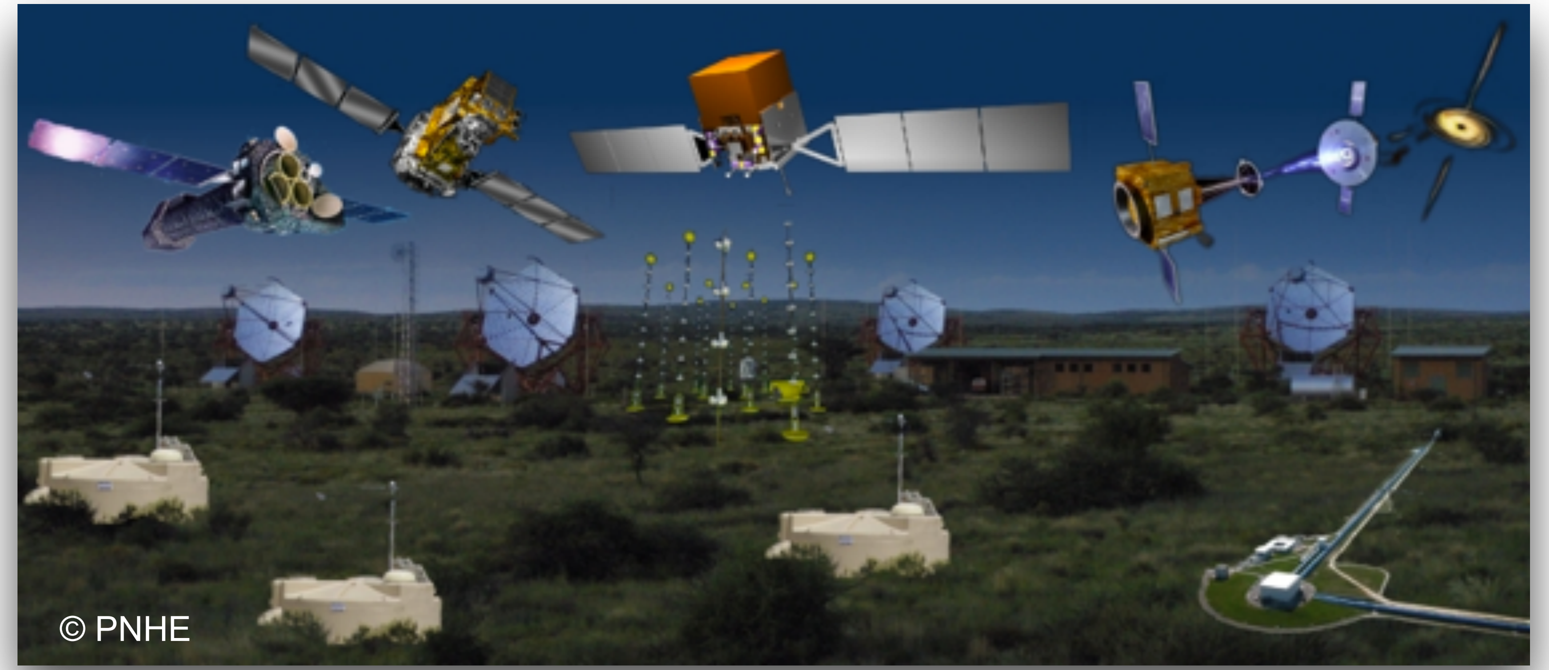
cea

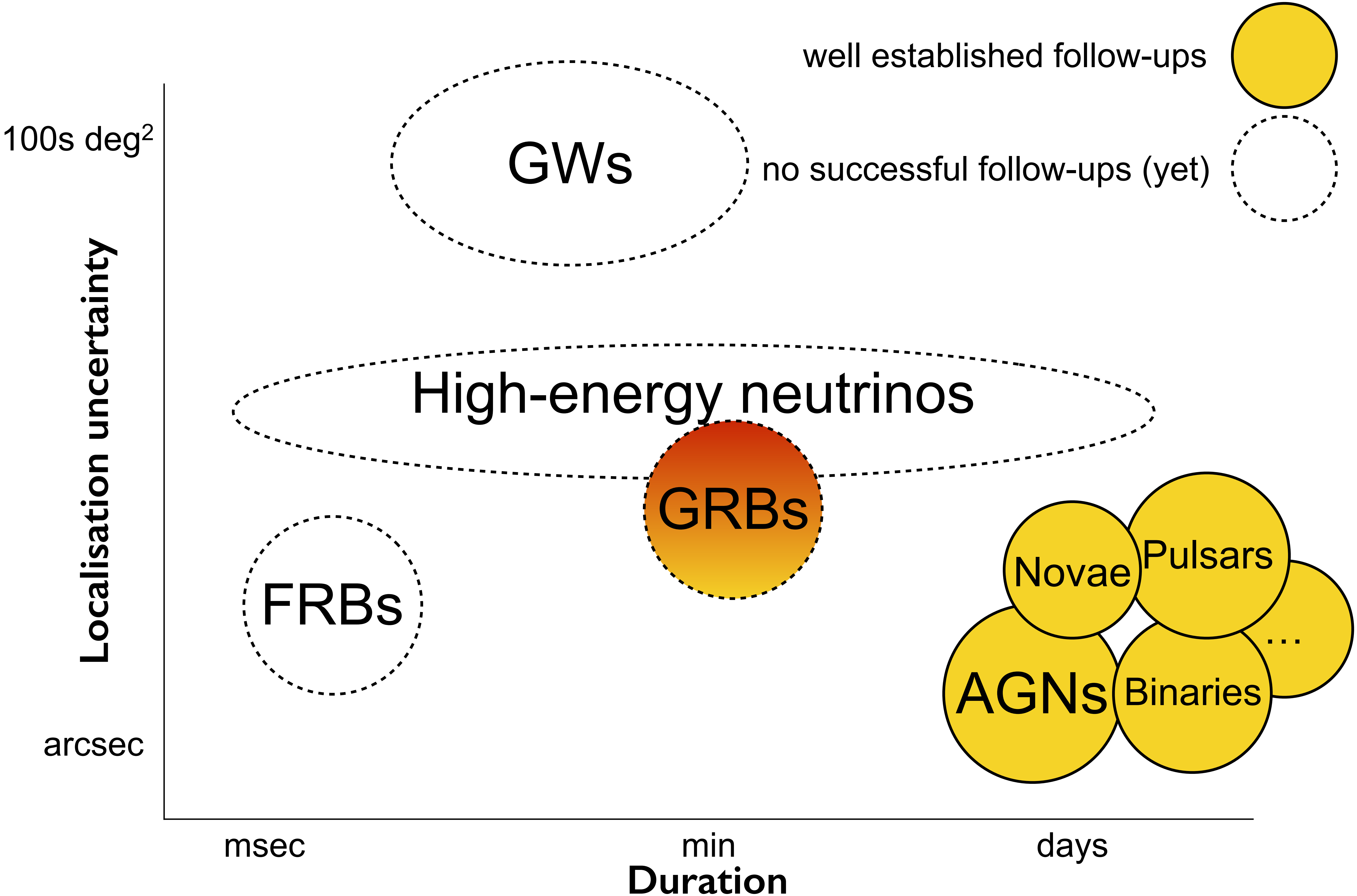
Fabian Schüssler (Irfu/CEA-Saclay)

Radio-Gamma workshop, Amsterdam, 09/2017

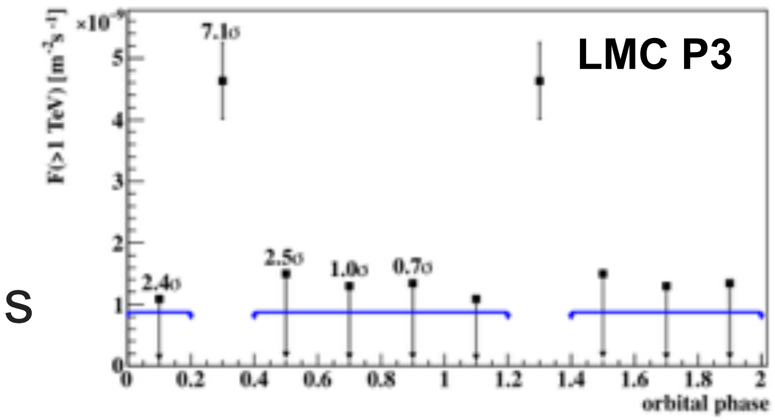
The H.E.S.S. transient and multi-messenger program

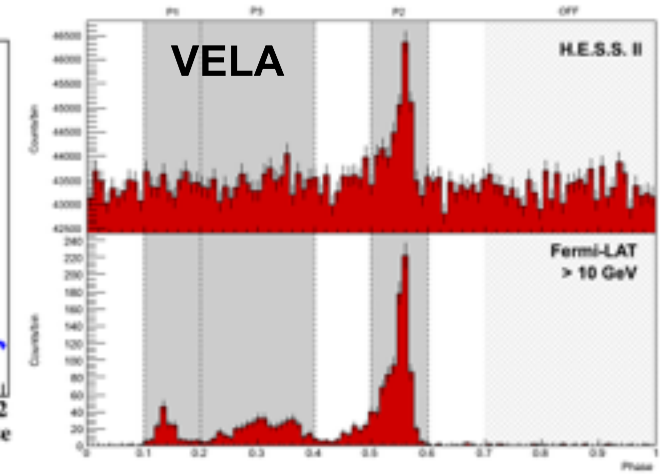
- AGN flares, binaries, novae, etc.
  - broad MWL input; typical timescales: hours-days
  - typically manual scheduling of follow-ups
- Gamma-ray bursts
  - driving science case for the rapid transient program (rapidity, low energy threshold, etc.)
- Gravitational waves
  - follow-up difficult due to large localization uncertainties
    - important input from additional EM detection, galaxy catalogs, etc.
    - benefit from large FoV
- Neutrinos
  - high-energy events (e.g. HESE)
  - neutrino ”flares”
- Fast Radio Bursts
  - manual -> automatic (?)



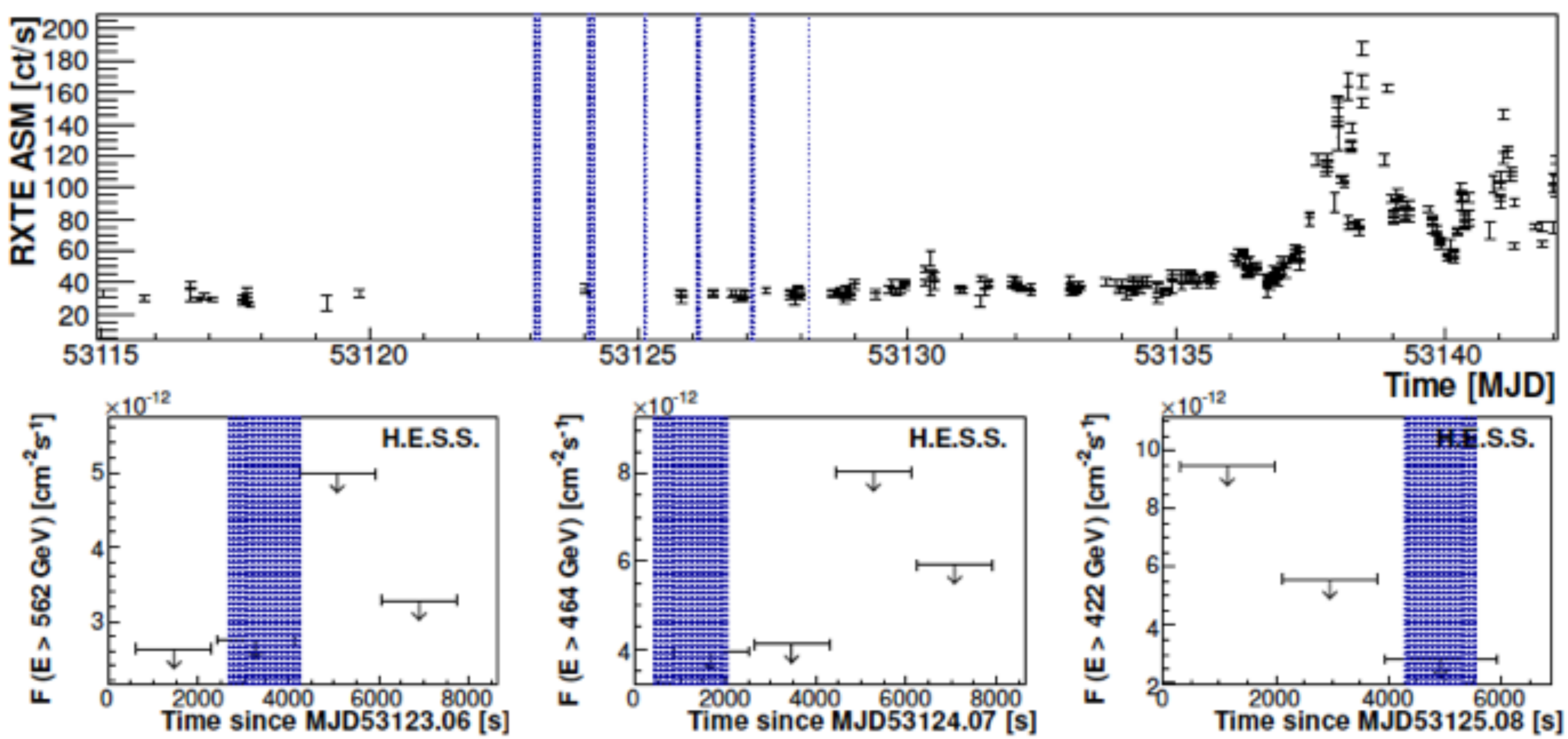

well established follow-ups
no successful follow-ups (yet)
100s deg^2
arcsec
Localisation uncertainty
GWs
High-energy neutrinos
GRBs
FRBs
Novae
Pulsars
...
AGNs
Binaries
msec
min
days
Duration

Galactic transients





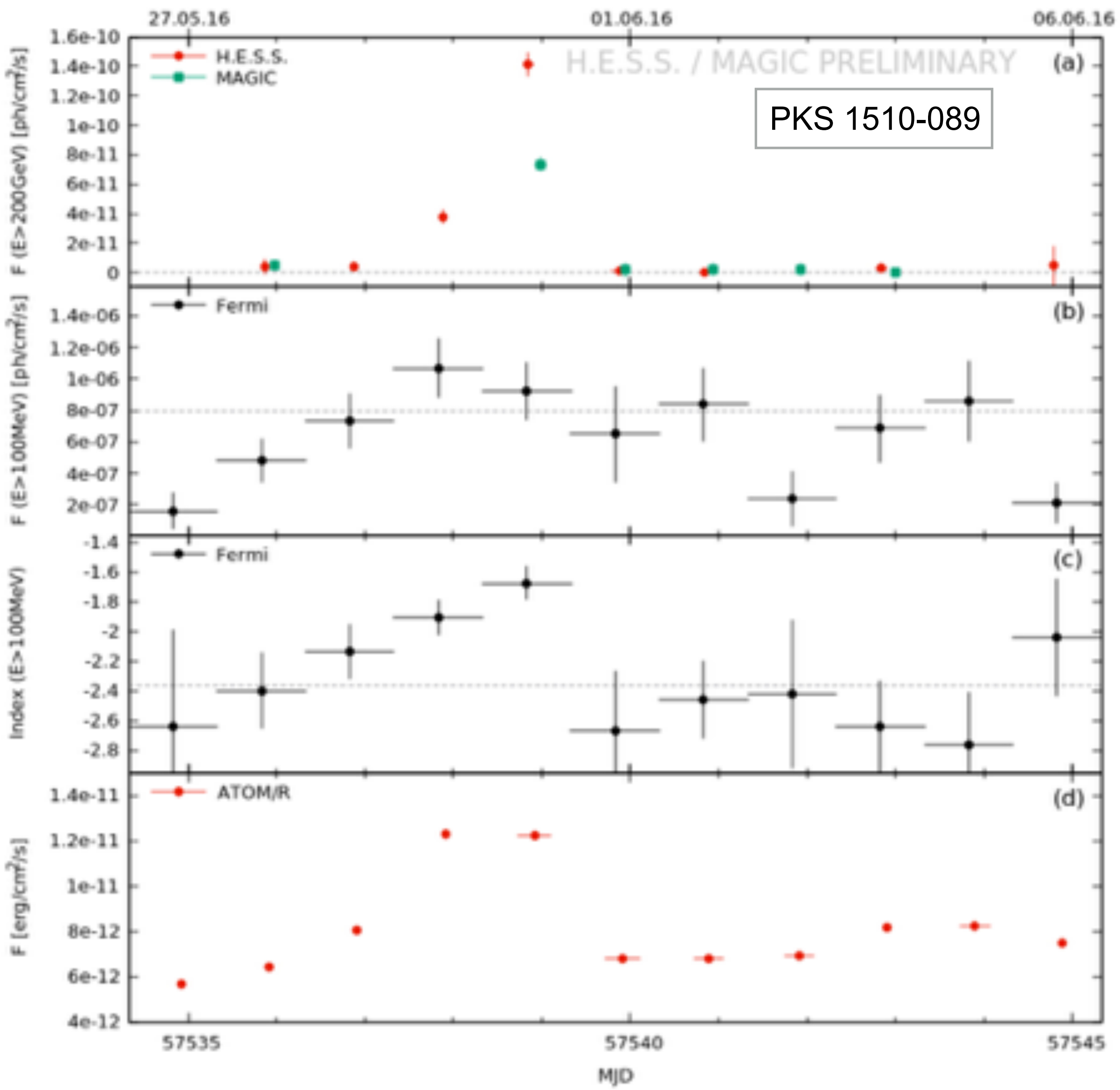
- Pulsars, Binaries, etc.
  - known periods, scheduled observations
- Microquasars
  - state transitions in X-rays (e.g. low-hard to high-soft: jet disruption, plasma ejections, etc.)
  - e.g.: GRS 1915+105, Circinus X-1, and V4641 Sgr
    - no detection (observation times not very promising)

