Astroparticle Physics at RICAP-2011

Paolo Lipari
RICAP-2011
Roma 27th may 2011

Main “Themes” (with many inter-connections) :

DARK MATTER [?]

Cosmic Rays

Gamma Astronomy [!]

Neutrino Astronomy [...]

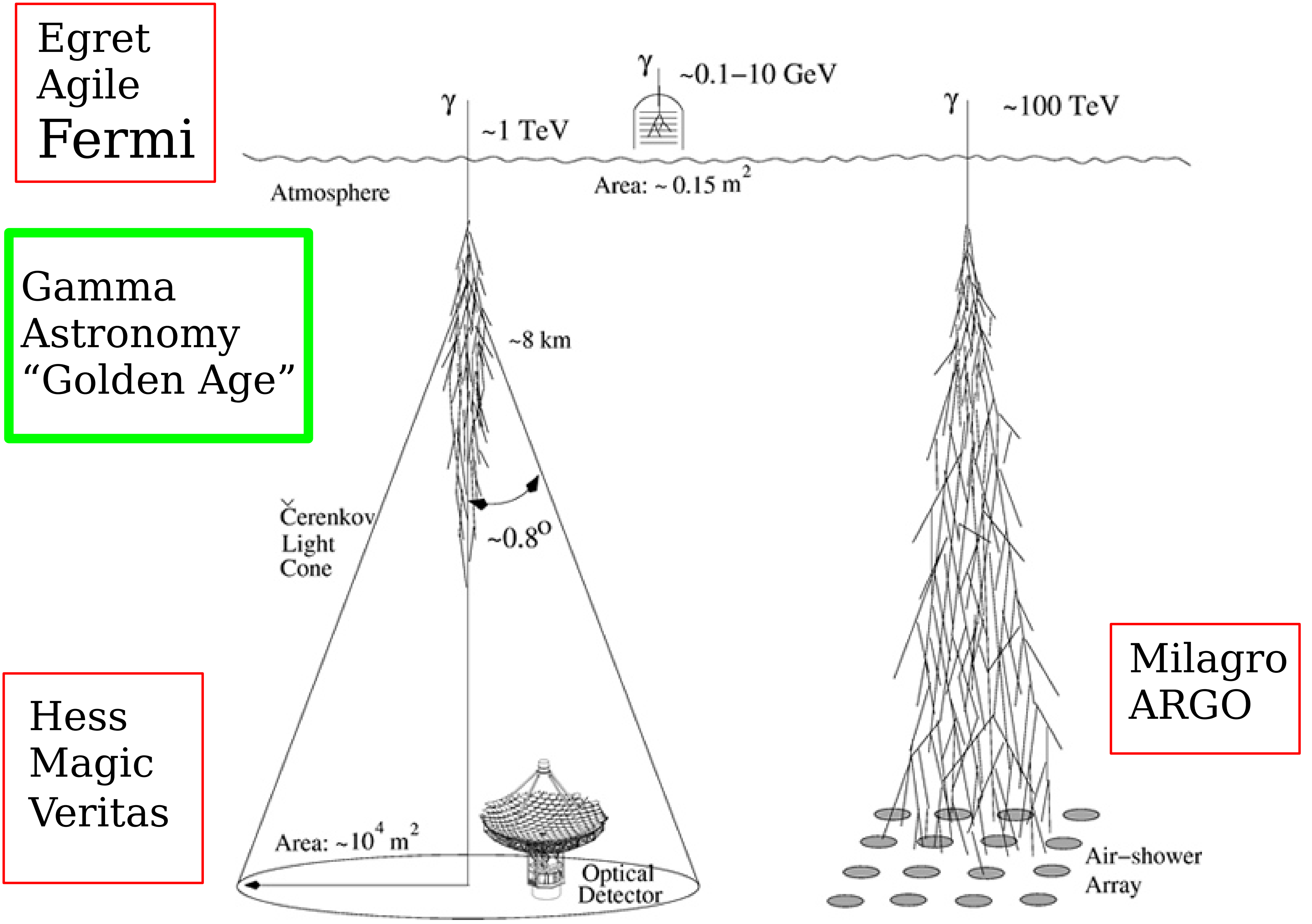
“Counter Themes”

Methods + techniques to observe and study The “High Energy Universe”

Space, Ground, Sea, Ice,.....

New “Telescopes” for gamma rays,
Neutrinos, cosmic rays

Radio, acoustic, ...


Egret
Agile
Fermi
Gamma
Astronomy
“Golden Age”
Hess
Magic
Veritas
Milagro
ARGO
γ
~0.1–10 GeV
γ
~1 TeV
γ
~100 TeV
Atmosphere
Area: ~ 0.15 m²
~8 km
Čerenkov
Light
Cone
~0.8°
Area: ~10⁴ m²
Optical
Detector
Air–shower
Array

Amazing “Beasts” in the sky

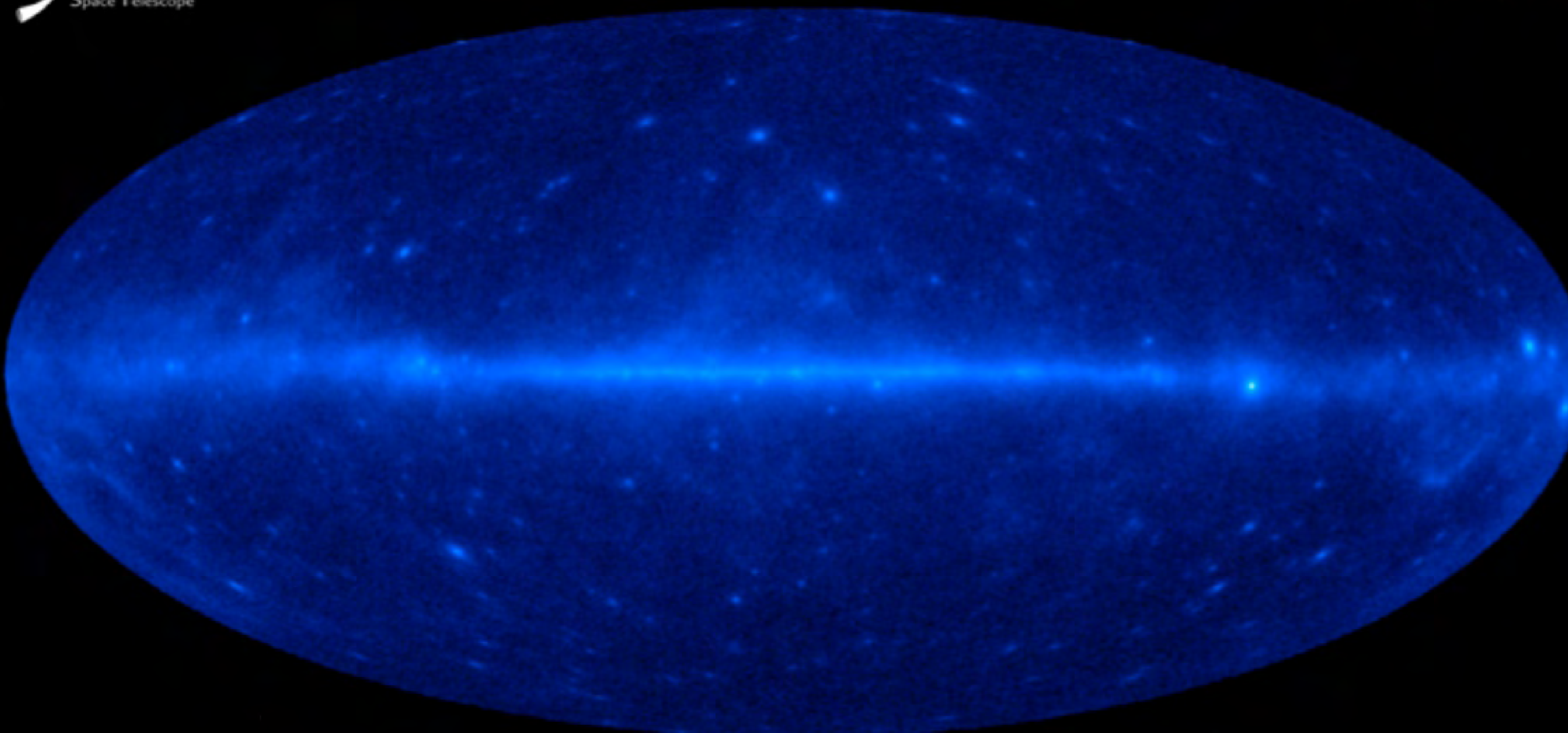
High energy astrophysical sources
and the Physical Processes that control them

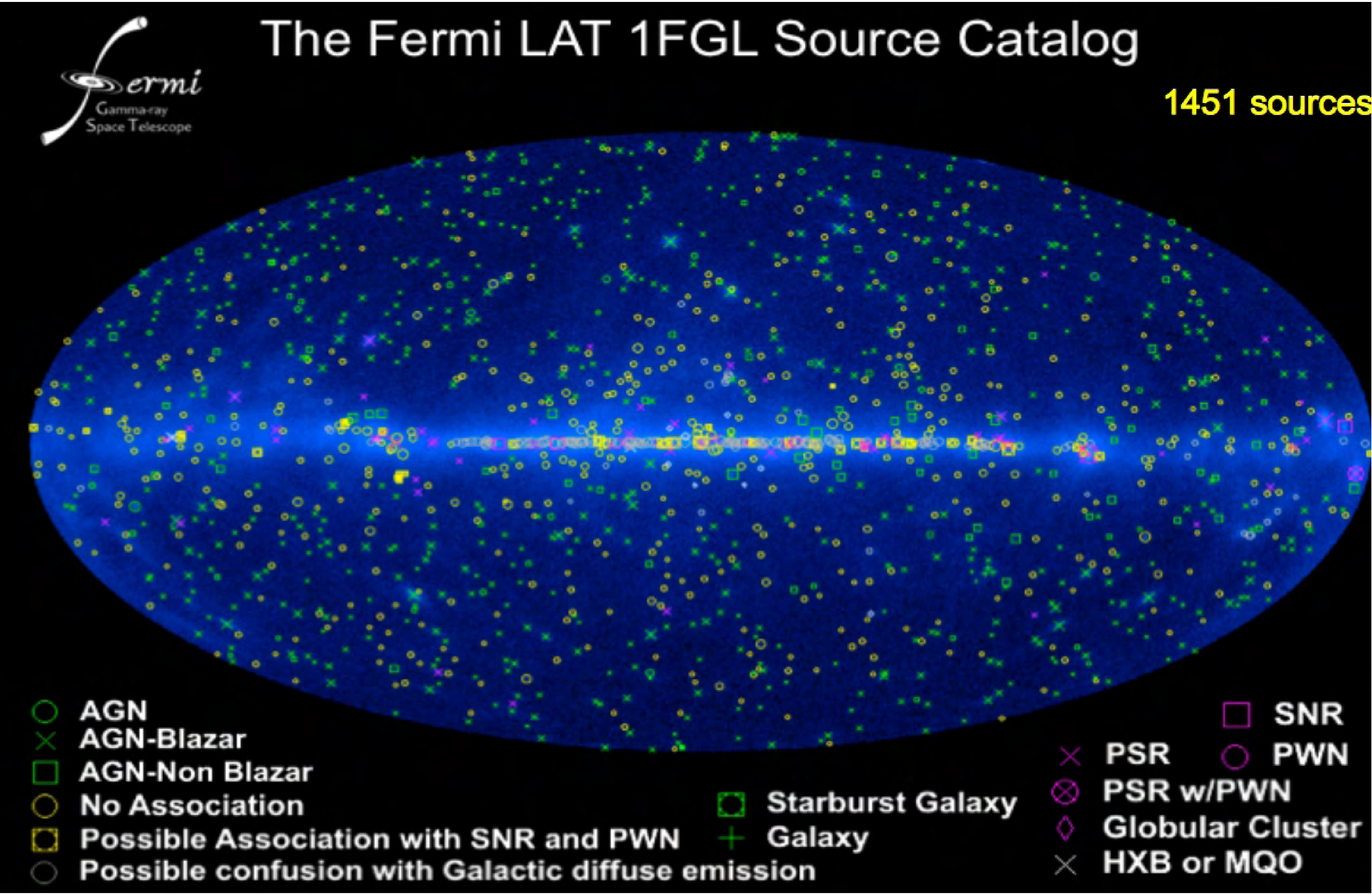
- PULSARS (PSR)
- Pulsar Wind Nebulae (PWN)
- Binary Systems
- SuperNova Remnant (SNR)
- Active Galactic Nuclei (AGN)
- Gamma Ray Bursts (GRB)
- ....novae, globular clusters, starburst galaxies, ...

The Fermi LAT 1FGL Source Catalog

Fermi Gamma-ray Space Telescope

1451 sources




The Fermi LAT 1FGL Source Catalog
fermi
Gamma-ray Space Telescope
1451 sources
AGN
AGN-Blazar
AGN-Non Blazar
No Association
Possible Association with SNR and PWN
Possible confusion with Galactic diffuse emission
Starburst Galaxy
Galaxy
SNR
PSR
PWN
PSR w/PWN
Globular Cluster
HXB or MQO

- **Towards the Second Fermi LAT Catalog 2FGL:**

Type	Number	Percentage of total
Active Galactic Nuclei	832	44%
Candidate Active Galactic Nuclei	268	14%
Unassociated	594	32%
Pulsars (pulsed emission)	86	5%
Pulsars (no pulsations yet)	26	1%
Supernova Remnants/ Pulsar Wind Nebulae	60	3%
Globular Clusters	11	< 1%
Other Galaxies	7	< 1%
Binary systems	4	< 1%
TOTAL	1888	100%

Dave Thompson

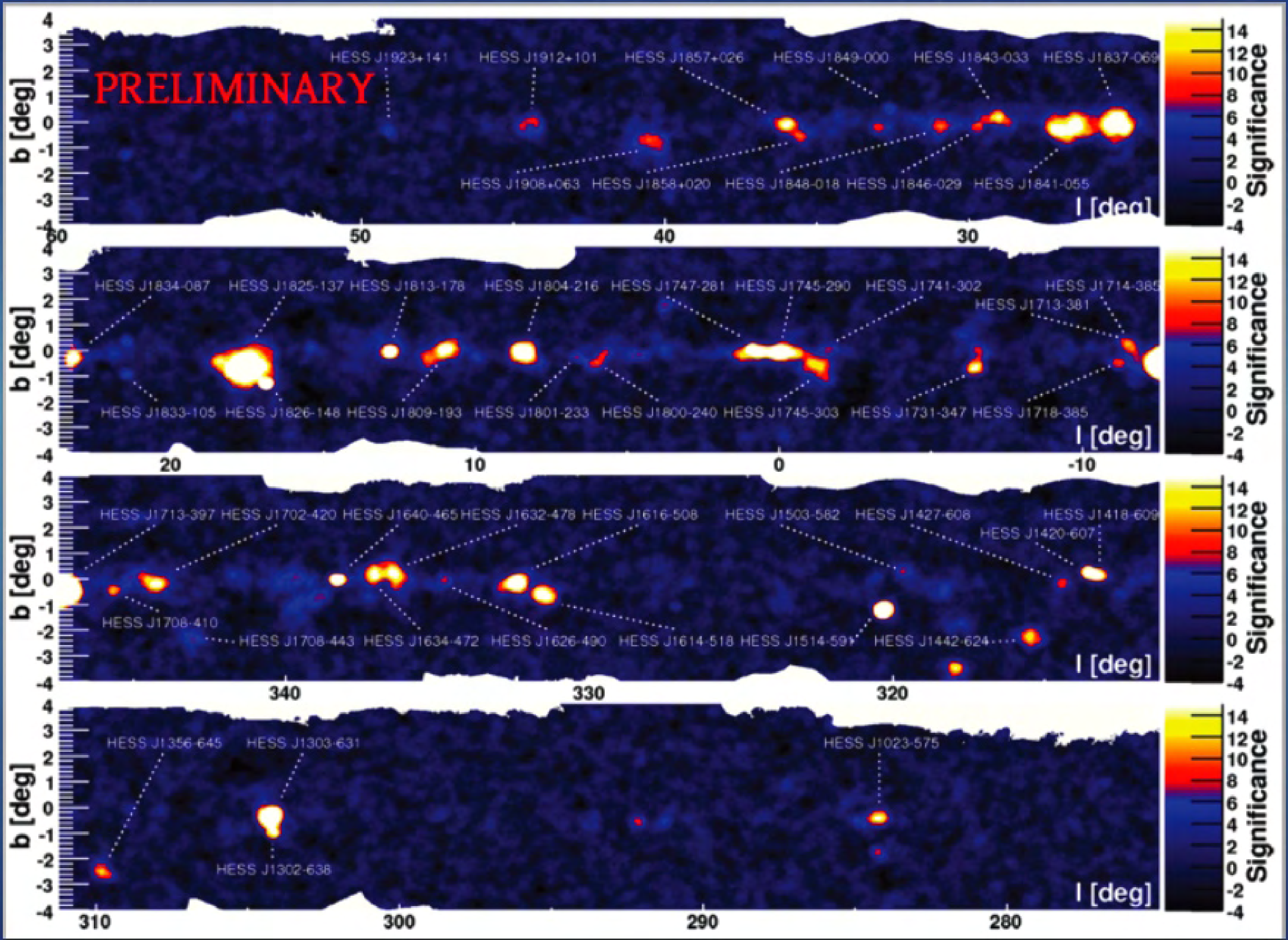
Very Preliminary - Work Still In Progress

IACT installations: the Key Players

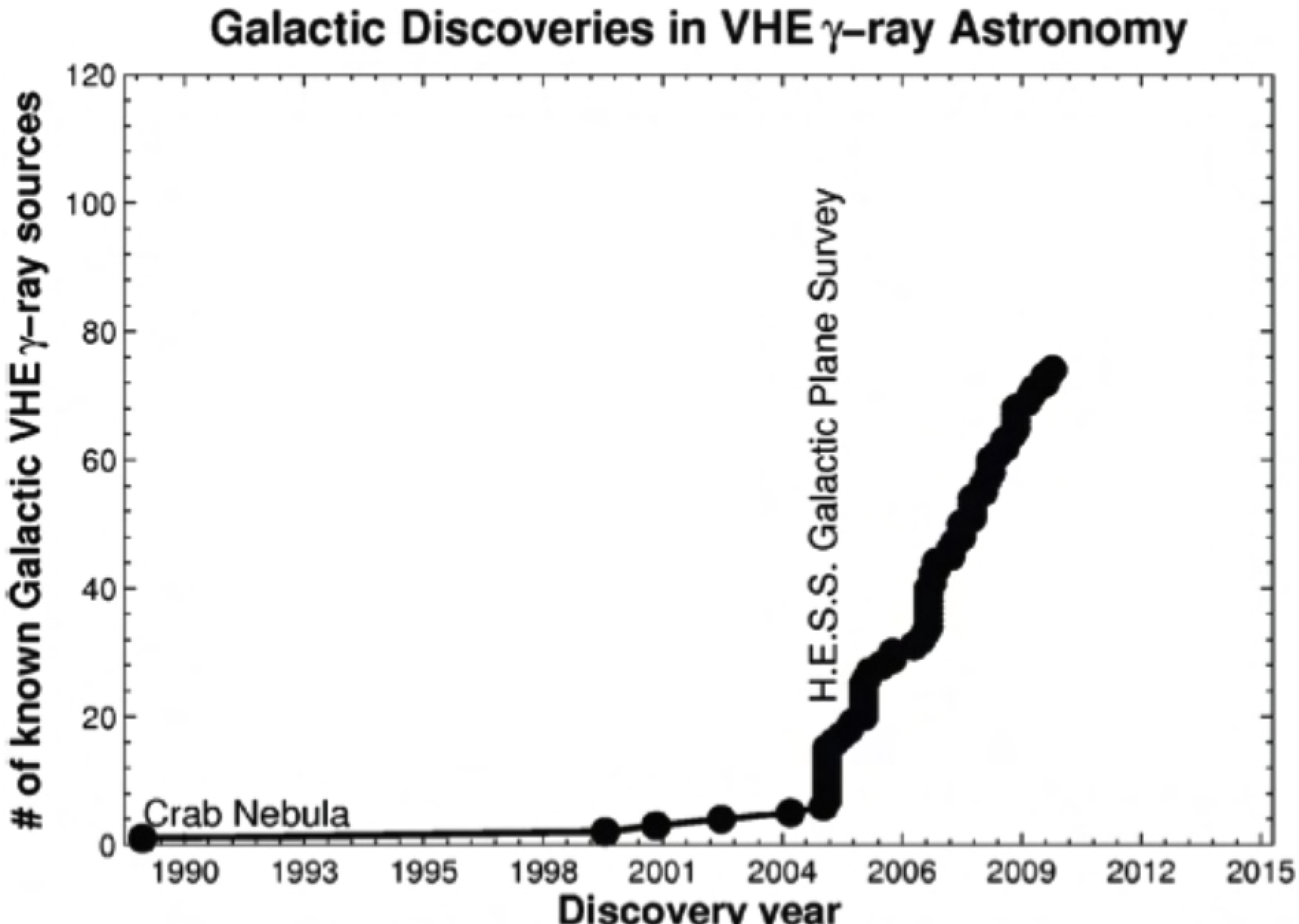
IACT installations: the Key Players

HESS Galactic Plane Scan

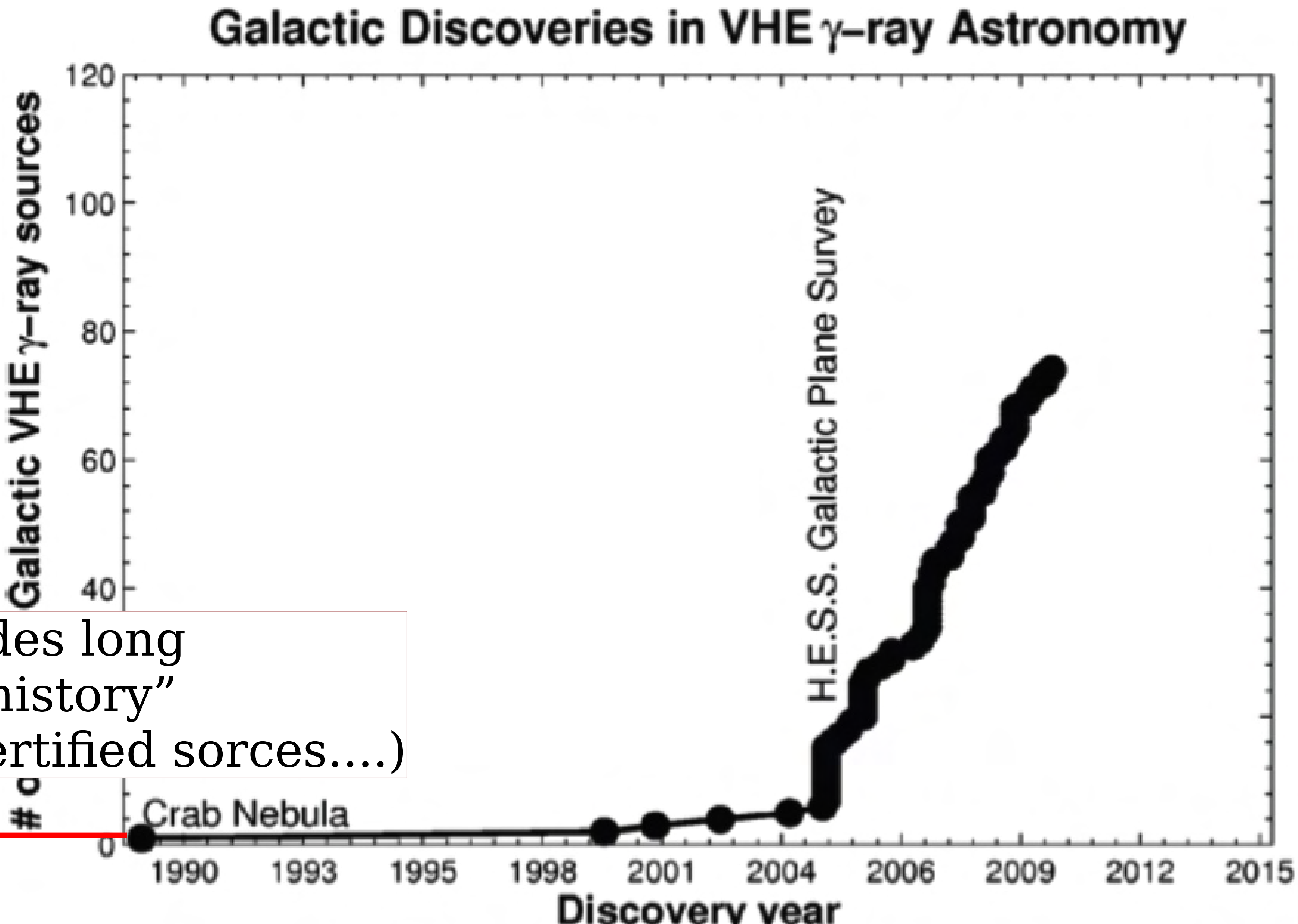
Eger, HESS galactic observations
Thu parallel



“History” of a new Field:



“History” of a new Field:

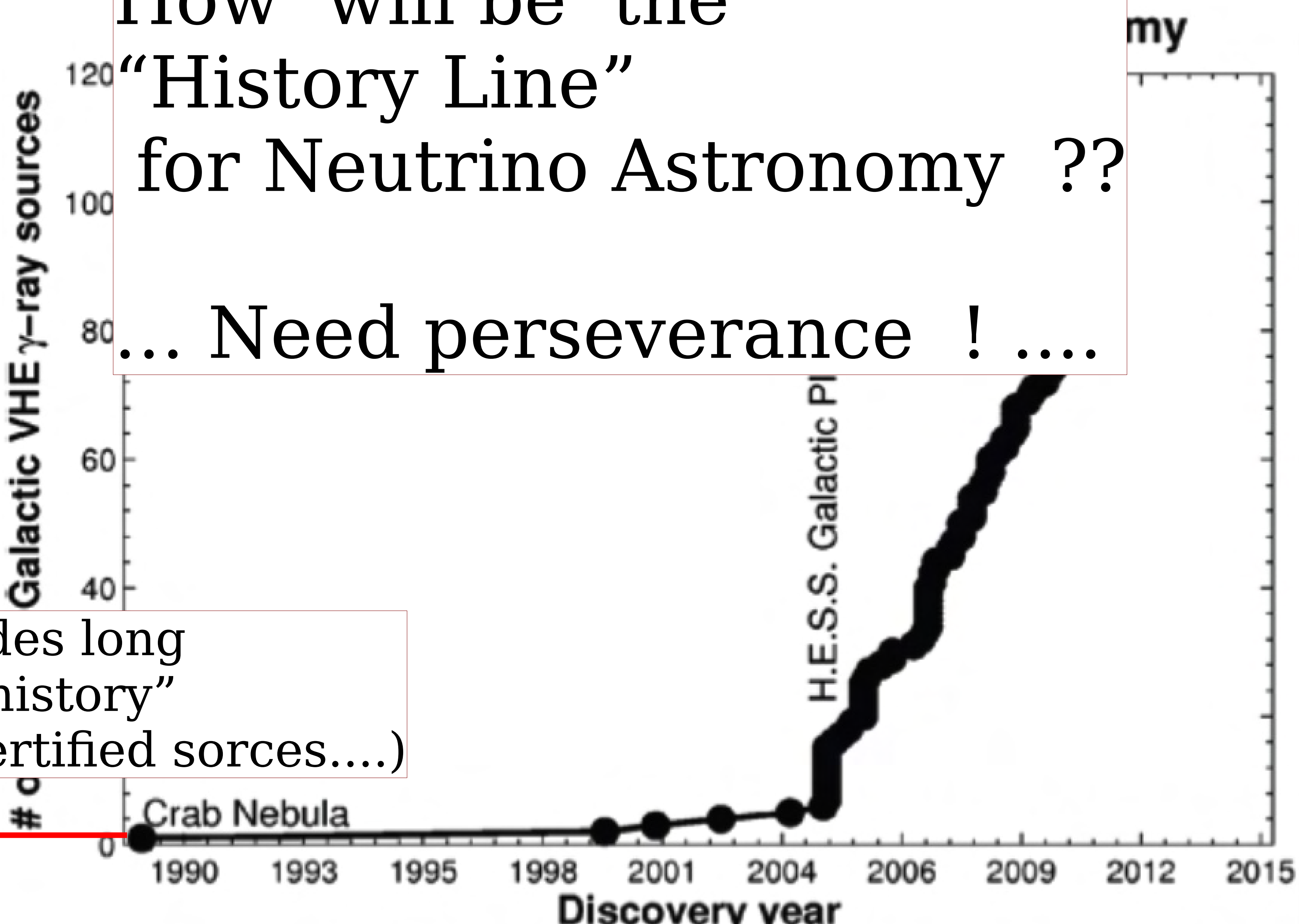


Decades long
“Pre-history”
(no certified sorces....)

“History” of a new Field:

How will be the “History Line” for Neutrino Astronomy ??

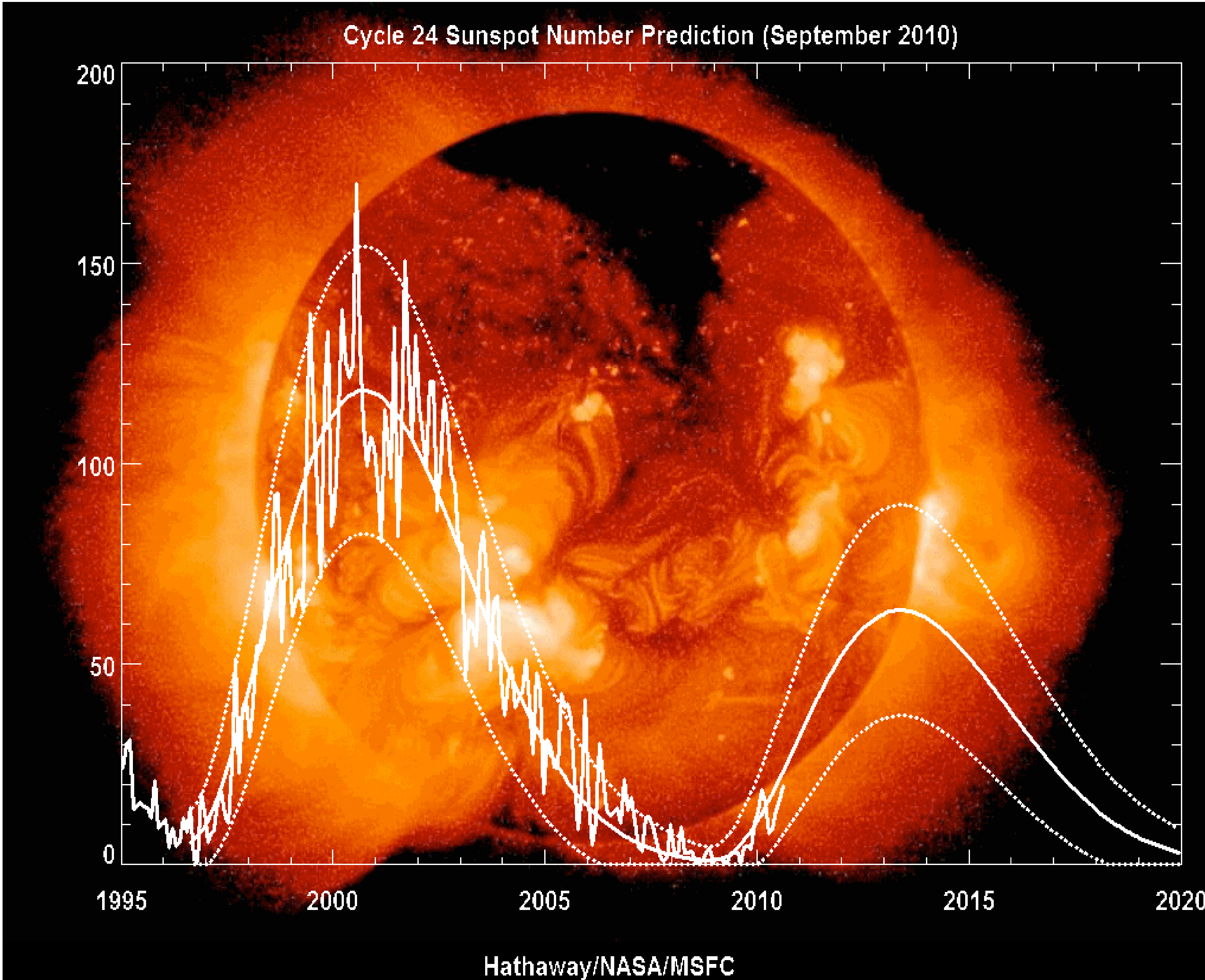
… Need perseverance ! ….



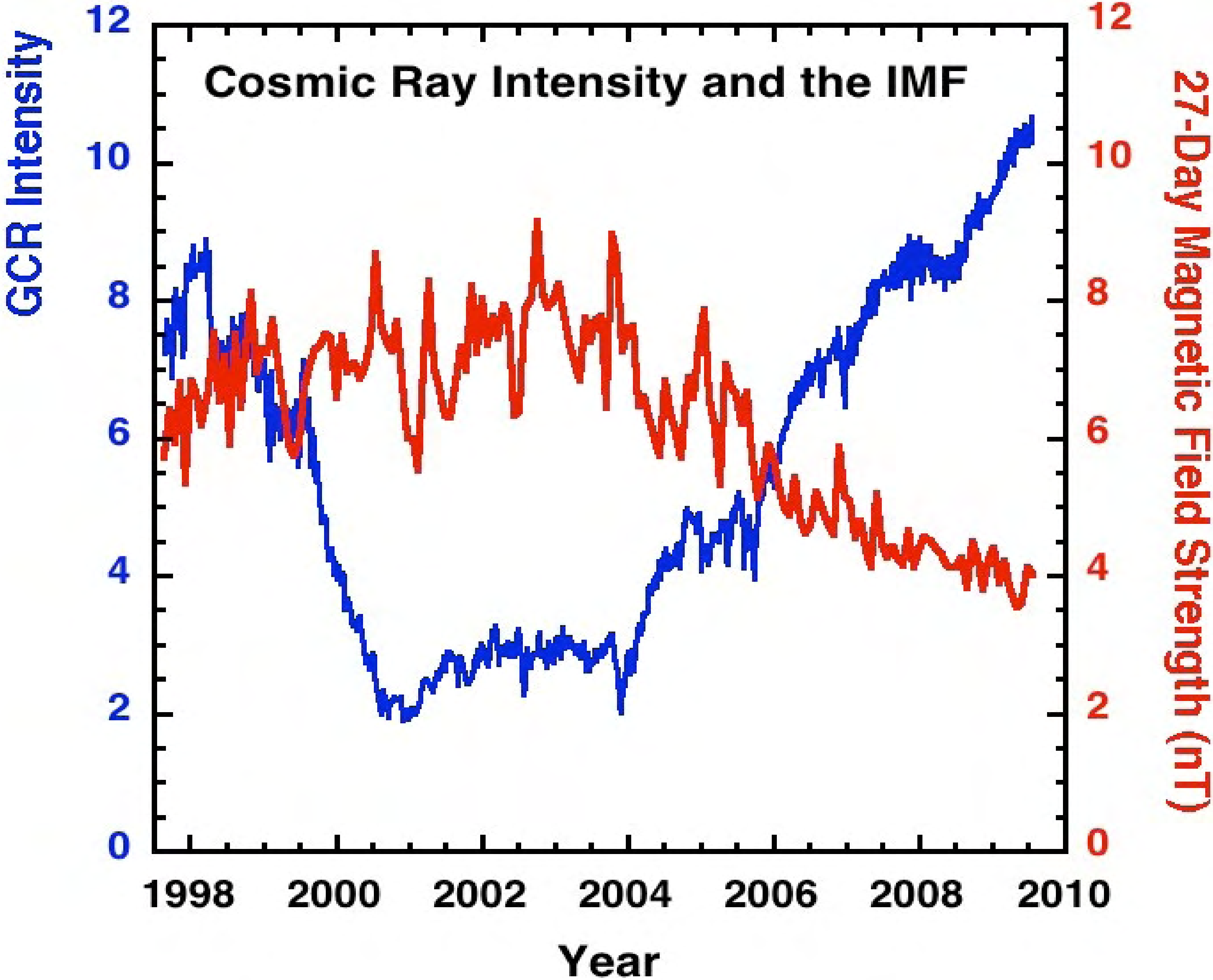
Decades long “Pre-history” (no certified sorces….)

The SUN

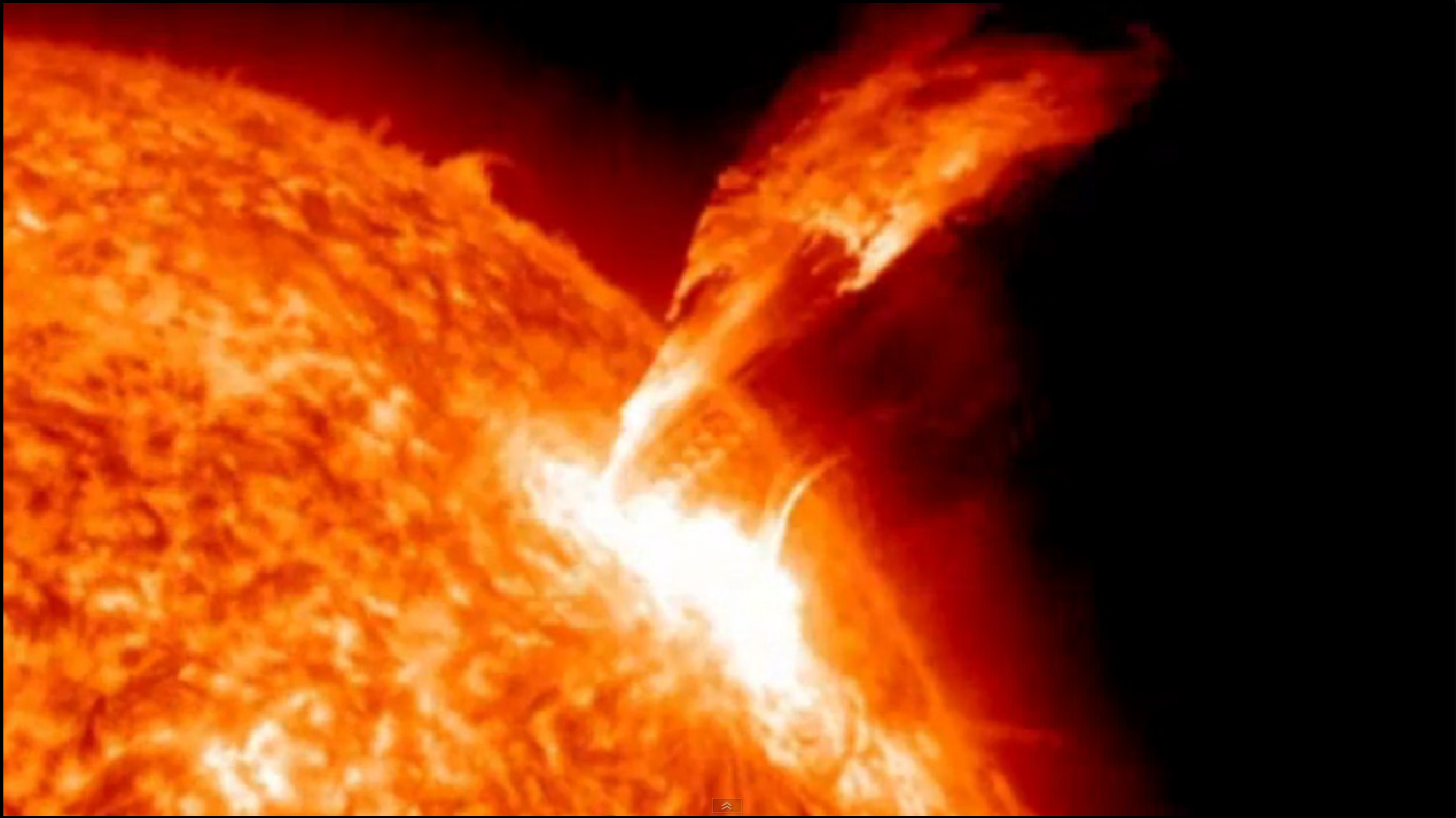
as a “laboratory” for CR Acceleration and Transport



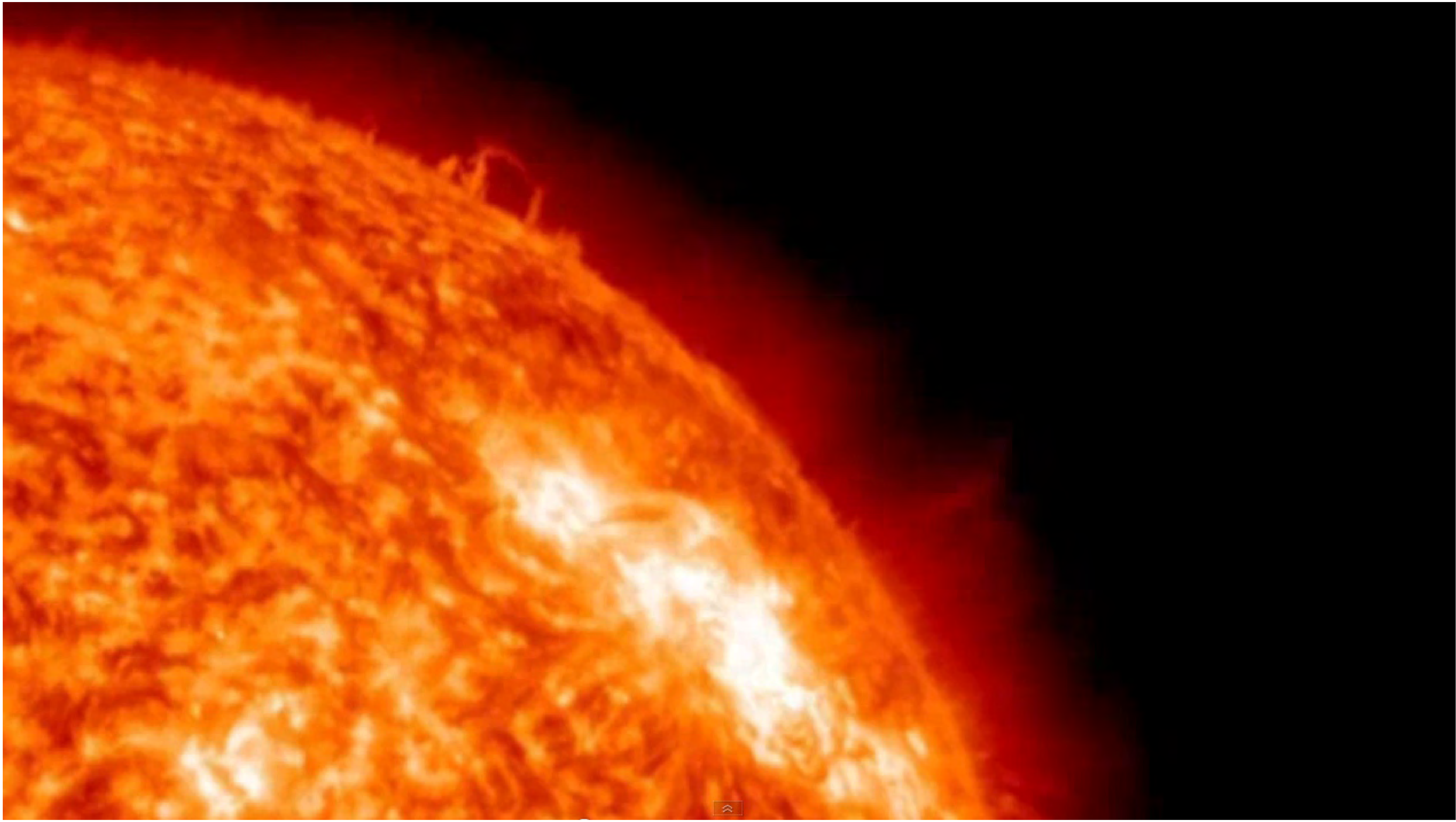
Cycle 24 Sunspot Number Prediction (September 2010)
200
150
100
50
0
1995
2000
2005
2010
2015
2020
Hathaway/NASA/MSFC

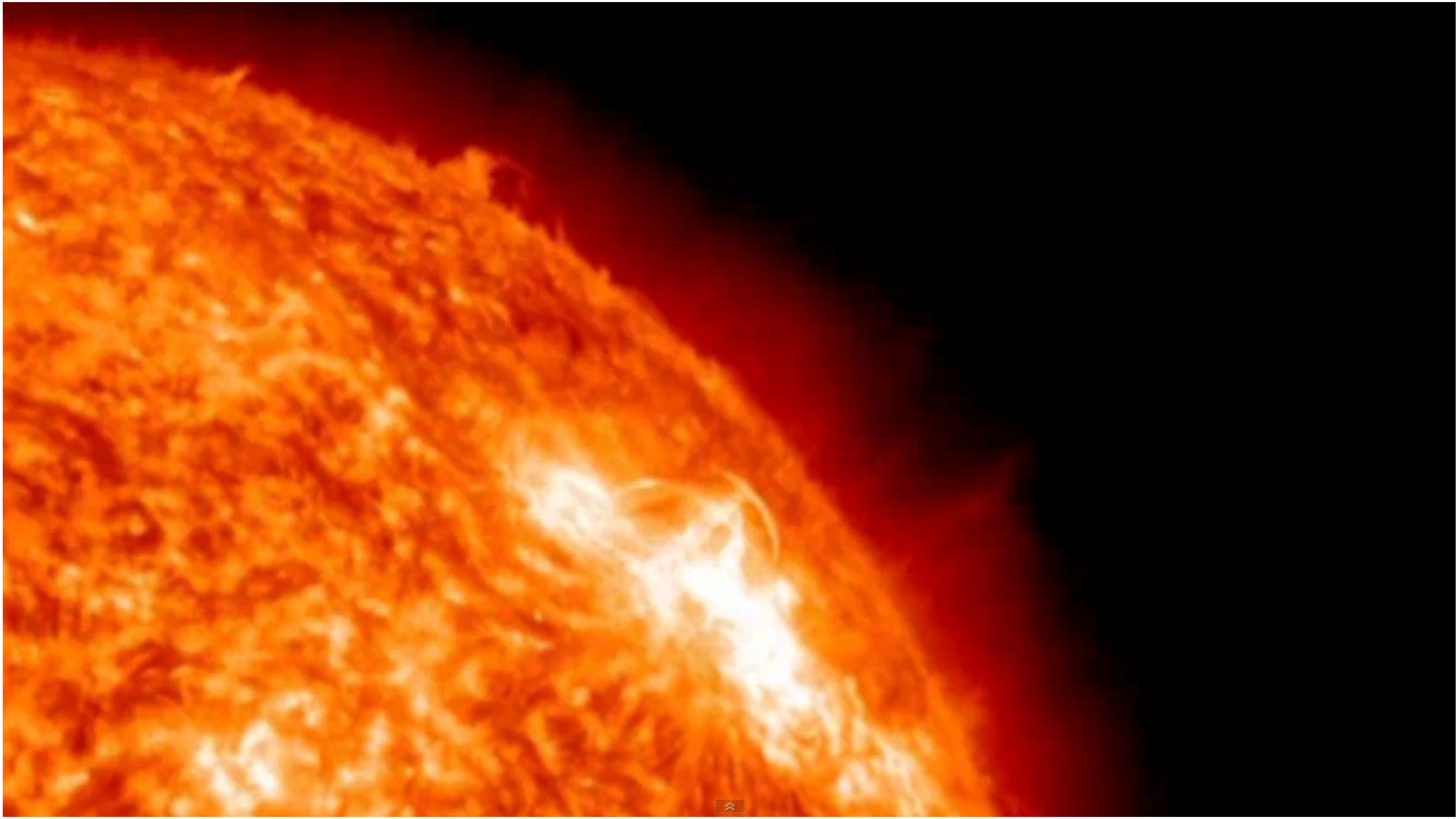


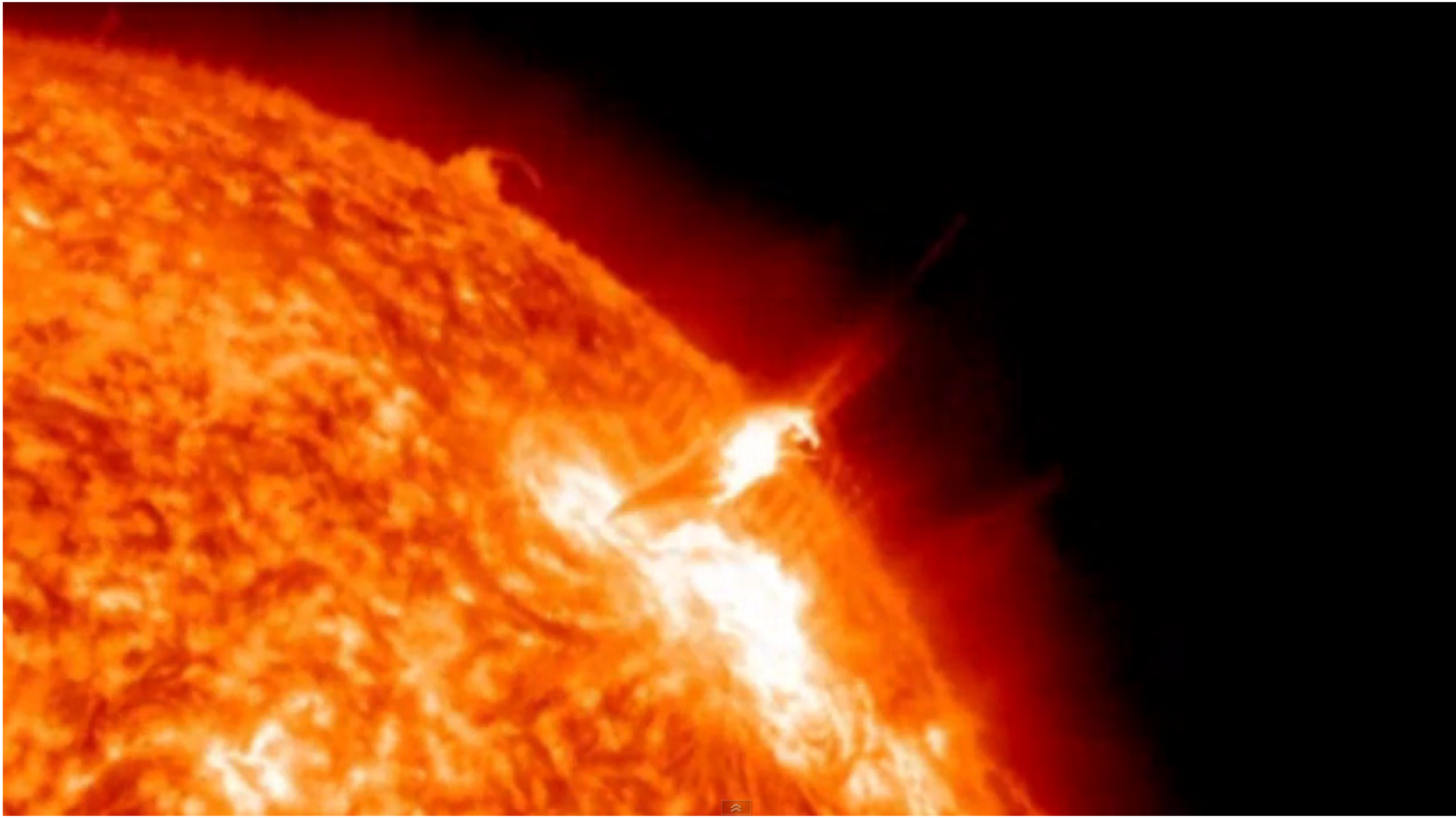
Cosmic Ray Intensity and the IMF
GCR Intensity
27-Day Magnetic Field Strength (nT)
Year
0
2
4
6
8
10
12
1998
2000
2002
2004
2006
2008
2010

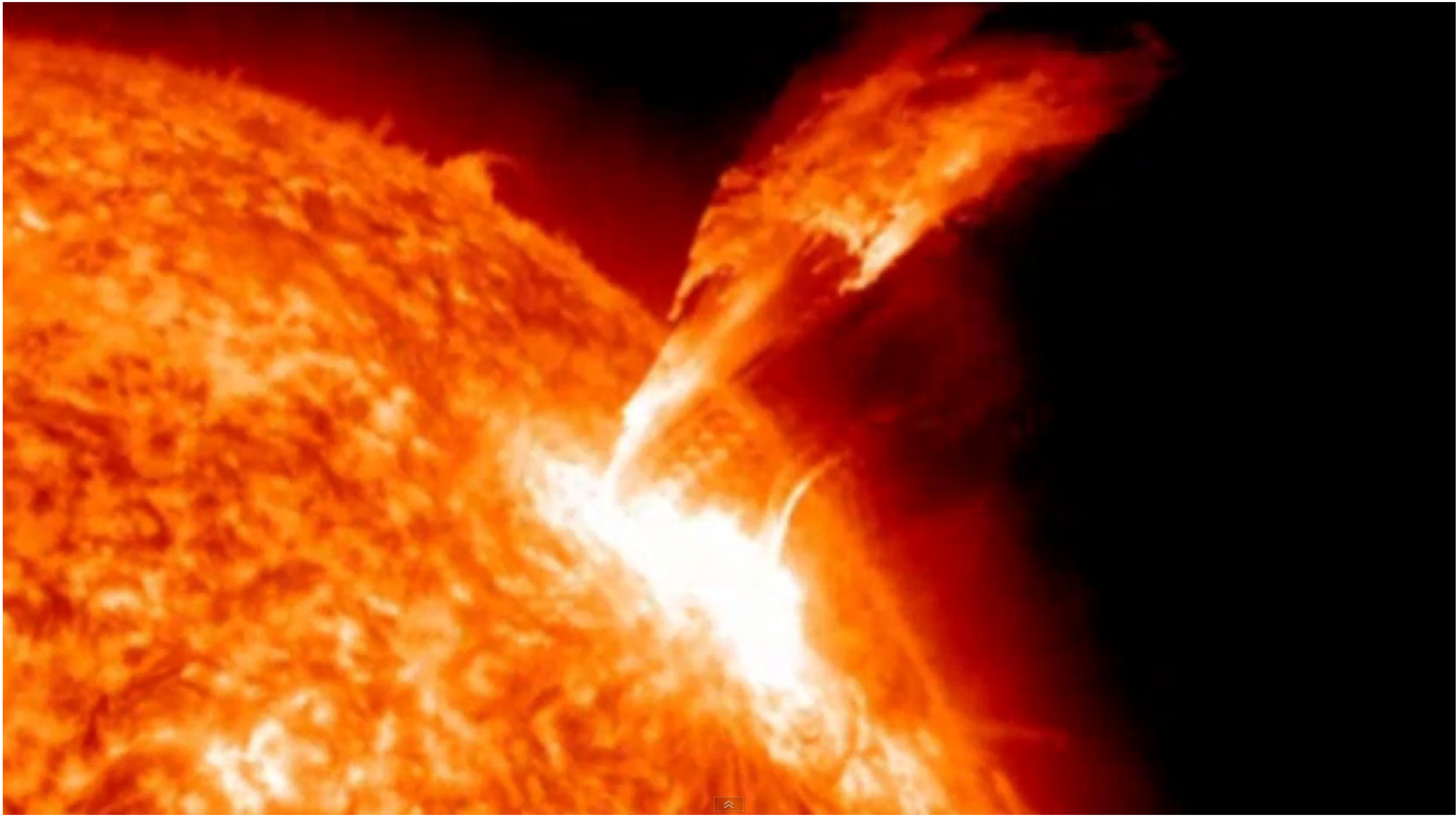


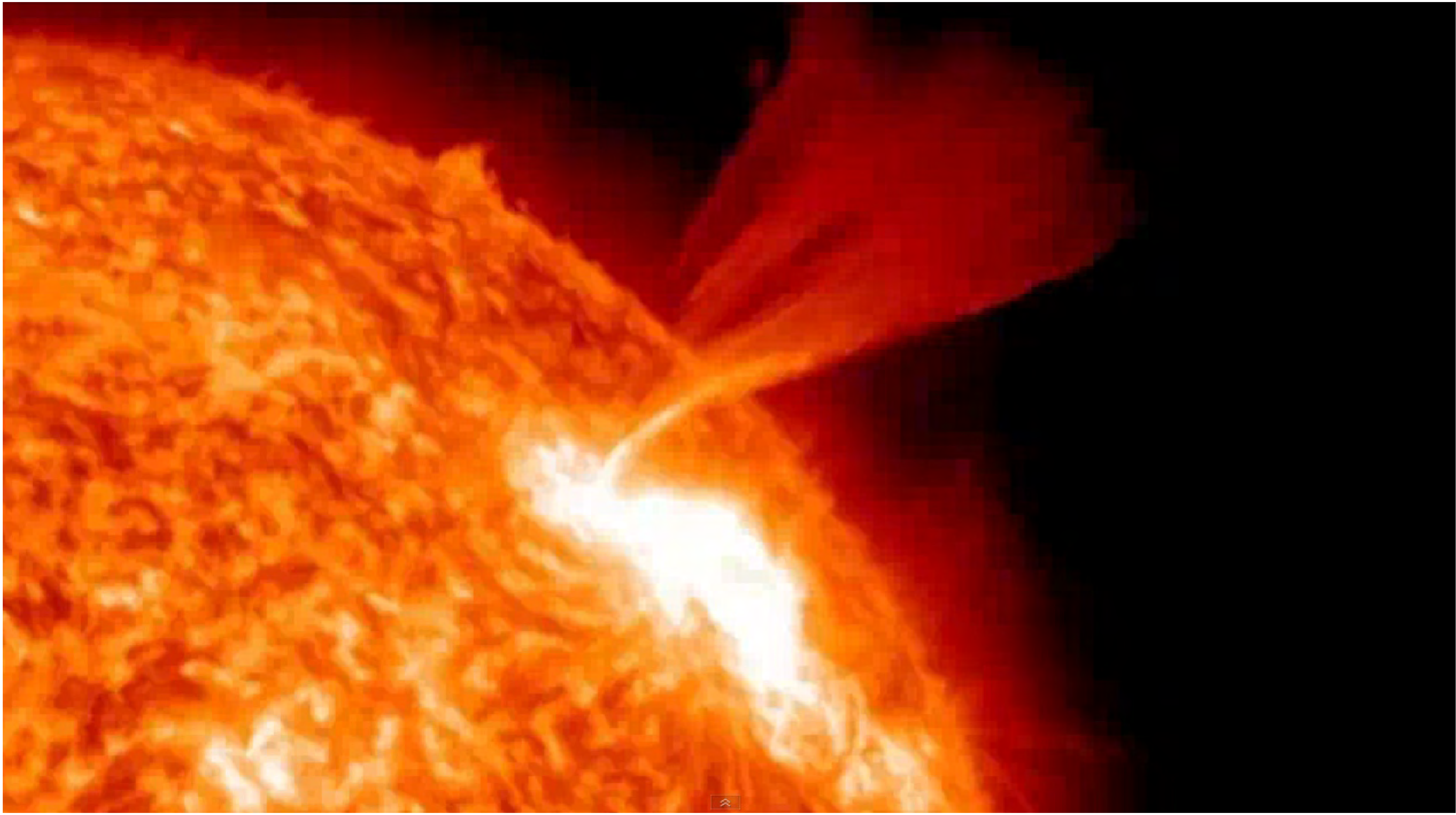
7th march 2011. 20:02 UT

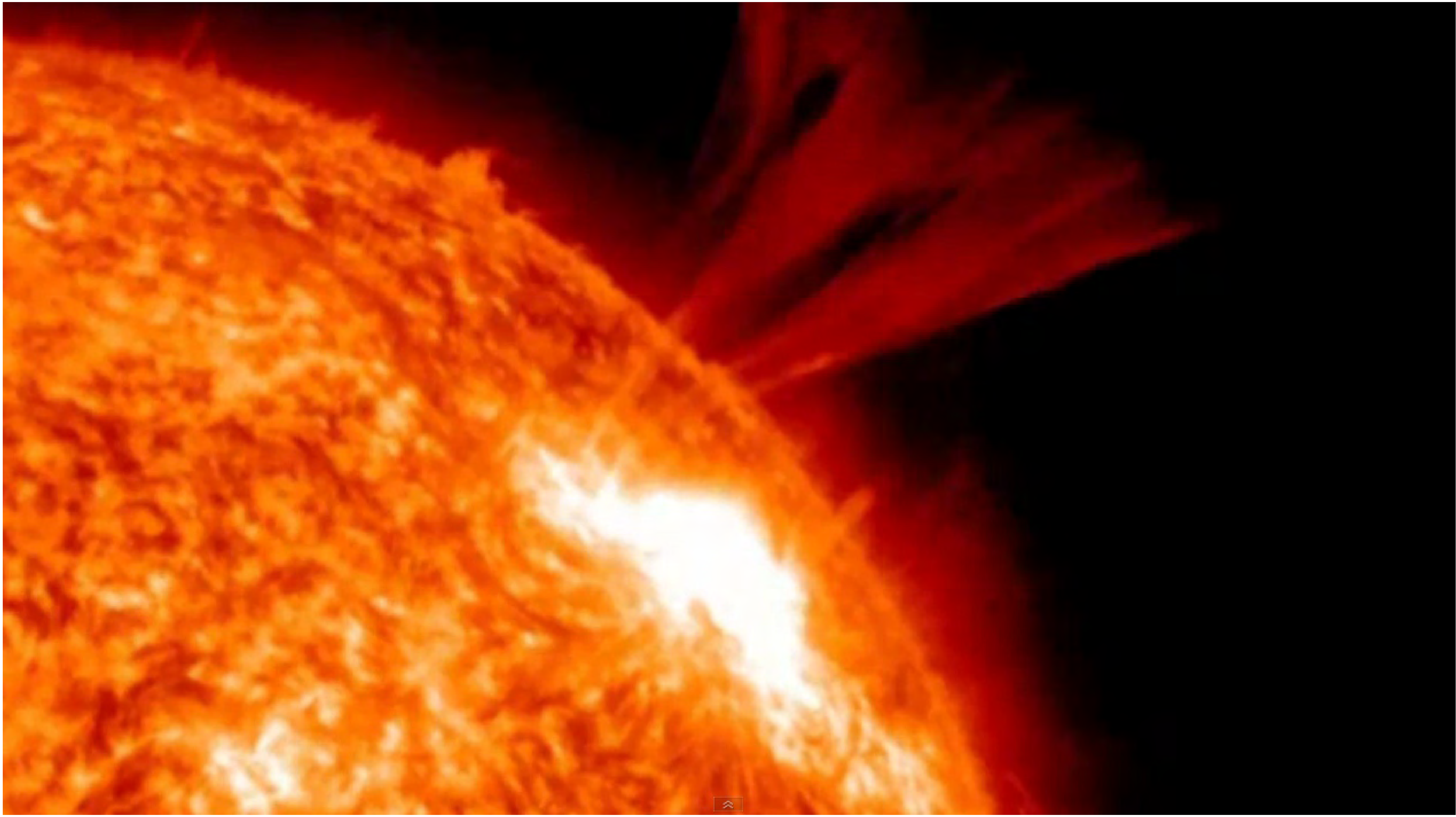






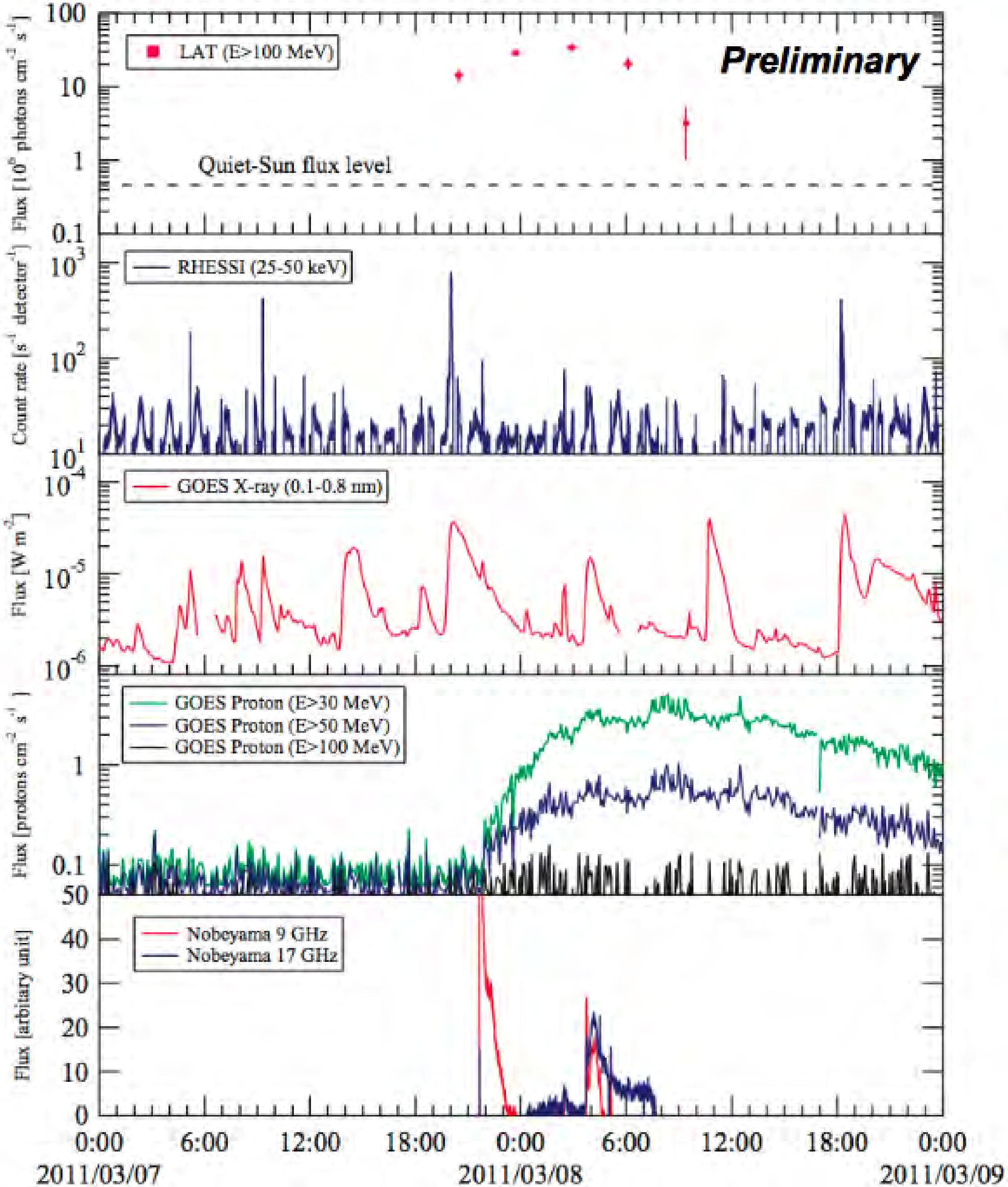






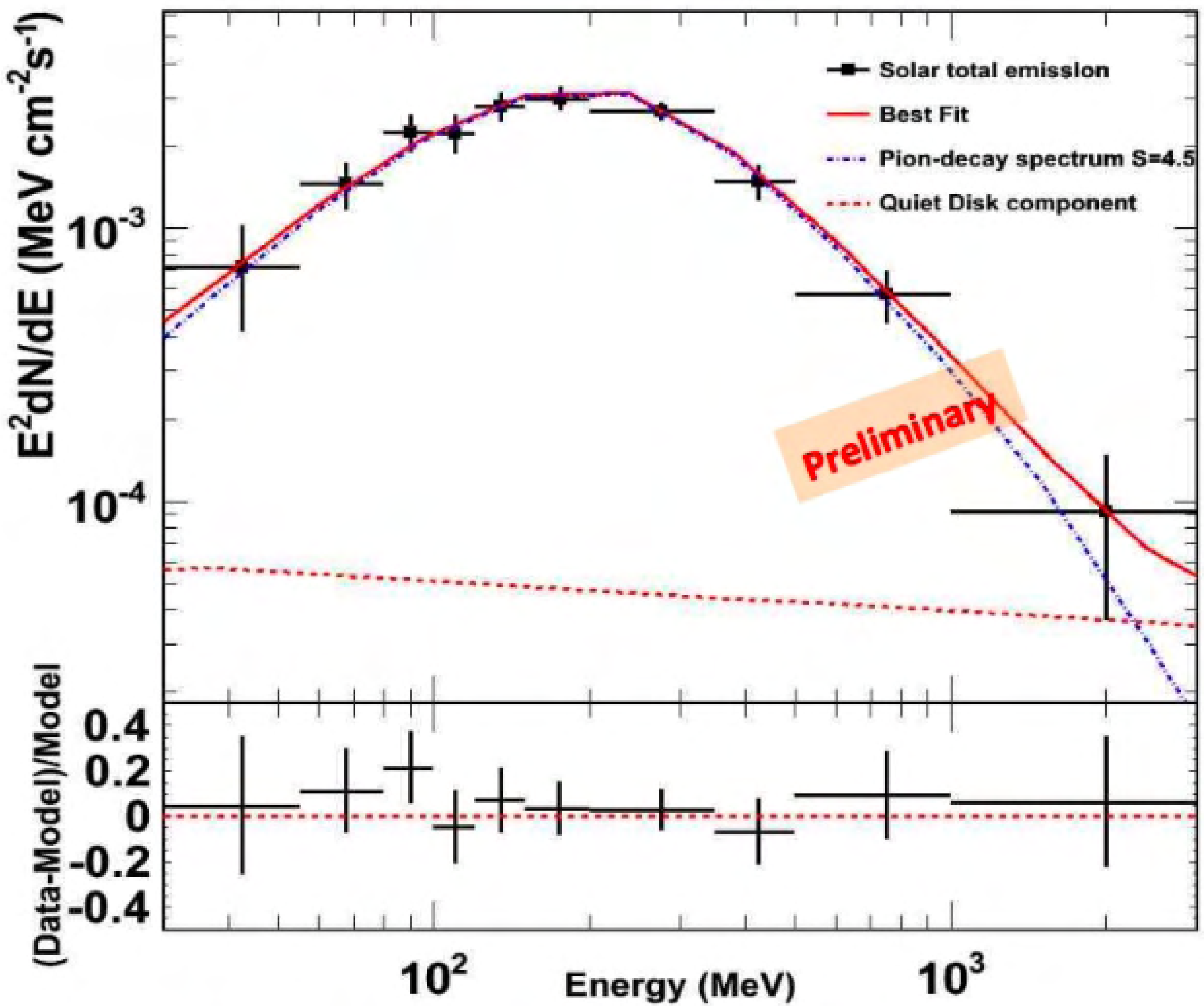

This aurora image was taken on March 10, 2011 by Zoltan Kenwell near Edmonton, Alberta, Canada.
©2011 Zoltan Kenwell

Multi-wavelength light curve



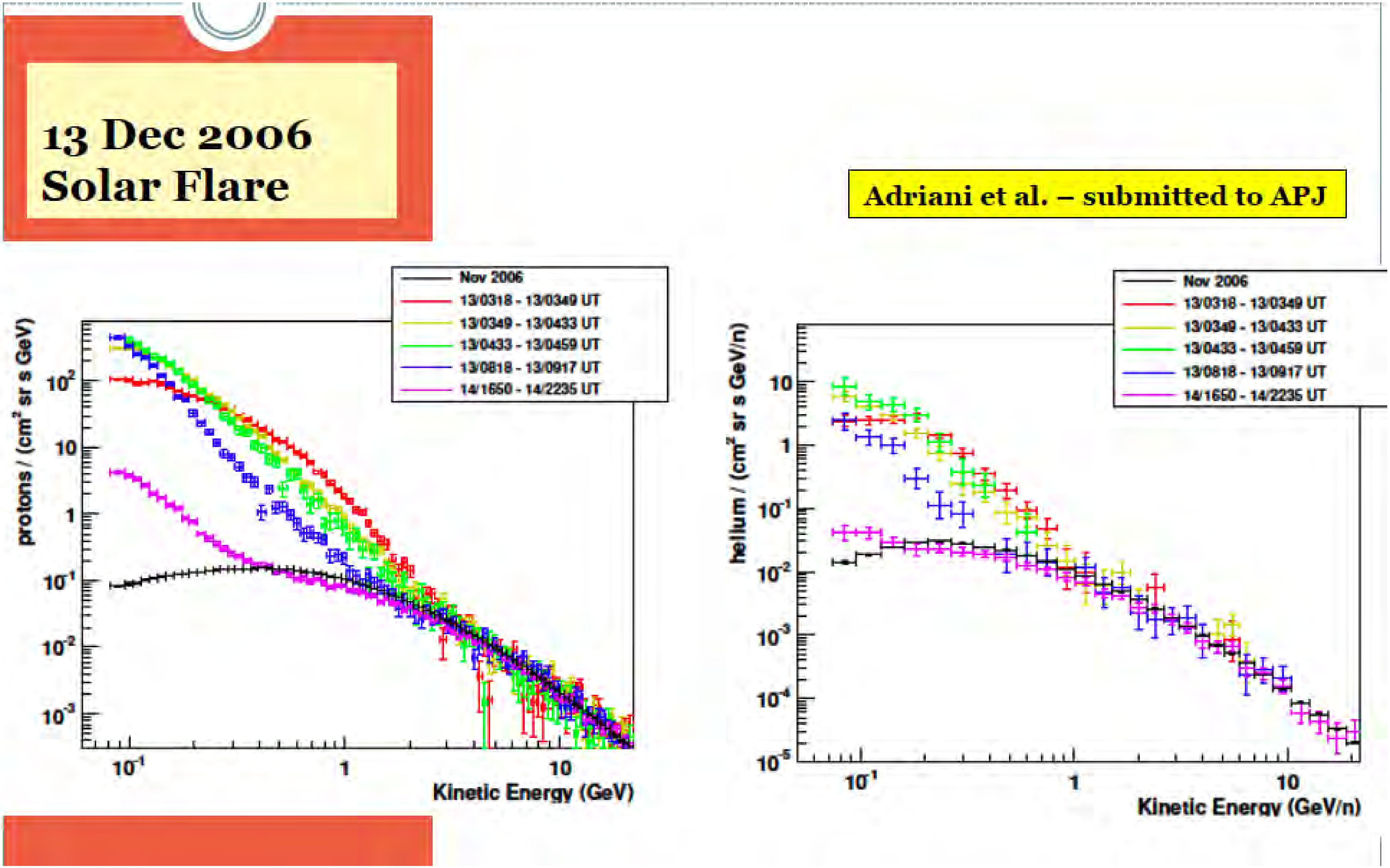
- Following M3.7 flare at ~20 UT on March 7, Fermi-LAT detected long-lasting HE emission over ~12 hours
- LAT flux showed clear rising profile
- No corresponding long-lasting enhancements were seen in hard X-ray (RHESSI), soft X-ray (GOES), and radio (Nobeyama) bands
- GOES proton monitor at 1AU detected solar energetic protons above 50 MeV, suggesting that CME-driven shock indeed accelerated protons

LAT spectrum

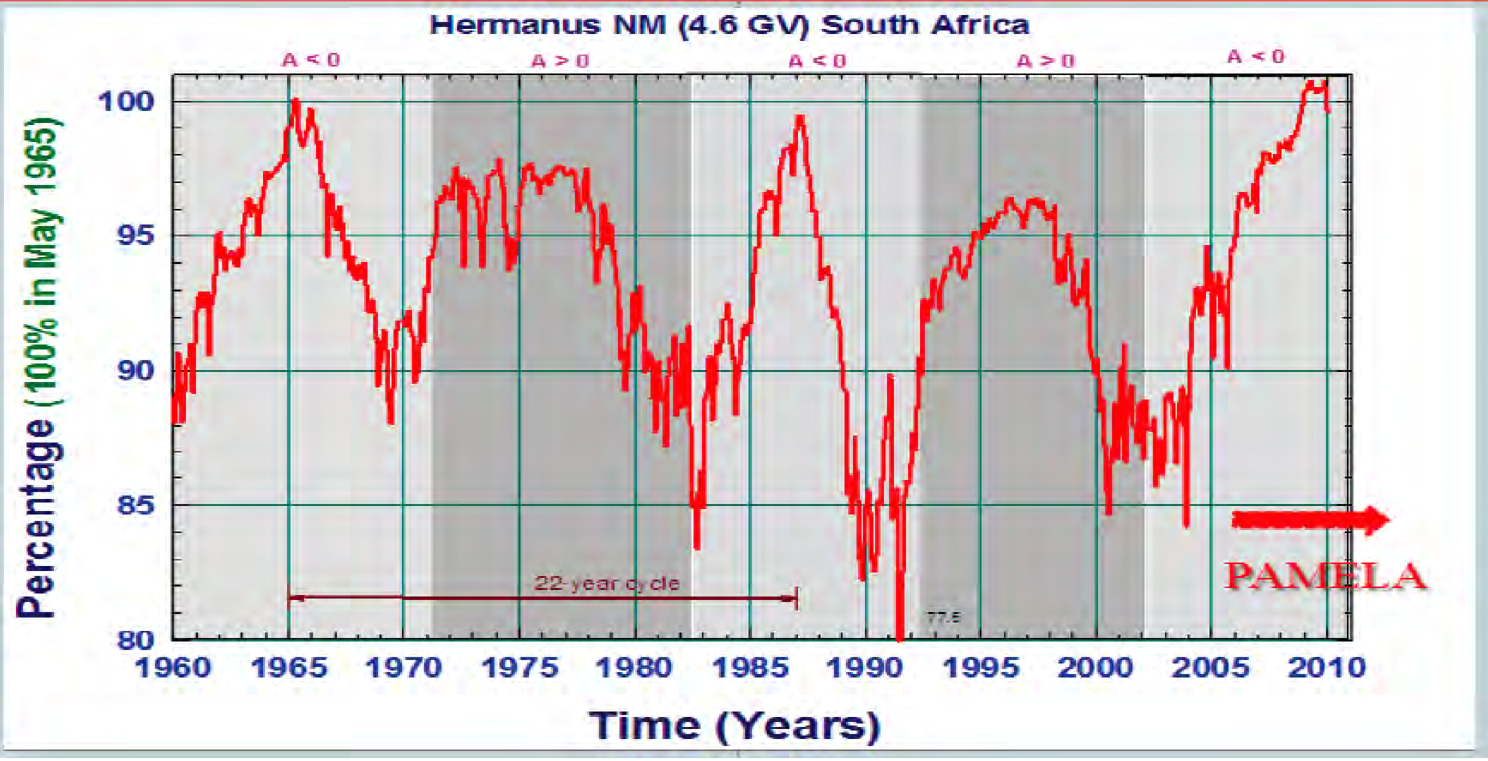


- The LAT data are accumulated for the whole flare duration
- The LAT spectrum showed clear turn over around 200 MeV

