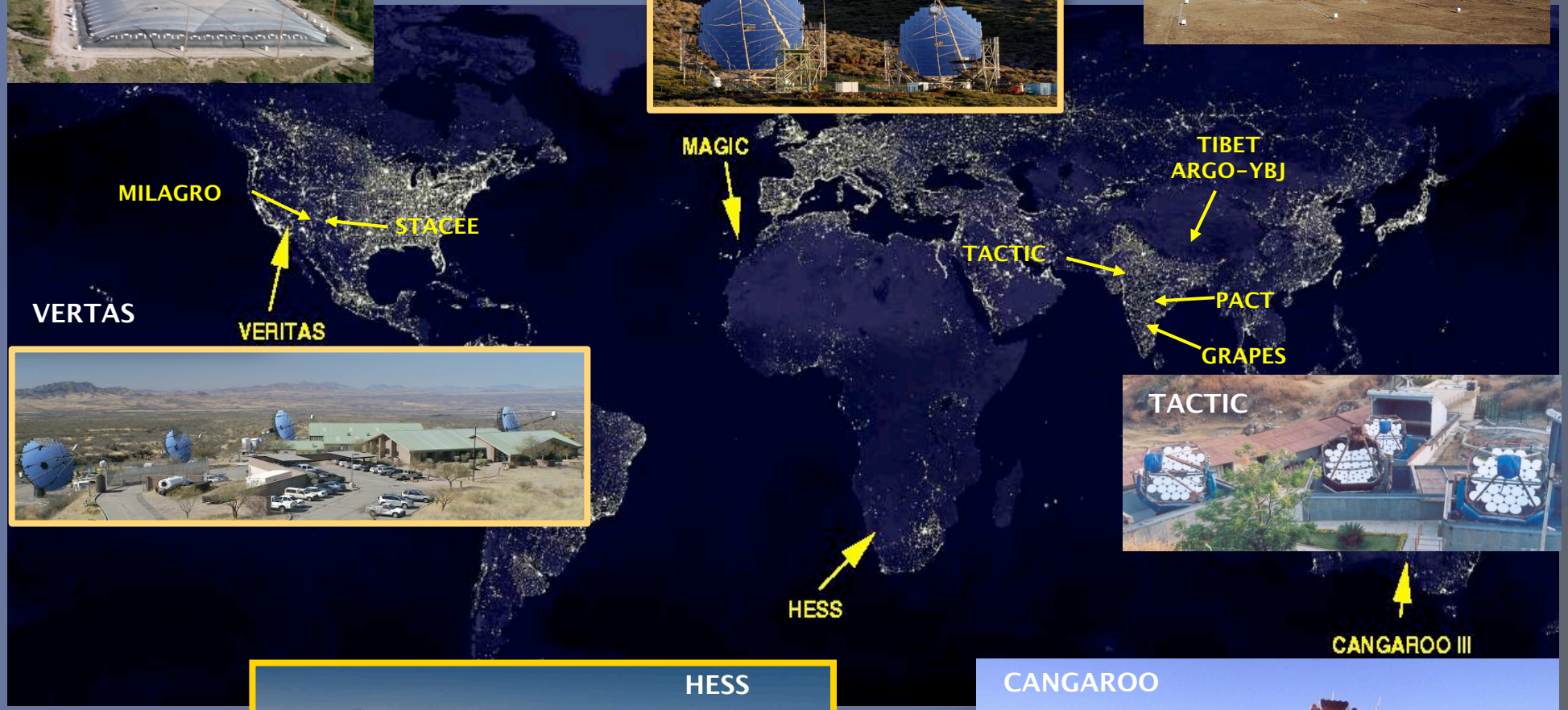
Max-Planck-Institute for Physics
Masahiro Teshima

VHE Instruments

MILAGRO

MAGIC

TIBET



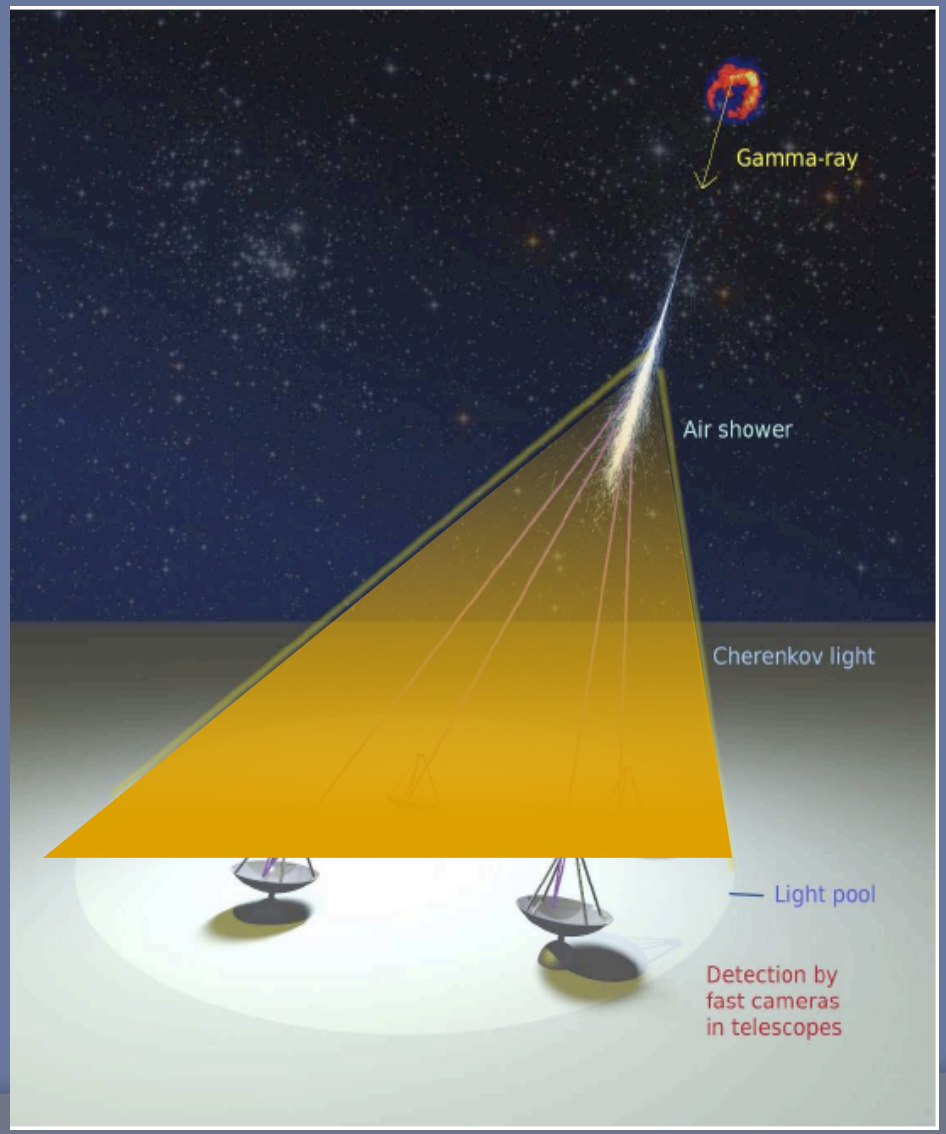
VERTAS

TACTIC

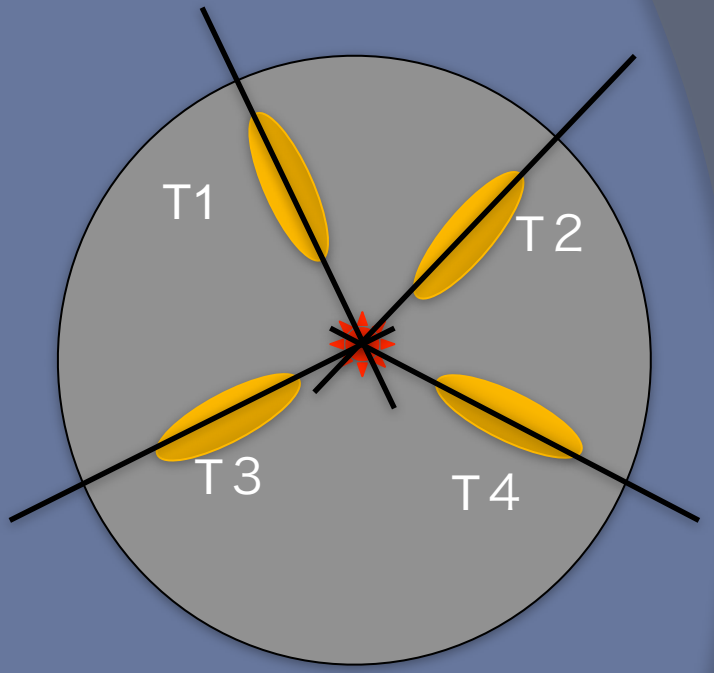
HESS

CANGAROO

Imaging Air Cherenkov



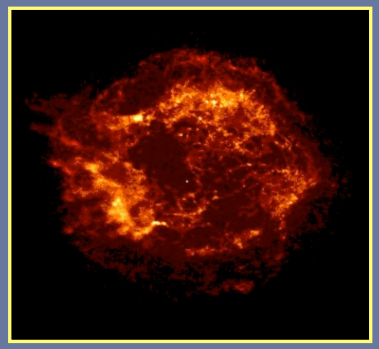
Cherenkov Light
50photons/m^2 (5 pe/m^2) at 1TeV
➔ MAGIC 2 x240 m^2, HESS 4 x106 m^2



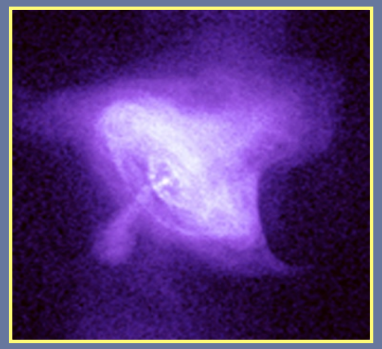
Typical parameters

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

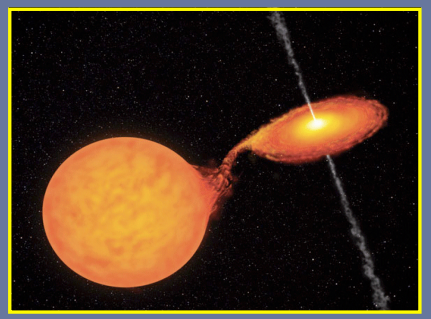
Physics objectives



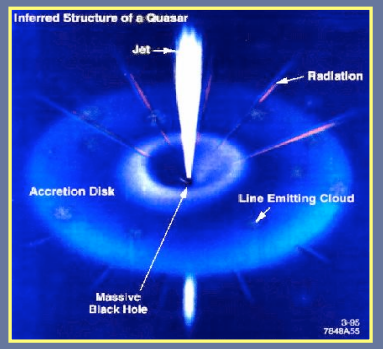
SNRs



Pulsars
and PWNe



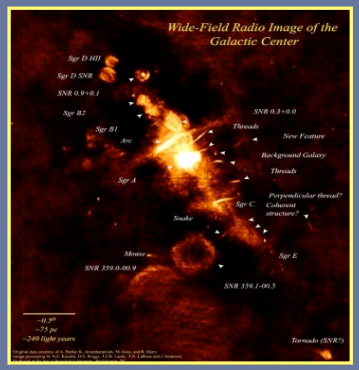
Micro quasars
X-ray binaries



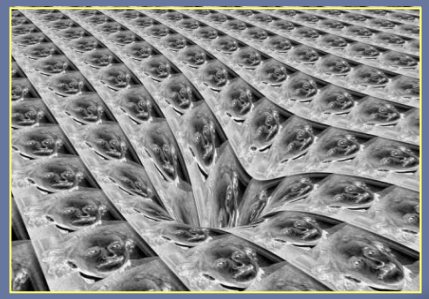
AGNs

GRBs

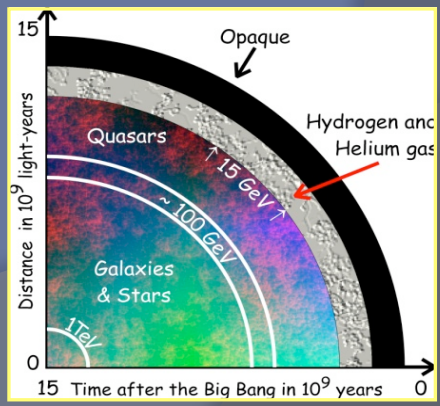
Origin of
cosmic rays



Dark matter

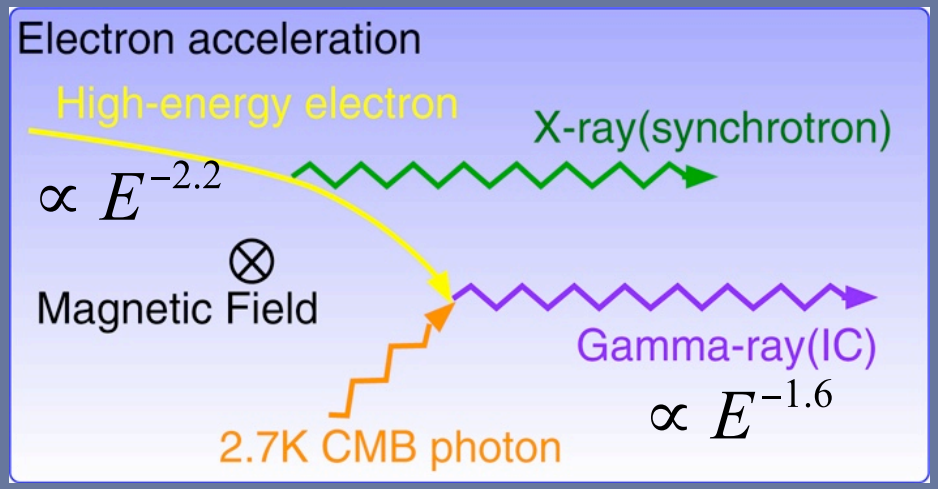


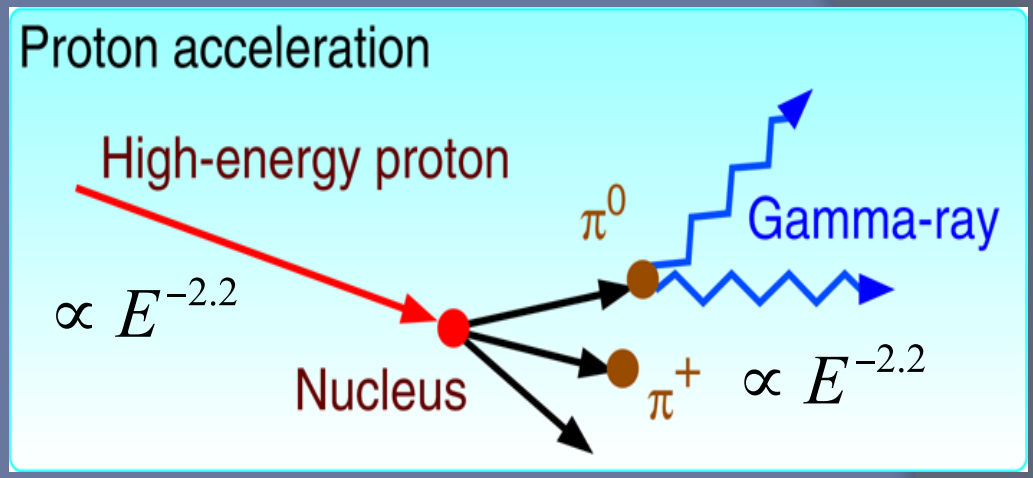
Space-time
& relativity



Cosmology

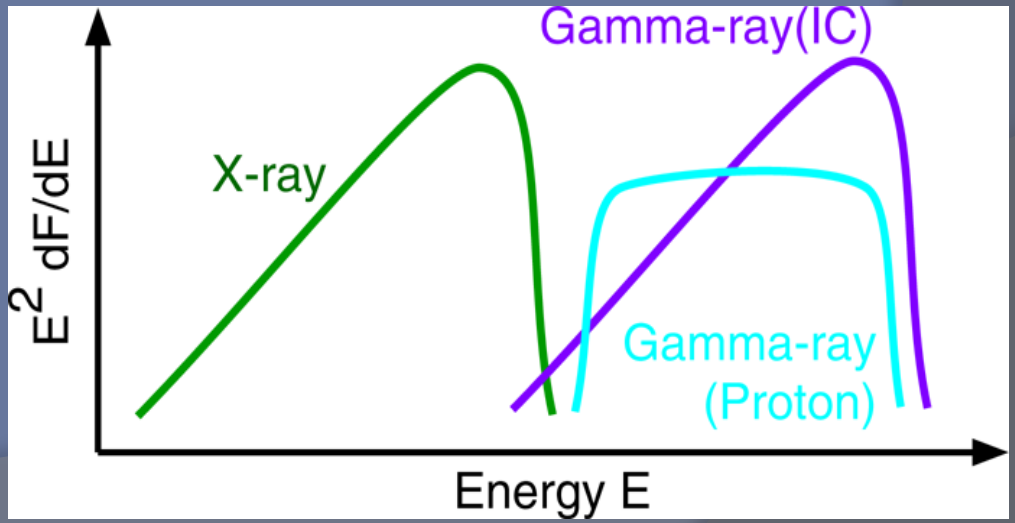
Gamma-Ray Emission Processes(1)
Astrophysical process





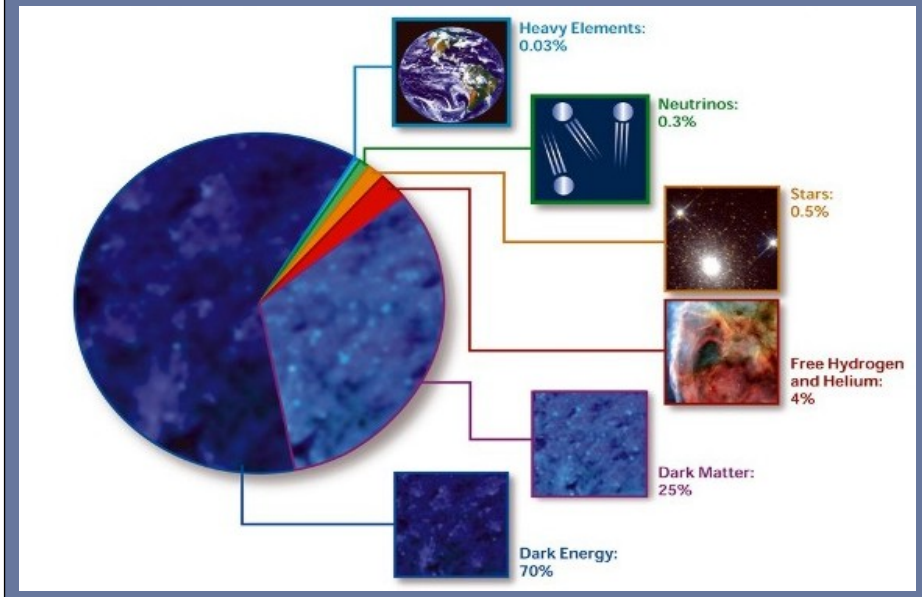
$$\left(\frac{dE}{dt}\right)_{\text{I.C.}} = \frac{4}{3}\sigma_T c \tilde{a}^2_{\max} U_{\text{photon}}$$

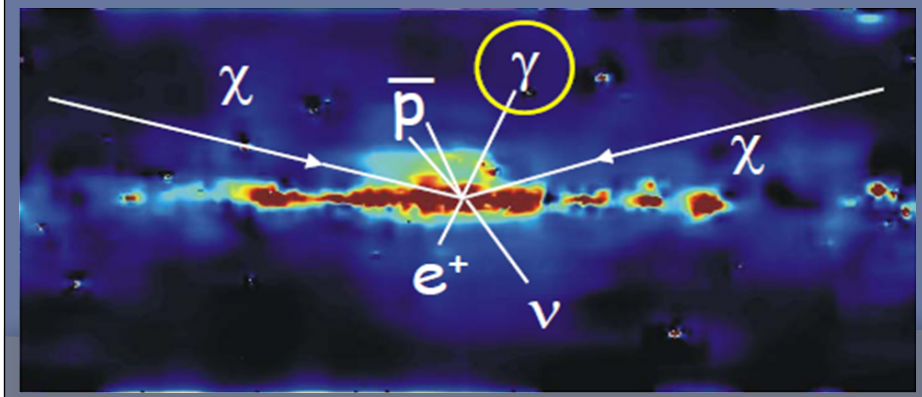
$$\left(\frac{dE}{dt}\right)_{\text{Sync}} = \frac{4}{3}\sigma_T c \tilde{a}^2_{\max} \frac{B^2}{2}$$



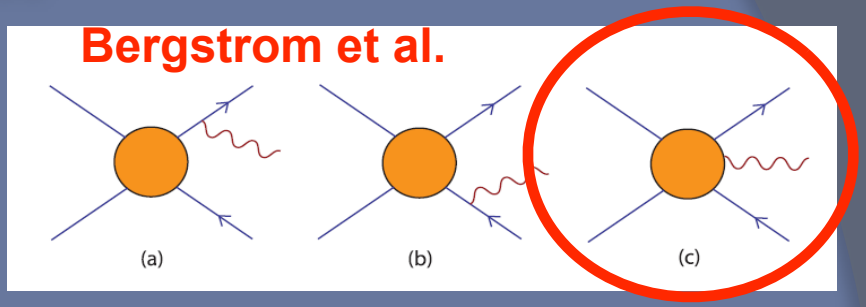
Gamma ray emission process from DM Annihilation

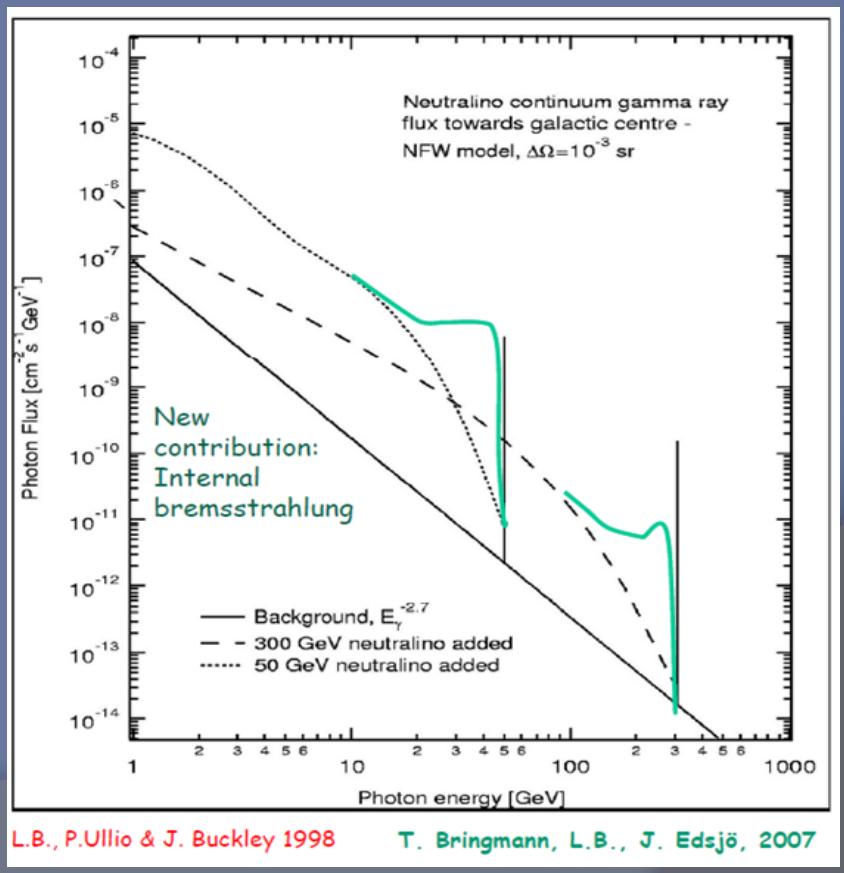
Dark Matter Annihilations





Bergstrom et al.

