PHENOMENOLOGICAL RESULTS

Paolo Lipari
5th WAPP workshop
Ooty 17th december 2010

1. Gamma Astronomy "Golden Age"

2. Unsolved problems in COSMIC RAYS


300
301

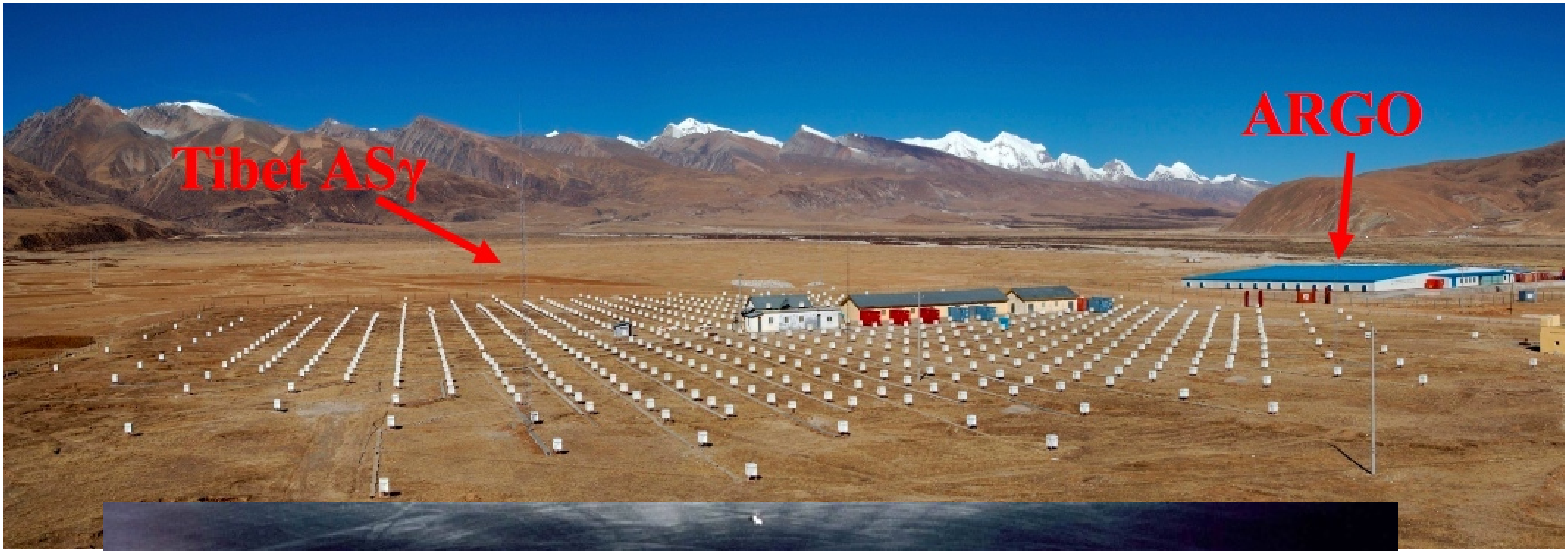
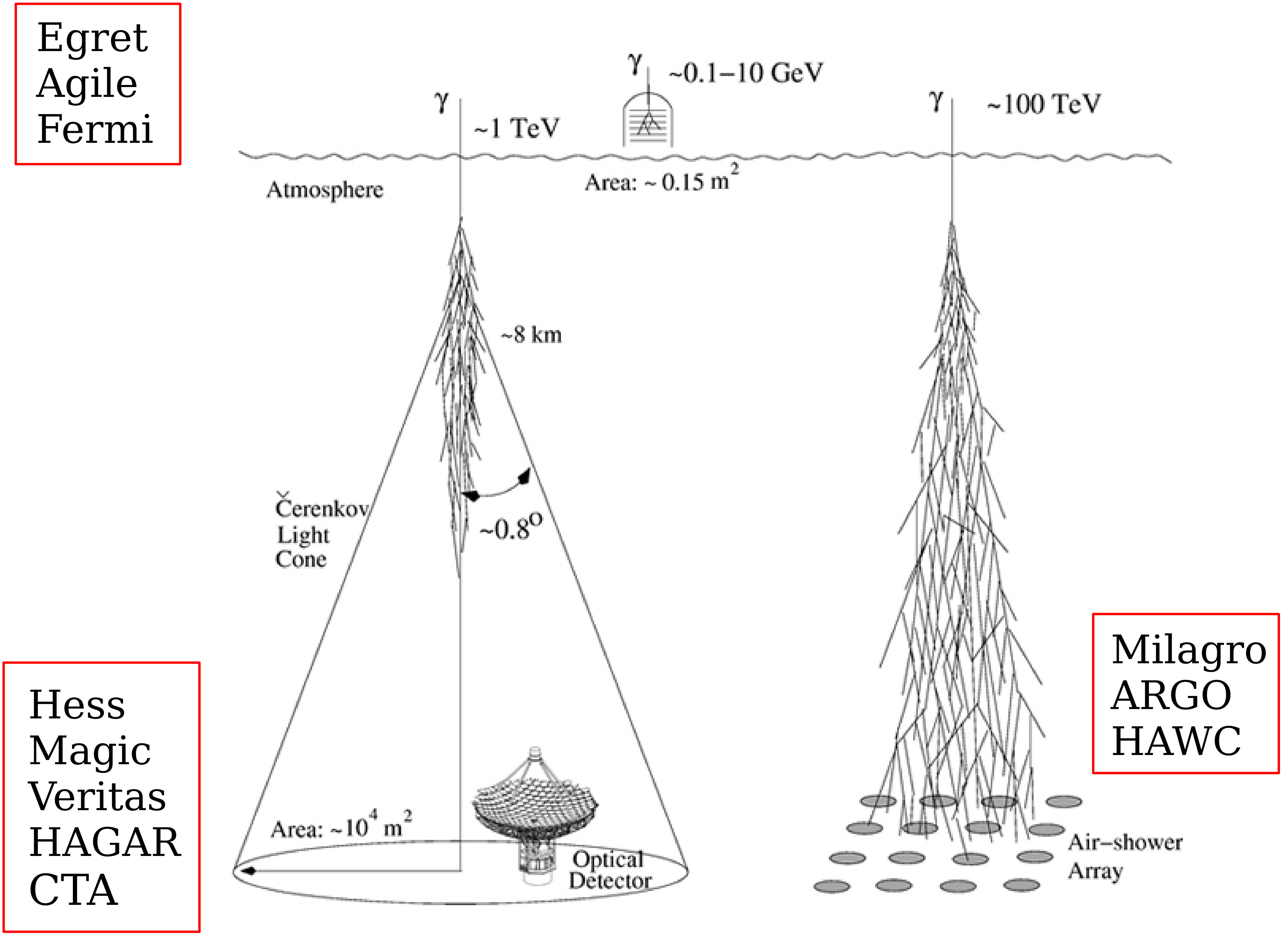
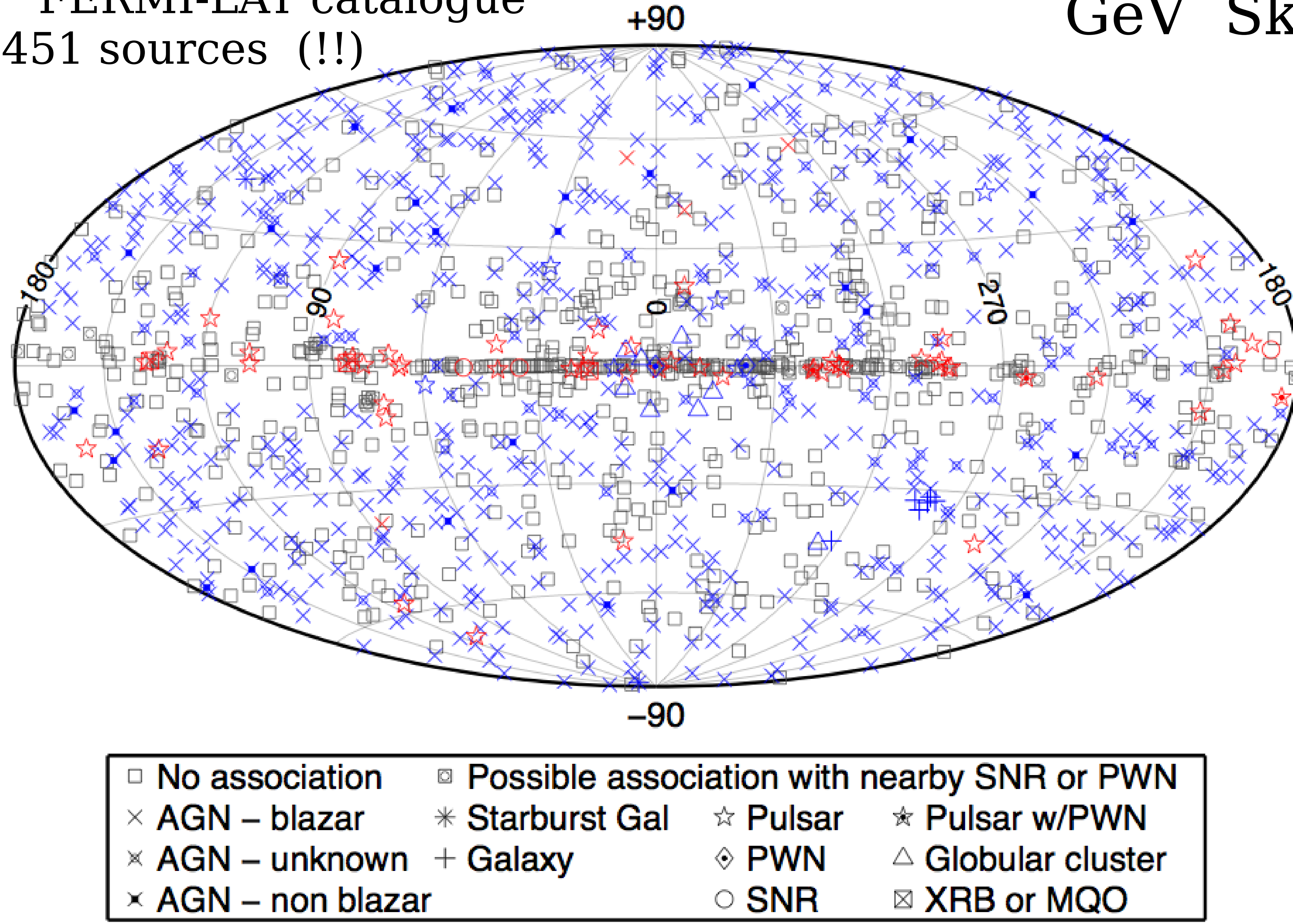

Tibet ASγ
ARGO


Photo © Rick Dingus

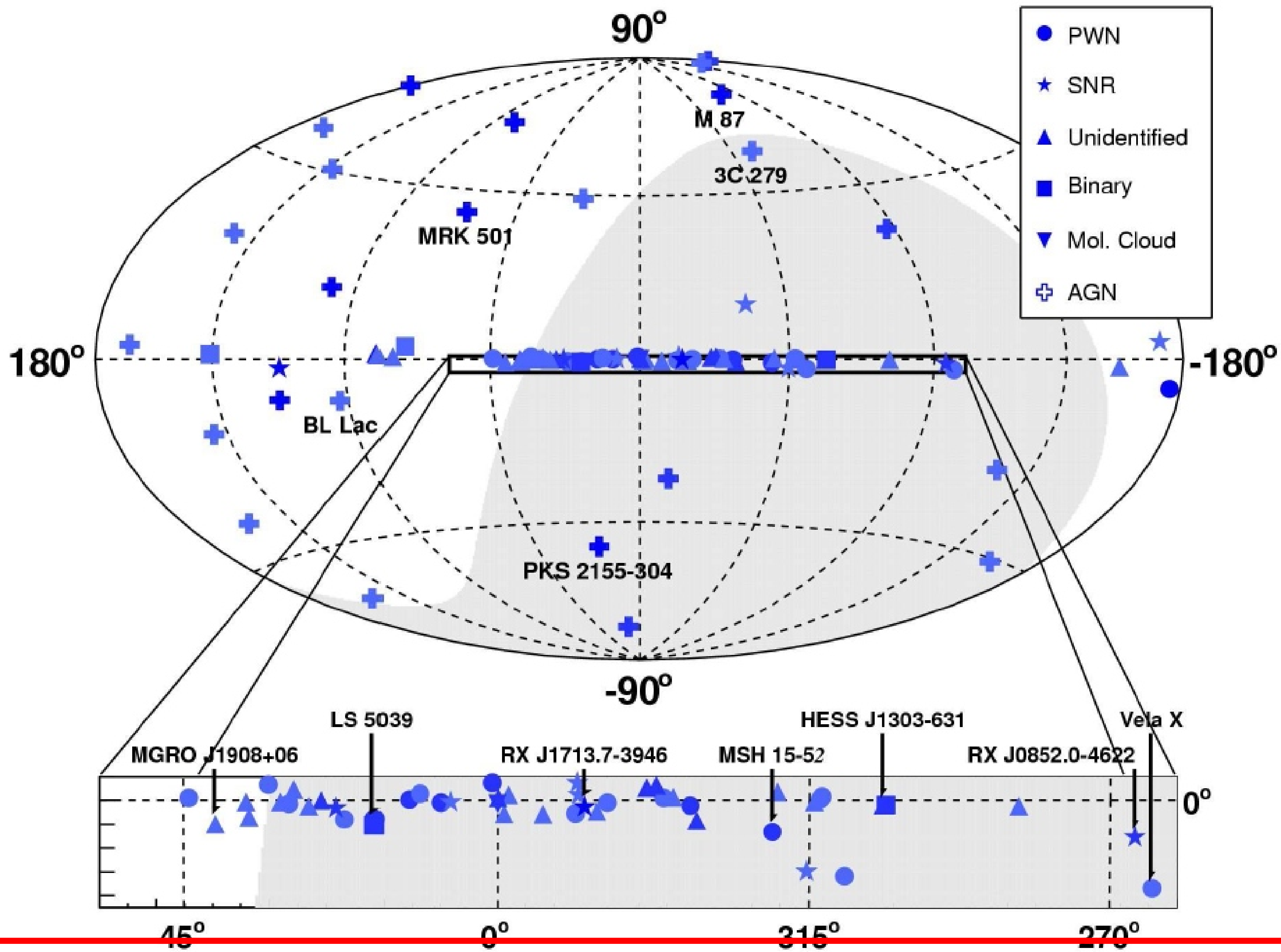

Egret
Agile
Fermi
γ
~1 TeV
γ
~0.1–10 GeV
γ
~100 TeV
Atmosphere
Area: ~ 0.15 m2
~8 km
Čerenkov
Light
Cone
~0.8o
Area: ~10⁴ m²
Optical
Detector
Air–shower
Array
Hess
Magic
Veritas
HAGAR
CTA
Milagro
ARGO
HAWC

1st FERMI-LAT catalogue
1451 sources (!!)

GeV Sky

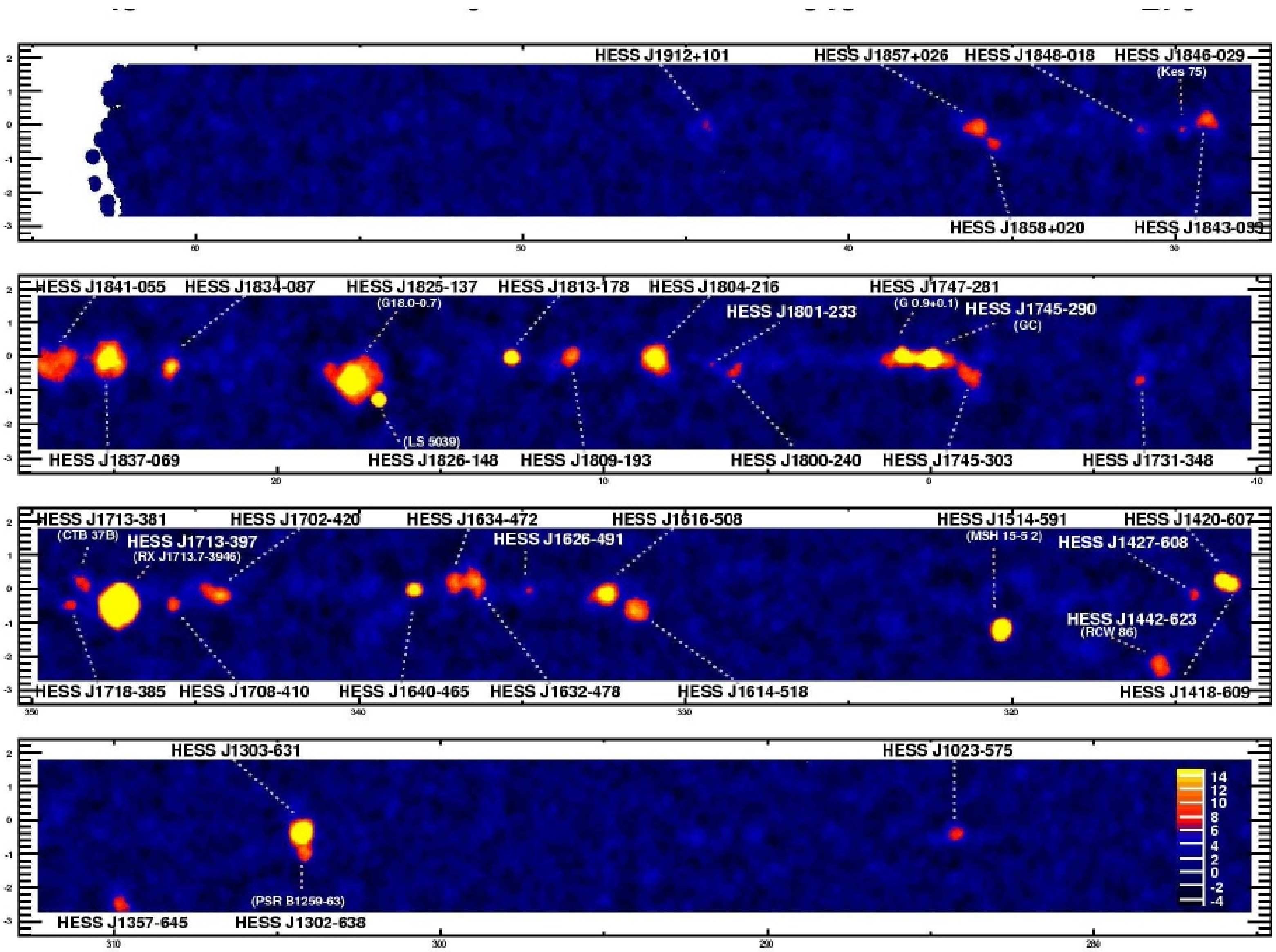


TEV SKY

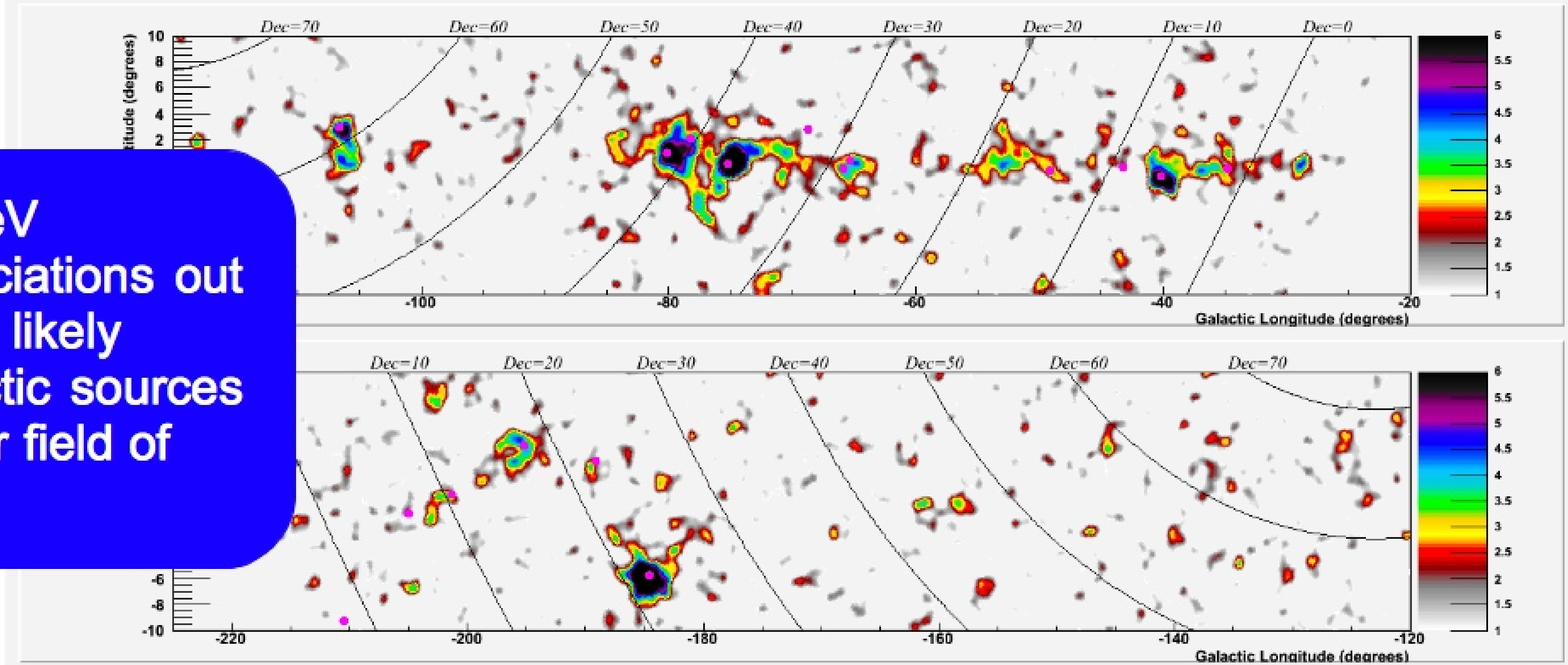


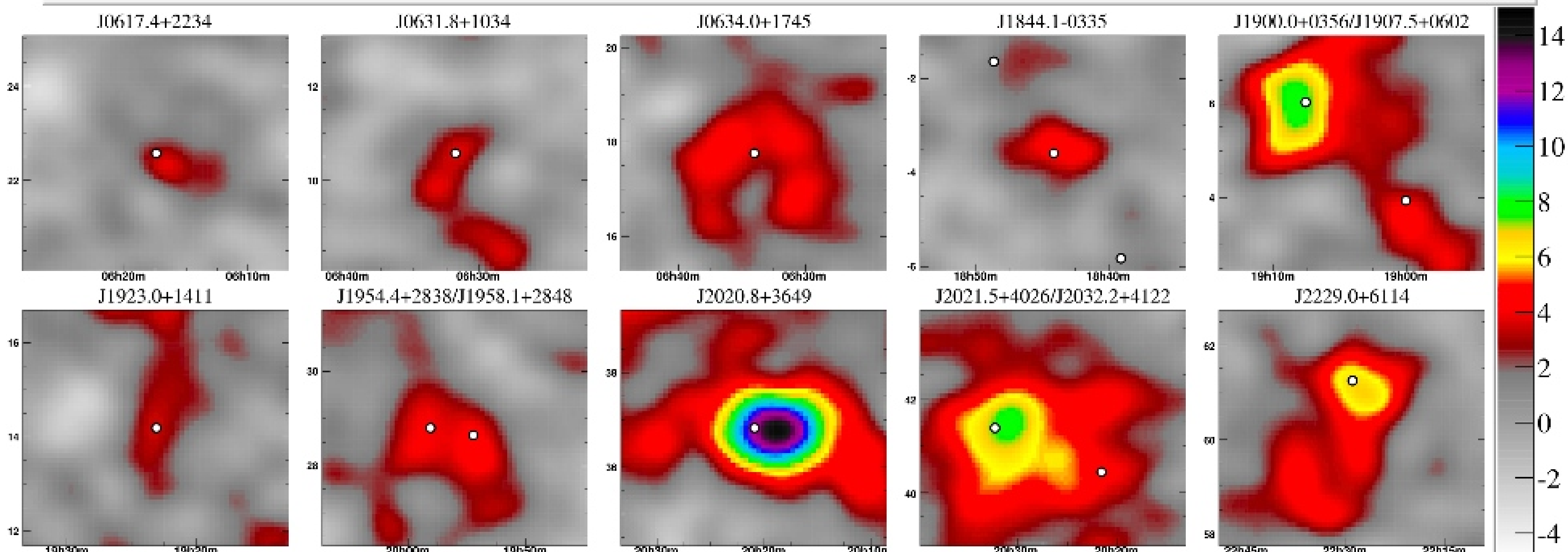
The TeV sky is approaching 100 sources belonging to several different classes:

HESS scan of the Galactic plane

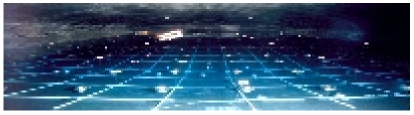


16 TeV associations out of 34 likely galactic sources in our field of view



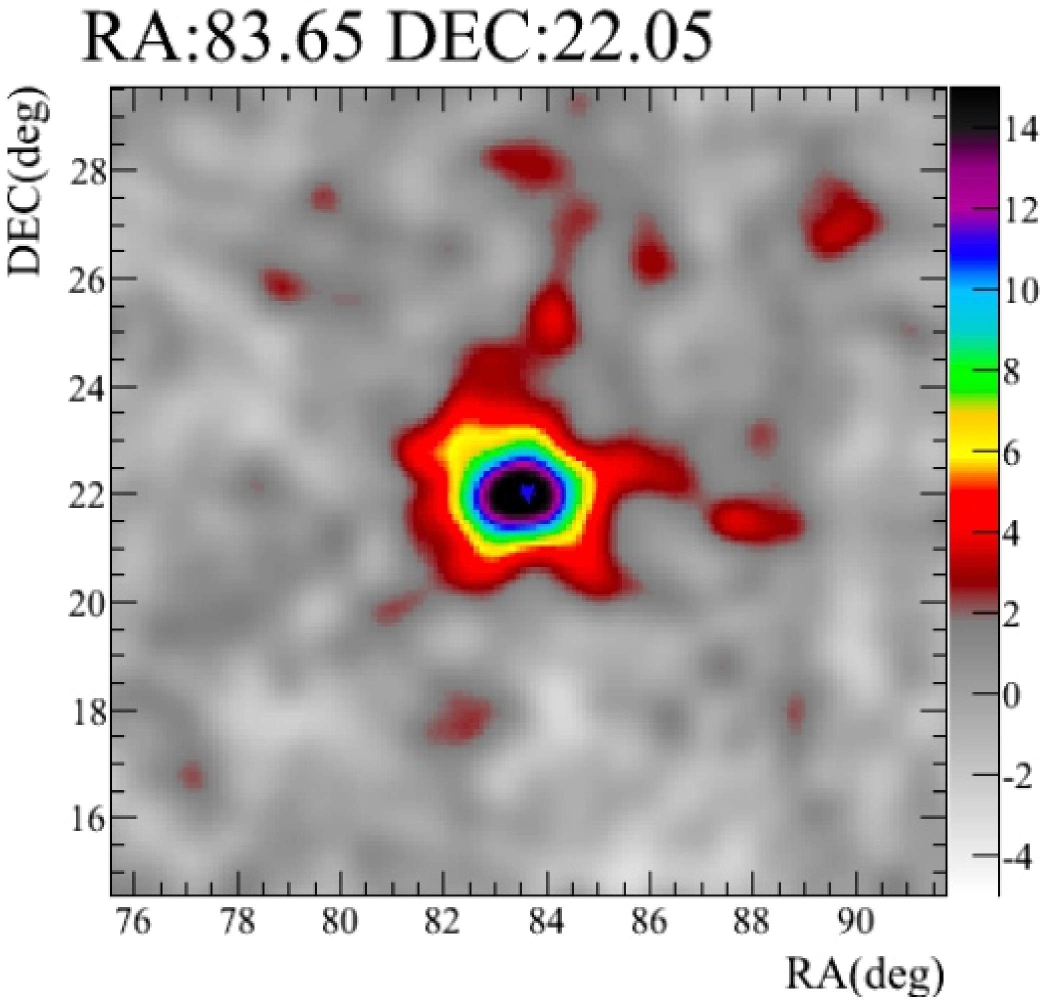


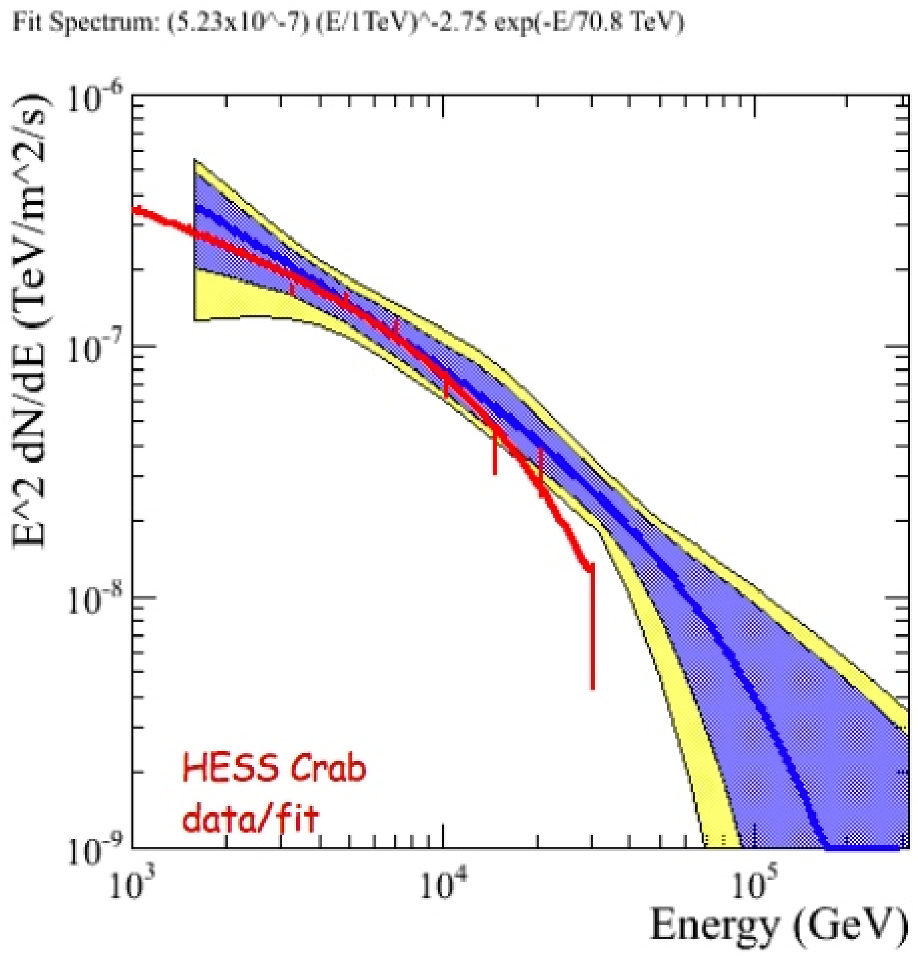
Abdo et al



Jordan Goodman

Spectrum of the Crab

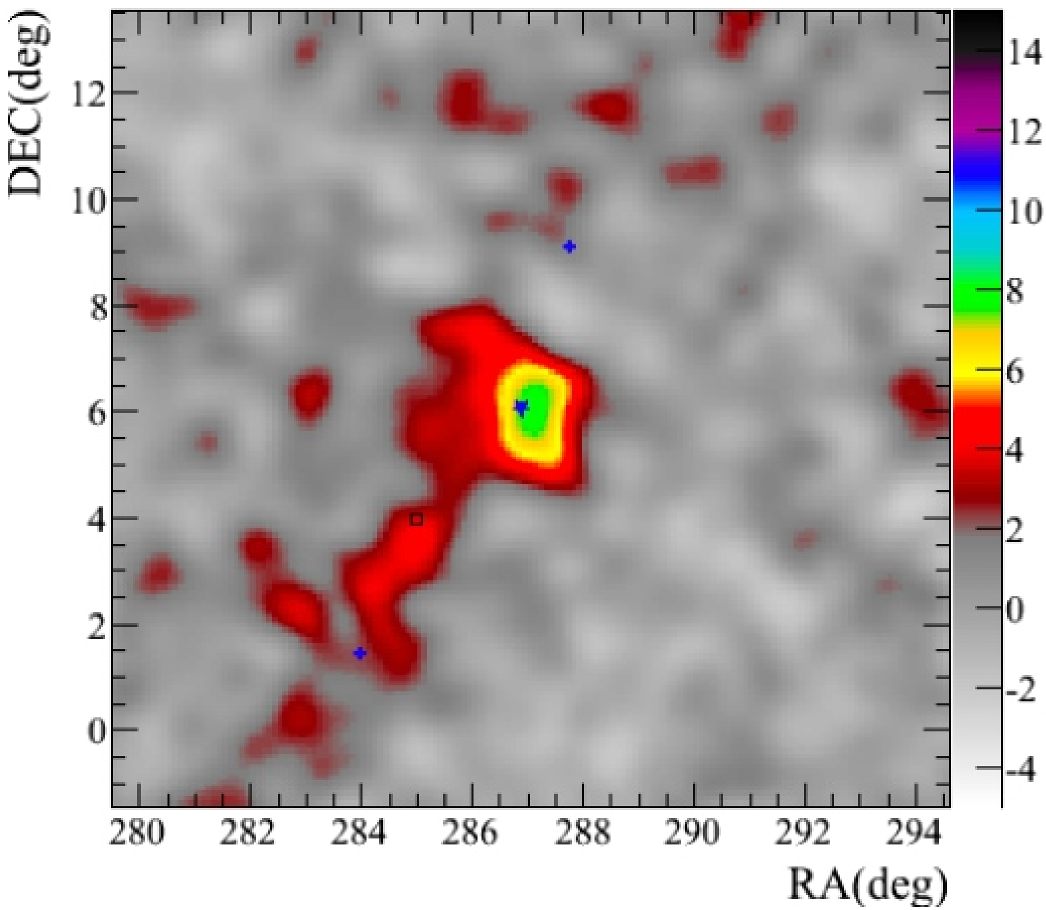


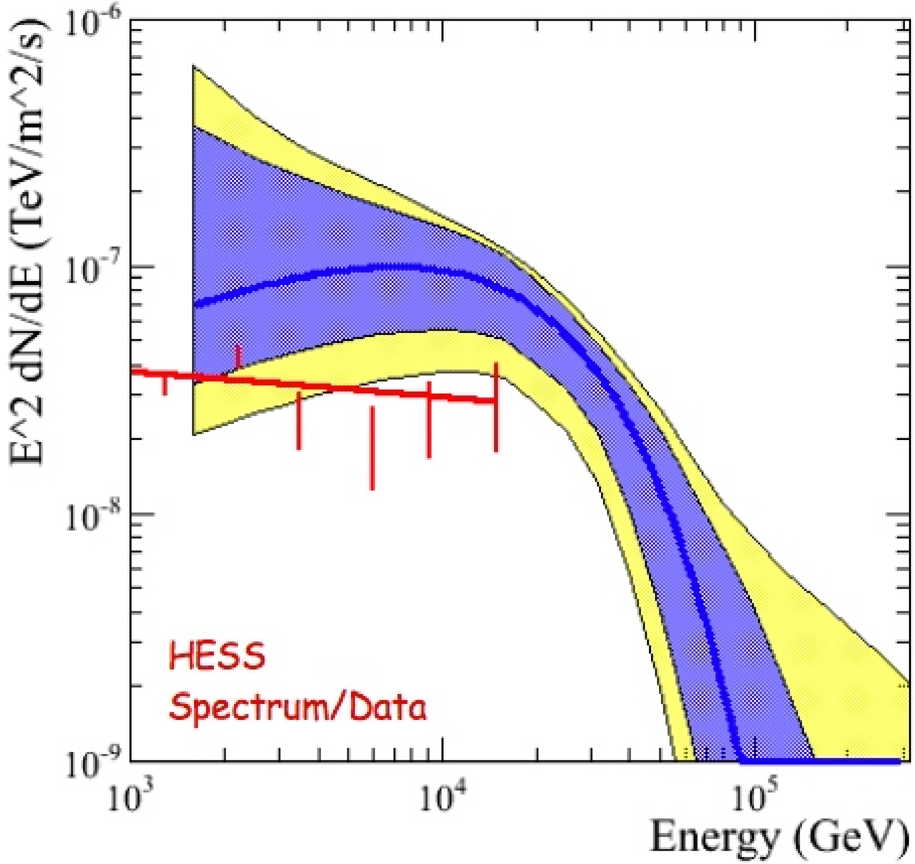


Jordan Goodman

MGRO J1908+06

RA:287.05 DEC:6.05



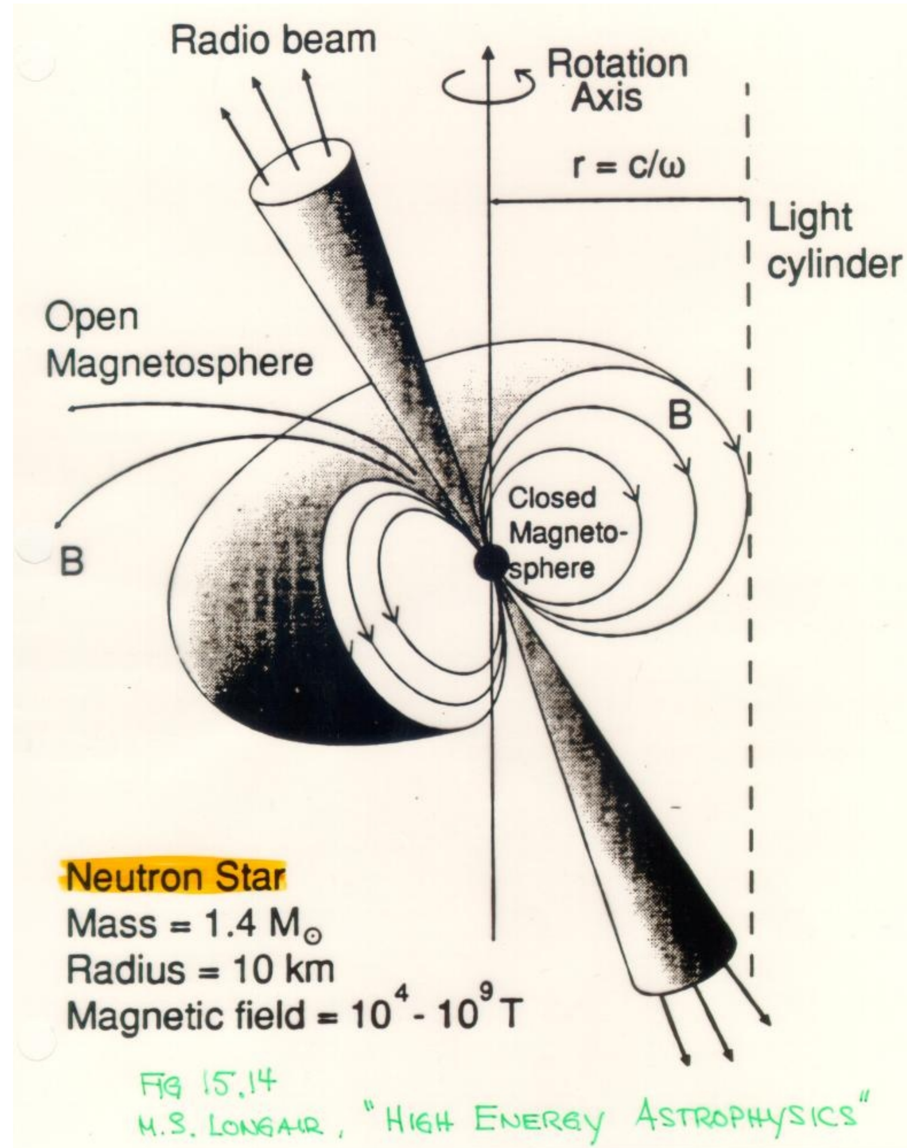


Jordan Goodman

- PULSARS (PSR)
- Pulsar Wind Nebulae (PWN)
- SuperNova Remnant (SNR)
- Active Galactic Nuclei (AGN)
- Gamma Ray Bursts (GRB)

