Gamma-ray Astronomy, Origin of Cosmic rays, and Energy region higher than TeV

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- Status and Prospect for TeV γ-ray astronomy ? :
  ～10 sources will increase to ～100,
  and then ～1000 sources ?
- Origin of Cosmic Rays ?
- in the era of the new generation of IACTs
-
- Energy region from “knee” to “ankle”
- of cosmic rays ?

Motivation

- ASHRA and Purpose of this Work Shop?

- Ground-based γ-rays has abandoned the PeV region
  (Cyg X-3, Her X-1,...?) ; some day we shall return?

  Ultra High Energy Region:
  beyond TeV energy up to 10^{20}eV

- Only resident in the PeV region at present:
- Observation for Highest energy CRs,
- High energy neutrino
-
- Often said by neutrino people:
  "Final answer" for PP→πproduction
  will be given by neutrino detection
-

Origin of CRs:
why VHE region not share sources with EGRET?

- SNRs associated with EGRET unID
- Are they too old ?

  Cut-off energy of acceleration ?
  Is it consistent with CR spectrum ?

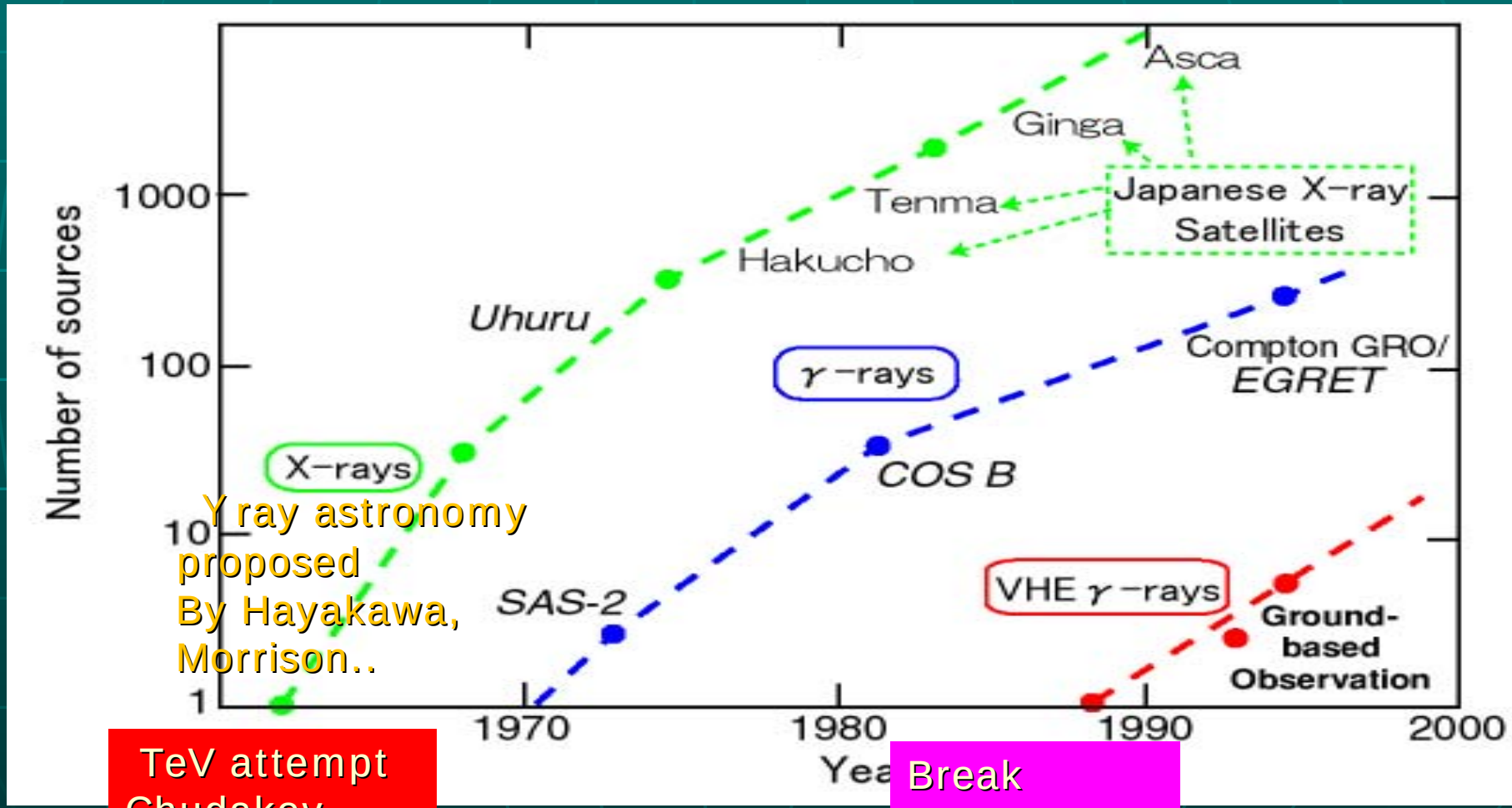
- Electrons as progenitor? : IC-synchrotron regime
- Point-like sources vs diffuse disc emission ?
  How can we identify “proton sources”?
-

