



Irfu

Institut de recherche
sur les lois fondamentales
de l'Univers

SOUTHERN
GAMMA-RAY
SURVEY
OBSERVATORY

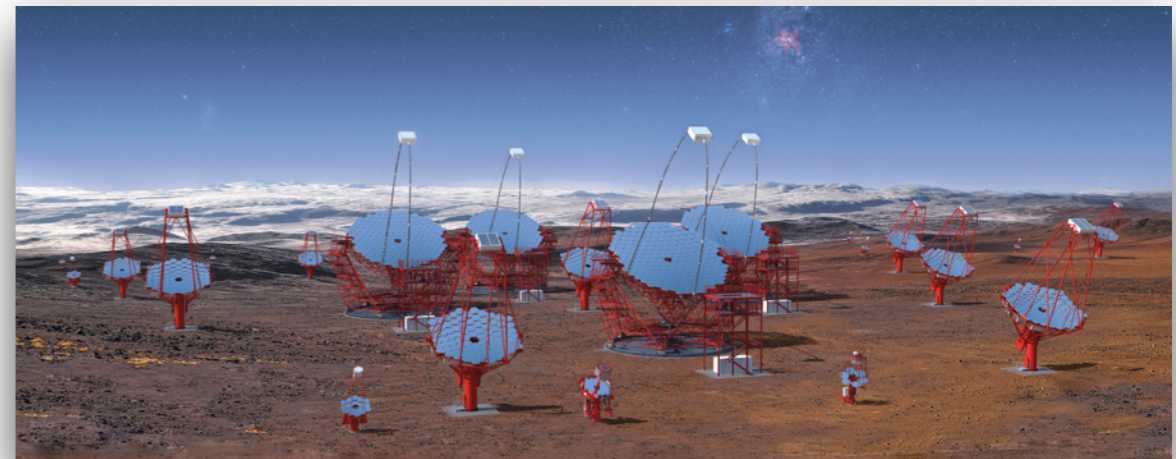
Science with SGSO

Fabian Schüssler

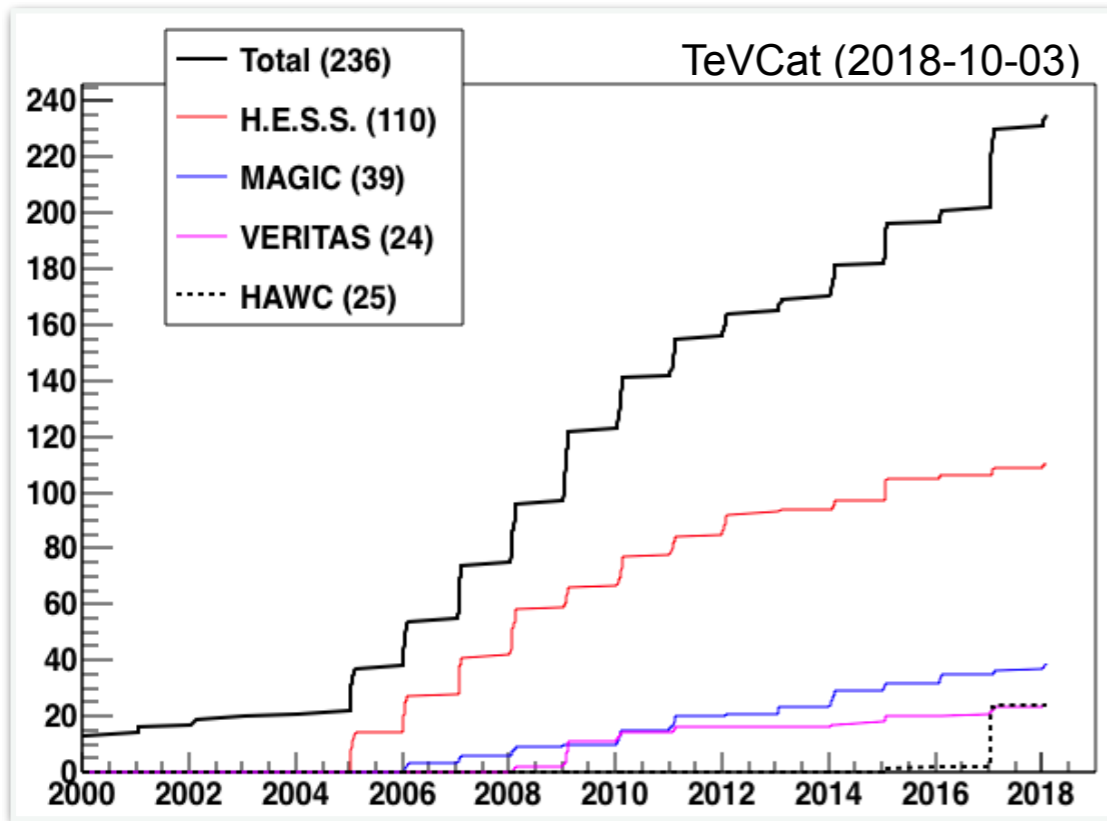
on behalf of everybody involved in the
Science Case White paper

Overview

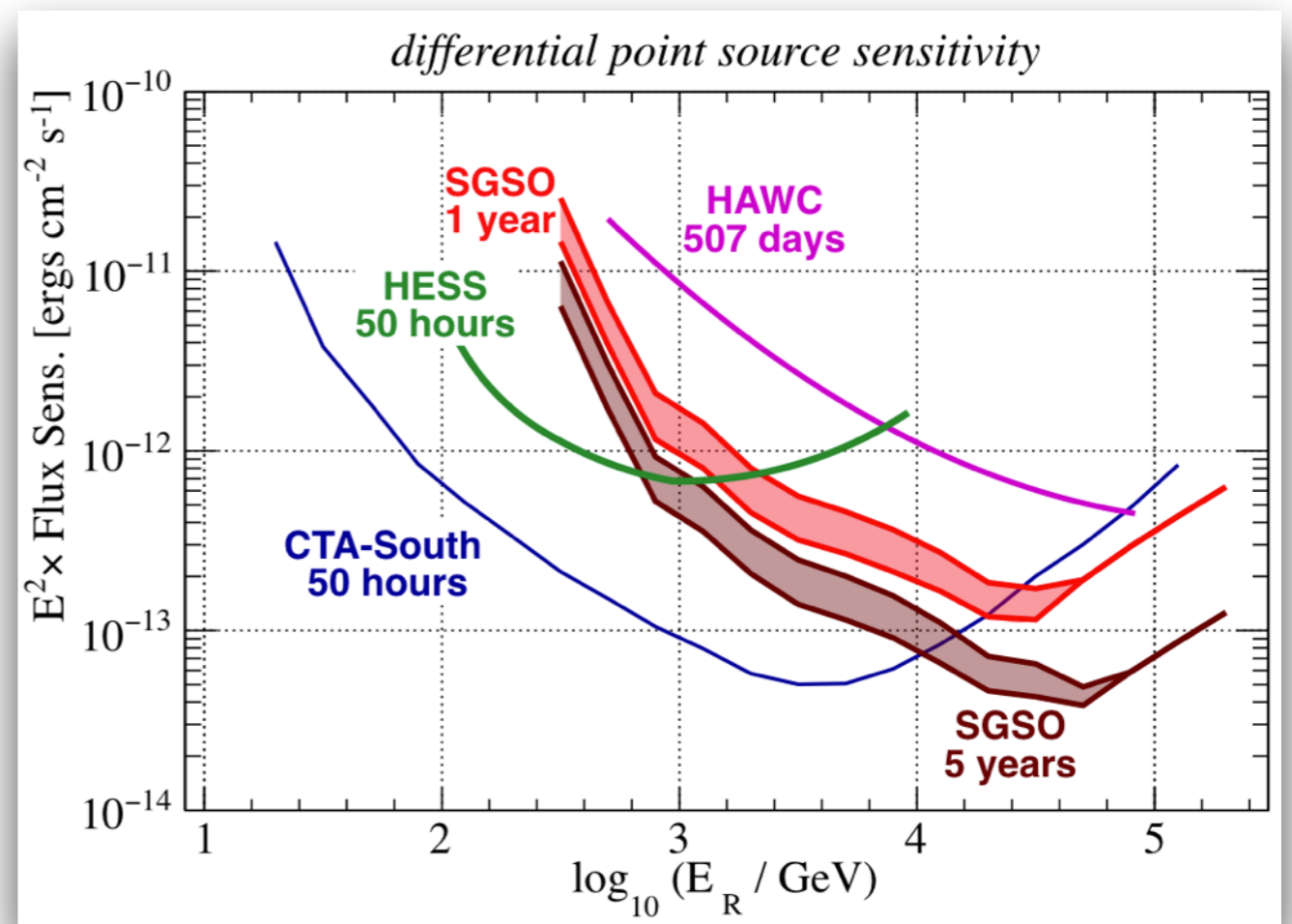
- The (Southern) TeV Sky
 - State of the art: H.E.S.S. / H.E.S.S.-II
 - upcoming: CTA-South (and LHAASO)
 - combine with results from HAWC
- Main science drivers
 - Galactic accelerators
 - Pevatrons/Galactic Center
 - extended sources
 - Transient sources
 - AGNs
 - Multi-messenger transients
 - Beyond the SM
 - Dark Matter, LIV, PBHs, ...
 - Cosmic rays



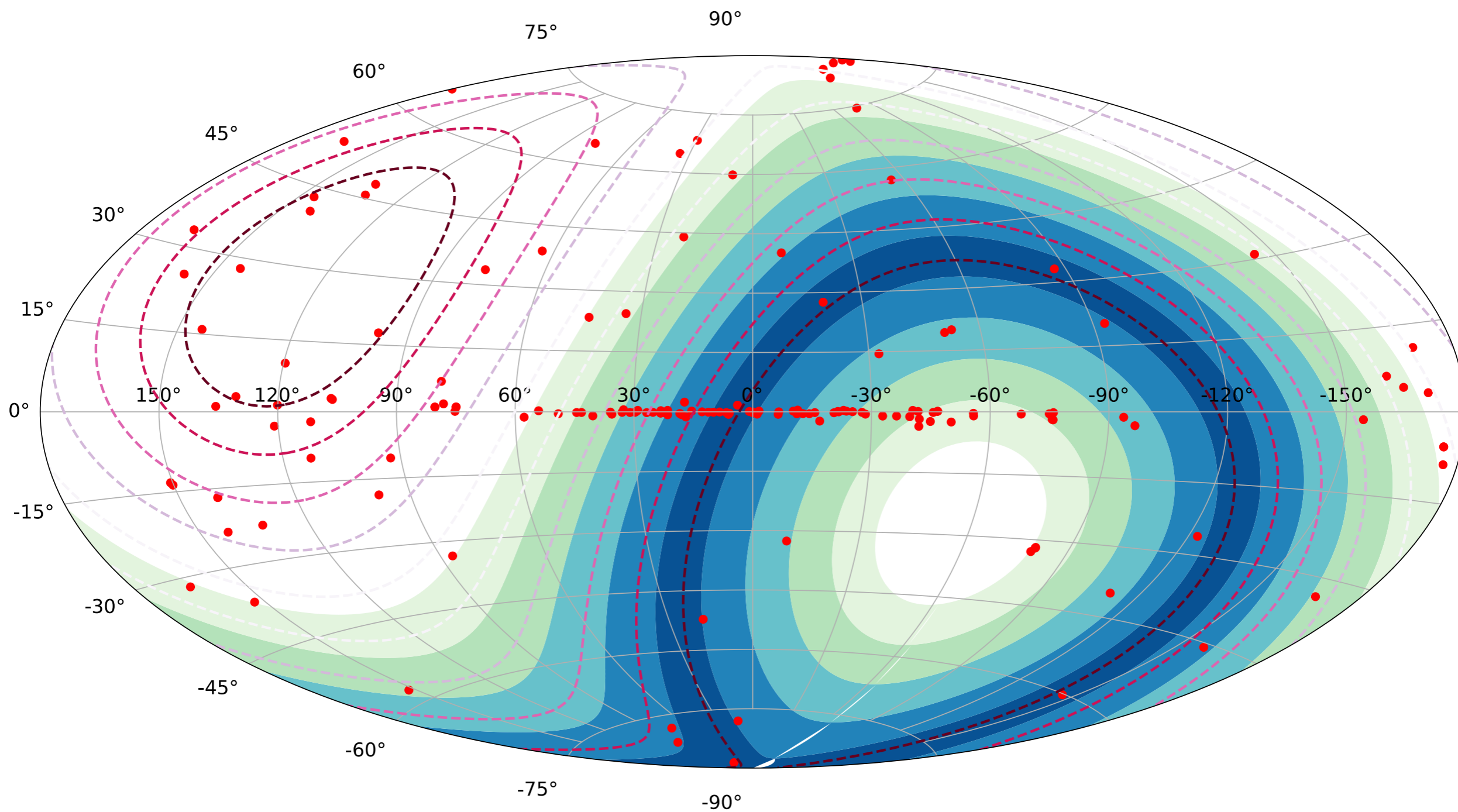
Status of TeV gamma-ray astronomy



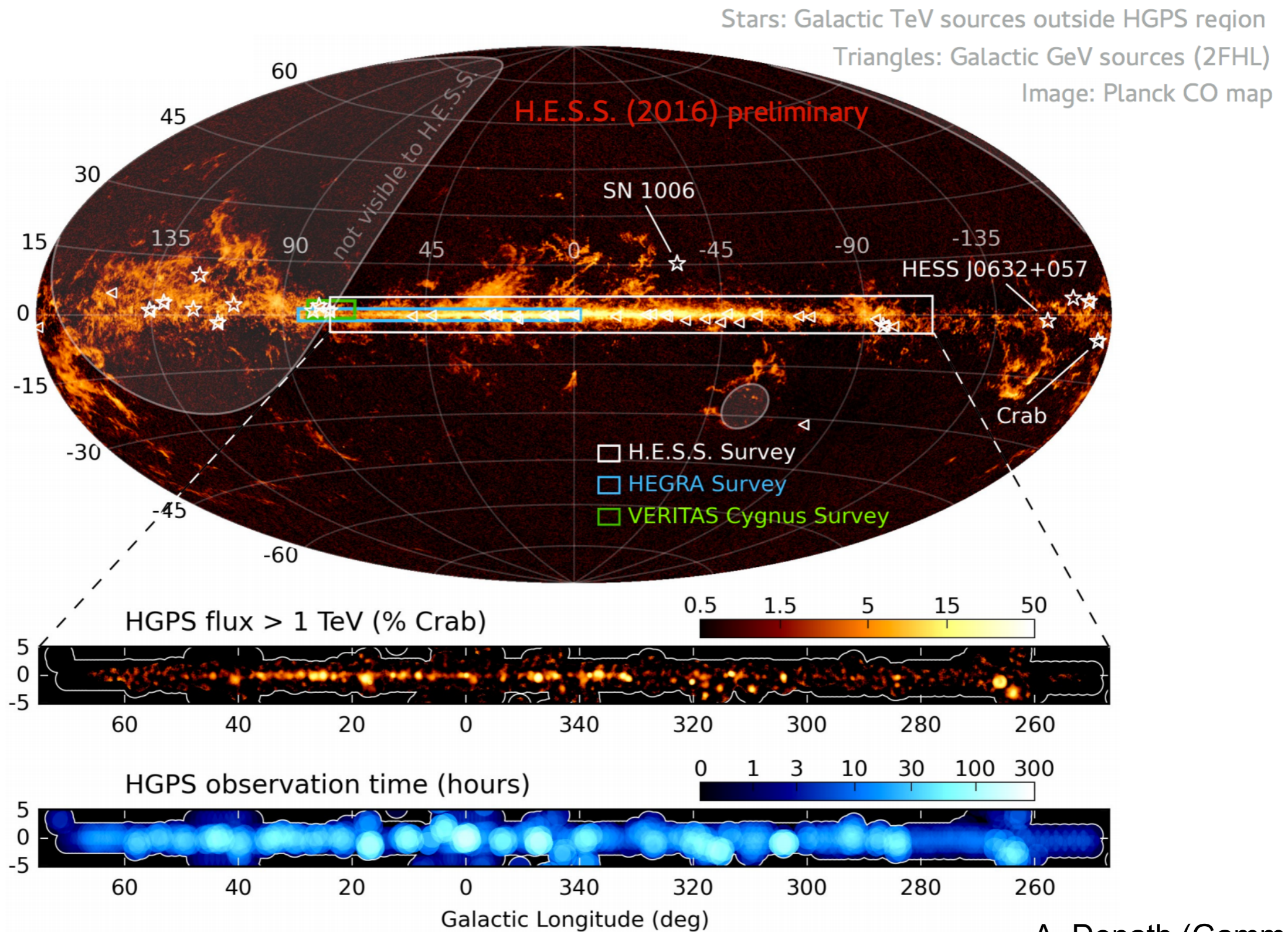
- almost 250 TeV sources
 - rich harvest in the Southern Sky
 - HAWC competitive with IACTs
- Next generation observatories on the Southern Sky: CTA + SGSO



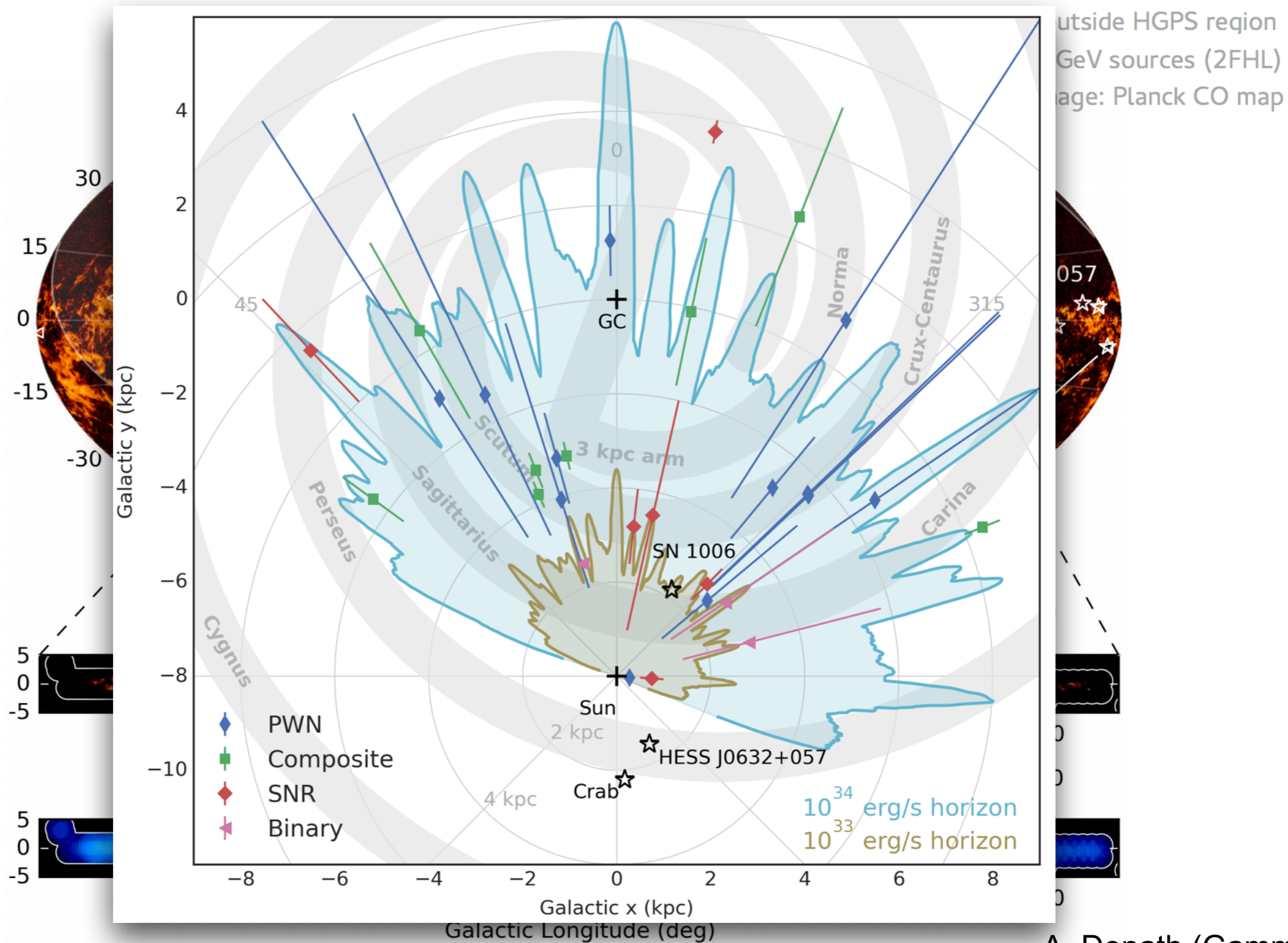
The Southern sky



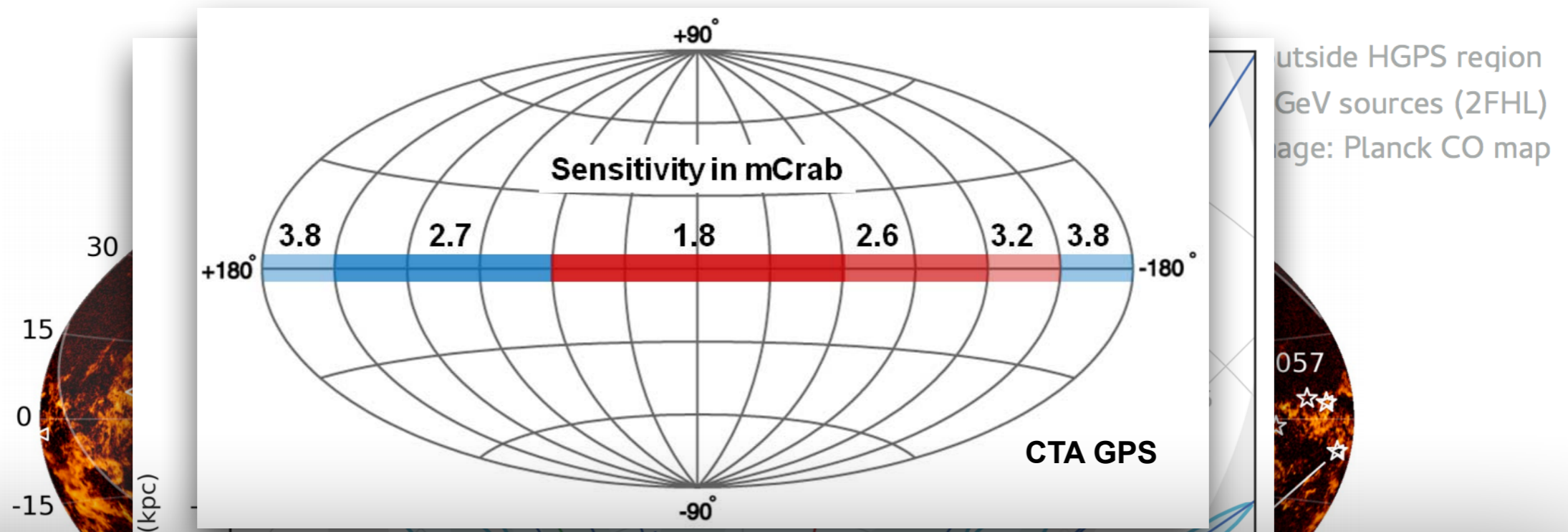
The H.E.S.S. Galactic Plane Survey



The H.E.S.S. Galactic Plane Survey



The H.E.S.S. Galactic Plane Survey



Southern Hemisphere => Galactic Plane *state of the art*

- ~ half of the Galaxy covered down to 10% Crab
- need high angular resolution to avoid source confusion
- CTA will do an even deeper Galactic Plane Scan