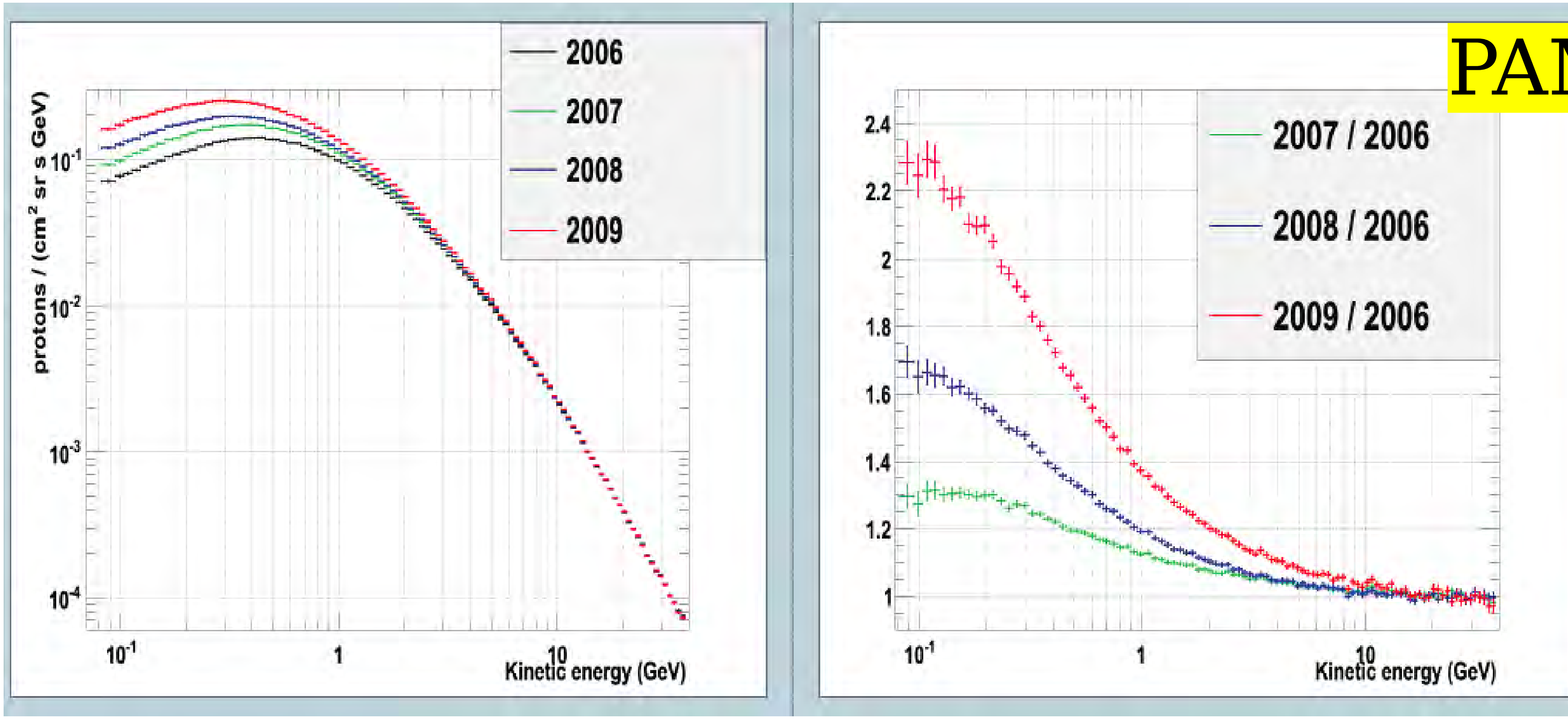
PAMELA: Solar Flare 13/dec/2006



Solar modulation depends on Sun magnetic field orientation

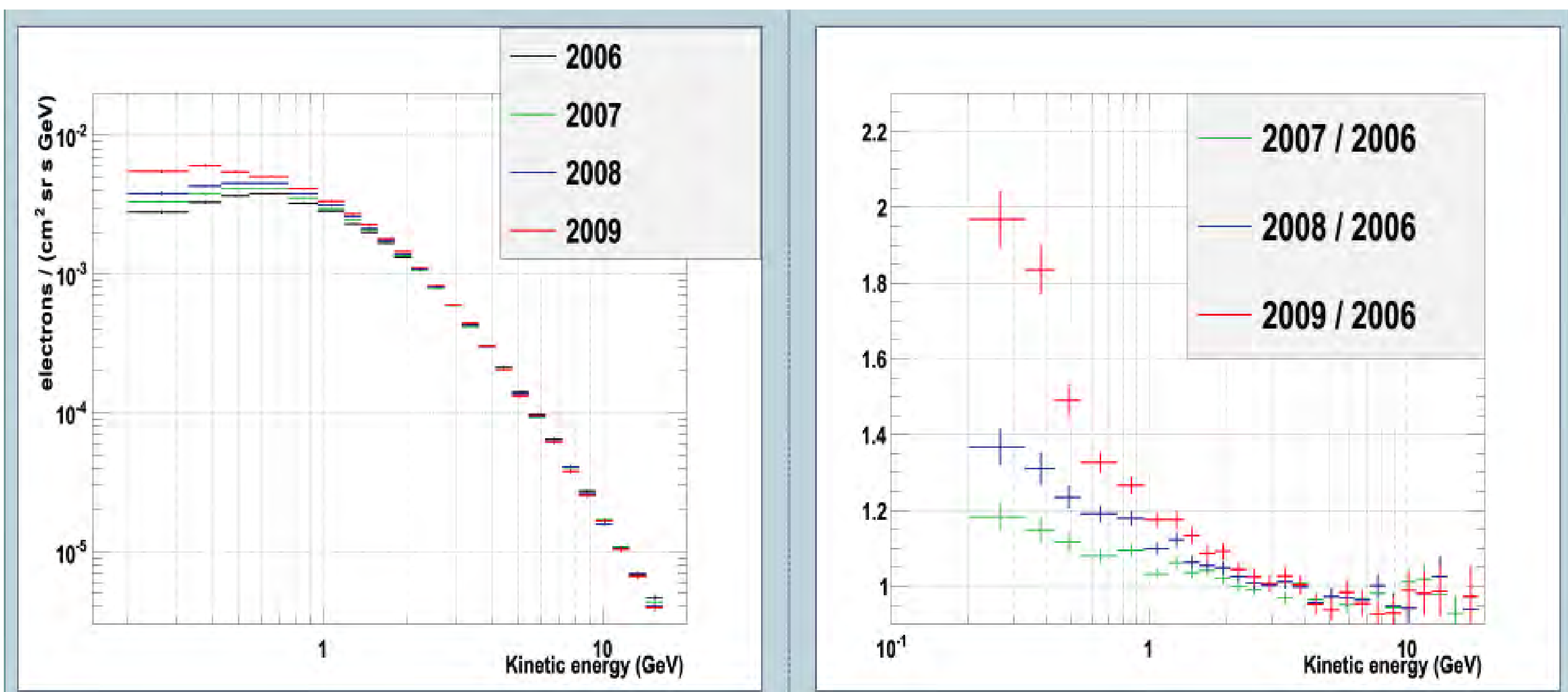


PAMELA



2006
2007
2008
2009
protons / (cm² sr s GeV)
Kinetic energy (GeV)
2007 / 2006
2008 / 2006
2009 / 2006
Kinetic energy (GeV)

p

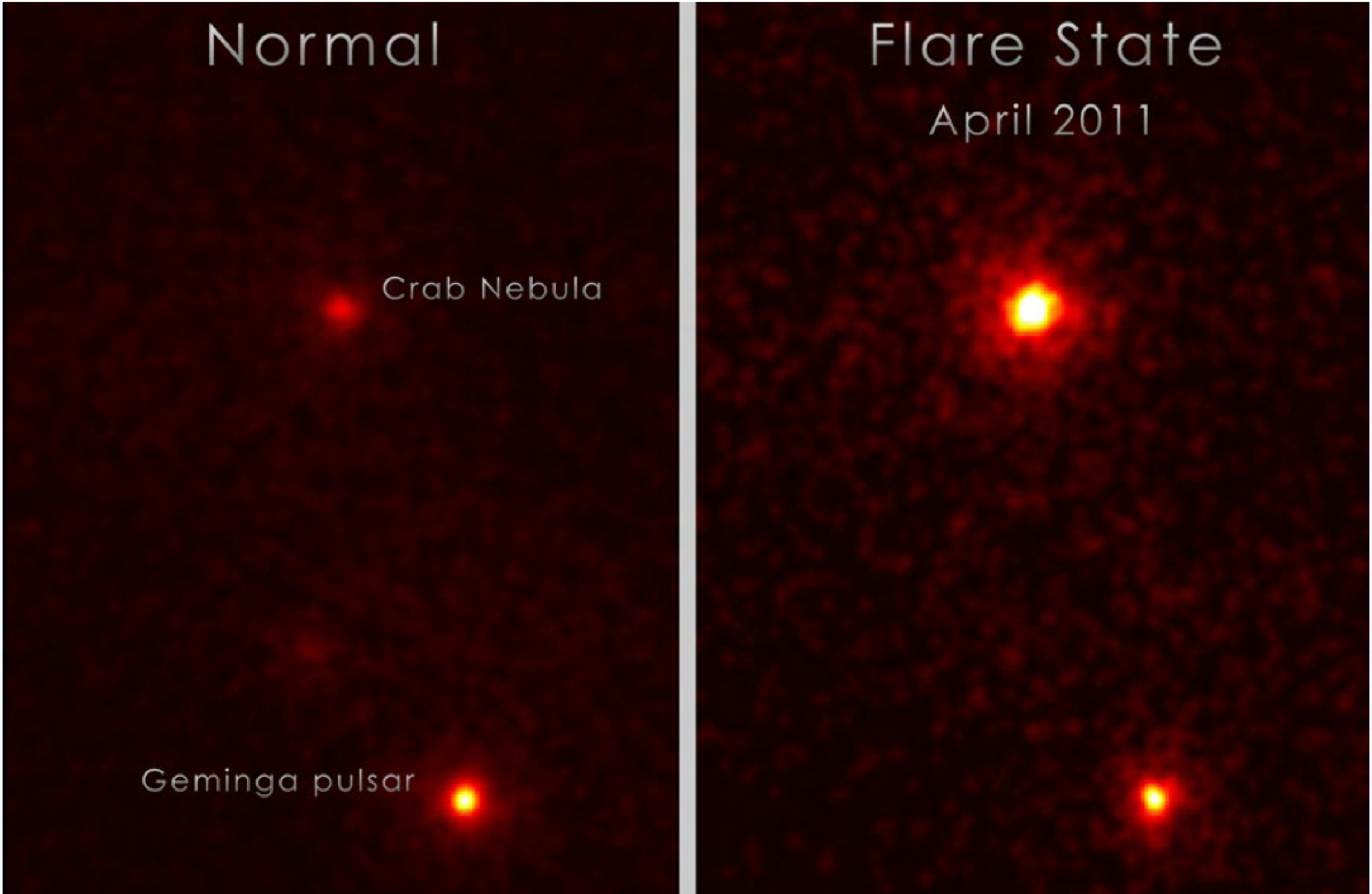


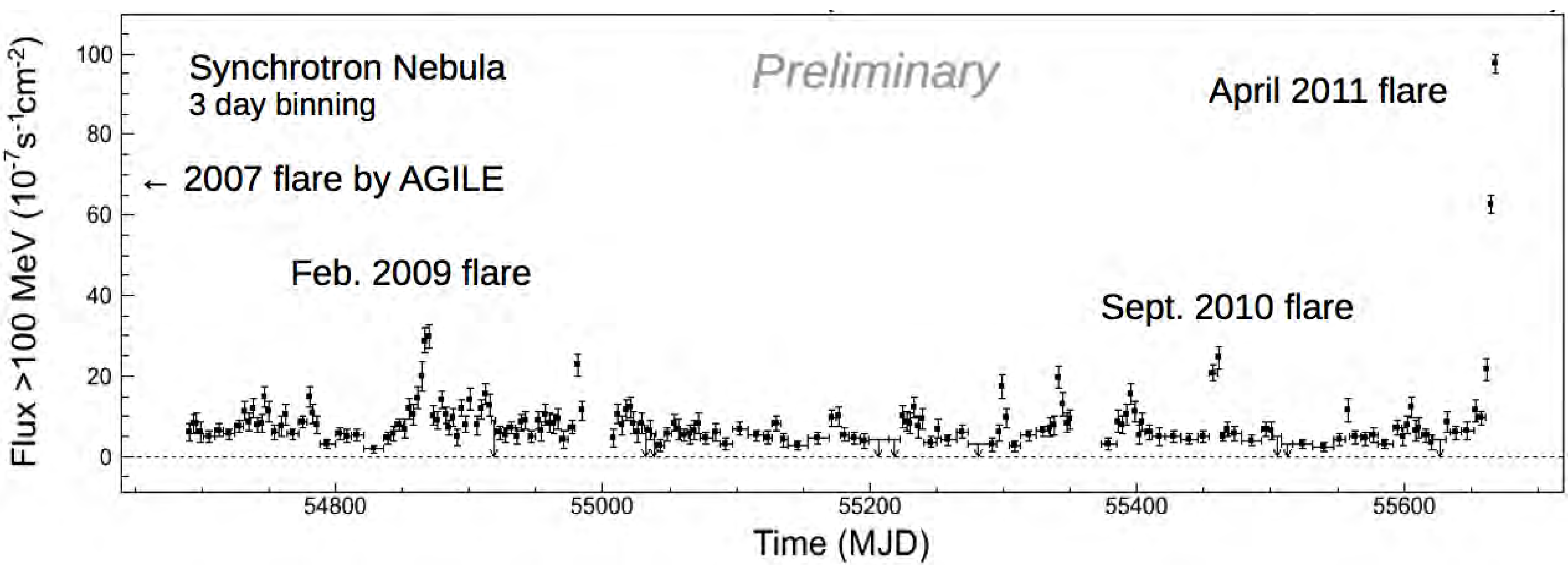
2006
2007
2008
2009
electrons / (cm² sr s GeV)
Kinetic energy (GeV)
2007 / 2006
2008 / 2006
2009 / 2006
Kinetic energy (GeV)

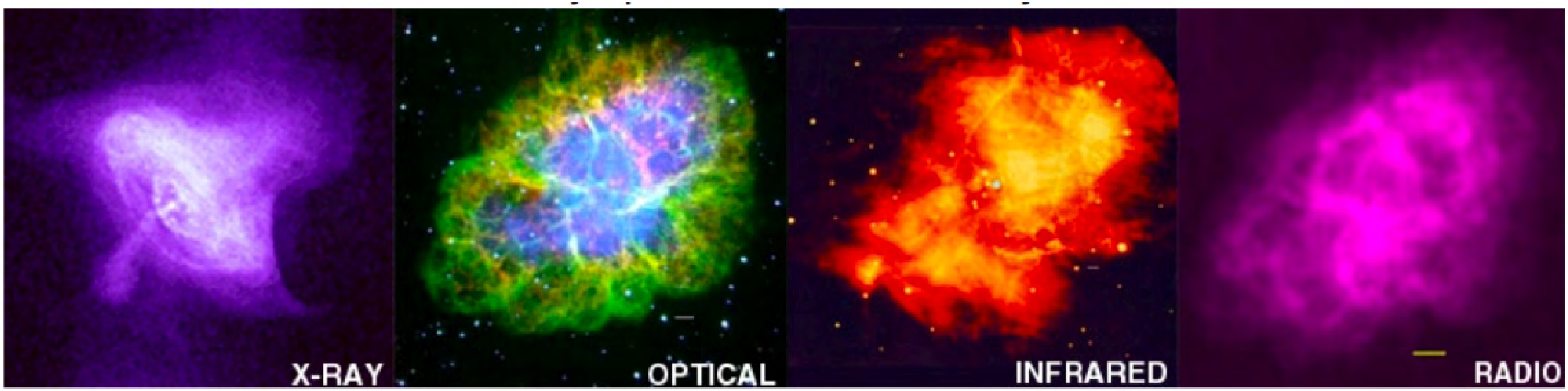
e

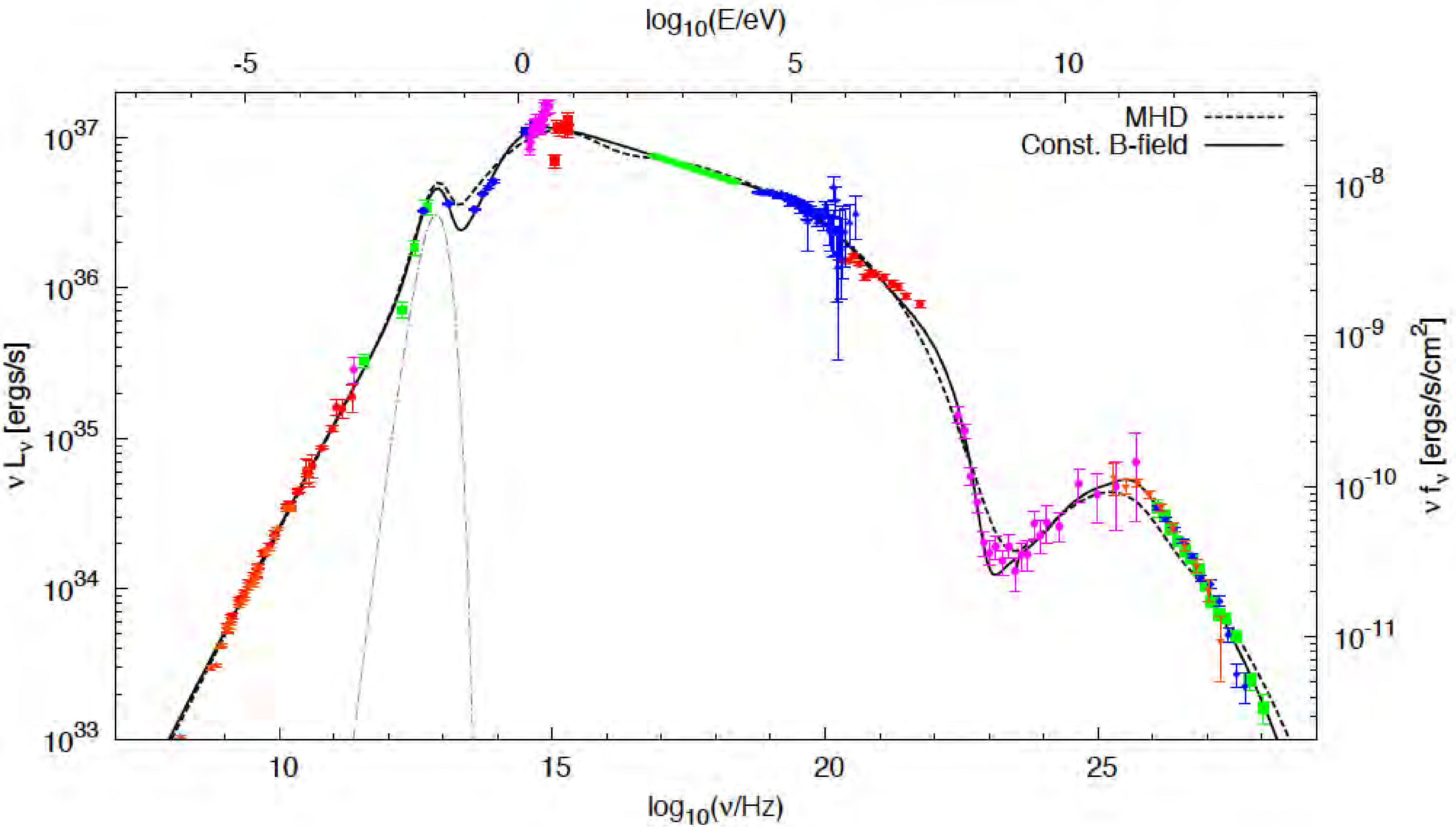
The CRAB Nebula

CRAB NEBULA Flaring [!]




Synchrotron Nebula
3 day binning
Preliminary
April 2011 flare
← 2007 flare by AGILE
Feb. 2009 flare
Sept. 2010 flare
Flux >100 MeV ($10^{-7}s^{-1}cm^{-2}$)
Time (MJD)
100
80
60
40
20
0
54800
55000
55200
55400
55600


X-RAY
OPTICAL
INFRARED
RADIO



log10(E/eV)
-5
0
5
10
MHD
Const. B-field
10^37
10^36
10^35
10^34
10^33
ν L_ν [ergs/s]
10^-8
10^-9
10^-10
10^-11
ν f_ν [ergs/s/cm^2]
10
15
20
25
log10(ν/Hz)

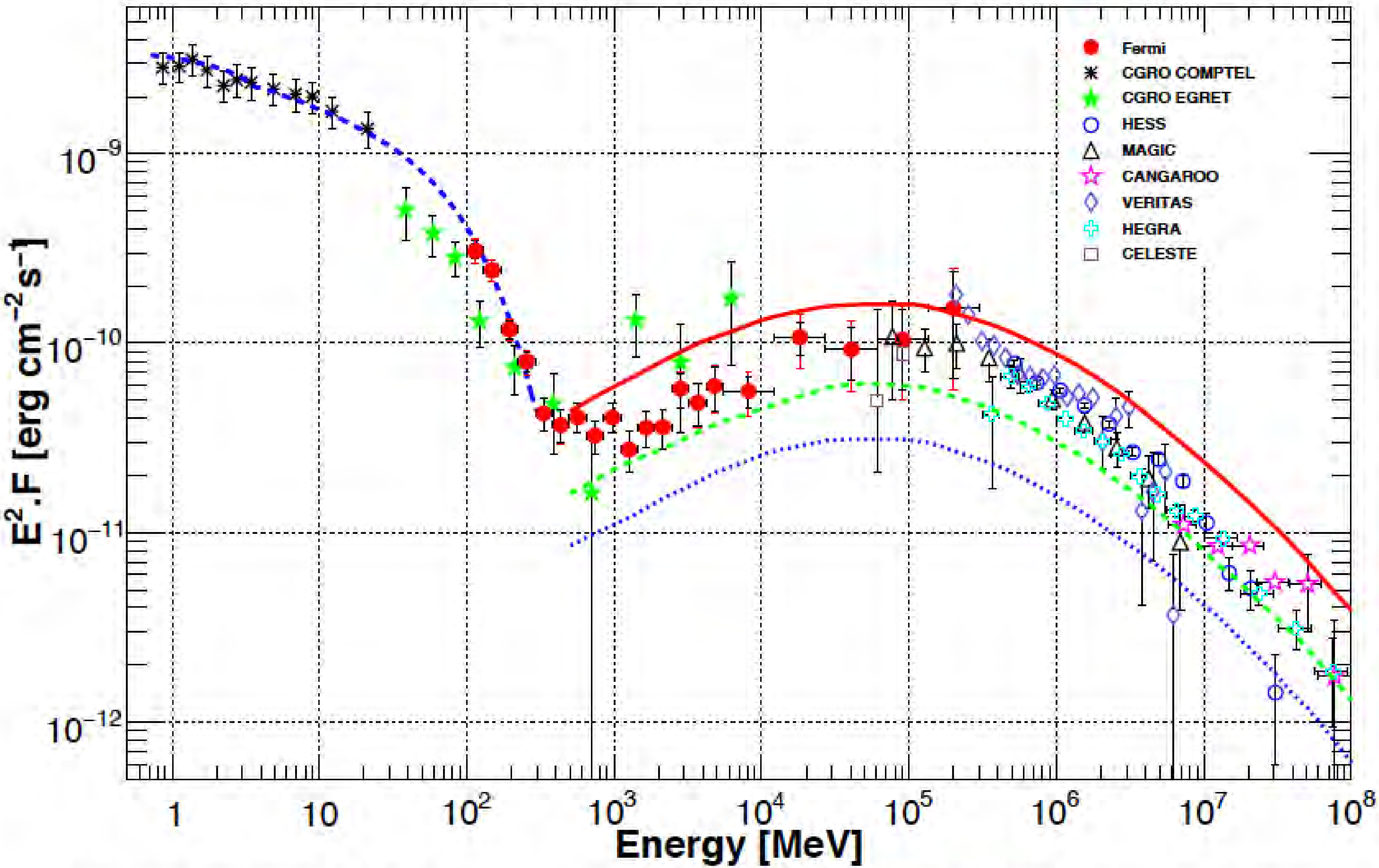


FIG. 9.— The spectral energy distribution of the Crab Nebula from soft to very high energy γ-rays. The fit of the synchrotron component, using COMPTEL and LAT data (blue dashed line), is overlaid. The predicted inverse Compton spectra from Atoyan and Aharonian (1996) are overlaid for three different values of the mean magnetic field: 100 μG (solid red line), 200 μG (dashed green line) and the canonical equipartition field of the Crab Nebula 300 μG (dotted blue line). References: CGRO COMPTEL and EGRET: Kuiper et al. (2001); MAGIC: Albert et al. (2008); HESS: Aharonian et al. (2006); CANGAROO: Tanimori et al. (1997); VERITAS: Celik (2007); **HEGRA: Aharonian et al. (2004); CELESTE: Smith et al. (2006)**


Yangbajing Cosmic Ray Laboratory - TIBET
ARGO-YBJ
4300 m a.s.l.
Longitude 90° 31’ 50” East
Latitude 30° 06’ 38” North

September 2010 flare

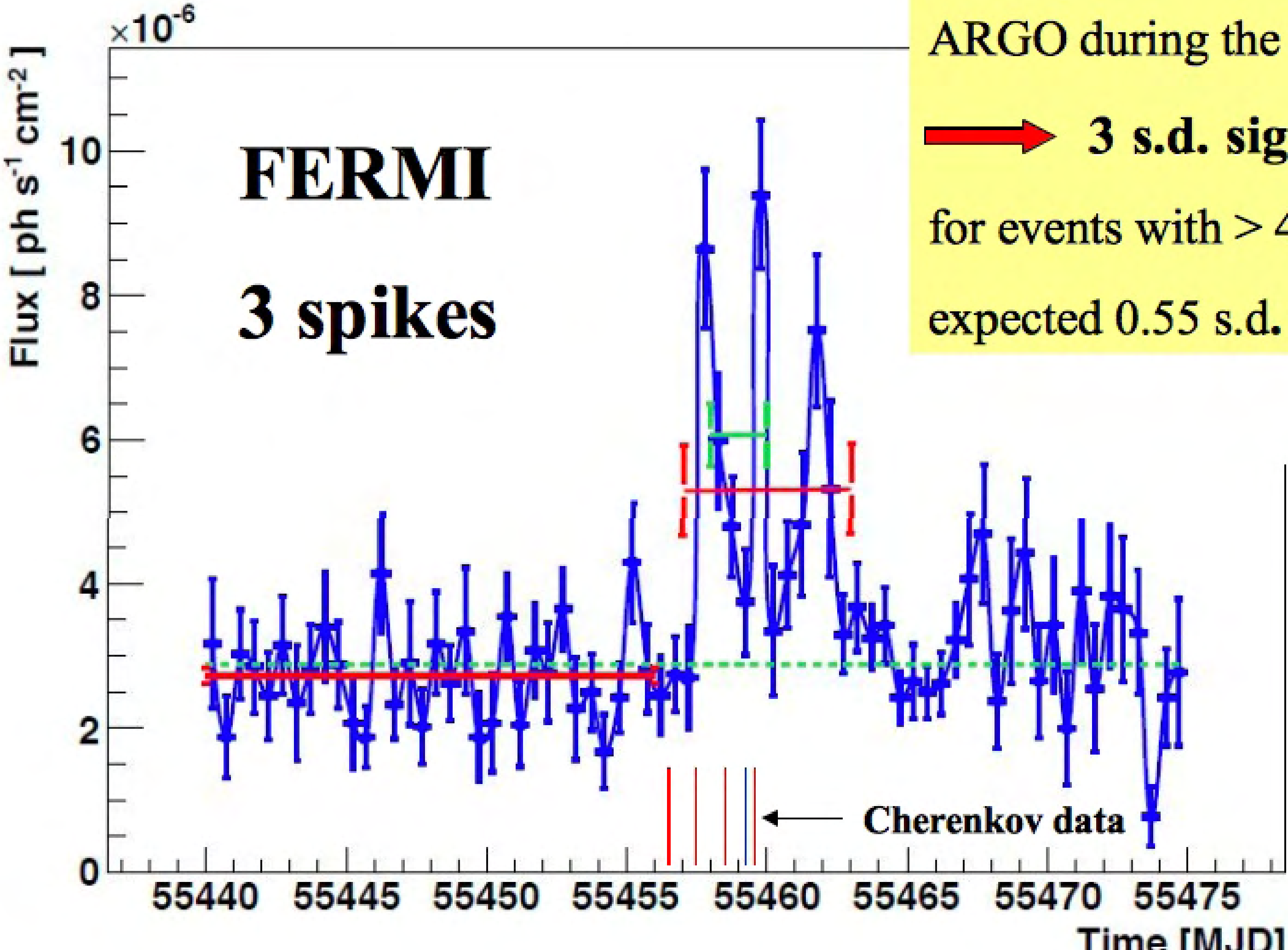
PRELIMINARY !!!

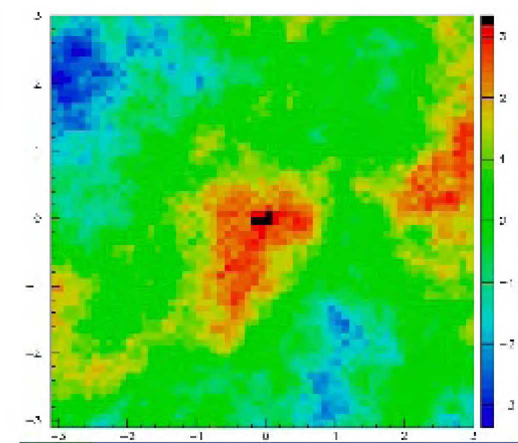
ARGO during the 3 Fermi spikes:

→ **3 s.d. signal**

for events with > 40 hits (E ⊠ 1 TeV)

expected 0.55 s.d. from steady flux

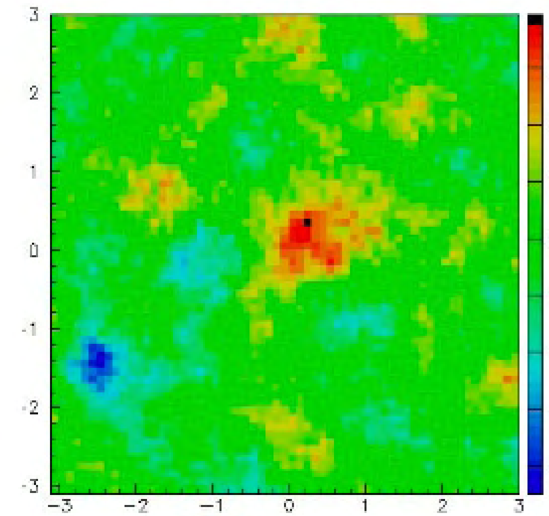




Balbo et al. A&A 527 L4, 2010

April 2011 flare

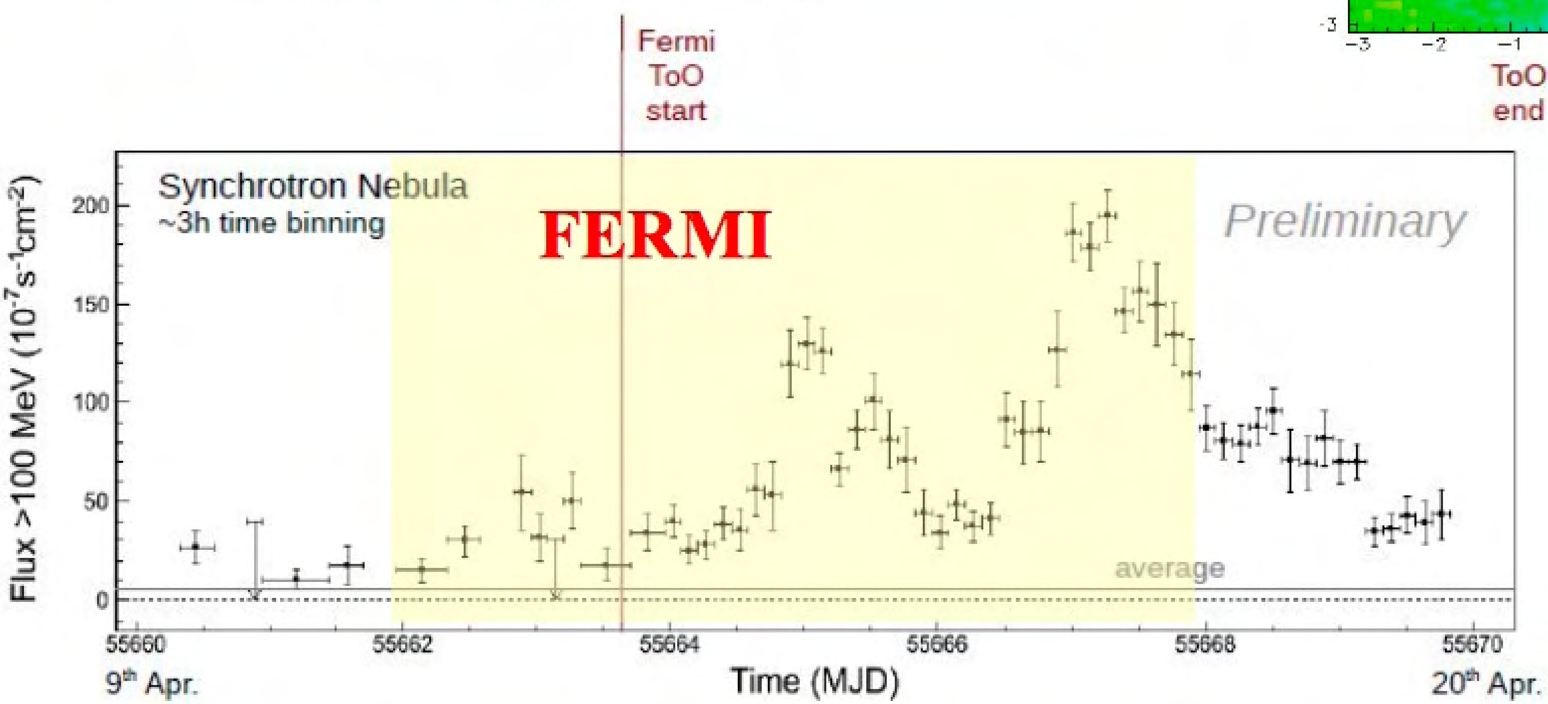
VERY PRELIMINARY !!!



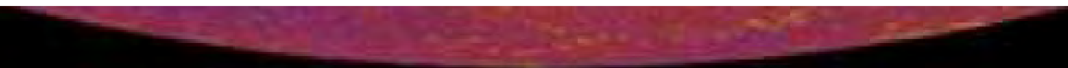
ARGO in 6 days :

➡ **> 3 s.d. signal**

for events with > 500 hits (E [illegible] 10 TeV)



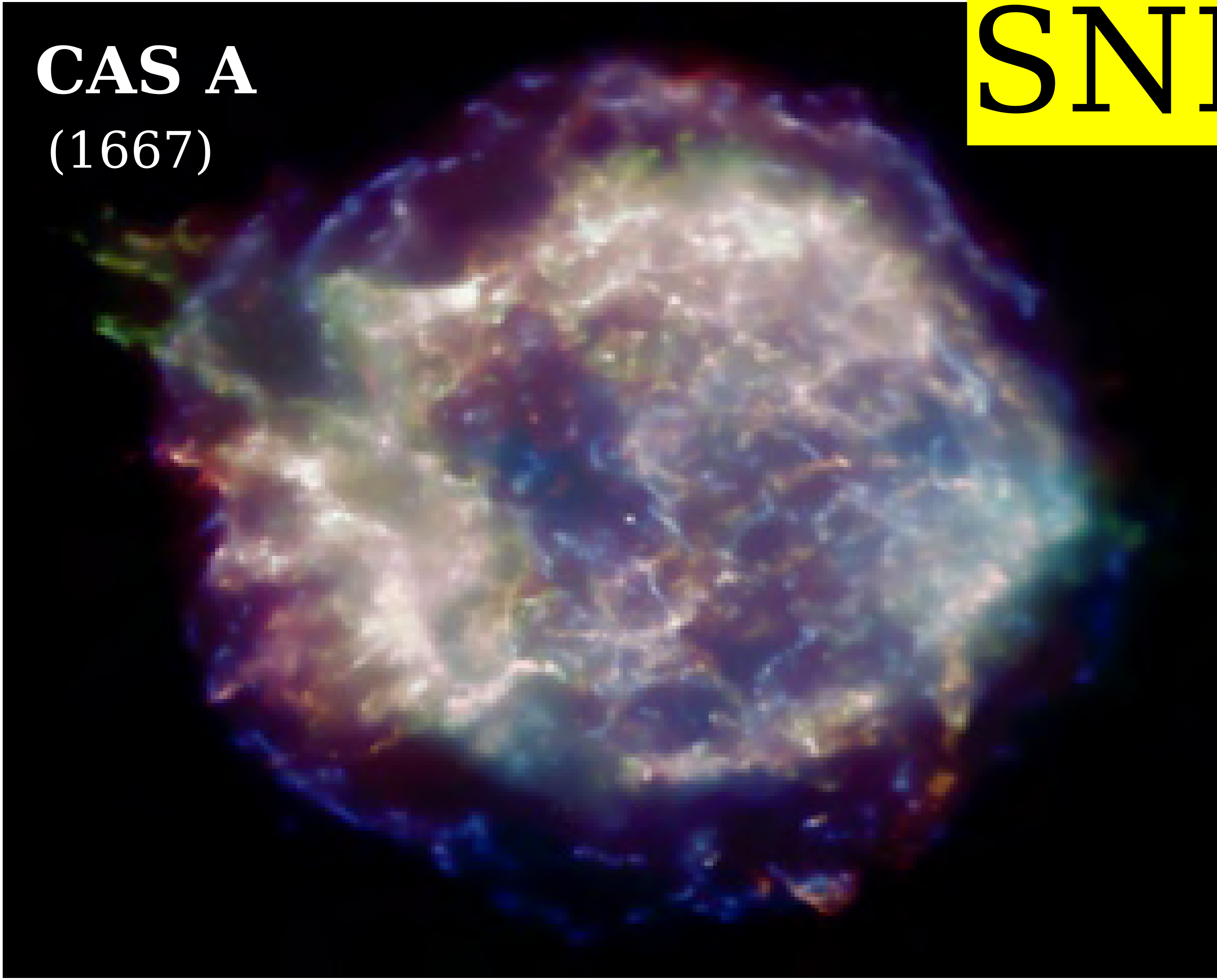
Buehler, Fermi Symposium 2011



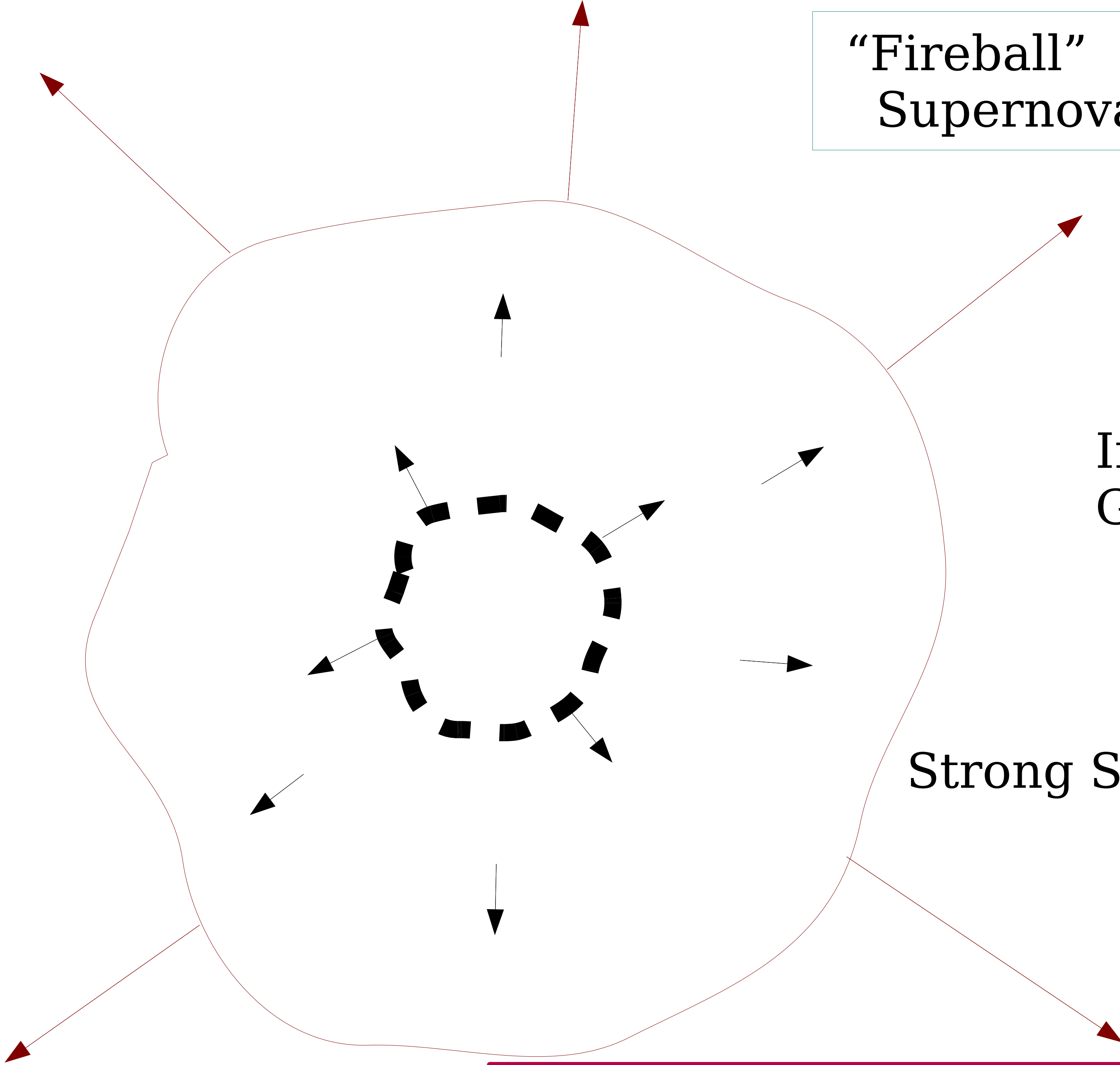
«Those who have reached the stage of no longer being able to marvel at anything simply show that they have lost the art of reasoning and reflection.»

Max Planck

SNR

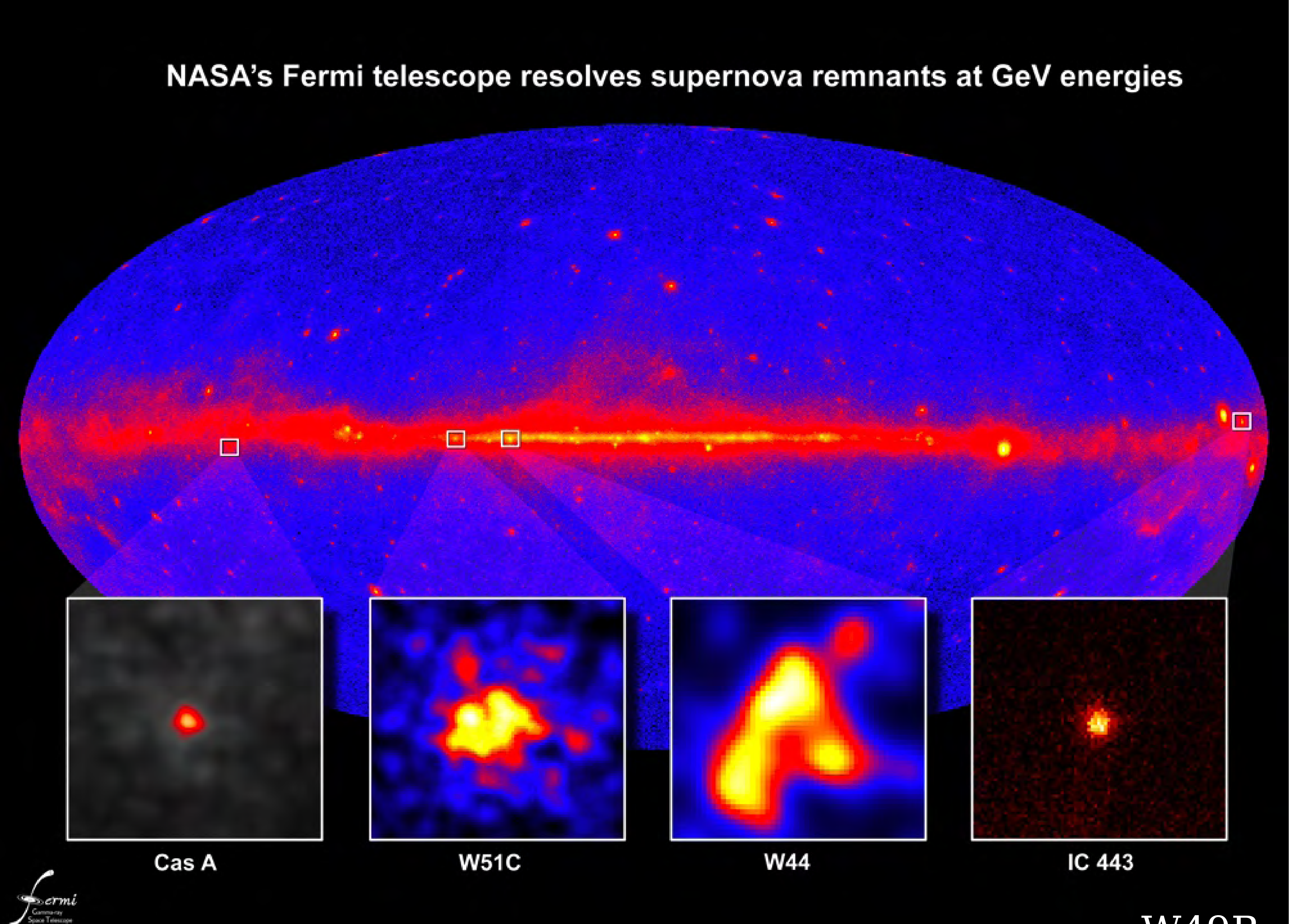


“Fireball” of an Supernova explosion

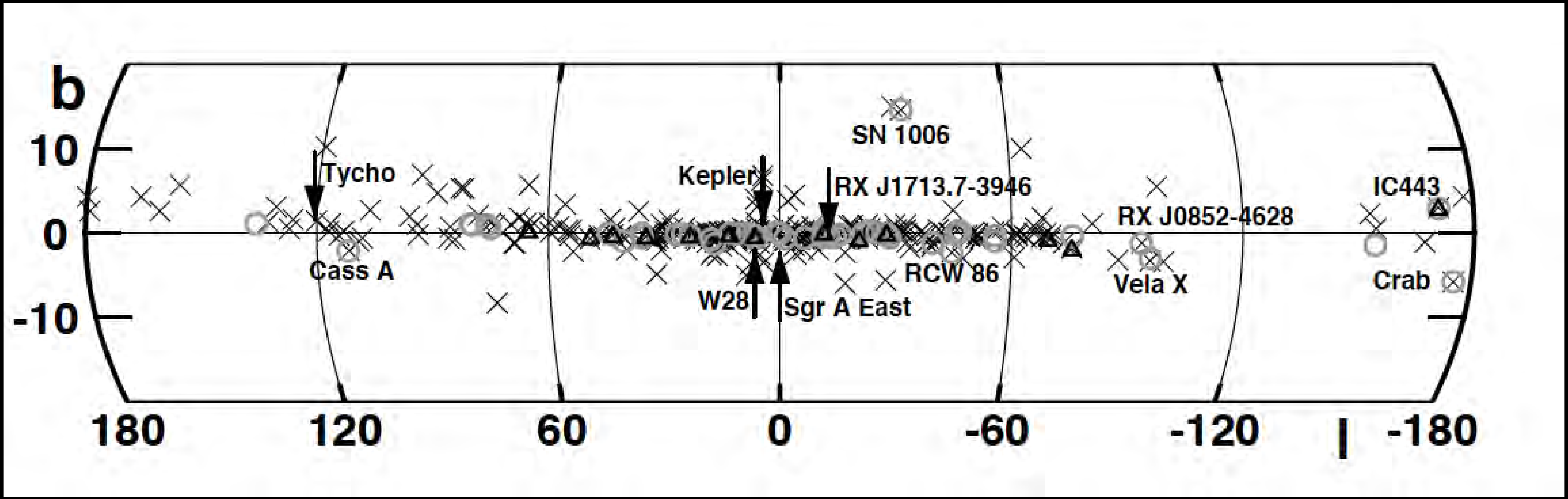


Fermi 1st order acceleration

$$q(E) \propto E^{-(2+\varepsilon)}$$


NASA's Fermi telescope resolves supernova remnants at GeV energies
Cas A
W51C
W44
IC 443

W49B



274 SNR remnants detected in radio (Green catalog)

High energy gamma Rays detections.
Too few detections?
Properties as expected?

A. Letessier-Selvon, T. Stanev, "Ultrahigh Energy Cosmic Rays," [arXiv:1103.0031 [astro-ph.HE]].

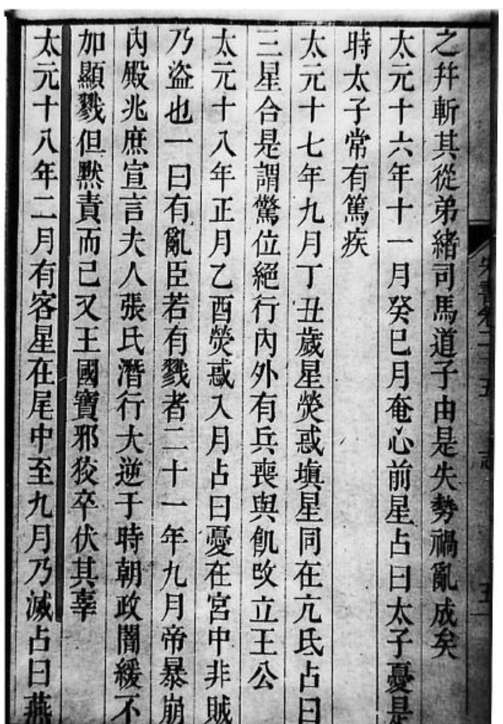
SuperNova 393A
RX J1713.7-3946

Observed in AD 393
By chinese court astromers
22-october, 19-november

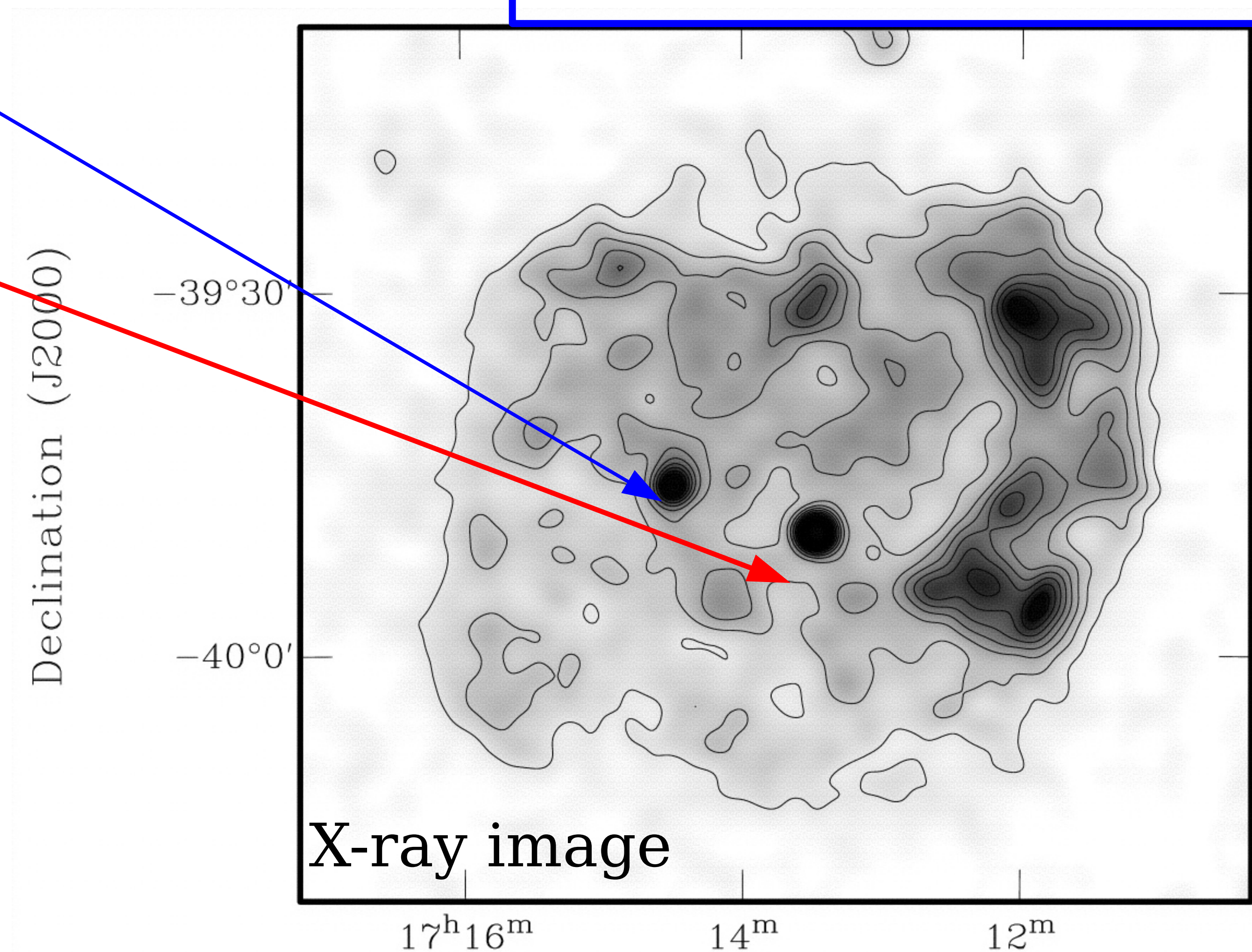
(Re)-discovered in 1996
by the Roentgen Satellite

Foreground star

Neutron Star



之幷斬其從弟緒司馬道子由是失勢禍亂成矣
太元十六年十一月癸巳月奄心前星占曰太子憂是
時太子常有篤疾
太元十七年九月丁丑歲星熒惑填星同在亢氐占曰
三星合是謂驚位絕行內外有兵喪與飢改立王公
太元十八年正月乙酉熒惑入月占曰憂在宮中非賊
乃盜也一曰有亂臣若有戮者二十一年九月帝暴崩
內殿兆庶宣言夫人張氏潛行大逆于時朝政闇緩不
加顯戮但默責而已又王國寶邪狡卒伏其辜
太元十八年二月有客星在尾中至九月乃滅占曰燕

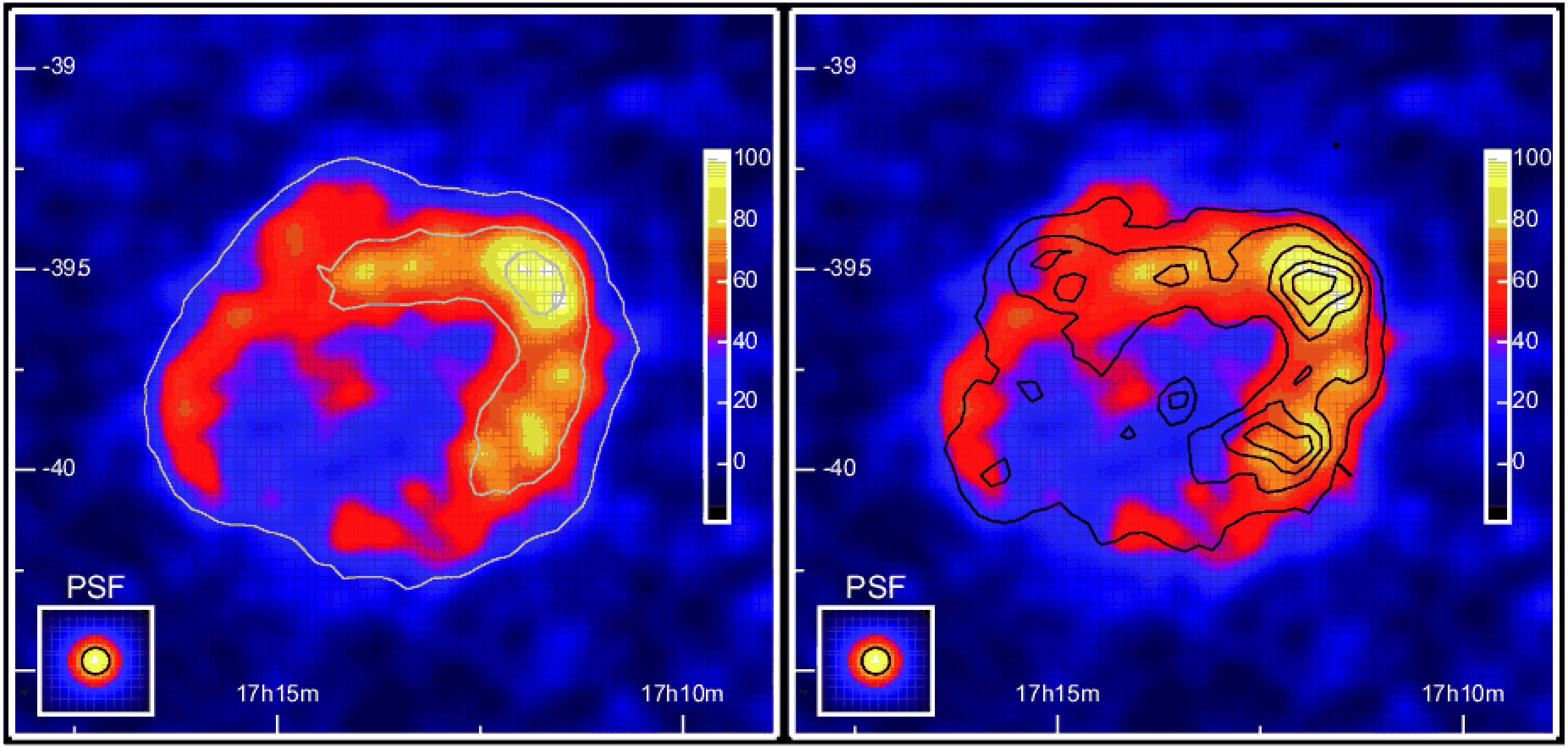


Detected in 2004 by HESS in TeV gamma rays

HESS Telescope

Observations with TeV photons

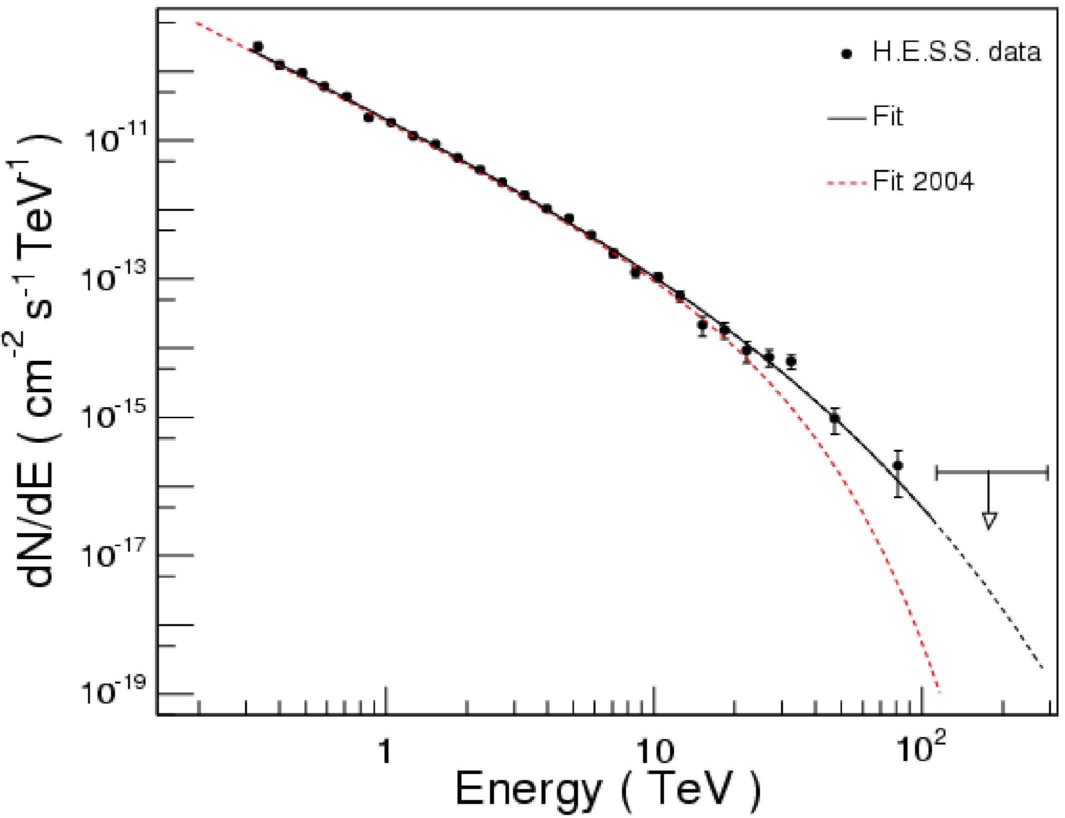
SuperNova RX J1713.7-3946



Comparison with ROSAT observation

Energy Spectrum

$\phi_\gamma(>1\ \mathrm{TeV}) = (1.47 \pm 0.17 \pm 0.37) \times 10^{-7}\ \mathrm{m}^{-2}\,\mathrm{s}^{-1}$



$$\phi_\gamma(E) = K\,E^{-\Gamma}$$

$$\Gamma = 2.19 \pm 0.09 \pm 0.15$$

Assuming: (p)

$$\frac{dN_\gamma}{dt} \propto N_p \times n_{\mathrm{target}} \times \sigma_{pp}\, c$$

Hess estimate

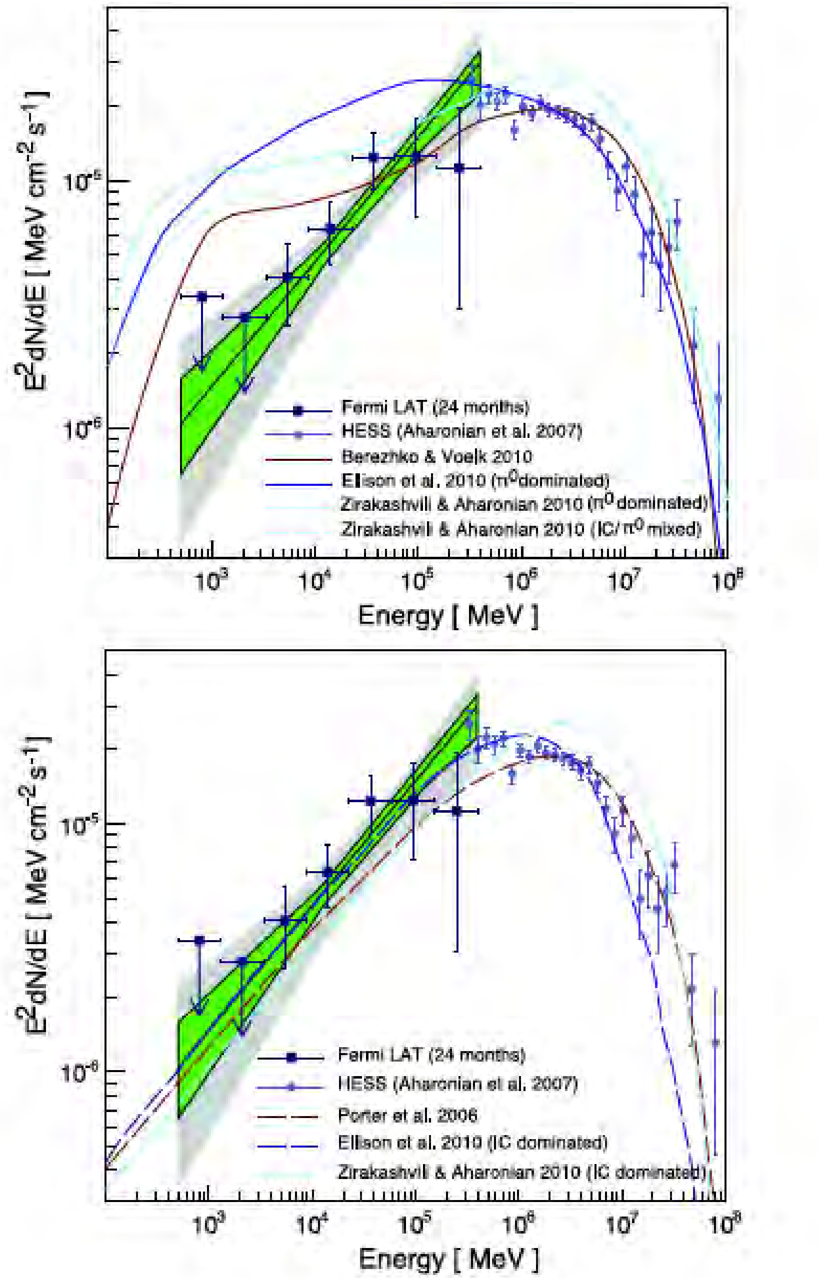
$$E^{\mathrm{tot}}_{\mathrm{relativistic}\ p} \simeq 0.2 \times 10^{51}\ \mathrm{erg}$$

> 10% of the explosion kinetic energy → Relativistic protons.

Observations of the young Supernova remnant RX J1713.7−3946 with the *Fermi* Large Area Telescope

astro-ph/1103.5727.
29th march 2011

Favors
leptonic interpretation.



Have we proved that SNR are the source of the bulk of the Galactic Cosmic Rays ?

The evidence is accumulating.
Fermi, Hess results

Perhaps case not closed...
[different opinions]

A picture more complex that the "simplest scheme" is probably emerging

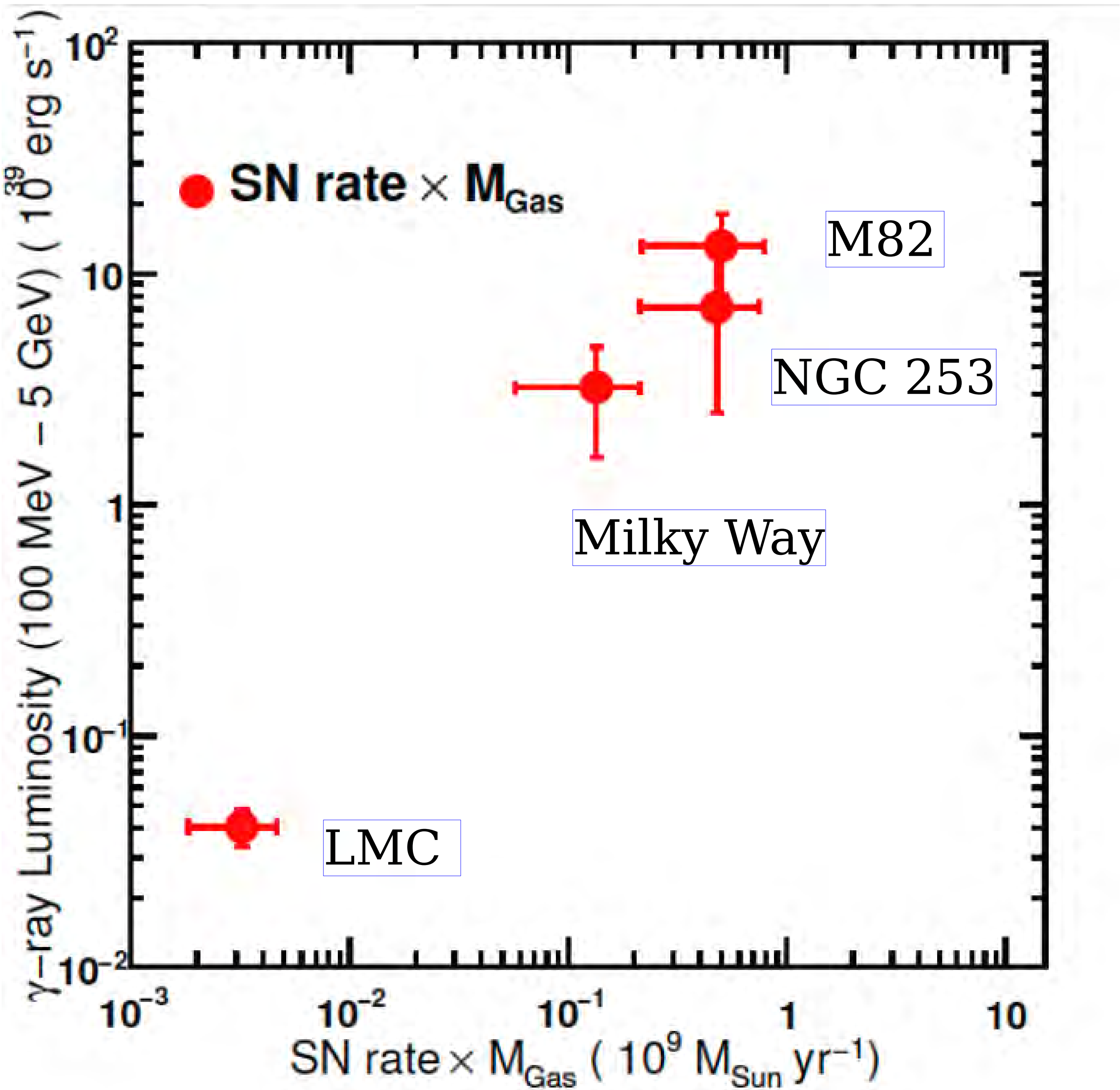
FERMI
Telescope
work:

Detection of
Starburst galaxies

Gamma Ray
Luminosities
(> 100 MeV)

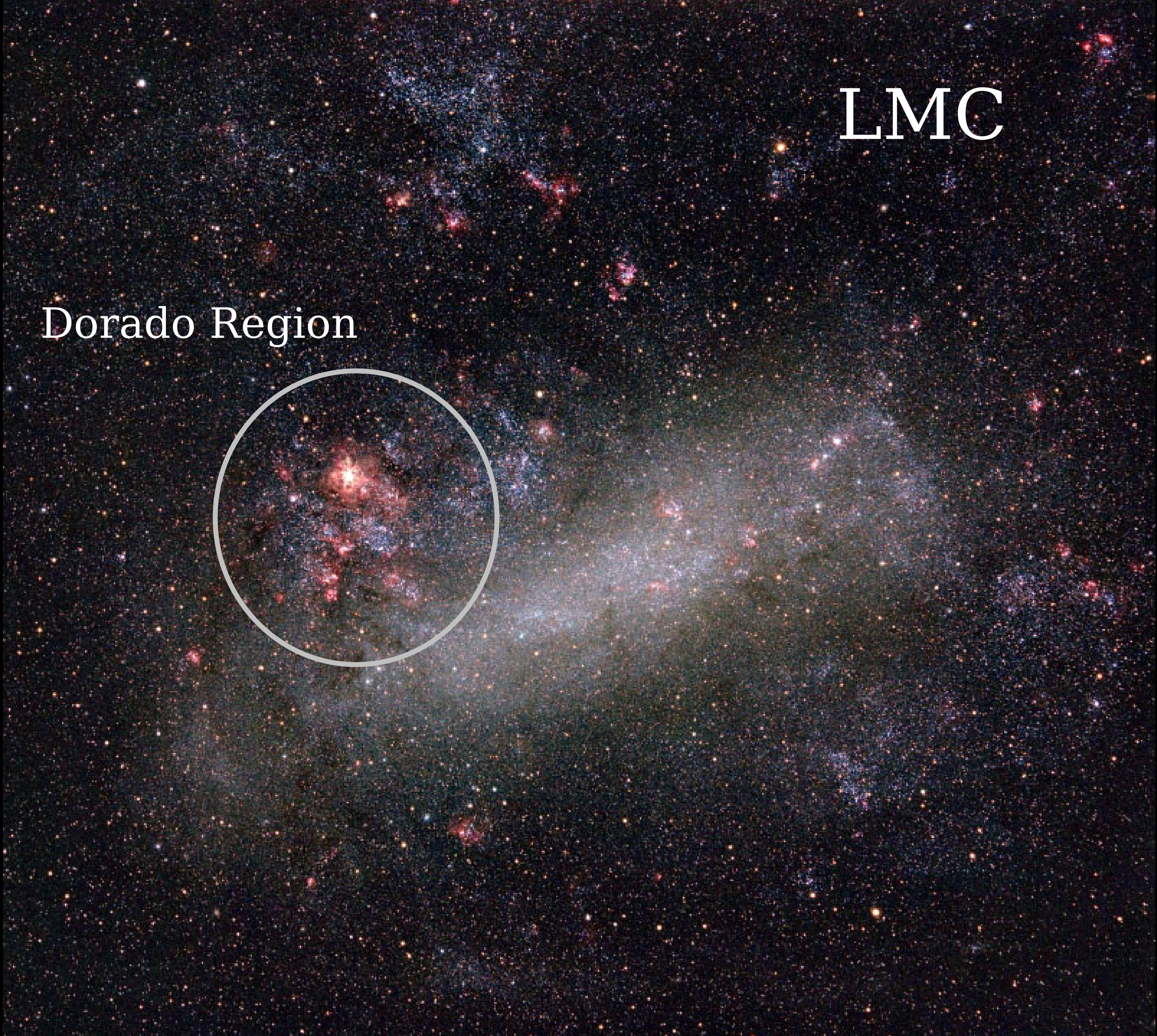
$$p + p_{\mathrm{ISM}} \rightarrow \pi^\circ$$

$$\pi^\circ \rightarrow \gamma\gamma$$



Determination
of the Milky Way luminosity
[consistent with π° Decay


M81, M82


LMC
Dorado Region

Bottom line:

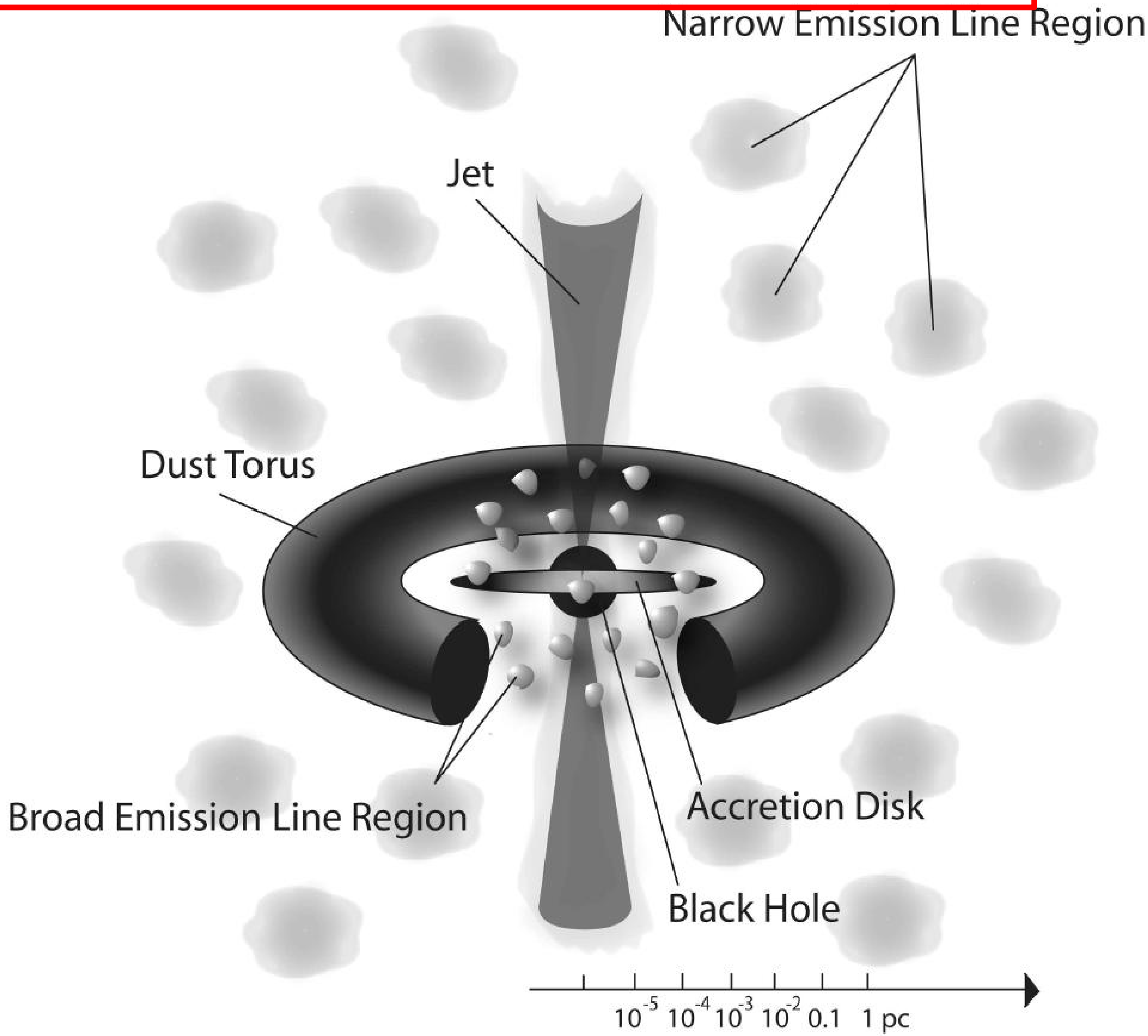
The Acceleration of CR is very likely correlated
to the Star Formation Rate
(and therefore Star “Death” Rate)

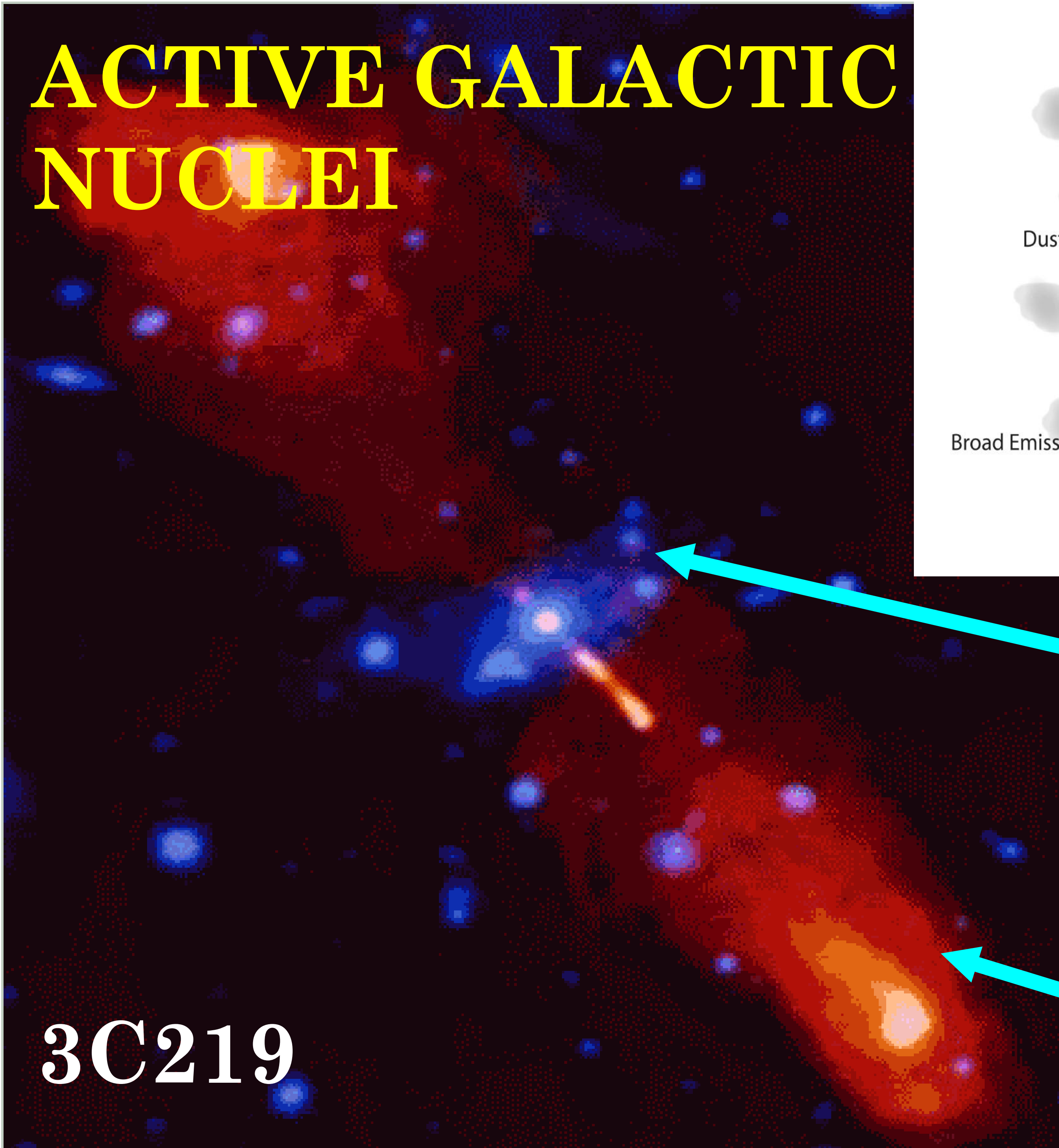
Compatible with the “standard scenario”.

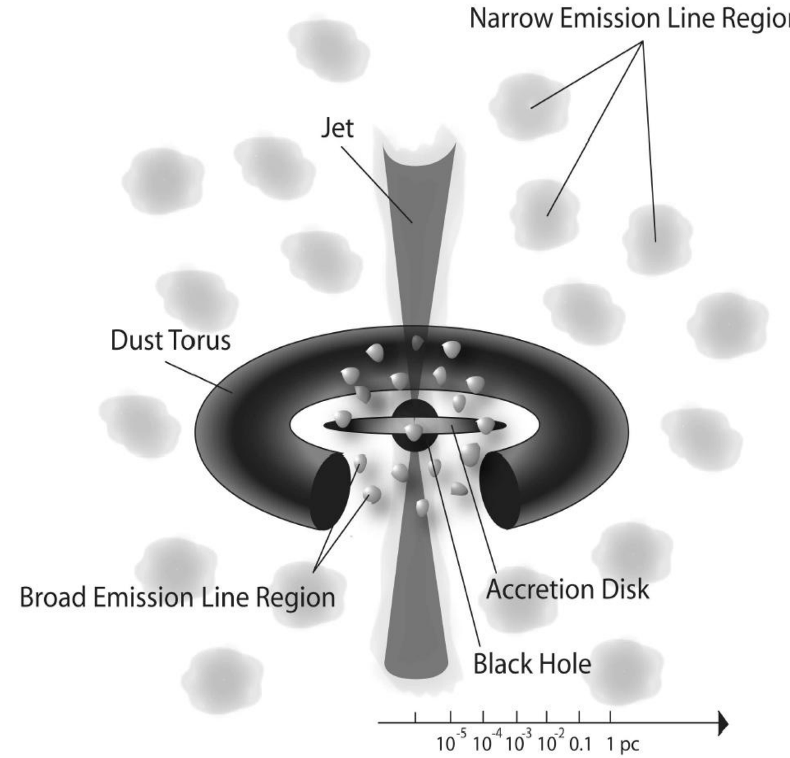
FERMI diffusive acceleration in SNR blast waves
is not the only possible solution.

“Wild at Heart” the Galactic center!

