"PeV γ-ray in relevance to ν, CR and particle physics":

Can we peep into γ-ray PeV region through "cosmic cascade" ?

by T. Kifune, a talk in ICRR, Oct 3, 2014

Many related ? talks in this meeting

- "CTA Key Science Projects" 井上 進（東大宇宙線研 & MPI)

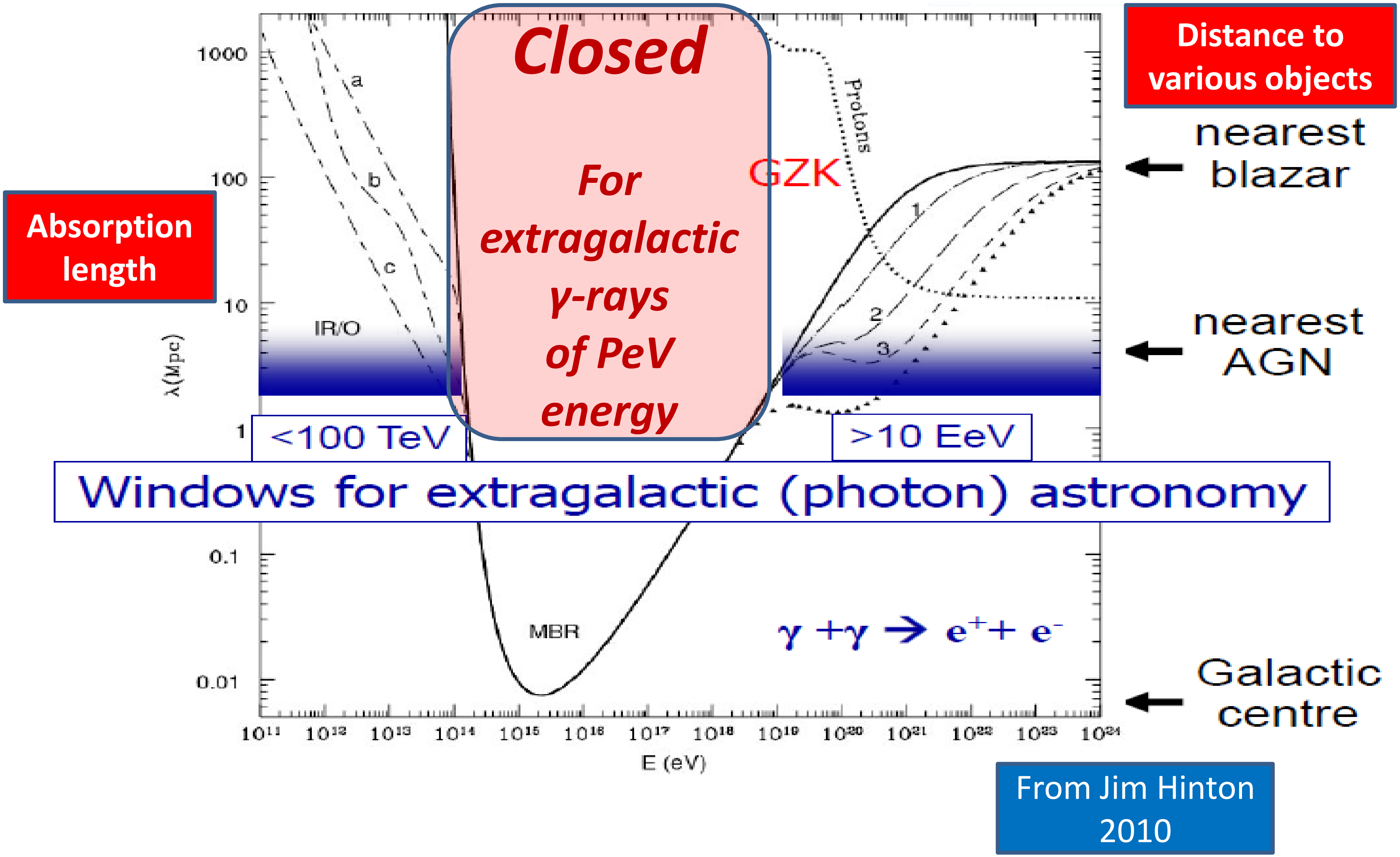
Necessary to observe PeV gamma rays ?

- 「活動銀河「ジェットを"持たない"銀河からの高エネルギーガンマ線放射」 林田 将明（東大宇宙線研）
- 風からのガンマ線と超高エネルギー宇宙線」 井上 進（東大宇宙線研 & MPI）

- 「最高エネルギー宇宙線による極限宇宙観測」 野中 敏幸（東大宇宙線研）
- "Current status and future prospects for ultrahigh-energy cosmic rays from a theoretical point of view" 高見 一（KEK）

- "Recent results from IceCube" 石原 安野（千葉大学）
- 「低光度活動銀河核からの高エネルギーニュートリノ放射」 木村 成生（大阪大学）

- 「宇宙近赤外線放射観測の現状」 津村耕司（東北大学）
- "Can gamma-ray observations probe the cosmic infrared background radiation?" 井上芳幸 (ISAS)



Closed
For extragalactic γ-rays of PeV energy
Distance to various objects
nearest blazar
nearest AGN
Galactic centre
Absorption length
GZK
Protons
IR/O
MBR
a
b
c
1
2
3
<100 TeV
>10 EeV
Windows for extragalactic (photon) astronomy
γ +γ → e⁺+ e⁻
λ(Mpc)
E (eV)
From Jim Hinton 2010

“PeV γ-ray in relevance to ν, CR and particle physics”:

Can we peep into γ-ray PeV region through “cosmic cascade” ?

by T. Kifune, a talk in ICRR, Oct 3, 2014

1. PeV ガンマ線の検出
   Try to “observe”
   PeV γ rays
   from TeV region

PeV γ-ray astronomy ?

Gamma rays from pion decay ハドロン起源ガンマ線?

2. 展望
   Prospect for
   UHE CR and universe

Implication of IceCube event ?

Origin of cosmic rays 宇宙線の起源 ？

3. 究極の物理
   basic concept

the viewpoint of Planck scale, “LIV” ?

Elementary particle and Universe「素粒子的宇宙像」？

Outline of the talk

extended halo around AGN ?

intrinsic 1ry γ-ray emitted from AGN

$\gamma + \varepsilon \rightarrow e^{+}e^{-}$, $e + \varepsilon \rightarrow e + \gamma$

Can we look into PeV γ-ray region from TeV ?

i PeV Gamma rays

Cosmic cascade ?

TeV Gamma rays

$\Theta_{int} \approx (m_e/E) \cdot N^{0.5}$

$\Theta_{mag} \approx (R_{Larmor}/\lambda) \cdot N^{0.5}$

$N \approx \lambda/\text{distance}$

λ : absorption length

$p + \varepsilon \rightarrow p(n) + \pi$, $\pi \rightarrow \gamma, \nu$

modification of γ-ray spectrum

Emission of PeV γ-rays

2ry γ-ray emitted in extragalactic space by extragalactic CRs

ii ***Ice Cube ν event***

PeV peaked neutrino ?

constraint, restriction, information

iii ***PeV energy region, and LIV, QG***

Contents

Free, Association Thoughts (空想、迷想、連想.....の放談)

関連論文

i — *Cosmic cascade ?*

"Search for extended emission around AGN ...." – HESS AA 562, A145(2014), arXiv 1401.2915

"Pair halo", "Magnetically Broadened Cascade"

$\gamma + \varepsilon \rightarrow e^+ e^-$,
$e + \varepsilon \rightarrow e + \gamma$

"Role of line of sight CR Int. of distant blazars .... to TeV γ and HE ν" Essey et al. ApJ 731, 51 (2011) arXiv 1303.0300 (2013)

Cascade process of "CR interaction In extragalactic space"

$p + \varepsilon \rightarrow p(n) + \pi$
$\pi \rightarrow \gamma, \nu$

"Cosmic neutrino pevatrons: A brand new pathway to astronomy, astrophysics, and particle physics" Journal of High Energy Astrophysics 1–2 (2014) 1–30

ii — *PeV ν*

"First observation of PeV-energy neutrinos with IceCube" **arXiv 1304.5356** (2014)

iii — *LIV, QG*

"The CTA Sensitivity to Lorentz-Violating Effects on the Gamma-Ray Horizon" arXiv:1401.8178v2 by M.Fairbairn, A.Nilsson, J.Ellis, J.Hinton, R.Whited

"A Relational Argument for a ~ PeV Neutrino Energy Cutoff" J.G. Learned and T.J. Weiler; arXiv 1407.0739

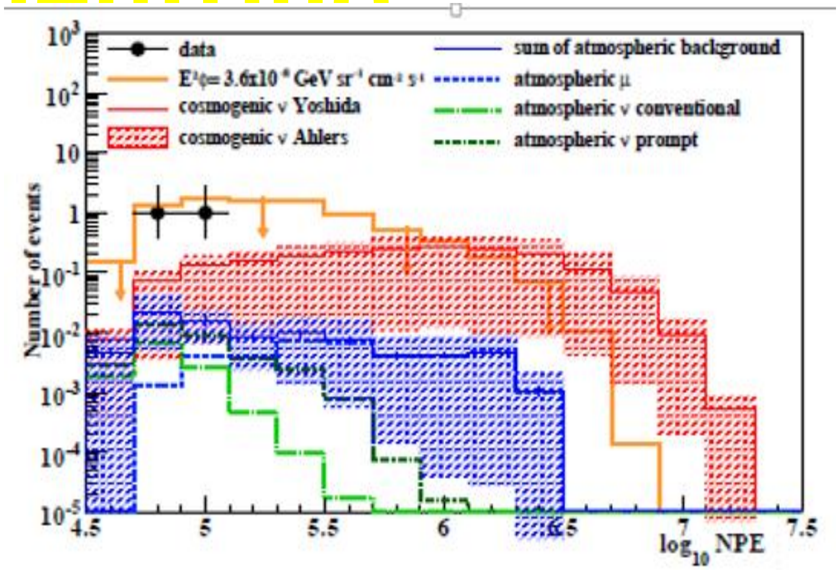
"Detection method and observation data of high energy gamma rays under the influence of QG" T. Kifune, ApJ 787, 4 (2014)

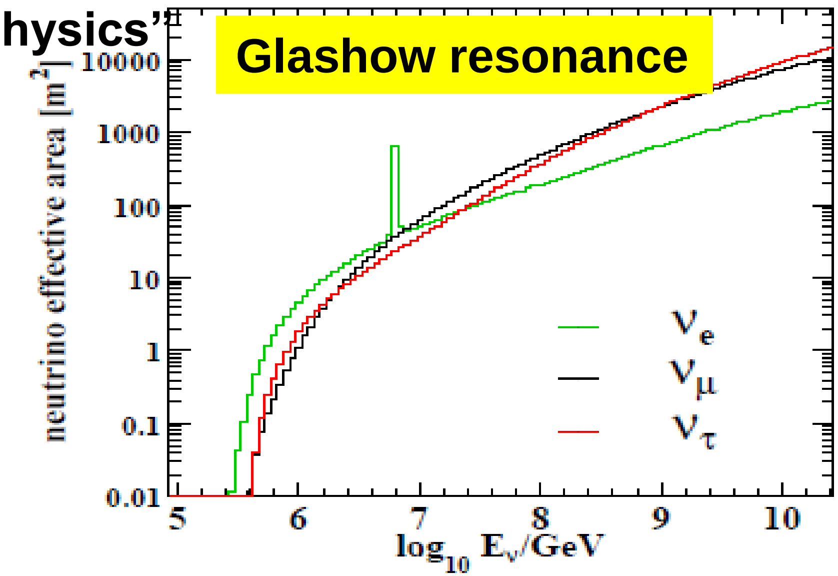
"Tests of Lorentz Invariance Violation with Gamma Rays to probe Quantum Gravity" ,..... G.Sinnis,.....arXiv:1305.0264

Ice Cube neutrino

PeV peaked neutrino ?

First of all, if the neutrino flux is indeed a Fermi-shock flux falling as an unbroken E^{-2} ν power-law **spectrum(Fermi,1949) would lead to about 8–9 events above 1PeV**, which thus far are not observed:
From “Review Cosmic neutrino pevatrons: A brand new pathway to astronomy, astrophysics, and particle physics”





- 616 days = 5.3×10^7 sec Area = 10 m^2 = 10^5 cm^2, ST = 5×10^{12} $cm^2 s$
- flux is about 2×10^{-13} $cm^{-2}s^{-1}$ = 10^2 eV $cm^{-2}s^{-1}$ at 10^{15}eV

There may be a high-energy cutoff of neutrino events in IceCube data. In particular**, IceCube does not observe the Standard Model Glashow-resonance events expected at 6.3 PeV**.

