Cosmic Rays in the Galaxy

1, Over View

Discovery : Legendary baloon flight of Victor Hess

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Time variation : => 4, Solar Modulation $\lesssim 10^{13}$

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3, Some Results from AMS02 and Some Other Precision Measurements

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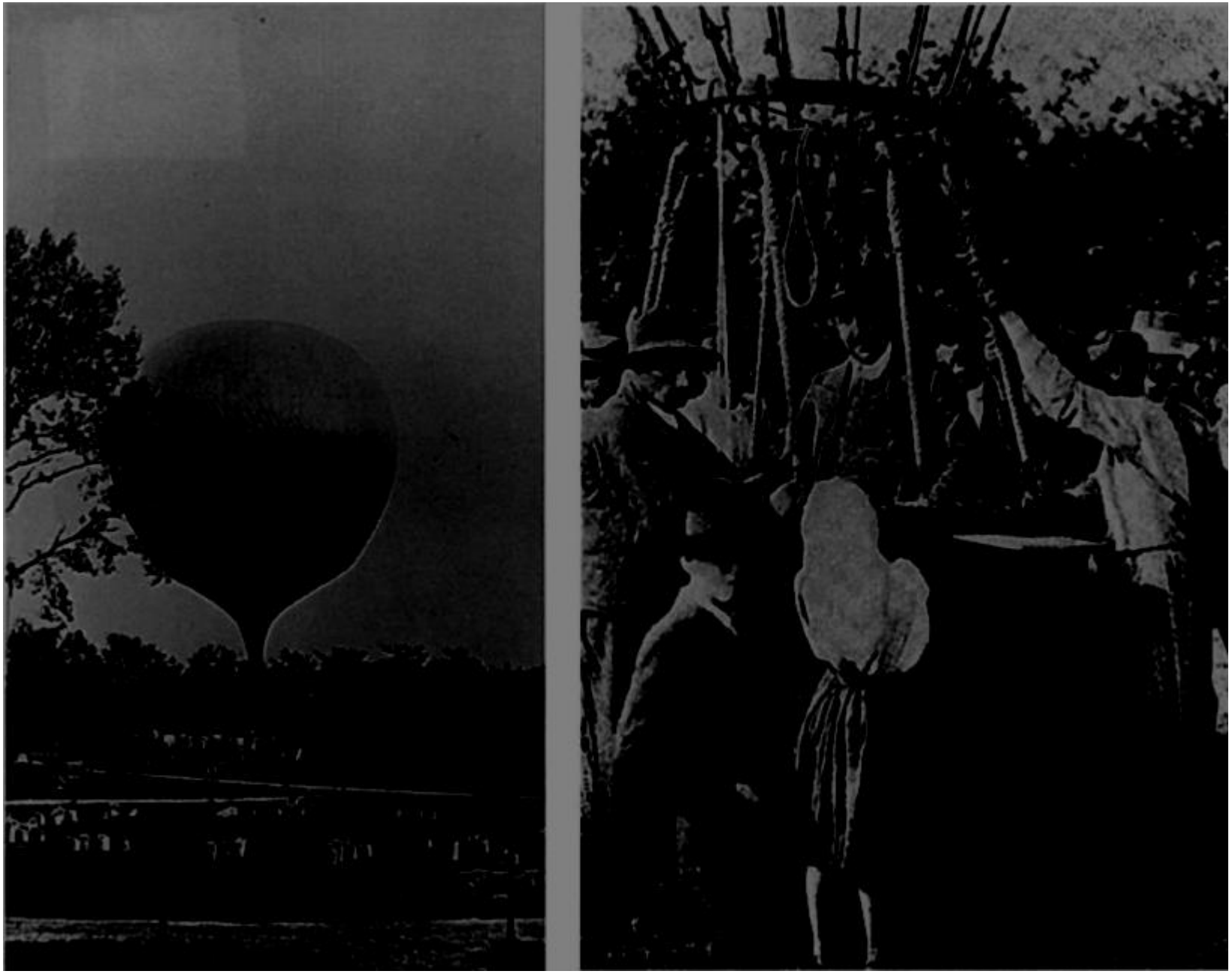
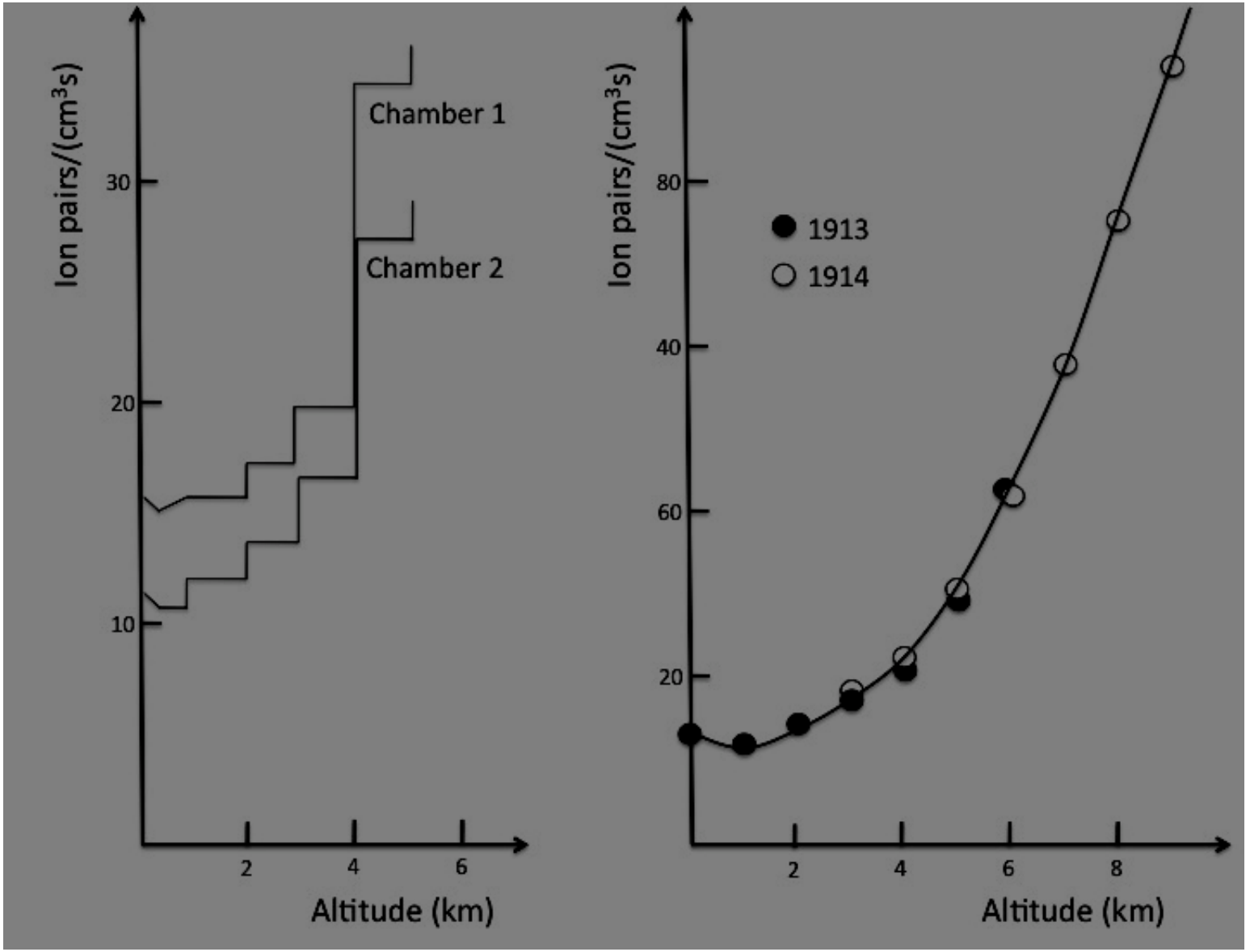
Legendary Balloon Flight of V.F. Hess



Expected was radiation of ground, then decrease of Ion Pair as Balloon Ascended.
But, it increased ! => Radiation is Coming from the Sky



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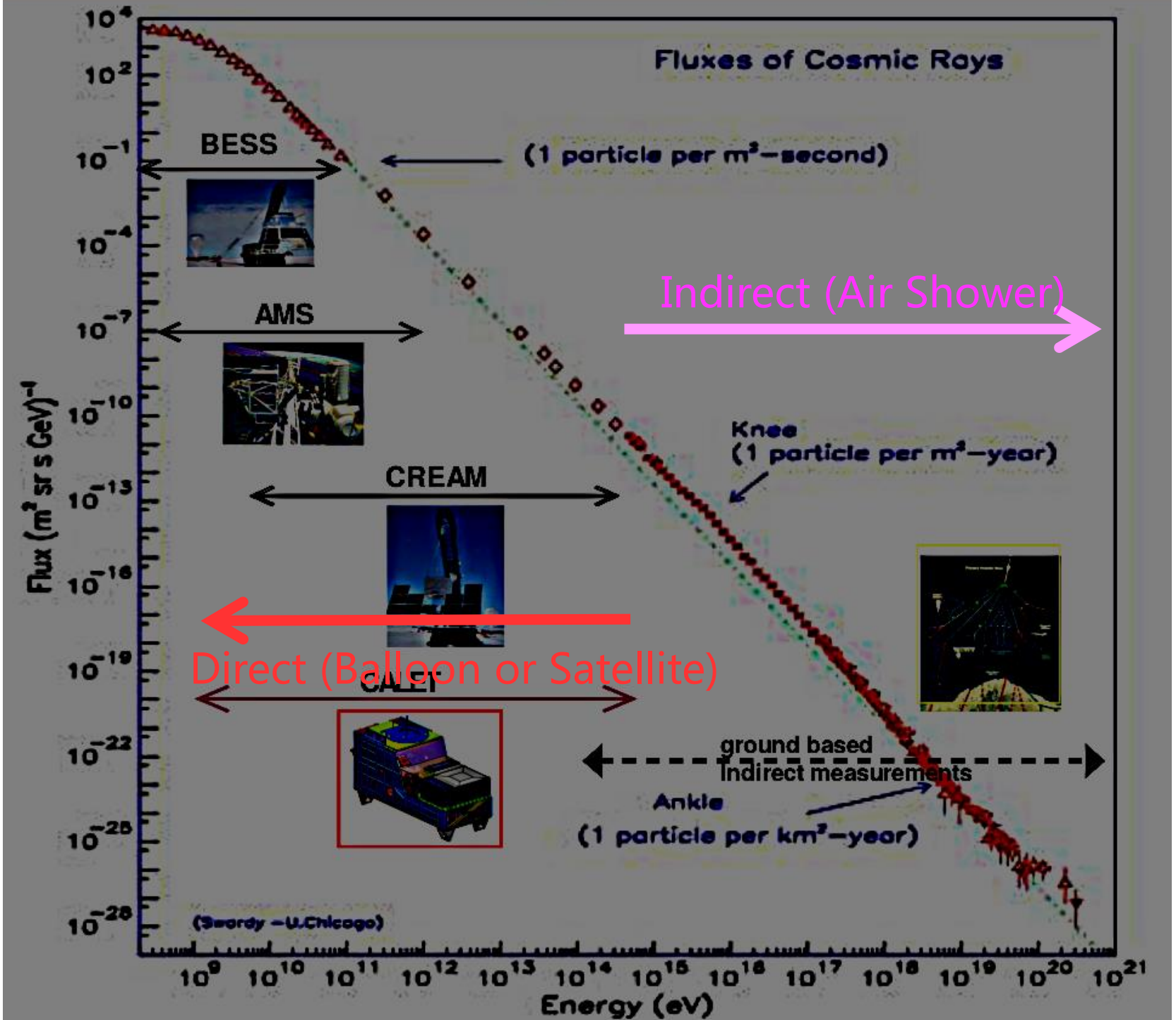
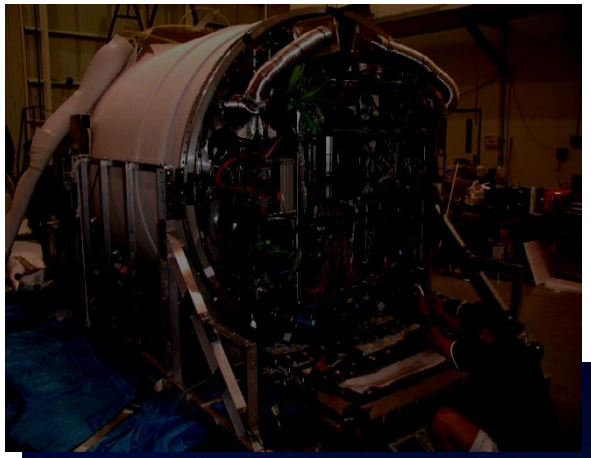
Cosmic ray Observation

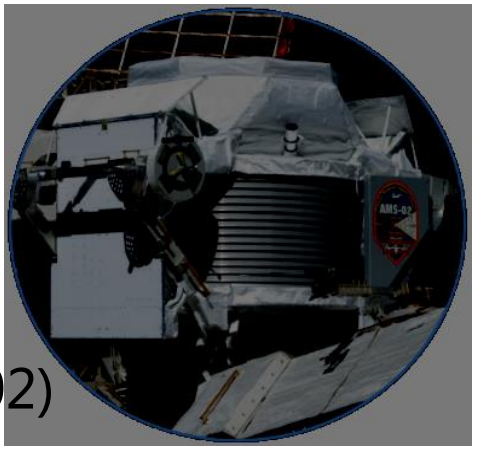


Direct Observation

Balloon Borne (BESS)