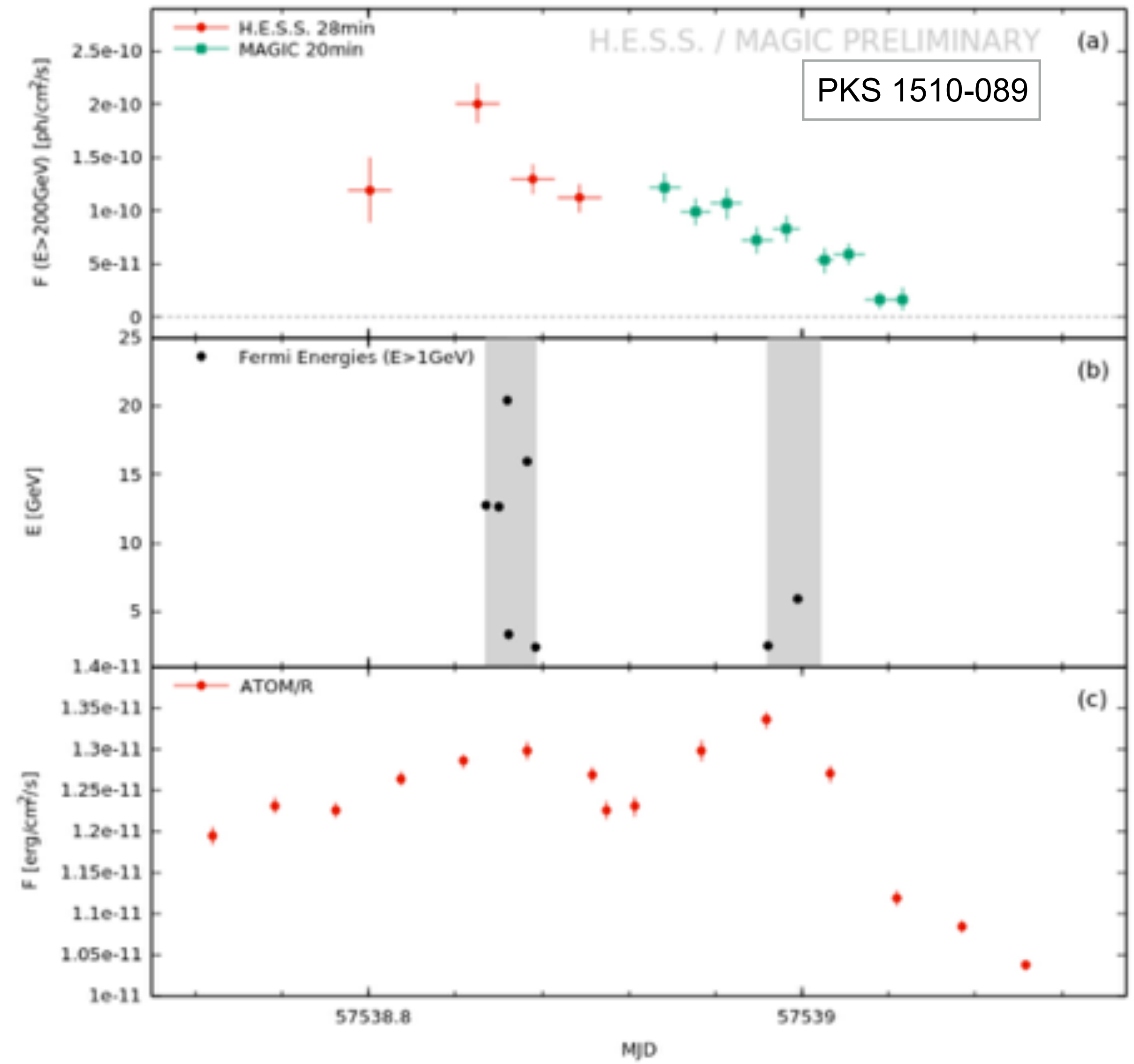


H. Abdalla et al. (H.E.S.S.), A&A 2016, arXiv: 1607.04613

Flares from Active Galactic Nuclei

- high flux enables/facilitates source detections + detailed analyses
- H.E.S.S. monitoring program
  - e.g. PKS 1510-089 => flare in May 2016

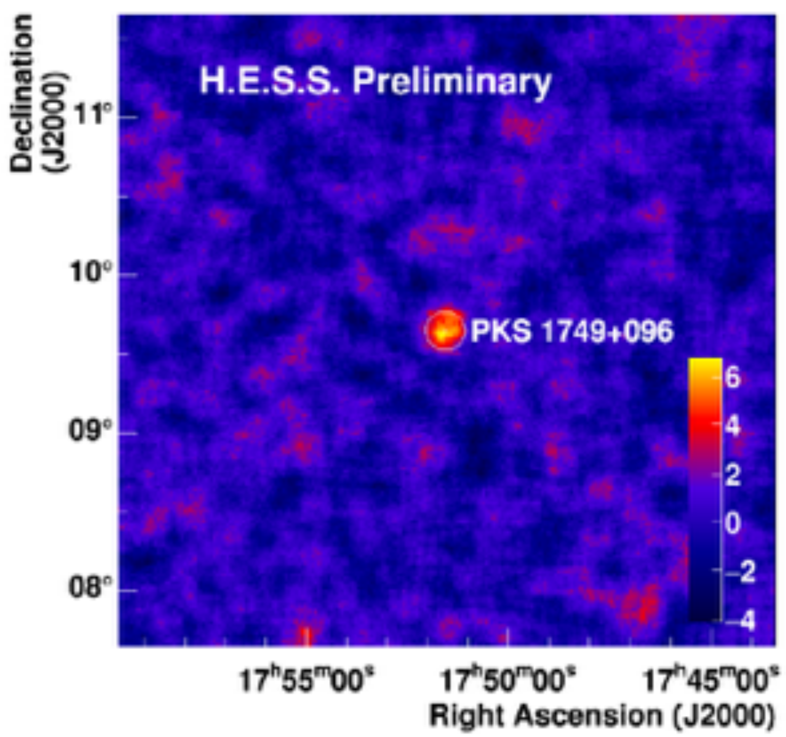


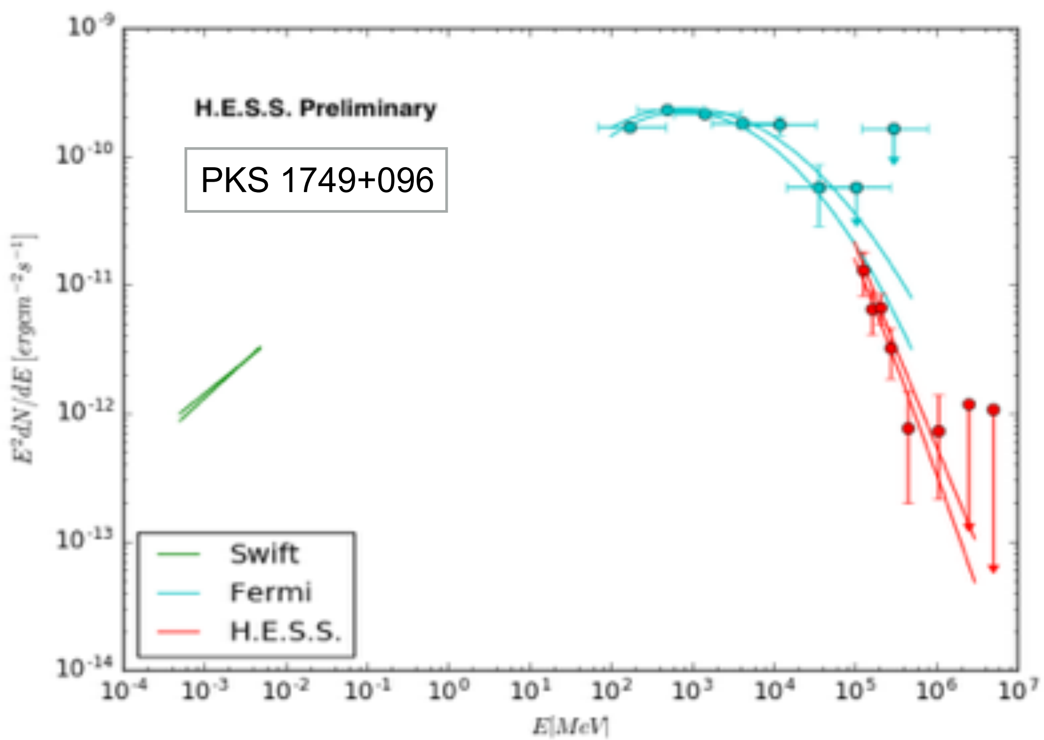


M. Zacharia et al., PoS(ICRC2017)654+655

Flares from Active Galactic Nuclei

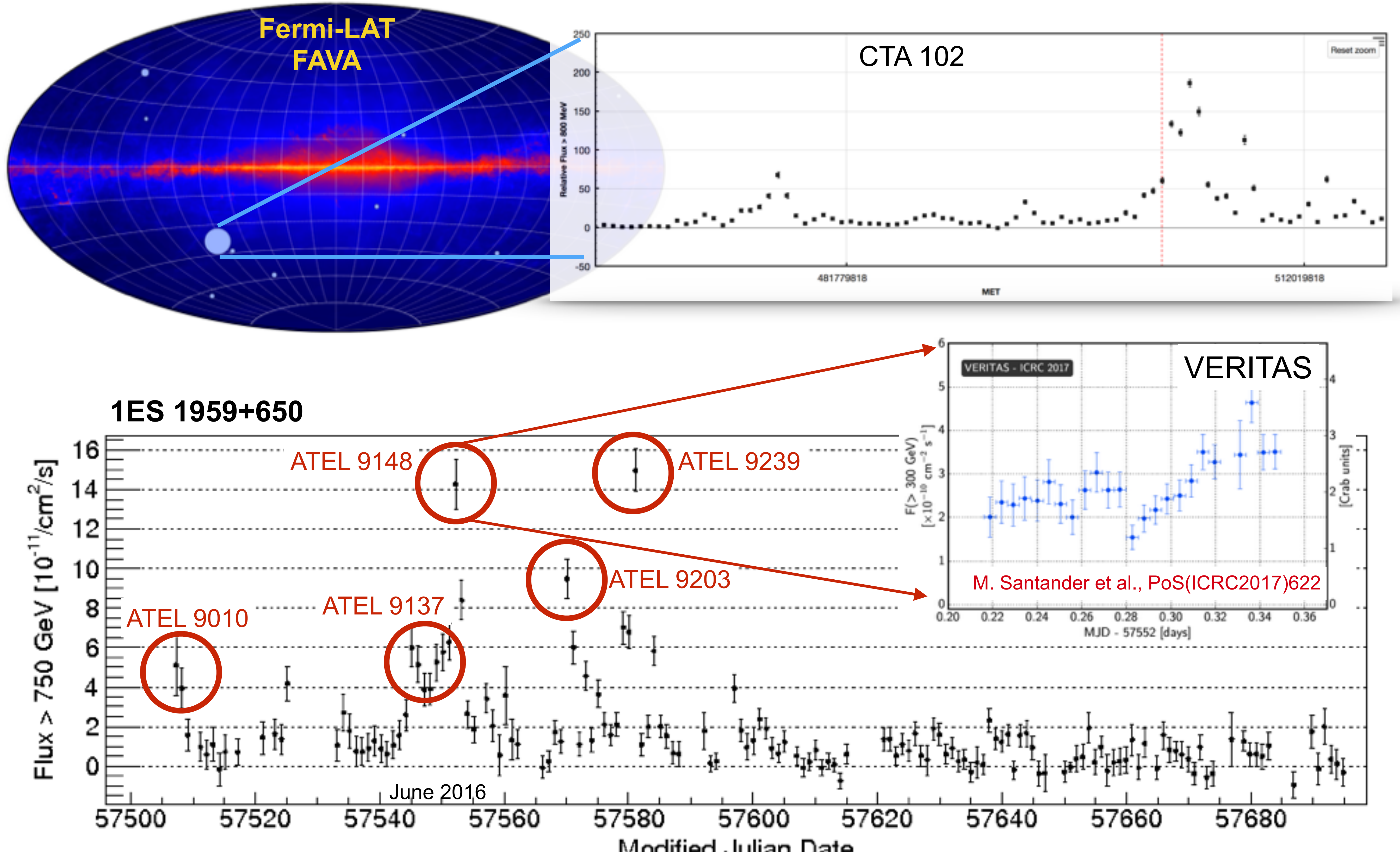
- high flux enables/facilitates source detections + detailed analyses
- H.E.S.S. monitoring program
  - e.g. PKS 1510-089 => flare in May 2016
- input from other observatories
  - automatic Fermi-LAT analyses (e.g. FlaapLUC)
  - dedicated monitoring shifts
  - triggering of MWL follow-up (e.g. ATOM, Swift, etc.)
- recent TeV discovery: PKS 1749+096 (together with MAGIC)





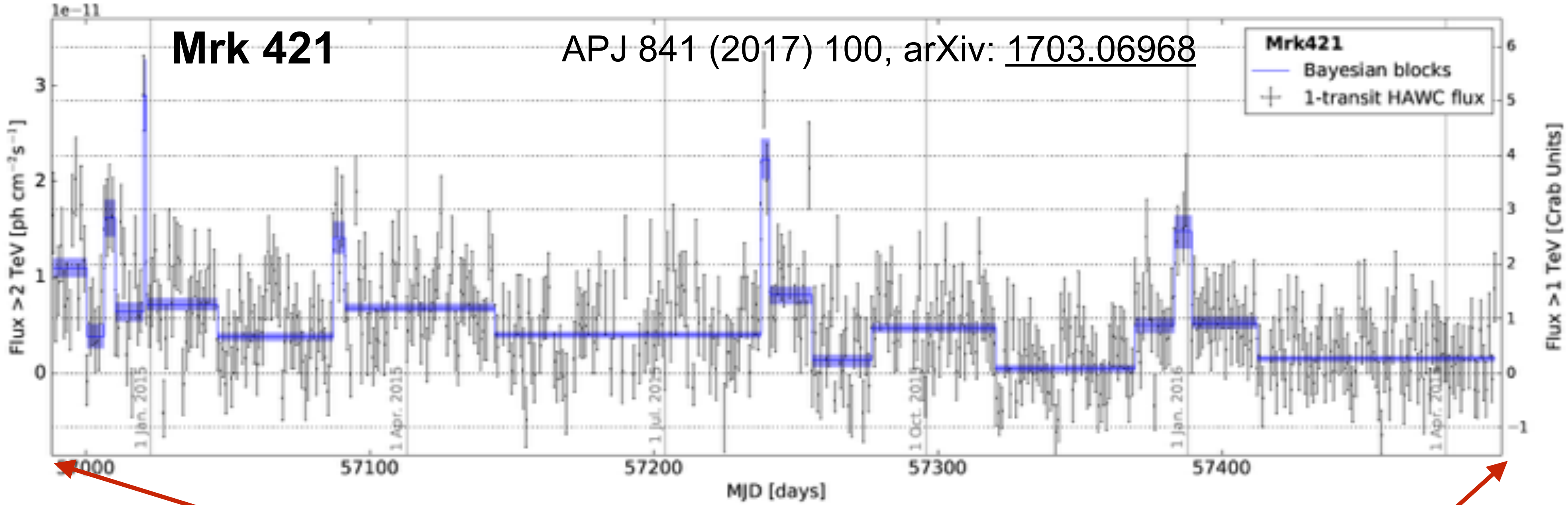
M. Seglar-Arroyo et al., PoS(ICRC2017)652

