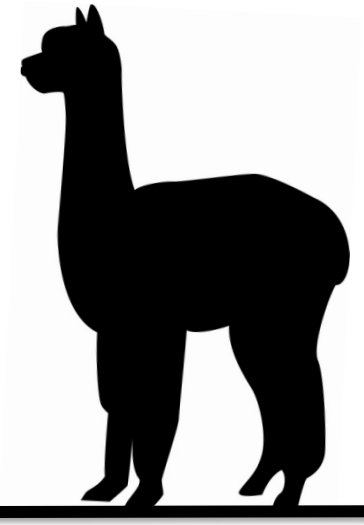
ALPACA Project :
100 TeV Gamma Ray Observation in the Southern Sky



Kazumasa KAWATA
(ICRR, University of Tokyo)
For the ALPACA Collaboration

Workshop on a wide field-of-view Southern Hemisphere TeV gamma ray observatory
2016 Nov 10th

The ALPACA Experiment

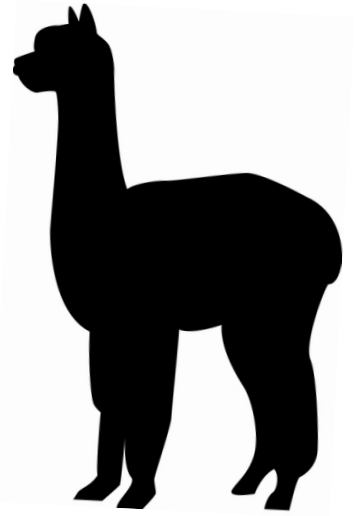
Andes

Large area

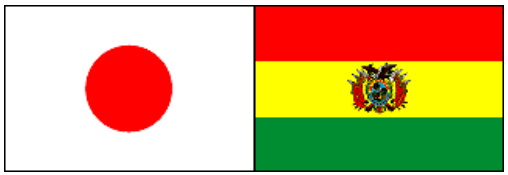
PArticle detector for

Cosmic ray physics and

Astronomy



ALPACA Collaboration



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Almost members from BASJE, GRAPES-3, Tibet ASγ

Outline

- Why in Bolivia?
- ALPACA Site
- ALPACA Experiment
- Sensitivity & Targets in South
- Other Sciences
- Summary

Why in Bolivia?

- Motivation : Galactic Center
  - Most Promising candidate as cosmic-ray origin
- High altitude >4000m, & flat land
  - To observe γ rays above 10 TeV with high efficiency
- Long term collaboration b/w Japan & Bolivia
  - Since 1962 in the CR field, for example, BASJE

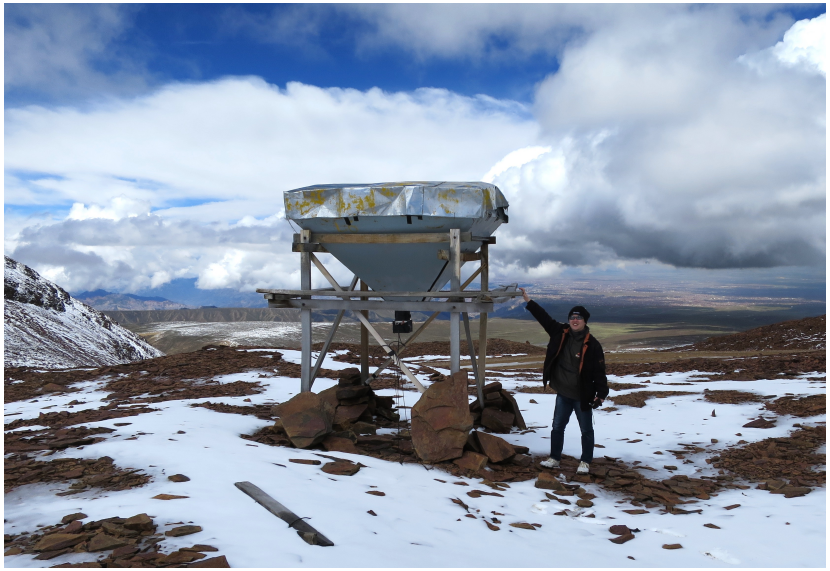
Site Location

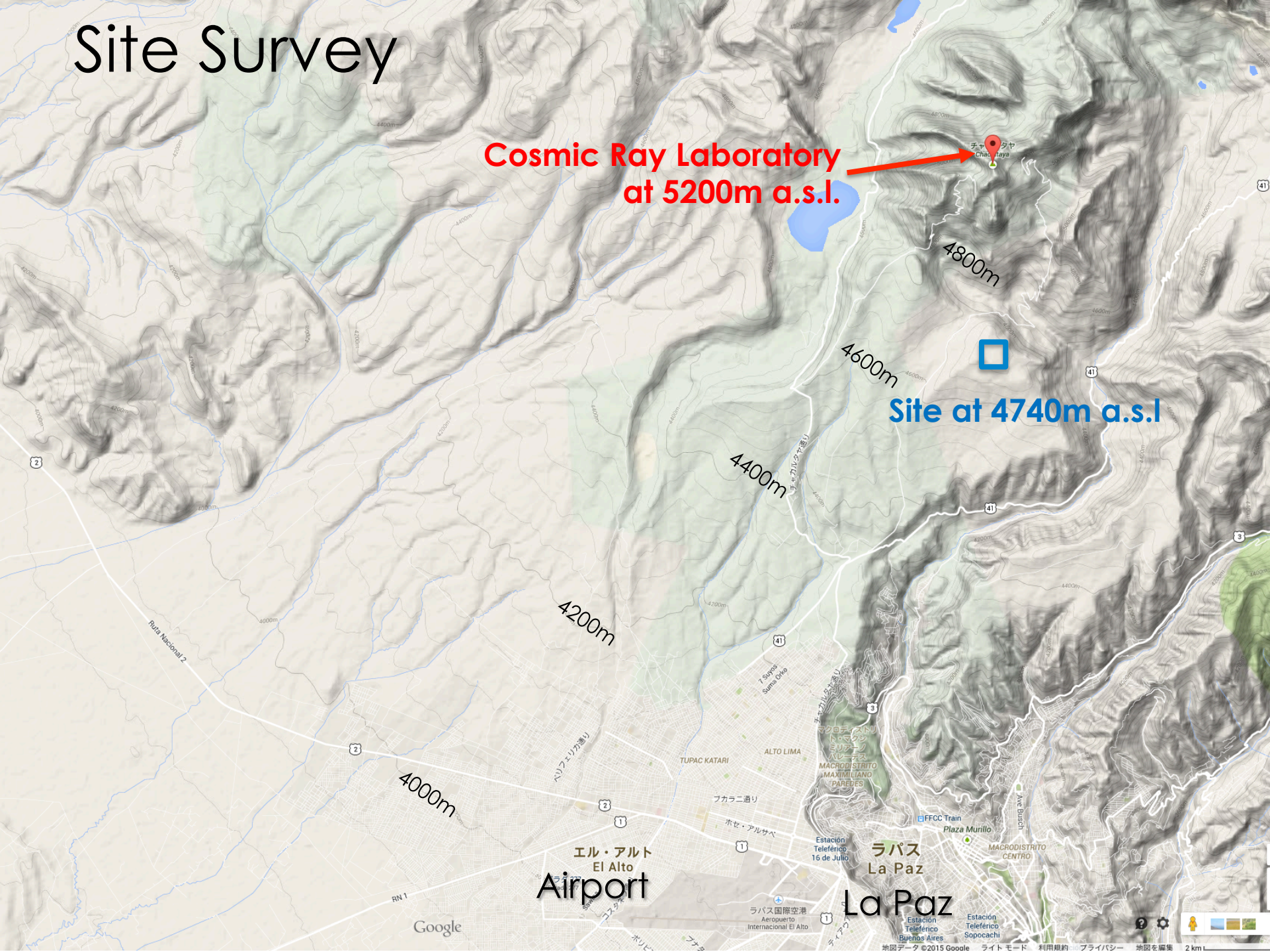
Mt. Chacaltaya, in Bolivia

Narita→Dallas→Miami (16 hours)
Miami→La Paz (7 hours)

Cosmic Ray Laboratory

- ✓ Top of Mt. Chacaltaya at 5200m a.s.l.
- ✓ World height cosmic ray site
- ✓ Pion was discovered by C. F. Powell in1947 (1950 Nobel prize)
- ✓ BASJE experiment had been running (shutdown in 2015)