New era of TeV γ-ray astronomy:

CANGAROO, H.E.S.S., MAGIC, VERITAS, ……

- Fine mapping of TeV gamma-ray sky with arc of minutes angular resolution
- Explore the energy region down below 100 GeV by challenging to huge aperture IACT

A decade of years, since TeV window was opened.



Y ray astronomy proposed By Hayakawa, Morrison..

TeV attempt Chudakov, Porter,。。。

Break through by imaging

1000 sources ?

- "all the factors integrated"
  at the age of 20 years old: X-ray:10^3, GeV γ :300
  ground-based telescope continually improved

- Extrapolation from other bands
  GLAST: ~10^4 (>5σ) from all sky survey
  Highest energy CRs ? (likely extended)

- SNRs : $10^{3\sim5}/10^2 \approx 10^{2\sim3}$
- Blazars: ~10^4 ; more with larger distances
- galaxies : s/s_0 ?
- GRBs : transient and ~10^3 per years
- unID (binaries, μ quasar,..?) : 10~100?

the goal of "Origin of Cosmic Rays" ?: "established" theories/models ?

- Proto-type of VHE γ-ray sources? : personal retrospect
  Kifune(1990:Astrophysical Aspects of the most Energetic CRs(Kofu Conf))
  Extrapolation from "EGRET SNRs" by $\alpha \approx 2.7$

- Standard model $\alpha \approx 2.0$???: γ-rays $\propto E^{-2}$ from SNRs?
  Naito, Takahara(1992);
  Drury, Aharonian, Völk(1992)

- Acceleration Region; Emission Regions (B, n_p,...); Near-by Region; .....
  something like a "Nested leaky box"
  Galactic Disc emission

- Confinement time; diffusion

- M.Oda: (1)Acc. Source? (2)Propagation?
  (3)Ptcl. Int.(phys.law; relevance to Evolution of Universe)
  All these are now not separately solved; mixed and integrated.

A “tough” but exciting time to overcome

Earlier detection to be confirmed

- SN1006: H.E.S.S. Upper Limit < 8% of CANGAROO flux
- How about other objects?

H.E.S.S., with better sensitivity at lower threshold energy, detected TeV sources from which CANGAROO had difficulty to obtain signal in spite of long-continued efforts :

- PKS2155-304 (necessary to be blessed by outburst)
- PSR1259-63 (emission only near at periastron?)

What will follow from now on (my private view) ?

$(4.6\pm0.6\pm1.4)\times10^{-12}$cm^{-2}s^{-1}: E>1.7±0.5 TeV
$(2.4\pm0.6\pm0.7)\times10^{-12}$cm^{-2}s^{-1}: E>3±1 TeV
(Tanimori et al. ApJ 497 L25(1998)

- Repeated observation of CANGAROO is going on with better $\Delta\theta$ and reduced $E_{threshold}$
- Details of H.E.S.S. result?

Estimation of the flu
- $\Delta\theta$: depending o source" or "exten
- Spectral shape as
- (Effects due to sk
- .....

Soft/hard spectrum
arc of minutes morphology
Correlation with X-rays
Or molecular clouds

The efforts for solving the above "problems" hopefully lead to
- better knowledge on the spectral shape and morphology of TeV γ-ray emission
- Confirmation of newer sources with improved sensitivity

Time and spatial scales, energy spectra, ….

Time variable signal from SNR etc ?
IC-synchrotron regime ?

