HIGH ENERGY COSMIC AND GAMMA RAYS

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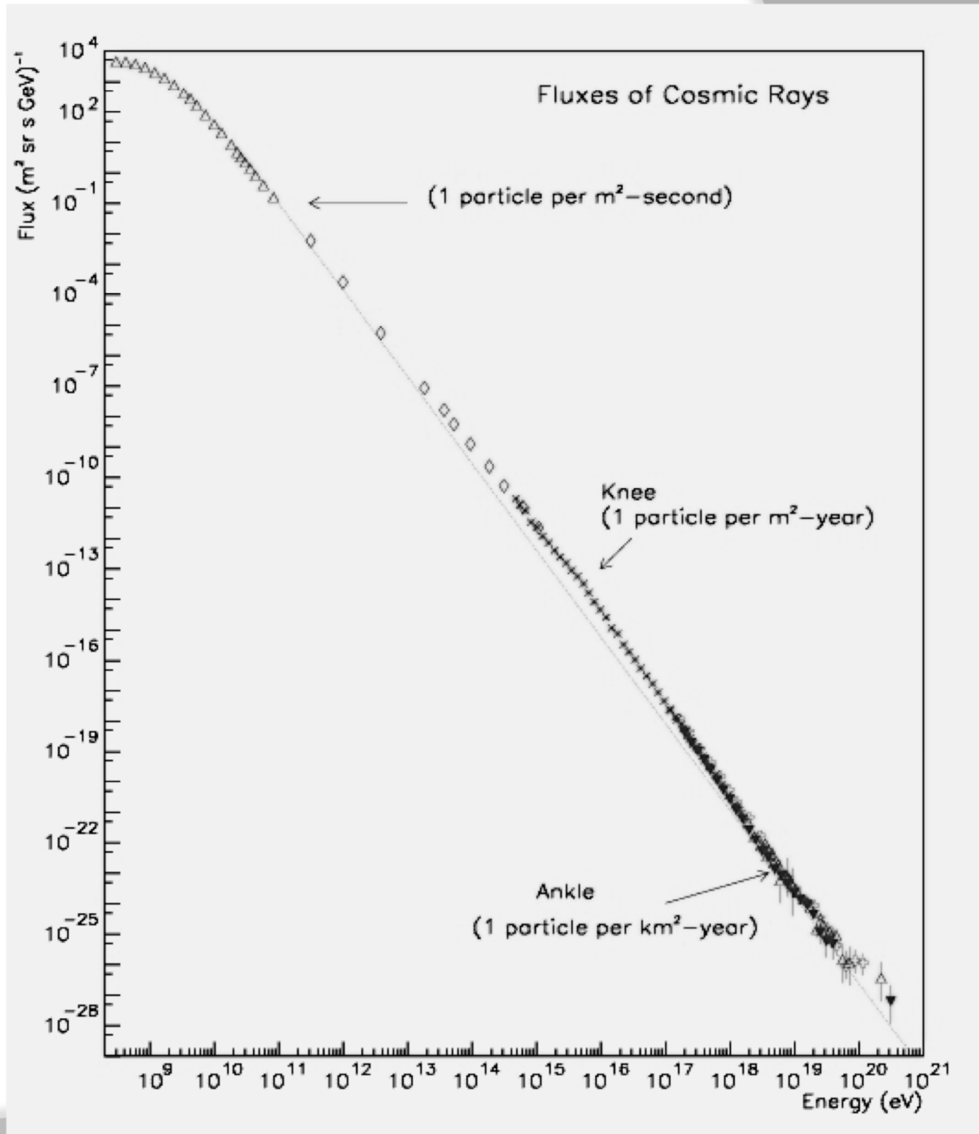
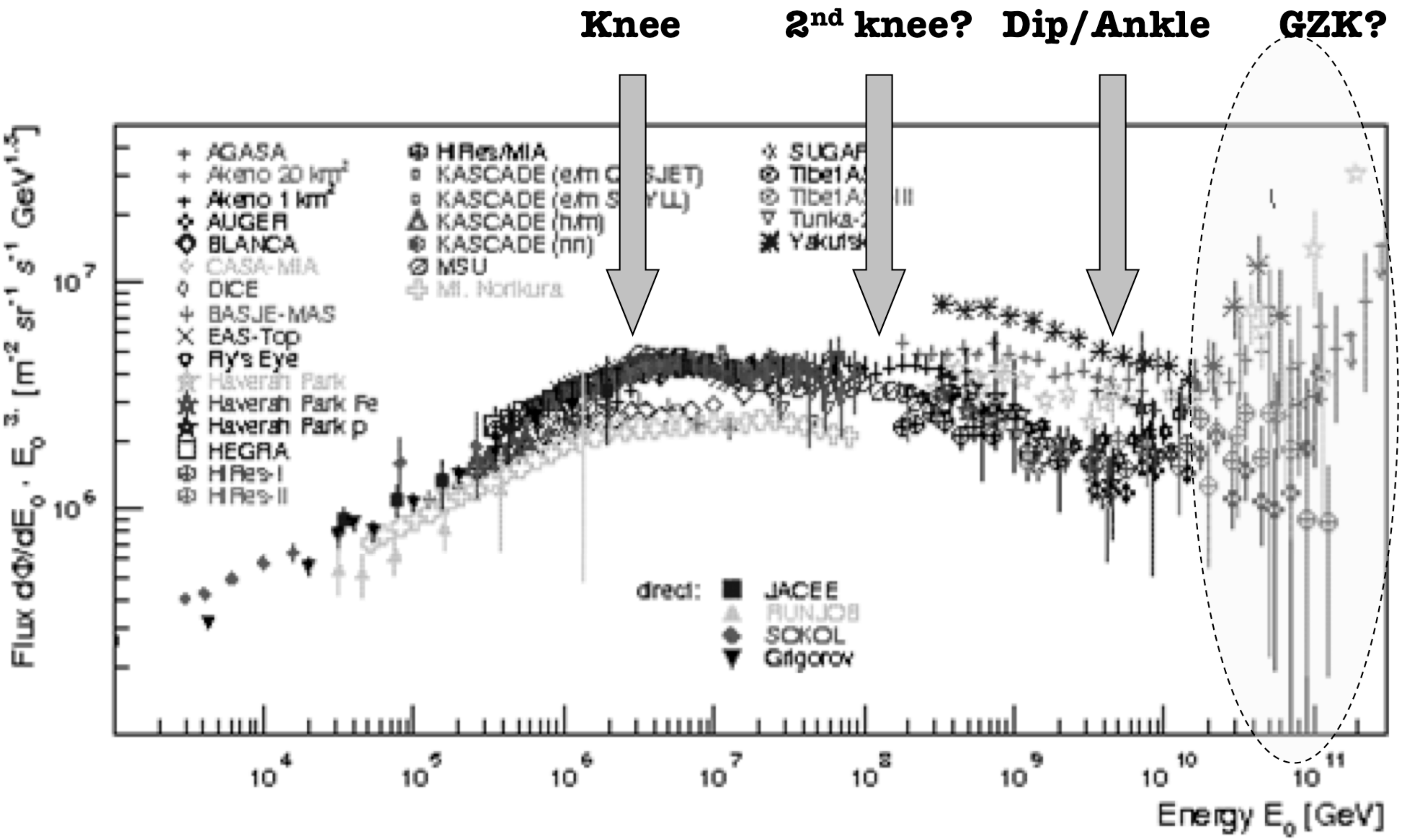
Cosmic Ray Energy Spectrum

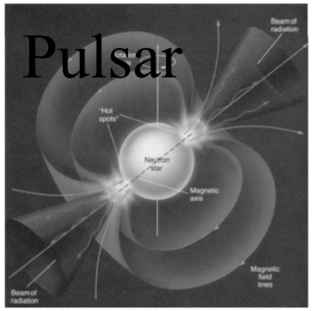
- Cosmic Rays
  - 10^{8}eV ~10^{20}eV
- Power law spectrum
  - $\propto E^{-2.7}$ $E<10^{15.5}$eV
  - $\propto E^{-3.1}$ $E>10^{15.5}$eV
  - $\propto E^{-2.7}$ $E>10^{18.5}$eV
- Major components
  - P, He, ,,,, Fe
  - Anti-p, e^-, e^+

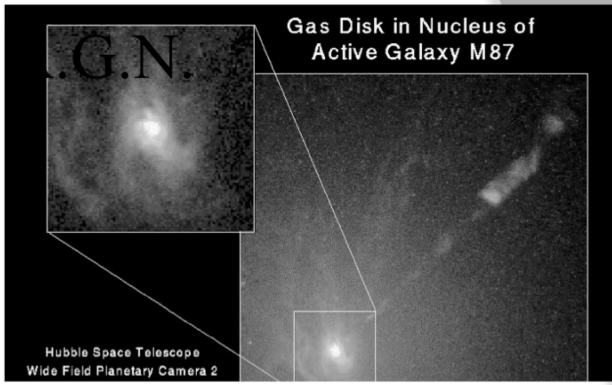


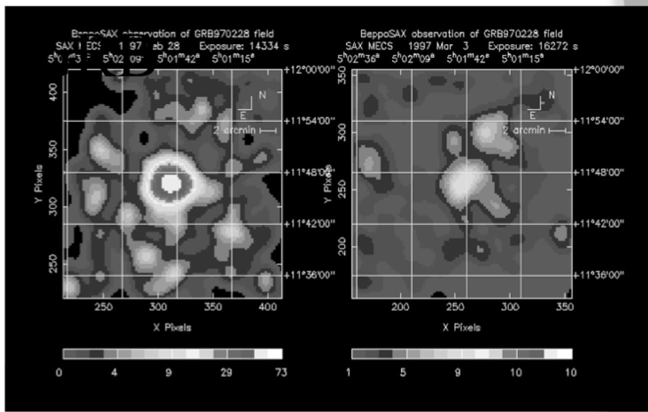
X E^3 Spectrum

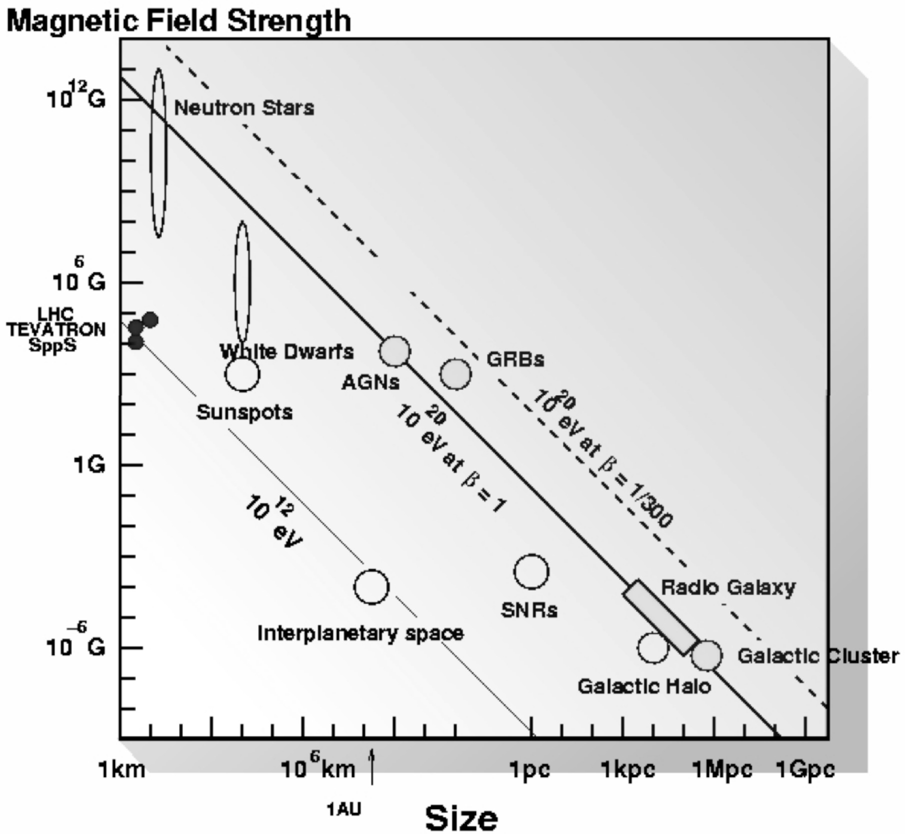


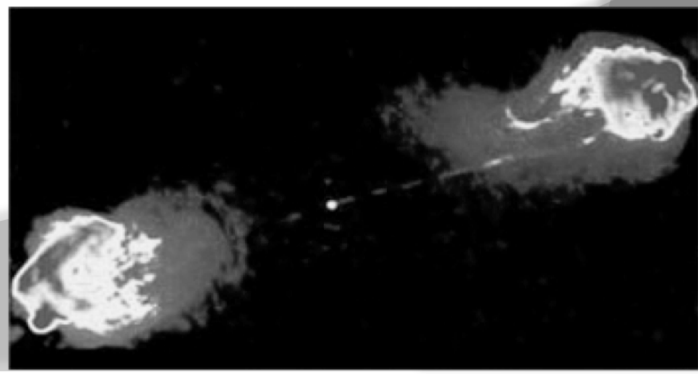
Cosmic Ray accelerators

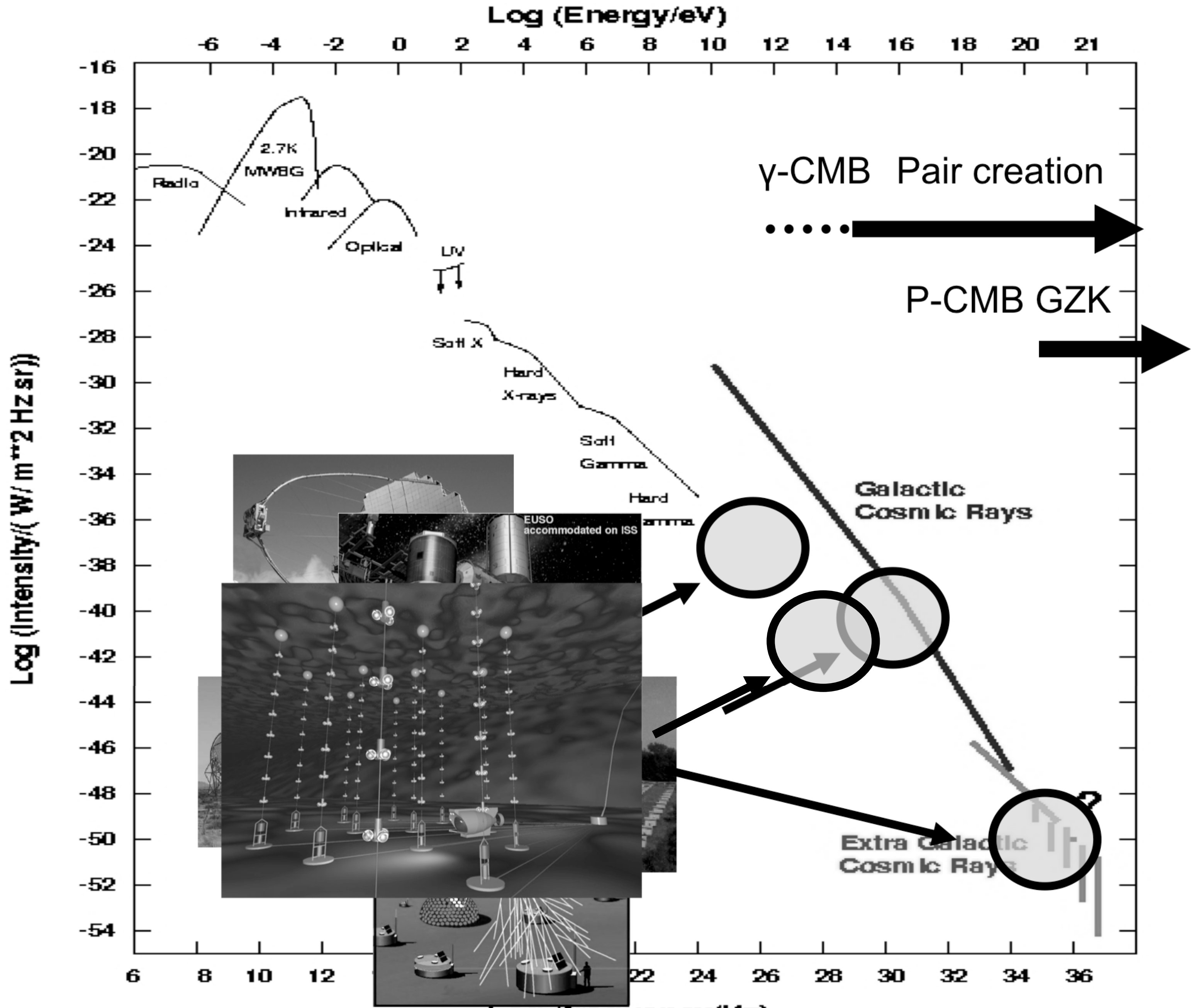










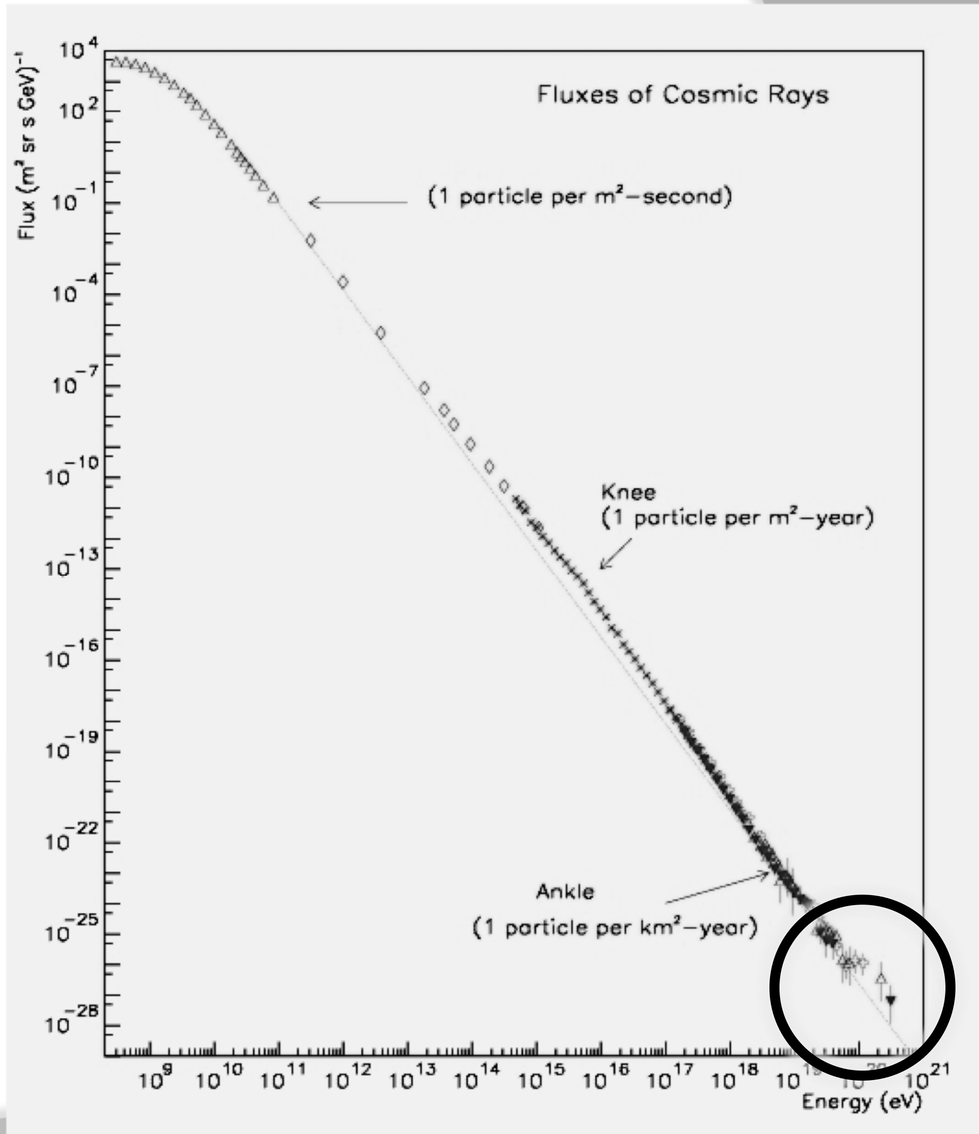


Log (Energy/eV)
-6 -4 -2 0 2 4 6 8 10 12 14 16 18 20 21
Log (Intensity/(W/ m**2 Hz sr))
-16 -18 -20 -22 -24 -26 -28 -30 -32 -34 -36 -38 -40 -42 -44 -46 -48 -50 -52 -54
Radio
2.7K MWBG
Infrared
Optical
UV
Soft X
Hard X-rays
Soft Gamma
Hard
γ-CMB Pair creation
P-CMB GZK
Galactic Cosmic Rays
Extra Galactic Cosmic Rays
?
EUSO accommodated on ISS
6 8 10 12 22 24 26 28 30 32 34 36
Log (frequency/Hz)

ULTRA HIGH ENERGY COSMIC RAYS

Cosmic Ray Energy Spectrum

- There is a special interest at the highest energy
  - Extreme energy of 10^{20}eV
  - Extragalactic origin
    - Where are they produced?
  - Big accelerator?
    - How are they accelerated?
  - Energy loss due to pion production with CMB
    - GZK effect > 6×10^{19}eV
    - L <100Mpc
  - Energy loss due to pair creation with CMB
    - Pair creation >10^{18}eV
    - L <1.5Gpc
  - High rigidity ➔ Astronomy with UHECRs
- Flux is extremely low
  - ~ 1 / 1000km^2 sr yr, >10^{20}eV



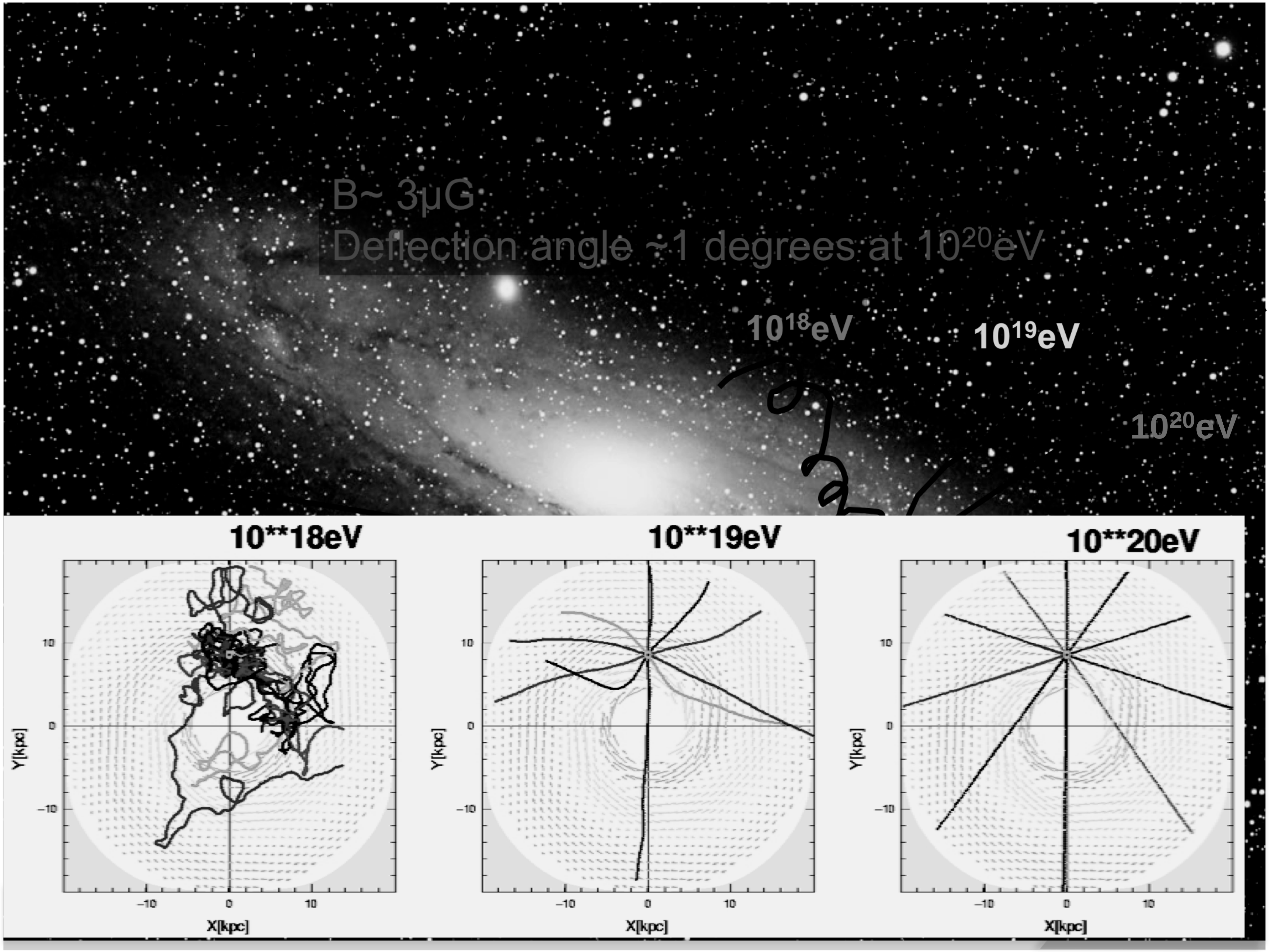
Some stupid calculation Universe is 10^{20}eV Collider

- Flux is extremely low, but
- ~ 1 particle/min on the entire Earth
  - No phase transition of the vacuum at 100TeV @cms in the Earth

- 10^{20}eV CRs are universal in the Universe, p-p collision is possible at an extreme energy (10^{20}eVx10^{20}eV)
  - P(10^{20}eV) $\rho \sim 10^{-25} m^{-3}$
  - Interaction rate of P(10^{20}eV) x P(10^{20}eV)
    - $c \times \rho^2 \times \sigma \sim 10^{-72}\ m^{-3}\ s^{-1}$
  - Volume of universe L~ 10^{26}m, V ~$10^{78} m^3$
  - Event Rates ~ 10^6 per Universe s^{-1} ~MHz
  - Total ~10^{24} collisions per Universe (in 13Byr)

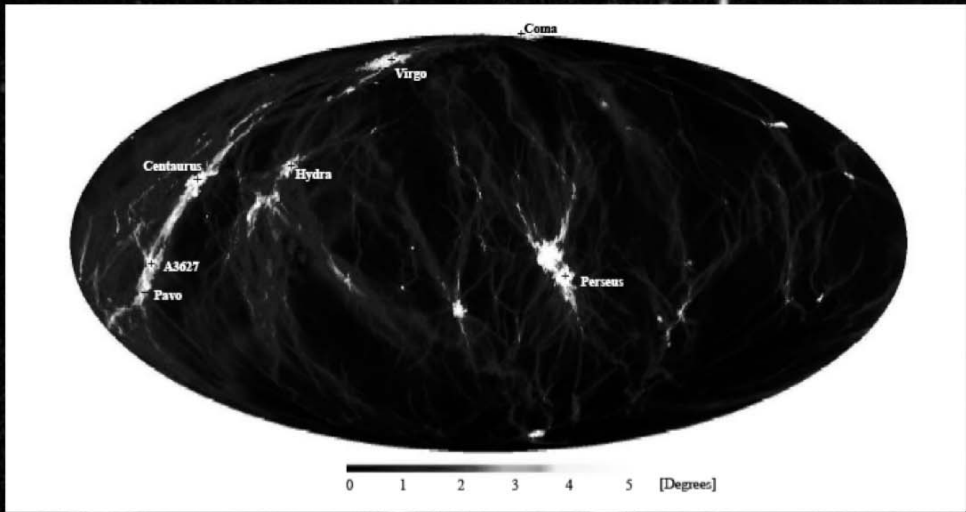
- Universe seems to be stable
  - Even if you build the 10^{20}eV collider in future, you have no chance to test the phase transition of the vacuum

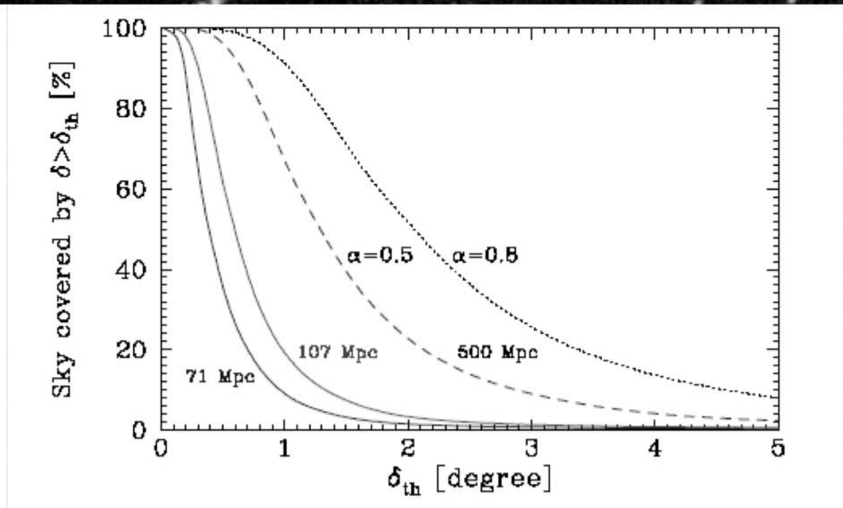
- Do calculation by yourself!!


B~ 3μG
Deflection angle ~1 degrees at 10^20eV
10^18eV
10^19eV
10^20eV
10**18eV
10**19eV
10**20eV
Y[kpc]
X[kpc]
10
0
−10

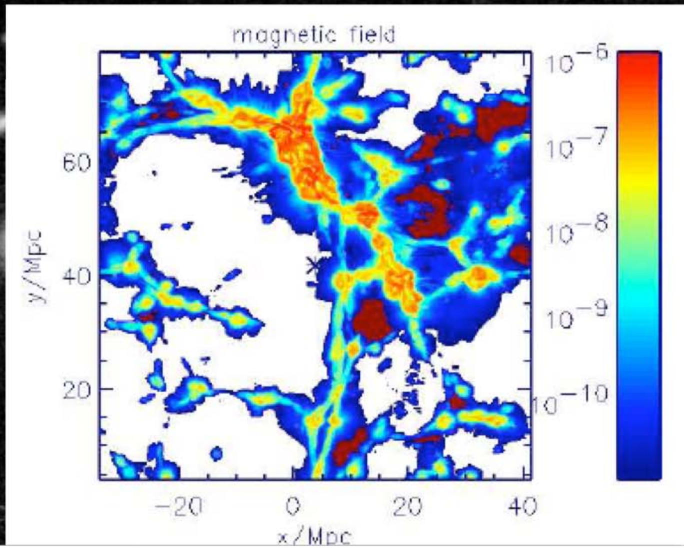
Deflection in the intergalactic space

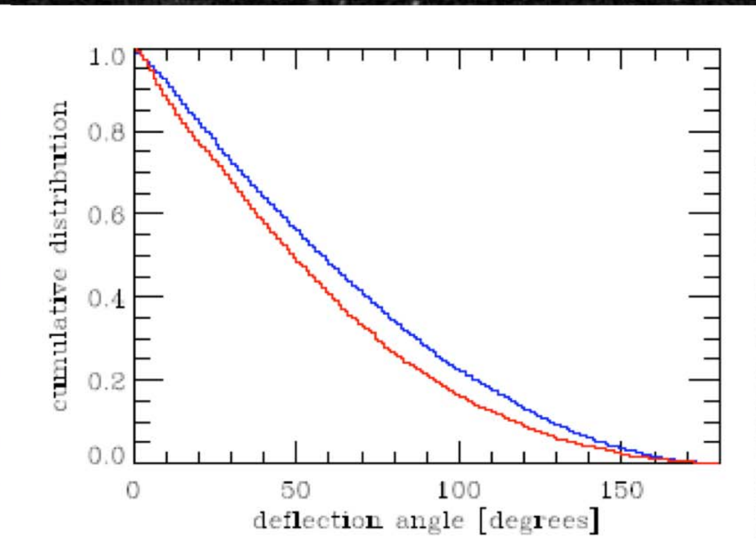
K. Dolag, D. Grasso, V. Springel and I. Tkachev





By Sigl et al.



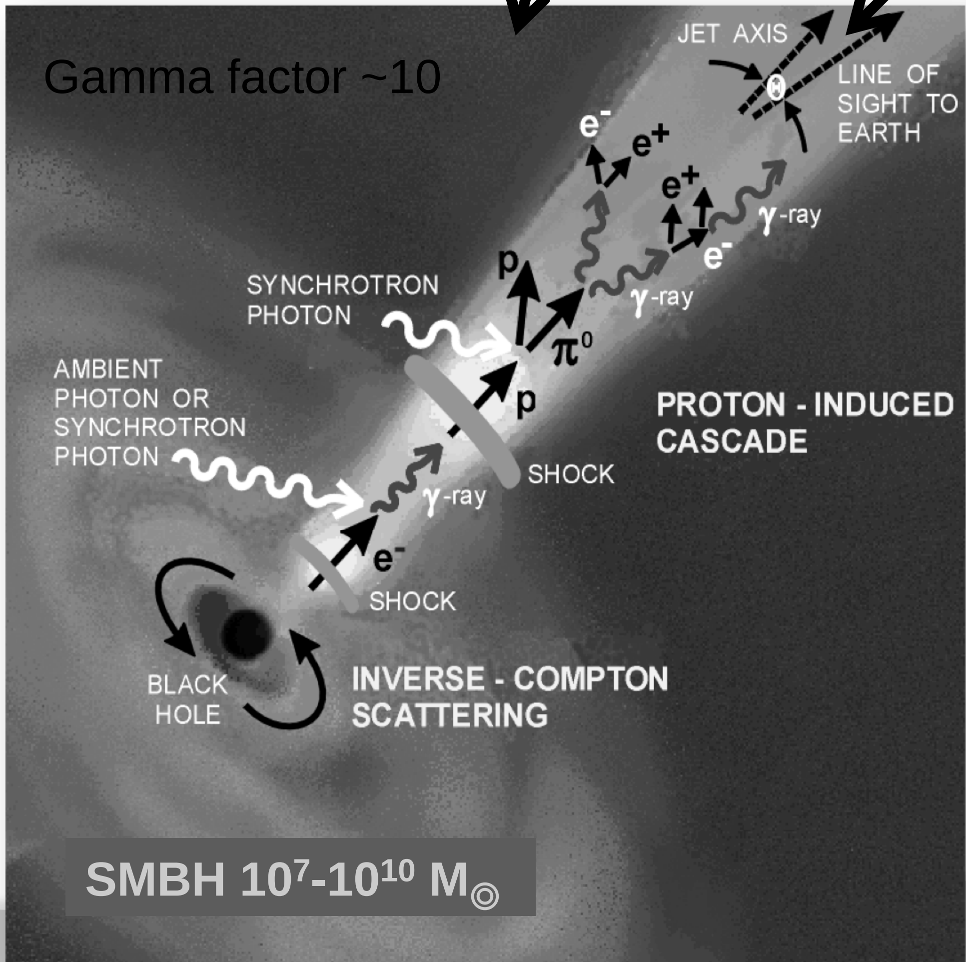


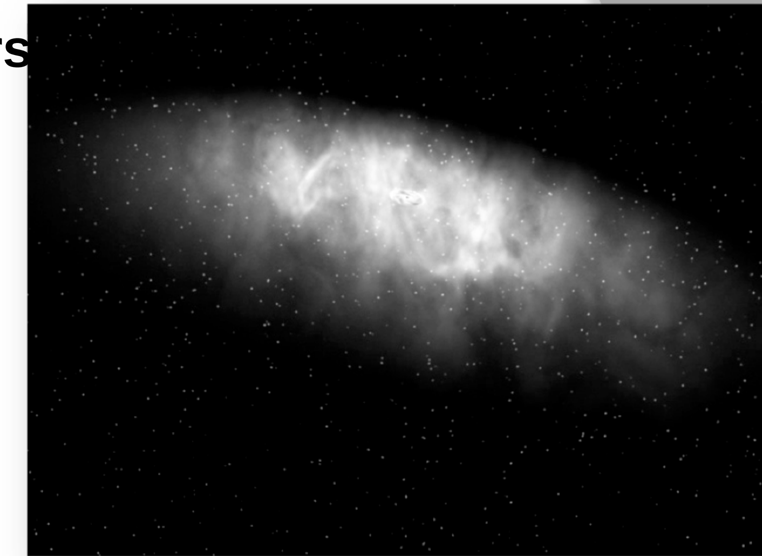
Hubble Deep Field
Looking at one suc
of the sky.
1996/01/

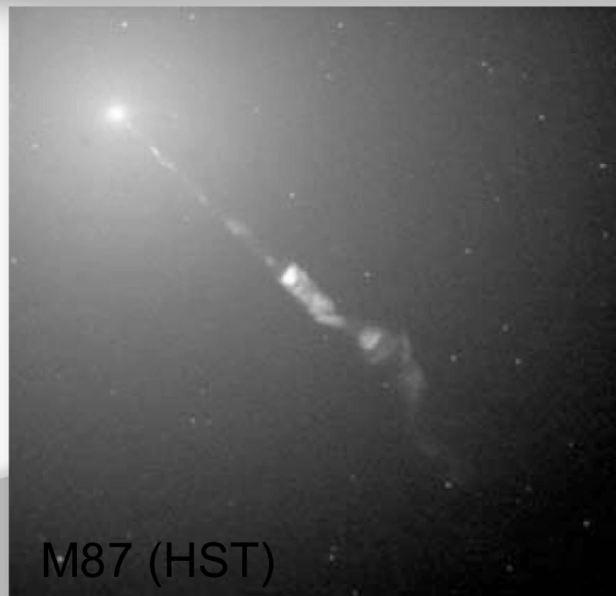
Cosmic Ray accelerator
Active Galactic Nuclei

FRI, FRII

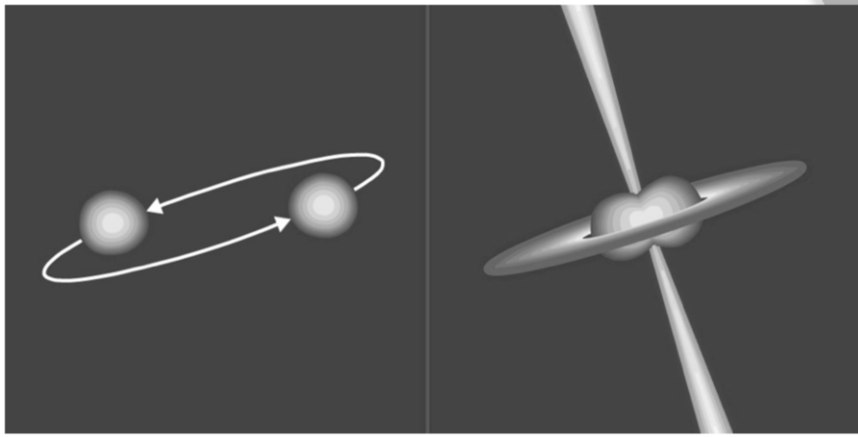
Blazars



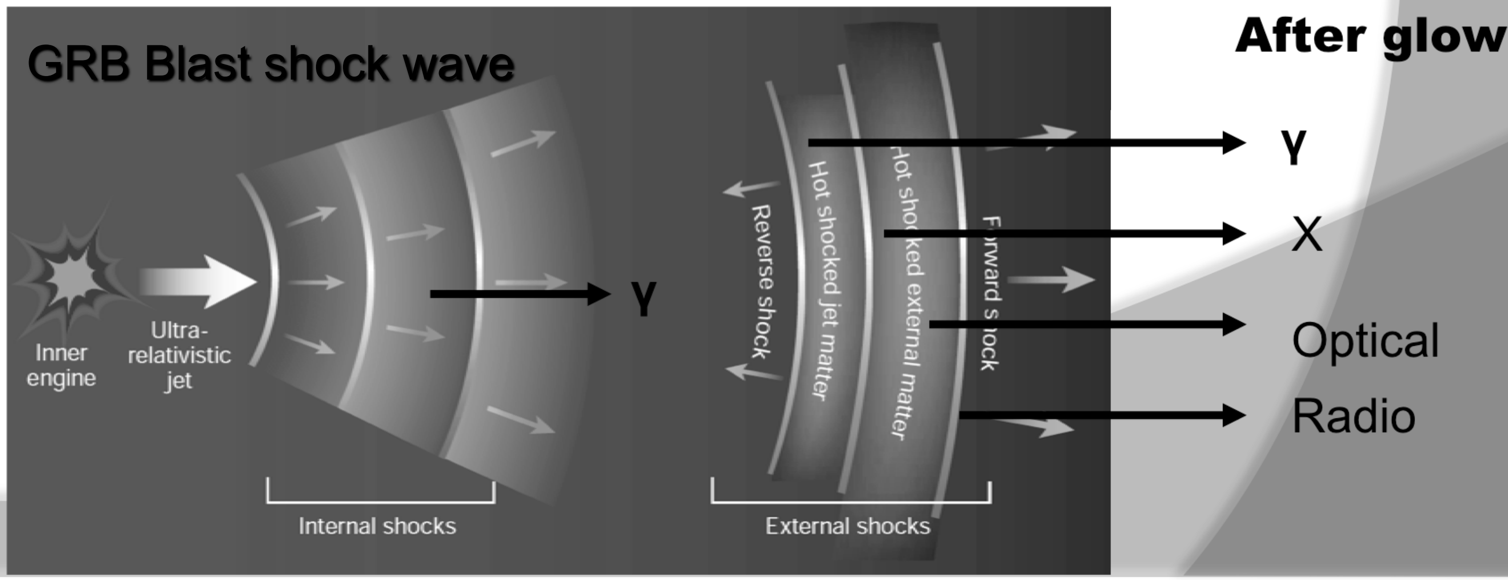


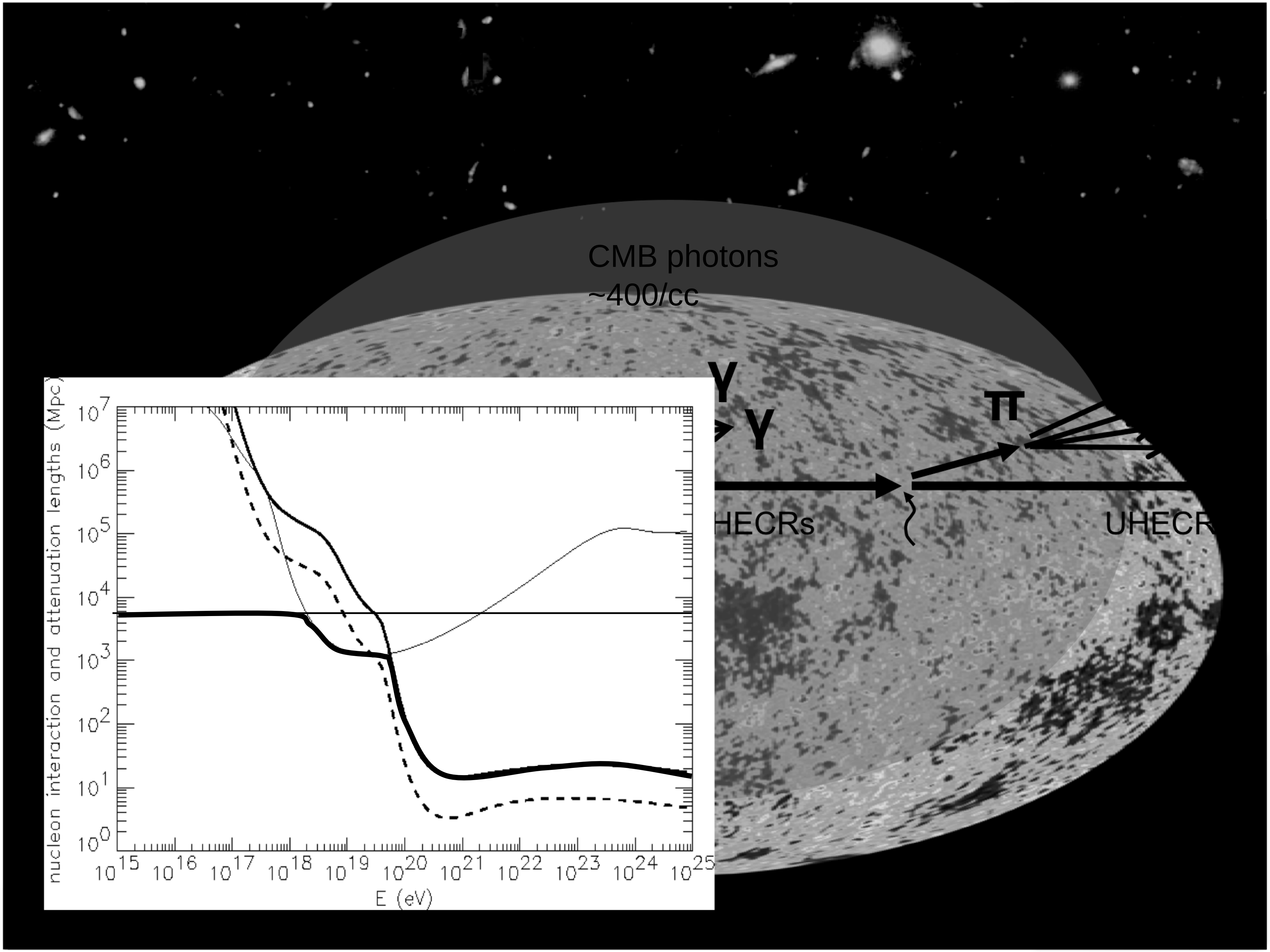


Gamma ray bursts

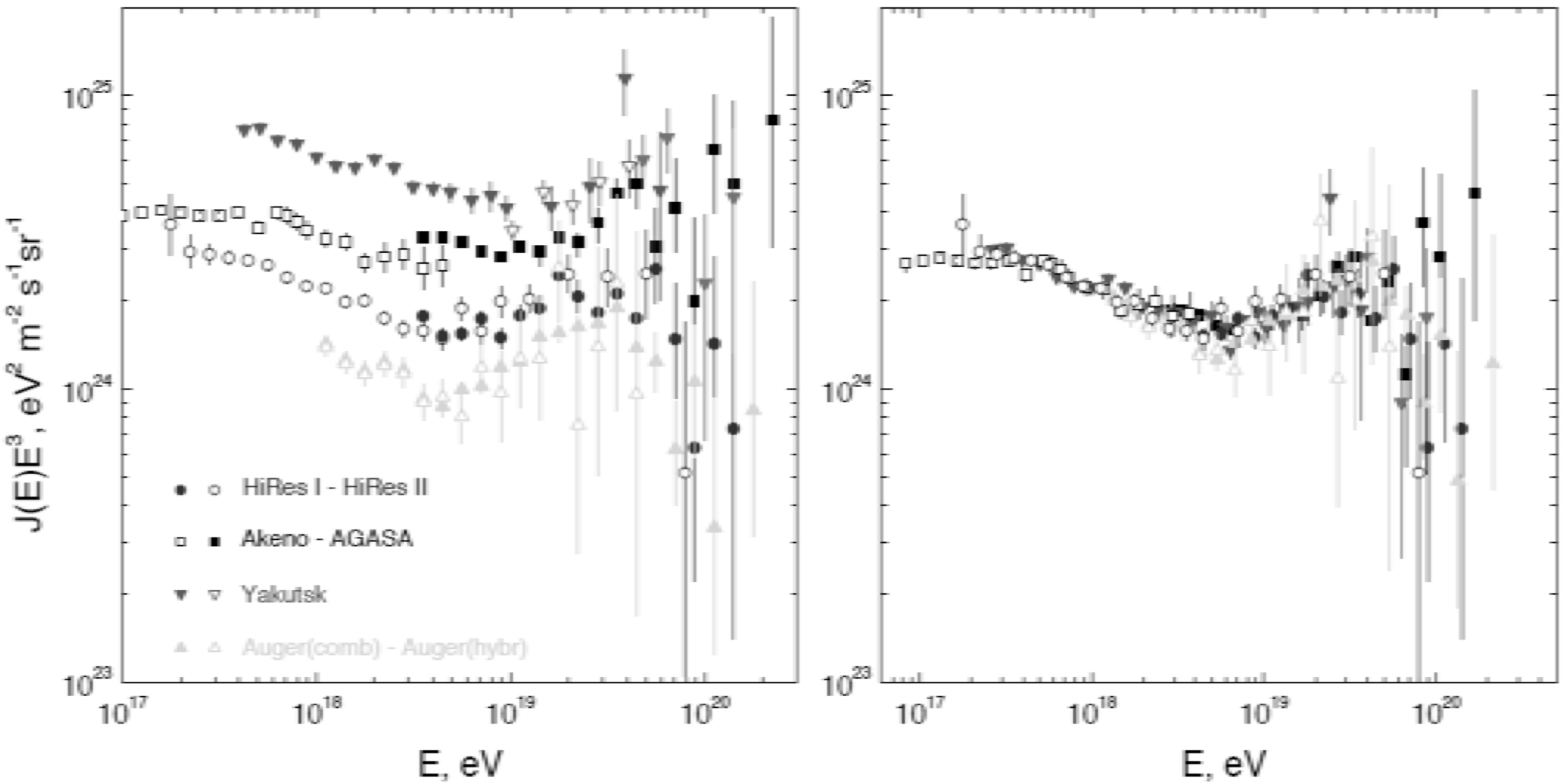


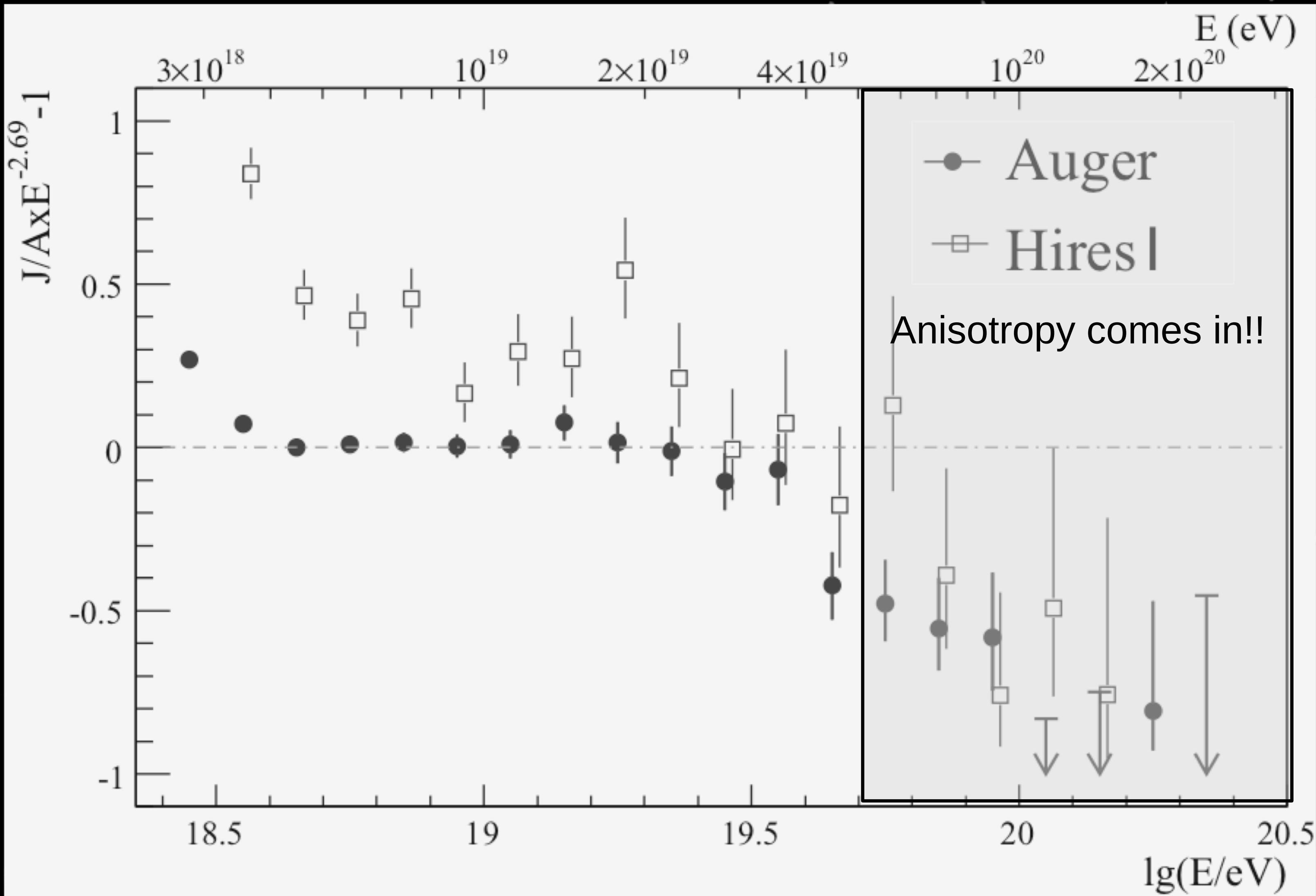
Binary neutron stars



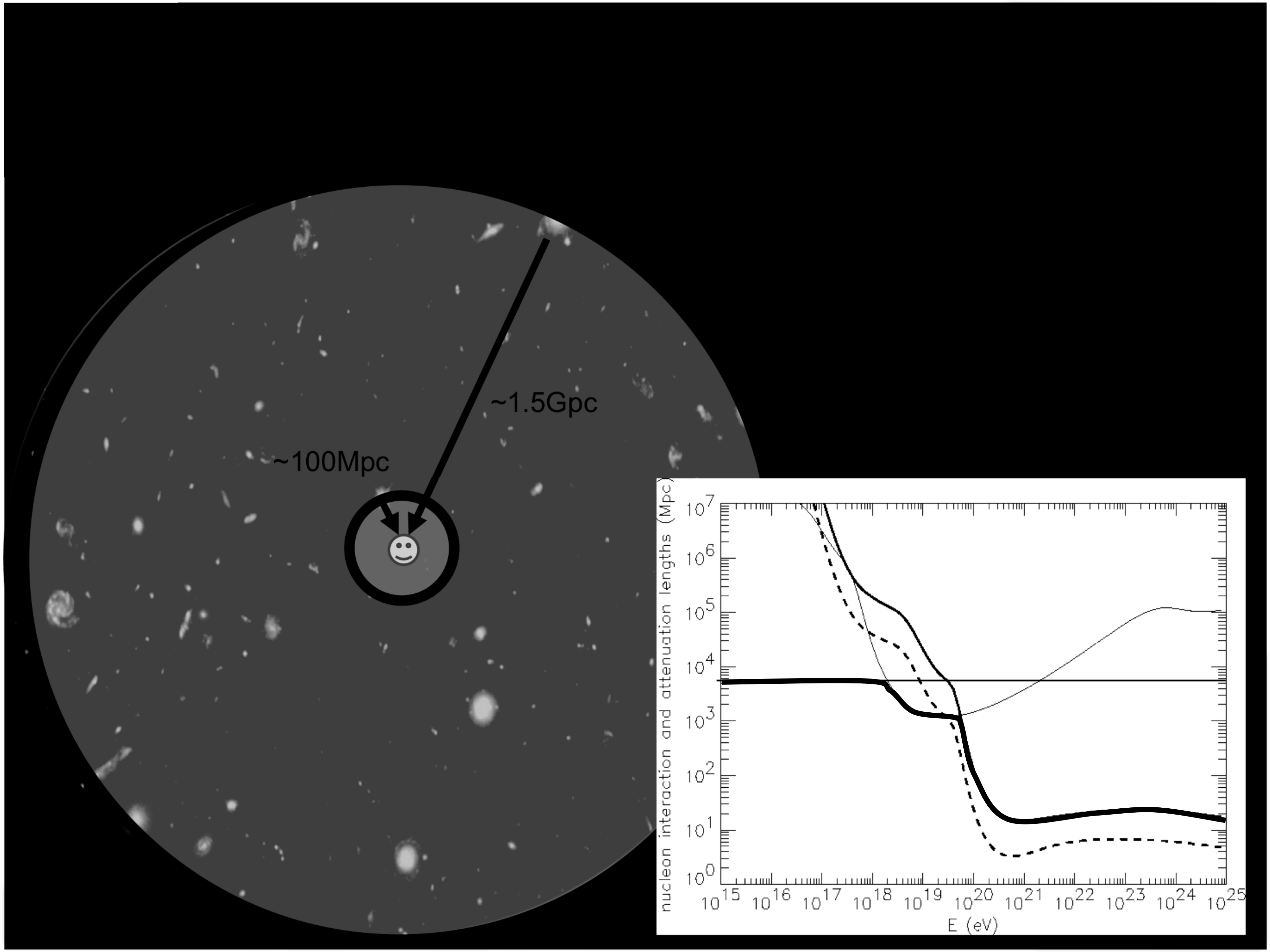

CMB photons
~400/cc
γ
γ
π
UHECRs
UHECR
nucleon interaction and attenuation lengths (Mpc)
E (eV)

