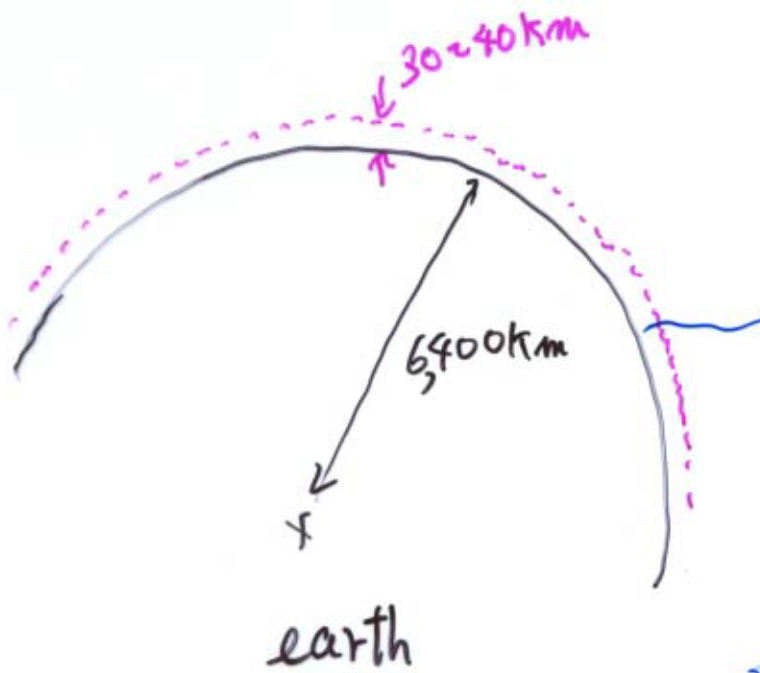


# Cosmic-Ray Physics $\equiv$ Your Neighbor

Technical Background for HEP Physicists

$\Delta t$   $\star$  NS?  
 Black hole?  
 Dark Matter?  
 String?



1 atm  
 $= 1 \text{ kg/cm}^2$   
 $30 \times 10^3$   
 $10^7$

shower max  
 10 km @ TeV  
 ?  
 0.3 atm

$n \sim \frac{1}{0.0003}$   
 $1 + 0.0003 P$

@ 1 atm    30 MeV e  
 $\theta \sim 1.2^\circ$

- ✓ Total Absorption Cal
- ✓ Transparent
- ✓ Uniform

- ✓ Large Area
- ✓ Cheap

ground based

"Cherenkov Calorimetry"

I A C T

(Imaging Atmospheric Cherenkov Telescope)

for

Cosmic TeV  $\gamma$ -ray  
~ sub-TeV

R. ENOMOTO

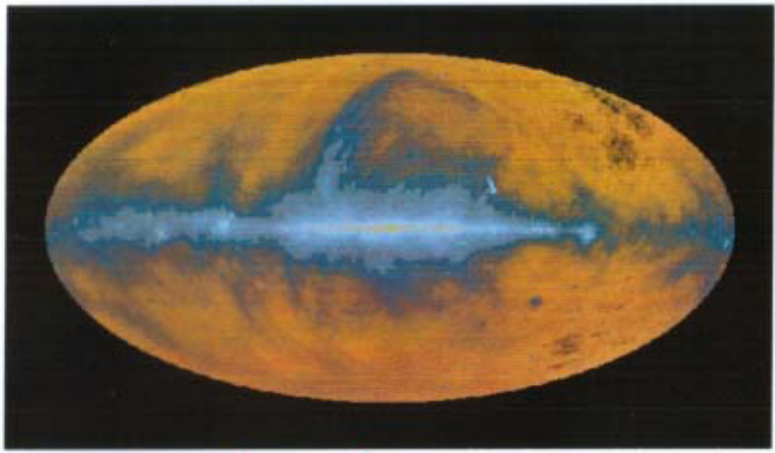
Camgaroo Collaborati

ICRR (U. Tokyo)

# Galactic Coordinate

## Galactic Coordinate

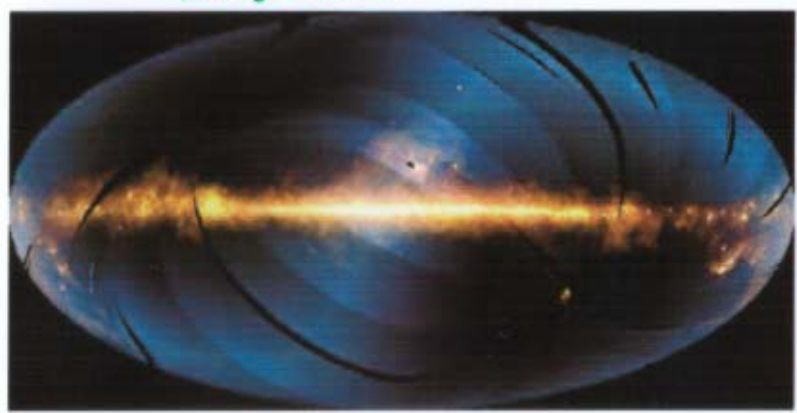
Micro Wave



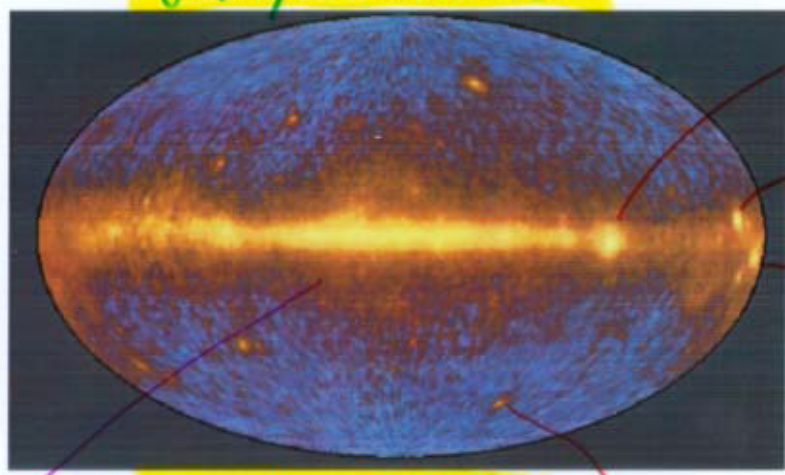
Visible Light



Infrared



$\gamma$ -ray " $\sim 100$  MeV"



Vela pulsar

Centaurus

Crab pulsar

Compton Satellite

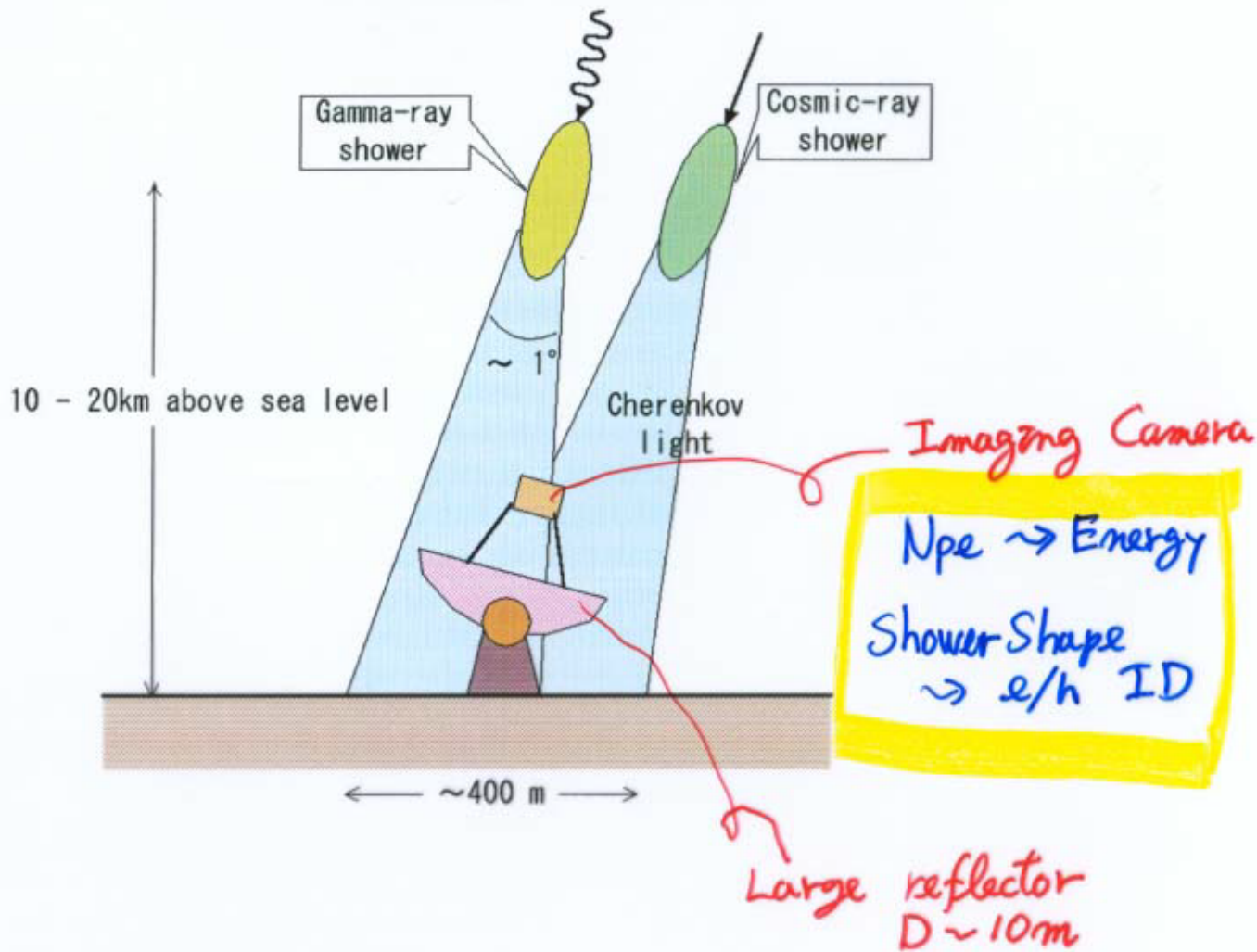
Many Unidentified Sources

AGN

What's happening in Higher Energy?