- $\Delta x_{0.1pc}/c < 1$year
- τ_{acc} ; τ_{escape} ; $\tau_{energy\ loss}$;
-

$$dE/dt = E/\tau_{acc} - E/\tau_{loss}$$

$$dN/dt = -N/\tau_{escape} + D\Delta N$$

- $\tau_{sync} = 4 \cdot 10^{13} B^{-2}_{-6} E^{-1}_{10TeV}$ sec
- $\tau_{escape} = 3 \cdot 10^{8} \cdot B_{-6} E^{-1}_{10TeV} \cdot (\Delta x_{0.1pc})^{2}$ sec
-
- variation time scale of B ?
  small spatial (random) scale: turbulence
- jitter radiation

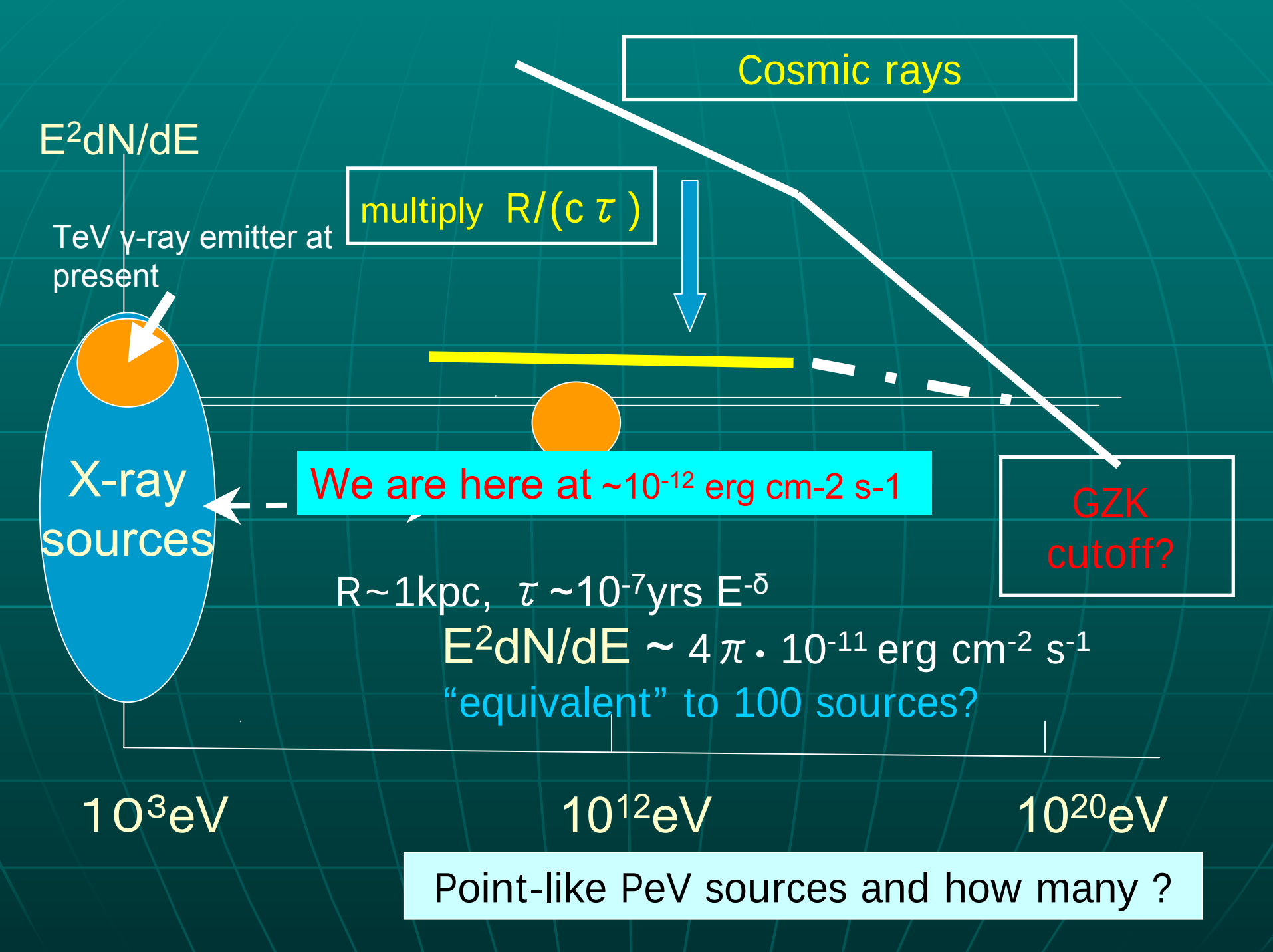
Origin of CRs: PeV~EeV region

- Retreat of gamma-rays in ~ 1990 from observing:
  Cyg X-3, Her X-1, Cen X-3; GRB, SGR,....
  Akeno, CASA, HEGRA, ...

