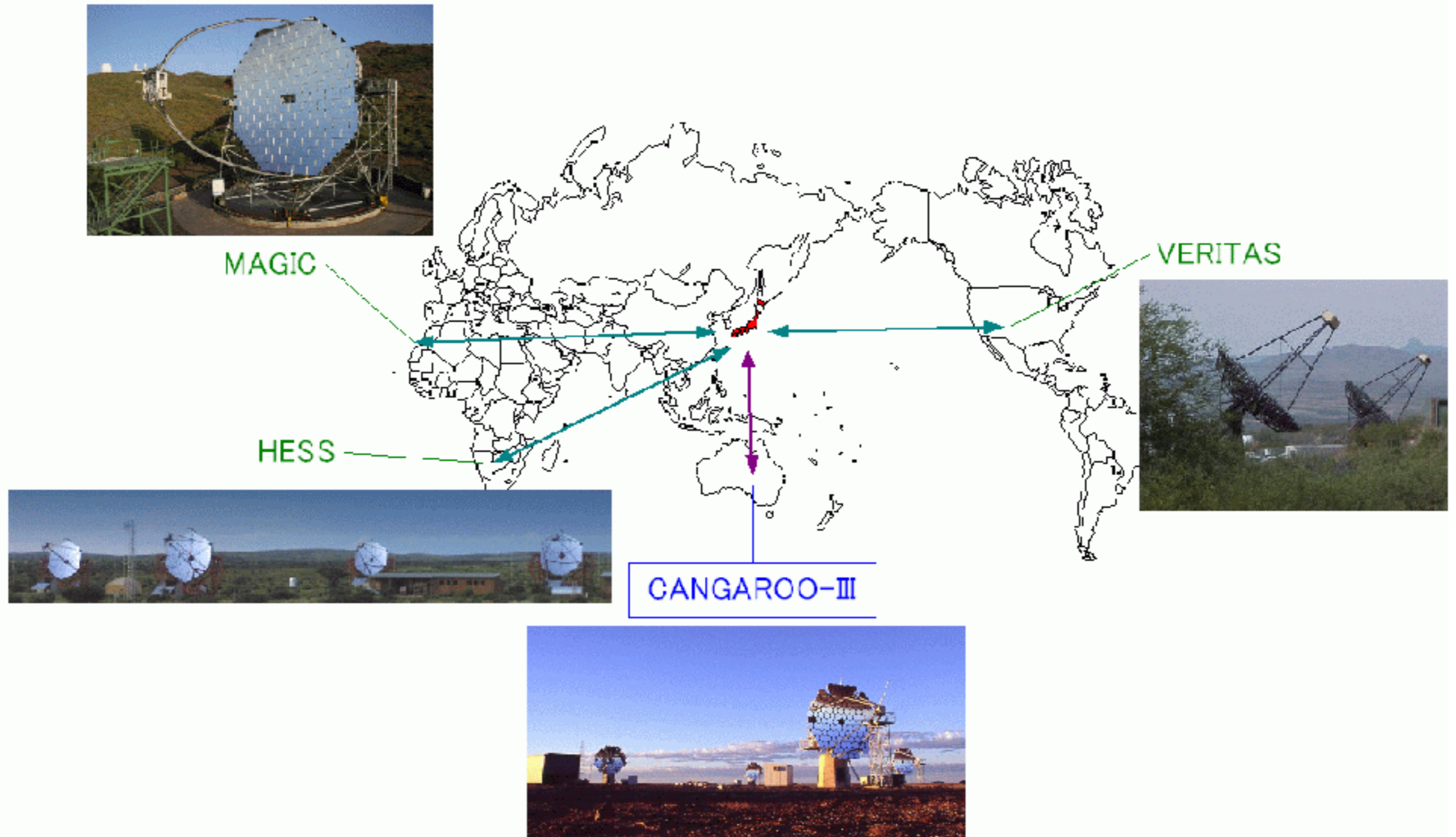


# 大気チェレンコフ望遠鏡による 宇宙線起源の研究： 現状と将来計画

吉越貴紀@東大宇宙線研

2006年8月31日@100 TeV 研究会

# 現状：解像型大気チェレンコフ望遠鏡ネットワーク



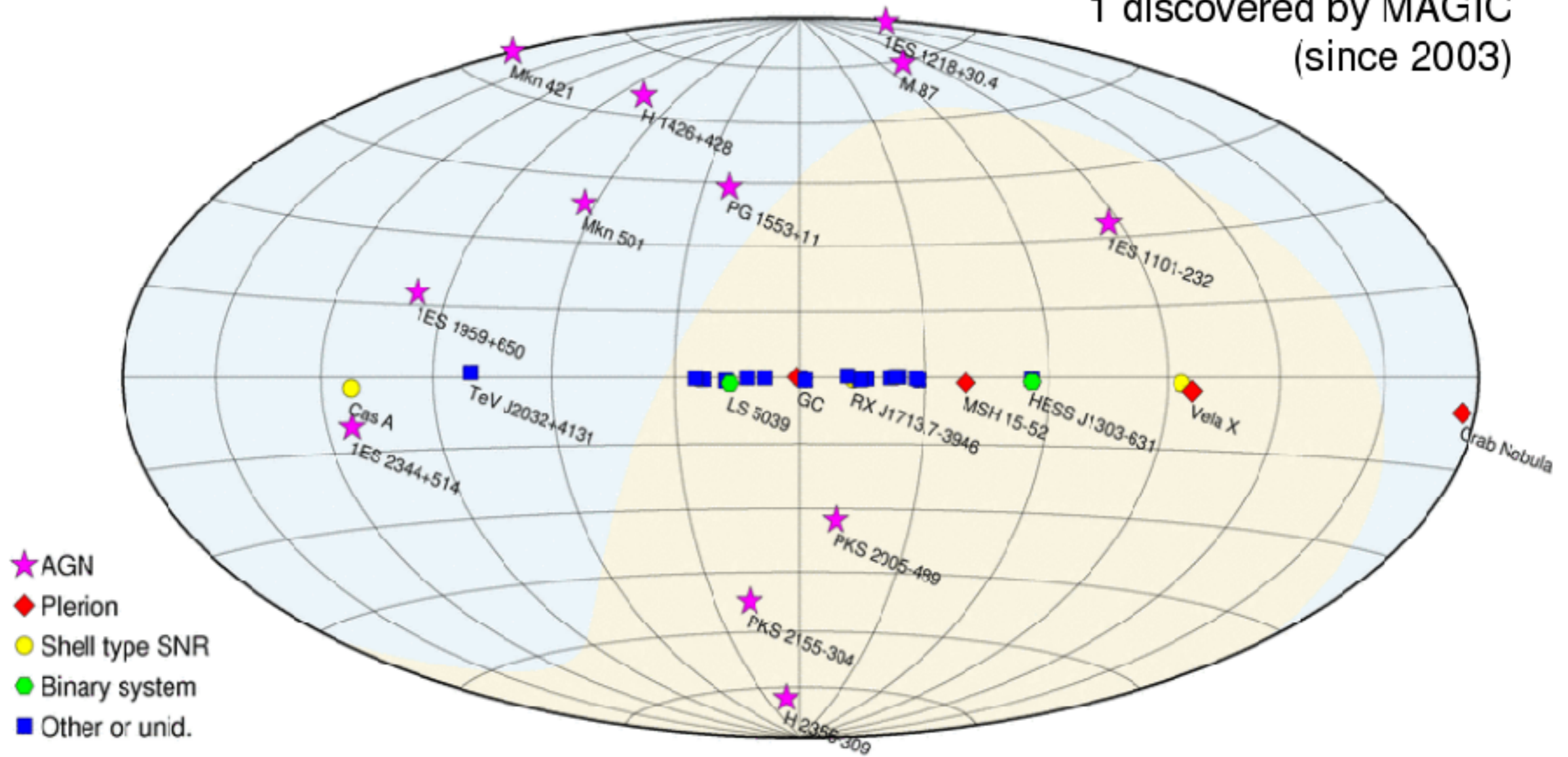
# ~ 40 TeV Gamma-Ray Sources in 2006

## The High-Energy Gamma Ray Sky (2006)

39 sources ( $E > 100$  GeV)

(Galactic coordinates)

28 discovered by H.E.S.S.  
1 discovered by MAGIC  
(since 2003)



