Lecture 2: Gamma-ray Astrophysics

Ultra High Energy \\ Cosmic Rays

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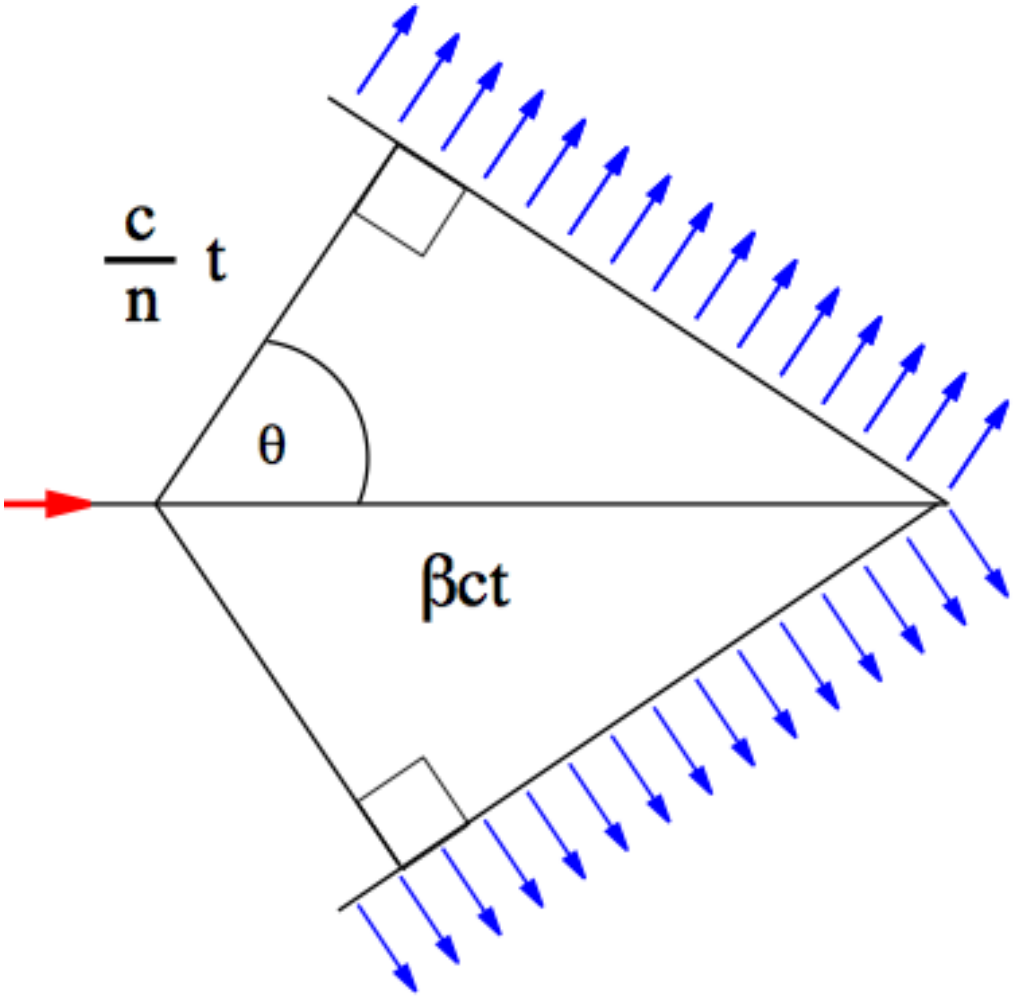
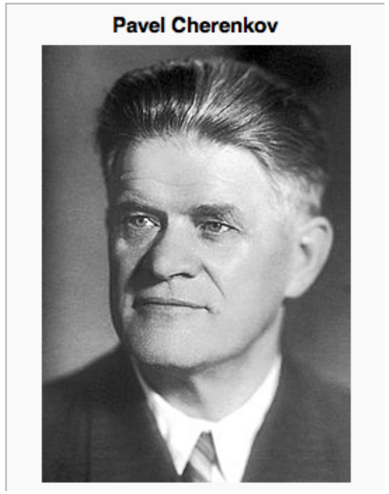
Overview:

- Cherenkov radiation
- Detection technics
- Present and future experiments
- Galactic gamma-ray sources and diffused background
- Extragalactic sources and backgrounds
- Study of intergalactic magnetic fields
- Indirect detection of Dark Matter
- Conclusions

Cherenkov radiation

Cherenkov radiation





Discovery 1934

Nobel prize 1958

Cherenkov radiation

$V > V_m = c/n$

n is refractive index of medium

$n = 1.008$ air

$n = 1.33$ water

The charged particles polarize the molecules, which then turn back rapidly to their ground state, emitting prompt radiation

Cherenkov light is emitted under a constant Cherenkov angle with the particle trajectory, given by

$$\cos\delta = \frac{V_m}{V} = \frac{c}{nV} = \frac{1}{\beta n}$$

$$\gamma_{\min} = \frac{n}{\sqrt{n^2 - 1}}$$

- Minimal energy of charge particle

Main processes used in gamma-ray astrophysics

$$\gamma + \gamma_B \Rightarrow e^- + e^+$$

$$e^\pm + \gamma_B \Rightarrow e^\pm + \gamma$$

$$e^\pm + B \Rightarrow e^\pm + \gamma_{synch}$$

$$e^\pm + A_B \Rightarrow e^\pm + A_B + \gamma_{brems}$$

$$P + \gamma_B \Rightarrow N + \pi$$

$$P + P_B \Rightarrow N + N + \sum \pi$$

$$\pi^0 \Rightarrow 2\gamma$$

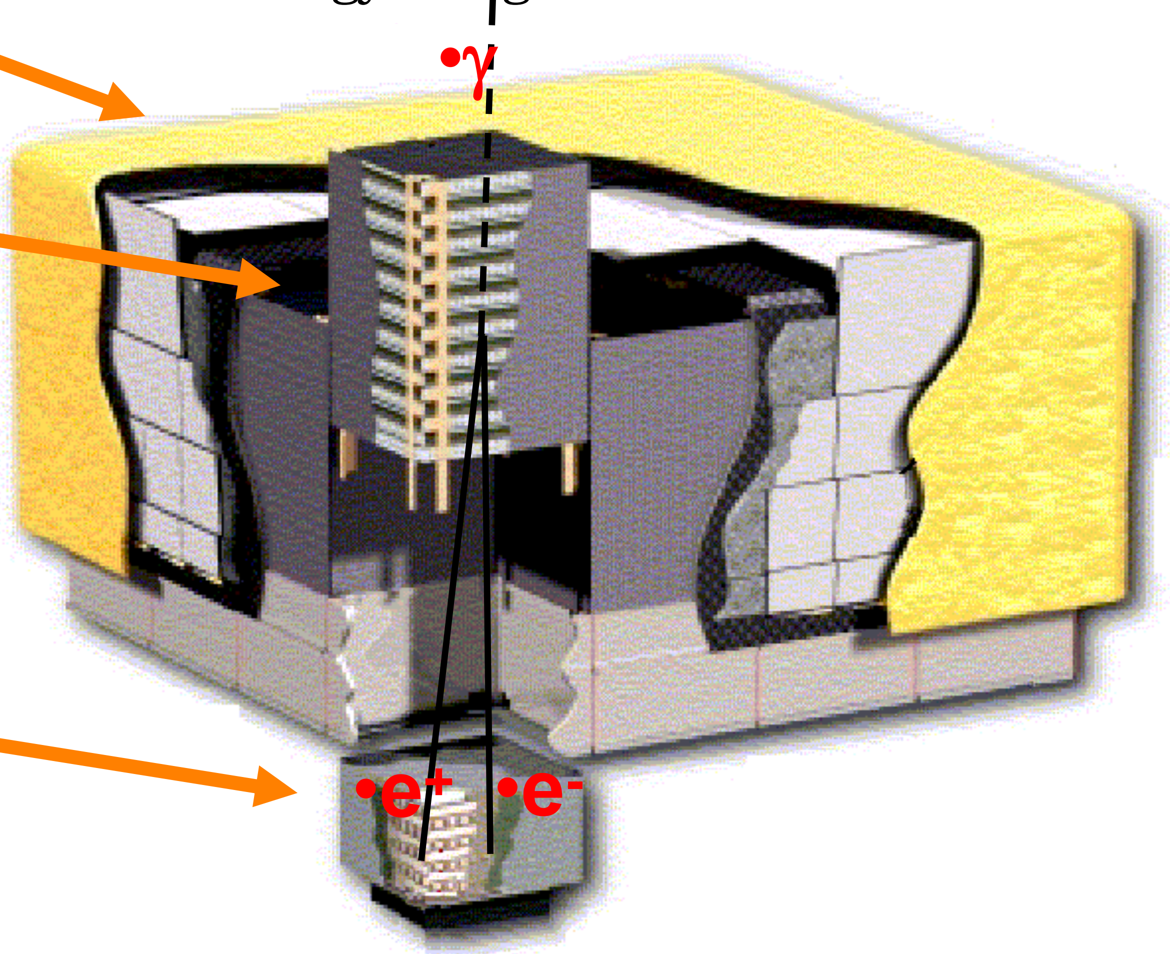
Detection technics

Fermi Large Area Telescope (LAT)

Large Field of View >2.4 sr

Broad Energy Range 20 MeV - >300 GeV

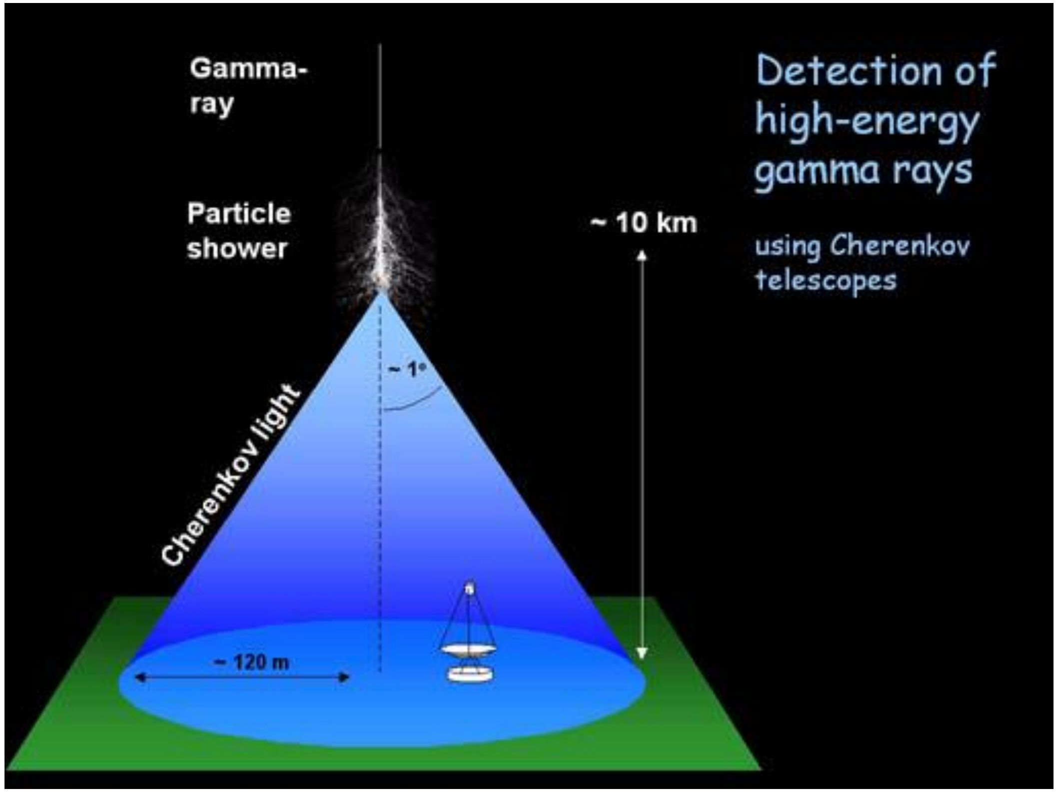
- **ACD**
- scintillator
- 89 tiles
- **Tracker**
- Si strip detectors
- Tungsten foil converters
- pitch = 228 um
- 8.8×10^5 channels
- 18 planes
- **Calorimeter**
- CsI crystals
- hodoscopic array
- 6.1×10^3 channels
- 8 layers



Cherenkov telescopes

Very high energies, above 50 GeV

- Crab nebula: flux(E > 1 TeV) = 2 x 10^{-11} cm^{-2} s^{-1}
- Large effective detection areas (>30 000 m^2) needed
- -> Back to the ground
- Use the atmosphere as a
- huge calorimeter and
- detect γ-ray-induced
- atmospheric showers
- through Cherenkov light
-



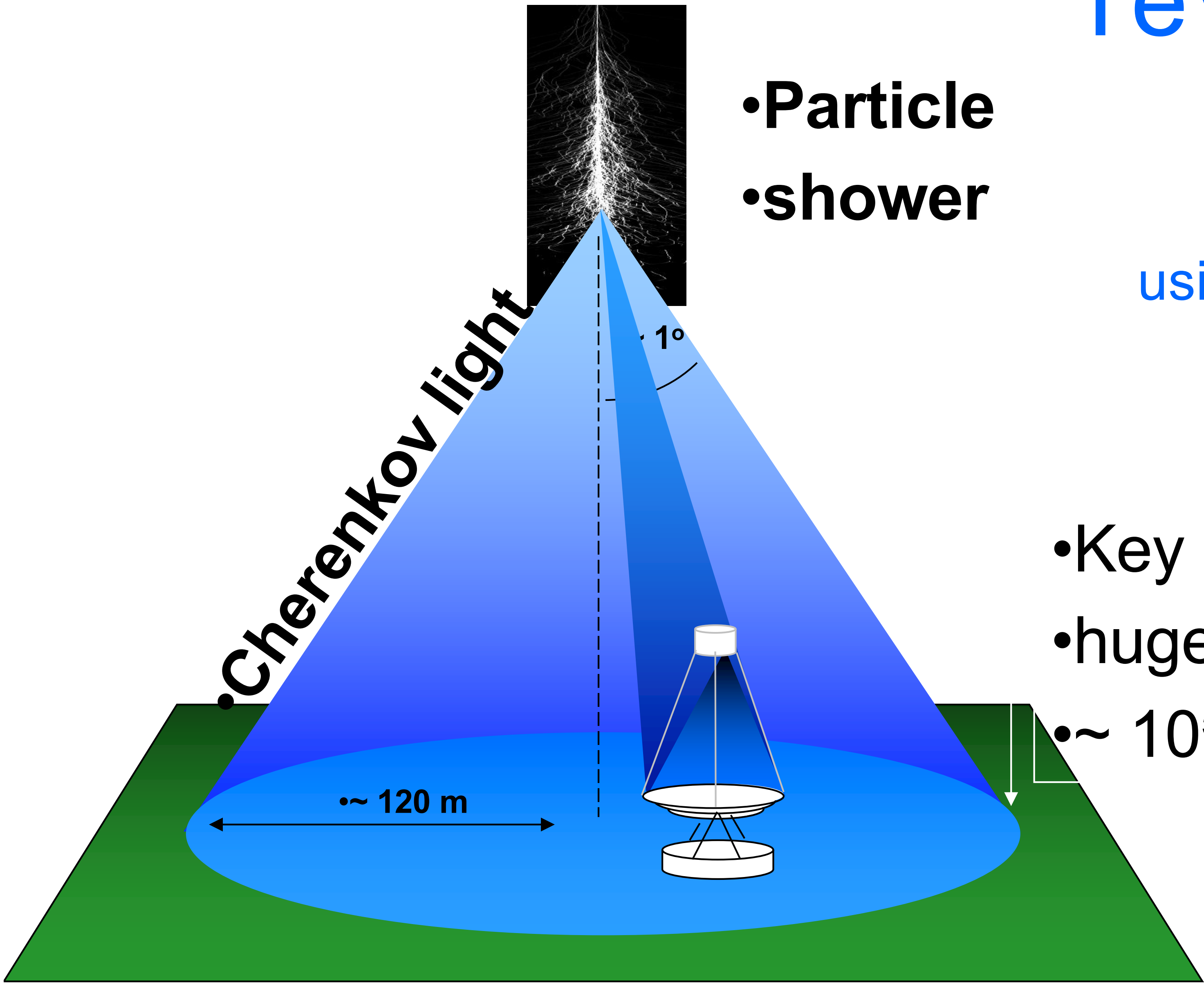
Experimental challenges

- Reduce the energy threshold as much as possible

  Try to get some overlap region with space observations
- Increase flux sensitivity
- **Remove the huge background** of showers induced by charged particles **(cosmic ray protons, ions and electrons)**

Detection of TeV gamma rays

using Cherenkov telescopes



- Key issue:
- huge detection area
- ~ 10^5 m^2

From W.Hofman

Hardonic rejection

- Image shape:

  Electromagnetic showers:

  elongated, quasi-elliptic shape

  Hadronic showers:

  more irregular shape

- Image direction:

  Electromagnetic showers:

  point to the source (the center of the field of view)

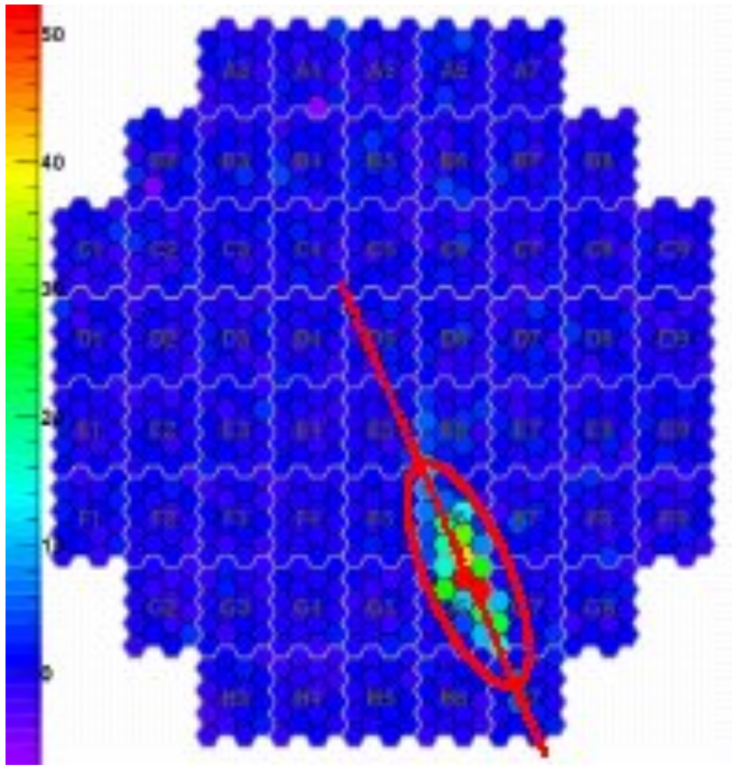
  Hadronic showers:

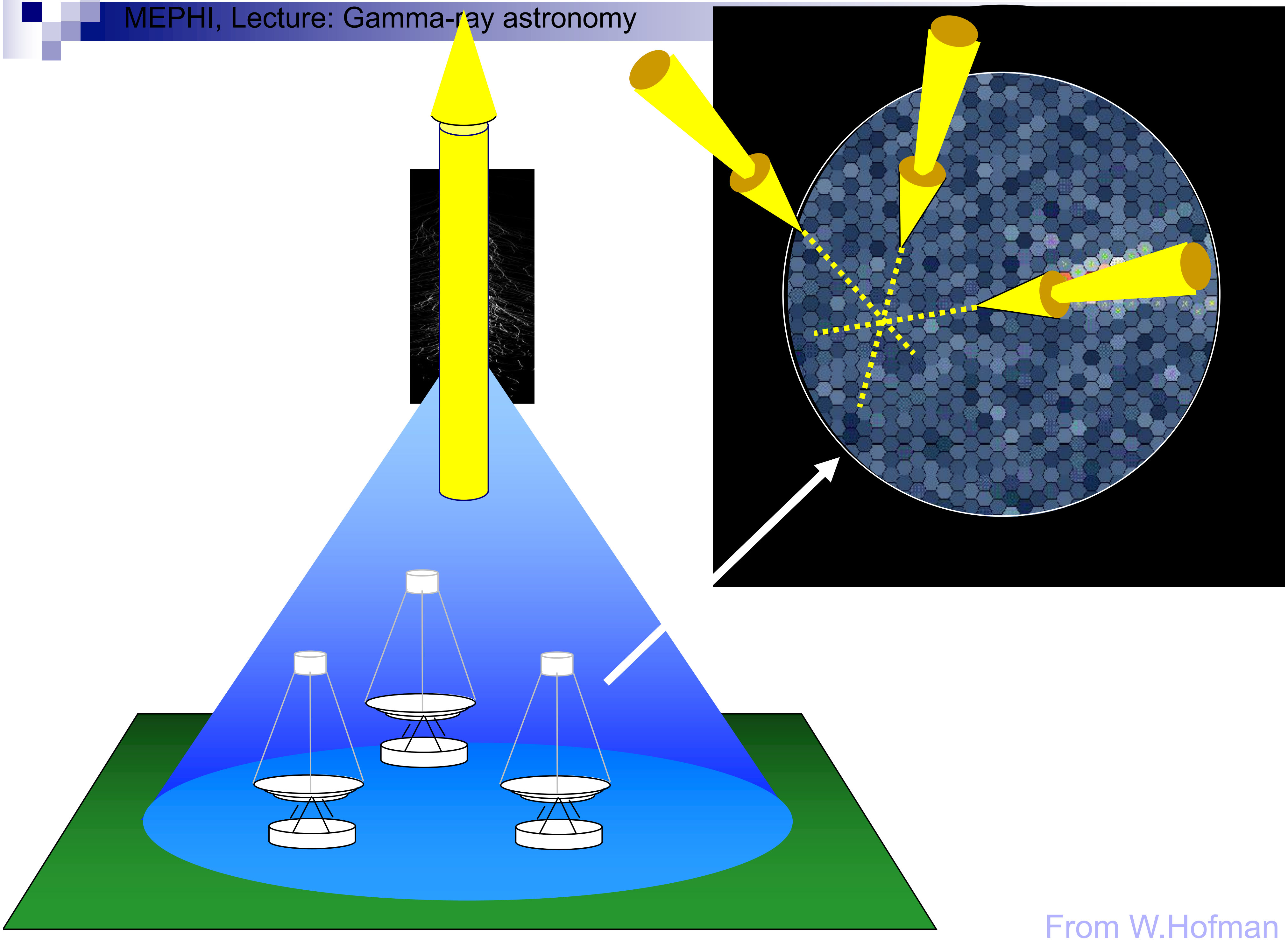
  randomly oriented in the focal plane

- Image light profiles

  (longitudinal and transverse)

  help finding the source position

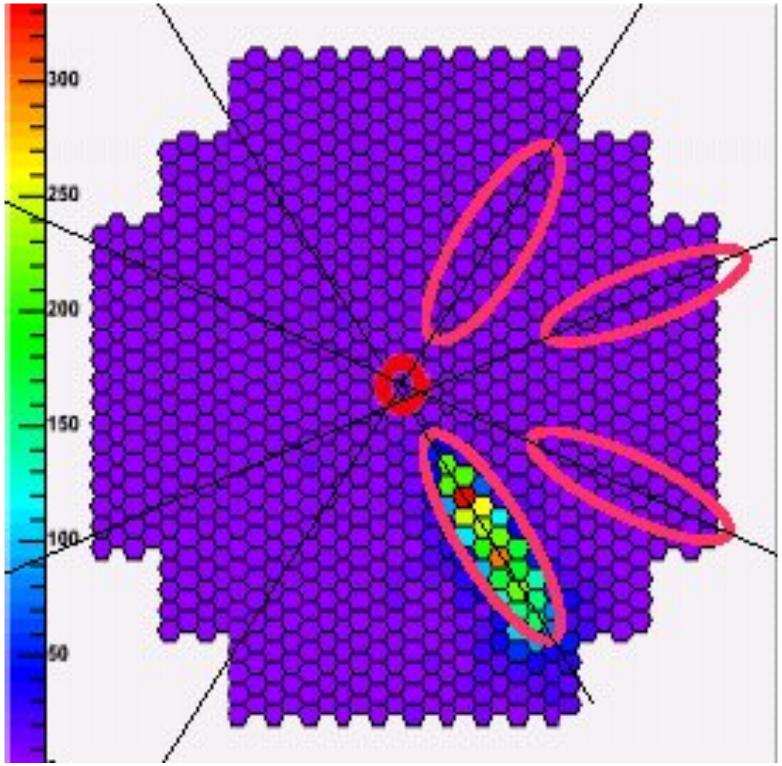


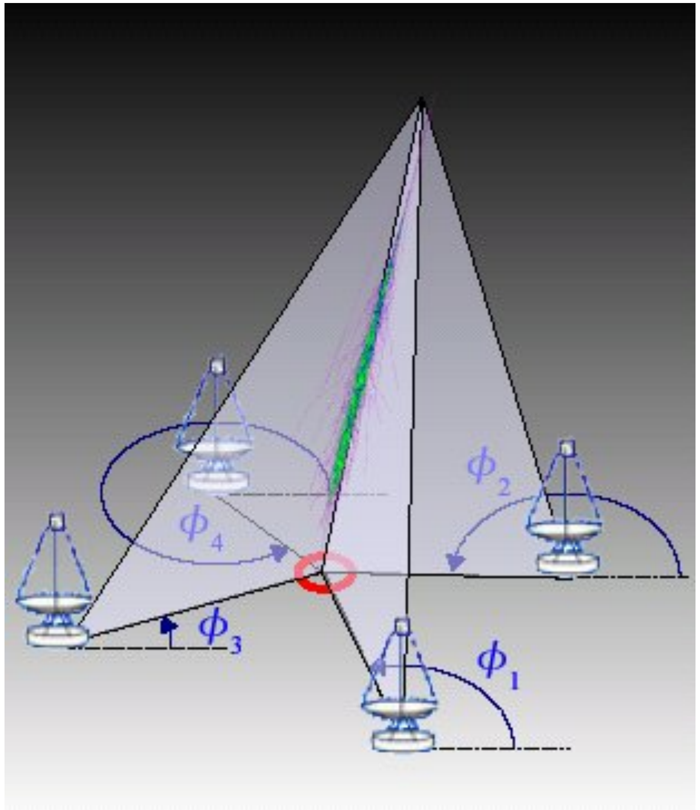


From W.Hofman

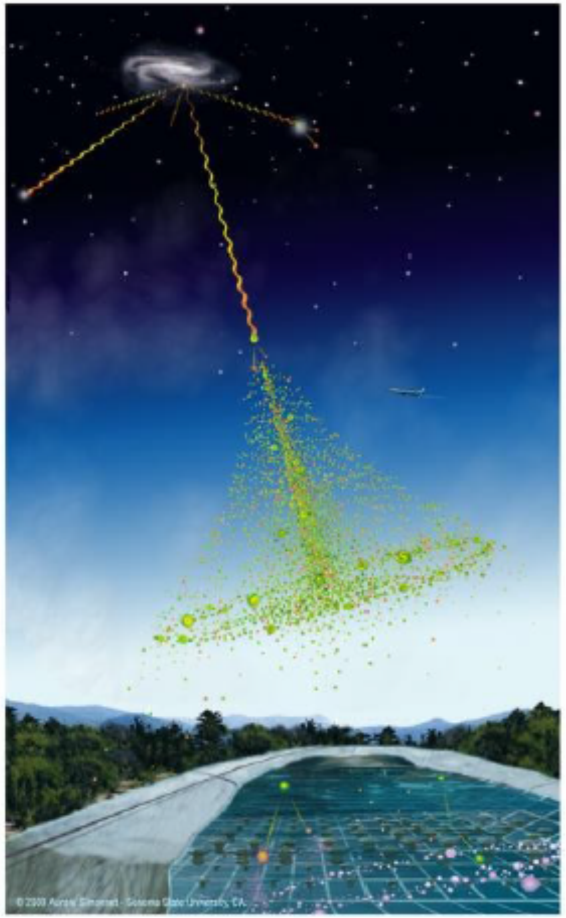
Stereoscopic measurement (e.g. HEGRA, H.E.S.S. VERITAS, MAGIC)

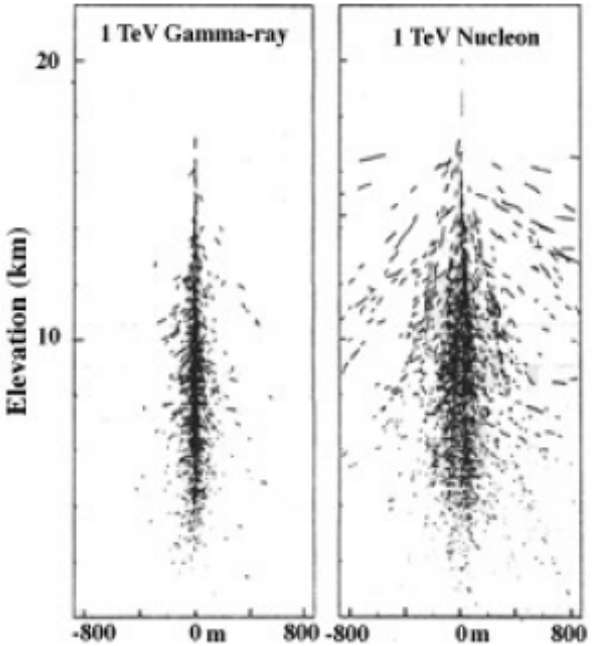
- Direct measurement of the **γ-ray origin** in the field of view (important for extended sources)
- Direct measurement of the **impact on the ground** (important for energy measurement)
- Better hadronic rejection
- Much better angular resolution

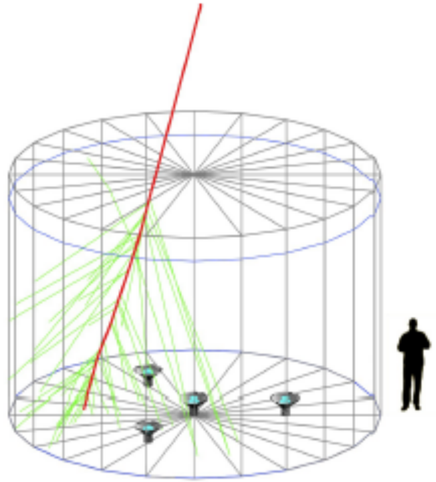




Detection Technique of the EAS Arrays



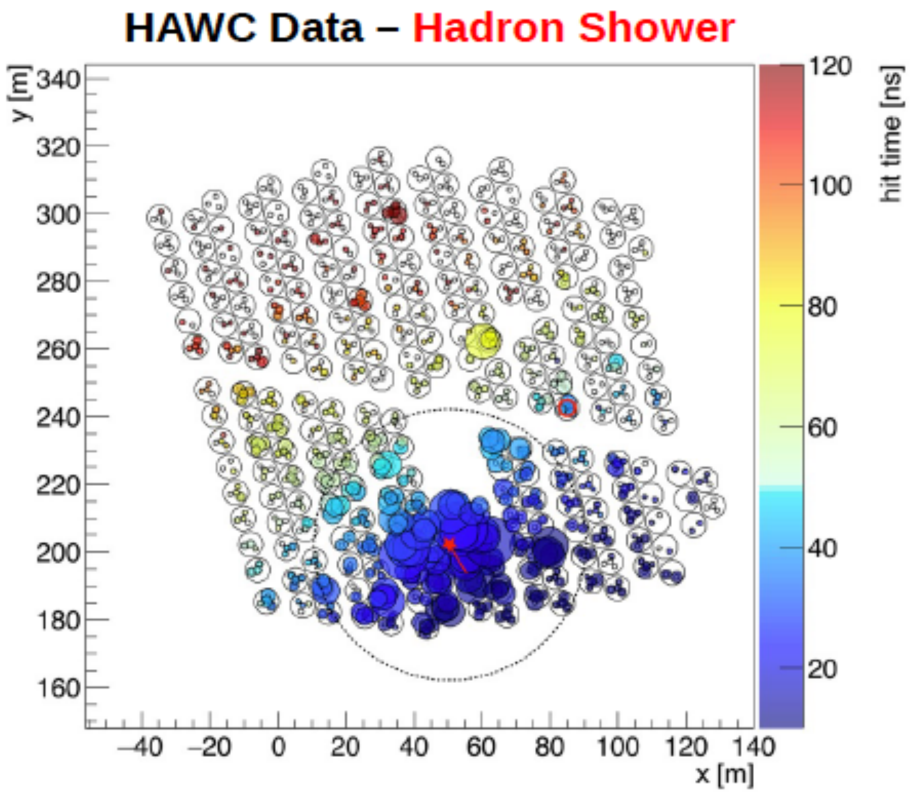


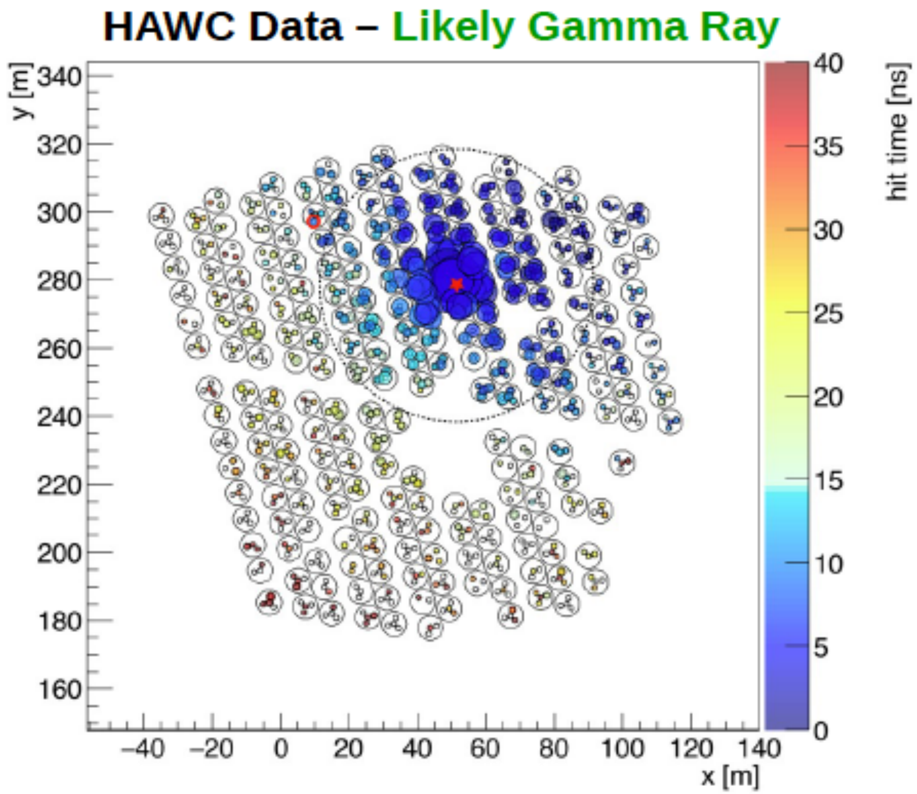


- The particle detectors can be tanks full of water. Particles from the shower pass through the water and induce Cherenkov light detected by PMTs.
- Gamma/hadron can be discriminated based on the event footprint on the detector. Although is one of the challenges of this kind of detectors.