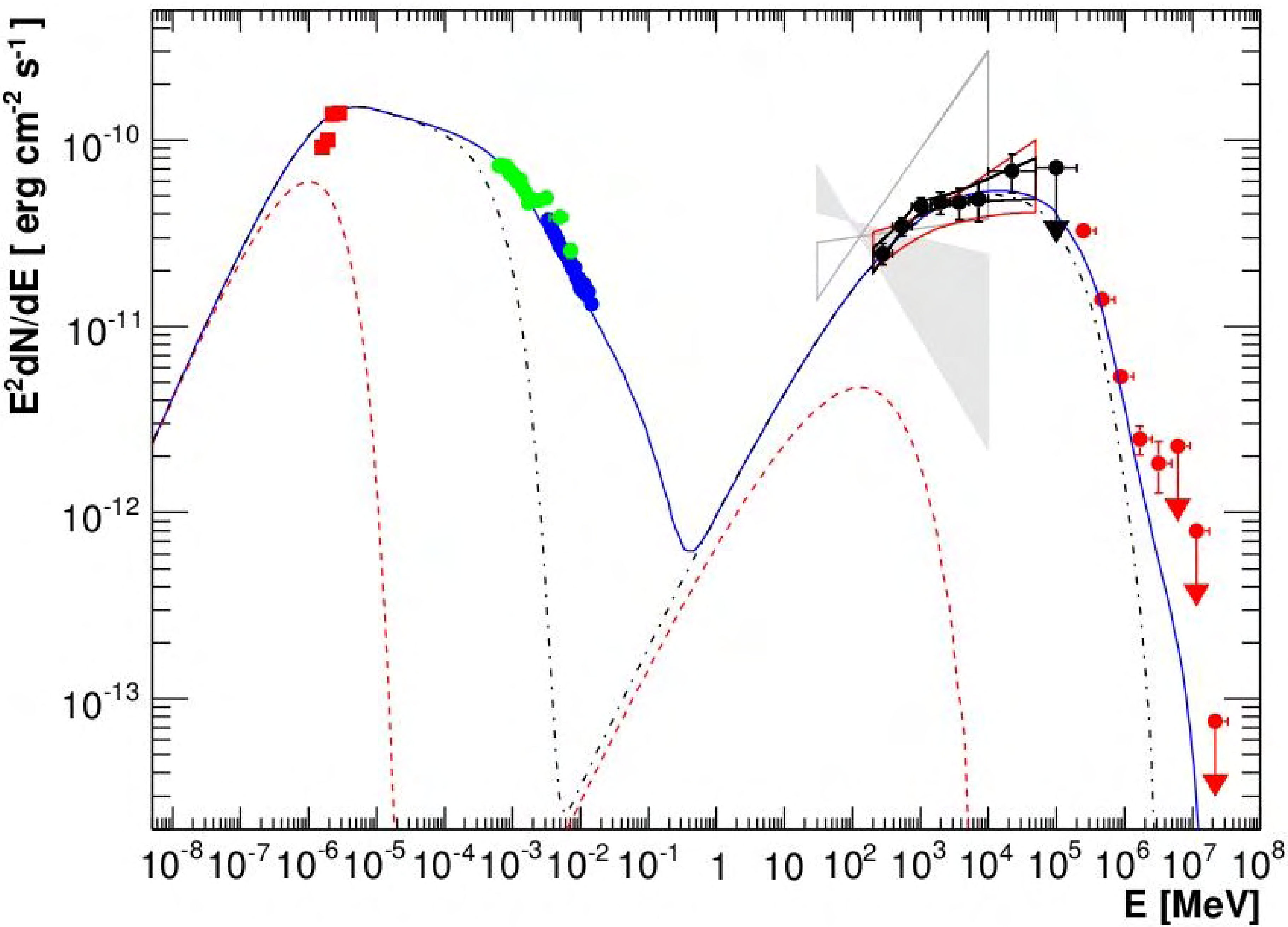
ACTIVE GALACTIC NUCLEI



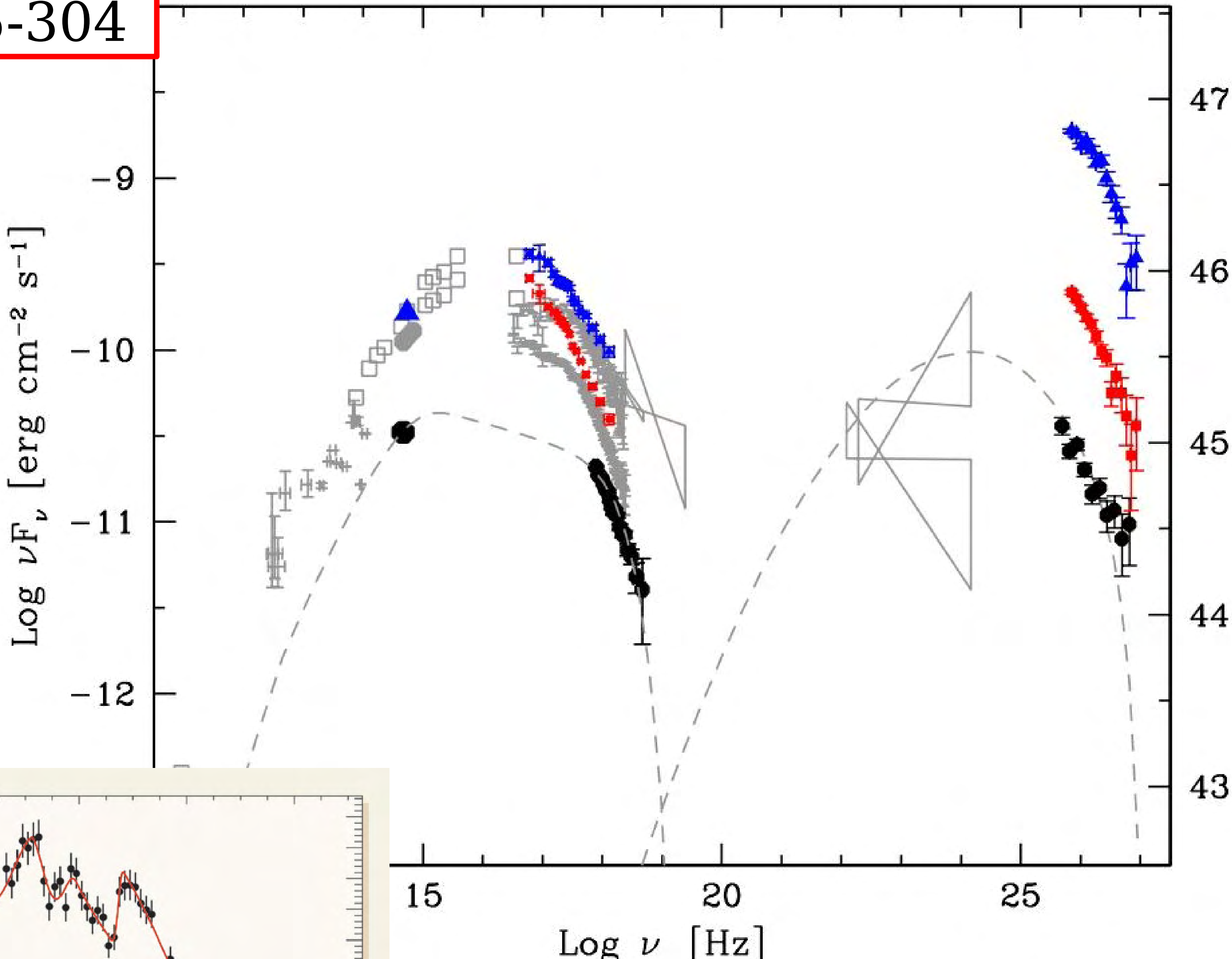

ACTIVE GALACTIC NUCLEI
3C219
Optical
Radio

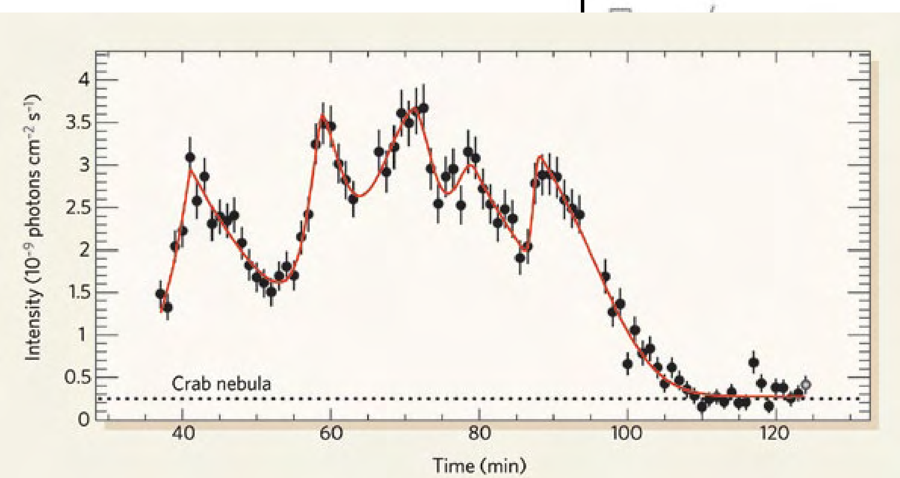

Narrow Emission Line Region
Jet
Dust Torus
Broad Emission Line Region
Accretion Disk
Black Hole
10^-5 10^-4 10^-3 10^-2 0.1 1 pc

PKS 2155-304


E2dN/dE [erg cm-2 s-1]
10-10
10-11
10-12
10-13
10-8 10-7 10-6 10-5 10-4 10-3 10-2 10-1 1 10 102 103 104 105 106 107 108
E [MeV]

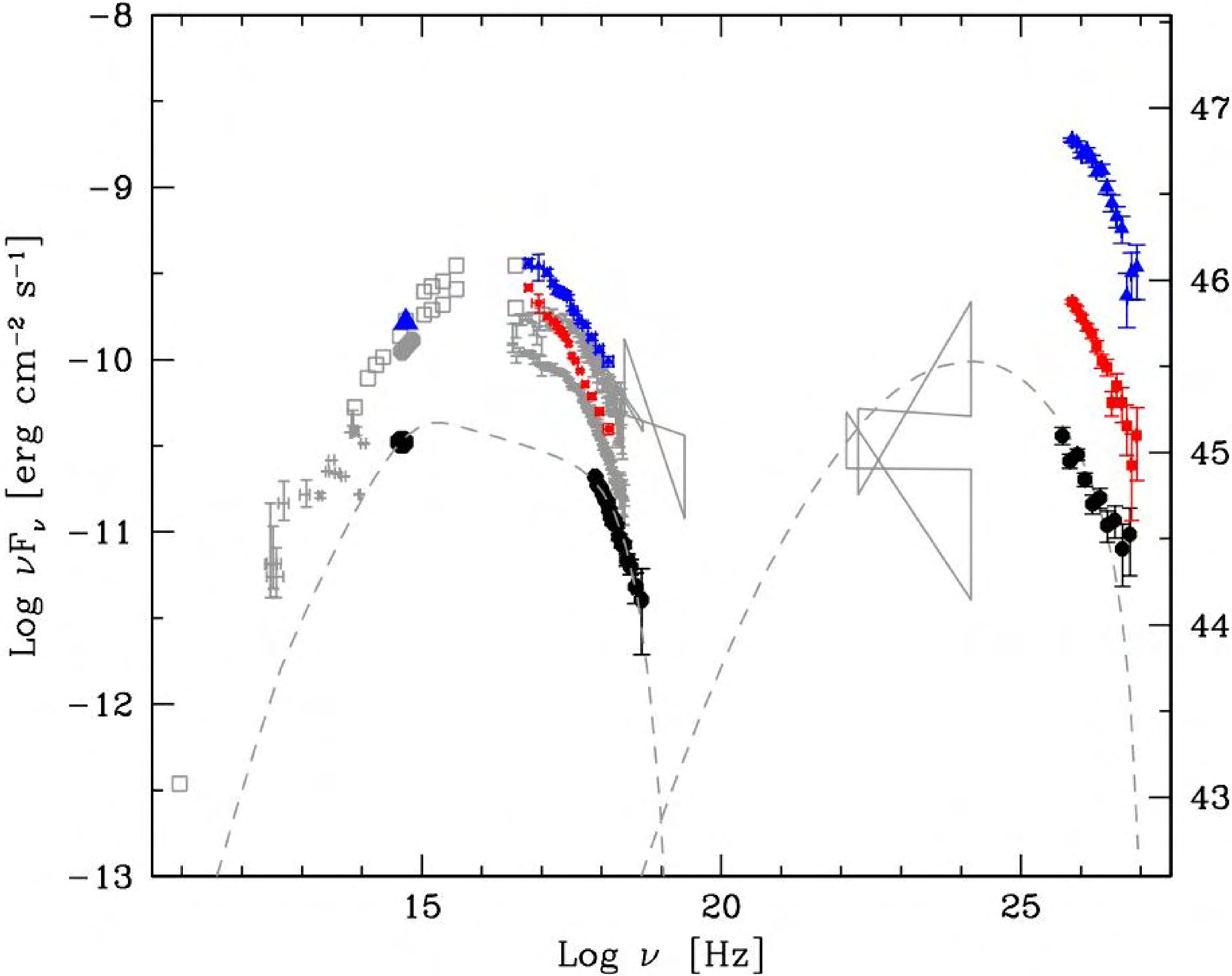
PKS 2155-304





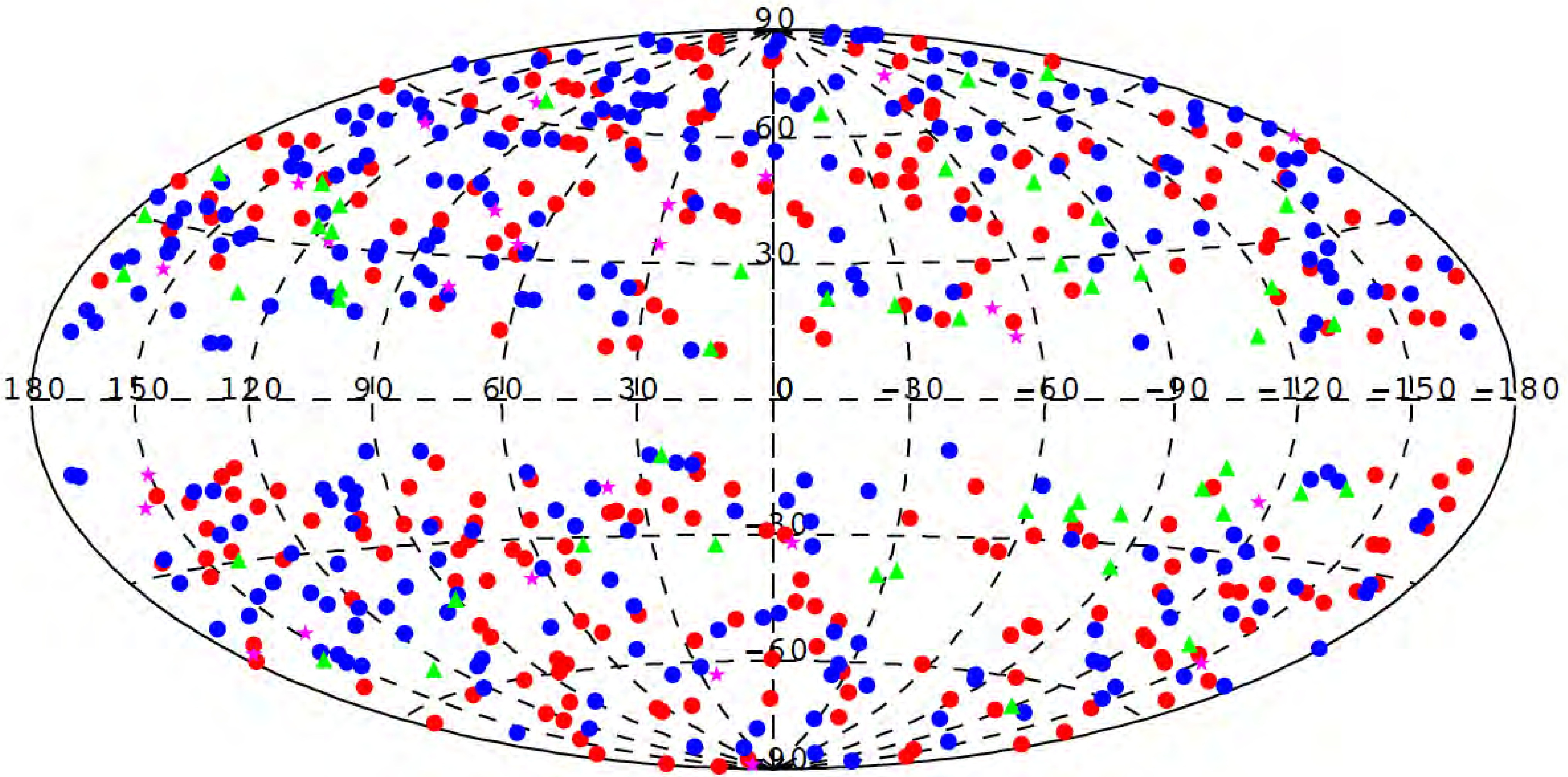
(Very rapid time variations)

PKS 2155-304



AGN observed by FERMI:

671 AGN's



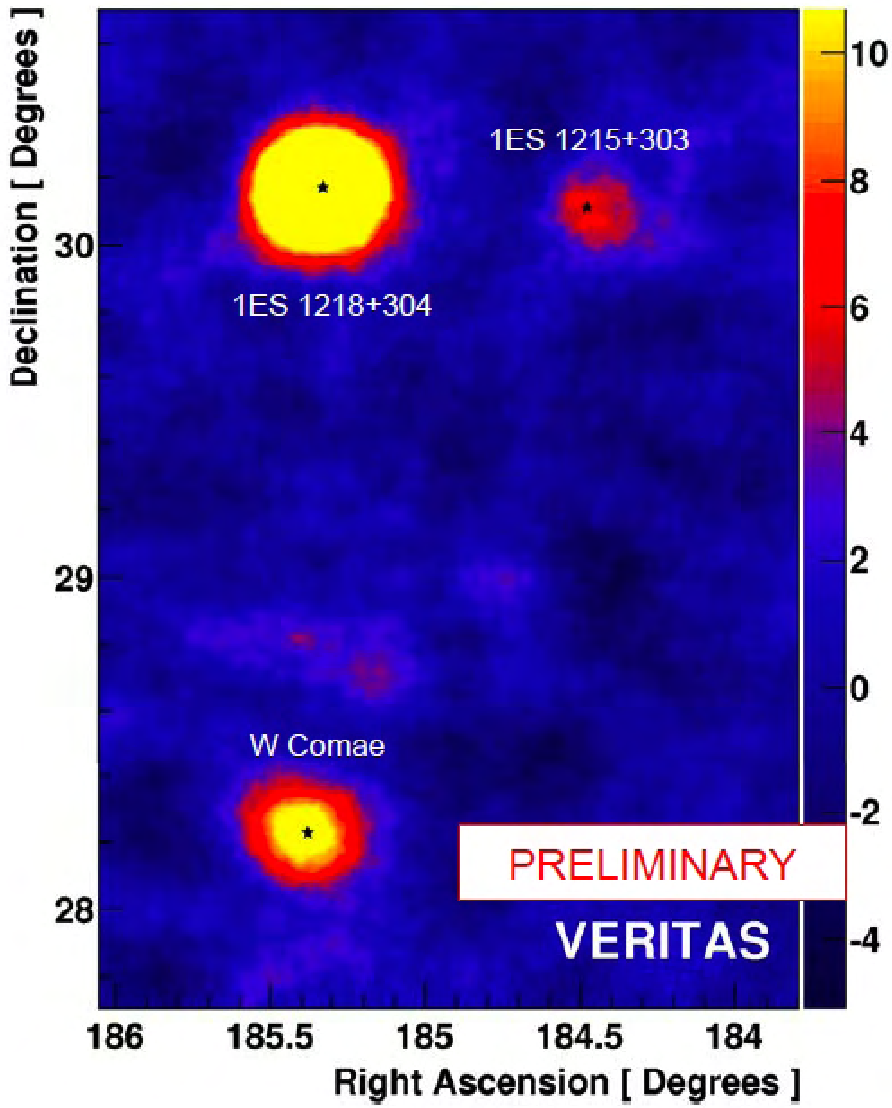
Red: FSRQ
Blue: Blac
Magenta: Radio Galaxies

Extragalactic results: the blazar list

Source	Type	Redshift z	Discovery?
Markarian 421	HBL	0.031	Whipple
Markarian 501	HBL	0.034	Whipple
1ES 2344+514	HBL	0.044	Whipple
1ES 1959+650	HBL	0.048	
H 1426+428	HBL	0.129	Whipple
1ES 1218+304	HBL	0.182	
1ES 0806+524	HBL	0.138	Y
W Comae	IBL	0.102	Y
3C 66A	IBL	0.444 (?)	
RGB J0710+591	HBL	0.125	Y
PKS 1424+240	IBL	unknown	Y
RGB J0521.8+2112	HBL	unknown	Y
RBS 0413	HBL	0.190	Y
1ES 0502+675	HBL	unknown	Y
1ES 0229+200	HBL	0.140	
RXS J0648.7+1516	HBL	0.179	Y
1ES 0414+009	HBL	0.287	
PG 1553+113	HBL	unknown (>0.43)	
1ES 1440+122	IBL	0.162	Y
1ES 1215+303	HBL	0.130 (?)	

- Several blazars at $z>0.18$
- Will allow strong constraints on EBL

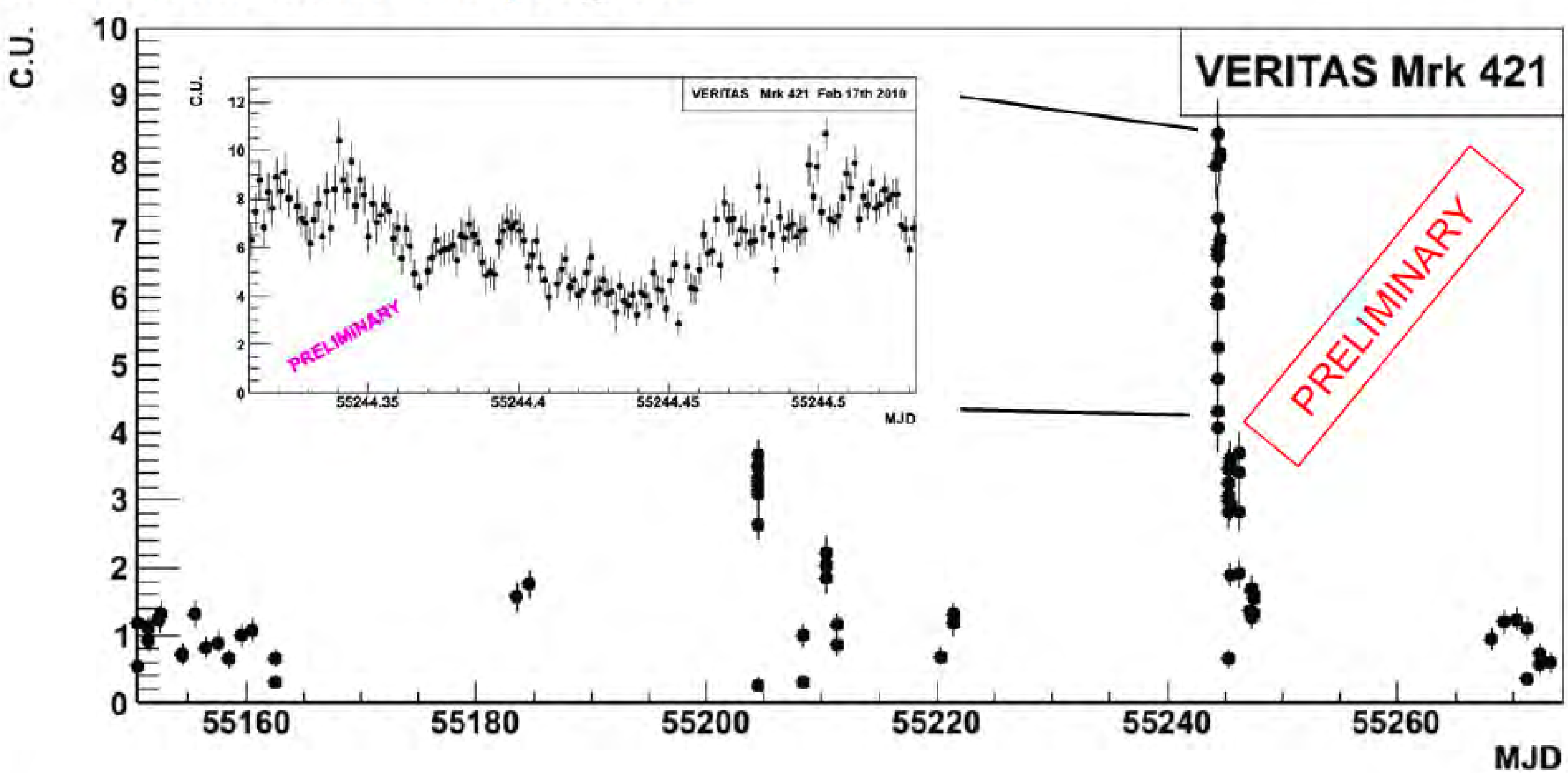
Extragalactic results II: the first triple-AGN field!



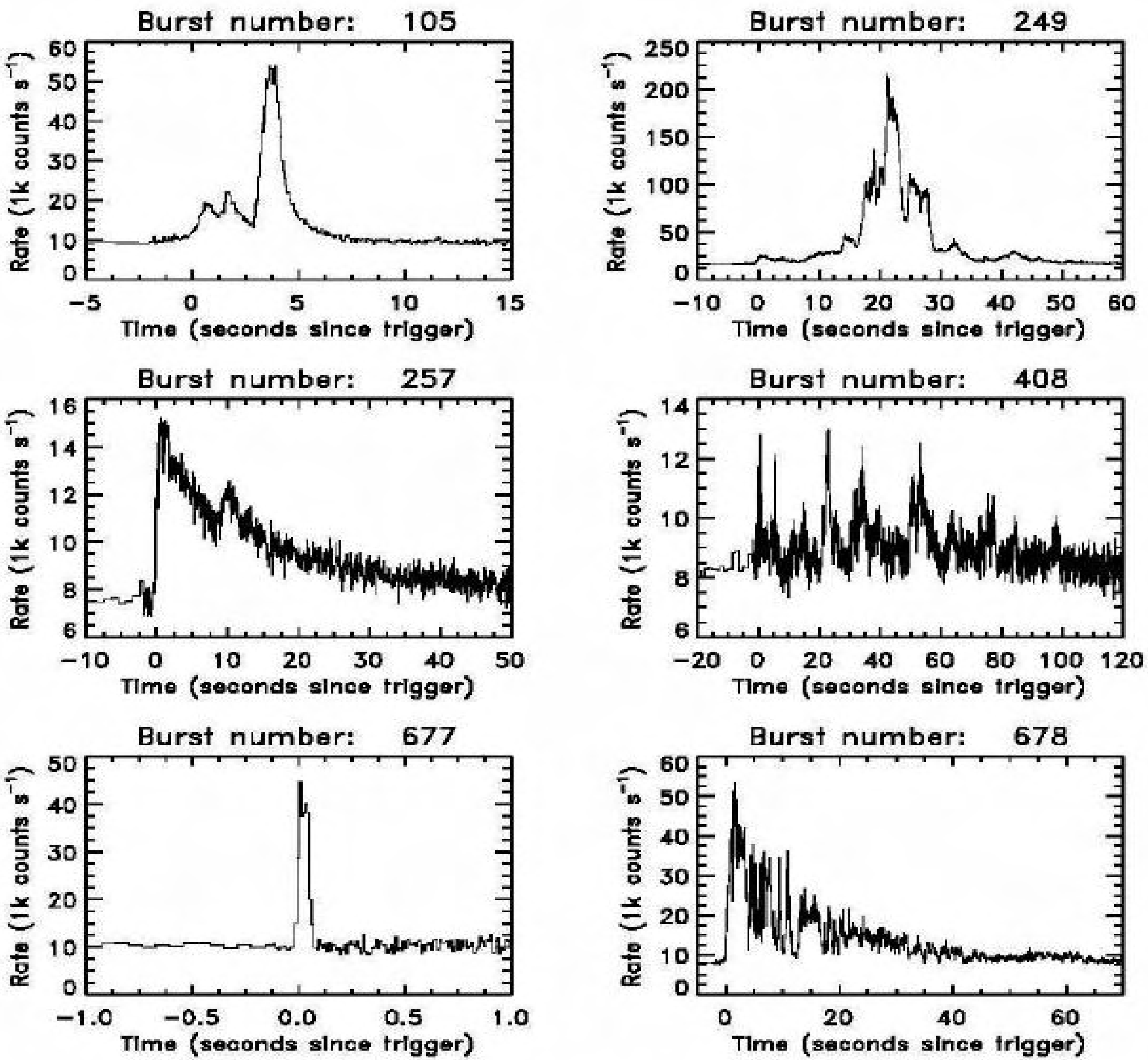
"Make that a trio…"

Extragalactic results III: Mrk 421 flaring

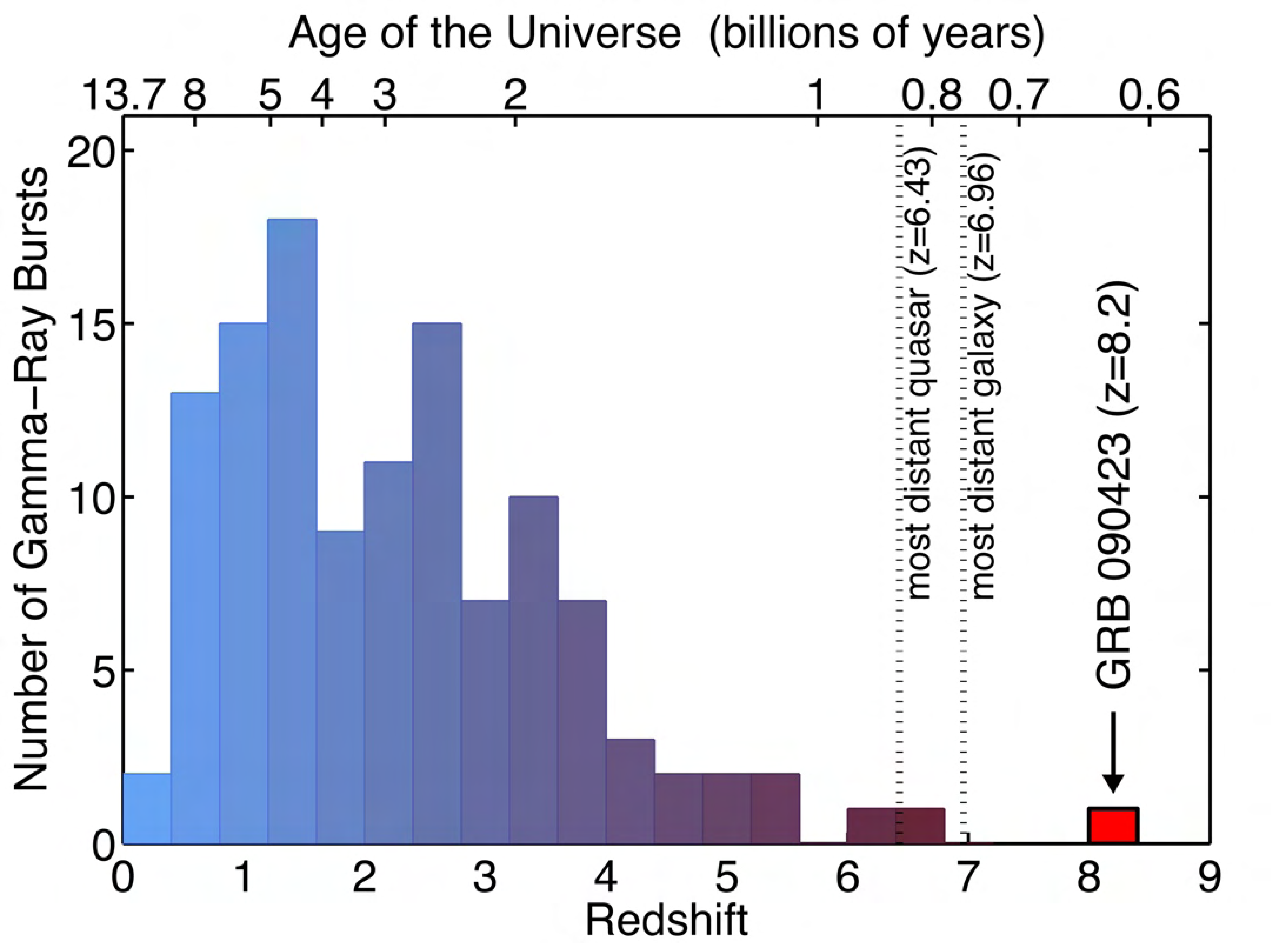
- Regular monitoring allows detections of flares
  → Deep observations and multiwavelength campaigns
- Ex.: Markarian 421 (Feb 2010) – flared to > 10x Crab Nebula
- Strong enough to allow 2-minute binning!
- Spectral-evolution studies in progress

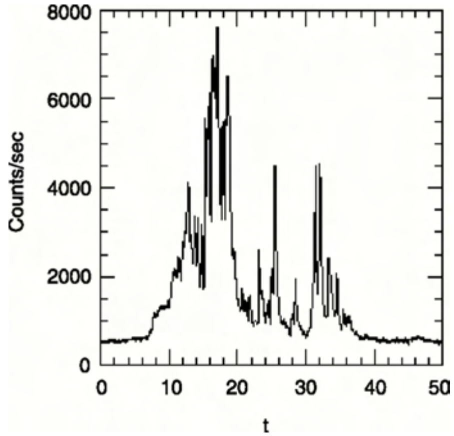


GAMMA RAY BURSTS (GRB's)

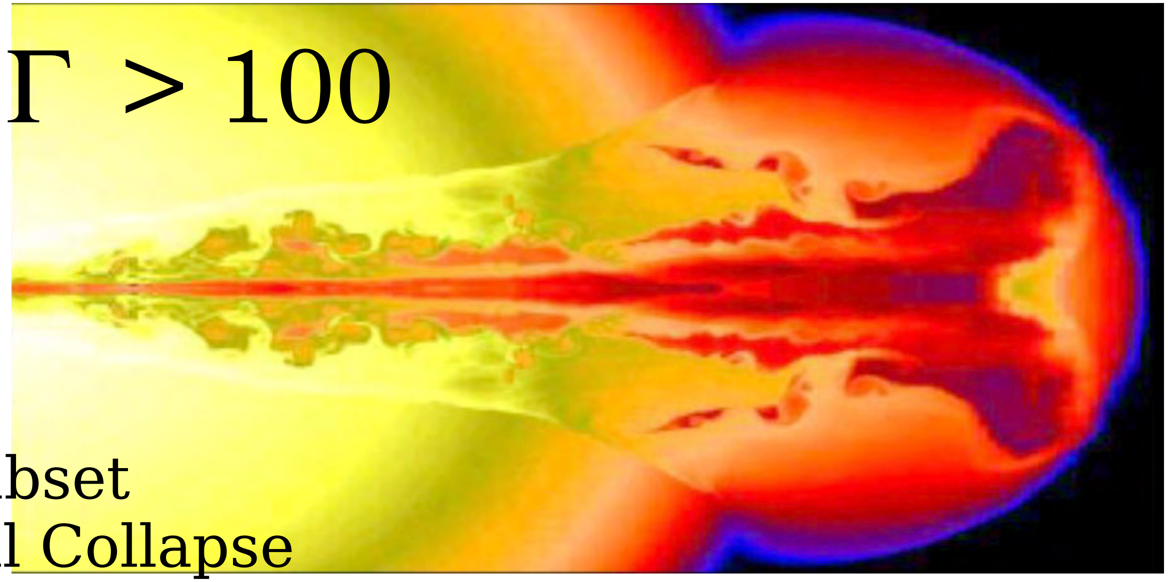


Proposed source
Of the CR

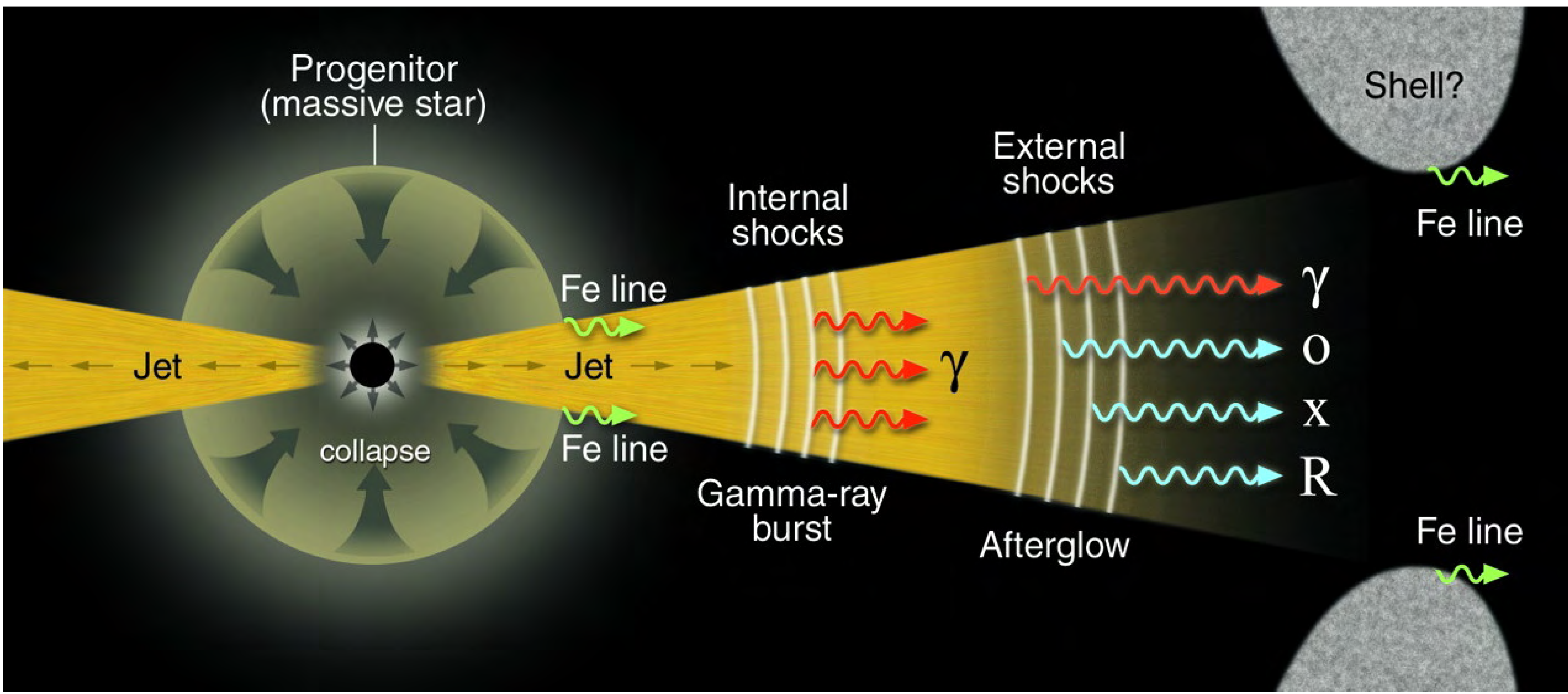

Age of the Universe (billions of years)
13.7 8 5 4 3 2 1 0.8 0.7 0.6
Number of Gamma-Ray Bursts
0
5
10
15
20
most distant quasar (z=6.43)
most distant galaxy (z=6.96)
GRB 090423 (z=8.2)
0 1 2 3 4 5 6 7 8 9
Redshift



$\Gamma > 100$

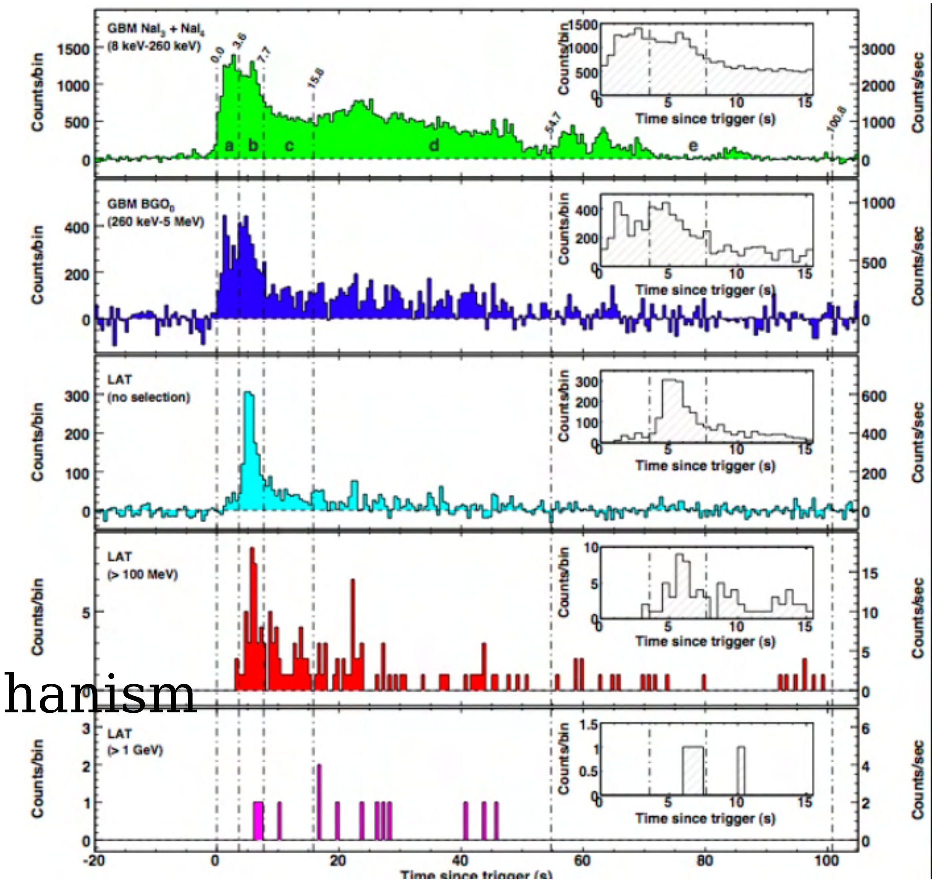


GRB : associated with a subset
of SN Stellar Gravitational Collapse



GRB 080916C
Z = 4.3
(Fermi)

Most Powerful emission
ever recorded
(assuming isotropy)
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.

GRB's Fermi detections

Bottom line

- The broad band spectra seen by Fermi **does not** fit into any of the frameworks of existing models.

- Fermi results forces us to re-think of questions that were thought to be solved.

Pe'er

Extraordinary amount of new information
From Gamma Astronomy

But some key/fundamental questions
About the high energy sources remain quite open

GRB
AGN
SNR
Pulsars
PWN

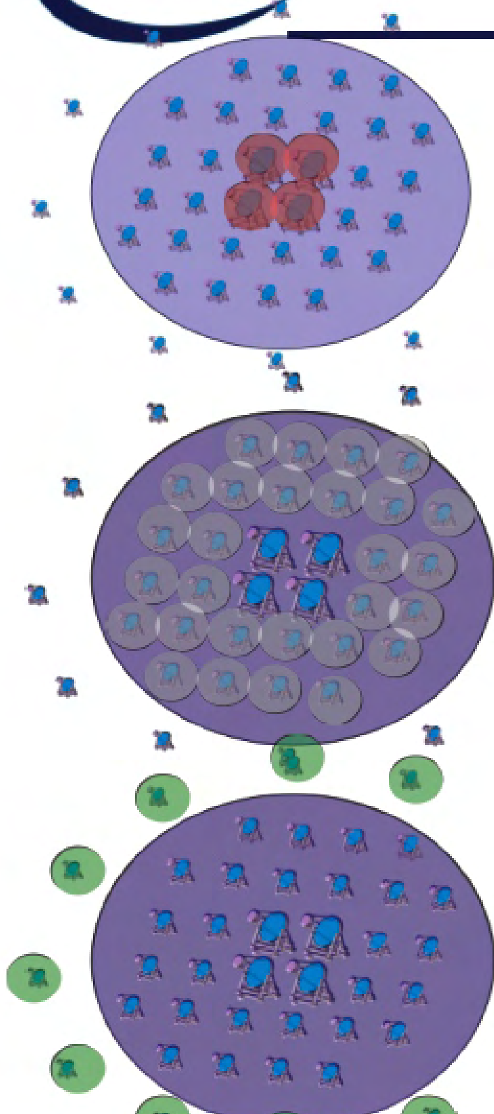
[Bright] Future for (ground based) Gamma Ray Astronomy

CTA

HAWC

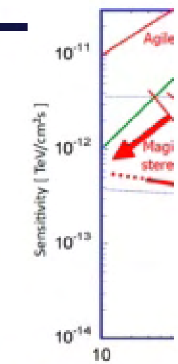
LHAASO

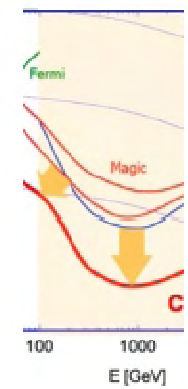
CTA concept



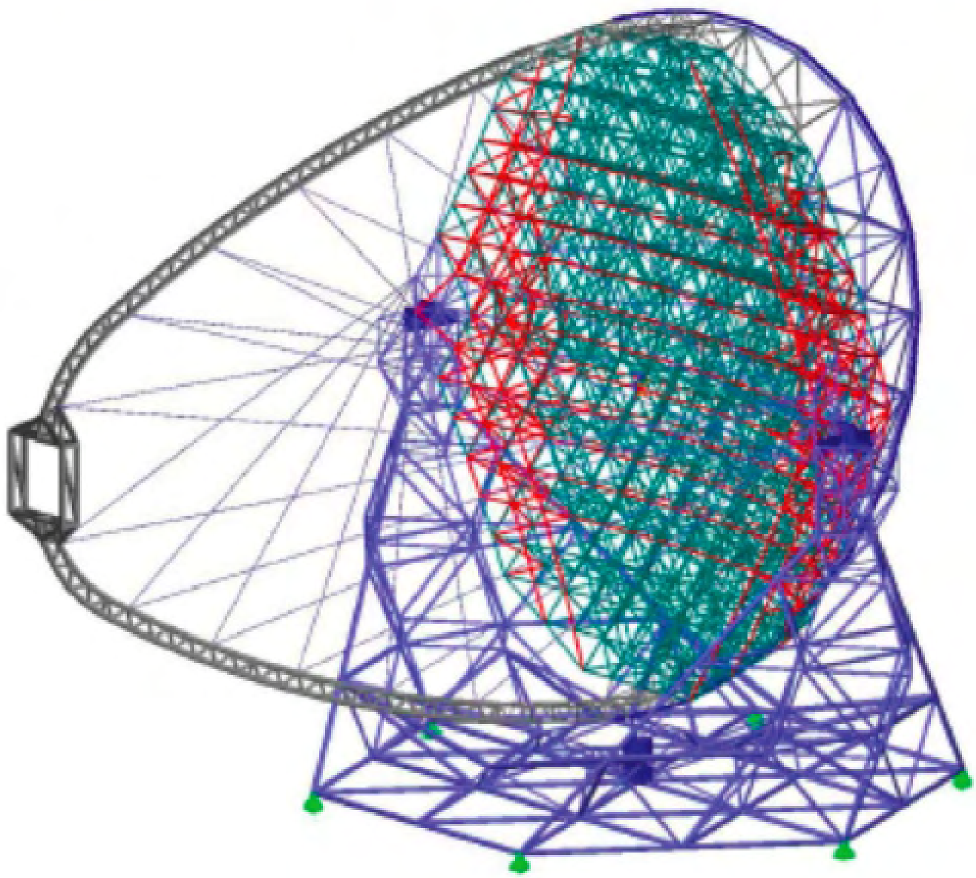
- Few Large Size Telescopes should catch the sub-100 GeV photons
  - Large reflective area
  - Parabolic profiles to maintain time-stamp
  - Contained FOV
- Several Medium Size Telescopes perform 100 GeV-50 TeV observation
- well-proven techniques (HESS, MAGIC)
- goal is to reduce costs and maintenance
- core of the array
- act as VETO for LSTs

- Several Small Size Telescopes perform ultra-50 TeV observation
- challenging design
- Large field-of-view (8°)
- New camera technology



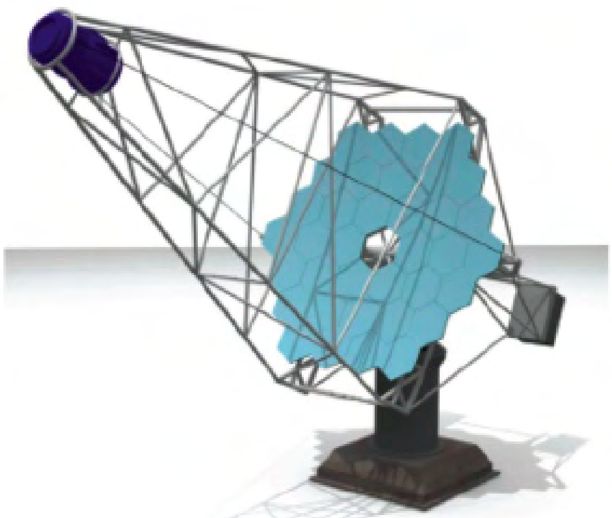


Large Size Telescope



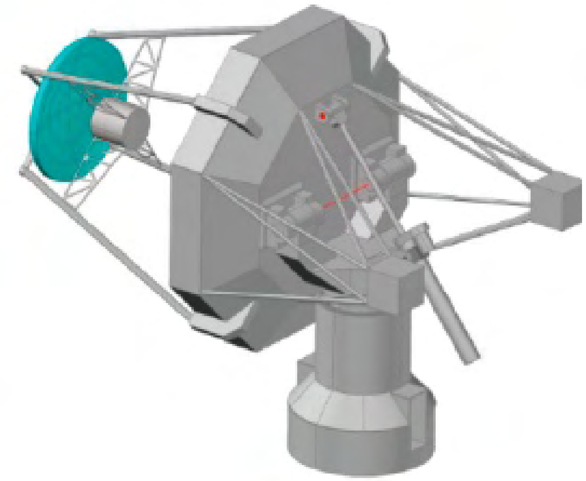
- Dish Diameter D=23m
- Focal length F=28m
- F/D=1.2
- FOV=4.5 degrees
- Pixel size=0.1 degrees

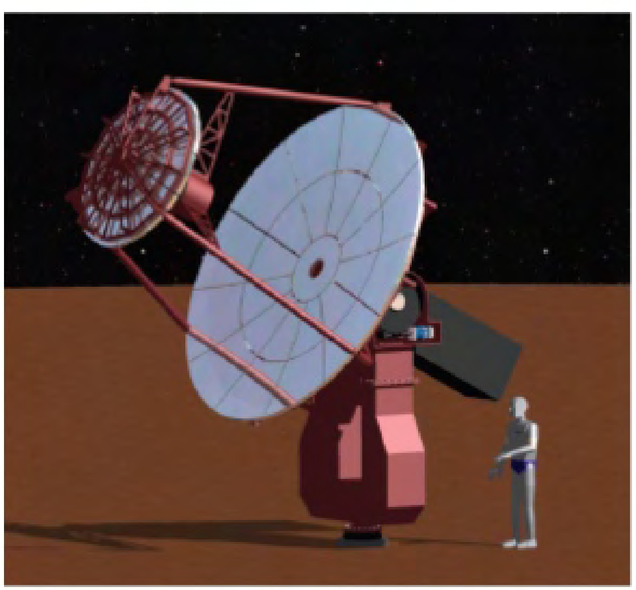
Small Size Telescope



3 different designs:

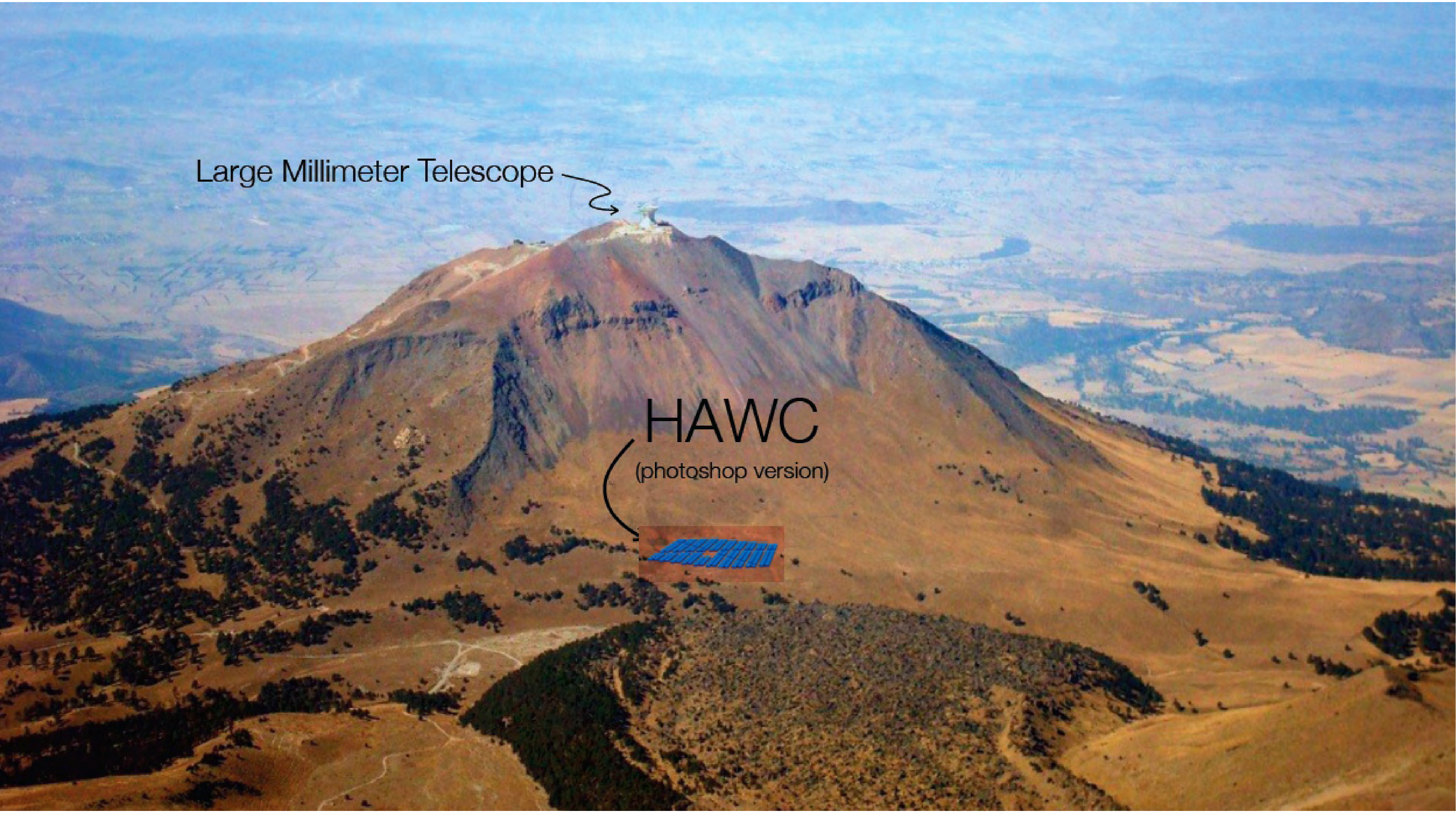
- -1 Polish D-C
- -1 Italian S-C
- -1 Anglo-French S-C





Primary Mirror diameter: 4.3 m (tessellated)
Secondary Mirror diameter: 1.8 m (monolithic)
F#: 0.5
Equivalent focal length: 2150 mm
FoV diameter: 9.6 degrees
Pixel: 0.16°

HAWC



Project Overview LHAASO

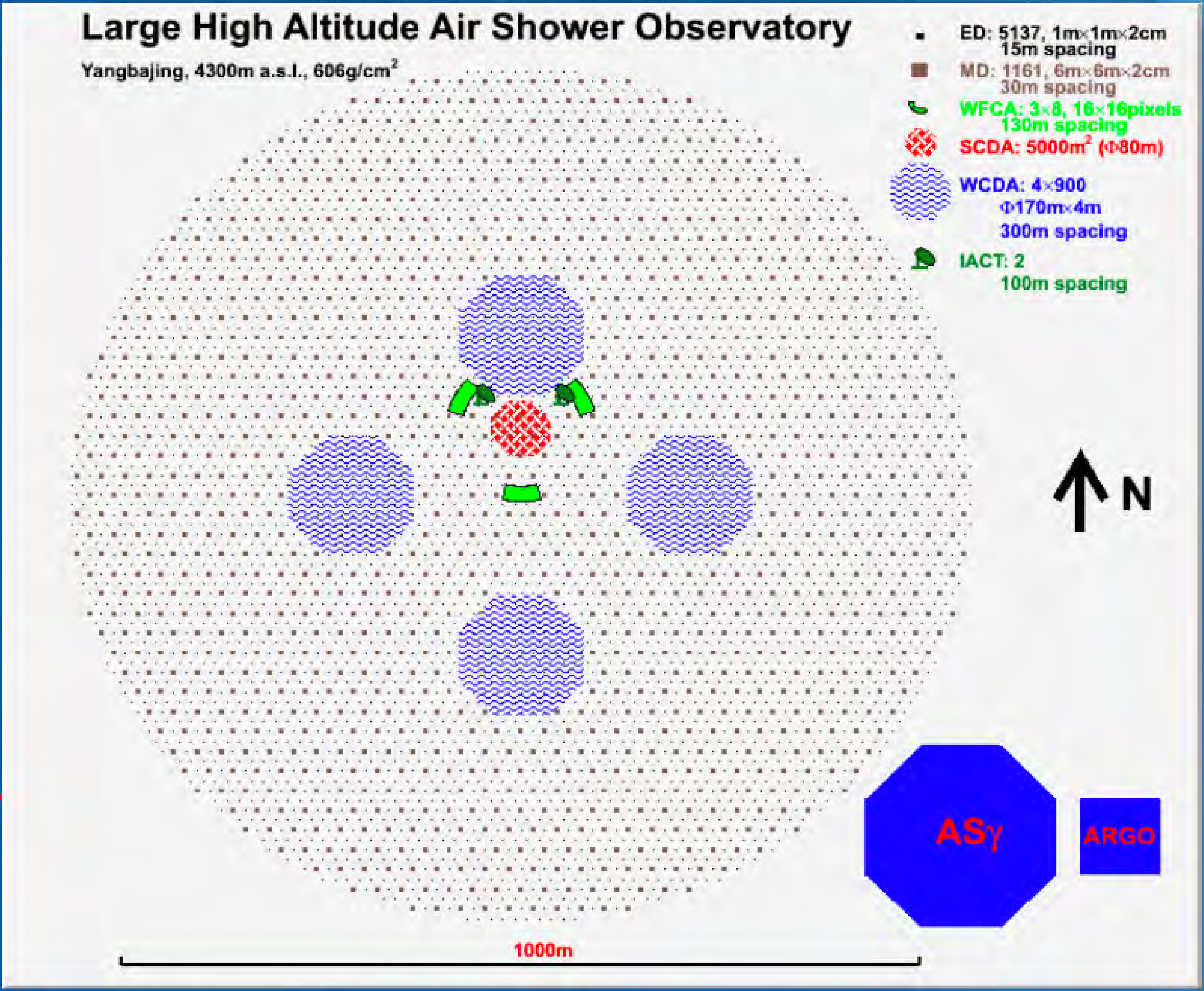
Charged Particle Array

K Detector Array

Water C Array

Wide FOV C-Telescope Array &

Core Detector Array



The Cosmic Ray spectrum

Sharp feature at 230 GV [Pamela] [?!]

proton/nuclei/electron/positron/antiproton acceleration

Anisotropies [Milagro, Argo, IceCube, ...]

The Knee

From the "knee" to the "ankle" [Kascade Grande]
2 knees ? 3 knees ?? ......

Galactic to extra-galactic transition

UHECR [Auger, HiRes, Telescope Array]

PAMELA

detector

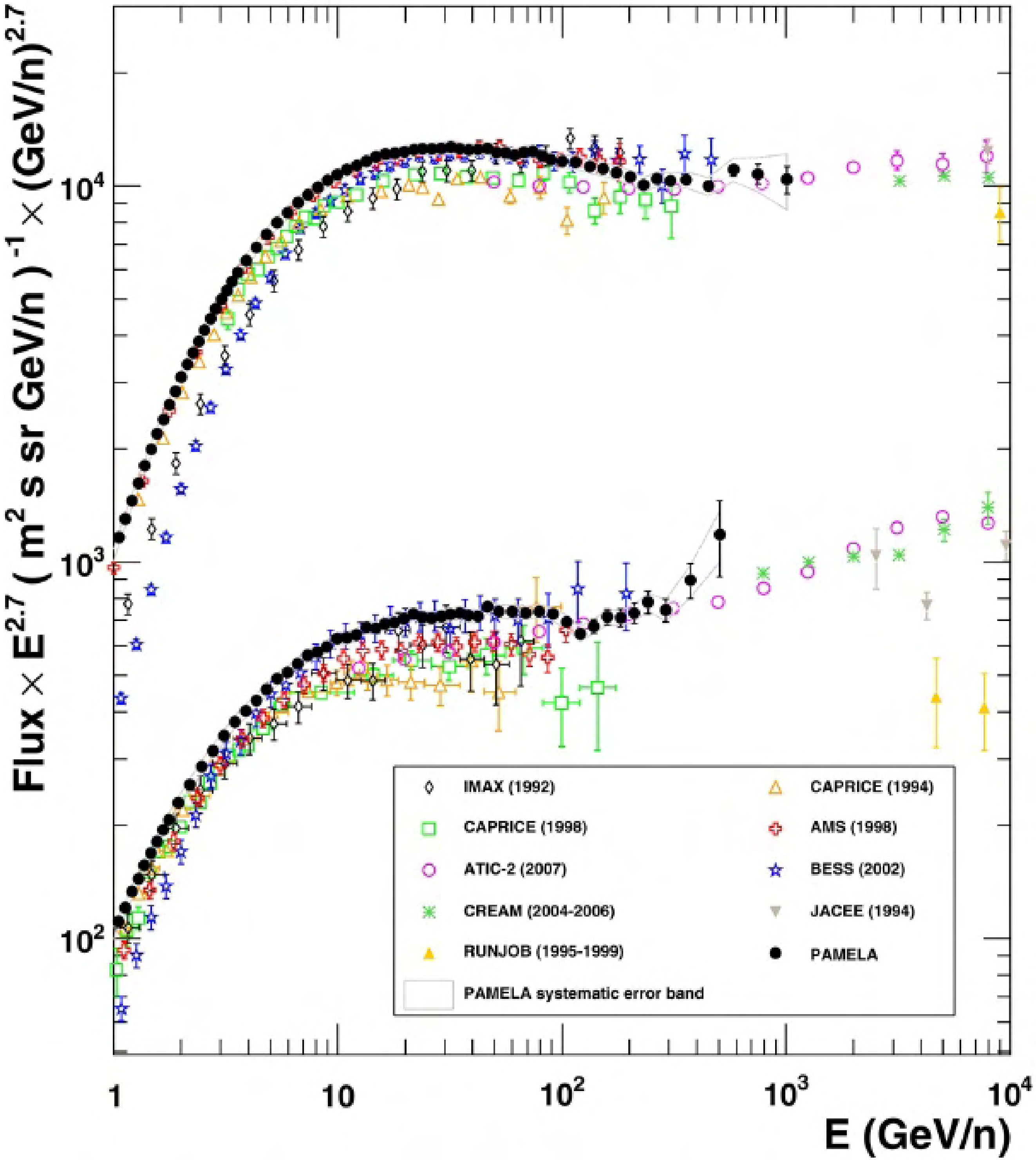
Launch
15th june 2006

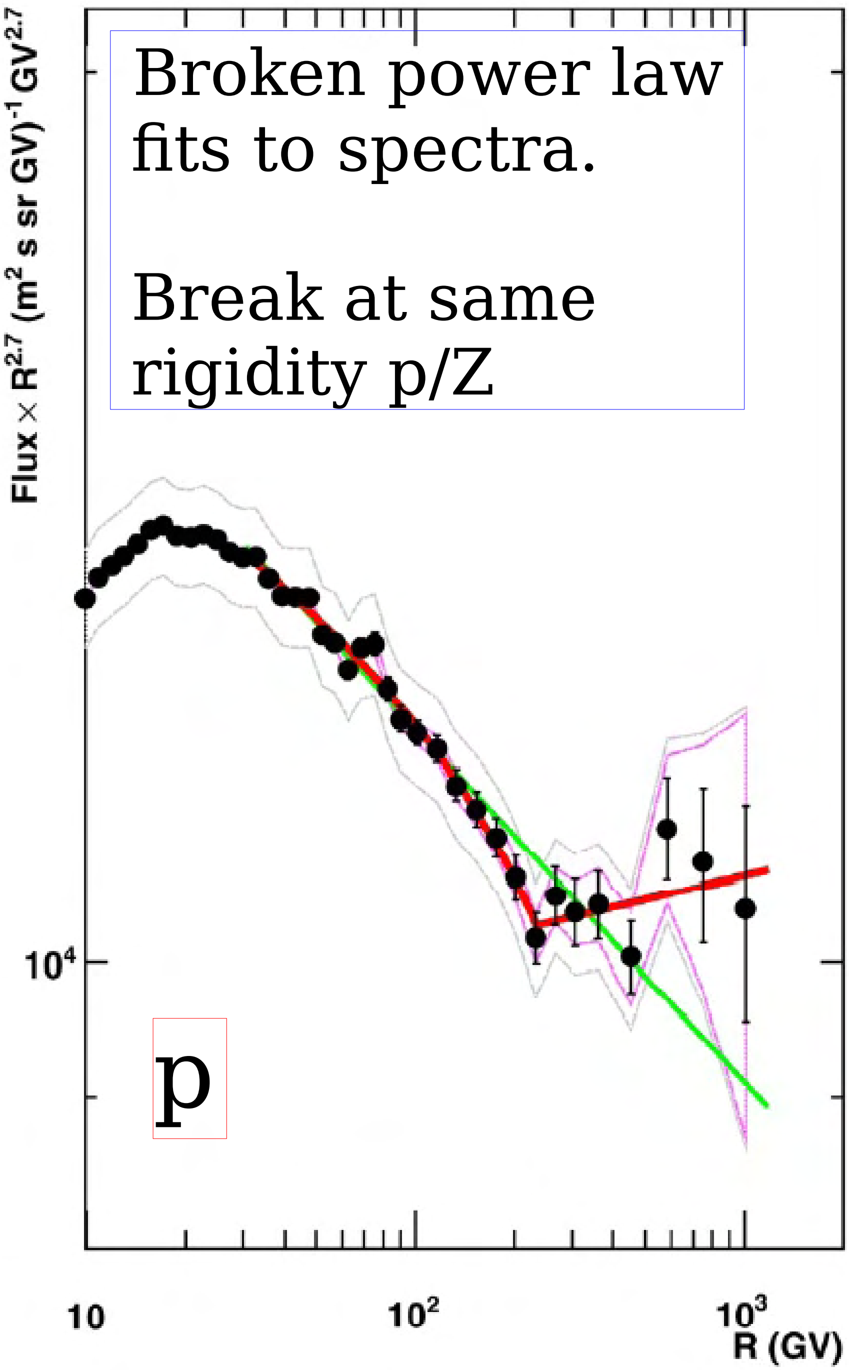
The "positron excess":
Evidence for DM ??
or astrophysical effect ?

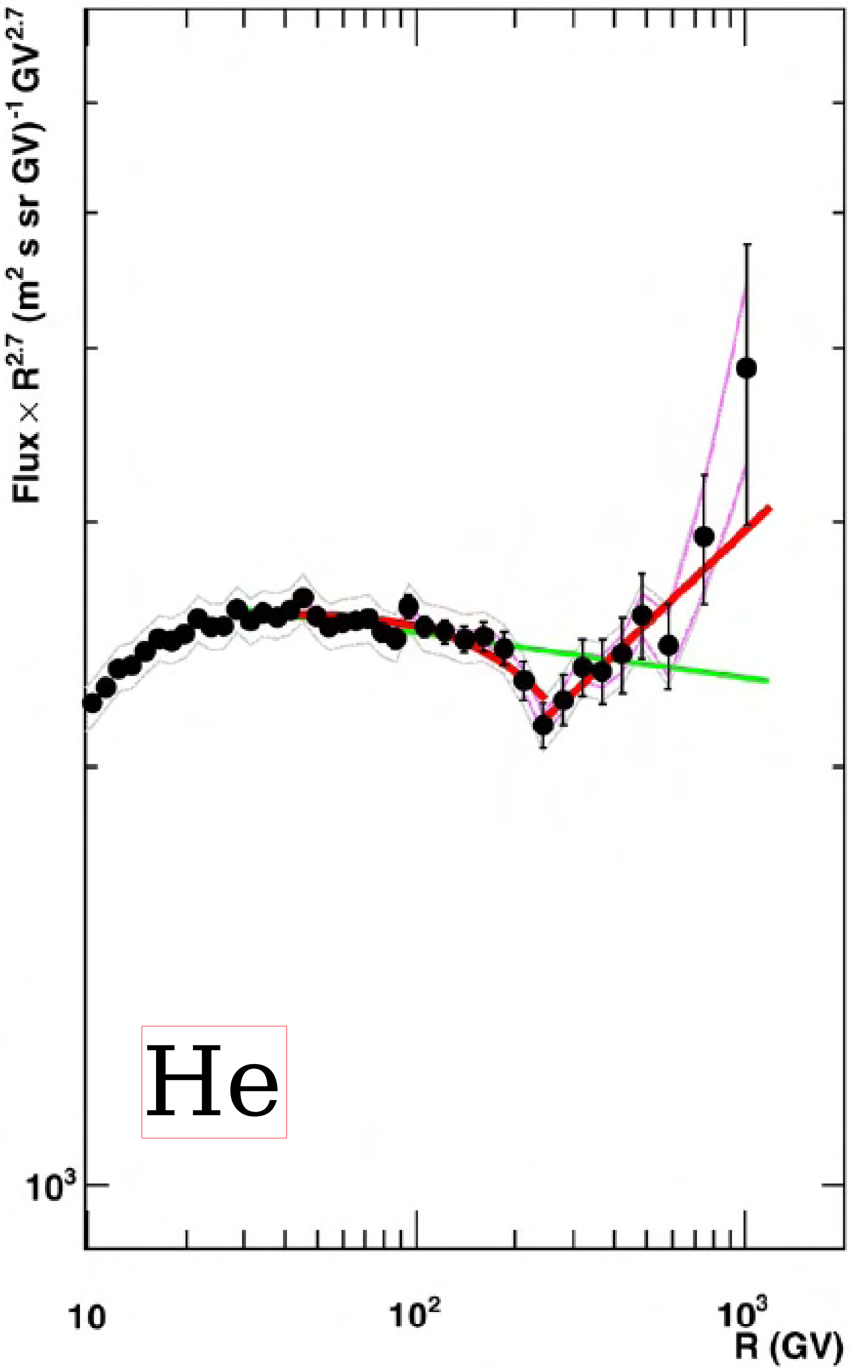
PAMELA

Proton/Helium
CR fluxes
1 GV – 1.2 TV

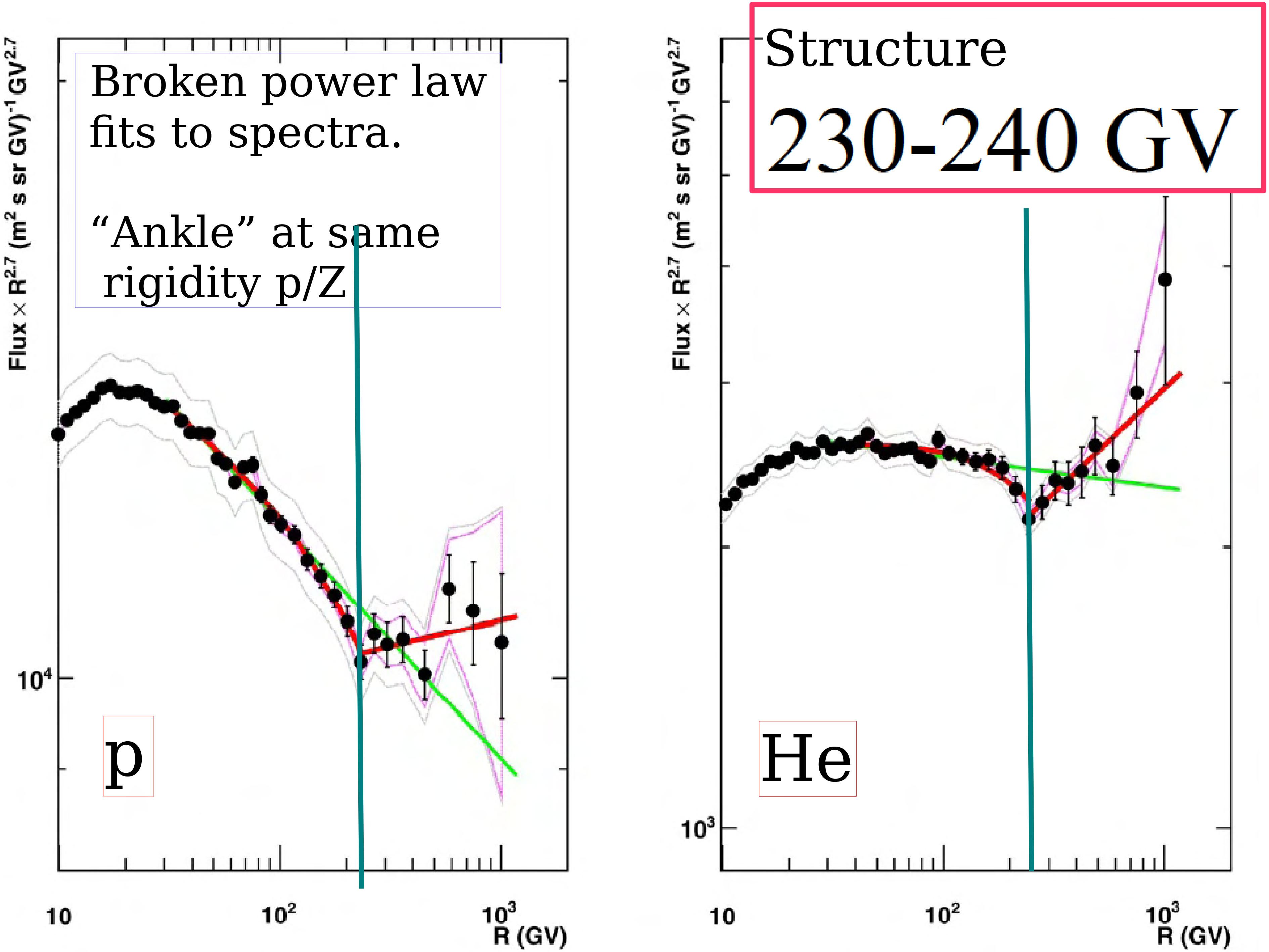
Science in press
(march 2011)







Surprising and important result.



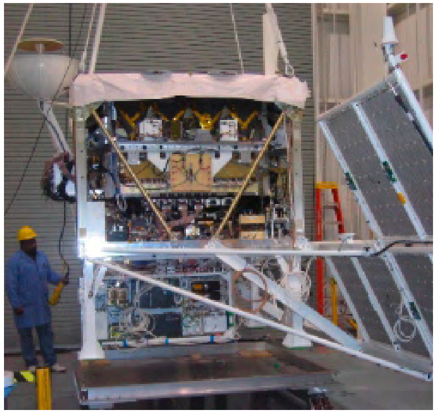
Surprising and important result.

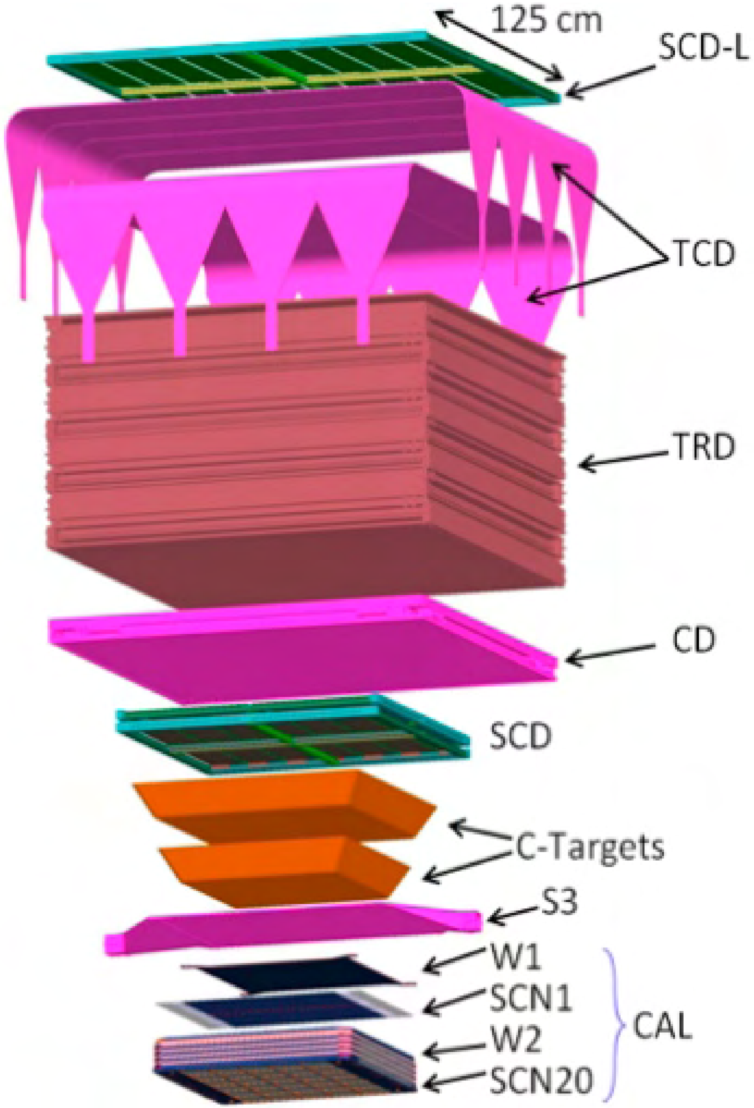
Sciencexpress Report

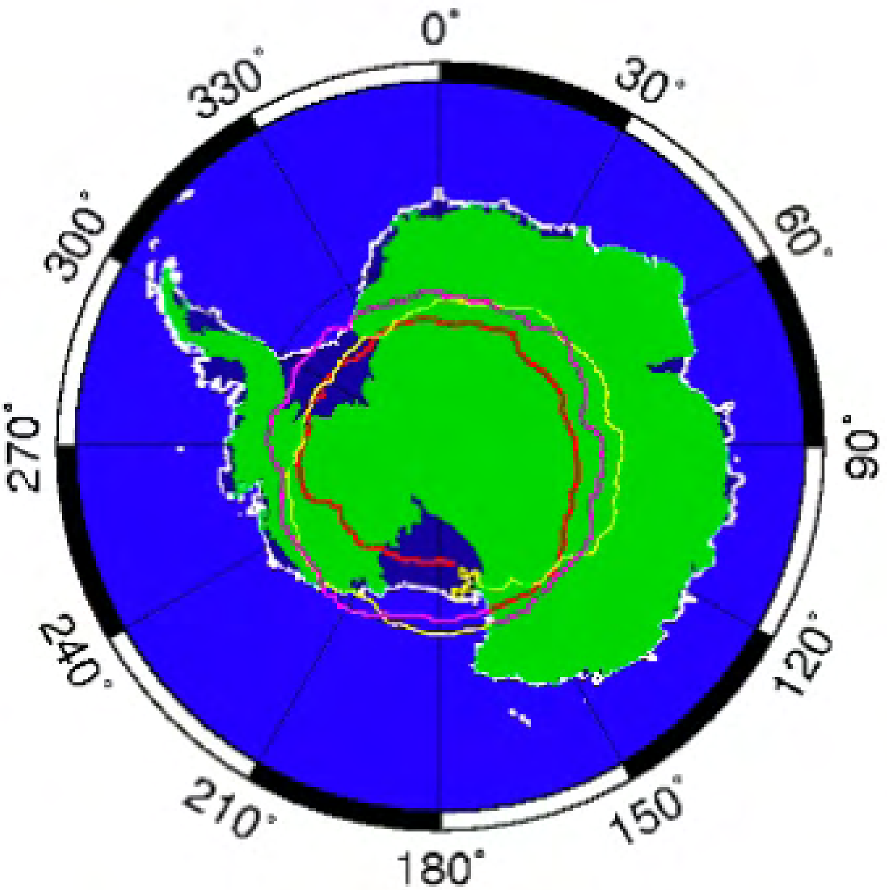
PAMELA Measurements of Cosmic-Ray Proton and Helium Spectra

We report precision measurements of the proton and helium spectra in the rigidity range 1 GV-1.2 TV performed by the satellite-borne experiment PAMELA. We find that the spectral shapes of these two species are different and cannot be well described by a single power law. These data challenge the current paradigm of cosmic-ray acceleration in supernova remnants followed by diffusive propagation in the Galaxy. More complex processes of acceleration and propagation of cosmic rays are required to explain the spectral structures observed in our data.