Background colours indicating northern / southern sky

# TeV ガンマ線天体の内訳

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## ■ Extragalactic: 13

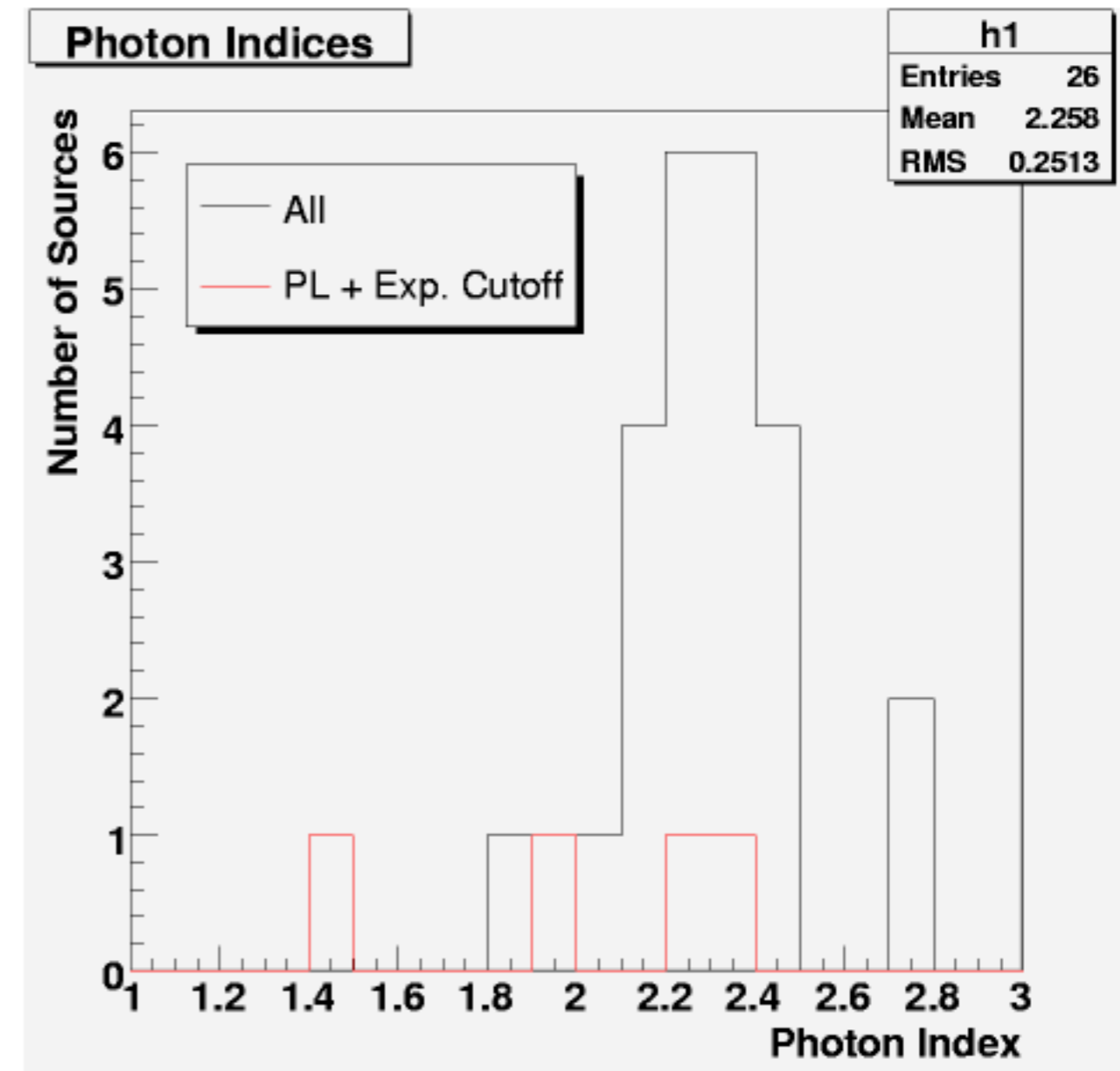
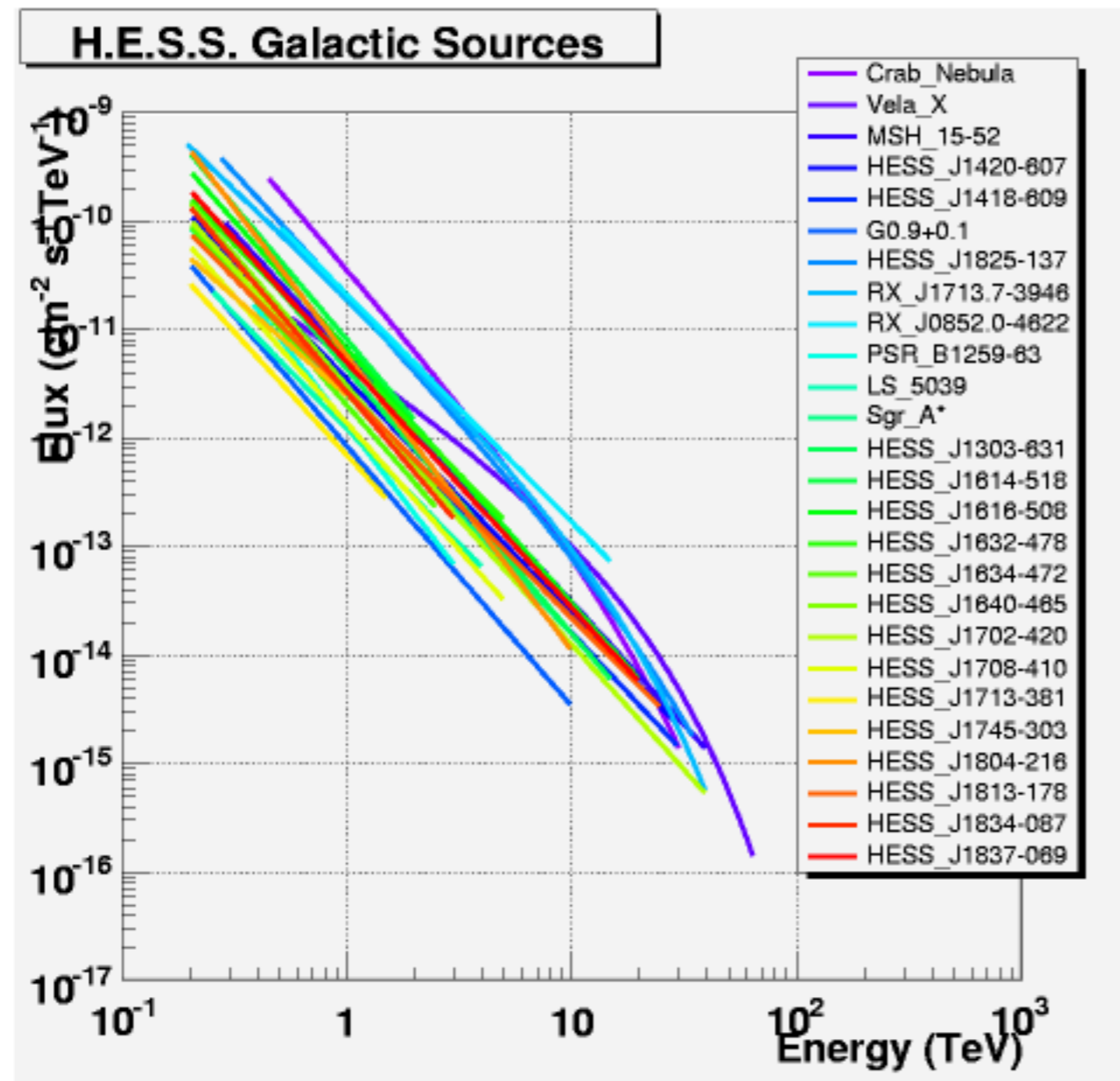
- Blazar: 11 (Mkn 421, Mkn 501, ...)
- Radio galaxy: 1 (M 87)

## ■ Galactic: 30

- Plerion (PWN): 6 (Crab, Vela X, MSH 15-52, Kookaburra, ...)
- Shell Type SNR: 3 (RX J1713, RX J0852, Cas A)
- Binary: 3 (PSR B1259, LS 5039, LS I +61 303)
- Diffuse: 2 (GC Region, Cygnus Region)
- Other / UnID: 16 (GC + H.E.S.S. Survey (10) + UnID (5))

# Galactic TeV Sources: H.E.S.S. Spectra

## ■ 全体的に硬いスペクトル



# ガンマ線観測による宇宙線の起源

## ■ シェル型超新星残骸は宇宙線起源か？

- 陽子起源ガンマ線を捕える（電子起源を分離）

## ■ 3 つの strategy:

- ガンマ線スペクトルの精密測定 + 多波長スペクトル
- ガンマ線 morphology の精密測定 + 多波長比較
- ガンマ線スペクトルの高エネルギー端の観測
  - ▶ 電子起源スペクトルの cutoff (cooling, Klein-Nishina)

