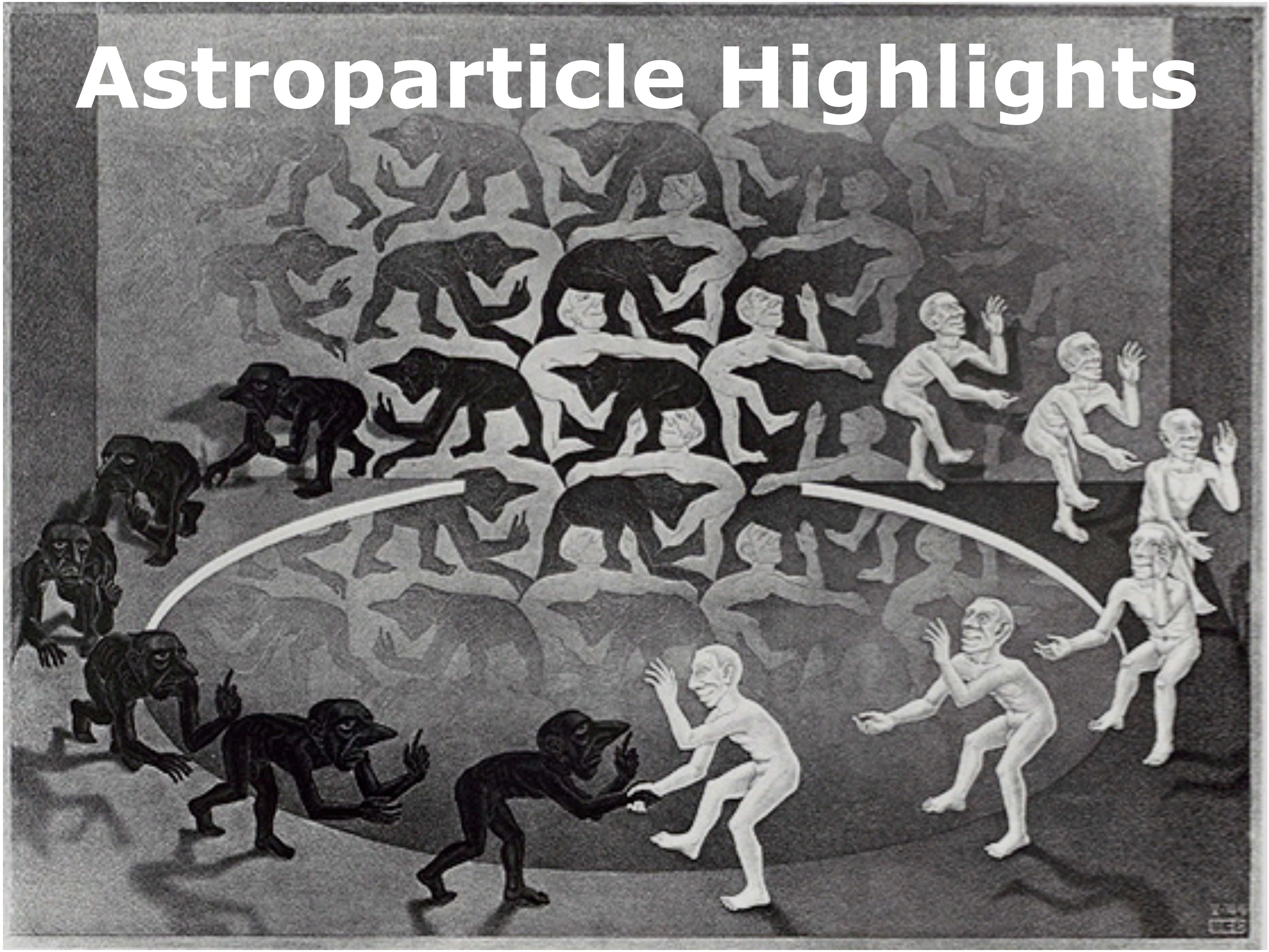
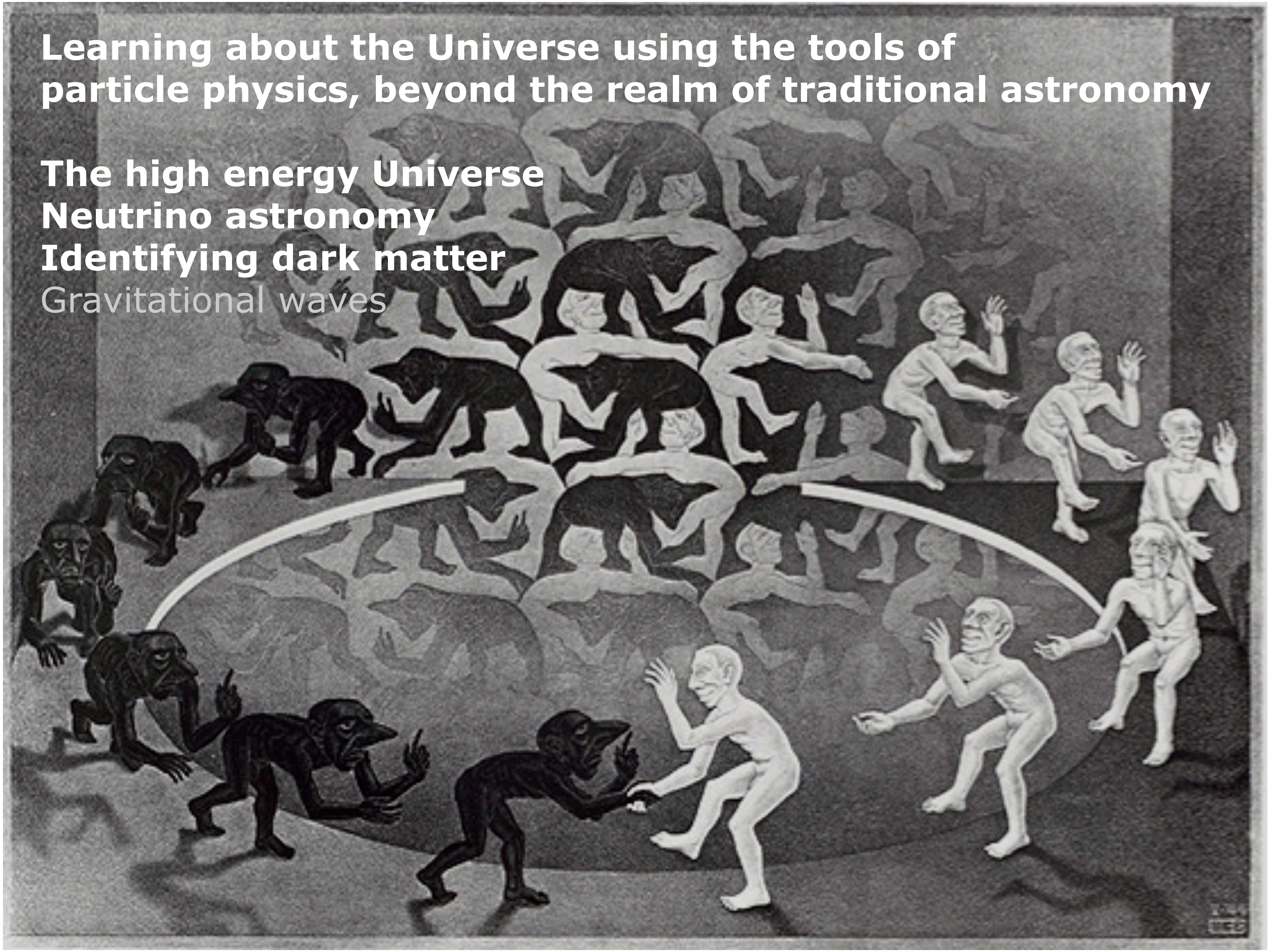
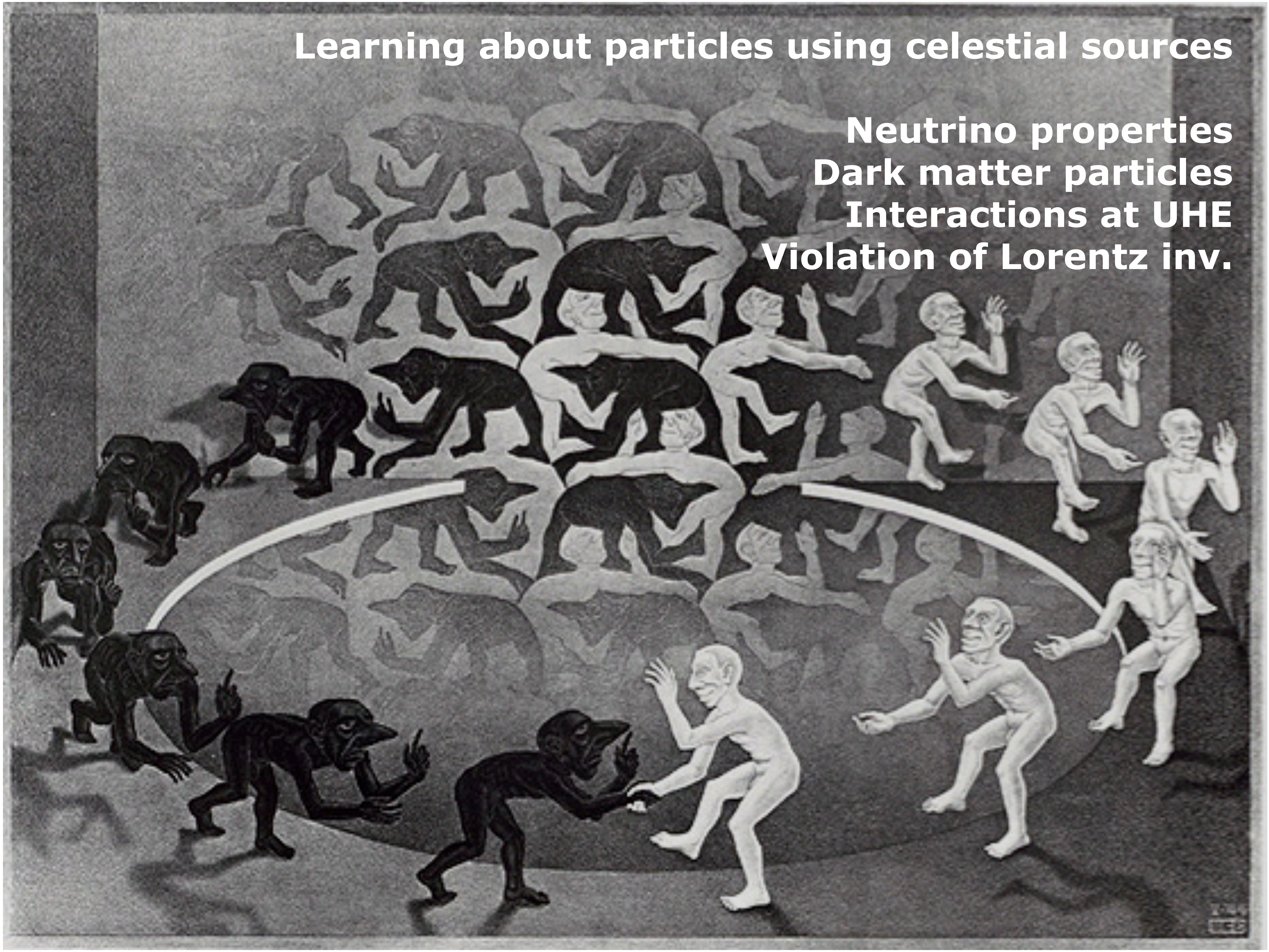
Astroparticle Highlights




Learning about the Universe using the tools of particle physics, beyond the realm of traditional astronomy
The high energy Universe
Neutrino astronomy
Identifying dark matter
Gravitational waves


Learning about particles using celestial sources
Neutrino properties
Dark matter particles
Interactions at UHE
Violation of Lorentz inv.

Outline

subjective selection, focus on results rather than future plans

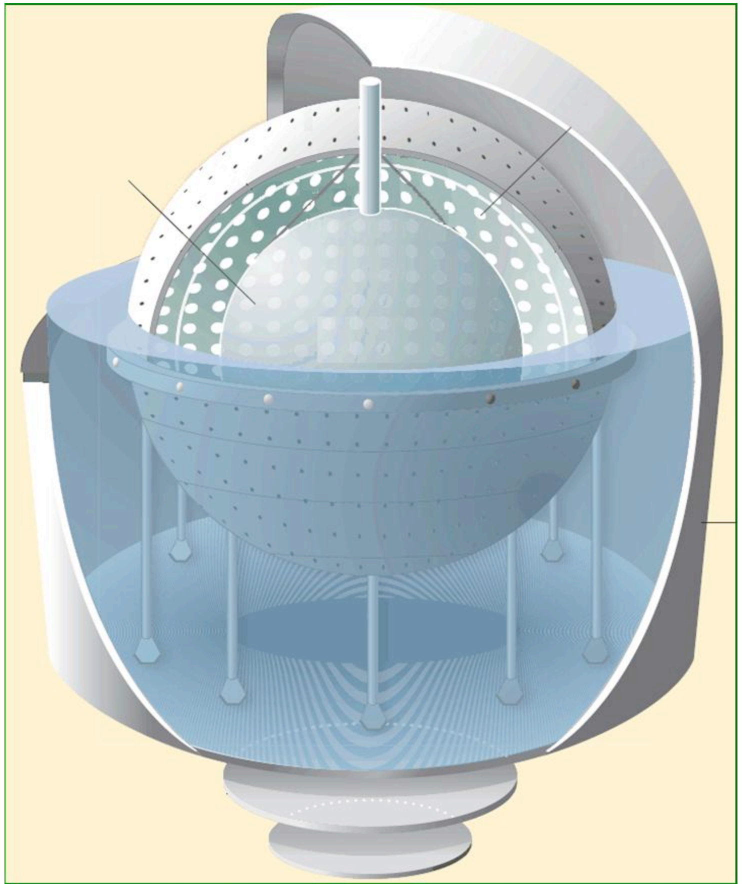
Low-energy neutrino astroparticle physics

The high-energy Universe & Cosmic particle accelerators
- UHE cosmic rays
- High-energy gamma-ray astronomy
- High-energy neutrino astronomy

Violation of Lorentz invariance and quantum gravity

(Dark matter ➔ previous talks)

A new neutrino source: Geo-neutrinos



Borexino detector:
inner vessel 278 t of
liquid scintillator

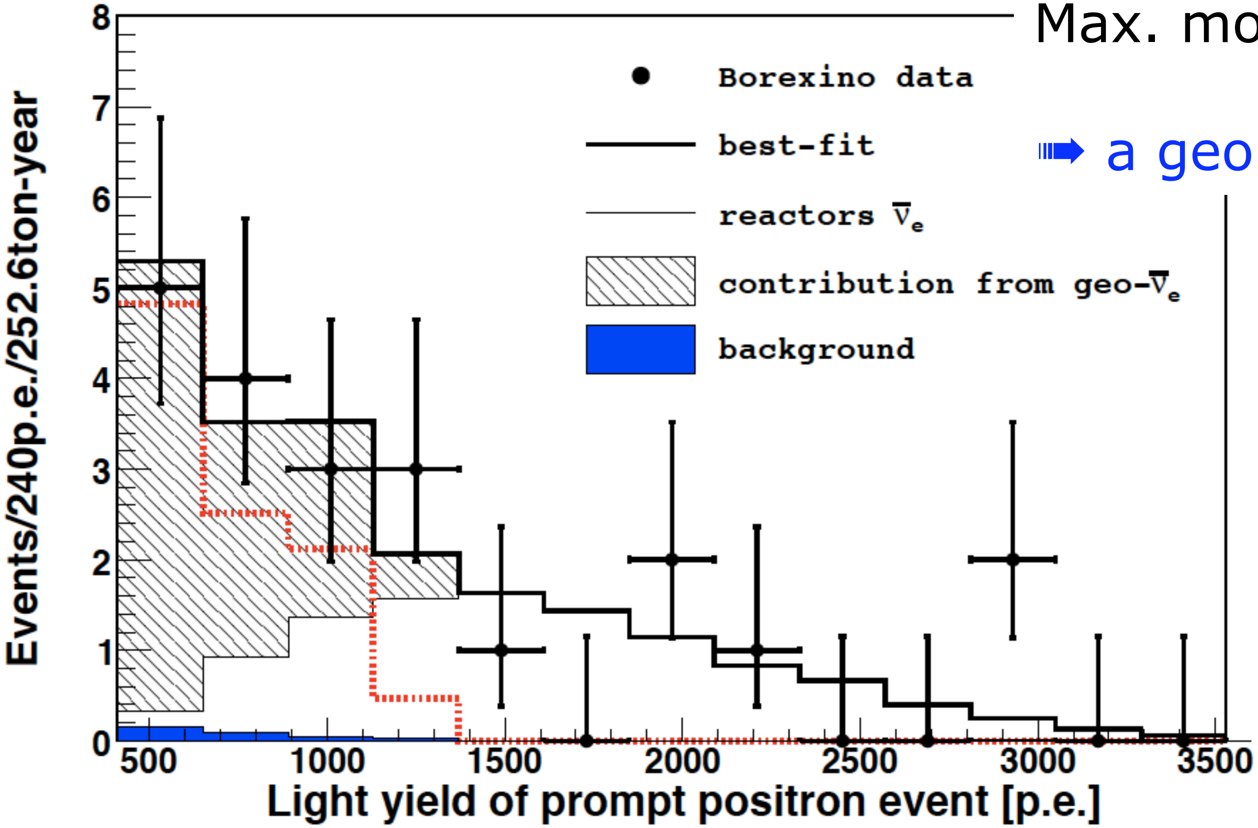
Detection

$\bar{\nu} + p \rightarrow n + e^+$

Prompt signal: positron annih.
Delayed signal ($< 1.3\ \mu s$):
neutron capture on H

Kamland Collab., Nature 436, 2005 ($2.5\ \sigma$)
Borexino Collab., arXiv:1003.0284 ($4.2\ \sigma$)

A new neutrino source: Geo-neutrinos



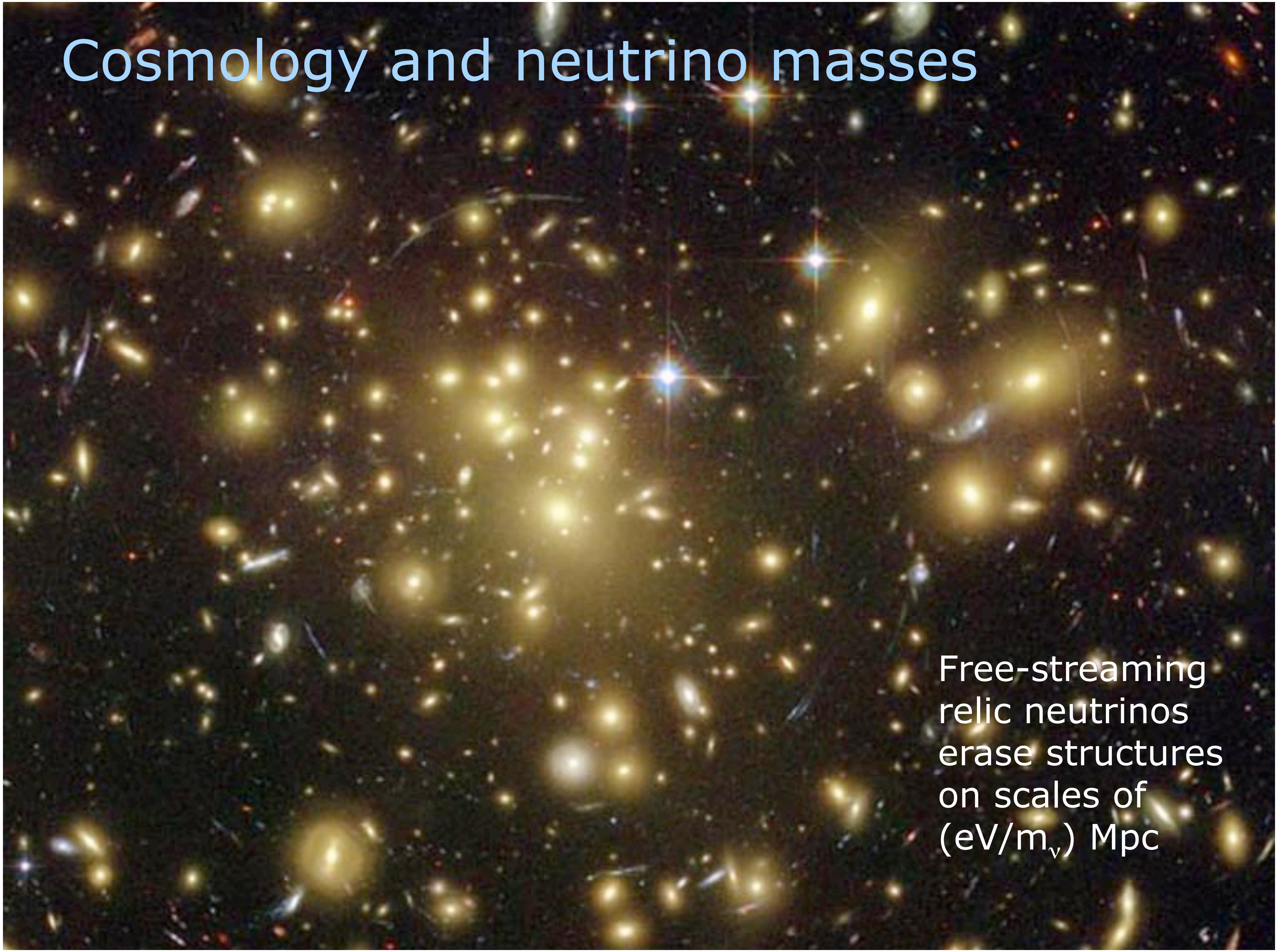
Borexino:

Rates (events/100 t yr)