Best fit flux $E^2\phi=(0.95\pm0.3)\times10^{-8}$ [GeV cm^{-2} s^{-1} sr^{-1}] with a hard cut off around 2.0 PeV or a softer spectra with a spectral index $\gamma=2.3\pm0.3$: from Ishihara’s talk

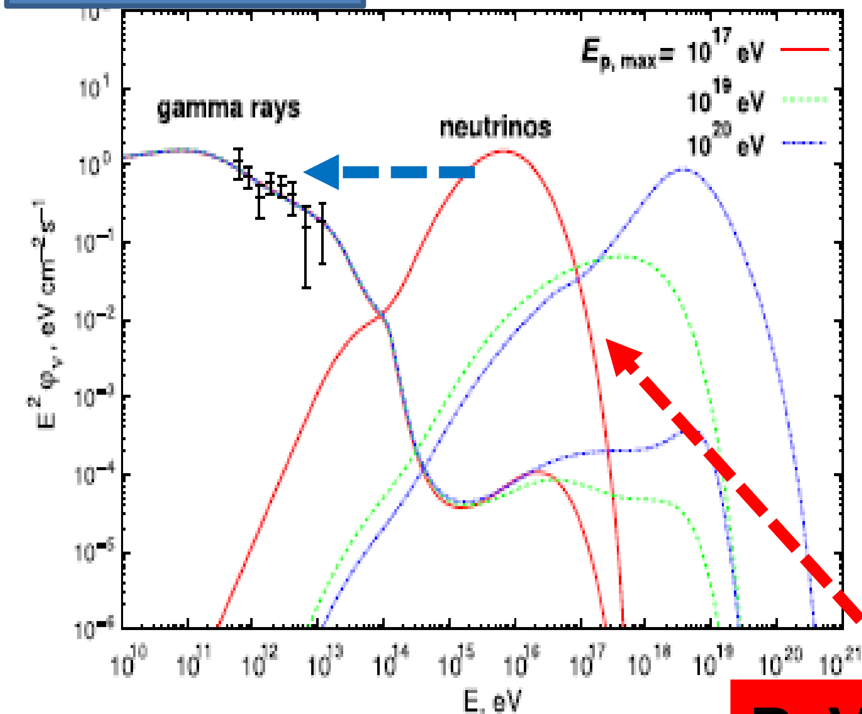
ICE Cube Neutrino ?

"Point source" emission from blazar

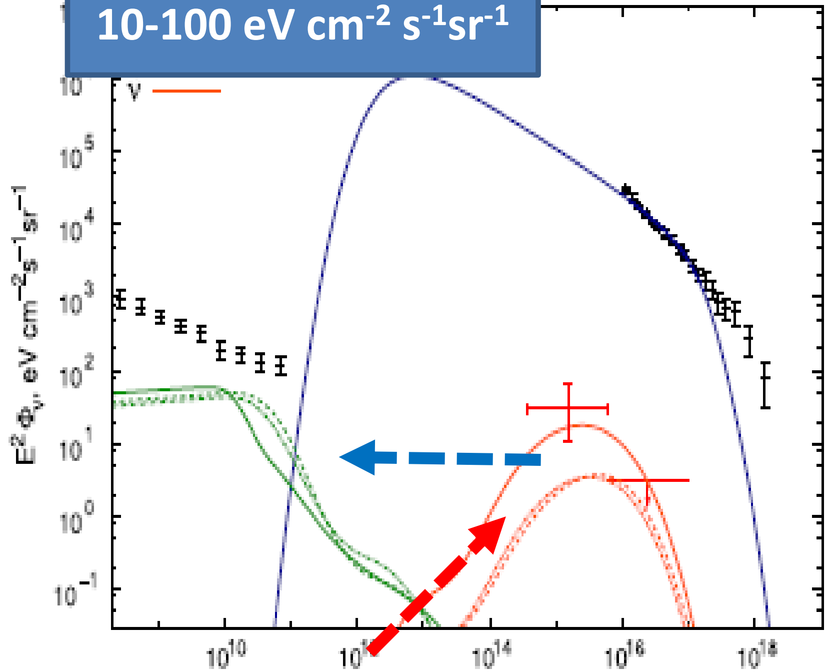
extragalactic diffuse γ-ray

L.A. Anchordoqui et al. / Journal of High Energy Astrophysics 1–2 (2014) 1–30 19

1-10 eV cm^{-2} s^{-1}



10-100 eV cm^{-2} $s^{-1}sr^{-1}$



PeV peaked neutrino

A peaked neutrino spectrum accompanies secondary gamma rays produced in line-of-sight interactions of cosmic rays emitted by Blazars (Essey and Kusenko,2010; Esseyetal.,2010,2011b). The lowest position of the peak is at1PeV. Assuming that **a distribution of AGN with respect to maximal proton energy *Ep*,max is a decreasing function of *Ep*,max, a decreasing function of *Ep*,max**

...uced in line-of-sight interactions of cosmic rays emitted by blazars (Essey and Kusenko, ...uming that a distribution of AGN with respect to maximal proton energy $E_{p,max}$ is a

The proton injection spectrum has a spectral index α=2.6 and maximum energy *Ep*,max = 3 × 10^{17}eV.
Also shown are the predicted gammaray (lower curves Below 10TeV) and cosmic ray (upper curve) fluxes.

et al., 2012); the diffuse gamma ray background data points below 1 TeV are due to Fermi (Abdo et al., 2010b). See text and Kalashev et al. (2013) for details.

There may be a high-energy cutoff of neutrino events in IceCube data. In particular, IceCube does not observe the Standard Model Glashow-resonance events expected at 6.3 PeV.
From “End of the cosmic neutrino energy spectrum”
arXiv:1404.0622v2 Anchordoqui et al. (**... Learned, ... Pakvasa,)**

PeV peaked neutrino ?

“A Relational Argument for **a ~ PeV Neutrino Energy Cutoff**”
J.G. Learned and T.J. Weiler; arXiv 1407.0739

ニュートリノがとり得るエネルギーに最大値が存在する！？

$$E^{\nu}_{\max} = \frac{m_\nu M_{\rm Planck}}{M_{\rm weak}} \quad (1)$$
$$= 1.2 \left(\frac{m_\nu}{0.1\,{\rm eV}}\right) \left(\frac{M_{\rm Planck}}{1.2\times10^{28}\,{\rm eV}}\right) \left(\frac{100\,{\rm GeV}}{M_{\rm weak}}\right) {\rm PeV}\,.$$

This new phenomenon at the Planck scale may take several forms.
Some possibilities are
(i) ***Gravity becomes strong*** for the neutrinos ***at the Planck scale***, either preventing the formation of the neutrino wave packet or presenting a strong cross section for neutrino scattering o gravity/geometry, with significant loss of neutrino energy.
(ii) ***Space-time manifests itself as foam at the Planck scale***, either preventing the formation of the neutrino wave packet or presenting a strong neutrino-foam scattering cross-section with significant loss of neutrino energy. These continued foam interactions are reminiscent of the quantum Zeno effect.
(iii) ***Lorentz Invariance is violated (LIV) at the Planck scale***. A simple manifestation of LIV, broken rotational symmetry, results if space dimensions are latticized at the Planck scale, as often discussed over the past decades; in the the scale present context, the manifestation of LIV is the apparent maximum neutrino energy.
(iv) ***The neutrino may even transit from our brane into extra space dimension(s) having size natural to gravity, the Planck length***.

"PeV gamma ray ……
Quantum Gravity, LIV ? "

From Kifune ApJ 787, 4 (2014)

$E^2 = p^2 + m^2 + p^{n+2}/M^n$, M ≈ Planck mass

10TeV-PeV gamma ray の：

"Planck scale での LIV"を仮定すると、実は

1. **放出機構**： 通常の conventional な理解は、 ^ ***正しくないのではないか***？

   Emission mechanism Inverse Compton

2. **吸収・伝播**の効果： 地球に、 ***到達できるのではないか***？

   Propagation/absorption effect

3. **検出方法**： ***通常の方法では、正しく効率よく検出できないのではないか***？

   Detection mechanism/efficiency

「観測データ」、その「常識的解釈」は信用できるか？

- ***Obsrvation data tell us the truth ?***
- ***Are we seeing the true image of the Universe?***
- ***Can we get "smoking gun" evidence ?***

Critical energy E_*, ε_*

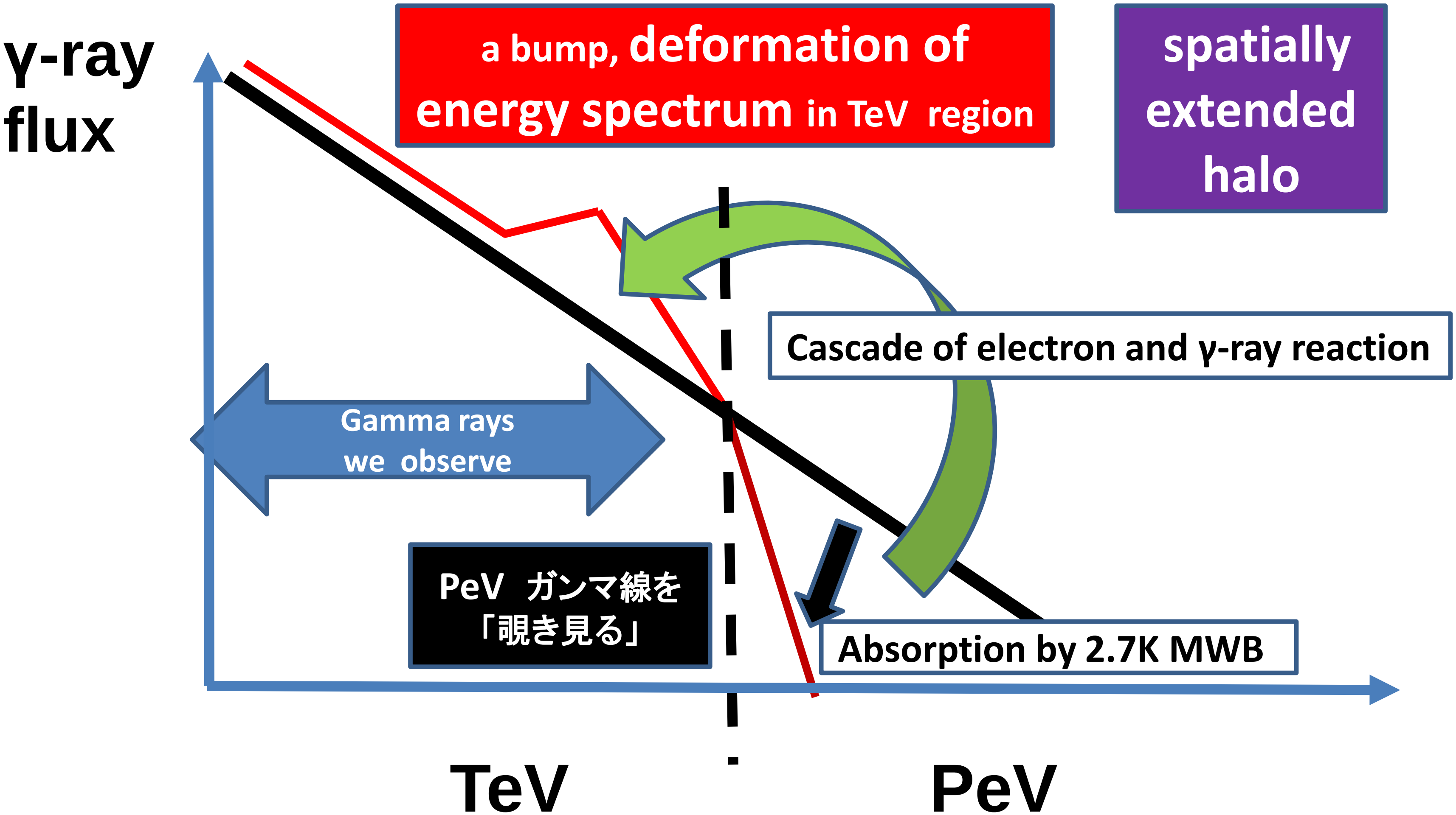
n=1

$E_* = (M m_e^2)^{1/3} \approx 10^{13}$ eV,
$\varepsilon_* = (m_e^4/M)^{1/3} \approx 10^{-2}$ eV

n=2

$E_* = (M m_e)^{1/2} \approx 10^{17}$ eV,
$\varepsilon_* = (m_e^3/M)^{1/2} \approx 10^{-4}$ eV

Propagation of γ-rays : absorbed by CMB, EBL causing "cosmic cascade"



Flux of PeV γ-ray
as large as the PeV ν of the IceCube events

if LIV effect of n=1 is true,
1ry (HESS): partly diminished,
2ry (Essey etal.) → 0

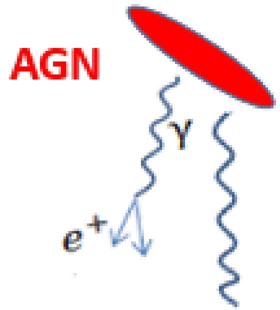
Case 1

1ry

AGN of HESS analysis for "Halo"

1ES 1101-232, 1ES0229+200, PKS 2155-304 obs time 63-165 hrs, flux, Γ= 3.1, 2.6 and 3.4

These AGN are in the preferable redshift range and have emission extending into the multi-TeV energy, thus making them ideal candidates of this study.