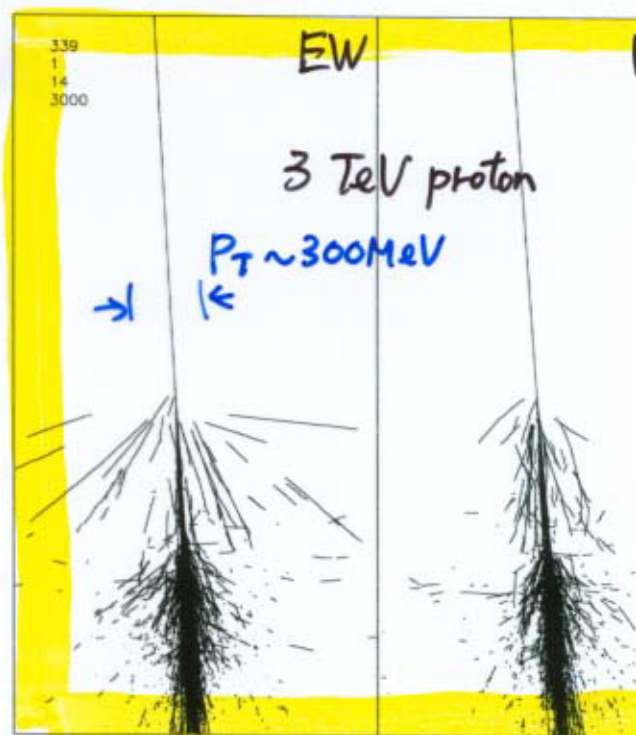
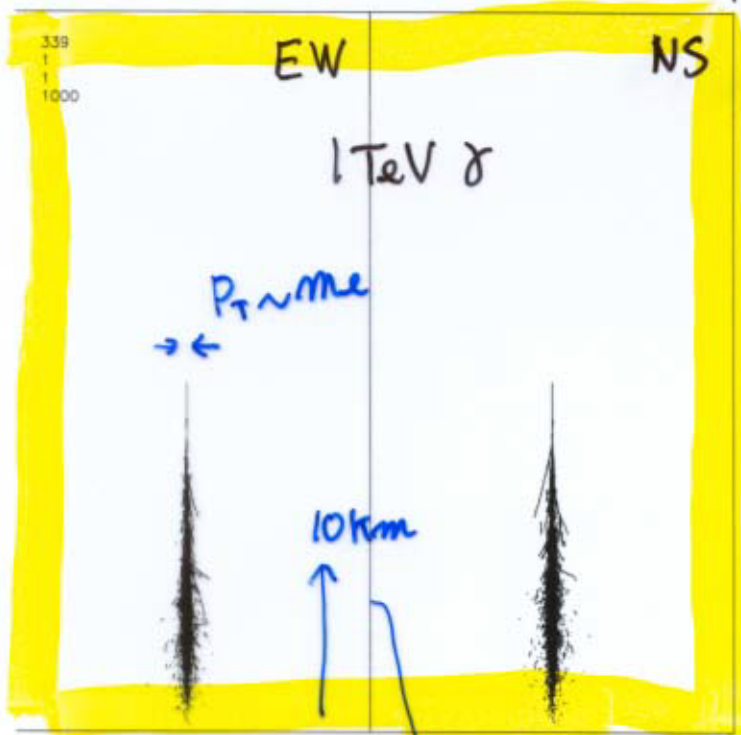


# IACT





# Atmospheric Shower

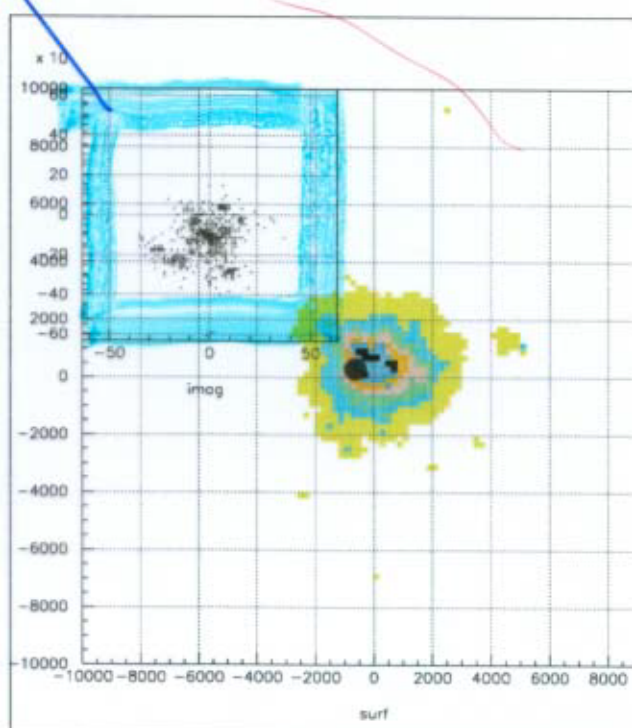
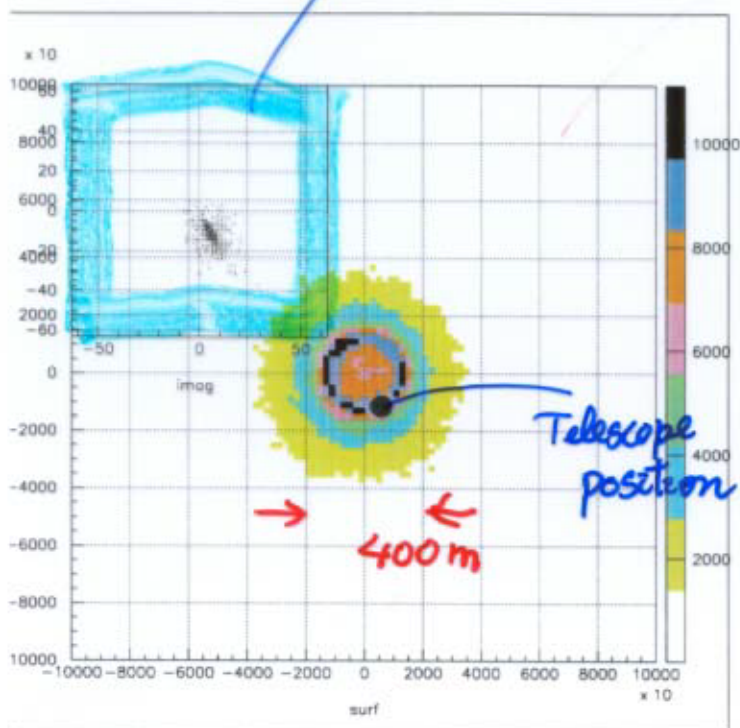


$n_{air} \sim 1.0001$   
 $E_{th} \sim 30 \text{ MeV}$   
 $\theta \sim 0^\circ$

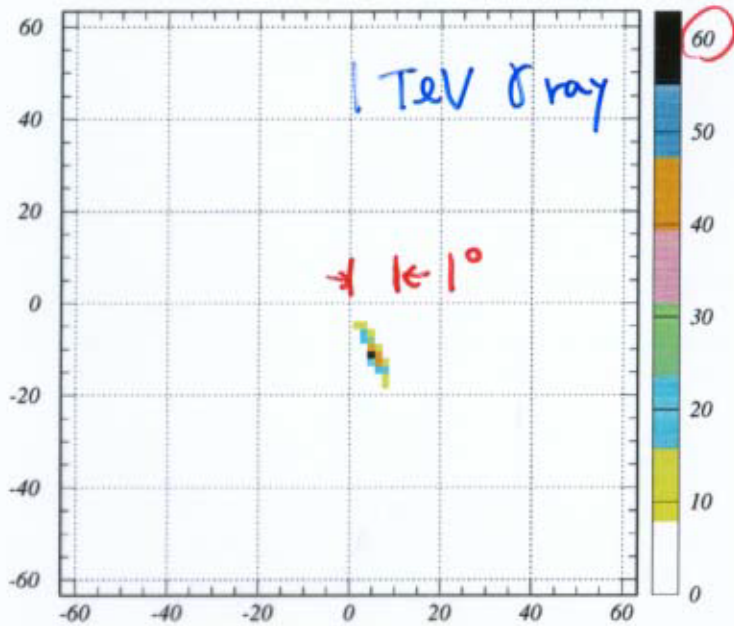
$\vec{B} \sim 0.3 \text{ Gauss}$   
 $R_{1\alpha\text{ev}} \sim 100$   
 $\Omega_{MS} \leftarrow 20 \text{ MeV}$