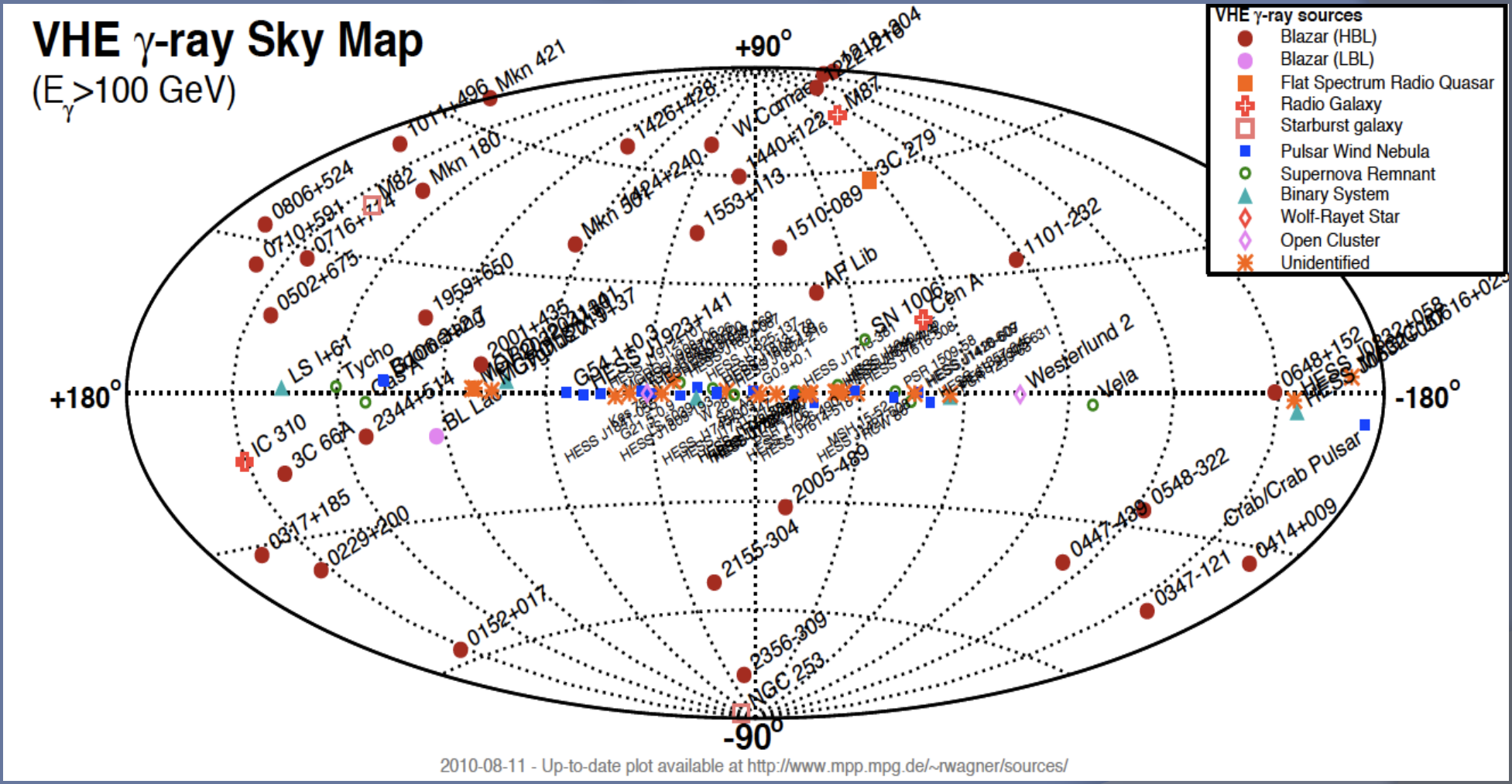




L.B., P.Ullio & J. Buckley 1998

T. Bringmann, L.B., J. Edsjö, 2007

VHE Skymap

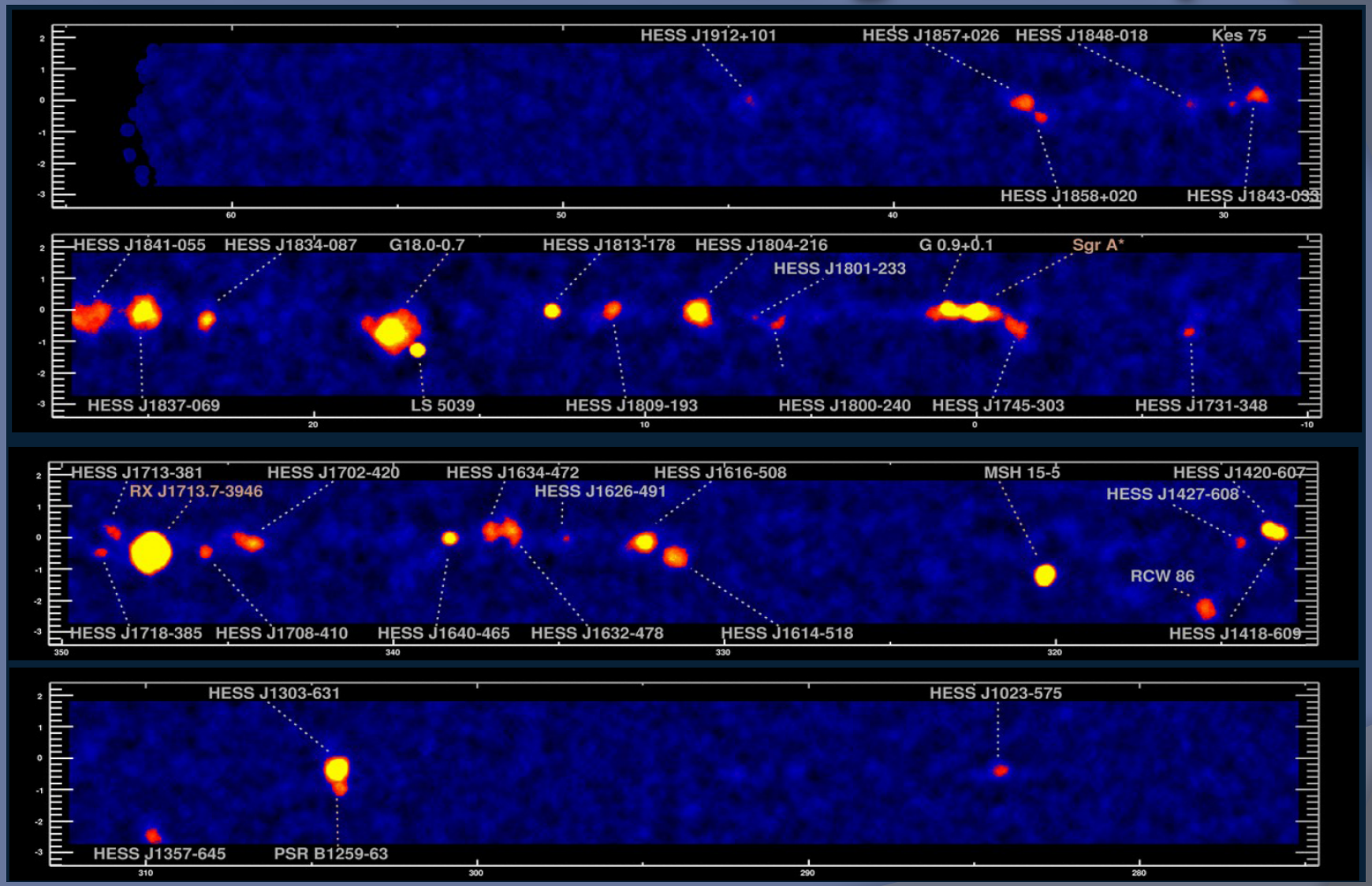


103 sources (42 Extragalactics + 61 Galactics) in July 2010

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

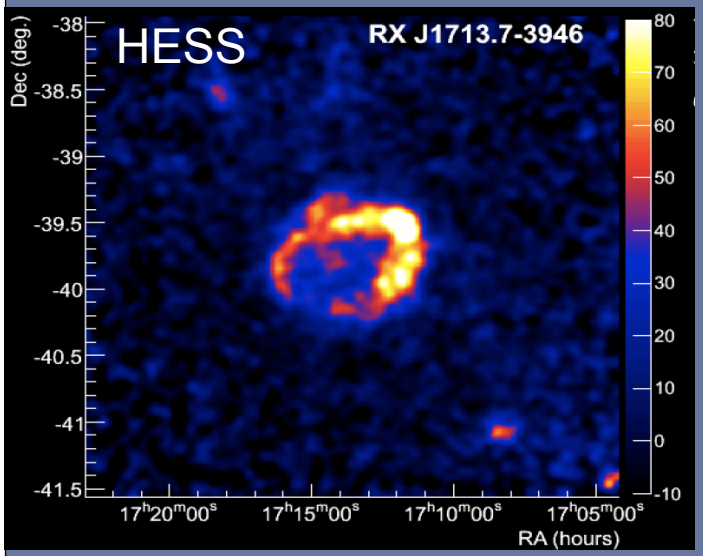

GALACTIC SOURCES
SNRS, PWNE

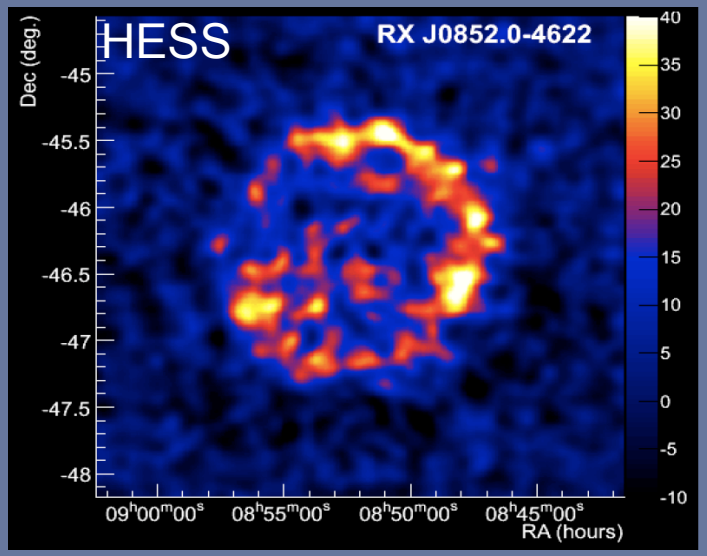
Great success!! HESS galactic plane



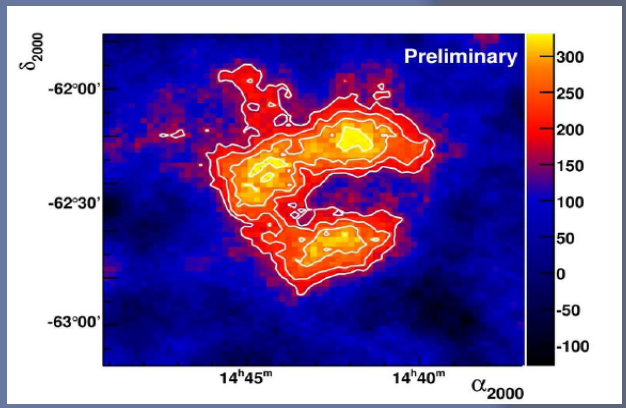
PWNe, SNRs, Binaries, un-IDs

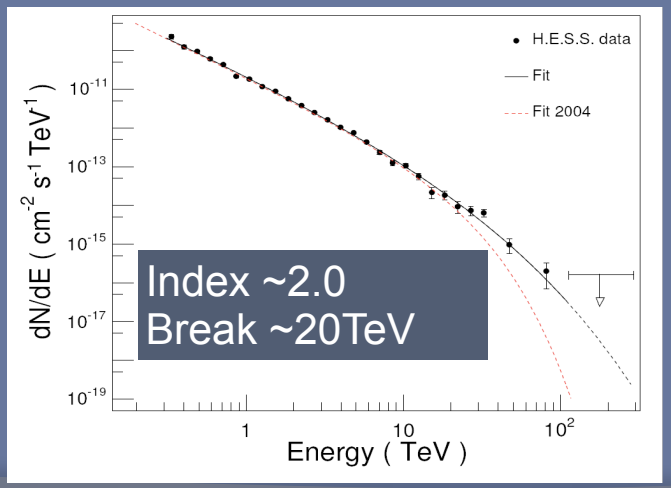
HESS: Shell type SNRs(7)
RX J1713, RX J0852, RCW86

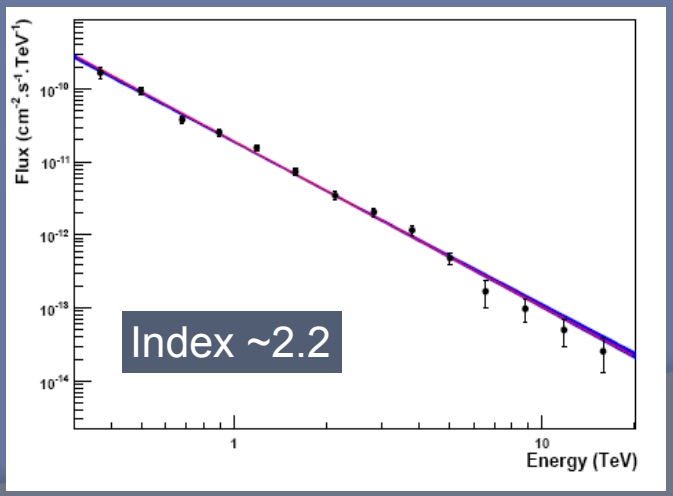


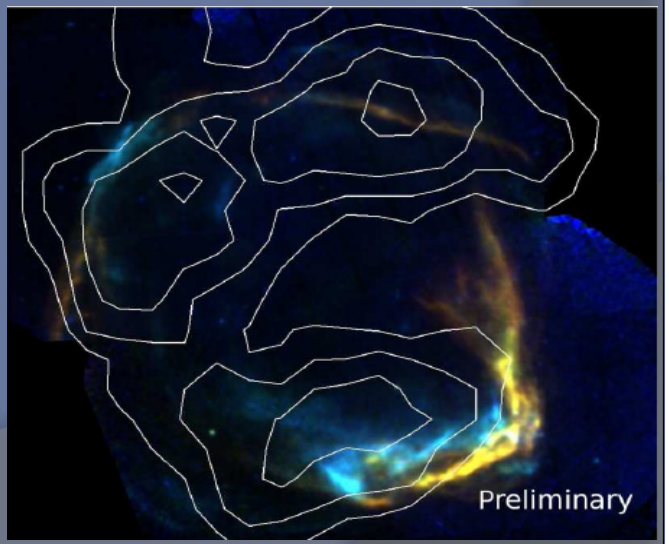


HESS RCW86



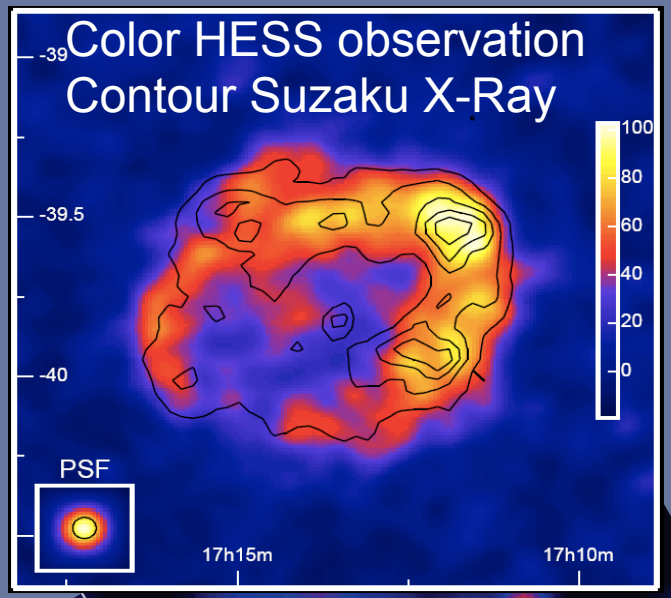


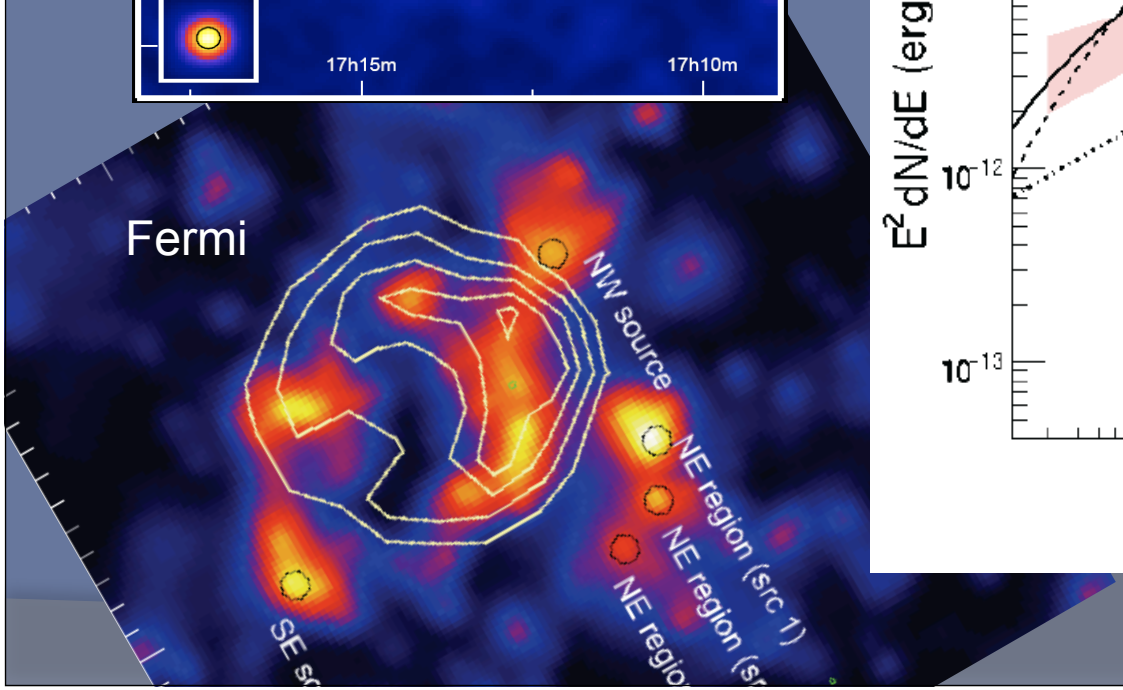




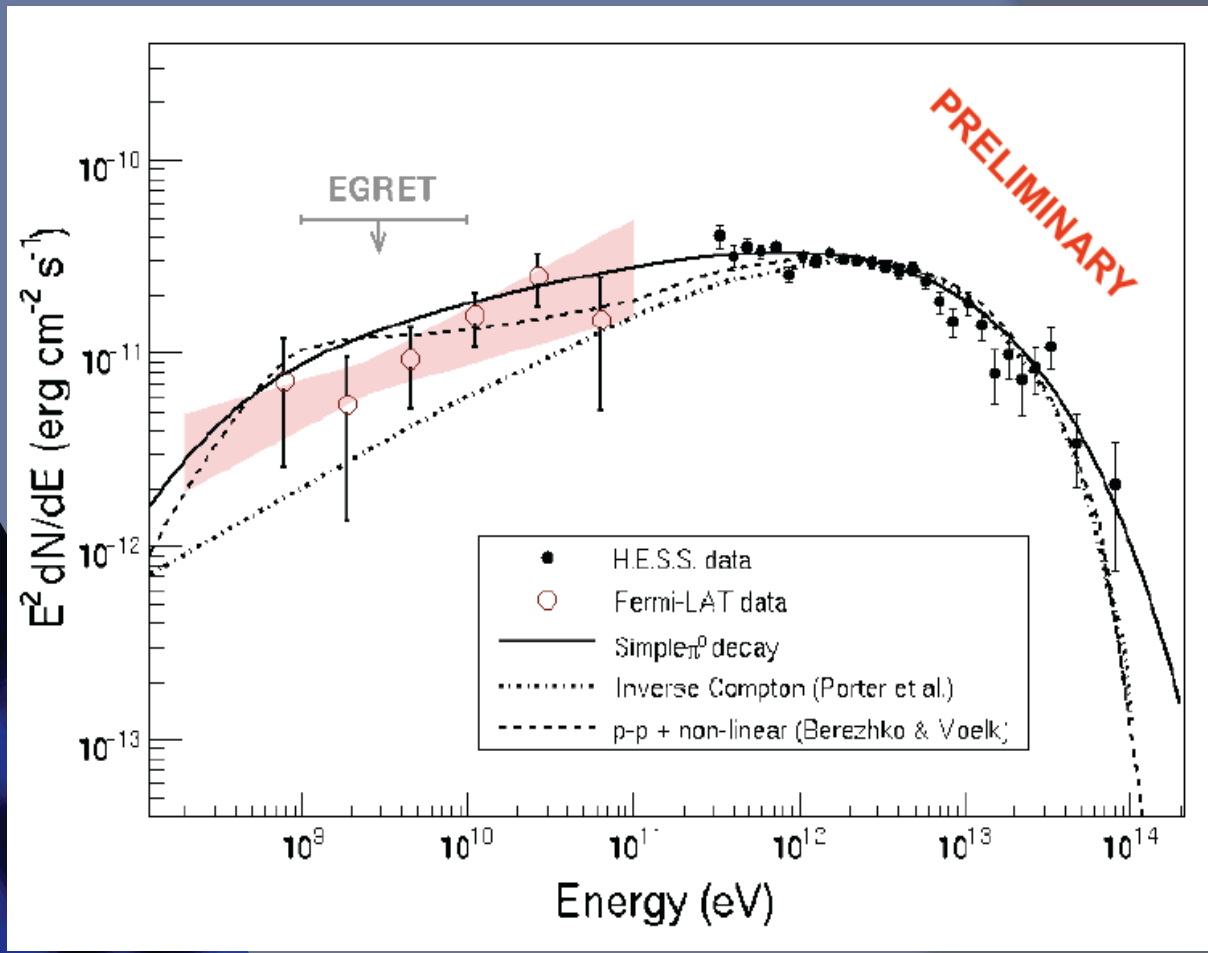
XMM-Newton, HESS

SNR Study

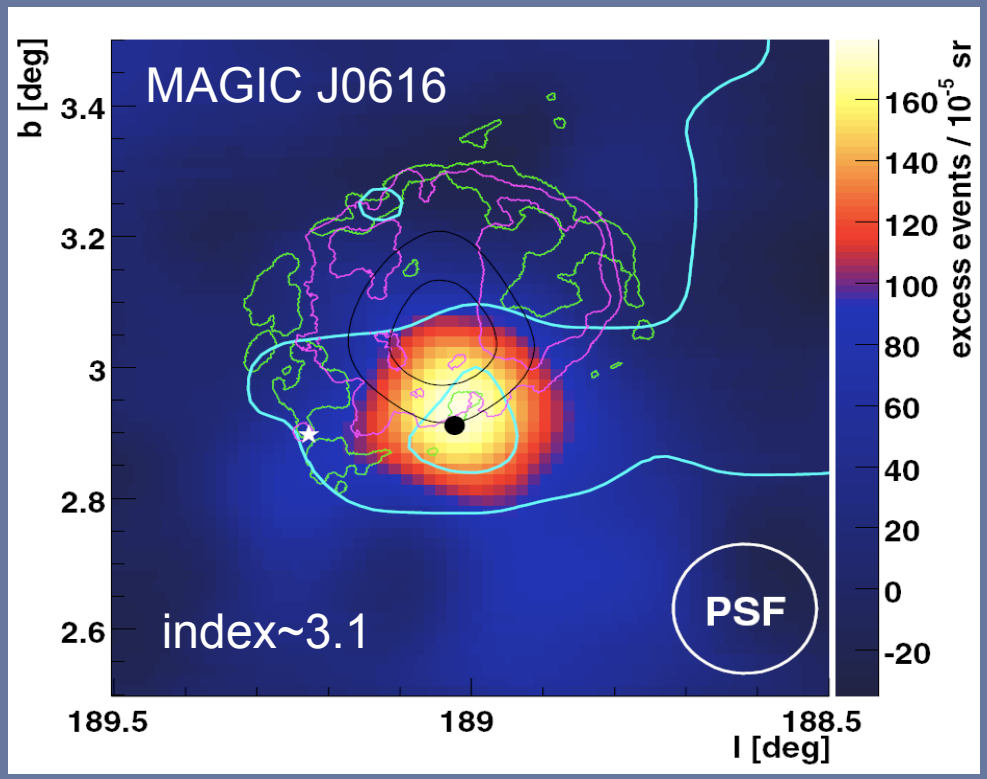


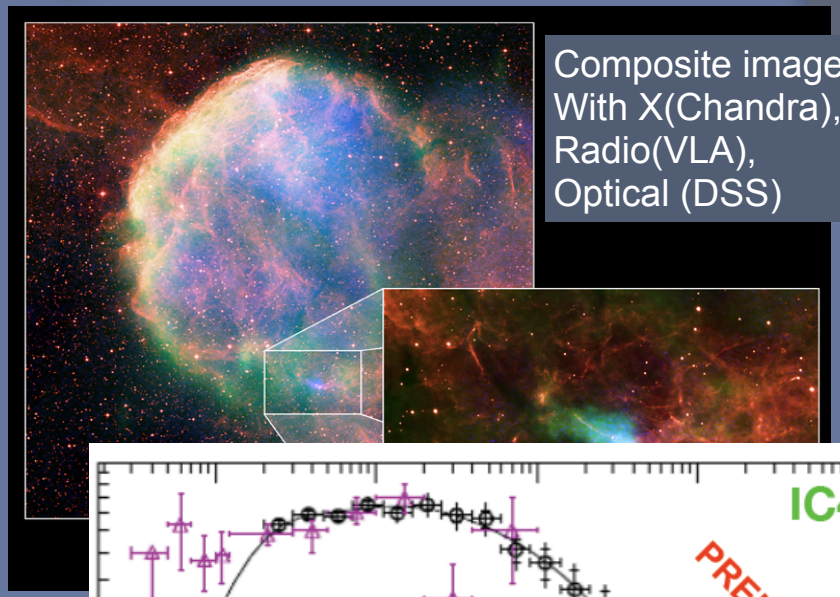


Concaved spectrum (non-linear effect)??

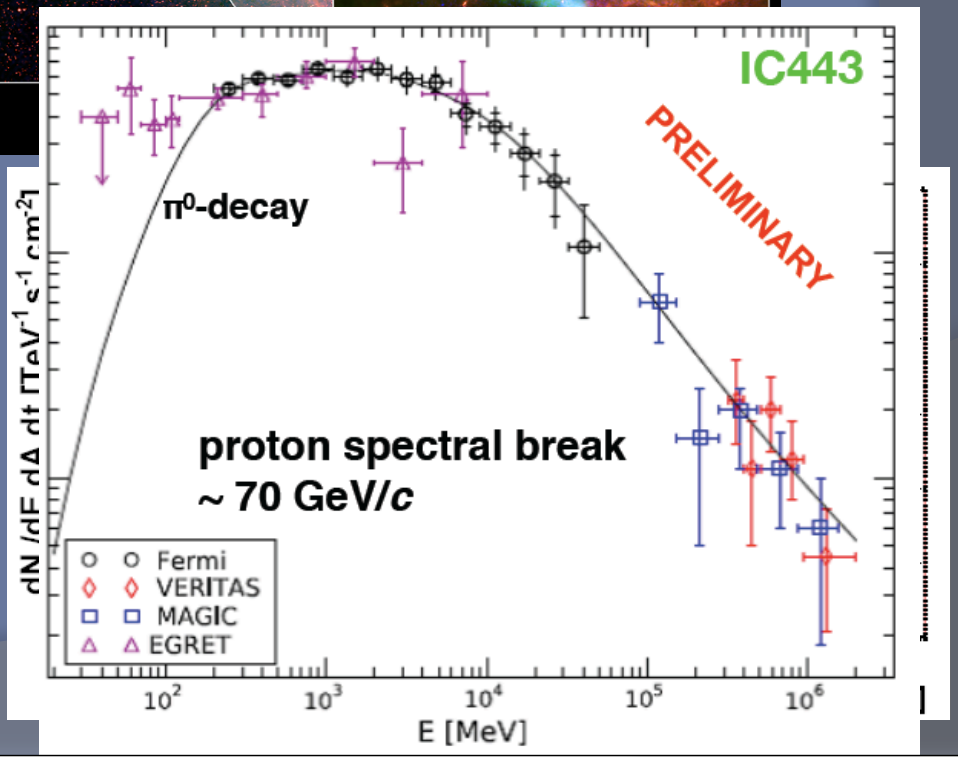


Shell type SNRs
IC443(MAGIC J0616)



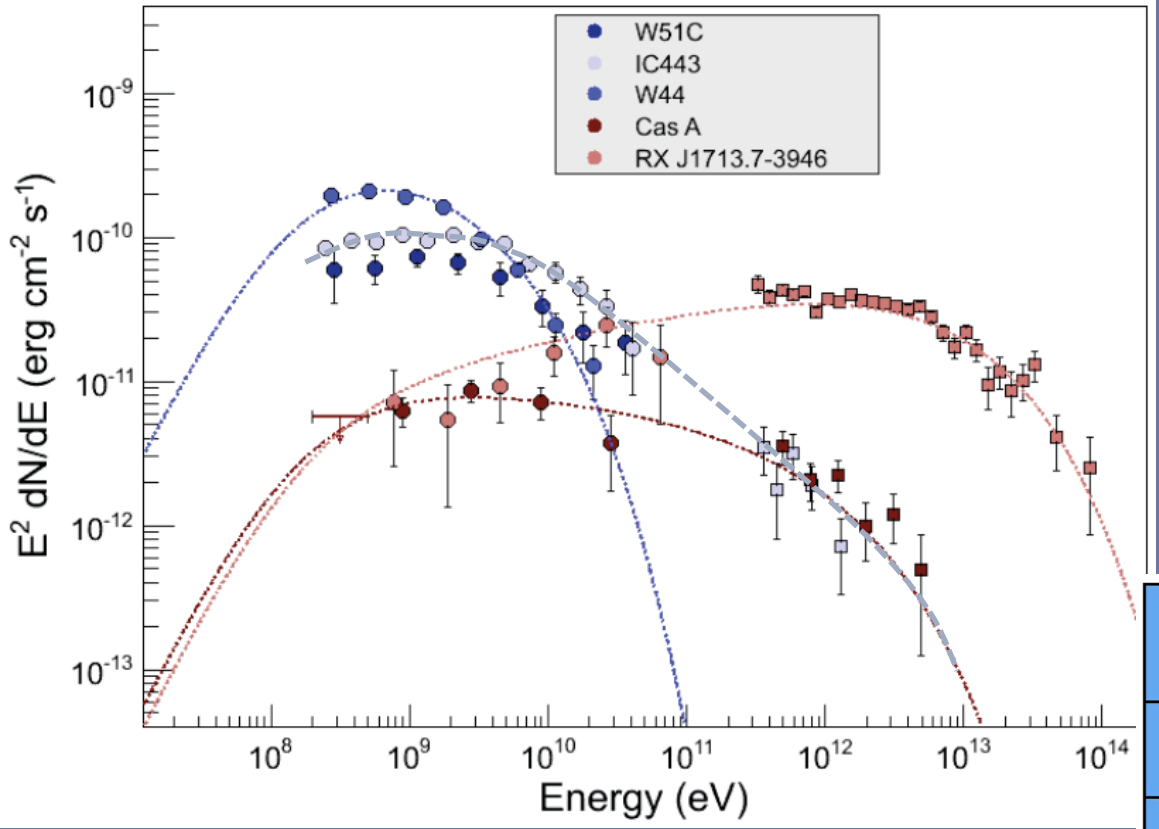


Composite image
With X(Chandra),
Radio(VLA),
Optical (DSS)



