



# Future of Ground-based Gamma-Ray Astronomy

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ICRR, The University of Tokyo



# HE/VHE Gamma-Ray detectors



MAGIC-II



VERITAS



HAWC



Fermi Gamma-Ray Satellite

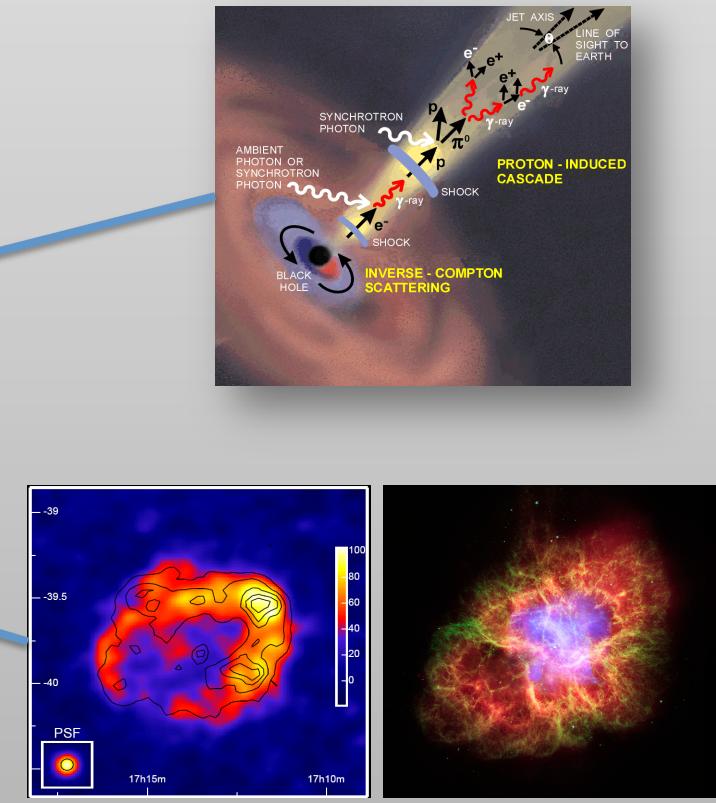
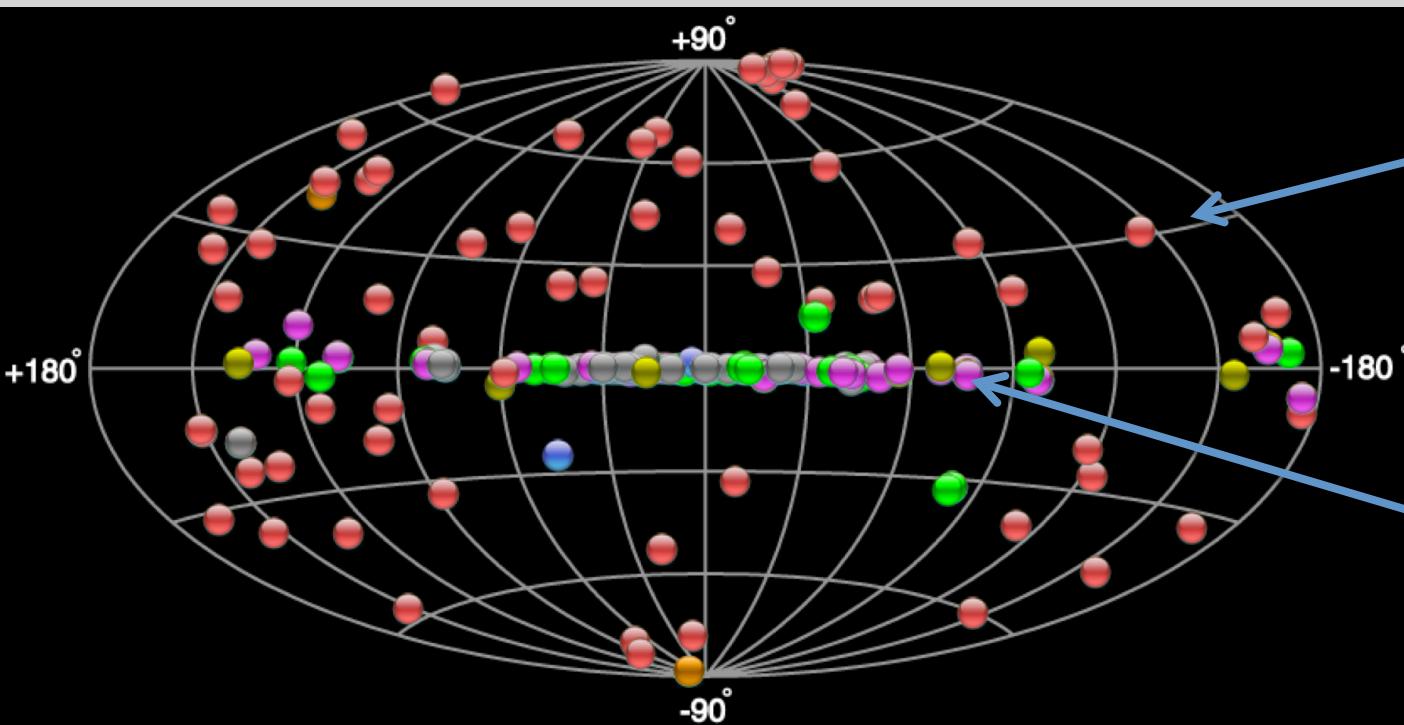
HESS-II



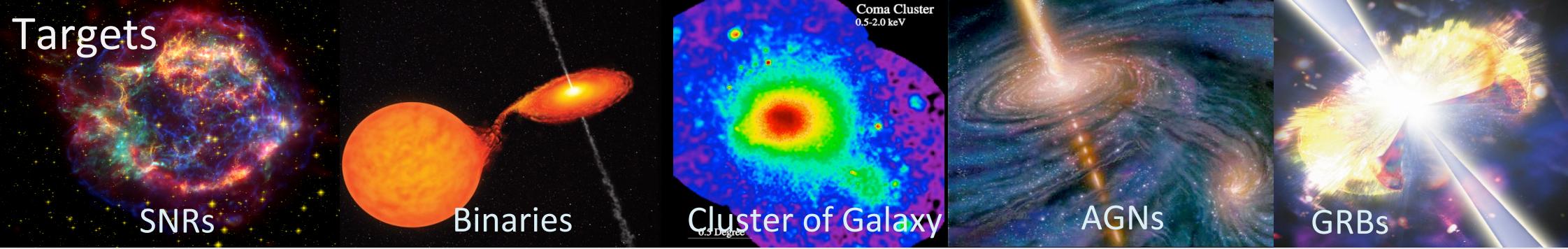
# VHE Gamma Ray Astronomy

## A New Window to the Universe and Energy Frontier in Astrophysics

- HESS, MAGIC, VERITAS observed more than 180 sources
- CTA will expand the visible universe up to  $z = 4$  with the superior sensitivity, and broad band energy coverage, and will observe  $>1000$  sources
- CTA will have  $10^4$  times higher sensitivity than Fermi LAT for the transient/flaring sources, like gamma ray bursts and AGN flares.

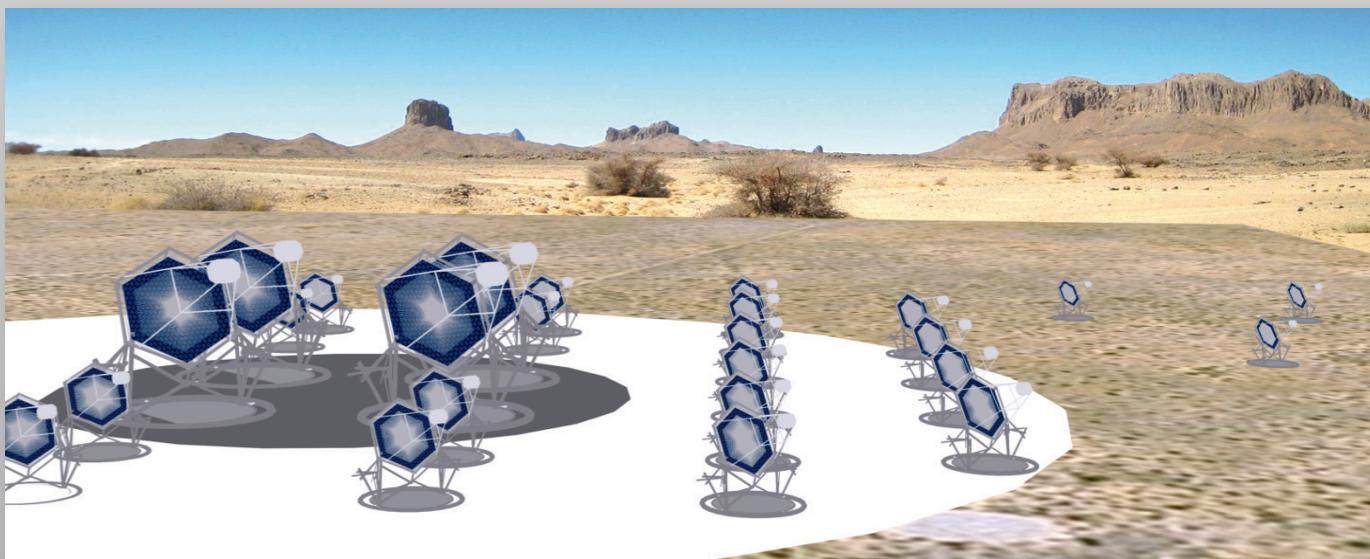


# Targets

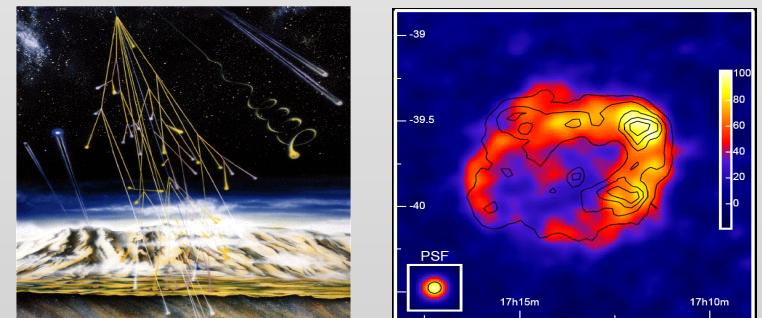


## Cherenkov Telescope Array High Energy Gamma Ray Astronomy

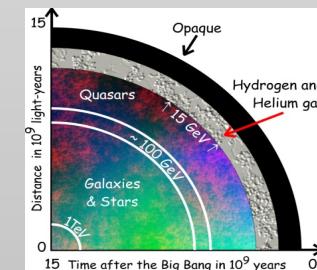
- Origin of Cosmic Rays
- High Energy Astronomical Objects
- Super Massive Black Holes
- EBL Study → Cosmology (Star formation rate)
- Search for Dark Matter



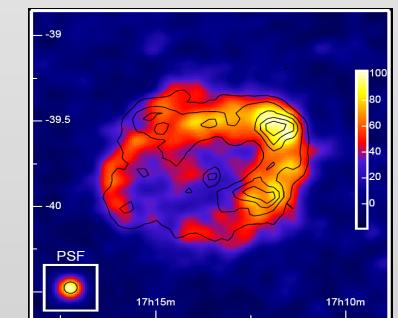
## Science Objectives



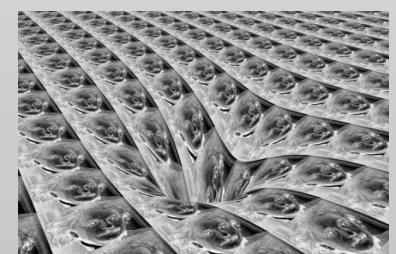
Cosmic Ray Origin



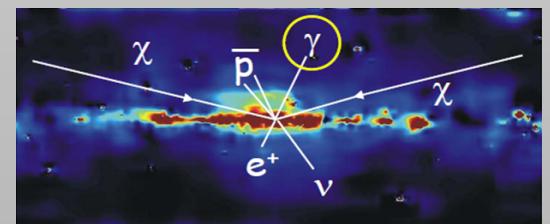
Cosmology



High Energy Objects

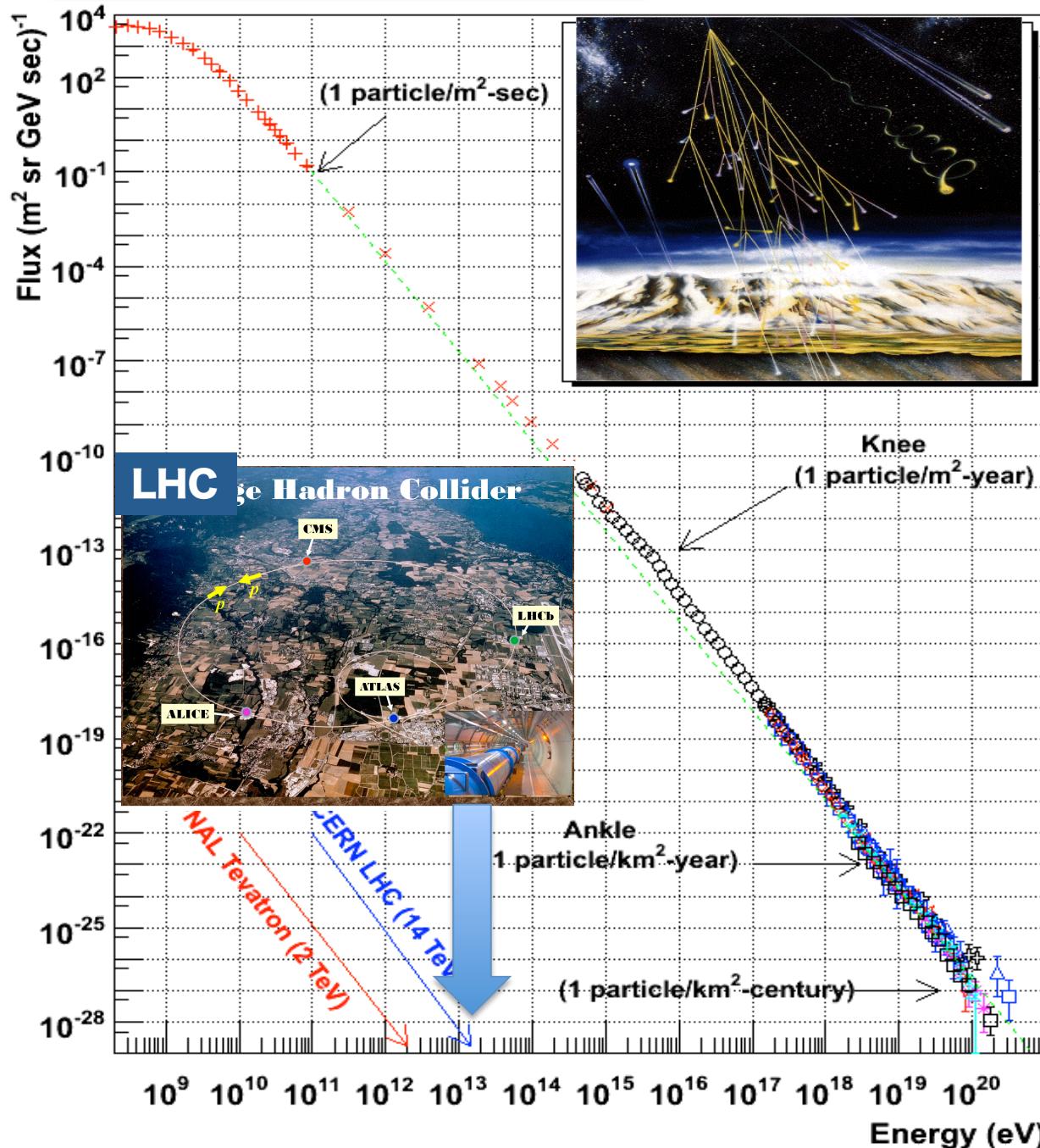


Space & Time

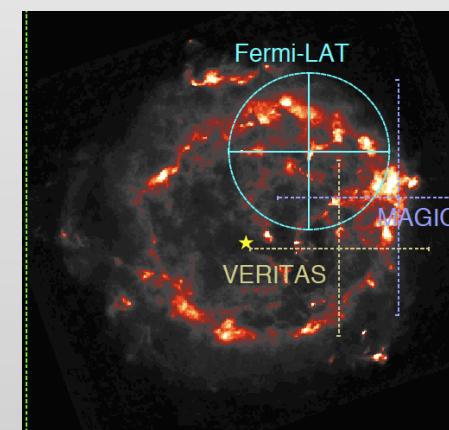


Dark Matter

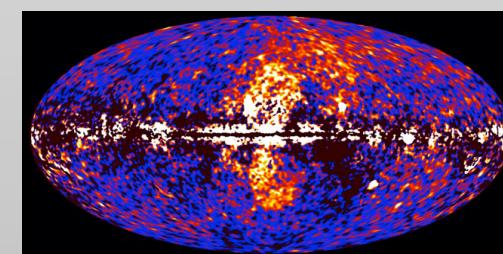
# Cosmic Ray Energy Spectrum



## Observation of accelerators in the Universe with HE/VHE gamma rays



SNRs  
(Cas-A)



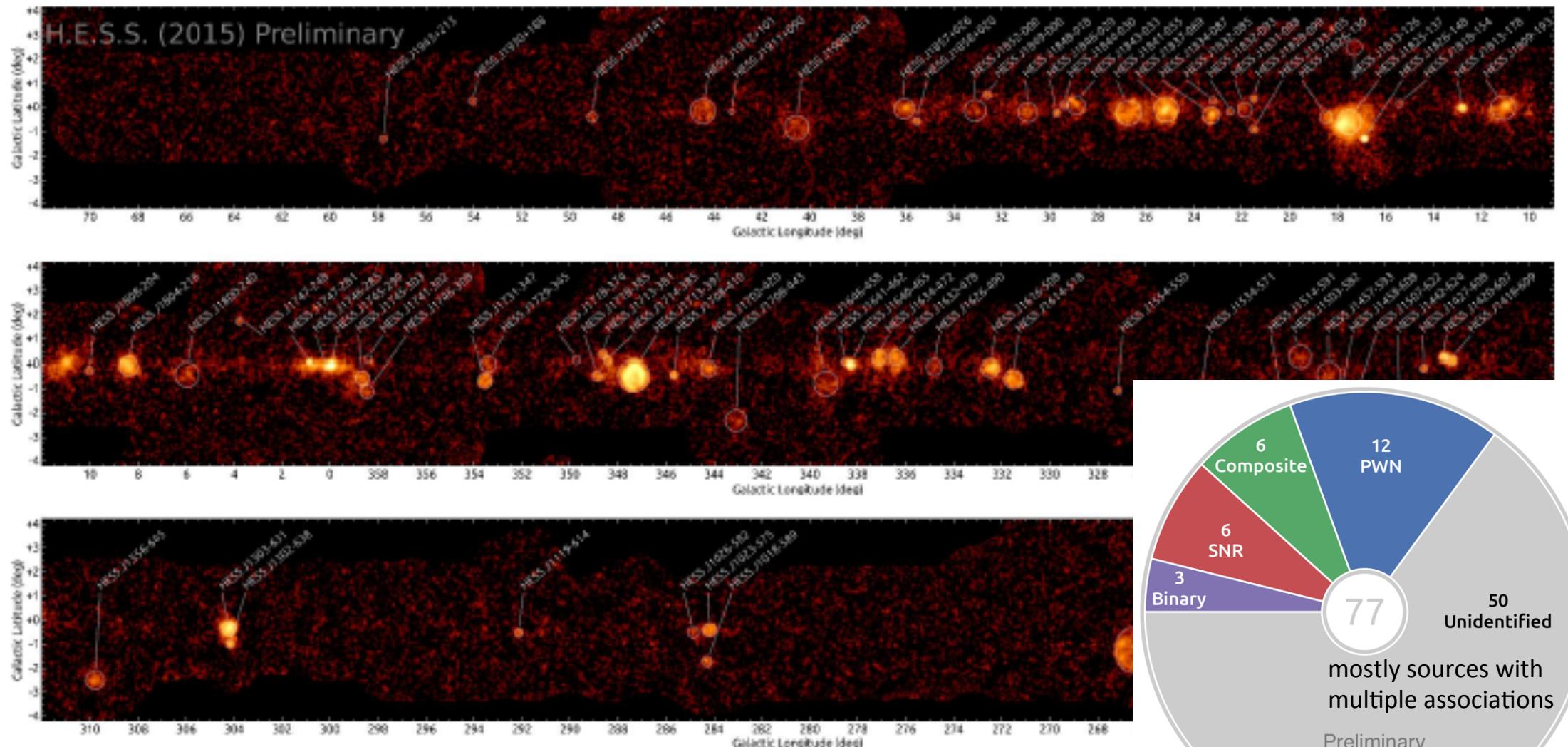
Large Structure  
in our galaxy  
(Fermi bubble)



AGNs  
(M87)