## ■ 超新星残骸による宇宙線加速は普遍的か？

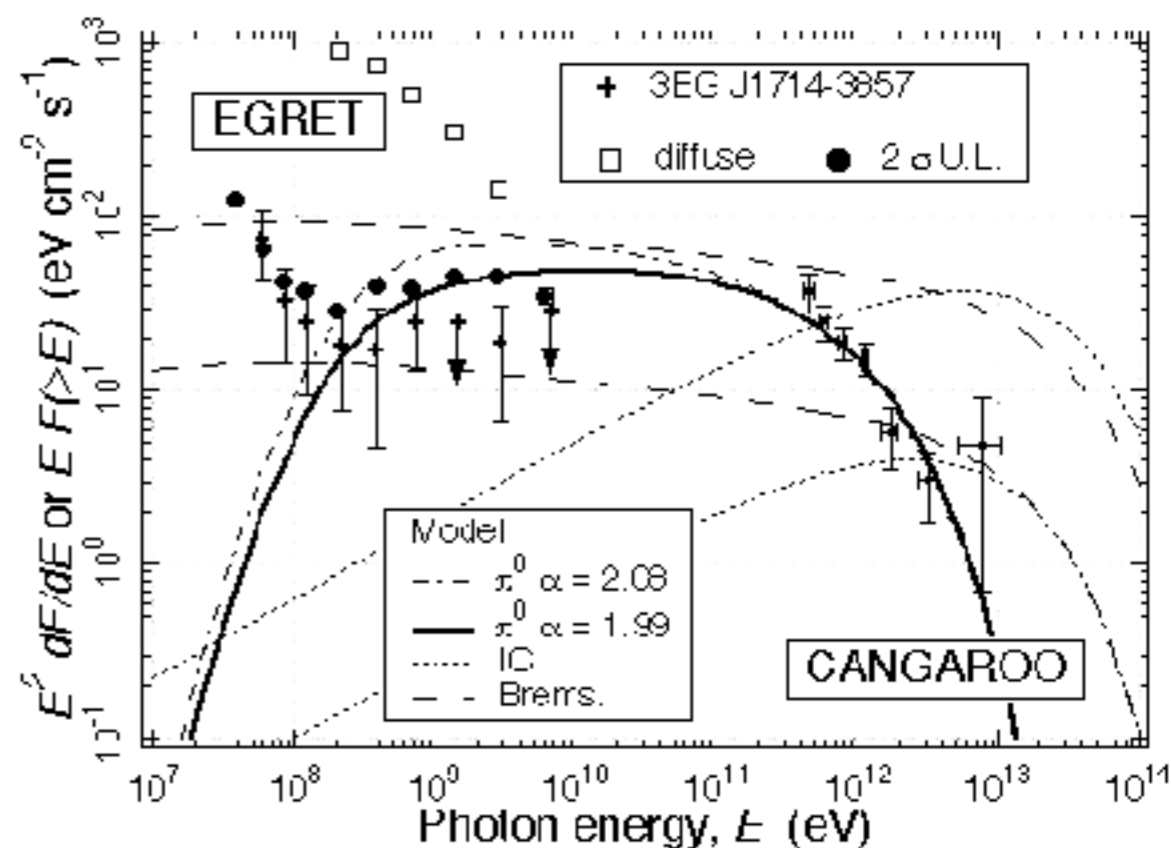
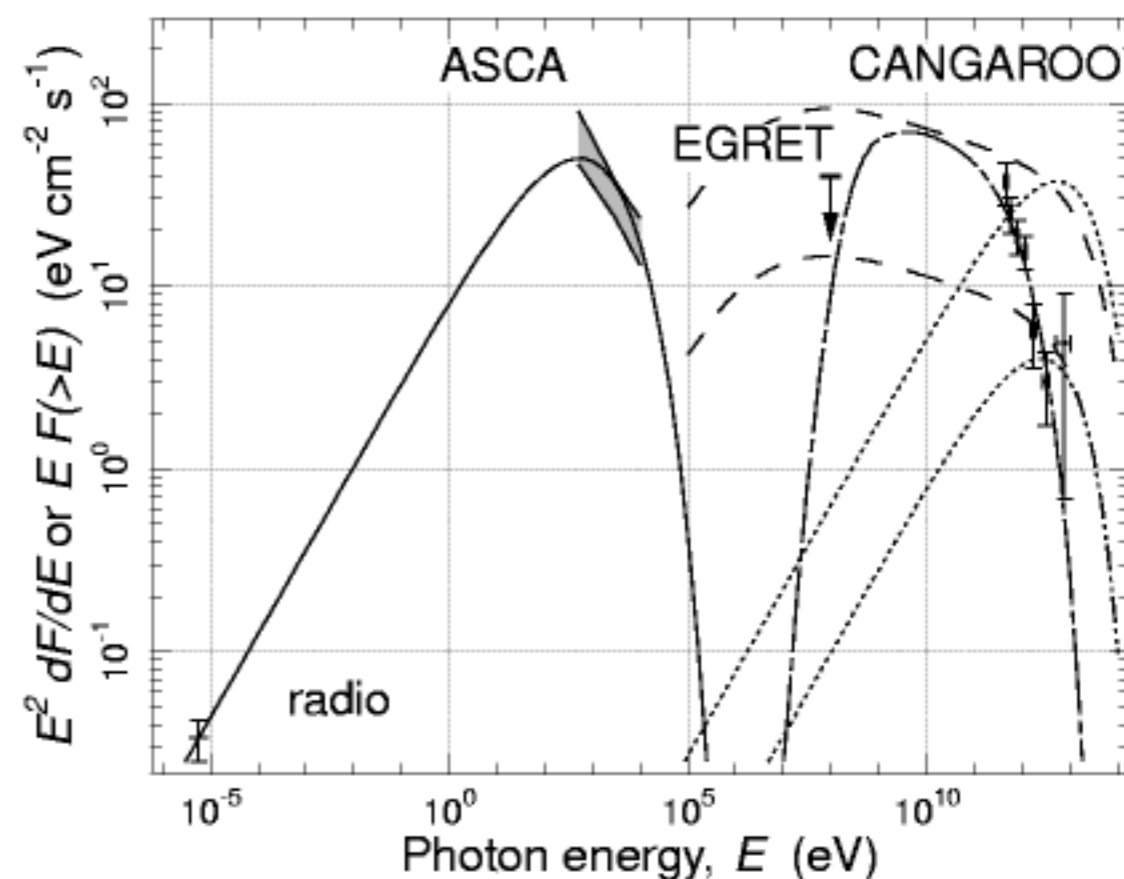
- 天体数を増やす → エネルギー収支
- 他銀河の観測

## ■ 超新星残骸による加速限界

- Knee まで説明できるか？

# RX J1713 の観測 (CANGAROO-II)

- 陽子／電子成分分離の最初の例
- Debate after the Nature publication
  - EGRET 上限値と矛盾?
  - Two zone model?



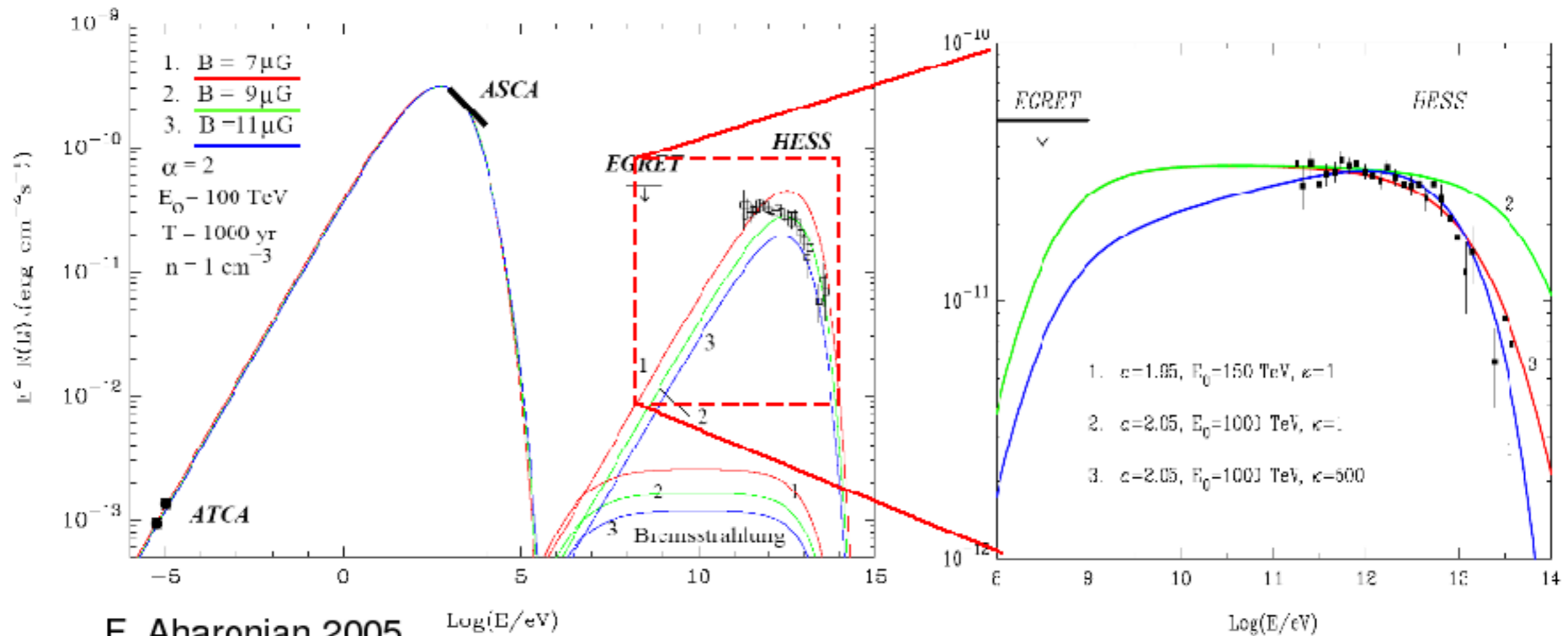
# RX J1713 の観測 (H.E.S.S.)



## Emission model for RX J1713

### Leptonic Model

### Hadronic Model



Leptonic Model seems to be unlikely; low B-field vs fine filaments

Larger lever arm in energy needed (low and high Energy)

What is the maximum energy ? The knee ?



# RX J1713 の観測 (H.E.S.S.)

## ■ Morphology

- X 線の結果 (ASCA) と酷似  
→ 電子起源?