Molecular Cloud
Radio
X-ray
EGRET 3EG J0617+2238
Pulsar CXOU J061705.3+222127

SNRs in different



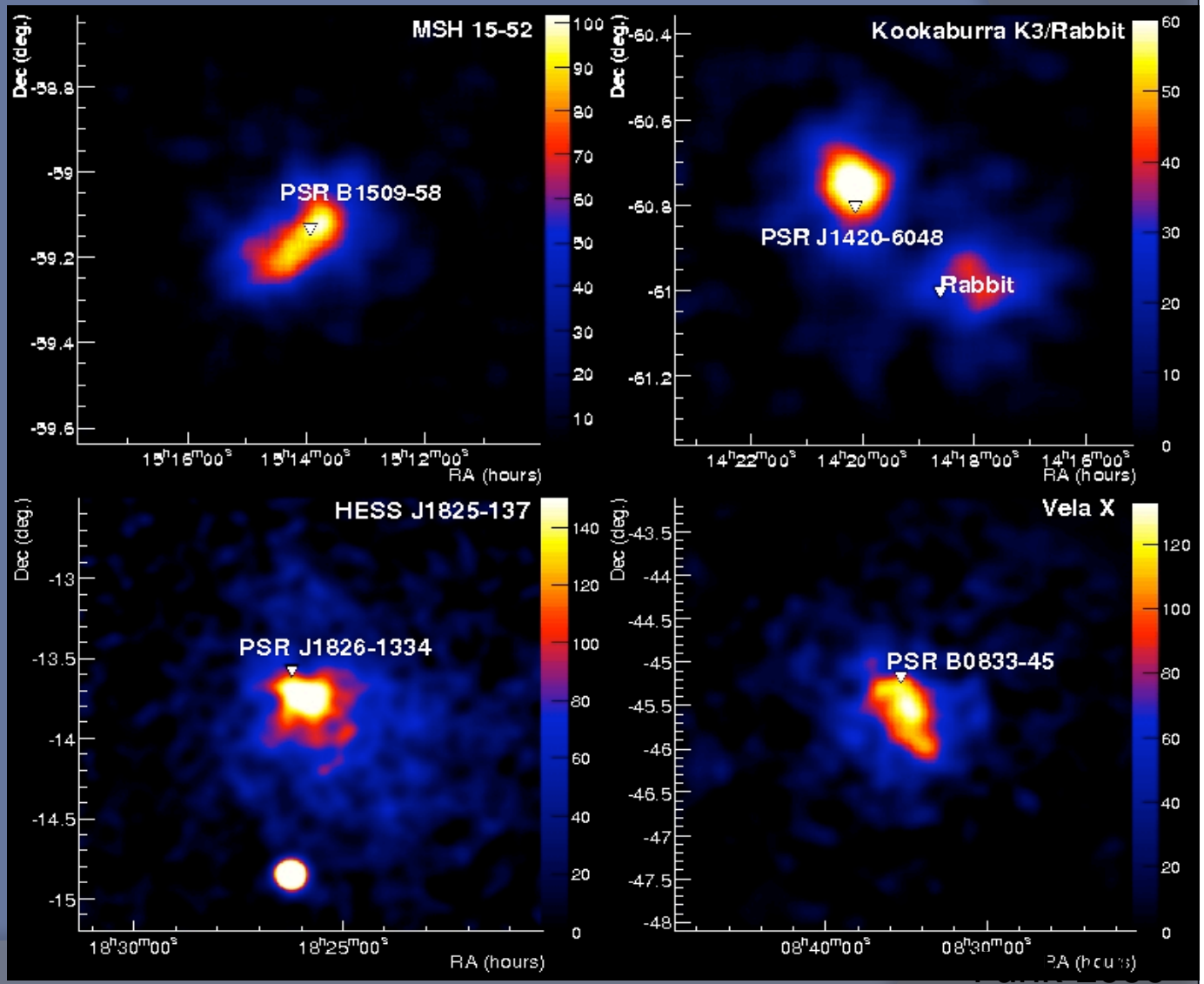
Courtesy of S.Funk

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%

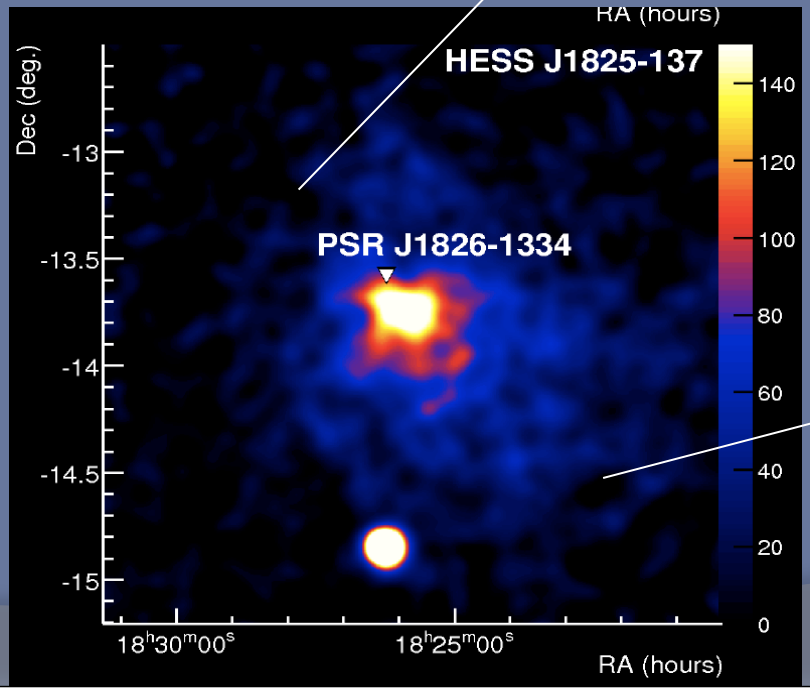
Pulsar Wind Nebulae observation by

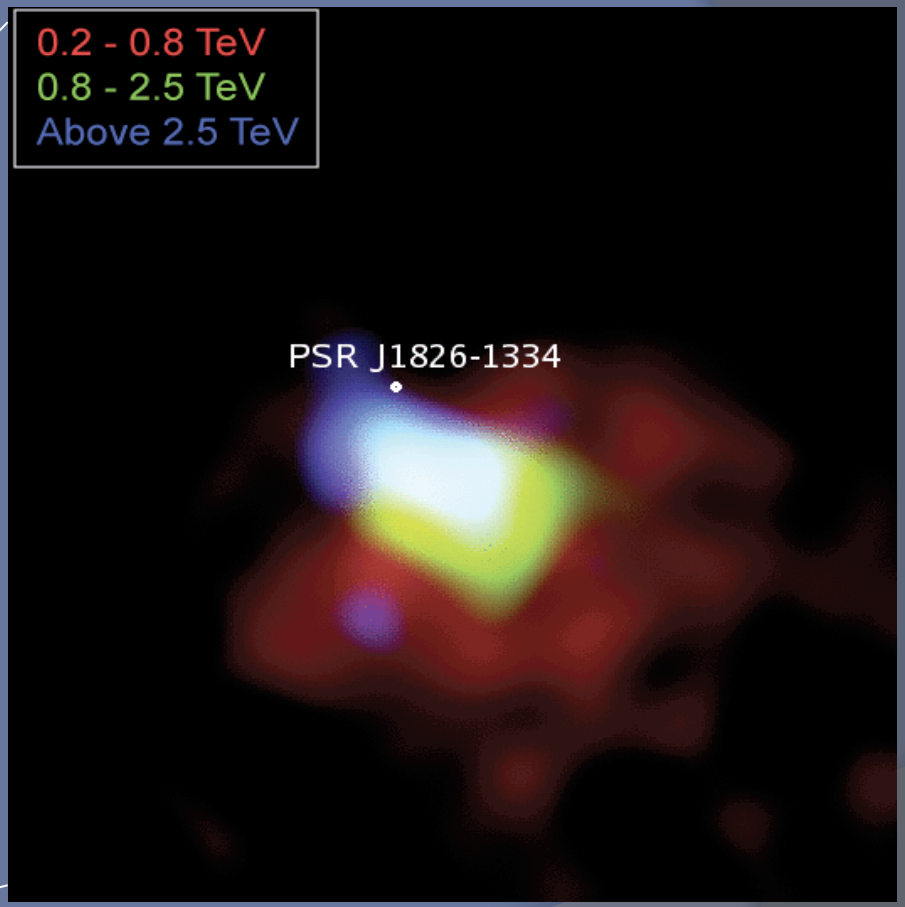
- Major galactic TeV source population
  - Associated with relatively young (<10^5 year old) and energetic pulsars
- Generally believed that we see inverse Compton emission of 1-100 TeV electrons
- 1% of Spin-down energy goes to VHE gamma rays



Pulsar Wind Nebula HESS J1825-137

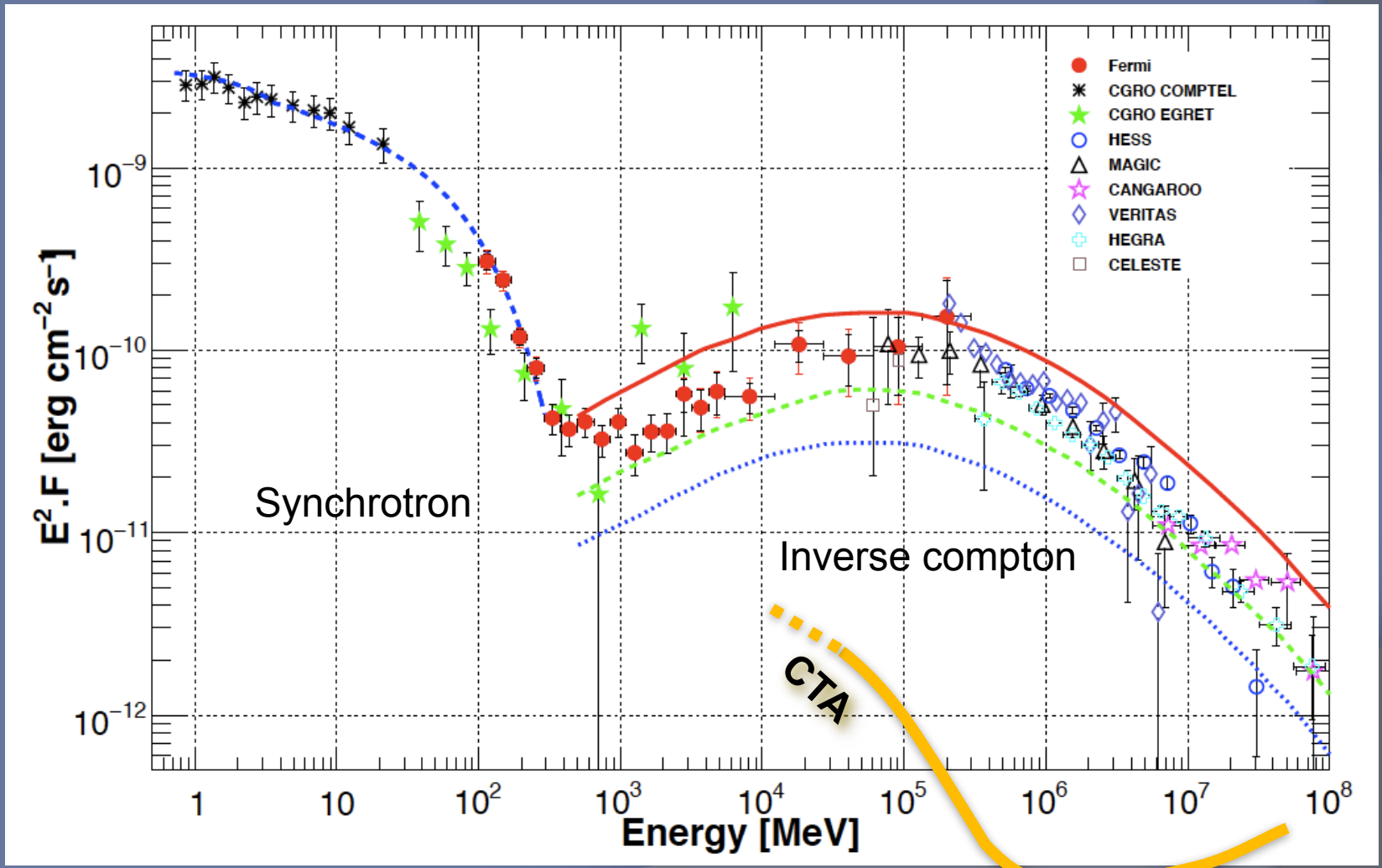
- Major galactic TeV source population
  - Associated with relatively young (<10^5 year old) and energetic pulsars
- Generally believed that we see inverse Compton emission of 1-100 TeV electrons
- 1% of Spin-down energy goes to VHE gamma rays



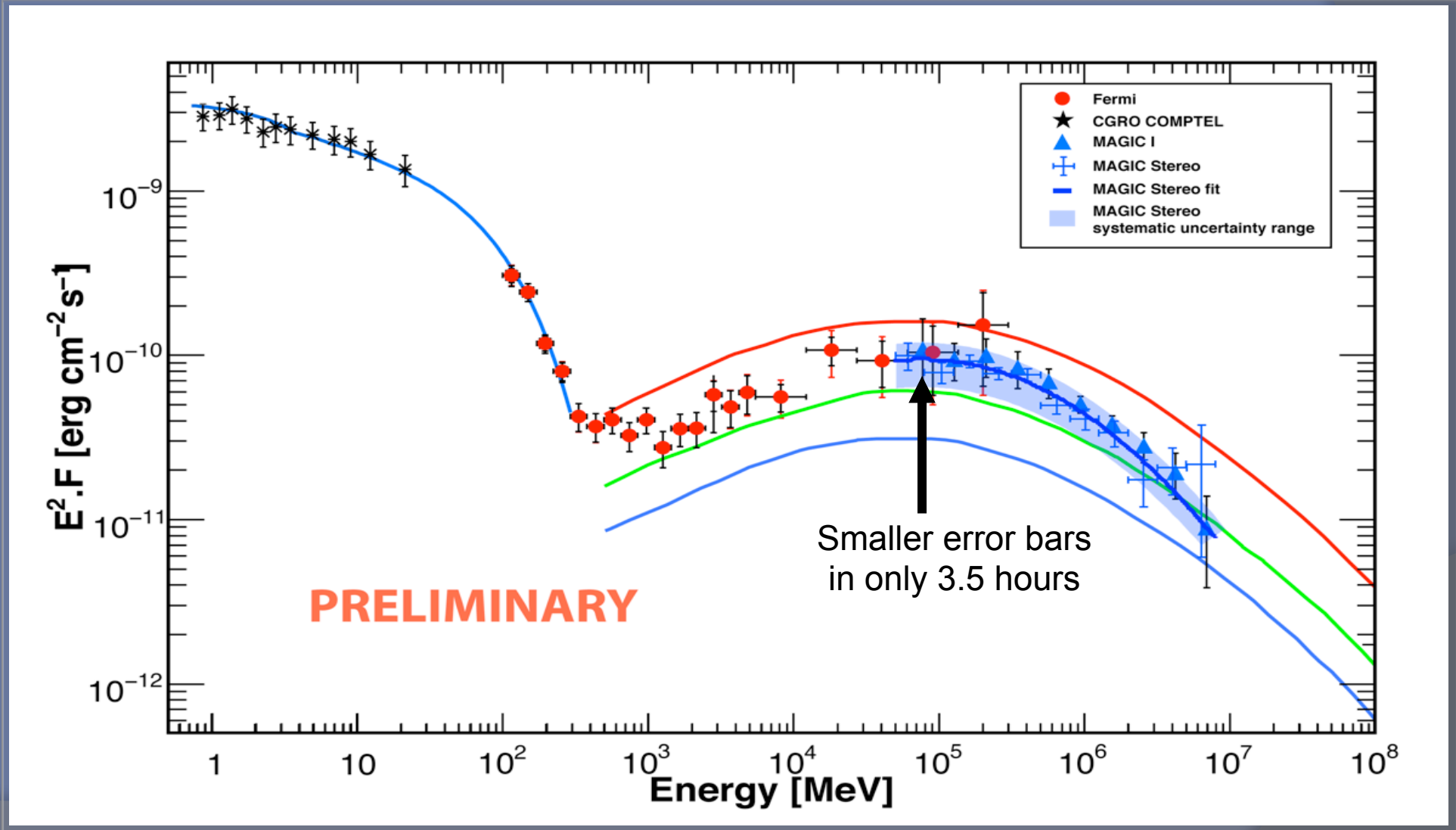


- Clear evidence for cooling of electrons in the Nebula

Crab Nebula


Fermi
CGRO COMPTEL
CGRO EGRET
HESS
MAGIC
CANGAROO
VERITAS
HEGRA
CELESTE
Synchrotron
Inverse compton
CTA
$E^2.F$ [erg $cm^{-2}s^{-1}$]
Energy [MeV]
10^{-9}
10^{-10}
10^{-11}
10^{-12}
1
10
10^2
10^3
10^4
10^5
10^6
10^7
10^8

Crab Nebula spectrum

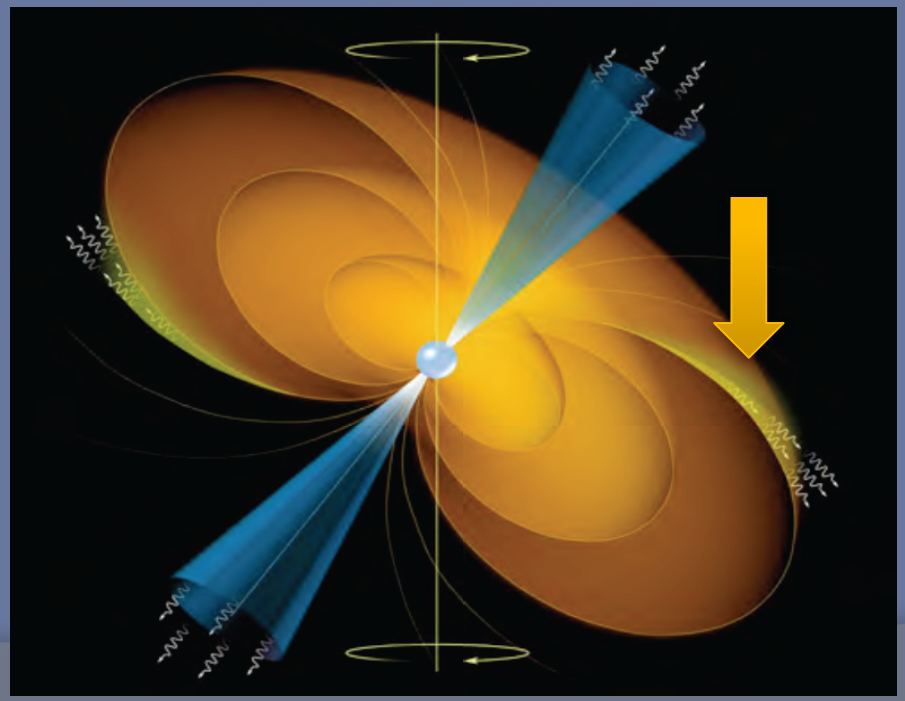


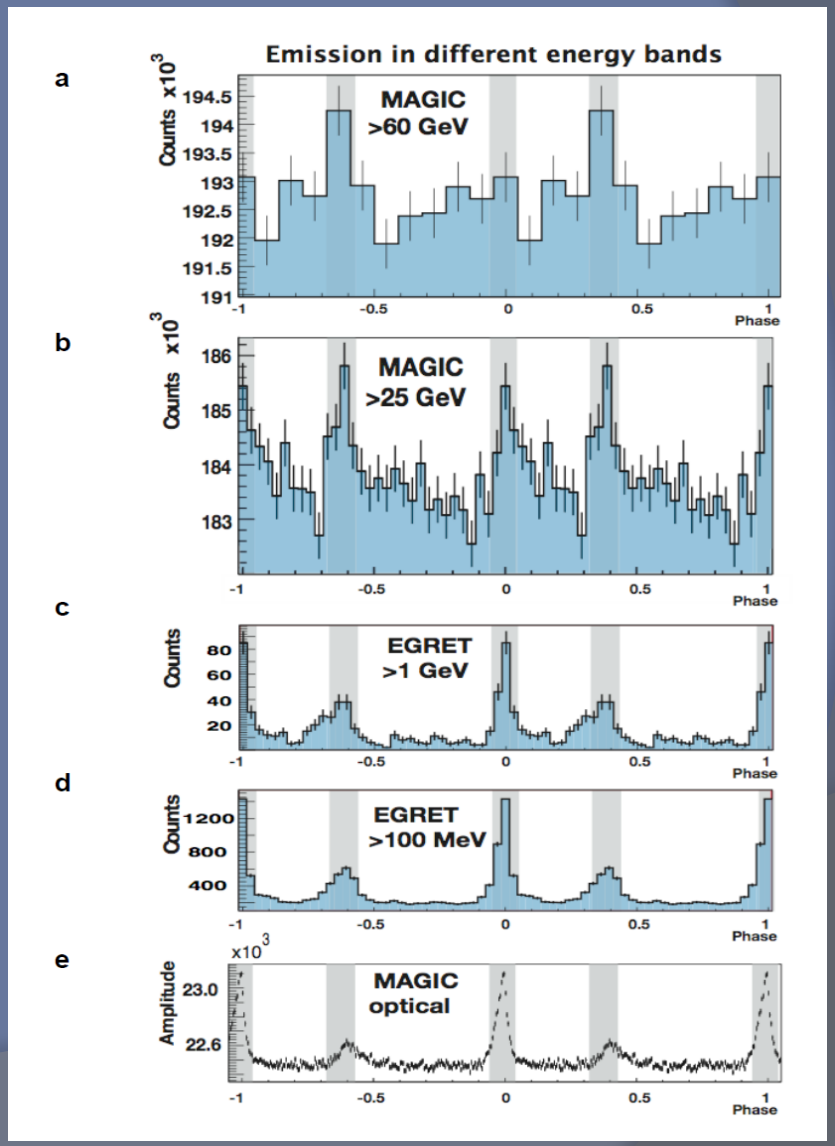
Pulsar Study

MAGIC result: Published in Science in 2008

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

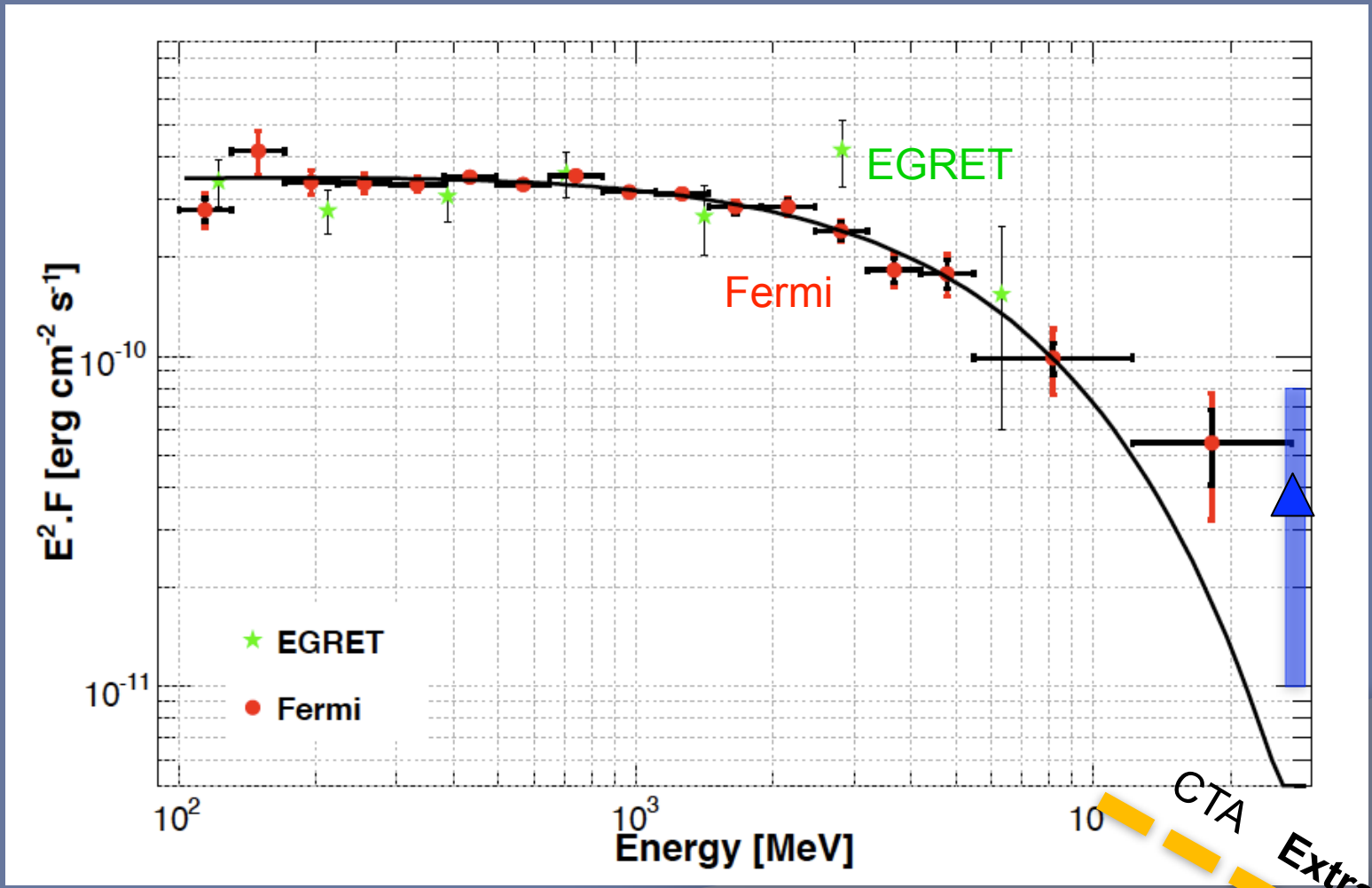
Polar cap: double exponent
Outer gap: simple exponent