CREAM (calorimeter on balloon)
(5 flights in Antartica. Total of 156 days)

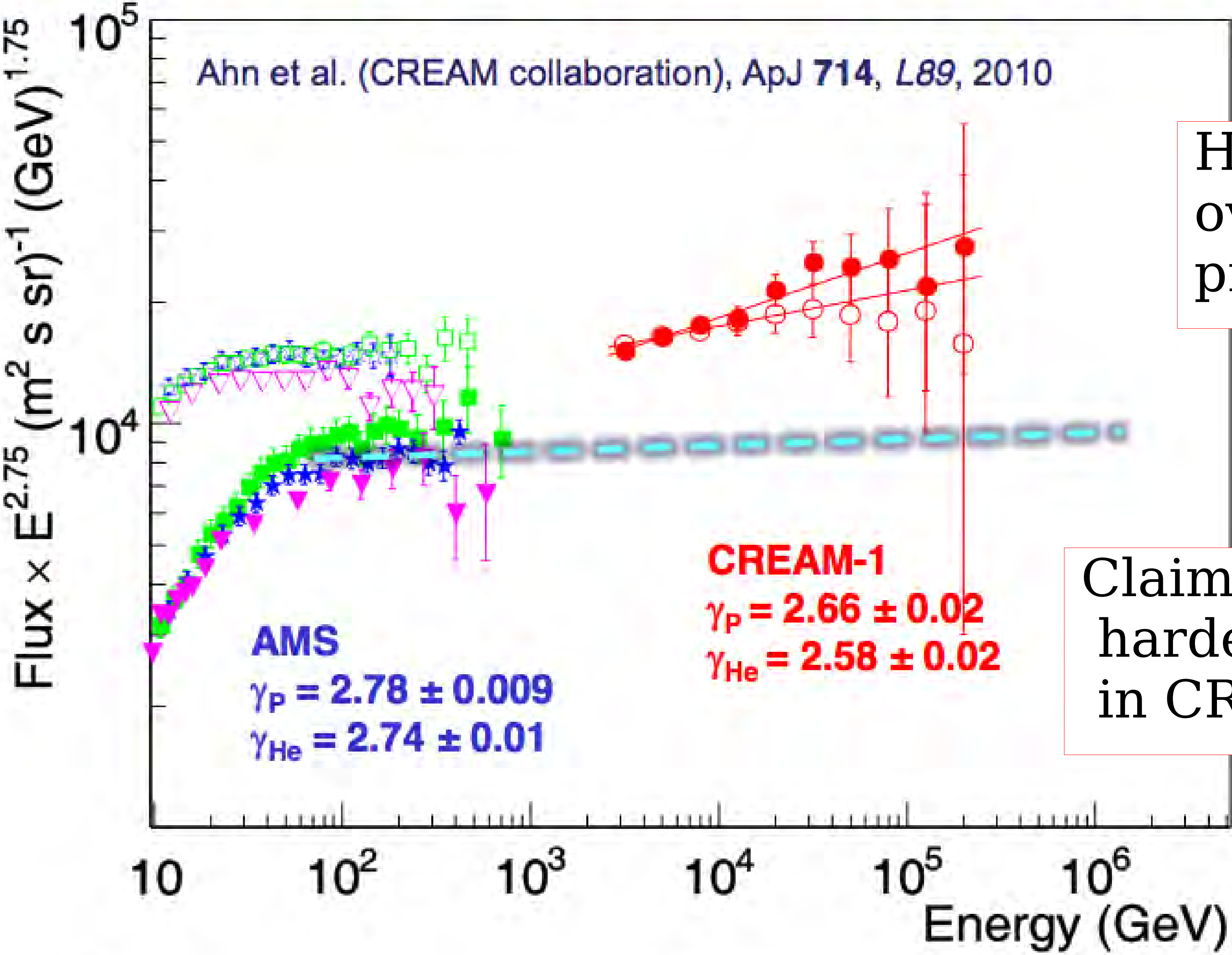






Cream 5 trajectory
37 days 12/2009-01/2010

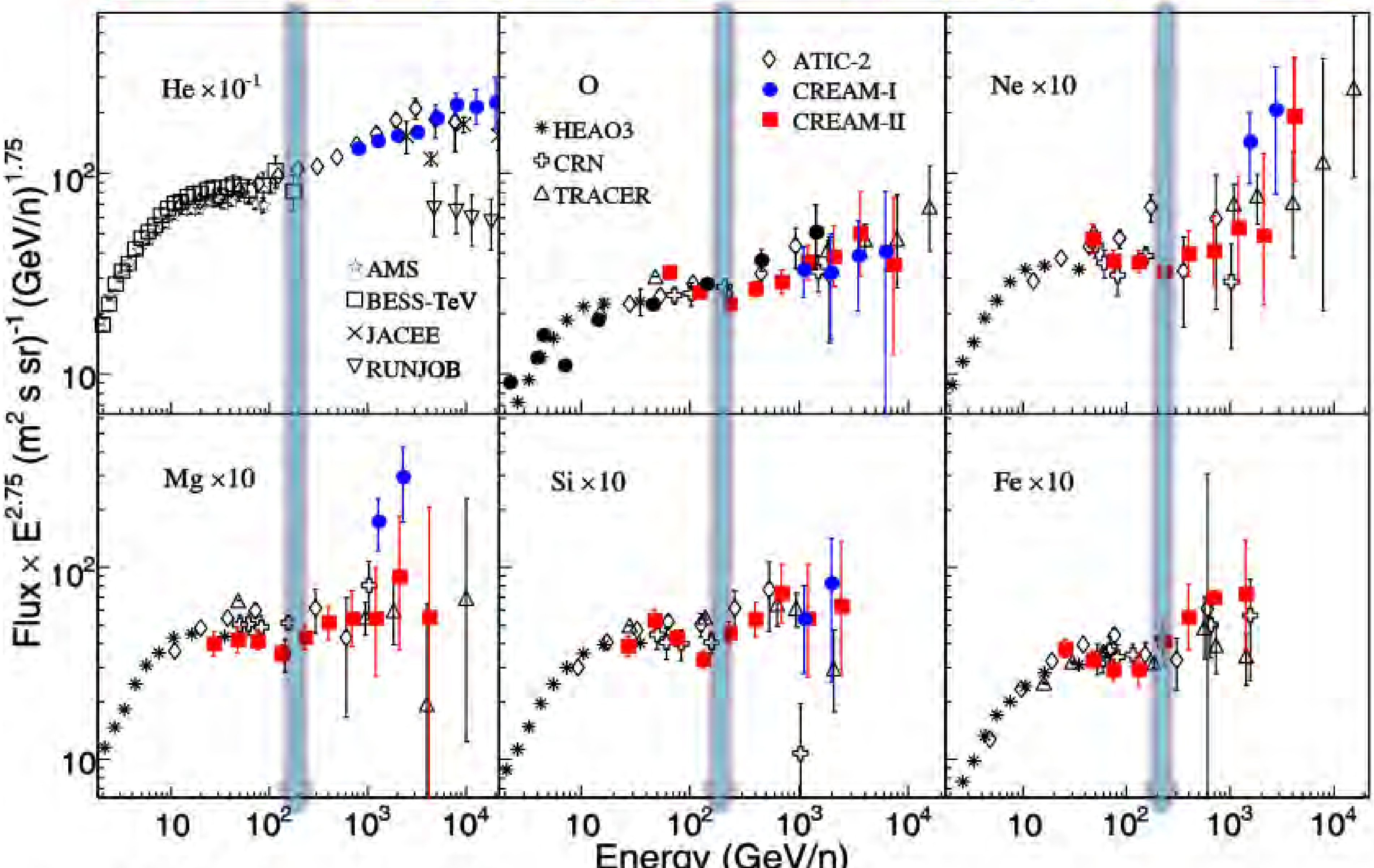
TeV spectra are harder than spectra < 200 GeV/n

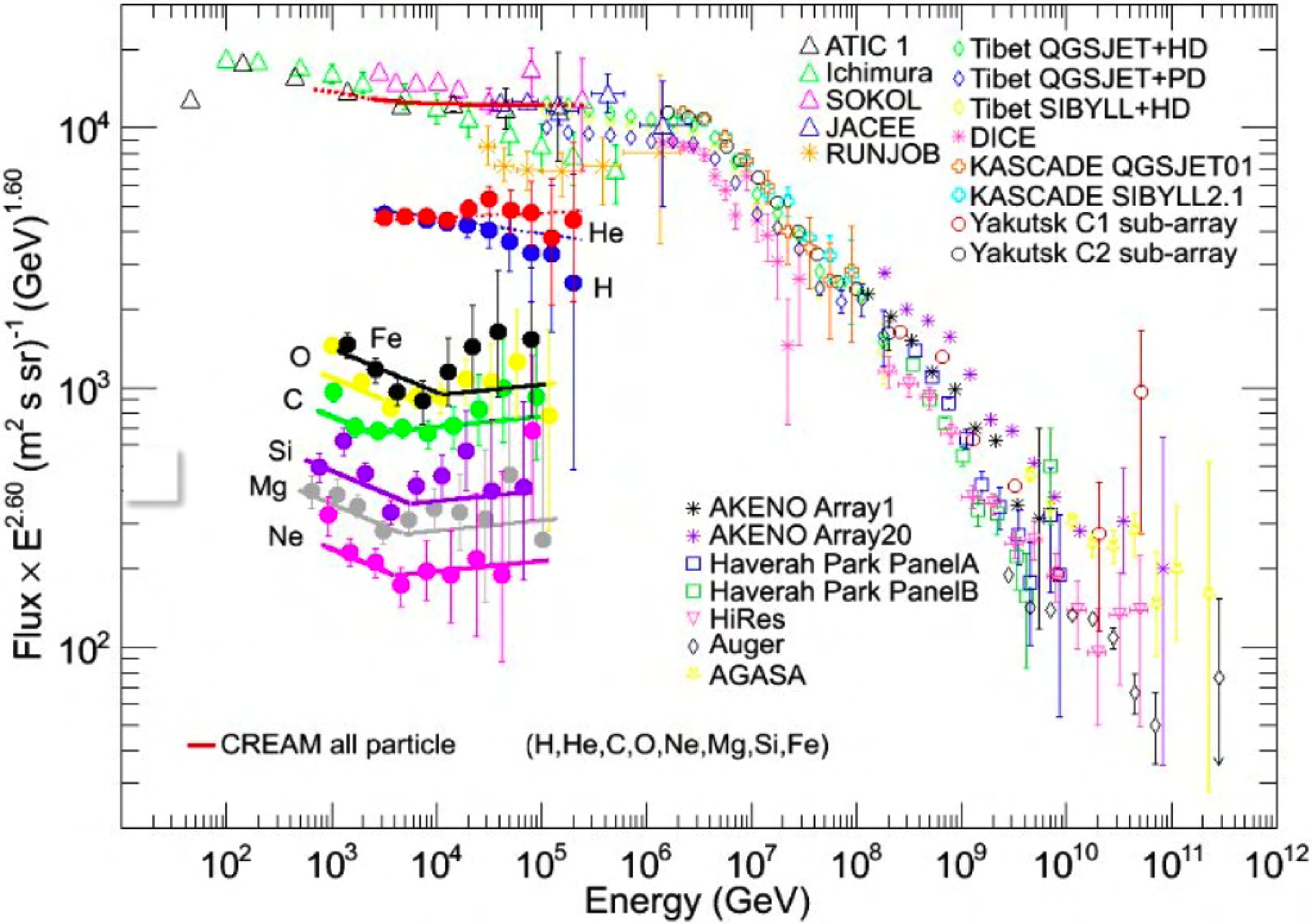


Helium overtakes protons (!)

Claim of “break” hardening in CR spectra

Discrepant hardening



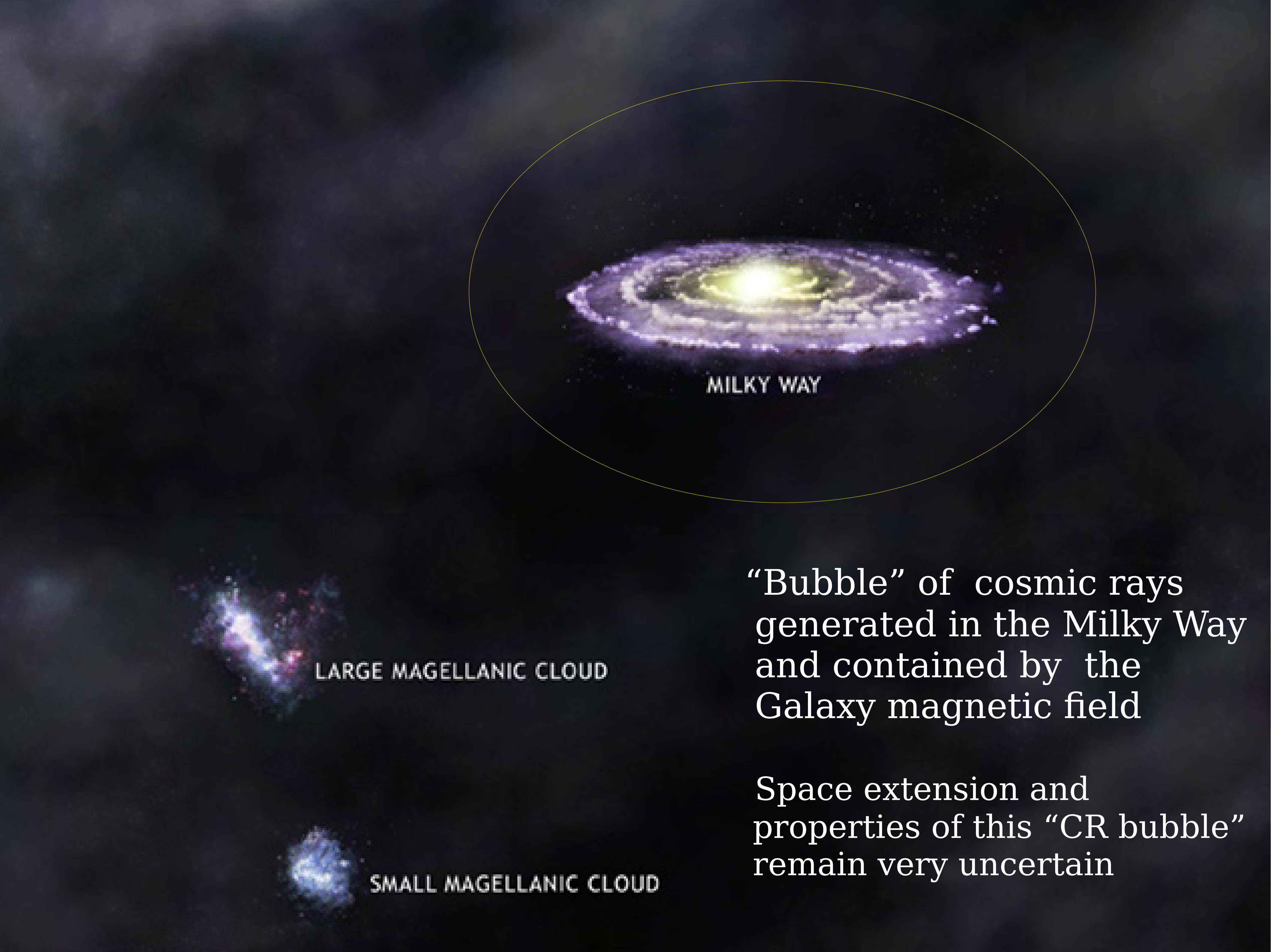


ATIC 1
Ichimura
SOKOL
JACEE
RUNJOB
Tibet QGSJET+HD
Tibet QGSJET+PD
Tibet SIBYLL+HD
DICE
KASCADE QGSJET01
KASCADE SIBYLL2.1
Yakutsk C1 sub-array
Yakutsk C2 sub-array
He
H
Fe
O
C
Si
Mg
Ne
AKENO Array1
AKENO Array20
Haverah Park PanelA
Haverah Park PanelB
HiRes
Auger
AGASA
CREAM all particle
(H,He,C,O,Ne,Mg,Si,Fe)
Flux × E^2.60 (m^2 s sr)^-1 (GeV)^1.60
Energy (GeV)


+00 00 31

COSMIC RAY

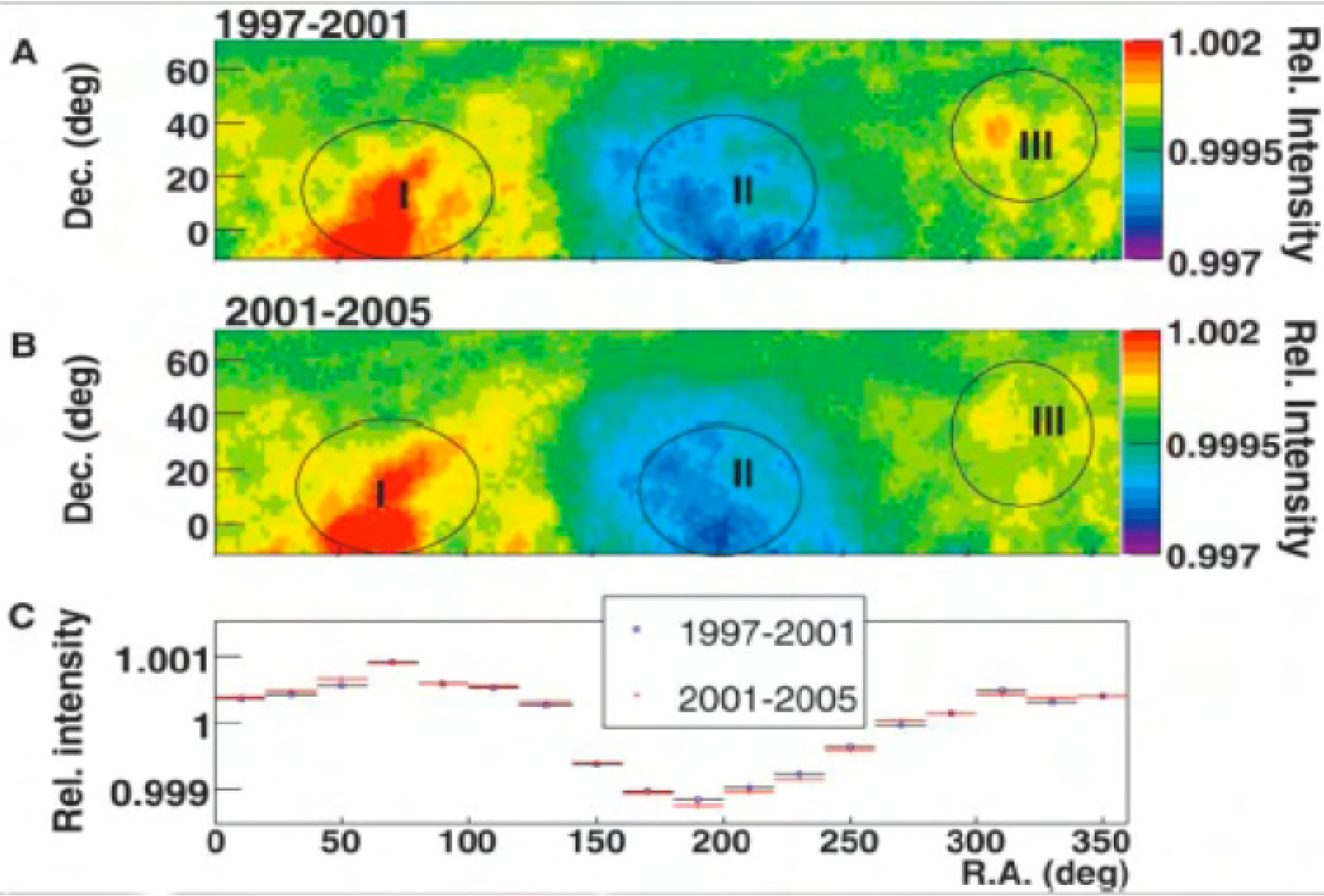
ANISOTROPIES



“Bubble” of cosmic rays generated in the Milky Way and contained by the Galaxy magnetic field

Space extension and properties of this “CR bubble” remain very uncertain

Tibet ASγ (verified by ARGO + IceCube)



M. Amenomori et.al. Science, 2006

TIBET AS-Gamma

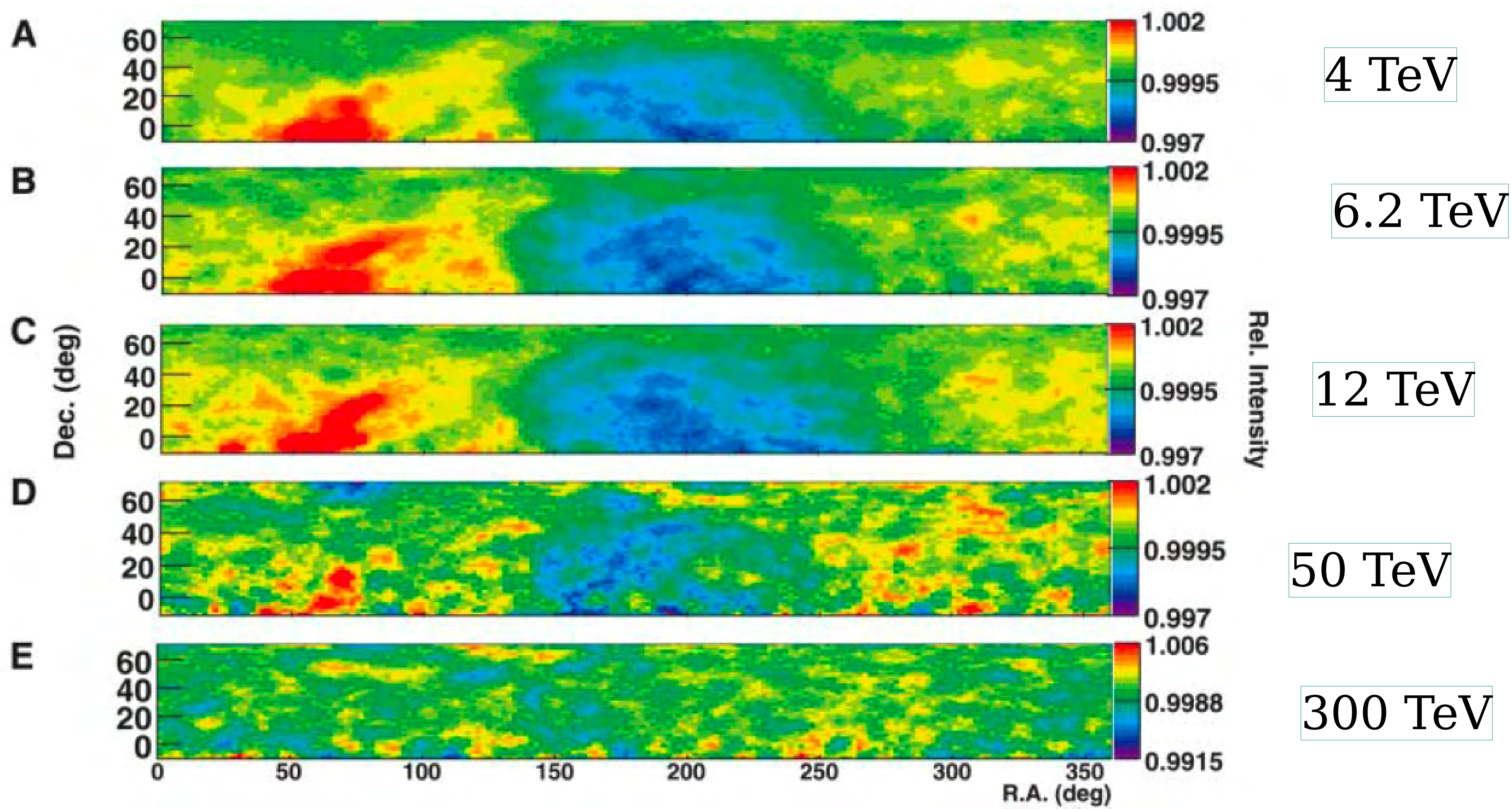
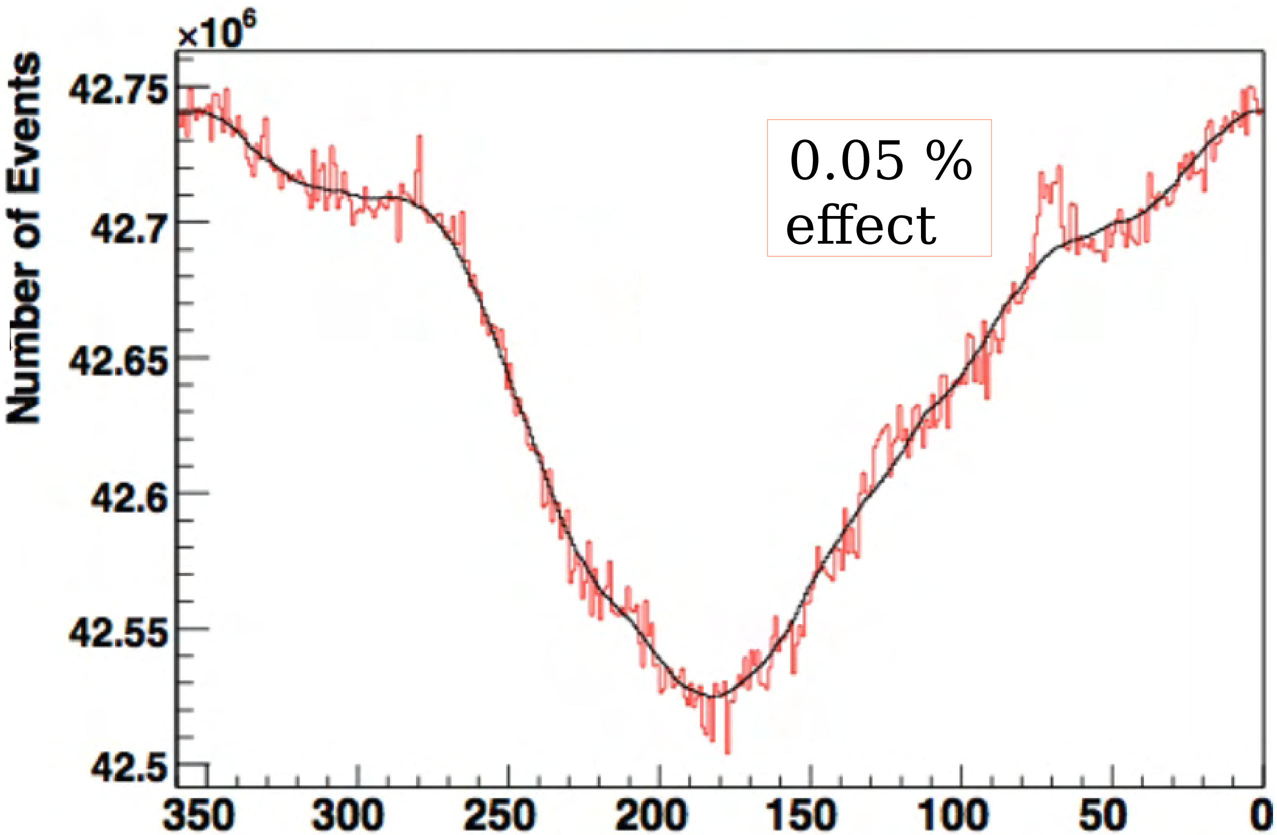


Fig. 3. Celestial CR intensity map for different representative CR energies. (**A**) 4 TeV; (**B**) 6.2 TeV; (**C**) 12 TeV; (**D**) 50 TeV; (**E**) 300 TeV. Data were gathered from 1997 to 2005. The vertical color bin width is 2.5×10^{-4} in [(A) to (D)] and 7.25×10^{-4} in (E) for different statistics, all for the relative CR intensity.

MILAGRO data (10 TeV hadrons).

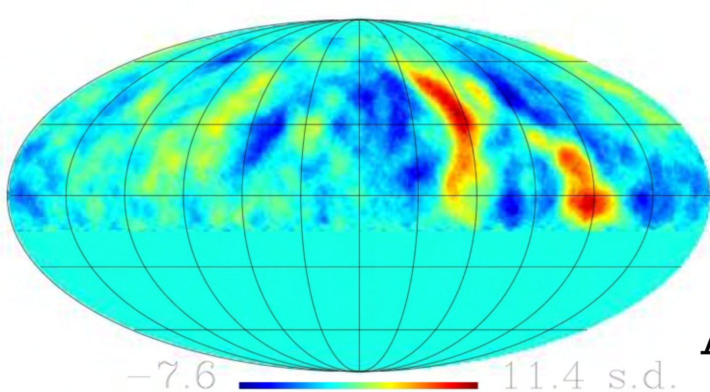


Right ascension

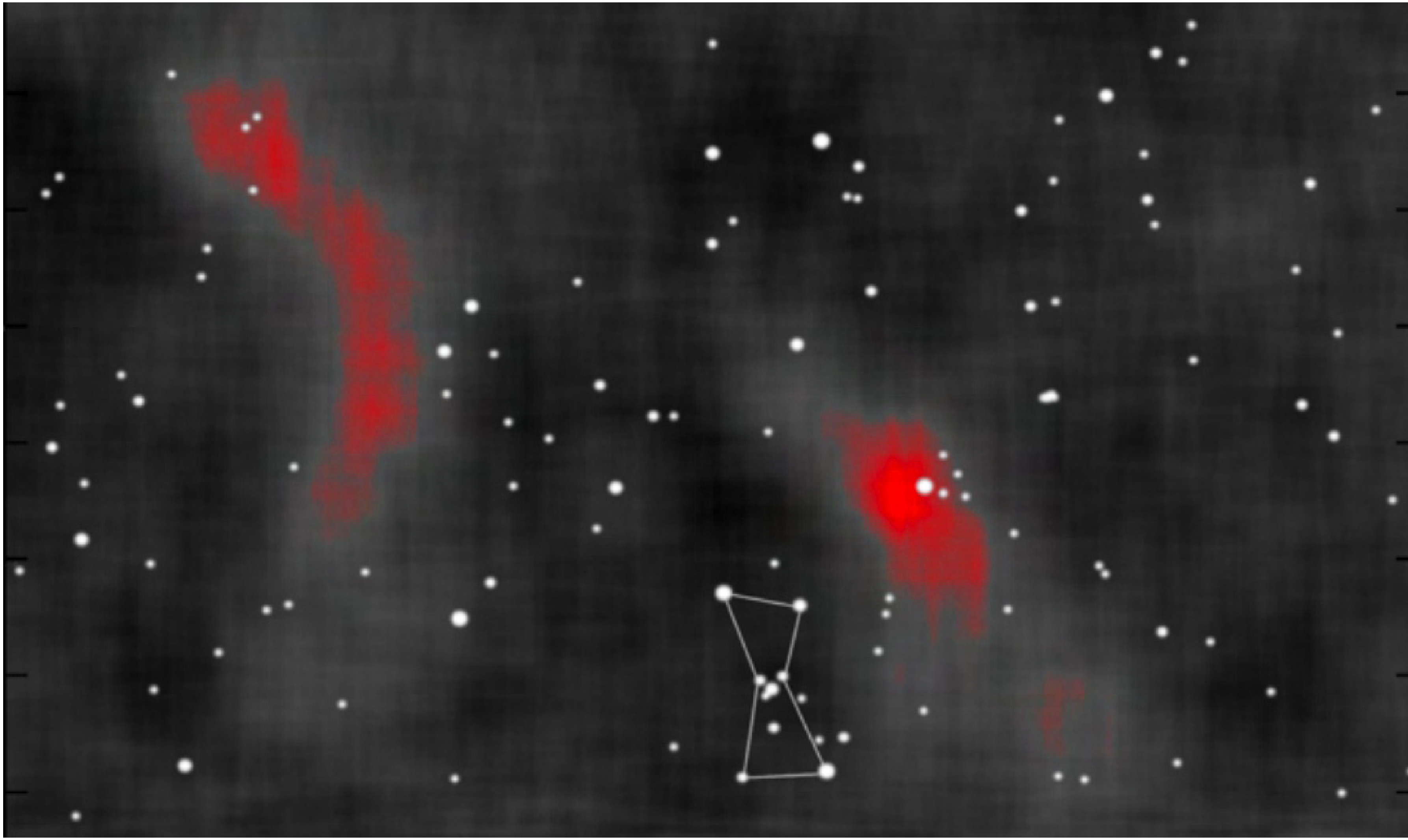
0.5 %
effect

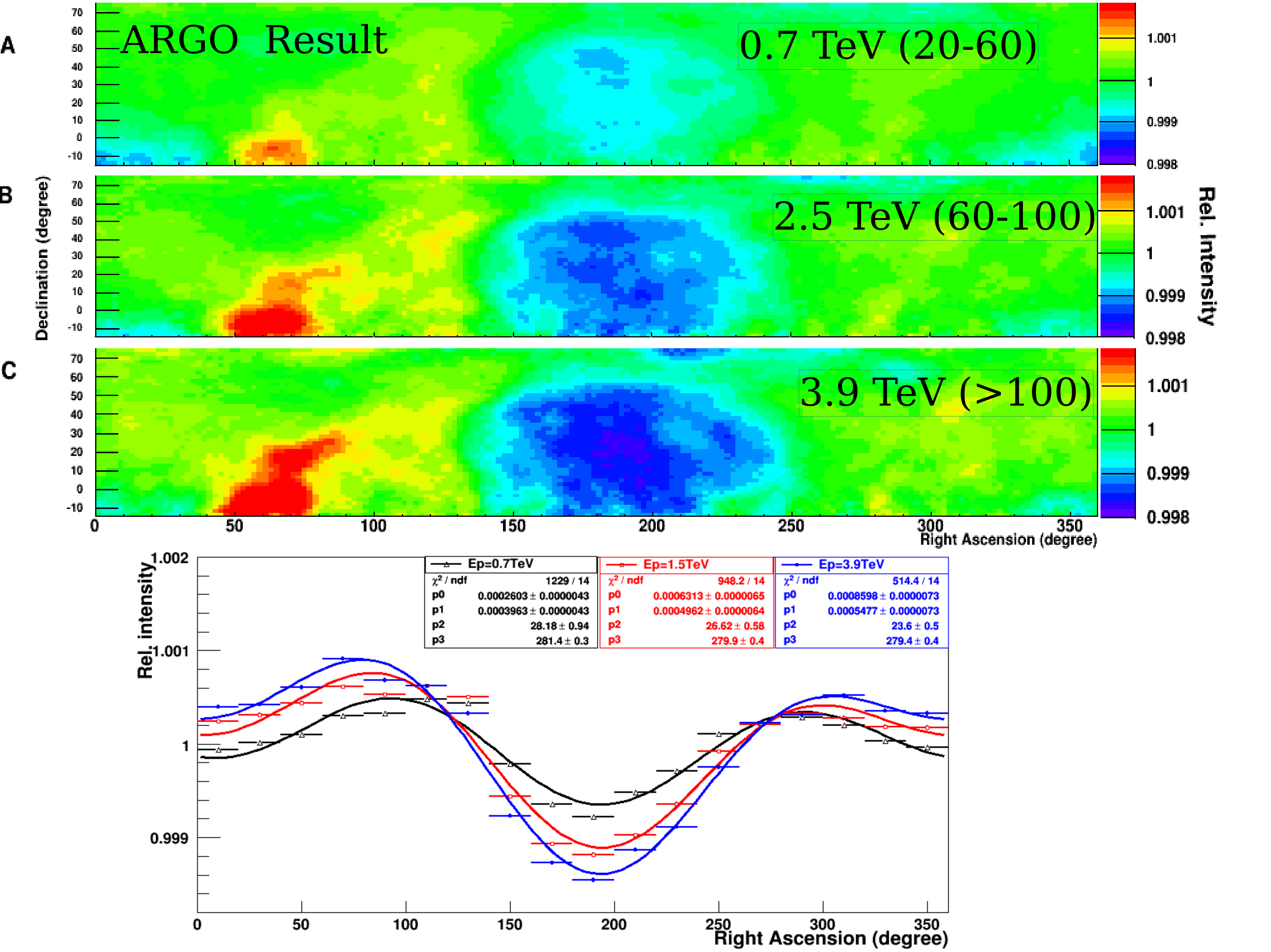
Milagro “hot spots”

2



Argo

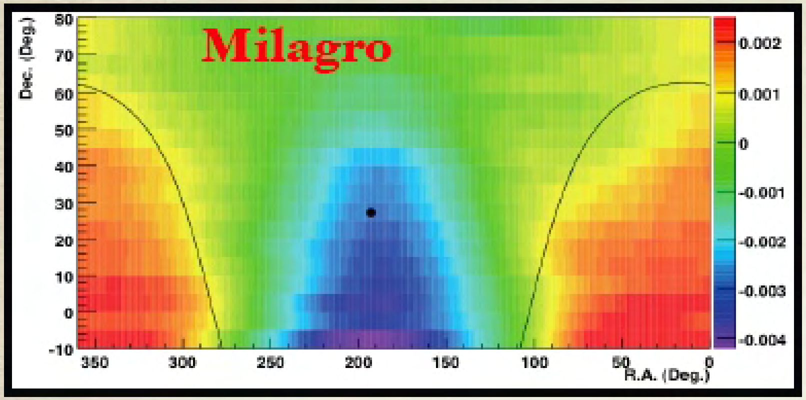


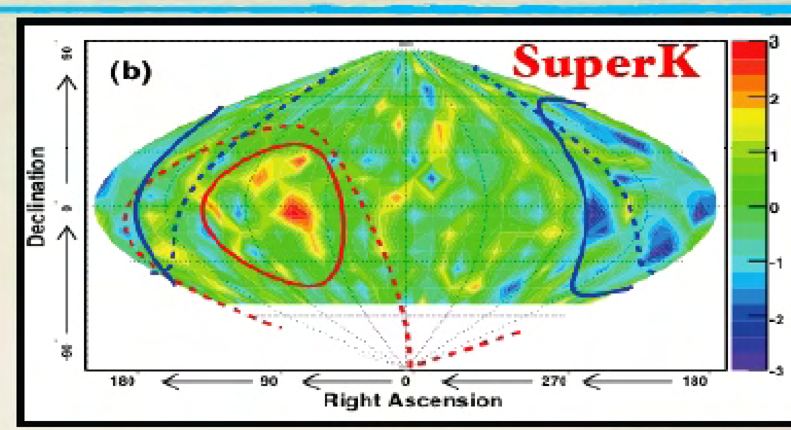


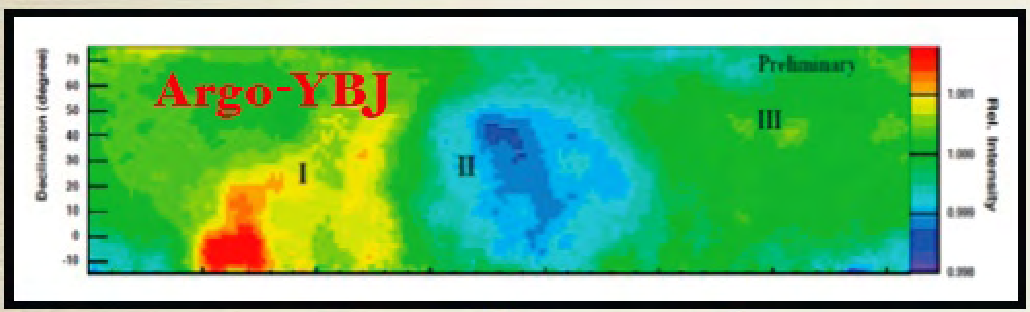
A
ARGO Result
0.7 TeV (20-60)
B
2.5 TeV (60-100)
C
3.9 TeV (>100)
Declination (degree)
Rel. Intensity
1.001
1
0.999
0.998
Right Ascension (degree)
Ep=0.7TeV
χ² / ndf 1229 / 14
p0 0.0002603 ± 0.0000043
p1 0.0003963 ± 0.0000043
p2 28.18 ± 0.94
p3 281.4 ± 0.3
Ep=1.5TeV
χ² / ndf 948.2 / 14
p0 0.0006313 ± 0.0000065
p1 0.0004962 ± 0.0000064
p2 26.62 ± 0.58
p3 279.9 ± 0.4
Ep=3.9TeV
χ² / ndf 514.4 / 14
p0 0.0008598 ± 0.0000073
p1 0.0005477 ± 0.0000073
p2 23.6 ± 0.5
p3 279.4 ± 0.4
Rel. intensity
Right Ascension (degree)

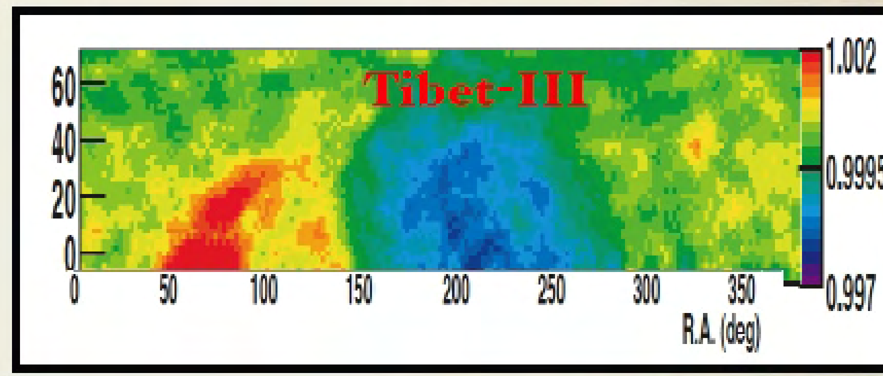
Observation of the CRs large scale anisotropy

There have been several observations of *large-scale, part- per-mille anisotropy* in cosmic ray arrival directions between 0.1 and 100 TeV.

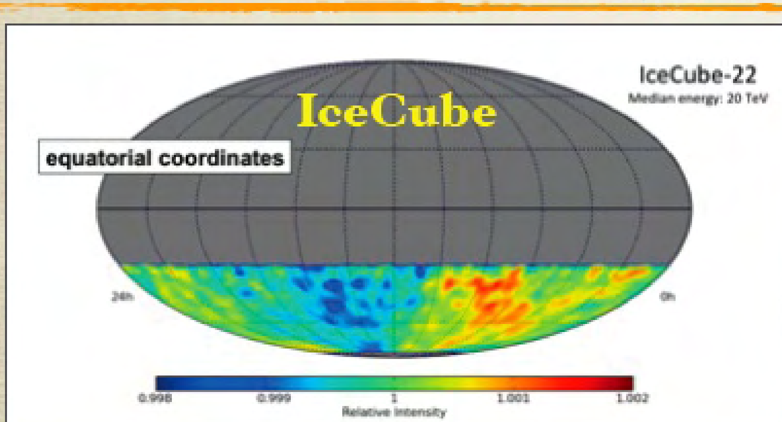






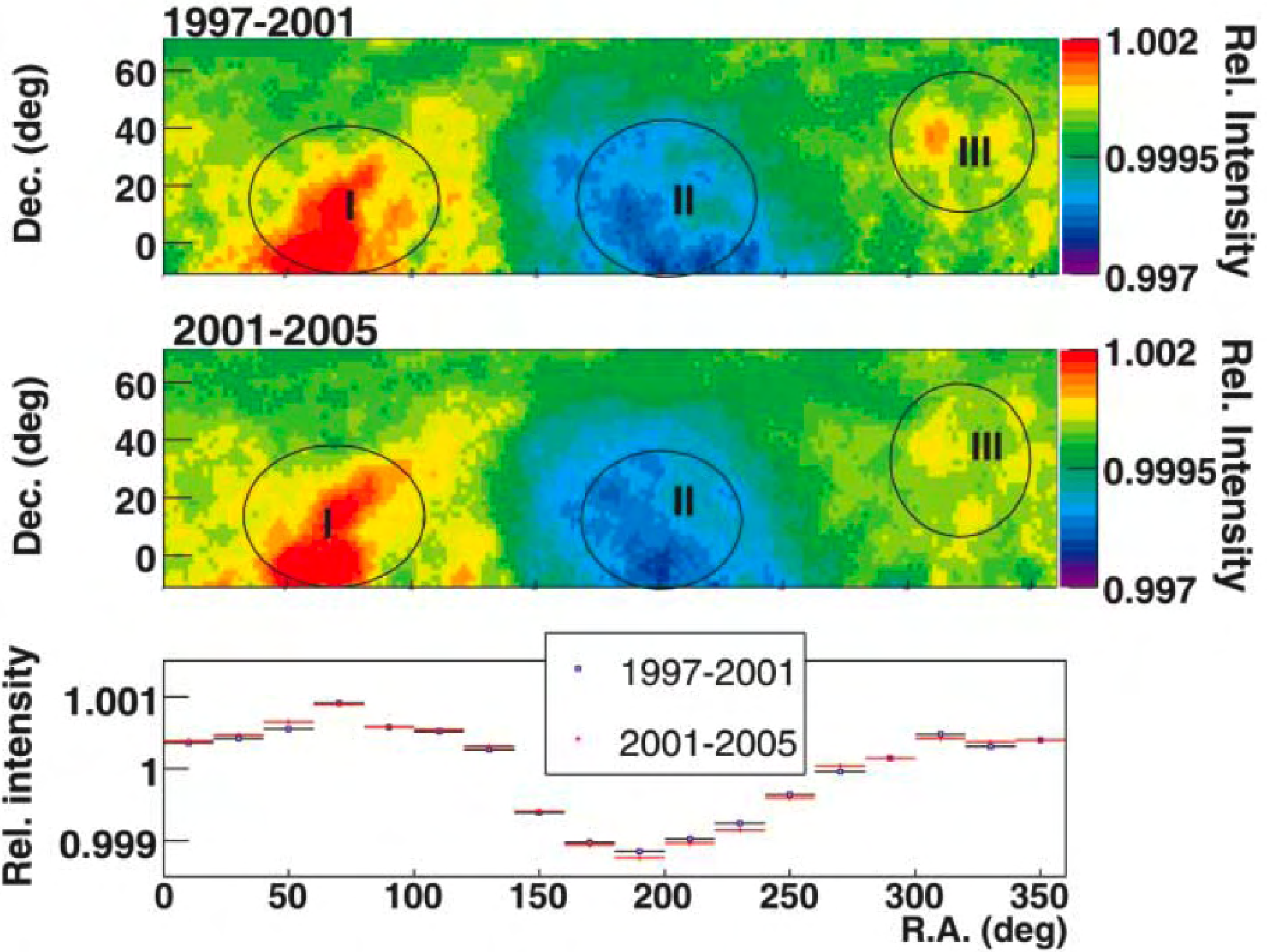


Northern Sky

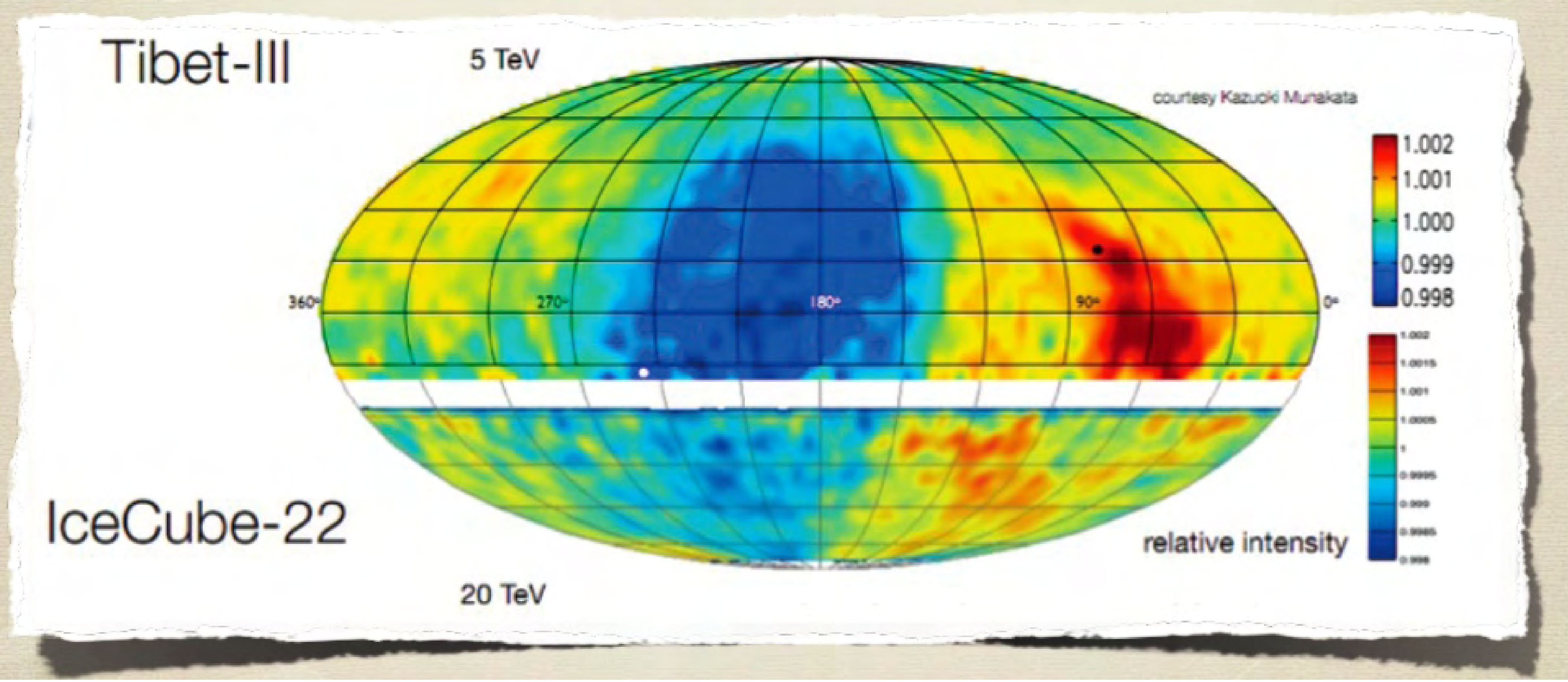


Southern Sky

Tibet ASγ	M. Amenomori et al., Astrophys. J 626 (2005) L29
SuperK	G. Guillian et al., Phys. Rev. D 75 (2007) 062003
Milagro	A. Abdo et al., Astrophys. J. 698 (2009) 2121
ARGO-YBJ	S. Vernetto, Proc. 31st ICRC, 2009
EAS-Top	M. Aglietta, Astrophys. J. 692 (2009) L130
IceCube	R. Abbasi *et al*, Astrophys. J. 718 (2010) L194

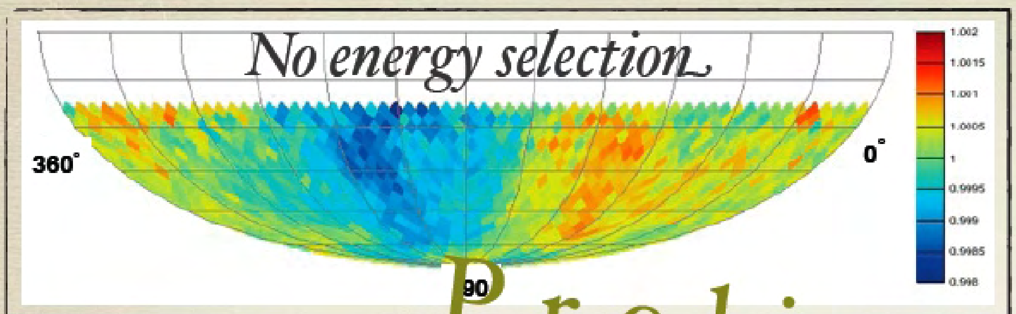


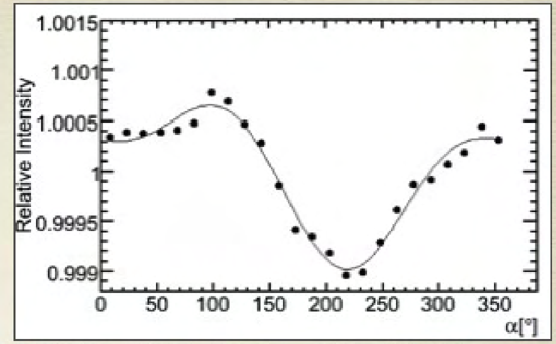
1997-2001
Dec. (deg)
60
40
20
0
I
II
III
1.002
0.9995
0.997
Rel. Intensity
2001-2005
Dec. (deg)
60
40
20
0
I
II
III
1.002
0.9995
0.997
Rel. Intensity
1997-2001
2001-2005
Rel. intensity
1.001
1
0.999
0
50
100
150
200
250
300
350
R.A. (deg)

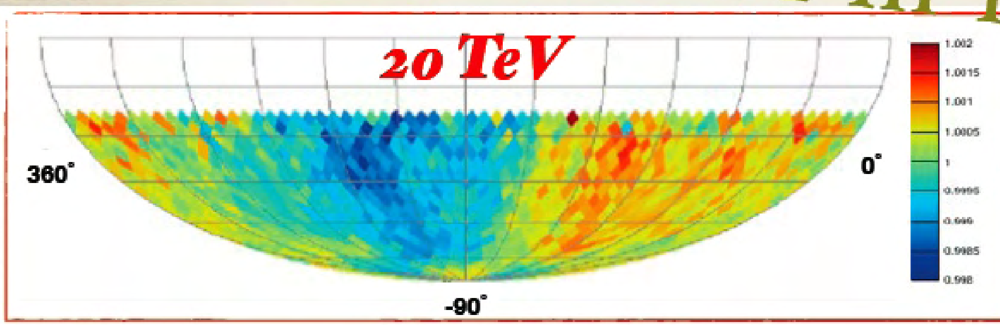

Tibet-III
5 TeV
courtesy Kazuoki Munakata
1.002
1.001
1.000
0.999
0.998
360°
270°
180°
90°
0°
1.002
1.0015
1.001
1.0005
1
0.9995
0.999
0.9985
0.998
IceCube-22
relative intensity
20 TeV

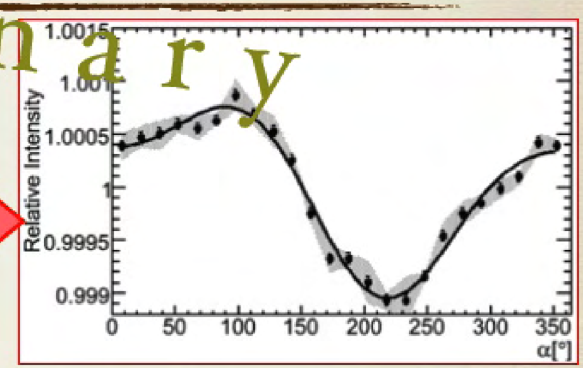
Relative Intensity

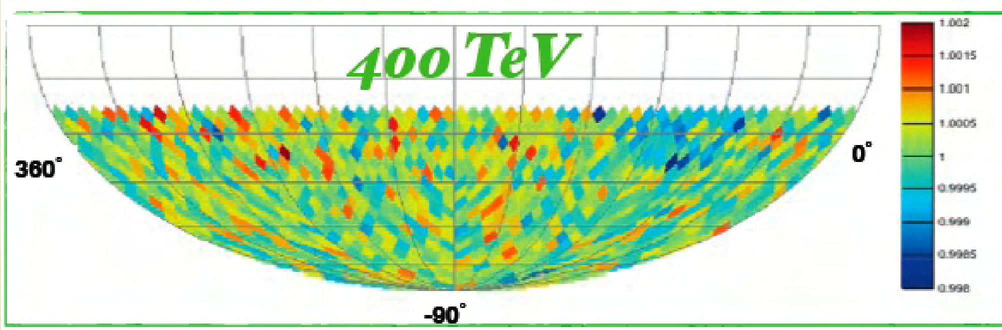
Equatorial sky maps in HEALPix with NSide= 16, ***pix resol ~ 3°***

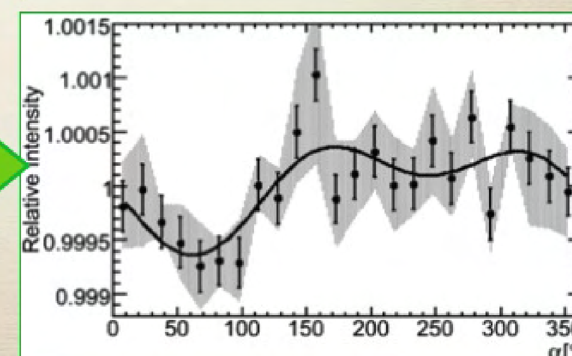










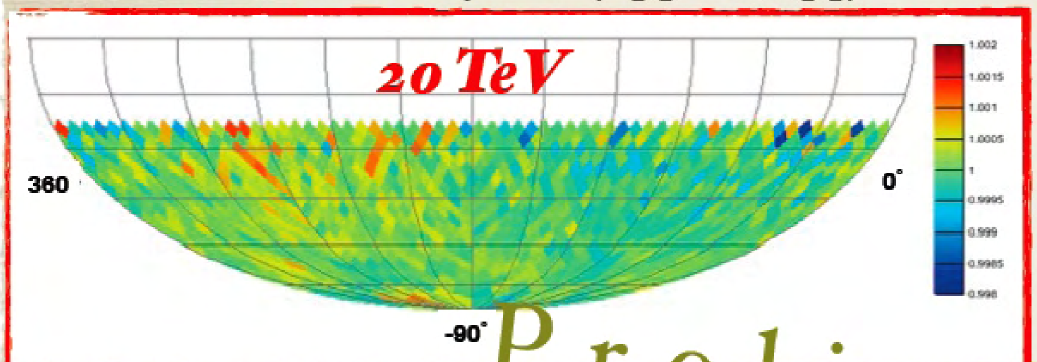


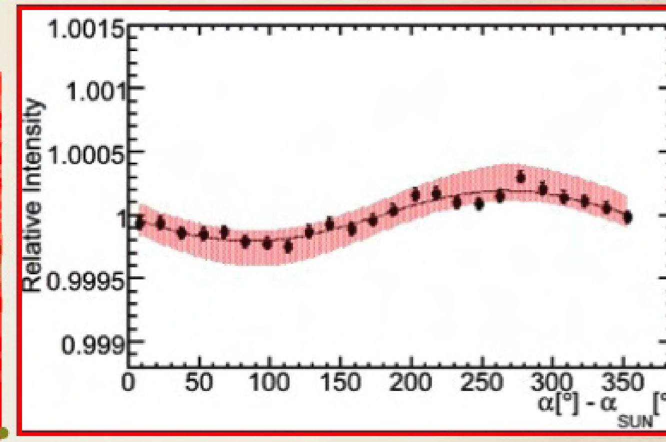
Energy dependence of the Solar dipole

✳ IceCube observes the Solar dipole in both energy bins. The observed amplitude is compatible with the expectations within the stat. and sys. uncertainties.

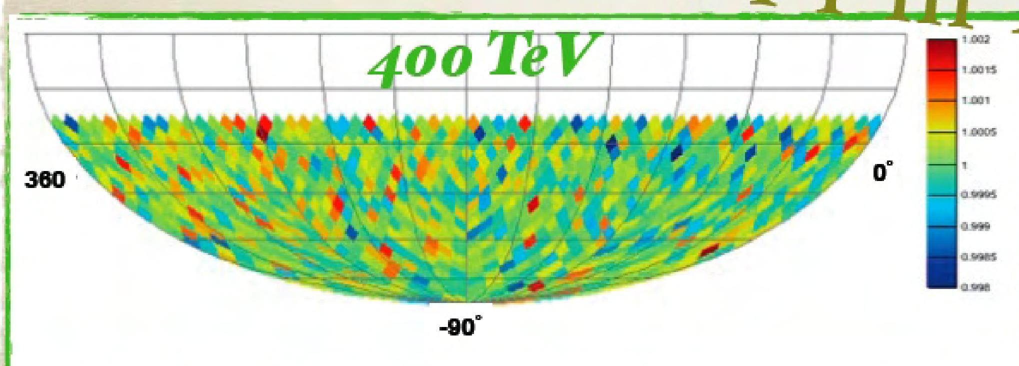
✳ The observation of the solar dipole supports the observation of the sidereal anisotropy in cosmic ray arrival direction.

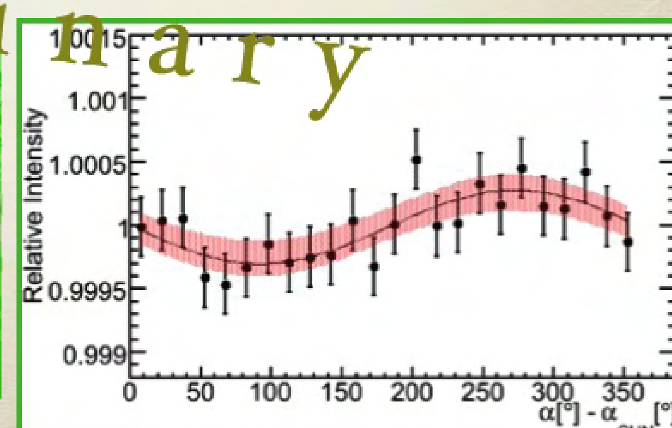
relative intensity Vs. ($\alpha[^\circ]$ - $\alpha_{SUN}[^\circ]$)





Preliminary



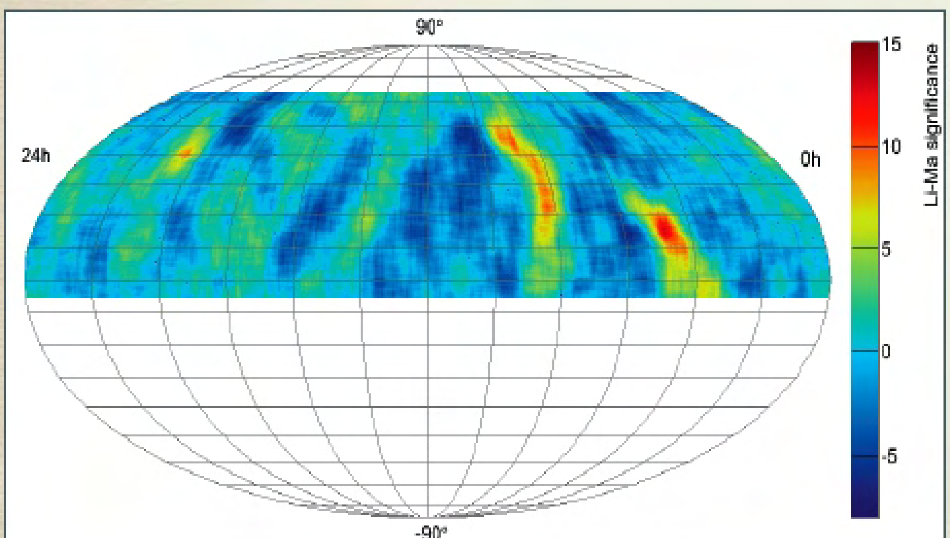


Small scale anisotropy

Several experiments have discovered anisotropies on scales of about 10°

✳ Milagro observes two localized regions with **significance > 10σ** in the total data set of 2.2 10^{11} events recorded over 7 years. The "hot" regions have fractional excesses of order several times **10^{-4}** relative to the background.

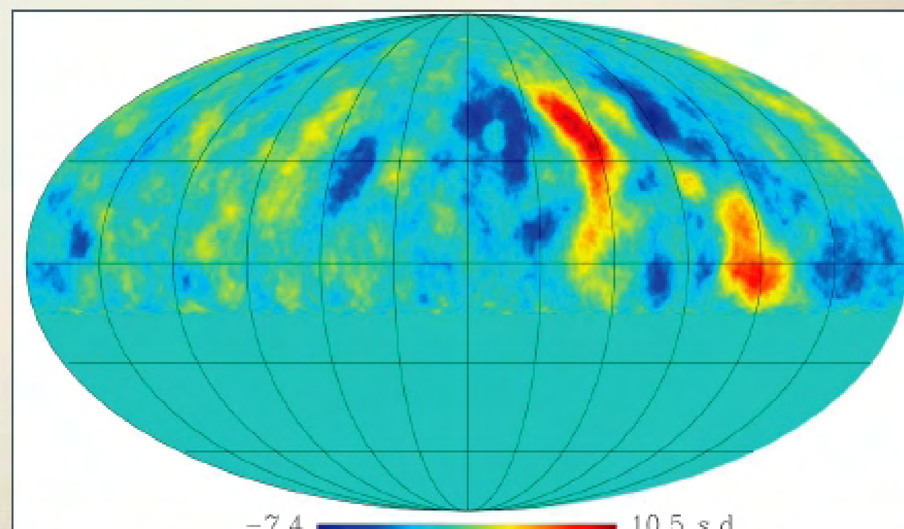
✳ Same structures observed by ARGO-YBJ.



A. Abdo et al., PRL 101 (2008) 221101

Milagro

Median Energy: 1 TeV



S. Vernetto, Proc. 31st ICRC, 2009

ARGO-YBJ

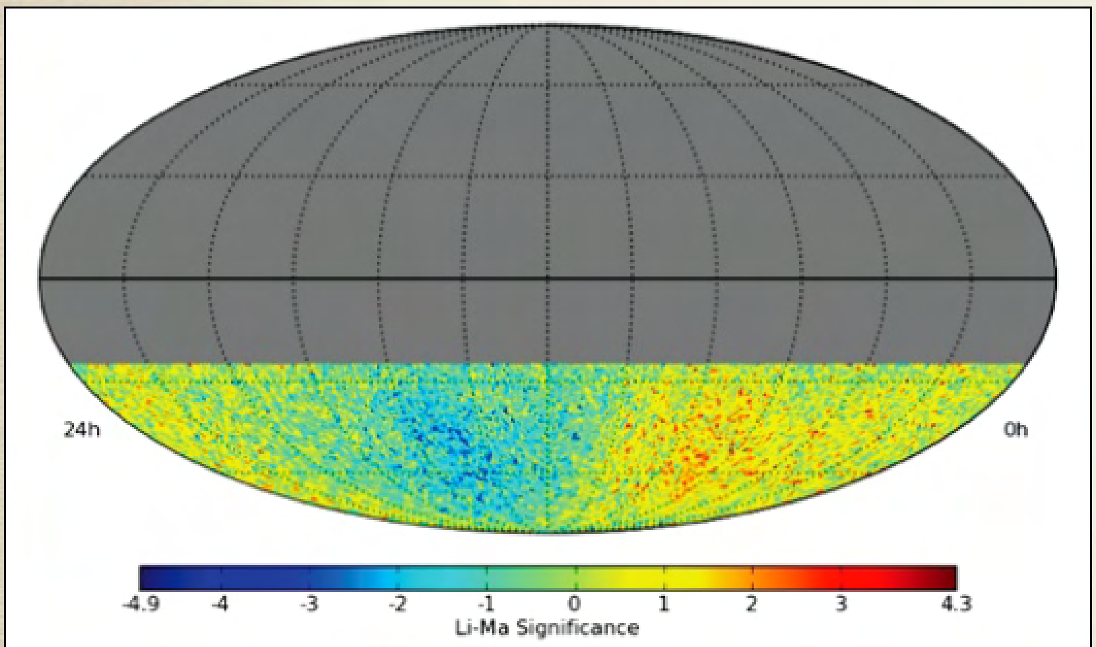
Median Energy: 2 TeV

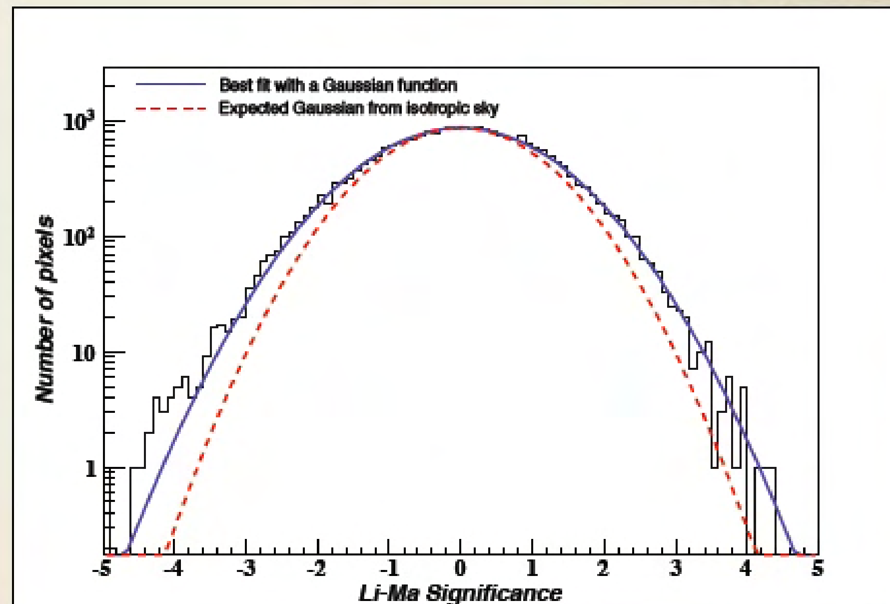
Significance map

Significance calculation:

$$s = \sqrt{2}\left\{ N_{\rm on} \ln\left[\frac{1+\alpha}{\alpha}\left(\frac{N_{\rm on}}{N_{\rm on}+N_{\rm off}}\right)\right] + N_{\rm off}\ln\left[(1+\alpha)\left(\frac{N_{\rm off}}{N_{\rm on}+N_{\rm off}}\right)\right]\right\}^{1/2} \qquad \alpha = 1/20$$

Li, T., & Ma, Y. 1983, ApJ, 272, 317





Dipole and quadrupole fit

$$\delta I(\alpha,\delta) = m_0$$ **monopole**

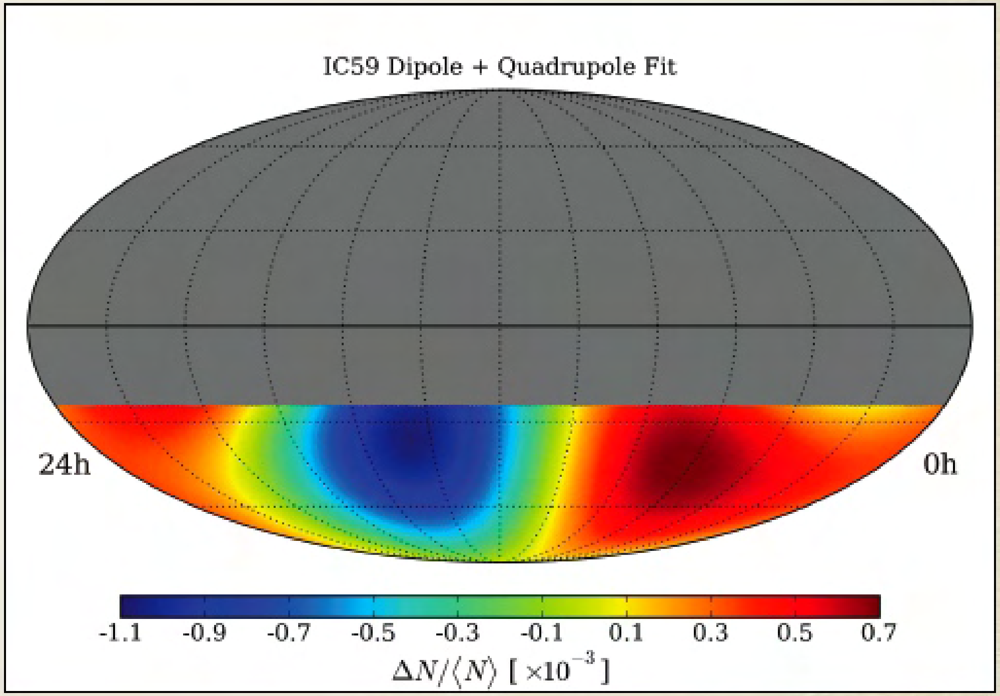
$$+p_x \cos\delta\cos\alpha + p_y\cos\delta\sin\alpha + p_z\sin\delta$$ **dipole**

$$+\frac{1}{2}Q_1(3\cos^2\delta - 1) + Q_2\sin 2\delta\cos\alpha + Q_3\sin 2\delta\sin\alpha + Q_4\cos^2\delta\cos 2\alpha + Q_5\cos^2\delta\sin 2\alpha$$ **quadrupole**

Coefficient	Fit Value
m_0	0.320 ± 2.264
p_x	2.435 ± 0.707
p_y	-3.856 ± 0.707
p_z	0.548 ± 3.872
Q_1	0.233 ± 1.702
Q_2	-2.949 ± 0.494
Q_3	-8.797 ± 0.494
Q_4	-2.148 ± 0.200
Q_5	-5.268 ± 0.200

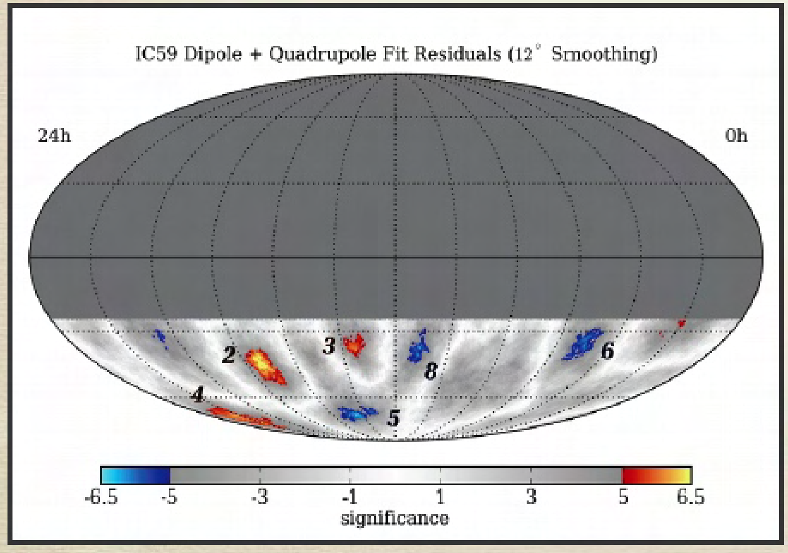
$$\chi^2/\mathrm{ndf} = 14743.4/14187$$

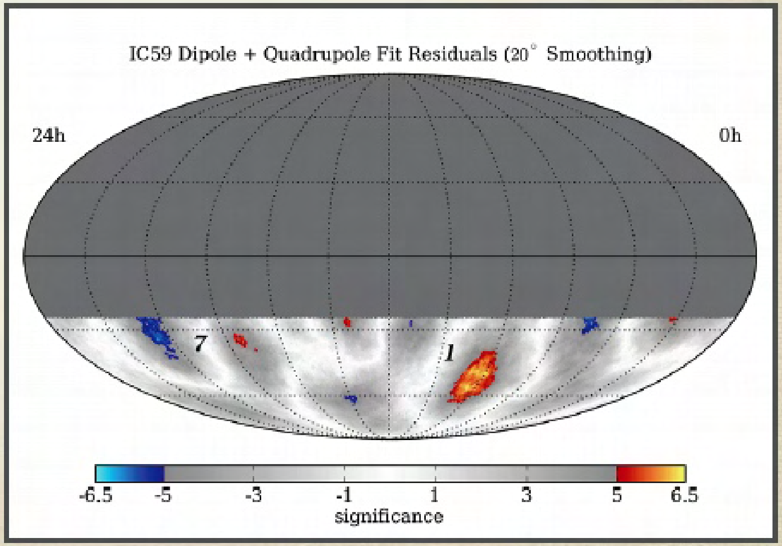
$$\Pr(\chi^2|\mathrm{ndf}) = 5.5\times 10^{-4}$$



Identification of significant structures

region	right ascension	declination	optimal scale	peak significance	post-trials
1	$(122.4^{+4.1}_{-4.7})°$	$(-47.4^{+7.5}_{-3.2})°$	22°	7.0σ	$\boxed{5.3\sigma}$
2	$(263.0^{+3.7}_{-3.8})°$	$(-44.1^{+5.3}_{-5.1})°$	13°	6.7σ	4.9σ
3	$(201.6^{+6.0}_{-1.1})°$	$(-37.0^{+2.2}_{-1.9})°$	11°	6.3σ	4.4σ
4	$(332.4^{+9.5}_{-7.1})°$	$(-70.0^{+4.2}_{-7.6})°$	12°	6.2σ	4.2σ
5	$(217.7^{+10.2}_{-7.8})°$	$(-70.0^{+3.6}_{-2.3})°$	12°	-6.4σ	-4.5σ
6	$(77.6^{+3.9}_{-8.4})°$	$(-31.9^{+3.2}_{-8.6})°$	13°	-6.1σ	-4.1σ
7	$(308.2^{+4.8}_{-7.7})°$	$(-34.5^{+9.6}_{-6.9})°$	20°	-6.1σ	-4.1σ
8	$(166.5^{+4.5}_{-5.7})°$	$(-37.2^{+5.0}_{-5.7})°$	12°	-6.0σ	-4.0σ



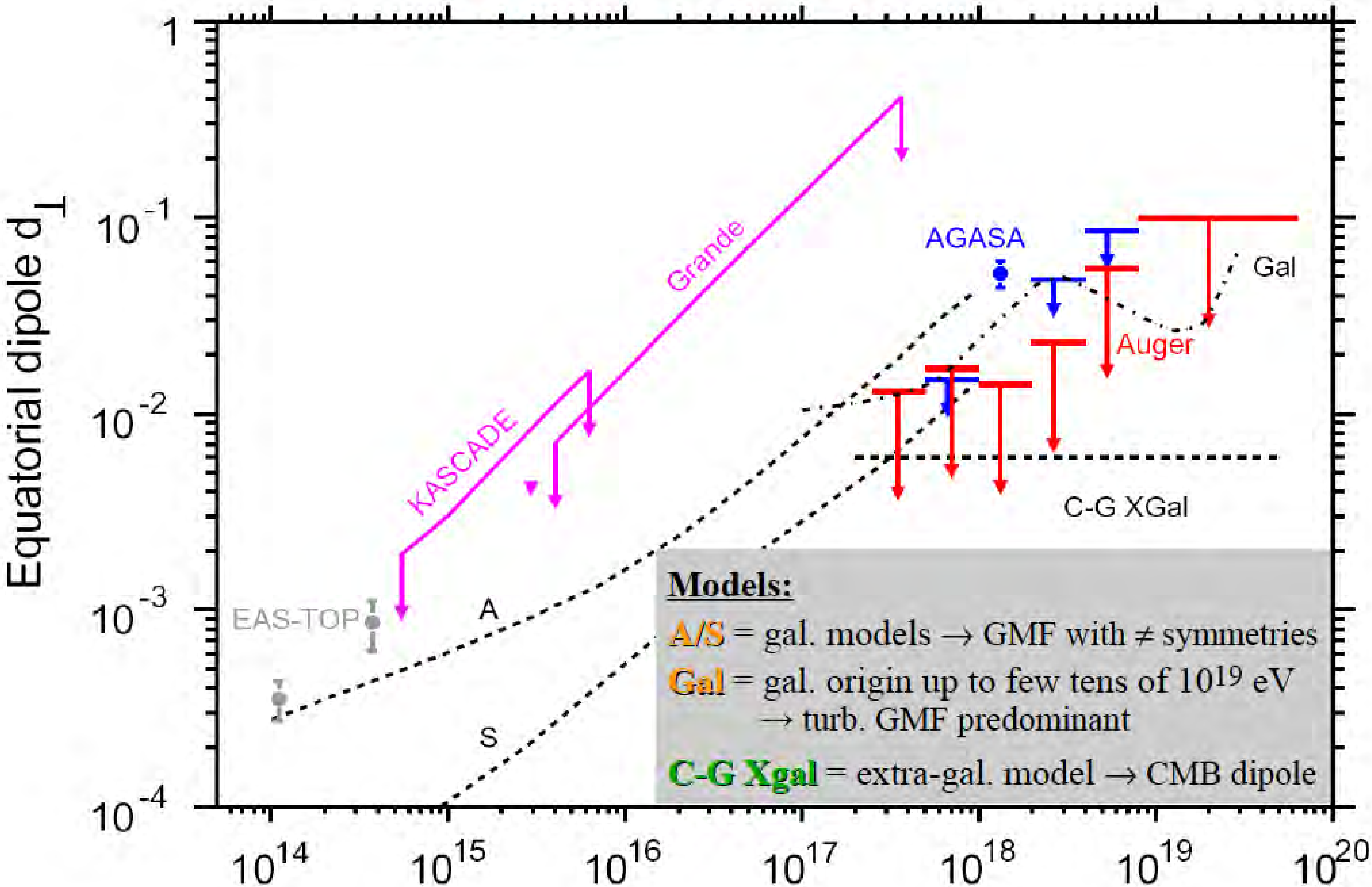


Need measurements [and understanding]
of Large Scale anisotropy in all energy range

from TeV to UHECR

AUGER

Upper limits



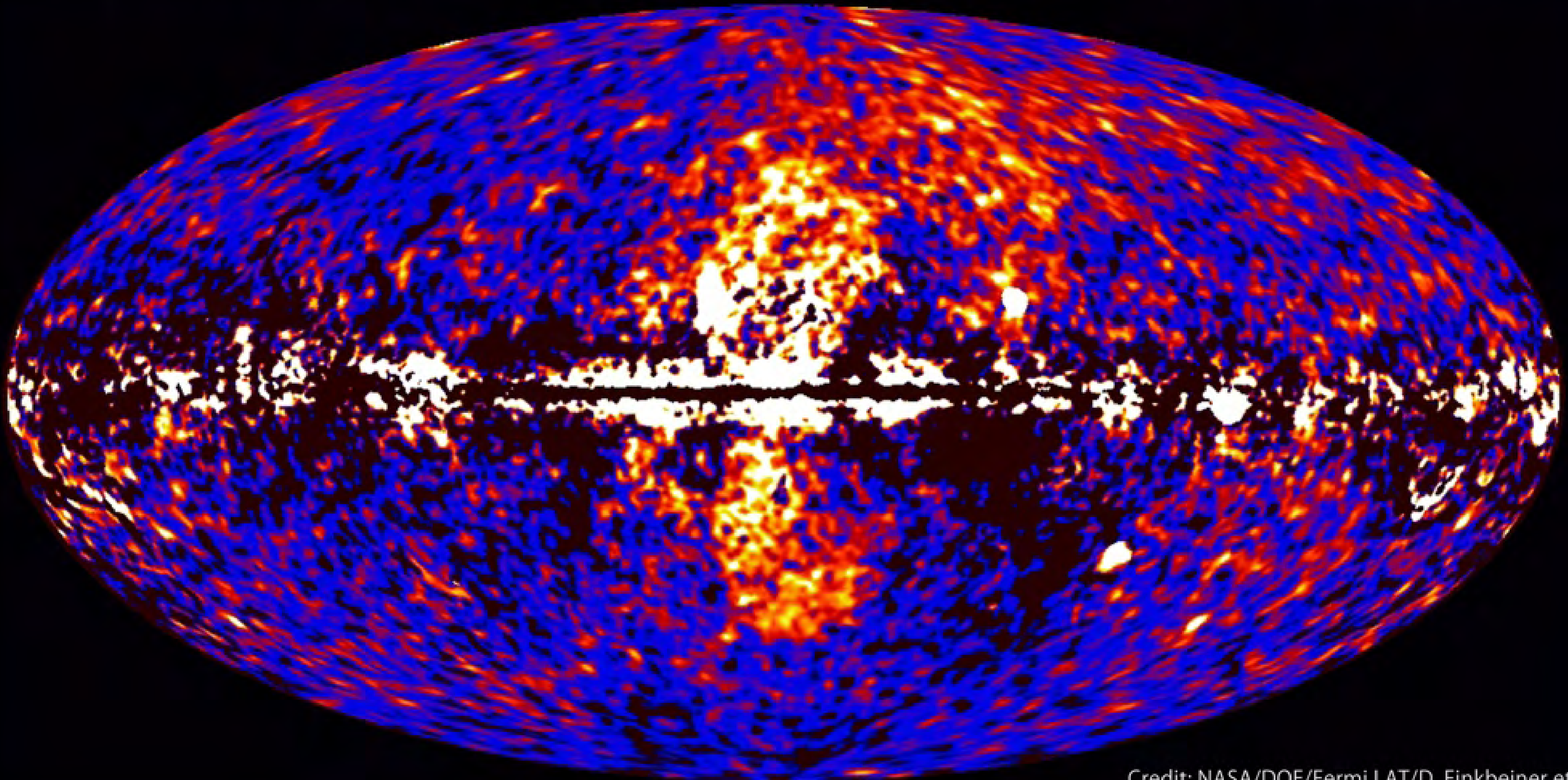
The

“FERMI BUBBLES”

“hidden in plain sight (!)”