Focal Plane Image

Light Pool on surface

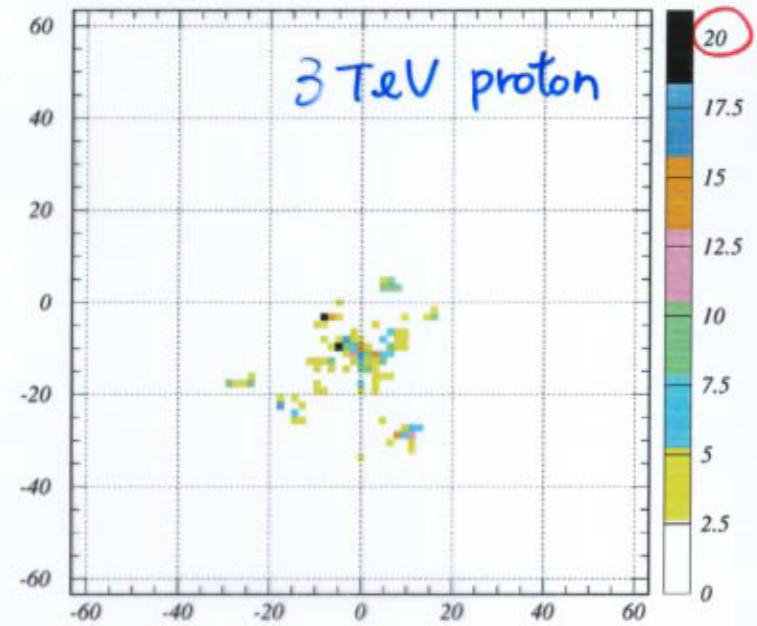


# Focal Plane



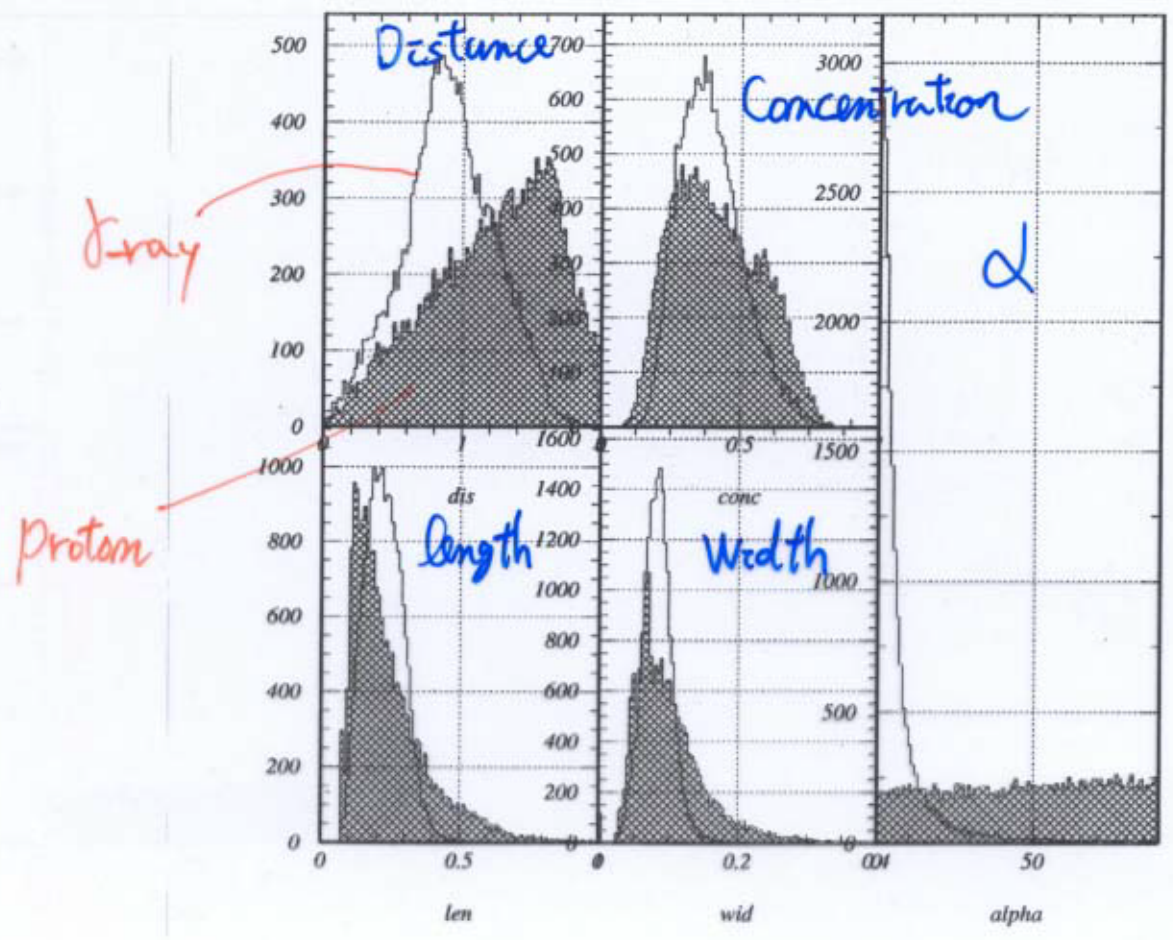
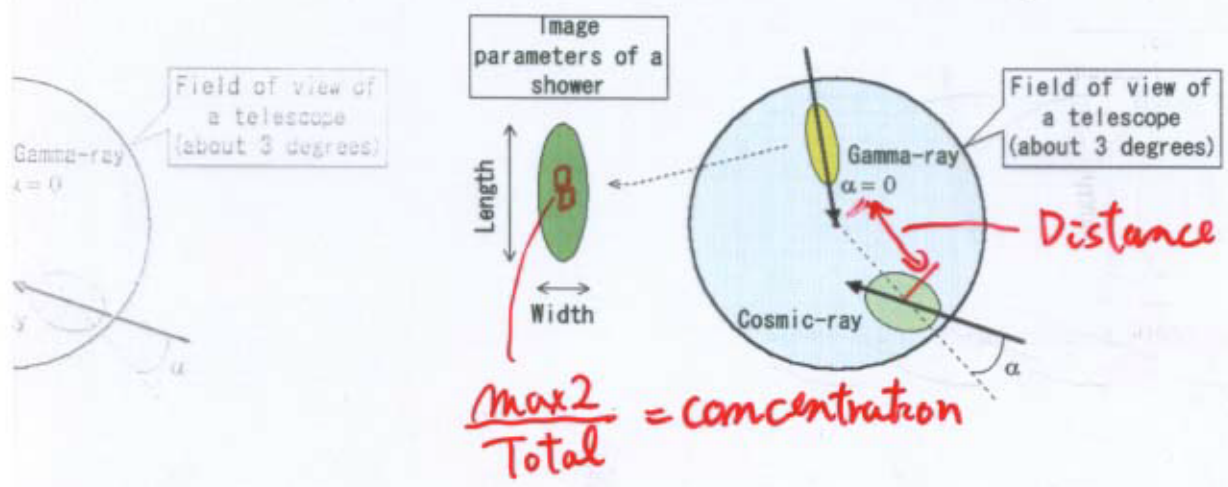
image

Concentrated  
Sharp



image

# Shower Shape



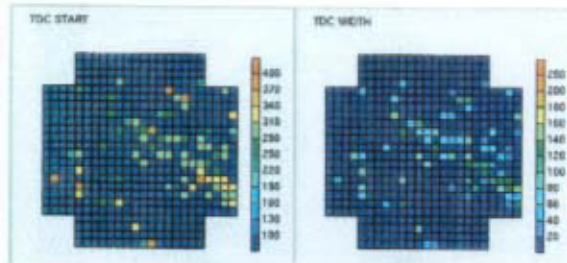


# Real Images

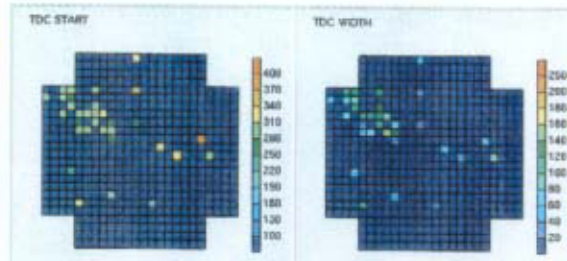
(Online)

## Event samples (1)

- Hadron-like event



- Gamma-like event

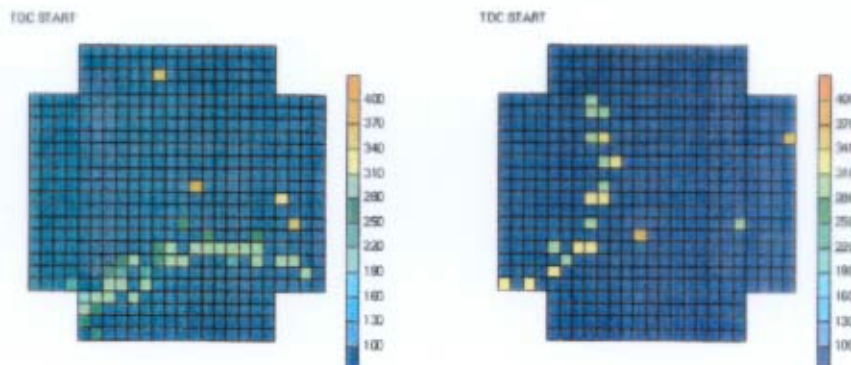


↑  
Pulse Height

↑  
Timing

## Event samples (2)

- Muon rings are useful for calibration...



obtained by Cangaroo II

# CANGAROO II

Collaboration of Australia and Nippon for a Gamma Ray Observatory  
in the Outback



- ICRR
- U. Adelaide
- ANU
- Ibaraki U.
- Ibaraki PU HS
- ISAS
- RIKEN
- Kanagawa U.
- Kohan U.
- U. Kyoto
- NAO
- STE Lab
- Tokai U.
- TIT
- Yamagata U.
- Yamaguchi Gakuin

~ 30 people



{ population 300  
Super Market x 1  
Hotel x 1



Cangaroo I (3.8m)