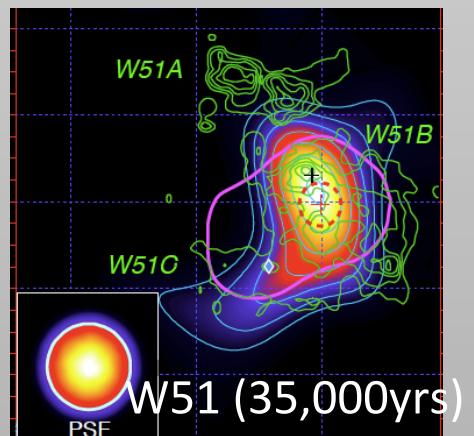
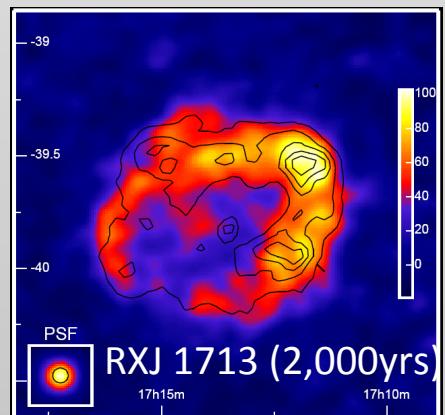
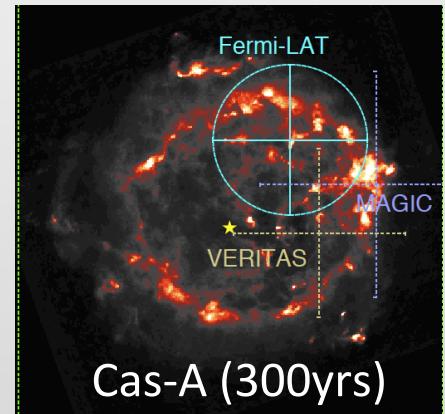
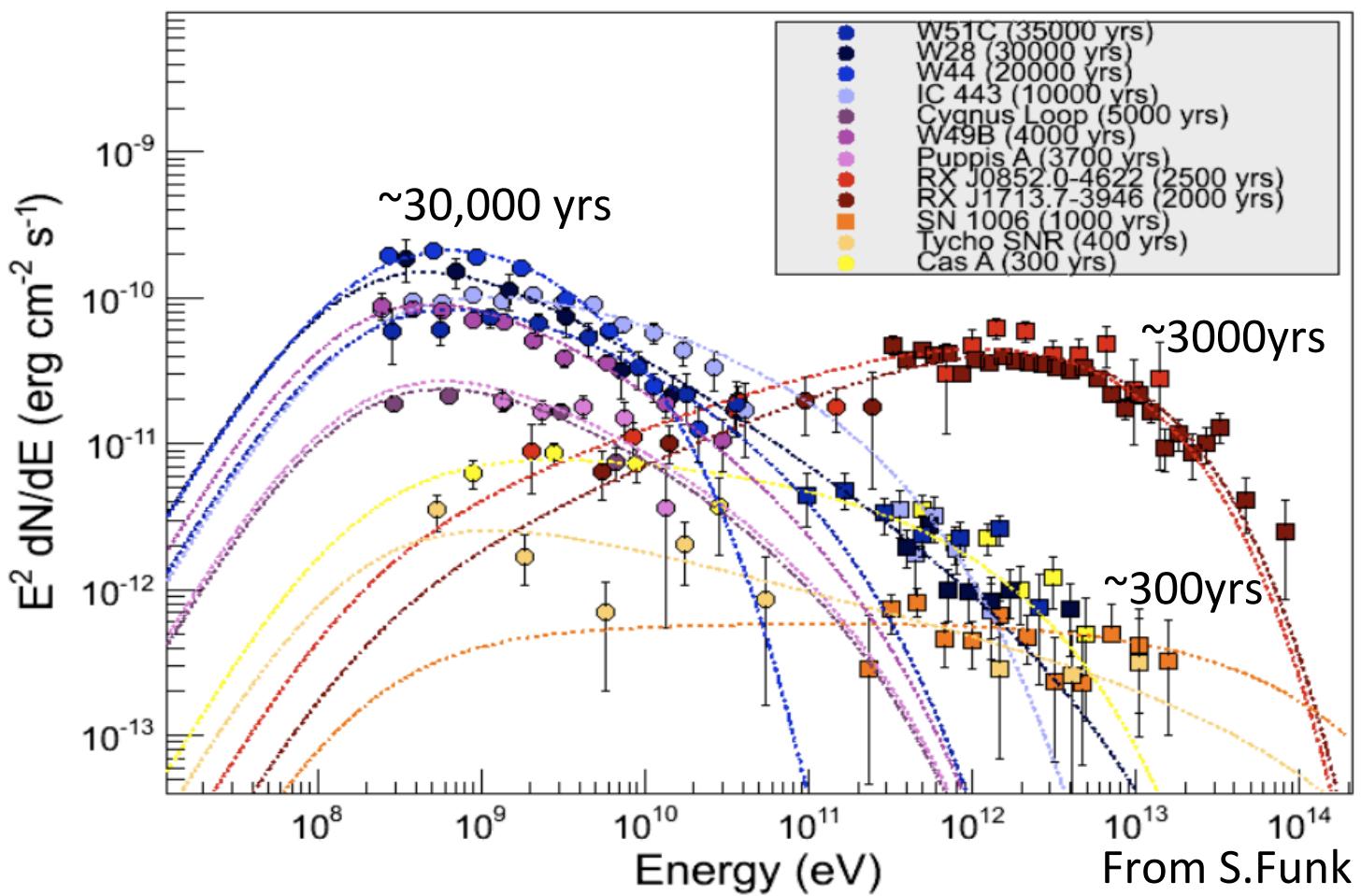
# HESS Galactic Plane Survey

## Deil et al. ICRC 2015 and Chaves TeVPA 2015



Preliminary

# $E < 10^{15}$ eV Cosmic Rays $\leftrightarrow$ Shell type SNRs



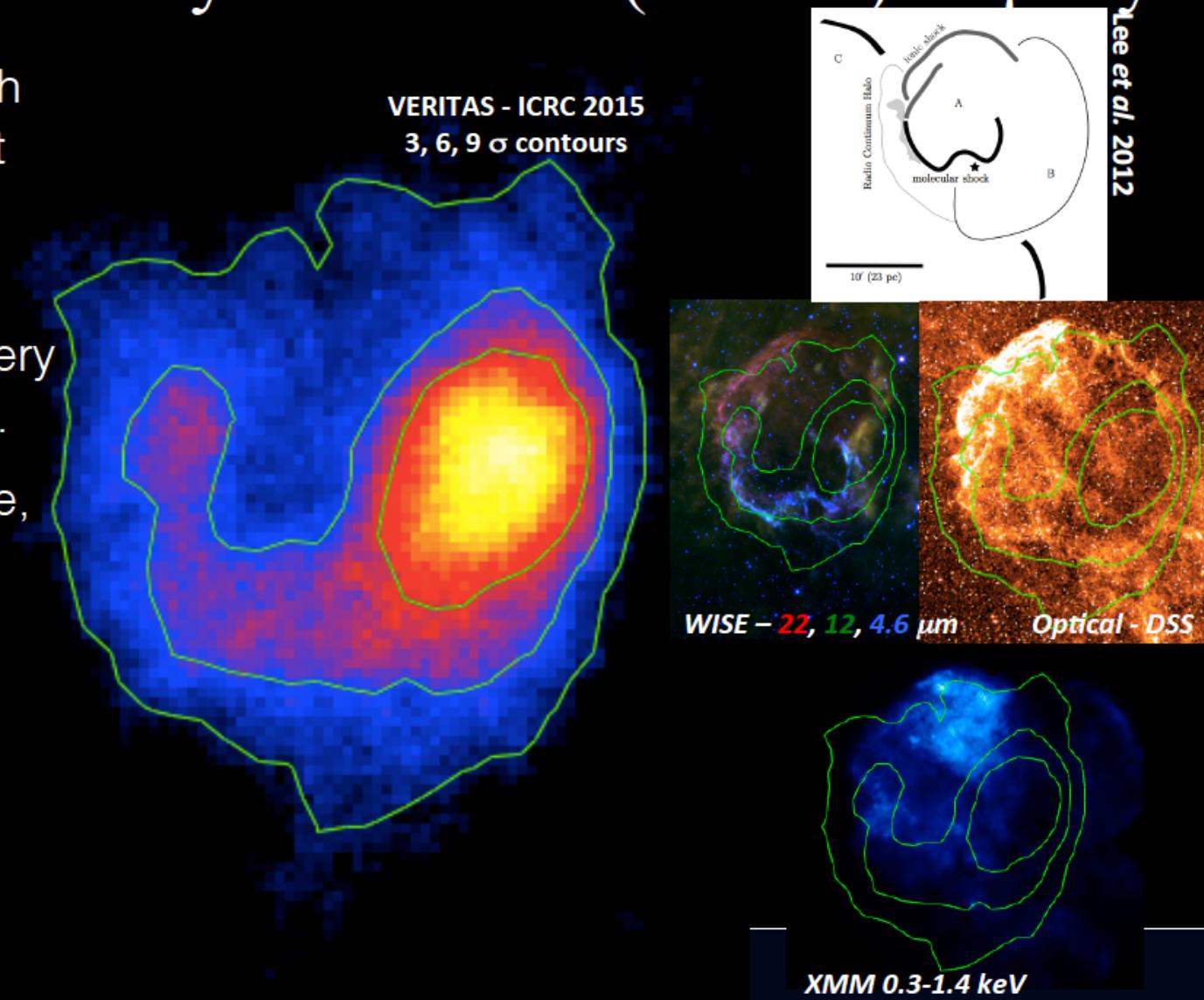
- Different stages of SNRs as cosmic ray accelerator
- CTA will deliver more information on SNRs as cosmic ray accelerators
- We can survey most of SNRs in our galaxy → C.R. energetics

# VERITAS IC443

## Humensky ICRC2015 & Mukherjee TeVPA

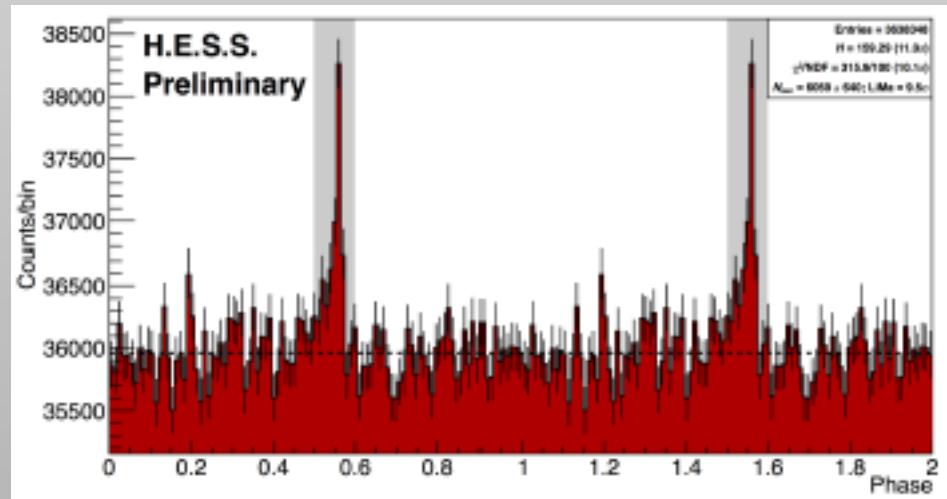
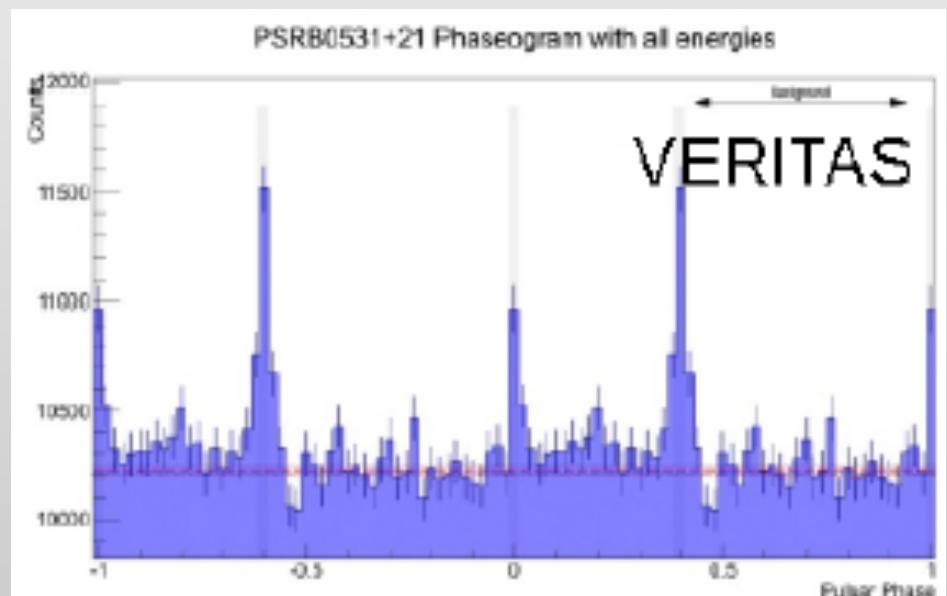
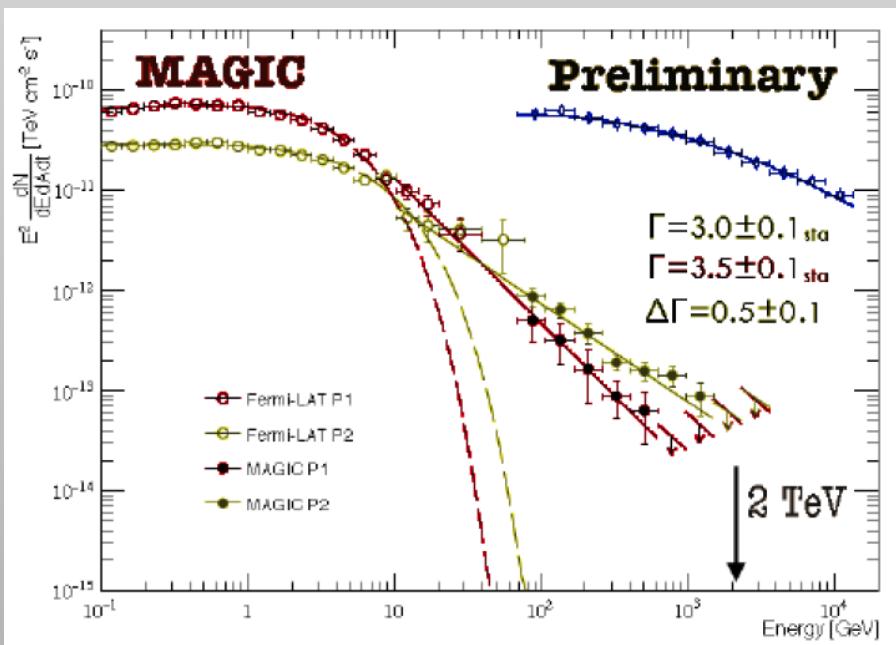
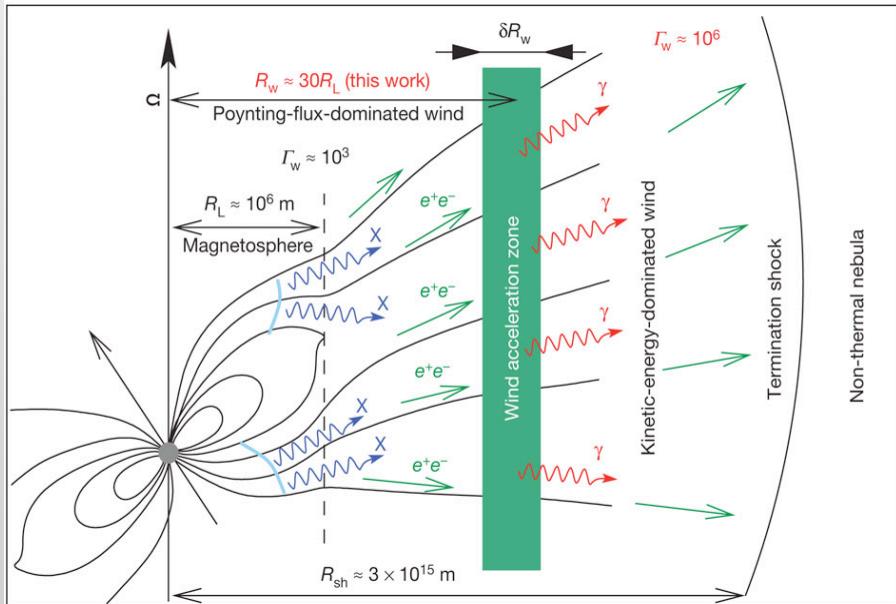
### Summary: Resolving the Jellyfish Nebula (IC 443) in $\gamma$ -rays

- ❖ A deep observation of IC 443 with VERITAS has resolved significant VHE emission from the entire northeast lobe.
- ❖ Pass-8 Fermi-LAT data reveals very similar morphology above 5 GeV.
- ❖ The  $\gamma$ -ray emission spans multiple, very different, environmental conditions.
  - *Can extract spectra from different regions to probe the environmental dependence of cosmic-ray diffusion.*



# Crab Pulsar & VELA Pulsar

## ICRC 2015



# Galactic Center Diffuse with HESS PeVATRON?

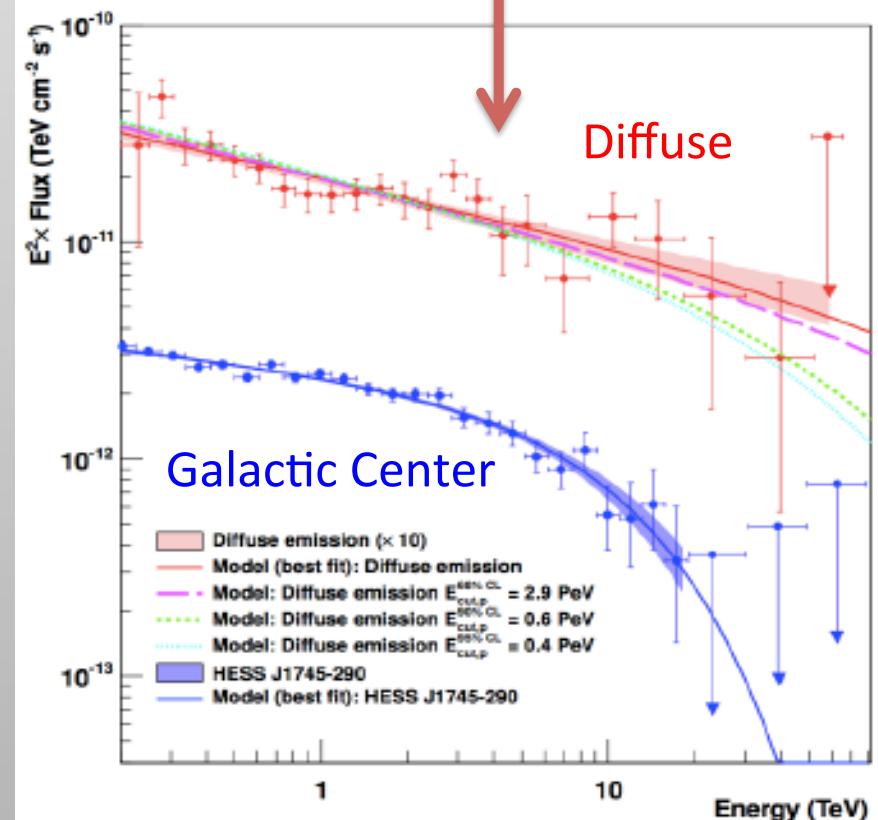
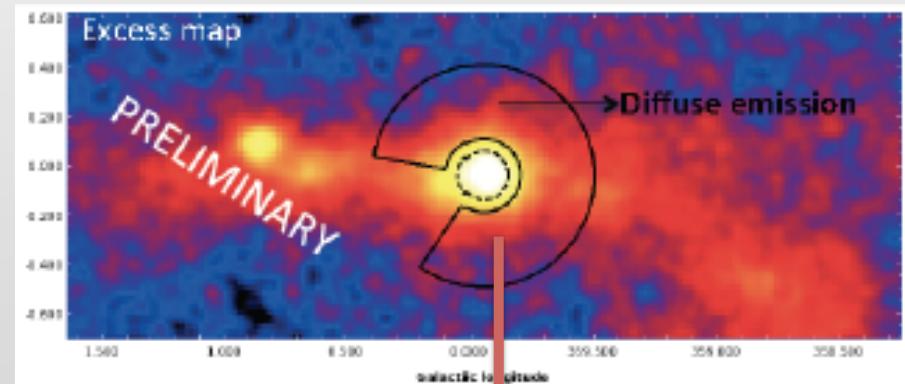
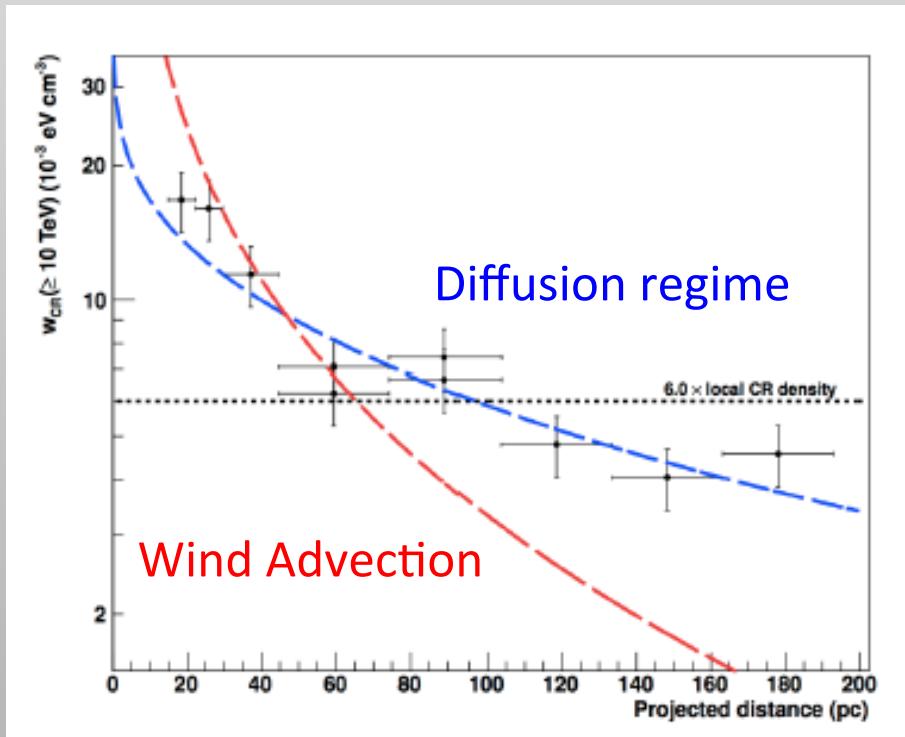
HESS Deep Observation of 250hrs