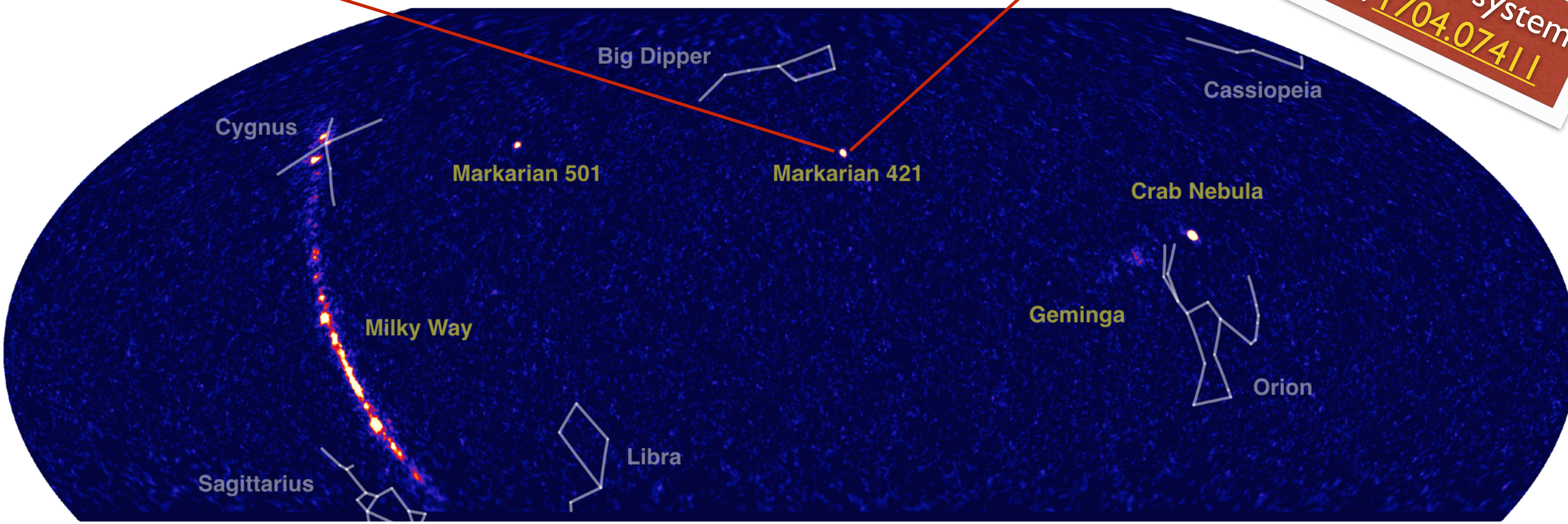
Dedicated, long-term monitoring



D. Dorner et al., PoS(ICRC2017)608

HAWC: full-sky monitoring

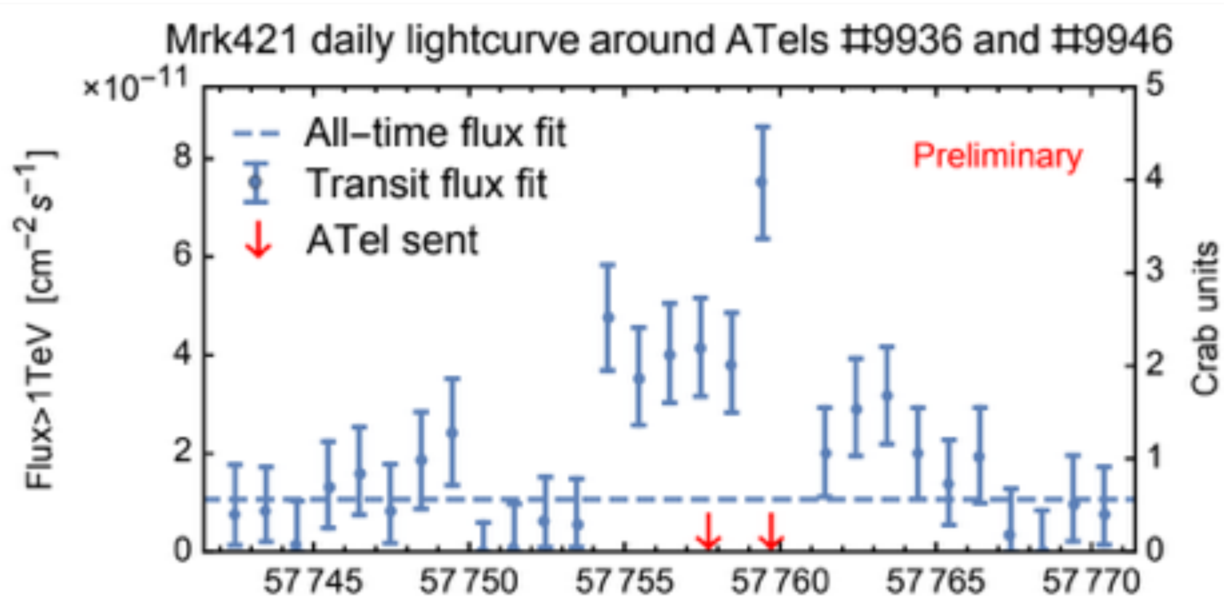




Online alert system
arXiv: 1704.07411

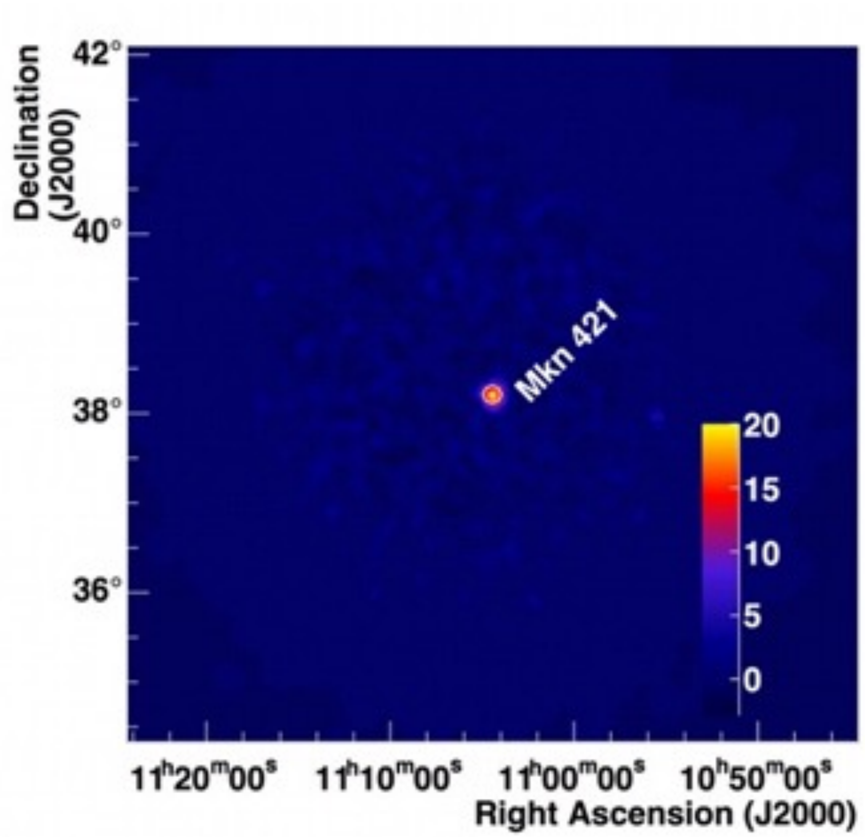
H.E.S.S.

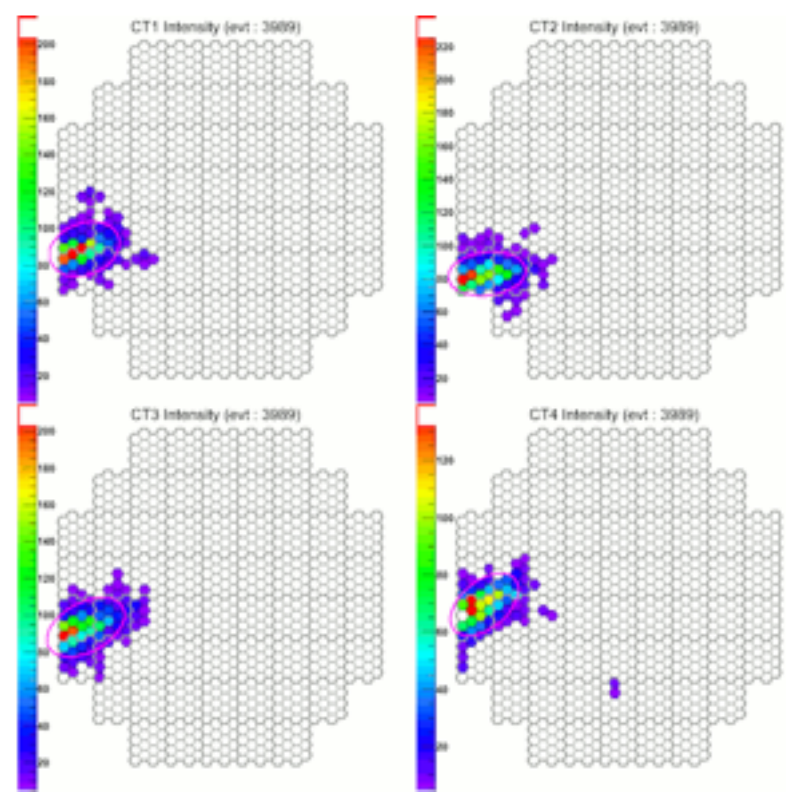
HAWC: Mrk421 flare in January 2017



I. Martinez-Castellanos et al.(ICRC2017)

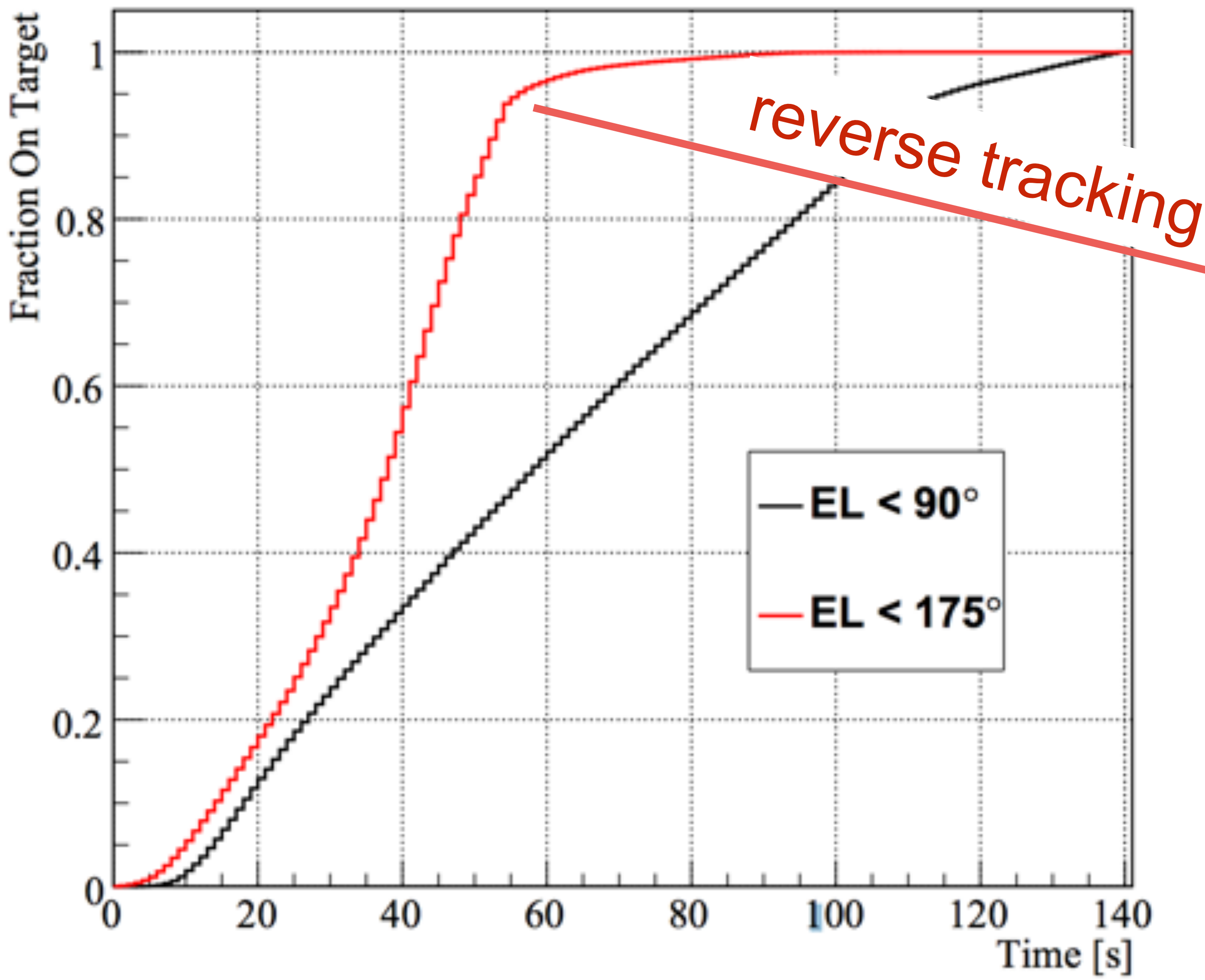
H.E.S.S. upgrade
<u>Source of the Month</u>





H.E.S.S. II: ToO follow-up performance

- 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

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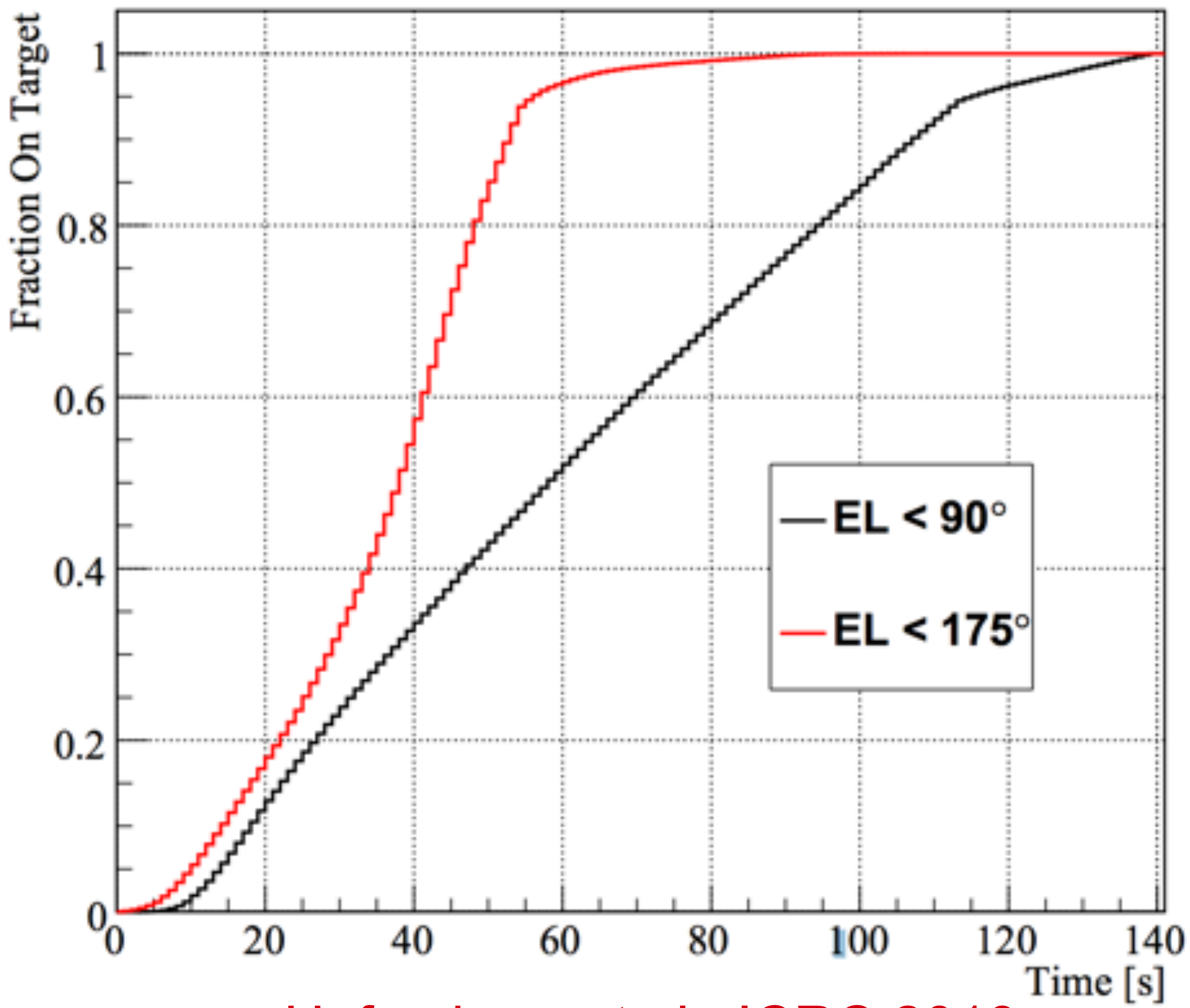


Hofverberg et al., ICRC 2013

- ToO+DAQ re-organization in 2014/2015
  - reaction time dominated by slewing: O(60s)

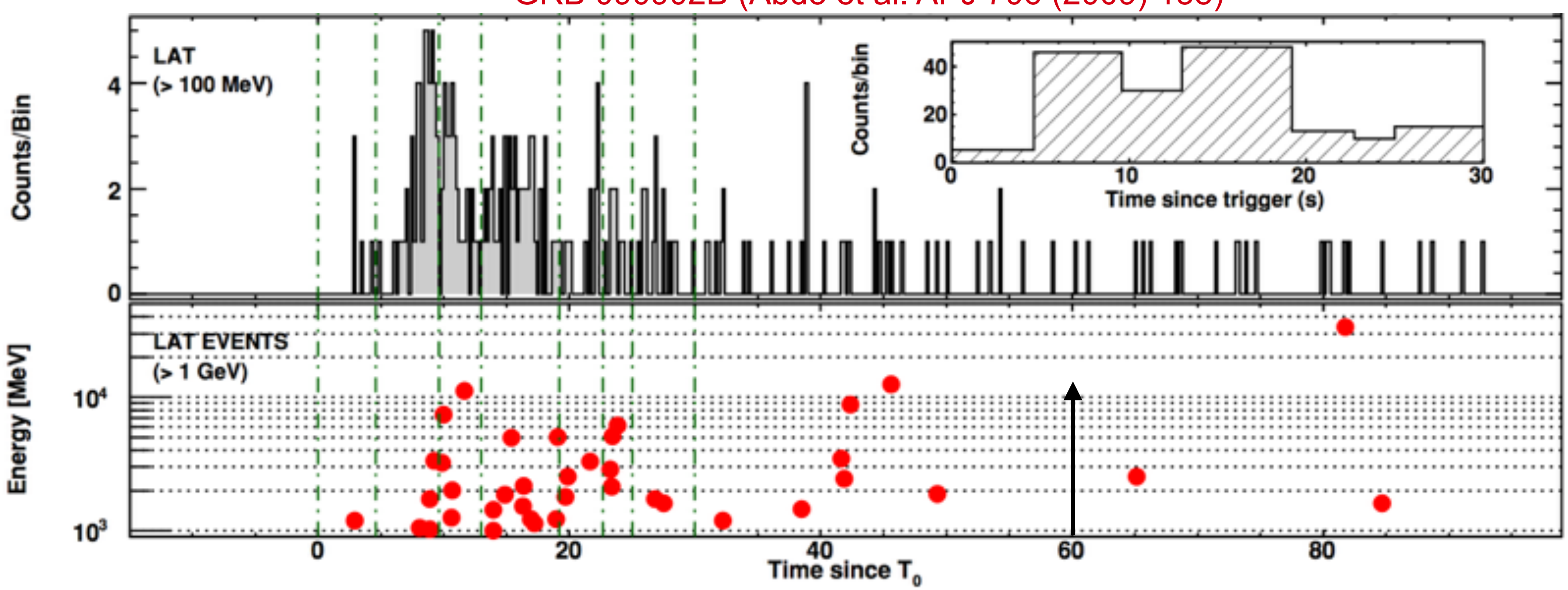
VoEvent alert system

- **Details in the talk by Stefan Ohm**

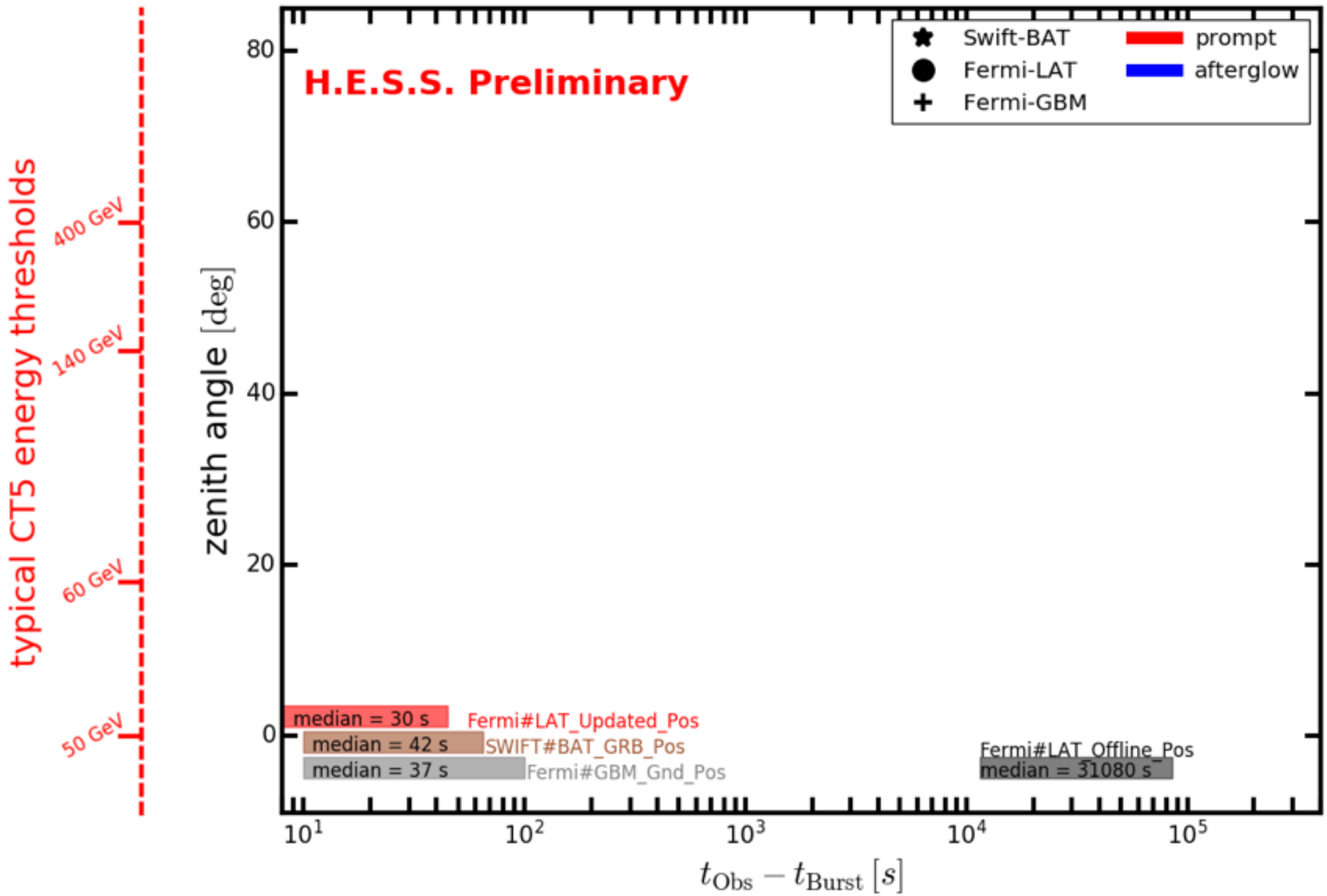
GRB follow-up with H.E.S.S.