Gamma/Hadron Separation

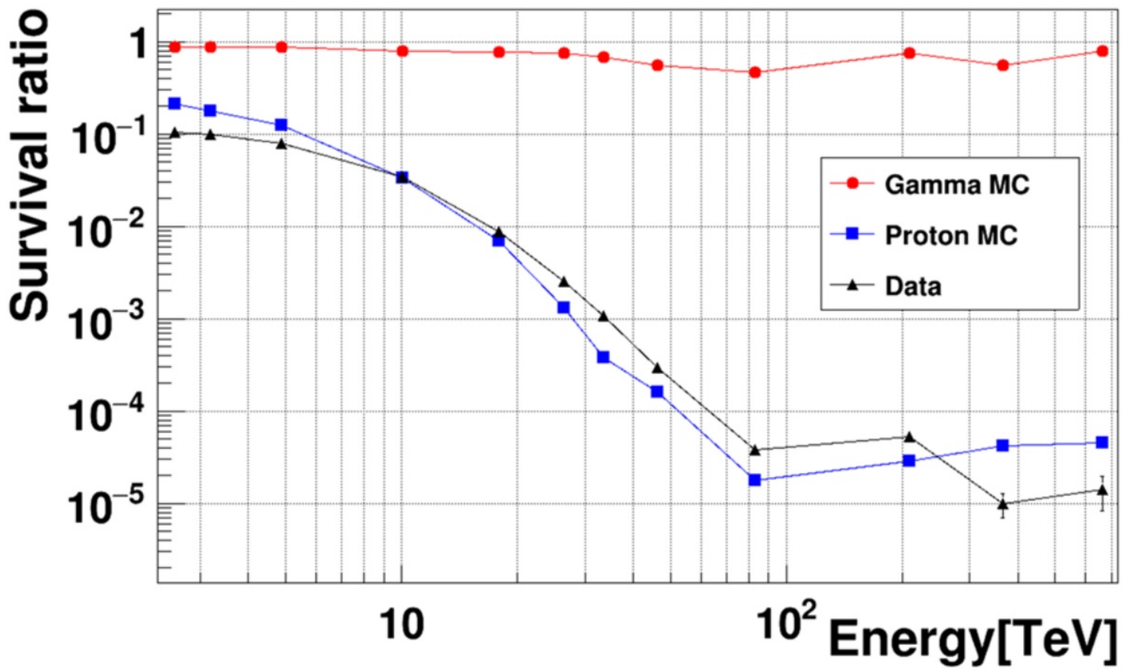
- Main background is hadronic CR, e.g. 400 γ/day from the Crab vs 15k CR/s.
- In gamma-ray showers, most of the signal at ground level is located near the shower axis.
- In charged cosmic rays tend to "break apart", much messier signals at ground level.





γ/P discrimination of ¼ KM2A

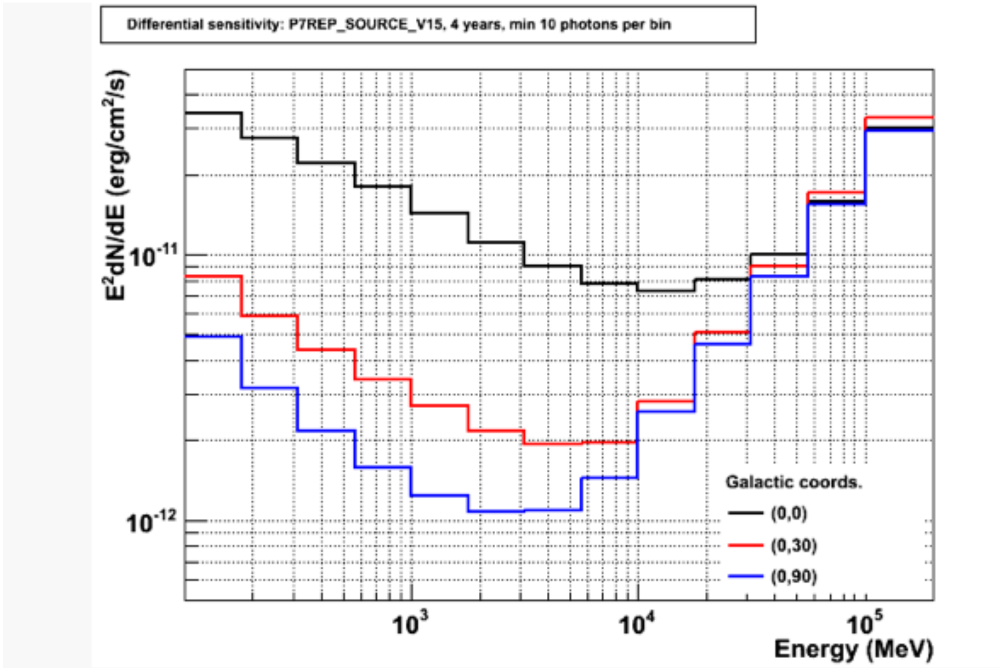
Background rejection >10^4@100 TeV



•LHAASO meeting Jan 2020

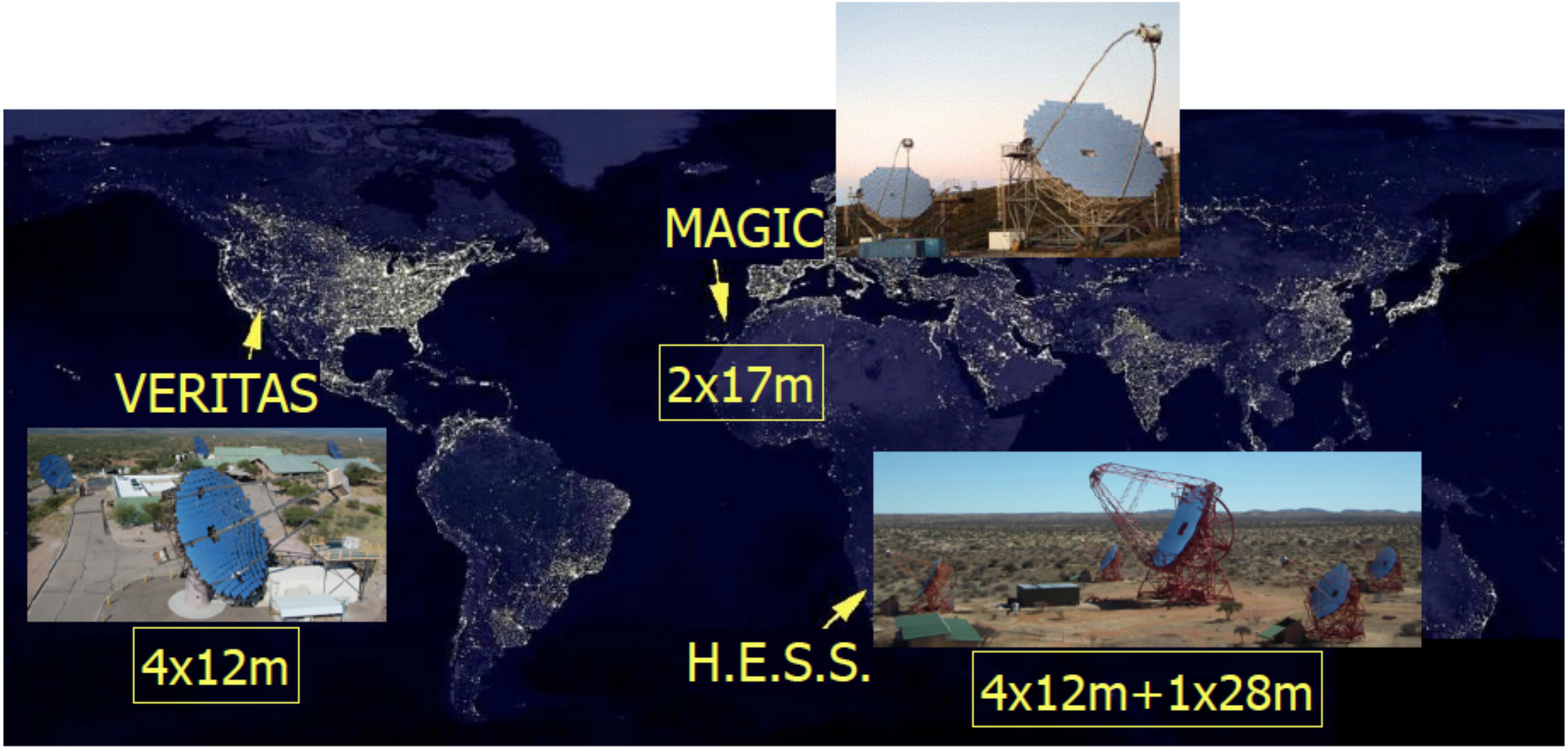
Fermi LAT gamma-rays 40 MeV-1 TeV

Fermi LAT


Differential sensitivity: P7REP_SOURCE_V15, 4 years, min 10 photons per bin
E²dN/dE (erg/cm²/s)
10⁻¹¹
10⁻¹²
10³
10⁴
10⁵
Energy (MeV)
Galactic coords.
(0,0)
(0,30)
(0,90)

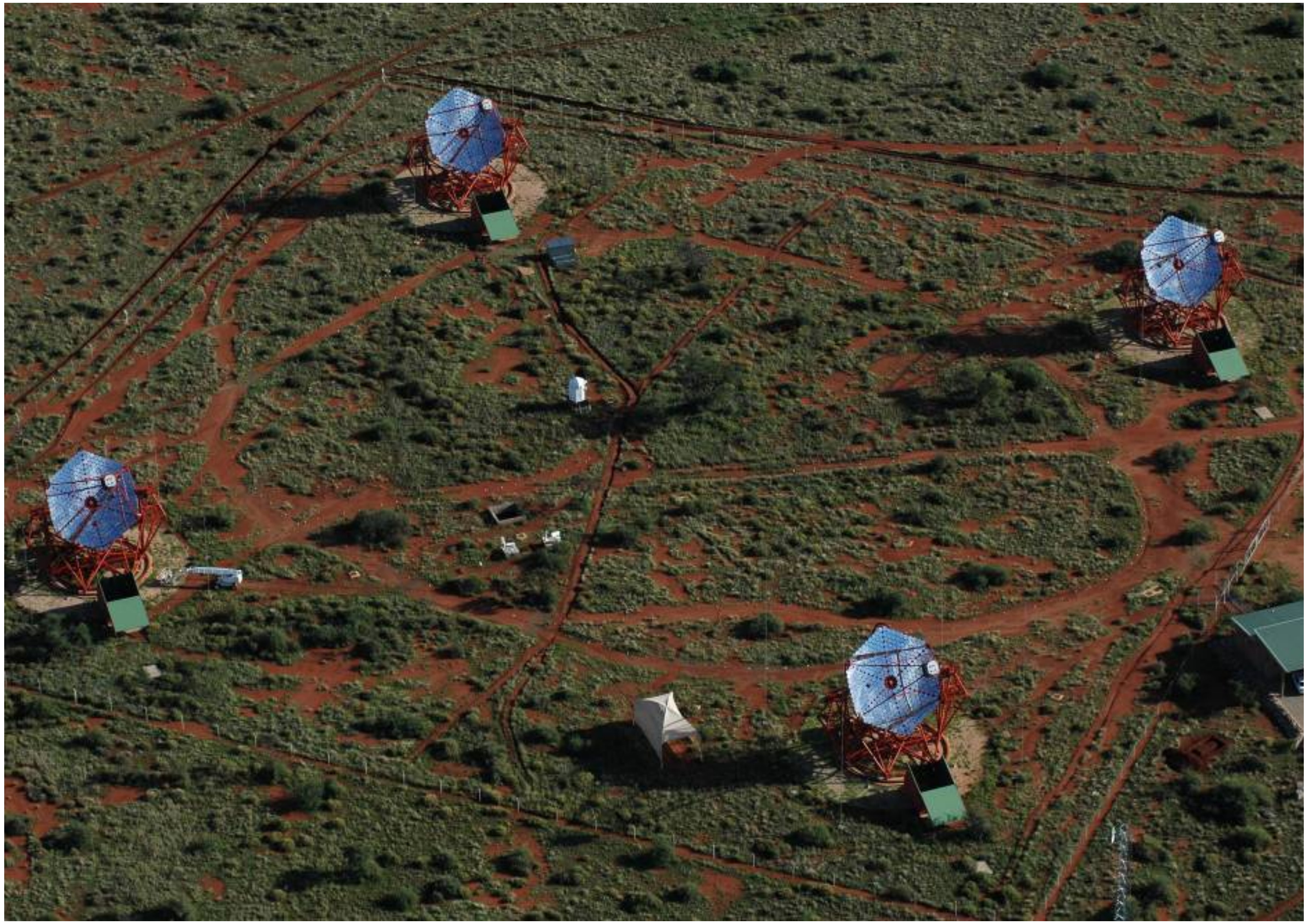
TeV telescopes
50 GeV-20 TeV

Cherenkov telescopes today



•HESS

- •European Collaboration; M.P.I (Heidelberg)
- •4 x 12 m Telescopes
- •Completed in Dec. 2003; located in NAMIBIA



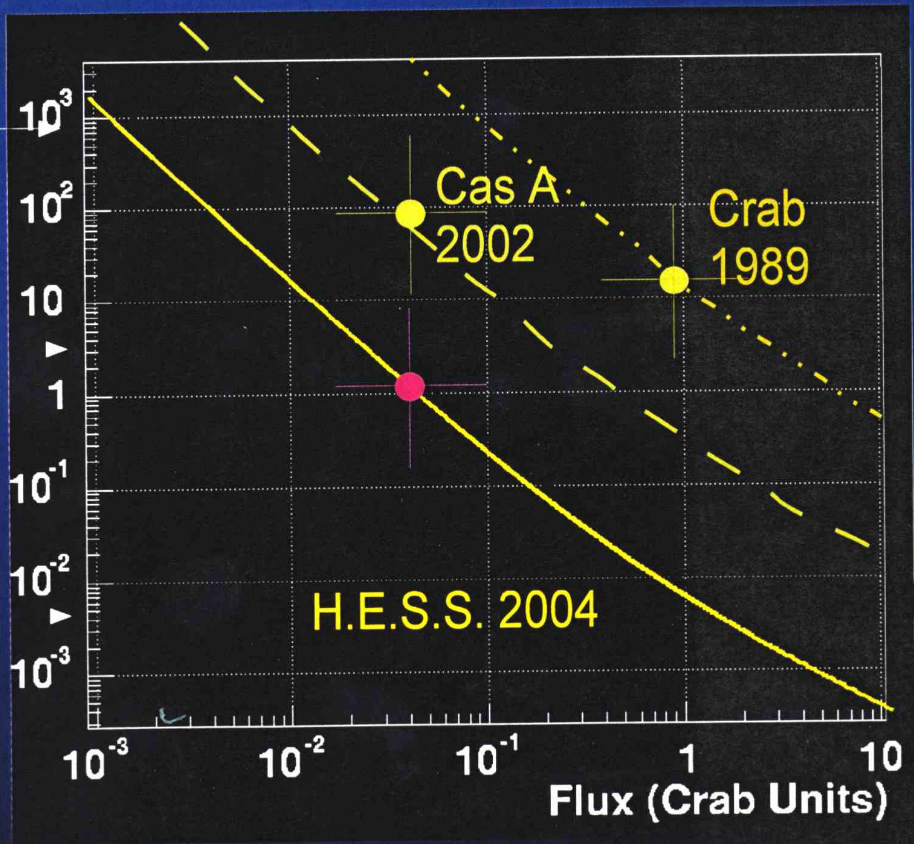
H.E.S.S. Sensitivity

- HEGRA
  - 5% of Crab flux in 100 hours
- H.E.S.S.
  - 5% of Crab in 1 hour
  - 0.5% in 100 hours

1 year

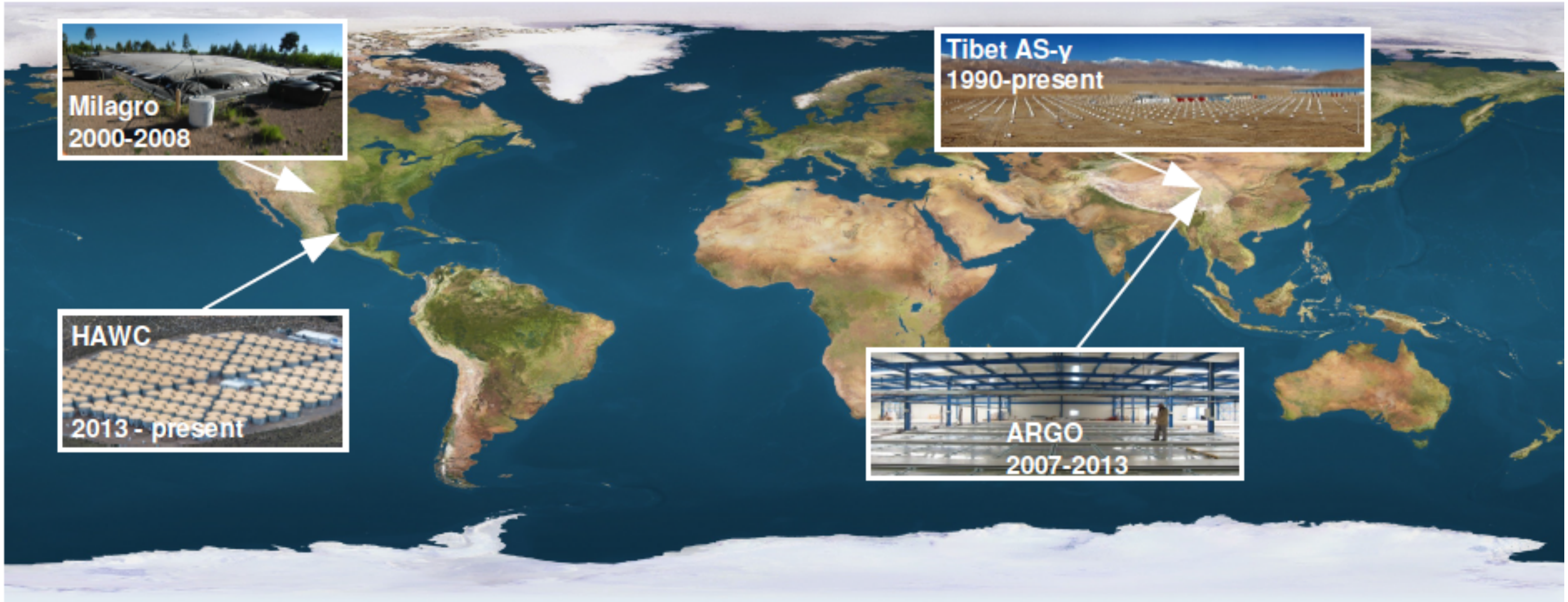
1 night

30 sec.

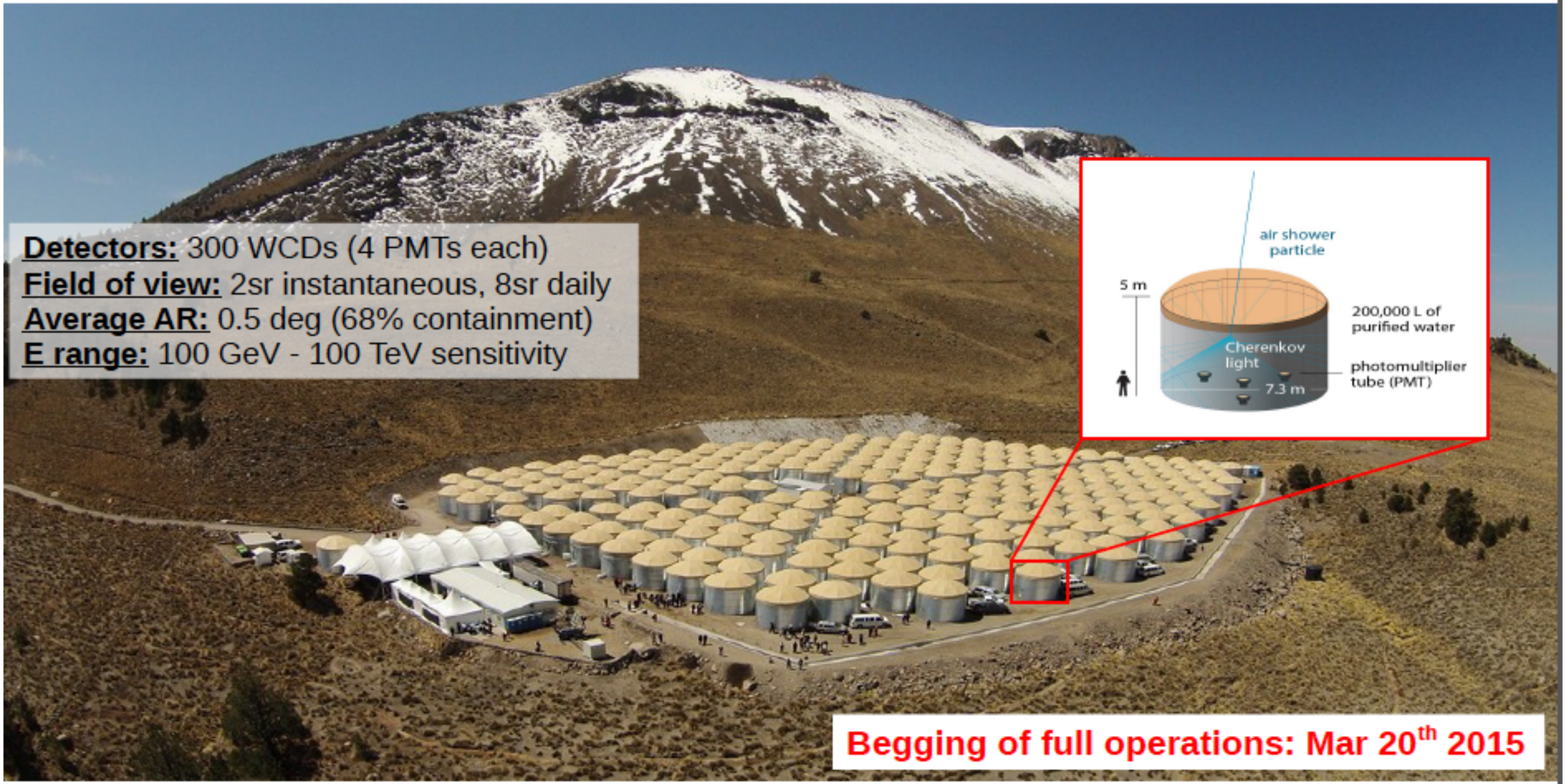


EAS Detectors

- Several EAS arrays have been operational using different detection techniques.
- It is time for second generation experiments like HAWC.



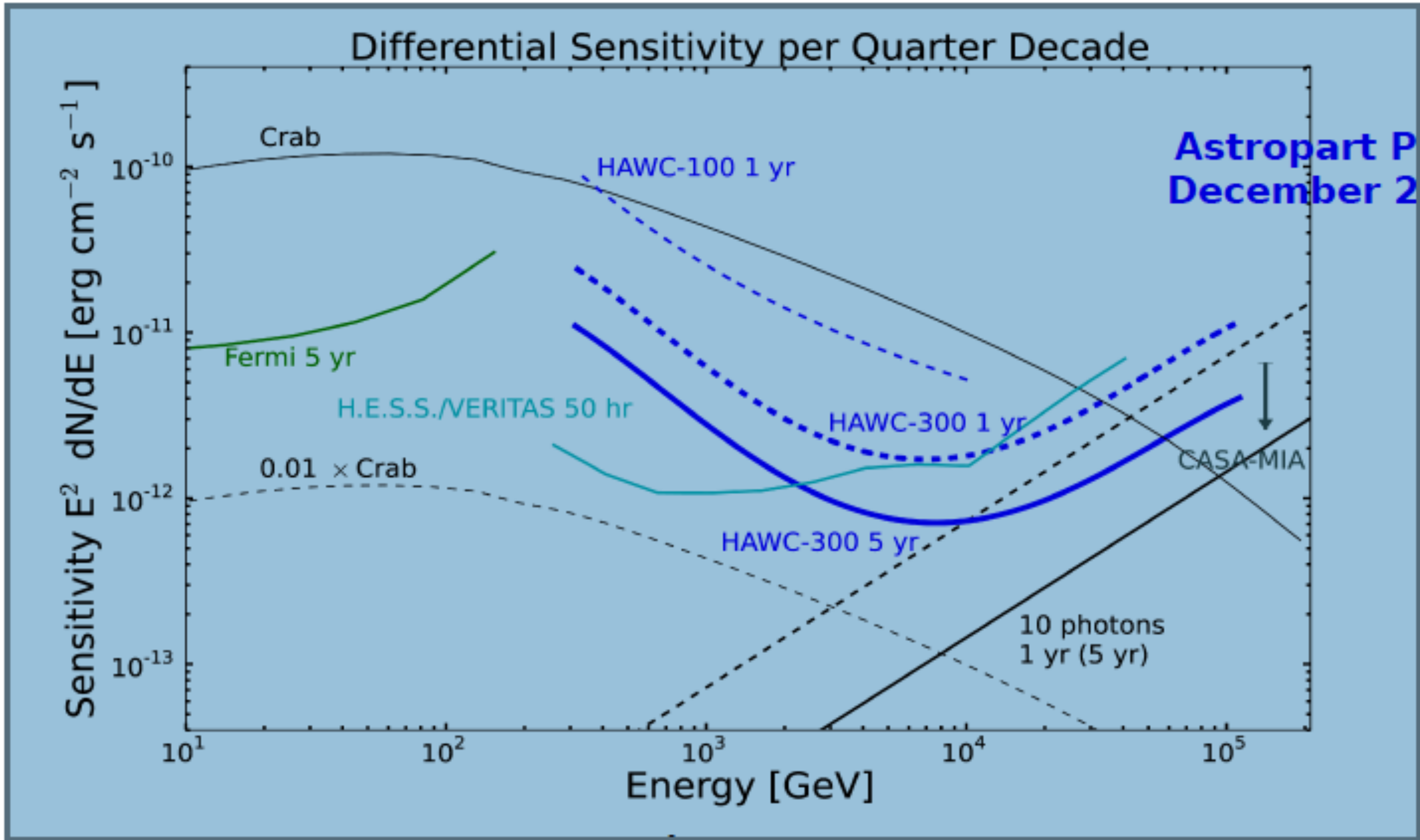
HAWC Inauguration



HAWC Designed Sensitivity

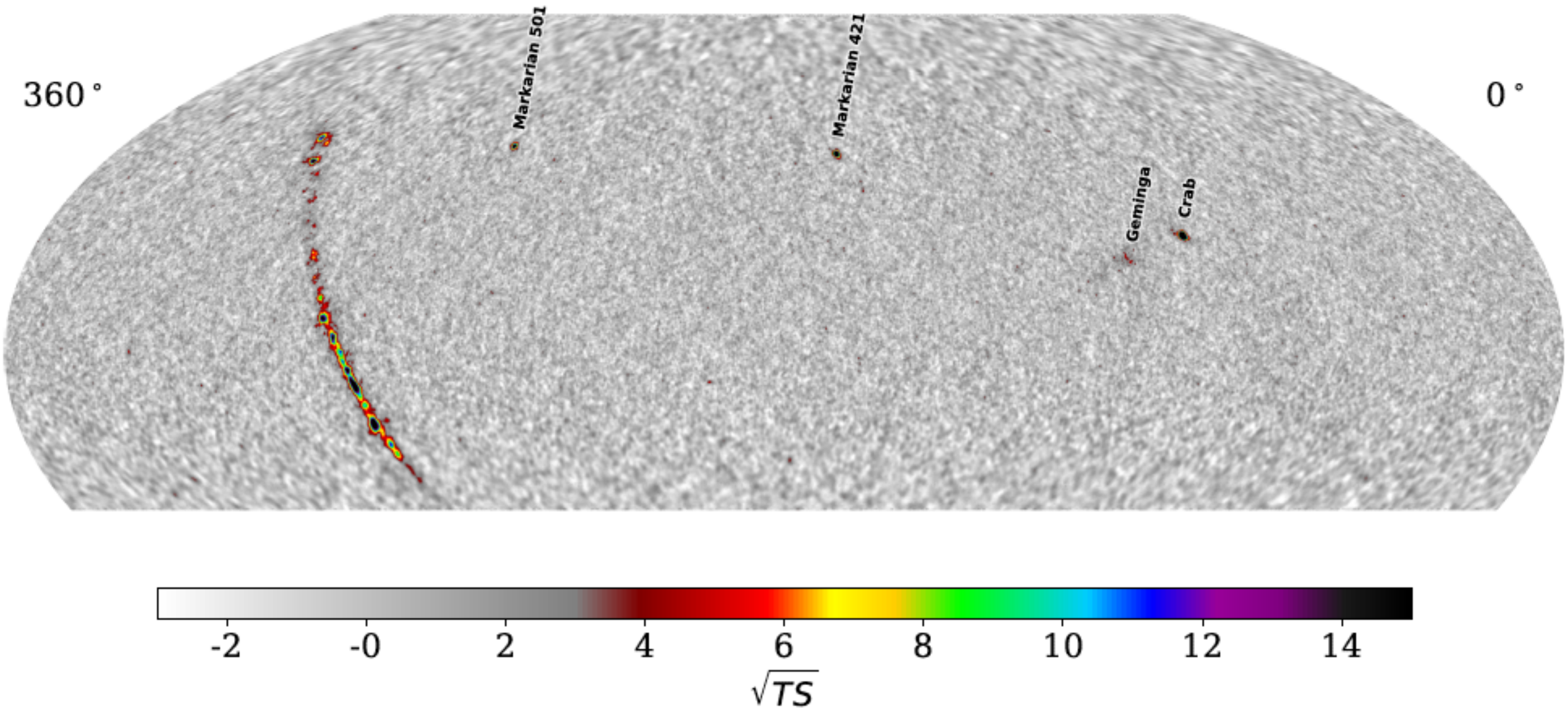
- Instantaneous sensitivity 15-20x less than IACTs.
- Exposure (sr/yr) is 2000-4000x higher than IACTs.

Survey > half the sky to:
40 mCrab [5σ] (1yr)
<20 mCrab [5σ] (5yr)

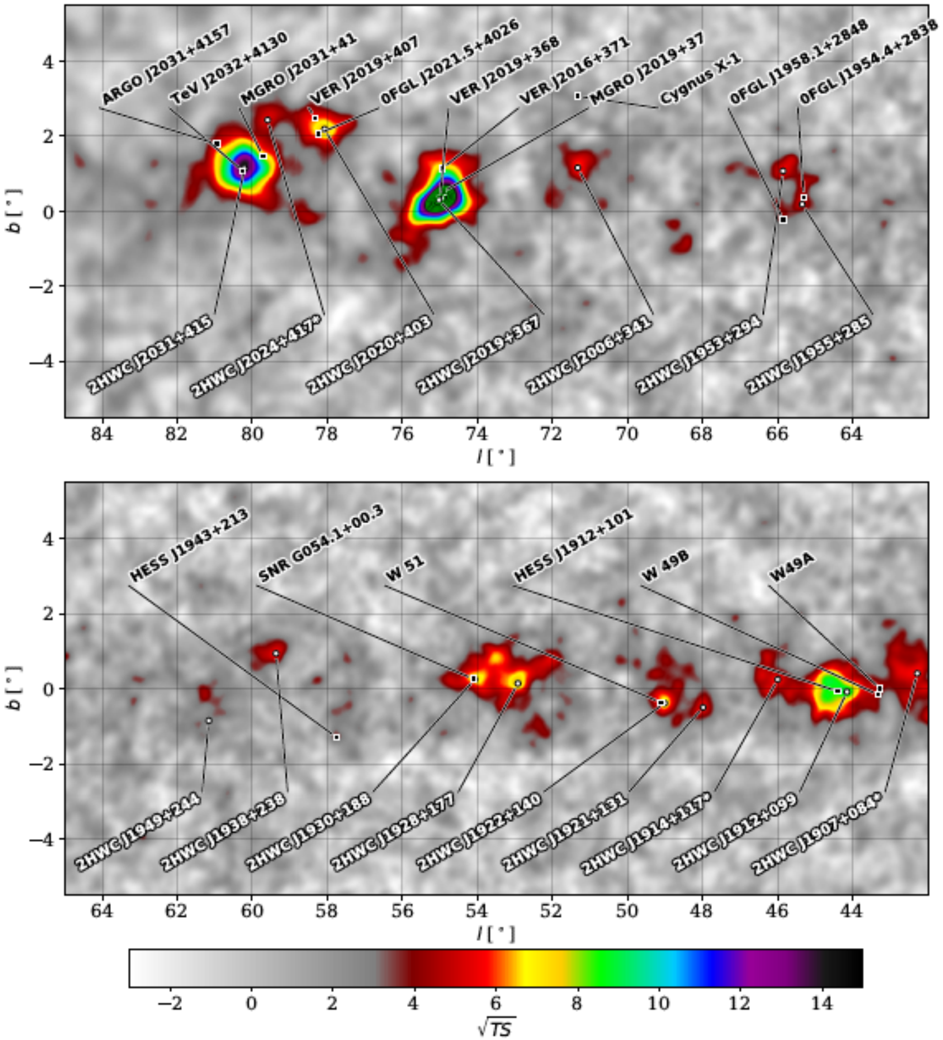


Astropart Phys 50-52, December 2013, 26-32

HAWC sky map


360 °
0 °
Markarian 501
Markarian 421
Geminga
Crab
-2
-0
2
4
6
8
10
12
14
√TS

HAWC galactic plane



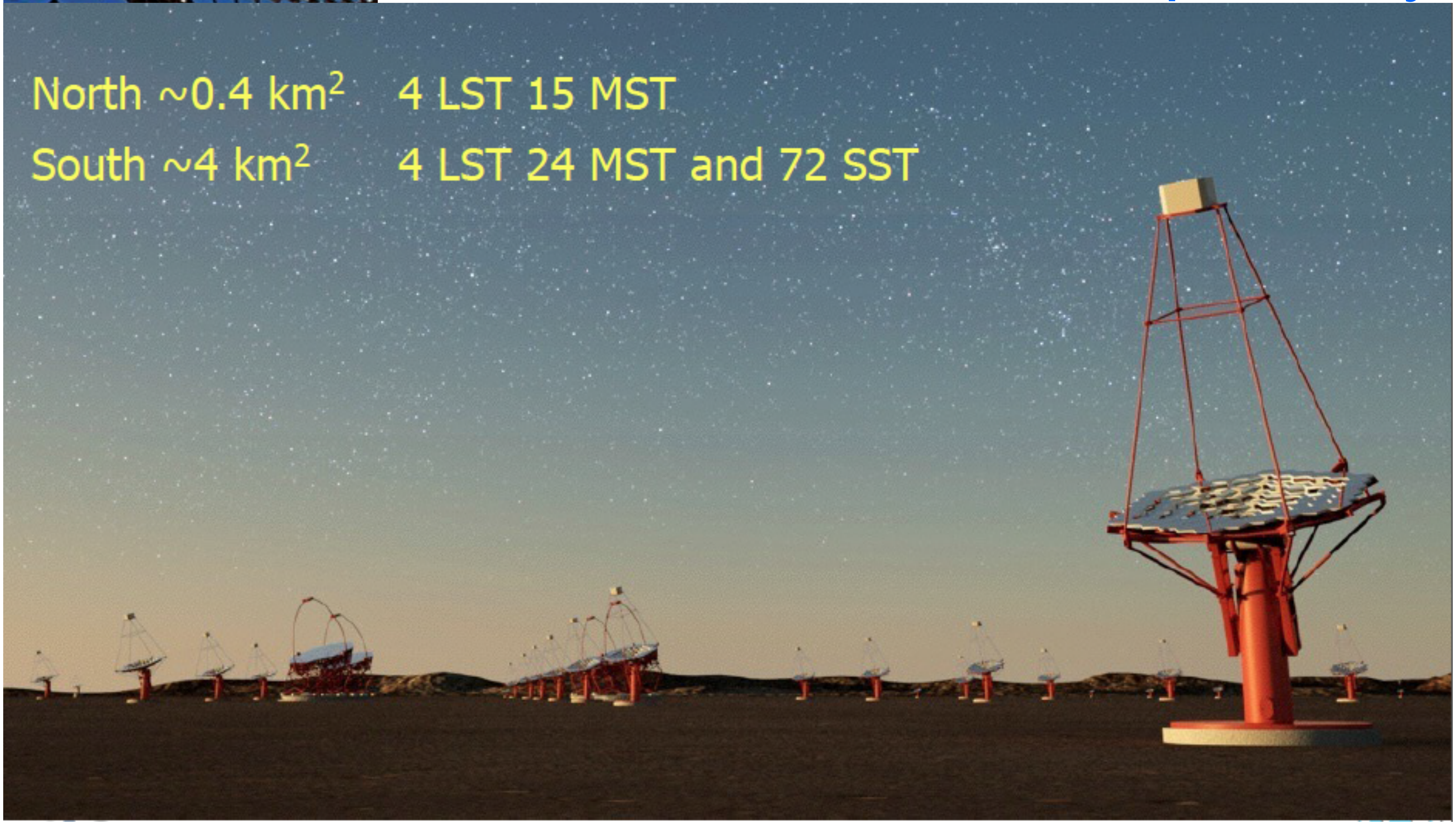
Future TeV telescopes

Wish list

- Higher sensitivity at TeV energies (x 10)
  - more sources
- Lower threshold (some 10 GeV)
  - pulsars, distant AGN, source mechanisms
- Higher energy reach (PeV and beyond)
  - cutoff region of Galactic accelerators
- Wide field of view
  - extended sources, surveys
- Improved angular resolution
  - structure of extended sources
- Higher detection rates
  - transient phenomena