Extreme blazar

Case 2

2ry

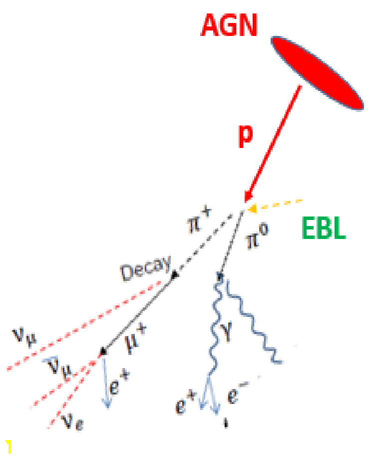
AGN of Essey et al. (Kalashev et al.) for "CR cascade" from PeV neutrino event

1ES 1101-232, 1ES0229+200, 1ES 0347-121; EBL model, L_p

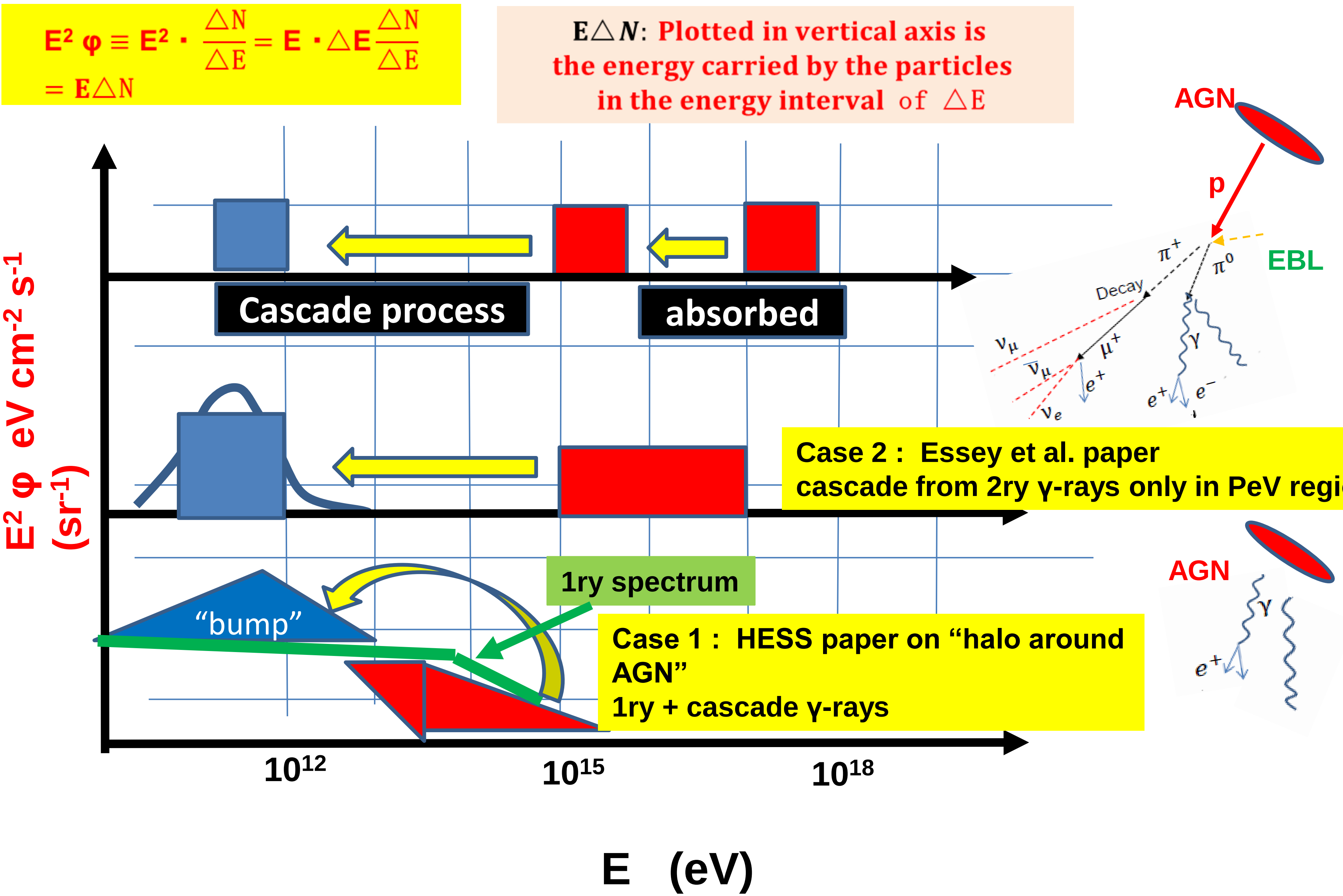
PeV peaked γ

We have chosen three most distant blazars observed in the TeV en

which show no variability.
We fit the spectra with secondary gamma rays produced by cosmic-ray interactions along the line of sight.



The observed high-energy gamma-ray signals from distant blazars may be dominated by secondary gamma rays produced along the line of sight by the interactions of cosmic-ray protons with background photons.



E² φ ≡ E² · △N/△E = E ·△E △N/△E
= E△N
E△N: Plotted in vertical axis is
the energy carried by the particles
in the energy interval of △E
AGN
p
EBL
Decay
Cascade process
absorbed
Case 2 : Essey et al. paper
cascade from 2ry γ-rays only in PeV regi
AGN
"bump"
1ry spectrum
Case 1 : HESS paper on "halo around AGN"
1ry + cascade γ-rays
E² φ eV cm⁻² s⁻¹ (sr⁻¹)
10¹²
10¹⁵
10¹⁸
E (eV)

Extended halo around AGN – HESS AA(2014), arXiv 1401.2915

Both extended pair halo (PH) and magnetically broadened cascade (MBC) emission from regions surrounding a blazar.

1ES 1101-232, 1ES 0229+200 and PKS 2155-304

H.E.S.S. Collaboration et al.: Search for Extended Emission around AGN

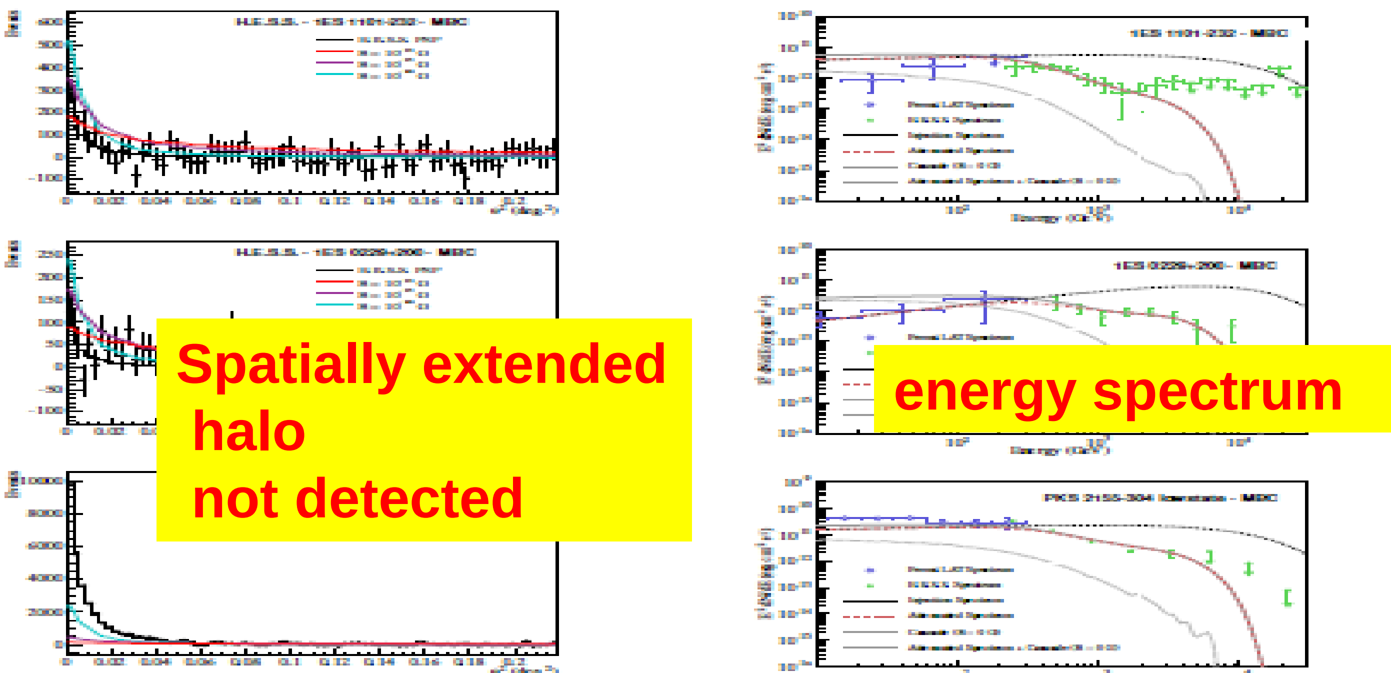


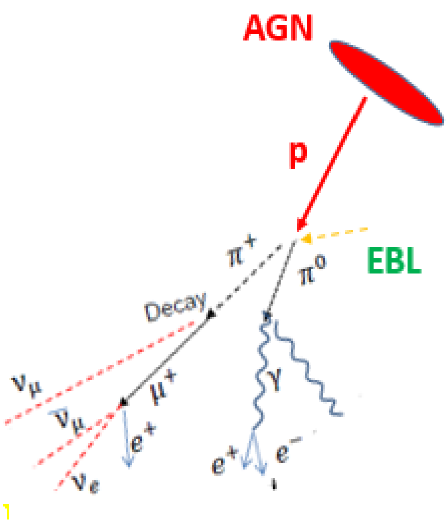
Fig. 4. Angular distribution of excess events of 1ES 1101-232 (top), 1ES 0229+200 (middle) and the PKS 2155-304 low state (bottom). The H.E.S.S. data (black points) is plotted against the angular distribution of the magnetically broadened cascade model for varying magnetic field strengths. The red, violet and cyan lines correspond to the maximum cascade flux for magnetic field strengths of 10^{-14}, 10^{-15} and 10^{-16} G, simulated under the assumption of the Franceschini et al. (2008) EBL model.

Fig. 5. The 1ES 1101-232 (top), 1ES 0229+200 (middle) and PKS 2155-304 (bottom) spectral energy distributions (Γ = 1.9, 1.5 and 1.9 respectively), including *Fermi* data (blue empty circles) as well as the H.E.S.S. results (green solid circles). The dotted grey line shows the expected cascade SED assuming the EGMF strength is 0 G, and the solid grey line shows this component added to the attenuated direct emission SED (dashed red line).