1992 ~ 1997

LMC



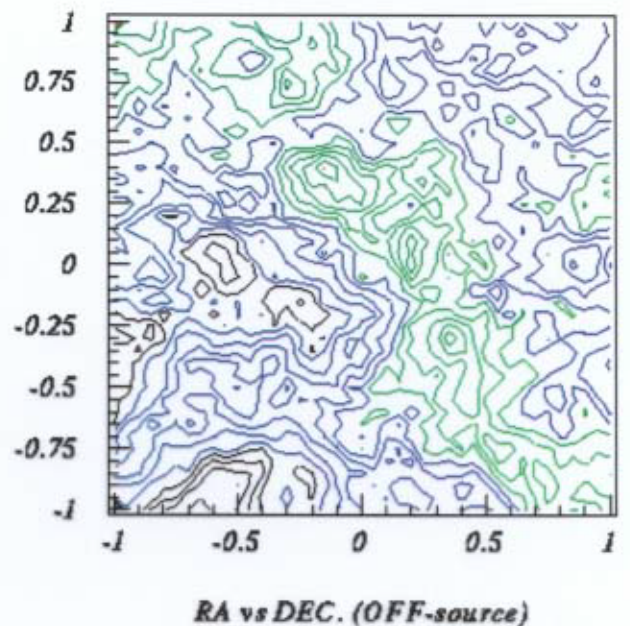
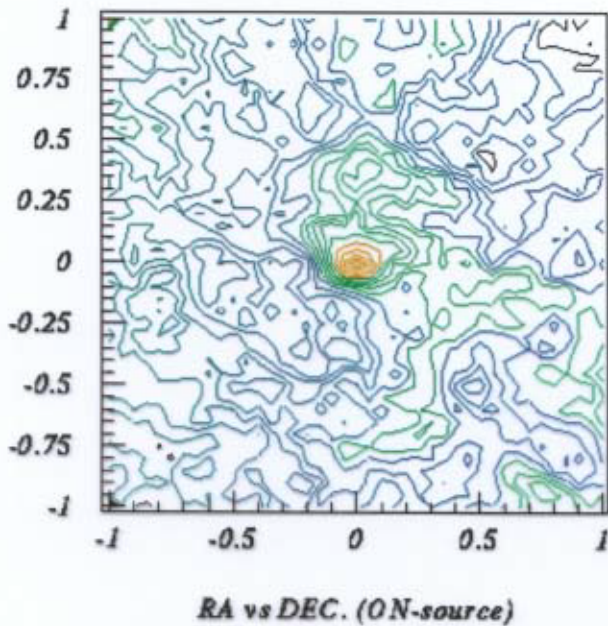
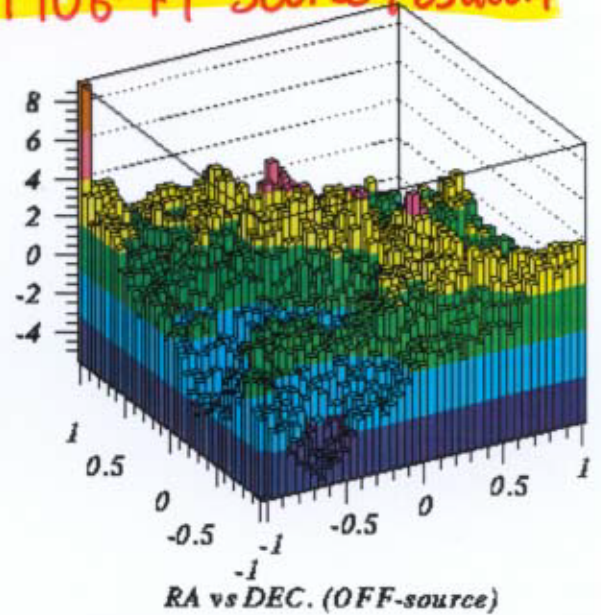
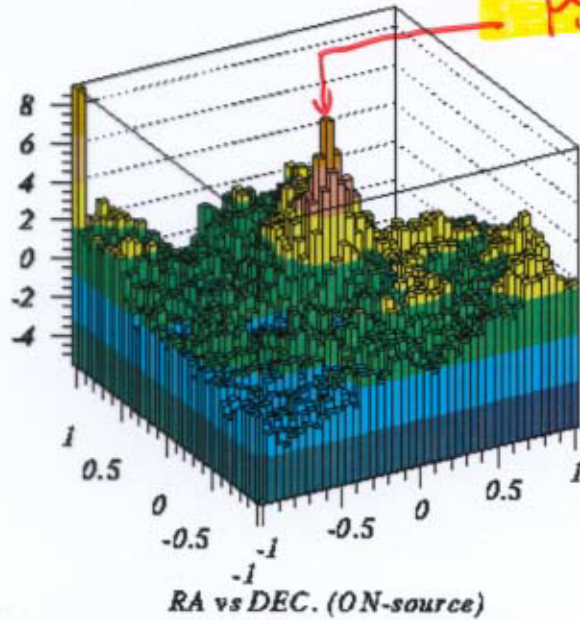
NSB  $\equiv$  Night Sky Background  
 $\approx 17 \text{ MHz}$



(From  $\alpha$  distribution)

(Supernova Remnant)

PSR 1706-44 Source Position



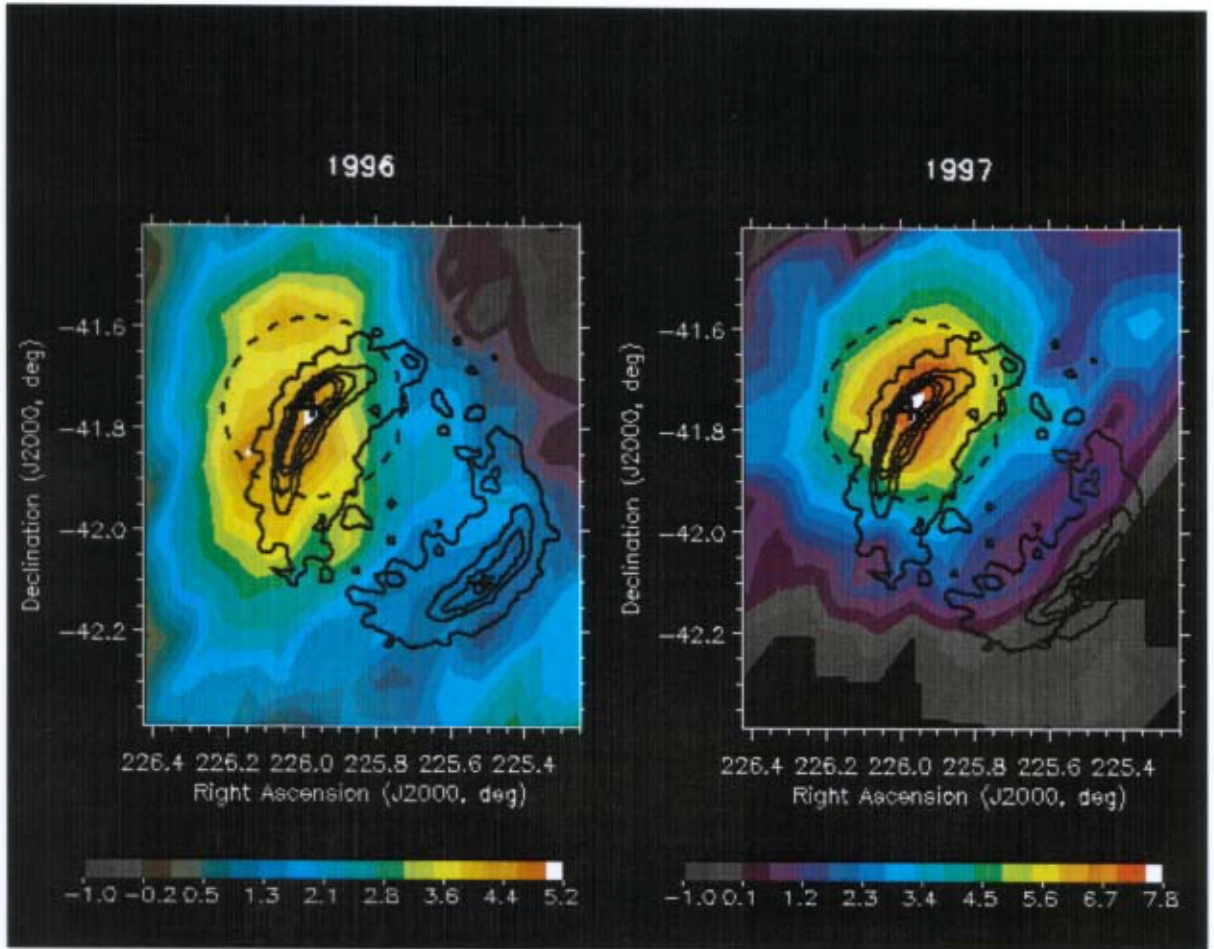
"ON"

"Significance Map" "OF"