Discovery space for SGSO

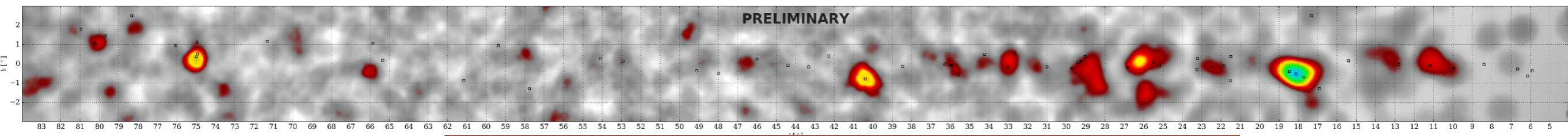
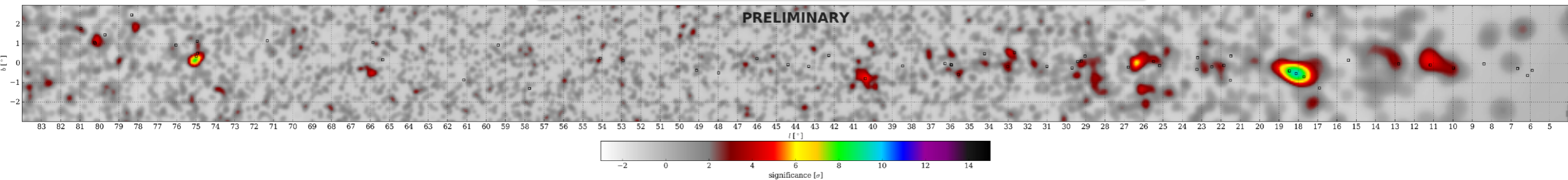
- sensitivity at high energies
- extended sources (limited by source confusion), see later

Pevatrons

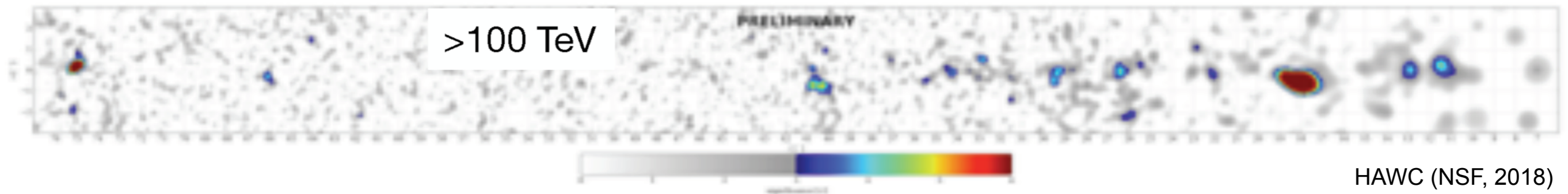
- a first unbiased look at the GP at high energies with HAWC
 - more to come thanks to the HAWC outrigger array

$E_{\text{rec}} > 56$ TeV, point source model

C. Rivière, APS 2018



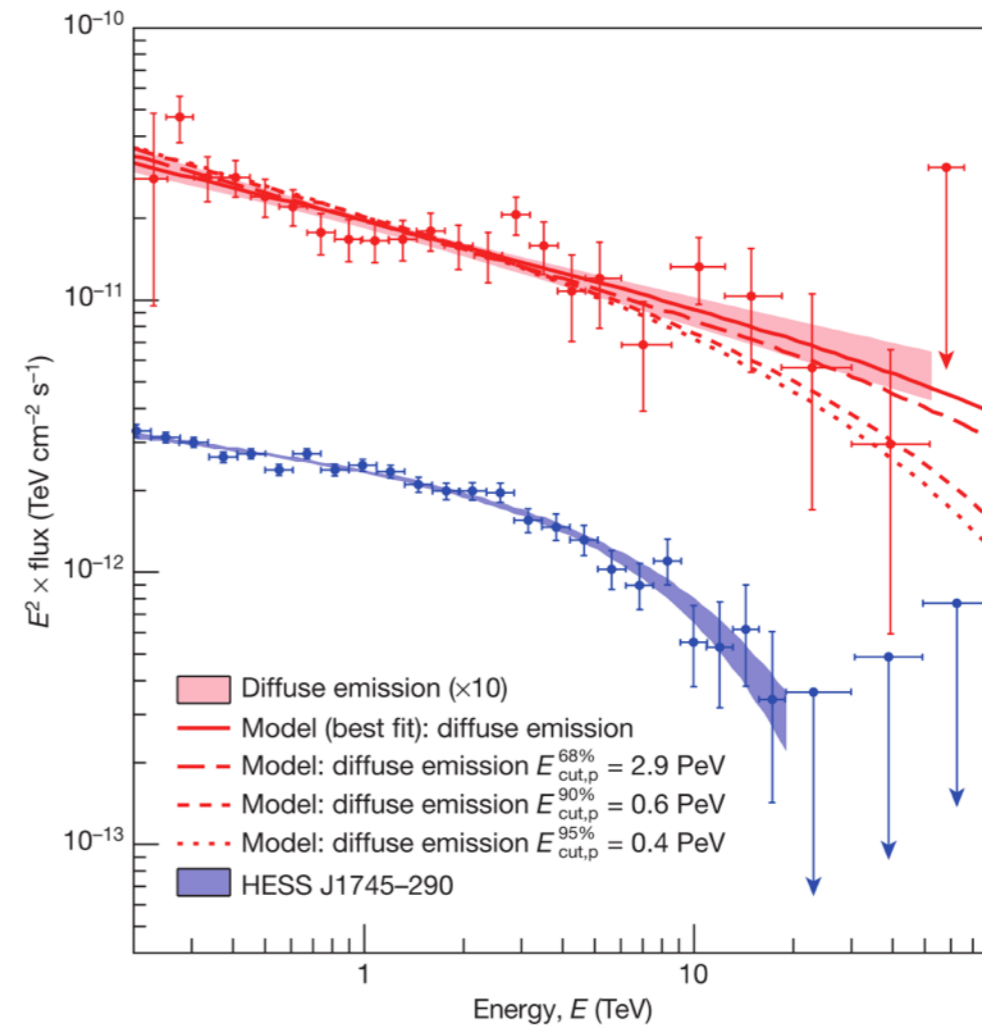
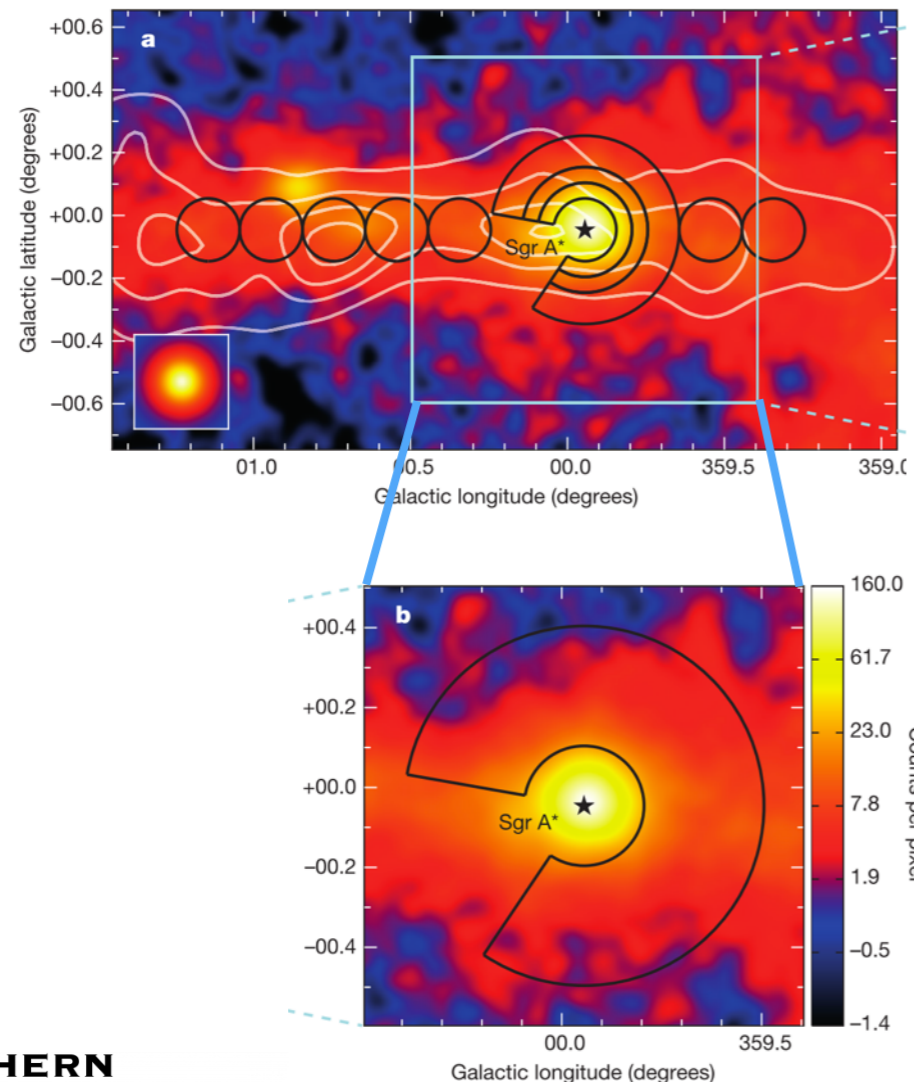
$E_{\text{rec}} > 56$ TeV, 0.5° extended source model



HAWC (NSF, 2018)

Pevatrons in the GC

- Galactic Center after 10 years of H.E.S.S. observations
 - central source + extended diffuse emission without energy cutoff
- many other possibilities: HESS J1641-463 / J1741-302 / J1826-130 / ...
- LMC: superbubble 30 Dorades C; SNR N132 D, ...



Pevatrons in the GC

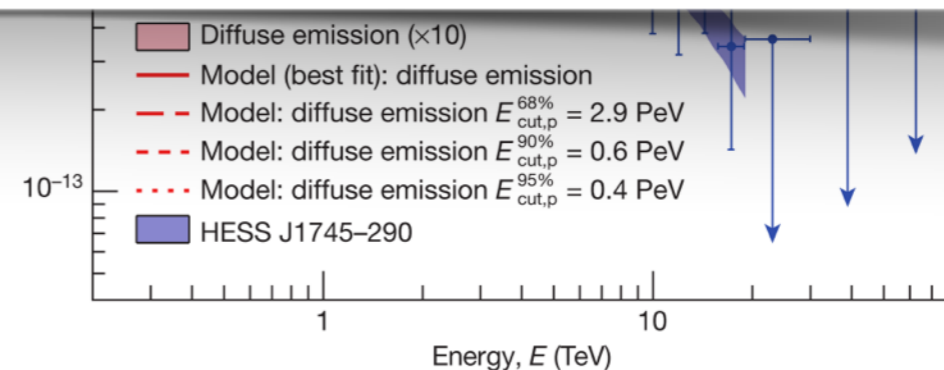
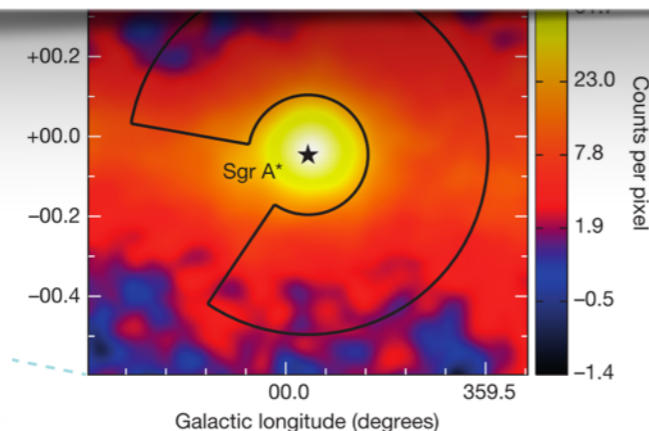
- Galactic Center after 10 years of H.E.S.S. observations
 - central source + extended diffuse emission without energy cutoff

Pevatrons *state of the art*

- very deep and high resolution data available (e.g. GC)
- Northern part of the GP in reach for HAWC (+LHAASO)
- dedicated CTA program

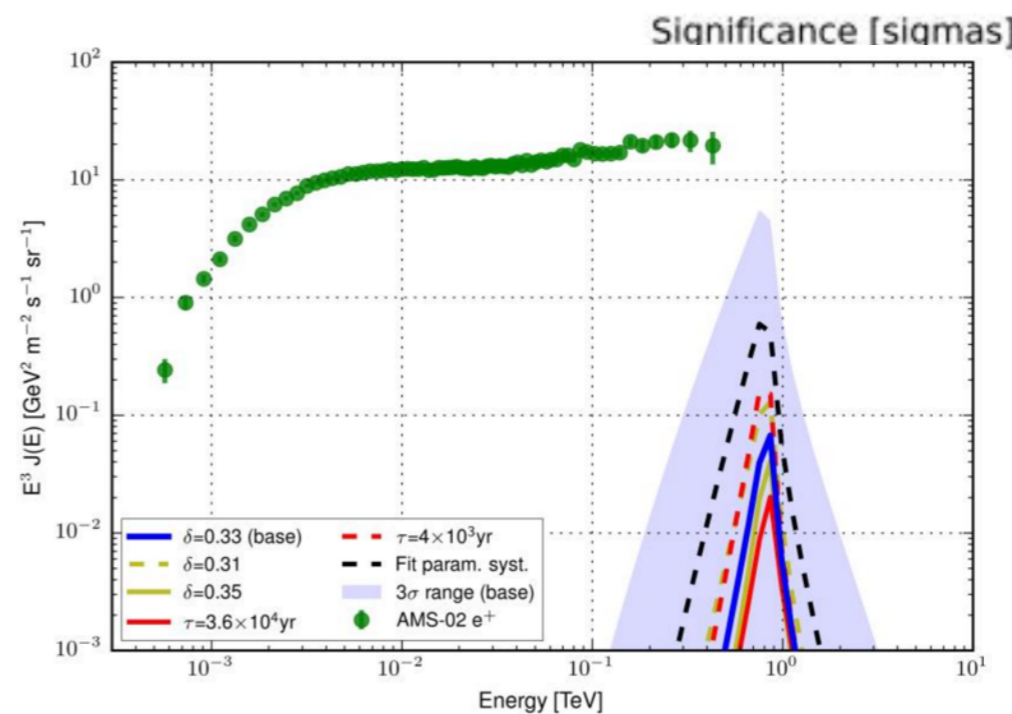
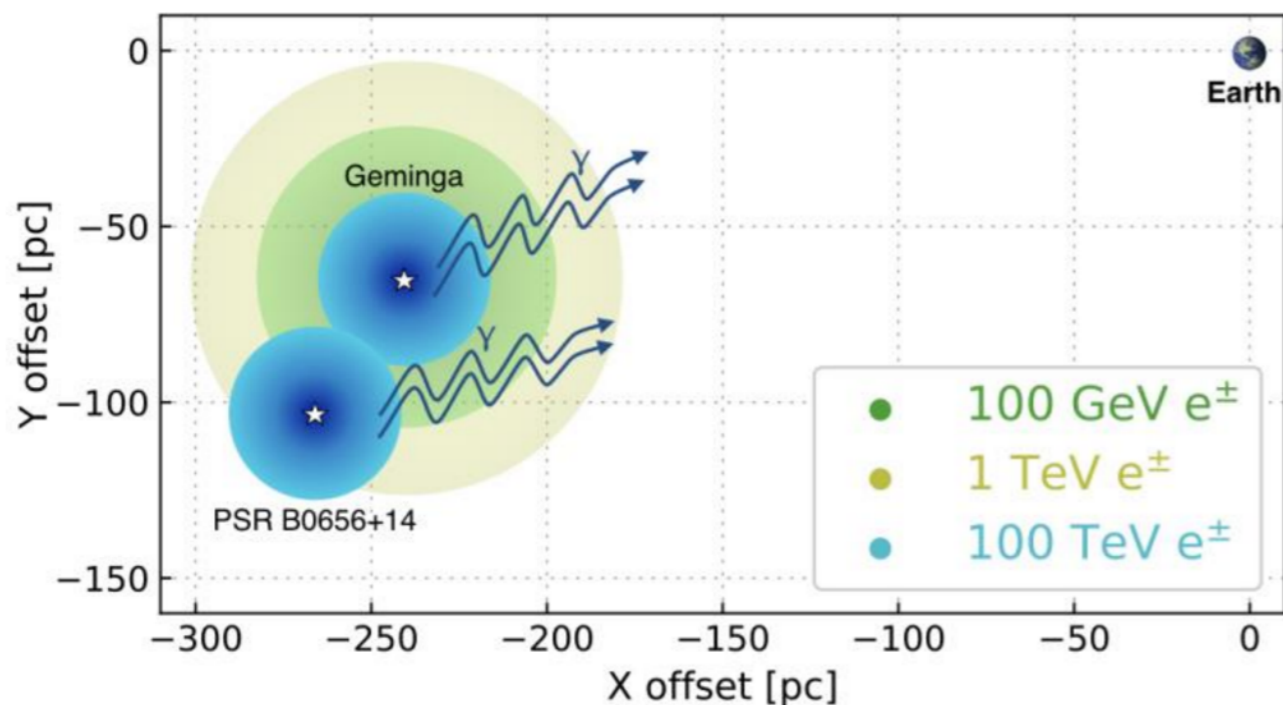
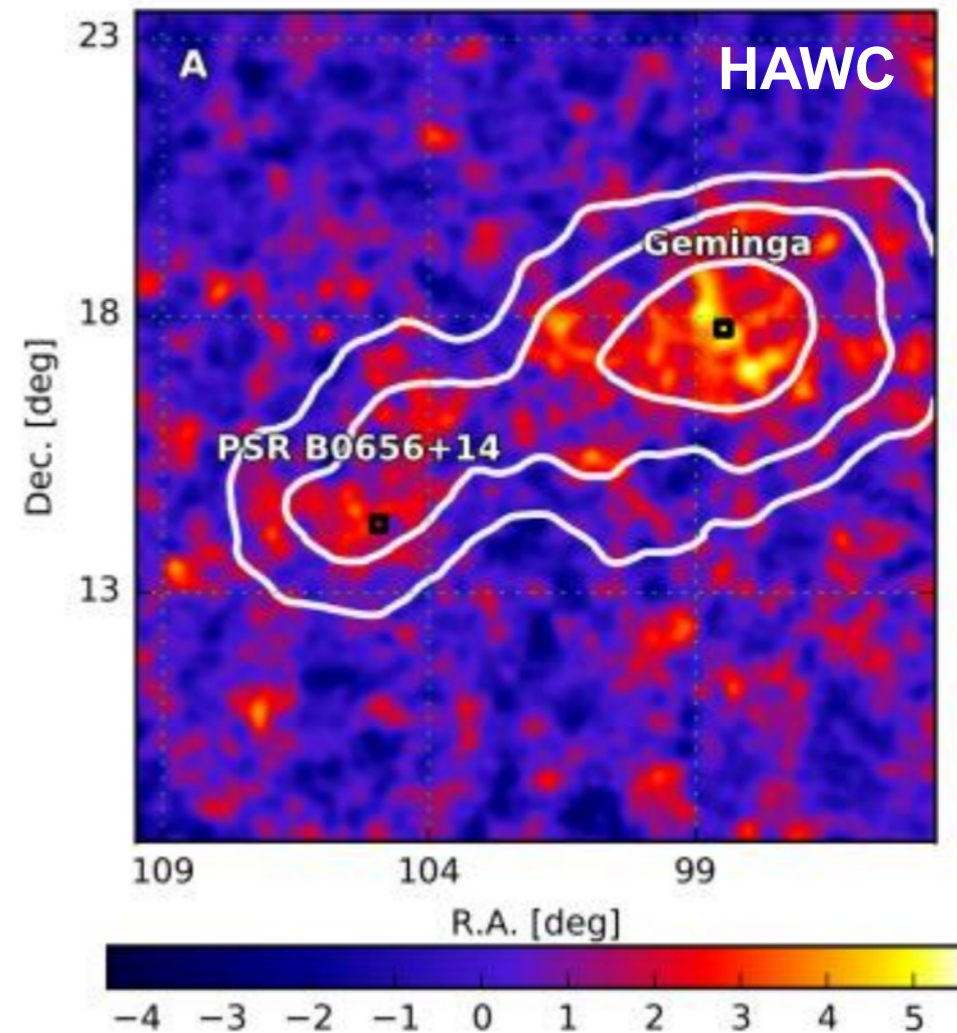
Science with SGSO