Essey et al.
ApJ 731, 51(2011)
Role of Line of sight CR int. …. from AGN

The total flux" = "EBL intensity" x L_p

1ES 1101-232, 1ES0229+200, and 1ES 0347-121



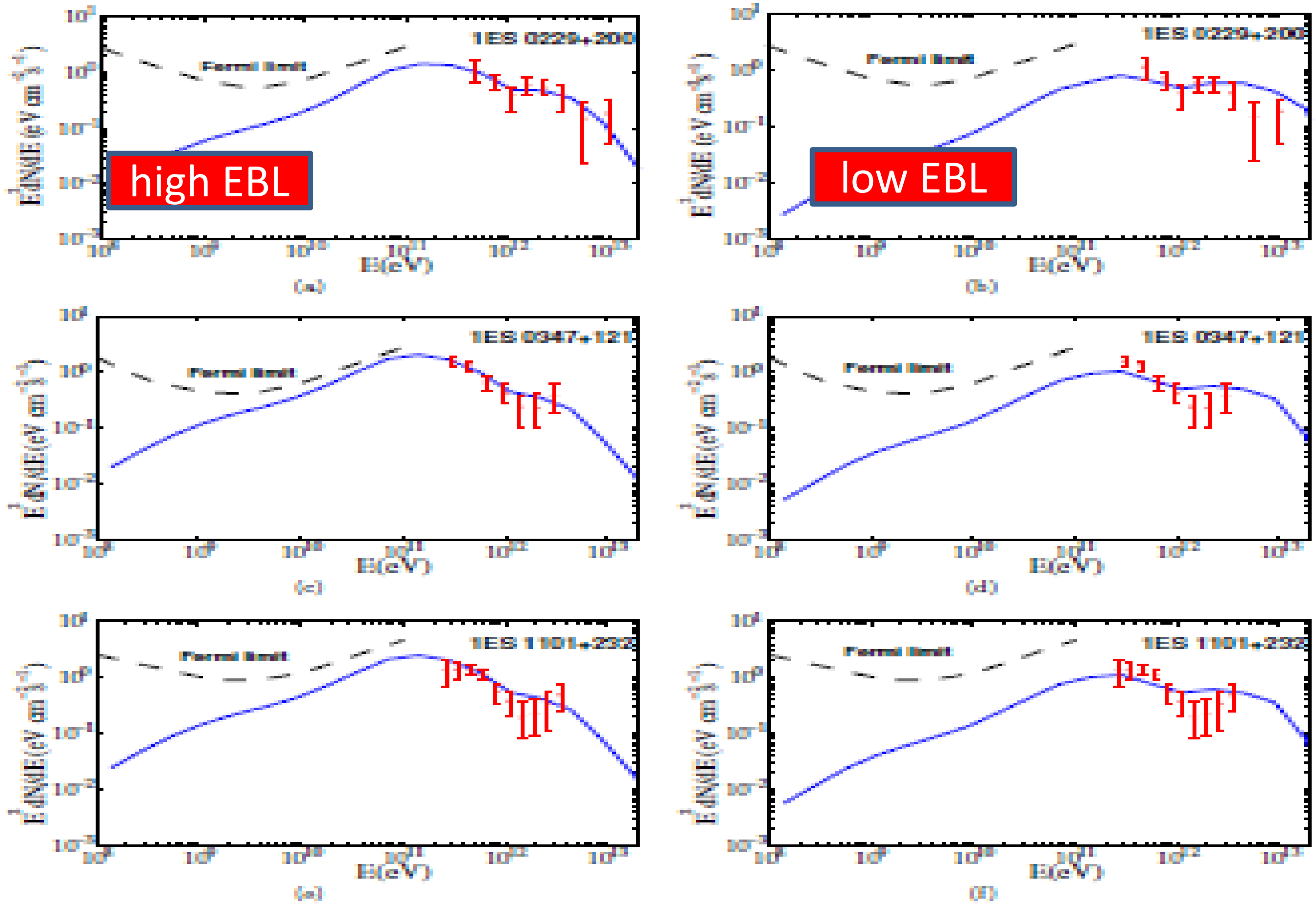
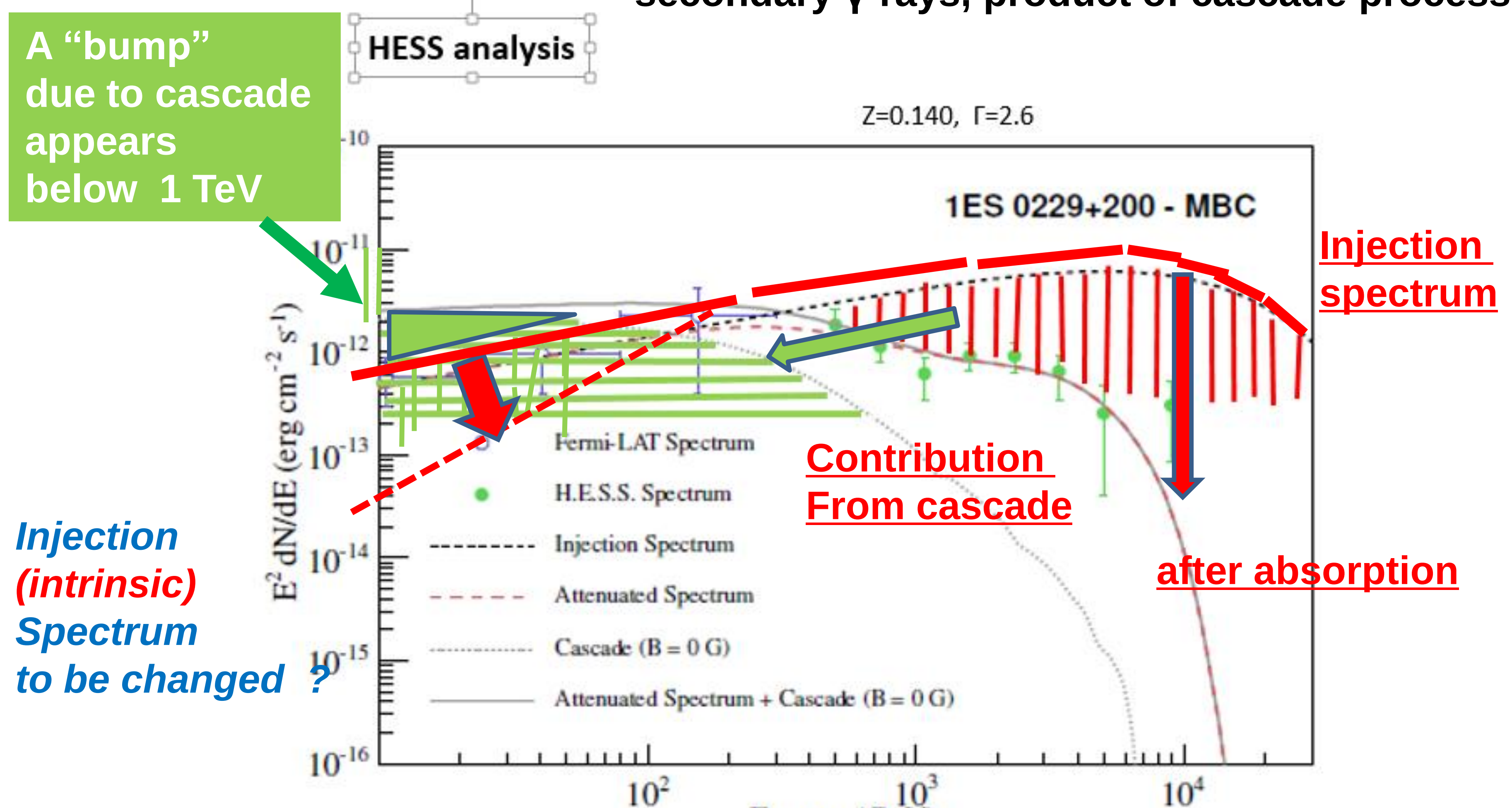


Figure 1. Comparison of the predicted spectra with the H.E.S.S. data for three blazars: panels (a) and (b) show model prediction and the data for 1ES 0229+… (Aharonian et al. 2007b); panels (c) and (d) show the predicted spectrum and the data for 1ES 0347−121 (Aharonian et al. 2007a); panels (e) and (f) show the …

The data show some preference for high EBL, although it is not significant . (this is in contrast with the limit set on EBL under the assumption that all the observed gamma rays are primary).

How the cascade process modifies γ-ray spectrum ?

A part of the observed flux is secondary γ-rays, product of cascade process.



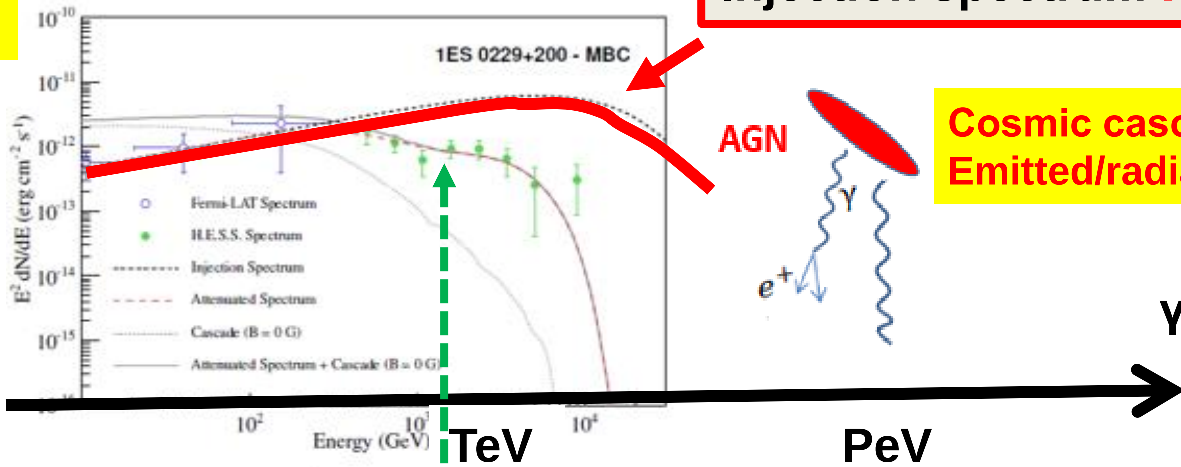
本来の (intrinsic) ガンマ線スペクトル？

two models compared for 1ES0229+200

Observed spectrum of TeV γ-rays can be fitted by a F(TeV-PeV) + (1-a) G(PeV) where 0 < a < 1

HESS analysis

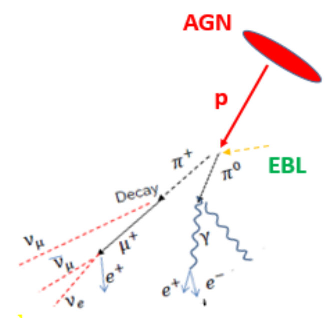
Injection spectrum F (TeV-PeV)



Cosmic cascade of γ-rays Emitted/radiated from AGN

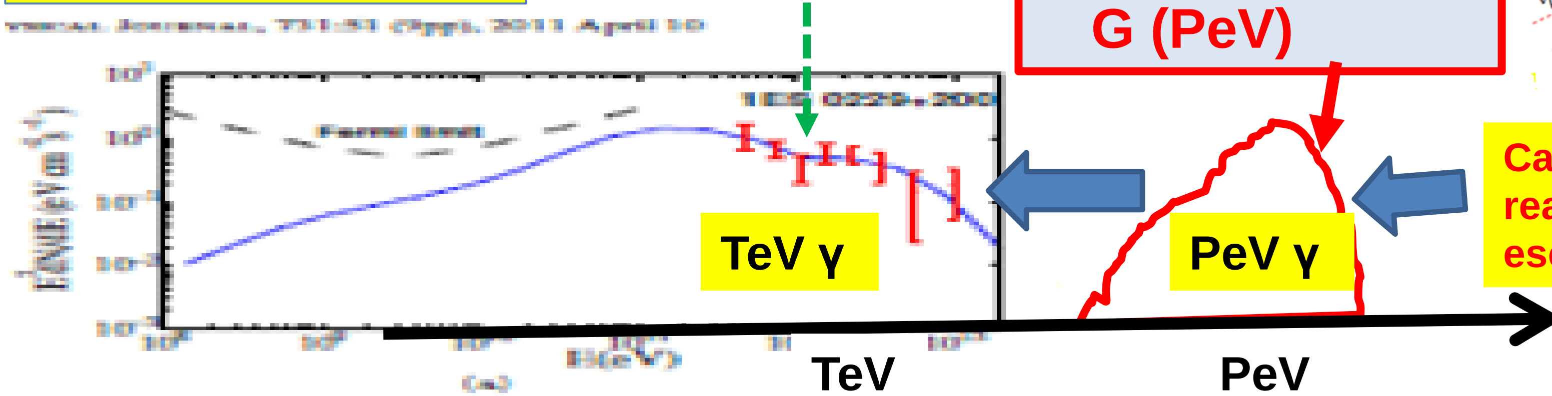
γ –ray energy

Same observation data in TeV region



Essey et al. analysis

Injection spectrum G (PeV)



Cascade of proton reactions emitted/ escaped from AGN

Conclusion /discussion from HESS paper on the halo

- **HESS and Fermi data shows no indication of such (extended halo) emission.**
- Upper bound on past 5 years activity; time variability for the primary gamma ray and no variability for the secondary.
- Some constraint on high energy electrons in extragalactic space and extragalactic magnetic field.

