Prolog :TeV γ rays, neighboring fields and sciences aimed at

Why TeV γ-rays ?

not other bands such as ……

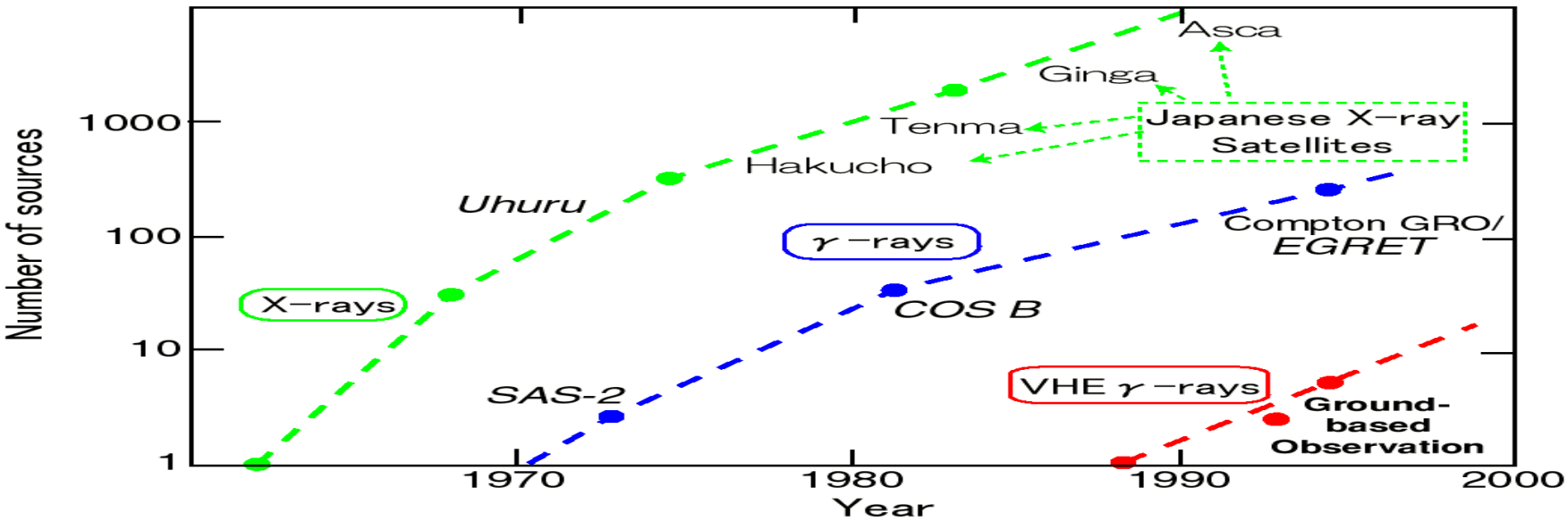
- **X-ray astronomy**
- **GeV γ-rays**
- **Astroparticle physics**
  - **Ultra high energy cosmic rays**

……

What type of telescope?

Direction, destination ?

- **Astrophysics using many sources?**
- **Earlier Universe beyond the horizon?**
- **Enigmatic high energy interactions?**



Nasty questions

- Felix Aharonian asked a “nasty question”,

  “Do we need > 10 TeV region?”

  and I believe that he meant the answer is yes:

- I like to address a question even more nasty,

  for which answer we now do not know :

  - Will “TenTen” give us science

  that the existing telescopes can not?

Nearby galaxies, 10^{20}eV CRs, and VHE γ-rays beyond 10TeV

- Existing projects and its Future plan

  towards CTA (H.E.S.S. and MAGIC) : EU

  next stage of VERITAS : USA

  other efforts on-going

"TenTen"

- **Going to higher energies implies less number of sources, and**

  The science aimed at must be well focused

  when compared with other on-going projects

- **Independent way to find / choose targets, hopefully**

  survey mode / all sky monitor ? (EUSO type IACT)

Outline of talk

- **Prospect Beyond 10TeV？**

Origin of cosmic rays? ---
unique contribution by “TenTen” ?

- galaxies in our neighborhood
- to challenge the region, **100 TeV to EeV,**
  which has been **studied only through detection of cosmic rays,**
- Comments on Instrumentation

“Origin of CRs”;

“The standard way” in the current stage seems to be

To detect gamma rays from many Galactic objects like SNR, PWN, ….

to know

spectra, cut off energy, morphology

of individual sources

However,
we rely on existing projects to choose observation targets,
and we are not sure
How many objects do we have to see
before we can rest on a conclusion ?

“Origin of CRs”;

Point Sources → CR confinement in Disk / emission
To Higher energy region

alternatively / in parallel

Extragalactic sources ?

Milky Way Galaxy In comparison with other nearby galaxies

To study high energy non-thermal process of galaxies

Nearest galaxies: LMC, SMC, M31(Andromeda) ?

Implication of EGRET results on LMC and SMC :
CRs of our Galaxy are not of extragalactic origin

