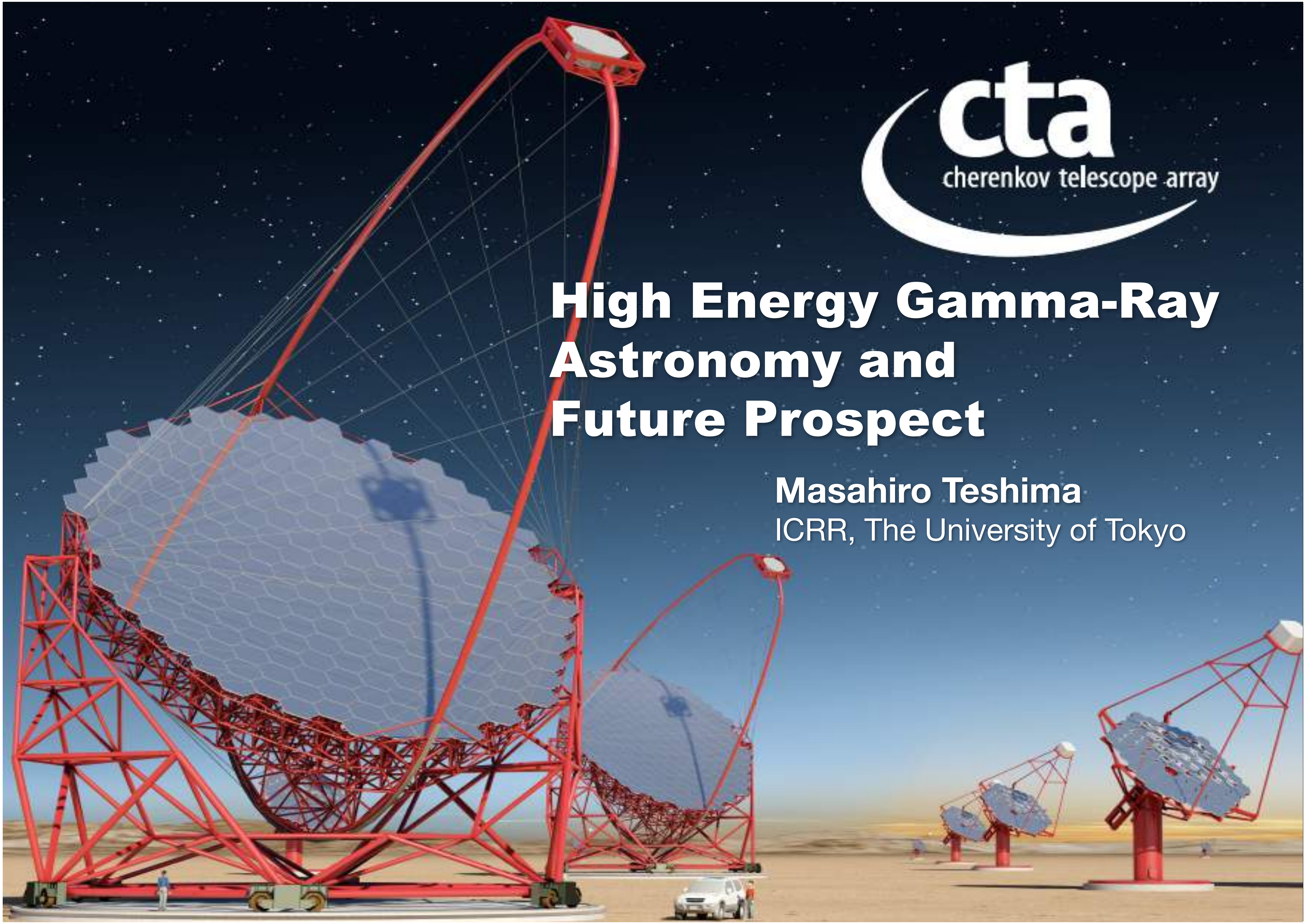
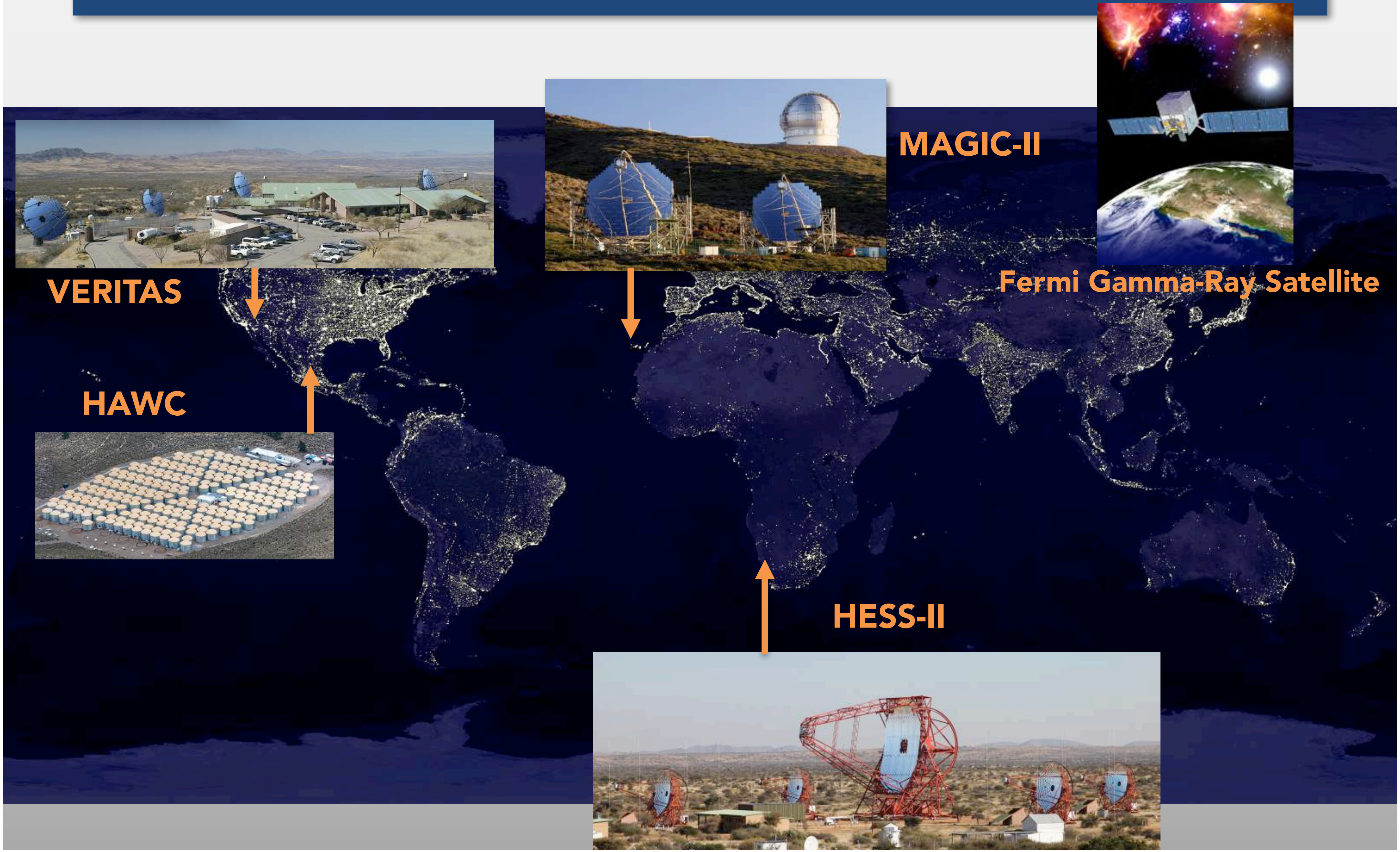


cta
cherenkov telescope array

High Energy Gamma-Ray Astronomy and Future Prospect

Masahiro Teshima
ICRR, The University of Tokyo

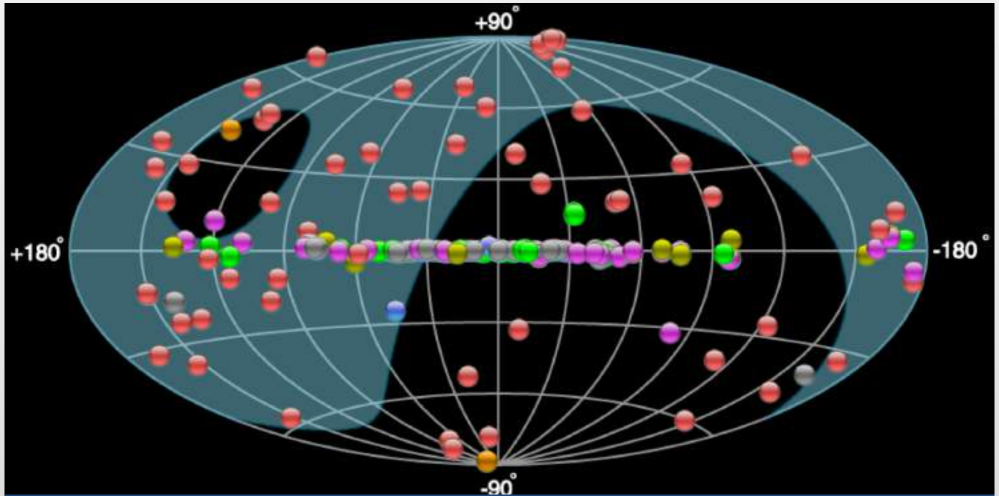
HE/VHE Gamma-Ray detectors



MAGIC TELESCOPES

International collaboration with 150 scientists from 10 countries

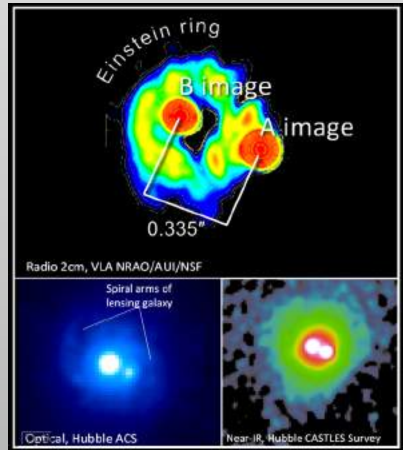
MAGIC Telescopes
(17 m diameters) on La Palma in Canaries



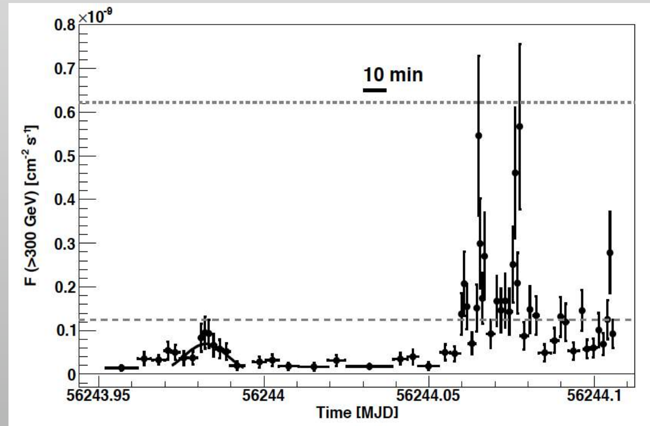
more than 170 HE sources are discovered with HESS, MAGIC and VERITAS last 10 years

MAGIC Telescopes (~10^{12}eV)

- 17m dia. Cherenkov Telescopes
- Sensitivity 0.6% Crab Flux
- Angular Resolution 0.06 °
- Energy Resolution 15%

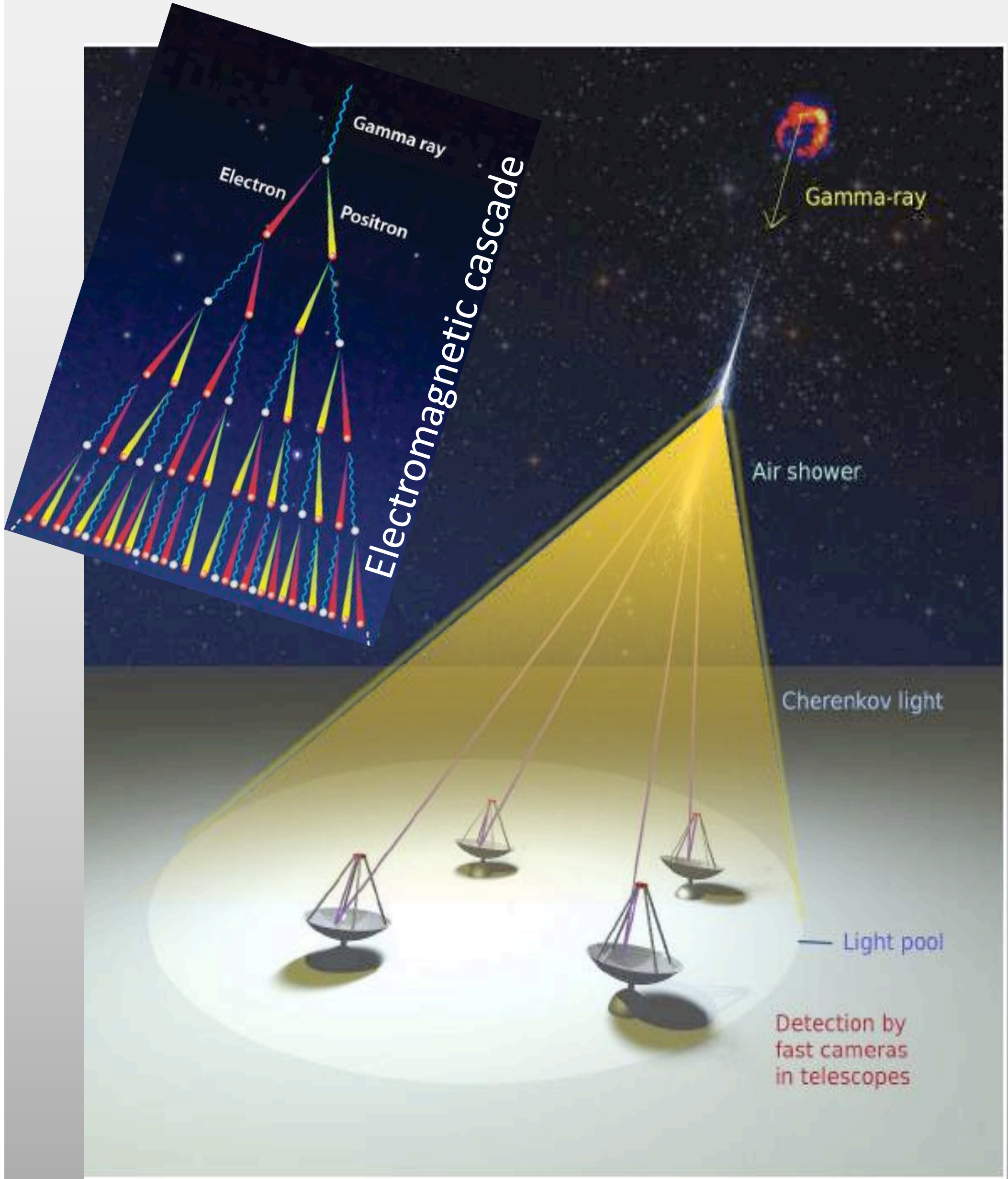


S3 0218+35 (z=0.944) gravitational lensed quasar is discovered

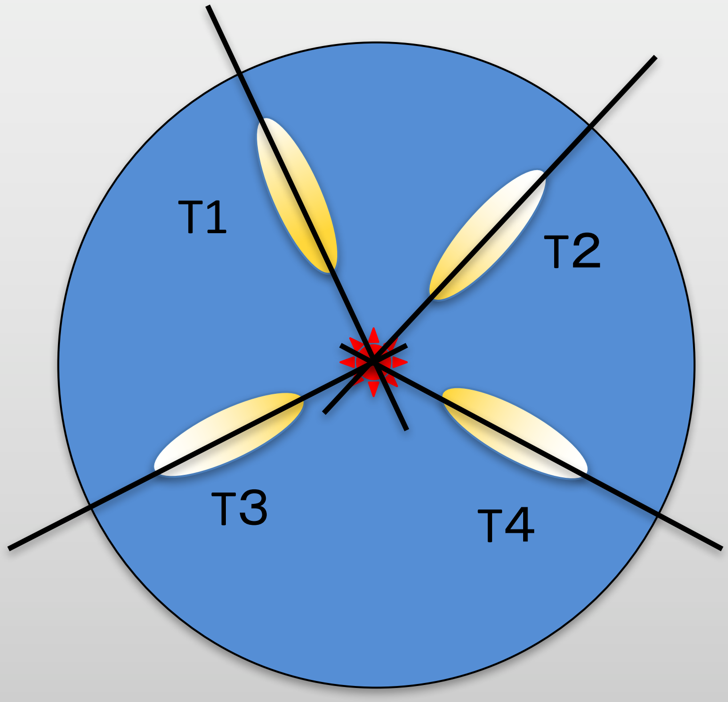


Very fast flare of IC310
~1mins variation < BH size (25mins)

Imaging Atmospheric Cherenkov Telescope

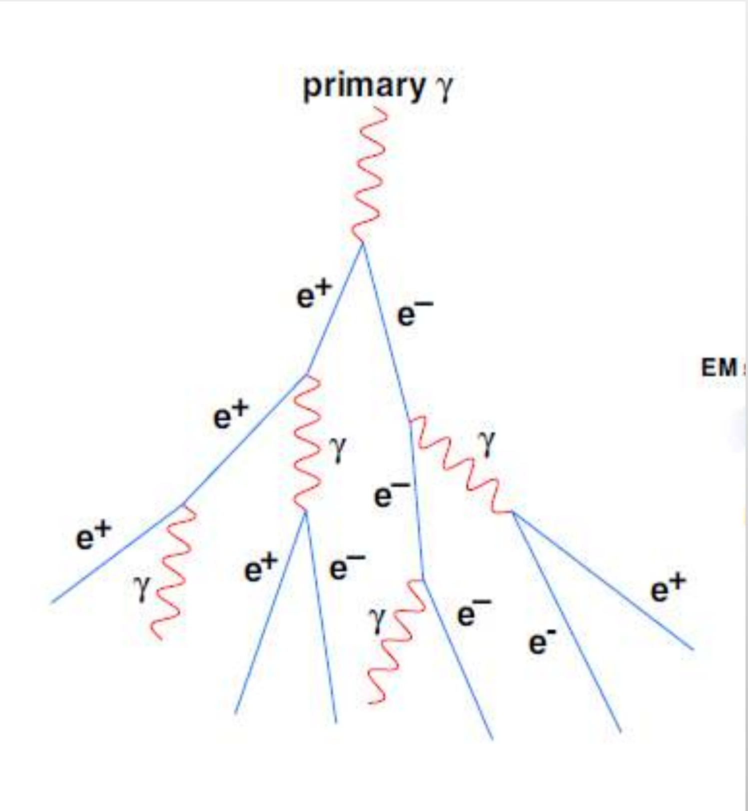


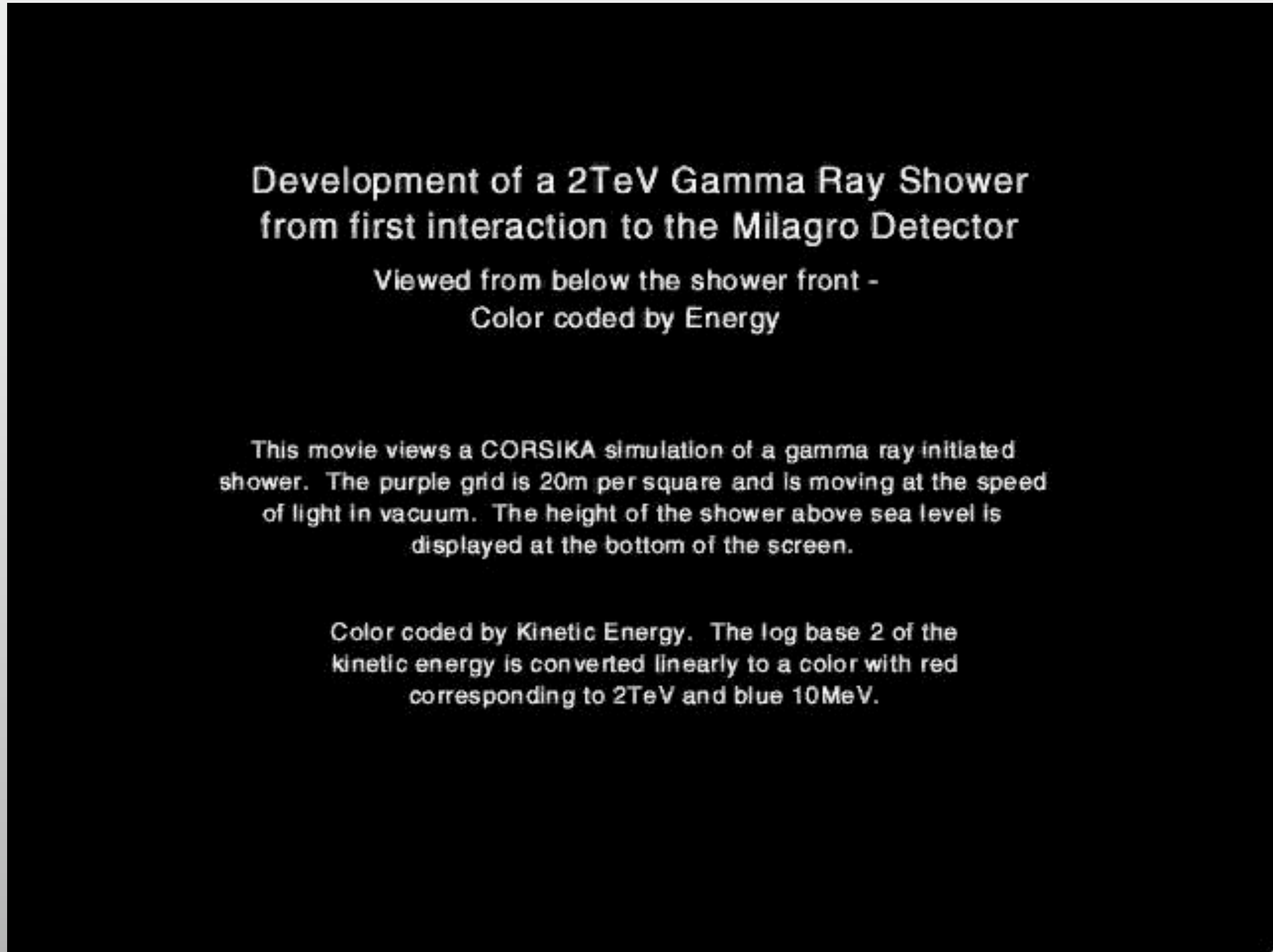
\# of Photons: 50photons/m^2 at 1TeV



- Energy range 50GeV ~ 10TeV
- CR Rejection ~99.5%
- Angular Res. ~0.06 degrees
- Energy Res. ~20%
- Effective Area ~10^5m^2
- Sensitivity ~0.6% Crab Flux (10^{-13} erg/cm^{2}s)

TeV ガンマ線からの空気シャワー



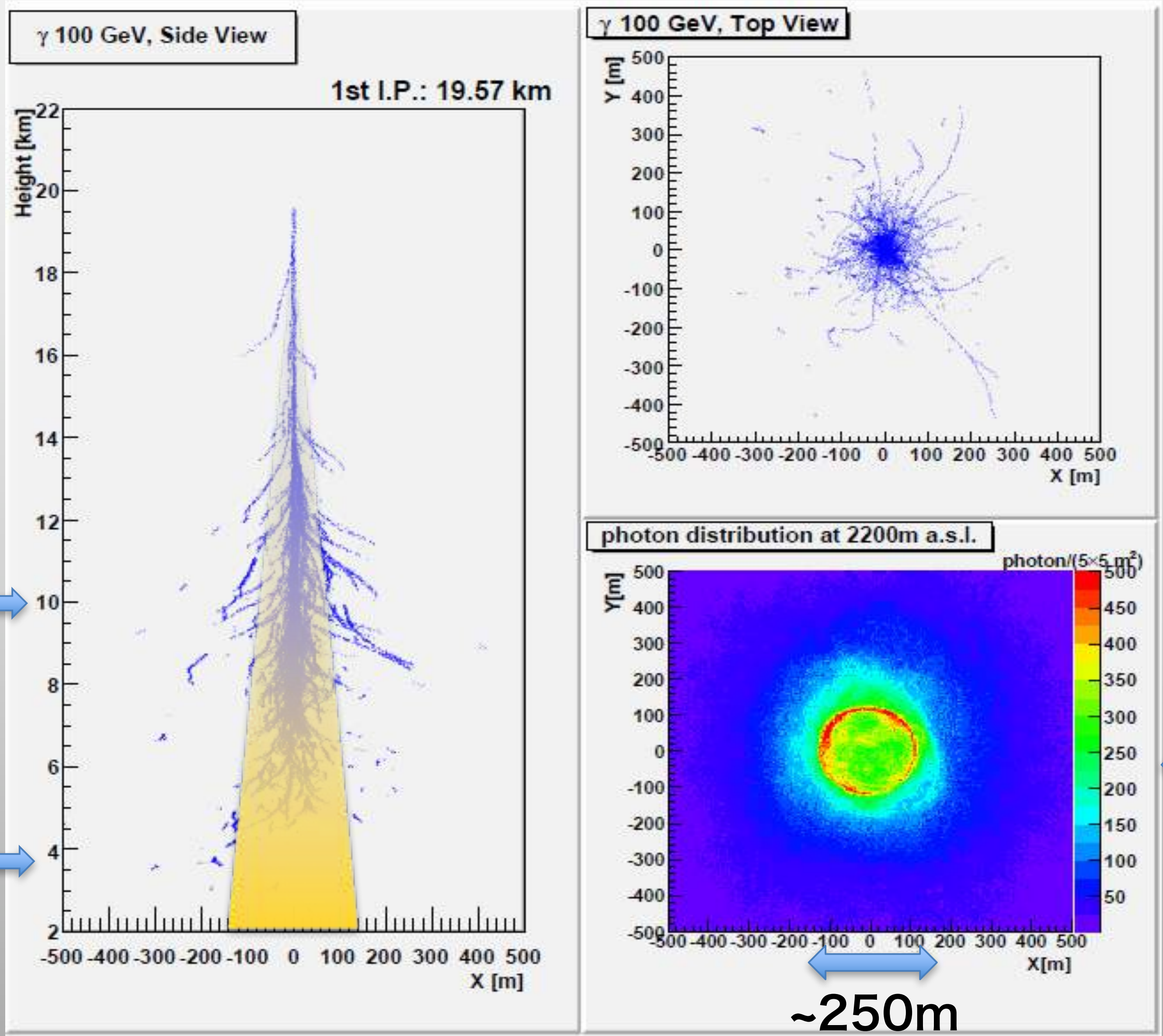


宇宙ガンマ線（100GeV）→ シャワー → チェレンコフ光

高度

飛行機

富士山



大気の屈折率
n = 1.000292

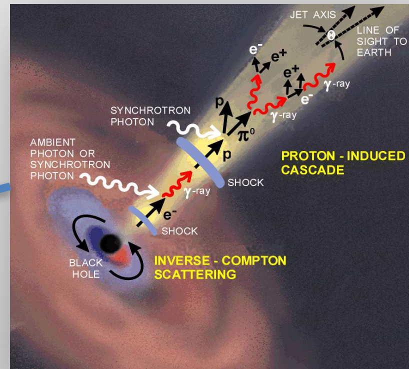
大気中の光の速度
c’ = c/1.000292
= 0.9997 c

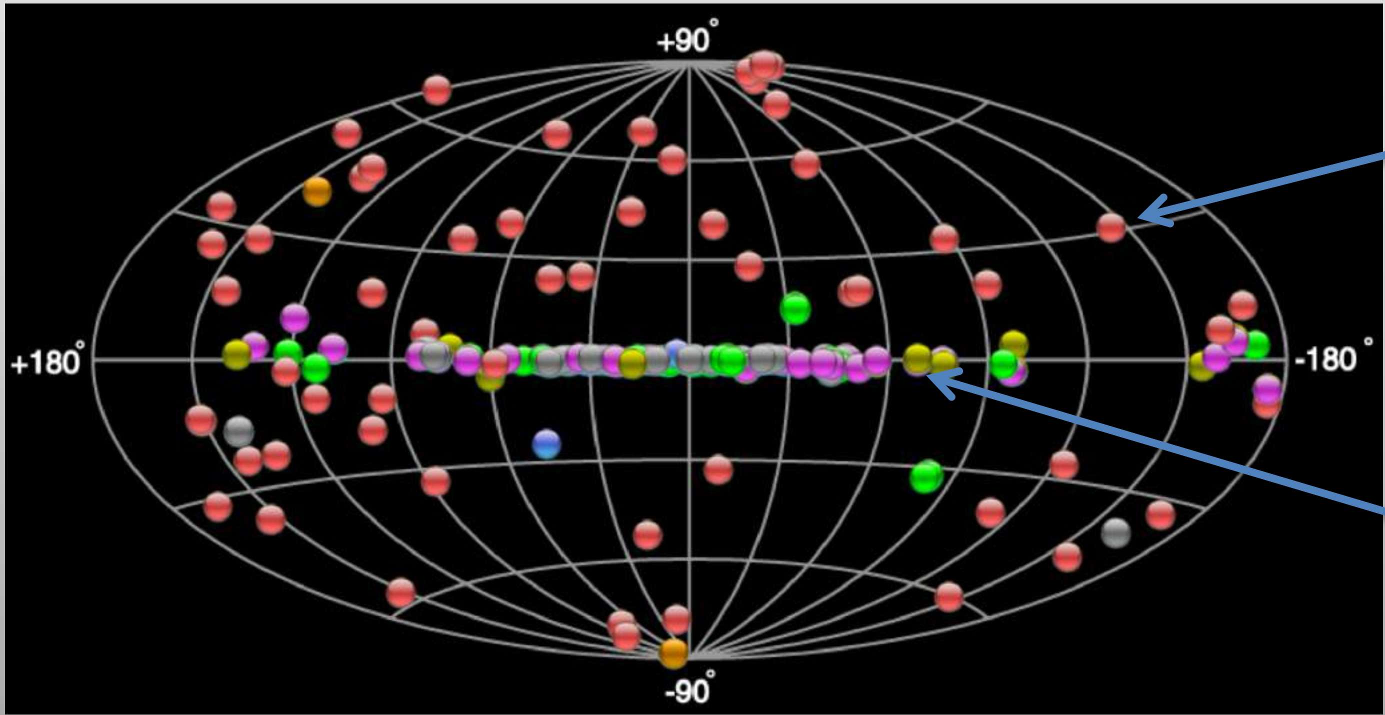
粒子の速度
v > 0.99998 c

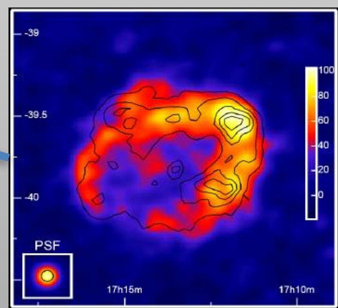
地上に到達した
チェレンコフ光

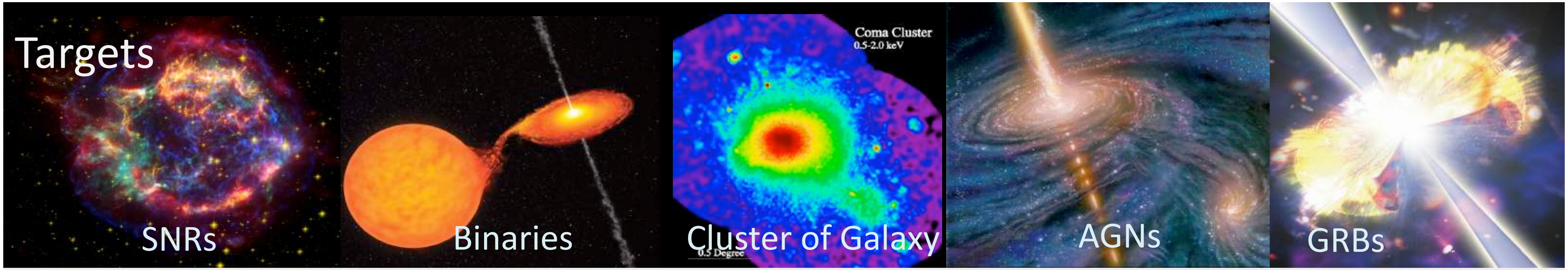
VHE Gamma Ray Astronomy
A New Window to the Universe and Energy Frontier in Astrophysics

- HESS, MAGIC, VERITAS observed more than 170 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 104 times higher sensitivity for the transient/flaring sources, like gamma ray bursts and AGN flares.