Spectrum:

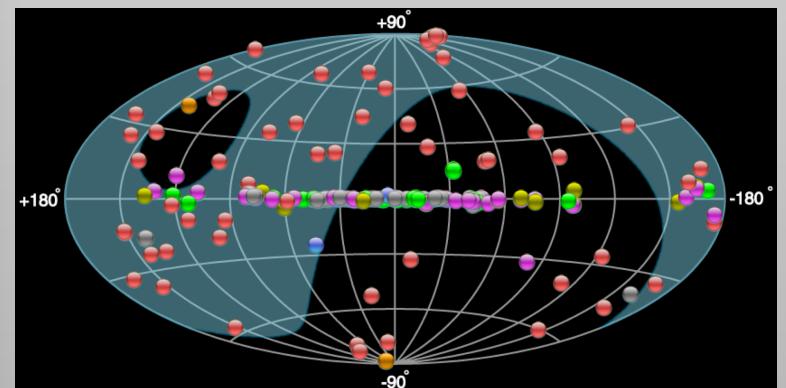
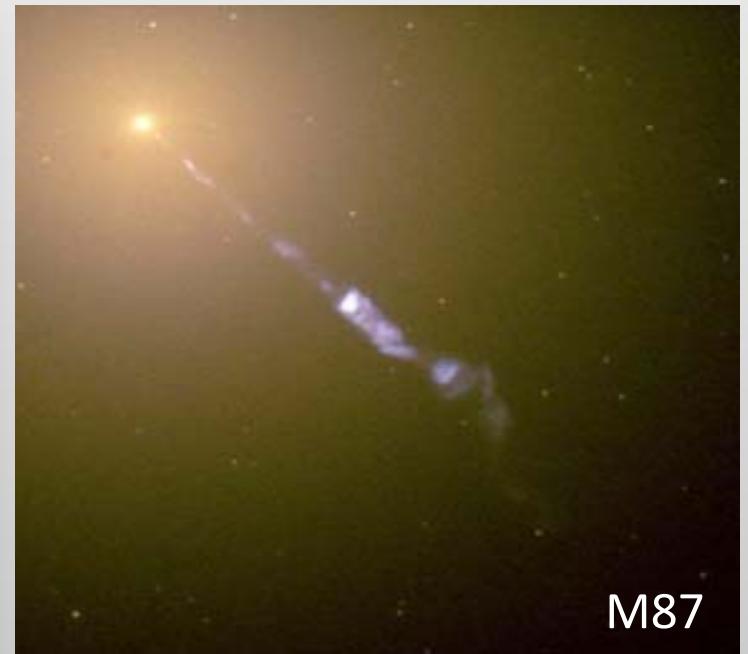
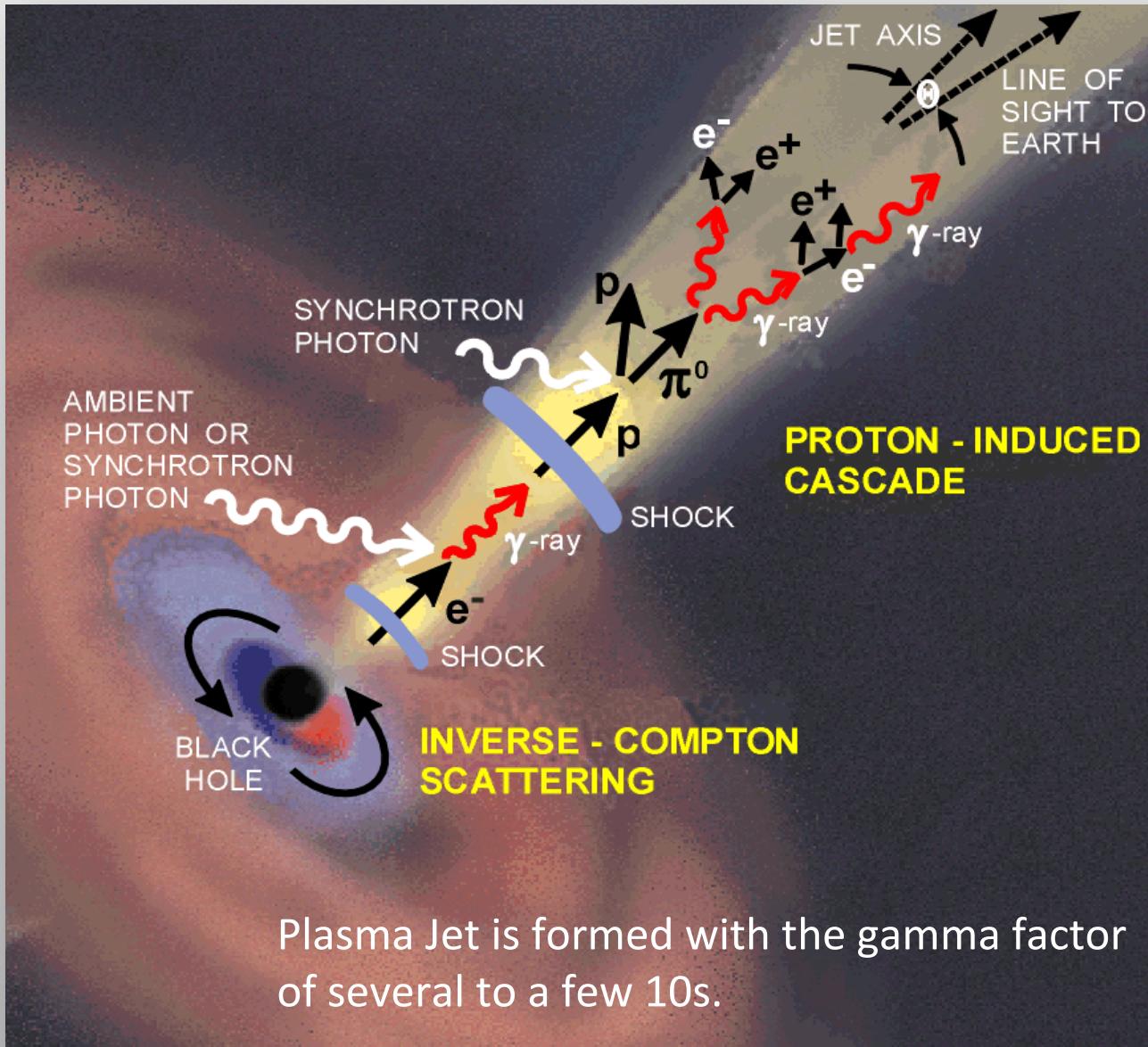
Parent proton could be 1PeV → PeVATRON?

Radial distribution  $1/r$ :

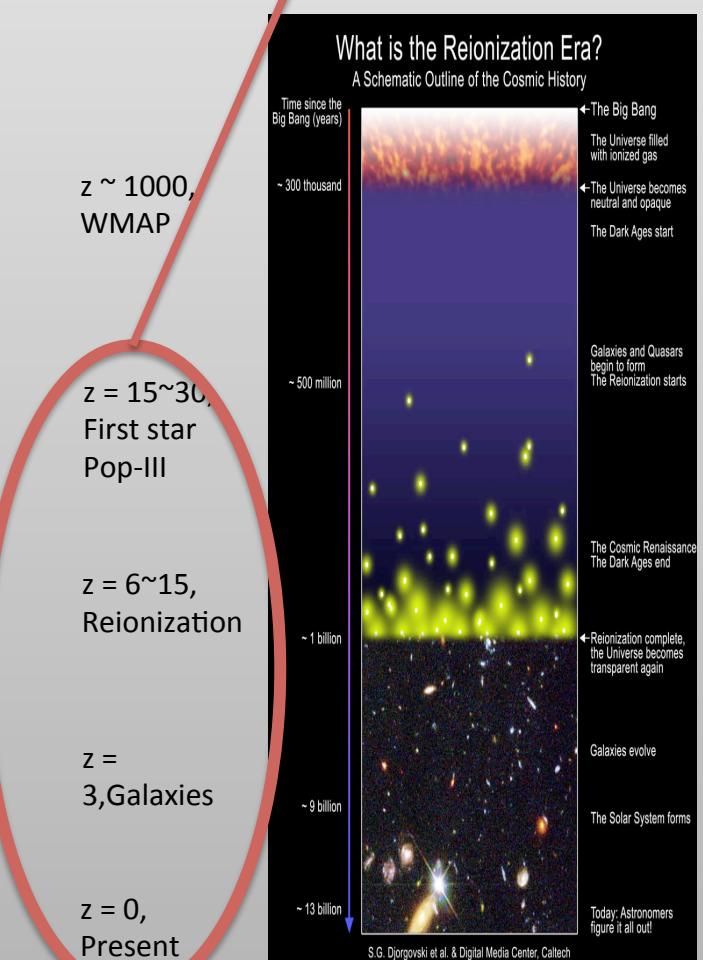
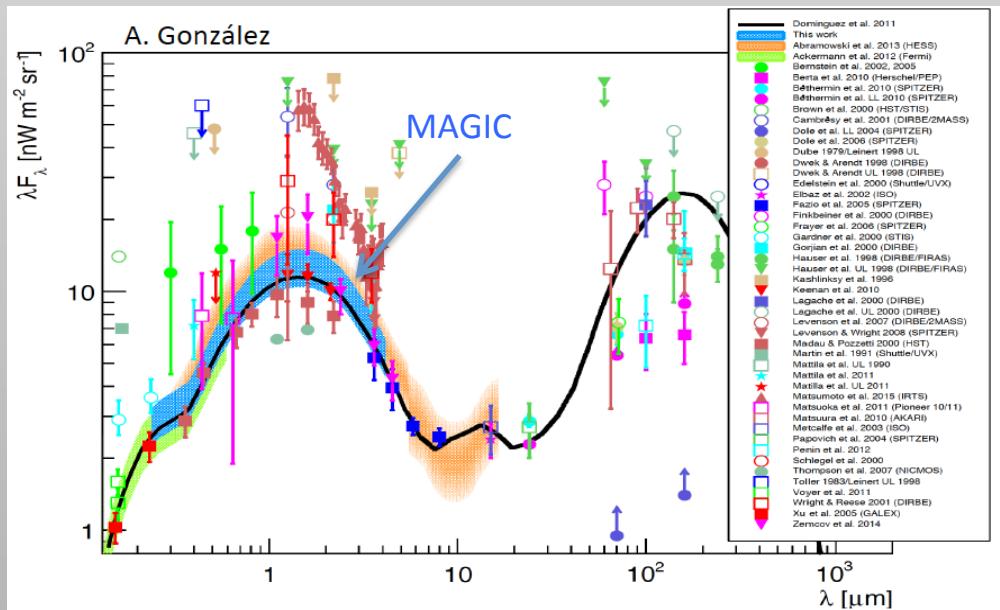
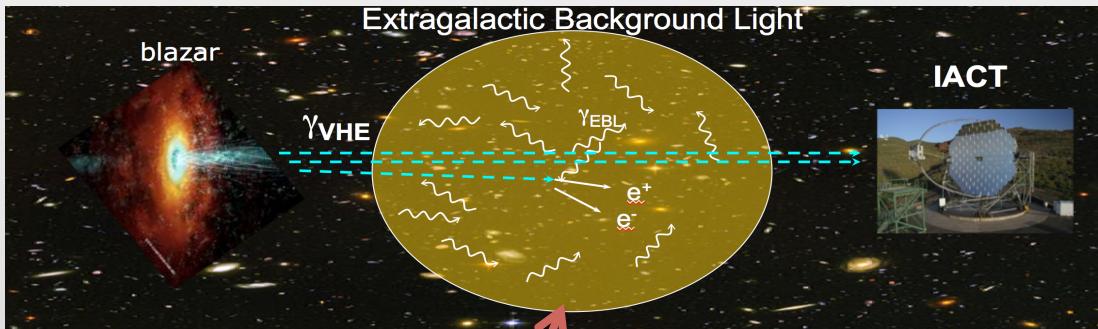
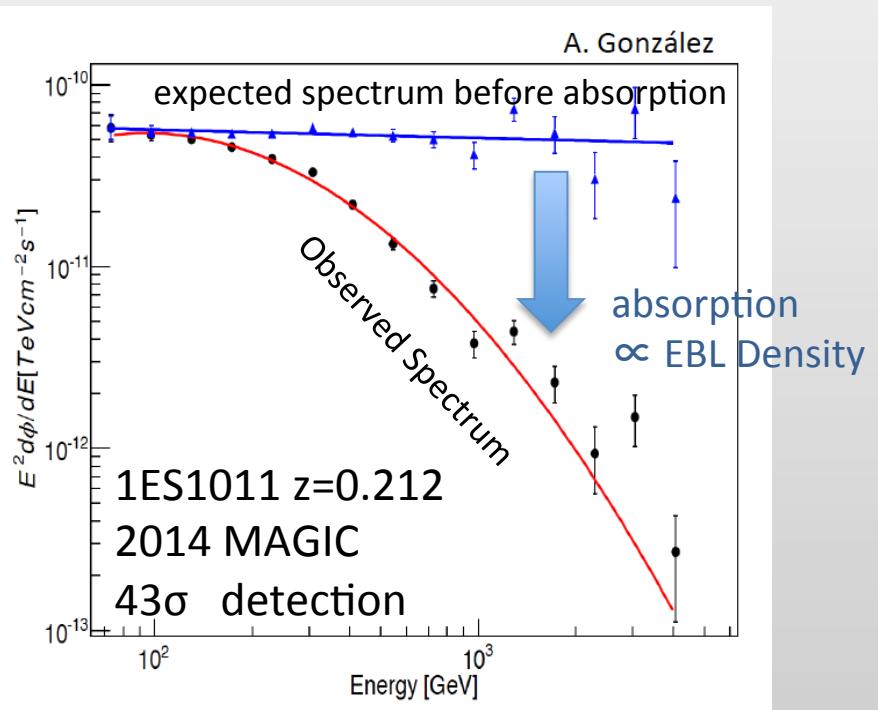
Consistent with the diffusion from the central BH



# Supermassive Blackholes $\sim 10^8 M_{\odot}$ Particle accelerators

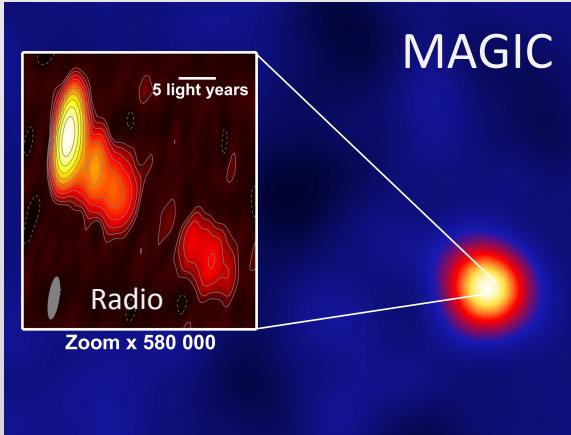


# Study of Extragalactic Background Light 1ES1011 observed with MAGIC in 2014



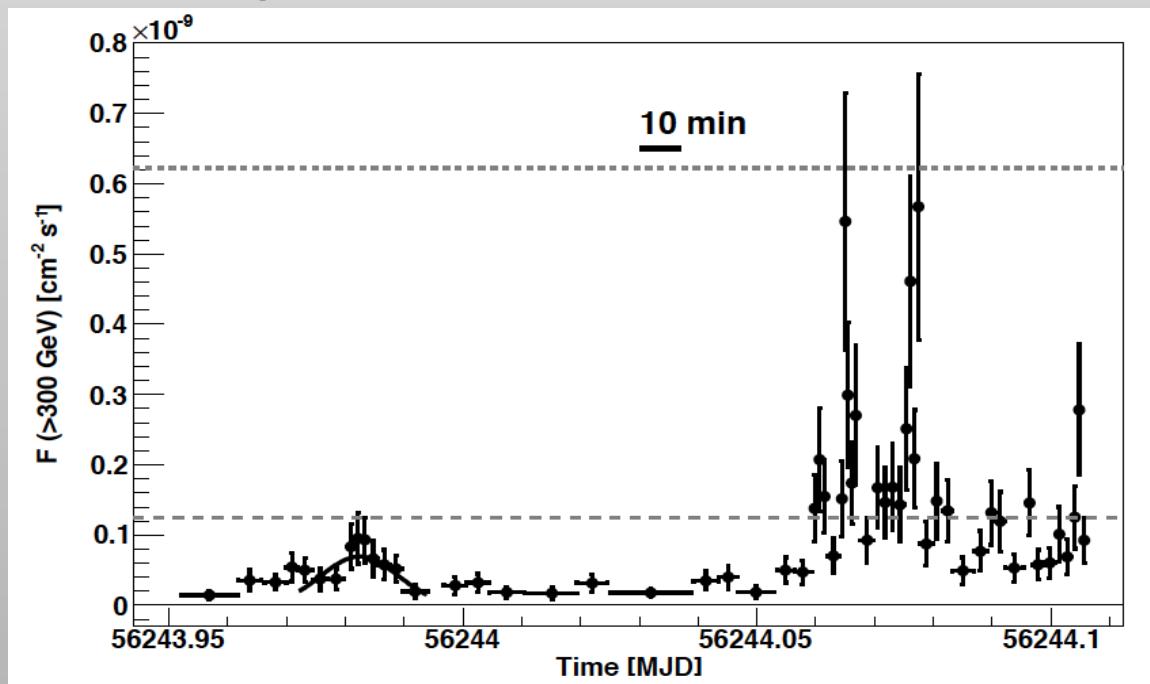
# IC310 Radio Galaxy / Blazar

## MAGIC Observation published in Science

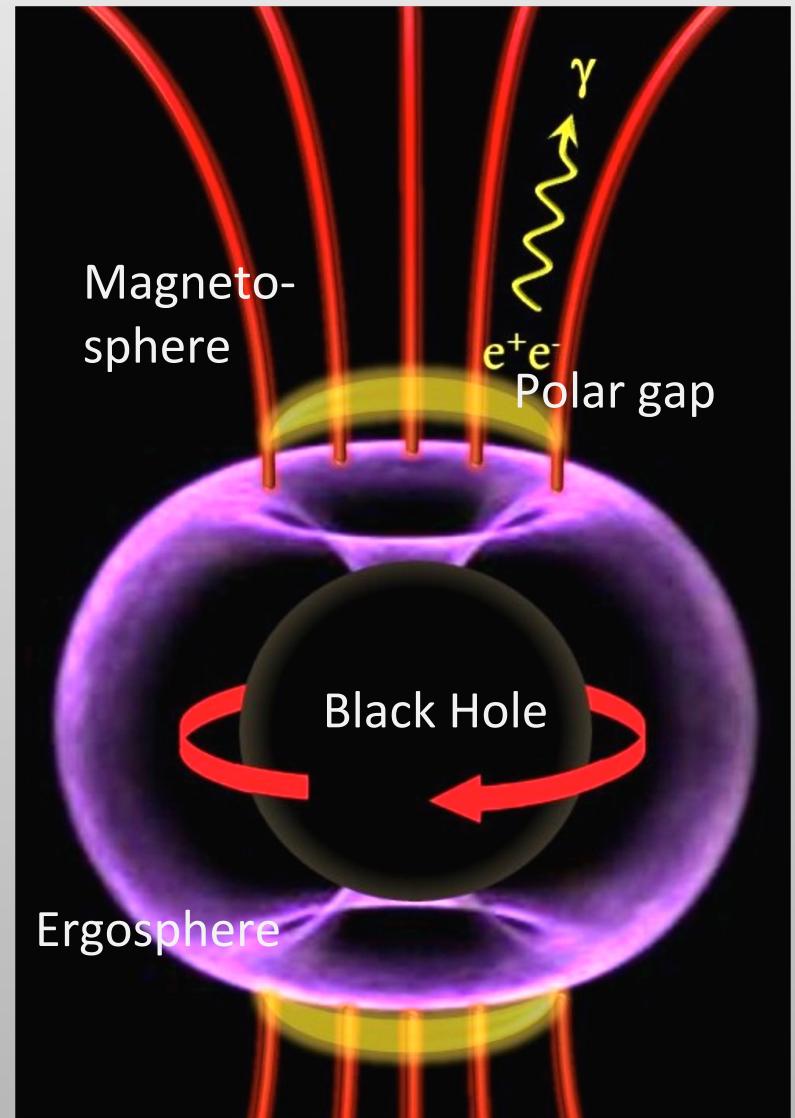


- Nov.12 2012 MAGIC obs.
- Flare  $\sim 100 \times$  Low State
- Time variation  $\sim 1$  min
- B.H. mass  $3 \times 10^8 M_{\odot}$ 
  - Crossing Time  $\sim 25$  mins
  - $\Gamma$ -factor of jet  $\sim 5$

IC310 Light curve



Possible Model

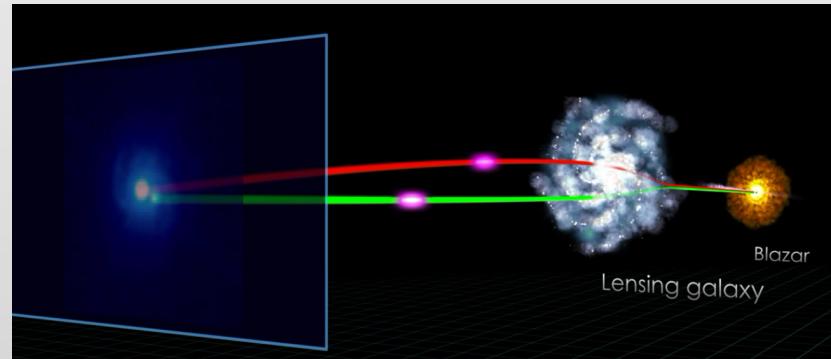
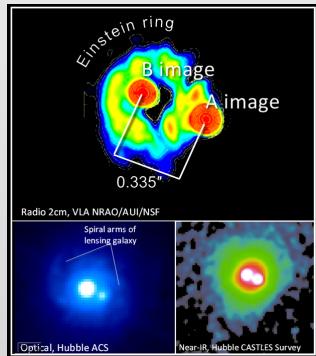