- extensive follow-up program during H.E.S.S. phase I (e.g. A&A 495, 505-512 (2009))
- follow-up speed significantly increased with H.E.S.S. II
  - rapid slewing speed
  - fully automatic repositioning after the reception of a GCN alert
  - dedicated operation mode (e.g. data taking starts as soon as *source* enters the FoV)
  - GRBs have highest ToO priority (following all accessible alerts)

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



Gamma Ray Bursts with H.E.S.S.



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

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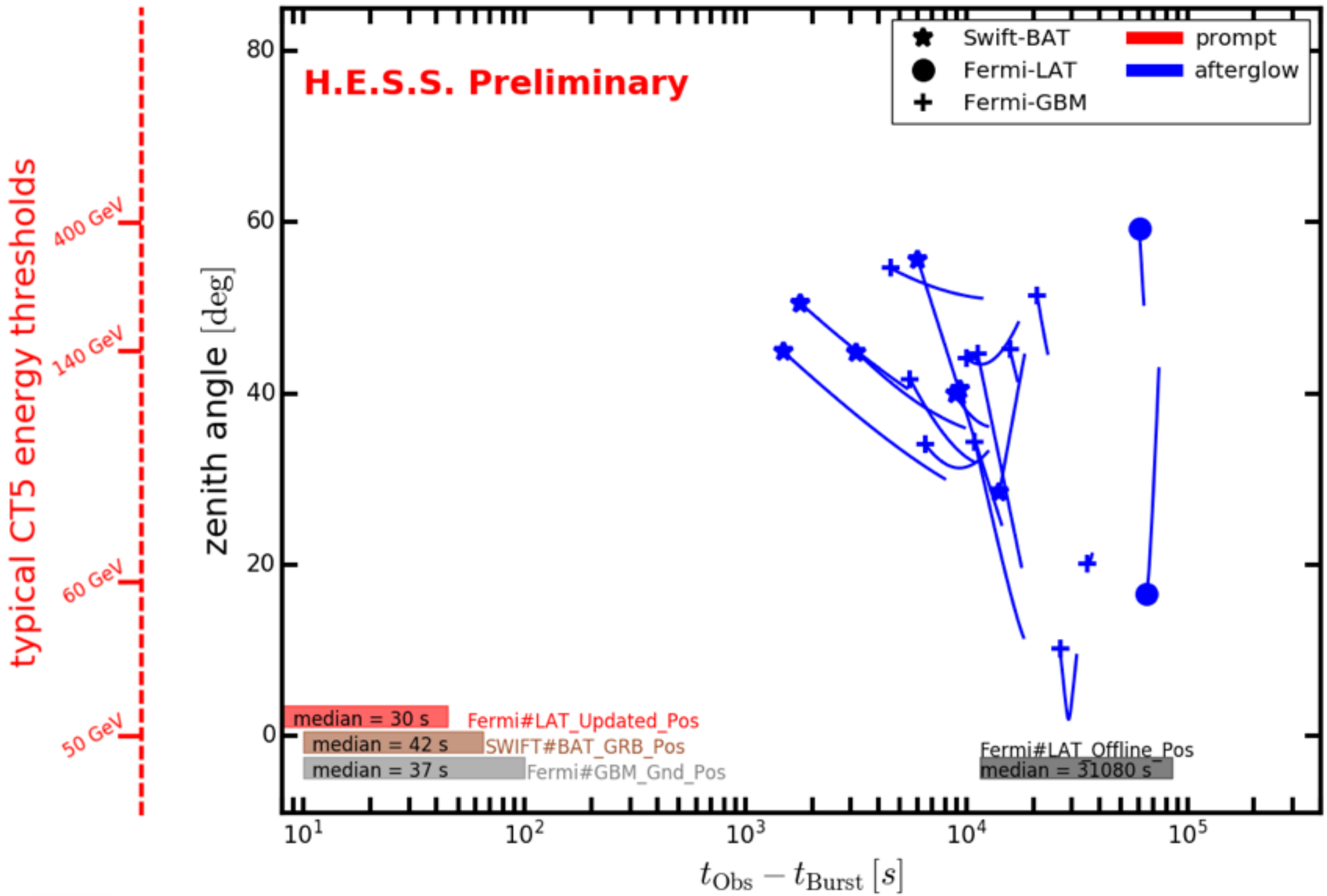

C. Hoischen et al., PoS(ICRC2017)636

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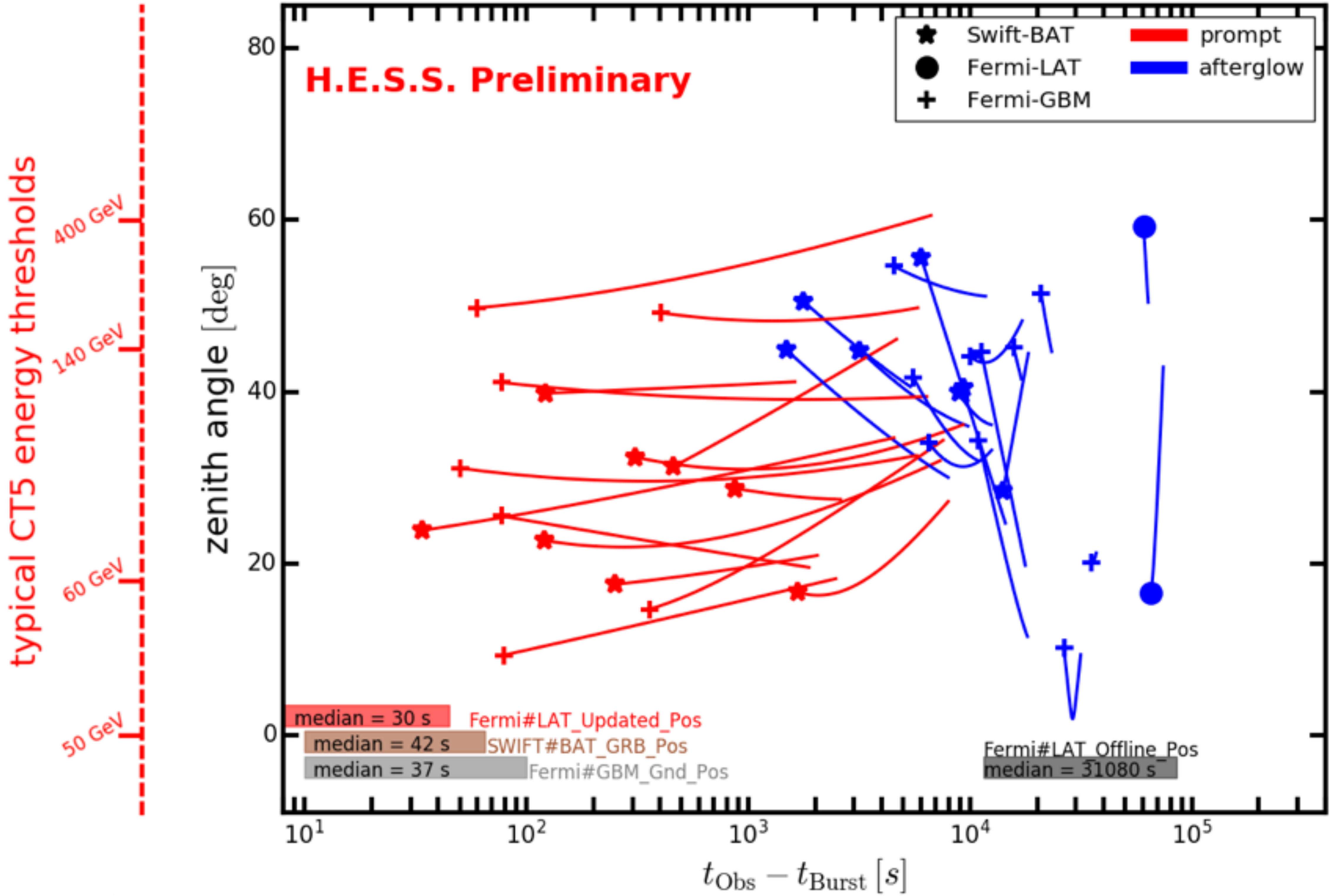

C. Hoischen et al., PoS(ICRC2017)636

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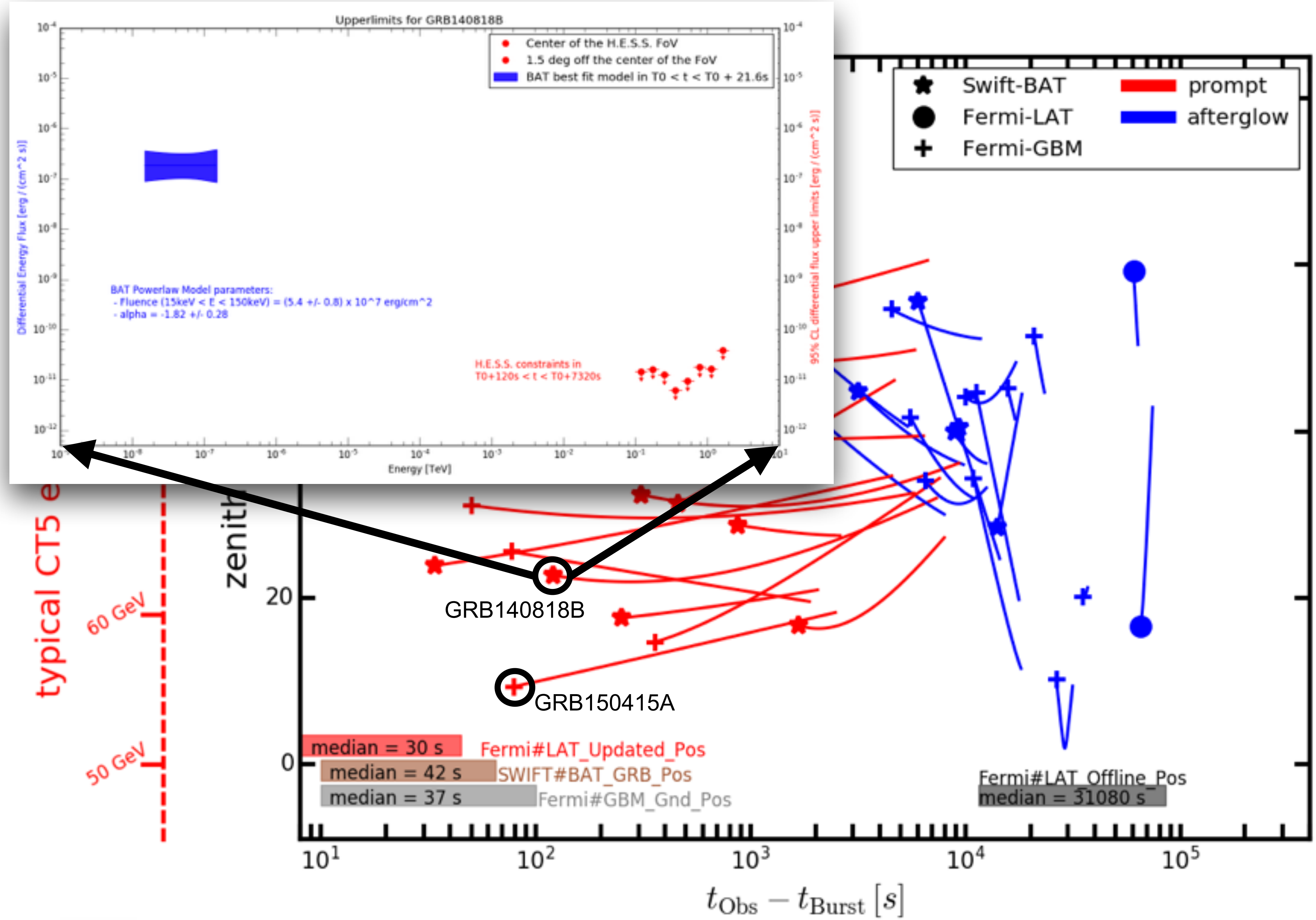
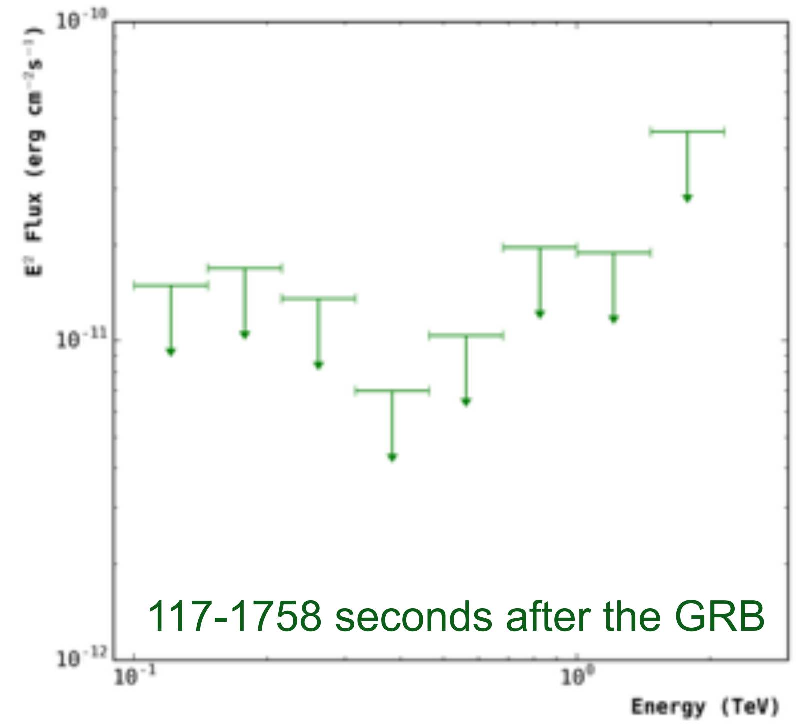
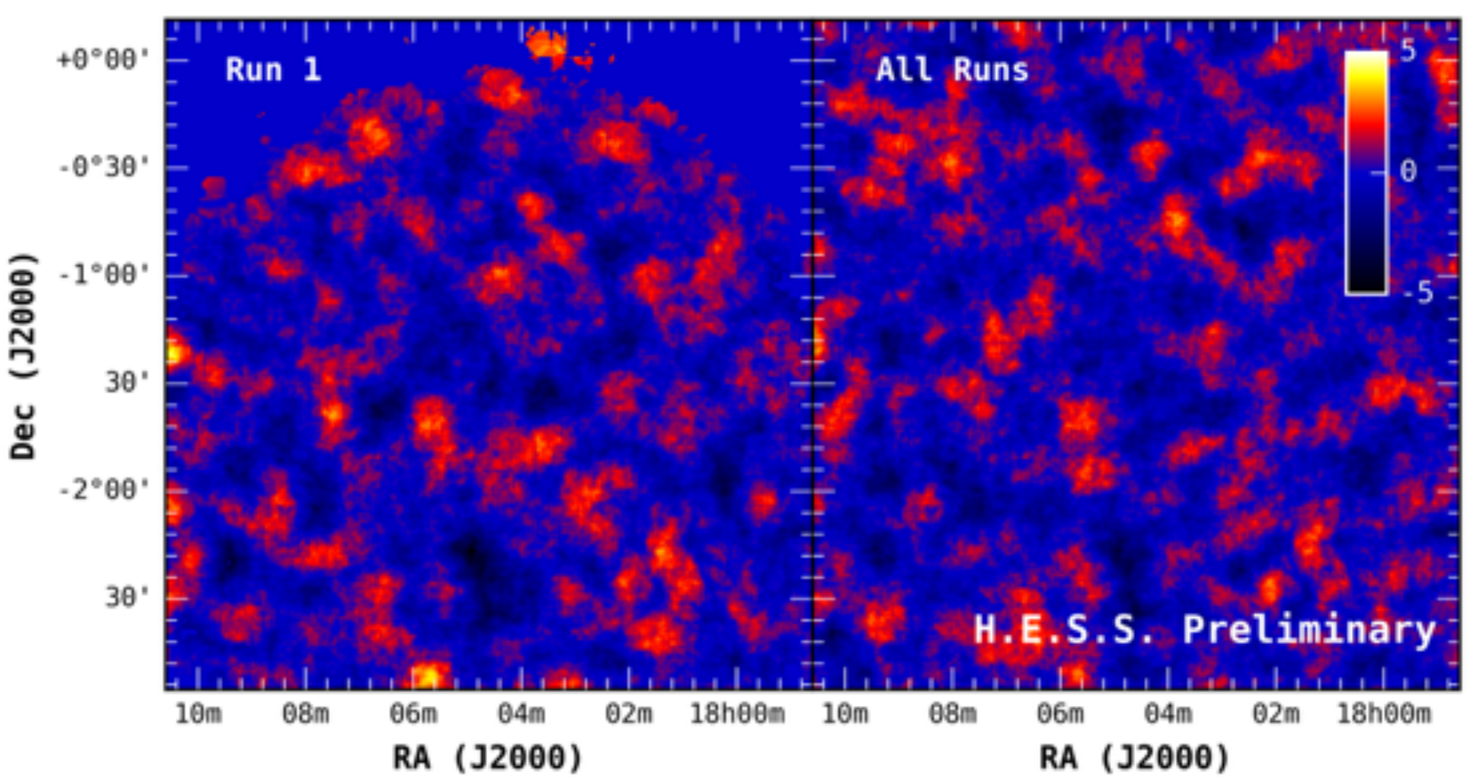


