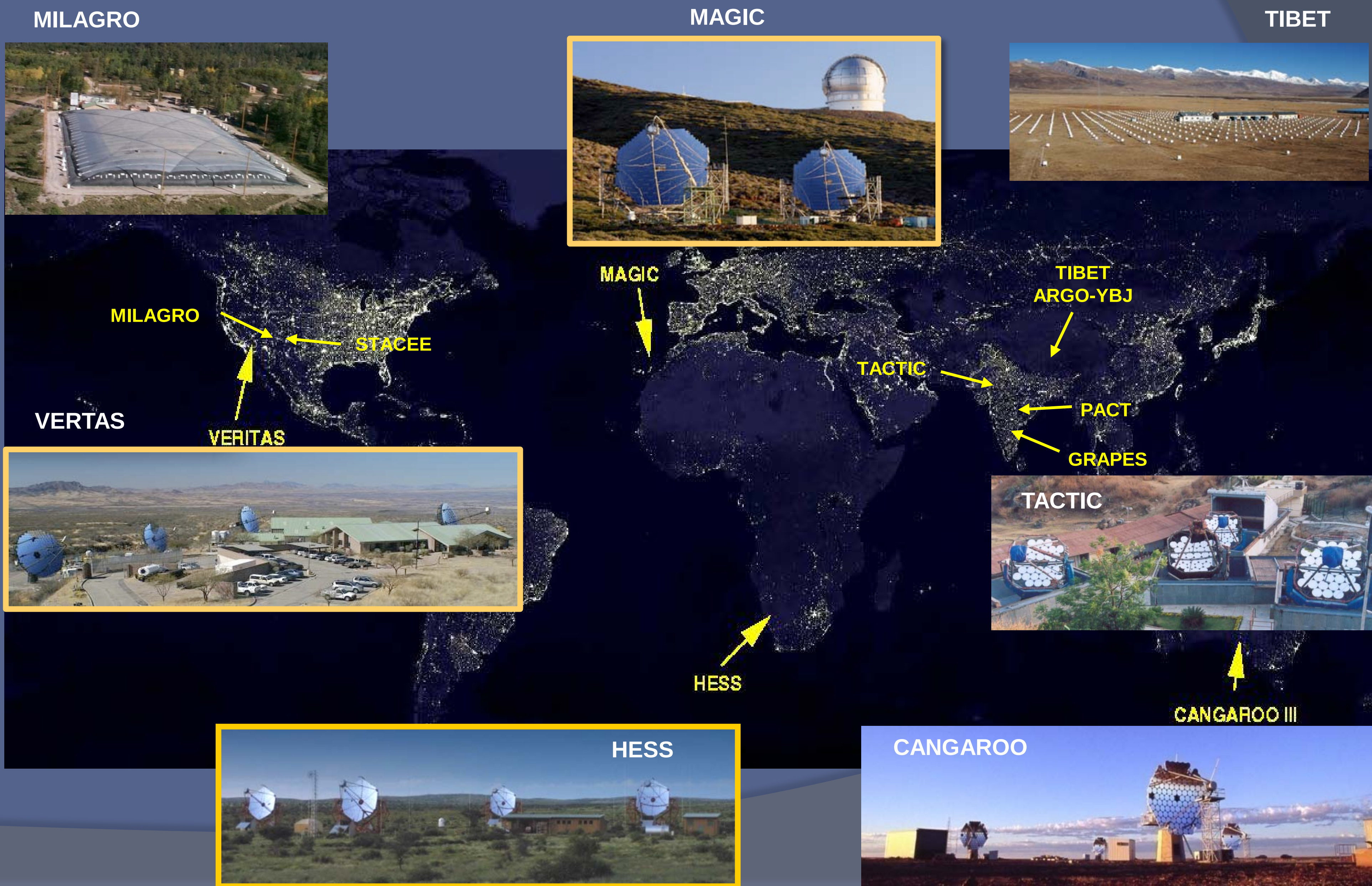
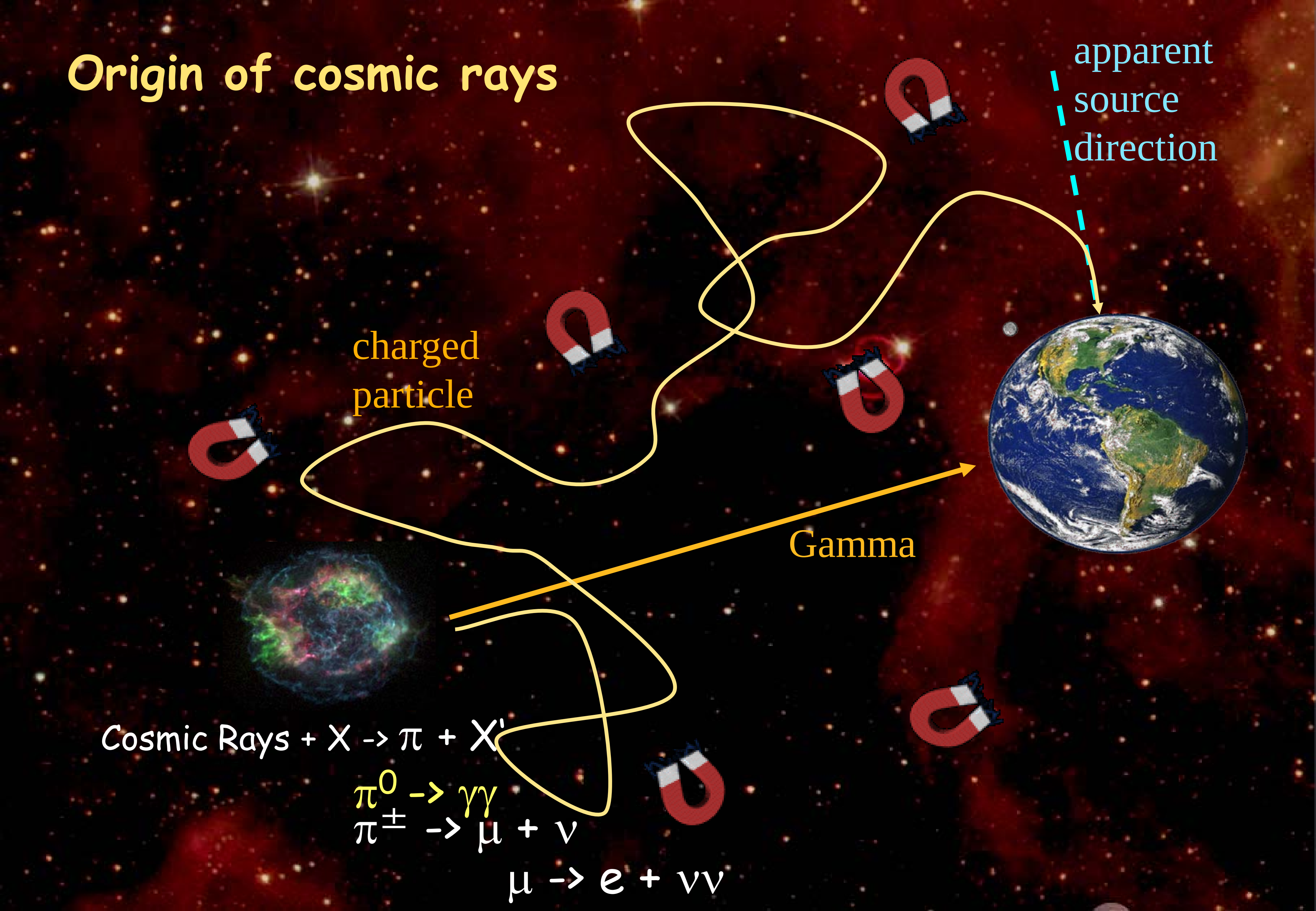
VHE GAMMA RAY ASTRONOMY PRESENT RESULTS AND FUTURE PROSPECTS

ICRR, University of Tokyo
Max-Planck-Institute for Physics

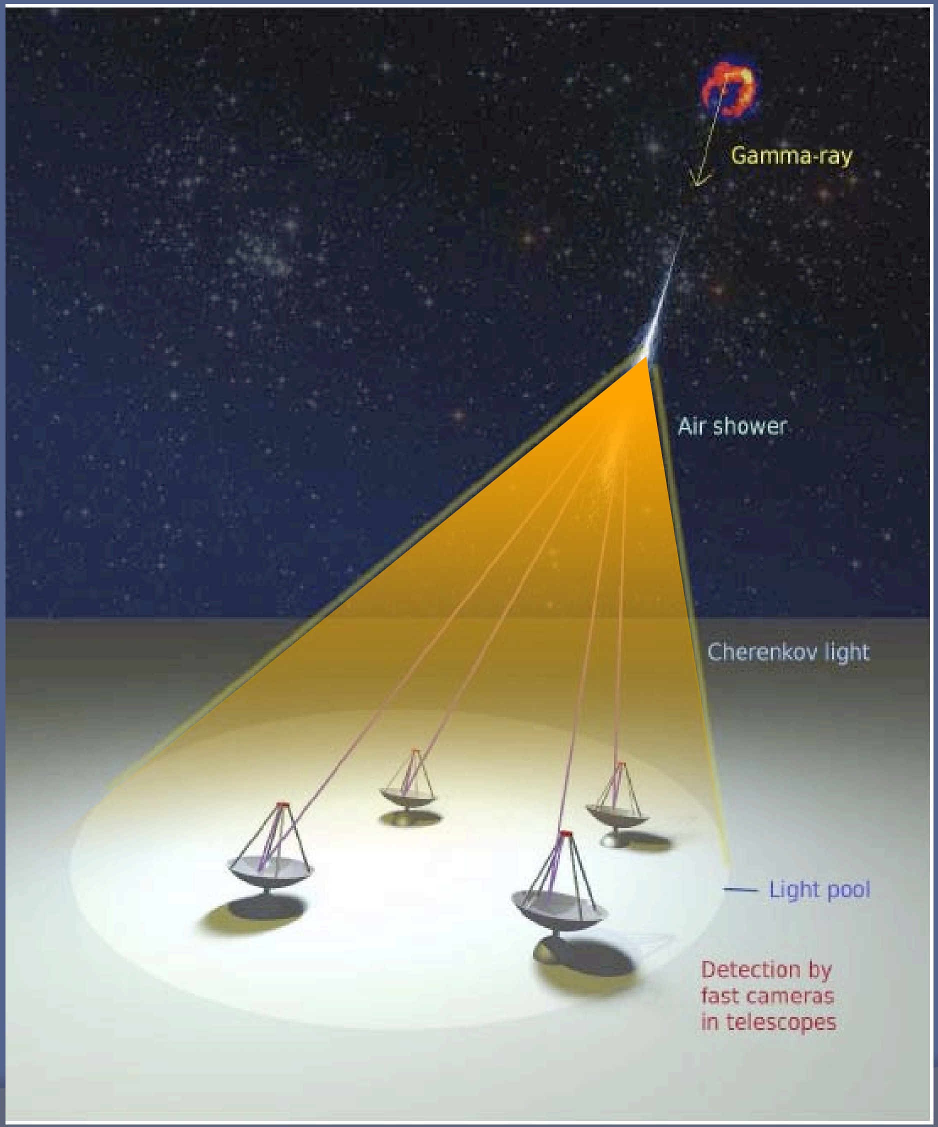
Masahiro Teshima

VHE Instruments

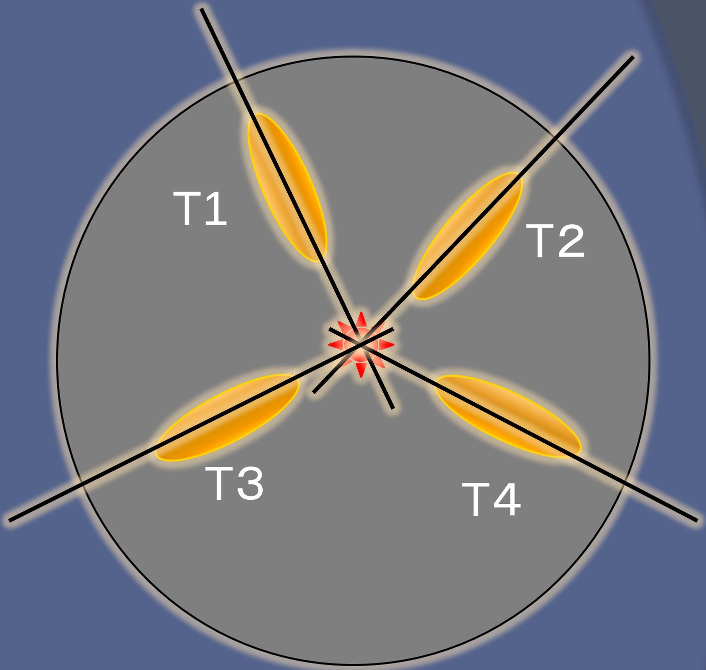



Origin of cosmic rays
apparent
source
direction
charged
particle
Gamma
Cosmic Rays + X -> π + X'
π0 -> γγ
π± -> μ + ν
μ -> e + νν

Imaging Air Cherenkov Telescope



Cherenkov Light
50photons/m^2 (5 pe/m^2) at 1TeV
➔ MAGIC 2 x240 m^2, HESS 4 x106 m^2



Typical parameters

Energy range 50GeV ~ 10TeV
CR rejection power >99%
Angular resolution ~0.1 degrees
Energy resolution ~20%
Detection area ~10^{5}m^2
Sensitivity ~1% Crab Flux (10^{-13} erg/cm^{2}s)

MAGIC Telescopes

New technologies
to lower the threshold energy

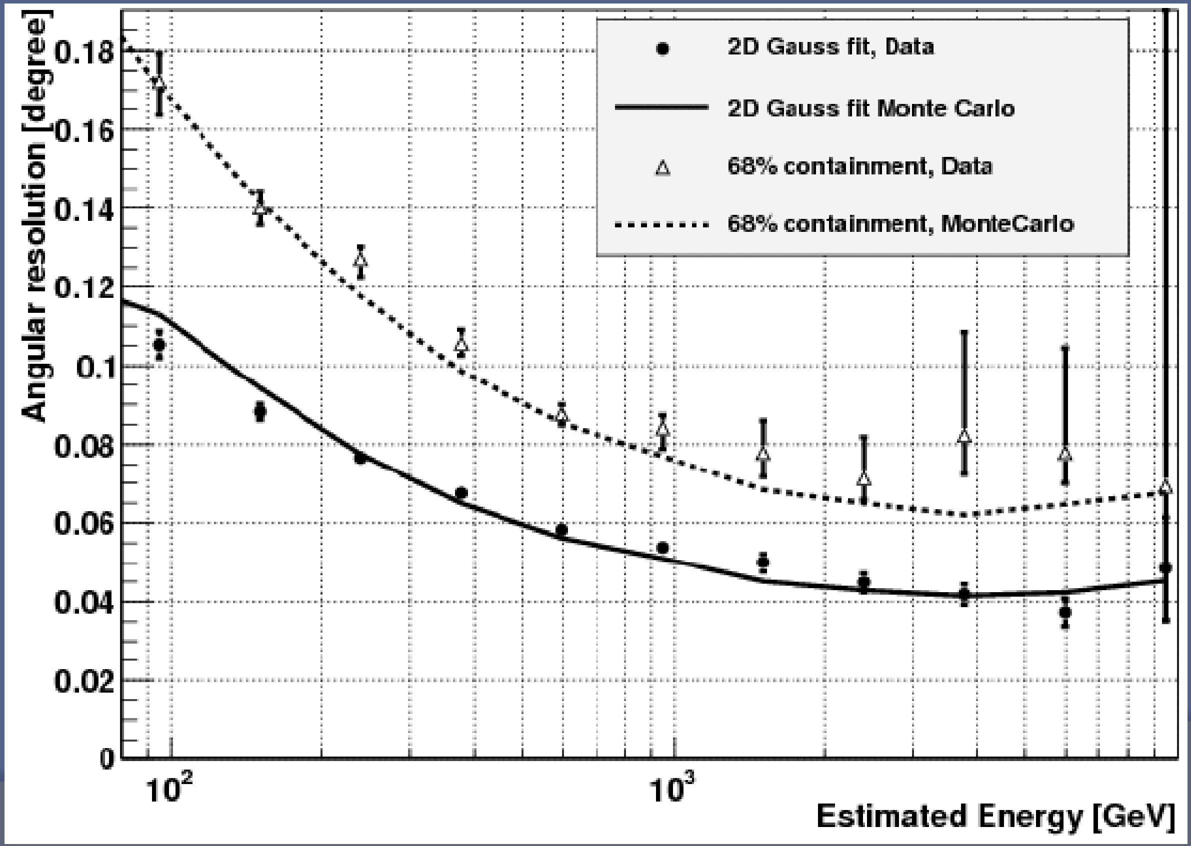
17m diameter world largest Cherenkov tel.
0.1° High resolution camera
Hemispherical High QE PMT
Optical fibre analogue signal transmission
2GS/sec Ultra Fast FADCs
Fast rotation for GRB ~20secs/180deg.
Trigger threshold ~50GeV ➔ ~25GeV

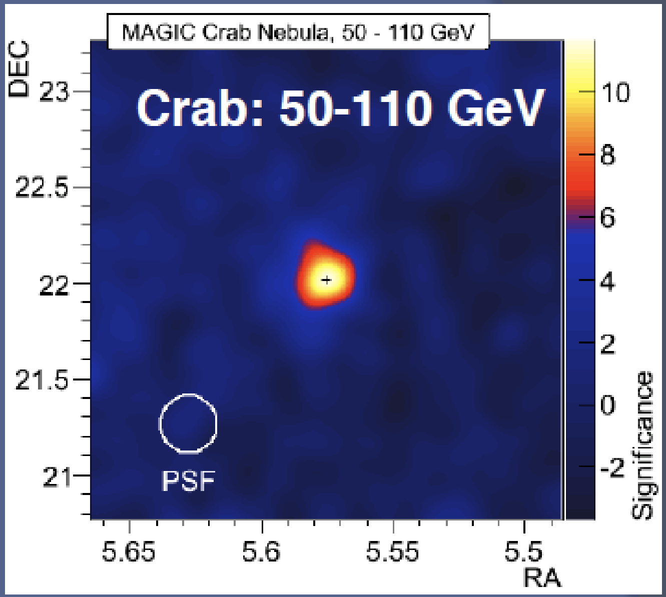
Upgrade from MAGIC to MAGIC Stereo
Regular operation since September 2009

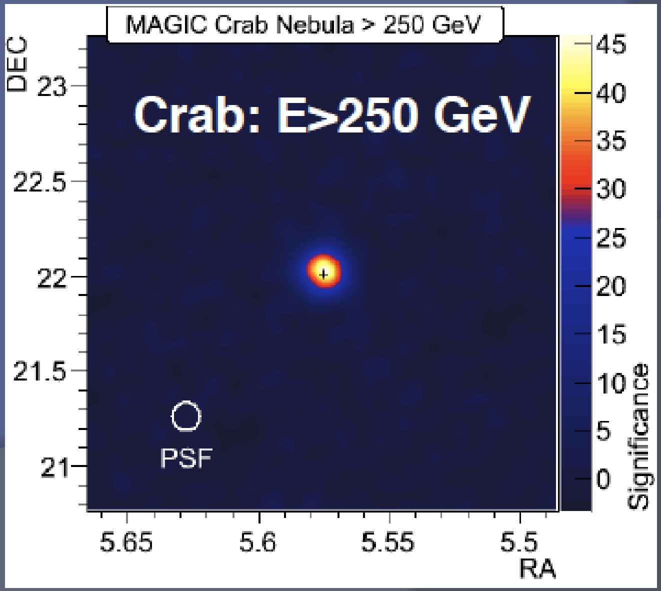
Sensitivity 1.6% Crab ➔ ~0.6% Crab (50hrs)
Angular resolution 1.0 deg ➔ 0.06 deg
Energy resolution 25% ➔ 15%

Angular Resolution in MAGIC Stereo

Data and MC agrees very well !!
~ 0.1 degrees at 100GeV
~ 0.5 degrees at 1000GeV

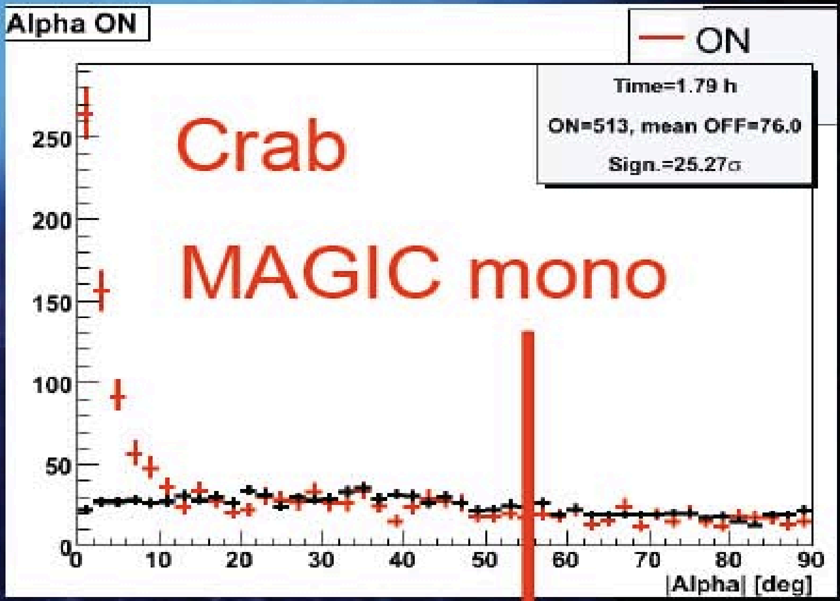


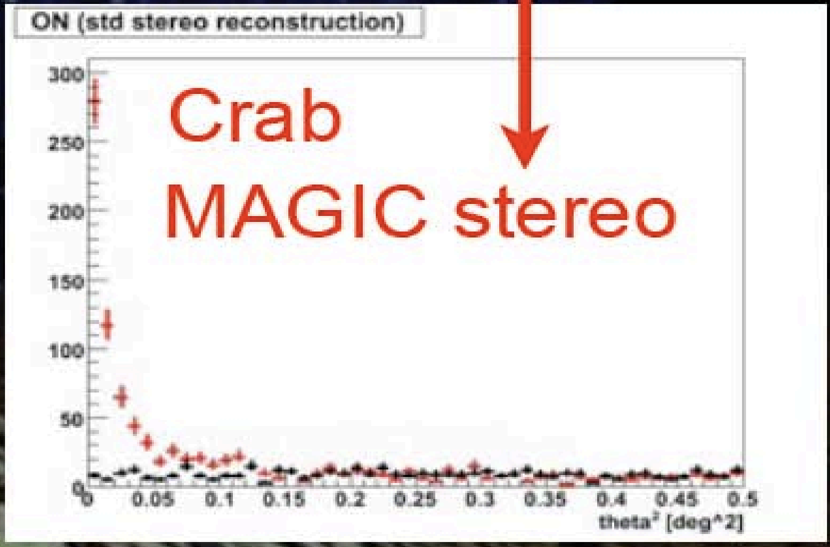


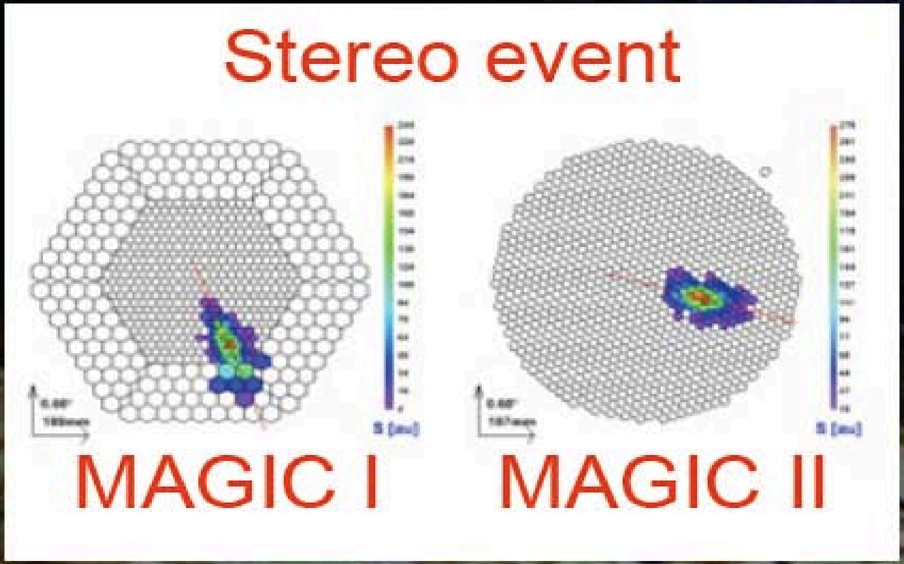


Started regular observations from October 2009

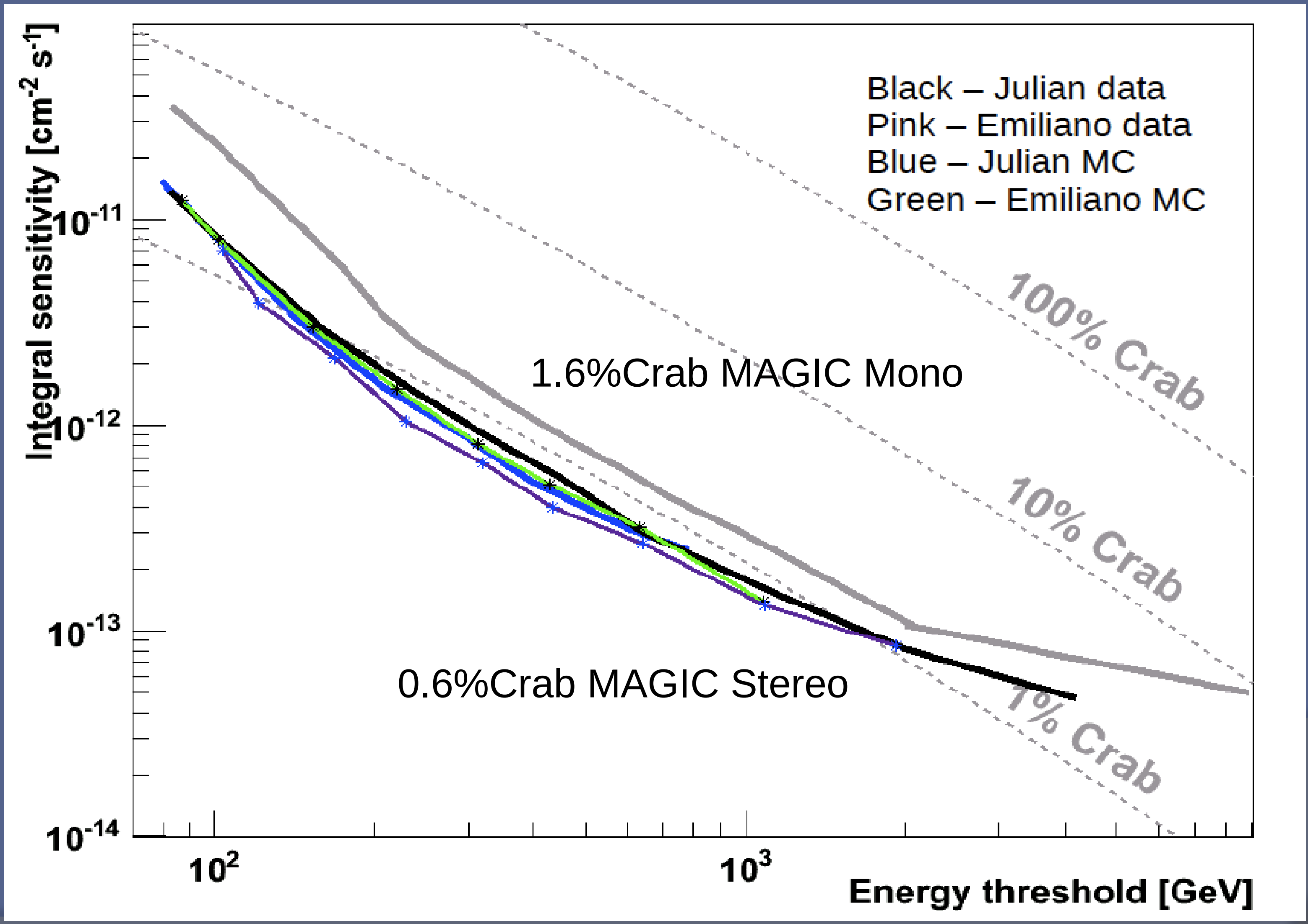
- Better hadron rejection
- Better angular resolution (0.06 degrees)
- Better energy resolution (25%-15%)
- Enhance the sensitivity over the whole energy range