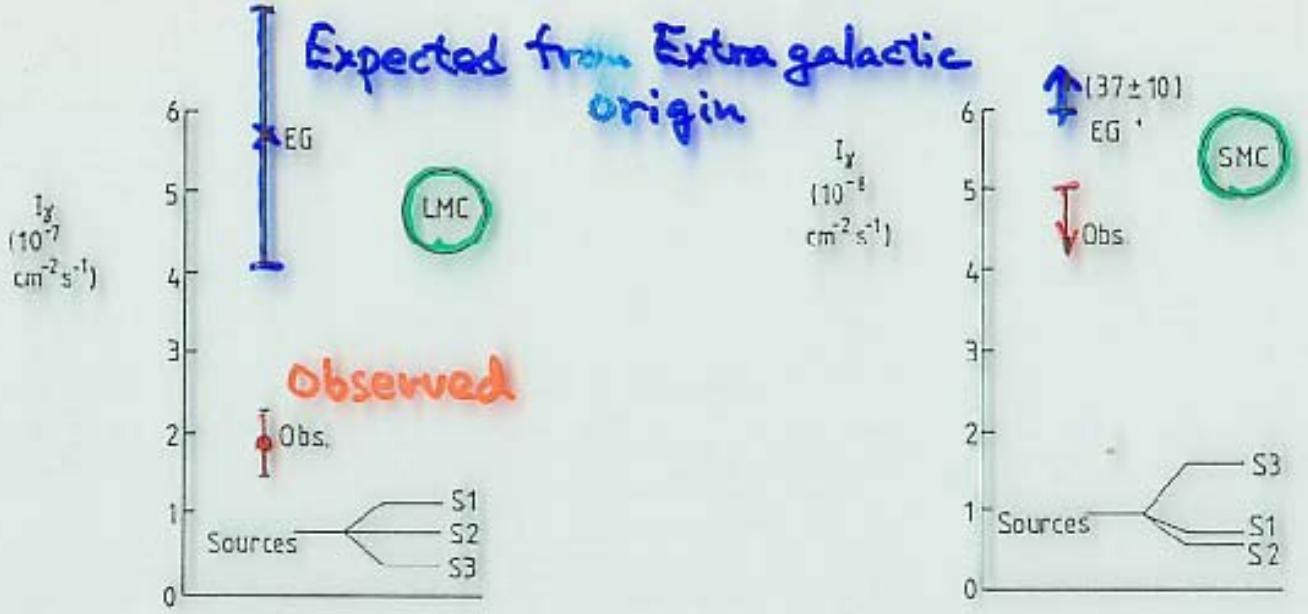
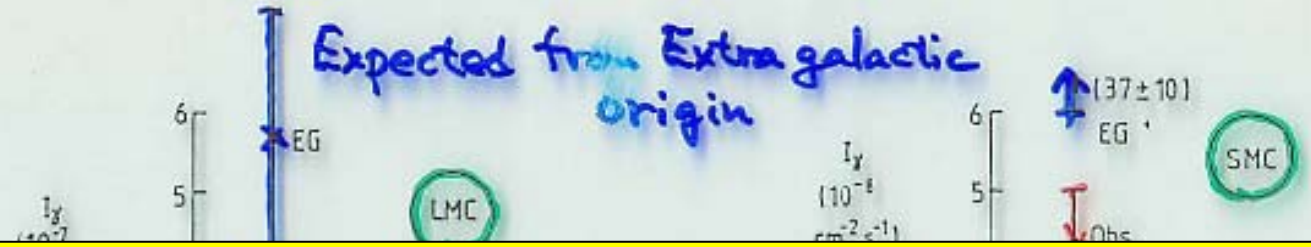


Figure 1. Gamma ray flux at energies above 100 MeV from the LMC. 'Obs.' denotes the measured flux reported by Fichtel *et al* (1992a); 'EG' denotes the flux expected if the cosmic rays detected at the Earth were all of extragalactic origin. The estimated discrete source contribution from the galaxy was calculated for different indicators of discrete source activity: S1, supernova remnant/X-ray/star formation; S2, blue luminosity; S3, mass of molecular hydrogen. The arithmetic mean of S1, S2 and S3 has been adopted for use in the analysis.

Figure 2. Gamma ray flux at energies above 100 MeV from the SMC by various models, in comparison with observation ('Obs.'). The 'observed' flux (flux $< 0.5 \times 10^{-7}$ cm^{-2}s^{-1}) was derived from the data and sky coverage given by Bignami (1992). Key as for figure 1.

Implication of EGRET results on LMC and SMC :

CRs of our Galaxy are not of extragalactic origin



New insights obtained from studying total emission from galaxies

Such as

Knee energies of various different galaxies,

Confinement time (galaxy mass)

……

……

Upper limits / flux from objects in nearby galaxies

SN1987A in LMC	$<5\times10^{-13}$cm^{-2}s^{-1} (5TeV)	$<10^{37}$erg s^{-1}	0.05Mpc	**CANGAROO**
Whole of M31	$<2\times10^{-11}$cm^{-2}s^{-1}	$<2\times10^{39}$erg s^{-1}	0.8Mpc	**VERITAS**
objects in M31	$<3\times10^{-12}$cm^{-2}s^{-1}	$<3\times10^{38}$erg s^{-1}	0.8Mpc	**HEGRA**
M87	~ 10^{-13}cm^{-2}s^{-1}	3×10^{40}erg s^{-1}	16Mpc	**HESS**
Perseus cluster	$<(3\text{-}8)\times10^{-12}$cm^{-2}s^{-1}	$<(2\text{-}4)\times10^{42}$erg s^{-1}	75Mpc	**VERITAS**

Sensitivity of 10^{-14}~ 10^{-13} cm^{-2}s^{-1} is required,

and

Number of γ rays for>10TeV with 10km^2 detection area

(10^{-14}~ 10^{-13} cm^{-2}s^{-1}) x 10 km^2 x 10^5 s

(1days, ~10nights obs)

≈ 100 ~ 1000 gamma rays

EGRET observation on SMC, LMC and M31

LMC 2×10^{-7} $cm^{-2}s^{-1}$ > 100 MeV

SMC $< 5 \times 10^{-8}$ $cm^{-2}s^{-1}$ > 100 MeV

M31 $<1.8 \times 10^{-8}$ $cm^{-2}s^{-1}$ > 100 MeV

- $L_{TeV} \sim L_{egret} \cdot (100MeV/1TeV)^{(\alpha-1)} = L_{egret} \cdot 10^{-4(\alpha-1)}$

  α =2.2~2.6: power index of gamma ray spectrum ?