C. Hoischen et al., PoS(ICRC2017)636

GRB follow-up: first results

- strict data blinding procedure fixing reconstruction, cuts, analysis strategy, etc.
- GRB140818B
  - RA= +18h 04m 35s ; Dec=-01d 21' 40" (J2000)
  - T0: 18:44:16 UTC
- H.E.S.S. observations
  - starting 18:45:42 UT (<2min after the GRB)
  - *mono* analysis optimized for low energies



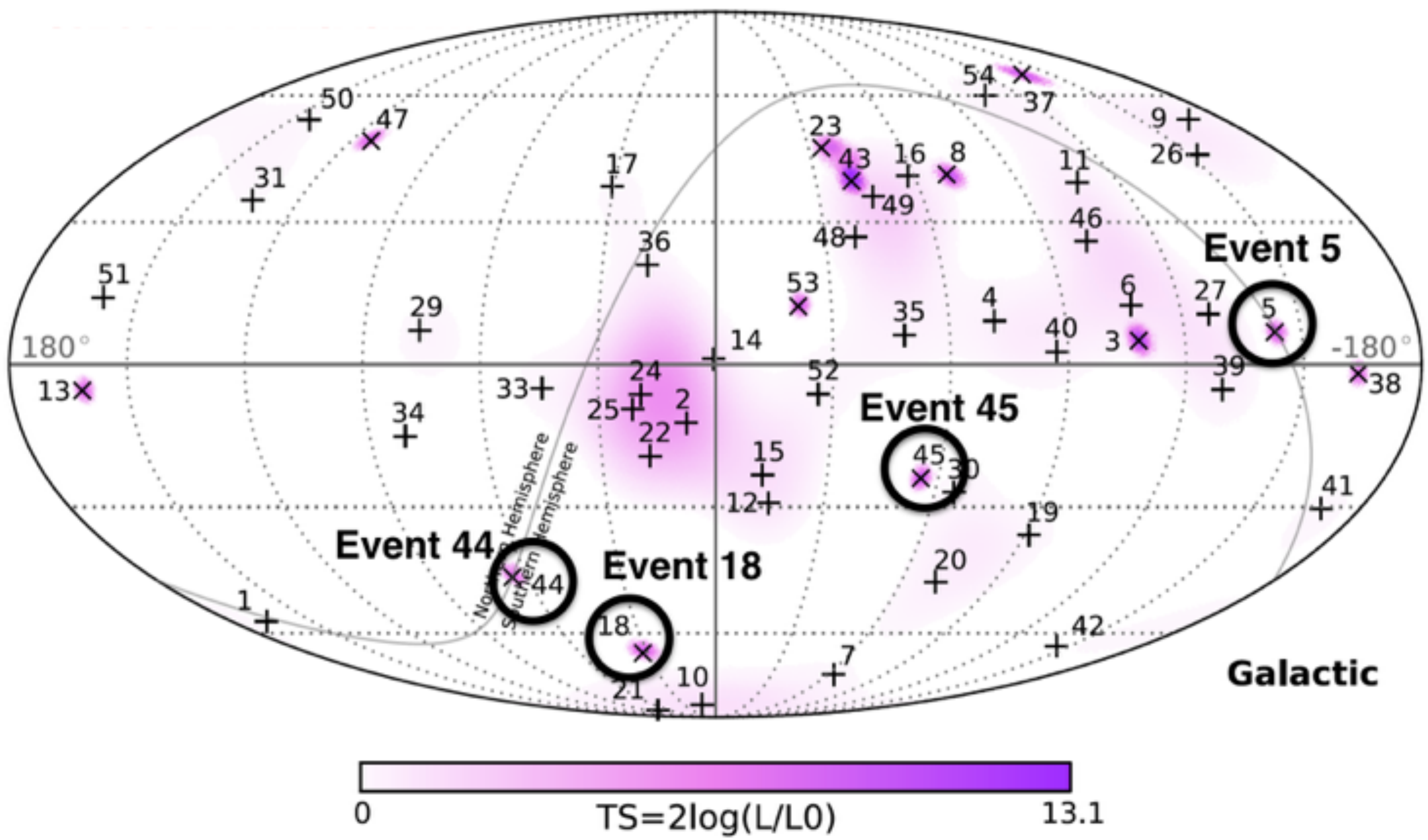


Run	Time since T0 [min]	Integral Flux (E>100GeV) [$m^{-2}\ s^{-1}$]
1	2-30	3.9e-11
2	31-59	2.6e-11
3	60-88	5.1e-11
4	89-117	1.8e-11

Multi-messenger program: IceCube HESE tracks

- H.E.S.S. observations of IceCube High Energy Starting Events
  - track like events (angular uncertainty < FoV)
  - H.E.S.S. visibility + constrains by other observations
  - high energy, etc.

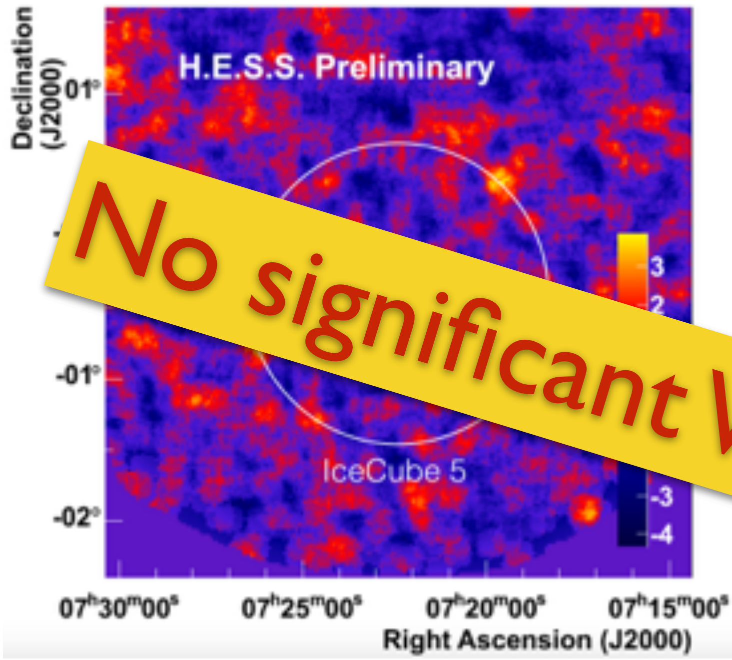
C. Kopper, ICRC 2013



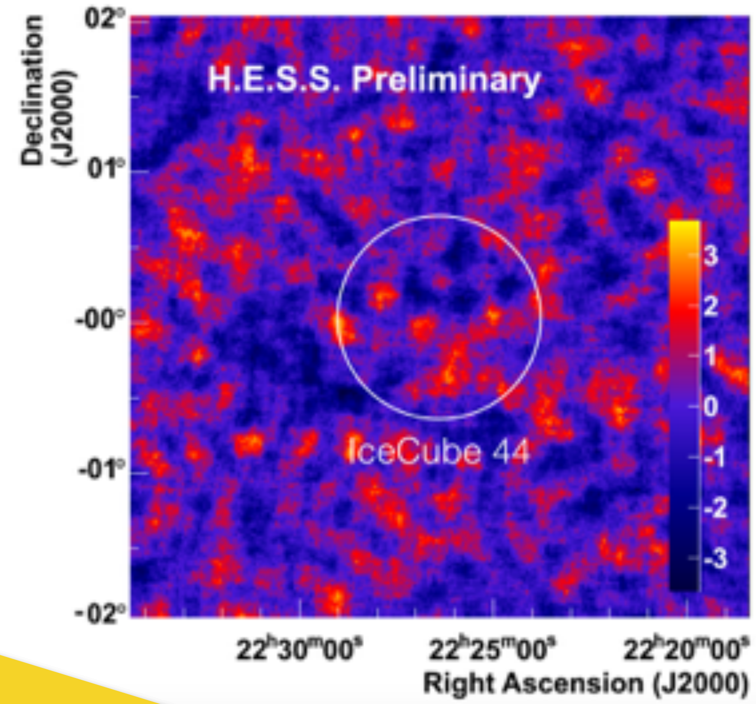
IceCube HESE tracks: H.E.S.S.

FS et al., ICRC 2015, arXiv:1509.03035
FS et al., Gamma 2016

- IceCube 5

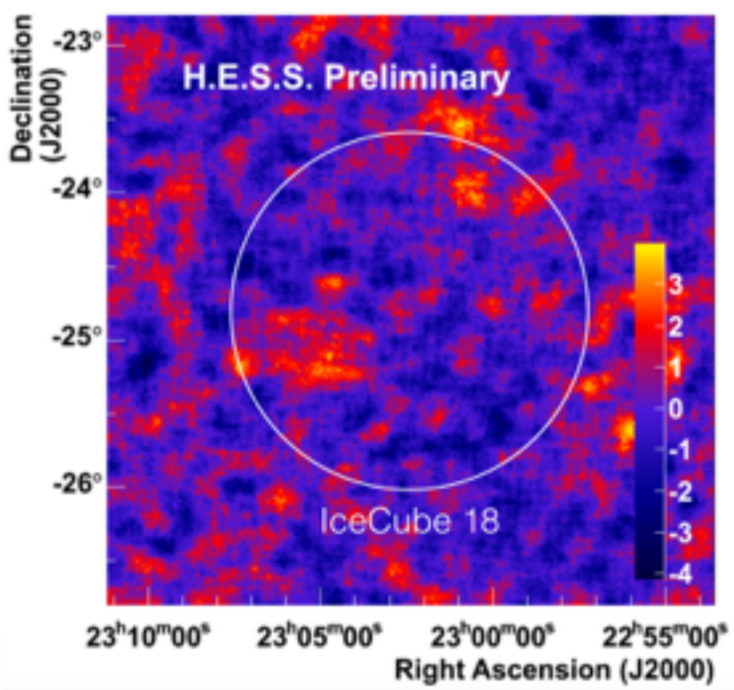


- IceCube 44

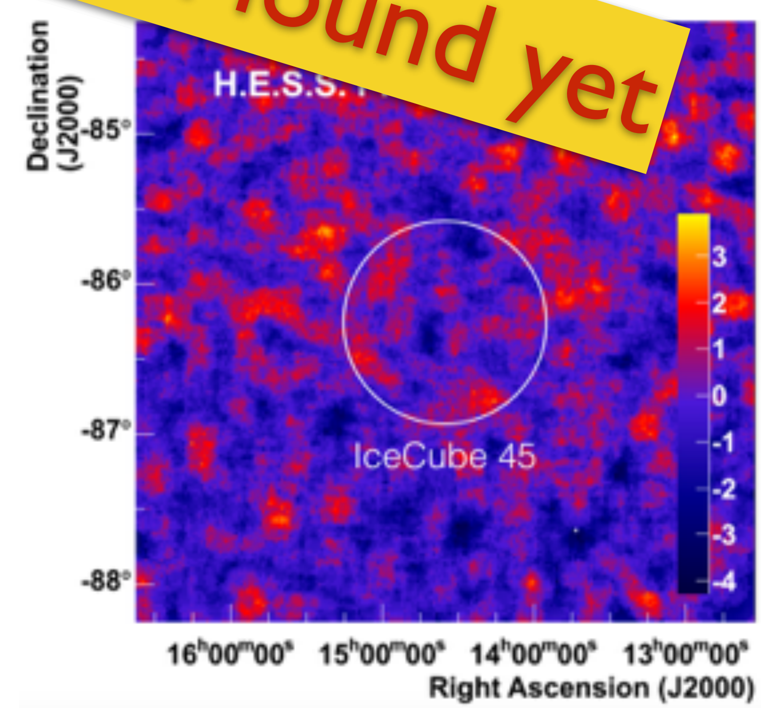


No significant VHE gamma-ray emission found yet

- IceCube 18

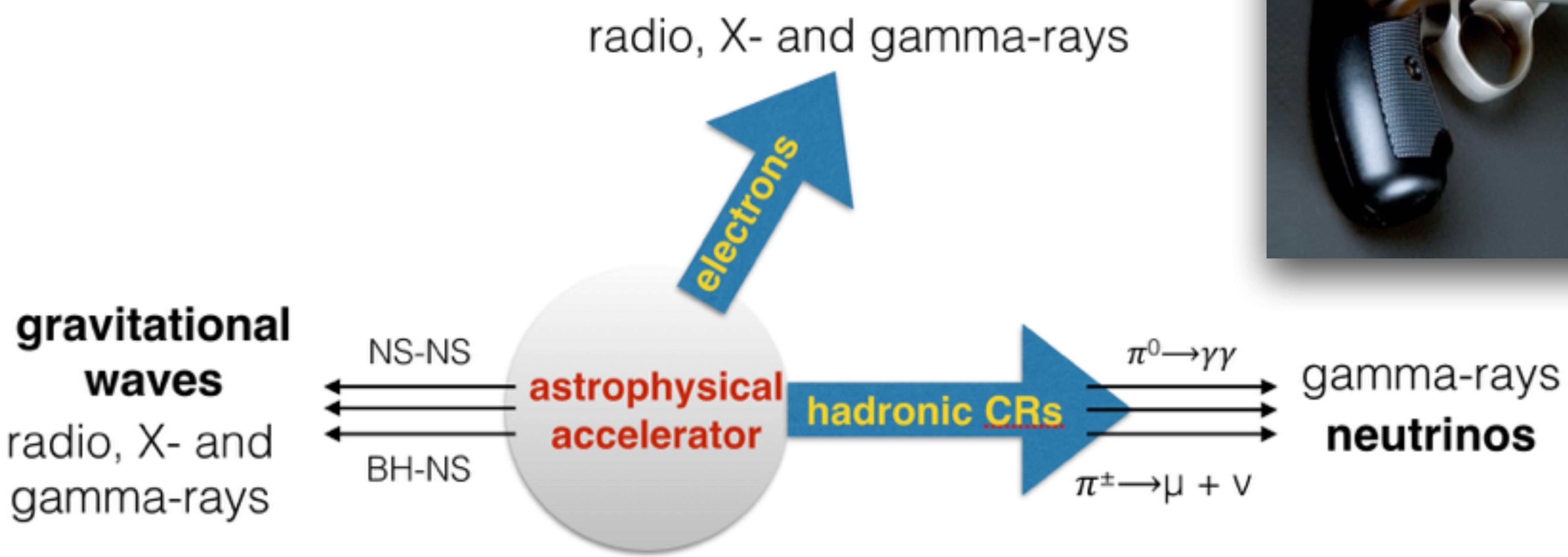


- IceCu



Future of the H.E.S.S. Multi-messenger program: alerts and ToOs

- Interpretation of potential gamma-ray source within the neutrino error box difficult (has to rely on basic energetics and follow-up observations)
- **Space and time correlations** would provide ”smoking gun” signal for joint emission processes => CR interaction/acceleration



H.E.S.S. reaction to Multi-messenger alerts and ToOs

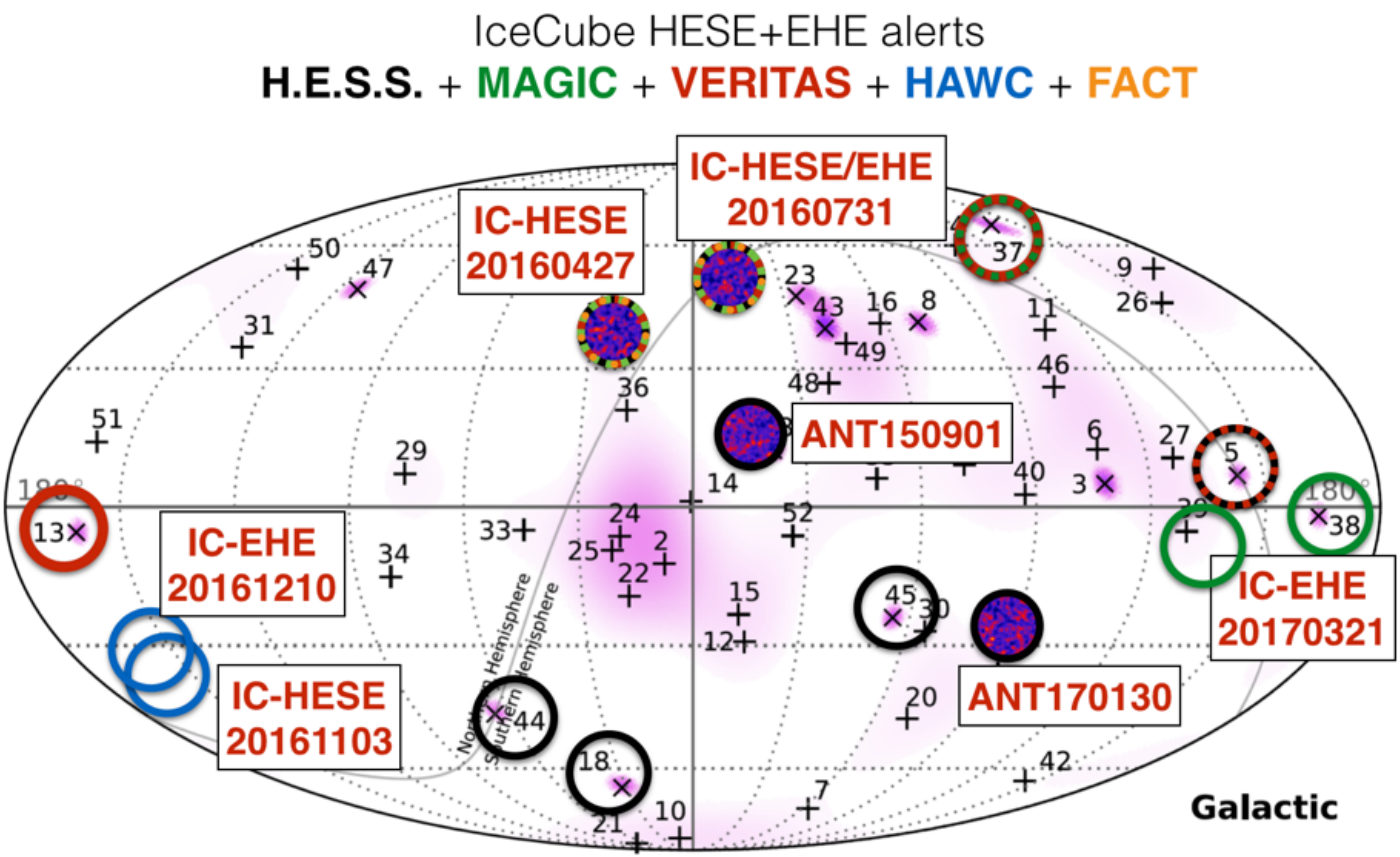
- IceCube
  - real-time alerts on HESE + EHE events
  - expected delays O(min)