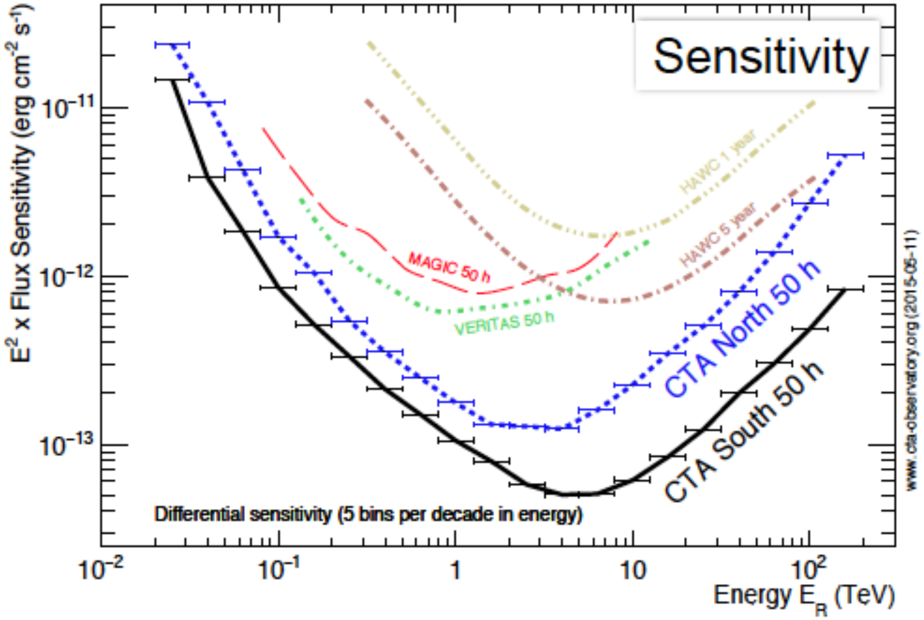
•CTA

The Next Generation: The Cherenkov Telescope Array

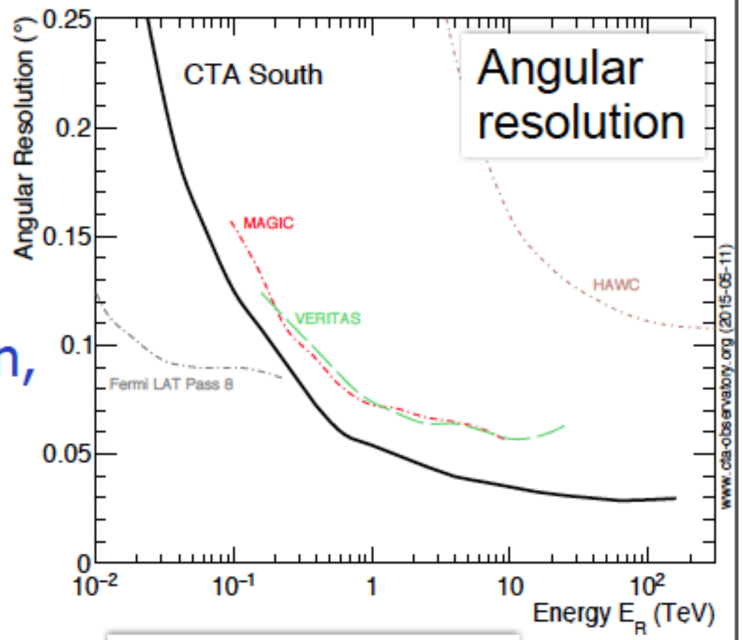


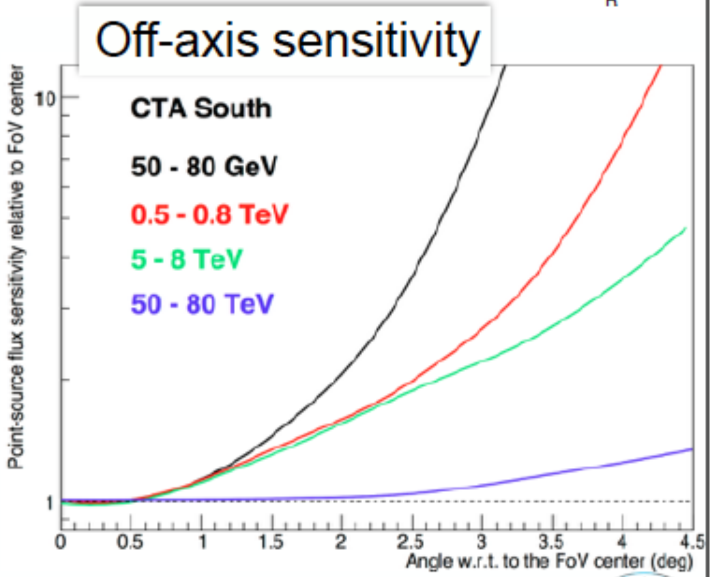
CTA Performance

> Result of large-scale simulations (900 telescopes for layout optimisation, CTA-GRID) and analysis

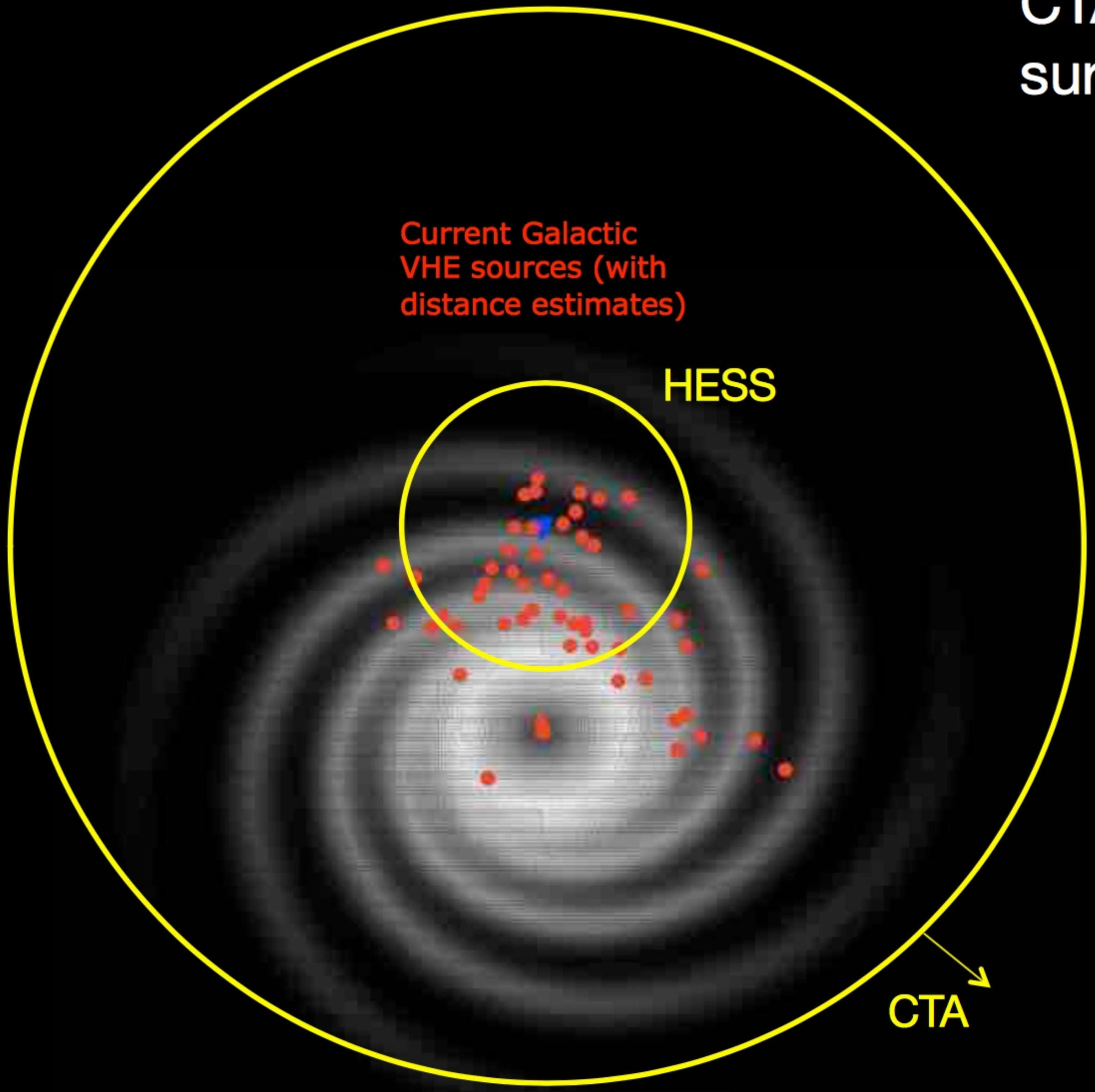


https://portal.cta-observatory.org/CTA_Observatory/performance/SitePages/Home.aspx





> MC Prod3 started recently – more realistic estimation of CTA performance



CTA as ultimate survey machine

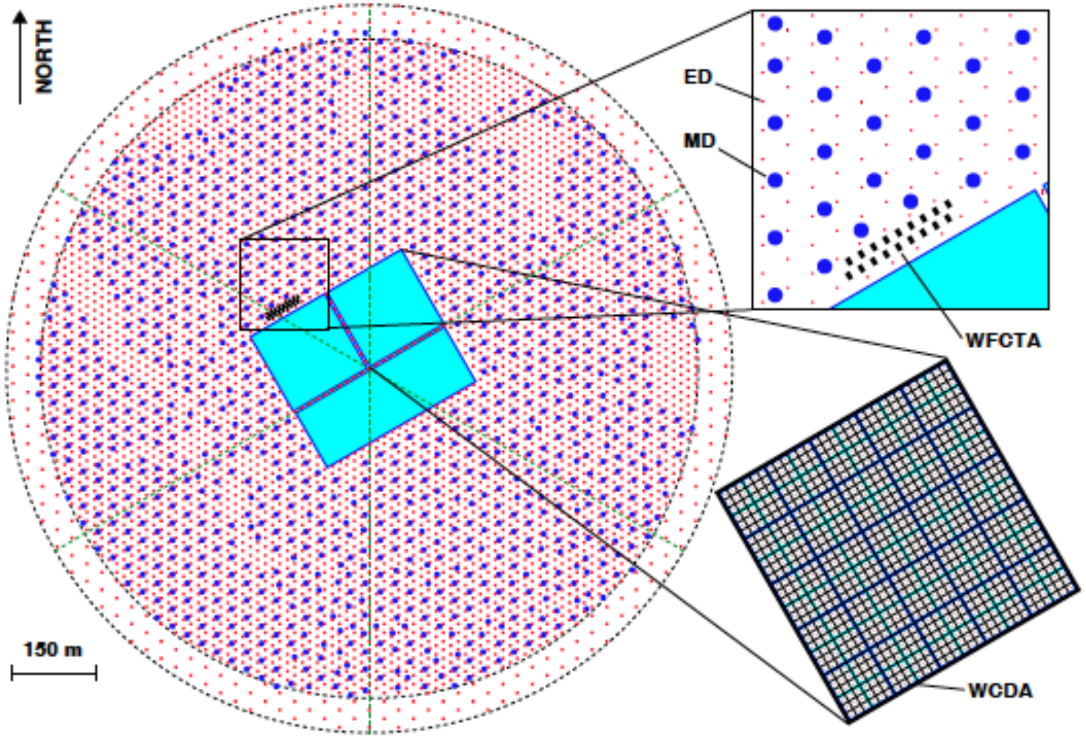
CTA as ultimate machine to study flares

at 25 GeV, for flares 10000 times more sensitive than Fermi

Coherent full-sky coverage from two sites

The LHAASO experiment

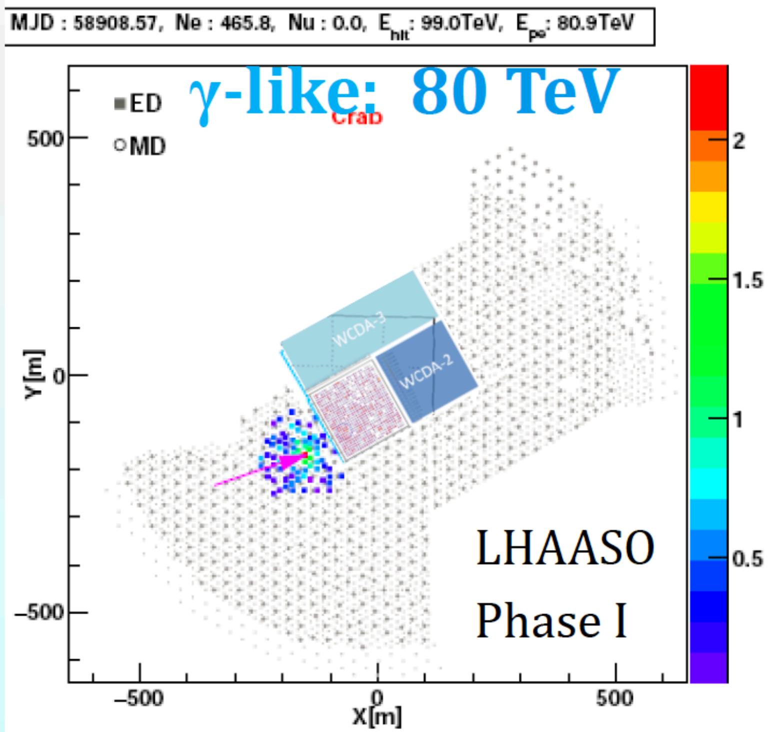
- 1 km^2 array, including 4941 scintillator detectors 1 m^2 each, with 15 m spacing.
- An overlapping 1 km^2 array of 1146, underground water Cherenkov tanks 36 m^2 each, with 30 m spacing, for muon detection (total sensitive area ≈ 42,000 m^2).

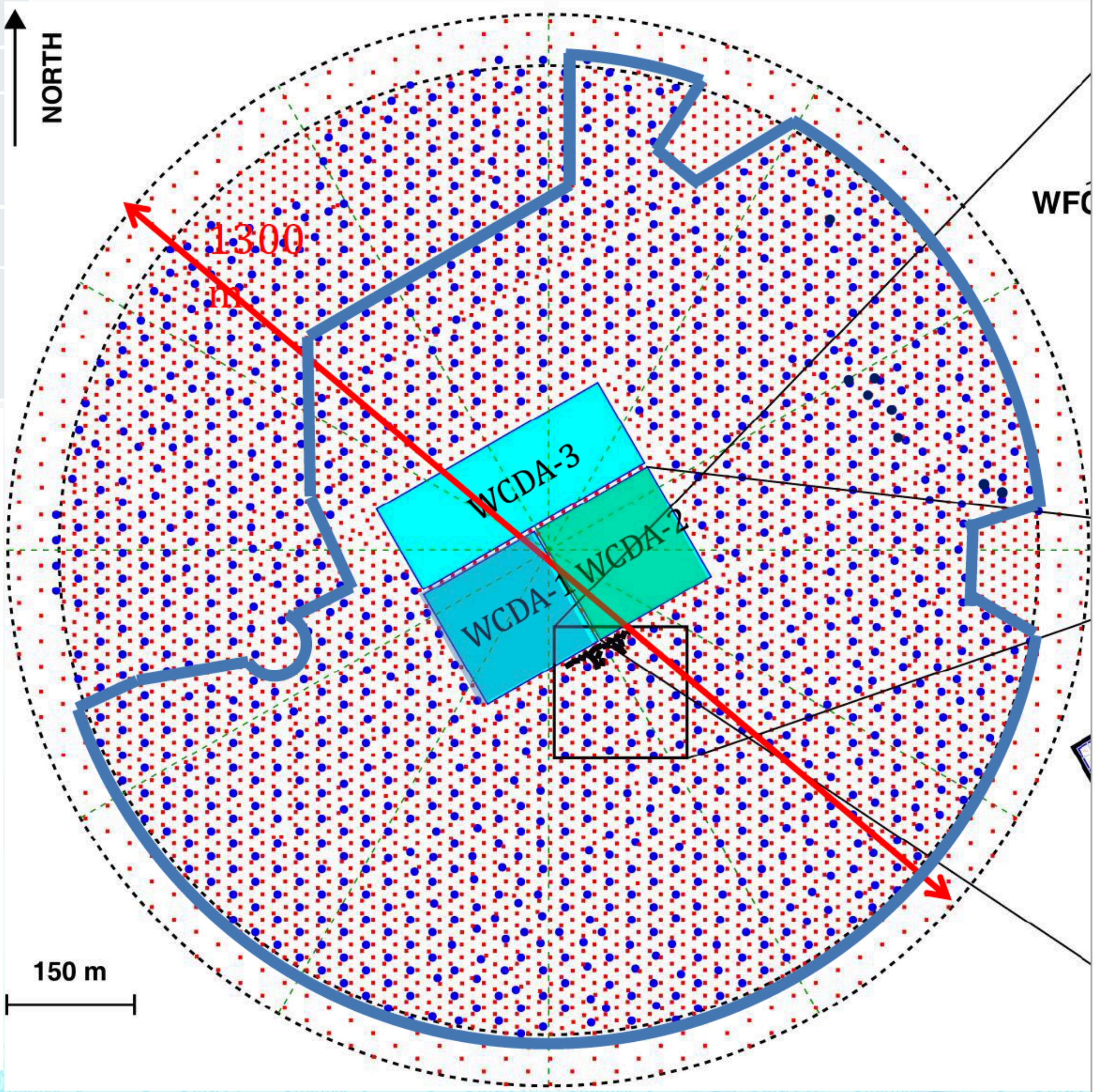


- A close-packed, surface water Cherenkov detector facility with a total area of 80,000 m^2.
- 18 wide field-of-view air Cherenkov (and fluorescence) telescopes.

LHAASO Phase-II: Dec,2020—

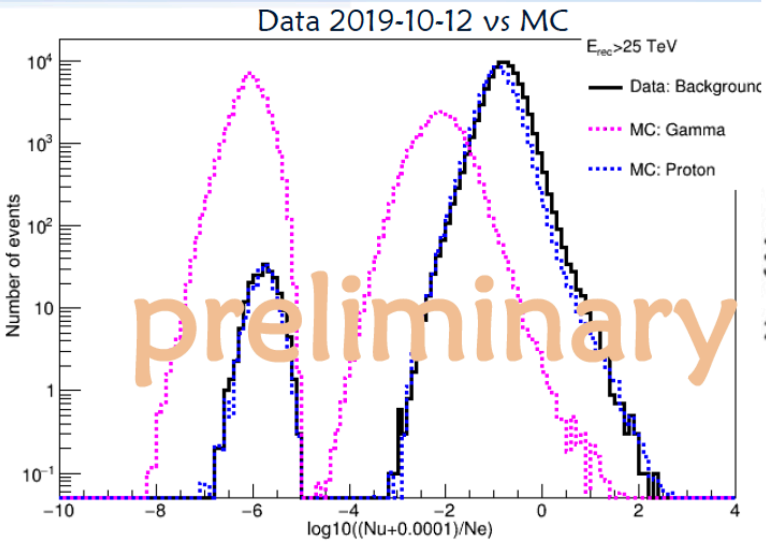
2019-12-12	Muon Counter	Scintillator Detector
operating	594	2514
2010-11-30		
operating	**917**	**3978**
Percentage of designed sensitivity	**88%**	

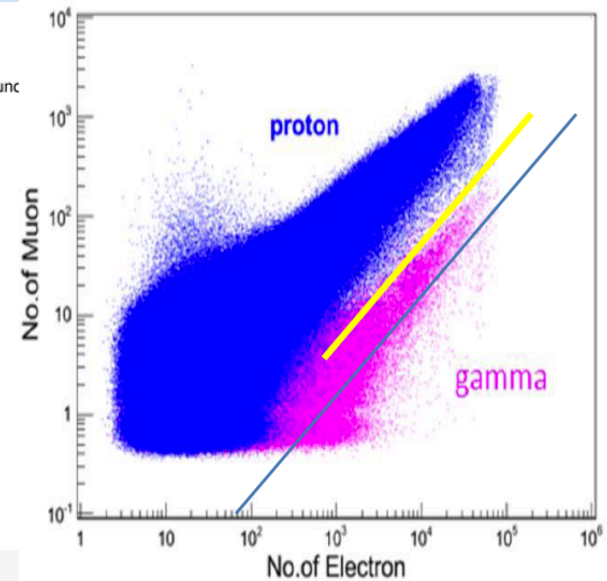


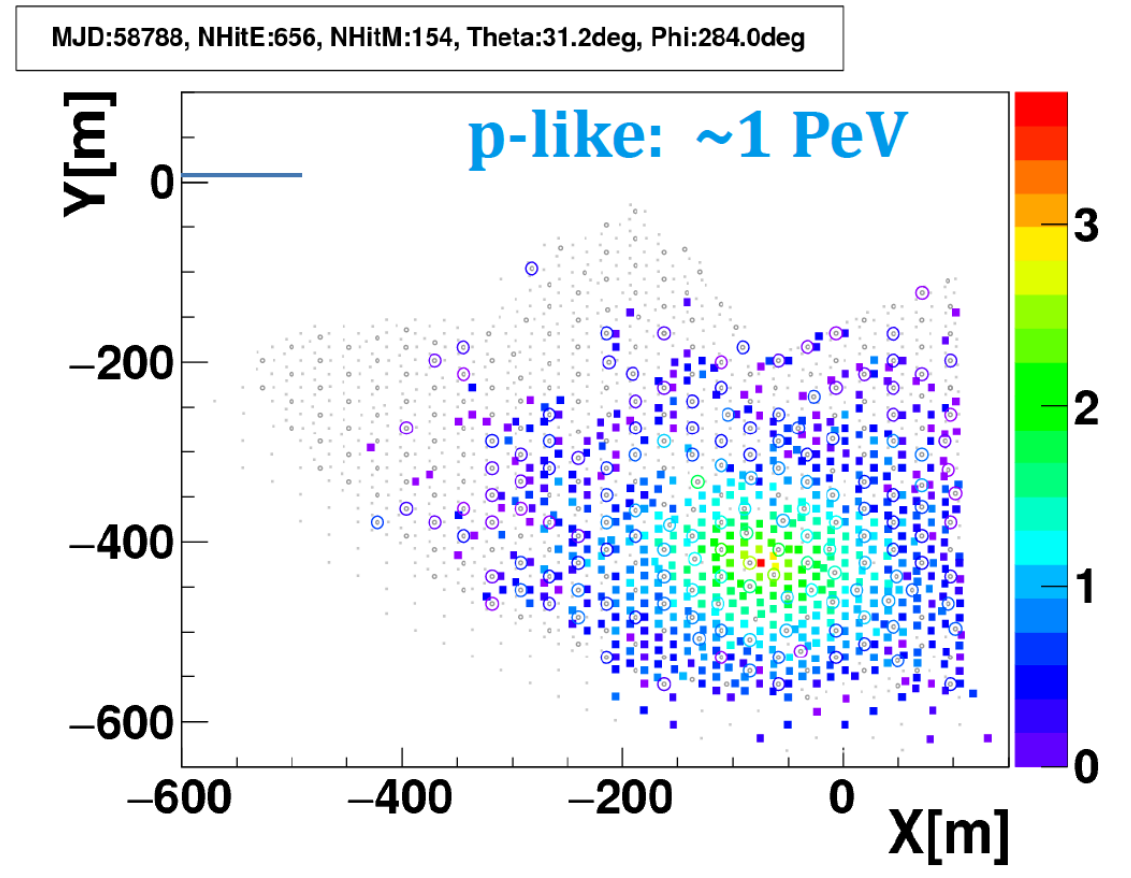


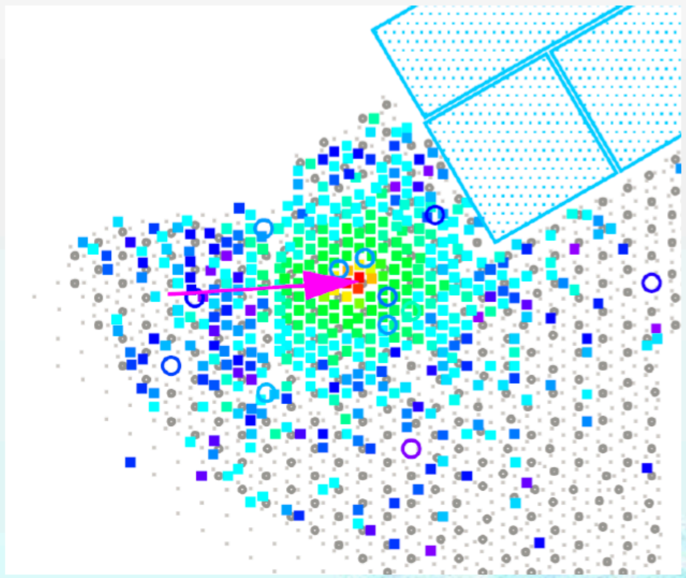
LHAASO 高海拔宇宙线观测站

γ/proton Separation: μ-content



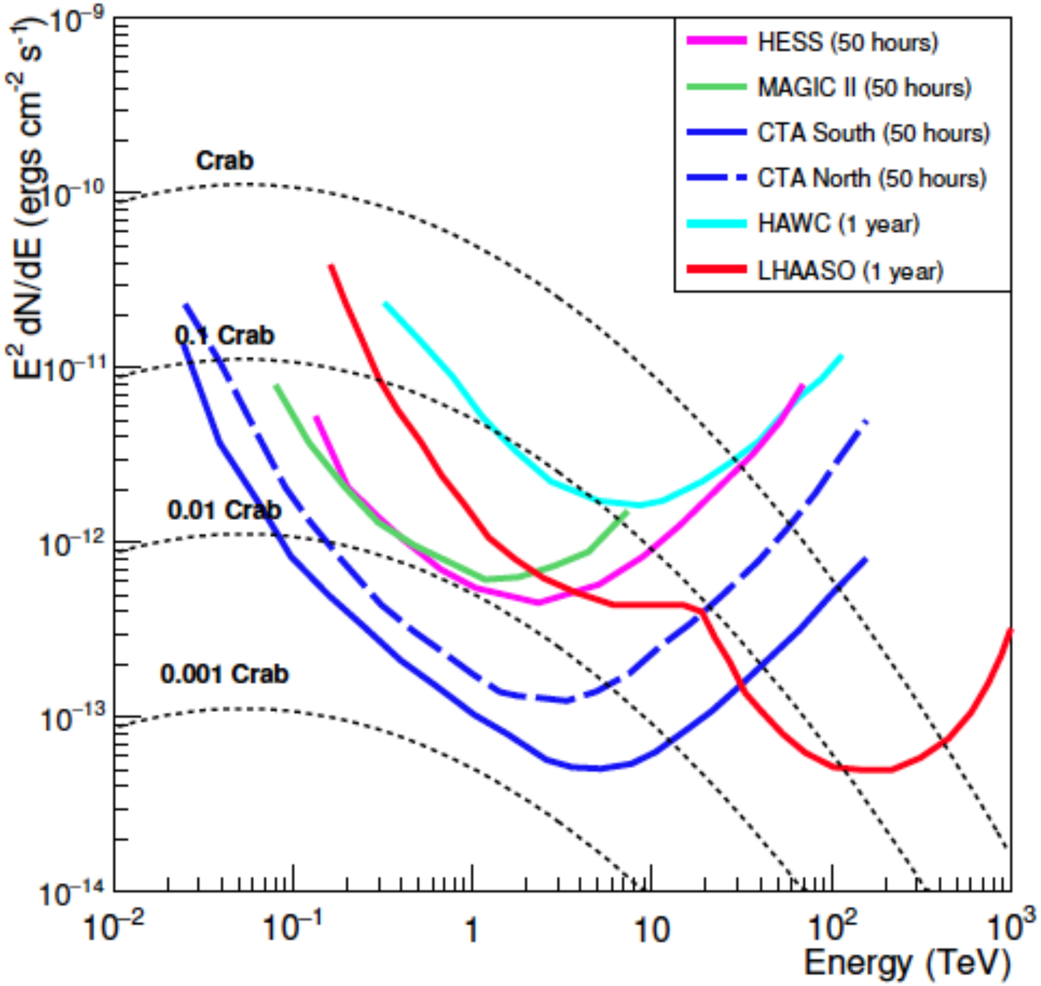






γ-like: ~ 1 PeV

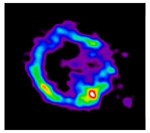
Sensitivity future detectors



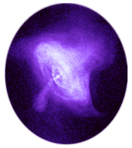
Overview of TeV gamma-ray Science

I. Astronomy and Astrophysics

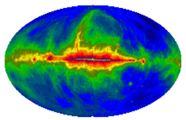
A. Galactic sources



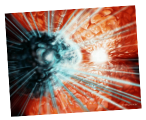
- **Shell-type Supernova Remnants**



- **Pulsar wind nebula**
- **Binary systems**
- **Microquasars**
- **Central black hole**



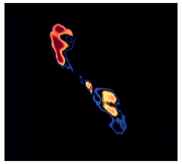
- **Galactic Diffuse Emission**



- **Galactic Cosmic Ray Origin**
- **Dark sources**

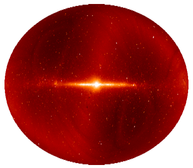
Overview of gamma-ray Science

B. Extra Galactic sources

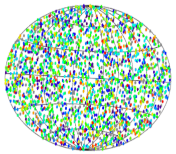


Radio galaxies

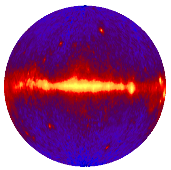
- **Blazars**



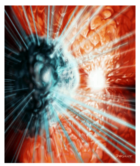
- **Extragalactic Background Light**



- **Gamma Ray Bursts**



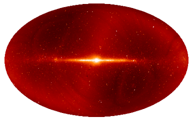
- **Unidentified Sources**



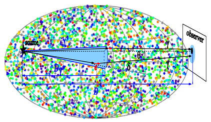
- **Ultra-High Energy Cosmic Ray Origin**