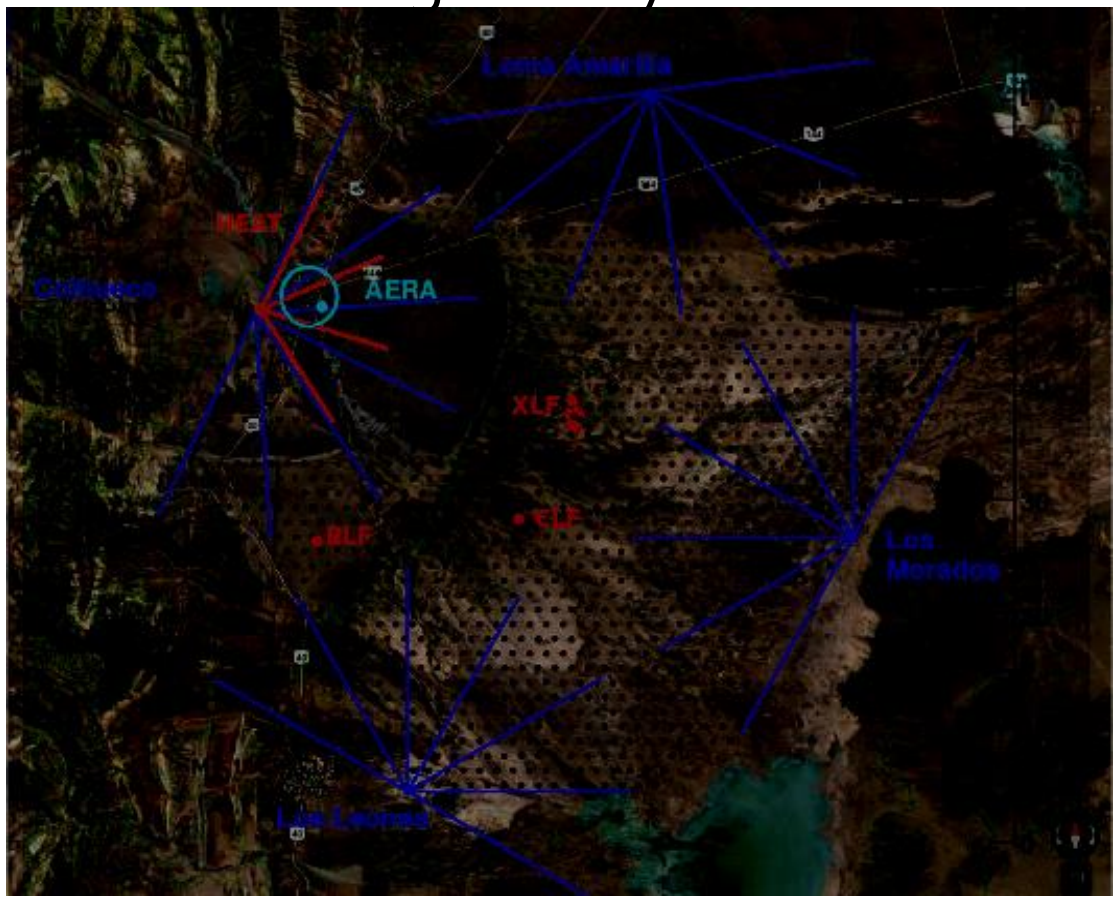


Satellite (ISS, AMS02)

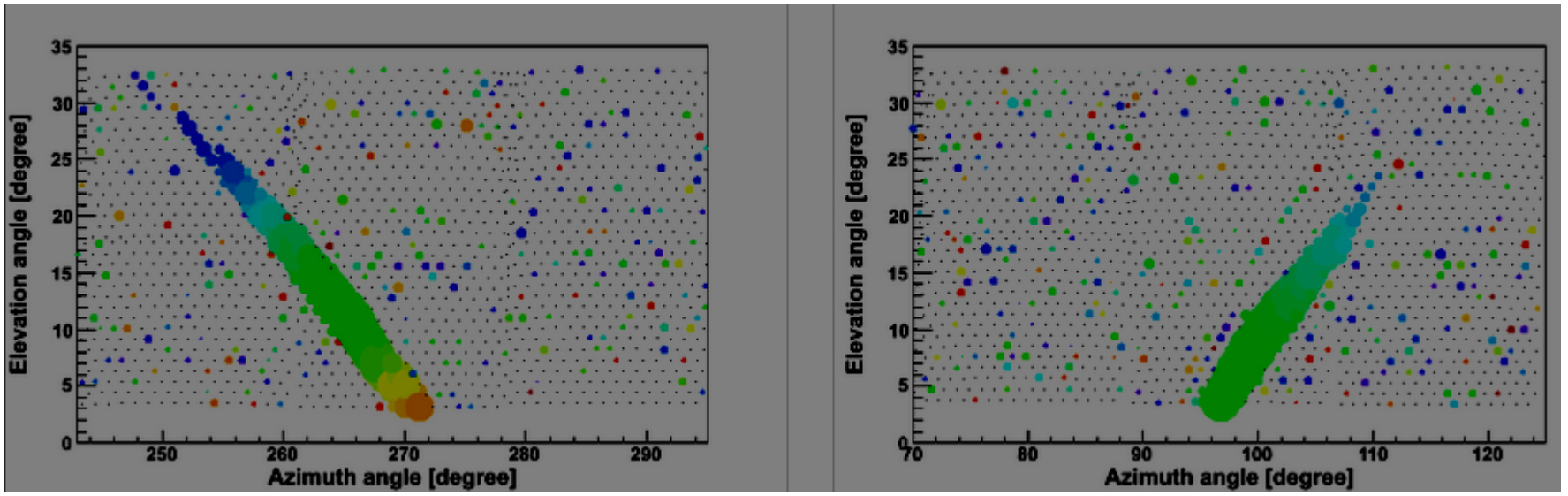


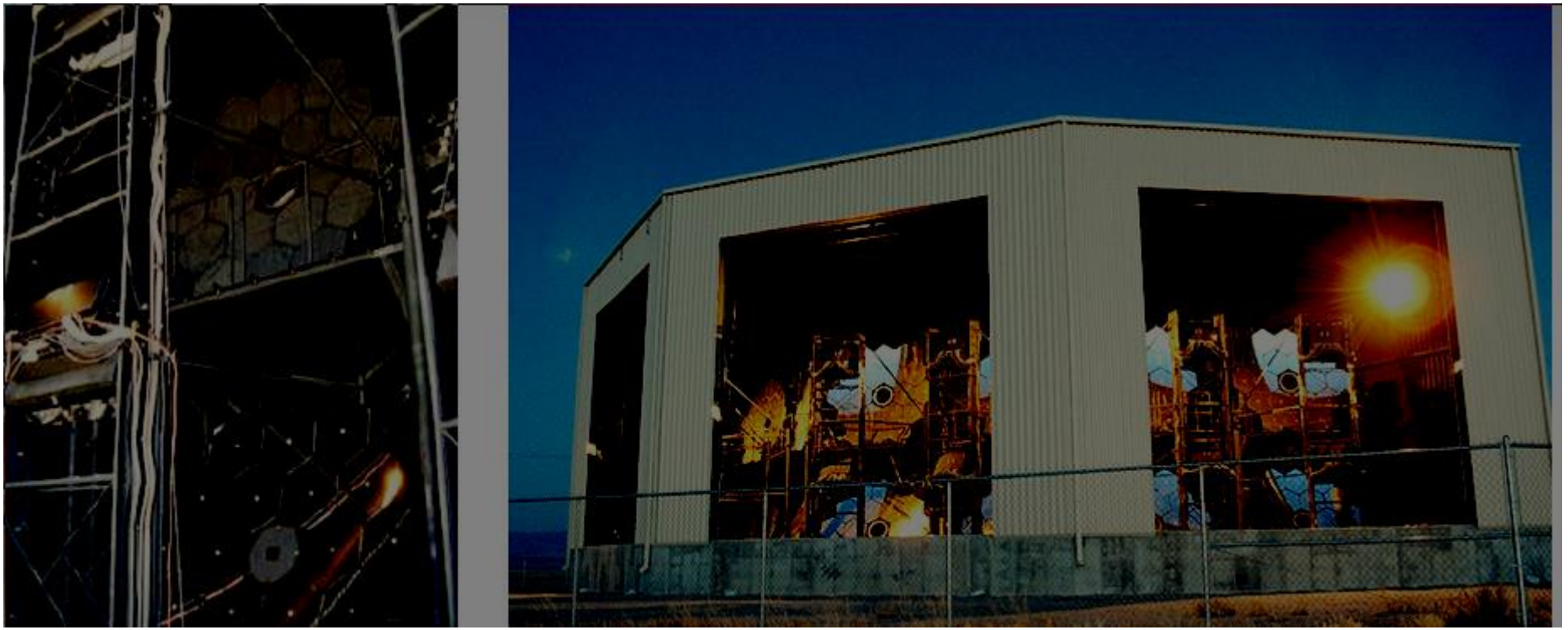
Indirect Observation (Air Shower)

Auger Array

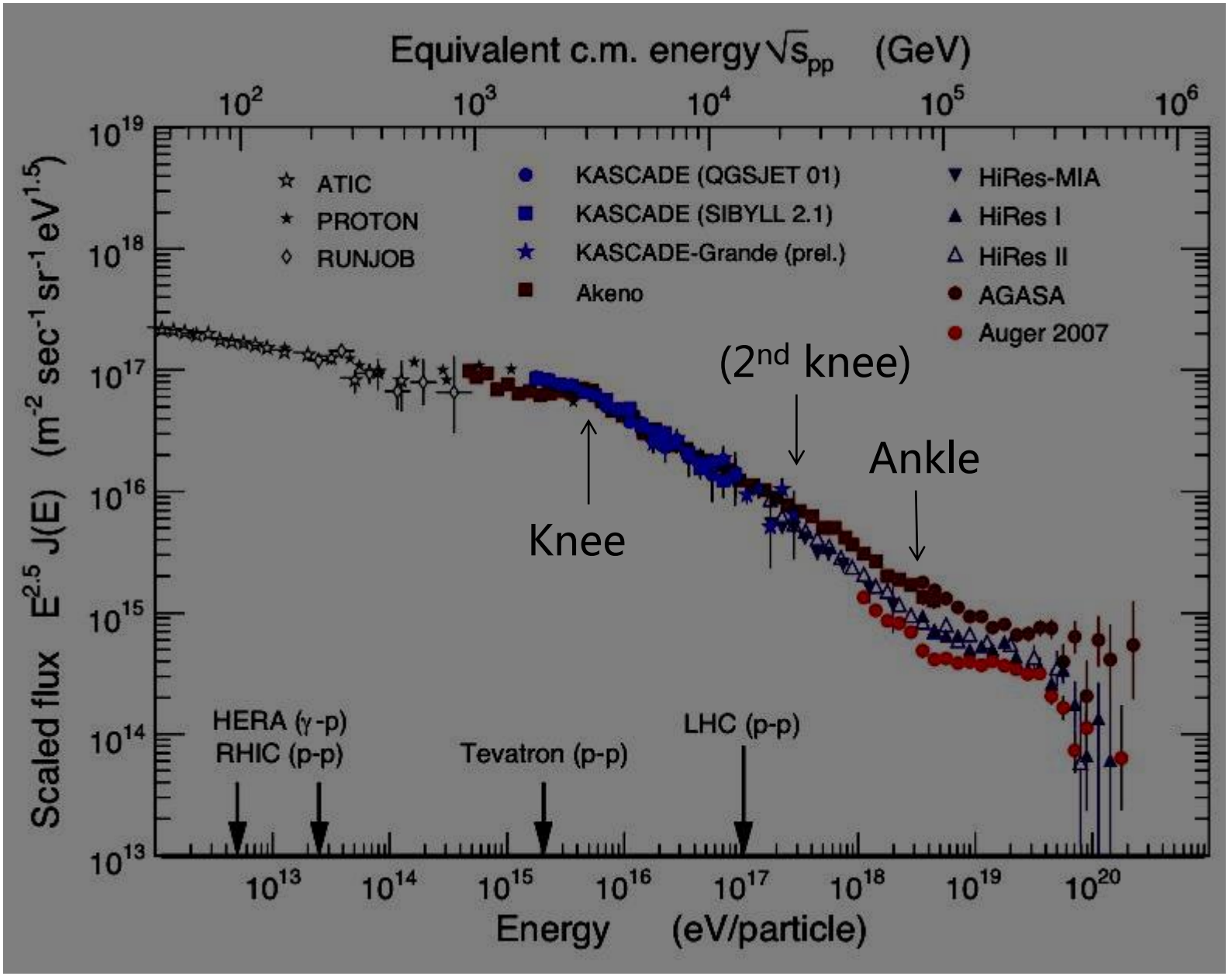


Yangbajing Tibet, China


Elevation angle [degree]
Azimuth angle [degree]
0
5
10
15
20
25
30
35
250
260
270
280
290
70
80
90
100
110
120