- ν and gamma rays from GZK cutoff ?
- Cosmic rays still exist …….
- GRB, blazars, ……..
-

Can we expect point-like sources at energies higher than TeV ?
(1) limited size of SNRs

- π^0 γ-rays and ν require sufficient matter,
  Is it available in acceleration region?
  $\tau_{escape} \sim x_0^2/D \sim E^{-\delta}$, thus
  emission is likely to be
  more extended at higher energies and
  to be merged in disk emission
- Consisitency with γ-ray observation at lower energies
  - neutrino?
  - morphology:angular resolution
  - disc emission of ν ?


Cosmic rays
E²dN/dE
multiply R/(c τ)
TeV γ-ray emitter at present
X-ray sources
We are here at ~10-12 erg cm-2 s-1
GZK cutoff?
R~1kpc, τ ~10-7yrs E-δ
E²dN/dE ~ 4π・10-11 erg cm-2 s-1
"equivalent" to 100 sources?
10³eV
10¹²eV
10²⁰eV
Point-like PeV sources and how many ?

Can we expect point-like sources at PeV energies ?

(2) limited active time of SNRs: Eacc < knee

- Acceleration by Shock of Galactic scale

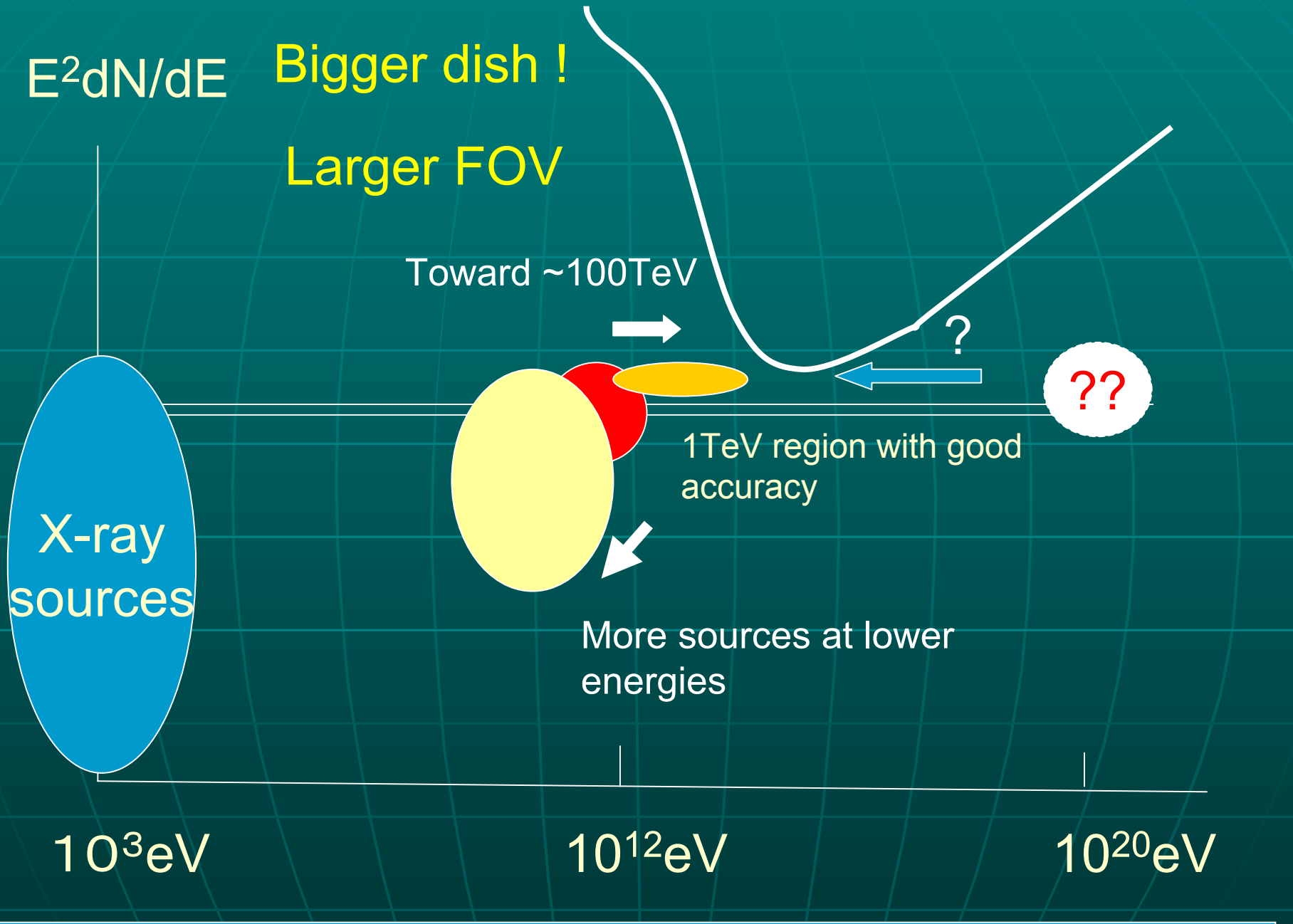
$10^{3\text{-}4}$yrs, and Eacc < 10^{15}eV? Modification of standard theory ?