Site Survey
Cosmic Ray Laboratory
at 5200m a.s.l.
4800m
4600m
Site at 4740m a.s.l
4400m
4200m
4000m
Airport
La Paz
エル・アルト
El Alto
ラパス
La Paz
Google

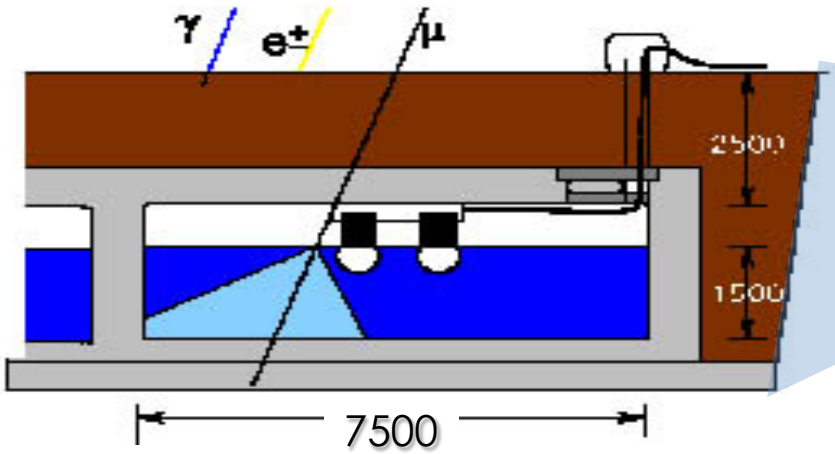
ALPACA Site : Cerro Estuqeria (セロ・エストケリア)

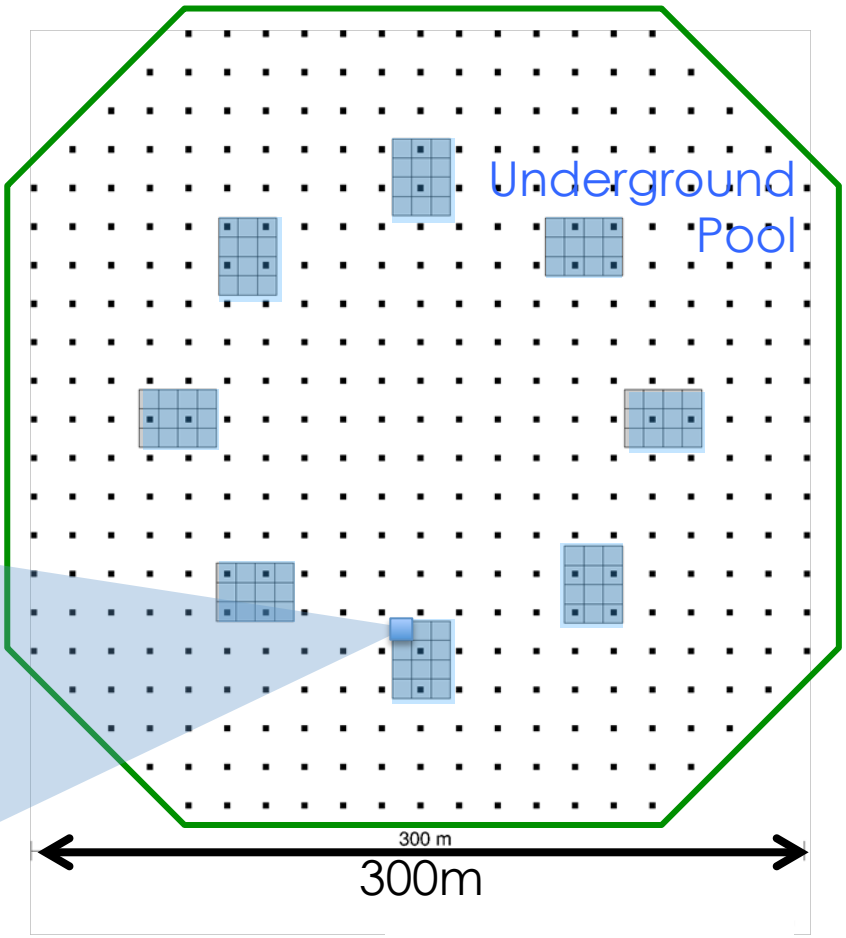
- 16°23'S, 68°08' W
- ~1 hour from La Paz
- 4740m a.s.l. (~570g/cm^2)
- 250,000m^2 (500m×500m)
- flat land within ~±1°

ALPACA Experiment

1. **Air Shower Array ~83,000m^2**
   = 401 x 1m^2 scintillation detectors

2. **Water Cherenkov Type muon detector ~5400m^2**
   underground 2.5m (~19X_0)
   = 56m^2 with 20"ϕ PMT x 96 cells



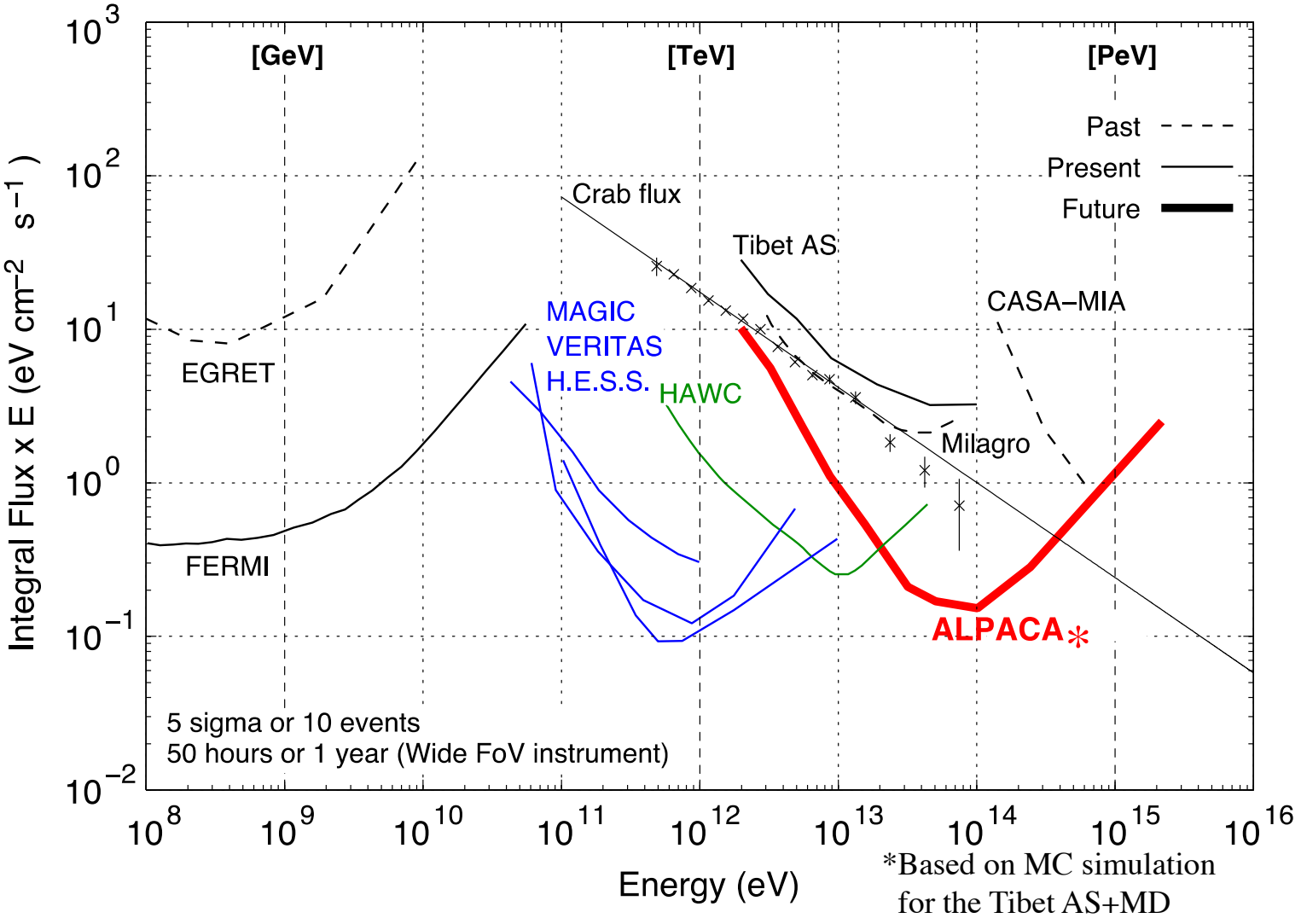


- ✓ Gamma-ray air shower has much less muons.
  Background cosmic rays can be rejected by >99.9% @100TeV.
- ✓ Wide FoV (~2sr) observation regardless day/night and weather