# Discovery of Very High Energy Gamma-Ray Emission From Gravitationally Lensed Blazar S3 0218+357 With the MAGIC Telescopes

ATel #6349; **Razmik Mirzoyan (Max-Planck-Institute for Physics) On Behalf of the MAGIC Collaboration**

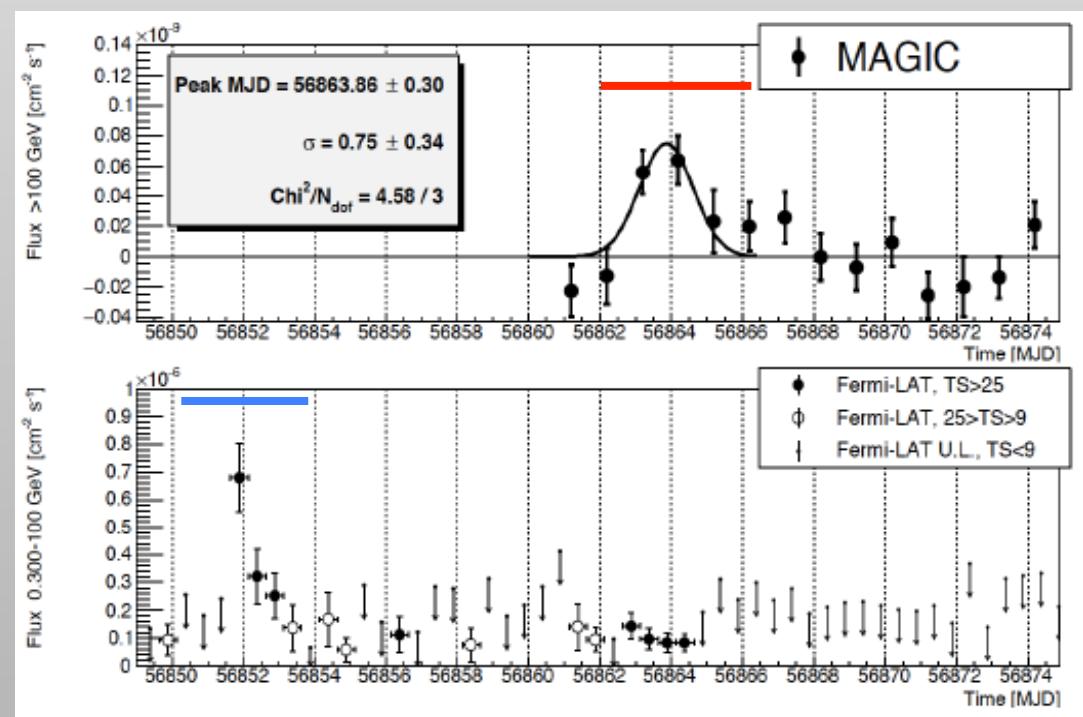
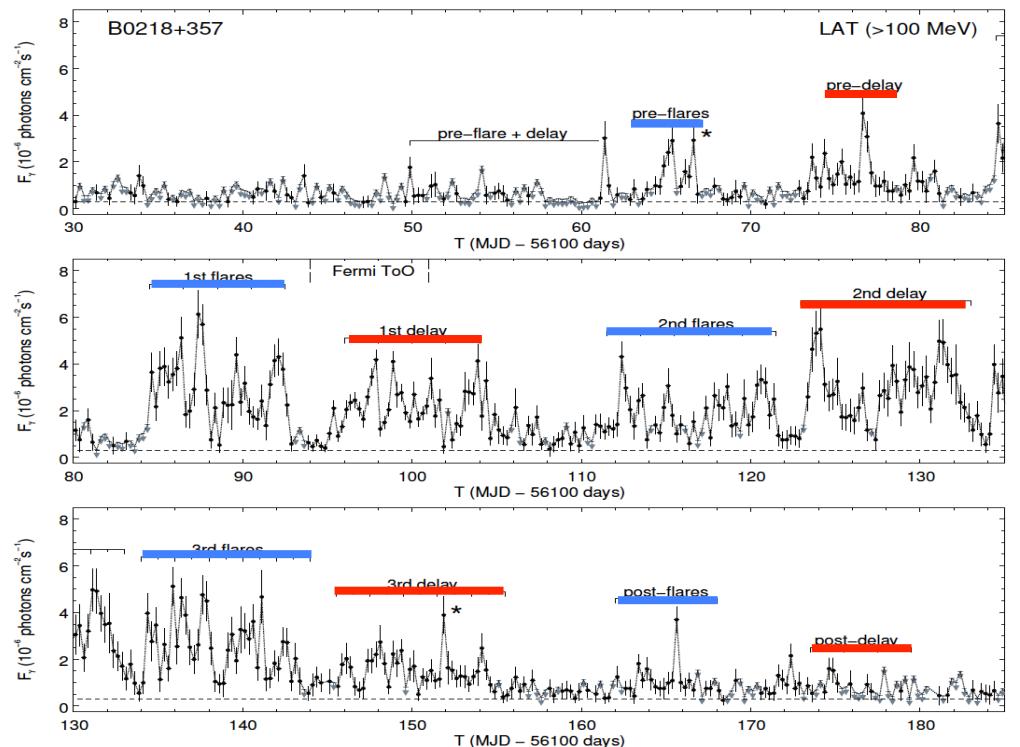
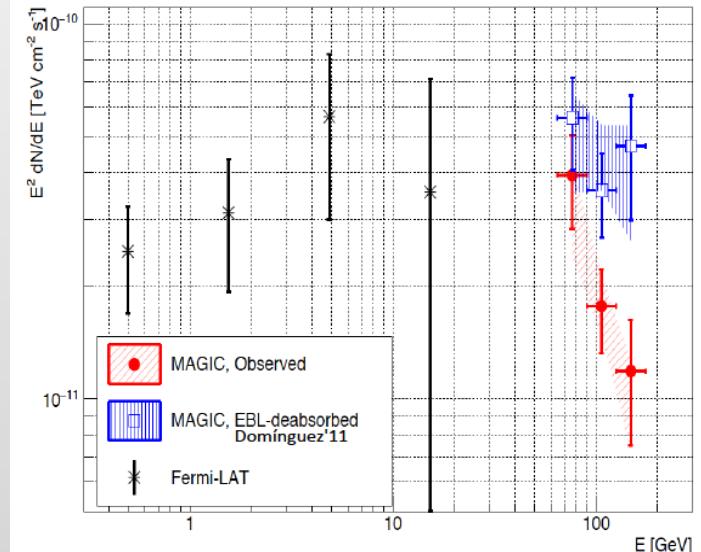
on 28 Jul 2014; 14:20 UT

Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)



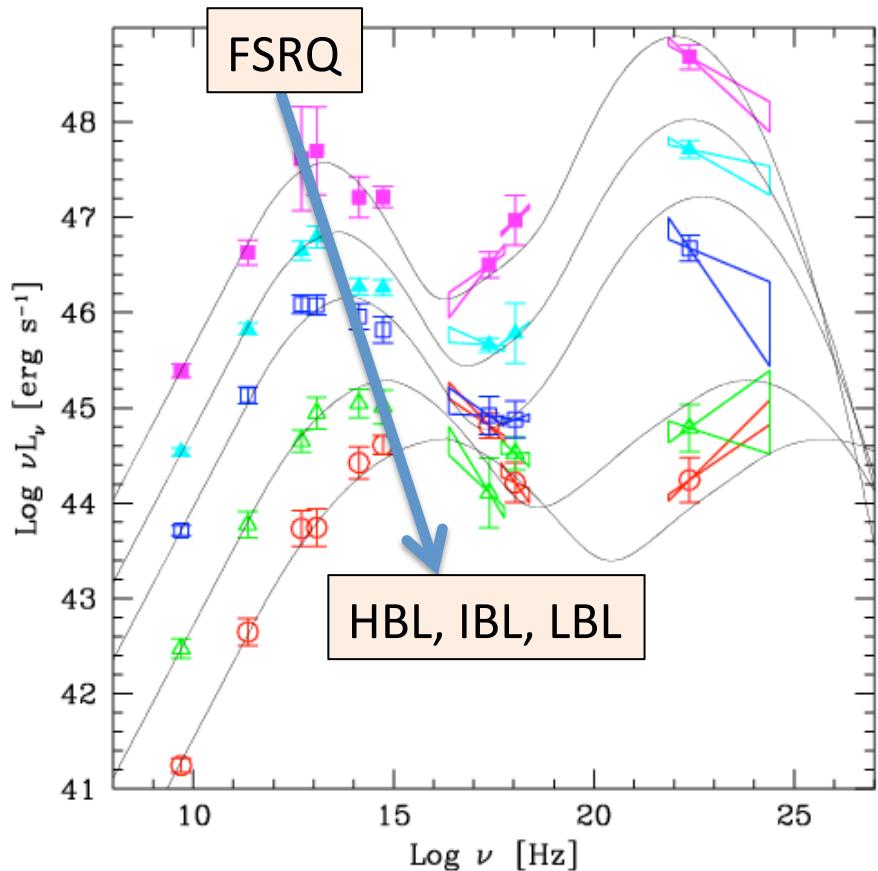
## FSRQ S3 0218+357 z =0.944

J. Sitarek, from B0218 MAGIC paper draft



# Flat Spectrum Radio Quasars

## Blazar Sequence



- FSRQ is much brighter than HBL and LBL (3-4 orders of Magnitudes --- high accretion rate)
- Only 6 FSRQs are observed among about 60 Blazars
- Useful to explore super massive black hole in the Early Universe
- MAGIC observed 6 FSRQs
- AGN evolution can be studied with CTA

Source	Redshift	Discoverer	Year
3C 279	0. 5362	MAGIC	2006
PKS 1510-089	0. 361	HESS	2009
4C +21. 35 (PKS 1222+216)	0. 432	MAGIC	2010
S30218+35	0. 936	MAGIC	2014
S4 0954+65*	0. 368	MAGIC	2015
PKS 1441+25	0. 939	MAGIC	2015

# High Altitude Water Cherenkov detector

- 4100 meter site in Mexico
- 22,000 m<sup>2</sup> detector area.
- 300 4.5m high, 7.3m diameter Water Cherenkov Detectors
- 100 GeV - 100 TeV Sensitivity
- Average Angular Resolution (68% Cont.) 0.25-0.5°.



# HAWC

## Differential Sensitivity

### How to think about HAWC Sensitivity:

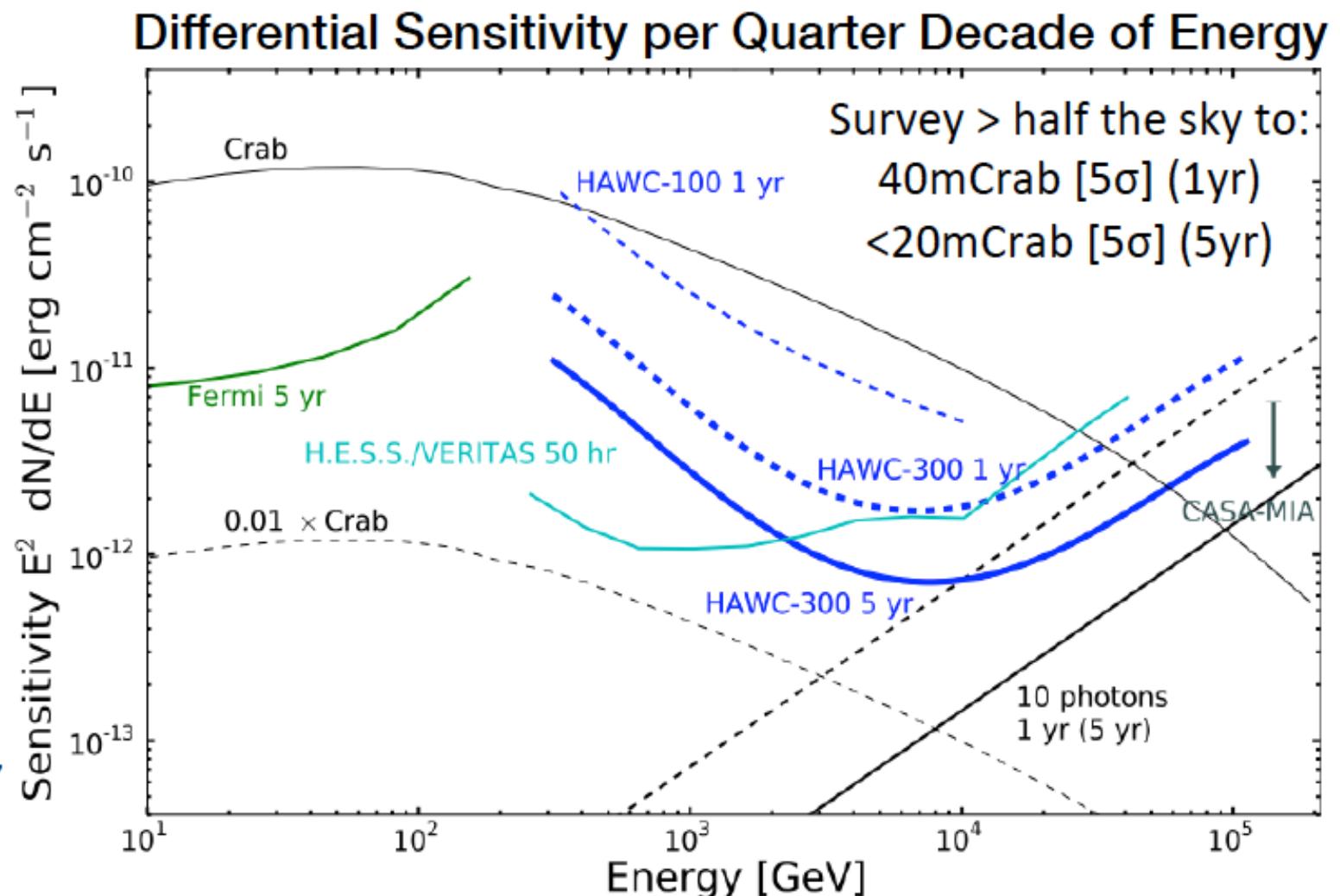
Instantaneous sensitivity about 15-20x less than IACTs:

- ~2-3x from Angular Resolution
- ~5x from energy threshold.

Exposure (sr yrs) is 2000-4000x higher.

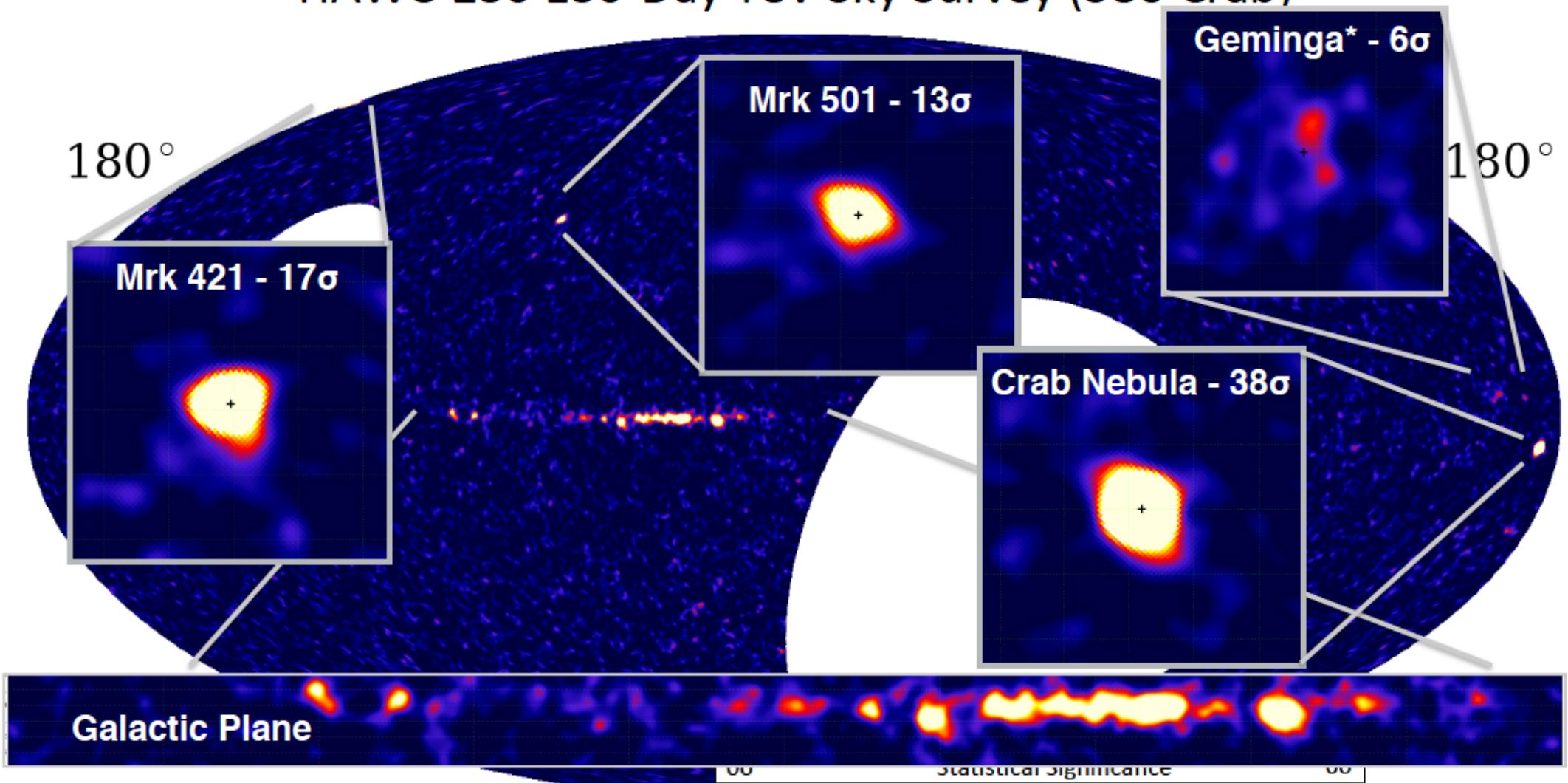
~1500 hrs/src/yr

For hard or extended sources, HAWC improves relative to IACTs



# Sky seen by HAWC-250

HAWC-250 150-Day TeV Sky Survey (38 $\sigma$  Crab)





www.GOV.cn

# 中华人民共和国中央人民政府

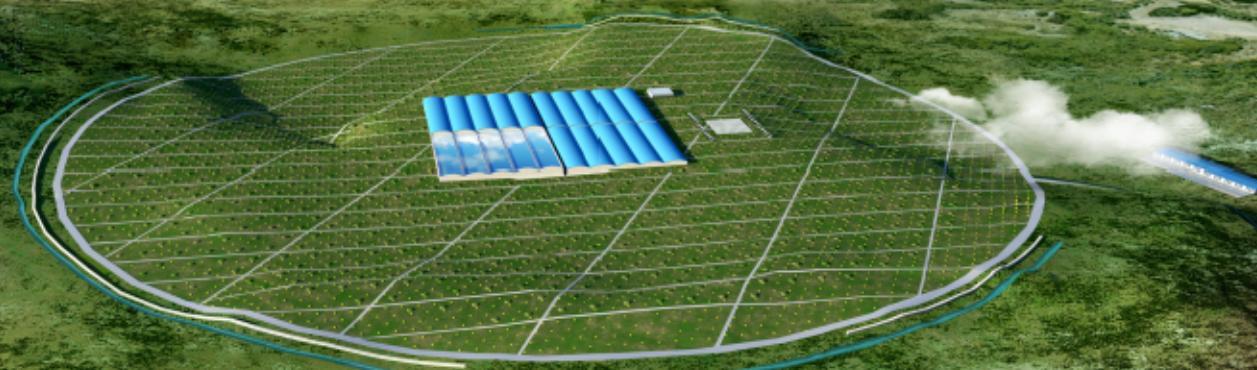
The Central People's Government of the People's Republic of China