PULSARS

Proposed as possible Accelerators of e+ e-



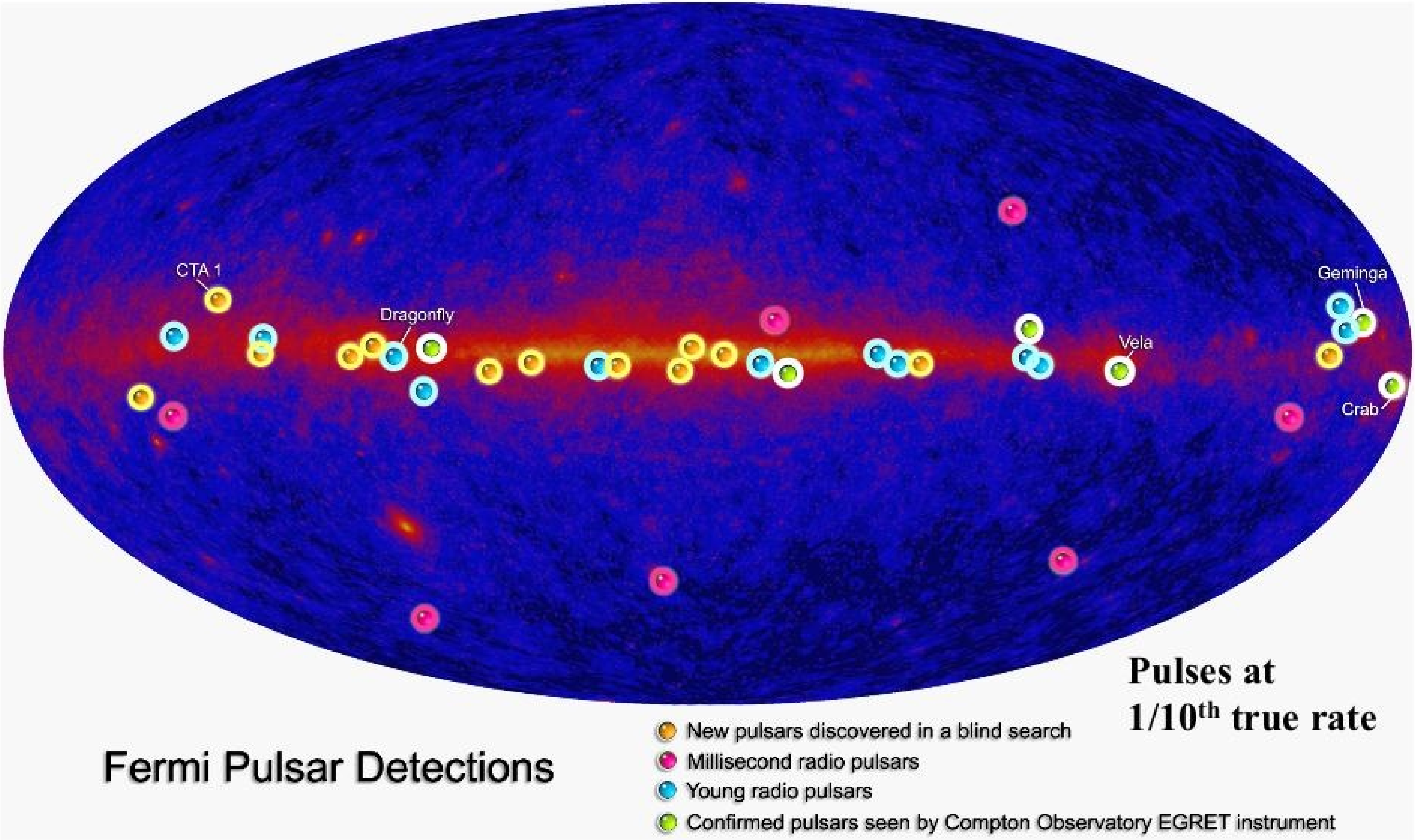
CRAB Nebula

$$P_{\rm Crab} = 0.0334 \ {\rm s}$$

$$\dot{P}_{\rm Crab} = 4.2 \times 10^{-13} \ {\rm s}$$

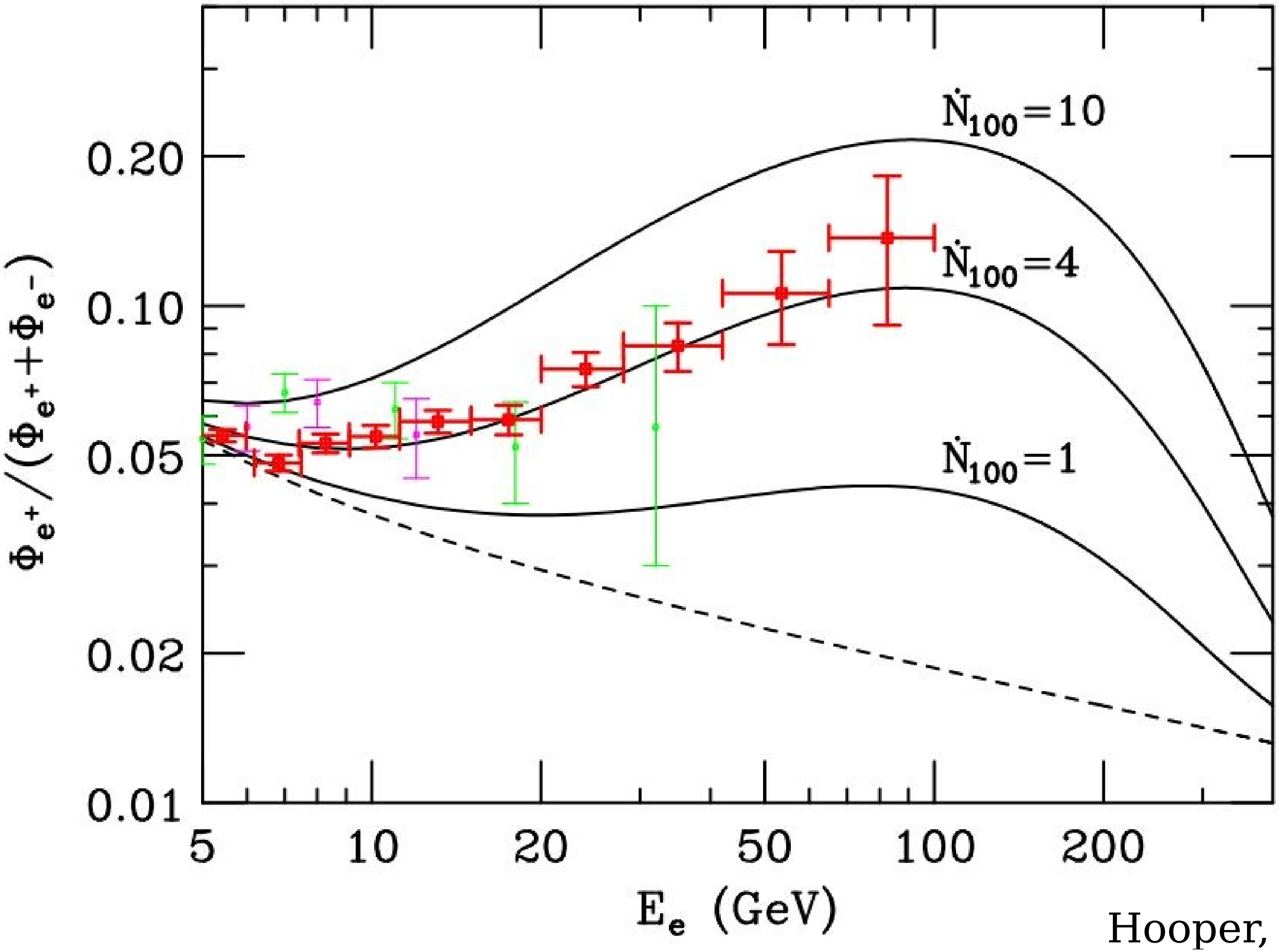
$$(\Delta P_{\rm Crab})_{\rm year} = 13.2 \times 10^{-6} \ {\rm s}$$

Fermi Pulsar detection



Explanation of the
"PAMELA POSITRON EXCESS"

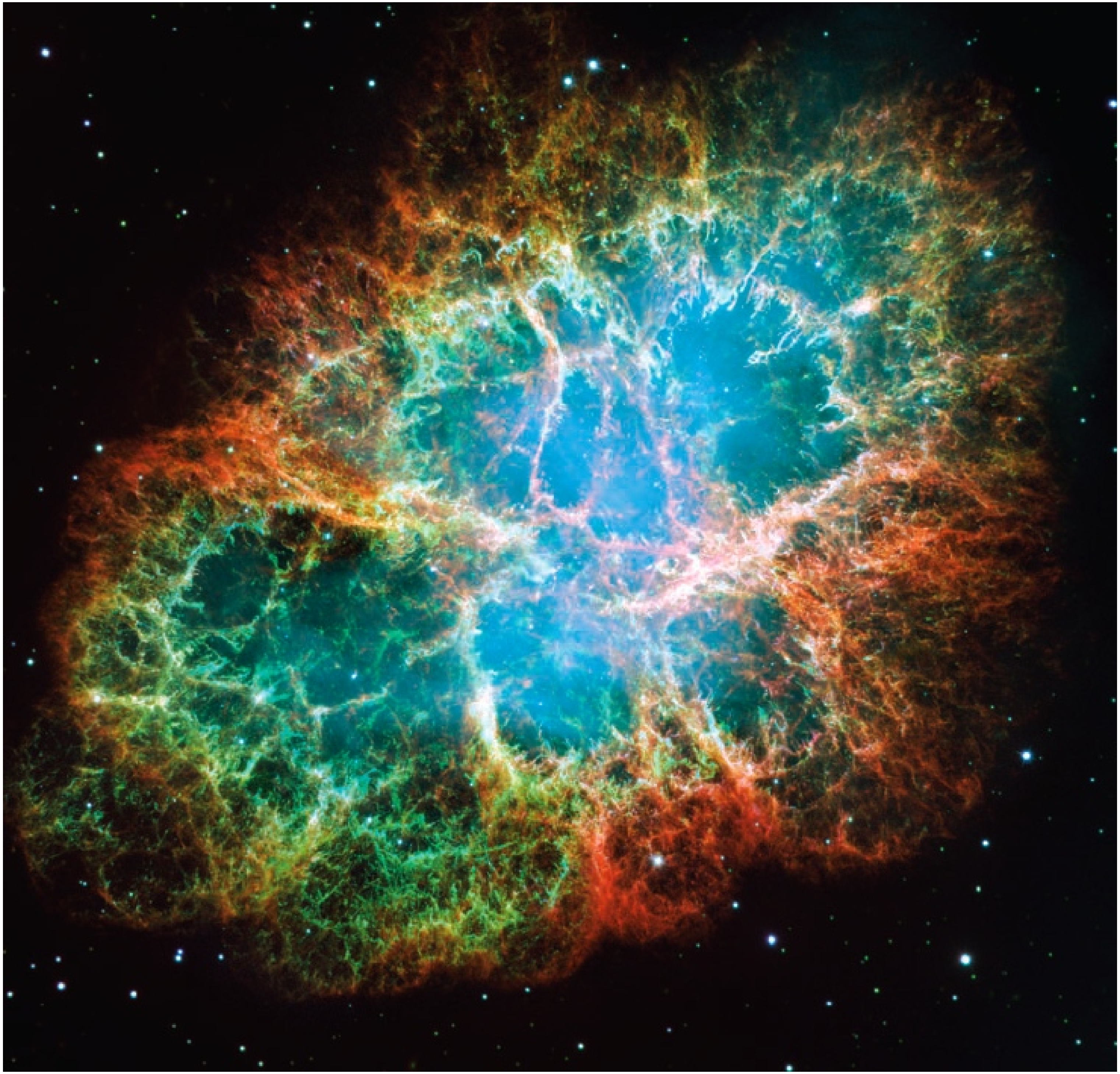
Contribution
from all Pulsars

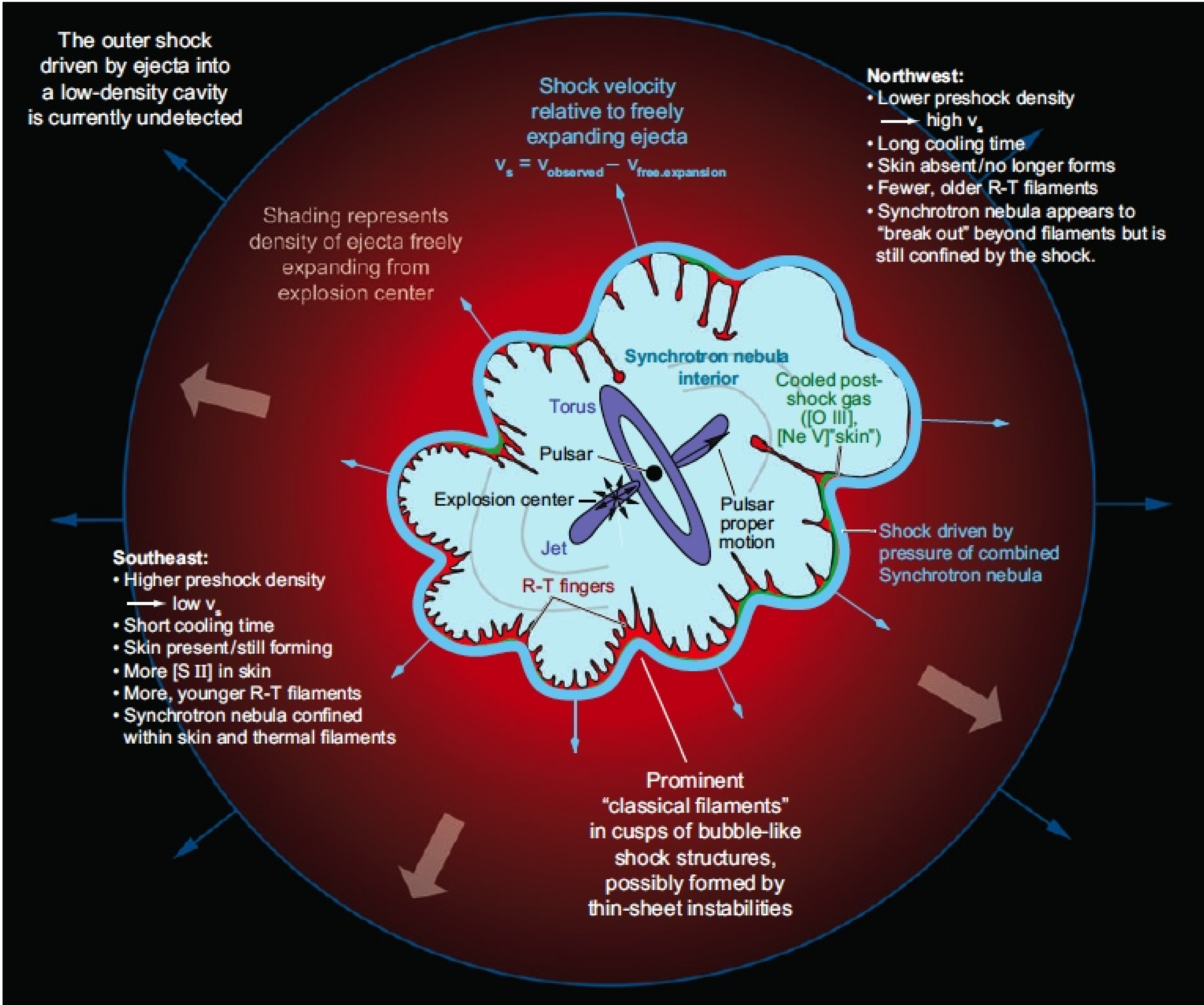


Hooper, Blasi, Serpico 2008

$$\frac{dN_e}{dE_e} \approx 8.6 \times 10^{38}\,\dot{N}_{100}\,(E_e/\mathrm{GeV})^{-1.6}\,\exp\left(-E_e/80\,\mathrm{GeV}\right)\,\mathrm{GeV}^{-1}\,\mathrm{s}^{-1}$$

CRAB Nebula

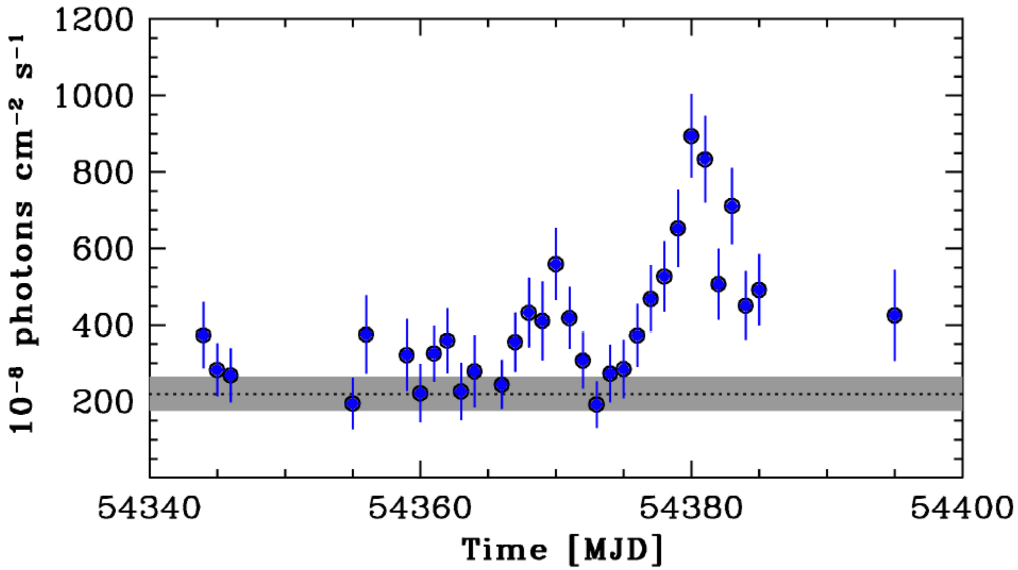




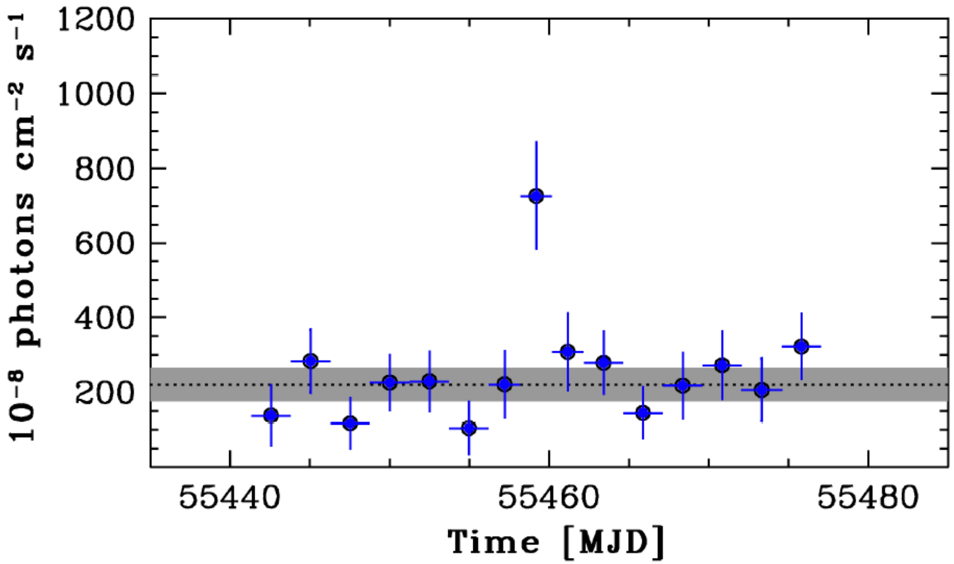
The outer shock driven by ejecta into a low-density cavity is currently undetected
Shock velocity relative to freely expanding ejecta
$v_s = v_{observed} - v_{free.expansion}$
Northwest:
• Lower preshock density → high v_s
• Long cooling time
• Skin absent/no longer forms
• Fewer, older R-T filaments
• Synchrotron nebula appears to "break out" beyond filaments but is still confined by the shock.
Shading represents density of ejecta freely expanding from explosion center
Synchrotron nebula interior
Cooled post-shock gas ([O III], [Ne V]"skin")
Torus
Pulsar
Explosion center
Jet
Pulsar proper motion
Shock driven by pressure of combined Synchrotron nebula
R-T fingers
Southeast:
• Higher preshock density → low v_s
• Short cooling time
• Skin present/still forming
• More [S II] in skin
• More, younger R-T filaments
• Synchrotron nebula confined within skin and thermal filaments
Prominent "classical filaments" in cusps of bubble-like shock structures, possibly formed by thin-sheet instabilities

Discovery of Powerful Gamma-Ray Flares from the Crab Nebula

AGILE
(Science in Press)

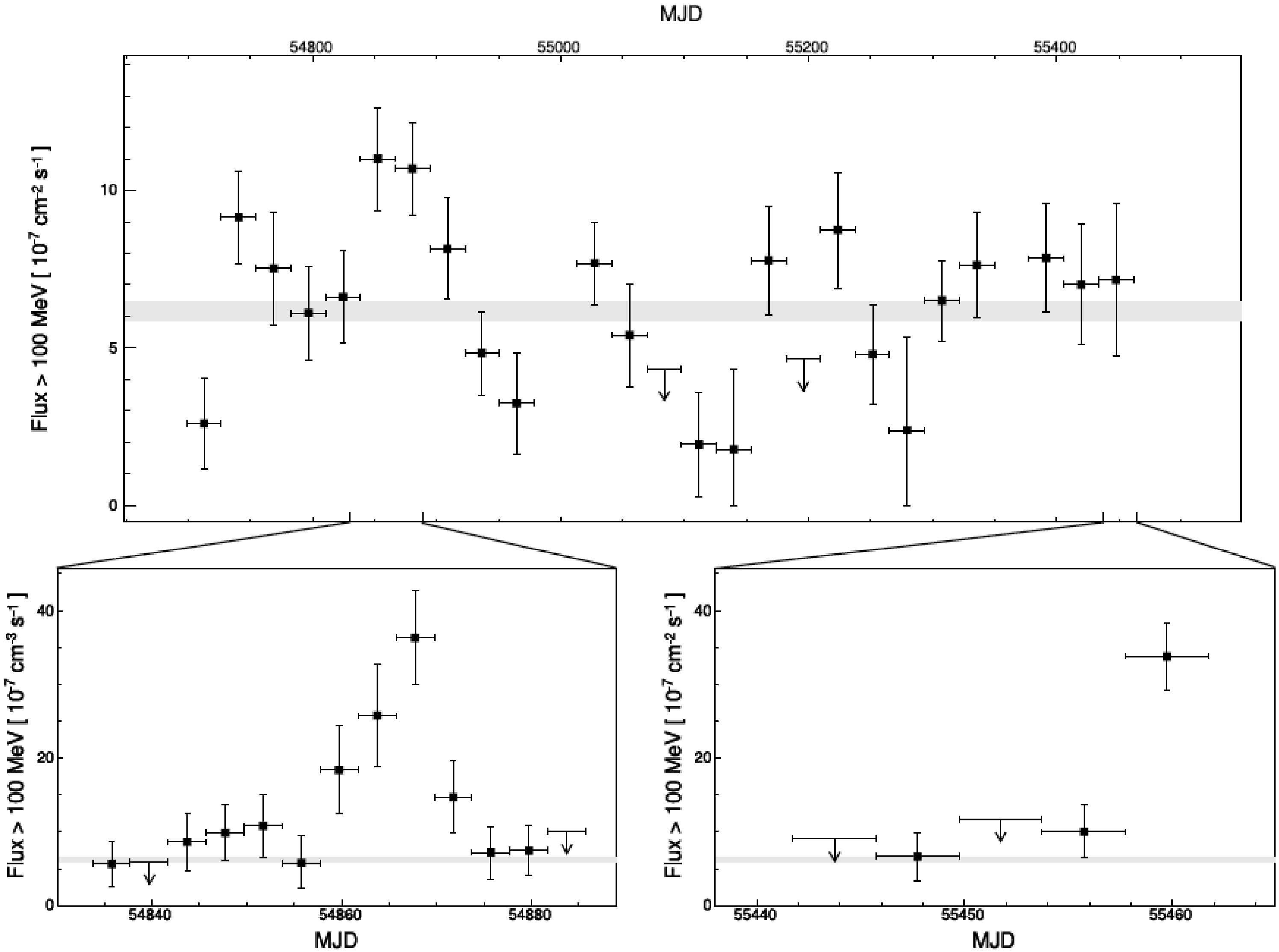


February 2007



September 2010

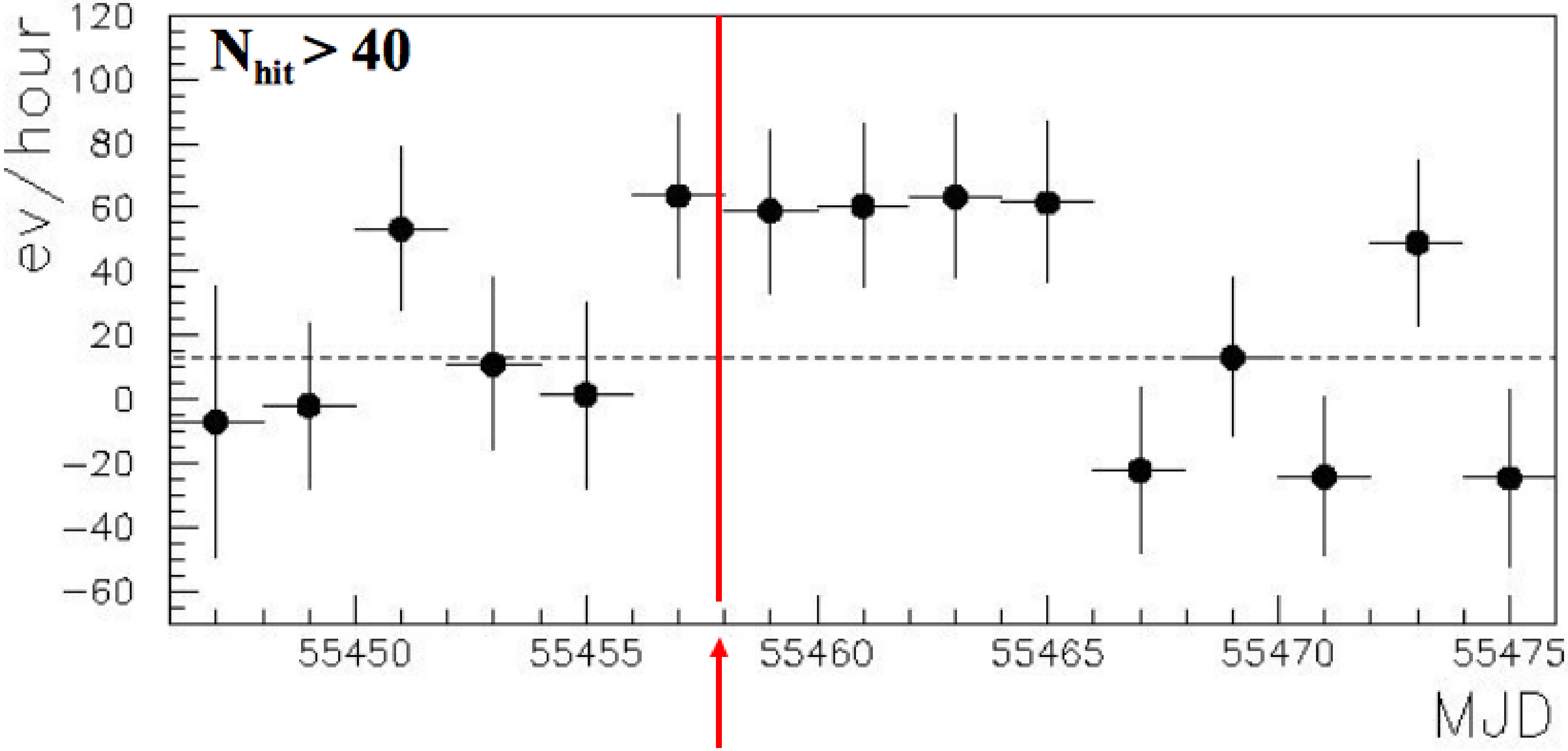
FERMI



February 2009

September 2010

Crab light curve - 2 days bin

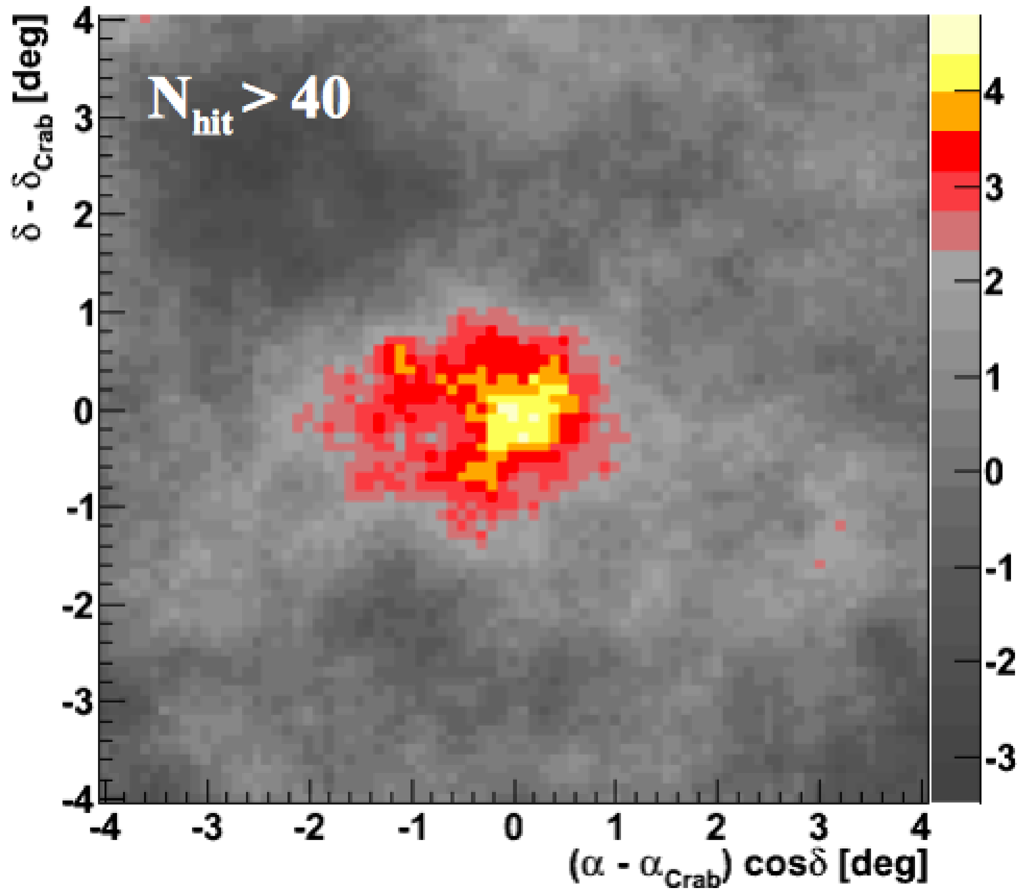


September 19th - flare onset

ARGO light curve

Silvia Vernetto

Crab Nebula 19-26 September



8 days

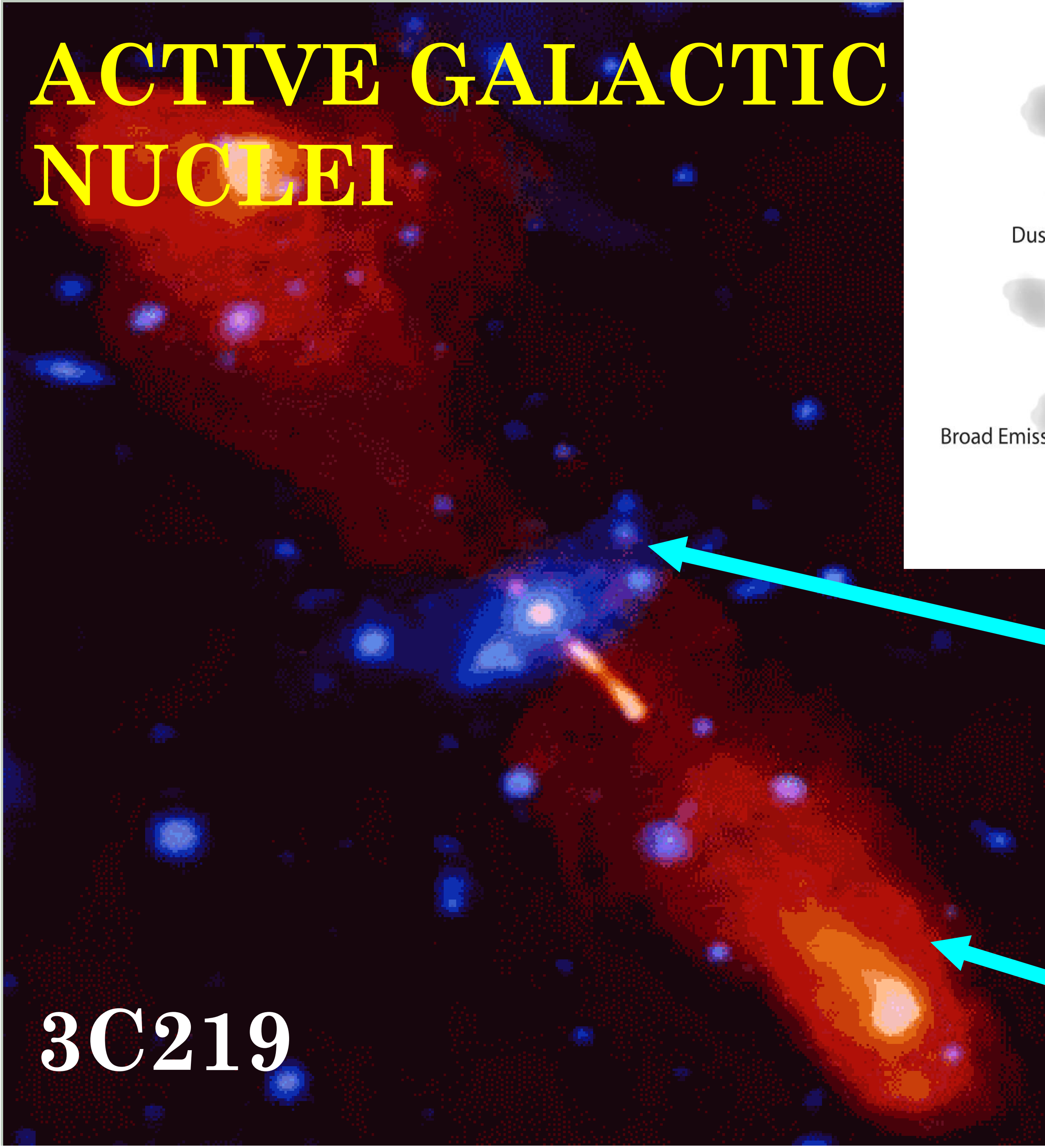
46 observation hours

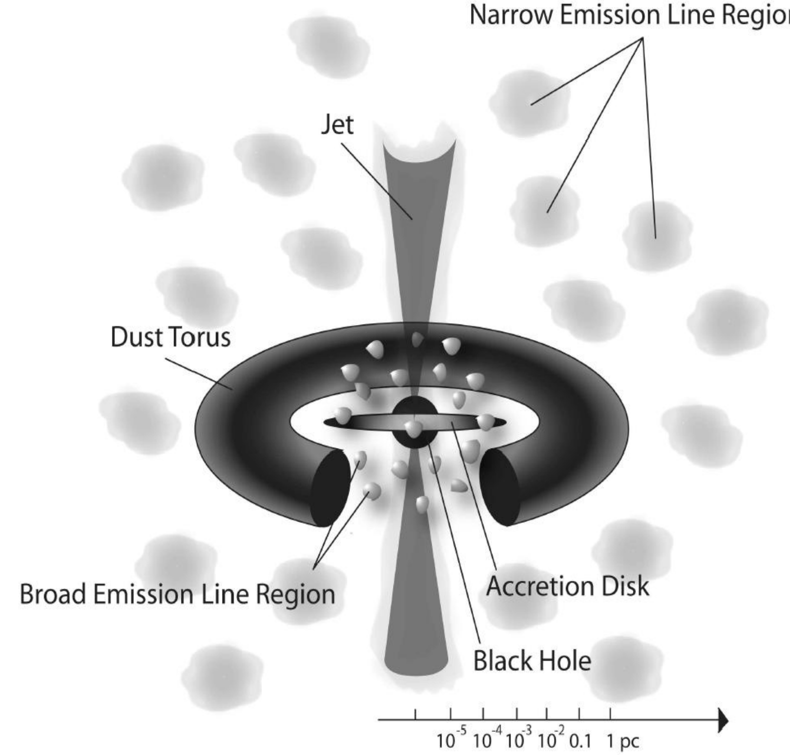
Significance 4.8

Expected 1.0 from steady flux

Chance probability: $p = 6.6 \; 10^{-5}$

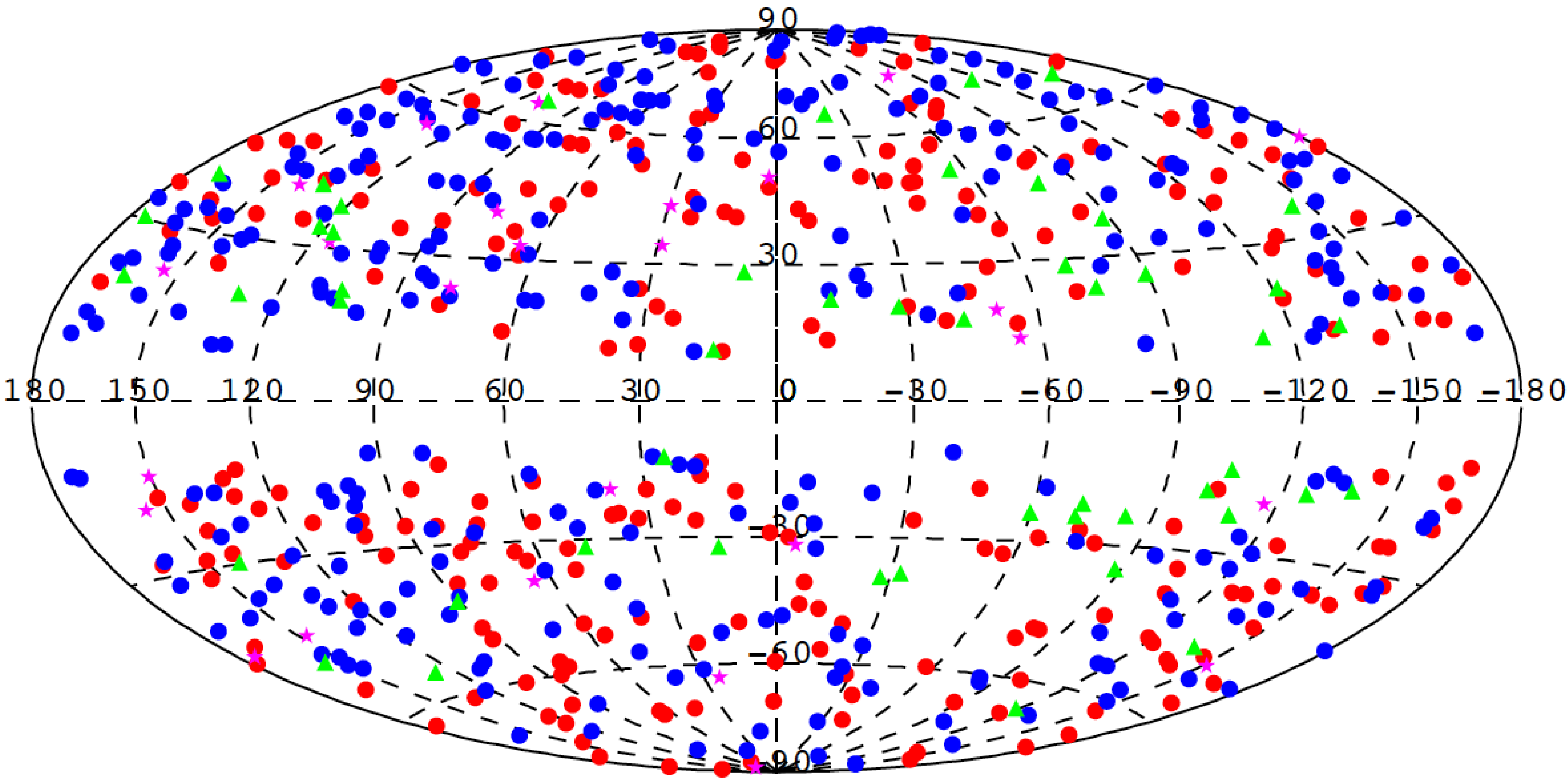
Silvia Vernetto


ACTIVE GALACTIC NUCLEI
3C219
Optical
Radio


Narrow Emission Line Region
Jet
Dust Torus
Broad Emission Line Region
Accretion Disk
Black Hole
10^-5 10^-4 10^-3 10^-2 0.1 1 pc