- TeV flux extrapolated from the EGRET

  α = 2.2 ~ 2.6:

  < $2x10^{-13} \sim 2x10^{-15}$ $cm^{-2}s^{-1}$ for M31

  $2x10^{-12} \sim 2x10^{-14}$ $cm^{-2}s^{-1}$ for LMC

Emission from a galaxy

- Emissivity q, size of galaxy a~10kpc : $\mathbf{F_{disk} = qa}$
- galaxy at Distance : $\mathbf{F_{out} = qa^3 D^{-2}}$
- $F_{out} / F_{disk} = (a/D)^2 \sim \mathbf{10^{-4}} (D/1\text{Mpc})^{-2}$
- **EGRET**: **(1~3)x10^{-4}cm^{-2}s^{-1}sr^{-1} (>100MeV)**

  $\Delta\Omega = 0.1 \rightarrow \sim 10^{-5}$ cm^{-2}s^{-1}

  α = 2.2~2.6 → 10^{-11} ~10^{-13} cm^{-2}s^{-1}(>10TeV)

  x 10^{-4} → 10^{-15} ~10^{-17} cm^{-2}s^{-1}(>10TeV, 1Mpc)

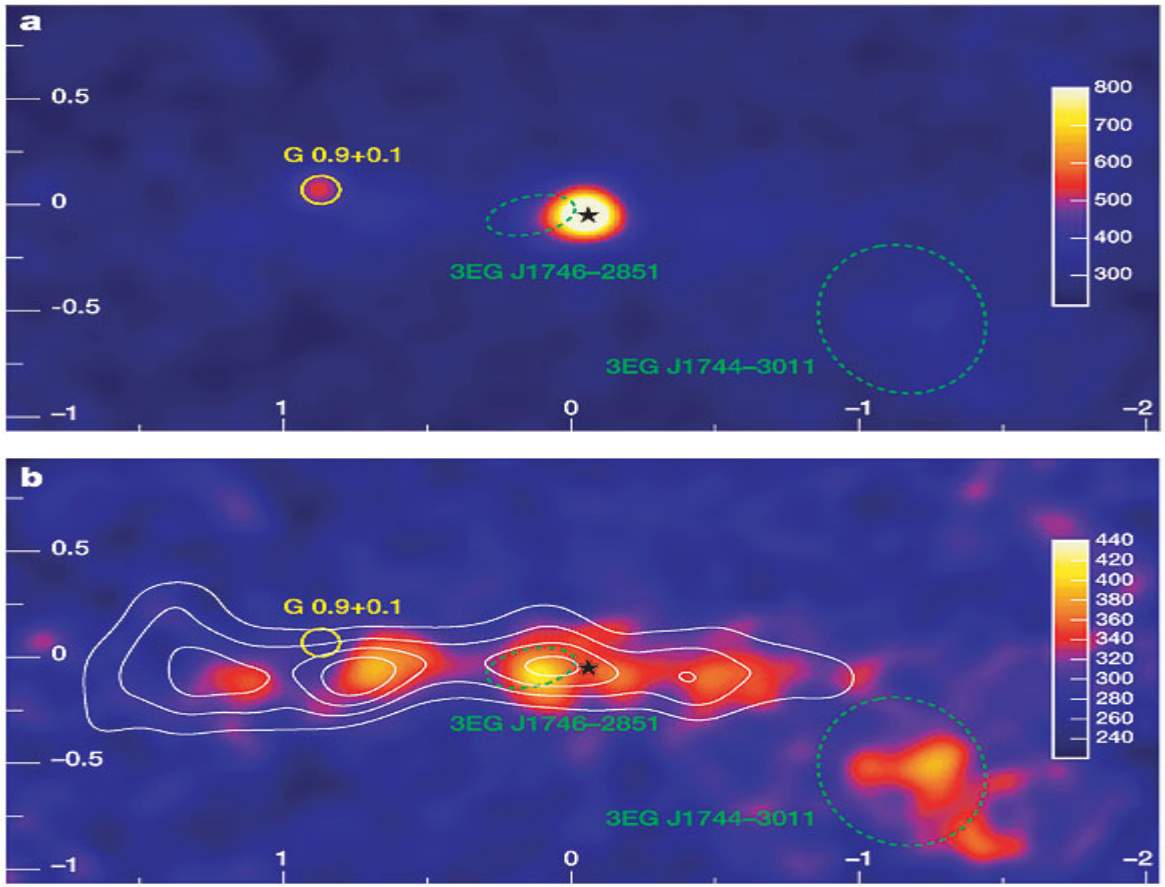
HESS : 10^{-9}cm^{-2}s^{-1}sr^{-1} (>10TeV) and Milagro

$\Delta\Omega = 0.1 \sim 0.01 \rightarrow 10^{-10} \sim 10^{-11}$ cm^{-2}s^{-1} (>10TeV)

x 10^{-4} → 10^{-14} ~10^{-15} cm^{-2}s^{-1}(>10TeV, 1Mpc)

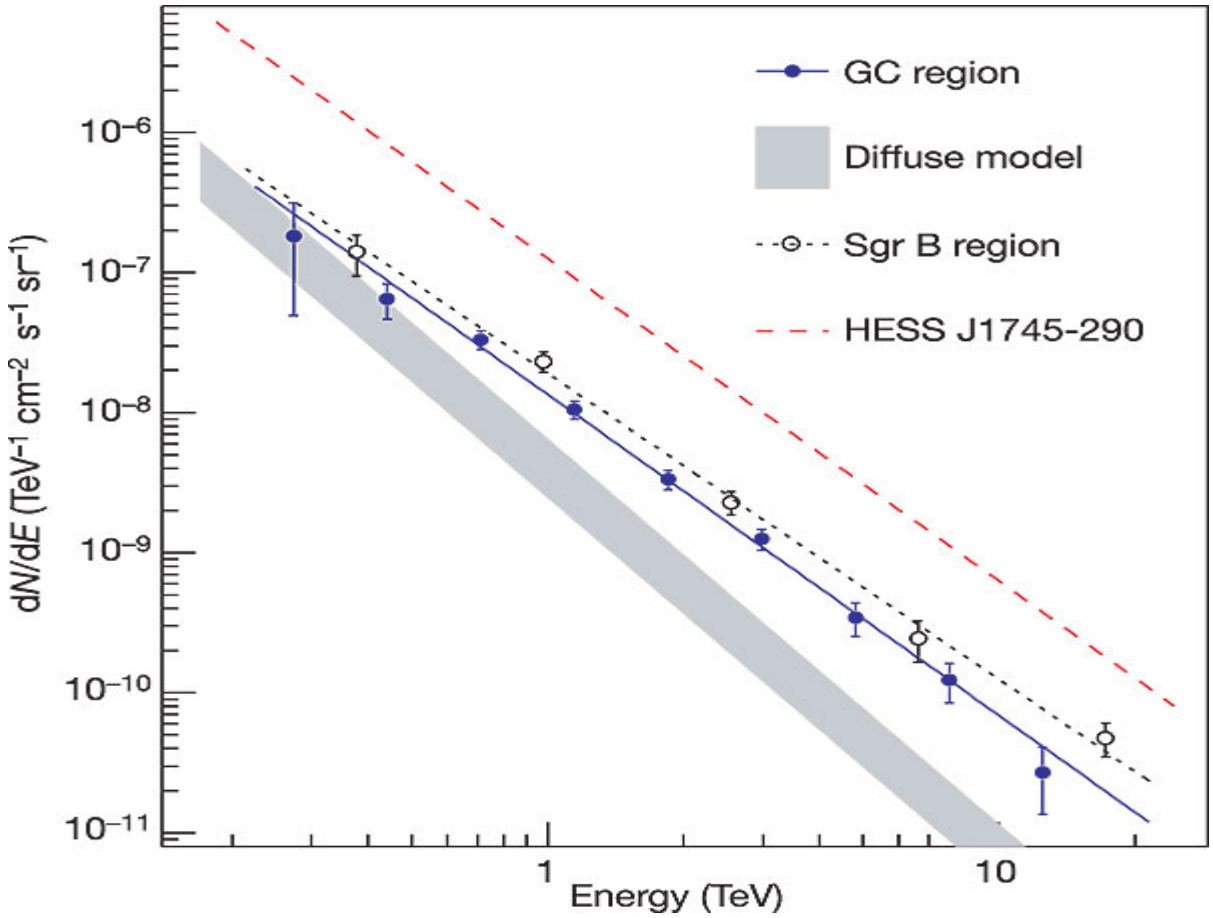
Survey for Galactic Sources And diffuse gamma rays