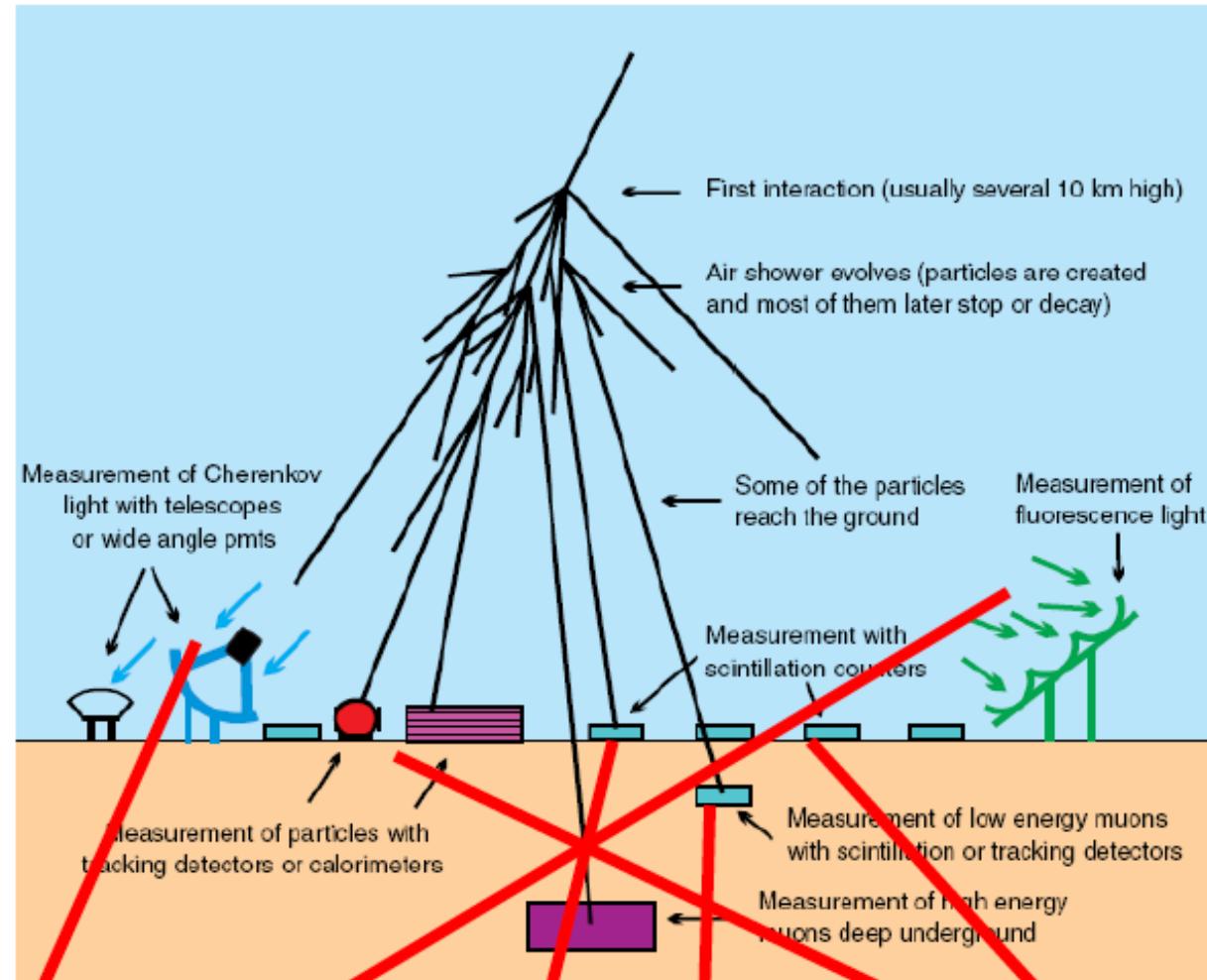
## 国务院关于印发国家重大科技基础设施建设 中长期规划（2012—2030年）的通知

国发〔2013〕8号

LHAASO is one of the 16 high-priority projects  
in the 12th Five-year Plan of China



# Hybrid Detection of Extensive Air Showers by LHAASO



**WFCTA:**  
18 telescopes  
1024 pixels each



**KM2A:**  
5195 EDs  
1171 MDs

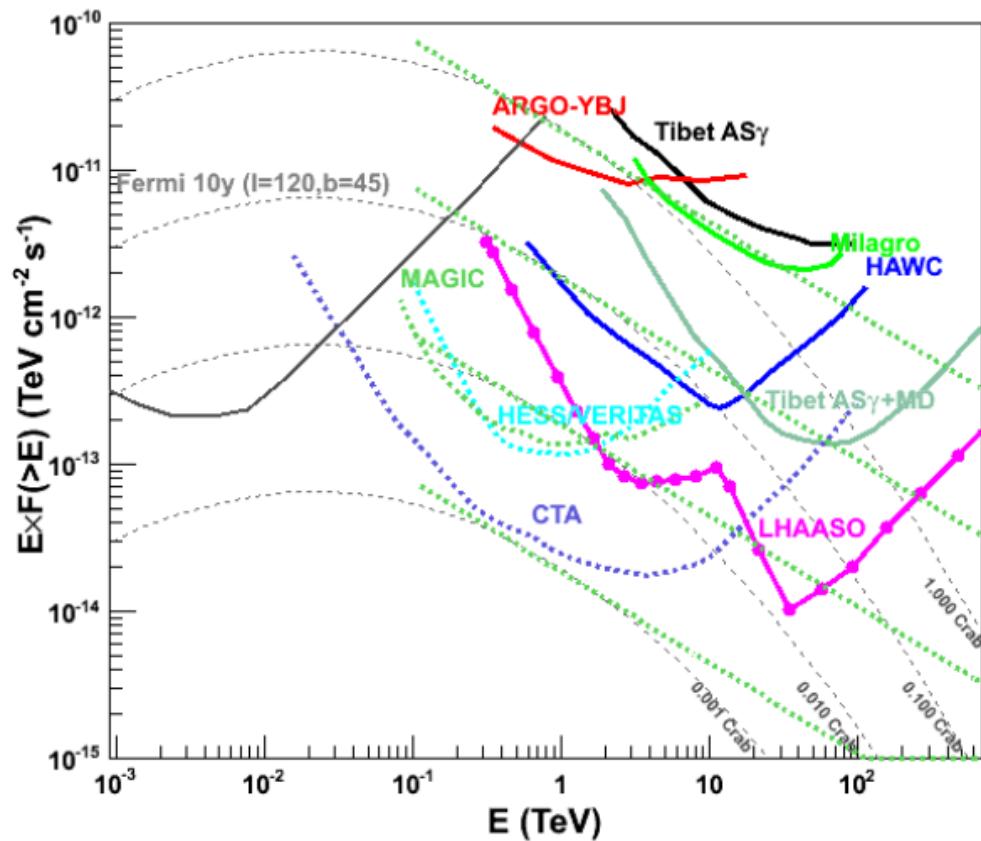


**WCDA:**  
3000 cells

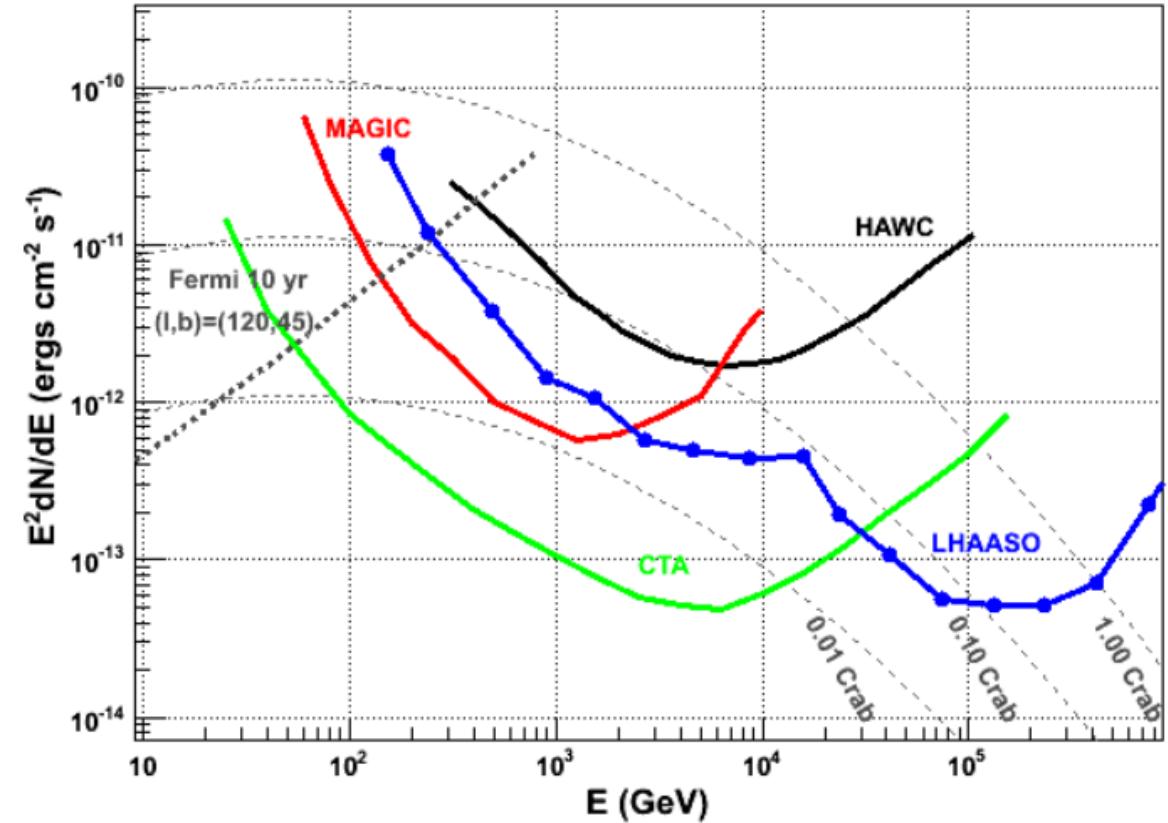


# LHAASO Sensitivity Curves

## Integral



## differential



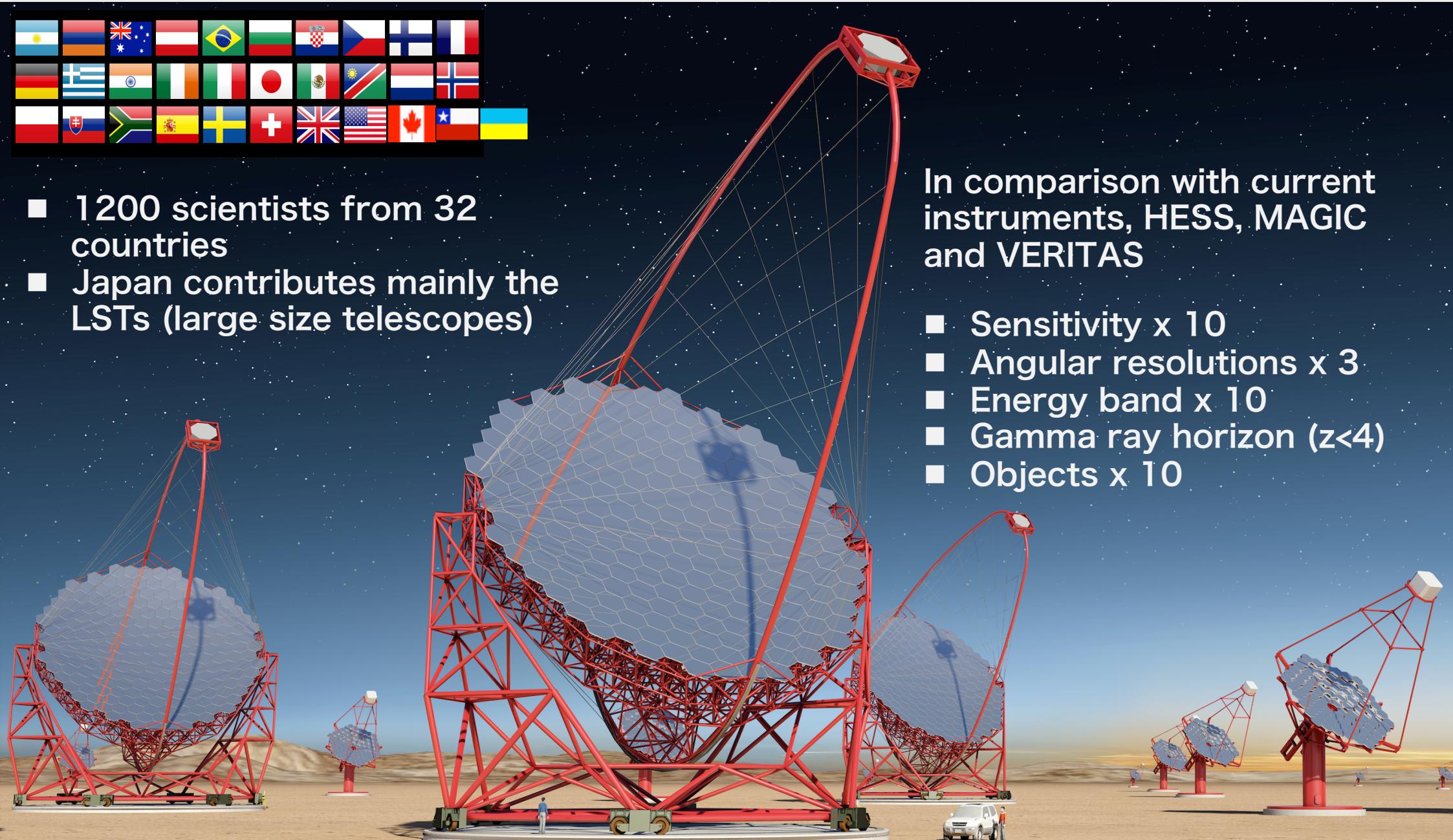
# CTA: Big International Project



- 1200 scientists from 32 countries
- Japan contributes mainly the LSTs (large size telescopes)

In comparison with current instruments, HESS, MAGIC and VERITAS

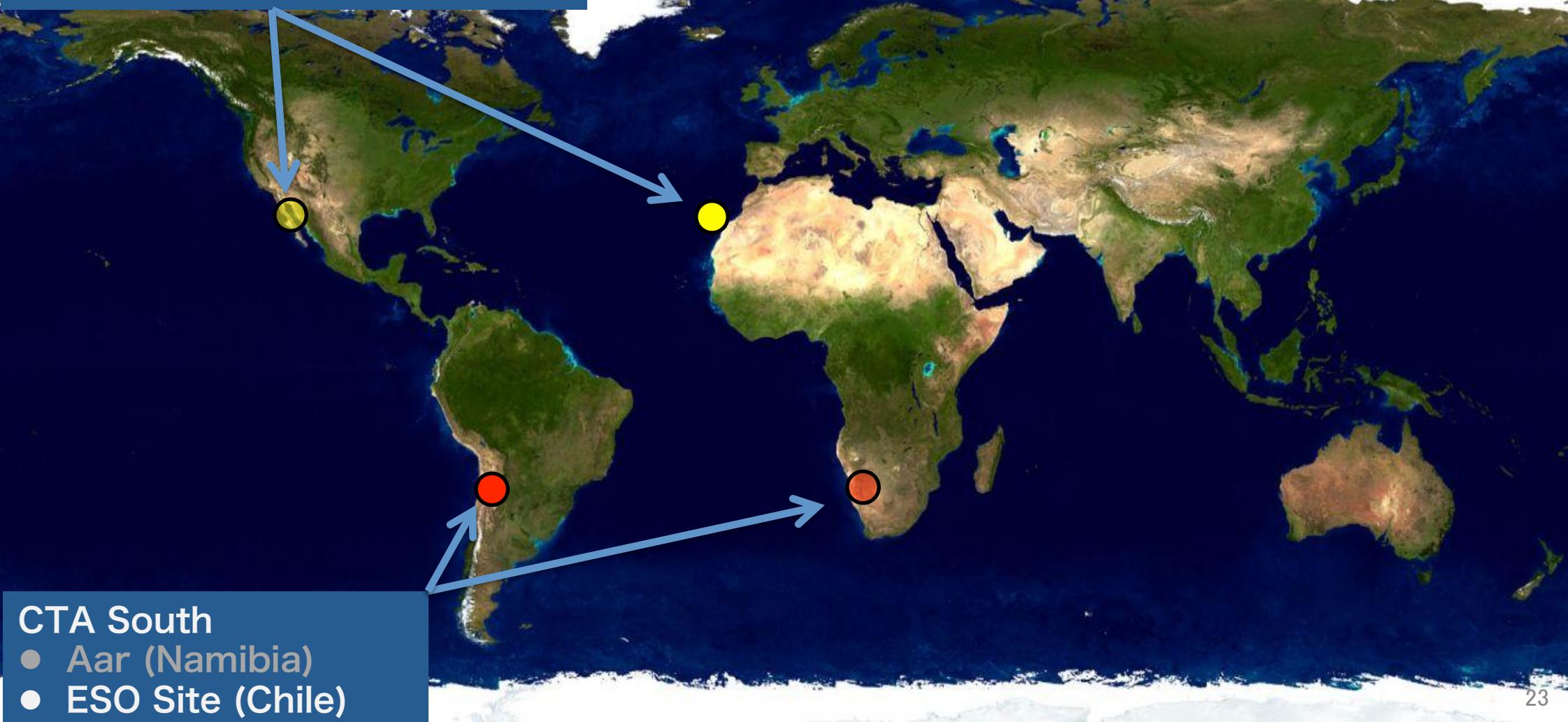
- Sensitivity x 10
- Angular resolutions x 3
- Energy band x 10
- Gamma ray horizon ( $z < 4$ )
- Objects x 10



# Two CTA Sites in South and North

CTA North

- Canaries (Spain)
- San Pedro Martir (Mexico)

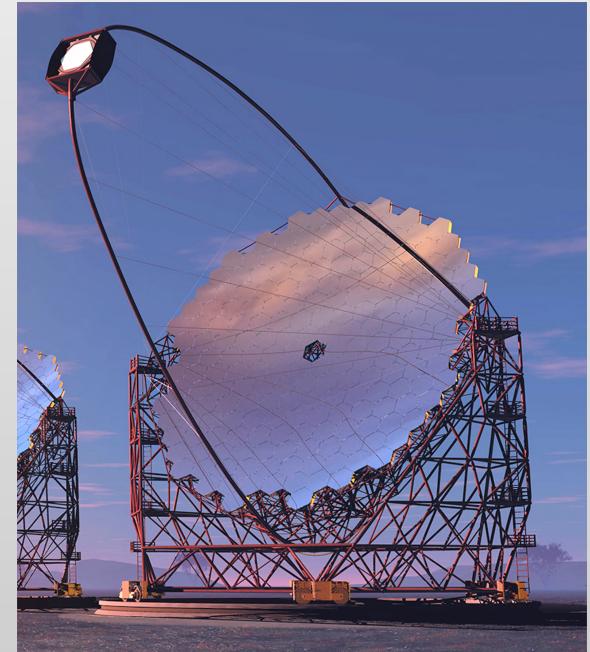
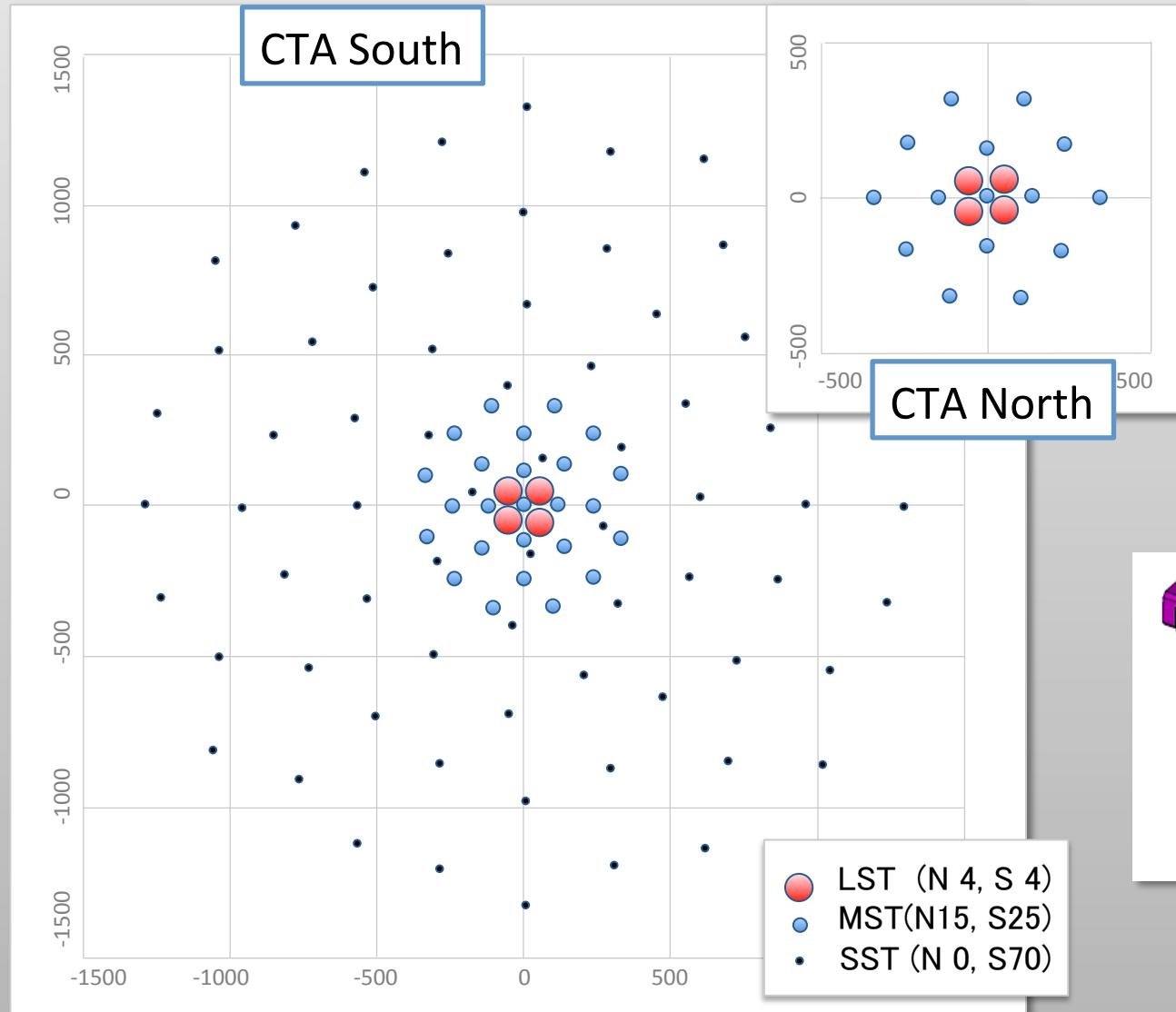