Example: **IC-HESE-160427**

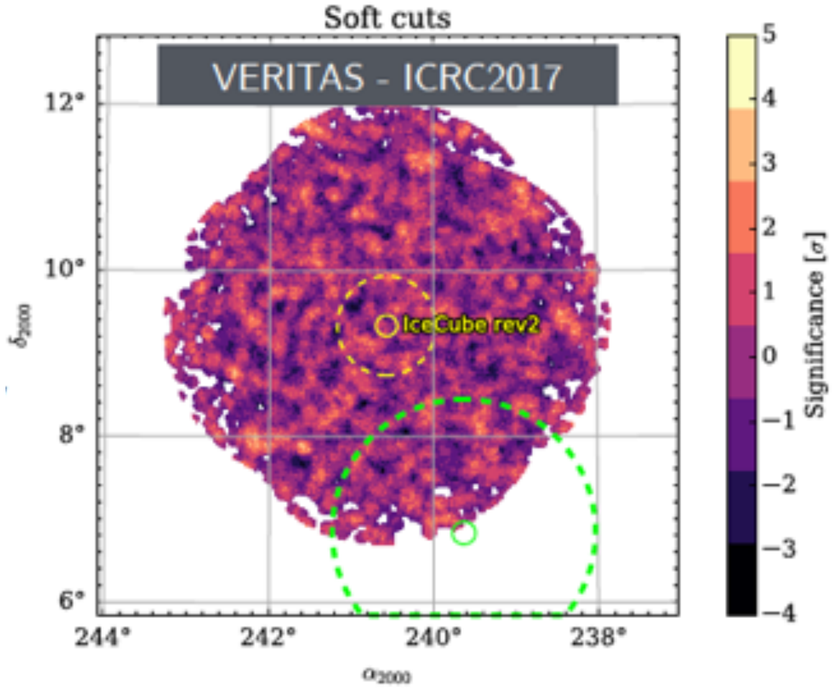
- ANTARES
  - online reconstruction and rapid alert emission: TAToO (Ageron et al., APP 35 (2012) 530)
  - delays O(10s)

Example: **ANT170130A**

Follow-up of alerts from high-energy neutrino telescopes



Example: IC-HESE-160427



VERITAS

- 3.2 hrs obs
- 120s delay

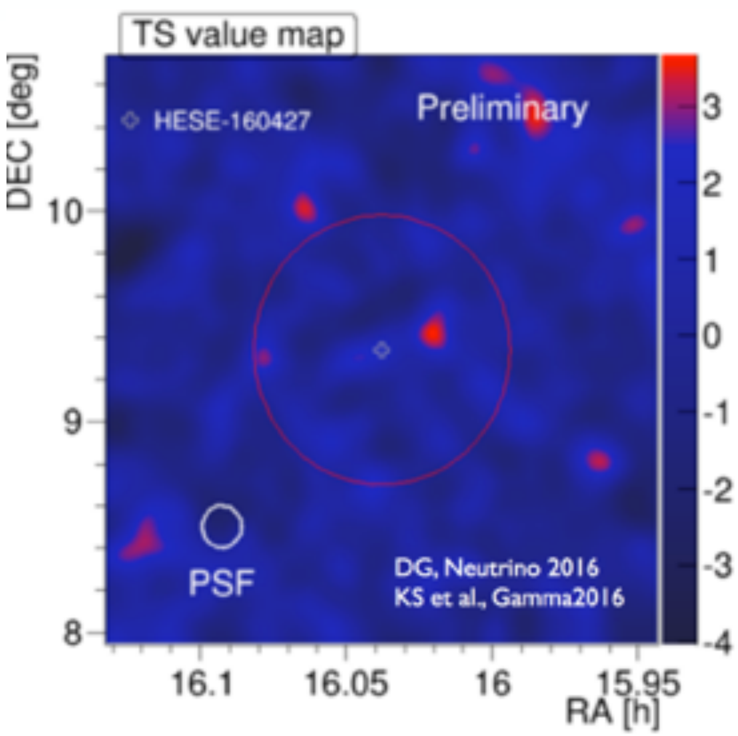
GCN Circular #19377

FACT

GCN Cicular #19427

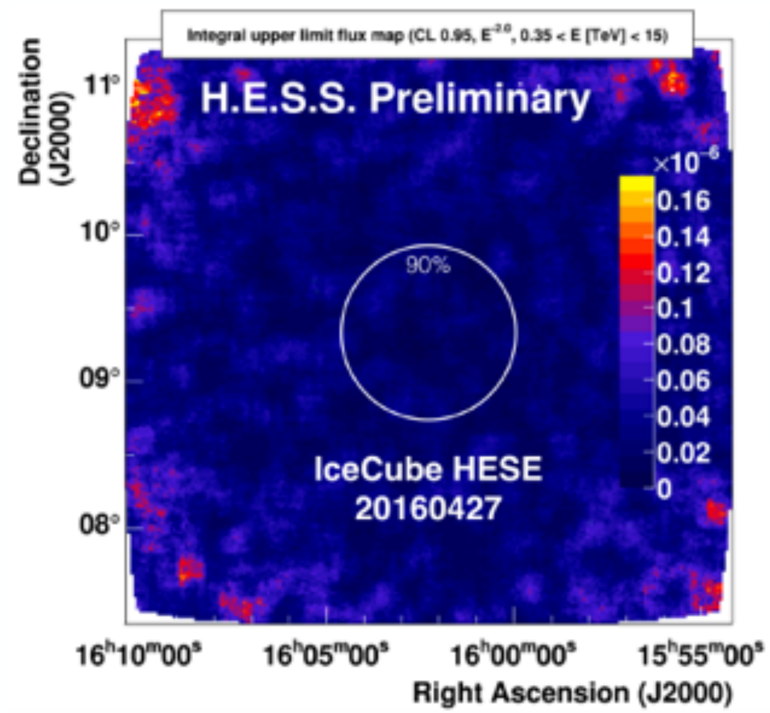
4.2 hr obs, ~20 hr delay

```
TITLE:   GCN CIRCULAR
NUMBER:  19427
SUBJECT: FACT follow-up of the IceCube event 160427A
DATE:    16/05/13 13:02:18 GMT
FROM:    Daniela Dorner at U of Wuerzburg  <dorner@astro.uni-wuerzburg.de>

A. Biland (ETH Zurich) and D. Dorner (University of Wuerzburg, FAU
Erlangen) report on behalf of the FACT collaboration:

On April 27th, 2016, the IceCube collaboration reported the detection
of a high-energy neutrino (GCN #19363) with the updated position of
RA=240.57d and DEC=+9.34d (J2000) and a position error of 0.6 degrees
radius provided at 23:24:24 UTC on April 27th.
```



MAGIC

- 2 hrs obs
- 42 hr delay
- E_{thres} ~ 120 GeV



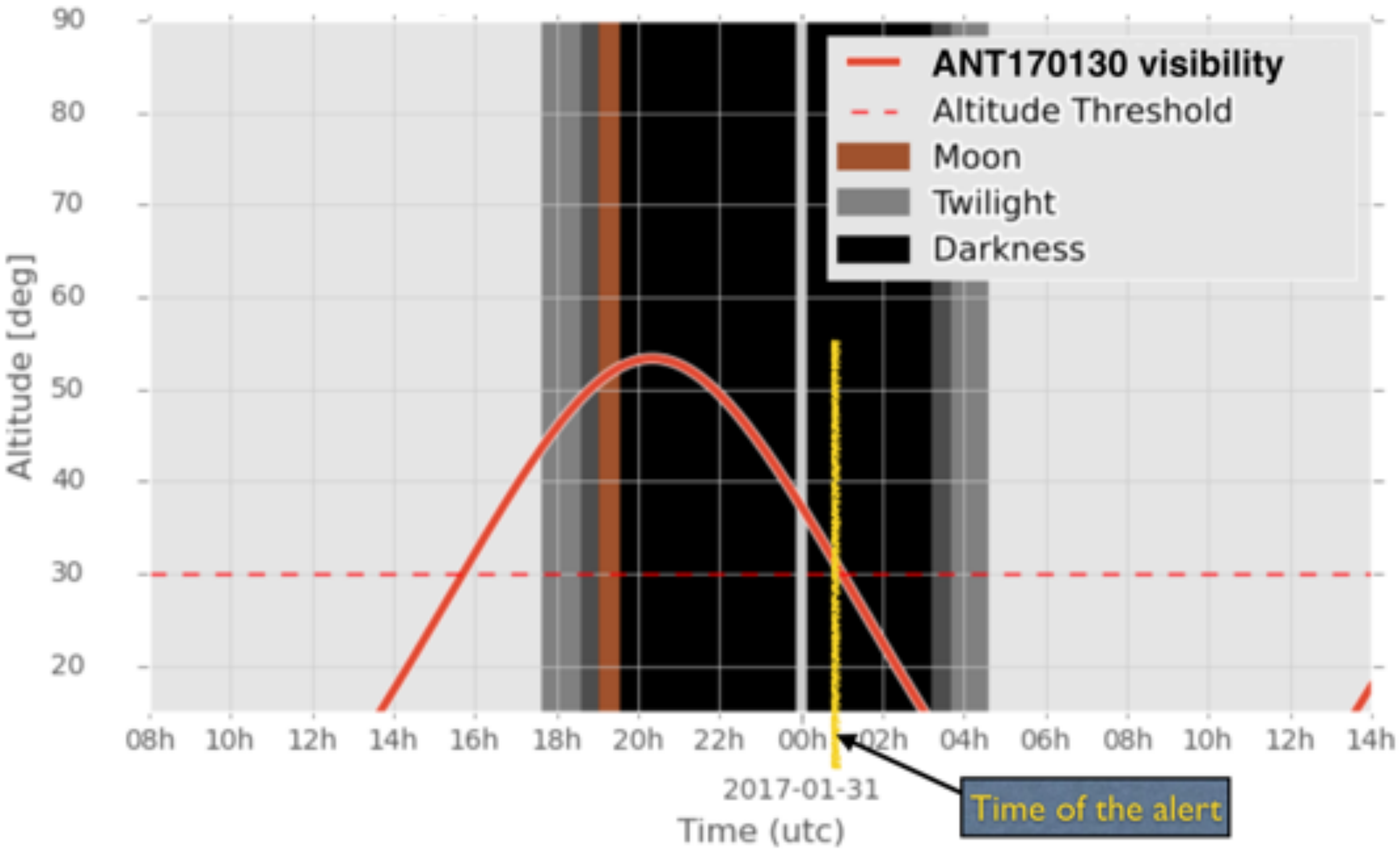
H.E.S.S.

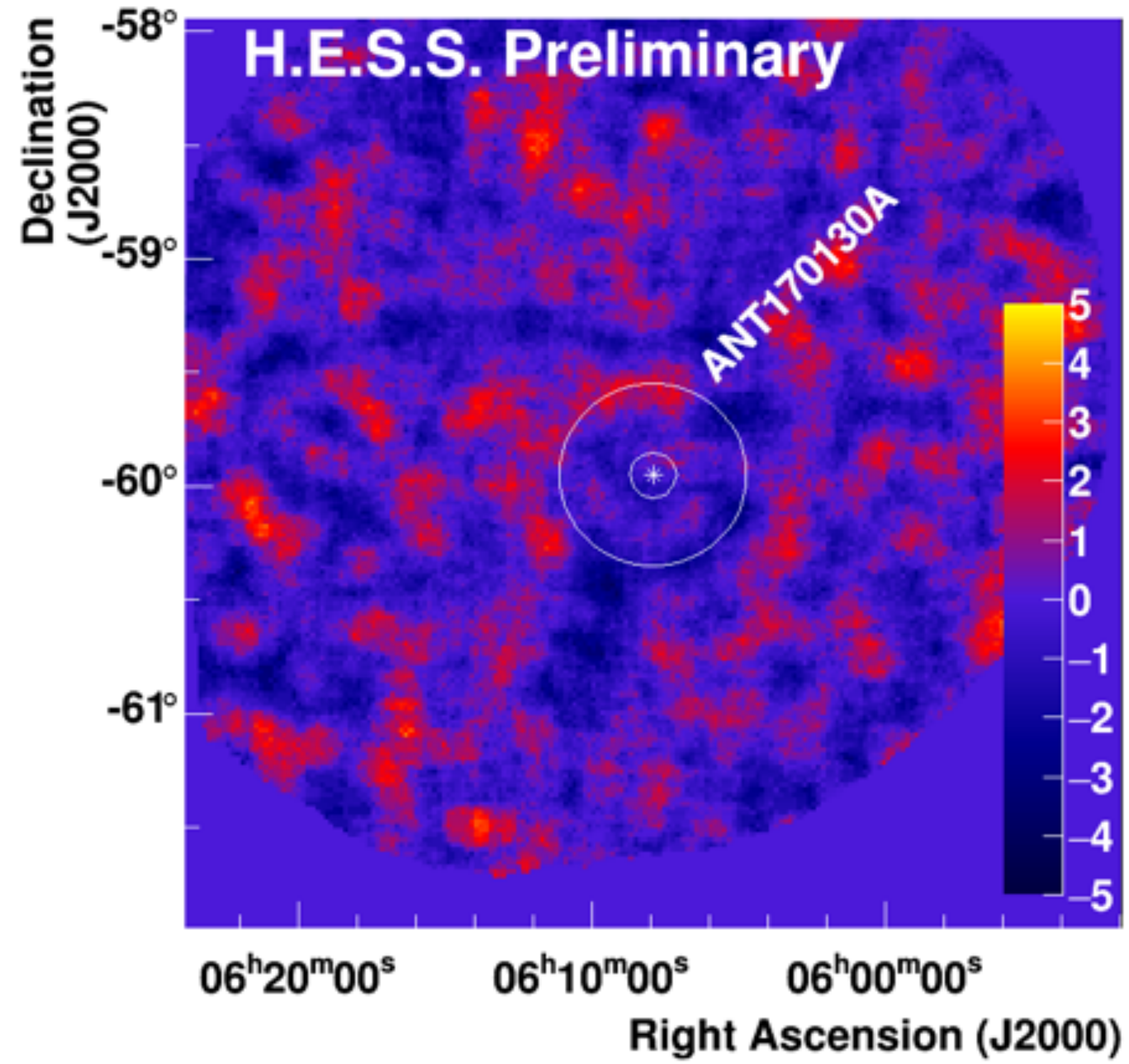
- 1.7 hrs obs
- ~ 63 hr delay
- E_{thres} ~ 350 GeV

M. Santander et al., PoS(ICRC2017)618
FS et al., PoS(ICRC2017)653

Antares: ANT160130A

- 2017-01-30: high-energy neutrino seen by Antares
- automatic reaction of H.E.S.S.: time delay between neutrino interaction and start of gamma-ray data taking: **32 seconds**