The Energy spectrum of cosmic ray multiplied by $E^{2.5}$ (All particle)



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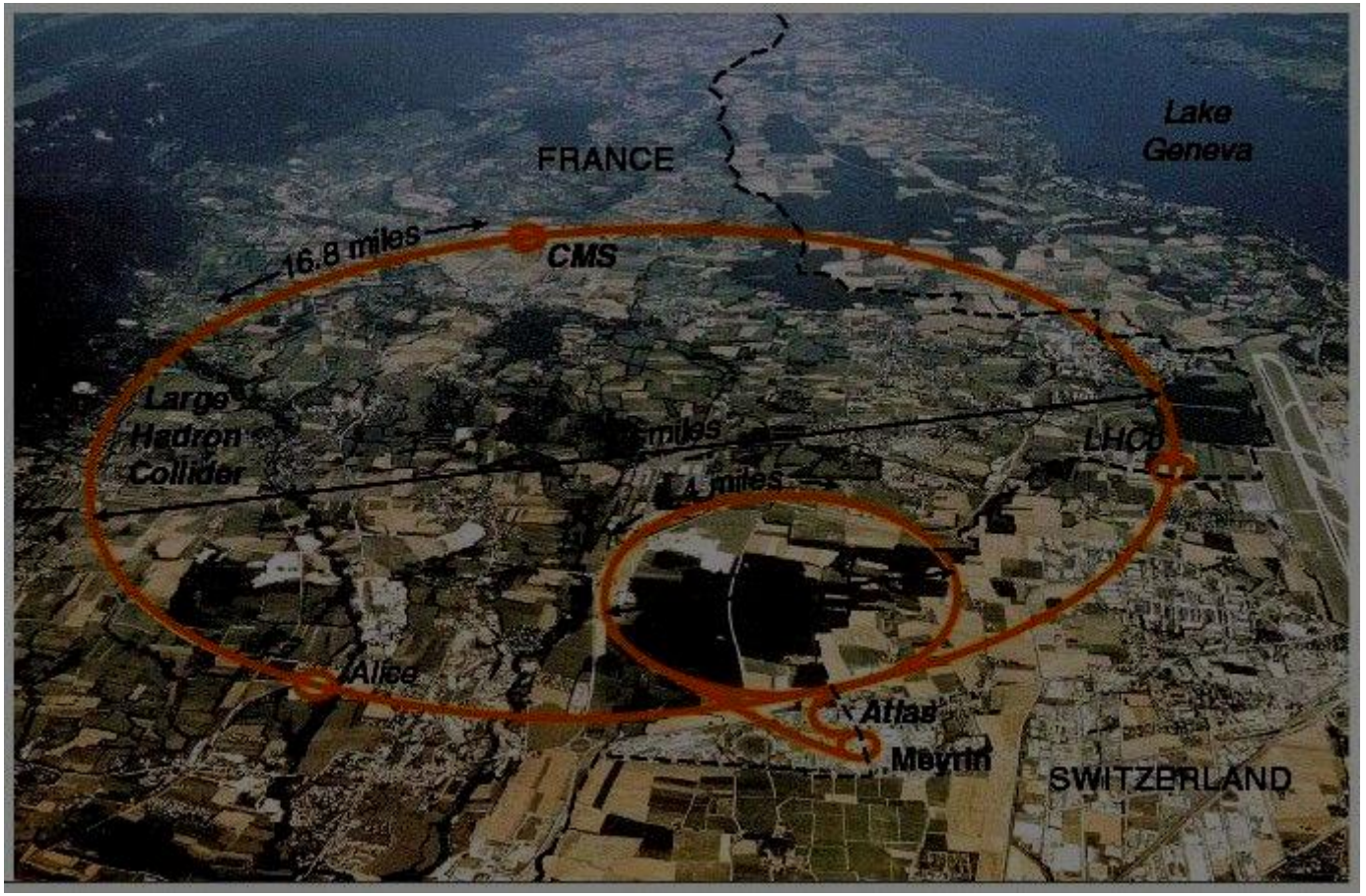
$$r_g = \frac{\gamma m v_\perp}{|q|B}.$$

$$(\frac{E}{1\,GeV}) \leq 0.3 \times (\frac{r_g}{1\,m})(\frac{B}{1\,T})$$

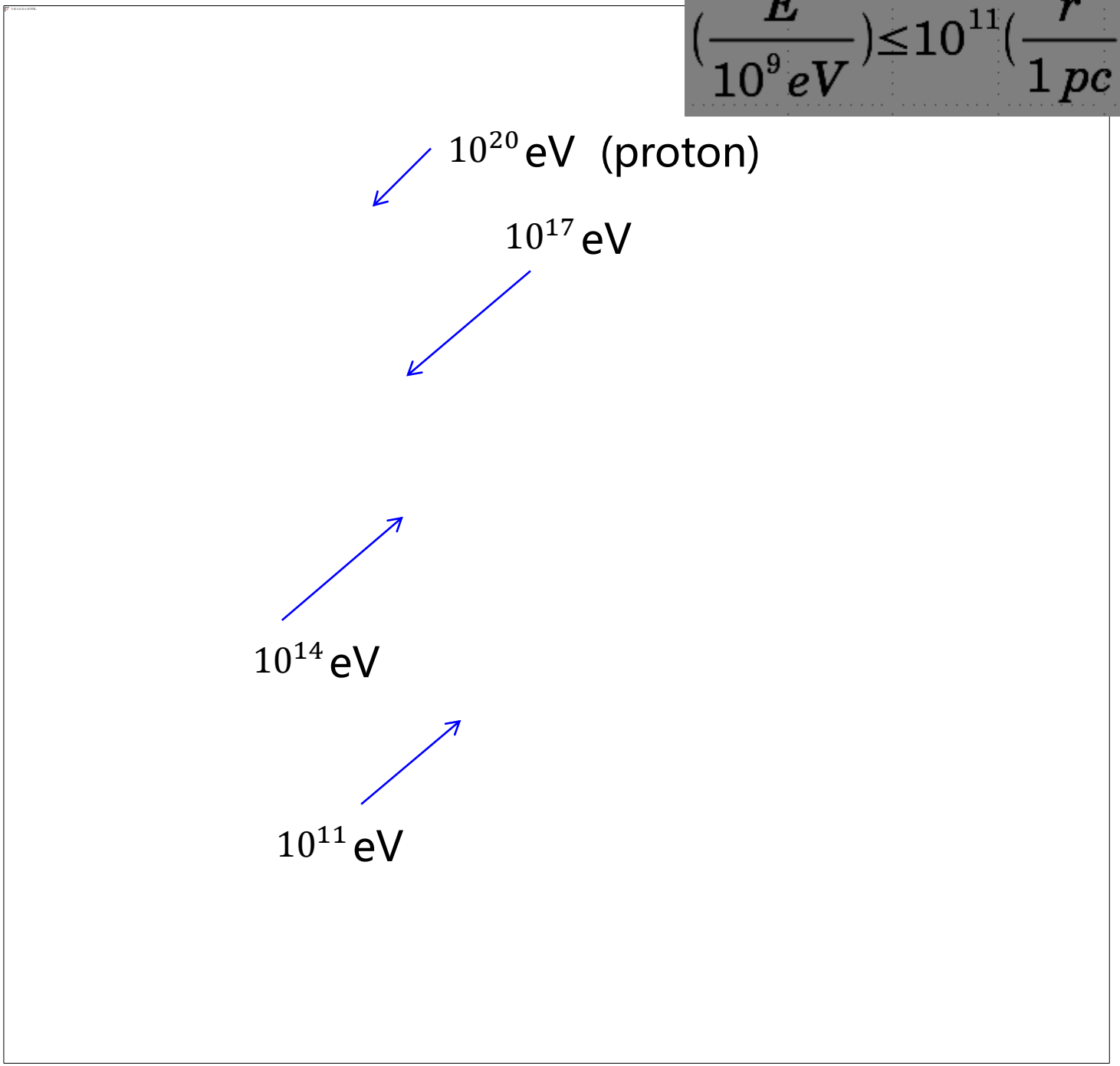
LHC : Man Made Largest Accelerator



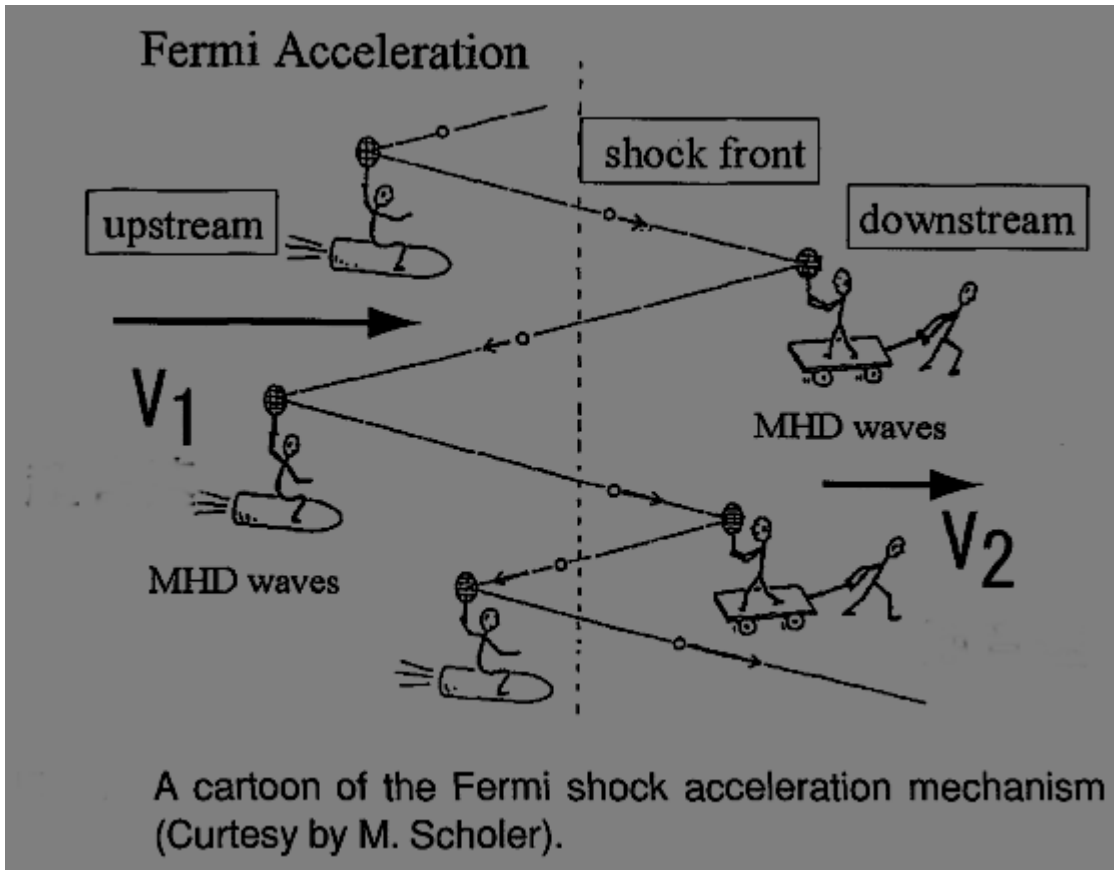
For 14TeV and 10T ,We get r_g ~4.6km

Hillas Diagram (List of Cosmic Ray Accelerator)

$$\left(\frac{E}{10^{9}\,eV}\right) \leq 10^{11}\left(\frac{r}{1\,pc}\right)\left(\frac{B}{10^{-4}\,T}\right)$$



Main Mechanism => Shock of Super Nova



A cartoon of the Fermi shock acceleration mechanism (Curtesy by M. Scholer).