Overview of gamma-ray Science

Cosmology

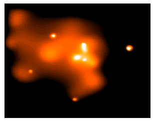


- **Extragalactic Background Light**
- **Primordial magnetic field**

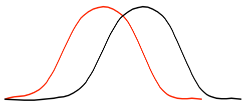


- **Distant Gamma Ray Bursts (GeV)**

Particle physics



- **Dark Matter**

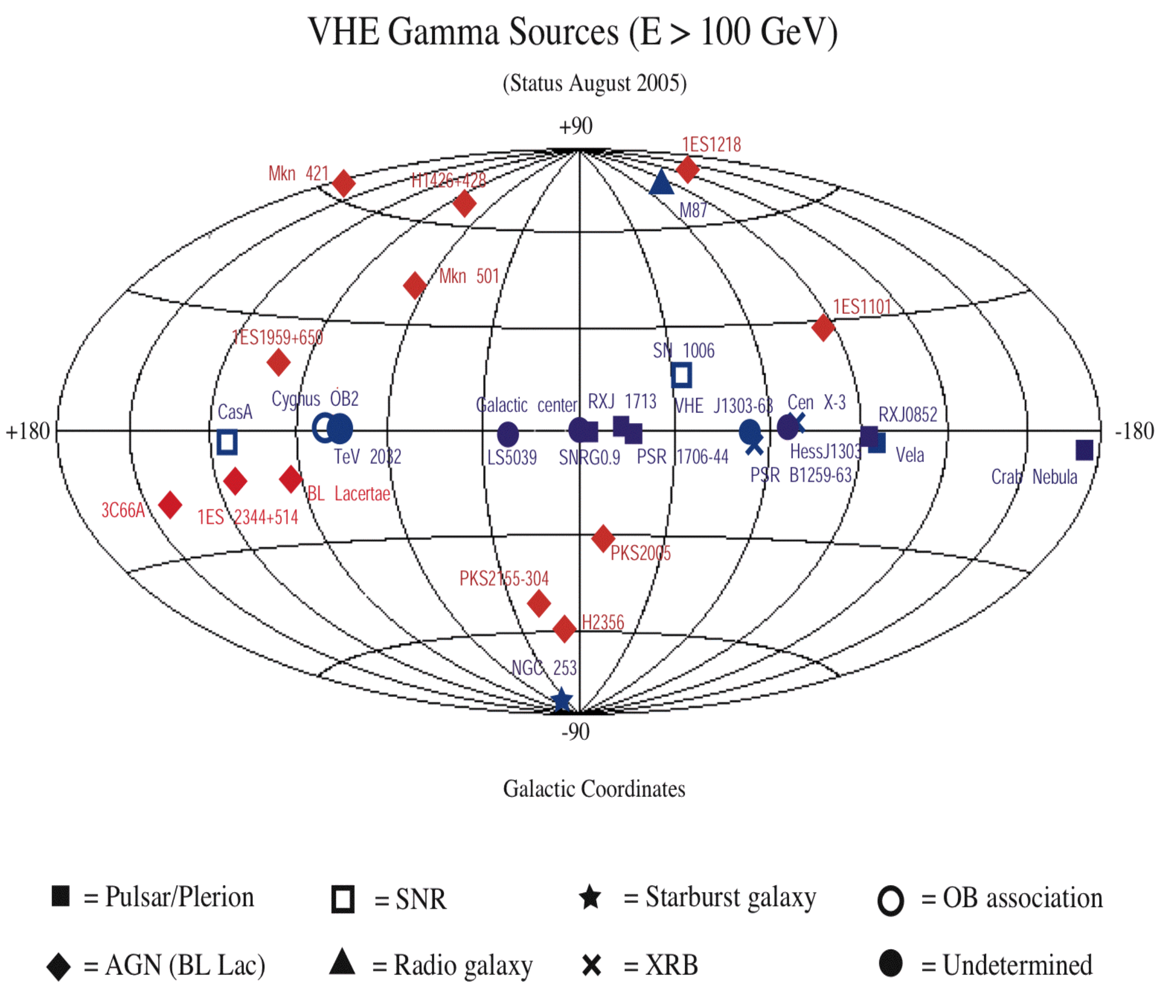


- **Lorentz symmetry violation**

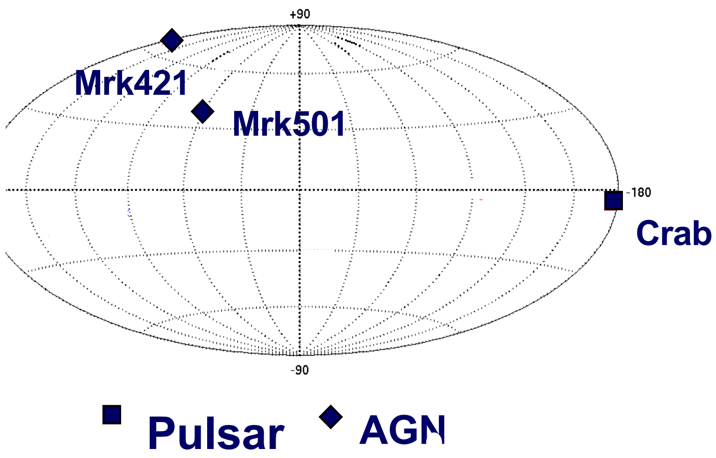
Gamma-ray sky

The VHE γ ray sky

2005

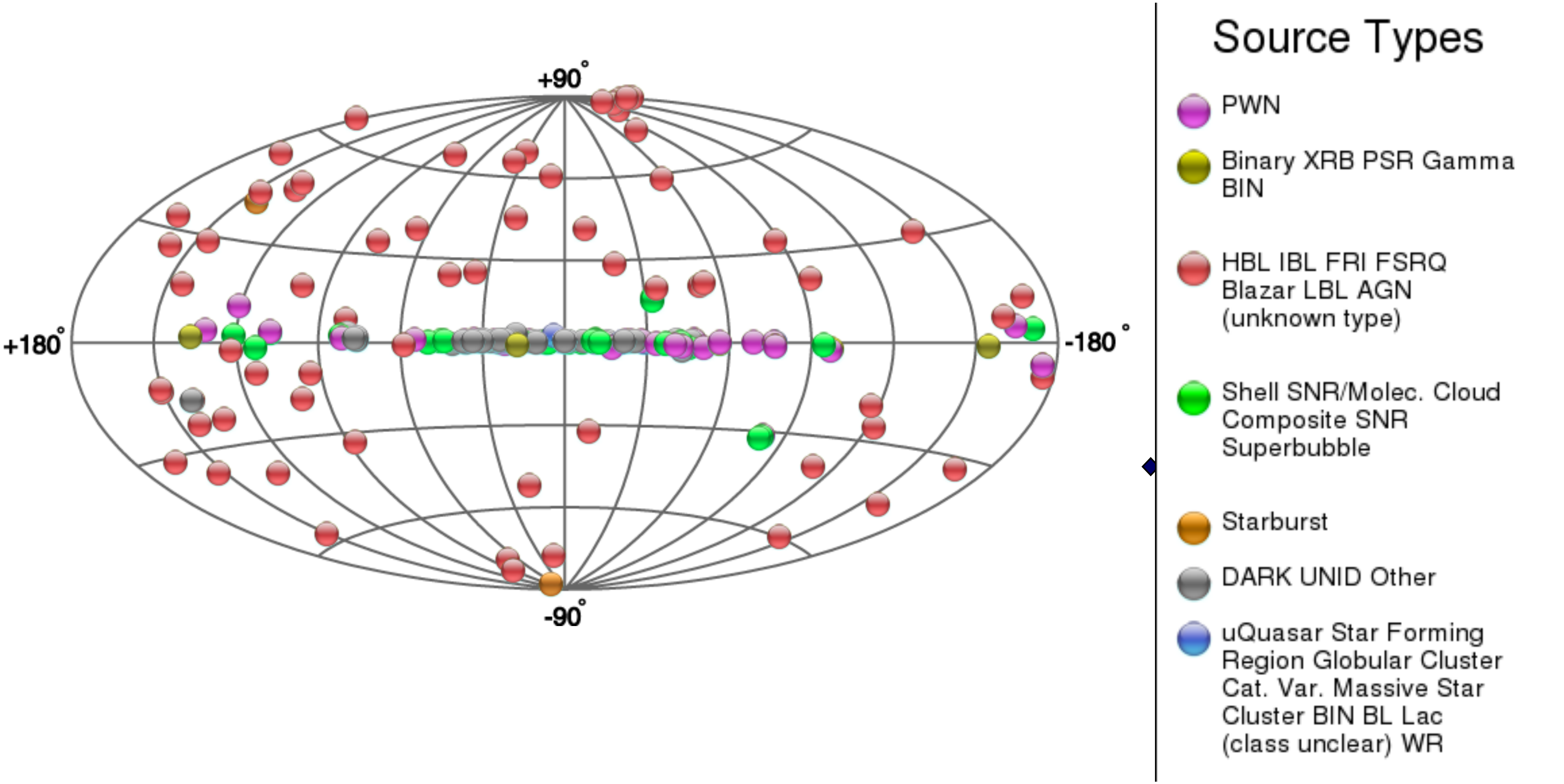


1995



The VHE γ ray sky Dec 2015

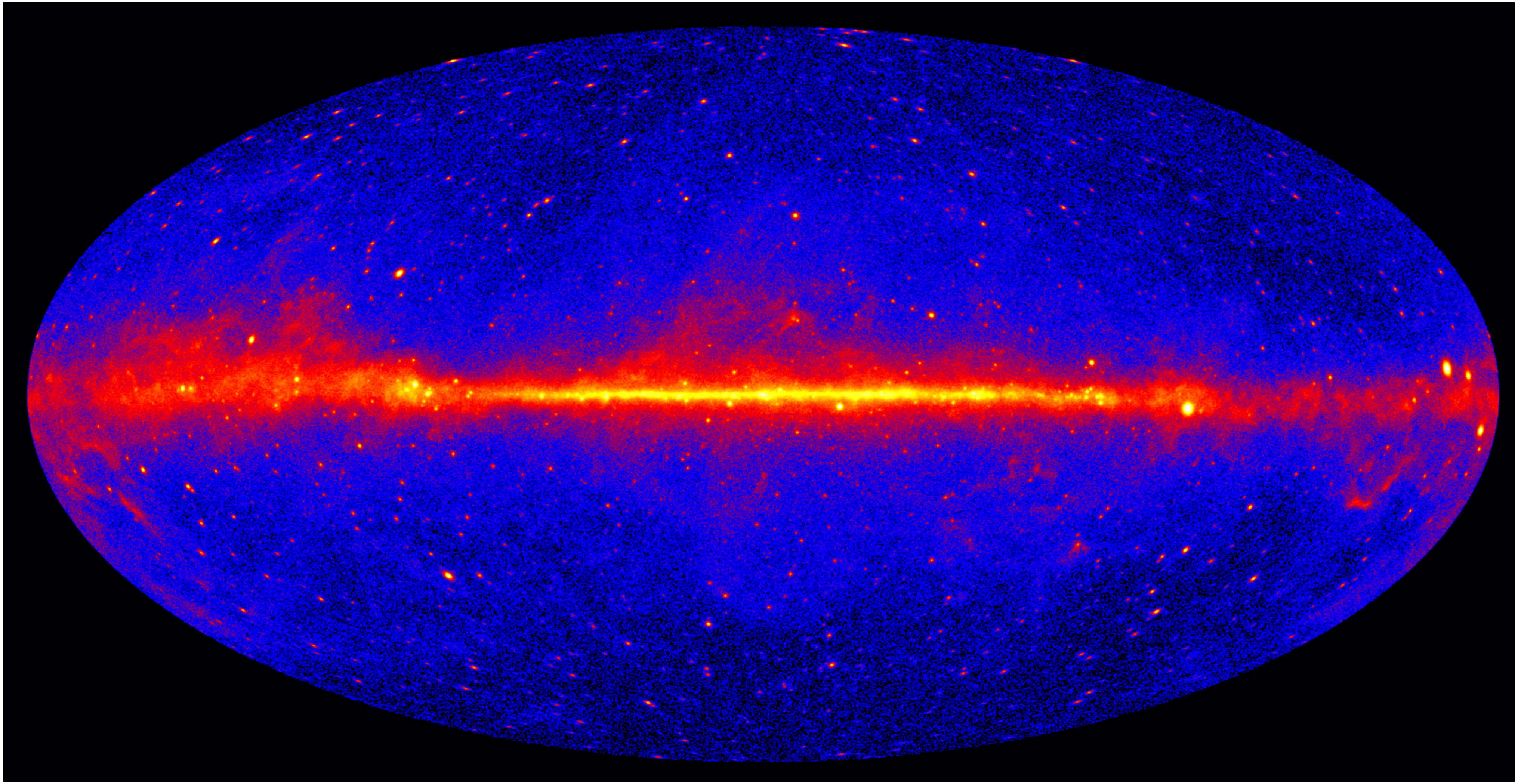
176 sources



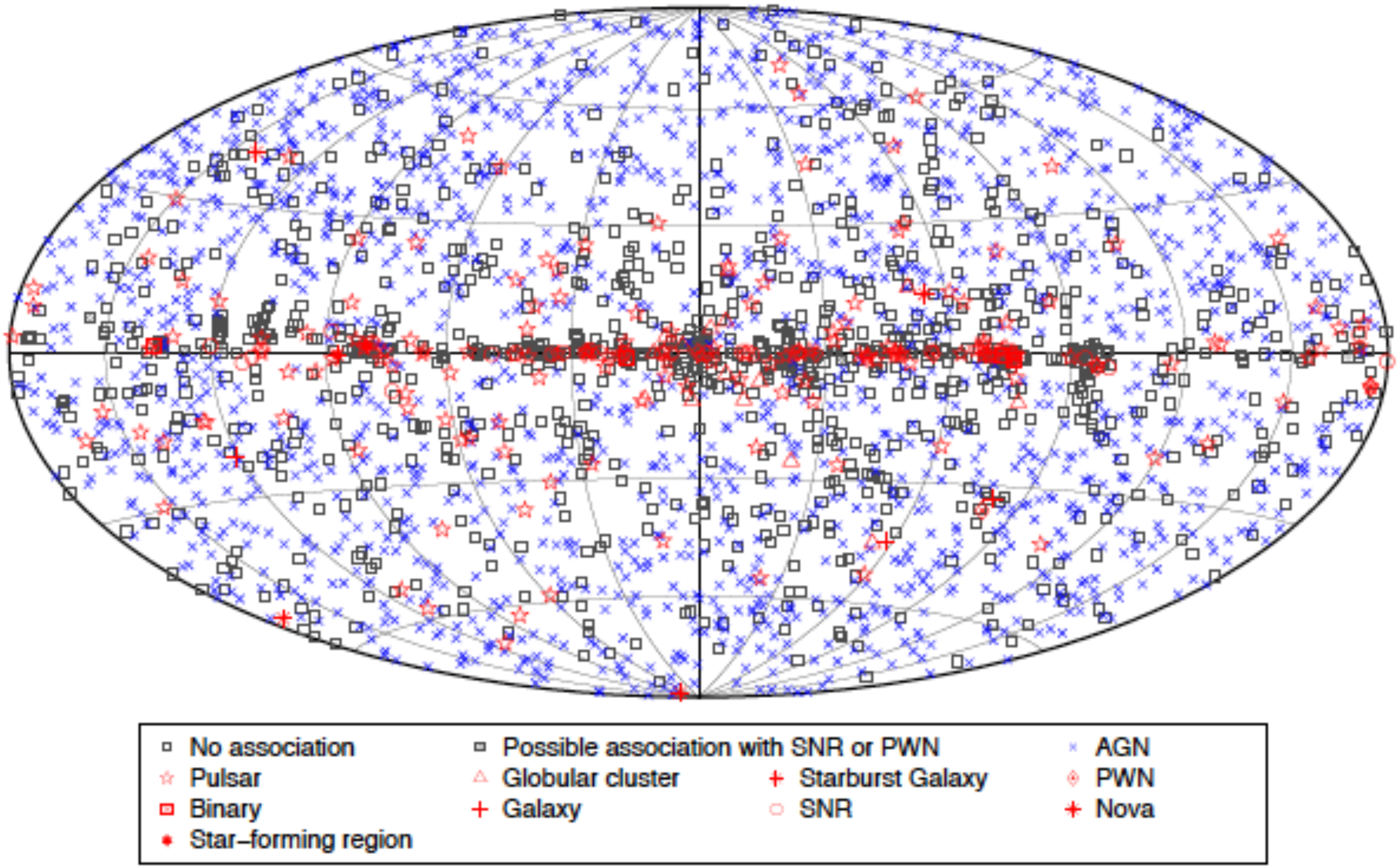
Source Counts

Source Type*	1995	2005	2015
Pulsar Wind Nebula (e.g. Crab, MSH 15-52 …)	1	5	37
Supernova Remnants (e.g. Cas-A, RXJ 1713 …)	0	4	15
Binary systems (B1259-63 etc)	0	1	6
X-ray binary	0		4
Galactic Center	0	0	1
		1	
Superbubble	0	1	2
Star clusters	0	0	4
Molecular clouds	0	0	2
BL LACs (e.g. Mkn 421, PKS 2155 …)	2	9	55
FSRQ	0	0	5
AGNs (M87, Cen A	0	1	4

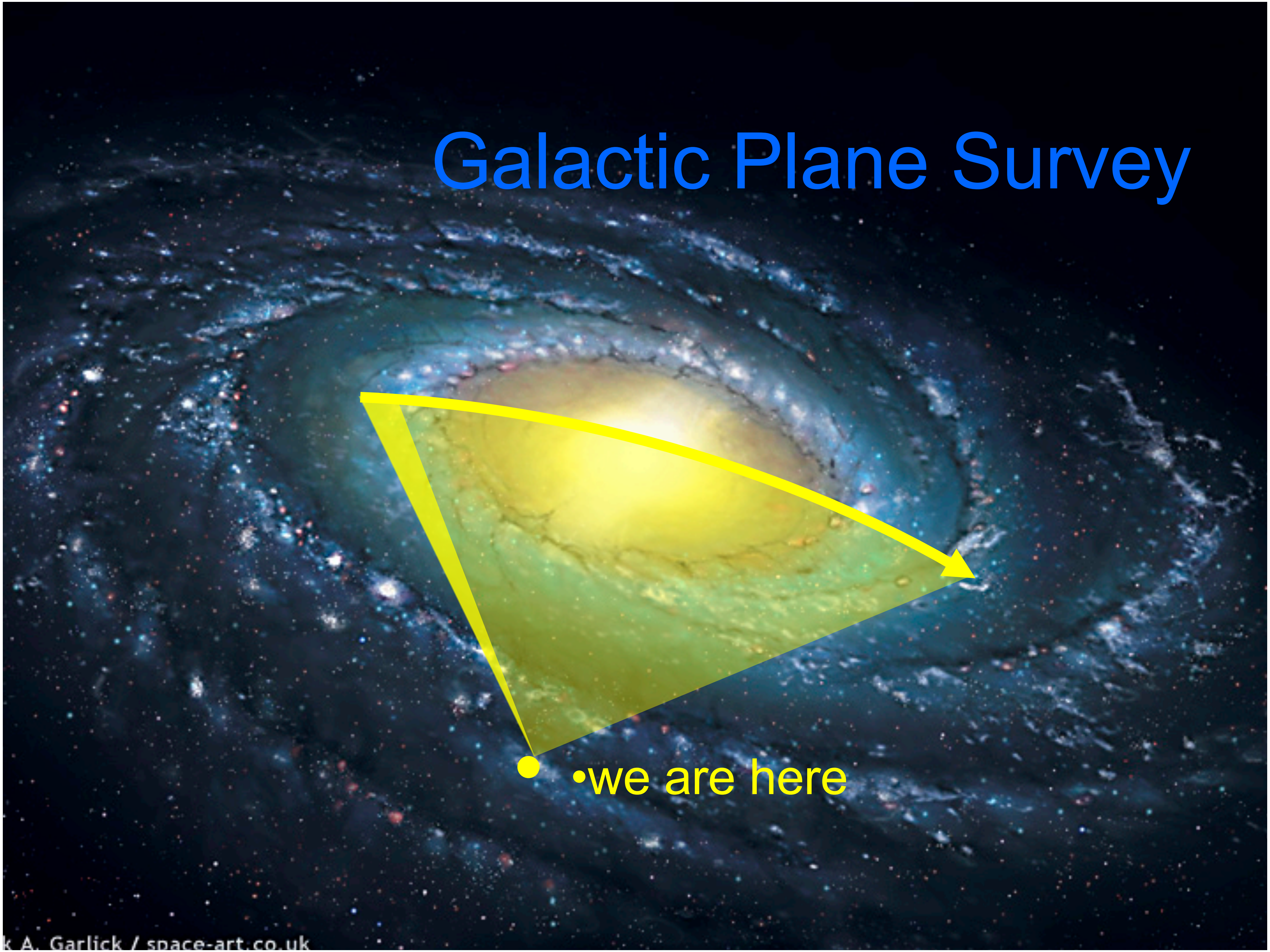
Fermi LAT 5 years all sky 1GeV



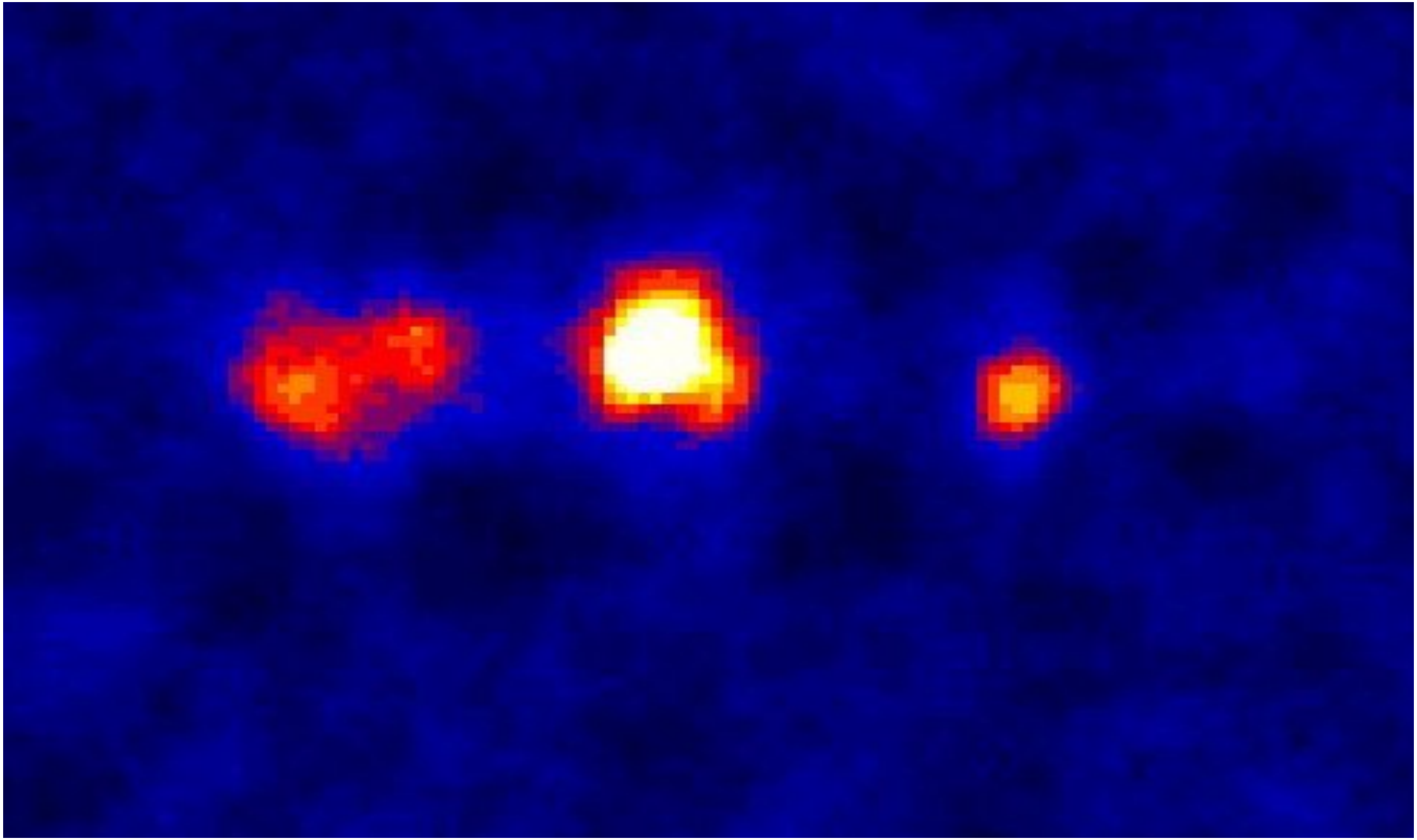
Fermi LAT source catalog: 3000 sources



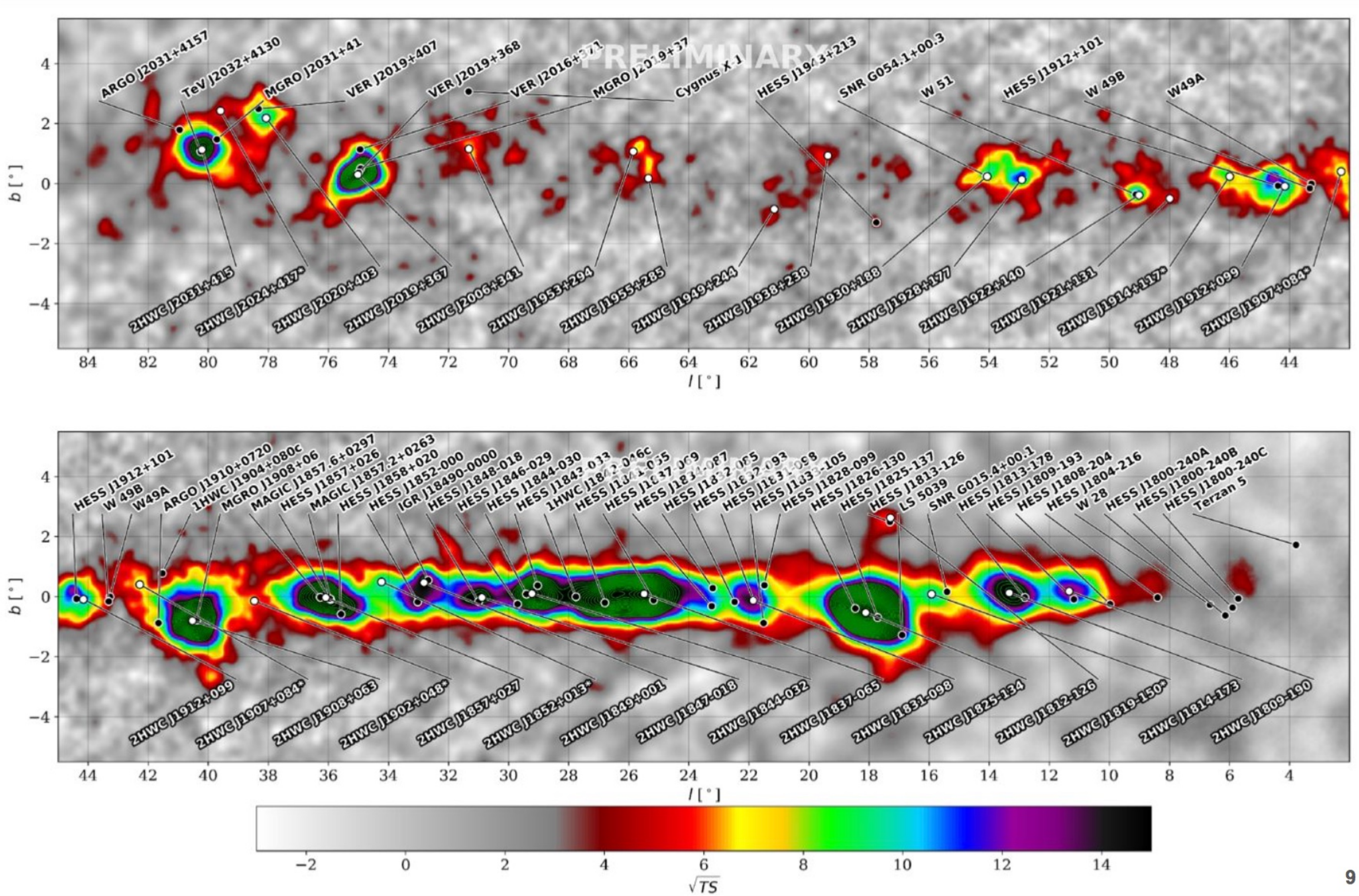
Galactic sources


Galactic Plane Survey
•we are here
k A. Garlick / space-art.co.uk

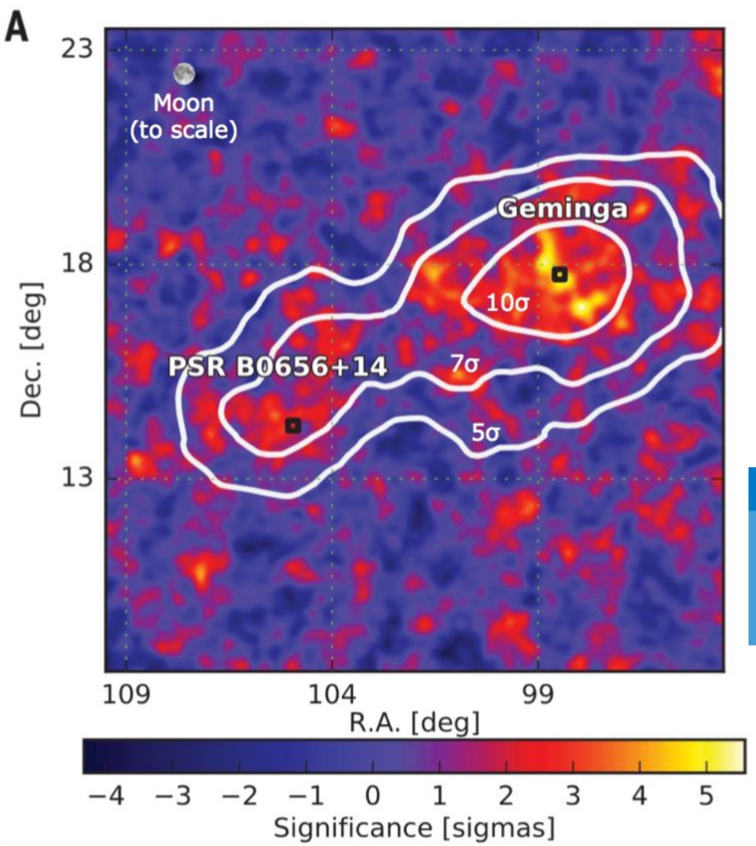
H.E.S.S Galactic Plane Survey



HAWC inner Galaxy



HAWC Geminga SN

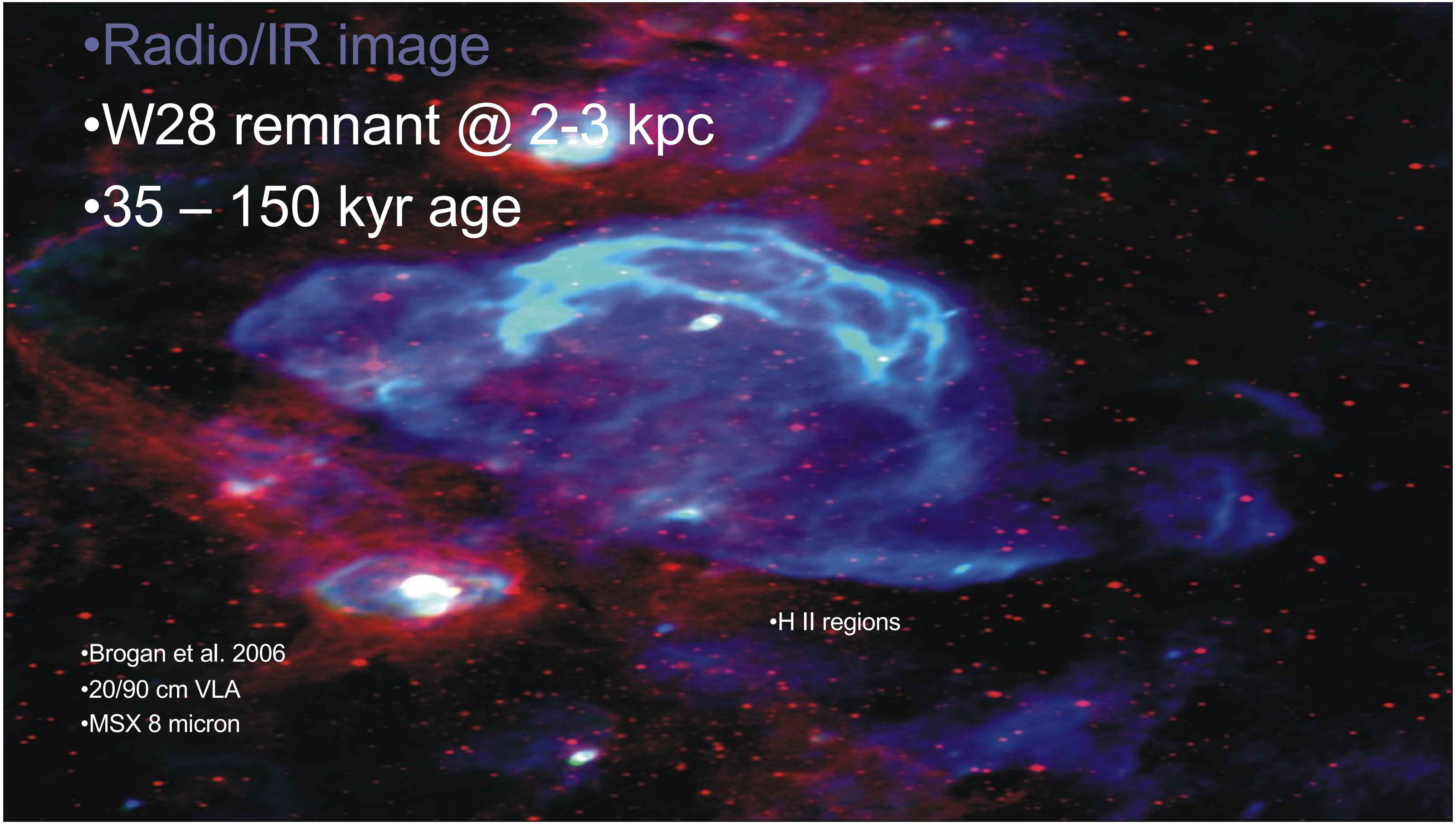


- **HAWC observes extended emission from both the Geminga and Monogem (PSR B0656+14) pulsars**
- **These are both nearby, middle-aged pulsars that could be producing the observed local positrons**

	Geminga	Monogem
$\dot{E}$ [erg/s]	3.2×10^{34}	3.8×10^{34}
Age [yr]	3.42×10^{5}	1.1×10^{5}
Dist. [pc]	250	288

Science 358 (2017) no.6365, 911-914

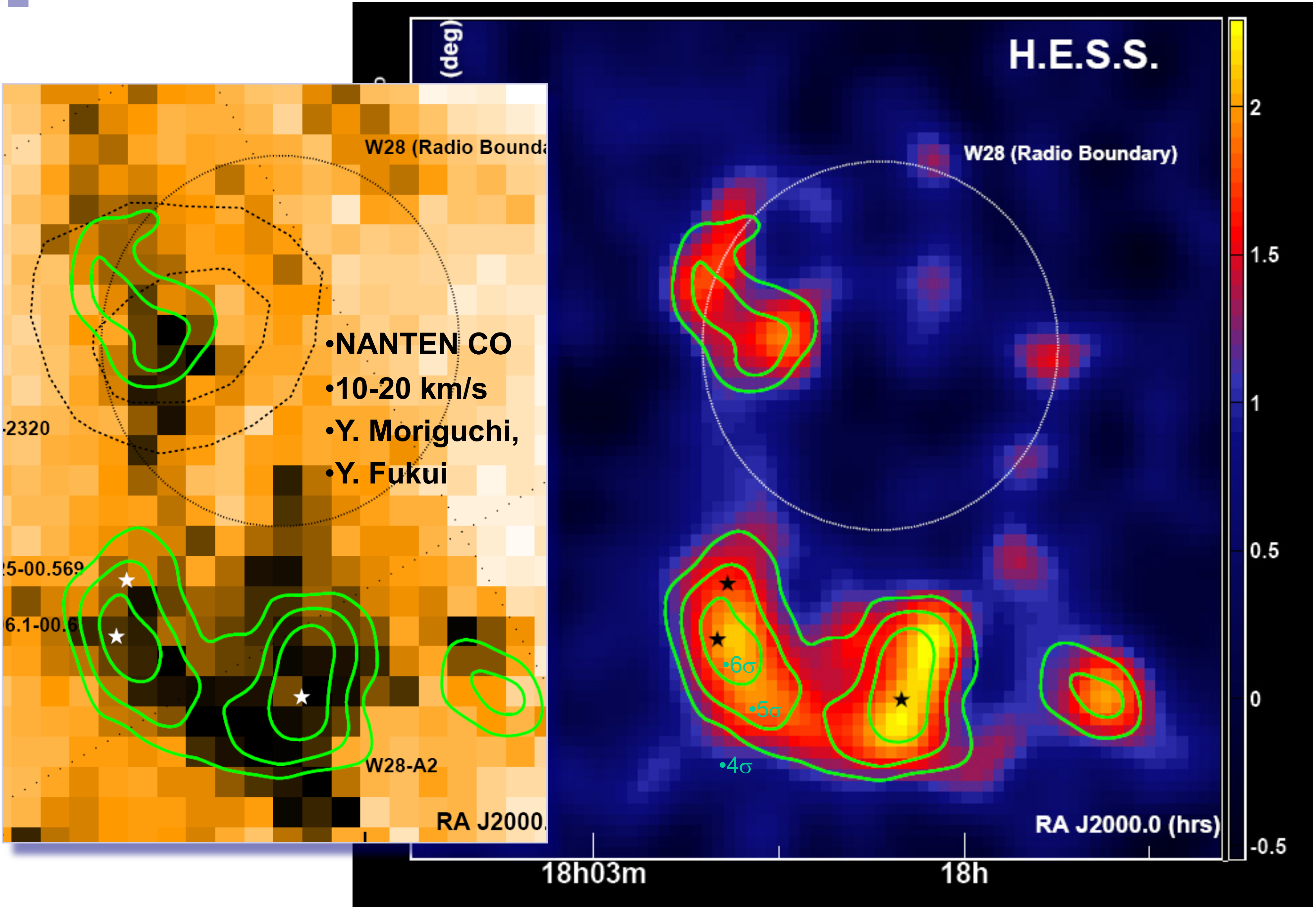
Old SNRs & interacting SNRs



- Radio/IR image
- W28 remnant @ 2-3 kpc
- 35 – 150 kyr age

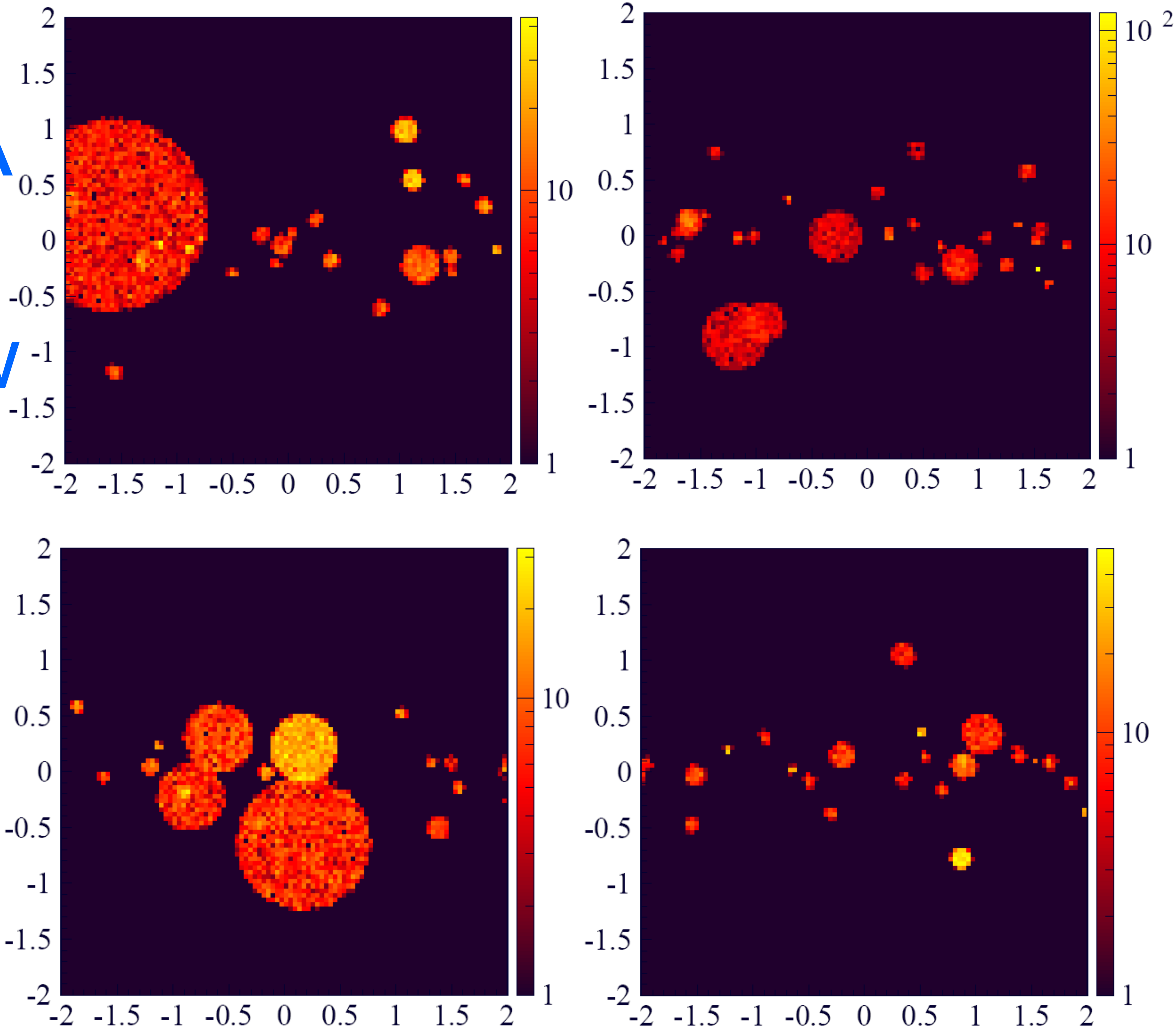
- H II regions

- Brogan et al. 2006
- 20/90 cm VLA
- MSX 8 micron


W28 (Radio Bounda
•NANTEN CO
•10-20 km/s
•Y. Moriguchi,
•Y. Fukui
-2320
5-00.569
6.1-00.6
W28-A2
RA J2000.
H.E.S.S.
W28 (Radio Boundary)
•6σ
•5σ
•4σ
RA J2000.0 (hrs)
(deg)
18h03m
18h
2
1.5
1
0.5
0
-0.5