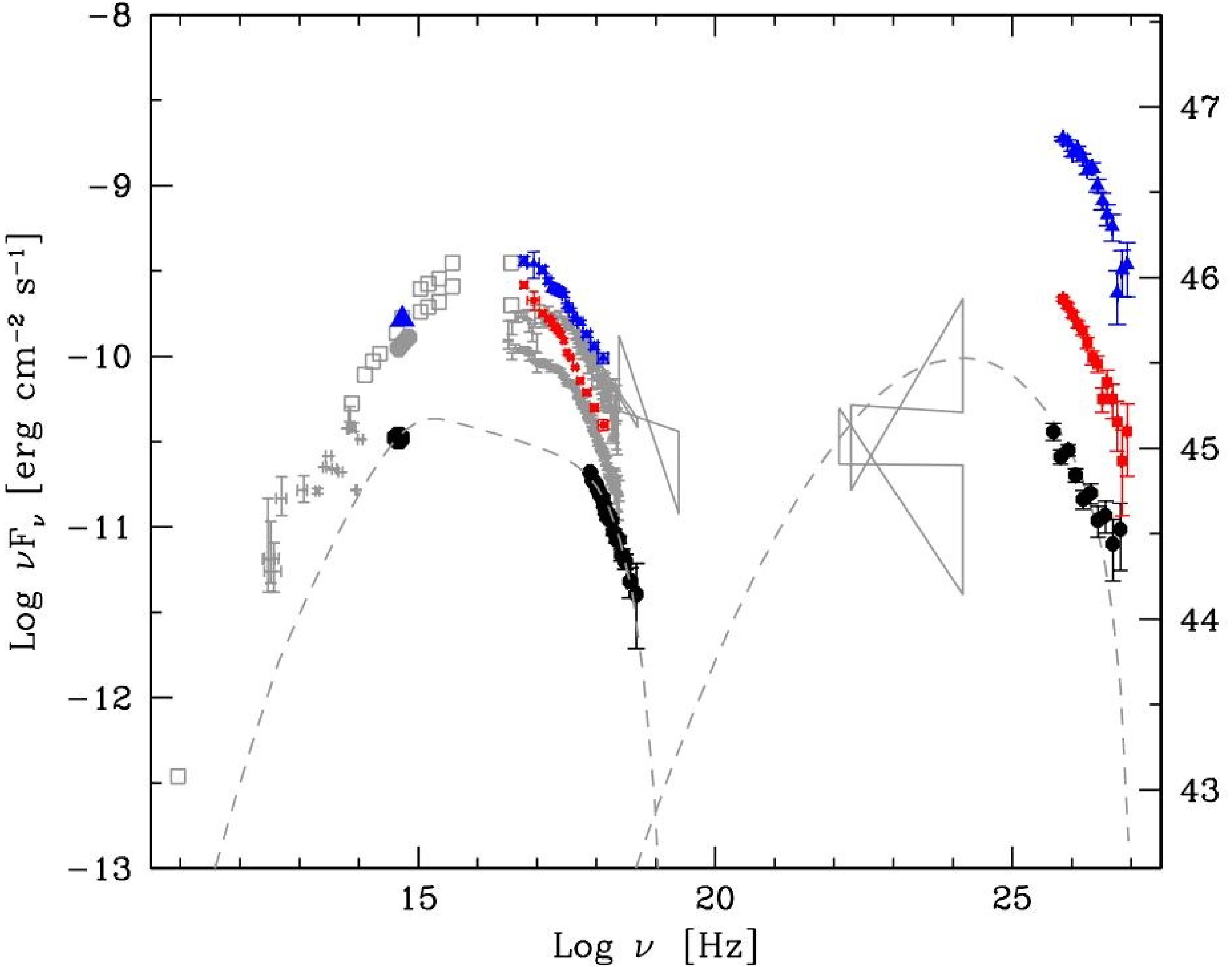
AGN observed by FERMI:

671 AGN's

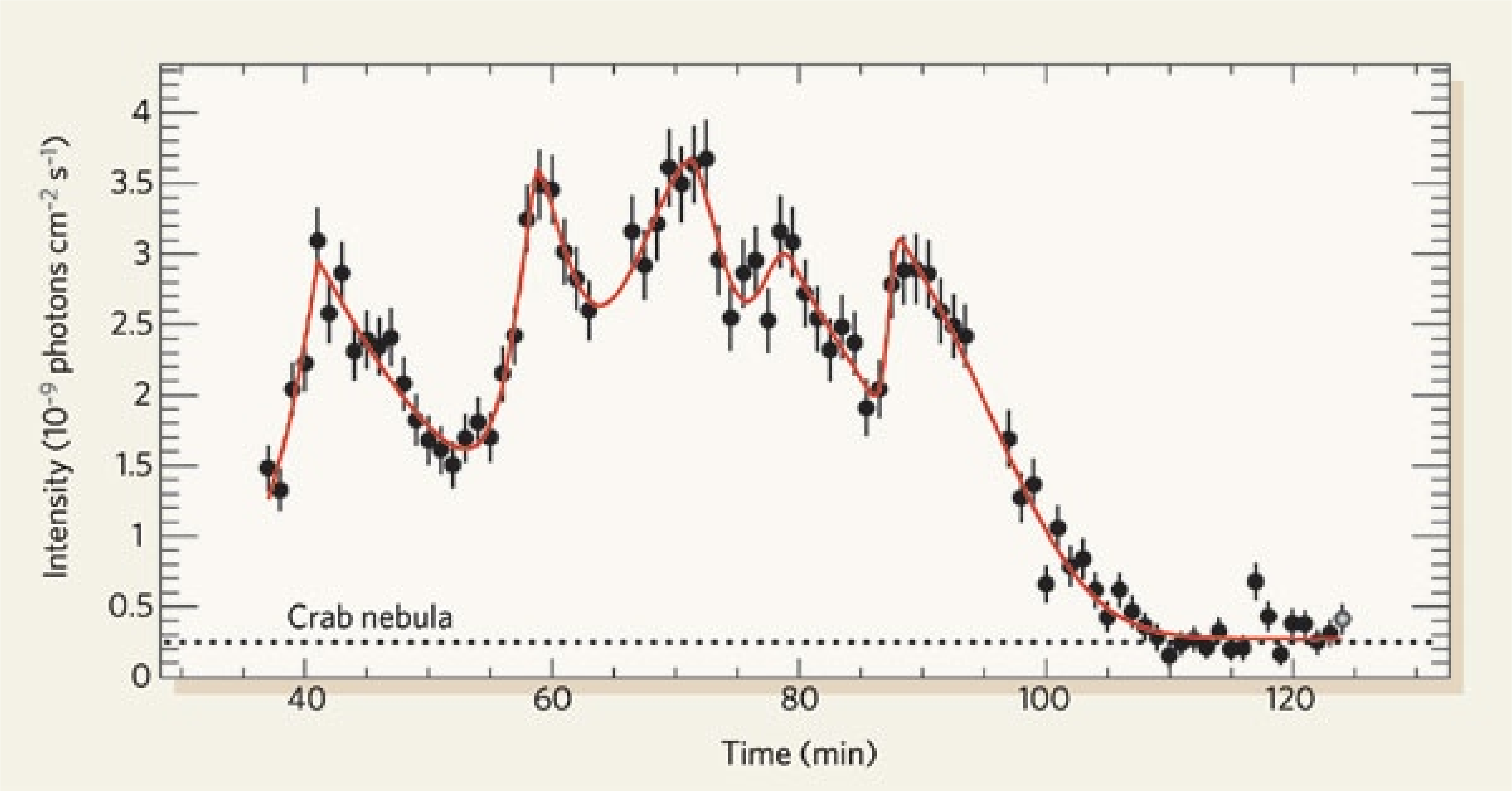


Red: FSRQ
Blue: Blac
Magenta: Radio Galaxies

PKS 2155-304



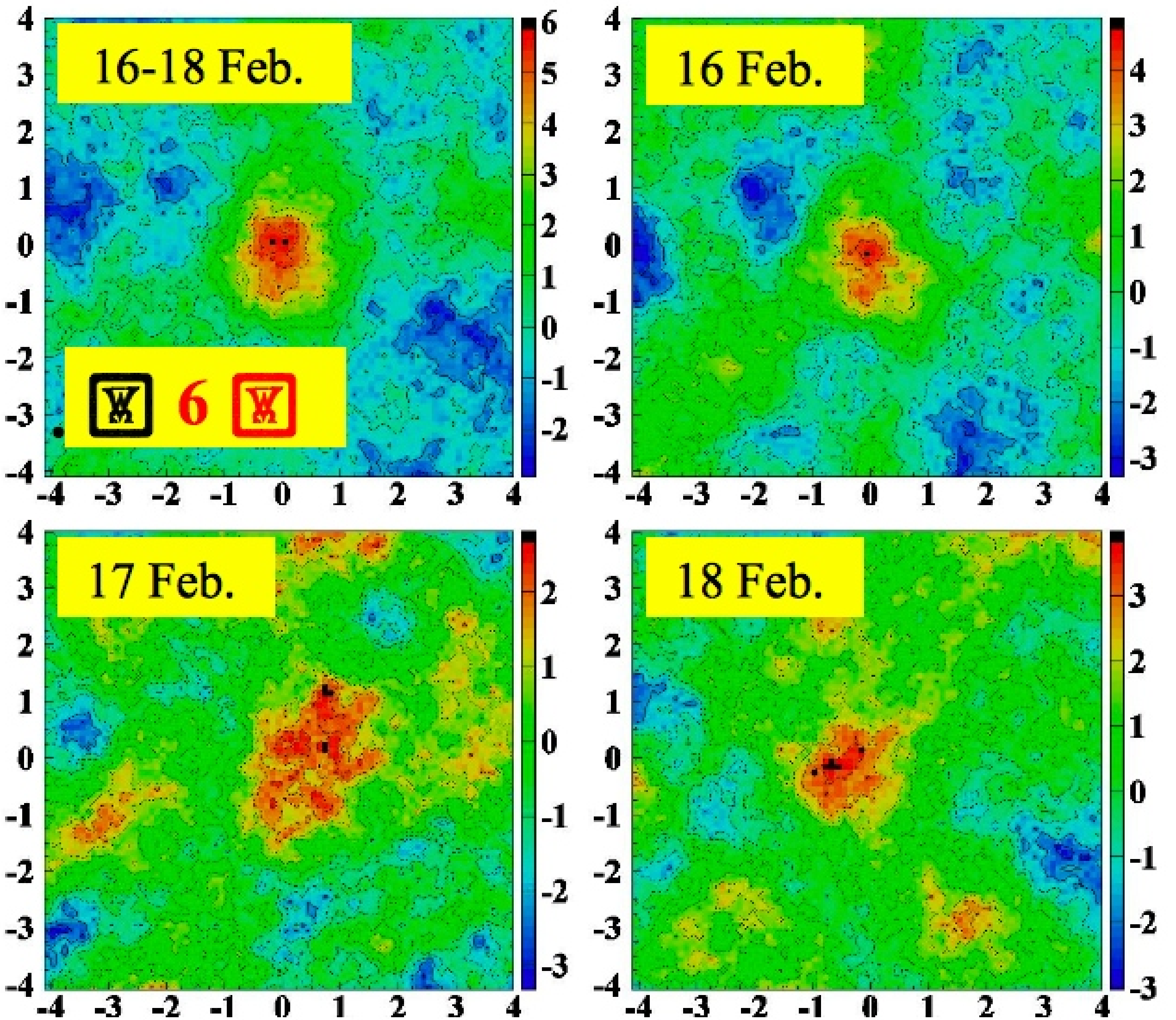
PKS 2155-304 (HESS measurements)



Mrk421 16-18 Feb 2010

- **ARGO observed a strong flare on 16-18 Feb. at 6 s.d.**
- Flux > 3 Crab

  Peak flux (16 Feb) > **10 Crab**
- For the first time an EAS-array observed a TeV flare at 4-5σ on a daily basis.
- VERITAS reported similar observation in Atel #2443.



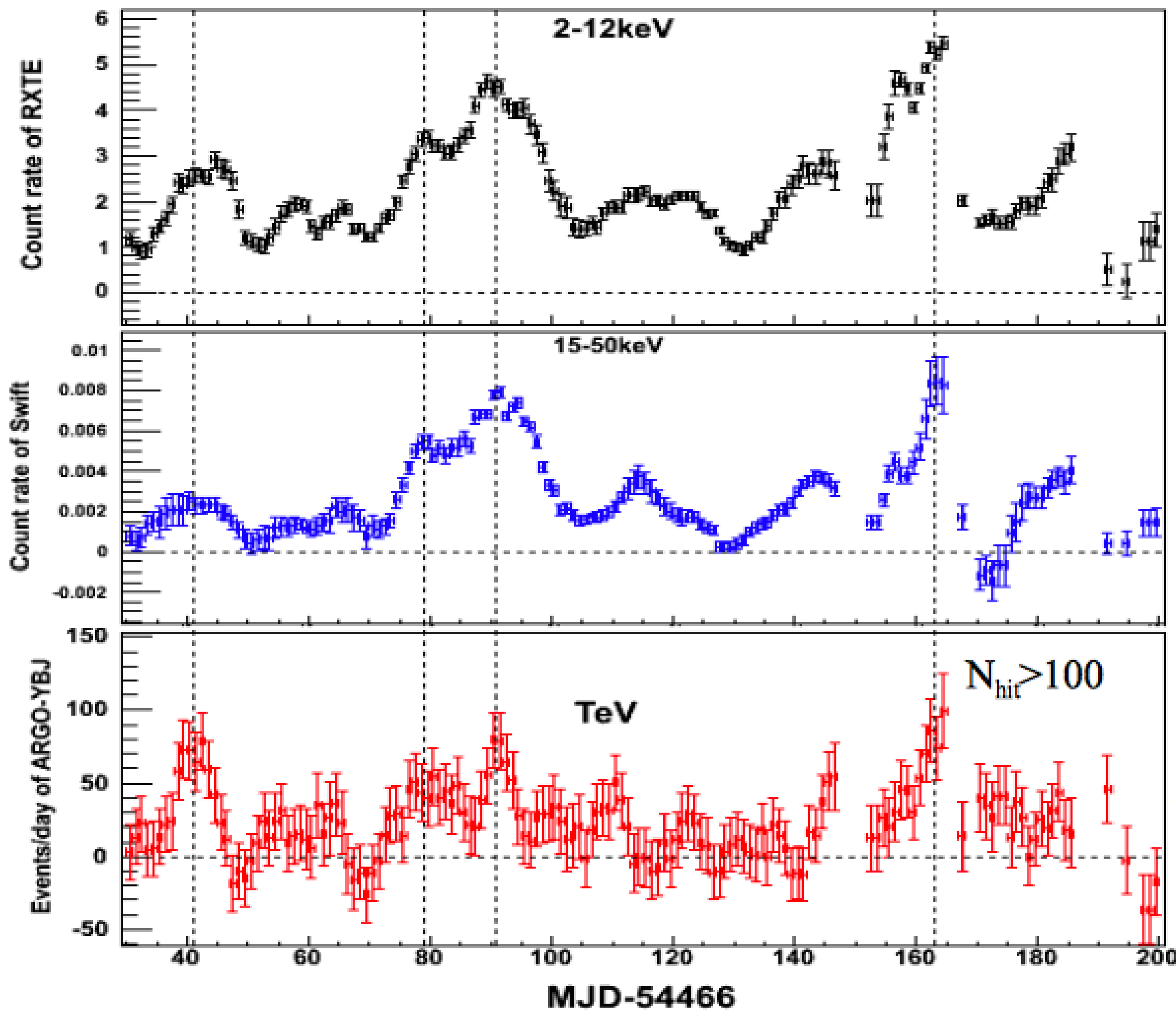
Silvia Vernetto

Ligth curve during the 2008 active period

RXTE

SWIFT

ARGO

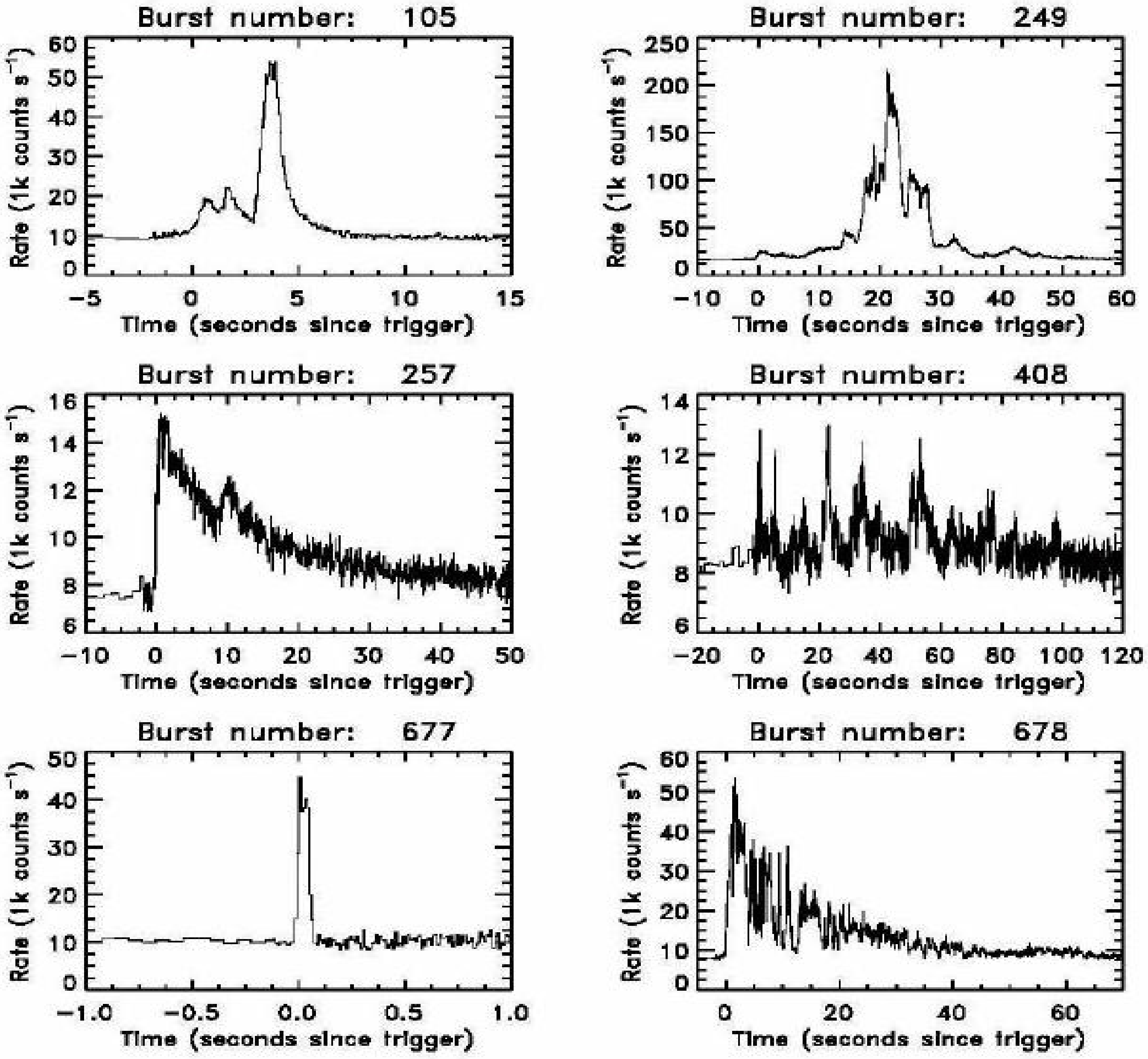


Daily counting rate

Running average on 5 days

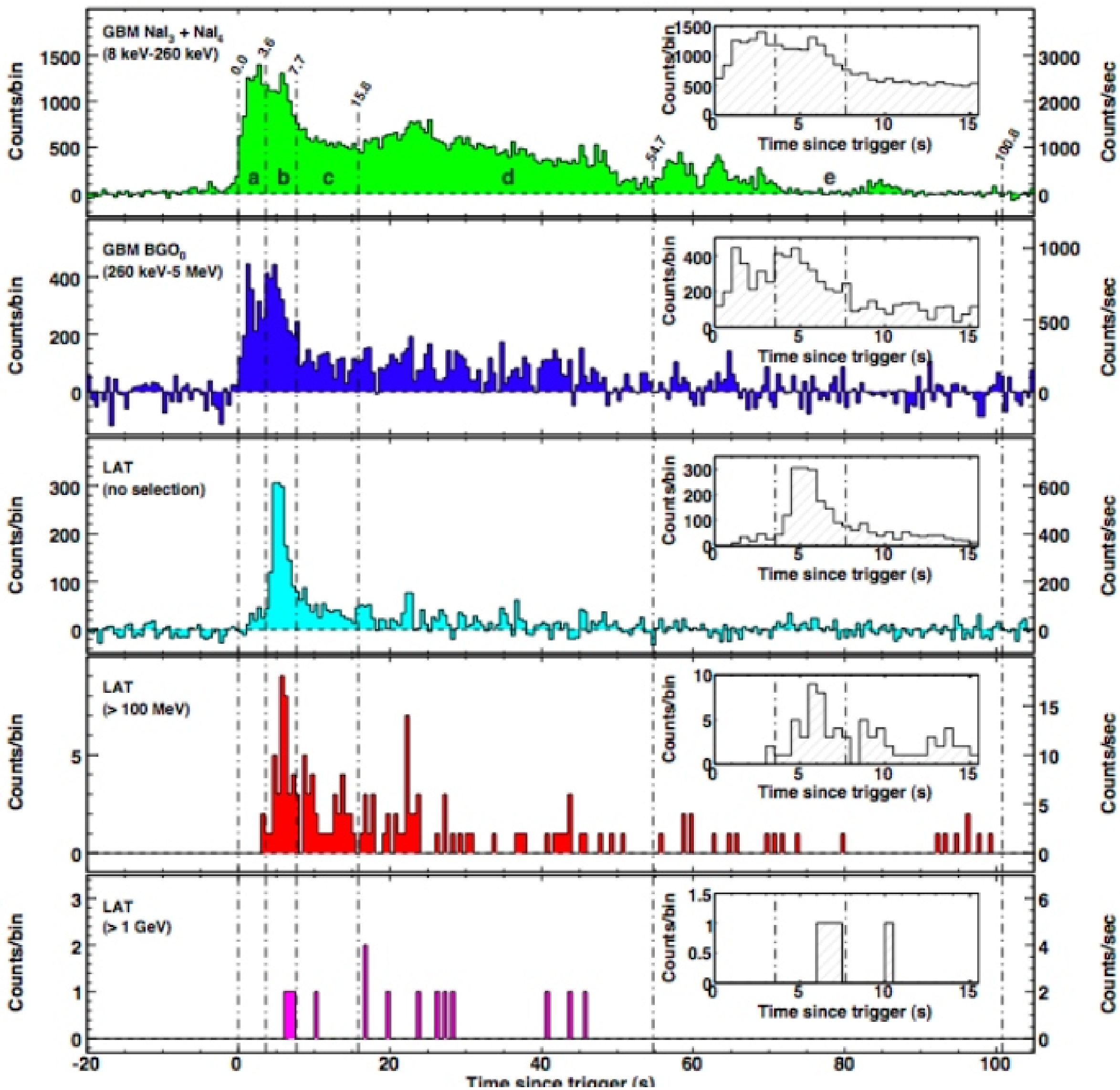
Silvia Vernetto

GAMMA RAY BURSTS (GRB's)



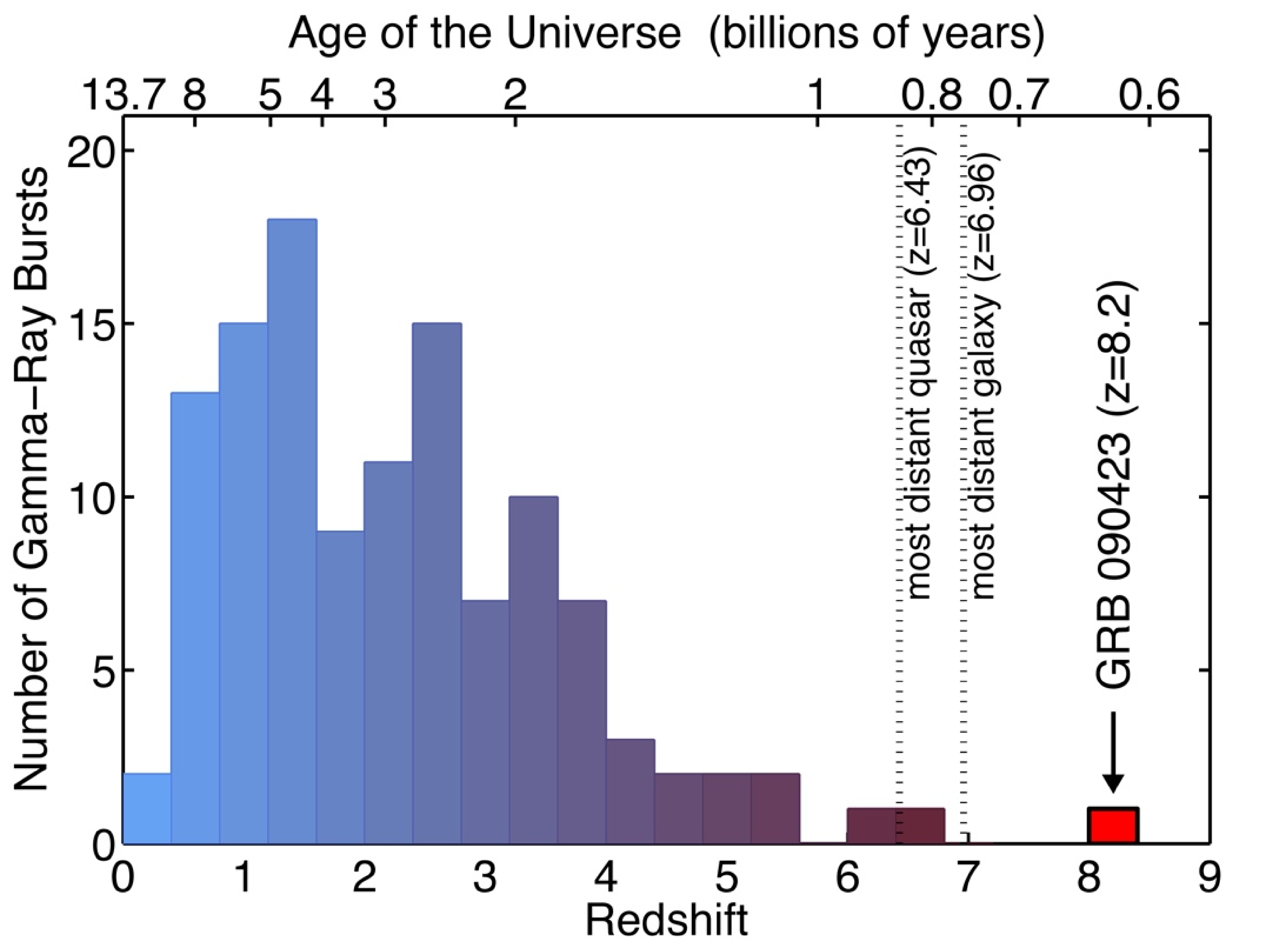
Proposed source
Of the CR

GRB 080916C
Z = 4.3
(Fermi)



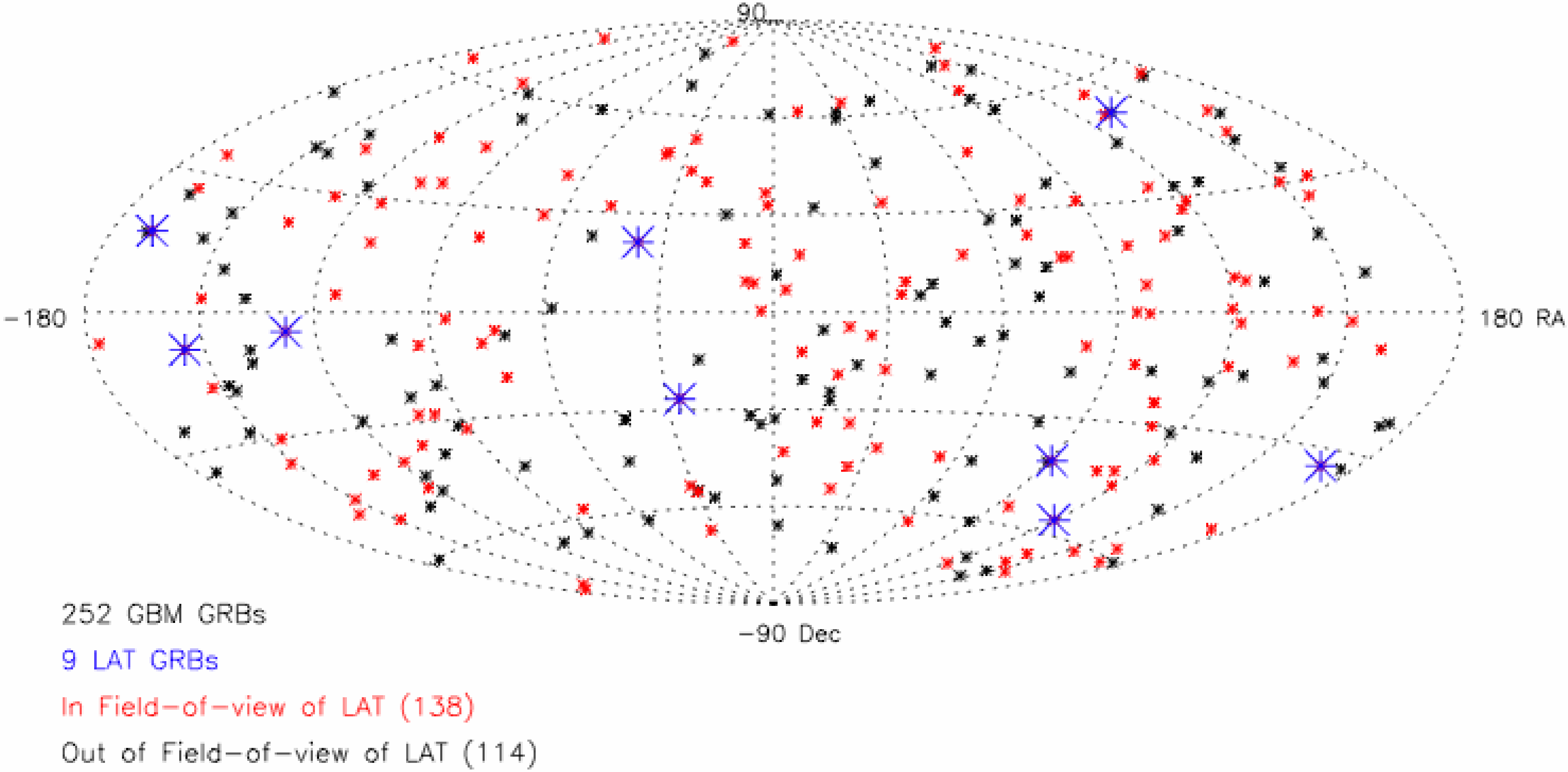
Most Powerful emission of energy
Ever recorded (assuming isotropy)

Narayana Bhat



Age of the Universe (billions of years)
13.7
8
5
4
3
2
1
0.8
0.7
0.6
Number of Gamma–Ray Bursts
20
15
10
5
0
most distant quasar (z=6.43)
most distant galaxy (z=6.96)
GRB 090423 (z=8.2)
0
1
2
3
4
5
6
7
8
9
Redshift

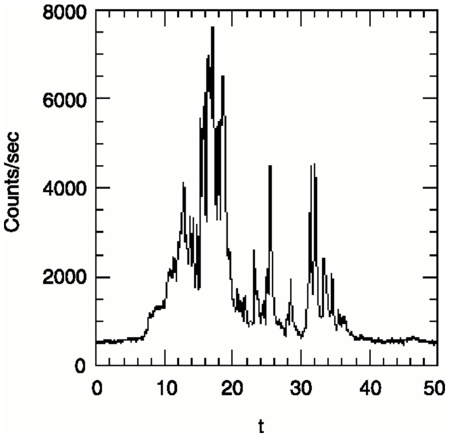
Fermi GRBs as of 090713

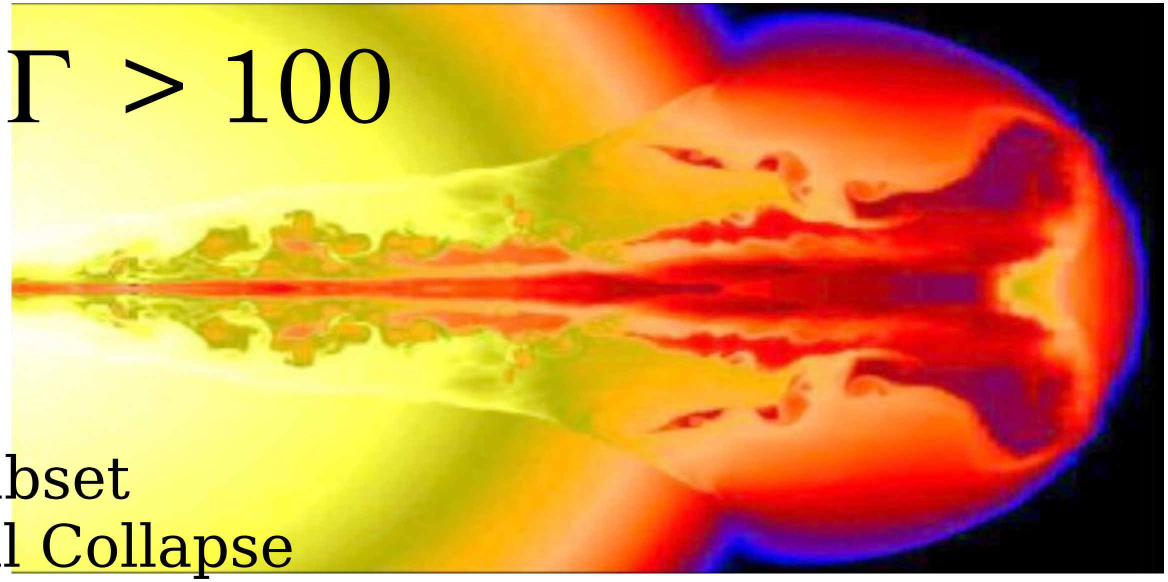


Narayana Bhat

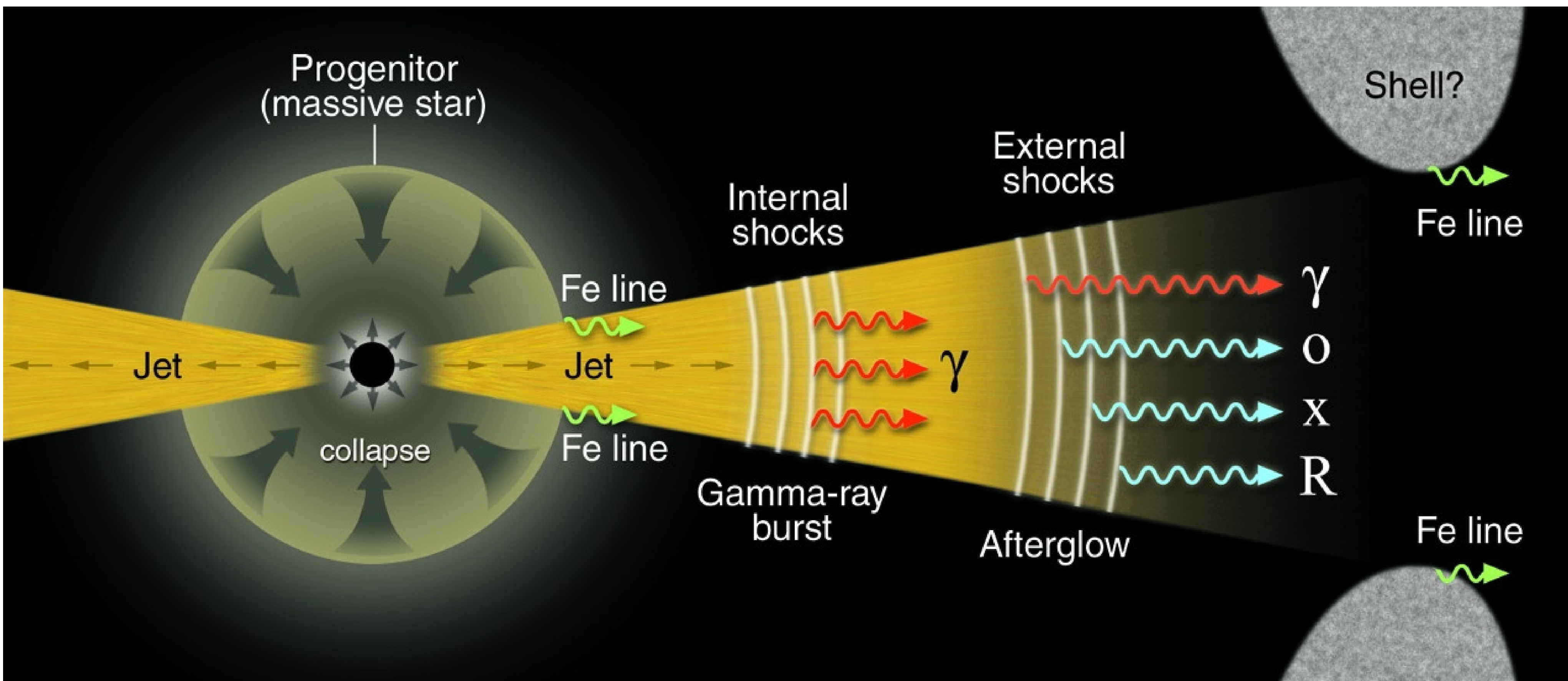
GRB	Angle from LAT	Duration	# of events > 100 MeV	# of events > 1 GeV	Delayed HE onset	Long-lived HE emission	Extra spectral comp.	Highest photon Energy	Redshift
080825C	~ 60°	long	~ 10	0	?		X	~ 600 MeV	
080916C	49/52°	long	> 100	> 10			?	~ 13.2 GeV	~ 4.35
081024B	21°	short	~ 10	2			?	3 GeV	
081215A	~ 86°	long	—	—	—	—	--	—	
090217	~ 34°	long	~ 10	0	X	X	X	~ 1 GeV	
090323	~ 55°	long	~ 20	> 0	?		?	?	3.57
090328	~ 64°	long	~ 20	> 0	?		?	?	0.736
090510	~ 14°	short	> 150	> 20				~ 31 GeV	0.903
090626	~ 15°	long	~ 20	> 0	?		?	?	
090902B	51°	long	> 200	> 30				~ 33 GeV	1.822
090926	~ 52°	long	> 150	> 50				~ 20 GeV	2.1062
091003A	~ 13°	long	~ 20						0.8969
091031	~ 22°	long	~ 30	2					
100116A	~ 29°	long	< 10	0					

Narayana Bhat





GRB : associated with a subset of SN Stellar Gravitational Collapse



But:

A complete understanding of the mechanism behind GRB's remains elusive.

Their possible role as the source of UHECR
(or even of ALL Cosmic Rays)
Remains only a speculation.