Conclusion of Essey et al. paper

- **The surprisingly low attenuation of high-energy gamma rays**; secondary gamma rays produced in interactions of cosmic-ray protons with background photons in the intergalactic space.
- We have obtained excellent fits to observed spectra of several distant blazars.
- At low energies **the spectra are harder than predicted by theoretical models** (Malkov & Drury 2001; Stecker et al. 2007).
- Secondary gamma rays expected to show no temporal variability. **a strong discriminant between 1ry and 2ry gamma rays**.
- **predictions for secondary neutrino** signals from blazars at about 1–10eV cm^{-2} s^{-1}, depending on source and model parameters.
- **predictions for neutrinos, besides the spectral shape**. (1), there should be no temporal variability observed for neutrinos. (2), the luminosity of sources should vary with distance as $1/d$, as opposed to the usual $1/d2$ scaling law. more distant sources observable, as compared to predictions for primary neutrinos. (3), the flavor structure of the observed signal should differ from primary neutrino models.
- A new powerful method to probe the radiation and magnetic field contents of intergalactic space, as well as AGN properties.

Implication of EBL and CR acceleration model

- **The overall flux depends on the EBL multiplied by the unknown and poorly constrained L_p. …At present, the data show some preference for high EBL, although it is not significant . (this is in contrast with the limit set on EBL under the assumption that all the observed gamma rays are primary).**

ここまでを まとめると……

HESS paper: 1, 2 …. Essey et al. paper: 3, 4

1. **No extended halo** : some constraint on extragalactic mag. Field
2. **Upper bound on past 5 years activity; time variability**
3. **dependence on IR-FIR EBL intensity, distance**

   "The total flux" = "EBL intensity" x L_p (in the case of Essey et al.)
4. "γ-ray flux 1-10 eV cm^{-2} s^{-1} = 10^{-12}-10^{-11} erg cm^{-2} s^{-1} from the AGNs" can be explained as consistent with IceCube ν

0. **The two models explain the same observational data :**

Interpretation of observed data is ambigous

a F(TeV- PeV) + (1-a) G(PeV), "intrinsic" spectrum ?

Gの形も任意！

Questions from the viewpoints of this talk

A. Can we peep into PeV γ-ray sky?
PeV を覗き見ることができるか？
B. Some information about **LIV effect** in PeV region ?
"cosmic cascade model" は **LIV effect 否定,**
i.e. No absorption due to 2.7K MWB の clear evidence
となりえるのか ？

Yes/No E_{max} ?, G(PeV)?

A. **maximum energy and "shape" of γ-rays radiated by "galaxy"**

B. **Too ambigous, situation is too complicated, not as simple as to examine/claim just "no LIV".**

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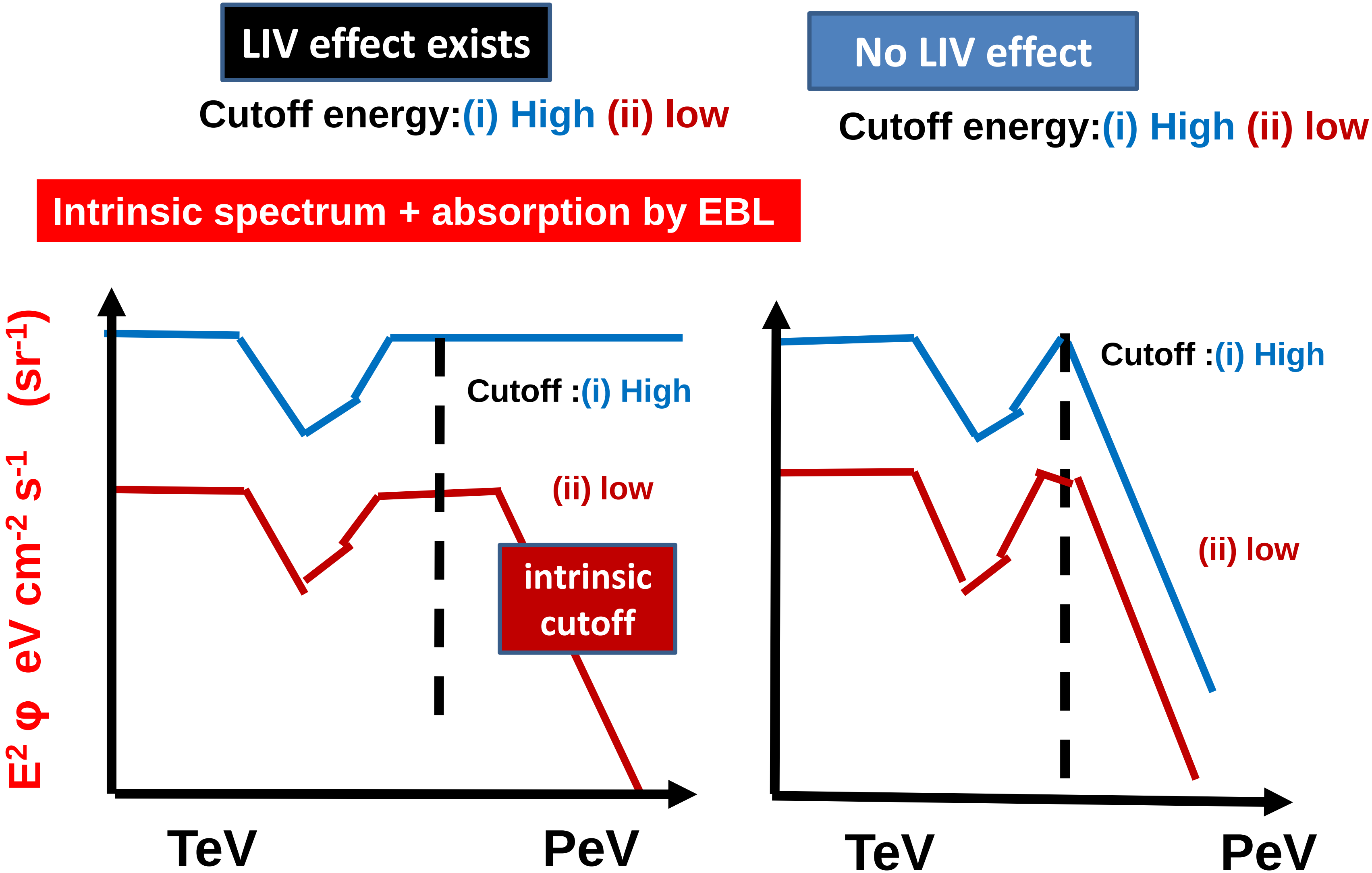
(1) "intrinsic" γ-ray spectrum from extragalactic sources ?
observed spectrum ≉ "intrinsic spectrum" from AGN

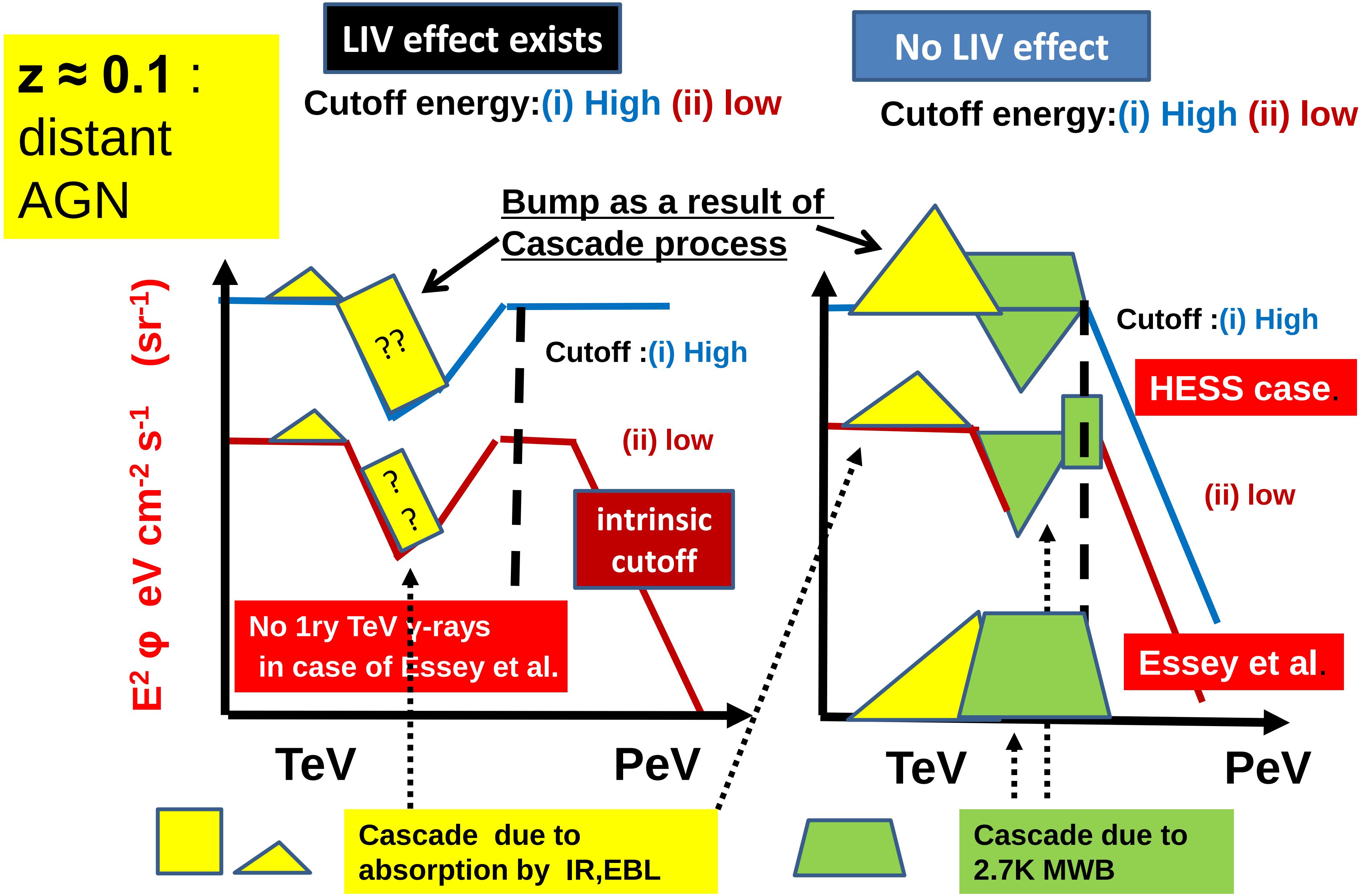
(2) Are we required to detect ν signal, PeV γ-ray signal from AGNs, in order to correctly understand AGN, Origin of CRs, …….. ?

われわれは どう対処すべきか？ How to diminish ambiguity ?