MEPHI

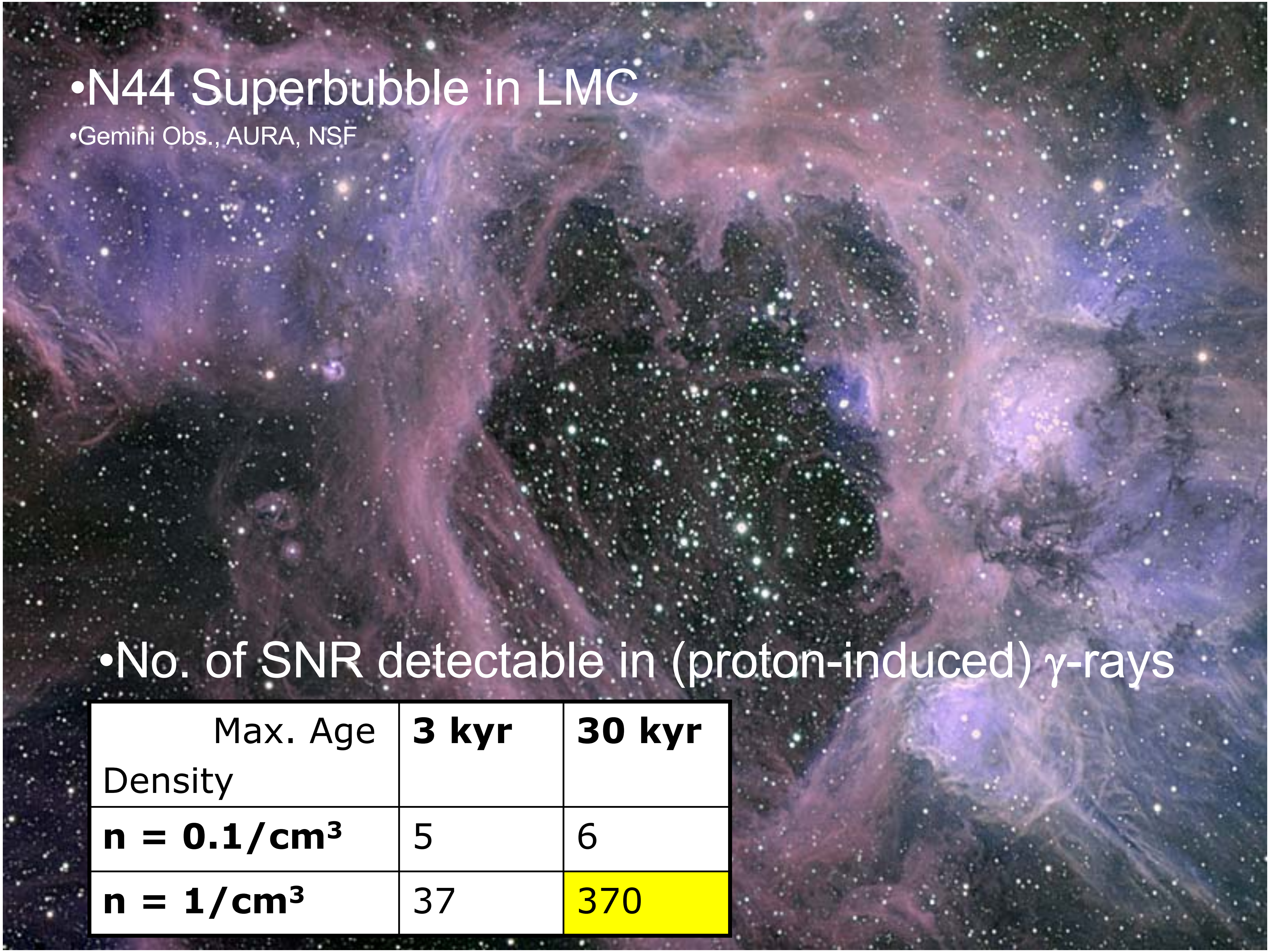
A CTA field of view



- SNR models
- using DAV 9
- n = 1
- ε = 0.1

- (consistent
- with HESS
- plane scan)

- assuming
- 1 mCrab



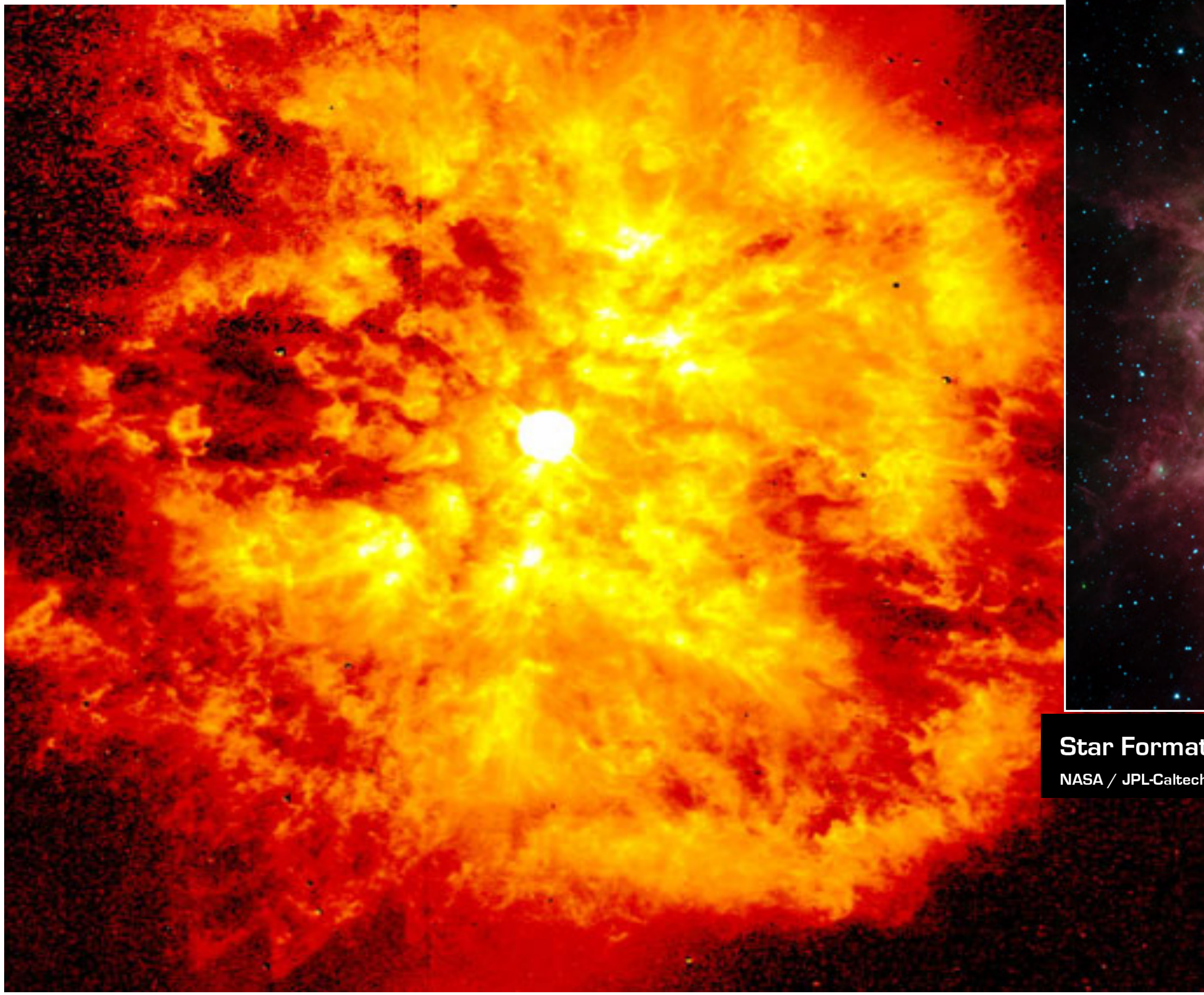
•N44 Superbubble in LMC

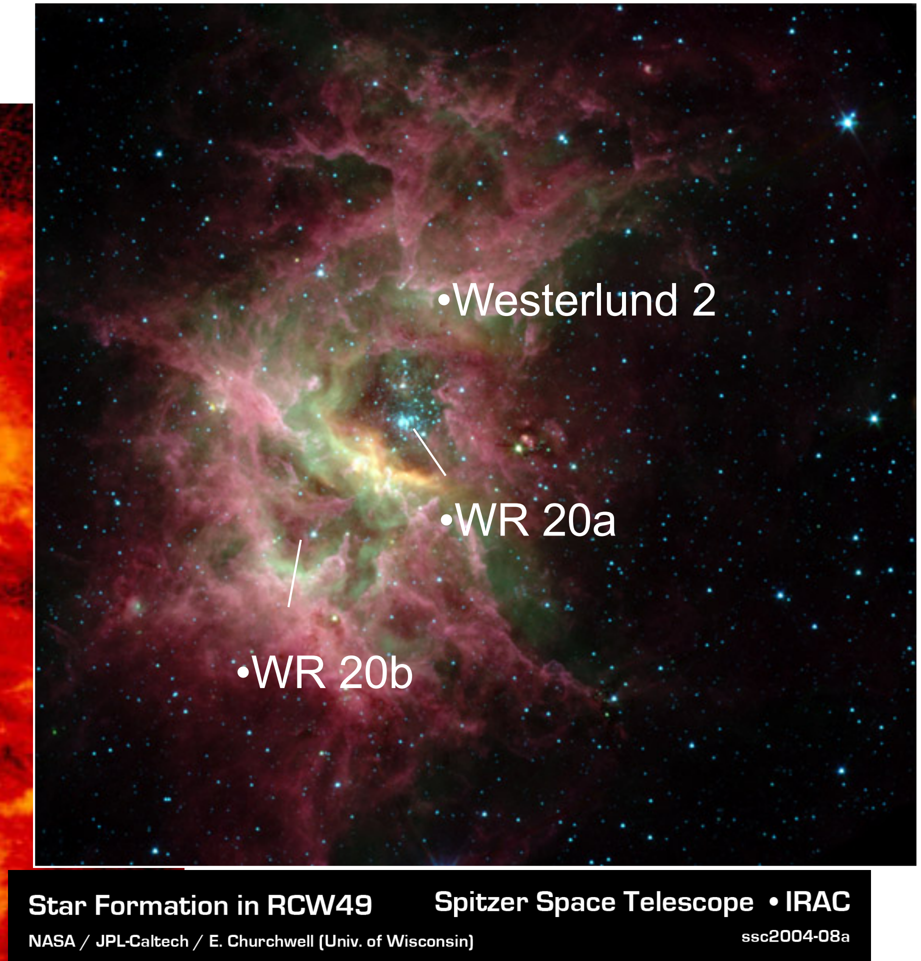
•Gemini Obs., AURA, NSF

•No. of SNR detectable in (proton-induced) γ-rays

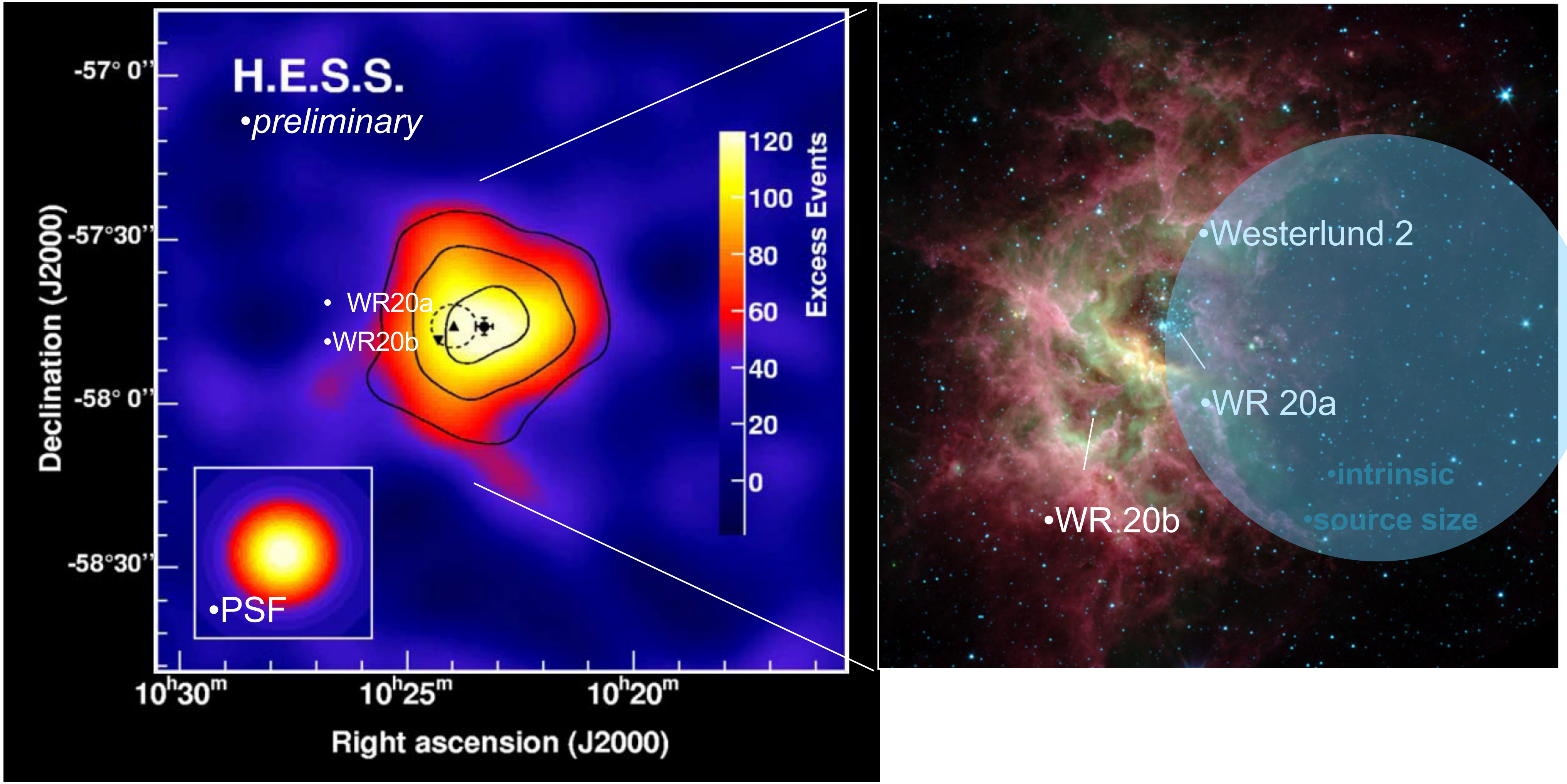
Max. Age / Density	**3 kyr**	**30 kyr**
n = 0.1/cm³	5	6
n = 1/cm³	37	370

RCW 49:
Stellar Winds as Cosmic Accelerators





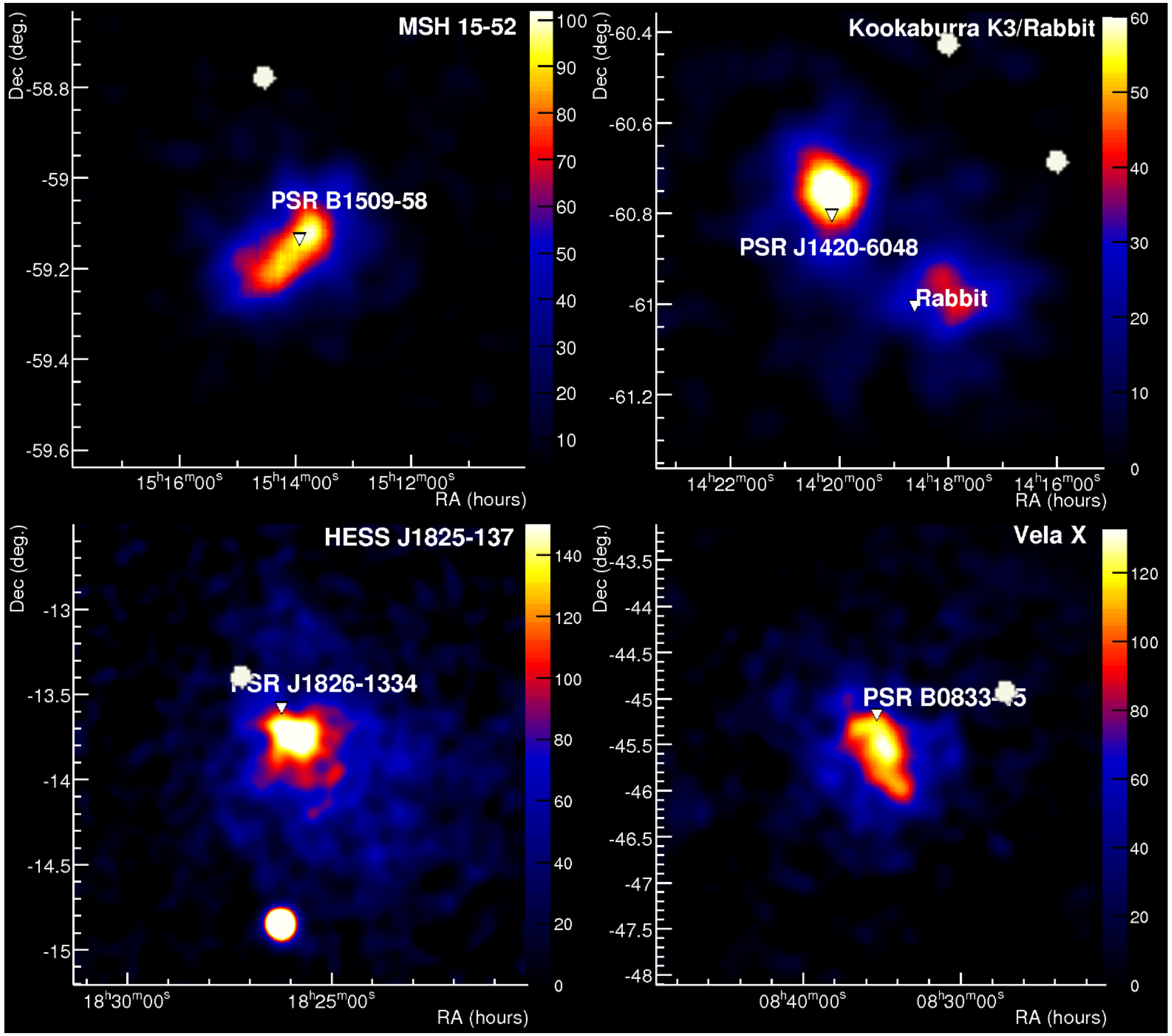
HESS J1023-575



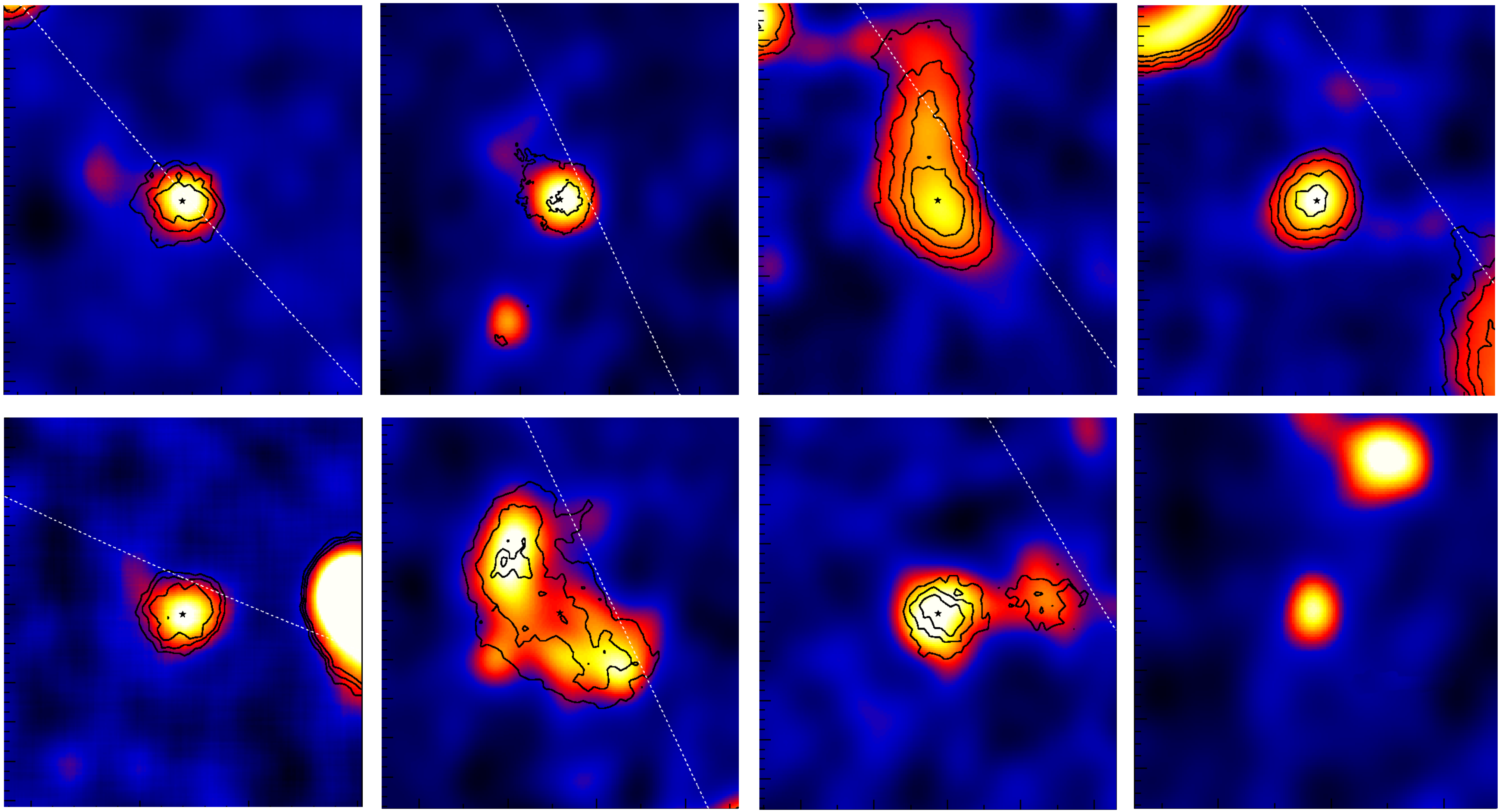
Pulsar Wind Nebulae

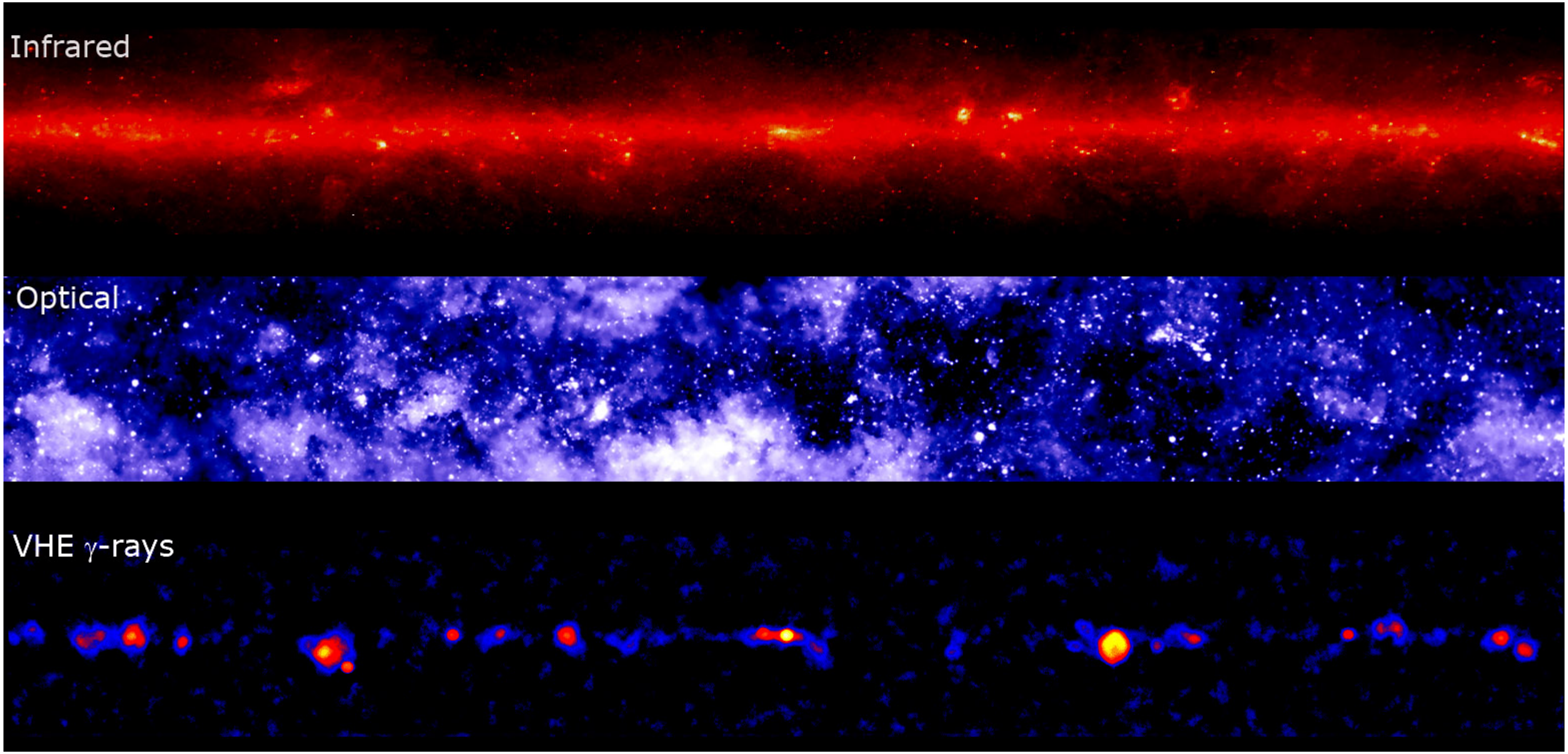
Extended

γ-ray sources



“Dark” sources: Objects which only shine in gamma rays !

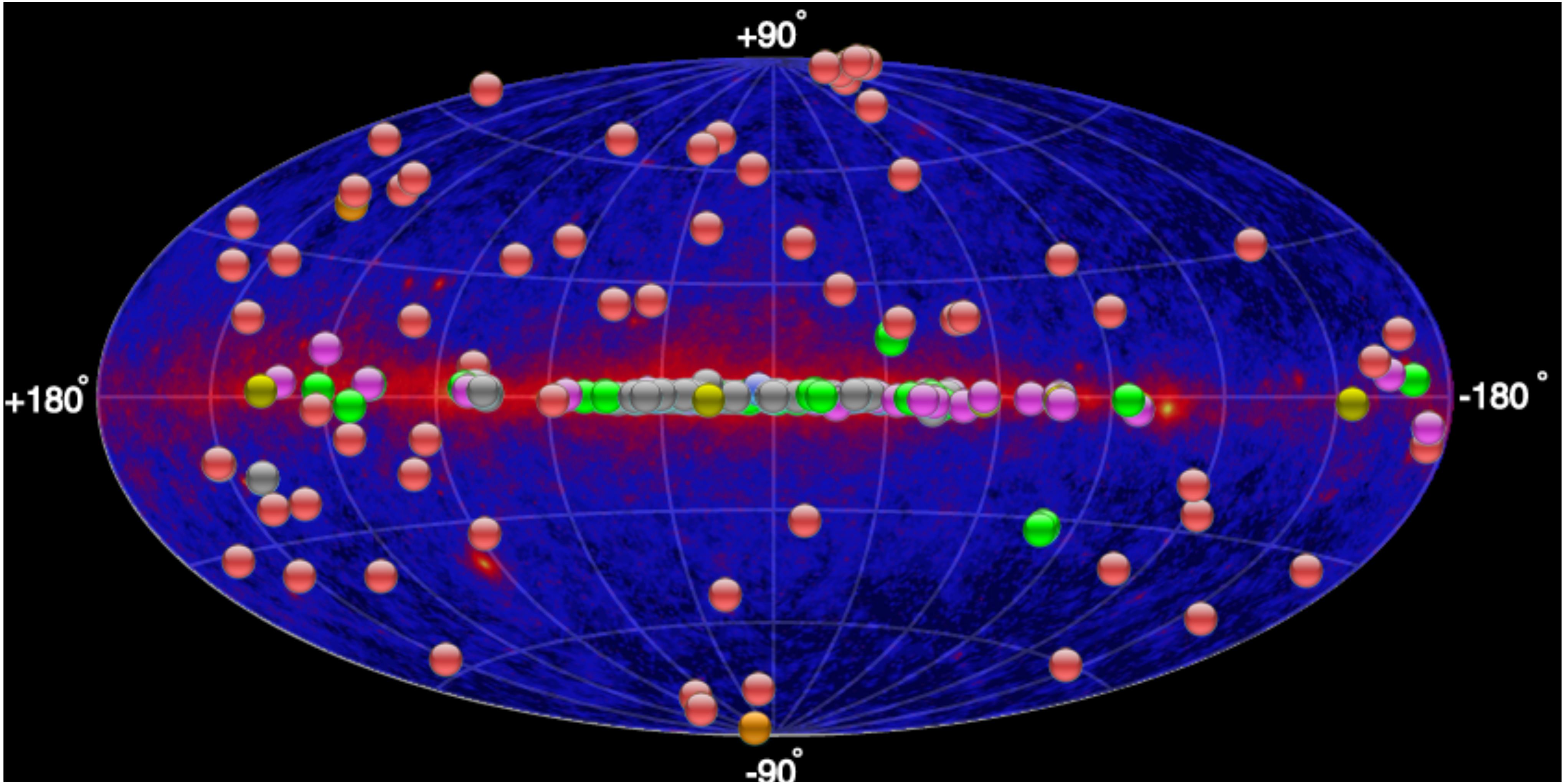




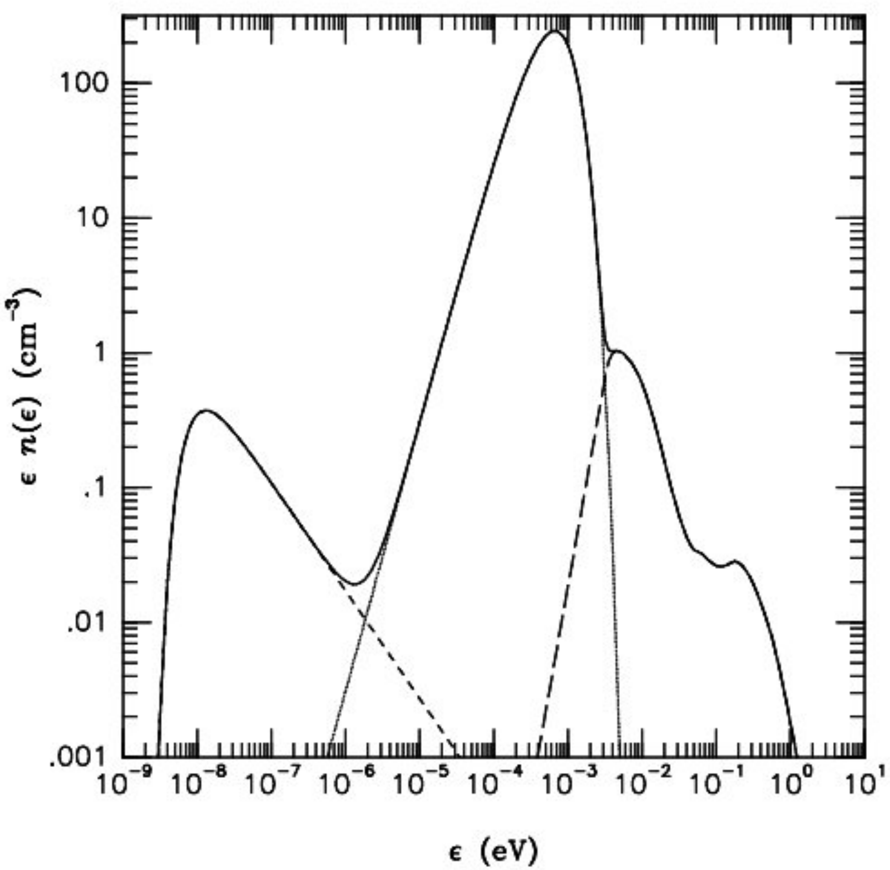
•The age of real VHE gamma ray astronomy has started

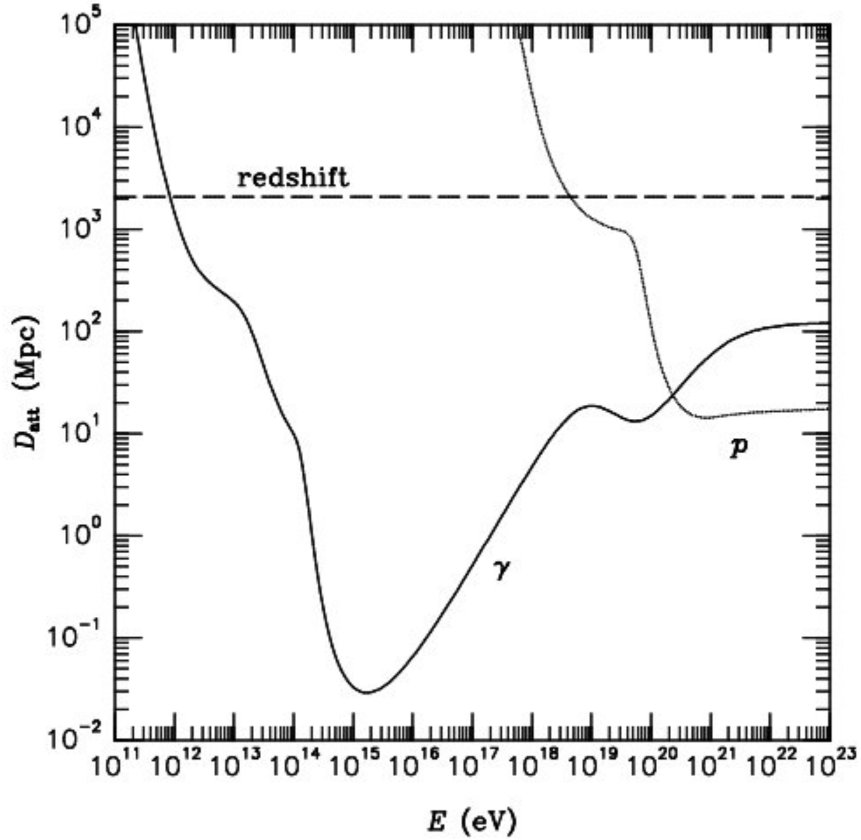
Extra-galactic gamma-ray sources and extragalactic background light

1000 sources in GeV and 60 in TeV



Diffuse backgrounds



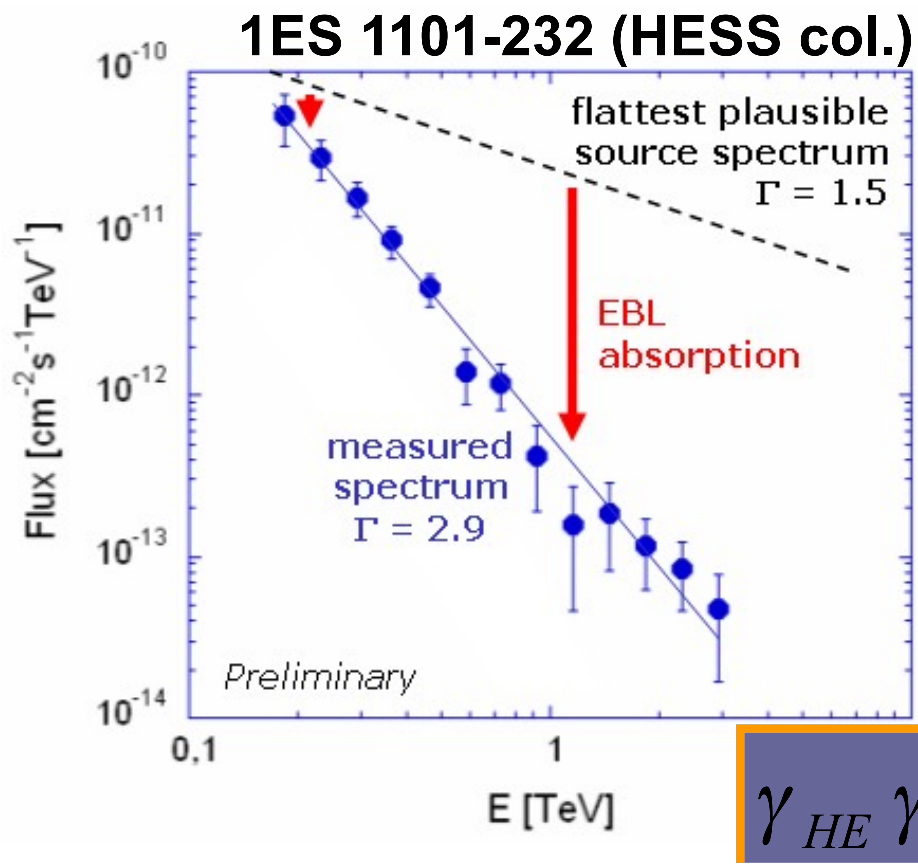


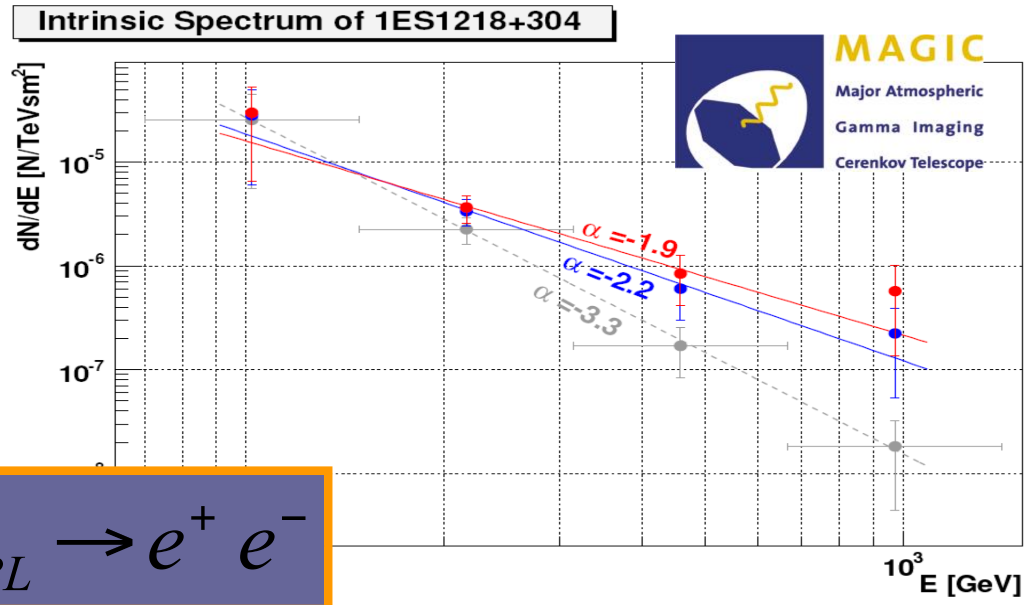
Extrag. Background Light

Cosmological radiation from star formation and evolution.