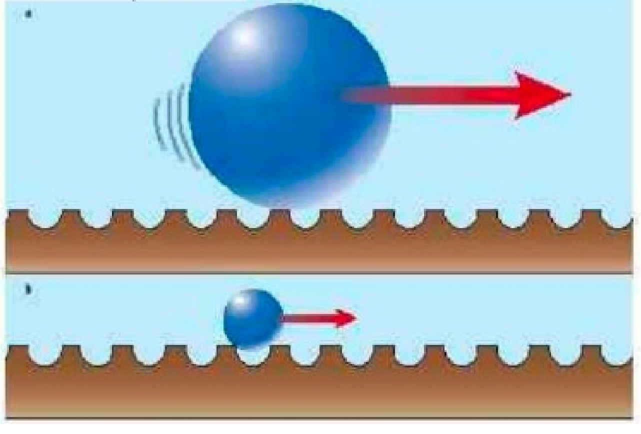
Short distance structure of space time

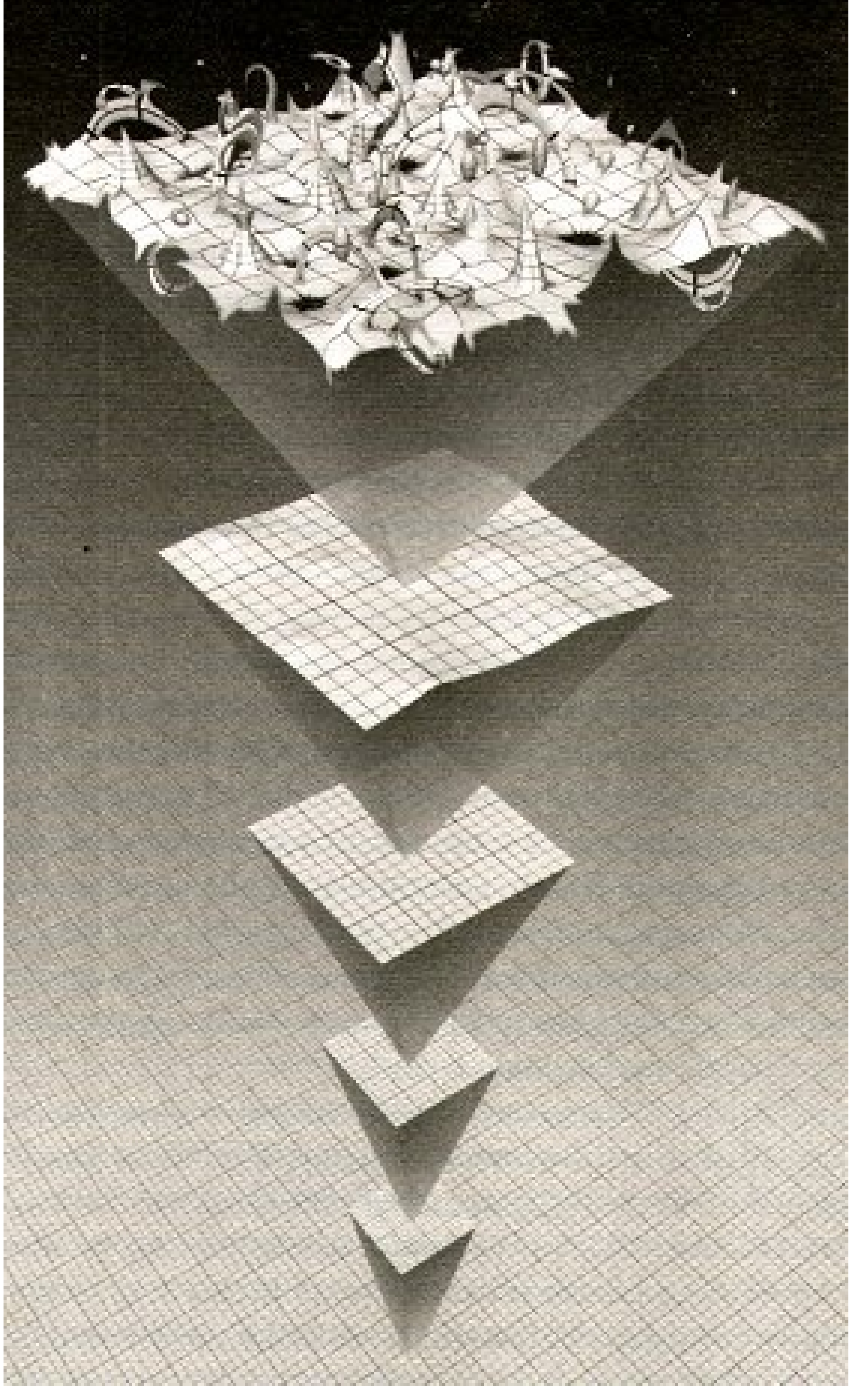
$$c(E) = c \times \left(1 - \xi \frac{E}{M_{\text{Planck}}} + \ldots\right)$$

$$\Delta t \simeq \xi \frac{E}{M_{\text{Planck}}} \frac{L}{c}$$

$$\Delta t \simeq 0.06\, E_{\text{GeV}}\, z$$

Delay of high energy photons



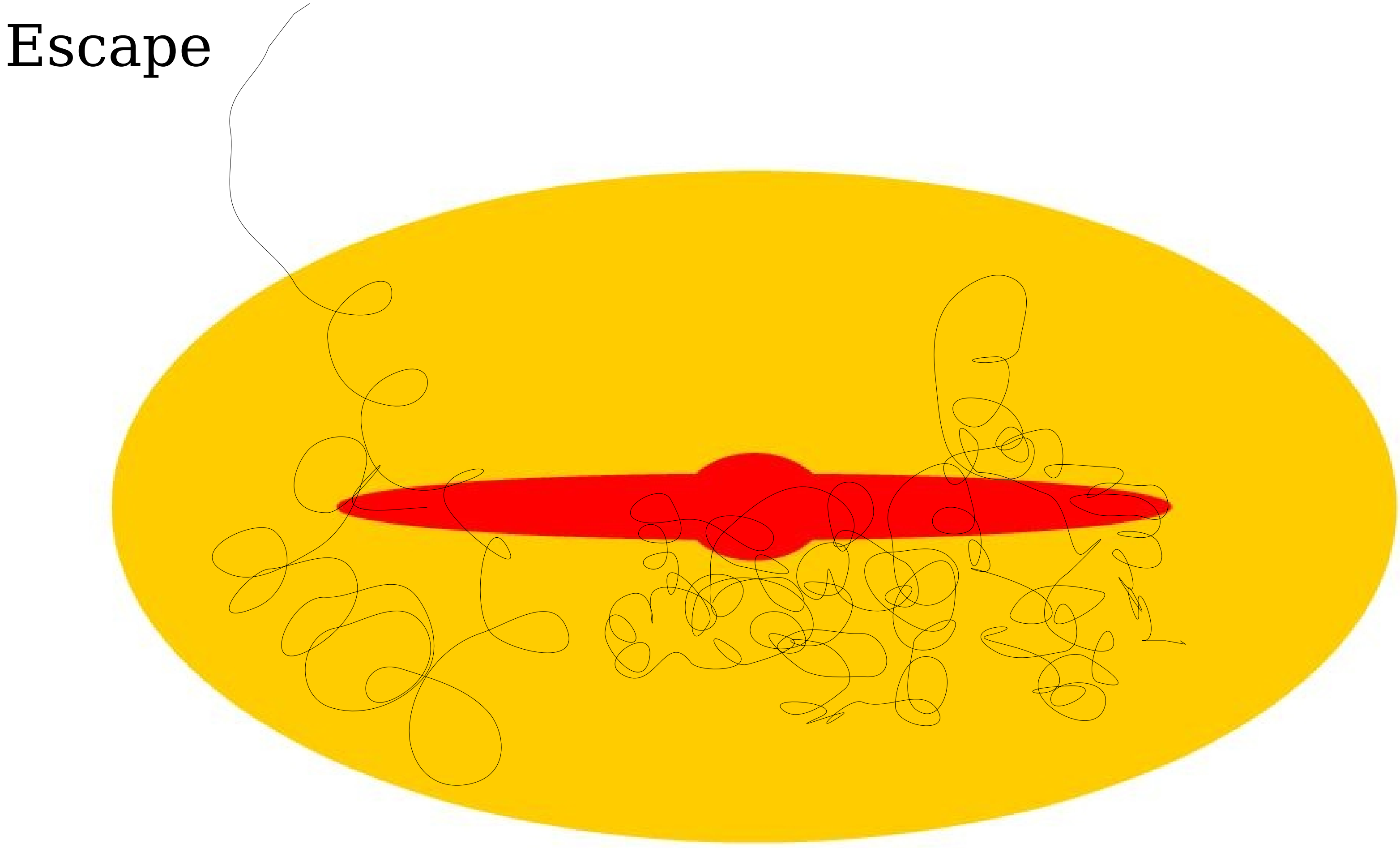



The HAWC
(High Altitude Water Cherenkov)
Observatory

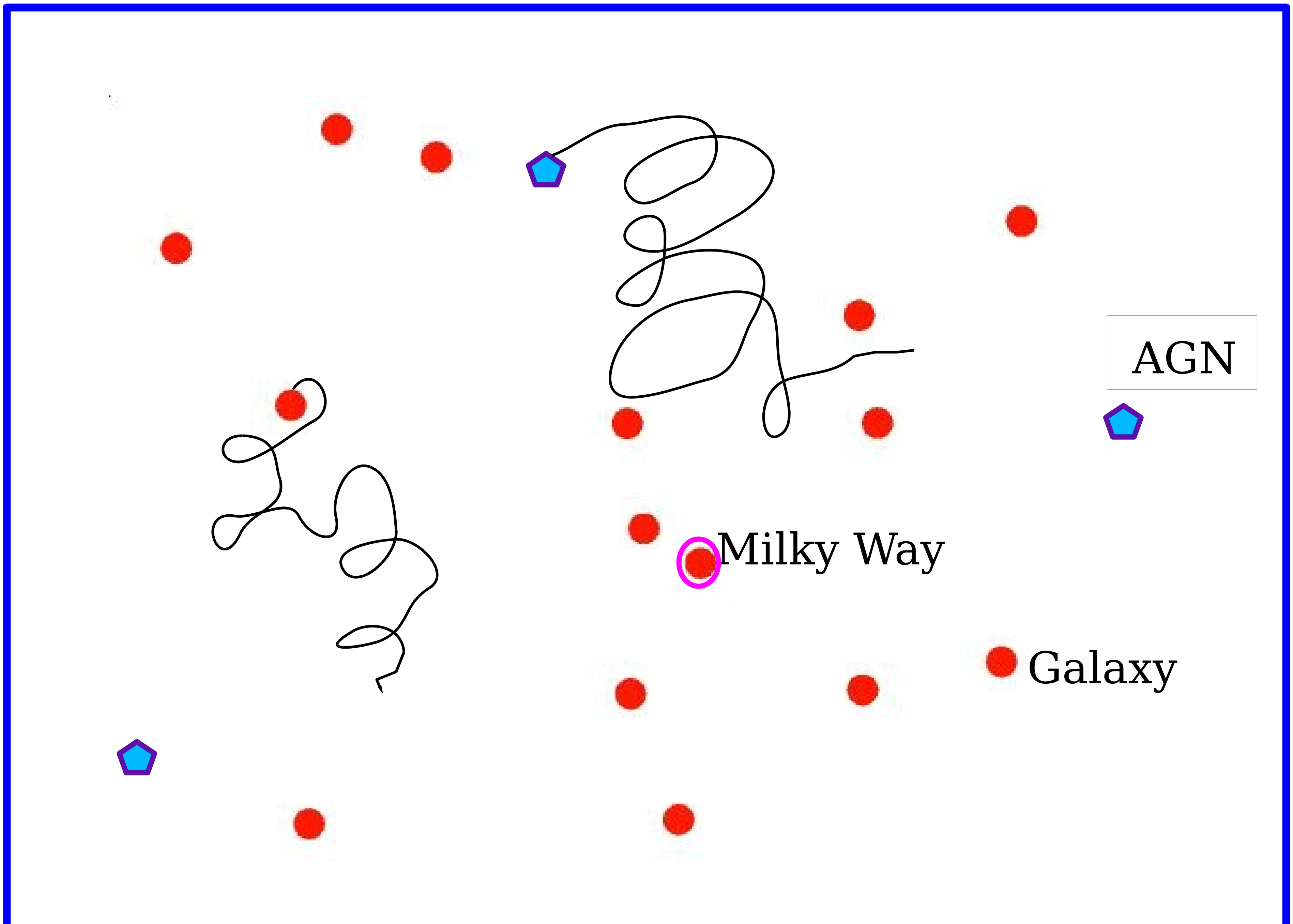
COSMIC RAYS

1. Below the Knee
2. The Knee
3. More knees ??
4. Galactic to Extragalactic transition
5. The “End” of the spectrum

Charged Particles: magnetic confinement

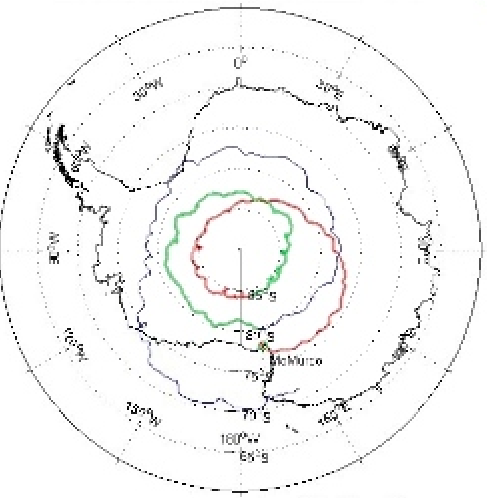


Piece of extragalactic space: Non MilkyWay-like sources

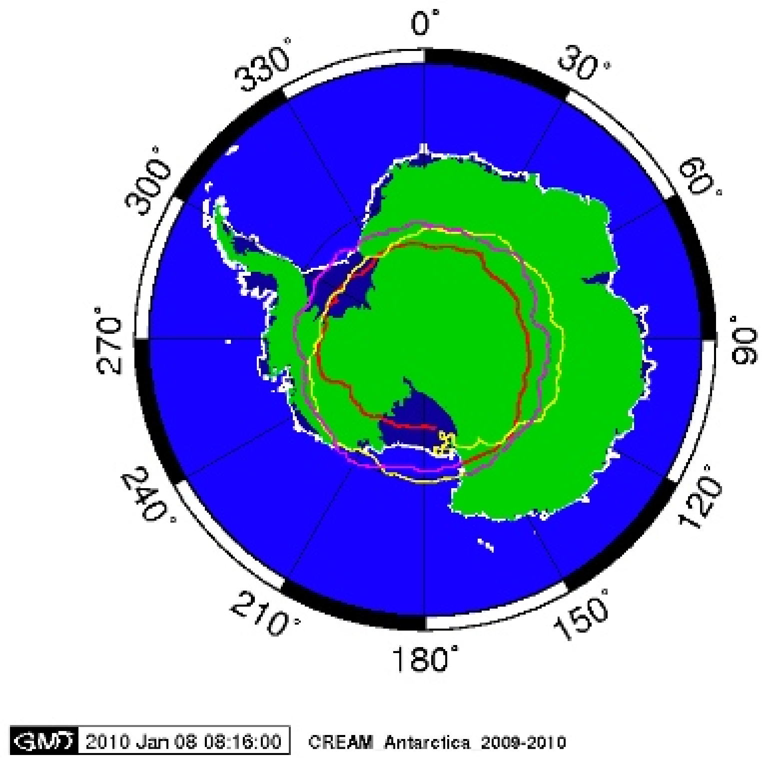


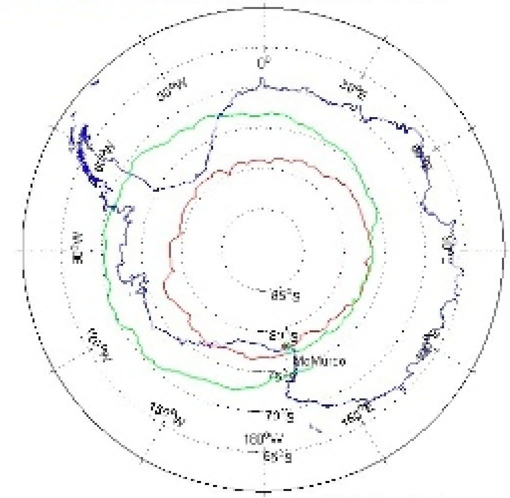
Five successful Flights: ~ 156 days cumulative exposure

CREAM-VI currently awaiting launch in Antarctica

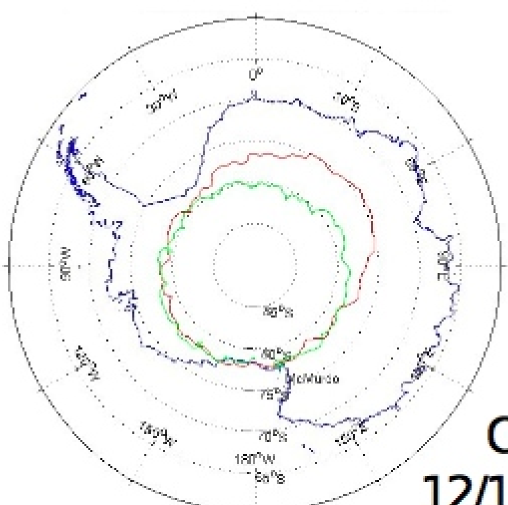


CREAM-I
12/16/04 – 1/27/05
42 days



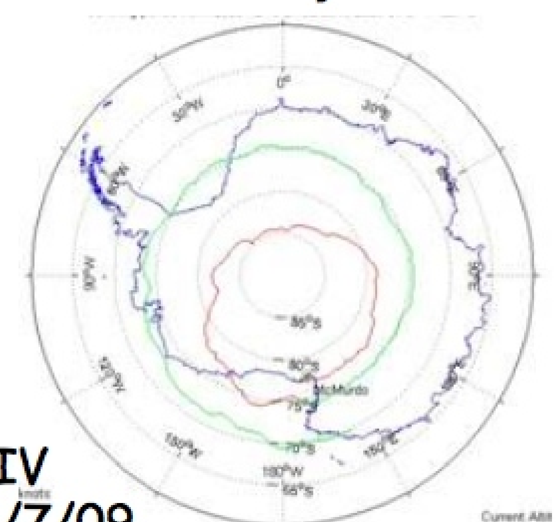


CREAM-II
12/16/05-1/13/06
28 days



CREAM-V
12/1/09 – 1/8/10
37 days 10 hrs

CREAM-III
12/19/07-1/17/08
29 days



CREAM-IV
12/19/08 – 1/7/09
19 days 13 hrs

Vernon Jones

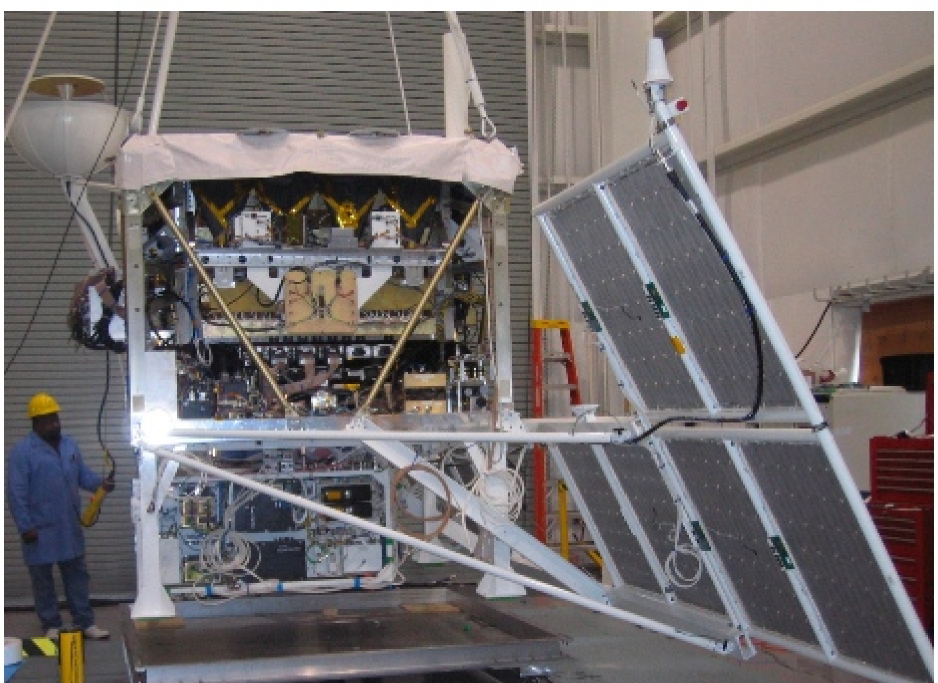
Cosmic Ray Energetics And Mass (CREAM)

Eun-Suk Seo, University of Maryland, PI

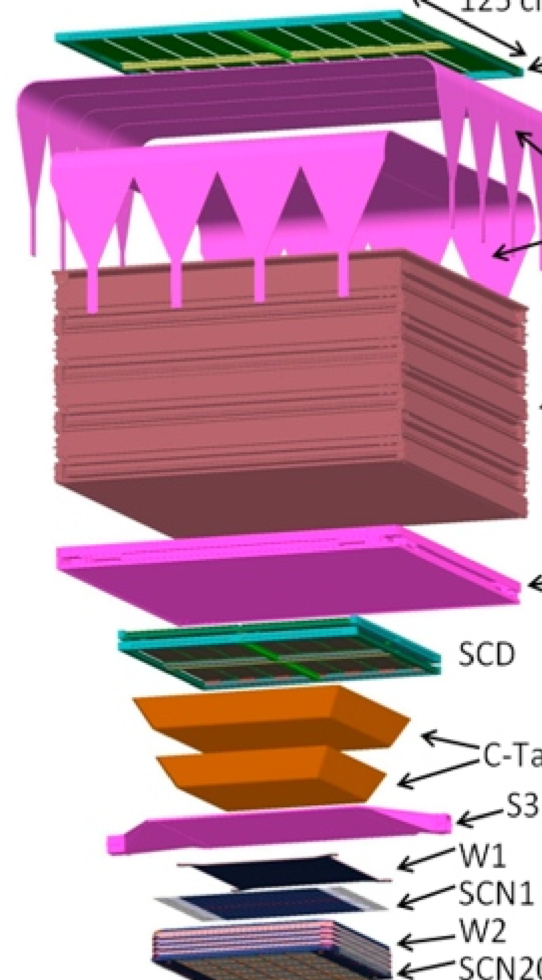
0

Seo et al. Adv. in Space Res., **33** (10), *1777*, 2004; Ahn et al., NIM A, **579**, 1034, 2007

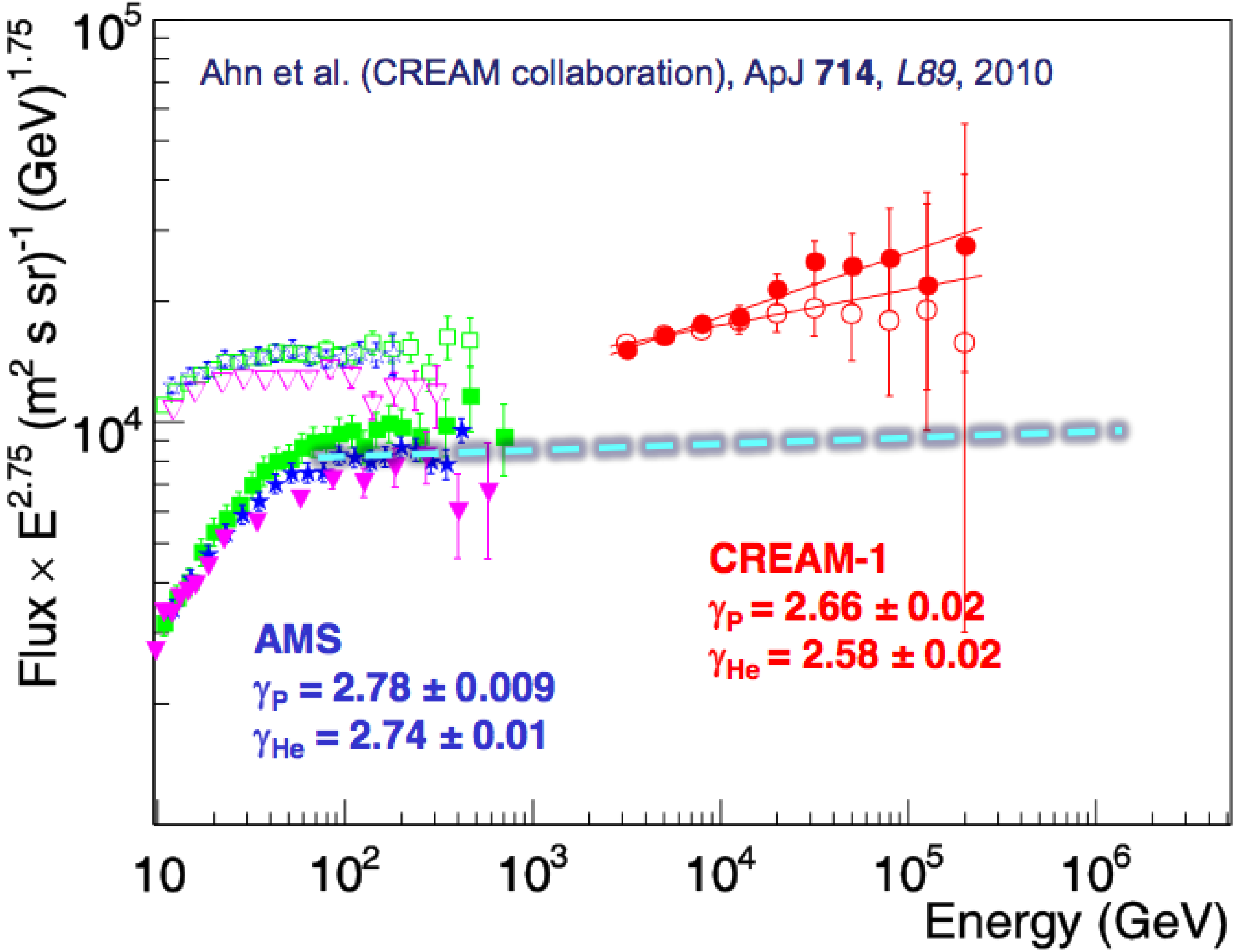
- Transition Radiation Detector (TRD) **and** Tungsten Scintillating Fiber Calorimeter
  - In-flight cross-calibration of energy scales for Z > He
- Silicon detector to measure particle charge in presence of shower backscatter
- Flared, segmented carbon target with tracking scintillator hodoscopes
- Hodoscopes for particle tracking through the instrument



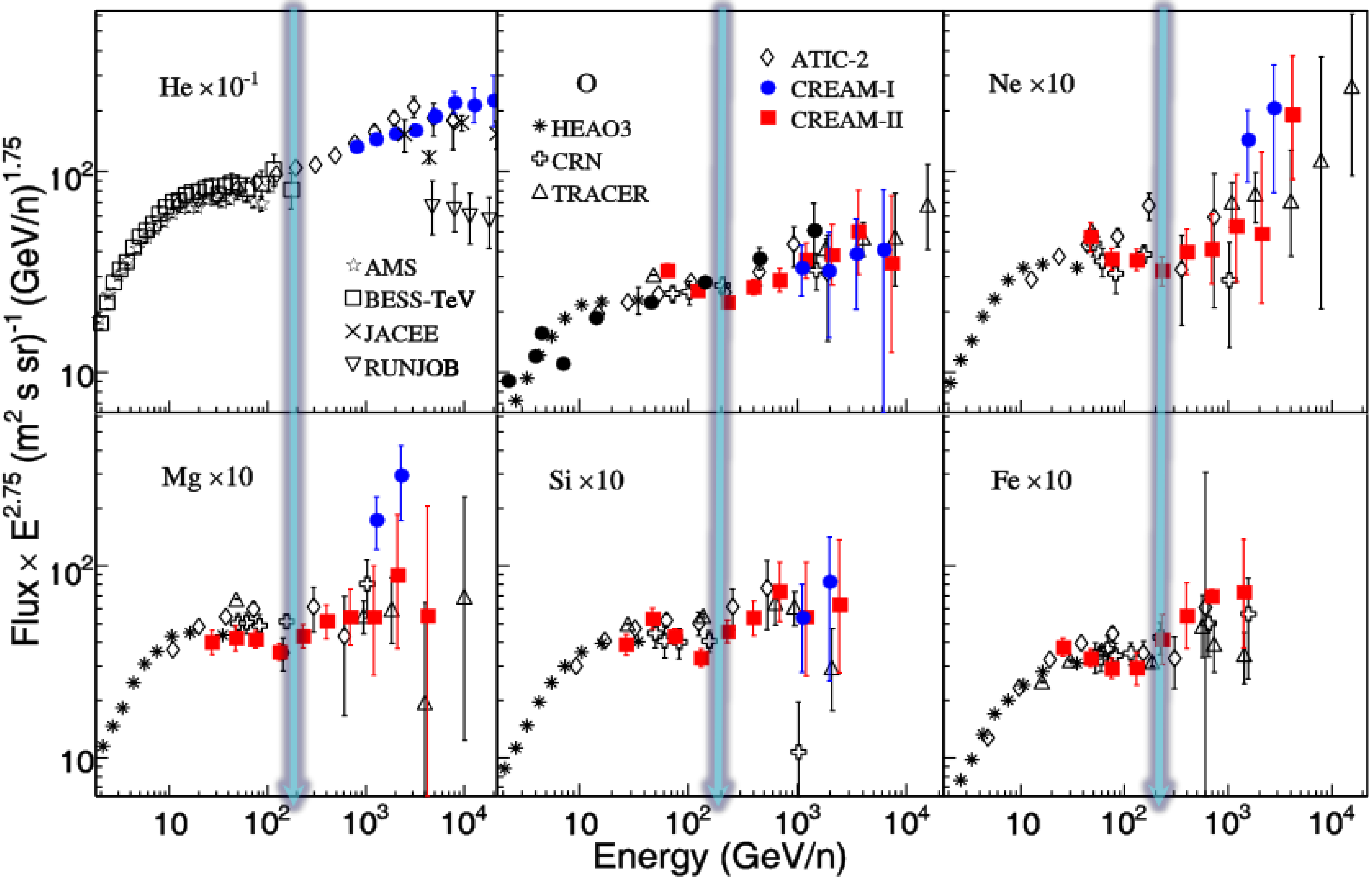
- **CREAM uses two designs**
  - With and without the TRD
- This exploded view shows the "With TRD" design
- The "Without TRD" design uses Cherenkov Camera



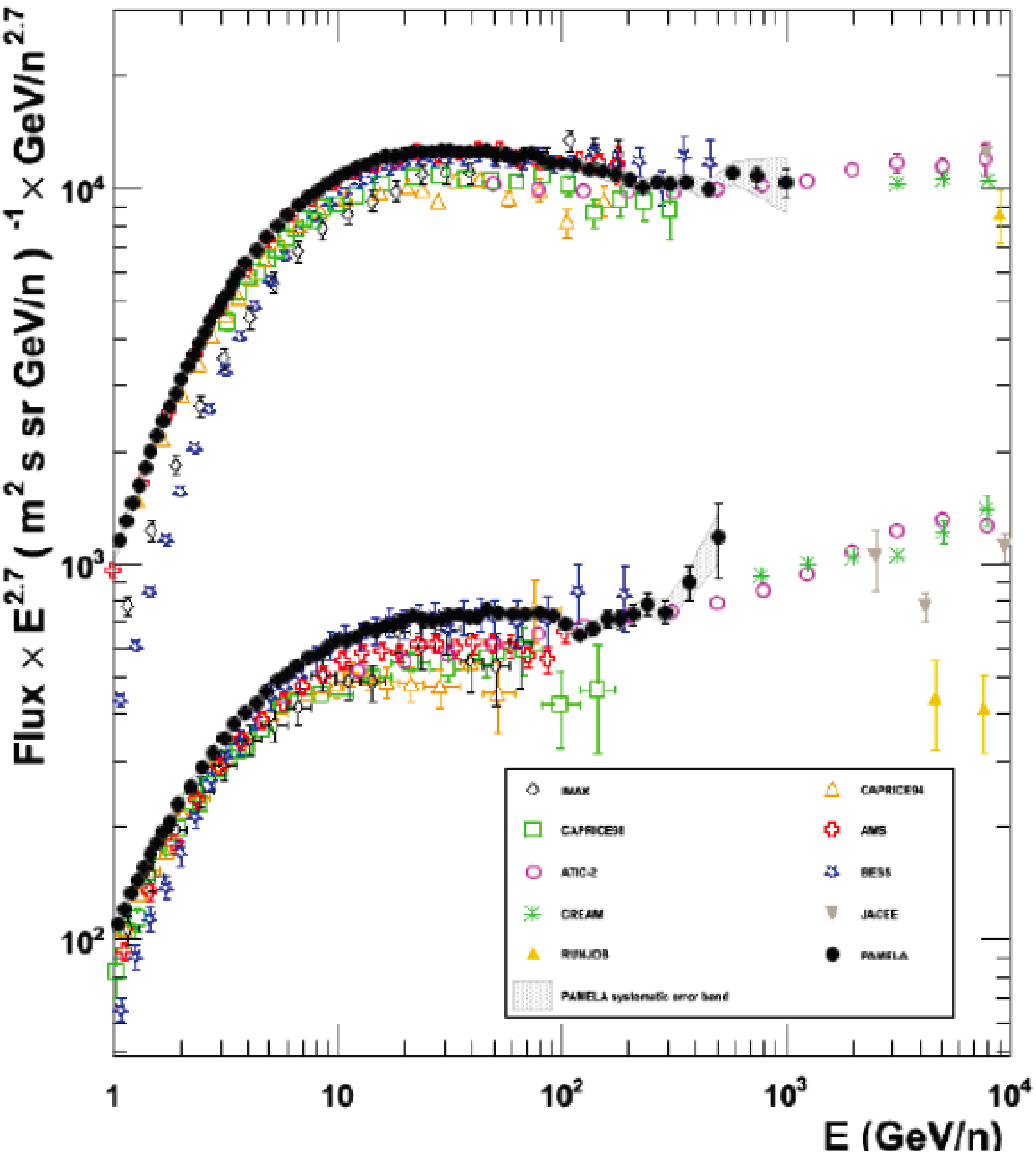
TeV spectra are harder than spectra < 200 GeV/n



Discrepant hardening



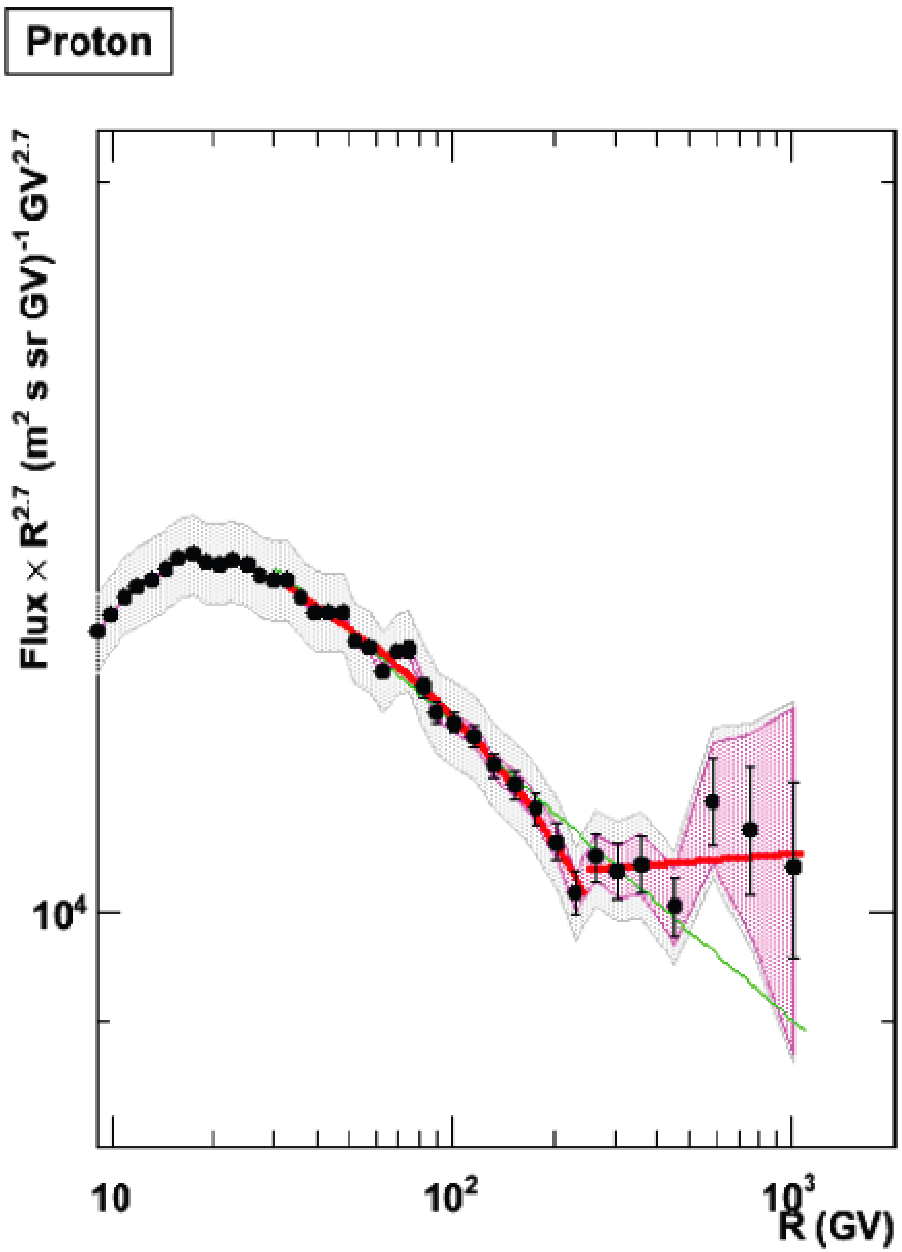
PAMELA PROTON AND HELIUM FLUX

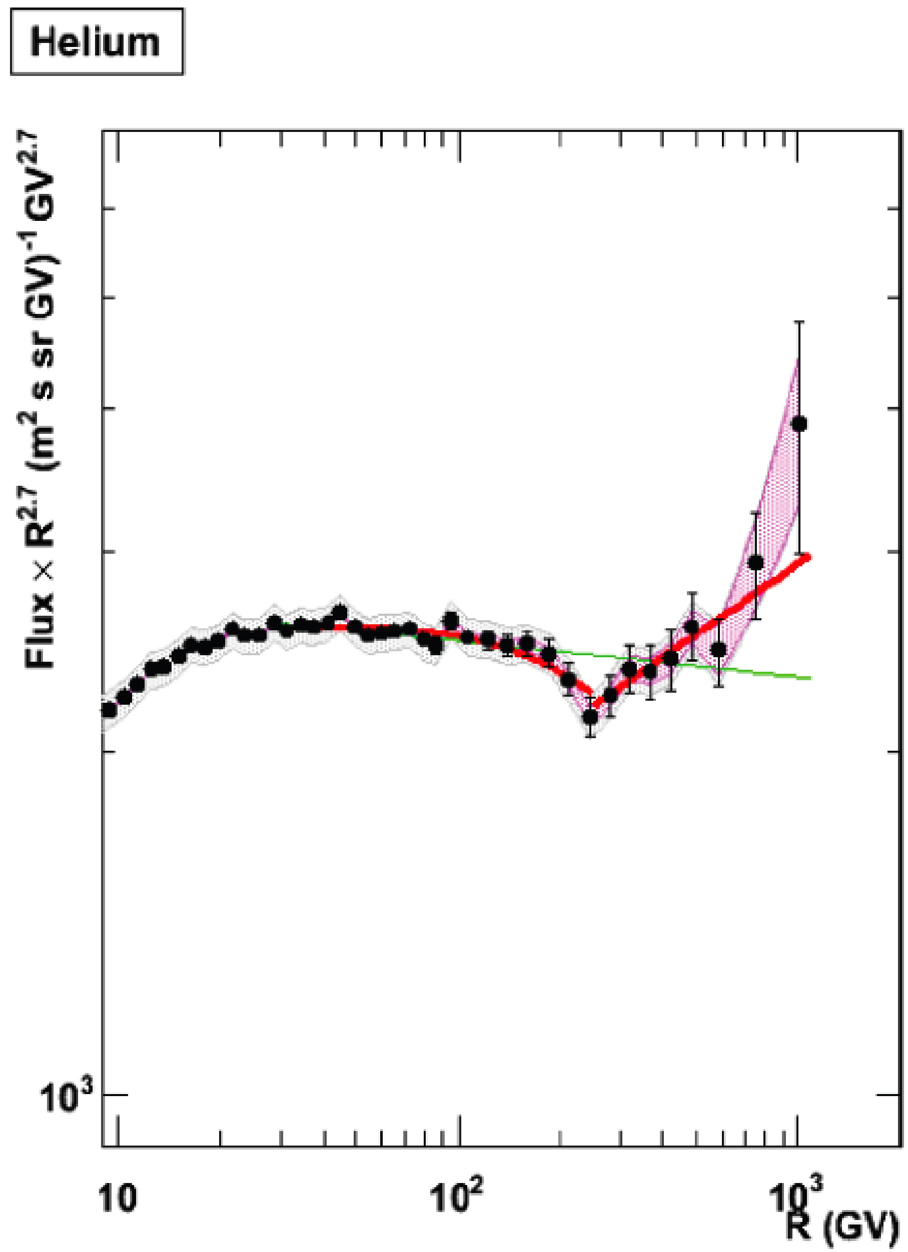


Accepted by SCIENCE
In press

Hardening of the proton and helium spectra at 200 GV, corresponding to 200 GeV for p and 100 GeV/n for He