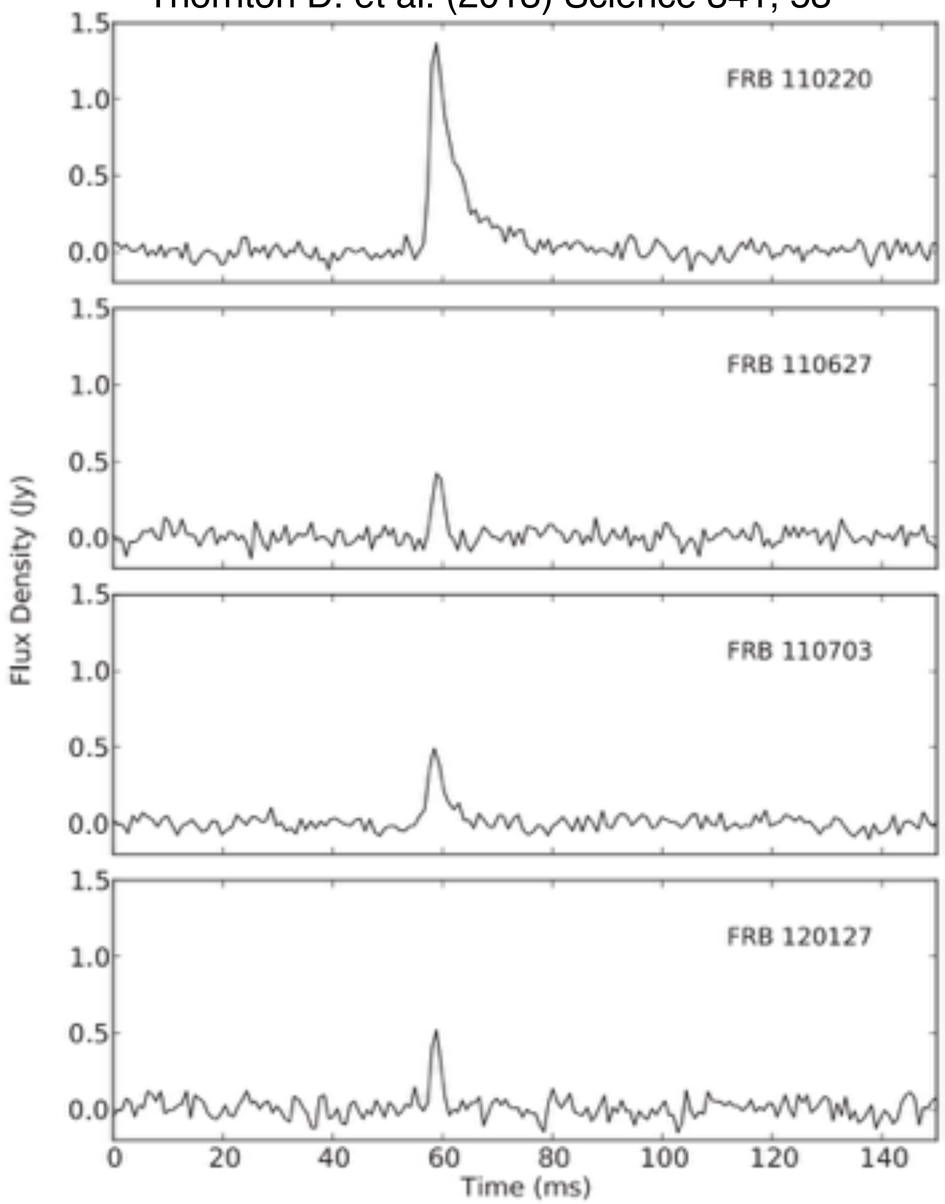




Fast Radio Bursts

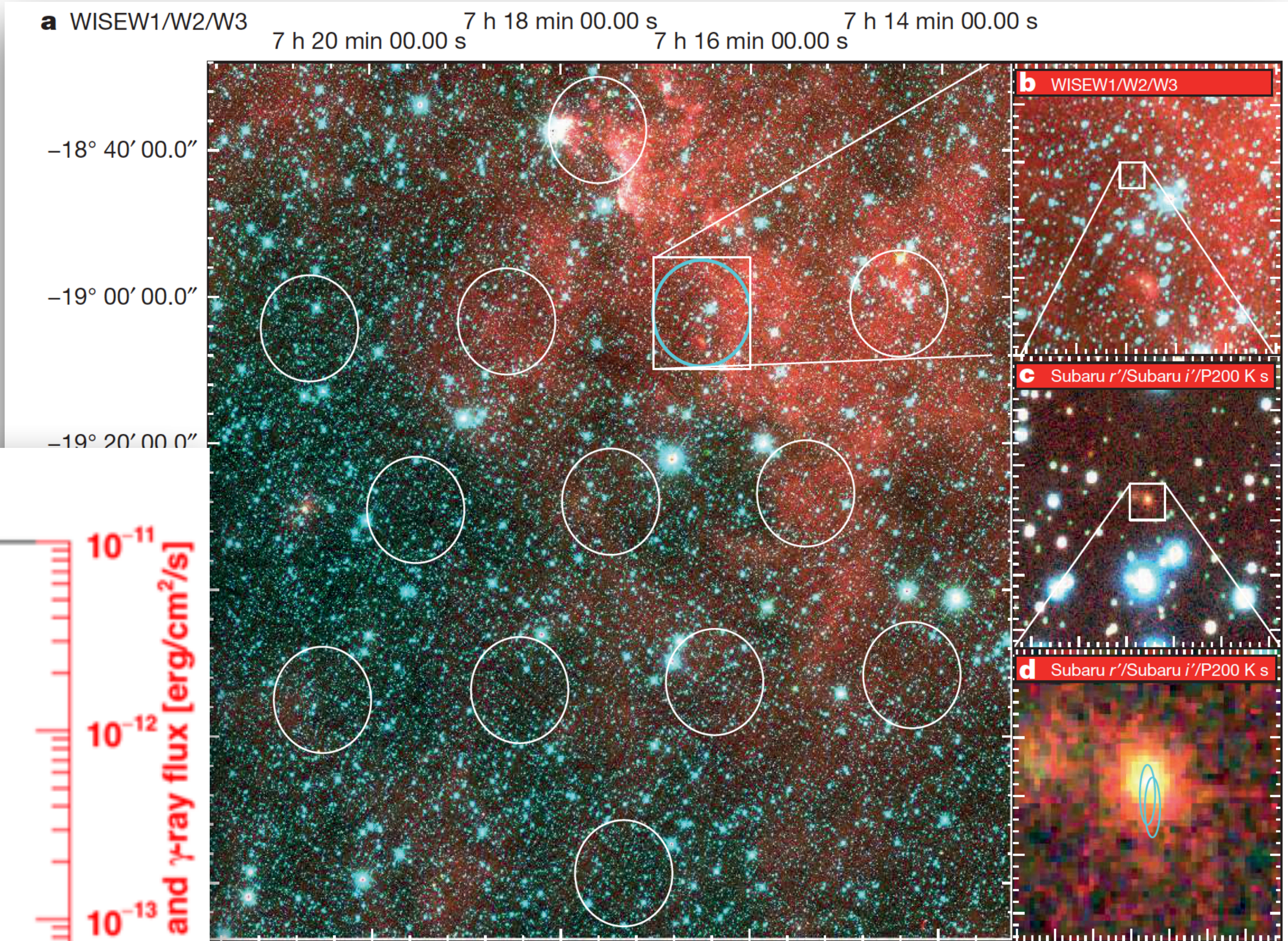
- strong, millisecond radio burst of possibly extragalactic origin
- H.E.S.S. takes part in the SUPERB project @ Parkes
  - online searches for FRBs and other radio transients

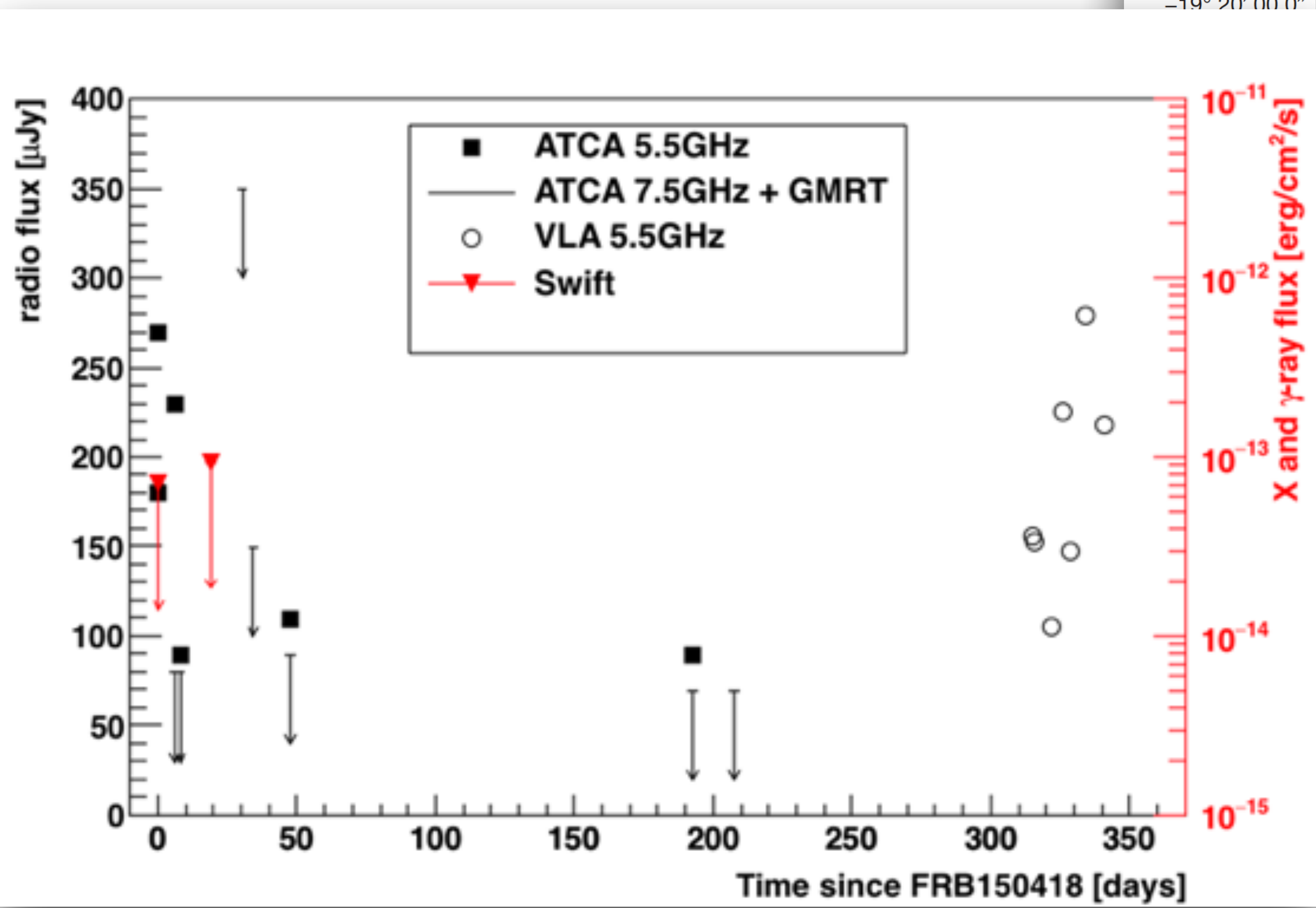
Thornton D. et al. (2013) Science 341, 53



FRB150418

- detected 2015 April 18 04:29:07.056 UTC at SUPERB@Parkes
- ATCA: fading radio afterglow during ~6days
    - optical identification of galaxy at z=0.492



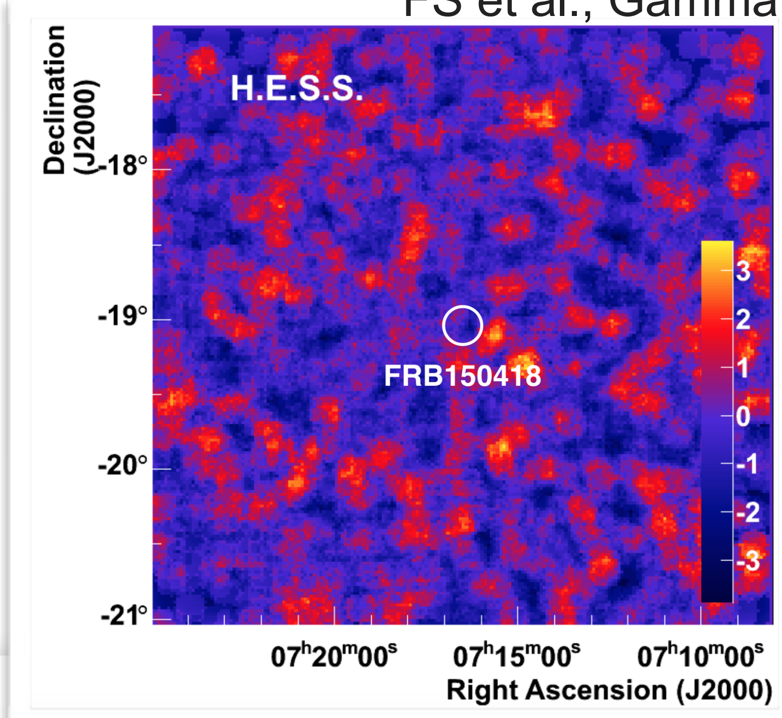


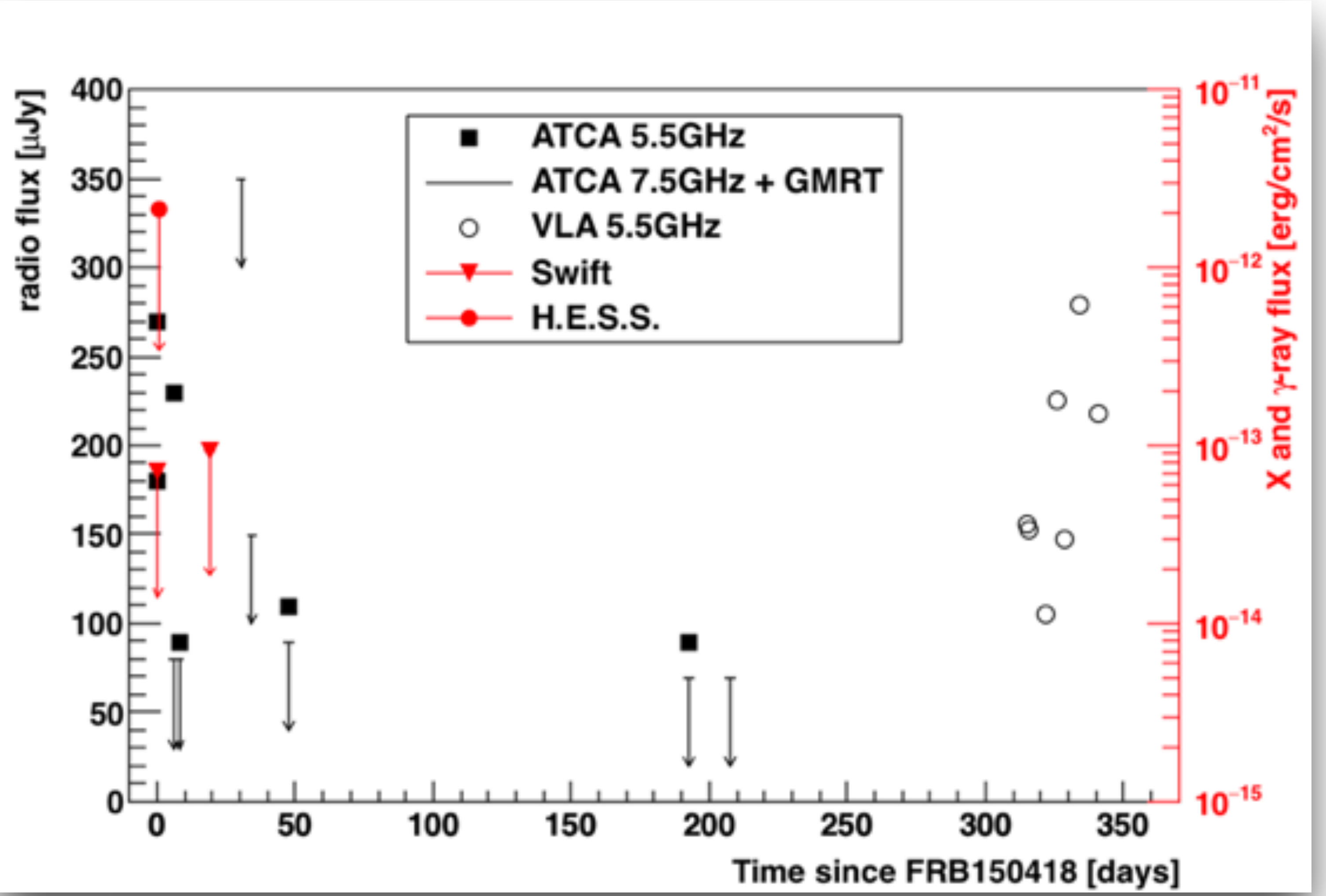
E. Keane et al., Nature 530 (2016)

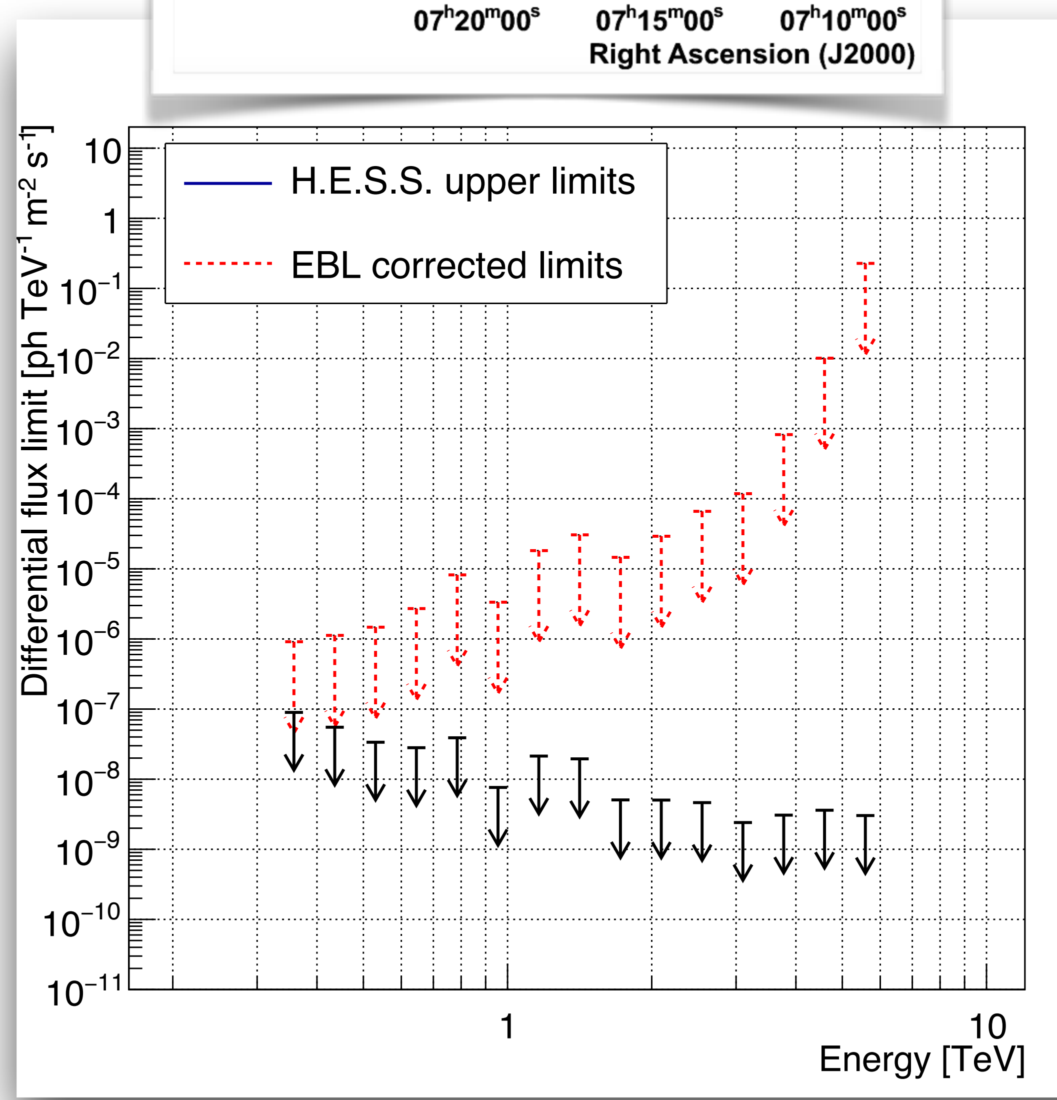
HESS+SUPERB, A&A 597 (2017), arXiv:1611.09209
FS et al., Gamma 2016

FRB150418

- detected 2015 April 18 04:29:07.056 UTC at SUPERB@Parkes
- 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
  - $\Phi(E>350GeV) < 1.3 \times 10^{-8}\ m^{-1}\ s^{-1}$ (E^{-2}, 99% C.L.)