- **to examine spectra of γ-rays from galaxies of various distances : CTA observation at ~100 TeV ? ---- F-N-Ellis-Hinton-W paper**



LIV effect exists
Cutoff energy:(i) High (ii) low
No LIV effect
Cutoff energy:(i) High (ii) low
Intrinsic spectrum + absorption by EBL
E² φ eV cm⁻² s⁻¹ (sr⁻¹)
Cutoff :(i) High
(ii) low
intrinsic cutoff
TeV
PeV
Cutoff :(i) High
(ii) low
TeV
PeV



Schematic explanation of cascade effect (the effect might be a bit exaggerated)

From Jim Hinton 2010

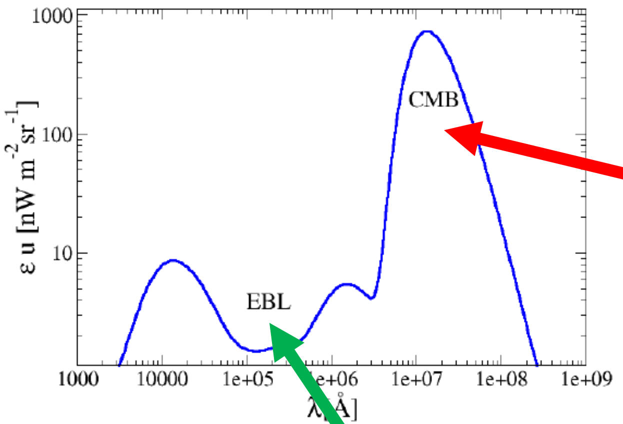
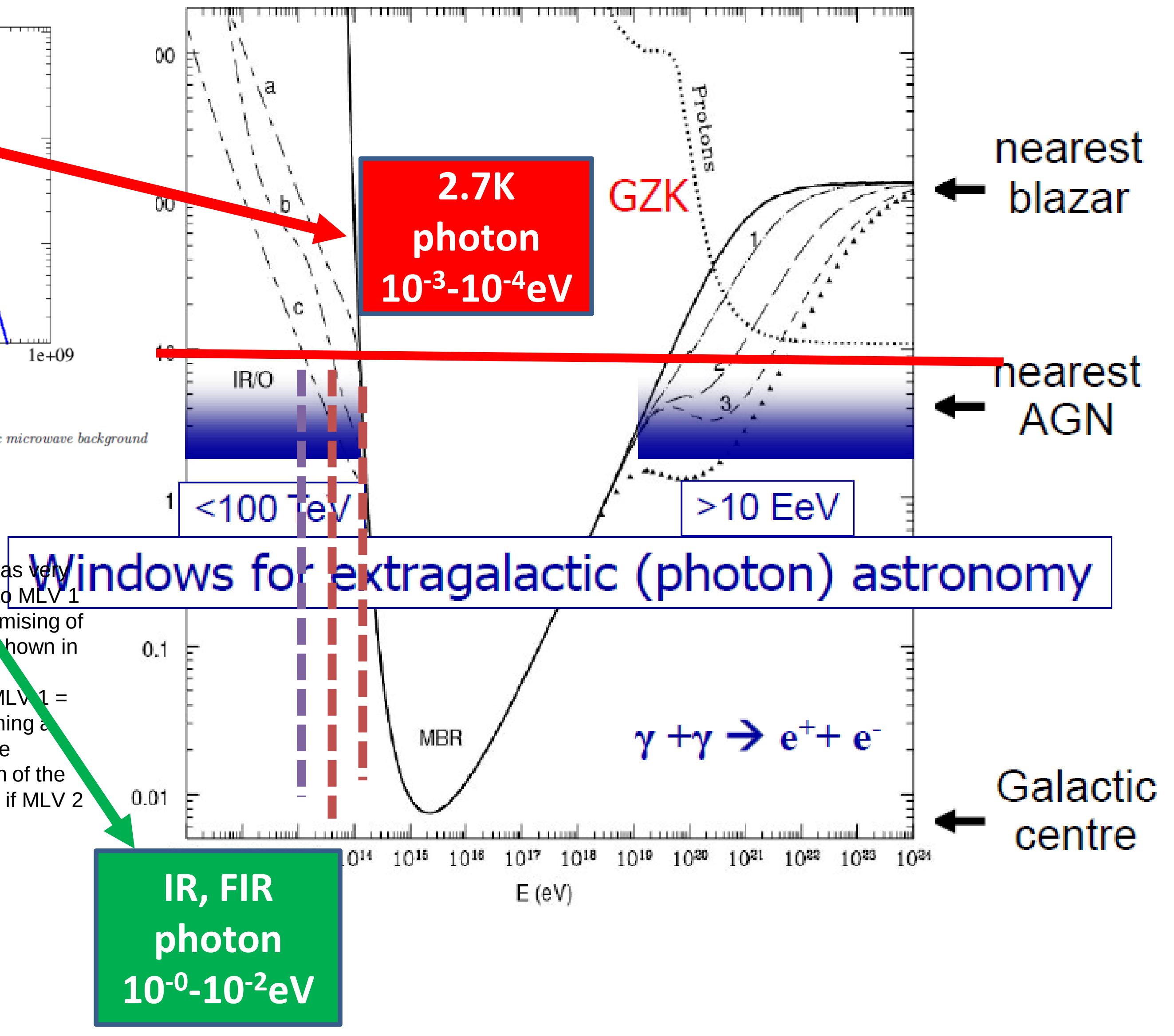


Figure 1. *Spectrum of the extragalactic background light (EBL) and the cosmic microwave background (CMB) obtained as described in the text.*

We have shown in this paper that CTA potentially has very competitive sensitivity to Lorentz violation, namely to MLV 1 1019 GeV and MLV 2 1011 or more. The most promising of the sources we have studied is Markarian 501. As shown in Table 1, assuming a power-law spectrum with no exponential cut-off, we estimate a 5- sensitivity to MLV 1 = 4:51020 GeV after 50 hours of observations, assuming a continuing power-law emission flux. Under the same assumptions, in the case of a quadratic modification of the photon dispersion relationone could detect photons if MLV 2 = 5:9 1012 GeV for n = 2.



“The CTA Sensitivity to Lorentz-Violating Effects on the Gamma-Ray Horizon”
M.Fairbairn, A.Nilsson, J.Ellis, J.Hinton, R.Whited. arXiv:1401.8178v2,
J. Cosmology Astroparticle Phys

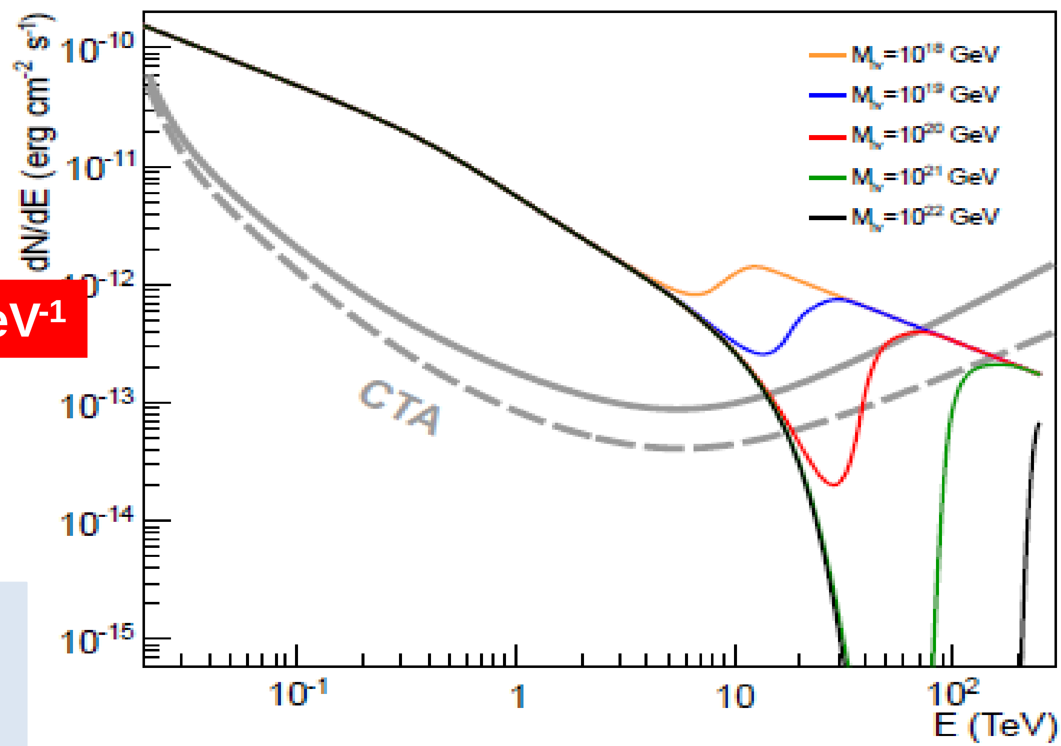
distance that leads to just absorption, no cascade
due to EBR (IR, FIR) photon

● Mrk 501 z=0.034 137Mpc

5.8×10^{-12} (E/1TeV)$^{-2.72}$ cm^{-2}s^{-1}TeV^{-1}

50 hrs observation,
3-5 sigma result claimed

Mrk 501 to testify LIV effect



... The expected spectrum of the AGN Markarian 501 for different values of M_{LV1} vs the ... urve is that presented in [23], whereas the lower (da... removes the requirement of 10 photons per bin as expl...

● Mrk 421 z=0.03 125Mpc
Cutoff of energy spectrum at 1.4 TeV

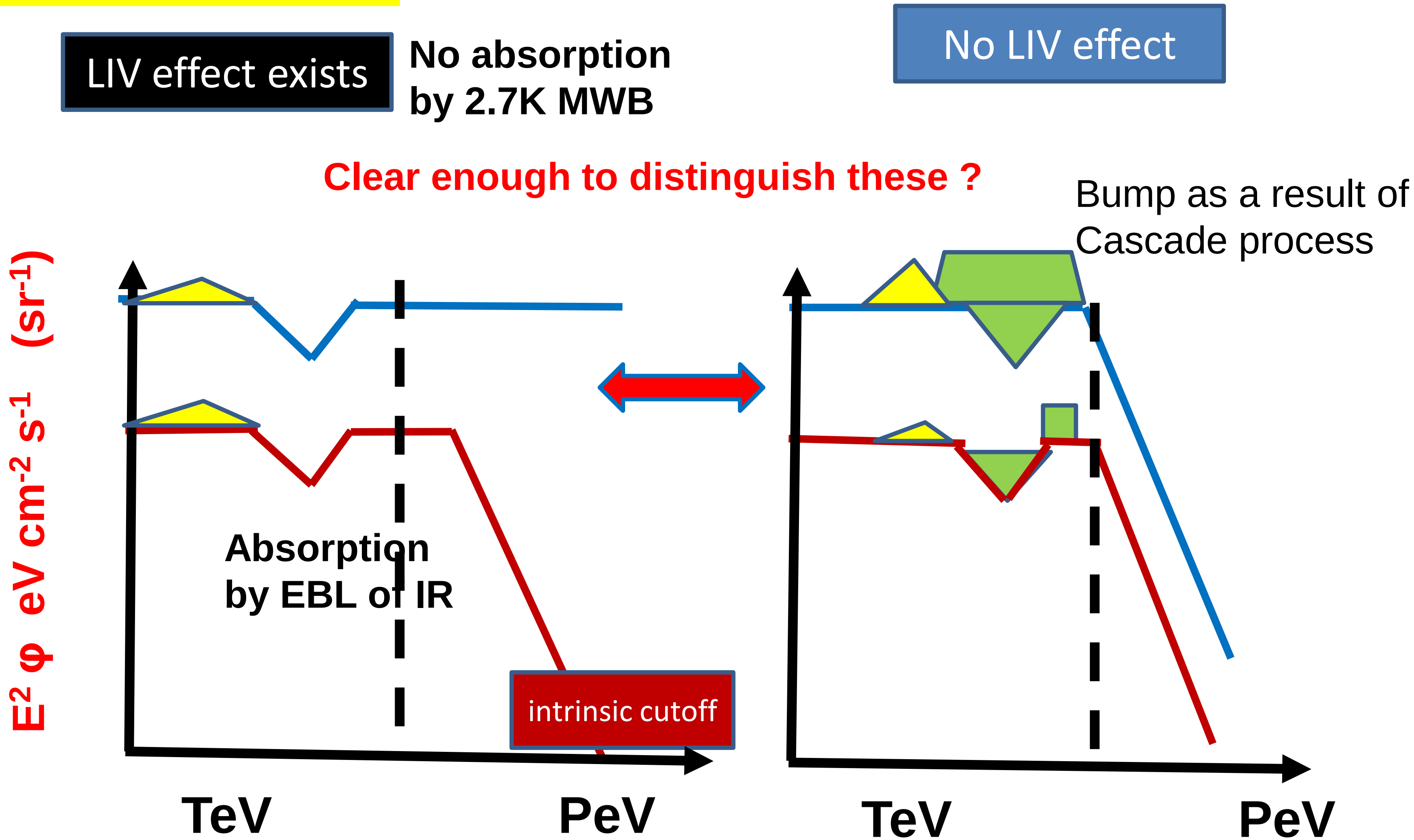
1.6×10^{-9} (E/0.2TeV)$^{-2.2}$ exp(-E/1.4TeV)cm^{-2}s^{-1}TeV^{-1}

To fall too steeply above 1TeV for a useful flux ti be exoected at 100TeV

● M87 z=0.0044 18Mpc; too near

7.1×10^{-12} (E/0.3TeV)$^{-2.21}$ cm^{-2}s^{-1}TeV^{-1}

z ≈ 0.03 : Mrk 501



…some other fundamental physics mechanism,,,,(e.g. axion-like particles)….We would also like to emphasize that different modifications of fundamental physics, such as energy non-conservation, might conspire to diminish or even eliminate the effect discussed here. Despite these caveats, we think that our analysis opens up a physics area of great potential interest for CTA. and ….. (conclusion---Fairbairn, Nilsson, Ellis, Hinton and White)