Energy Spectrum at the highest energy region



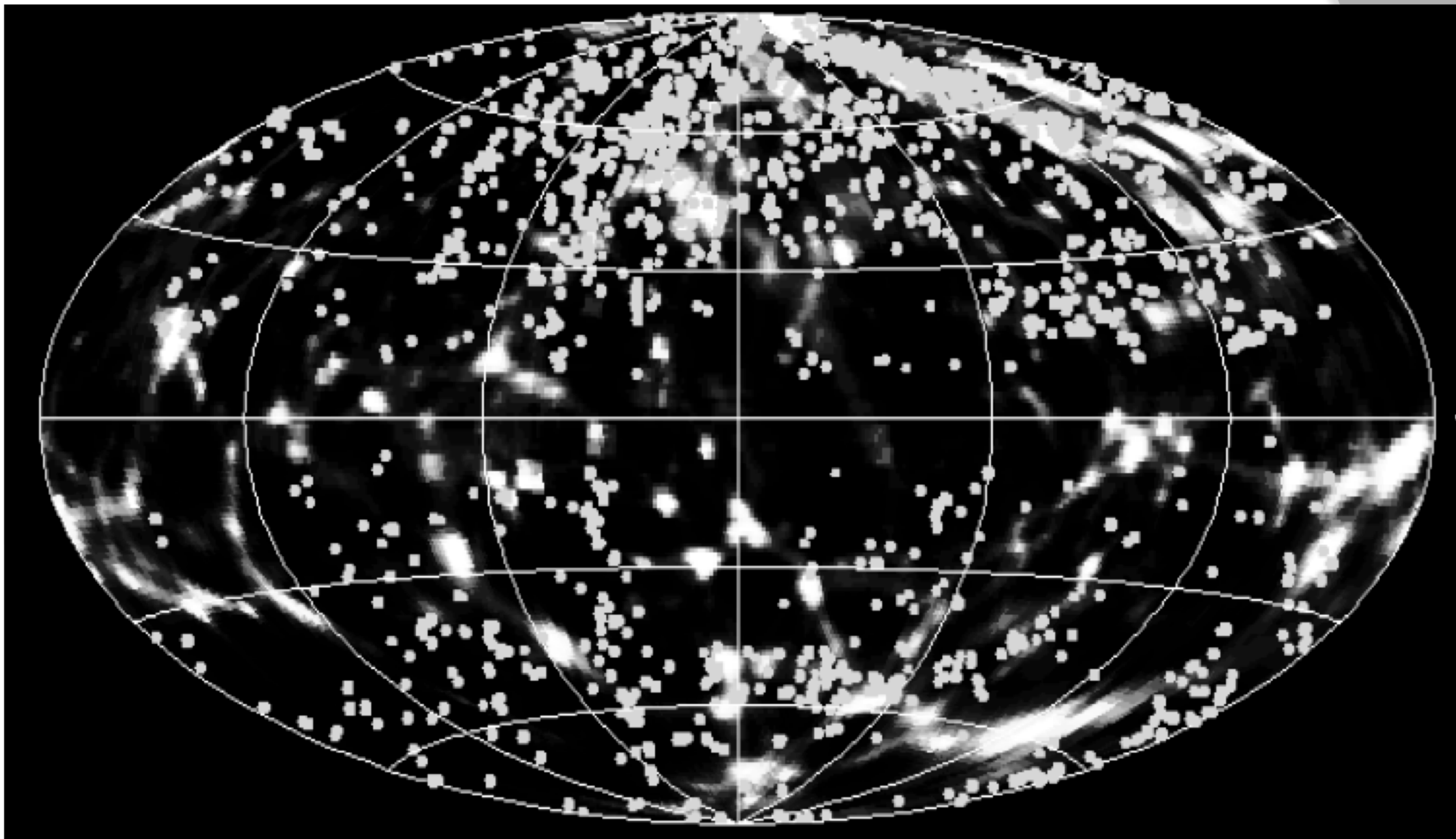


E (eV)
3×10^18
10^19
2×10^19
4×10^19
10^20
2×10^20
J/AxE^-2.69-1
1
0.5
0
-0.5
-1
Auger
Hires I
Anisotropy comes in!!
18.5
19
19.5
20
20.5
lg(E/eV)

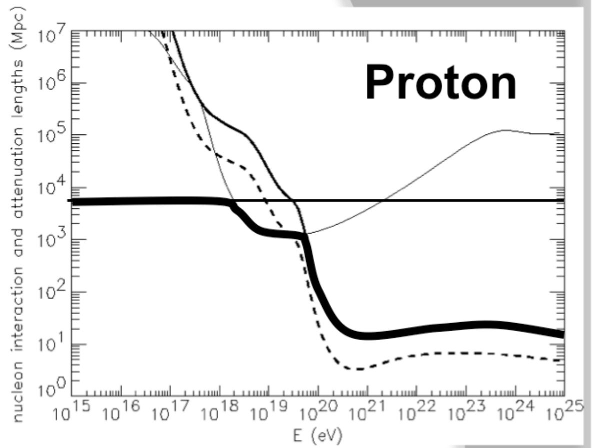

~1.5Gpc
~100Mpc
nucleon interaction and attenuation lengths (Mpc)
E (eV)

Matter (90Mpc) and Galaxies (45Mpc)

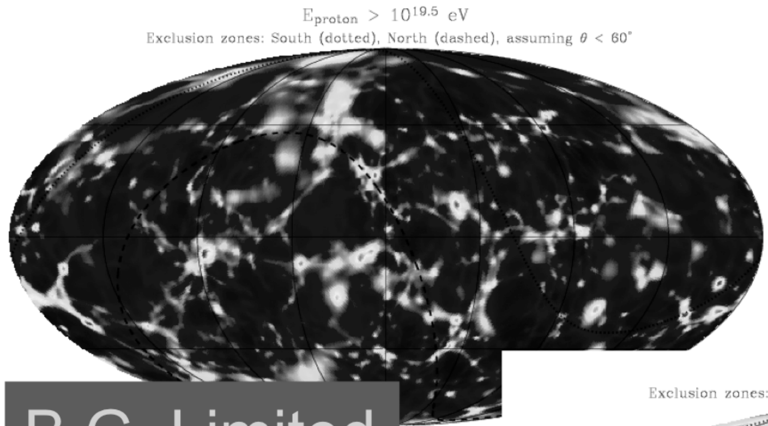
By A.Kravtsov



Expected UHECR Skymaps (A.Onlinto and E. Armengaud)

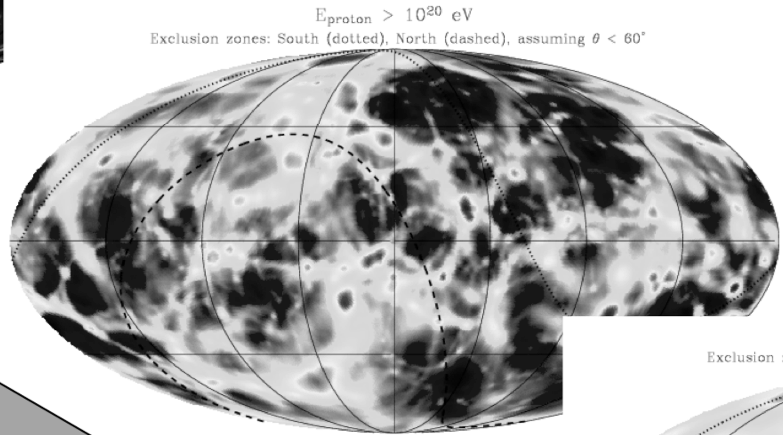


E>$10^{19.5}$ eV

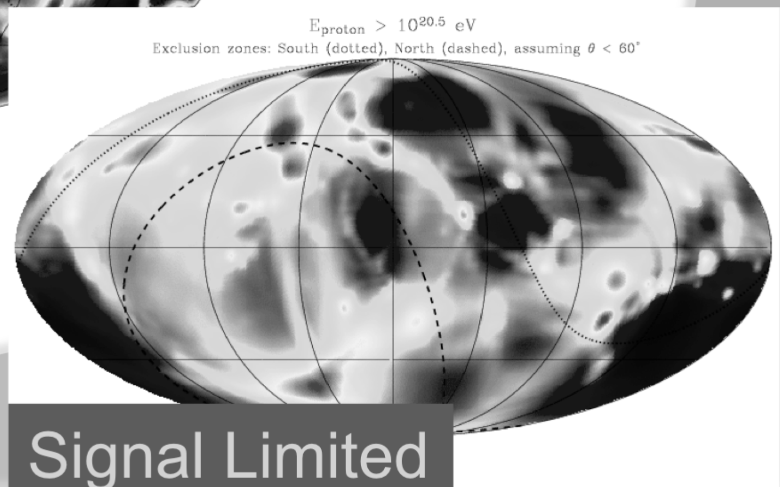


B.G. Limited

E>10^{20} eV



E>$10^{20.5}$ eV



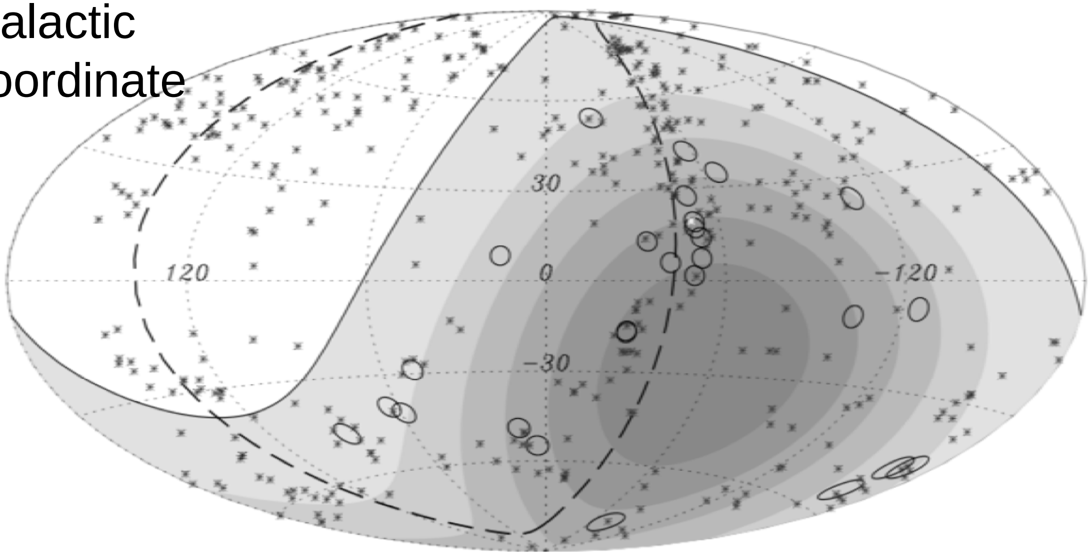
Signal Limited

GZK attenuation :
- larger CR density contrasts
- constrasts on larger scales

Auger Anisotropy

27 events (E > 57EeV), 442 AGNs (z <0.017)

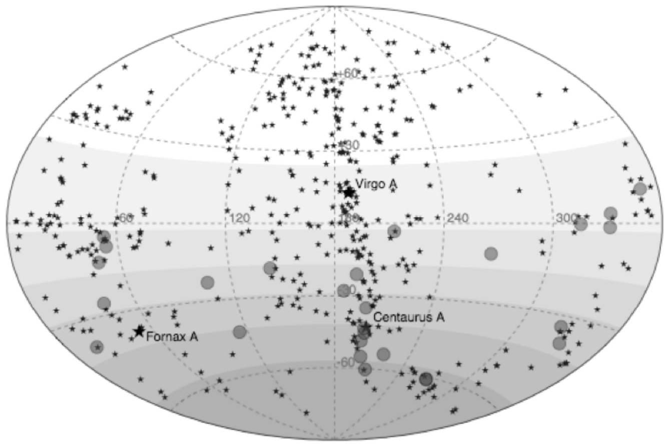
Galactic coordinate

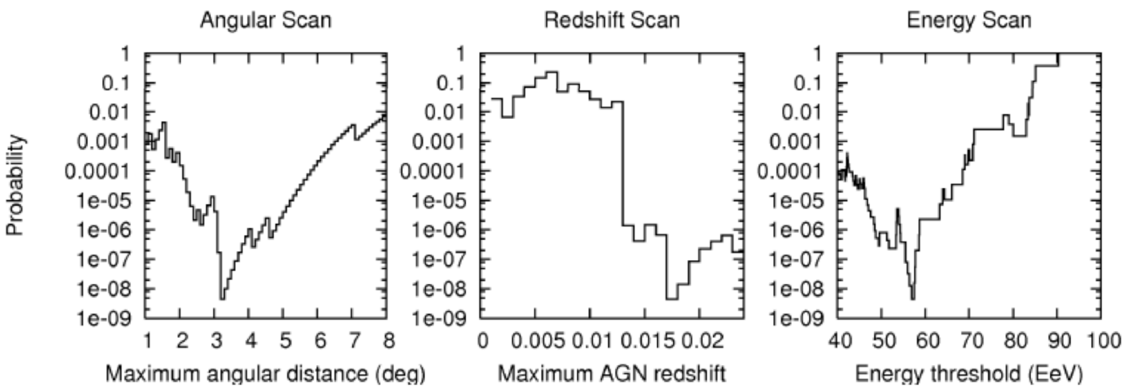


~10,000 L (km2 sr yr)

~1ML ➔ 3000 events

Equatorial coordinate

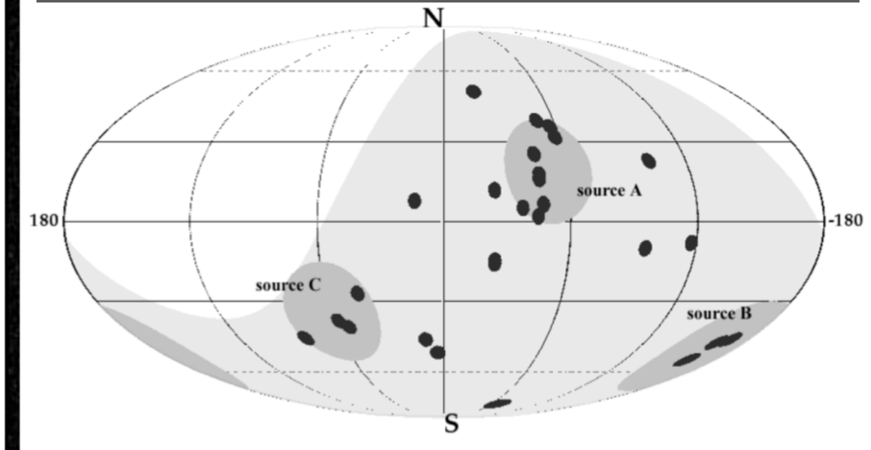




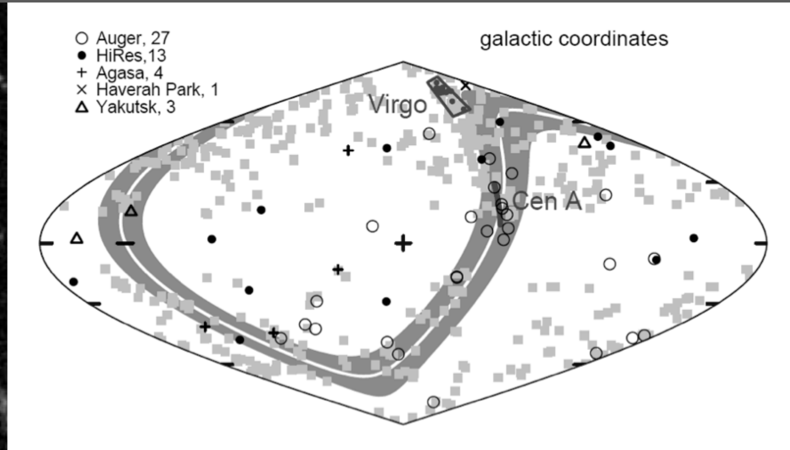
6 pairs /27 events (6 degrees) ➔ #S > 61

[illegible] scientific discussions after the publication

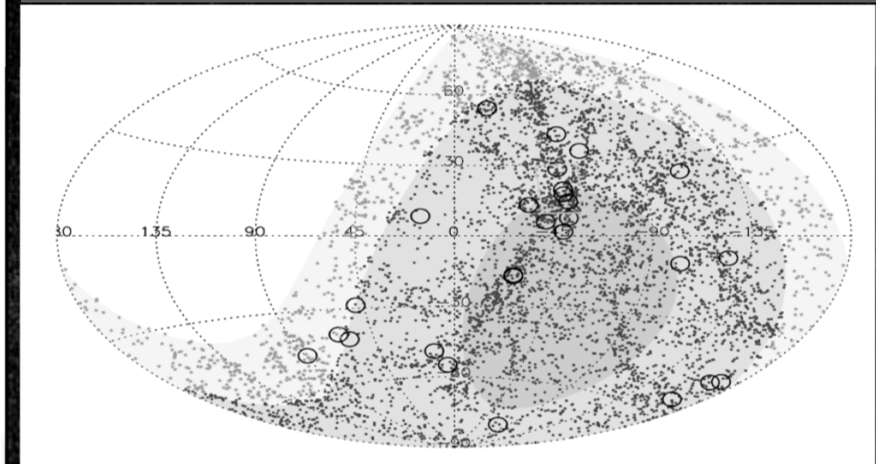
Heavy particles from a few sources



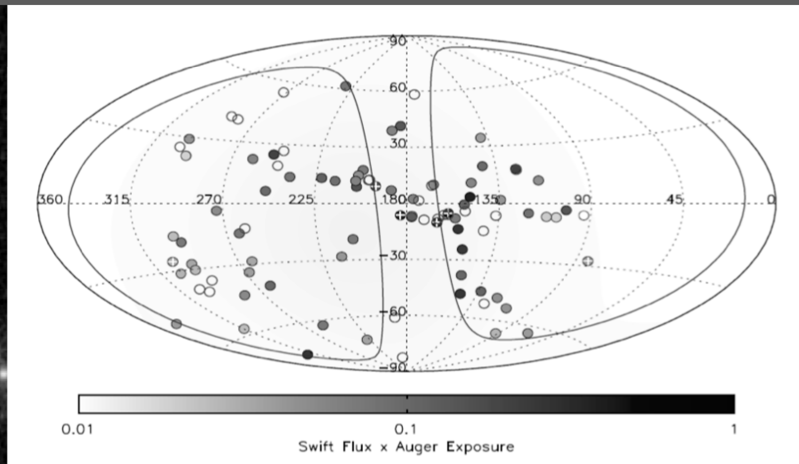
Correlation with Super galactic plane



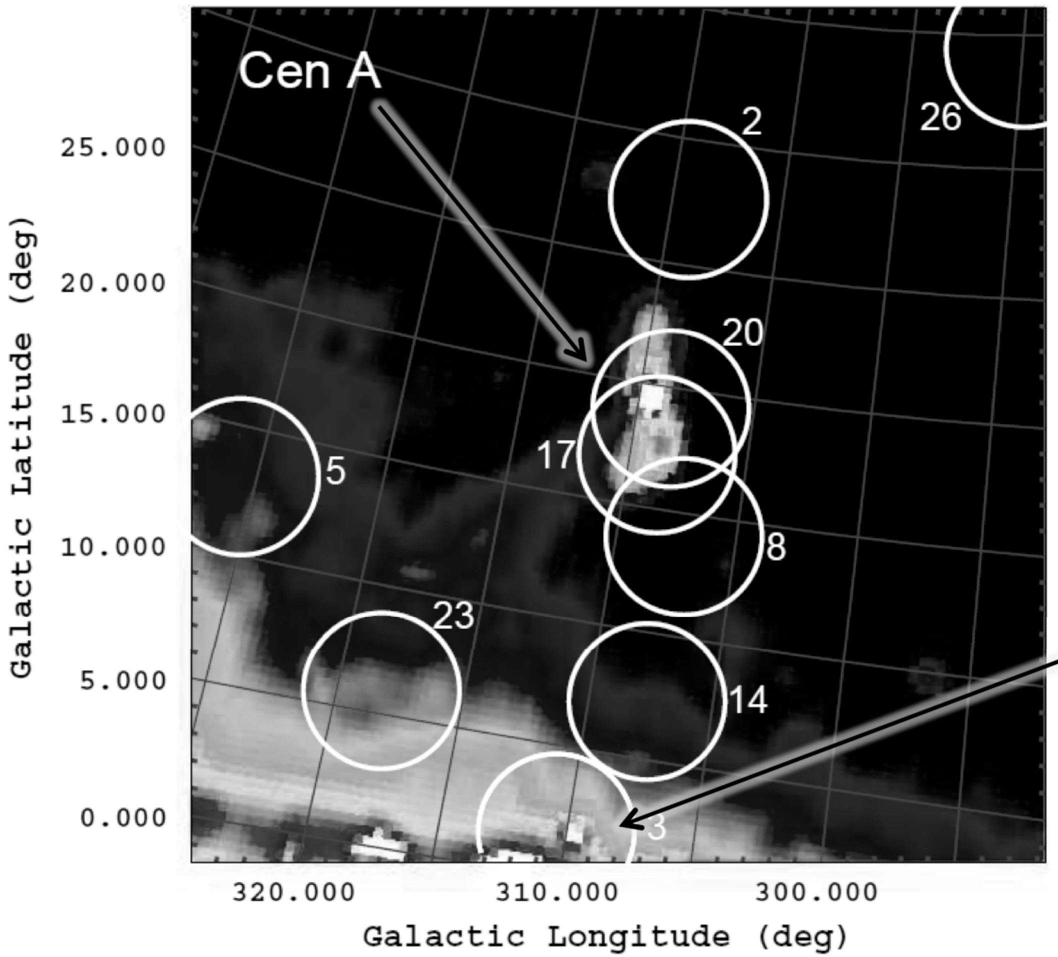
Correlation with H1 galaxies ➔ GRBs?

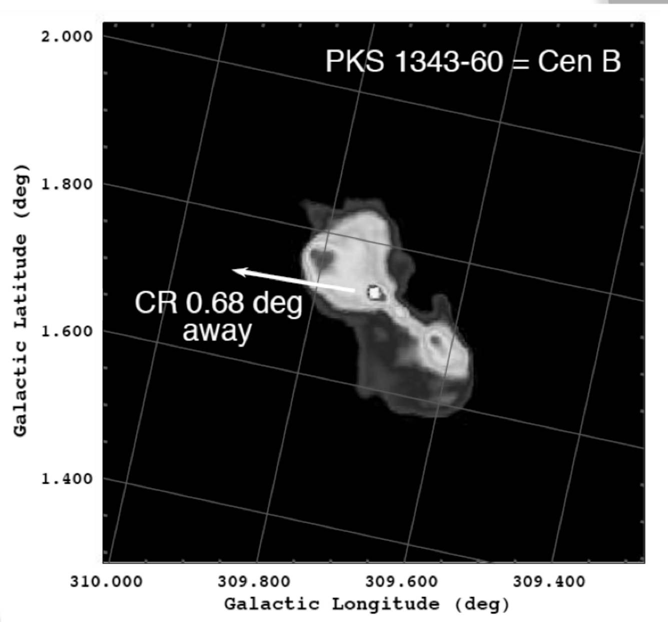


Correlation with Hard X-Ray BAT AGNs



Morphological studies of potential sources
Cen A (3.4Mpc) & Cen B (56Mpc)
Moskalenko et al. 0805.1260v1





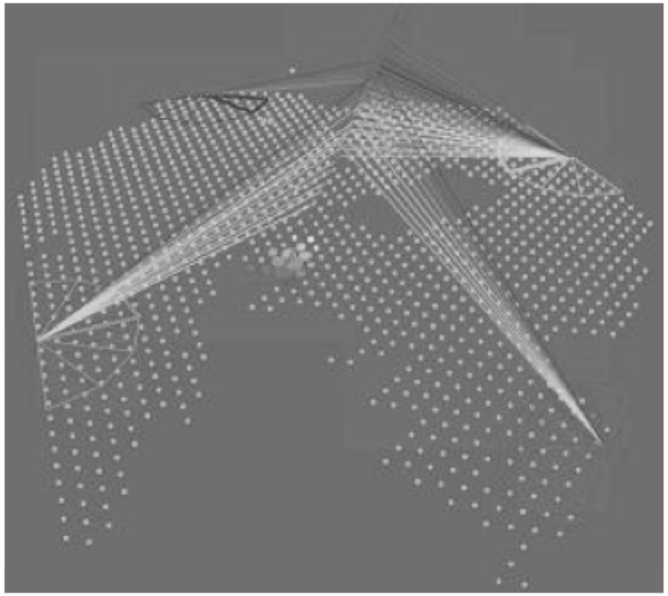
nature.com

In the Field

The *Nature* reporters' blog from conferences and events

MAY 03, 2009

APS 2009: Pierre Auger backs off claims for cosmic ray source



The mysterious origin of ultra-high energy cosmic rays is, it seems, still a mystery. Two years ago, scientists at the Pierre Auger Observatory in Argentina thought they had it solved. They published a paper in Science, based on two dozen particles, that there was a correlation with the location of Active Galactic Nuclei -- supermassive black holes that accelerate jets of material at near-light speed throughout the universe. At the time of the announcment, there was some doubt: The Hi-Res project, which scans the northern sky like Auger does the south, found no such correlation.

And now, today, Stefan Westerhoff, an Auger scientist from the University of Wisconsin at Madison, said that, based on new particle detections -- they have more than 50 now -- the correlation no longer holds. "The signal strength is certainly considerably weaker now," he told his audience. "This is certainly a disappointment."

But the correlation isn't so weak that they can give up. The 70% correlation between the cosmic rays and the AGN at the time of the Science publication has now dropped to about 40% -- considerably less, but not enough to support the null hypothesis. What could cause some particles to come from AGN, but not others? Westerhoff says it might have something to do with their composition. Maybe the protons come from the AGN, whereas higher mass cosmic rays, say iron nuclei, do not.

Westerhoff says this will be sorted out as they track more particles -- which can only come with more time and bigger detectors. If Pierre Auger is the size of Rhode Island, the proposed Pierre Auger North, not too far from Denver, would be the size of Massachusetts -- and Westerhoff showed a slide how they can get the necessary statistics in a decade or two. No offense to the lovely state of Colorado, but I say keep the cow pasture free of Cerenkov detectors, and give folks like JEM-EUSO a chance to stick their 2.5-meter camera on the space station.

Image: Pierre Auger

Posted by Eric Hand at 05:16 PM | Permalink | Comments (2) | TrackBacks (0)

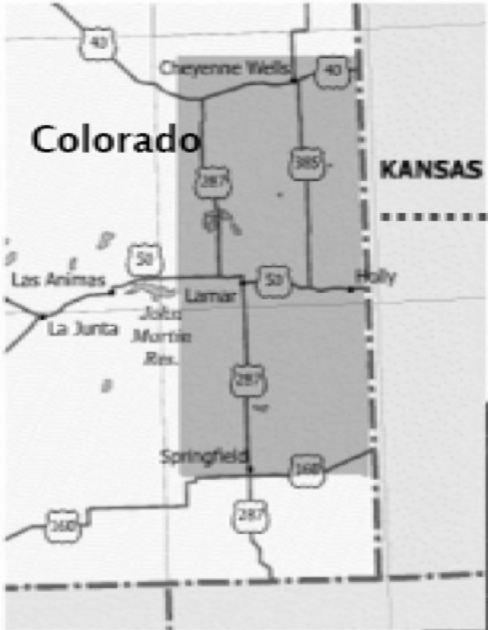
PIERRE AUGER OBSERVATORY

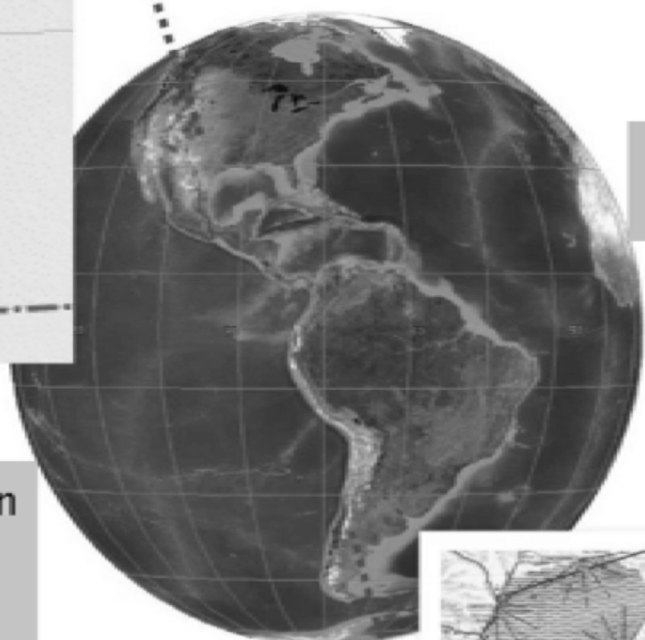
The Pierre Auger Observatory – 2 Sites

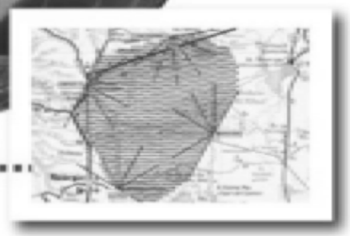
Need for 2 sites realized since beginning of project

Northern Site: Colorado

- Retain features & functionality of Southern Site
  - Hybrid detection & energy calibration
  - Water Cherenkov surface array
    - 4000 stations, 10,370 km^2
    - Square mile grid







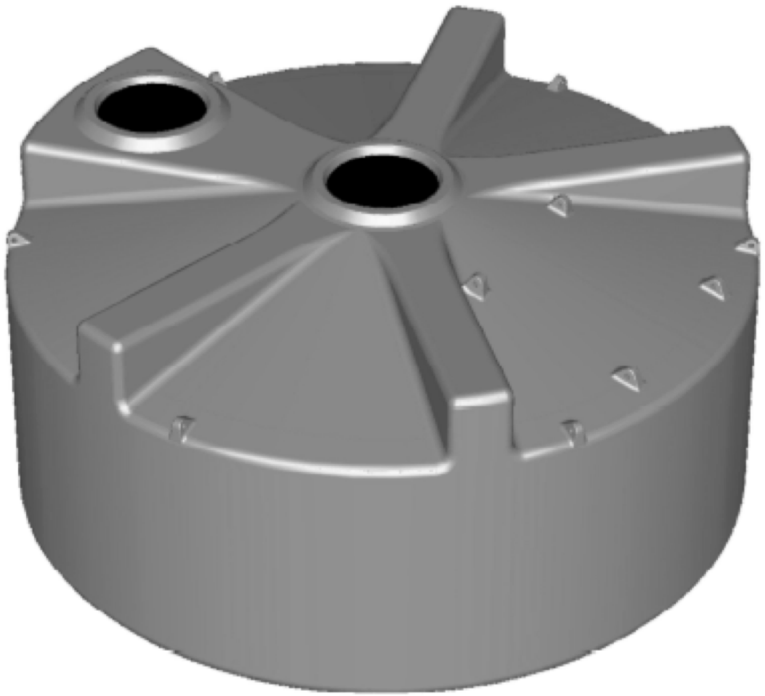
Altitude and latitude are similar

Southern and Northern sites are shown at the same scale

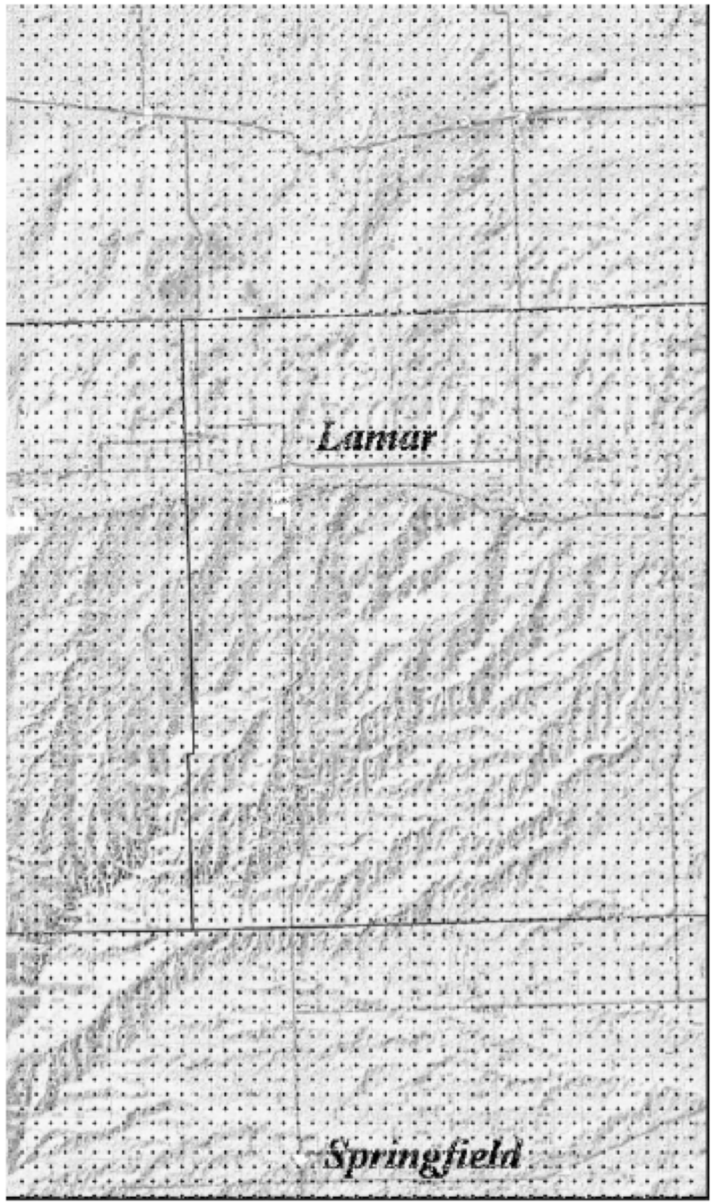
Southern Site: Mendoza

- Hybrid detection & energy calibration
- Water Cherenkov surface array
  - 1600 stations, 3000 km^2
  - 1.5 km triangular grid
- Completion end 2007
- Science flowing – 38 papers here

Surface Array

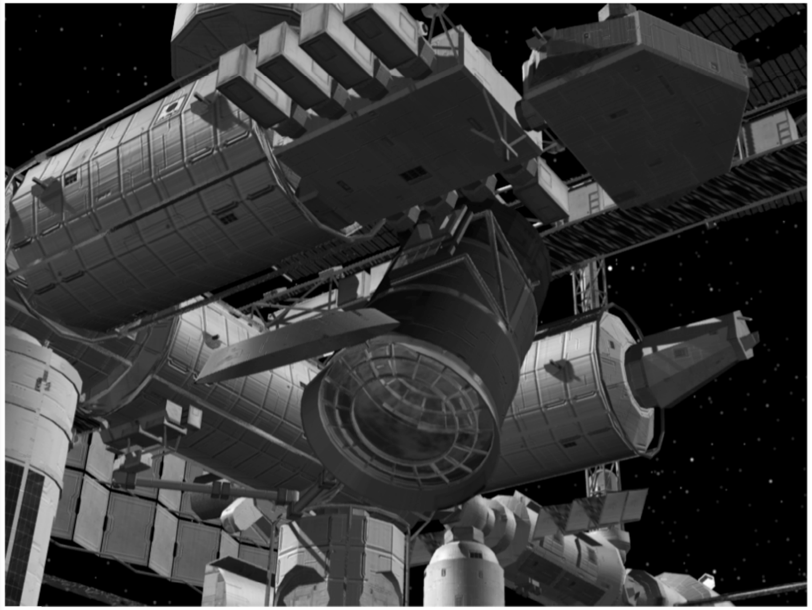


- Tank with internal rotationally molded polyethylene foam insulation
  - Northern site is colder
- Central hatch for single large PMT
  - Cost reduction refinement
- 2nd hatch for assembly access

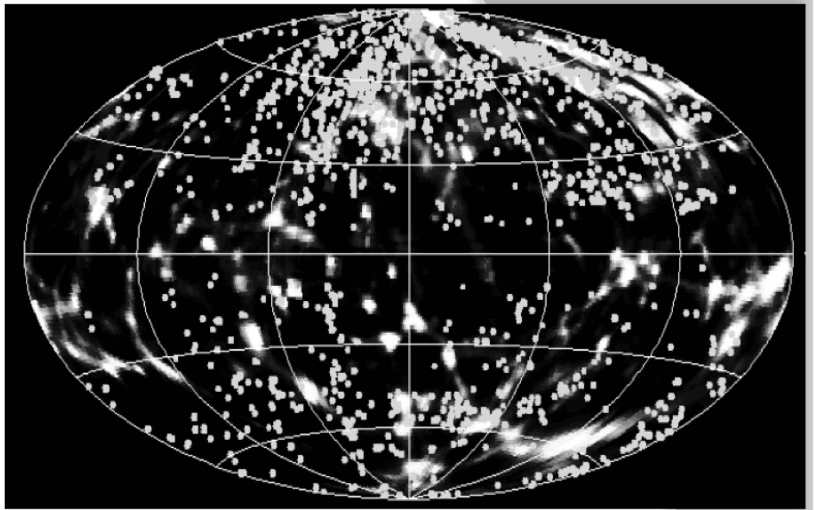


Dots indicate positions of 4032 tanks

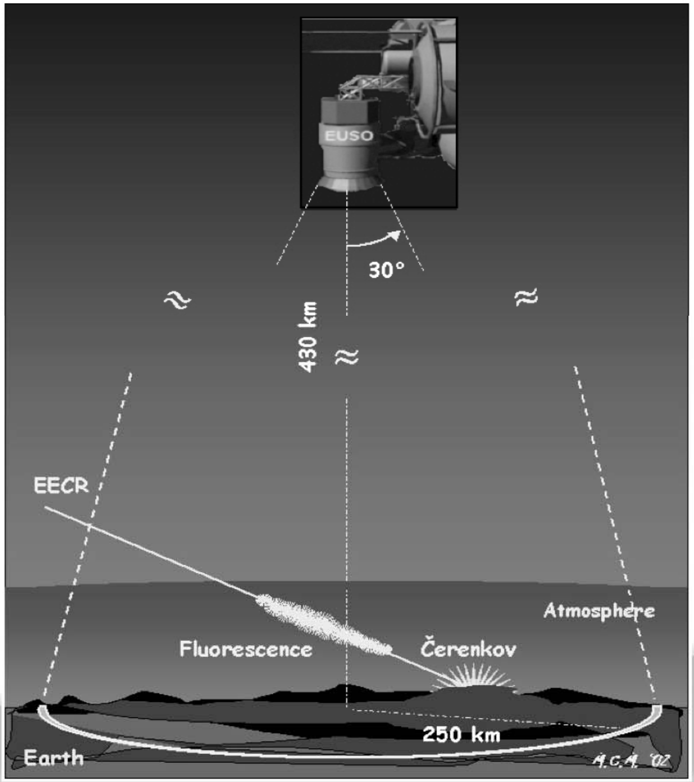
Astronomy with UHECRs
JEM-EUSO

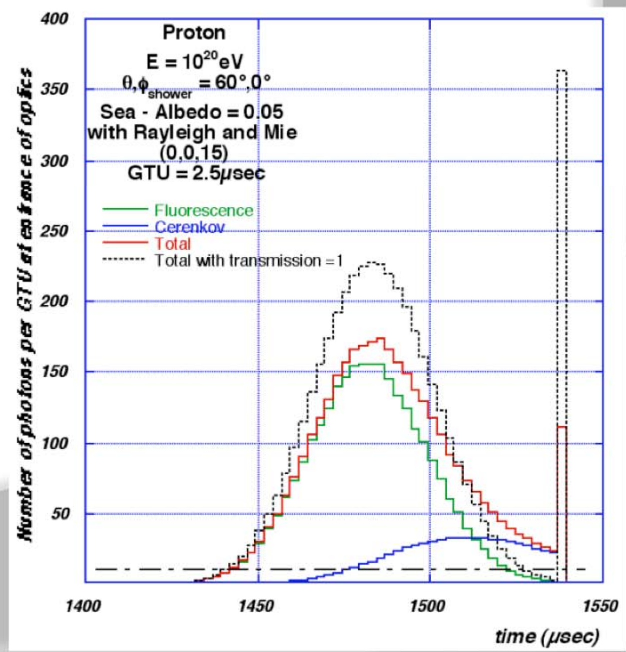


Matter (<90Mpc), Galaxies (<45Mpc) by A.Kravtsov



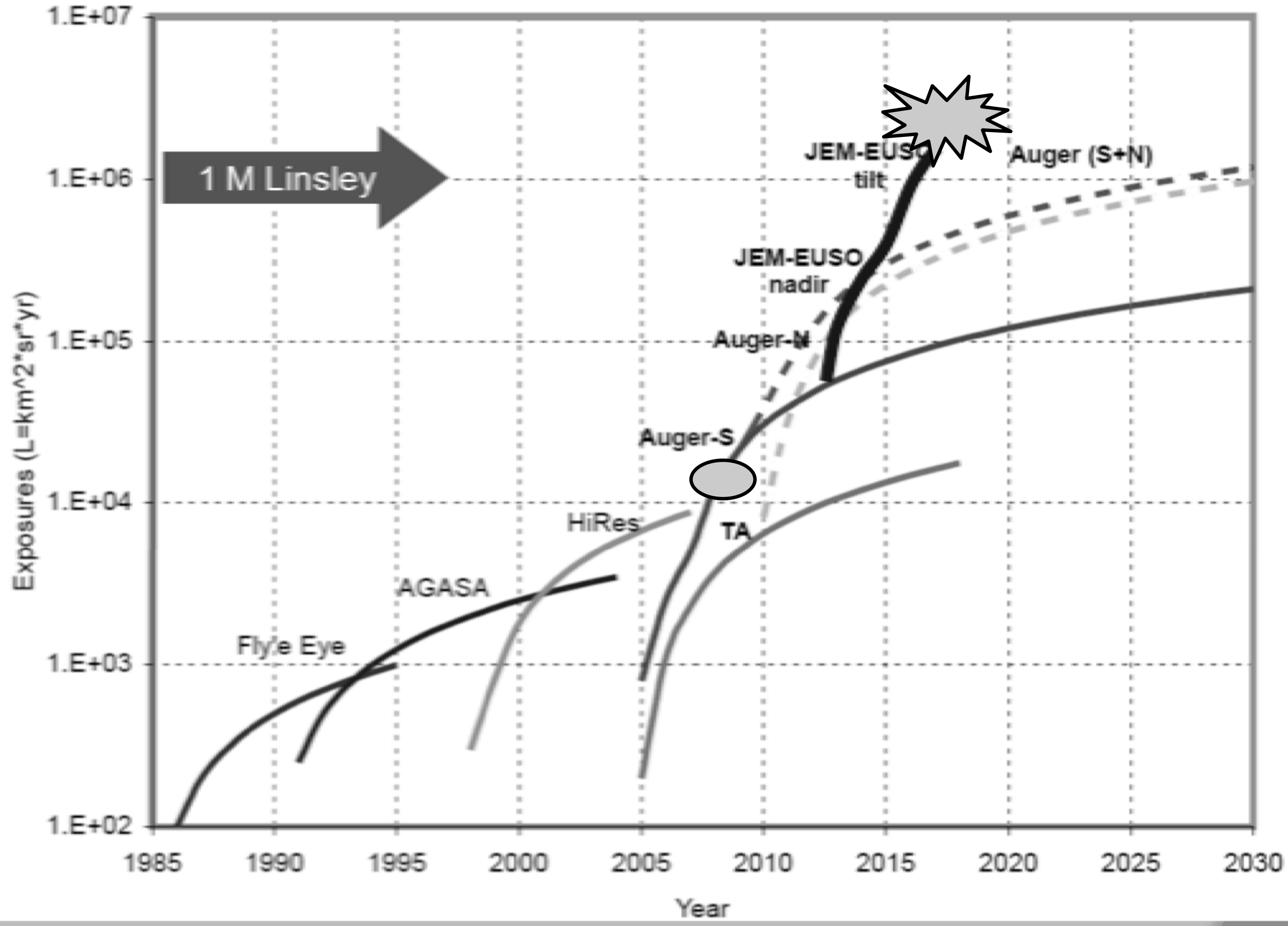
X30 Auger South
UHECRs 2×10^6 km^{2}sr year
UHE ν 20 Tera-Ton year