Spectral signature from gg absorption for Eg ~ 50-2000 GeV.

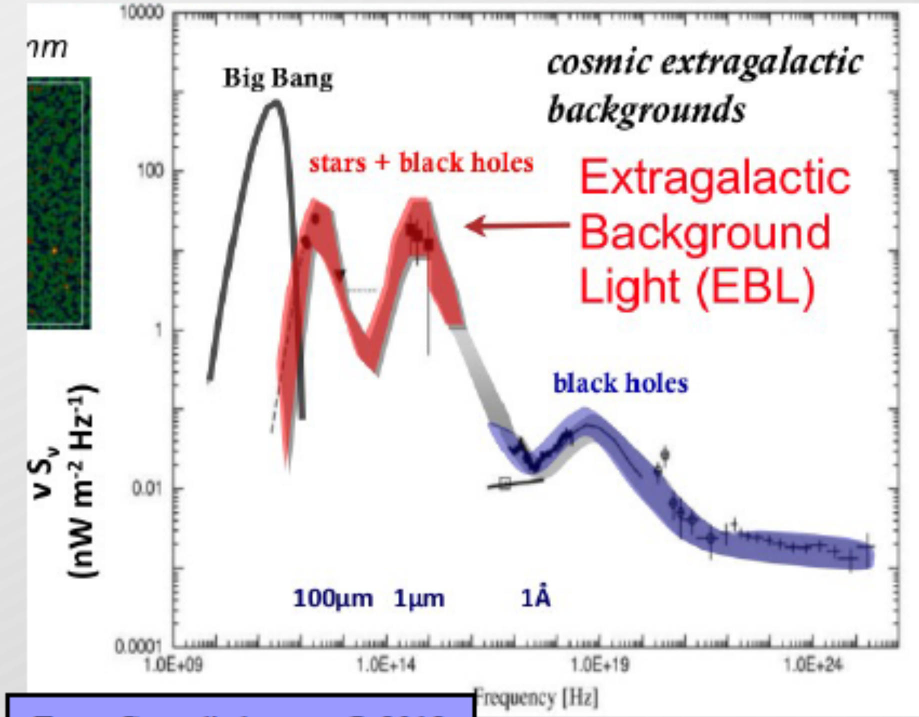
Use measured AGN spectra to constrain EBL.





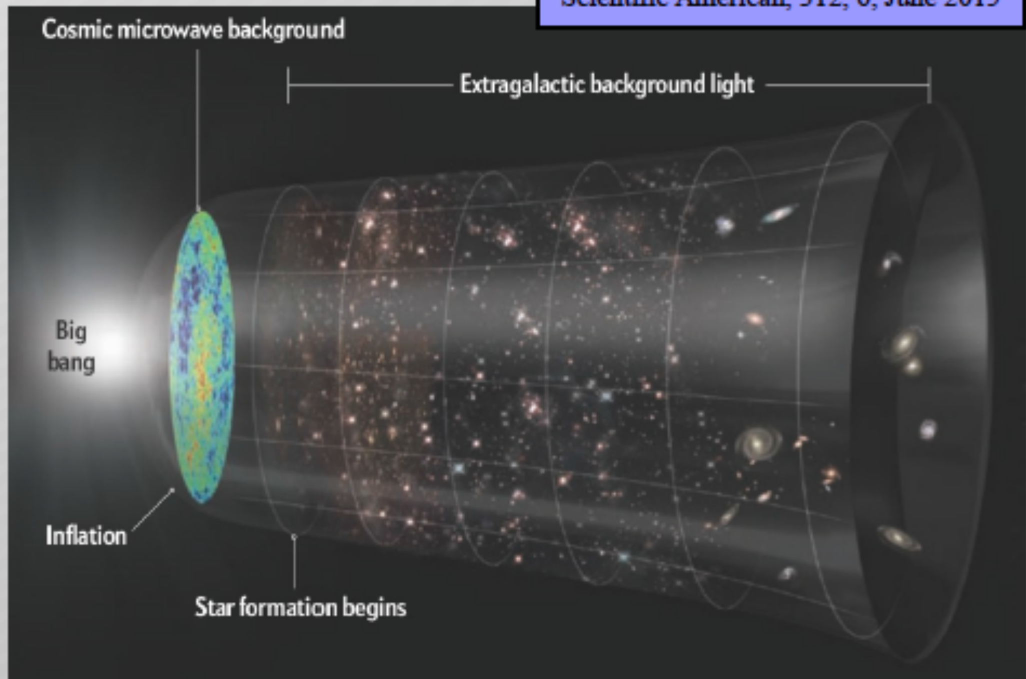
$$\gamma_{HE}\,\gamma_{EBL} \rightarrow e^+ e^-$$

Diffuse extragalactic backgrounds



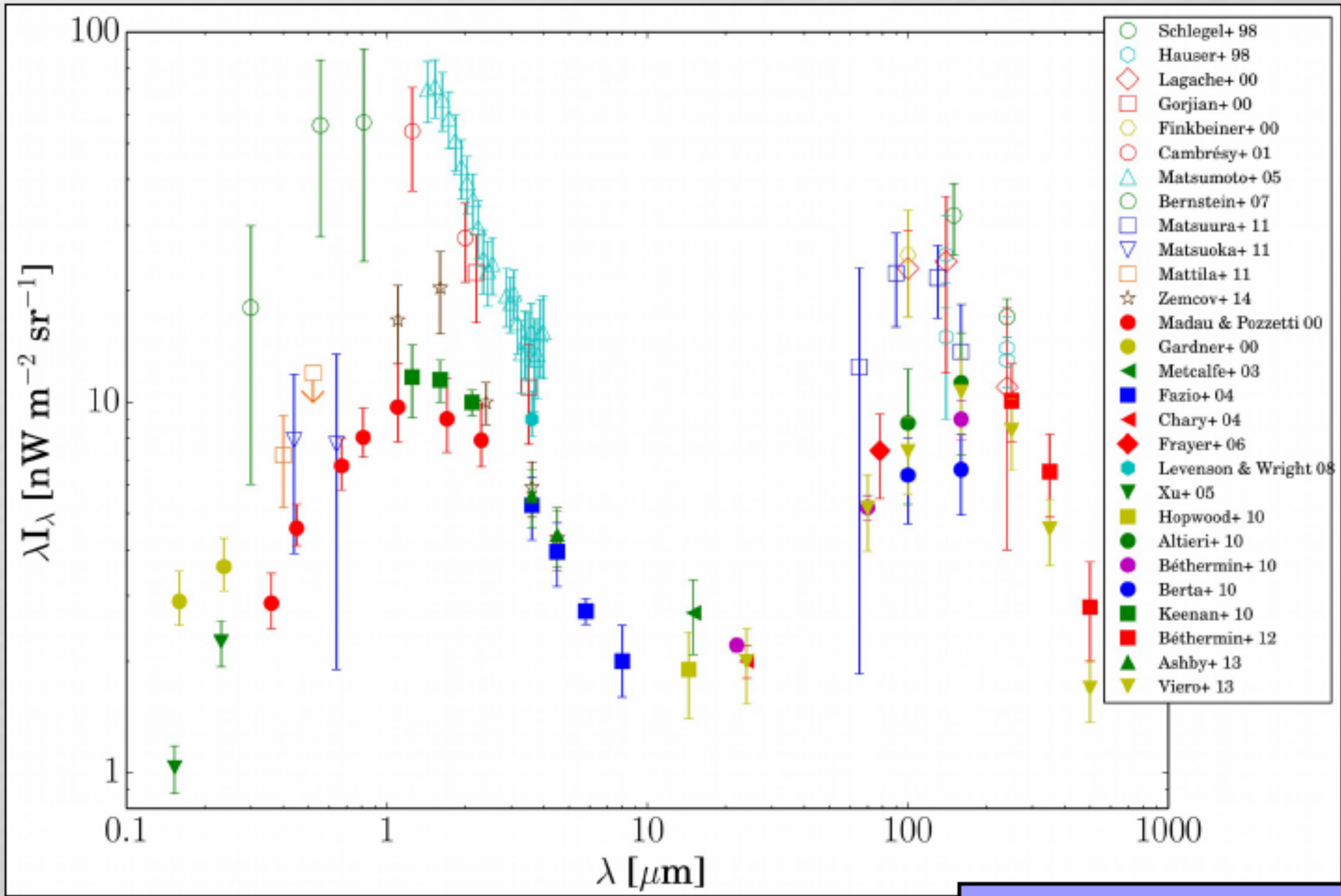
From Genzel's lecture @ 2013 Jerusalem Winter School

Scientific American, 312, 6, June 2015



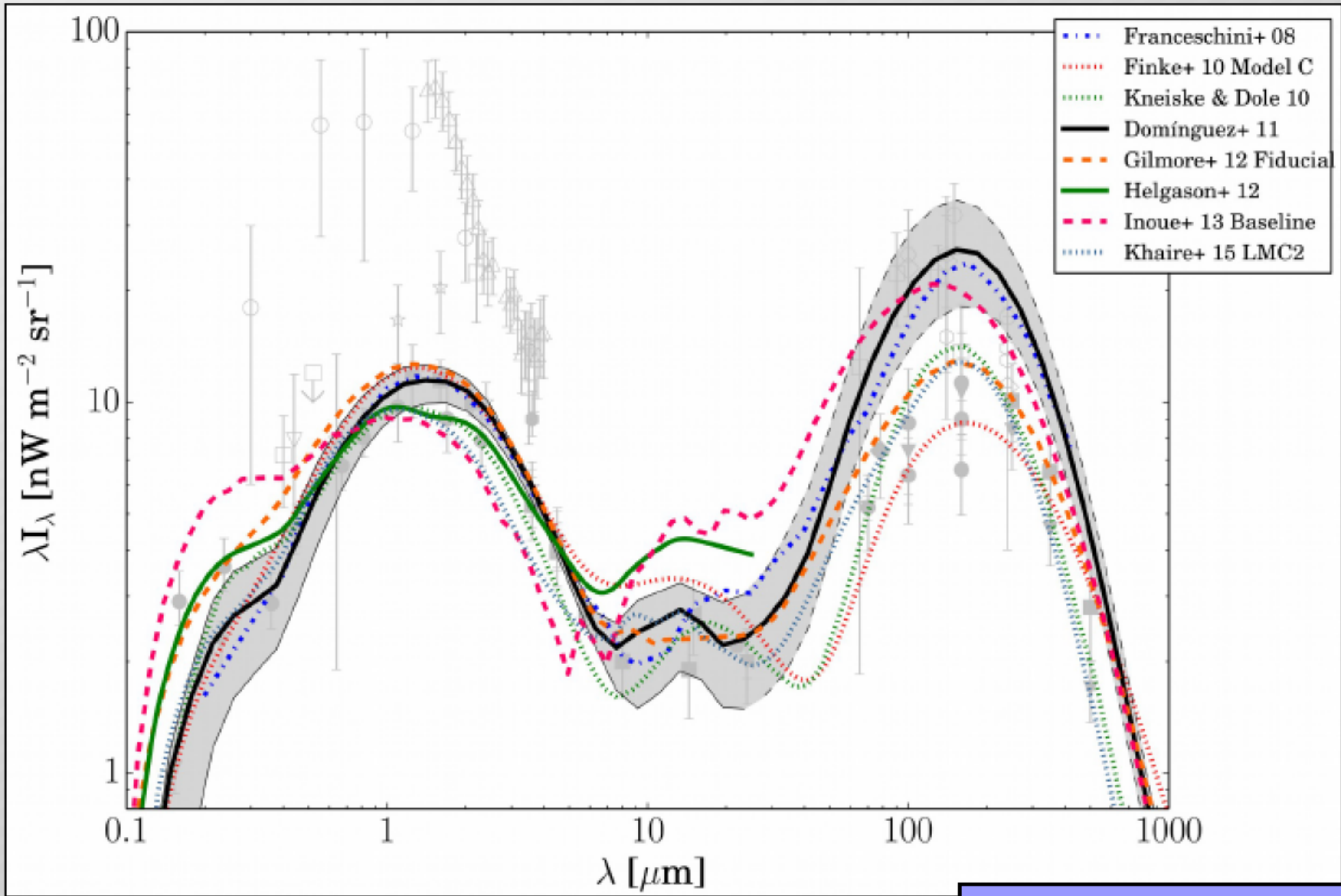
- The EBL is the accumulated diffuse light produced by star formation processes and accreting black holes over the history of the Univere from the UV to the far-IR.
- It contains fundamental information about galaxy evolution, cosmology, and it is essential for the full energy balance of the Universe.

Local EBL: Data and Models



Domínguez & Primack, 15 in prep.

Local EBL: Data and Models

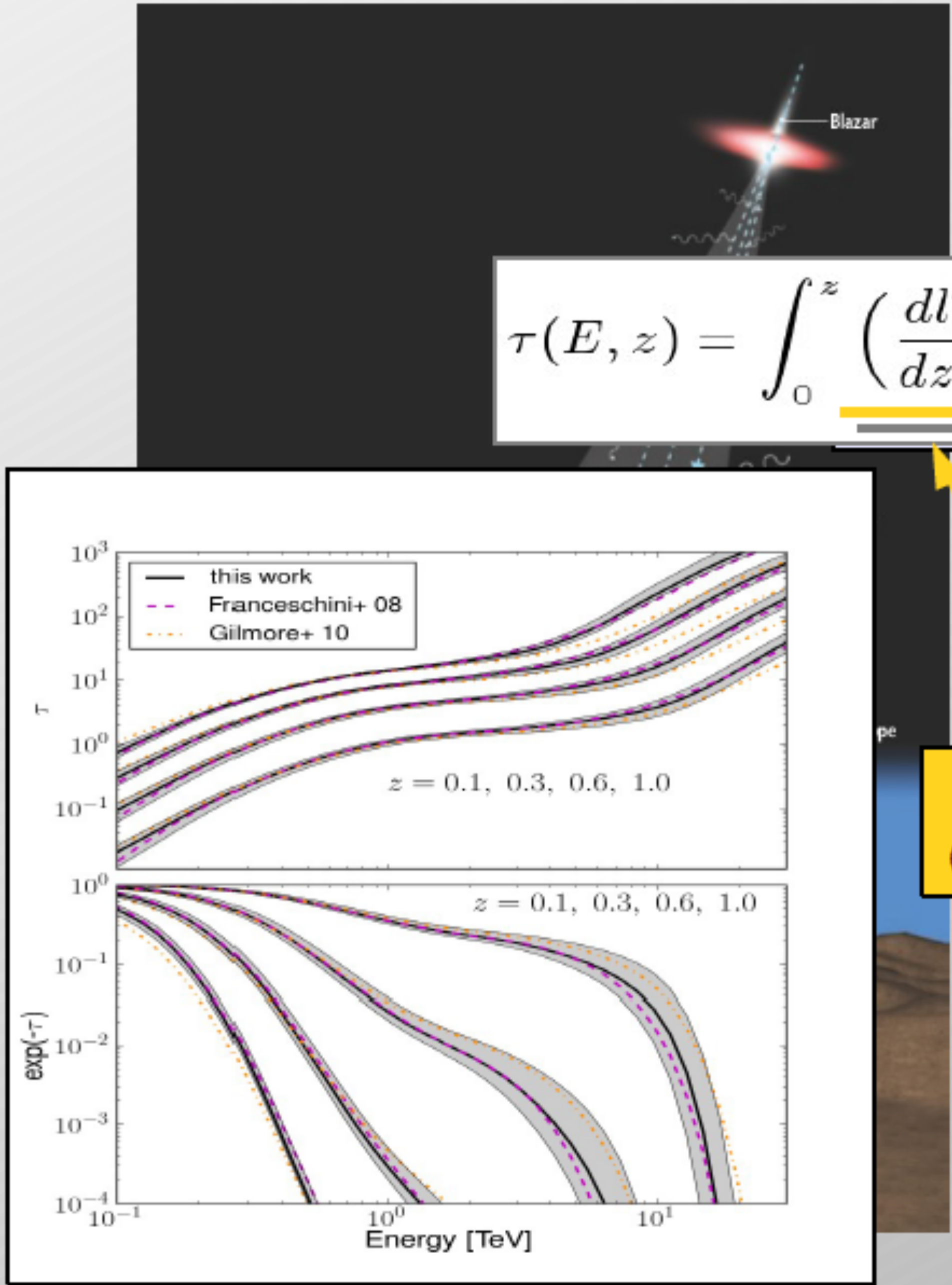


Domínguez & Primack, 15 in prep.

Gamma-Ray Attenuation

$$\left.\frac{dN}{dE}\right|_{obs} = \left.\frac{dN}{dE}\right|_{int} \exp\left[-\tau(E,z)\right]$$

$$\tau(E,z) = \int_0^z \left(\frac{dl'}{dz'}\right) dz' \int_0^2 d\mu \frac{\mu}{2} \int_{\varepsilon_{min}}^{\infty} d\varepsilon' \; \sigma_{\gamma\gamma}(\beta') n(\varepsilon', z')$$



Distance (cosmology)

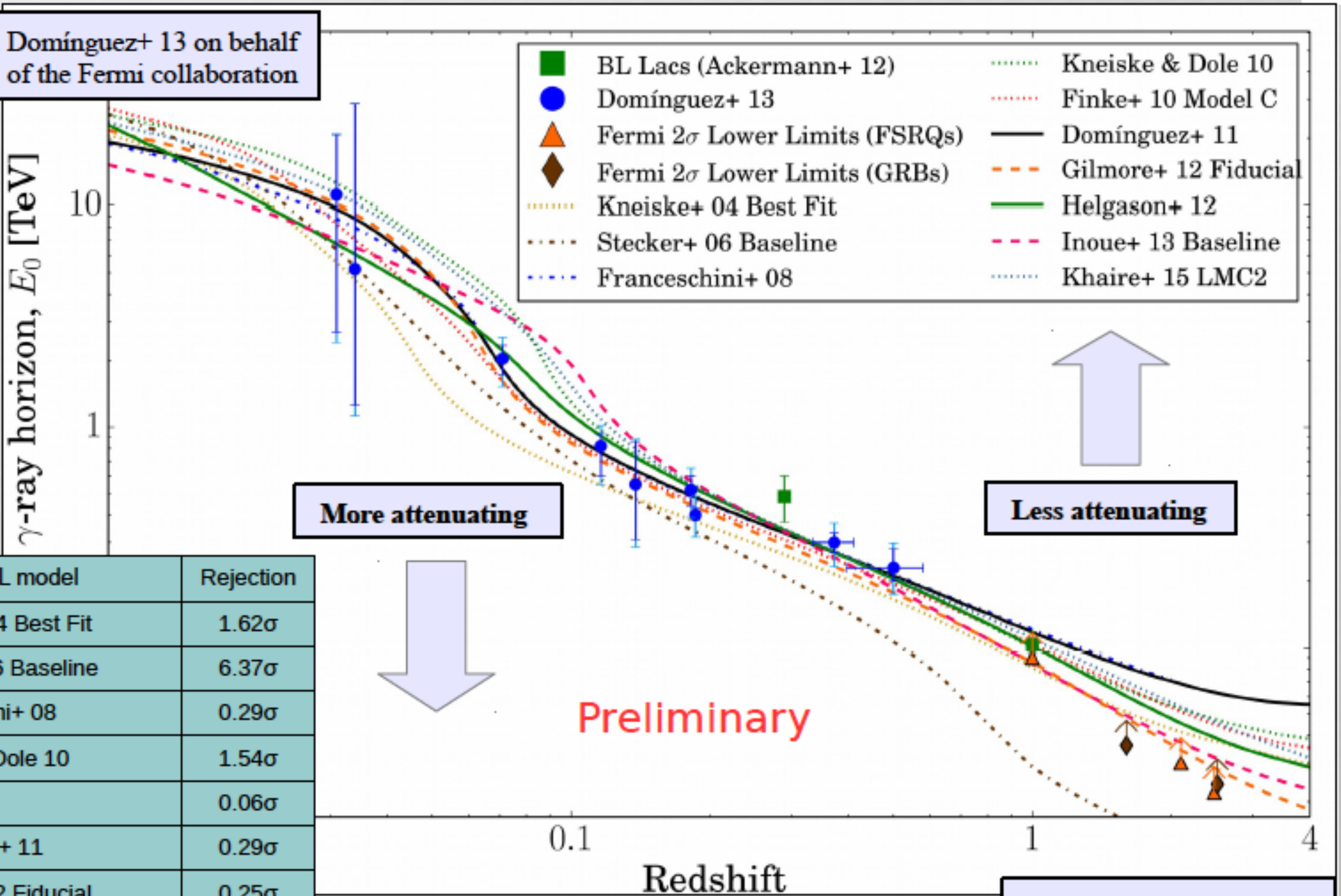
Interaction angle

Cross section

EBL photon density evolution (cosmology)

Cosmic γ-ray Horizon: Results

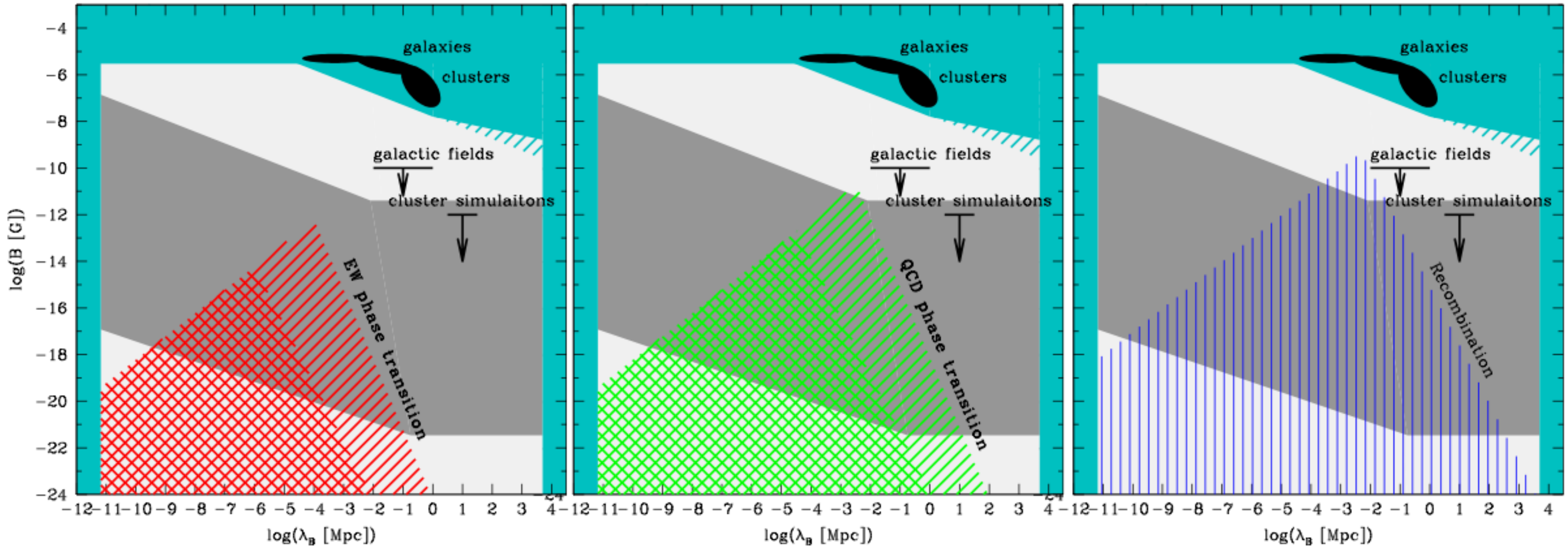
Domínguez+ 13 on behalf of the Fermi collaboration



EBL model	Rejection
Kneiske+ 04 Best Fit	1.62σ
Stecker+ 06 Baseline	6.37σ
Franceschini+ 08	0.29σ
Kneiske & Dole 10	1.54σ
Finke+ 10	0.06σ
Domínguez+ 11	0.29σ
Gilmore+ 12 Fiducial	0.25σ
Helgason+ 12	0.09σ
Inoue+ 13 Baseline	2.12σ
Khaire+ 15 LMC2	1.27σ

Preliminary data courtesy of Marco Ajello

Extra-galactic sources and determination of magnetic field



A.Neronov, D.S., PRD 2009, arXiv:**0910.1920**

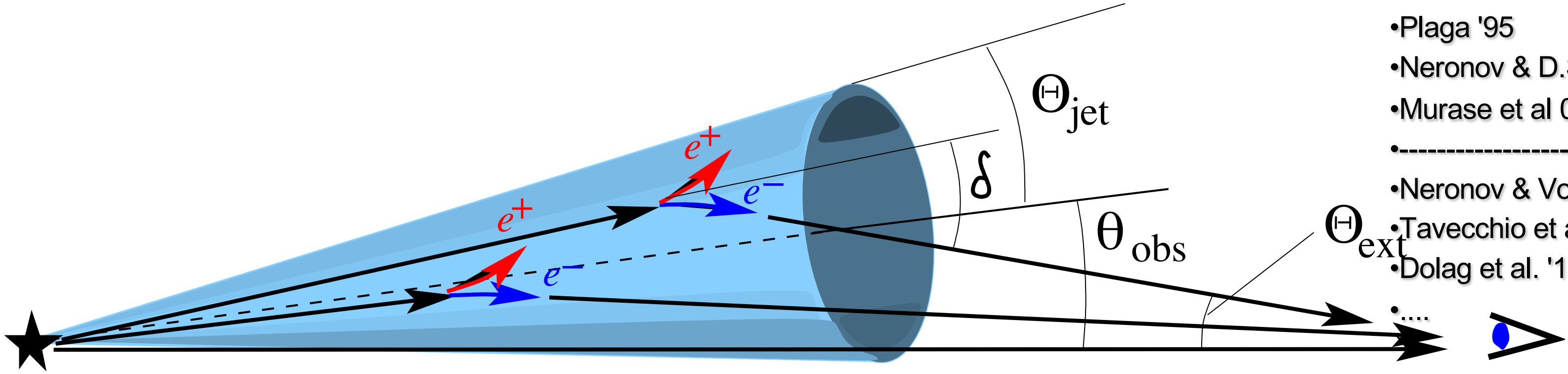
•Magnetic fields might be generated via "battery" effects during phase transitions in the Early Universe.

•In principle, the initial magnetic field energy density might provide non-negligible contribution to the overall energy density of the Universe.

•Magnetic field correlation length could not exceed the size of cosmological horizon; strength of magnetic field averaged over large distance scales could not exceed the "causality" limit

•Damping processes remove small-scale magnetic fields in the course of cosmological evolution.

•IGMF measurement with gamma-ray telescopes



- Plaga '95
- Neronov & D.S. '07, '09
- Murase et al 08
- -----------------------------
- Neronov & Vovk '10
- Tavecchio et al. '10
- Dolag et al. '10
- ....

•γ-rays with energies above ~0.1 TeV are absorbed by the pair production on the way from the source to the Earth.

$$D_{\gamma_0} = \frac{1}{n_{\rm IR}\sigma_{PP}} \propto 150\ {\rm Mpc}\ \frac{4\ {\rm TeV}}{\rm E}\frac{10nW/(m^2 sr)}{(\nu F(\nu))_{IR}}$$

$$E_{\gamma 0} = 2E_e \qquad \lambda_e = \frac{1}{n_{\rm CMB}\sigma_{ICS}} \sim 1\ {\rm kpc}$$

•e^+e^- pairs re-emit γ-rays via inverse Compton scattering of CMB photons.