Energy gain in a round trip

$$\left\langle \frac{\Delta\varepsilon}{\varepsilon} \right\rangle \simeq \frac{4}{3}\left(\frac{V_1 - V_2}{c}\right)$$

After l times round trip

$$\frac{\varepsilon_l}{\varepsilon_0} \simeq \left(1 + \frac{4}{3}\frac{V_1 - V_2}{c}\right)^l$$

Survive Probability in l' s round trip

$$S(l) = \left(1 - \frac{4V_2}{c}\right)^l$$

Finally formed energy spectra

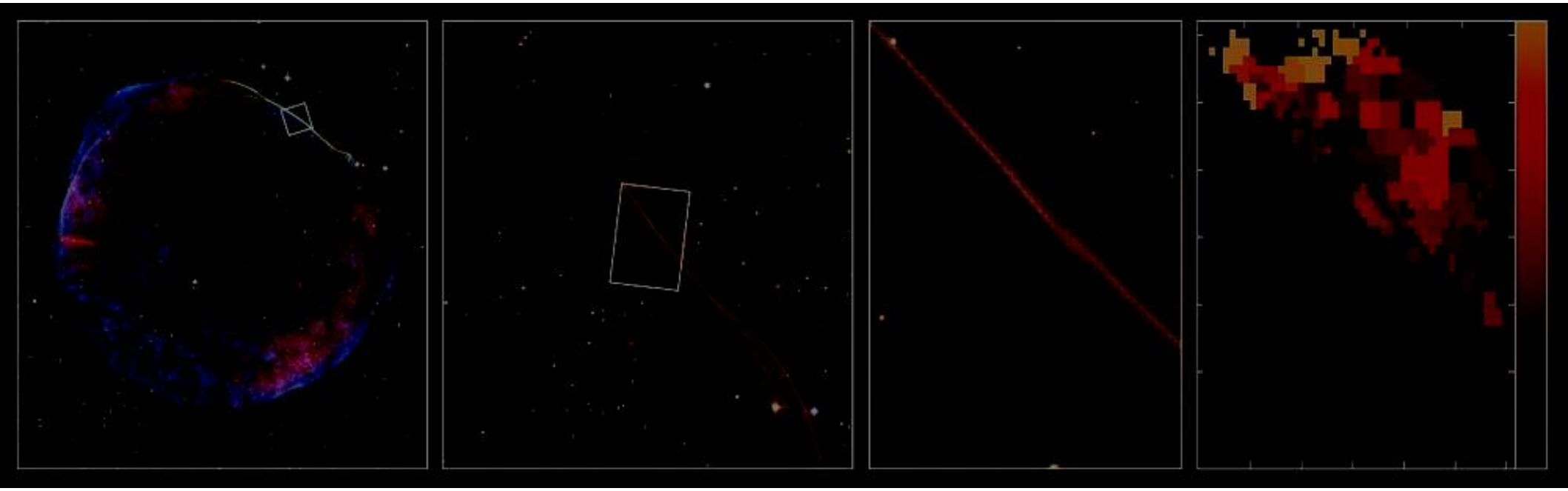
$$N(\varepsilon) \propto \varepsilon^{-s},\ s = \frac{V_1/V_2 + 2}{V_1/V_2 - 1}$$

In strong shock M>1, $v_1/v_4 = 4$ then we g $s = 2$

This is very close to spectral index of cosmic rays at low energies.

Observed Shock in Super Nova Remnant

$$\frac{14 \times 10^3}{20} = 3.3 \cdot \frac{14 \times 10^3}{20} = 2.3$$



But, is the mechanism same up to high energy end ?

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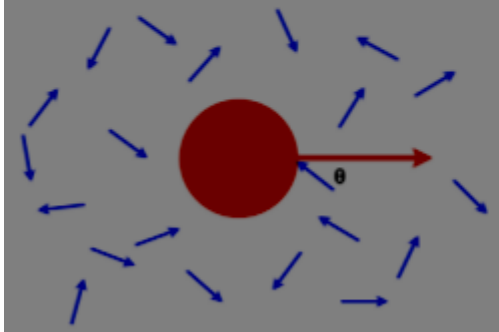
a known anisotropy

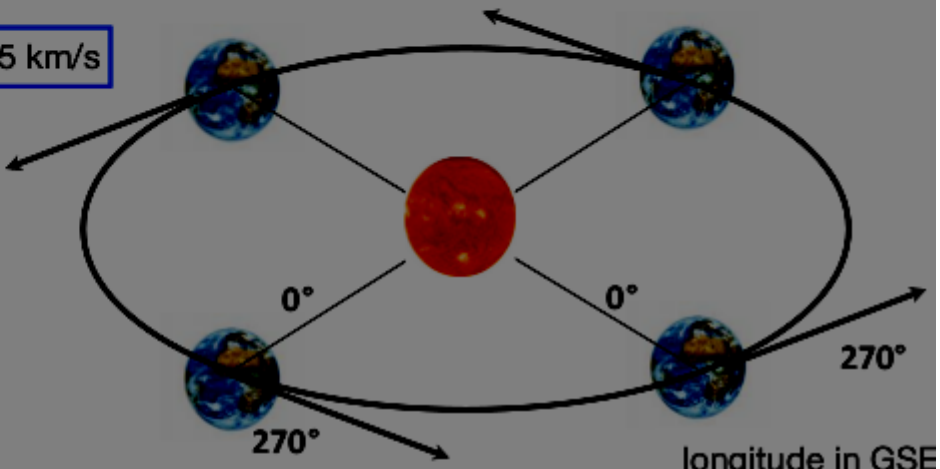
Earth's motion around the Sun

Compton & Getting, Phys. Rev. 47, 817 (1935)
Gleeson, & Axford, Ap&SS, 2, 43 (1968)

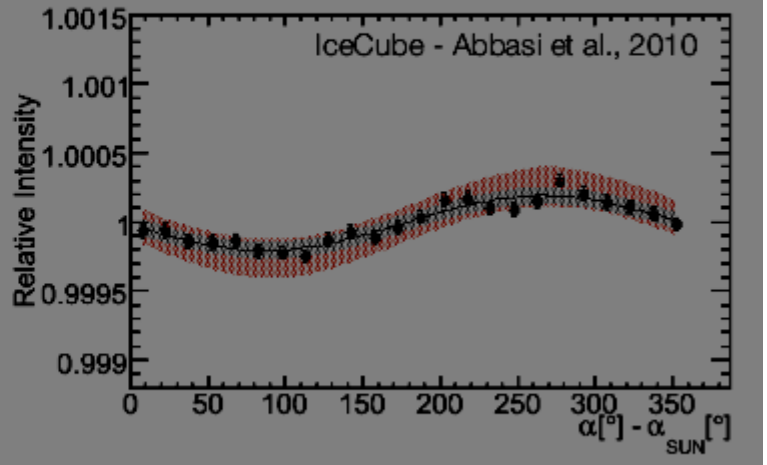


v = 29.8 ± 0.5 km/s

$$\frac{\Delta I}{I} = (\gamma + 2)\frac{v}{c}\cos\theta$$



- produced by Earth's revolution around the Sun
- visible as **solar diurnal modulation**
- **predictable** and used as **benchmark**
- **heliospheric physics** effects below O(100) GeV



THE
PHYSICAL REVIEW
A Journal of Experimental and Theoretical Physics
VOL. 47, NO. 11 JUNE 1, 1935 SECOND SERIES

An Apparent Effect of Galactic Rotation on the Intensity of Cosmic Rays

ARTHUR H. COMPTON, *University of Chicago and Oxford University* AND IVAN A. GETTING, *Oxford University*
(Received April 12, 1935)

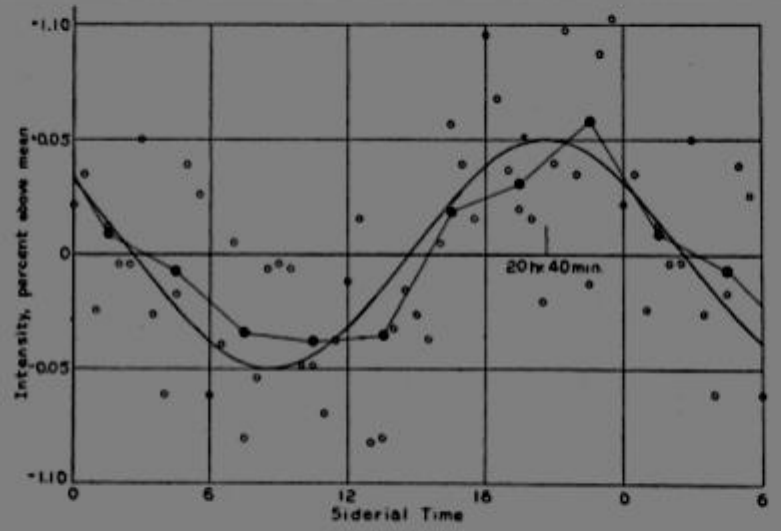
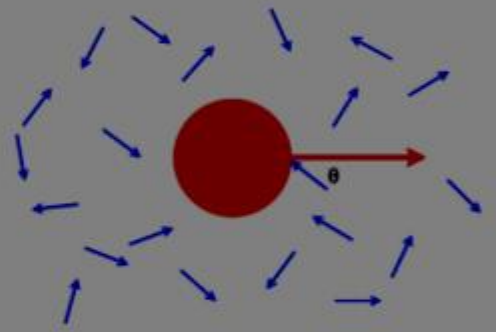


FIG. 2. Percentage variation in intensity of the cosmic rays with sidereal time. Curve, predicted effect due to galactic rotation. Data, Hess and Steinmaurer; open circles, half-hour means; solid circle, 3-hour means.

Its existence would imply that an important part of the cosmic rays originates outside of our galaxy. If its magnitude is found to be as great as we have predicted, it will imply that practically all the cosmic radiation has an extragalactic origin.

Compton-Getting Effect



$$\frac{\Delta I}{I} = (\gamma + 2)\frac{v}{c}\cos\theta$$

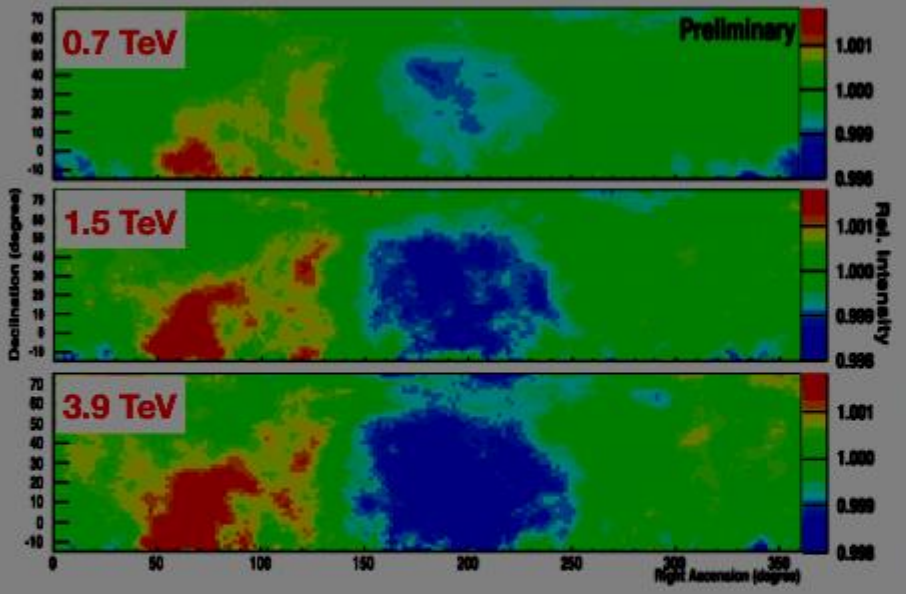
convective effect to produce a **dipole** anisotropy (**sidereal diurnal** anisotropy)

Compton & Getting, Phys. Rev. 47, 817 (1935)
Gleeson, & Axford, Ap&SS, 2, 43 (1968)

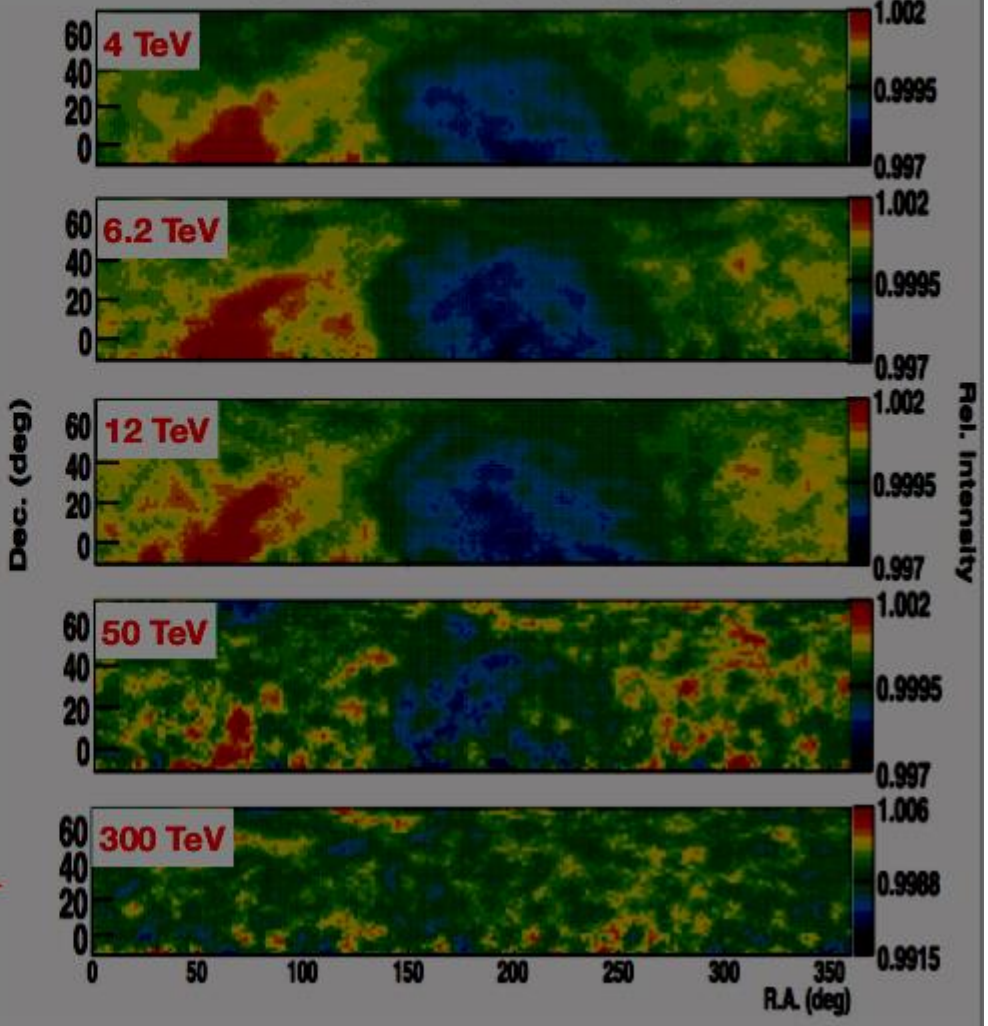
large scale anisotropy
energy dependence