Exposures for UHECRs

x100-200 times larger exposure is necessary

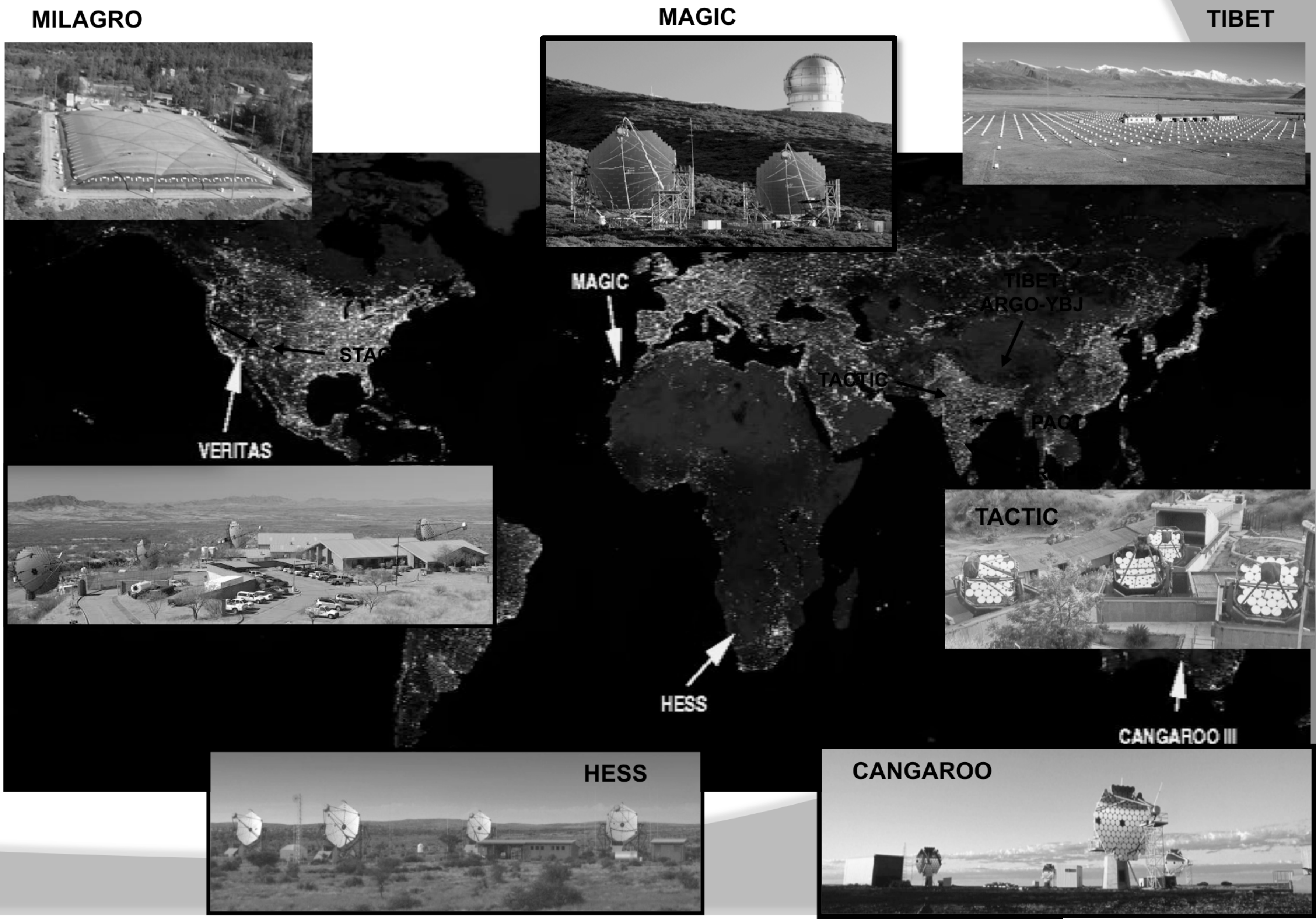


Summary: Ultra High Energy Cosmic Ray

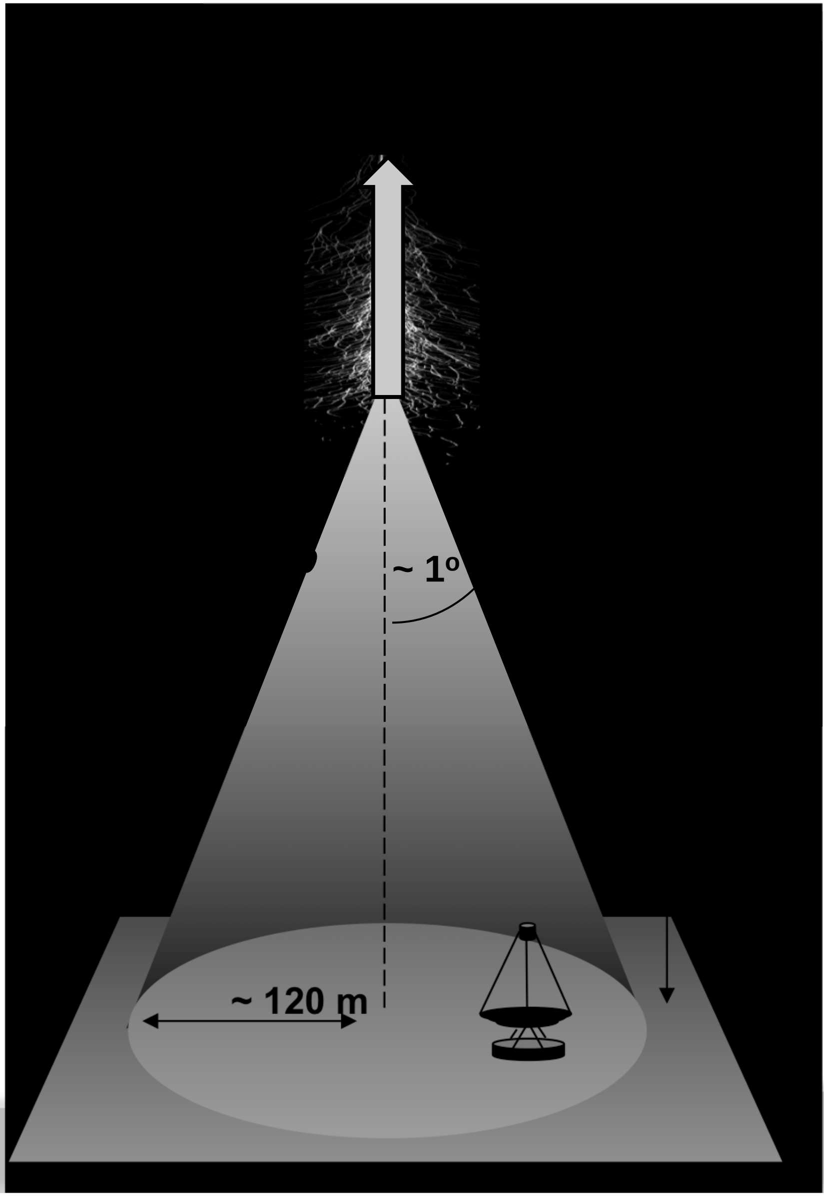
- GZK like energy spectrum
  - CR flux suppression above $6x10^{19}$eV – 6 sigma effect
  - GZK effect or the acceleration limit?
- Anisotropy above $6x10^{19}$eV
  - Correlation with the local matter density distribution
    - Super galactic plane
    - Hard X-ray selected AGNs
    - HI Galaxies ➔ GRBs, Mangetors in normal galaxies?
  - Auger AGNs – individual source power is not enough ➔ Giant flare of AGNs (Farrer et al.)
- Still we do not understand the origin of UHECRs !!
  - We may need 30-100 times more exposure to establish UHECR-astronomy (~1M Linsley) ➔ 1000~3000events above GZK
  - Comprehensive measurements: Cosmogenic neutrinos, GZK gamma rays, recovery of the spectrum from GZK
  - Plans: Auger North and JEM-EUSO are under discussion

HIGH ENERGY GAMMA RAYS

VHE Instruments

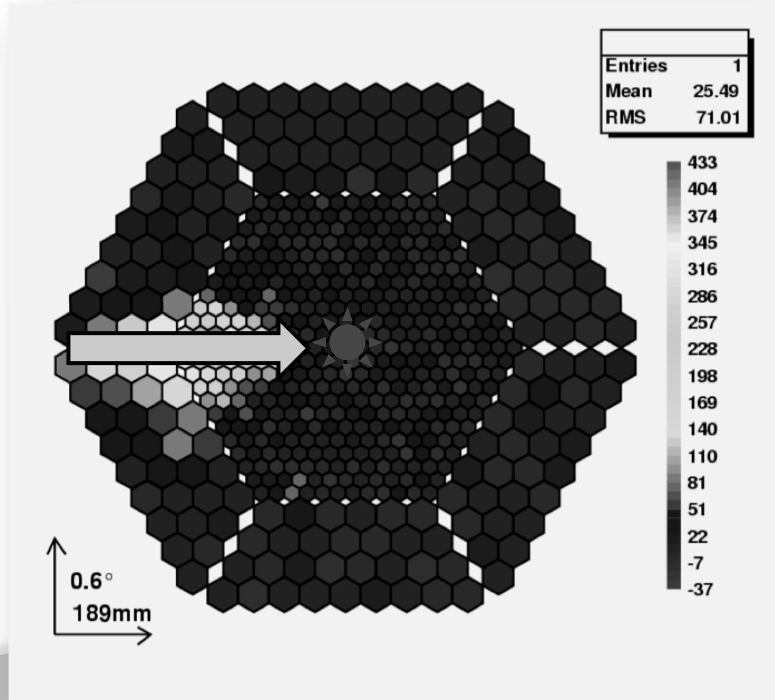


Atmospheric Imaging Cherenkov Telescope

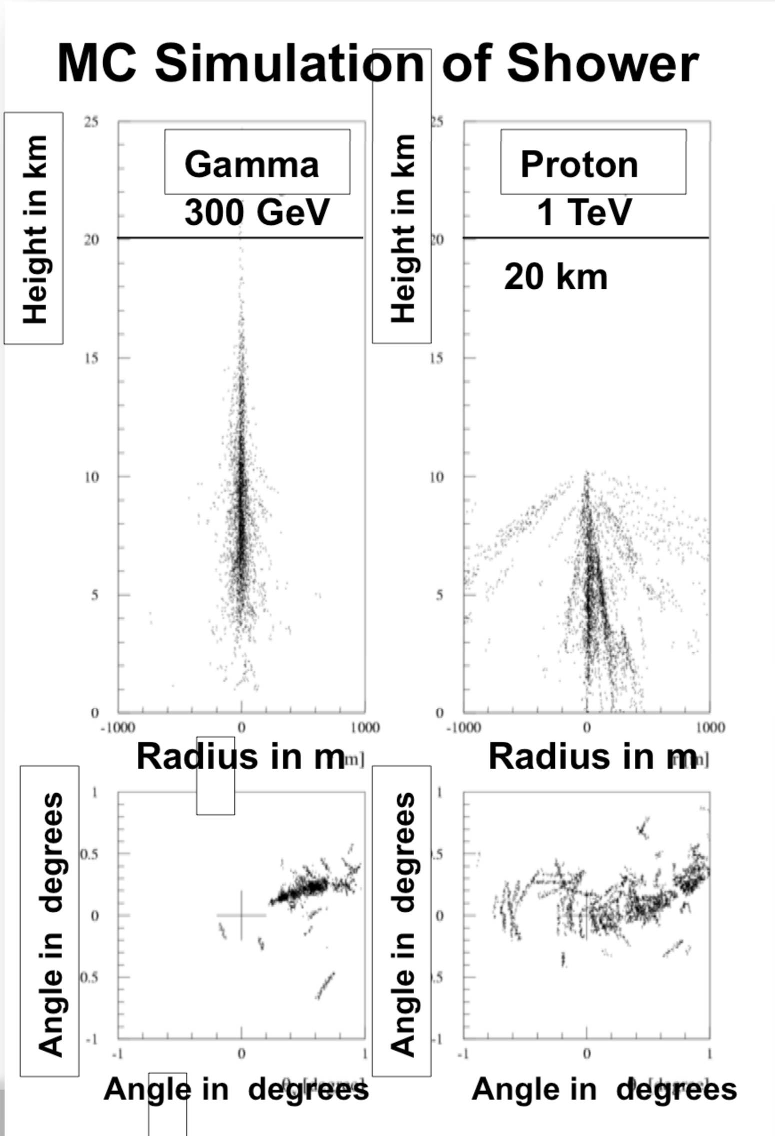


Observe Cherenkov light from gamma ray showers

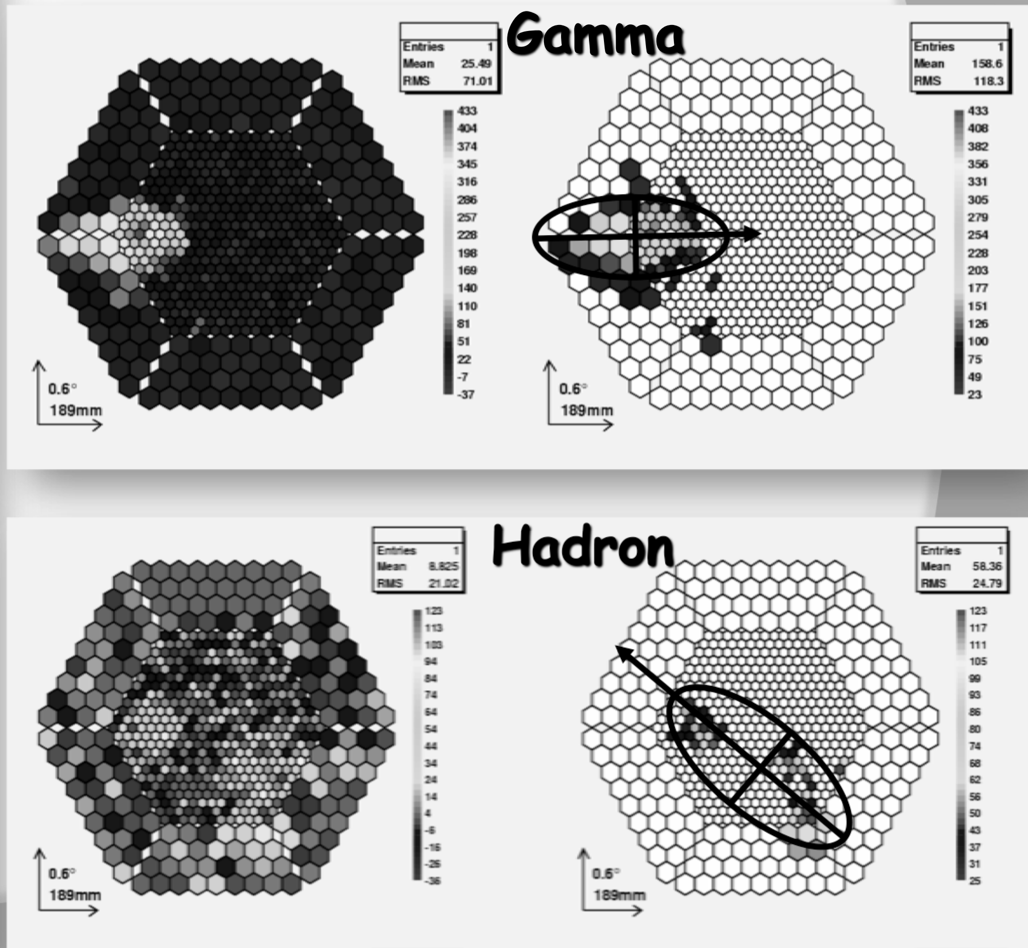
Effective area ~ $10^5 m^2$



Imaging Technique
Gamma / Hadron (CR) separation

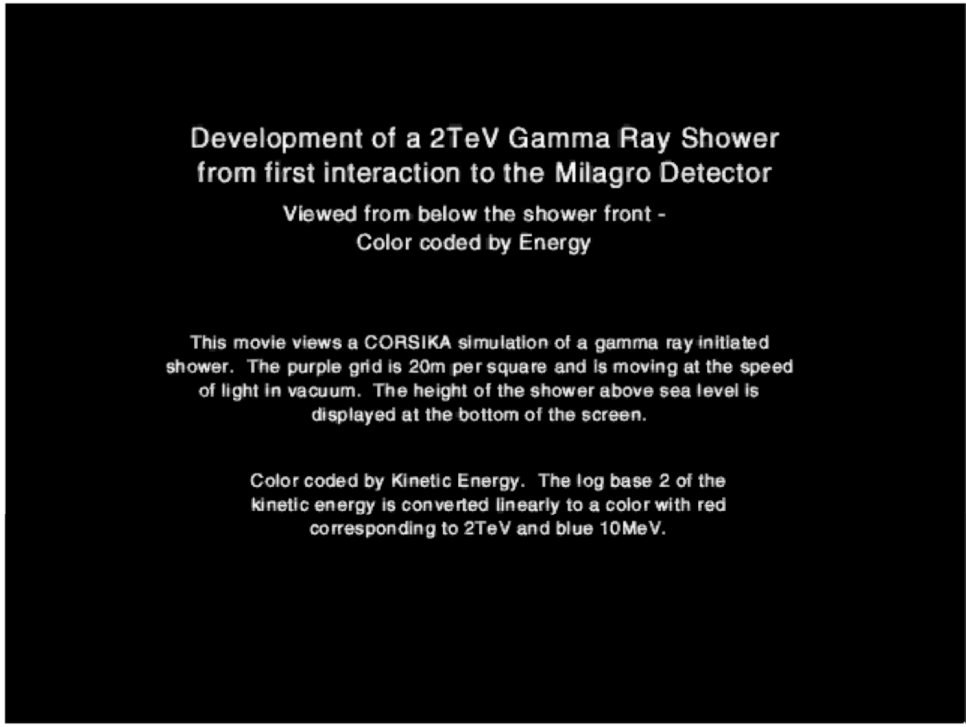


Hadron Rejection by Image ~99%

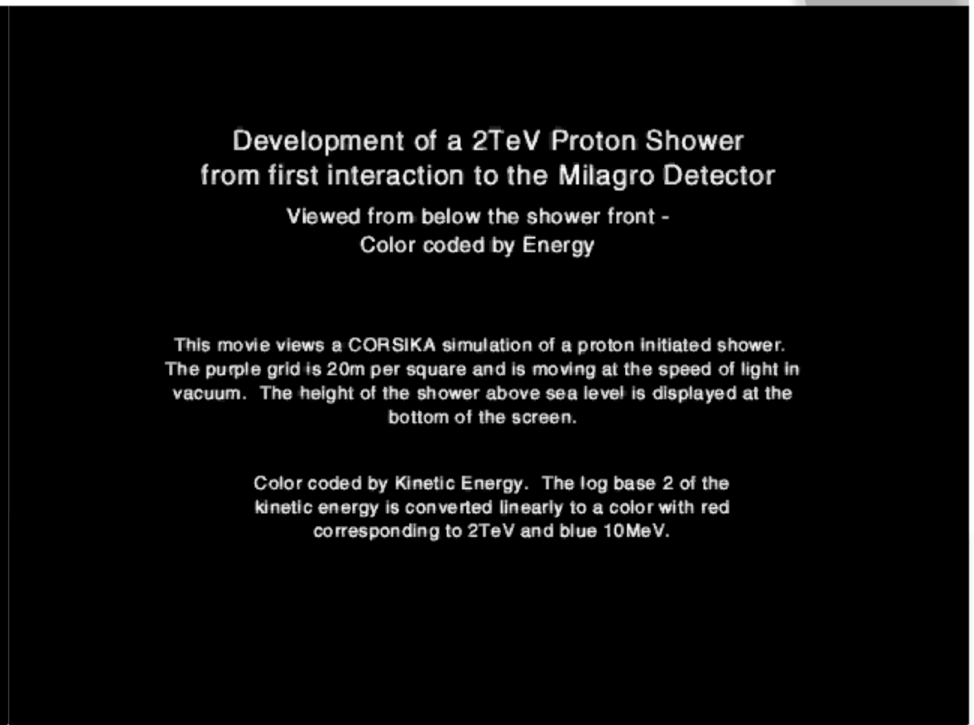


Gamma and Hadron showers

Gamma Shower

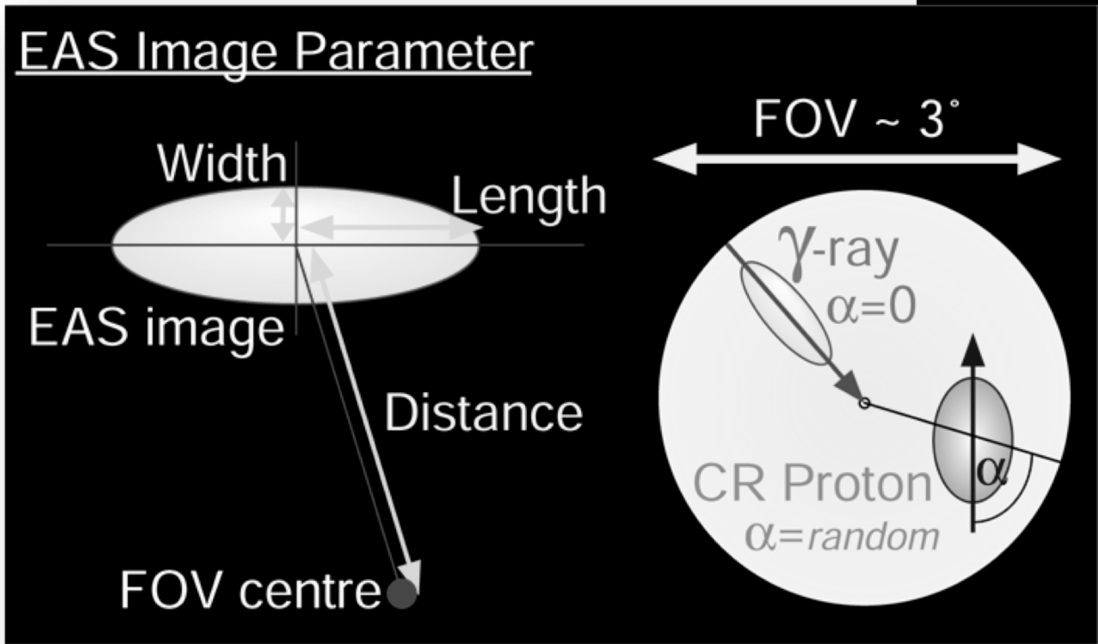


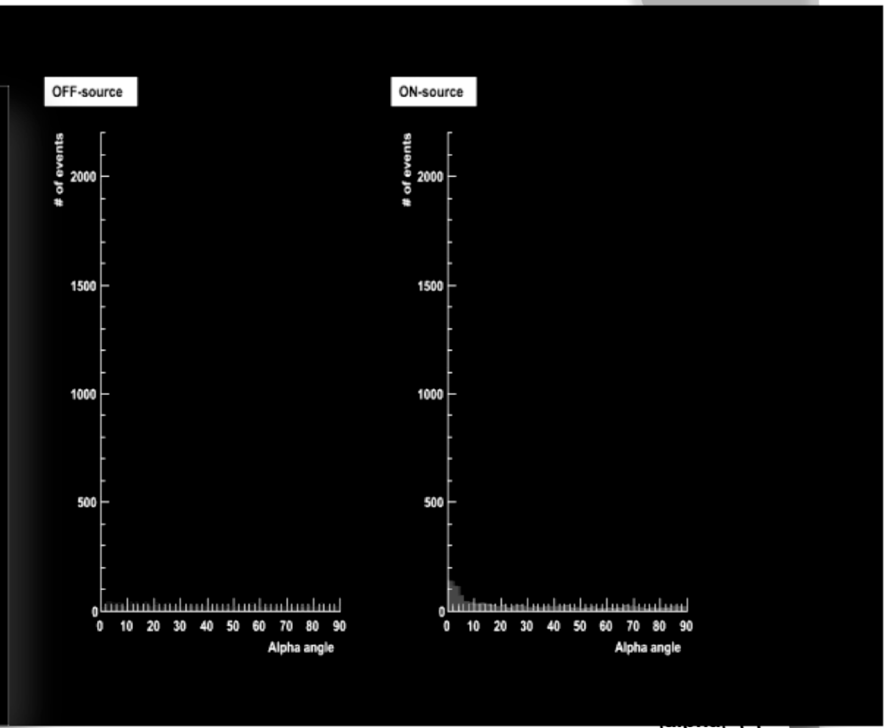
Hadron shower



Alpha (Orientation angle) distribution

Hadron rejection by orientation α~90%





Before Image/Orientation cut N_S/N_B **~1/1000**
After Image/Orientation cut N_S/N_B **~1/1**

MAGIC Telescopes

New technologies to lower the threshold energy

17m diameter world largest Cherenkov tel.
0.1°High resolution camera
Hemispherical High QE PMT
Optical fibre analogue signal transmission
2GS/sec Ultra Fast FADCs

Current MAGIC-I Performance

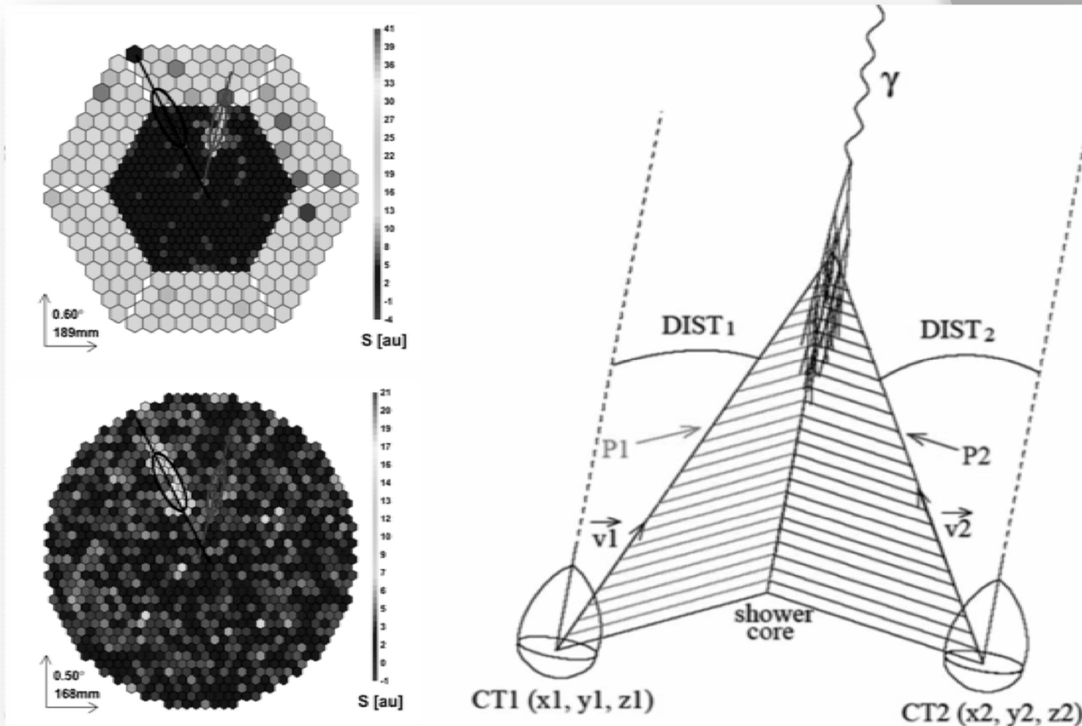
Fast rotation for GRB < 40secs
Trigger threshold ~55GeV ➔ ~25GeV
Sensitivity ~1.6% of Crab (50hrs)
Angular resolution ~0.1 degrees
Energy Resolution 20-30%

MAGIC-II is completed
First Light Ceremony April 2009

Improve sensitivity by a factor of three
Effectively lower the threshold energy
(upgrade with HPD 55%QE photodetectors)

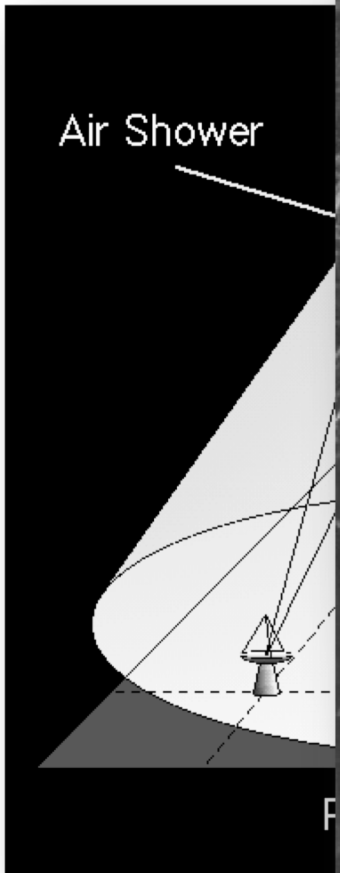
MAGIC-II Monte Carlo Studies

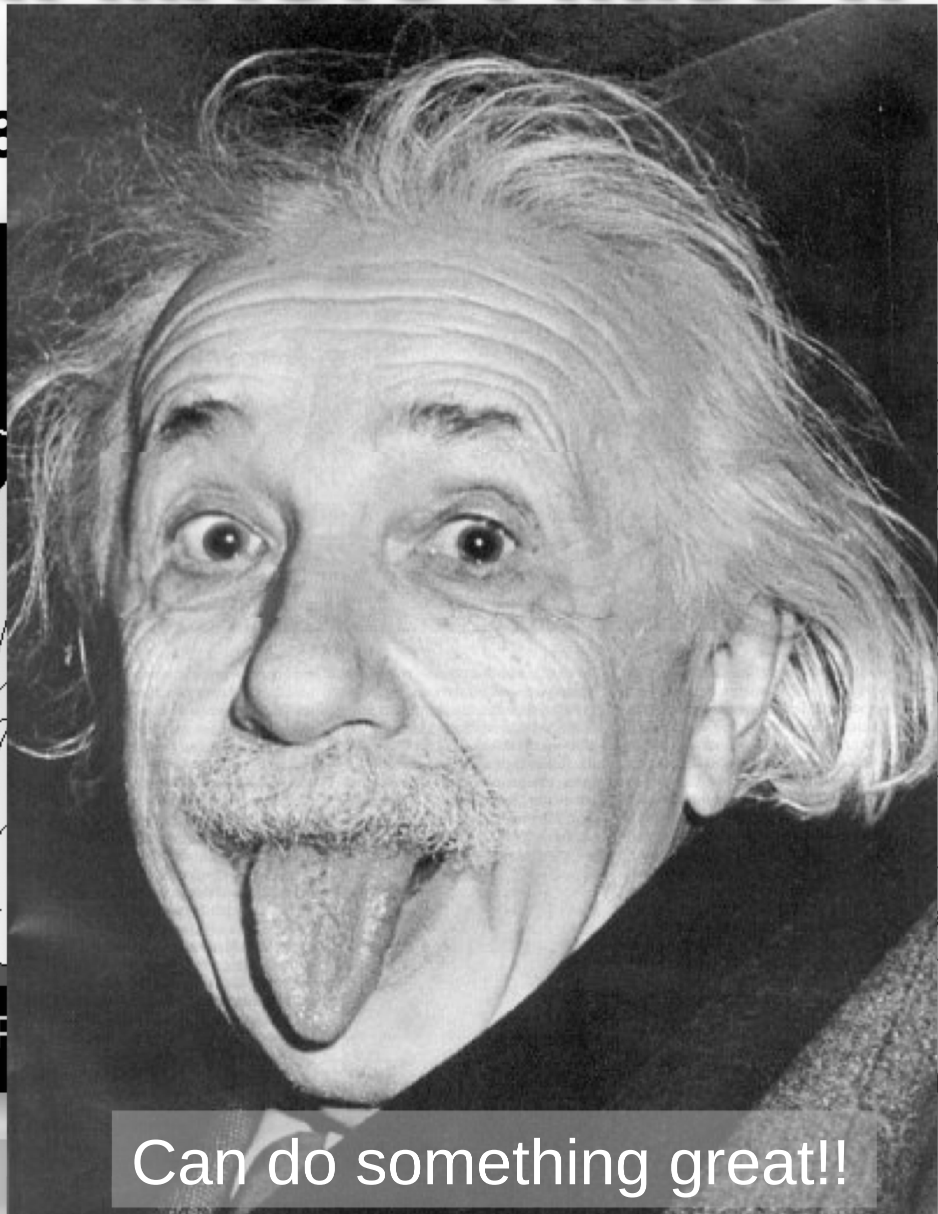
- Stereo reconstruction
  - 3-D geometry
    - Core location
    - Arrival direction
  - Shower characterization
    - Better Muon rejection
    - Shower max height
      - π^0 shower rejection
- Aspects
  - Better hadron rejection
  - Better angular resolution
  - Better energy resolution
  - Enhance the sensitivity in the low energy around 100GeV

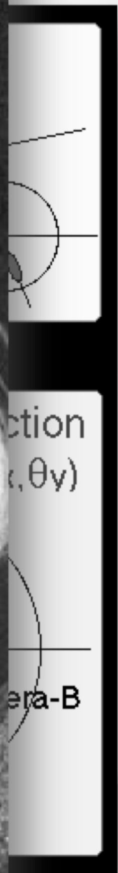


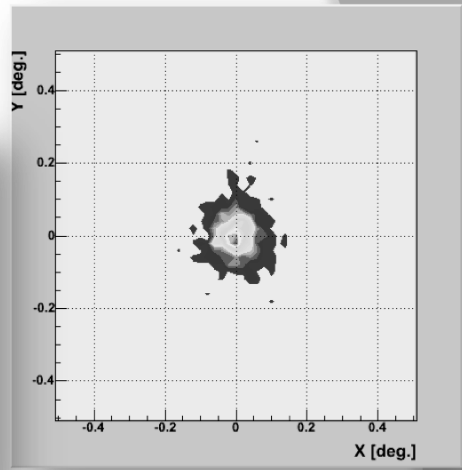
Stereo Reconstruction in MAGIC Phase-II

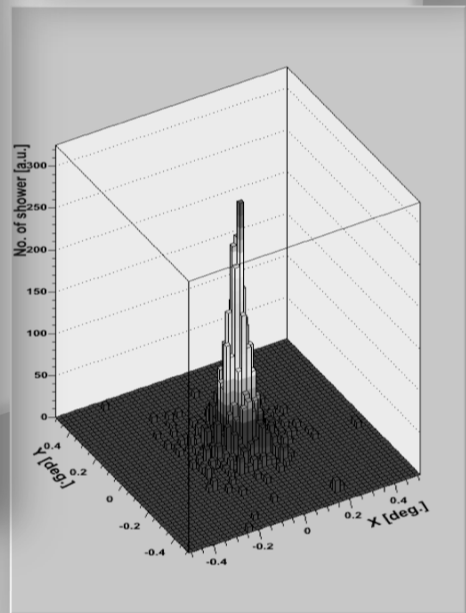
$\delta\,\theta \sim 3$



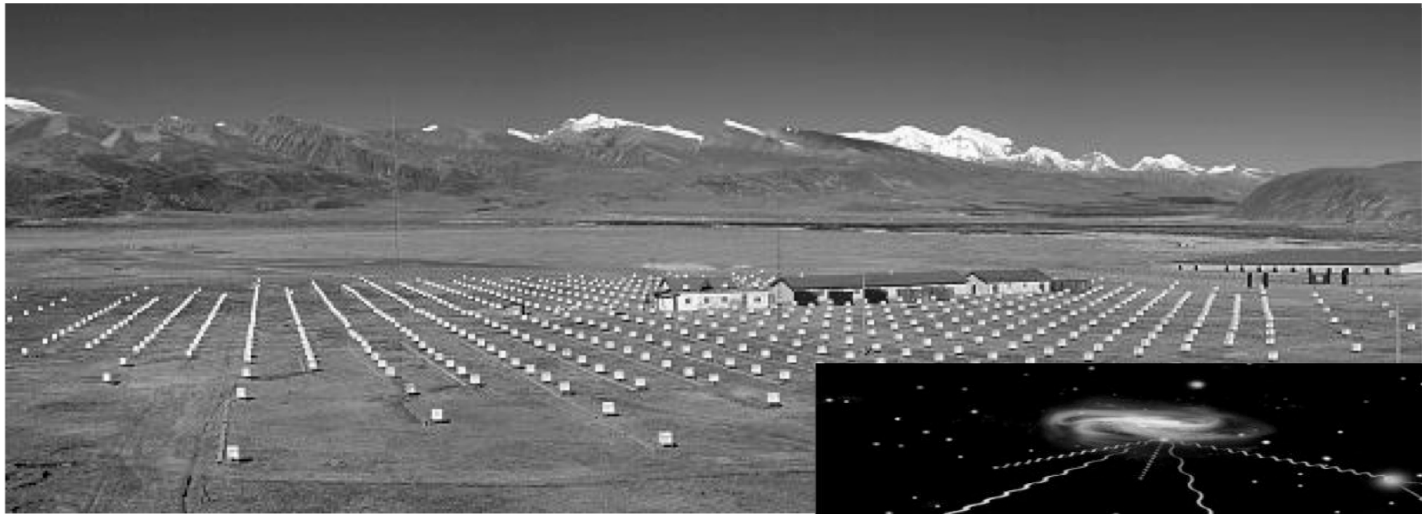


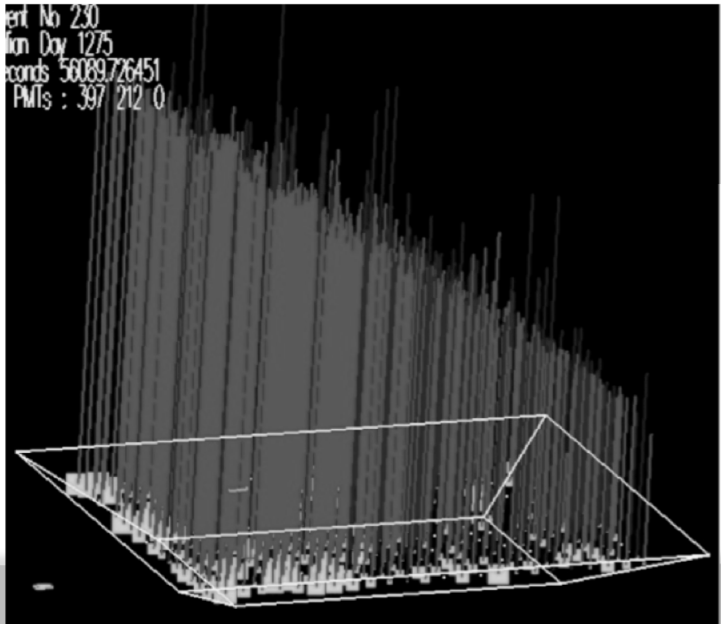






Water C-pool and AS array at high altitude Non-biased Sky Survey





Why do we study VHE gamma rays? by T. Weekes

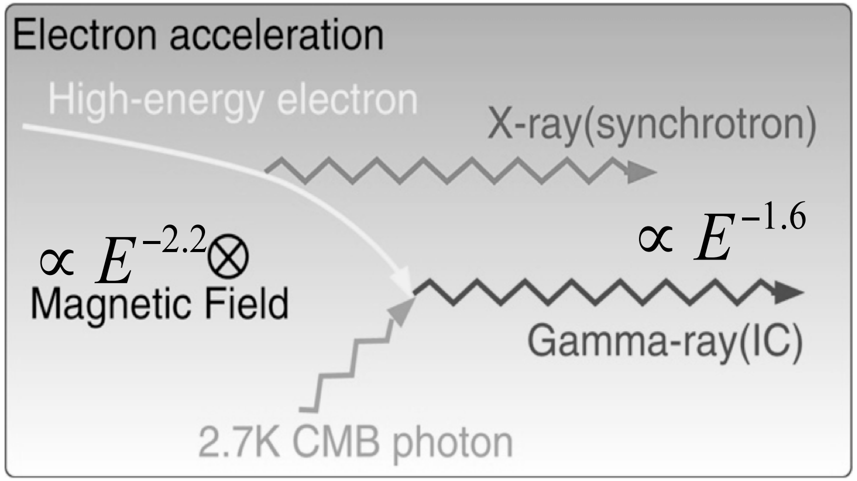
- Why go to such high energies?
- Why do we study elephants when mosquitoes are easier and more plentiful?
- Elephants and VHE gammas are more interesting!!