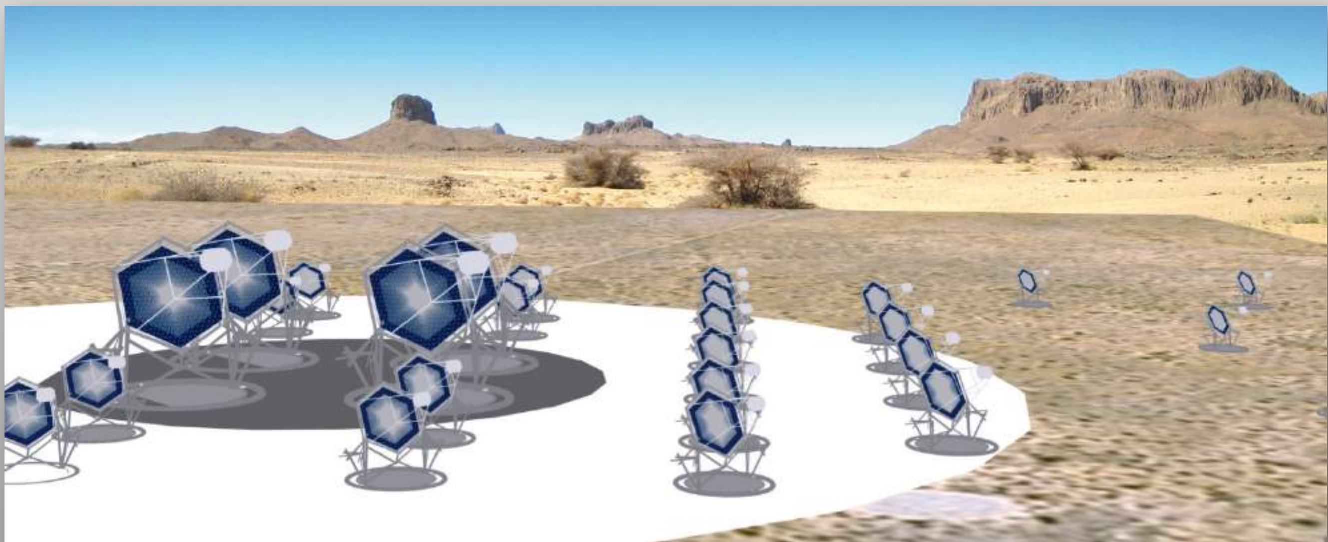




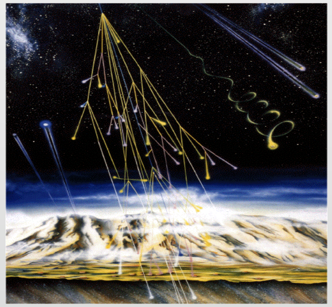


Cherenkov Telescope Array
High Energy Gamma Ray Astronomy

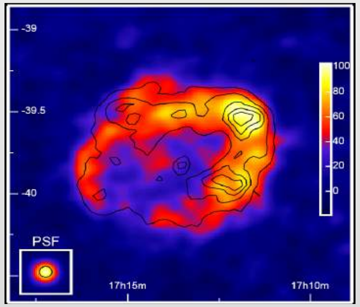
- Origin of Cosmic Rays
- High Energy Astronomical Objects
- Super Massive Black Holes
- EBL Study ➔ Cosmology (Star formation rate)
- Search for Dark Matter



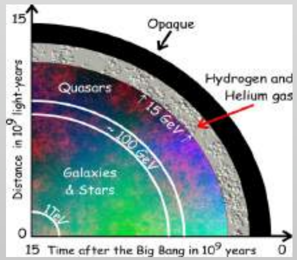
Science Objectives



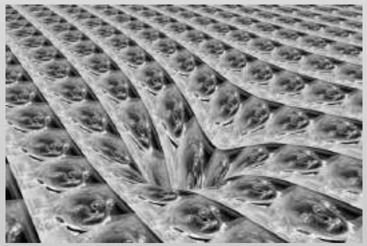
Cosmic Ray Origin



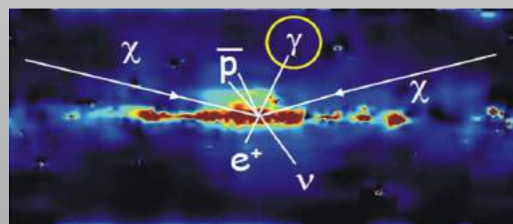
High Energy Objects



Cosmology

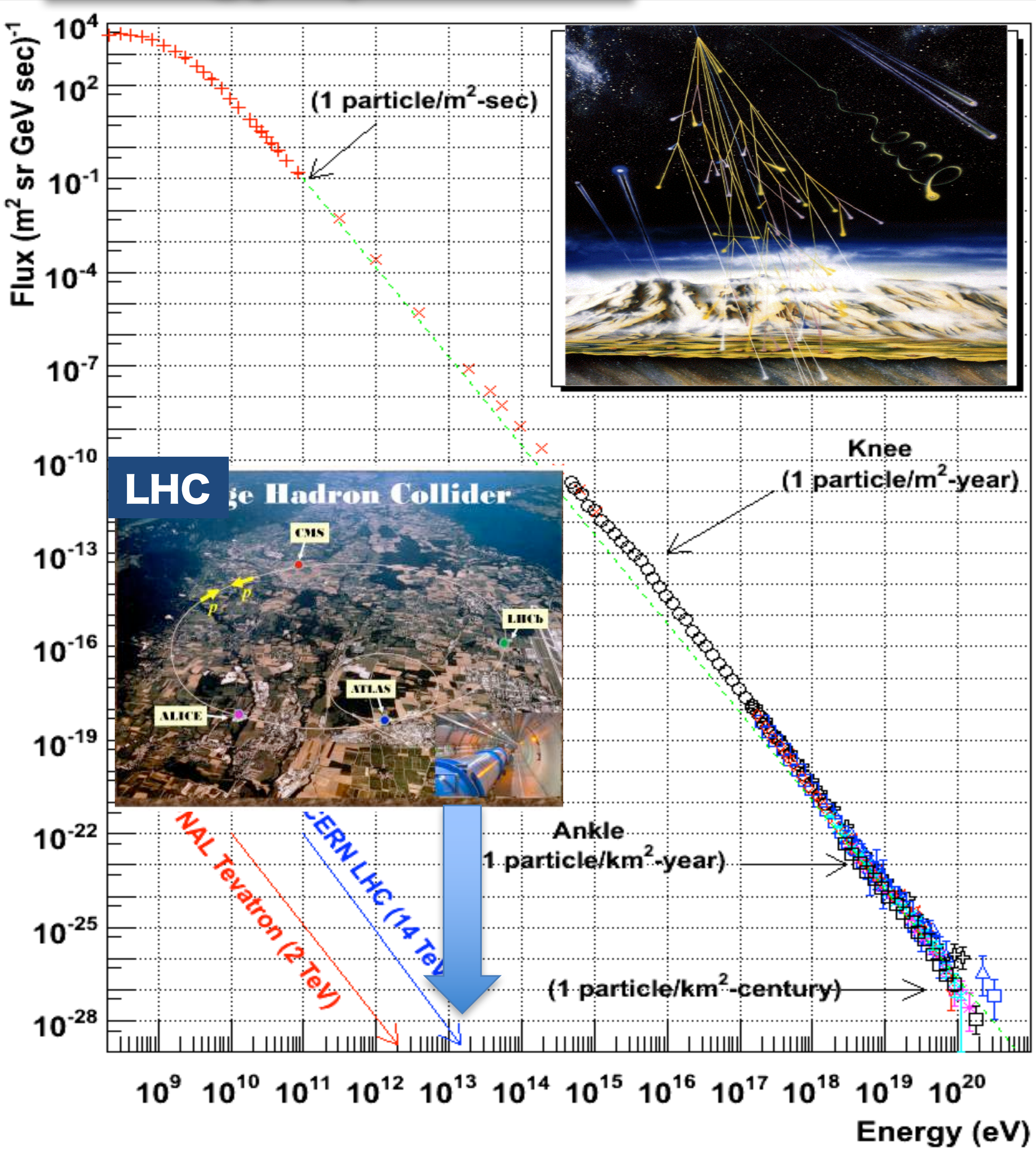


Space & Time

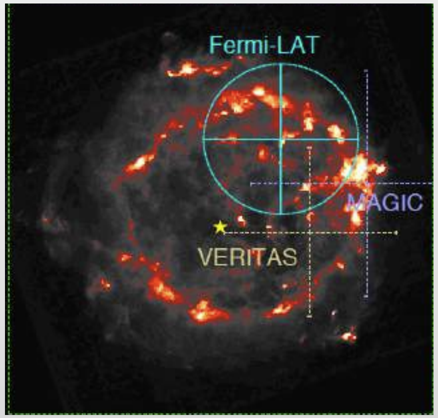


Dark Matter

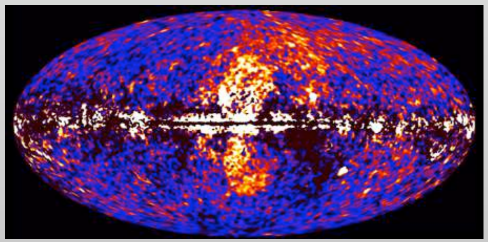
Cosmic Ray Energy Spectrum



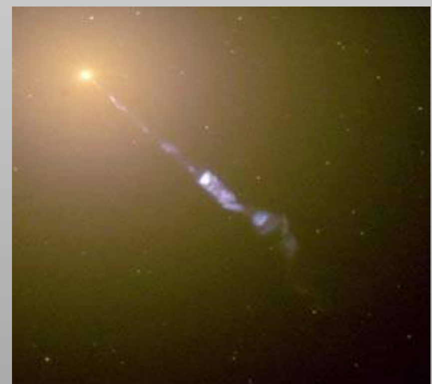
Observation of accelerators in the Universe with HE/VHE gamma rays



SNRs
(Cas-A)

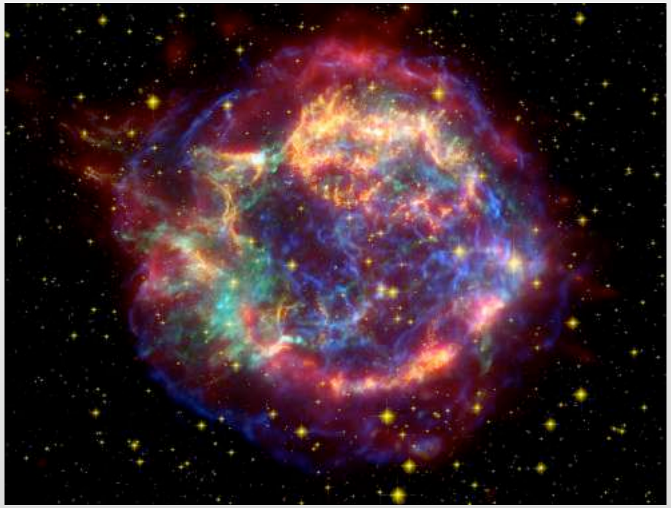


Large Structure
in our galaxy
(Fermi bubble)

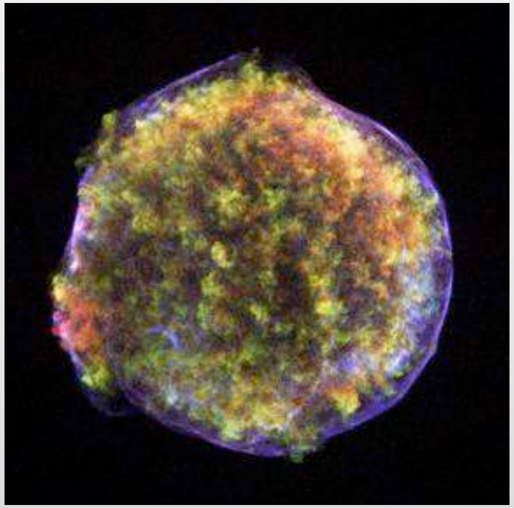


AGNs
(M87)

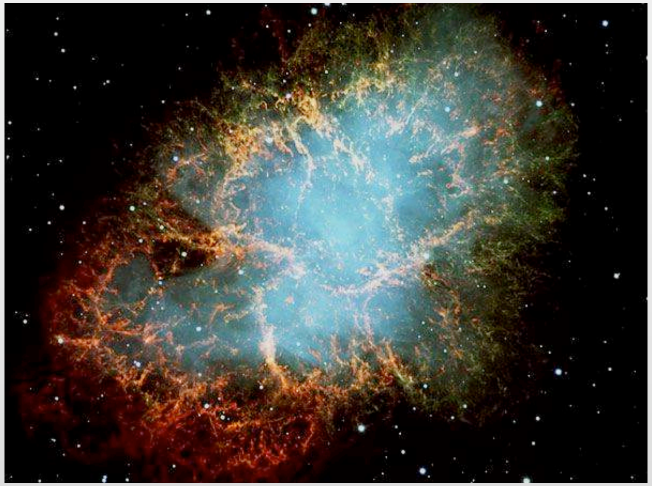
きわめて怪しい超新星残骸たち　（ギンツブルグ、早川）
(ガンマ線を放出している)



カシオペア-A　(300yr)

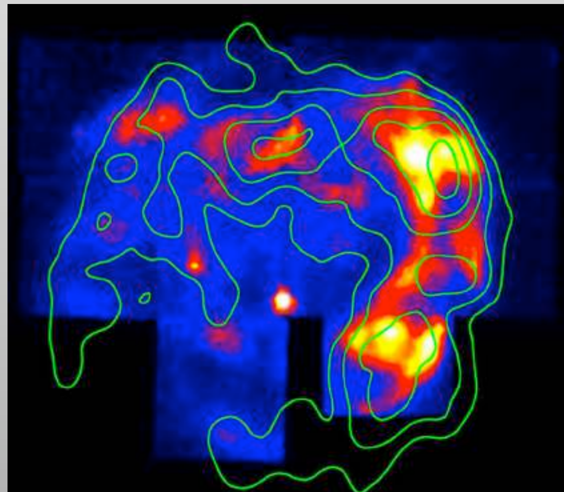


SN1572 Tycho (400yr)

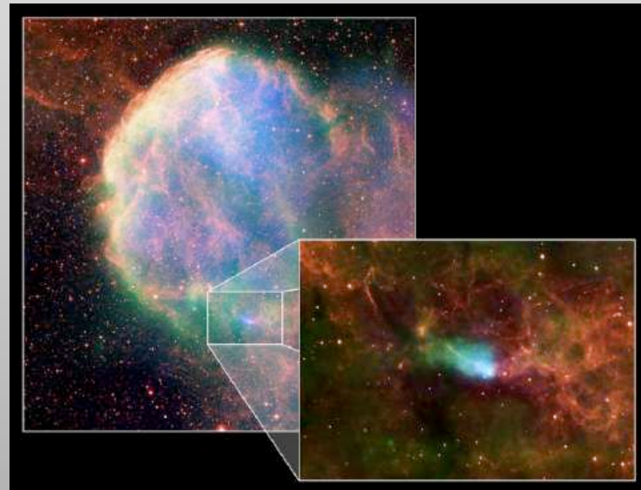


SN1054 かに星雲(1000yr)

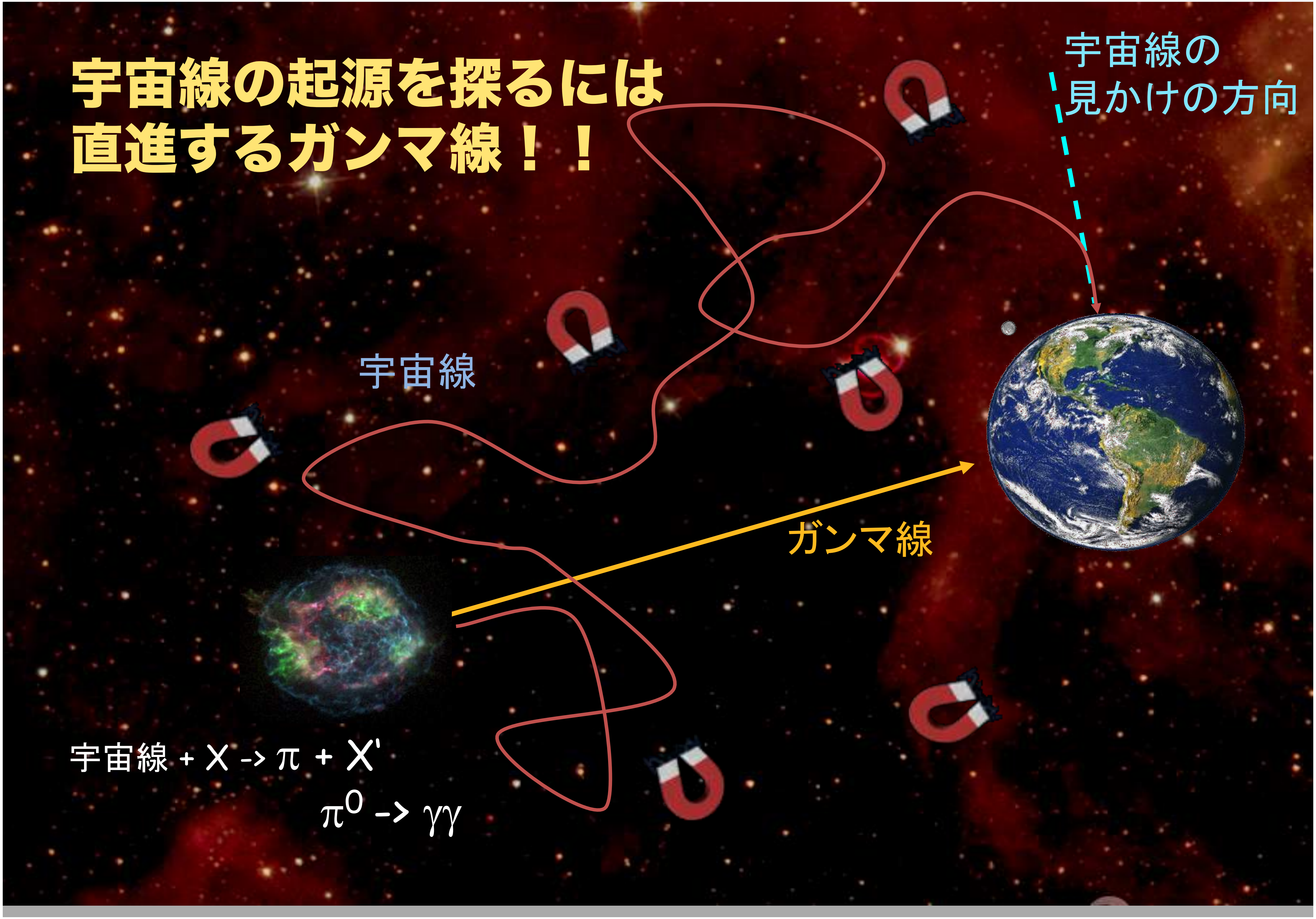
SN 1006 (1000yr)



RX J1713 (2600yr)

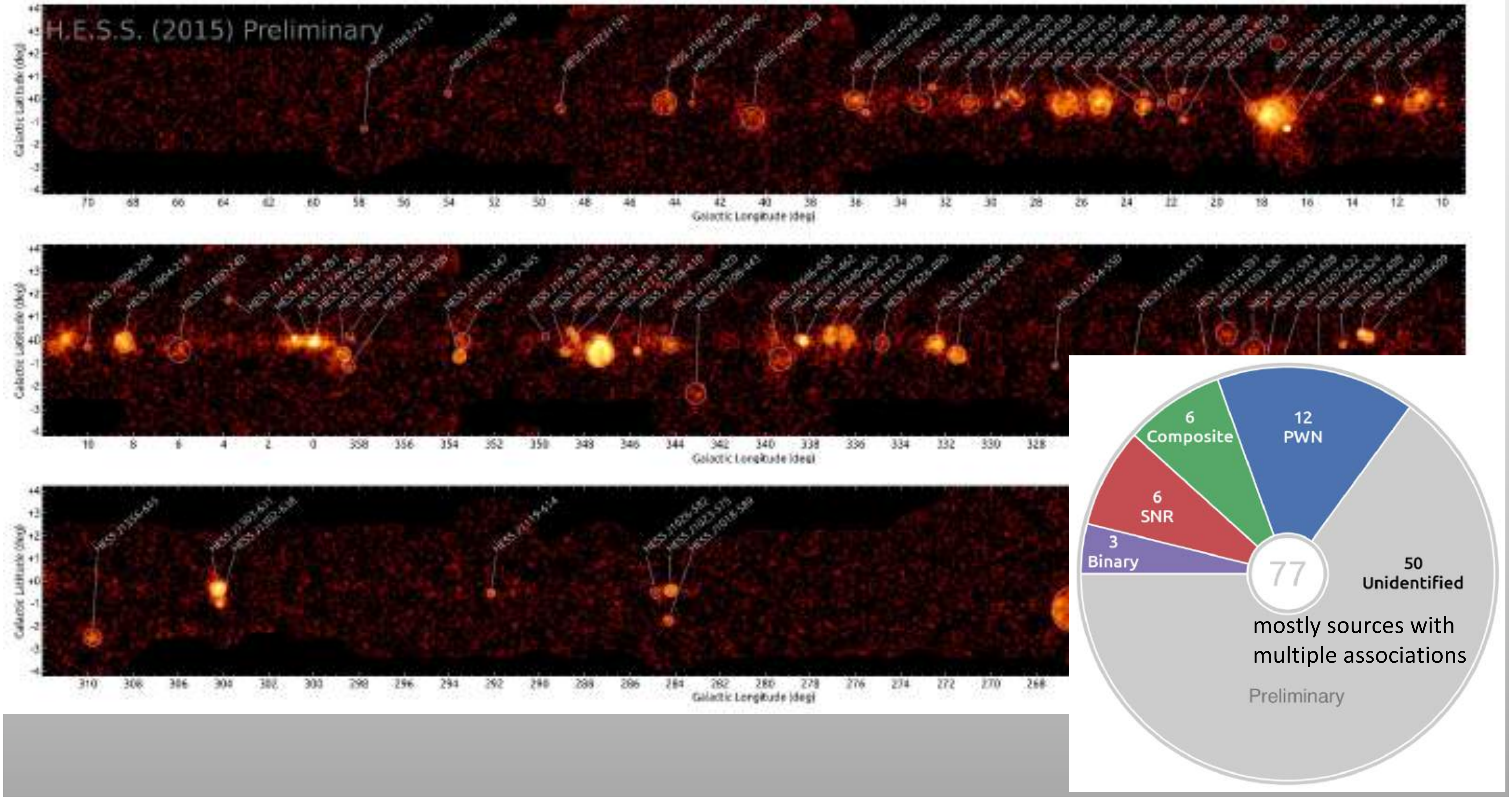


IC443(10,000yr)

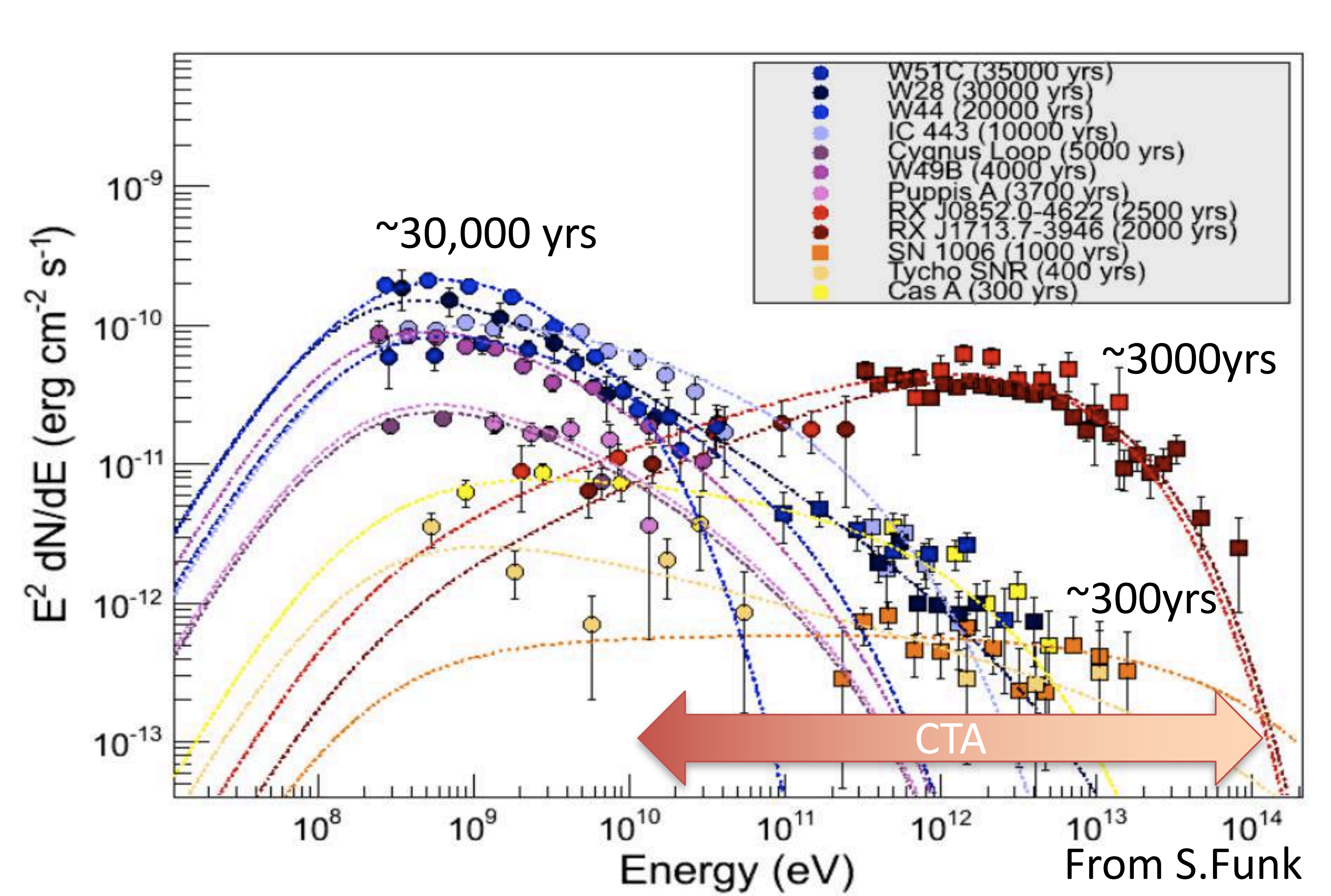

宇宙線の起源を探るには
直進するガンマ線！！
宇宙線の
見かけの方向
宇宙線
ガンマ線
宇宙線 + X -> π + X'
π^0 -> γγ

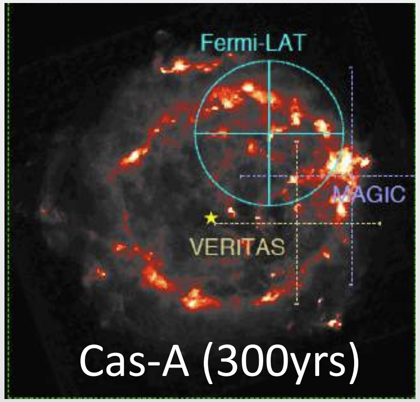
HESS Galactic Plane Survey

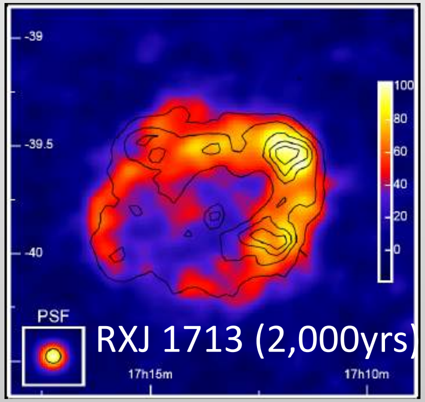
Deil et al. ICRC 2015 and Chaves TeVPA 2015

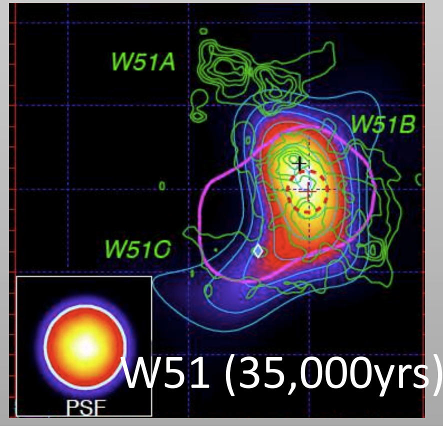


$E<10^{15}$eV Cosmic Rays ←→ Shell type SNRs



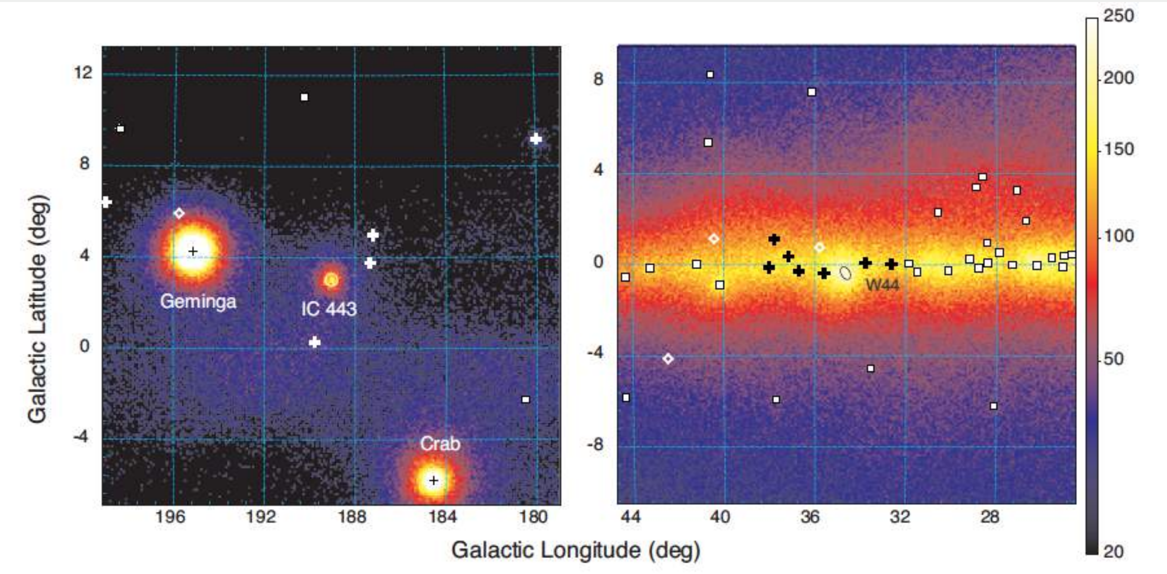


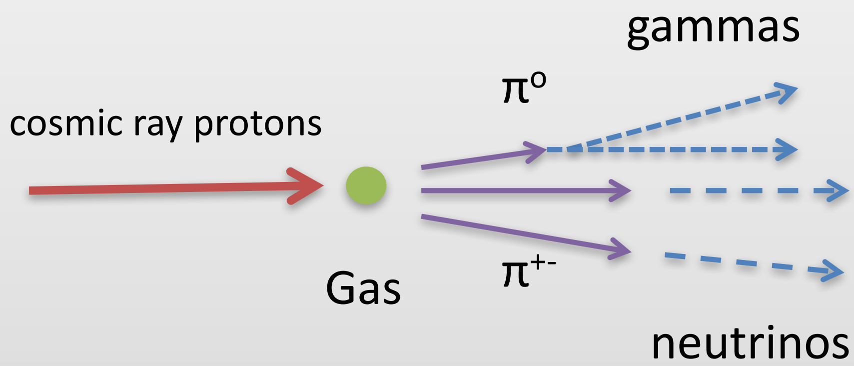


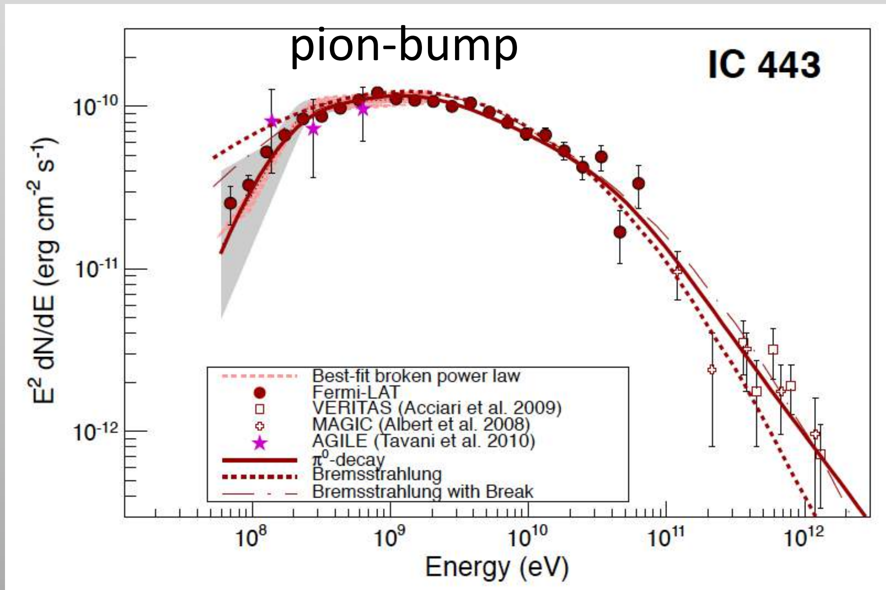


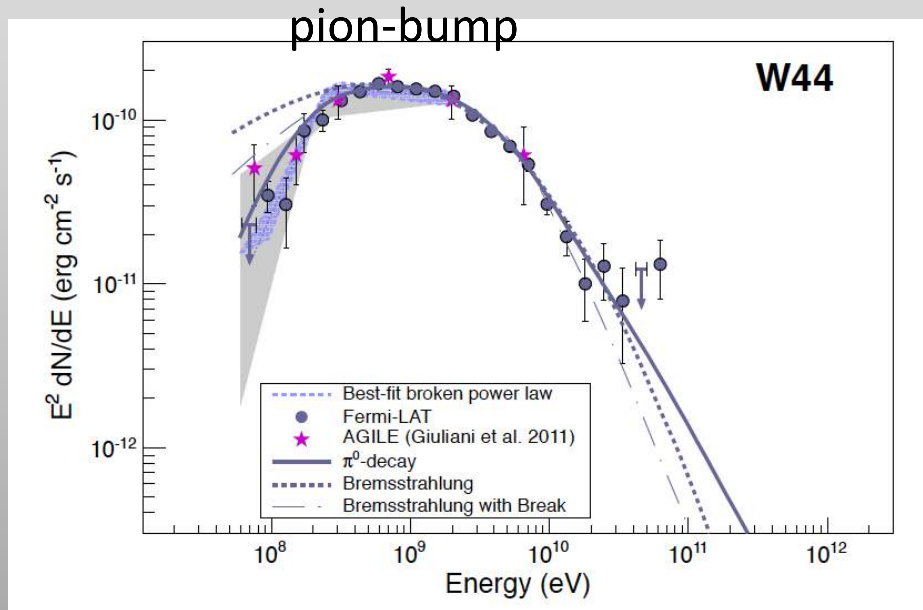
- Different stages of SNRs as cosmic ray accelerator
- CTA will deliver more information on SNRs as cosmic ray accelerators
- We can survey most of SNRs in our galaxy → C.R. energetics

Super Nova Remnants as cosmic ray accelerators IC443 and W44, FERMI Collaboration (in Science)