CTA South

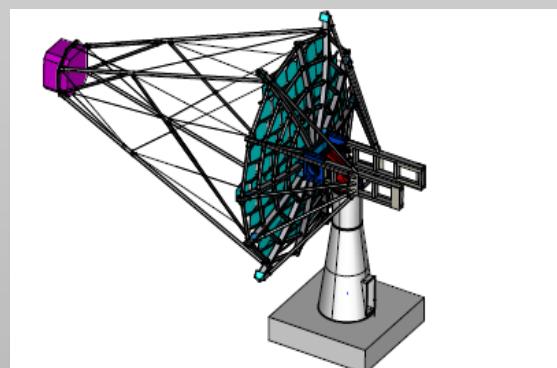
- Aar (Namibia)
- ESO Site (Chile)

# CTA Array Configuration (Cherenkov Telescope Array)

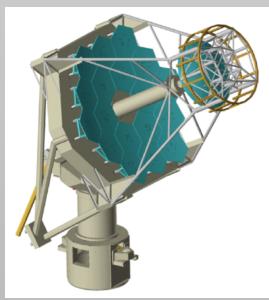
CTA is all sky observatory consisting of two stations in South and North



LST 23m



MST 12m



SST 4.3m

# CTA Large Size Telescope

## Major specifications

- Threshold energy >20GeV
- Telescope Structure
  - Diameter of dish 23 m
  - Parabolic optics 389 m<sup>2</sup>
  - focal length 28 m
  - Weight 100 tons
  - CFRP mirror supp. structure
  - Fast rotation 180°/20sec
  - Tracking accuracy 14 arcsec



# LST Project : International Effort

BR, CH, DE, ES, FR, IN, IT, HR, JP, SE

FPI/Elec (JP/IT/ES)

Camera body (ES/DE)

CSS (FR/IT)

MIR (JP)

Interface PL (DE/BR/JP)

Actuator (JP/CH)

CMOS-Cam (DE/JP)

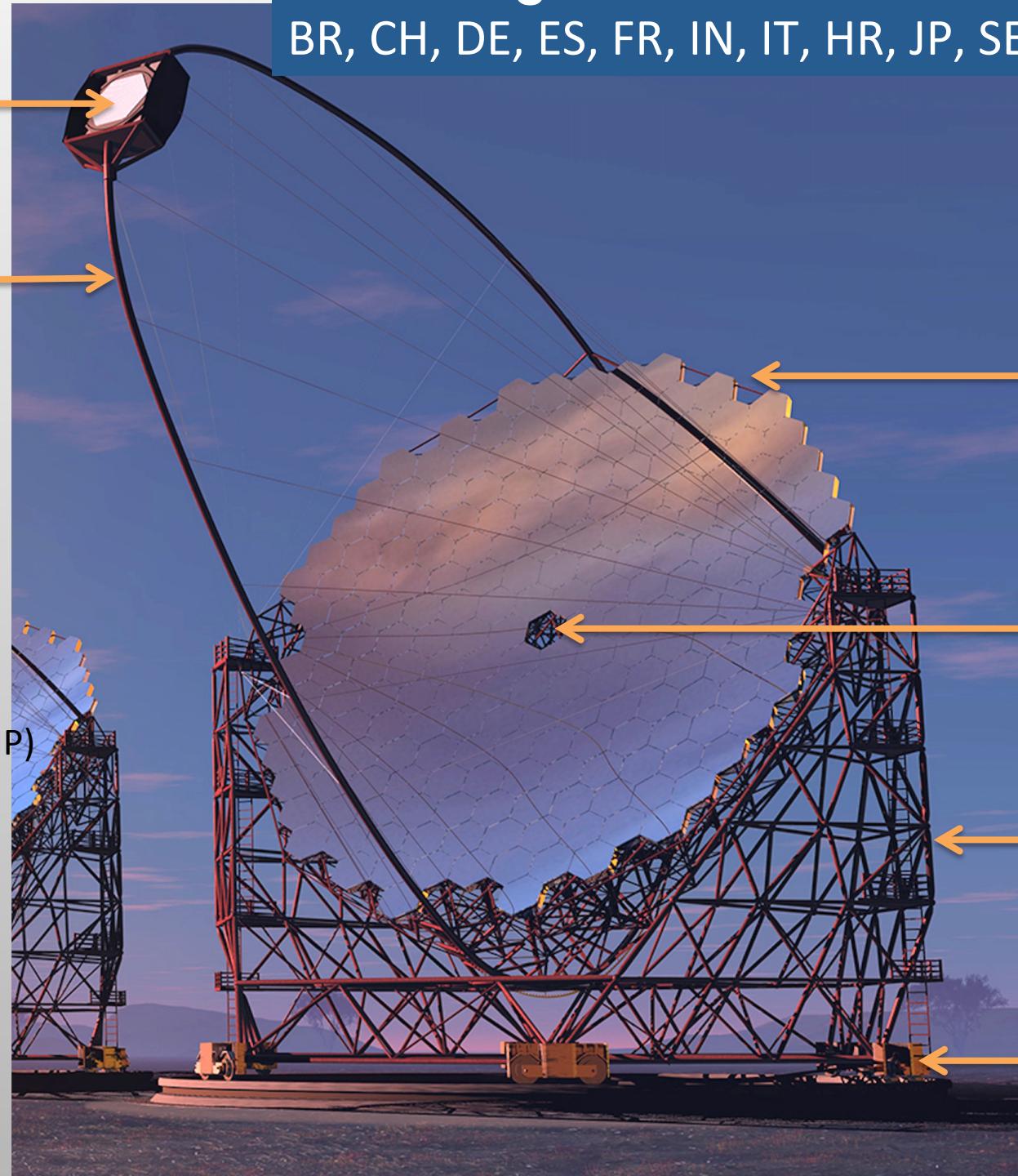
Flywheel, UPS (DE/ES/JP)

Comp. (ES/DE/DATA)



StarGuider (SE)

CalibBox (IN/IT)



Structure (DE)

Access Tower (DE/ES)

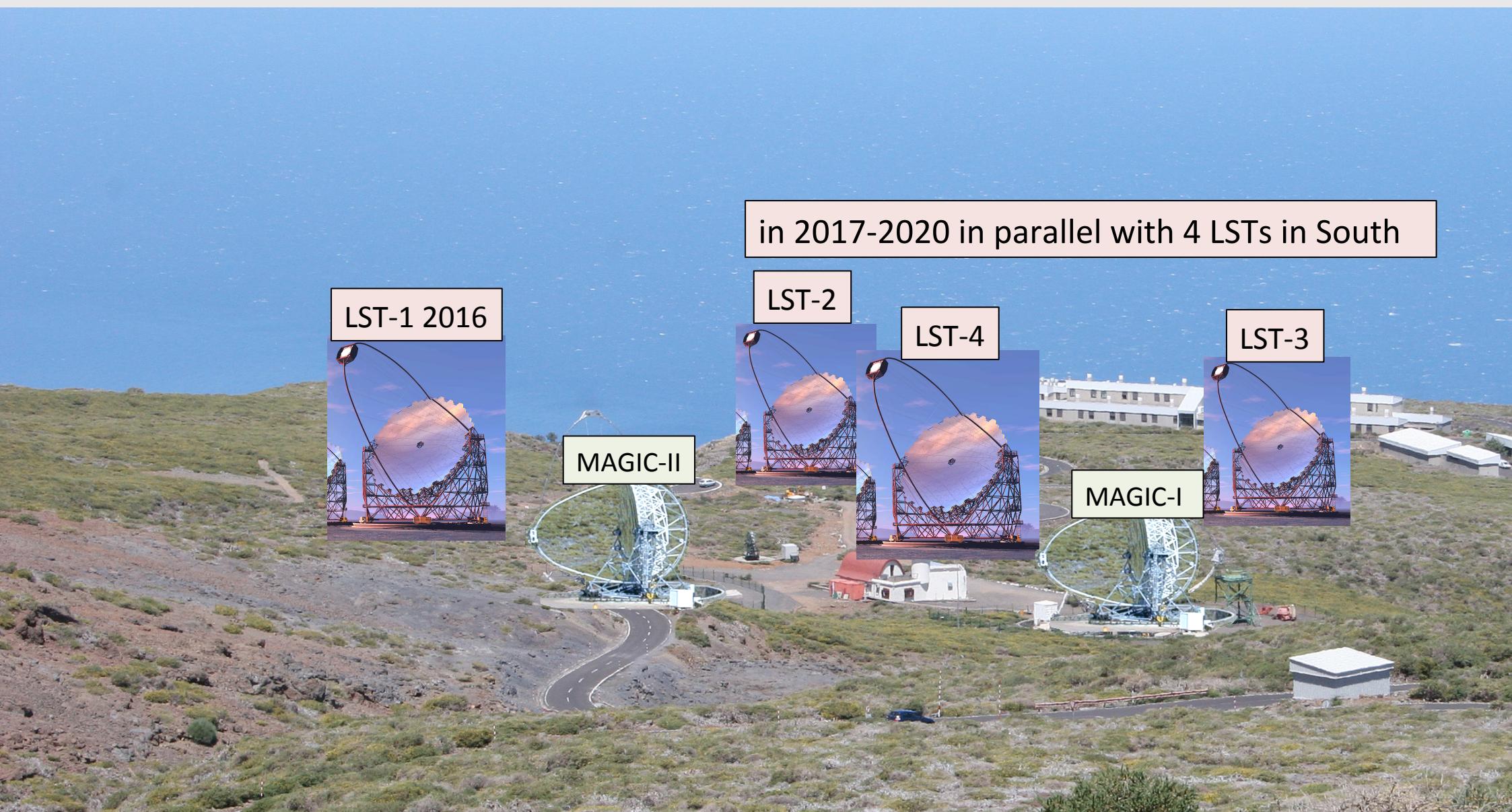
Drive (DE/FR/ES)

Bogie (DE/ES)

Rail (DE/ES)

Found. (DE/ES/INFRA)

# 4 LSTs at ROM if La Palma is selected as CTA North



# The corner stone ceremony of the first CTA - LST at La Palma

## Many politicians and MT



IAC Director  
Rafael Rebolo



These include the study of the origin of cosmic rays and their impact on the constituents of the Universe and the study of the ultimate nature of matter and physics beyond the Standard Model, searching for dark matter and effects of quantum gravity.

Prof. Takaaki  
ICRR Director



# Diario de Avisos <sup>com</sup>

*"Si viéramos realmente el Universo, tal vez lo entenderíamos"* Jorge Luis Borges

**El Cabildo eliminará el puente de Los Rodeos para reducir las colas**

El presidente insular, **Carlos Alonso**, confirma que en 2016 continuarán con la reordenación de los enlaces en la autopista del Norte y se actuará en El Coromoto

**TENERIFE.** A lo largo del próximo año, el Consorcio de Transportes de la capital canaria mejorará la red metropolitana. Según informó el presidente

Cabildo continúa los trabajos en la autopista del Norte (TP-5) para intentar reducir los habituales atascos en esta vía en dirección a la zona insular. Carlos Alonso, tras la actuación que se ejecuta en estos momentos en Las Chumberas, se recomendará la rotonda de El Coronato, se instalarán en las próximas semanas en la carretera de Benítez y se reestructurará el enlace de Los Rodeos y la TP-5 con la eliminación del antiguo puente.

El Parlamento de Canarias debatirá un "estatuto de las islas periféricas"

**POLÍTICA.** La Agrupación Socialista Gomera (ASG), que preside Gasimiro Curbelo, defenderá en el pleno que celebrará el Parlamento regional esta próxima semana una propuesta sobre la elaboración de un "estatuto jurídico singular para las islas no capitalinas".

**ECONOMÍA**  
Melchior: "La demanda llenaría la fase I del puerto de Granadilla" Página 5

**Y ADEMÁS...**

**Construcción** Óscar Izquierdo sustituye a Antonio Plasencia al frente de Fepeco

### **Meteorología**

Protección Civil avisa de la llegada de lluvias

~~oferta~~

# Los Cherenkov, la gran llave para despejar los enigmas del Universo

La hoja de ruta de 31 países para construir **20 telescopios** de rayos **gamma** se inicia en **El Roque** con la colocación de la **primera piedra** del prototipo del LST

Eugenio Paiz  
Garafía

En el Roque de Los Muchachos se escribirá parte de la historia de la humanidad. La colocación de la primera piedra del prototipo del telescopio LST del grupo de los Cherenkov, que tuvo lugar ayer en el observatorio palmero, supone el inicio de una hoja de ruta que terminará con la instalación de una veintena de estos grandes telescopios, con los que se contestarán a preguntas fundamentales para conocer más y mejor el Universo.

mejor el Universo.

Decenas de autoridades entre representantes nacionales, regionales e insulares, pero fundamentalmente la numerosa presencia de científicos de algunos de los 31 países que participan en este proyecto y entre los que



# MEDIUM-SIZED 12 M TELESCOPE

OPTIMIZED FOR THE 100 GEV TO ~10 TEV RANGE

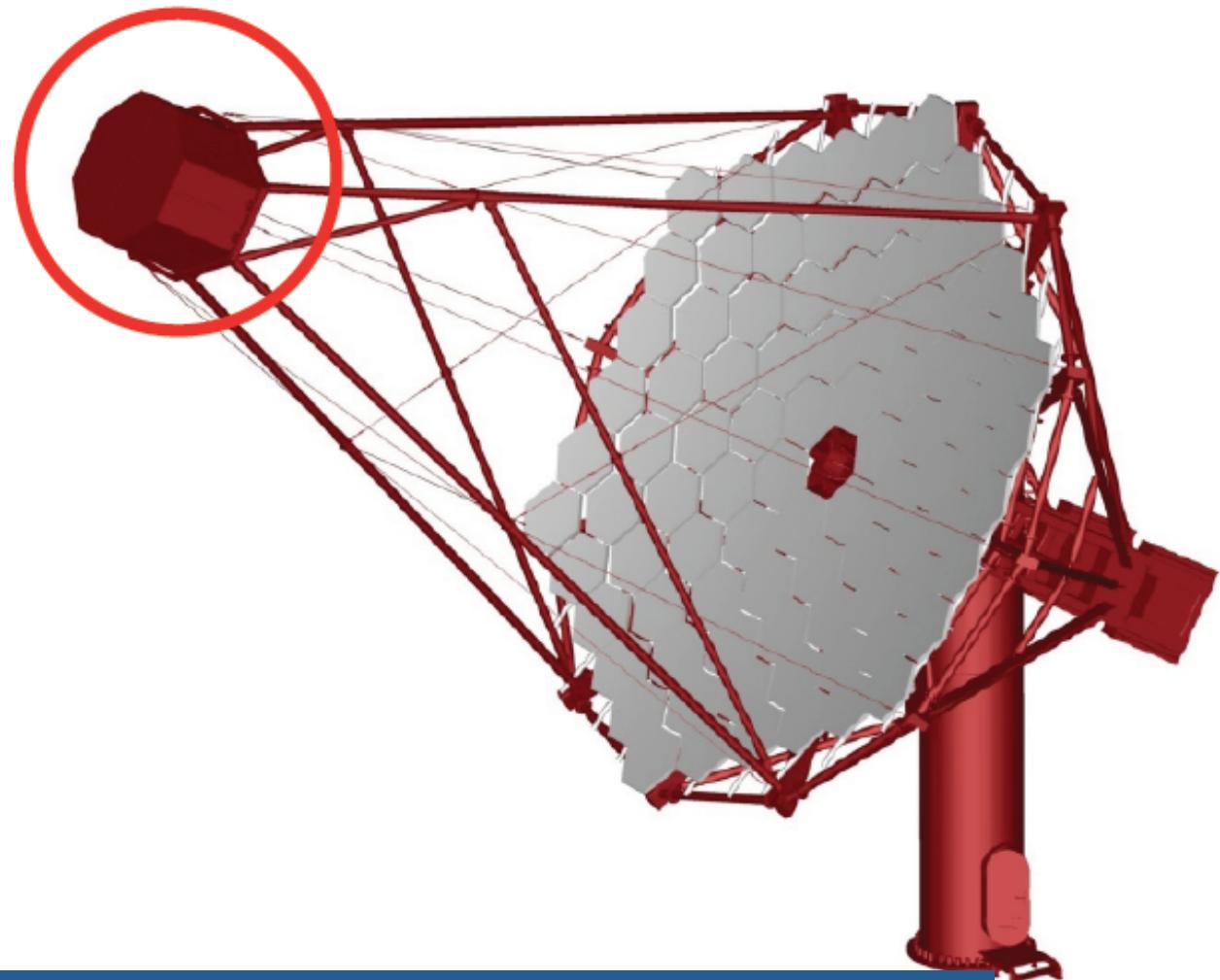


100 m<sup>2</sup> dish area  
16 m focal length  
1.2 m mirror facets

7-8° field of view  
~2000 x 0.18° pixels

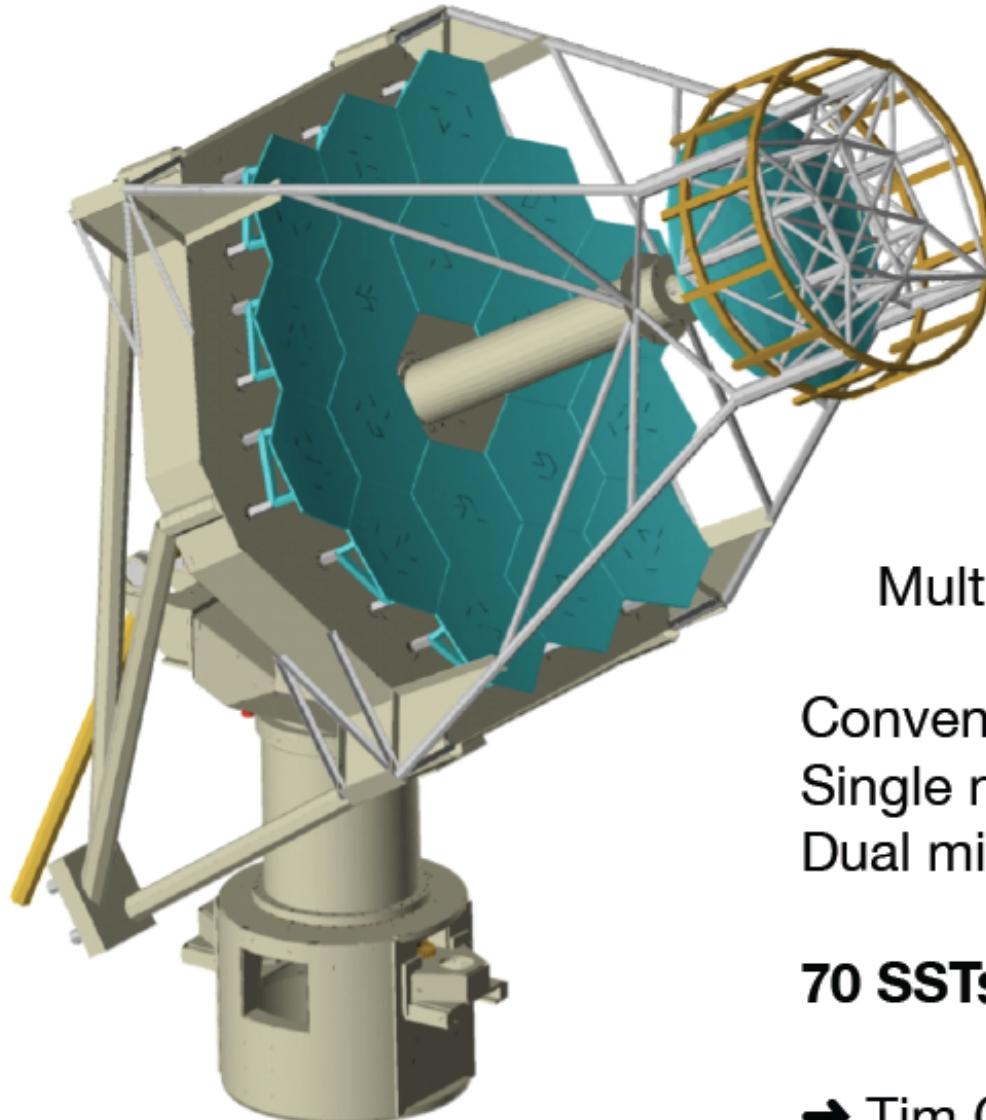
**25 MSTs on South site  
15 MSTs on North site**

→ Stefan Schlenstedt



Achieve the best sensitivity of 1mCrab at 1TeV and  
survey our galaxy

# SMALL TELESCOPE OPTIMIZED FOR THE RANGE ABOVE 10 TEV



ASTRI Design  
4.3 m mirror  
 $9.6^\circ$  foV  
 $0.25^\circ$  pixels

Multiple options under study:

Conventional single mirror, PMT camera  
Single mirror, silicon sensor camera  
Dual mirror optics, silicon & MAPMT camera