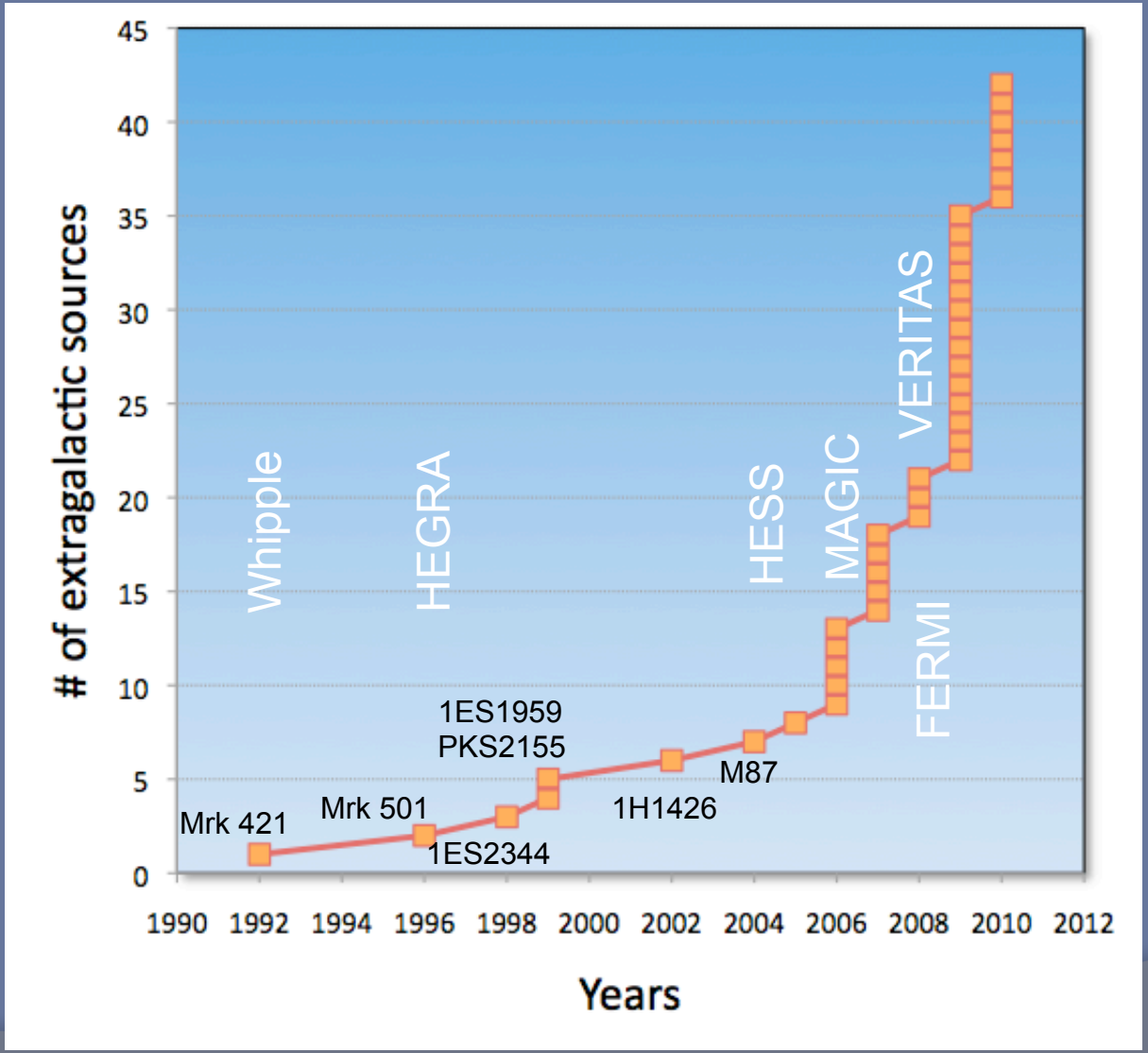
Crab Pulsar

Cut off feature of Spectrum: Exponent or Power-Law




EXTRAGALACTIC
SOURCES

Number of extragalactic



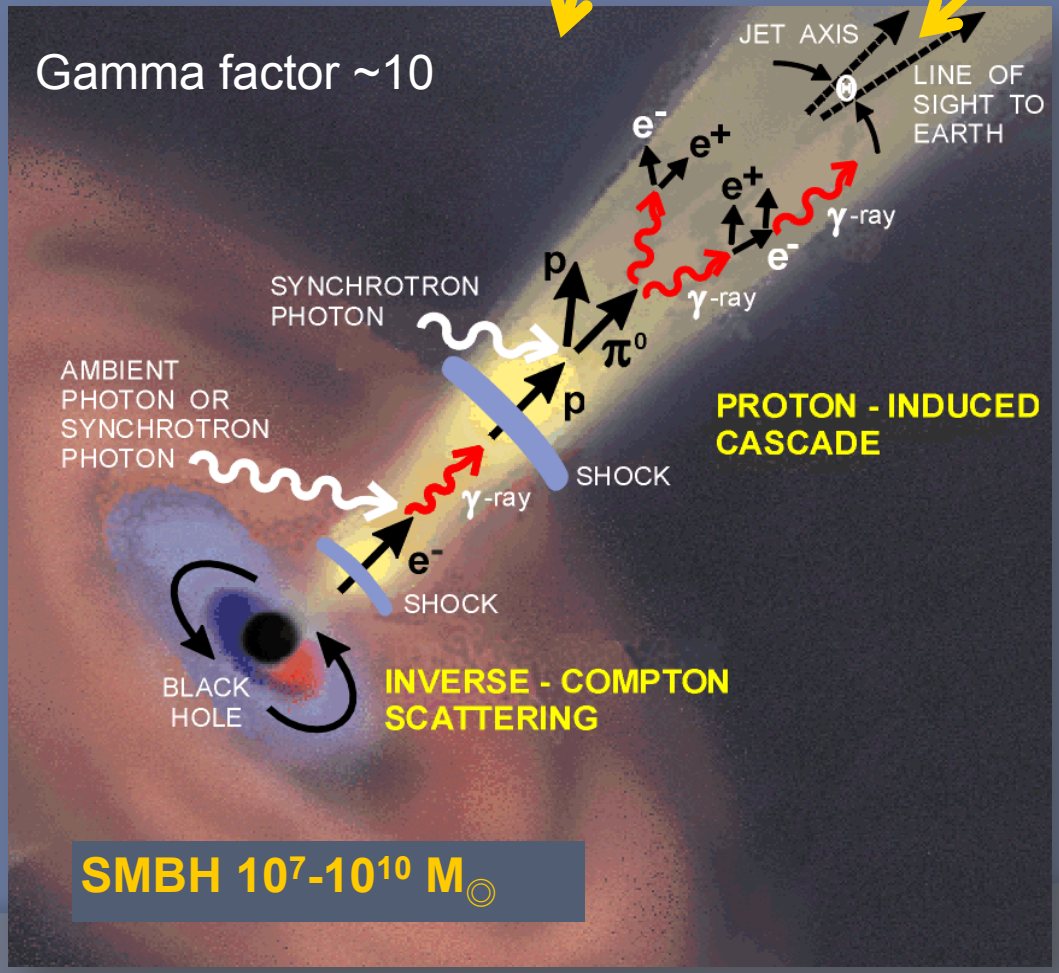
Fermi

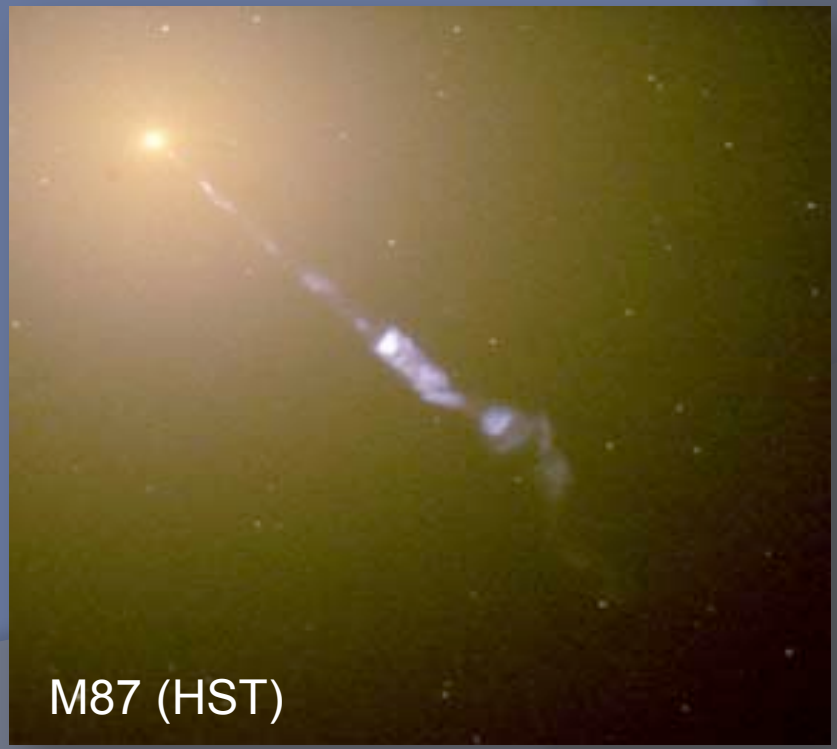
Cosmic Ray accelerator

Active Galactic Nuclei

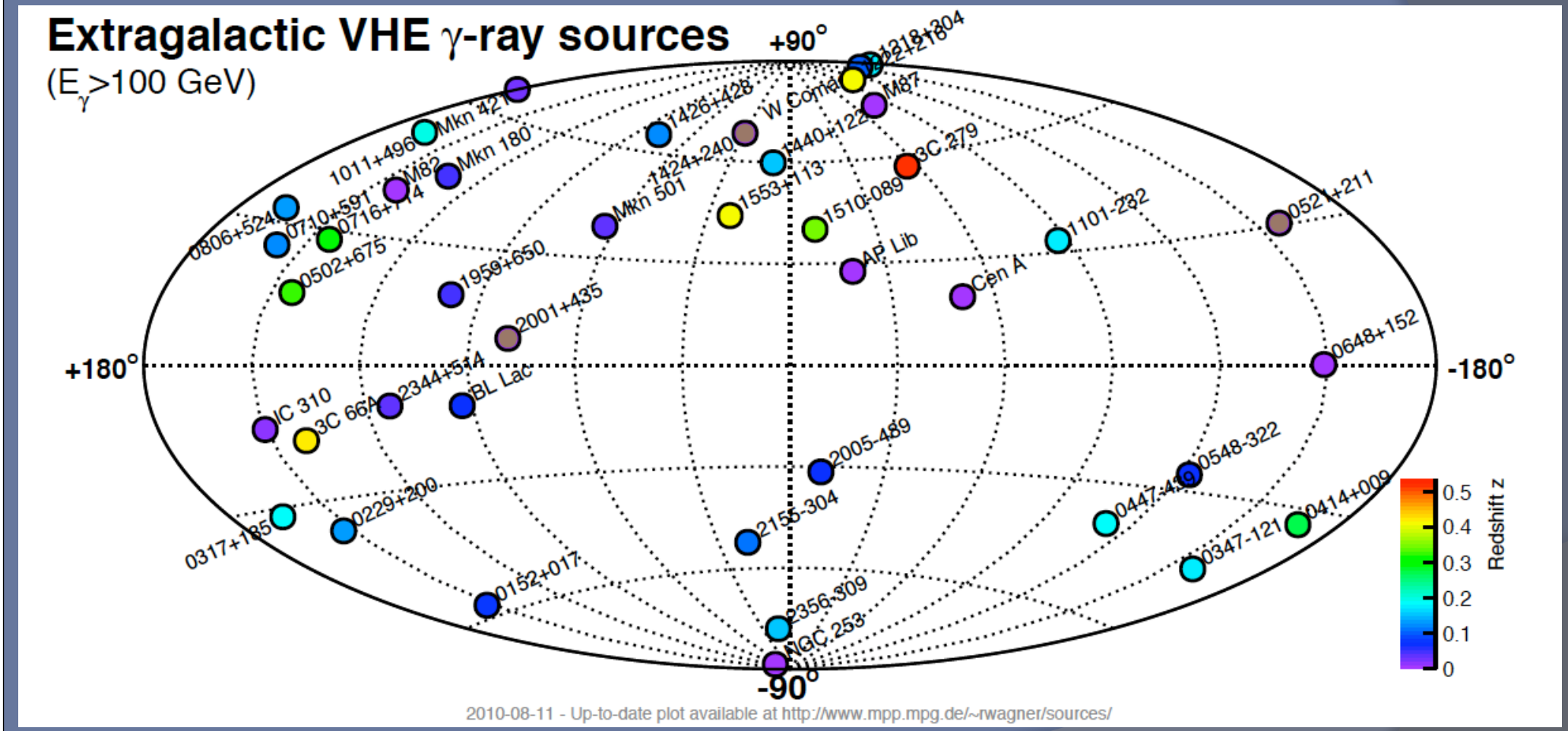
FRI, FRII

Blazars





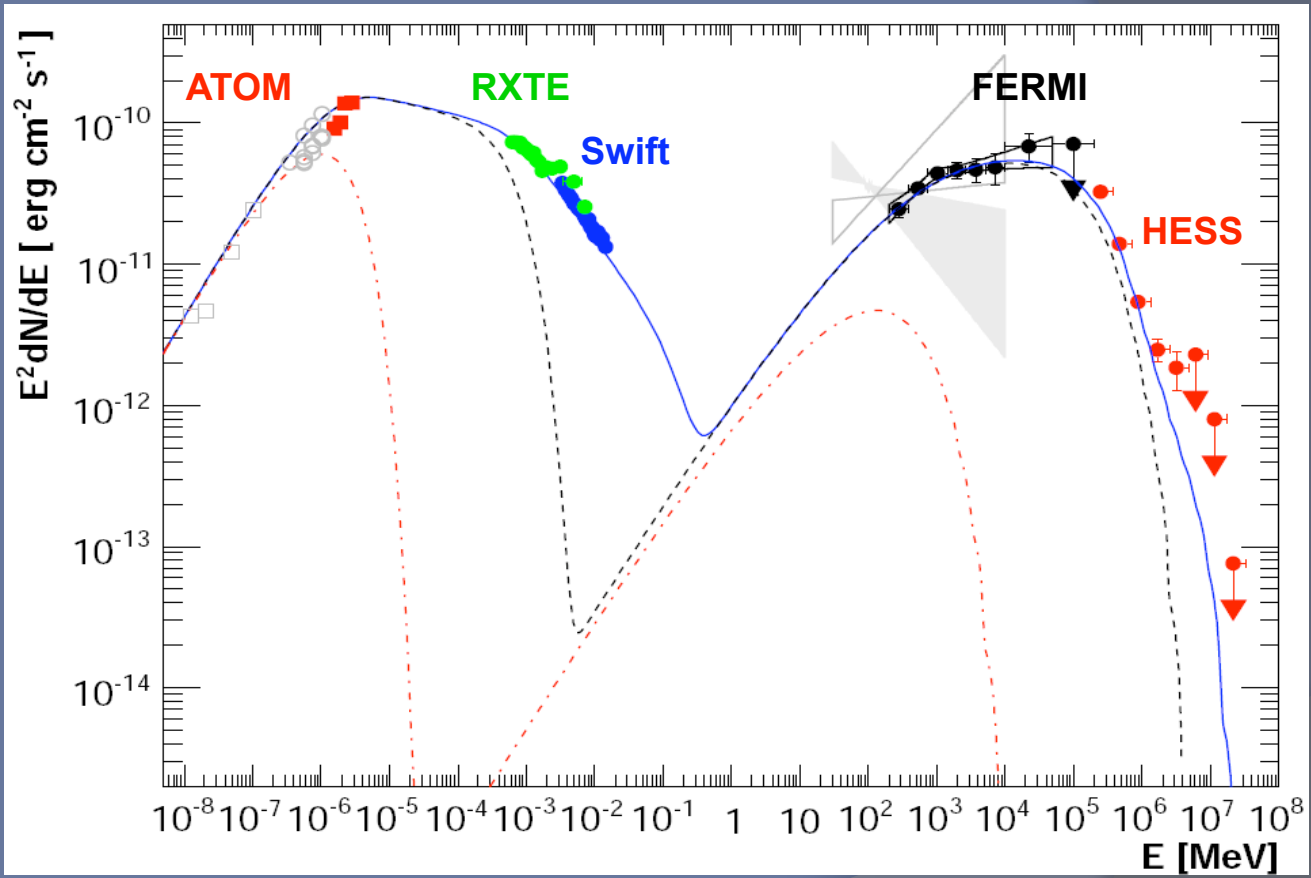
Extra-galactic sources



42 sources (3 x FR-I, 2 x Starburst galaxies, 3 x FSRQs, 34 BL Lacs)

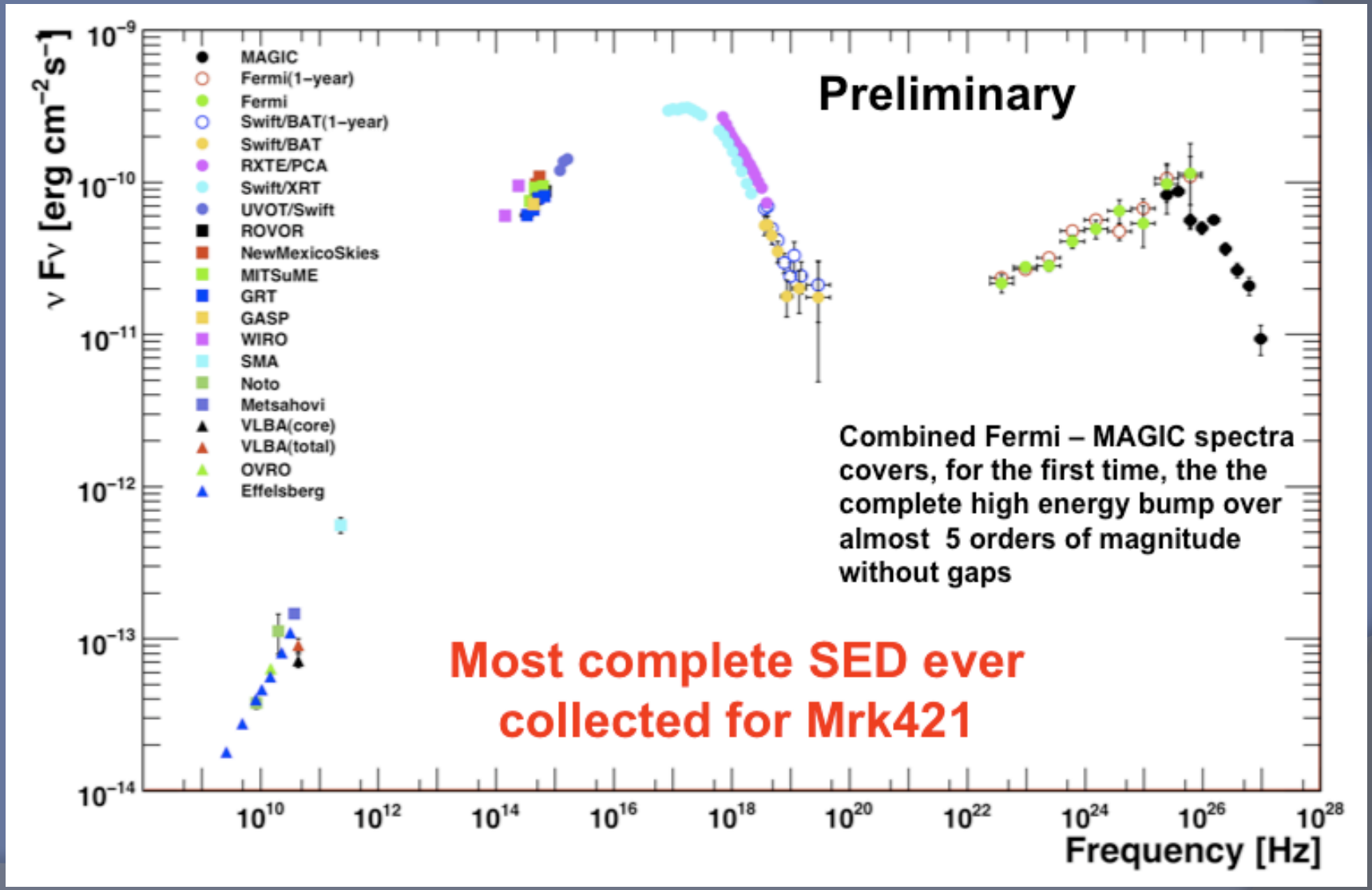
PKS 2155–304
Spectral Energy Distribution

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

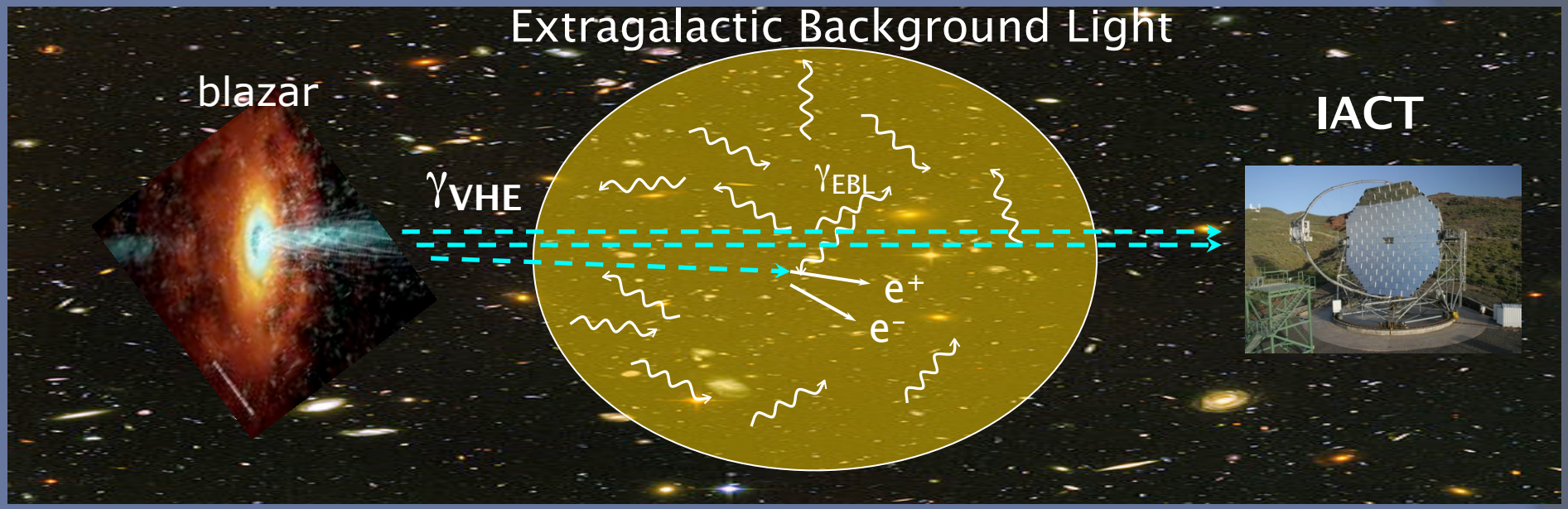


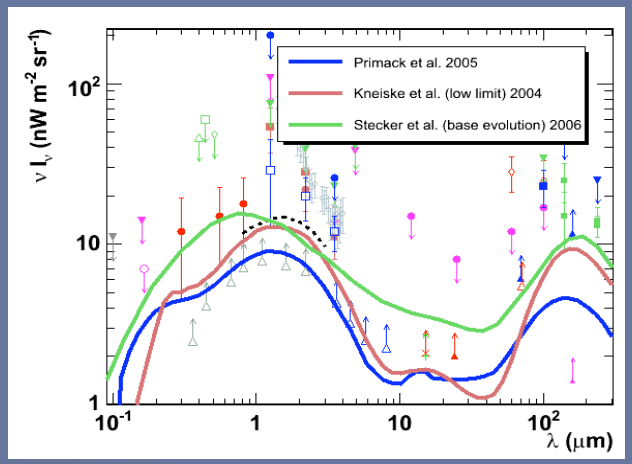
Highest energy electrons (γ_e>2×10^5) produce the X-ray emission, but contribute relatively little above 0.2 TeV

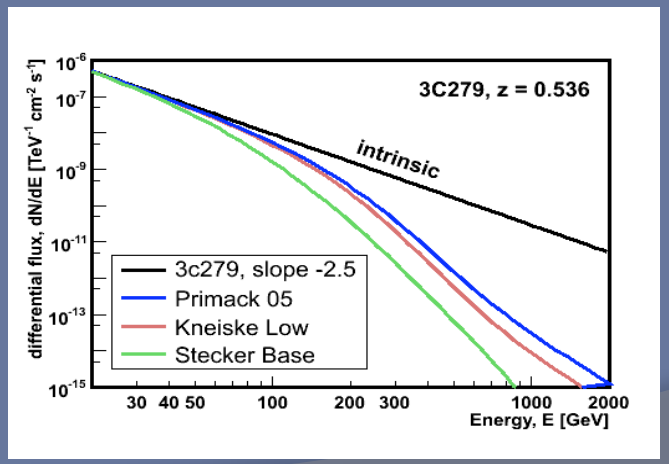
Mrk421 MWL SED

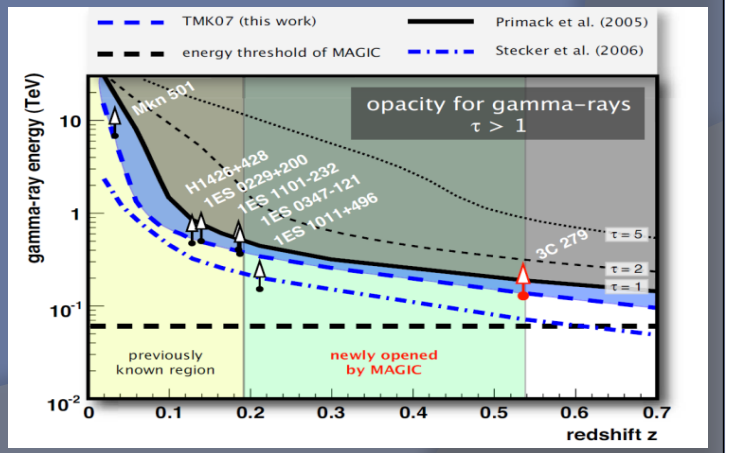


EBL (Extragalactic Background Light)