- reach beyond the energy frontier of IACTs
- Klein-Nishina regime



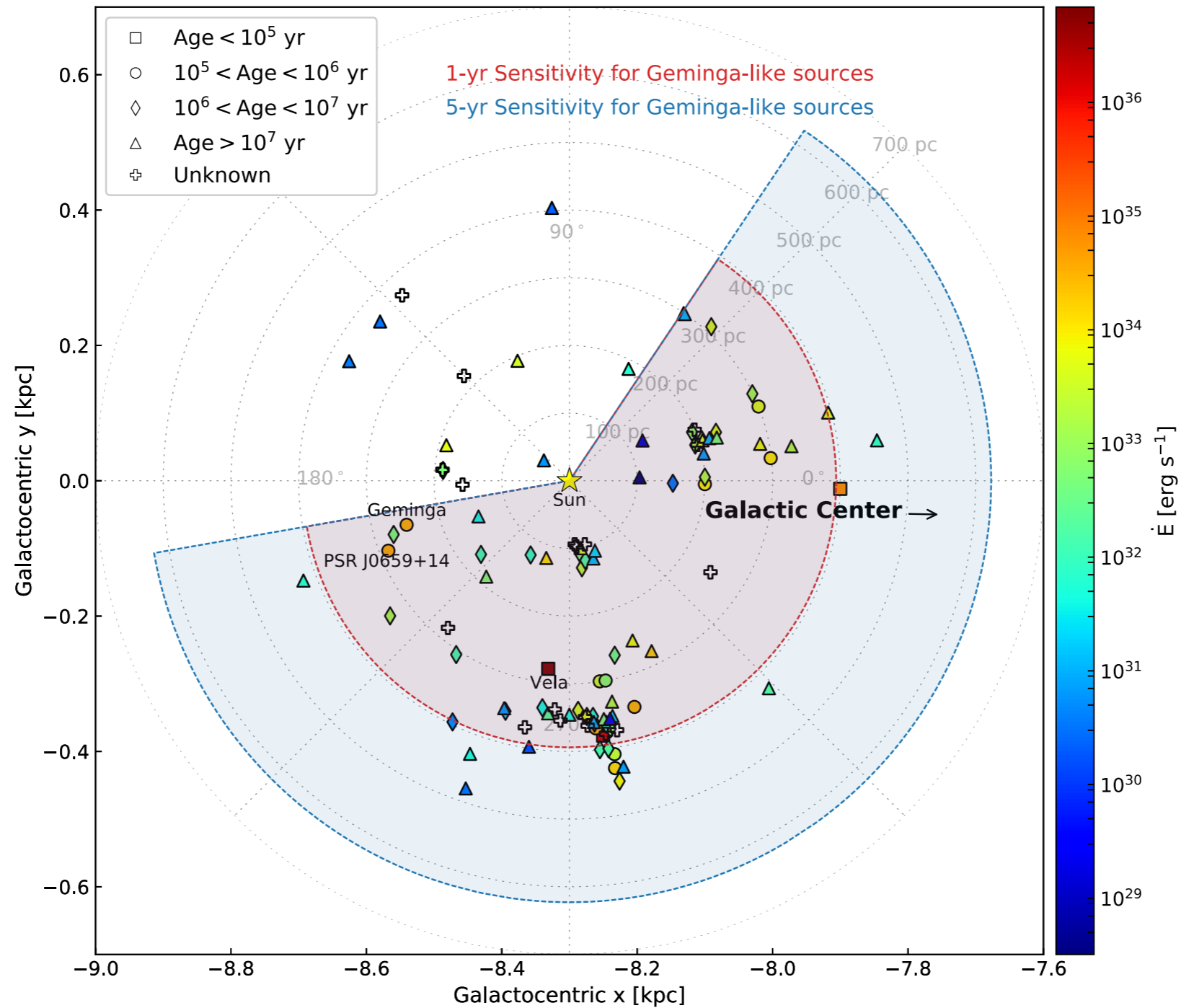
PWNe TeV halos

- very extended halos around nearby PWN detected by HAWC
- energy dependent morphologies allow to derive cosmic ray diffusion coefficient: ~ 100 times smaller than expected thus not able to explain the positron excess observed by AMS



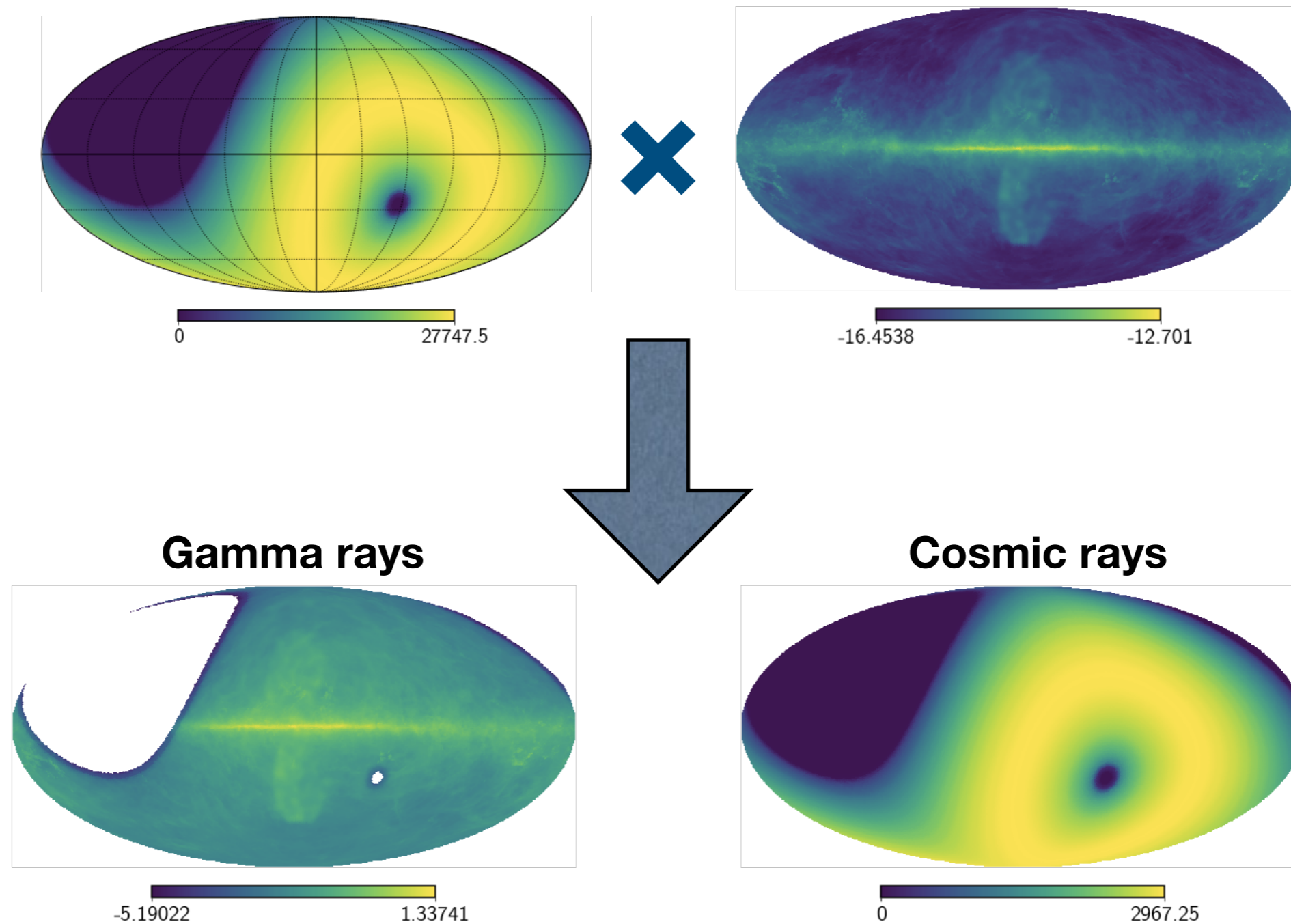
Pulsars in our Galaxy

- a significant portion of the pulsar population accessible by SGSO



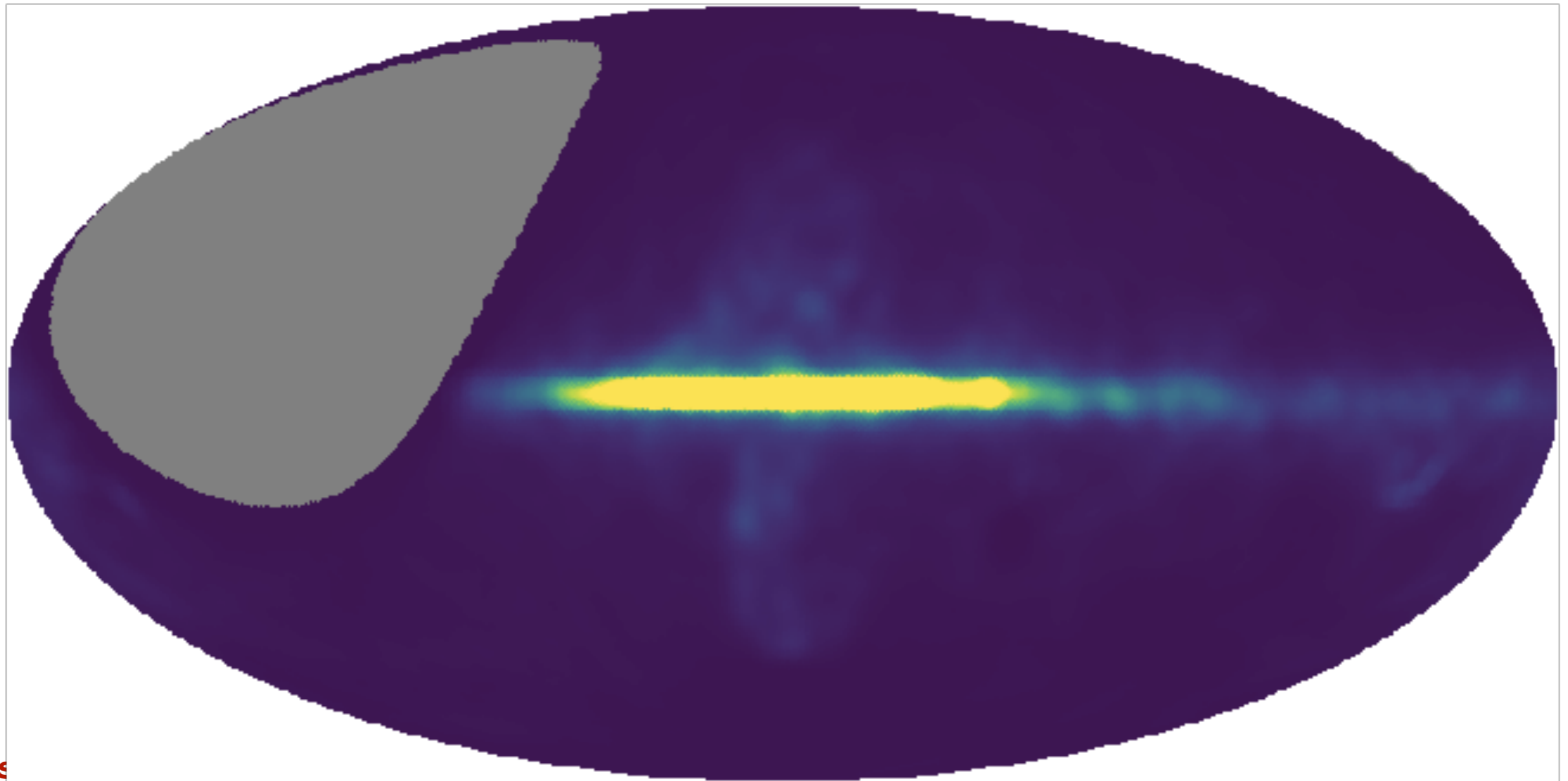
Diffuse emission

- input: SGSO acceptance + Fermi diffuse model



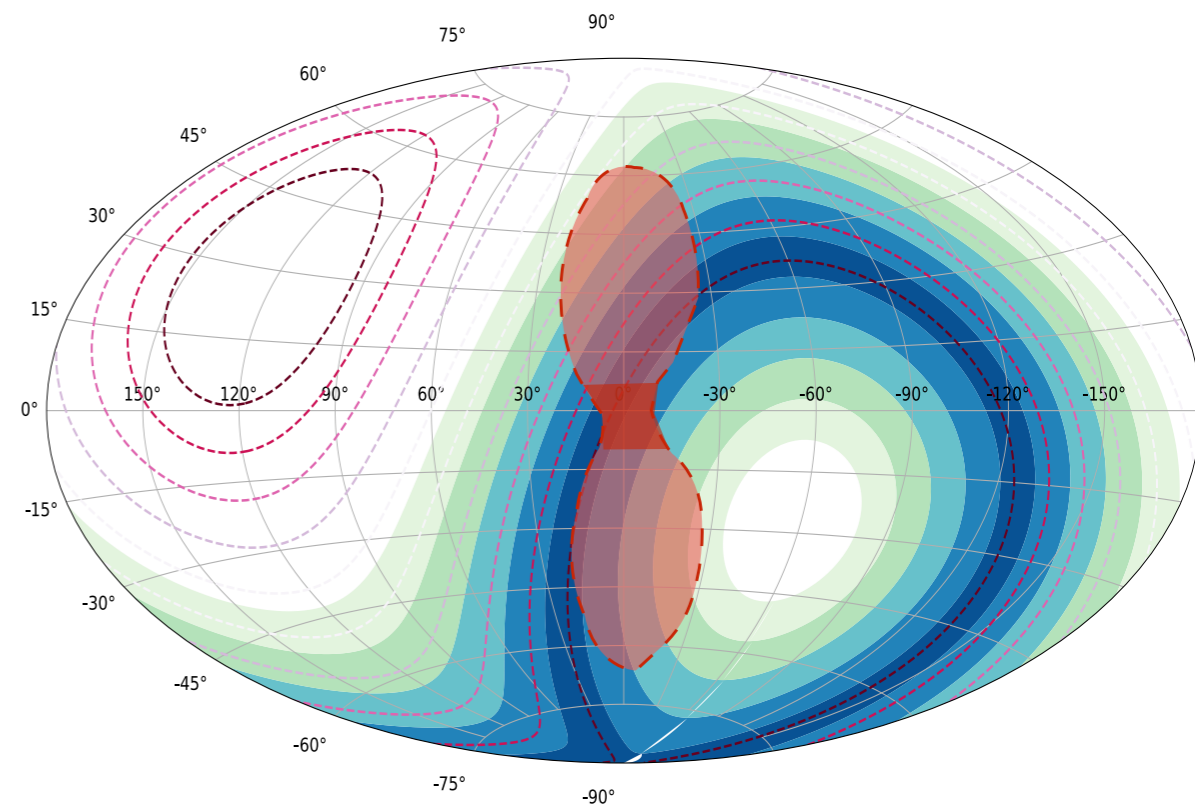
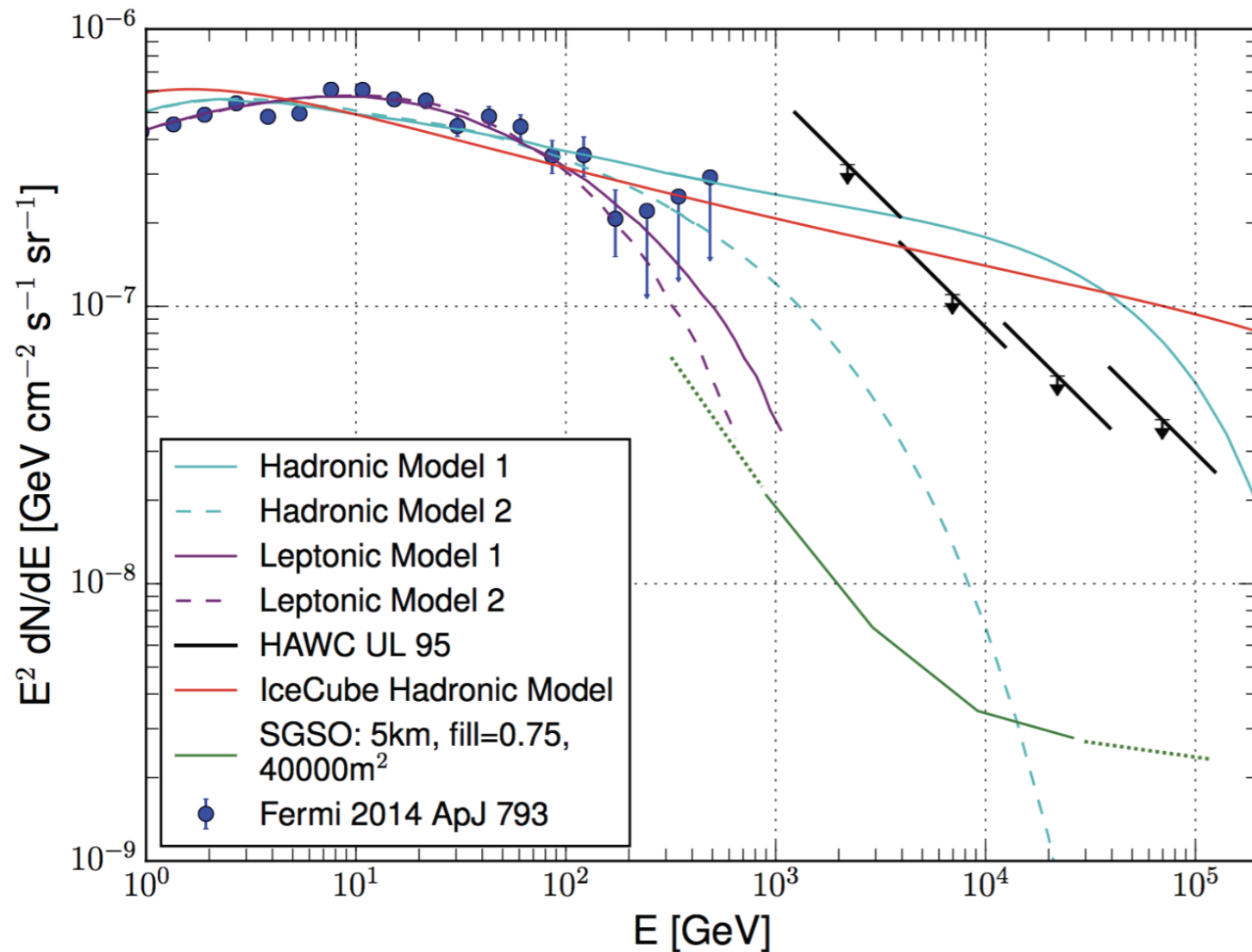
Diffuse emission

- 1 yr exposure with 3° smoothing. Perfect knowledge of the background level (S/\sqrt{B})
- High significance detection of the inner-Galactic emission + Fermi bubbles



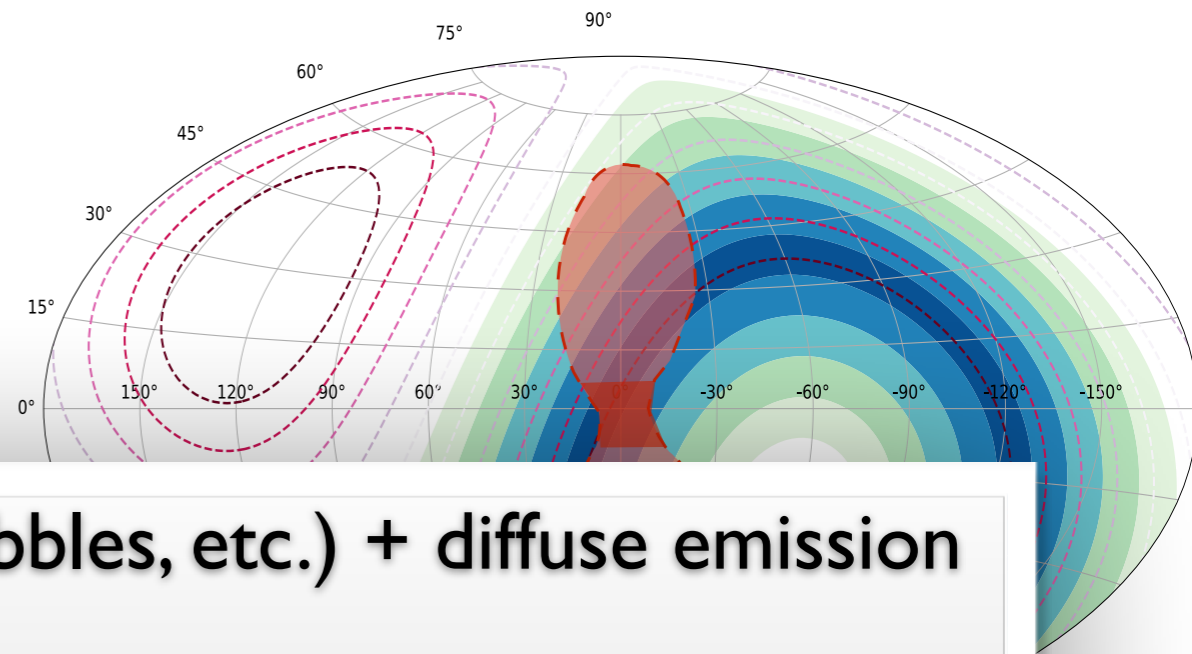
Fermi bubbles

- good visibility for SGSO: 70% every day
- SGSO will be able to constrain hadronic models