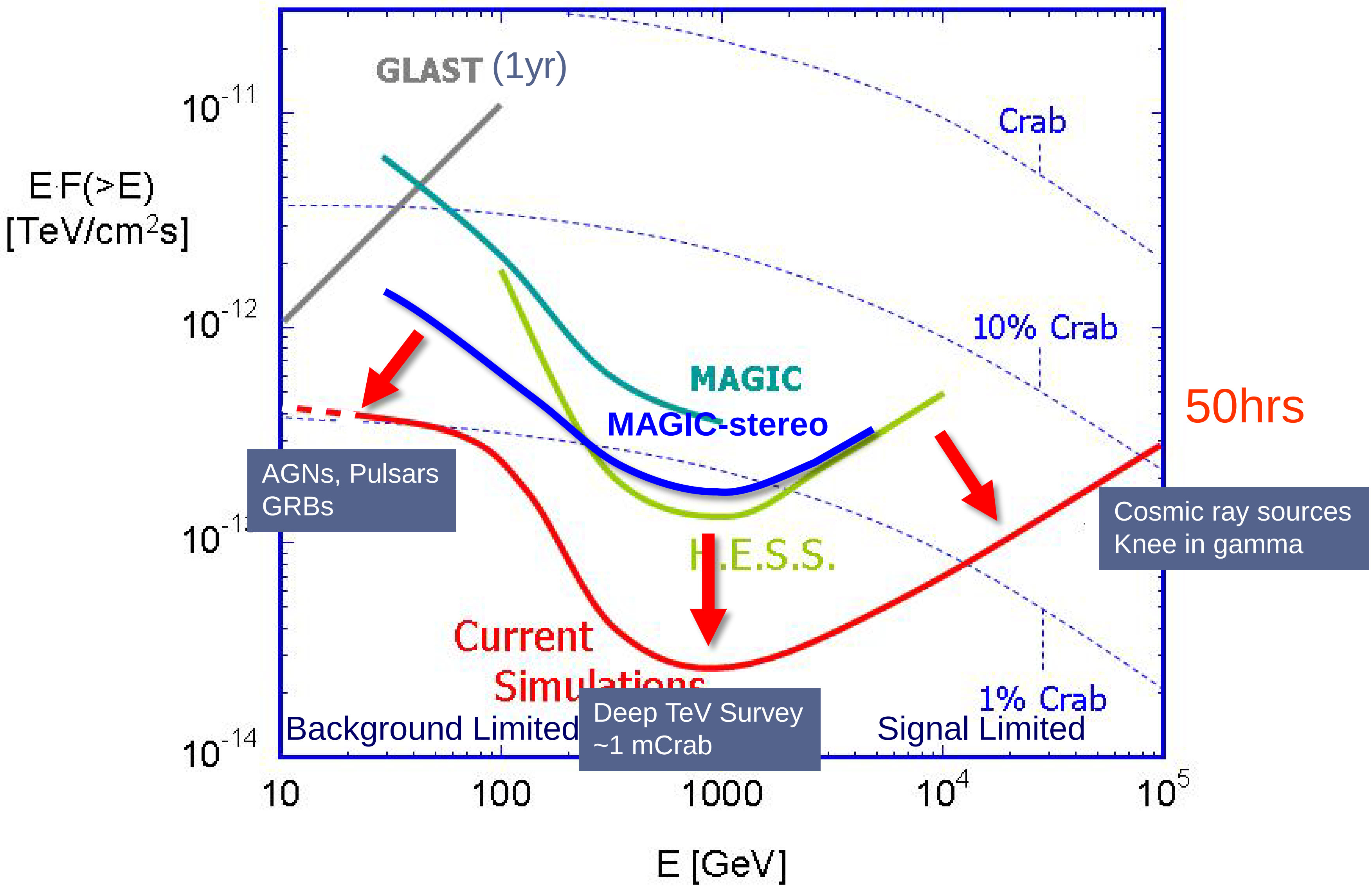




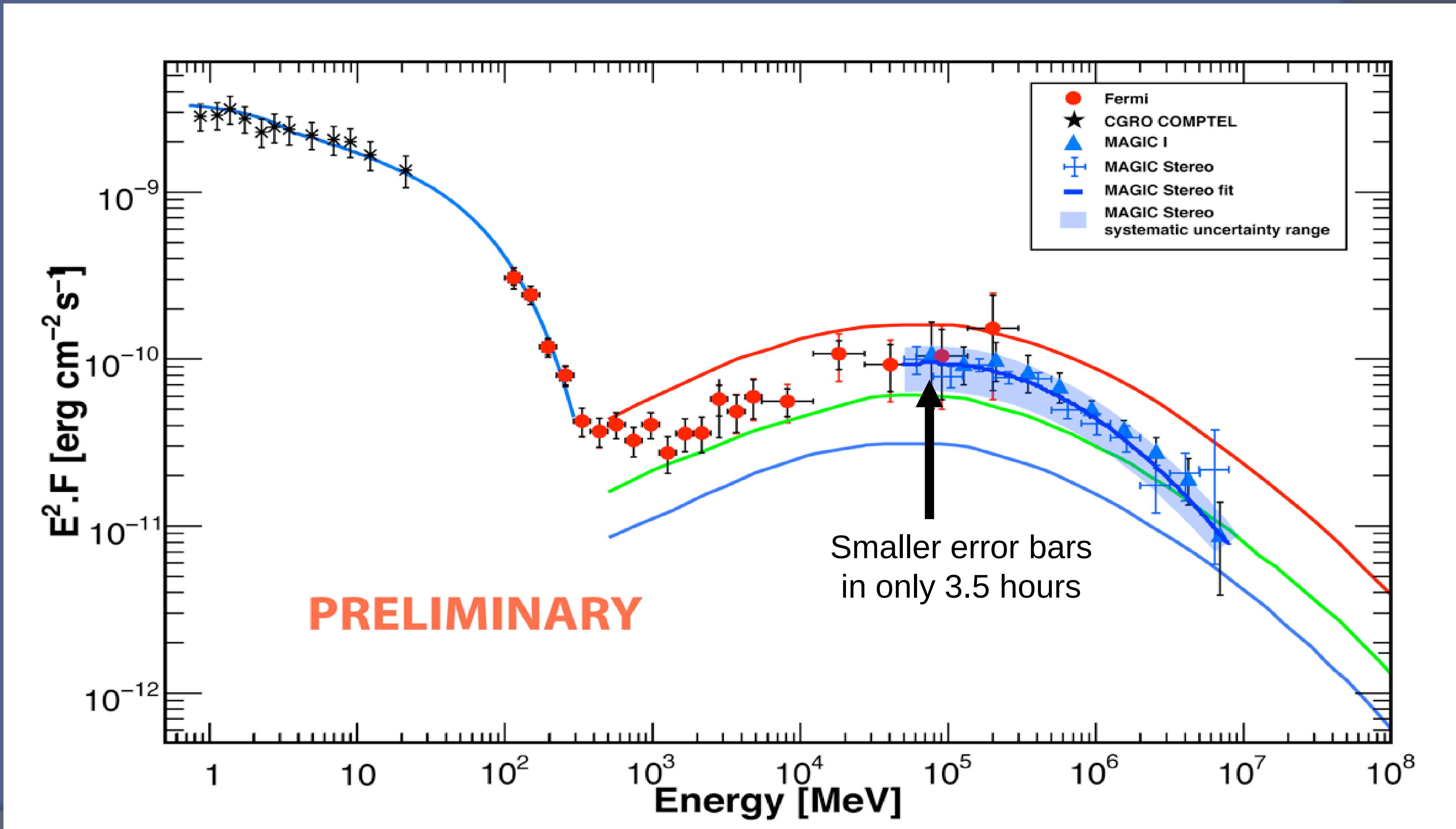
Sensitivity of MAGIC Stereo achieved (~0.6% Crab), factor 3 better than mono



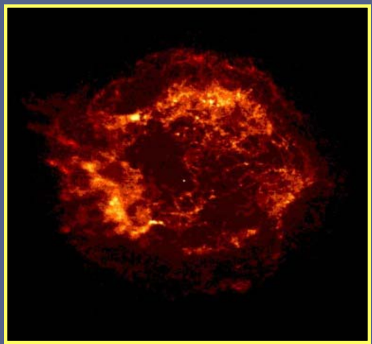
Sensitivity of MAGIC Stereo achieved (~0.6% Crab)



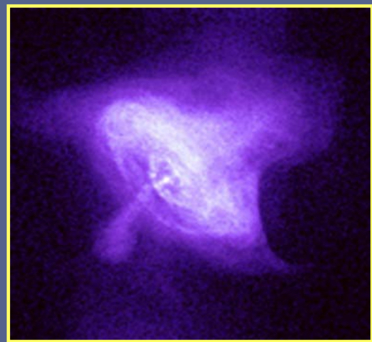
Crab Nebula 3.5hr observation with MAGIC-Stereo



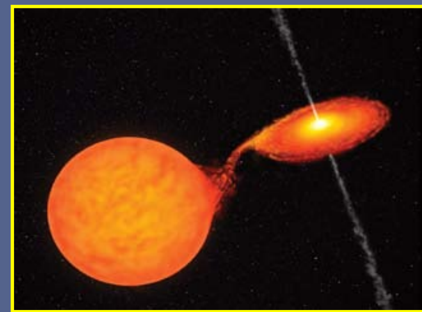
Physics objectives



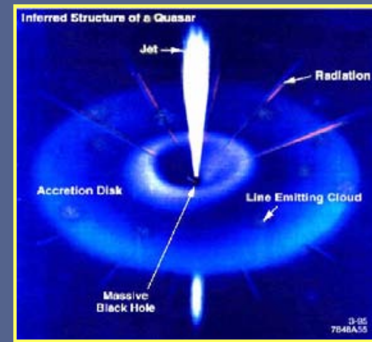
SNRs



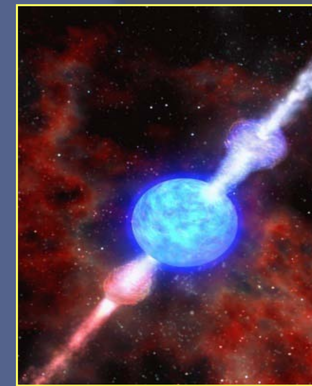
Pulsars
and PWNe



Micro quasars
X-ray binaries



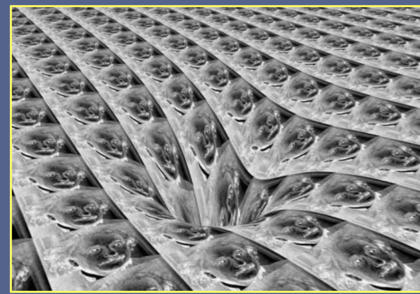
AGNs



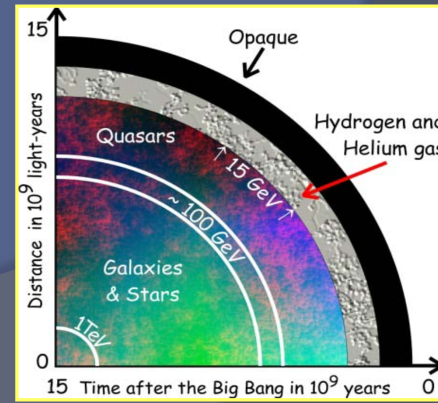
GRBs

Origin of
cosmic rays

Dark matter

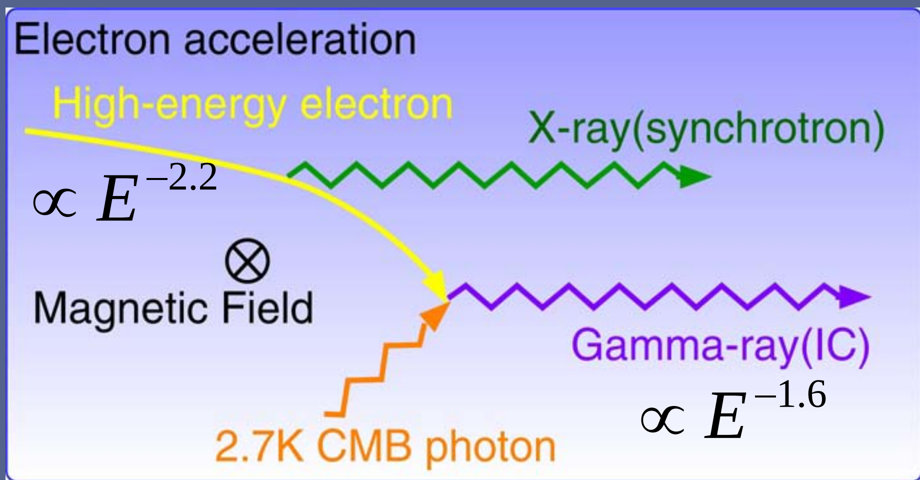


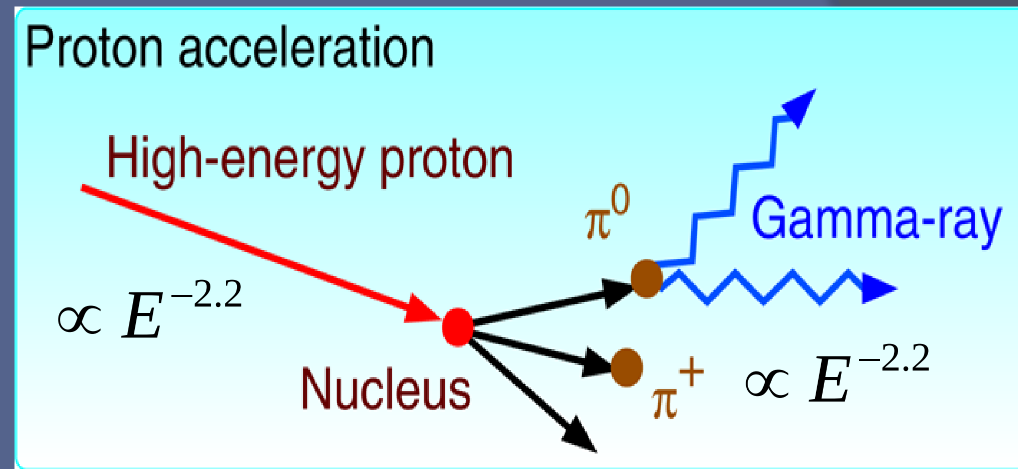
Space-time
& relativity



Cosmology

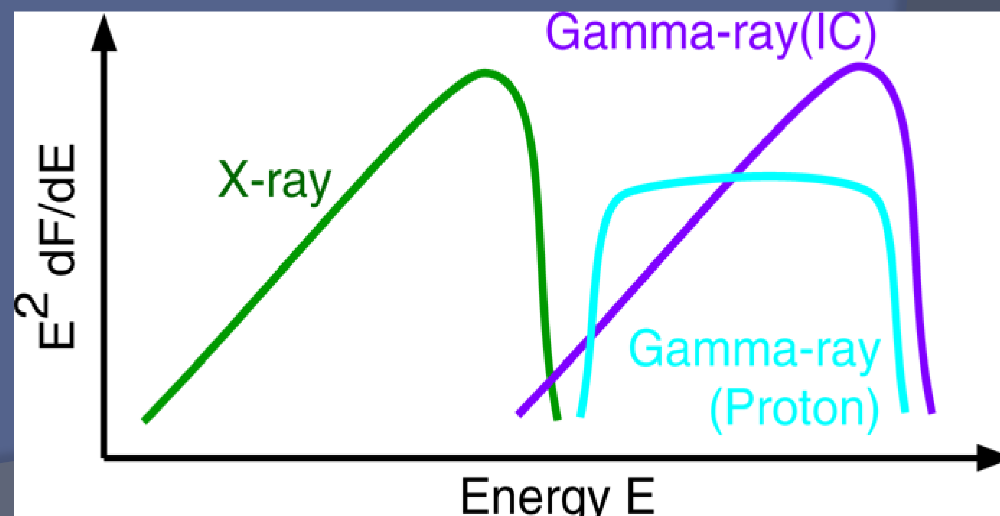
Gamma-Ray Emission Processes(1)
Astrophysical process





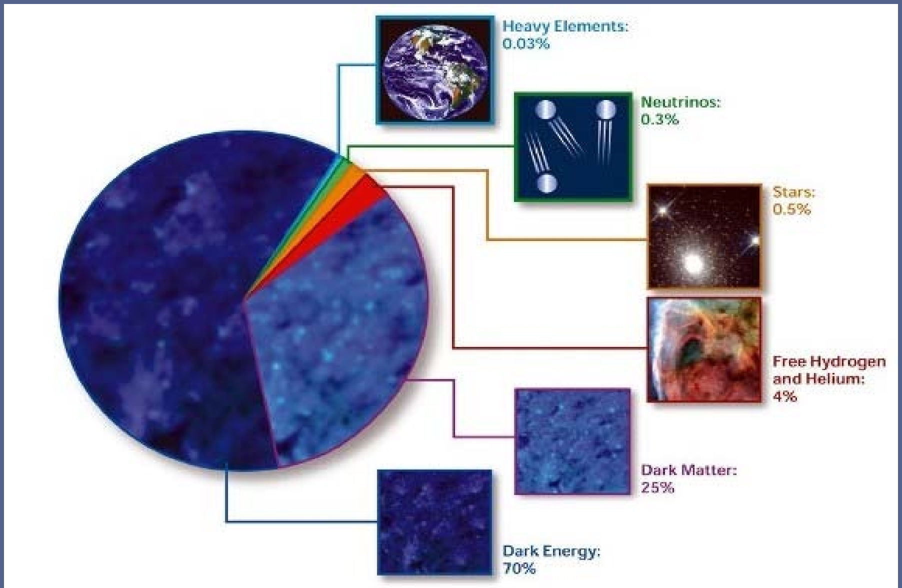
$$\left(\frac{dE}{dt}\right)_{\mathrm{I.C.}} = \frac{4}{3}\sigma_{\mathrm{T}}\, c\, \gamma_{\max}^{2}\, \mathrm{U}_{\mathrm{photon}}$$

$$\left(\frac{dE}{dt}\right)_{\mathrm{Sync}} = \frac{4}{3}\sigma_{\mathrm{T}}\, c\gamma_{\max}^{2}\, \frac{B^{2}}{2}$$

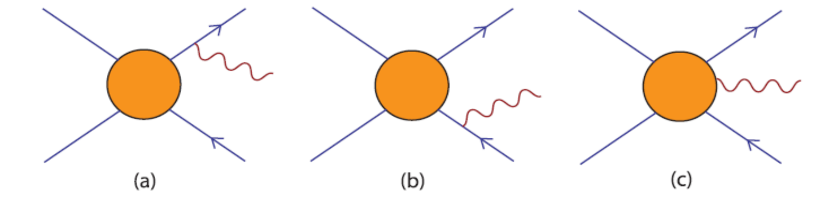


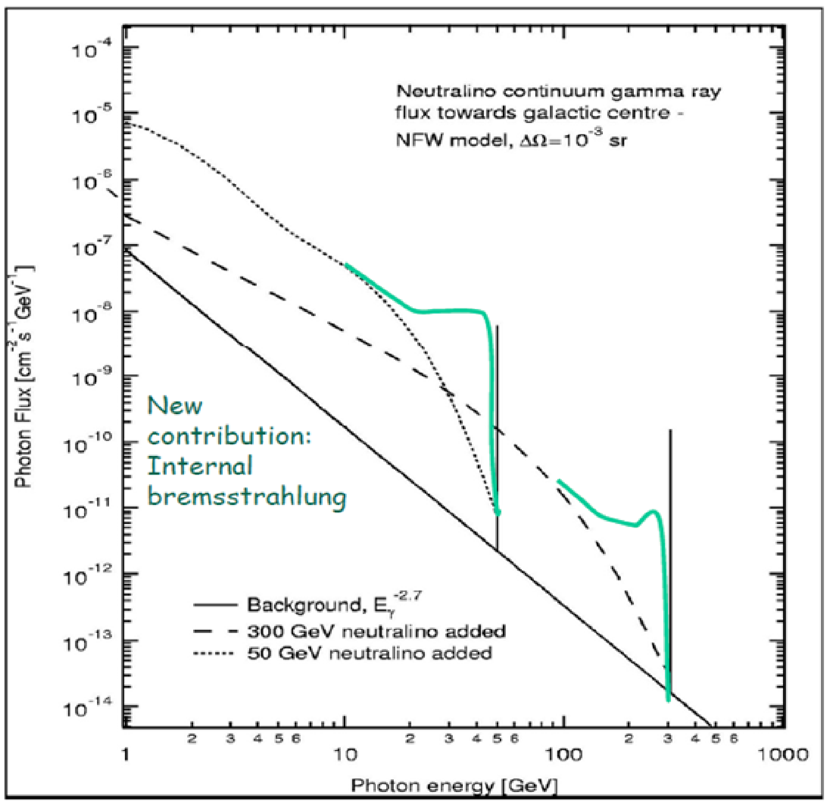
Gamma ray emission process from DM Annihilation

Dark Matter Annihilations

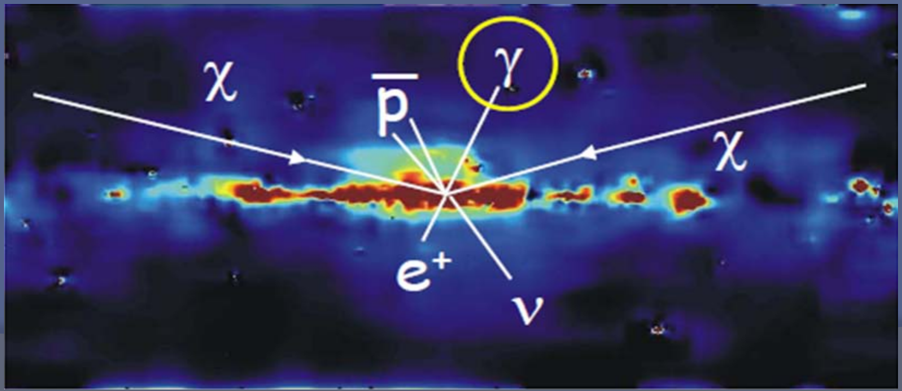


Bergstrom et al.

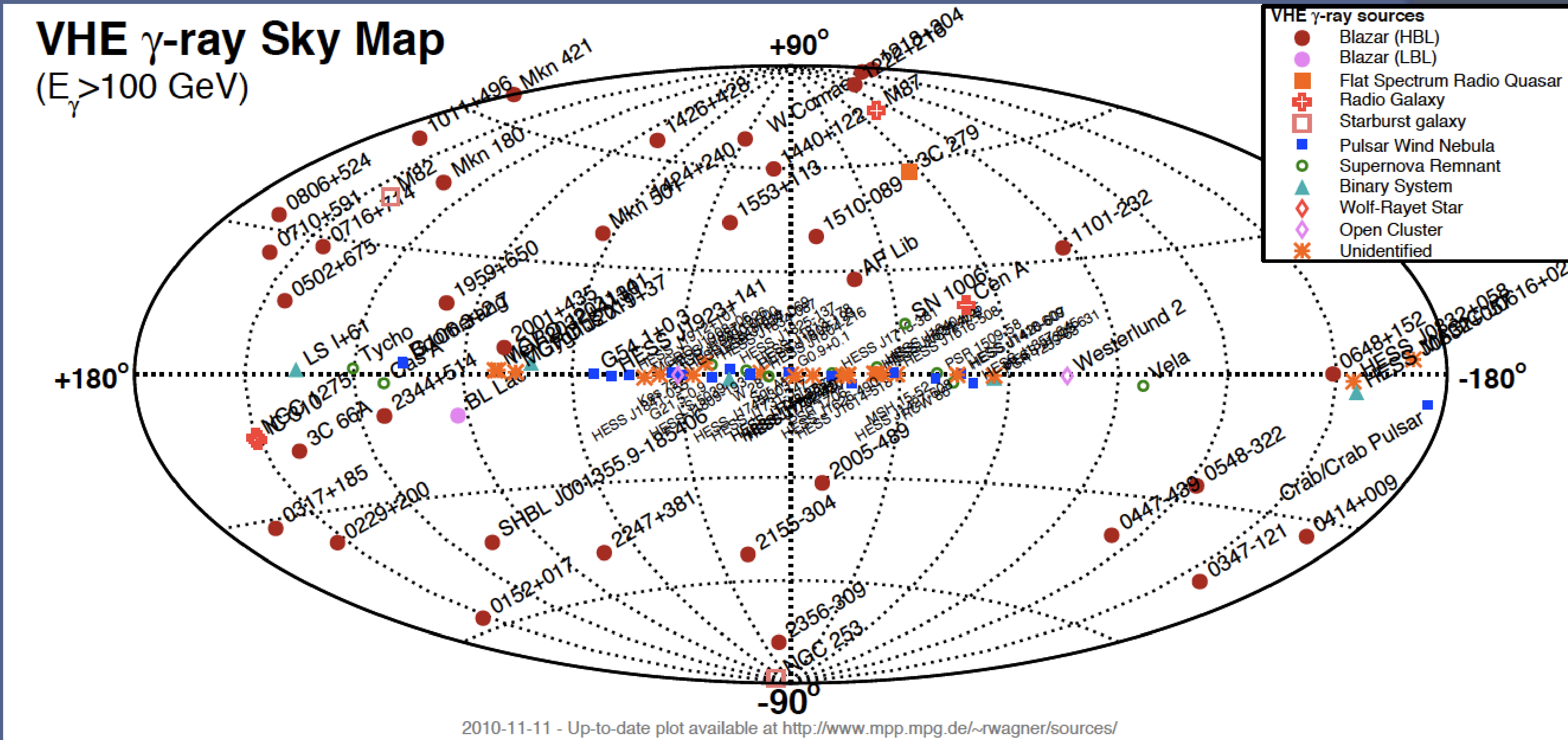




L.B., P.Ullio & J. Buckley 1998 T. Bringmann, L.B., J. Edsjö, 2007



VHE Skymap

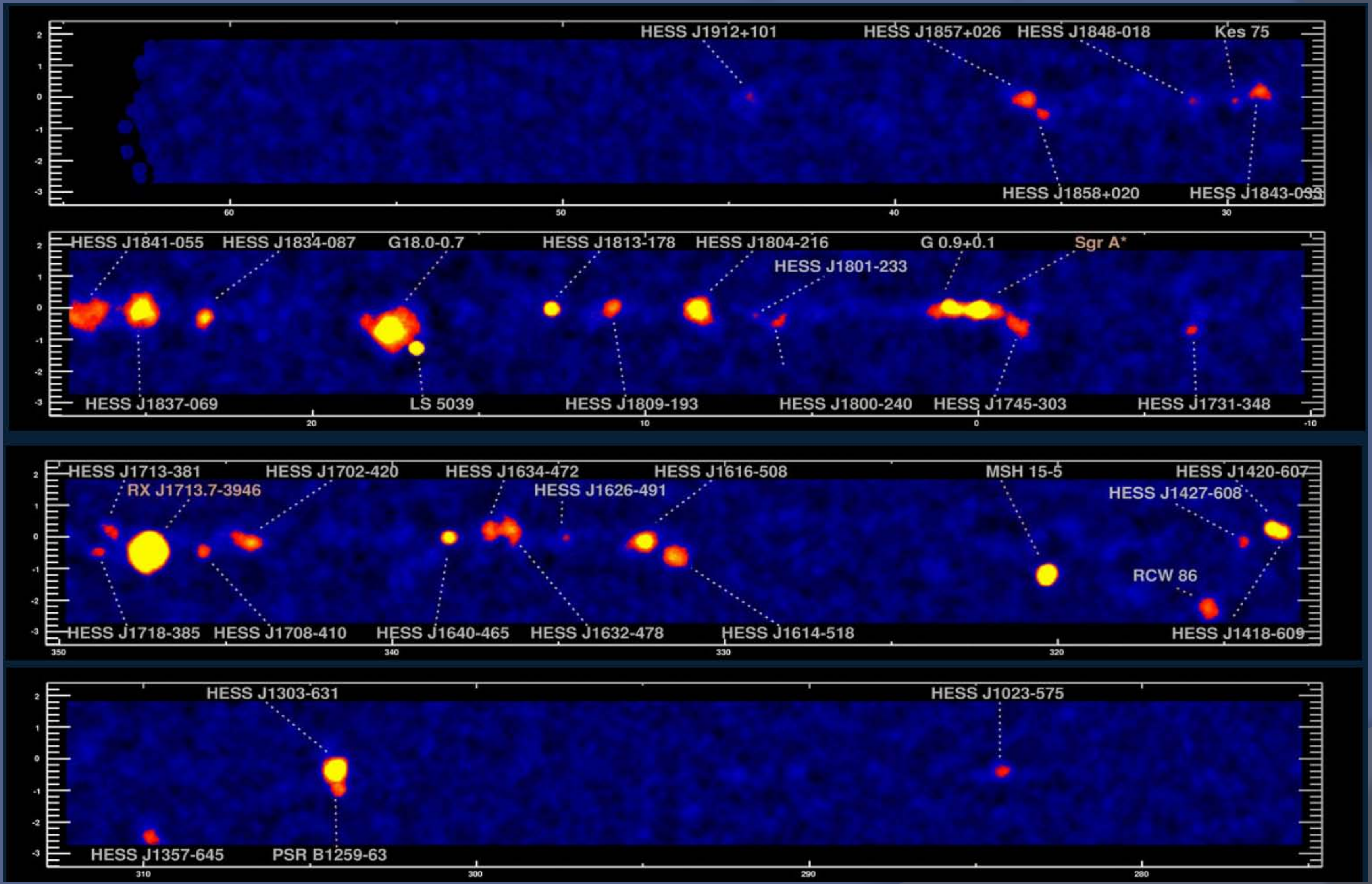


106 sources (45 Extragalactics + 61 Galactics) in Nov 2010

Blazars, FSRQs, FR-I, Starburst galaxies SNRs, PWNe, Pulsar, Binaries, un-IDs

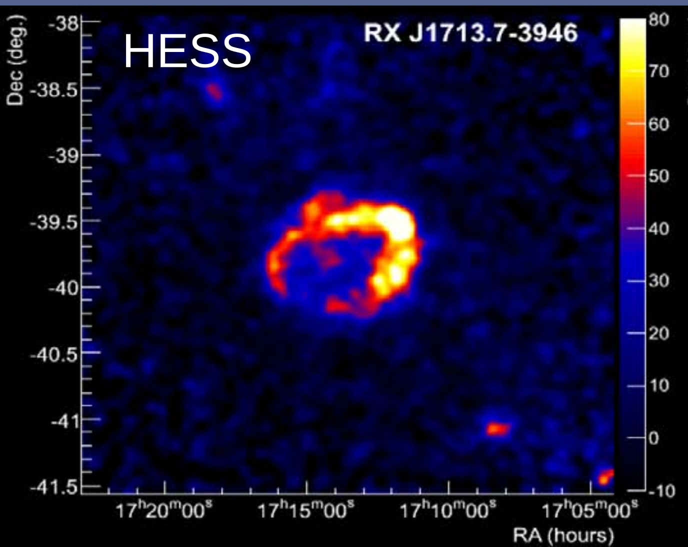
[redacted]

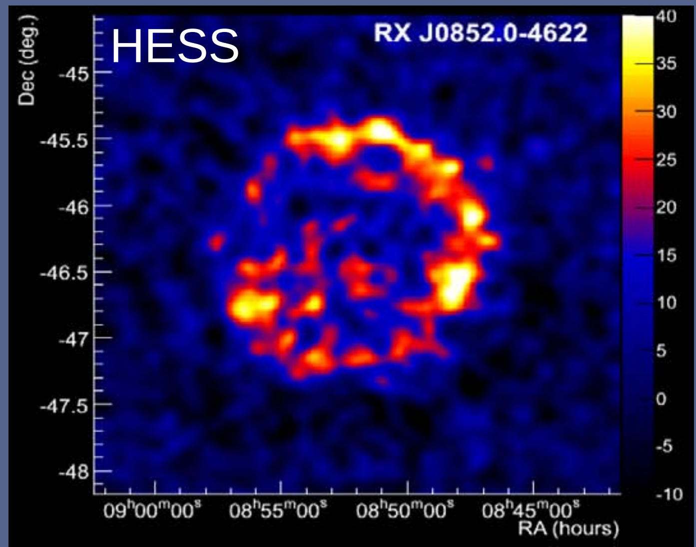
Great success!! HESS galactic plane survey



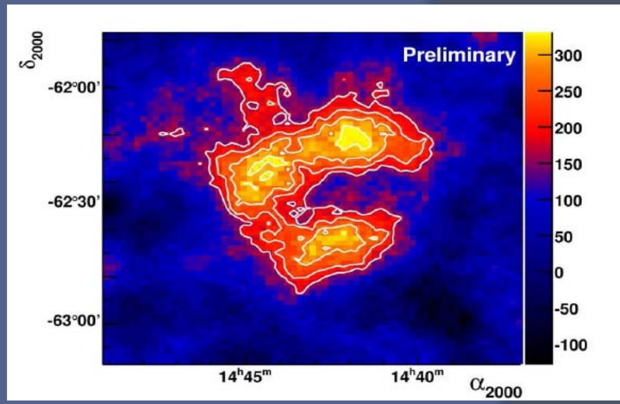
PWNe, SNRs, Binaries, un-IDs

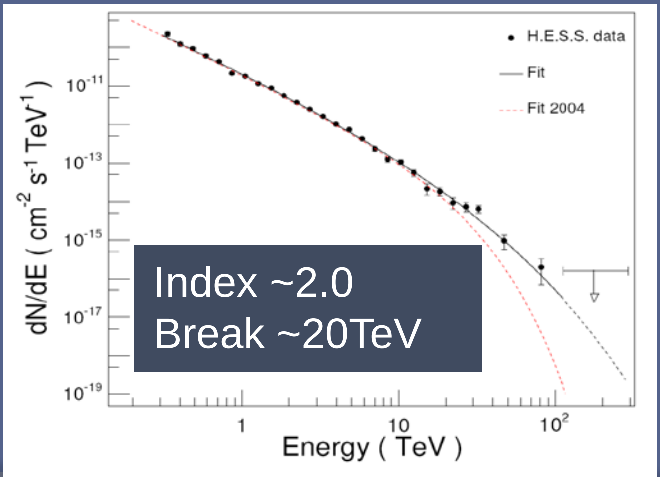
HESS: Shell type SNRs
RX J1713, RX J0852, RCW86