Scientific American news. Title:

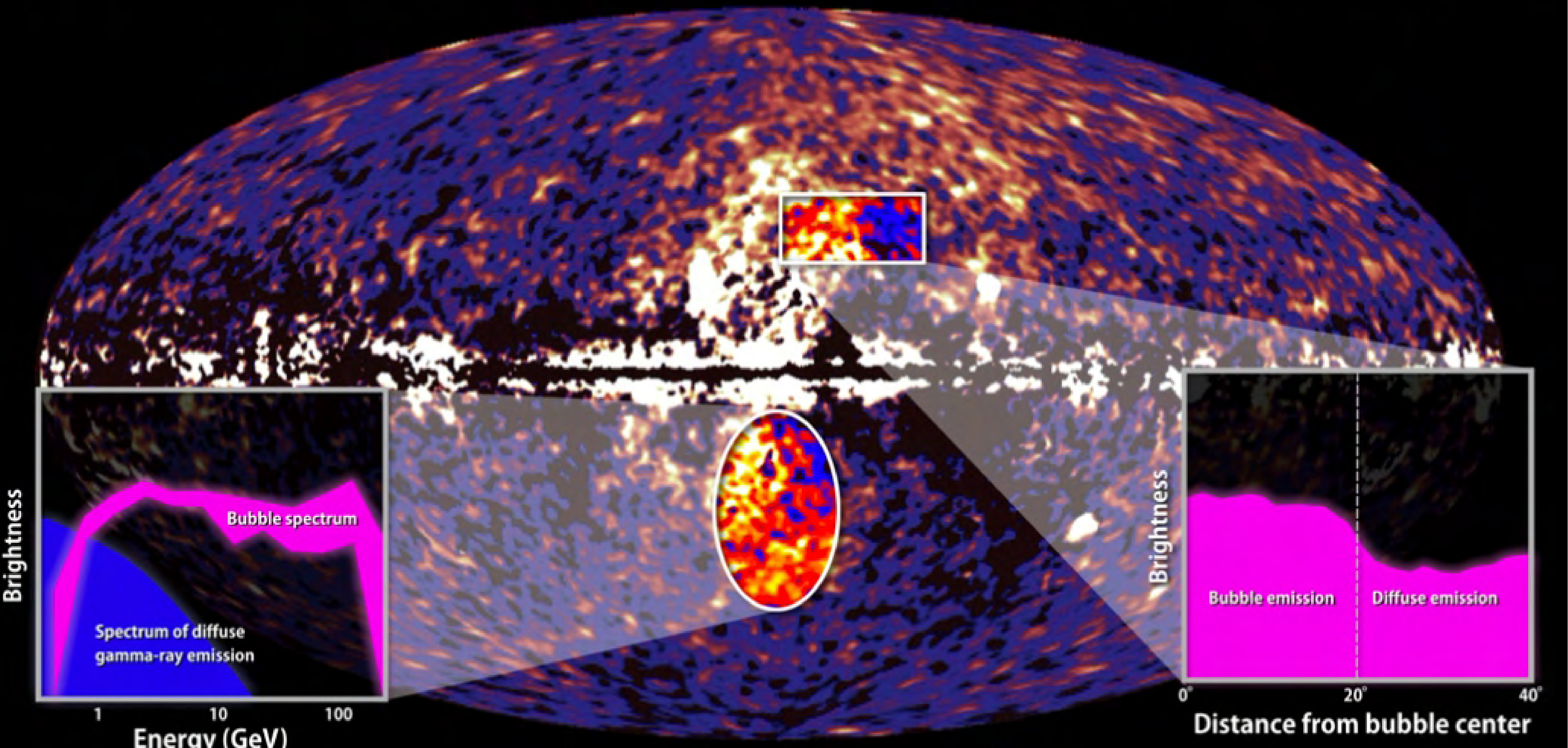
Hidden in Plain Sight: Researchers Find Galaxy-Scale Bubbles Extending from the Milky Way



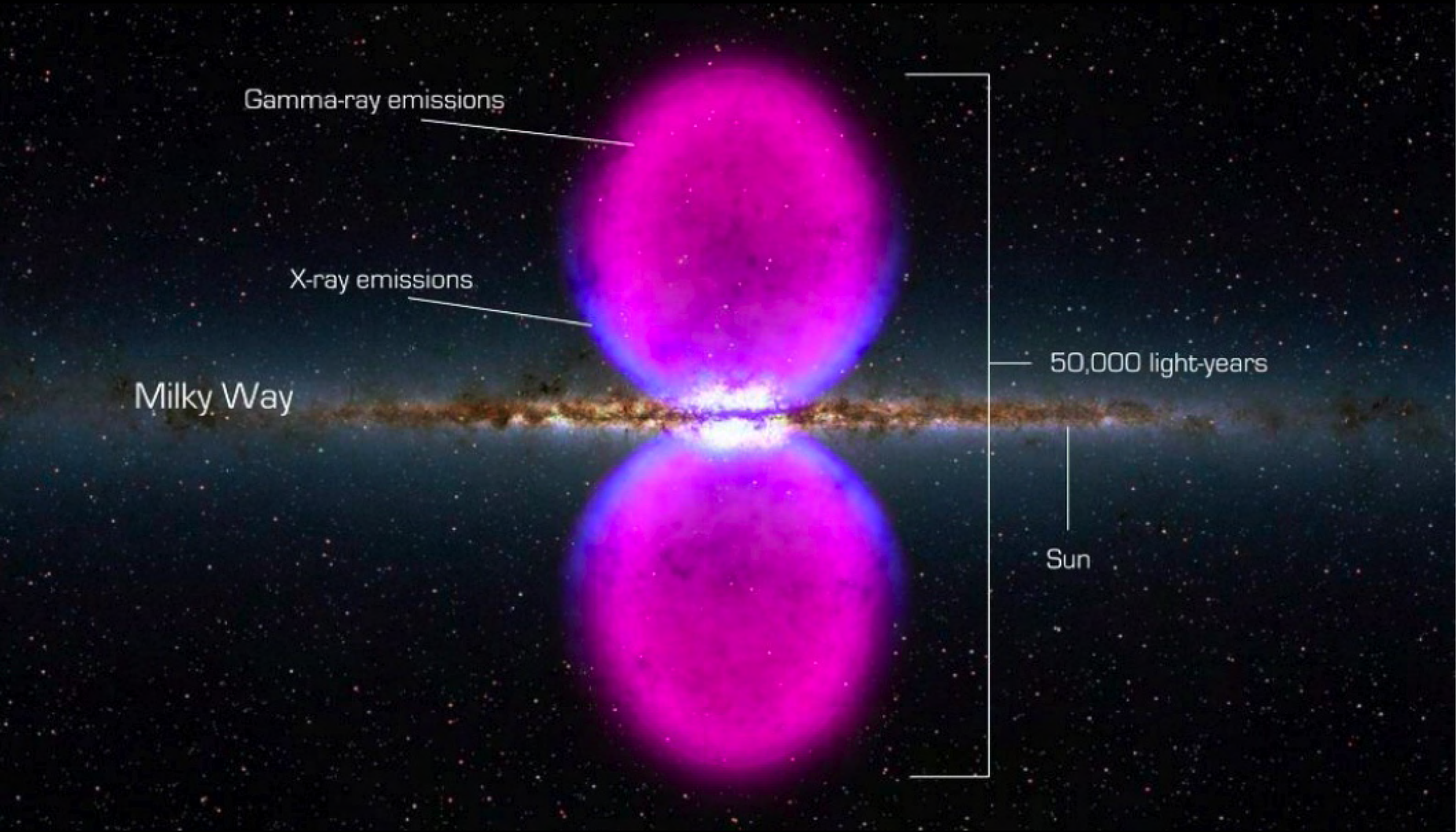
Credit: NASA/DOE/Fermi LAT/D. Finkbeiner et al.

M. Su, T. R. Slatyer, D. P. Finkbeiner,
"Giant Gamma-ray Bubbles from Fermi-LAT: AGN Activity or Bipolar Galactic Wind?,"
Astrophys. J. **724**, 1044-1082 (2010). [arXiv:1005.5480 [astro-ph.HE]].

Bubbles show energetic spectrum and sharp edges

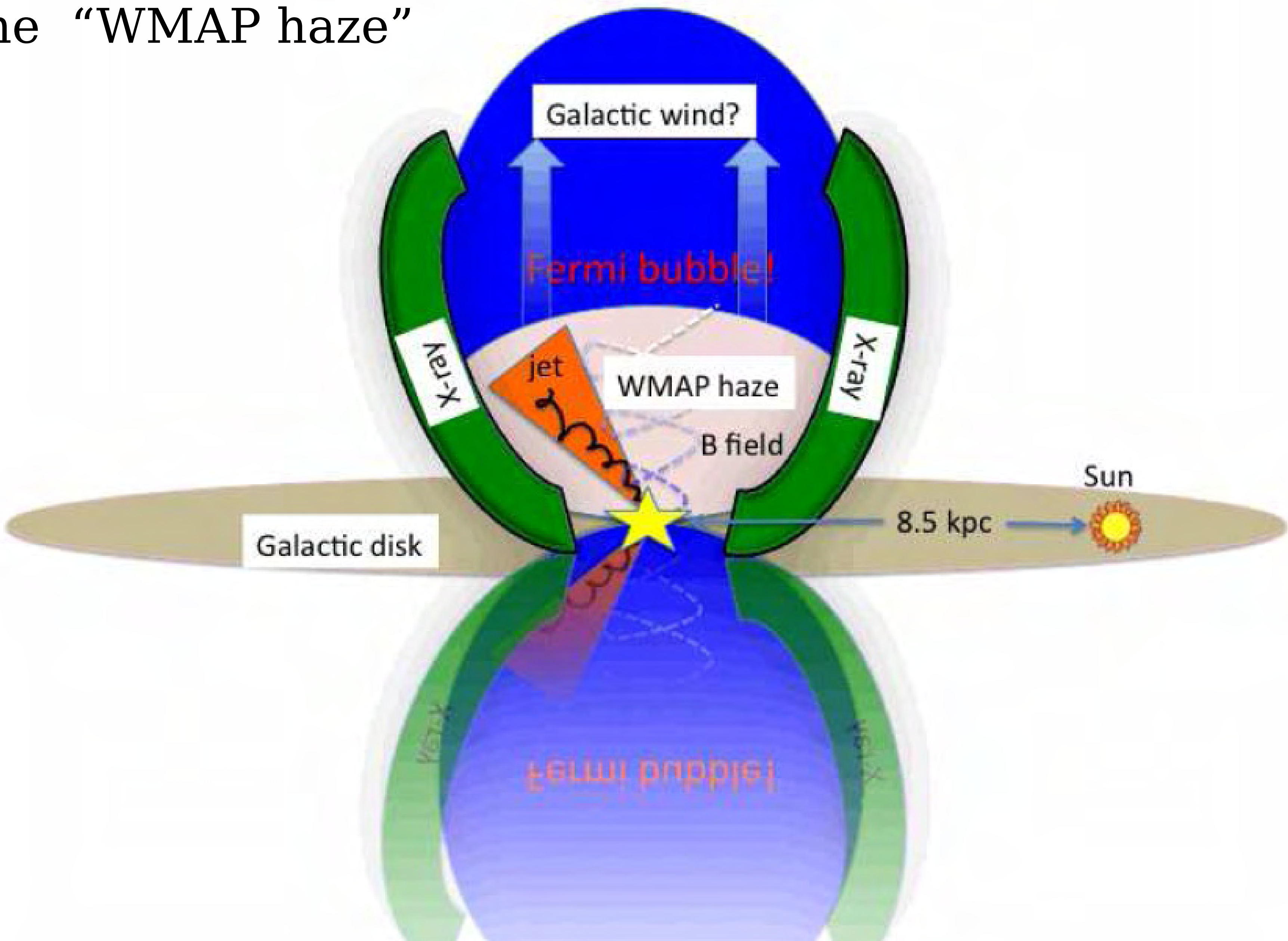


Credit: NASA/DOE/Fermi LAT/D. Finkbeiner et al.



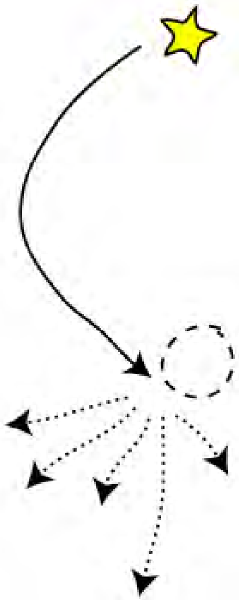
from NASA website

Connection with The "WMAP haze"

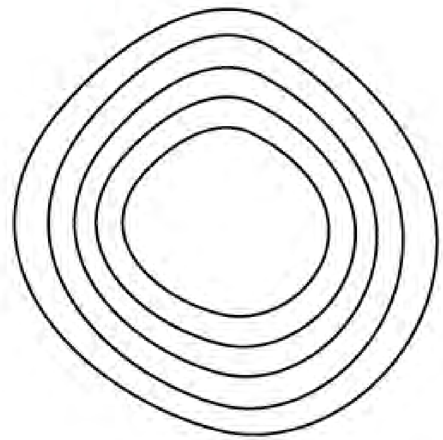


Leptonic model

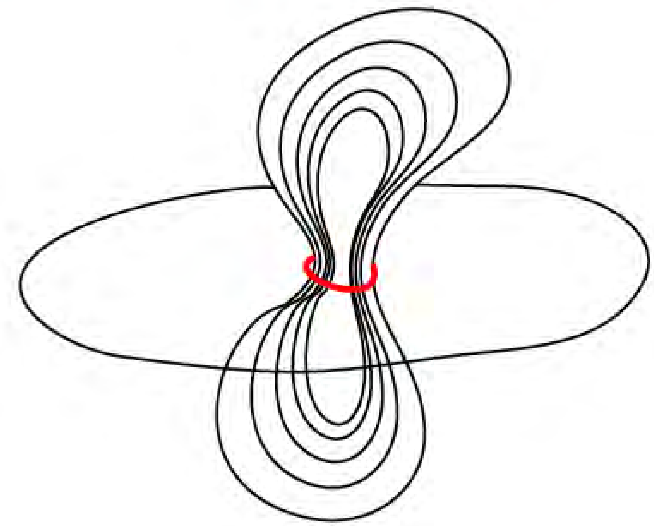
Cheng *et al.*, ApJL **731** (2011) L17



disruption of stars
by central black hole



hundreds of
concentric shock
fronts

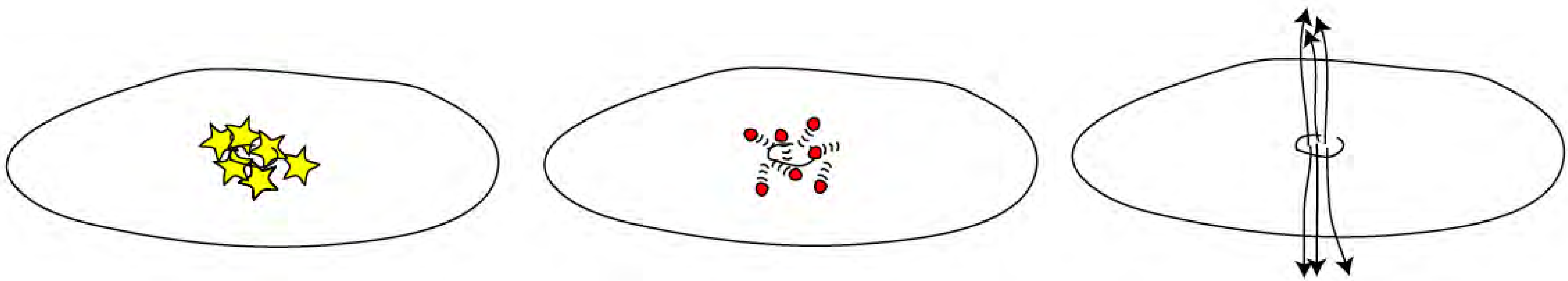


shocks constricted in
galactic disk
→ bubble shape

Local acceleration of electrons inside the bubbles

Hadronic model

Aharonian & Crocker, PRL, **106** (2011) 101102



increased star formation rate close to GC

acceleration of CR protons and nuclei in SNRs

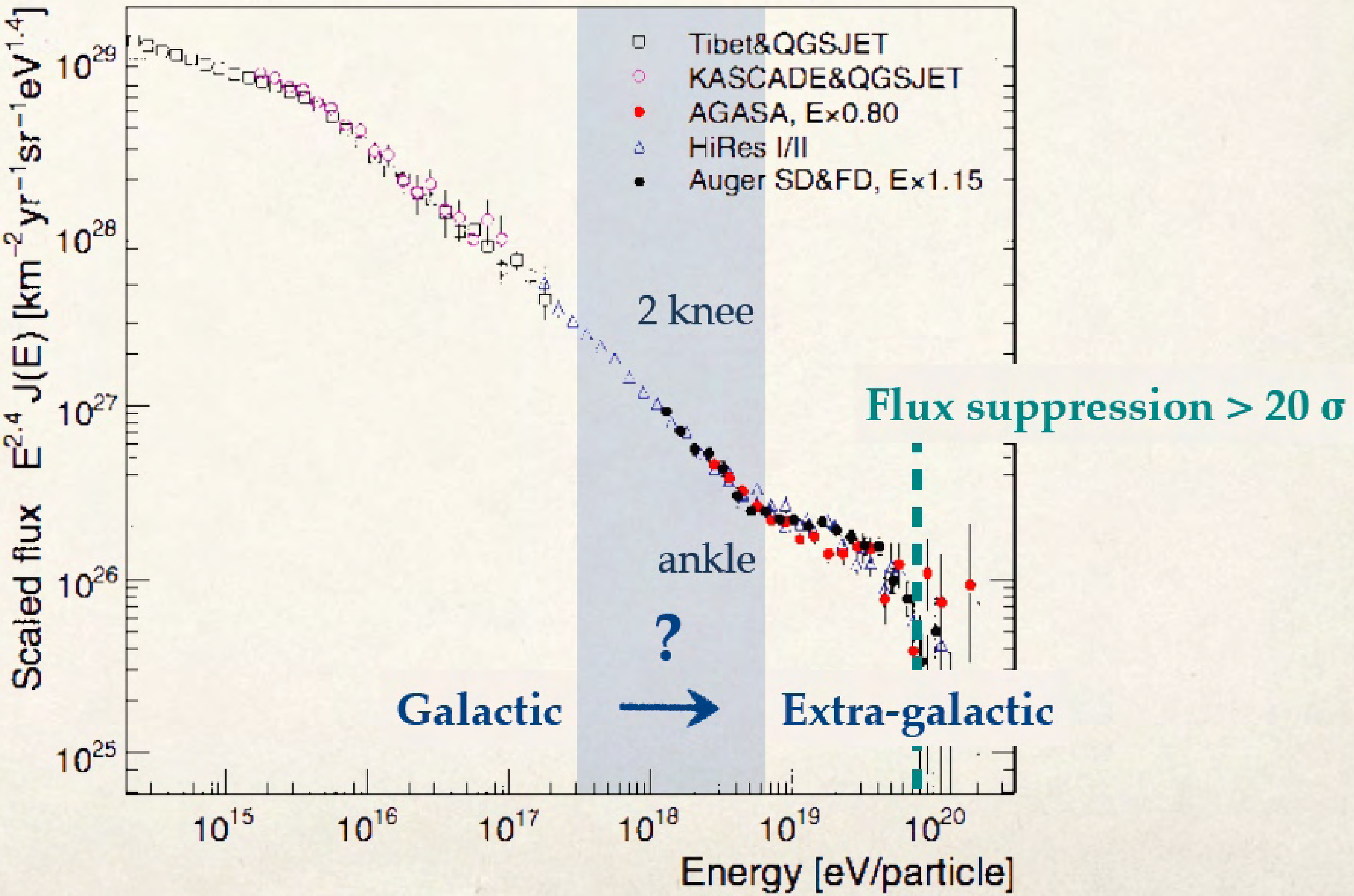
wind convects CRs away from disk

R. M. Crocker, F. Aharonian,
"The Fermi Bubbles: Giant, Multi-Billion-Year-Old Reservoirs of Galactic Center Cosmic Rays,"
[arXiv:1008.2658 [astro-ph.GA]].

COSMIC RAYS

from the KNEE

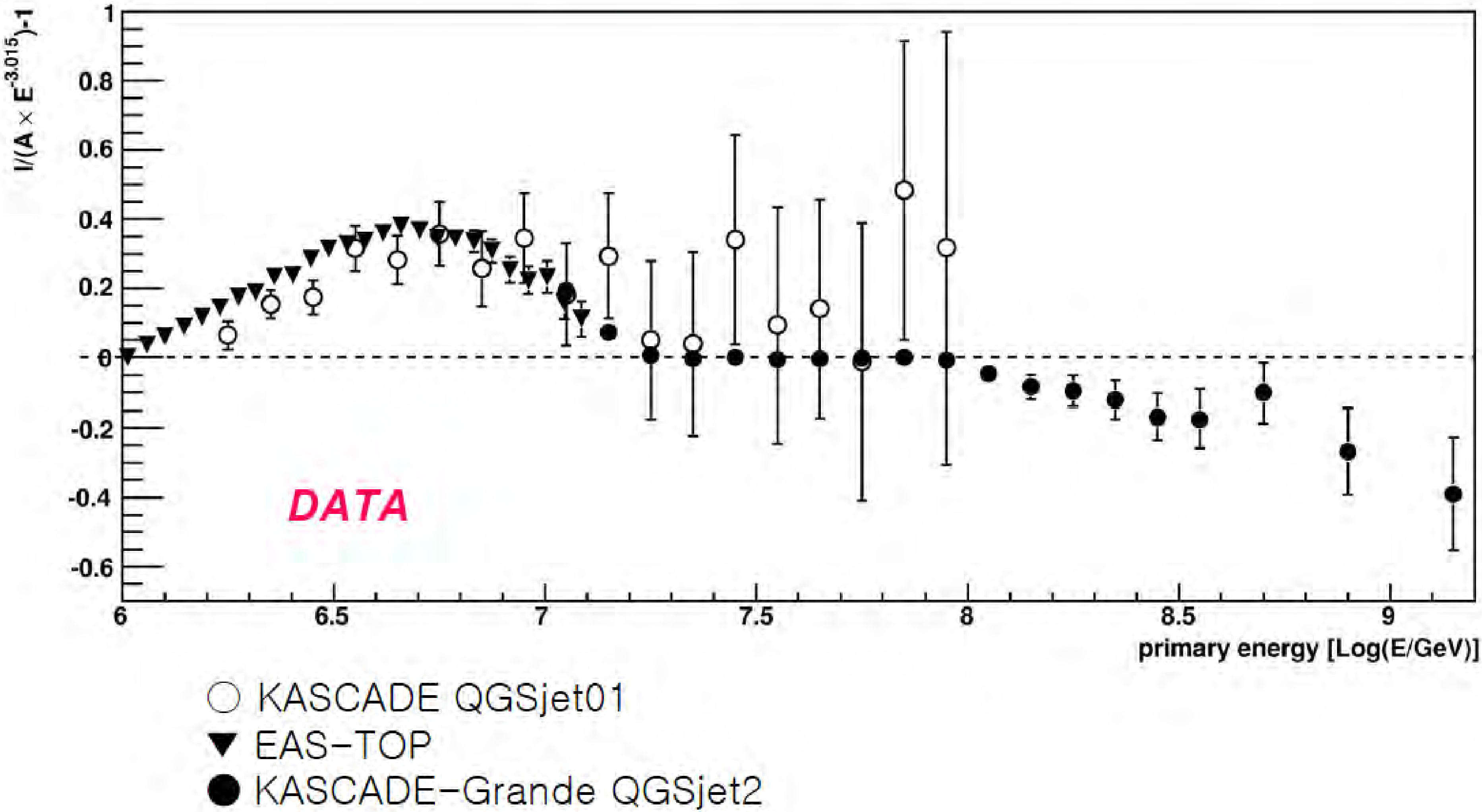
to the ANKLE

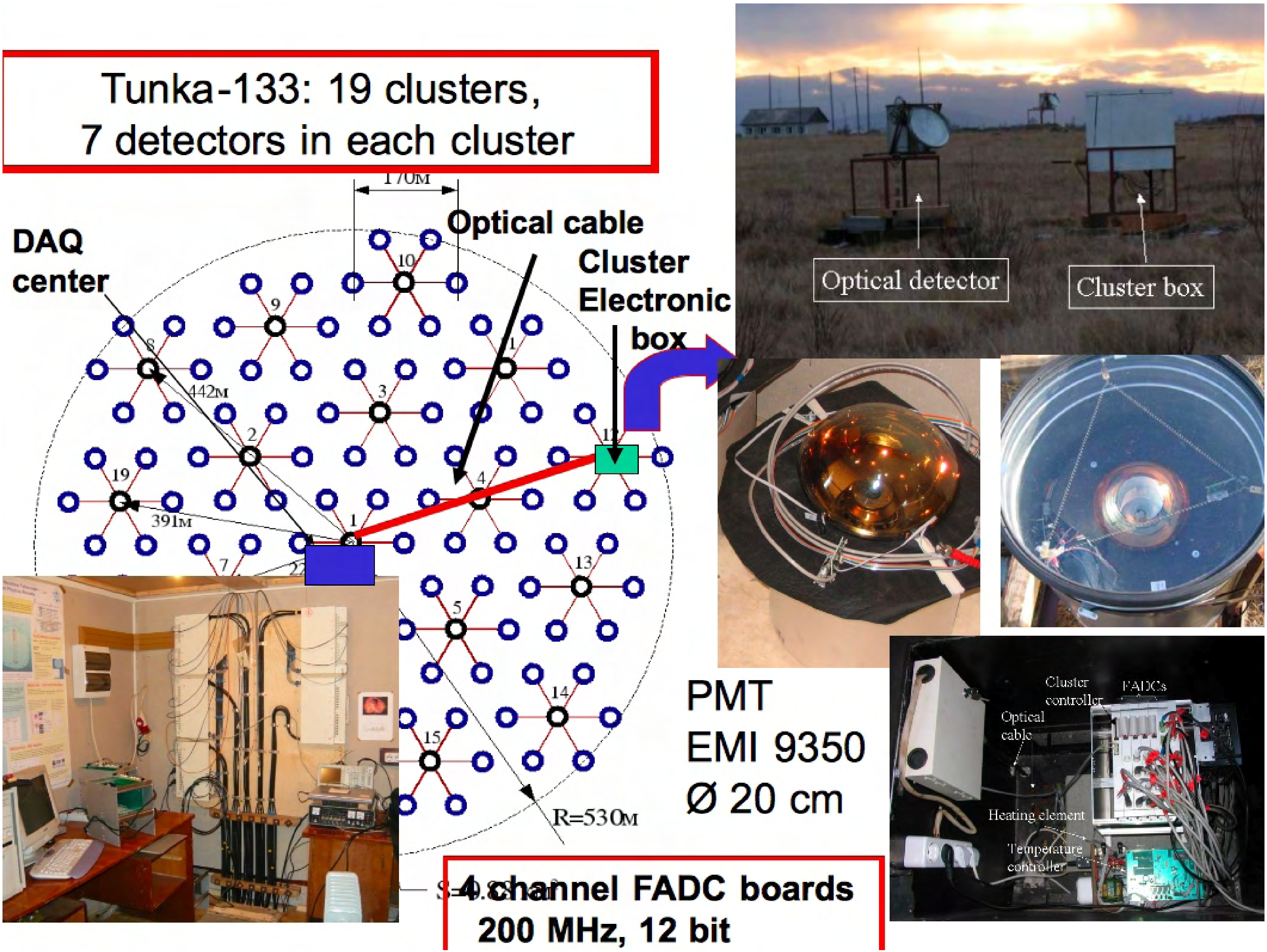


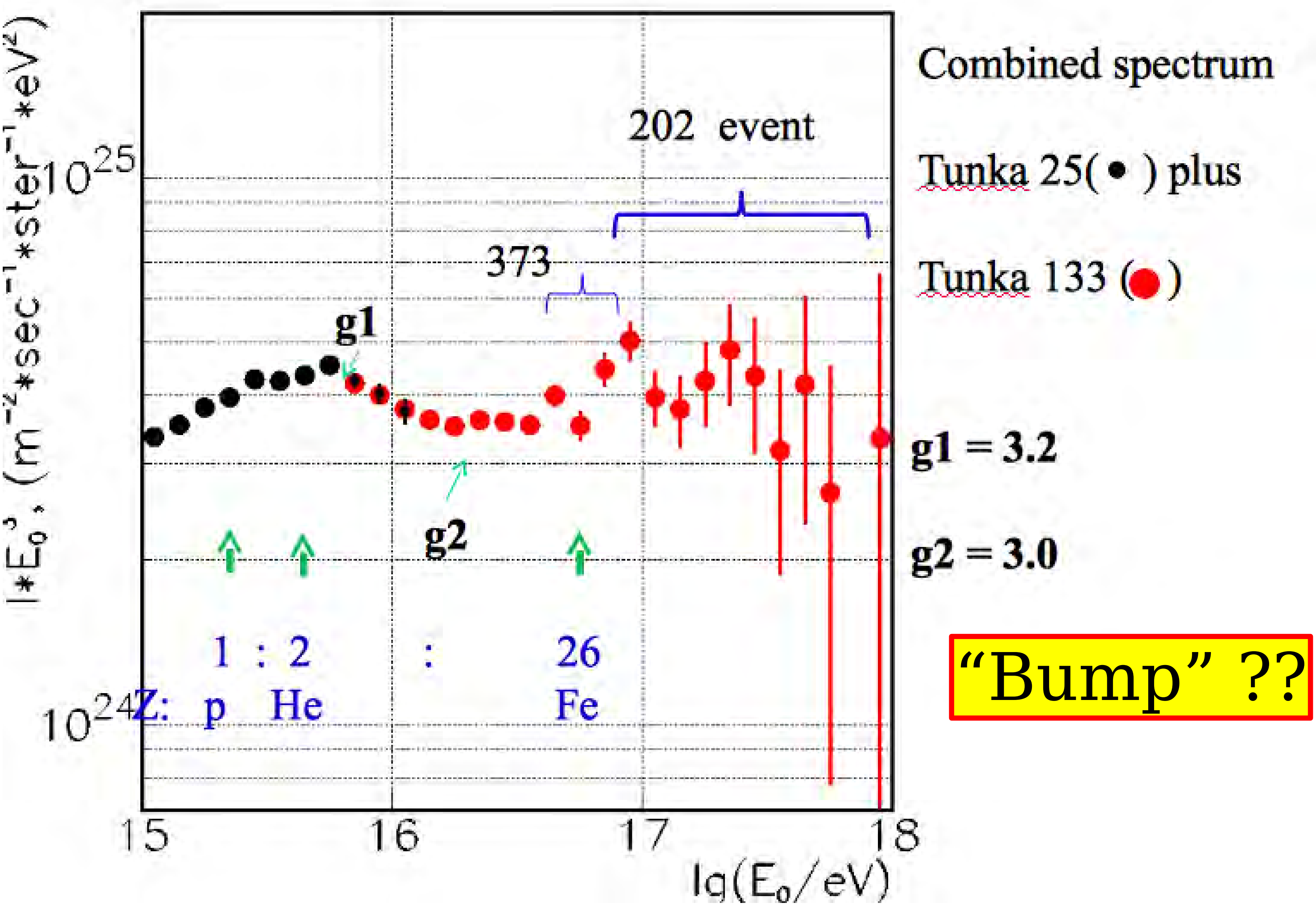
Tibet&QGSJET
KASCADE&QGSJET
AGASA, E×0.80
HiRes I/II
Auger SD&FD, E×1.15
2 knee
ankle
?
Flux suppression > 20 σ
Galactic
Extra-galactic
Scaled flux $E^{2.4}$ J(E) [$km^{-2}yr^{-1}sr^{-1}eV^{1.4}$]
Energy [eV/particle]
10^{25}
10^{26}
10^{27}
10^{28}
10^{29}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}

KASCADE-GRANDE

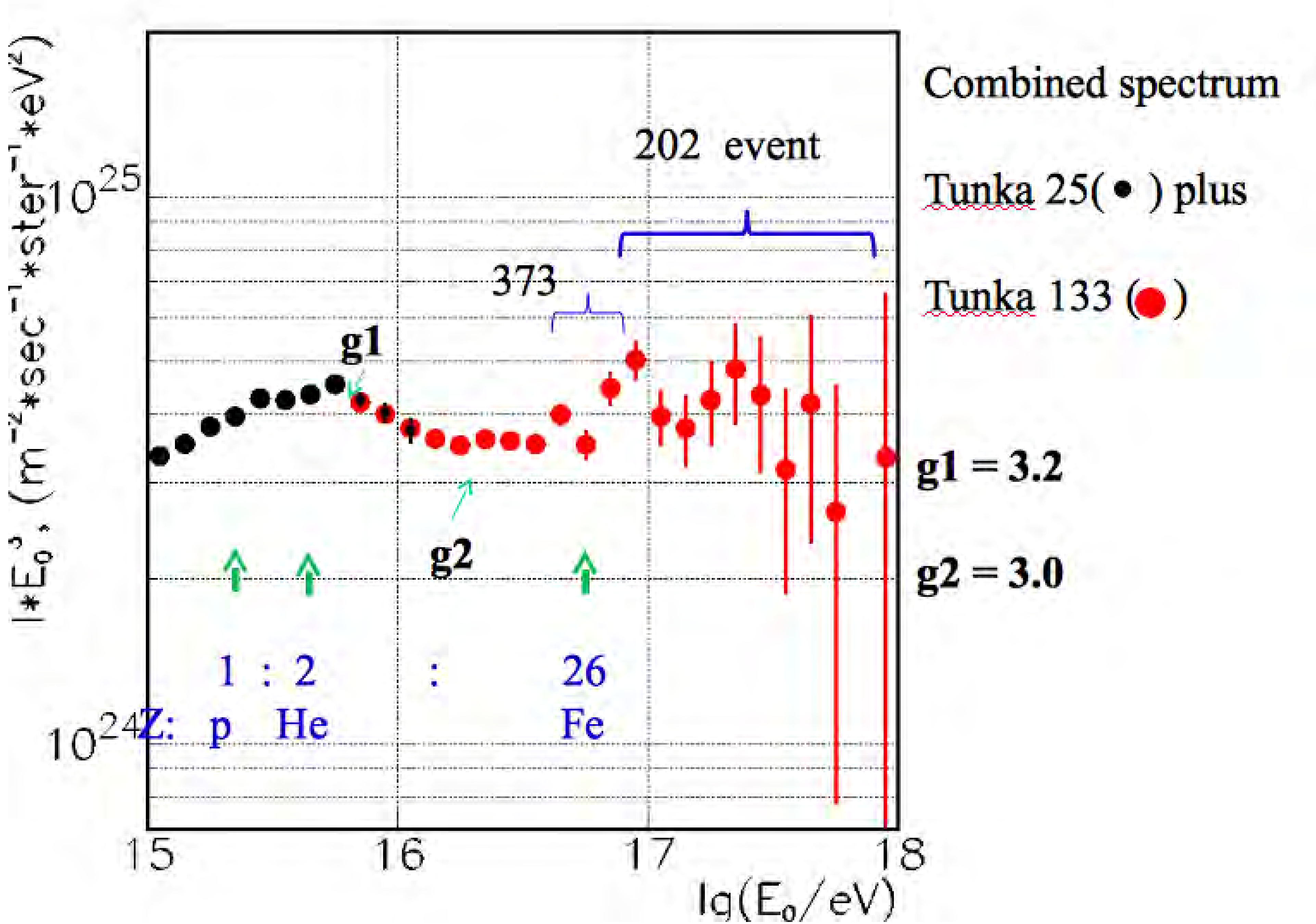
Comparison with KASCADE & EAS-TOP




Tunka-133: 19 clusters,
7 detectors in each cluster
170м
DAQ
center
Optical cable
Cluster
Electronic
box
442м
391м
R=530м
1
2
3
4
5
7
8
9
10
11
12
13
14
15
19
22
Optical detector
Cluster box
PMT
EMI 9350
Ø 20 cm
Cluster
controller
FADCs
Optical
cable
Heating element
Temperature
controller
4-channel FADC boards
200 MHz, 12 bit



Combined spectrum
202 event
Tunka 25(•) plus
Tunka 133 (●)
373
g1
g2
g1 = 3.2
g2 = 3.0
1 : 2 : 26
Z: p He Fe
10^{25}
10^{24}
15
16
17
18
$I*E_0^3$, $(m^{-2}*sec^{-1}*ster^{-1}*eV^2)$
$lg(E_0/eV)$
"Bump" ??



Combined spectrum
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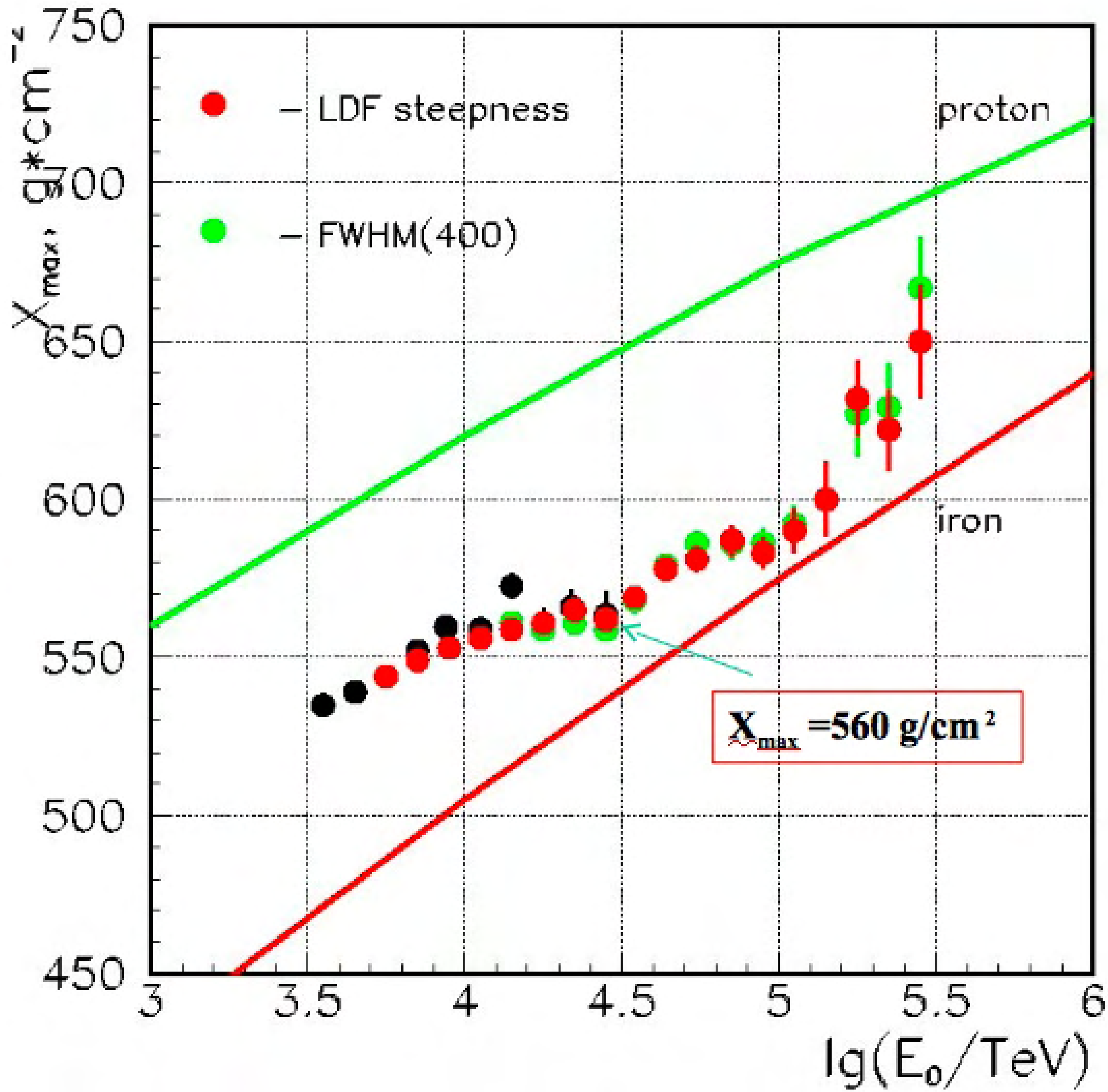
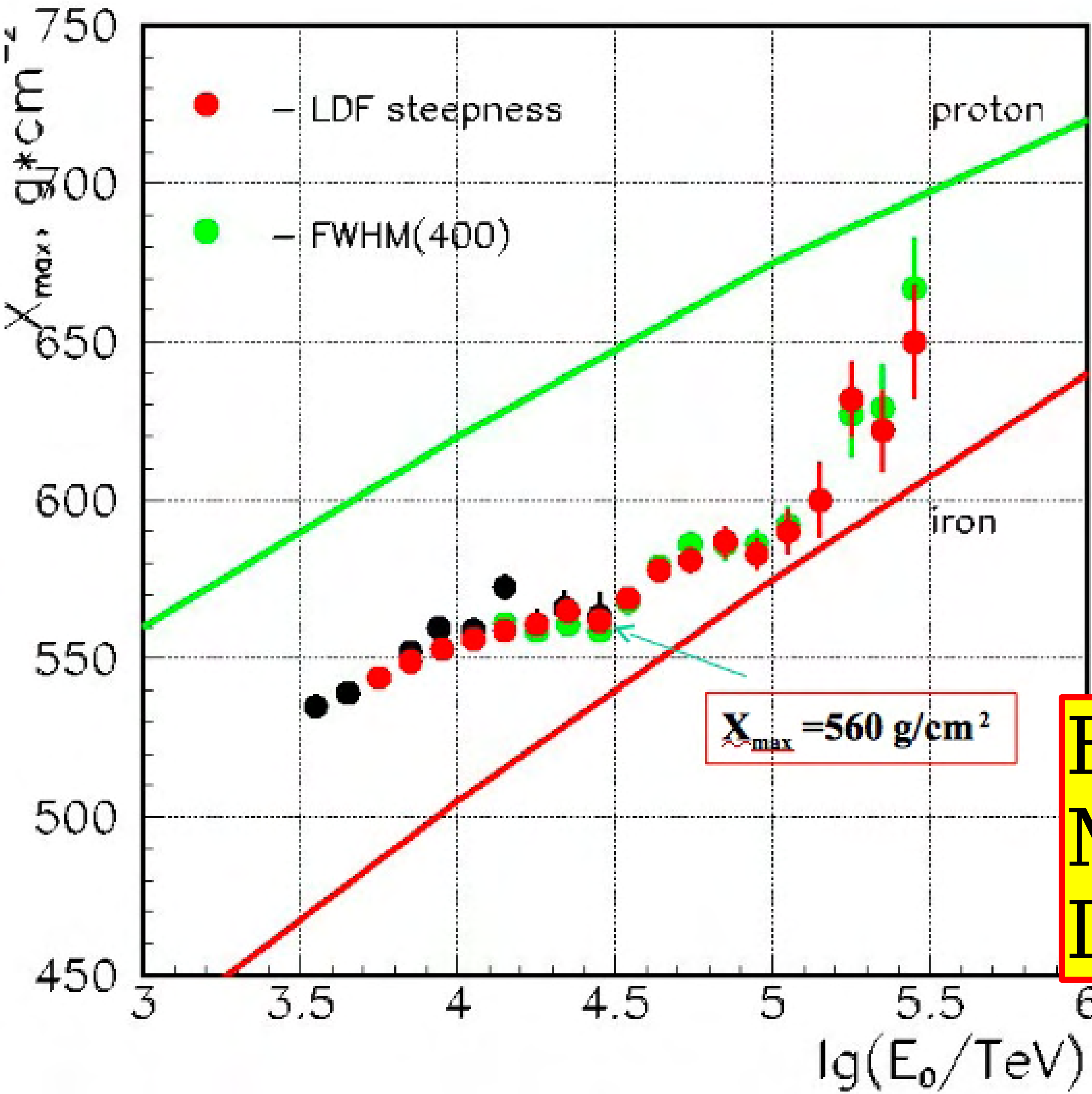
10^{25}
10^{24}
15
16
17
18
$lg(E_0/eV)$

Very Preliminary



● Tunka-25

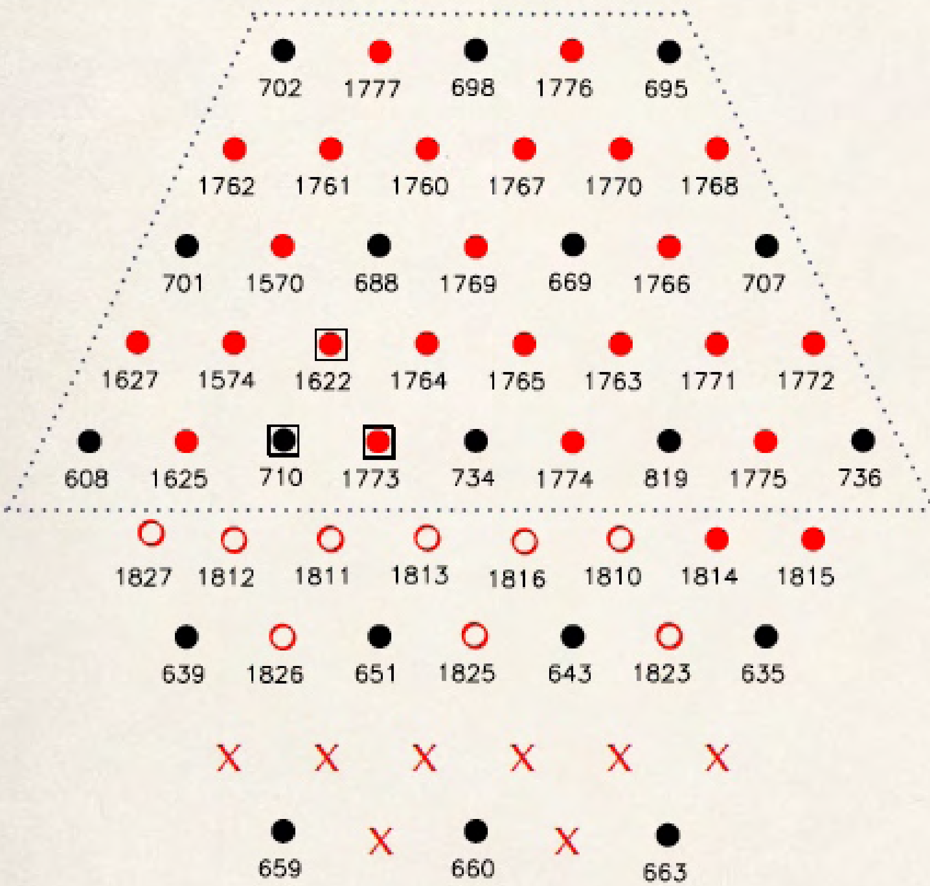
Very Preliminary



● Tunka-25

Hadronic Model Dependence

AMIGA
Auger Muons & Infill for the Ground Array



- 1500 m grid stations
- 750 m grid stations (infill stations)
- infill stations just installed
- associated muon detectors
- 8 missing infill stations

Total area: 23.5 km²

Near future:
+24 stations in a 433 m grid ~ 5.9 km²

Data taking since August 2008

Water Cherenkov detectors: electromagnetic component + muons
Muon detectors: muons

UHECR

Crucial Problem:

Galactic
Extragalactic
Transition

1. Energy Spectrum
2. Anisotropy
3. Composition

UHECR

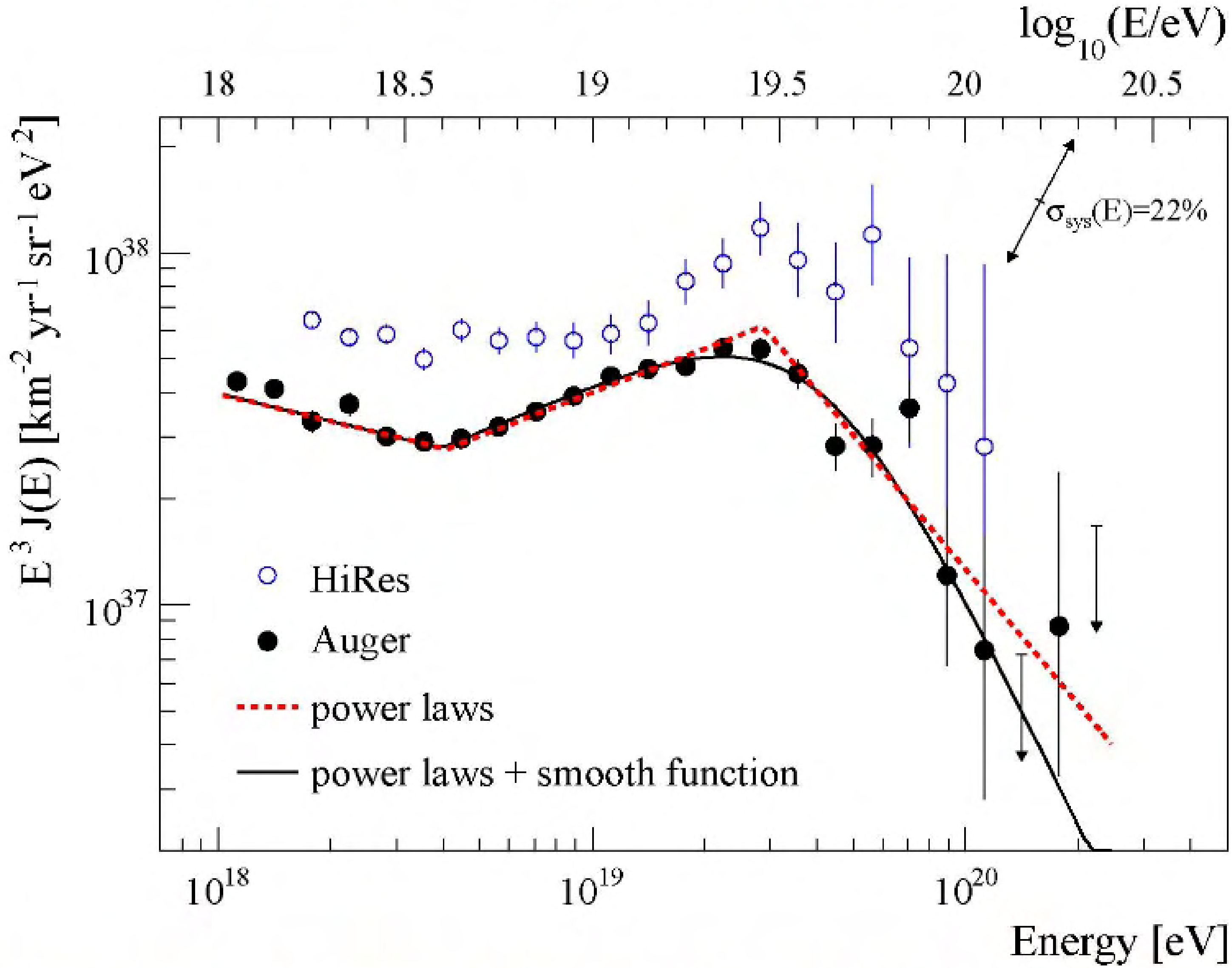
1. Energy Spectrum

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

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

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

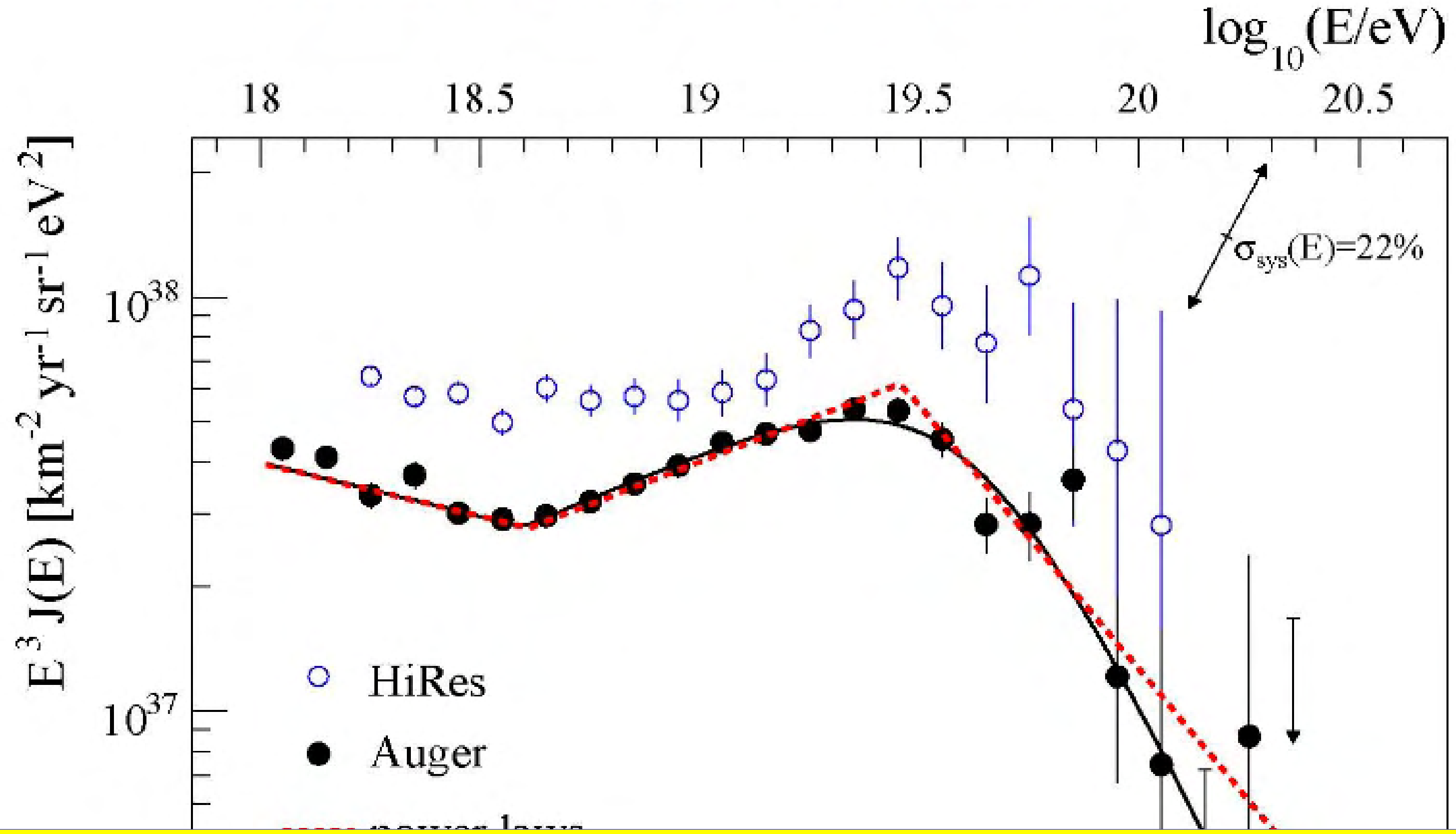
About 20 % energy scale difference !



HiRes/ TA – Auger observe the GZK suppression

But : problem on the energy scale

About 20 % energy scale difference !



HiRes/TA/Auger observe a High energy Suppression
That could be the GZK suppression
[or photo-disintegration of Iron]
[or Source Cutoff]

HiRes/ TA – Auger observe the GZK suppression

But : problem on the energy scale

UHECR

Crucial Problem:

Galactic
Extragalactic
Transition

1. Energy Spectrum

2. Anisotropy

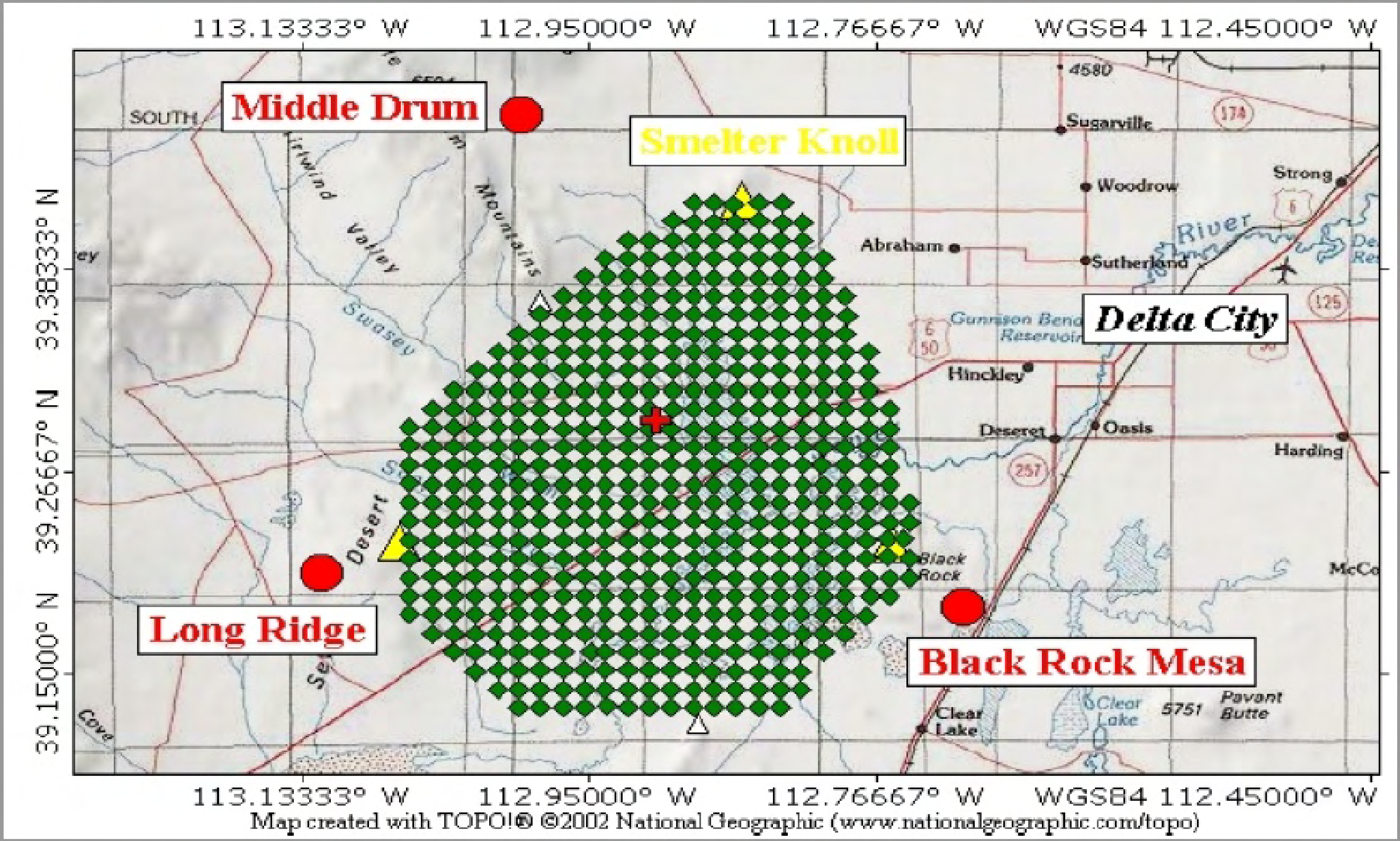
3. Composition

Significant
Experimental
Discrepancies

Auger/Hires/TA

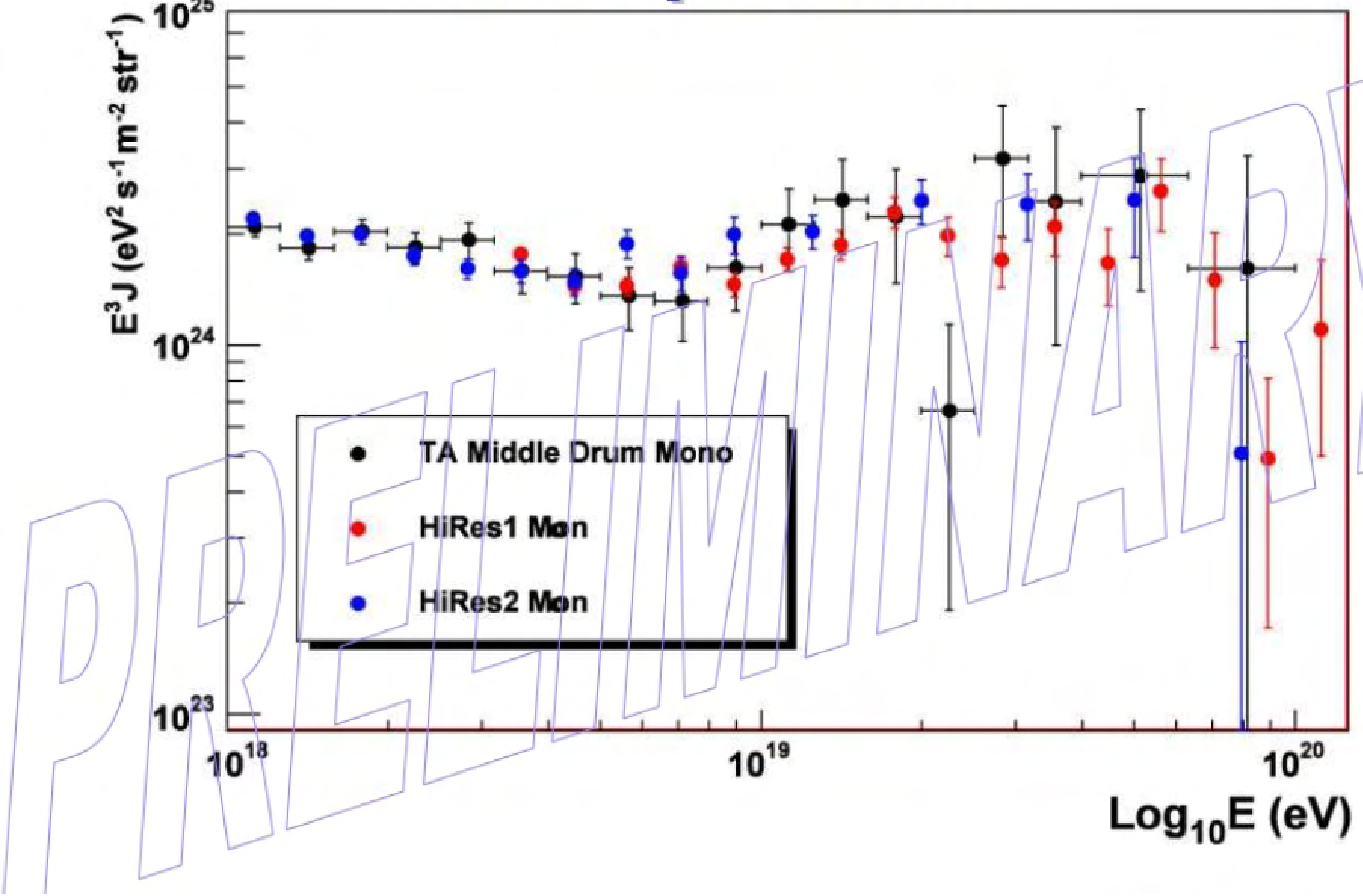
Confusing
situation.

TELESCOPE ARRAY HYBRID DETECTOR

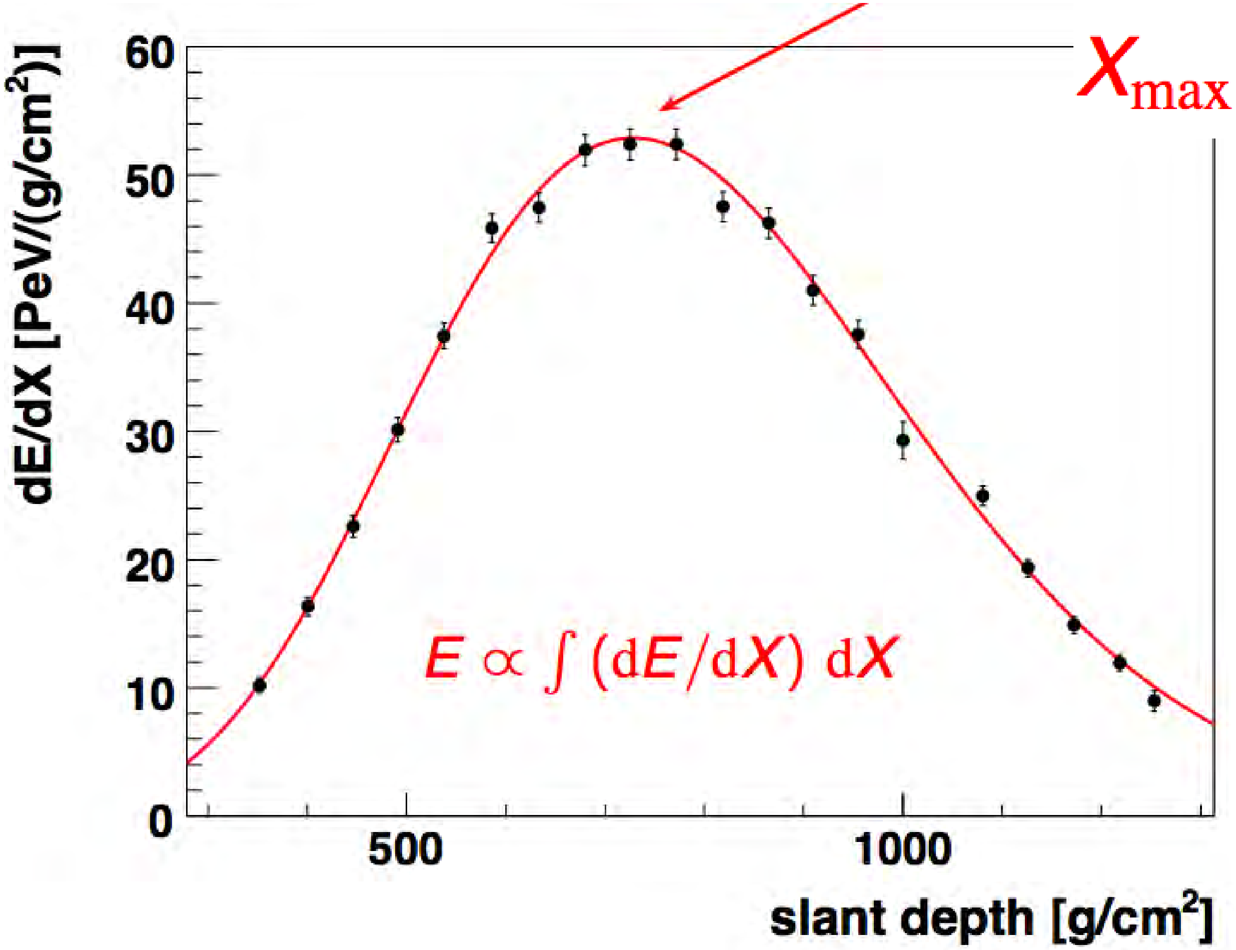


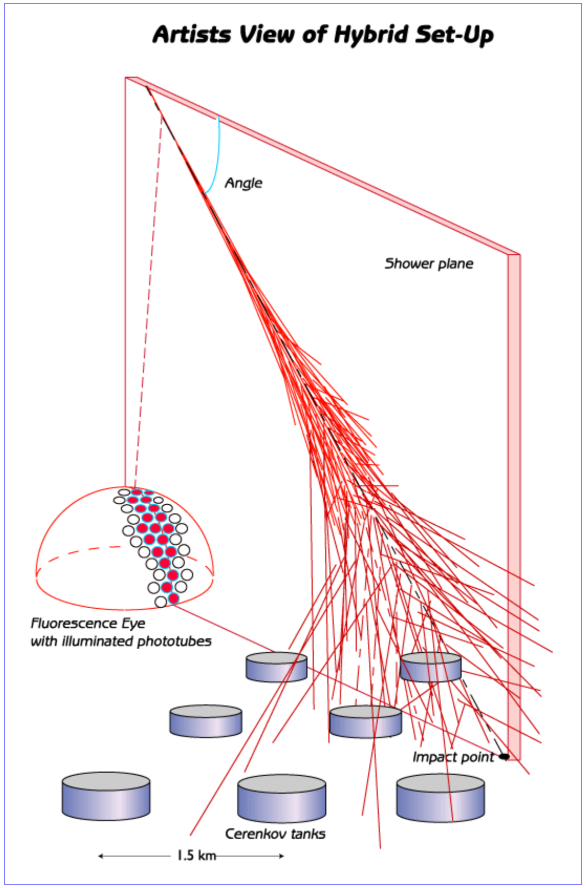
- 507 scintillator detectors covering 680 km^2
- 3 fluorescence sites, 38 telescopes
- Surface detector fully operational from March 2008
- SD relative size: TA $\sim 9 \times$ AGASA $\sim$ PAO/4

MD Spectrum



10^{25}
10^{24}
10^{23}
E^3J (eV^2 s^{-1} m^{-2} str^{-1})
10^{18}
10^{19}
10^{20}
Log$_{10}$E (eV)
TA Middle Drum Mono
HiRes1 Mon
HiRes2 Mon
PRELIMINARY



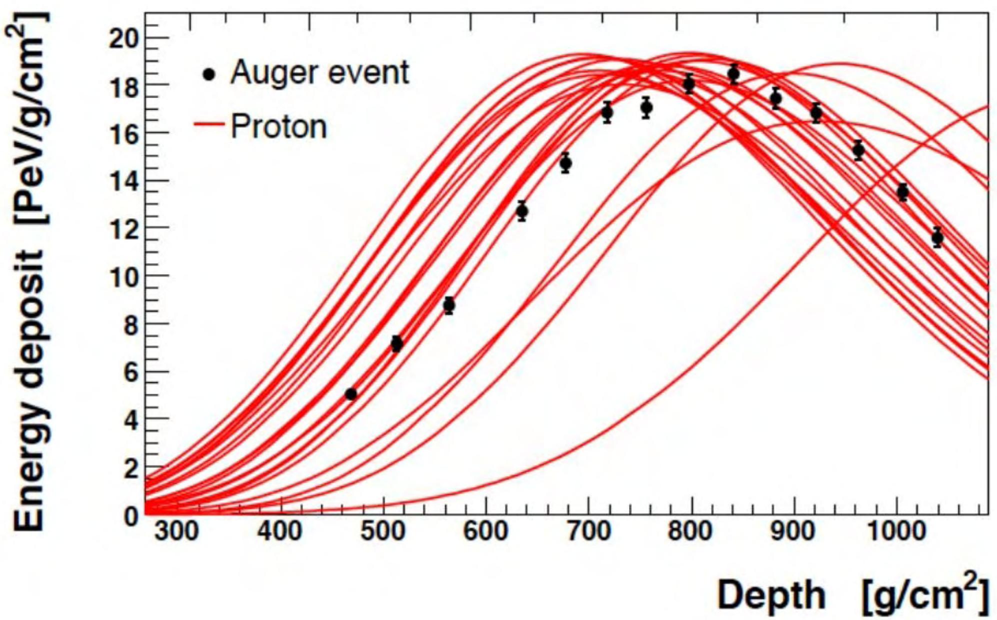


$$E_{\text{ionization}} = \int dX\; N_e(X)\left\langle -\frac{dE}{dX}\right\rangle$$

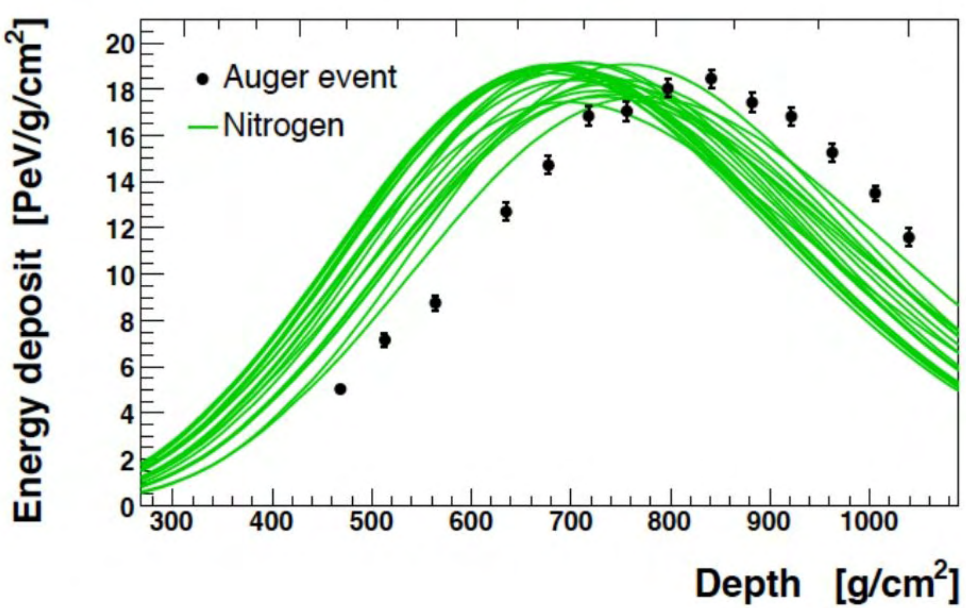
Area $\propto$ Energy

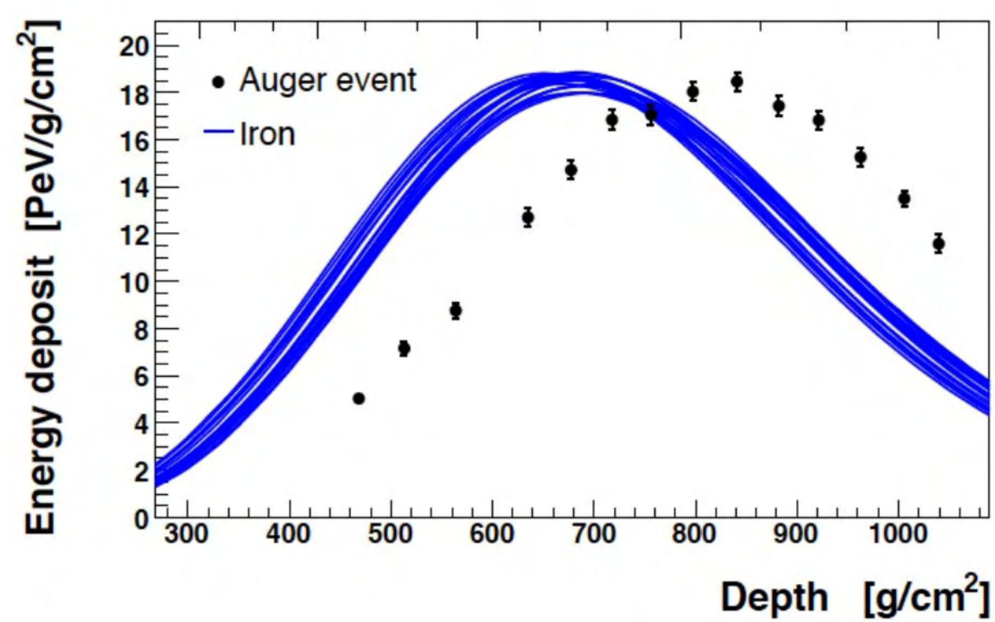
Shape depends on :

- Primary Identity
- Interaction Model

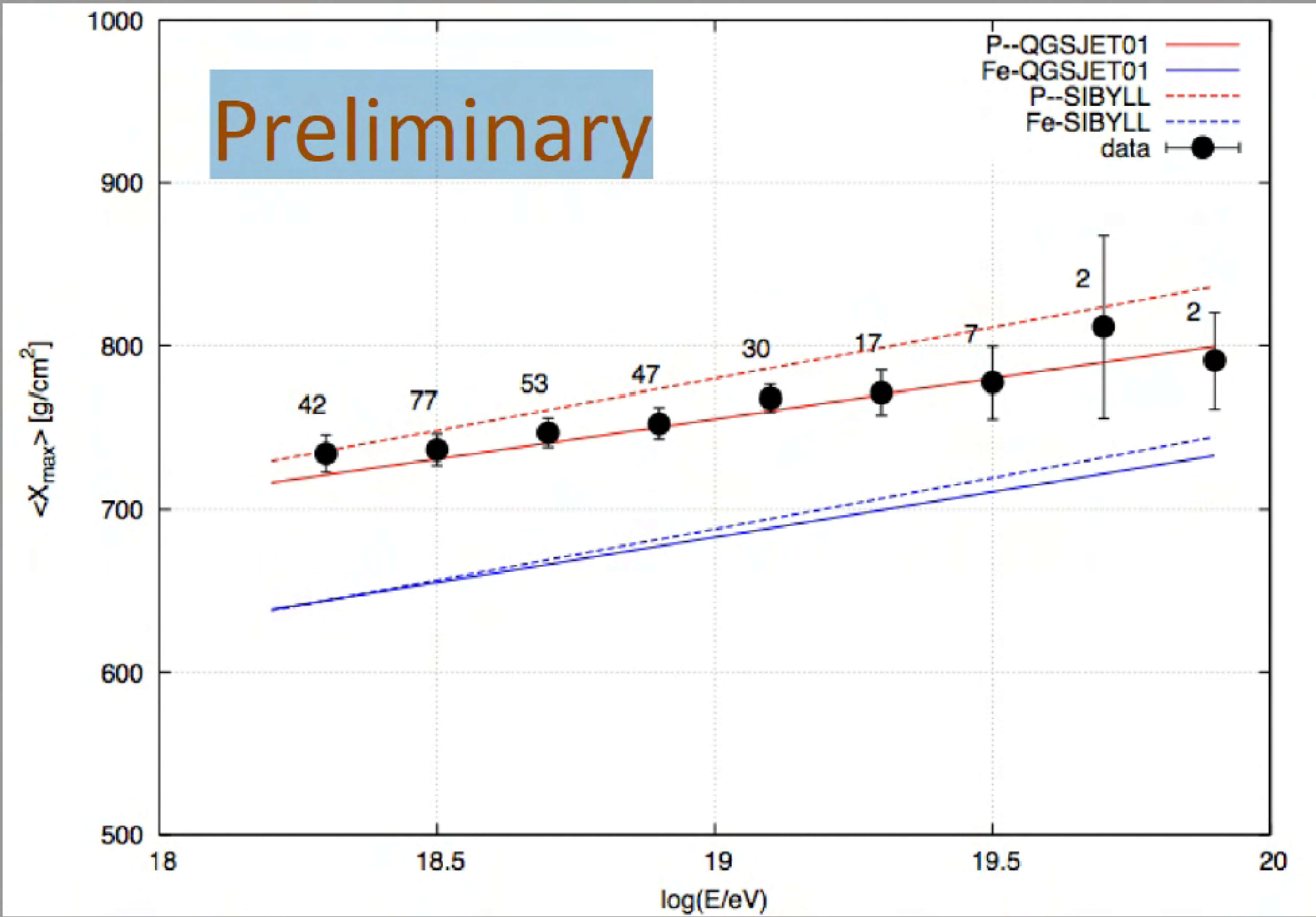


$$E \simeq 10^{20}\ \text{eV}$$

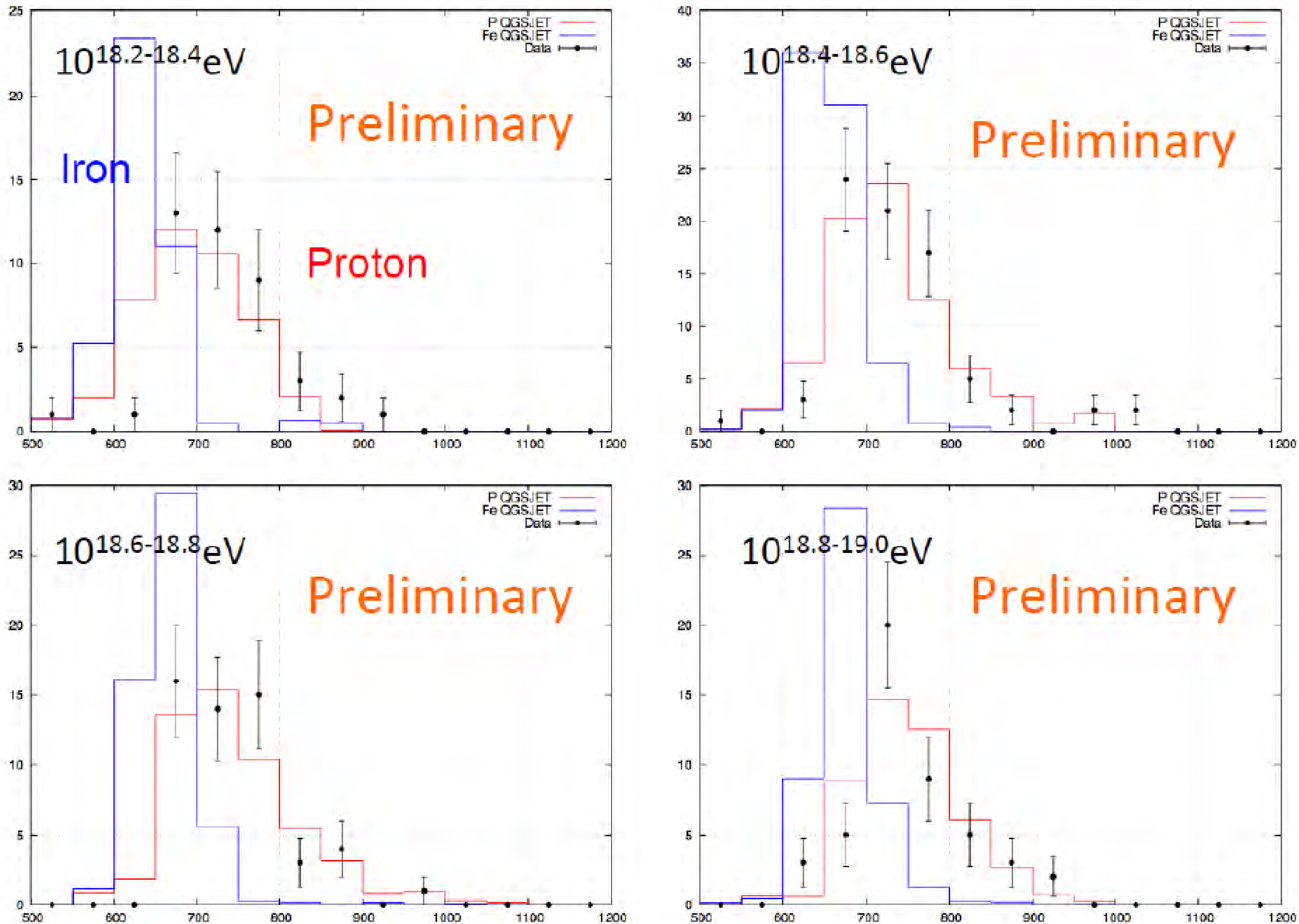


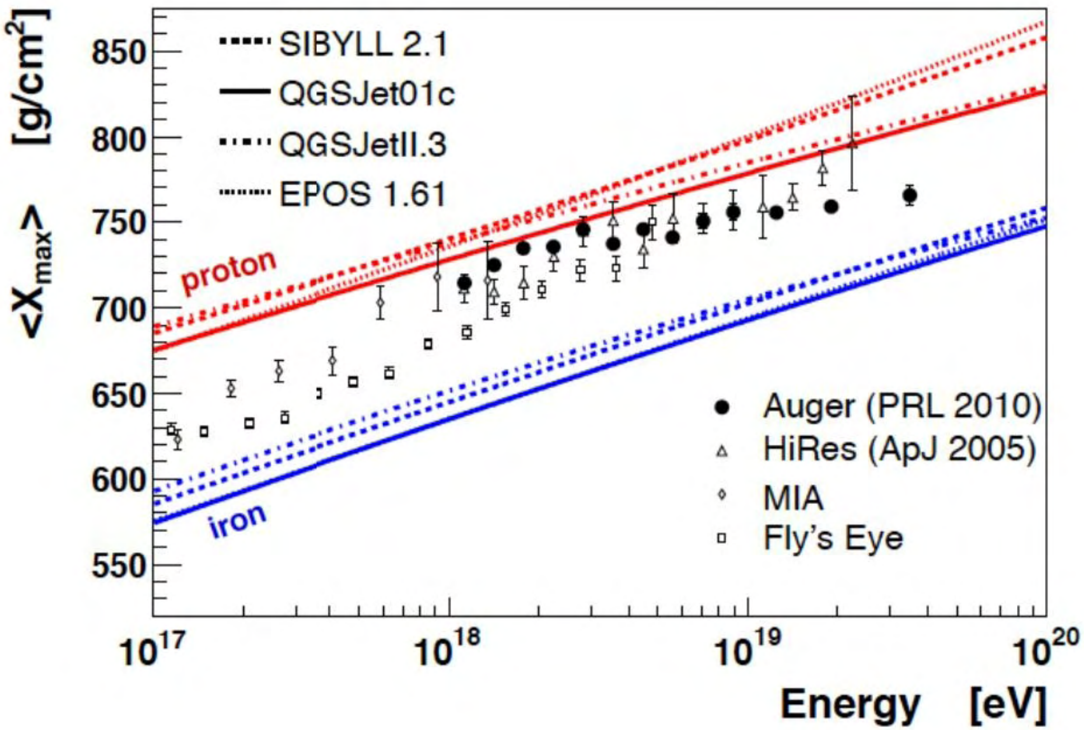


Telescope Array stereo result



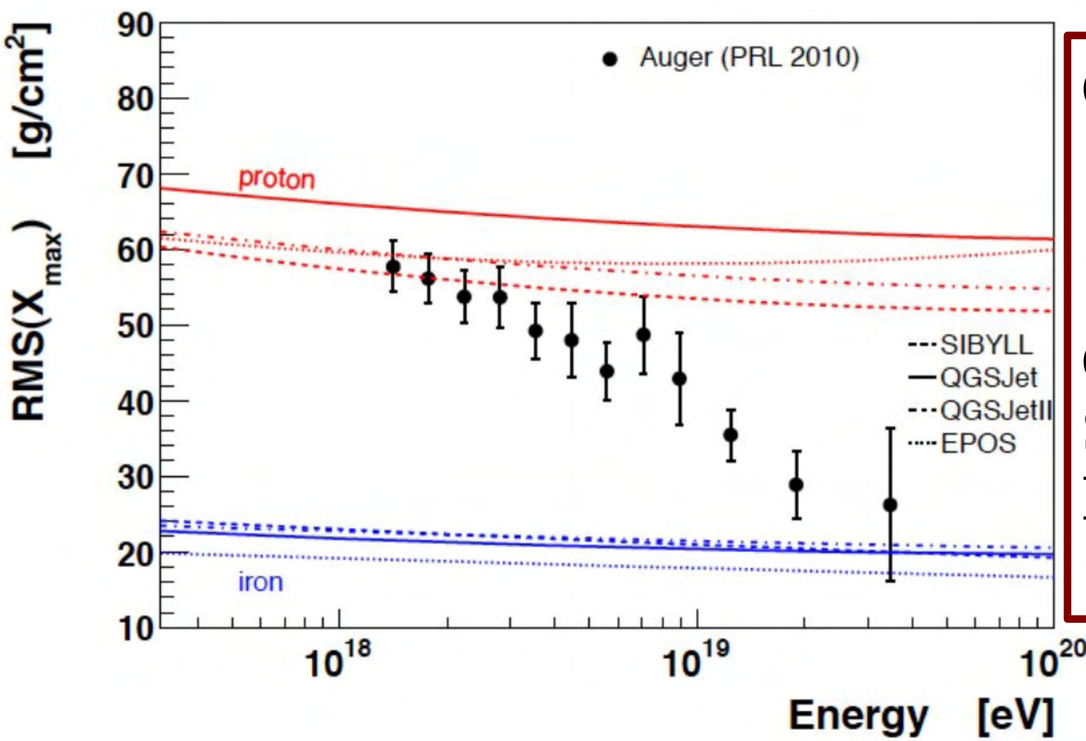
Xmax Distribution (QGSJET01)





Mass Composition
becoming heavy ?
at very high energy ?