## ■ 更に高角分解能での形態比較

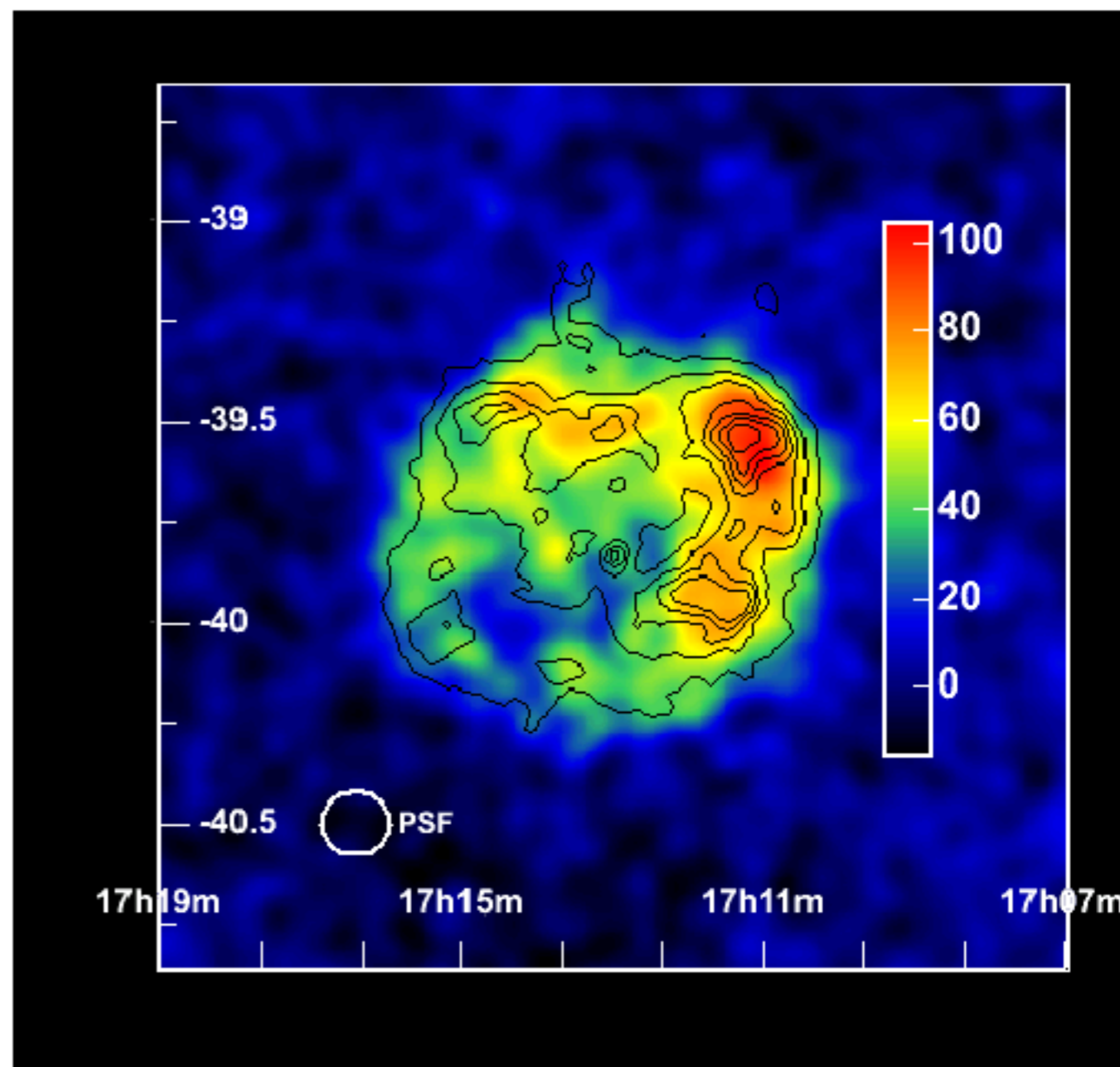
- X 線: Chandra → high B  
→ 電子起源×?
- ガンマ線: ?

## ■ GLAST の観測が鍵

- 2007 年打ち上げ

## ■ Cutoff @ 12 TeV

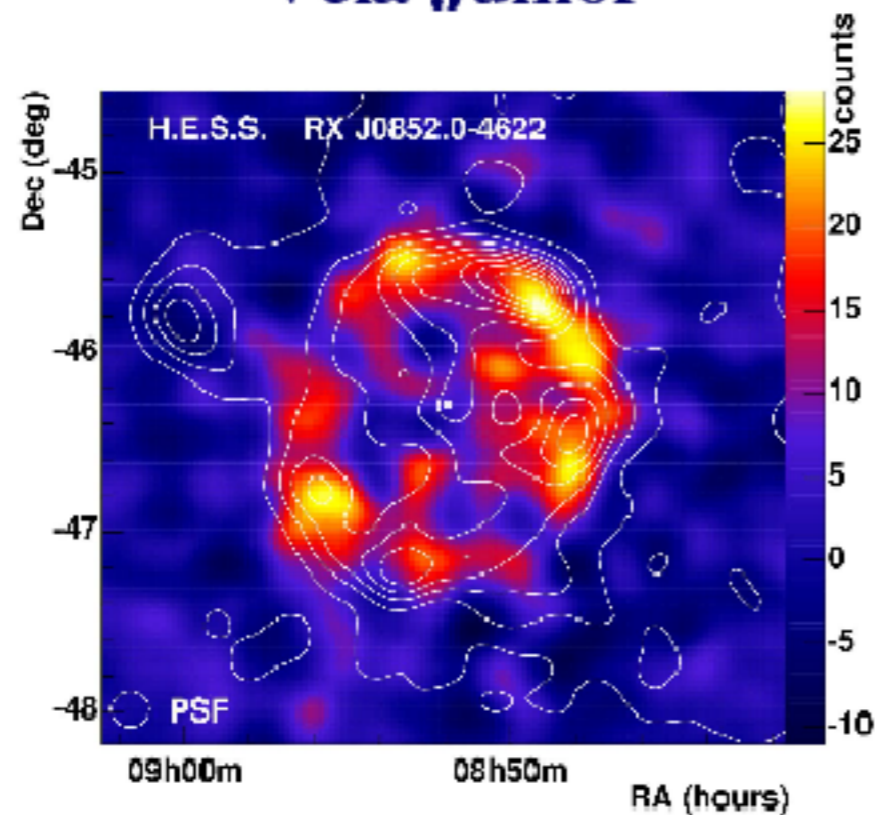
- Knee までは説明出来ない



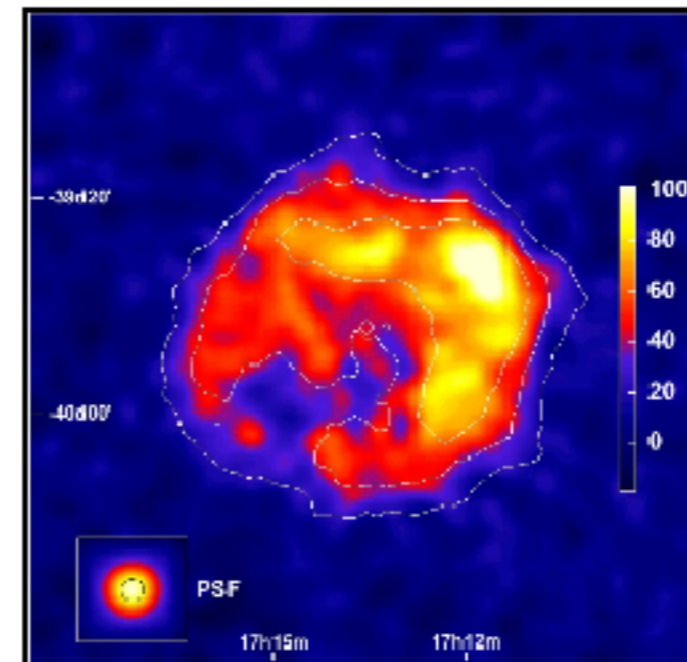
# More TeV SNRs?