HESS observation



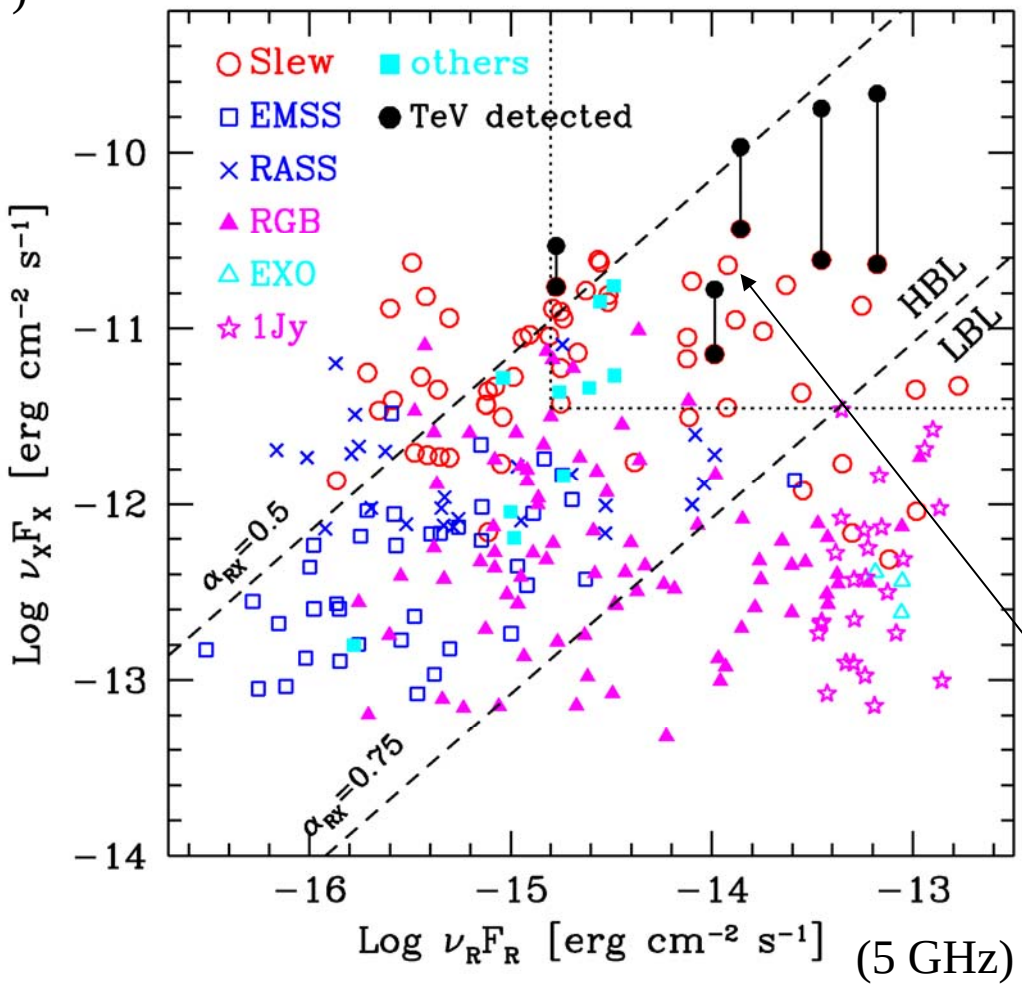
2×10^{-8} cm^{-2}s^{-1}sr^{-1} for > 1TeV

2×10^{-9} cm^{-2}s^{-1}sr^{-1} for > 10TeV



AGN : radio and X-ray flux

(1 keV)



(5 GHz)

Figure: L Costamante, PhD thesis, 2001

From left to right:

1ES1426+428

1ES2344+514

PKS2155-304

Markarian 421

Markarian 501

1ES1959+650

from VERITAS presentation

X-ray and TeV flux

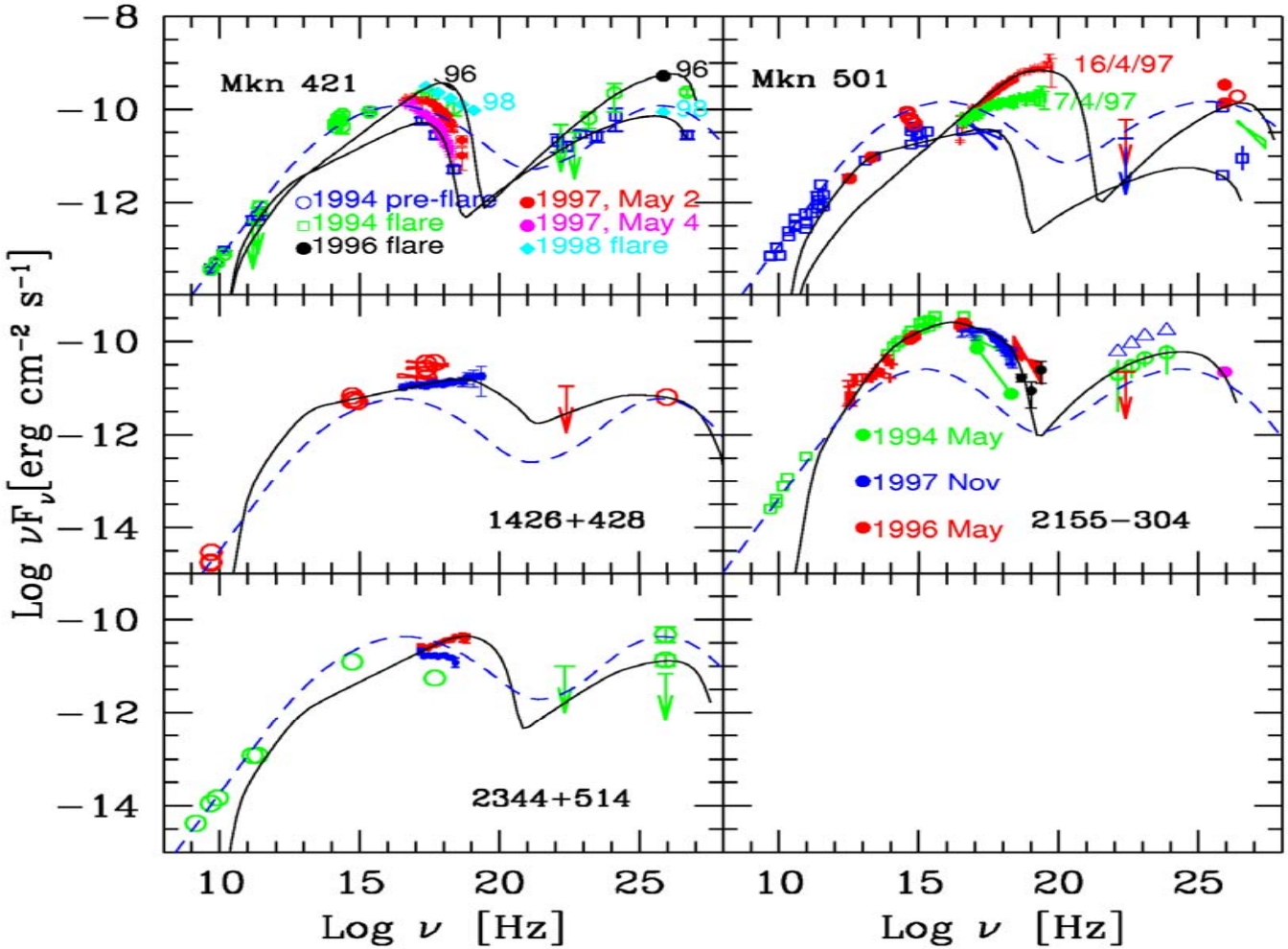


Figure: L Costamante, PhD thesis, 2001

Gamma rays from massive BH in the center of galaxy ?

- TeV Blazars

  $F_X \approx F_\gamma \sim 10^{-11} \sim 10^{-10}$ erg s^{-1} cm^{-2}

- Nearby galaxies

  Compact x-ray sources in the center of 21 out of 39 nearby face-on and spiral galaxies with available ROSAT HRI data, as to have

  L_X (2-10keV) ~ $10^{38} \sim 10^{40}$ erg s^{-1}

  F_X (2-10keV) ~ $10^{-13} \sim 10^{-11}$ erg $s^{-1} cm^{-2}$

  from Colbert and Mushotzky, Ap J (1999)

  $F_\gamma \sim 10^{-13} \sim 10^{-11}$ erg $s^{-1} cm^{-2}$??

>10TeV γ rays from nearby galaxies

- LMC 10^{-13}~ 10^{-15} $cm^{-2}s^{-1}$ extrapolated from EGRET
- **"normal galaxies" (similar to Milky Way Galaxy) at D = 1Mpc**

  10^{-14} ~10^{-17} $cm^{-2}s^{-1}$ estimated from EGRET and HESS

  - more gamma rays from more massive galaxies
  - Milky Way Galaxy :1.4 x 10^{11} Msun, LMC :1.0 x 10^{10} Msun, SMC :1.7 x 10^{9} Msun
  - SN explosion rate ,
  - Confinement time, …….