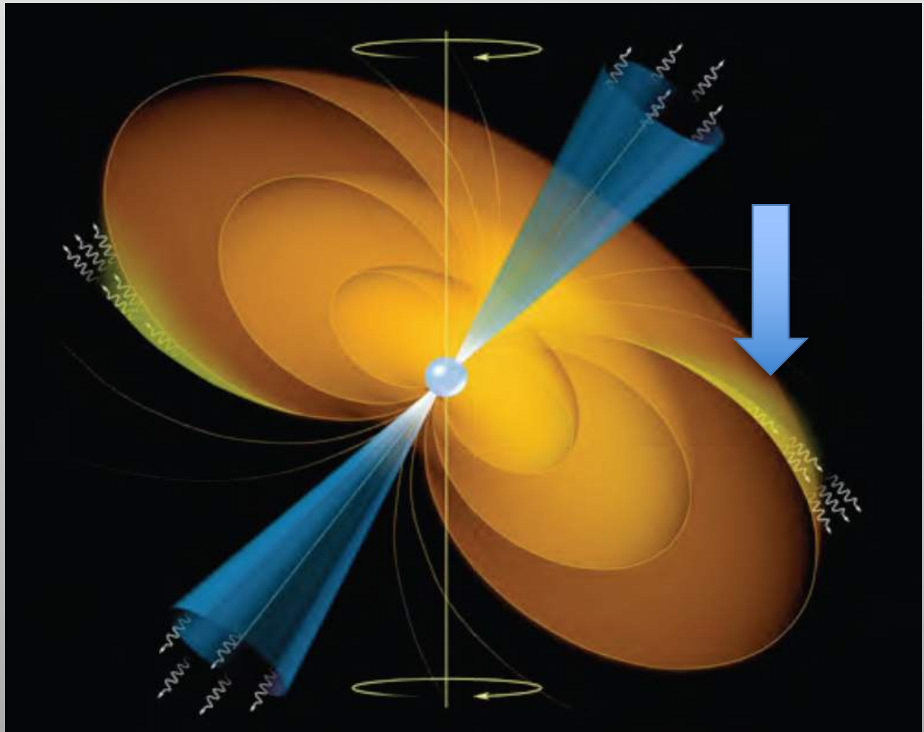


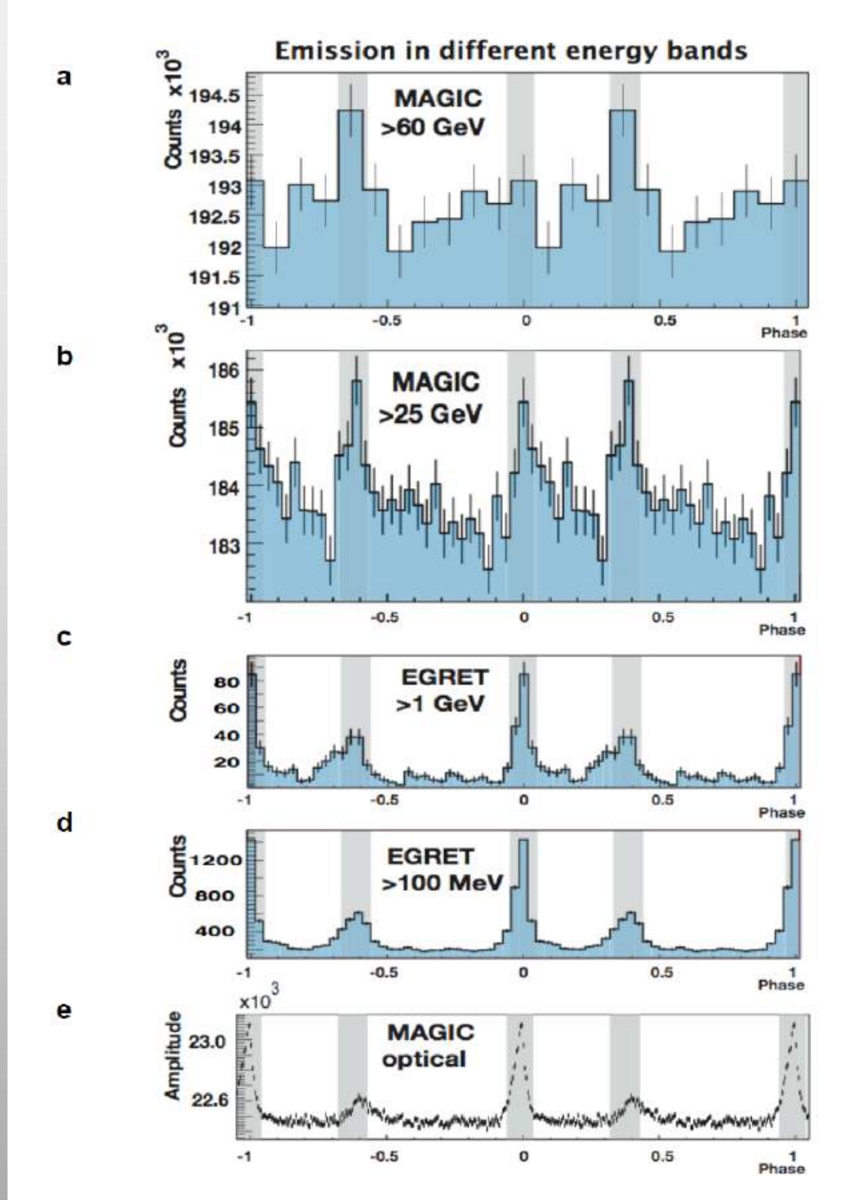
Crab Pulsar observation with MAGIC in 2008

MAGIC result: Published in Science in 2008

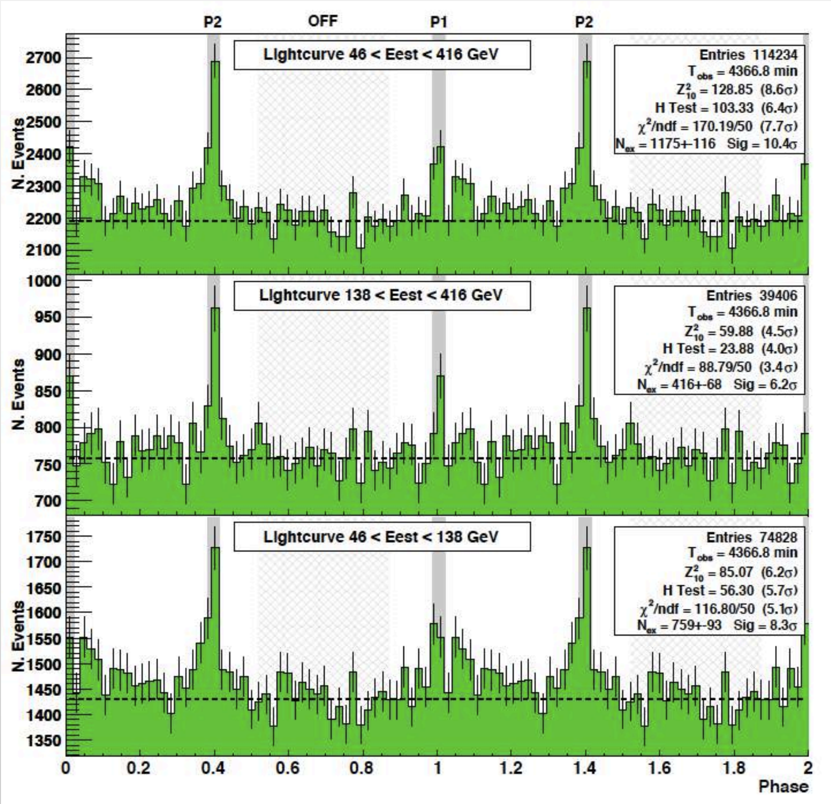
Measuring the spectrum around cutoff
or at high energies is important to distinguish
the emission model

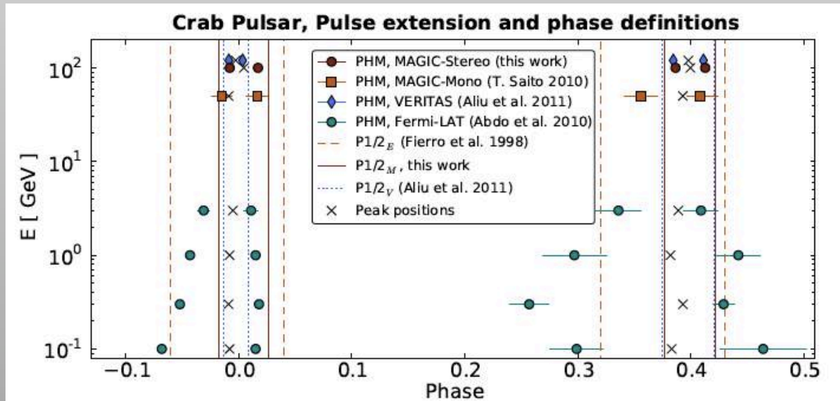
Polar cap: double exponent
Outer gap: simple exponent

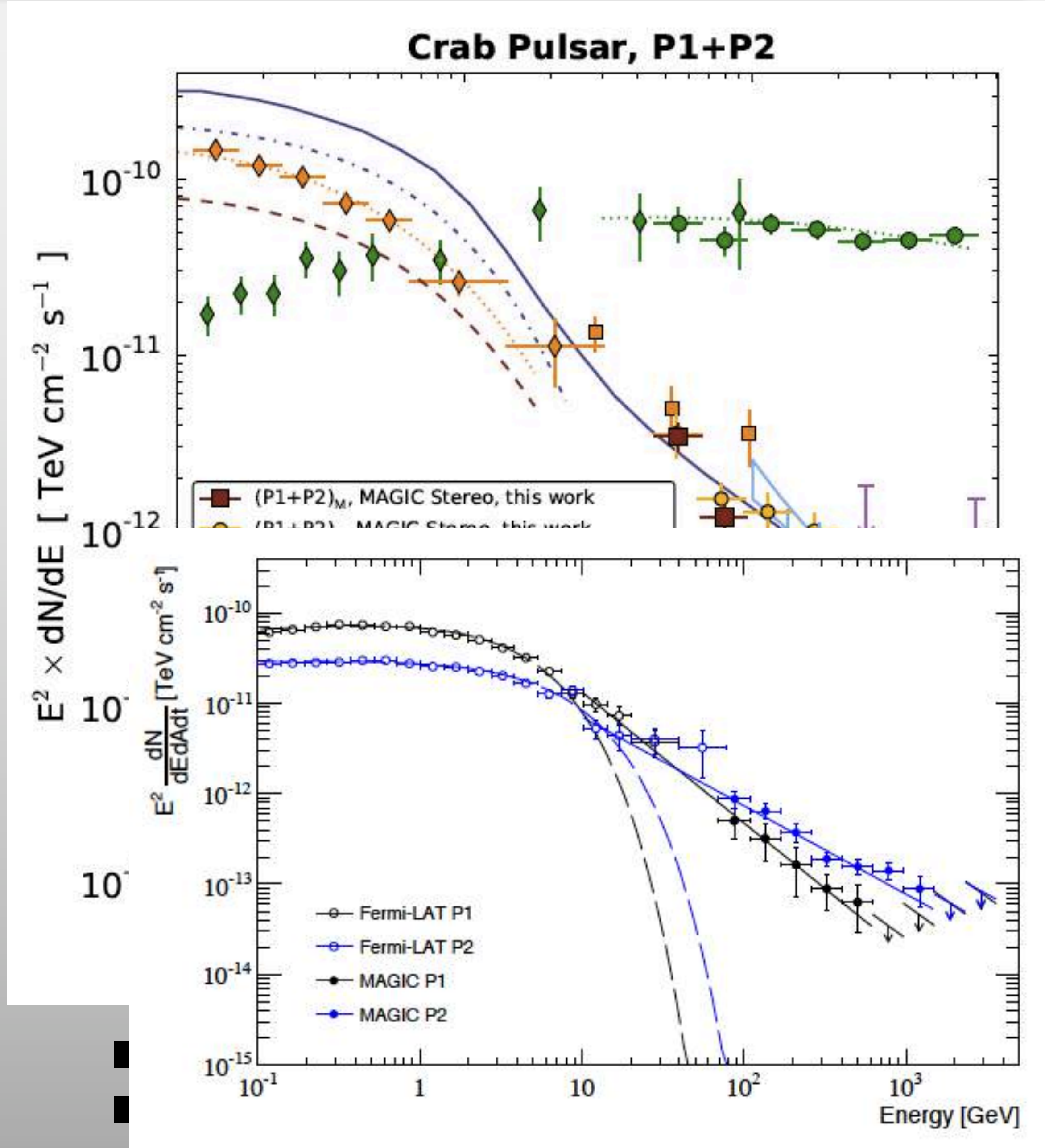




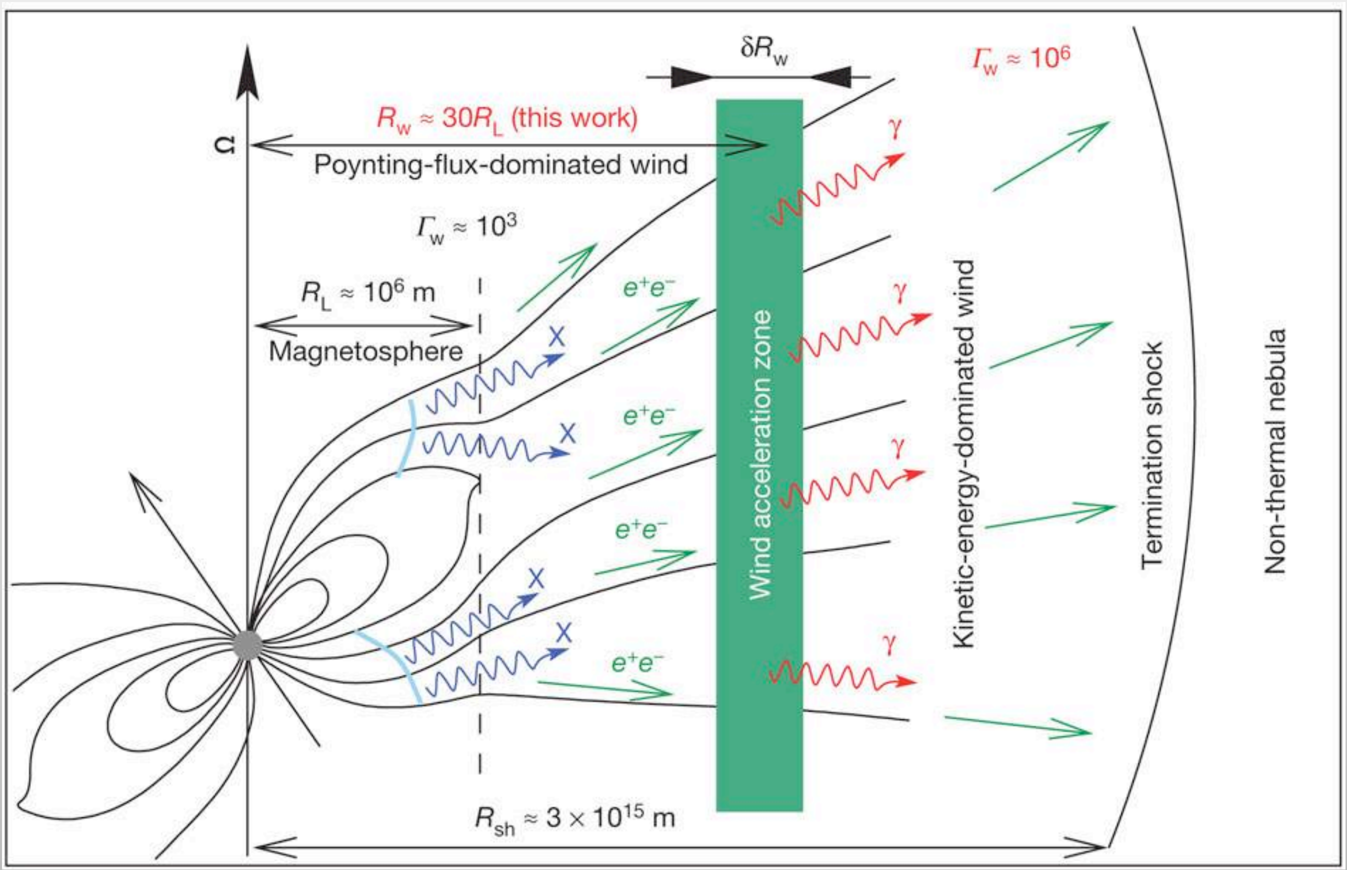
Crab Pulsar with MAGIC Stereo

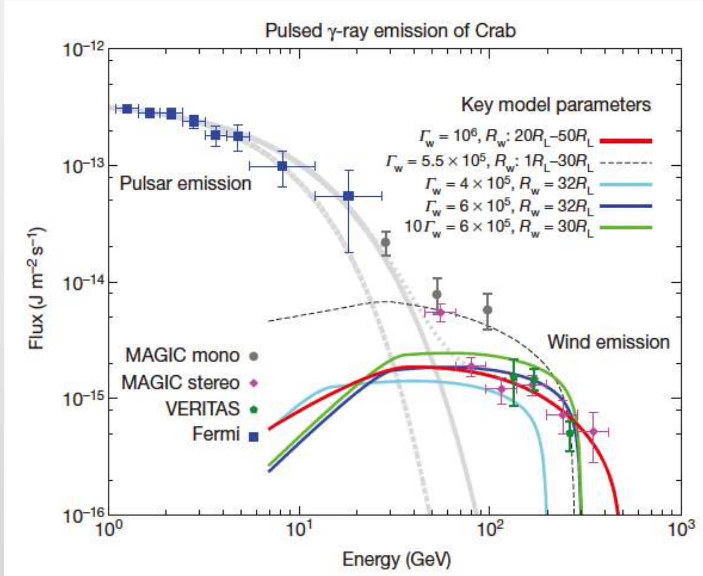


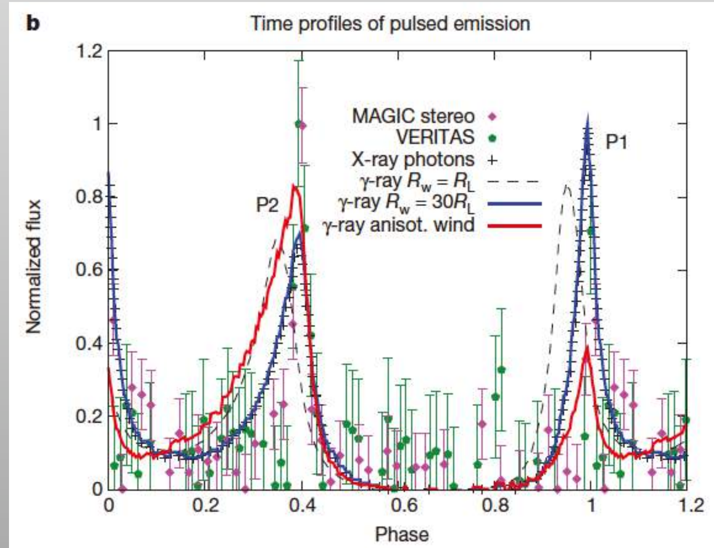




Abrupt acceleration with ultra relativistic cold wind, Aharonial et al. 2012 Nature





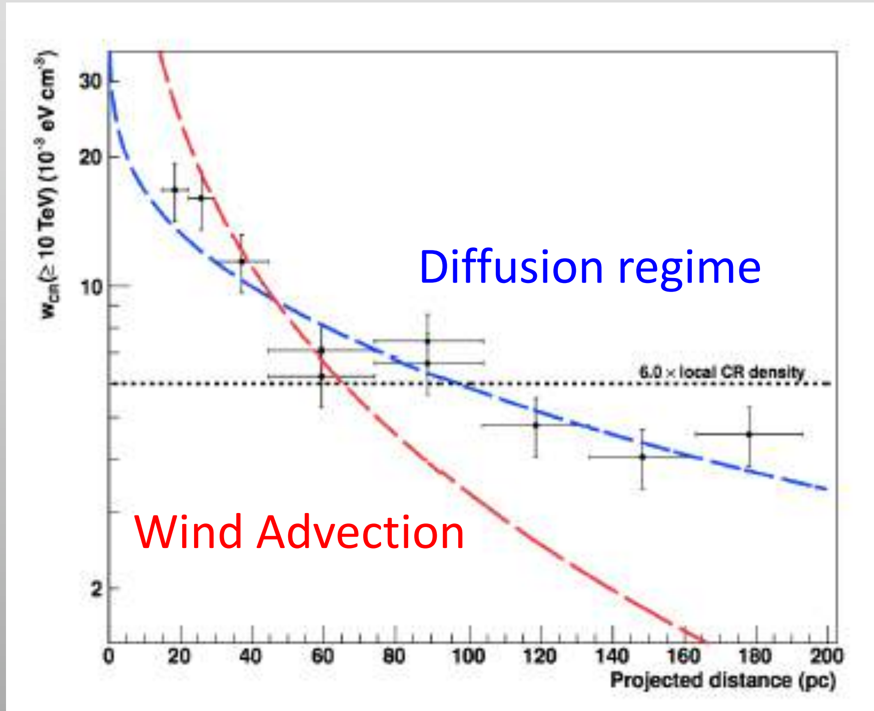


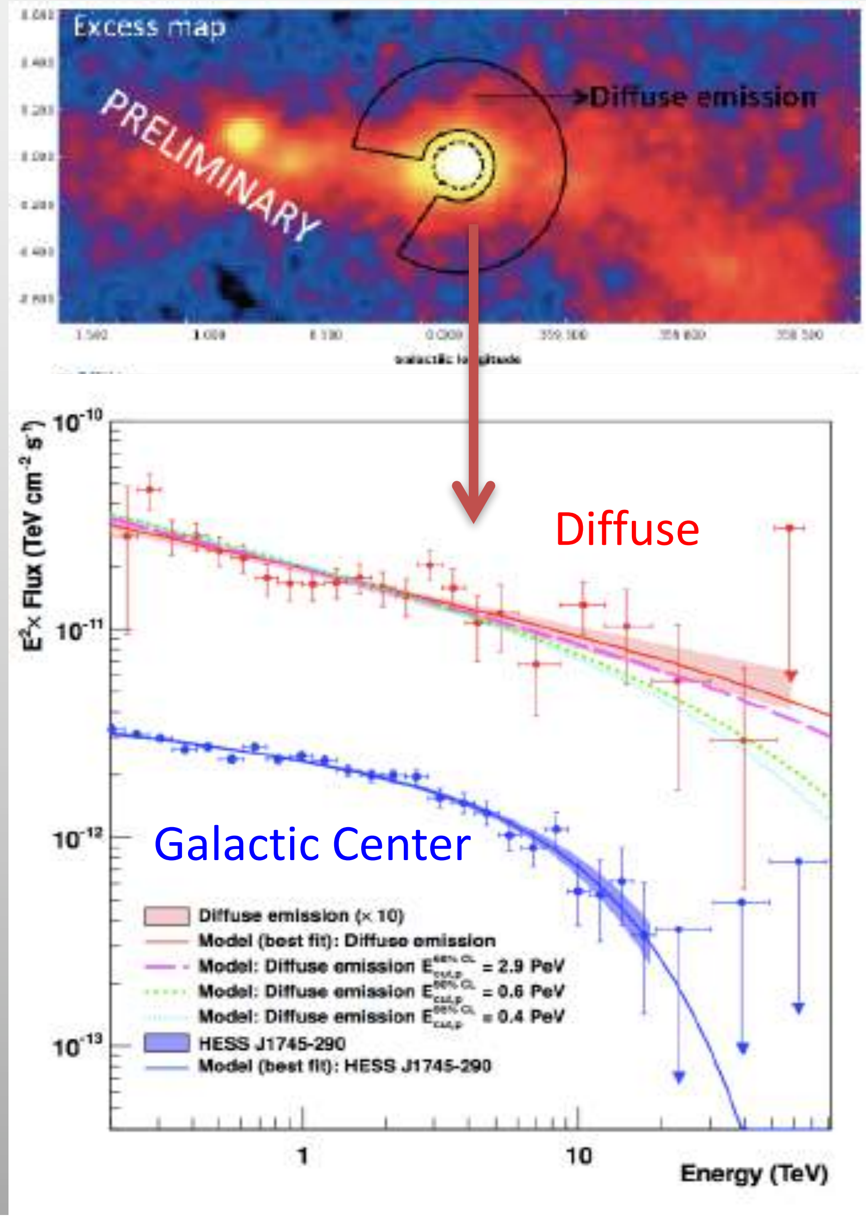
Galactic Center Diffuse with HESS PeVATRON?

HESS Deep Observation of 250hrs

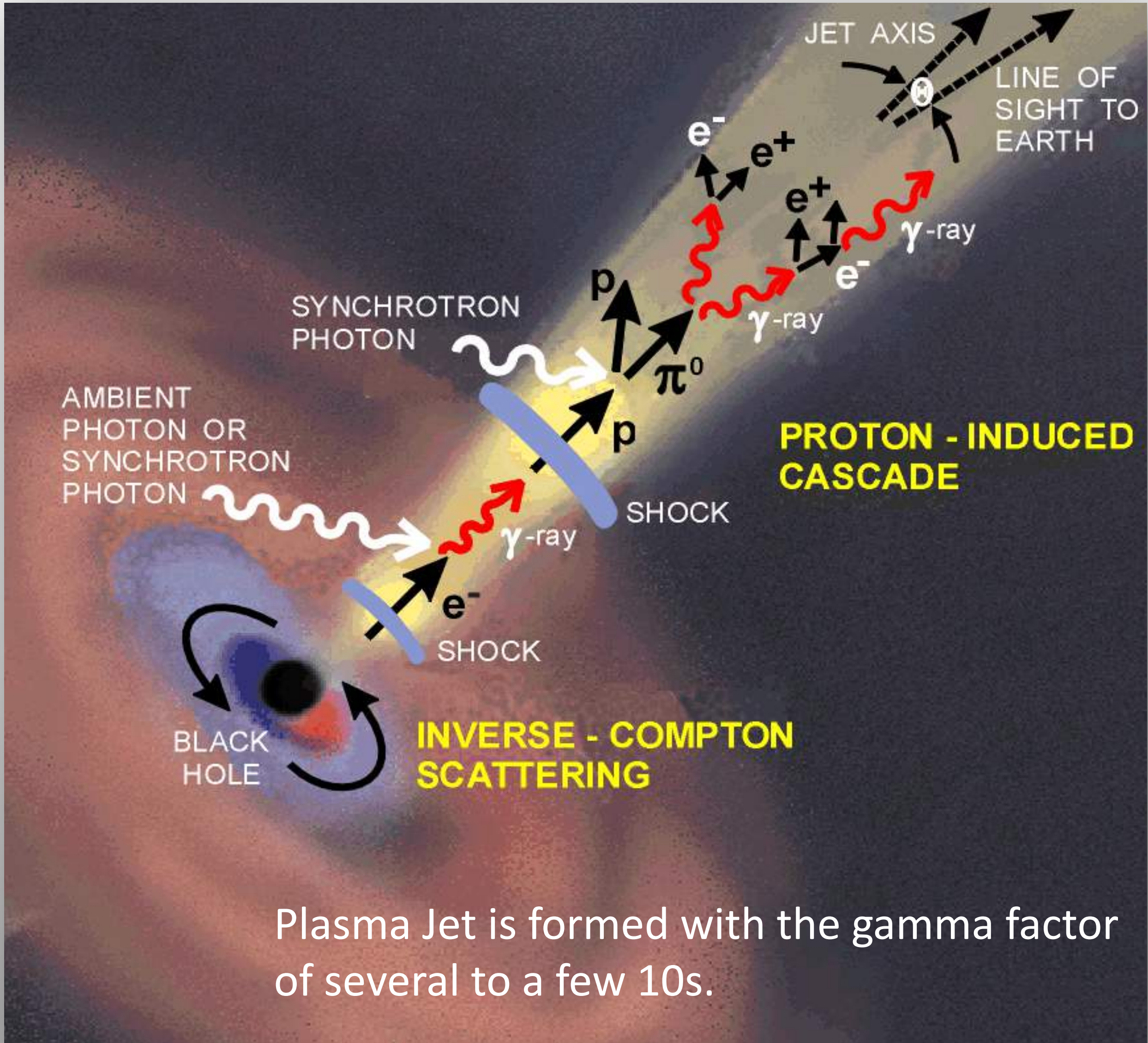
Spectrum:
Parent proton could be 1PeV ➔ PeVATRON?

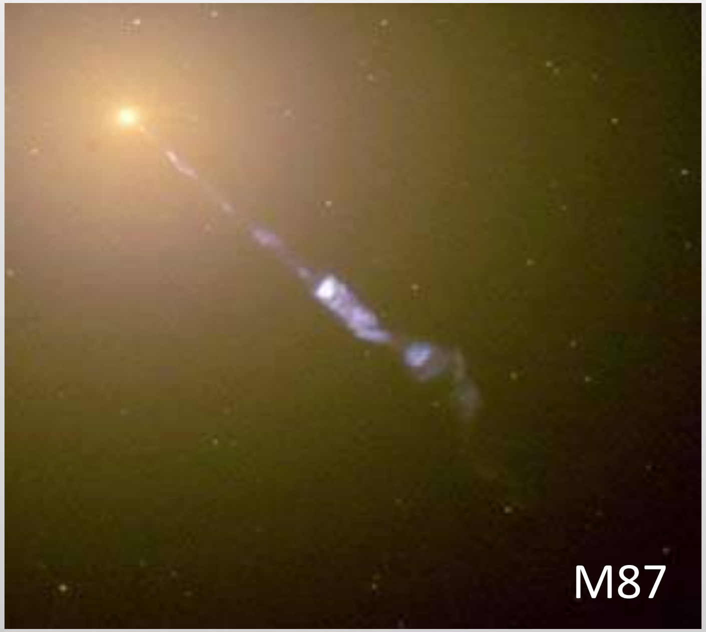
Radial distribution 1/r:
Consistent with the diffusion from the central BH

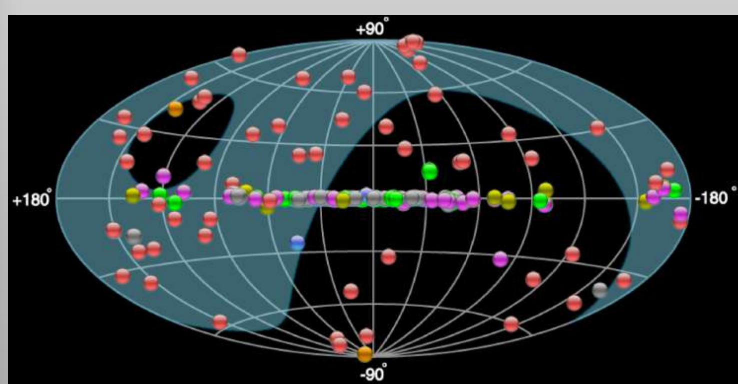




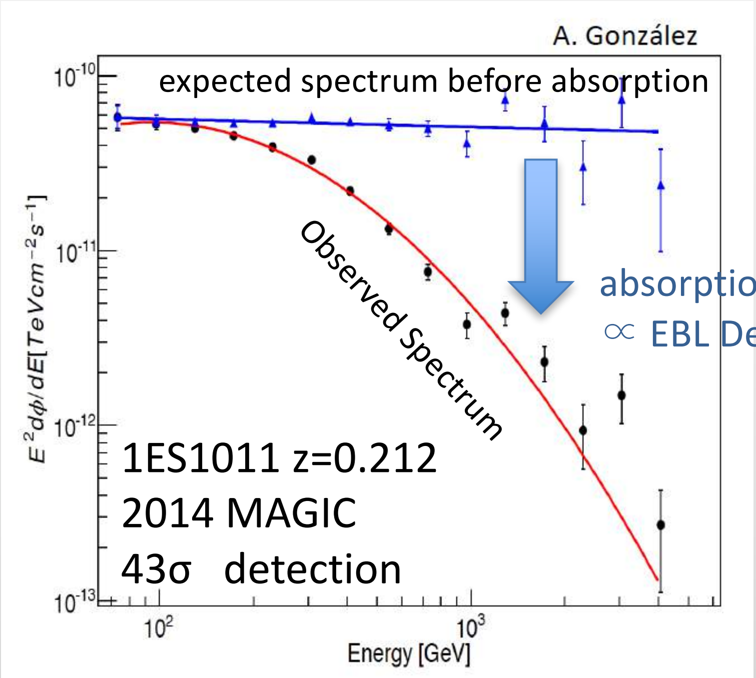
Supermassive Blackholes ~ $10^8 M_{\odot}$
Particle accelerators

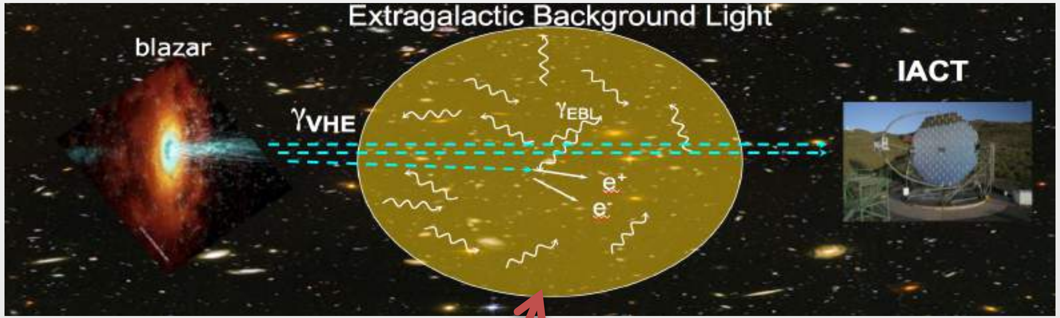


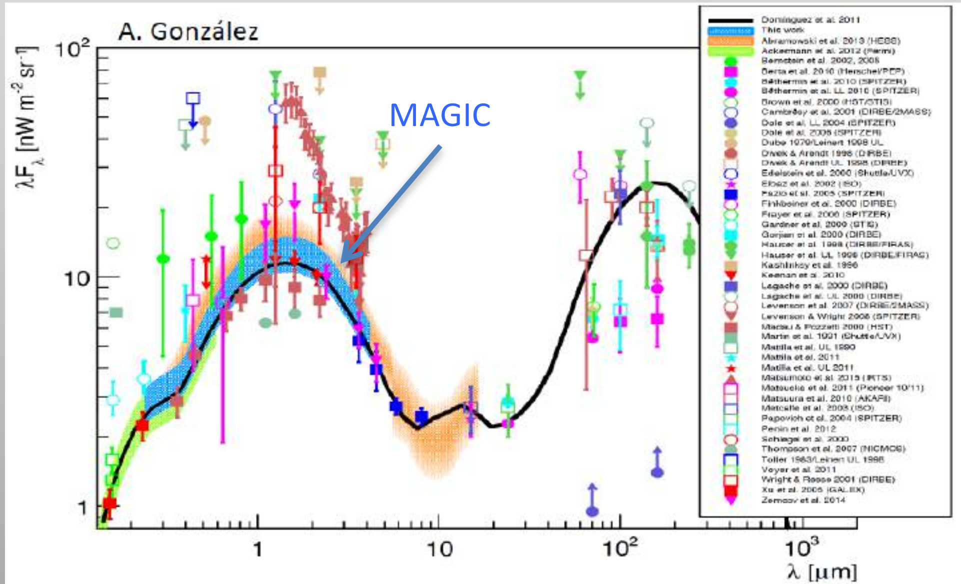




Study of Extragalactic Background Light 1ES1011 observed with MAGIC in 2014







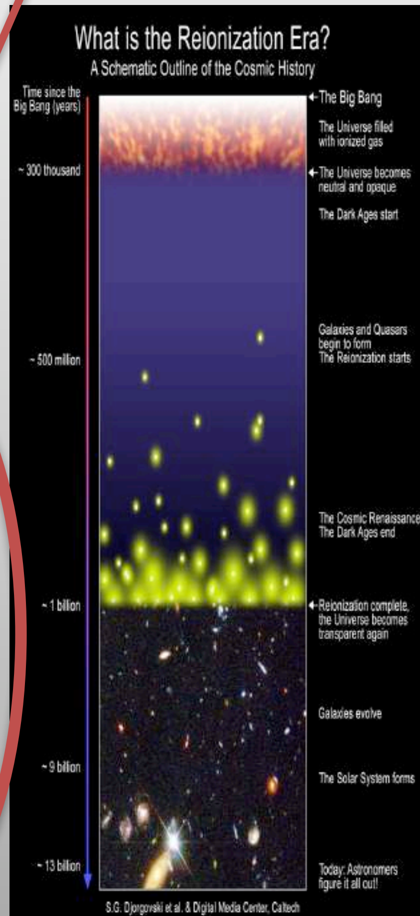
z ~ 1000, WMAP

z = 15~30, First star Pop-III

z = 6~15, Reionization

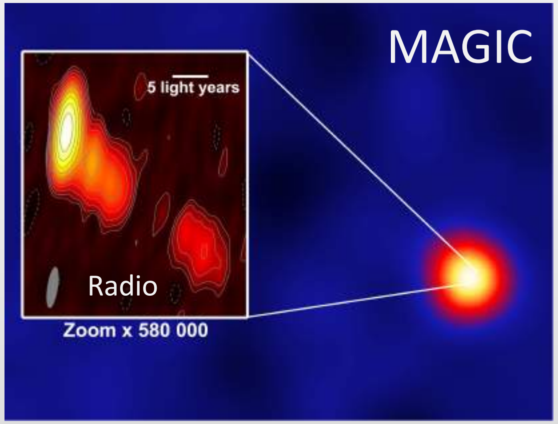
z = 3, Galaxies

z = 0, Present



IC310 Radio Galaxy / Blazar

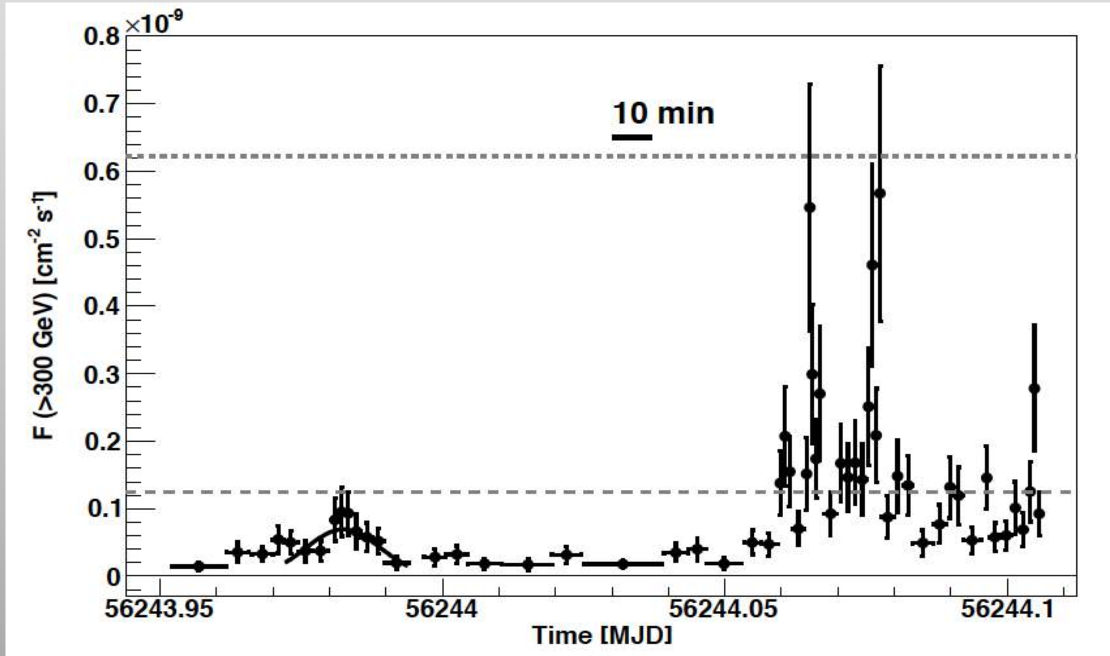
MAGIC Observation published in Science



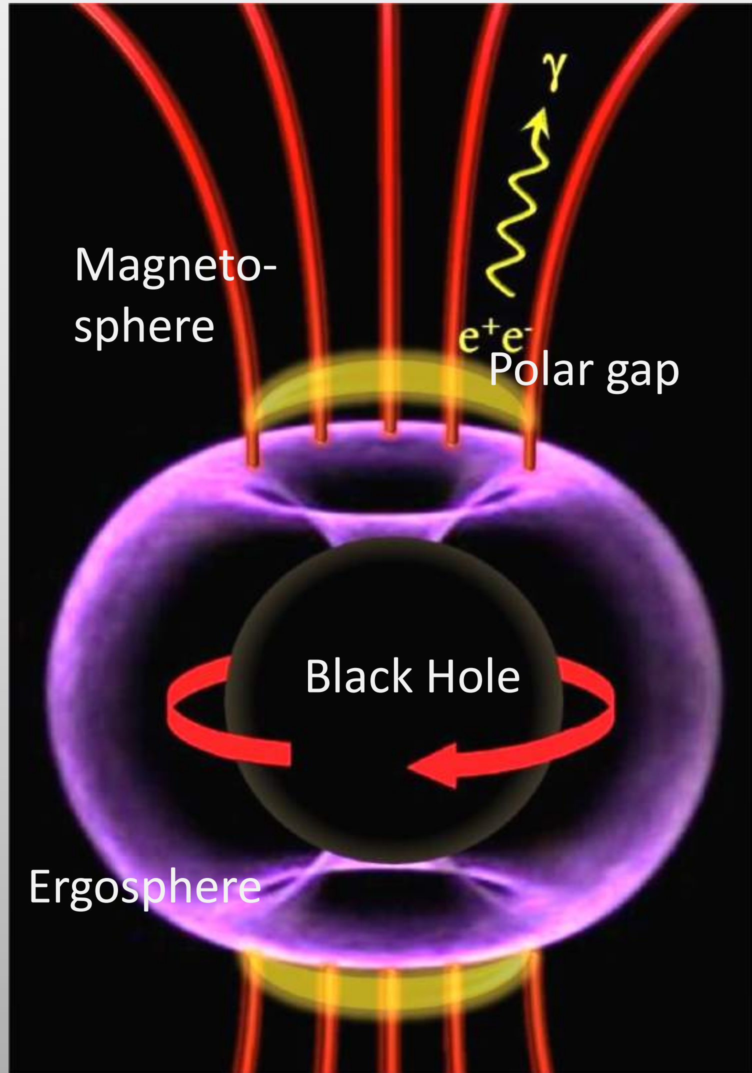
- Nov.12 2012 MAGIC obs.
- Flare ~ 100 x Low State
- Time variation ~ 1 min