Fermi bubbles

- good visibility for SGSO: 70% every day
- SGSO will be able to constrain hadronic



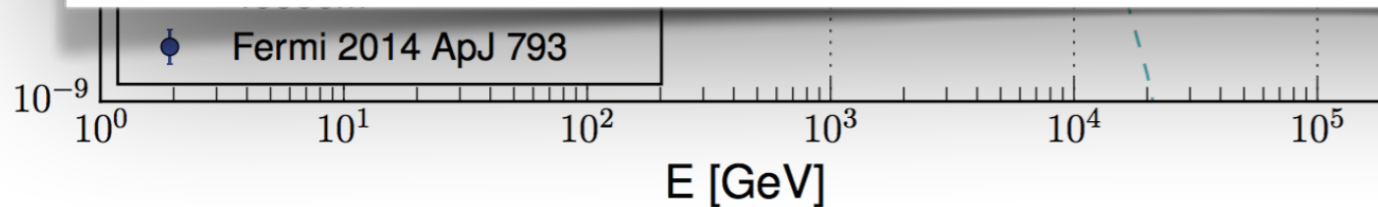
Extended sources (TeV halos, Fermi bubbles, etc.) + diffuse emission

- very difficult for current IACTs
- CTA has larger FoV + divergent pointing; novel analysis tools necessary

Science with SGSO

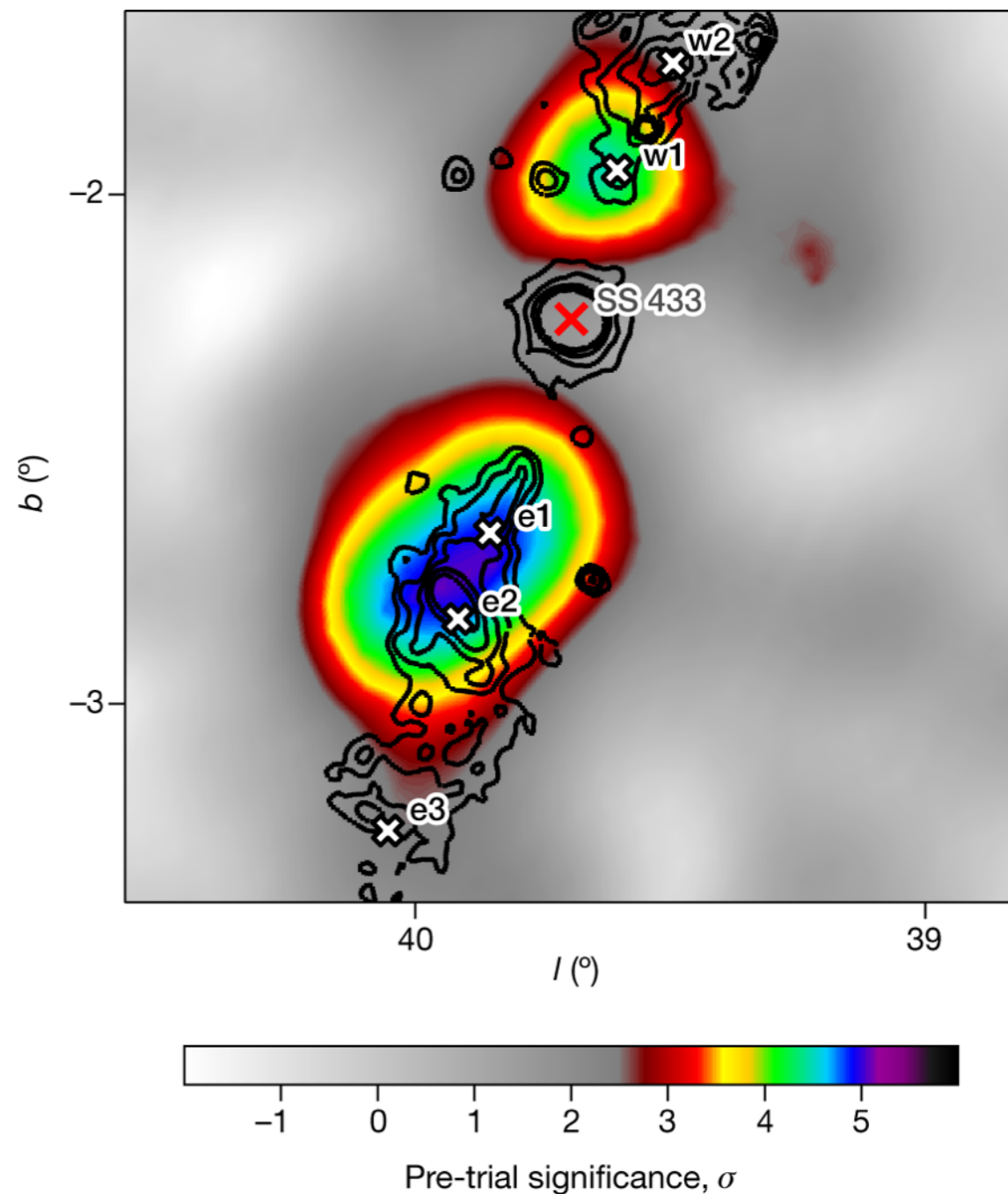
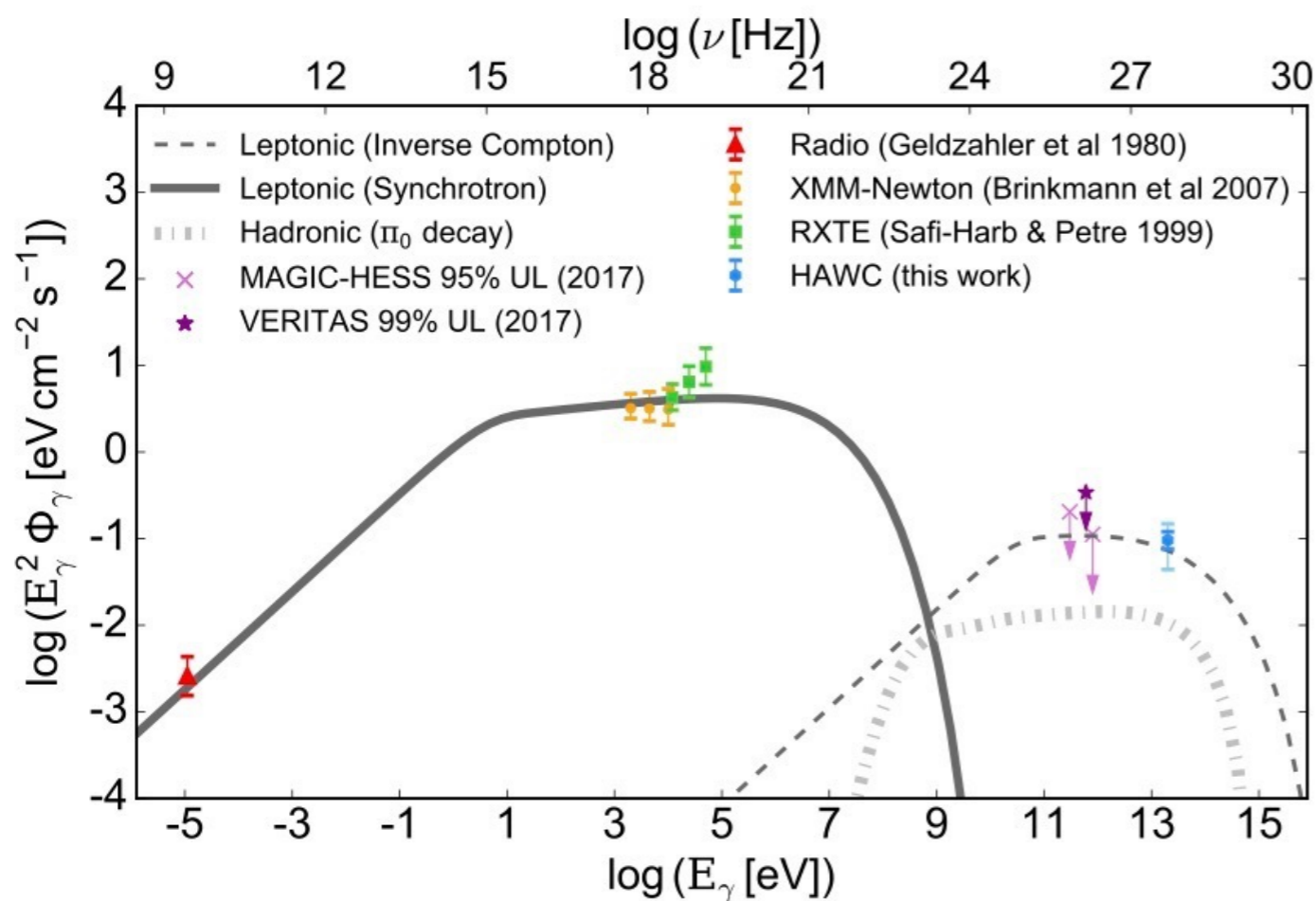
- prime science case
 - how does source confusion in the GP affect us?
- gamma/hadron separation crucial

$E^2 \frac{dN}{dE} [\text{GeV cm}^{-2} \text{s}^{-1} \text{sr}^{-1}]$



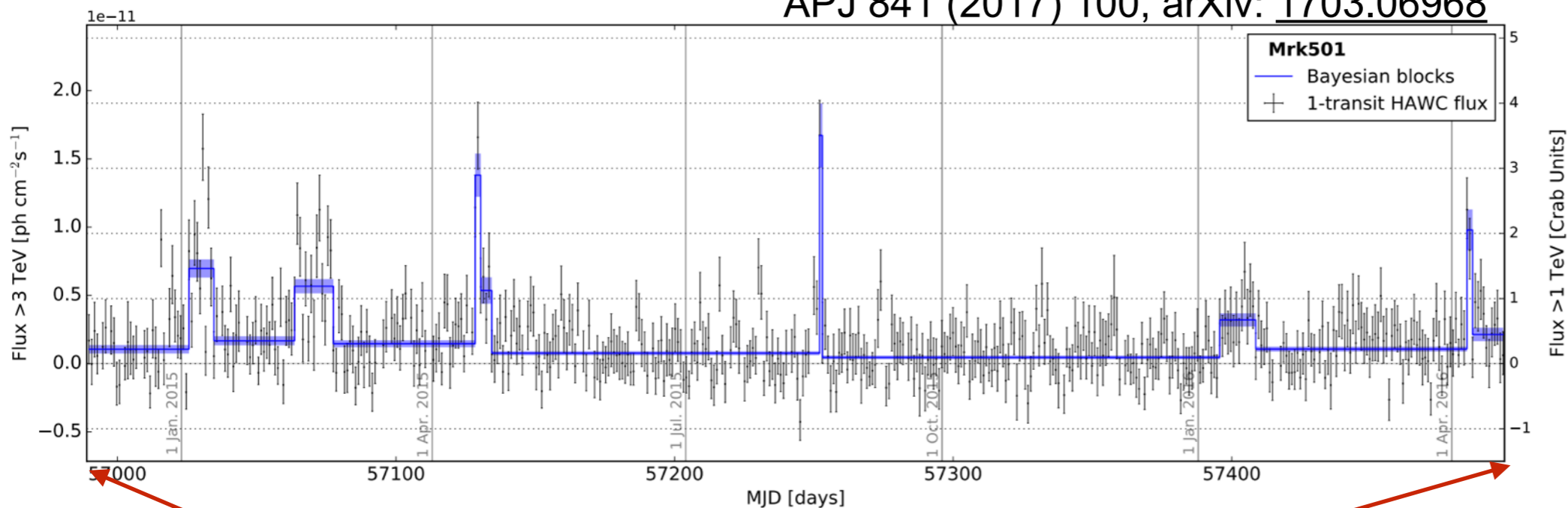
New insights into microquasars: SS433

- microquasars are able to accelerate electrons (?) to VHE energies
- acceleration timescales?
- link to state transitions?

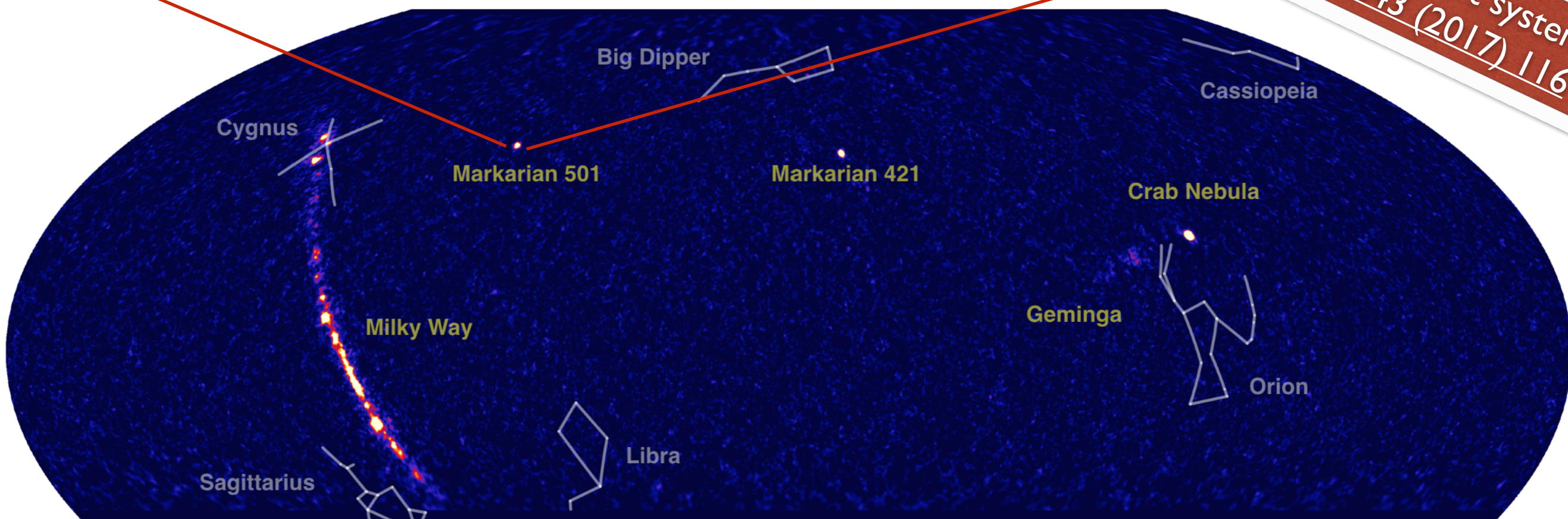


HAWC: monitoring the (Northern) TeV sky

APJ 841 (2017) 100, arXiv: 1703.06968

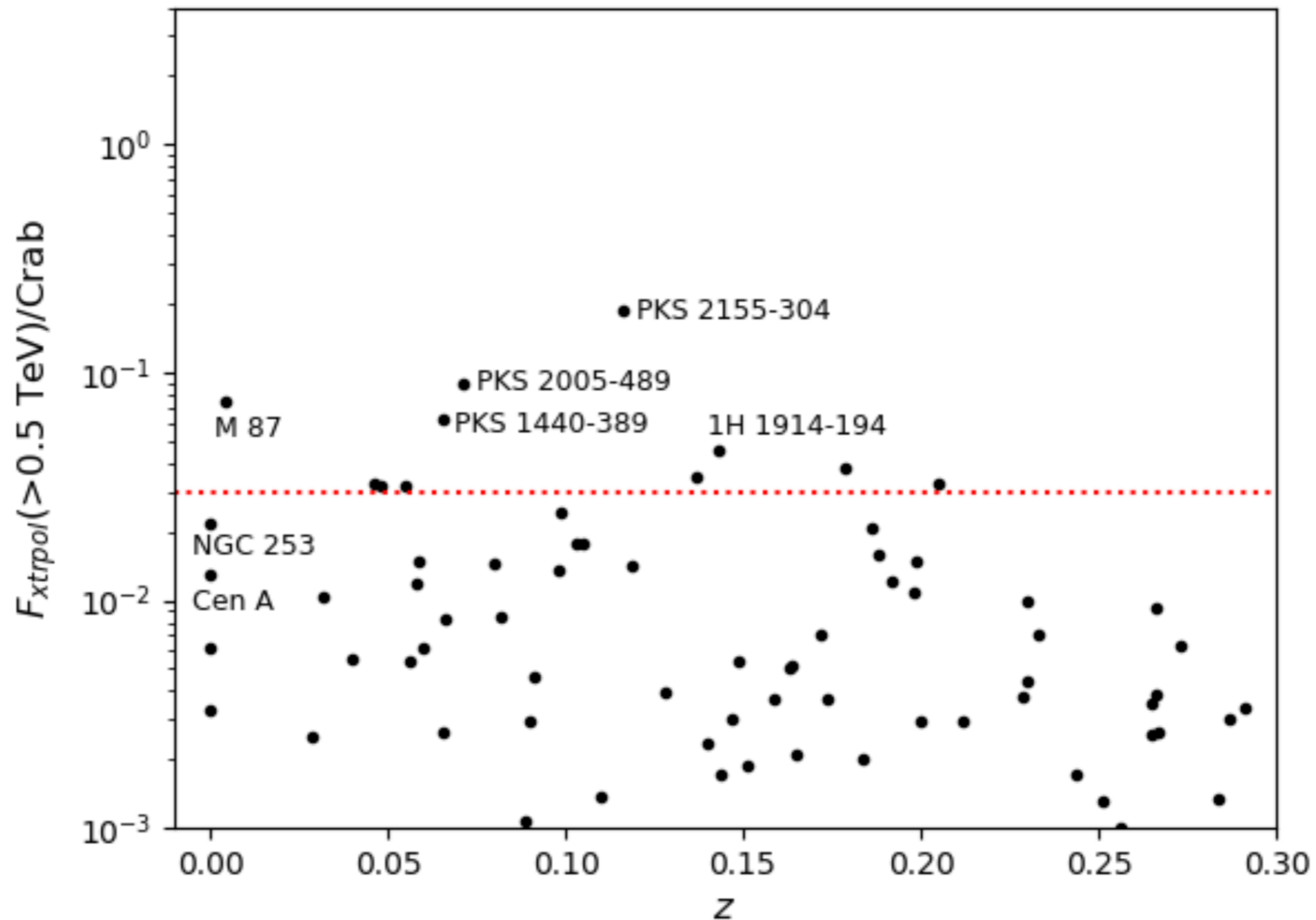


Online alert system
ApJ 843 (2017) 116

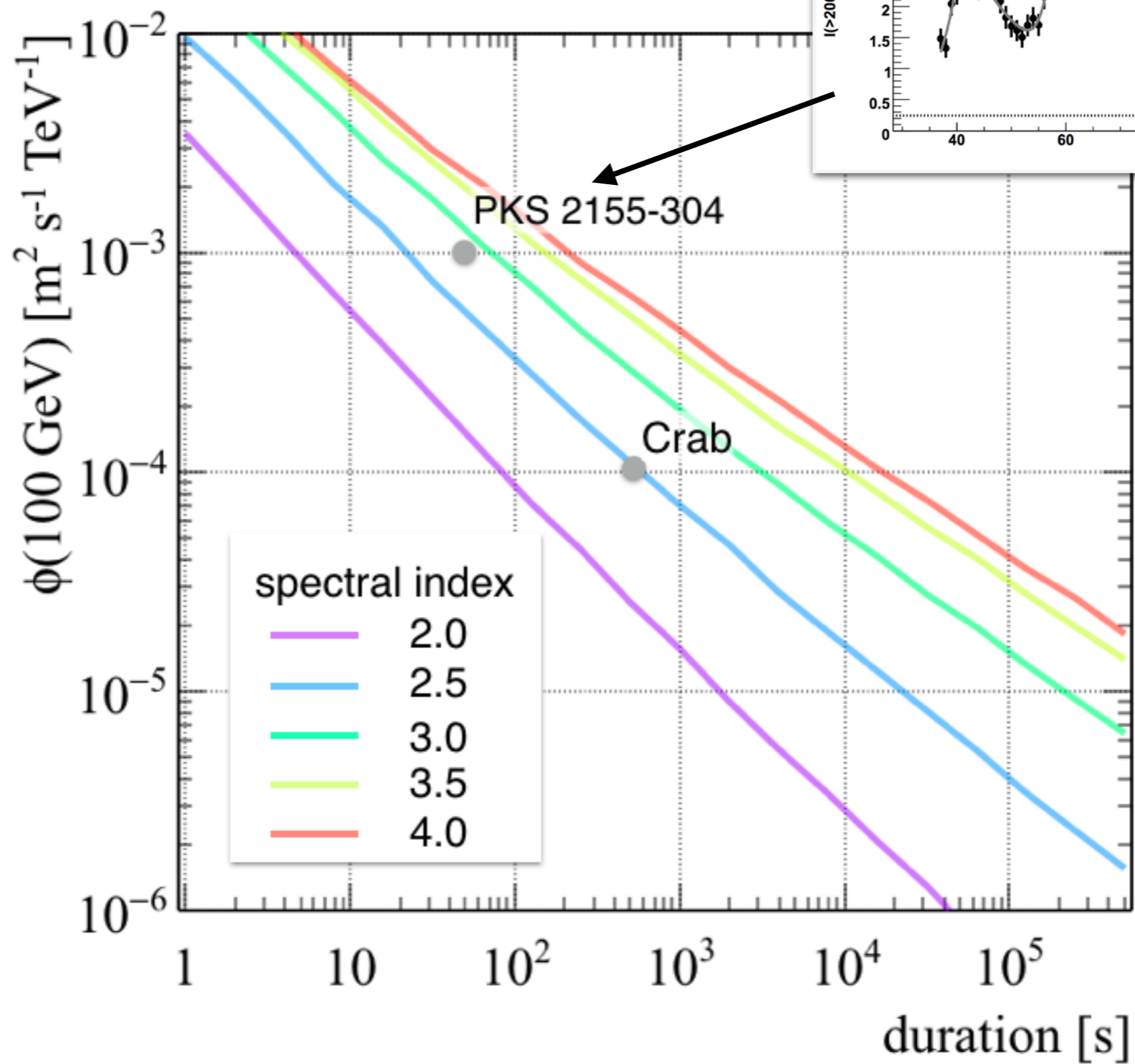


AGNs with SGSO

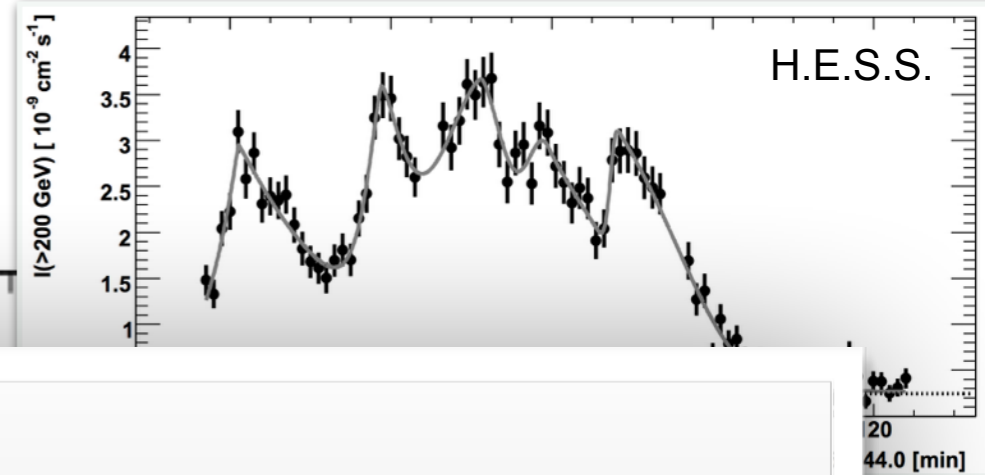
- extrapolation from the Fermi range to SGSO (incl. EBL absorption)