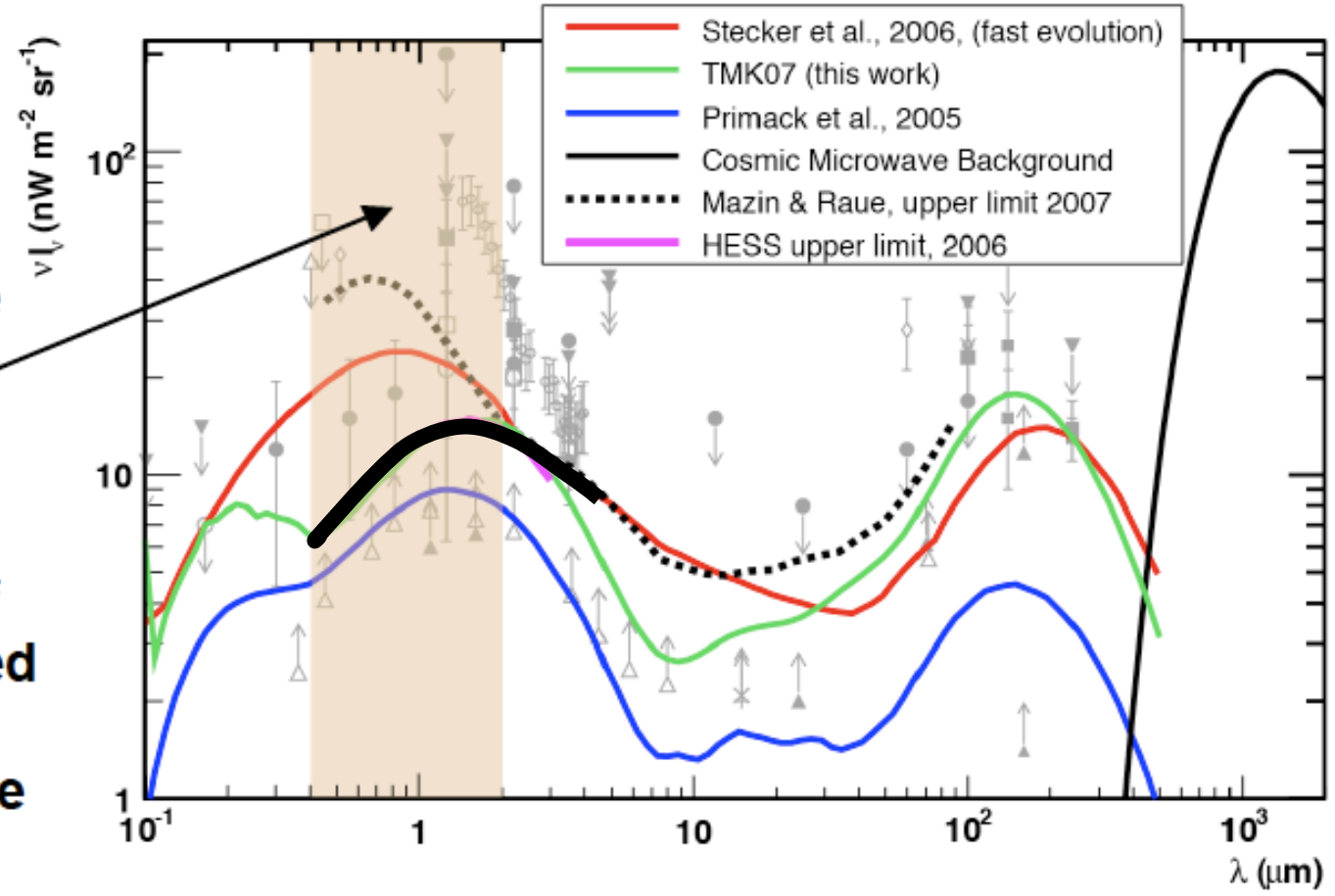




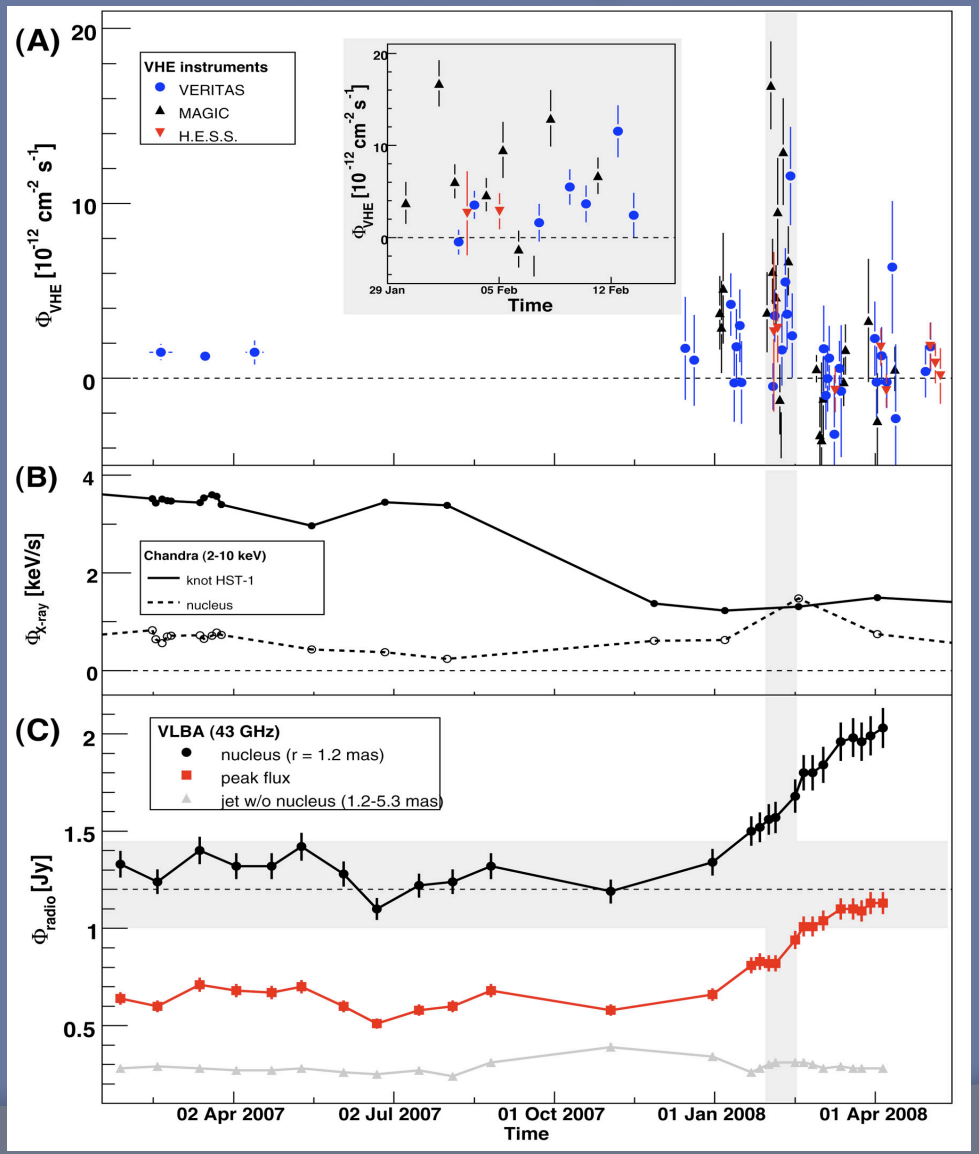
EBL upper limit by MAGIC and

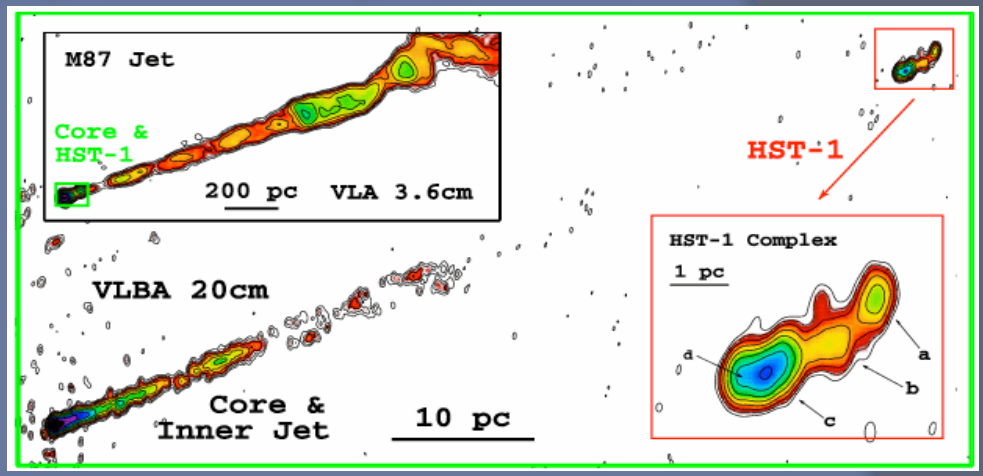
Probing new range of the EBL

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

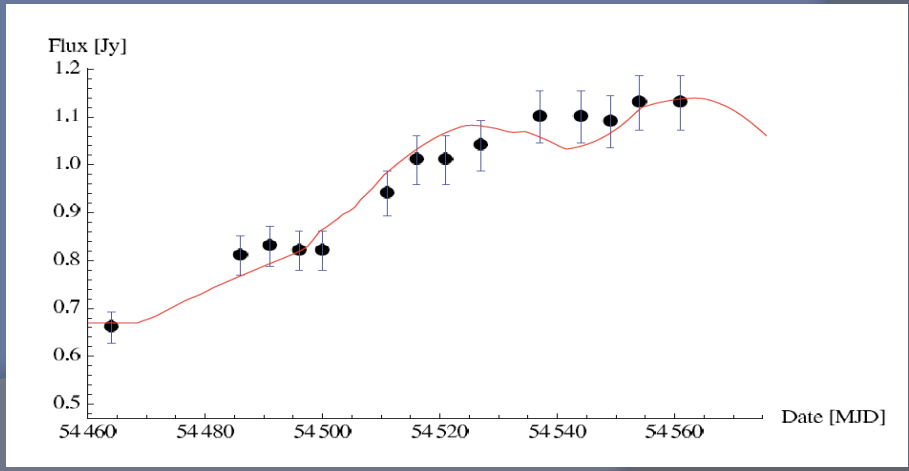


M87 flare in 2008: MAGIC, VERITAS, HESS, VLBA

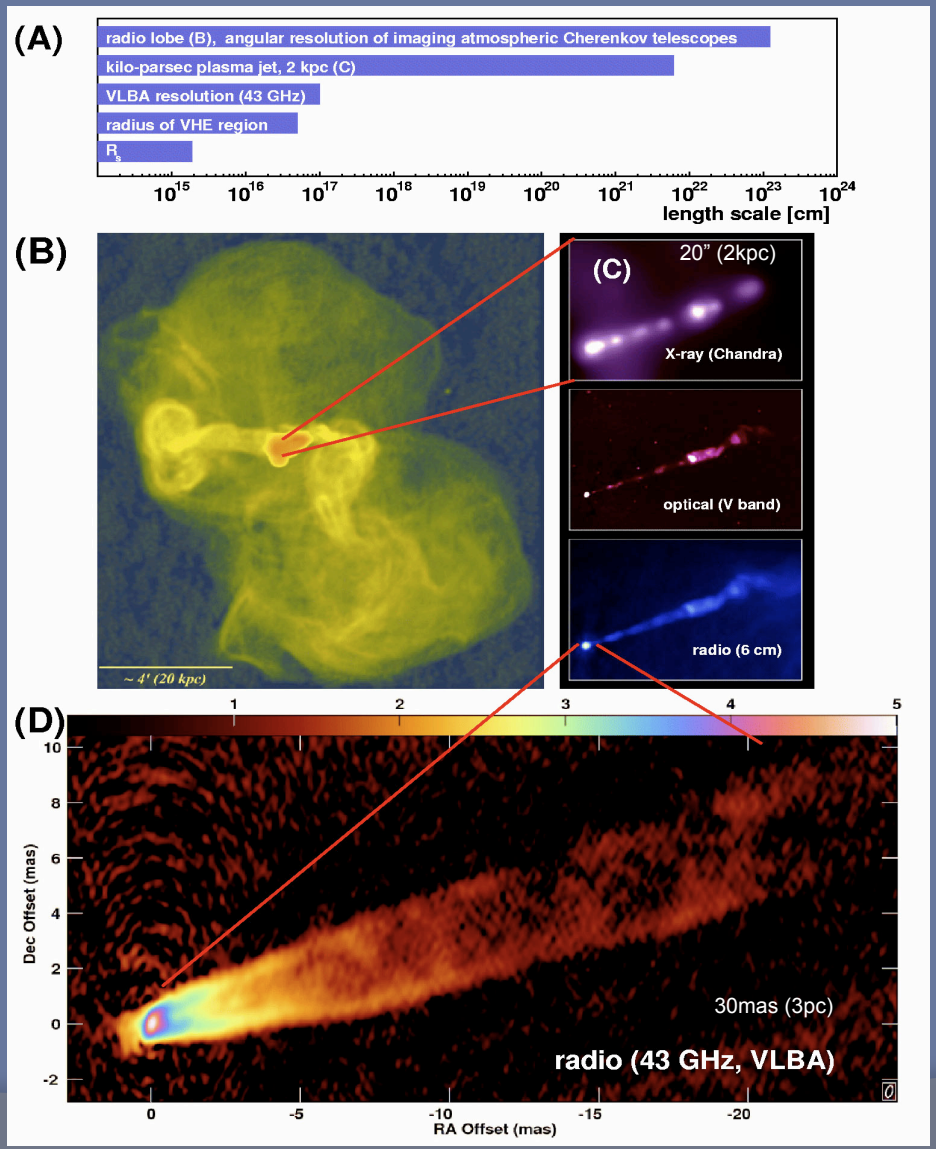


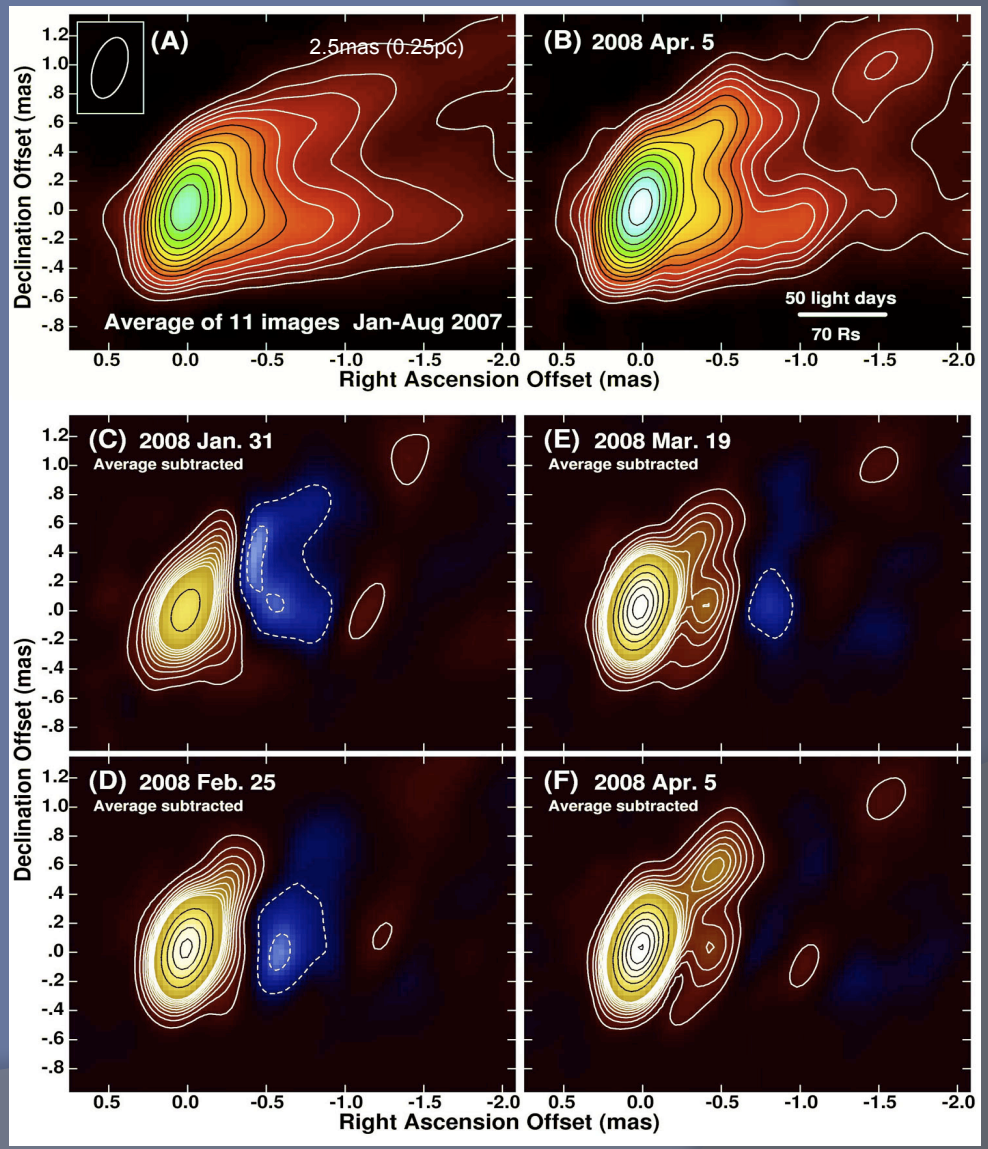


Model of 43GHz Radio flux
using the measured VHE gamma flux

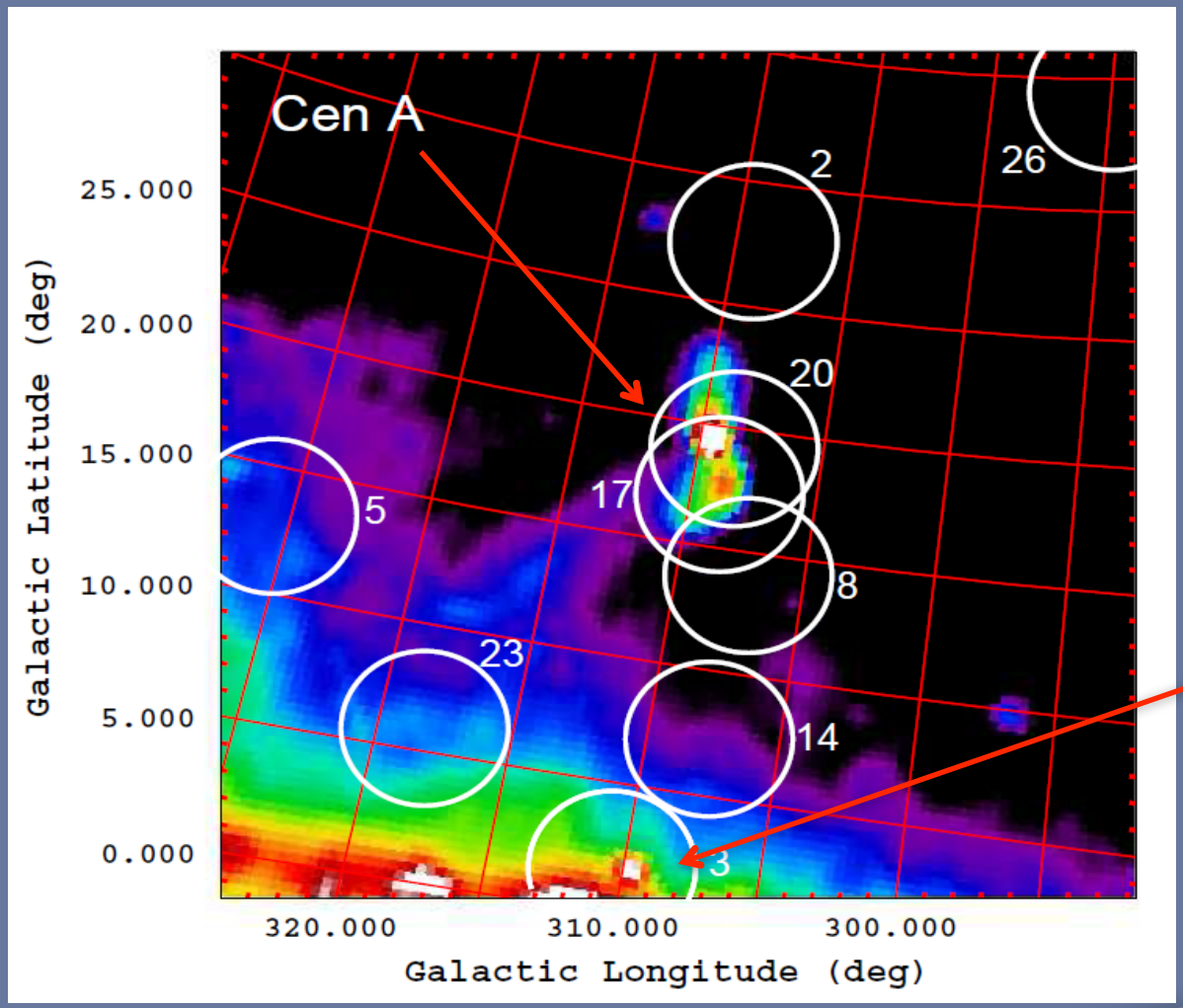


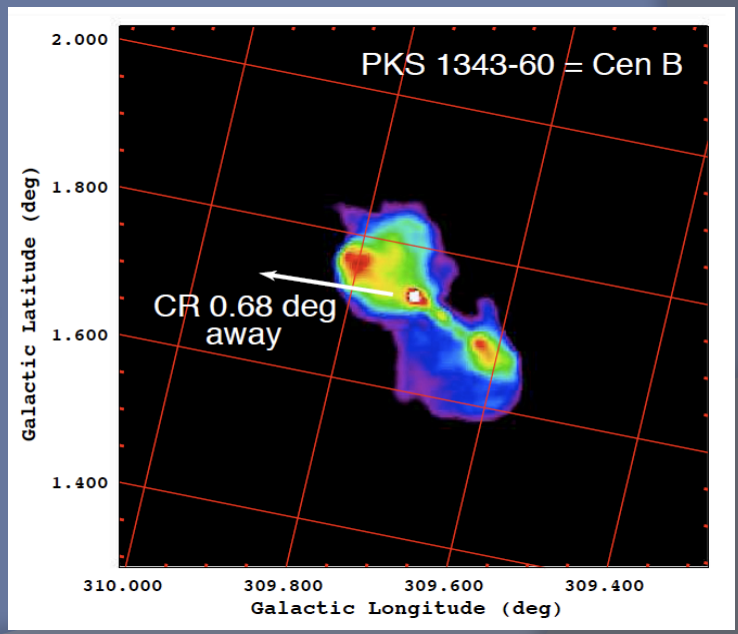
M87 flare in 2008:
MAGIC, VERITA, HESS, and VLBA



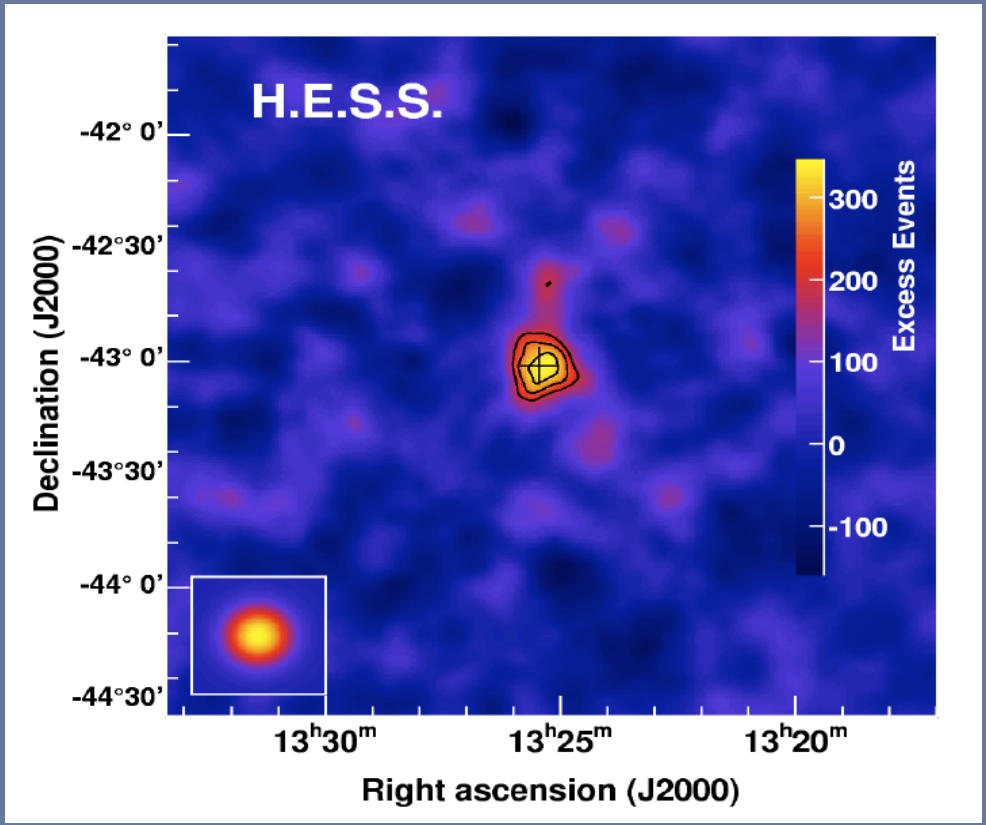


Morphological studies of potential sources
Cen A (3.4Mpc) & Cen B (56Mpc)

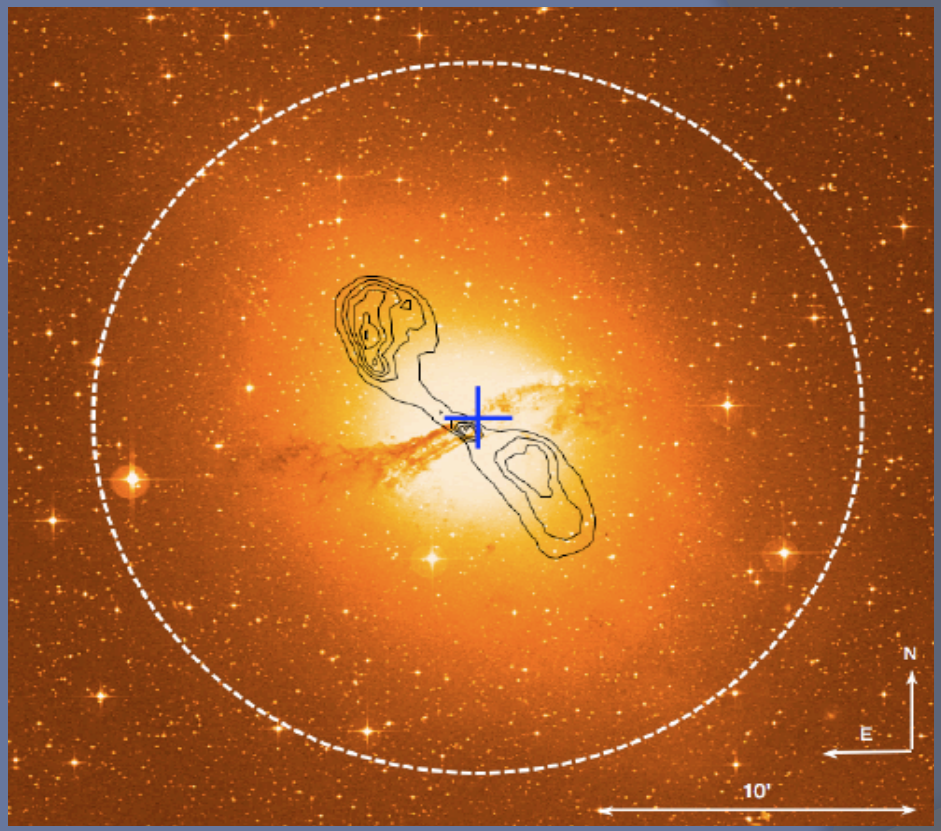




Cen A: HESS detection



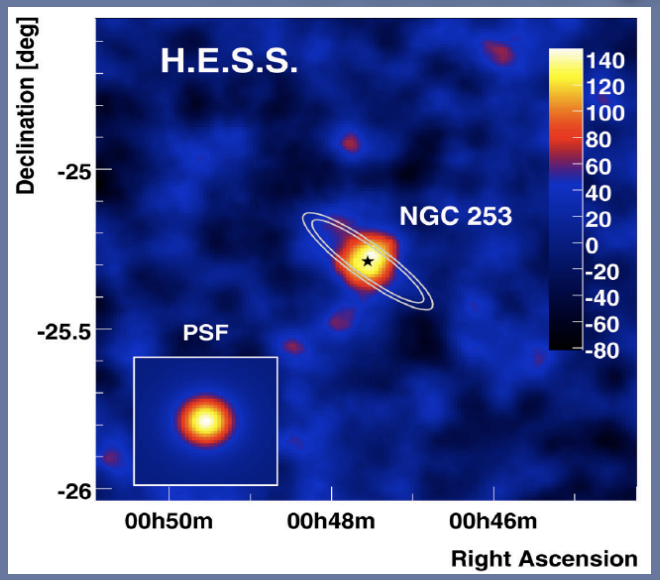
Distance: 3.8Mpc
Flux: 0.8% in Crab Unit
Spectral Index: -2.7