Performance of ALPACA

- AS Array 1m^2 x 401detectors
  - Effective area for AS ~83,000m^2
  - Modal energy ~5 TeV
  - Angular resolution ~0.2° @100TeV
  - Energy resolution ~30% @100TeV
  - Field of view ~2 sr
- MD Array 56m^2 x 96 detectors
  - Effective area for muons ~5400m^2
  - CR rejection power >99.9% @100TeV (gamma ray efficiency ~90%)

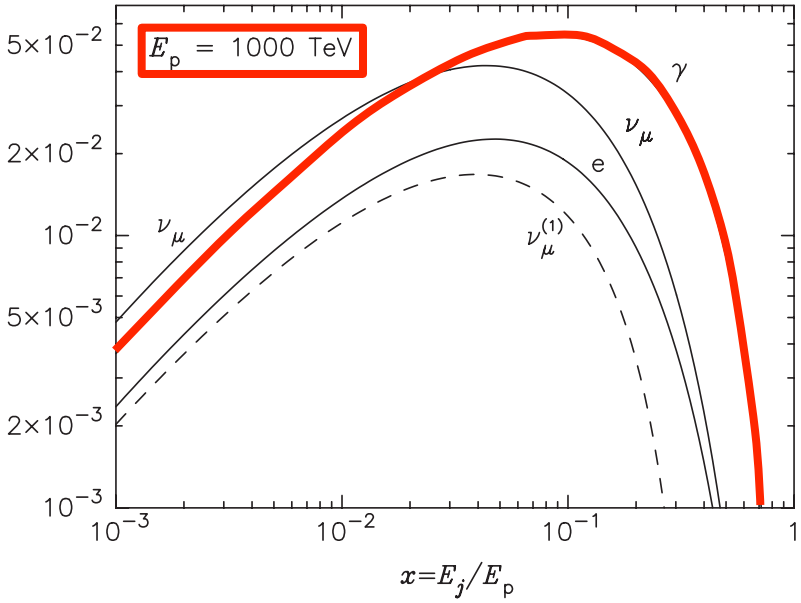
Sensitivity to the Point Source



Origin of Cosmic Rays at the Knee

- ✓ CRs acceleration up to PeV is possible by shock wave acceleration at SNR. The Knee = 4 PeV is explained by the Galactic origin?

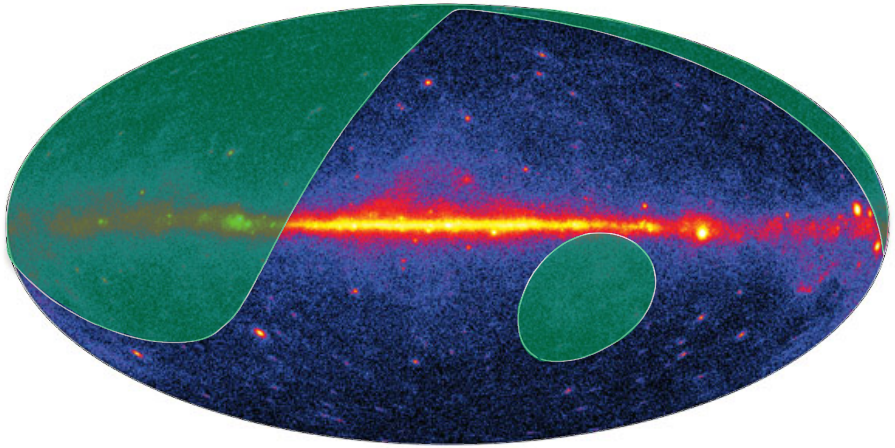
$x^2 F_j(x, E_p)$ *Kelner et al., PRD 74, 034018 (2006)*



- ✓ CR+ISM → π^0+⋯→ 2γ
- ✓ E of γ/ν O(1/10 of Ep_{MAX})

100 TeV γ-Ray Observation
PeVatron = Key of CR Origin

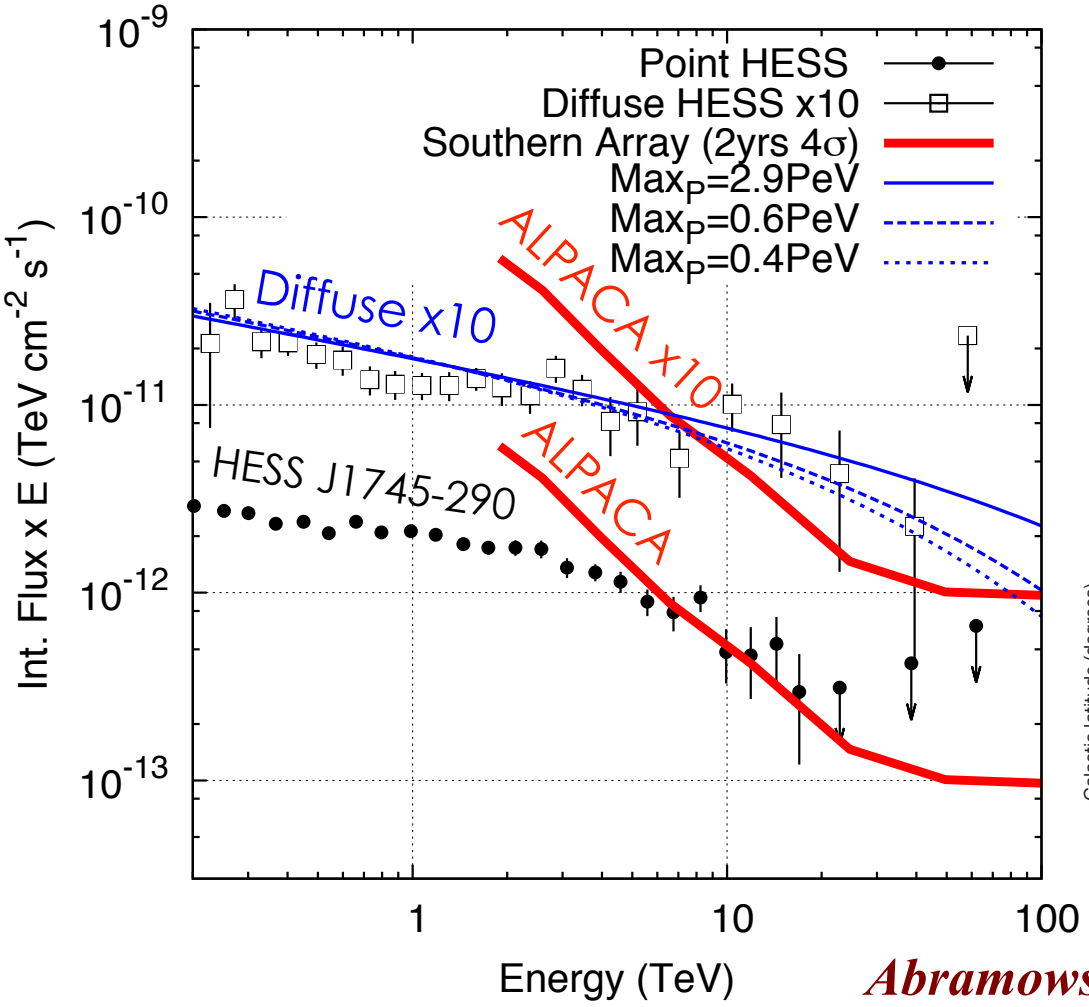
100TeV γ-Ray Astronomy in South



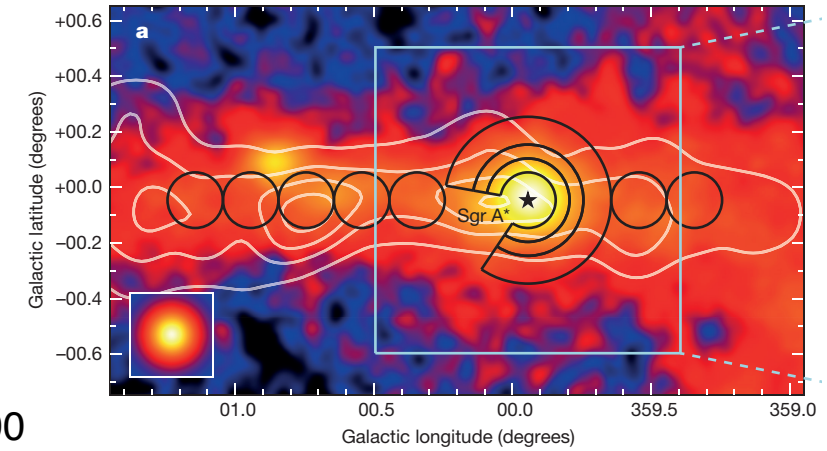
- Galactic Center
- Fermi Bubbles
- Young SNRs
- Other Galactic Sources
- Nearby Extragalactic Sources

Search for PeVatron !!