Flare detection with SGSO



Flare detection with SGSO



GeV + variable sources *state of the art*

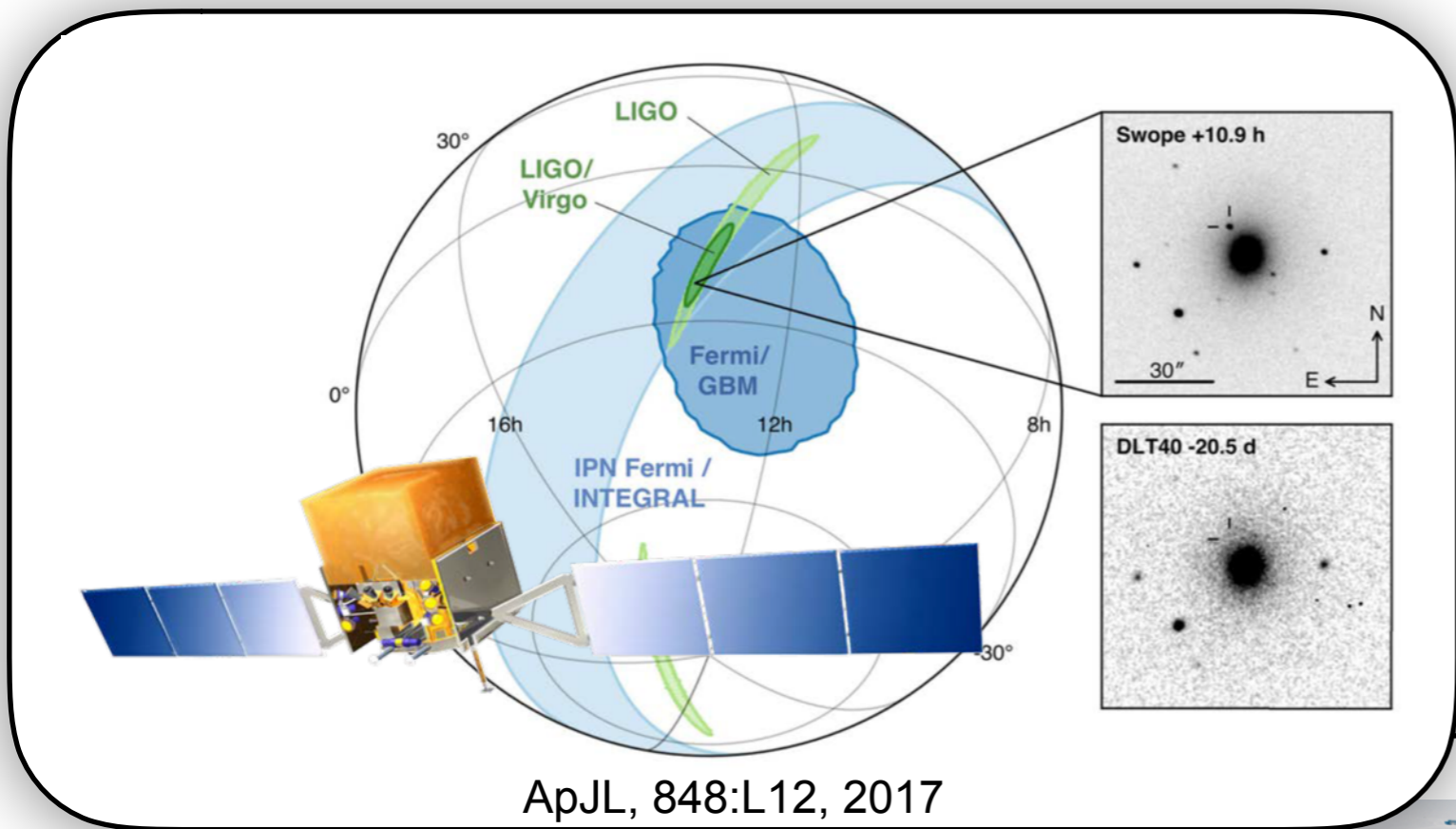
- periodic sources: very deep and high resolution data available
- flaring sources: (longterm) monitoring difficult (Fermi!)

Science with SGSO

- low energy threshold crucial for science case(s)
- long-term monitoring crucial
 - Galactic: microquasars, (binaries), etc.
 - Extragalactic:
 - AGN flares! => MWL follow-up incl. CTA
 - long-term light curves, flare duty-cycles, etc.
 - long-term modulations (e.g. PG 1553+133)

1 10 10⁻¹ 10⁻² 10⁻³ 10⁻⁴ 10⁻⁵ 10⁻⁶ duration [s]

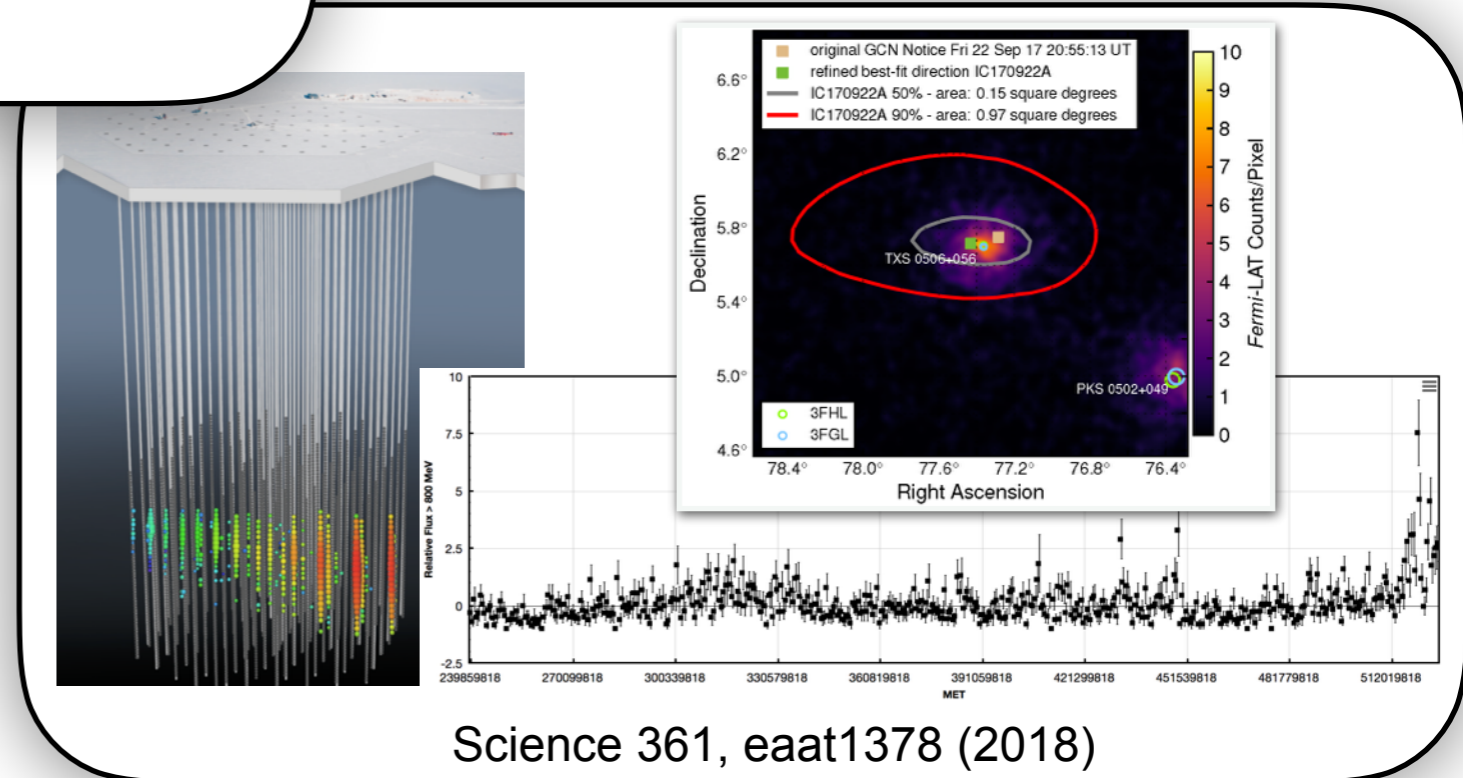
Time-domain multi-messenger astronomy



ApJL, 848:L12, 2017

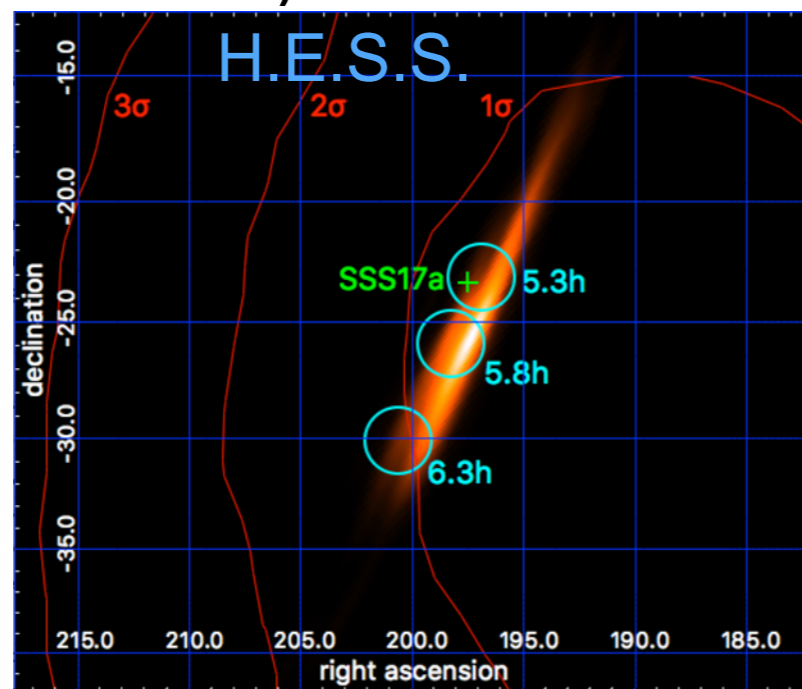
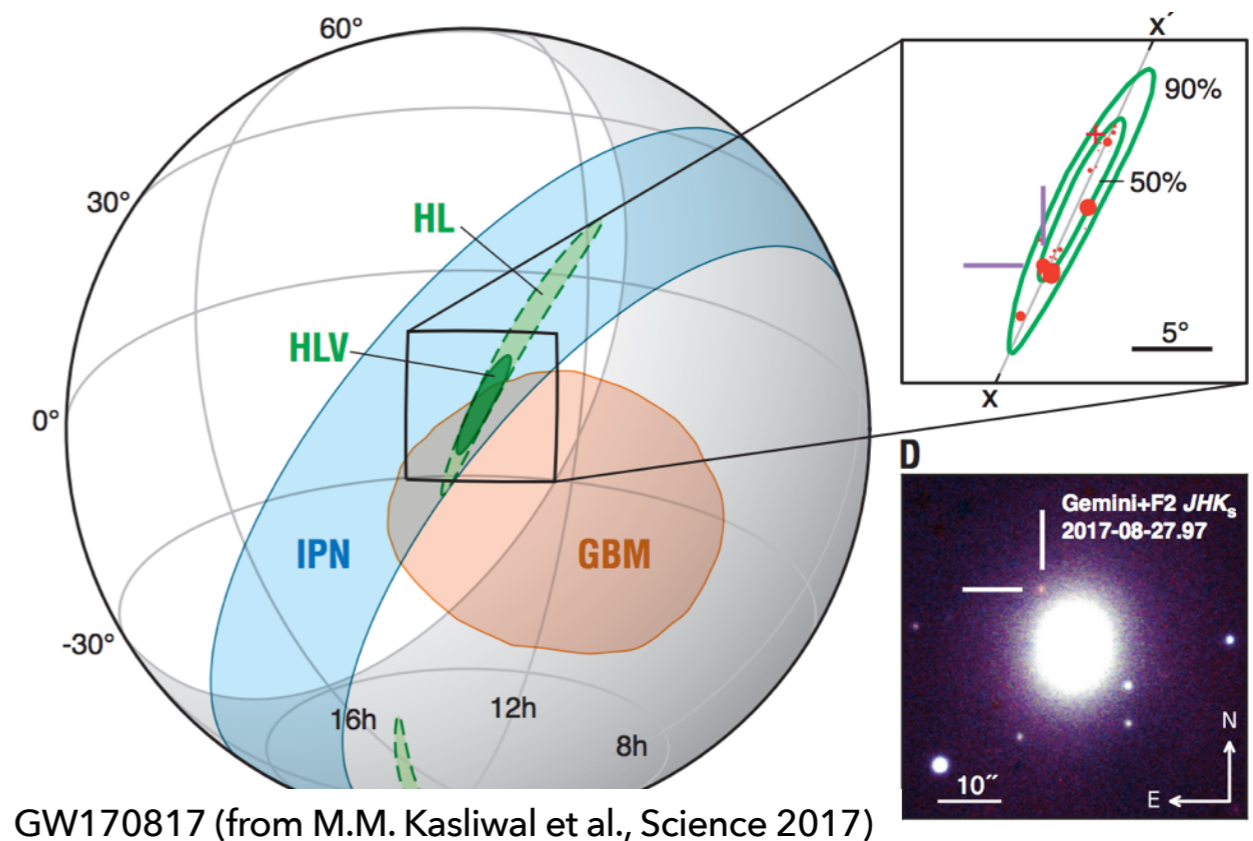
Gravitational waves

High-energy neutrinos

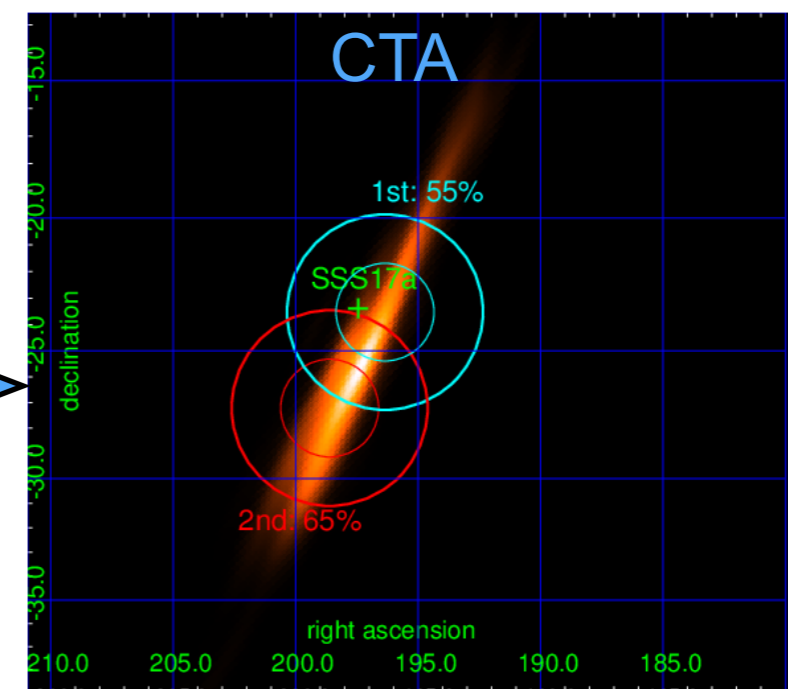


Gravitational waves (and Gamma-Ray Bursts)

- sizable uncertainty regions
- significant number of events
 - 4-80 BNS/yr for Adv. Virgo/LIGO
 - 11-180 BNS/yr for Adv. Virgo+/Ligo+
- GW data analysis + alert emission delays ≈ 5 min
 - only SGSO can "go back in time"
- TeV observations provide interesting results (e.g. B limits)



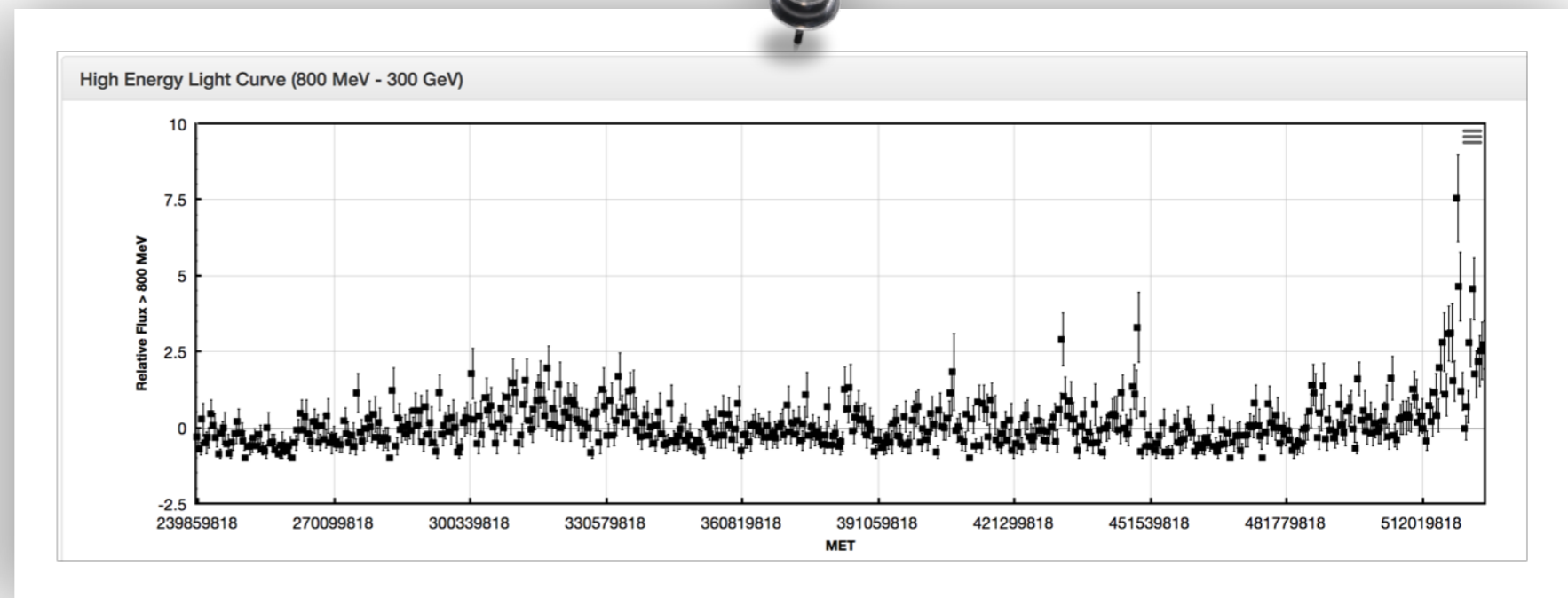
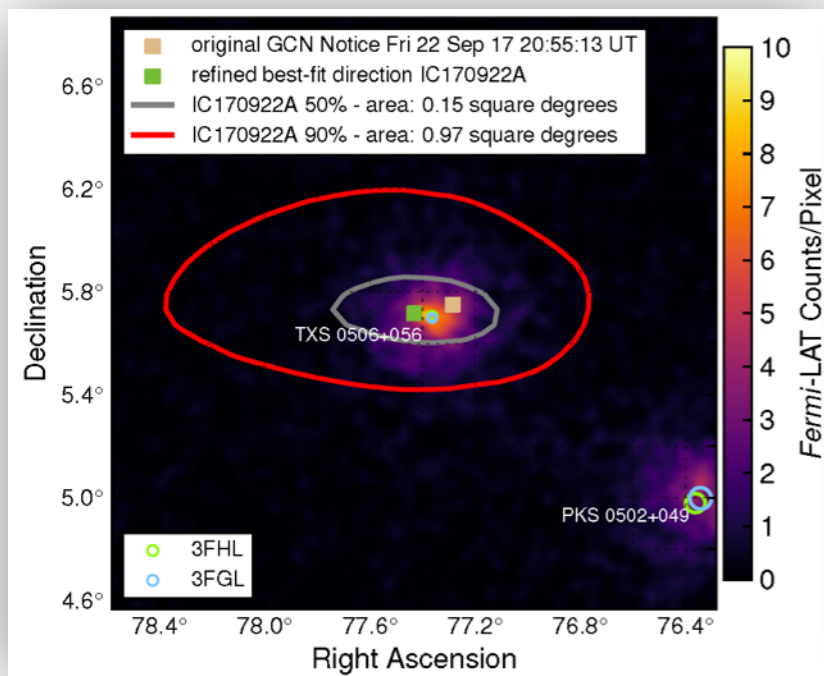
H.E.S.S., ApJL (2017)