Fit with 2 spectral indexes





Cosmic Ray Nuclear Composition

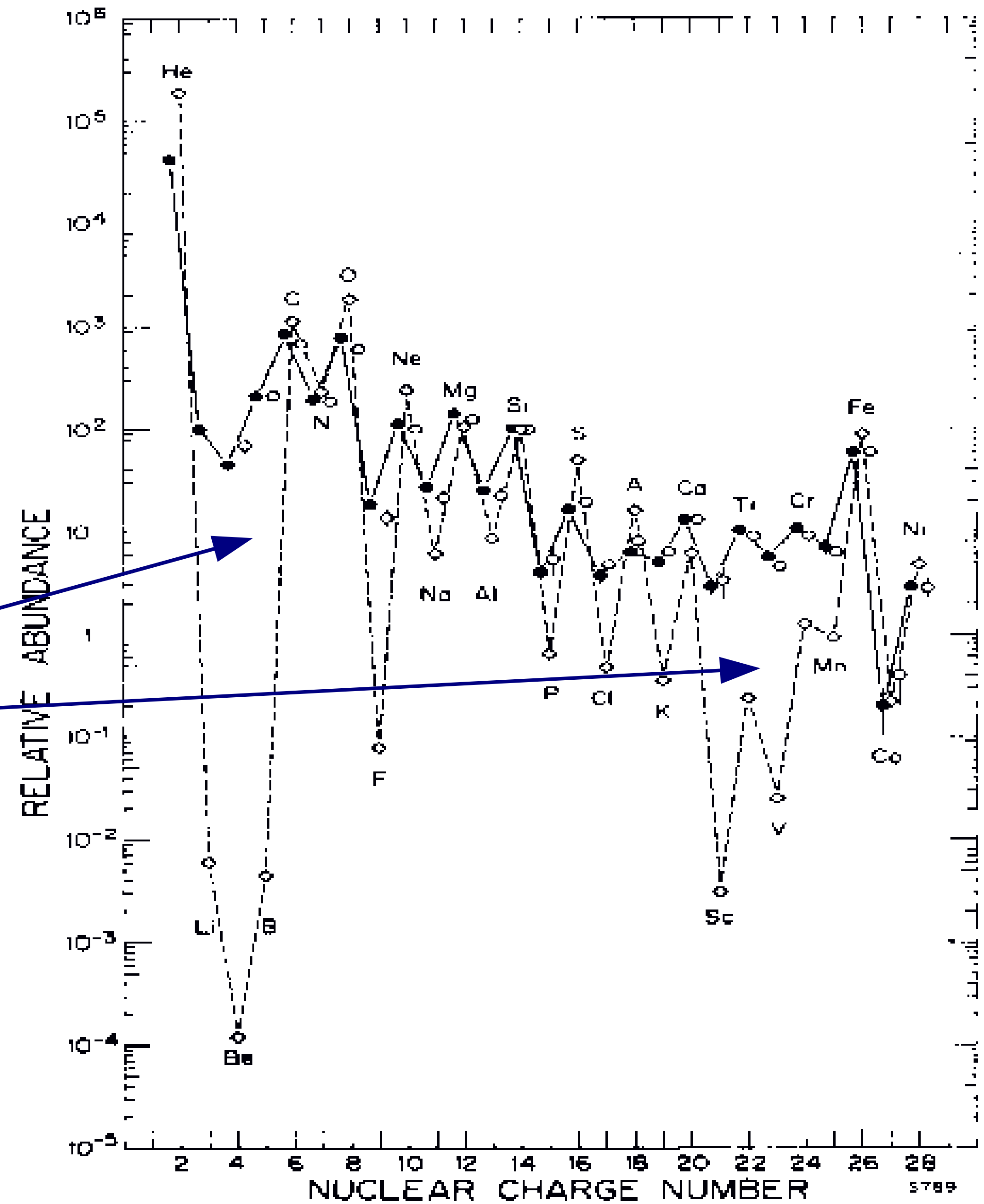


Figure 1. The relative abundance distribution of the elements in the cosmic radiation and in the solar system (normalized to Si = 100) from He to Ni (solid circles, 70–280 MeV per nucleon; open circles, 1000–2000 MeV per nucleon; open diamonds, solar system abundance distribution). [*Reproduced with permission from J. A. Simpson (1983). Ann. Rev. Nucl. Part. Sci. 33 by Annual Reviews, Inc.*]

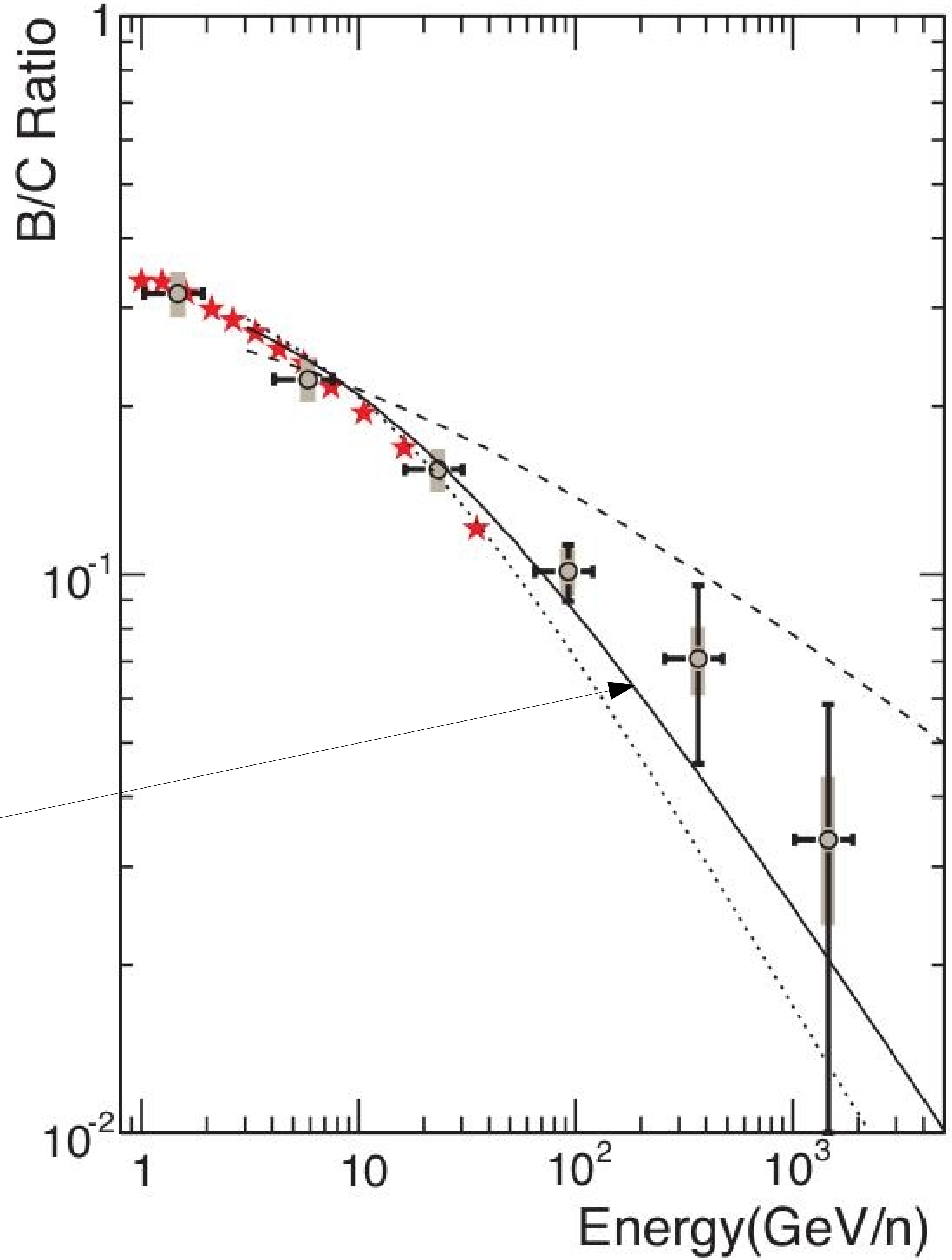
Overabundance of Li, Be, B

Sub-iron elements

Spallation effect:

Column density Confinement time

From CREAM



tau(E) ~ $E^{-0.6}$

Two Approaches to CR Anisotropy

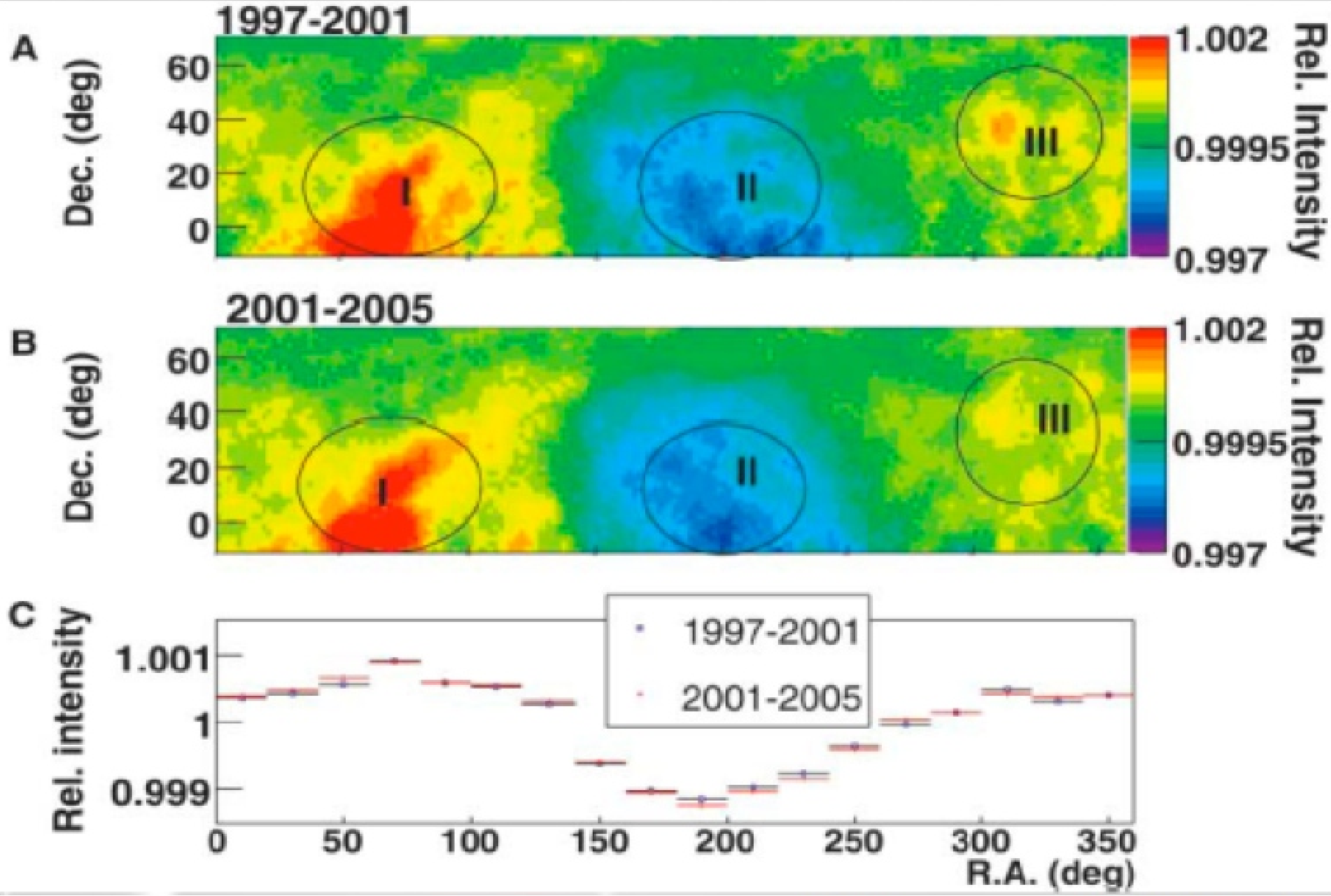
1) Forward backward asymmetry method to study "large scale anisotropy".

Derive shape of large scale features.

2) "Direct Integration" background subtraction to study "intermediate scale anisotropy".

Background derived from vicinity of source. High pass filter.

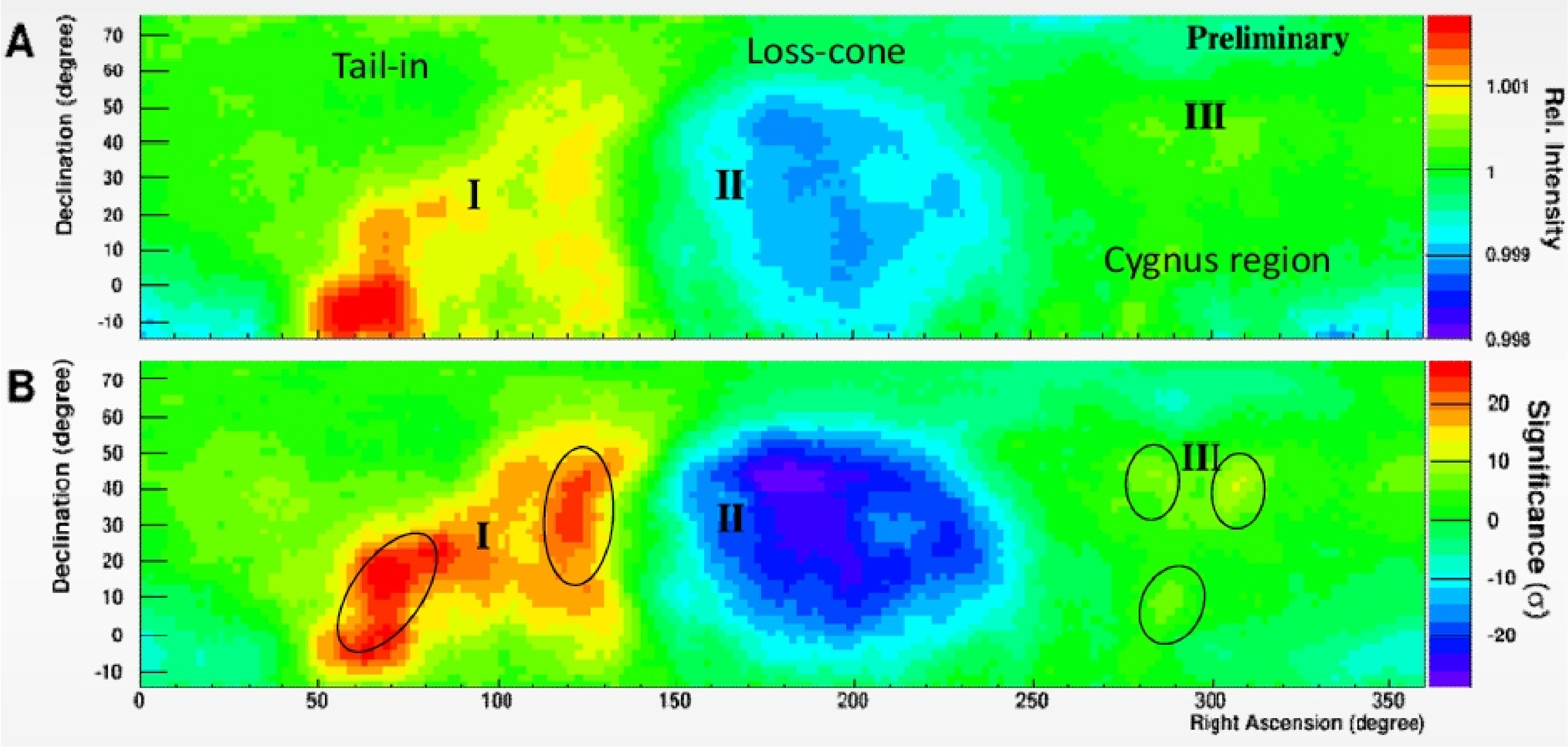
Tibet ASγ



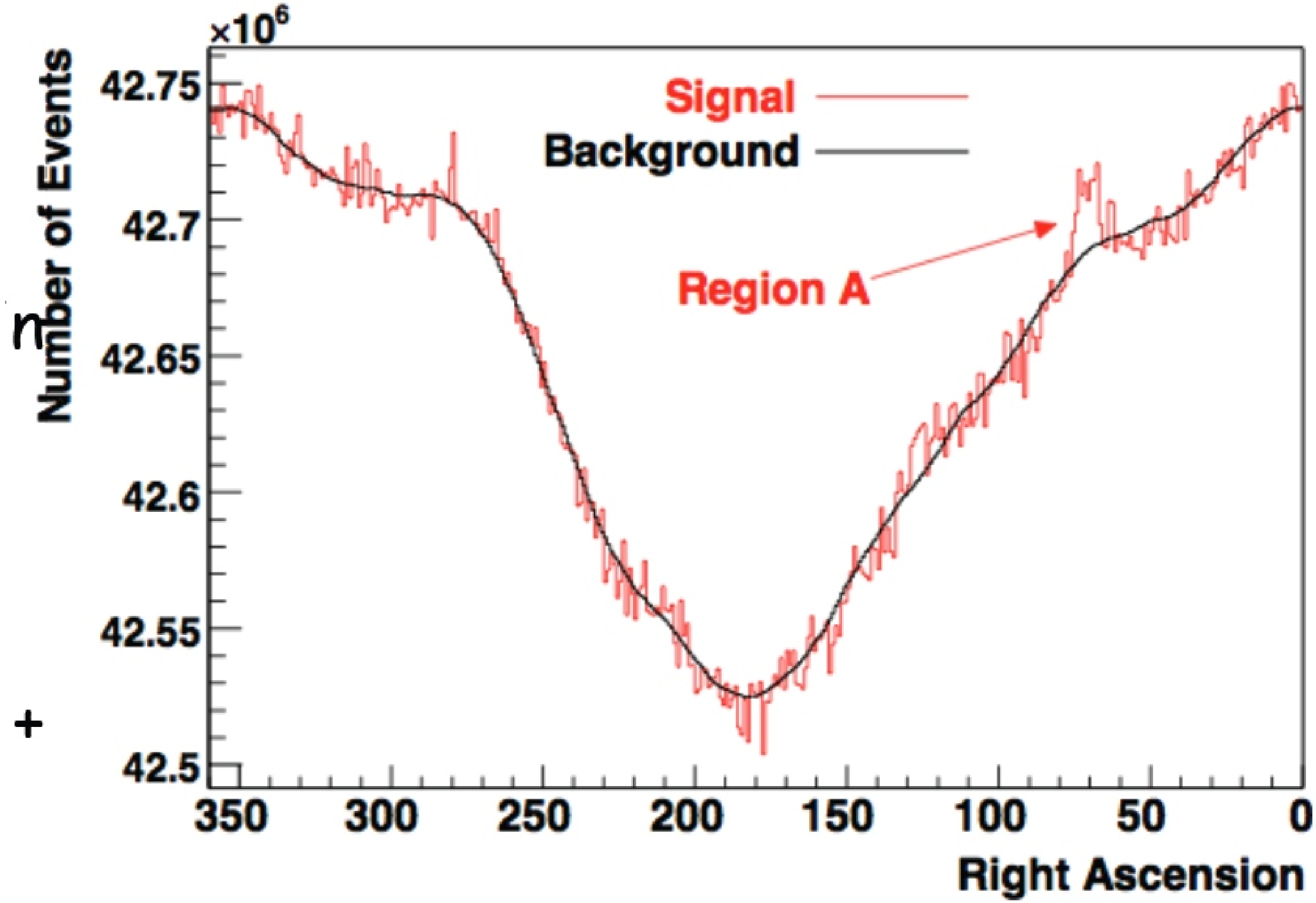
M. Amenomori et.al. Science, 2006

Large scale anisotropy

ARGO-YBJ DATA: 2008 and 2009



Paolo Camarri

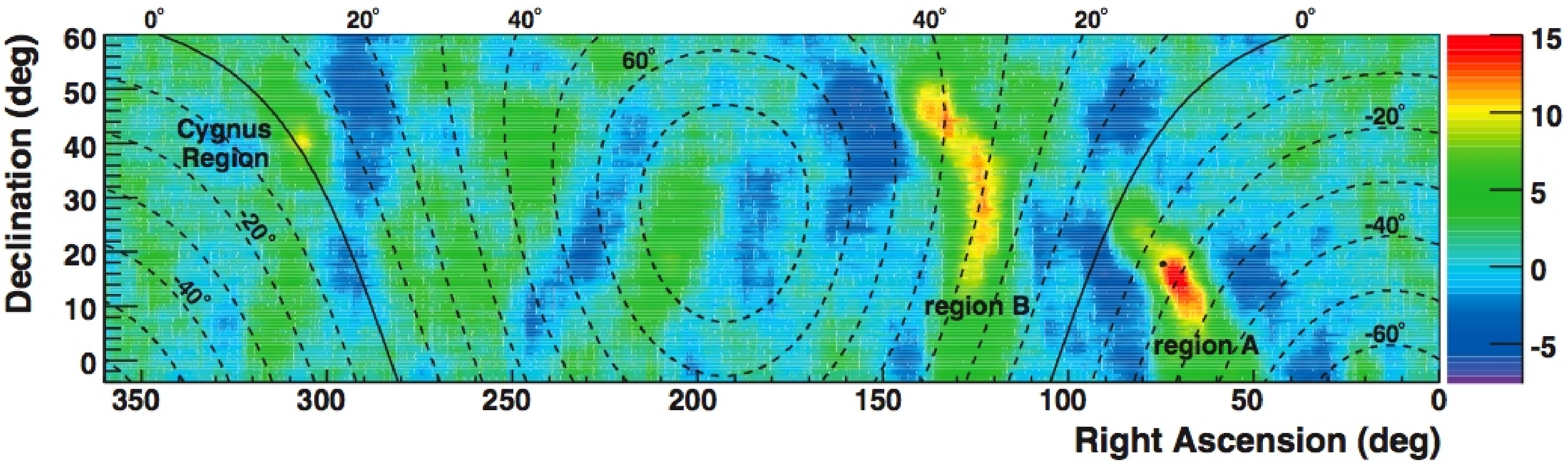

×10^6
42.75
42.7
42.65
42.6
42.55
42.5
Number of Events
Signal
Background
Region A
350
300
250
200
150
100
50
0
Right Ascension

0.5 % effect

Milagro collaboration

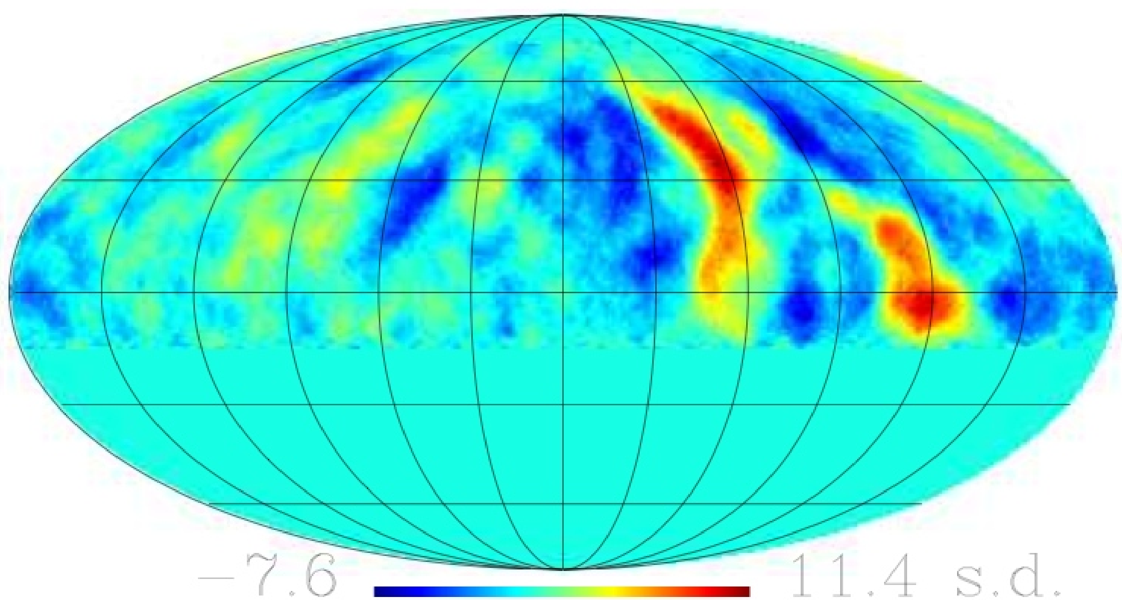
Selected for a Viewpoint in *Physics*
PRL **101,** 221101 (2008) PHYSICAL REVIEW LETTERS week ending 28 NOVEMBER 2008

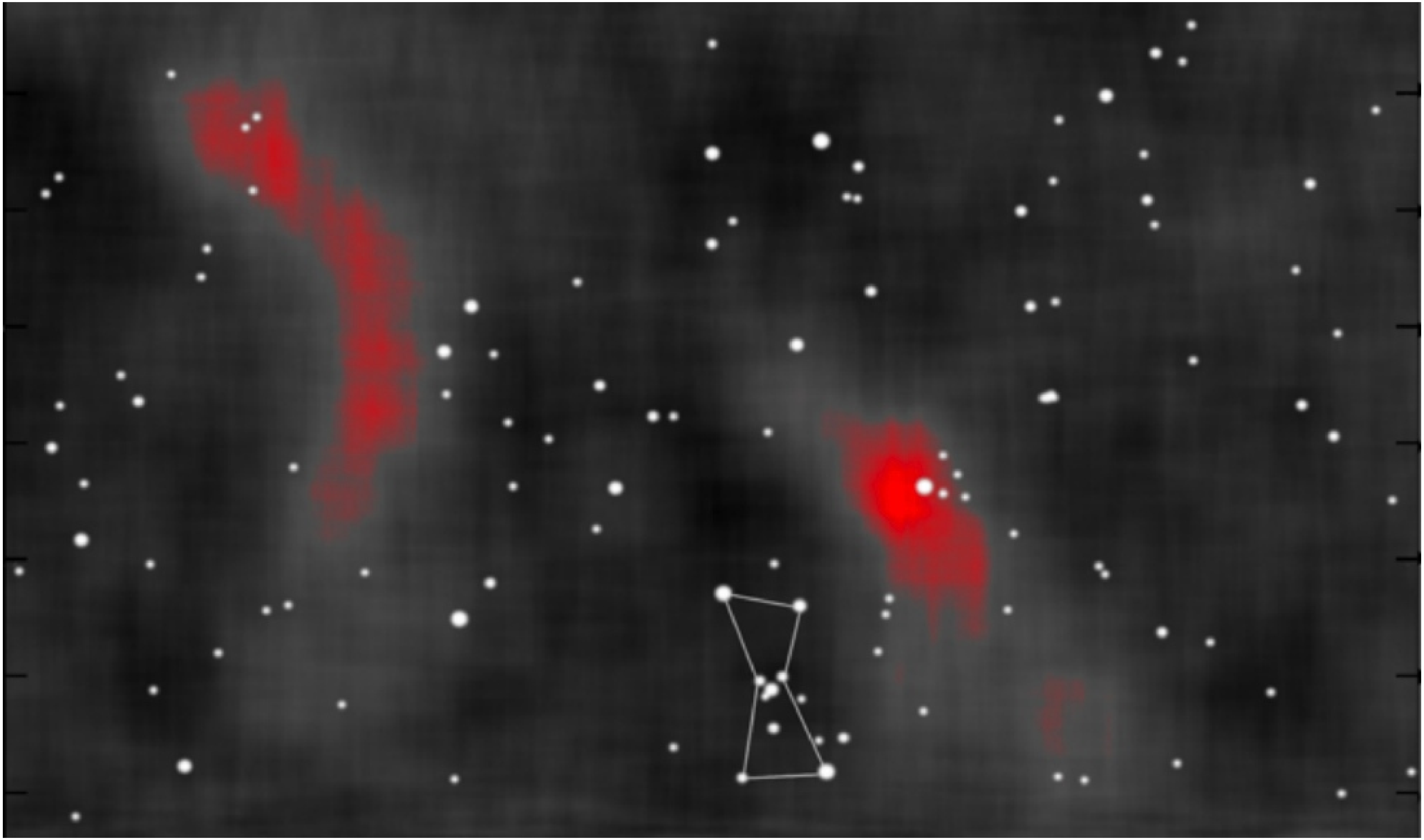
Discovery of Localized Regions of Excess 10-TeV Cosmic Rays



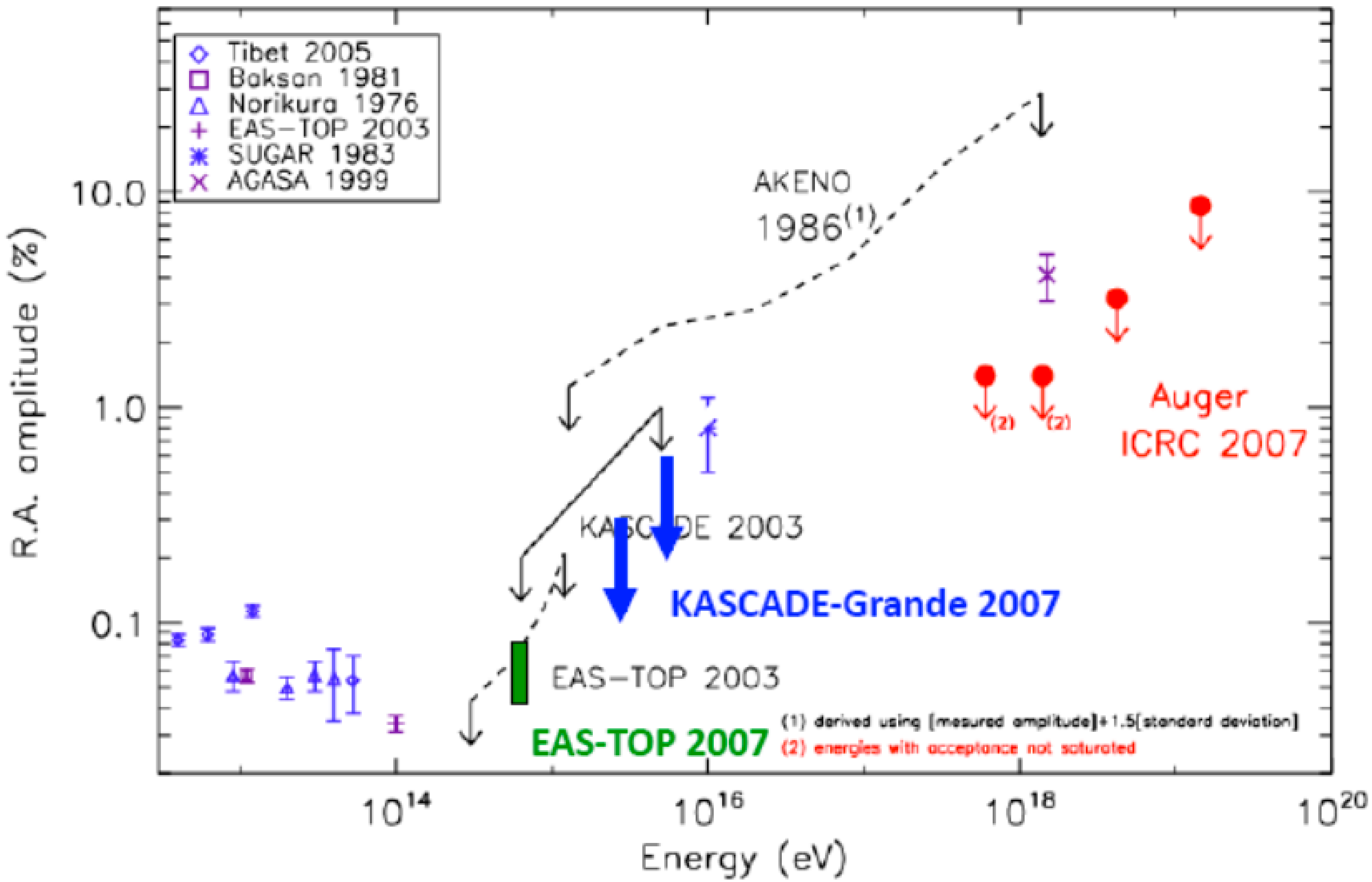
ARGO

VERNETTO *et al.* SKY MONITORING WITH ARGO-YBJ



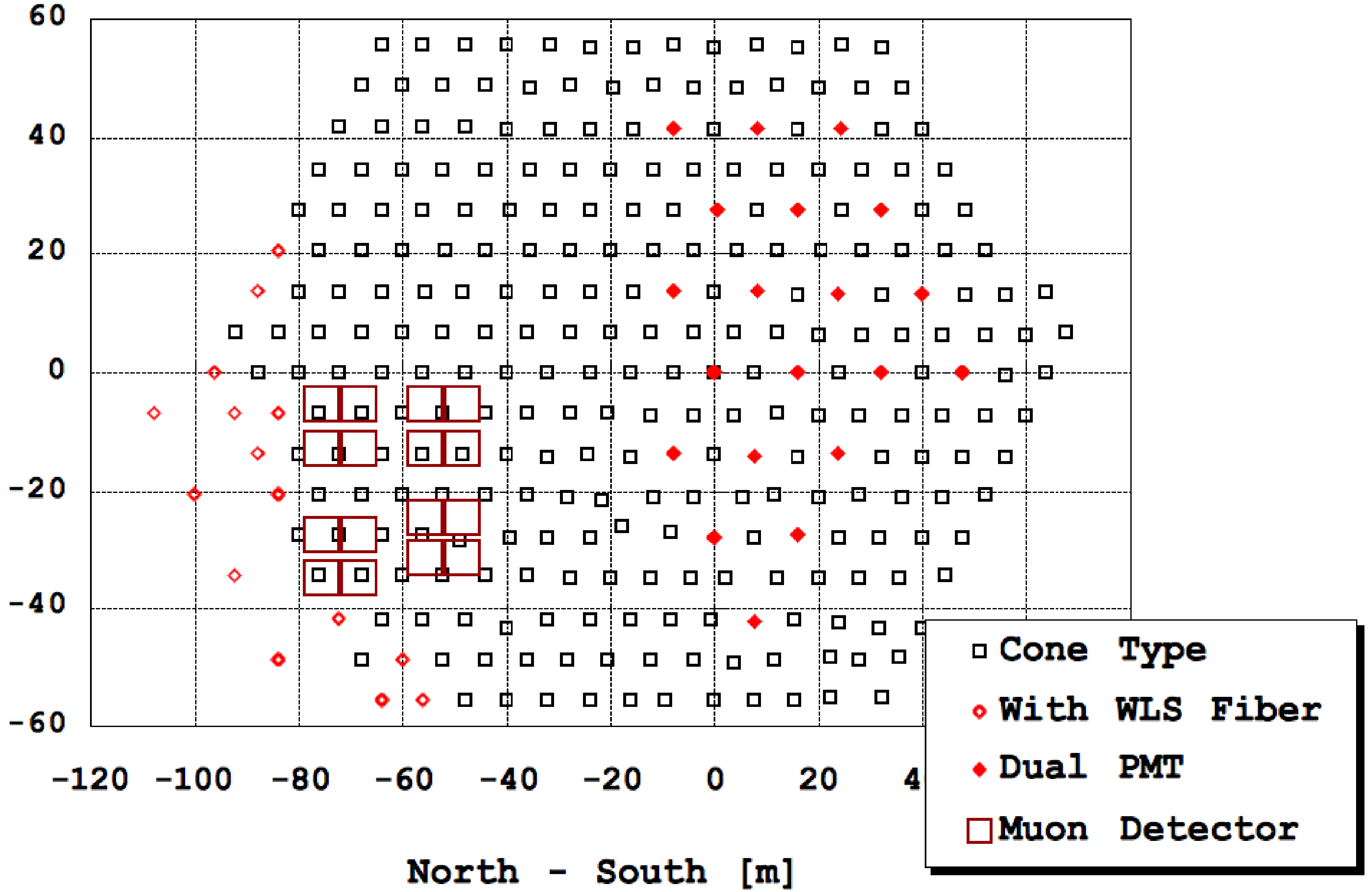


Large Scale Anisotropy



First Results from KASCADE-Grande (ICRC 2007)

GRAPES-3 at Ooty



Yoshio Hayashi

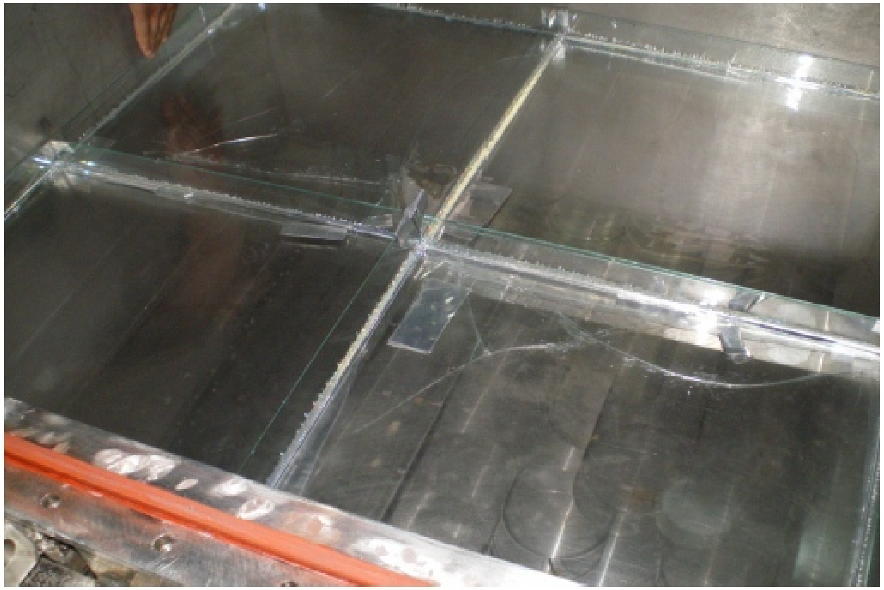
In-house technology for the Fabrication of Various Detector Components

Plastic Scintillator development:

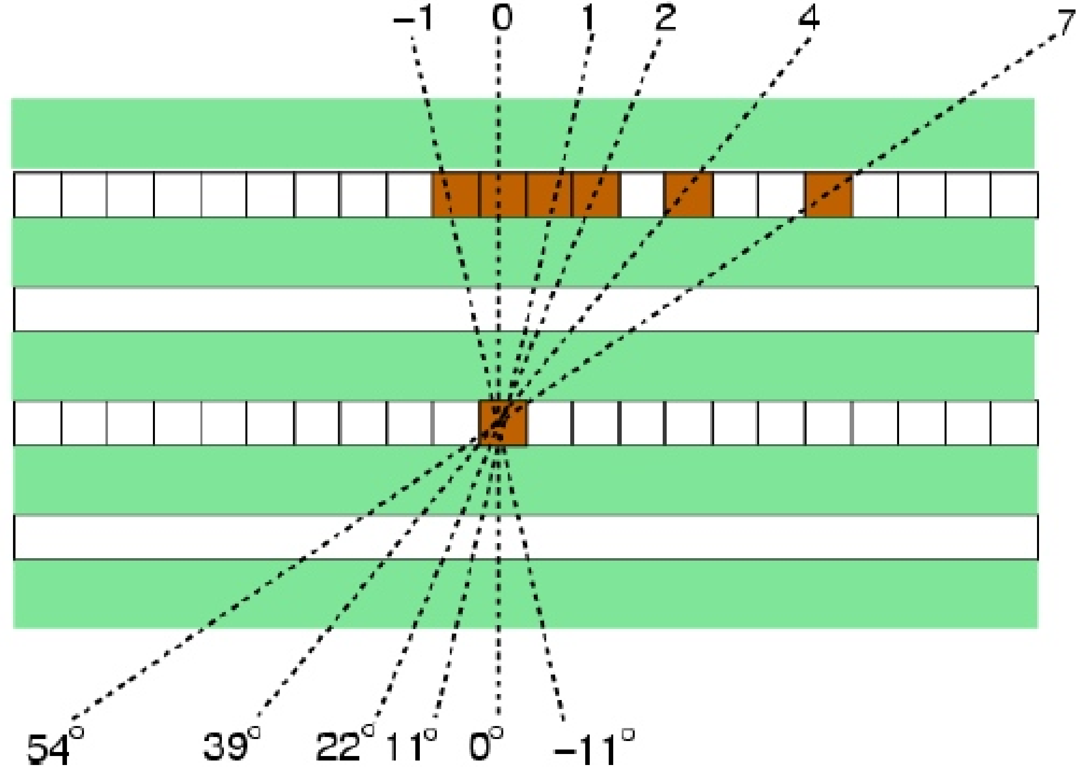
Decay Time= 1.6 ns
Light Output = 85% Bicron (54% anthracene)
Timing 25% faster
Atten. Length $\lambda = 100$cm
Cost ~10% of Bicron
Max Size 100cmX100cm
Total > 2000

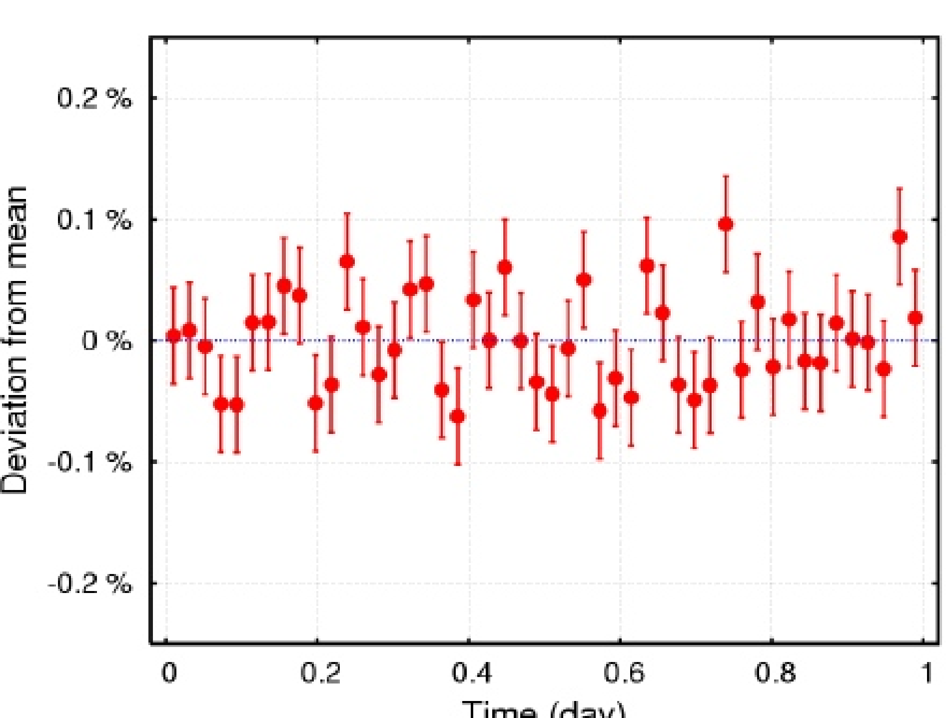
CERN, Osaka, IUAC Delhi, Bose, VECC, BARC etc.