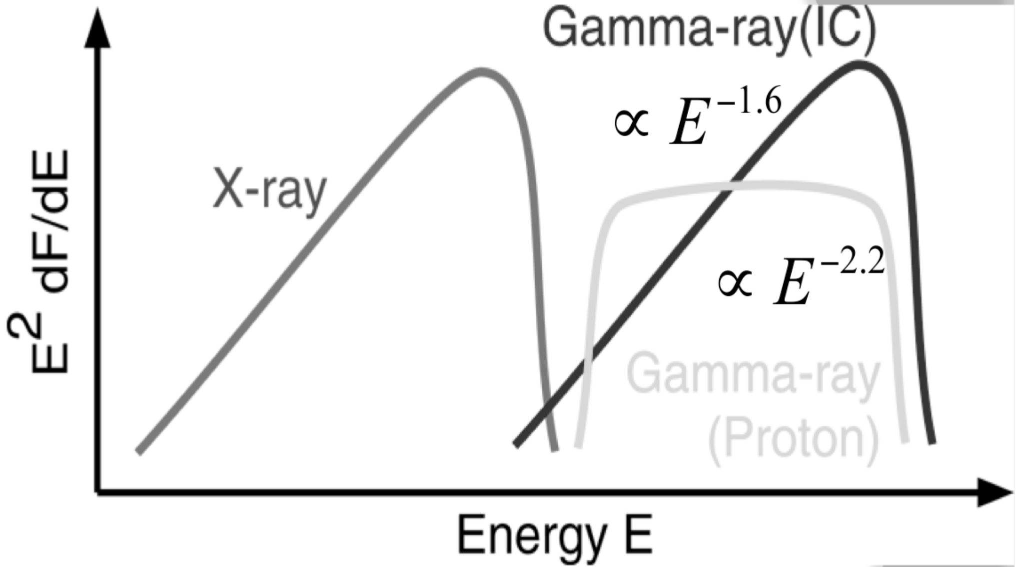
- To find the origin of the cosmic radiation

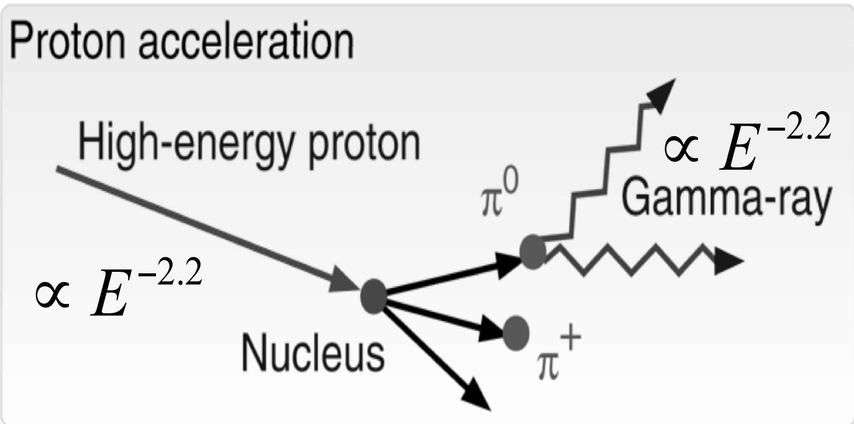
  (The Holy grail of cosmic ray studies!)


apparent
source
direction

Gamma-Ray Emission Processes(1)
Astrophysical process



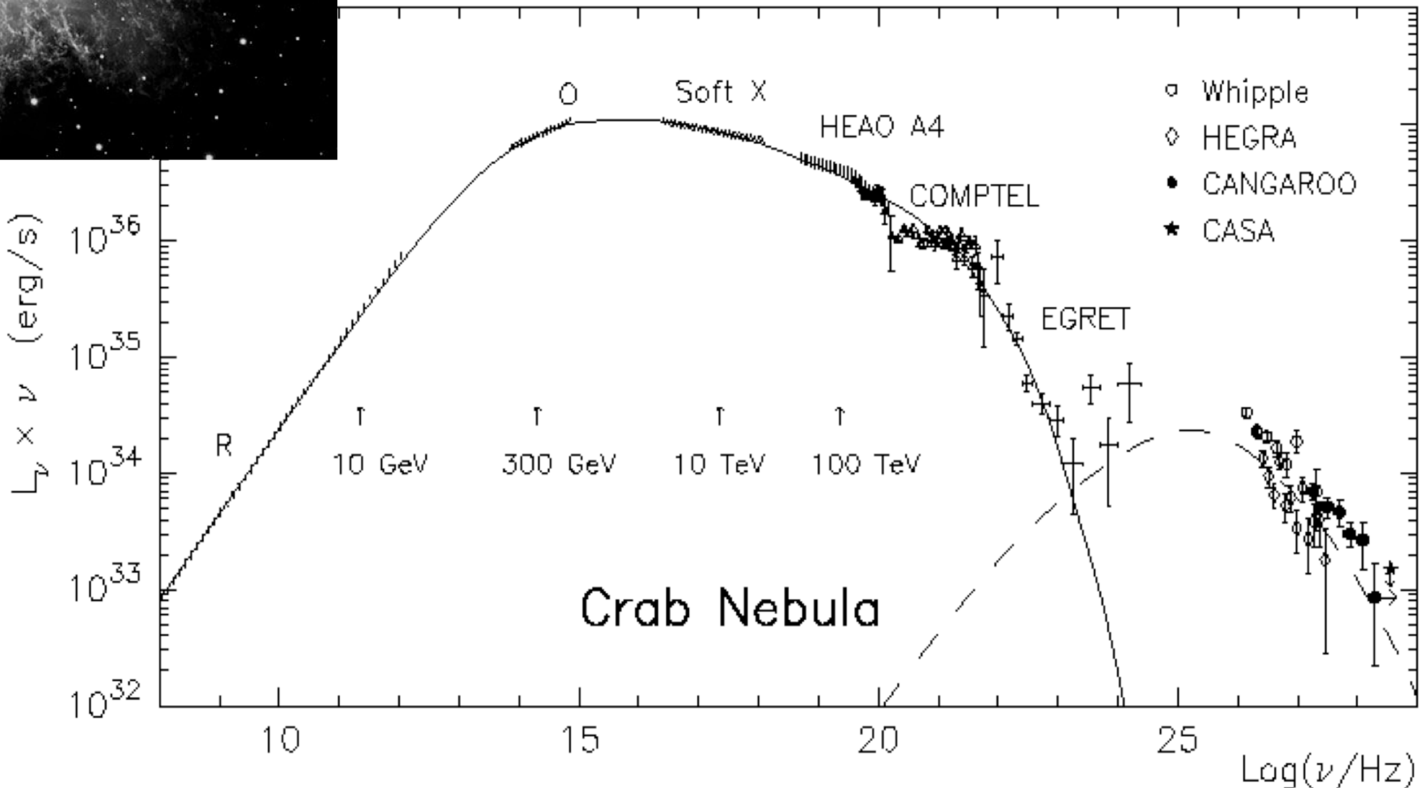




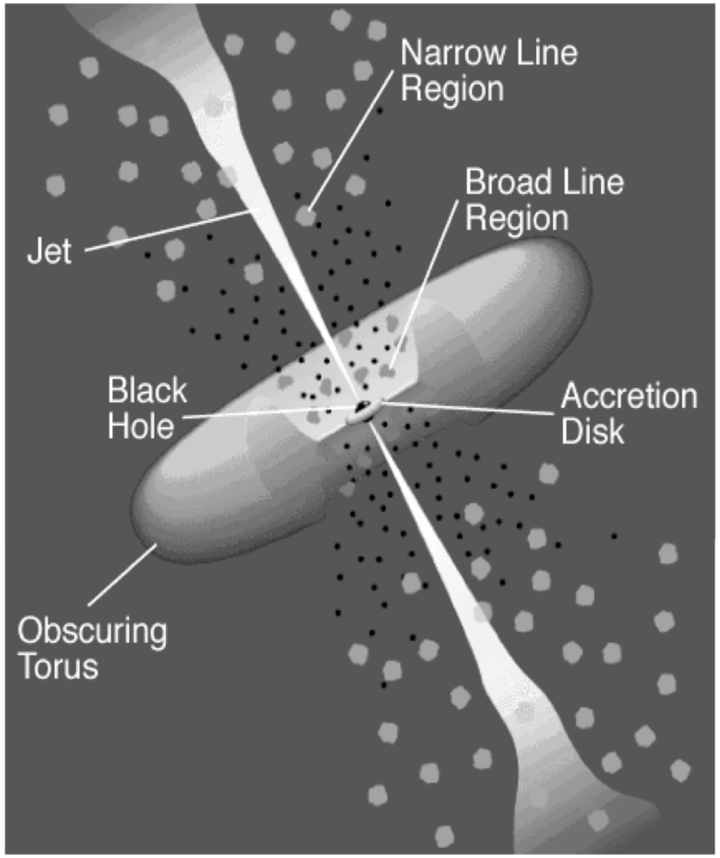
$$\left(\frac{dE}{dt}\right)_{\mathrm{I.C.}} = \frac{4}{3}\sigma_{\mathrm{T}}\, c\, \gamma_{\mathrm{max}}^{2}\, \mathrm{U}_{\mathrm{photon}}$$

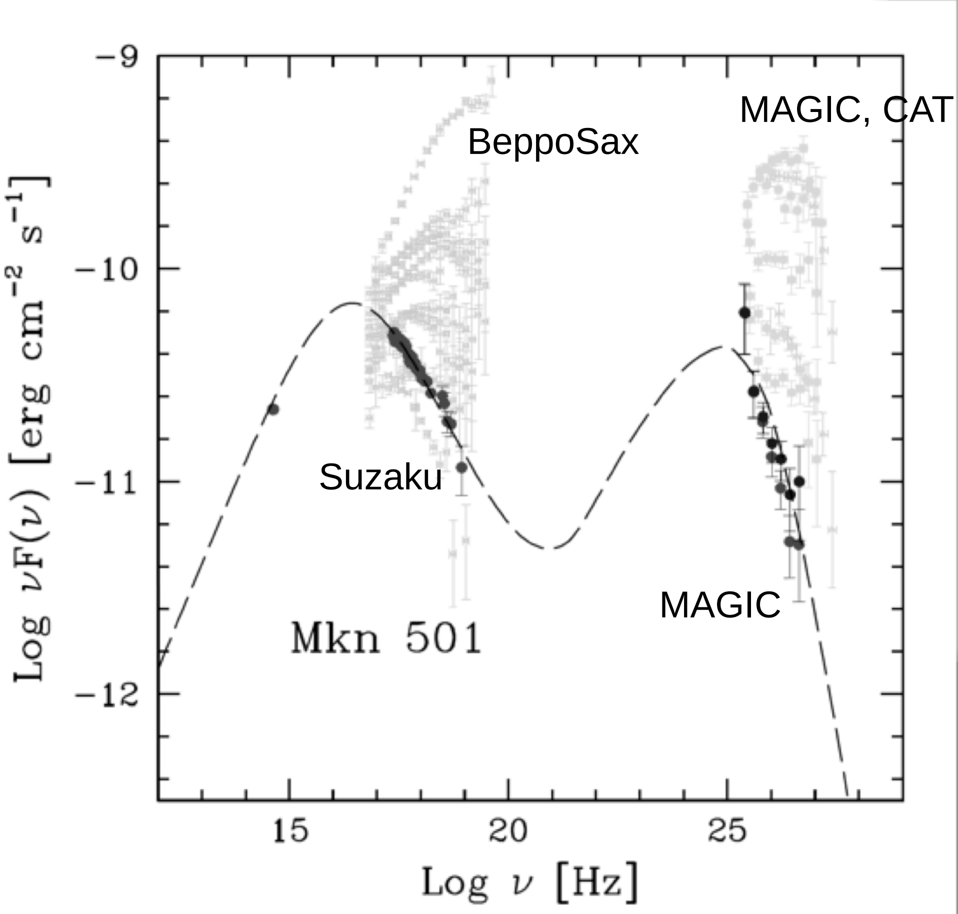
$$\left(\frac{dE}{dt}\right)_{\mathrm{Sync}} = \frac{4}{3}\sigma_{\mathrm{T}}\, c\gamma_{\mathrm{max}}^{2}\, \frac{B^2}{2}$$

Synchrotron and IC emission Example: Crab Nebula

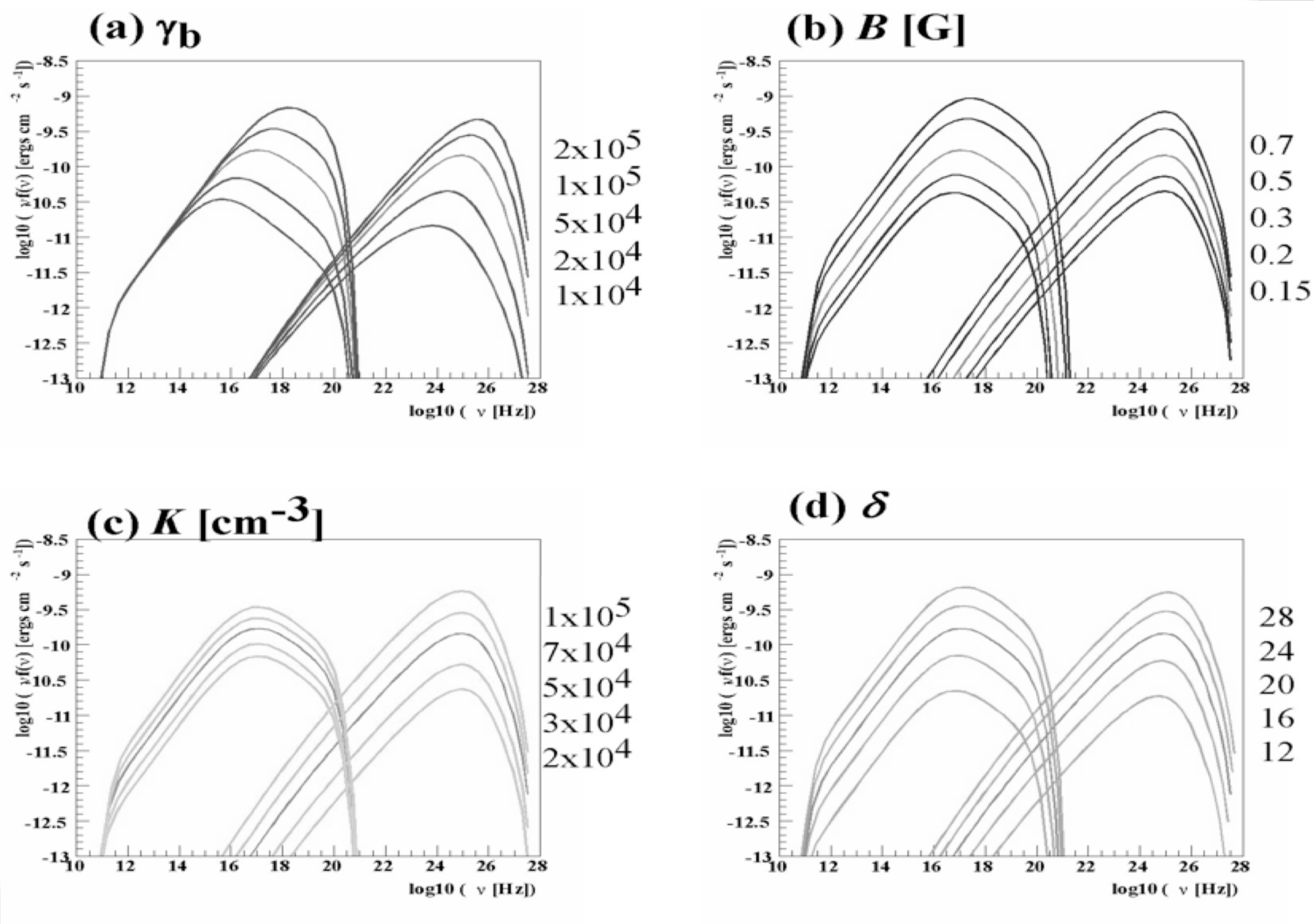


Synchrotron and IC emission Example: Mkn501 (AGN, Blazar)



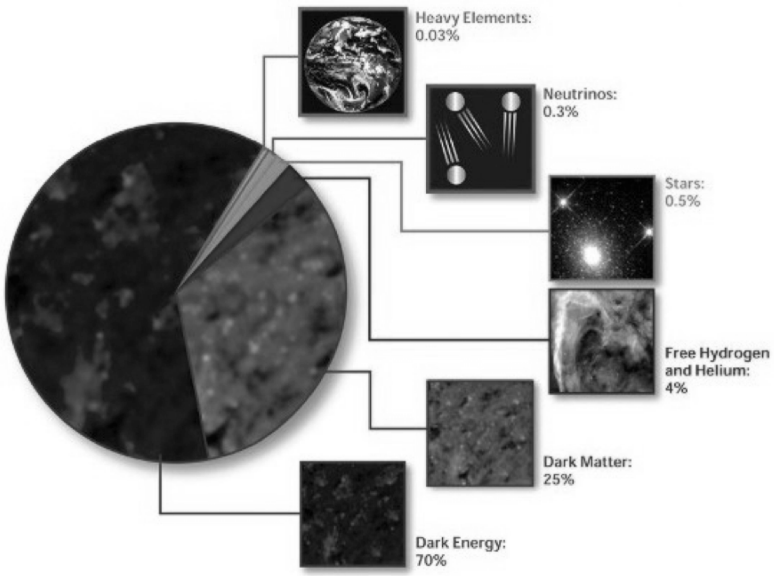


Physics parameter dependence in Spectra (SSC model)

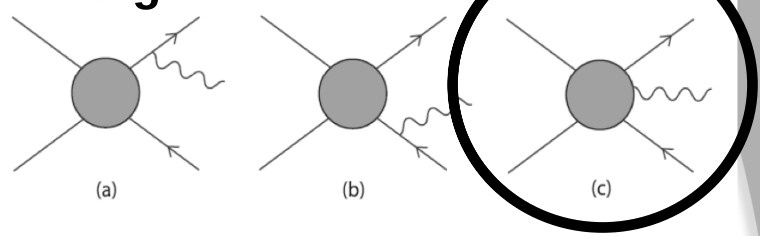


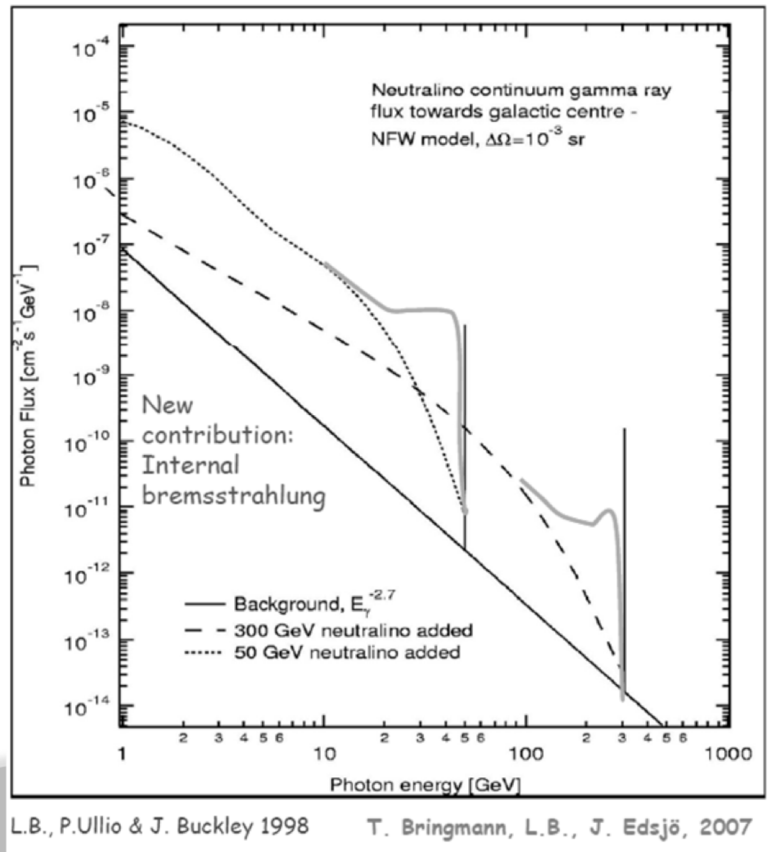
Gamma ray emission processes (2) Exotic processes (DM, Mini-BHs)

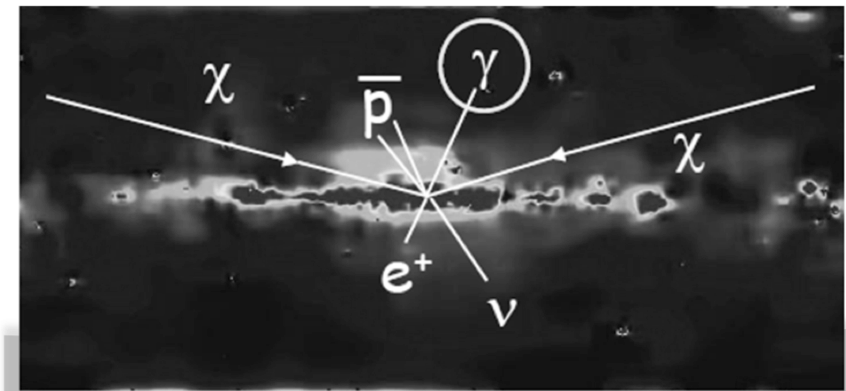
Dark Matter Annihilations



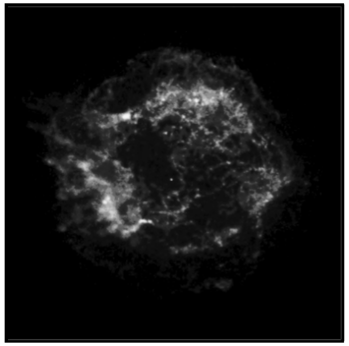
Bergstrom et al.



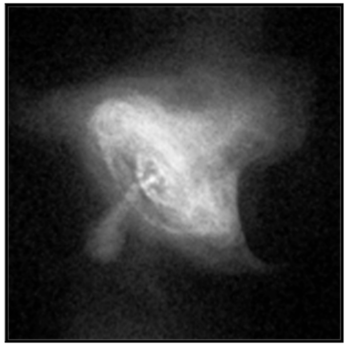




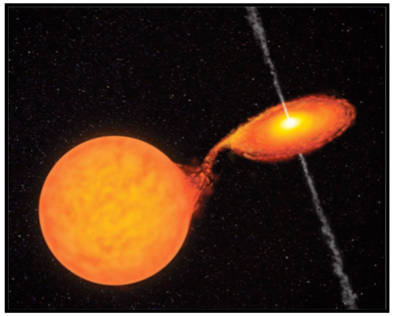
Scientific Objectives



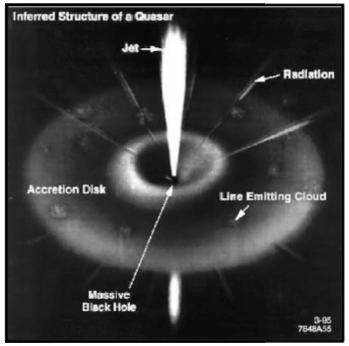
SNRs



Pulsars and PWNe

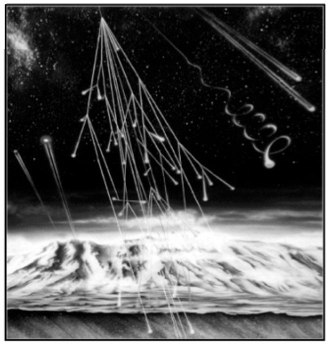


Micro quasars X-ray binaries

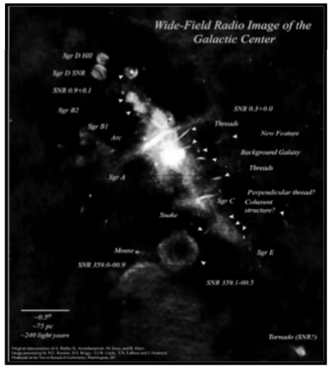


AGNs

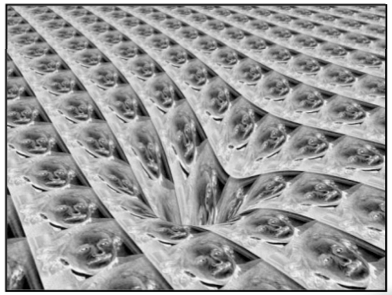
GRBs



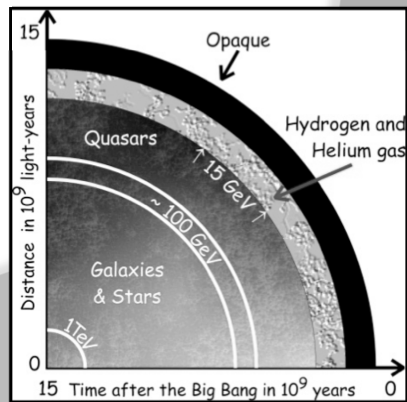
Origin of cosmic rays



Dark matter

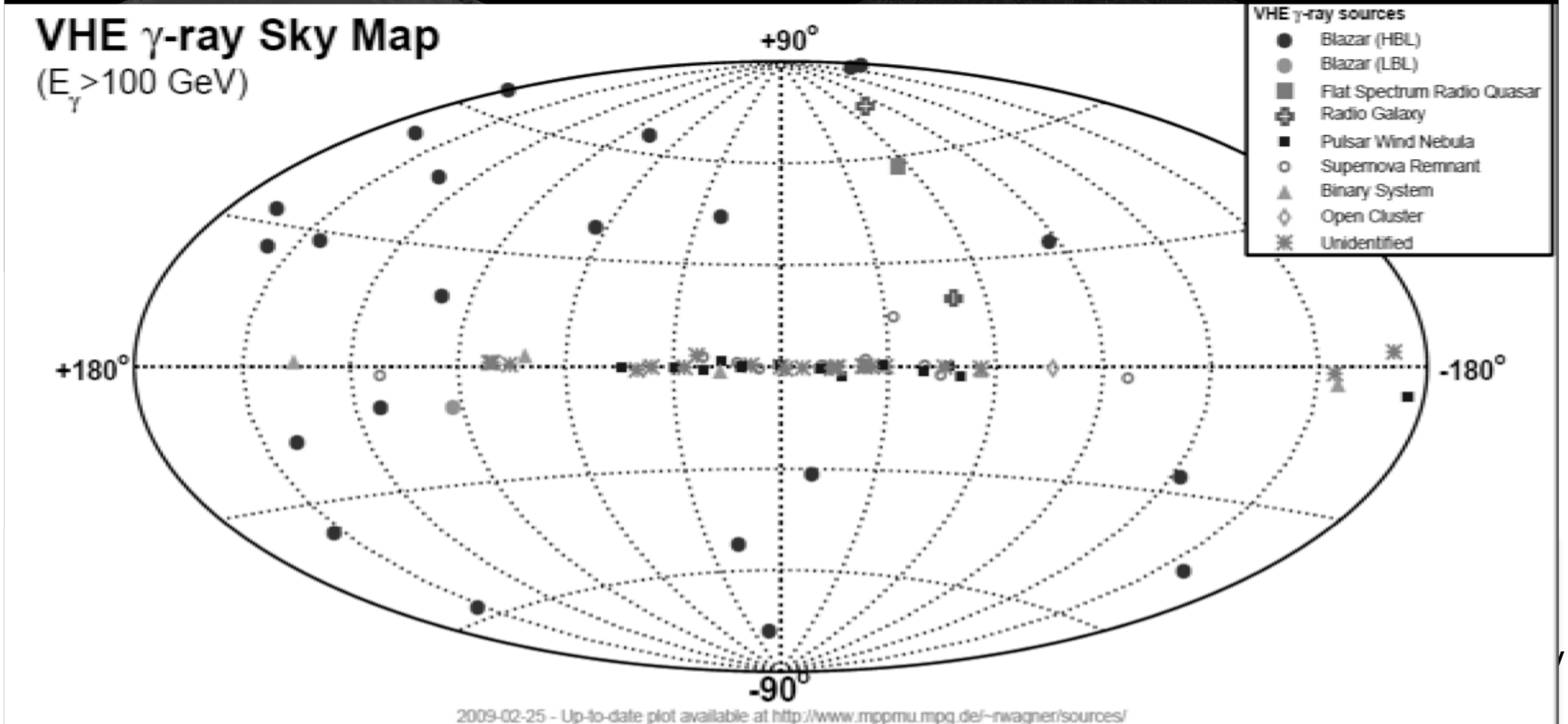


Space-time & relativity



Cosmology

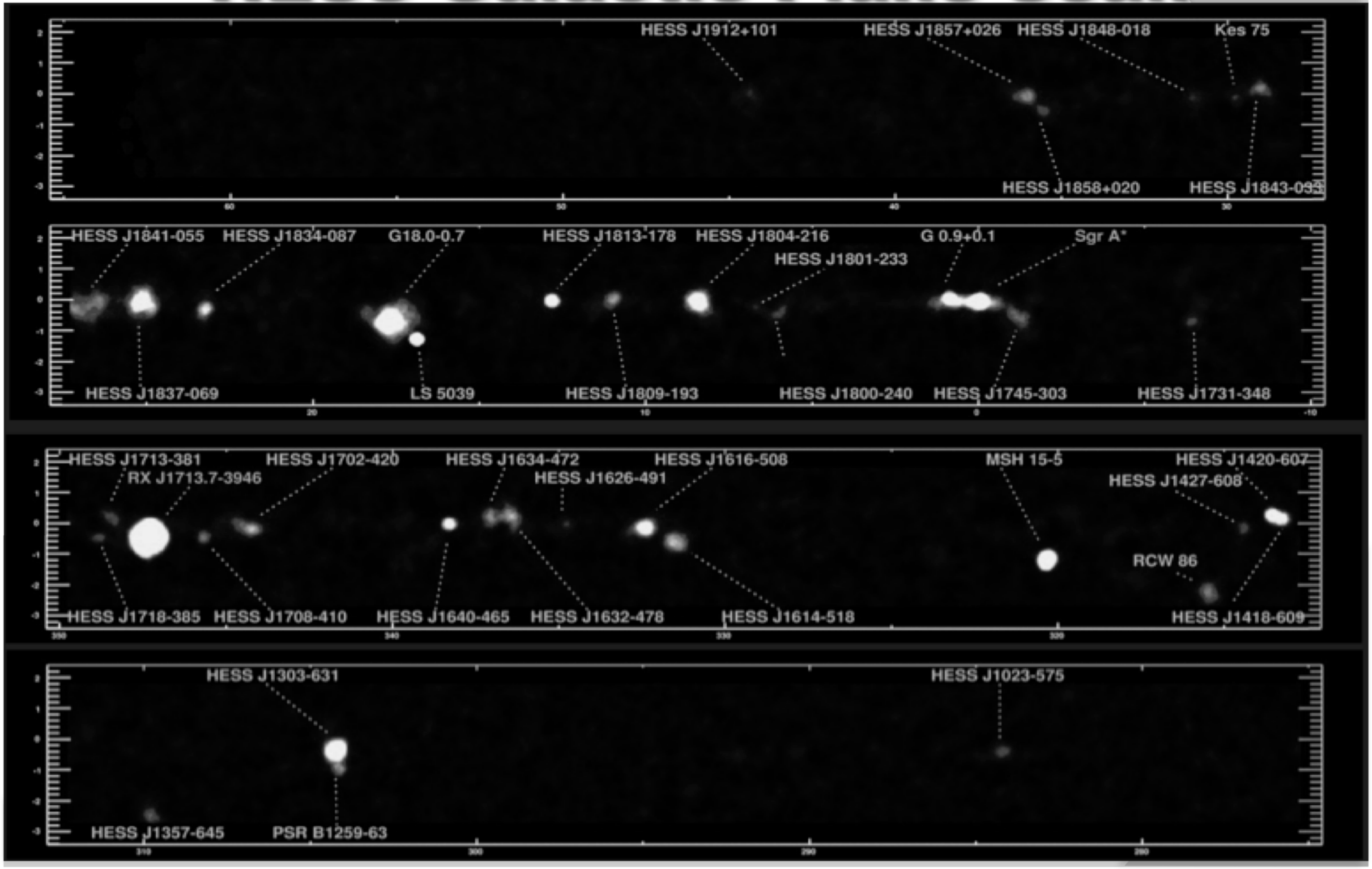
Universe in different energies



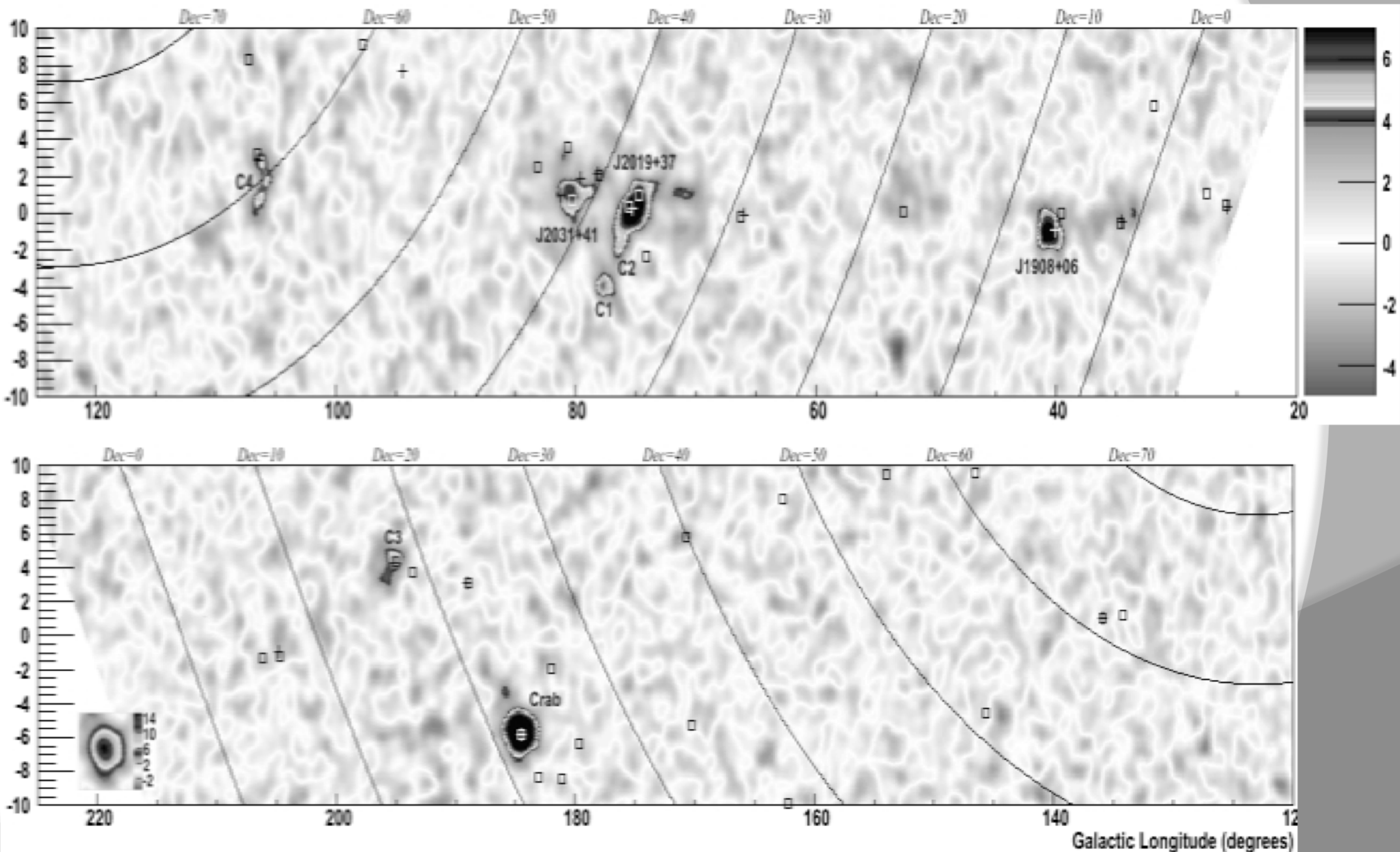
VHE Gamma Ray Astronomy is a newly emerging field
(81 sources today)

GALACTIC SOURC
SNRS, PWN

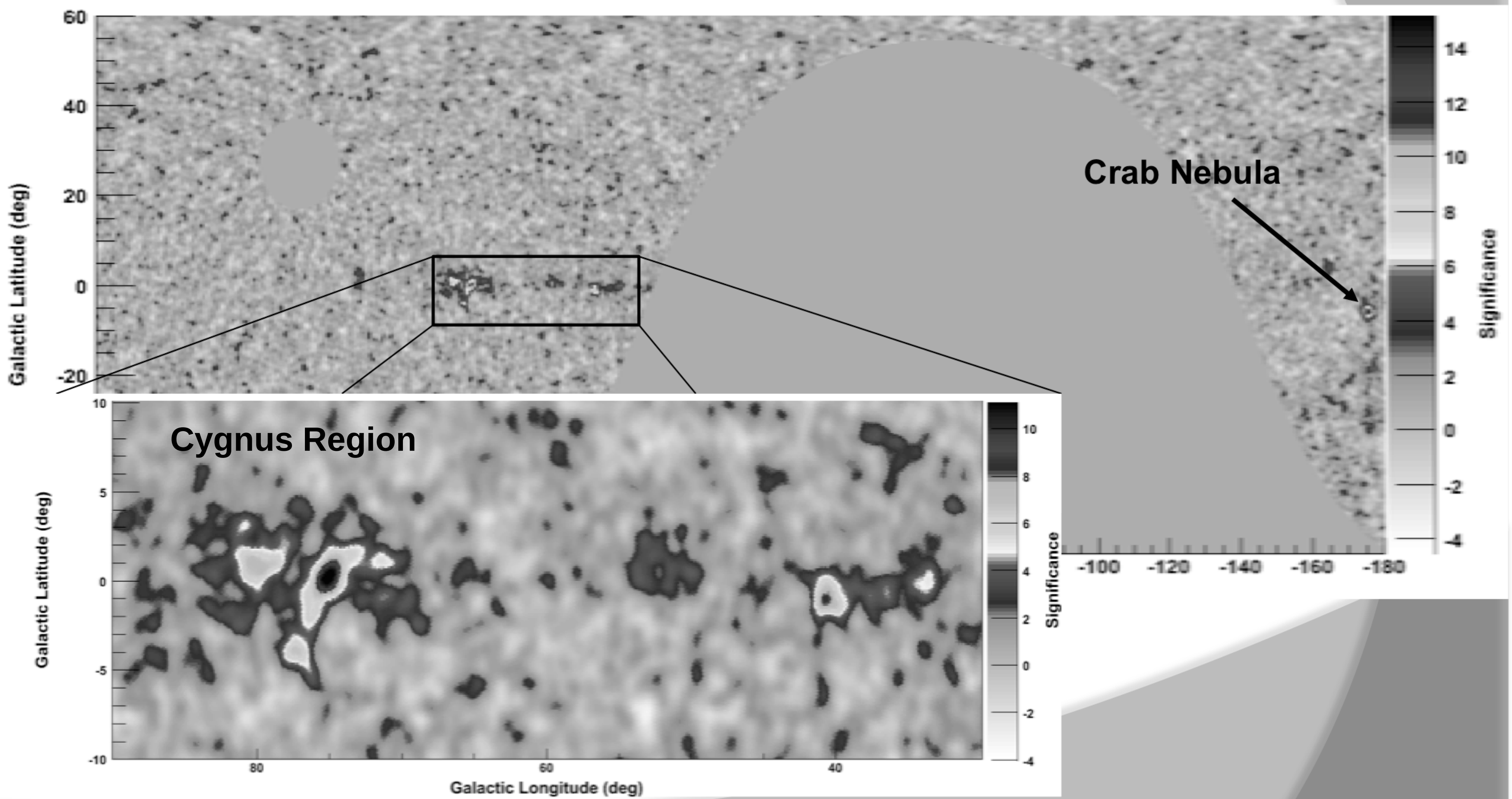
Great success!!
HESS Galactic Plane Scan



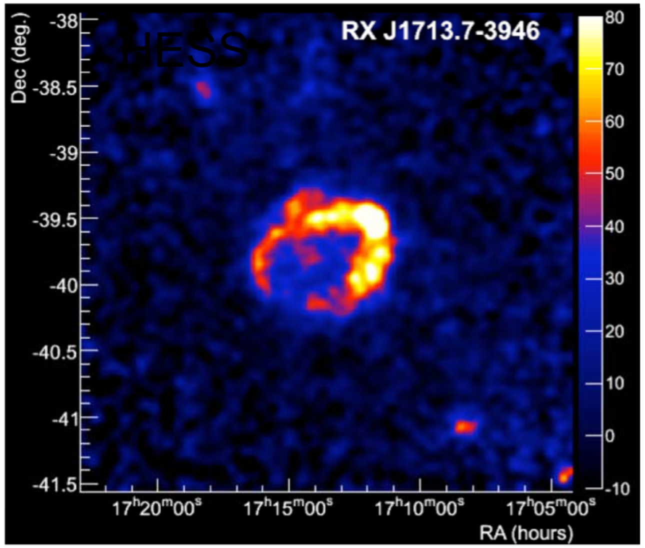
MILAGRO Galactic plane observation

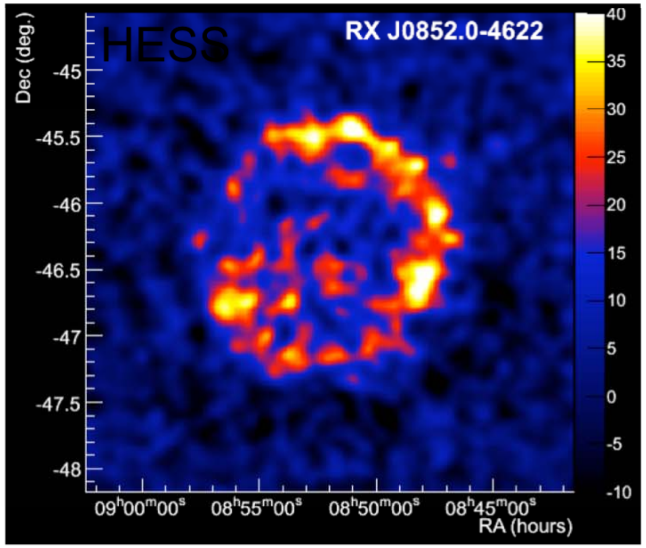


MILAGRO Observation in Galactic Coordinate

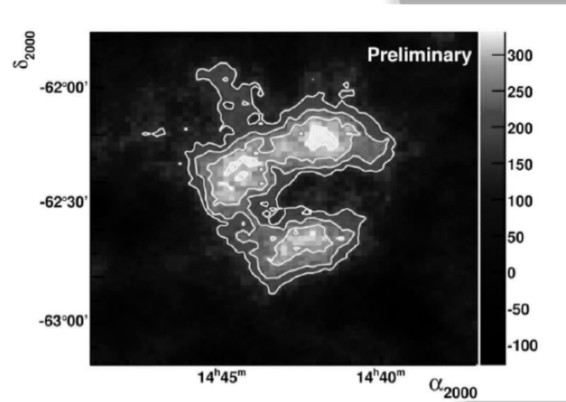


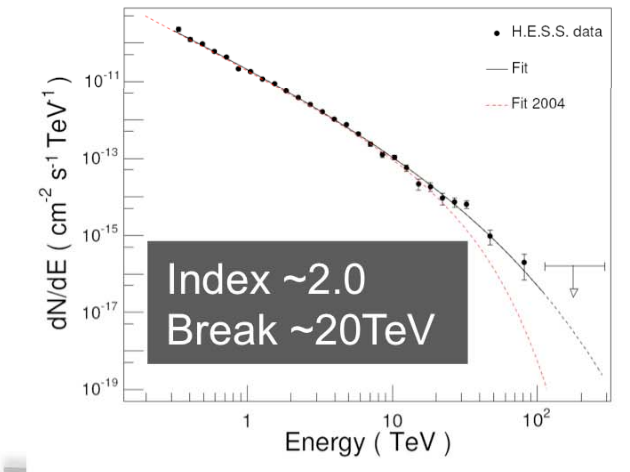
HESS: Shell type SNRs(7)
RX J1713, RX J0852, RCW86

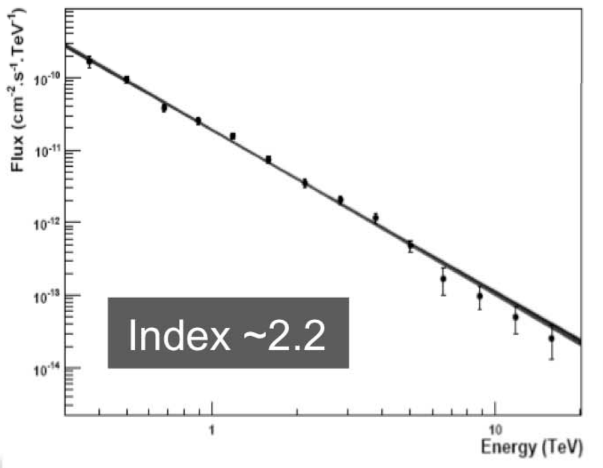


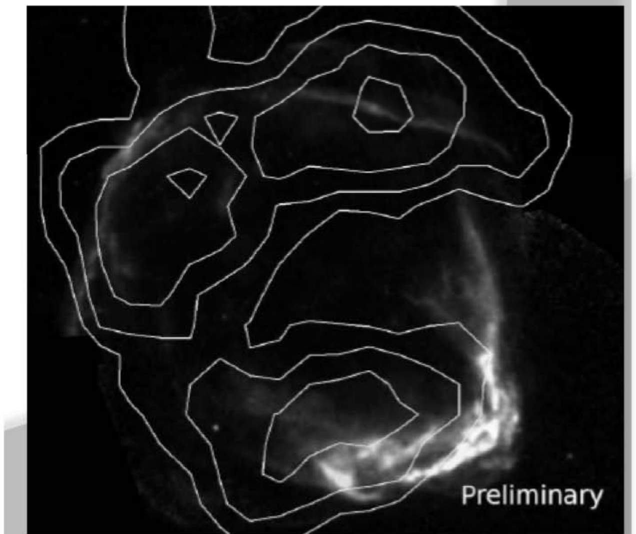


HESS RCW86



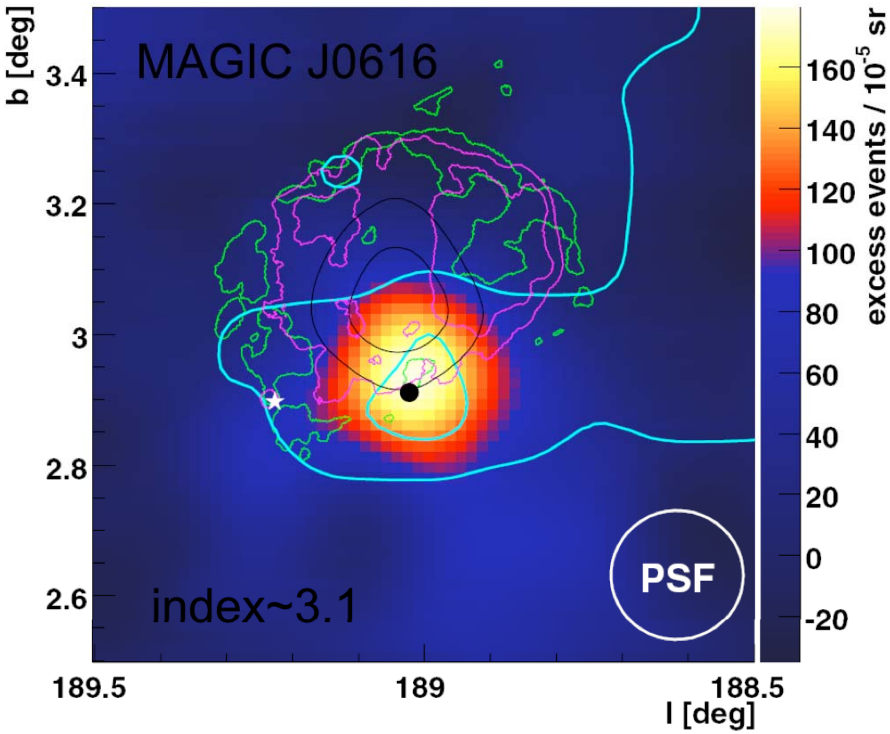


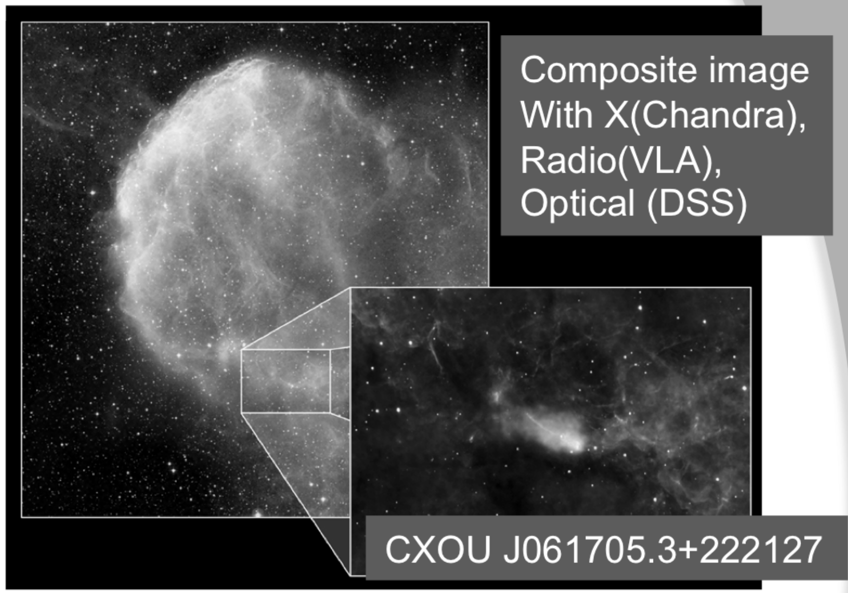


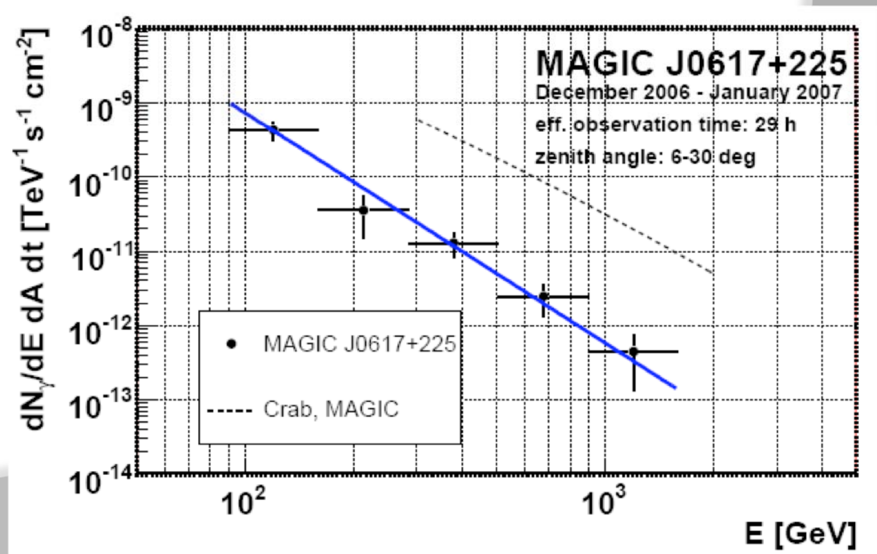


XMM-Newton, HESS

Shell type SNRs
IC443(MAGIC J0616)