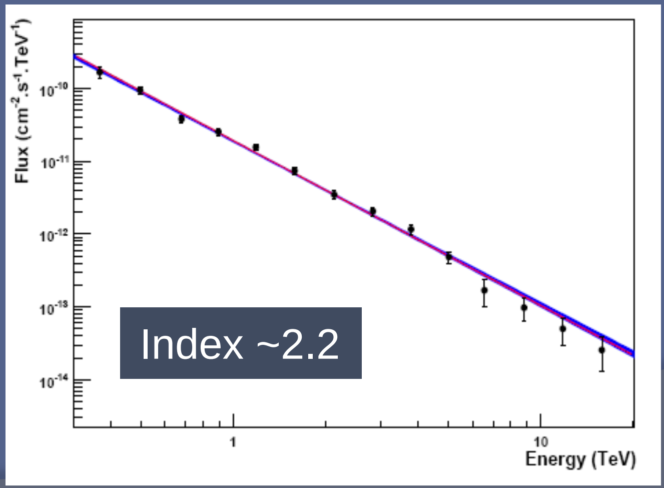


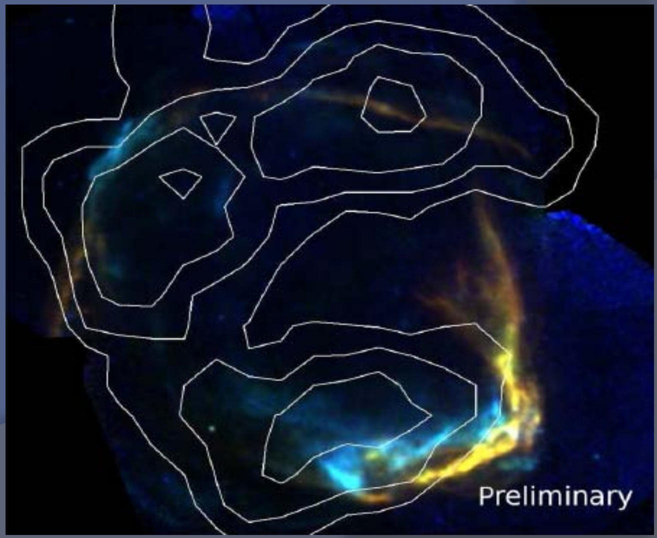


HESS RCW86



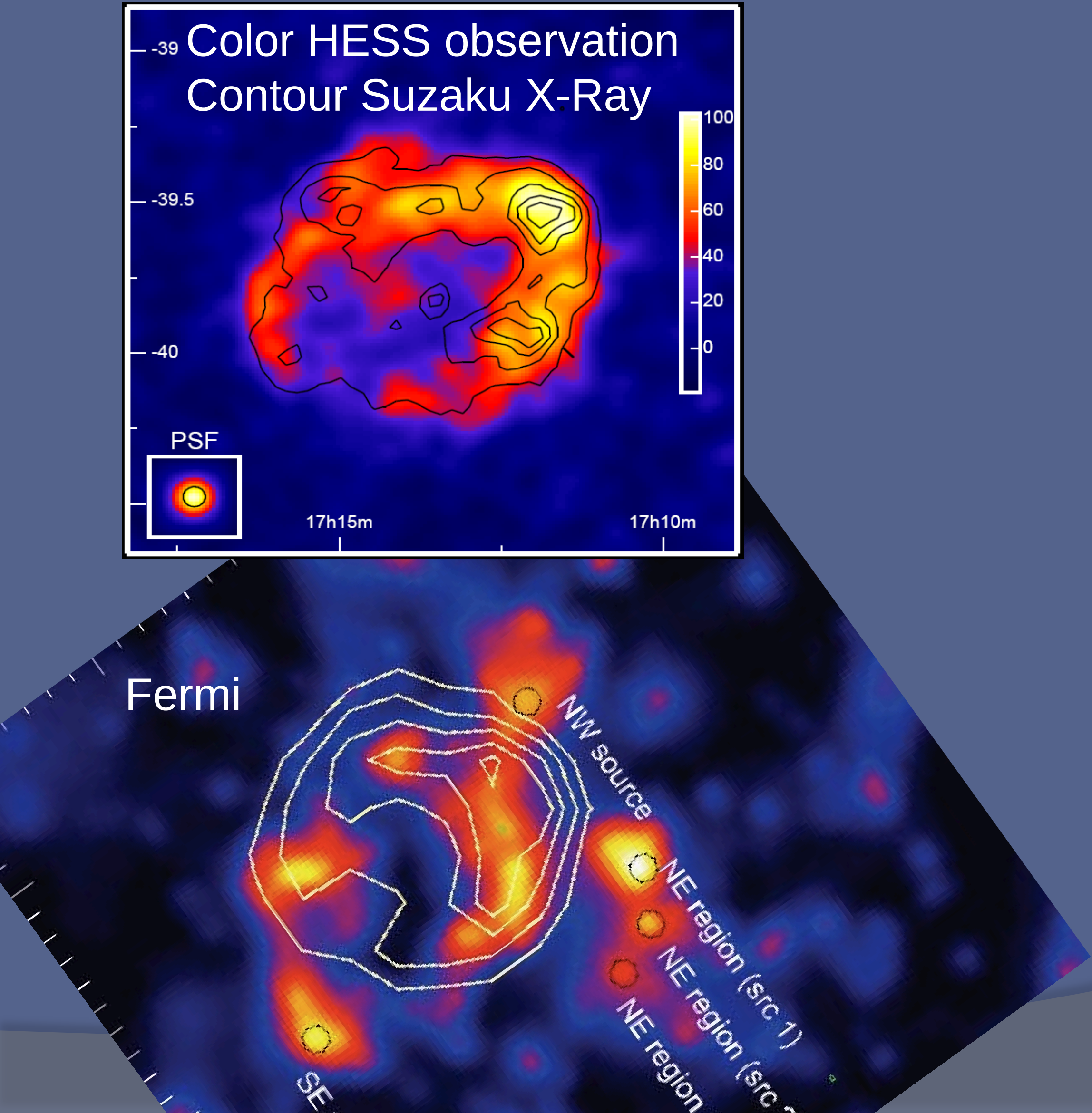


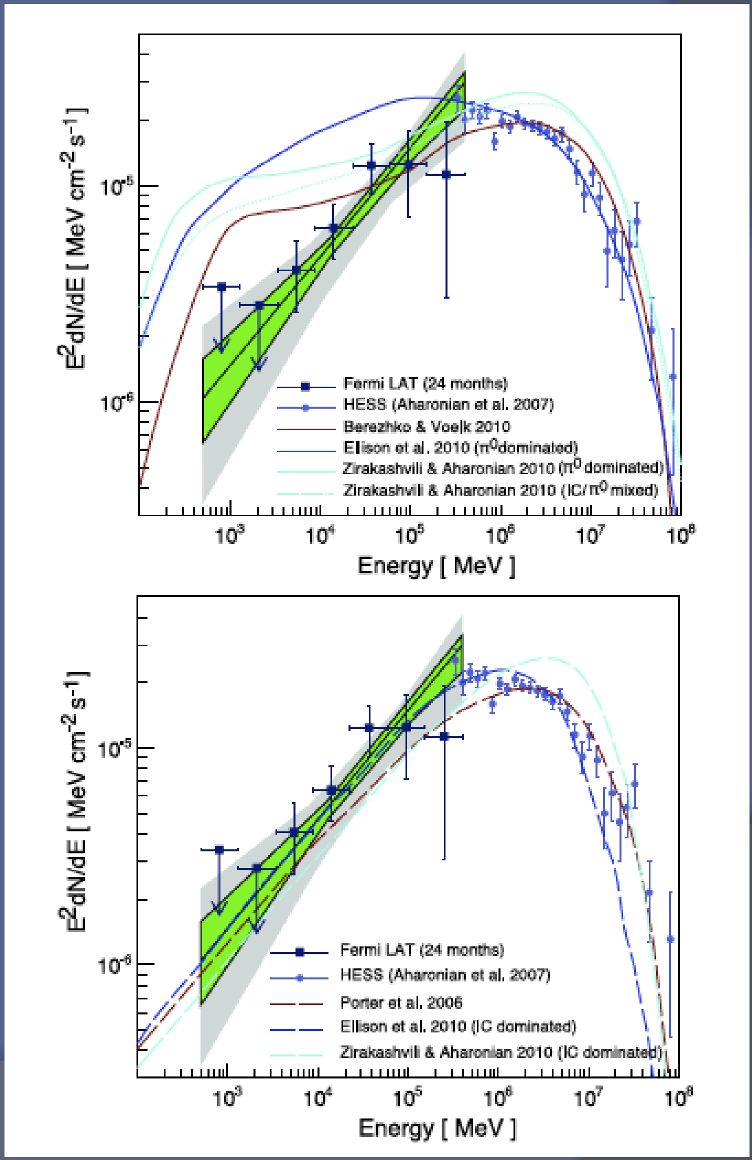




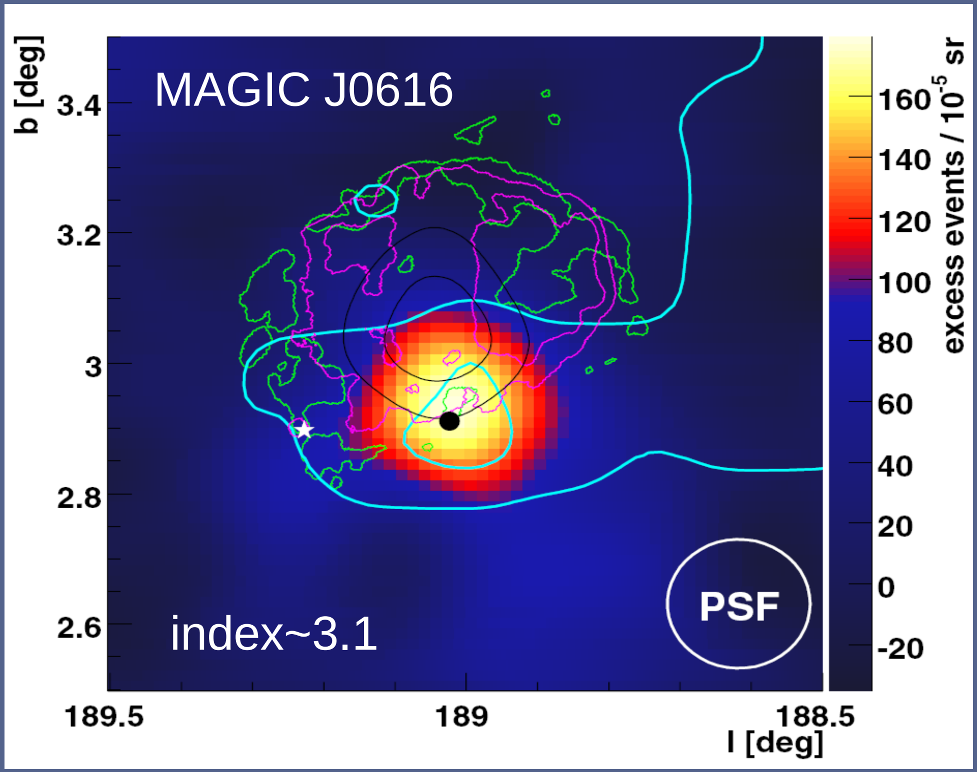
XMM-Newton, HESS

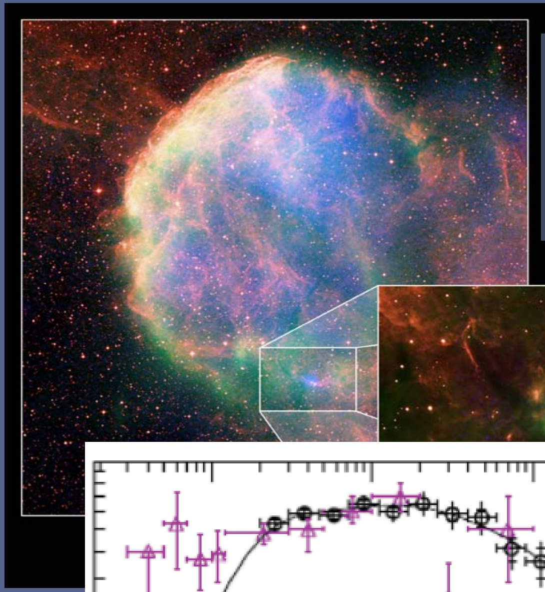
SNR Study
RX J1713 HESS + Fermi



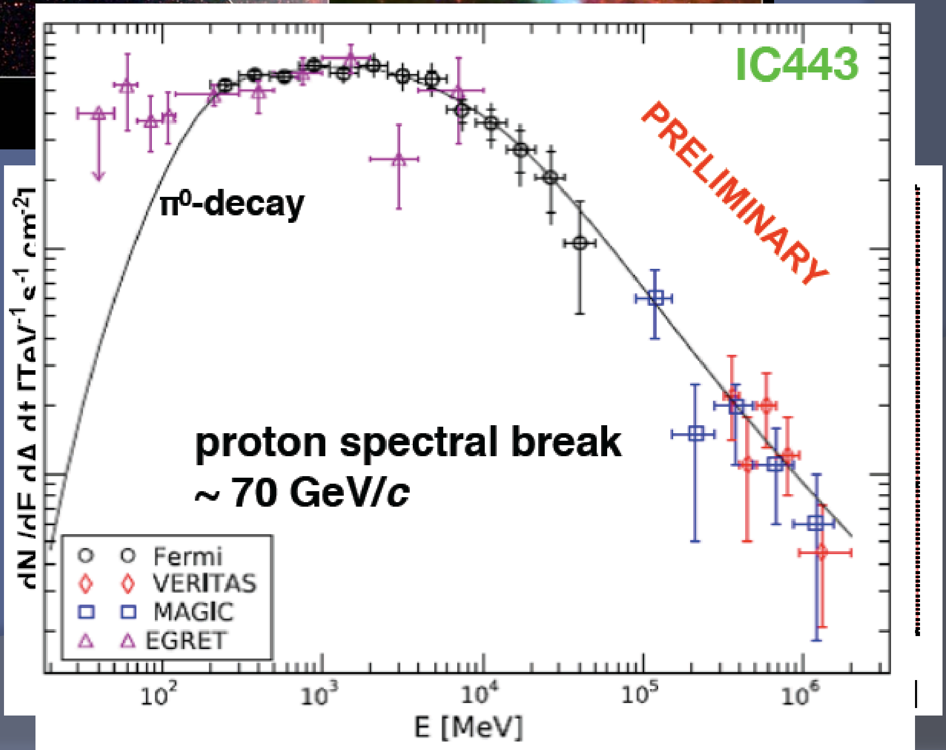


MAGIC: Shell type SNRs
IC443(MAGIC J0616)





Composite image
With X(Chandra),
Radio(VLA),
Optical (DSS)



Molecular Cloud

Radio

X-ray

EGRET 3EG J0617+2238

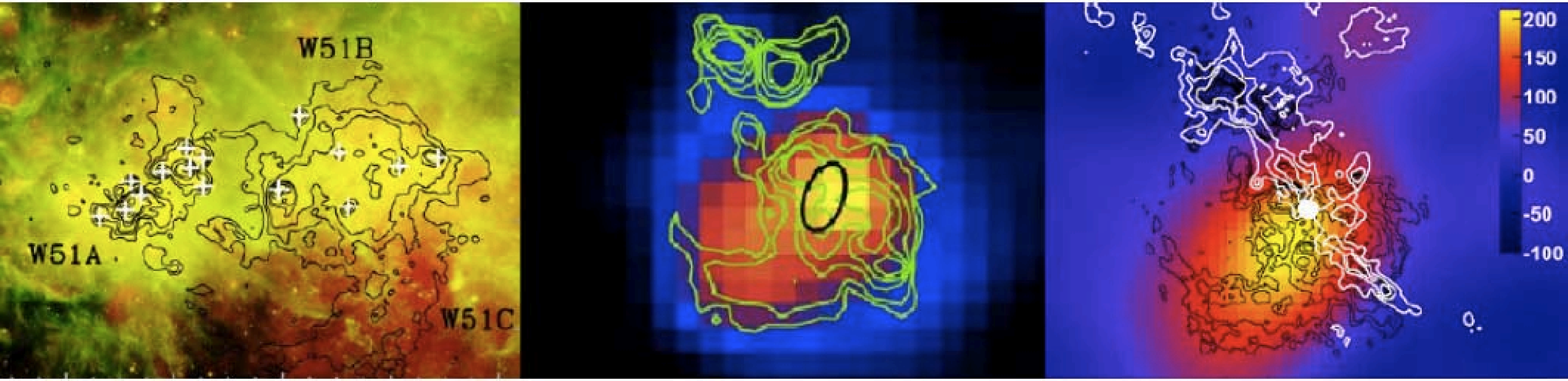
Pulsar CXOU J061705.3+222127

SNR W51

MIPS & IRAC
24 (red) & 8.0 (green) μm
Miju Kang et al. 2009 ApJ 706 83

Fermi / LAT
2-10 GeV
arXiv:1104.1197v1

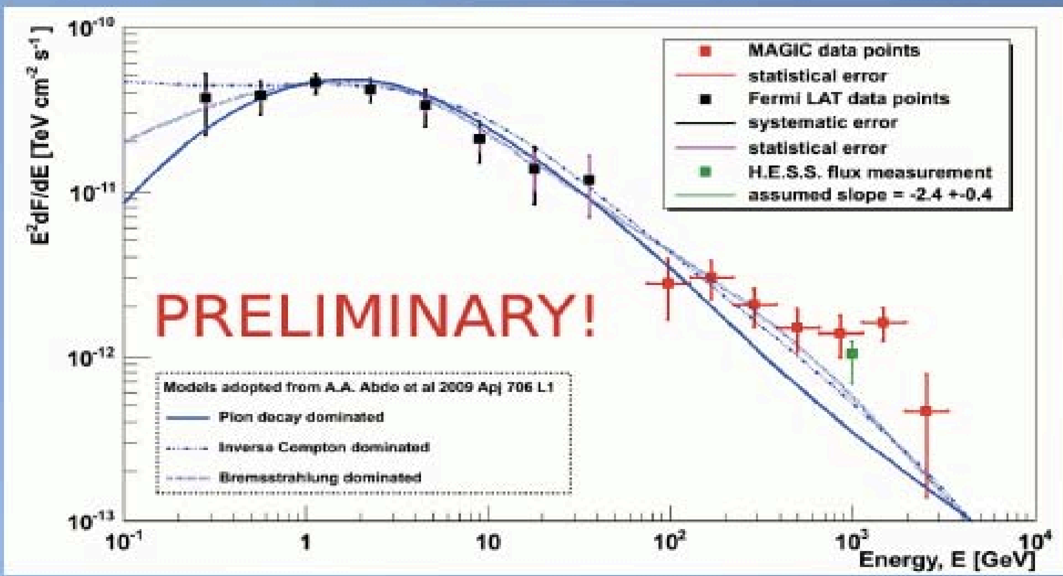
H.E.S.S.
>1 TeV
ICRC 2009



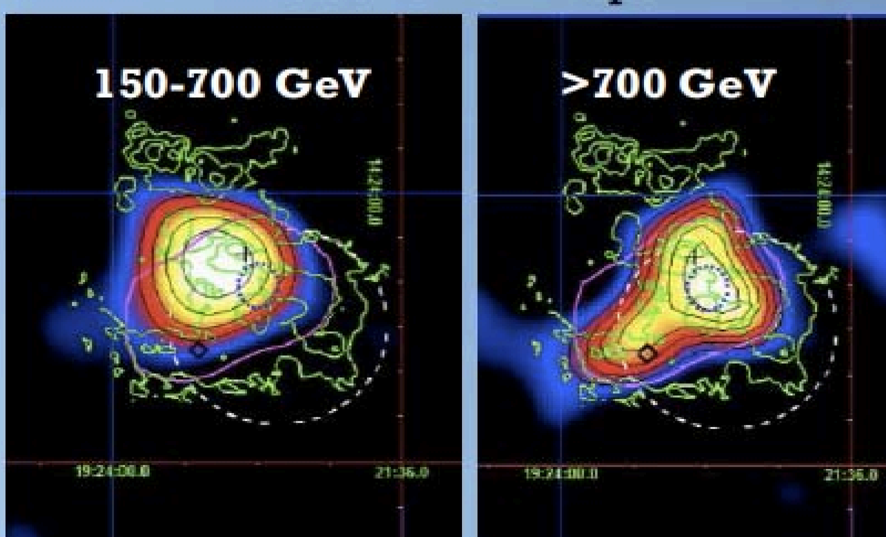
One of the most luminous star forming region (distance ~ 6kpc)
W51C is a medium age (~30kyr) Super Nova Remnant
Shell of the remnant is interacting with surrounding molecular cloud
Discovery by Fermi/LAT (GeV) and HESS (4.4 σ at 1TeV)

Promising candidate SNR to test and study cosmic ray acceleration

MAGIC results for W51C

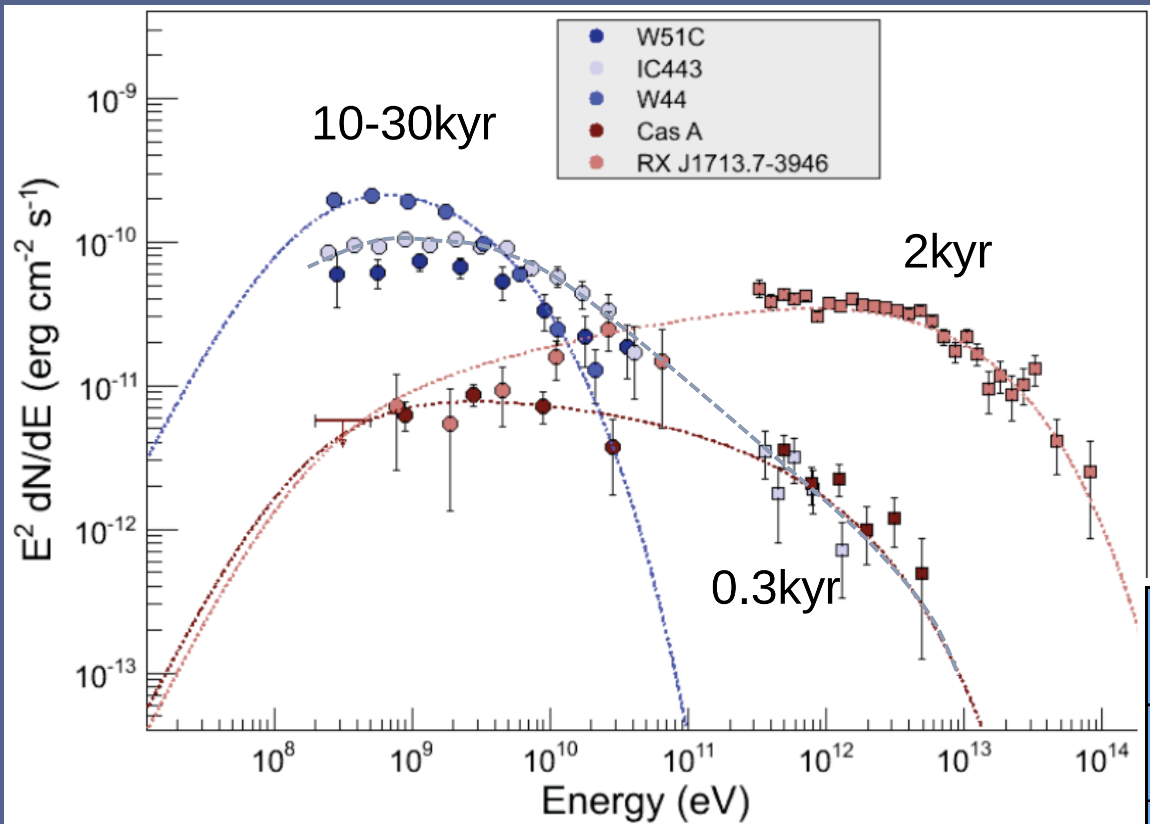


Relative Flux Maps



- Observation: 31.1 h in 2010
- Extended emission: 0.16°
- Maximum of the emission coincides with the shocked cloud regions
- Models based on Fermi / LAT + radio data predict a too softer spectrum than MAGIC sees
- Morphology suggests hadronic or other mechanisms:
  - particle spectrum hardens at high energies
  - High energy particles penetrate more effectively dense regions
  - other sources > 100 GeV

SNRs in different evolutionary stages



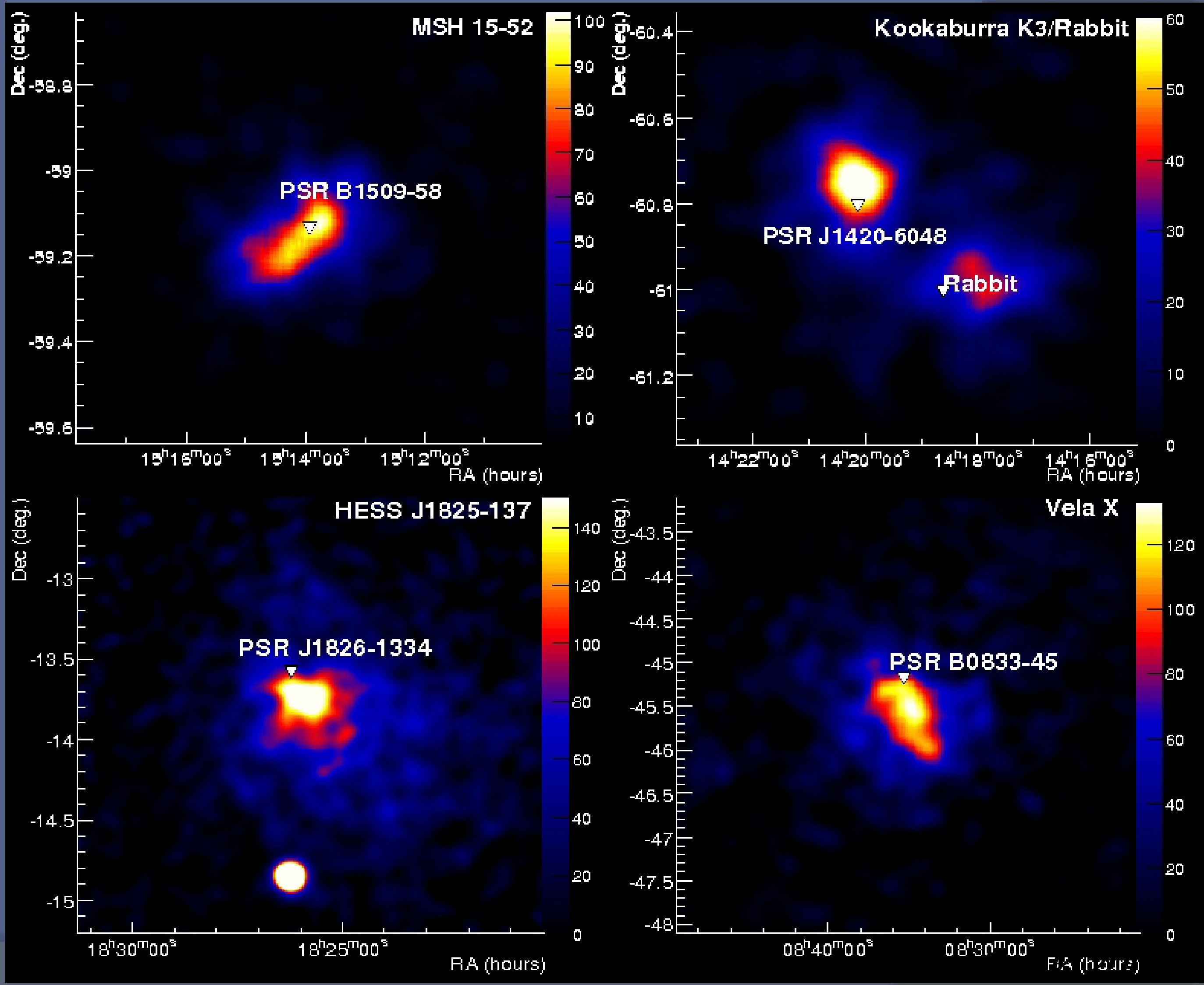
We can study SNRs in different evolutionary stages

	Cas A	RX J1713.7 -3946	IC443	W44	W51C
Age (kyears)	0.3	2	10	20	30
$n_{average}$ (cm-3)	10	0.1	10	100	10
$CR_{fraction}$	2%	50%	25%	5%	10%

Courtesy of S.Funk

Pulsar Wind Nebulae observation by HESS

- Major galactic TeV source population
  - Associated with relatively young (<10^5 year old) and energetic pulsars
- Generally believed that we see inverse Compton emission of 1-100 TeV electrons
- 1% of Spin-down energy goes to VHE gamma rays



Pulsar Wind Nebula HESS J1825-137 Energy Dependent Morphology

- Major galactic TeV source population
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- Generally believed that we see inverse Compton emission of 1-100 TeV electrons
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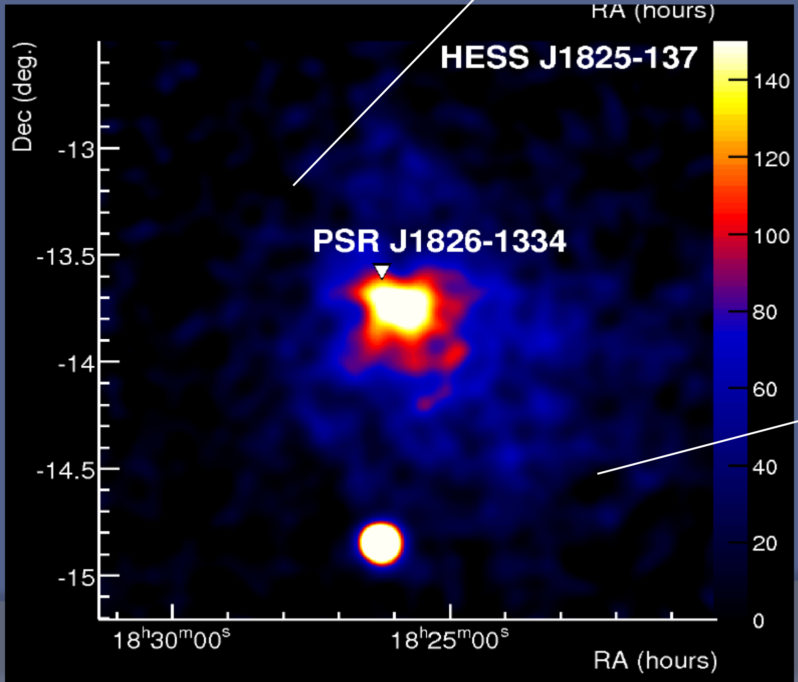
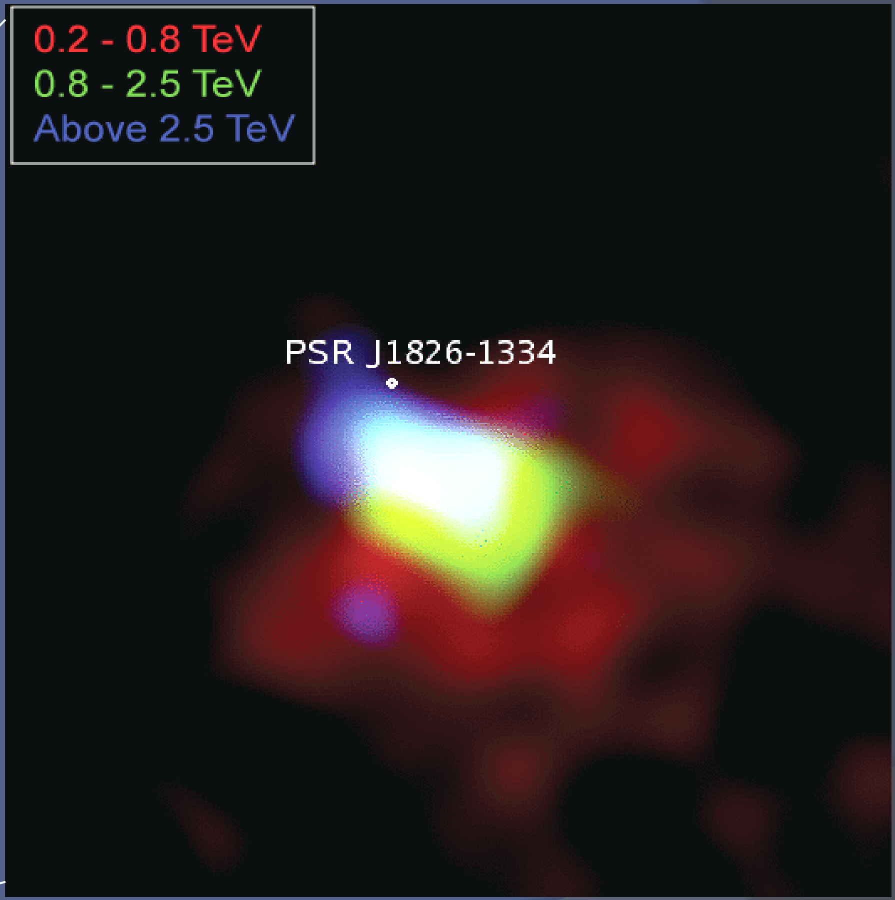
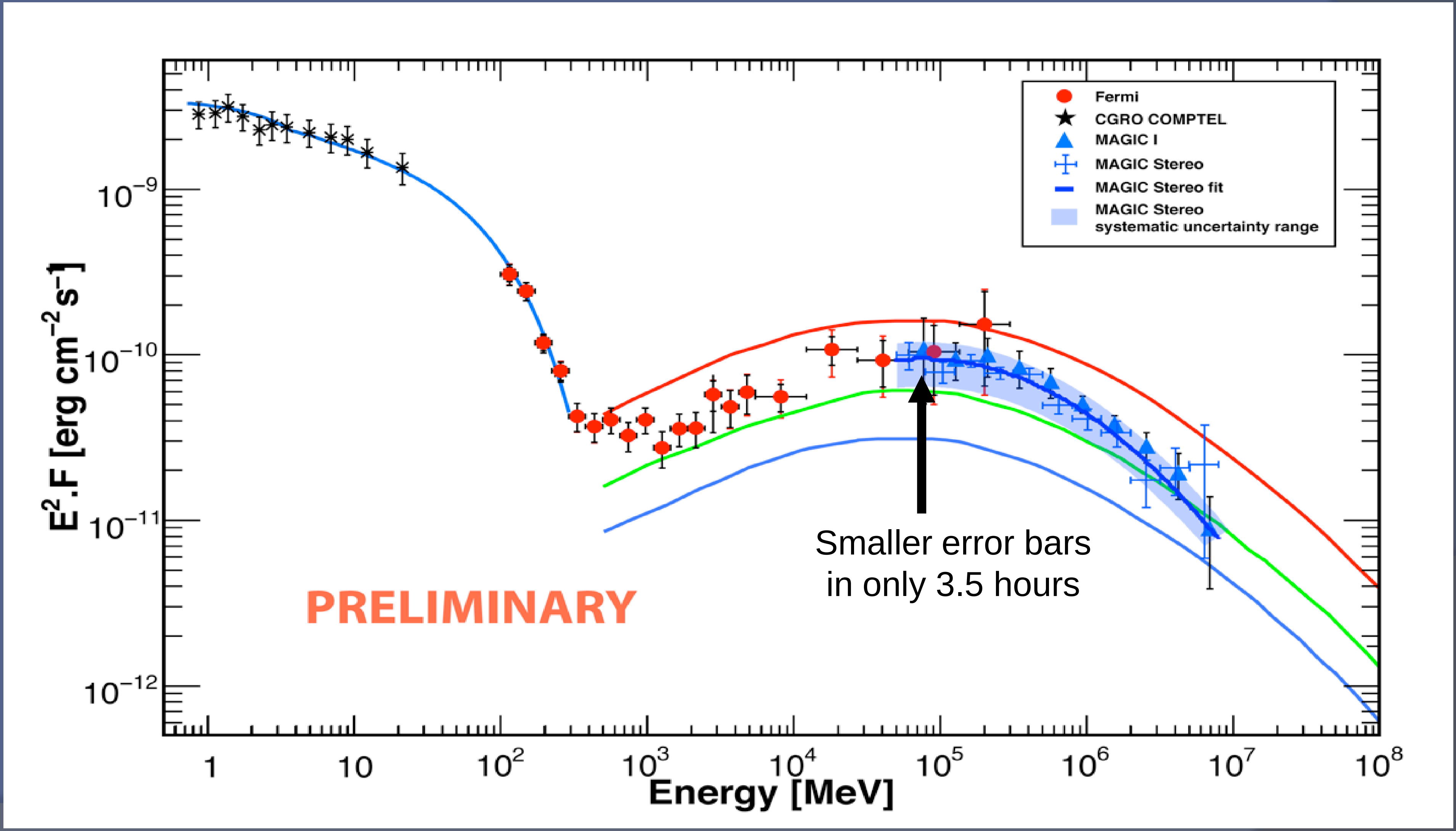