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

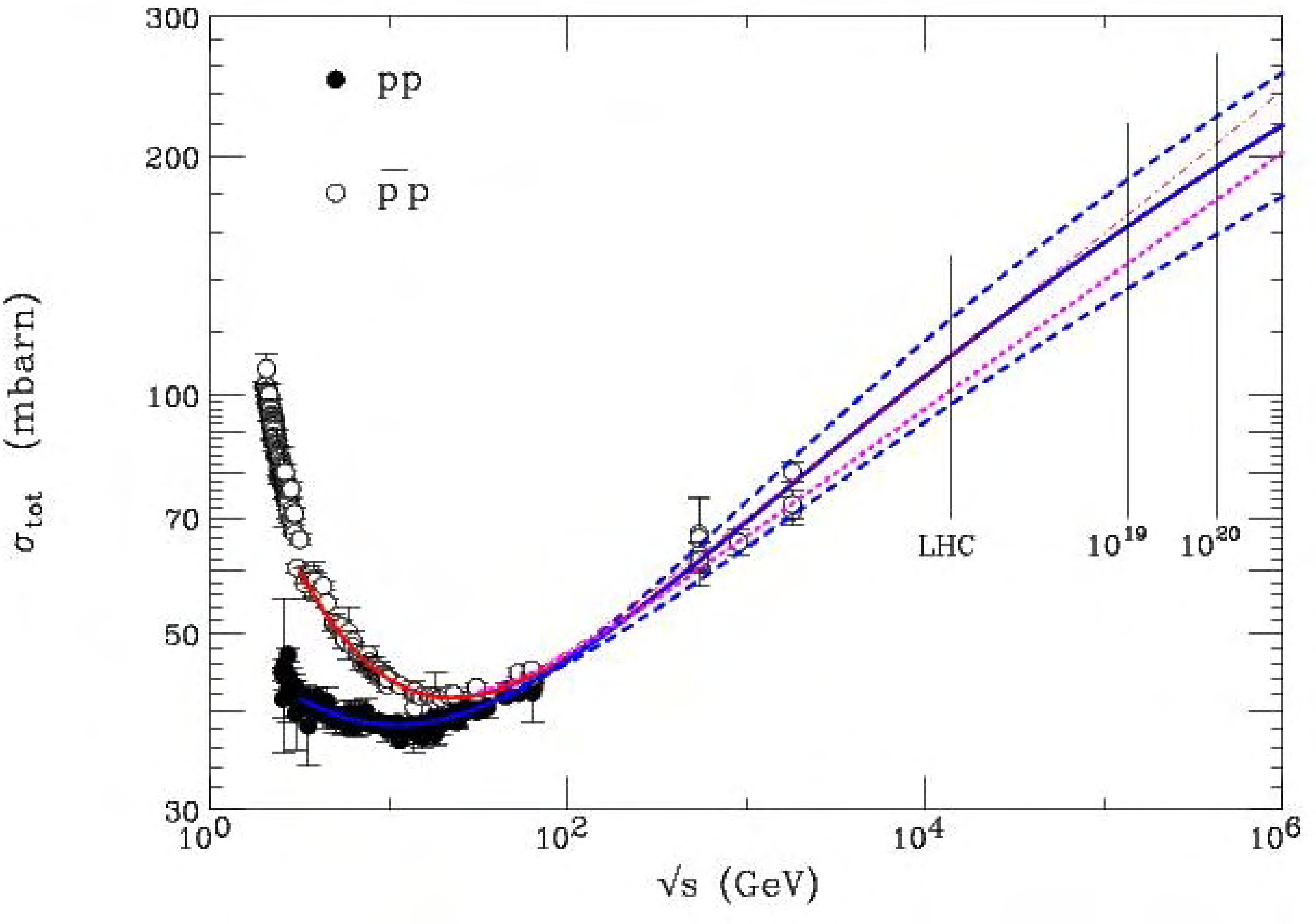


Observational controversy
NON confirmation
of HiRes

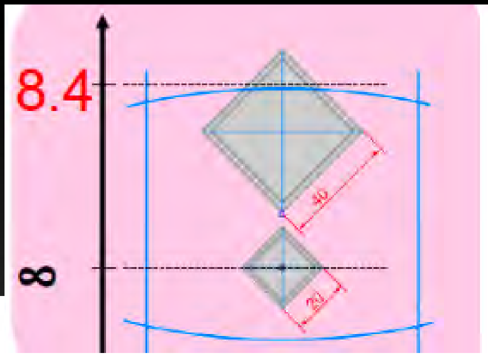
Correlation with sources
Small deviation in magnetic
Fields (Z < 3 ?)

LHC and Ultra-High Energy Cosmic Rays

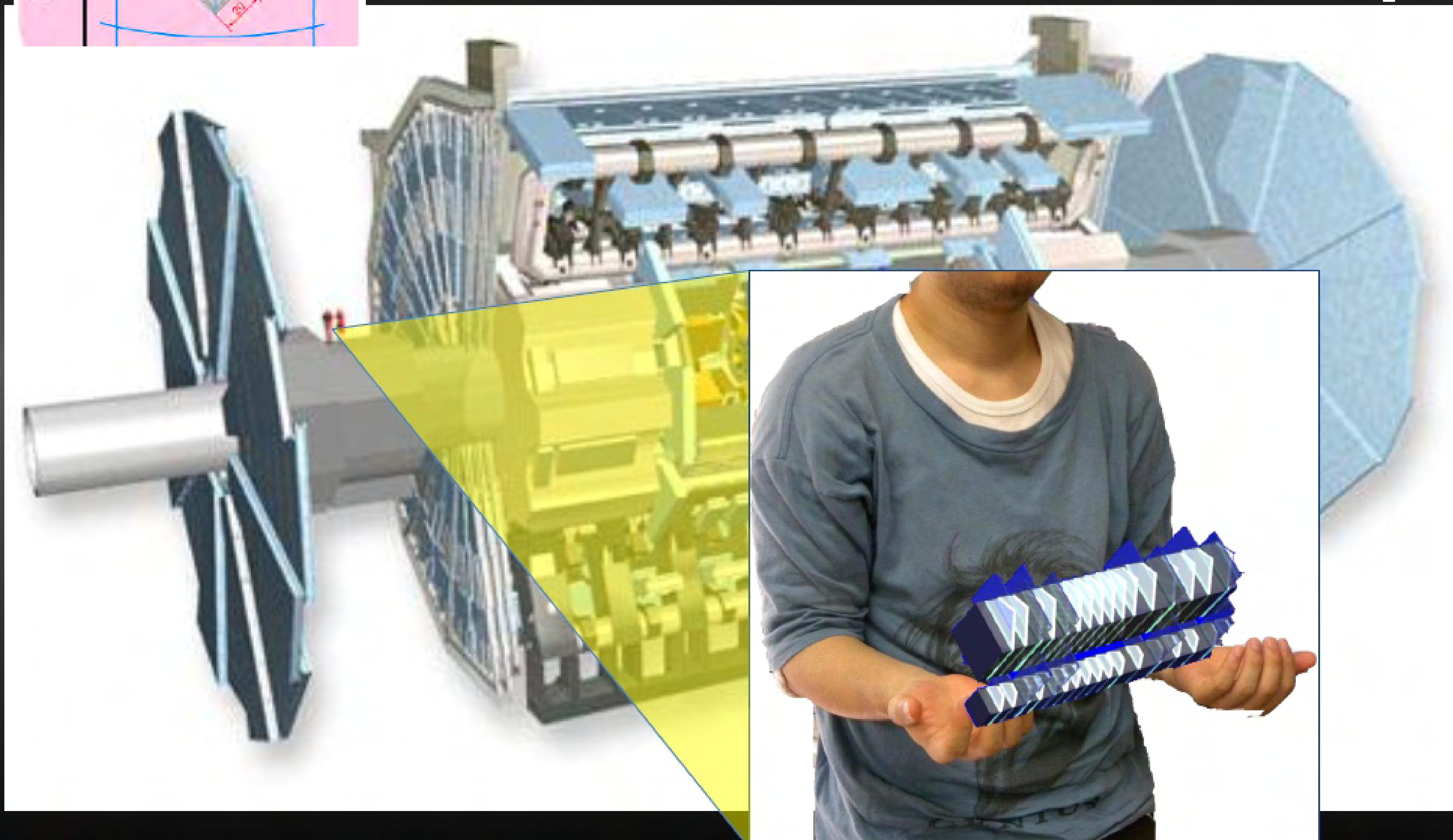
Total pp Cross Section



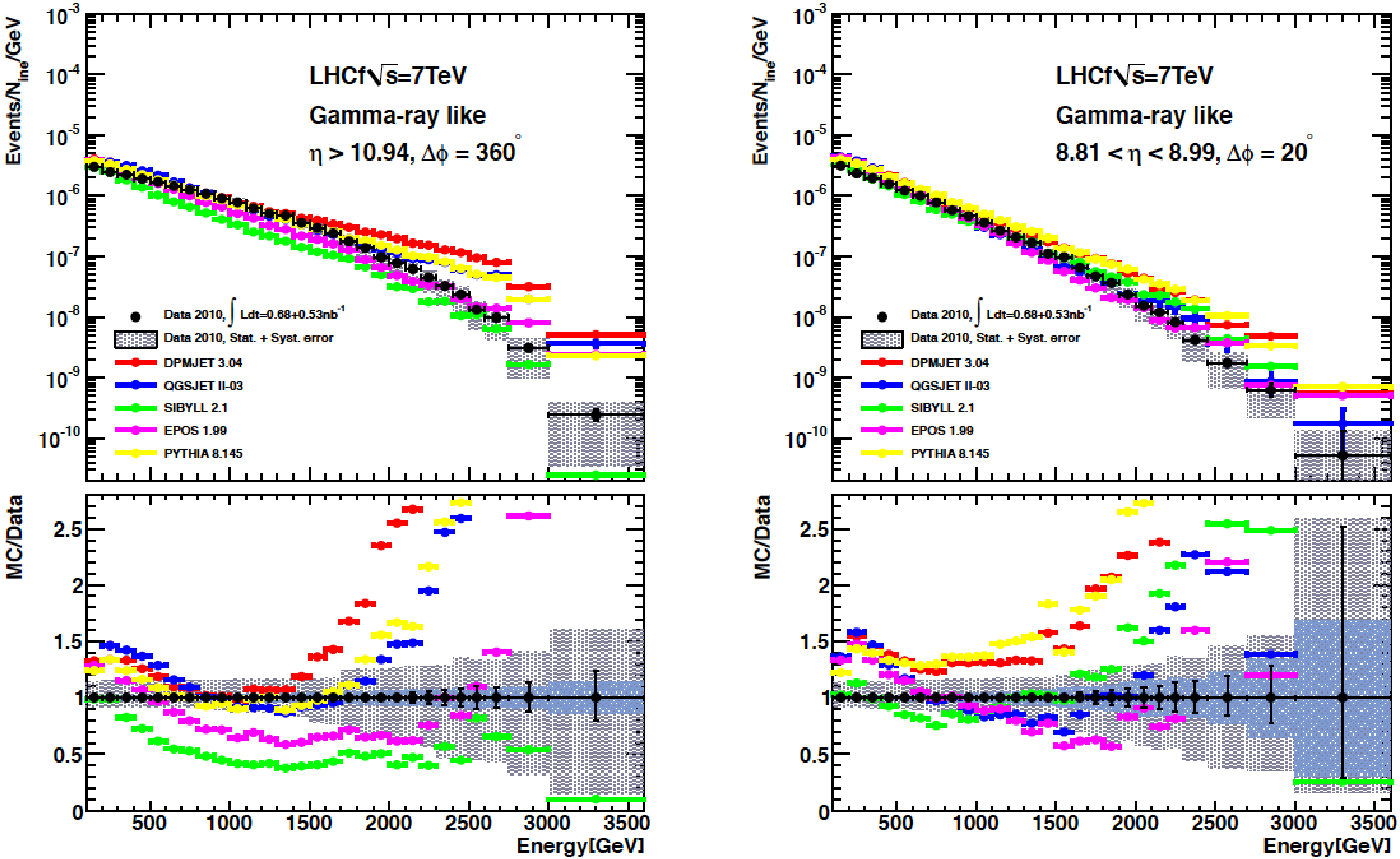
ATLAS & LHCf



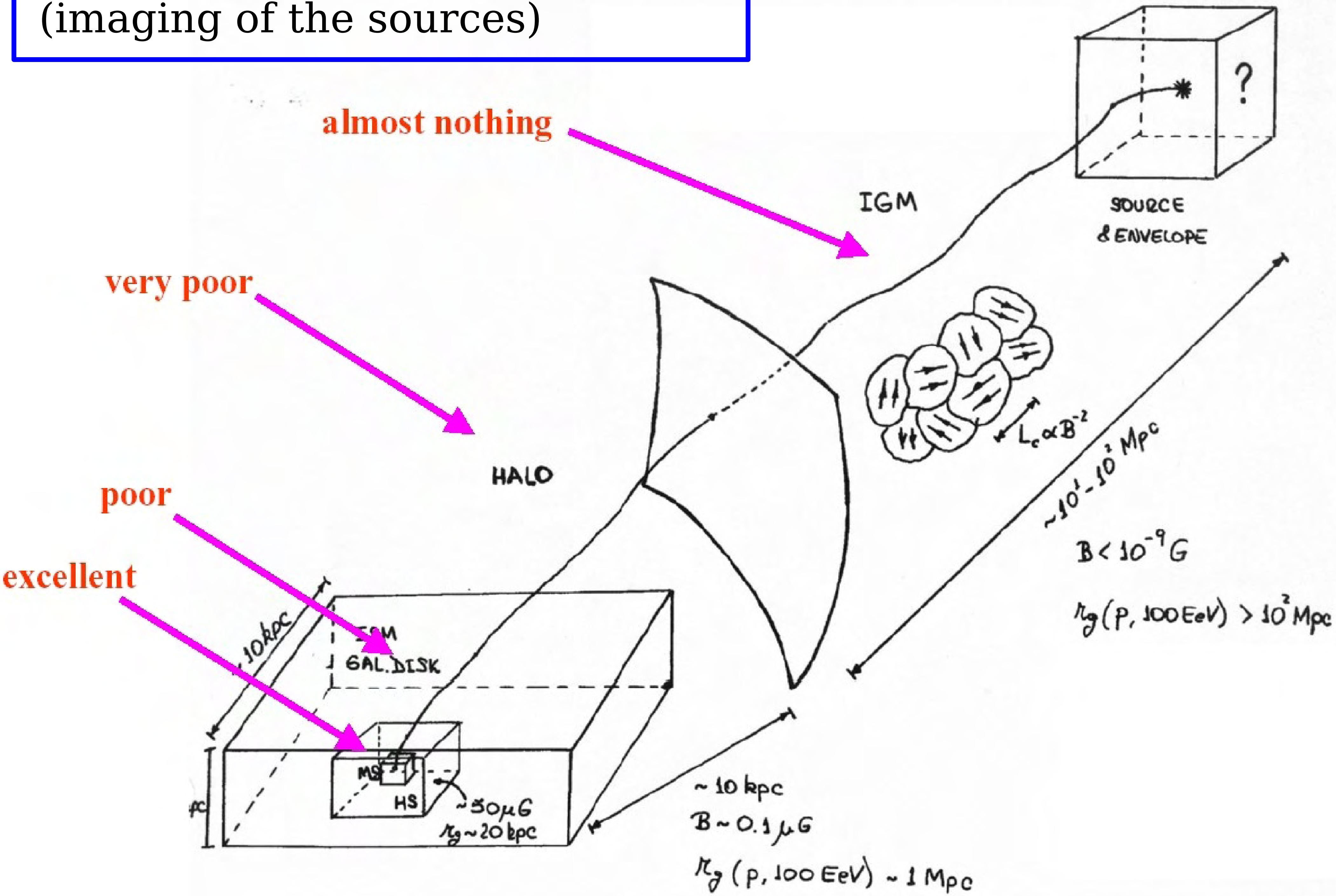
140 m from interaction point



LHCF first DATA publication



COSMIC Ray ASTRONOMY [?!]
(imaging of the sources)

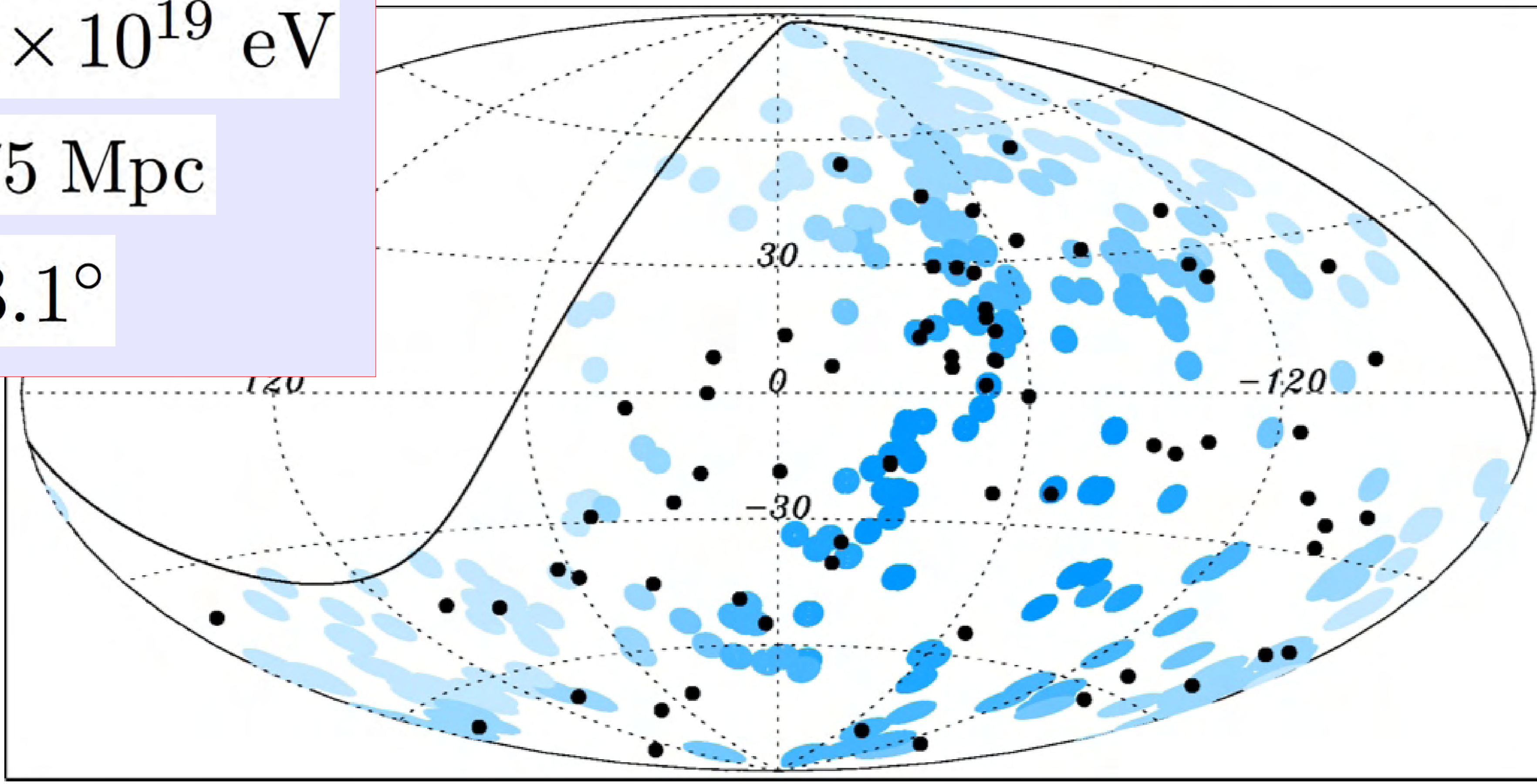


AUGER result on Correlations with the VCV AGN catalogue November 2008. Update september 2010.

6×10^{19} eV

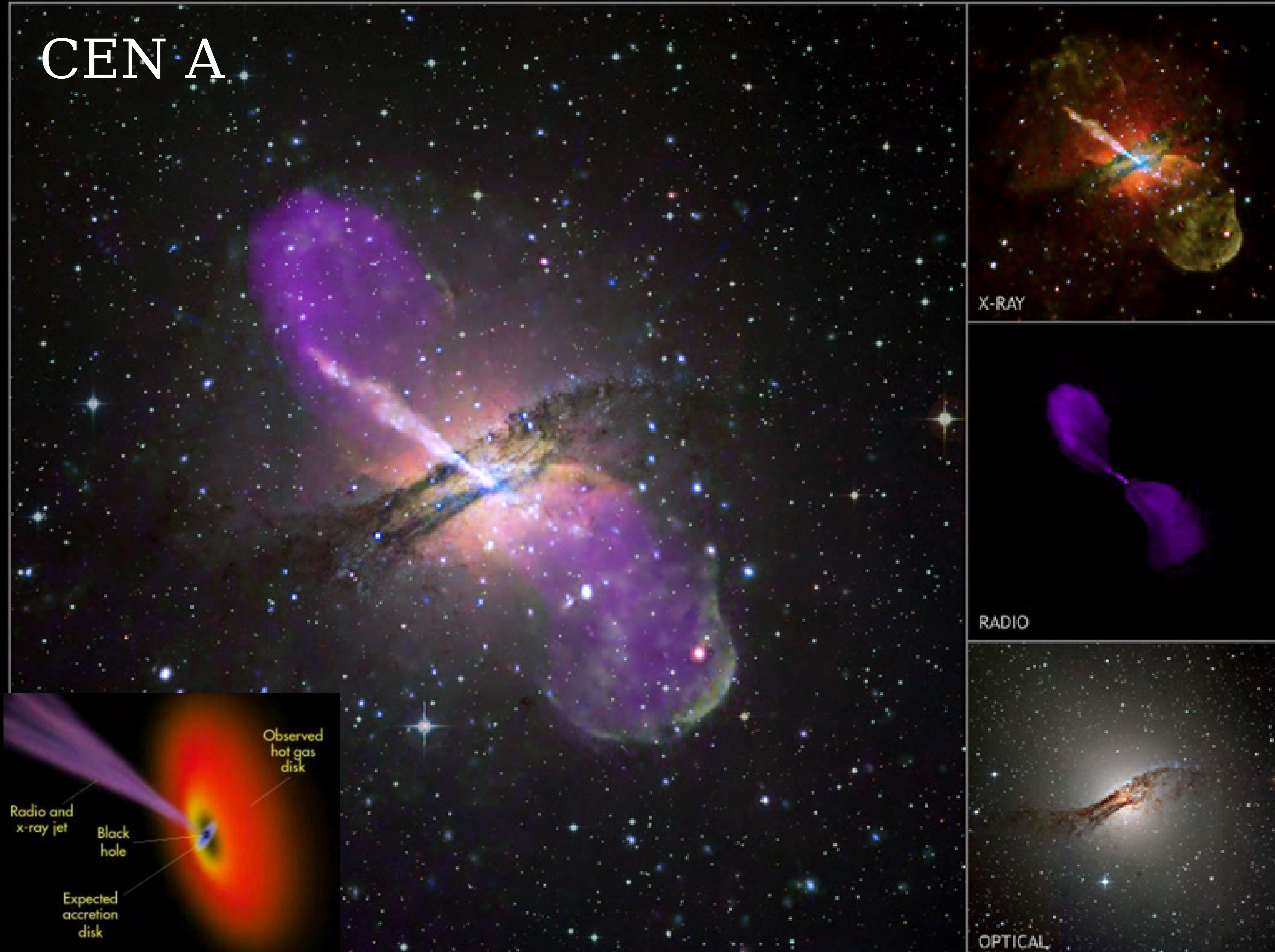
75 Mpc

$3.1°$

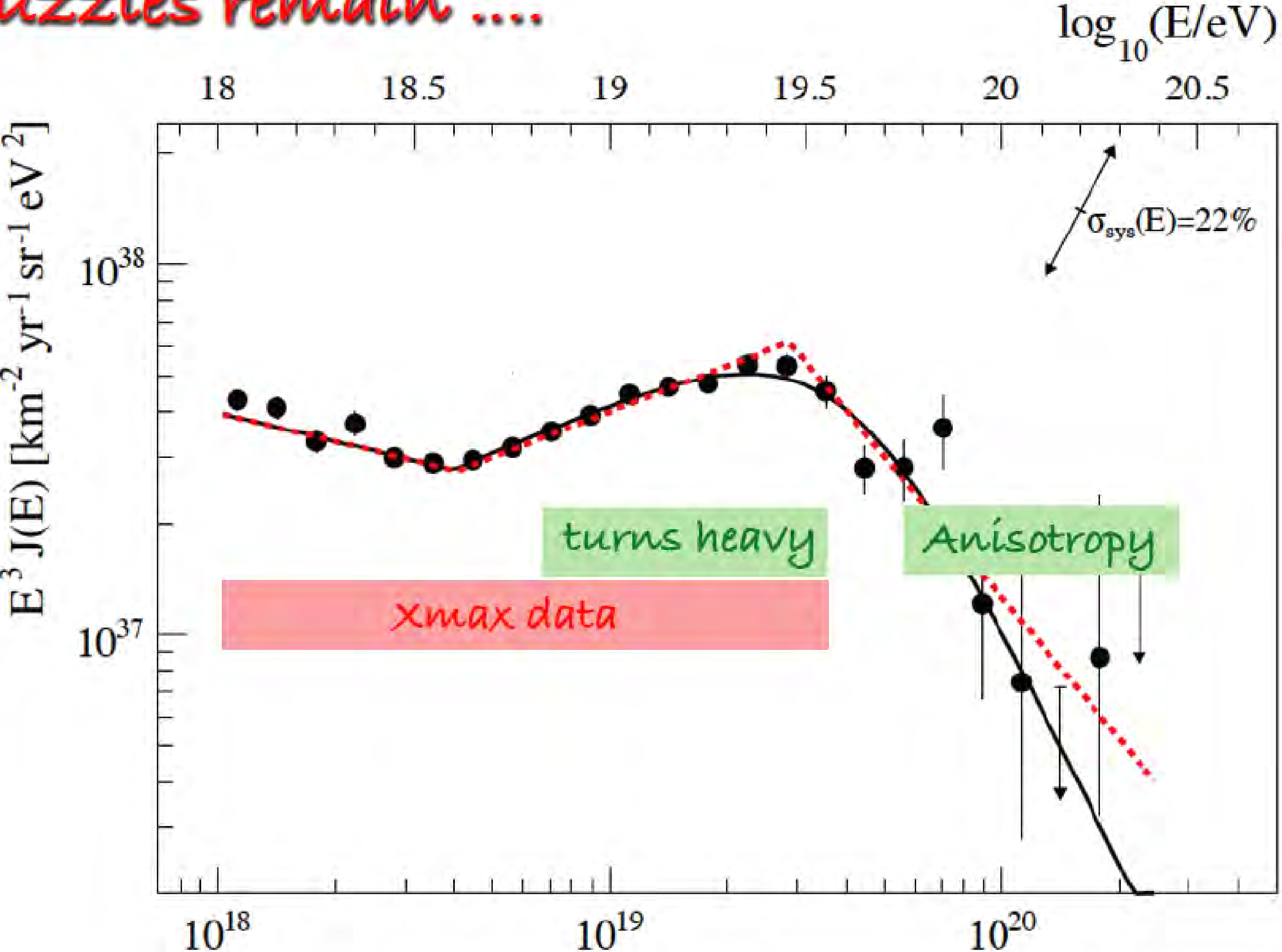


Significant dilution
[but not disappearance]
of the statistical significance

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


CEN A
X-RAY
RADIO
OPTICAL
Observed hot gas disk
Radio and x-ray jet
Black hole
Expected accretion disk

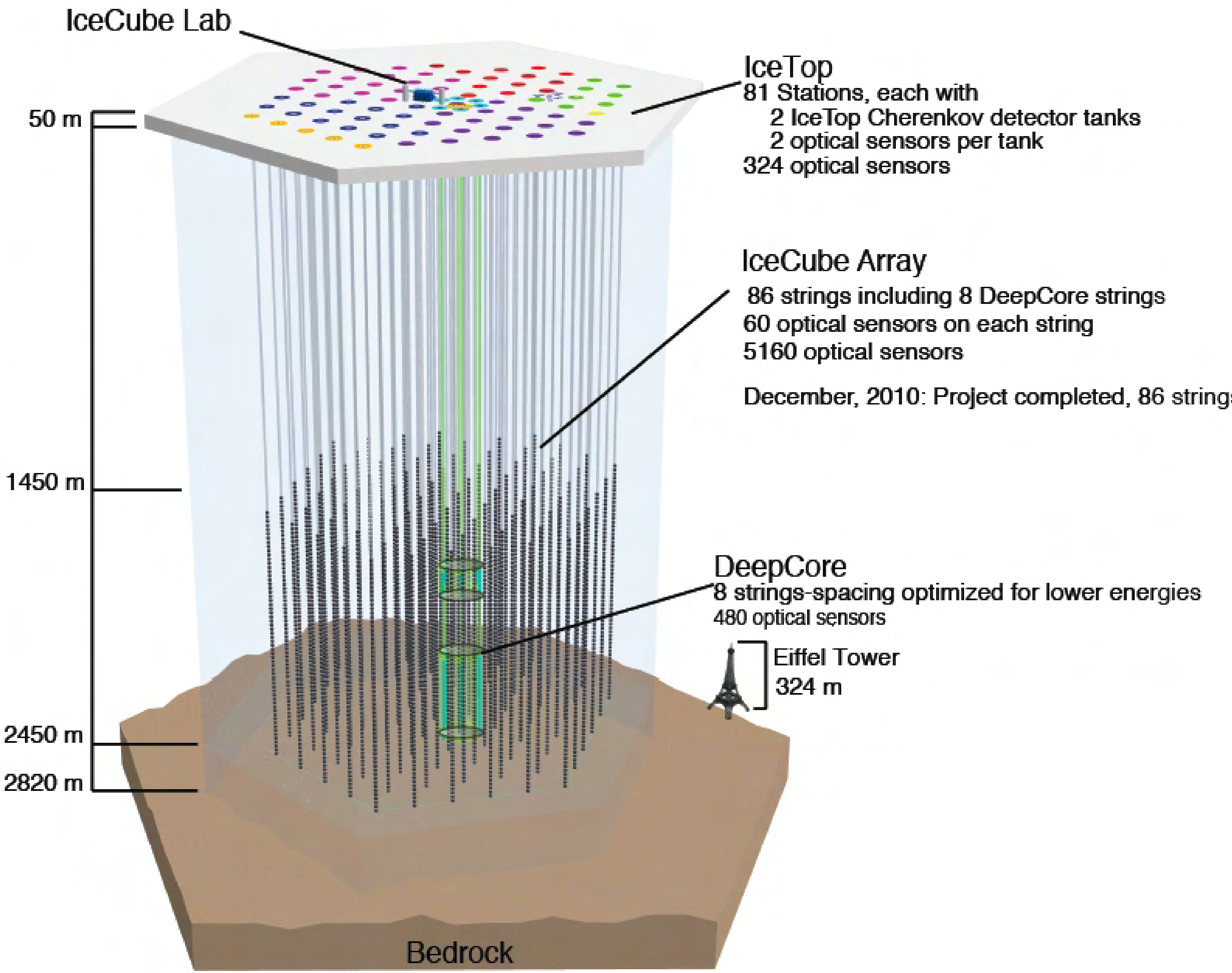
Puzzles remain ....

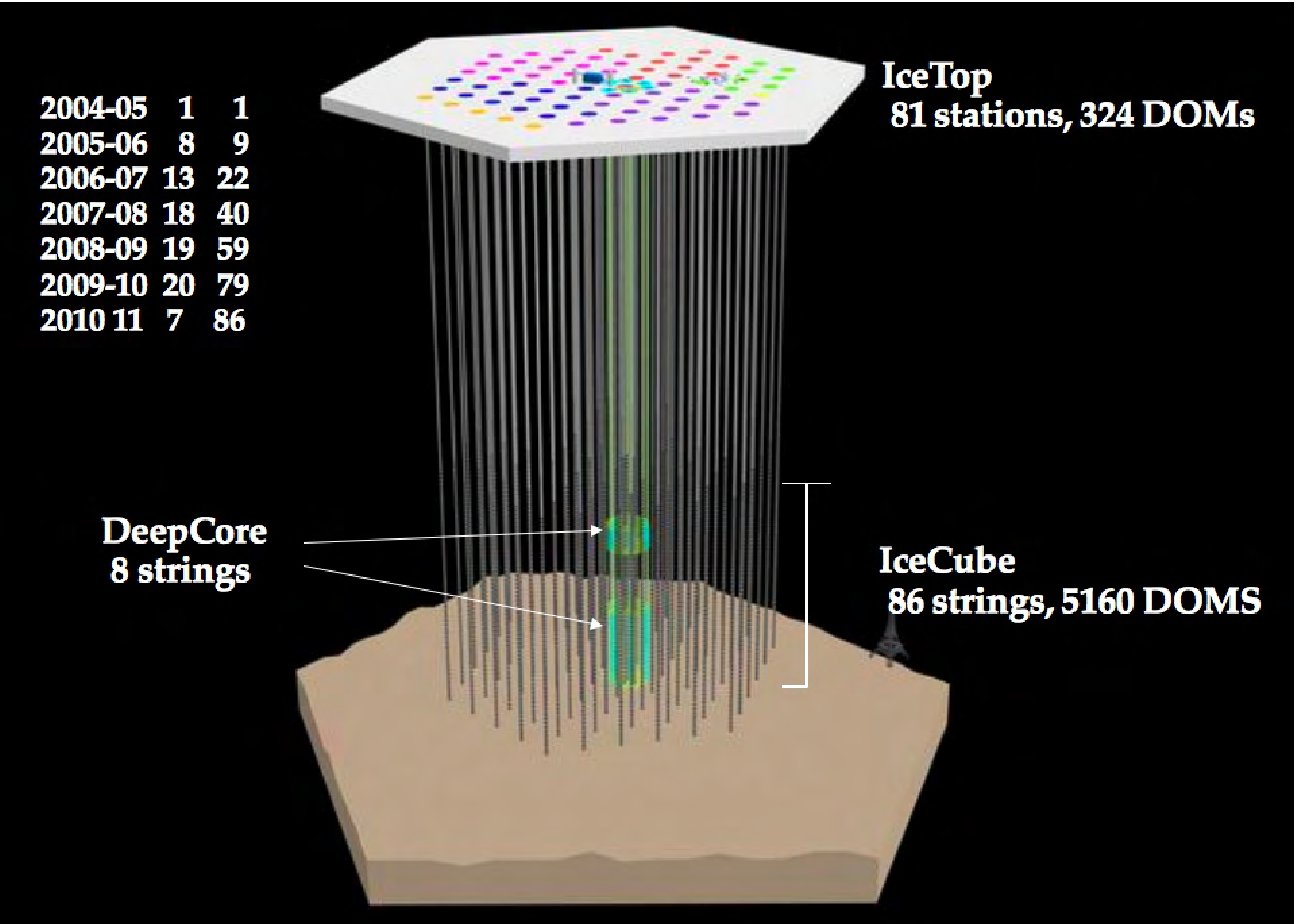


Johannes Knapp

NEUTRINO ASTRONOMY

....The moment of truth for IceCube ....

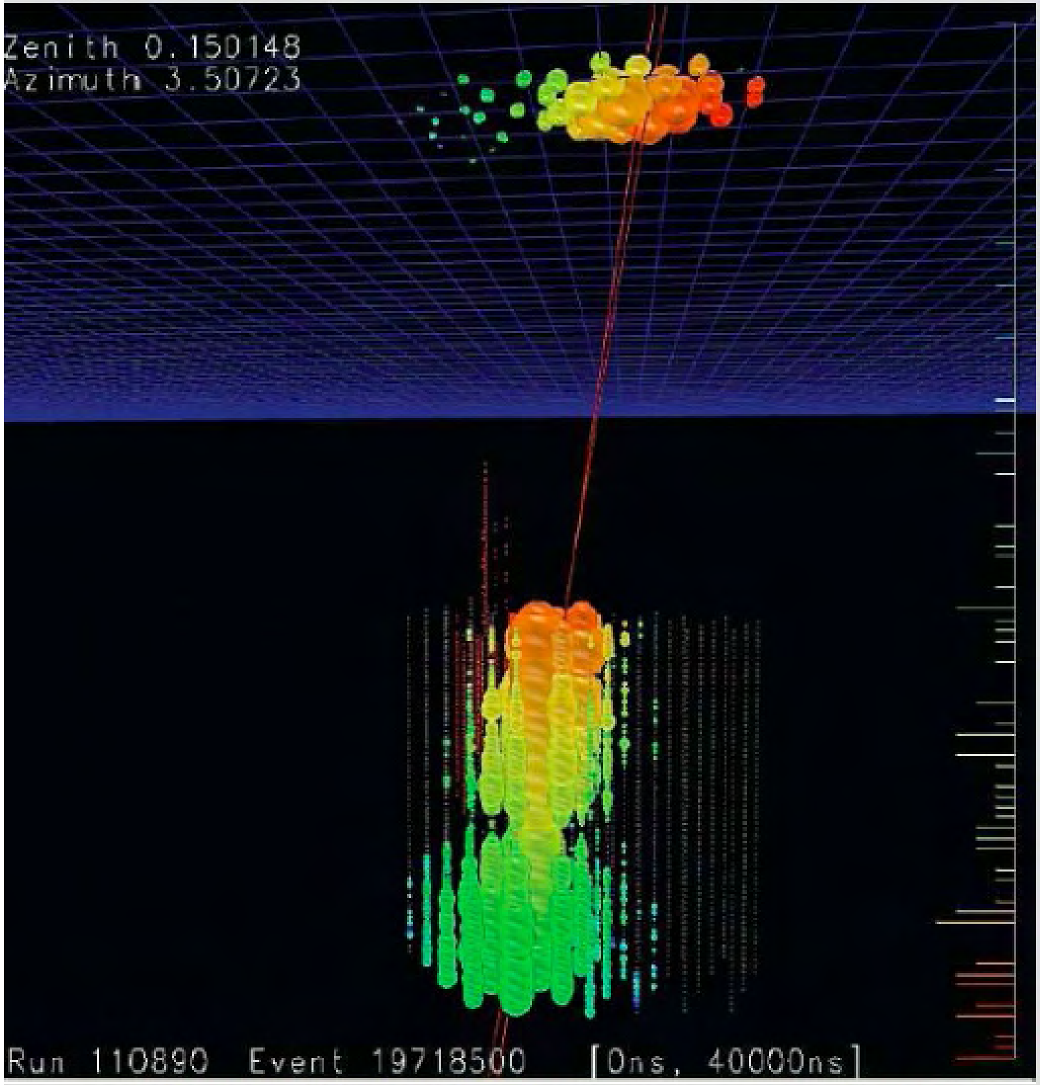

IceCube Lab
IceTop
81 Stations, each with
2 IceTop Cherenkov detector tanks
2 optical sensors per tank
324 optical sensors
IceCube Array
86 strings including 8 DeepCore strings
60 optical sensors on each string
5160 optical sensors
December, 2010: Project completed, 86 strings
DeepCore
8 strings-spacing optimized for lower energies
480 optical sensors
Eiffel Tower
324 m
50 m
1450 m
2450 m
2820 m
Bedrock

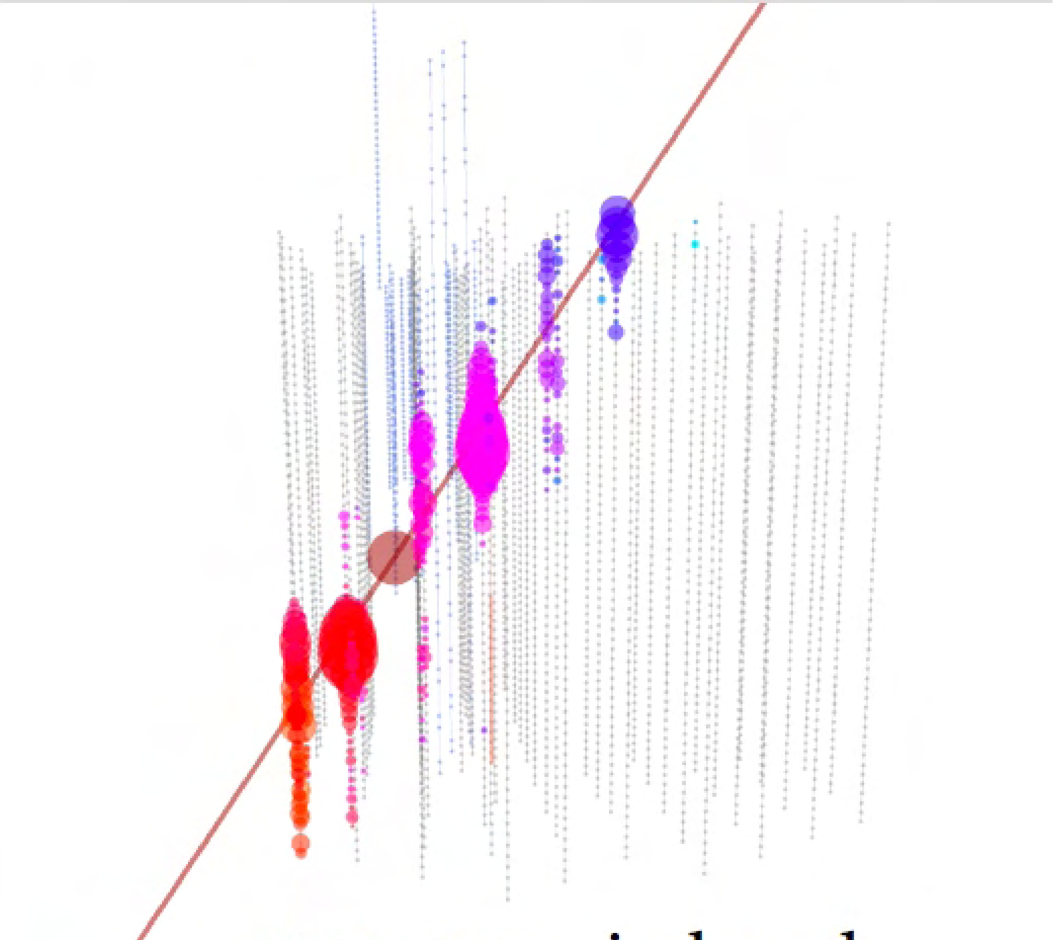


2004-05 1 1
2005-06 8 9
2006-07 13 22
2007-08 18 40
2008-09 19 59
2009-10 20 79
2010 11 7 86
IceTop
81 stations, 324 DOMs
DeepCore
8 strings
IceCube
86 strings, 5160 DOMS

High-energy events in IceCube-40

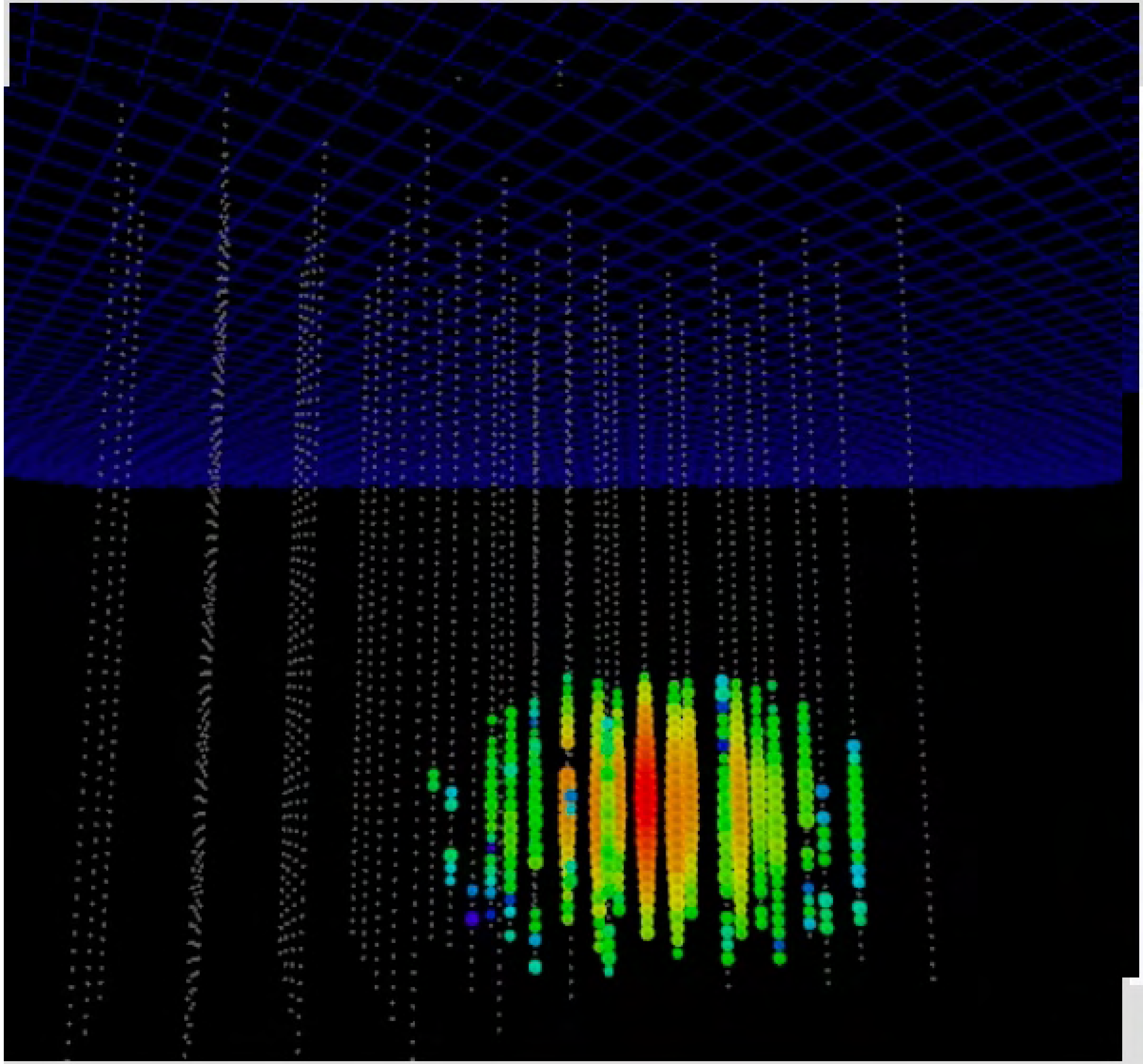
~ EeV air shower

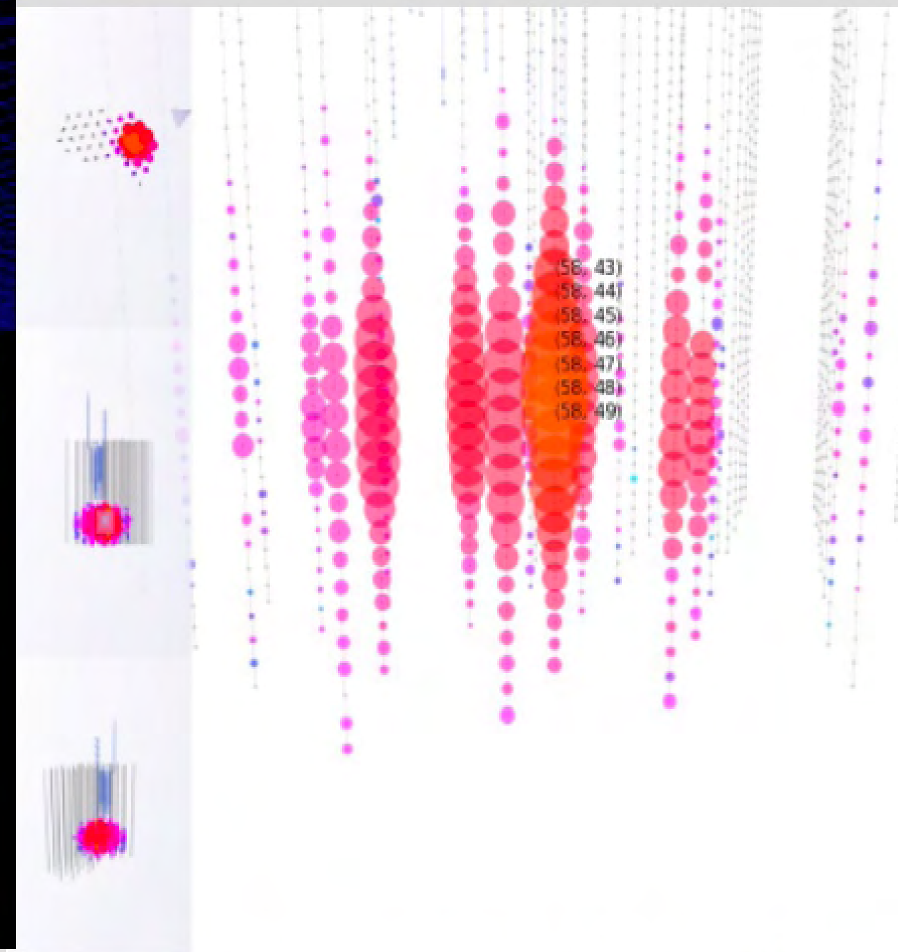




~100 TeV nm induced muon

More events

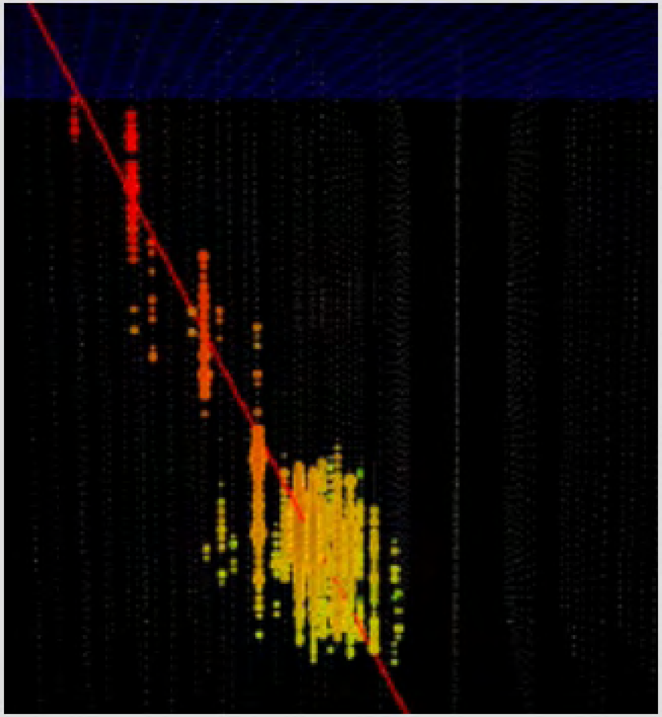


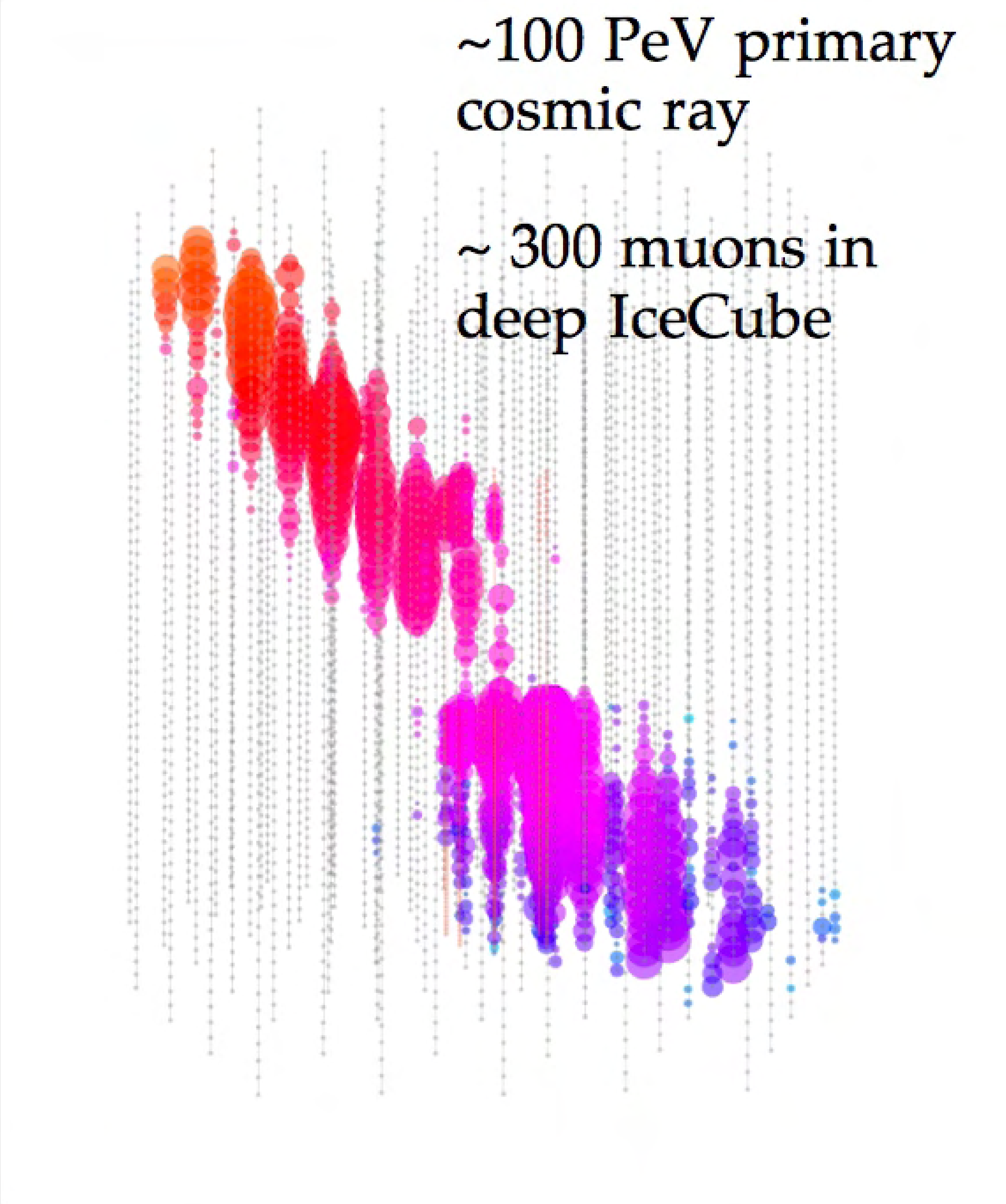


A cascade event, candidate for a high energy **ne** ~50 TeV

IC-79 events illuminate deep core

IceCube Deep Core talk by Ty DeYoung in afternoon session





EXTRA-GALACTIC NEUTRINOS

UNRESOLVED FLUX

Sum of all High Energy
Neutrino Sources

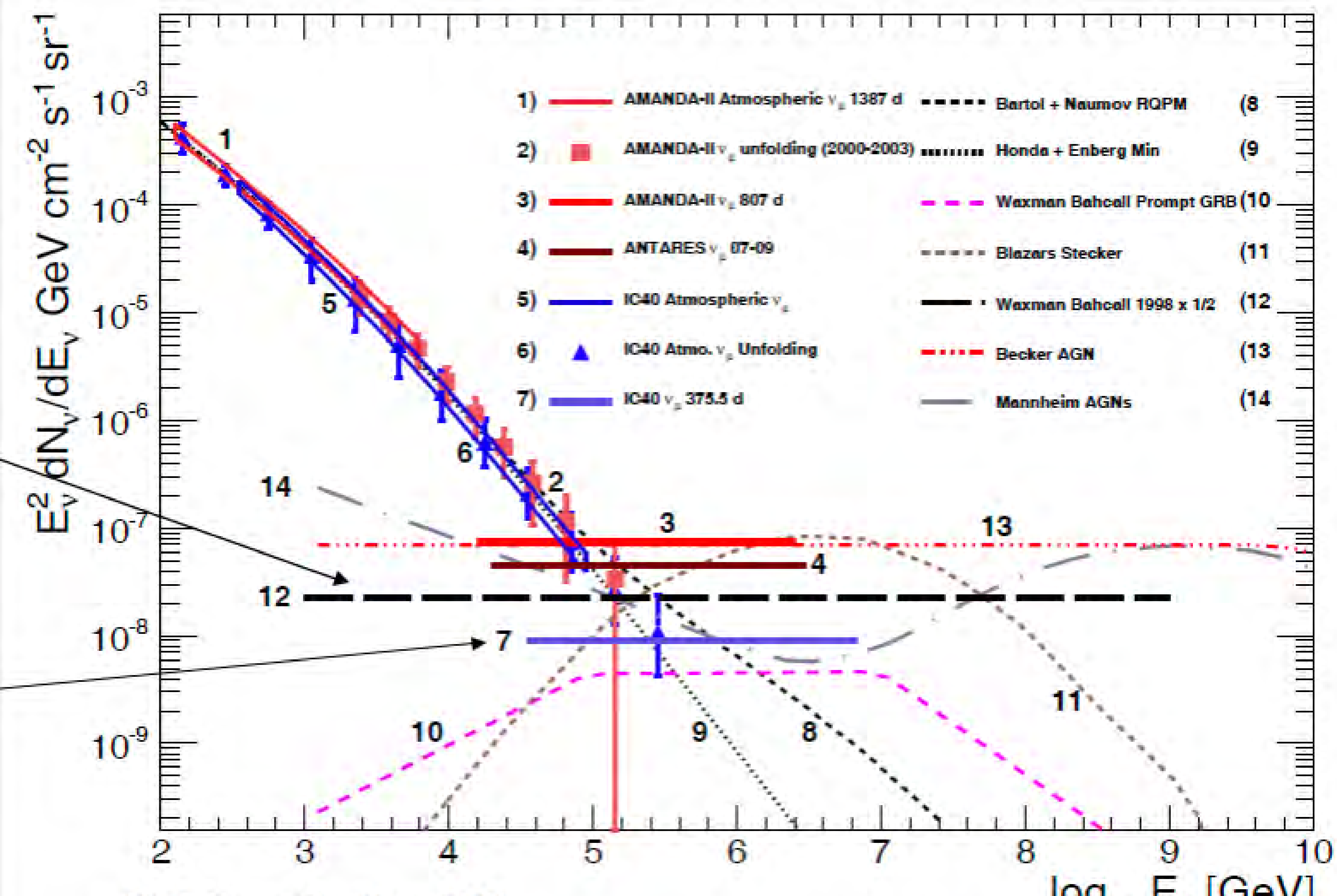
Individual Sources

AGN
GRB's

IceCube nm: measurements & limits

Waxman -Bahcall Limit

IceCube 40
arXiv:1104.5187

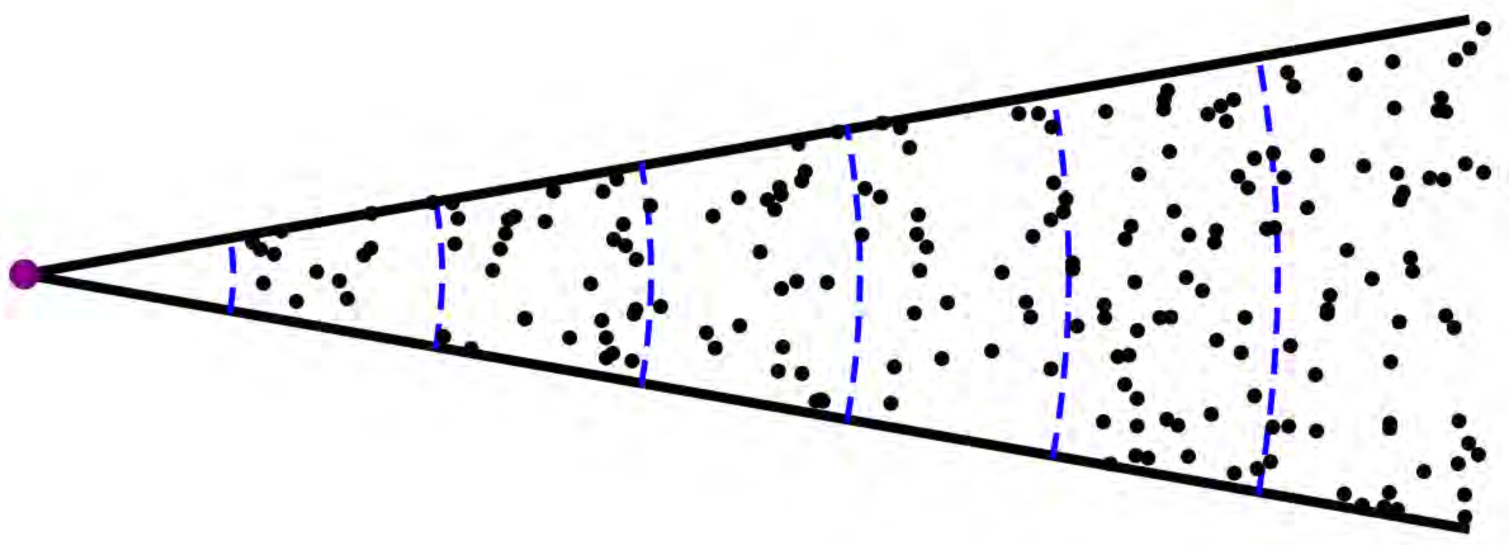


Plot: Sean Grullon, UW

INCLUSIVE Extra-Galalactic Neutrino Flux

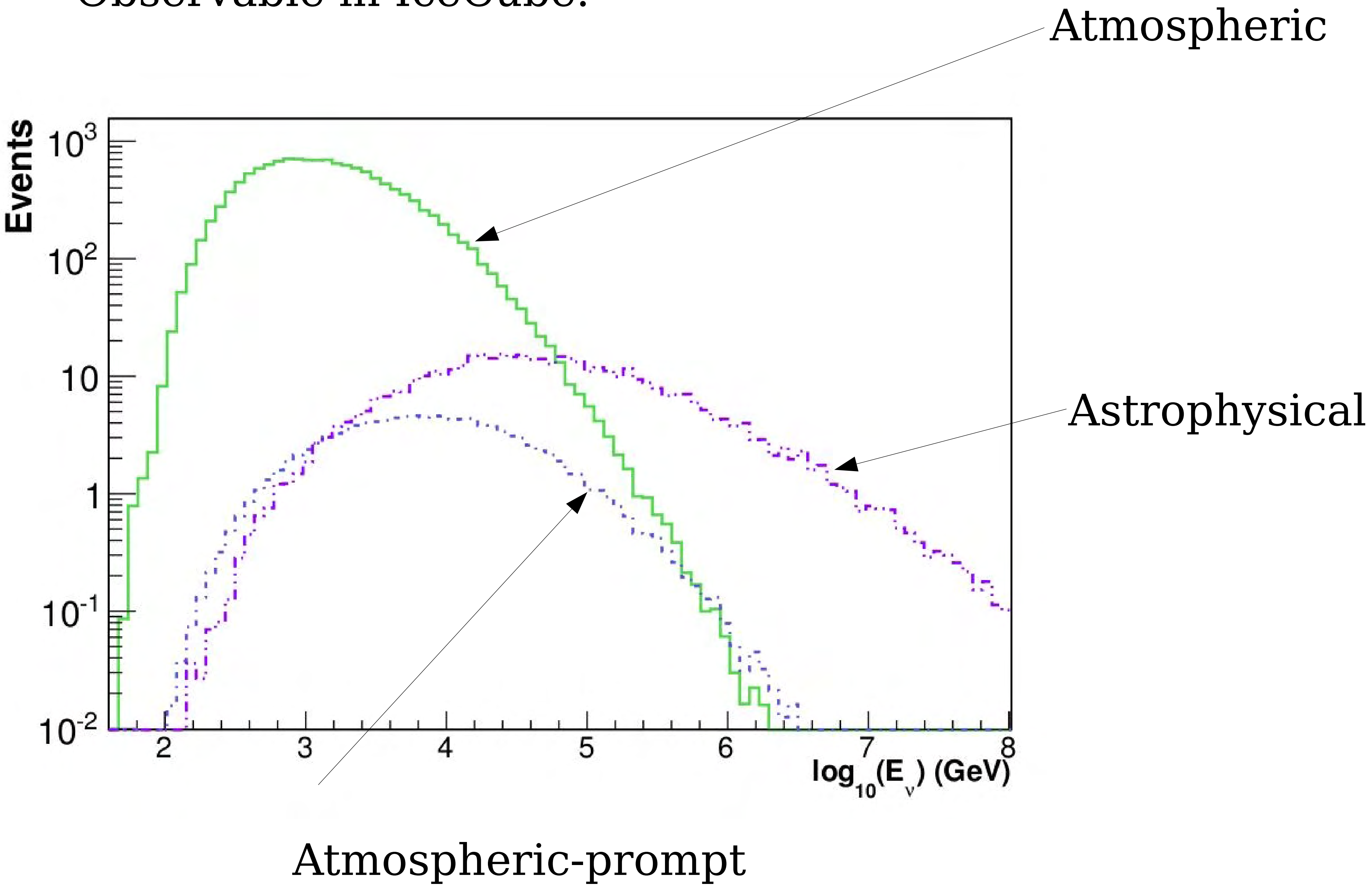
$$\phi_{\rm inclusive} = \sum_{\rm all\ sources} \phi_{\rm single\ source}$$

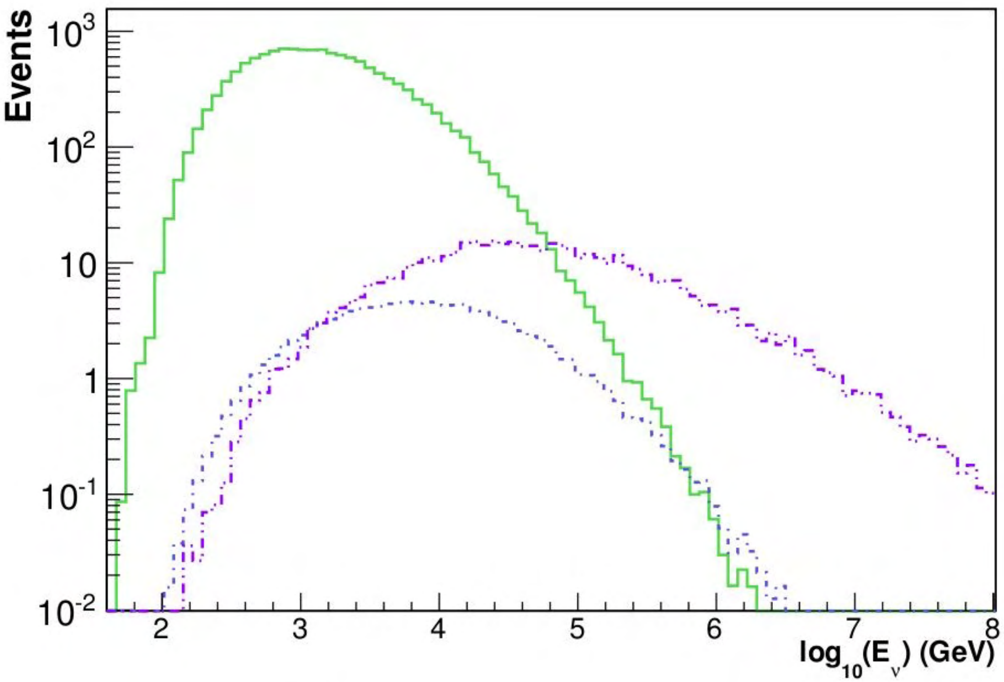
$$\phi_{\rm inclusive} = \int_{\rm all\ space} d^3r\ \phi_{\rm source}(\vec{r})$$



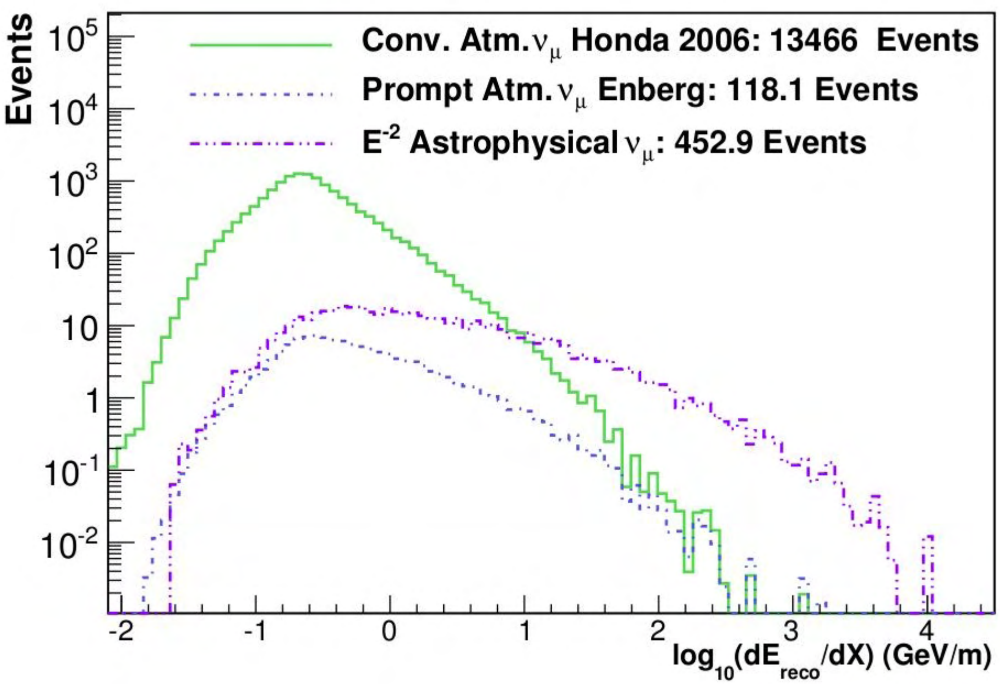
Integral dominated by large distances

[MonteCarlo] Energy Spectrum of Neutrinos Observable in IceCube.