Galactic Center as the PeVatorn?



- ✓ Diffuse component observed by HESS
- ✓ Possible >100TeV γ-rays
- ✓ Observation of the high-energy end

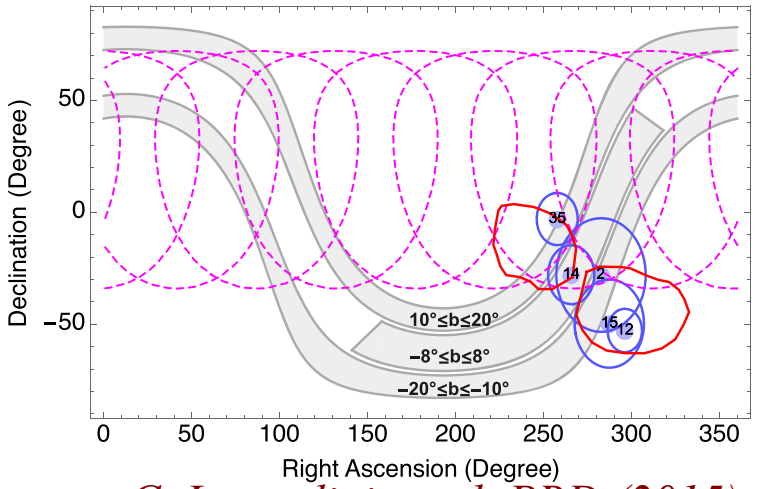


Abramowski, et al (H.E.S.S.), Nature (2016)

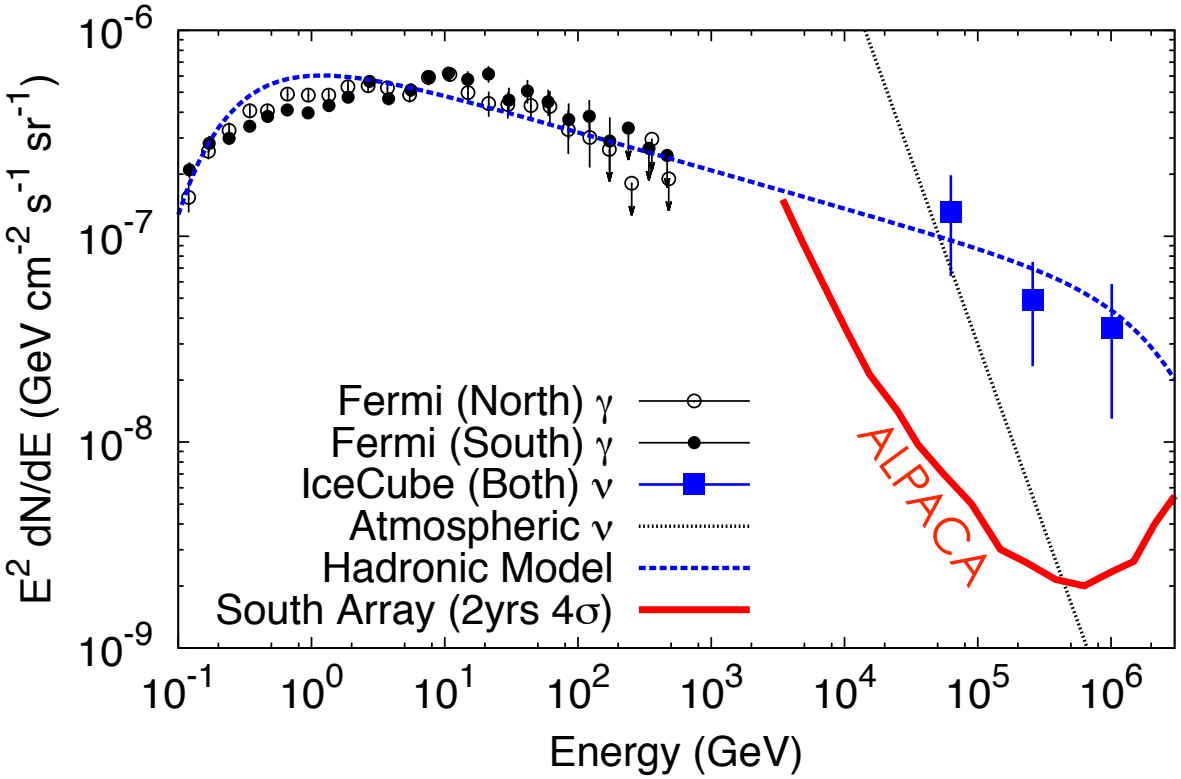
"Acceleration of petaelectronvolt protons in the Galactic Centre"

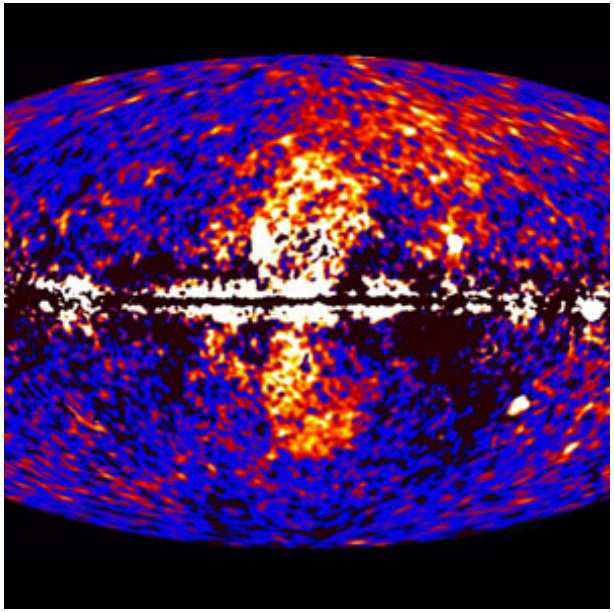
Fermi Bubbles

- ✓ If origin of the IceCube neutrinos are hadronic in FBs, they might be observed by sub-PeV gamma rays (1 order better).
- ✓ Difficult to observe by IACTs with small FoV, because total solid angle of the Fermi Bubbles is huge (~0.8sr)