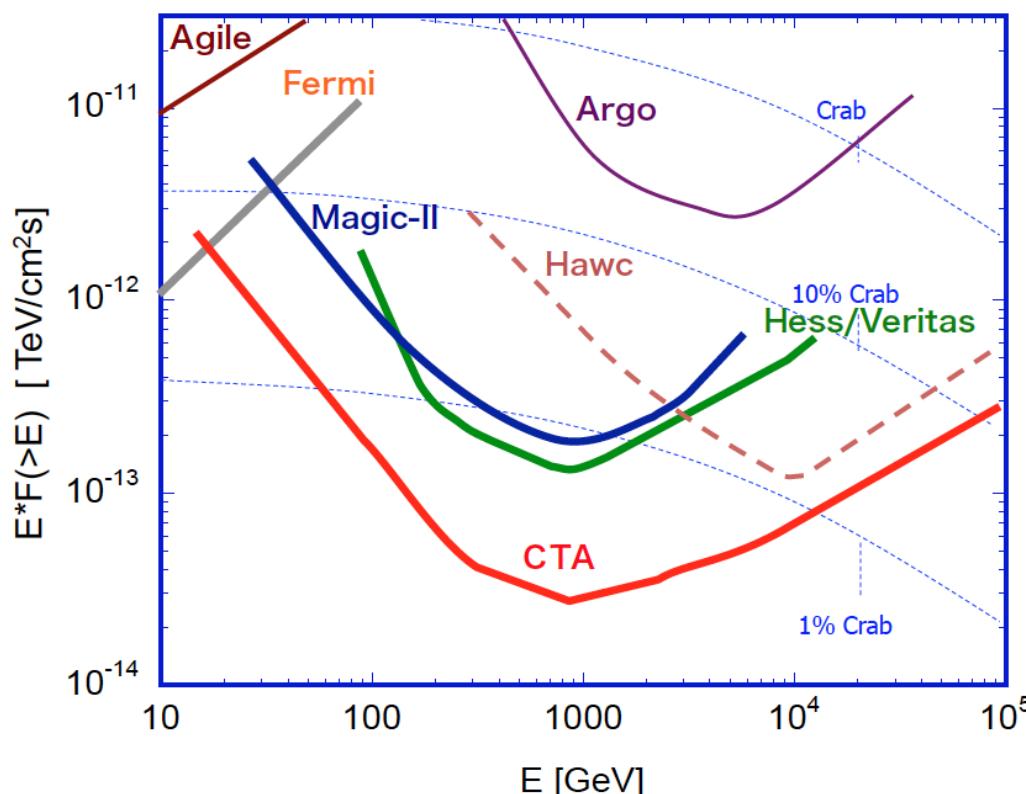
**70 SSTs on Southern site**

→ Tim Greenshaw

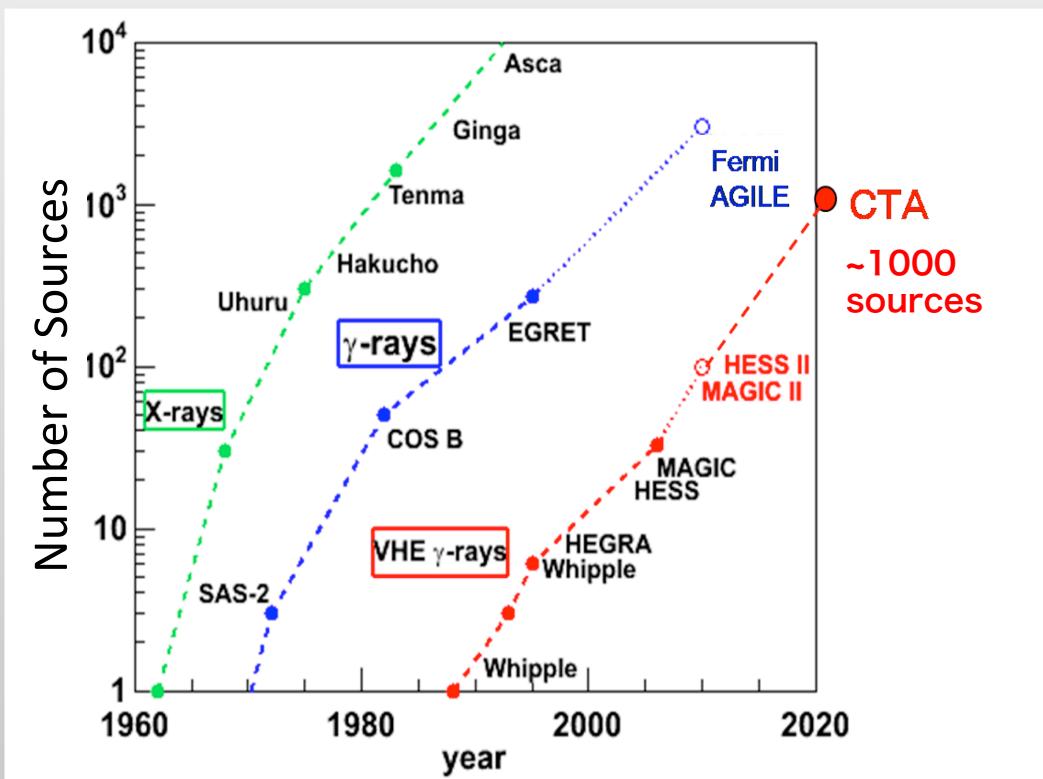
Look for PeVatron in our galaxy

# CTA (Cherenkov Telescope Array) covering 20GeV-100TeV

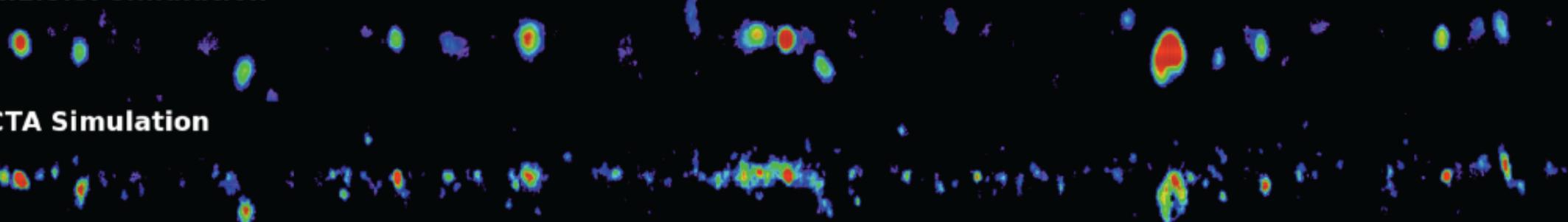
An order of magnitude better sensitivity  
Wide energy coverage



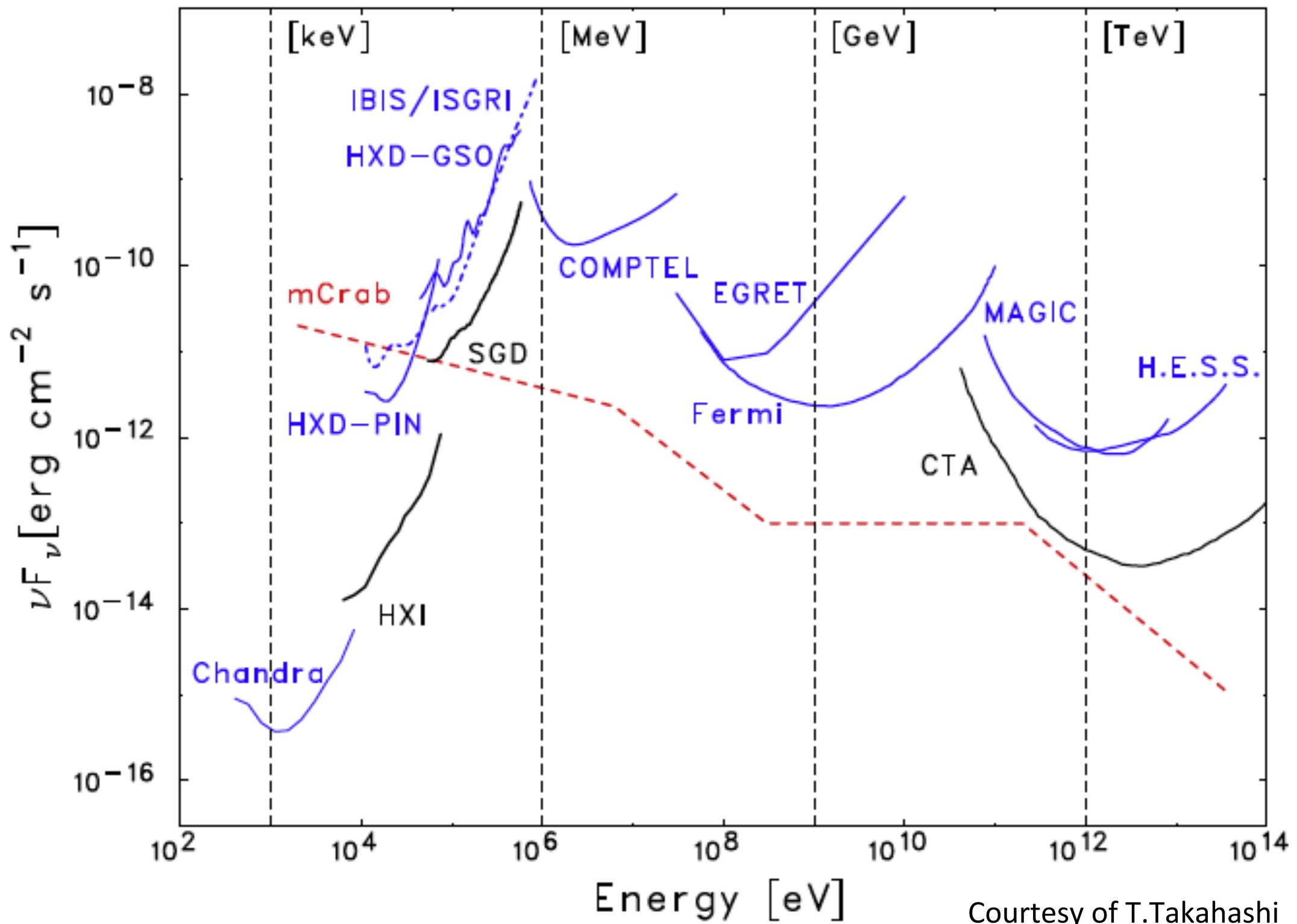
More than 1000 sources will be discovered



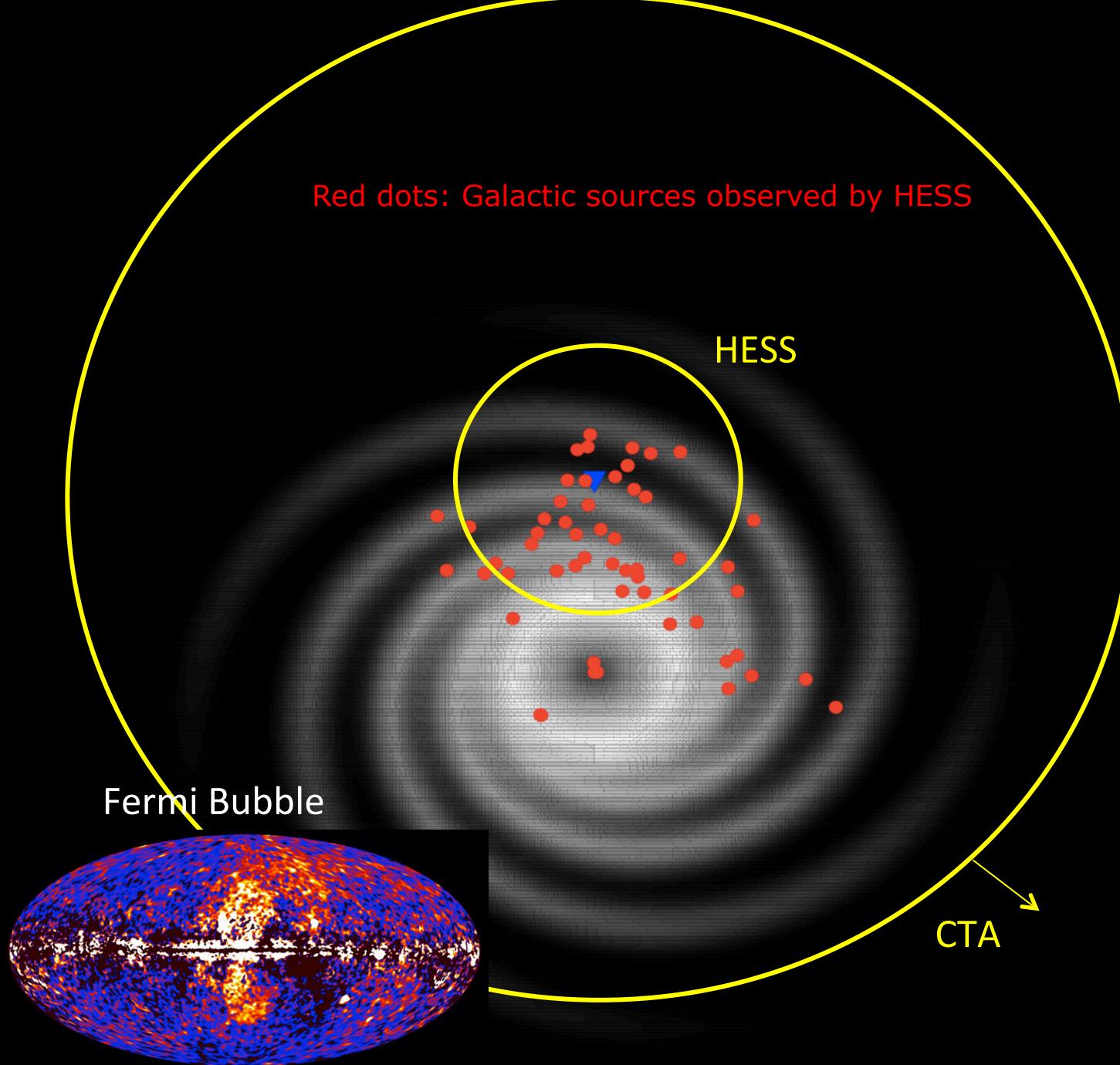
H.E.S.S. Simulation



Simulation Galactic Plane scan (HESS and CTA)

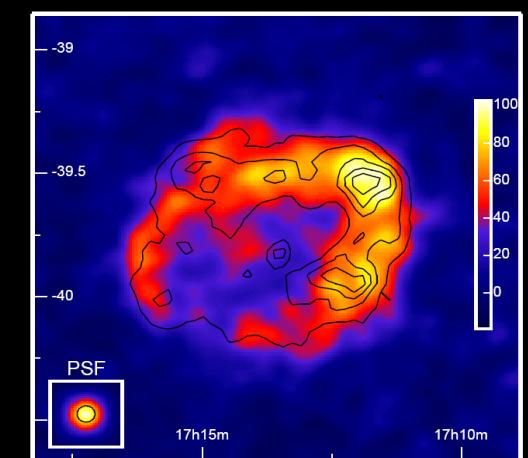


# CTA : Ultimate Survey instrument

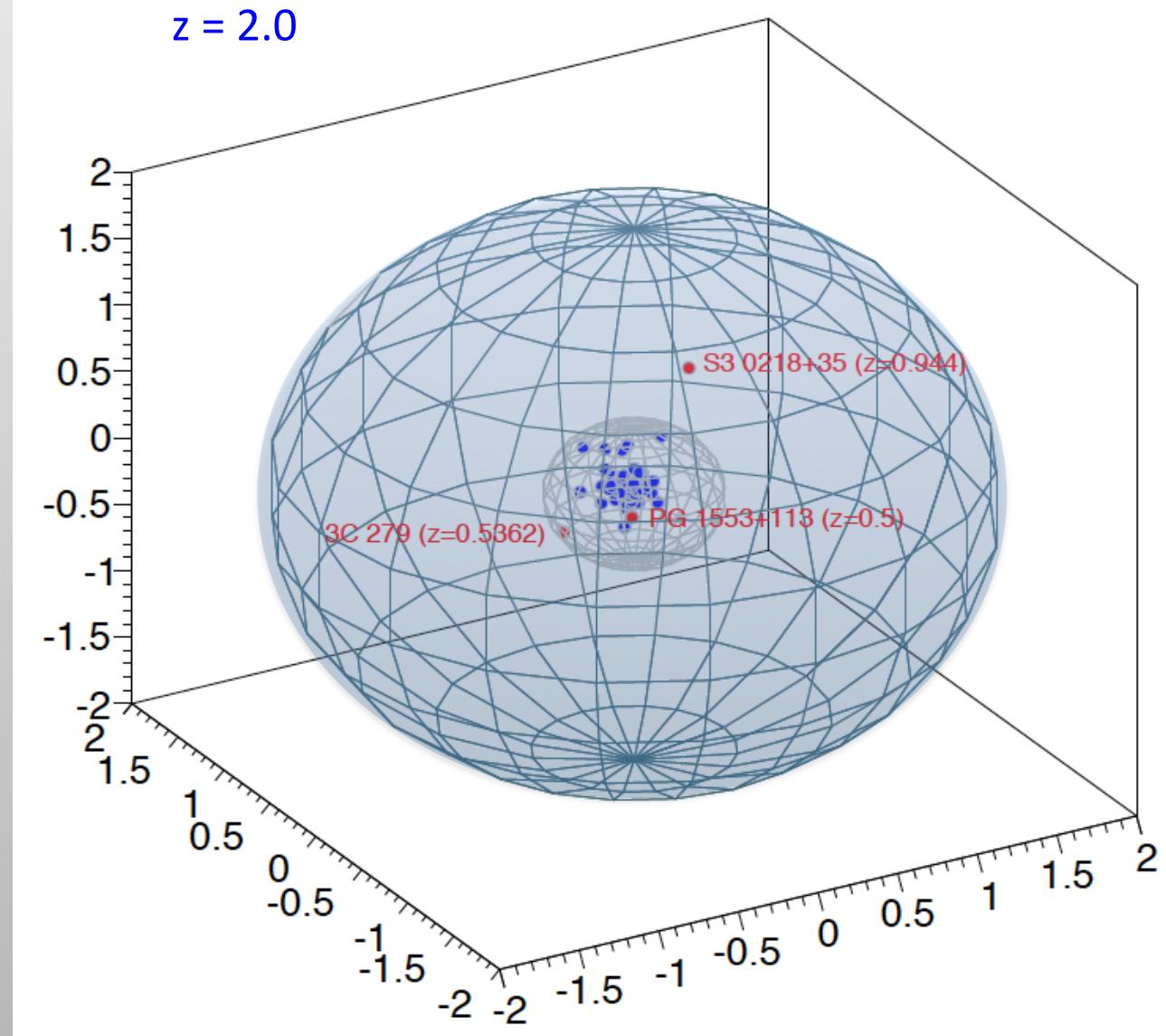
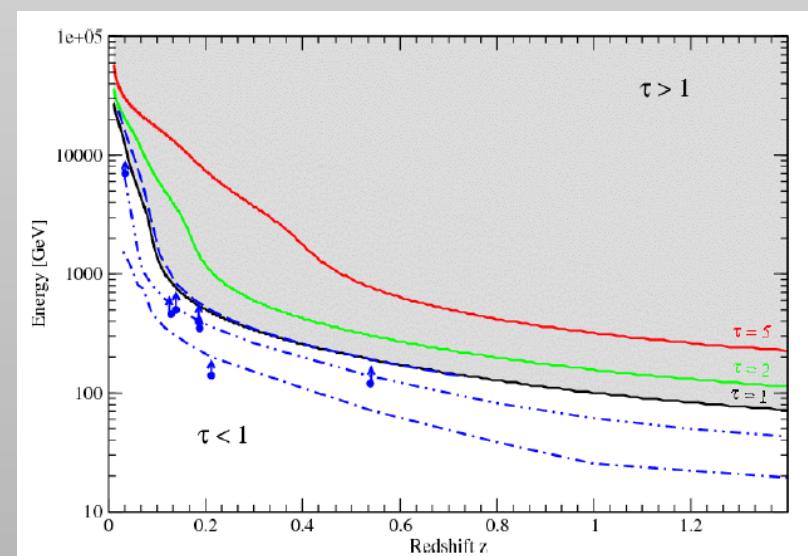
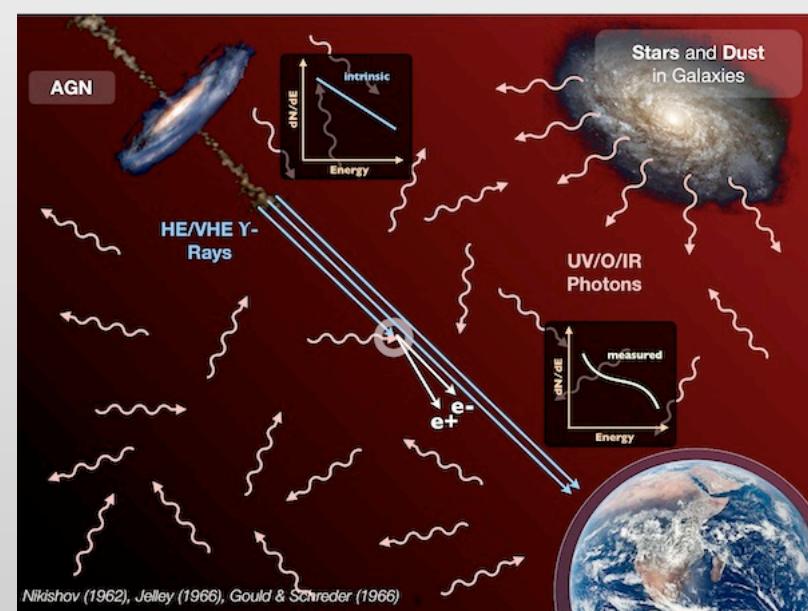