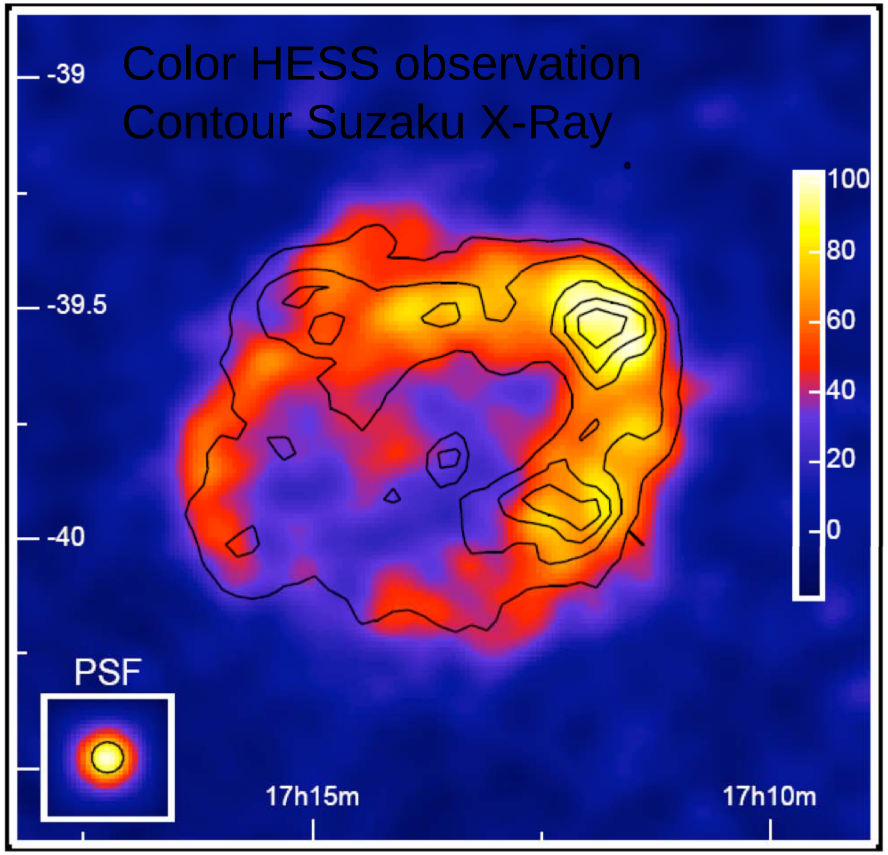


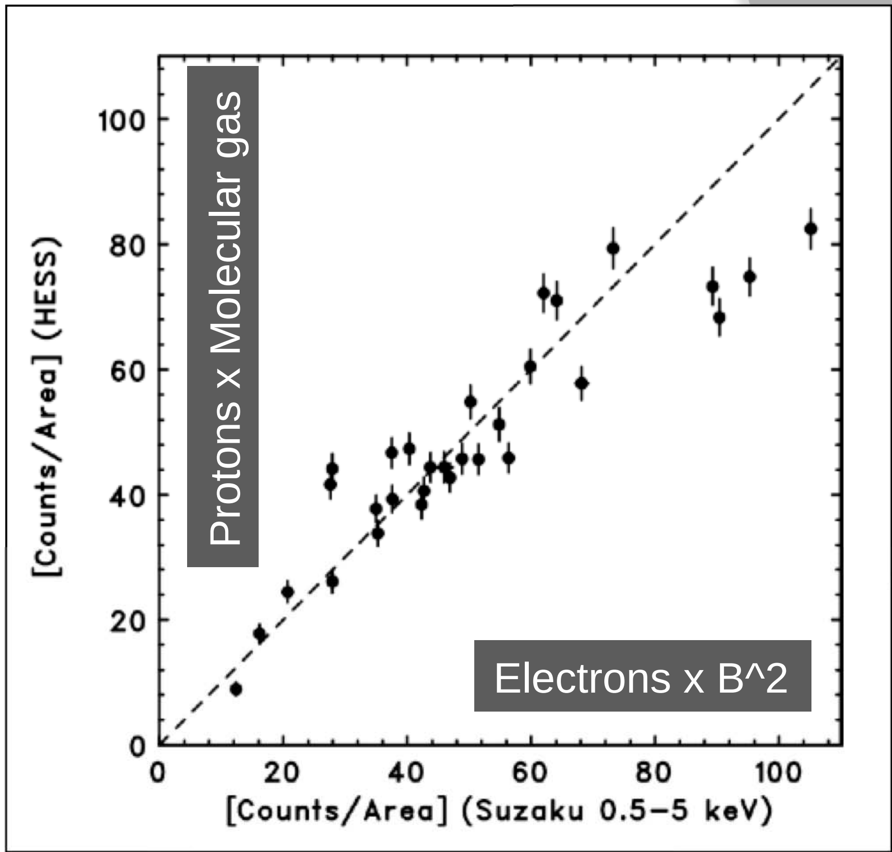


Molecular Cloud
Radio
X-ray
EGRET 3EG J0617+2238
Pulsar CXOU J061705.3+222127

RX J1713
X-ray vs. Gamma-Rays

SED and Strong B in the shell suggest Hadronic origin of VHE gammas

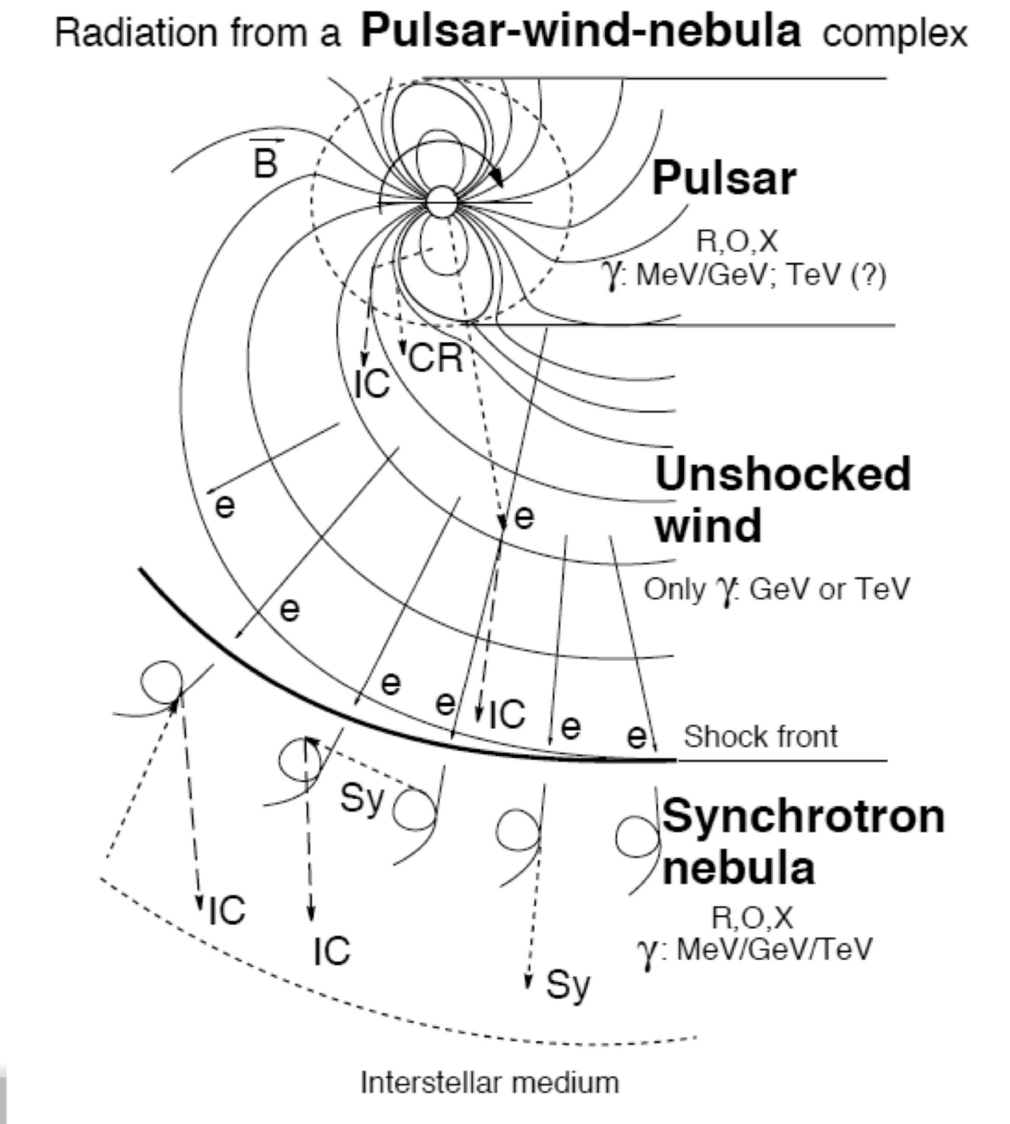




Y. Uchiyama, T. Takahashi
Texas Symp. 2006

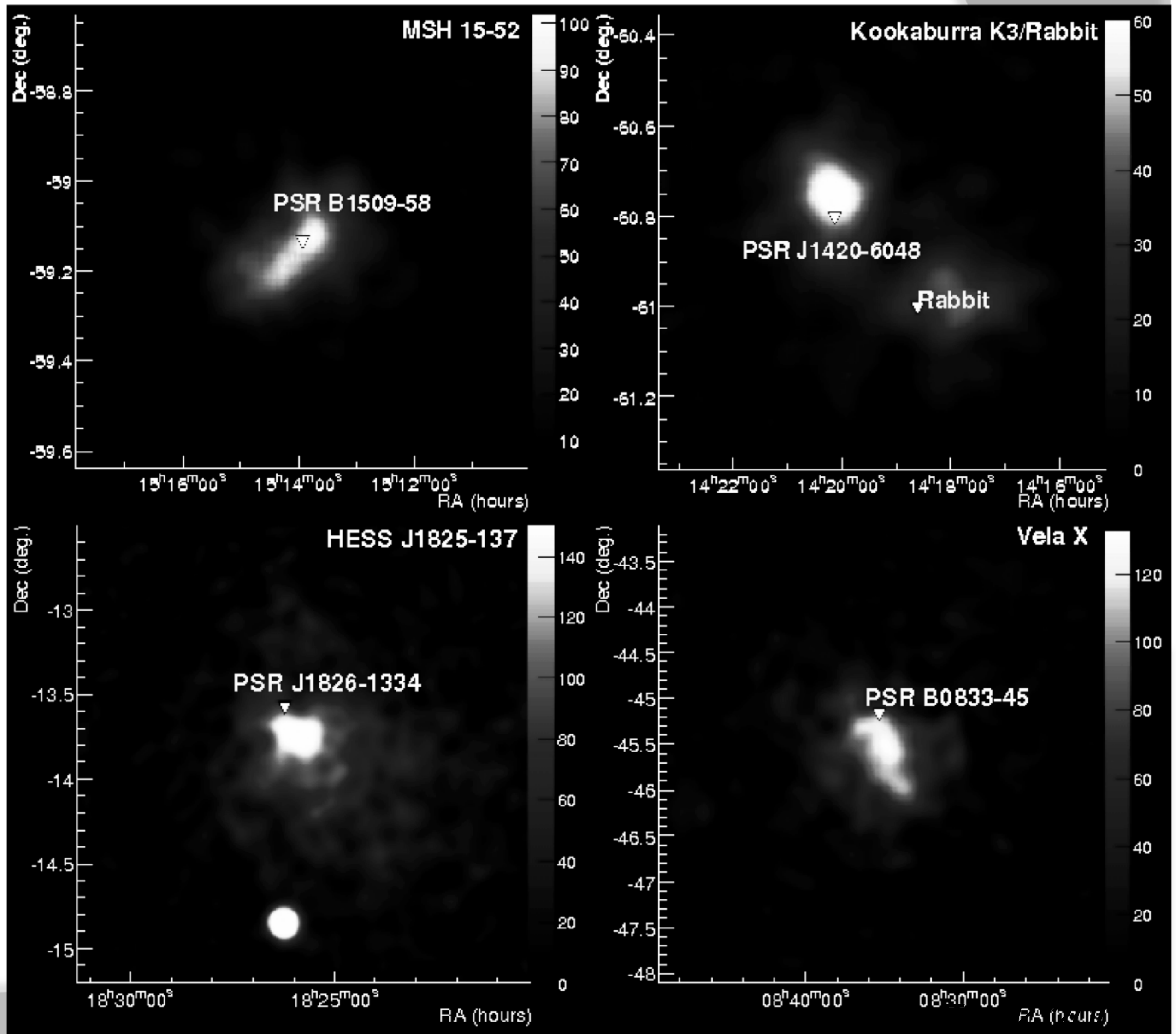

PULSAR WIN
NEBULA
MOST POPULAR SOURCES
GALA

Pulsar Wind-Nebula
by Aharonian and Vogovalov



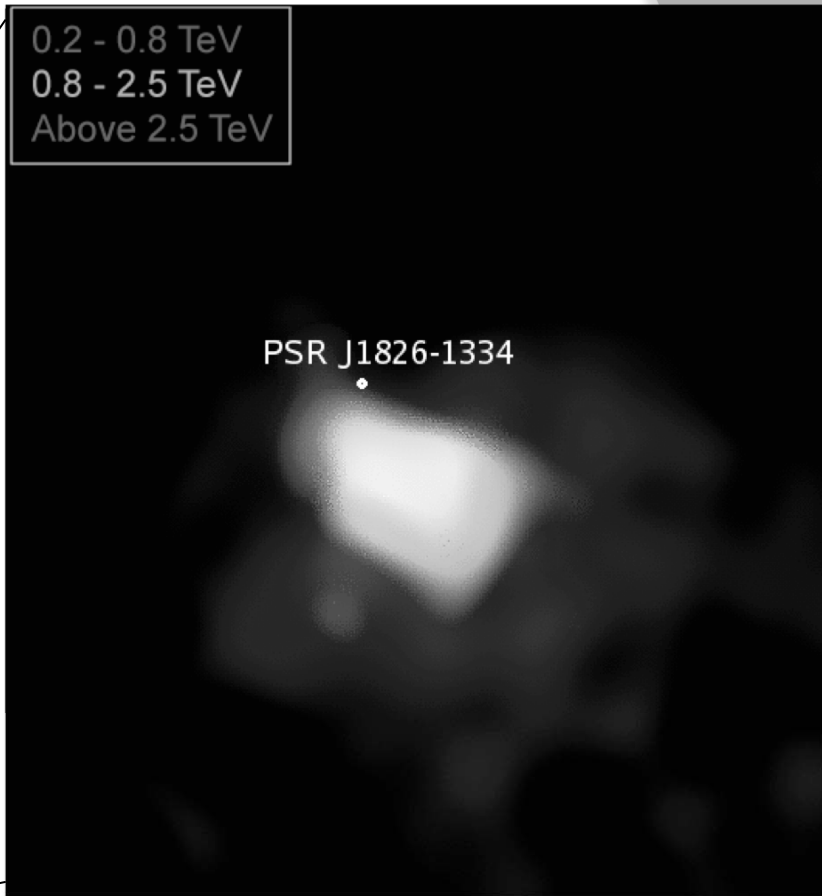
Pulsar Wind Nebulae observation by HESS

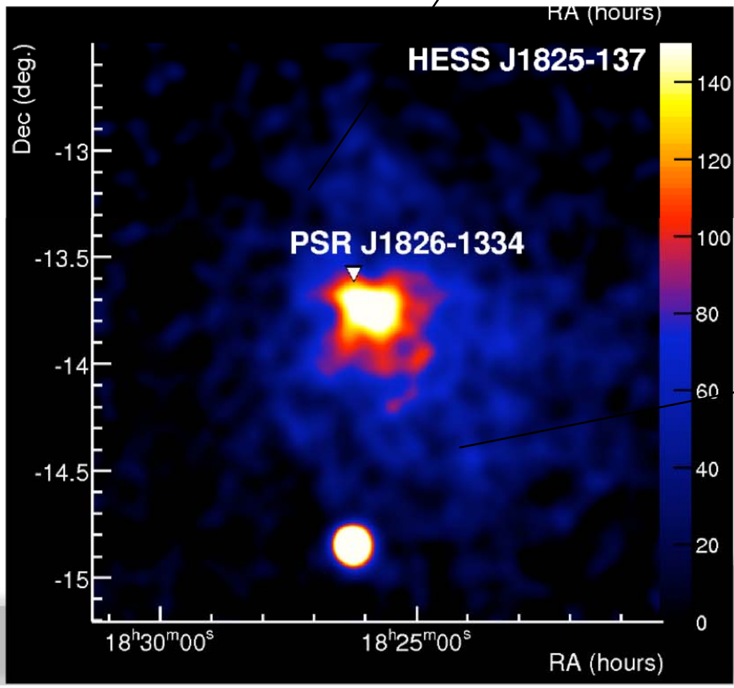
- Major galactic TeV source population
  - Associated with relatively young (<10^5 year old) and energetic pulsars
- Generally believed that we see inverse Compton emission of 1-100 TeV electrons
- 1% of Spin-down energy goes to VHE gamma rays



Pulsar Wind Nebula HESS J1825-137 Energy Dependent Morphology

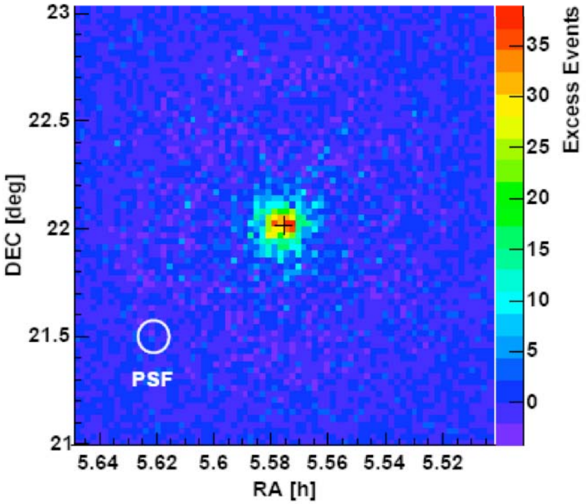
- HESS J1825-137 is energetic PWN
- Spectral steepening seen away from the pulsar
- Clear evidence for cooling of electrons in the Nebula

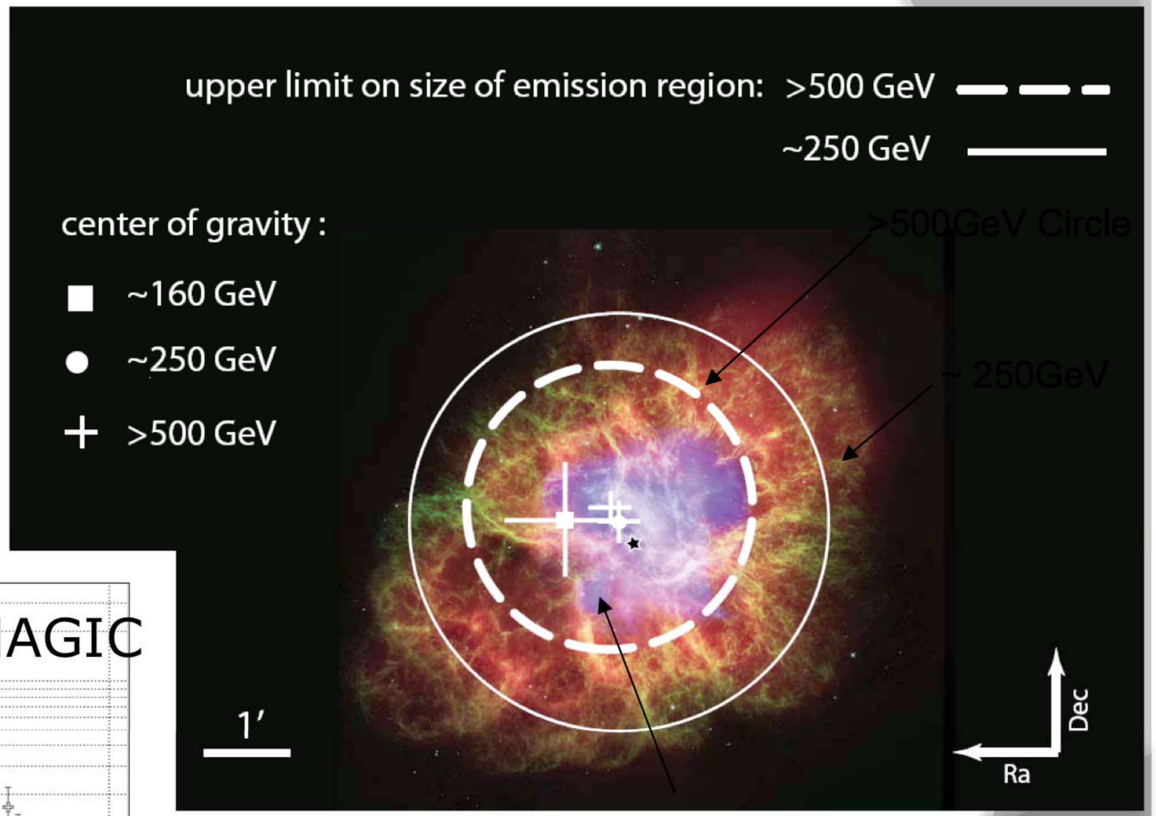




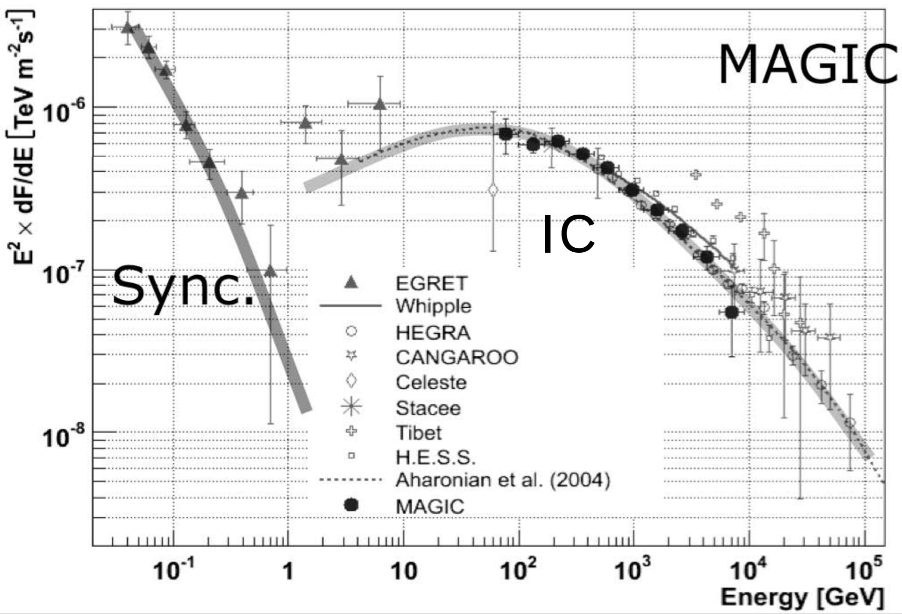
MAGIC Crab Nebula (PWN)

Gamma Ray Signals from Crab ~ 0.4Hz





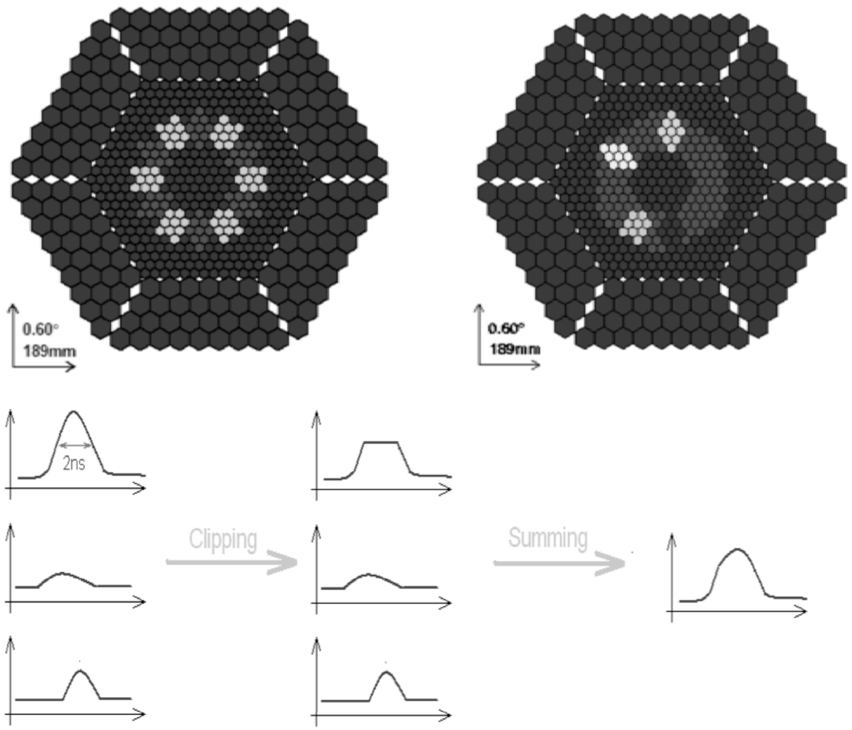
Position of Pulsar

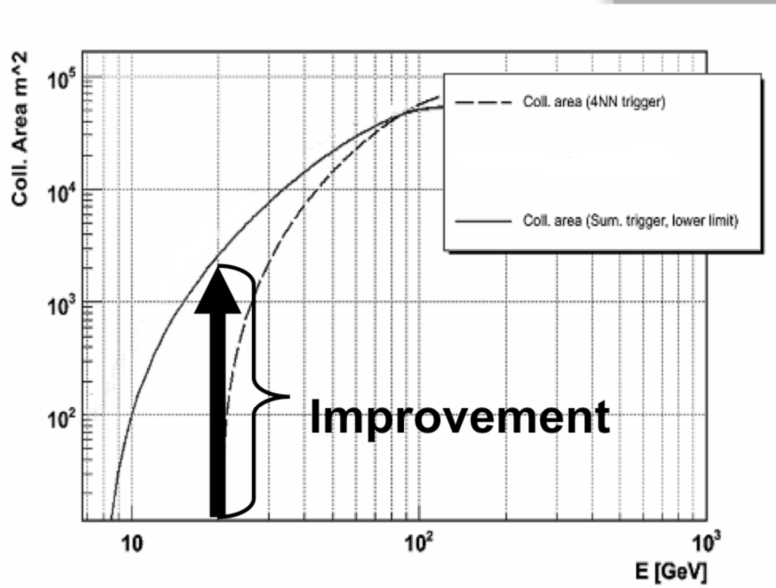


IC peak is estimated to be

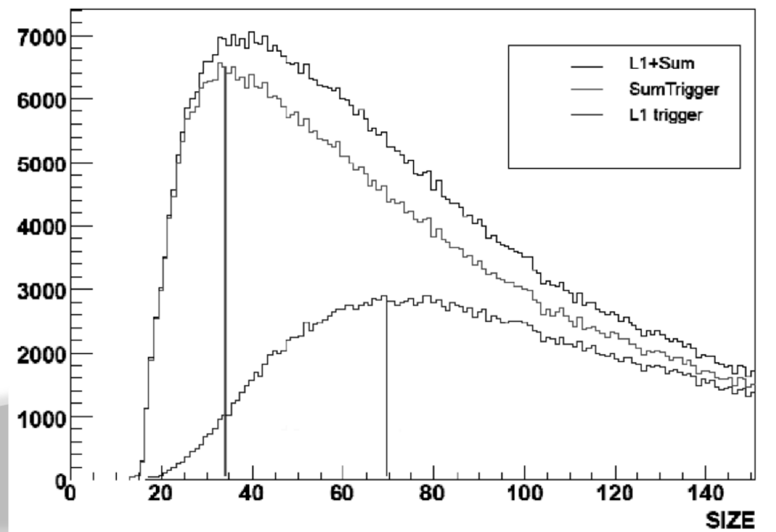
IC_peak = 77 ± 35 GeV

Sum Trigger (~25GeV)
analogue sum pattern trigger after clipping signal



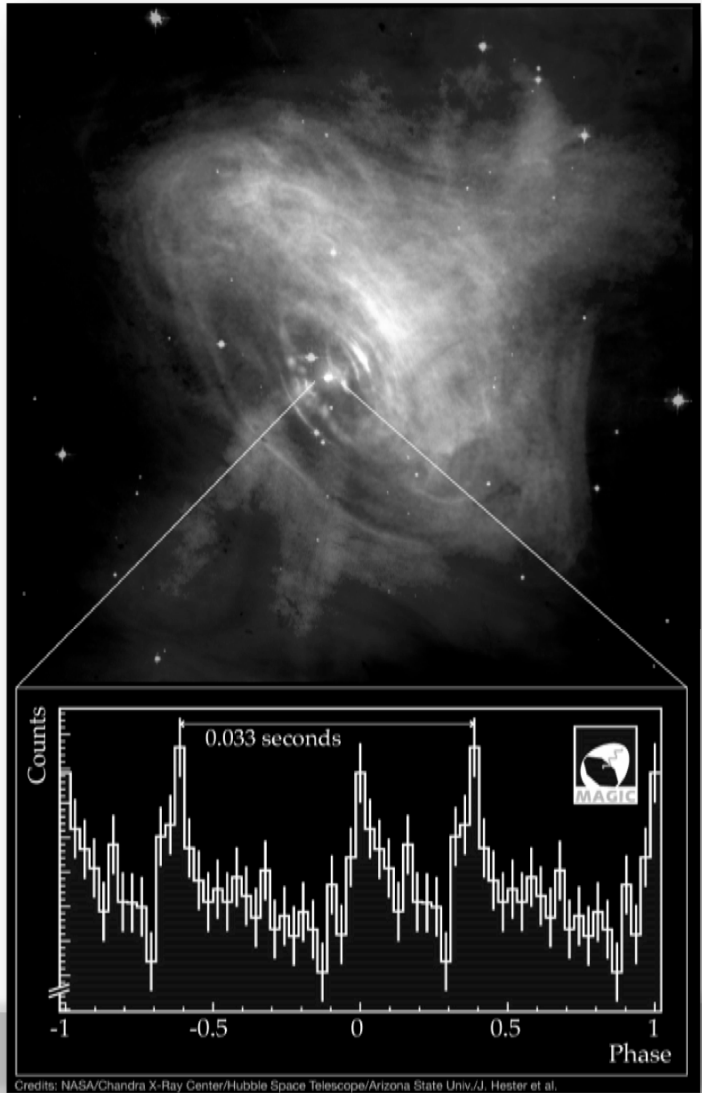


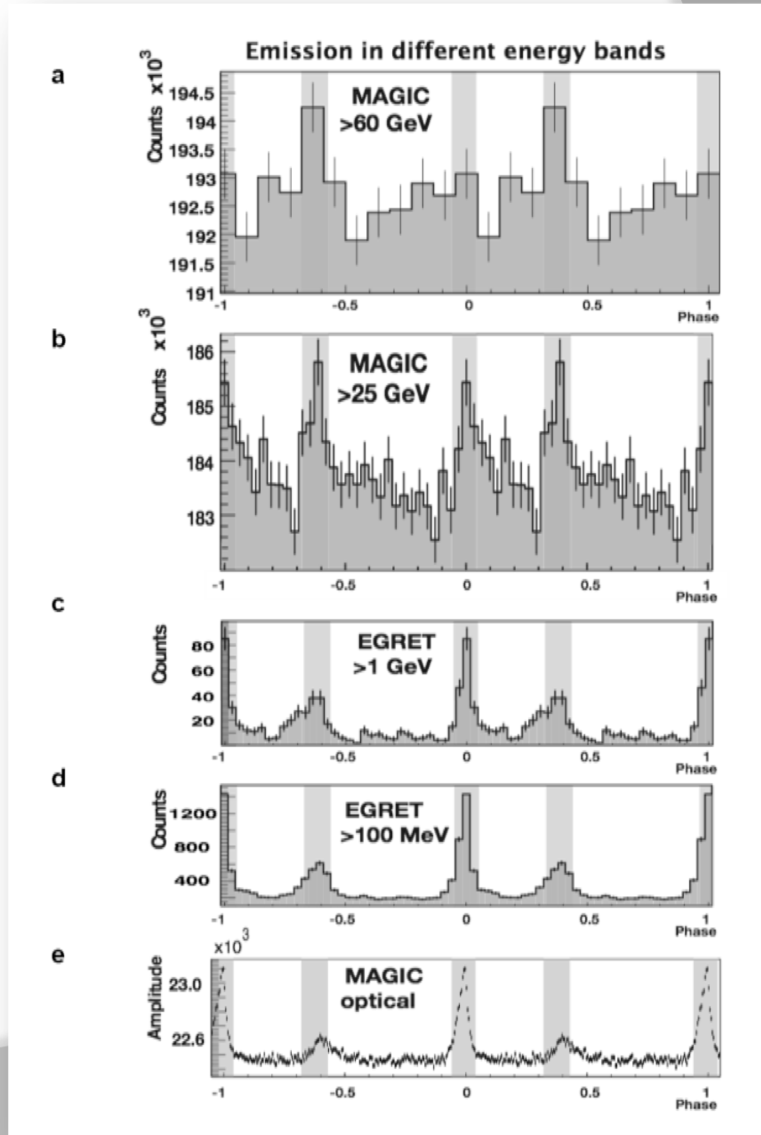
SIZE DIST for SUMTRIGGER (red) and for LVL1 (blue)



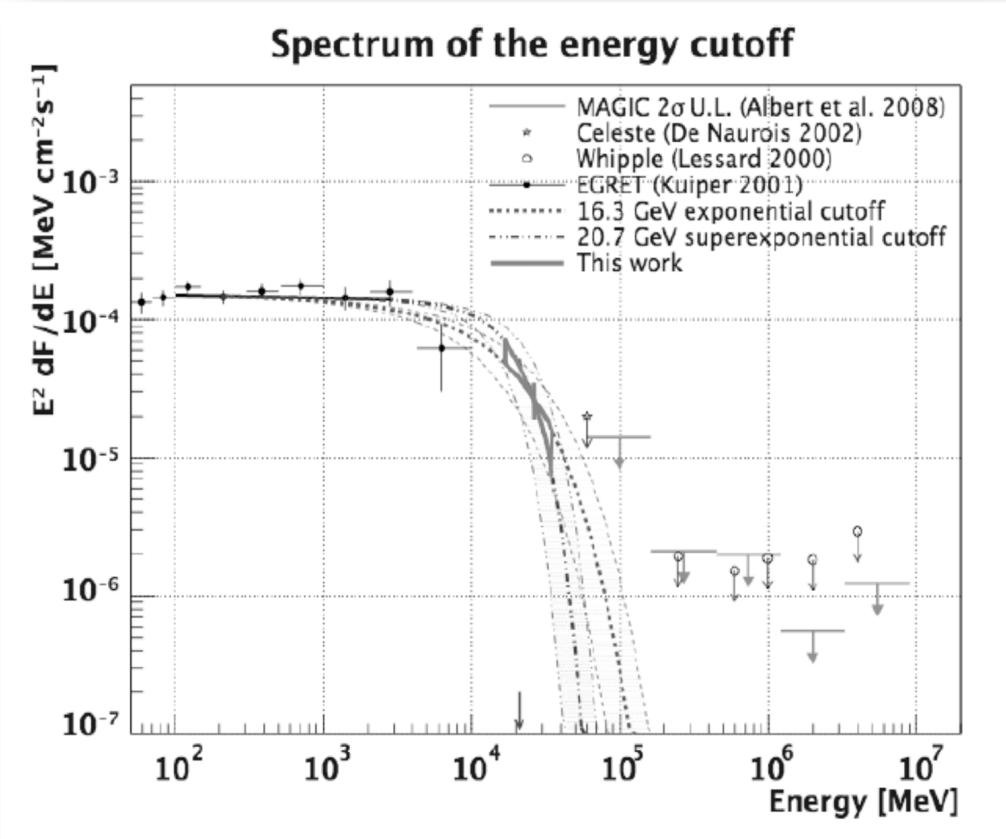
Detection of Crab Pulsar after 20 years long effort

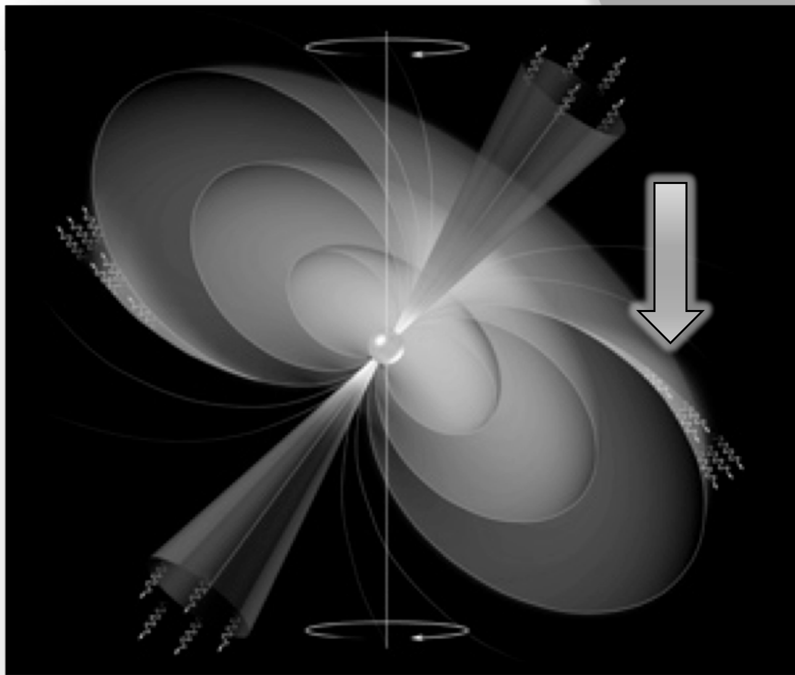
Published in Science in 2008

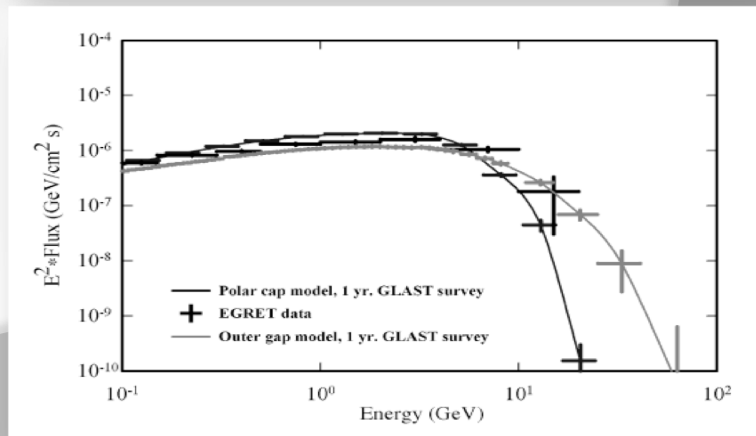


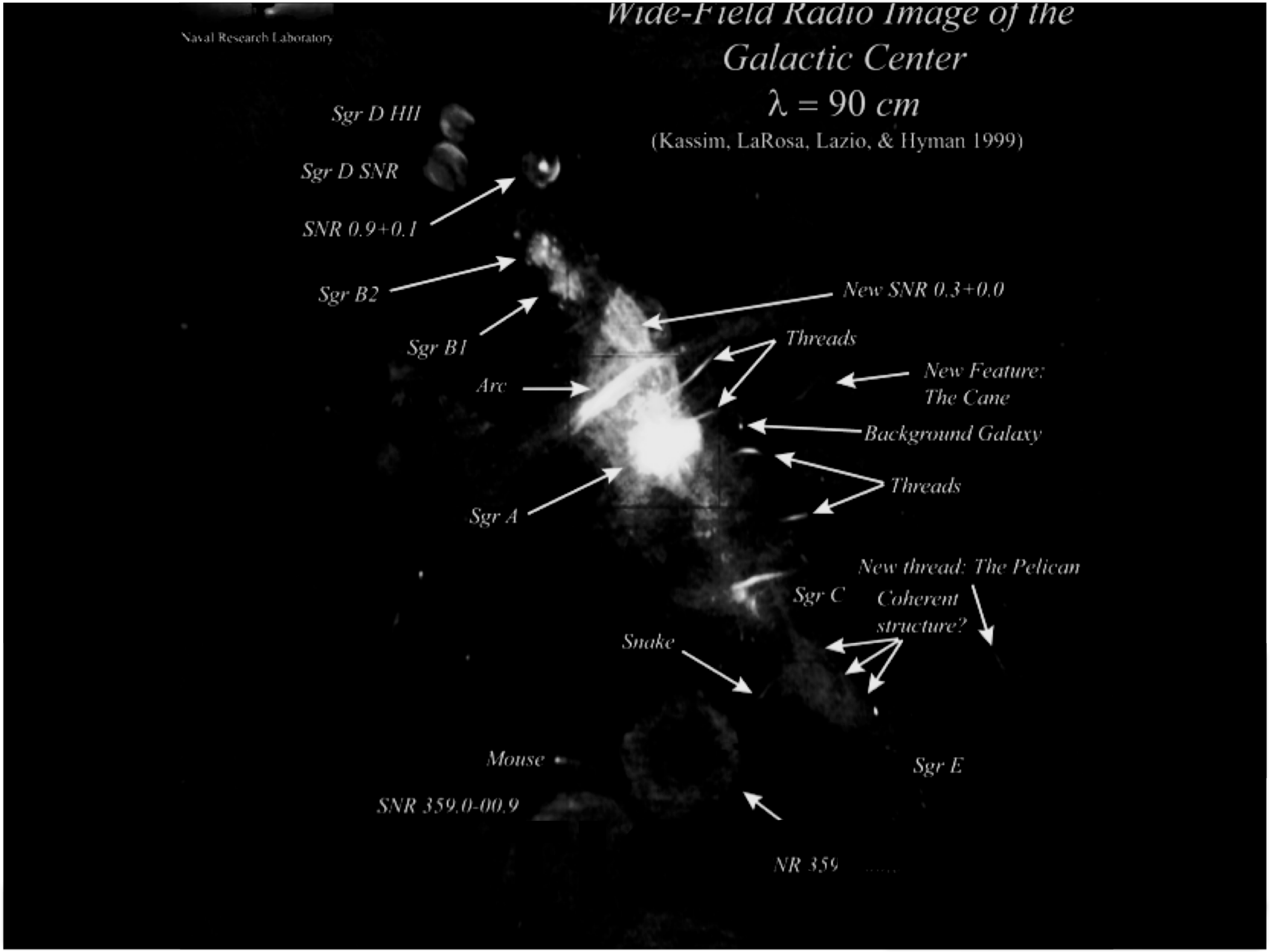


The MAGIC measurement clarified the emission mechanism

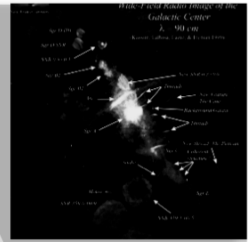




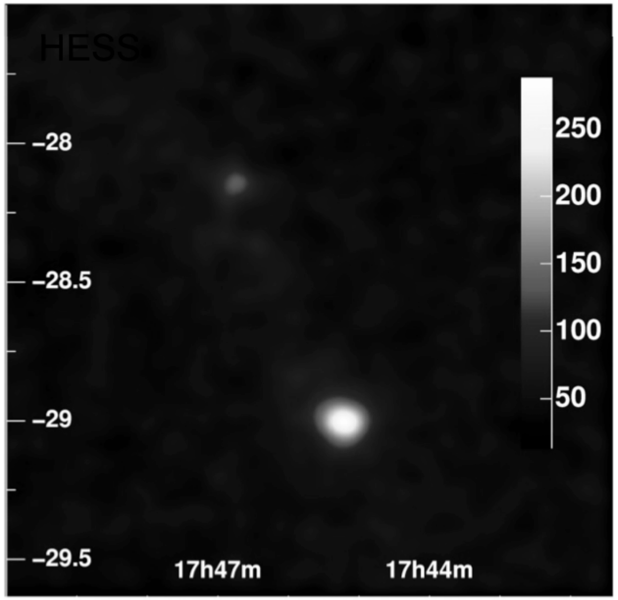


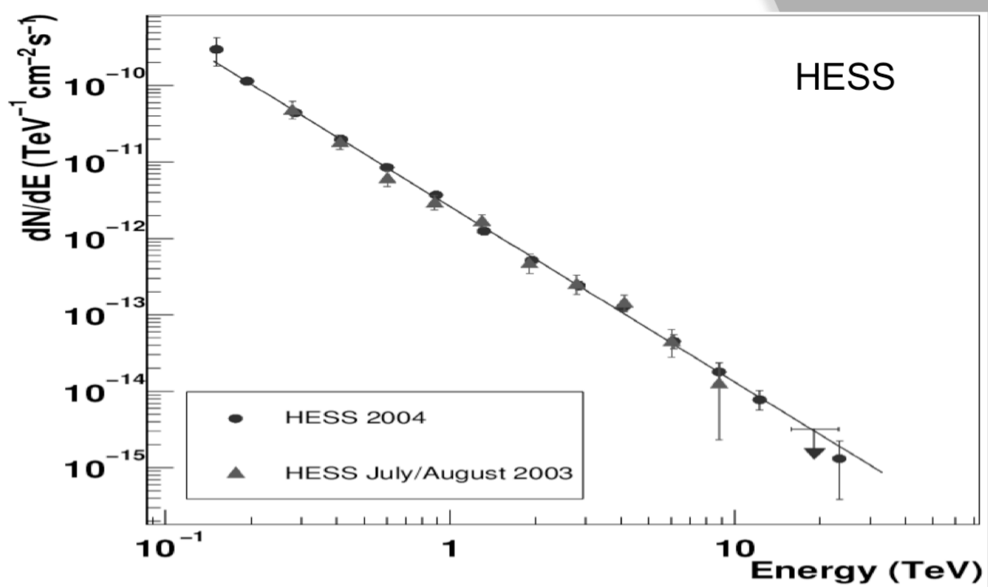

Naval Research Laboratory
Wide-Field Radio Image of the
Galactic Center
λ = 90 cm
(Kassim, LaRosa, Lazio, & Hyman 1999)
Sgr D HII
Sgr D SNR
SNR 0.9+0.1
Sgr B2
Sgr B1
New SNR 0.3+0.0
Threads
New Feature:
The Cane
Arc
Background Galaxy
Threads
Sgr A
New thread: The Pelican
Sgr C
Coherent
structure?
Snake
Mouse
Sgr E
SNR 359.0-00.9
NR 359

Galactic Center
B.H., SNR, DM?

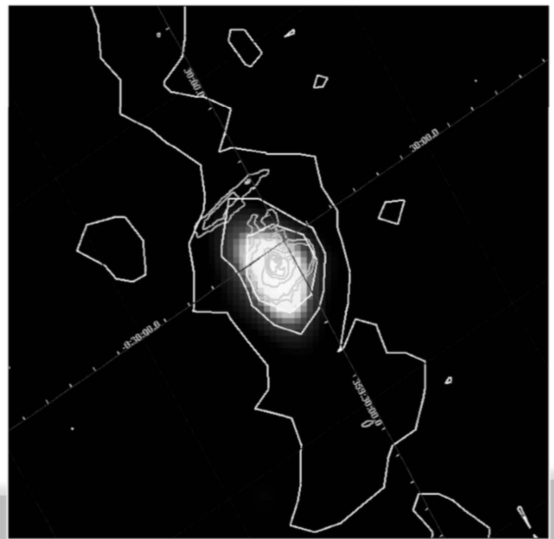


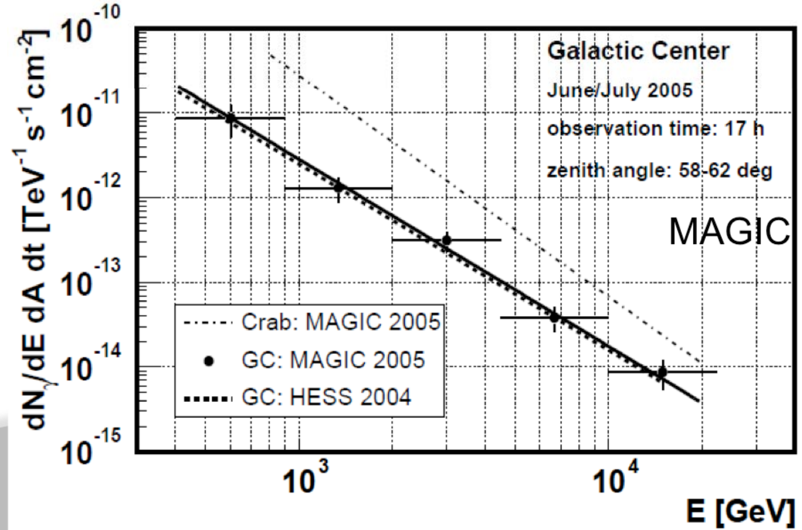
HESS
Observation



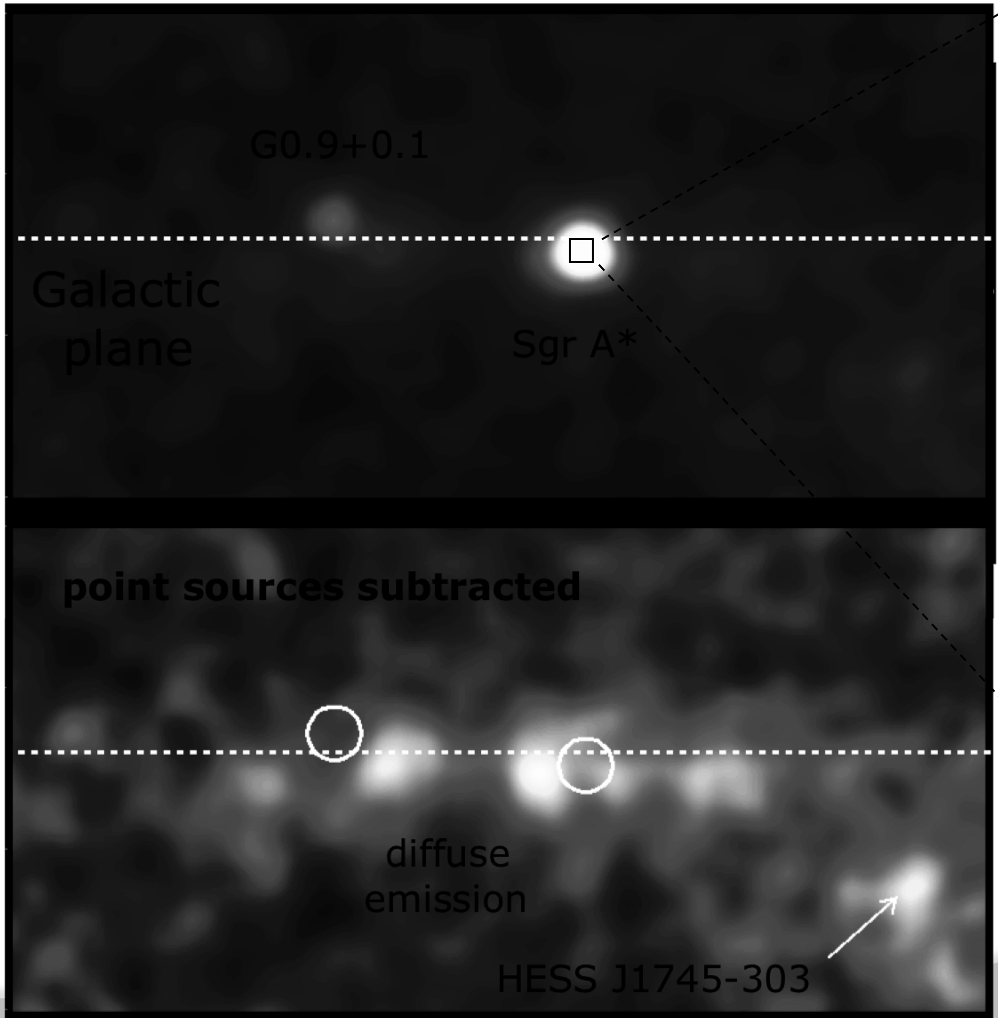


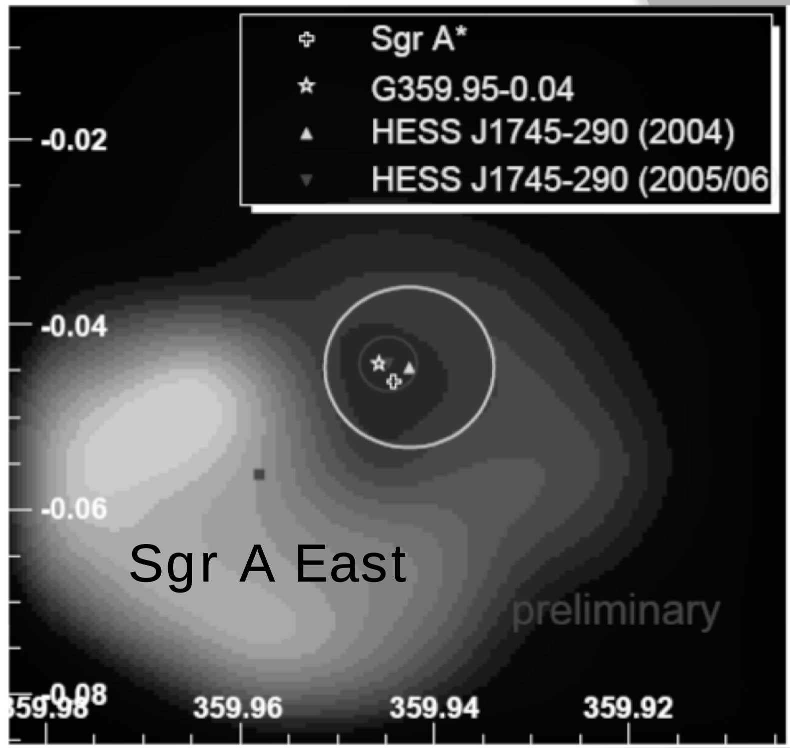
MAGIC
Observation





Galactic Center

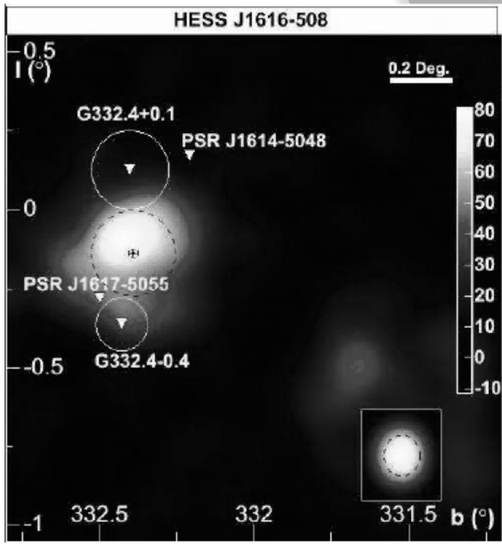




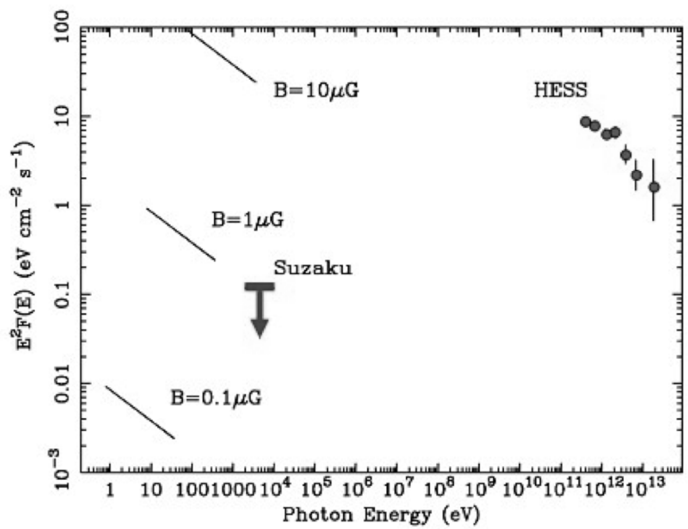
Error on GC source location:
6” stat., 6” syst.
(van Eldik, ICRC07)