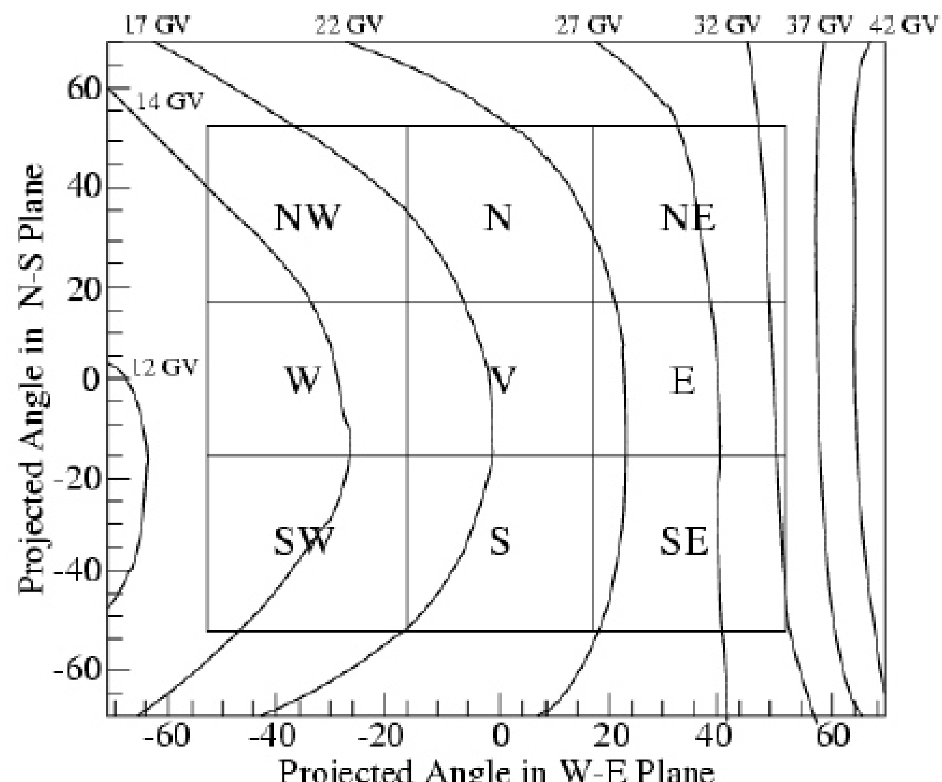


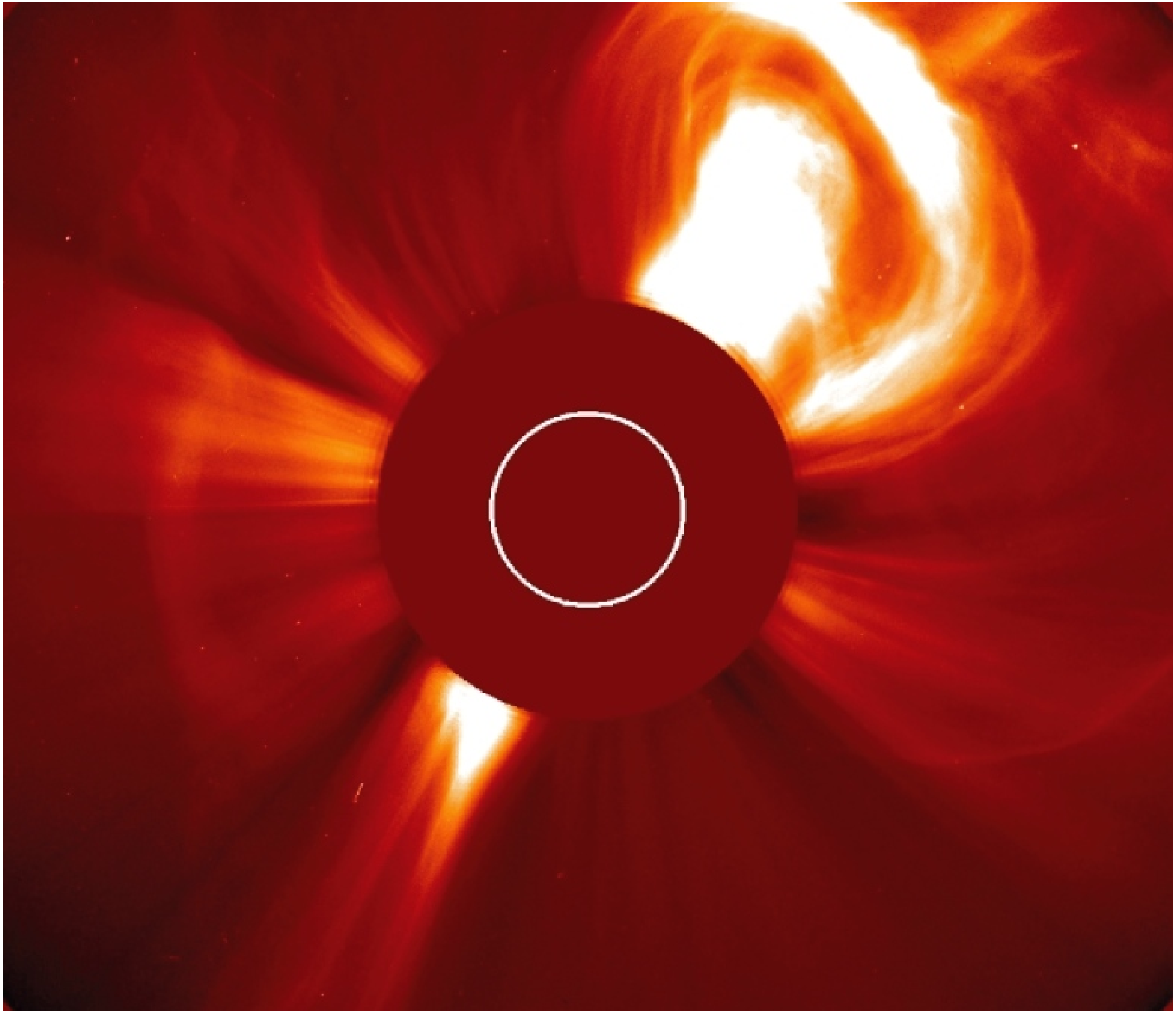



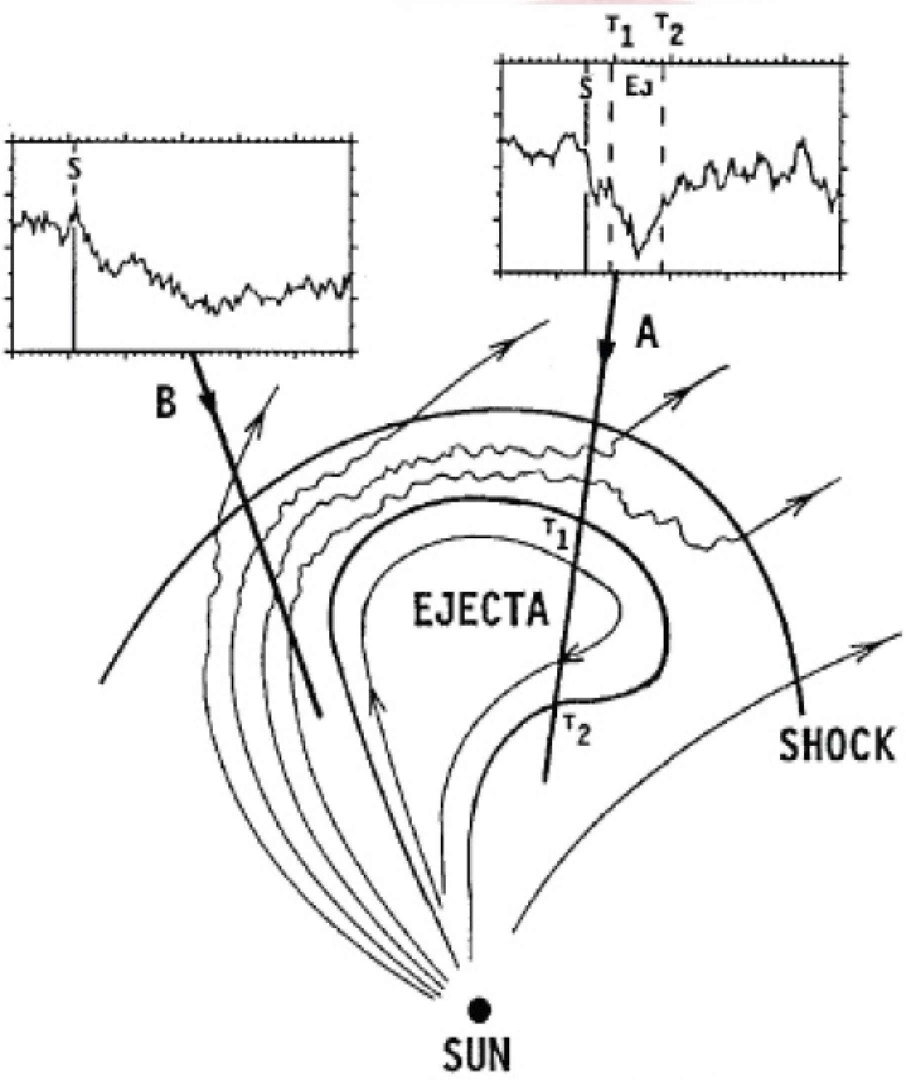
Solar phenomena





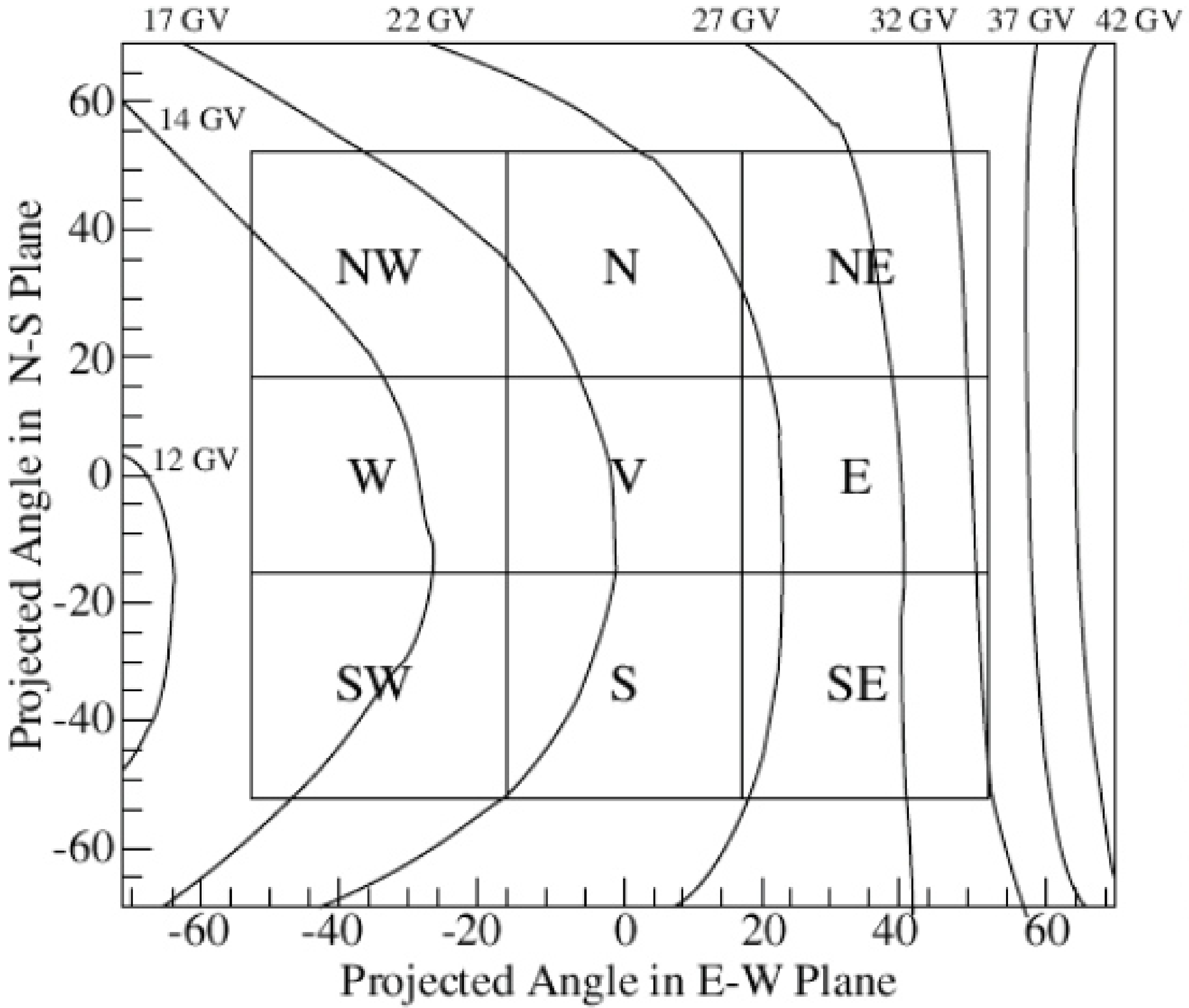



2002/12/02 19:26

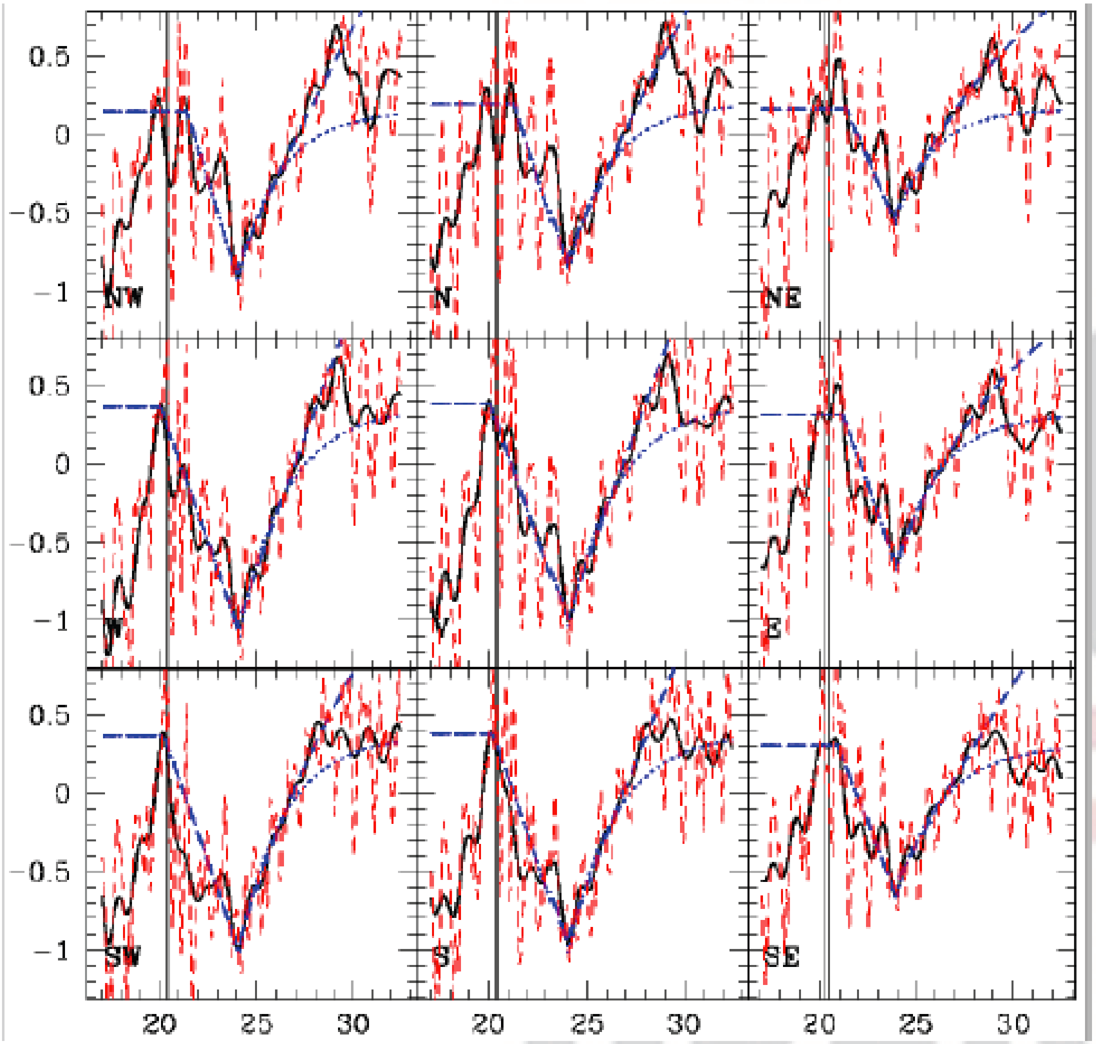


Forbush decreases (from Cane 2000)

9 directional bins make GRAPES-3 a multi-rigidity instrument

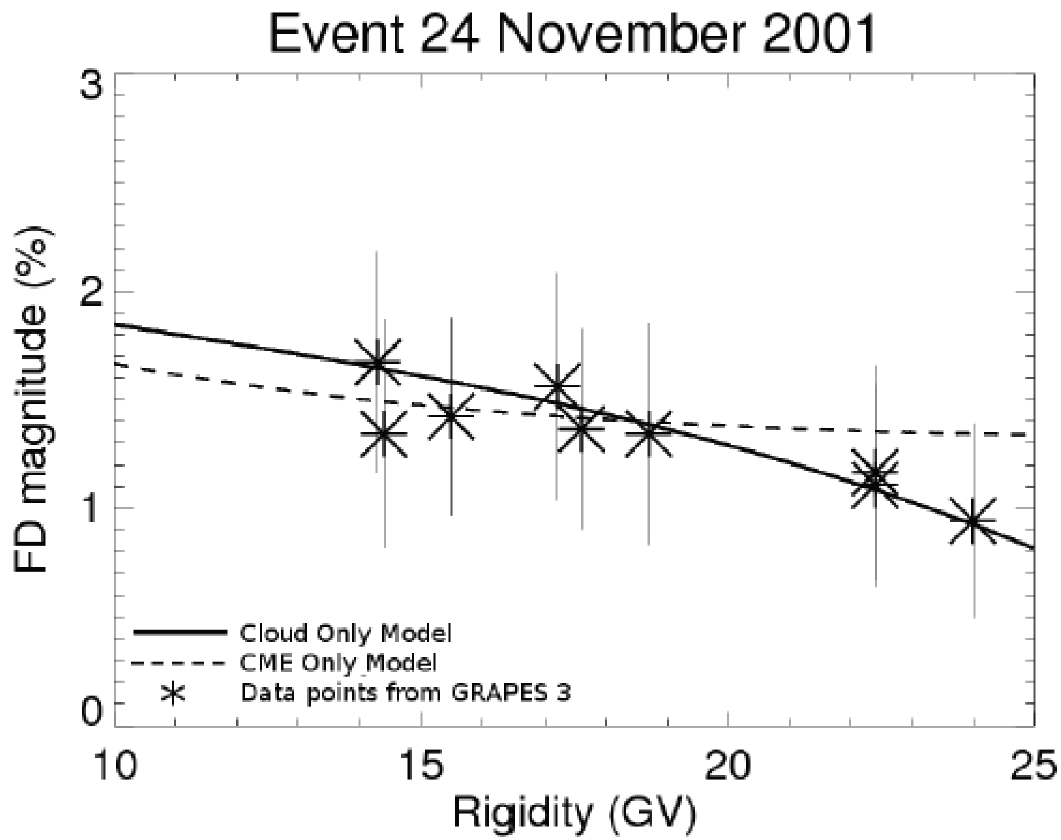


Event of 20th November 2003



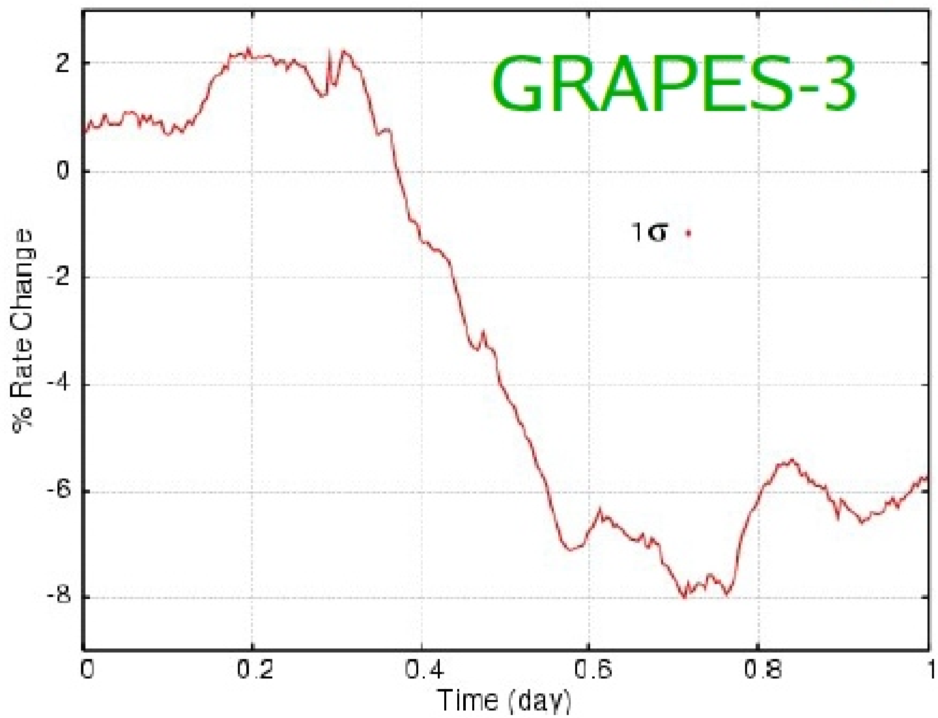
Forbush decrease on Nov 20 2003 observed with GRAPES-3

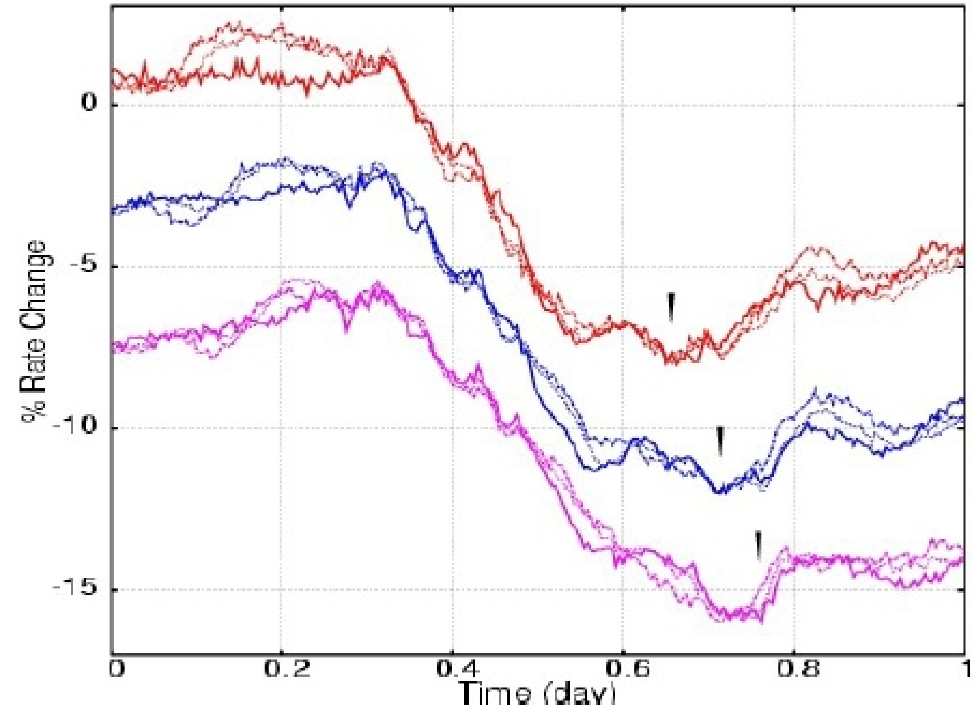
Prasad Subramanian

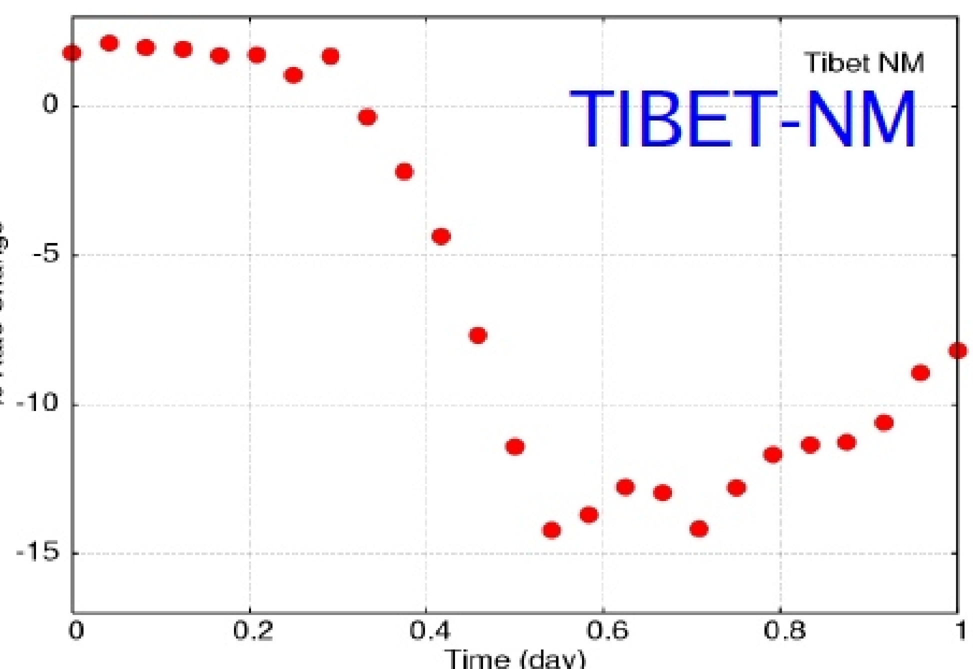


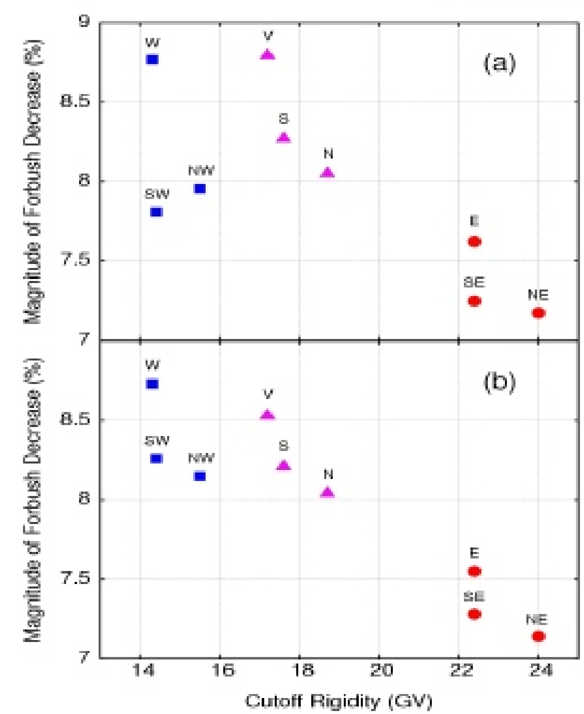
For CME-only model, $\sigma = 8\%$,
while for shock-only model $\sigma_{\rm ambient} = 100$ %!
Typical quiet sun turbulence level σ (at 15 – 50 $R_{\odot}$) $\approx$ 6–15 % (Spangler 2002).

Coronal Mass Ejection (28 October 2003)