- Clear evidence for cooling of electrons in the Nebula

Crab Nebula spectrum Fermi and MAGIC-Stereo

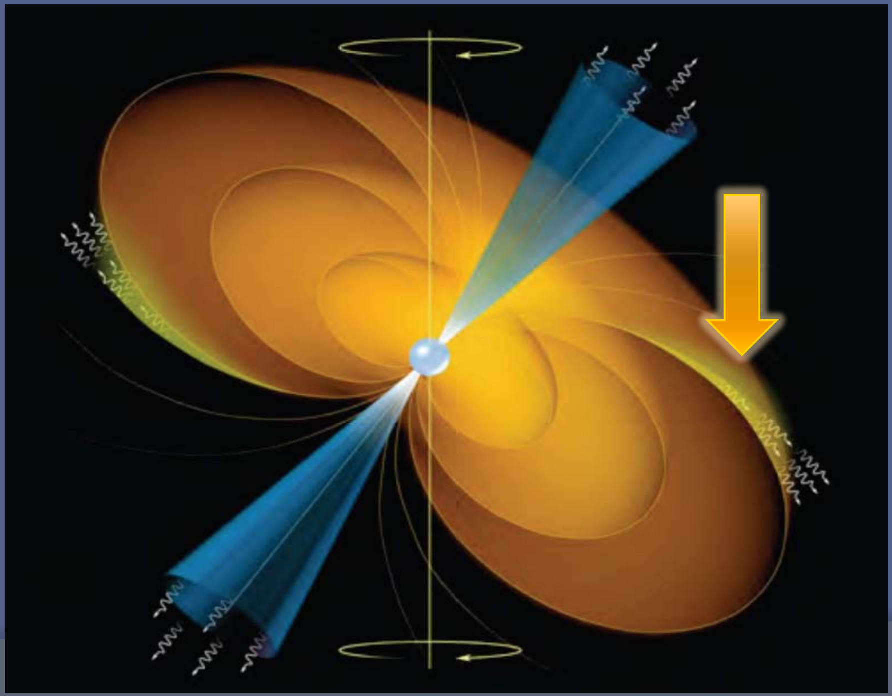


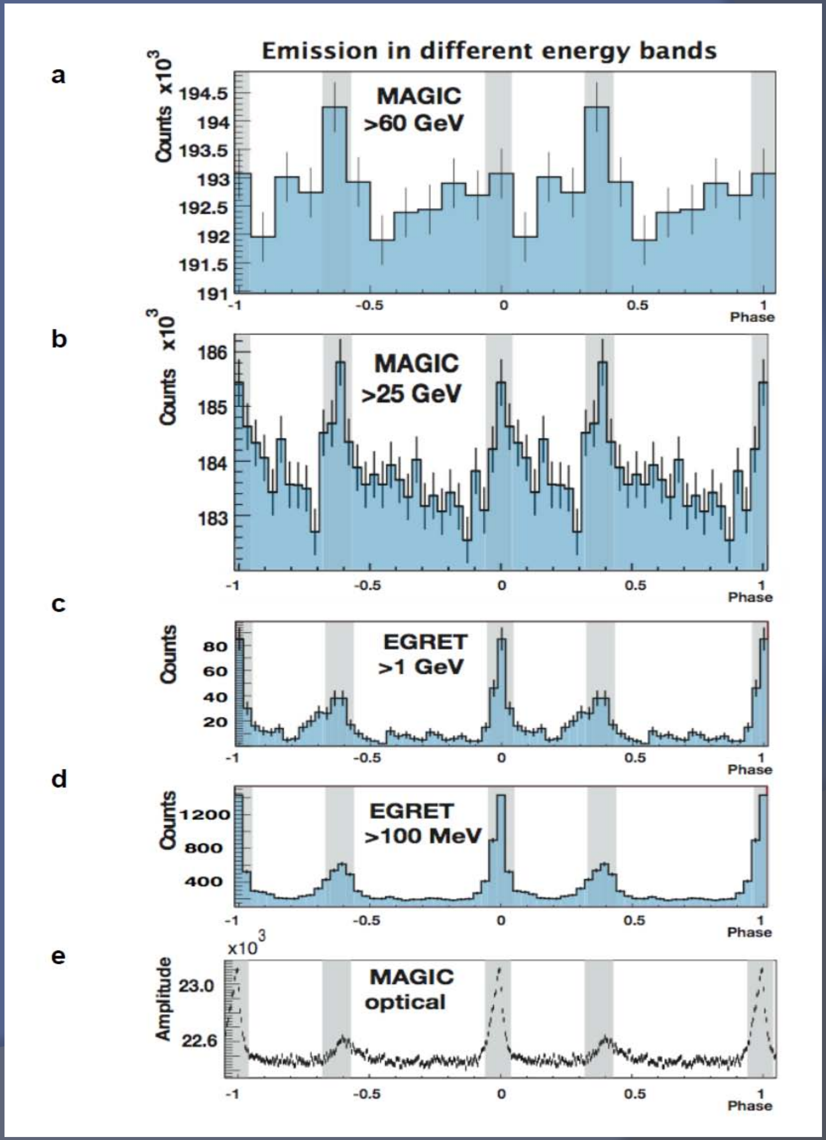
Pulsar Study

MAGIC result: Published in Science in 2008

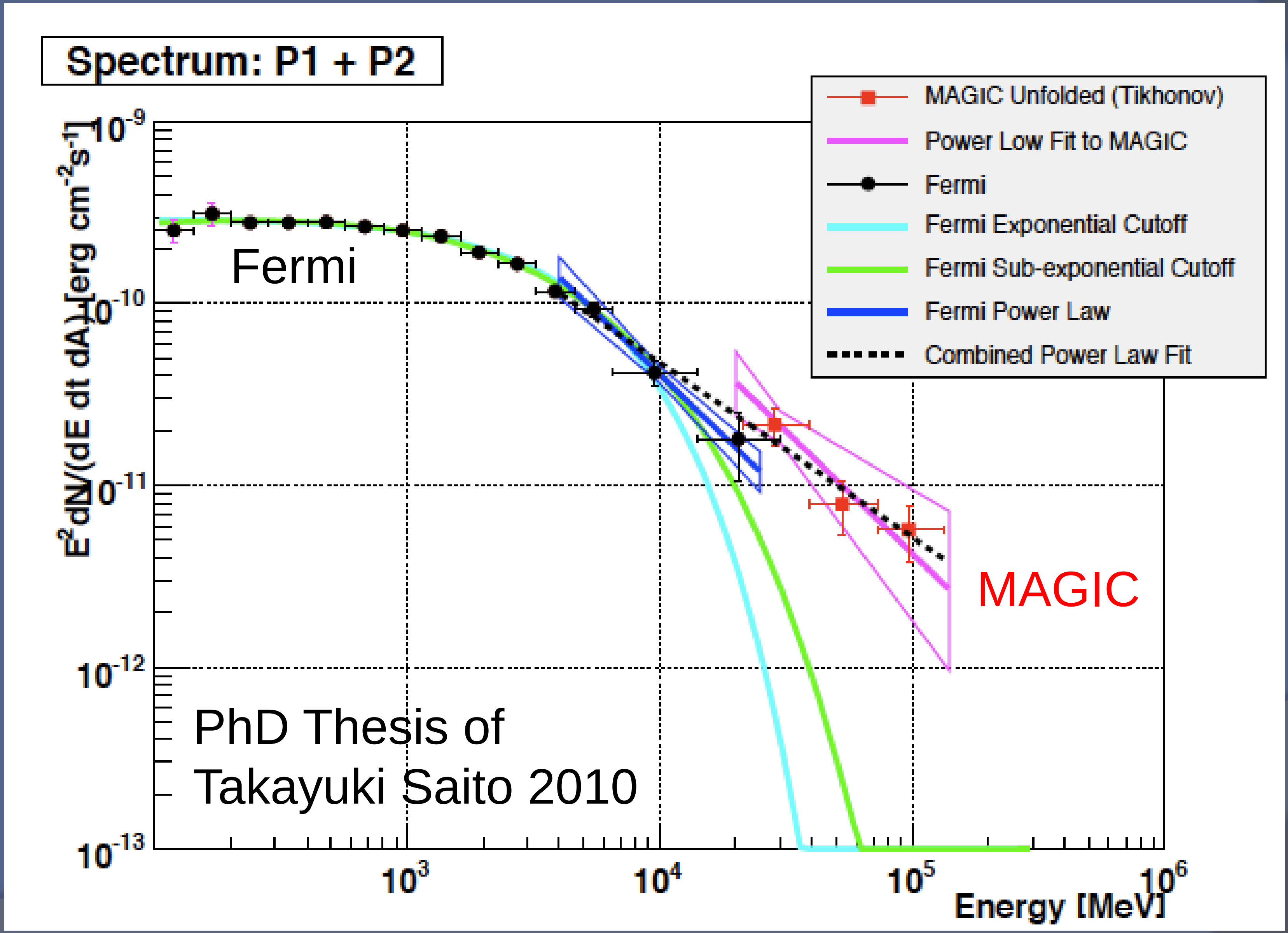
By measuring the spectrum around cutoff or at high energies is important to distinguish the emission model

Polar cap: double exponent
Outer gap: simple exponent





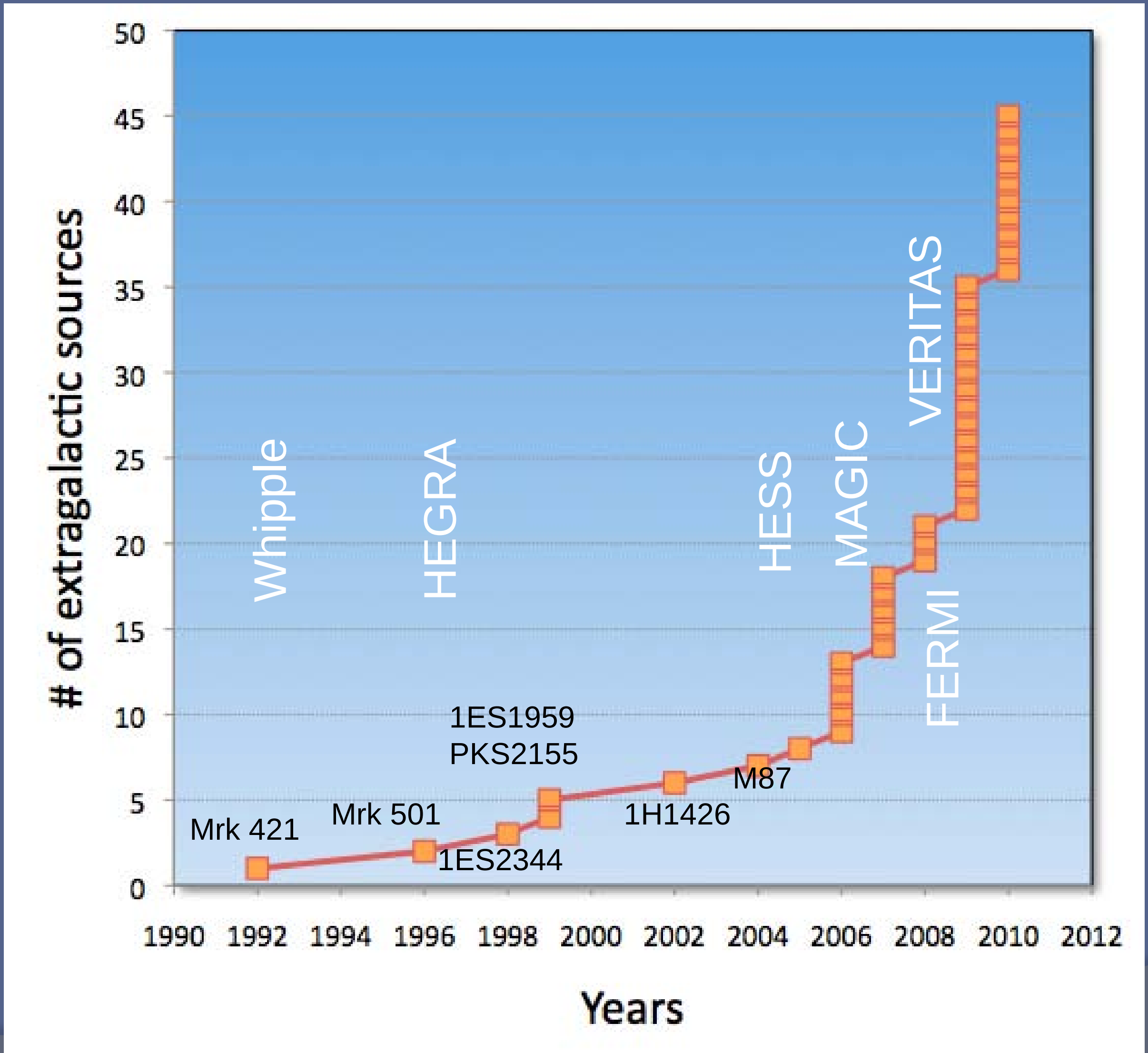
Crab Pulsar



MAGIC


EXTRAGALACTIC
SOURCES

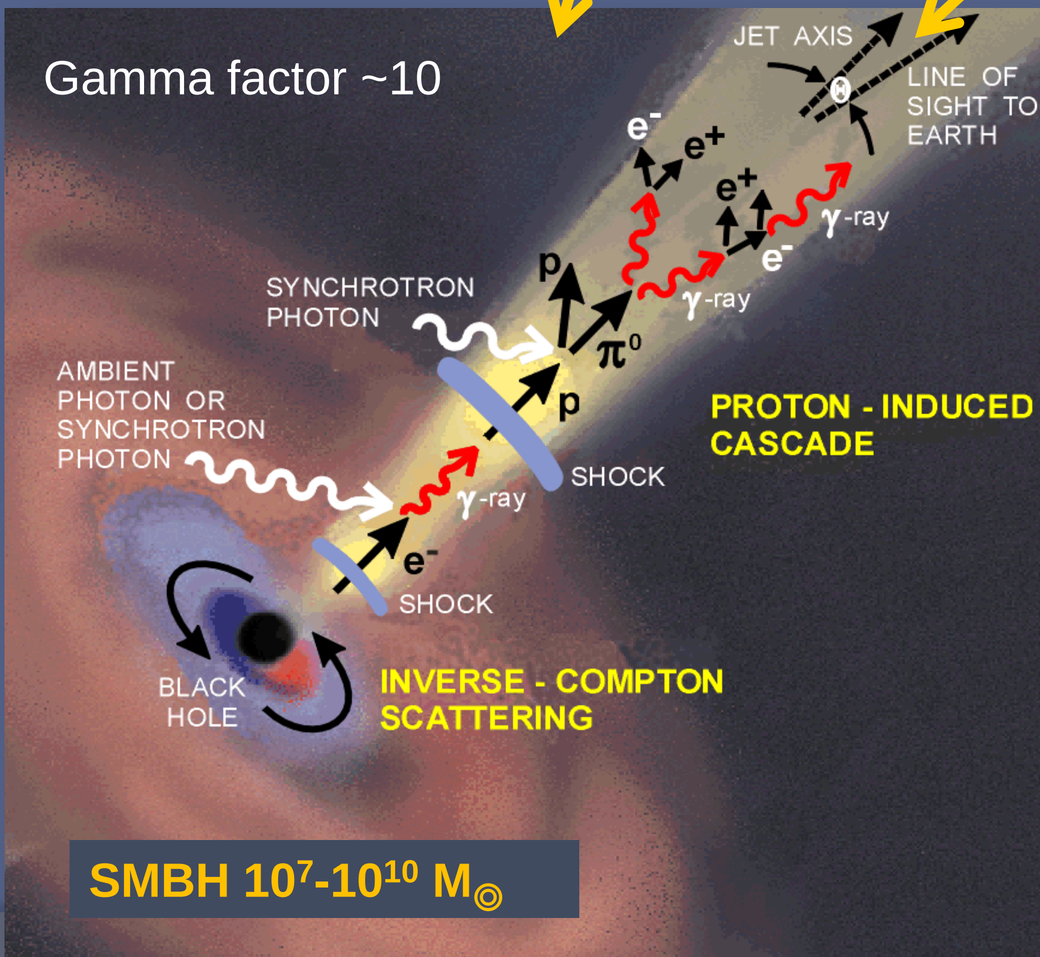
Number of extragalactic VHE Sources (45)

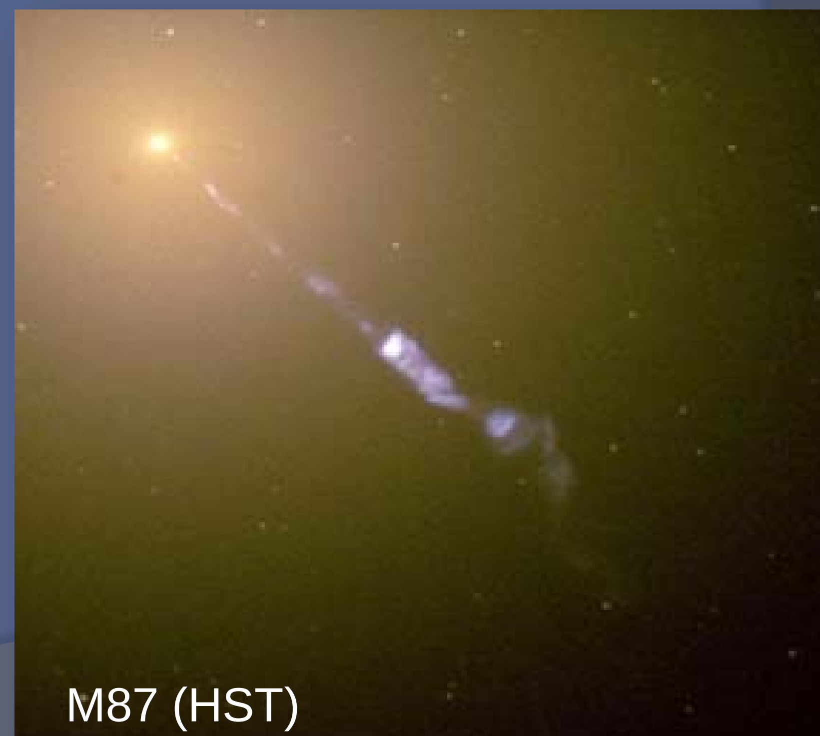


Fermi

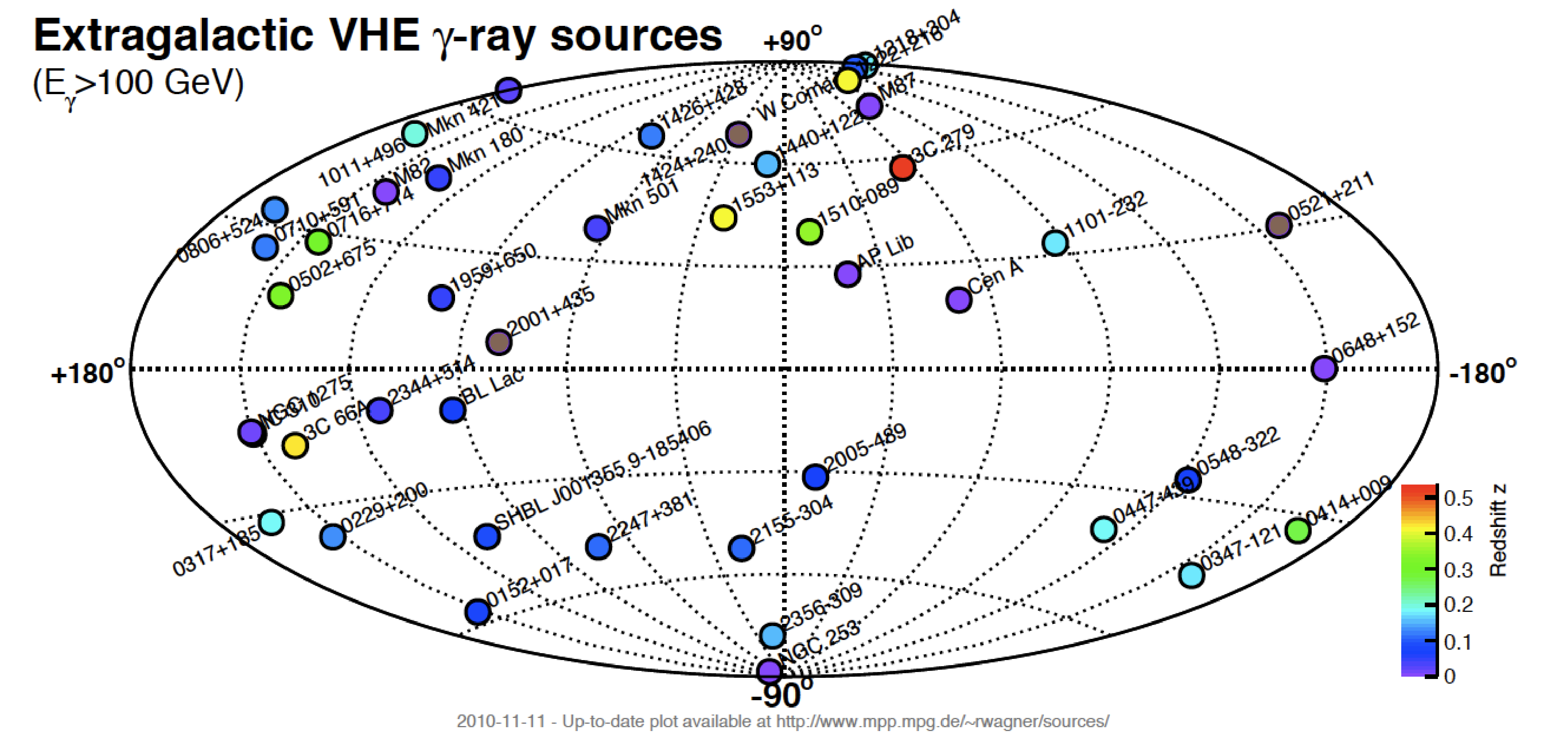
Cosmic Ray accelerator
Active Galactic Nuclei

FRI, FRII **Blazars**





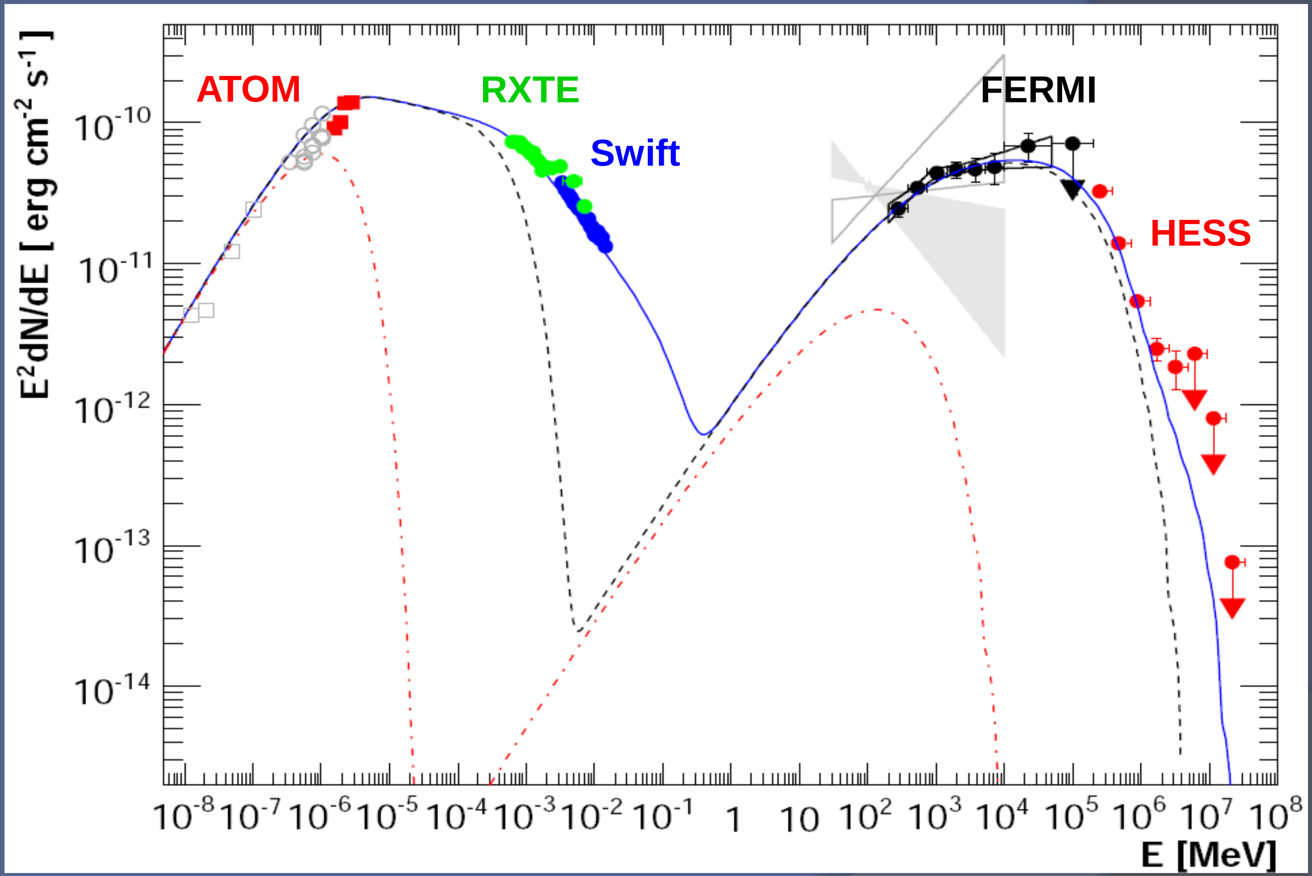
Extra-galactic sources



45 sources (3 x FR-I, 2 x Starburst galaxies, 4 x FSRQs, 36 BL Lacs)

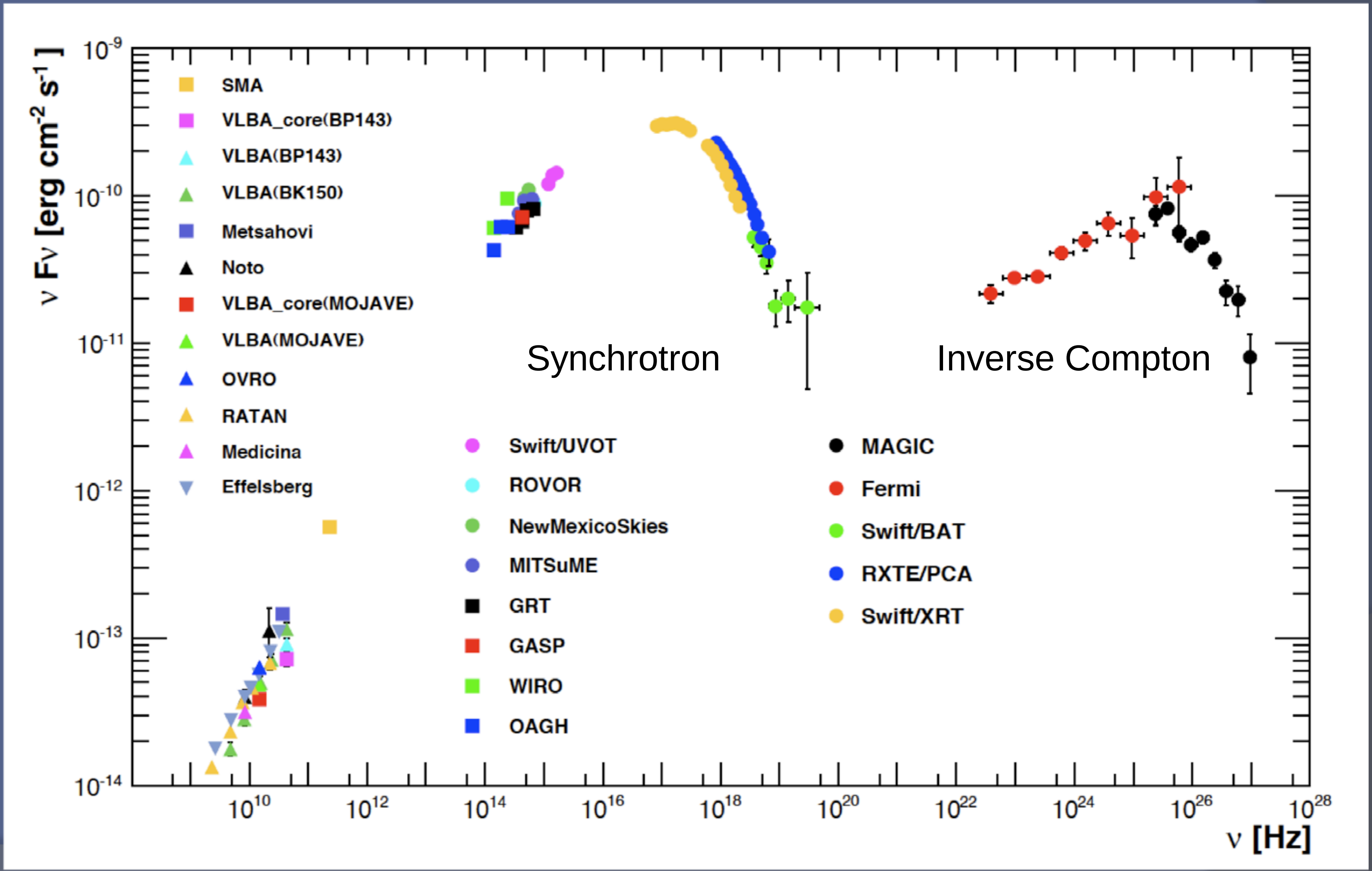
PKS 2155–304 (HESS Observation) Spectral Energy Distribution

- Time-averaged SED is well described by a single zone SSC model:

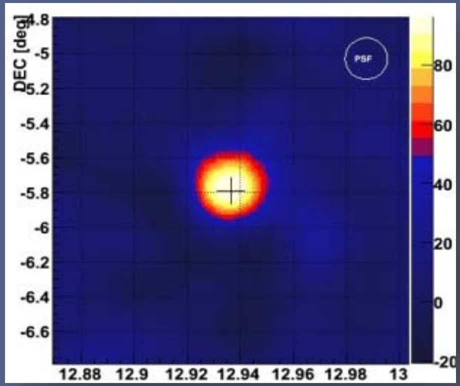


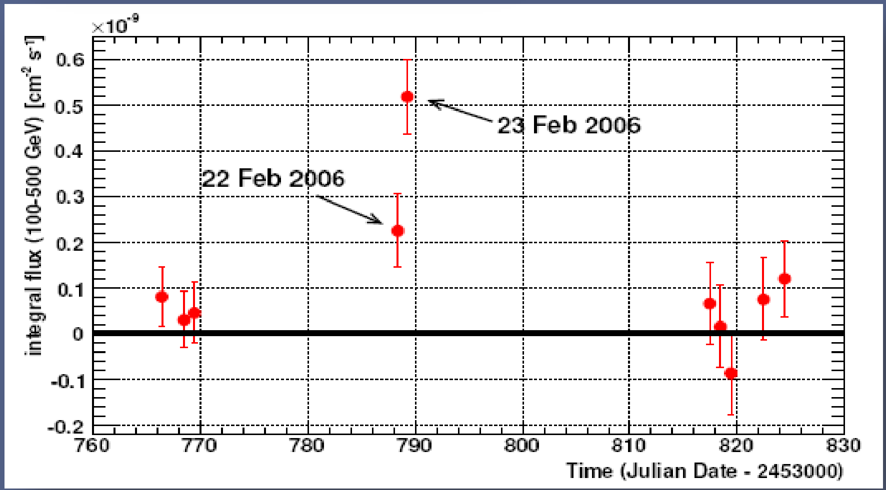
Highest energy electrons ($\gamma_e > 2\times10^5$) produce the X-ray emission, but contribute relatively little above 0.2 TeV

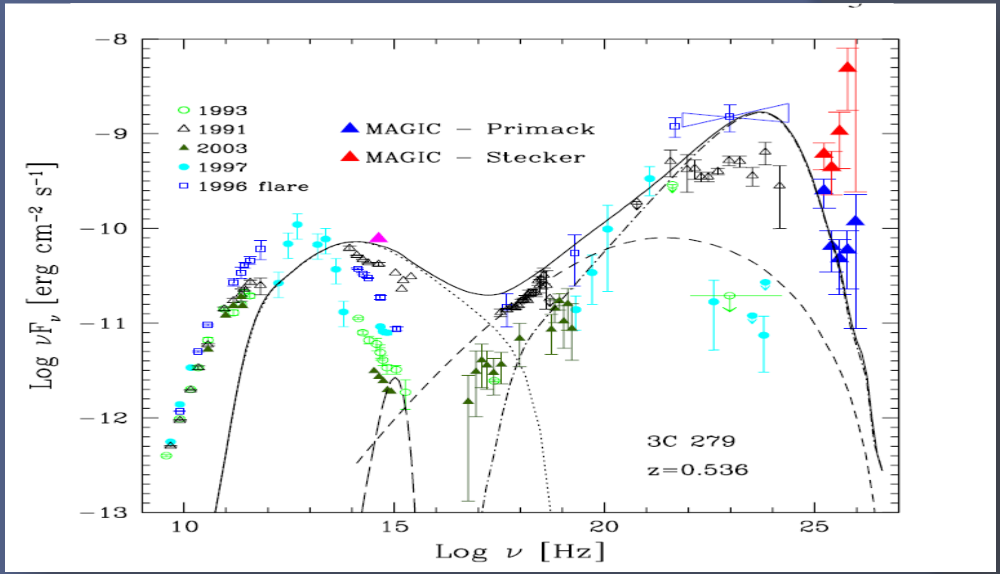
Mrk421 MWL SED

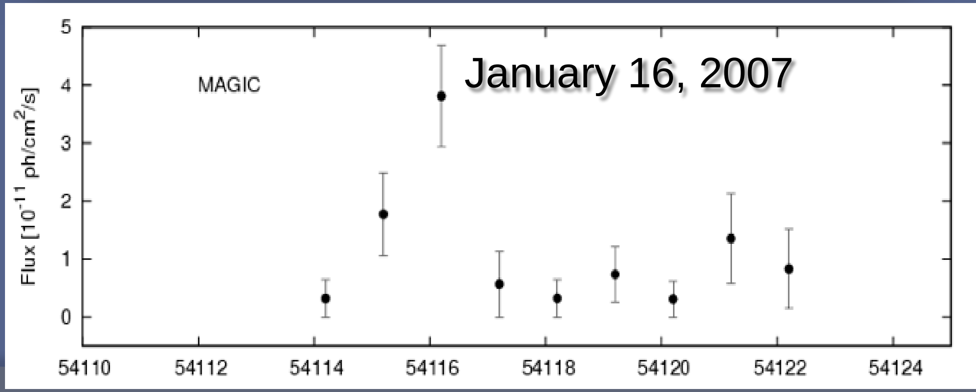


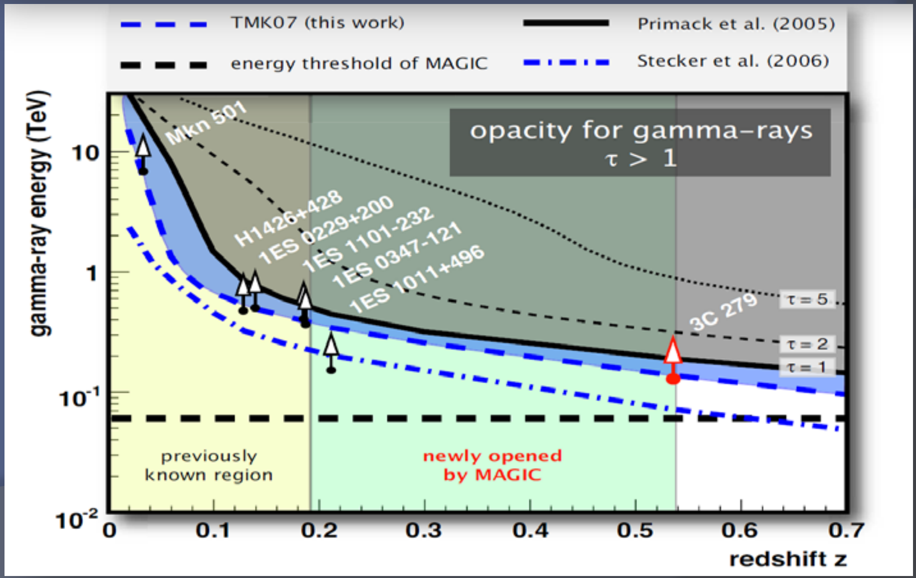
FSRQ 3C279 (z=0.536) MAGIC
Most distant 100GeV AGN



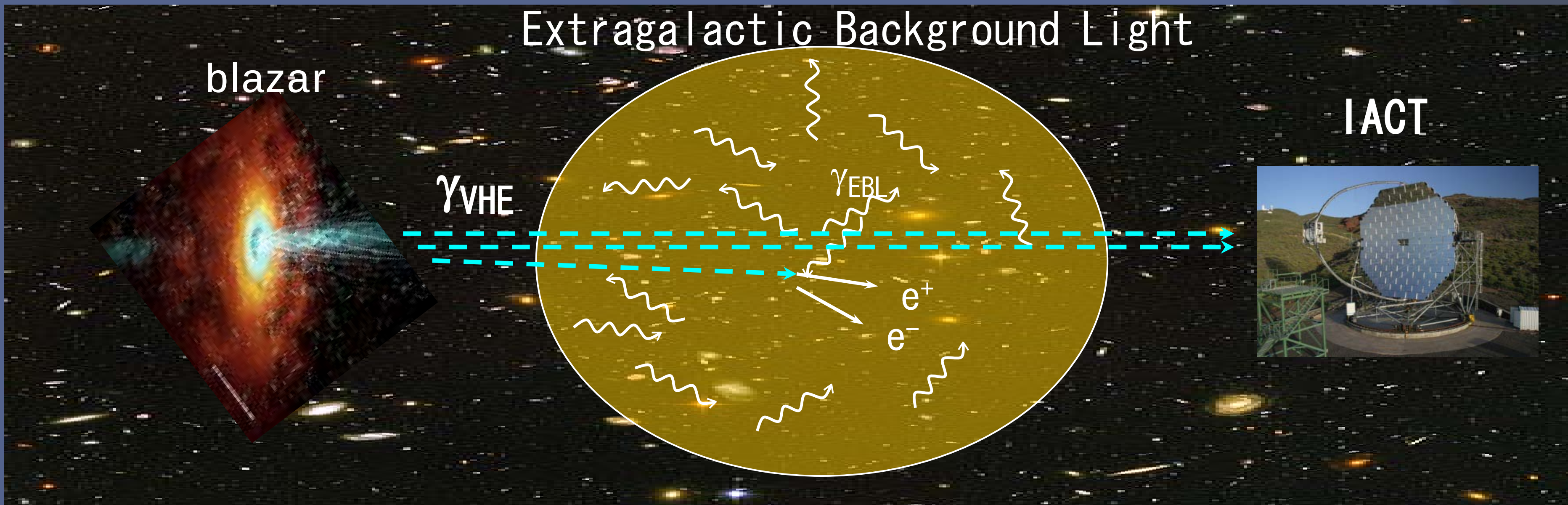


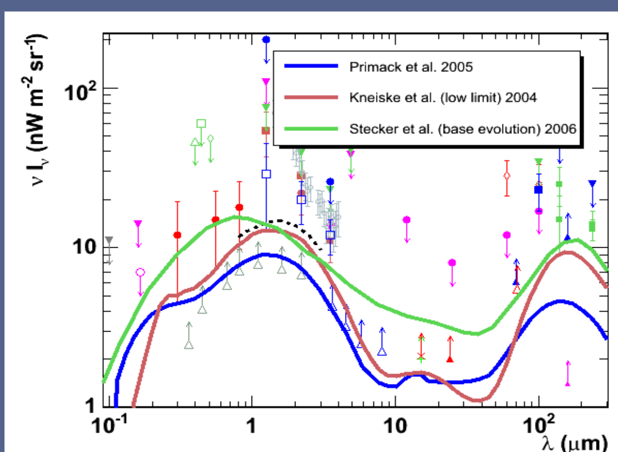


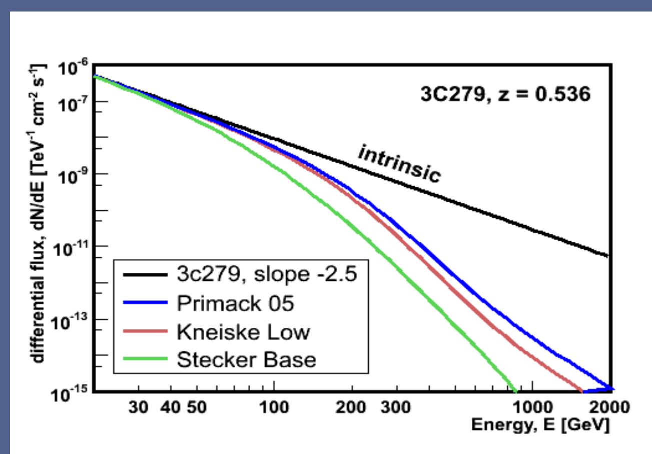


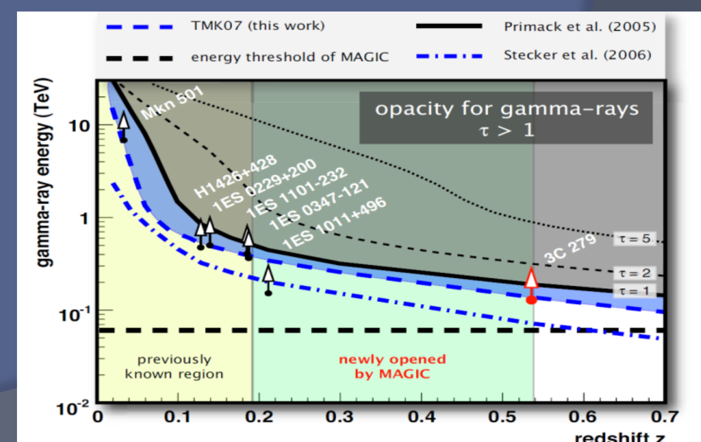


EBL (Extragalactic Background Light)



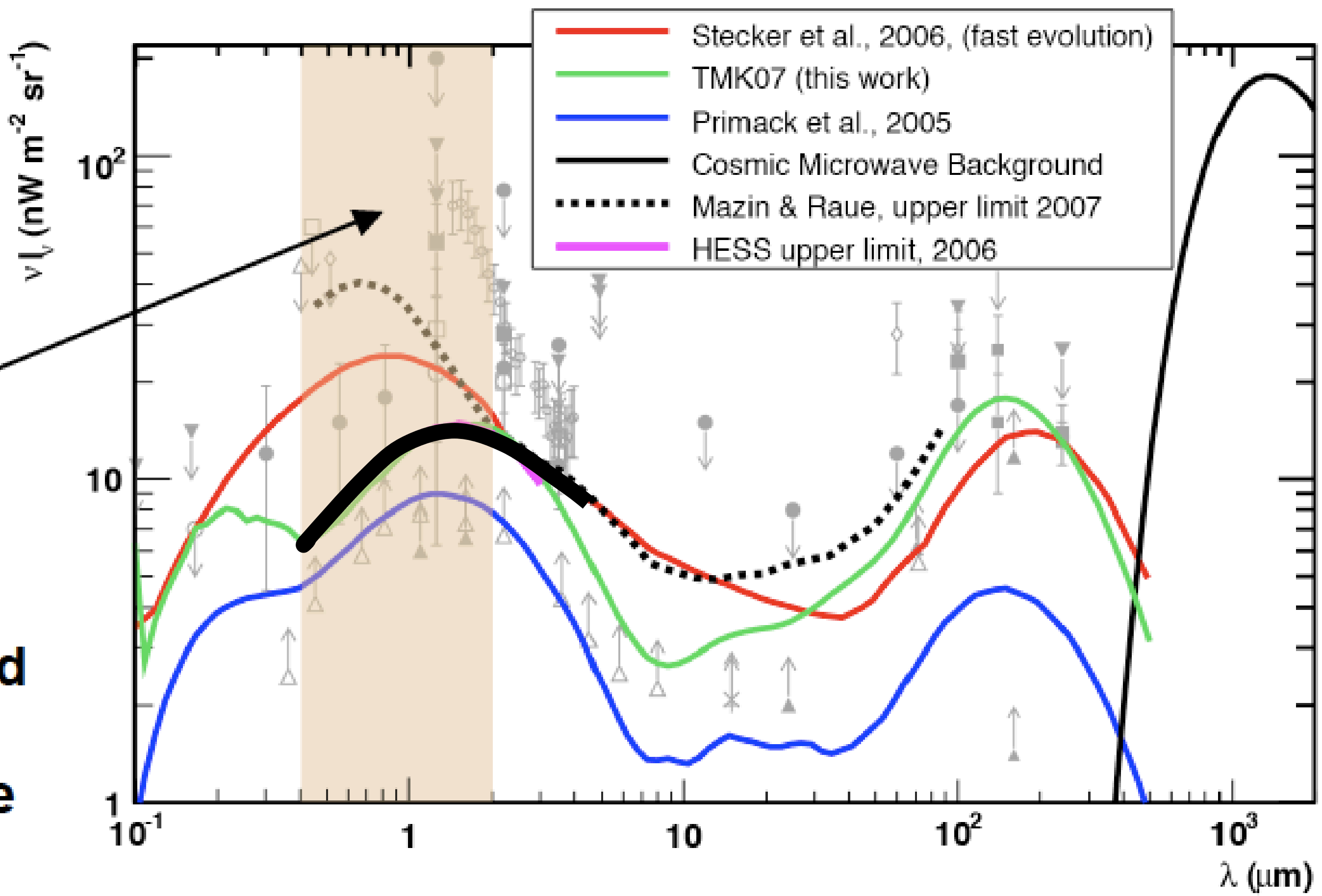






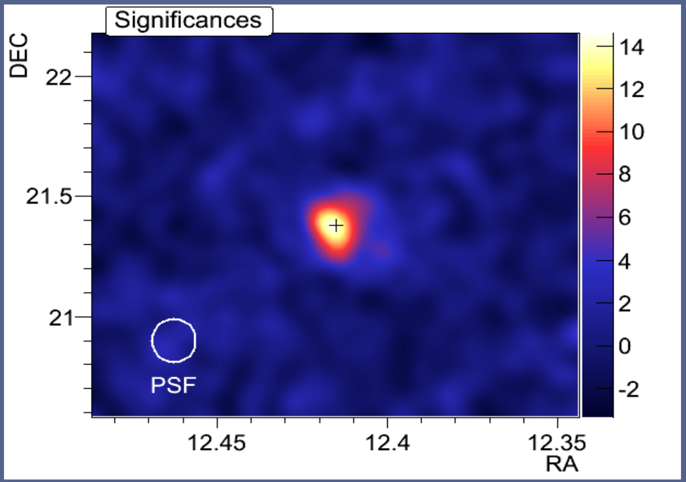
EBL upper limit by MAGIC and HESS observations

Probing new range of the EBL

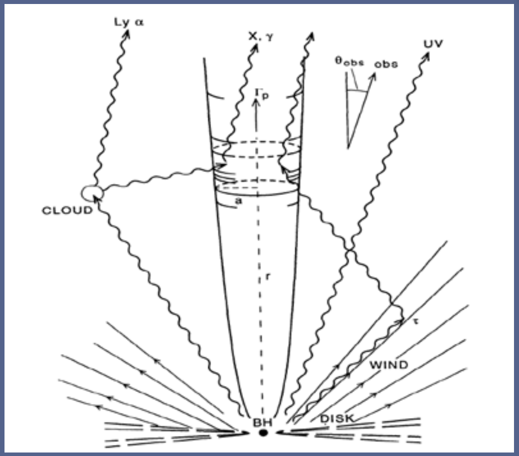


Green line: model of Kneiske et al., tuned to the 3C 279 spectrum using the Γ=1.5 criterion

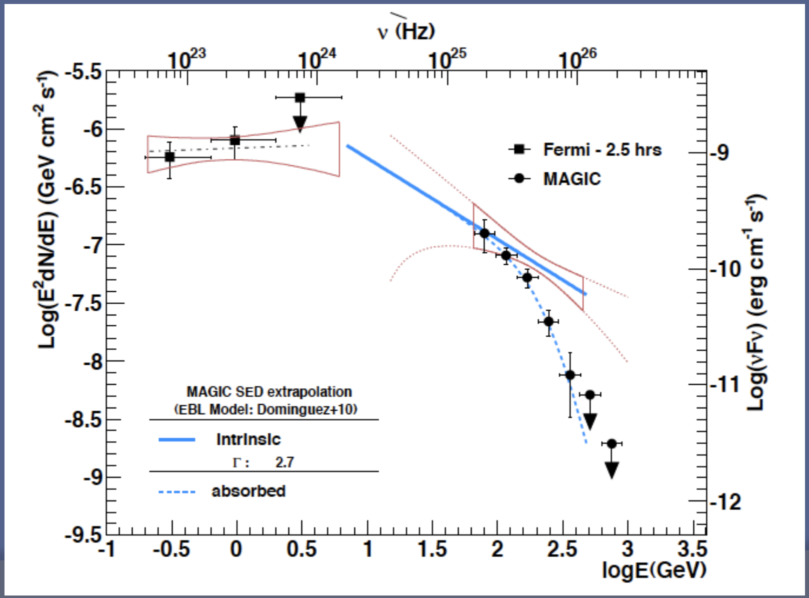
Second most distant 100GeV source FSRQ PKS1222 (4C +21.53) (z=0.436)

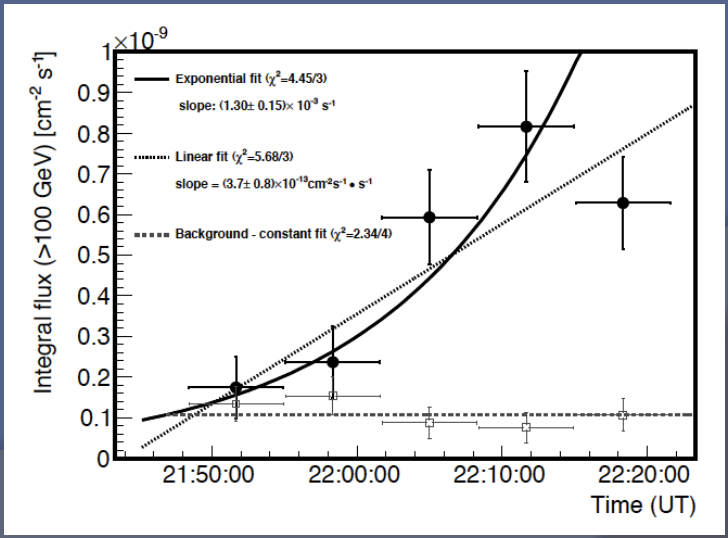


>10 sigma
in 30min

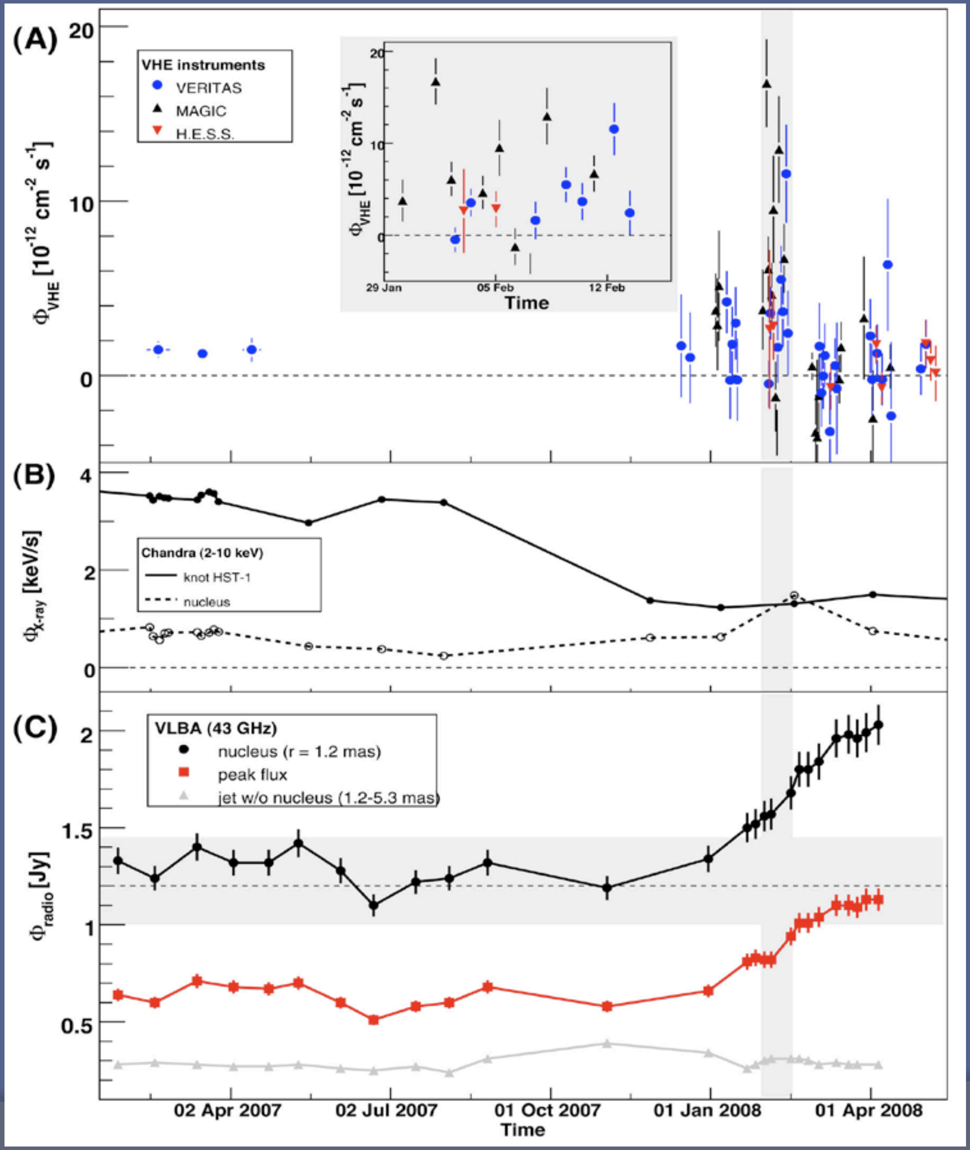


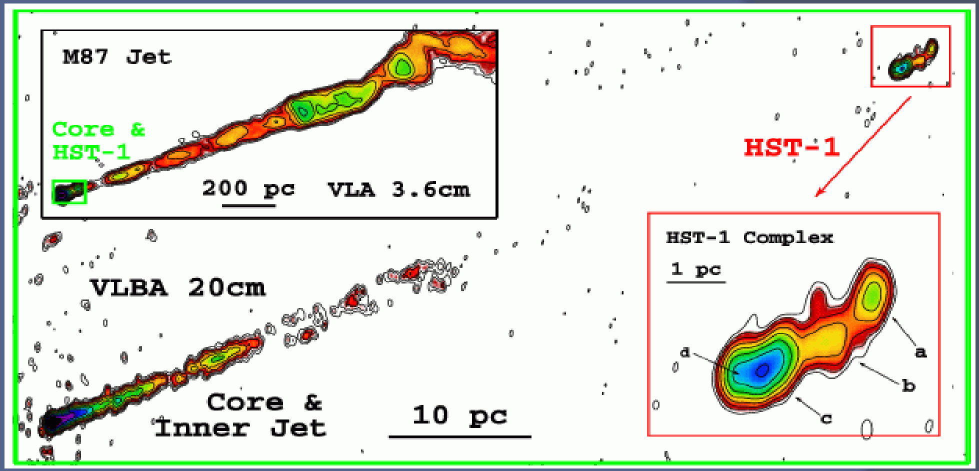
~10mins doubling time
maybe inconsistent with EC model