Detected	3.9+1.6-1.3
Min. model	1.9
Max. model	3.9

➠ a geo-reactor has < 3 TW

Cosmology and neutrino masses



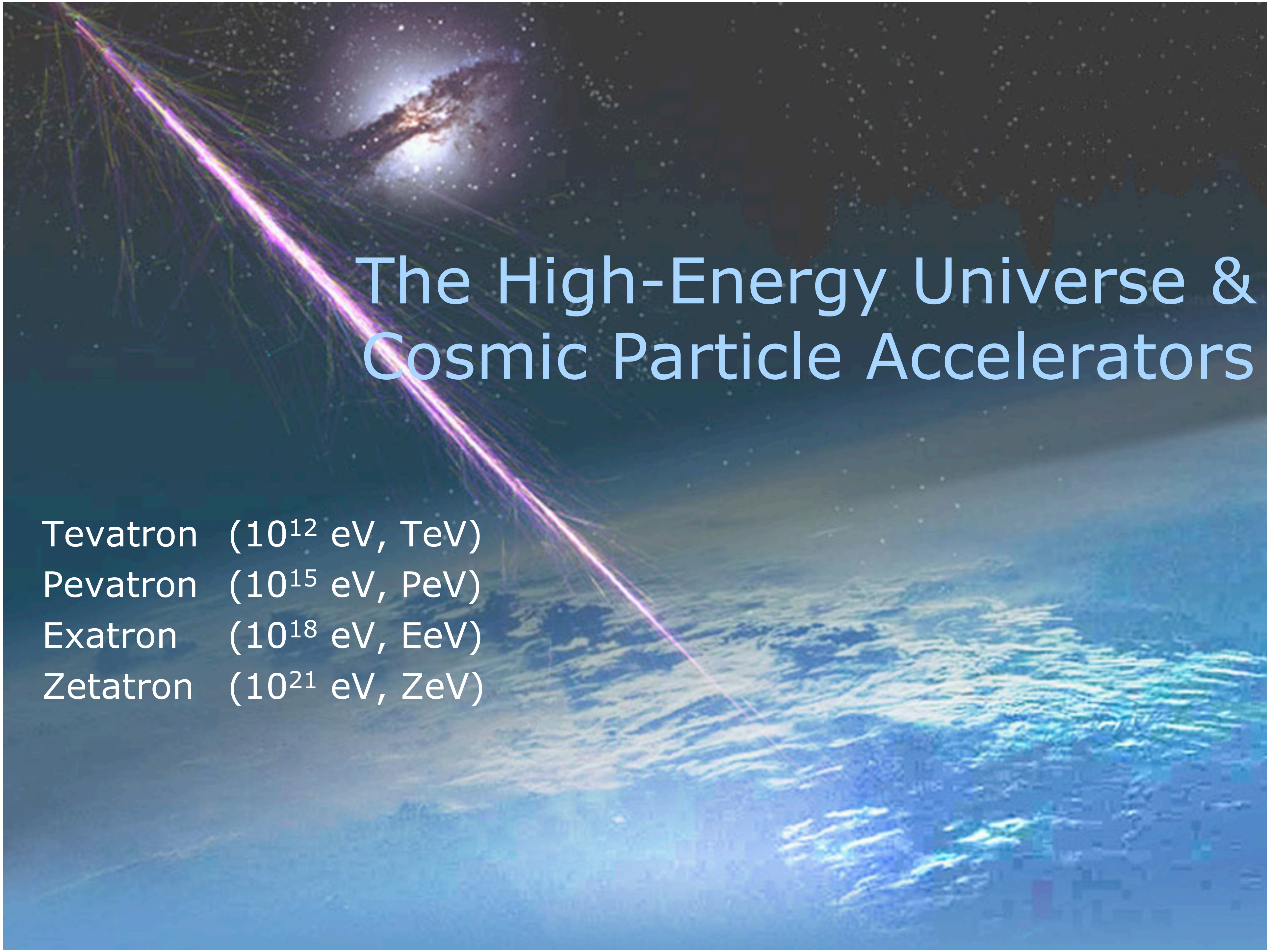
Free-streaming relic neutrinos erase structures on scales of (eV/m_{ν}) Mpc

Cosmology and neutrino masses

WMAP + Sne + MegaZ-LRG galaxy survey + …

$\Sigma\ m_{\nu} < 0.28$ eV (95% CL)

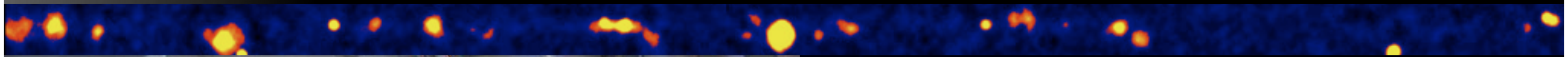
cf Mainz: $m_{\nu e} < 2.3$ eV
Katrin sensitivity: 0.2 eV



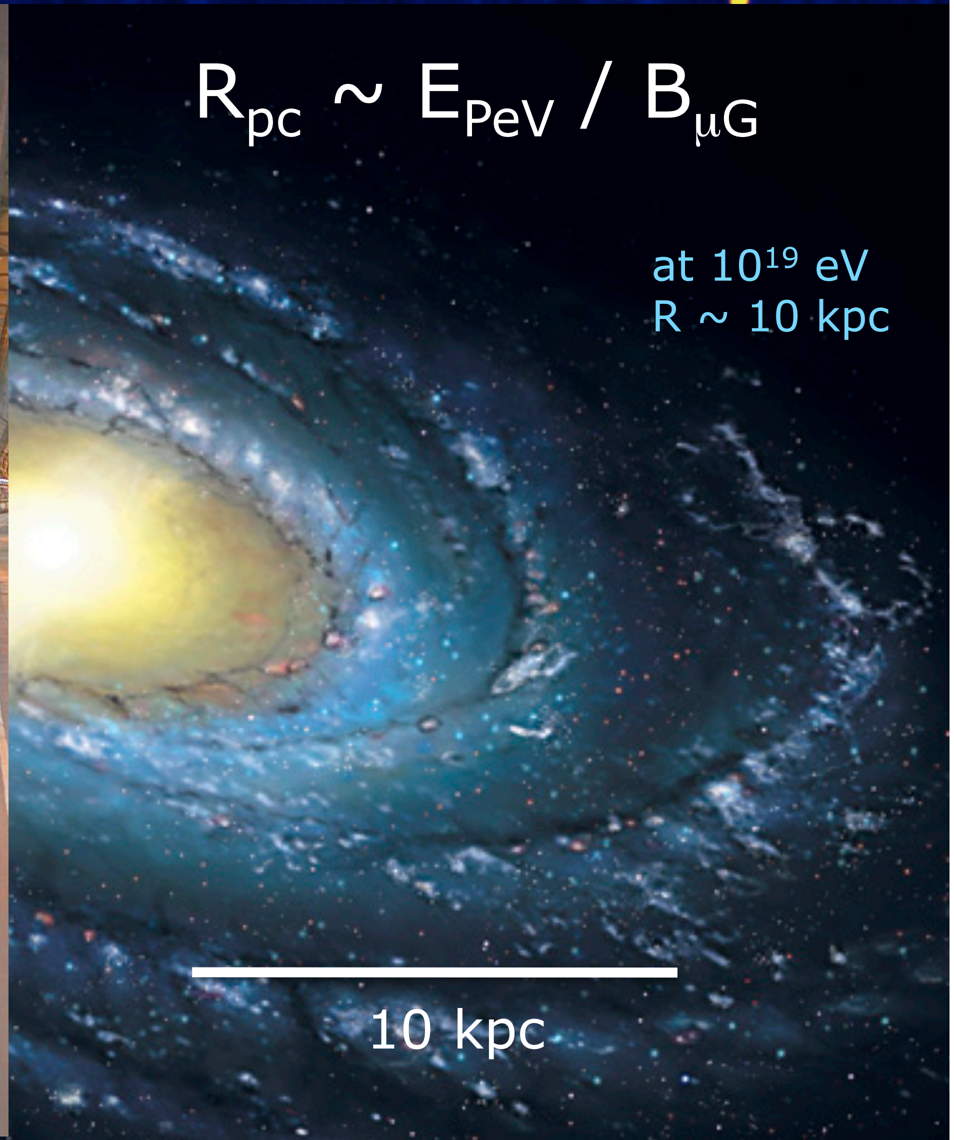
The High-Energy Universe & Cosmic Particle Accelerators

Tevatron (10^{12} eV, TeV)
Pevatron (10^{15} eV, PeV)
Exatron (10^{18} eV, EeV)
Zetatron (10^{21} eV, ZeV)

Units

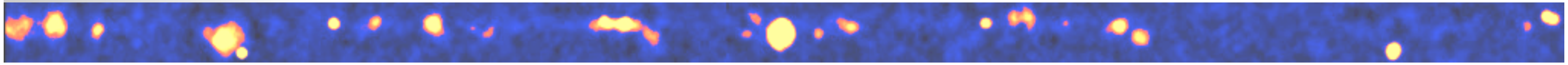


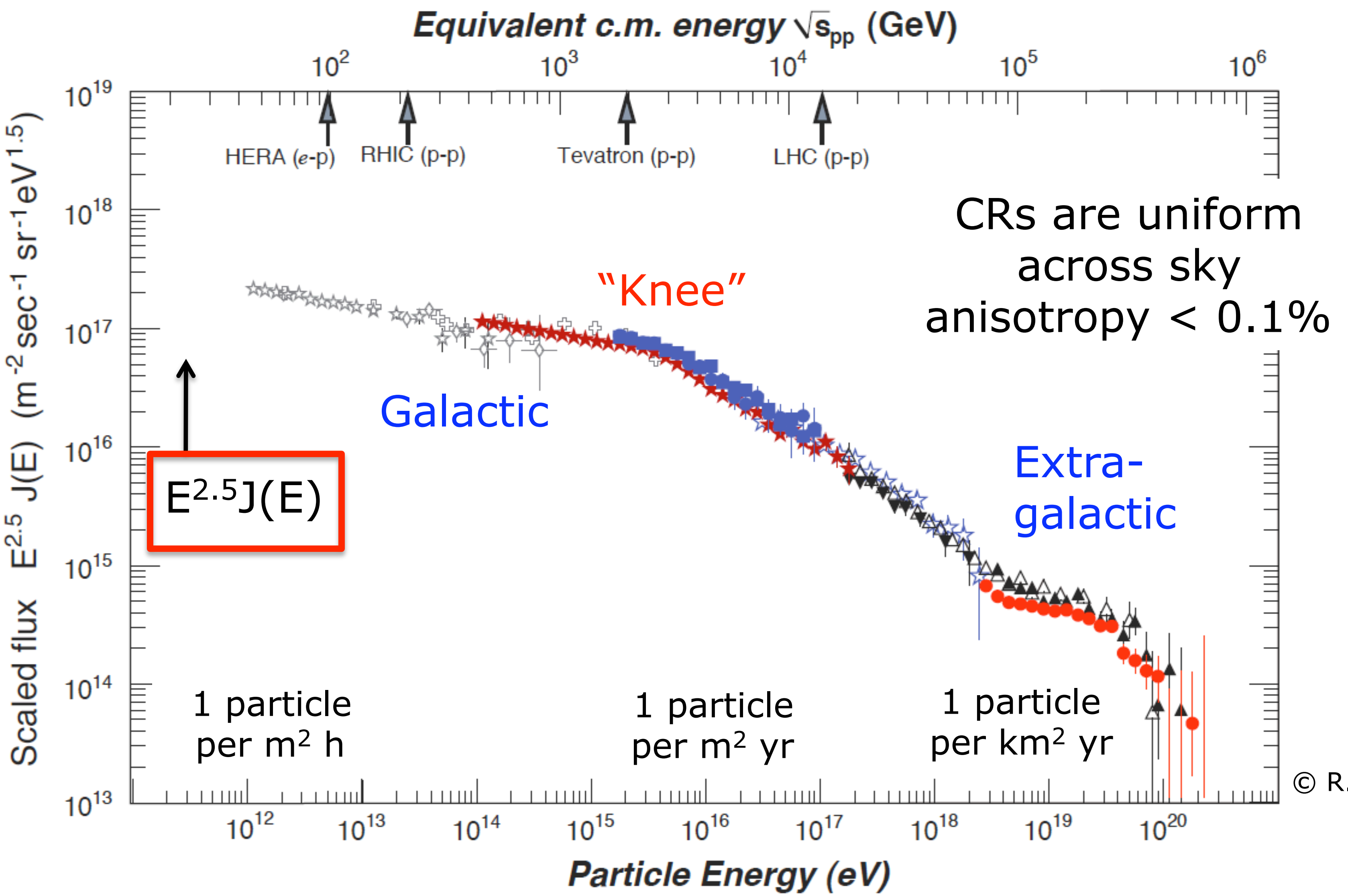
$R_{km} \sim 3E_{TeV} / B_T$



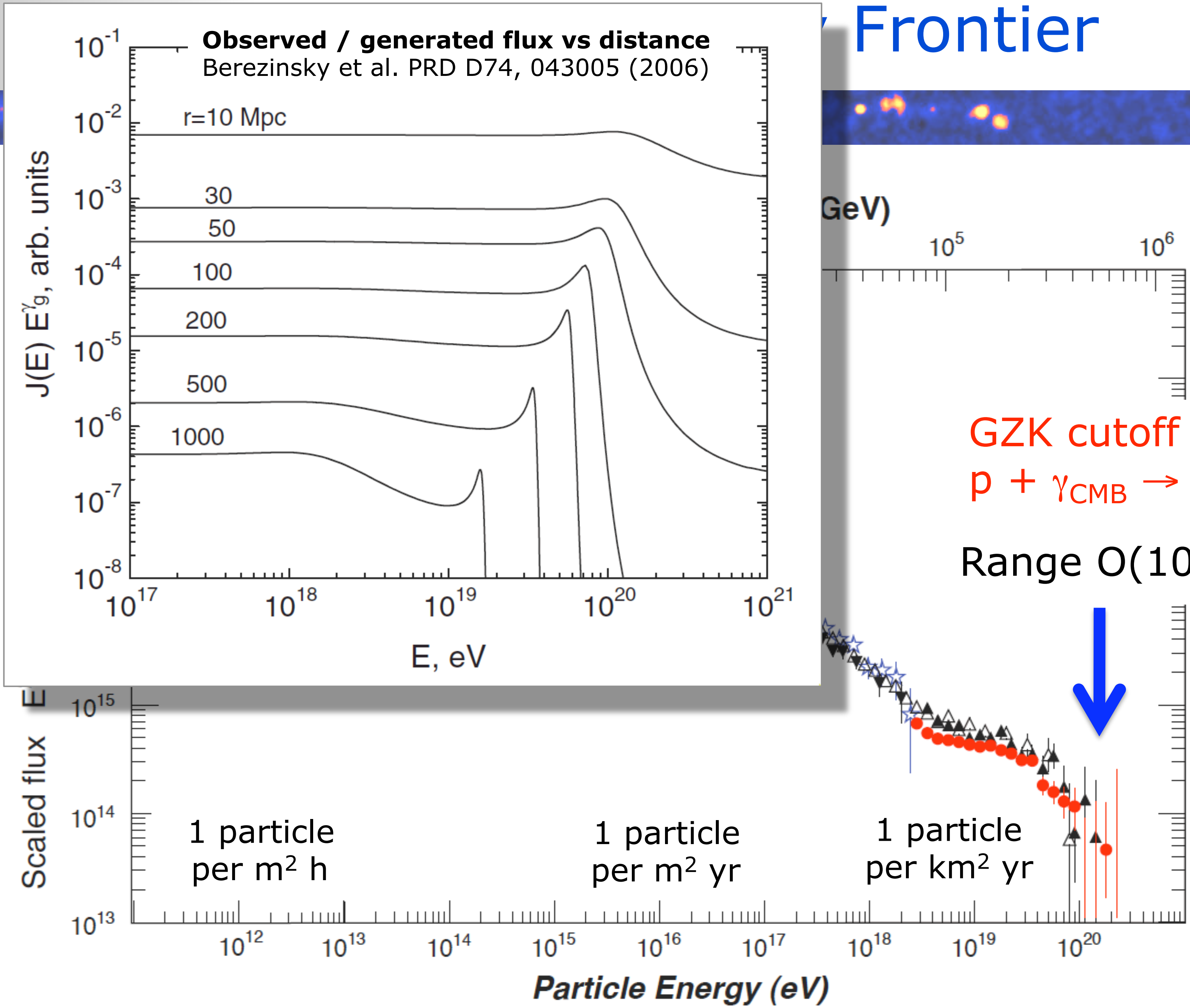
$R_{pc} \sim E_{PeV} / B_{\mu G}$

Cosmic Rays: the Energy Frontier





… Frontier

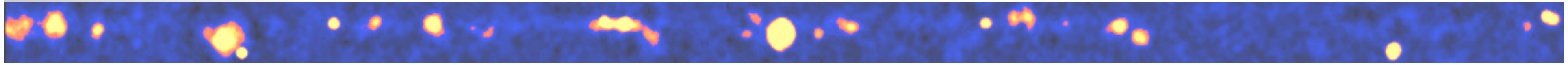


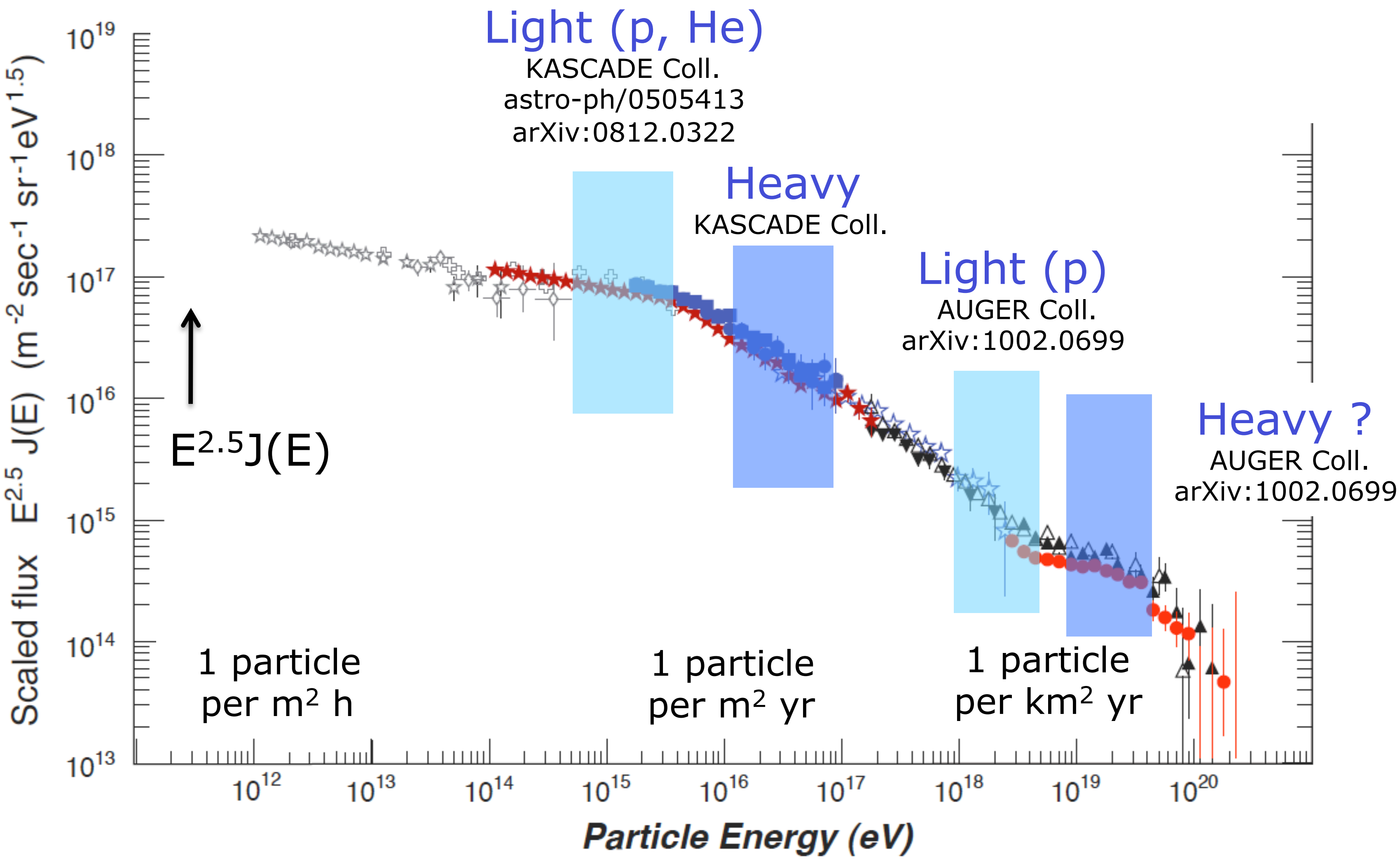
GZK cutoff (?)

$p + \gamma_{CMB} \rightarrow p + \pi^0$

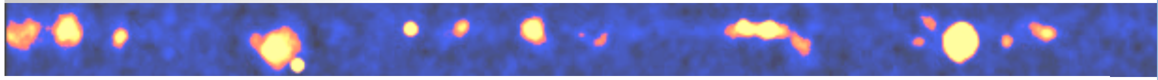
Range O(100 Mpc)