- B.H. mass 3 x $10^8 M_\odot$
  - Crossing Time ~ 25mins
  - Γ-factor of jet ~ 5

IC310 Light curve



Possible Model



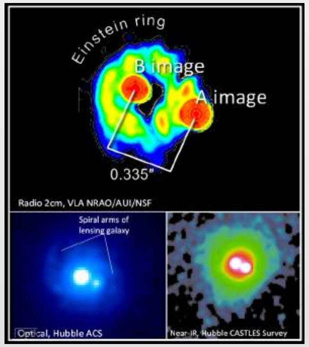
Discovery of Very High Energy Gamma-Ray Emission From Gravitationally Lensed Blazar S3 0218+357 With the MAGIC Telescopes

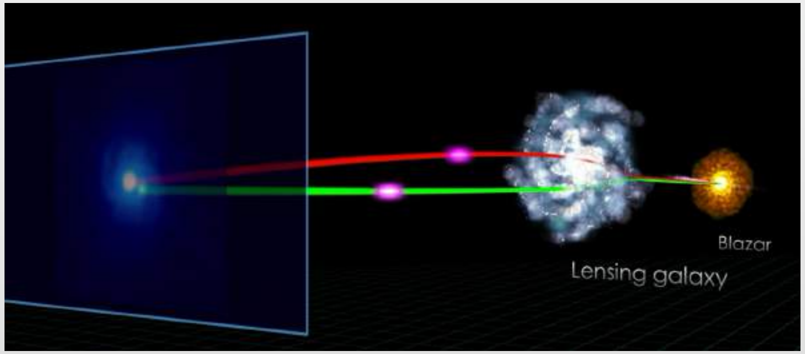
ATel #6349; ***Razmik Mirzoyan (Max-Planck-Institute for Physics) On Behalf of the MAGIC Collaboration***

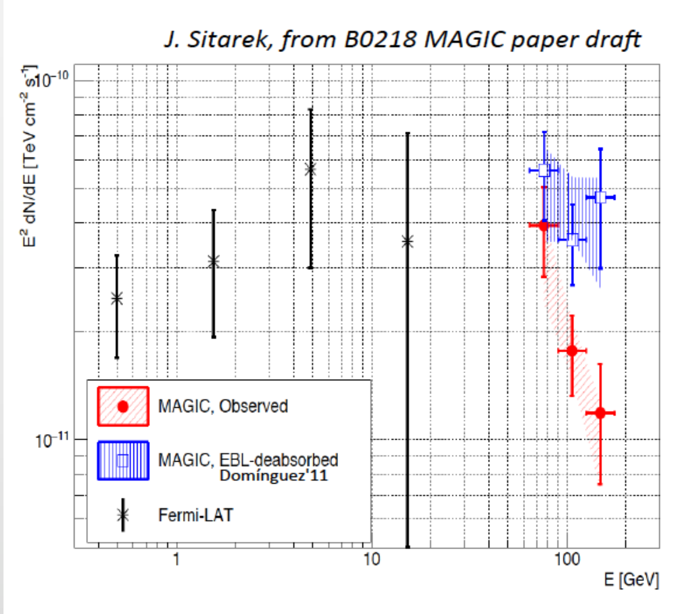
on 28 Jul 2014; 14:20 UT

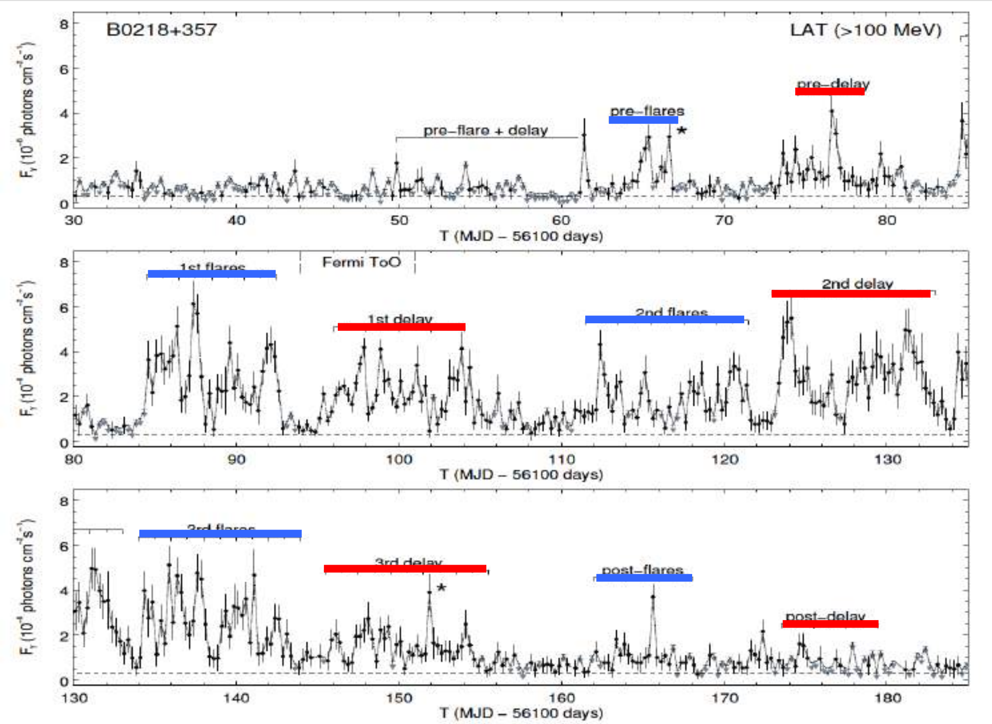
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

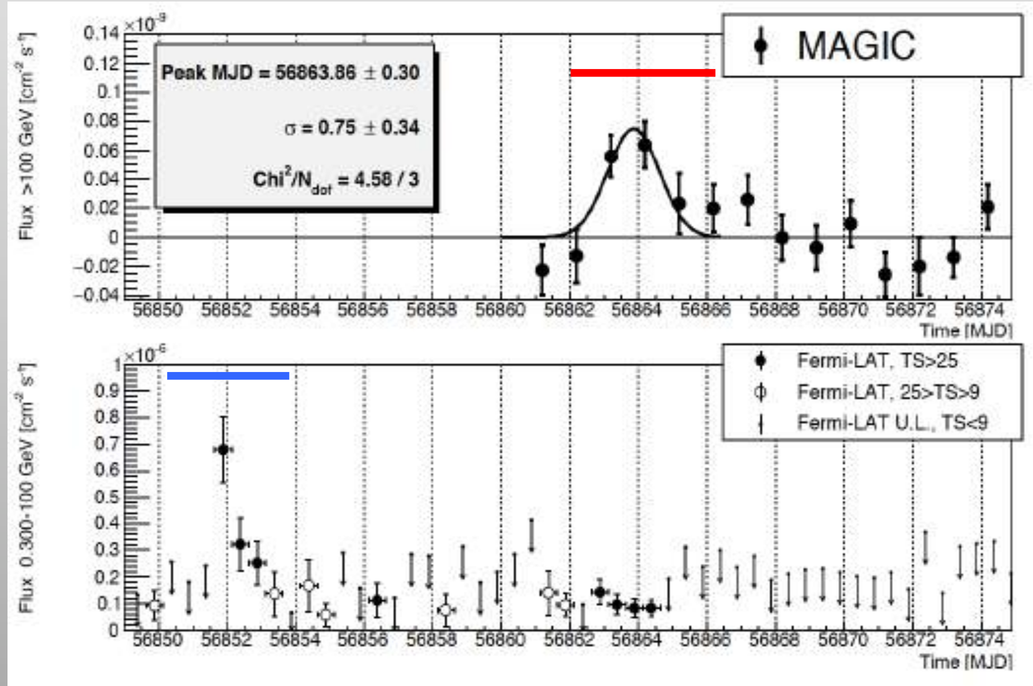
FSRQ S3 0218+357 z =0.944





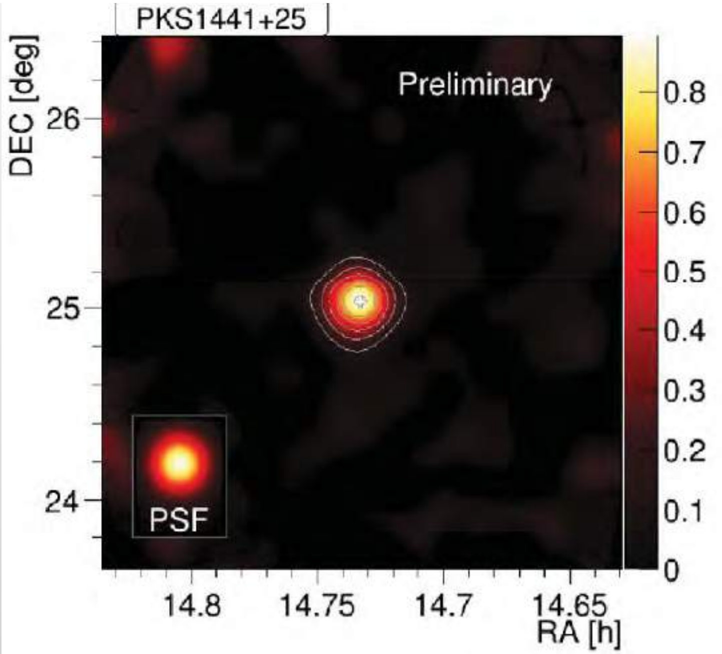




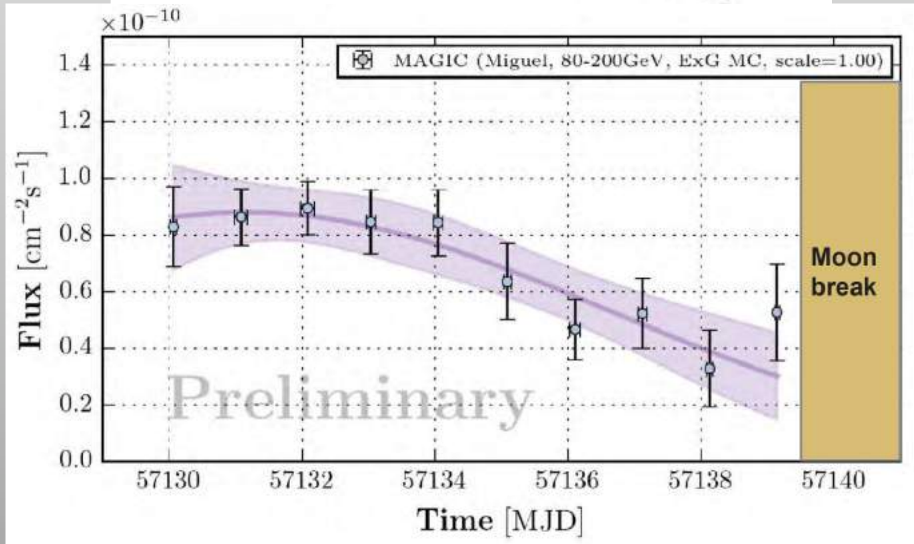


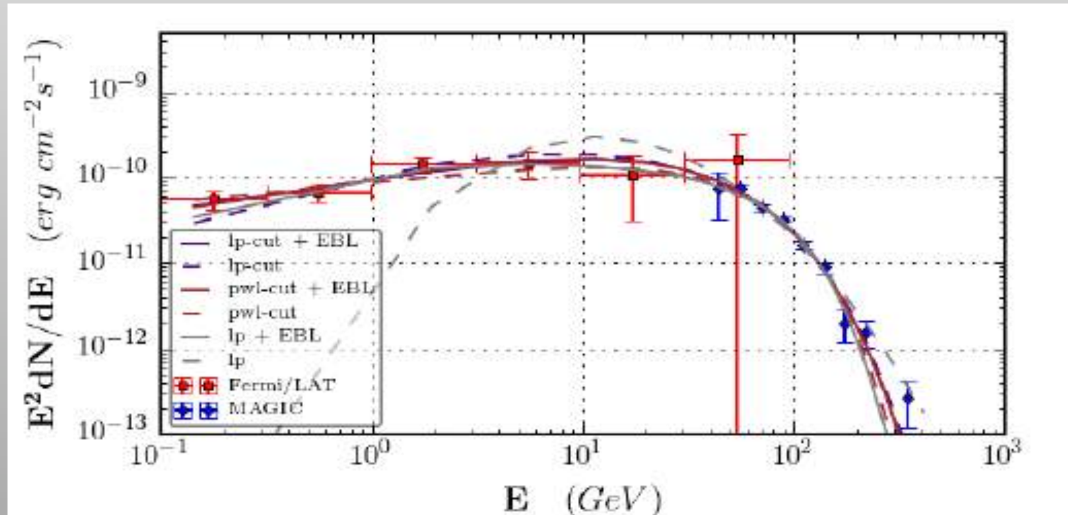
Discovery of Very High Energy Gamma-Ray Emission from the distant FSRQ PKS 1441+25 with the MAGIC telescopes

ATel #7416; *R. Mirzoyan (Max-Planck-Institute for Physics)*
on 20 Apr 2015; 02:09 UT
Credential Certification: Masahiro Teshima (mteshima@mppmu.mpg.de)



- PKS1441+25
  - Flat Spectrum Radio Quasar
  - **z = 0.939**
- MAGIC detection Significance ～25 σ



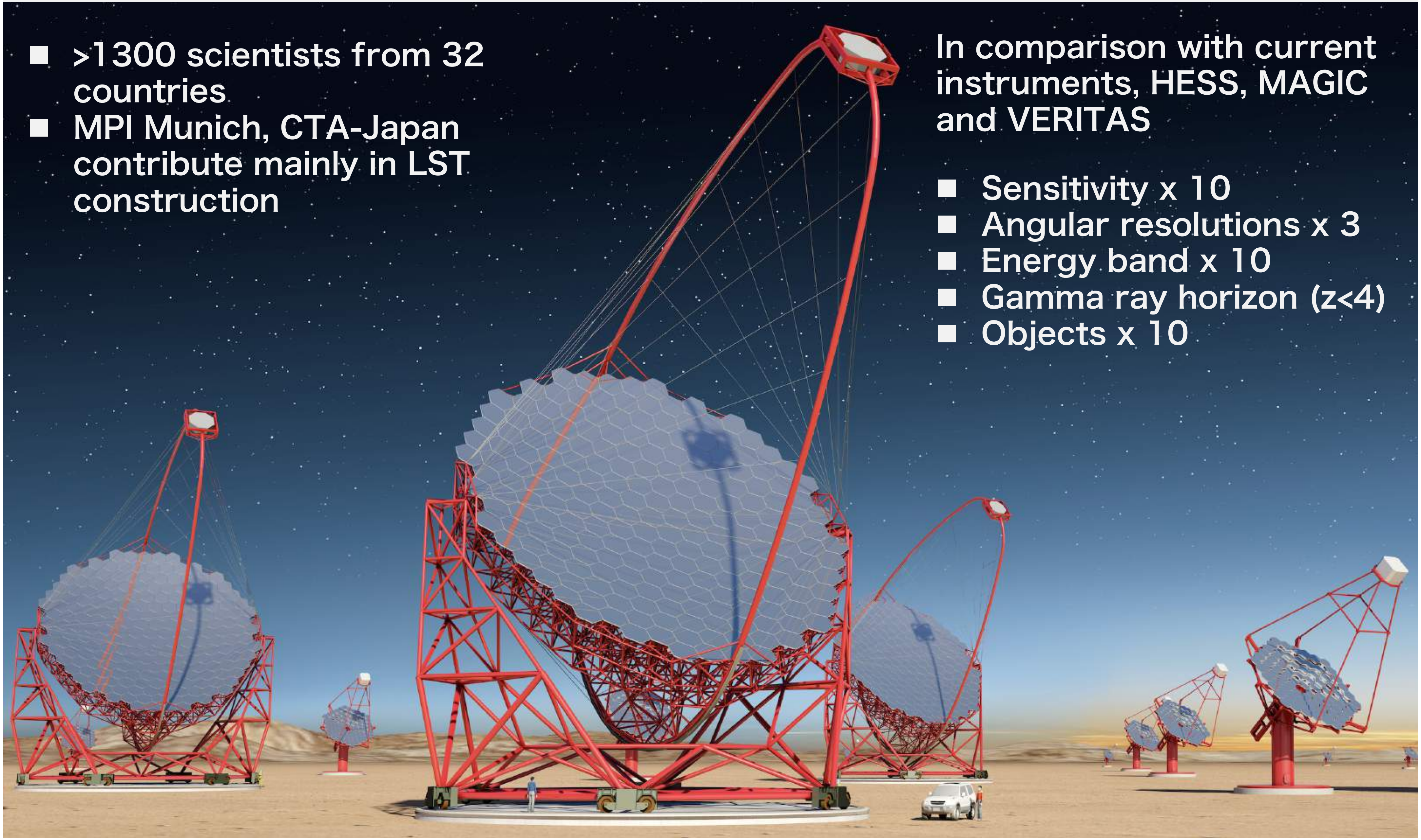


CTA: Big International Project

- >1300 scientists from 32 countries
- MPI Munich, CTA-Japan contribute mainly in LST construction

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

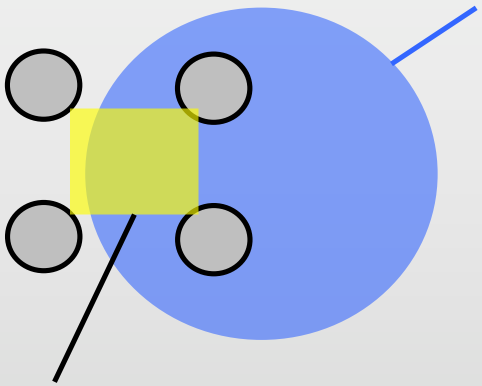


Two CTA Sites in South and North decided July 2015

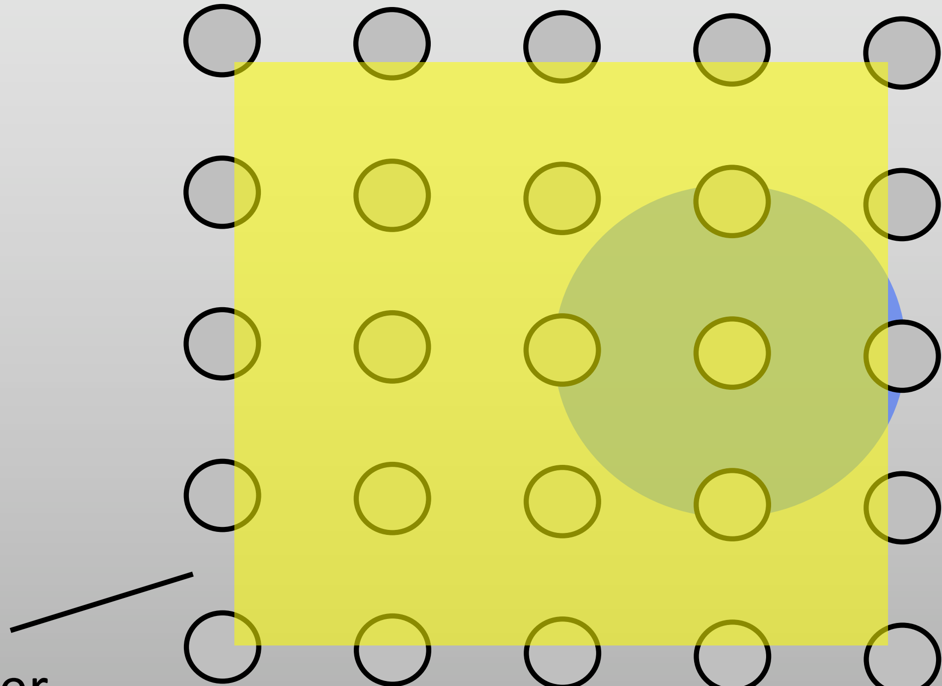
NEWS: 19 Sept 2016
IAC-CTA agreement signed

From current arrays to CTA

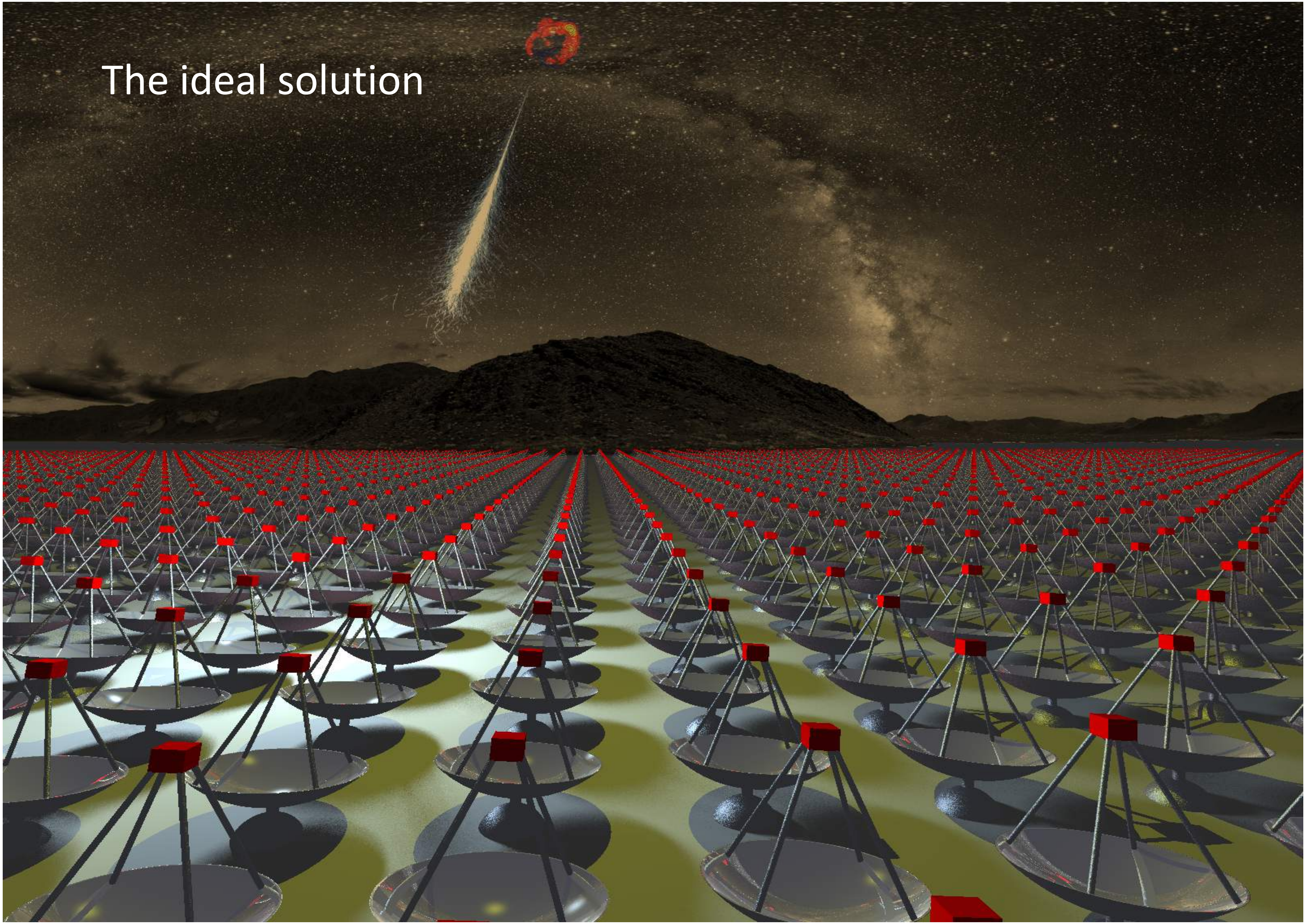
light pool radius
R ≈100-150 m
≈ typical telescope spacing

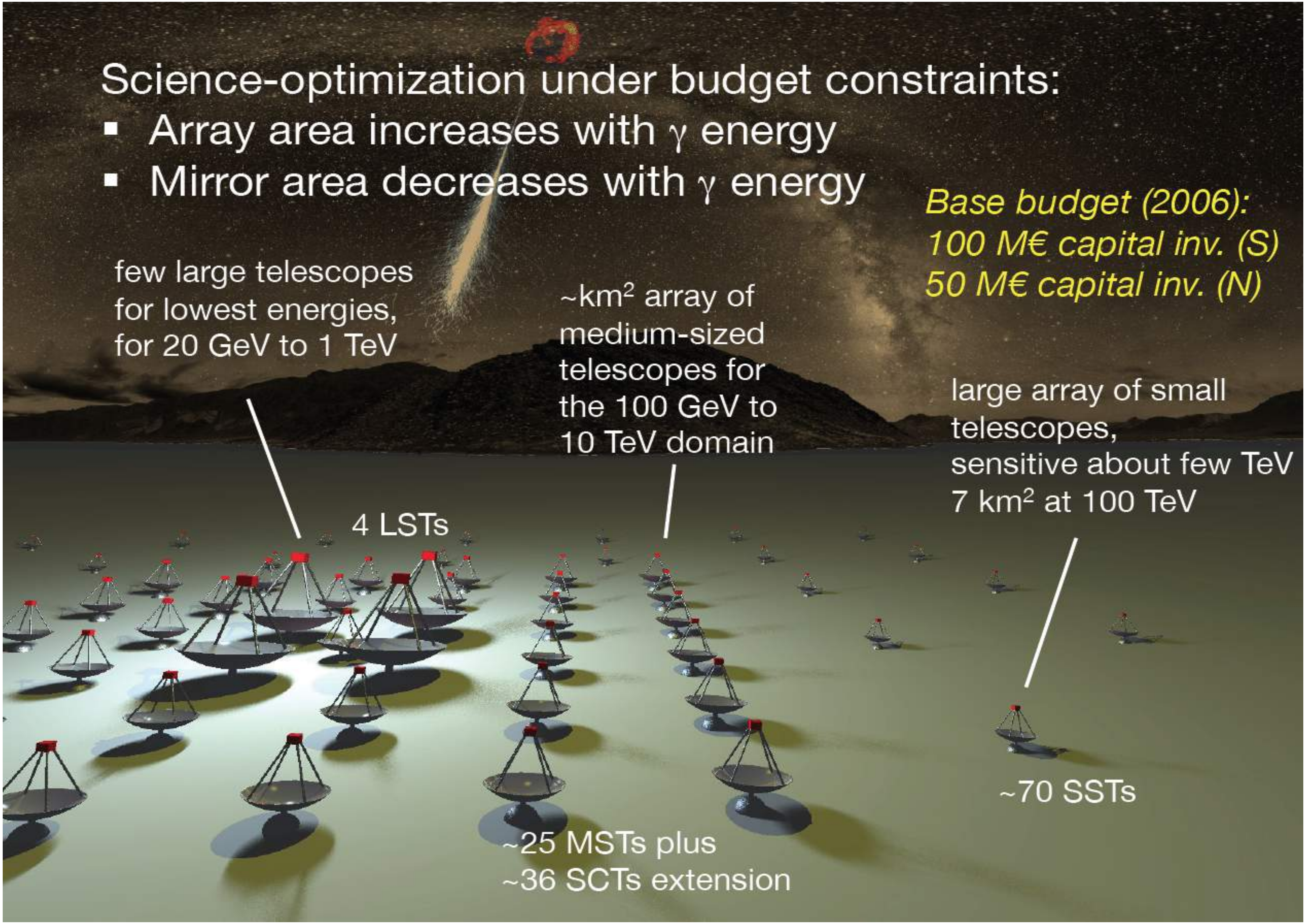


Sweet spot for
best triggering
and reconstruction:
most showers miss it!