Un-IDs (Dark Sources)

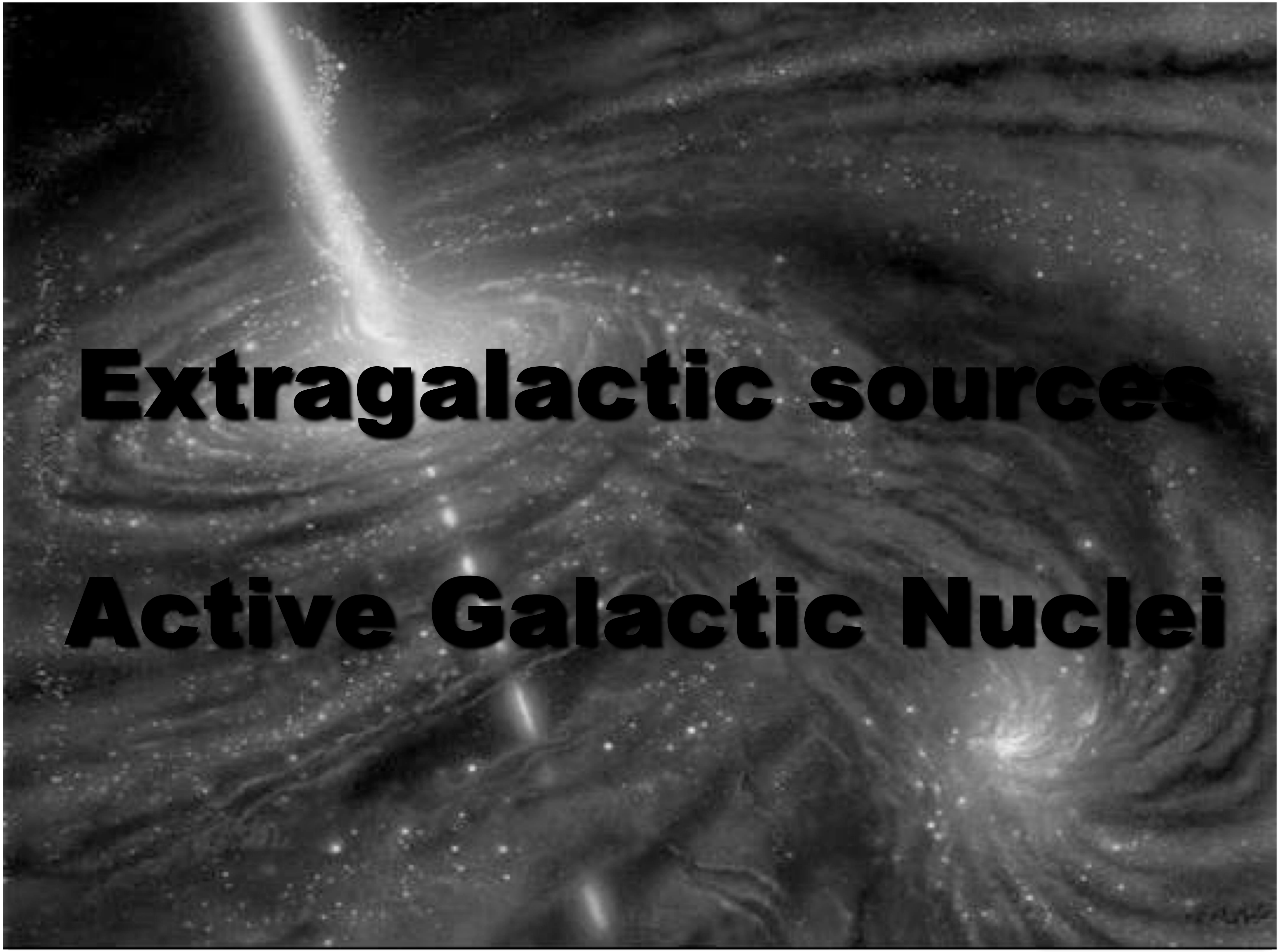
Category	Source	Discovery	Observation
Un-ID	TeV J2032+4130	HEGRA	
Un-ID	HESS J1303-631	HESS	
Un-ID	HESS J1614-518	HESS	
Un-ID	HESS J1702-420	HESS	
Un-ID	HESS J1708-410	HESS	
Un-ID	3EG J1744-3011 ?	HESS J1745-303	



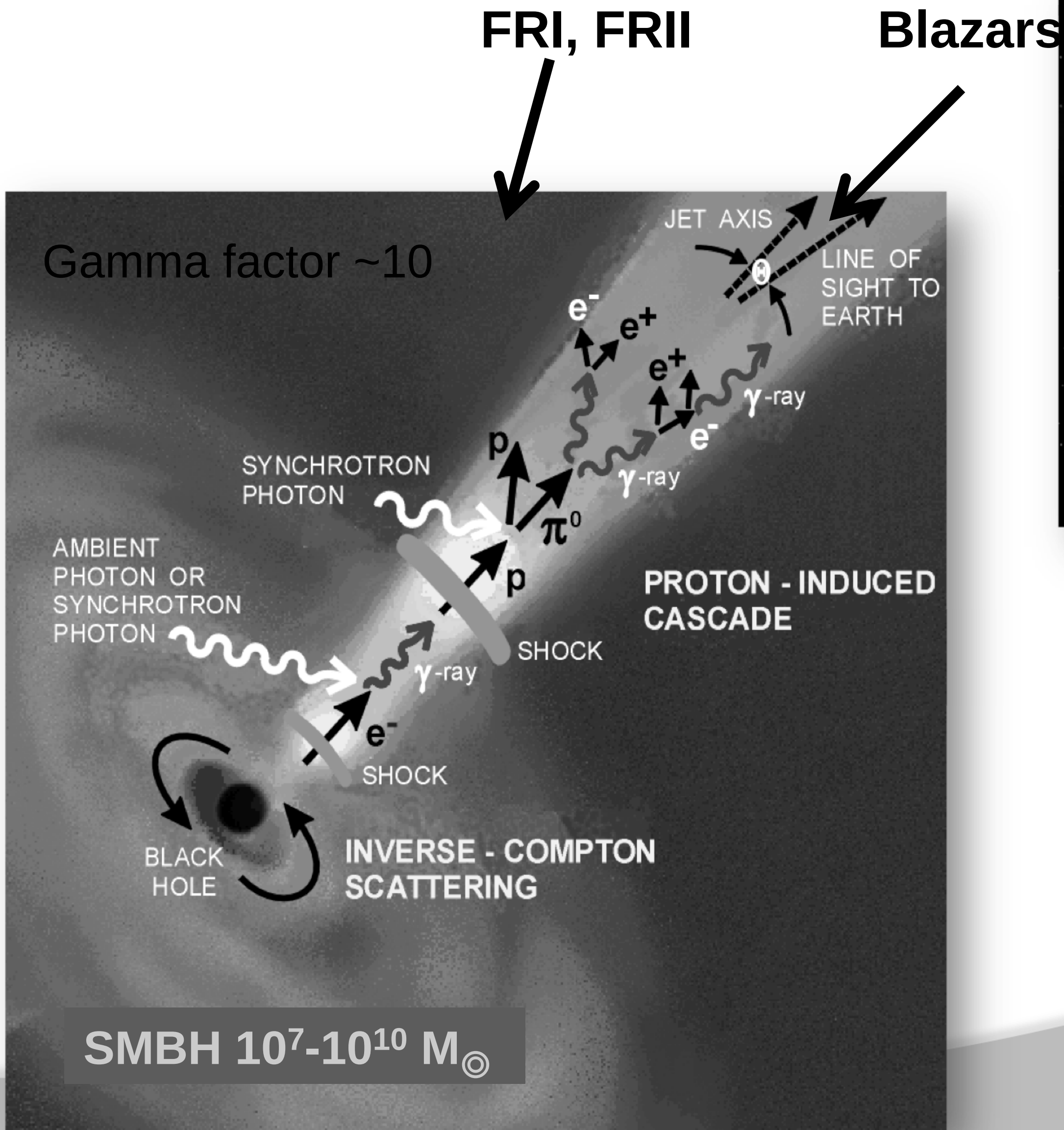
Name	Possible counterpart	Type[a]	$\Gamma^b_{\rm TeV}$	$f^c_{\rm TeV}$	$N^d_{\rm H}$	$\Gamma^e_{\rm X}$	$f^f_{\rm X}$	$f_{\rm TeV}/f_{\rm X}$	Reference[g]
HESS J0852−463	RX J0852−4622	SNR	2.1	6.9	4	2.6	~10	~0.7	1, 2, 3
HESS J1303−631	—	?	2.4	1.0	20	2.0	<0.64	>1.6	4, 5
HESS J1514−591	PSR B1509−58	PWN	2.3	1.6	8.6	2.0	3.2	0.5	6, 7
HESS J1632−478	AX J1631.9−4752	HMXB?	2.1	1.7	210	1.6	1.7	1.0	8, 9
HESS J1640−465	G338.3−0.0	SNR	2.4	0.71	96	3.0	0.30	2.4	8, 10
HESS J1713−397	RX J1713.7−3946	SNR	2.2	3.5	8	2.4	54	0.065	11, 12
HESS J1804−216	Suzaku J1804-2142	?	2.7	0.48	2	-0.3	0.025	19	8, 13
HESS J1804−216	Suzaku J1804-2140	?	2.7	0.48	110	1.7	0.043	11	8, 13
HESS J1813−178	AX J1813−178	?	2.1	0.89	110	1.8	0.70	1.3	8, 14
HESS J1837−069	AX J1838.0−0655	?	2.3	1.4	40	0.8	1.3	1.1	8, 15
TeV J2032+4130	—	?	1.9	0.20	?	?	<0.20	>1.0	16
HESS J1616−508	—	?	2.4	1.7	4.1	2.0	<0.031	>55	This work

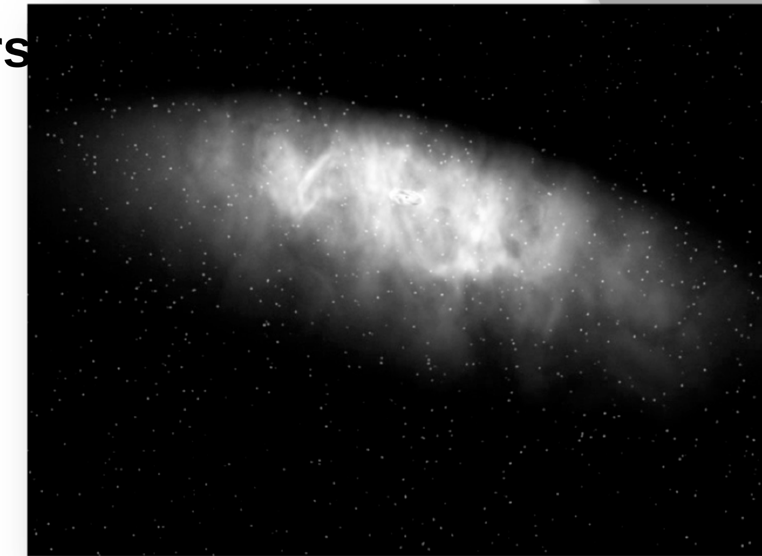


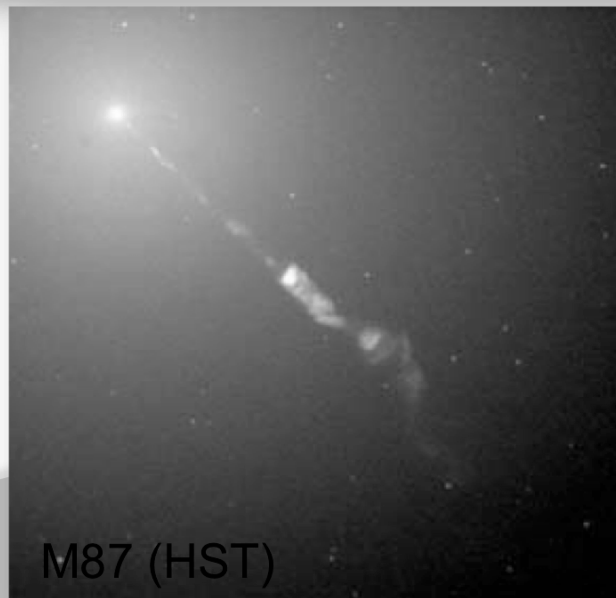
Suzaku (Matsumoto et al. 1996)


Extragalactic sources
Active Galactic Nuclei

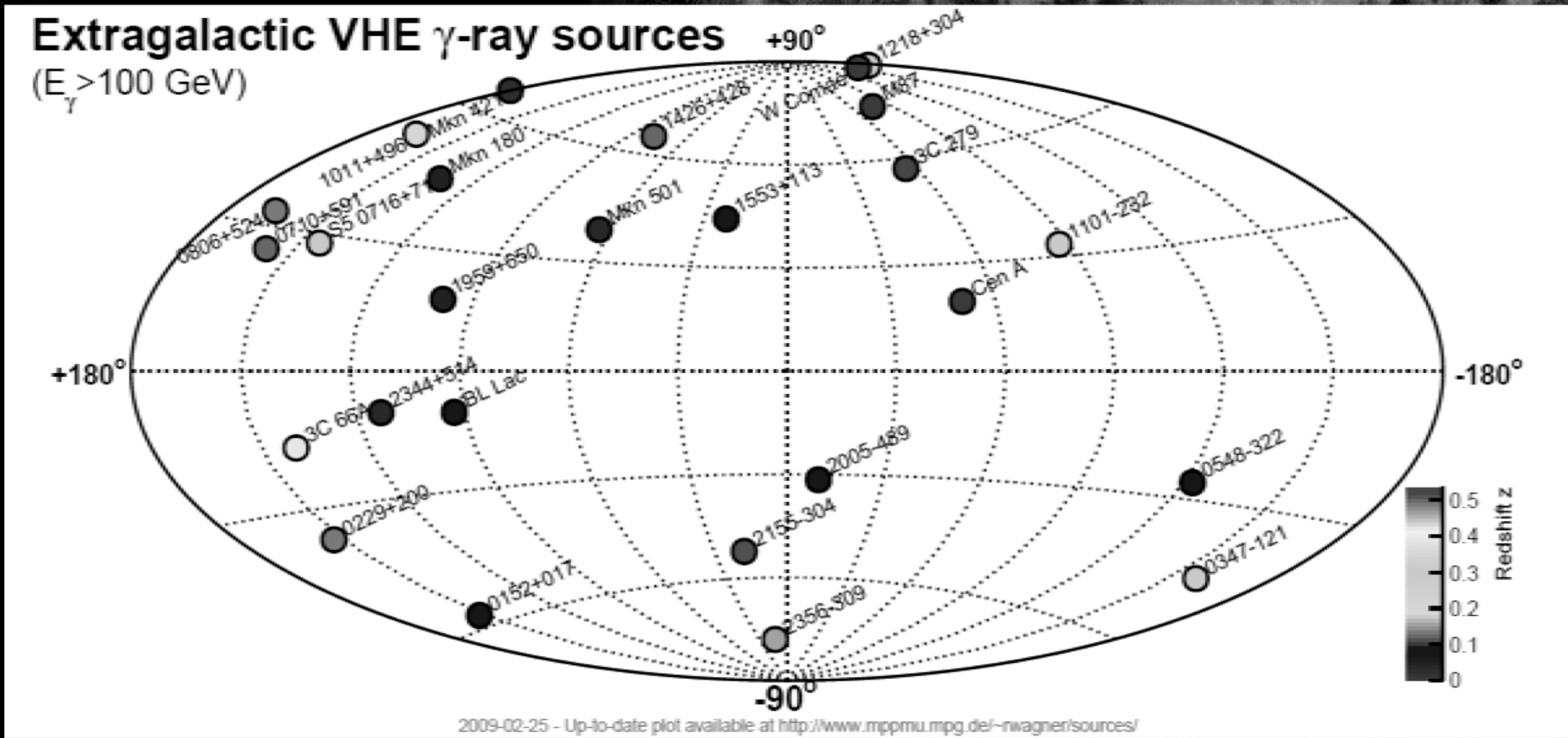
Cosmic Ray accelerator
Active Galactic Nuclei



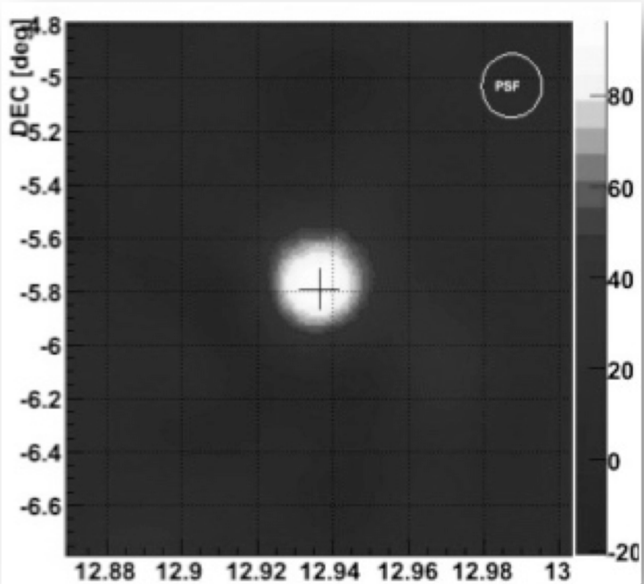


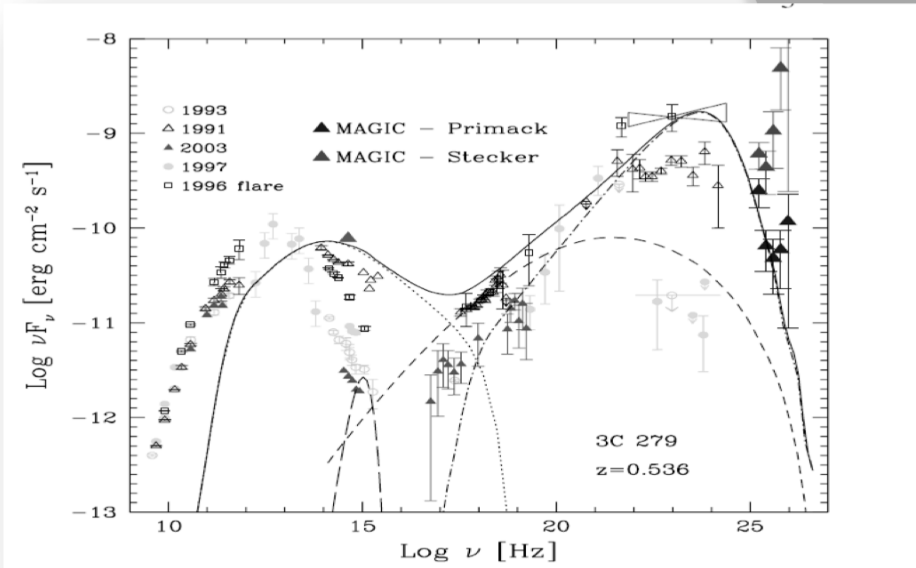


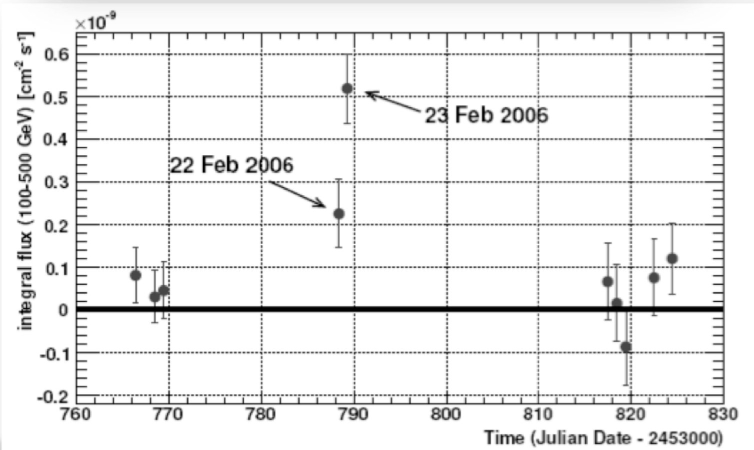
Extragalactic sources AGNs

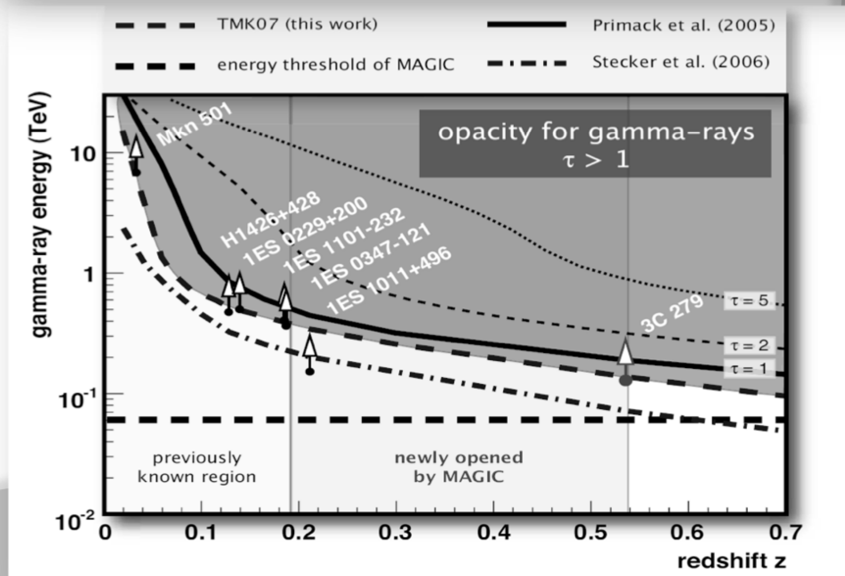


FSRQ 3C279 (z=0.536)
Most distant 100GeV AGN

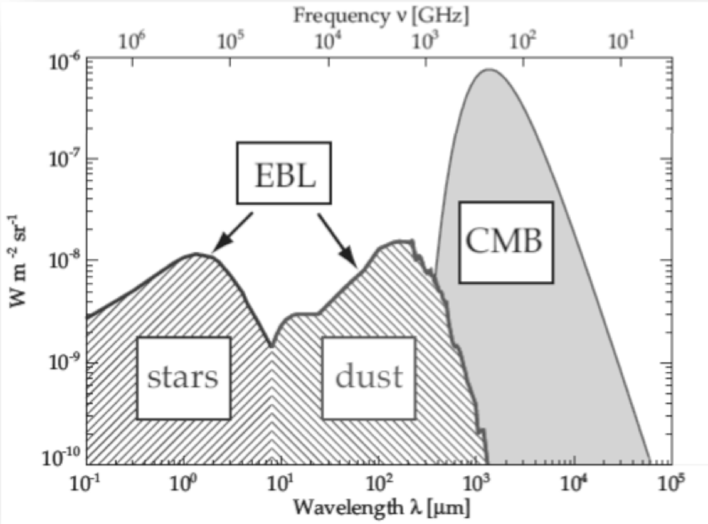


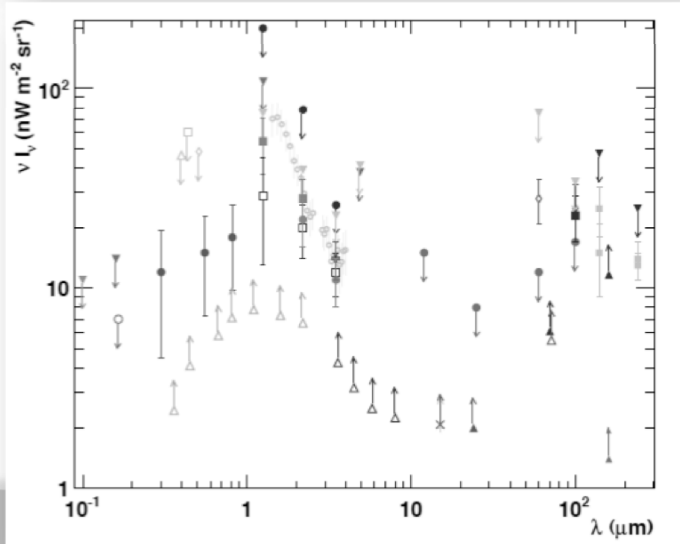


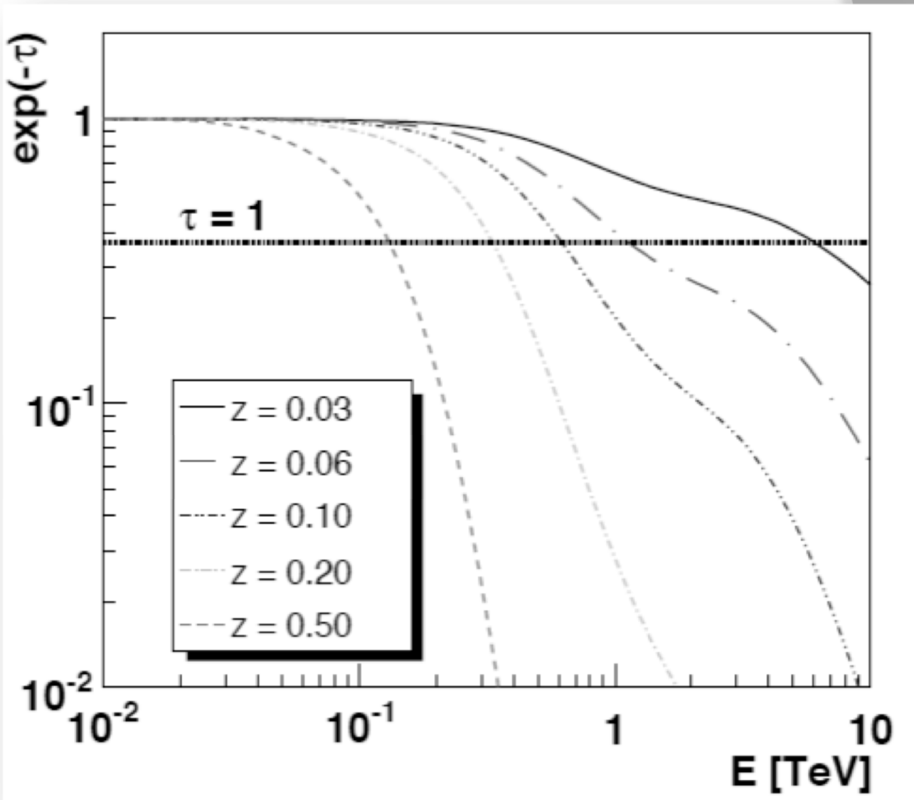




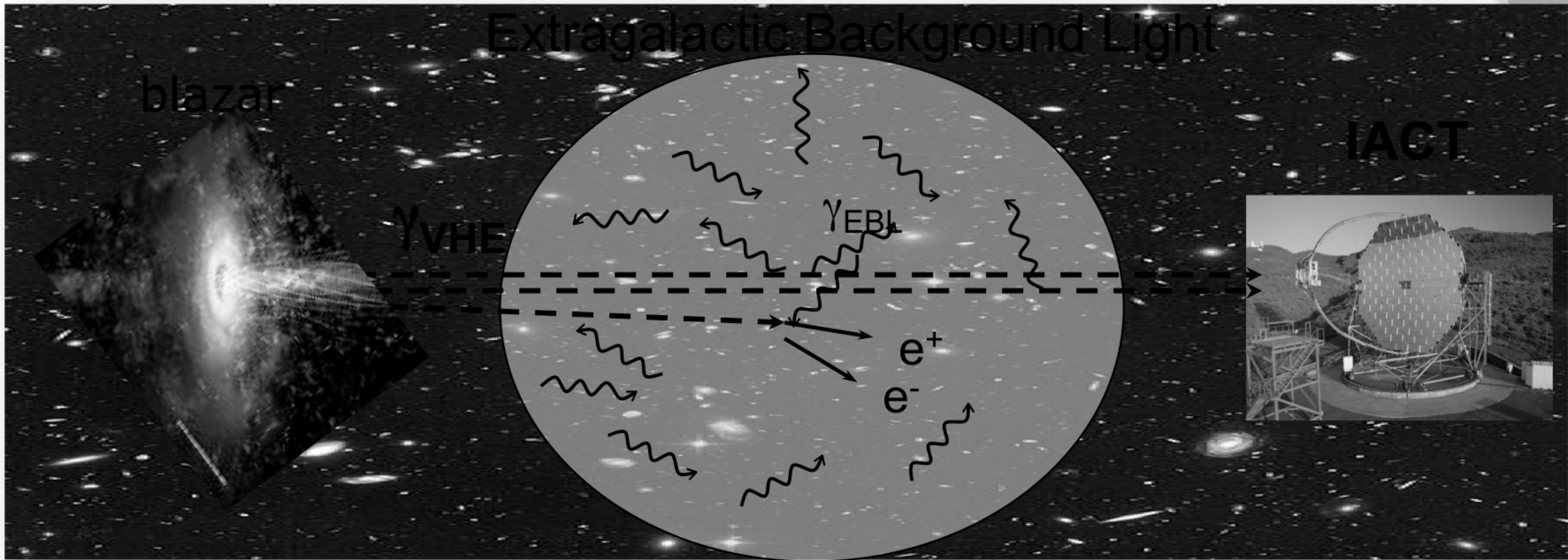
Absorption by EBL
(Extragalactic Background Light)

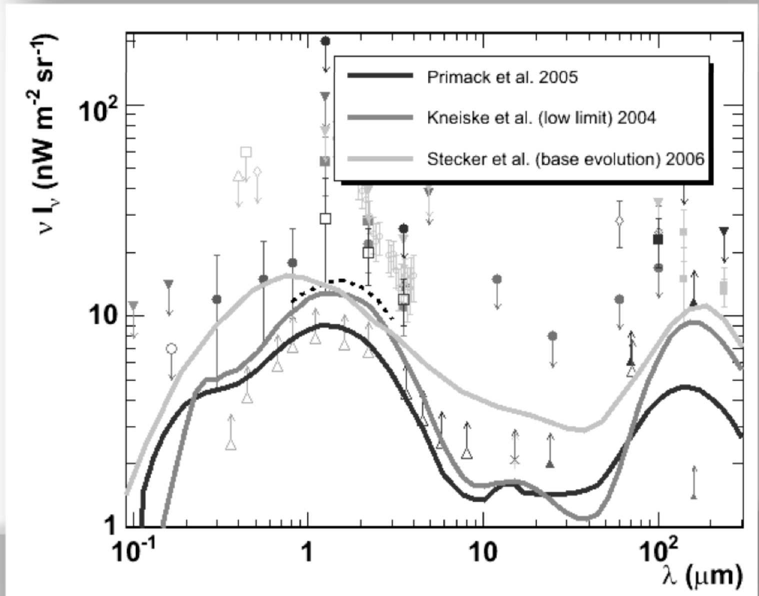


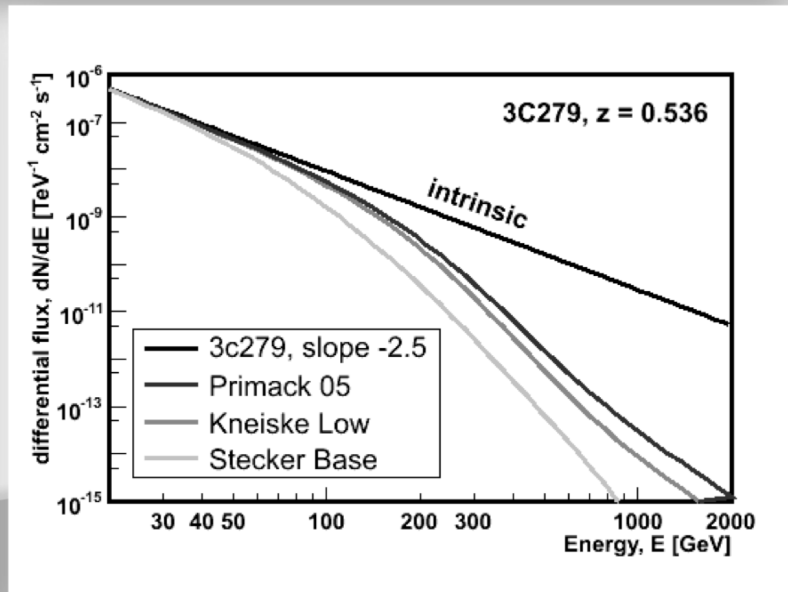




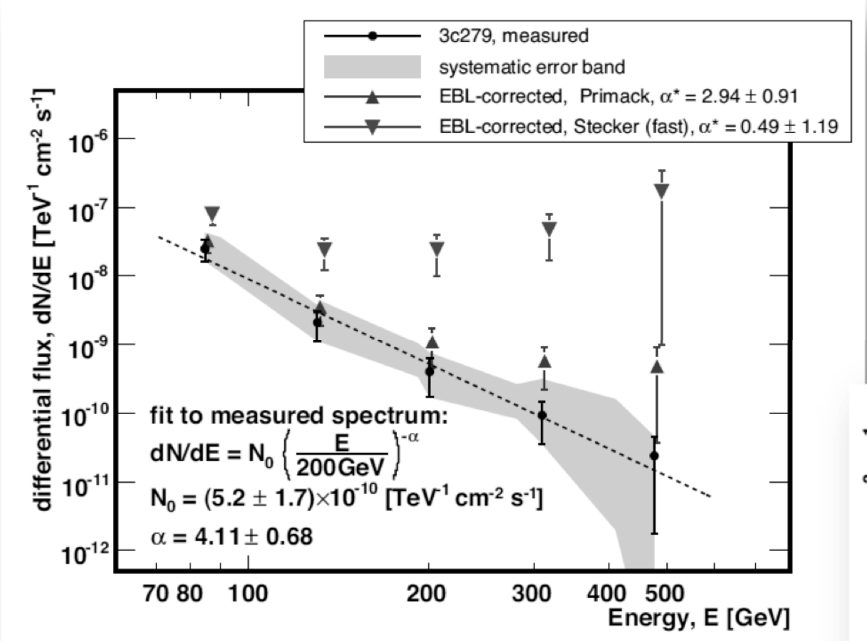
EBL Absorption

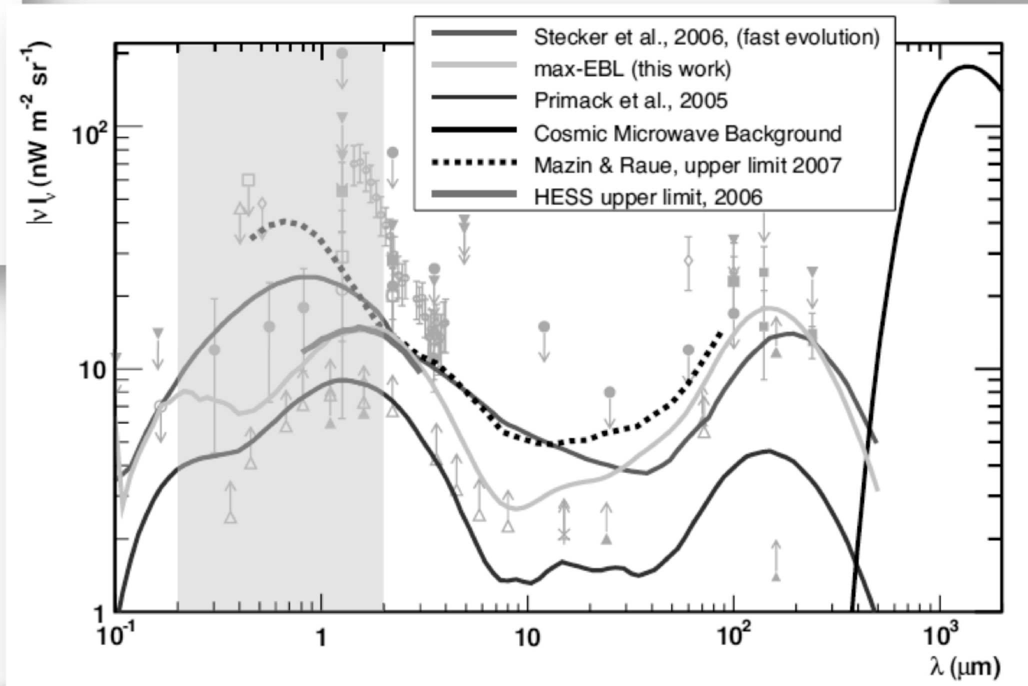




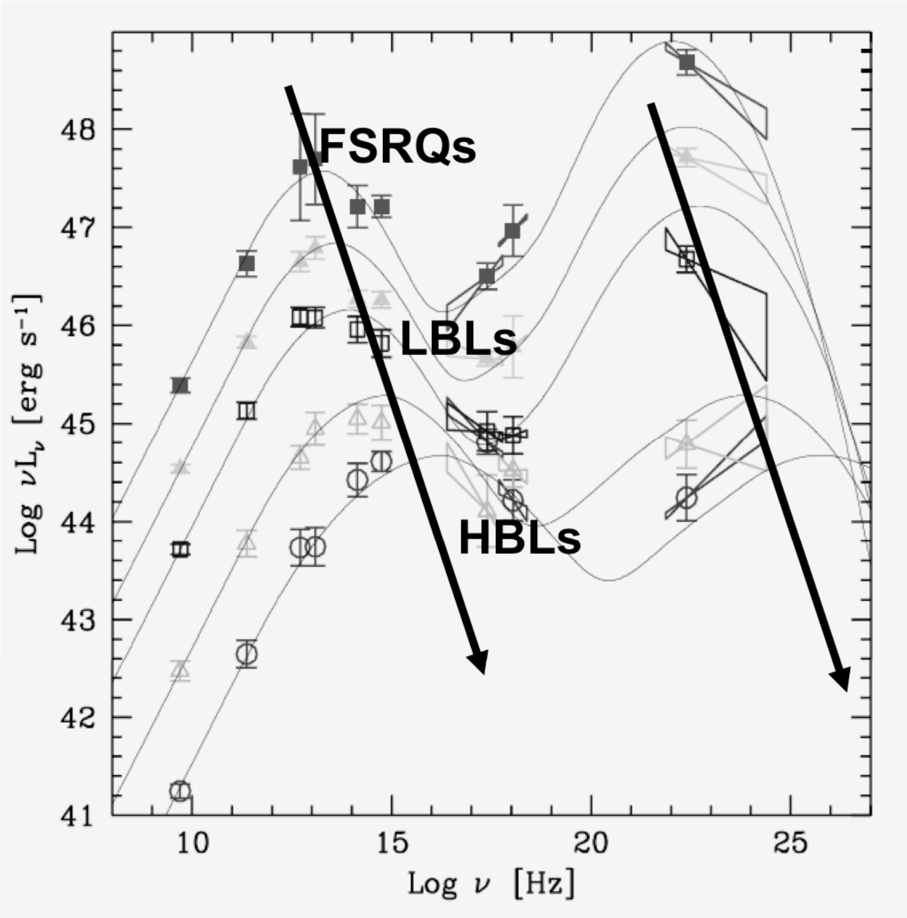


Limit on EBL spectrum

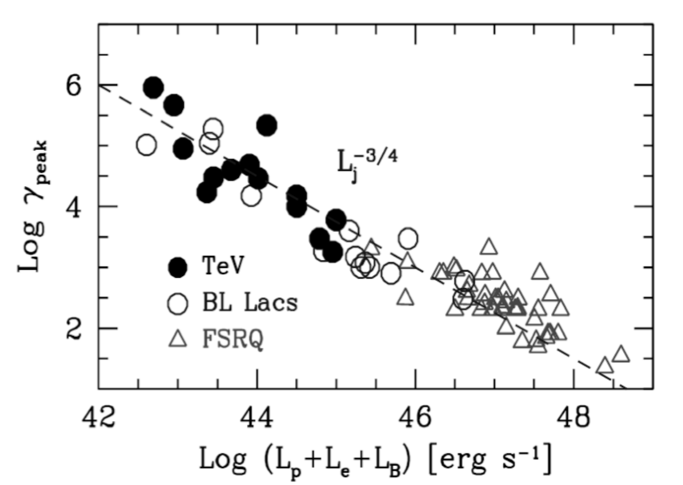




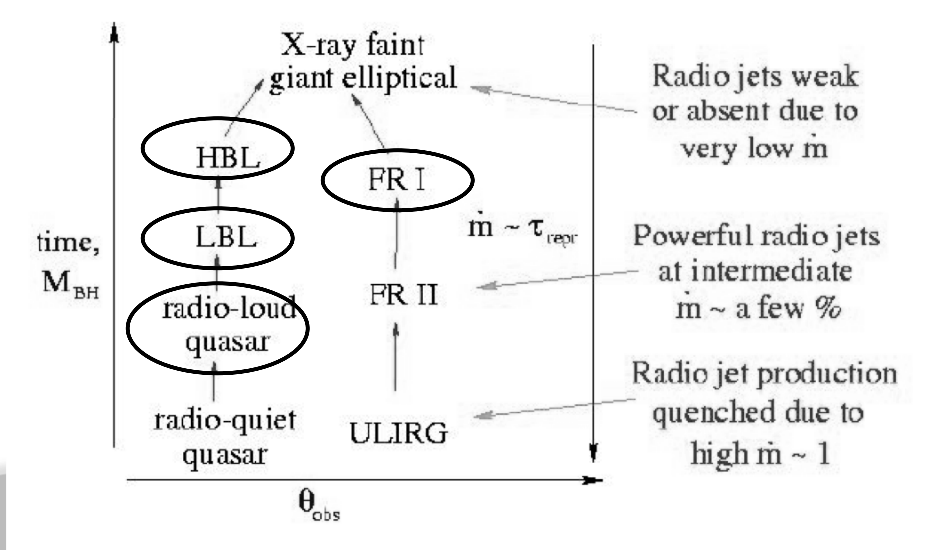
Blazar's Sequence



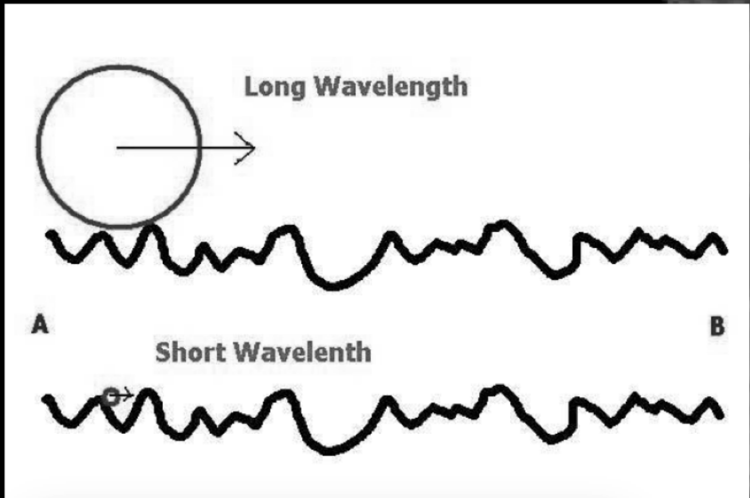
Fosatti et al. 1998



Celotti & Ghisellini 2007



Probe Quantum Gravity
with long flying HE gamma rays



$$E_{Pl} = \sqrt{\frac{\hbar c^5}{G}} \approx 1.22 \times 10^{19}\, GeV$$

If Gravity is a Quantum theory,
at a very short distance it may show a very complex "foamy" structure due to quantum fluctuation.