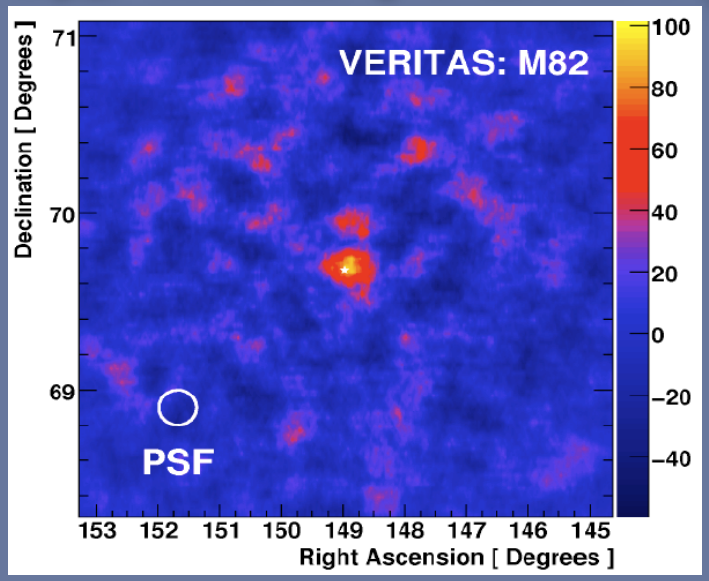


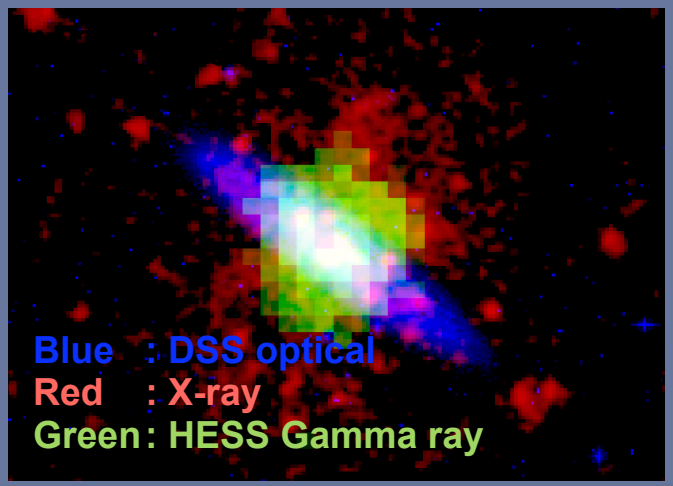
Cross: the best location (COG)
Circle: 95% C.L. VHE extension limit

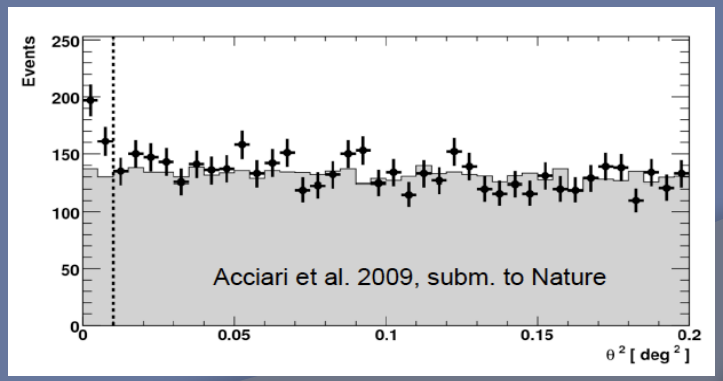
L_{VHE} ~ 2.6 x 10^{39} erg s-1
L_{UHECR} ~ 10^{40} erg s-1

Starburst galaxies
NGC253 (by HESS), M82 (VERITAS)





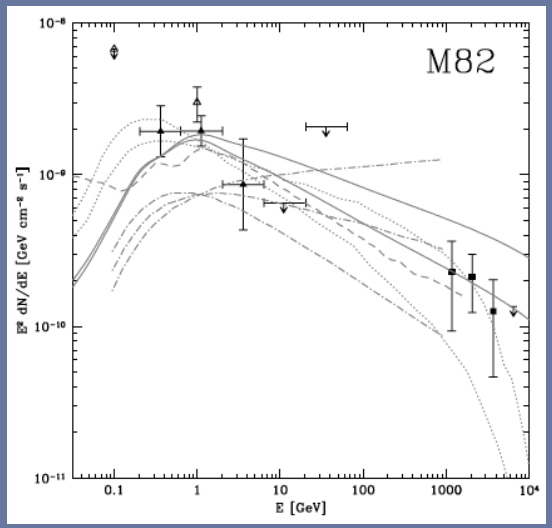


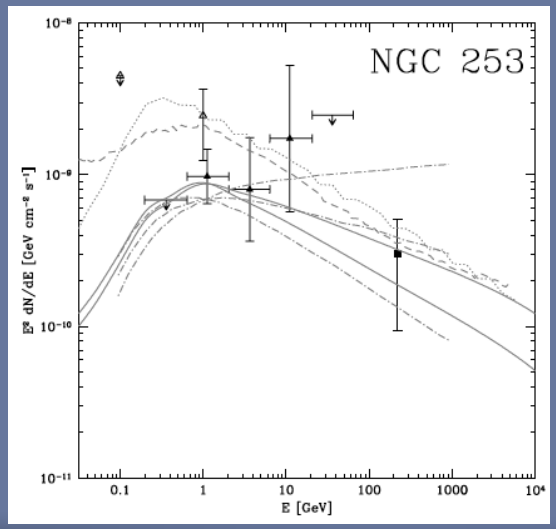


119hrs, >220GeV, 247 photons, 0.6% Crab

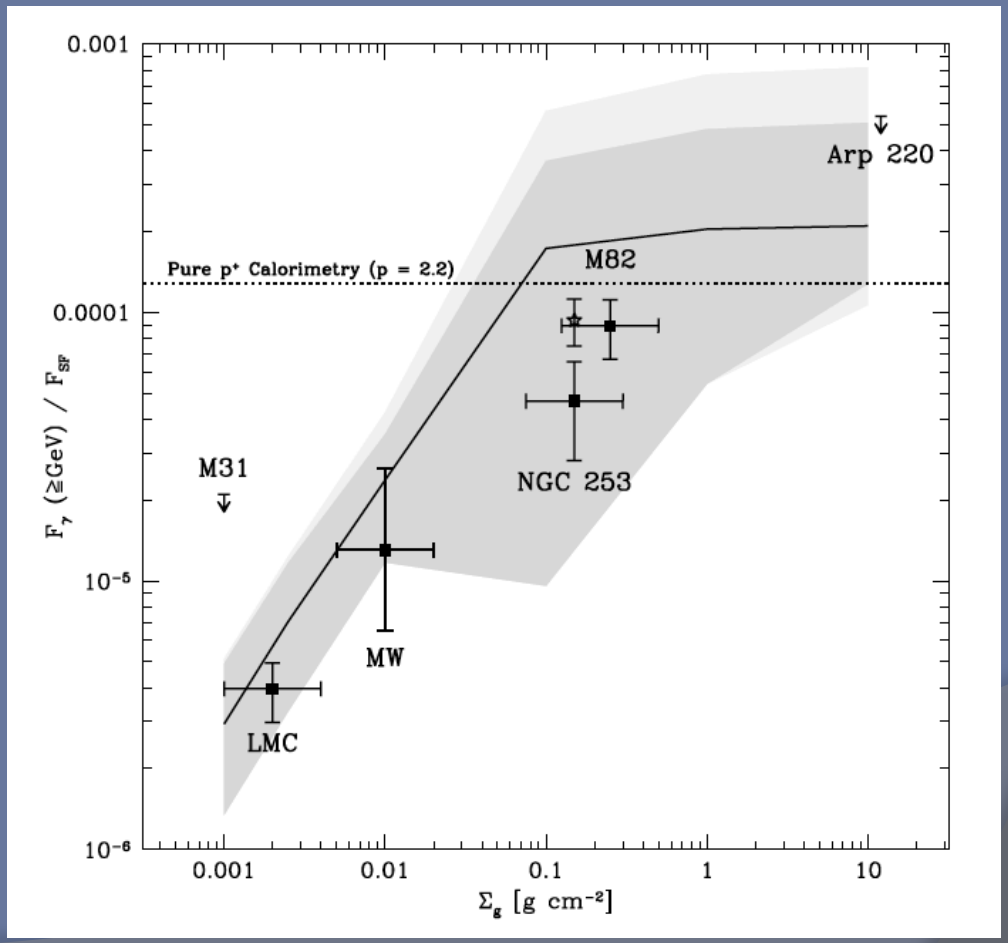
137hr, >700GeV, 91photons, 0.9 % Crab

General picture of CR and

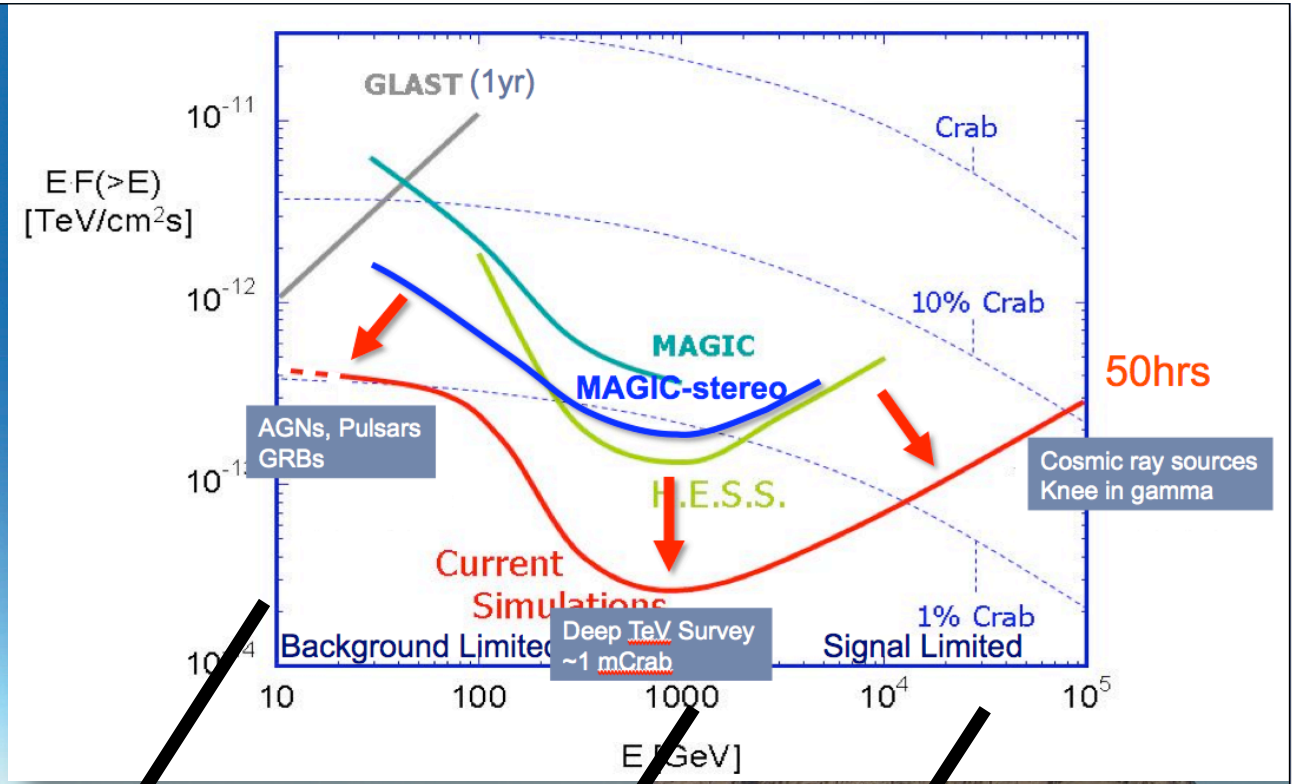


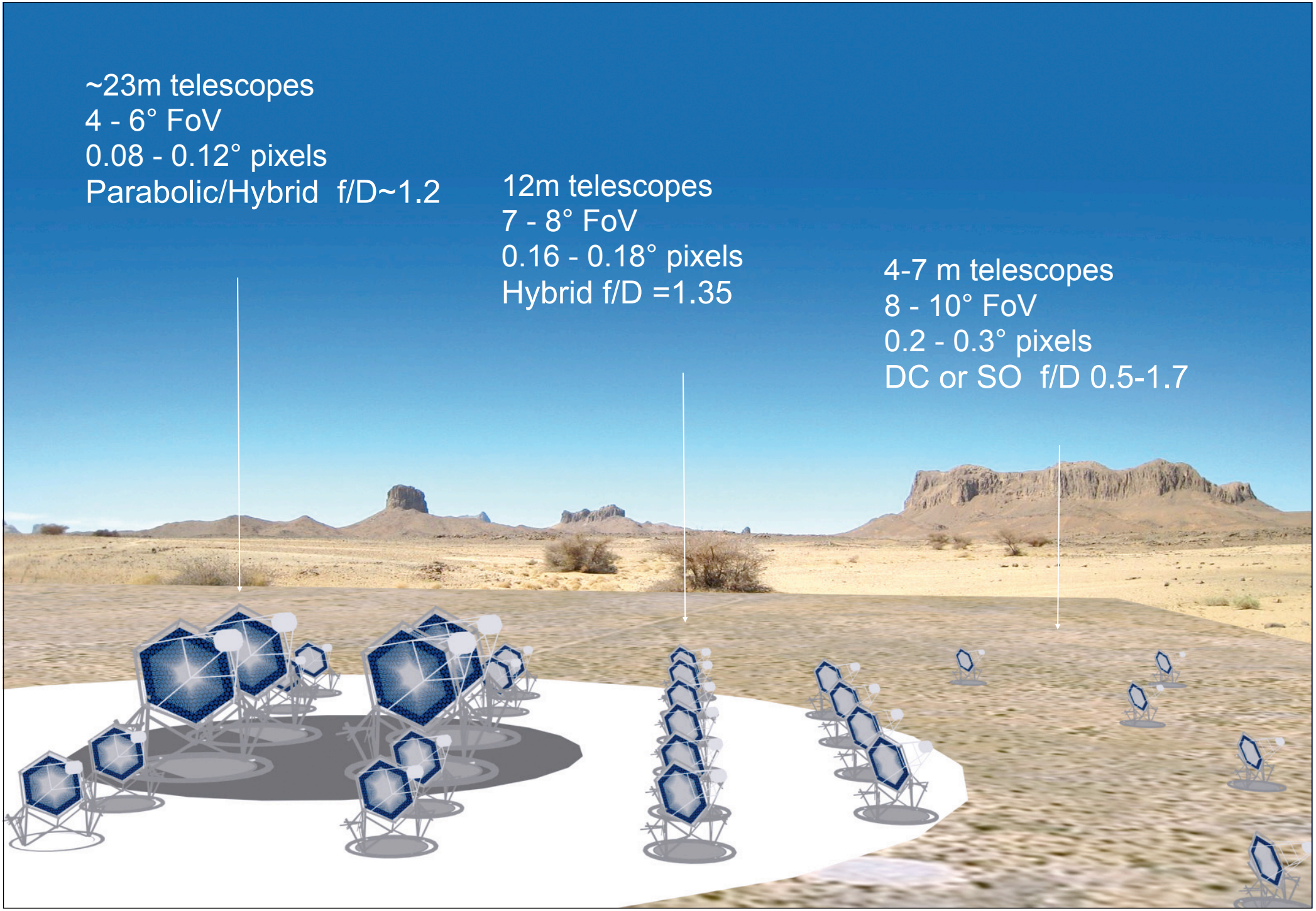


Lacki et al. 2010, **arXiv:1003.3257**



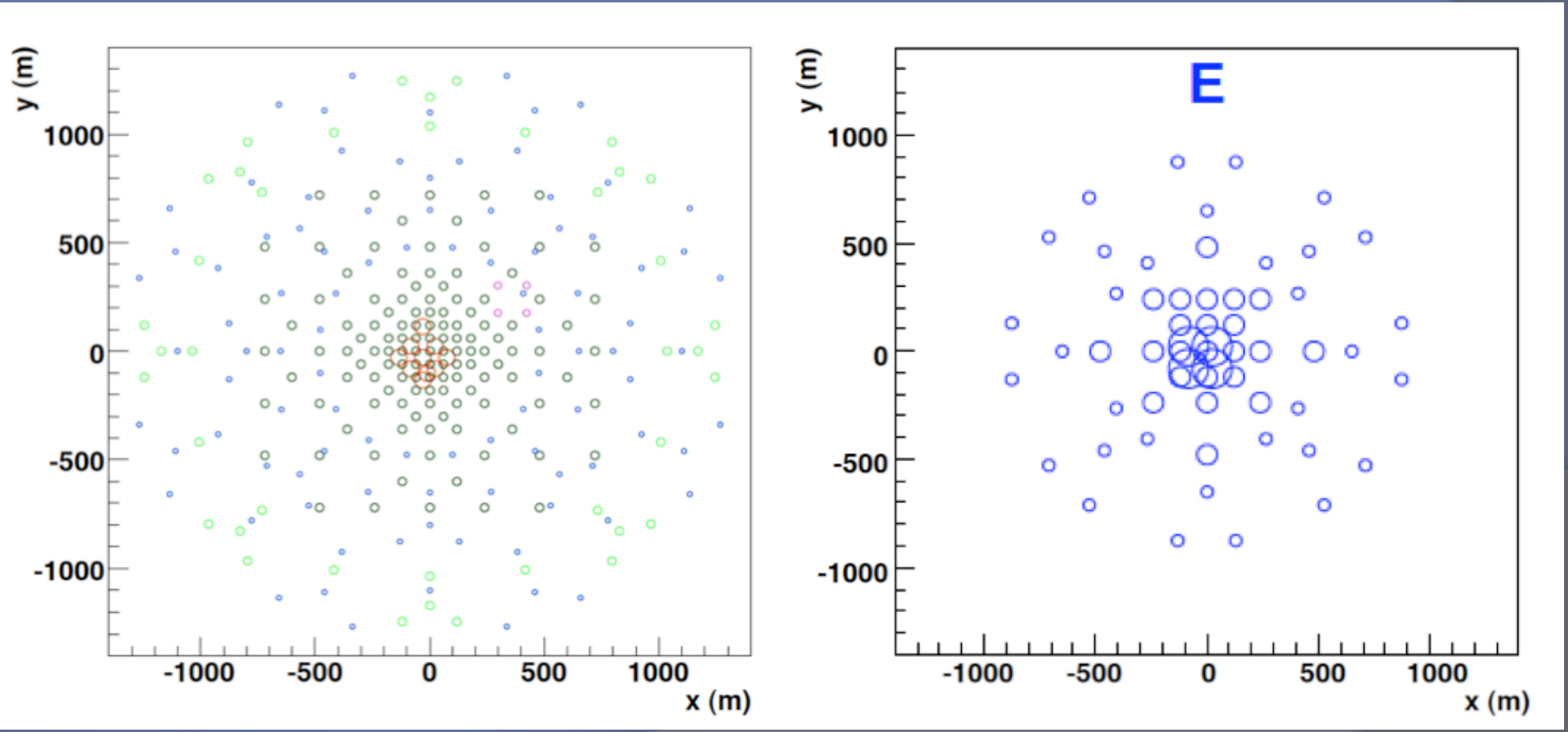
CTA


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

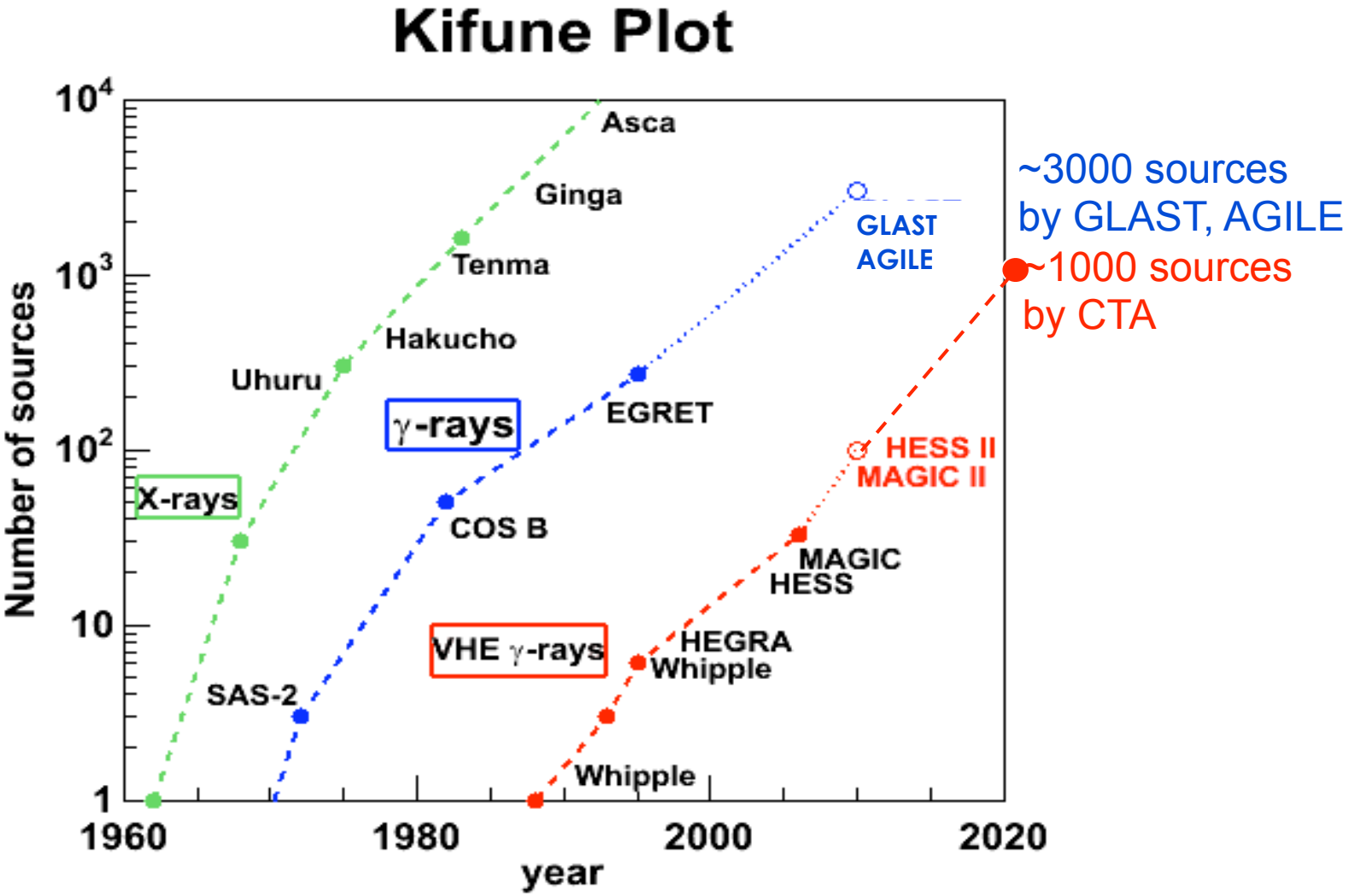

~23m telescopes
4 - 6° FoV
0.08 - 0.12° pixels
Parabolic/Hybrid f/D~1.2
12m telescopes
7 - 8° FoV
0.16 - 0.18° pixels
Hybrid f/D =1.35
4-7 m telescopes
8 - 10° FoV
0.2 - 0.3° pixels
DC or SO f/D 0.5-1.7

Possible array configuration

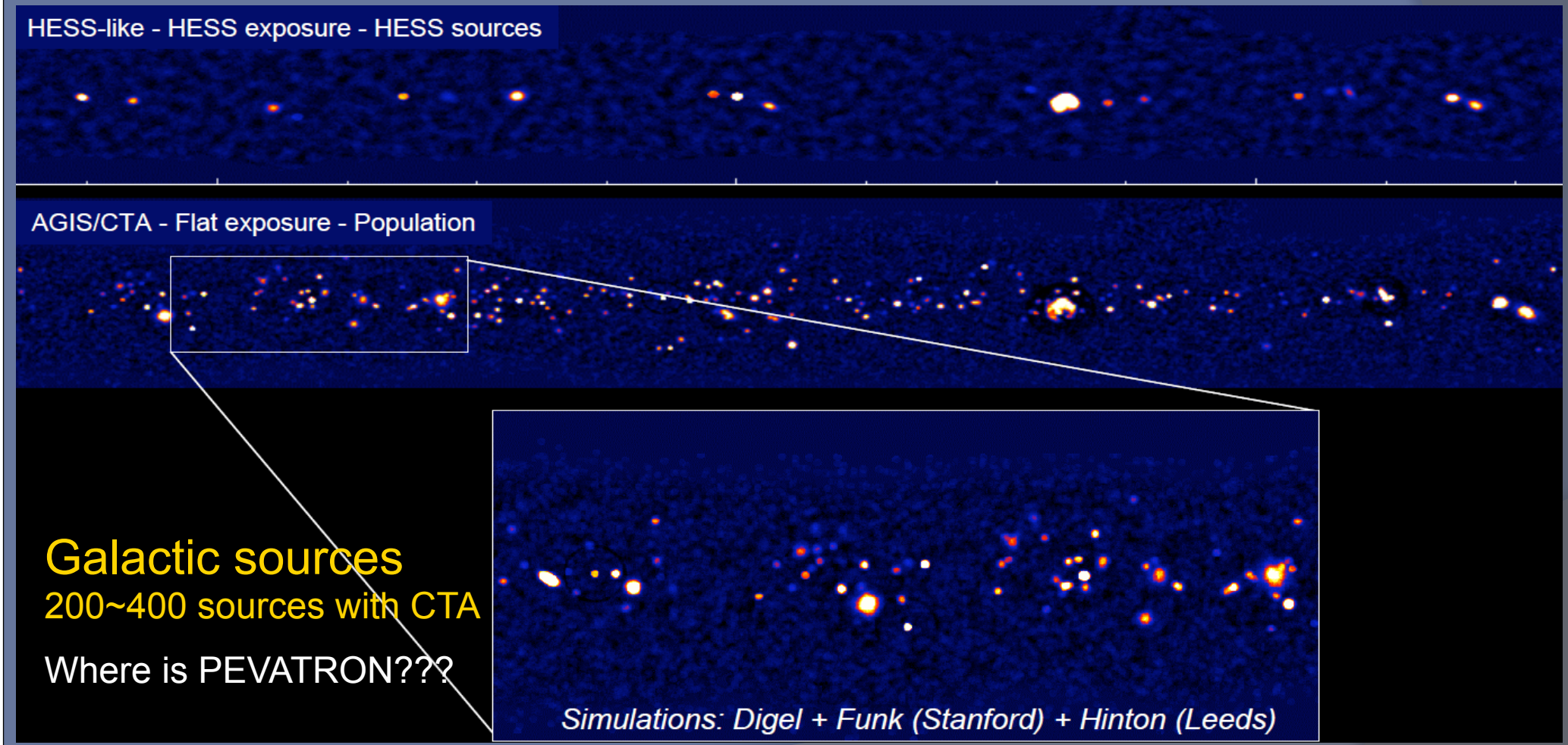
Configuration E:
LST x 4, MST x 23, SST x 32