two young “1Crab” strength shell type SNRs

**Vela Junior**



**RXJ1713.7-3946**



*flux and spectrum - similar, morphology - rather different*

# 進行中の計画

## ■ H.E.S.S. II

- 口径 28 m
- 15 ~ 25 GeV threshold
- 2008 年完成予定



## ■ MAGIC II

- 2 基目を建設中
- Advanced photodetectors
  - ▶ HPD
  - ▶ Silicon PM



## ■ Cherenkov Telescope Array (CTA)

- H.E.S.S. - MAGIC joint project
- 予算規模 150 M ユーロ

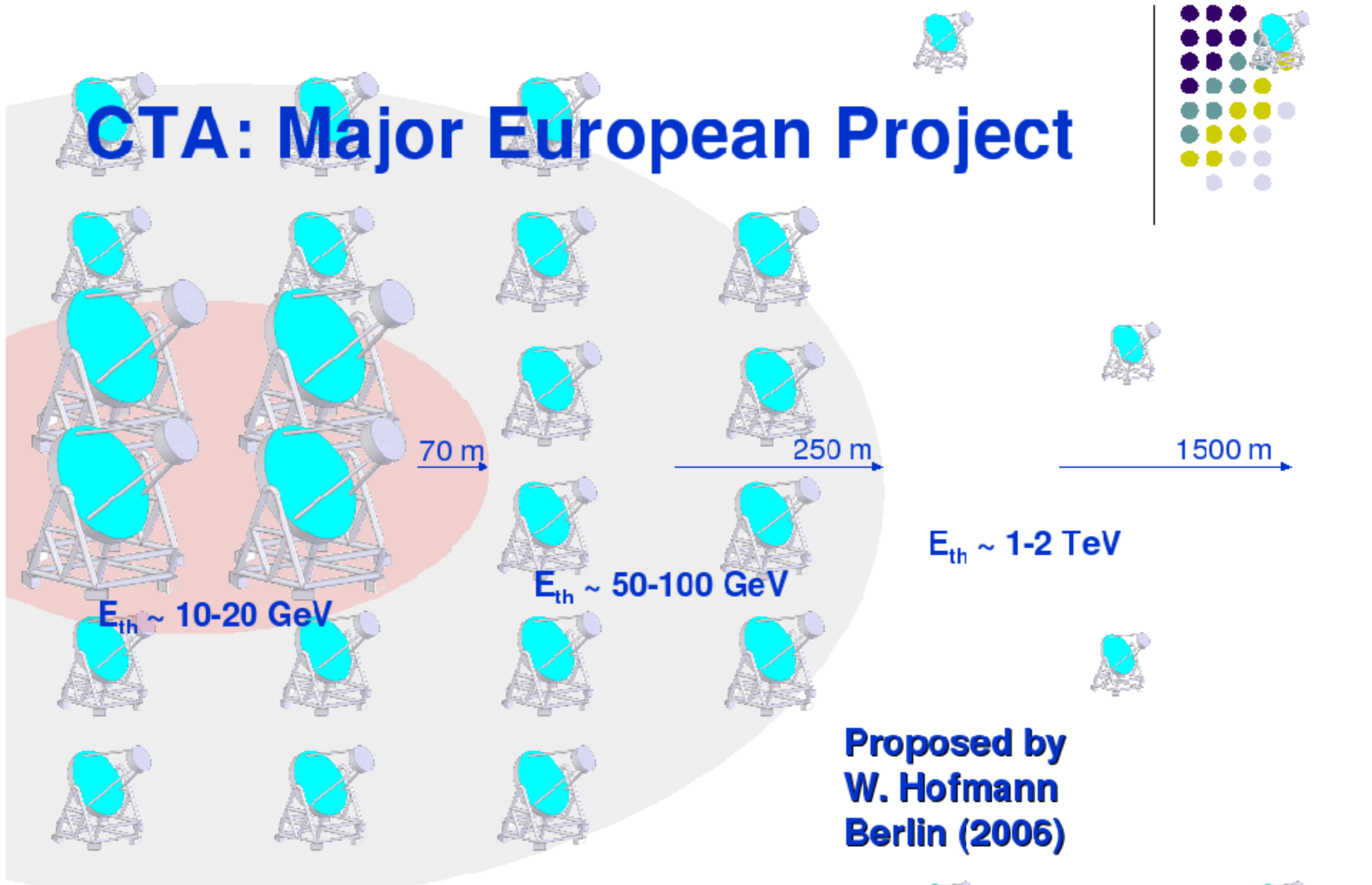
## ■ TenTen

- High energy ( $> 10$  TeV) に特化した Cherenkov telescope array
- Adelaide グループ中心

## ■ Track Imaging Cherenkov Experiment (TrICE)

- "Direct Cherenkov" from primary → 化学組成の測定
- Argonne, Chicago, Utah

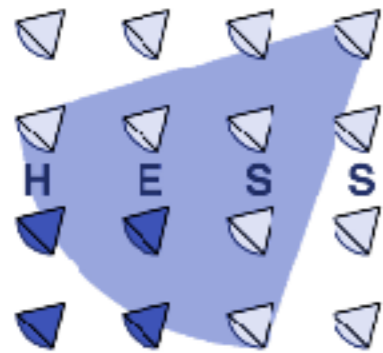
# Cherenkov Telescope Array (CTA)



Santa Fe, May 11-12, 2006

Workshop: "Ground-based Gamma-ray  
Astronomy: Towards the Future II"

A. Konopelko @ Santa Fe Workshop (2006)



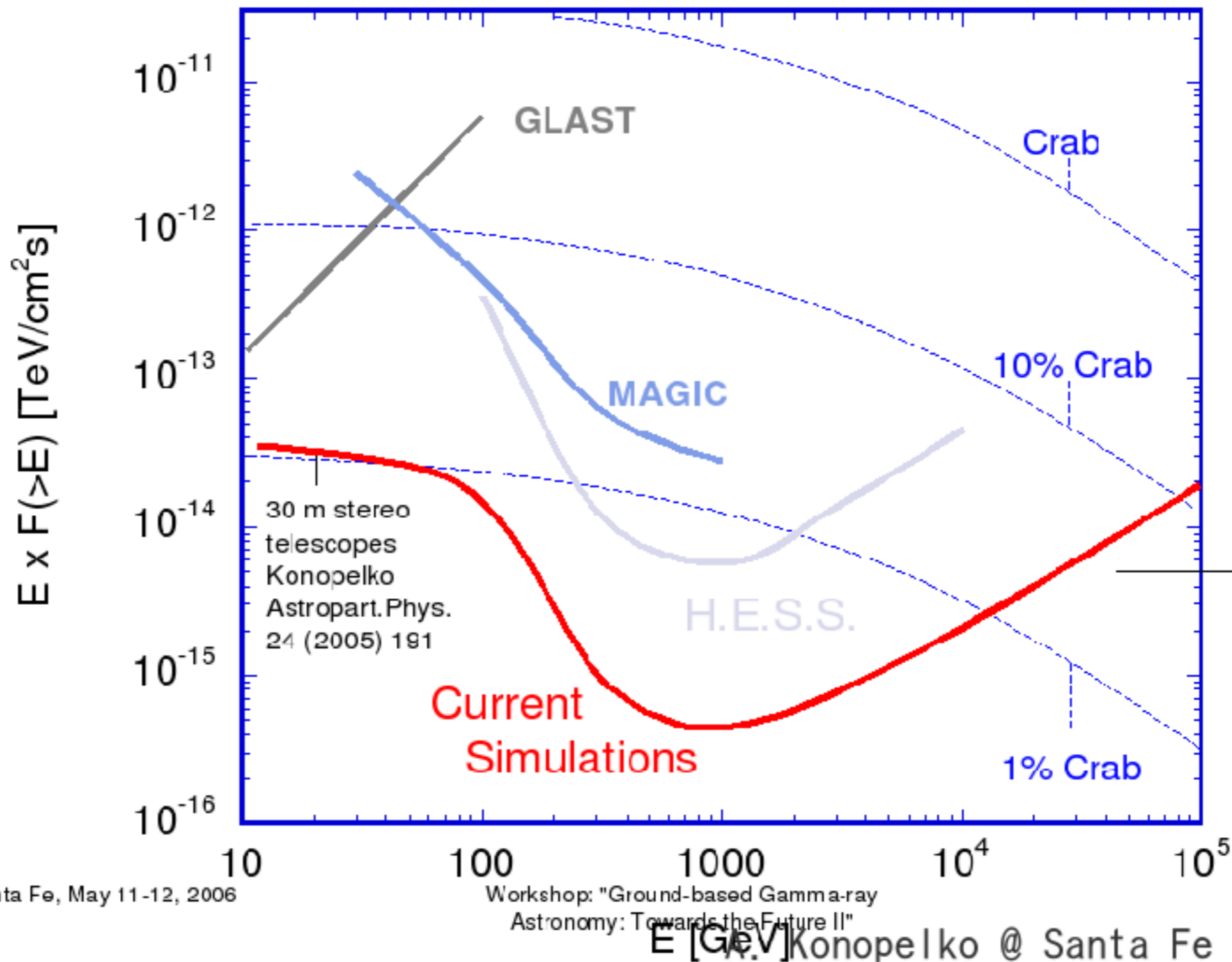
## H.E.S.S. - MAGIC – CTA meeting

Berlin, May 4-5, 2006



- 1) Identification of **common physics goals** / interests.
- 2) **Definition of a procedure** to find out which possible designs of a future observatory could meet the physics goals ?
- 3) Identification of **criteria to evaluate** possible designs.
- 4) Implementation of common **working groups** and definition of their **tasks**.
- 5) Last not least:  
**bring together** people who work in the same field, but (still) in different experiments

## Sensitivity of CTA



W. Hofmann  
CTA Talk  
(2006)

20 wide-angle  
10 m telescopes  
de la Calle  
Perez,  
Biller, astro-ph  
0602284