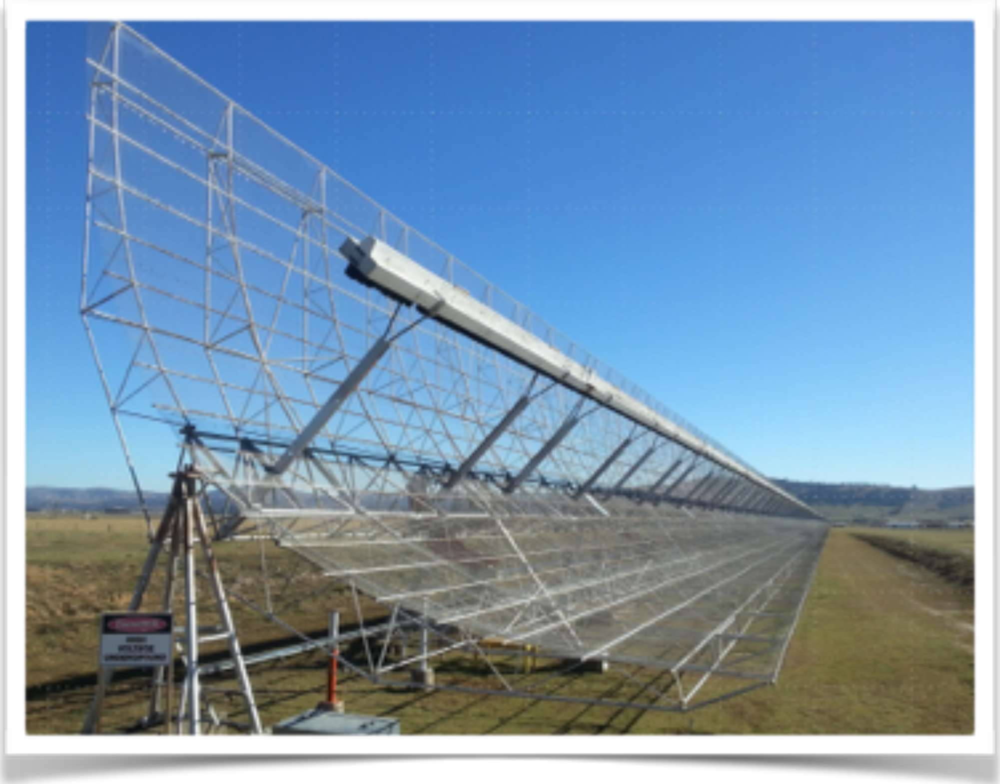


FRBs

- extension of the follow-up program to other radio observatories under discussion
  - CRAFT@ASKAP
  - Molonglo/UTMOST
  - …

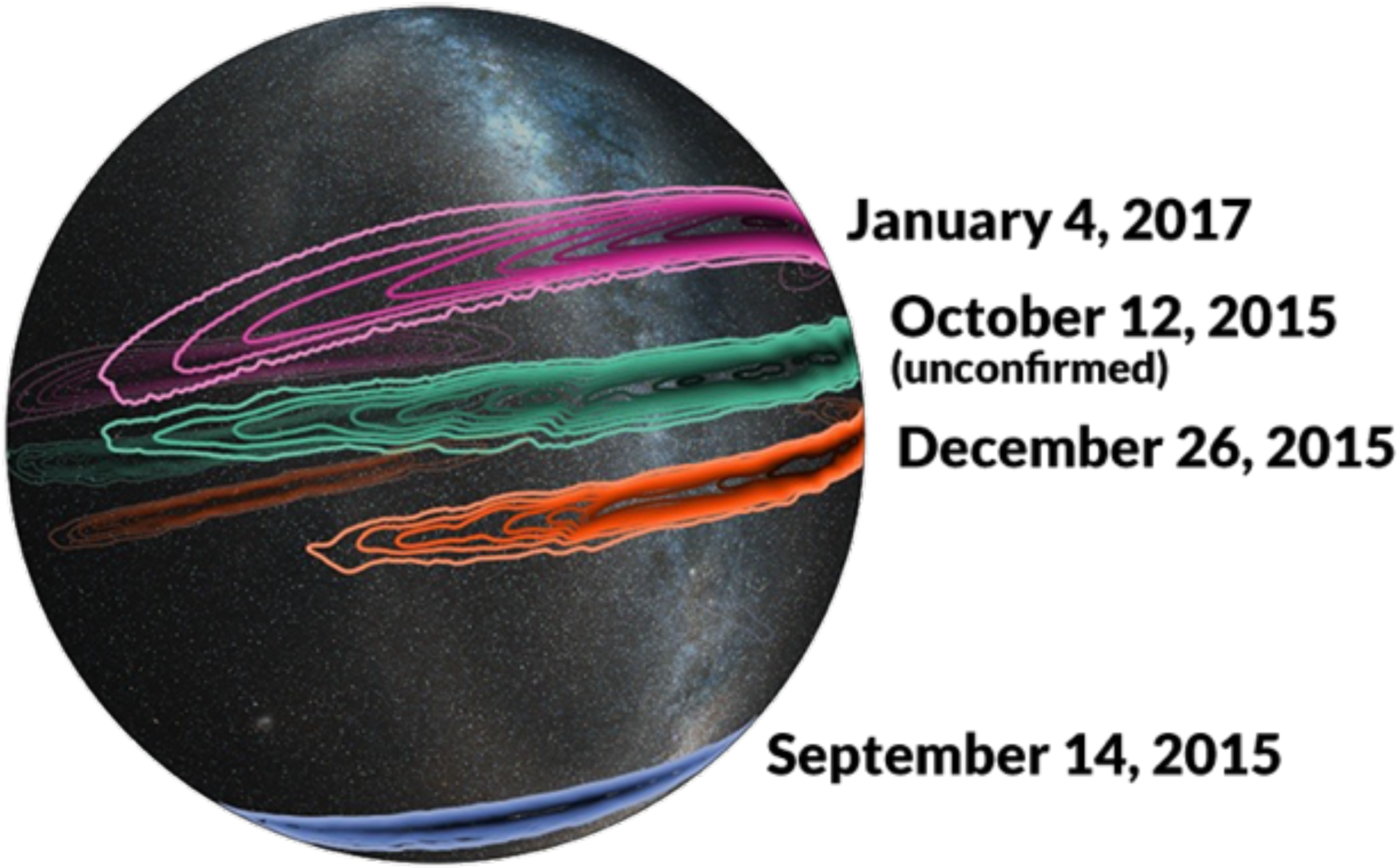
significant progress on FRB detection in real-time

- repeating burst FRB121102
  - large MWL campaign this week!
    - Arecibo heavily affected by hurricane Maria :-(
  - quite north for H.E.S.S. => large zenith angles => highest energies



Gravitational Waves

- Second physics run of Advanced LIGO/Virgo ended August 25
- H.E.S.S. part of the EM follow-up program since 2014
- rapid slewing, relatively large FoV
- dedicated algorithms to determine optimized scheduling



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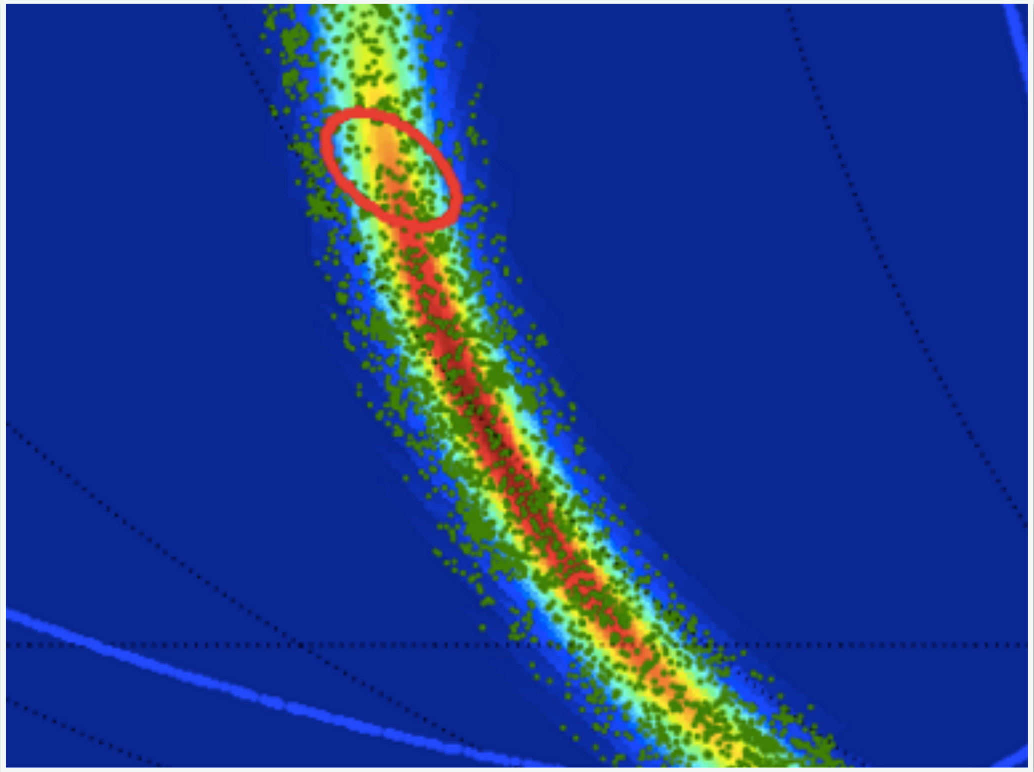
  - full 3D-correlation with galaxy catalog (GLADE) vs. 2D coverage of GW uncertainty region
  - running fully automated within the VoAlert system
  - decision on event-by-event basis
    - BBH: large distances, galaxy catalogs incomplete
    - BNS: nearby, complete catalogs



M. Seglar-Arroyo + FS, arXiv:1705.10138

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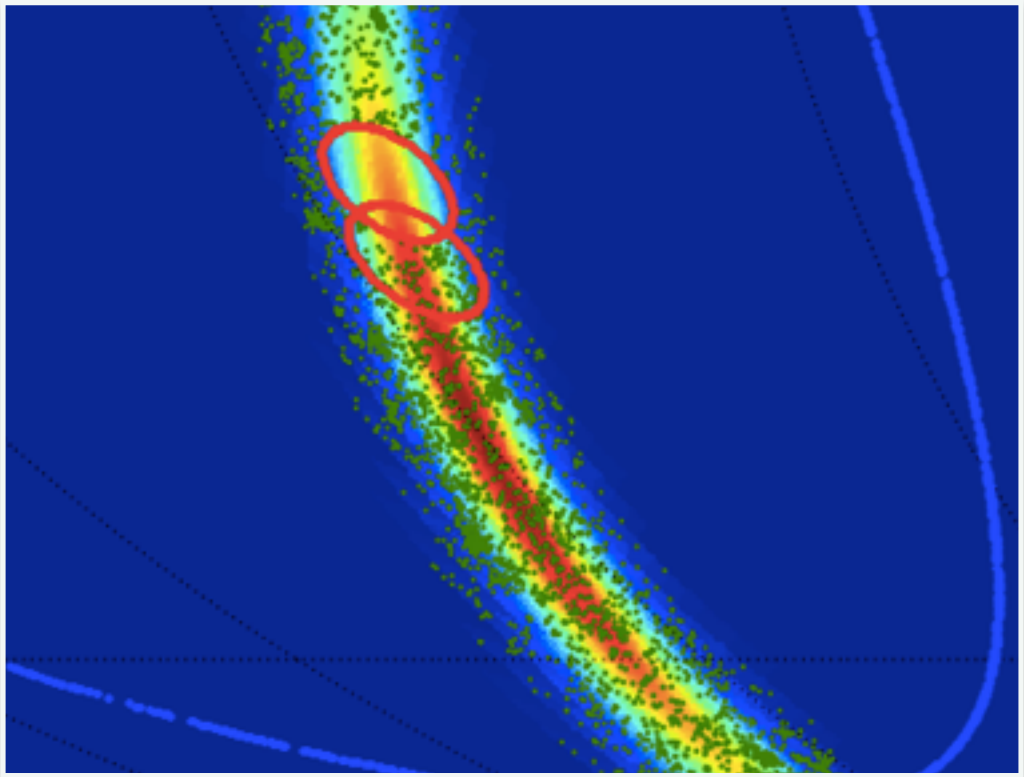

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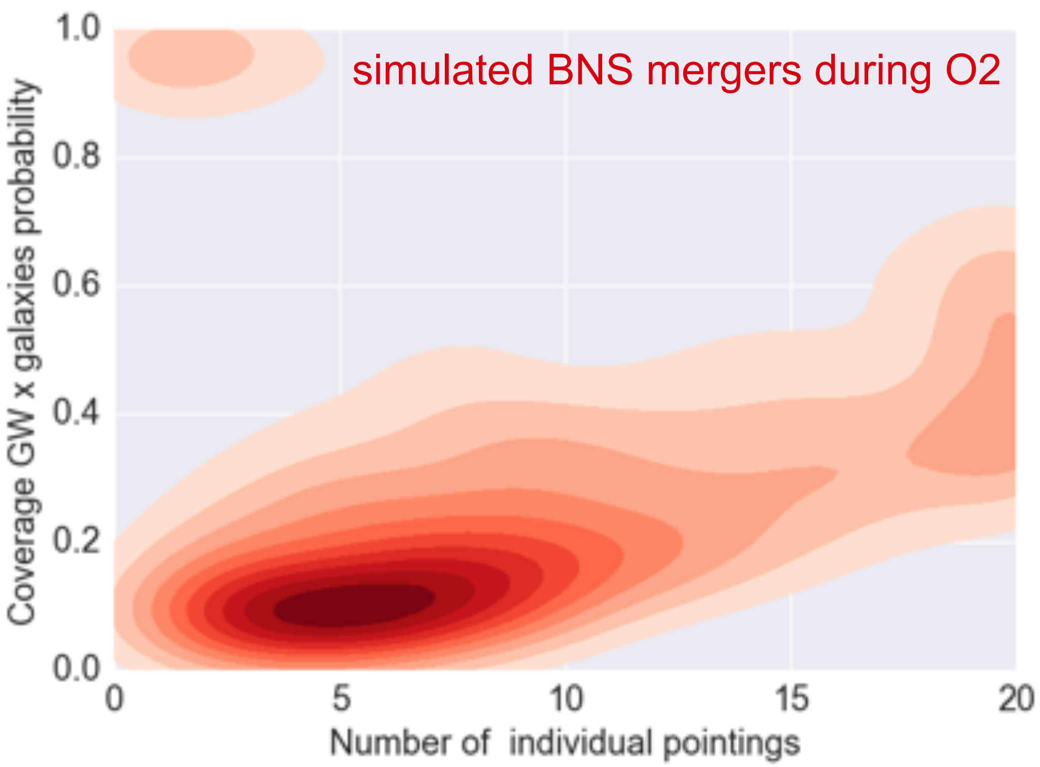

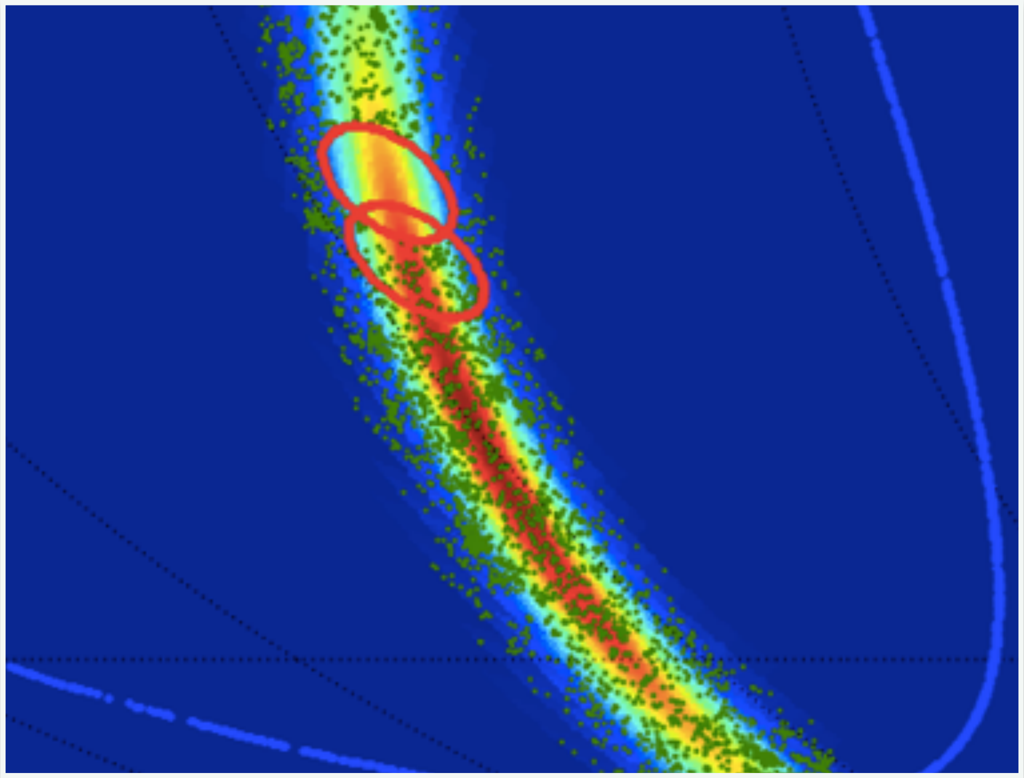

M. Seglar-Arroyo + FS, arXiv:1705.10138

Summary

- H.E.S.S. phase II: lower energy threshold and rapid response
- Galactic transients: mainly scheduled observations, ToO on microquasars
- Active Galactic Nuclei
  - multi-wavelength monitoring and ToOs
- Gamma-ray bursts
  - HESS-phase II: improved performance: reduced response time
  - highest priority observations, fully automatic response
- High-energy neutrinos
  - hotspots + HESE source searches
  - switched to ToO-only programs in 2016
- Fast Radio Bursts
  - decreased detection delays in preparation (e.g. ASKAP)
  - multi-wavelength monitoring campaigns for repeating burst (FRB 121102)
- Gravitational Waves
  - complex follow-up scheduling
  - THE hot topic at the moment, stay tuned ;-)

Antares/Swift ATEL: ANT150901

- 2015-09-01: Antares/TAToO alert to optical telescopes and Swift
- 2015-09-03: Swift detection of unknown, bright, variable X-ray source (ATEL 7987)
- 2015-09-03: H.E.S.S. follow-up
  - 1.5h of observations
  - $\Phi(E>320\text{GeV}, 99\%\text{CL}) < 2.4 \times 10^{-7}\ \text{m}^{-2}\ \text{s}^{-1}$