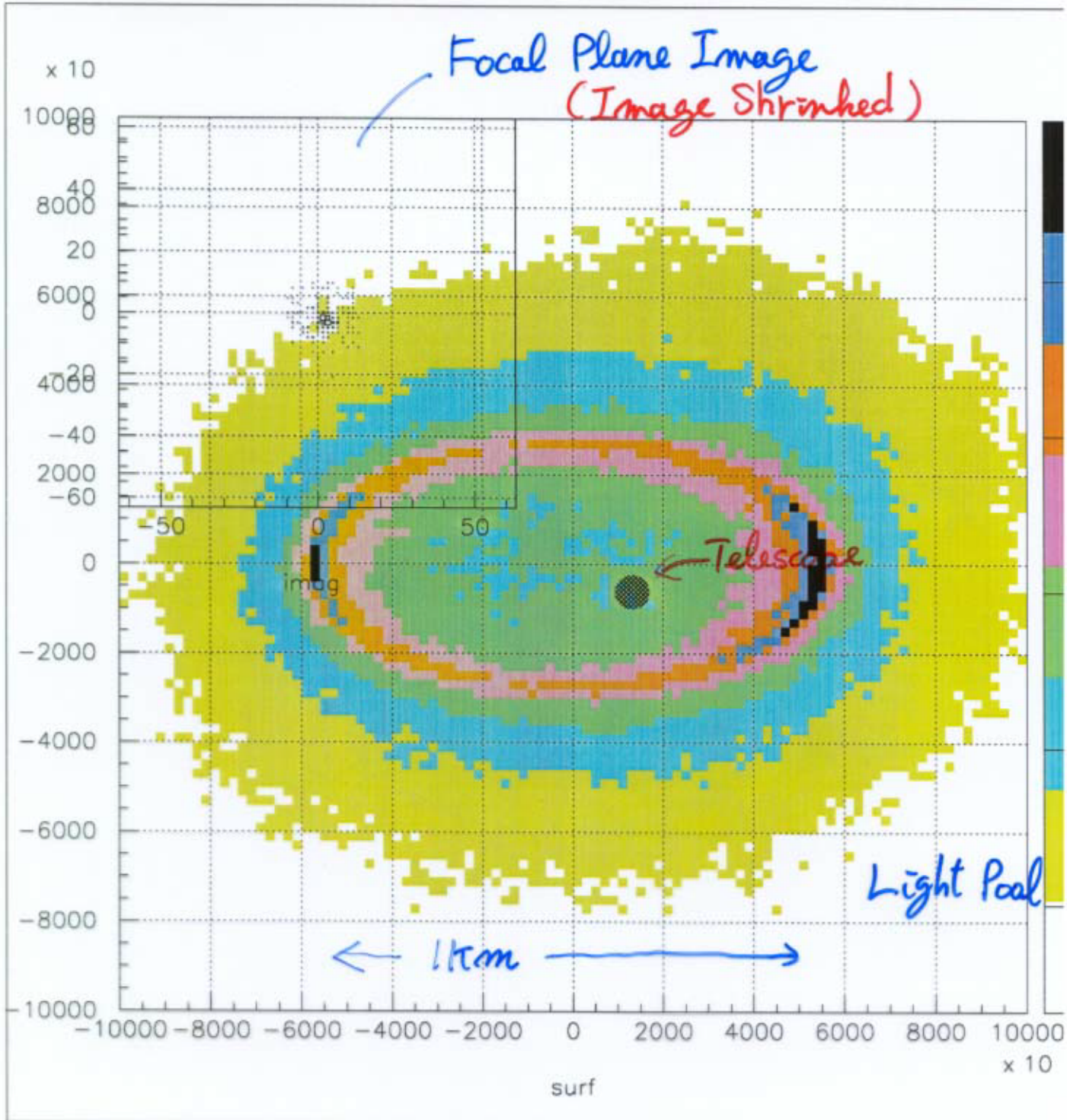
2D



# SN 1006



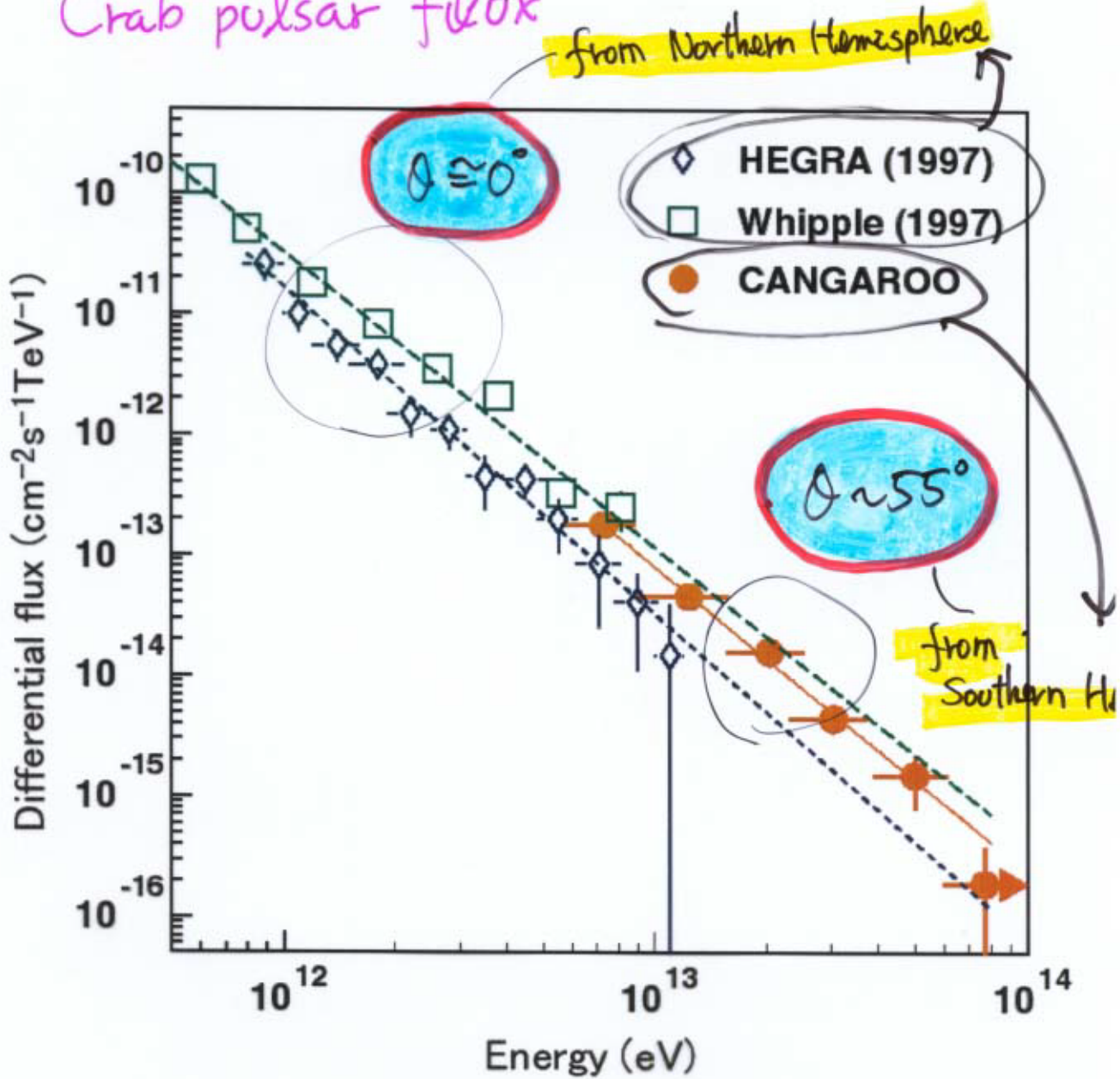
# Large Zenith Angle Observation



Very Sensitive to  $E \gtrsim 10 \text{ TeV}$   
Large Effective Area

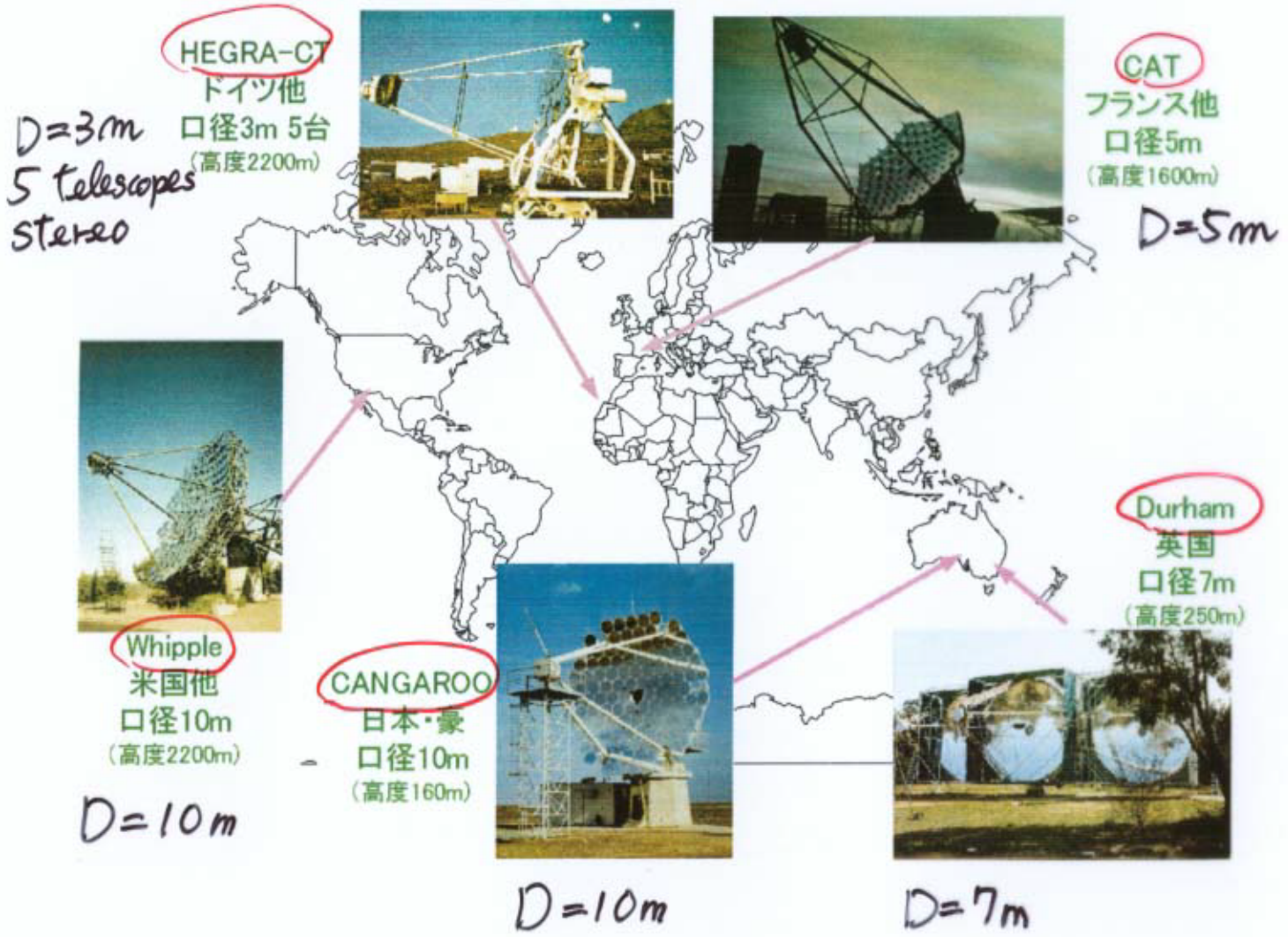


# Crab pulsar flux





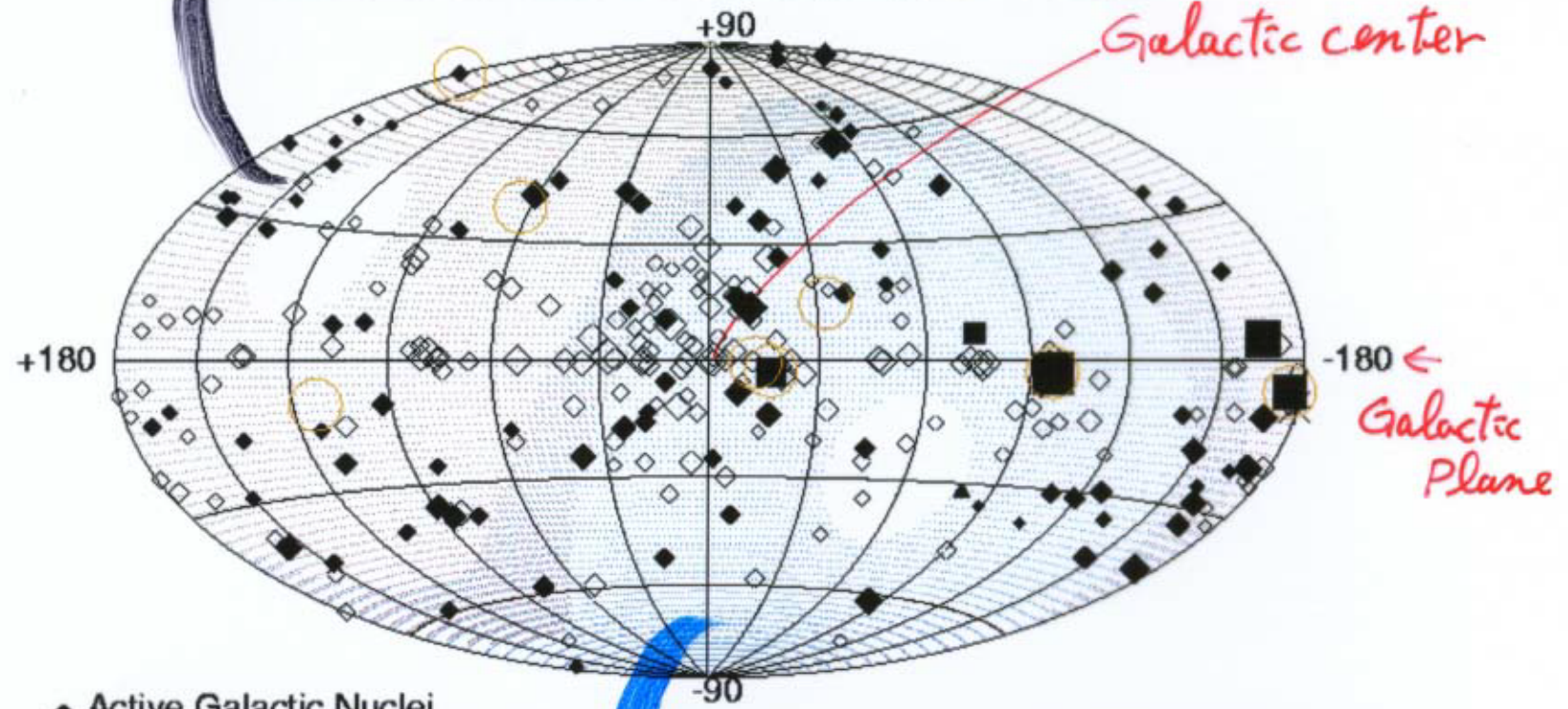
~ 1990



# North

**Many Observatories  
Necessary**

## GeV and TeV Gamma-ray Sources



- ◆ Active Galactic Nuclei
- ◇ Unidentified EGRET Sources
- Pulsars
- ▲ LMC \* Solar flare