Kifune Plot
(expectation from log S - log N)



Galactic sources

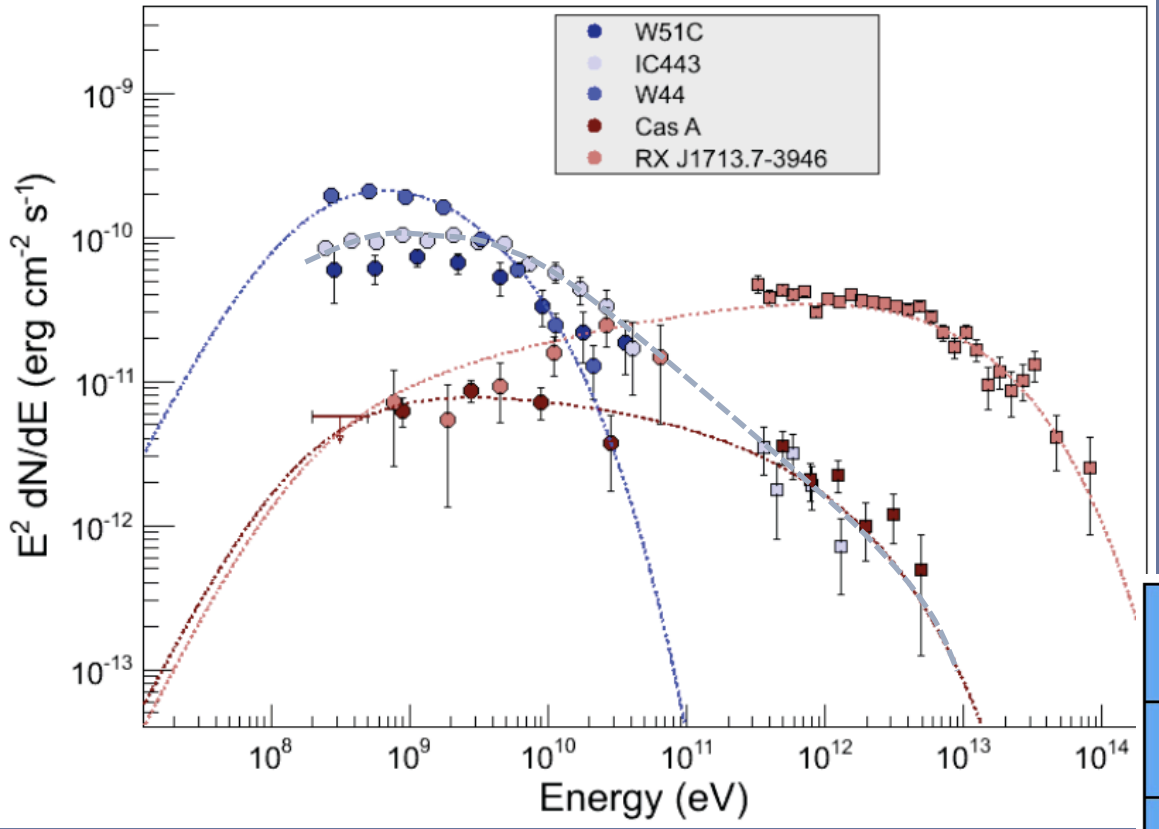


Galactic sources

200~400 sources with CTA

Where is PEVATRON???

CTA will deliver more



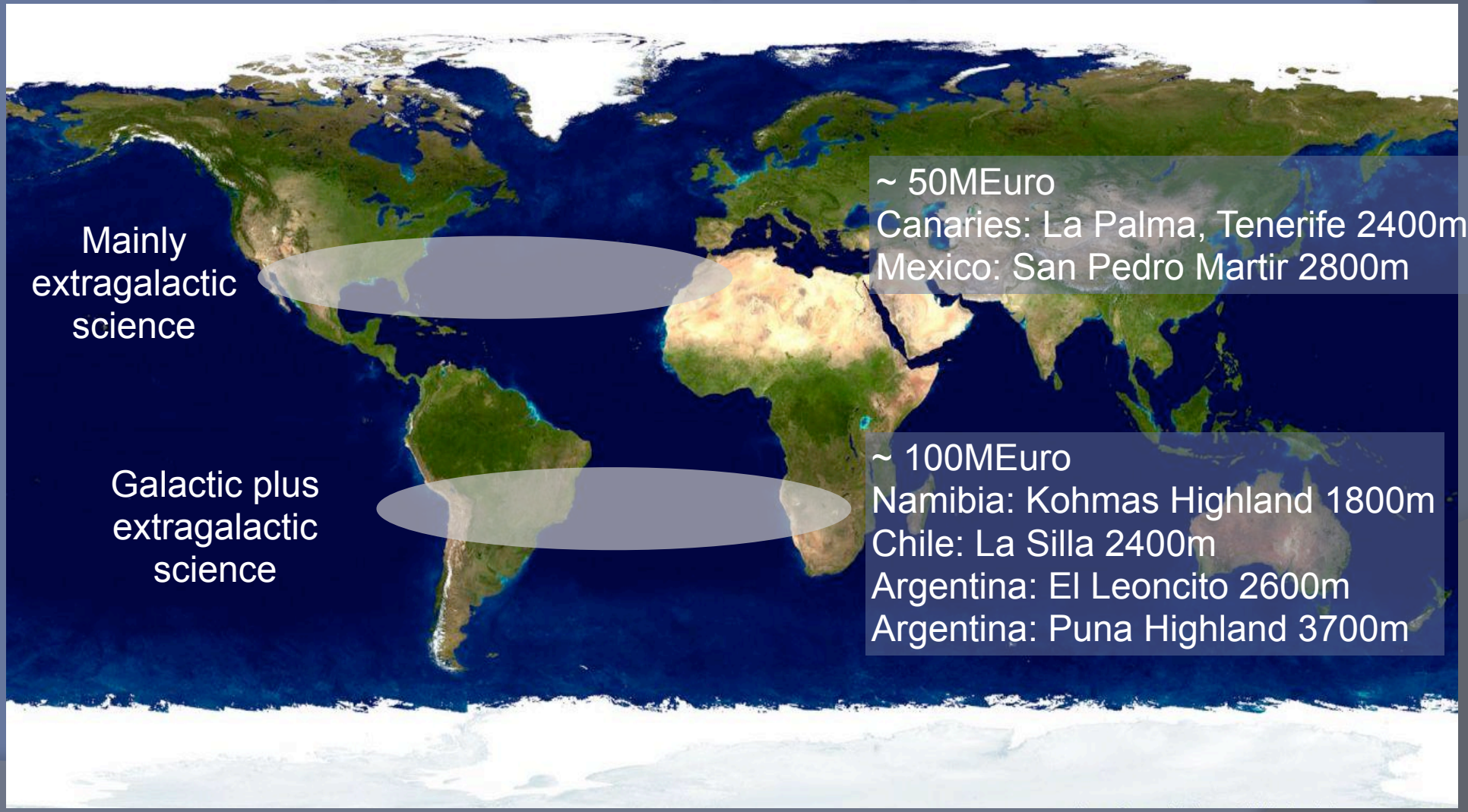
We can study SNRs in different evolutionary stages

	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%

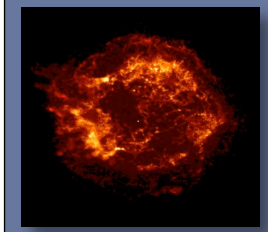
Courtesy of S.Funk

All sky observatory

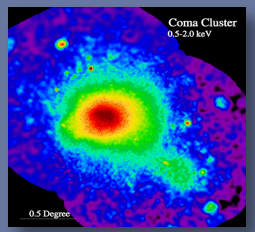
One observatory with two sites operated by one consortium



Specification and Physics



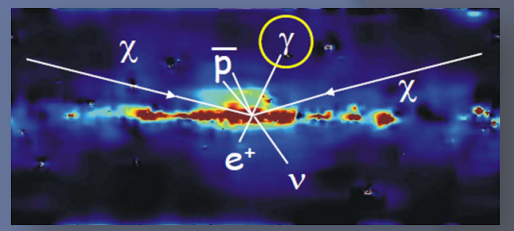
SNRs



New sources

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

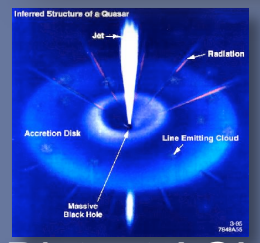
Energy Res. x2
(10% @ 1TeV)



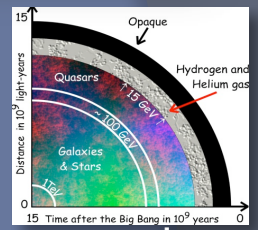
DM

Angular Res. x3
(2 arcmin @1TeV)

Low Threshold E x2
(20-30GeV)

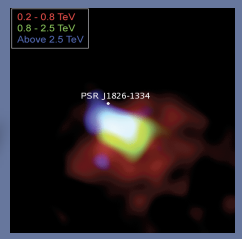


Distant AGNs



cosmology

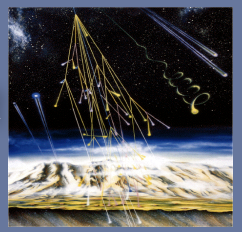
Morphology

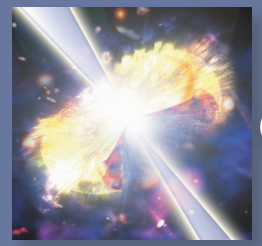


Large Accept. x30
(3x 10^6m^2 >1TeV)

Fast

Origin of CR

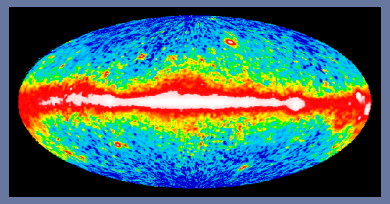




GRBs

Better

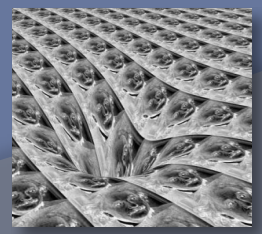
High Time Res. x10
(~1sec)



TeV - All sky map
Galactic diffuse

All Sky

Flexible



Space and Time

Tentative time schedule

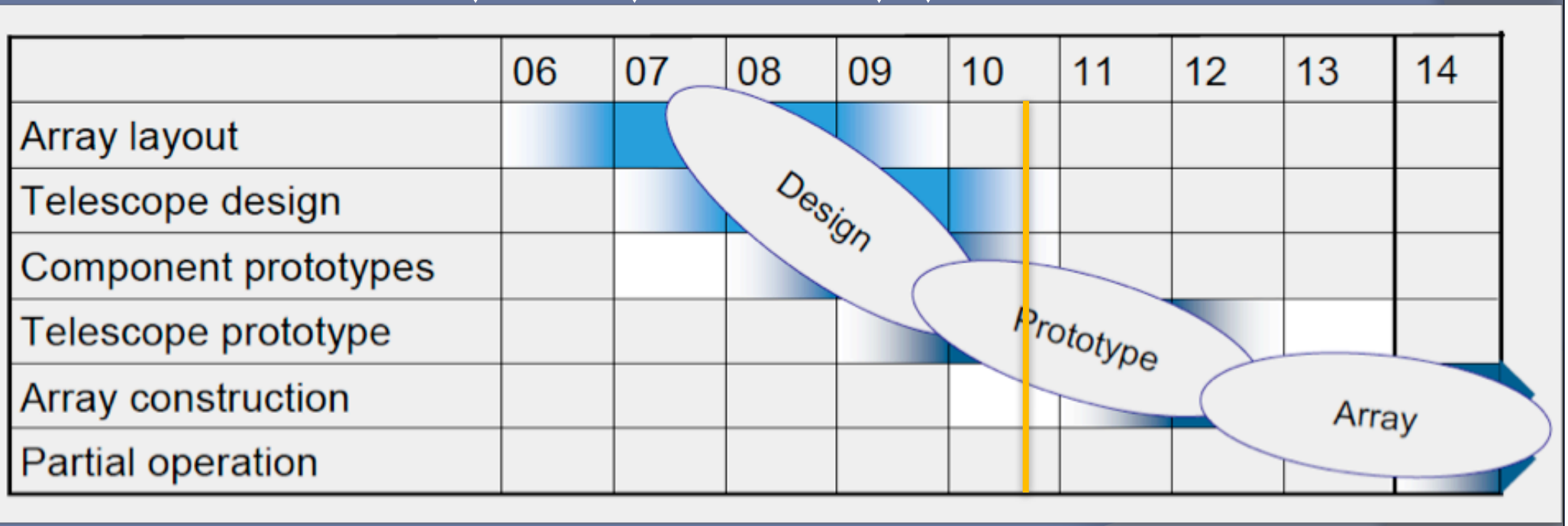
Applications

FP7 PP application

FP7 DS application

ASPERA application

ESFRI application



CTA general meetings

Barcelona

Padova

Crakow

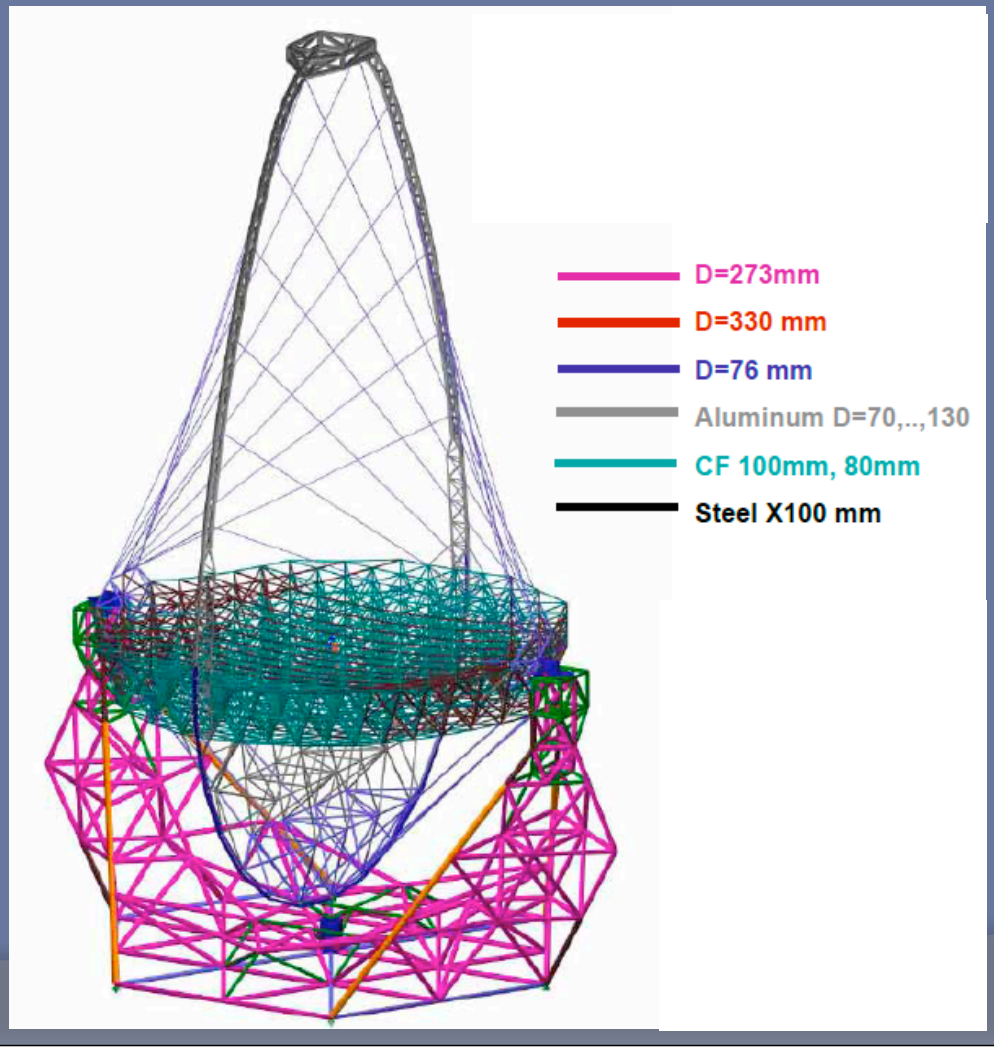
Zurich

Zeuthen

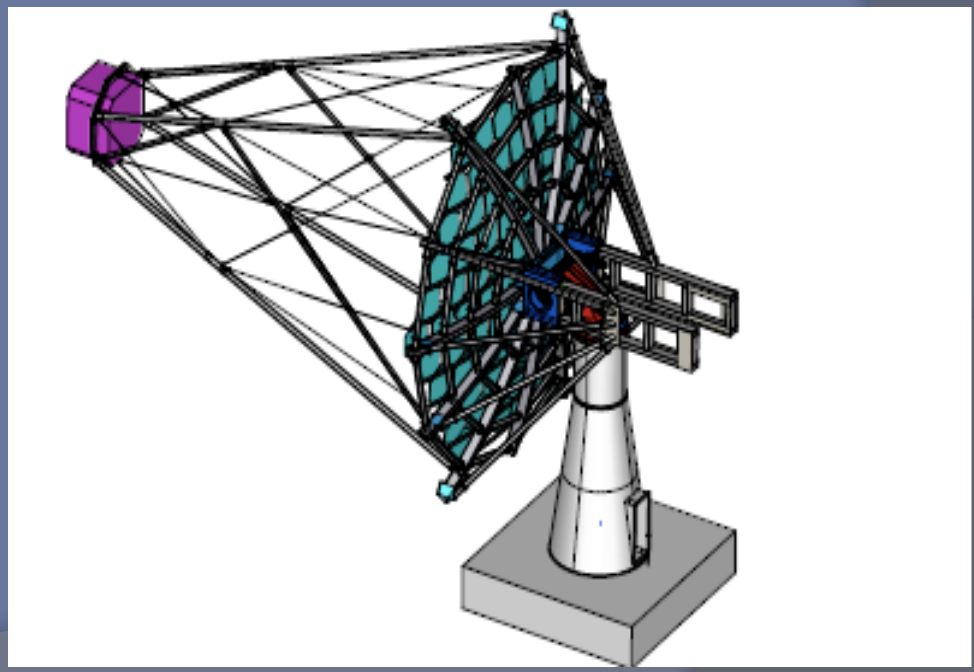
UK

23m Large size telescope and 12m Middle size telescope

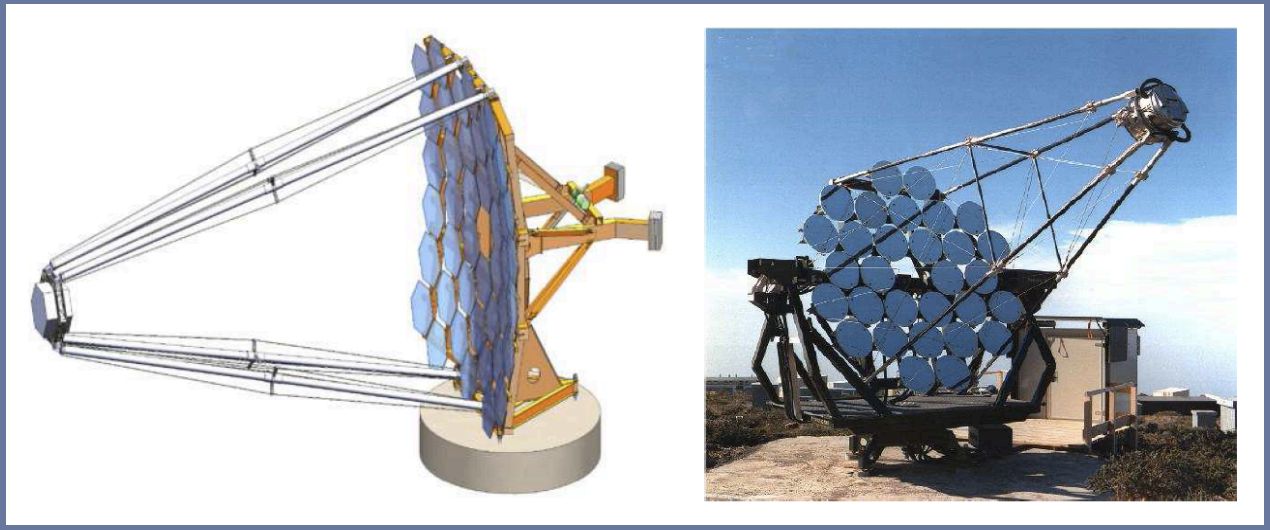
23m LST designed by MPI group

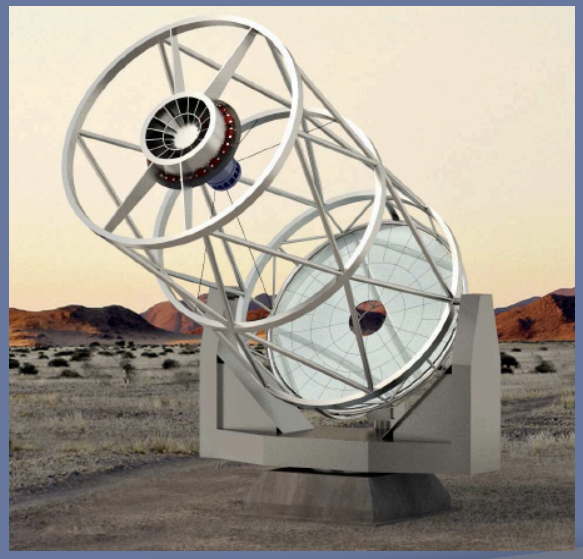


12m MST designed by DESY group

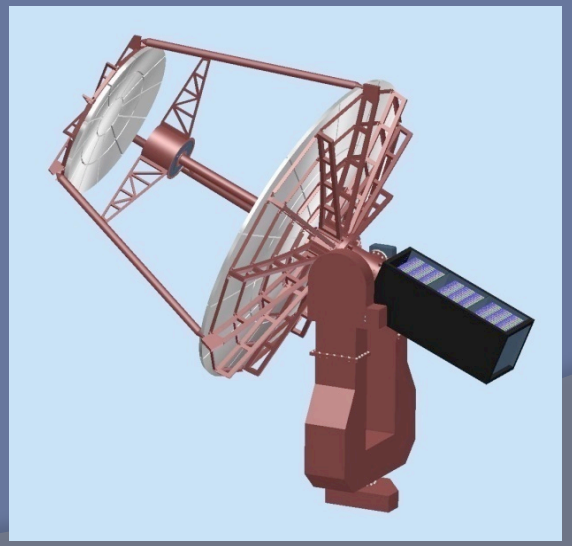


4-7m Small Size Telescope





Italian Design 7m

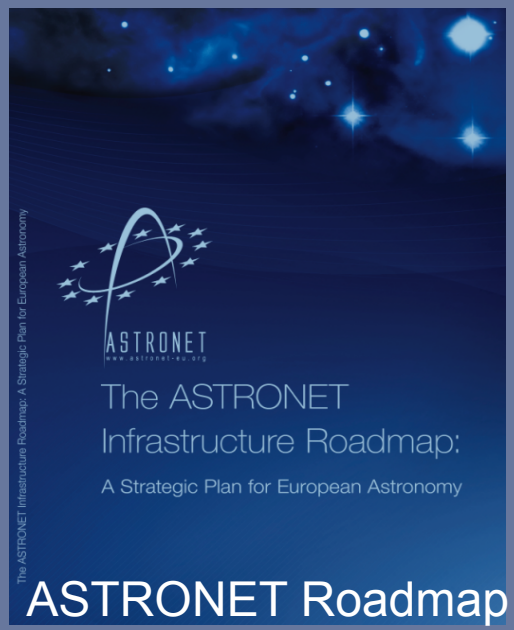


UK Design 4m

Recommendations and supports

ASPERA Roadmap

Magnificent Seven



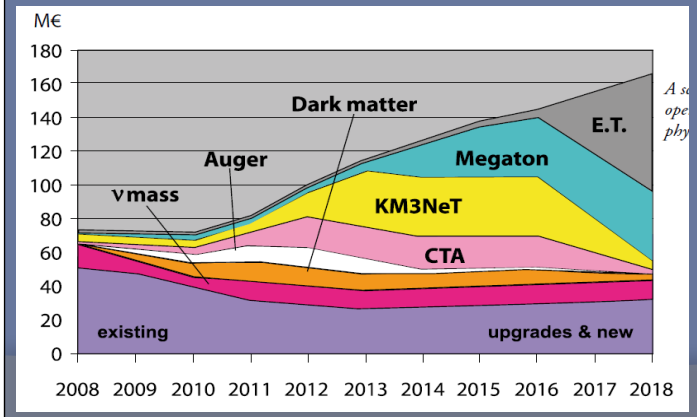
ASTRONET Roadmap

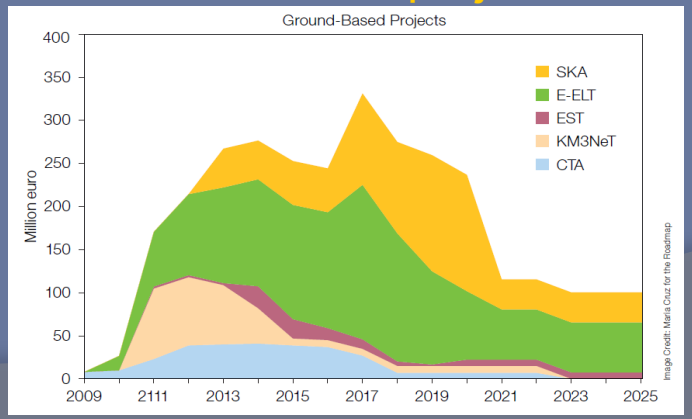
High Priority project

Ground based projects

8 Infrastructures

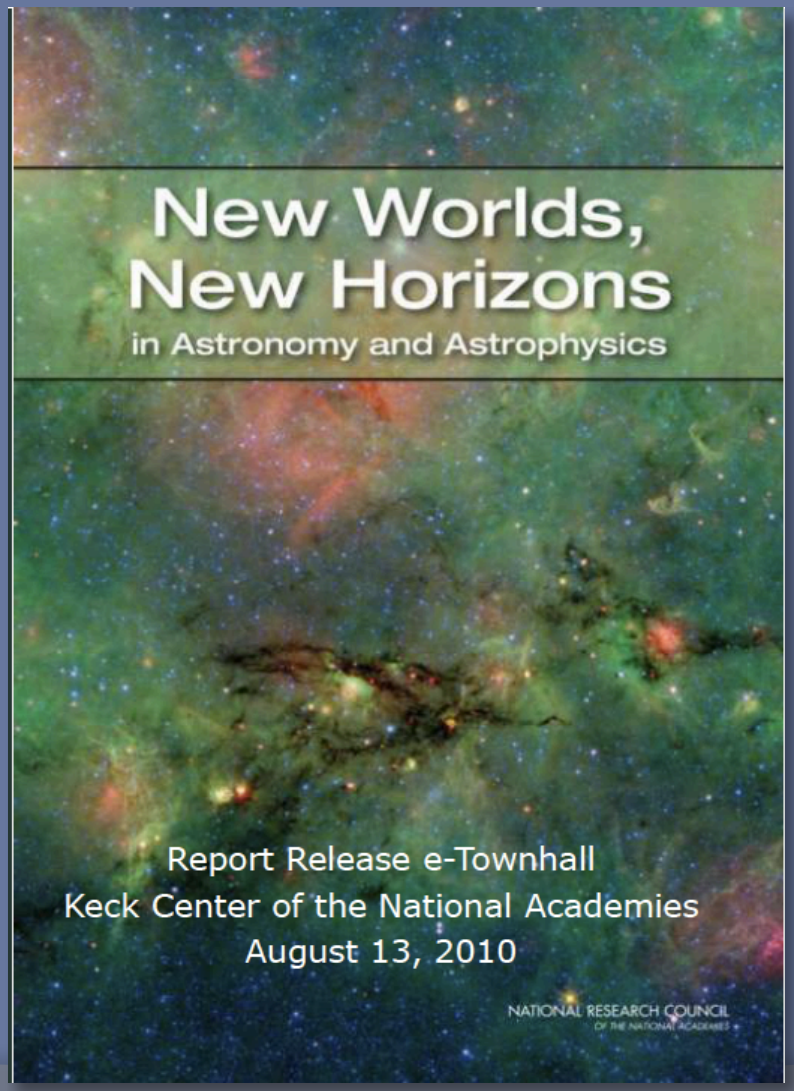
from Physics and eng





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)

Summary

- 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)

- Types of 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 will develop further VHE gamma ray astronomy and give opportunities to

Dear Gianni

We regret very much for missing you.