anisotropy amplitude increases with energy up to **10 TeV** scale

ARGO-YBJ Zhang et al., ICRC 2009

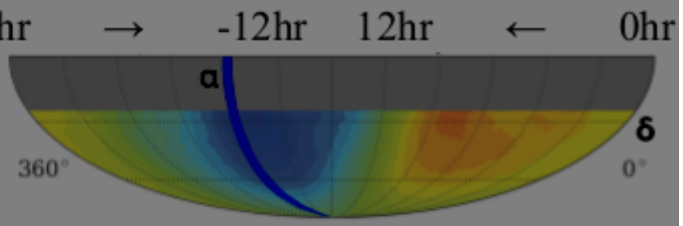


Tibet ASγ Amenomori et al., 2006



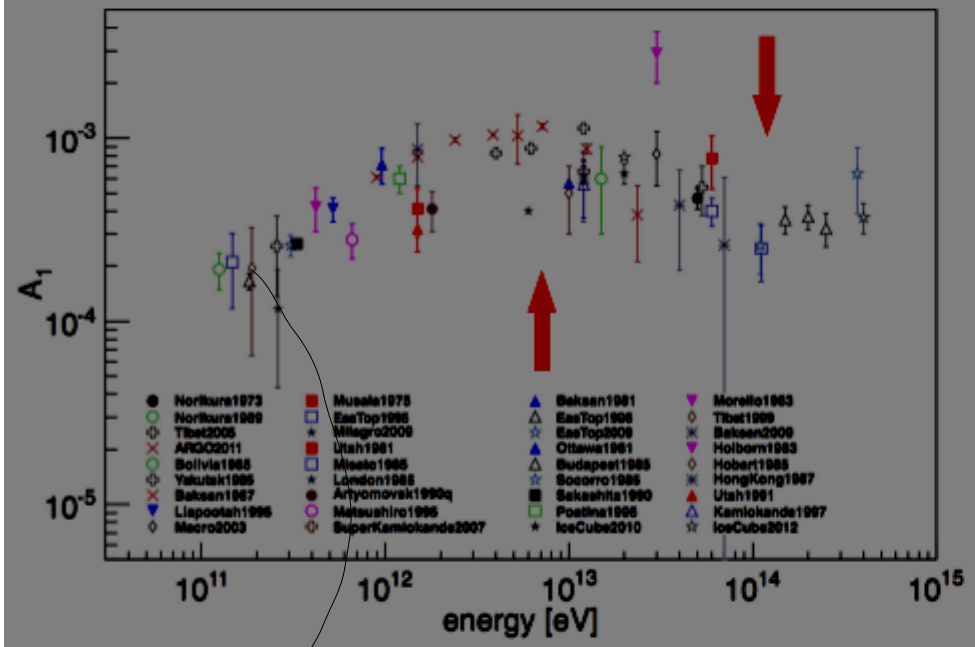
galactic co-rotation?

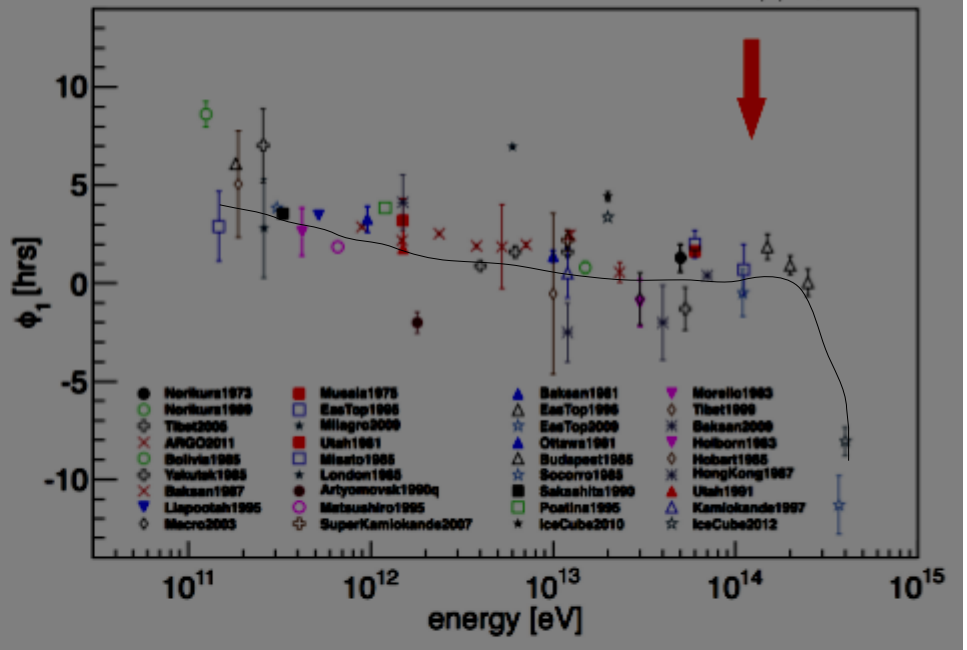
large scale anisotropy
energy dependence



amplitude & phase of first harmonic component (dipole)

Di Sciascio & Iuppa, 2014

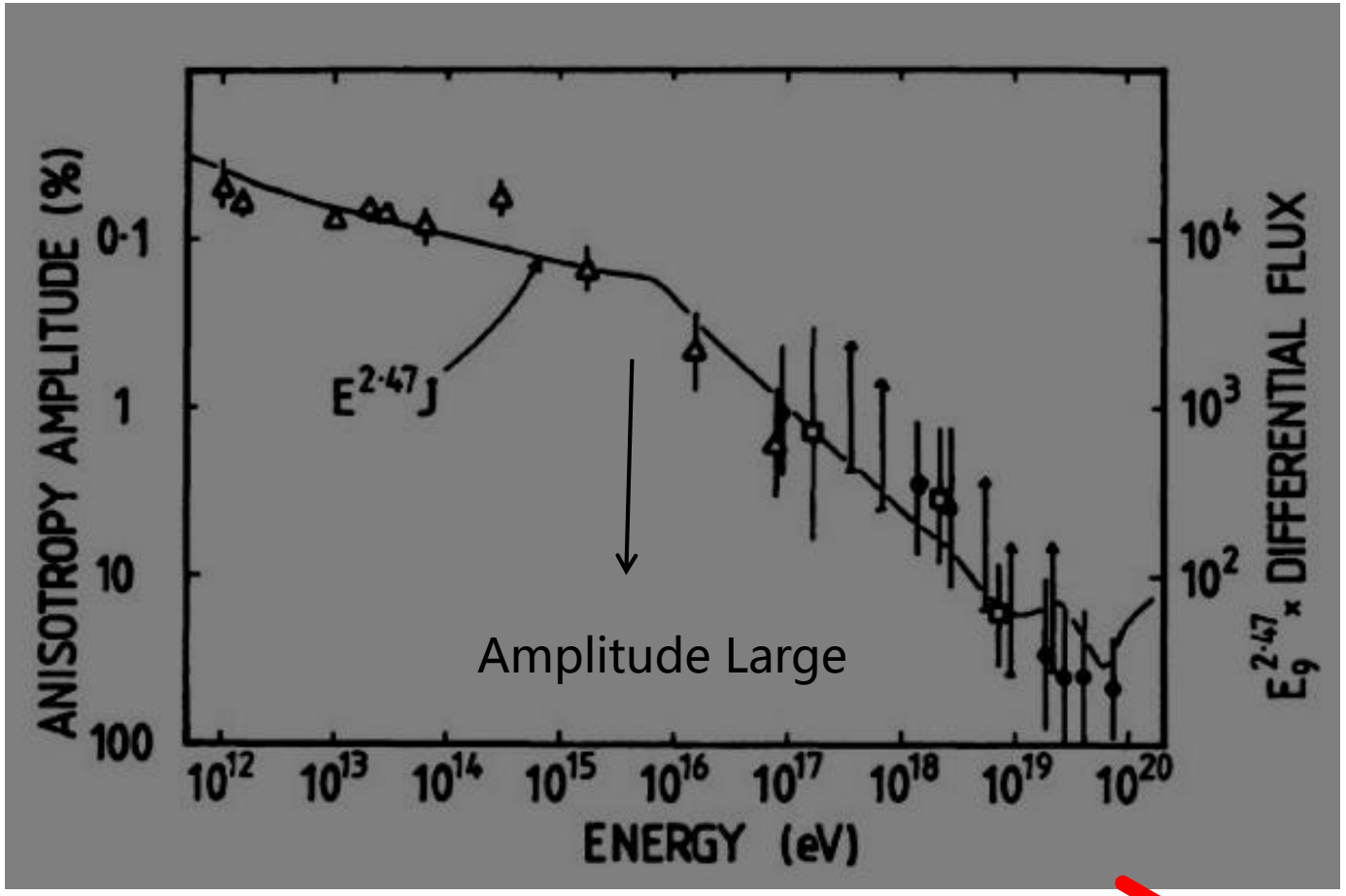




dipole amplitude increases up to order **10 TeV** and then it **decreases**

phase of **dipole** steadily migrates & suddenly **changes** or **flips**

Anisotropy Amplitude at Higher Energies



More Experimental Test Needed !

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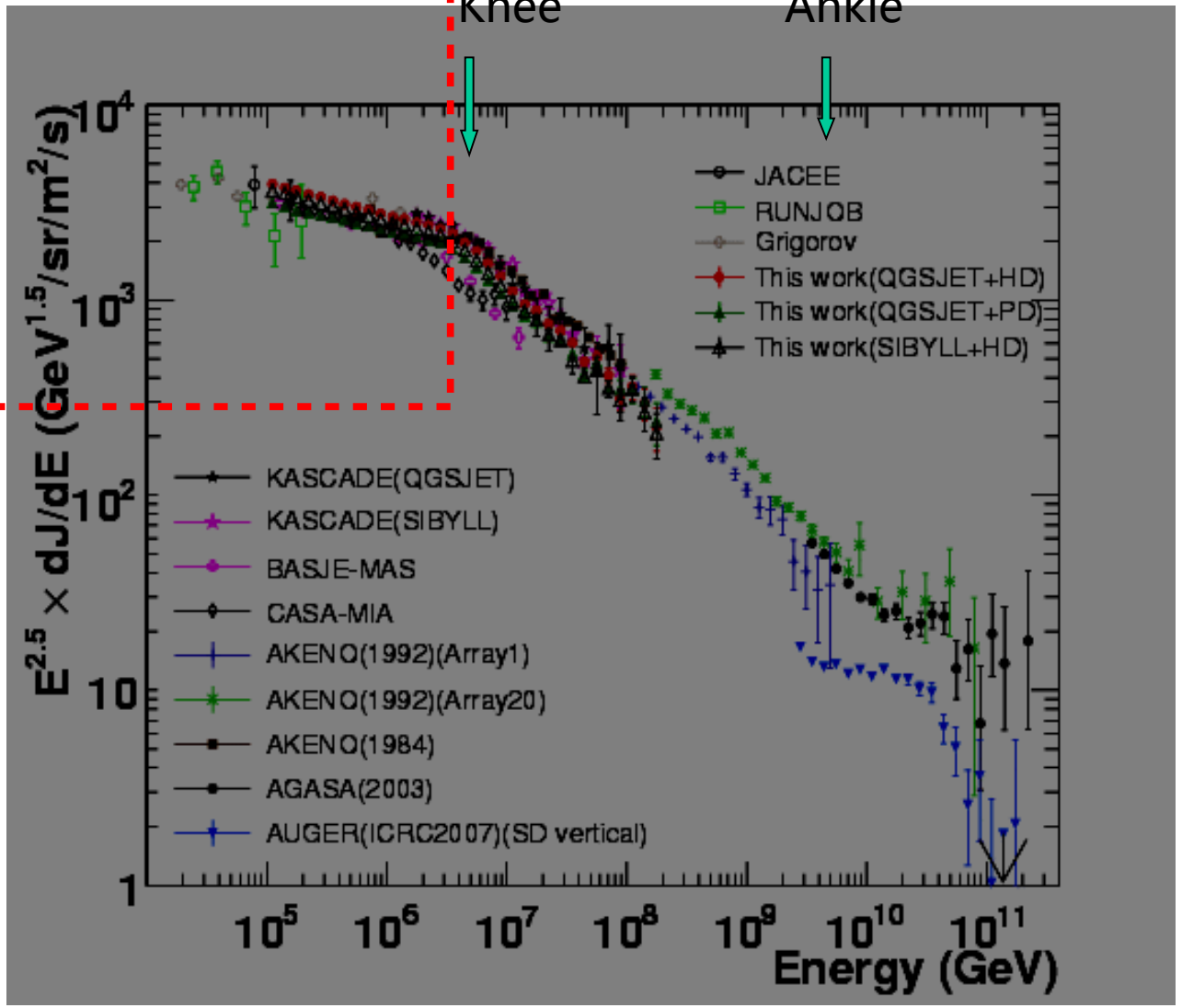
Cosmic Rays Responsible to Atmospheric Neutrino $\lesssim 100$ GeV