FS, TeVPA 2018

Sources of high-energy neutrinos (i.e. cosmic rays)

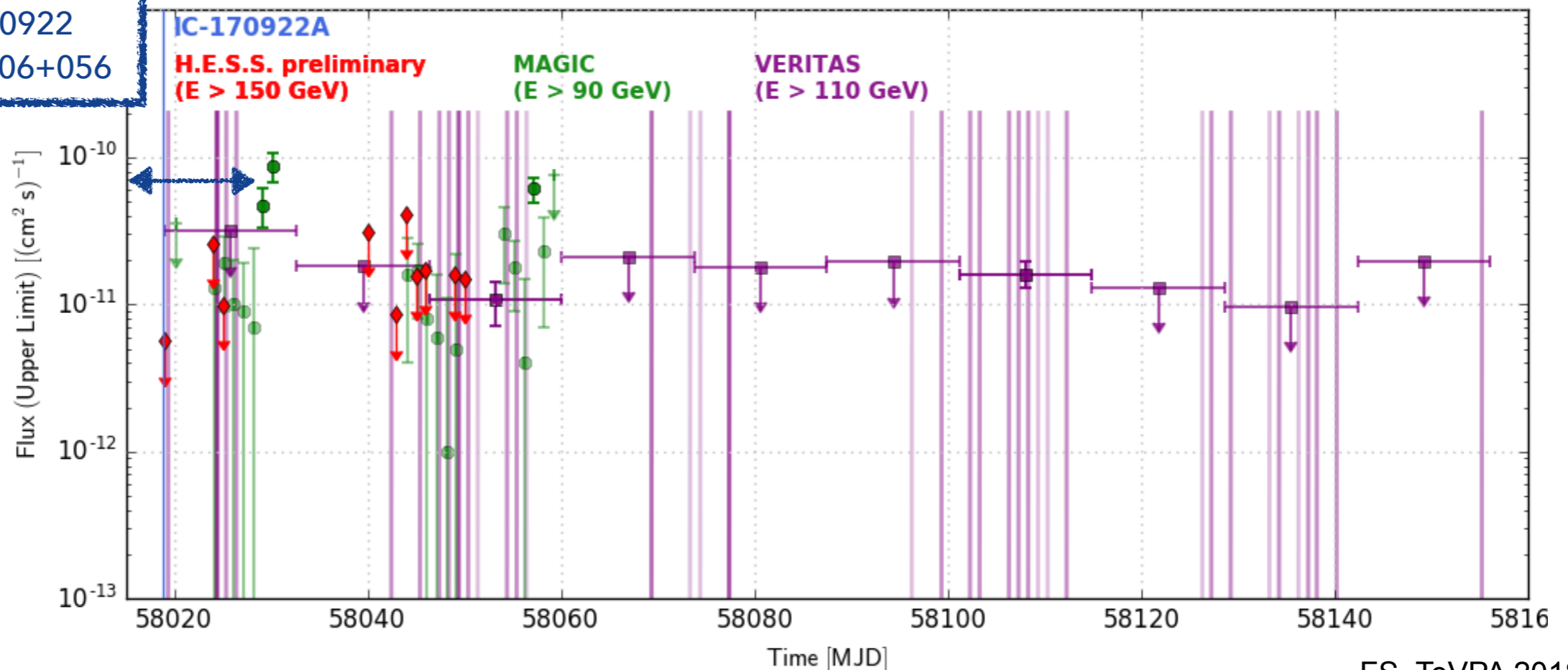
- Online reconstruction + alert emission by neutrino telescopes
 - follow-up campaigns with IACTs + HAWC
- September 22, 2017: detection of a flaring blazar in an IceCube error box
 - TXS 0506+056: flaring in the MeV-GeV band for several months + up to 400GeV by MAGIC



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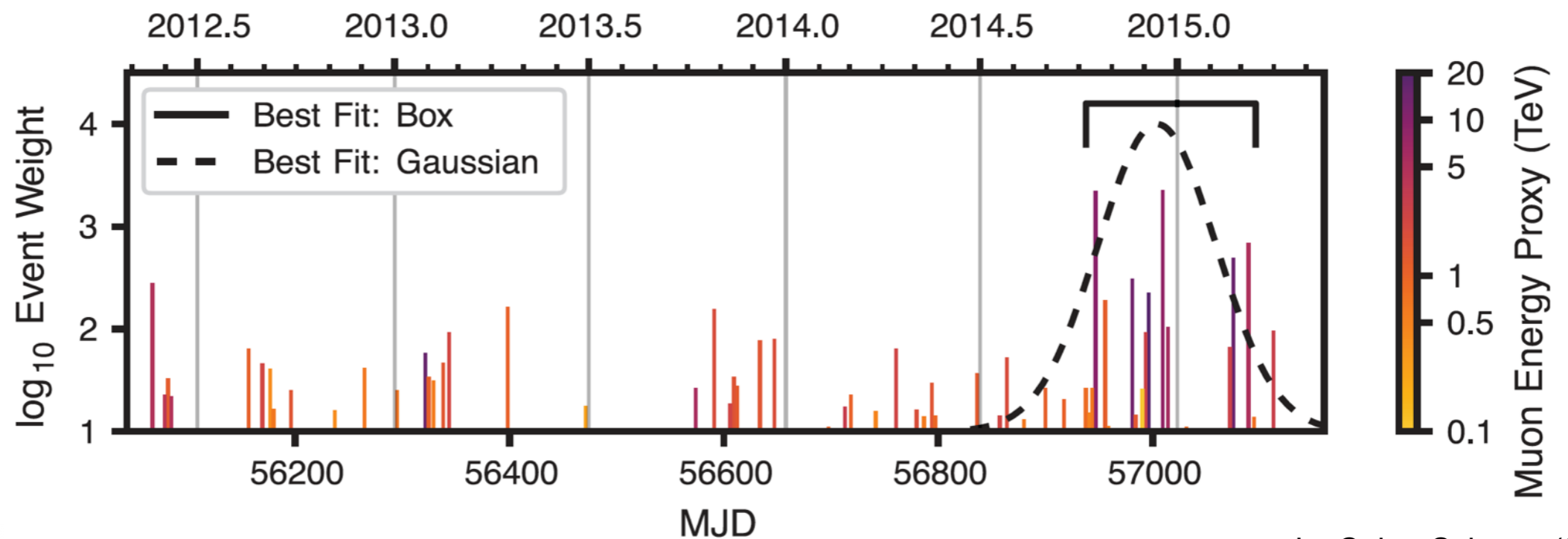
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 - no emission detected by rapid H.E.S.S. follow-up (~4h after the neutrino)
 - MAGIC detection only 11 days after the neutrino event

11 days between IC-170922 and TeV flare of TXS 0506+056



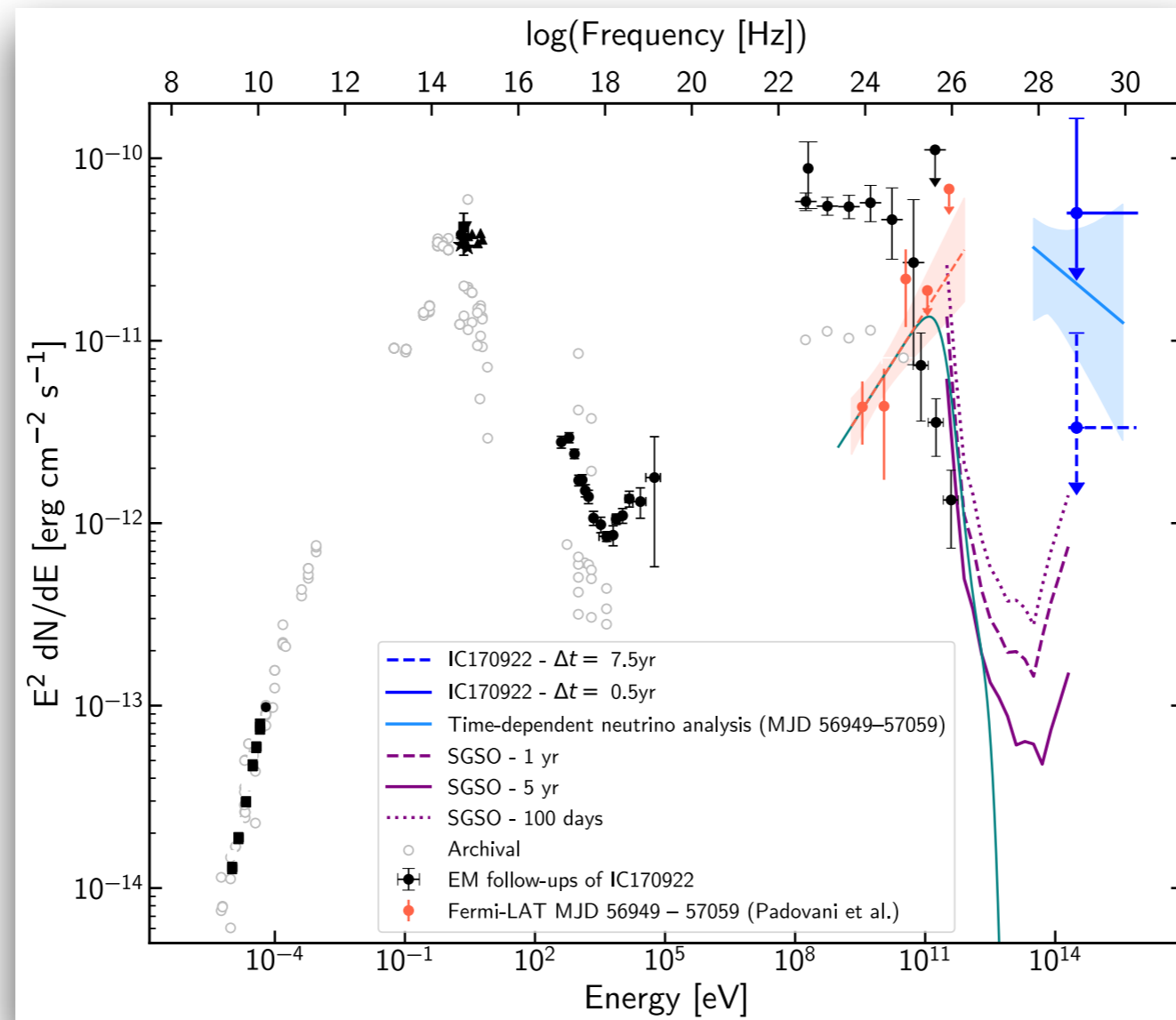
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- 2014/2015: neutrino flare recovered by dedicated IceCube analysis
 - only monitoring instruments are able to provide archival data (e.g. HAWC)



Sources of high-energy neutrinos (i.e. cosmic rays)

- SGSO can provide crucial information on the link between GeV/TeV and PeV energy range (depending on the source redshift!)
- archival data + longterm observations



Monitoring the Transient Sky

- Multi-messenger astrophysics is a reality now
 - many efforts with current and future IACTs
 - temporal coverage limited by alert emission delays
- Gamma-ray Bursts
 - extensive follow-up program with MAGIC + H.E.S.S.: no detection yet
- many other transient phenomena
 - Fast Radio Bursts (discovered in archival data; alert alert emission delays still significant)
 - Optical transient factories coming online (e.g. ZTF, LSST, etc.)

Monitoring the Transient Sky

- GRBs + multi-messenger transients *state of the art*
 - first contributions by IACTs (GW170817, TXS 0506+056)
 - interesting results but very time consuming
 - still no GRB detection

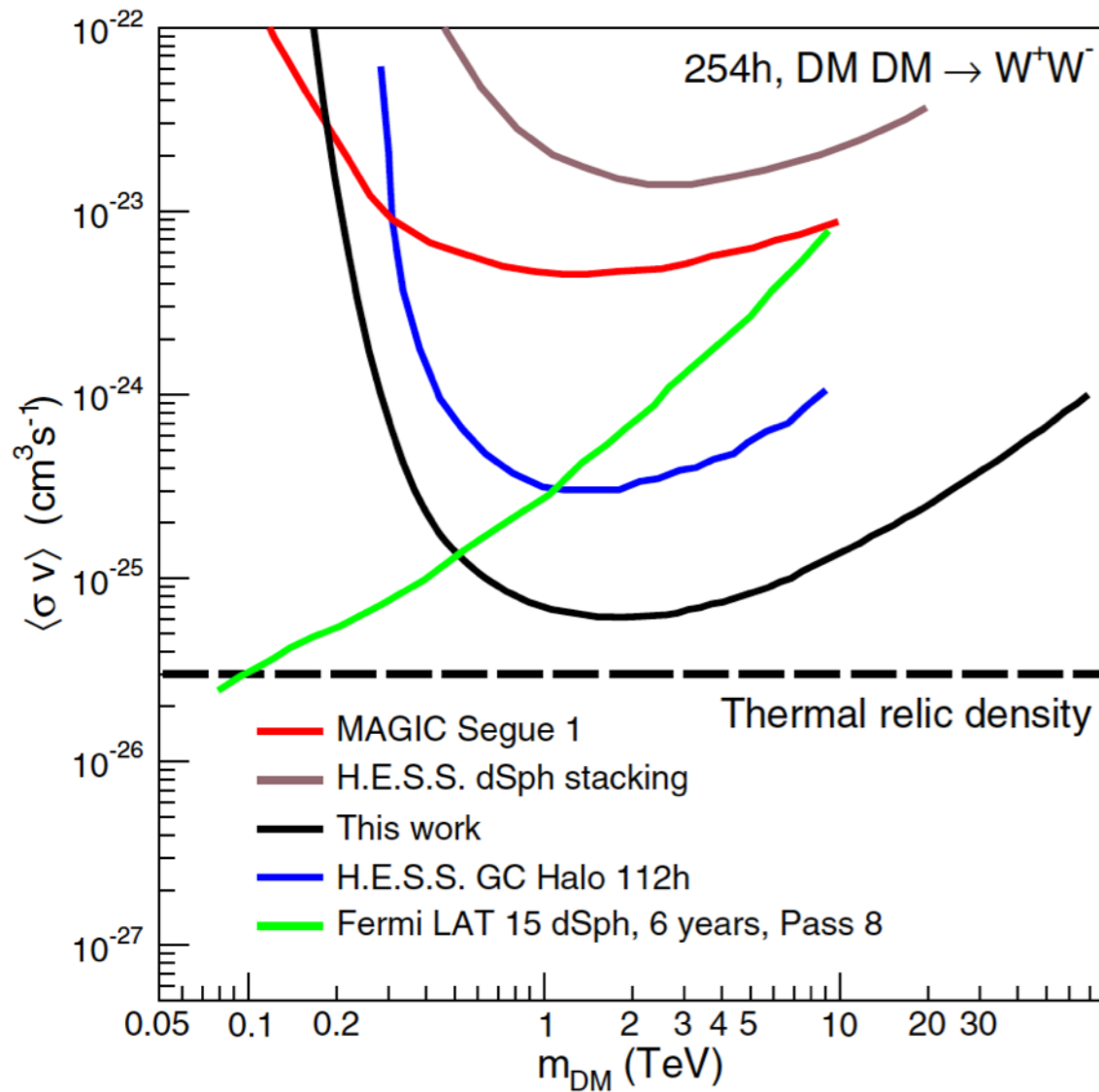
Science with SGSO

- low energy threshold crucial for most science case(s)
- large FoV + monitoring capabilities
 - retro-active and unbiased follow-up of MM alerts
 - high-energy neutrinos (IceCube $\sim 1 \text{ deg}^2$)
 - Gravitational Waves (10s-100s deg^2)
 - significant increases in the number of alerts expected
 - IceCube-Gen2, Adv.Virgo+/Ligo+, ...

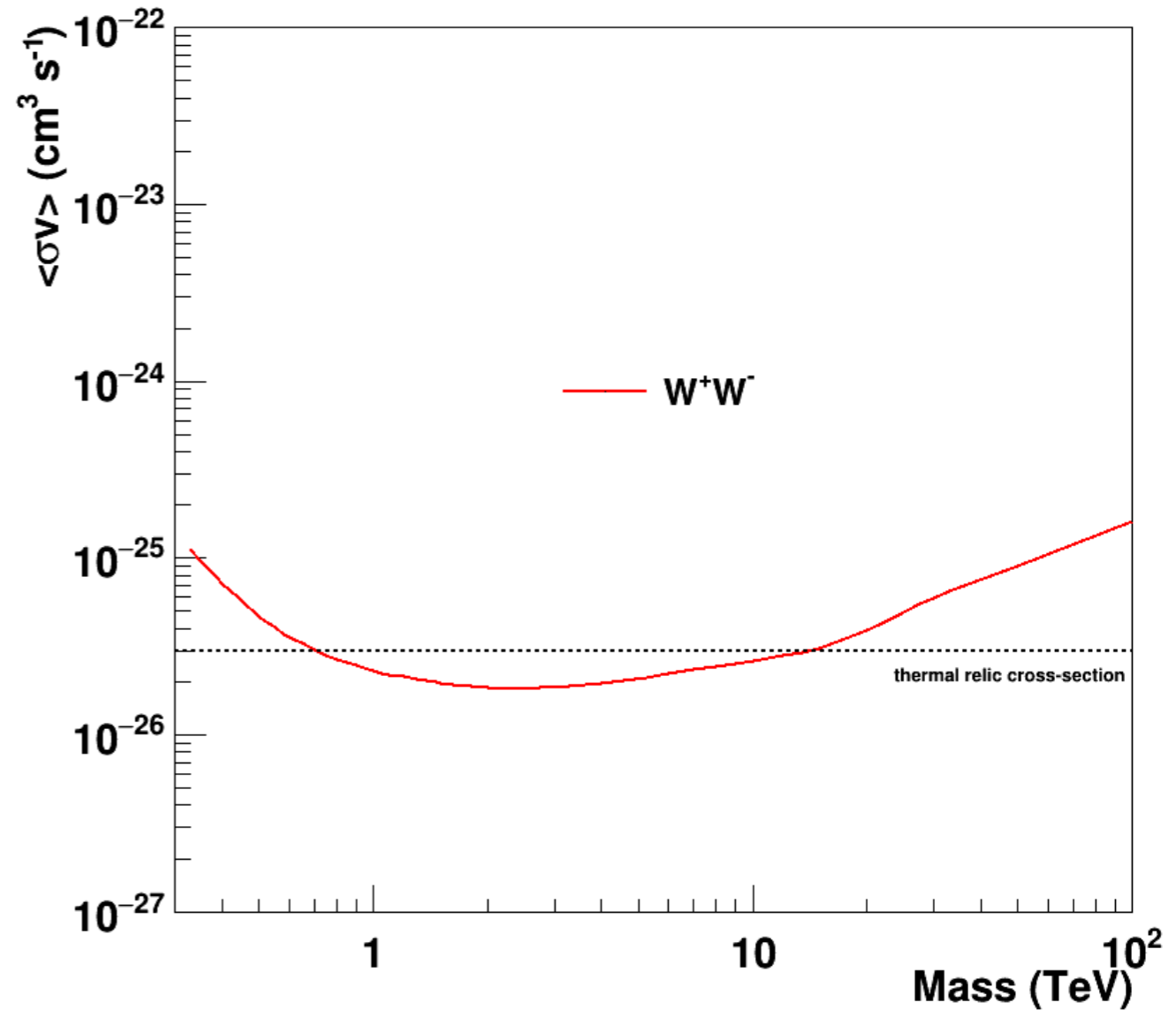
Physics beyond the SM: dark matter searches

- 10 years of H.E.S.S.
- 2D-likelihood (spatial + energy)

- 10 years of SGSO
- 2D-likelihood (spatial + energy)