- **Starburst galaxy, active galactic nuclei of jet axis off line of sight, ….**

  galaxy nuclei having massive black holes

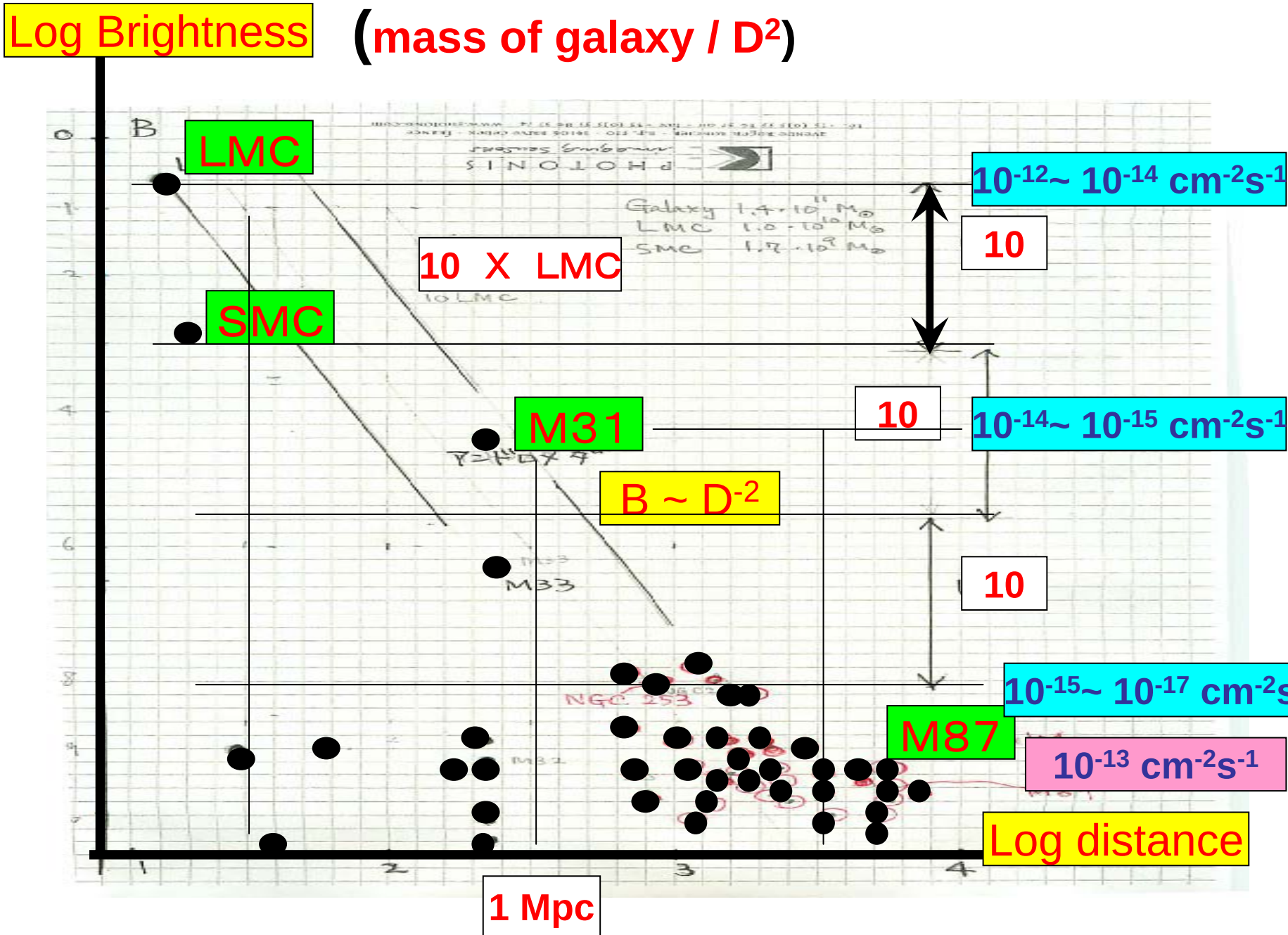
  10^{-14} ~ 10^{-12} $s^{-1}cm^{-2}$?

- M87 : **D=16Mpc, time variable TeV gamma ray? 10^{9} solar mass BH**

  HESS: ~ 10^{-13} $cm^{-2}s^{-1}$ **(LTeV = 3 x 10^{40} erg s^{-1}, F = 10^{-12} erg cm^{-2} s^{-1})**

- ***Blazars***

Brightness of nearby galaxy



Detection of galaxies at ~10Mpc?

$\sim 10^{-15}$cm^{-2}s^{-1}($\sim 10^{-14}$erg cm^{-2}s^{-1})

- Detection area of **100km^2**

  Observation of 100 nights are required even with **10km^2**

Or

- All sky monitor with ~ 1 sr FoV :

  100km^2 ≈ 10km^2 1 sr

  with more than 10 galaxies observed simultaneously

Ultra High Energy Cosmic Rays up to 10^{20}eV

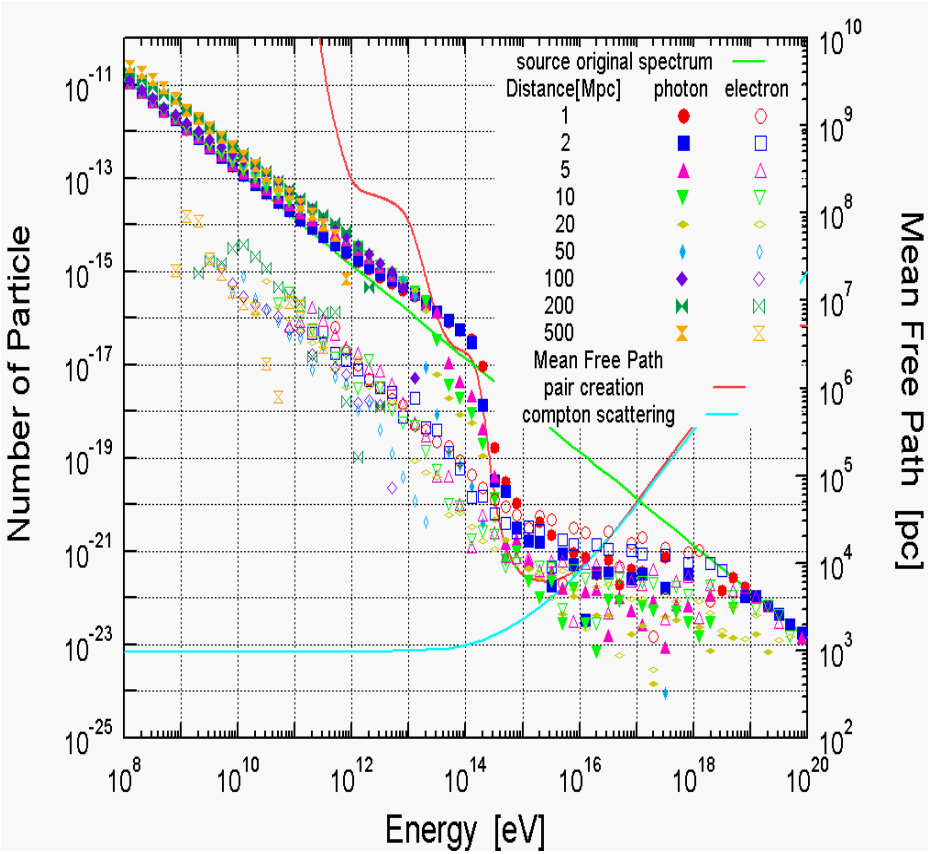
- GZK cutoff of energy spectrum ?
- Macro/micro anisotropy?
  doublet/triplet and point sources?
- AUGER results of the Southern sky ?