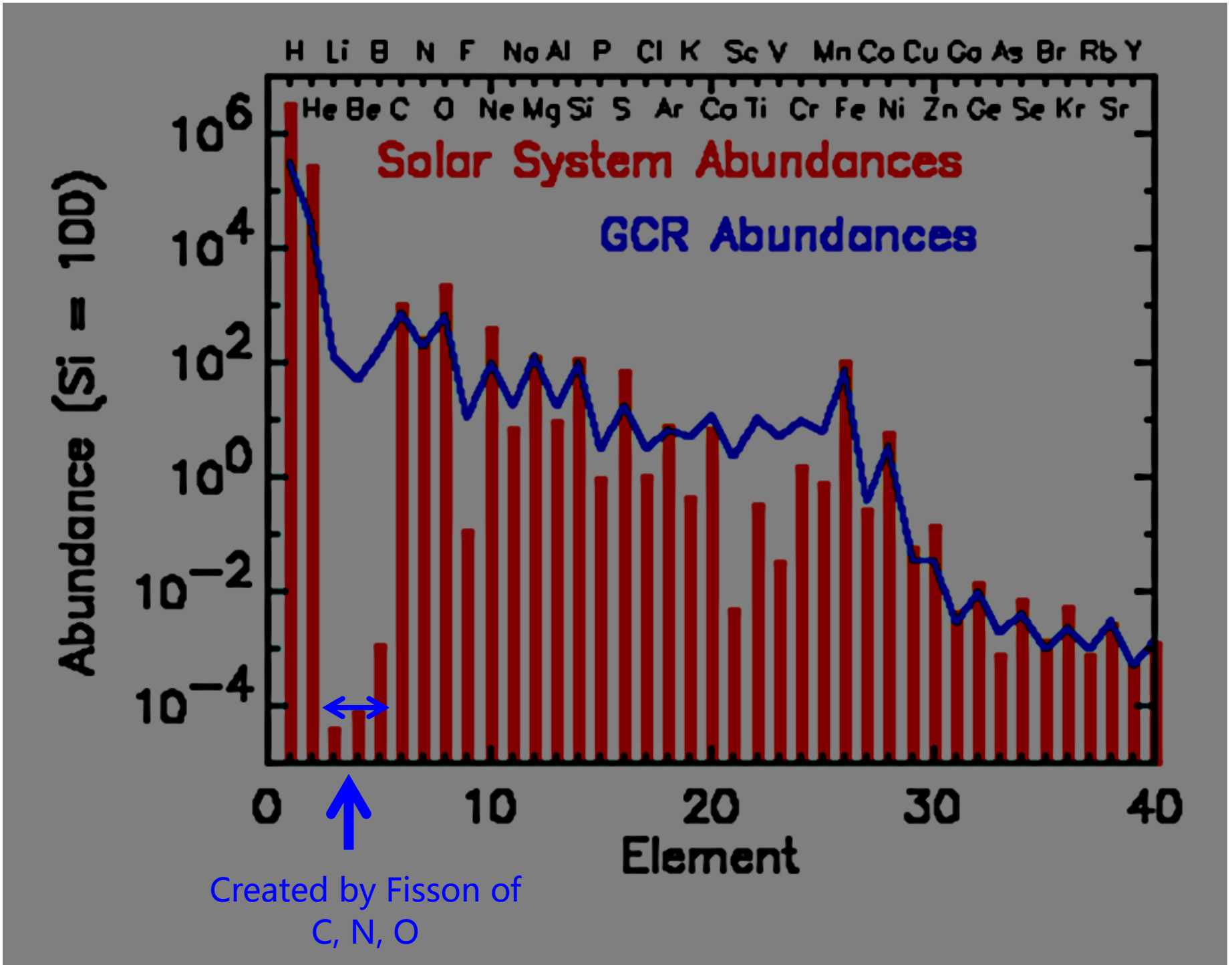
10^{15}-10^{16} eV
Knee

10^{18}-10^{19} eV
Ankle



Our target

Chemical Composition of Cosmic Rays



Solar Abundance ~ Cosmic Abundance

Nucleon Synthesis

Big Bang => P, He, Li (not all)

Inside of Star

Hydrogen Burning (D fusion PP chain, CNO sycle) => He

He Burning => Be, C, O, Ne, Mg, Si S, Ar, Ca, Ti, Cr, Fe, Ne

Li Burning => Be, (Breaking of Li in Brown Dwarf)