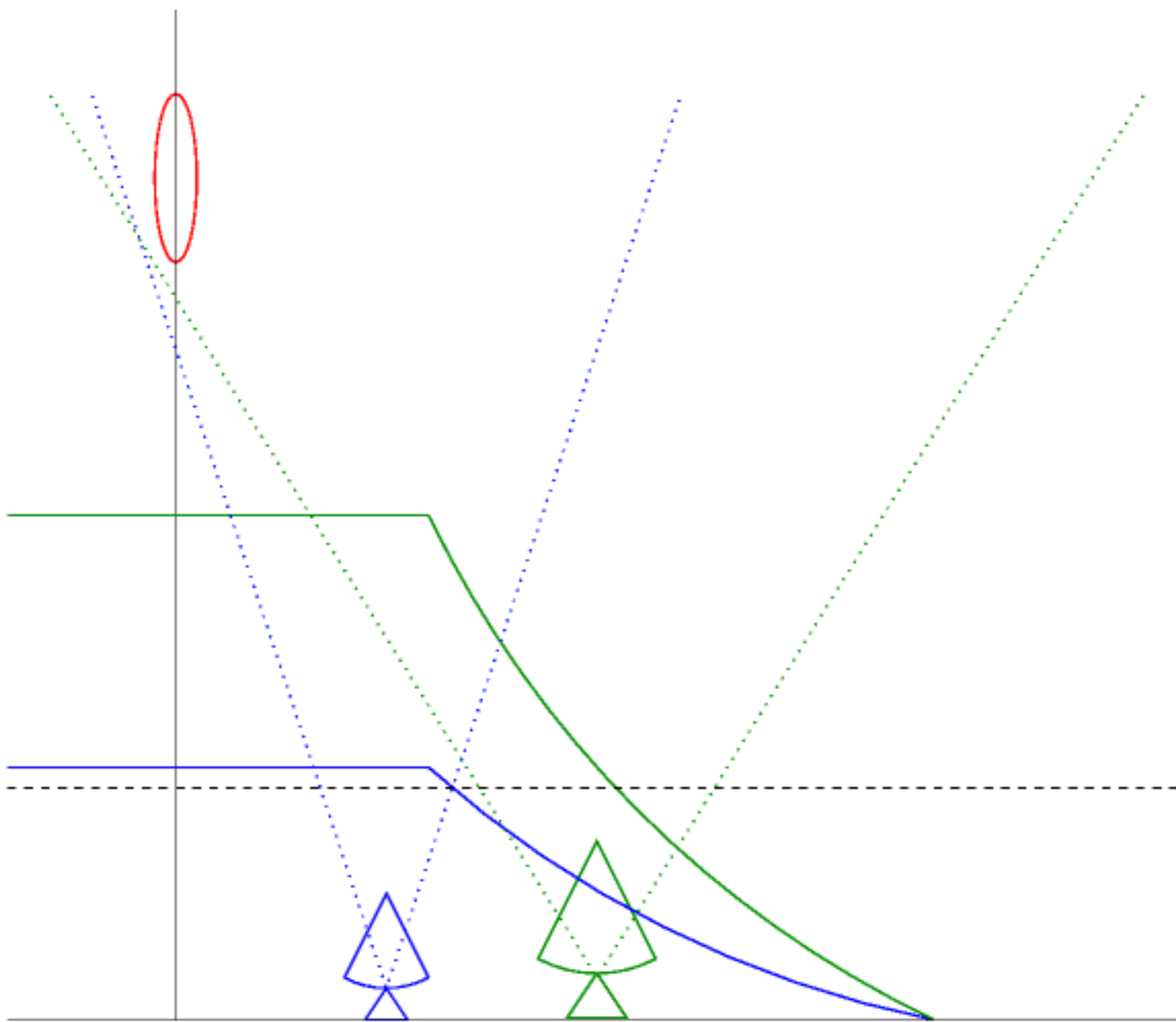
# TenTen Project

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- Effective area of 10 km<sup>2</sup> at energies 10 TeV and above
- Stereoscopic array of 30 ~ 50 telescopes (full scale)
  - Cost-effective design:
    - ▶ Inter-telescope spacing exceeding 250 m
    - ▶ Mirror area 10 ~ 20 m<sup>2</sup>
    - ▶ Field of view 5° ~ 10°
  - 30 times larger effective area than that of H.E.S.S.
- R&D application to the Australian Research Council (ARC)
  - Build one telescope first in Woomera
  - Continued support for CANGAROO-III



# TenTen Concept (Plyasheshnikov, et al. 2000)



■ Cherenkov plateau

● Radius  $\sim 150$  m

■ Cherenkov tail observable with larger aperture

● Expand effective area

■ Wider FOV necessary

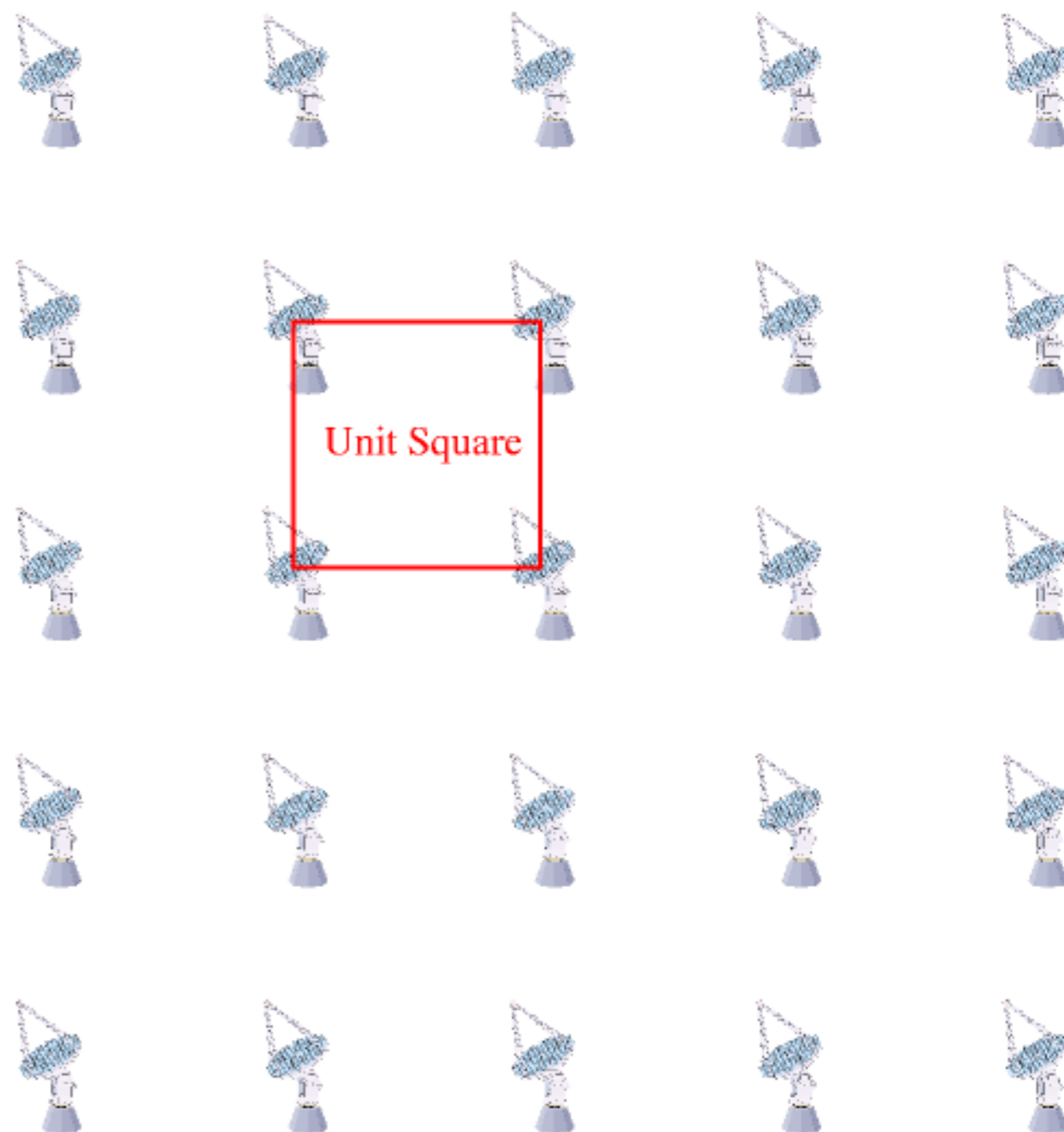
# 例：簡単なシミュレーション

## ■ Unit square の有効検出面積

- 口径／配置間隔の関数

## ■ 条件：

- CORSIKA 6.20
- Gamma rays from a vertical point source
- Geomagnetic field in Woomera
- Altitude: 160 m (Woomera)
- Parabolic reflector ( $f = 1$ )
- No blurring
- No NSB
- Pixel size =  $0^\circ .17$
- Trigger: 5 p.e.  $\times$  3 adjacent pixels  $\times$  any 2 telescopes