Neutrino Energy

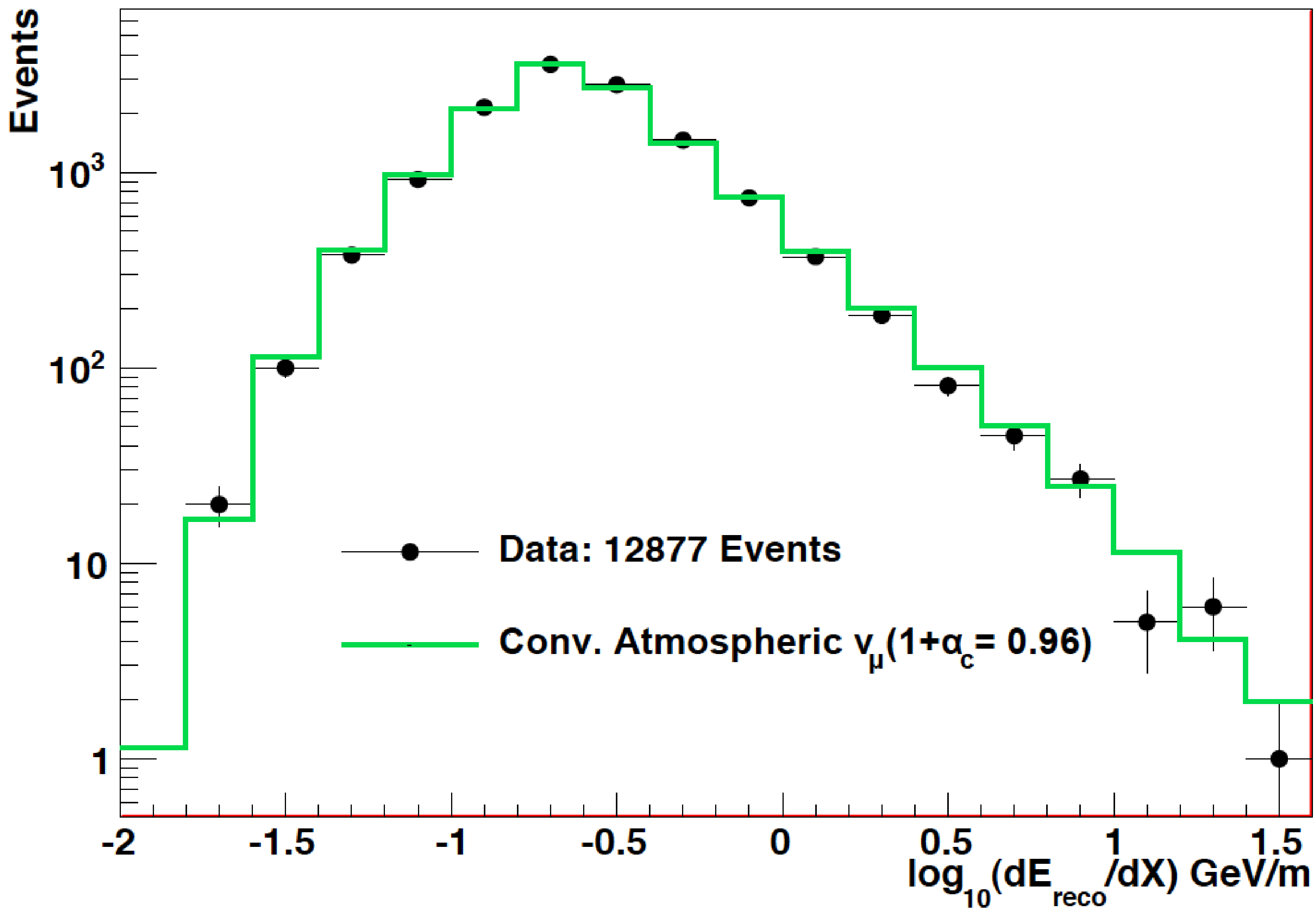


Reconstructed
Neutrino Energy

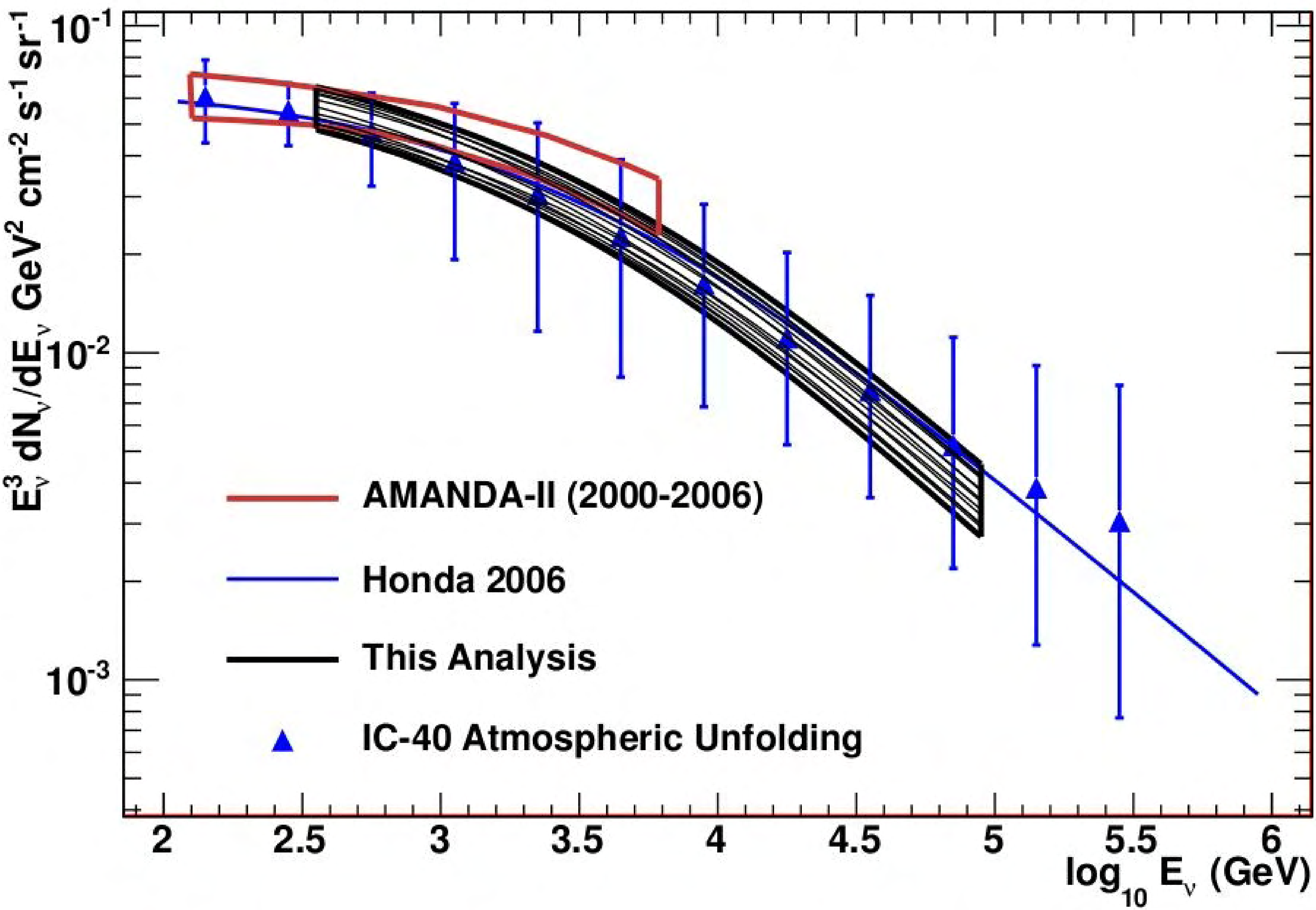
[From Muon Radiation]

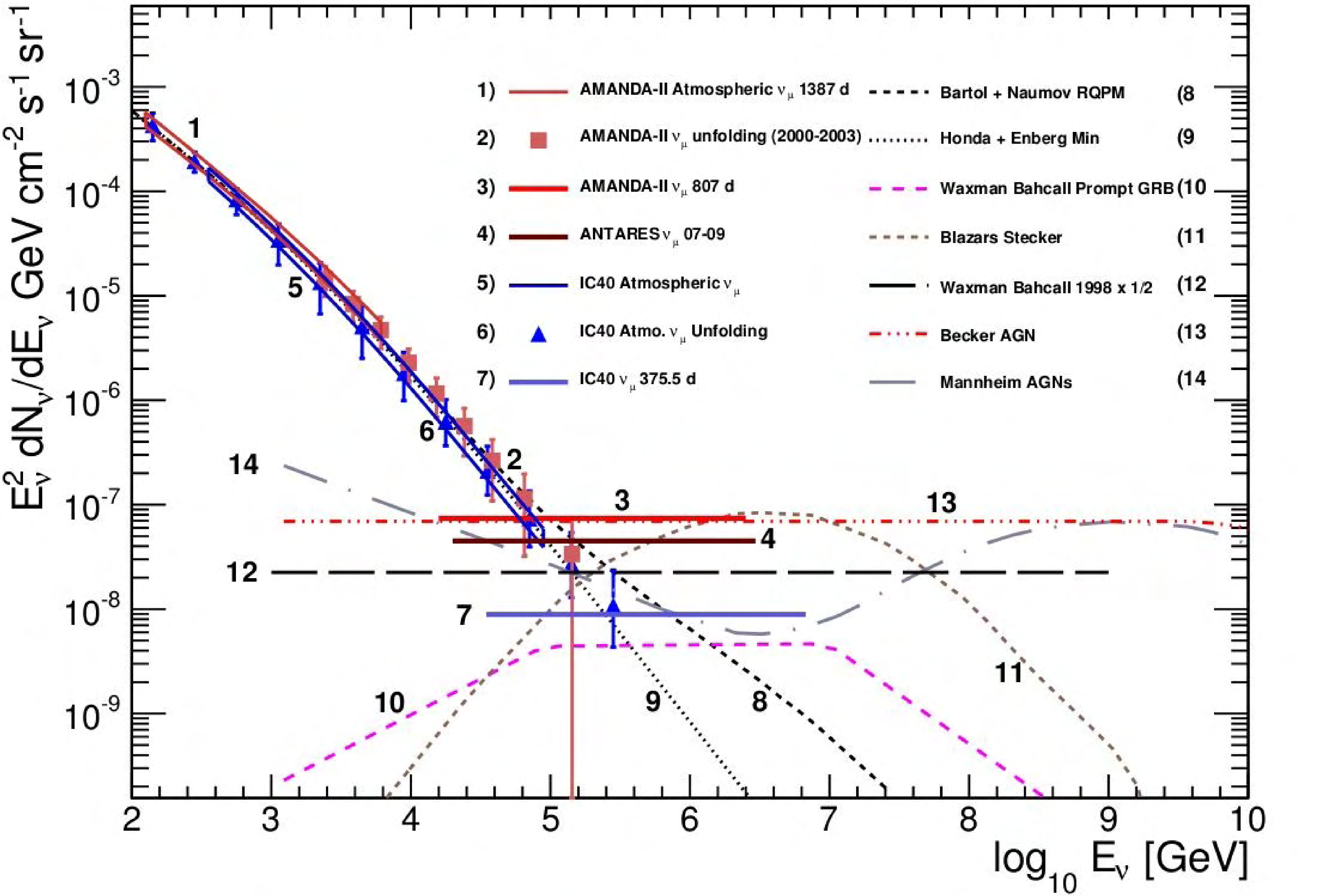
$$-\frac{dE}{dX} \simeq \alpha + \frac{E}{\lambda_\mu} = \alpha \left(1 + \frac{E}{\varepsilon_\mu}\right)$$

A Search for a Diffuse Flux of Astrophysical Muon Neutrinos with the IceCube 40-String Detector



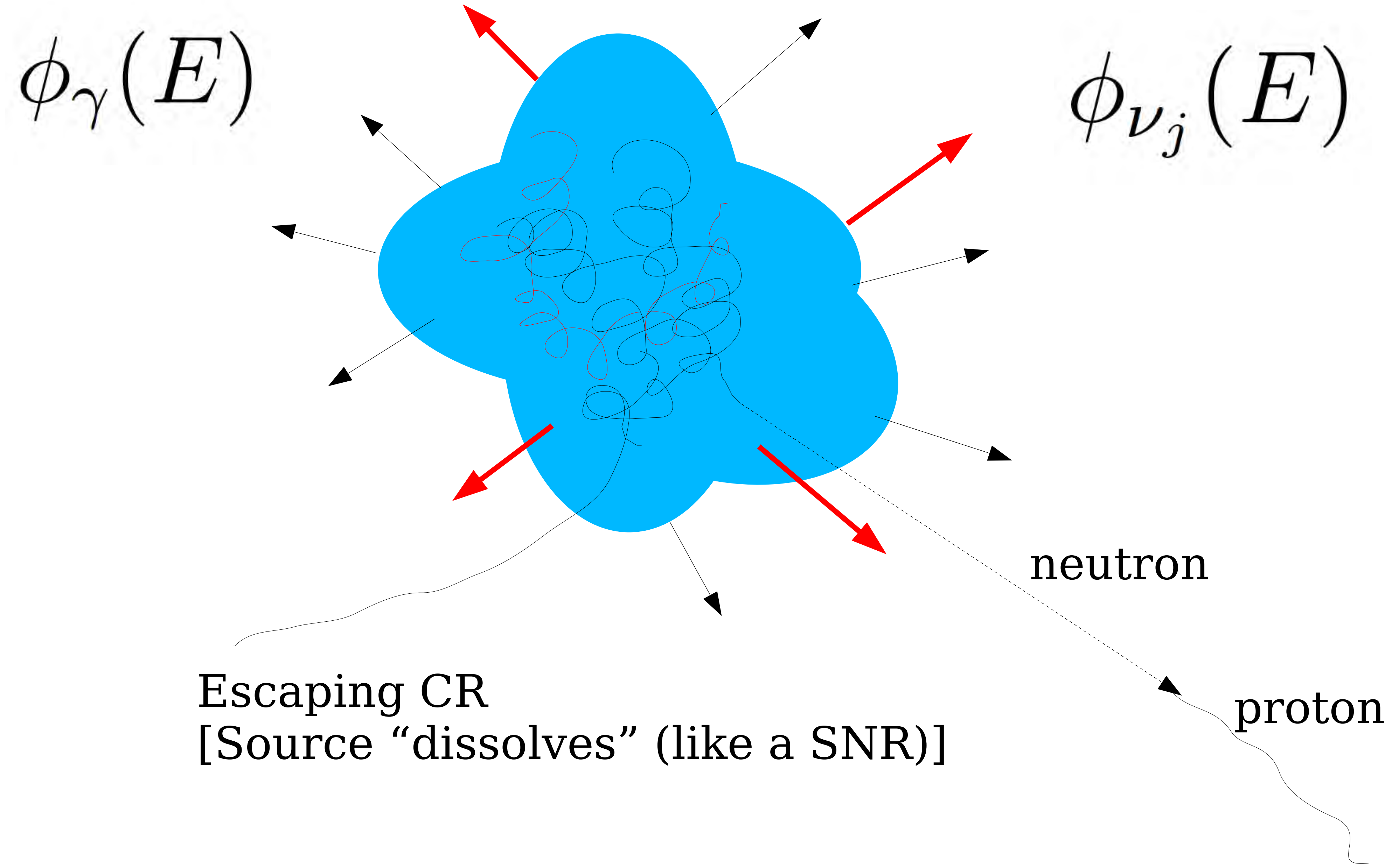
No excess over atmospheric neutrinos


$E_\nu^3\, dN_\nu/dE_\nu$ GeV^2 cm^{-2} s^{-1} sr^{-1}
10^{-1}
10^{-2}
10^{-3}
2
2.5
3
3.5
4
4.5
5
5.5
6
$\log_{10} E_\nu$ (GeV)
AMANDA-II (2000-2006)
Honda 2006
This Analysis
IC-40 Atmospheric Unfolding

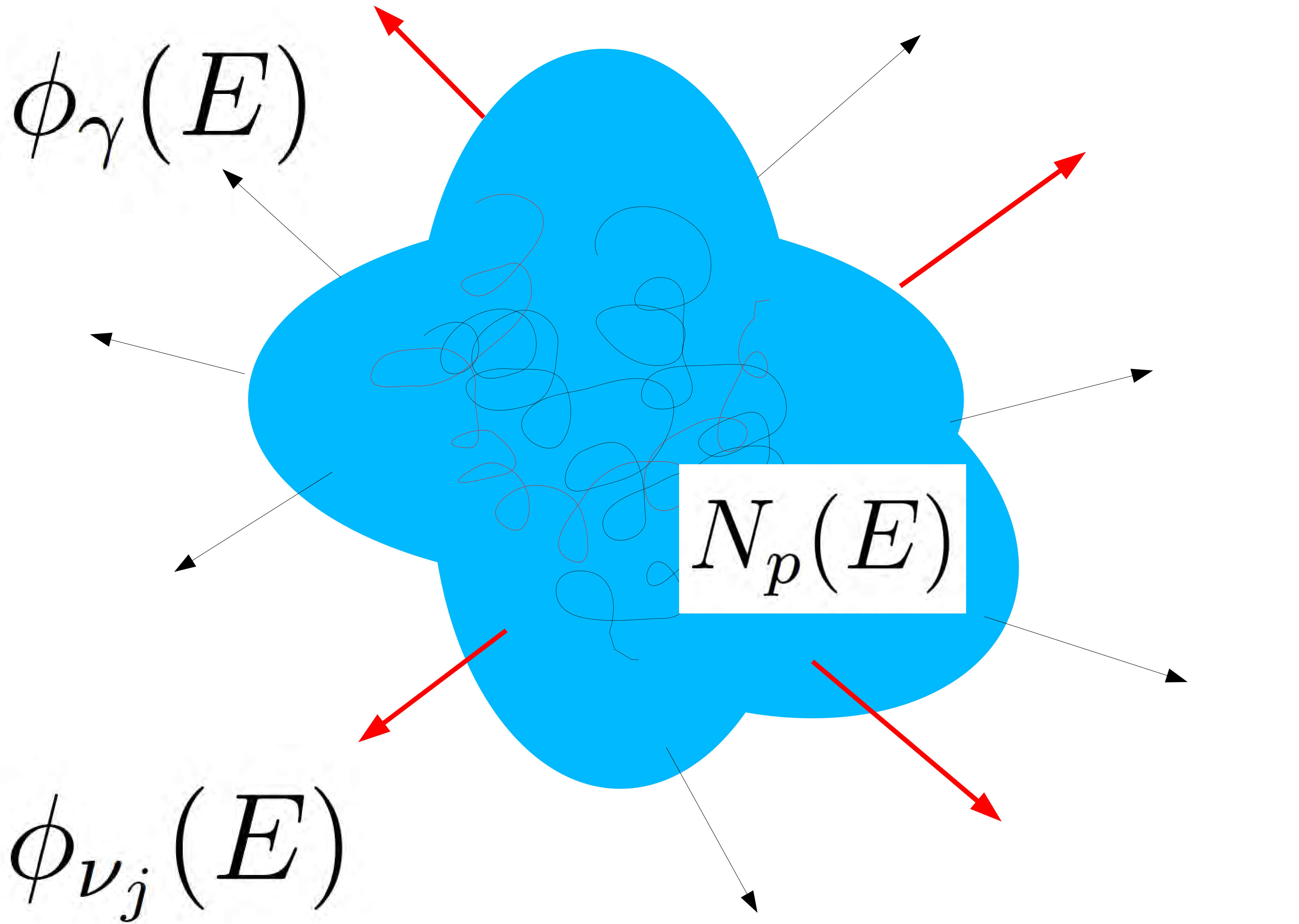


$E_\nu^2\, dN_\nu/dE_\nu$ GeV cm^{-2} s^{-1} sr^{-1}
$\log_{10} E_\nu$ [GeV]
1) AMANDA-II Atmospheric ν_μ 1387 d
2) AMANDA-II ν_μ unfolding (2000-2003)
3) AMANDA-II ν_μ 807 d
4) ANTARES ν_μ 07-09
5) IC40 Atmospheric ν_μ
6) IC40 Atmo. ν_μ Unfolding
7) IC40 ν_μ 375.5 d
Bartol + Naumov RQPM (8
Honda + Enberg Min (9
Waxman Bahcall Prompt GRB (10
Blazars Stecker (11
Waxman Bahcall 1998 x 1/2 (12
Becker AGN (13
Mannheim AGNs (14

Model	90% C.L.	3σ C.L.	5σ C.L	90% Energy Range (TeV-PeV)
E^{-2} $\left(\frac{\mathrm{GeV}}{\mathrm{cm^2\ s\ sr}}\right)$	0.89×10^{-8}	2.2×10^{-8}	4.0×10^{-8}	$35 - 7$
W-B Upper Bound	0.4	0.97	1.78	$35 - 7$
Stecker Blazar	0.1	0.32	0.42	$120 - 15$
BBR FSRQ	0.12	0.34	0.46	$35 - 7$
Mannheim AGN	0.05	0.21	0.4	$9 - 1$

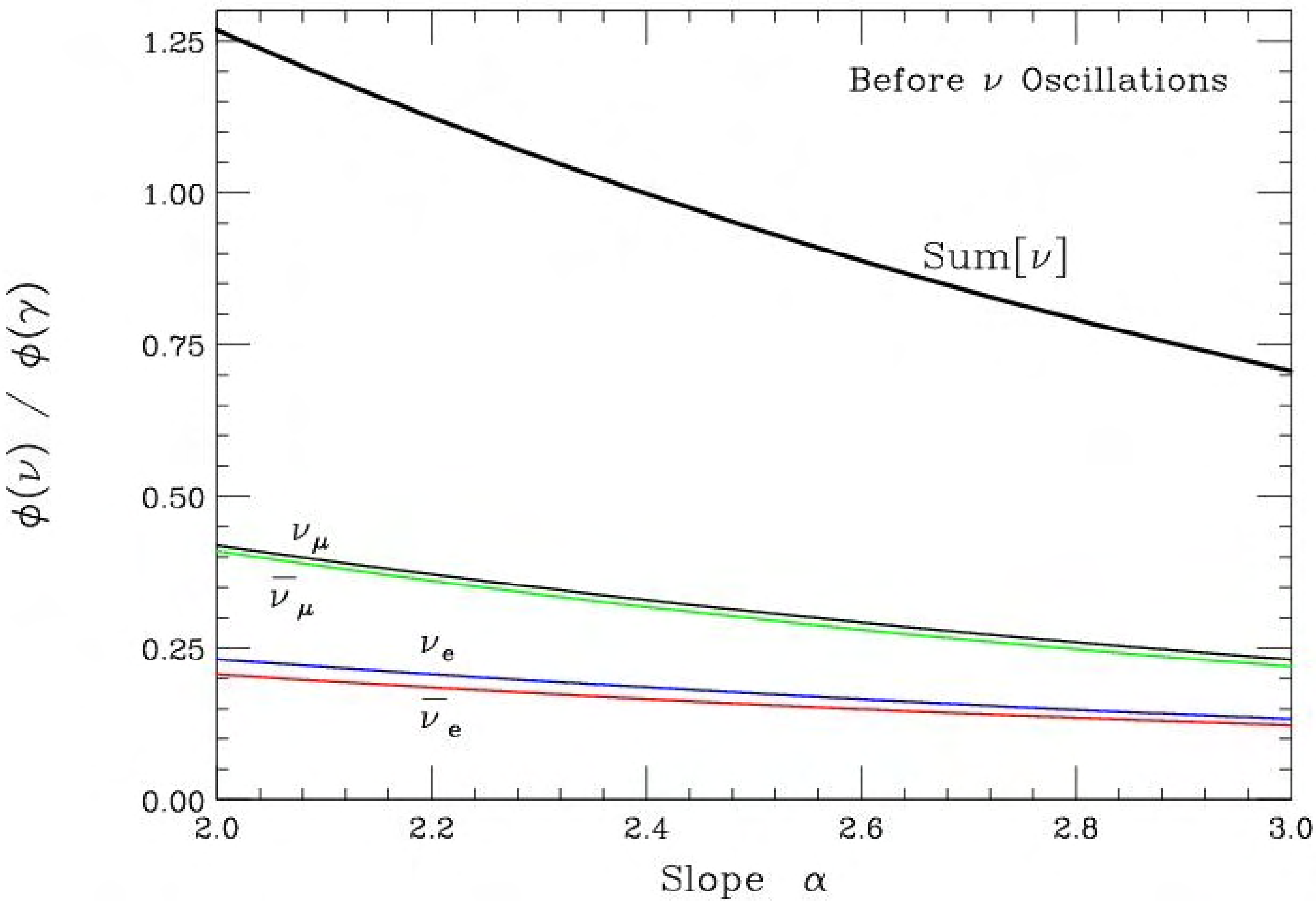


Production of Cosmic Rays
Versus Neutrino/Photon spectra

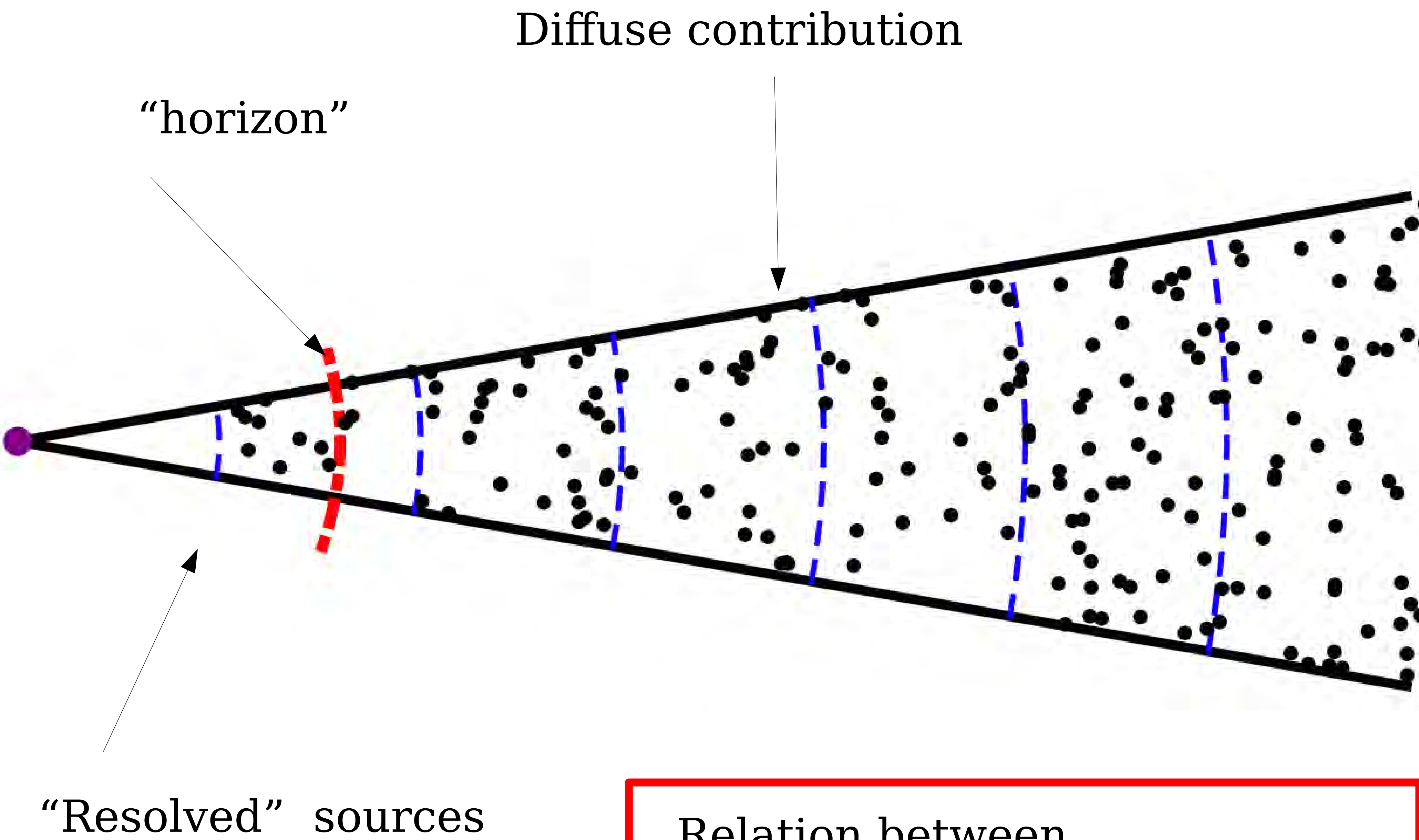


$\phi_\gamma(E)$
$N_p(E)$
$\phi_{\nu_j}(E)$

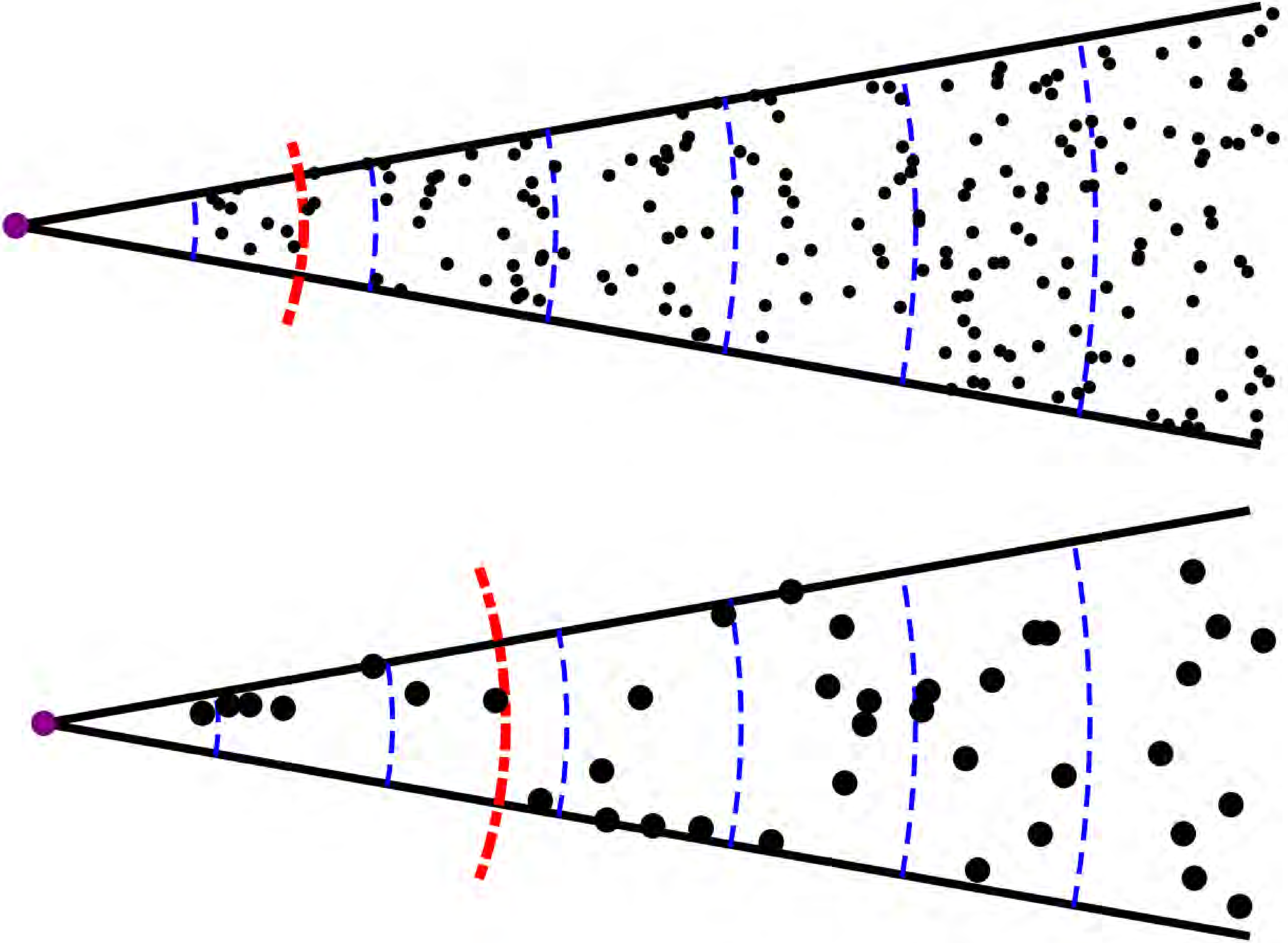
Ratio Neutrino-Photon $\phi(\nu)\ /\ \phi(\gamma)$



$$\{\nu_e, \overline{\nu}_e, \nu_\mu, \overline{\nu}_\mu, \nu_\tau, \overline{\nu}_\tau\} \simeq \{1+\epsilon, 1-\epsilon, 2, 2, 0, 0\}$$



Relation between
The diffuse flux
And the detected Point Sources

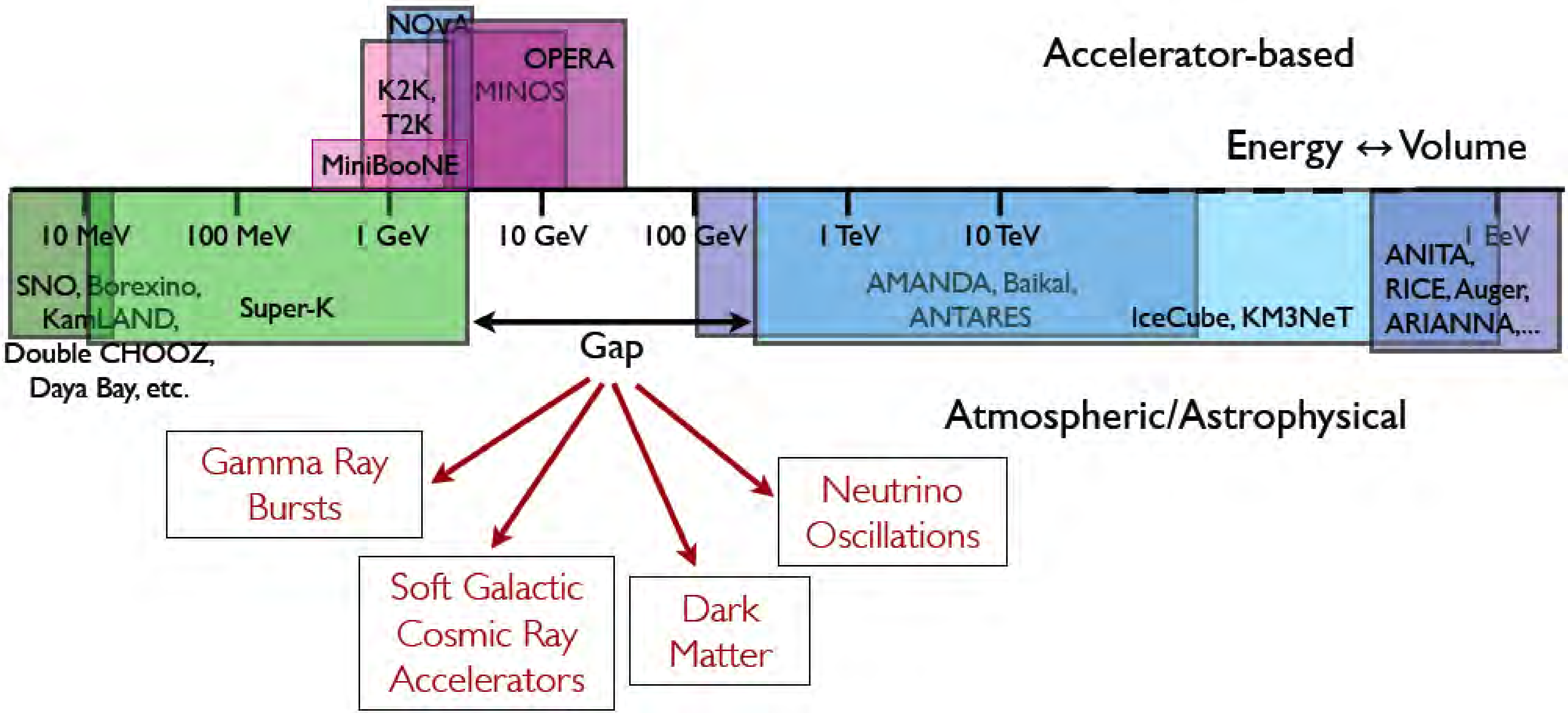


$$N_{[\mathrm{det\ \ sources}]} \propto \frac{\mathcal{L}}{\bar{L}} \left(\sqrt{L}\right)^3$$

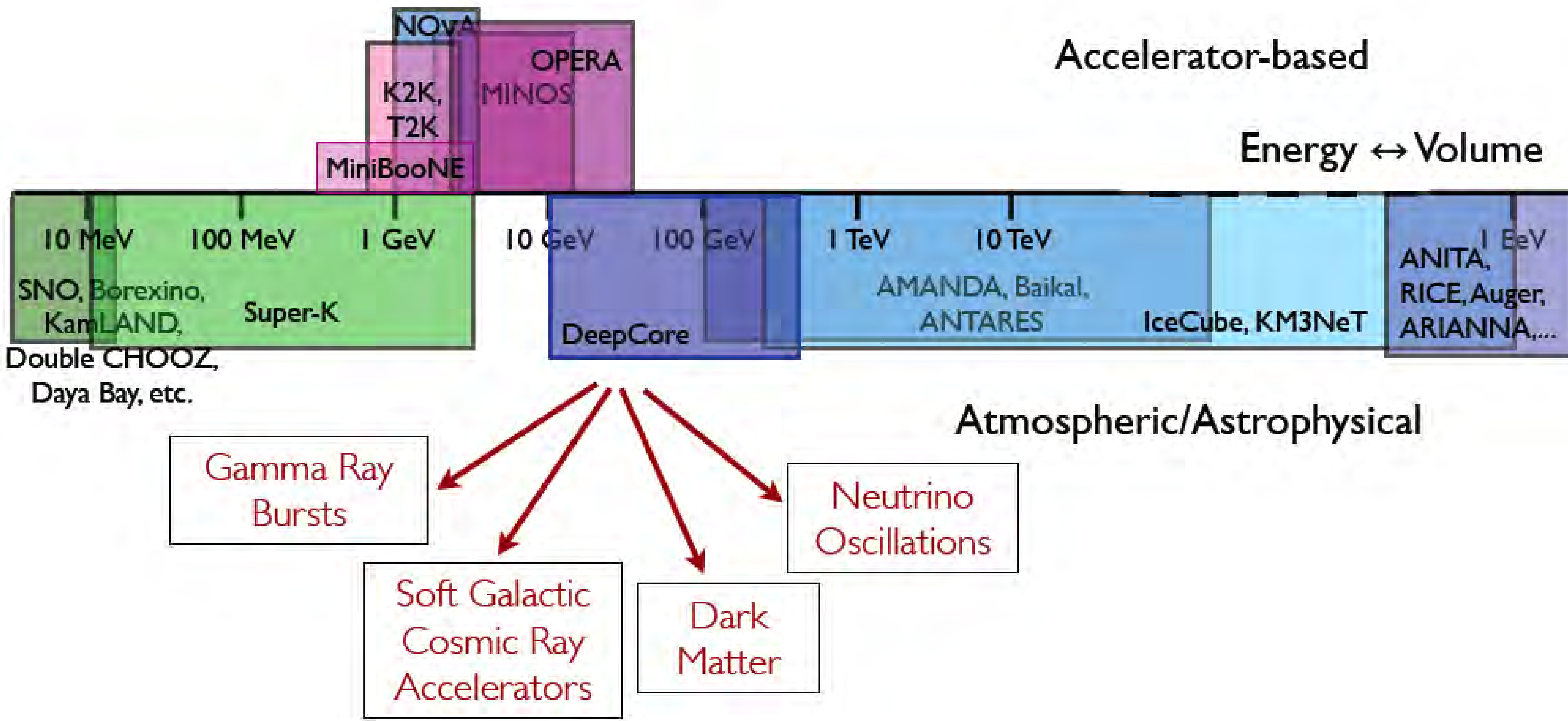
Obtain from diffuse flux

Estimate from
Astrophysical
considerations.

$$\boxed{N_{[\mathrm{det\ \ sources}]} \sim 1.2\, \mathcal{L}_{35}\, \sqrt{L_{45}}\, (A\, t)^{3/2}_{\mathrm{Km^2 yr}}}$$

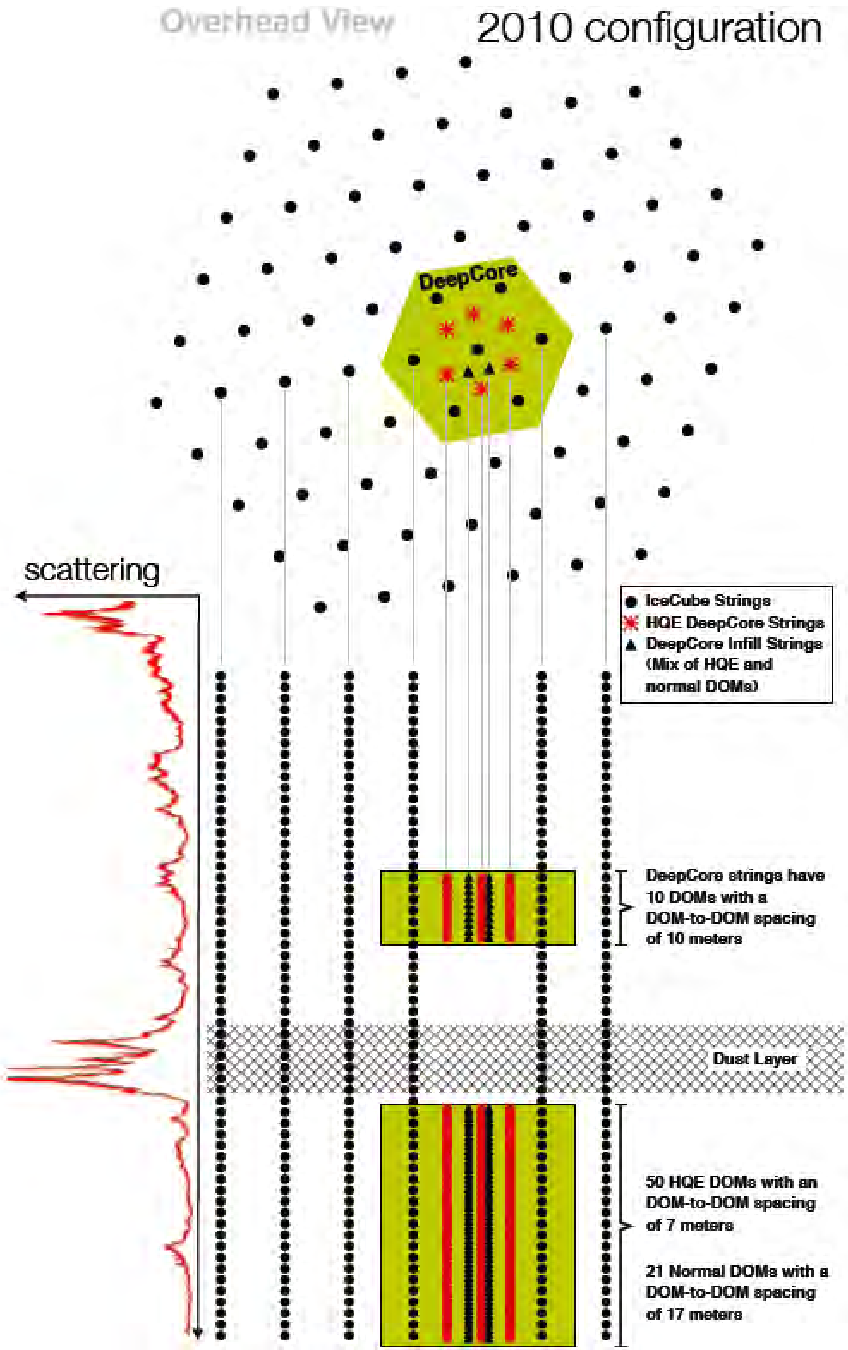

NOvA
OPERA
K2K,
T2K
MINOS
MiniBooNE
Accelerator-based
Energy ↔ Volume
10 MeV
100 MeV
1 GeV
10 GeV
100 GeV
1 TeV
10 TeV
1 EeV
SNO, Borexino,
KamLAND,
Double CHOOZ,
Daya Bay, etc.
Super-K
Gap
AMANDA, Baikal,
ANTARES
IceCube, KM3NeT
ANITA,
RICE, Auger,
ARIANNA,...
Atmospheric/Astrophysical
Gamma Ray
Bursts
Soft Galactic
Cosmic Ray
Accelerators
Dark
Matter
Neutrino
Oscillations

Deep Core



NOvA
OPERA
K2K,
T2K
MINOS
MiniBooNE
Accelerator-based
Energy ↔ Volume
10 MeV
100 MeV
1 GeV
10 GeV
100 GeV
1 TeV
10 TeV
1 EeV
SNO, Borexino,
KamLAND,
Double CHOOZ,
Daya Bay, etc.
Super-K
DeepCore
AMANDA, Baikal,
ANTARES
IceCube, KM3NeT
ANITA,
RICE, Auger,
ARIANNA,...
Atmospheric/Astrophysical
Gamma Ray
Bursts
Soft Galactic
Cosmic Ray
Accelerators
Dark
Matter
Neutrino
Oscillations

Deep Core



Overhead View
2010 configuration
DeepCore
IceCube Strings
HQE DeepCore Strings
DeepCore Infill Strings (Mix of HQE and normal DOMs)
scattering
DeepCore strings have 10 DOMs with a DOM-to-DOM spacing of 10 meters
Dust Layer
50 HQE DOMs with an DOM-to-DOM spacing of 7 meters
21 Normal DOMs with a DOM-to-DOM spacing of 17 meters

It is wrong to talk about:

NEUTRINO ASTRONOMY

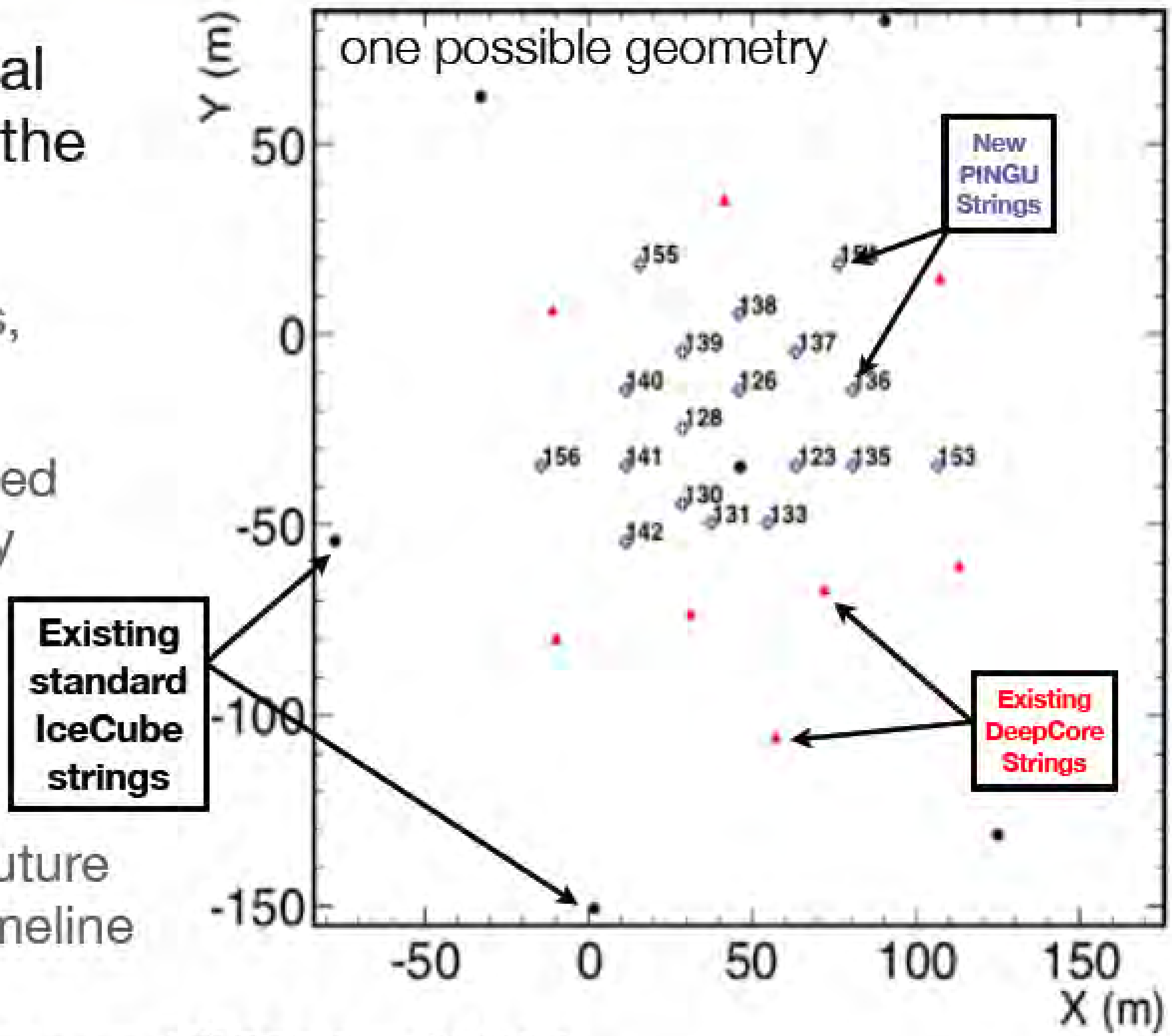
We should talk about

NEUTRINO ASTRONOMIES

10-100 GeV	(DM)
1-100 TeV	(Galactic Sources)
EeV	(Radio, EAS...)
....	

Beyond DeepCore: PINGU

- Now developing a proposal to continue to instrument the DeepCore volume
  - An additional 18-20 strings, 1000-1200 DOMs
  - Make use of well-established IceCube drilling technology
  - Might get to a threshold of ~1 GeV in a ~10 MTon volume
  - Also an R&D platform for future detectors on a ~decade timeline



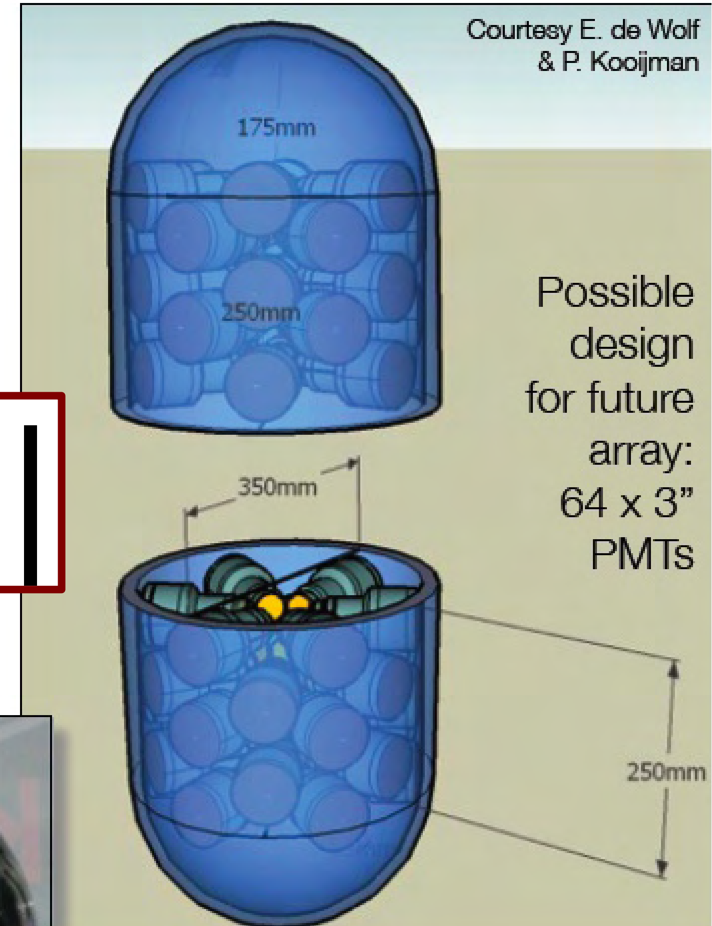
- Price tag expected to be around \$25M – \$30M

R&D: Multi-PMT Digital Optical Module

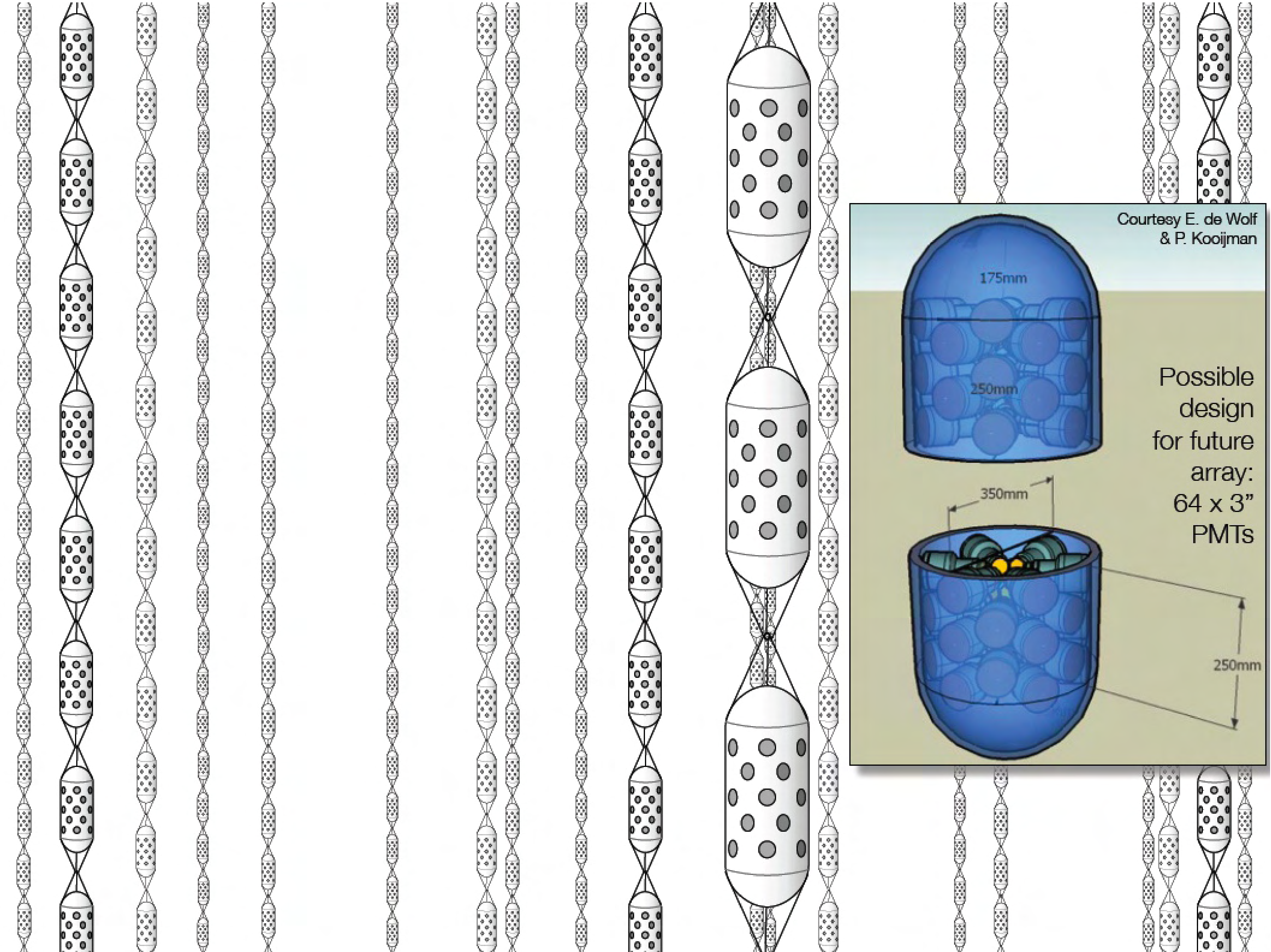
- Based on a KM3NeT prototype
- Glass cylinder containing 64 3” PMTs and associated electronics

“Dreaming ON !!|

  - Diameter similar to IceCube DOM, single connector



- Might enable Cherenkov ring imaging in the ice
  - Feasible to build a multi-MTon detector in ice with an energy threshold of 10’s of MeV?


Courtesy E. de Wolf
& P. Kooijman
175mm
250mm
350mm
250mm
Possible
design
for future
array:
64 x 3"
PMTs

……Difficult choices
in the Mediterranean….

….The moment of truth for IceCube ….

goal:

best possible design for KM3NeT

needed a new track reconstruction algorithm

based on generic probability dist. func.

directional scanning

multiPMT

questions

what does "best possible" actually mean?

floor design?

optical module design?

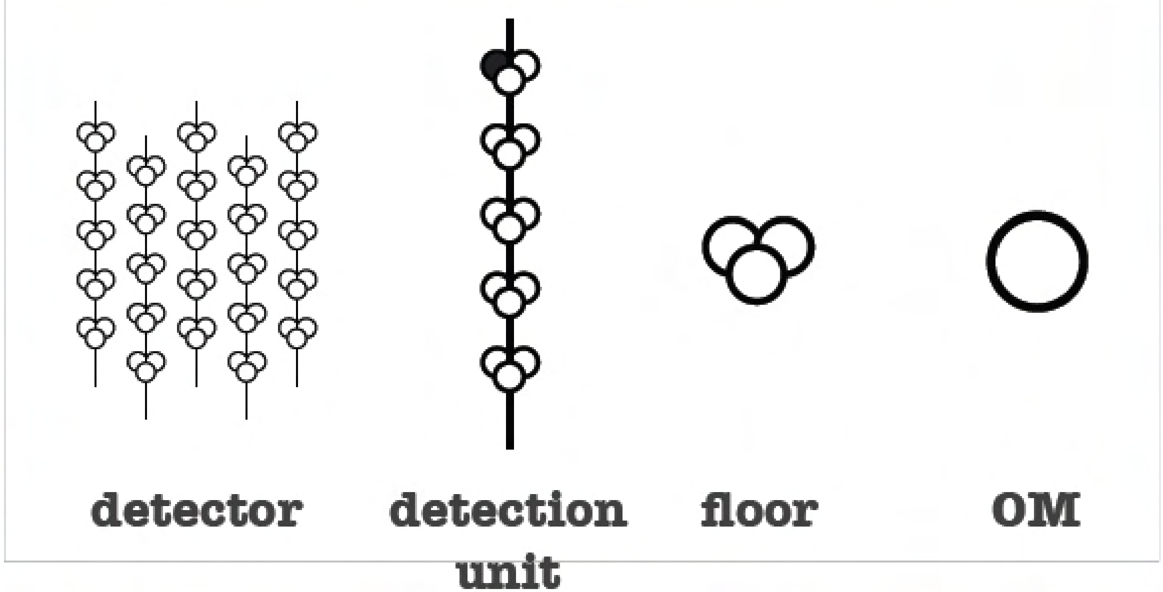
number of strings/ towers?

number of floors per DU?

placement of strings?

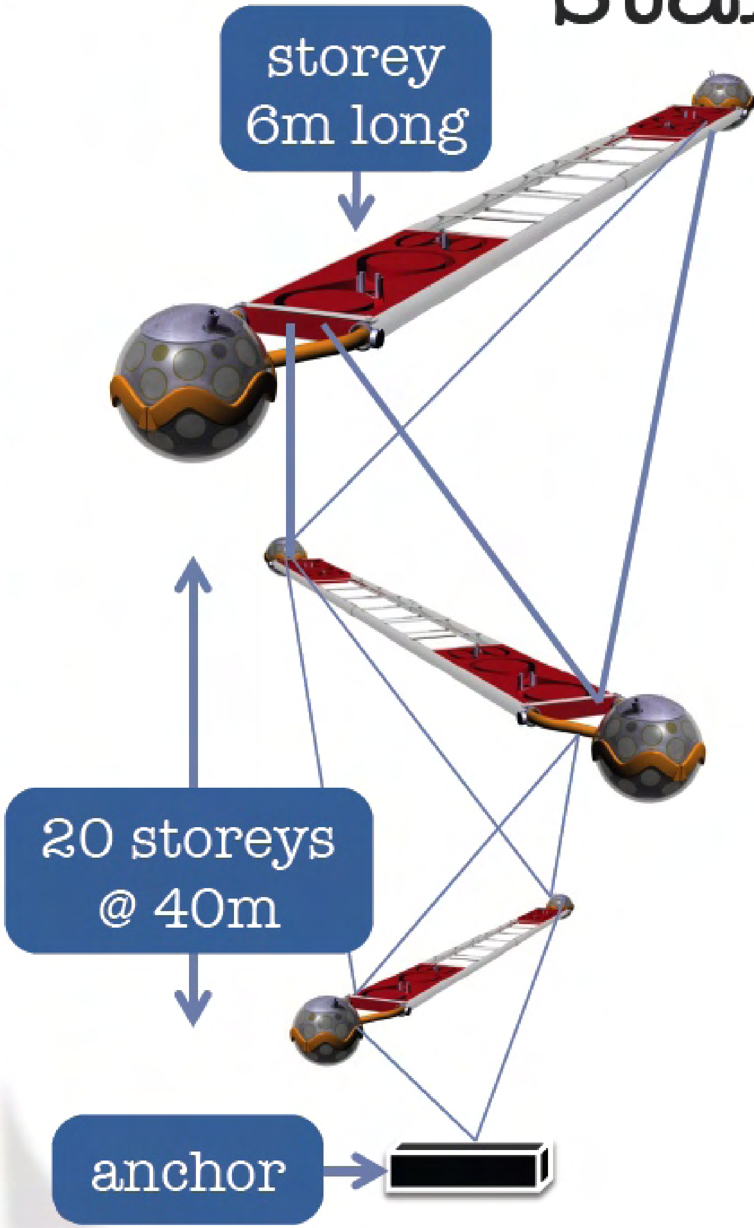
inter-tower distance?

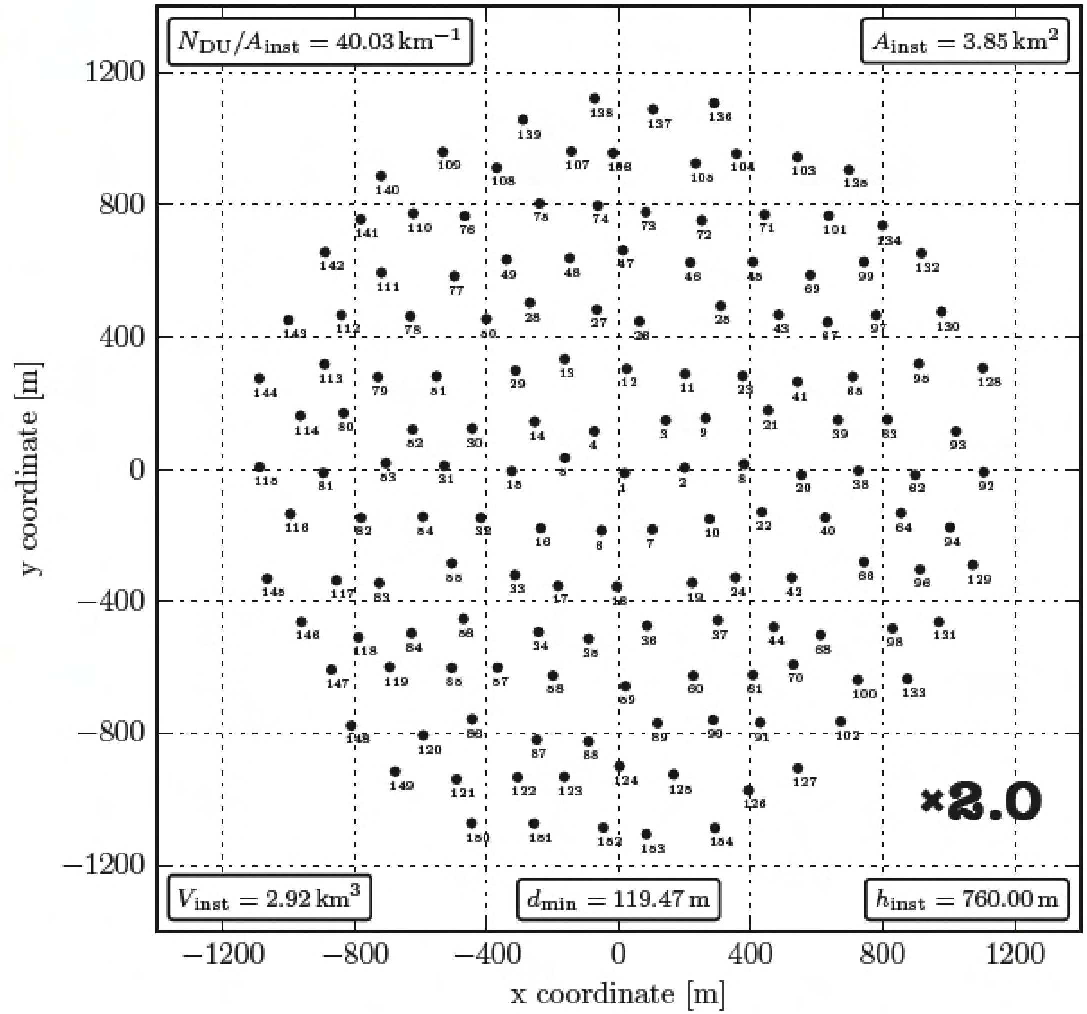
....



starting point

optimize!

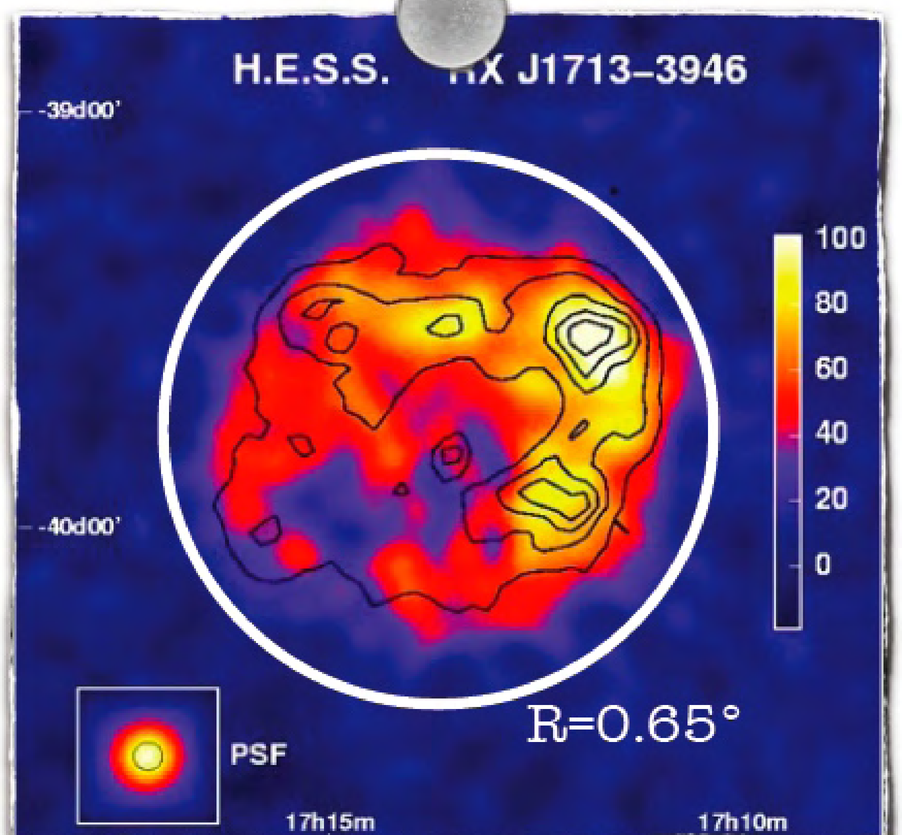




2x 127 towers, av. distance 180m

example source

use it as a benchmark



RX J1713.7-3946

$$k\,(E/\mathrm{TeV})^{-\gamma}\exp\left(-\sqrt{E/e}\right)$$

$$\begin{aligned} k &= 16.80 \cdot 10^{-15}\,\mathrm{GeV}^{-1}\mathrm{s}^{-1}\mathrm{cm}^{-2} \\ \gamma &= 1.72 \\ e &= 2.10\,\mathrm{TeV} \end{aligned}$$

assumed: disc with radius 0.65°

provided by A. Kappes

5σ detection of RX J1713

(5σ, one-sided in 50% of exp.)	disc with R=0.65°	point-like
6m bar length (starting point)	12 years	5.4 years
12m bar length	11 years	4.9 years
48m bar length	8.5 years	3.8 years

5σ detection of RX J1713

Is this a sufficiently interesting
Sensitivity to justify the Telescope
In the absence of signals from IceCube ?

6m bar length (starting point)	12 years	5.4 years
12m bar length	11 years	4.9 years
48m bar length	8.5 years	3.8 years

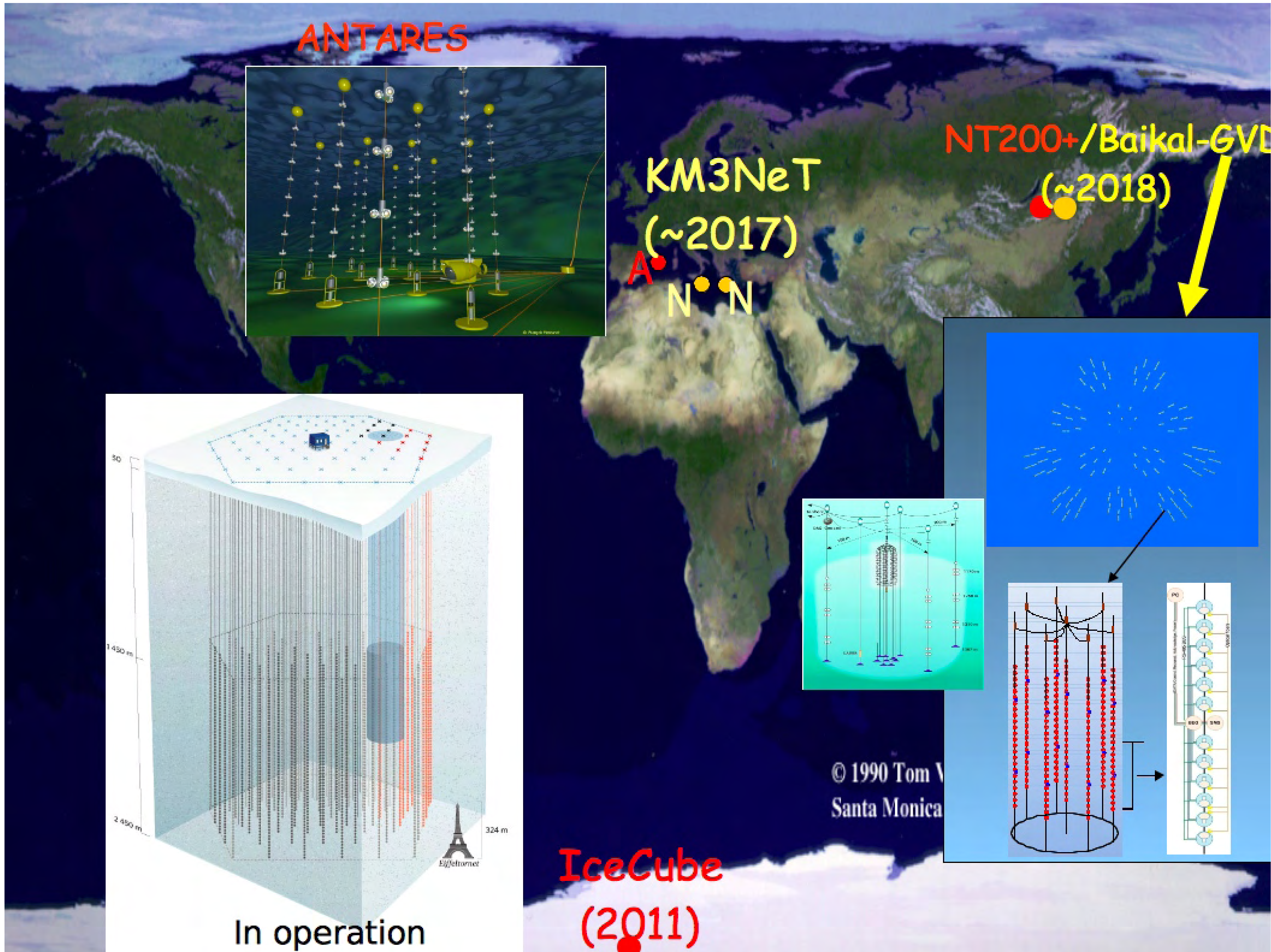
conclusions

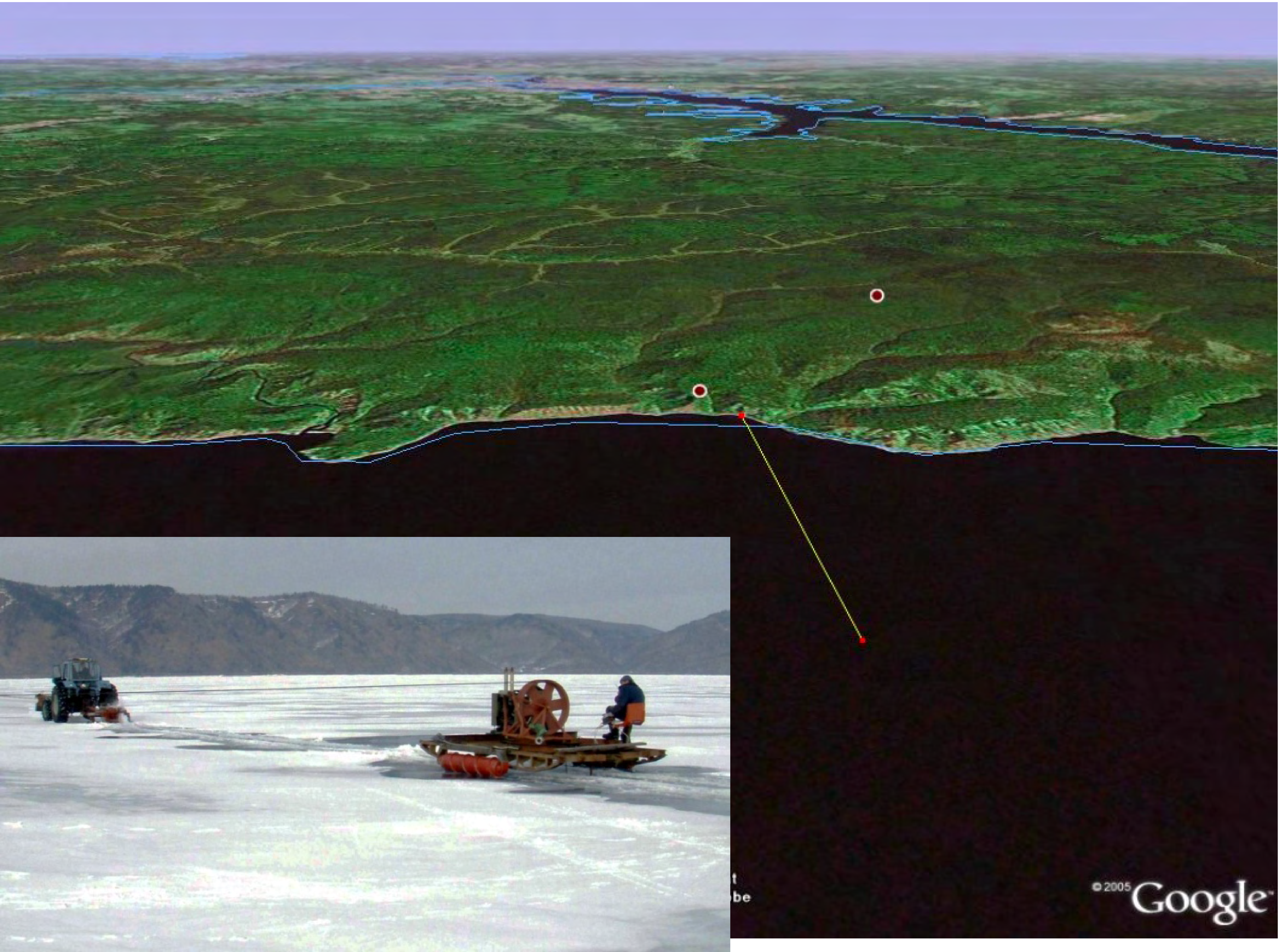
technology and software are in place

galactic sources are in reach for KM3NeT

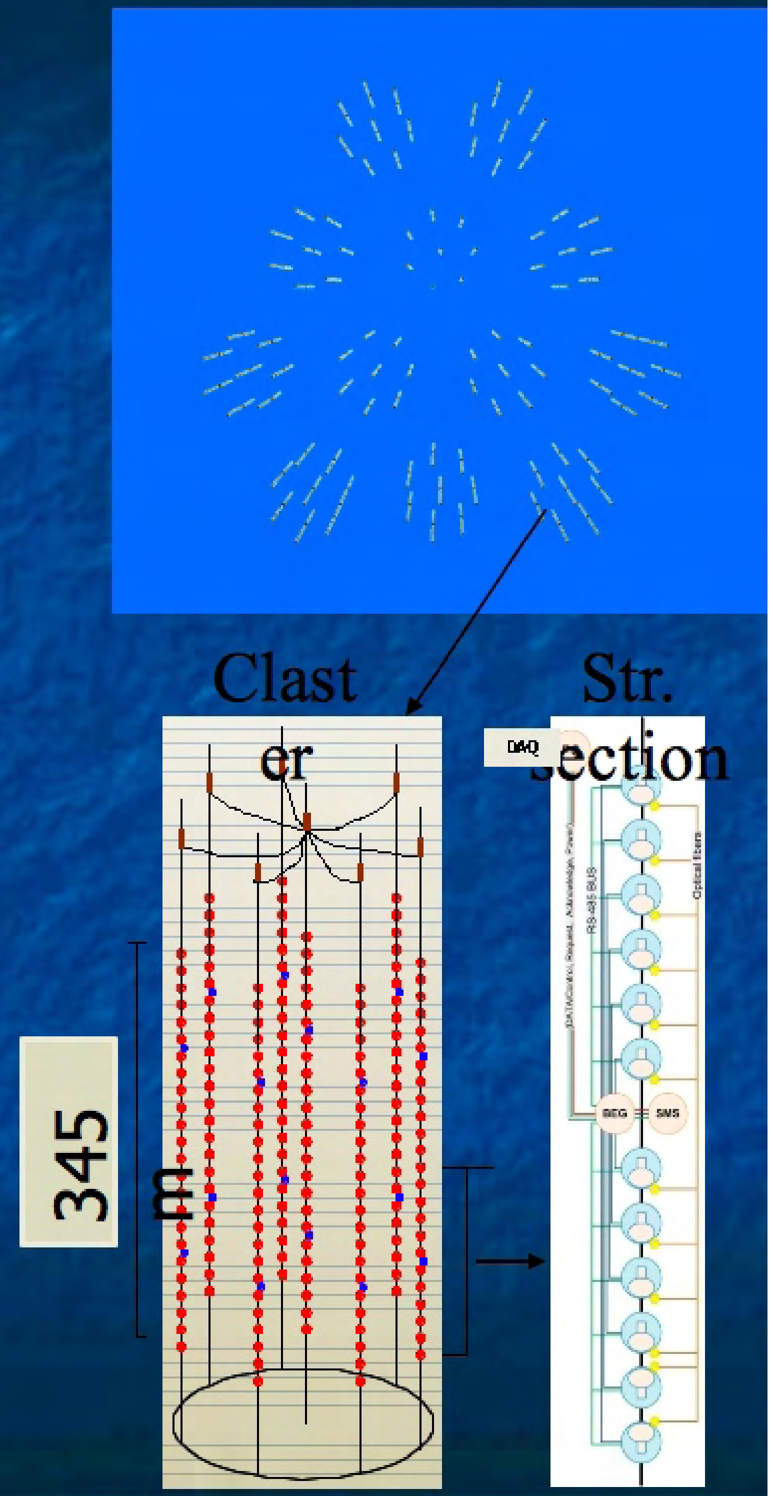
we'll know (for sure) if sources are hadronic or not

build it and get started with physics!


ANTARES
KM3NeT
(~2017)
NT200+/Baikal-GVD
(~2018)
A
N
N
© 1990 Tom V
Santa Monica
IceCube
(2011)
In operation
324 m
Eiffeltornet


©2005 Google

GVD - basic design



LAYOUT:

-2304 Optical Modules, 96 Strings, 12 Clusters.
String comprises 24 OMs, which are combined in
2 independent Sections.
Cluster contains 8 strings.

INSTRUMENTED VOLUME: 0.3 KM3

DETECTION PERFORMANCE

CASCADES: (E>100 TeV): **Veff ~0.2−0.7 km3**

δ(E/Esh) ~25%

δθmed~ 5o

MUONS: (E>5 TeV): **Seff ~ 0.2−0.8 km2**

δθmed ~ 0.5o

δlg(E/E m)

Neutrino Astronomy: beyond the “Km3 concept”

Radio, Acoustic,.....

Radio Detection of neutrinos

ANITA-II over Antarctica

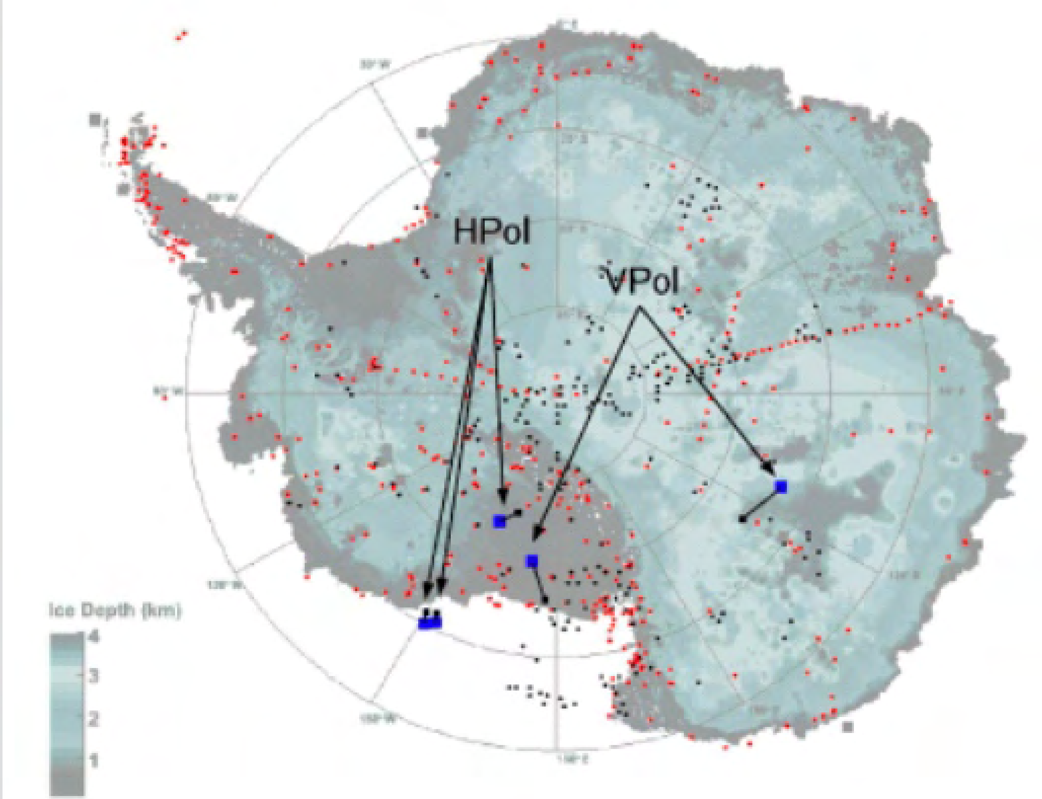


FIG. 3: Events remaining after unblinding. The Vpol neutrino channel contains two surviving events. Three candidate UHECR events remain in the Hpol channel. Ice depths are from BEDMAP [12].