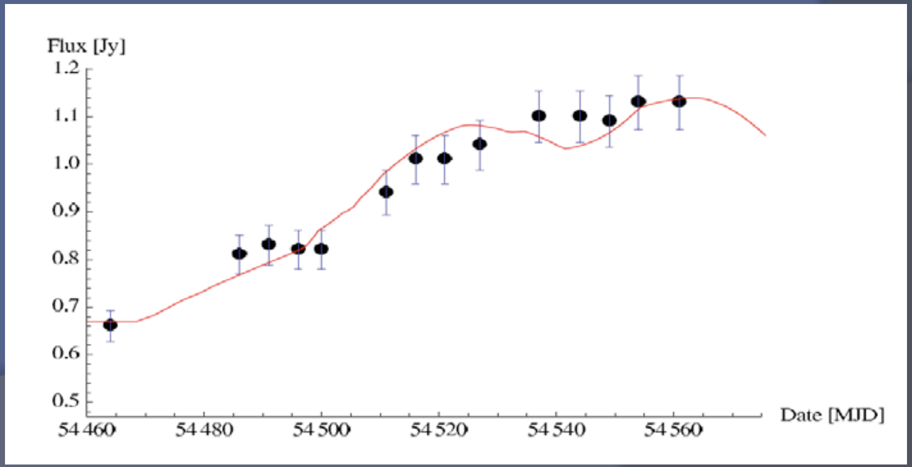


M87 flare in 2008:
MAGIC, VERITAS, HESS, VLBA

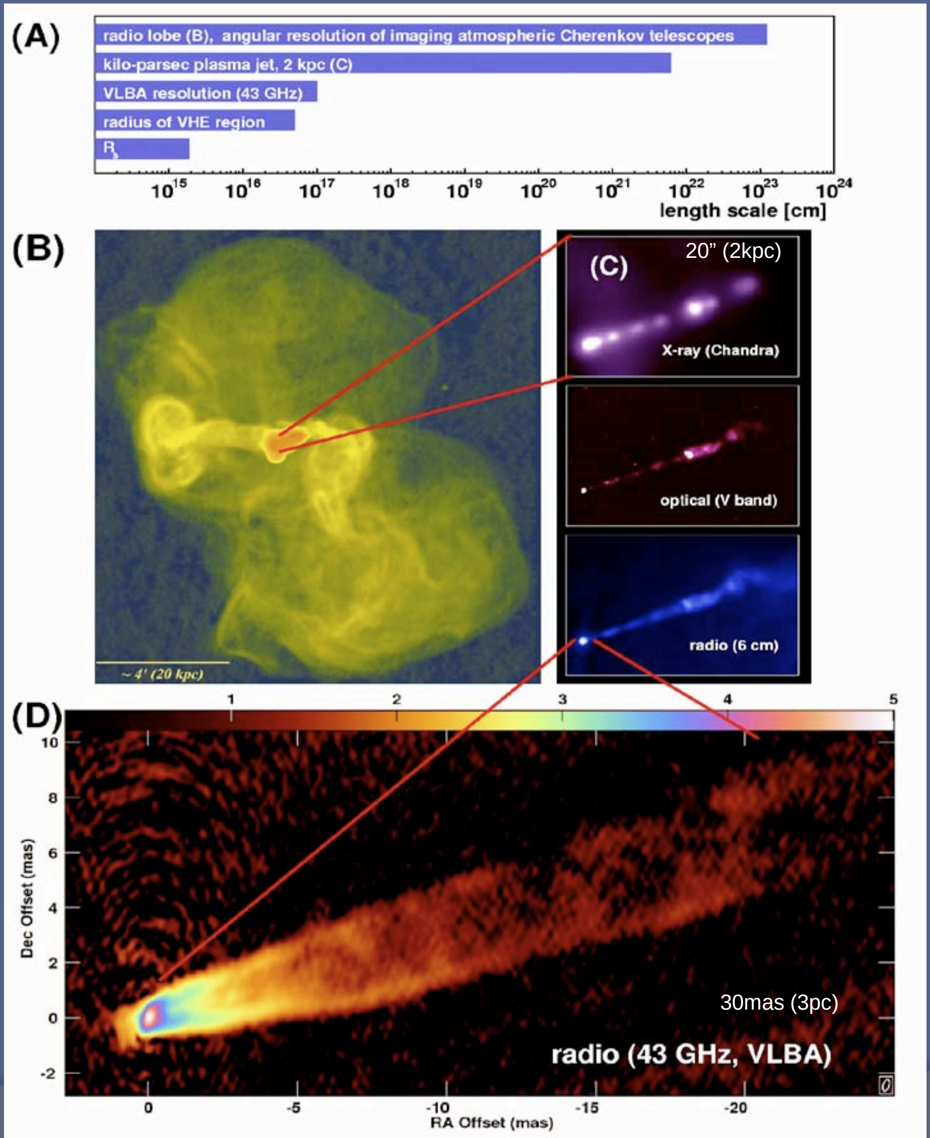


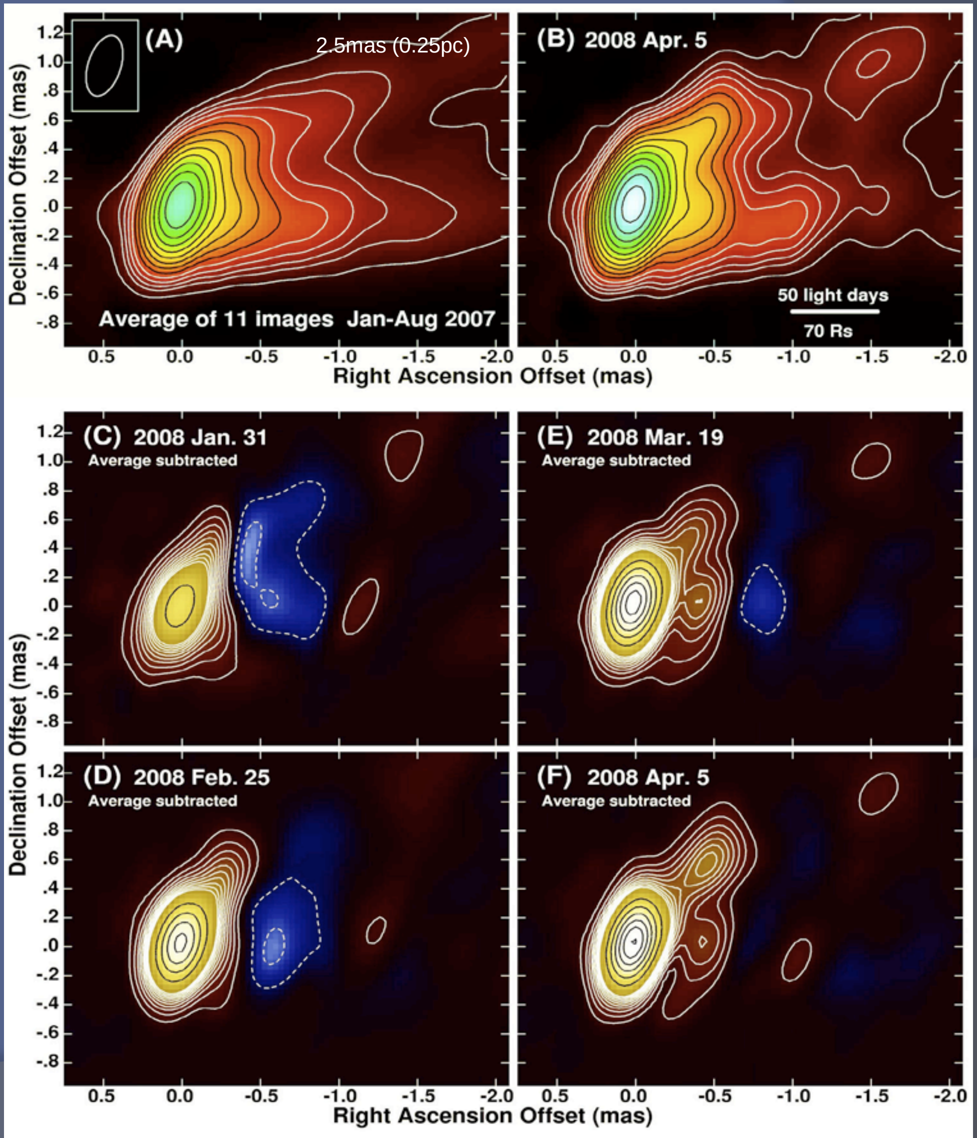


Model of 43GHz Radio flux
using the measured VHE gamma flux



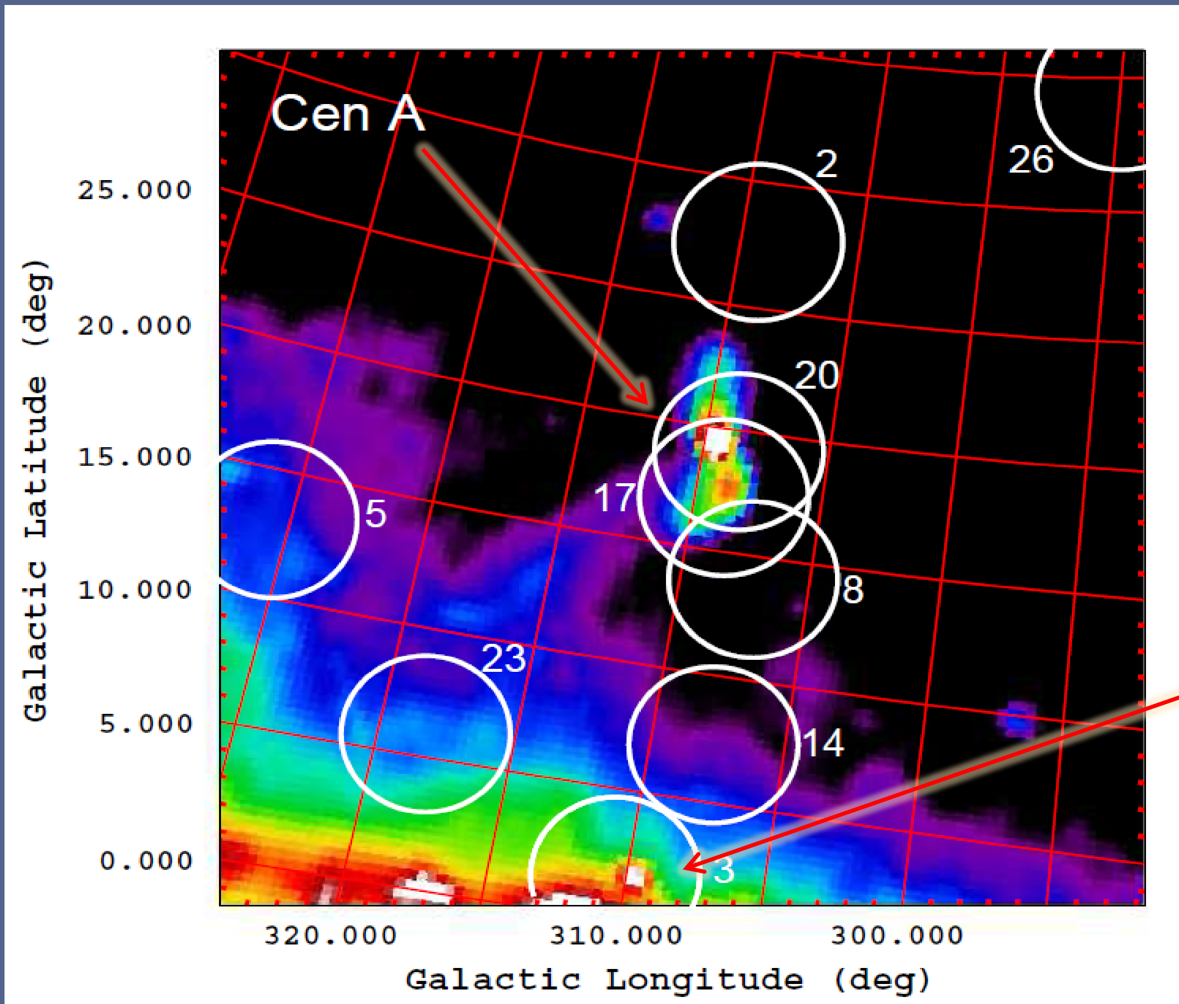
M87 flare in 2008:
MAGIC, VERITA, HESS, and VLBA

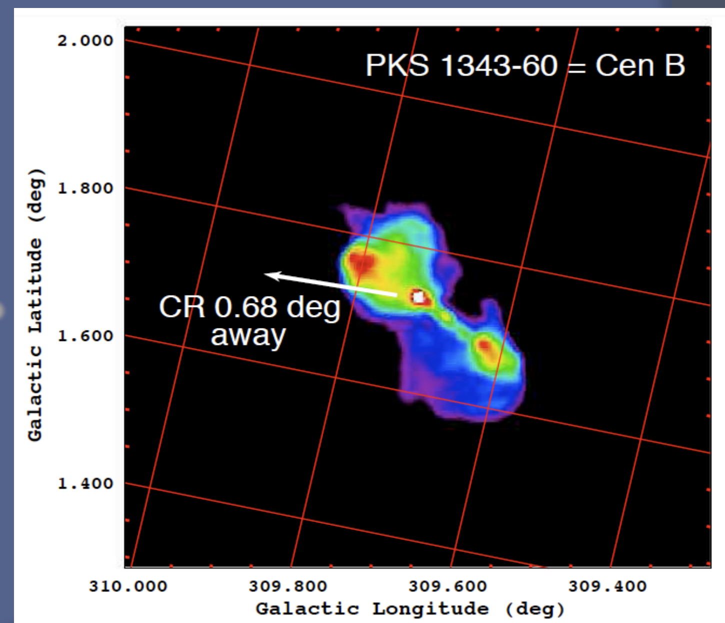




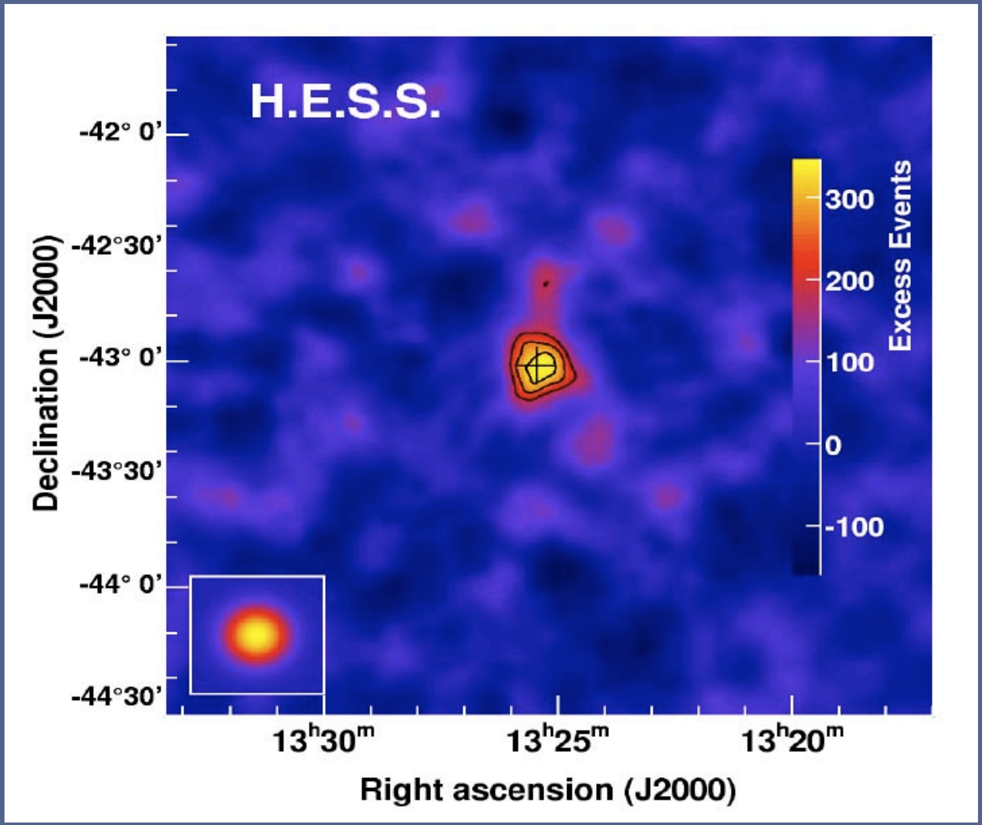
Morphological studies of UHECR potential sources Cen A (3.4Mpc) & Cen B (56Mpc)

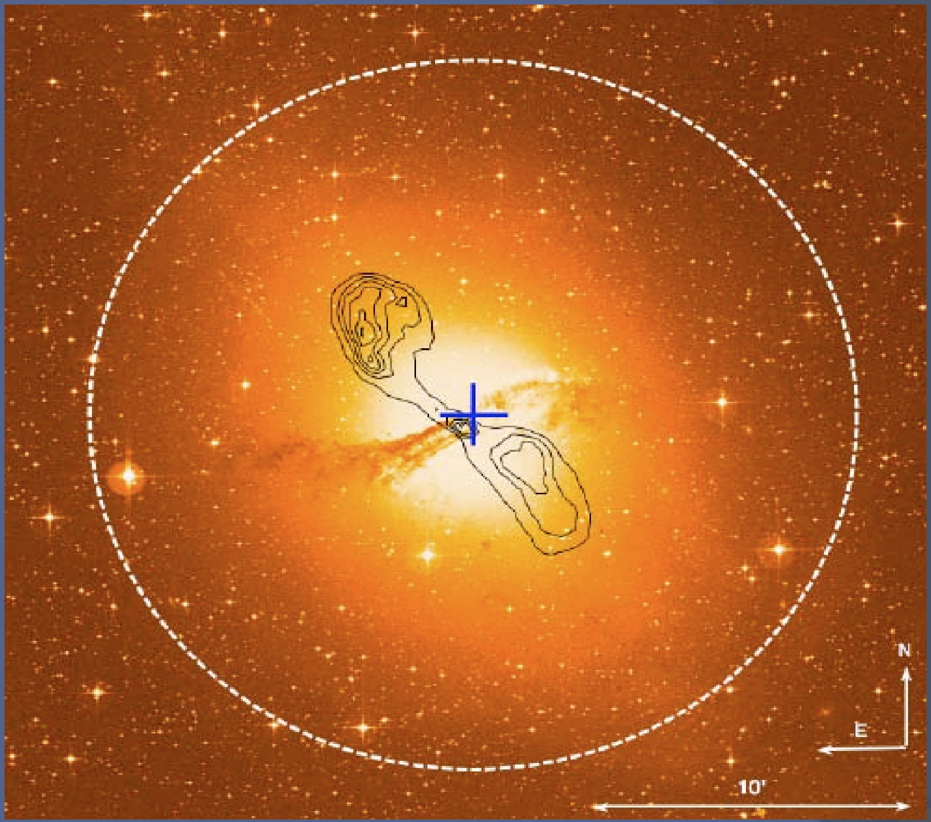
Moskalenko et al. 0805.1260v1





Cen A: HESS detection



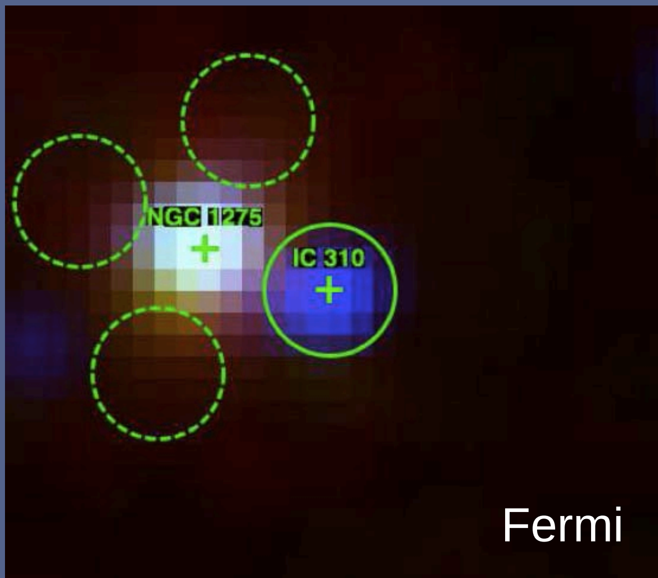


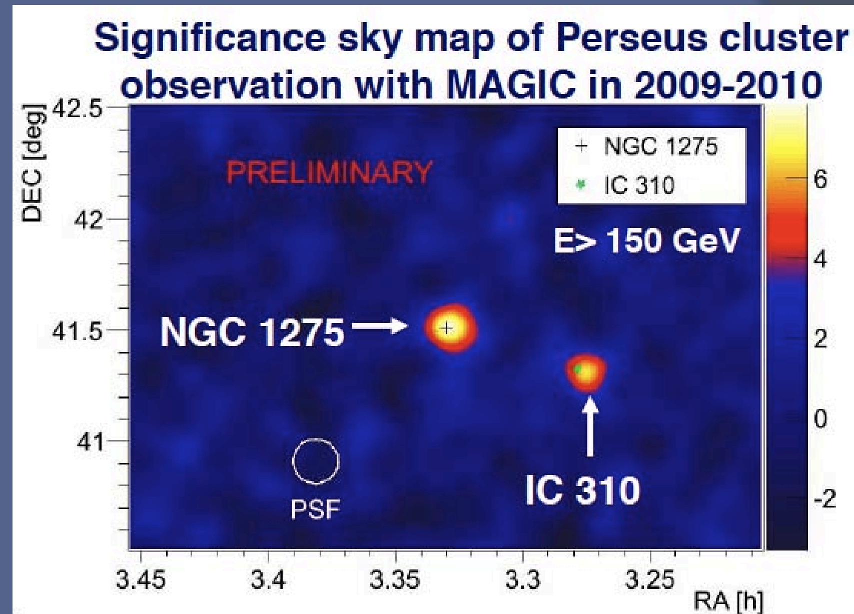
Distance: 3.8Mpc
Flux: 0.8% in Crab Unit
Spectral Index: -2.7

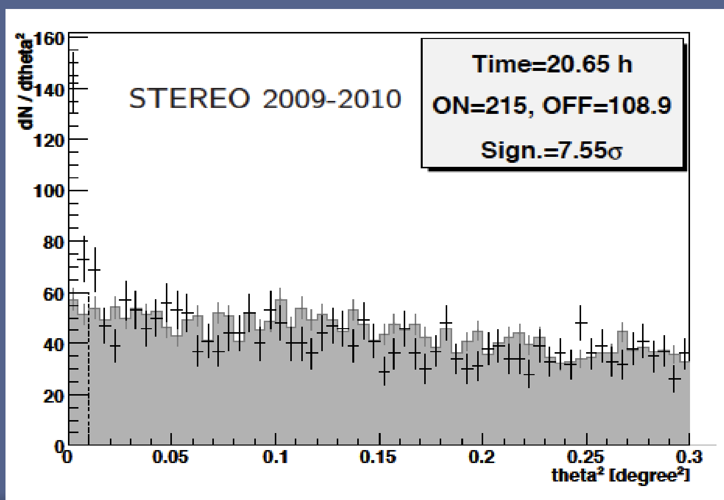
Cross: the best location (COG)
Circle: 95% C.L. VHE extension limit

L_{VHE} ~ 2.6 x 10^{39} erg s-1
L_{UHECR} ~ 10^{40} erg s-1

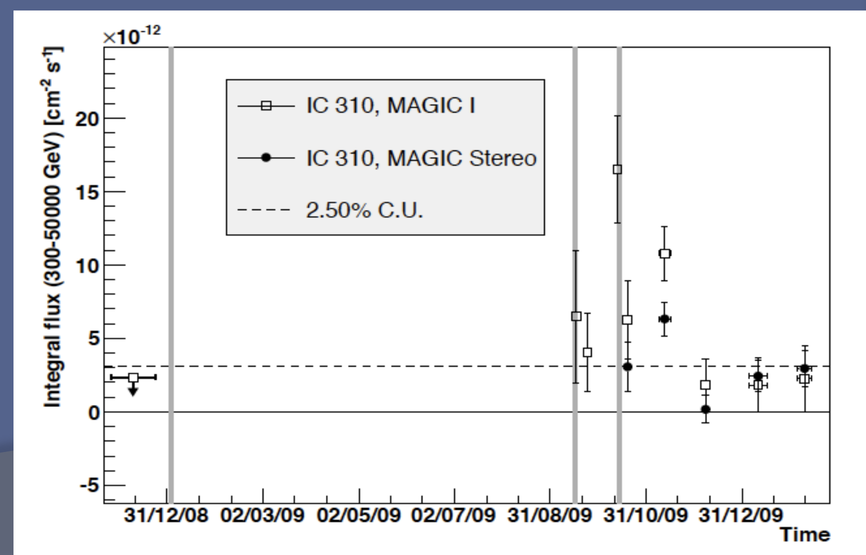
IC310 (FR-I Radio galaxy) is discovered, when observing Perseus cluster / NGC1275



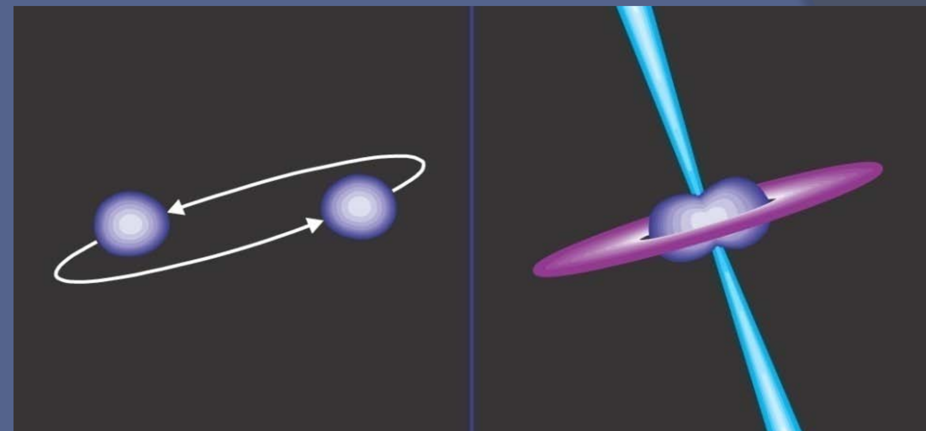




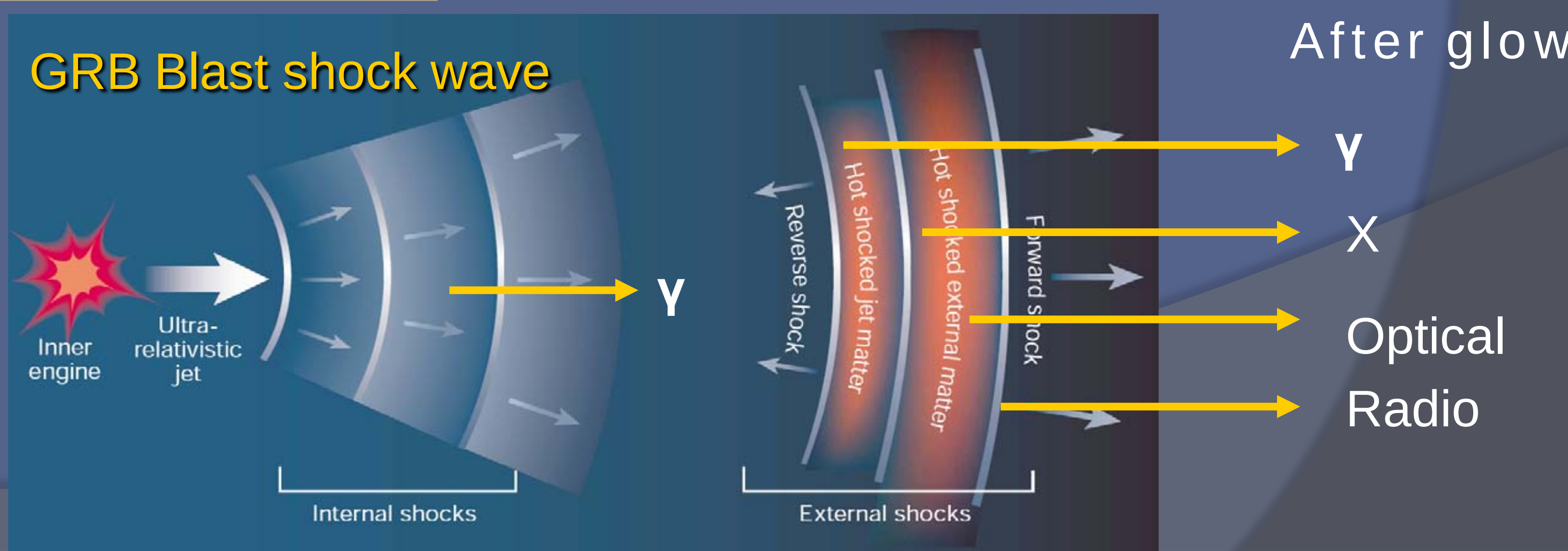
Too bright as an off-axis blazar



Gamma ray bursts



Binary neutron stars



10 GRBs observed by Fermi

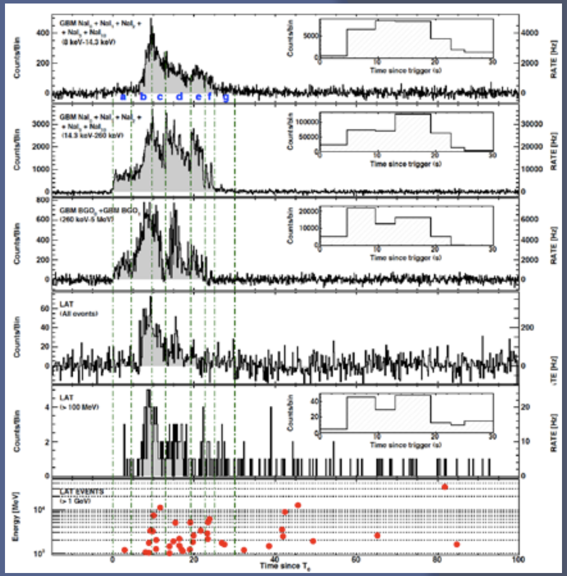
GRB	duration	# of events > 100 MeV	# of events > 1 GeV	delayed HE onset	Long-lived HE emission	Highest Energy	Redshift
080825C	long	~10	0	?	✔	~600 MeV	
080916C	long	>100	>10	✔	✔	~ 13.2 GeV	4.35
081024B	short	~10	2	✔	✔	3 GeV	
081215A	long	—	—	—	—	—	
090217	long	~10	0	x	—	~1 GeV	
090323	long	>10	>0	—	✔	—	3.57
090328	long	>10	—	—	✔	—	0.736
090510	short	>150	>20	✔	✔	~31 GeV	0.903
090626	long	—	—	—	✔	—	
090902B	long	>200	>30	✔	✔	~ 33 GeV	1.822

➔ 71 GeV (16.54s)

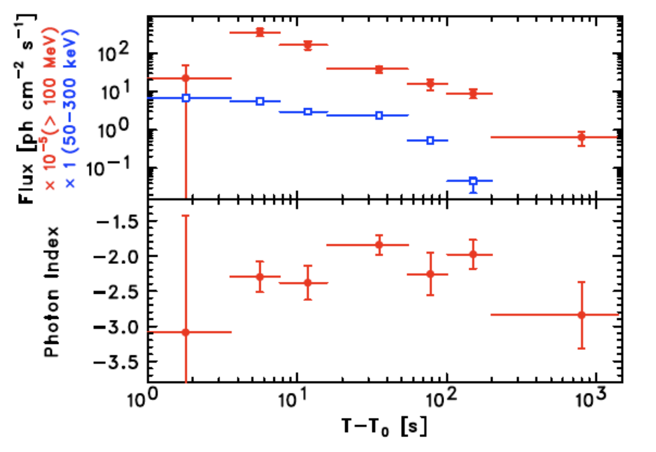
➔ 59 GeV (0.829s)

➔ 93 GeV (82s)

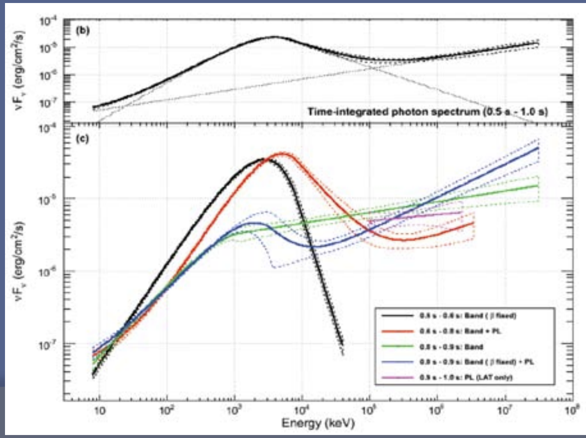
GRB090902B



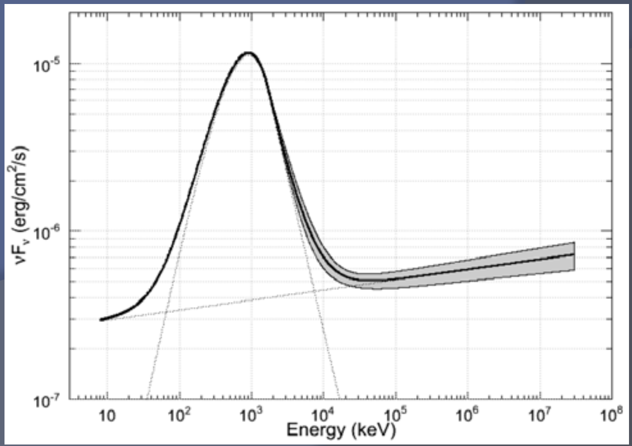
GRB080916C



GRB090510(short burst)



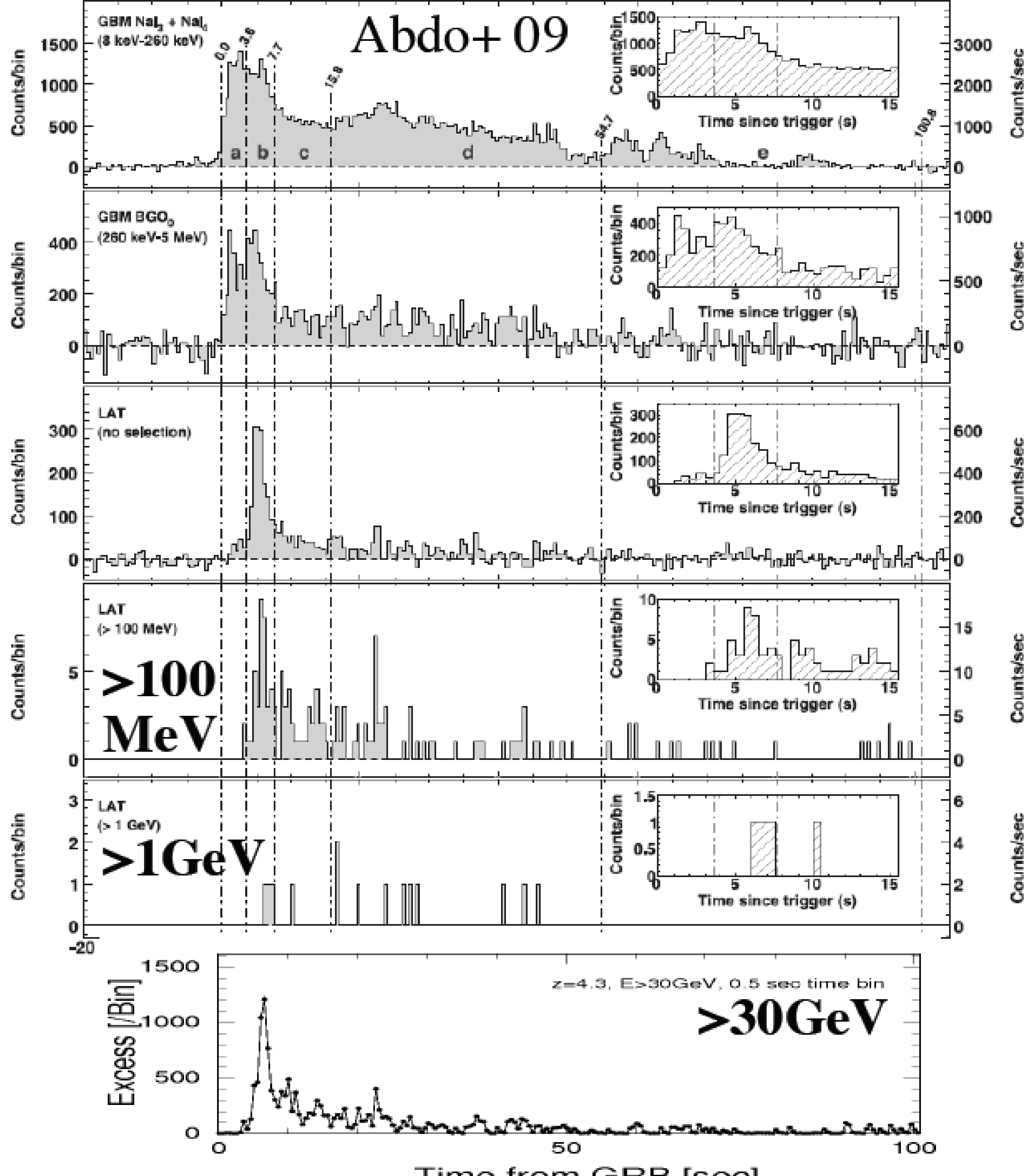
GRB090902B



GRB 080916C Fermi results +CTA simulation

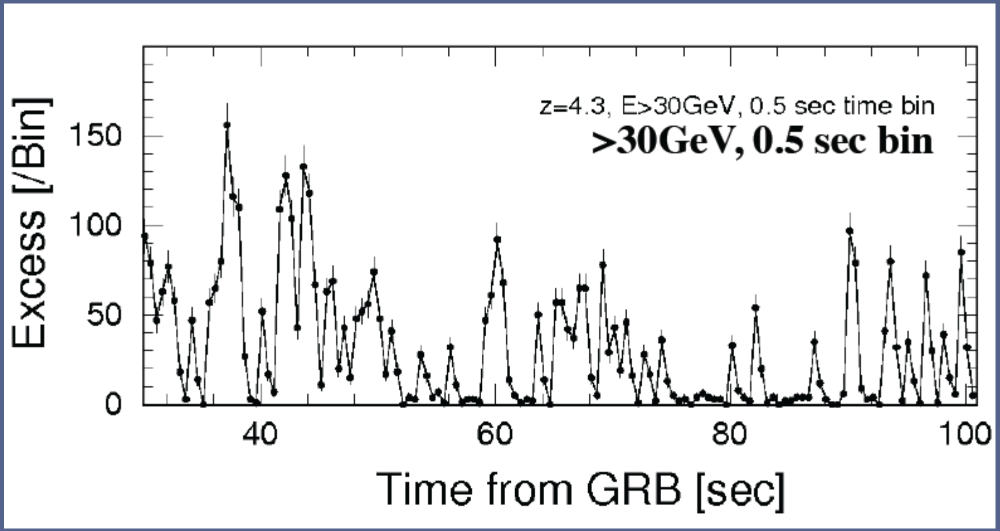
- normalize to GBM light curve
- extrapolate GBM+LAT spectra with Y. Inoue EBL
- simulate with D. Mazin's tool