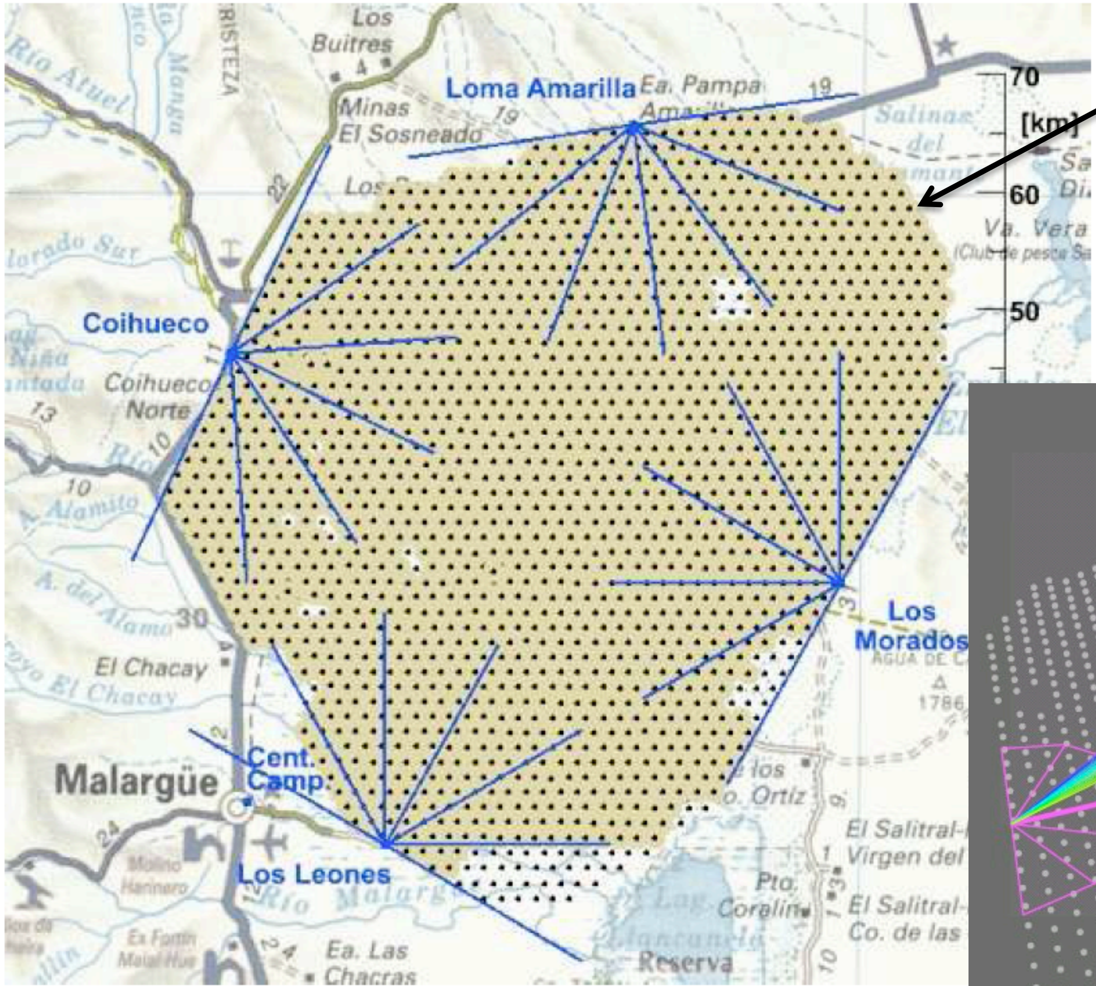
Element abundance @ high energies

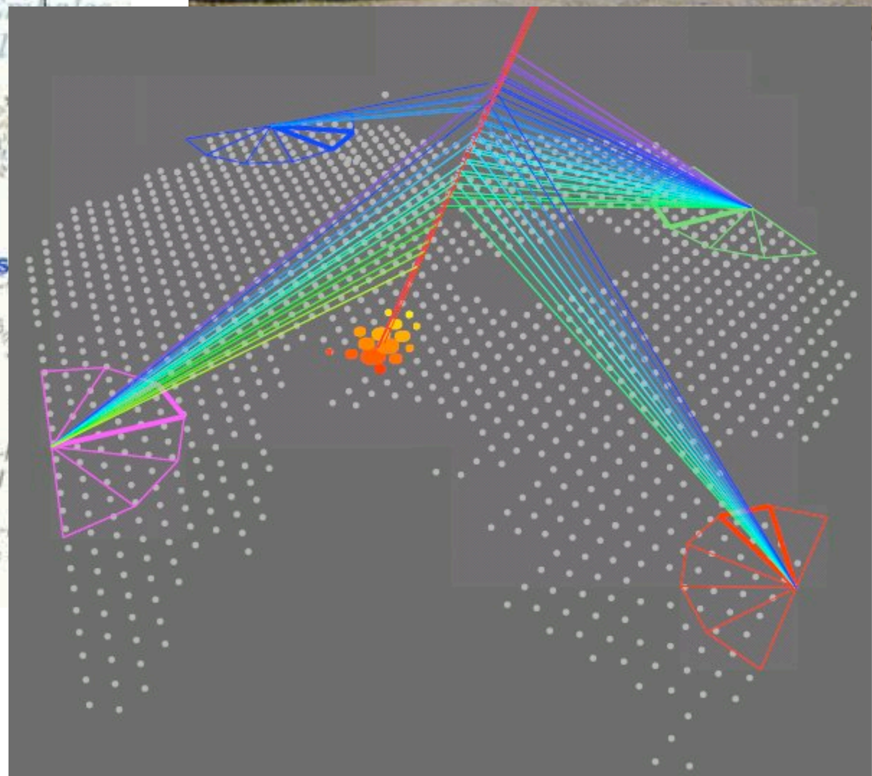




AUGER air shower array





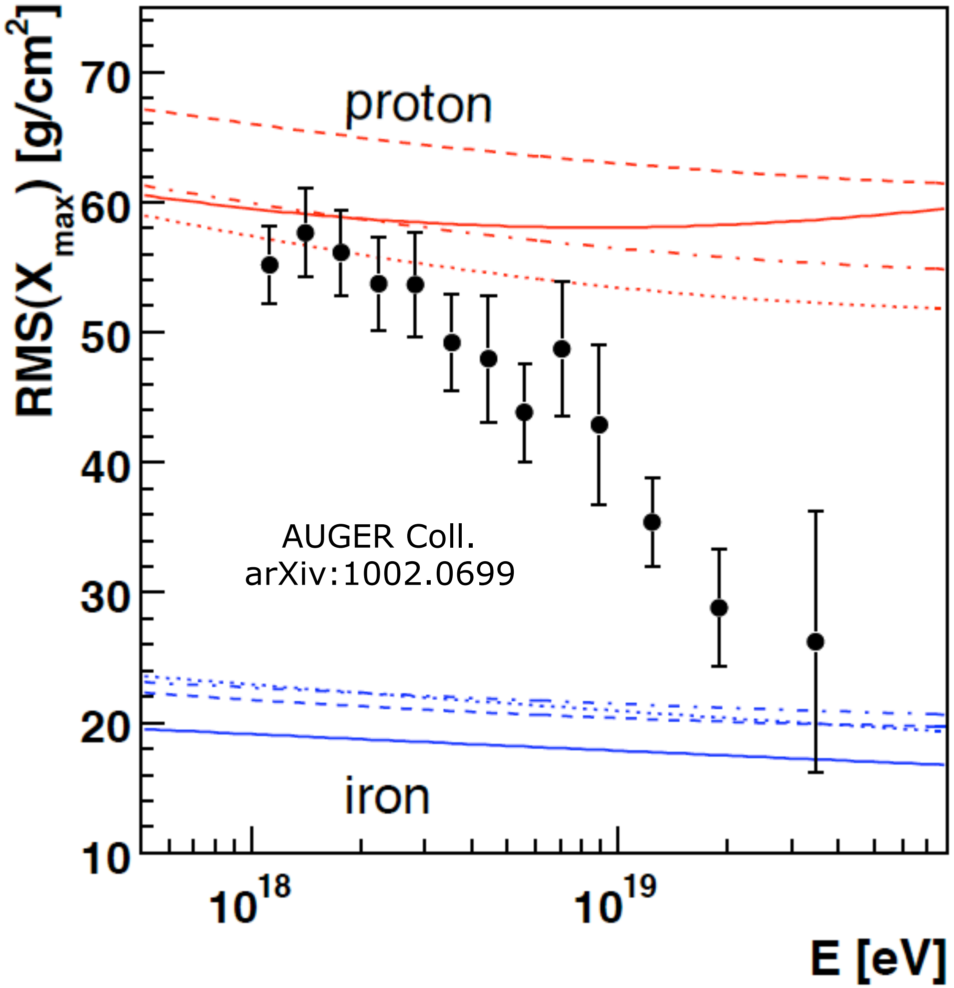


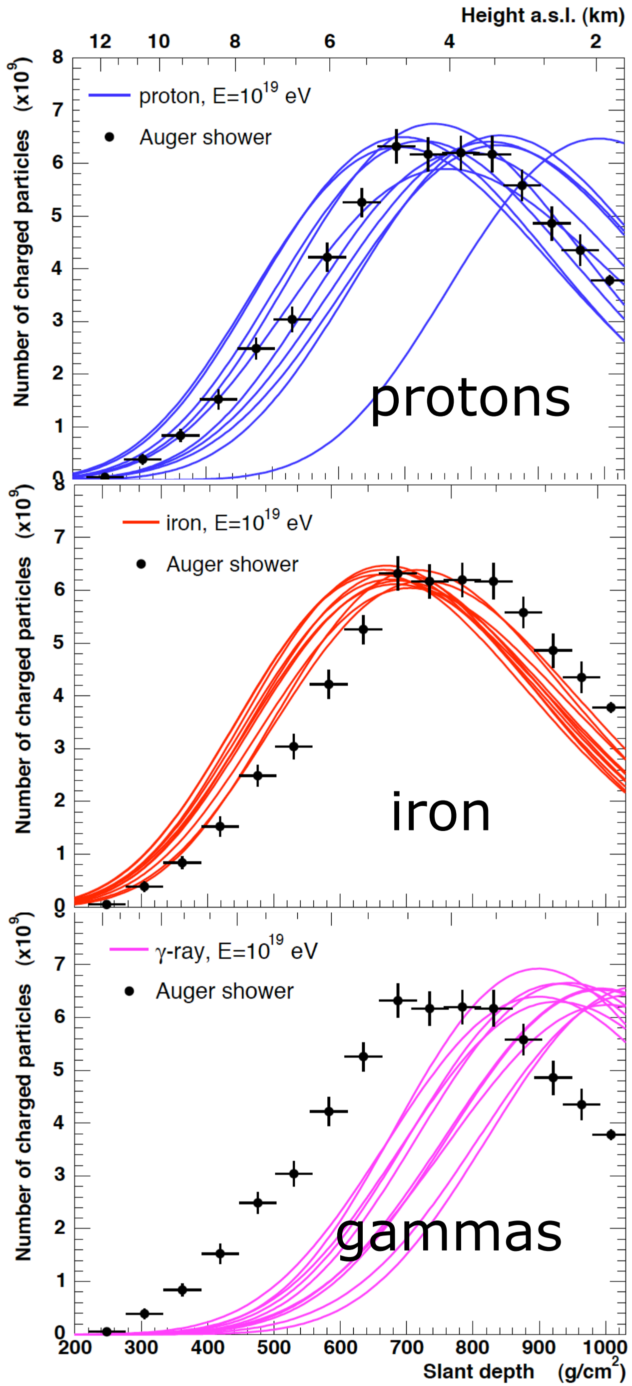
AUGER: 3000 km^2

Saarland: 2570 km^2

UHE CR Composition

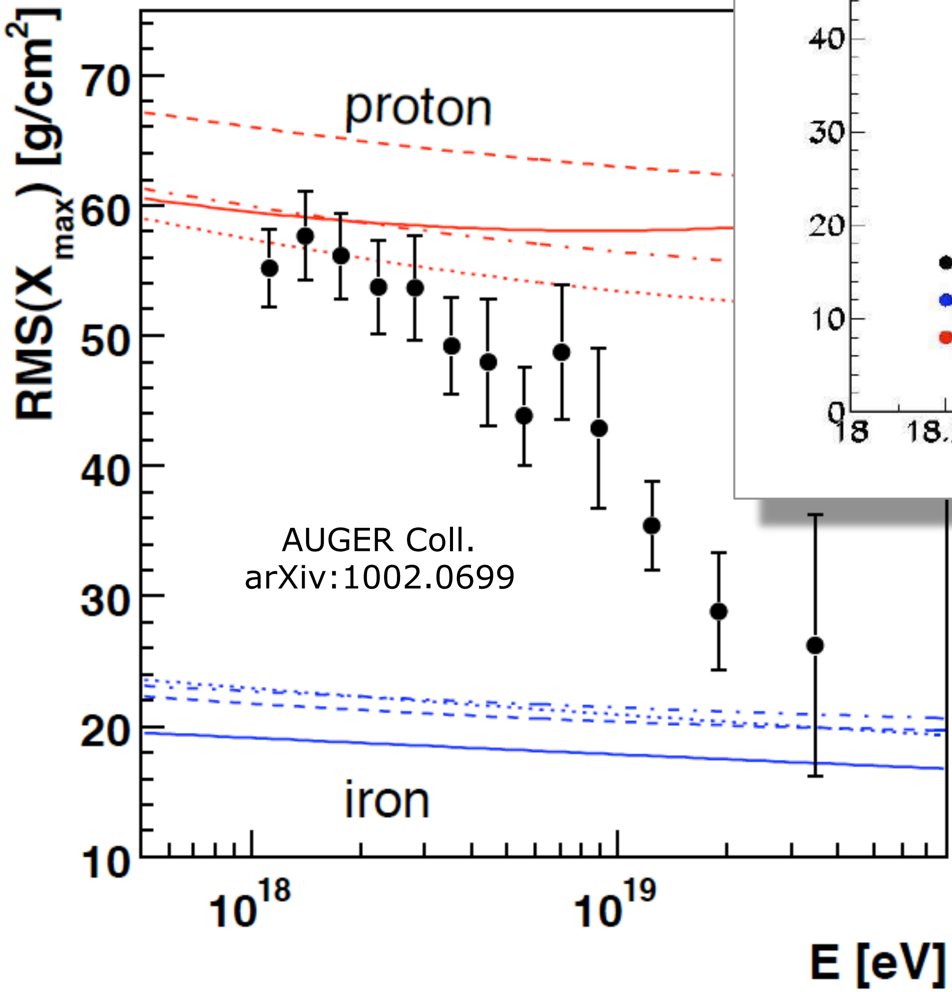
based on depth of shower maximum
and rms variation from shower to shower

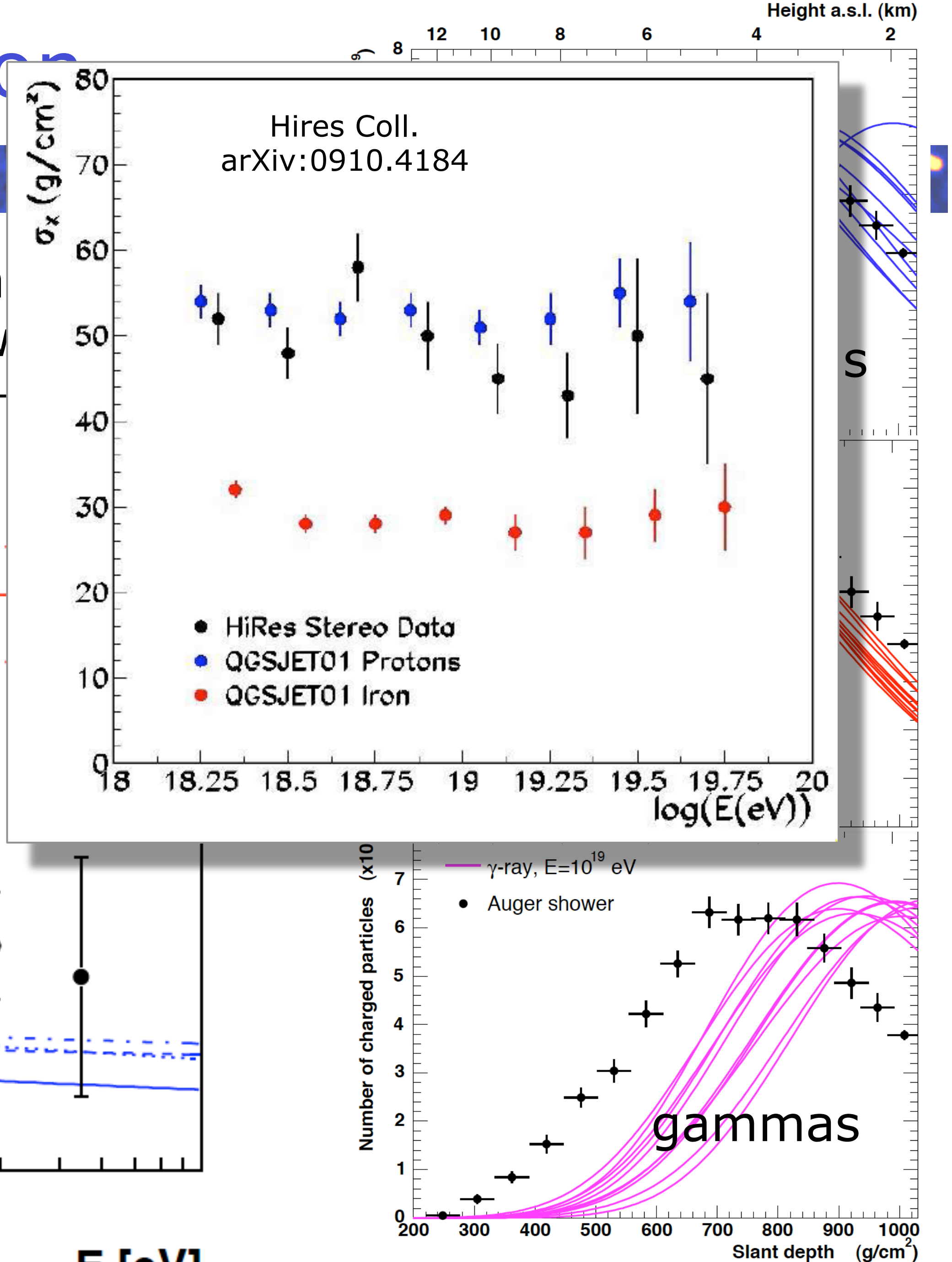




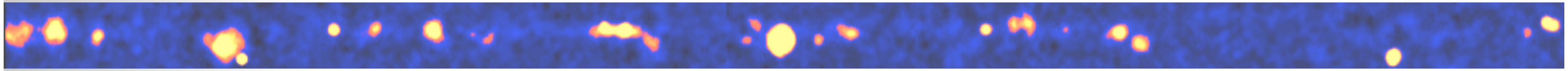
UHE CR Compositio

based on depth of shower m
and rms variation from show

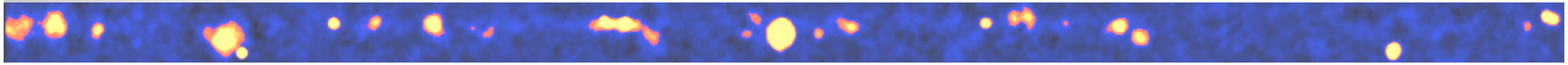




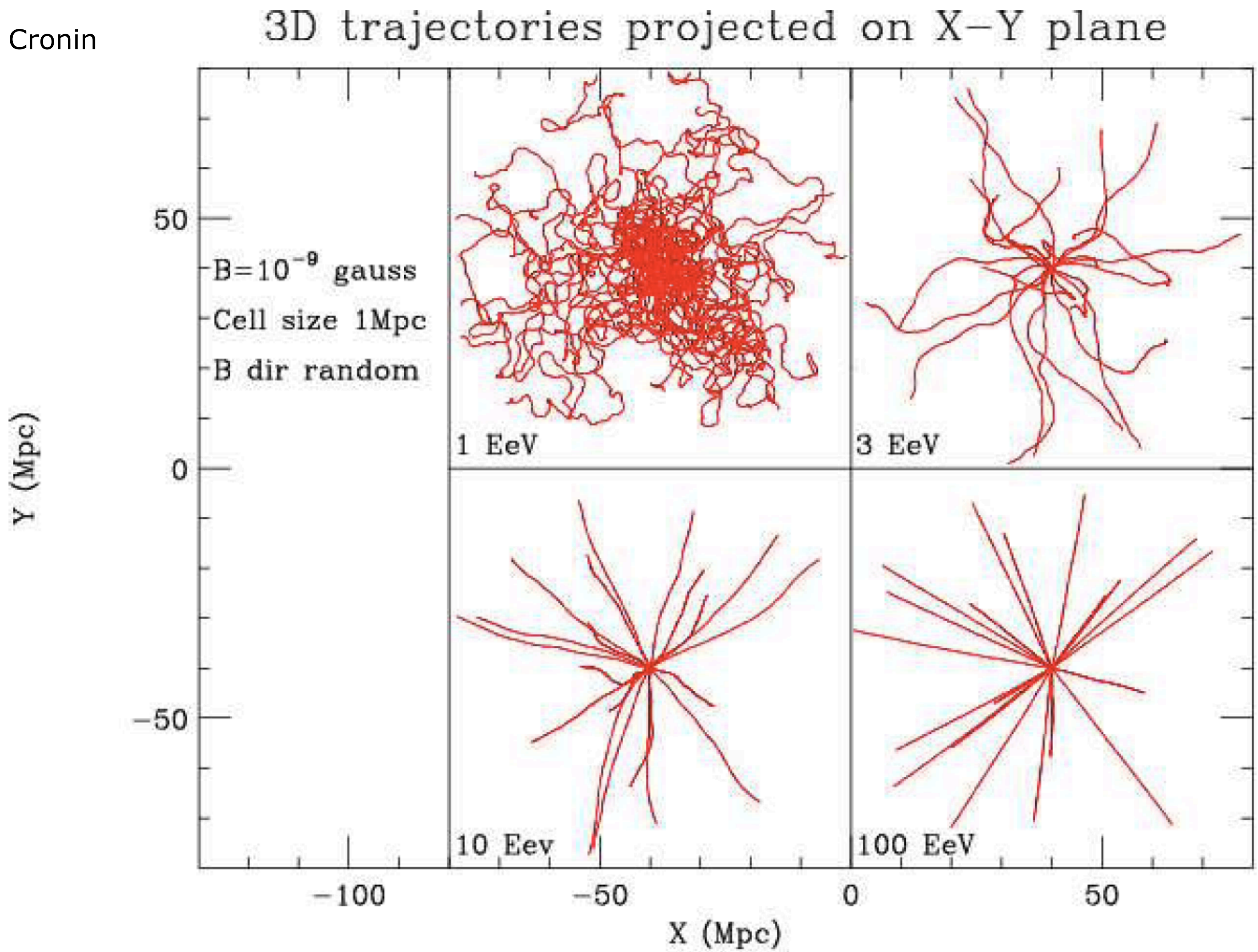
“Seeing” cosmic accelerators (I) the UHE CR frontier