- acc<10^{15}eV? Modificatiion of standard theroy ?
- $10^{3\text{-}4}$ yrs
- radiation by shock of Galactic scale

  Galactic wind from e.g. GC

  reacceleration?
- X-ray binaries such as Cyg X-3

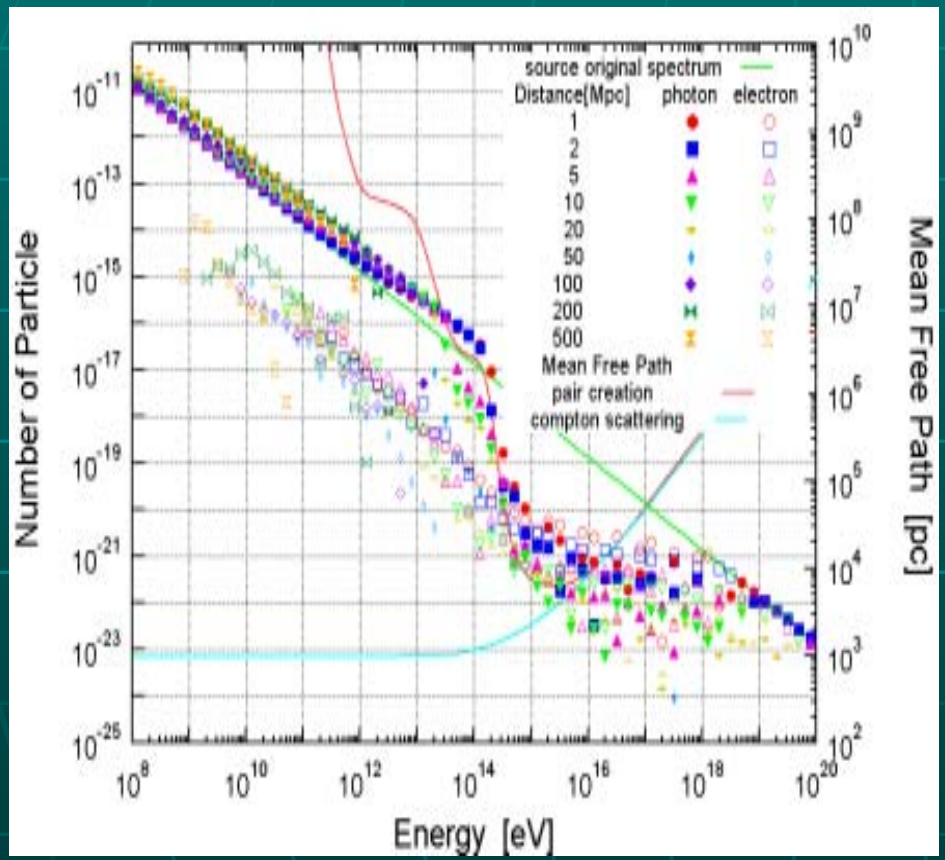
  Transient sources ?
- Extragalactic sources


E²dN/dE
Bigger dish !
Larger FOV
Toward ~100TeV
?
??
1TeV region with good accuracy
X-ray sources
More sources at lower energies
10³eV
10¹²eV
10²⁰eV