Carbon Burning => He, O, Ne, Na, Mg,

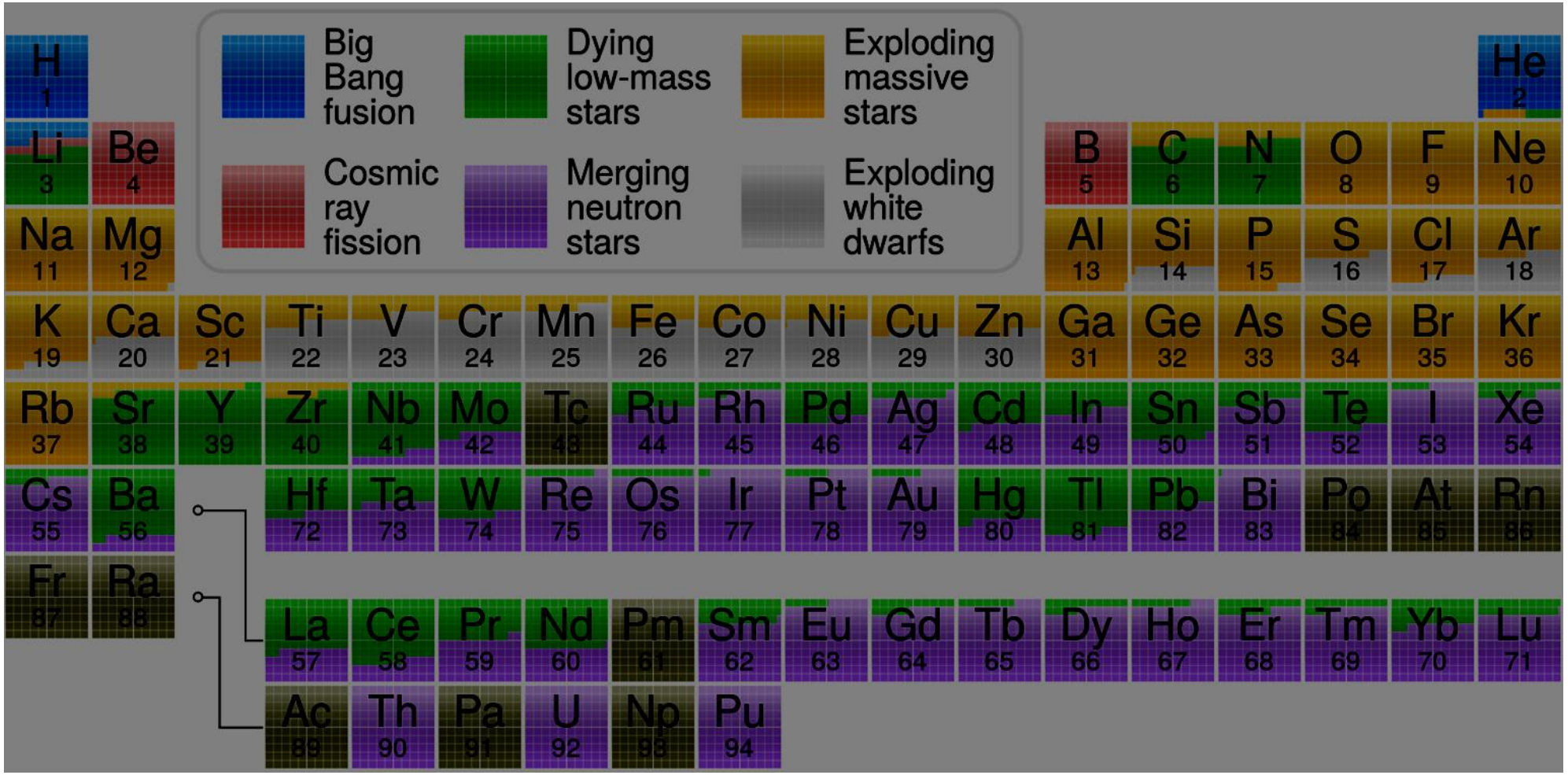
Oxygen Burning => Si, P, S, Mg

Silicon Burning => S, Ar, Ca, Ti, Cr,Fe, Ni, Zn

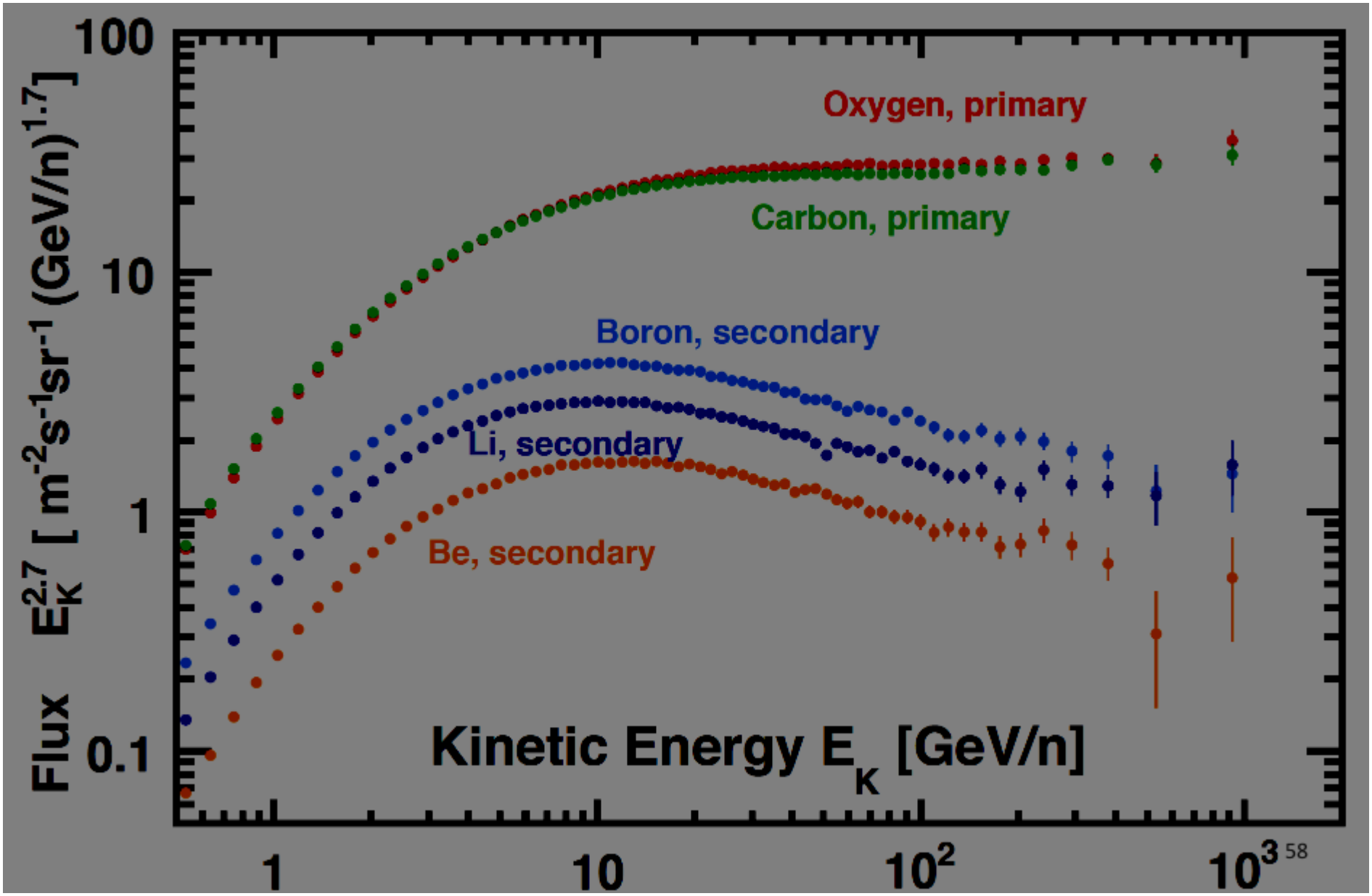
Super Nova or Brown Dwarf

R-process, S-process for heavier then Fe

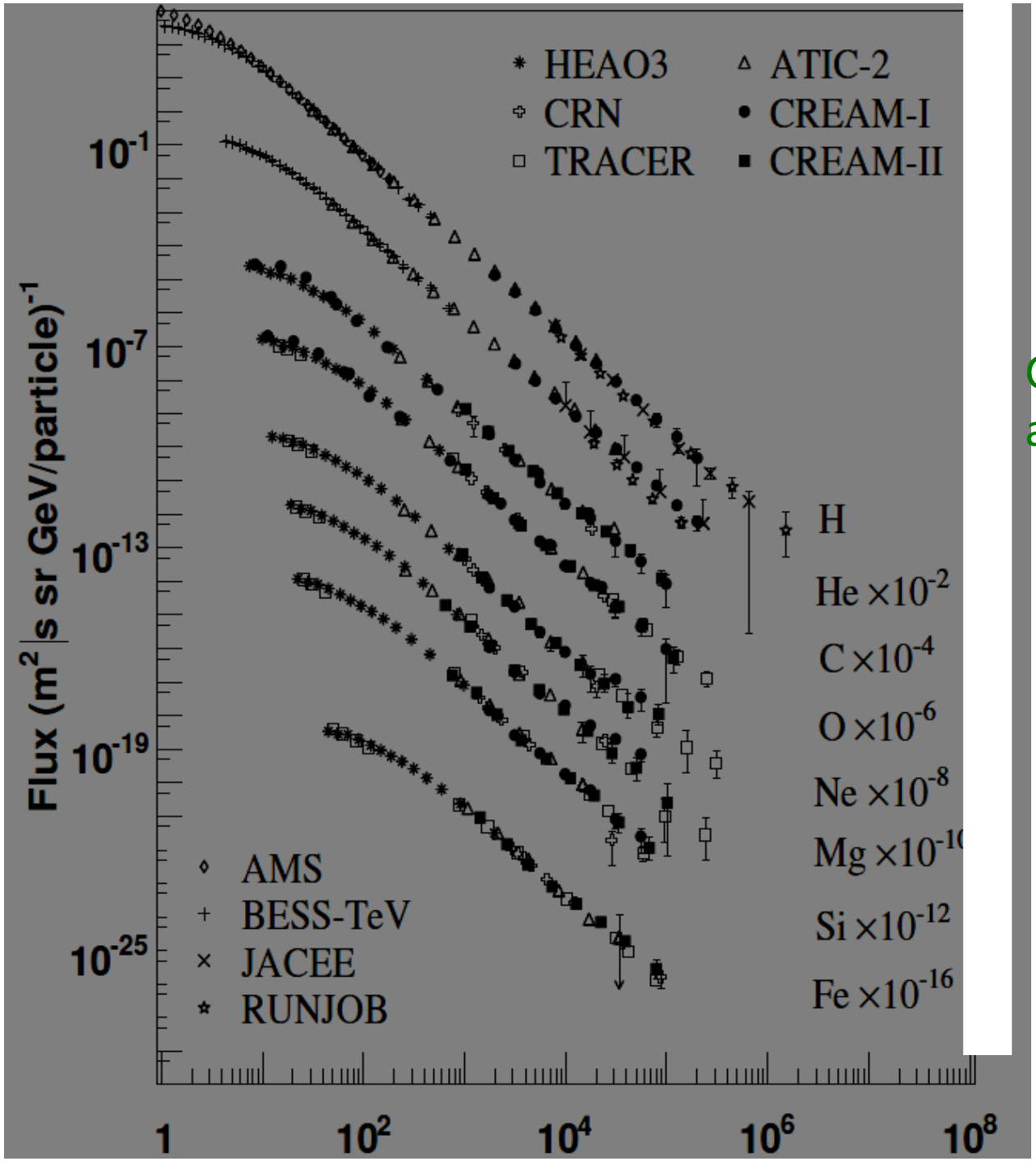
Nucleon Synthesis in Periodic Table



AMS02 observation of Li, Be, B



Energy Spectrum of Each Nucleon



From
E.S. Seo @ ICRC2009

Other chemical compositions
are also considered in the cal

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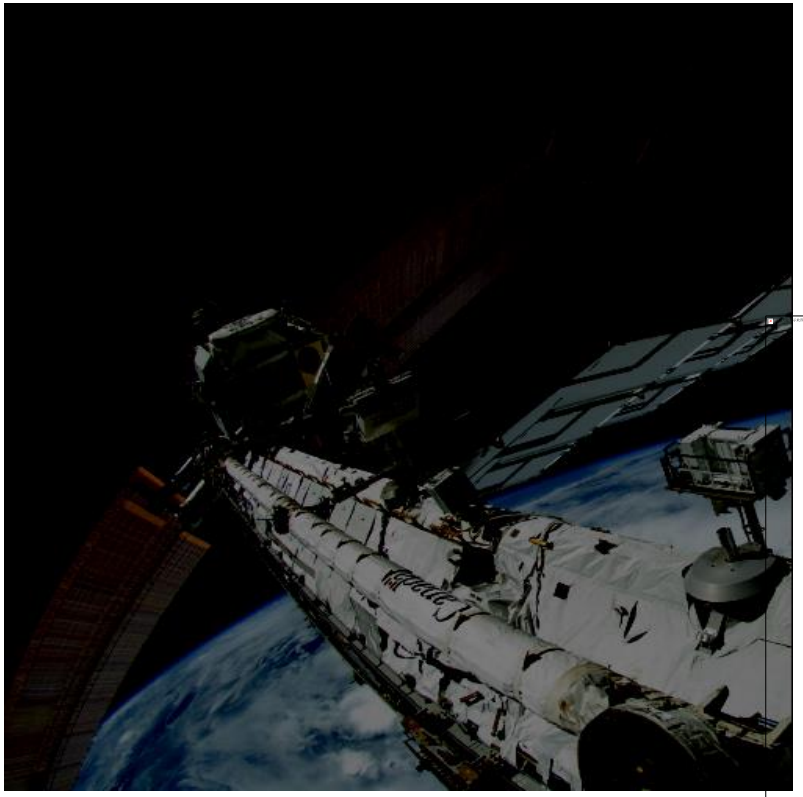
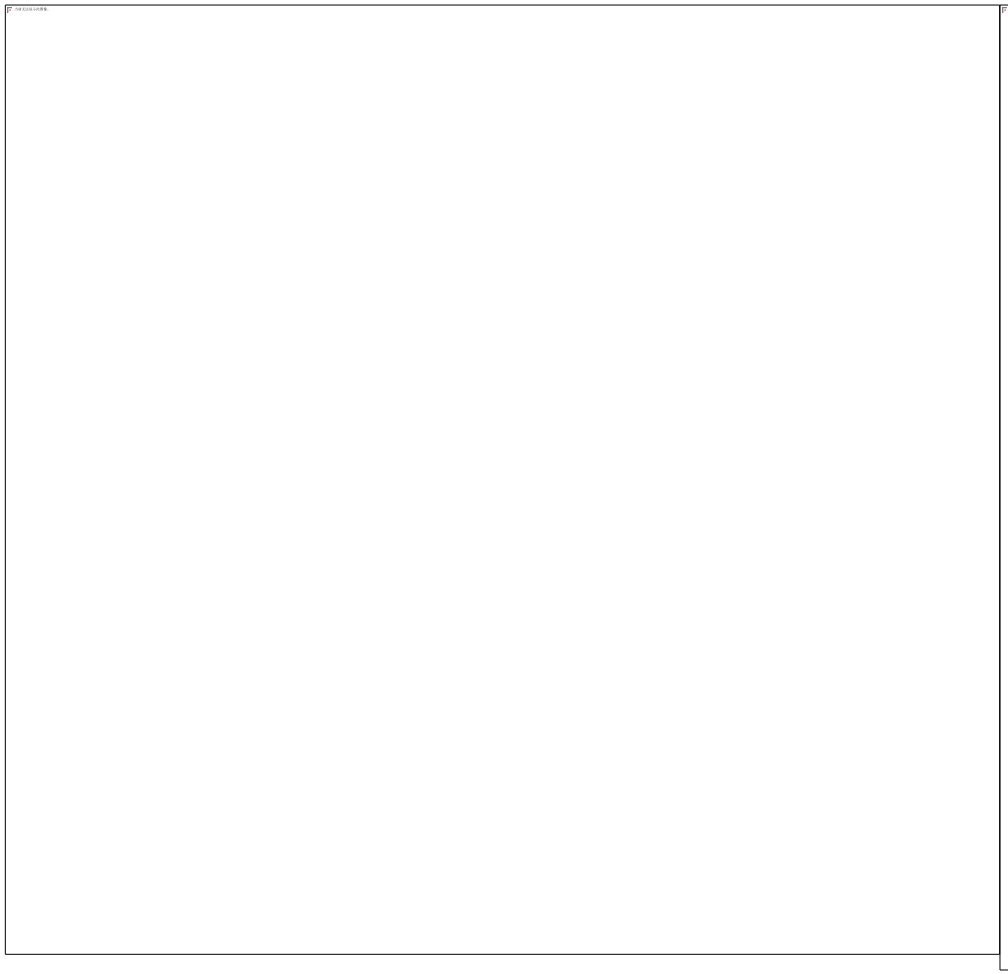
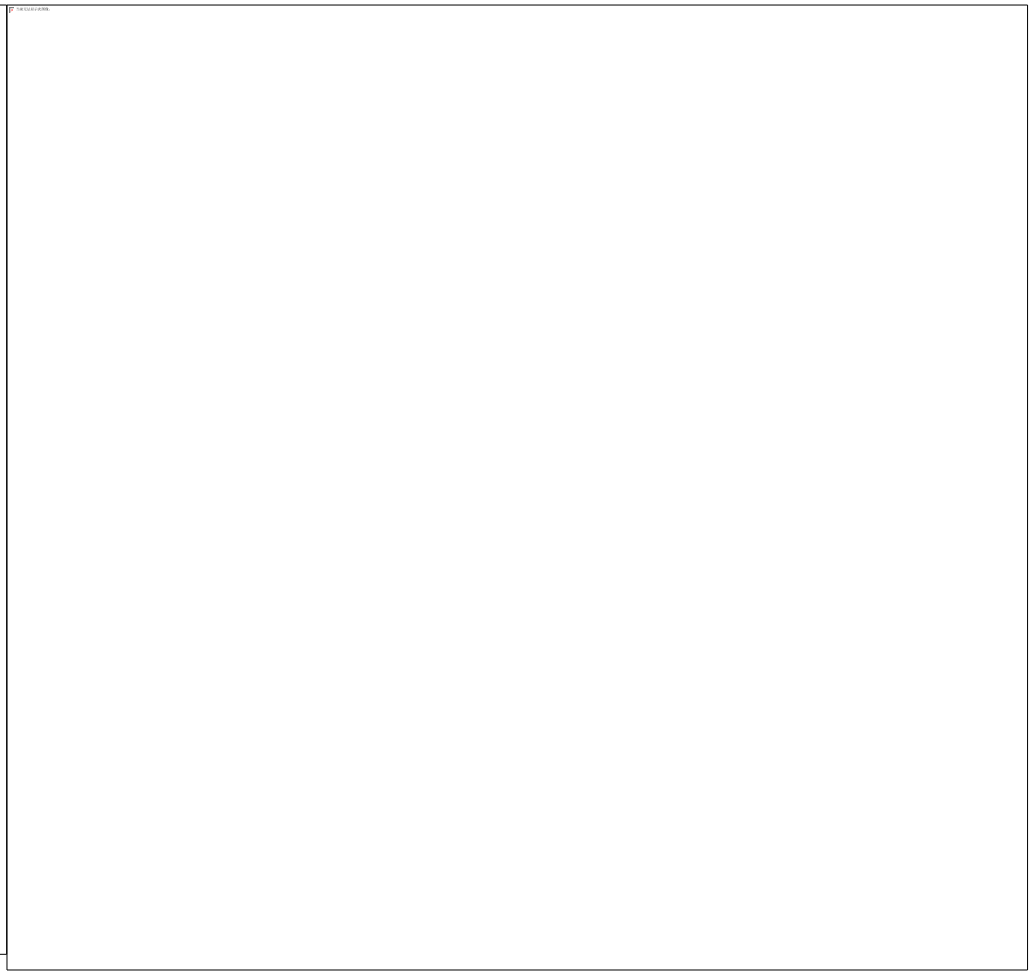
Some Results from Direct Observation