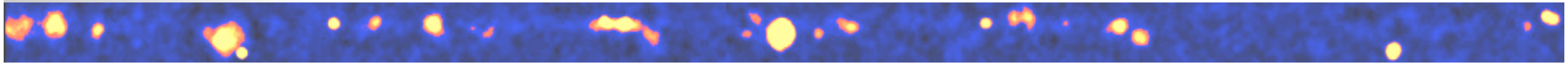
“Seeing” cosmic accelerators I

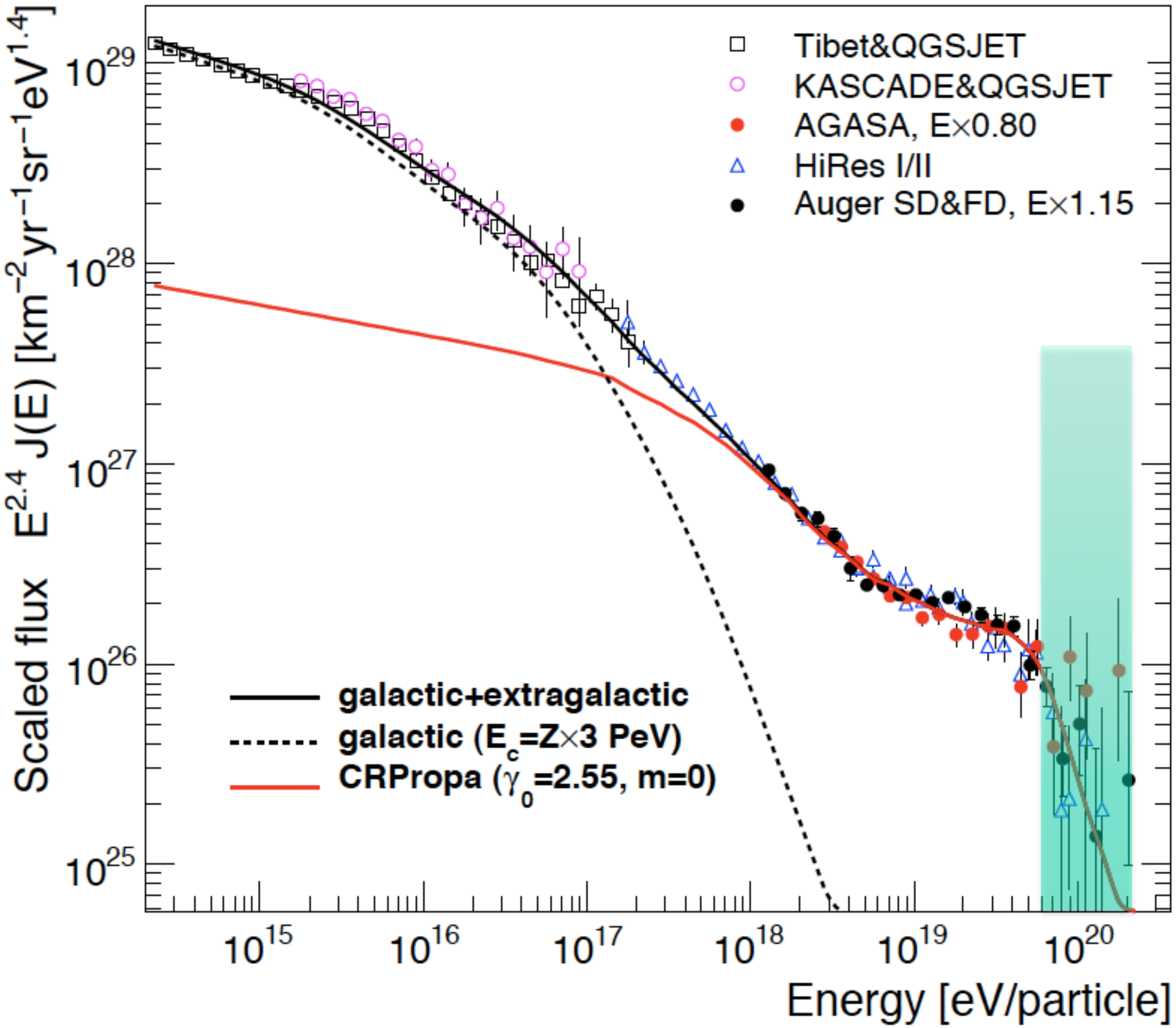


J. Cronin



Correlating UHE events & nearby AGN



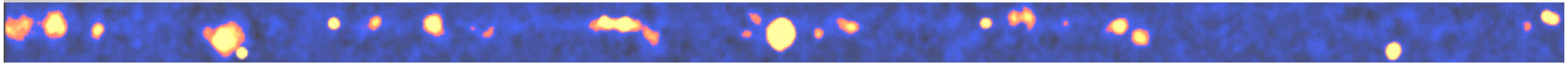


GZK (?) Cutoff

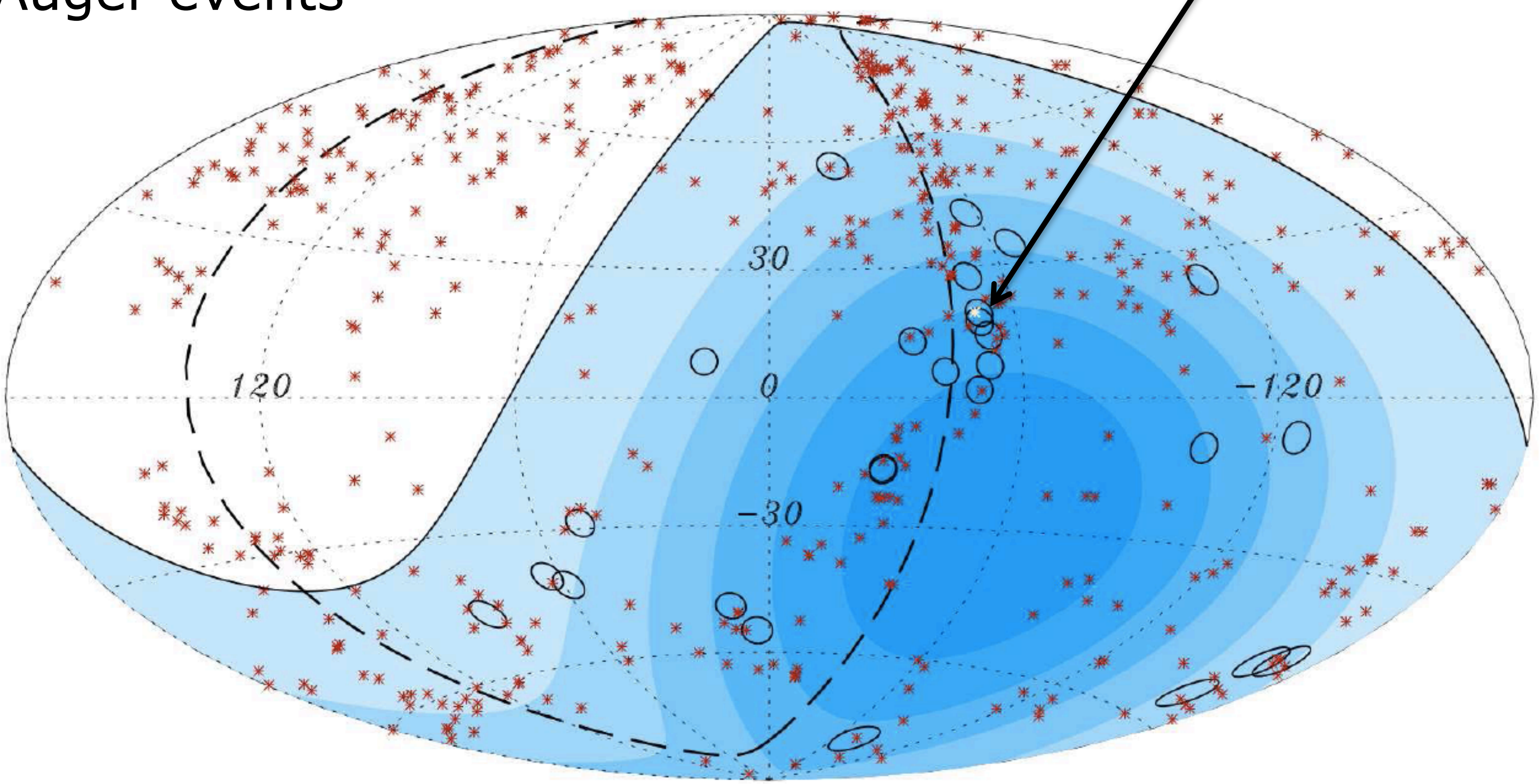
$p + \gamma_{CMB} \rightarrow p + \pi^o$

Sources?

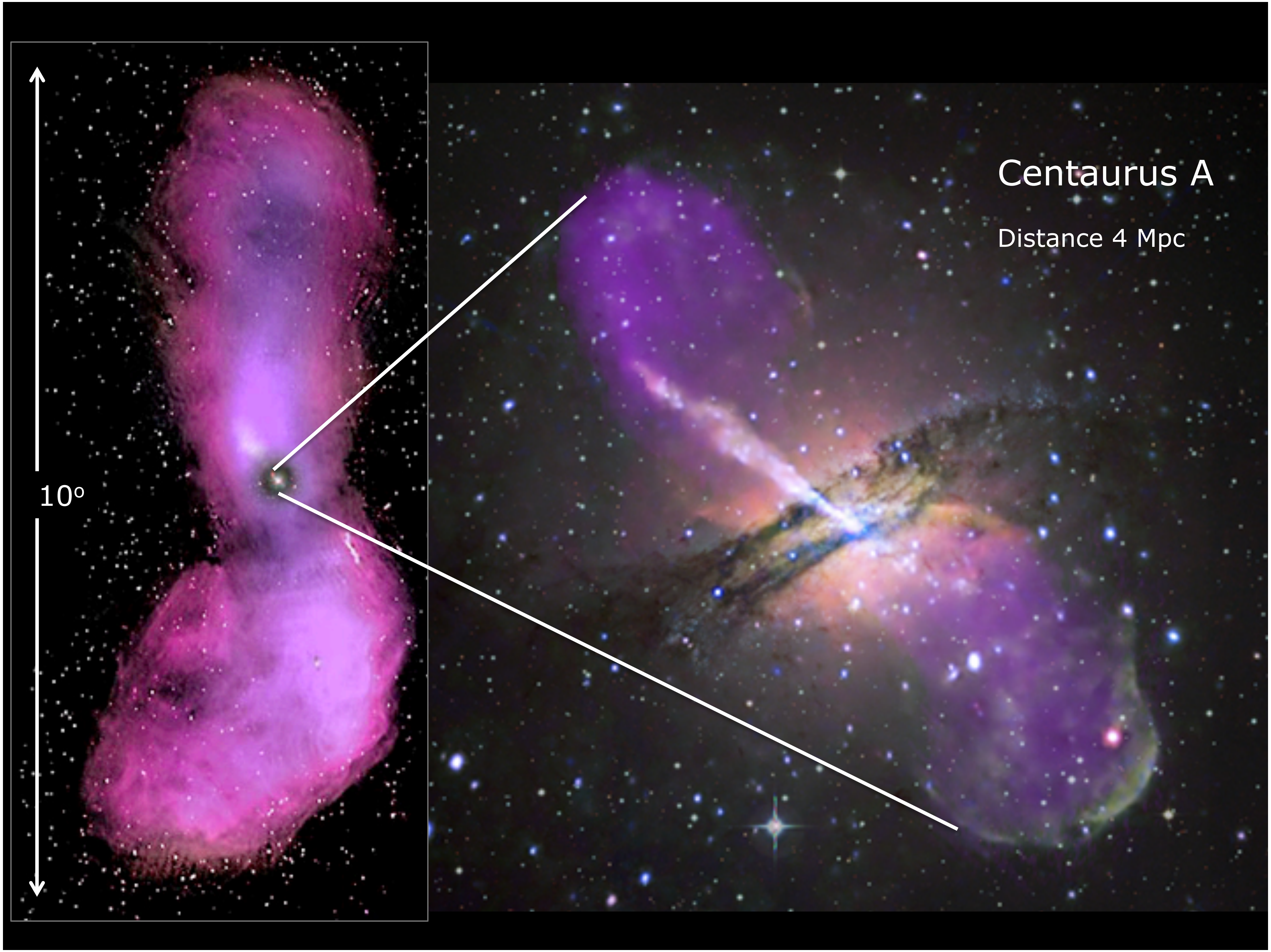
Auger 2007: significant correlation with nearby AGN (< 75 Mpc)



x nearby AGN
o UHE Auger events

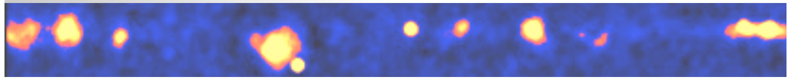


Auger Collaboration, Science 318 (2007)



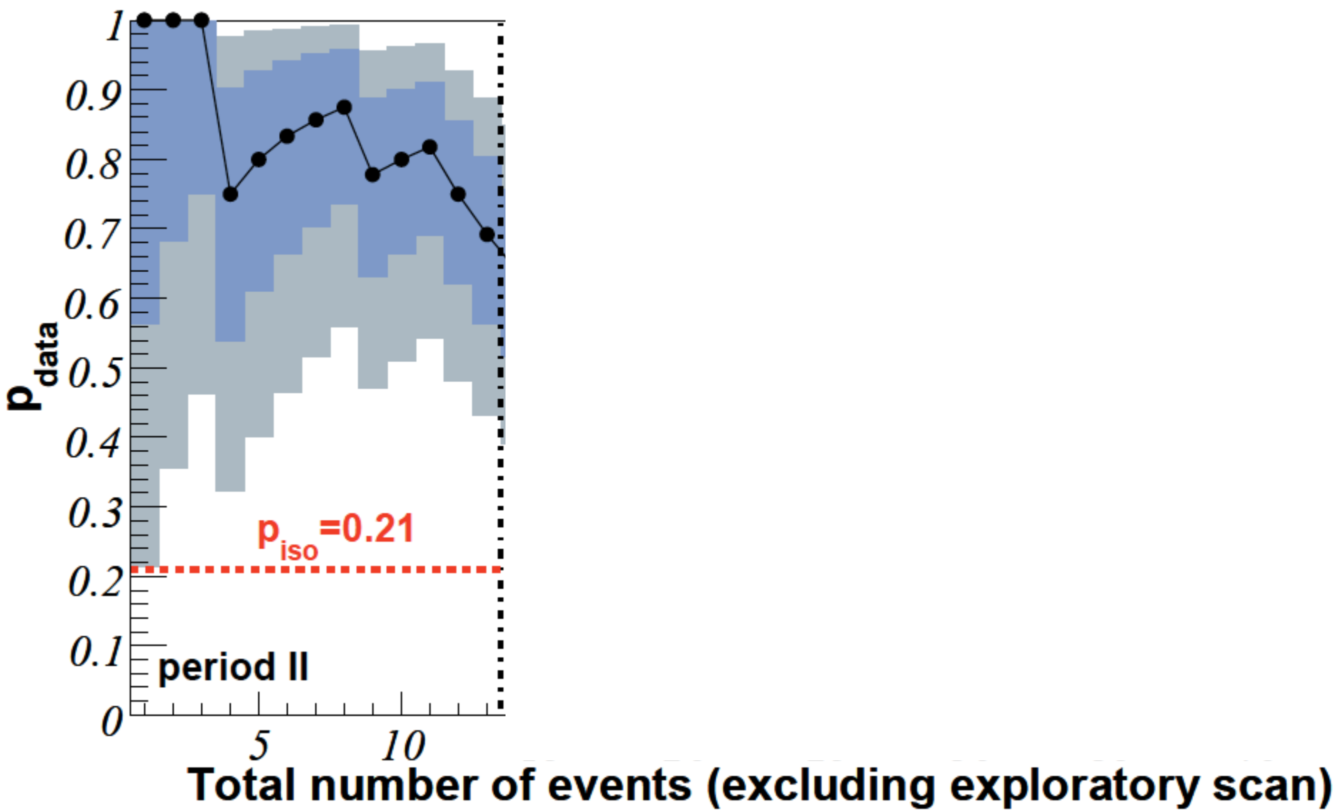
Centaurus A
Distance 4 Mpc
10°

Sources?



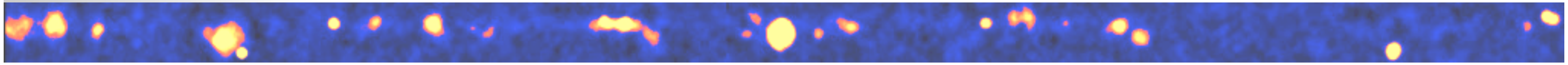
Auger 2007: significant correlation with nearby AGN (< 75 Mpc)

Fraction of events above 55 EeV within 3° of AGN

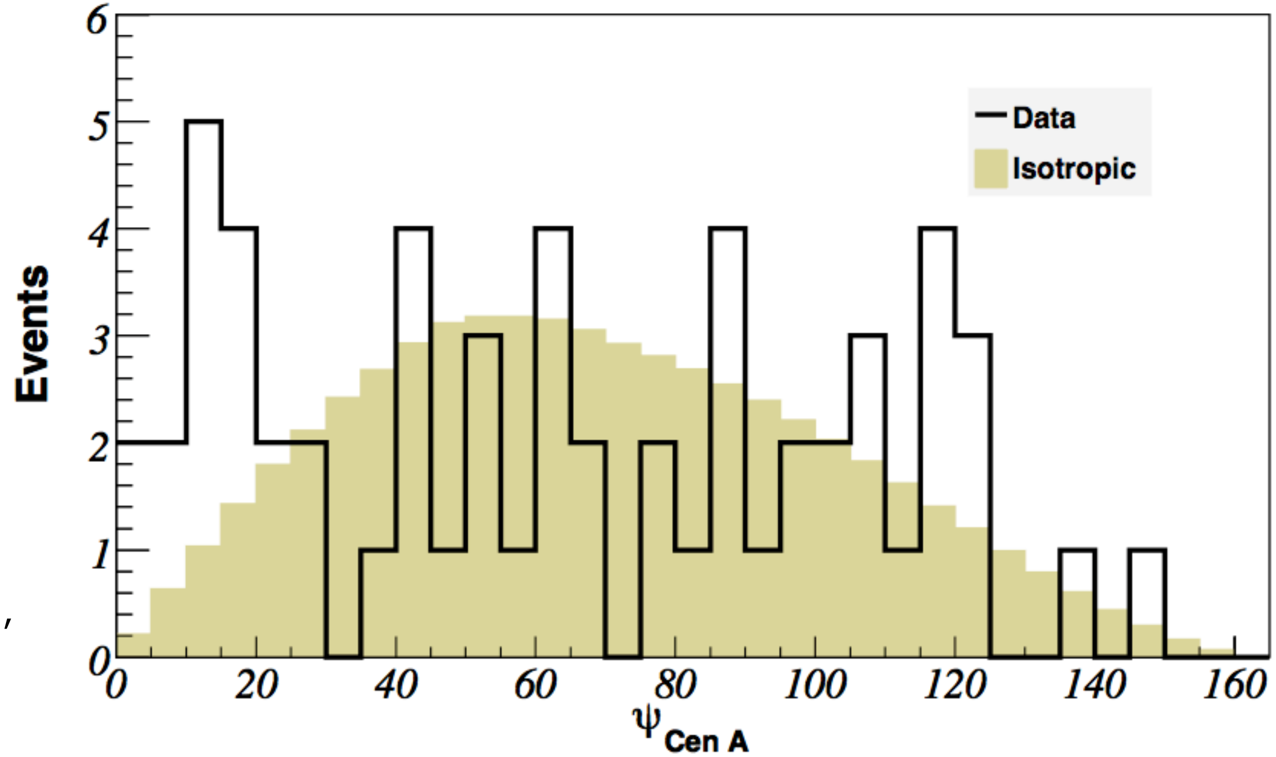


Auger Collaboration, arXiv:0906.2347
also HiRes Collaboration, arXiv:1002.1444

Centaurus A as a source of UHECR?



Chance probability 2%



Auger Collaboration, arXiv:0906.2347

Also: Correlation with Swift-BAT AGN density map:
Chance probability $\sim 10^{-5}$

UHECR: Auger vs HiRes

Auger

Southern sky
cutoff @ ~GZK energy
correlation with matter
heavy composition

HiRes

Northern sky
cutoff @ ~GZK energy
correlation with matter excluded
light composition

Explanations

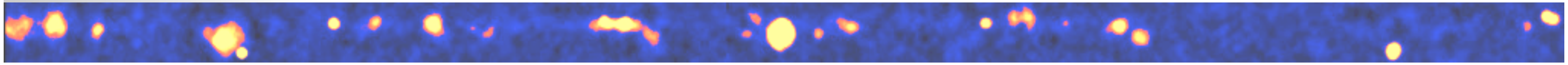
Very few sources dominate; North can easily differ from South
(but: spectra agree within systematic errors)

Not fully understood systematics

Low statistics

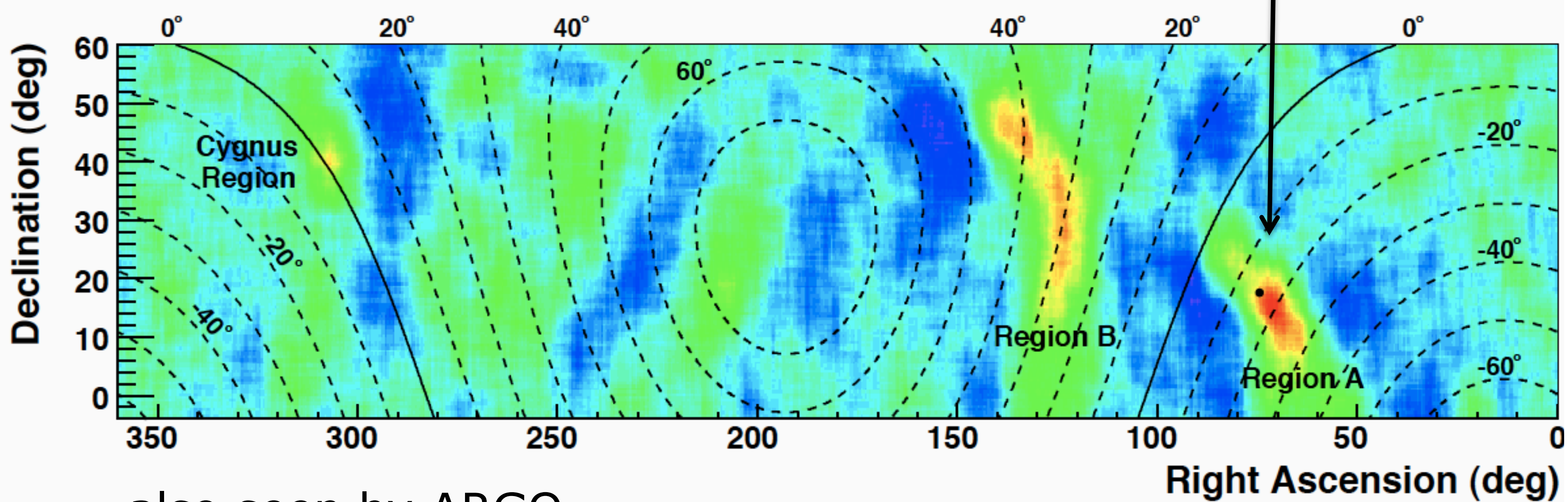
New physics in UHECR interactions

Puzzles: TeV CR “hot spots”



Milagro Collab.
Abdo et al.
0801.3827

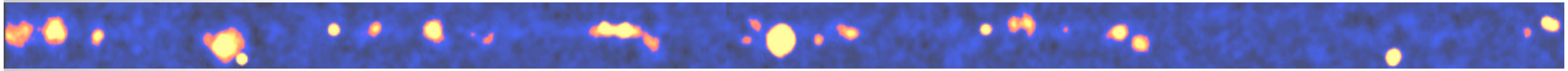
Excess 6×10^{-4}



also seen by ARGO

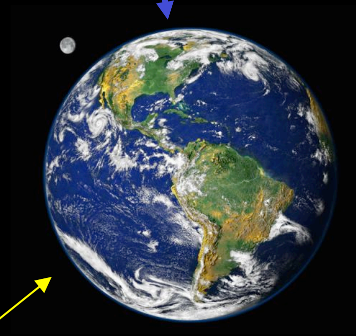
a message from your
neighborhood cosmic accelerator ?