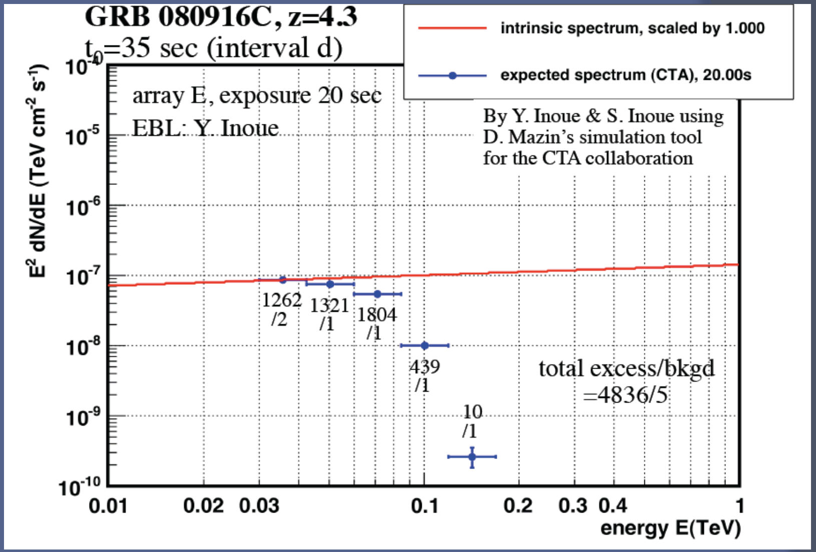
T. Yamamoto, Y. Inoue & R. Yamazaki

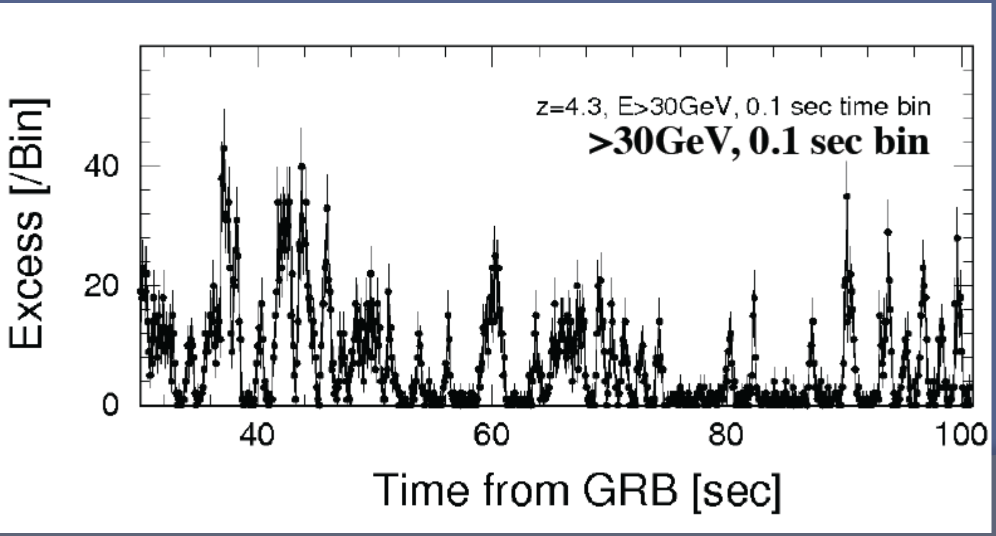


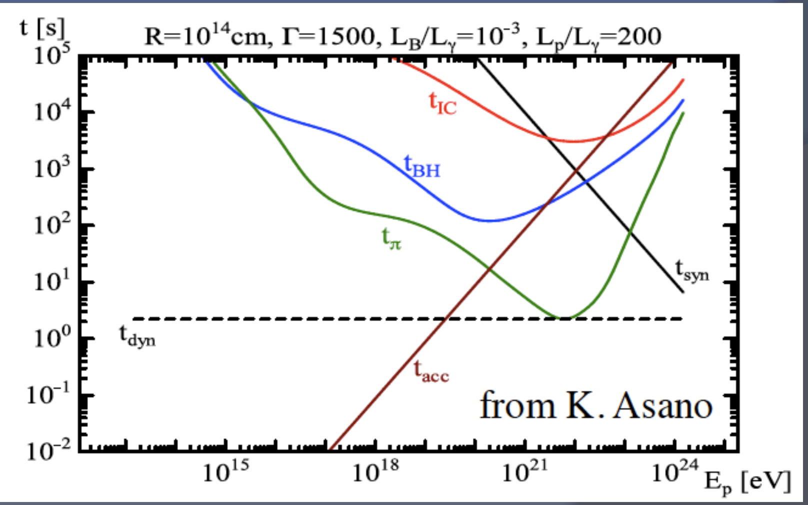
CTA Monte Carlo:
Expected Light curve for GRB at z=4.3

CTA performance study by S.Inoue, Y.Inoue, T.Yamamoto, et al





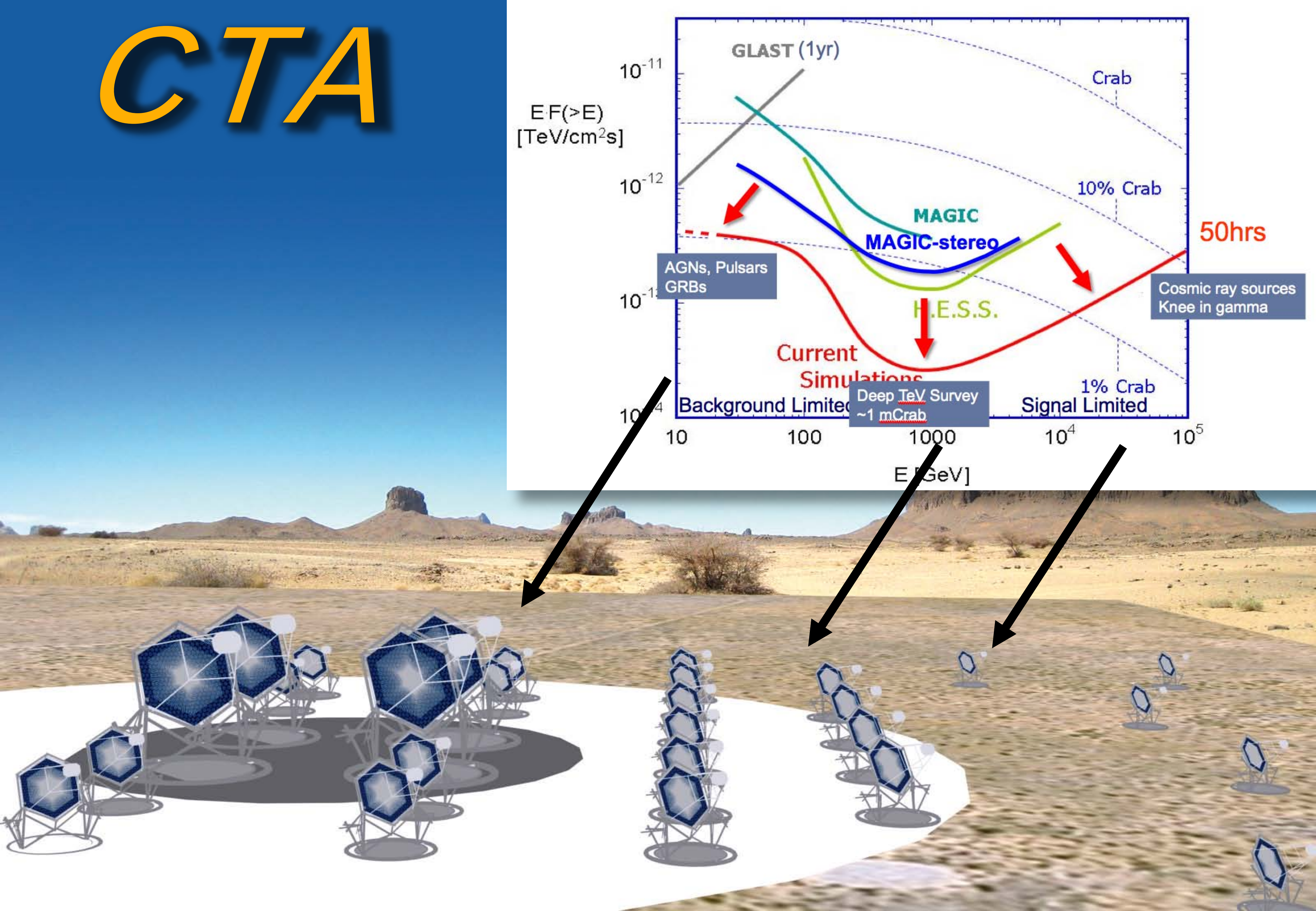


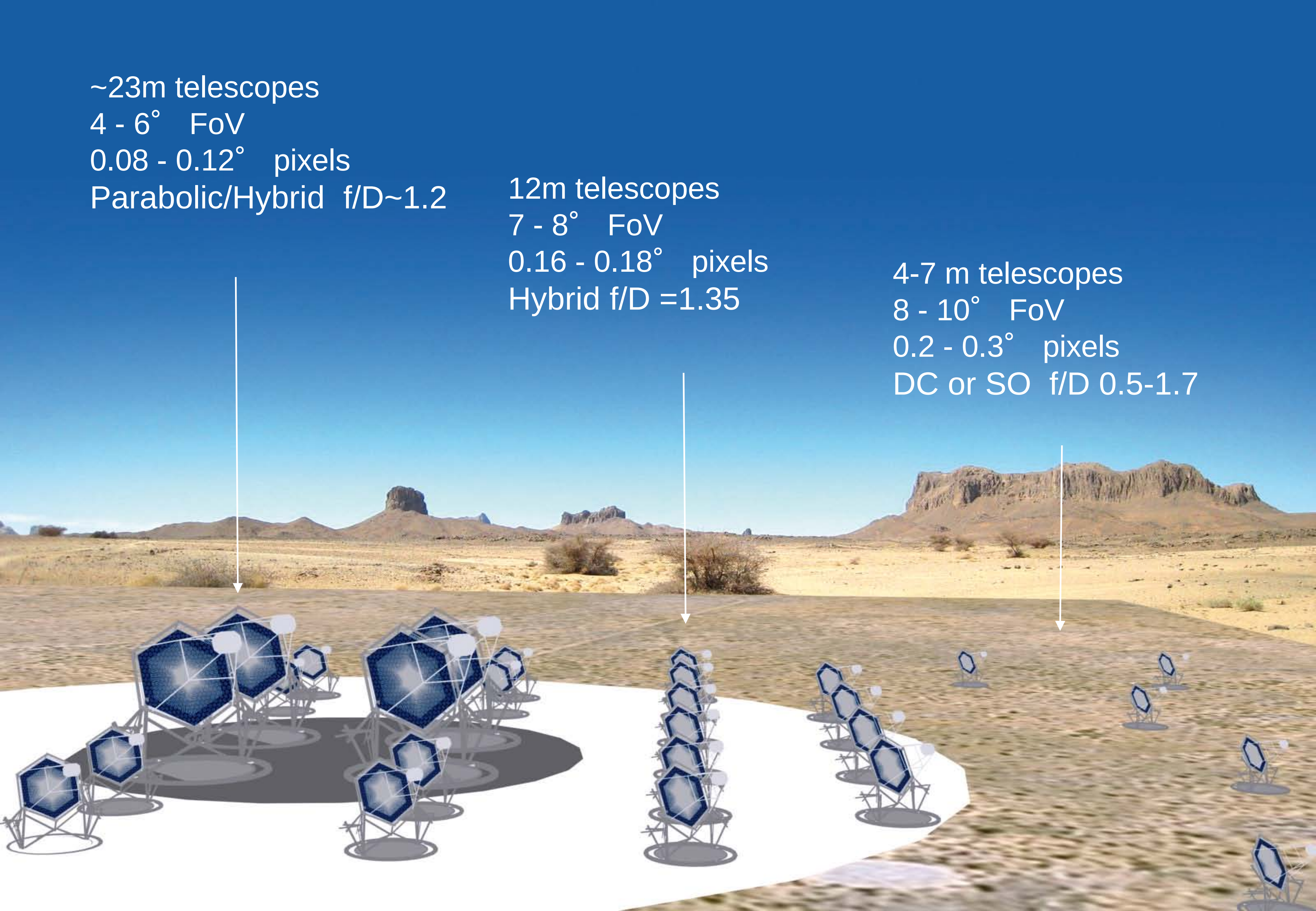


Summary of VHE gamma ray astronomy

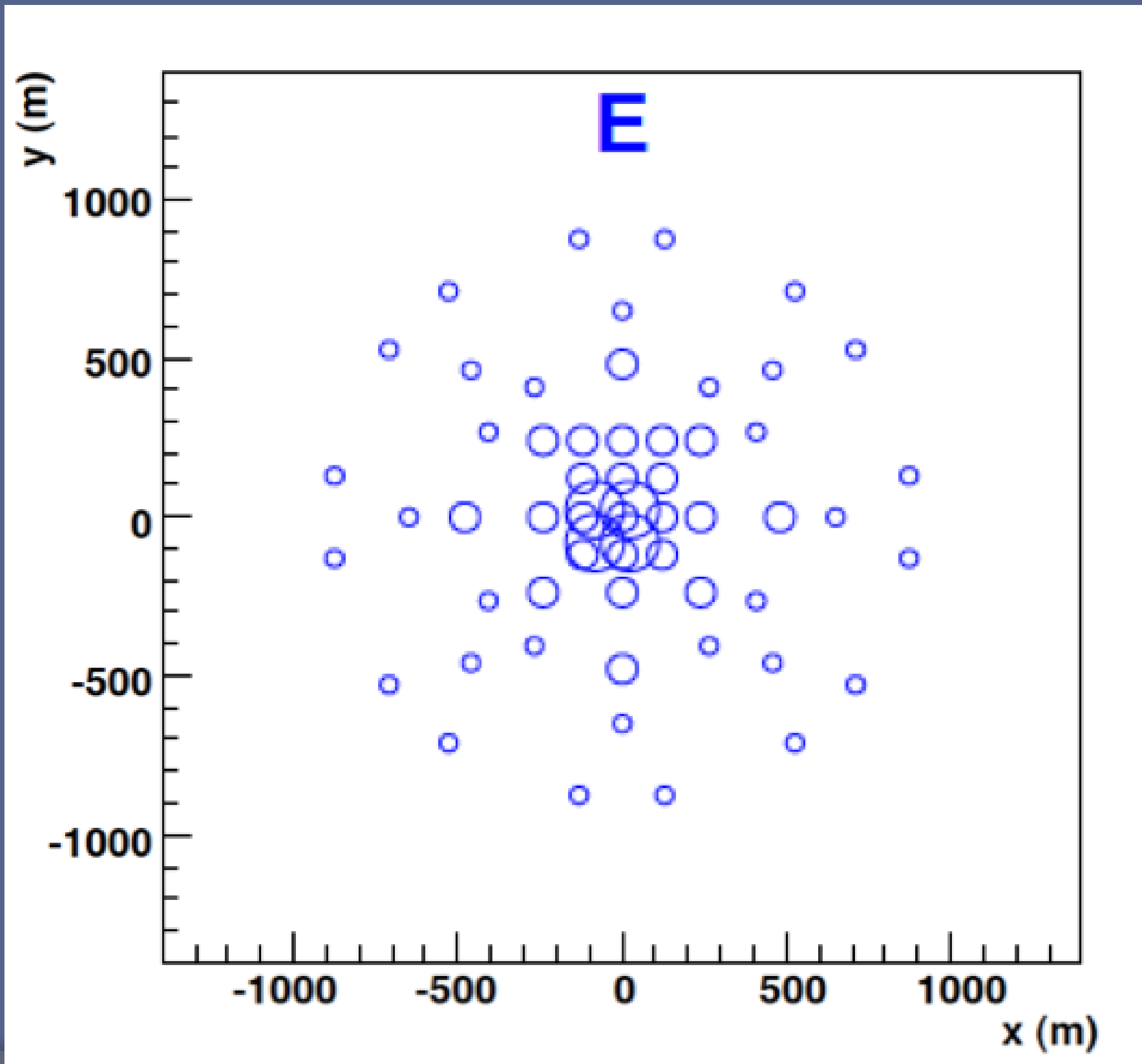
- The VHE gamma ray astronomy started with the discovery of VHE emission from Crab by Whipple observatory in 1989
- The third generation telescopes, HESS, MAGIC and VERITAS are increasing the number of VHE sources very rapidly (1-2 sources/months)
- More than 100 of VHE gamma ray sources
  - SNRs, Pulsar, PWNe, Binaries / BL Lacs, FSRQs, FR-I, Starburst Galaxies
- Galactic sources: SNRs
  - We can see several SNRs in different evolutionary stages with the different energy spectra
- Galactic sources: PWNe
  - Most popular galactic sources, asymetric morphologies, energy dependent morphology
- Nearby bright BL Lacs show the intensity variation of x 50
  - Mkn421, Mkn501, PKS2155
  - Very fast time variations of a few minutes are found in Mkn501 and PKS2155
- Distant sources:3c279, PKS1222
  - The room for the extra component (Pop-III) in EBL is now very slim

CTA


GLAST (1yr)
Crab
10% Crab
1% Crab
MAGIC
MAGIC-stereo
H.E.S.S.
50hrs
Current
Simulations
E·F(>E)
[TeV/cm²s]
AGNs, Pulsars
GRBs
Cosmic ray sources
Knee in gamma
Deep TeV Survey
~1 mCrab
Background Limited
Signal Limited
E [GeV]
10
100
1000
10⁴
10⁵
10⁻¹¹
10⁻¹²


~23m telescopes
4 - 6° FoV
0.08 - 0.12° pixels
Parabolic/Hybrid f/D~1.2
12m telescopes
7 - 8° FoV
0.16 - 0.18° pixels
Hybrid f/D =1.35
4-7 m telescopes
8 - 10° FoV
0.2 - 0.3° pixels
DC or SO f/D 0.5-1.7

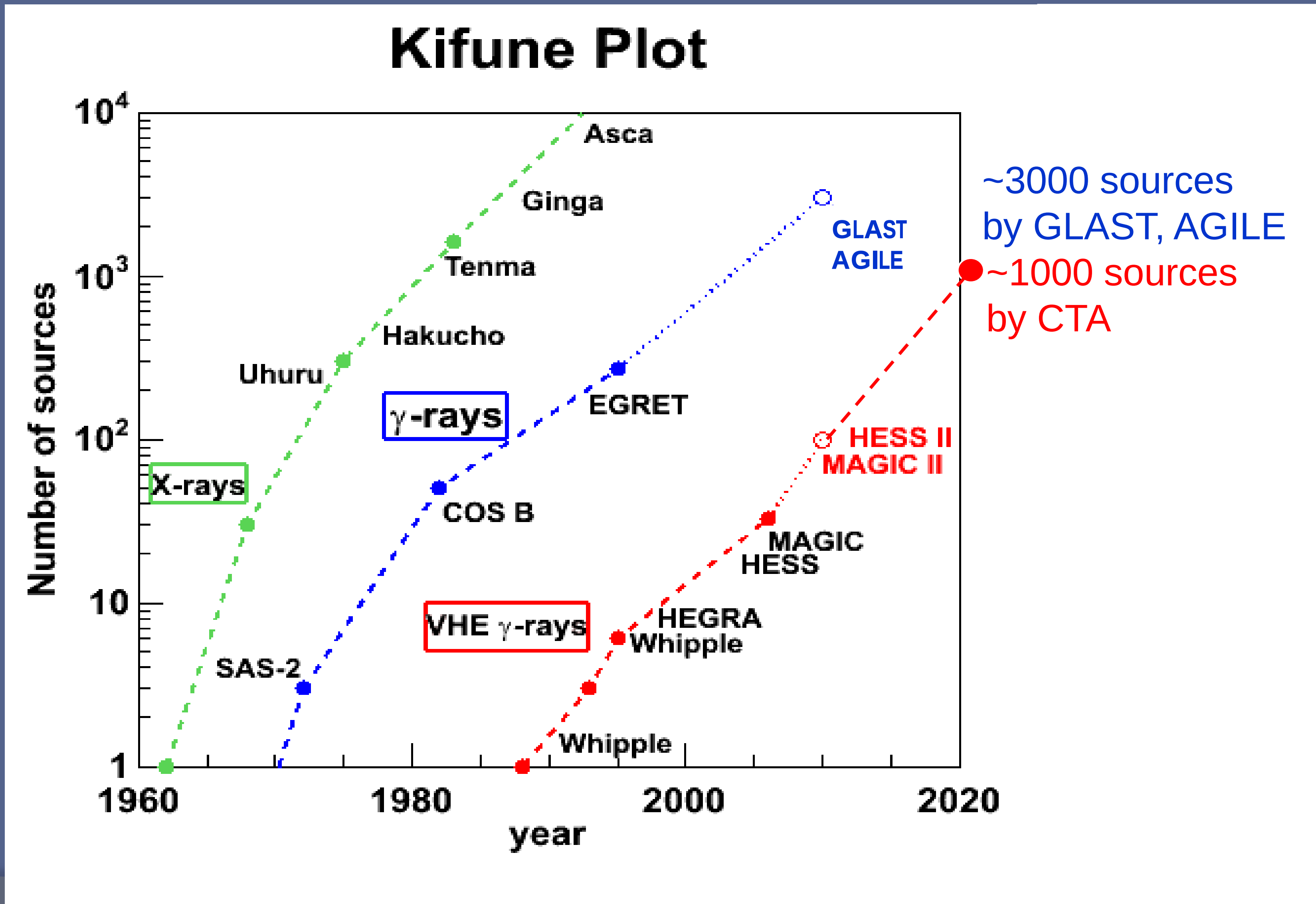
Possible array configuration



Configuration E:
LST x 4, MST x 23, SST x 32

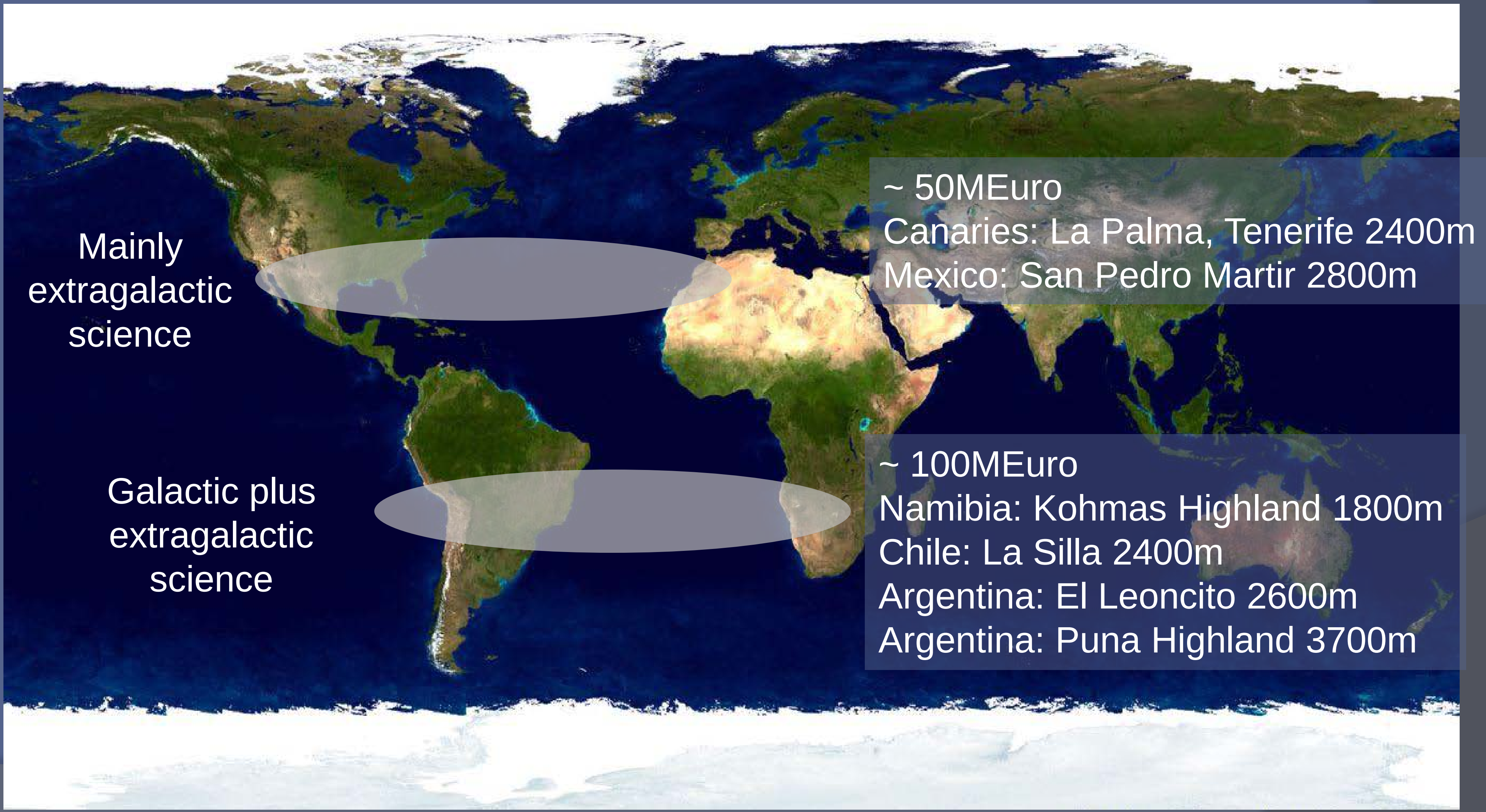
Acceptance 3km2

Kifune Plot
(expectation from log S - log N)

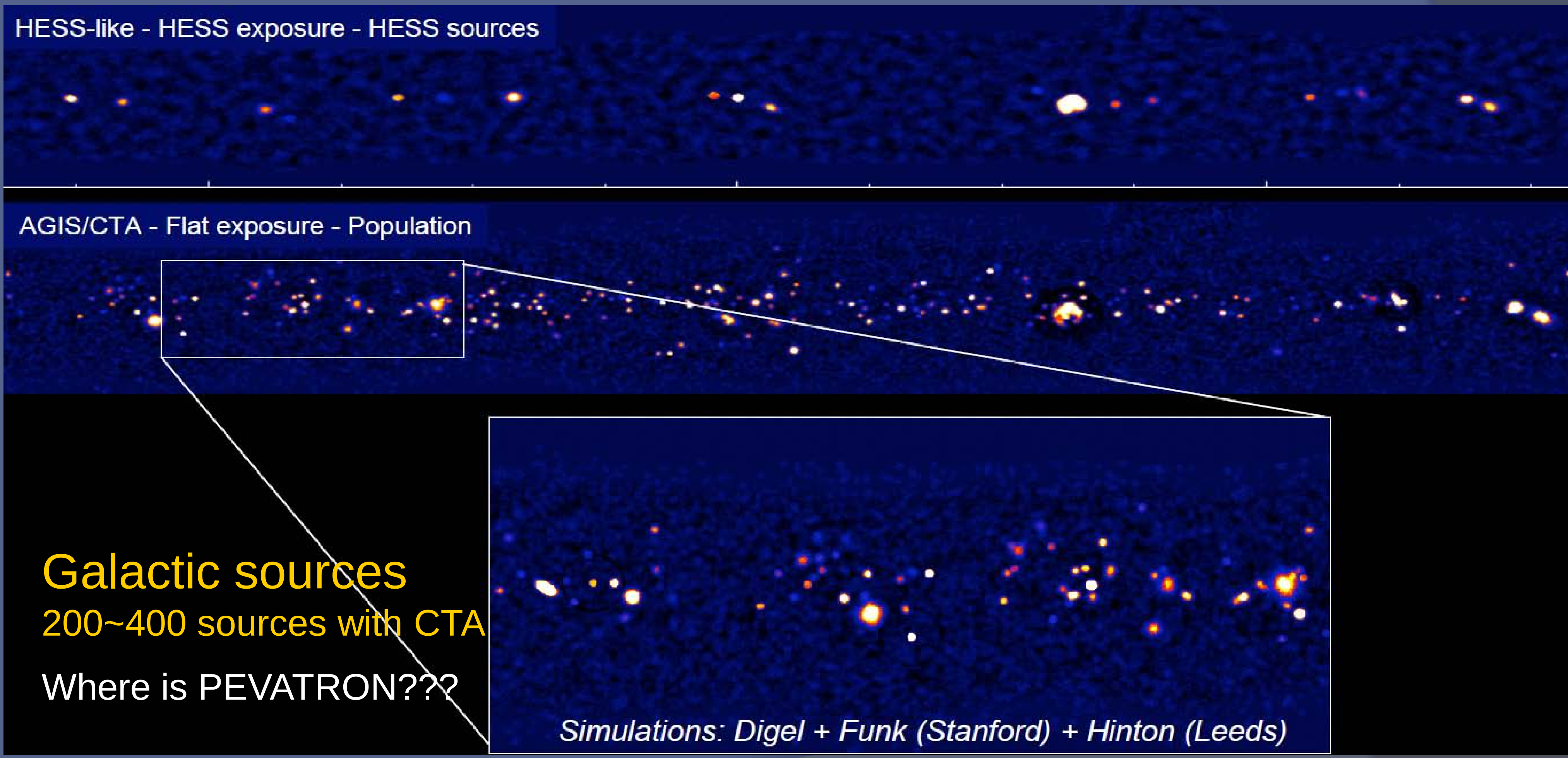


All sky observatory (2 stations in North and South)

One observatory with two sites operated by one consortium



Galactic sources

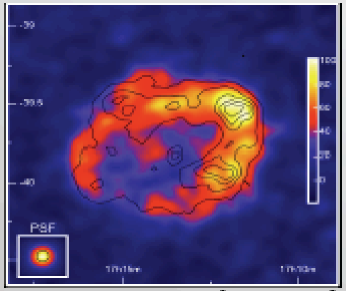


Galactic sources

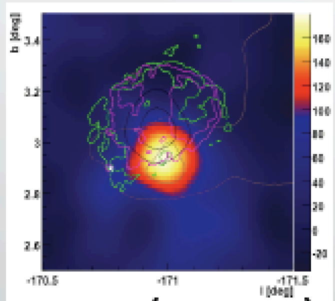
200~400 sources with CTA

Where is PEVATRON???