○ Positive detection: Crab, PSR B1706-44, Vela, Mrk 421, Mrk 501, 1ES2344+514, SN1006, RXJ1713-39

# South

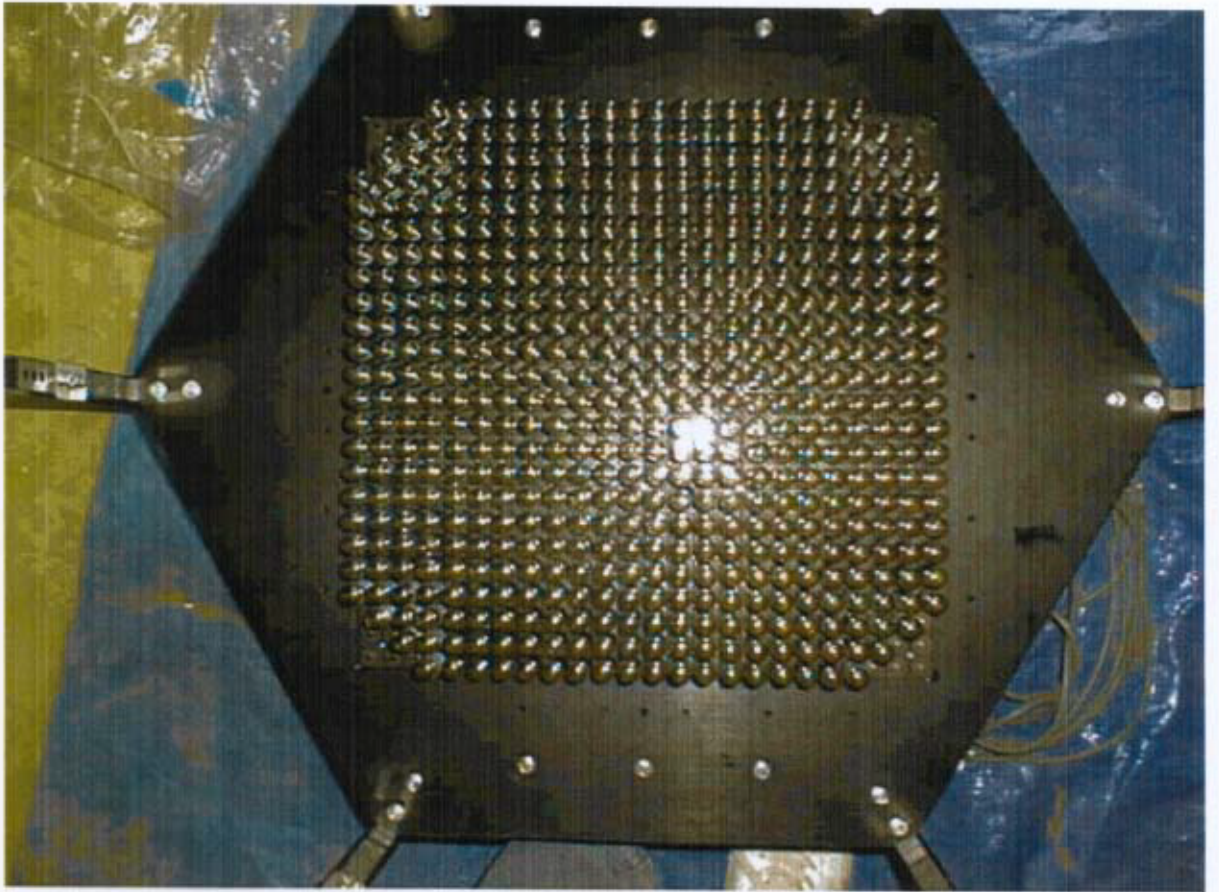


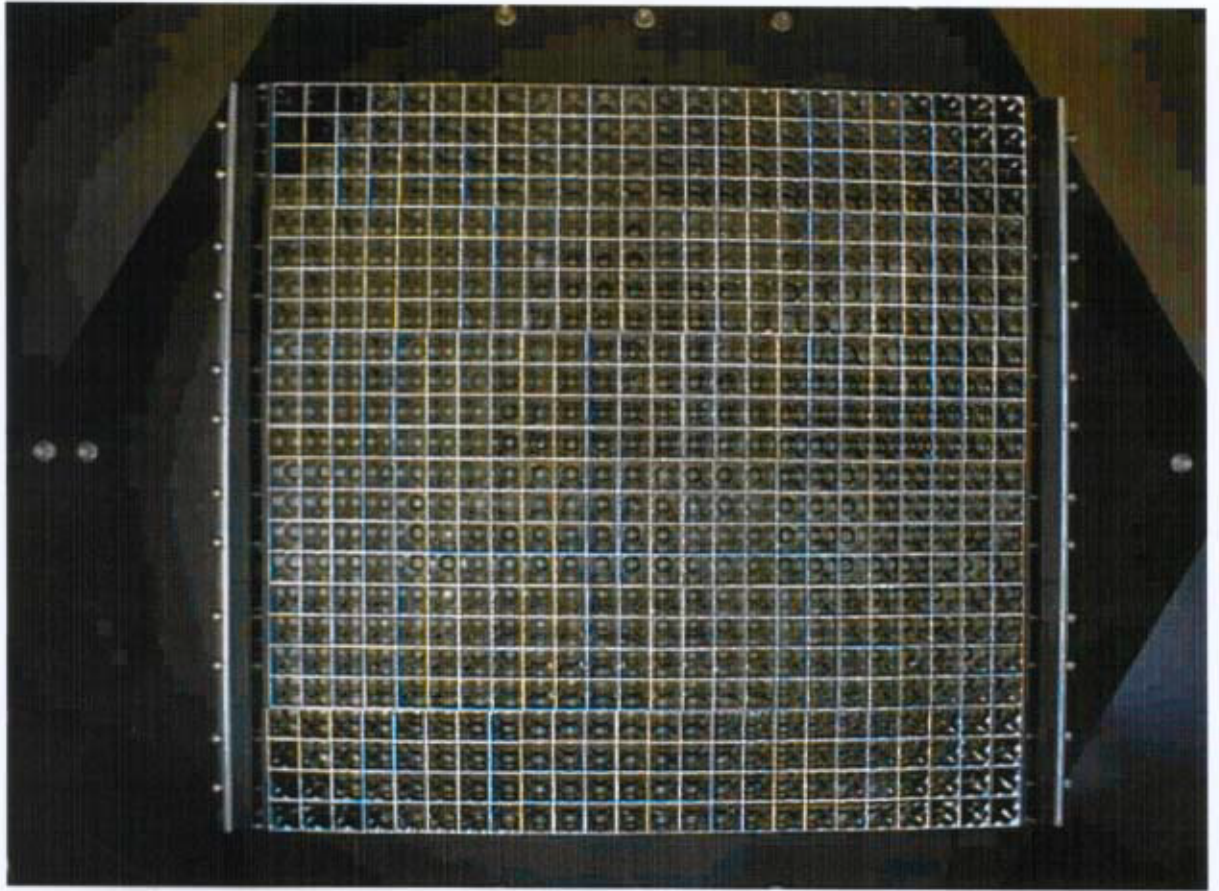
1999 ~















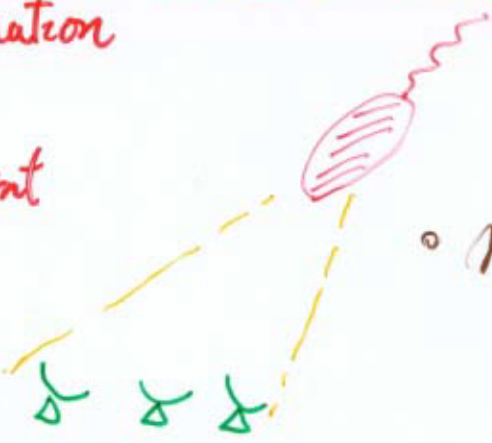
# Next Century

## Stereoscopic Observation with Large mirrors (D ≥ 10m)

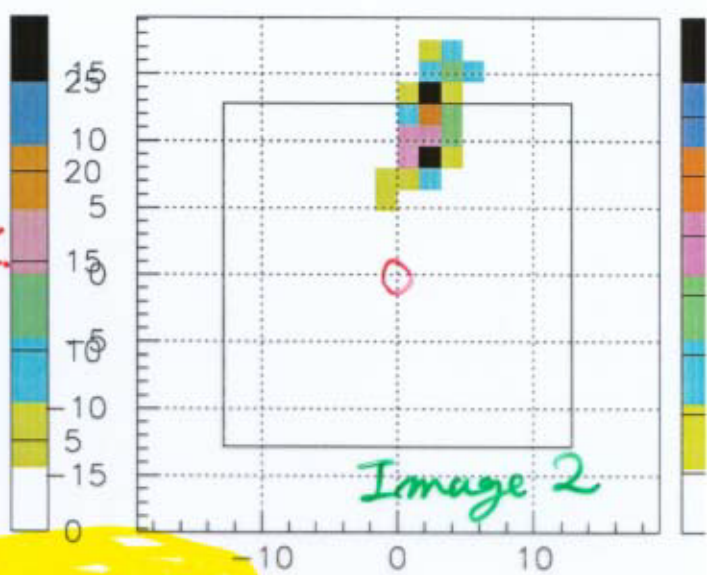
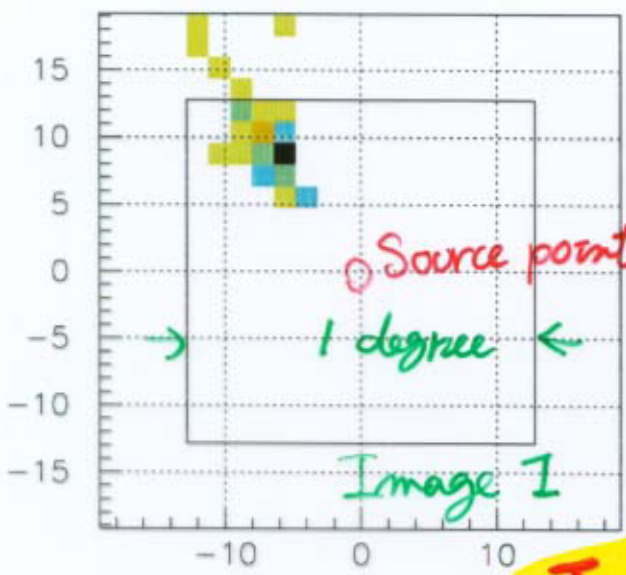
• Source point determination

0.2° @ 200 GeV  
Event by Event

⇓  
Broad Source OK!  
i.e., Galactic Plane  
SN remnant



• Minimal Mod  
 $S_N = N \times S_i$   
@ Threshold Energy



## Images

TRIGGERED

TRIGGERED

# CANGAROO-III

Woomera,  
South Australia

31°06' S  
136°47' E  
160 m a.s.l.