Use gamma ray beam from AGNs/GRBs
to study the space-time structure

Energy 1000GeV ~ $10^{-16} E_{Pl}$
Distance 100~1000Mpc (10^{16-17}sec)

Visible time delay ~ 1 - 10 sec

Linear deviation:

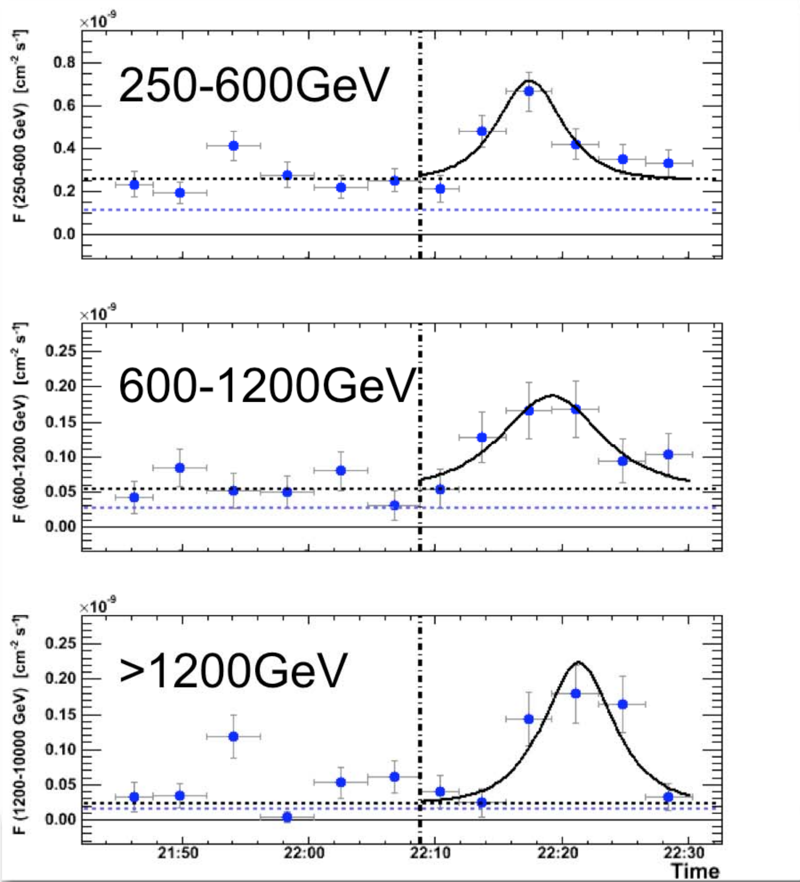
$$\xi_1 < 0; \quad v = c\left(1 - \frac{E}{M_{QG1}}\right); \quad n(E) = 1 + \frac{E}{M_{QG1}}$$

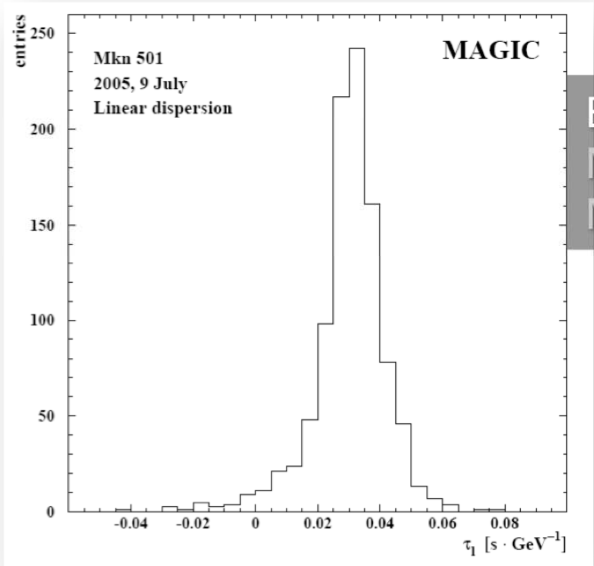
Quadratic deviation:

$$\xi_1 = 0; \quad \xi_2 < 0; \quad v = c\left(1 - \frac{E^2}{M_{QG2}^2}\right); \quad n(E) = 1 + \frac{E^2}{M_{QG2}^2}$$

Probing Q.G.
Mrk501 very fast flare MAGIC

Mrk501 flare
09. July.2005





Energy Cost Function

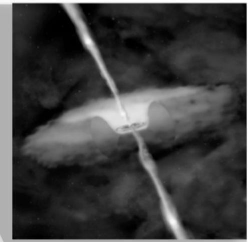
ECF method
M_{QG1} >0.26 x 10^{18}GeV
M_{QG2} >0.39 x 10^{11}GeV

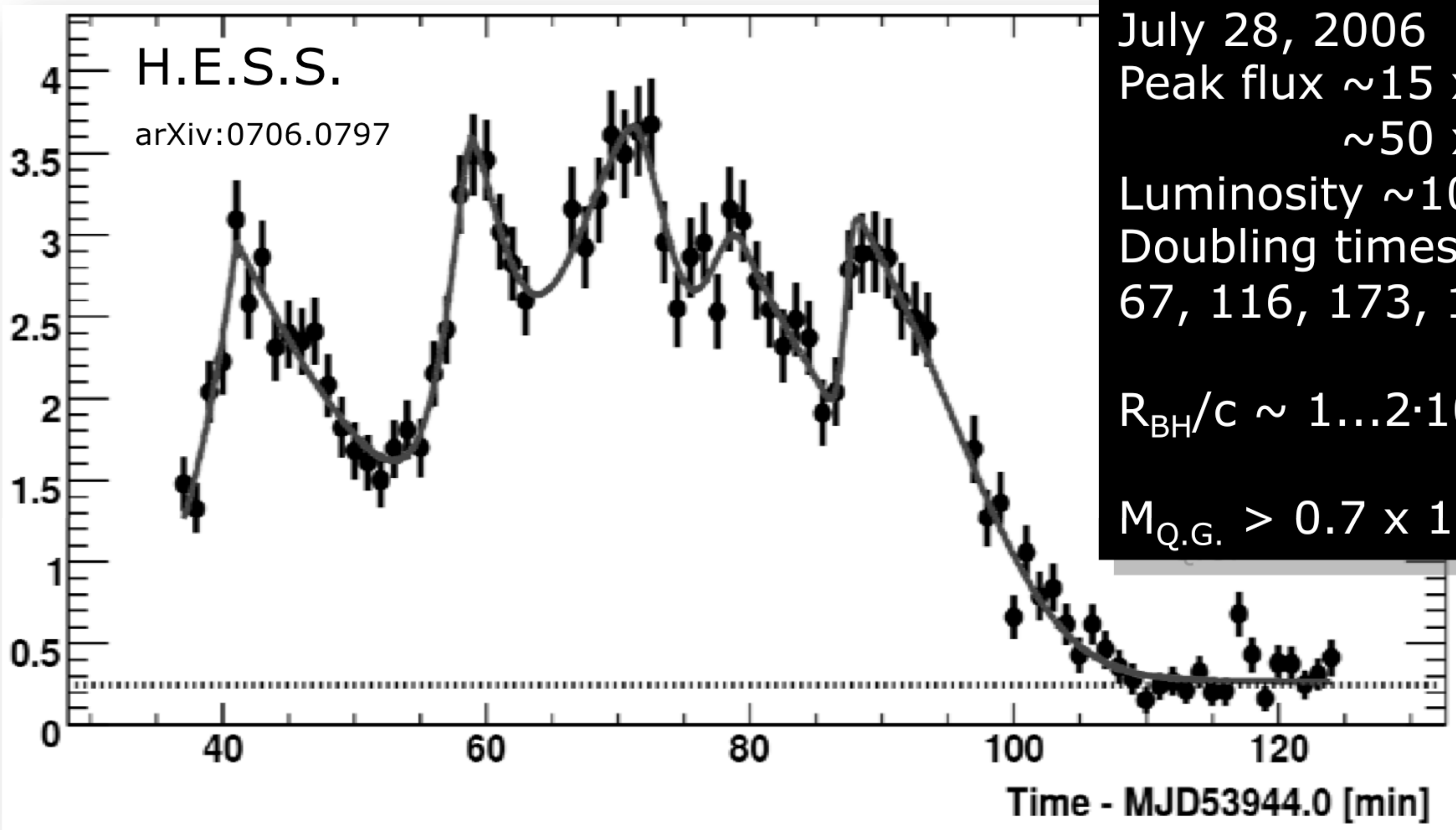
New records:

HESS: PKS2155 large flare, M_{QG1} >0.7x 10^{18}GeV

Fermi: GRB080916c, M_{QG1} > 1.3 x 10^{18}GeV

PKS2155 huge rapid flare by HESS





PKS 2155−304
z = 0.116

July 28, 2006
Peak flux ~15 x Crab
~50 x average
Luminosity ~10^{12} x Crab
Doubling times
67, 116, 173, 178 ±50 s

R_{BH}/c ~ 1...2·10^4 s

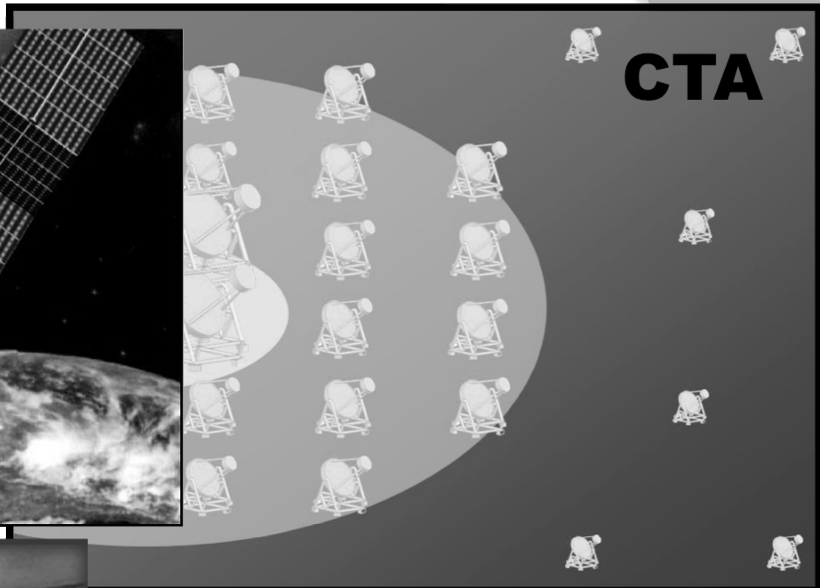
$M_{Q.G.}$ > 0.7 x 10^{18}eV


Future facilities for
HE Gamma Ray Astronomy

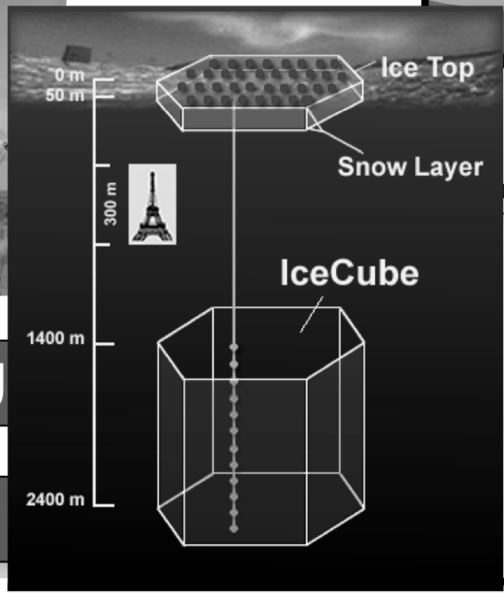
CTA
Next generation VHE Gamma ray Observatory

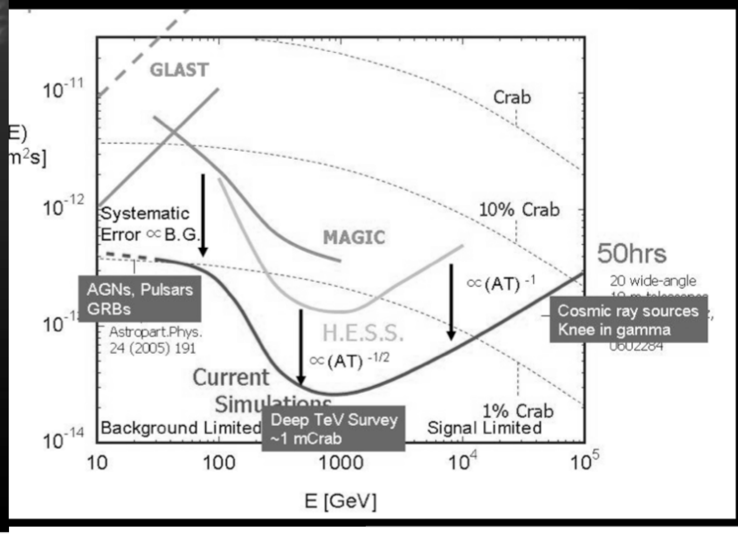
MAGIC Phase II (MAGIC-I + MAGIC-II) in 2009

>1000 sources will be discovered



HESS Phase II (HESS + 28m Tel

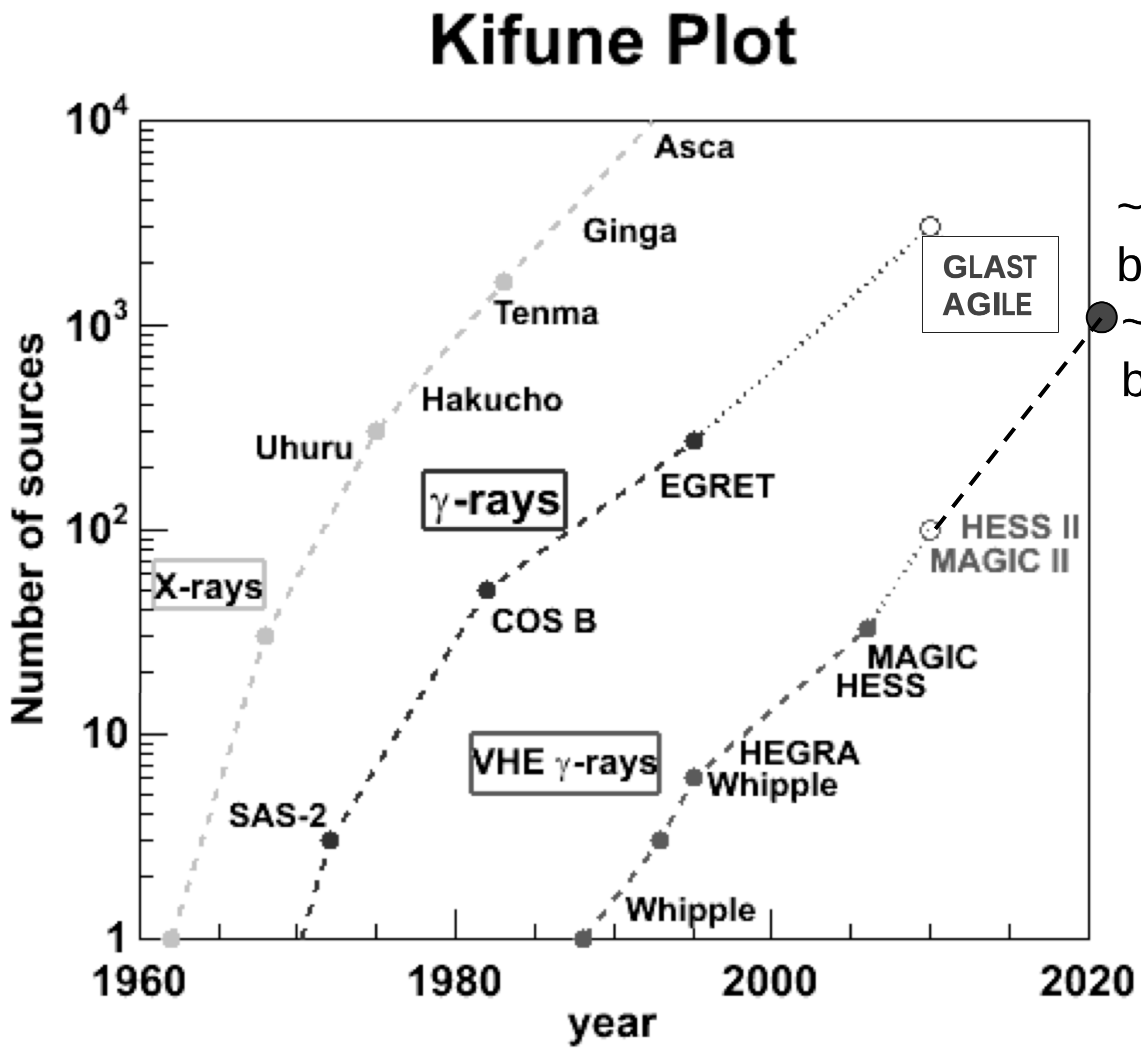




Astronomers in EU

JAPAN(EoI), US

Kifune Plot
(expectation from log S - log N)



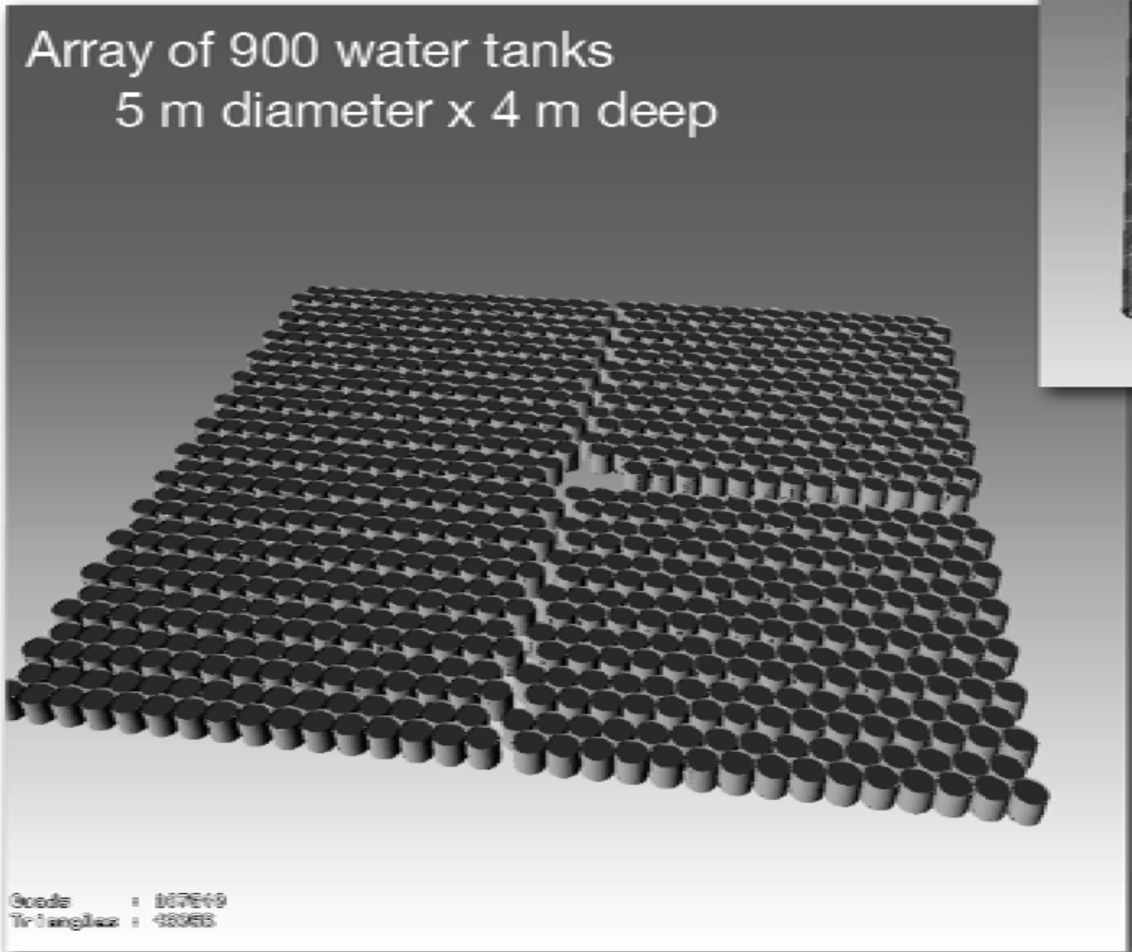
~3000 sources
by GLAST, AGILE
~1000 sources
by CTA

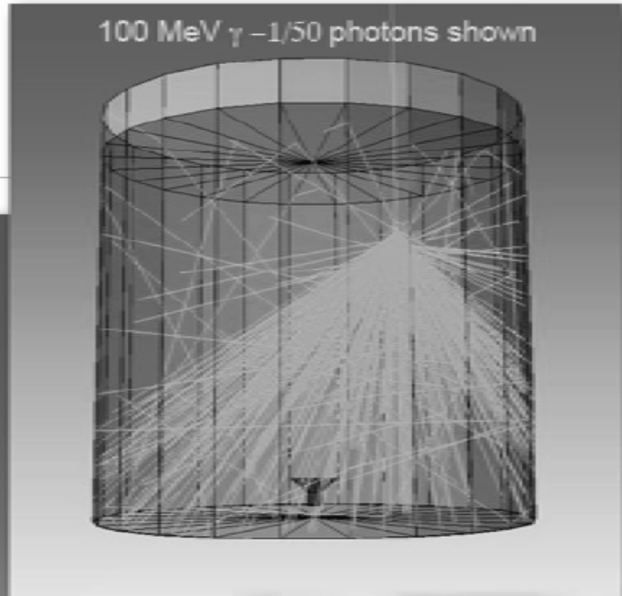
AGIS

Advanced Gamma
Imaging System
US-PROJECT

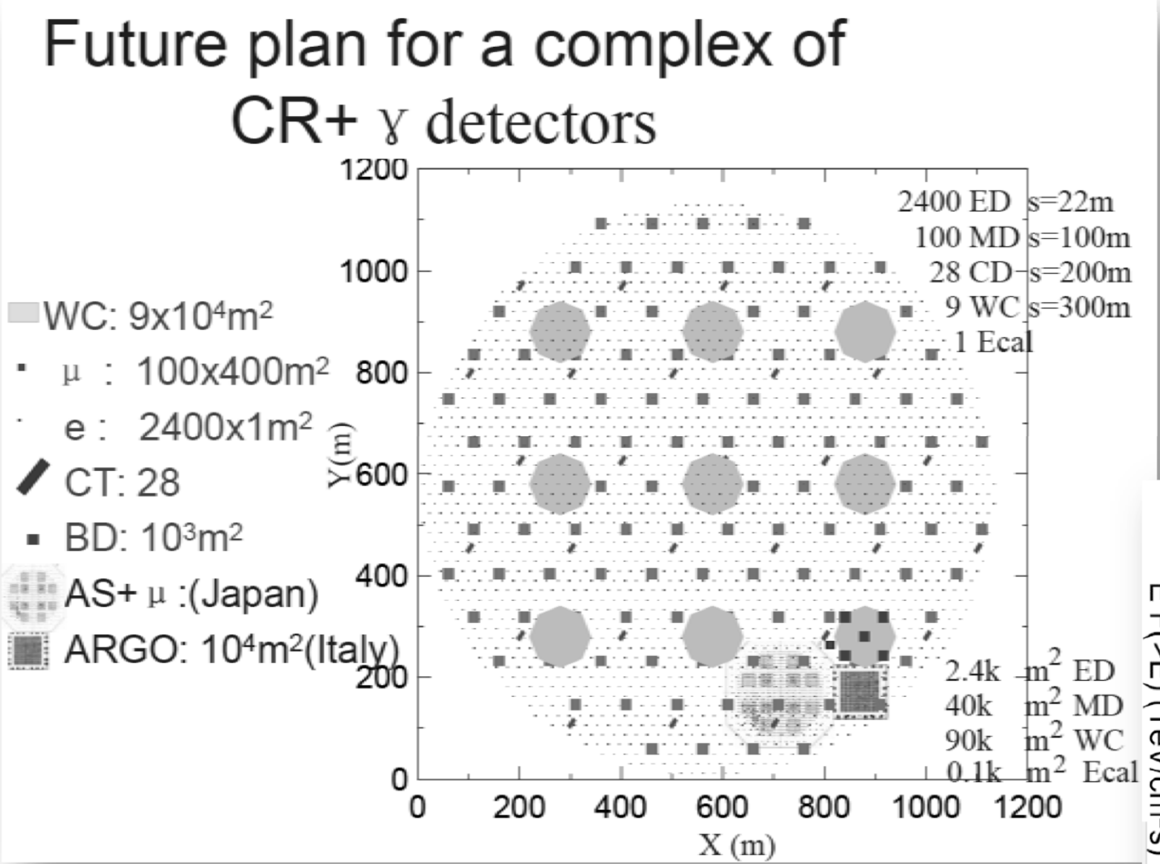
HAWC

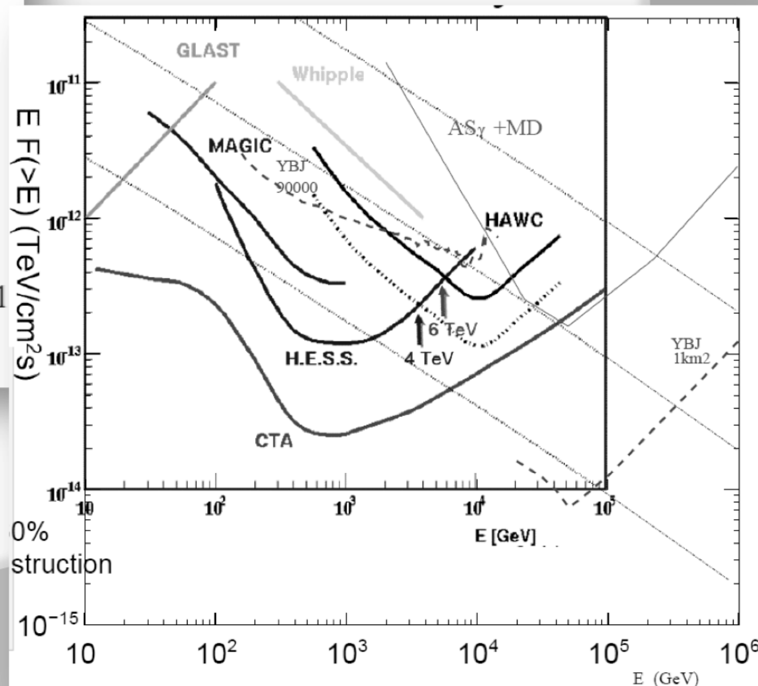
HAWC Design



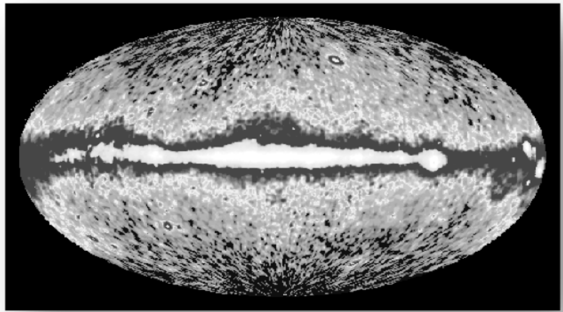


Extension of Tibet AS array

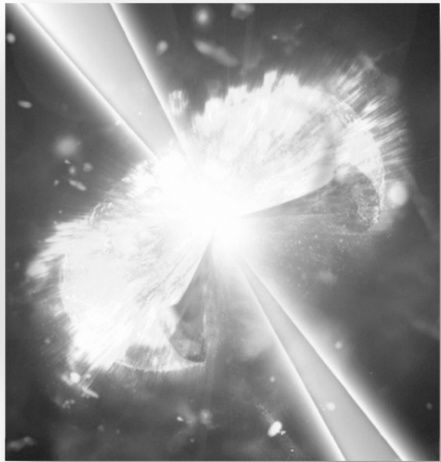




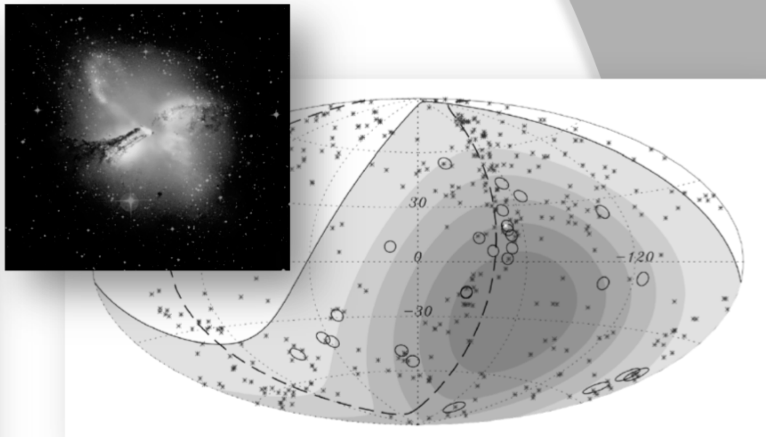
Possible New Classes of Sources



Galactic Diffuse

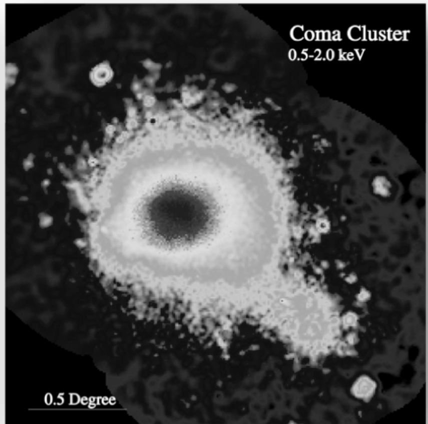


GRBs

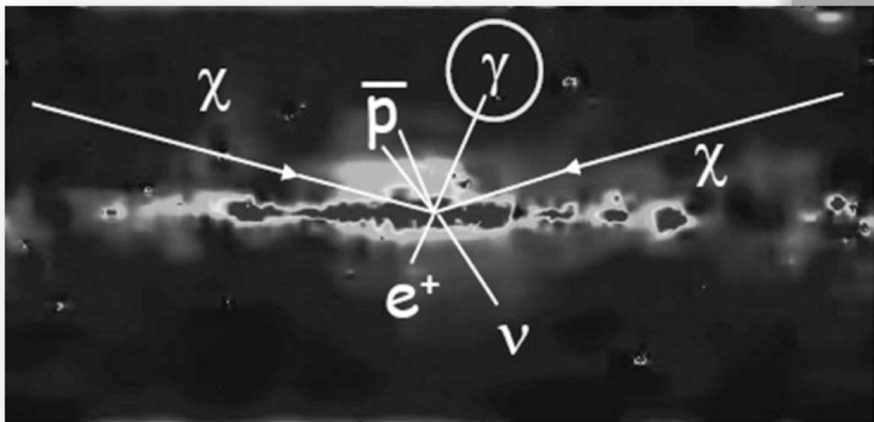


UHECR Sources

Starburst galaxies
Galaxy mergers



Clusters of galaxies

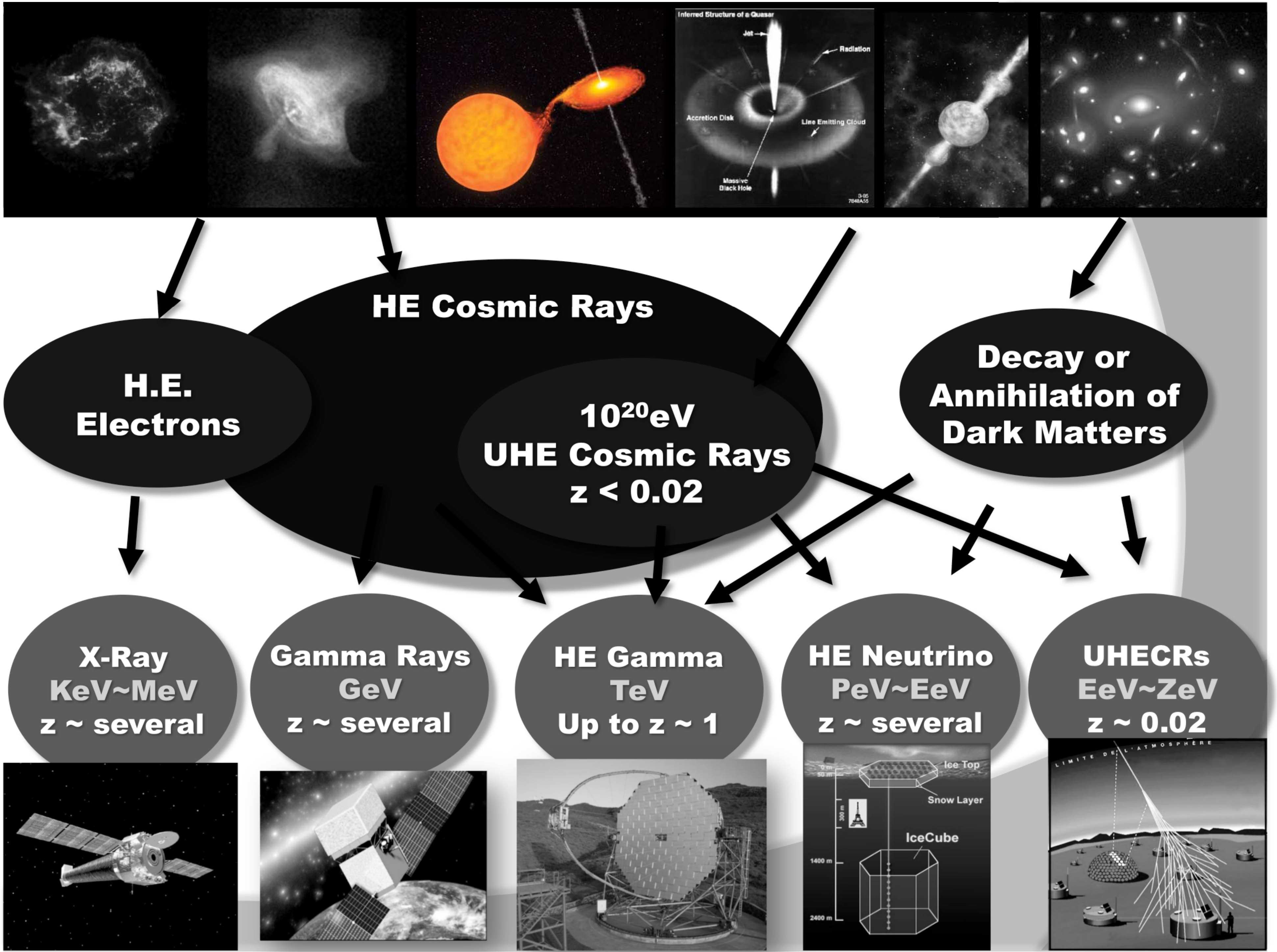


Dark Matter Annihilation

Summary

- Current Generation IACTs discovered many interesting sources and phenomena
- VHE gamma ray is very rich in Physics and Astrophysics
  - New sources will come; Pulsars, GRBs, Clusters of Galaxies, etc.
- There are still many open questions which must be solved
  - The origin of cosmic rays, where is our PEVATRON?
  - Very short flare from AGNs
  - Particle acceleration in the AGN jet
  - Hadronic sources, leptonic source
- Near Future
  - MAGIC-II (second phase of MAGIC) and HESS-II will come soon
  - # of sources will grow up a few hundreds in a few years
  - the next generation ultimate observatories CTA, AGIS,HAWC, and Extended Tibet AS array


Thanks

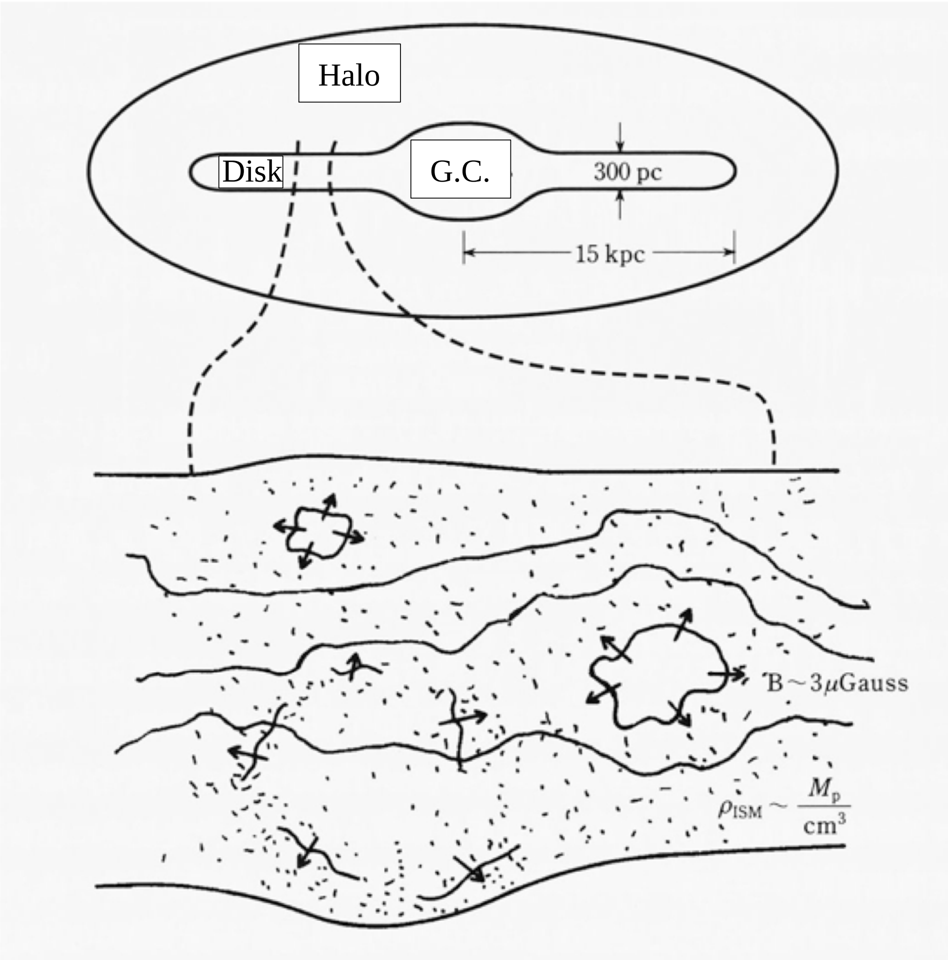


Inferred Structure of a Quasar
Jet
Radiation
Accretion Disk
Line Emitting Cloud
Massive Black Hole
HE Cosmic Rays
H.E. Electrons
10^{20}eV UHE Cosmic Rays z < 0.02
Decay or Annihilation of Dark Matters
X-Ray KeV~MeV z ~ several
Gamma Rays GeV z ~ several
HE Gamma TeV Up to z ~ 1
HE Neutrino PeV~EeV z ~ several
UHECRs EeV~ZeV z ~ 0.02
Ice Top
Snow Layer
IceCube
1400 m
2400 m

COSMIC RAY GENERAL

COSMIC RAYS IN OUR GALAXY

Cosmic Rays in our galaxy



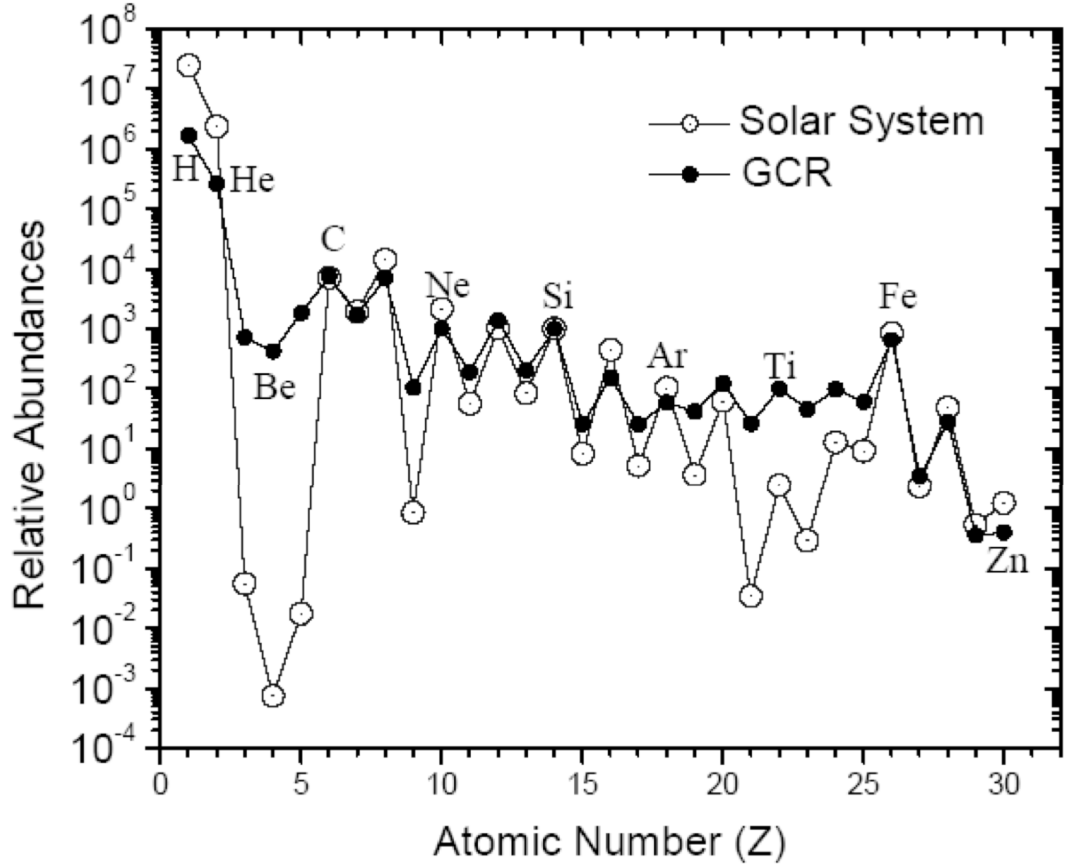
Curtsey of T.Gasser

- Cosmic rays
  - τ_{esc} ~ 5×10^6~10^7 yr
  - ω_{CR} ~ 1eV/cm^3
- Galactic Magnetic field
  - B~3μG
  - $B^2/8\pi$~0.3eV/cm^3
- Gas density
  - ~1particle/cm^3

Propagation of cosmic rays

The bulk of cosmic rays propagate diffusively in the Galaxy.
The abundances of light elements is the best proof.

~ 5g/cm^2 ➔ ~10^7 yr



- Less hydorgen
- Even-odd effect

- Li, Be, B
- Sc, Ti, V, Cr, Mn
- Quantitatively explained by spallation

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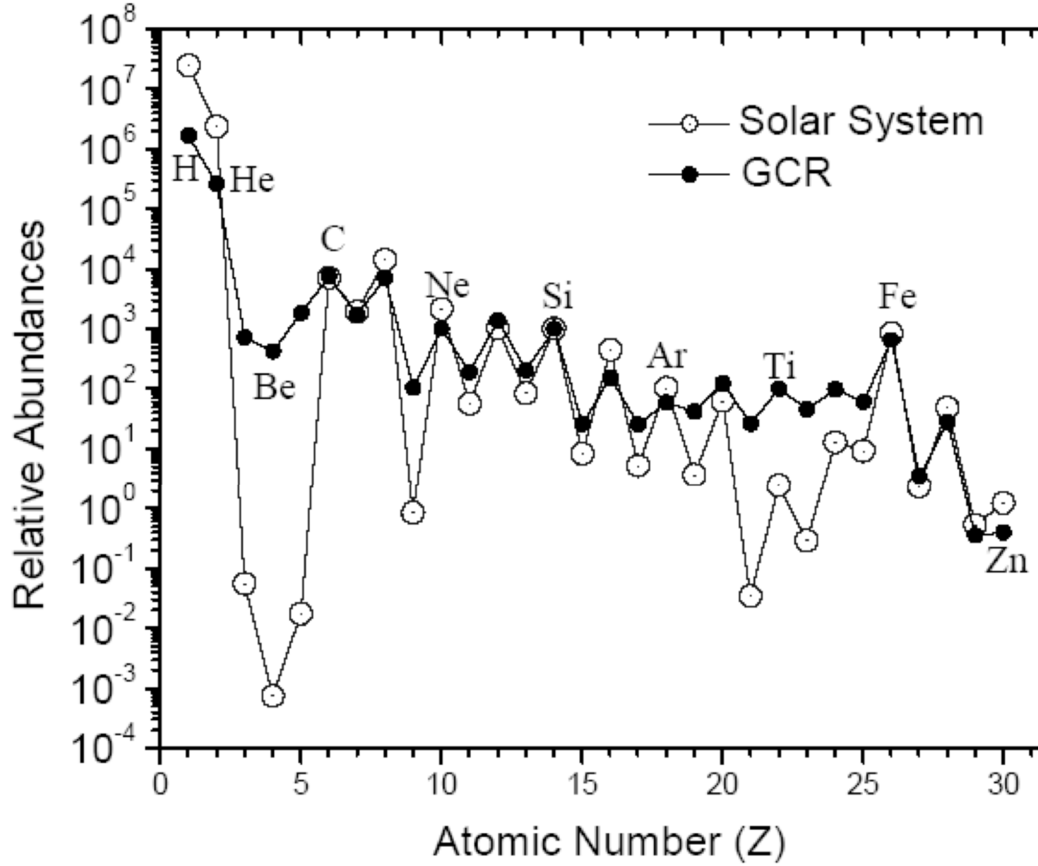


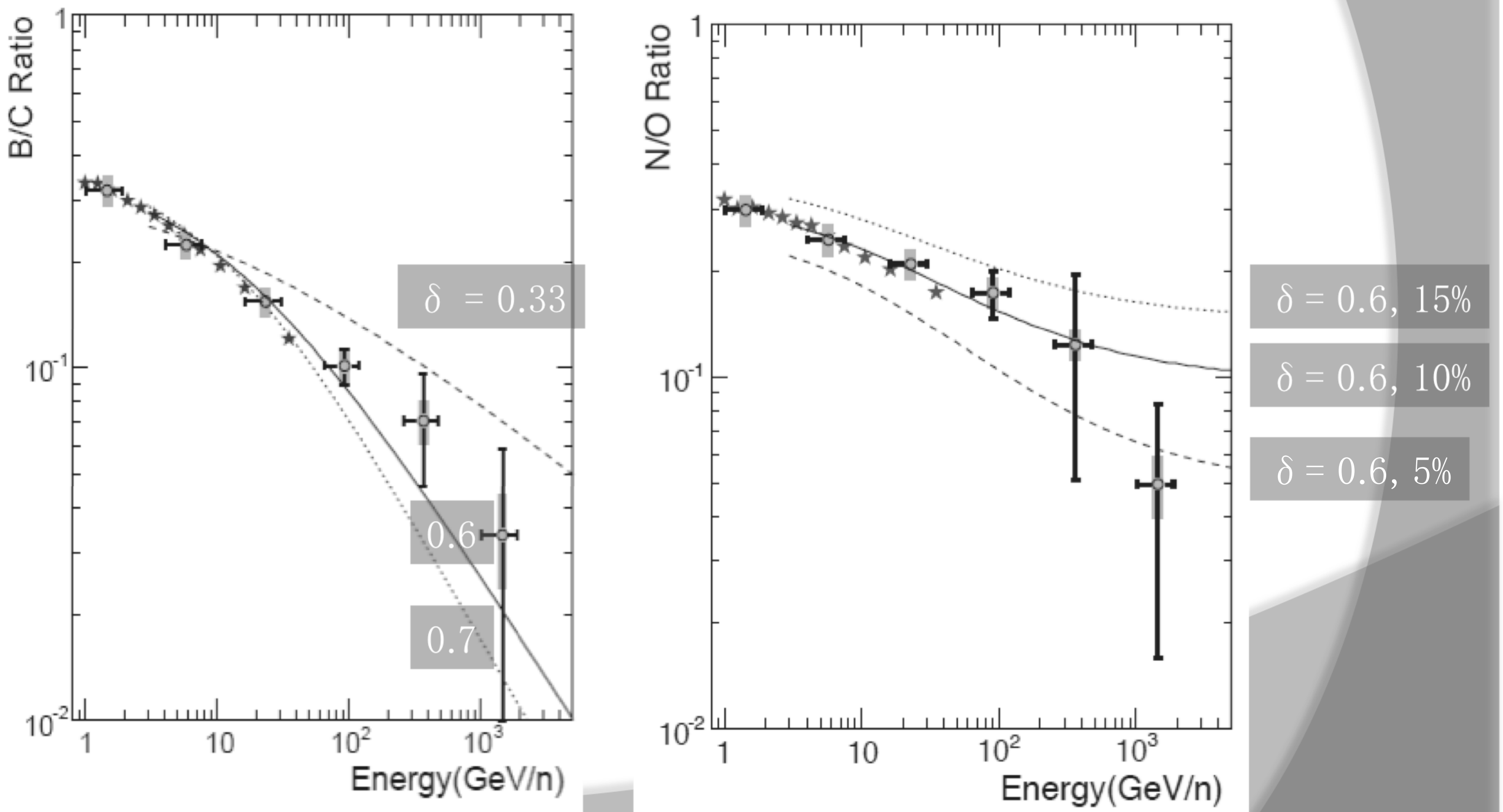
- ●Less hydorgen
- ●Even-odd effect

- ●Li, Be, B
- ●Sc, Ti, V, Cr, Mn
- ●Quantitatively explained by spallation

Secondary / Primary Ratio as a function of energy

$T_{esc} \propto E^{-\delta}$

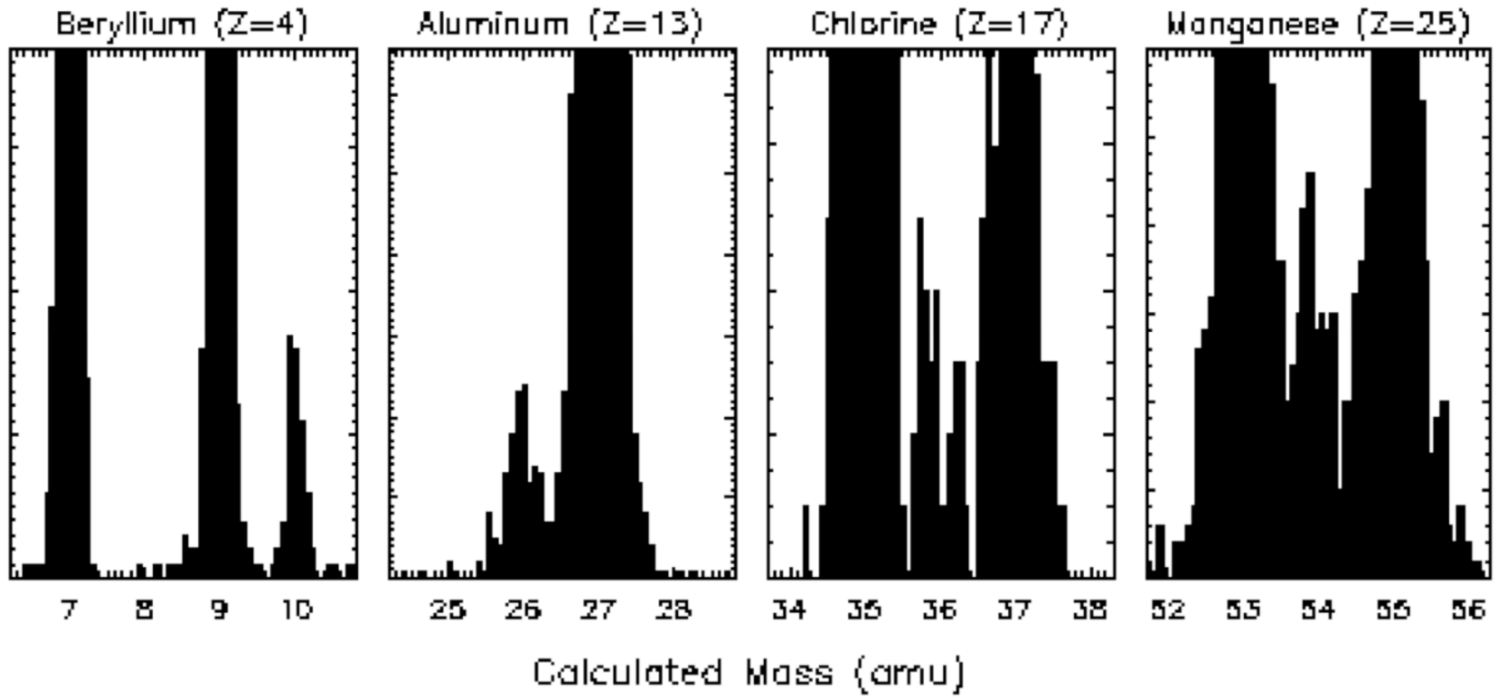
CREAM 2008



Radioactive Clock isotope with CRIS

Be-10 (1.6 million year halflife)
Al-26 (0.87 Myr)
Cl-36 (0.30 Myr)
Mn-54 (0.8 Myr estimated)

Again we obtain life time of $\sim 10^7$ year



Galactic Cosmic Rays

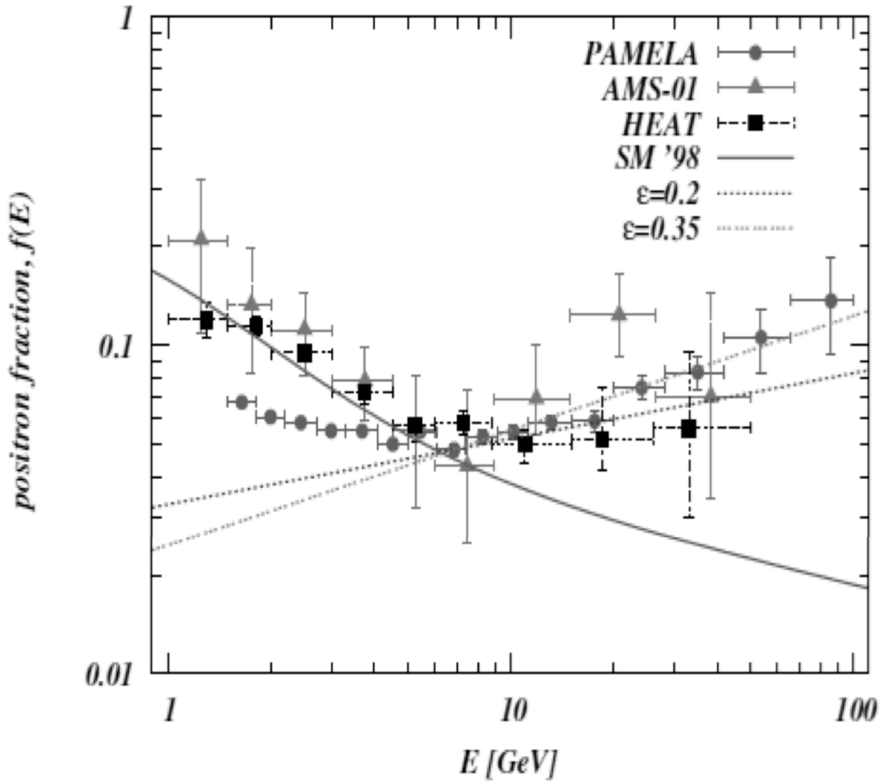
- Column density estimated from primary - secondary ratio
  - Life time is ~10^7 yr at 10GeV
  - Consistent with cosmic ray clock result

  - $T_{esc}(E) = 10^7 \, (E/10\text{GeV})^{-0.6}$ yr
  - Observed spectrum: $n(E) = dF/dE \propto E^{-2.7}$
  - $n(E) = Q(E) \times T_{esc}(E)$

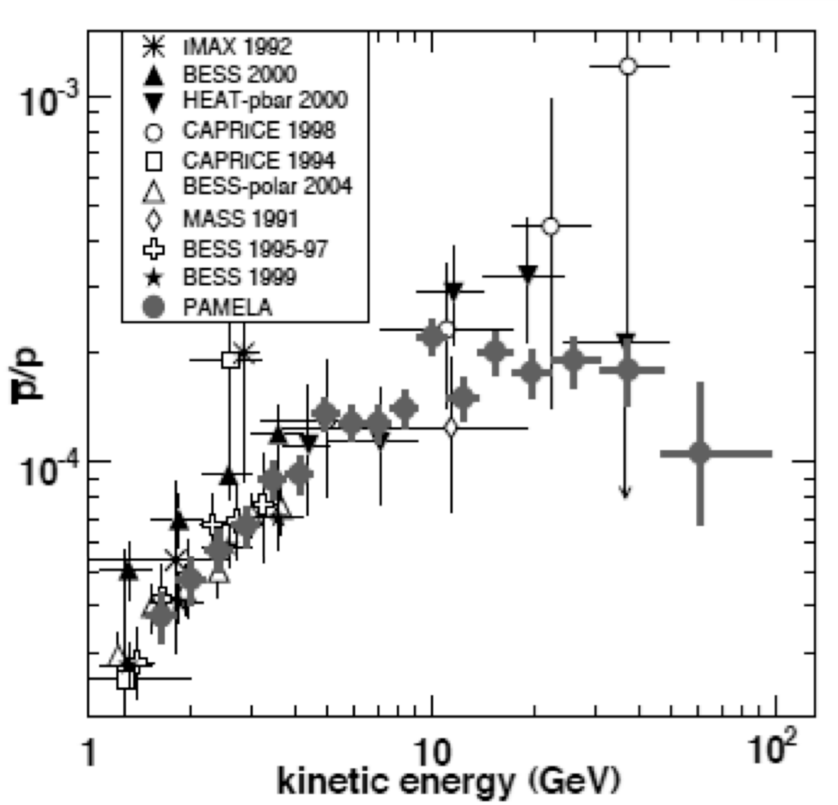
  - Source spectrum is estimated as $Q(E) \propto E^{-2.1}$
    - expected spectrum from Fermi acceleration

Some complications in the positron flux

e+ / (e+ + e-)



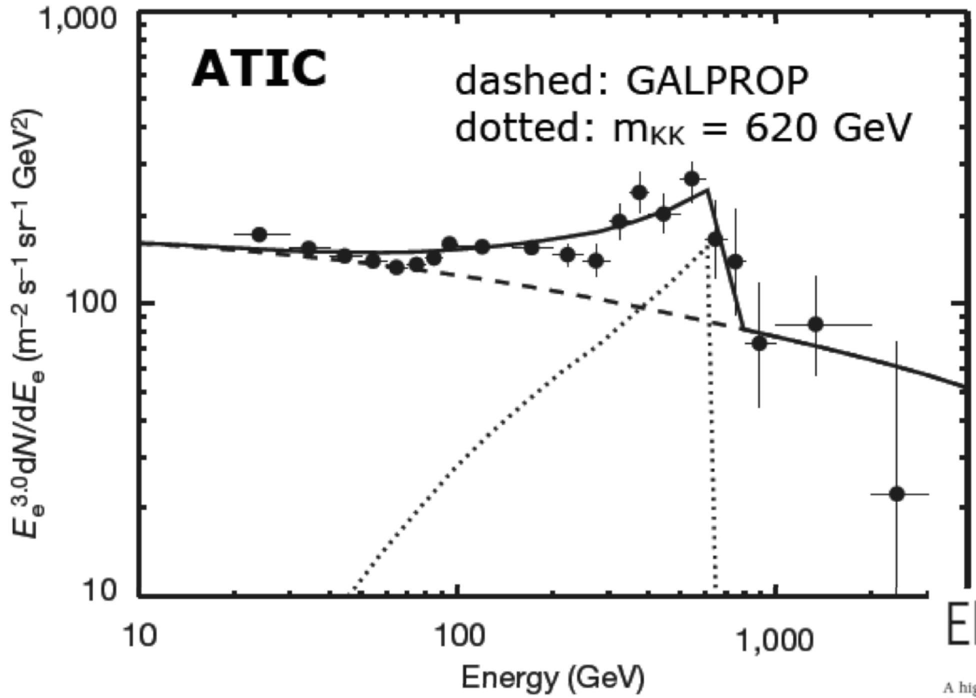
anti-p / p



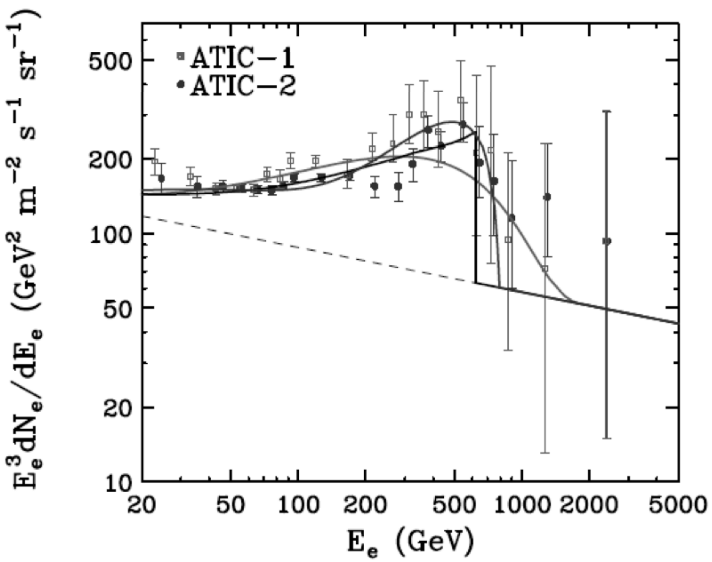
e+/e- ratio significant deviation from SM
➔ Maybe nearby pulsars, SNRs

There is no significant deviation form SM

Bump in the electron spectrum



Chang et al., Nature **456**, 362-365 (2008)



Nature 20.Nov.2008

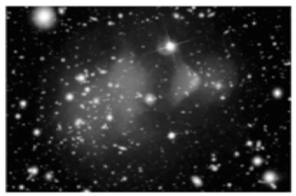
Electron 'bump' may confirm dark matter

A high-altitude balloon experiment above the Antarctic seems to have seen a possible signature of mysterious 'dark matter', similar to that spotted earlier this year by a European satellite.