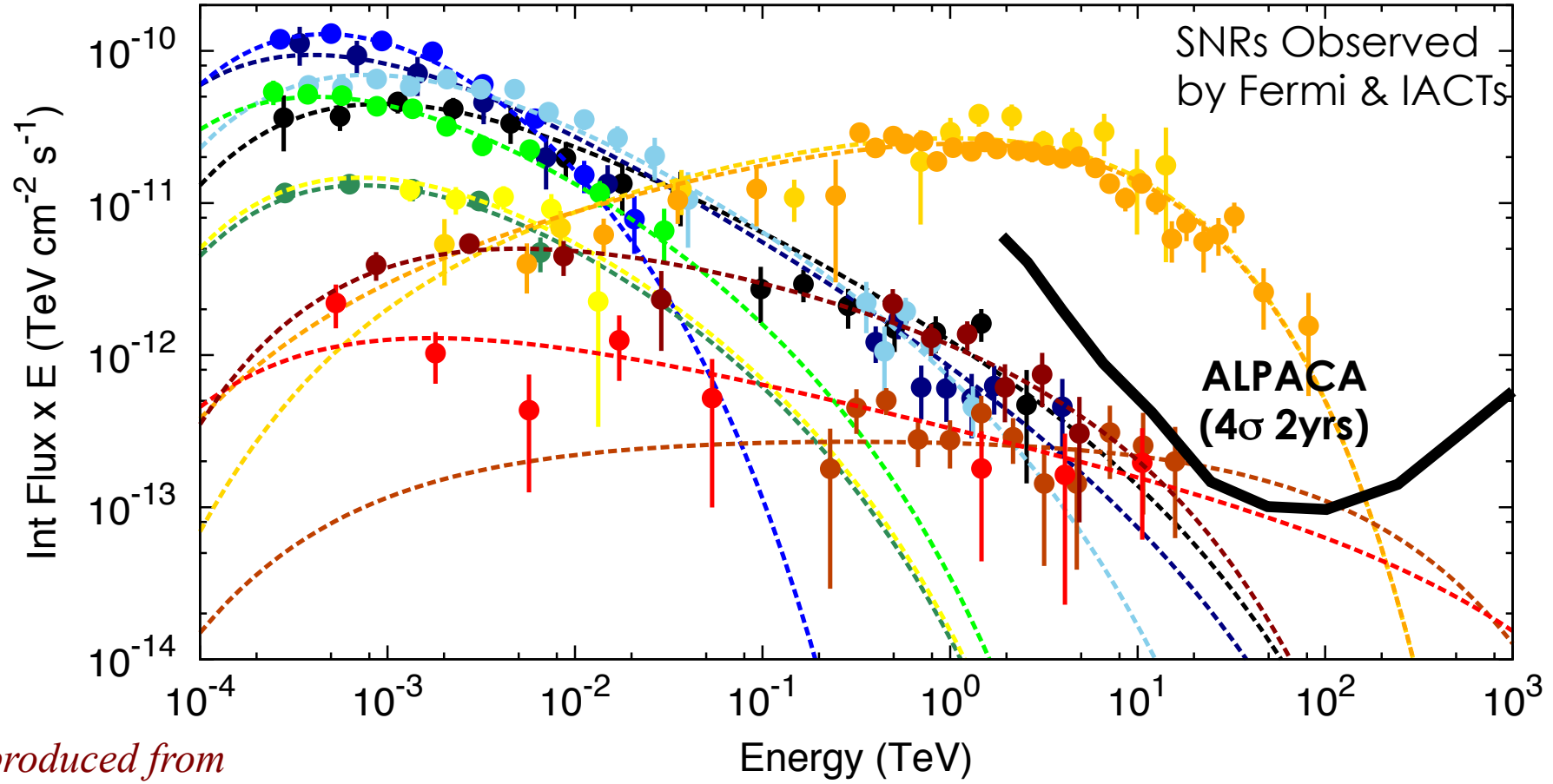
C. Lunardini, et al, PRD (2015)





Bubbles observed by Fermi-LAT

Young SNRs

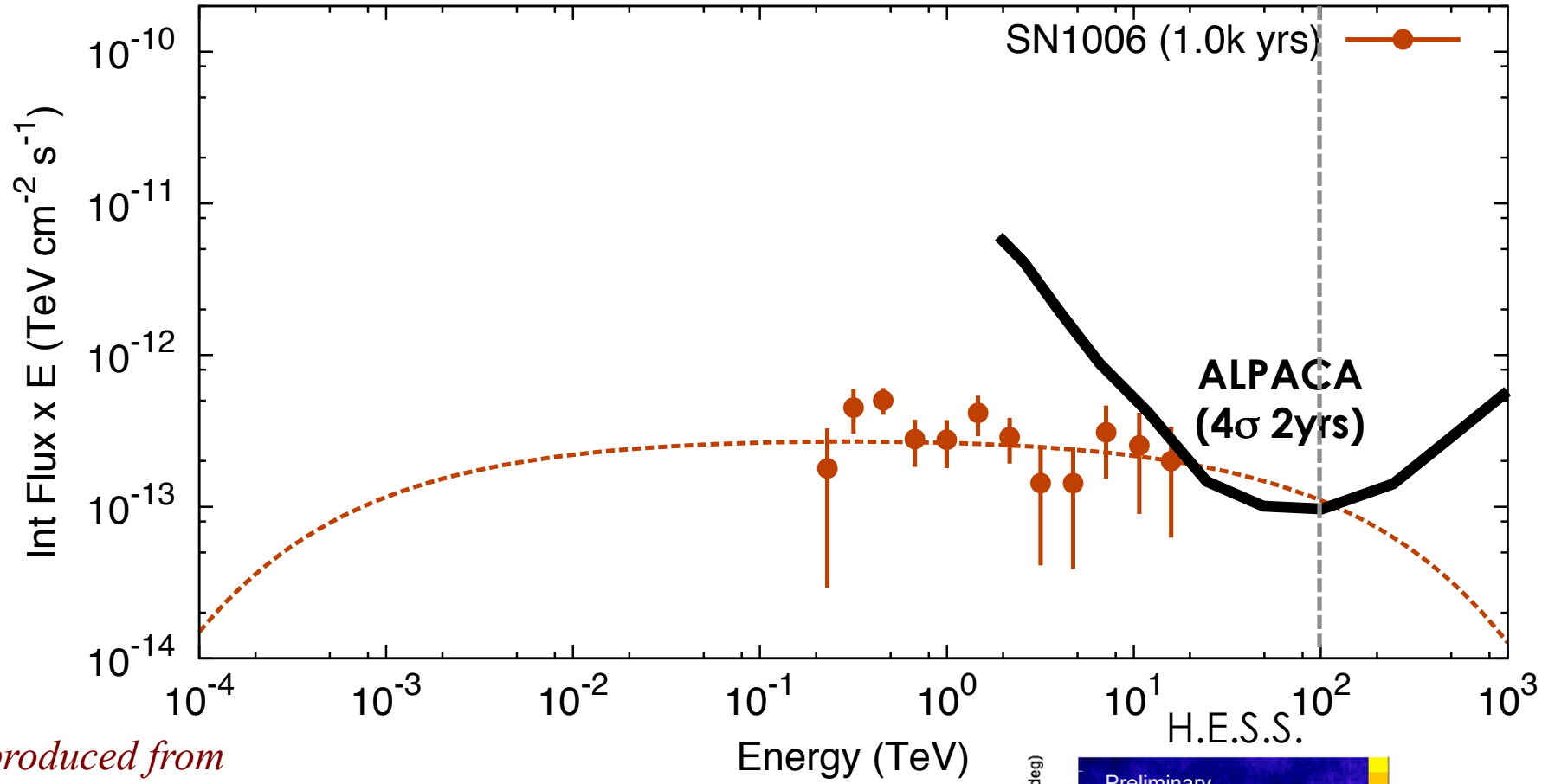


Reproduced from slides presented by S. Funk (TeVPA 2011)

W51C (35k yrs)
W28 (30k yrs)
W44 (20k yrs)
IC443 (10k yrs)
Cyg Loop (5.0k yrs)
W49B (4.0k yrs)

PuppisA (3.7k yrs)
RXJ0852 (2.5k yrs)
RXJ1713 (2.0k yrs)
SN1006 (1.0k yrs)
Tycho (0.4k yrs)
CasA (0.3k yrs)