- 10-100 TeV gamma rays as a product of cascade processes in extragalactic space

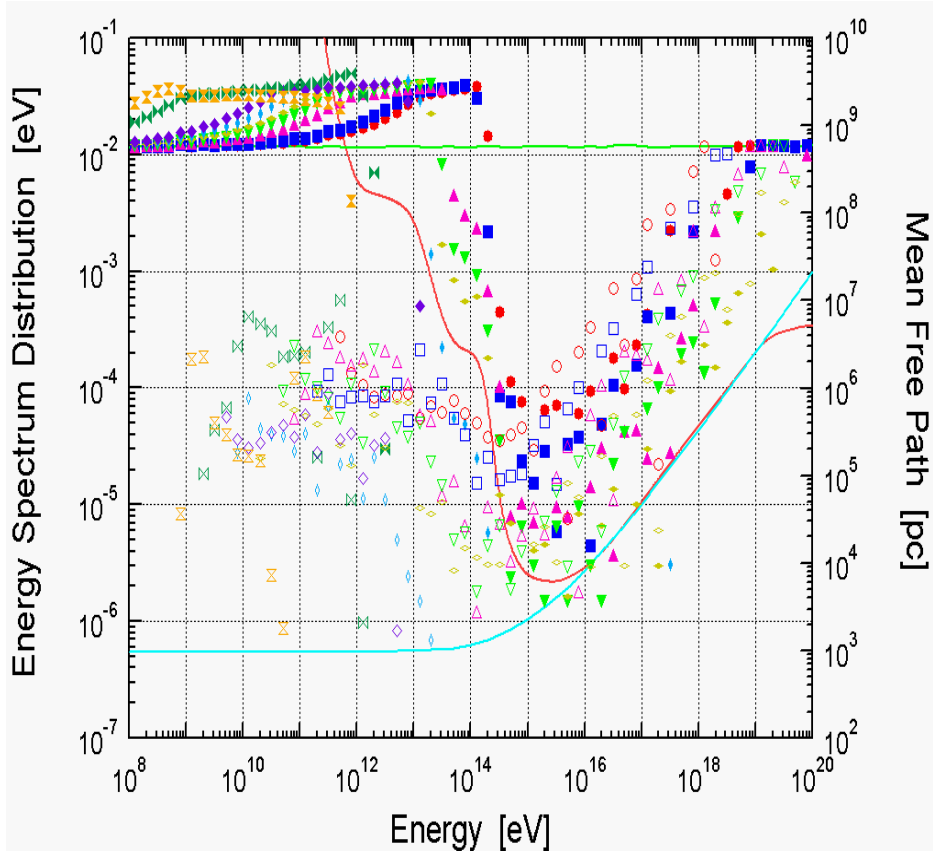
$$p + \varepsilon \text{ (ambient photon)} \rightarrow p + \pi$$
$$\pi^0 \rightarrow 2\gamma\,,\ \pi^{\pm} \rightarrow e^{\pm}\,\nu\,,$$
$$\gamma + \varepsilon \rightarrow e^+ + e^-,\ e^{\pm} + \varepsilon \rightarrow e^{\pm} + \gamma$$

Beyond the horizon?