"Seeing" cosmic accelerators
(II) The frontier in gamma rays



Seeing cosmic accelerators II

➔ Image accelerators with neutral secondaries
➔ **Gamma-ray** and Neutrino Astronomy



p + nucleus ➔ π +X

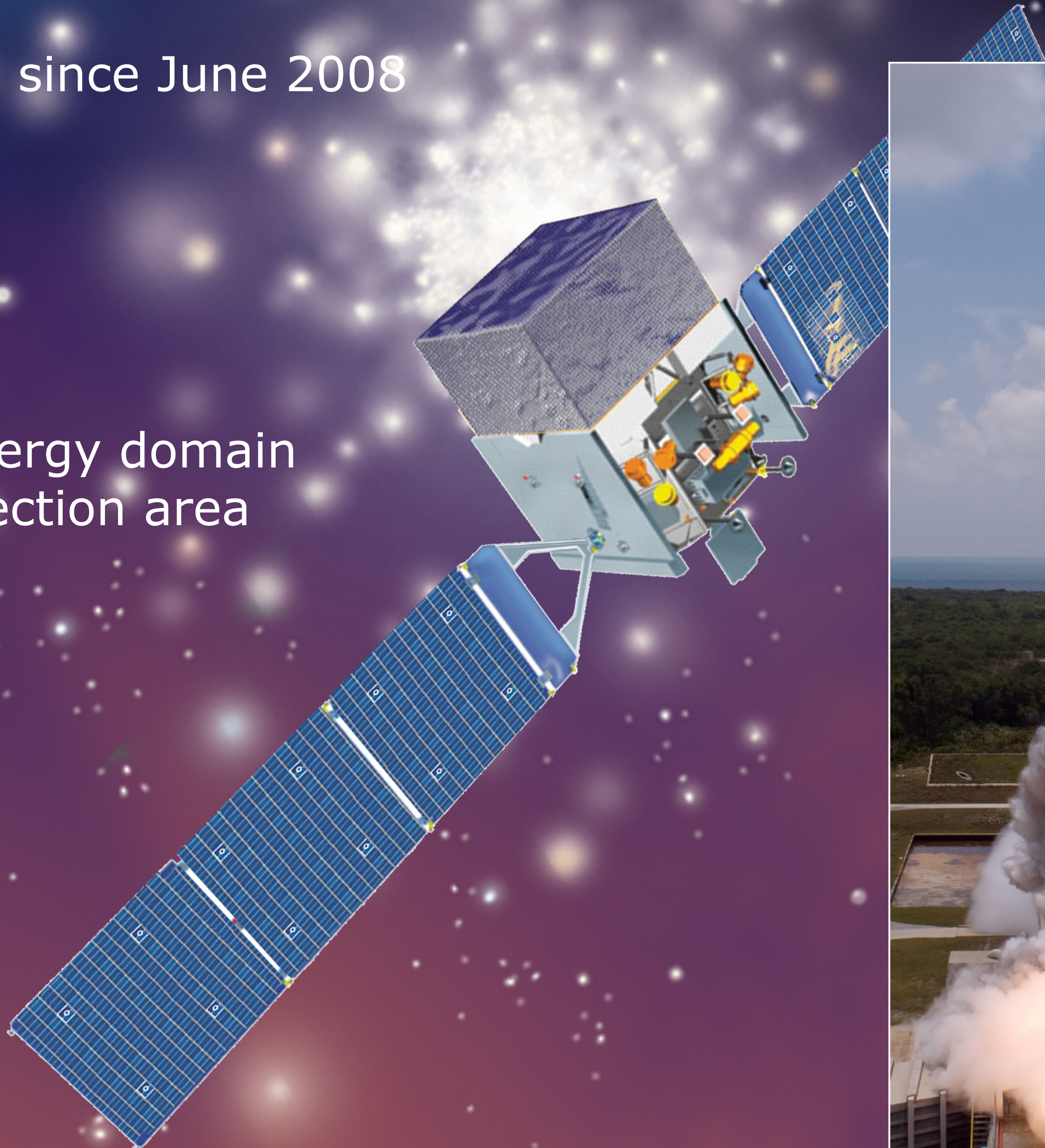
π^{o} ➔ $\gamma\gamma$
$\pi^{\pm}$ ➔ $\mu^{\pm}$ ν

Fermi Gamma-Ray Space Telescope

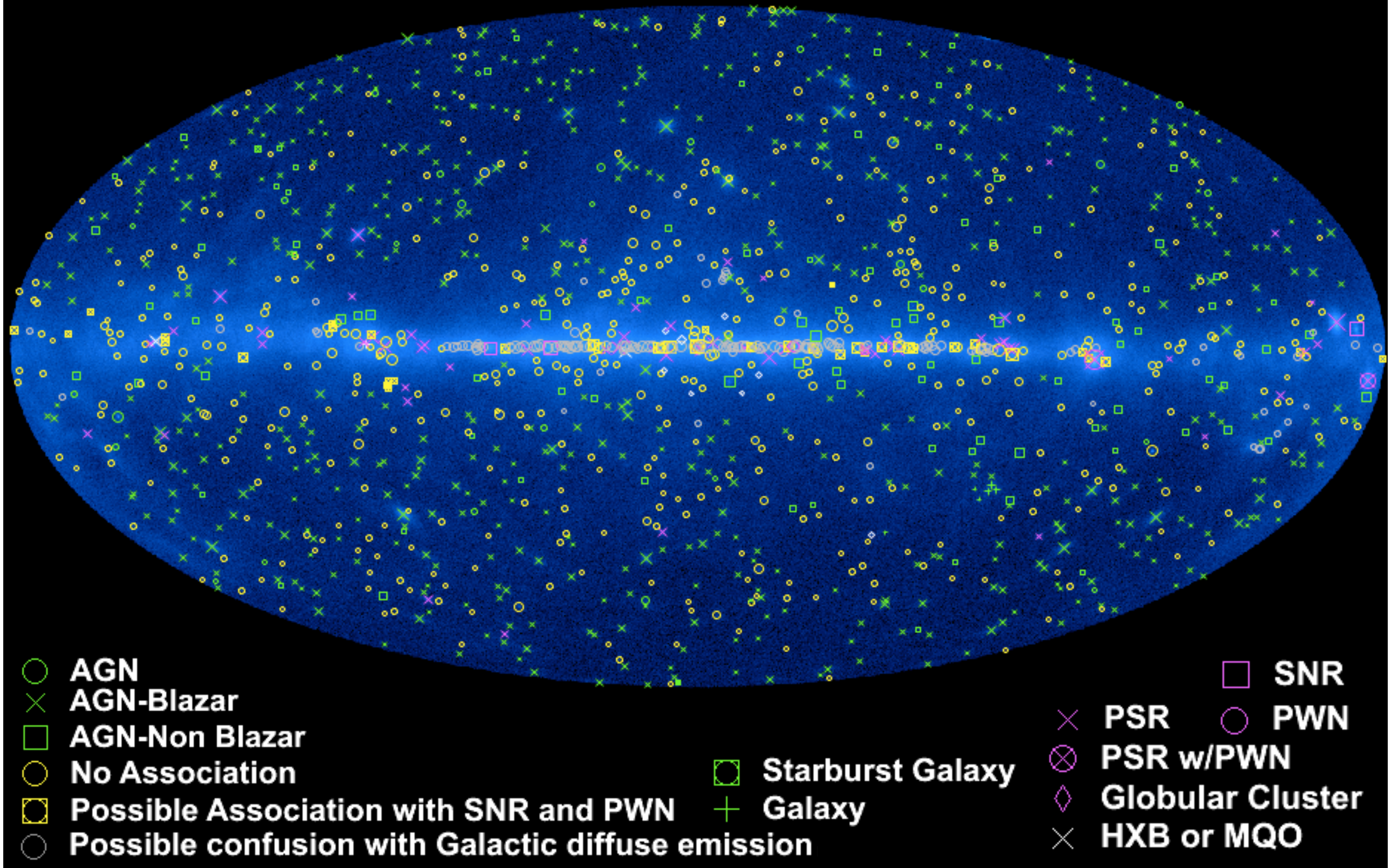
In orbit since June 2008

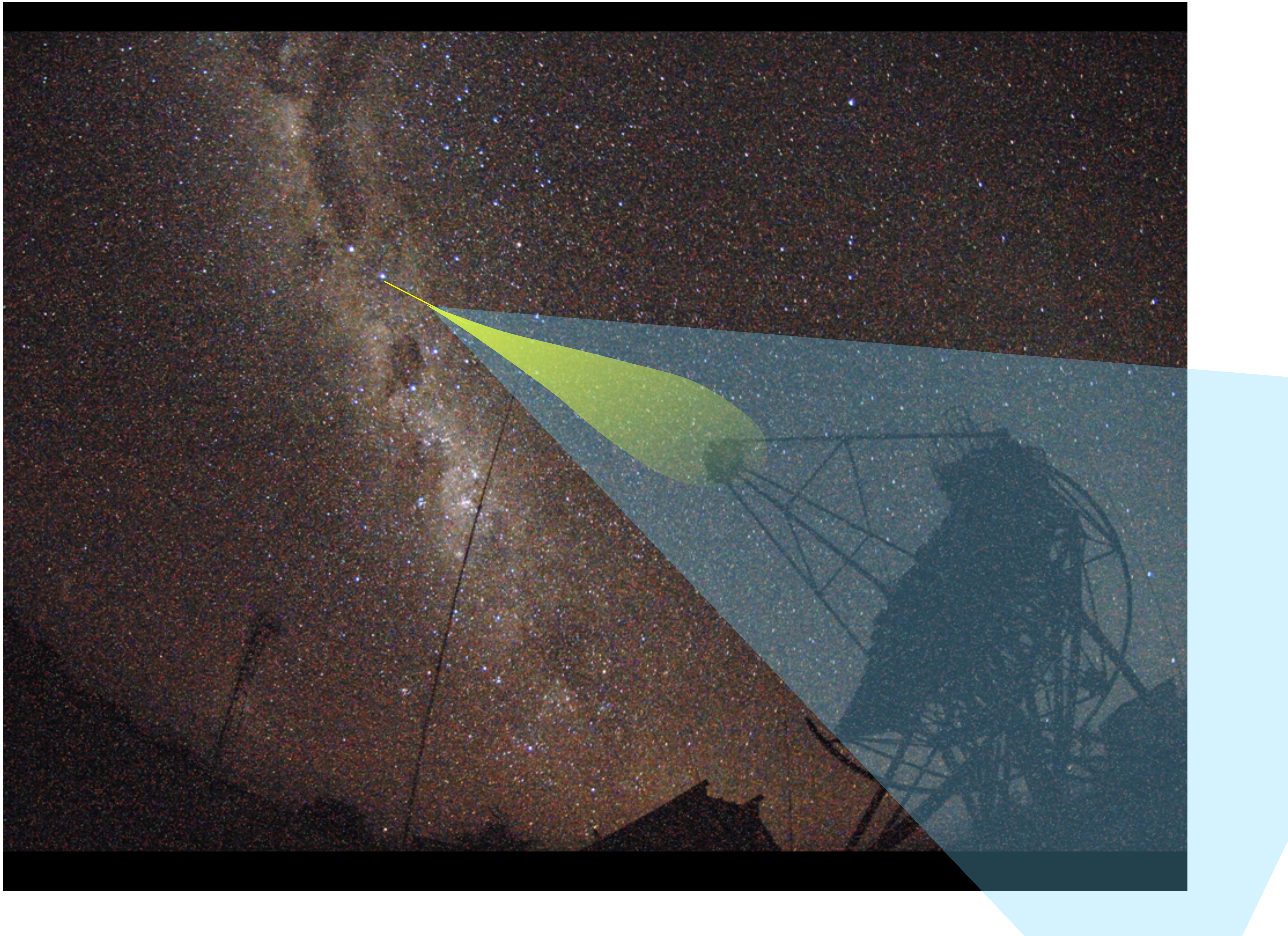
GeV energy domain

m^2 detection area

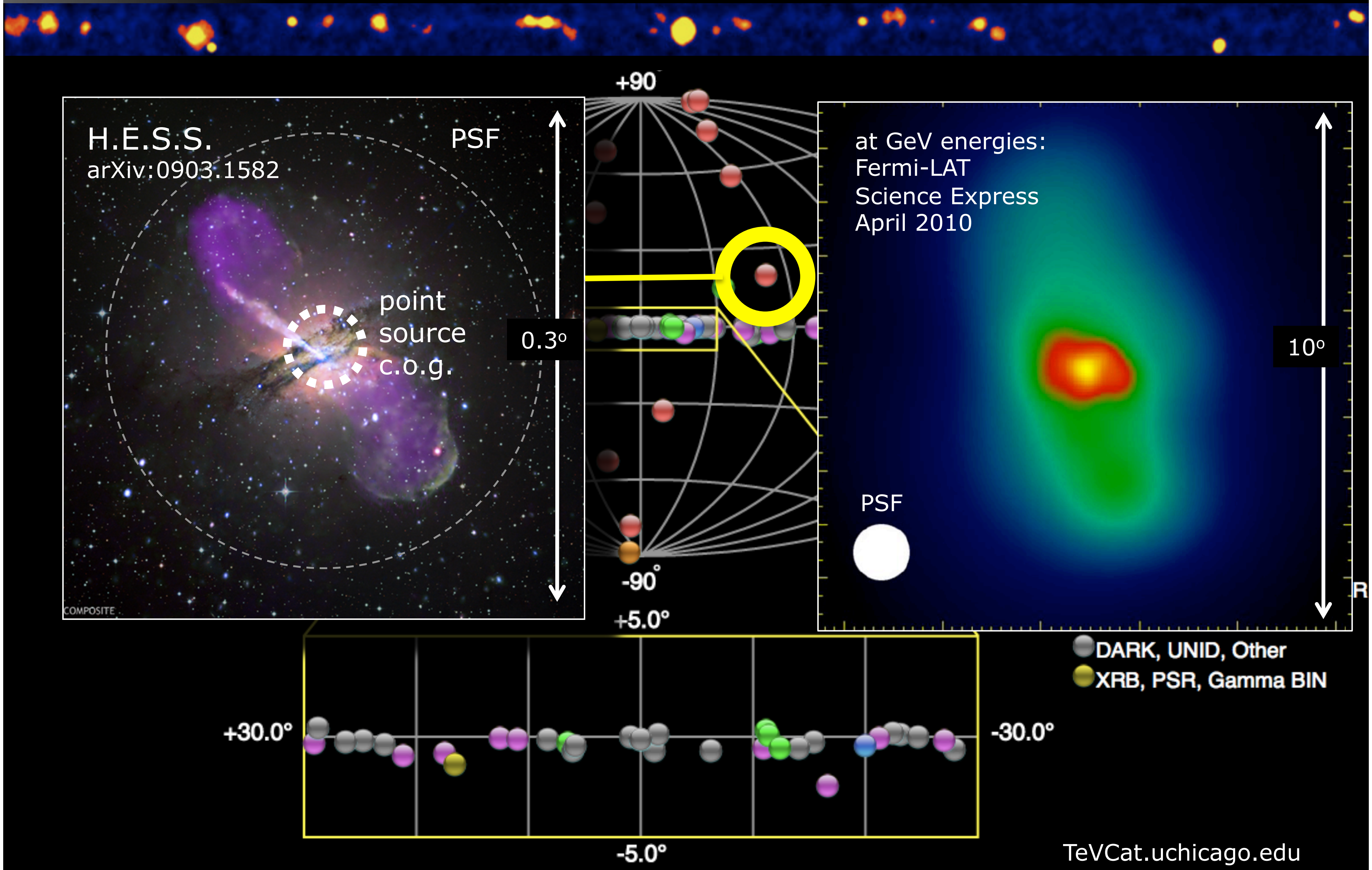


The GeV sky: ~1500 sources



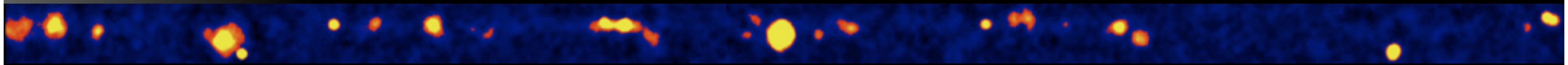


The TeV gamma ray sky: ~100 sources



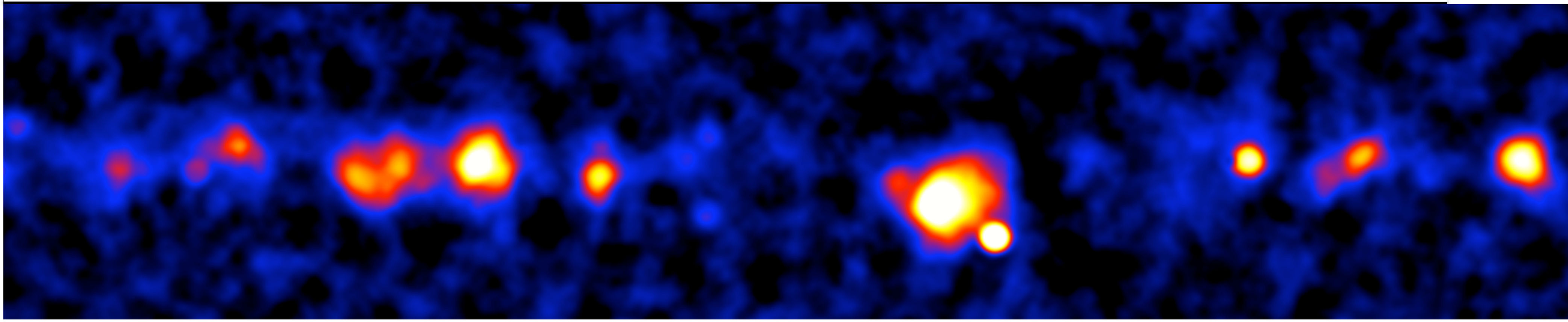
TeVCat.uchicago.edu

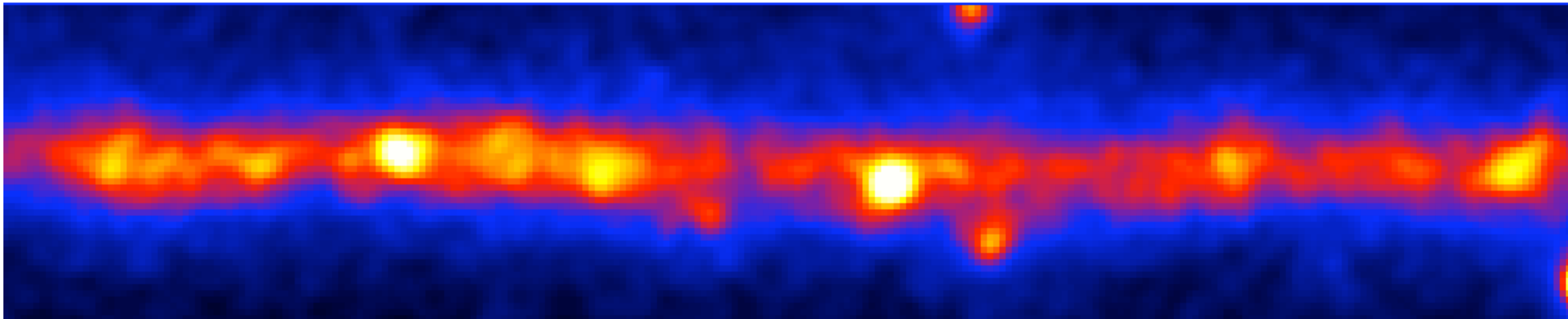
The Milky Way at GeV and TeV energies



Extended sources, size typically few 0.1°
few 10 pc

H.E.S.S. (~ 1 TeV)

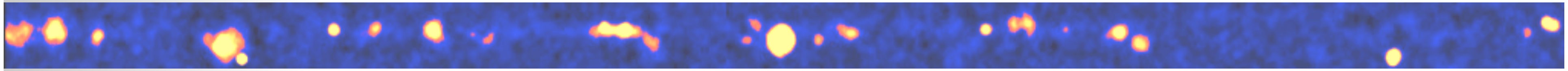




Fermi-LAT (>1 GeV)

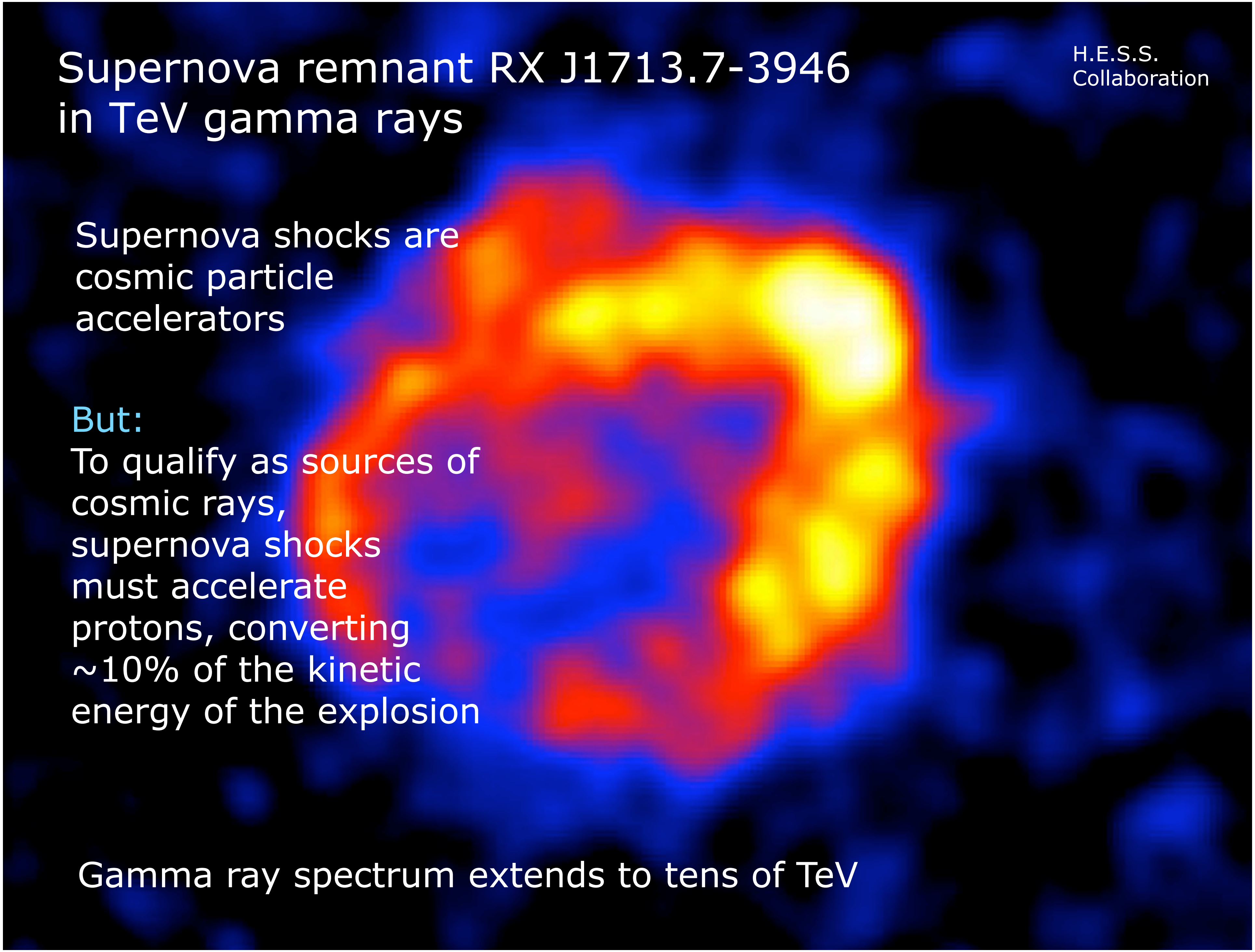
"Background" due to propagating
Galactic cosmic rays

Supernovae –
Sources of Galactic Cosmic Rays?