Cosmic Ray Spectra Model Based on AMS02 Observation





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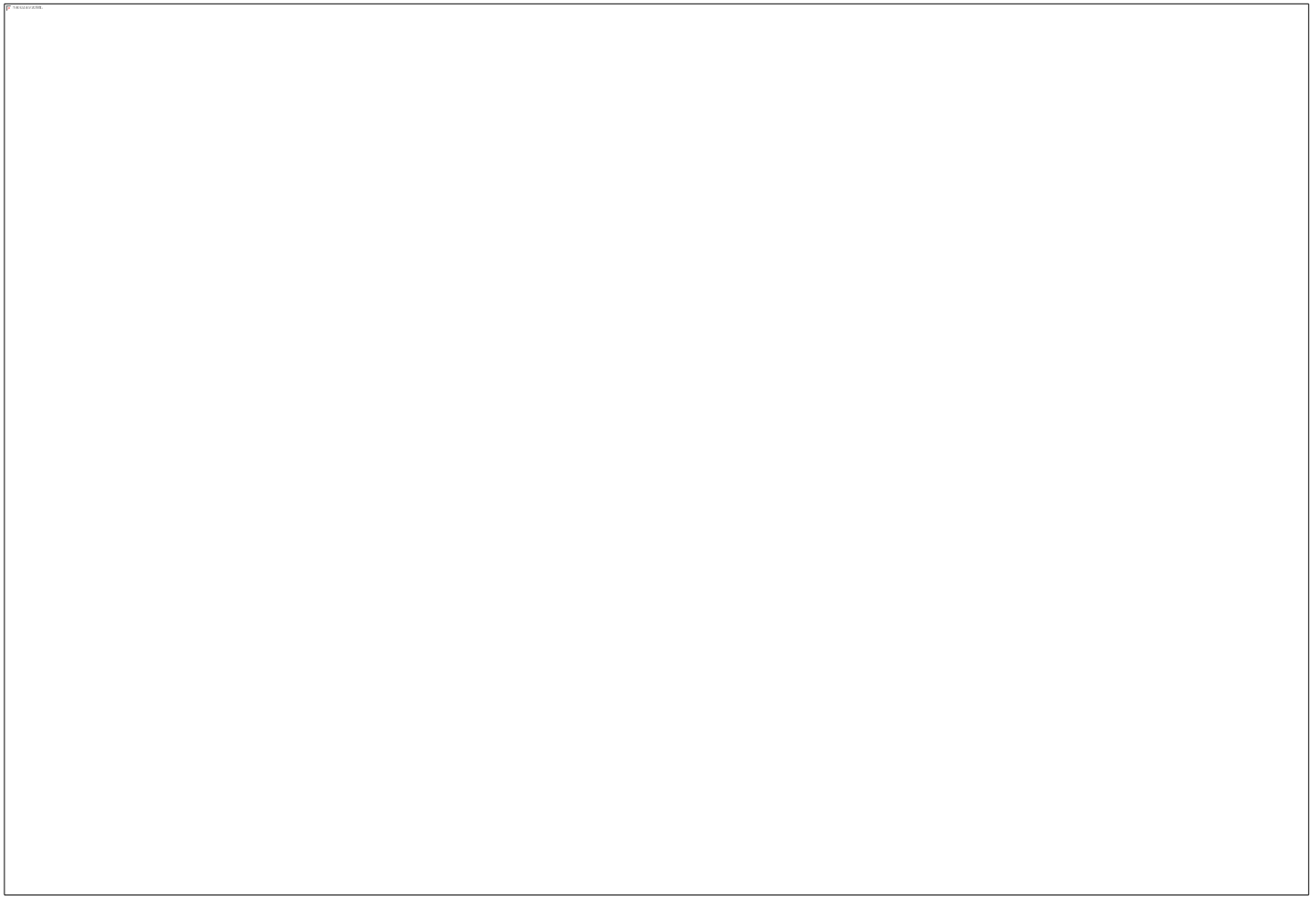
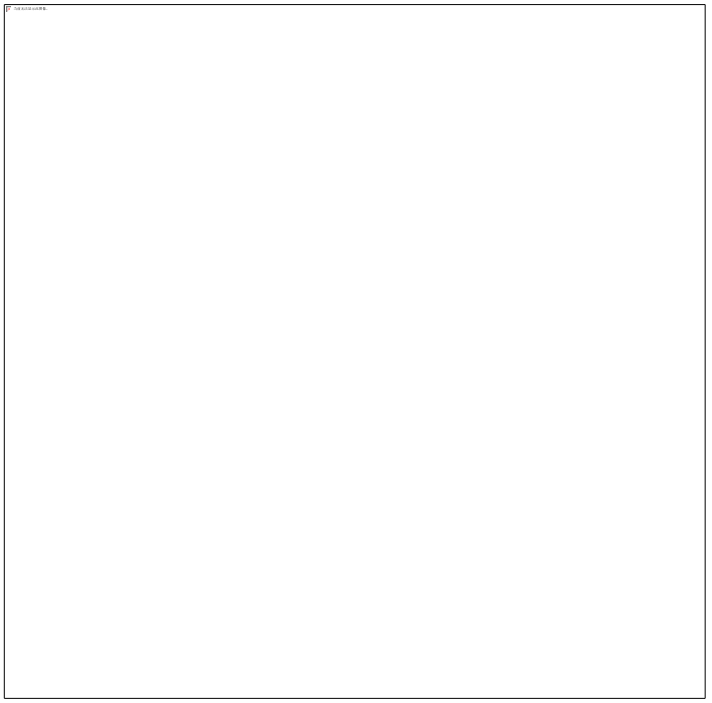
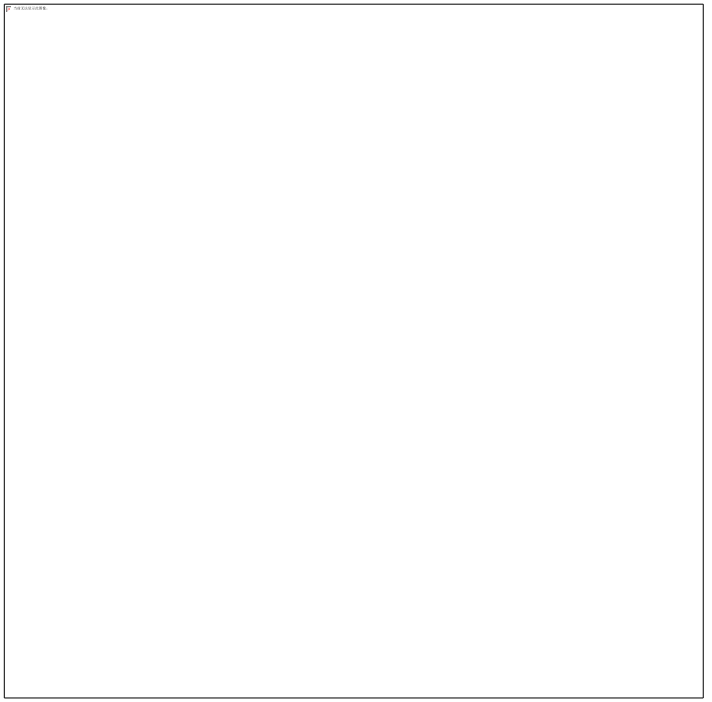
Solar Modulation and Neutron Monitor



Solar Modulated Flux at Fixed Energy

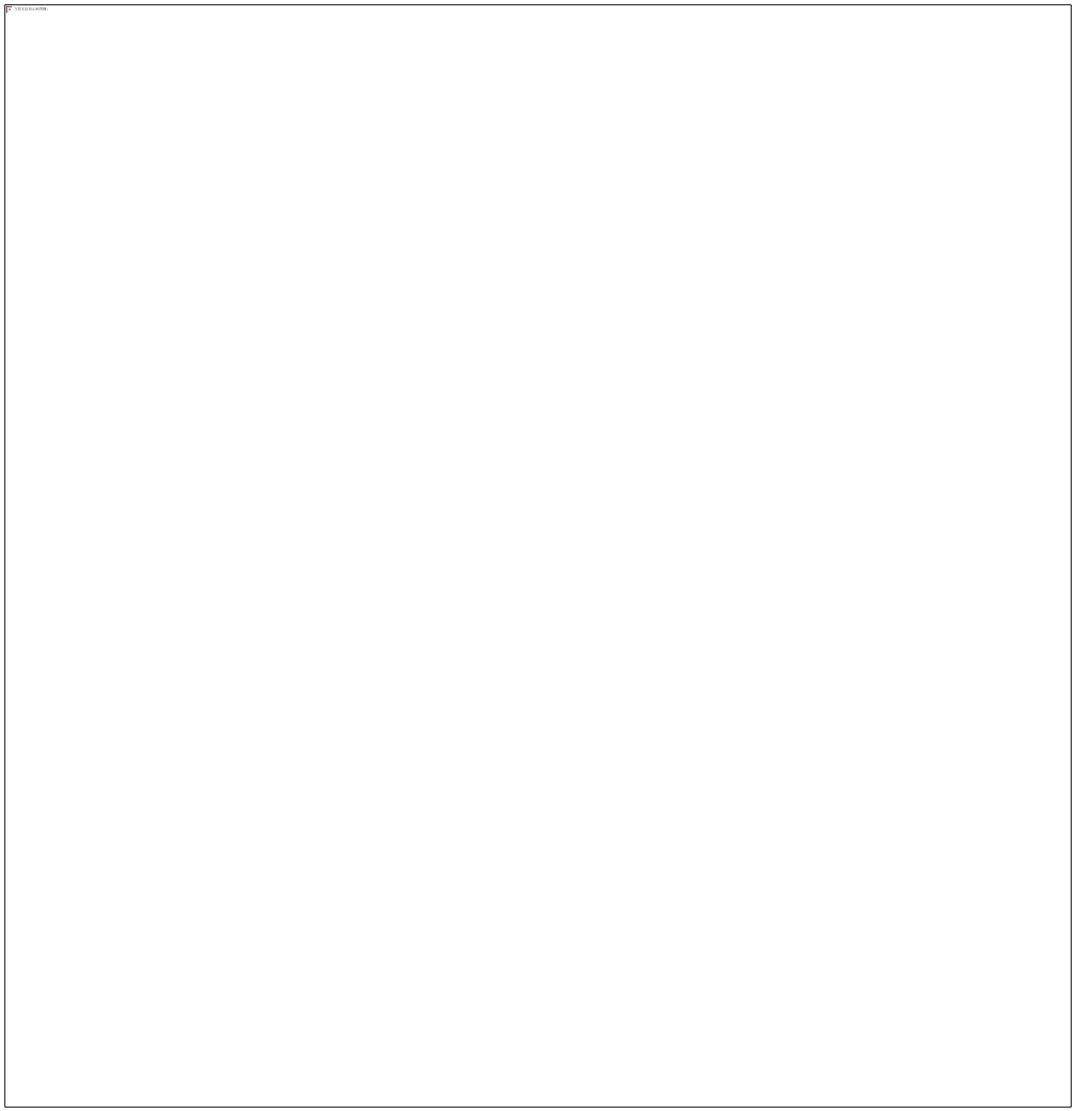


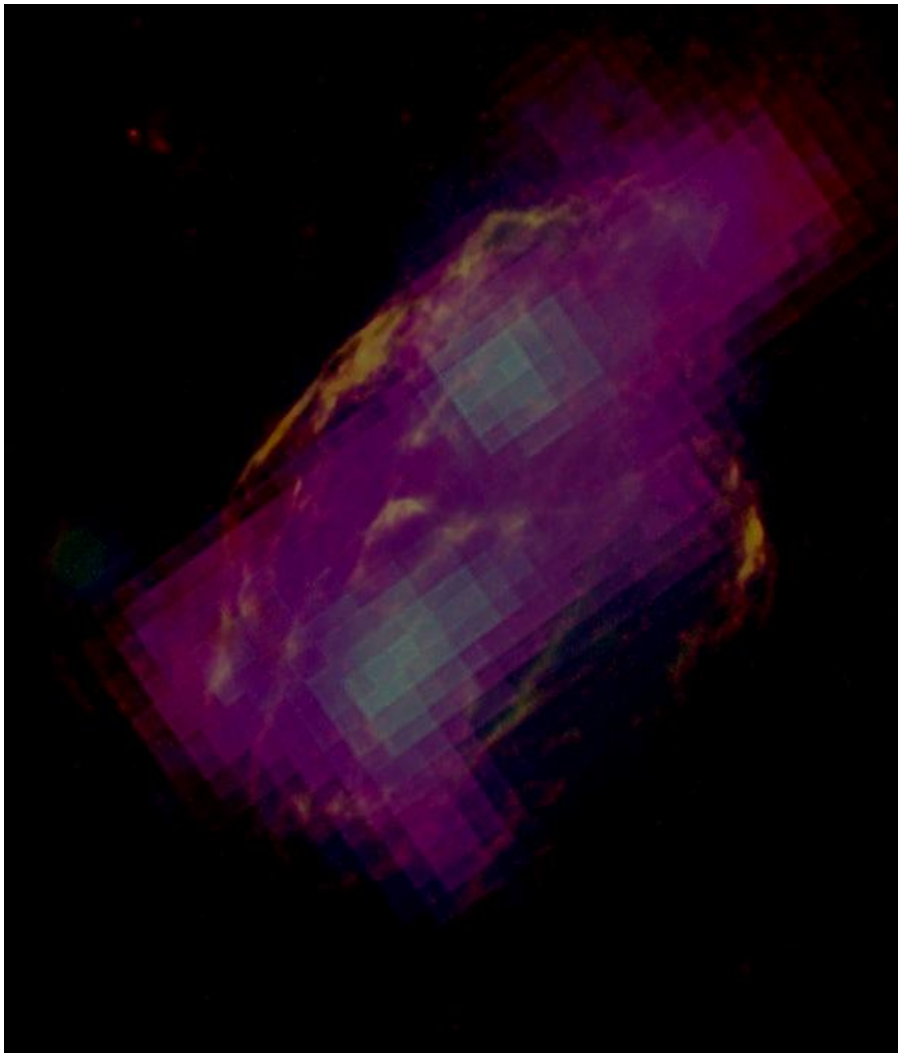


Practical Formula for Solar Modulation

$$\phi(E,N) = \begin{cases} \phi(E,3710)\exp(a\cdot(N-3710)) \\ \\ \phi(E,3710) \end{cases}$$

Where a is from right figure, and N is the Count of Newark Neutron Monitor.





The Energy spectrum of cosmic ray (All particle)