•Inverse Compton γ-rays could be detected at lower energies.

$$E_\gamma = 12\ {\rm GeV}\left(\frac{E_e}{2{\rm TeV}}\right)^2$$

Cascade component

- Fraction of electron energy in secondary photons in direction of observer

$$\alpha = \frac{\sum E_\gamma}{E_e}$$

- Fraction of voids on the way of primary photon

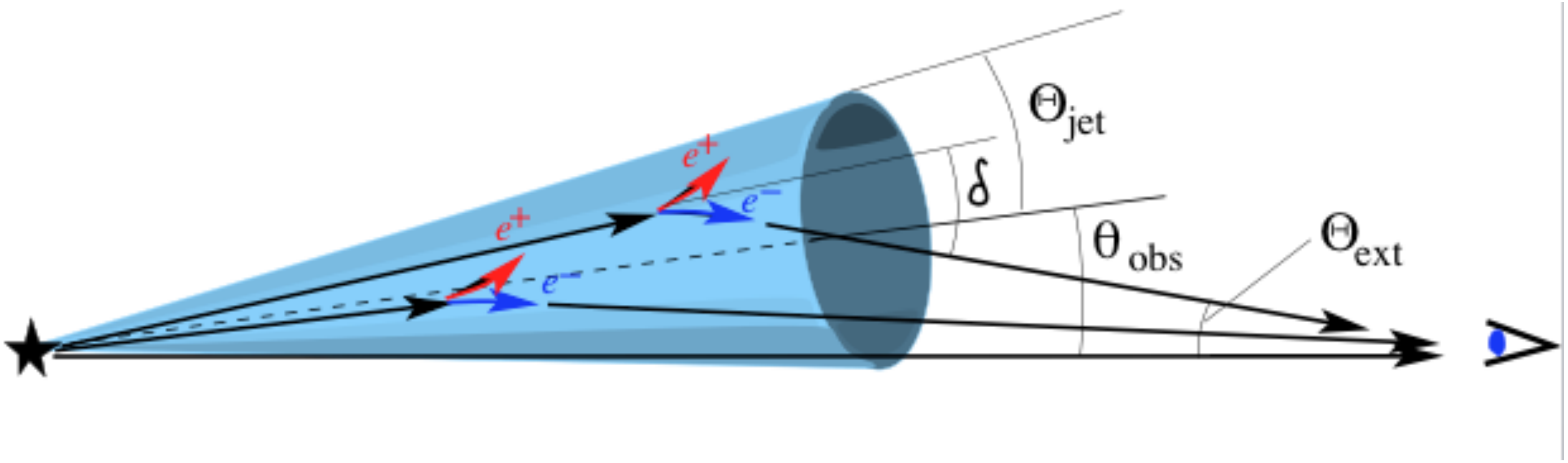
$$D_{void} = \Delta D_{\gamma_0}$$

- Ratio of point source flux at E_γ and $E_{\gamma 0}$

$$R = F(E_{\gamma_0}) / F(E_\gamma)$$

$$\mathrm{F_{ext}} = \alpha \cdot \mathrm{R} \cdot \Delta \cdot \mathrm{e}^{-\tau(\mathrm{E}_\gamma, \mathrm{z})} \left\langle F_{PS}(E_\gamma) \right\rangle$$

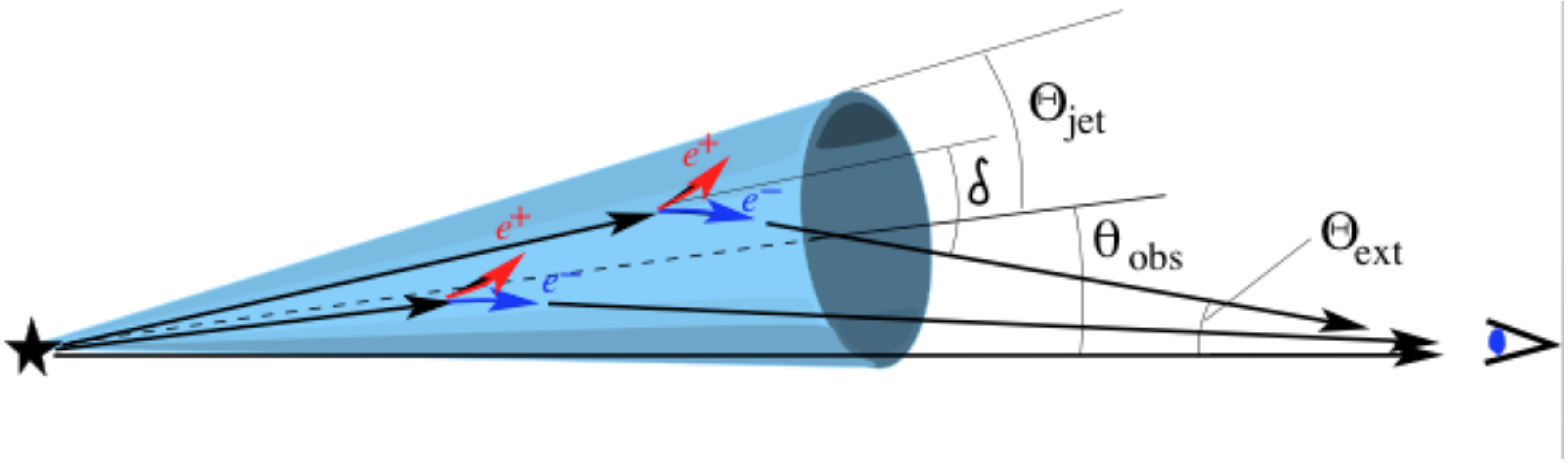
•Imaging of cascade: 3-d cascade needed



•3-d cascade in turbulent EGMF

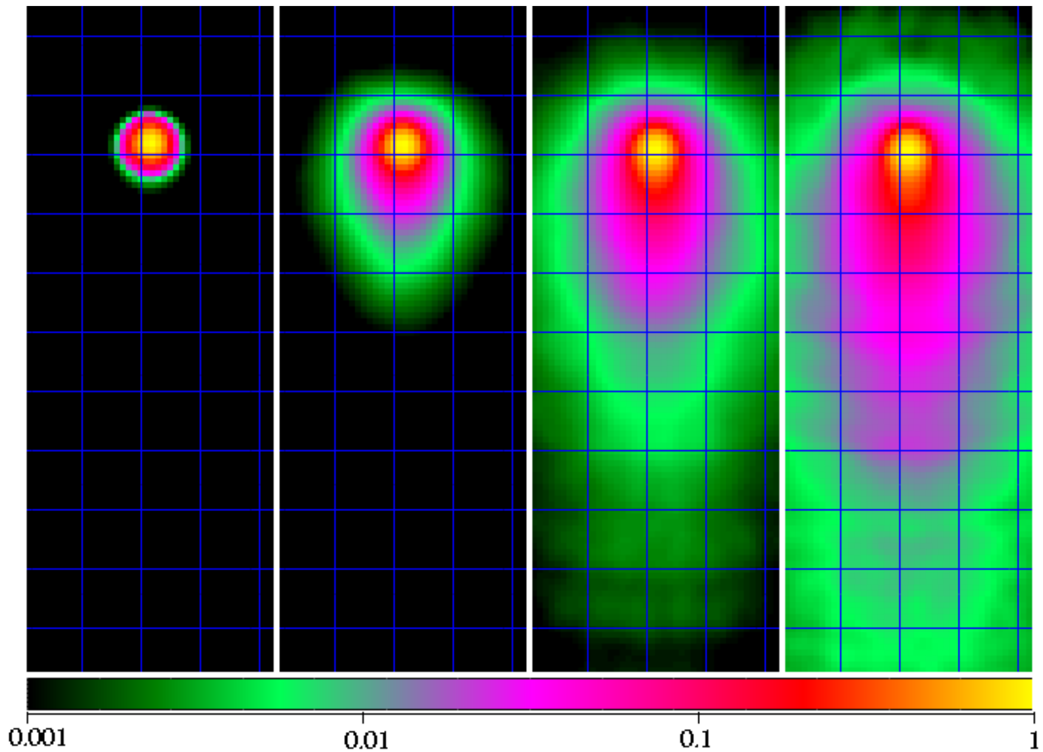
•A.Neronov, D.S., M.Kachelriess, S.Ostapchenko and A.Elyev , 2009

•Imaging of cascade: EGMF

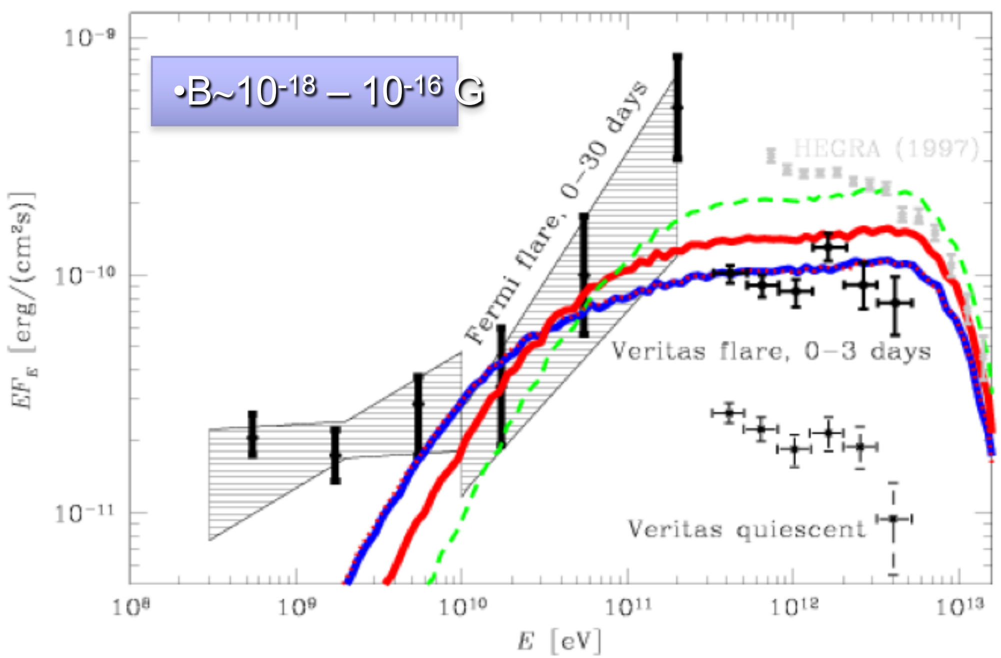


•**Imaging**: cascade component forms an extended emission around initially point source.

• – detectability depends on the telesope PSF and on the scale of angular deflections of e+e- pairs (i.e. on the strength of EGMF)



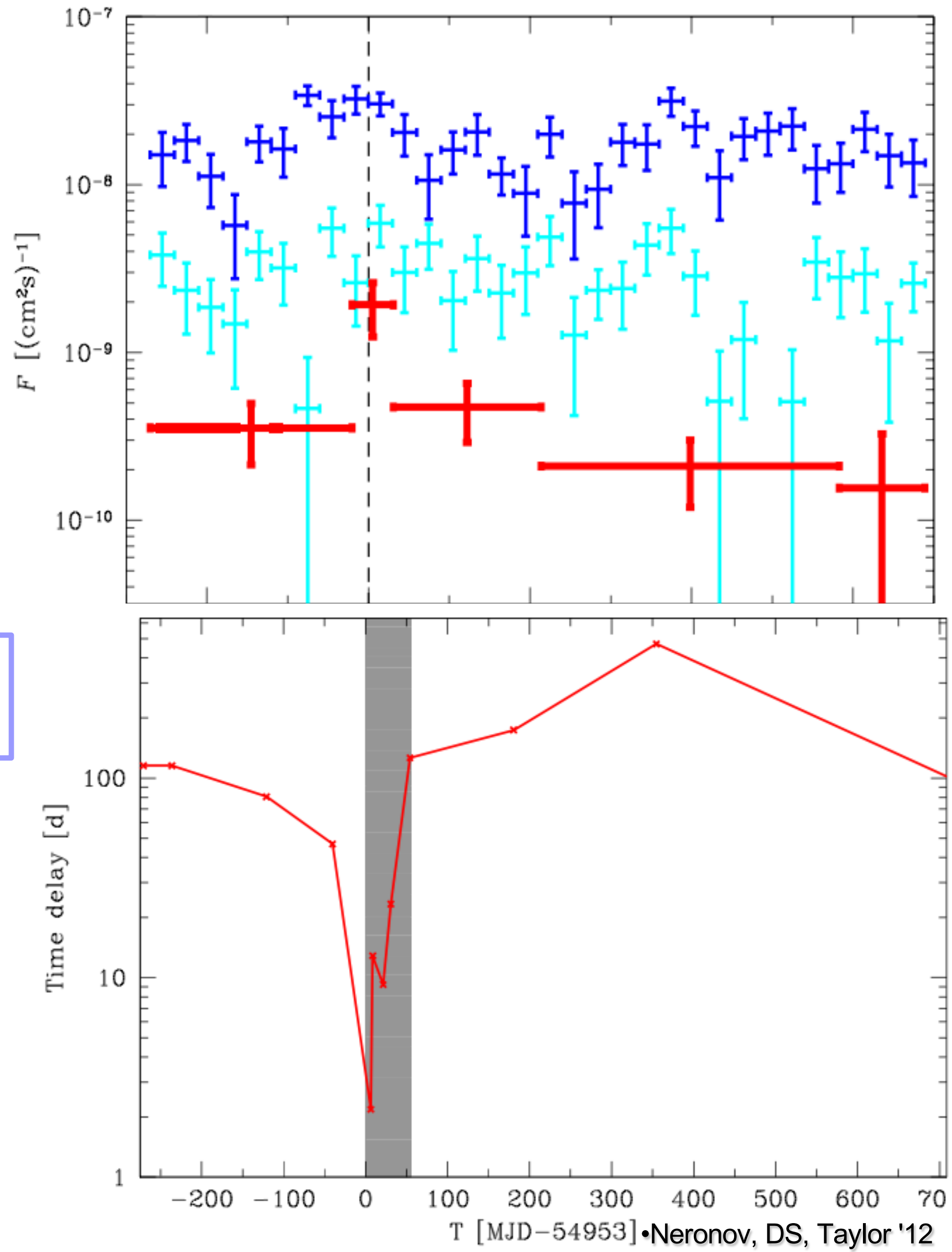
• Search for the time-delayed cascade emission



•The flare occurred during the multiwavelength campaing, including HE and VHE observations.

•Fermi data indicate that the flare lasted 30-50 days, but the VHE observations cover only the first three days of the flare.

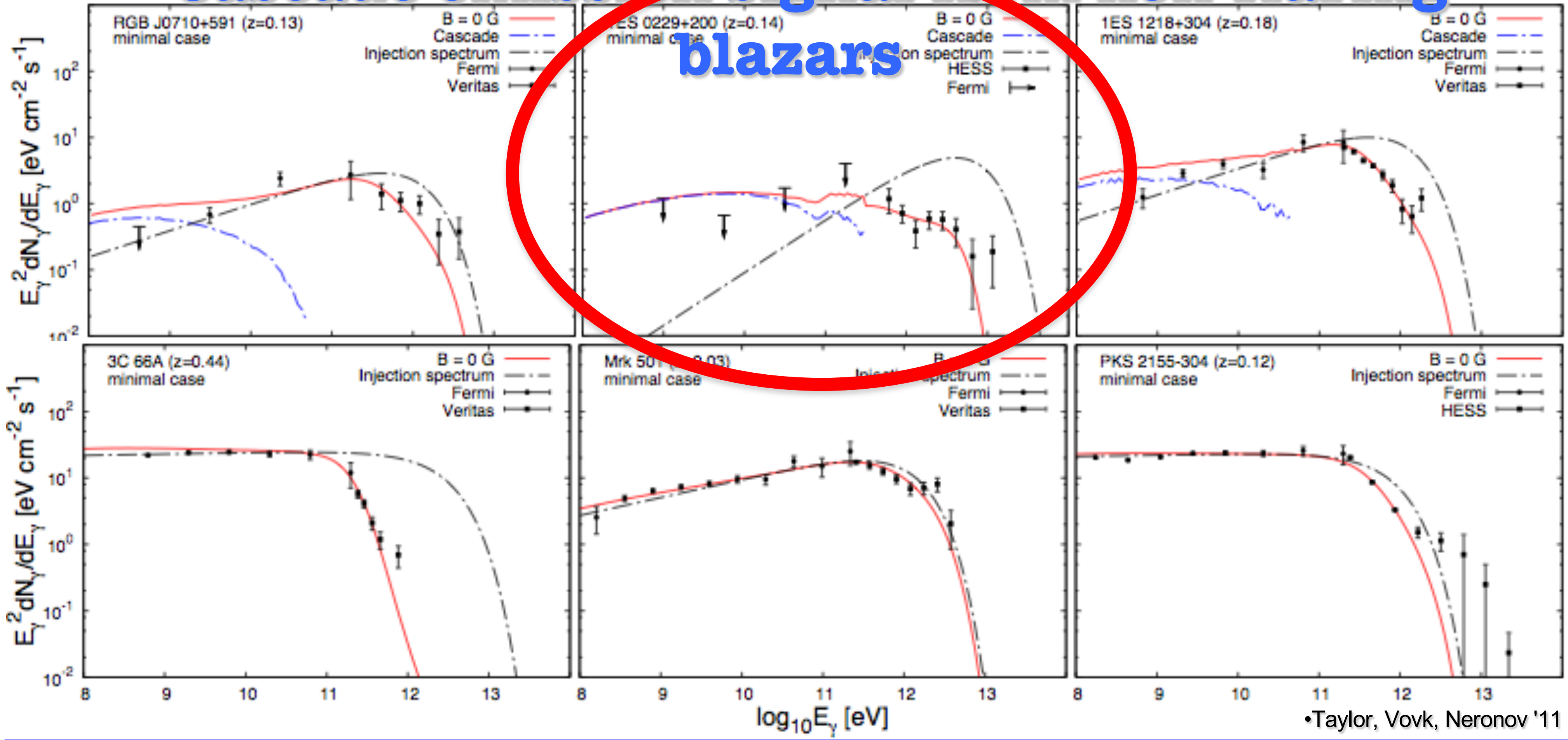
•Fermi data indicate a peculiar hardening of the spectrum above ~10 GeV during the flare. One possibility for the explanation of the hard component is the cascade emission suppressed at low energies by too-large time delay.



•Neronov, DS, Taylor '12

e.-m.cascade signatures in the spectrum of blazars

• Cascade emission signal from non-flaring blazars



•Taylor, Vovk, Neronov '11

•So far, (published) HE-VHE monitoring campaigns did not succeed to catch exceptionally bright flares of VHE blazars simultaneously in Fermi and ground-based telescopes, which would be most suitable for the search of the time-delayed cascade emission.

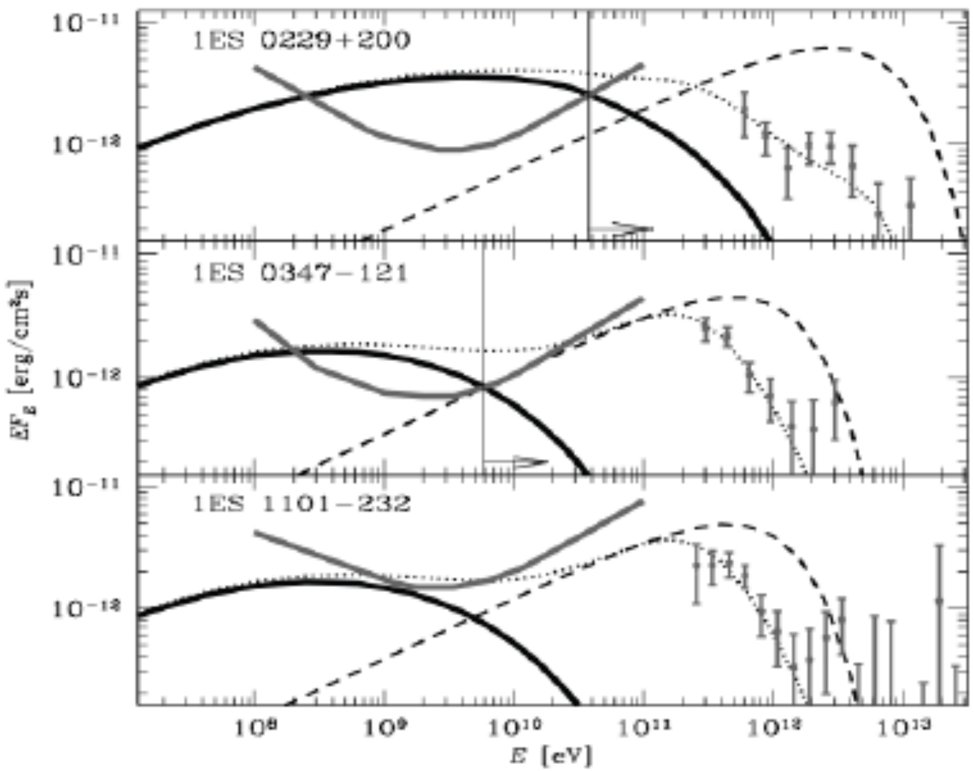
•.... waiting for the Big one

•Meanwhile, non-observation of the cascade signal in sources in which it would be detectable in the B=0 case, imposes lower bounds on the strength of intergalactic magnetic field at the level of

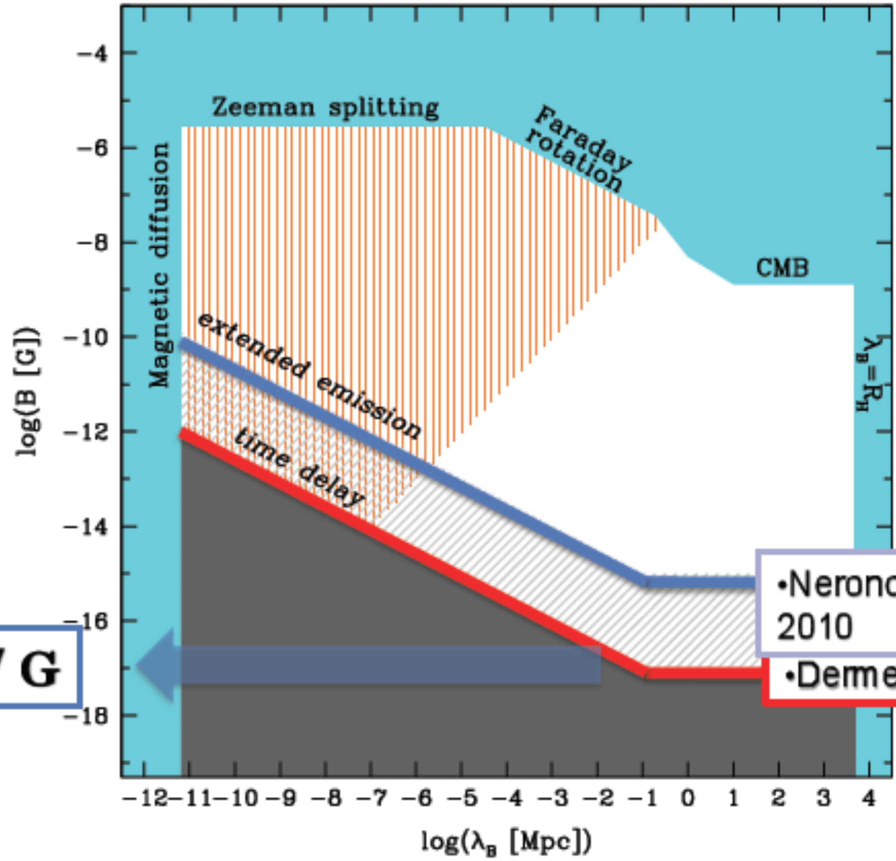
....

• Search for the GeV cascade signal in Fermi data

Neronov, Vovk '10



•Search for the GeV counterparts of the hard spectrum far-away sources of TeV gamma-rays within 1 year of Fermi telescope exposure did not reveal the cascade emission component.



•Neronov, Vovk, 2010, Tavecchio et al. 2010

•Dermer et al., 2011, Taylor et al. 2011

•$B_{IGM} > 10^{-17}$ G

•Non-detection of the cascade signal in the GeV band indicates that electrons and positrons are deflected by non-negligible IGMF which should have strength in excess of 10^{-17} G.

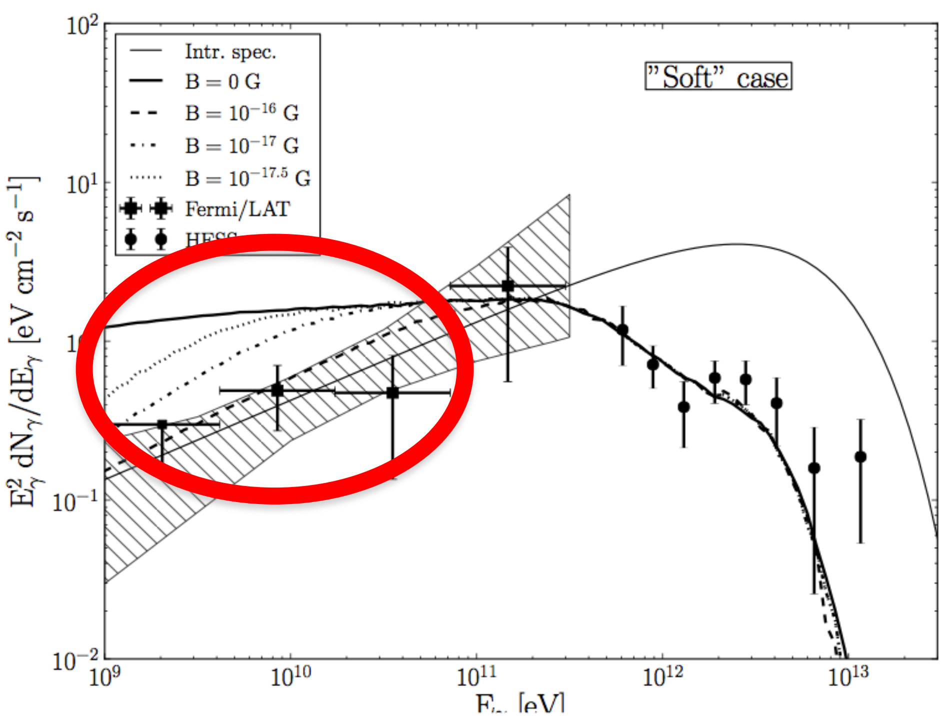
• The hardest VHE blazar 1ES 0229+200

•Blazar 1ES 0229+200 is considered to be the best candidate for the search of the cascade emission because it has very hard VHE spectrum extending into the ~10 TeV energy band, where γ-ray emission is strongly attenuated by the pair production effect.

•Most of the primary γ-ray beam power is removed and transferred to the cascade emission which should appear in the GeV energy band.

•The source is extremely weak in the Fermi energy band. It is detected only in the 3-year long exposure.

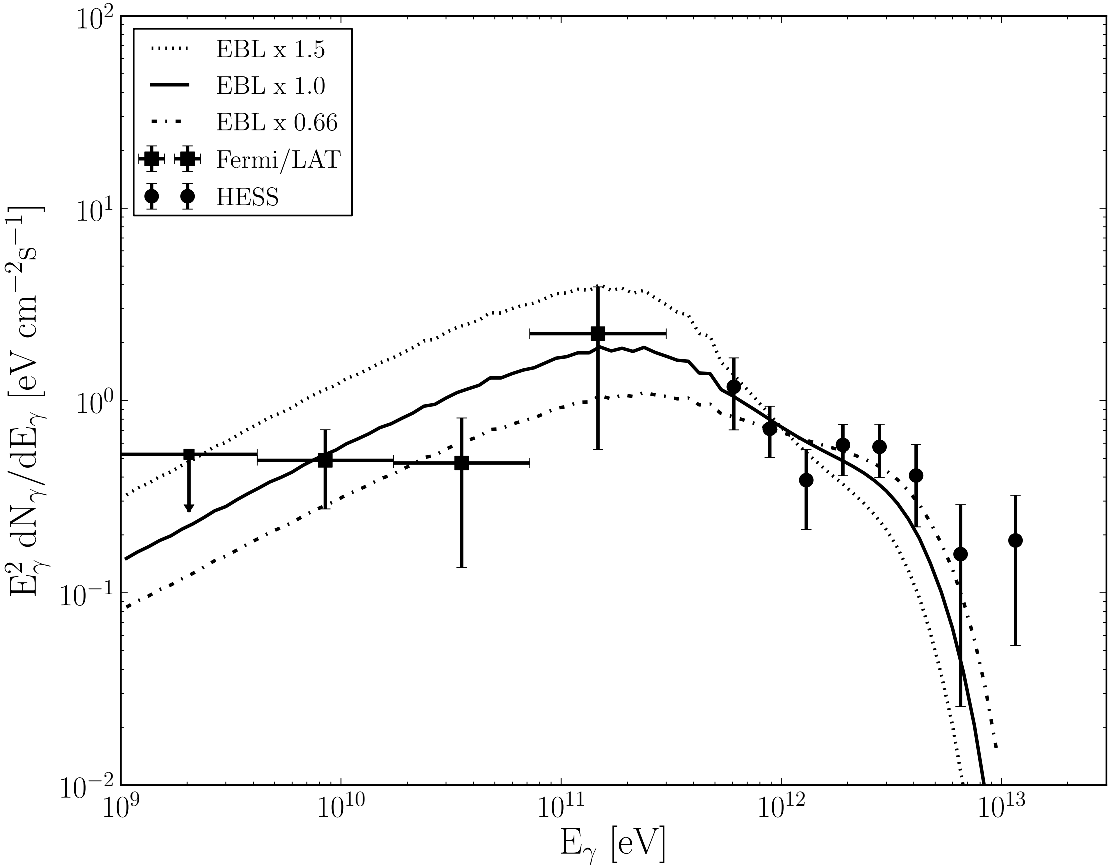
•The source is stable in the VHE band: no variability is found between observations made over ~5 yr time span.



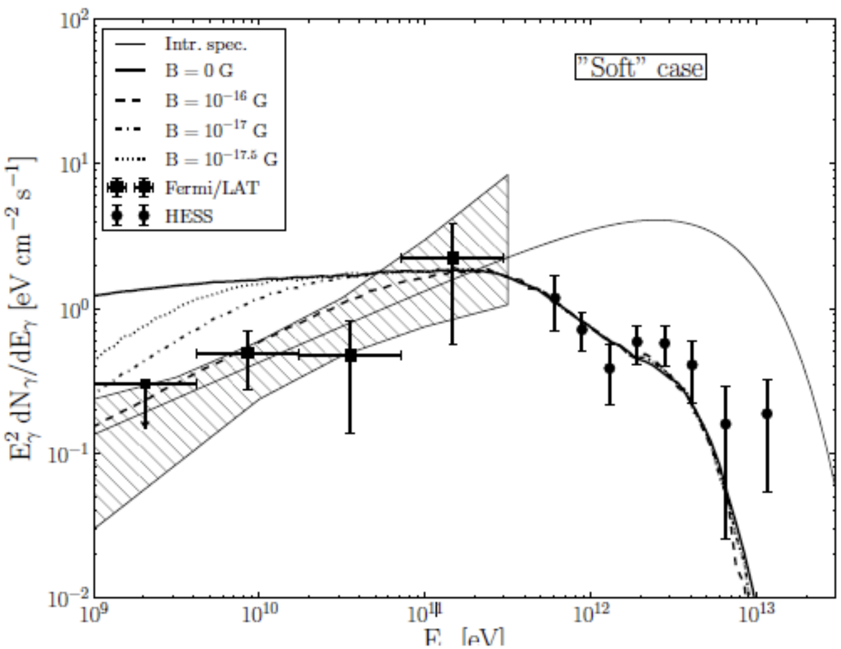
$$\Gamma = 1.36 \pm 0.25$$

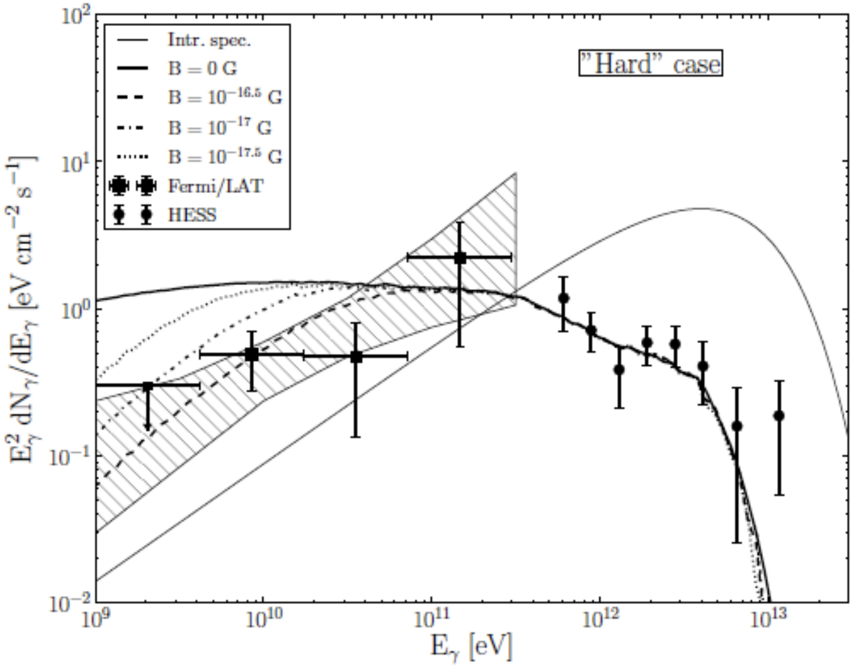
•Vovk, Taylor, Neronov, and DS 1112.2534

EGMF and EBL from 1ES 0229+200

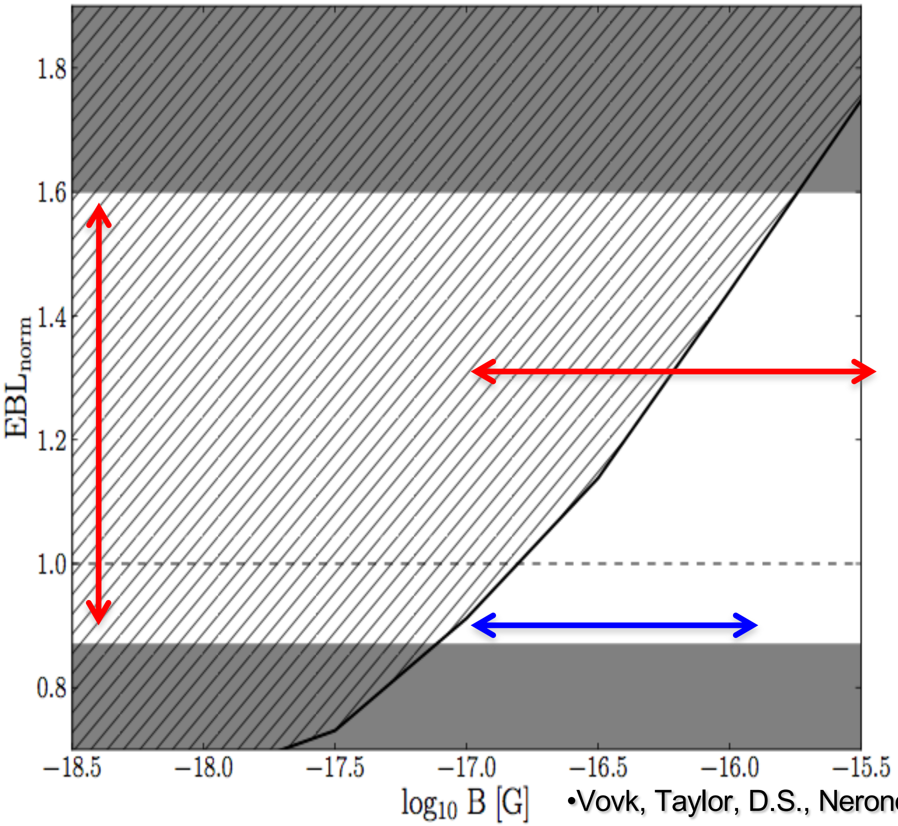


EGMF and EBL from 1ES 0229+200

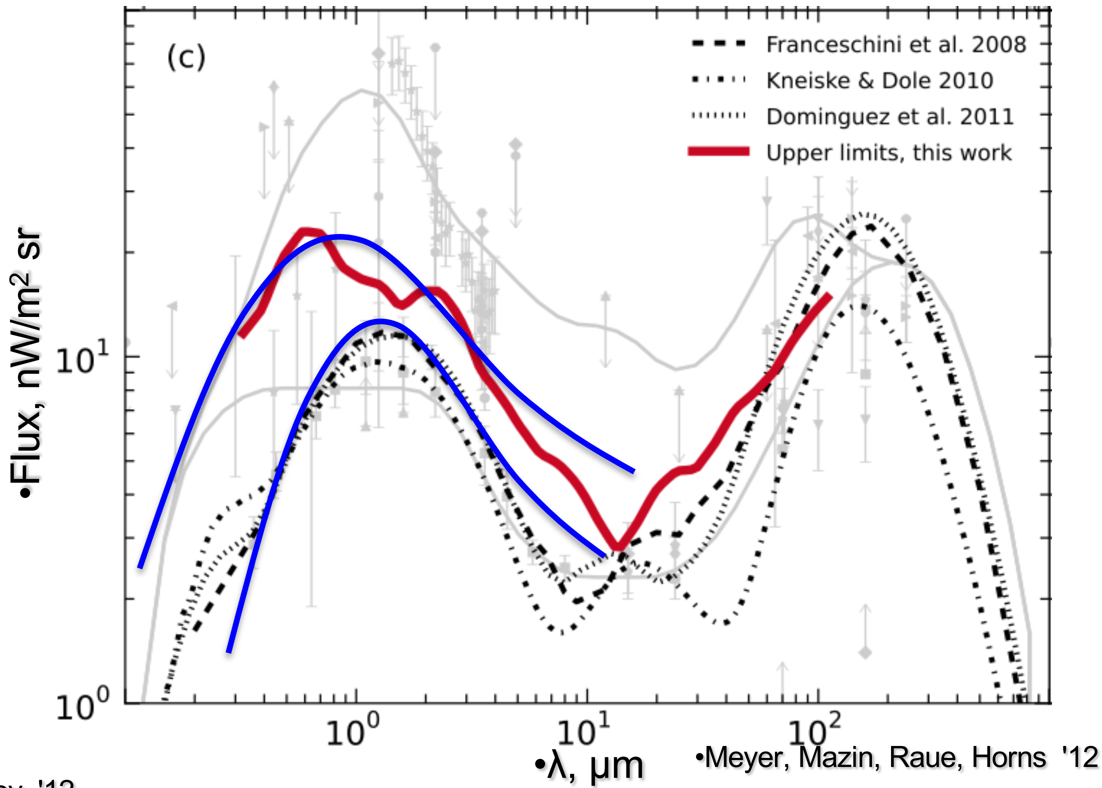




•Lower bound on IGMF



•Vovk, Taylor, D.S., Neronov '12



•Meyer, Mazin, Raue, Horns '12

•Strength of the suppression of the VHE gamma-ray flux via the pair production depends on the density/spectrum of the EBL

•. Uncertainty of our knowledge of EBL density was a factor of ~2 up to recent studies.

• Now it is 20-30 %

•This uncertainty introduces an order-of-magnitude (factor 2) uncertainty in the lower bound on the intergalactic magnetic field.

EGMF limits from 5 blazars

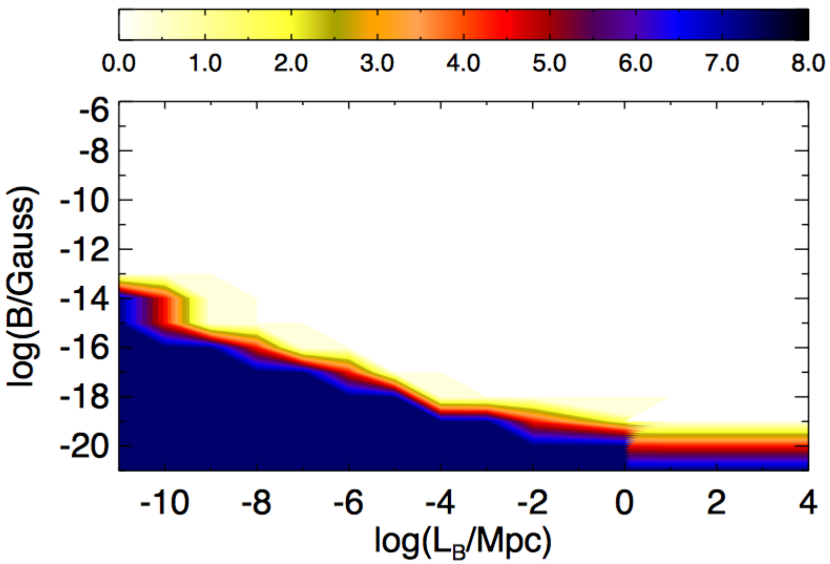


FIG. 4.— The values of parameter space of B and L_B ruled out
›r the combined *conservative* results of Section 4.1 for all of our
bjects. The contours represent the significance a particular region
f parameter space is ruled out, in number of sigma, as indicated
y the bar. These constraints assume the Finke et al. (2010) EBL
ıodel and $\theta_j = 0.1$ rad.