Supernova remnant RX J1713.7-3946 in TeV gamma rays

H.E.S.S.
Collaboration



Supernova shocks are cosmic particle accelerators

But:
To qualify as sources of cosmic rays, supernova shocks must accelerate protons, converting ~10% of the kinetic energy of the explosion

Gamma ray spectrum extends to tens of TeV

SN 1006

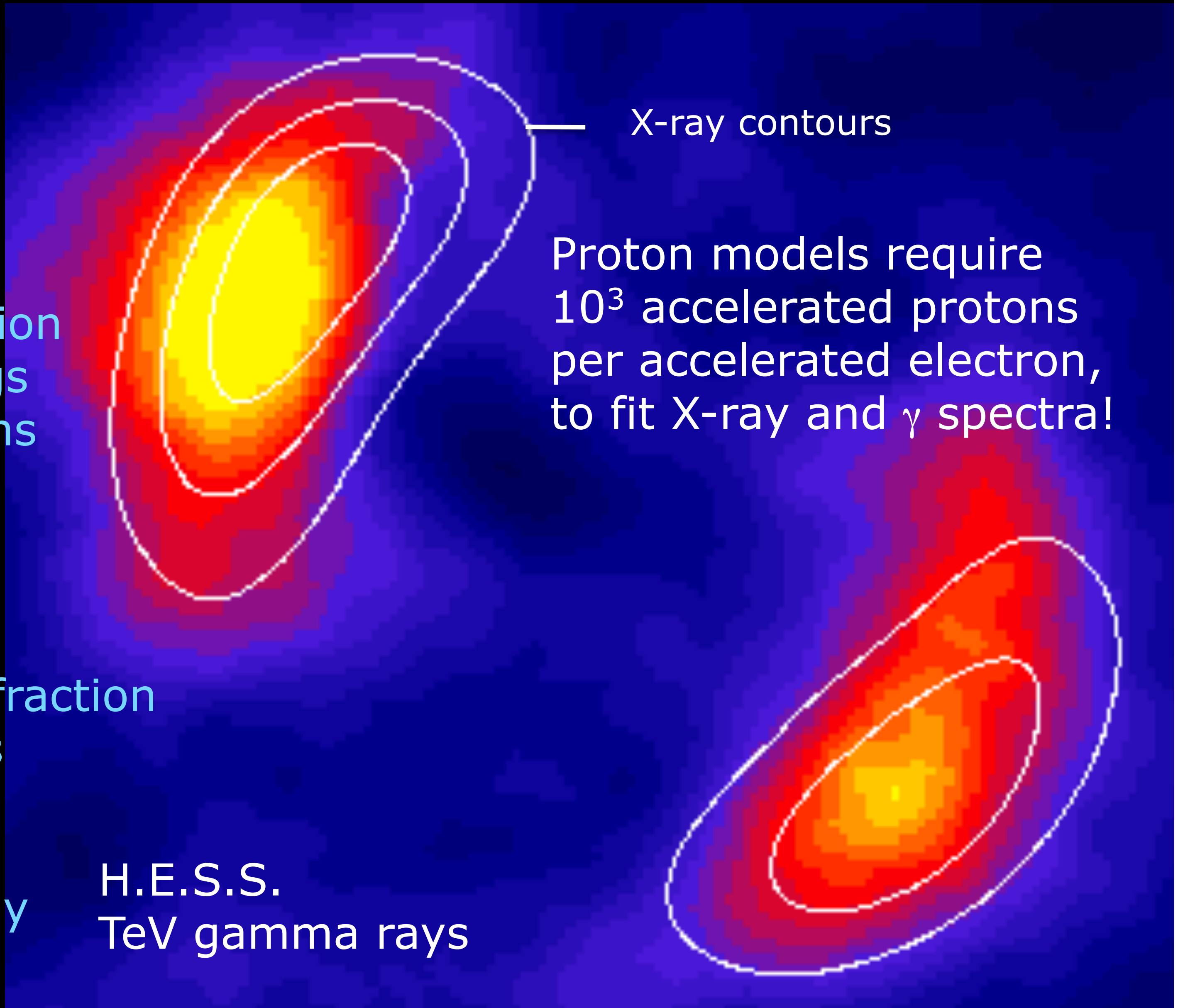
Explanations:

A very modest fraction of explosion energy of 10^{51} ergs carried by electrons (few 10^{47} ergs)

Or

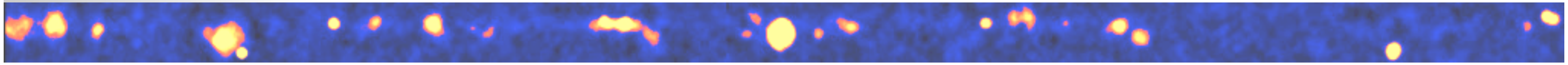
A relatively large fraction carried by protons (few 10^{50} ergs)

plus a bit of energy in electrons (for X-rays)

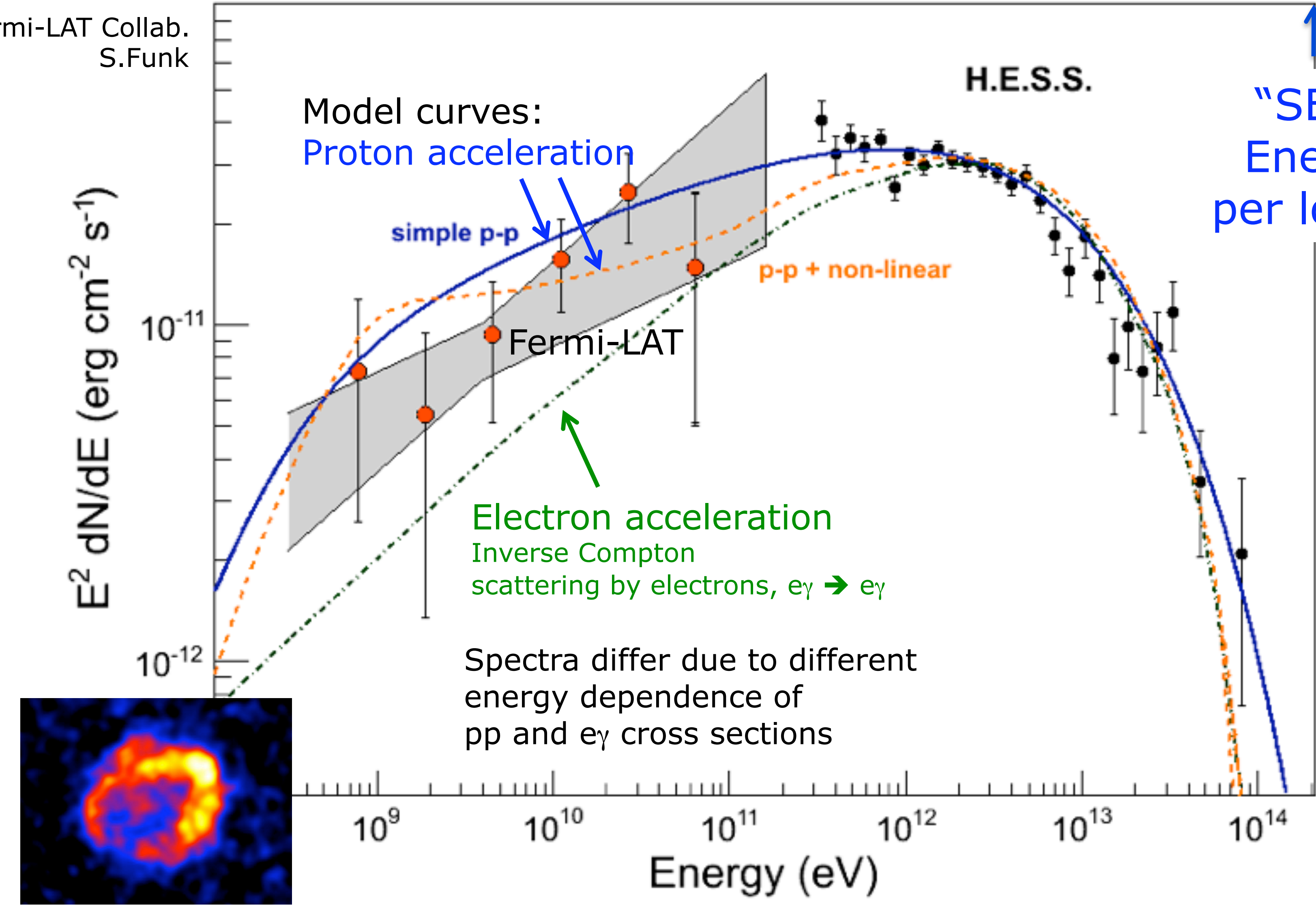


Electron or proton acceleration & acceleration efficiency:

Spectra of gamma rays (and X-rays)



Fermi-LAT Collab.
S.Funk



Model curves:
Proton acceleration

Electron acceleration
Inverse Compton
scattering by electrons, eγ ➔ eγ

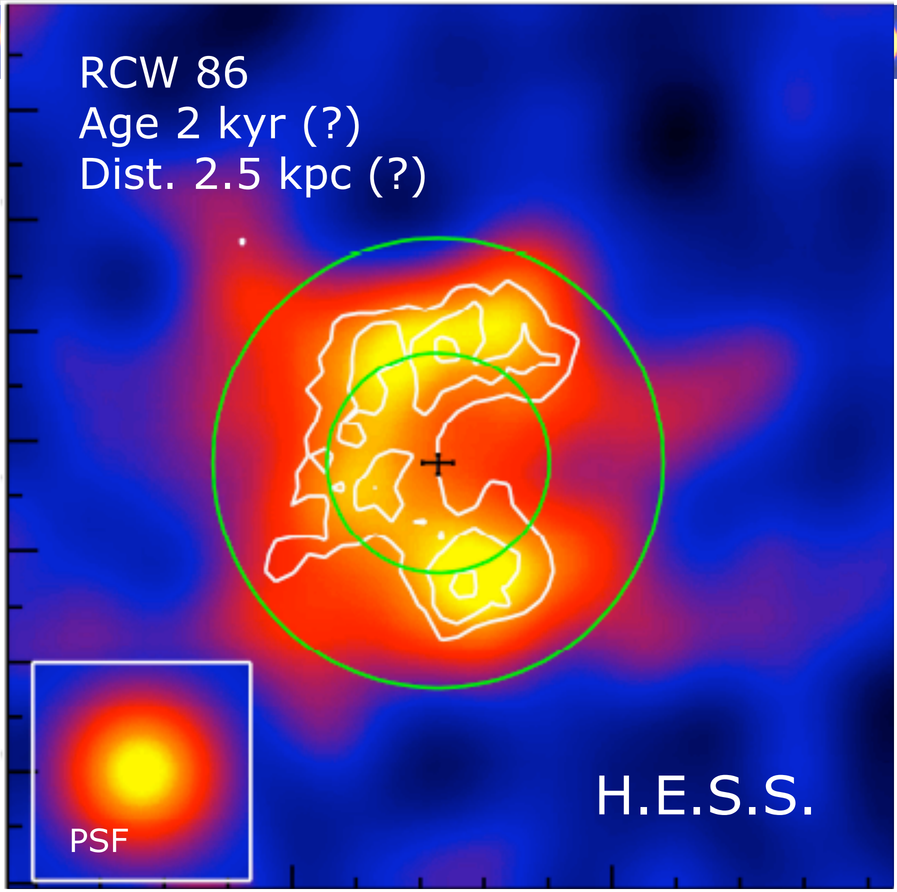
Spectra differ due to different
energy dependence of
pp and eγ cross sections

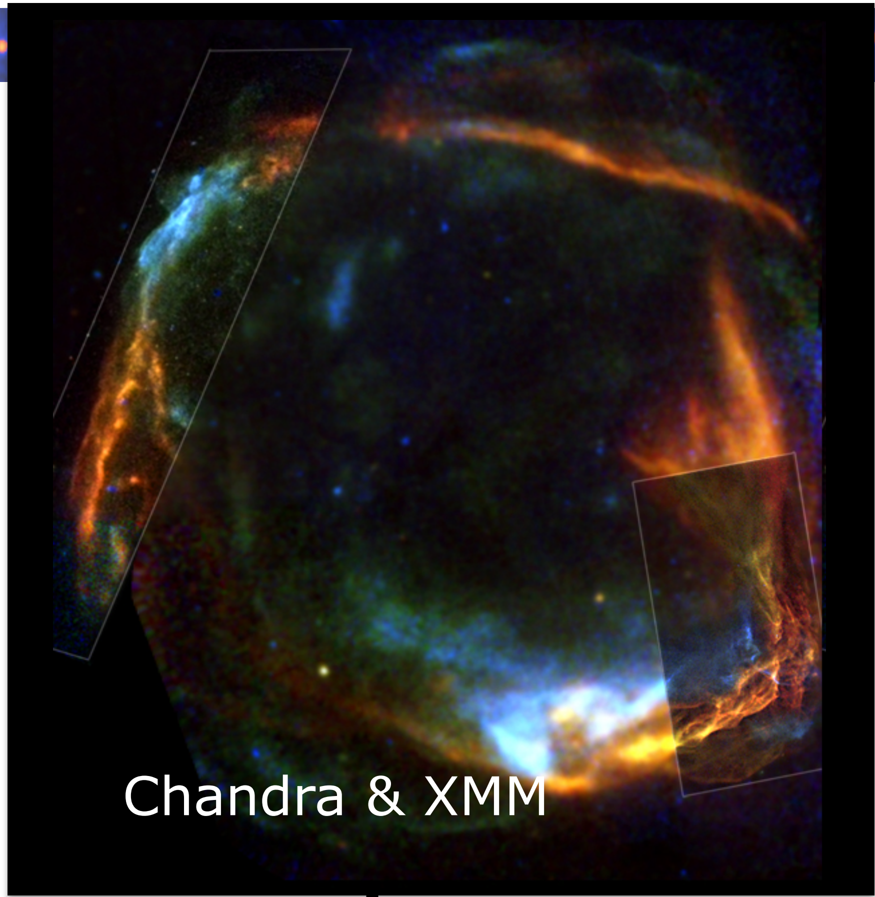
"SED"
Energy
per log(E)

Another approach to acceleration efficiency in SNR:

Energy conservation

Helder et al., Science 2009



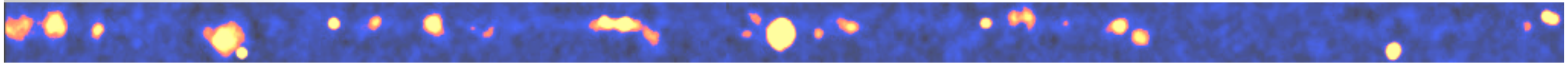


Measured shock velocity 6000±2800 km/s (Chandra 2004,07)
Expected post-shock gas temperature 42…70 keV
Measured post-shock temperature 2.3±0.3 keV (Hα line width)

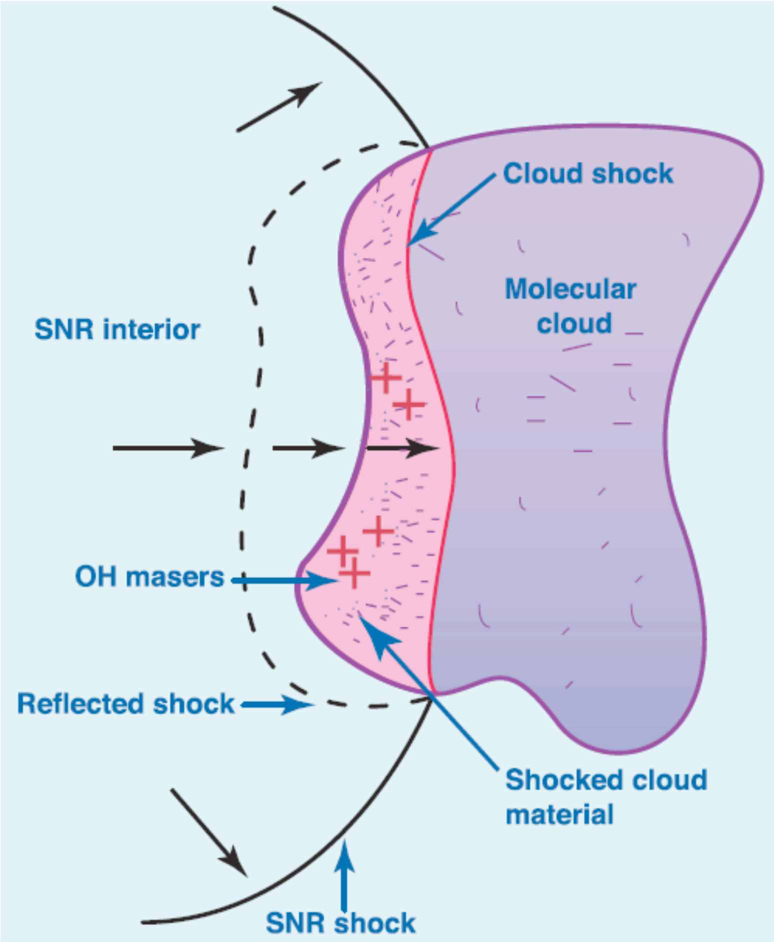
➔ >50% of energy in non-thermal component

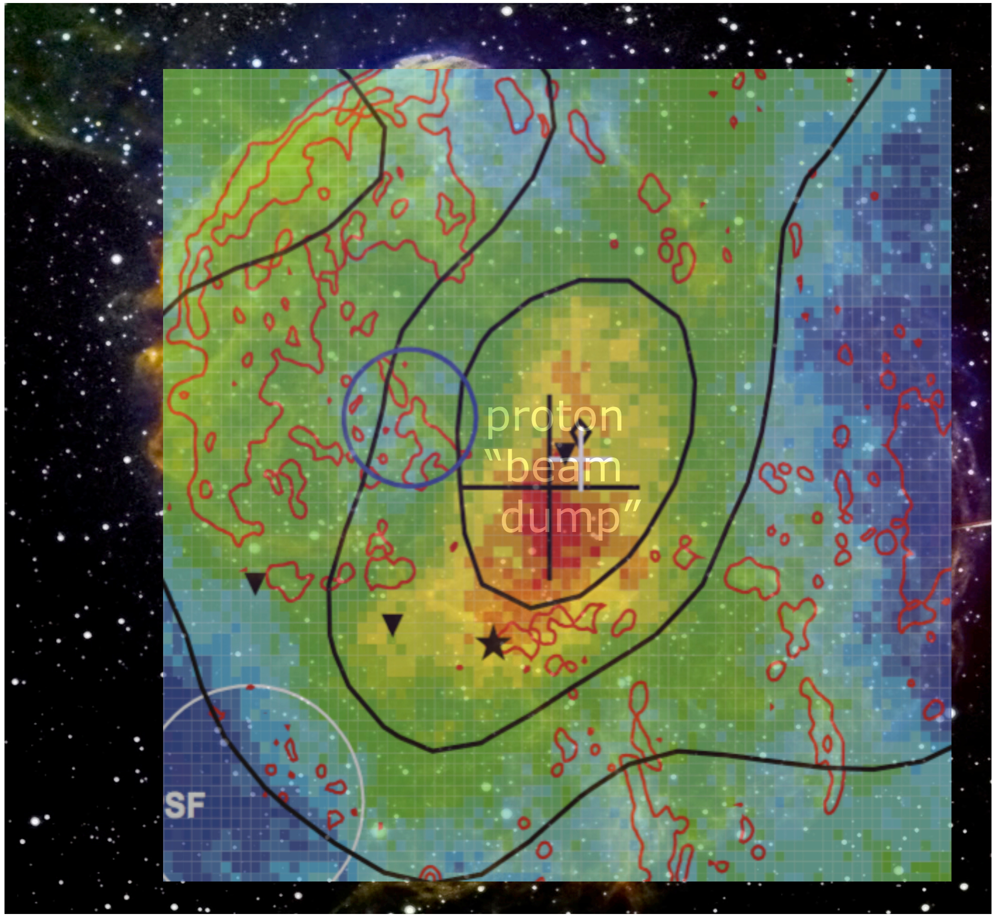
Yet another approach:

Supernovae interacting with molecular clouds



Wardle et al. 2002





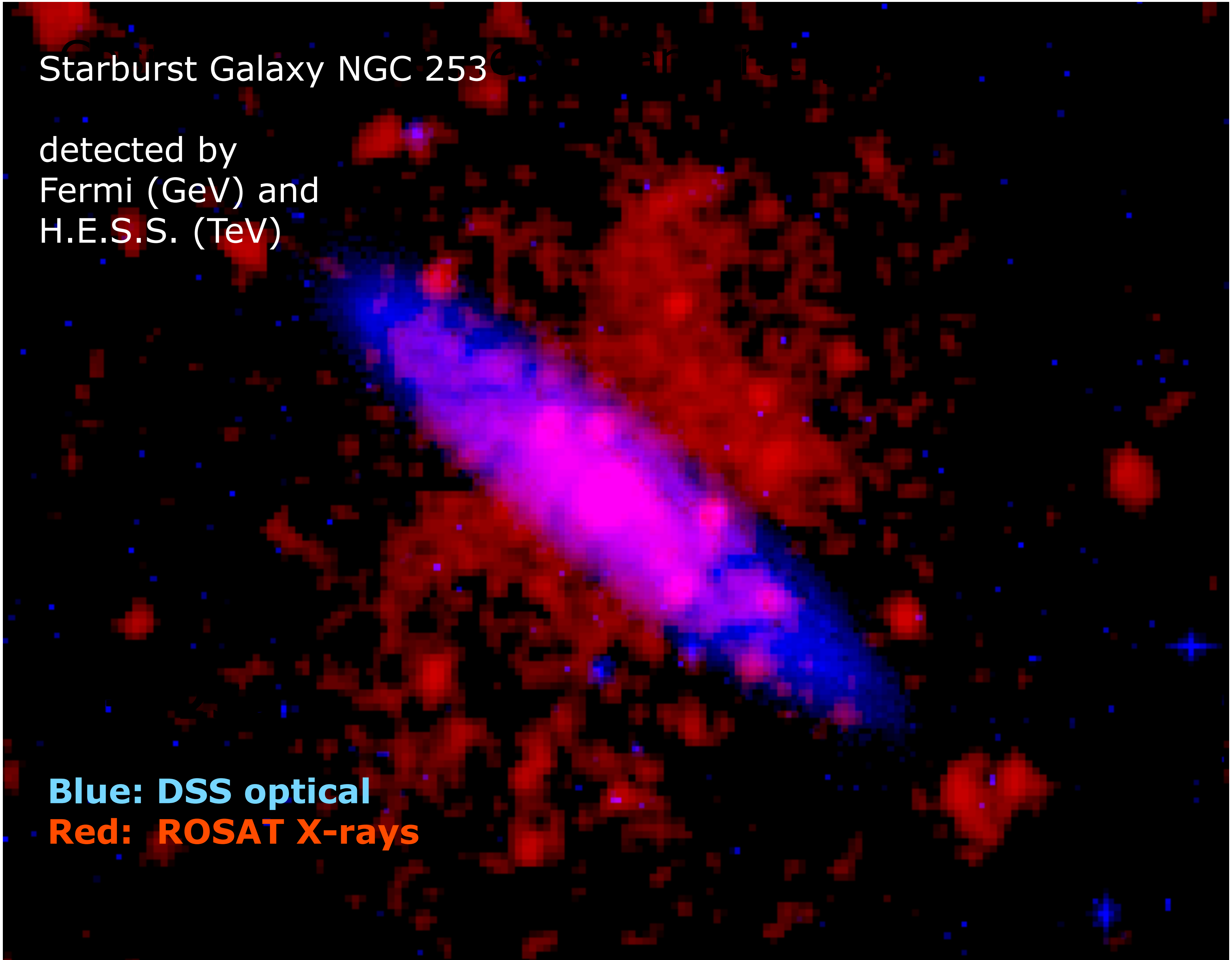
IC 443

MAGIC 2007, arXiv:0705.3119
VERITAS 2007, 2009: arXiv:0905.3291
AGILE 2010:arXiv:1001.5150