Gamma-rays from local group galaxies:

TeV gamma-ray detected **M87(16Mpc), Cen A(5Mpc), M82 (3.6Mpc), NGC253(3Mpc):**

arXiv 1012.1951

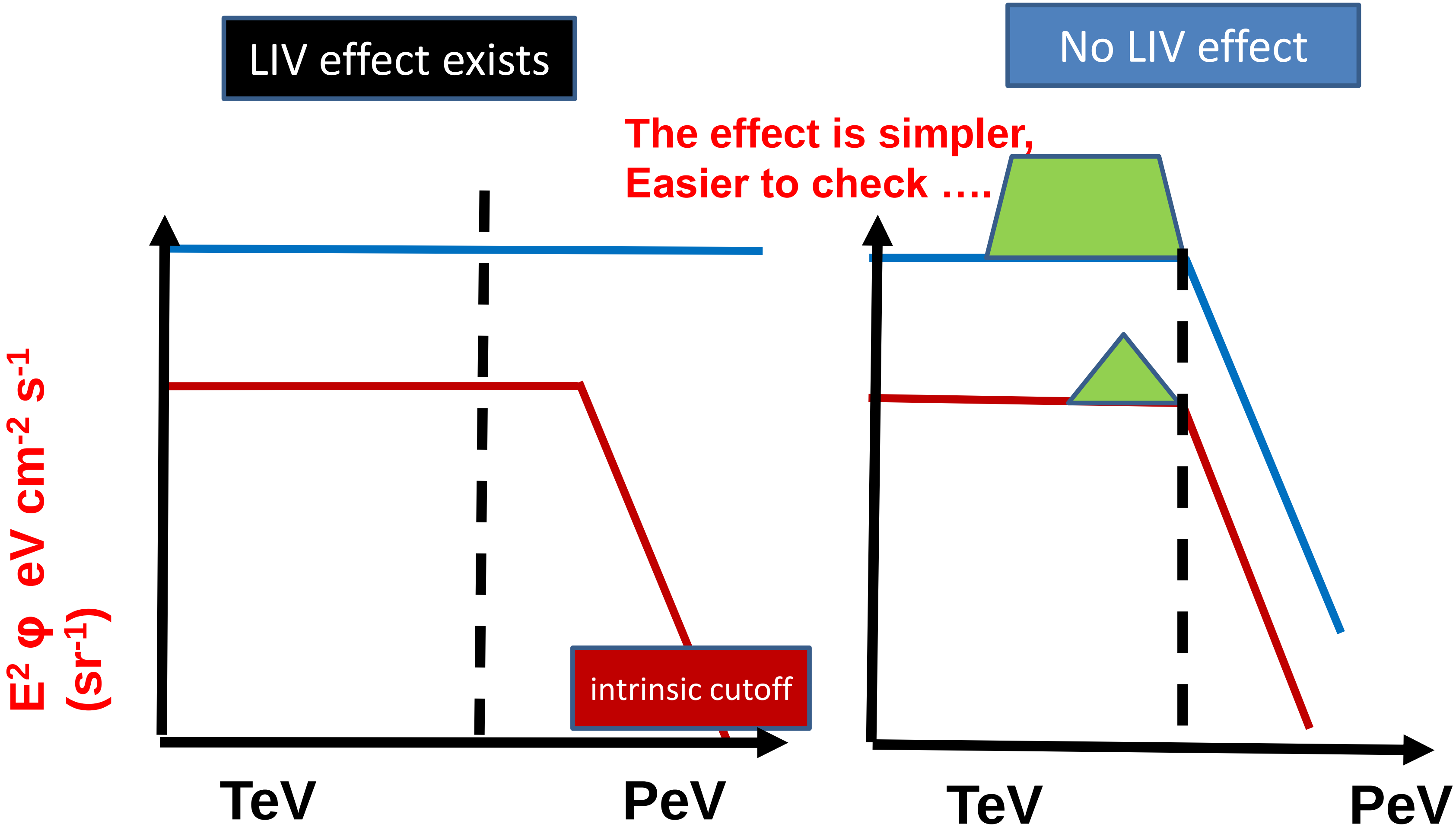
LAT collaboration: *Fermi*/LAT observations of Local Group galaxies: Detection of M31 and search for M33

Table 1. Properties and gamma-ray characteristics of Local Group and nearby starburst galaxies (see text).

Galaxy	d kpc	M_{HI} 10^8 $M_\odot$	M_{H_2} 10^8 $M_\odot$	SFR $M_\odot$ yr^{-1}	F_γ 10^{-8} ph cm^{-2} s^{-1}	L_γ 10^{41} ph s^{-1}	$\bar{q}_\gamma$ 10^{-25} ph s^{-1} H-atom^{-1}
MW	...	35 ± 4[7]	14 ± 2[7]	1 – 3[19]	...	11.8 ± 3.4[28]	2.0 ± 0.6
M31	780 ± 33[1]	73 ± 22[8]	3.6 ± 1.8[14]	0.35 – 1[19]	0.9 ± 0.2	6.6 ± 1.4	0.7 ± 0.3
M33	847 ± 60[2]	19 ± 8[9]	3.3 ± 0.4[9]	0.26 – 0.7[20]	< 0.5	< 5.0	< 2.9
LMC	50 ± 2[3]	4.8 ± 0.2[10]	0.5 ± 0.1[15]	0.20 – 0.25[21]	26.3 ± 2.0[25]	0.78 ± 0.08	1.2 ± 0.1
SMC	61 ± 3[4]	4.2 ± 0.4[11]	0.25 ± 0.15[16]	0.04 – 0.08[22]	3.7 ± 0.7[26]	0.16 ± 0.04	0.31 ± 0.07
M82	3630 ± 340[5]	8.8 ± 2.9[12]	5 ± 4[17]	13 – 33[23]	1.6 ± 0.5[27]	252 ± 91	158 ± 75
NGC253	3940 ± 370[6]	64 ± 14[13]	40 ± 8[18]	3.5 – 10.4[24]	0.6 ± 0.4[27]	112 ± 78	9 ± 6

Local group galaxies :

No Cascade process
Due to absorption
By EBL of IR photon



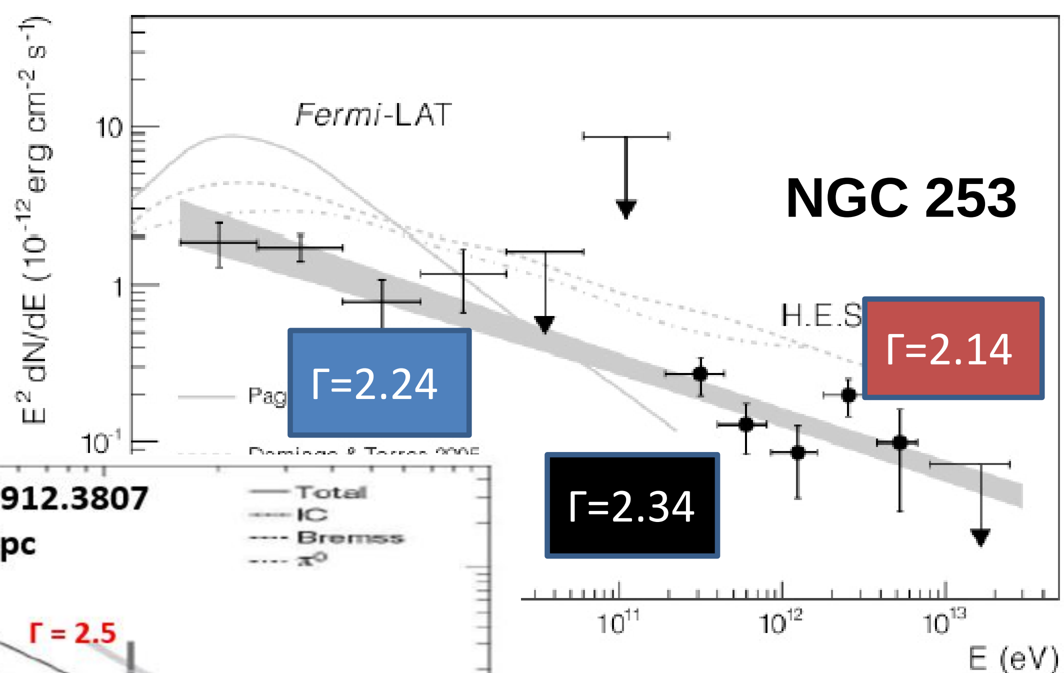
Just a Bump
as a result of Cascade process
due to absorption by 2.7K MWB

Local galaxies

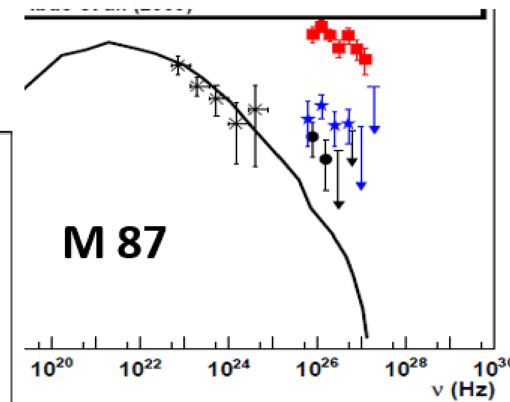
A. Abramowski *et al.* 2012 *ApJ* **757** 158

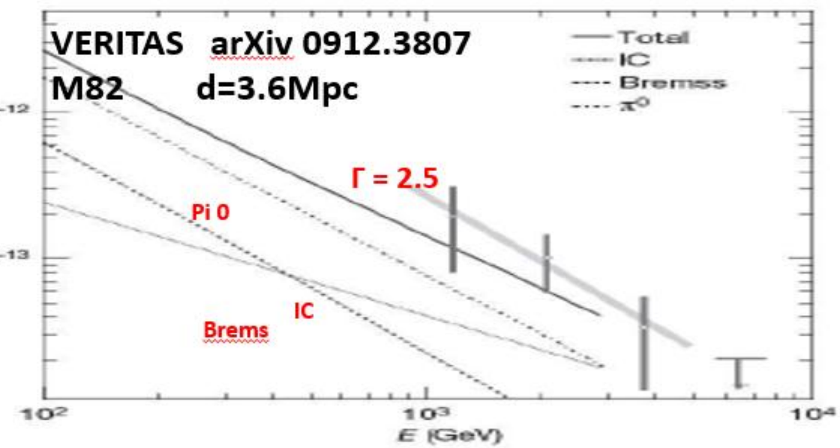
Γ=2.3, ….. 2.1

Analysis of the γ-ray emission from NGC 253



…h *MA* (shown as circles). Also shown is the LAT energy s… . For both spectra 1σ error bars are shown for spectral po… confidence band from the simultaneous fit to the *Fermi*-LA… -Santamaría & Torres (2005) (dashed grey) and Rephaeli…





Cosmic cascade
studied as a function of distance

γ-ray flux as high as ICECube ν
1-10 eV cm^{-2} s^{-1}

(1) AGN of z = 0.1 - 0.2 : 1-10 eV cm^{-2} s^{-1} = 10^{-12}-10^{-11} erg cm^{-2} s^{-1}
z = 0.117, 0.14, and 0.186, IR EBL contributes to cascade effect

dip & bump : γ-ray spectrum largely deformed

(2) Mrk 501 z = 0.03 1-10 eV cm^{-2} s^{-1}
(Mrk 421: cut off, M87: too near)

a "dip", but no "bump"

absorption due to EBL

a "bump", no "dip"

(3) Nearby active/local group galaxies
0.1-10 eV cm^{-2} s^{-1}

cascade effect due to 2.7K MWB

flux : dependence on distance, d^{-1} or d^{-2} ?

E_{max}: cutoff energy ?
correlation with jet, time-variability

extragalactic diffuse gamma ray

to observe direction of ν signal, PeV γ-ray signal ?