$D = 10\text{m} \times 4$

2nd Telescope

~ 2001 Summer (UT)

3,4th @ 2002



# VERITAS

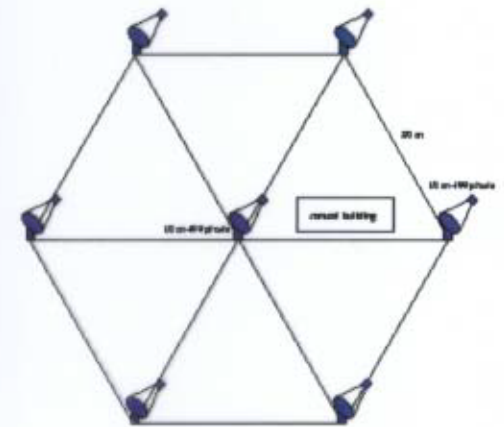
(Very Energetic Radiation Imaging Telescope Array System)



Mt. Hopkins, AZ  
(Montosa canyon  
or north site)

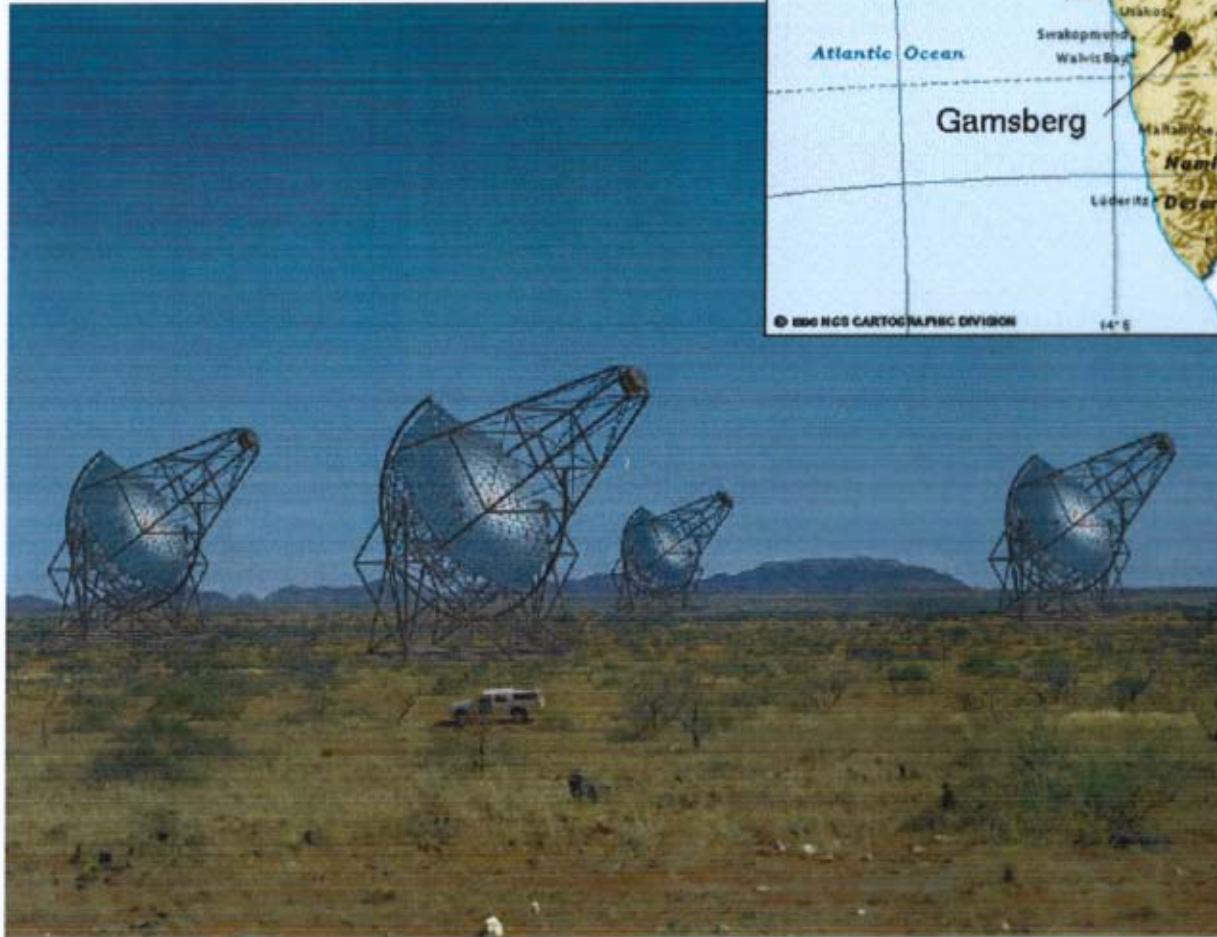


23° N  
111° W  
>2000 m a.s.l.



$D = 10\text{m} \times 7$

Budget ?



23°16'18" S  
16°30'00" E  
1800 m a.s.l.

$D=13\text{m} \times 16$

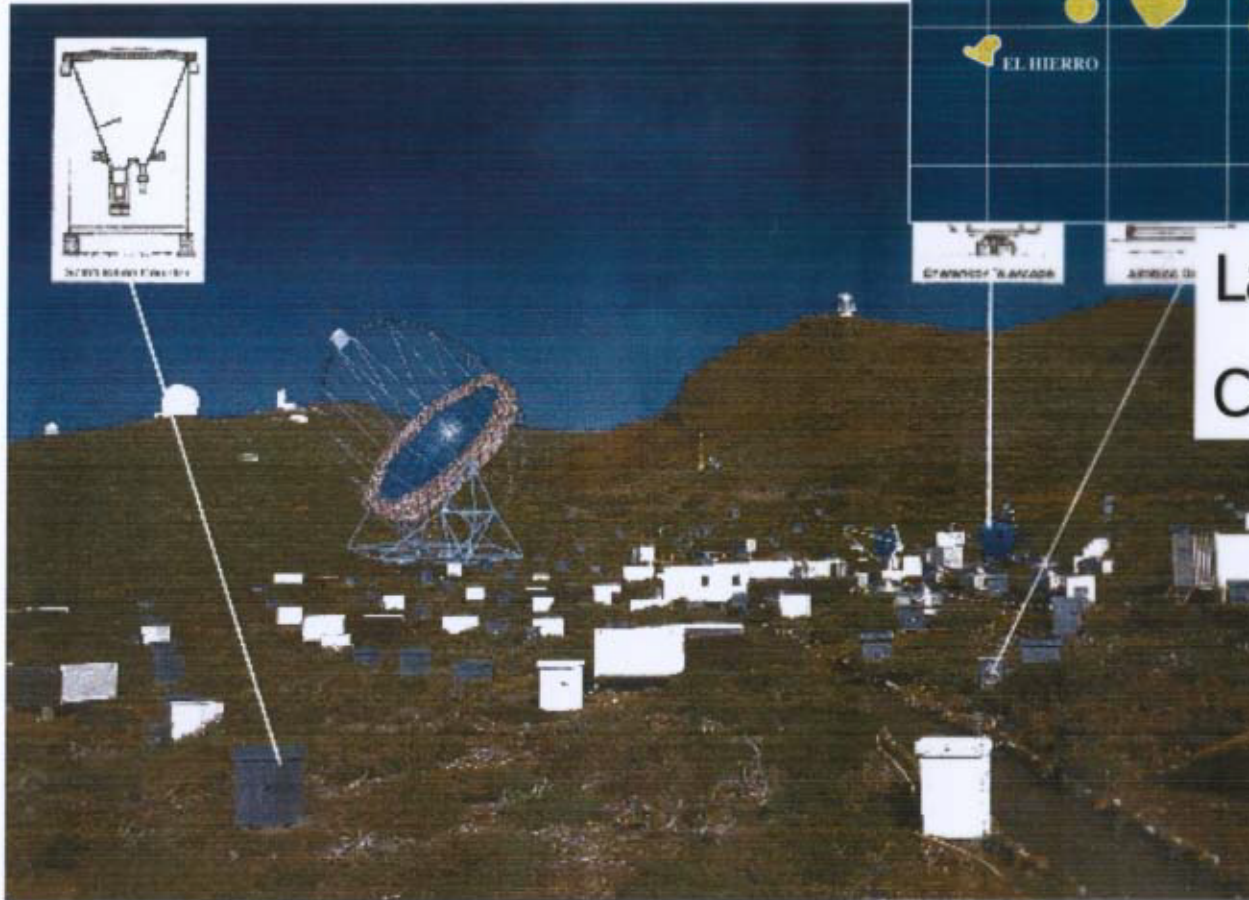
from 2002 ?  
No telescope yet!