SN1006



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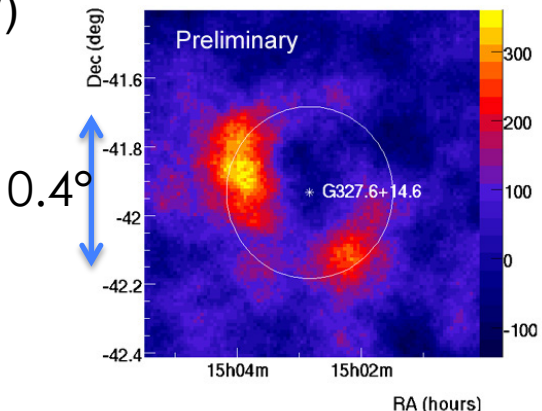
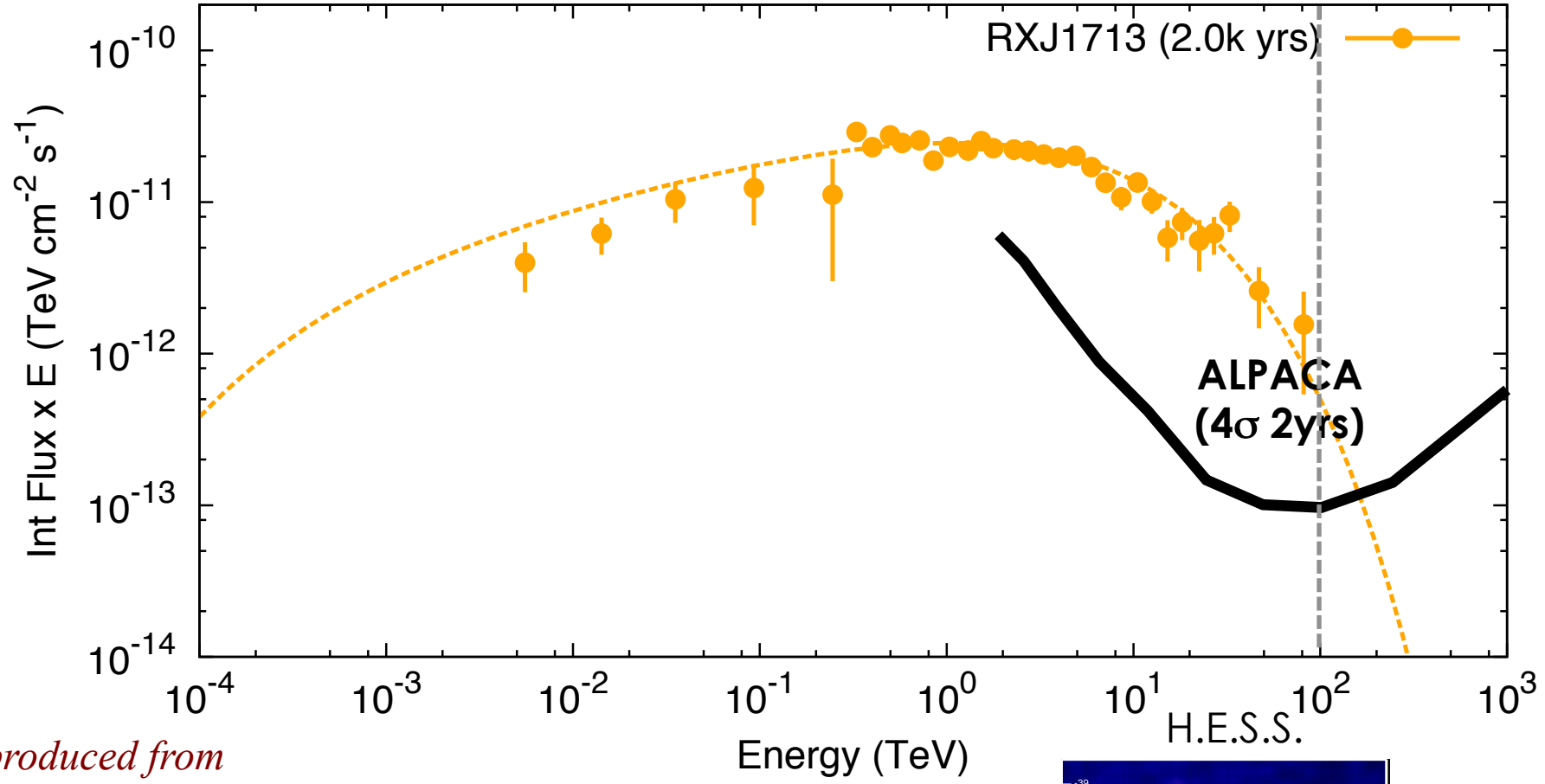


SNRs Observed by Fermi & IACTs

RX J1713.7-3946



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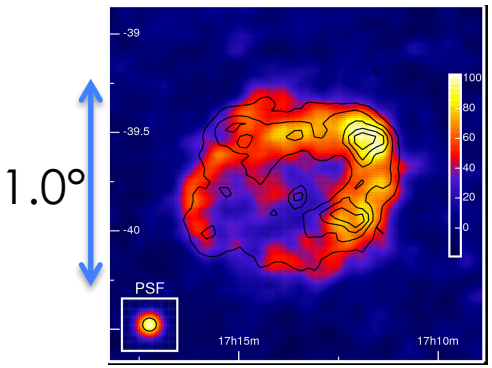
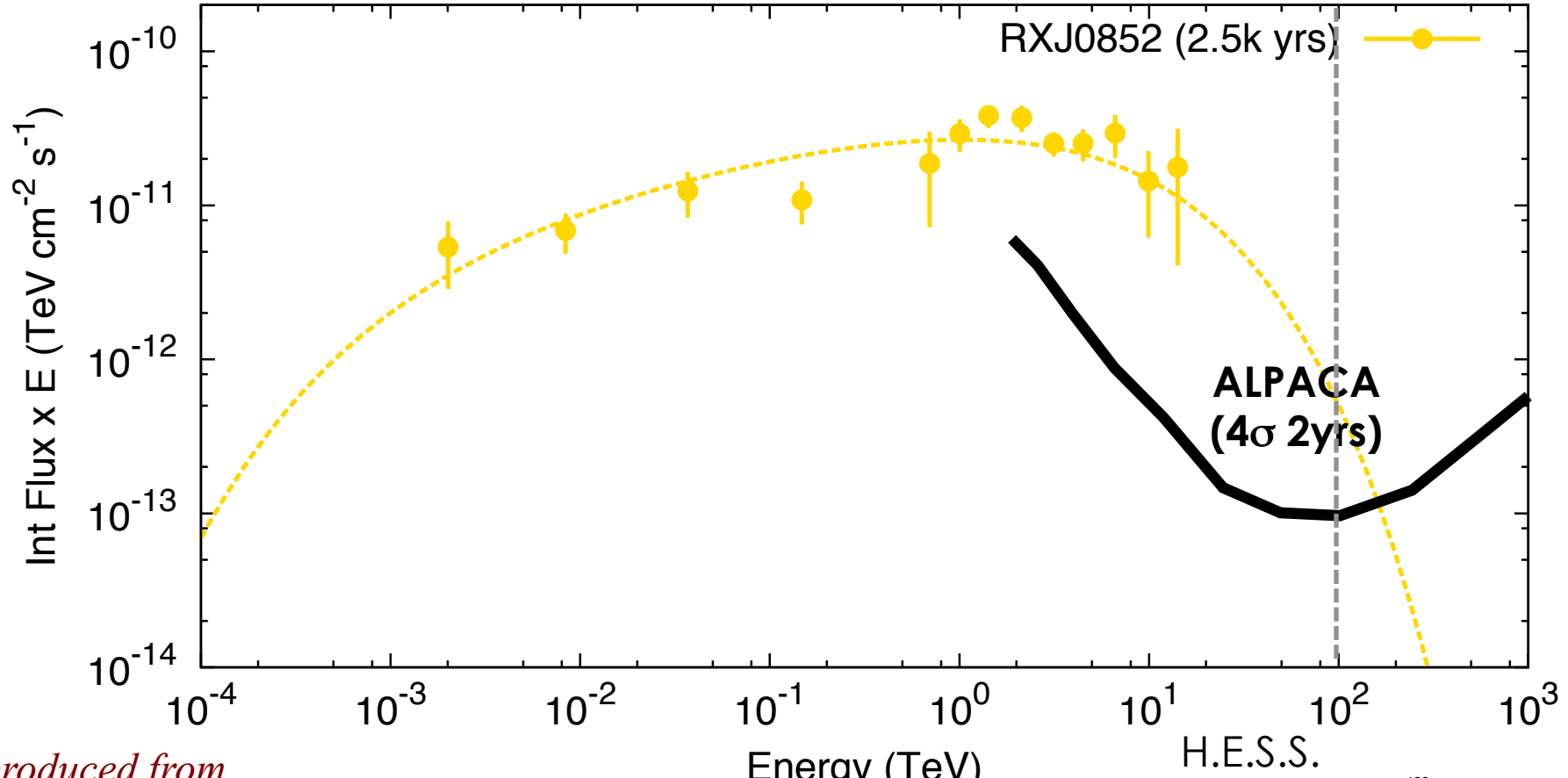
SNRs Observed by Fermi & IACTs