Propagation of gamma-rays （α=2.0）



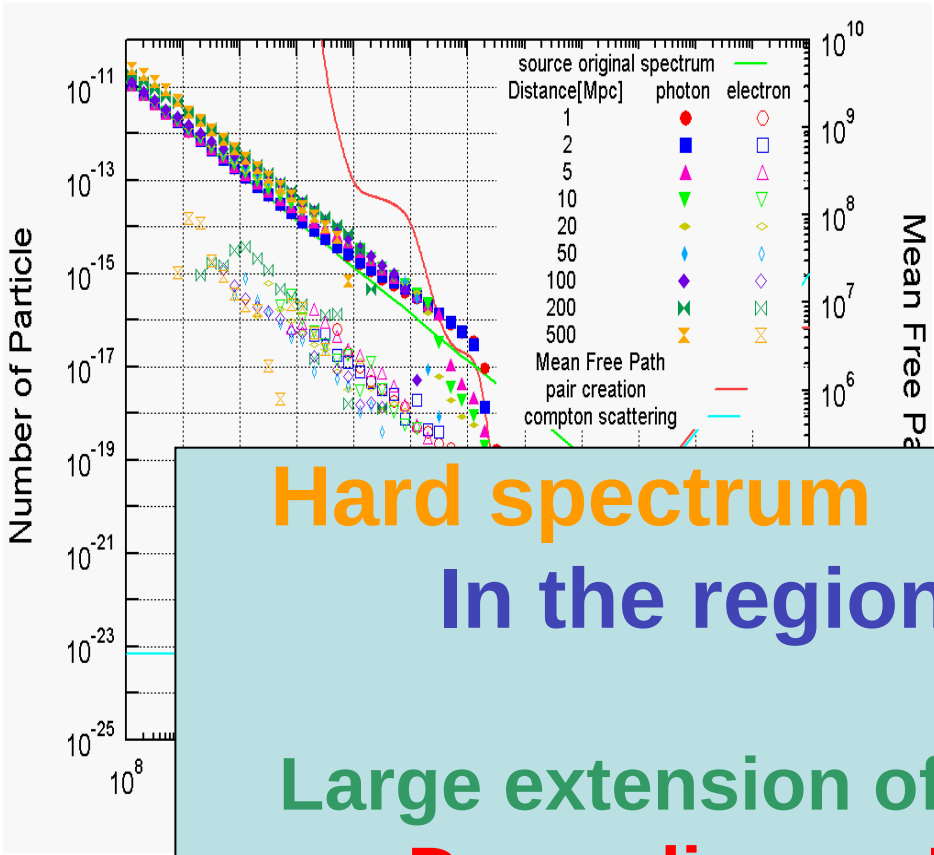
Distribution of photon number

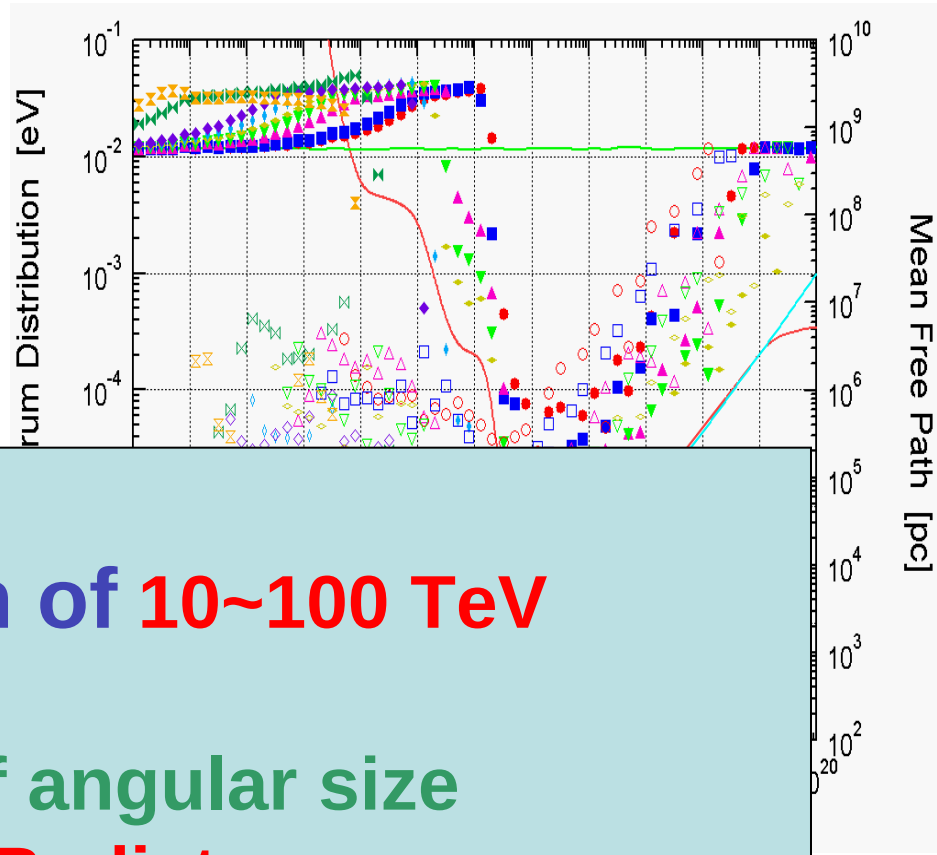


Energy

Beyond the horizon?

Propagation of gamma-rays （α=2.0）





Hard spectrum

In the region of 10~100 TeV

Large extension of angular size

Depending on B, distance, ……

Di

Energy flow of 10^{20}eV CRs

- **Flux of CRs >10^{20}eV**

  f = (0.5-5)x10^{-19}cm^{-2}s^{-1} (from all the sky)

  ≈ (one century · 1km^2)$^{-1}$ = 10^{-19}cm^{-2}s^{-1}

  F=10 eV cm^{-2}s^{-1} = 10^{-11} erg cm^{-2}s^{-1}

  One 10^{20}eV is equal to 10^8TeV photons,

  giving/corresponding to **TeV flux of ~ 10^{-11} erg cm^{-2}s^{-1}**

  if coming from only one source

- Number of sources

  F·4π D^2/L ~ 100 → 10^{-13} erg cm^{-2}s^{-1}

  for D=100Mpc, L = 10^{40}erg s^{-1}

Point Sources ?

- **Anisotropy, magnetic field, distance, ….**
- “Micro anisotropy”?

  8 doublets and 2 triplets

  out of 92 events (> 4x 10^{19}eV; AGASA, Fly’s Eye)

10^{-6} -10^{-5} Mpc^{-3} sources ; 10^{42}-10^{43} erg s^{-1}?

- If no anisotropy → Top-down mechanism?

Point Sources ?

- **Anisotropy, magnetic field, distance, ….**
- “Micro anisotropy”?

  8 doublets and 2 triplets

  out of 92 events (> 4x 10^{19}eV: AGASA, Fly’s Eye)

1 ?

TeV gamma ray
To solve the argued topics
of 10^{20}eV CRs

Estimate by numerical calculation

- **$F(E) = 7.4 \times 10^{-14} \cdot (L_{CR}/10^{43}\ \mathrm{erg\ s^{-1}}) \cdot (d/10\mathrm{Mpc})^{-2} \times (E/140\mathrm{TeV})^{-1/2}$ photons $\mathrm{cm^{-2}\ s^{-1}}$?**

  for $E < m_e^2/\varepsilon_{CMB} \sim 140\mathrm{TeV}$

  $\approx 10^{-13}$ photons $\mathrm{cm^{-2}\ s^{-1}}$ for 10 TeV

from Ferrigno, Blasi, De Marco,
Astroparticle Phys 23, 211 (2005)

~1sr FoV and “TenTen” ?

- **TenTeV 0.1 km^2 → TenTeV One km^2**
  → TenTeV Ten km^2

Better results from a system of more telescopes, and more telescopes may be brought by good results.
which will be the first? “Chicken” or “egg”?

- **To include 1sr IACT in the early phase (HAWC:0.02km^2)**
- **OneTeV 0.1km^2 (OneSr) : 1sr/10msr = 100 ~ number of objects in interest**
  TenTeV Onekm^2 (OneSr)
  TenTeV Tenkm^2 (OneSr)

- directions of 10^{19}-10^{20} eV CRs which are not known
- “Regenerated gamma rays” are likely extended
- Time variable objects like GRB

Conclusion

the flux of 10^{-14}~ 10^{-13} $cm^{-2}s^{-1}$ is expected

→ 100 ~ 1000 gamma ray photons

for

- **Nearby galaxies**

  M31 in the north and LMC and SMC in the south

  galaxies with active nucleus and at ~10Mpc

- **10^{20}eV CR sources if ~<100 sources**

However,

- **Most of "normal galaxy" at ~10 Mpc requires detection area > 10km^2**

One solution : ~1 sr FoV

“Origin of CRs”;

Milky way Galaxy
In comparison with many other nearby galaxies

high energy non-thermal process
of galaxies

L (M_{galaxy}) ? , type of galaxies ?, massive black hole ?
M_{galaxy} ~10^{10} · M_sun,
Why we have such a system of “galaxy” ?