Supernovae in other galaxies

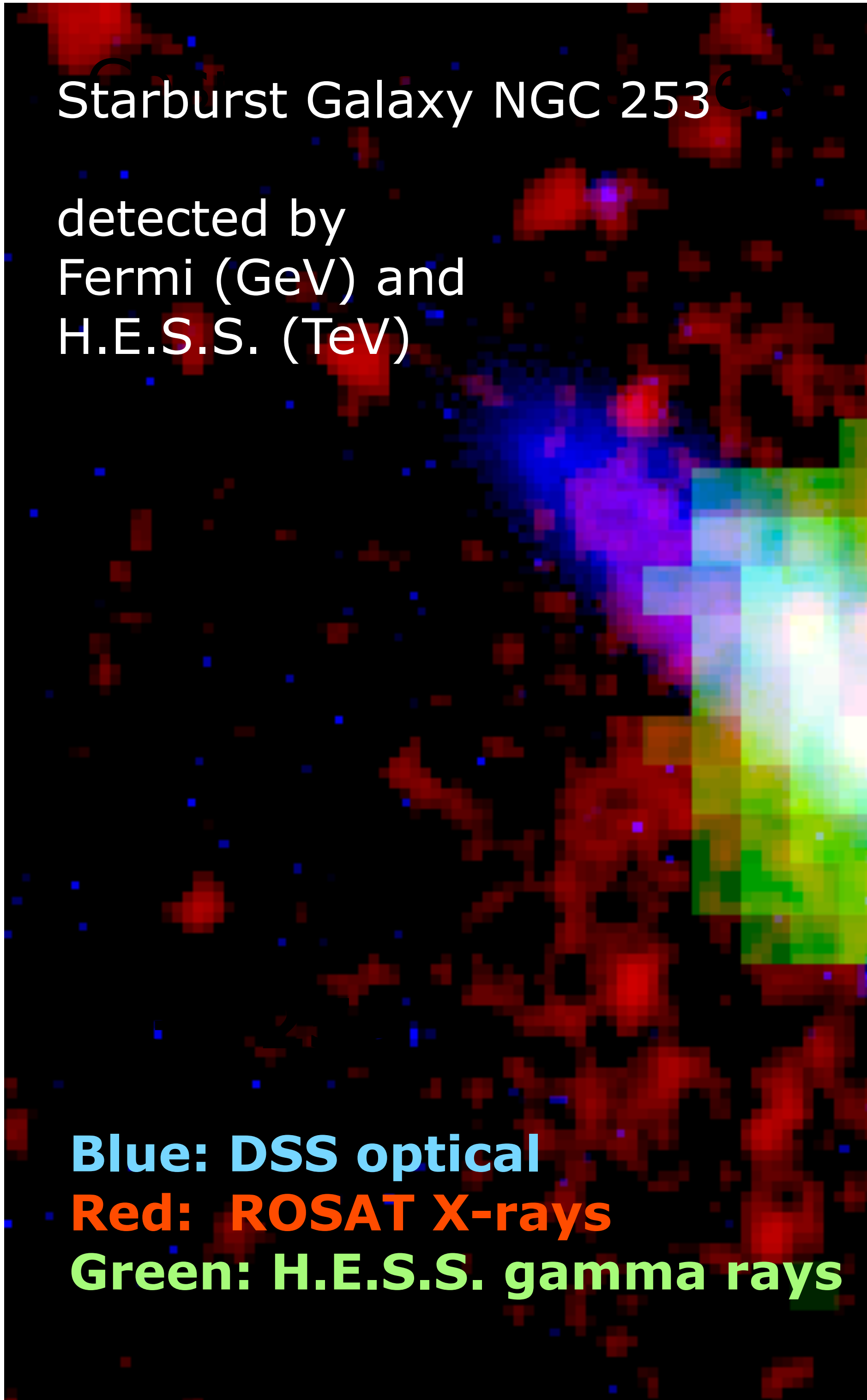
Starburst Galaxy M82

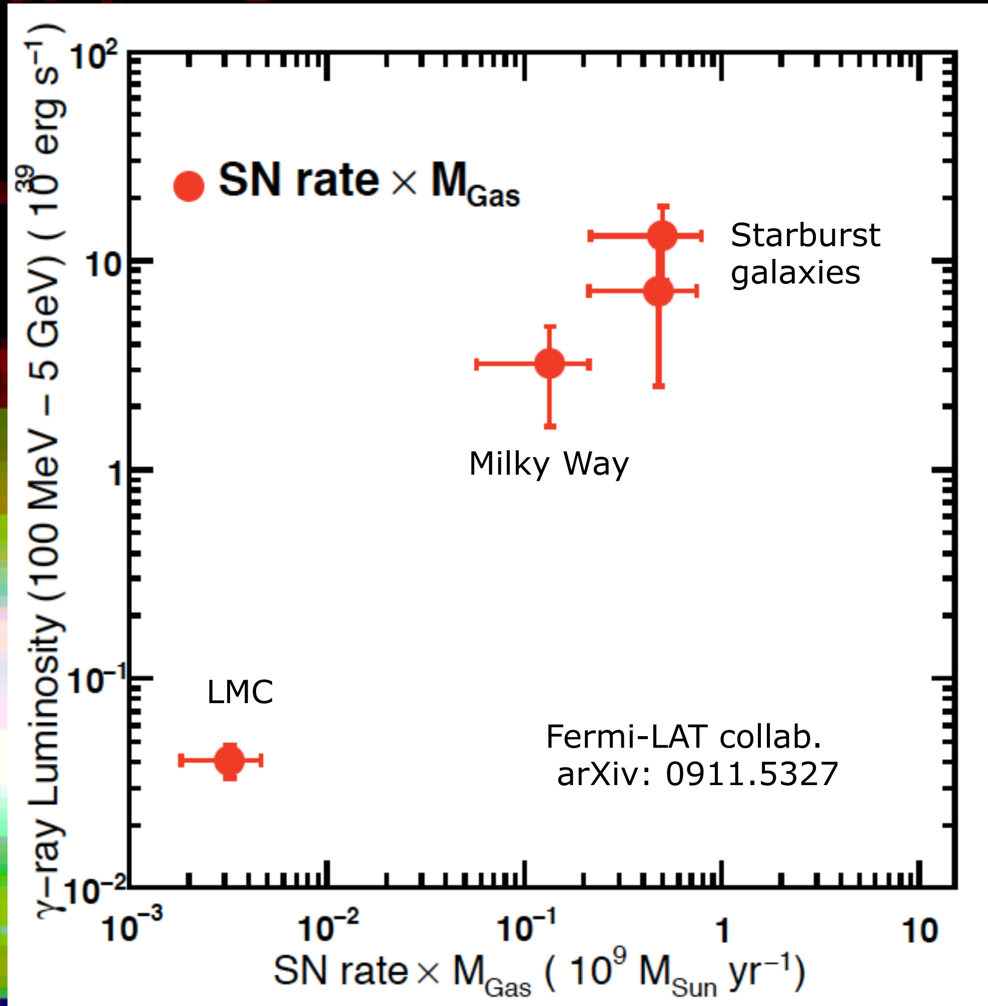
detected by
Fermi (GeV) and
VERITAS (TeV)


Starburst Galaxy NGC 253
detected by
Fermi (GeV) and
H.E.S.S. (TeV)
Blue: DSS optical
Red: ROSAT X-rays

Starburst Galaxy NGC 253

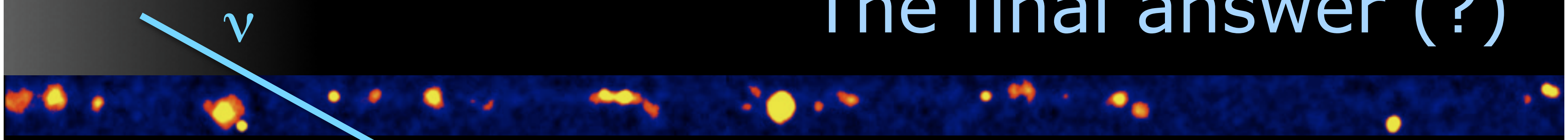
detected by
Fermi (GeV) and
H.E.S.S. (TeV)





Blue: DSS optical
Red: ROSAT X-rays
Green: H.E.S.S. gamma rays

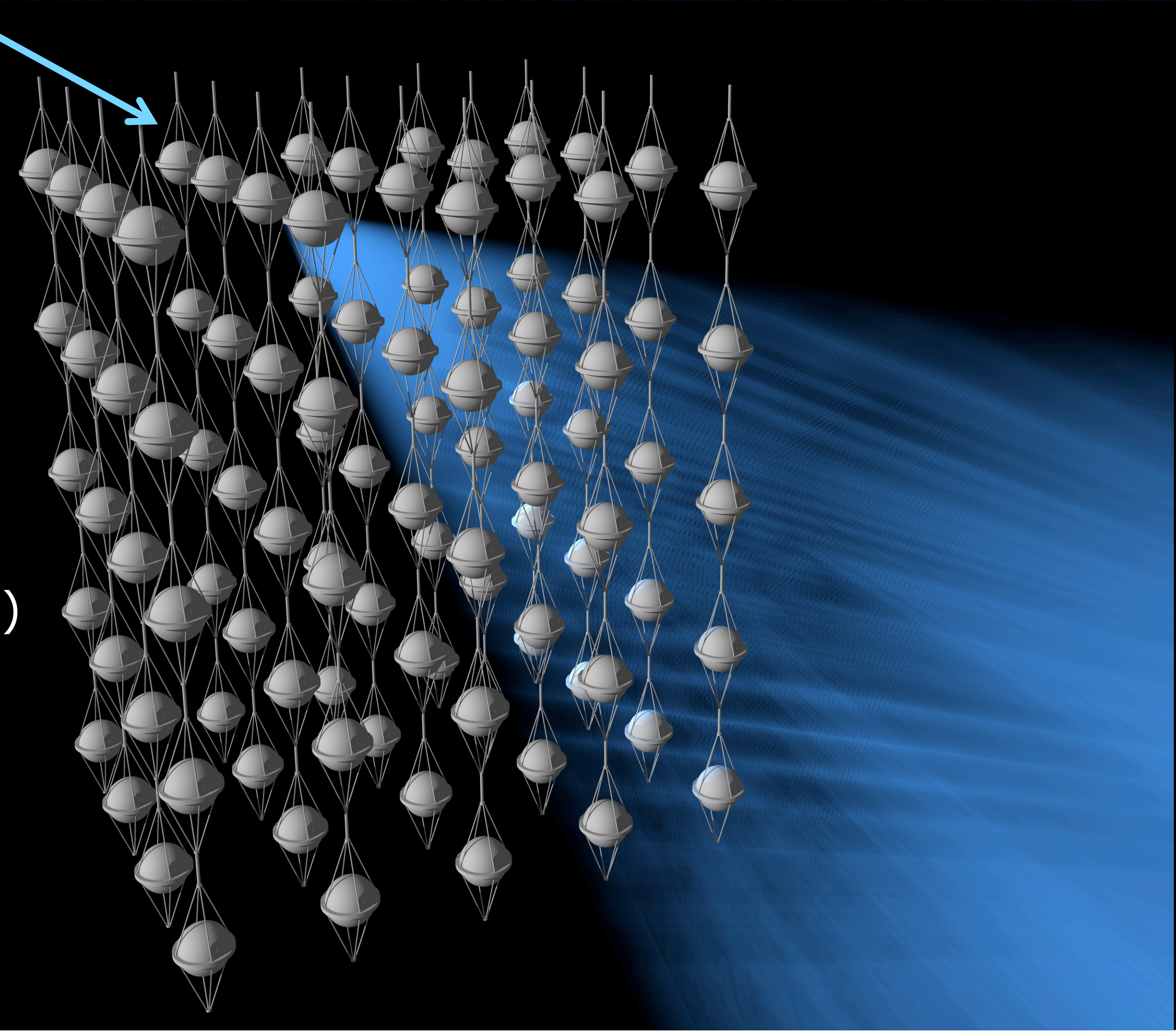
The final answer (?)



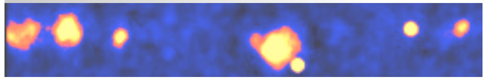
Neutrino detection im km³ detectors using water or ice

Only abundantly accelerated nuclei generate a (barely) detectable VHE neutrino flux

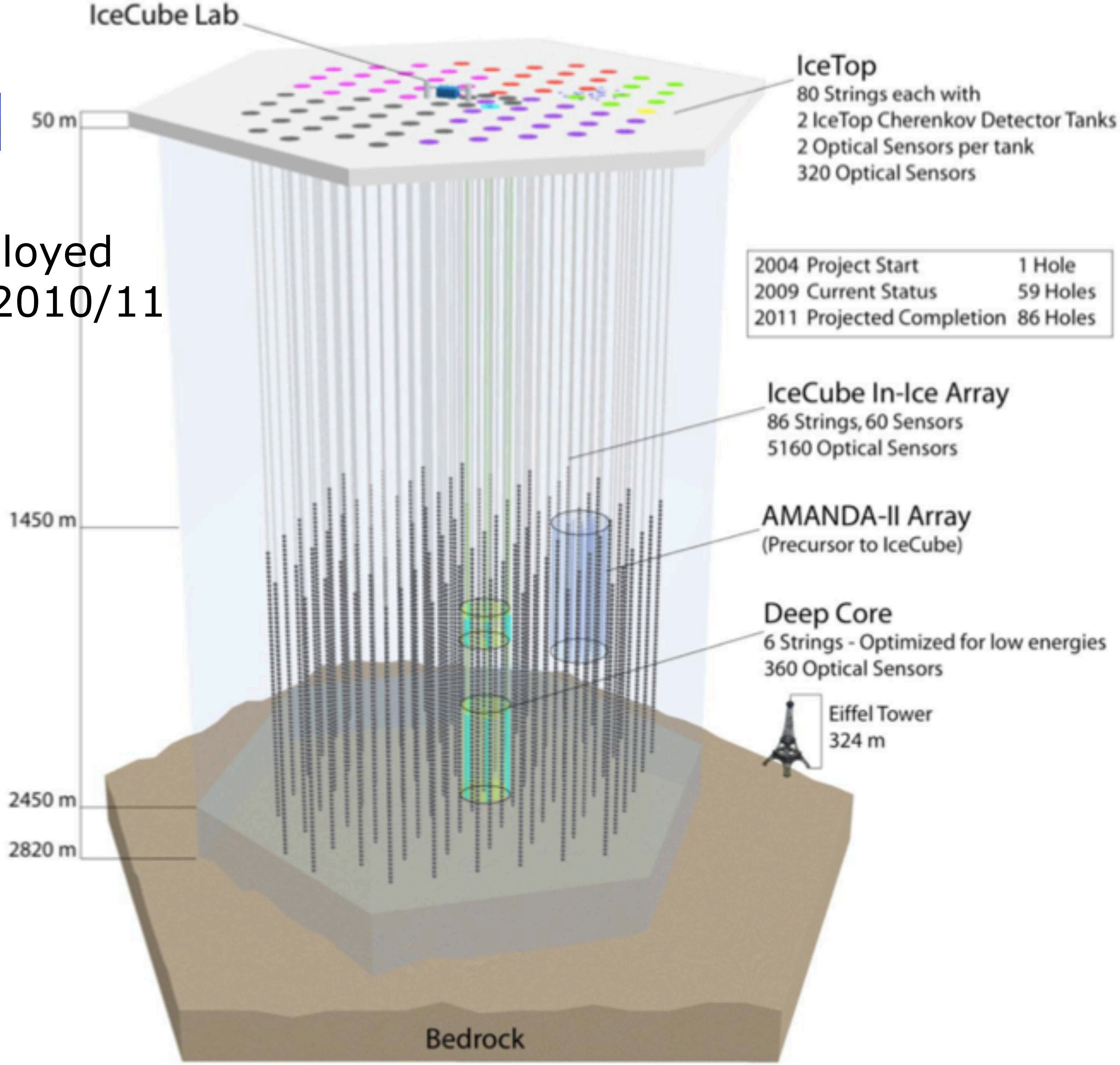
➔ ICECUBE
➔ KM3NET



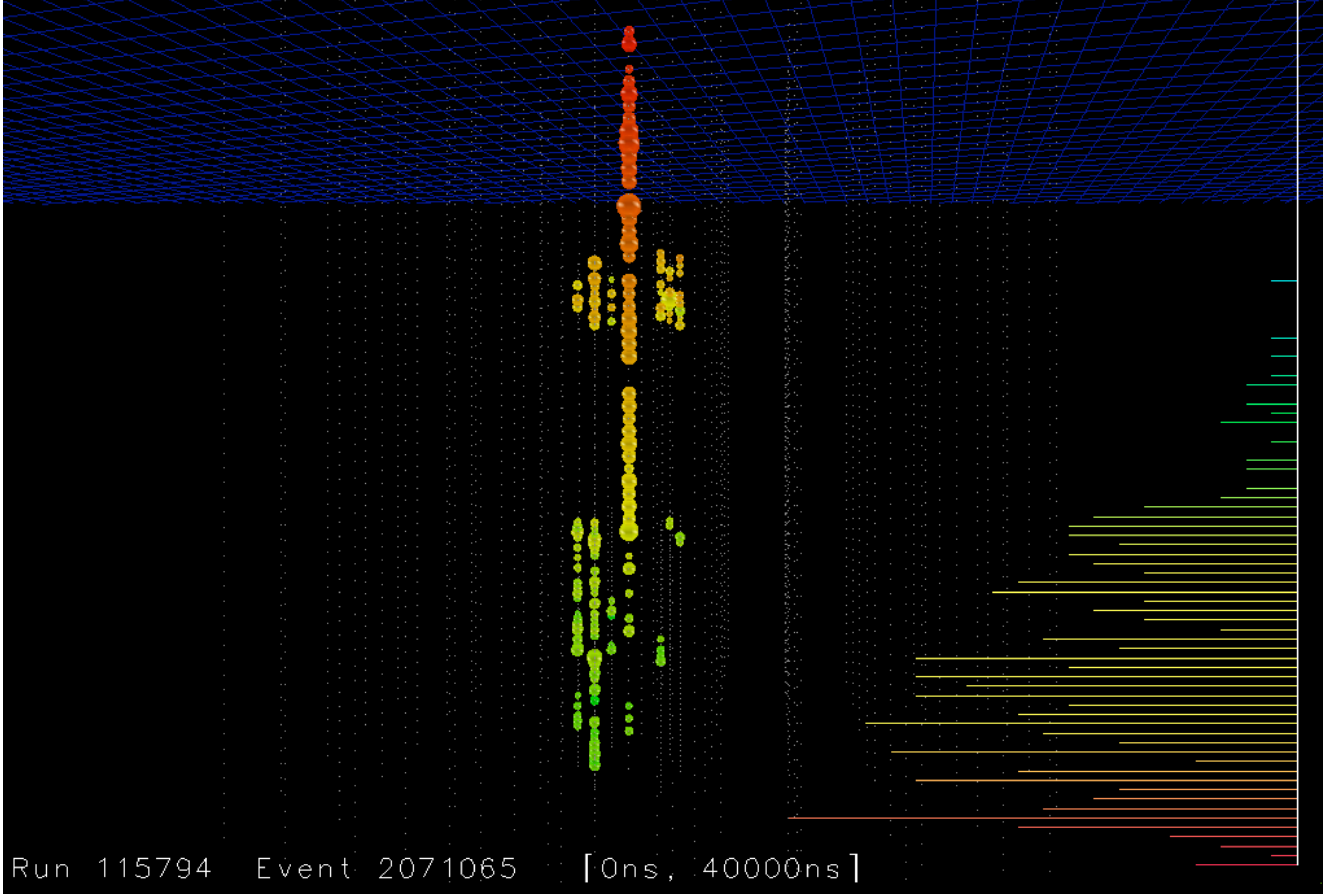
IceCube



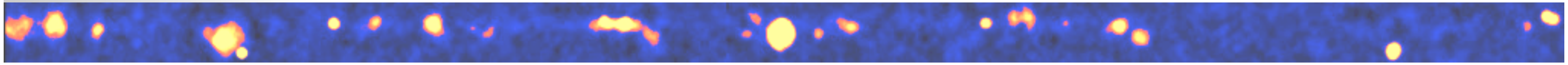
79 strings deployed
last 7 strings 2010/11



Muon in IceCube Deep Core

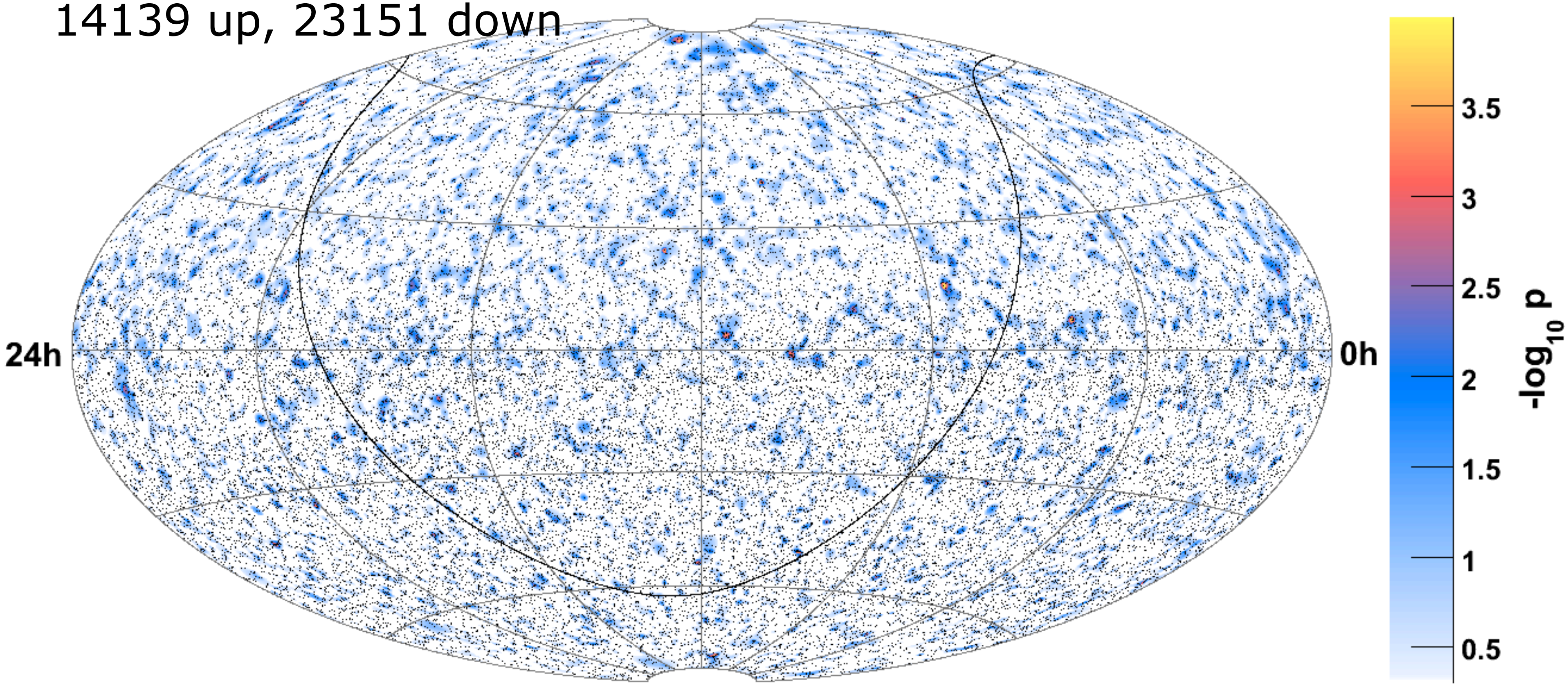


IC 40 Neutrino Sky



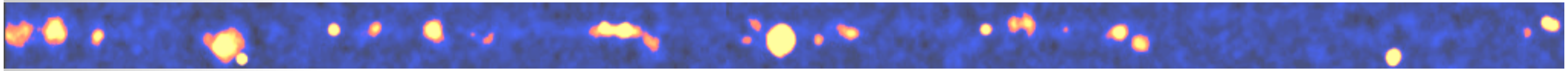
40 strings
375 days live
37290 Events
14139 up, 23151 down