多面的な視点
を加えて

Hopefully
diminish
uncertainties

P + ε → p + pion

LIV effect on radiation mechanism

LIV effect may change the estimation of

"CR proton (intergalactic space) + EBL photon→π production

$$4\,\varepsilon\,E_0 > \frac{a}{1-a} m_p^2 + \frac{1}{a} m_\pi^2 + F_n\, a(1-a) \frac{E_0^{n+2}}{M_n}$$

F_n = 1 or 3 for n=1 or 2, respectively

$a = K/E_0$, where K is pion energy

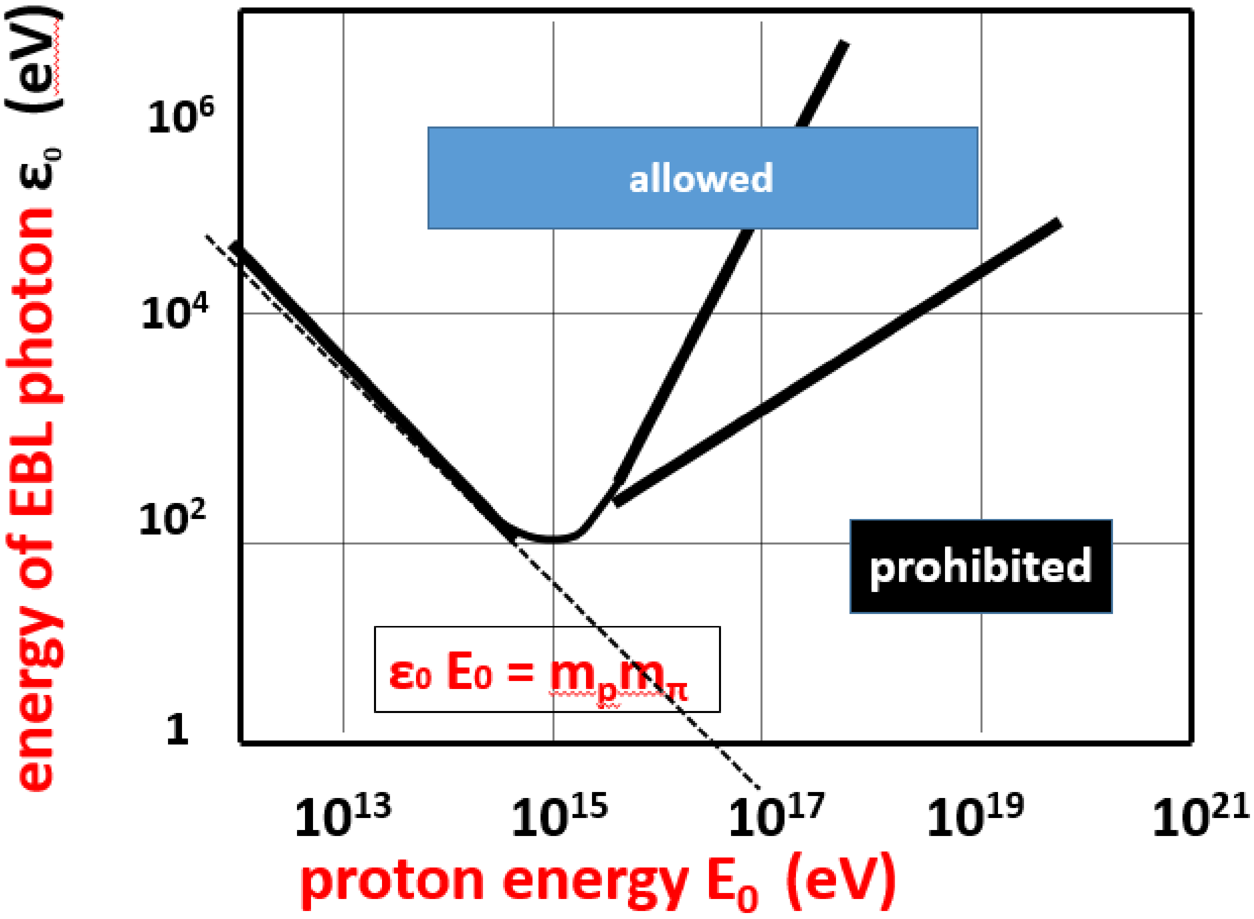
- Left-hand side > 1st term of right-hand side:
  $\varepsilon\, E_0 > m_p m_\pi \approx 10^{17}\,(\mathrm{eV})^2$
- Left-hand side > 2nd term of right-hand side
  $E_0 < (\varepsilon\, M)^{1/2} \approx 10^{14}\,\varepsilon^{1/2}$ eV, that is, $\varepsilon > 10^{-28}\,E_0^2$ eV

- suppression by LIV crosses at $E_0 = 10^{15}$ eV and **ε < 100 eV,**
  LIV effect of "photo-pion production" can bring about
  "PeV peaked neutrino" ?

Photo-pion production

$p + \varepsilon \rightarrow p/n + \pi^{0/+}$

$\rightarrow \gamma$ or ν



n=1

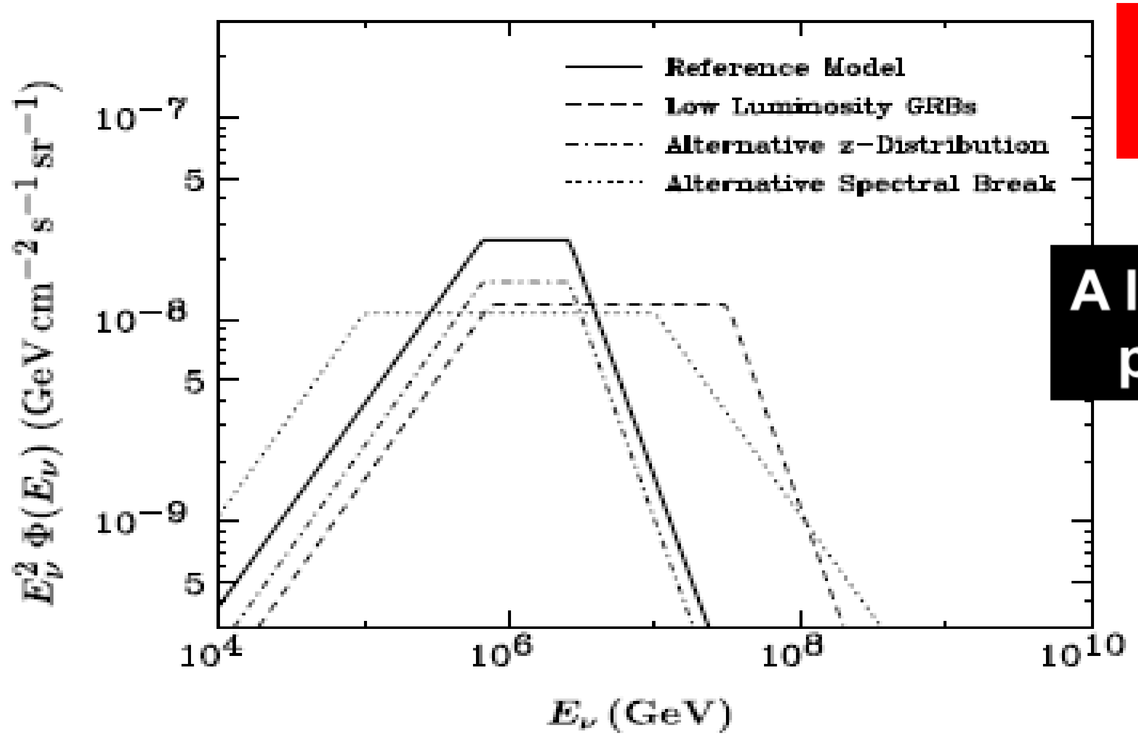
$E_* = (M m_p m_\pi)^{1/3} \approx 10^{15}$ eV,
$\varepsilon_* = (m_p^2 m_\pi^2/M)^{1/3} \approx 10^2$ eV

n=2

$(M^2 m_p m_\pi)^{1/4} \approx 3\times10^{18}$ eV,
$\varepsilon_* = (m_p^3 m_\pi^3/M^2)^{1/4} \approx 1$ eV

diffuse emission from GRB, …….

PeV peaked neutrino / gamma-ray?



Intense photons of short wavelengths

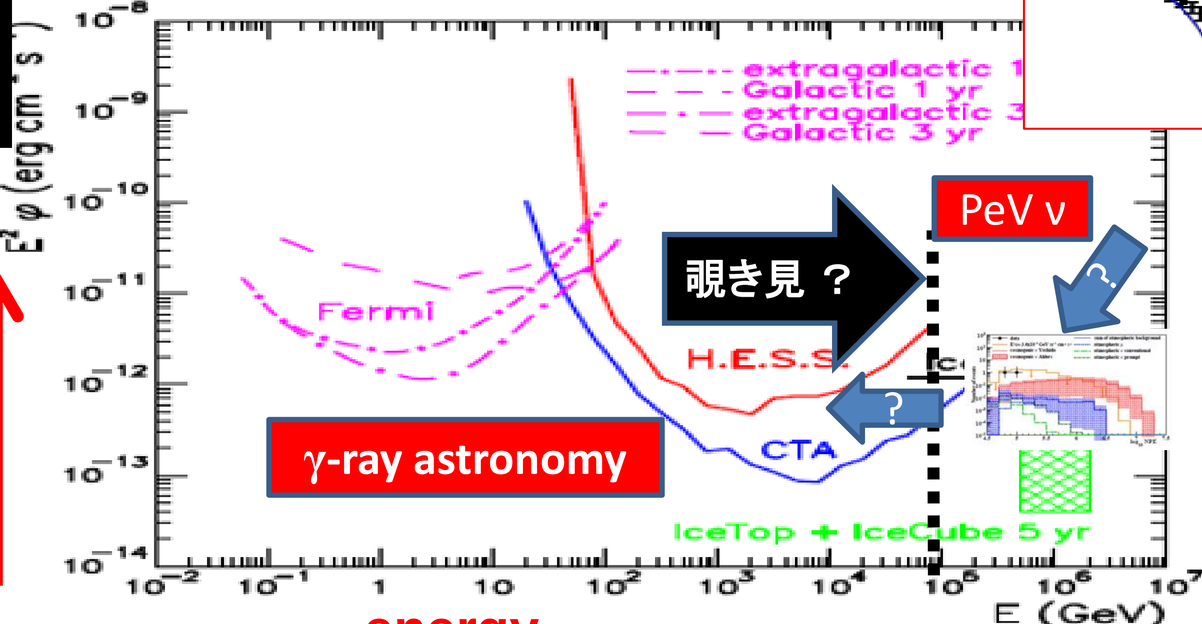
A large contribution from protons at ~PeV energy

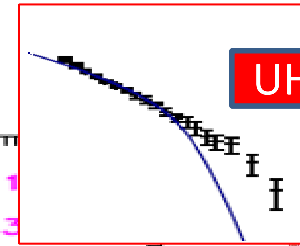
Fig. 11. The contribution of GRBs to the diffuse neutrino (plus antineutrino) spectrum. Results are shown for high luminosity (solid) and low luminosity (dashed) GRBs, calculated using default parameters, and for high luminosity GRB models with a suppressed high redshift distribution (dot–dash) and alternative spectral characteristics (dots). Each of these models yields a rate of PeV events which is comparable to that implied by the two most energetic events reported by IceCube. Plot taken from Cholis and Hooper (2013).

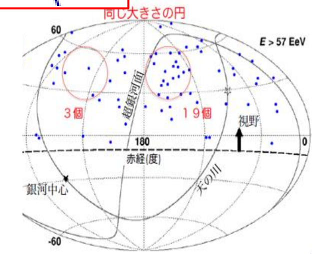
Summary and remarks

Necessary to directly detect PeV γ-rays ?

a tough road not paved as TeV γ-ray astronomy







Planck energy

?

"Cosmic Probes of Fundamental Physics": Community Planning Study: Snowmass 2013
Conveners: J.J. Beatty, A.E. Nelson, A. Olinto, G. Sinnis et al. : 29.5 Tough Questions

PeV region そして Planck scale のenergy region を、如何なる具体的方法で、窺い知るか？

- What are the roles of cosmic-ray, gamma-ray, and neutrino experiments for particle physics?
- **What future experiments are needed in these areas and why?**
- Are there areas in which these can have a unique impact?

How to conquer Uncertainties,
不定要素を、いかに総合的に理解し克服できるか？

(dark matter, axions, primordial black holes, Q-balls, Lorentz invariance violation, intergalactic magnetic fields, particle interactions at high energies, neutrino mass hierarchy, etc.)

Thoughts: coming up from what T.C. Weekes said some years ago

in a chat about 20 years ago,

"No energy threshold for astrophysical observation"

presented at the beginning of his talk , about 10 years ago,

(I heard from Trumper,)

Total energy of all the X-rays detected by ROSAT satellite is just equal to one TeV photon"

10^9 x 1 keV = 1TeV

10^{10} x 1 EeV = 10^{28}eV

X-ray astronomy ←→ TeV γ

UHE sky ←→ Plank scale

A comment
by a messenger
from the future:

「どらえもん」

You are misunderstanding !
To choose a way is not always to select a safe, paved one, easy to walk along !