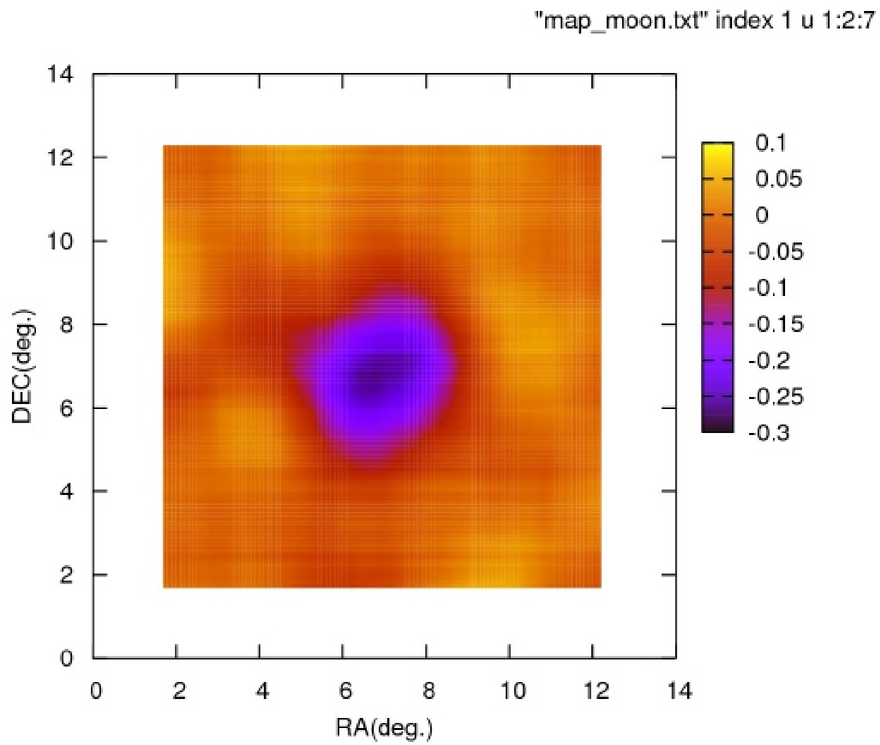


$A(r) = K \times r^{-\gamma}$

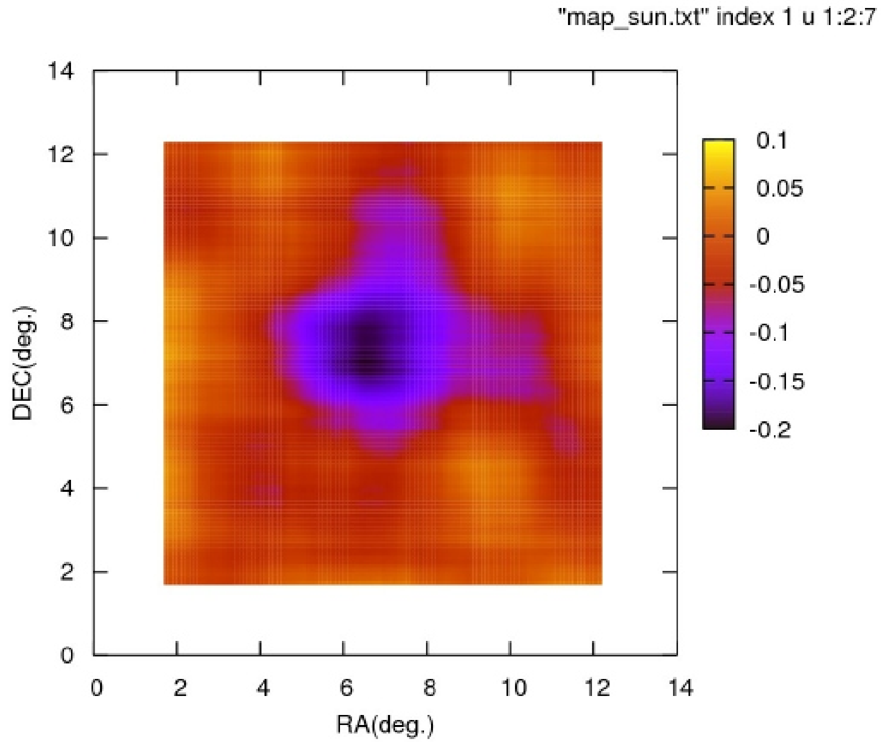
$K = (12.3 \pm 0.3)\%$

$\gamma = (0.53 \pm 0.04)$

$\gamma = 0.4 - 1.2$



Moon



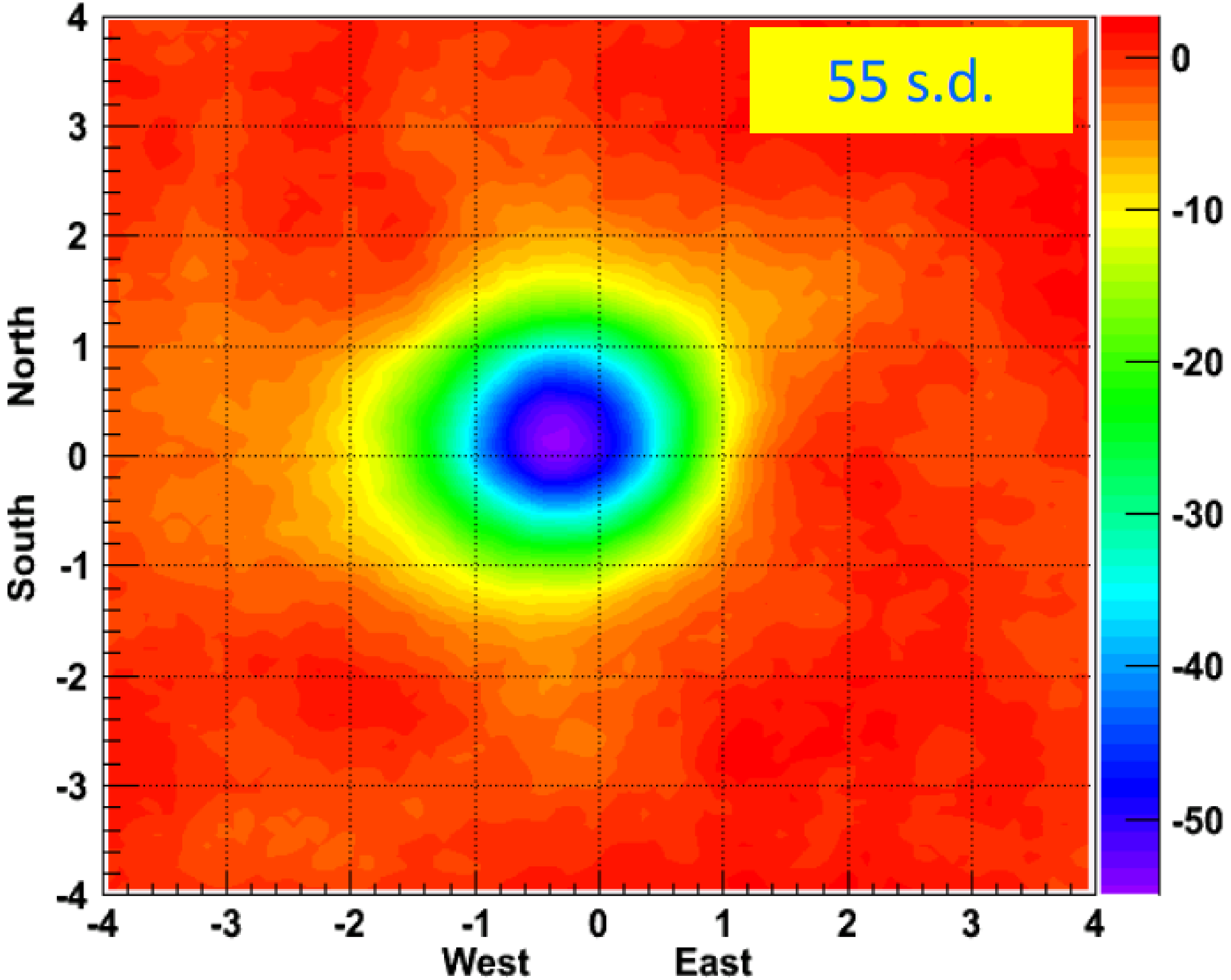
Sun

- Data: 2000 – 2006 (7years data)
- Moon and Sun are detected clearly

Akitoshi Oshima

All data: 2006 → 2009

ARGO
Moon shadow

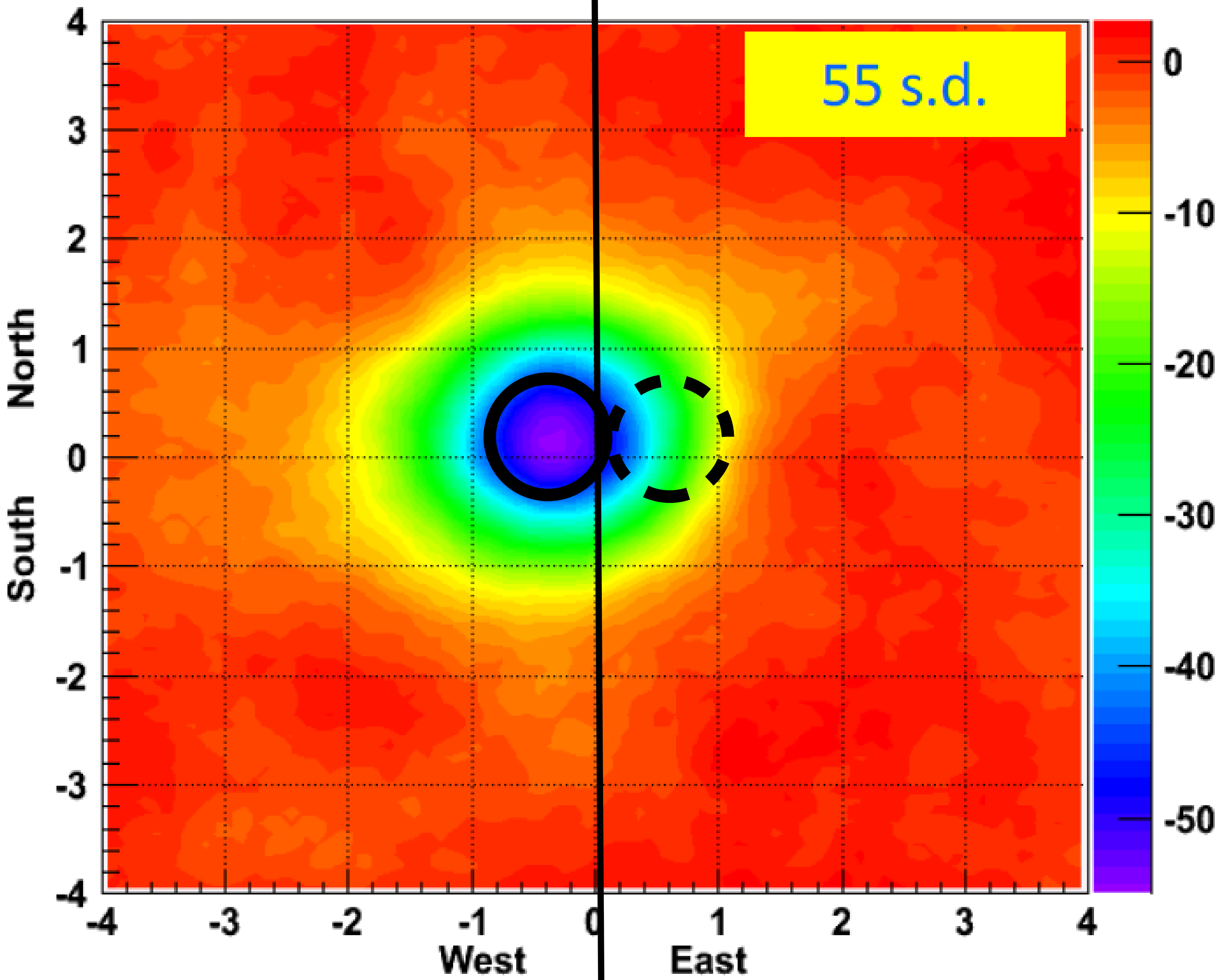


3200 hours on-source

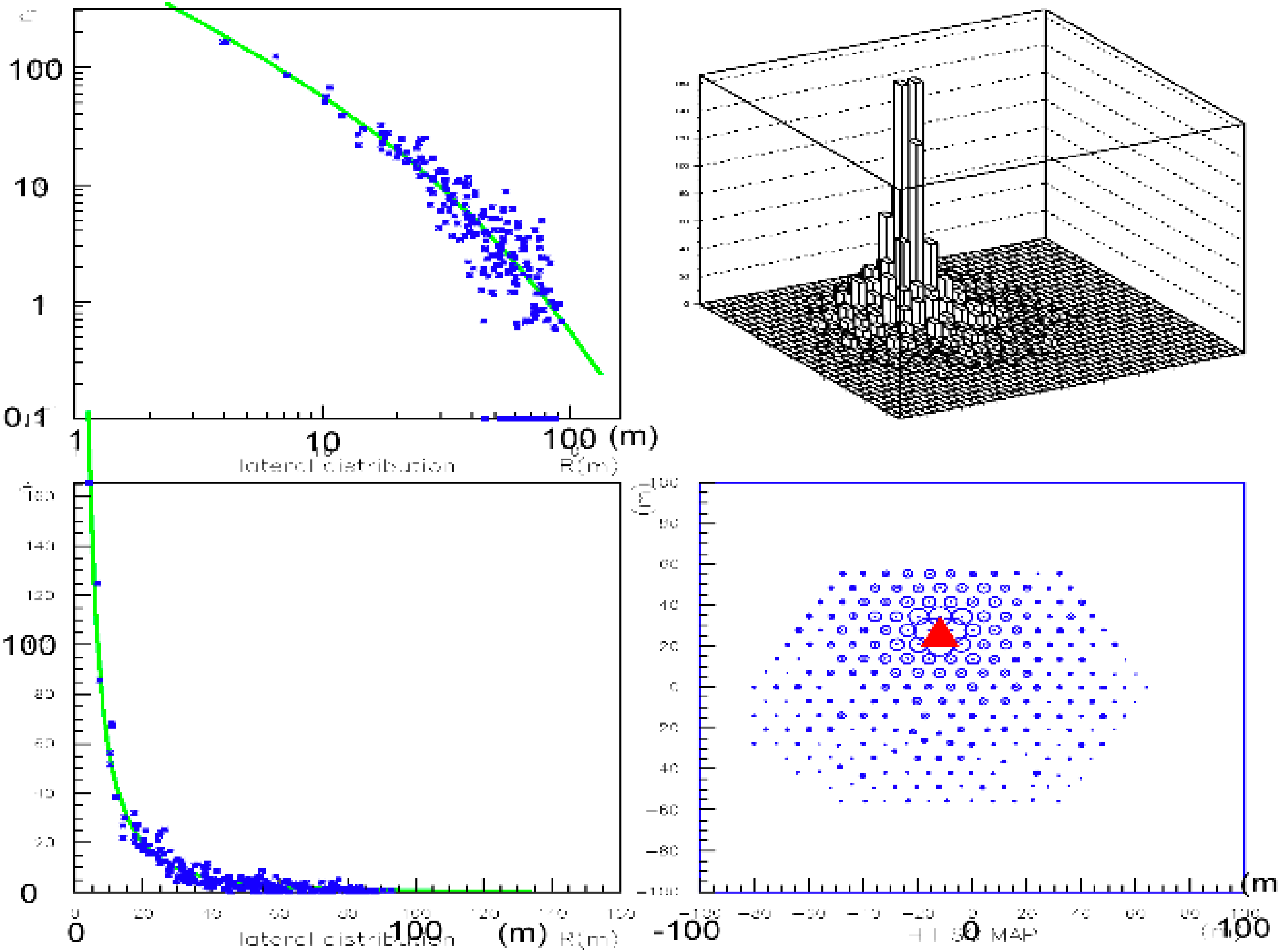
Paolo Camarri

Moon SHADOW

All data: 2006 → 2009



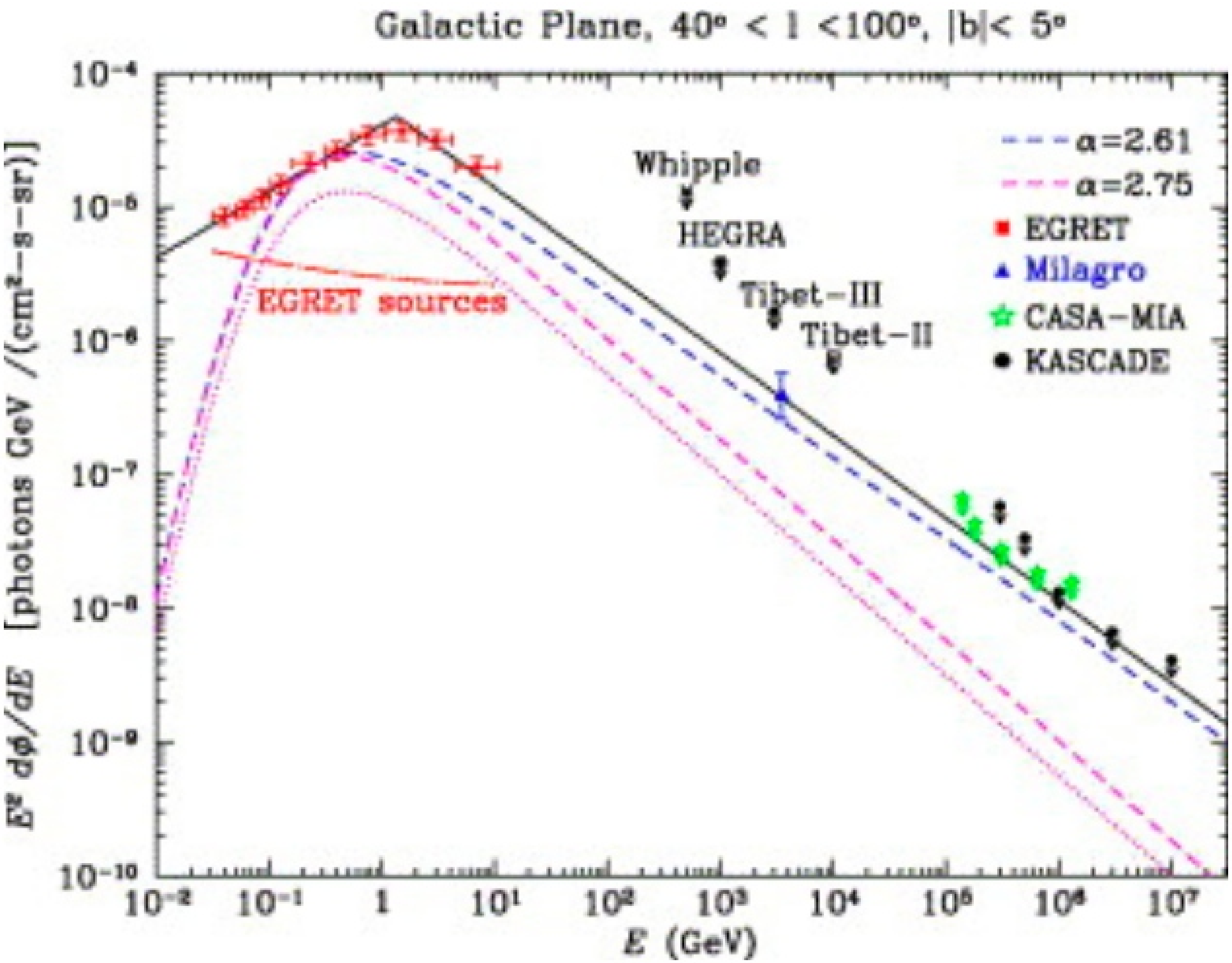
3200 hours on-source



100
10
1
0.1
1
10
100 (m)
lateral distribution
R(m)
100
0
0
100
(m)
lateral distribution
R(m)
(m)
-100
0
100
MAP

Diffuse Gamma Rays from Galactic Plane

Production Process
- CRs + ISM
  - IC scattering
  - Pion decay



T.Prodanovic, et al. Astrop... 10

Isotropic Gamma Rays due to UHECRs

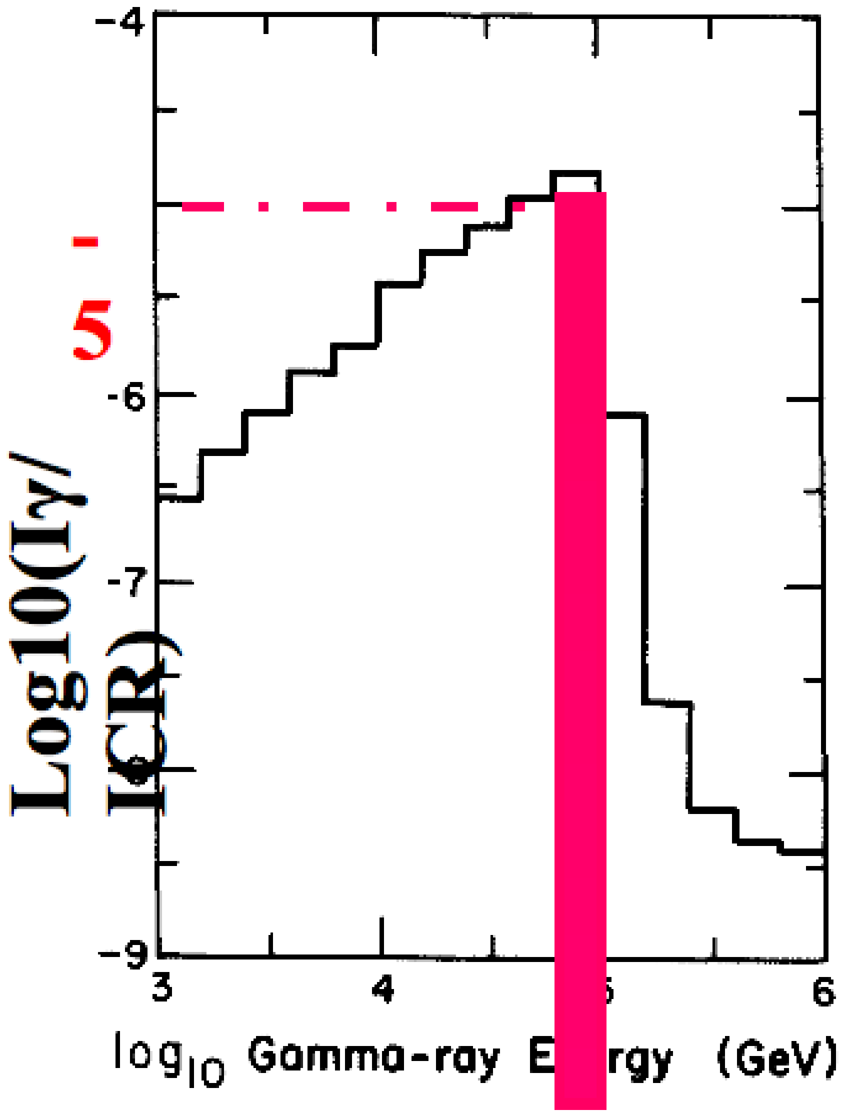
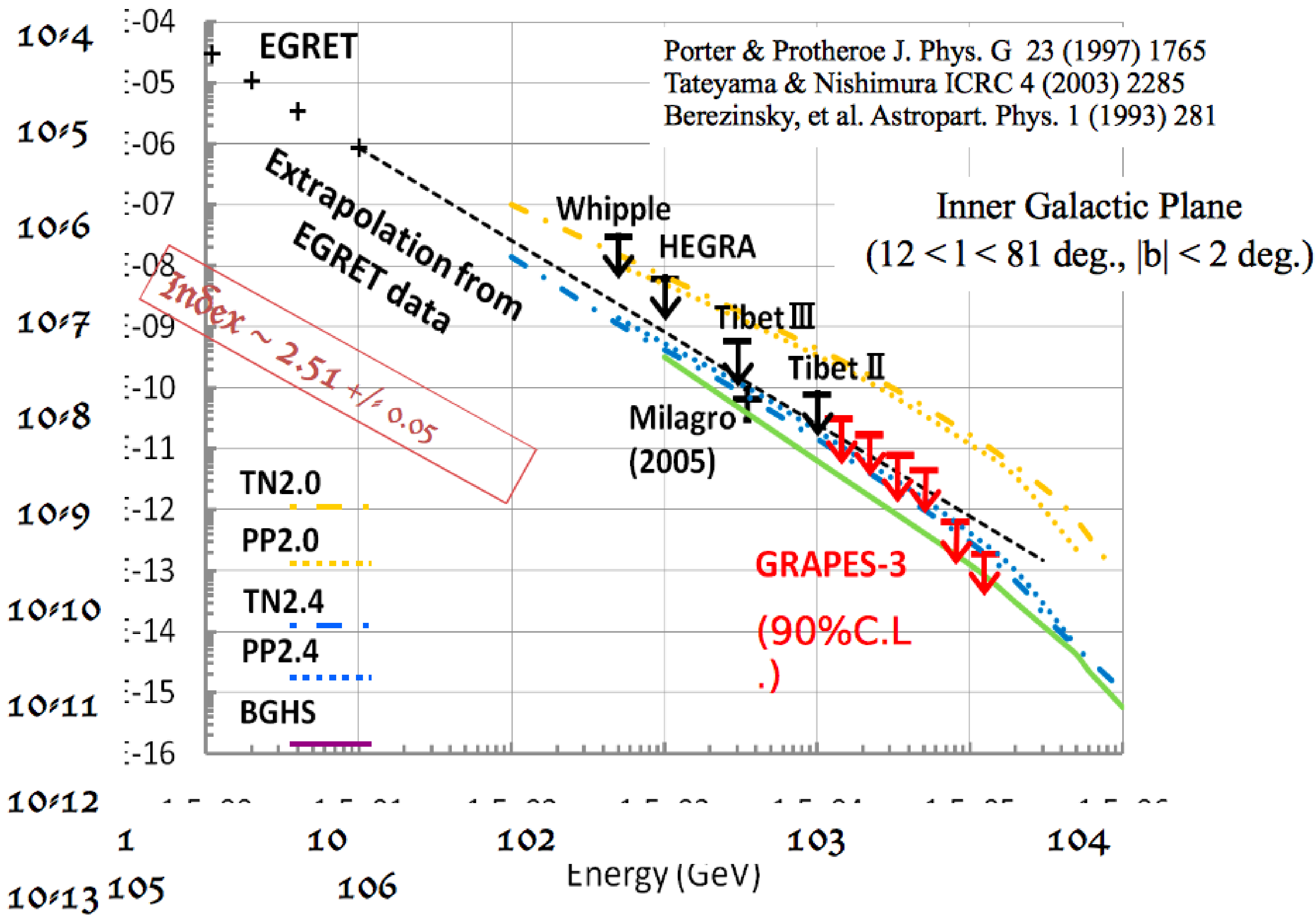


FIG. 4. Ratio R of the resulting diffuse γ-ray flux produced by extragalactic cosmic rays on the 3-K background photons, to the cosmic-ray flux in the TeV region.

Yoshio Hayashi

Integral Flux : Inner Galaxy



Yoshio Hayashi

- Upper Limit of Gamma rays from inner and outer Galactic plane (90% C.L.)

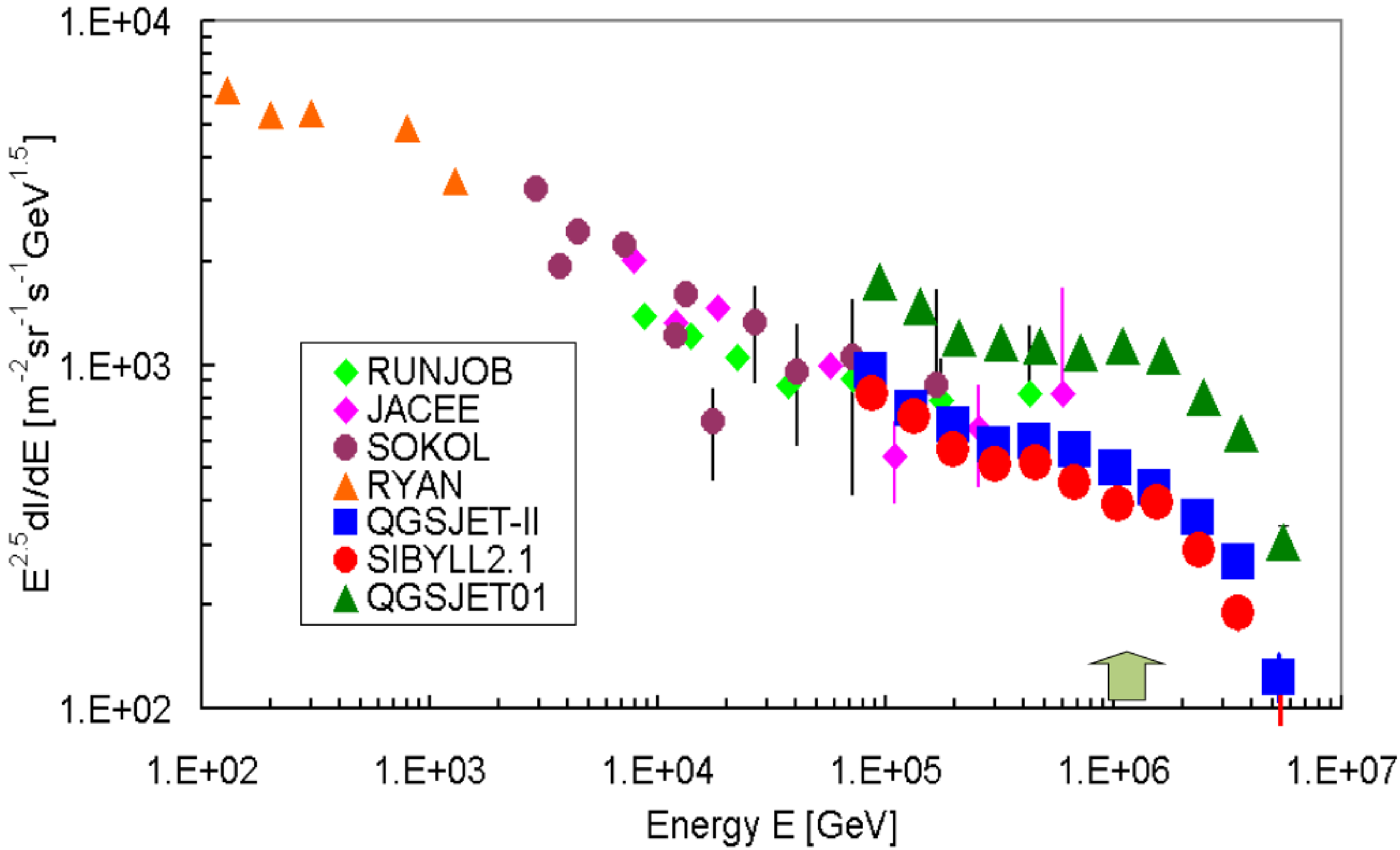
>E(TeV)	IG (cm-2s-1sr-1)	OG (cm-2s-1sr-1)
50	5.2x10-12	2.3x10-12
130	3.8x10-14	3.5x10-14

Upper Limit of Isotropic Diffuse Gamma Rays

- @85 TeV : 1.4x10-4 (90 % C.L.)
  @130 TeV : 4.2x10-5 (90 % C.L.)

Yoshio Hayashi

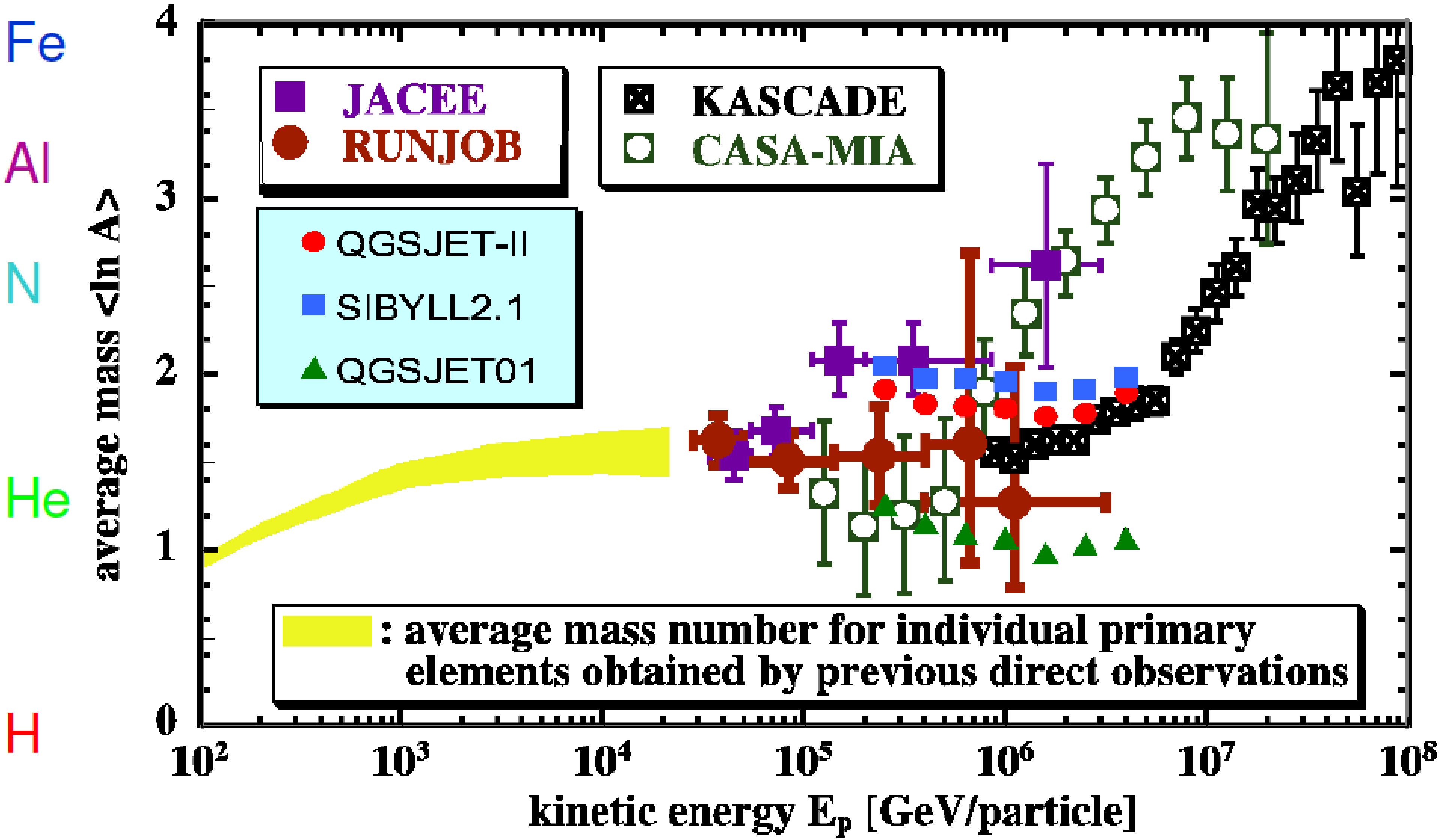
GRAPES-3 Cosmic Ray Spectrum



Comparison with direct measurements is possible

Sunil Gupta

Mean Mass Number



Lower threshold enables data to compare with direct measurements

Sunil Gupta

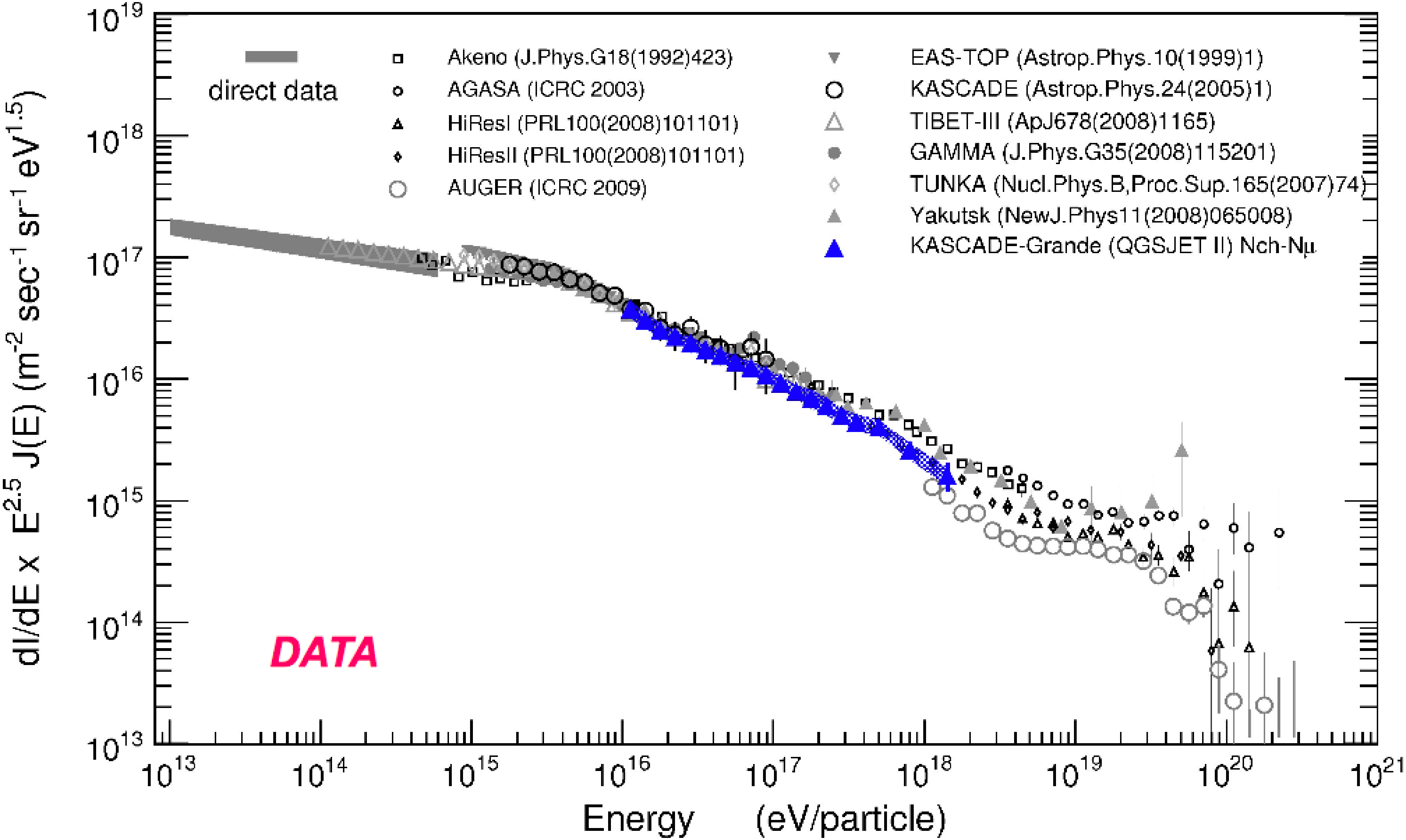
Going to higher energy:

The Knee

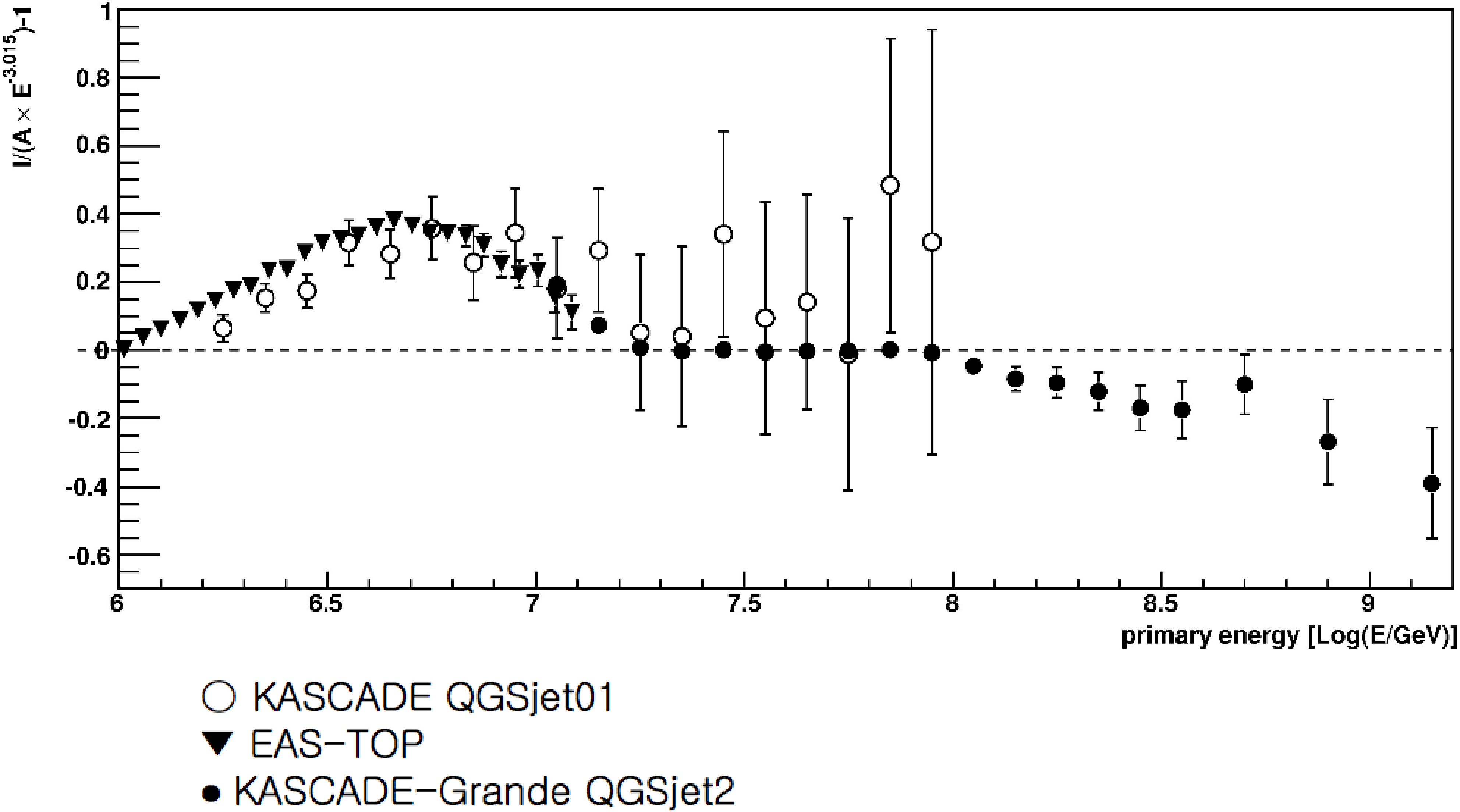
More structures ?

Galactic to Extragalactic Sources Transition [Extragalactic Sources]

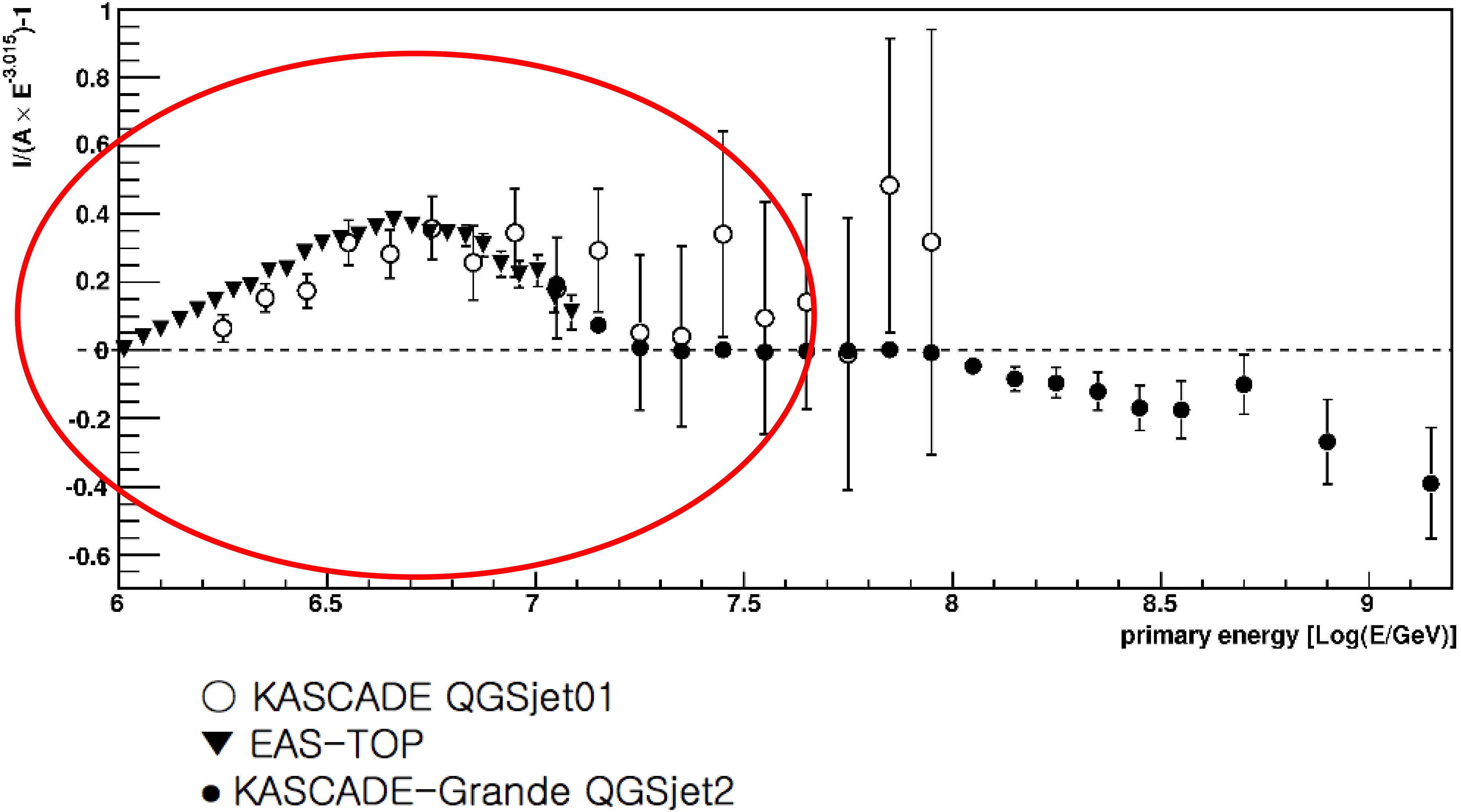
The “END of the SPECTRUM”



direct data
Akeno (J.Phys.G18(1992)423)
AGASA (ICRC 2003)
HiResI (PRL100(2008)101101)
HiResII (PRL100(2008)101101)
AUGER (ICRC 2009)
EAS-TOP (Astrop.Phys.10(1999)1)
KASCADE (Astrop.Phys.24(2005)1)
TIBET-III (ApJ678(2008)1165)
GAMMA (J.Phys.G35(2008)115201)
TUNKA (Nucl.Phys.B,Proc.Sup.165(2007)74)
Yakutsk (NewJ.Phys11(2008)065008)
KASCADE-Grande (QGSJET II) Nch-Nμ
DATA
dI/dE x E^2.5 J(E) (m^-2 sec^-1 sr^-1 eV^1.5)
Energy (eV/particle)

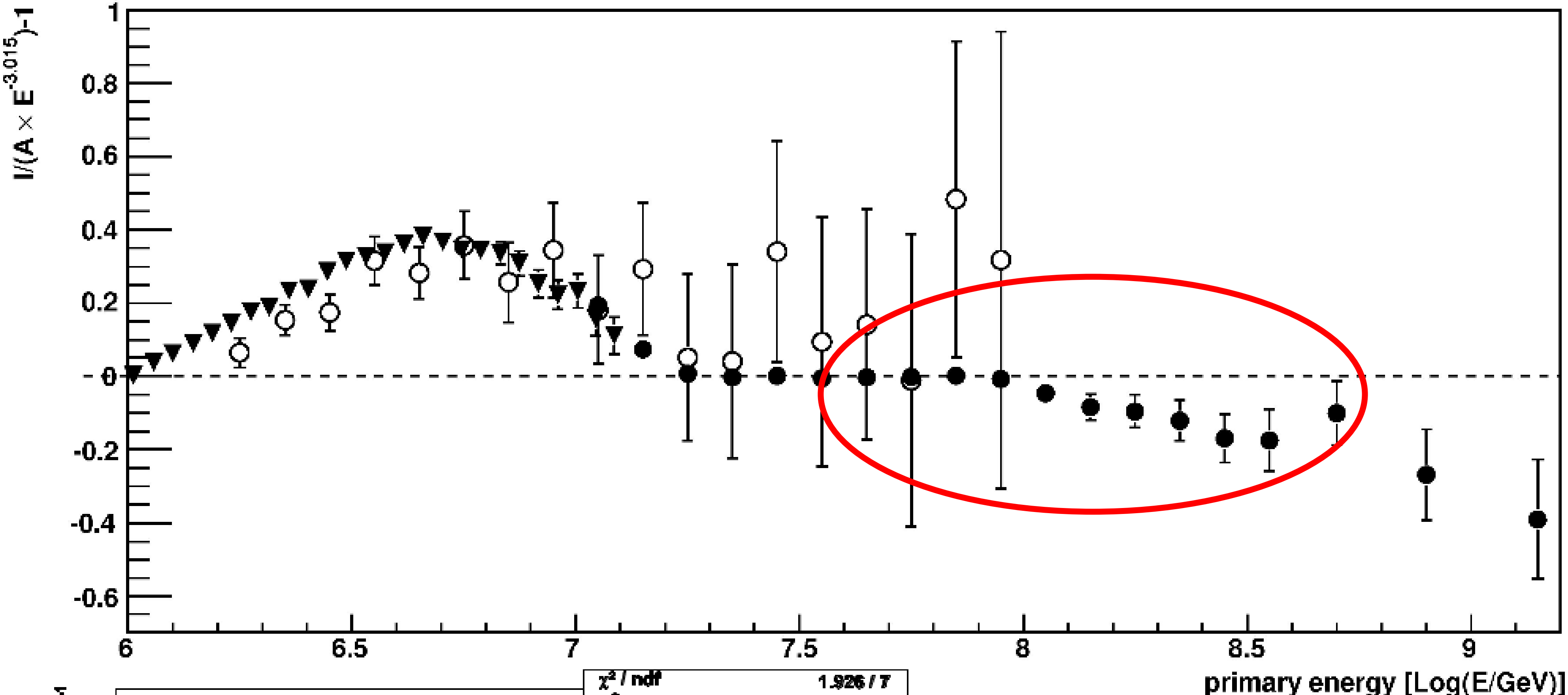


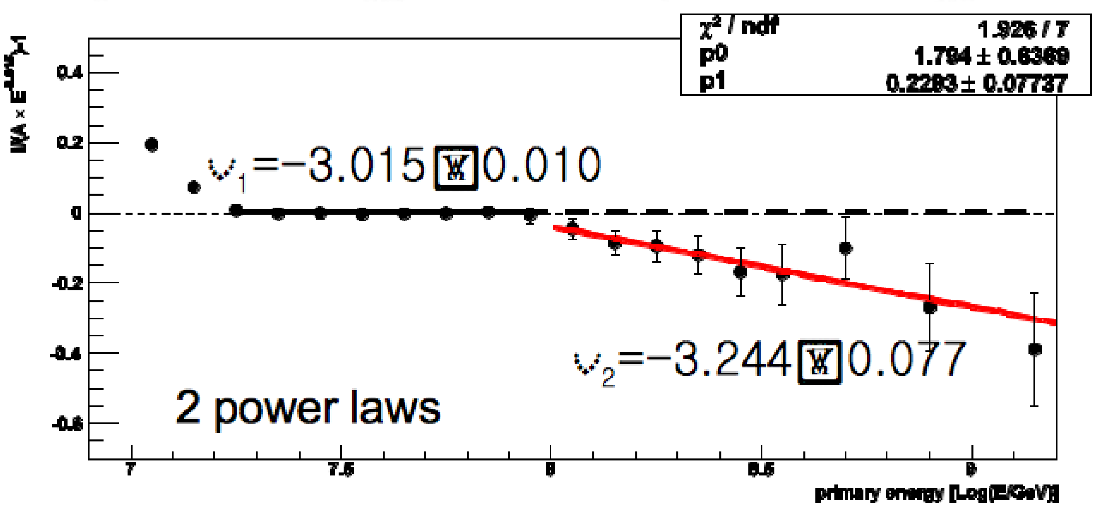
Mario Bertaina



"Shape of the Knee" (?!)