RX J0852.0-4622



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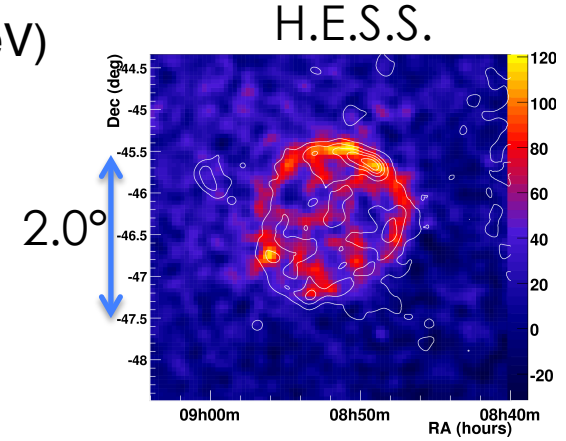
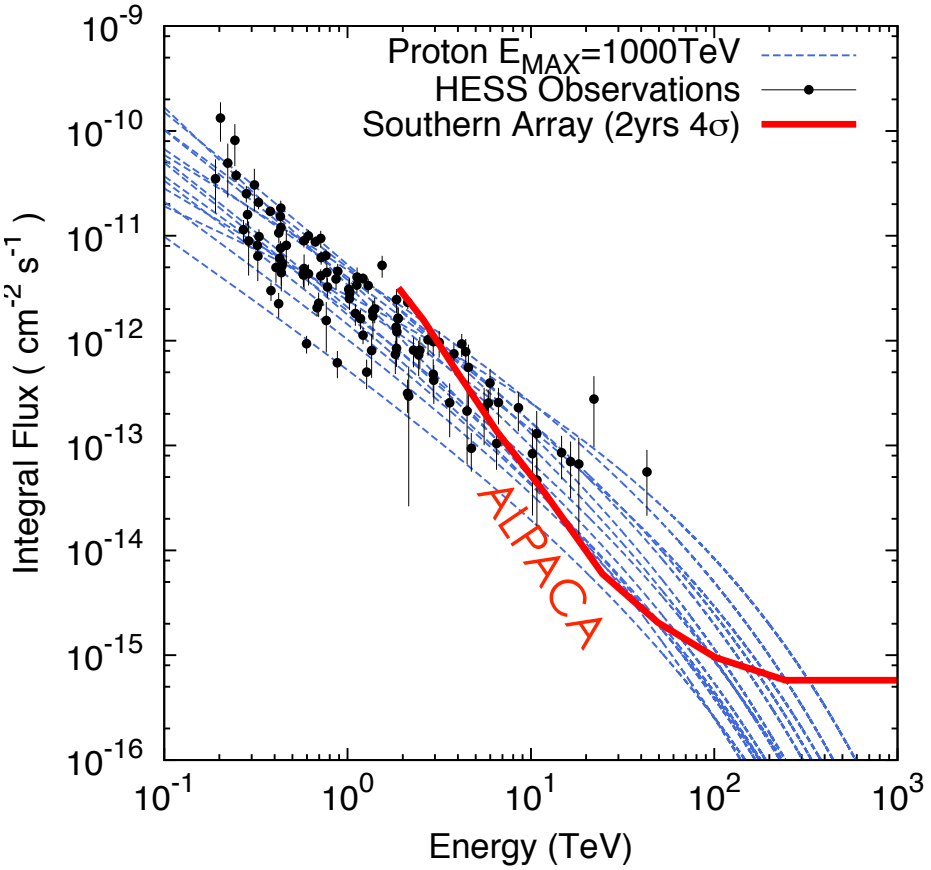
SNRs Observed by Fermi & IACTs

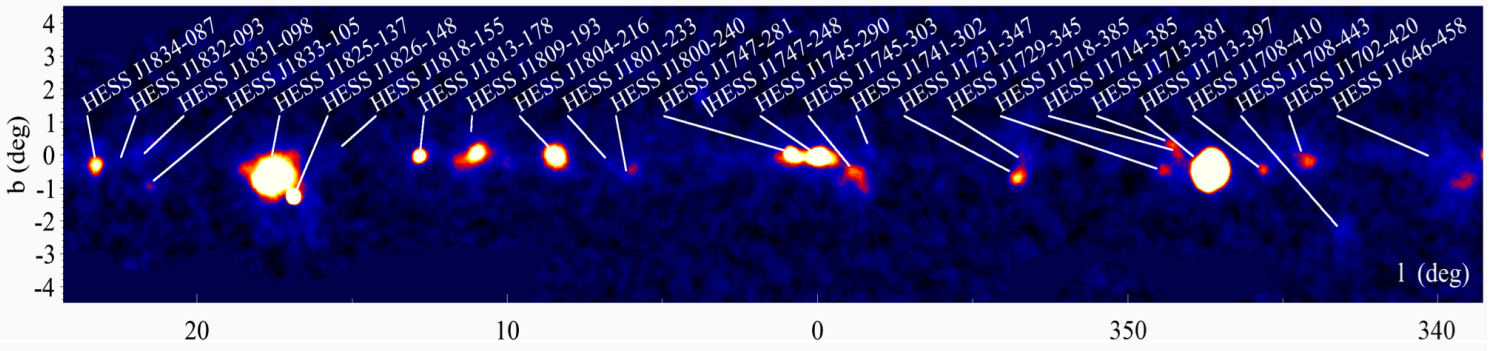


Other Galactic Sources

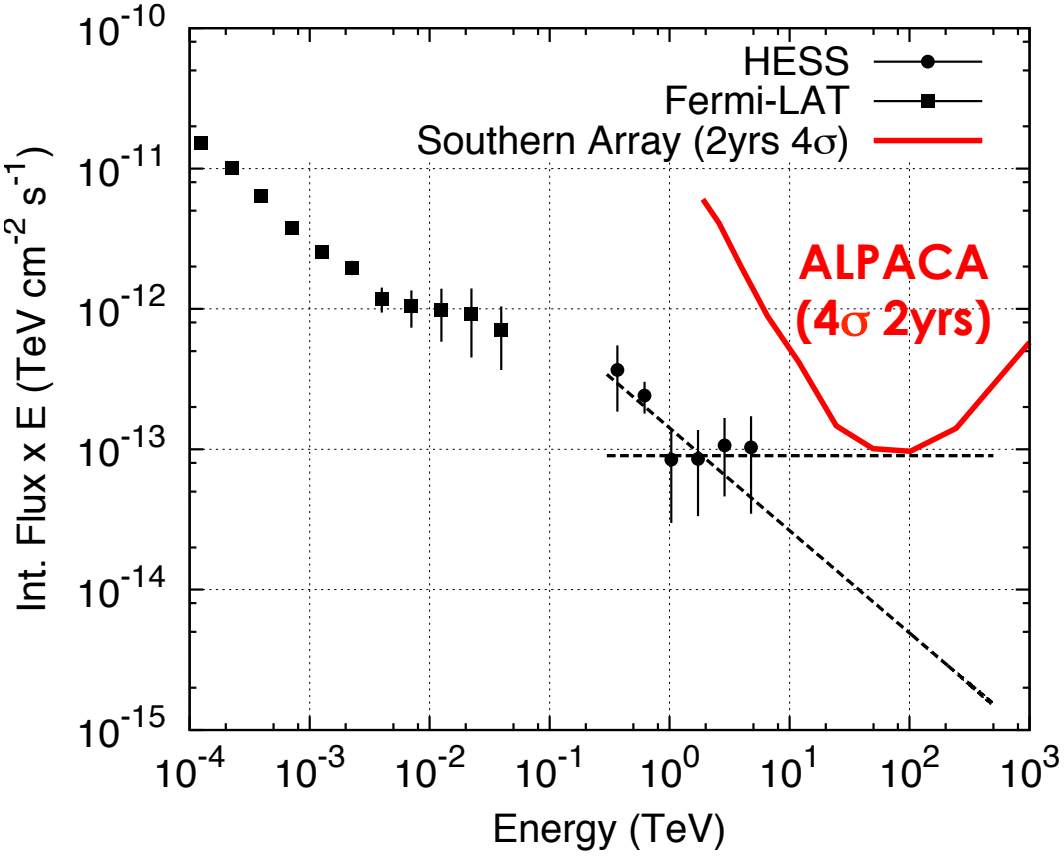


- ✓ More than dozen sources
- ✓ Many sources are dark in other wave length
  → Dark particle accelerator
- ✓ Many candidate of PWN (excess is located near pulsar)
- ✓ Diffuse γ from Galactic plane

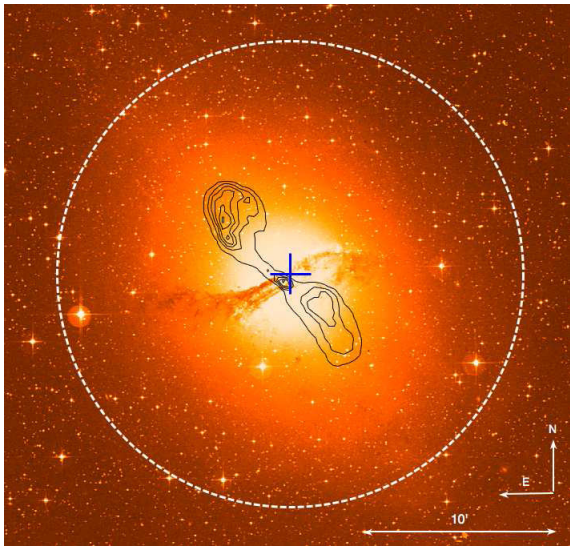
Aharonian et al, ApJ, 636, 777 (2006)



Nearby Extragalactic Source CenA



- ✓ Distance 3.8Mpc Nearby
- ✓ Relativistic jets
- ✓ Flat spectrum >TeV?
- ✓ No time variation?