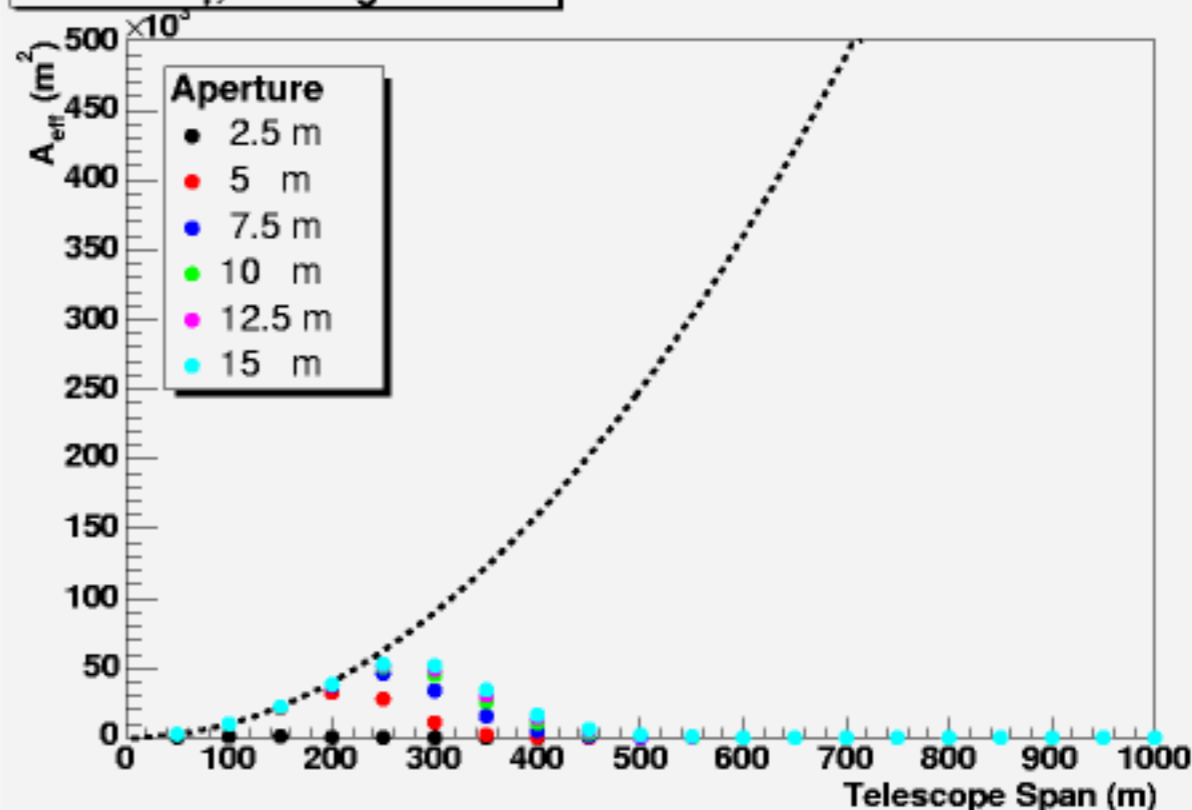
# Unit Square の有効検出面積

■ FoV  $\sim 6^\circ$

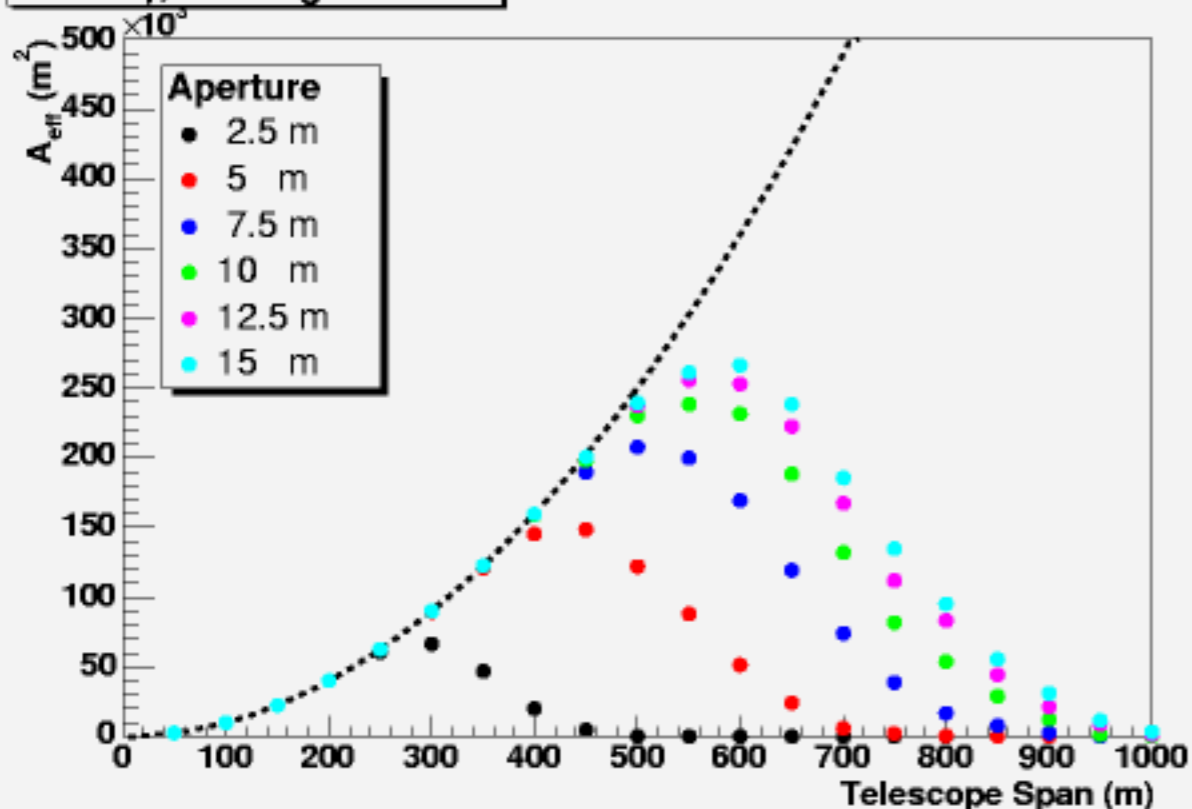
■ 10 TeV の場合

● 小口径 (2.5 m) でも間隔  $\sim 400$  m  
まで効率 100 %

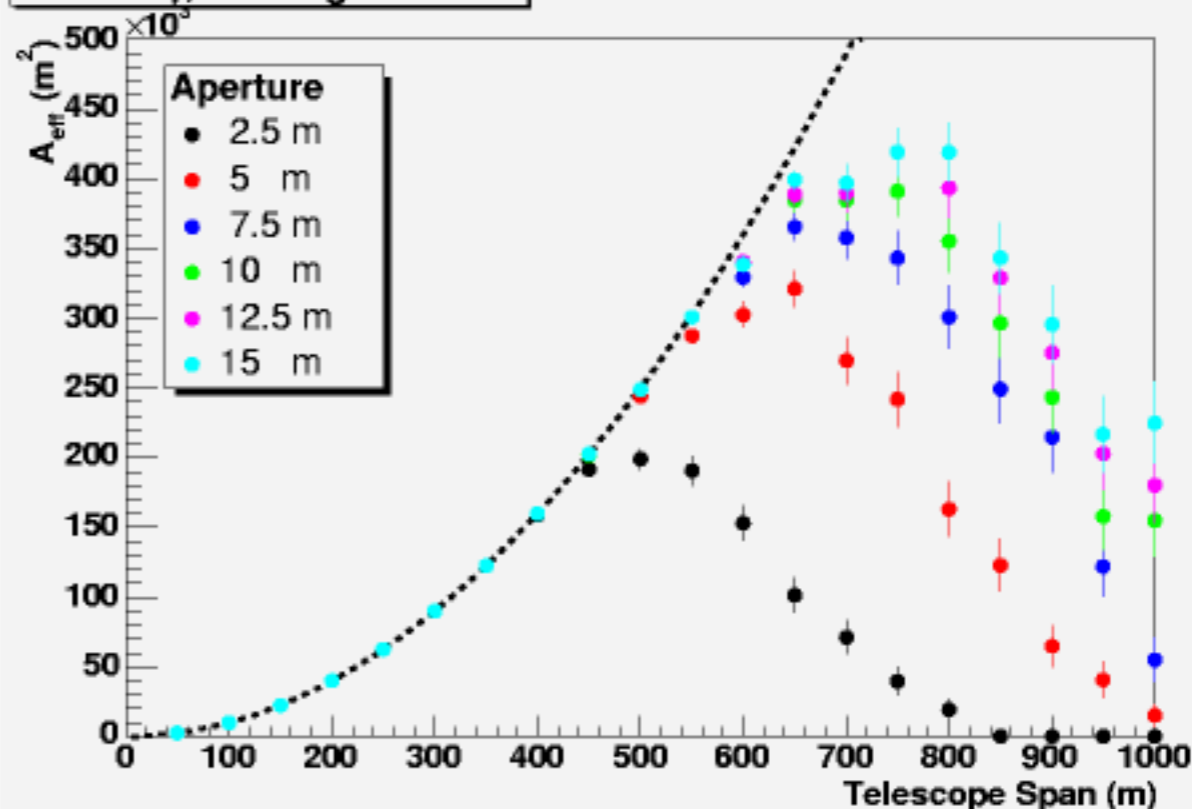
100 GeV  $\gamma$ , 20-Ring Camera



1 TeV  $\gamma$ , 20-Ring Camera



10 TeV  $\gamma$ , 20-Ring Camera



# International Workshop in Adelaide

アプリケーション アクション 7月12日 (水) 01:43

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http://www.physics.adelaide.edu.au/astrophysics/pev\_workshop/index.html

Red Hat, Inc. Red Hat Network Support Shop Products Training



## Locating PeV Cosmic-Ray Accelerators: Future Detectors in Multi-TeV Gamma-Ray Astronomy

Adelaide 6 - 8 December 2006

Home

Overview & Aims

Programme

Workshop Venue

Arrival, Accommodation & Travel Info

Registration & Abstract Submission

**Deadline: 10 Nov. 2006**

Local Organisation/Contact

Hosted by the [High Energy Astrophysics Group](#),  
University of Adelaide,  
Adelaide 5005



Image of the city of Adelaide. Copyright [2006 Australian Government](#).  
Images of TeV Gamma-Ray and E-Play sources (from [ICRAT](#) and [P003 AT](#)). Images available from the [ICRAT Collaboration](#) website.