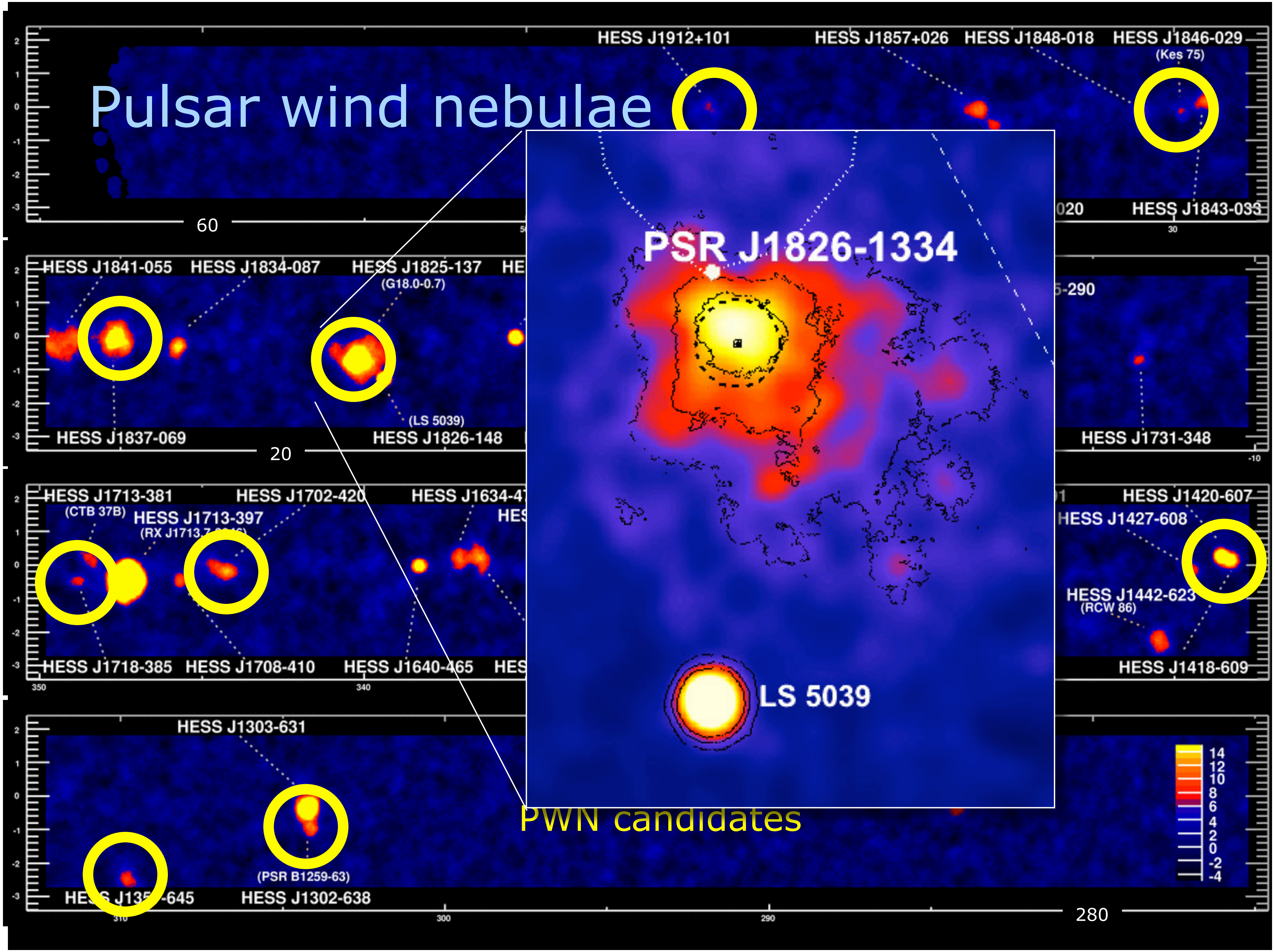
Full sky!



Sensitive above TeV energies

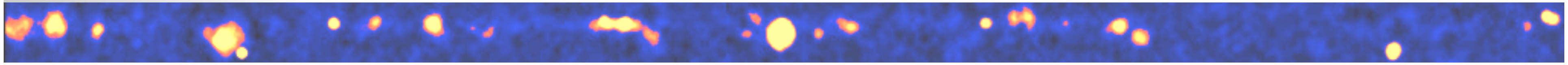
The "other" gamma ray sources

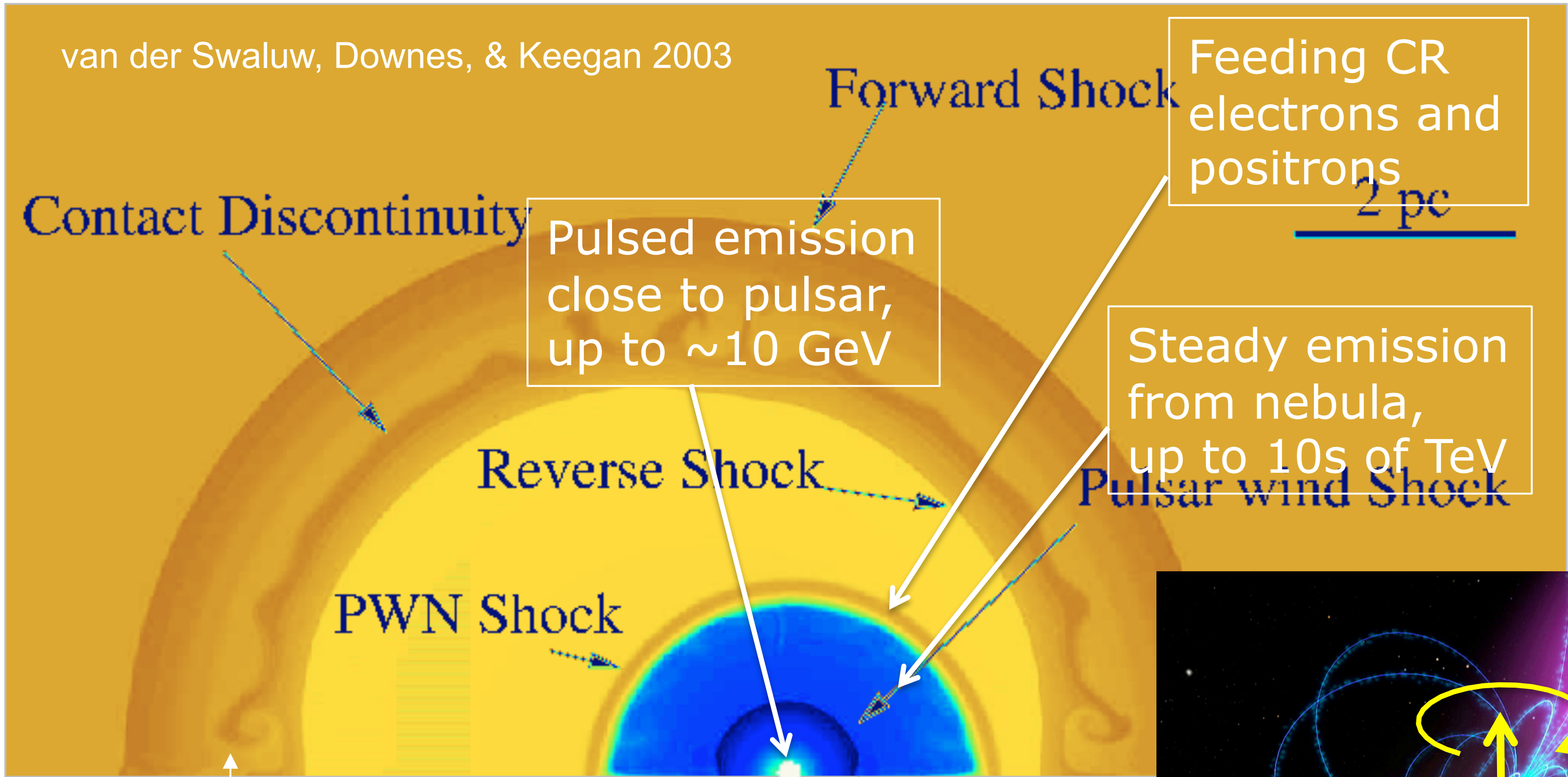


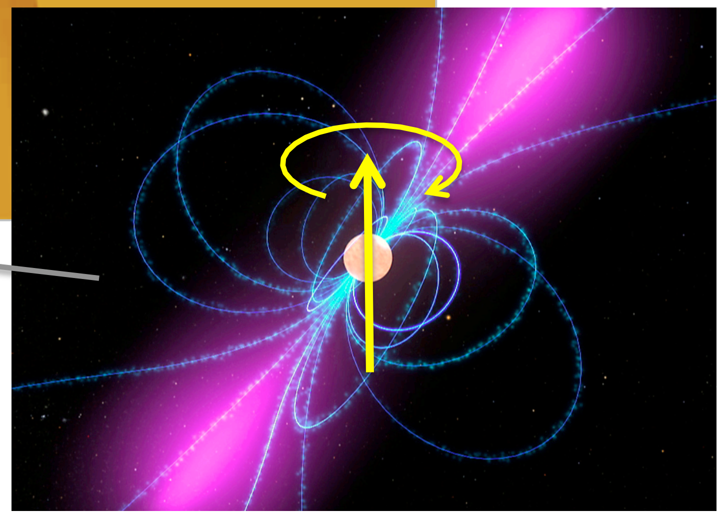


Pulsar wind nebulae
PWN candidates
PSR J1826-1334
LS 5039
HESS J1912+101
HESS J1857+026
HESS J1848-018
HESS J1846-029
(Kes 75)
HESS J1843-033
HESS J1841-055
HESS J1834-087
HESS J1825-137
(G18.0-0.7)
HESS J1837-069
(LS 5039)
HESS J1826-148
HESS J1731-348
HESS J1713-381
(CTB 37B)
HESS J1713-397
HESS J1702-420
HESS J1718-385
HESS J1708-410
HESS J1640-465
HESS J1420-607
HESS J1427-608
HESS J1442-623
(RCW 86)
HESS J1418-609
HESS J1303-631
(PSR B1259-63)
HESS J1302-638
60
20
280

Pulsar wind nebulae – why so many?



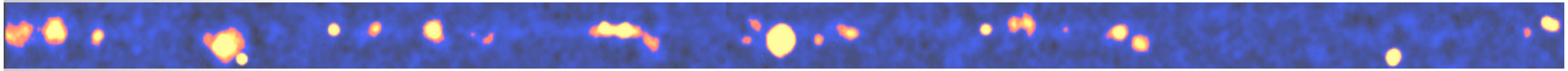




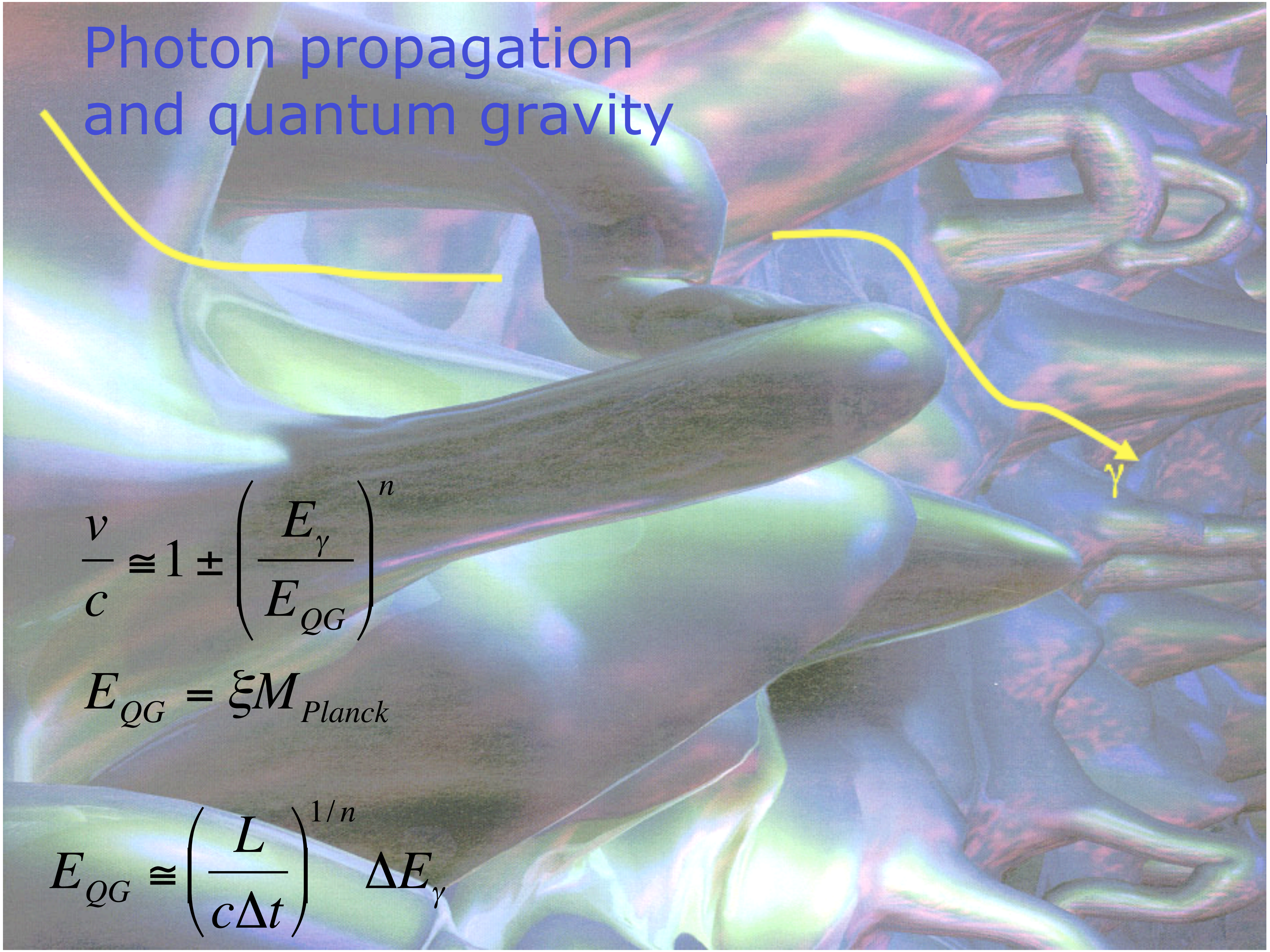
SN shock accelerates particles for O(1 ky)

Pulsar sustains pulsar wind nebula for O(100 ky)

back to extragalactic sources: Probing Lorentz invariance at high energies



Photon propagation and quantum gravity

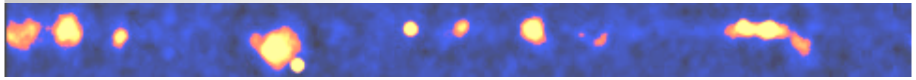


$$\frac{v}{c} \cong 1 \pm \left(\frac{E_\gamma}{E_{QG}} \right)^n$$

$$E_{QG} = \xi M_{Planck}$$

$$E_{QG} \cong \left(\frac{L}{c\Delta t} \right)^{1/n} \Delta E_\gamma$$

GRB 090510



$$\frac{v}{c} \cong 1 \pm \left(\frac{E_\gamma}{E_{QG}} \right)^n$$

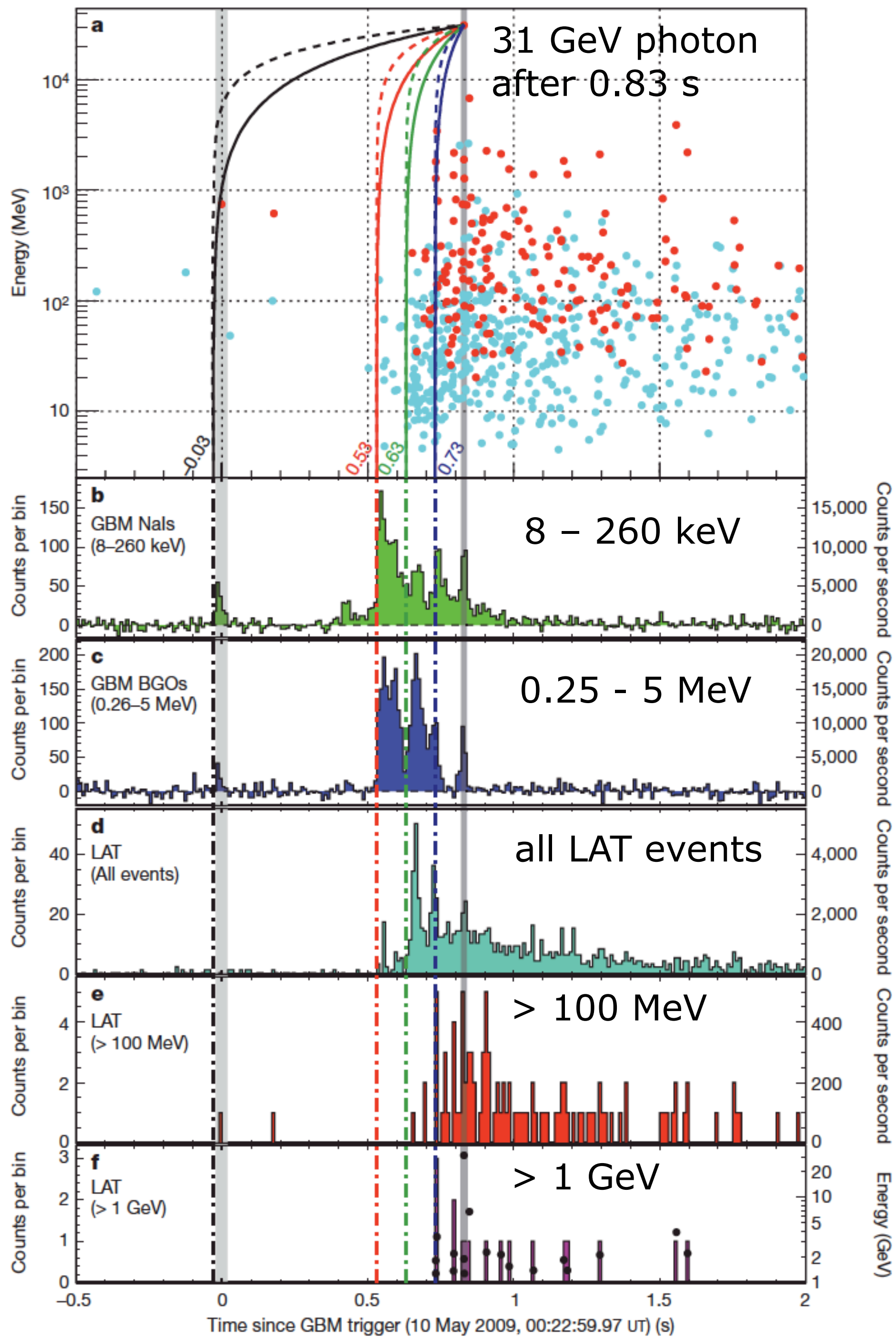
$$E_{QG} = \xi M_{Planck}$$

for n=1:

$$\xi > 1.2$$

GRB 090510
z = 0.903

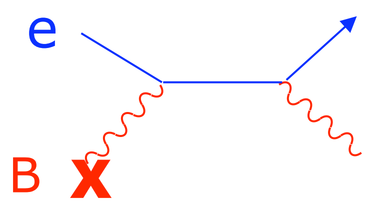
Abdo et al.
Fermi LAT Collab.
Nature 2009



for quadratic dispersion n=2,
mass scale >10^9 GeV
(H.E.S.S., arXiv:0810.3475,
MAGIC, arXiv:0708.2889)

More kinematic effects …

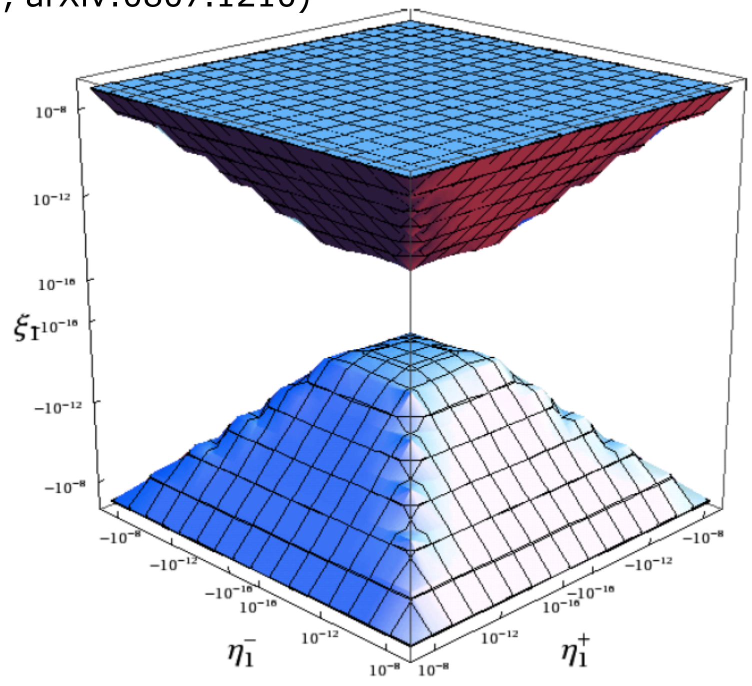
- Synchrotron emission is modified
- GZK cutoff is modified
- UHE photon absorption is modified



Synchrotron emission, Crab Nebula: $\xi > 10^5$ (Maccione et al., arXiv:0707.2673)
UHE CR: $\xi > 10^3$ (Maccione et al., arXiv:0902.1756)
Lack of UHE photons $\xi > 10^6$ (Galaverni & Sigl, arXiv:0807.1210)

But: more model dependence

- multiple correlated LV parameters for e, γ, p
- in some models propagation and interactions decouple (Ellis et al., arXiv: 1004.4167)




Status and Perspective
of Astroparticle Physics in Europe
ASPERA
Astroparticle Physics Roadmap Phase I
ApPEC
ASPERA


ASTROPARTICLE PHYSICS
the European strategy
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