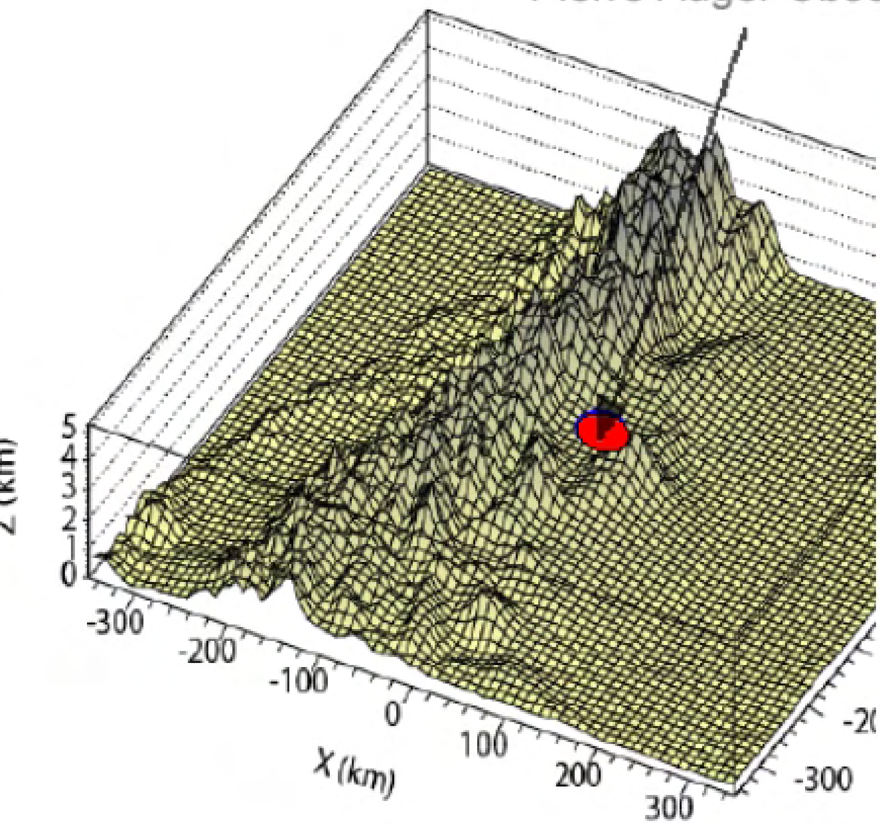
http://arxiv.org/abs/1003.2961

Vpol:1 neutrino candidate;

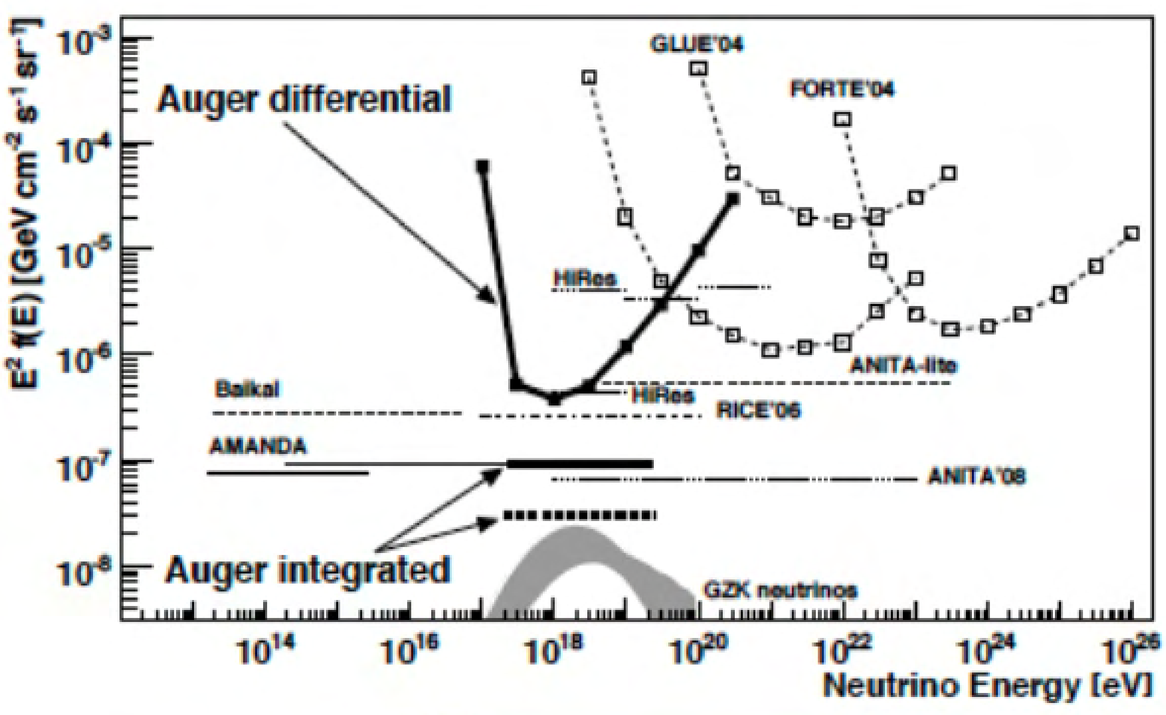
HPol:3 >25 1019 eV

EeV nt detection with Auger et al.

Pierre Auger Observatory



PRD 79 (2009) 102001

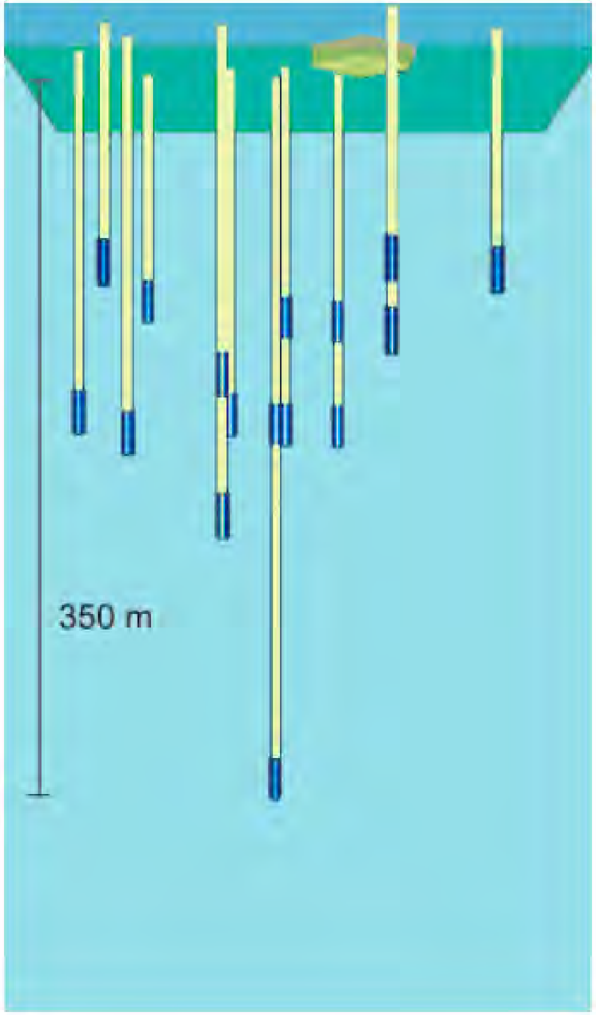


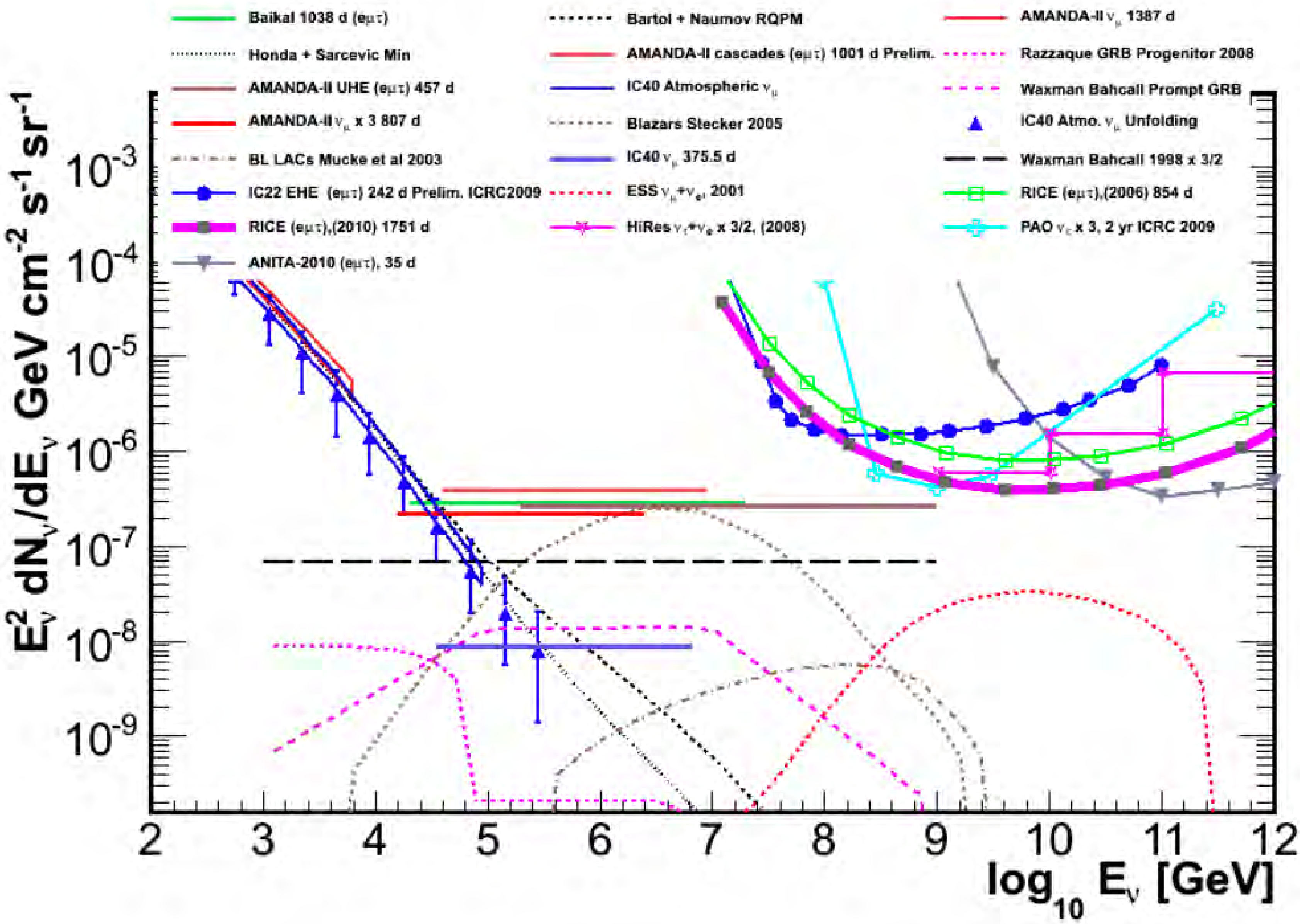
Gct ~ 100 km for Et ~ 2 x 1018 eV followed by t-decay shower

T. Weiler, D. Fargion

RICE experiment architecture

- Antarctic ice is neutrino target
- In-ice array of radio antennas
- 20 channels, 200-500 MHz
- Depths 100-300 meters
- Signal digitized at the surface
- Deployed near South Pole Station





Baikal 1038 d (eμτ)
Honda + Sarcevic Min
AMANDA-II UHE (eμτ) 457 d
AMANDA-II ν_μ x 3 807 d
BL LACs Mucke et al 2003
IC22 EHE (eμτ) 242 d Prelim. ICRC2009
RICE (eμτ),(2010) 1751 d
ANITA-2010 (eμτ), 35 d
Bartol + Naumov RQPM
AMANDA-II cascades (eμτ) 1001 d Prelim.
IC40 Atmospheric ν_μ
Blazars Stecker 2005
IC40 ν_μ 375.5 d
ESS ν_μ+ν_e, 2001
HiRes ν_τ+ν_e x 3/2, (2008)
AMANDA-II ν_μ 1387 d
Razzaque GRB Progenitor 2008
Waxman Bahcall Prompt GRB
IC40 Atmo. ν_μ Unfolding
Waxman Bahcall 1998 x 3/2
RICE (eμτ),(2006) 854 d
PAO ν_τ x 3, 2 yr ICRC 2009
E_ν^2 dN_ν/dE_ν GeV cm^-2 s^-1 sr^-1
log_10 E_ν [GeV]

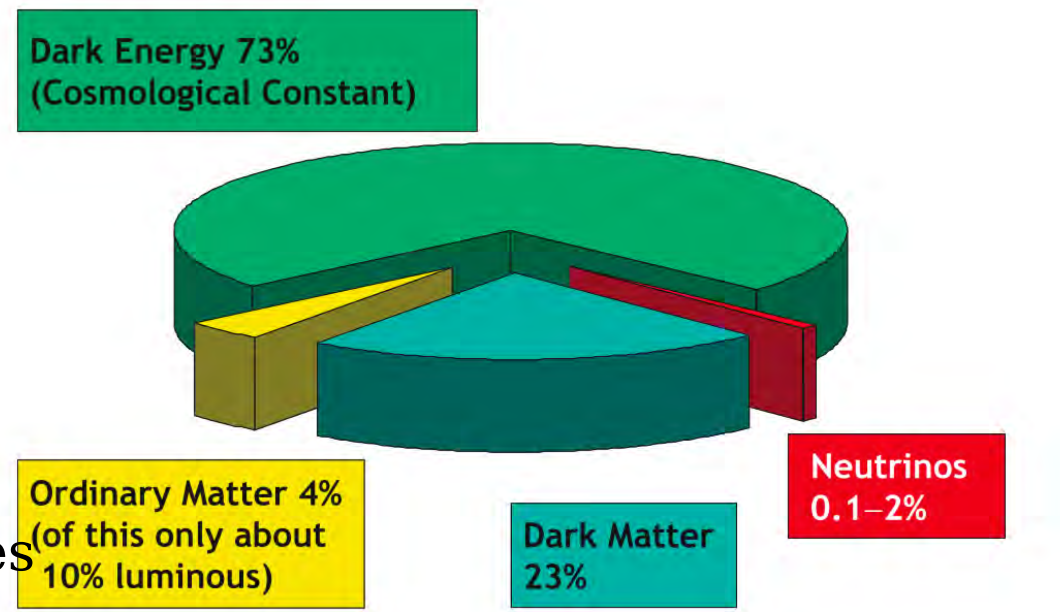
DARK

MATTER

Mysteries of the DARK UNIVERSE

DARK ENERGY :

Drives apart galaxies
and other large scale structures
[The energy of vacuum itself ?]



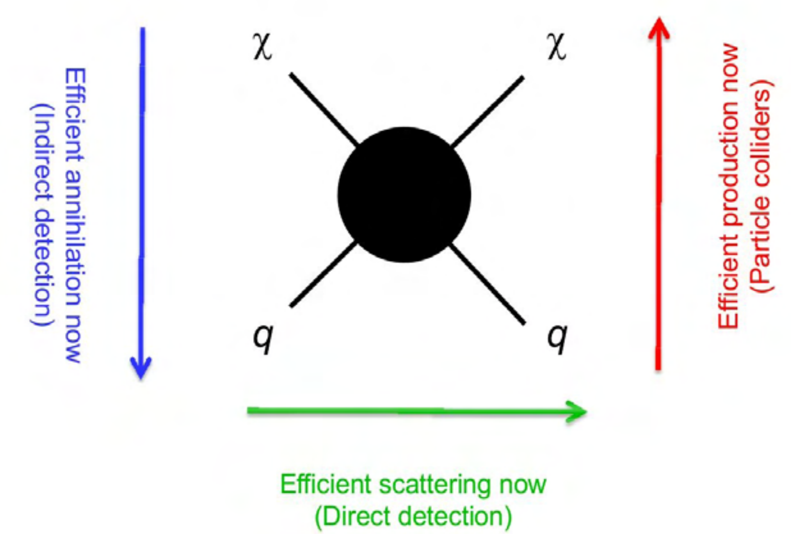
DARK MATTER:

Holds together galaxies
and other large scale structures
[A new elementary particle ?]

Exist at different scales:
Entire Universe
Clusters of Galaxies
Galaxy

See M. Roncadelli

Three roads to the study of the "WIMP" hypothesis:



1. Direct Detection

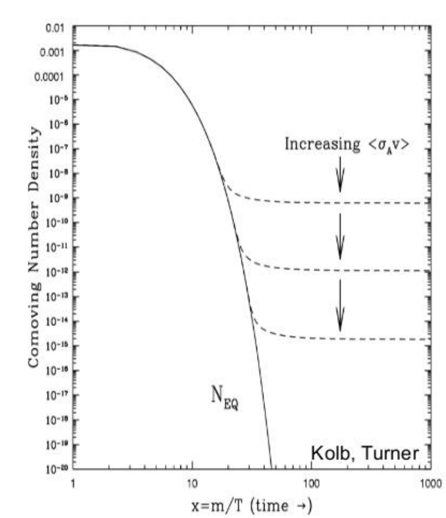
2. Indirect Detection
[Observation of annihilation products
In our own Galaxy]

3. Discovery of a new stable particle
In an accelerator [LHC]

$$\Omega_j^0 \simeq 0.3 \left[\frac{3 \times 10^{-26}\ \mathrm{cm}^3\,\mathrm{s}^{-1}}{\langle \sigma\, v \rangle}\right]$$

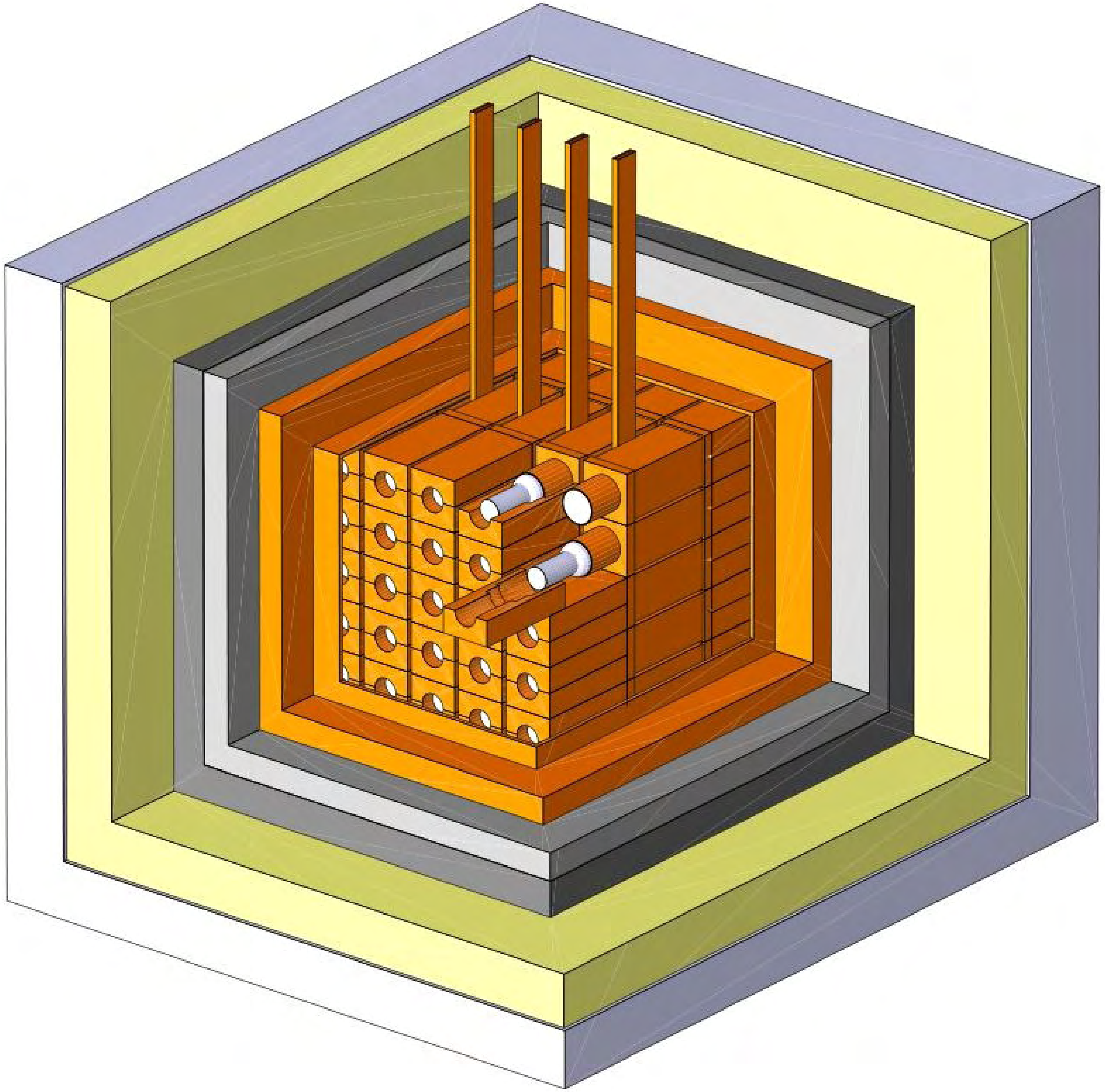
$$L(\vec{x}) = \frac{\rho(\vec{x})^2}{{M_\chi}^2} \langle \sigma\ v \rangle\ M_\chi$$

$$\chi + \chi \to \gamma \qquad e^+ \qquad \overline{p} \qquad \nu_\alpha$$



DAMA-LIBRA (Gran Sasso underground Laboratory)

250 Kg NaI scintillator.

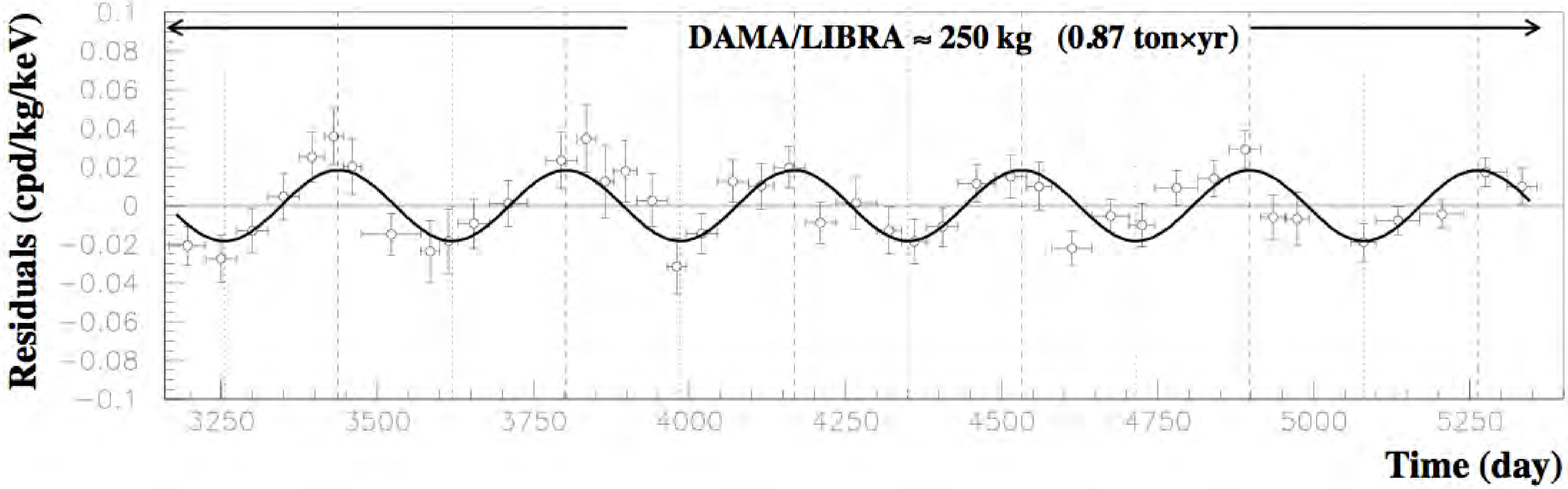


Observation
of sinusoidal
time-modulation of the
Energy Deposition Rate

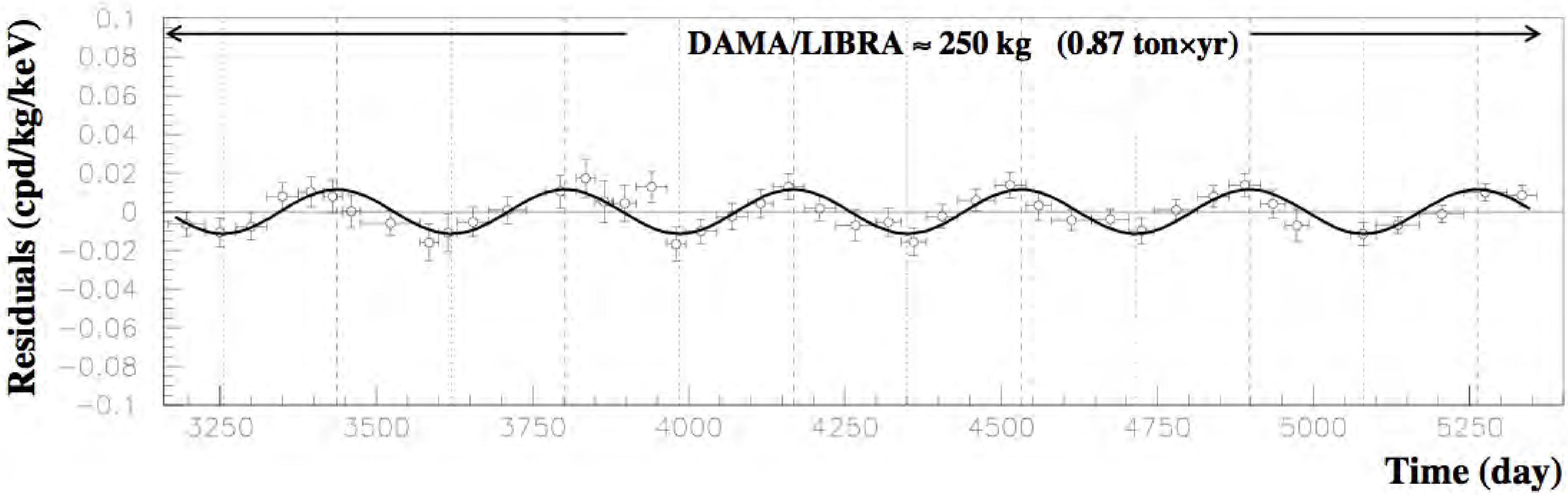
(controversial)
claim of evidence
of detection of
Galactic Dark Matter

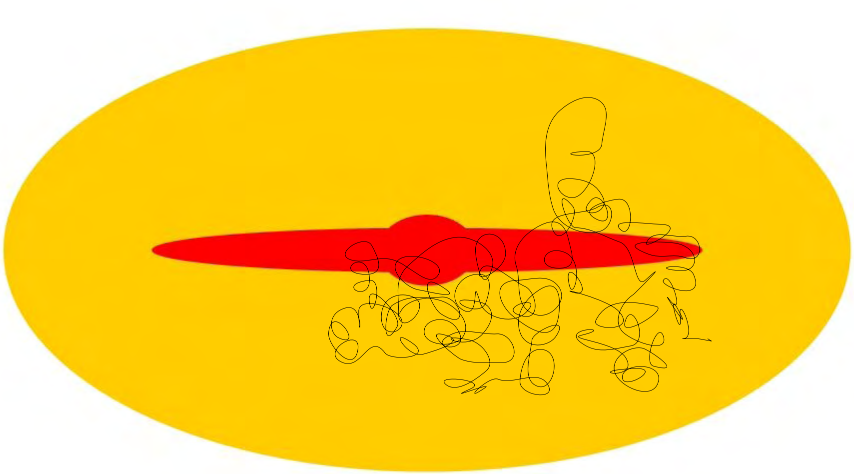
$$\boxed{1.17 \text{ ton} \times \text{yr}}$$

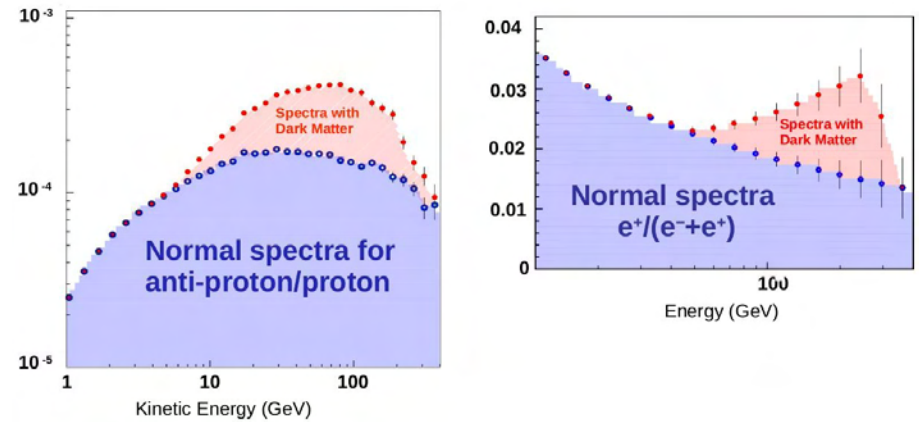
2-4 keV


DAMA/LIBRA ≈ 250 kg (0.87 ton×yr)
Residuals (cpd/kg/keV)
Time (day)

2-6 keV


DAMA/LIBRA ≈ 250 kg (0.87 ton×yr)
Residuals (cpd/kg/keV)
Time (day)





SOURCE(s) + Propagation → Observable Cosmic Rays

$$\chi + \chi \to e^+ + \ldots$$

$$p + p_{\rm ISM} \to e^+ \ldots$$

$$p + p_{\rm ISM} \to \pi^+ \ldots$$

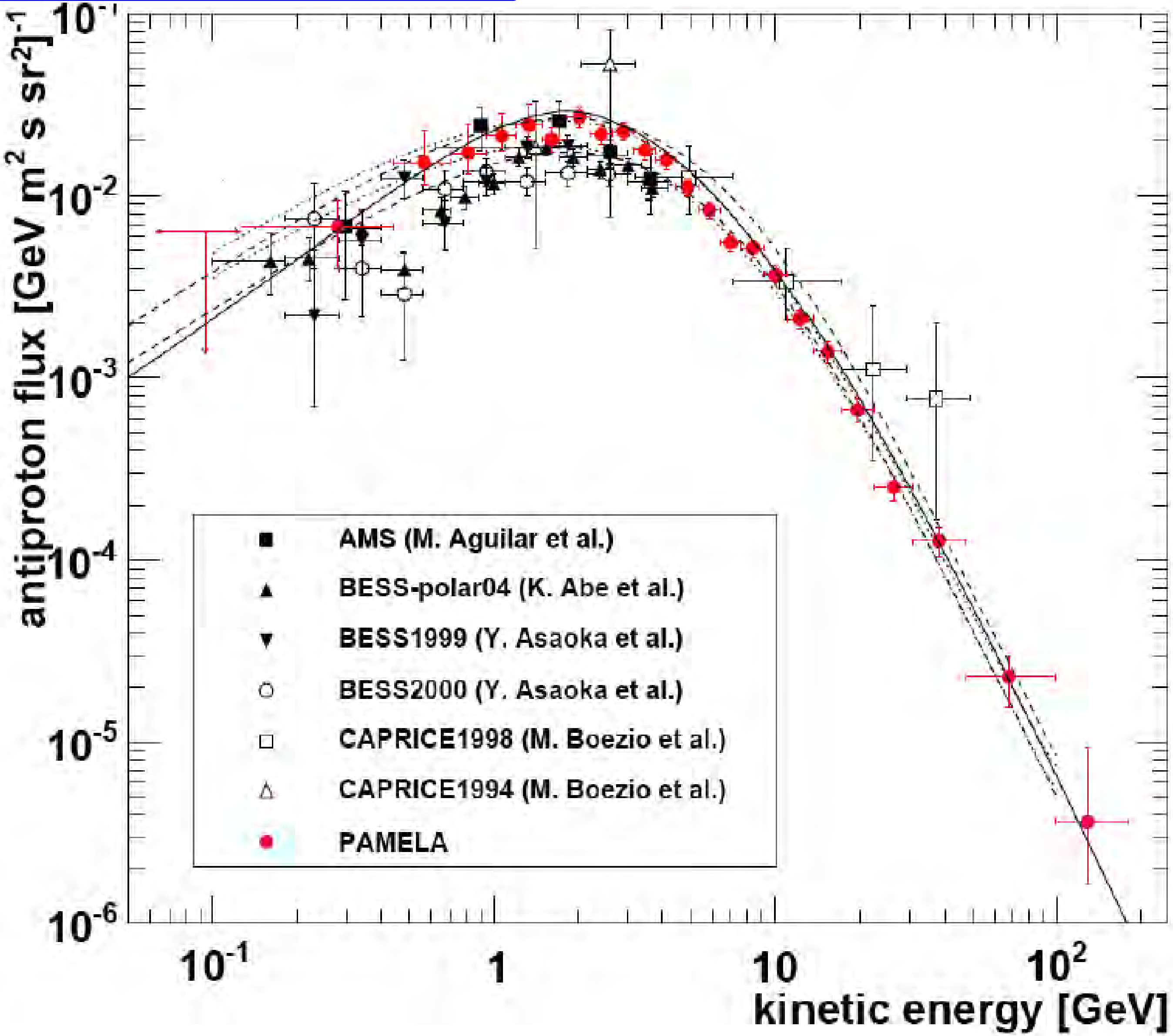
$$\pi^+ \to \mu^+ + \nu_\mu$$

$$\mu^+ \to e^+ + \nu_e + \overline{\nu}_\mu$$

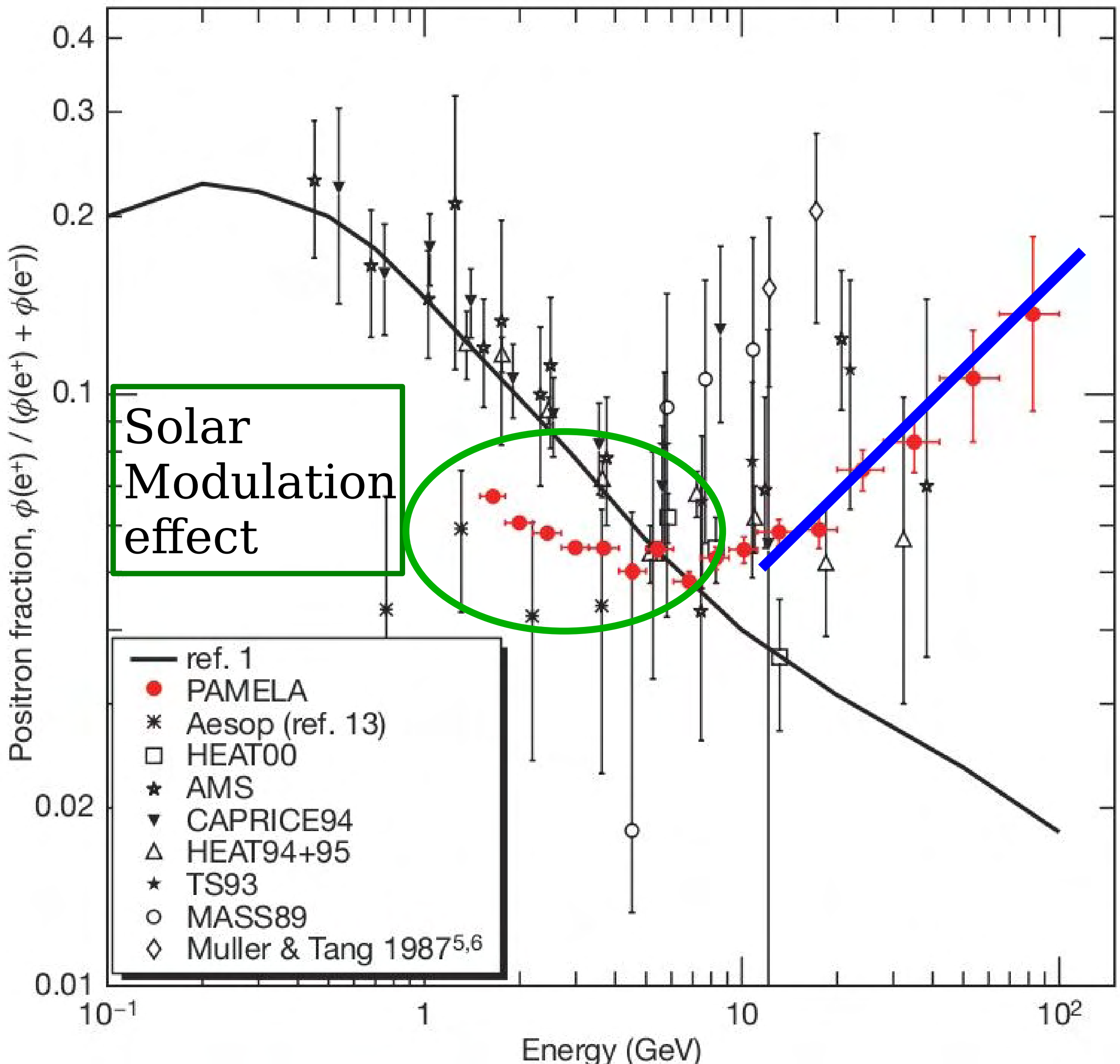
Possible
positron accelerators

PAMELA Antiproton result

Agreement with Standard production Mechanism



An anomalous positron abundance in cosmic rays with energies 1.5–100 GeV

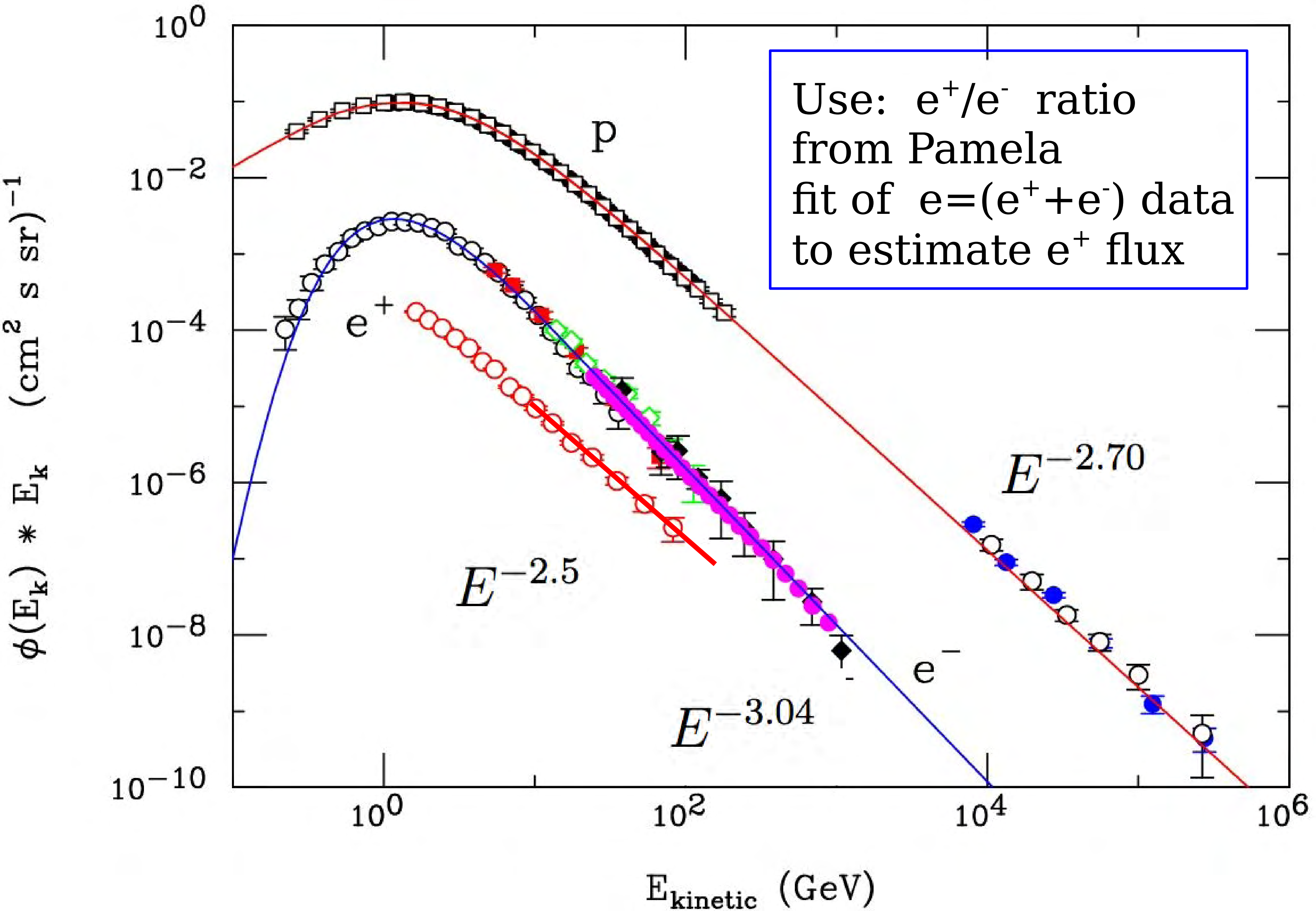


High energy: ratio e+/e- grow with E !!

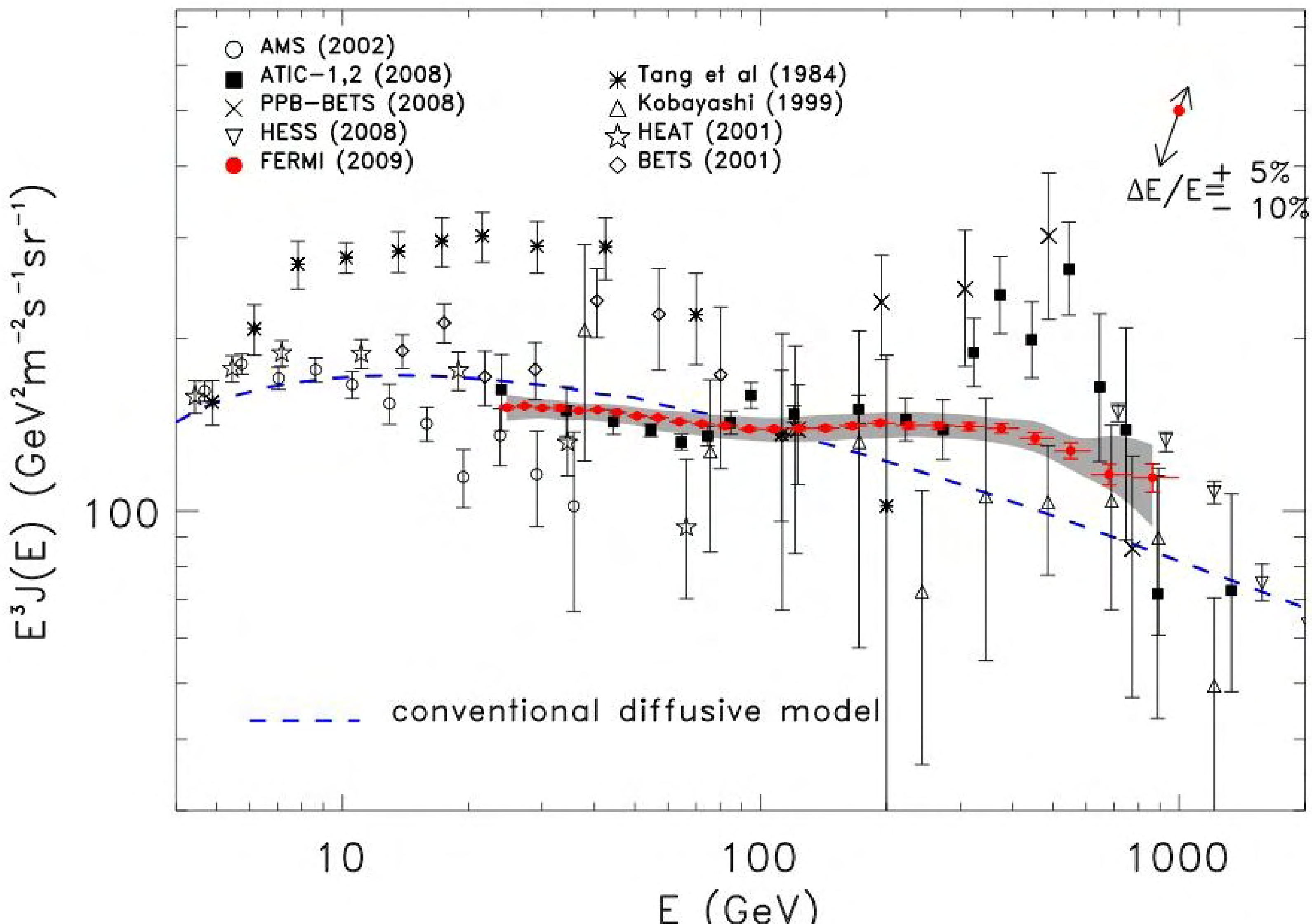
$$\frac{\phi_{e^+}}{\phi_{e^-}} \propto E^{0.52}$$

Very unexpected result !

Proton and electron + Positron energy spectra



FERMI: electron + positron flux



"Room" for
Extra- component ! Dark Matter ??!!

From : Cirelli

Results

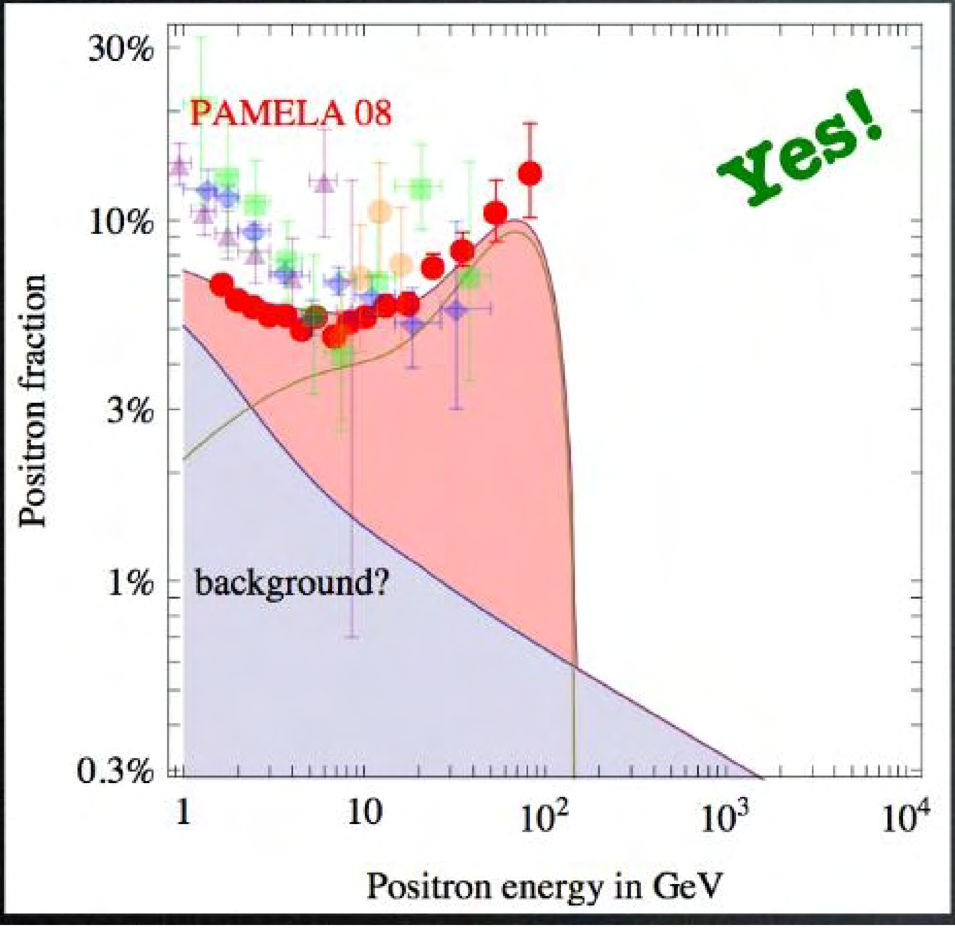
Which DM spectra can fit the data?

E.g. a DM with: -mass $M_{\rm DM} = 150\,{\rm GeV}$

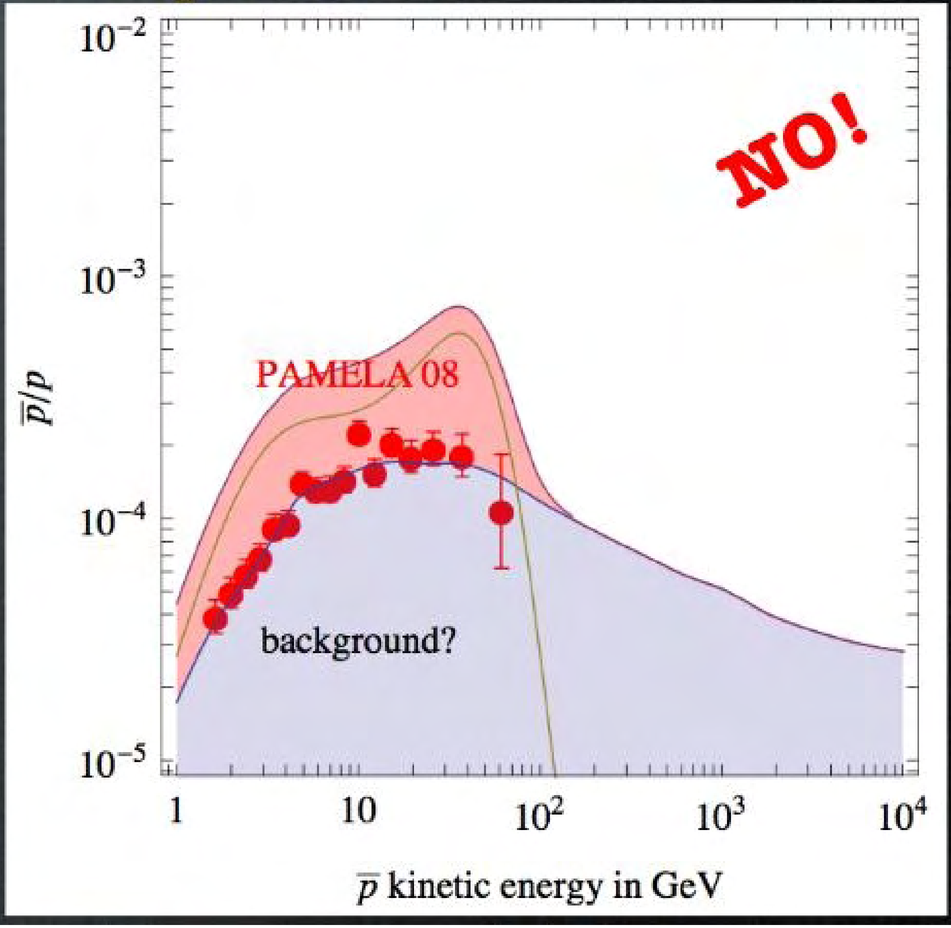
-annihilation $\mathrm{DM\ DM} \to W^+W^-$

(a possible SuperSymmetric candidate: wino)

Positrons:



Anti-protons:



Dark Matter explanation of the
"Pamela positron excess" in terms of the
"WIMP" model is possible, but not in its
simplest, most natural version.

[1.] The DM annihilation does not produce antiprotons
"Leptophilic" Dark Matter [?]
(no convincing dynamical explanation)

[2.] Include a large "Boost factor"
to increase the rate of the DM annihilations.
Very "clumpy" dark matter.
(very lucky in being close to a big clump)
"winning the jackpot" [?]

Is this "adding epicycles" to the wrong theory ?

Astrophysical interpretations for the positron excess

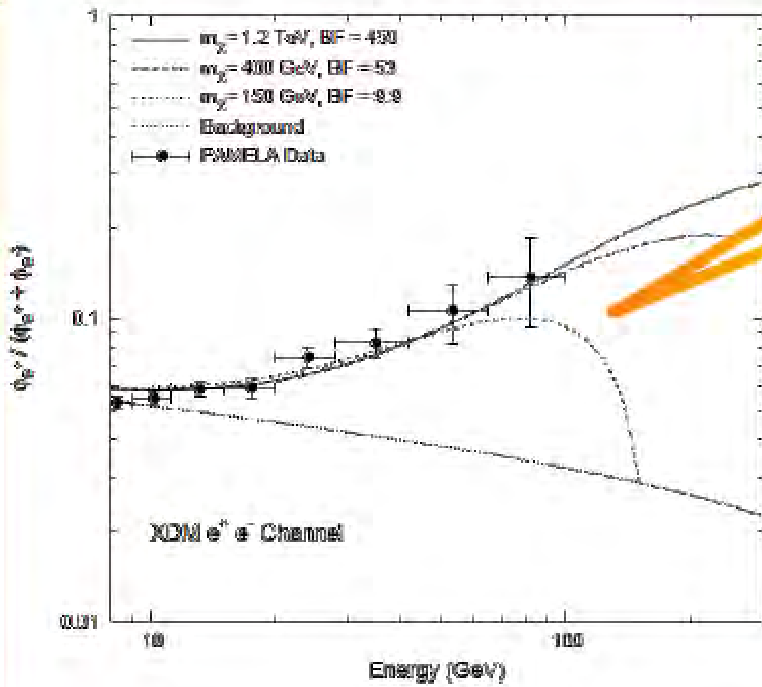
Positron-excess interpretations

Dark matter

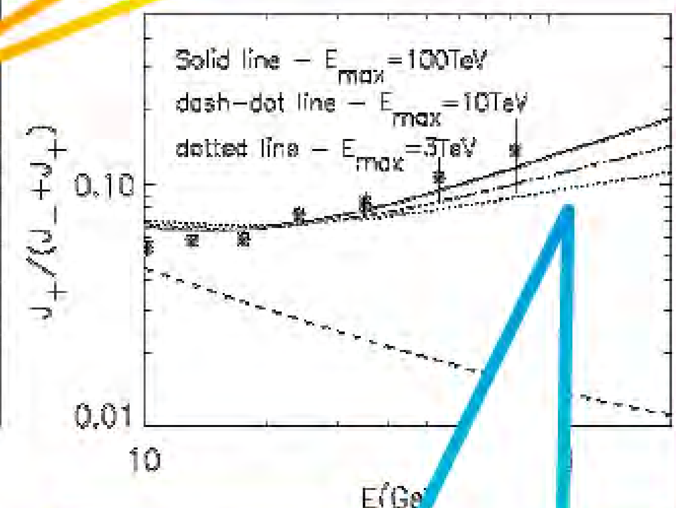
- boost factor required
- lepton vs hadron yield must be consistent with p-bar observation

Astrophysical processes

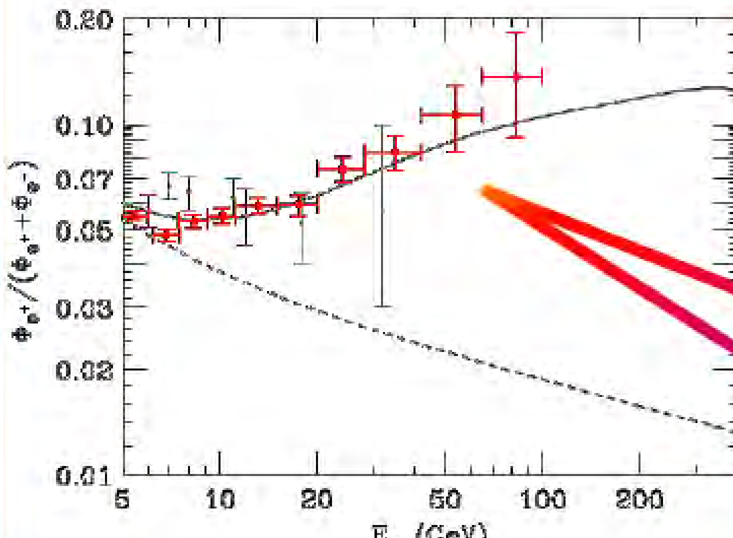
- known processes
- large uncertainties on environmental parameters



(Cholis et al. 2009)
Contribution from **DM annihilation**.

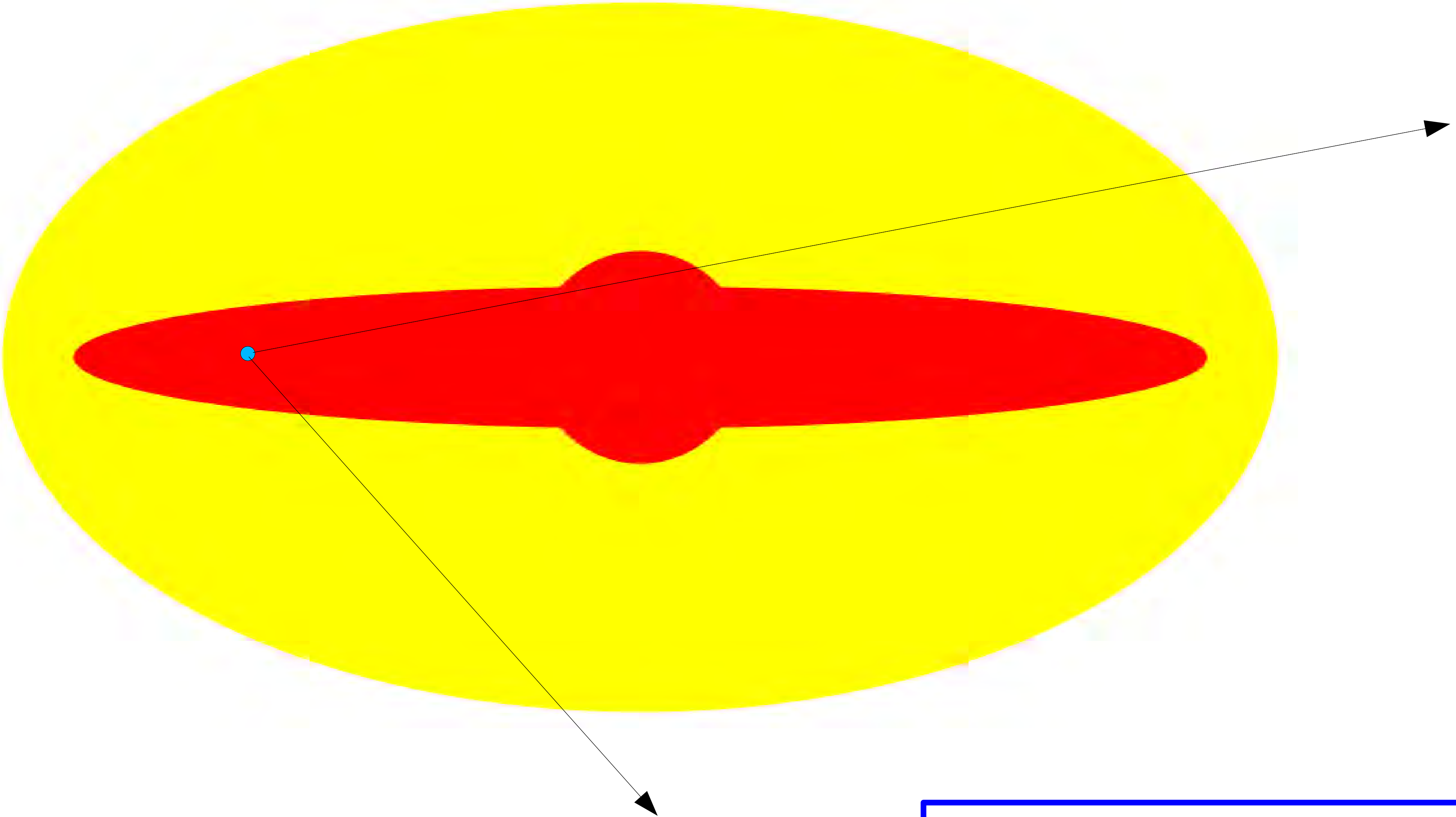


(Blasi 2009)
e+ (and e-) produced as **secondaries** in the CR acceleration sites (e.g. SNR)



(Hooper, Blasi and Serpico, 2009)
contribution from diffuse mature & nearby young **pulsars**.

Photon emission from DM annihilation



$$J(\Omega) = \frac{1}{R_\odot} \int d\ell \, \frac{\rho^2(\ell, \Omega)}{\rho_\odot^2}$$

No evidence
From Gamma Ray
measurements

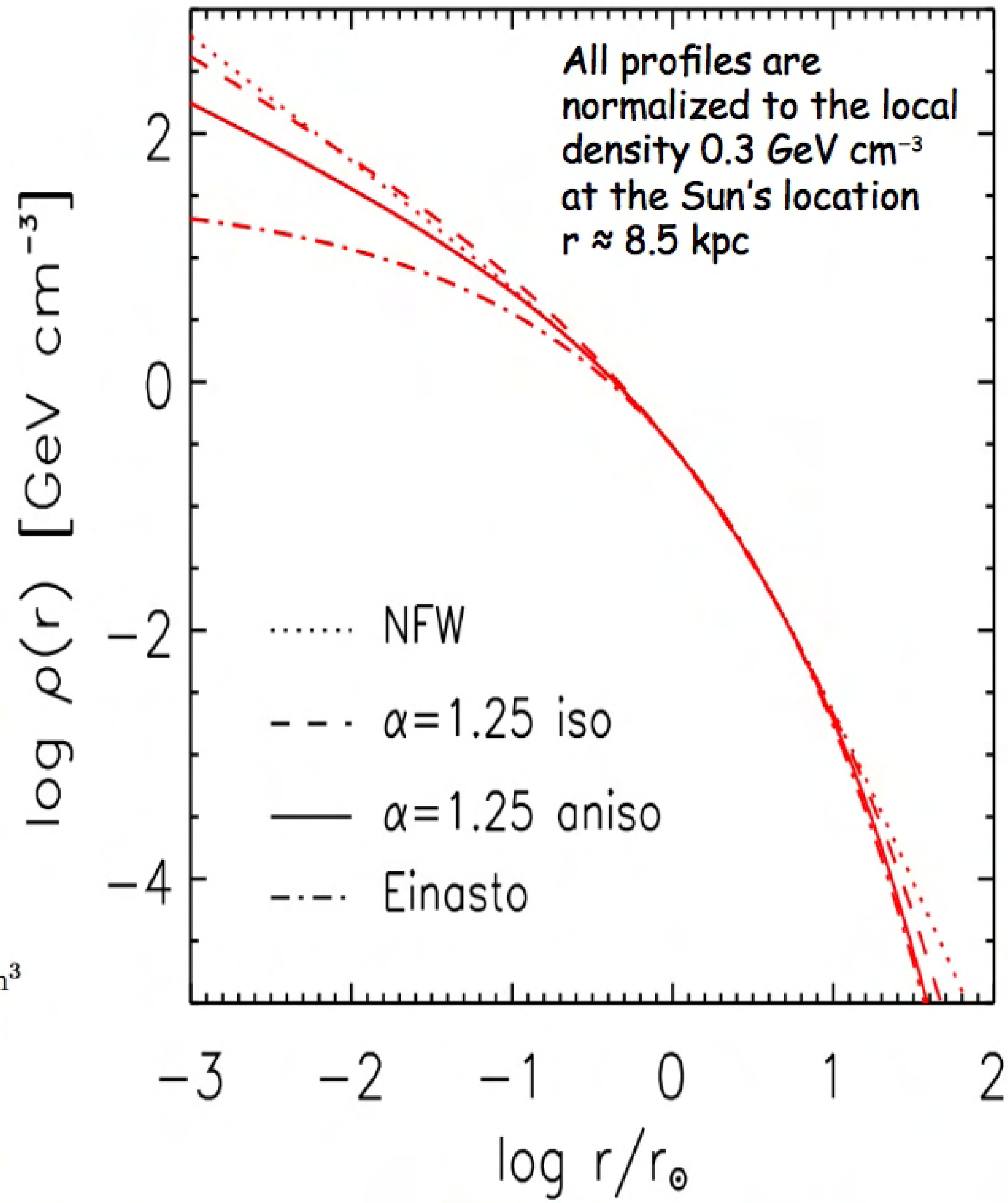
Milky Way Dark Matter Profiles

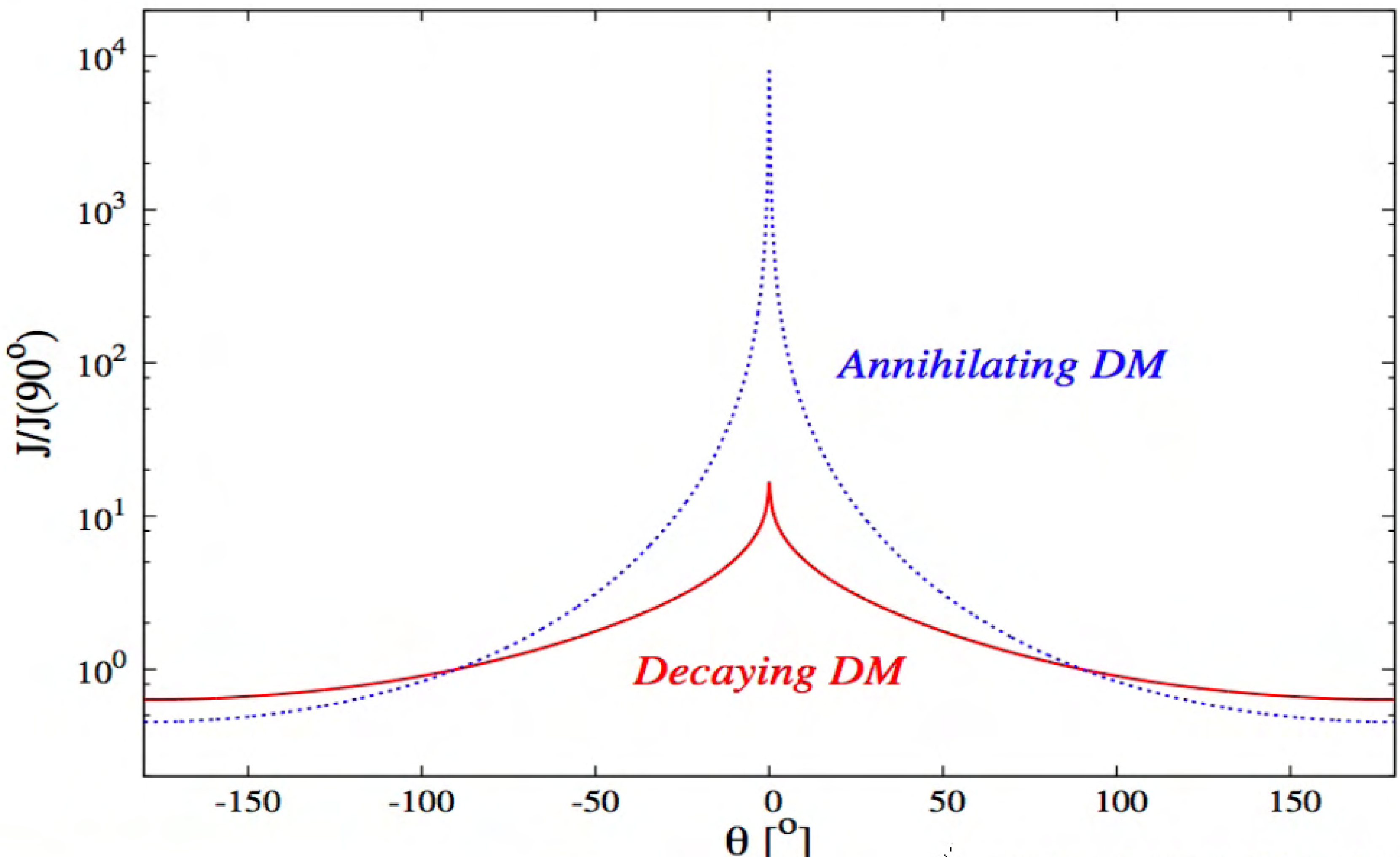
$$\rho(r) = \rho_\odot \left[\frac{r_\odot}{r}\right]^\gamma \left[\frac{1 + (r_\odot/r_s)^\alpha}{1 + (r/r_s)^\alpha}\right]^{(\beta-\gamma)/\alpha}$$

Halo model	α	β	γ	r_s in kpc
Cored isothermal	2	2	0	5
Navarro, Frenk, White	1	3	1	20
Moore	1	3	1.16	30

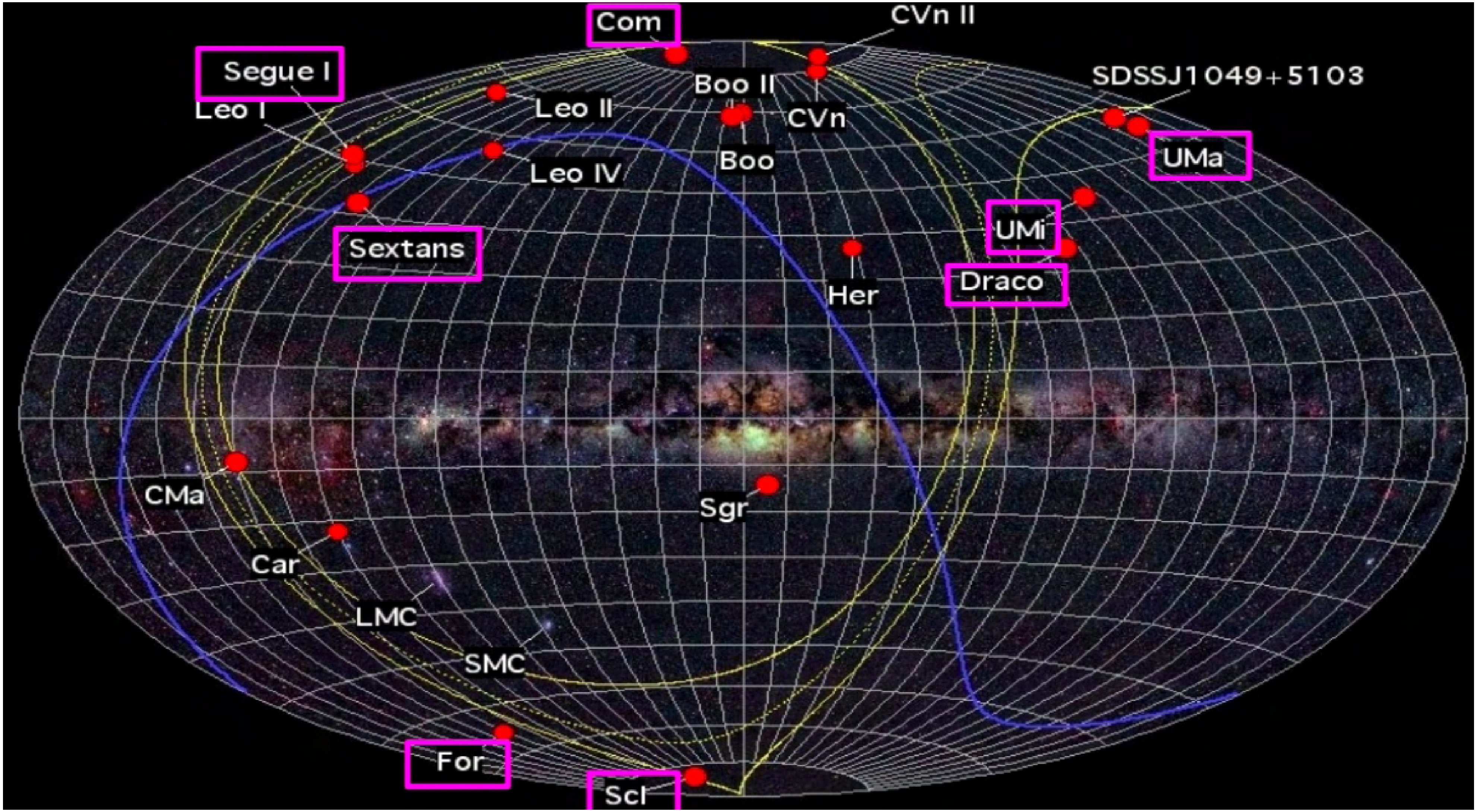
Einasto | $\alpha = 0.17$ $\quad r_s = 20\,\mathrm{kpc}$ $\quad \rho_s = 0.06\,\mathrm{GeV/cm^3}$

A.Lapi et al. arXiv:0912.1766

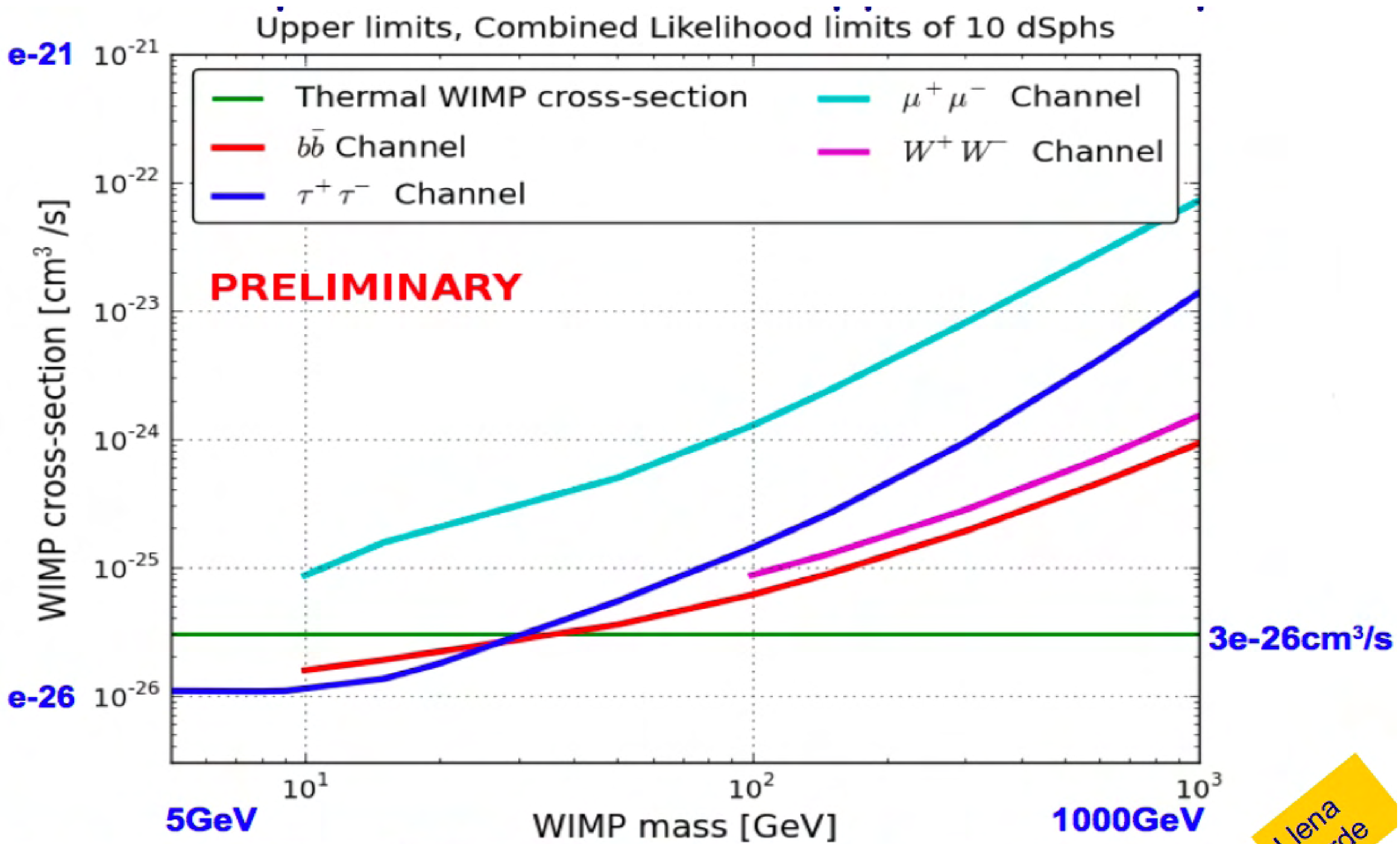




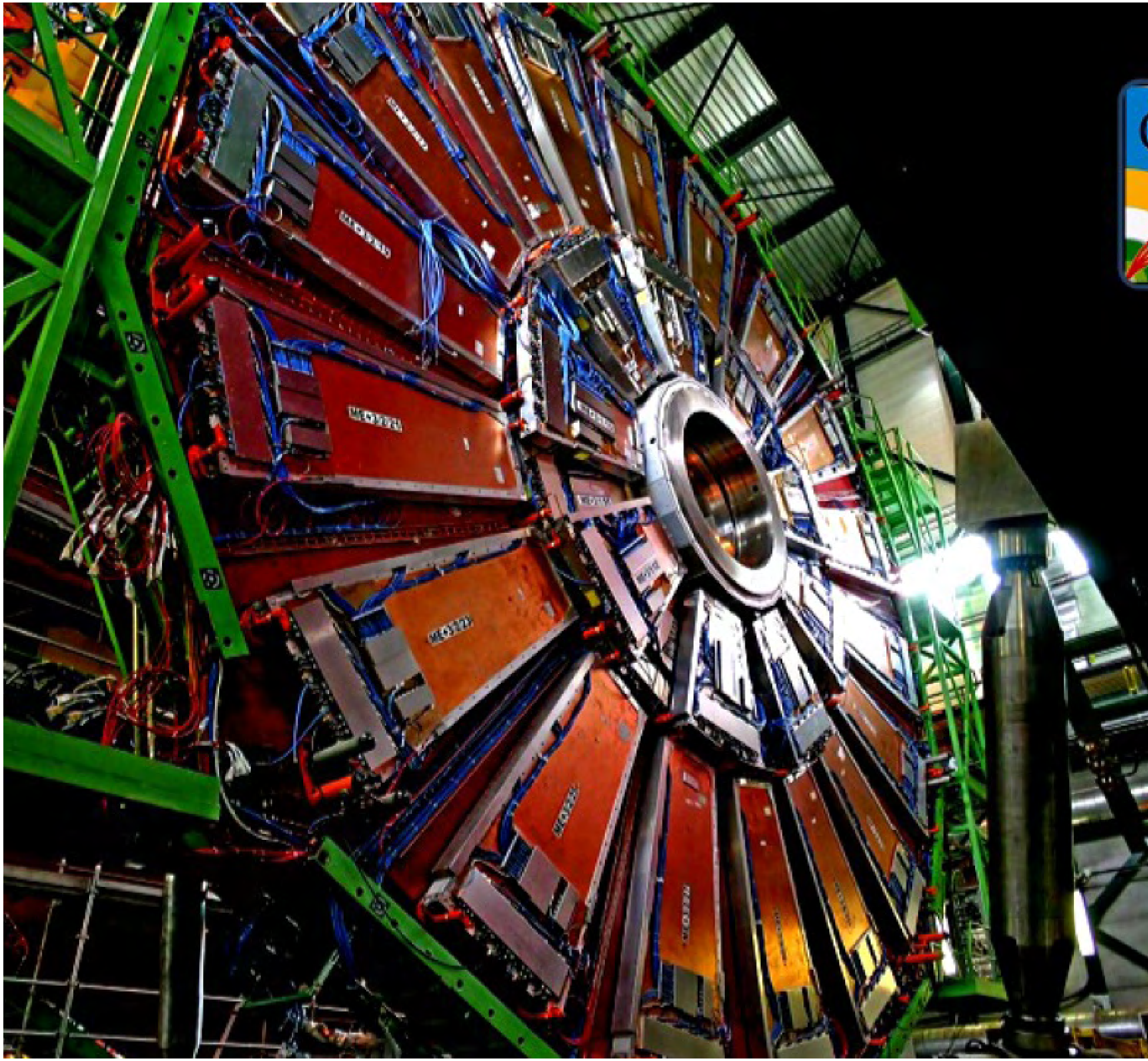
G.Bertone et al. 2007, JCAP 11, 003B



Com
CVn II
Segue I
Boo II
SDSSJ1049+5103
Leo I
Leo II
CVn
Boo
UMa
Leo IV
UMi
Sextans
Her
Draco
CMa
Sgr
Car
LMC
SMC
For
Scl

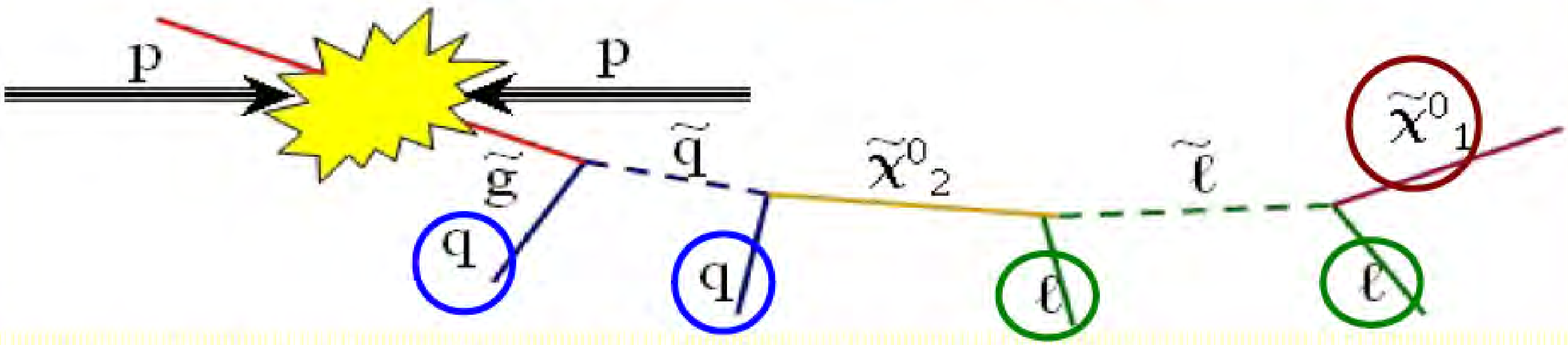


robust constraints including J-factor uncertainties



CMS

Typical signature



- Pair of gluinos/squarks produced by strong interactions
- Their decays give high-p_T jets and charginos/neutralinos
- Charginos/neutralinos decays can give leptons and the decay chain stops when the LSP is produced (R-parity conserving scenarios)
- The pair of stable LSP produced escapes the detector undetected leading to high transverse missing energy

multi-Jets + n leptons + E_T^{miss}

Standard Model backgrounds (tt, W+jets, Z+jets, QCD jets and dibosons)

Final Remarks:

The efforts to understand the objects and
the mechanisms that generate
high energy relativistic particles
in our Galaxy and in the universe
form a vibrant field with continuous
surprises and new discoveries.

This is beautiful Science, still very much controlled
by the data, with theorists continuously surprised.

Multi-messenger astrophysics is essential,
and [...sooner or later...] Neutrino Telescopes
will play a key role.

Search for Dark Matter remain
one of the most important problem for Science