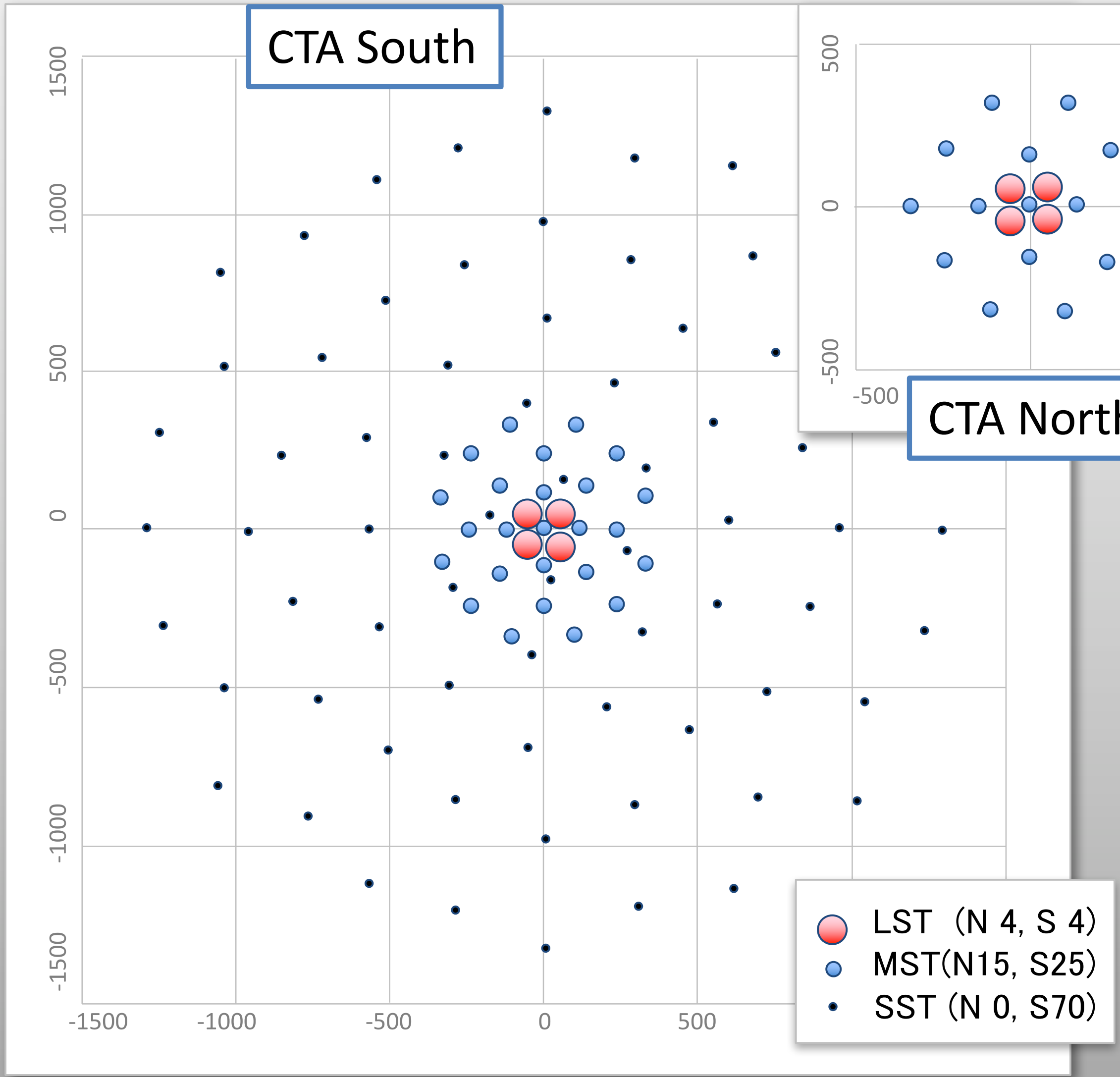
large detection area
more images per shower
lower trigger threshold

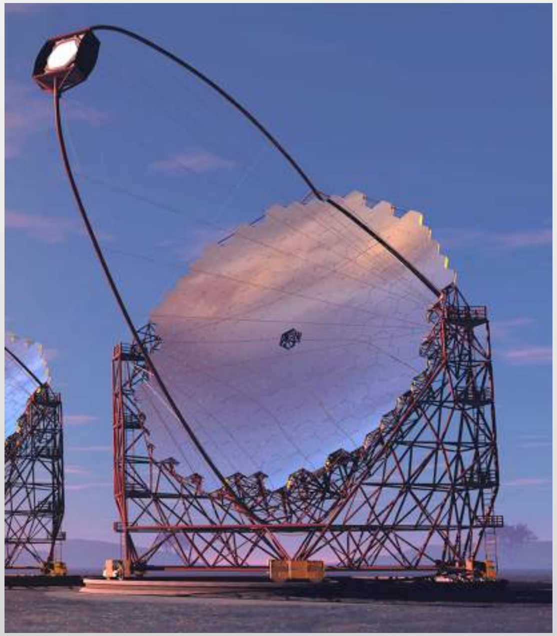

The ideal solution


Science-optimization under budget constraints:
▪ Array area increases with γ energy
▪ Mirror area decreases with γ energy
Base budget (2006):
100 M€ capital inv. (S)
50 M€ capital inv. (N)
few large telescopes for lowest energies, for 20 GeV to 1 TeV
~km² array of medium-sized telescopes for the 100 GeV to 10 TeV domain
large array of small telescopes, sensitive about few TeV 7 km² at 100 TeV
4 LSTs
~70 SSTs
~25 MSTs plus
~36 SCTs extension

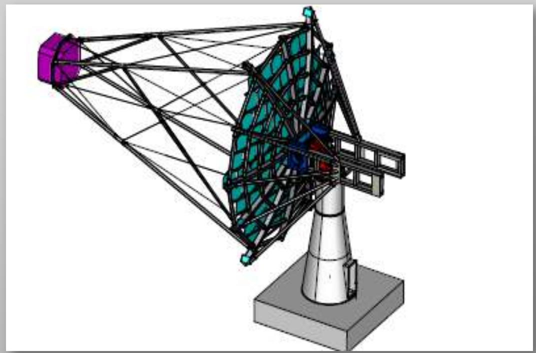
CTA Array Configuration
(Cherenkov Telescope Array)

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

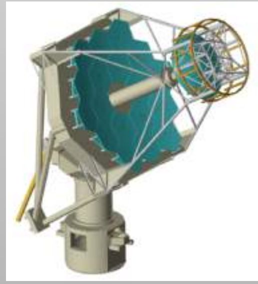




LST 23m



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^2
  - focal length 28 m
  - Weight 100 tons
  - CFRP mirror supp. structure
  - Fast rotation 180°/20sec
  - Tracking accuracy 14arcsec

MEDIUM-SIZED 12 M TELESCOPE

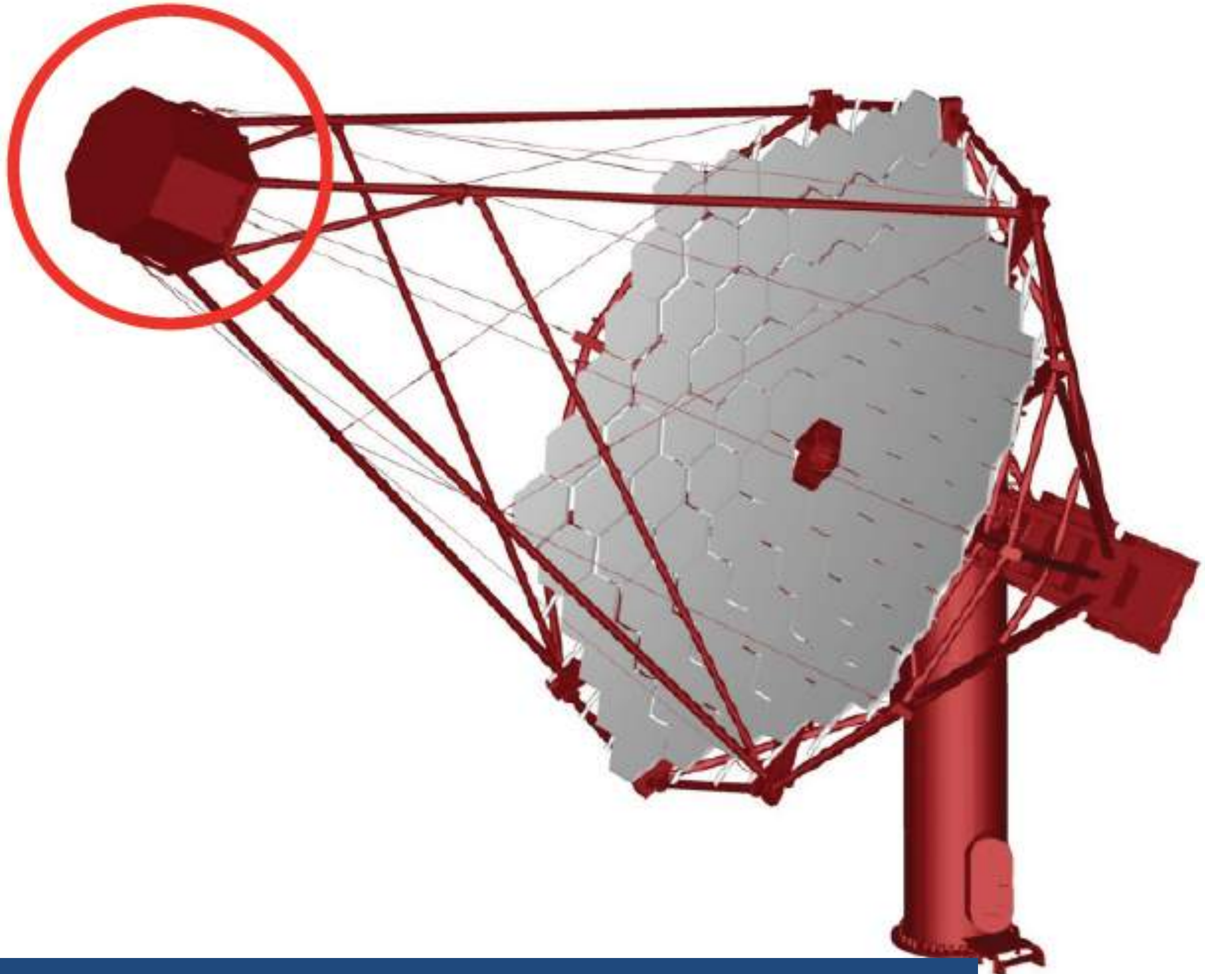
OPTIMIZED FOR THE 100 GEV TO ~10 TEV RANGE

100 m^2 dish area
16 m focal length
1.2 m mirror facets

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

25 MSTs on South site
15 MSTs on North site

➜ Stefan Schlenstedt

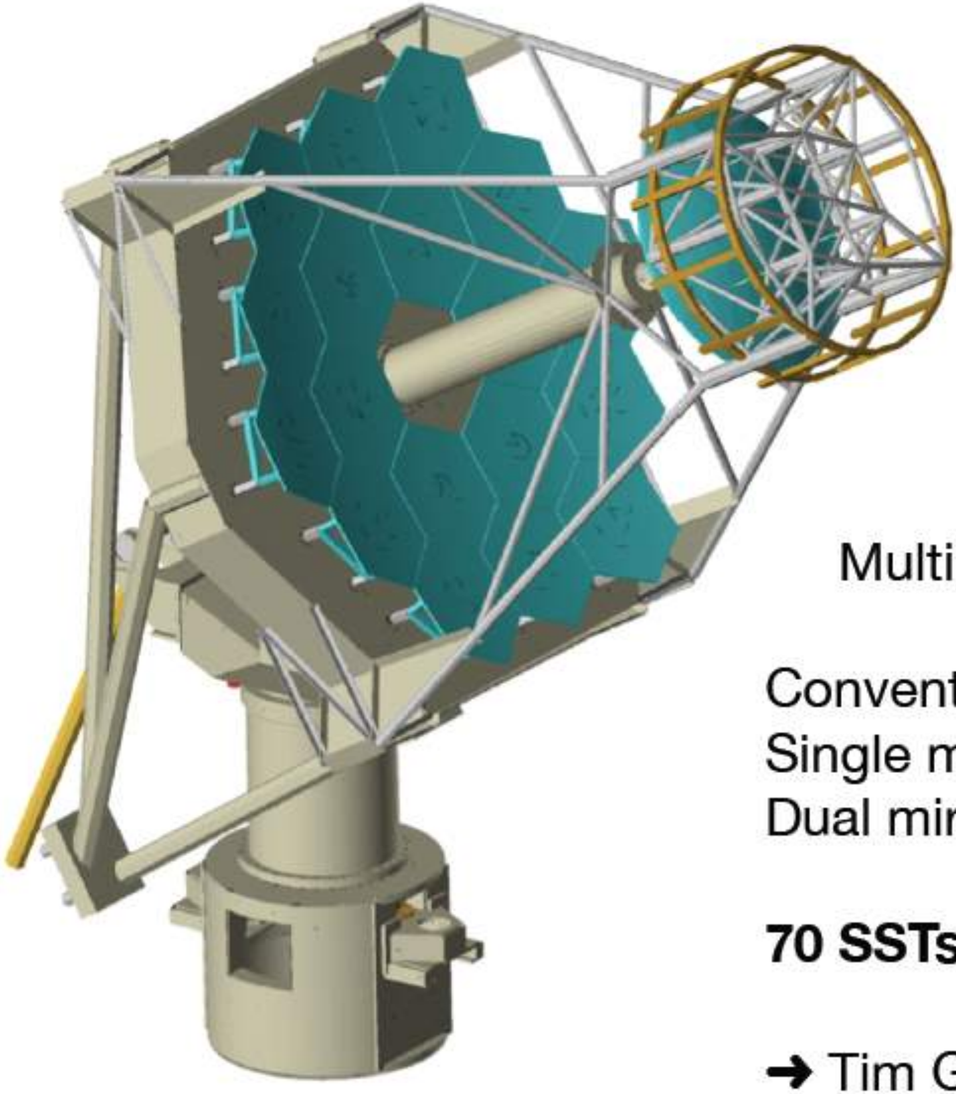


Achieve the best sensitivity of 1mCrab at 1TeV and survey our galaxy

SMALL TELESCOPE

OPTIMIZED FOR THE RANGE ABOVE 10 TEV

cta cherenkov telescope array



ASTRI Design
4.3 m mirror
9.6° foV
0.25° 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

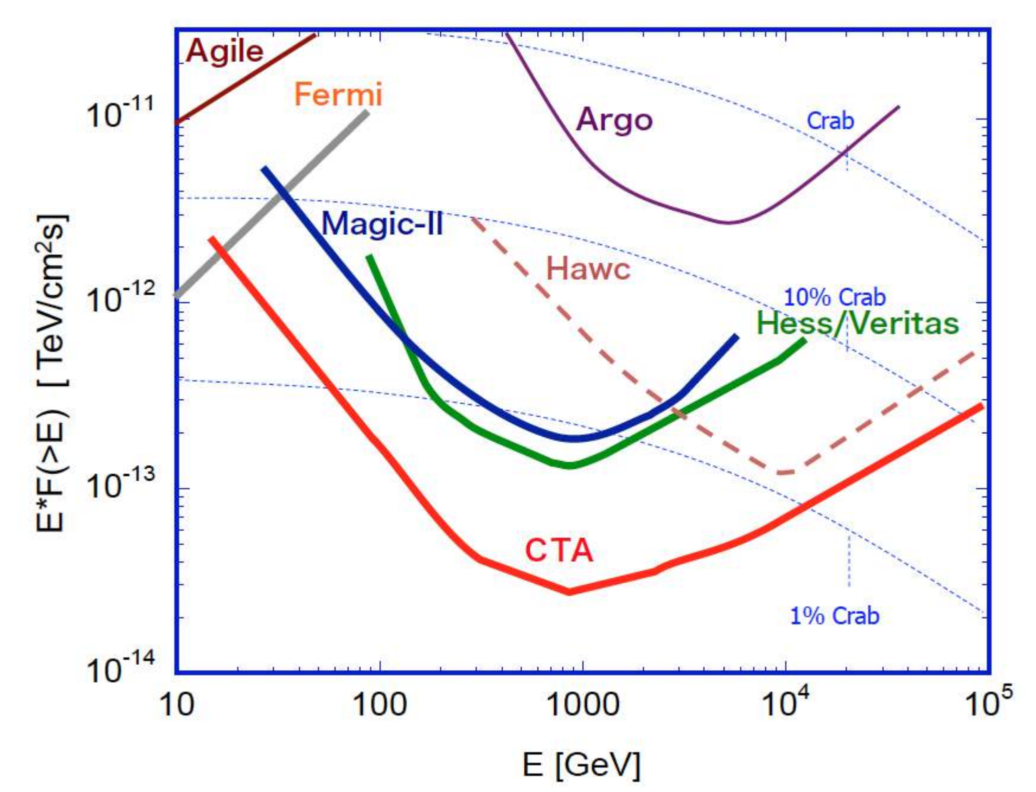
➜ Tim Greenshaw

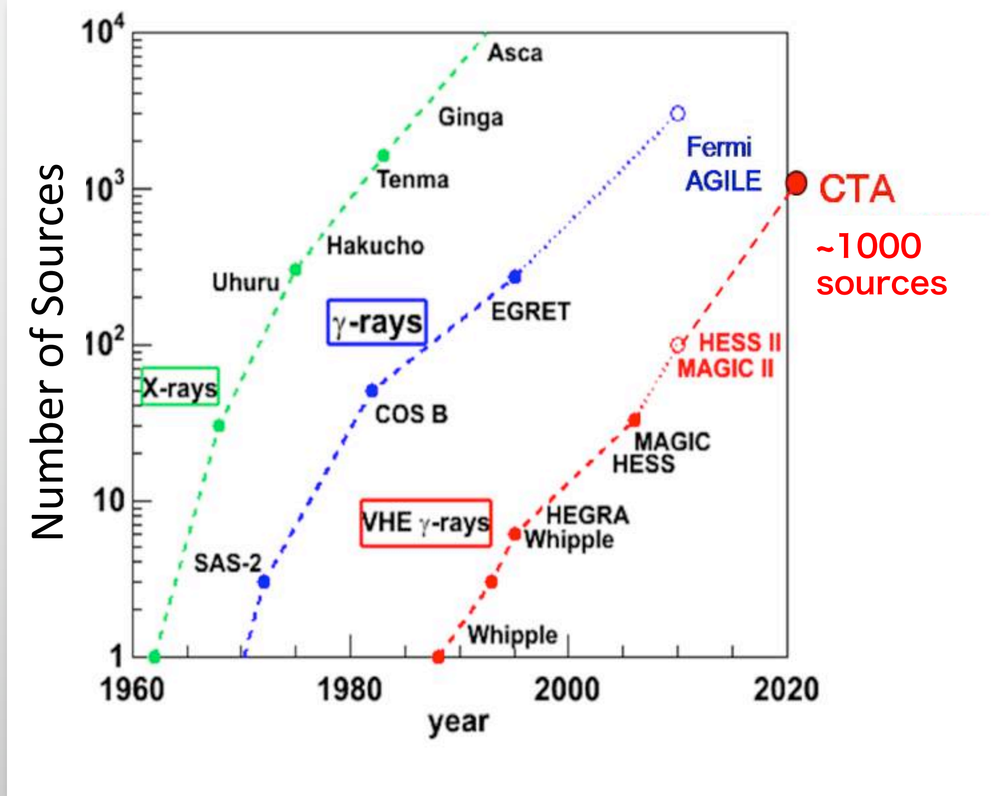
Look for PeVatron in our galaxy

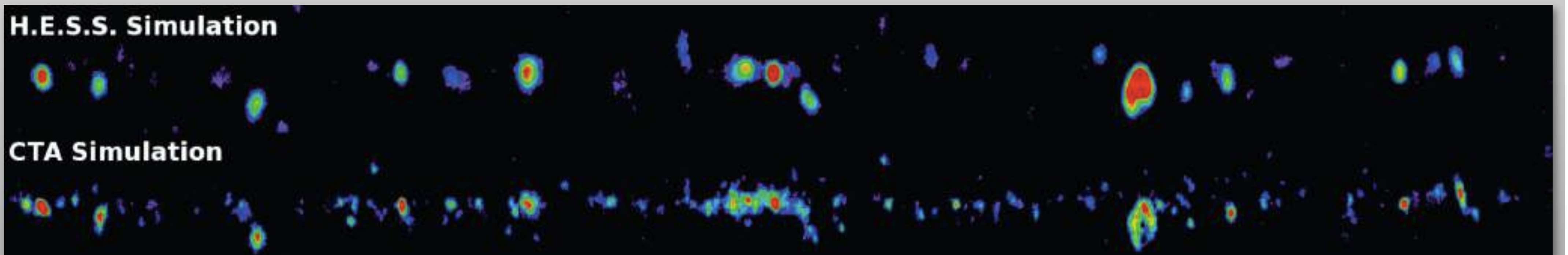
CTA（Cherenkov Telescope Array）covering 20GeV-100TeV

An order of magnitude better sensitivity
Wide energy coverage

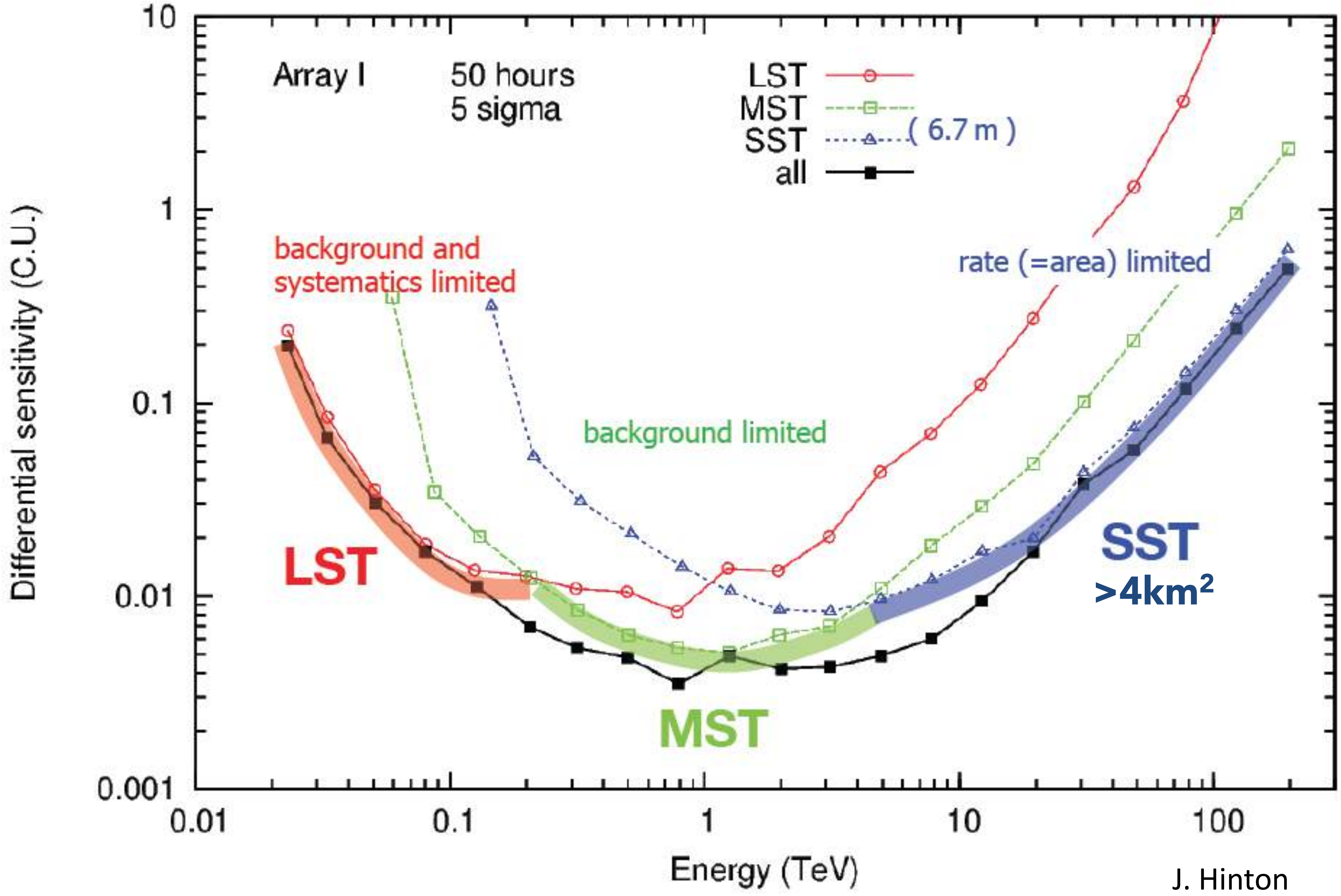
More than 1000 sources will be discovered

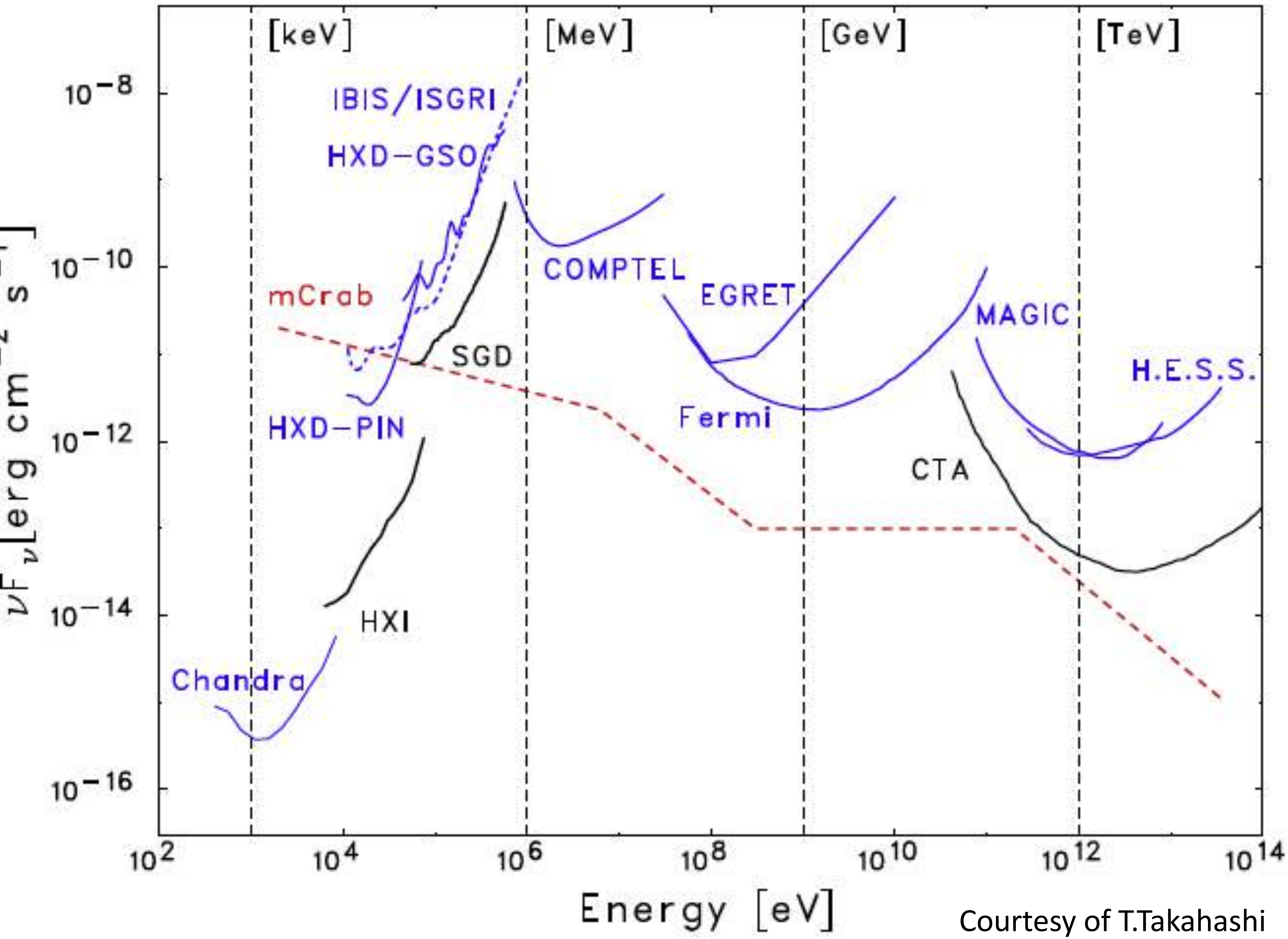






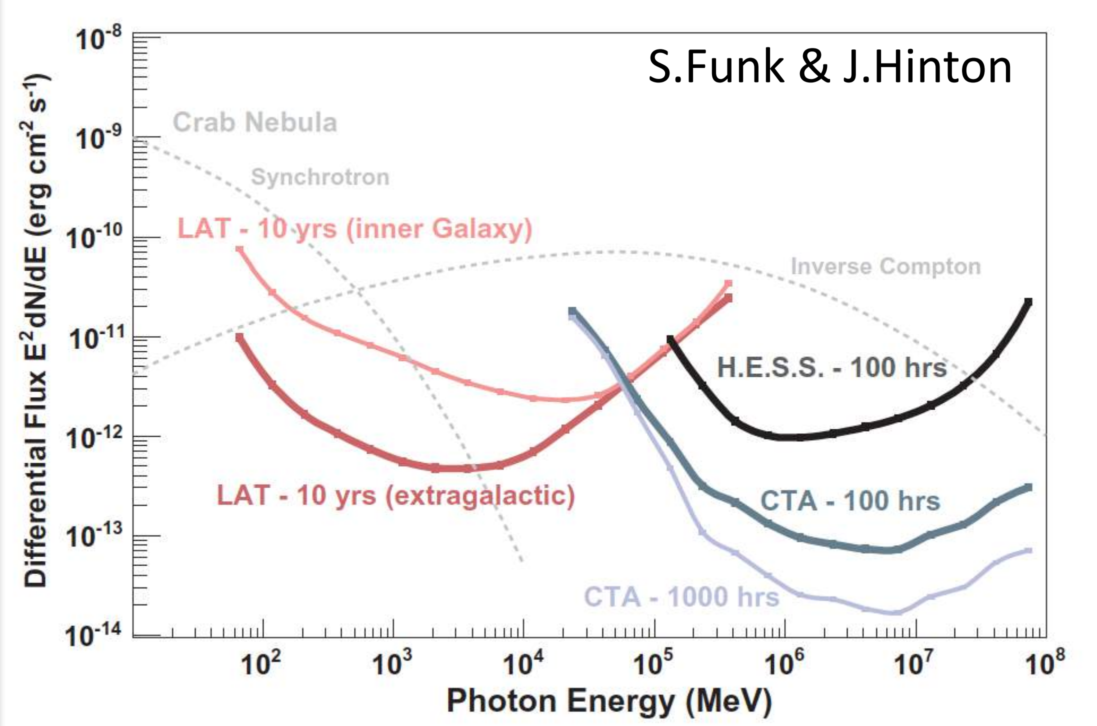
Simulation Galactic Plane scan（HESS and CTA）


Array I
50 hours
5 sigma
LST
MST
SST
all
(6.7 m)
background and
systematics limited
background limited
rate (=area) limited
LST
MST
SST
>4km²
Differential sensitivity (C.U.)
Energy (TeV)
10
1
0.1
0.01
0.001
0.01
0.1
1
10
100
J. Hinton



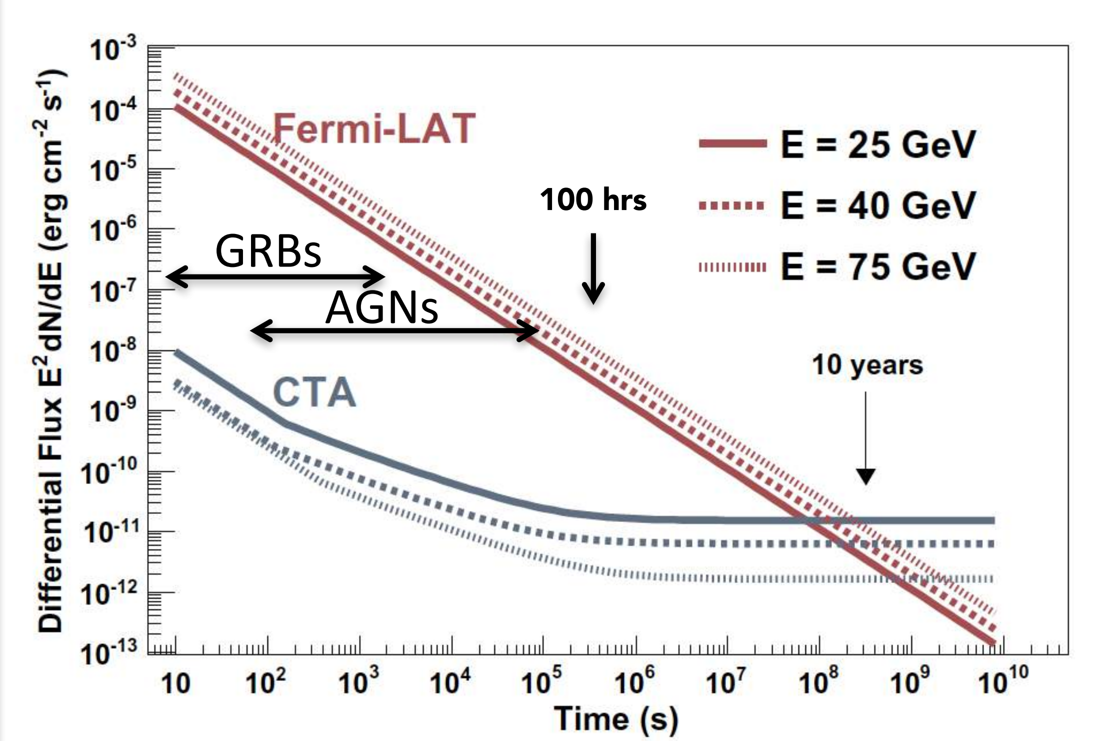
Courtesy of T.Takahashi

Comparison and Complementarity with Fermi



Cover 6 decades of Energy!!

After long observation, Crossing Energy is ~40GeV

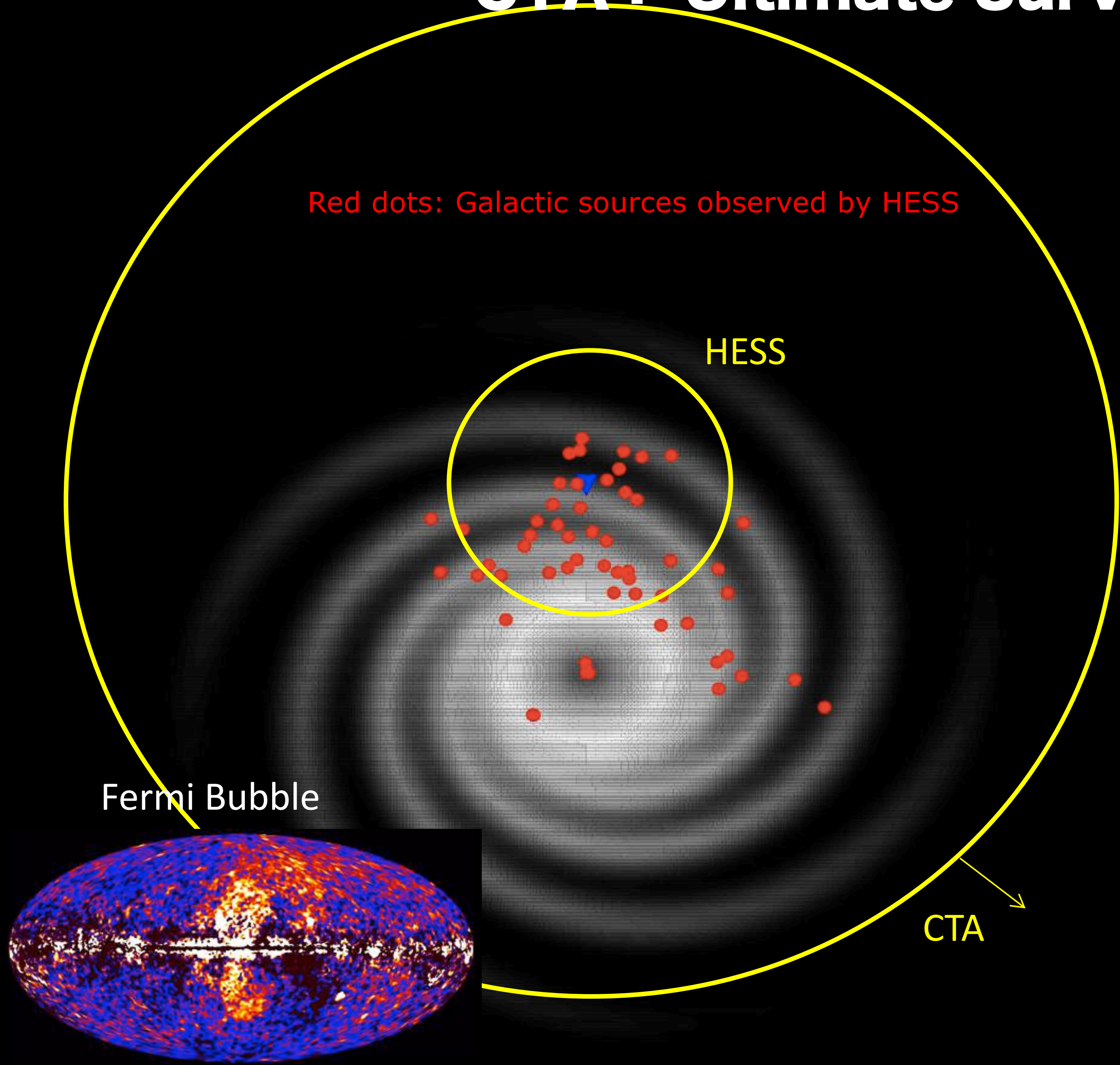


CTA-LSTs give a significant sensitivity for transient sources,

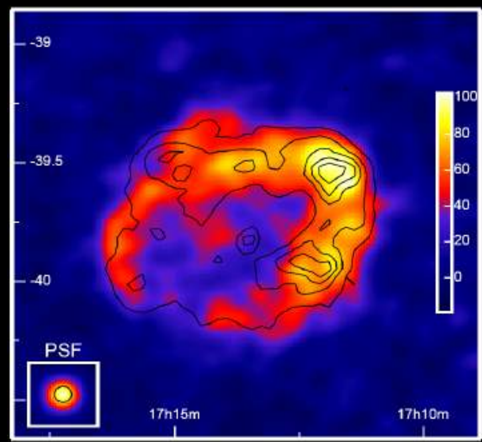
GRBs, AGNs, and Galactic Transients

CTA： Ultimate Survey instrument

- All sky survey with two stations in south and north



Supernova remnants



Simulation for RXJ1713

T.Nakamori et al.