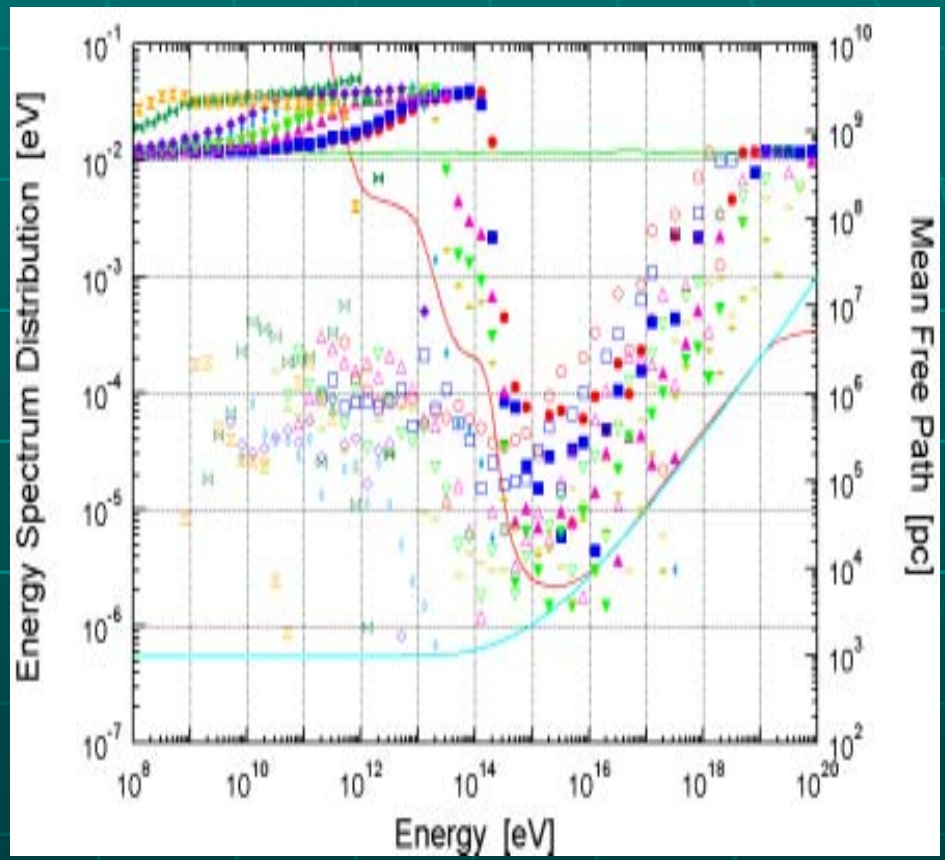
Cascade in cosmic space

- 10-100 TeV
- Angular spread
- B in extraglactic space?