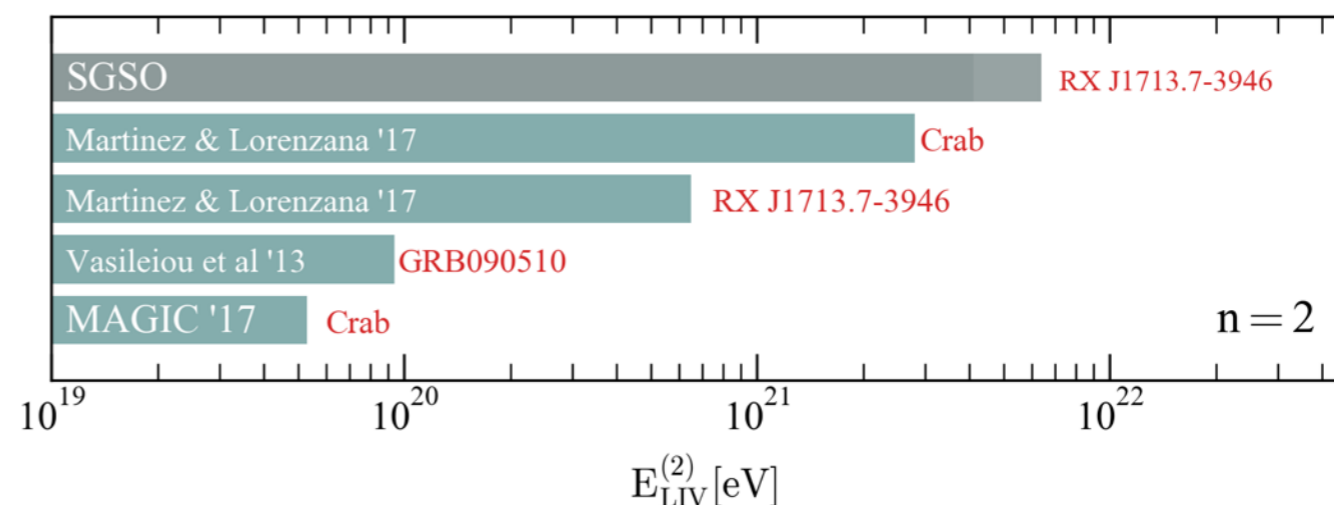
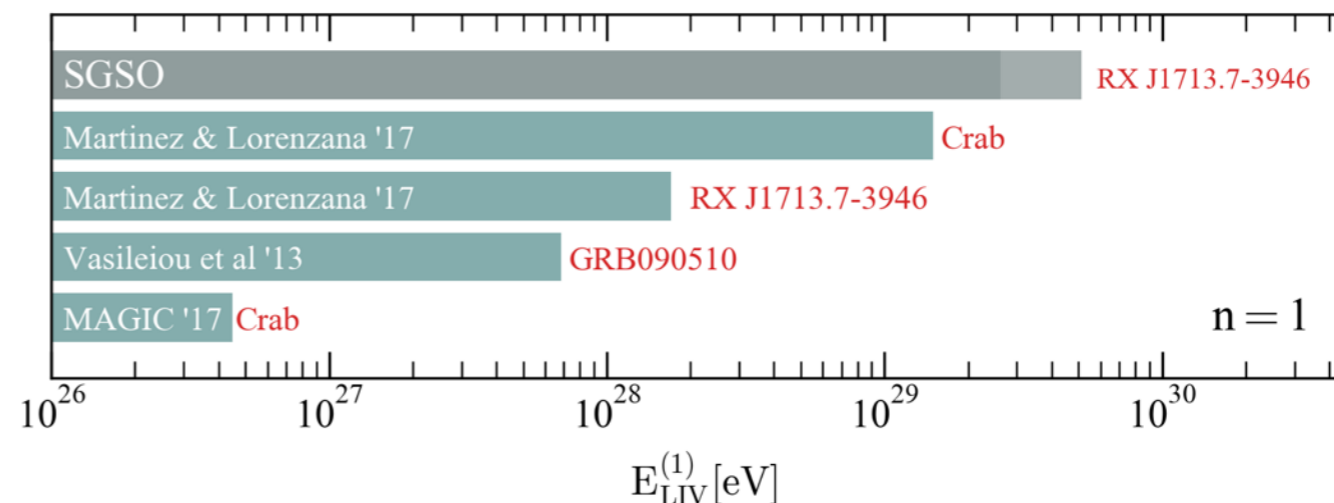


H.E.S.S., PRL (2016)



Other searches beyond the SM

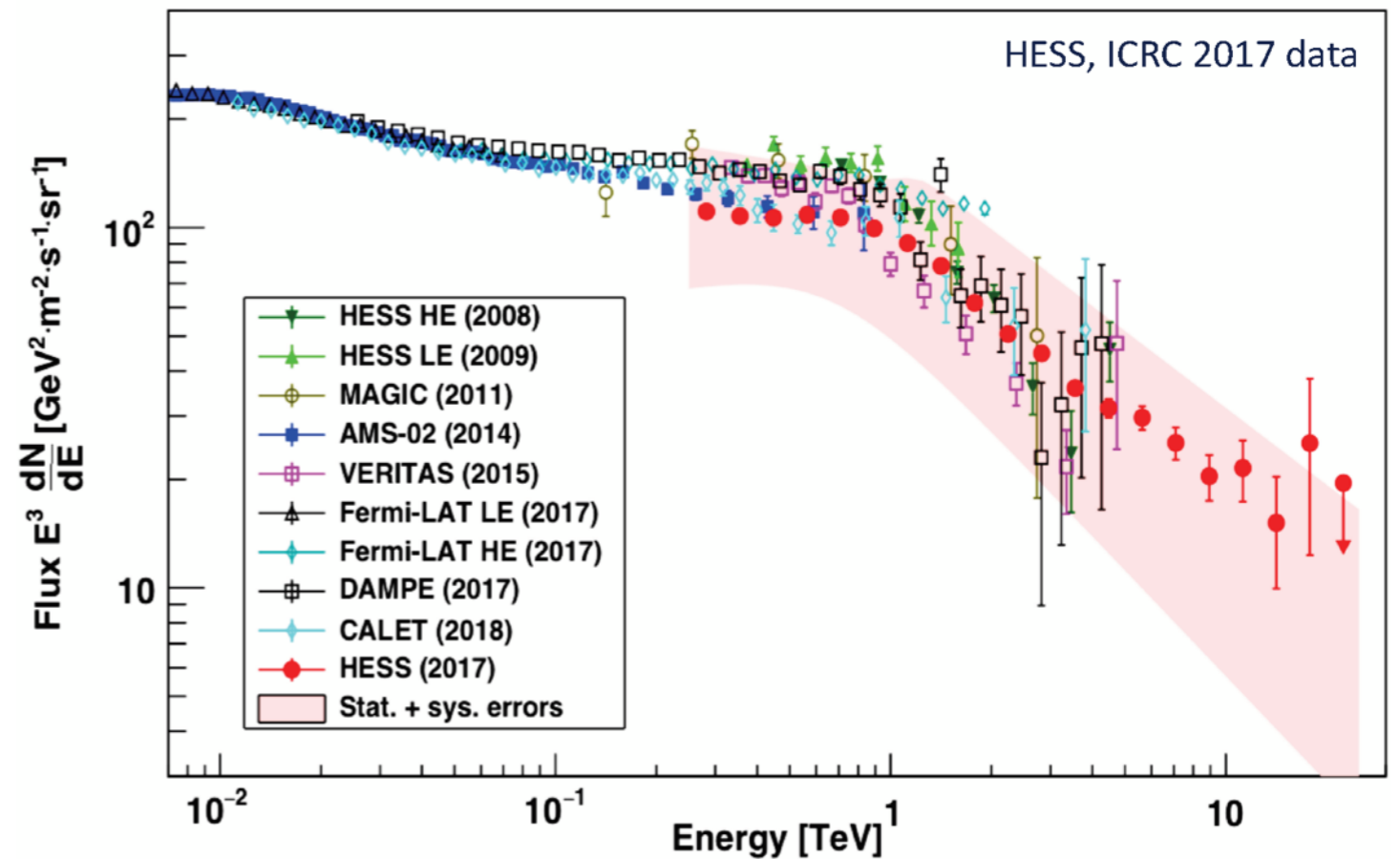
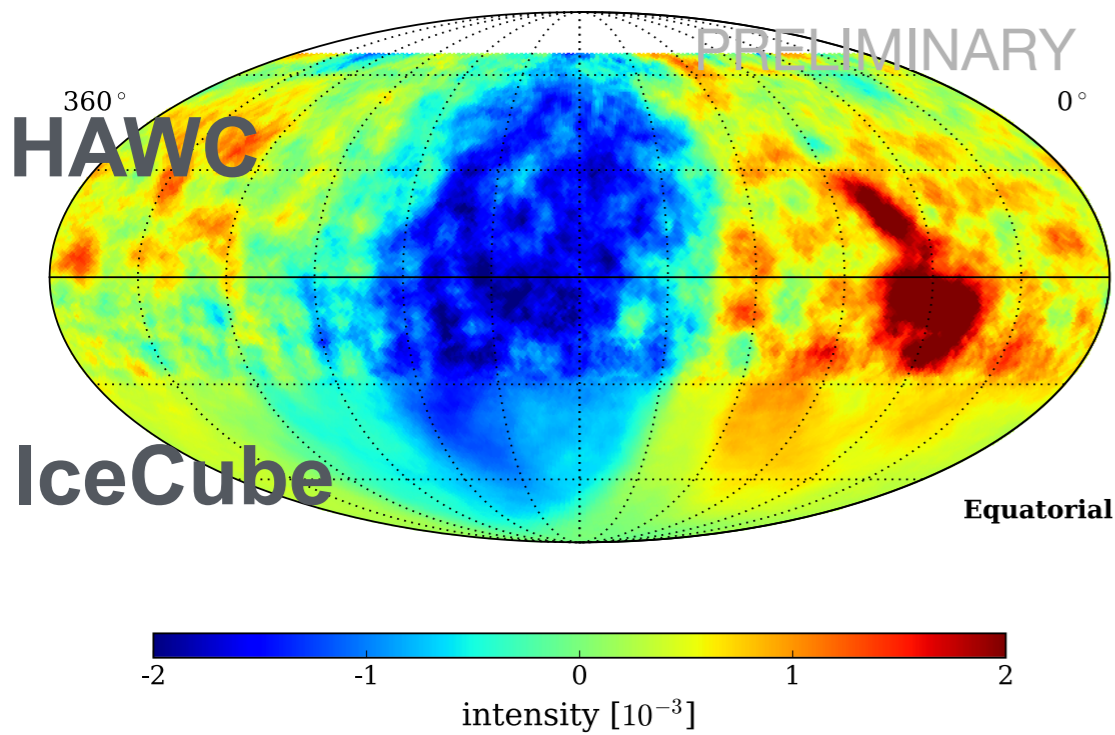
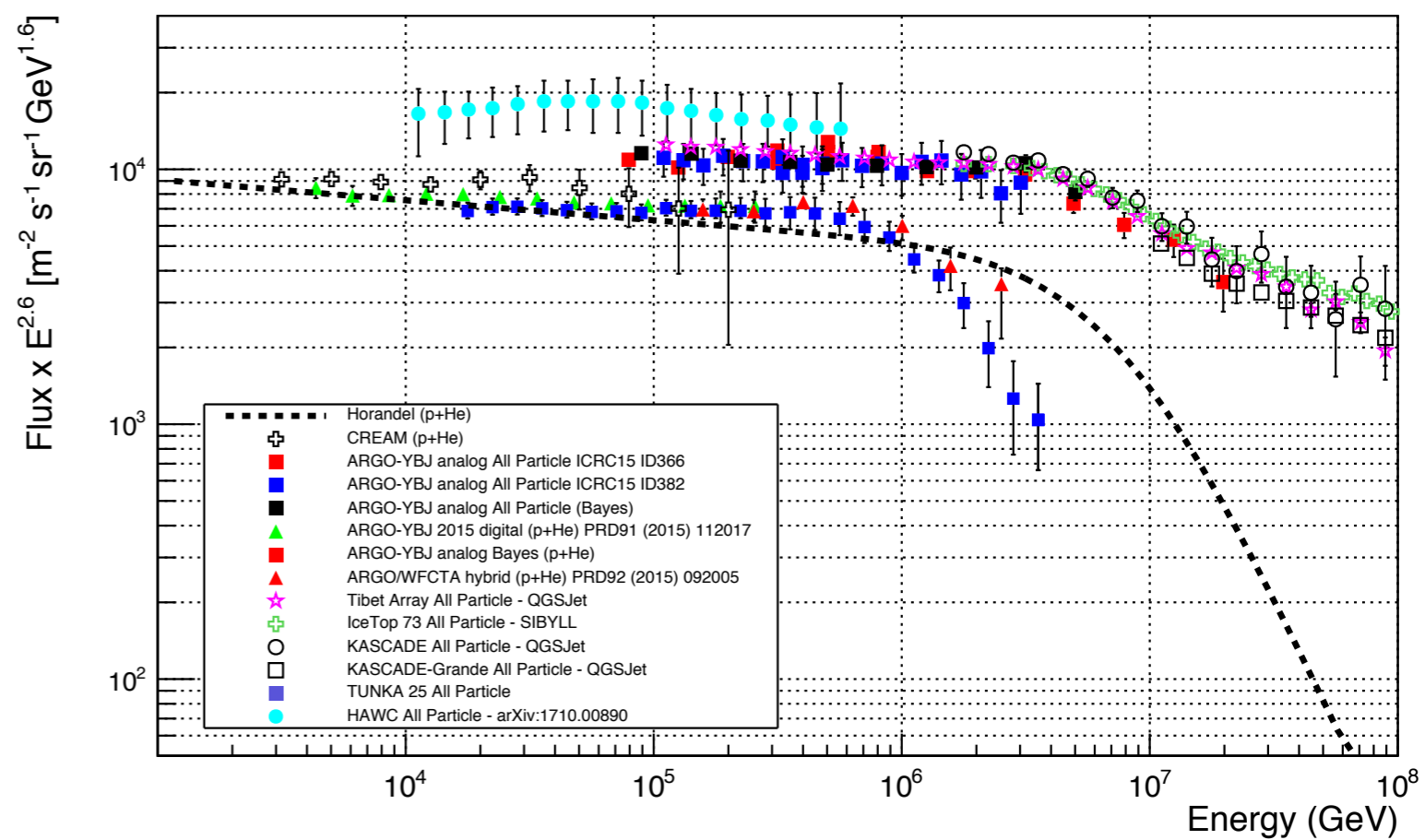
- Lorentz invariance violation
 - e.g. photon decay



- Primordial black holes: Hawking radiation during evaporation
 - other phenomena producing short bursts (e.g. low luminosity GRBs, FRBs, etc.)

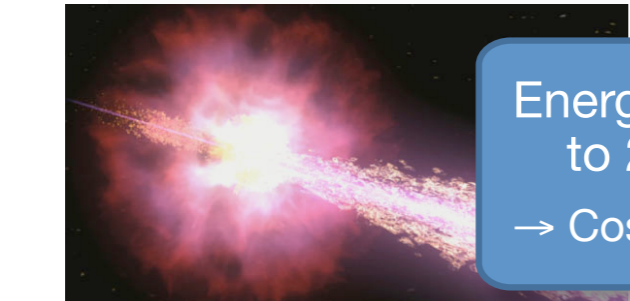
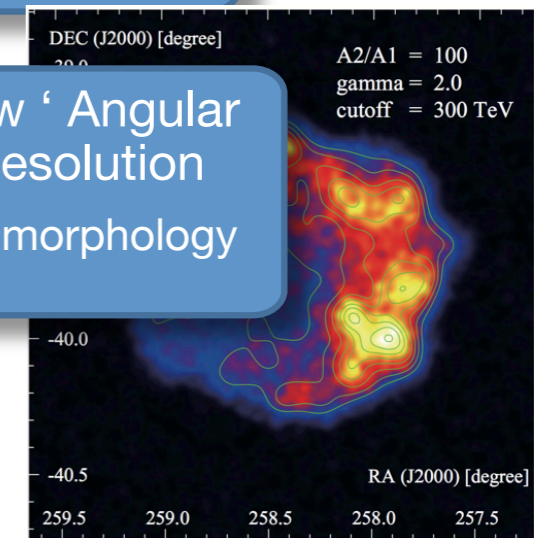
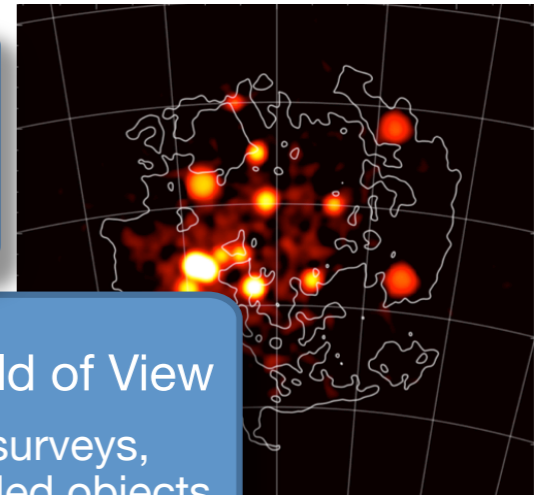
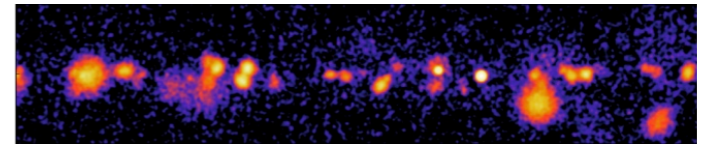
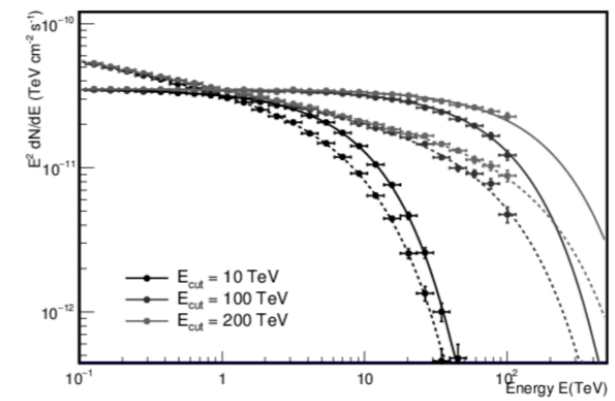
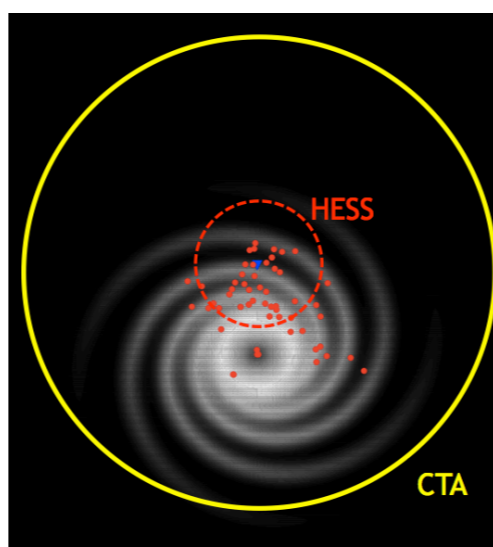
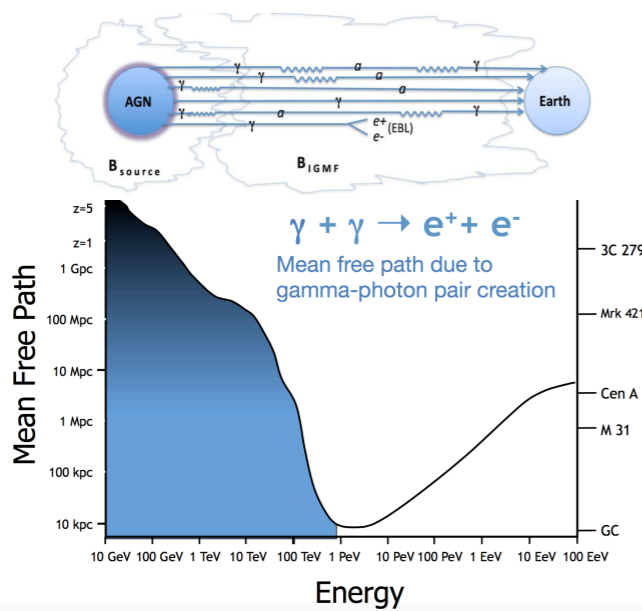
Cosmic rays

- interesting E range
- mass composition
 - muon tagging
- large scale anisotropies
- electron spectrum



Summary

- current IACTs:
 - extensive legacy datasets (e.g. HGPS, SNRs, etc.)
 - deep and high resolution observations of steady sources
 - low energy threshold and rapid responses (e.g. H.E.S.S.-II): the transient sky
 - high sensitivity but (usually) require external triggers
- HAWC
 - source catalog(s) at the highest energies
 - extended sources!
 - monitoring promising (e.g. Mrk flares), low energy sensitivity crucial!