Mario Bertaina

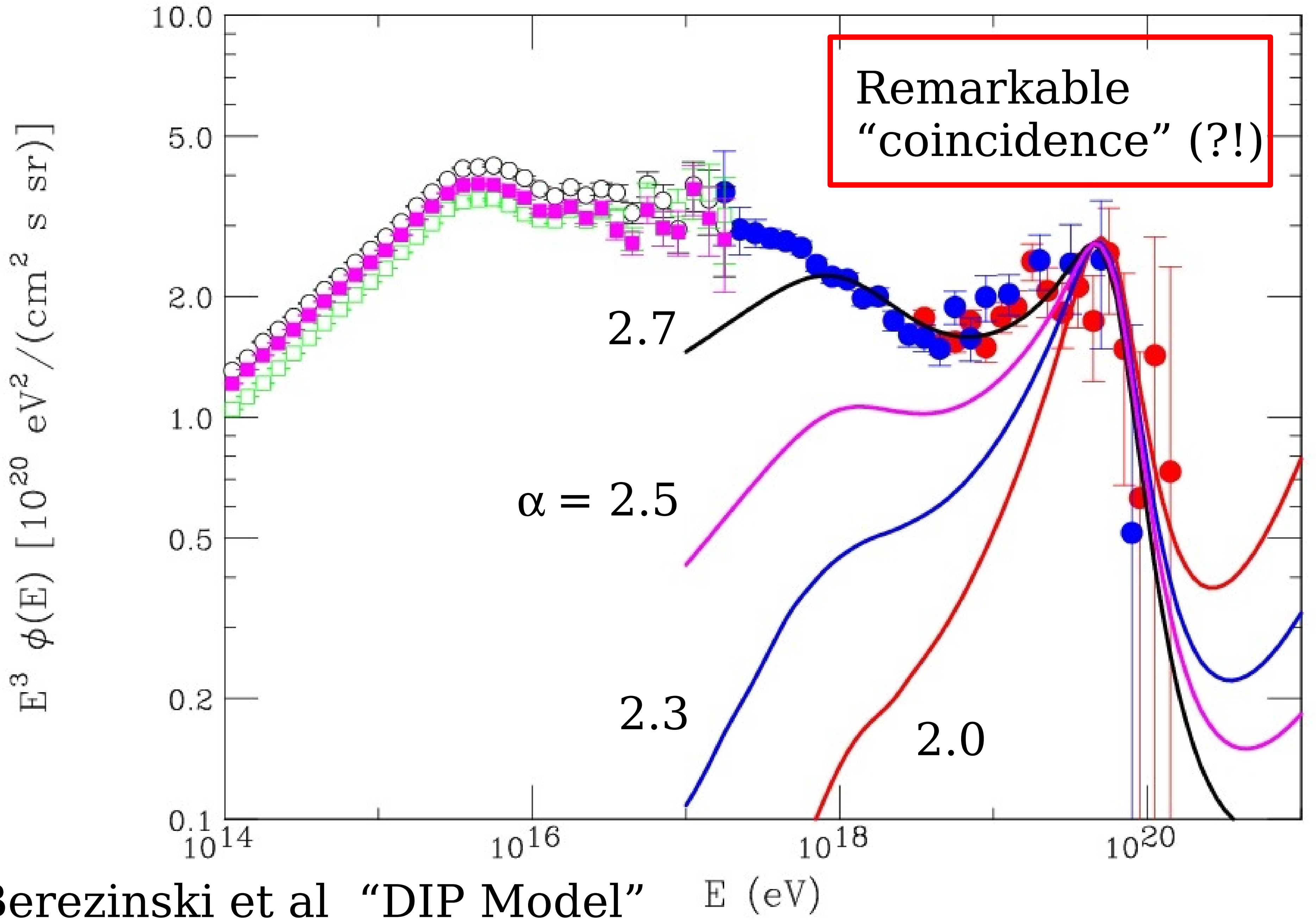




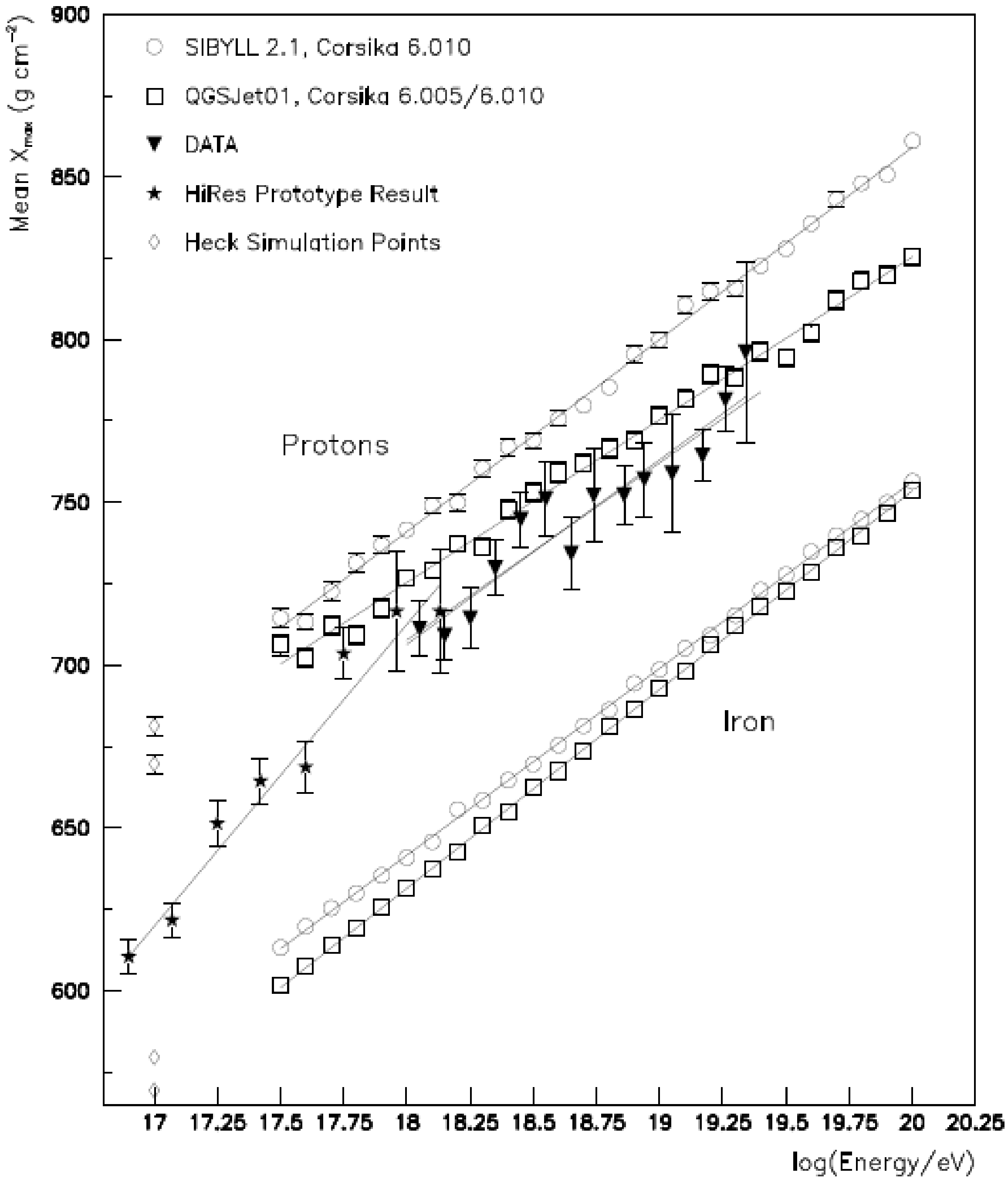
"Steepening"

Mario Bertaina

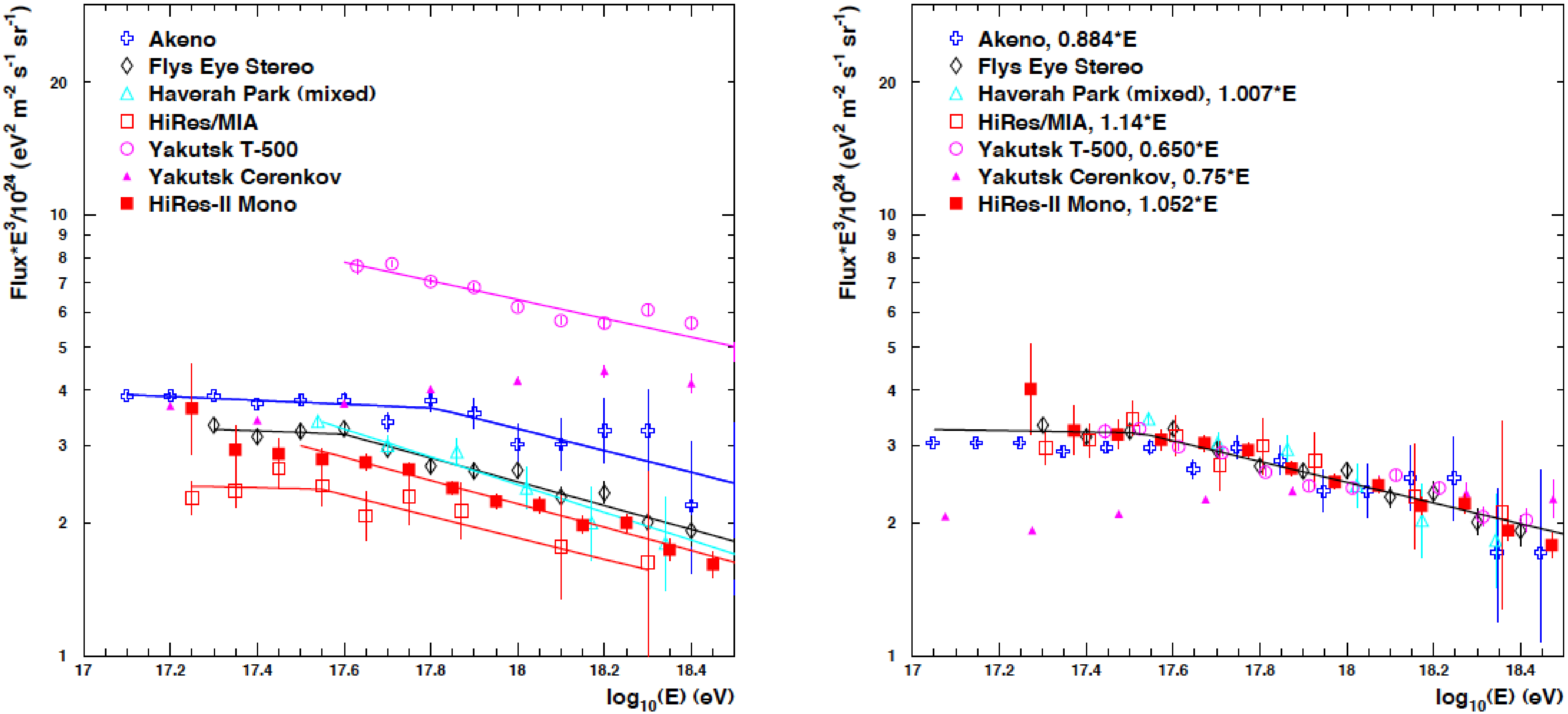
Power Law Injection (No Cosmic Evolution)



Berezinski et al “DIP Model”



Mean X$_{max}$ (g cm^{-2})
900
850
800
750
700
650
600
SIBYLL 2.1, Corsika 6.010
QGSJet01, Corsika 6.005/6.010
DATA
HiRes Prototype Result
Heck Simulation Points
Protons
Iron
17
17.25
17.5
17.75
18
18.25
18.5
18.75
19
19.25
19.5
19.75
20
20.25
log(Energy/eV)



Akeno
Flys Eye Stereo
Haverah Park (mixed)
HiRes/MIA
Yakutsk T-500
Yakutsk Cerenkov
HiRes-II Mono
Akeno, 0.884*E
Haverah Park (mixed), 1.007*E
HiRes/MIA, 1.14*E
Yakutsk T-500, 0.650*E
Yakutsk Cerenkov, 0.75*E
HiRes-II Mono, 1.052*E
Flux*E^3/10^24 (eV^2 m^-2 s^-1 sr^-1)
log10(E) (eV)

The Second Knee

Experiment (*reference*)	χ^2/DOF	Slope Below	Break Point $\log_{10}\left(\frac{E}{\text{eV}}\right)$	Slope Above
Akeno (Nagano et al. 1992)	$8.3/13$	3.04 ± 0.02	17.8 ± 0.2	3.25 ± 0.12
Fly's Eye (Bird et al. 1993)	$13.7/18$	3.04 ± 0.05	17.60 ± 0.06	3.27 ± 0.02
HiRes/MIA (Abu-Zayyad et al. 2001)	$2.5/5$	3.02	17.6 ± 0.2	3.23 ± 0.14
Haverah Park (Ave et al. 2003*a*)	$1.4/5$			3.32 ± 0.05
Yakutsk T-500 (Egorova et al. 2004)	$45.2/15$			3.213 ± 0.012
HiRes (Abbasi et al. 2007*a*)	$8.55/15$			3.26 ± 0.02
Global Fit (at Fly's Eye E scale)	$109.4/93$	3.02 ± 0.01	17.52 ± 0.02	3.235 ± 0.008

UHECR

1. Energy Spectrum

- Clear identification of a high energy suppression
  [the “END” (… well the “suppression”)
  of exotic/fundamental physics modeling for UHECR].

- Excellent agreement between experiments
  [“small” but important question about the energy scale].

- Physical interpretation strongly coupled to (2., 3.)
  (anisotropy + composition). [proton GZK ?]

UHECR

1. Energy Spectrum
2. Anisotropy
3. Composition

Significant Experimental Discrepancies

Auger/Hires

Confusing situation.

UHECR

1. Energy Spectrum

2. Anisotropy

3. Composition

Consistent interpretation of AUGER results is problematic.

“CRISIS” (?)

UHECR

Crucial Problem:

Galactic Extragalactic Transition

1. Maximum Energy of
   Milky Way sources

2. Power of Extragalactic CR sources

3. Shape of injection spectrum
   of extragalactic CR

Energy Spectrum
"feature"

Composition change

Isotropy effect

UHECR

Crucial Problem:

Galactic Extragalactic Transition

1. Maximum Energy of Milky Way sources

2. Power of Extragalactic CR sources

3. Shape of injection spectrum of extragalactic CR

Energy Spectrum "feature"

Composition change

Isotropy effect

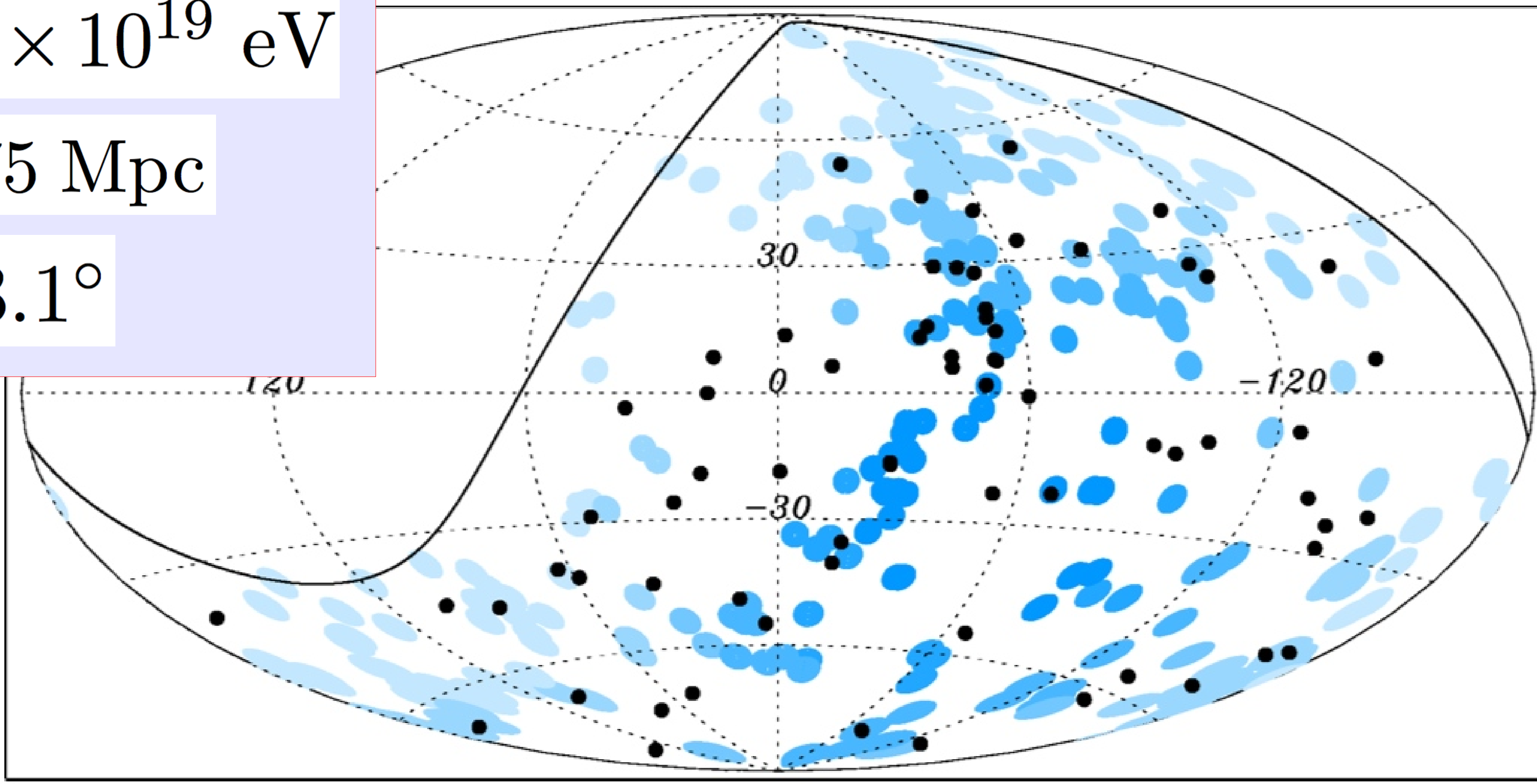
Not detected
Poorly predicted
MW large scale field

AUGER result on Correlations with the VCV AGN catalogue November 2008. Update september 2010.

6×10^{19} eV

75 Mpc

3.1°



Significant dilution
[but not disappearance]
of the statistical significance

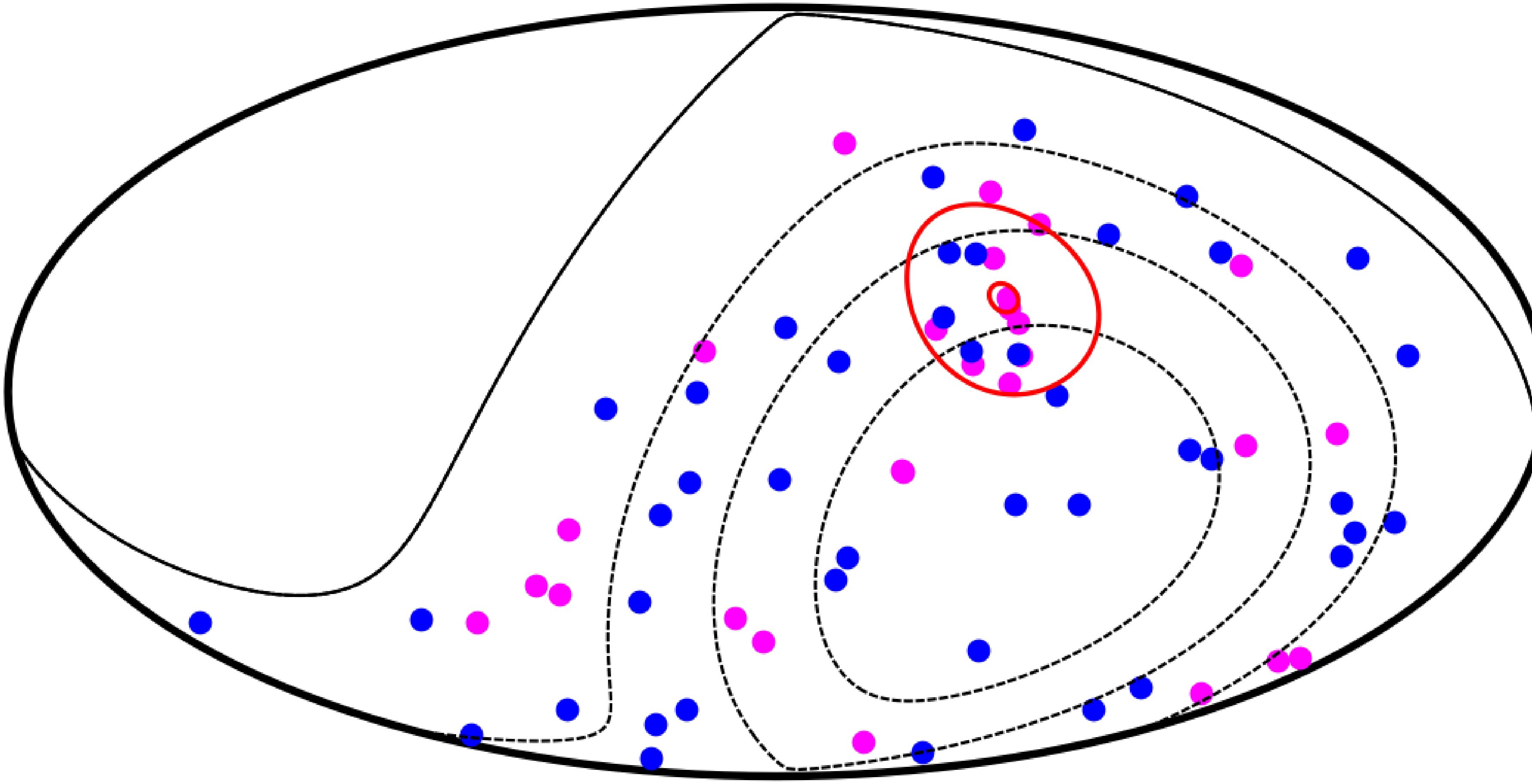
14 ev. 8 coincid. (2.9)
13 ev. 9 coincid. (2.7)
42 ev. 12 coincid.(8.8)

Discussion on CEN A

The AGN closest to us.

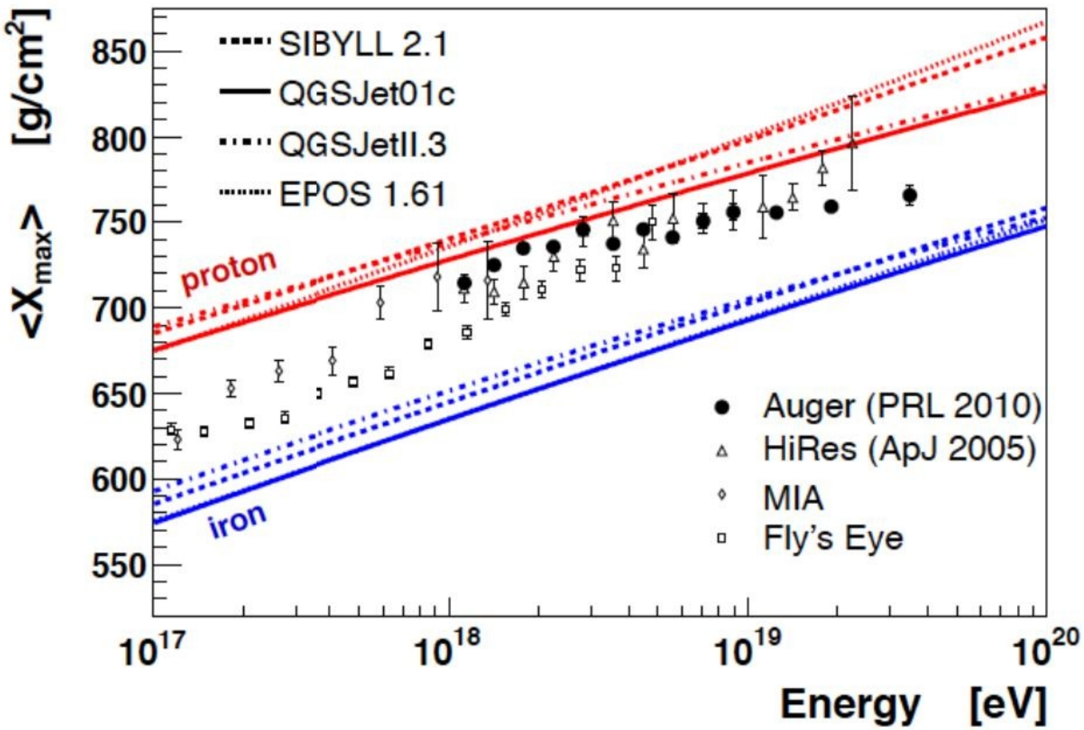
3 events within 3 degrees
8 events within 18 degrees

+0 events within 3 degrees
+5 events within 18 degrees



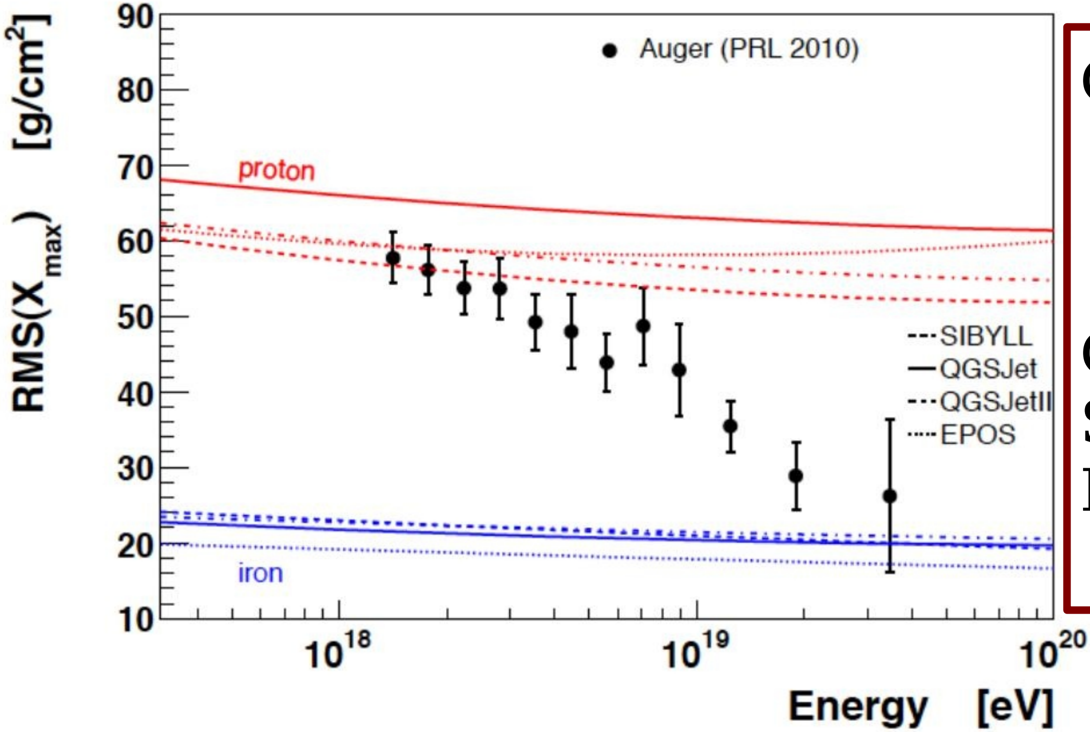
November 2008 (13 + 14 events)
Update september 2010 (+42 events)

3, 20 degrees circles



Mass Composition
becoming heavy ?
at very high energy ?

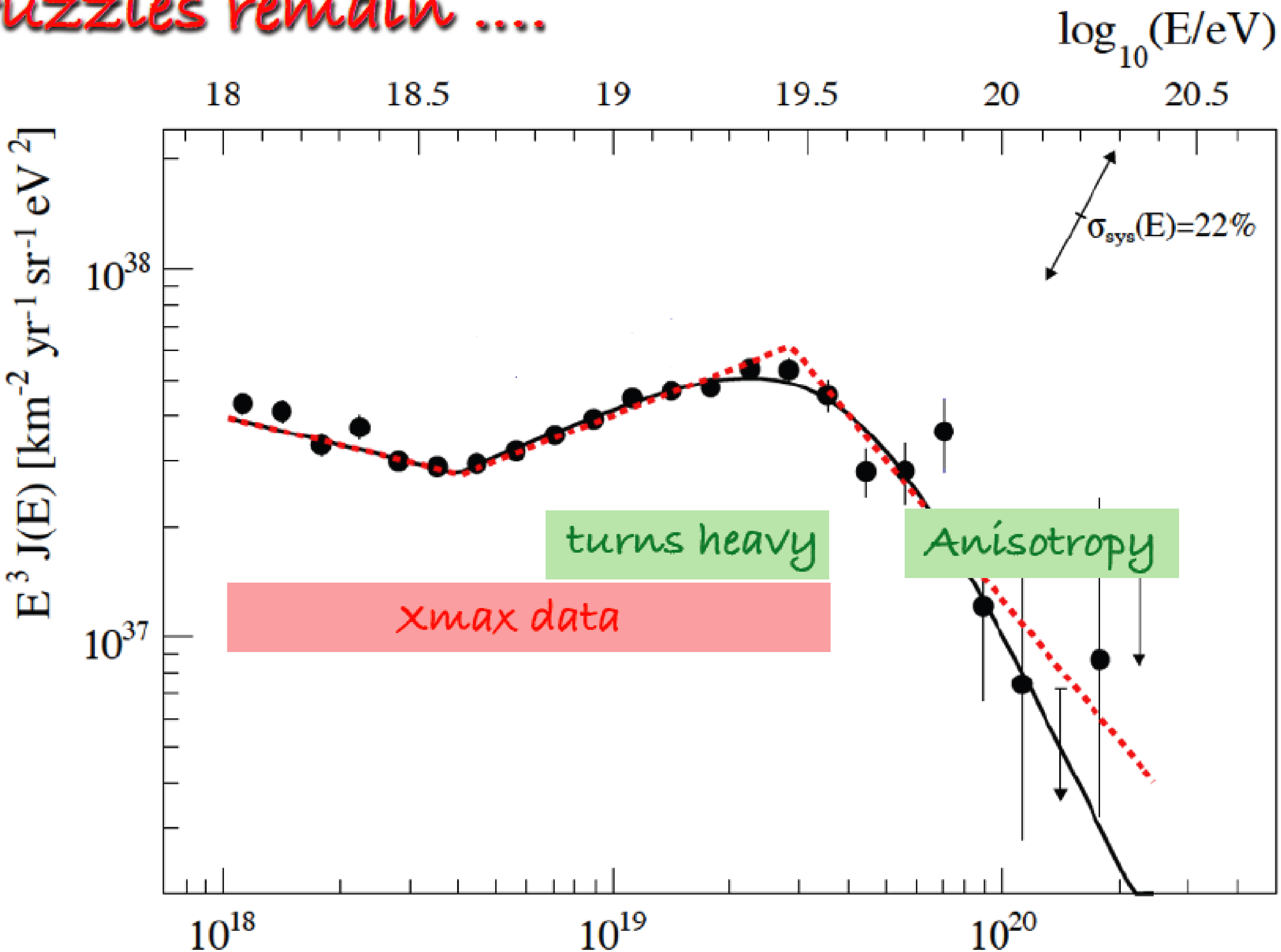
Significance would be
very important !
Constraints on the
structure and properties
of the astrophysical sources.



Observational controversy
NON confirmation
of HiRes

Correlation with sources
Small deviation in magnetic
Fields (Z < 3 ?)

Puzzles remain ....



Johannes Knapp

J. Cronin: astro-ph/0911.47141

"If these trends persist to the highest energies there would appear to be a conflict between conclusions that can be drawn from the anisotropy and the conclusions drawn from the elongation rate measurement."

"These results also demand a more careful review of what seemed to be an obvious conclusion that iron nuclei could not show an anisotropy because of galactic and perhaps extragalactic magnetic fields."

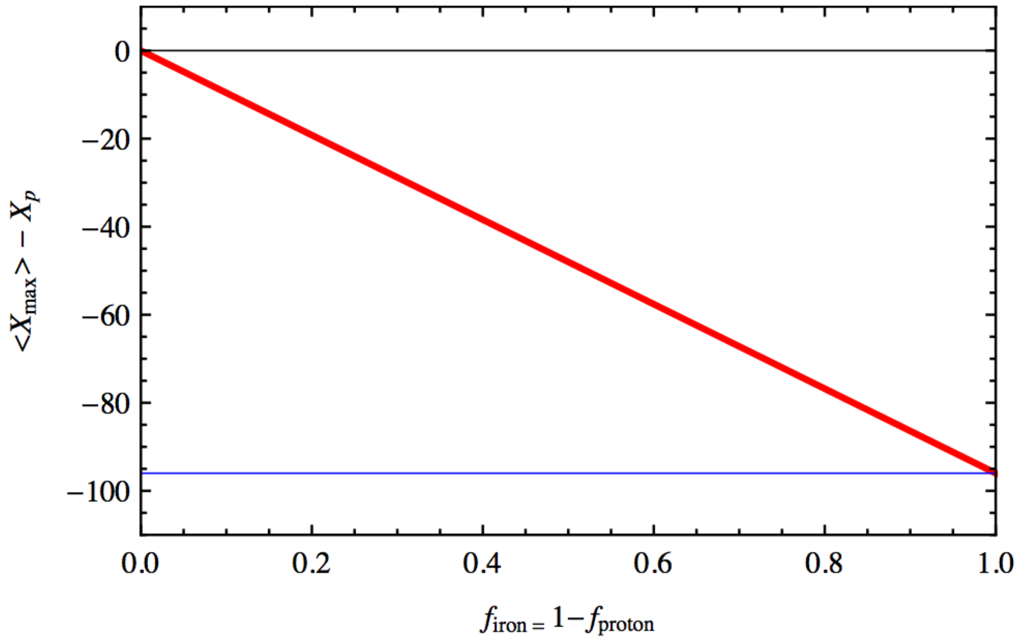
FLUCTUATIONS on $X_{\max}$

$$X_{\max} = X_{1\text{st}} + Y_{\max}$$

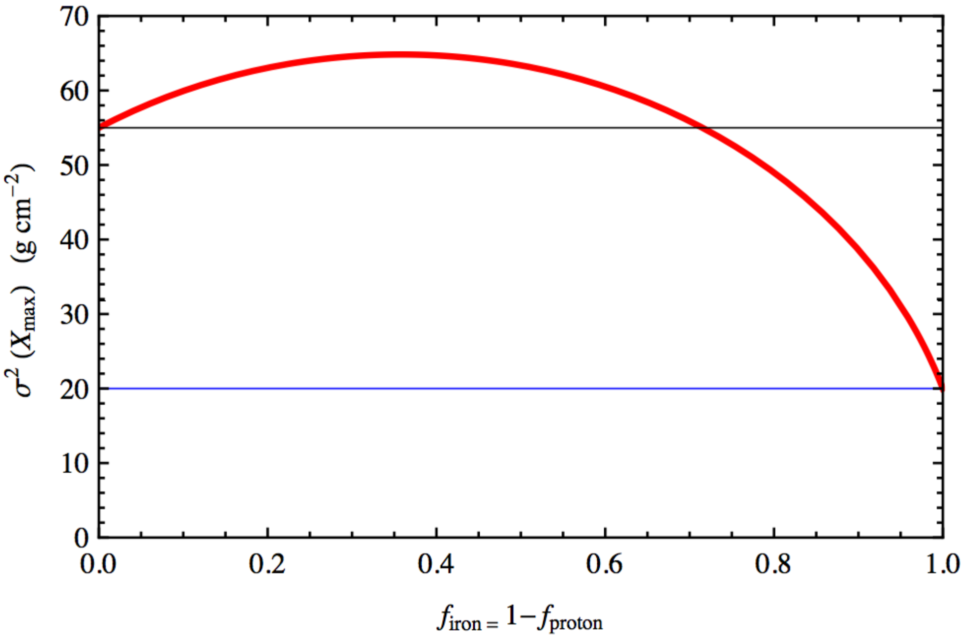
$$\sigma^2_{X_{\max}} = \sigma^2_{X_{1\text{st}}} + \sigma^2_{Y_{\max}}$$

$$\left(\sigma^{\text{proton}}_{\langle X_{\max}\rangle}\right)^2 \simeq \lambda_p^2 + \sigma^2_{Y_{\max}}$$

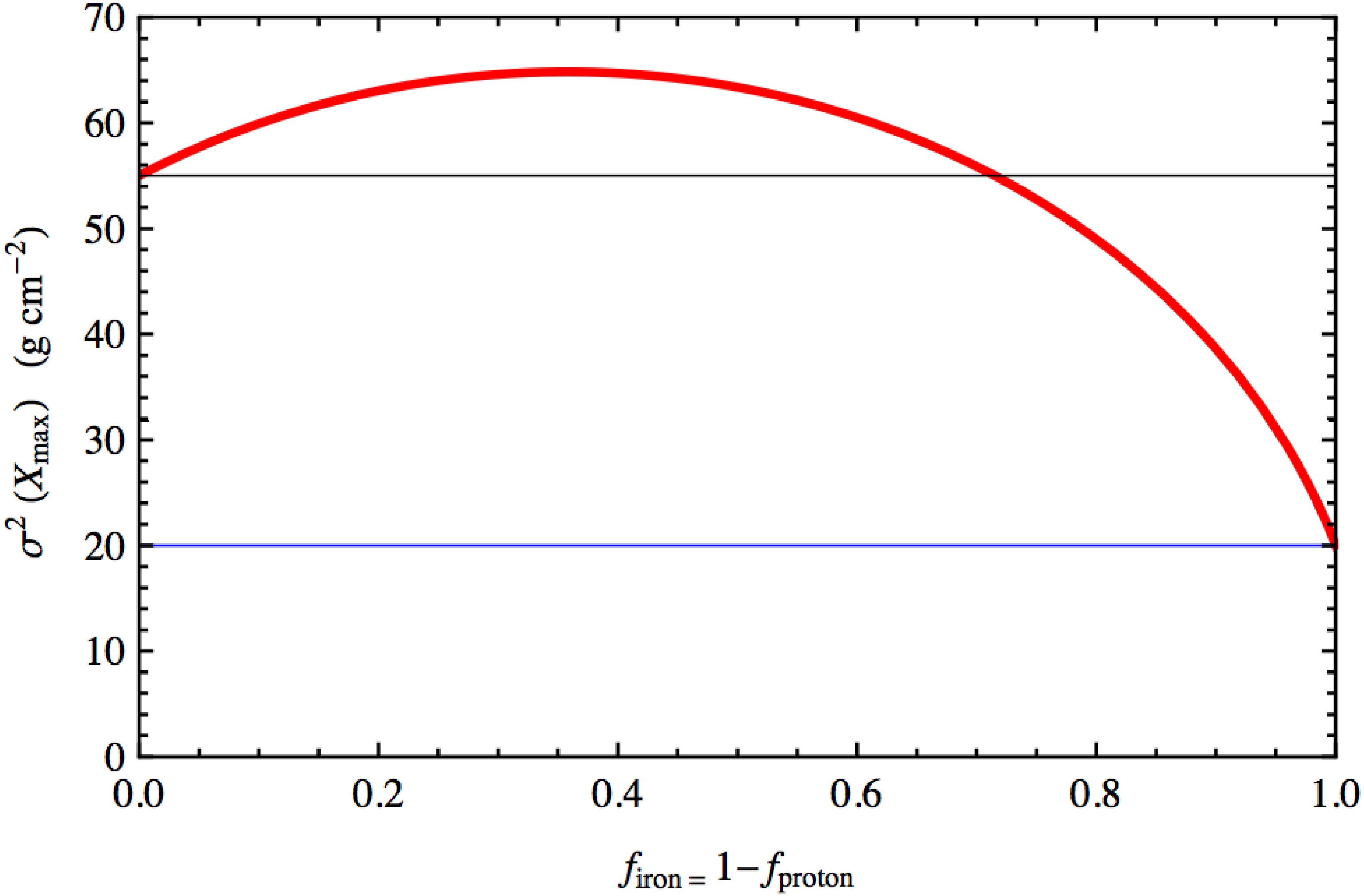
2 component model: Proton + Iron



$$\langle X_{\max}\rangle_{\rm obs} \simeq \langle X_p\rangle - D_p \, \langle \log A\rangle$$



$$\sigma_X^2 = f_p \, \sigma_p^2 + (1 - f_p) \, \sigma_{\rm Fe}^2 + f_p(1 - f_p) \, \left(\langle X_p\rangle - \langle X_{\rm Fe}\rangle\right)^2$$



70
60
50
40
30
20
10
0
0.0
0.2
0.4
0.6
0.8
1.0
$\sigma^2 (X_{max})$ (g cm^{-2})
$f_{iron} = 1 - f_{proton}$

Conclusions

2 points.

Conclusions

Particle Astrophysics is a vibrant field !
our understanding of the "High Energy Universe"
is progressing.
New Discoveries, Surprises.
We live in a good time to   do research in this field.

Conclusions

Particle Astrophysics is a vibrant field !
our understanding of the “High Energy Universe”
is progressing.
New Discoveries, Surprises.
We live in a good time to do research in this field.

In India is possible to perform “miracles”:
Finishing this building in such a short time.
Organizing this beautiful meeting.
Developing such a promising scientific activity

Ajai, Atul, …,Prabkhar,….
 ,Prasad,Pravata, …,
….. Shashi, ….,

Ajai, Atul, ...,Prabkhar,....
,Prasad,Pravata, ...,
..... Shashi, ...,

...... and

(of course and especially) SUNIL

!!!   THANKS a LOT   !!!