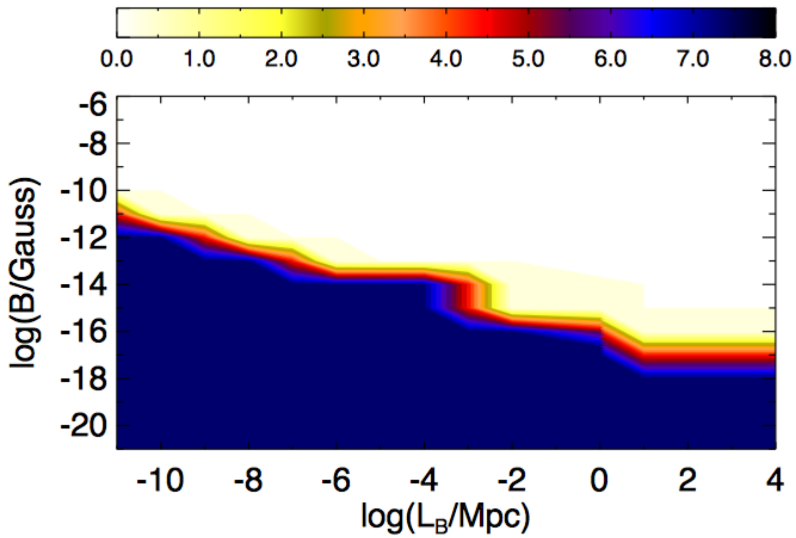
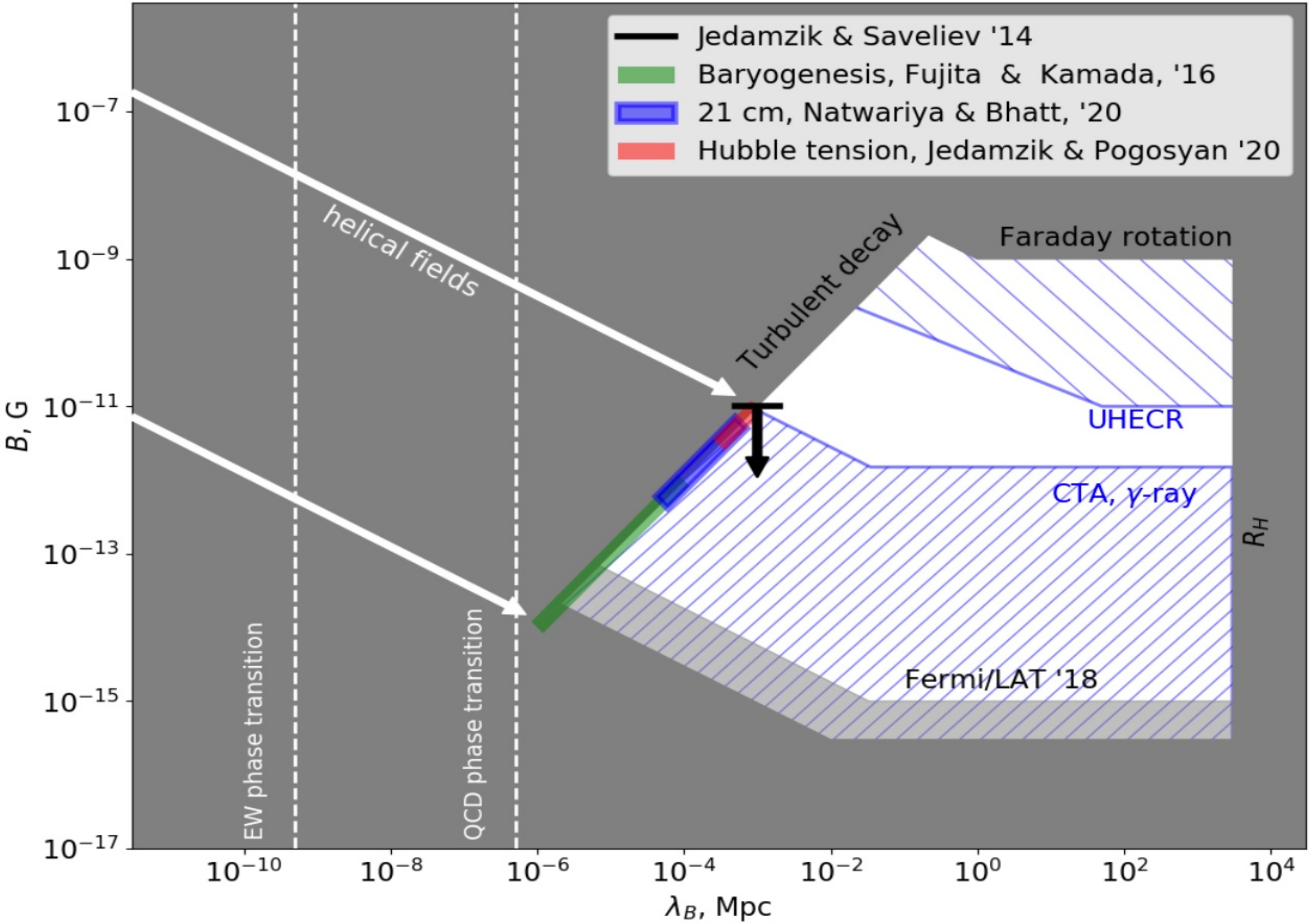


FIG. 7.— The same as Figure 4, only with less conservative
assumptions. Here $F_{cascade,min} = F_{cascade,max}$, and the cascade
was calculated assuming $t_{\rm blazar} = 1/H_0$ and E_{max} is the maximum
observed VHE photon bin from the source.

•Finke et al, 1510.02485



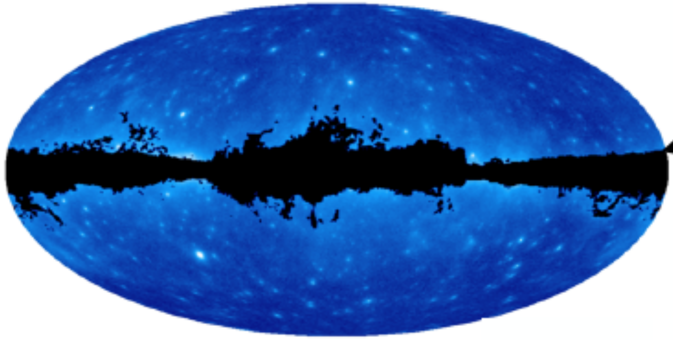
•Kalashev et al, 2007.14331

Conclusions on IGMF

- Gamma-ray observations provide for the first time an evidence for non-zero magnetic field in the intergalactic medium outside of LSS (if plasma heating is not relevant).
- This bound depends on EBL density and it is about $B>10^{-17}$ G for modern n_EBL models
- It is not clear at the moment if the intergalactic magnetic fields have primordial origin or they were spread recently by galactic winds.
- High-quality coordinated multi-wavelength observations of blazar flares in the GeV-TeV band might provide measurements of IGMF if it is in the range 10^{-17} – 10^{-16} G.
- Deep exposures with Fermi and Cherenkov telescopes might provide measurements of IGMF via detection of extended emission, if IGMF is in the range 10^{-16} – 10^{-12} G.

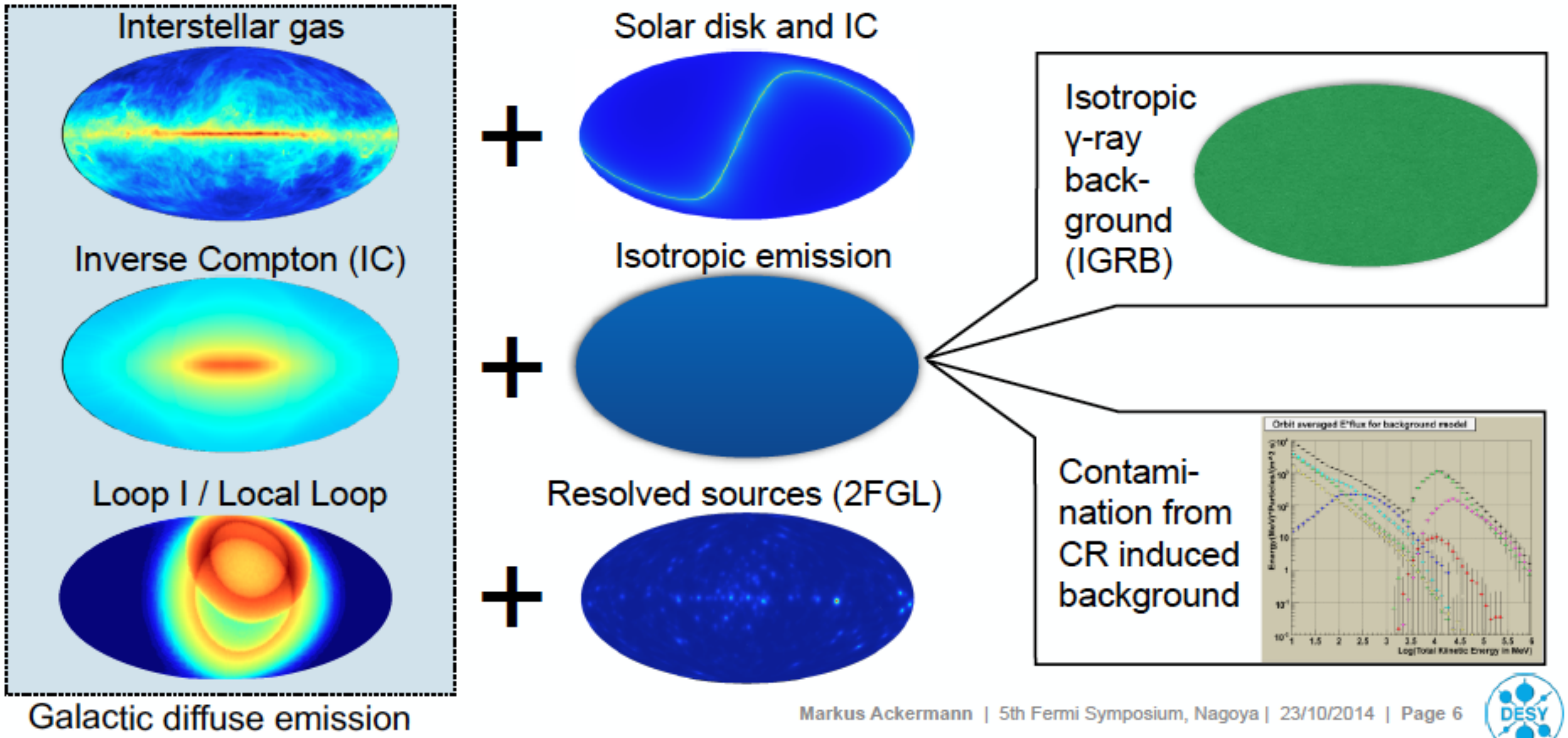
Diffuse gamma-ray background

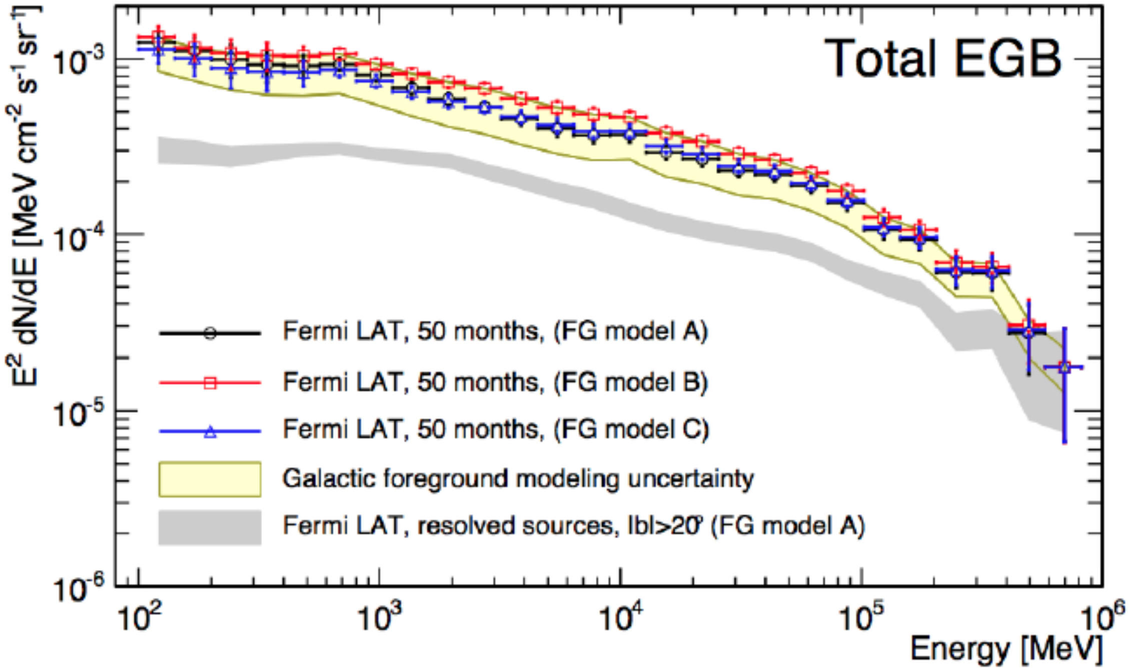
Derivation of the isotropic gamma-ray background



=

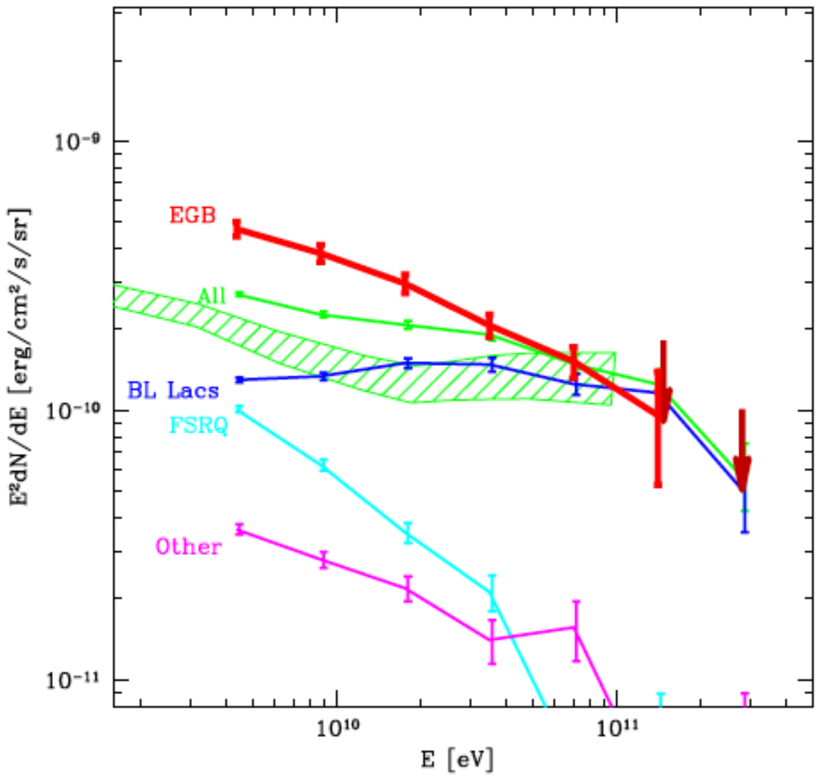
Not used in this analysis:
- Galactic plane
- Regions with dense molecular clouds
- Regions with non-local atomic hydrogen clouds

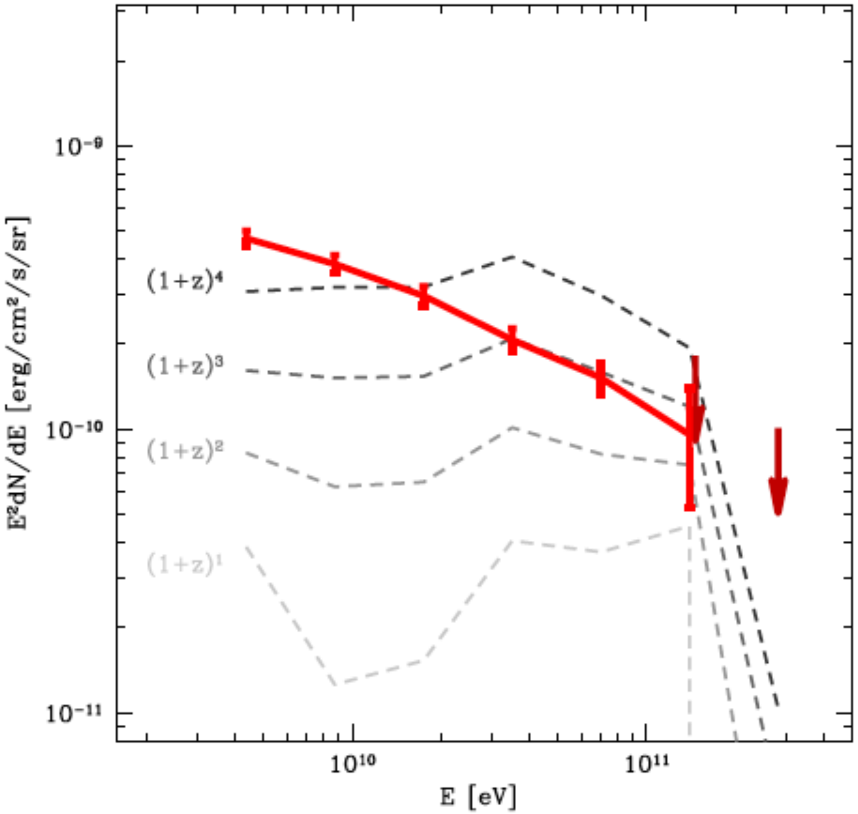




- **Sum of the intensities** of IGRB and the resolved high-latitude sources.
- Contribution of high-latitude Galactic sources **<< 5%.**
- Spectrum can be parametrized by **power-law with exponential cutoff**.
- Spectral index **~ 2.3**, cutoff energy **~ 350 GeV.**

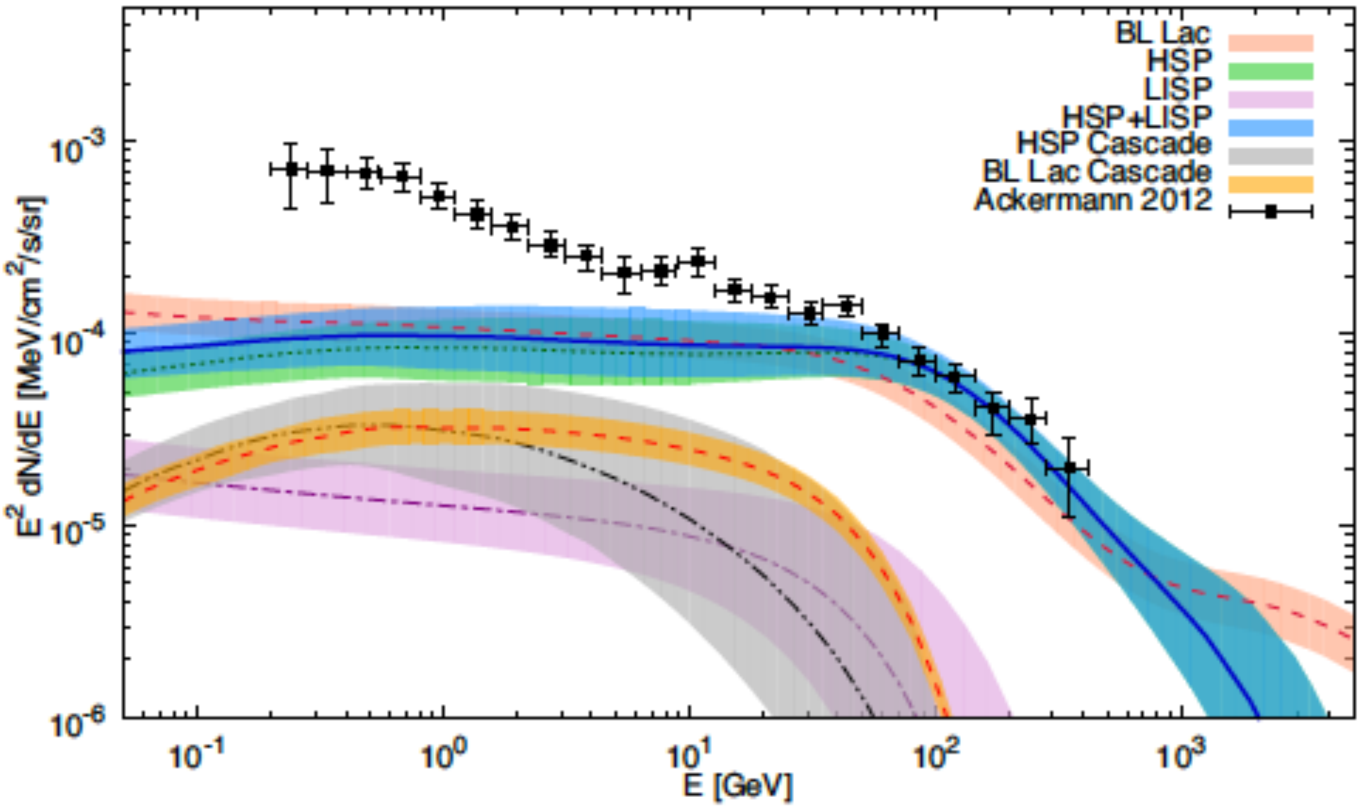
BL Lacs give main contribution to diffuse gamma-ray flux





A.Neronov, D.S. Astrophys.J. 757 (2012) 61

BL Lacs give main contribution to high energy part of diffuse gamma-ray flux



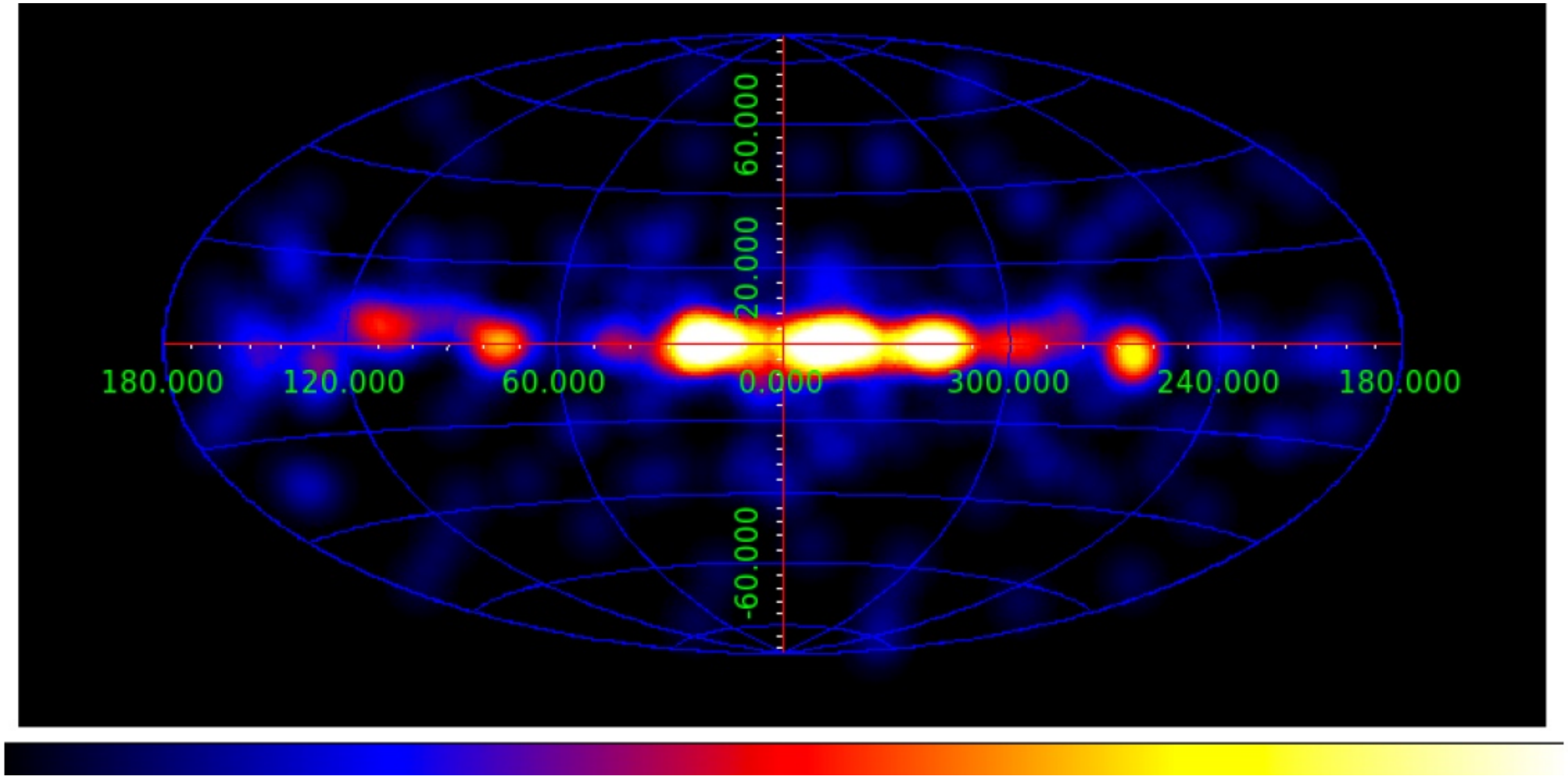
•M. Di Mauro et al, arXiv:1311.5708

Fermi confirmed resolution of BL Lac sources above 50 GeV

cm^{-2} s^{-1}). We employ a one-point photon fluctuation analysis to constrain the behavior of dN/dS below the source detection threshold. Overall the source count distribution is constrained over three decades in flux and found compatible with a broken power law with a break flux, S_b, in the range $[8 \times 10^{-12}, 1.5 \times 10^{-11}]$ ph cm^{-2} s^{-1} and power-law indices below and above the break of $\alpha_2 \in [1.60, 1.75]$ and $\alpha_1 = 2.49 \pm 0.12$ respectively. Integration of dN/dS shows that point sources account for at least $86^{+16}_{-14}\%$ of the total extragalactic γ-ray background. The simple form of the derived source count distribution is consistent with a single population (i.e. blazars) dominating the source counts to the minimum flux explored by this analysis. We estimate the density of sources

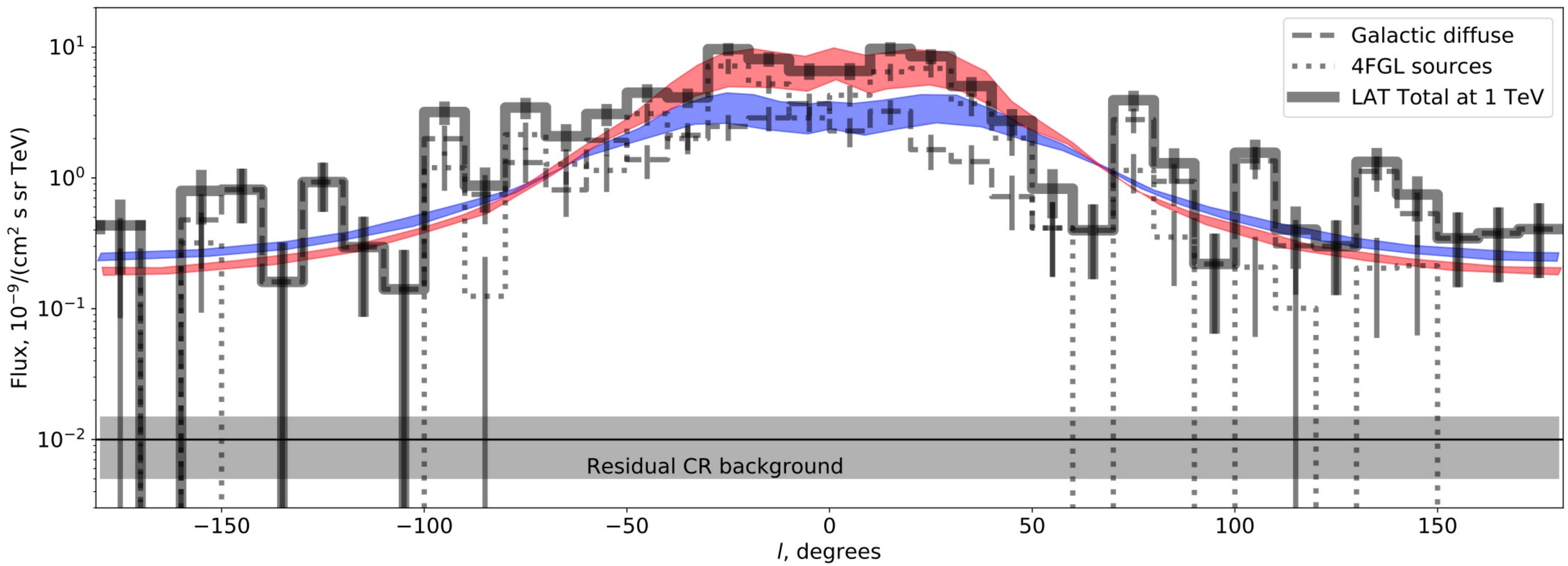
- **Fermi collaboration, arXiv:1511.00693**

Sky map E> 1TeV
10 years Fermi



- A.Neronov and D.S. , 1907.06061

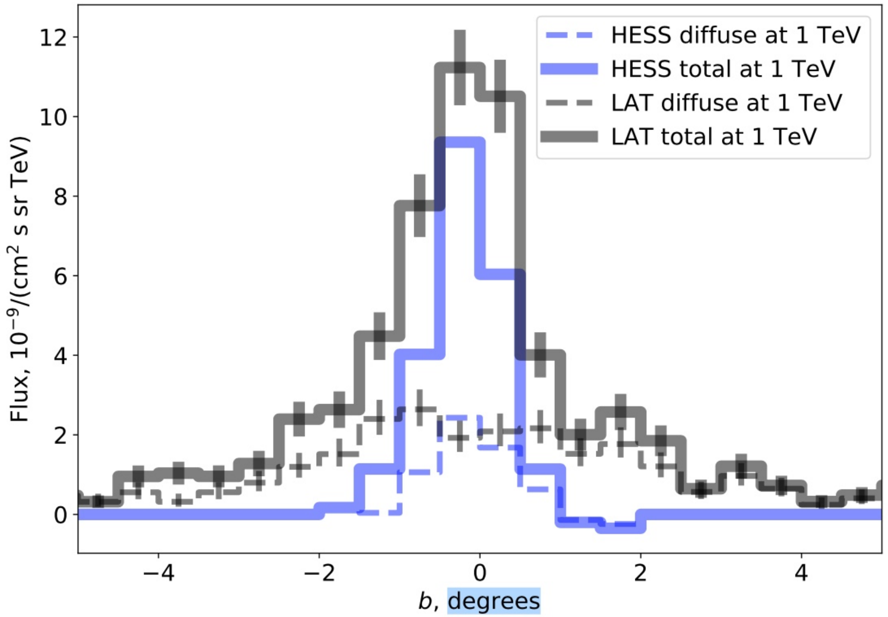
Galactic Plane |b|<2 deg, 1 TeV

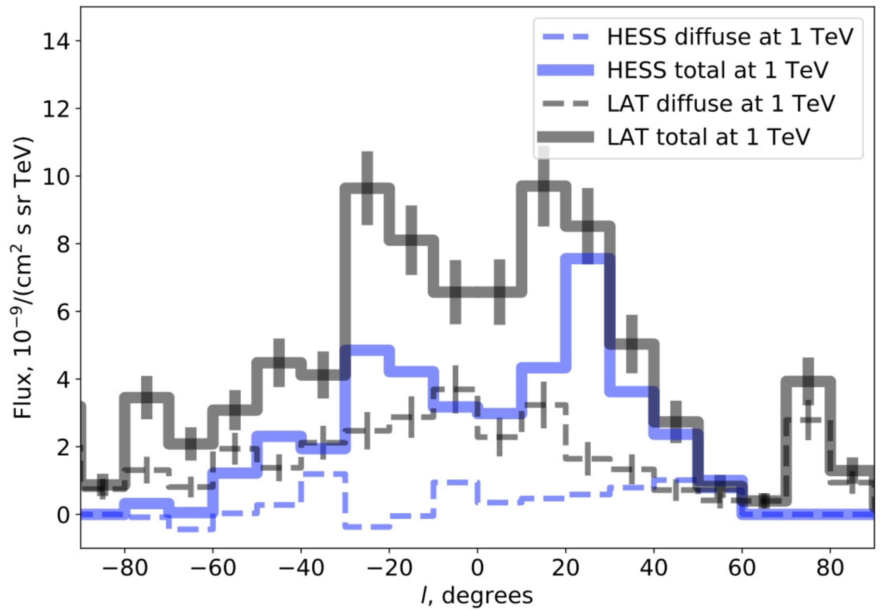


- Red and blue lines: model predictions from Cataldo et al , 1904.03894

- A.Neronov and D.S. , 1907.06061

Galactic Plane, Fermi and HESS

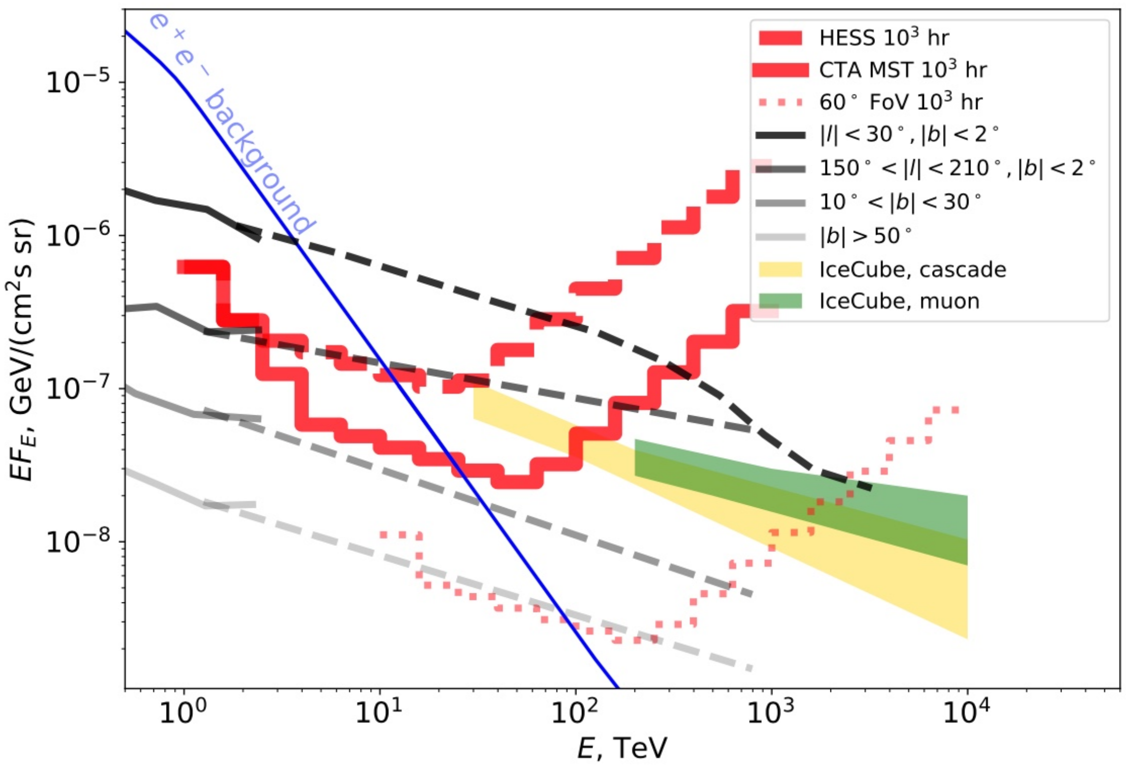




- A.Neronov and D.S. , 1907.06061

Gamma-ray sky at 10-100 TeV with Cherenkov telescopes

Galactic diffuse flux at 10-100 TeV energies with Cherenkov



•A.Neronov and D.S. , astro-ph/2001.00922