The Advanced Thin Ionization Calorimeter (ATIC), an experiment to search for charged particles from space, has spotted a surplus of high-energy electrons coming from somewhere in the cosmos (see Letter, page 362, and News & Views, page 329). Although the interpretation is far from certain, the electrons could be produced by dark matter — previously undetected particles that physicists believe make up 85% of all matter in the Universe.

ATIC's findings are similar to data from the PAMELA (Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics) satellite mission, a collaboration between Italy, Russia, Germany and Sweden that spotted an excess of high-energy positrons, or anti-electrons, at roughly similar energies (see *Nature* 454, 808; 2008). "In several respects the two measurements complement each other," says John Wefel, head of the ATIC collaboration and a physicist at Louisiana State University in Baton Rouge.

Wefel's team looked at data from two multi-day ATIC missions flown between 2000 and 2003 some 35 kilometres above the Antarctic ice. With 99.5% of Earth's atmosphere beneath them, the missions measured electrons that come from various galactic sources such as exploding stars. As predicted by theory, the experiment saw fewer electrons at higher energies. But between 300 gigaelectronvolts and 600 gigaelectronvolts, the number of electrons rose sharply before falling off to background levels.



Several experiments may have found dark matter, the existence of which is inferred here (blue).

NASA

PAMELA's results, as posted on the arXiv preprint server last month (O. Adriani *et al.* http://arxiv.org/abs/0810.4995; 2008) and also submitted to *Nature*, show positrons increasing up to 100 gigaelectronvolts. Although the collaboration did not report beyond this energy level, some suspect that the number of positrons may continue to increase at higher energies. And, because the PAMELA and ATIC data were measured in different ways, researchers believe that their findings probably confirm each other.

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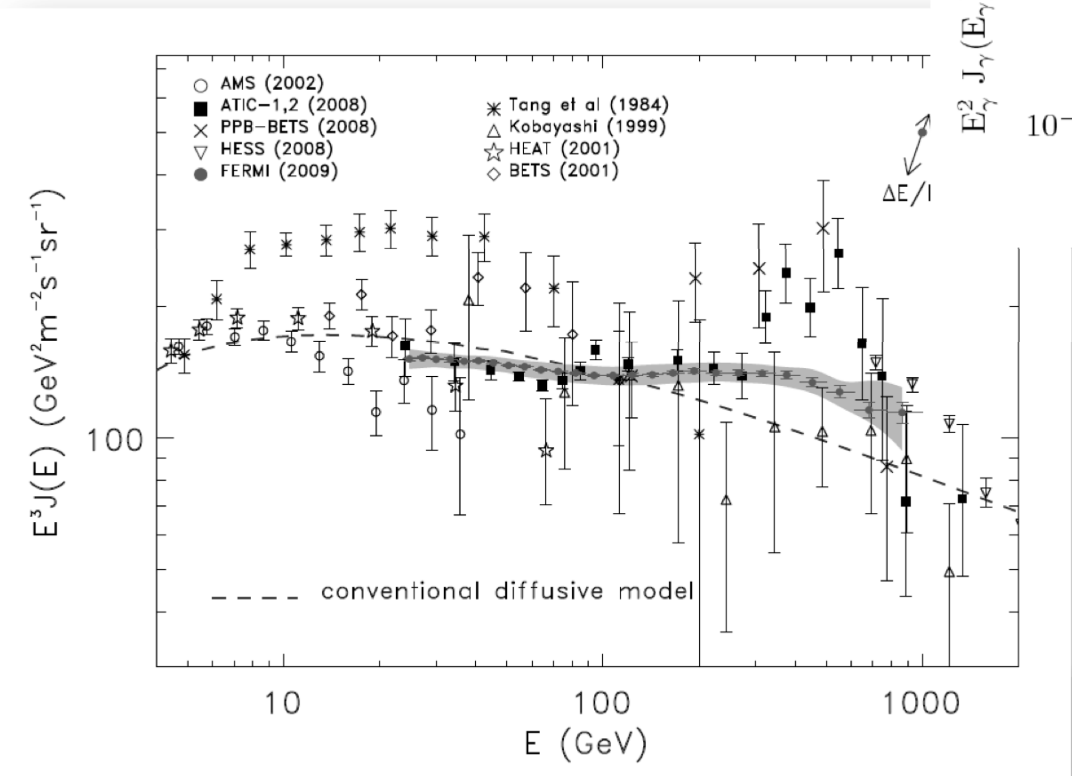
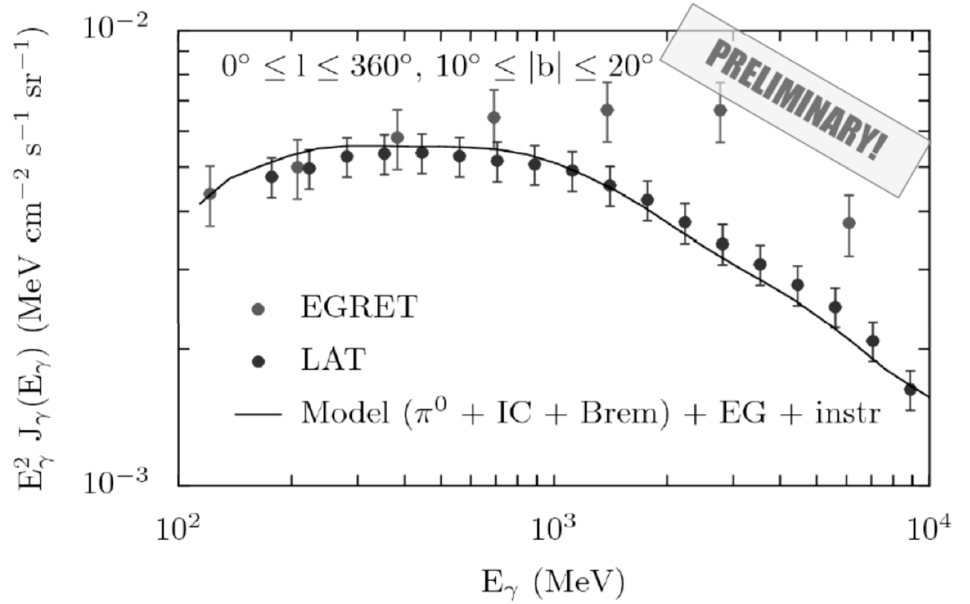
Electrons and galactic diffuse gammas with Fermi

There is some deviation from SM.
But no bump





It follows SM.

If we assume universal spectrum of electron with a bump at 600GeV, we also expect a bump in diffuse gammas around 1GeV.
(IC process with CMB)

Exercise 1: Life time of cosmic rays

- Assume GCRs pass through the matter of $5 g/cm^2$ column density
- Assume the average matter density in our galaxy as $\rho_H \sim 0.5$ proton $/cm^3$

- Q1. What is the typical life time of cosmic rays? Let's calculate by yourself.

  - $N_A = 6.02*10^{23}$
  - $5.0 g/cm^2 = 5.0*N_A$ protons$/cm^2$
  - $\rho_H \sim 0.5$ protons$/cm^3$

  - $L = 5.0*N_A / \rho_H = 5 \cdot 6 \times 10^{23} / 0.5 = 6 \times 10^{24}$ cm $= 6 \times 10^{22}$m
  - $T = L/c = 2 \times 10^{14}$sec $\sim 7 \times 10^6$yr

Exercise 2: Cosmic ray Energy in our galaxy

- Cosmic rays in our galaxy
  - $T_{esc} \sim 3x\ 10^{14}s = 10^7$ yr
  - $\omega_{CR} \sim 1eV/cm^3$
    - ≥90 % of energy density are from <100GeV C.R.

- Volume of CR reservoir, our Galaxy
  - $V \sim \pi \cdot 15kpc^2 \cdot 300pc \sim 10^{67}cm^3$

    $(1pc = 3.1 \times 10^{18}cm)$

- Q2: Stored Energy and necessary power for cosmic ray sources

  $(1eV = 1.6 \times 10^{-12}$ erg $= 1.6 \times 10^{-19}J)$

  - $Ecr \sim V \cdot \omega_{CR} \sim 10^{67}eV = 10^{67}\ eV \cdot 1.6 \times 10^{-12}$ erg/eV $= 1.6 \times 10^{55}$ erg

  - $W_{cr} \sim V \cdot \omega_{CR} / T_{esc} \sim 5x10^{40}$erg/s

Exercise 3: Power from Super Nova

- Type II Super Novae
  - Ejector's velocity u ~ 5x106 m/s (v/c~1/60)
  - Ejection of ~10M☉ (M☉~2x1030 kg)

- Q1 What is the kinetic energy of SN (erg)
  - 1/2 x 10M☉x u2 ~ 3 x 1051erg

- Q2 What is the energy supply rate (erg/sec)
  - assume SN rate ~ every 30years(~109sec)
  - ESNR/30yr ~ 3 x 1042erg/s ➔ ~60 times of necessary power for cosmic rays

Exercise 4: Power from Pulsars

- $E_{rot} \sim 2/5\ M\ R^2\Omega^2$
  - $M=1.4M_\odot$, $R=10km$, $\Omega= (2\pi/0.033)$ s-1

- What is the rotation energy of pulsar
  - $E_{rot} \sim 4 \times 10^{49}$ erg

- What is the energy dissipation rate?
  - assume decay of rotation ~3000yr~10^{11}sec
  - $- dE_{rot}/dt = 4\times10^{38}$ erg/sec per pulsar

- What is the total energy supply from pulsar?
  - assume pulsar rate v_{psr} = 1/30yr = 1/10^9sec
  - $L_{psr} \sim v_{psr} \times E_{rot} \sim 4 \times10^{40}$ erg/sec in our galaxy

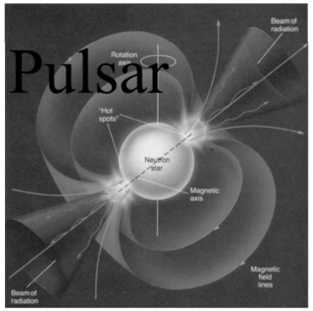
Note 1: Eddington Luminosity

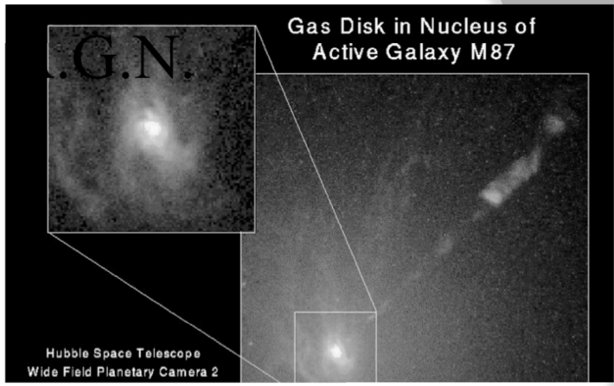
Maximum E.M. radiation from compact object

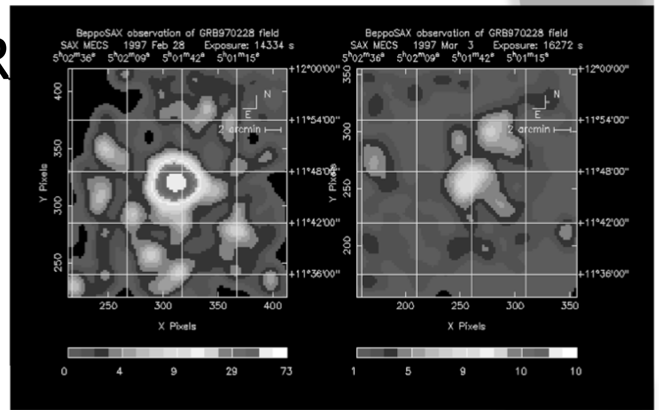
- $\sigma_T L_{Edd} / 4\pi R^2 c = GMm_p/R^2$
  - Radiation pressure for gas (electron) = Gravitational force for gas (Proton)
    ($\sigma_T = (8\pi/3) R_e^2 = 0.665 \times 10^{-28} m^2 = 0.665$ barn)
    ($R_e = e^2/m_e c^2 = 2.81 \times 10^{-15} m$)
- $L_{Edd} = 1.3 \times 10^{38} (M/M_\odot)$ erg/s
- Max. Luminosity from Pulsar ($\sim 1.4 M_\odot$) $\sim 10^{38}$ erg/s
- Max. Luminosity from AGNs($10^8 M_\odot$) $\sim 10^{46}$ erg/s
- c.f. Luminosity from our Sun $\sim 3.85 \times 10^{33}$ erg/s

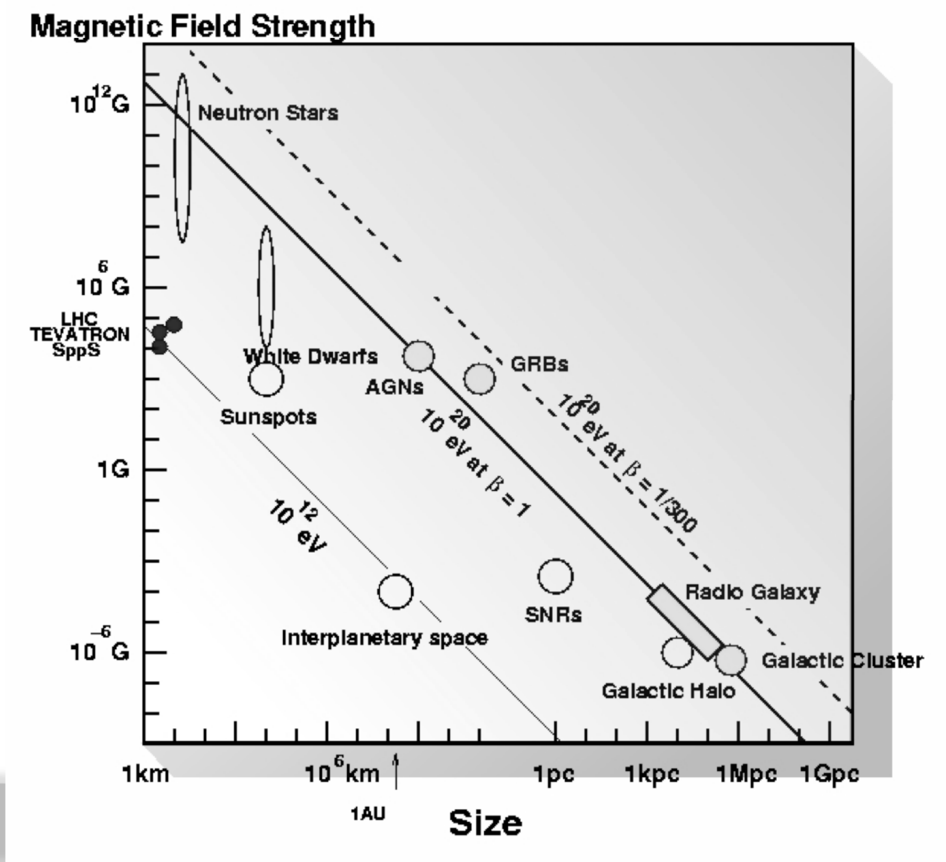
ACCELERATION OF COSMIC RAYS

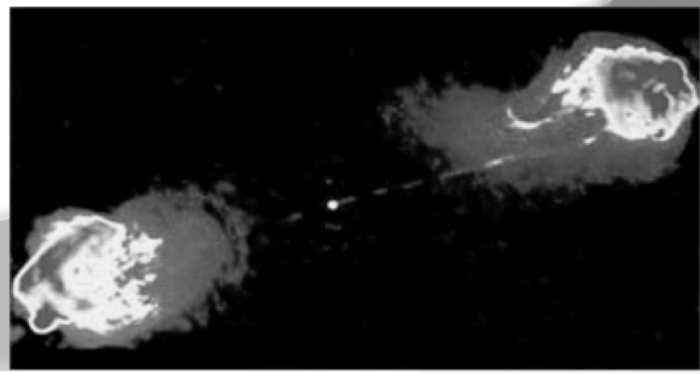
Candidates for UHE C.R. accelerator











Hillas Limit in particle acceleration

- Particle must be confined in the accelerator size
  - Larmor radius
    - $R_L = 1.08\ E_{15} / ZB_{\mu G}$ (in pc)
  - Size of the accelerator must be two times larger than Larmor Radius
    - $L_{pc} > 2R_L = 2.2\ E_{15} / ZB_{\mu G}$ (in pc)
  - $E_{max} < 0.5 \times L_{pc}\ ZB_{\mu G}$

Hillas Limit

- Other interpretation
- Moving magnetic field will produce electric field (for example, pulsars)
  - Induced electric field $E = \beta \times B$
  - In the size of L region, $\Phi_{max} = L \times \beta \times B$
  - $E_{max} < Z \times \Phi_{max} = Z\, L_{pc} \beta B_{\mu G}$

Excersize 5: Hillas limit to SNRs

- Q: What is the maximum energy in SNR acceleration
  - Shock velocity β= 0.01
  - Age T = 1000yr ➔ L = 10 lyr = 3pc
  - Inter stellar Magnetic field B = 3μG
  - $E_{15} = 0.5 \times L_{pc}\, \beta\, B_{\mu G}$ (in PeV)

  - $E_{max} = 0.5 \times 3 \times 0.01 \times 3 = 0.045 = 45$ TeV
  - ➔ this is not enough to explain the knee in the cosmic ray spectrum!!

Excersize 6:
Hillas limit to Pulsars

- What is the maximum energy in Pulsar acceleration
  - Radius R = 10km = 10^4m / 3×10^{16} m/pc ~ 3×10^{-13}pc
  - Magnetic Field = 10^{12}G = 10^{18}μG
  - Rotation $\omega = 2\pi \cdot 33\ s^{-1}$ ➔ $\beta = v/c = \omega R/c = 200 \cdot 10^4 m / 3\times10^8 m = 7 \times 10^{-3}$
  - Emax ~ R (ωR/C)B

- $E_{max} = 0.5\ R_{pc}\ \beta B_{\mu G}$

  $= 0.5 \times 3\times 10^{-13} \times 7\times10^{-3} \times 10^{18}$

  = 1000 PeV

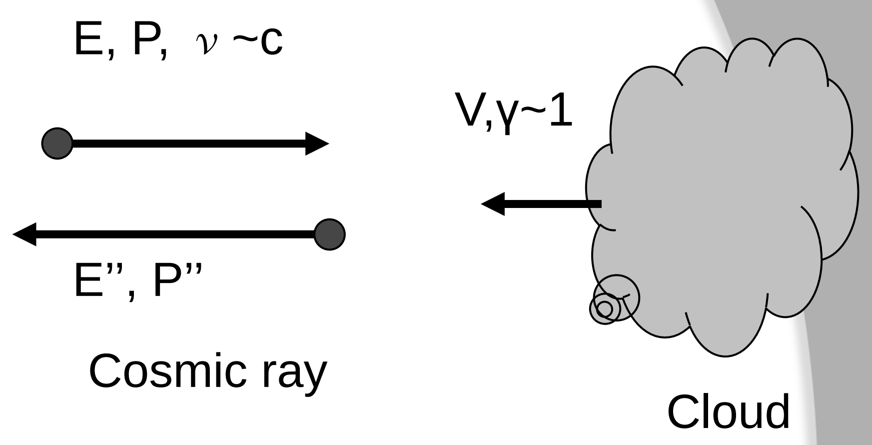
  = 10^{18}eV

- In reality: The synchrotron radiation, curvature radiation must be taken into accout

SECOND ORDER FERMI ACCELERATION (ORIGINAL FERMI'S IDEA)

Fermi Accleration (2nd order) p1

- Head on collision
  - in cloud frame
  - $E' = \gamma(E+VP)$
  - $P' = \gamma(P+VE/c^2)$



- After the reflection
  - E' after = E' before
  - P' after = - P' after

- Then transform to lab. Frame
  - $E'' = \gamma(E'+VP') = \gamma(\gamma(E+VP)+V\gamma(P+VE/c^2))$
    $= \gamma^2 (E+VP+VP+V^2/c^2E)$
    $= \gamma^2 ((1-V^2/c^2)E +2VP+2V^2/c^2E)$
    $= E + 2 \gamma^2 E V/c (V/c+ v/c)$
  - $\Delta E = 2 \gamma^2 E V/c (V/c +v/c)$ ← head-on
  - $\Delta E = -2 \gamma^2 E V/c (-V/c+v/c)$ ← following

Fermi Acceleration (2nd order) p2

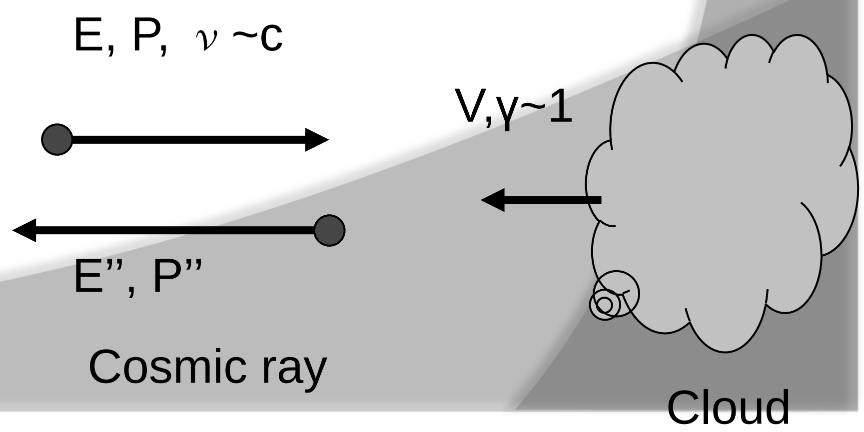
- Probability of head on and following collision
  - Head on ➔ v+V ➔(v+V)/2v
  - Following ➔v-V ➔(v -V)/2v

- Total energy gain after taking average
  - $\Delta E = (v+V)/2v \cdot 2\gamma^2 EV/c(V/c+v/c)$

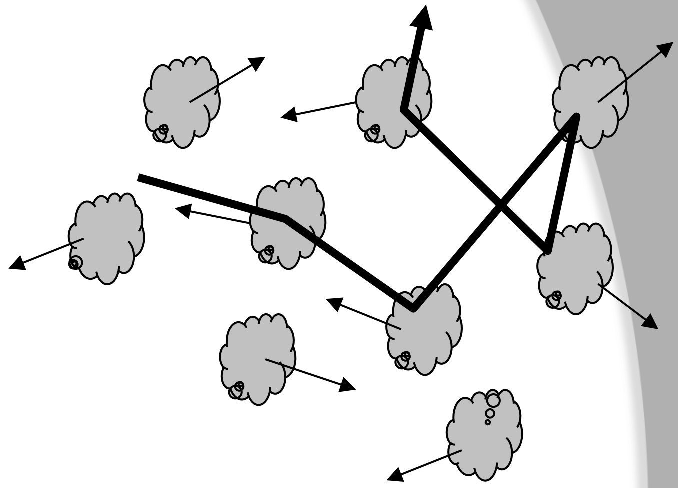
    $- (v-V)/2v \cdot 2\gamma^2 EV/c(v/c-V/c)$

    $= 4\gamma^2 E(V/c)^2 (v/c)$

    $\sim 4E(V/c)^2$



Fermi Acceleration (2nd order) p3



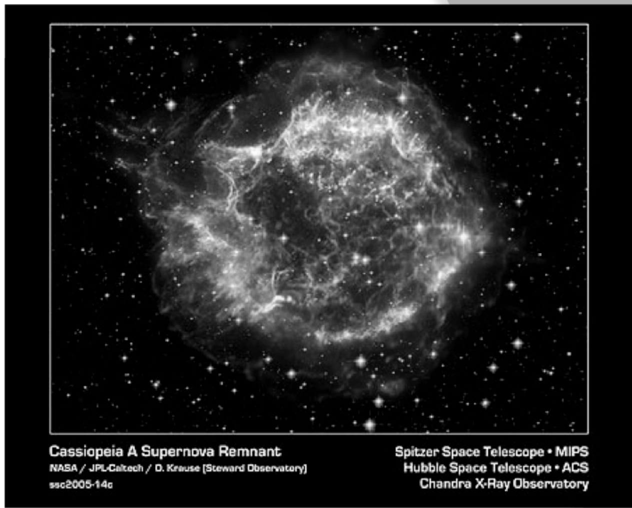
- $\Delta E/E = 4(V/c)^2$
- Collision rate M
- $dE/dt = 4M(V/c)^2E = \alpha E$
  - $E \propto \exp(\alpha t)$
- After k collisions,
  - $E = \beta^k E_0$, here $\beta=(1+4(V/c)^2)$
- Escape rate (1-P) in each collision (remaining probability = P)
  - $N = P^k N_0$
  - $\log(N/N0) / \log(E/E0) = \log(P)/\log(\beta)$
- $N \propto E^{(\log(P)/ \log(\beta))}$, $dN/dE \propto E^{(-1 + \log(P)/\log(\beta))}$

FIRST ORDER FERMI ACCELERATION

Shock wave in the atmosphere

Fermi Acceleration (1st order) p1

- Balndford and Ostriker 1978 ApJ 174,p253-

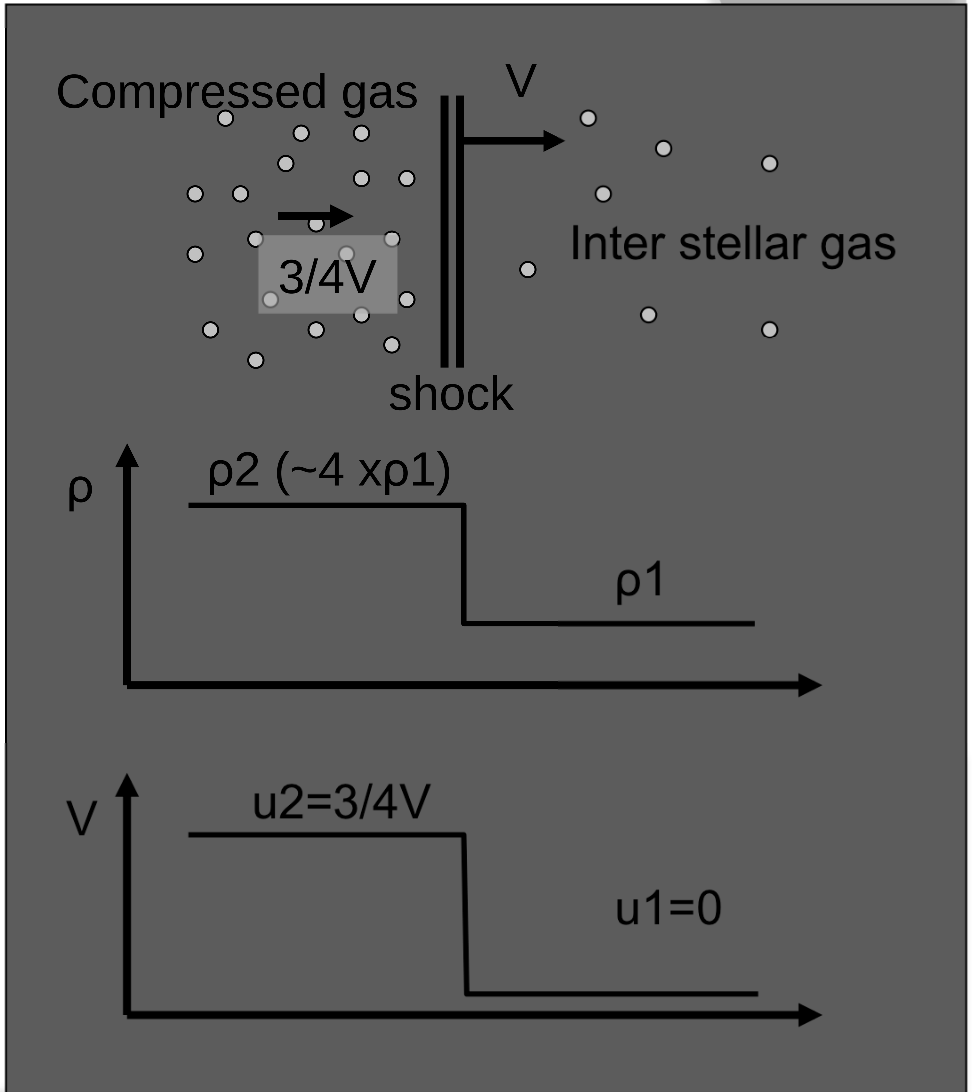


Cas-A exploded 300yr ago

- Shock wave
  - $V=10^4 kms^{-1}$
    (Sound velocity $10kms^{-1}$)
  - $\rho_2 / \rho_1 = \gamma+1/\gamma-1 \sim 4$
    - $\gamma=C_p/C_v$, fully ionized gas $\gamma= 5/3$
  - Exact ratio
    - $\rho_2 / \rho_1 = (C_p/ C_v + 1)M^2 / ((C_p/C_v - 1)M^2+2)$

Fermi Acceleration (1st order) P2

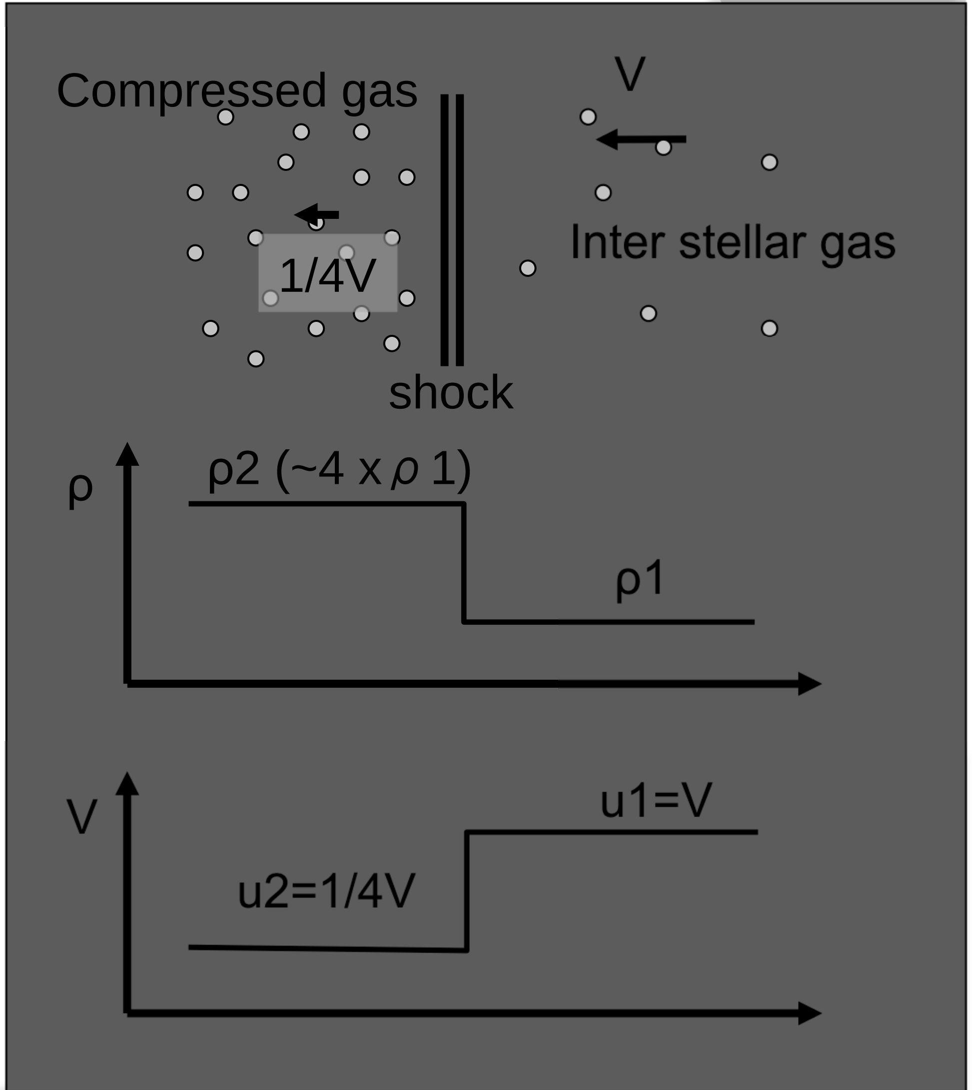
- $\rho_2 / \rho_1 = \gamma+1/\gamma-1 \sim 4$
- Gas is compressed by a factor of 4 and follow the shock with the relative velocity of 1/4V
- u_2 =3/4V, u_1 = 0



Observer's frame

Fermi Acceleration (1st order) P3

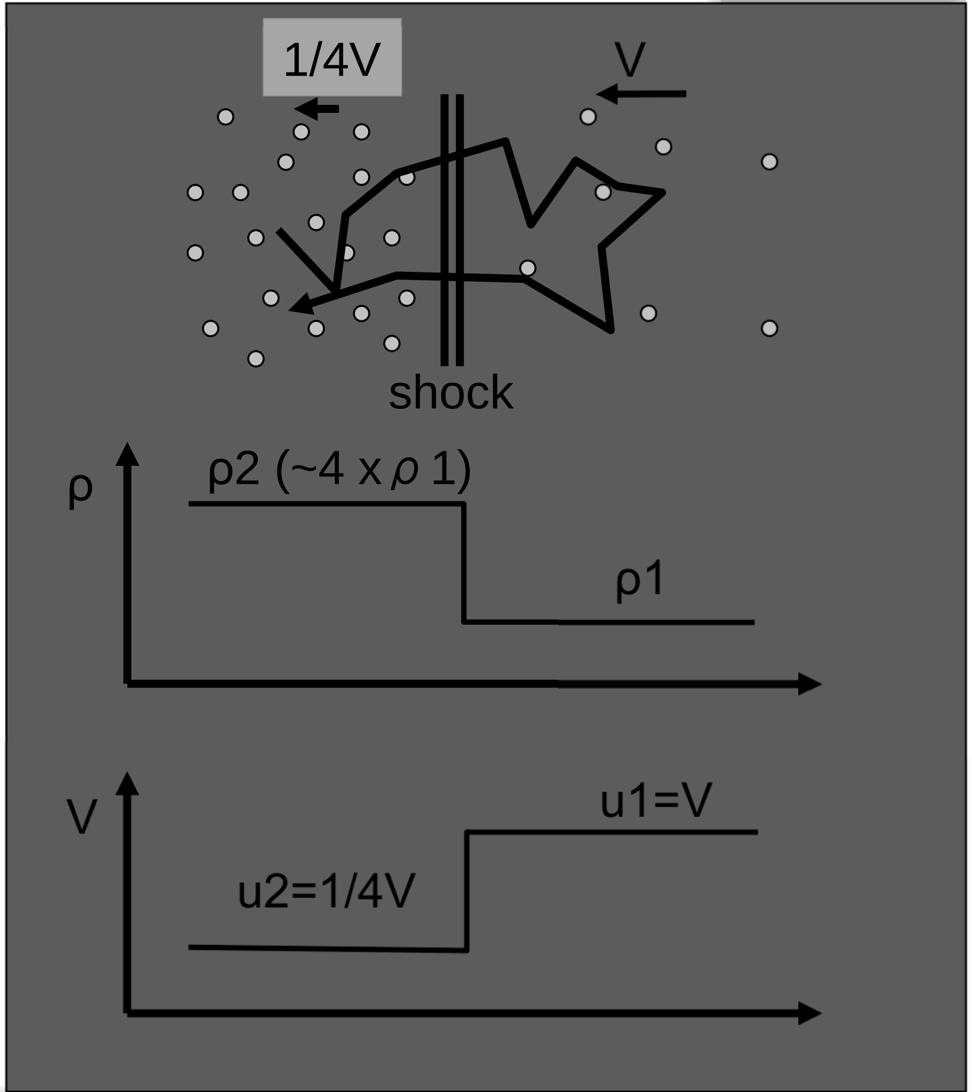
- $\rho_2 / \rho_1 = \gamma+1/\gamma-1 \sim 4$
- From the continuity of gas flow
  - $u_1 \times \rho_1 = u_2 \times \rho_2$
  - $u_2 = 1/4\ V$, $u_1 = V$



Shock frame

Fermi Acceleration (1st order) P4

- $\rho_2 / \rho_1 \sim 4$
- $u_2 = 1/4\ V$, $u_1 = V$
- $\Delta u = u_1 - u_2 = 3/4\ V$
  - converging flow
- cosmic ray particles crossing the shock
  - $E' = \gamma(E + \Delta u / c\ Pc)$
  - $E'' = \gamma(E' + \Delta u / c\ P'c)$
  - $E \sim Pc$, $\gamma \sim 1$
  - $E'' = E + 2\Delta u / c\ E$
- $\Delta E/E = 2\ \Delta u / c$
- $\Delta E/E = 4/3\ \Delta u / c$



Shock frame

Fermi Acceleration (1^{st} order) p5

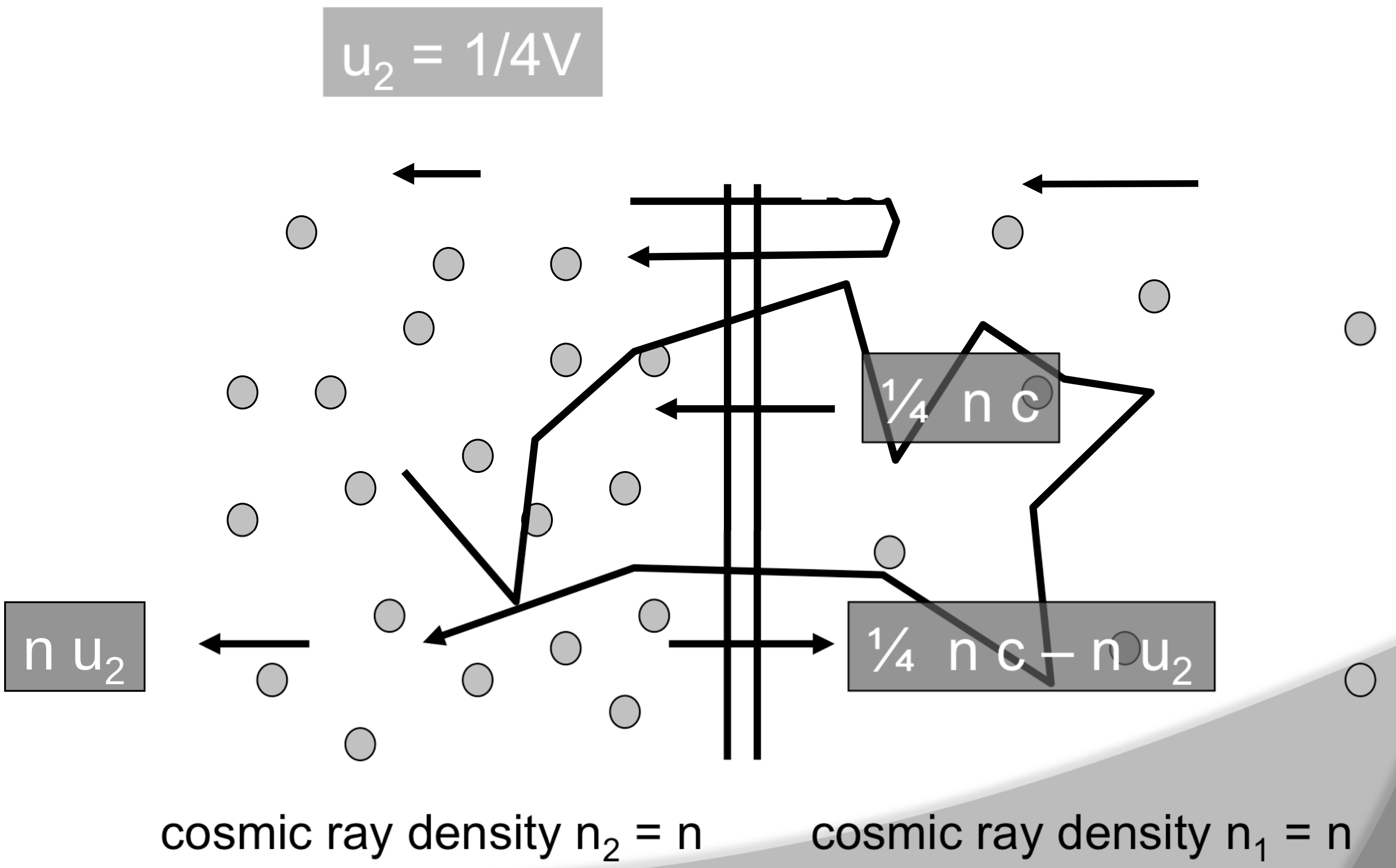
- after k-cycles
- $E=\beta^k E_0$
- here $\beta= (1+4/3\Delta u /c)$, $\log\beta \sim 4/3 \Delta u /c$

- cosmic rays in upstream must come back down stream
- But, cosmic rays in down stream will escape some probability from the system
- n1~ n2 ~n are cosmic ray densities in the upstream and downstream, respectively
- cosmic ray flux crossing the shock is 1/4 n c
- In downstream, cosmic ray flux of n x u2 escape from the system

- Then among the cosmic ray flux of 1/4 n c from upstream to downstream, the flux of n x u2 will escape in downstream and

  1/4 n c – n u2 will again go back to upstream

Fermi Acceleration (1st order) p6



Fermi Acceleration (1^{st} order) p7

- The probability to remain in the system
- $P = (1/4\ n\ c - n\ u_2) / (1/4nc) = 1 - 4\ u_2 / c$
- $\log(P) \sim -\ 4u_2/c$
- $\log(\beta) \sim -4/3\ \Delta u = -4/3(u_1 - u_2) = 4u_2$
- Then, $\log(P)/\log(\beta) = -\ \ 4u_2\ \ / 4u_2 = -1$

- Energy spectrum of cosmic rays by shock acceleration

  - $N \propto E^{-1}$, $dN/dE = E^{-2}$
  - ➔ Fermi Acceleration golden rule

Excersize 7: Expansion of SNR

- Let's calculate the lifetime of SNR (free expansion phase)
  - Assume $10M_{\odot}$ ejectors from SN,1proton/cm3 gas density in the enviroment and shock velocity of 1/60c
  - When the total ejector mass and accumulated gas becomes equal, the shock will start to dump (enter Sedov phase)
  - ($1M_{\odot}=2.0 \times 10^{30}$kg)

- Q1: calculate the time to shift from the free expansion phase to Sedov phase by yourself

  - $10M_{\odot}$ ~ expanding volume x 1 proton cm^{-3}
  - $10*2.0\times10^{30}$kg = 2×10^{34} x 6.02×10^{23} protons
  - $4\pi/3 \times Rc^3 = 12 \times 10^{57}$
  - $R_c \sim 3^{1/3} \times 10^{19}$ cm ~ 1.4×10^{19}cm ~ 5pc
  - T_c ~ 5pc/v ~15 lyr/(1/60c) ~ 1000 ly