(Major Atmospheric Gamma-ray Imaging Cherenkov Telescope)

# MAGIC

Very Large Mirror  $\sim 17\text{m}$

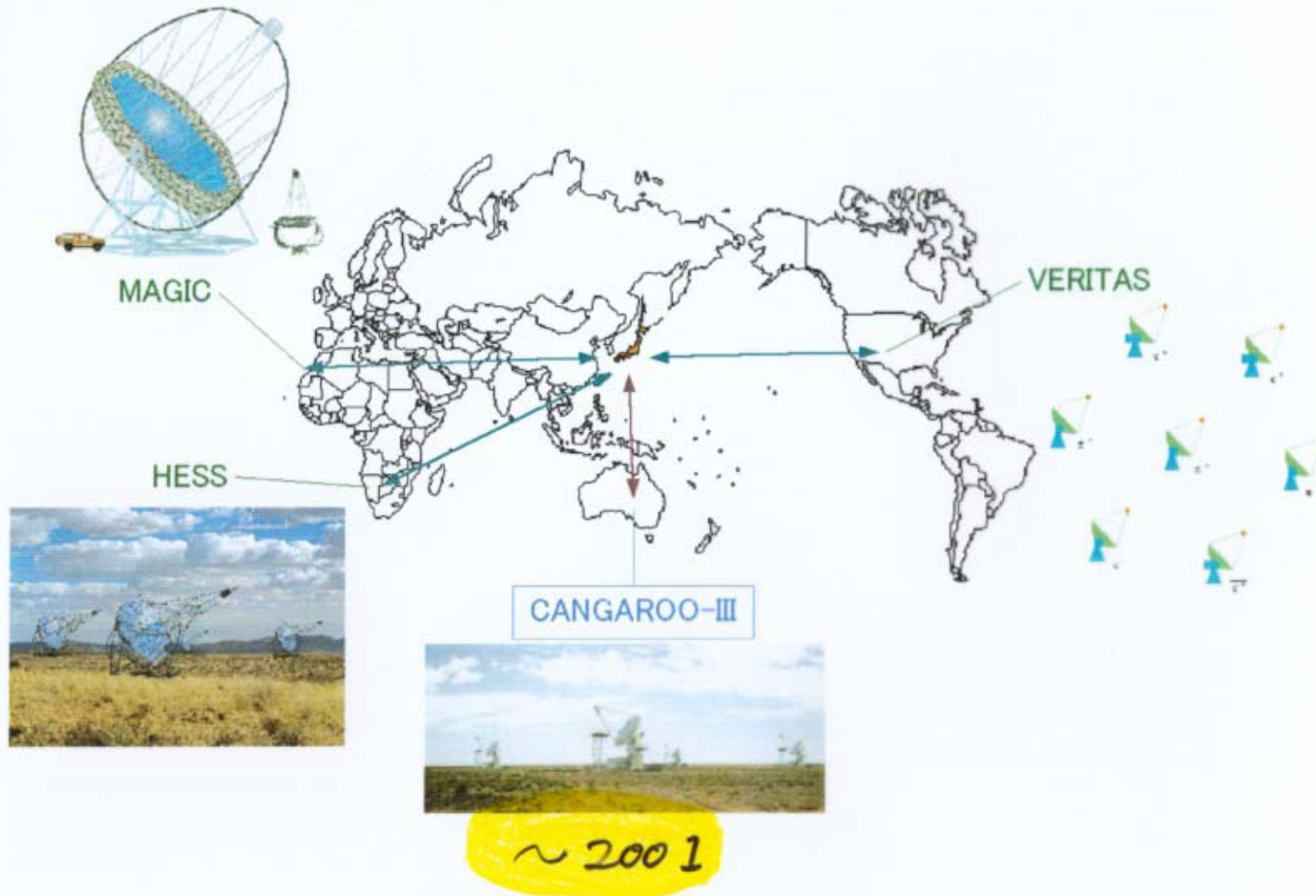


La Palma,  
Canary Island

28.75° N  
17.89° W  
2200 m a.s.l.

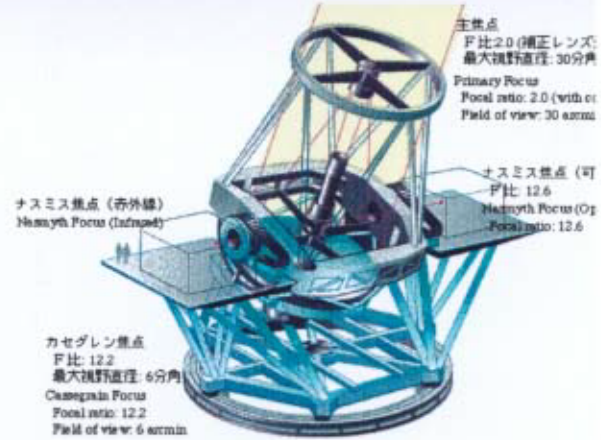
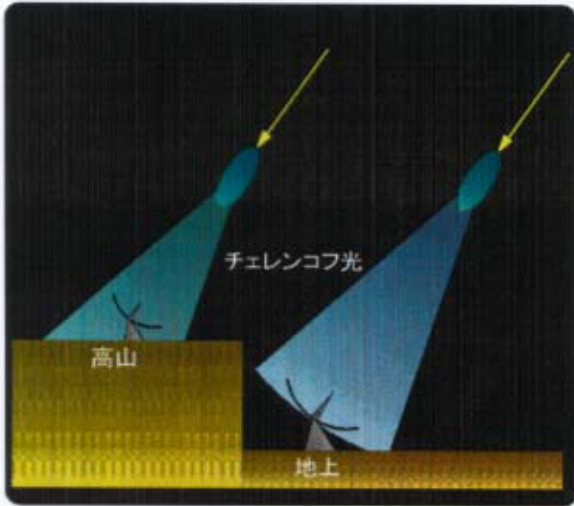
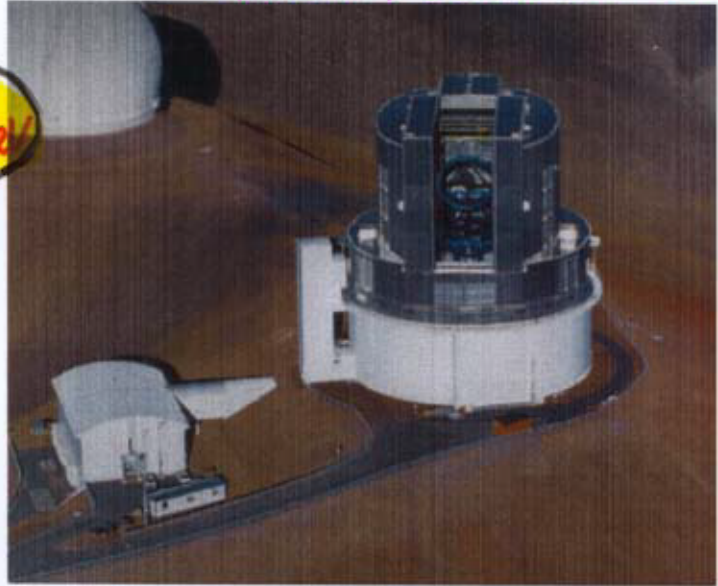


# Next generation projects



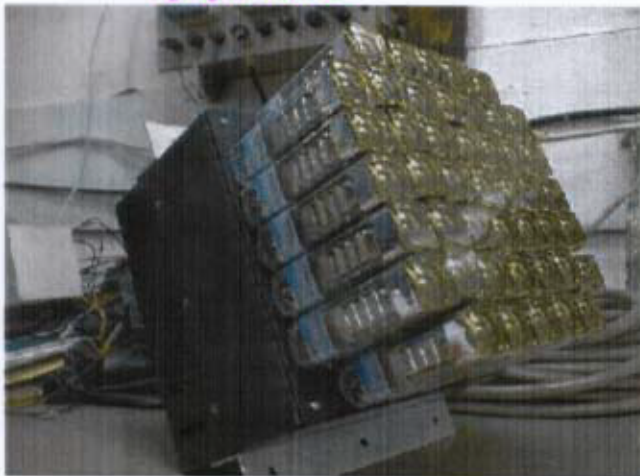
8.2m optical  
Hawaii, SUBARU Telescope

R&D for future  
Mountain ~ 5,000 m  
→ Lower Energy ~ 10keV



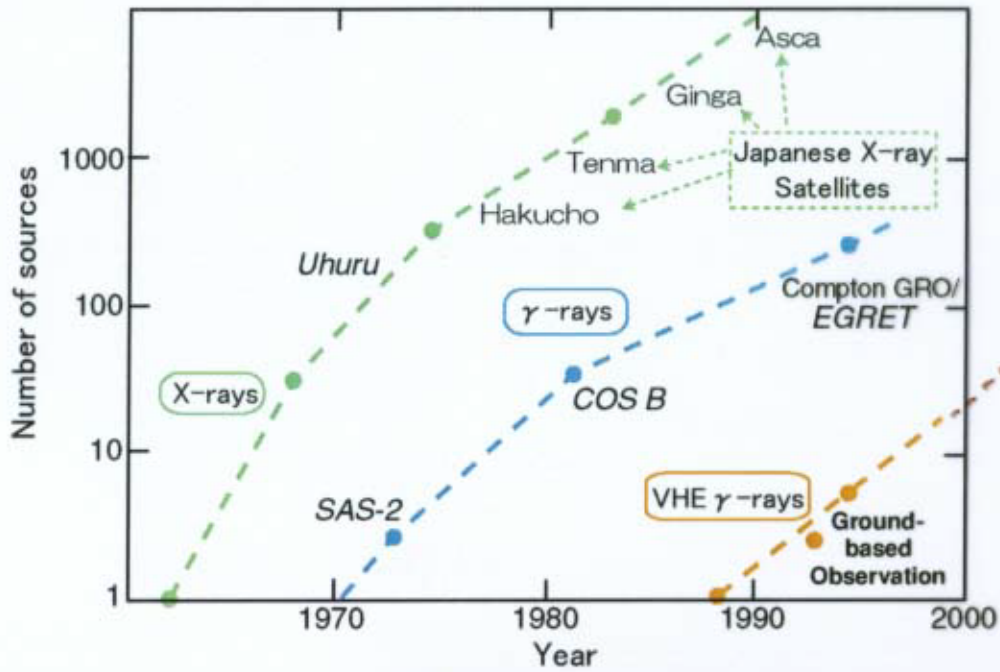
遠藤孝徳・画 日経サイエンス1998年2月号より  
Illustration by Takatoshi Endo, taken from Nihonki Science

Camera



with Electronics

~~cosmic rays & gamma rays~~



A New Science  
"gamma-ray Astrophysics"

**AGAIN!**