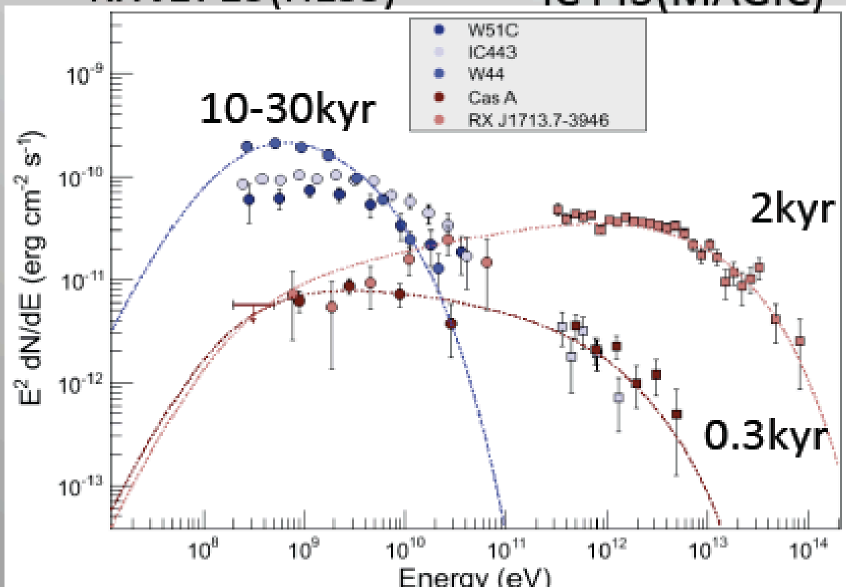
超新星は銀河宇宙線の源か？
超新星残骸の進化



RX J1713(HESS)

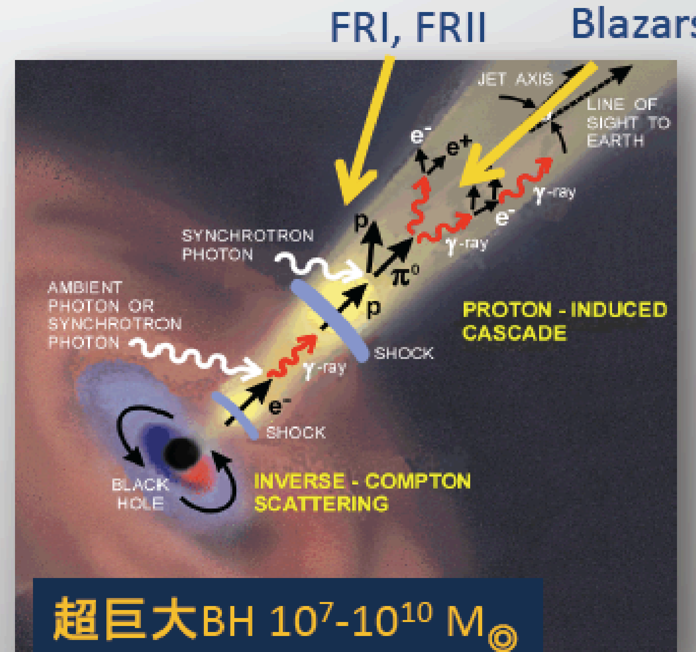


IC443(MAGIC)

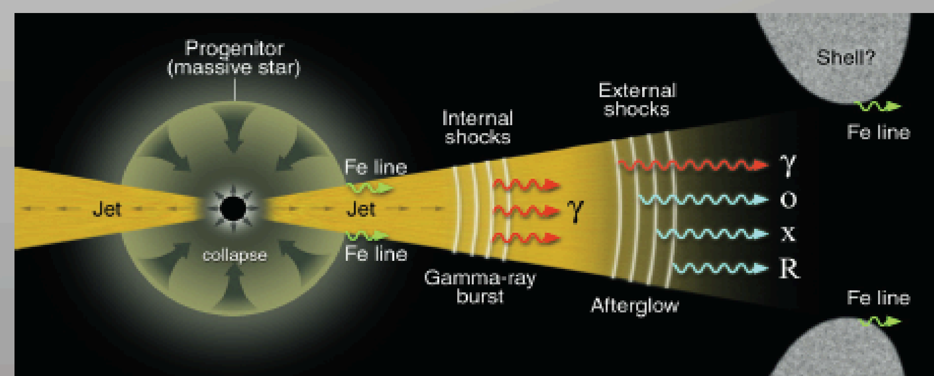


	Cas A	RX J1713.7 -3946	IC443	W44	W51C
Age (kyears)	0.3	2	10	20	30
$n_{average}$ (cm-3)	10	0.1	10	100	10

銀河系外の天体・相対論的ジェットの研究
最高エネルギー宇宙線の起源？

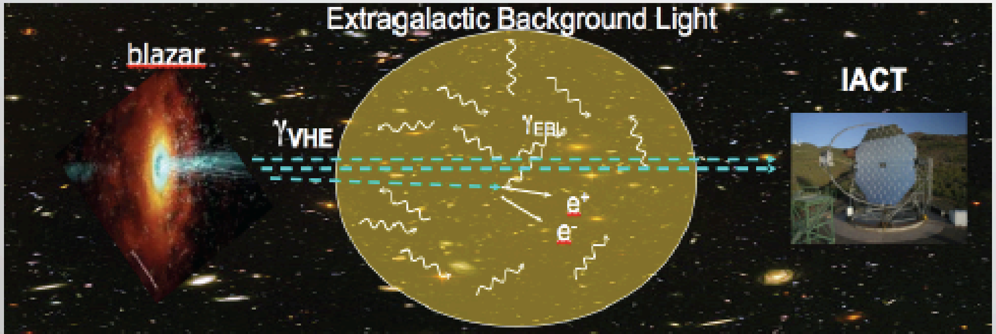


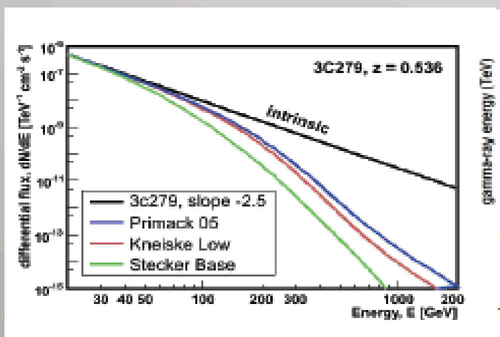
活動銀河核(赤方偏移 z<4)

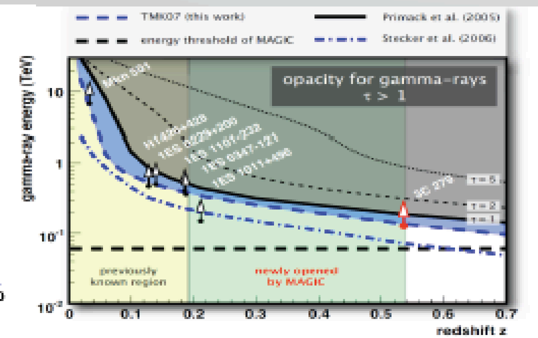


ガンマ線バースト (z<6)

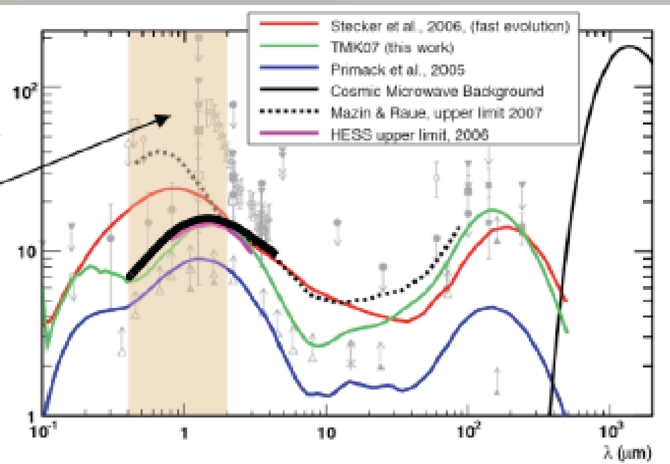
宇宙はどこまで透明か？ ➔ 宇宙の星形成史
宇宙論的な距離を飛来する高エネルギーガンマ線





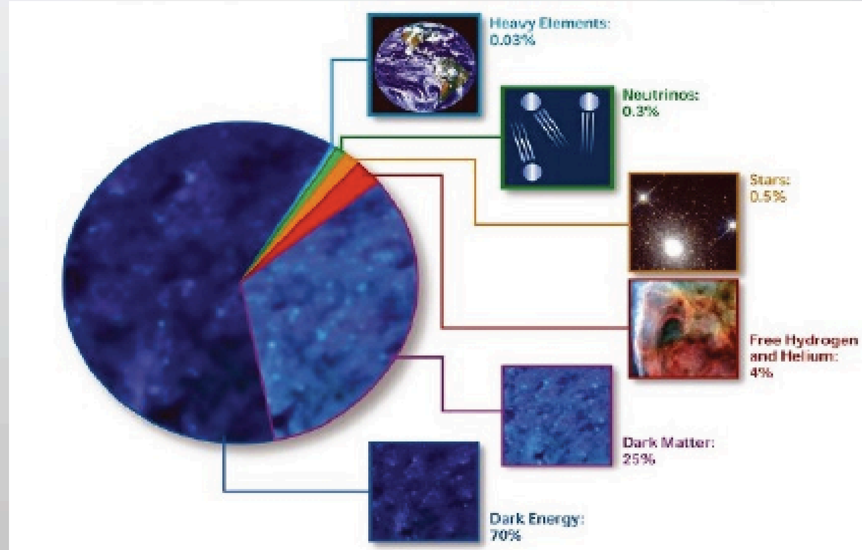


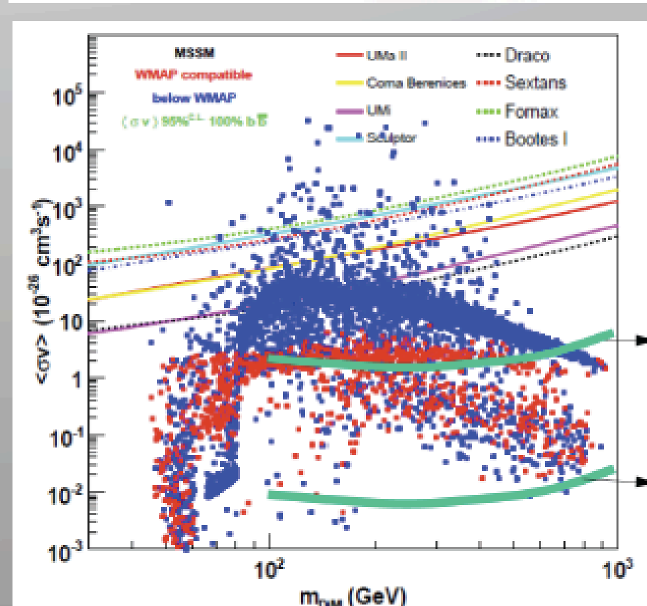
Probing new range of the EBL



Green line: model of Kneiske et al., tuned to the 3C 279 spectrum using the Γ=1.5 criterion

探究的研究　暗黒物質の探索
暗黒物質対消滅からのガンマ線を探る
ノーベル賞級の大発見なるか？



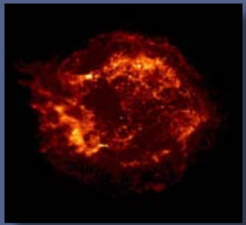


APJ 712, 147 (2010
arXiv: 1001.4531

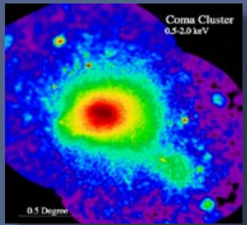
CTA
Sag. Dwarf

CTA
Gal.Halo

Specification and Physics

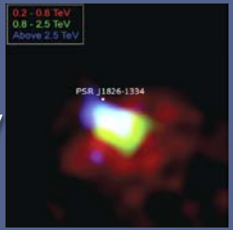


SNRs

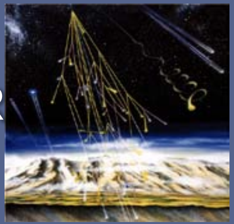


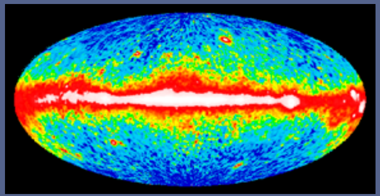
New sources

Morphology



Origin of CR





TeV - All sky map
Galactic diffuse

Sensitivity x10 (10^{-14}erg cm^{-2}s^{-1})

Energy Res. x2 (10% @ 1TeV)

Angular Res. x3 (2 arcmin @1TeV)

Low Threshold E x2 (20-30GeV)

Large Accept. x30 (3×10^6m^2 >1TeV)

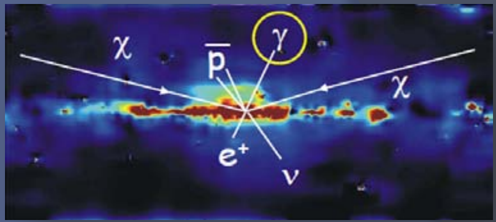
Fast rotation 20 sec/180˚

Better S/N x3 >99.9%

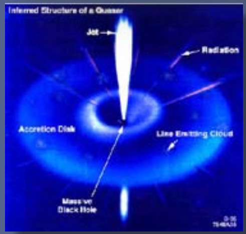
High Time Res. x10 (~1sec)

All Sky Observatory

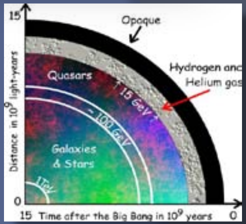
Flexible modes Scan / Monitor



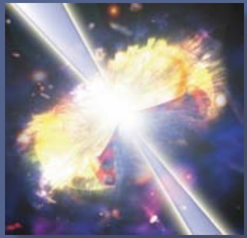
DM



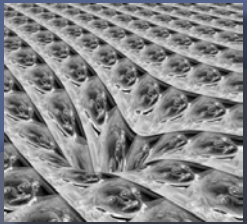
Distant AGNs



cosmology



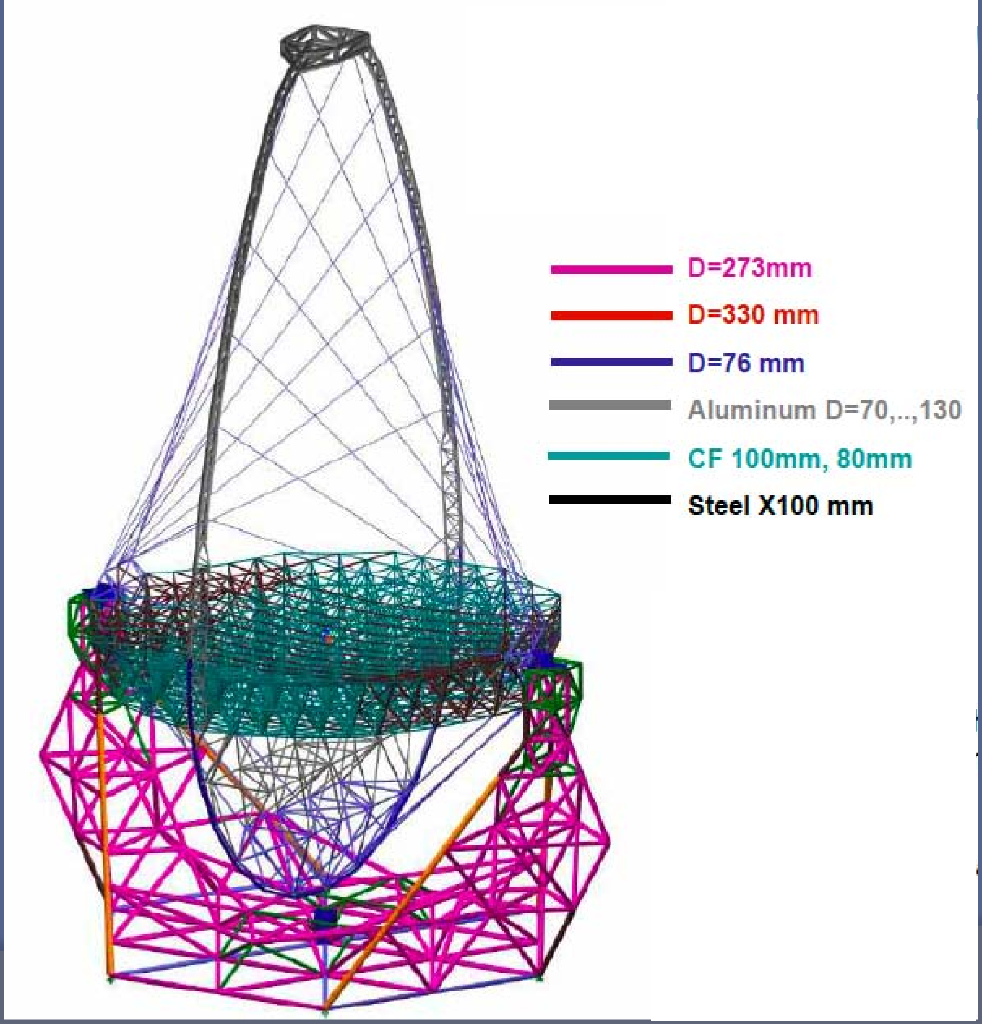
GRBs



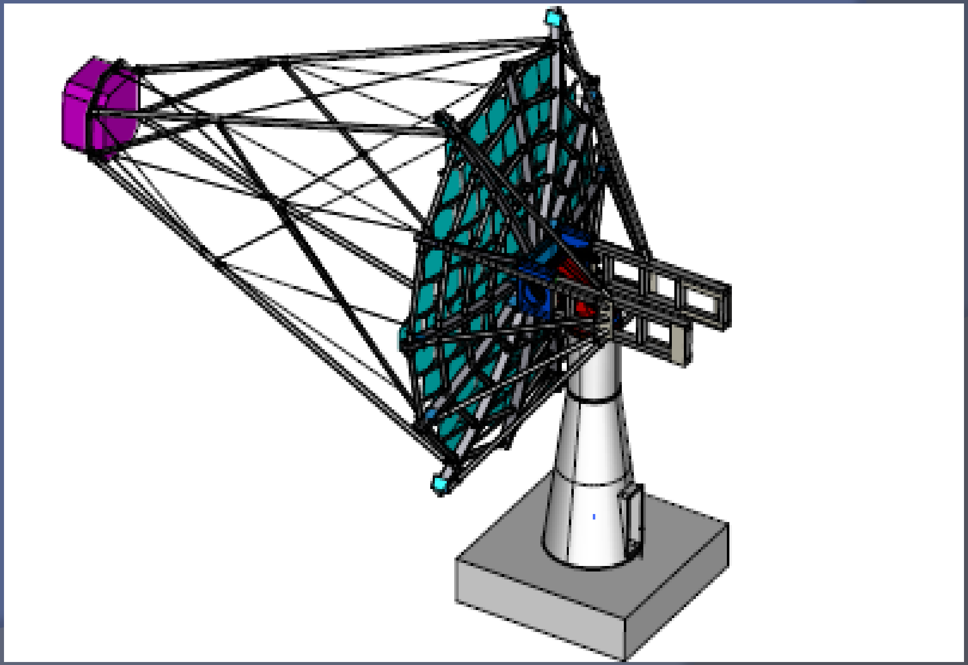
Space and Time

23m Large size telescope and 12m Middle size telescope

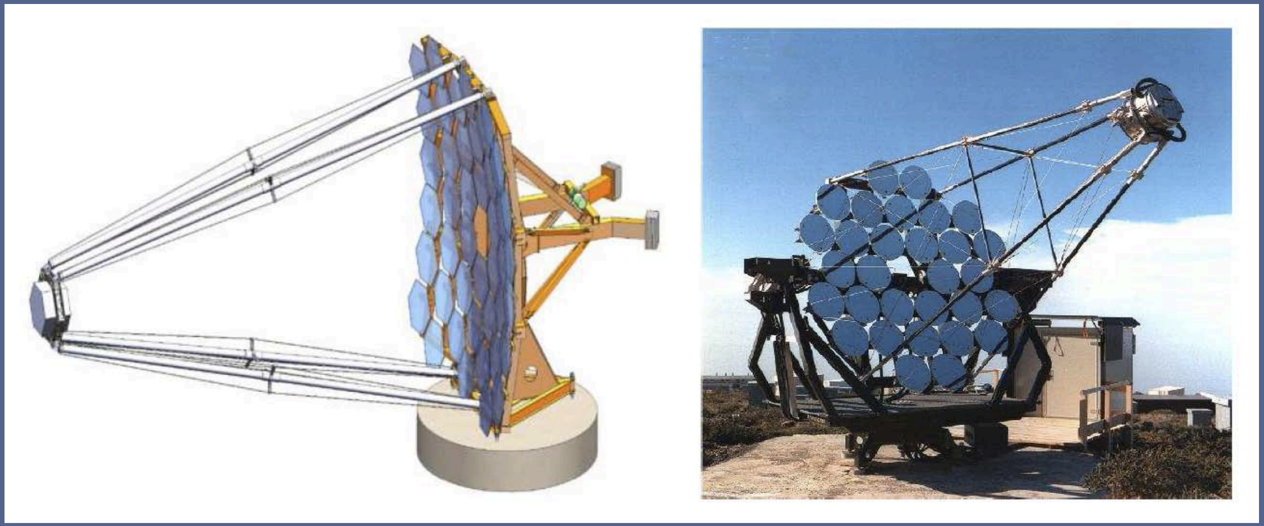
23m LST designed by MPI group



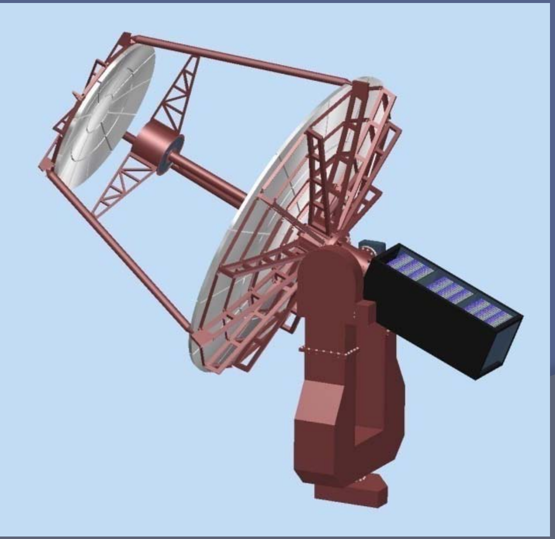
12m MST designed by DESY group



4-7m Small Size Telescope

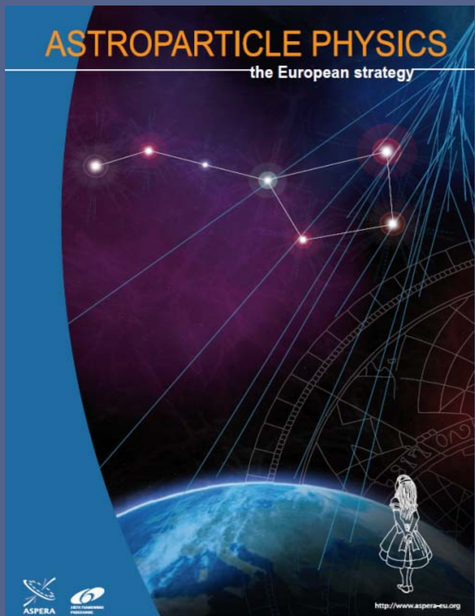


Italian Design 7m

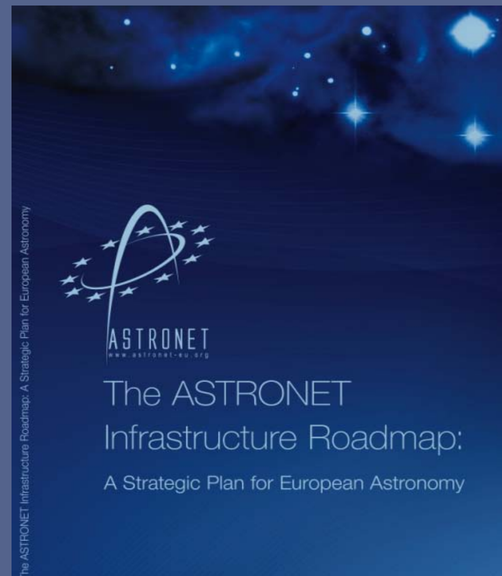


UK Design 4m

Recommendations and supports



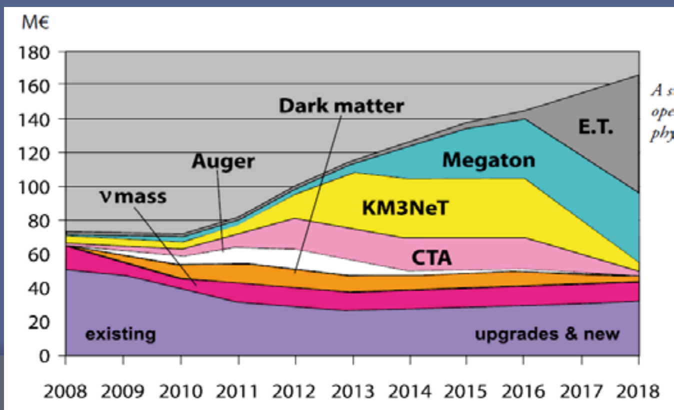
ASPERA Roadmap
Magnificent Seven

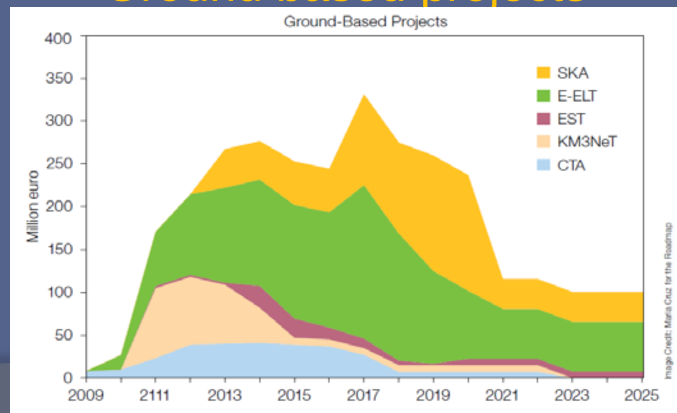


ASTRONET Roadmap

High Priority project
Ground based projects

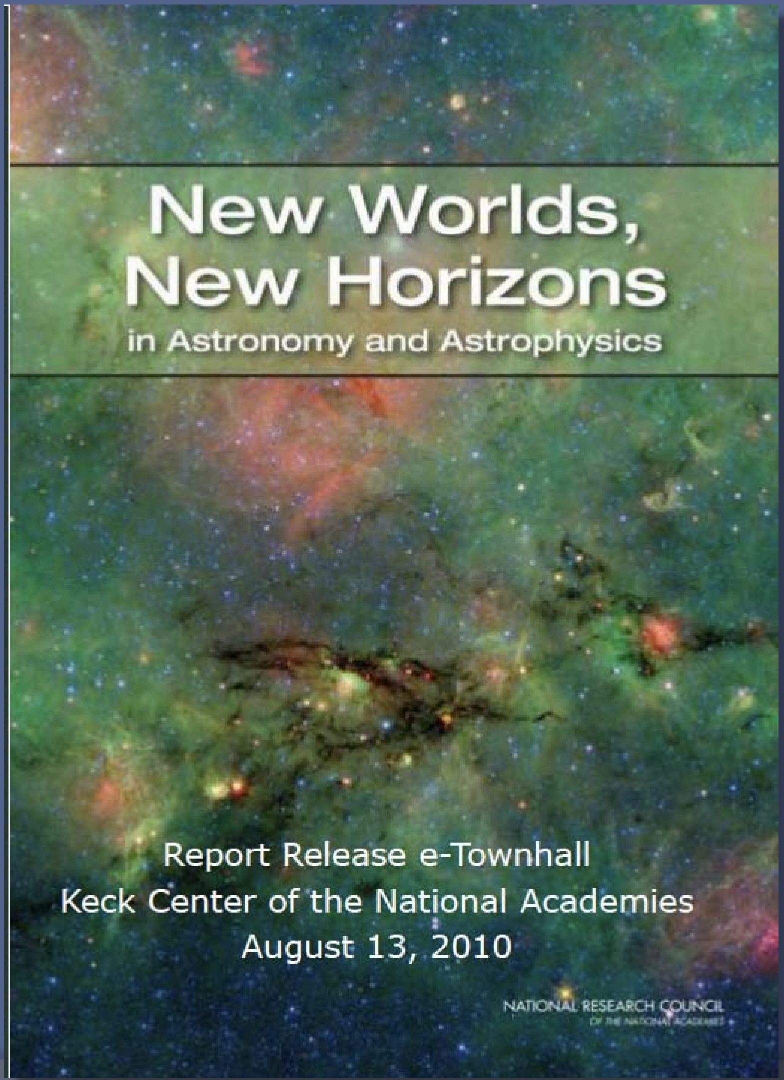
8 Infrastructures
from Physics and eng





CTA	150
E-ELT	950
ELI	400
FAIR	1187
KM3NeT	200
PRINS	1400
SKA (GLOBAL)	1500
SPIRAL2	196

Decadal Survey in Astronomy and Astrophysics in US

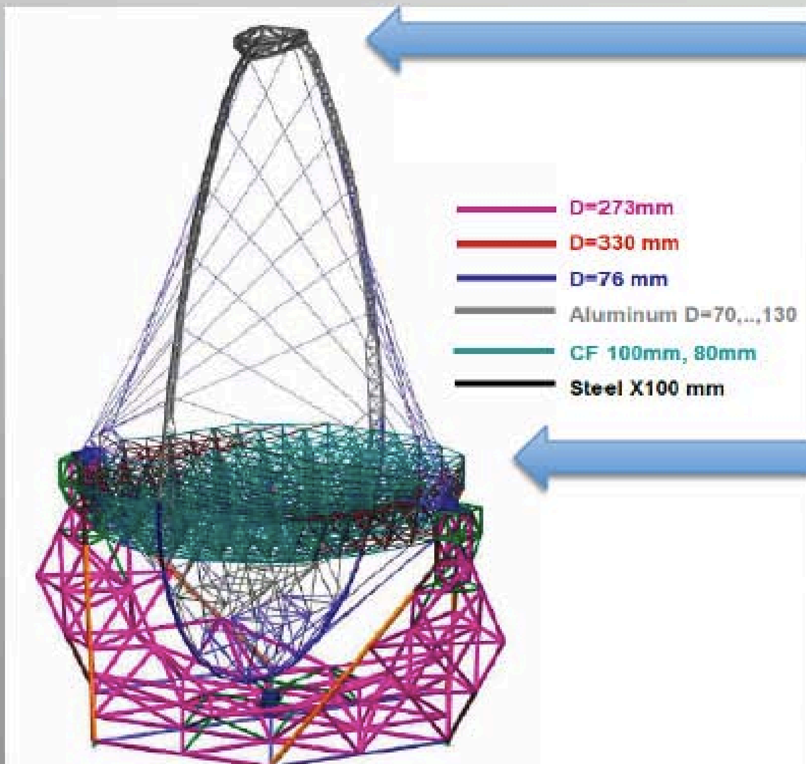


Ground-based projects ranked in order:
Large-scale

- Large Synoptic Survey Telescope (LSST)
- Innovations Program
- Giant Segmented Mirror Telescope (GSMT)
- Atmospheric Čerenkov Telescope Array (ACTA)

CTA Japan 活動
大口径望遠鏡プロトタイピング

- ✓CTAは日米欧の国際共同実験
- ✓日本は主にCTA-LST大口径望遠鏡に貢献
- ✓最終的には全体の20% の貢献をめざす
  - ✓日本グループ70名の研究者
  - ✓ハード：23m大型望遠鏡８台分のカメラと鏡
  - ✓ソフト：物理、シミュレーション、データ解析

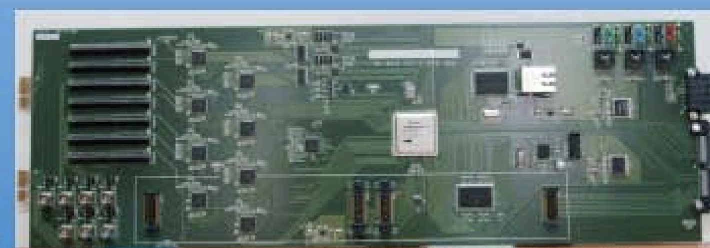


CTA LST(23m 大口径望遠鏡)

日本グループによる技術開発・技術貢献

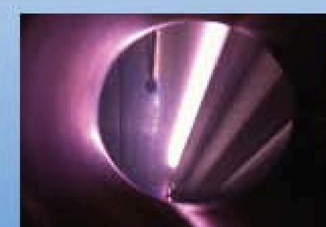
高分解能カメラ(MAGIC)

PMT、高圧、アンプ、スロー制御、読み出し回路



7ch 1GHz 超高速波形読み出し回路

1.5m サイズ
高精度分割鏡



大型スパッタリングチェンバー
Cr + Al + SiO2 + HfO2 による
マルチコート（長寿命、増反射）

Summary: CTA

- CTA will provide
  - 10 times better sensitivity
  - wider energy coverage (10GeV-100TeV)
  - All sky observation
  - ~1000 VHE sources
- High quality data will be delivered
  - Better energy resolution (10%)
  - Better angular resolution (2arc min)
- Time schedule
  - Preparatory Phase until 2014
  - Construction phase: 2015-
- Cost ~200MEuro
  - Contribution from CTA-Japan ~20% of total cost
- Expected contribution from CTA Japan
  - LST Camera
  - GHz sampling readout electronics
  - Large size mirrors
- よろしくご支援をお願いいたします。


THANKS