- All sky survey with two stations in south and north

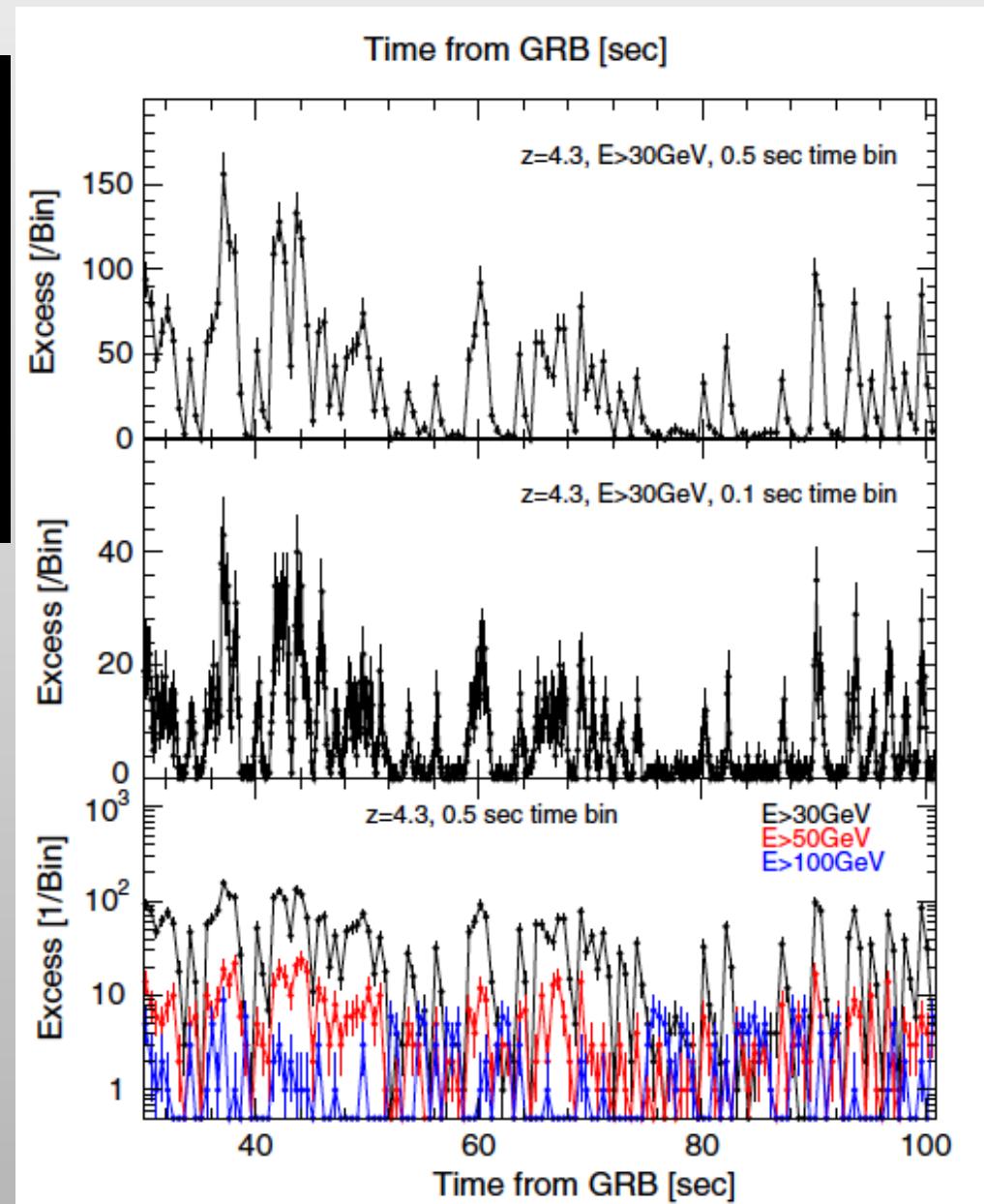
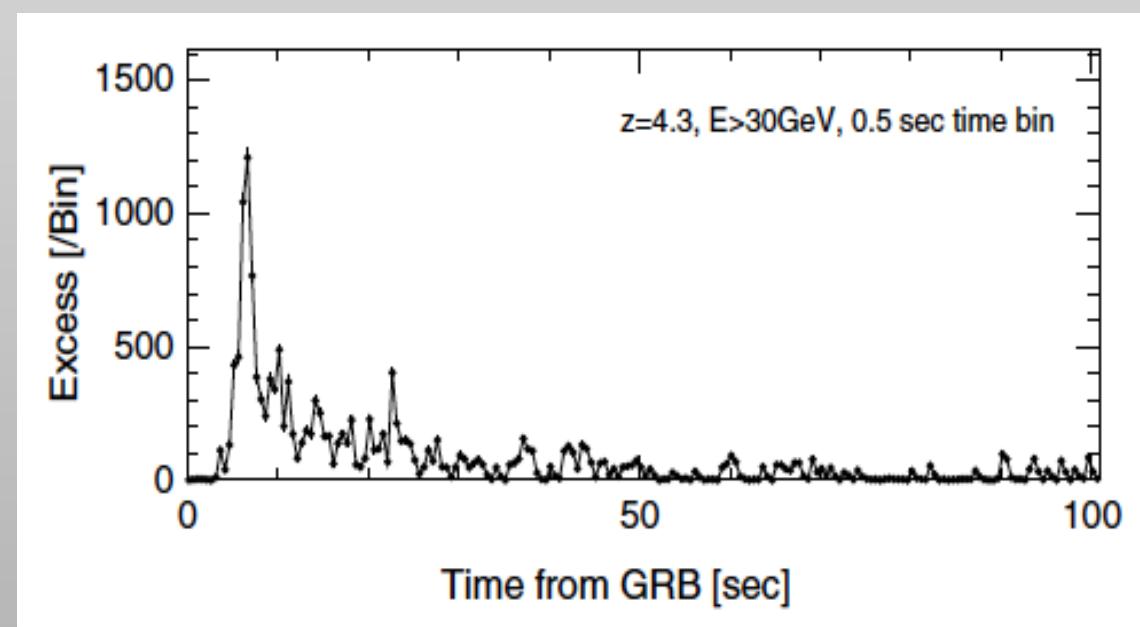
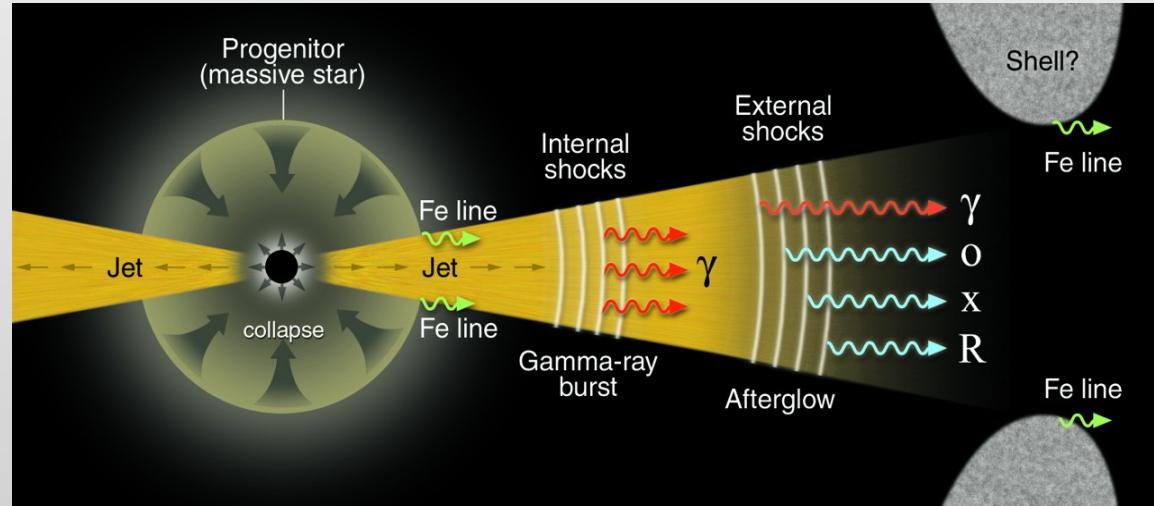
Supernova remnants



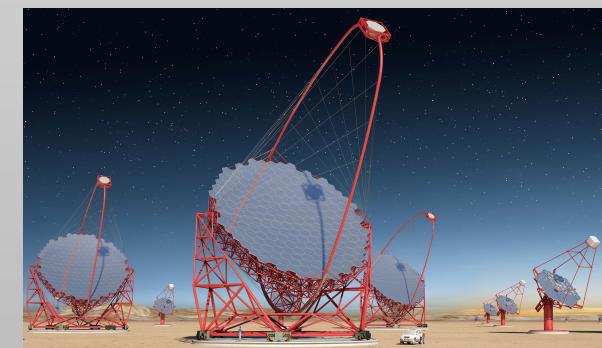
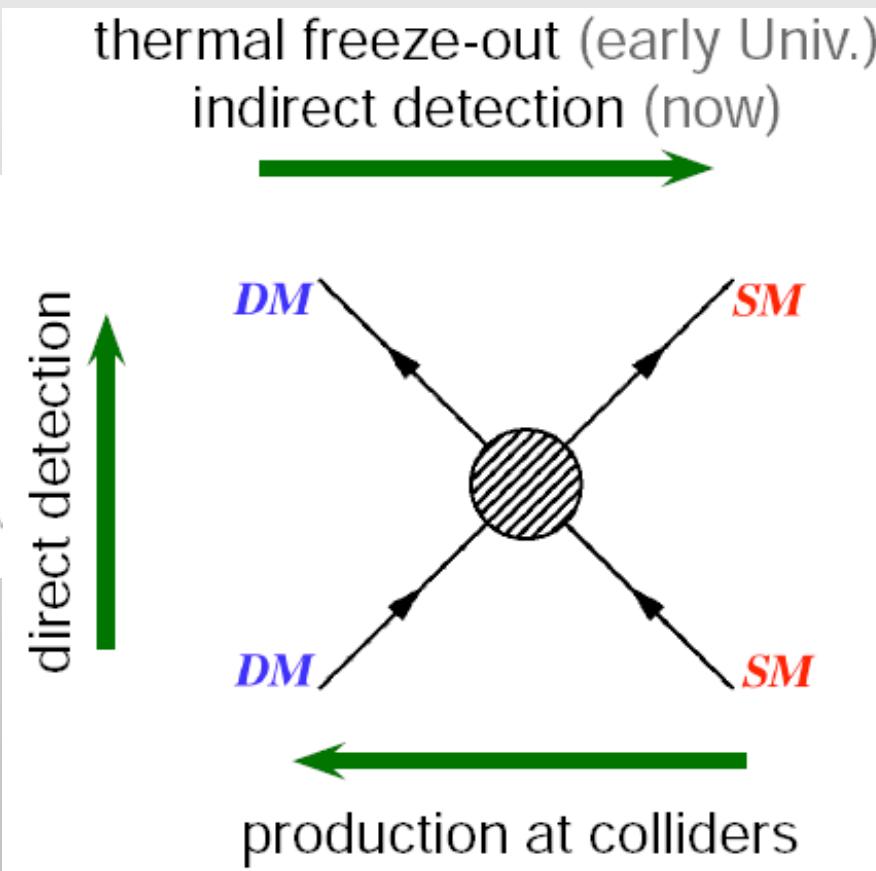
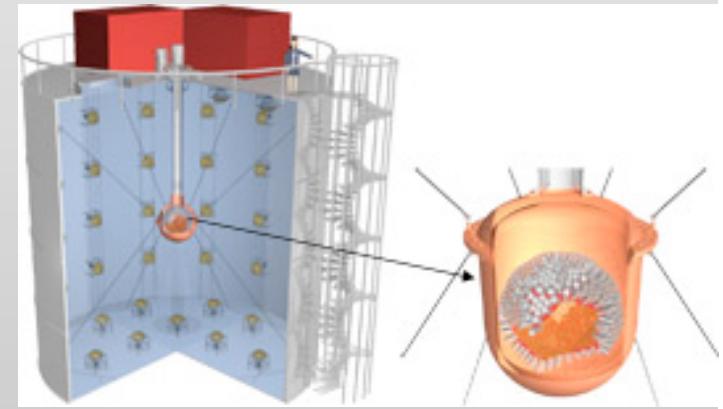
# Ultimate Survey Instrument for the extragalactic sources, AGN Survey ( $z < 2.0$ )



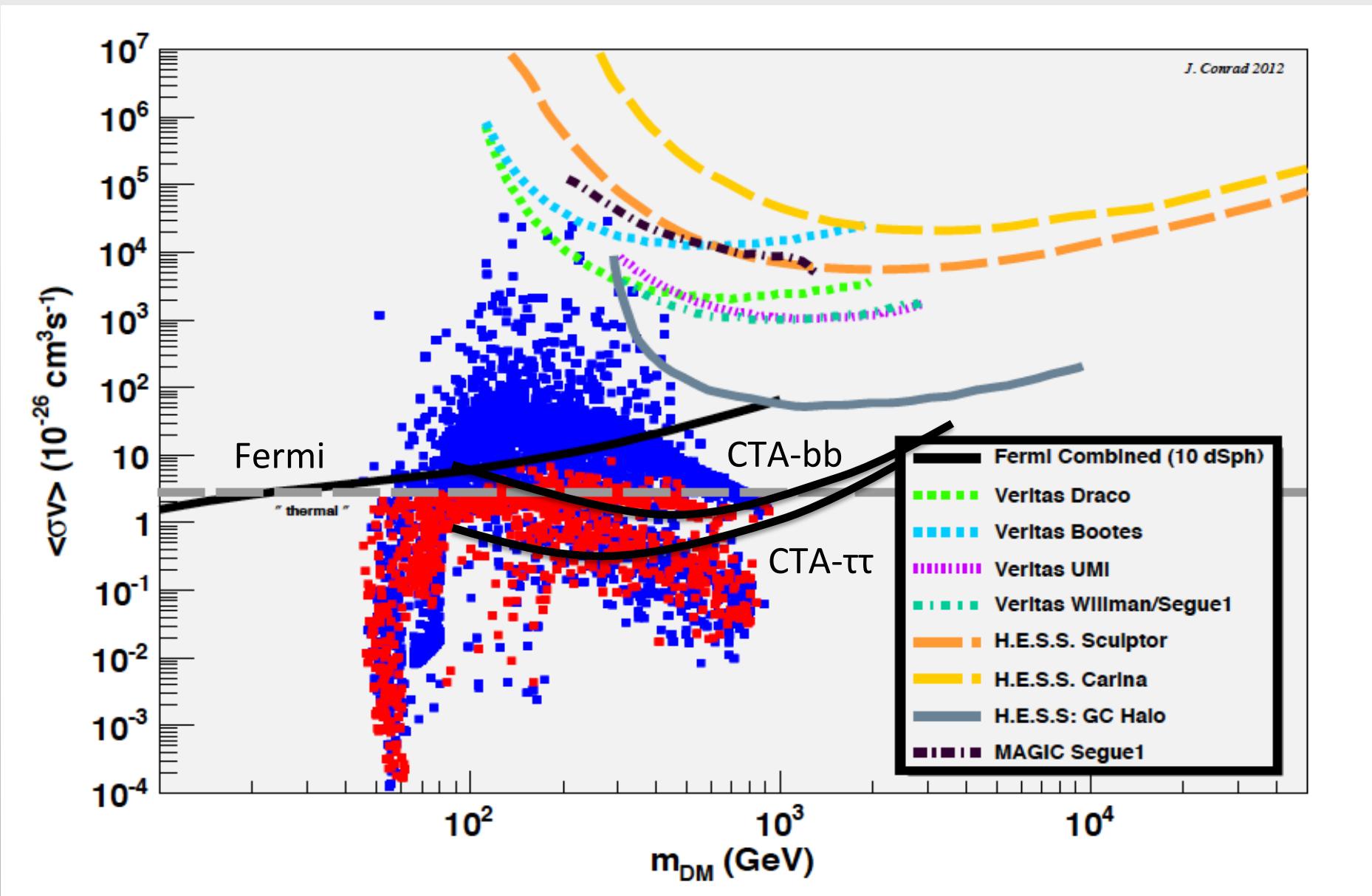
# GRB: Simulated light curve (template: GRB080916C)



# Search for DM $m_x \sim 50\text{-}2000\text{GeV}$



# CTA Sensitivities for G.C. Halo in 100 h (J. Conrad)



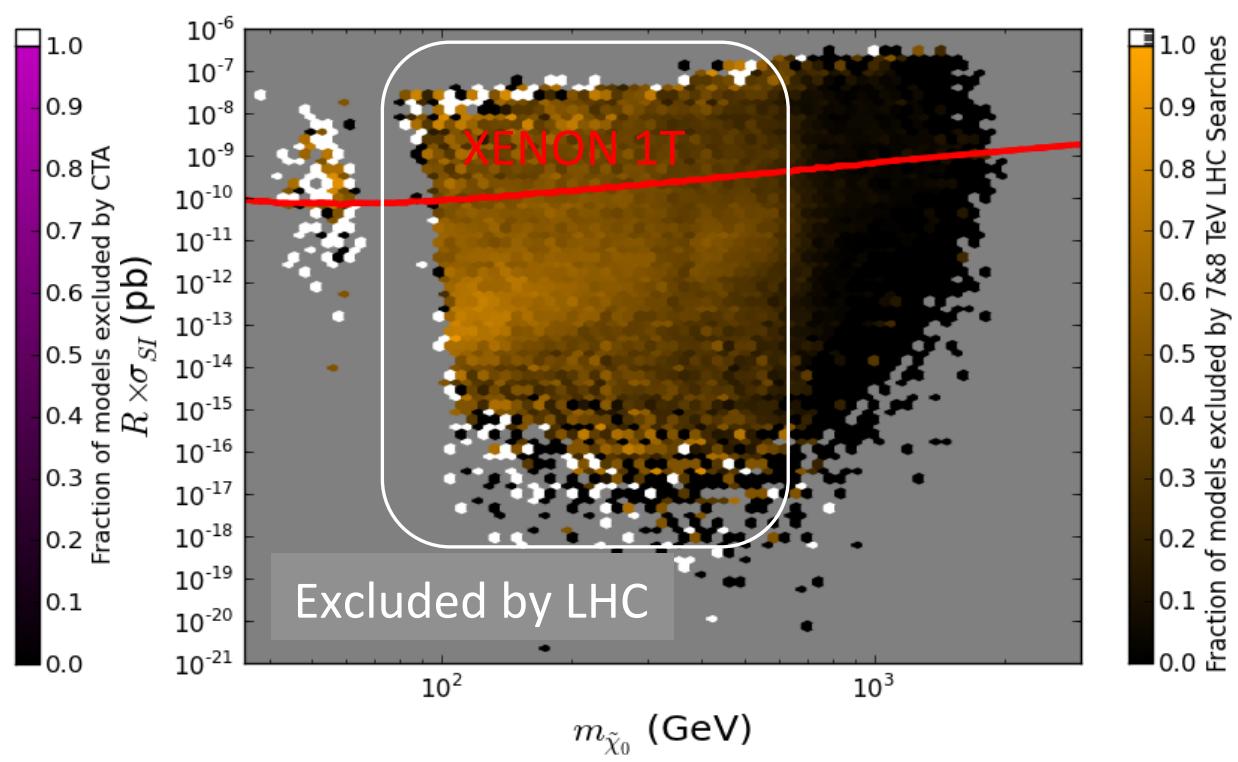
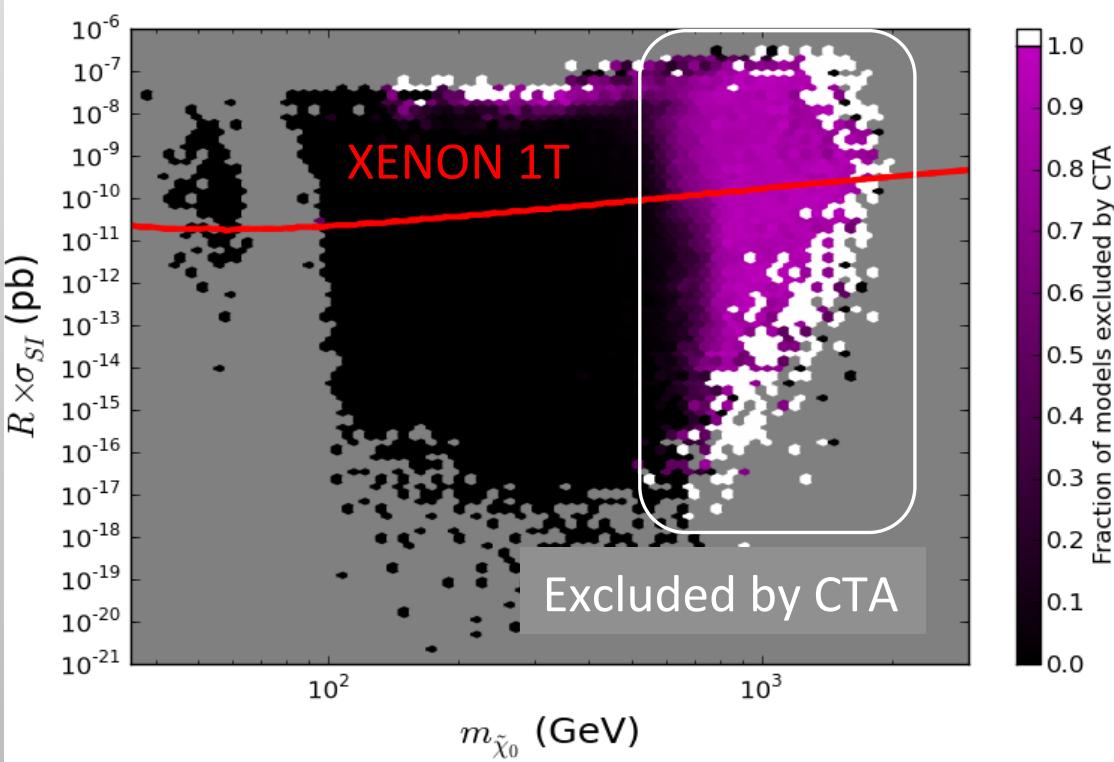
# Complementarity with Direct Search, Indirect Search, and accelerators

Red : XENON 1T Sensitivity

Purple : CTA Sensitivity

Brown : LHC Sensitivity

Cahill-Rowley+ hep-ph/1305.6921



# Summary

- VHE Gamma ray astronomy moves to the key science with the deep observation → matured phase
  - The discovery of new physics/phenomena and deep observation of the interesting source are now more important rather than the hunting of new sources
- Wide Angle Telescopes
  - HAWC was inaugurated and now in full operation
  - LHAASO will come soon
- The construction of CTA will start soon
  - CTA will study with an unprecedented sensitivity
  - Cosmic Ray Origin
  - Super Massive Blackholes, their environment and evaluation
  - Dark Matter at G.C. and dwarf galaxies