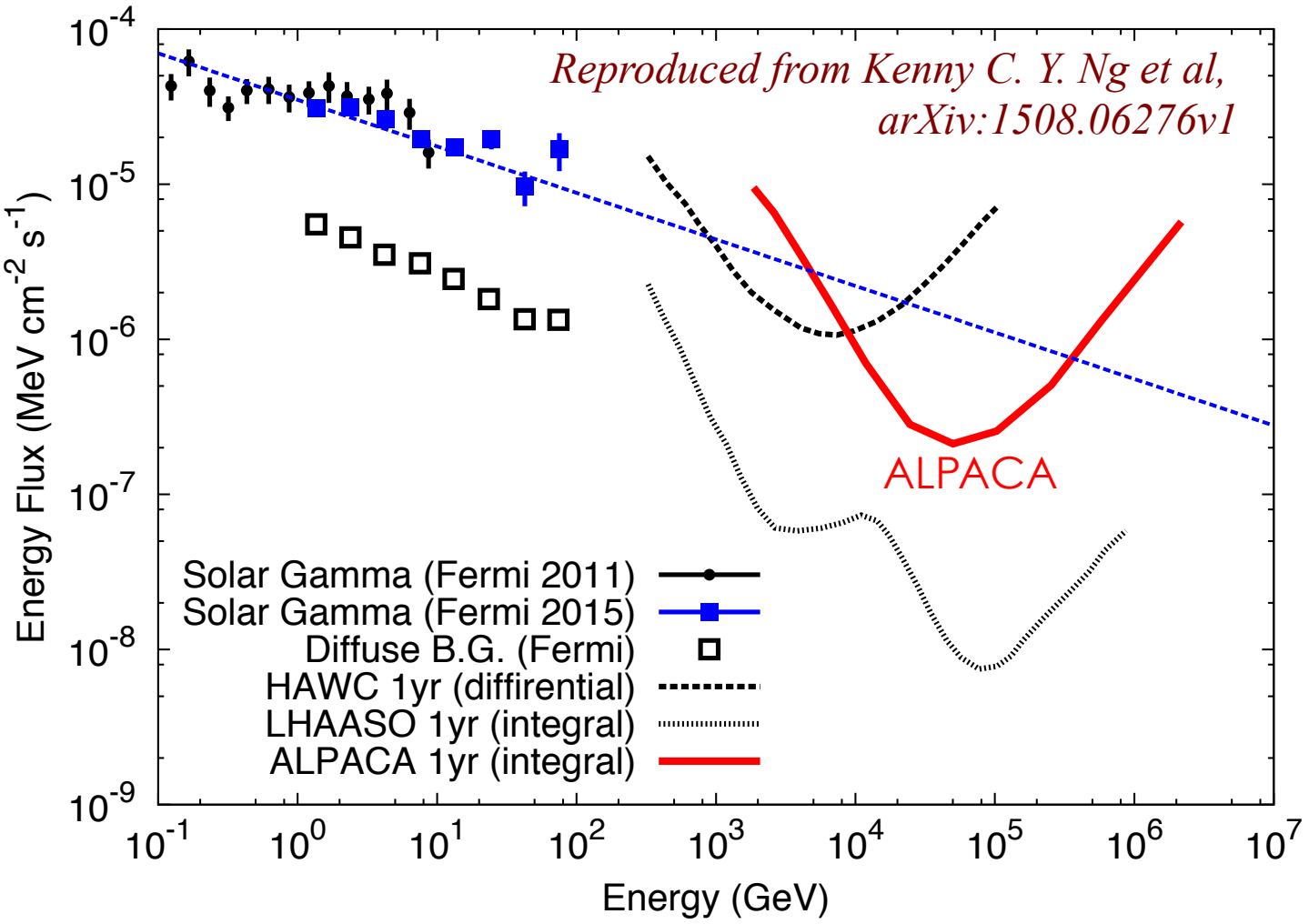


Aharonian et al, ApJ, 695, L40 (2009)
Sahakyan, et al, ApJ, 770, L6(2013)

Other Observations

- TeV Cosmic ray anisotropy
  - Complementary to IceCube (>20TeV)
- Sun's Shadow
  - Observation is possible through 1 year
  - Cosmic ray statistics will be twice
- Gamma ray from the Sun disk
  - Spectrum up to 100 GeV by Fermi-LAT
  - CRs interact with solar atmosphere ($\pi^0 \rightarrow 2\gamma$)

Sensitivity to Solar Disk γ-Ray

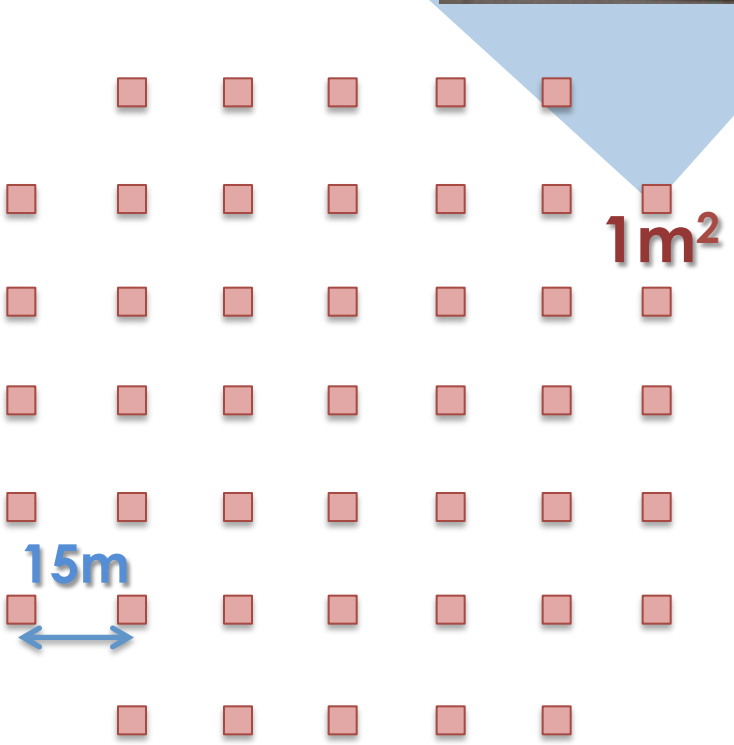


Detectable, if spectrum extends up to 10 TeV

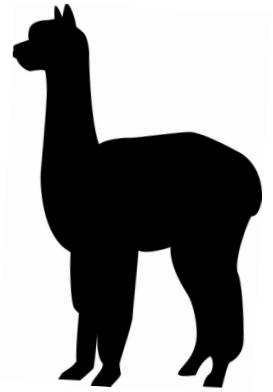
ALPAQUITA Array

- Prototype Array
  (ALPACA 1/10 Scale of AS)
  - 1m^2 Scinti. Det. 7x7-4、
    15m spacing
  → 8100m^2

Under preparation



Summary



- ALPACA Project：Mt. Chcaltaya 4,740m asl
  83,000m² AS array＋
  5,400m² Water-Cherenkov Muon Detectors
  → 100 TeV γ ray observation in the Southern sky

- Background rejection >99.9%@100TeV
  Point source sensitivity <20% Crabs/yr @40TeV
  Advantage for the extended sources

- Targets：
  G.C.、FB、Young SNRs、PWN、Nearby AGN
  → Search for PeVatrons

- Other Physics：
  CR Anisotropy in South, Sun's shadow through 1 year,
  Solar gamma ray search

- ALPAQUITA：8,100m²
  - Prototype air shower array will be constructed in 2017.