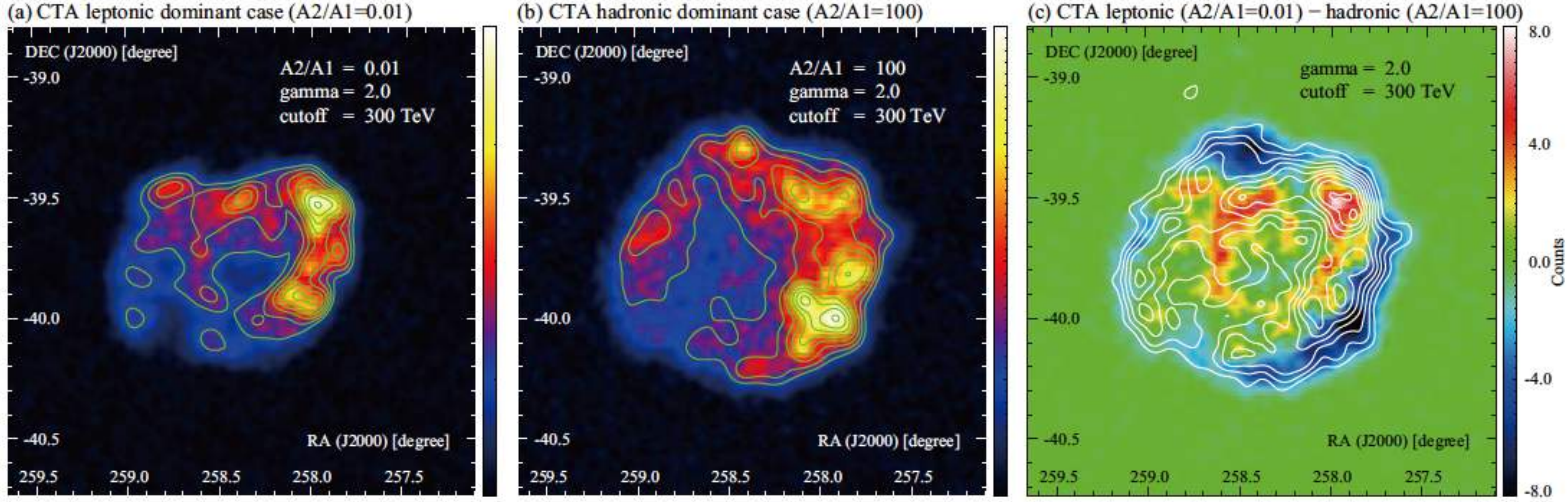
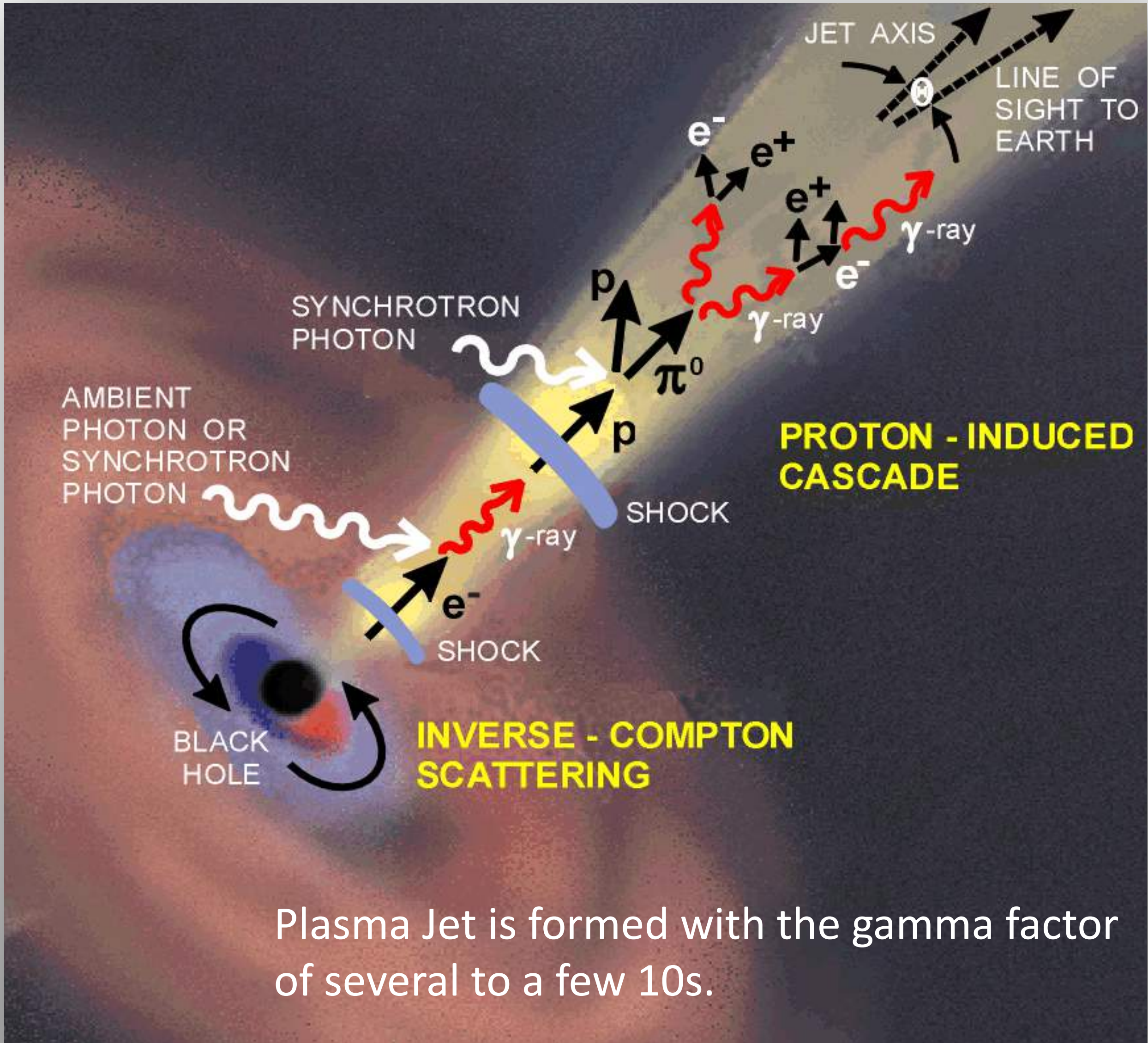
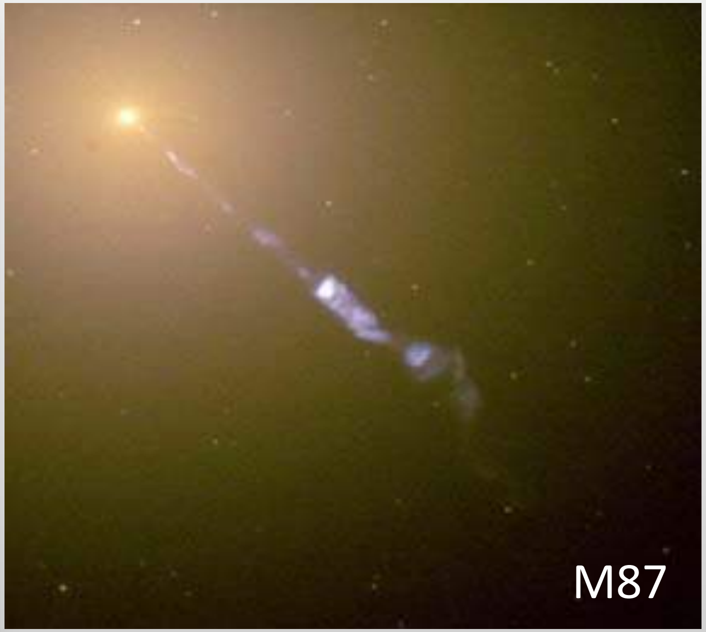


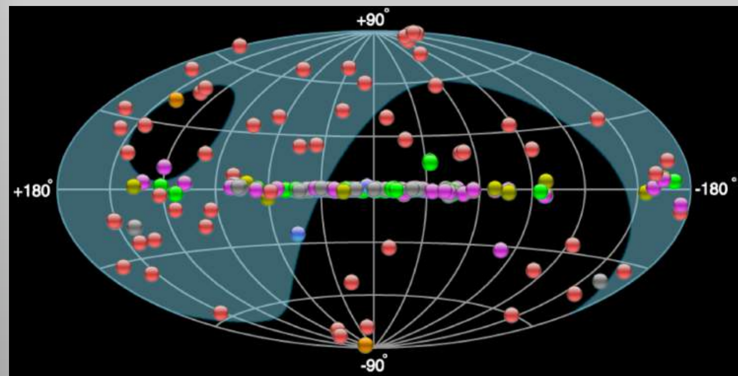
Fig. 1.— Simulated γ-ray images of (a) $A_2/A_1 = 0.01$ (leptonic dominant case) and (b) $A_2/A_1 = 100$ (hadronic dominant case) with $\Gamma_p = -2.0$ and $E_c^p = 300$ TeV. The green contours show (a) *XMM-Newton* X-ray intensity (e.g., Acero et al. 2009) and (b) total interstellar proton column density (Fukui et al. 2012), which smoothed to match the PSF of CTA. The subtracted image of (a)−(b) is also shown in (c). The white contours correspond to the H.E.S.S. VHE γ-rays (Aharonian et al. 2007a). The unit of color axis is counts/pixel for all pannels.

Supermassive Blackholes ~ $10^8 M_\odot$
Particle accelerators

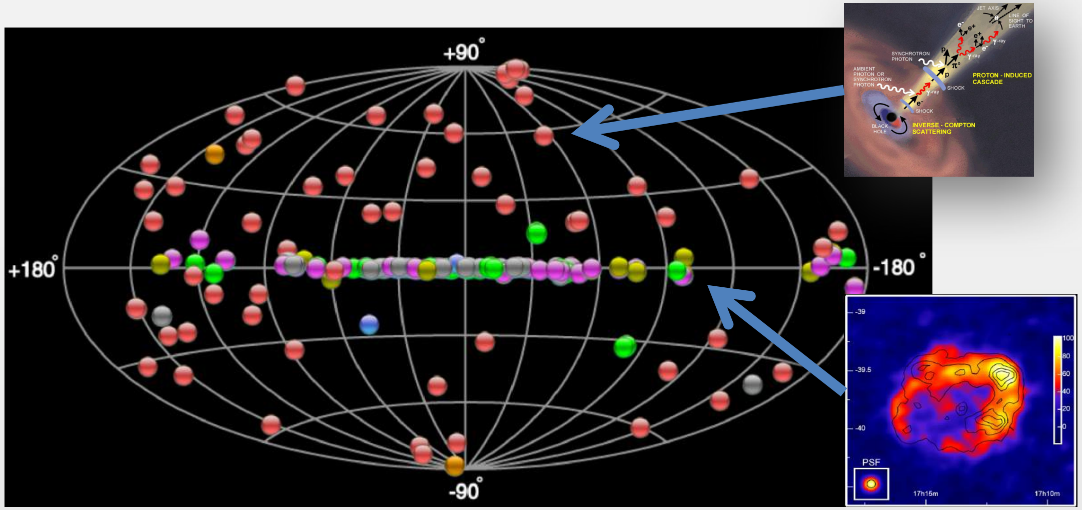


Plasma Jet is formed with the gamma factor of several to a few 10s.

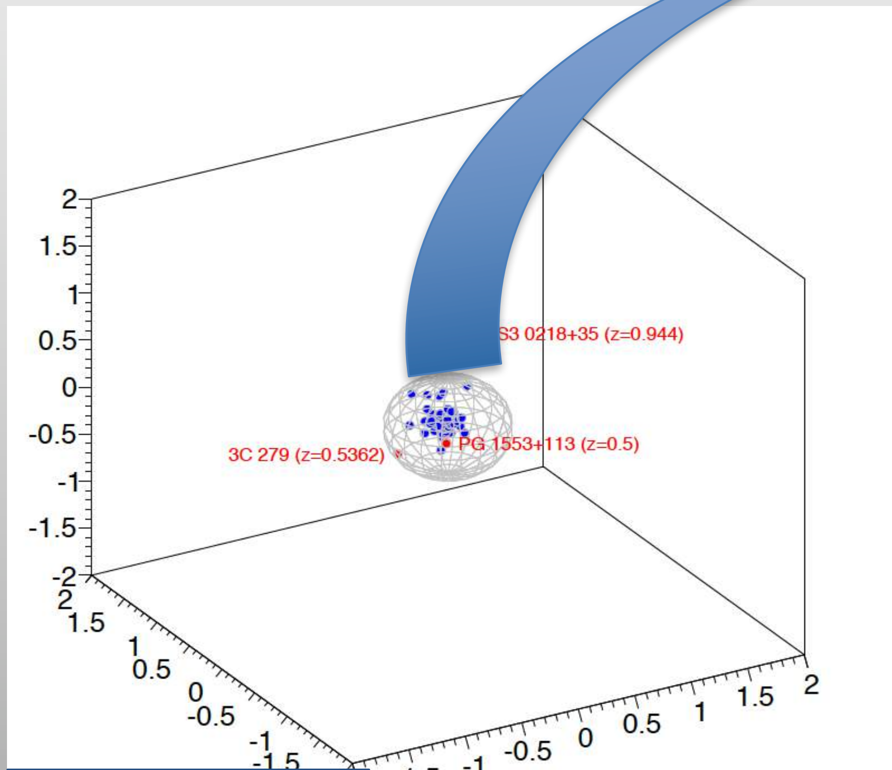




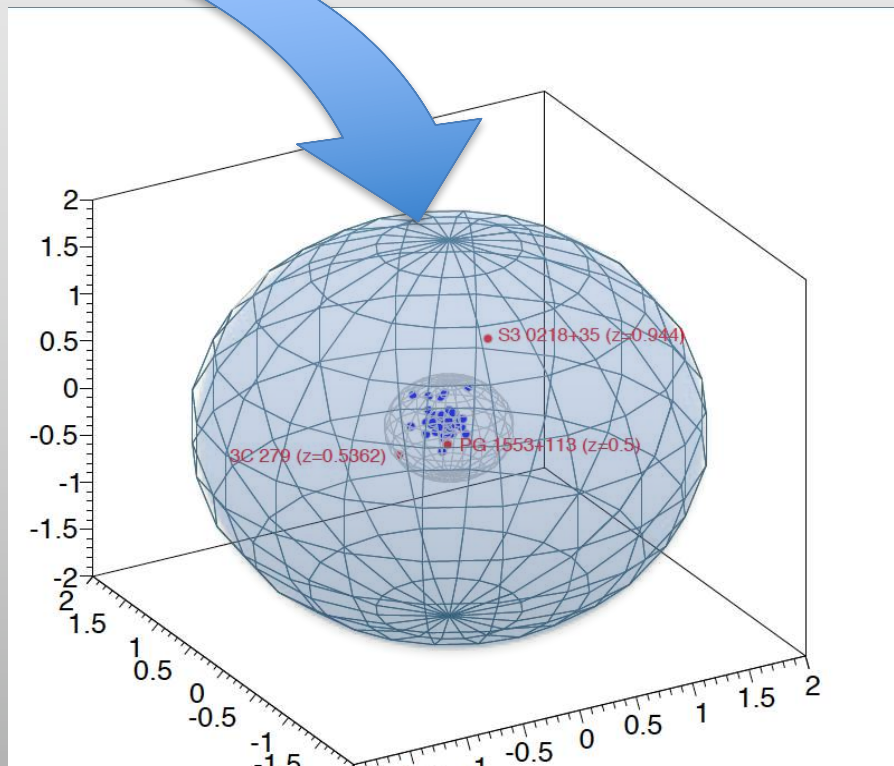
CTA:
Ultimate Survey Instrument we can see up to 1.6 Byr from Big bang



～200 VHE gamma ray sources have been discovered

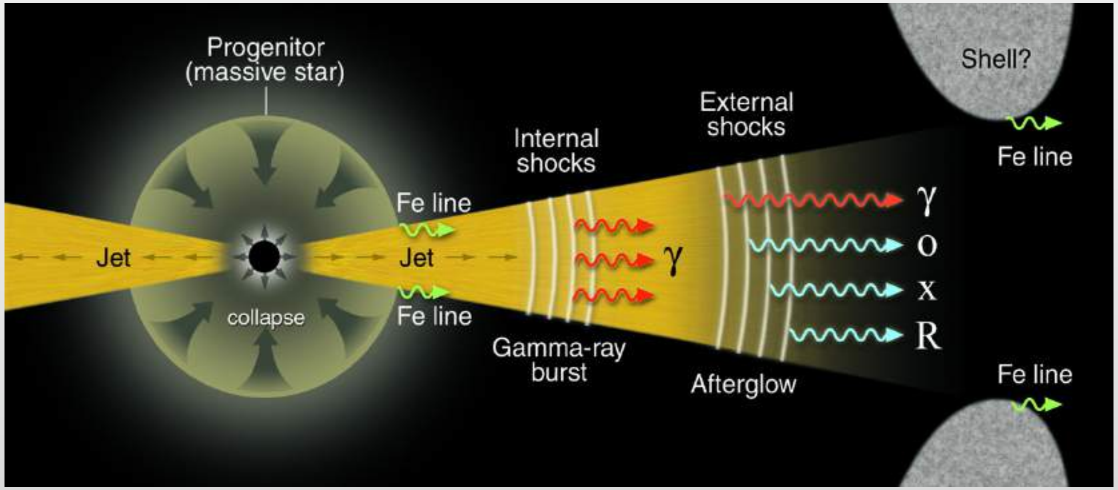


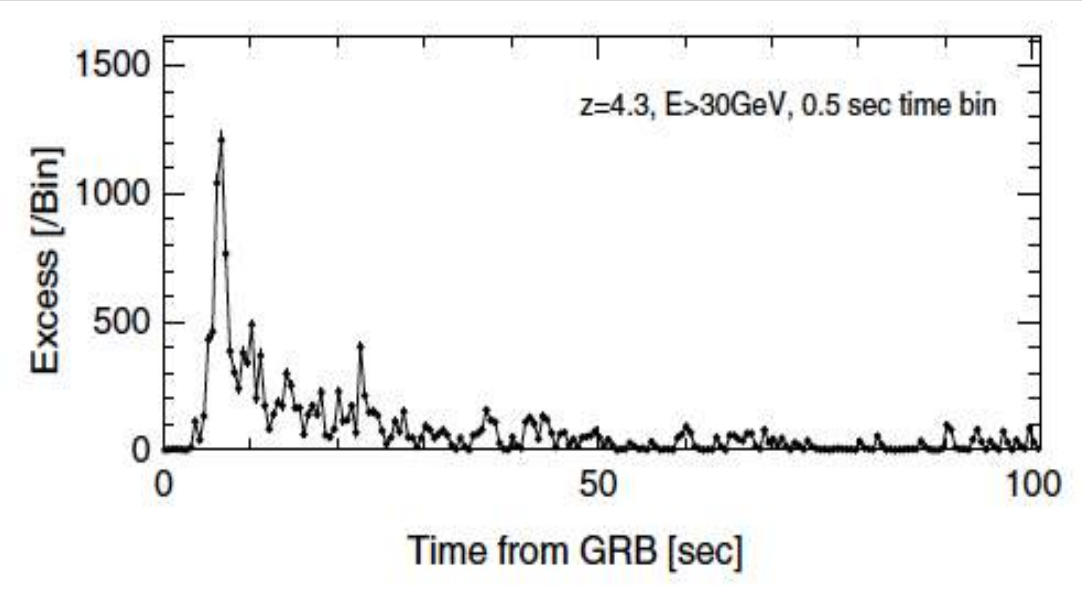
Visible Universe 9 Byr from Big Bang

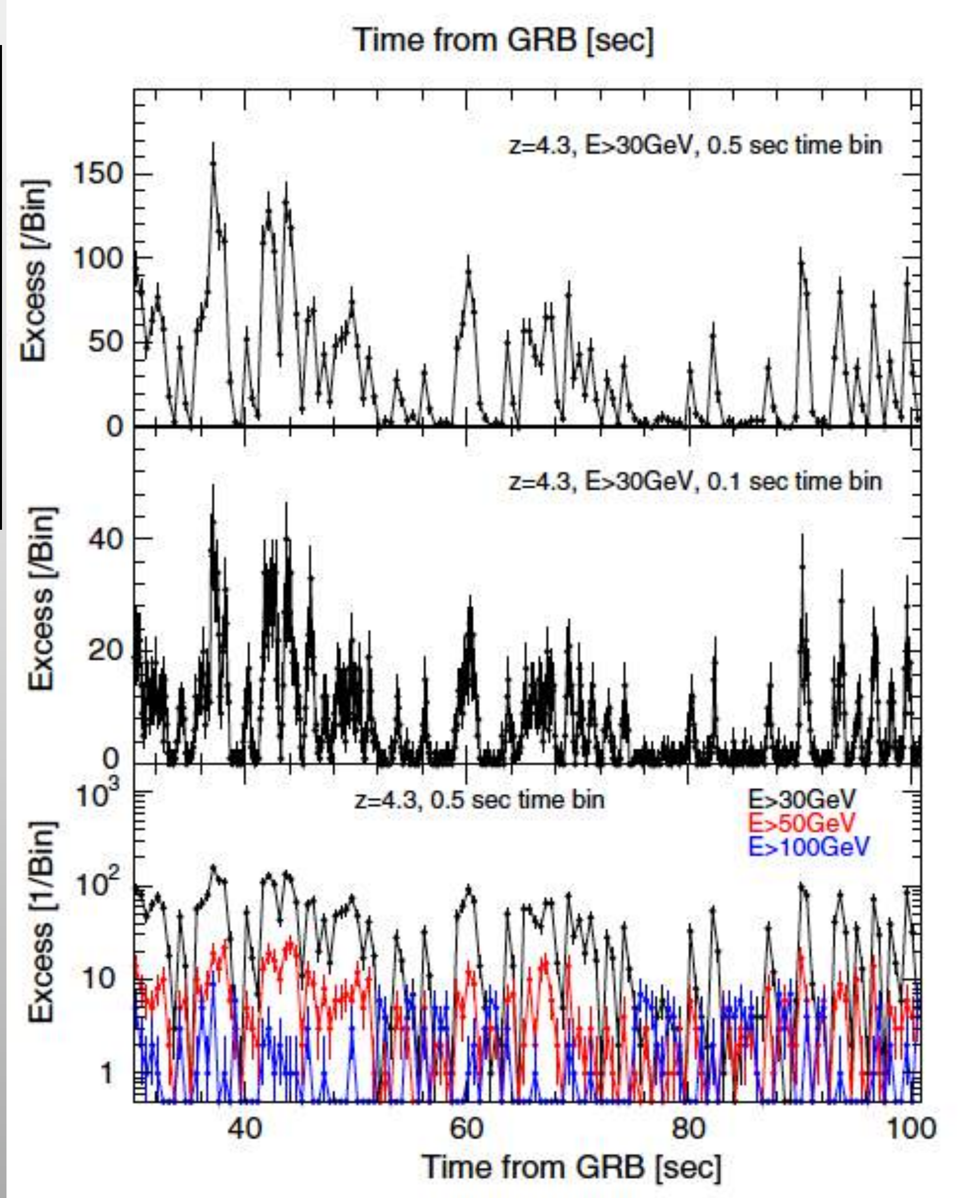


Visible Universe 1.6 Byr from Big Bang

GRB: Simulated light curve
(template: GRB080916C)

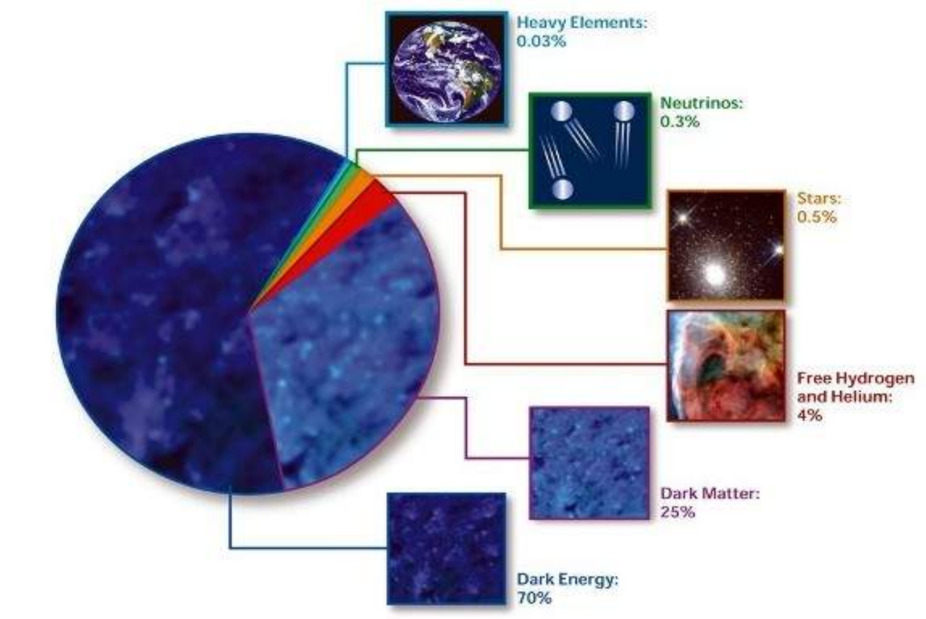


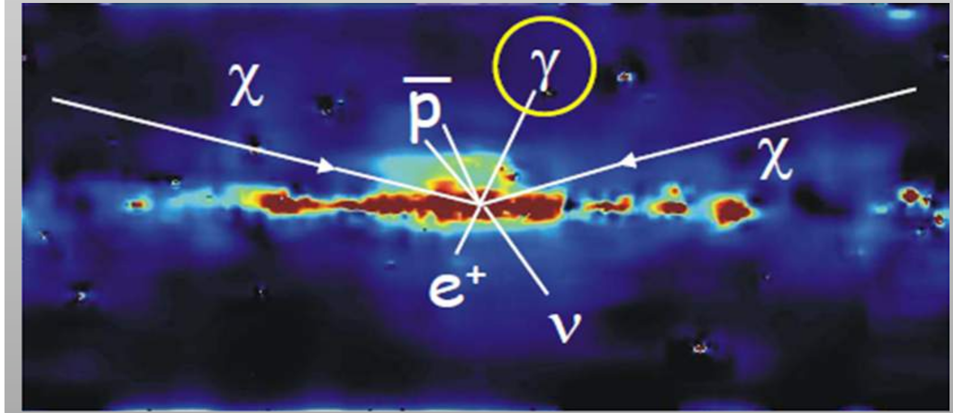




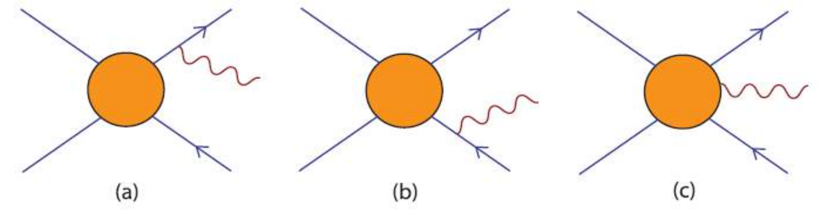
Gamma ray emission process from DM Annihilation

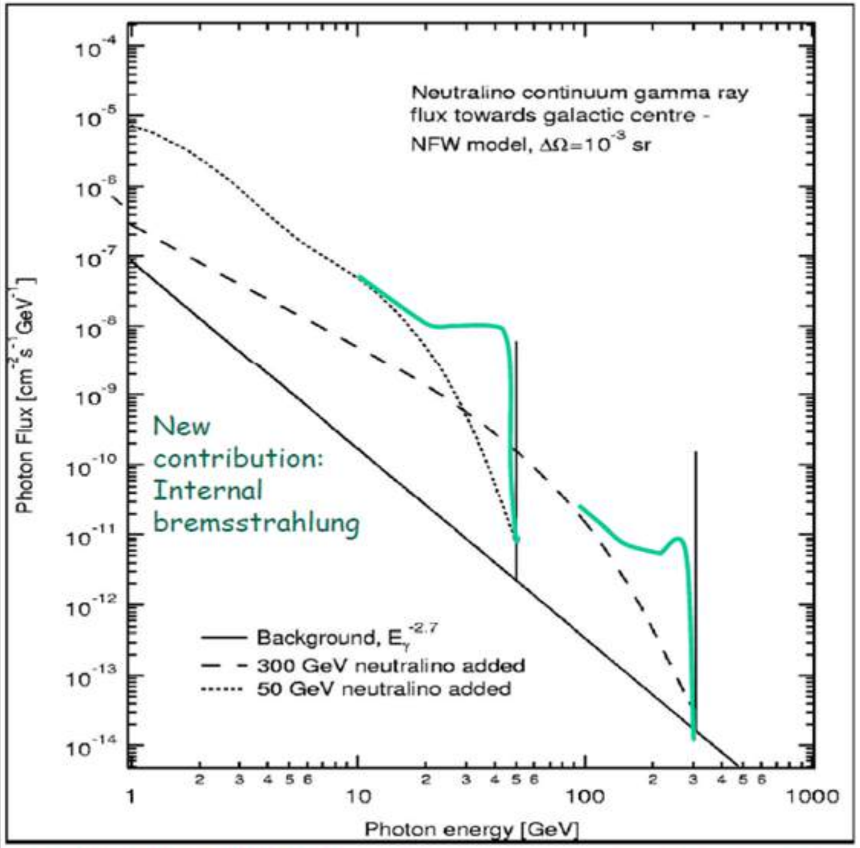
Dark Matter Annihilations





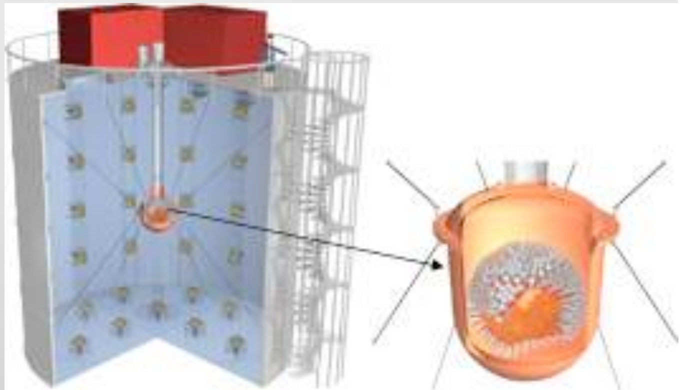
Bergstrom et al.