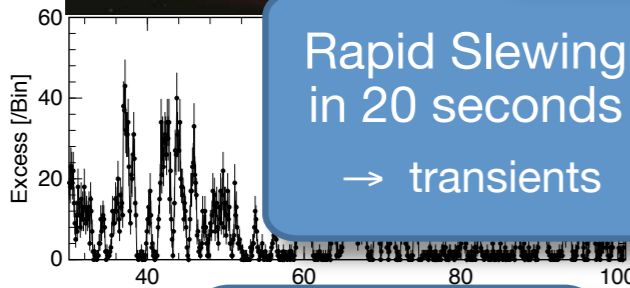
Energies down to 20 GeV
→ Cosmology++

10 x Sensitivity,
Large Collection Area
→ all topics

Energies up to 300 TeV
→ Pevatrons

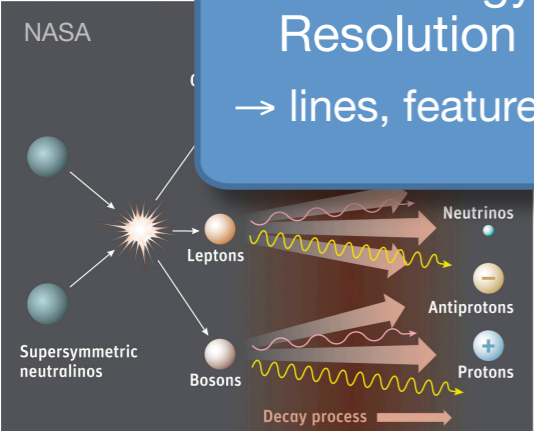
Rapid Slewing
in 20 seconds
→ transients

8° Field of View
→ surveys,
extended objects



10% Energy Resolution
→ lines, features

Few ' Angular Resolution
→ morphology



Some personal thoughts on the SGSO science case and links to performance requirements

- sensitivity at high energies: largely uncharted territory
 - Galactic Pevatron(s)
 - challenging due to limited angular resolution compared to IACTS
- low energy threshold: opens extragalactic sky (EBL absorption)
 - discovery space (no extensive surveys yet, CTA: 1/4 of the sky)
 - monitoring of transient phenomena
 - Galactic: microquasars, binaries, etc. => highly uncertain (but SS 443!!)
 - Extragalactic: AGNS, GRBs, multi-messengers, etc.
 - requires good fluence sensitivity and low energy threshold
 - alerts to the MWL community + deep follow-up with CTA

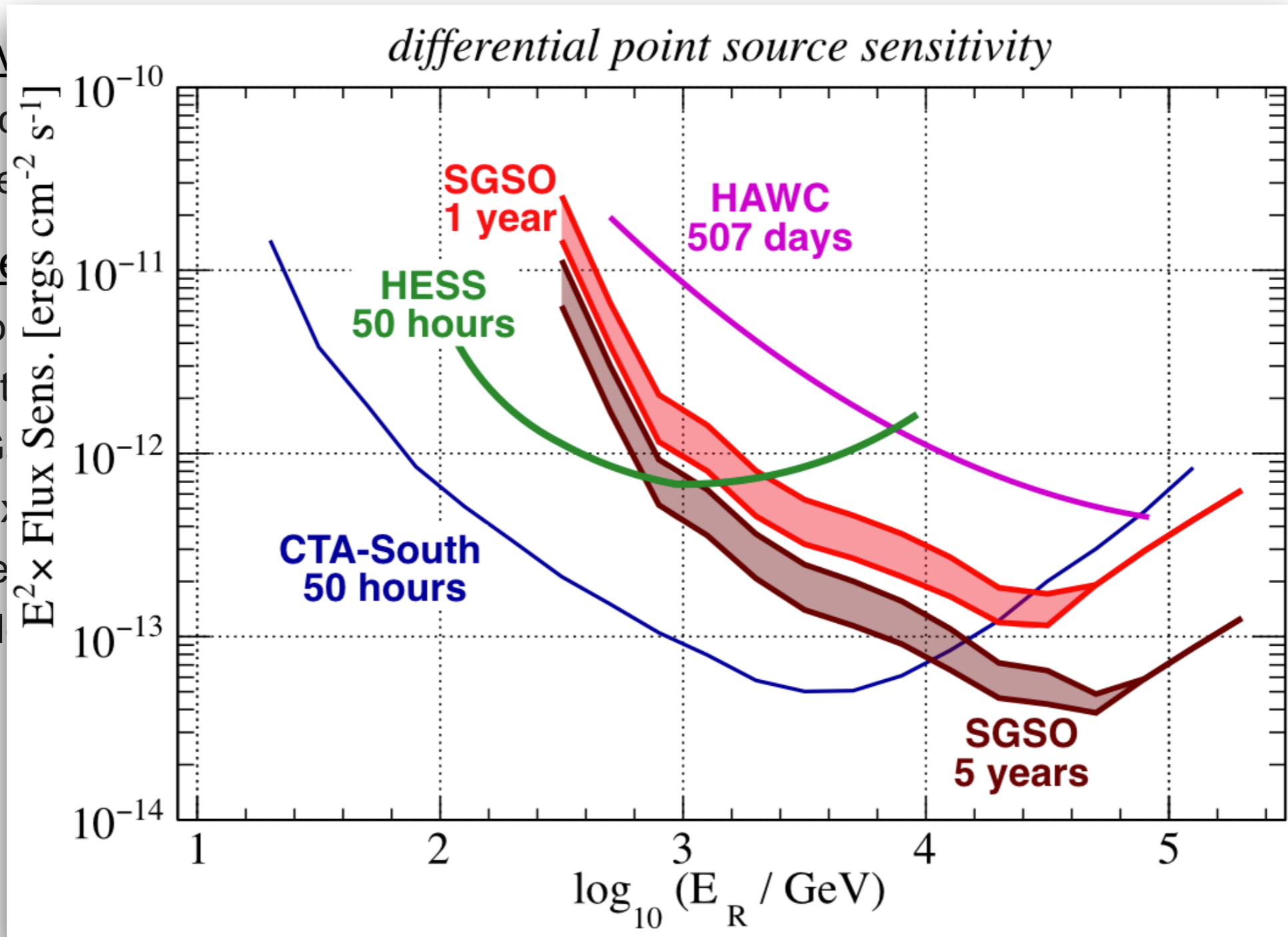
Some personal thoughts on the SGSO science case and links to performance requirements

- sensitivity

- Galac
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- low ene

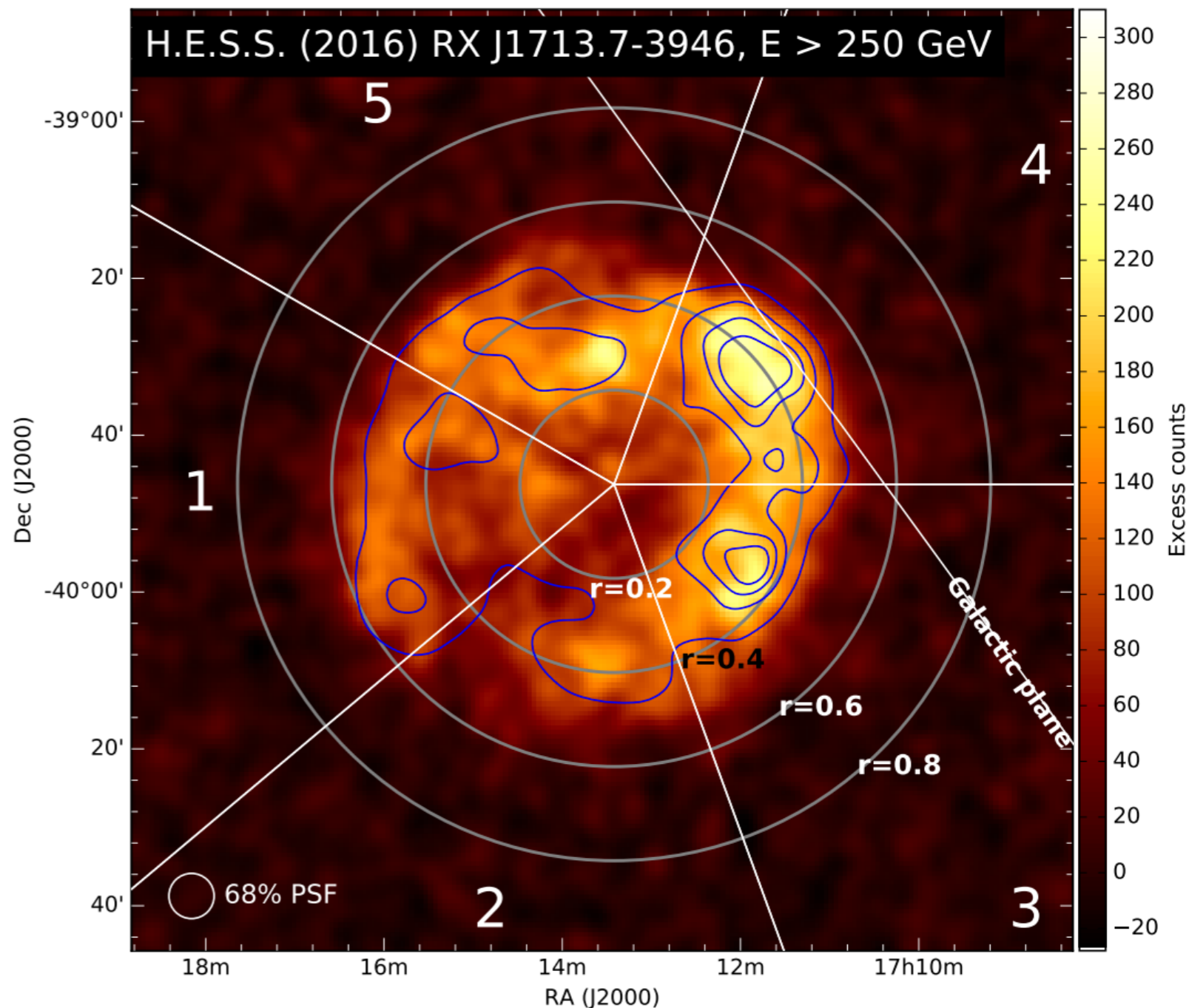
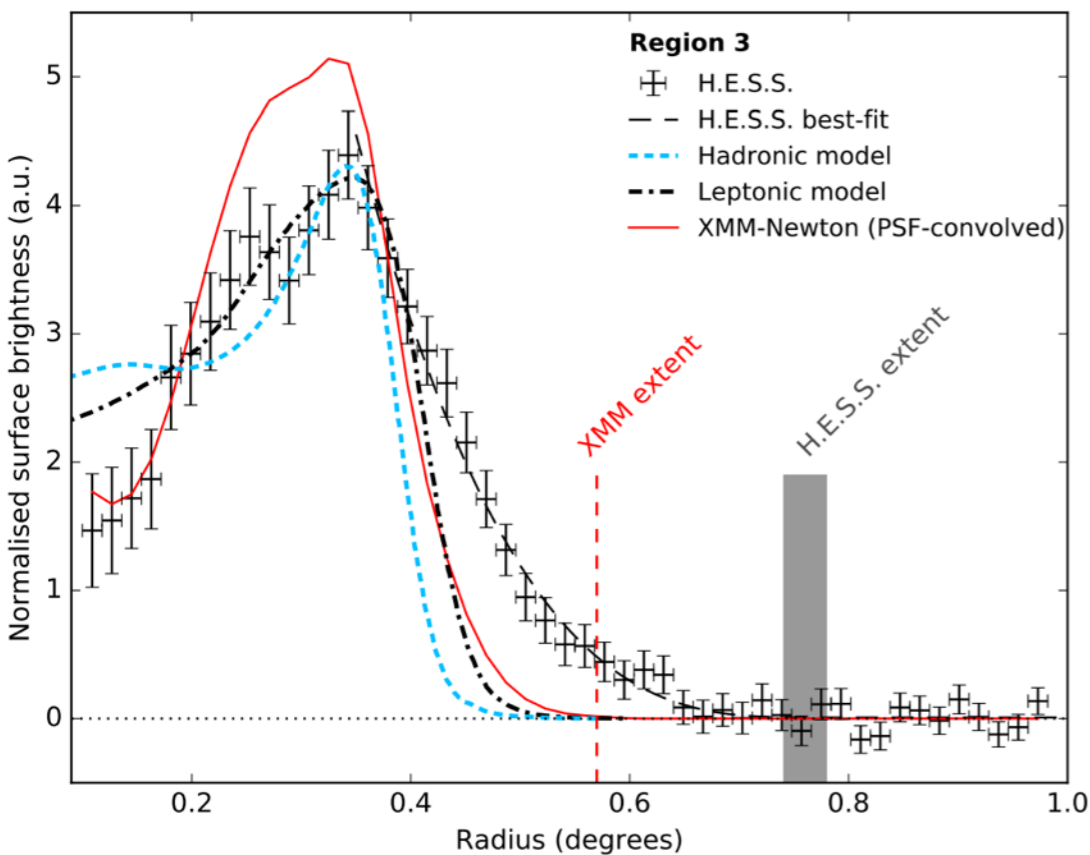
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Backup

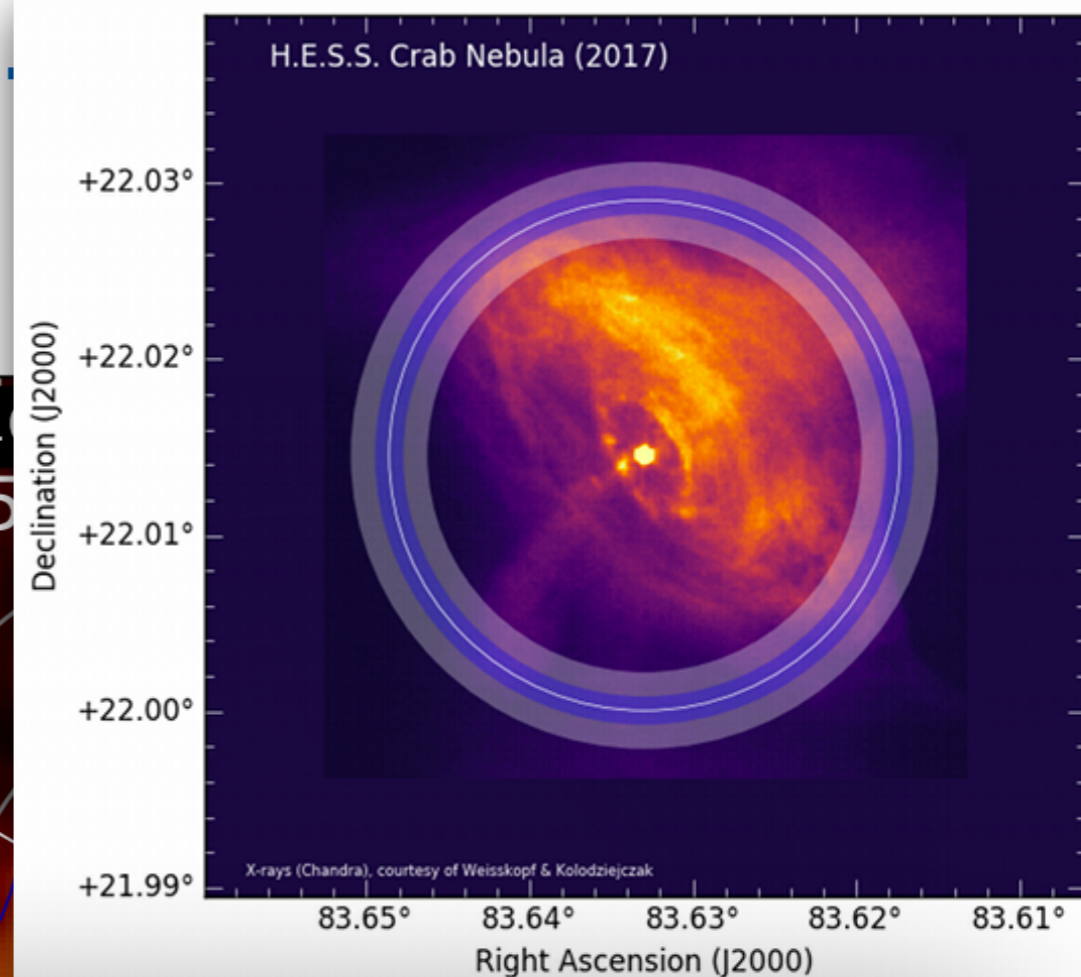
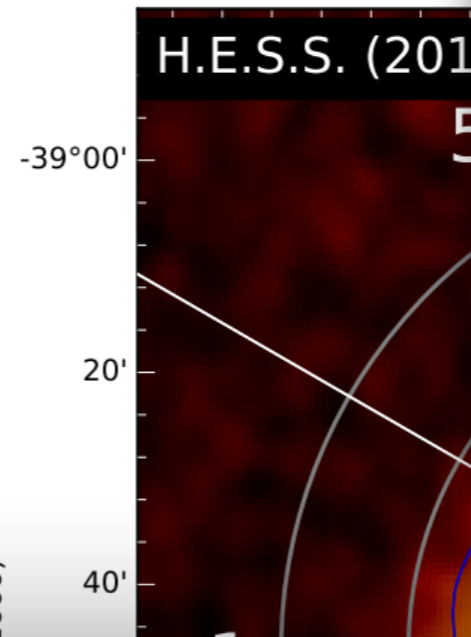
Individual sources (e.g. RXJ1713.7)

- 2004-2012
- livetime: 164h (spectrum:116h)
- comparison with X-rays (XMM)
 - high-energy particles leaving the acceleration region



Individual sources (e.g. RXJ1713.5-3946)

- 2004-2012
- livetime: 164h (spectrum:116h)
- comparison with X-rays (XMM)
 - high-energy particles leaving the acceleration region



Individual sources (SNRs, PWNs, etc.) *state of the art*

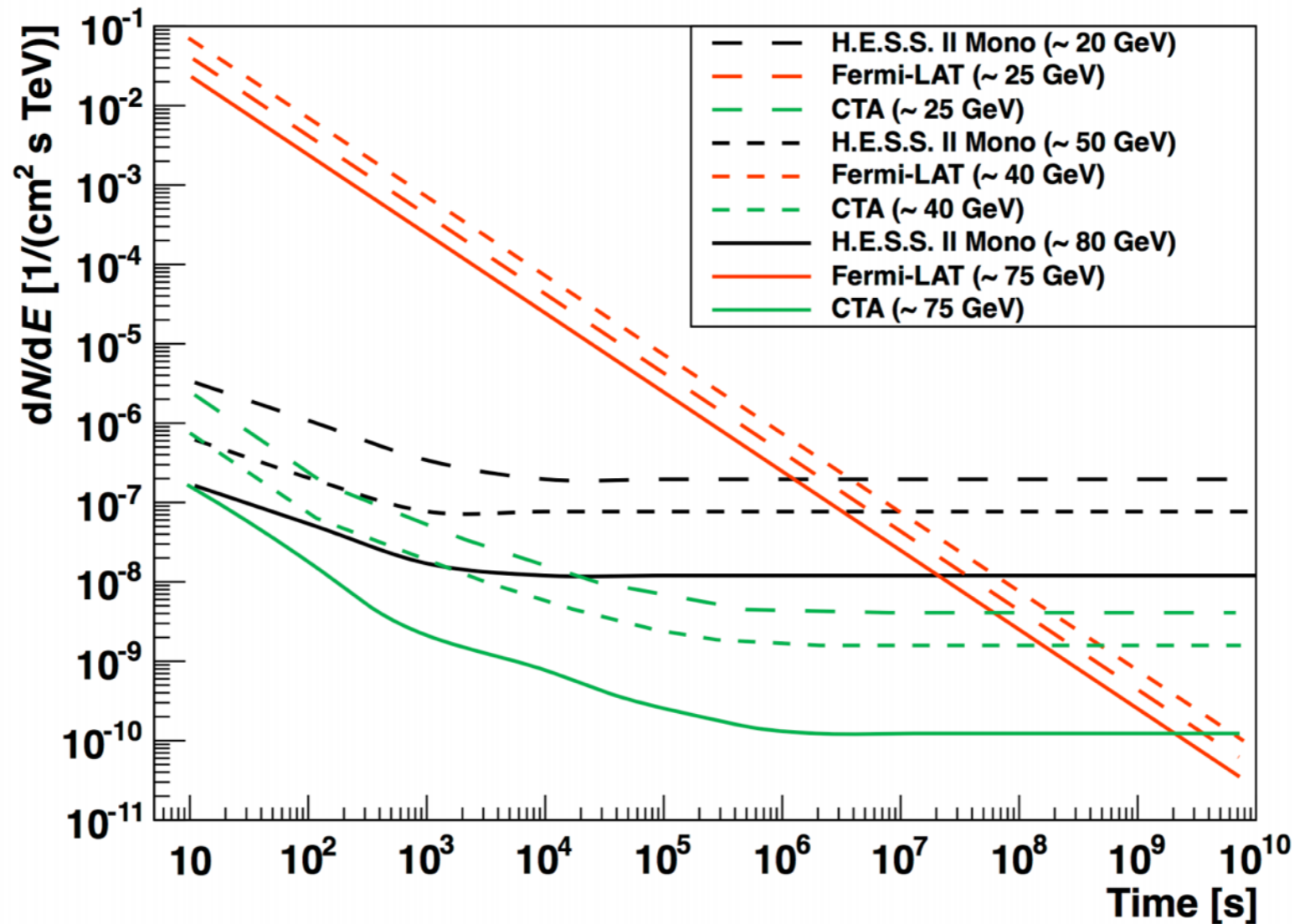
- deep and high resolution data available
- dedicated CTA observations

Science case for SGSO

- sensitivity at high energies (low energies lacking angular resolution)

Fast transients with IACTs

- decreasing response times + best sensitivity
 - incompressible delays due to alert emission
 - SGSO is full-sky and can "go back in time"



Transient phenomena: multi-wavelength connections

- GeV-TeV connection important
 - e.g. variable systems like binaries
 - (anti)- correlations between GeV-TeV domains
 - AGN flares