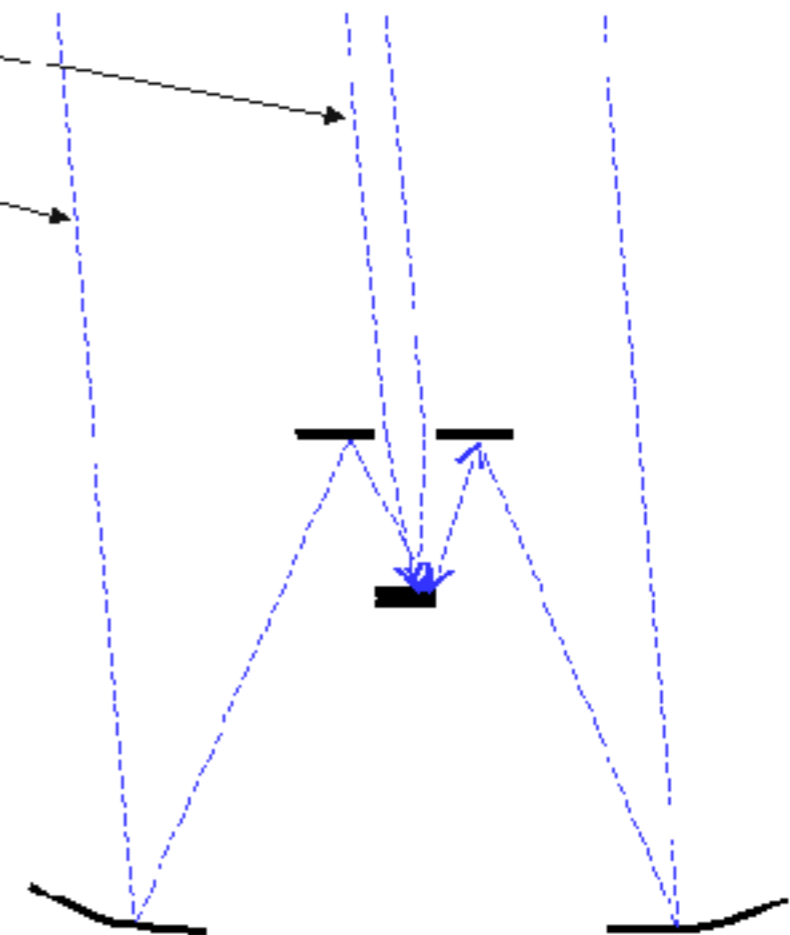
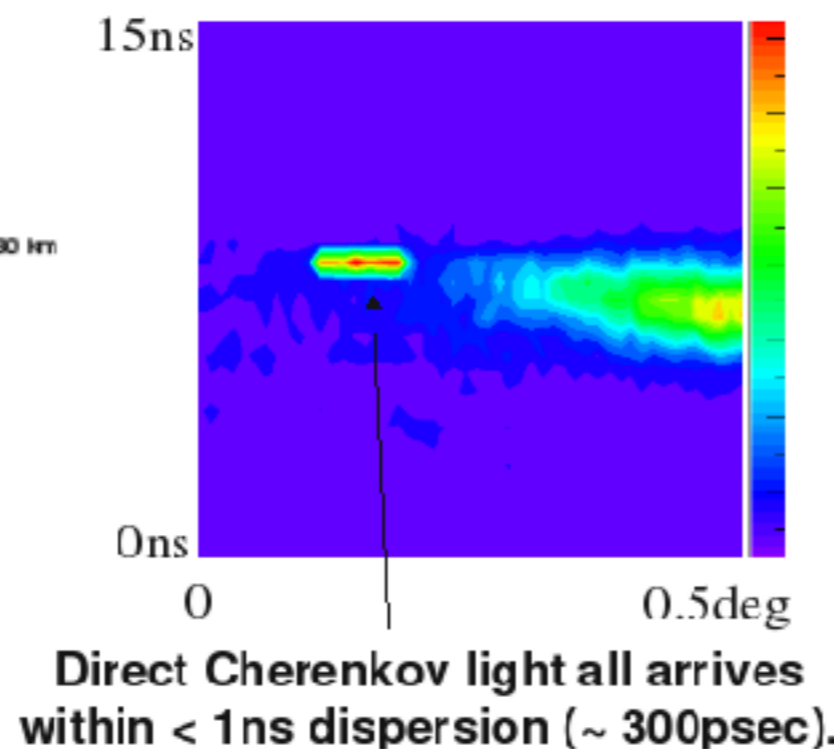
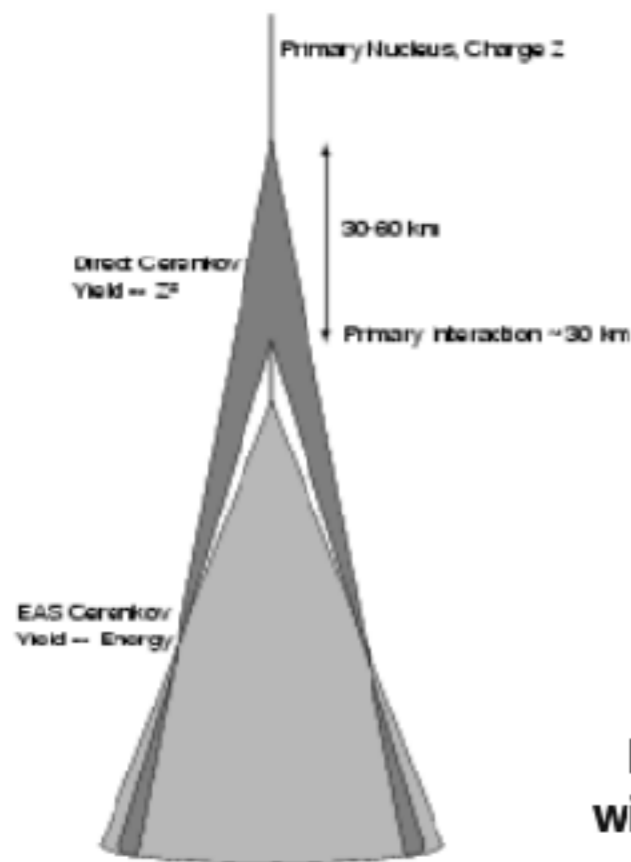
### Workshop Agenda

- Motivations for  $E > 10$  TeV Gamma-Ray and PeV Cosmic-Ray Astrophysics
- Status Reports in TeV Gamma-Ray, Cosmic-Ray, Neutrino and X-Ray Astronomies
- Current Activities in  $E > 10$  TeV Gamma-Ray Astronomy
- New Array of  $E > 10$  TeV Cherenkov Imaging Telescopes

# Track Imaging Cherenkov Experiment (TrICE)

## TrICE: The Mechanism (small pixels & fast timing)

- Use EAS Cherenkov signal as trigger: Light Yield  $\propto$  Energy ( $\sim$ TeV to PeV)
- Direct Cherenkov signal  $\propto Z^2$



EAS Cherenkov imaged through Fresnel lens.  
Direct Cherenkov imaged by spherical mirrors.  
Longer path length gives  $\sim 20$ ns time delay



# Rough Estimation (Direct Cherenkov)

## ■ Cherenkov 光子数:

$$N = 2\pi\alpha Z^2 l \left( \frac{1}{\lambda_1} - \frac{1}{\lambda_2} \right) \left( 1 - \frac{1}{\beta^2 n^2} \right)$$

## ■ 仮定:

- 大気深さ  $\sim 70 \text{ g/cm}^2$  (高度  $\sim 18 \text{ km}$ ) のところで  $n = \text{const.}$
- $Z = 1$  (陽子)

## ■ 地上での photon density $\sim 0.4 \text{ photons/m}^2$

- $5 \text{ m}^2$  鏡だと 2 photons  $\rightarrow$  観測不可
- $l \sim 5 \text{ km}$  だと direct Cherenkov photons は  $0^\circ$  .1 pixel に収まる

## ■ しかし鉄の場合 $Z^2 = 676$ 倍

# まとめ

- TeV ガンマ線天体 ～ 40 個 in 2006
  - Galactic sources は ～ 30 個 → 硬いスペクトル
- 超新星残骸の観測
  - RX J1713 (CANGAROO、H.E.S.S.)
    - ▶ 多波長スペクトル → 陽子起源?
    - ▶ Morphology → 電子起源?
    - ▶ GLAST / H.E.S.S. II の観測が鍵
    - ▶ Cutoff @ 12 TeV
- 100 TeV 領域ガンマ線将来計画
  - CTA (highest energy branch)
  - TenTen