シミュレーション結果1　α=2.0



個数スペクトル分布



エネルギースペクトル分布

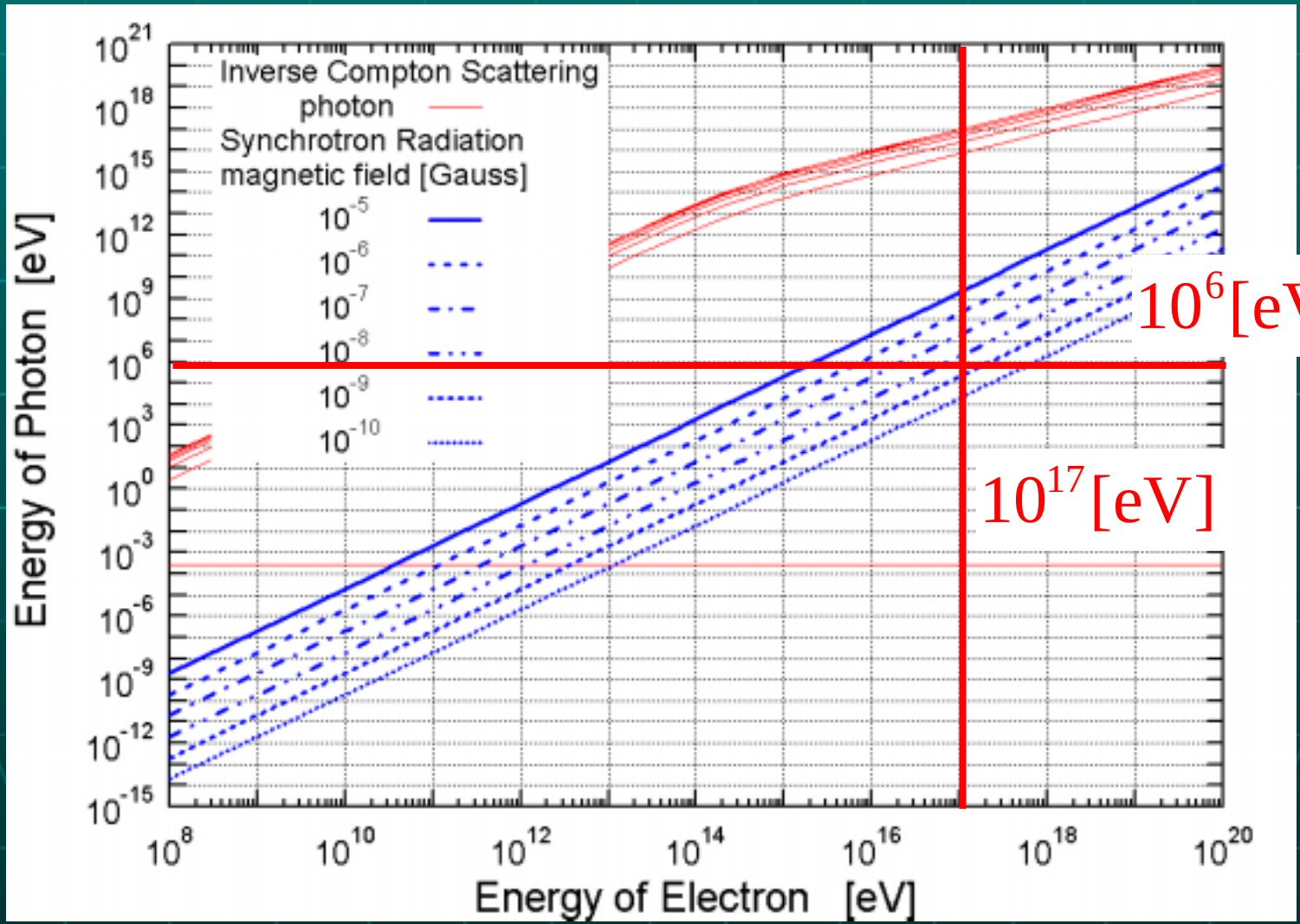
EeV electrons emit radiation at longer wavelengths

- Synchrotron radiation
- Cascade of electrons and gamma-rays
- Synchrotron radiation

  $K_{sync} \approx 2 \cdot 10^6 \, B_{-10} \, (E_e/1\mathrm{EeV})^2$ eV

  E^{-1} spectrum

IC and synchrotron radiation



summary:
sources beyond TeV energy

- 10^{-12} erg cm^{-2} s^{-1} from all the sky ?
- Absorption by 2.7K NWB and
  the Effect of ”cosmic cascade”
  energy spectrum, angular size, B-field,
  .....

Scheptical about neutrino

Morphology of gamma ray sky

- Galactic sources:
  not easy to expect
  transient and unknown population of sources
  mapping of good angular resolution necessary
- Extragalactic case:
  - Normal galaxies : better sensitivity required
  - AGN/GRBs etc.
  - Absorption effect : neutrino !

A personal view to my liking

- Wide FoV IACT of arc of minutes resolution
  A realistic path to 10^3 sources :
  factor of $10^3 = \Delta\Omega/\Delta\Omega_0$
  some notable resultants
  - ◊ diffuse/extended objects
  - ◊ transient phenomena
  - ◊ explore higher energies with “small” dishes

- Use for bridging TeV and highest energy CRs
  (easier, inexpensive)

- Of course, the main stream is to achieve
  novelty in technique; to be always pursued
  huge dishes: promising path but expensive

Questions to ASHRA

- ASHRA challenges what?
  - GZK neutrino shower ?
  - gamma rays above TeV ?
  - .....

On the above depends

- What will be to be concluded.

Conclusion

- 100 sources: Galactic
  1’ mapping of TeV sky
  spectral index α, cutoff energy?
  SNRs as extended sources
  extension will increase with energy
  CBS of X-rays: proton & transient ?
- CBS of X-rays: proton & transient ?
- 1000 sources: extragalactic
  Deeper observation at large distances
  structure formation; 宇宙進化と加速； B の起源