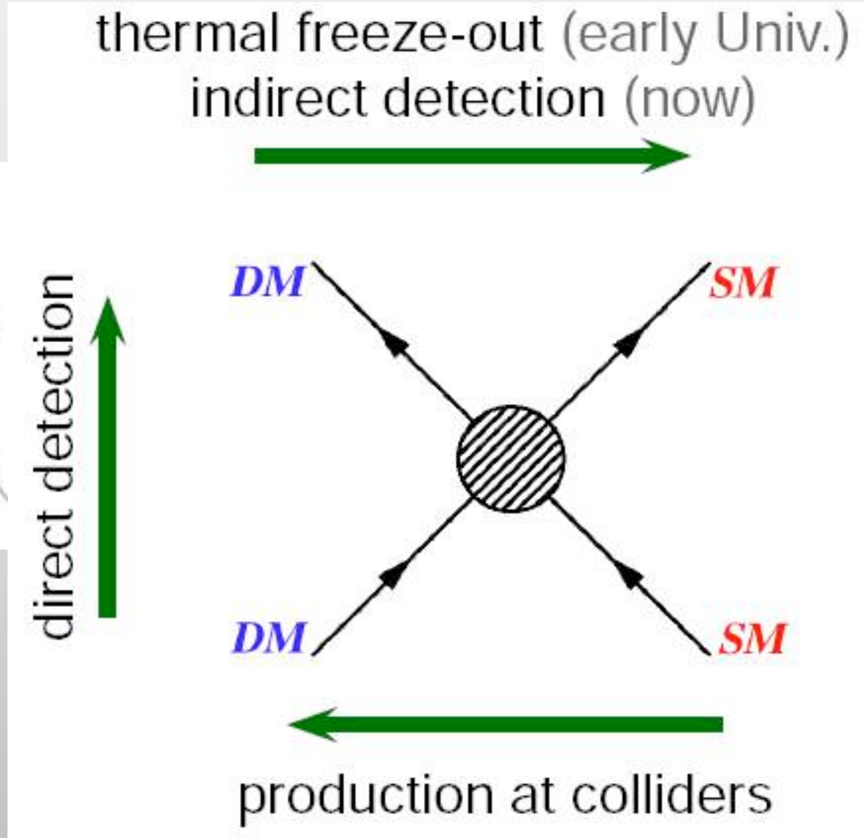


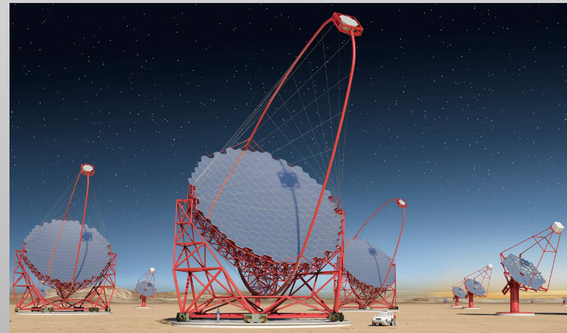


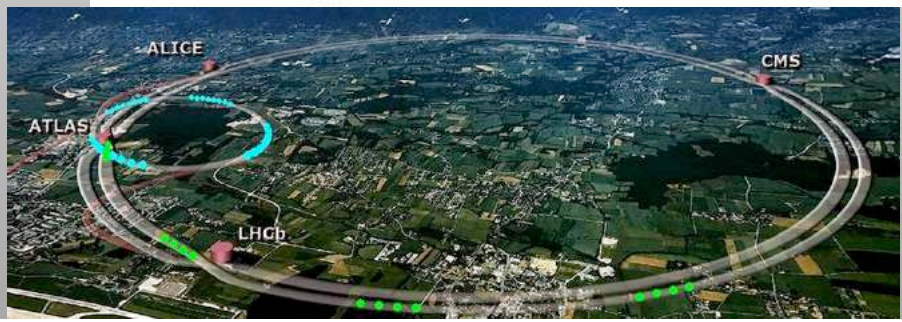
L.B., P.Ullio & J. Buckley 1998   T. Bringmann, L.B., J. Edsjö, 2007

Search for DM
$m_x \sim$ 50-2000GeV



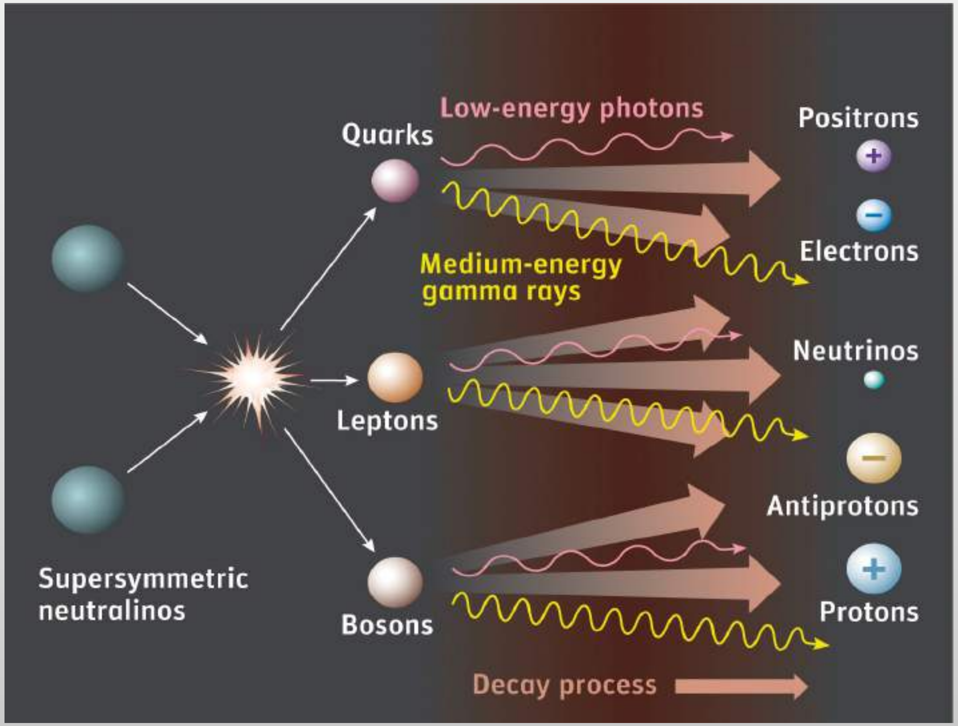


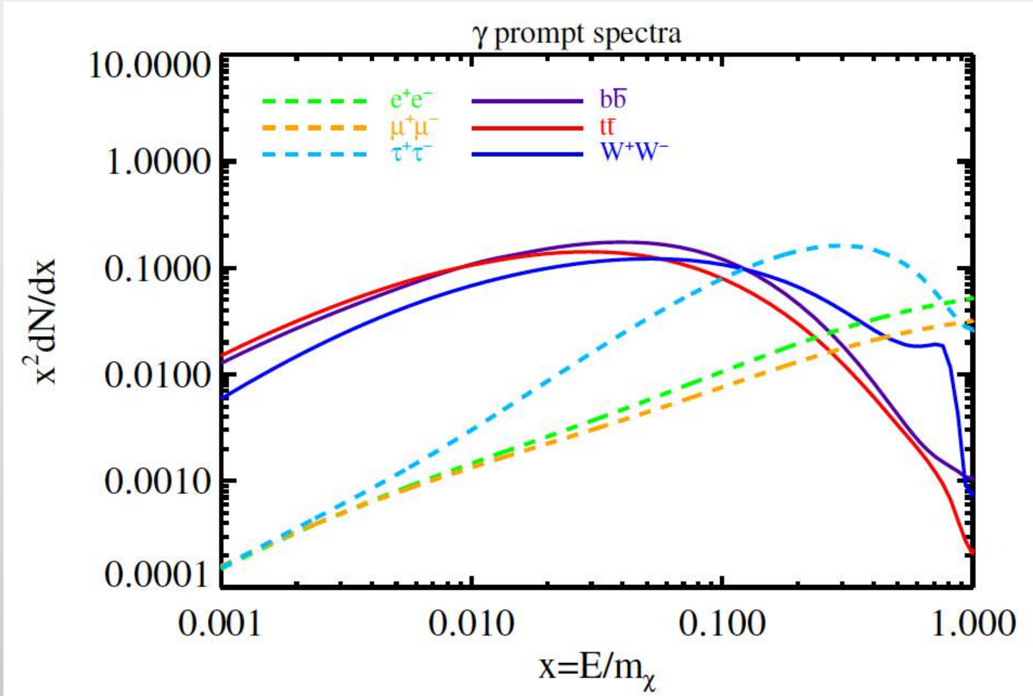




Gamma rays as secondary particles and Gamma Energy Spectra

In case mχ = 500GeV



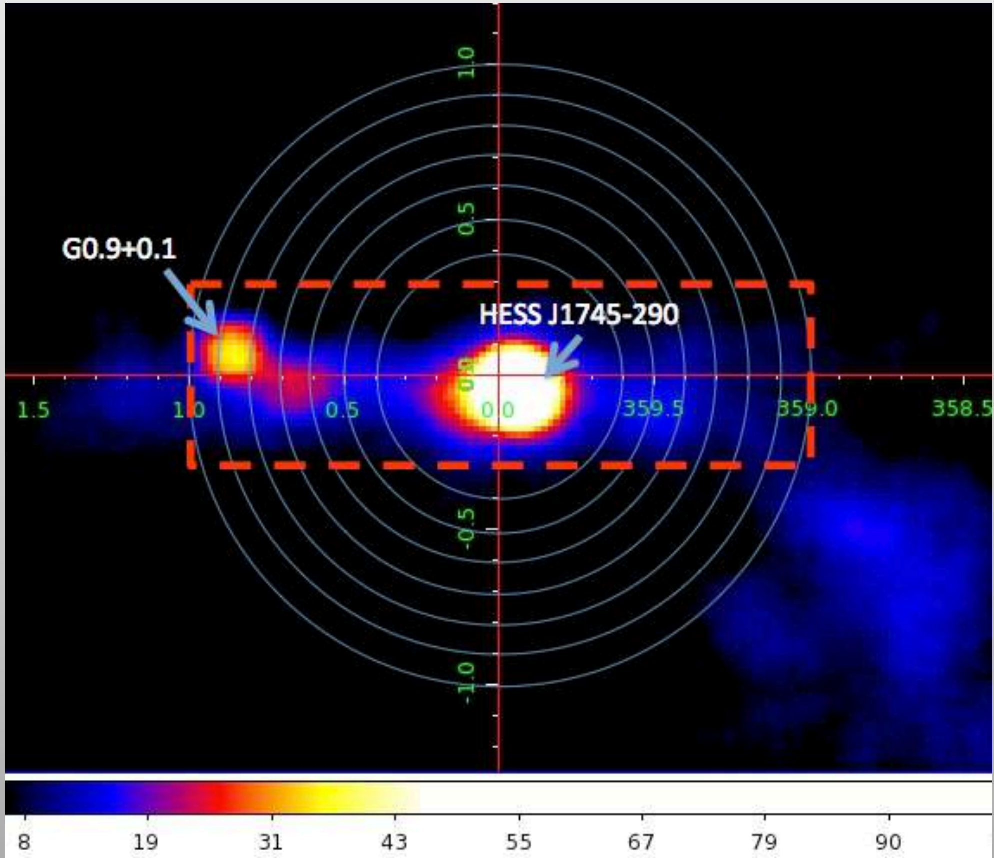


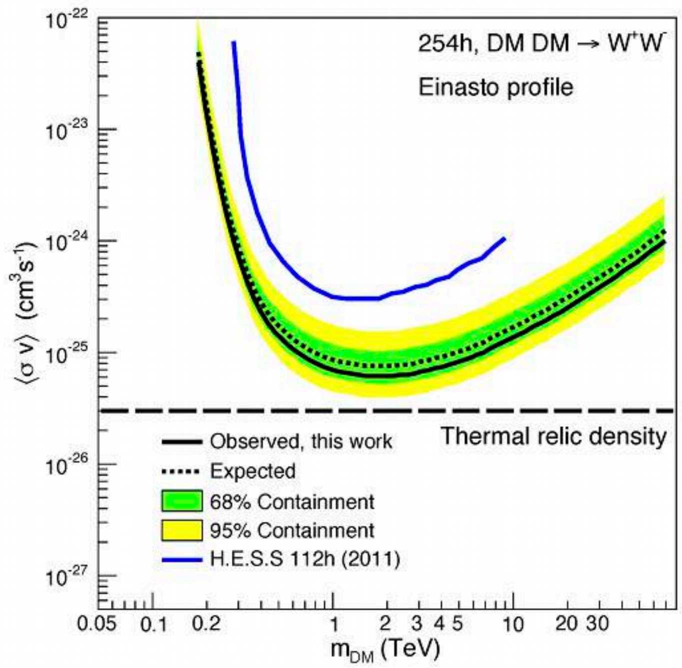
A large wide bump around 0.1 x E/mχ

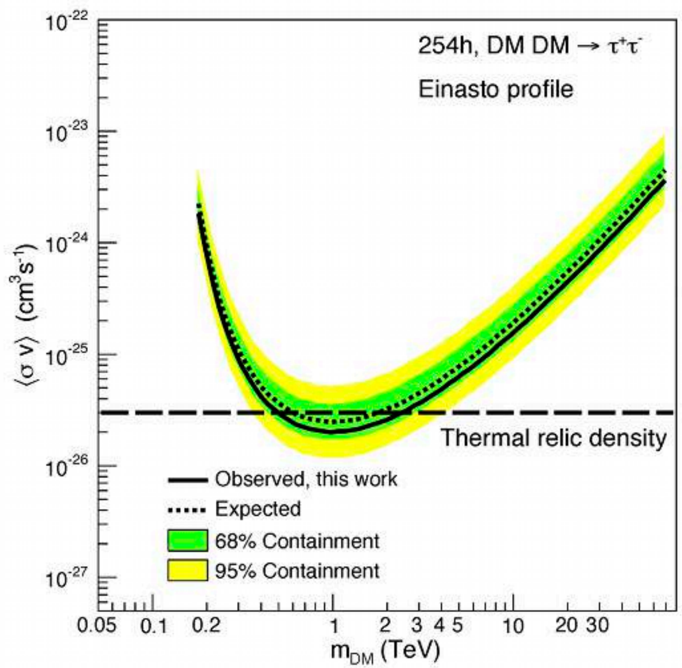
$$\frac{d\Phi_\gamma}{dE_\gamma} = \frac{1}{4\pi}\underbrace{\frac{<\sigma_{ann}v>}{2m^2_{WIMP}}\sum_f \frac{dN^f_\gamma}{dE_\gamma}B_f}_{\text{'Particle Physics'}} \times \underbrace{\int_{\Delta\Omega} d\Omega' \int_{los} \rho^2 dl(r,\theta')}_{\text{'Astrophysics' or } J(E)}$$

Galactic Center HESS Observation
new analysis 2015

HESS made the observation of inner 300pc from GC for 254hrs in 2004 – 2014. New analysis in 2016

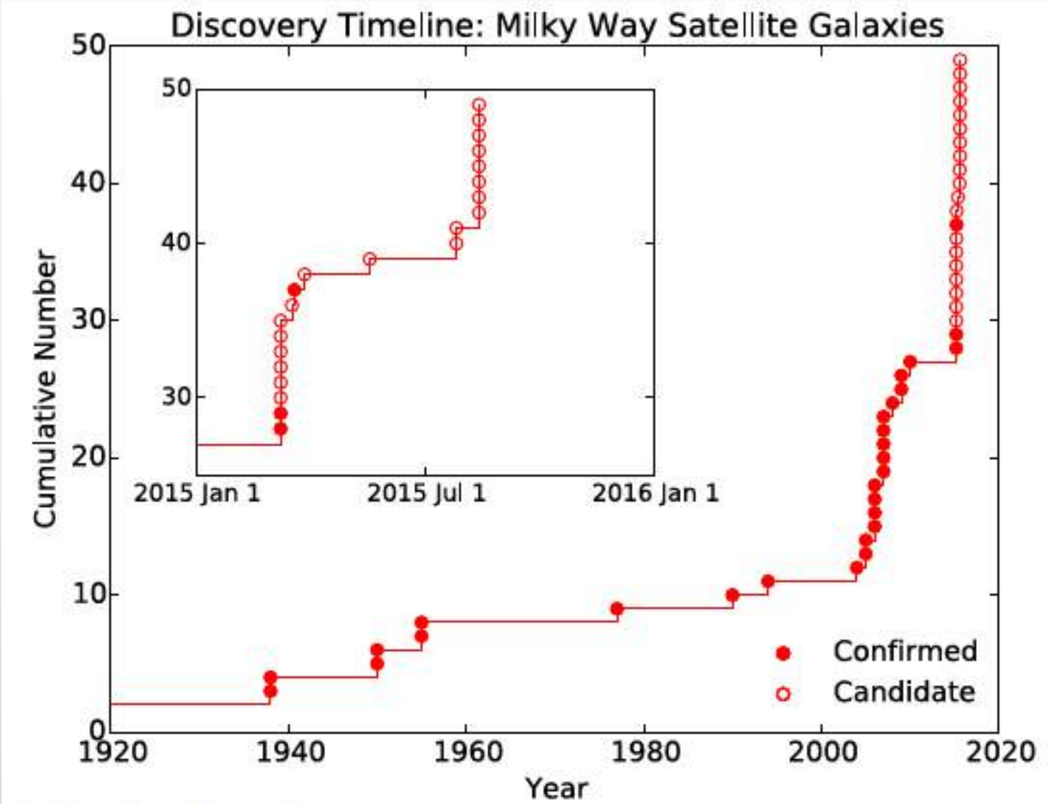




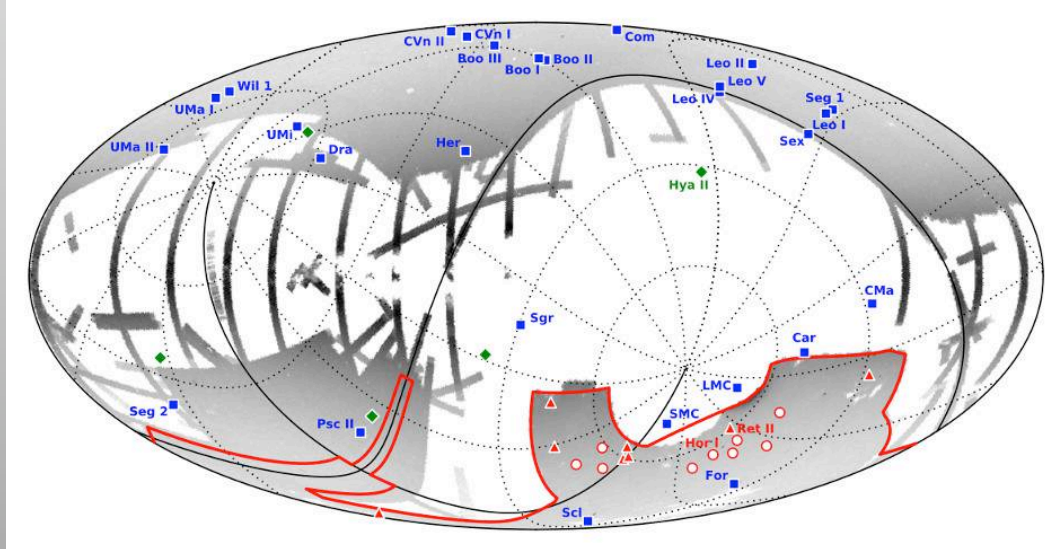


Dwarf Sph. Galaxies
SDSS & DES

Millennium simulation in MPE



k. bechtol 2015



Dwarf Sph. Galaxy Segue I with Fermi and MAGIC

Left

Fermi-LAT: 15 dwarfs

MAGIC: Segue 1

Right

Fermi-LAT: Segue1

MAGIC: Segue1

Fermi-LAT+MAGIC Segue 1

no J uncertainty

MAGIC Segue 1

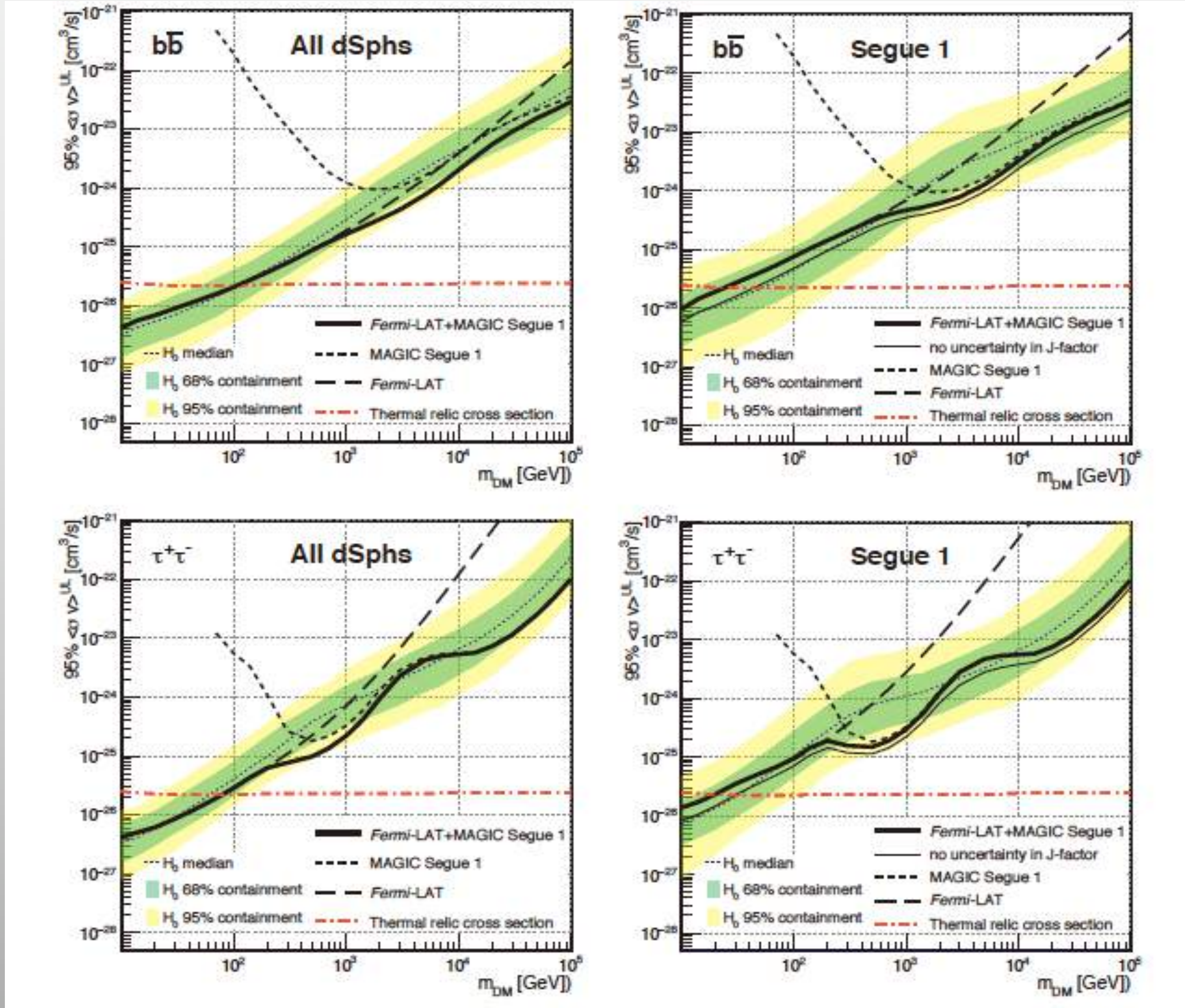
Fermi-LAT

Thermal relic cross section

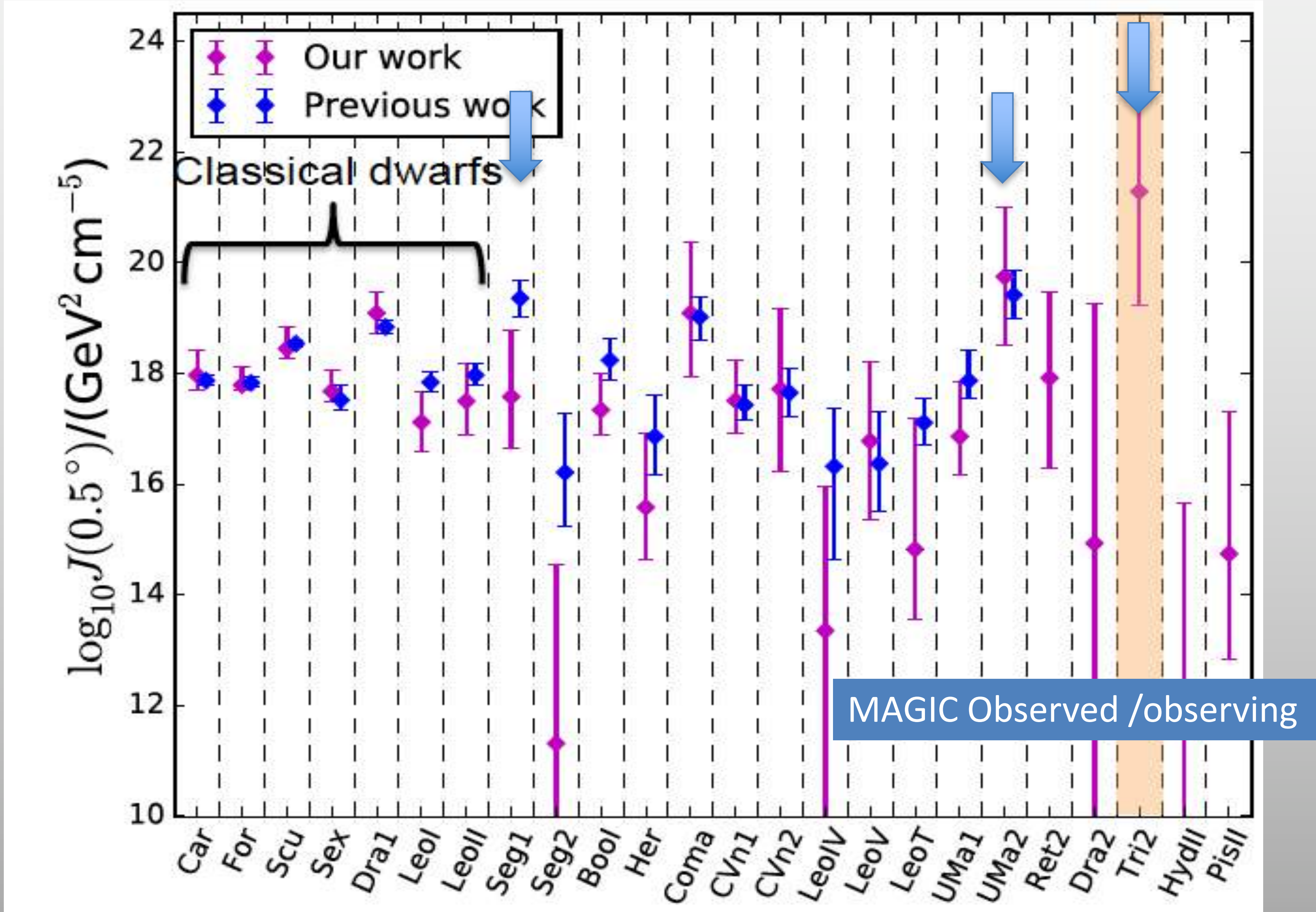
H_0 median

H_0 68% containment

H_0 95% containment



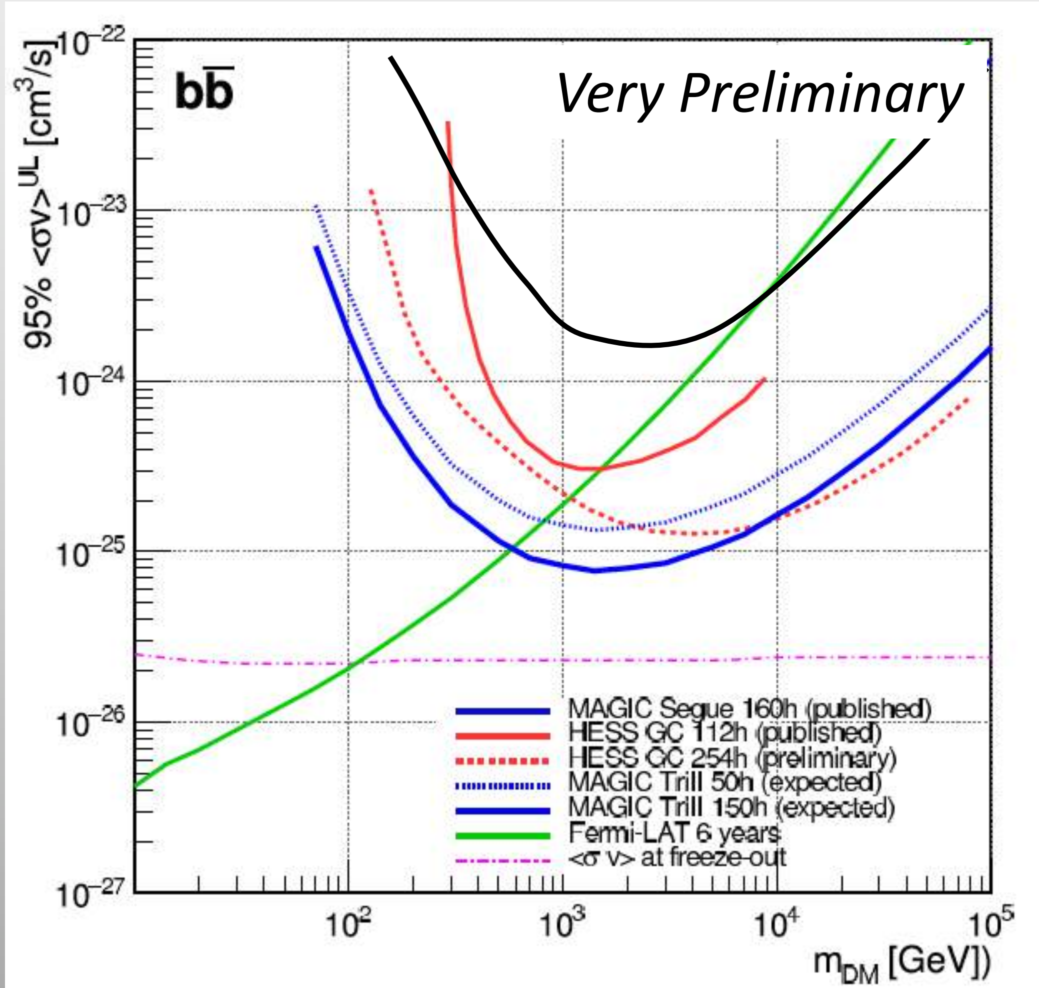
J-factors of Dwarf Sph. Gal.
K. Hayashi et al. 2015

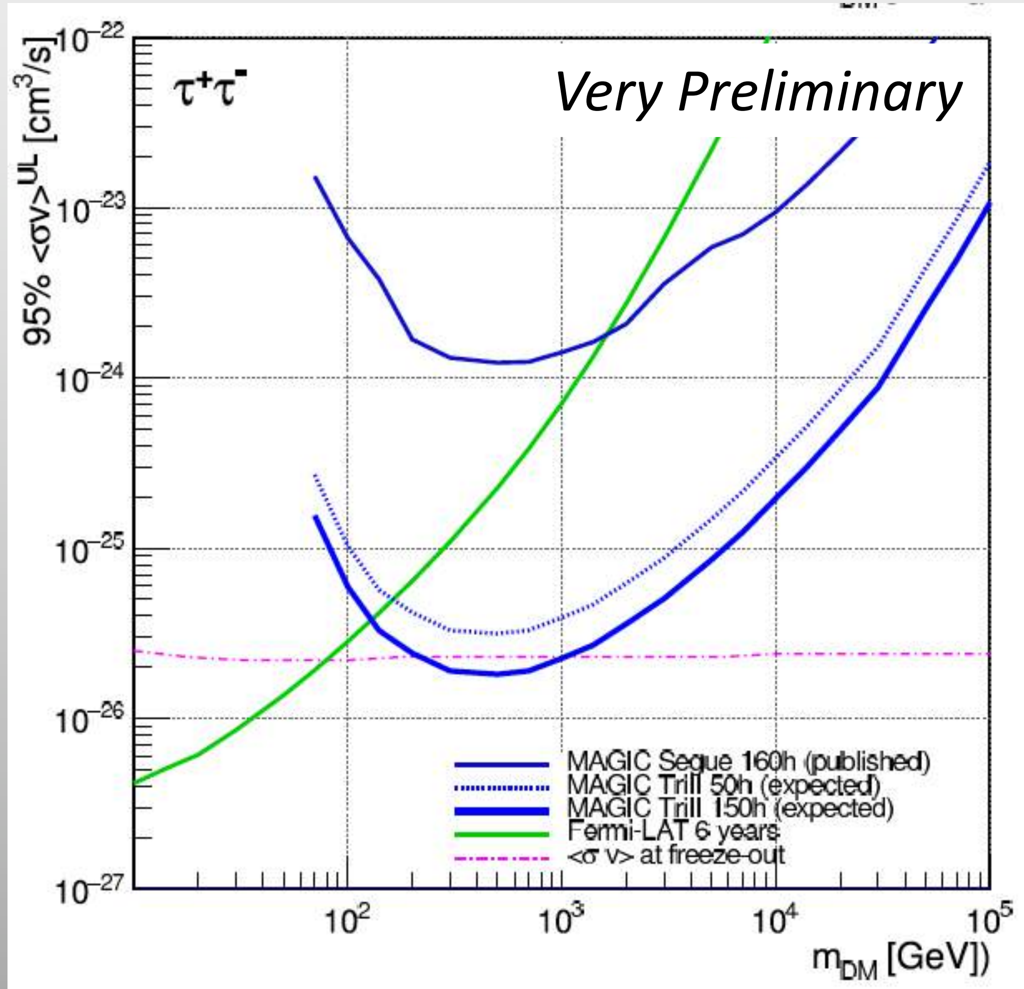


Dwarf Sph. Triangulum II
MAGIC is observing

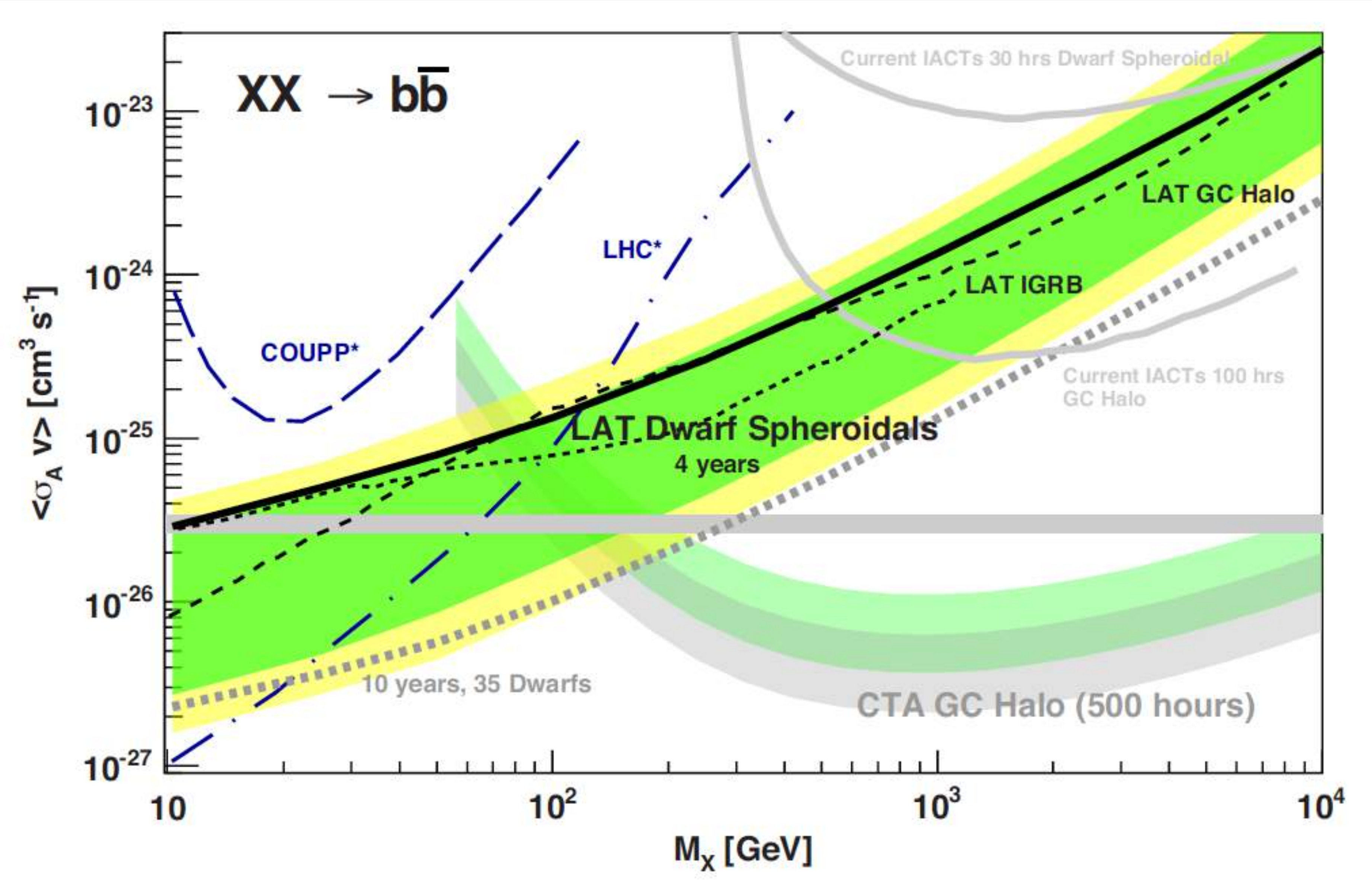
Triangulum II, α: 02:13:17.4, δ : +36:10:42.4, Dia. 3.2’, Distance =30kpc, Mass/Light = 3600,

Log(J (<0.1°)) = 20.8 ±0.7

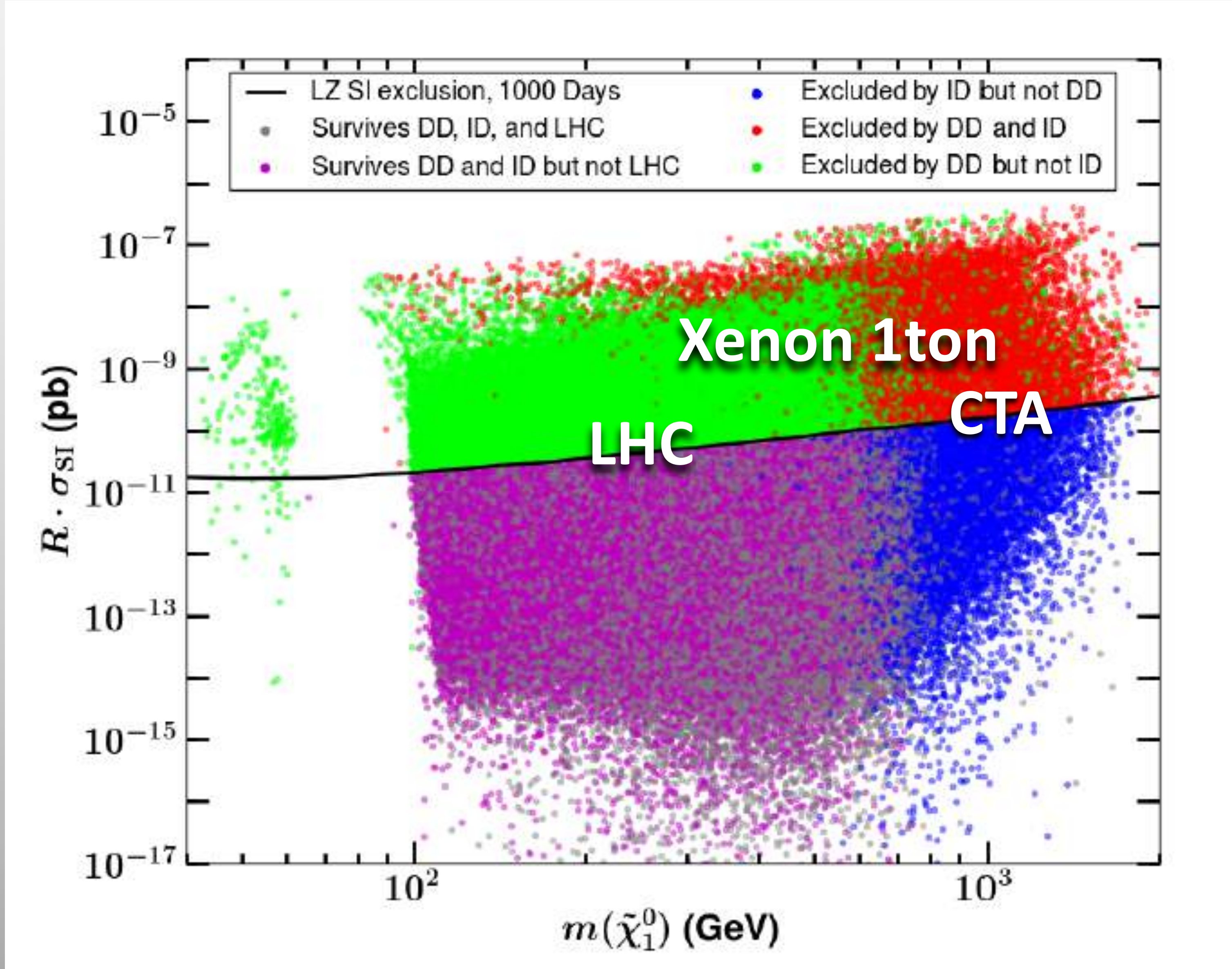




Global upper limits and expected limits by S. Funk 2015



complimentarity



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 (JP)

StarGuider (SE)
CalibBox (IN/IT)

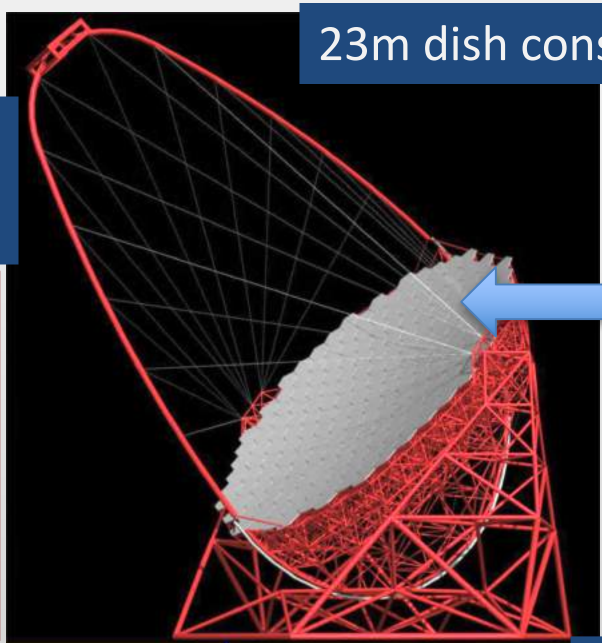
Structure (DE)
Access Tower (DE/ES)

Drive (DE/FR/ES)
Bogie (DE/ES)
Rail (DE/ES)
Found. (DE/ES)

Flywheel, UPS (JP)
Comp. (JP)

CTA-LST
1510mm Mirrors, Active Mirror Control, Fast Power

Flywheel
fast rotation
1MW >30sec

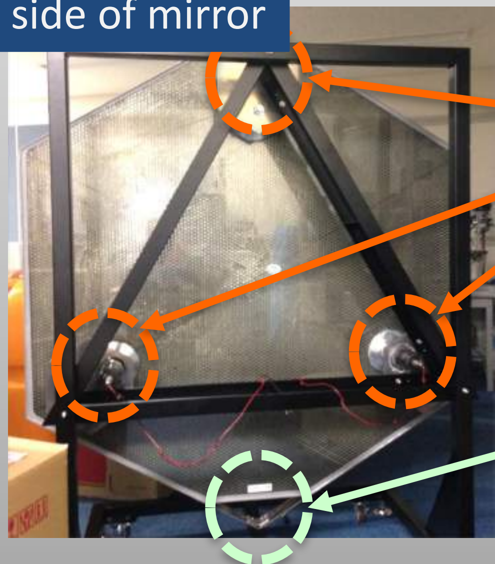


23m dish consists of 200 segmented mirrros

Mirror Spec.

- Area 2m^2
- Weight 47kg
- Life >10 years
- Reflectivity >93%
- Multi-layer coat

rear side of mirror



Actuators

CMOS Camera

Active Mirror Control

- CMOS Cameras read out the direction of segmented mirrors with the accuracy of 5 arcsec
- Actuators will control each segmented mirrors with 5 arcsec

Production of Segmented Mirrors

FY2014: 13 mirrors
FY2015: 30 mirrors
2016 July: 60 mirrors

Scheduled
FY 2016: 400 mirrors
FY 2017: 600 mirrors

PMT + CW-HV

- 1855 PMTs /cam

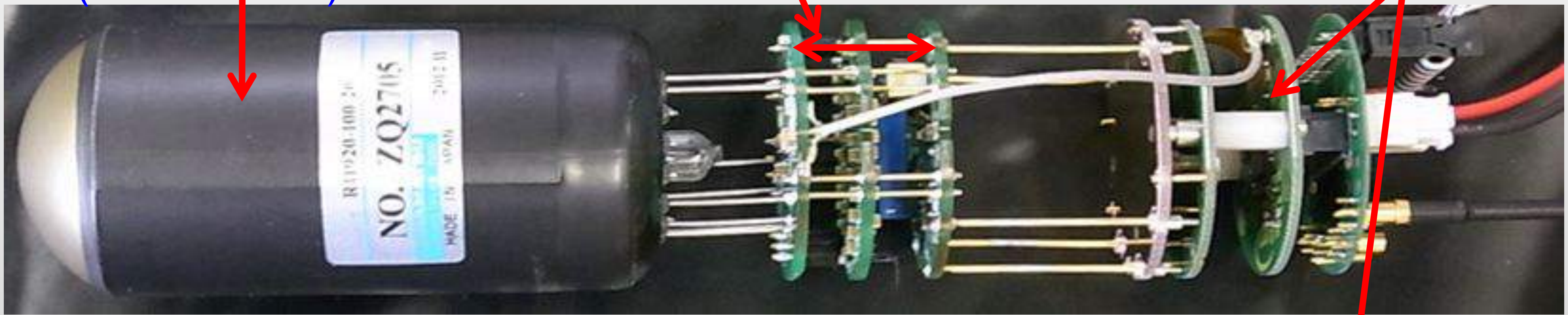
1.5”PMT
developed with HPK
(R11920-100)

Cockcroft-Walton HV

Low power consumption 50mW/ch

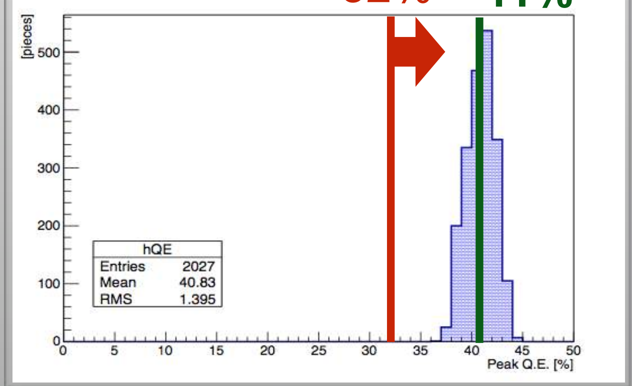
HPK, 850-1500V (1st Dy: 350V)

Preamp PCB



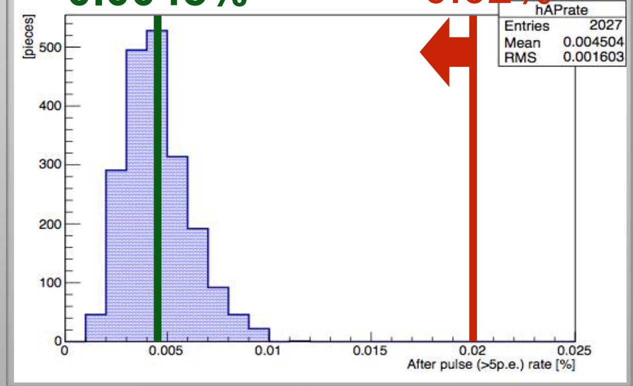
High Q.E.

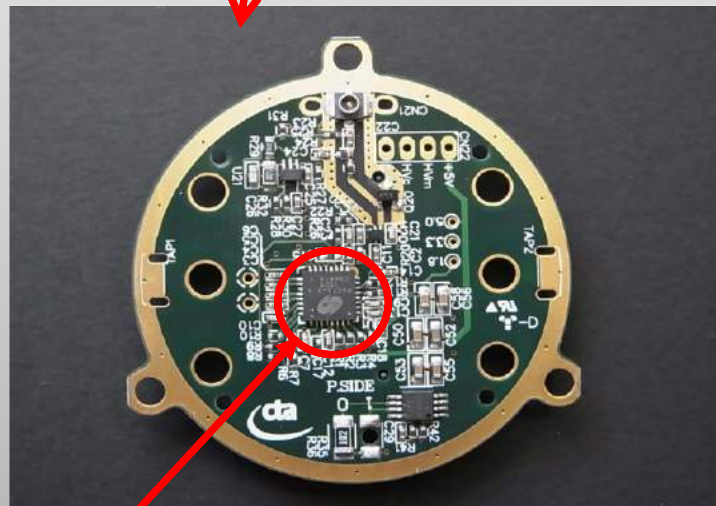
Req. >32%   average 41%



Low after pulse rate

Average 0.0045%   Req. <0.02%



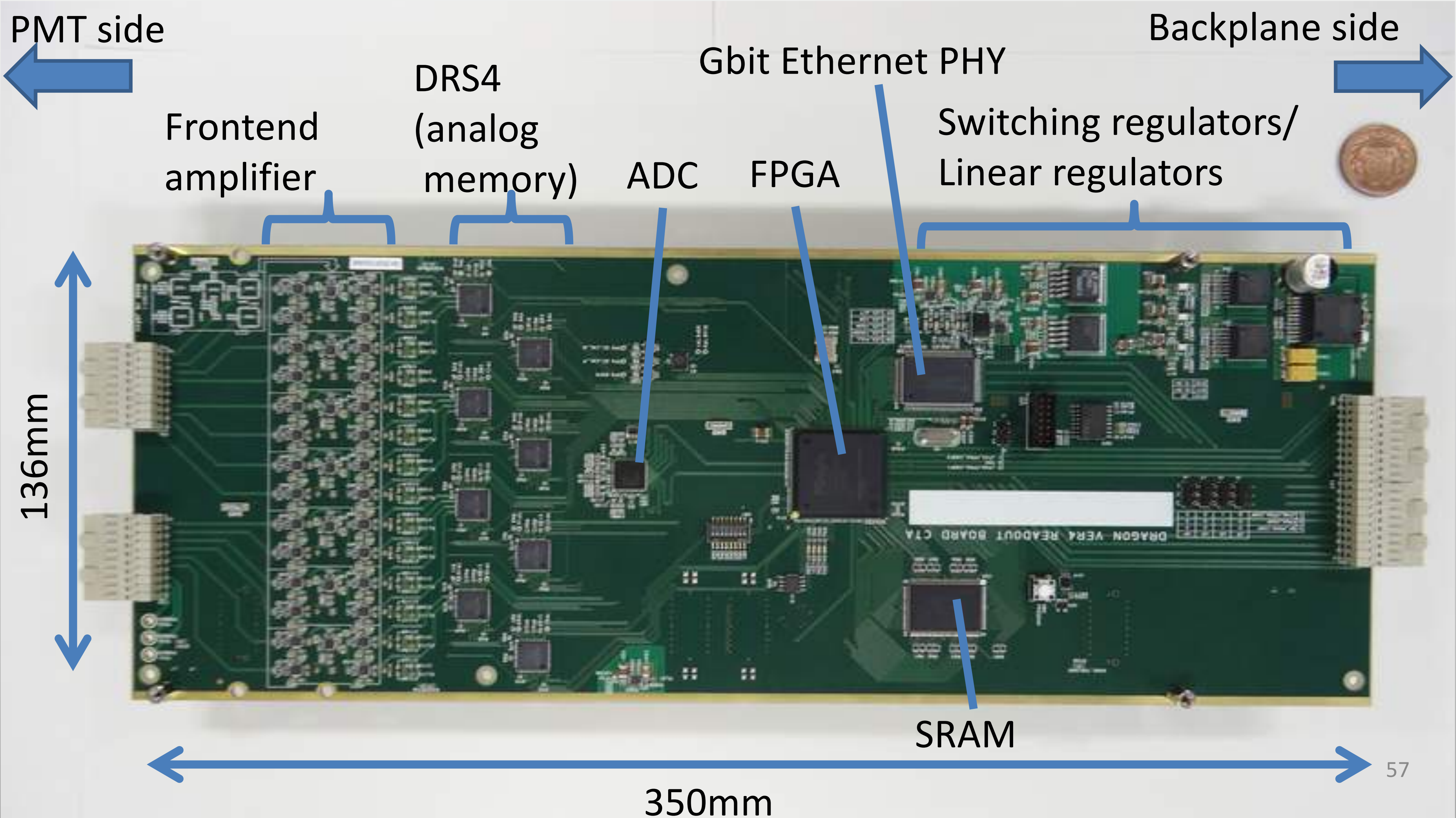


ASIC：Spain
Design：Japan

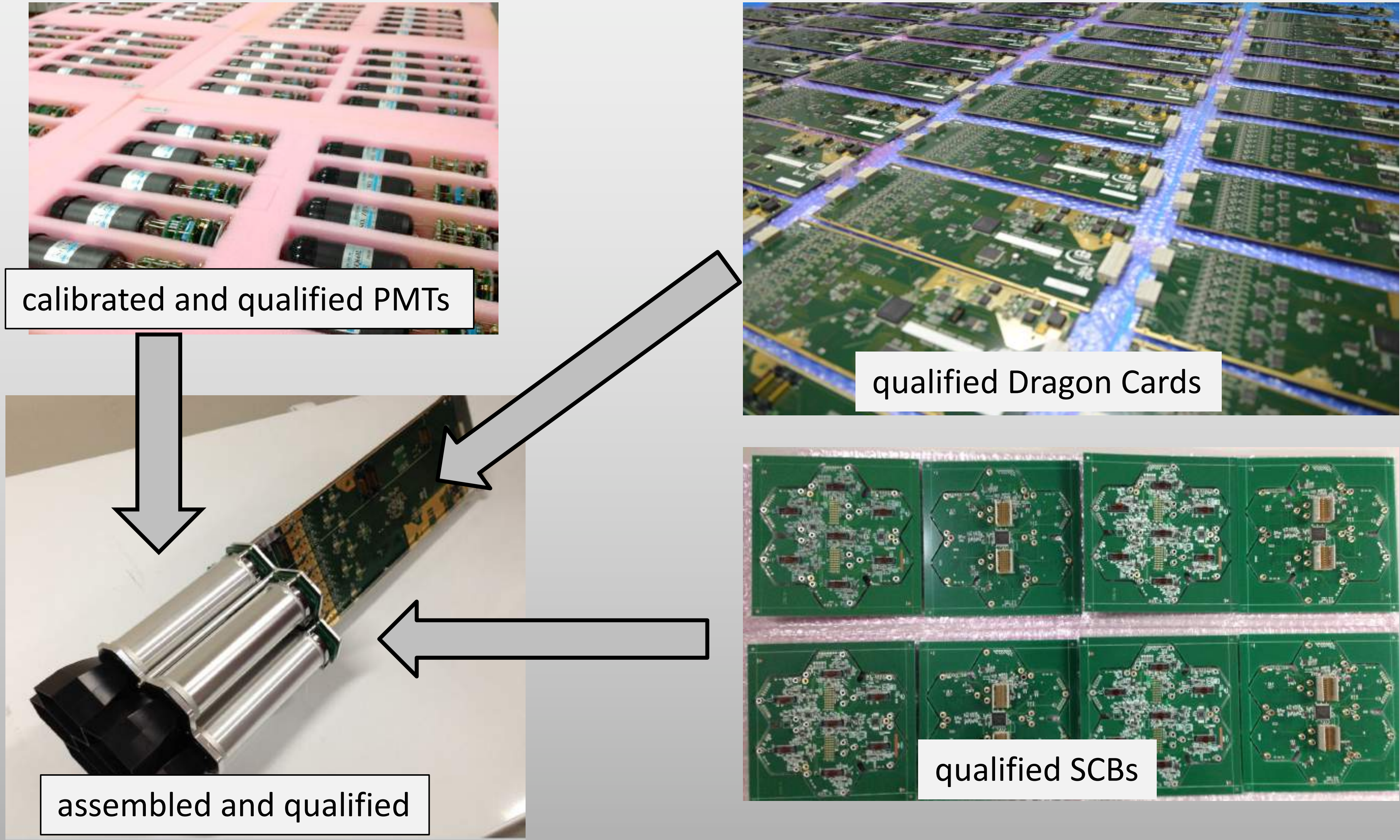
Readout electronics Dragon

Analog-memory *DRS4 chip from PSI*

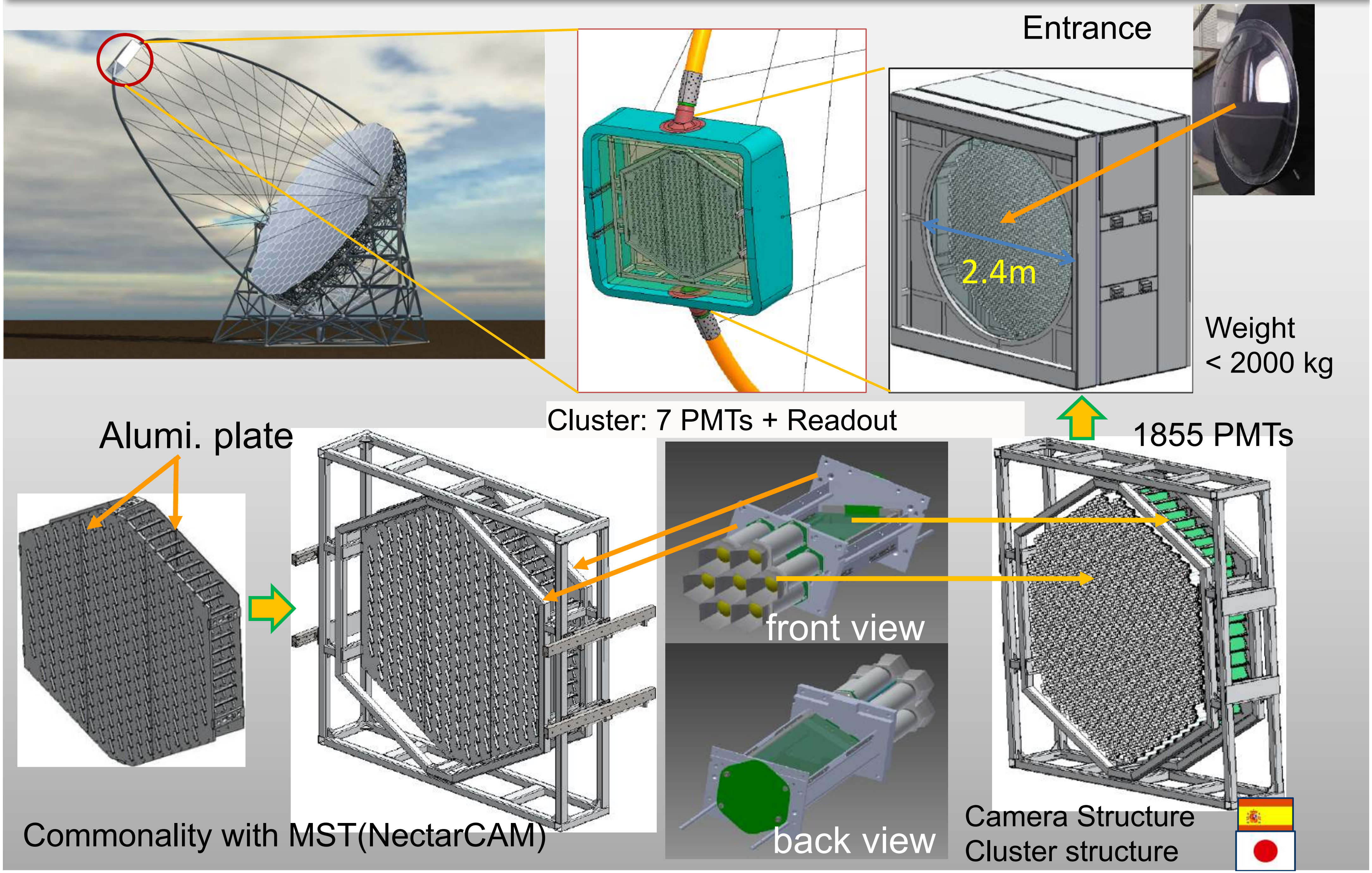
LST Readout 1G Sample/s × 4 µsec depth



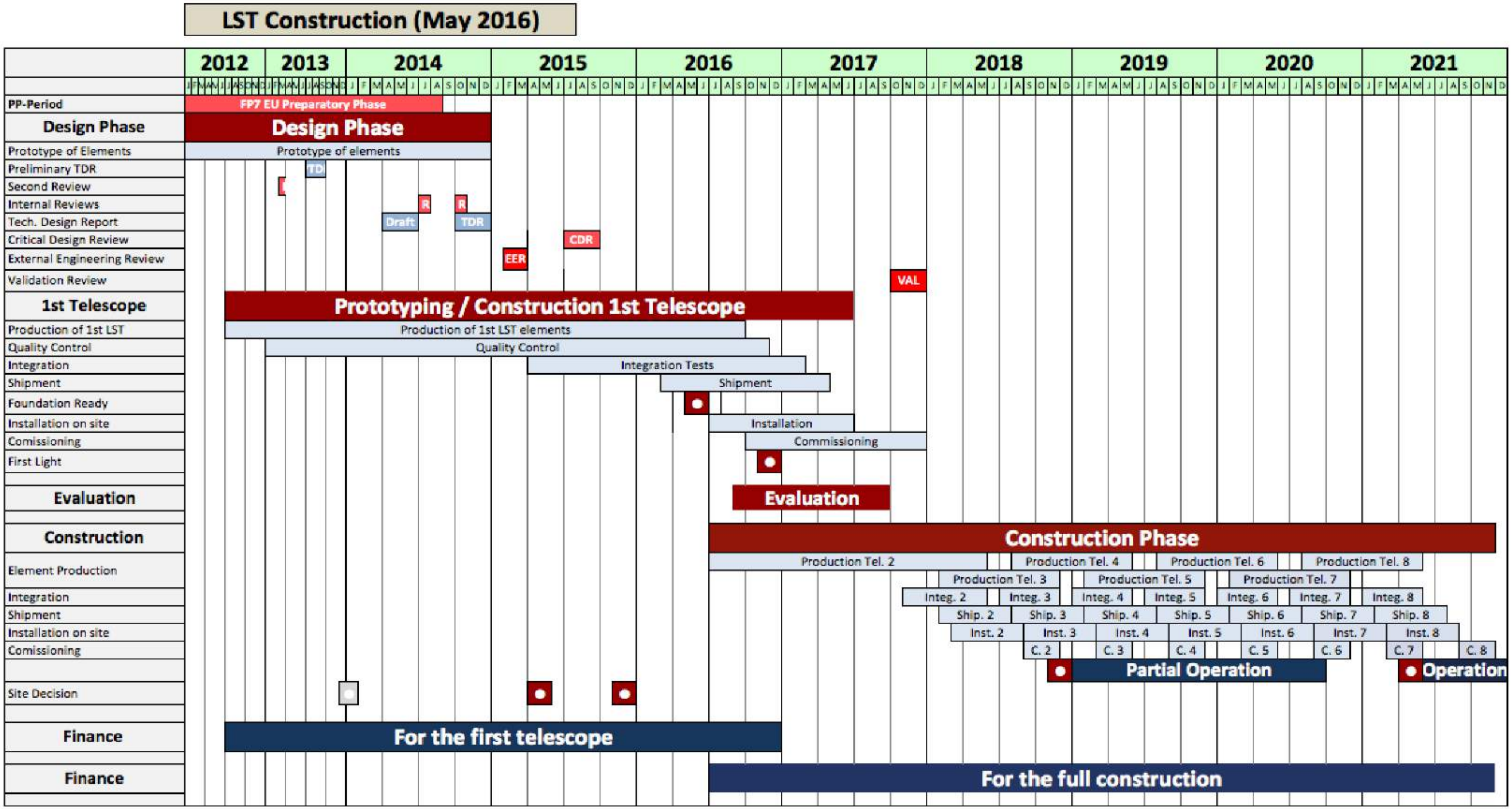
High Q.E. PMTS, and Electronics



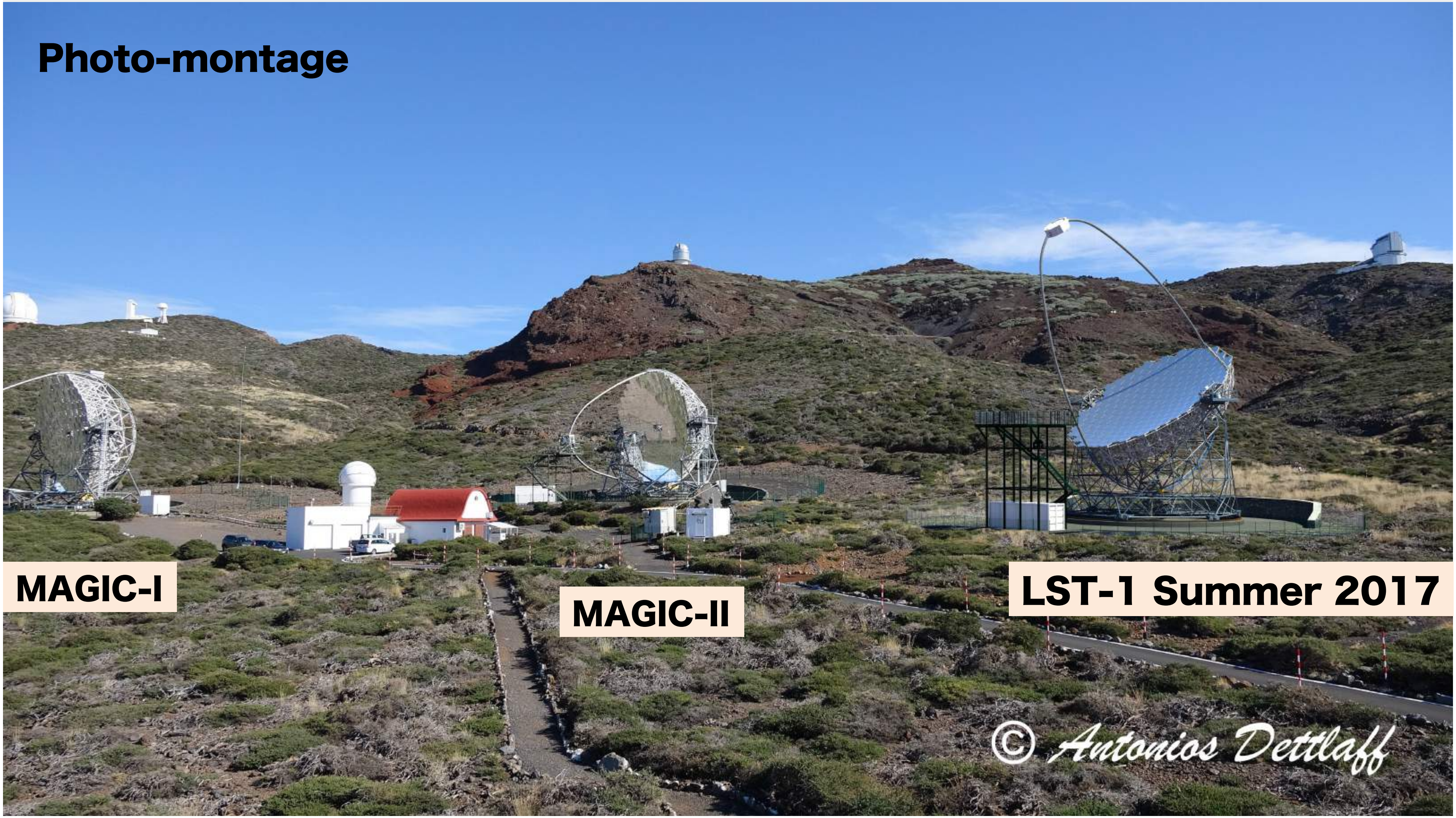
LST Camera Structure



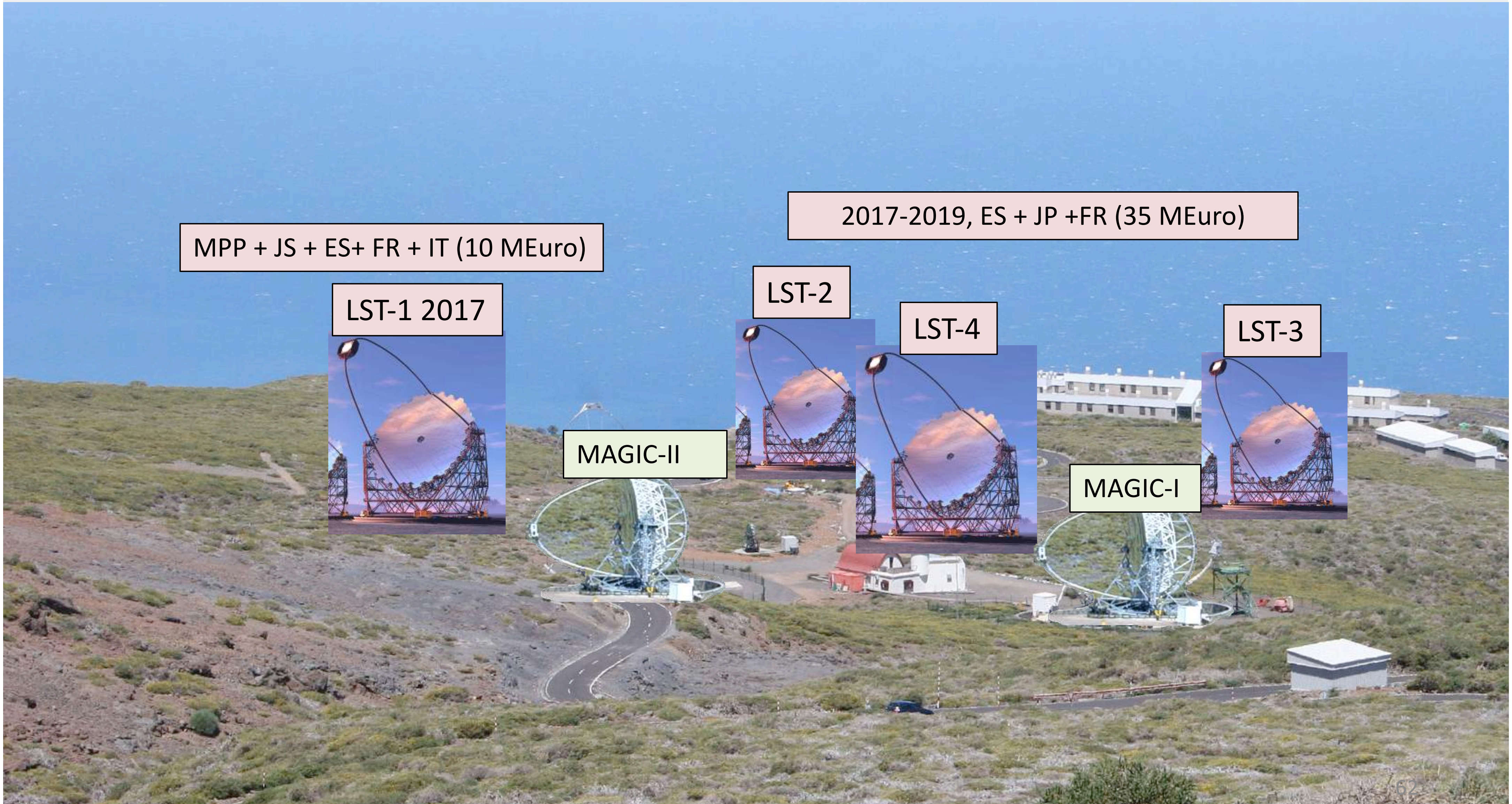
Schedule for LST1-8



First LST at ORM Summer 2017

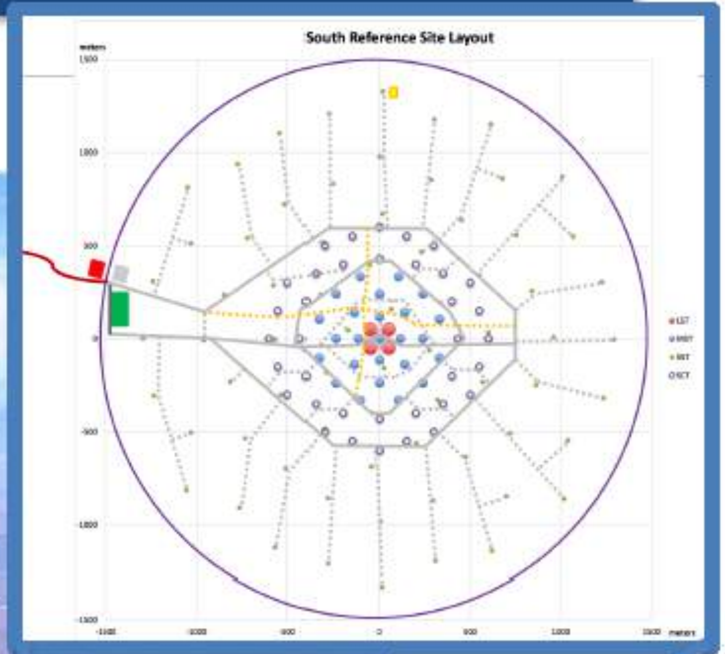


4 LSTs in CTA North



CTA North around 2022

Chile Paranal Site




Summary
CTA will study with an unprecedented sensitivity
Cosmic Ray Origin
Super Massive Blackholes, their environment and evoluation
Dark Matter at G.C. and dwarf galaxies
MPI Munich and CTA-Japan make a major contribution to CTA-LSTs
Construction 2016-2020