You are a great scientist in the field of Cosmic Ray and
Air shower physics.
I have enjoyed the discussion with you on the detail of CR physics,
the energy spectra, chemical compositions and anisotropy
of cosmic rays. You are a very friendly colleague.

Our science is progressing day by day, and I believe you are
watching what we are doing with a great interest.
You passed away too young.


THANKS

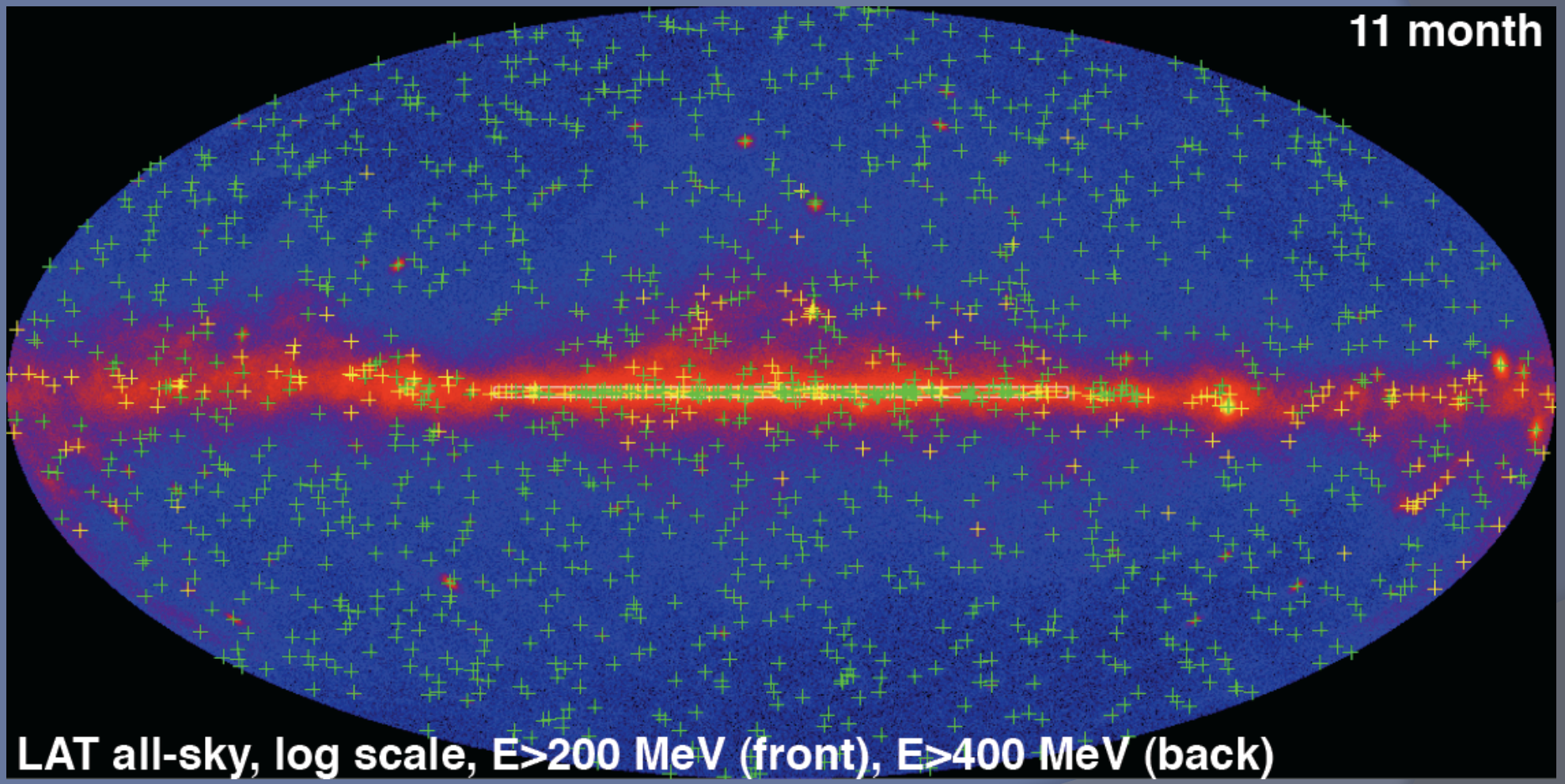

THANKS

Fermi Gamma Ray satellite

Parameters

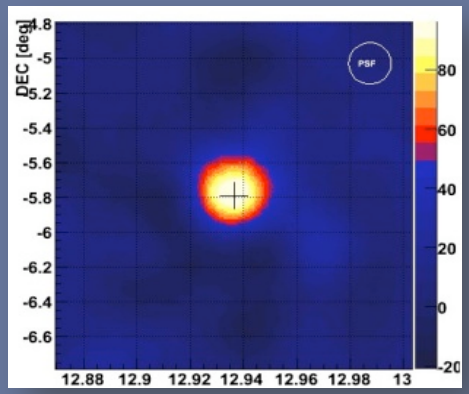
Energy range	30MeV ~ 100GeV
Background free	
Angular resolution	~ 0.8 deg at 1GeV
Effective area	~ $1m^2$

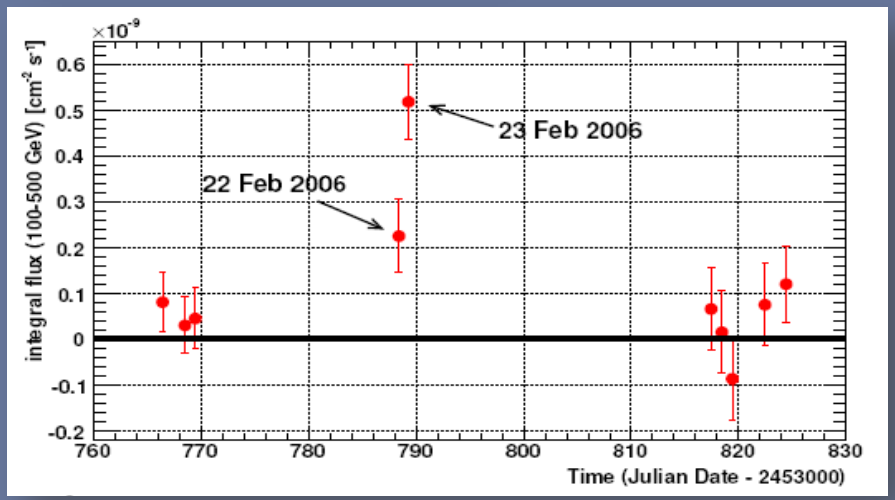
The first LAT catalog (1FGL)
Fermi 11 month data

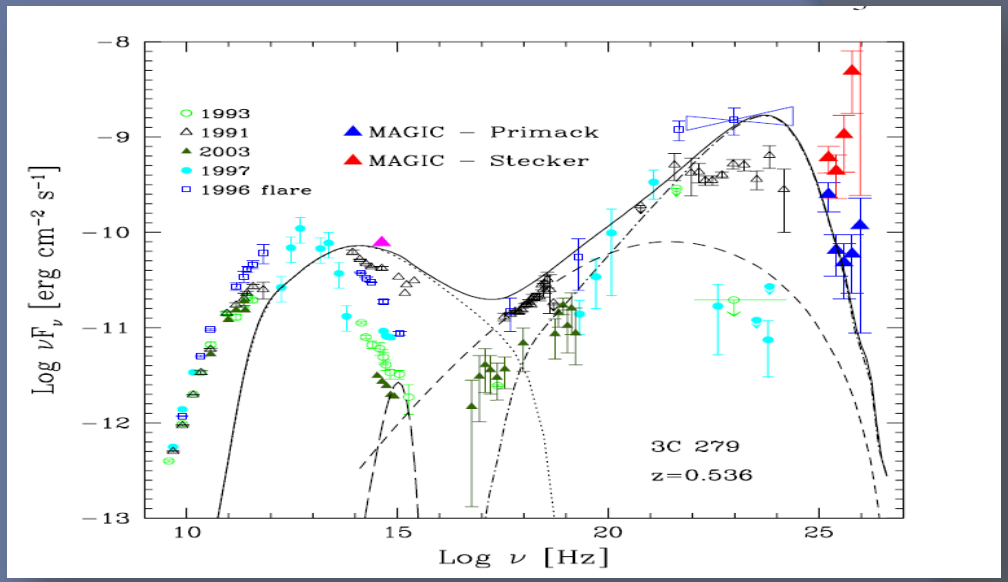


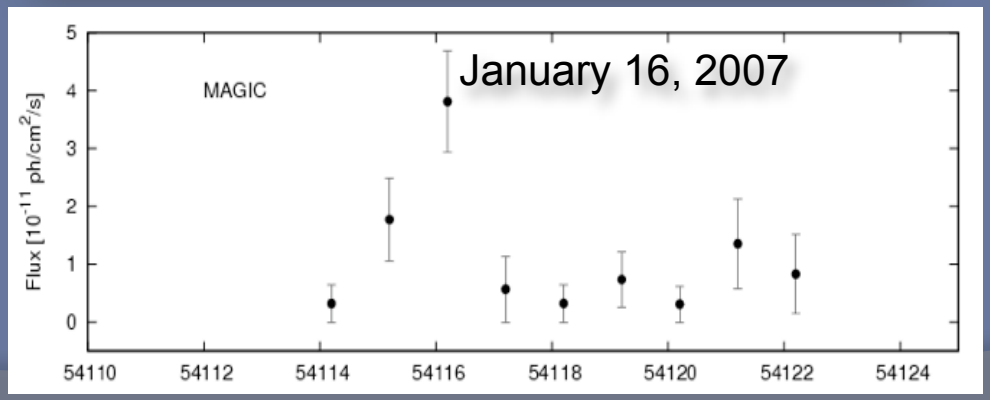
- >1000 sources for TS = 2 Δlog(likelihood) > 25 (~4σ for 4 D.o.F.)
- Typical 95% error radius is 10'. Absolute accuracy is better than 1'

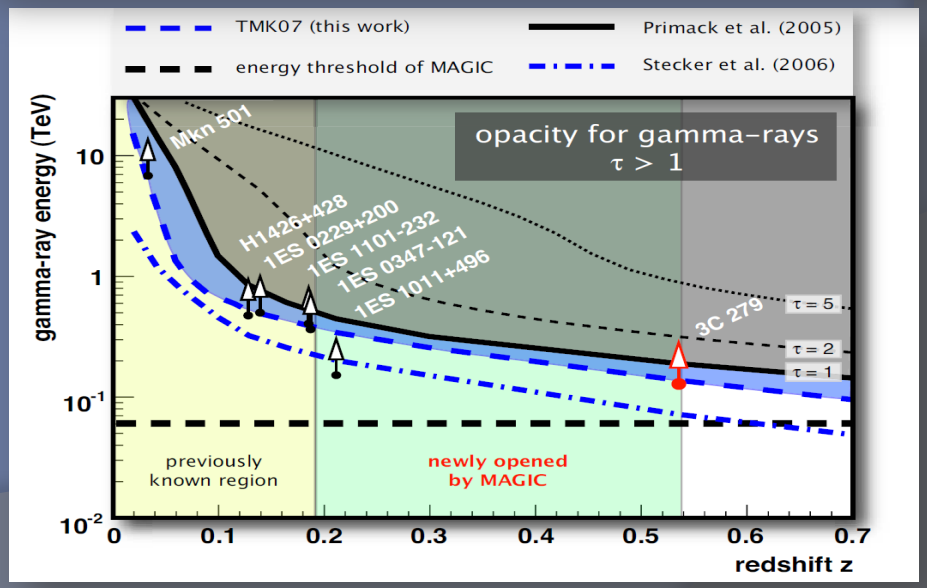
FSRQ 3C279 (z=0.536) MAGIC



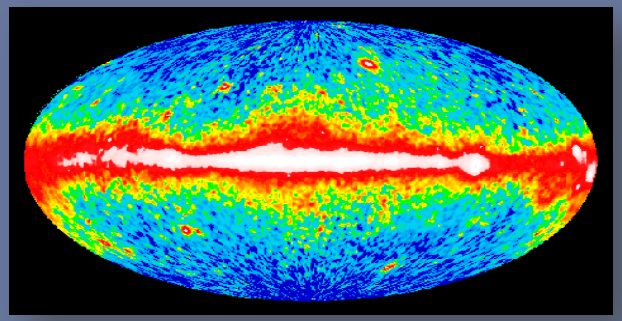




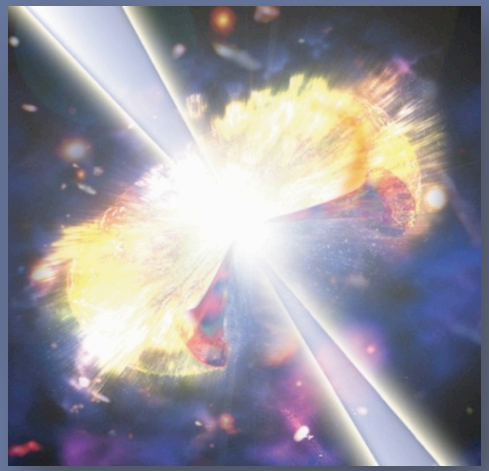




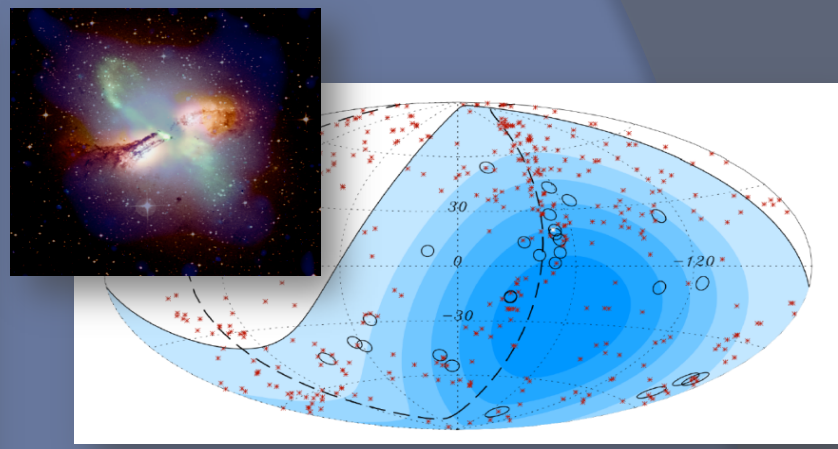
Possible New Classes of Sources in CTA



Galactic Diffuse

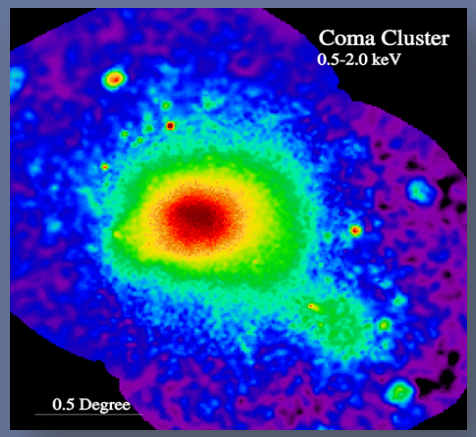


GRBs

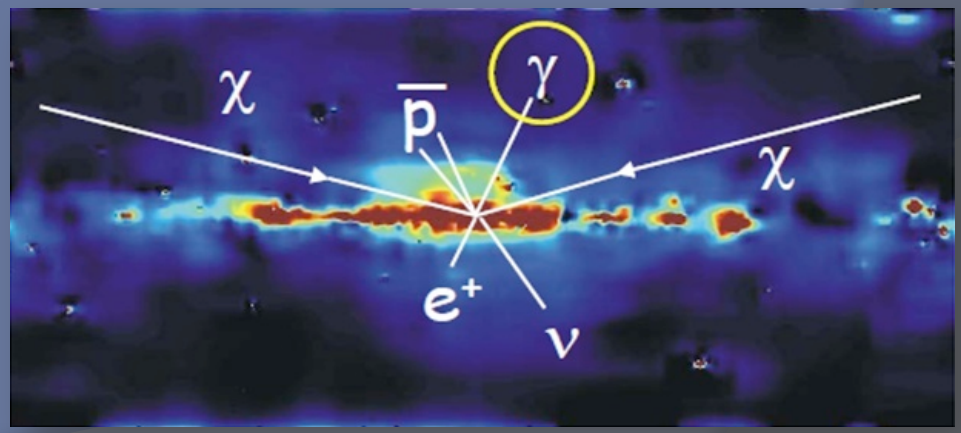


UHECR Sources

Starburst galaxies
Galaxy mergers



Clusters of galaxies



Dark Matter Annihilation

Summary

- VHE gamma ray astronomy started from the Crab detection ingis remarkable
- IACT 技術の熟成 ➔ CTA == 究極の IACT Array
  - 国際協力による次世代のインフラの構築
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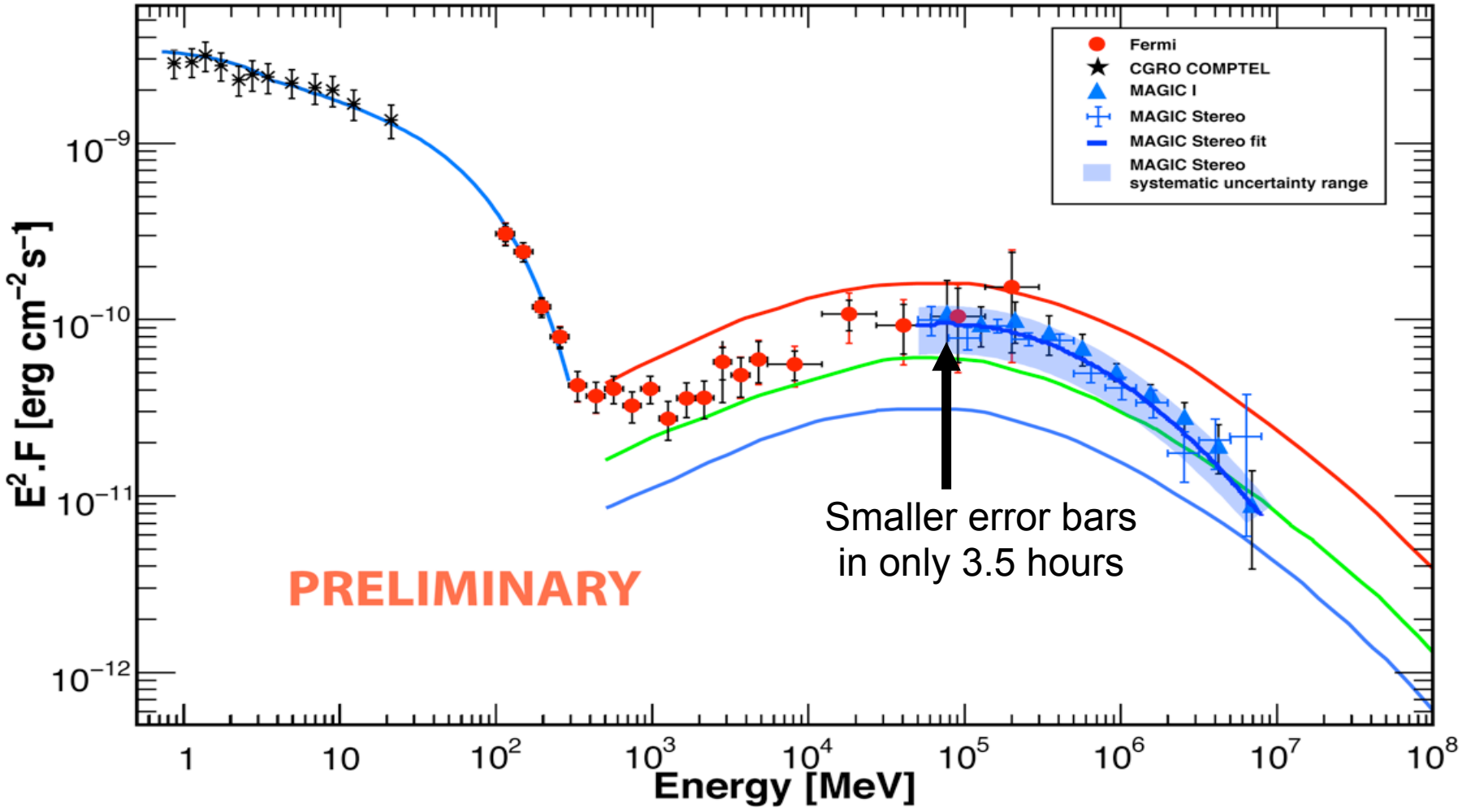
  - 基礎物理：相対論・量子重力効果、暗黒物質、宇宙論
- タイムスケジュール
  - 2010–2013プロトタイプ

Crab Nebula spectrum



10 GRBs observed by Fermi

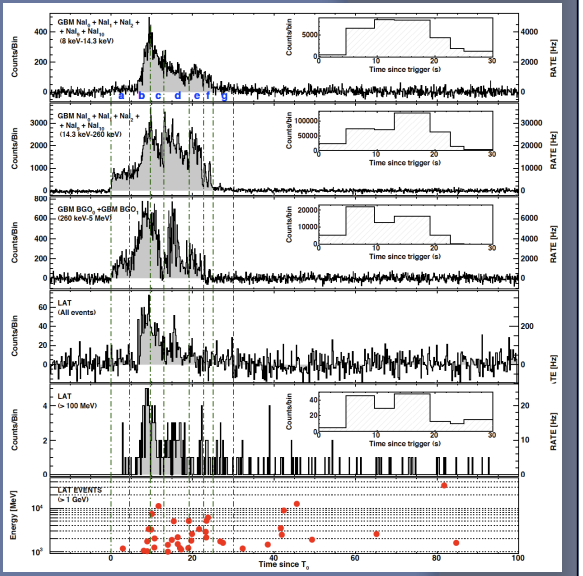
GRB	duration	# of events > 100 MeV	# of events > 1 GeV	delayed HE onset	Long-lived HE emission	Highest Energy	Redshift
080825C	long	~10	0	?	✔	~600 MeV	
080916C	long	>100	>10	✔	✔	~ 13.2 GeV	4.35
081024B	short	~10	2	✔	✔	3 GeV	
081215A	long	—	—	—	—	—	
090217	long	~10	0	x	—	~1 GeV	
090323	long	>10	>0	—	✔	—	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



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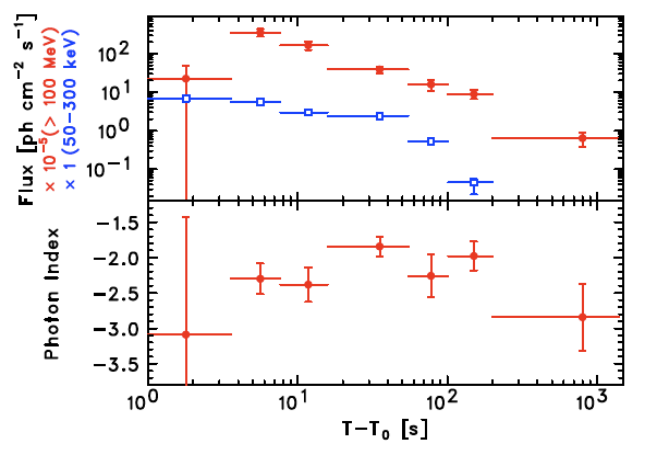
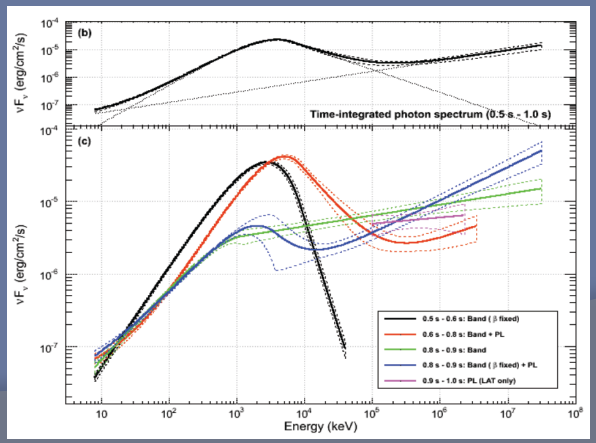


GRB090510(short burst)



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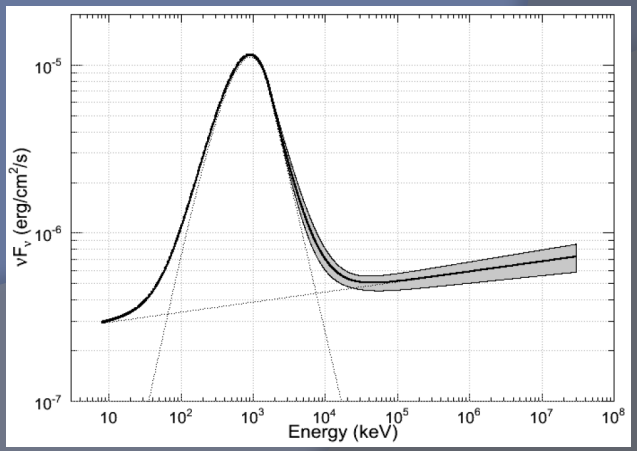
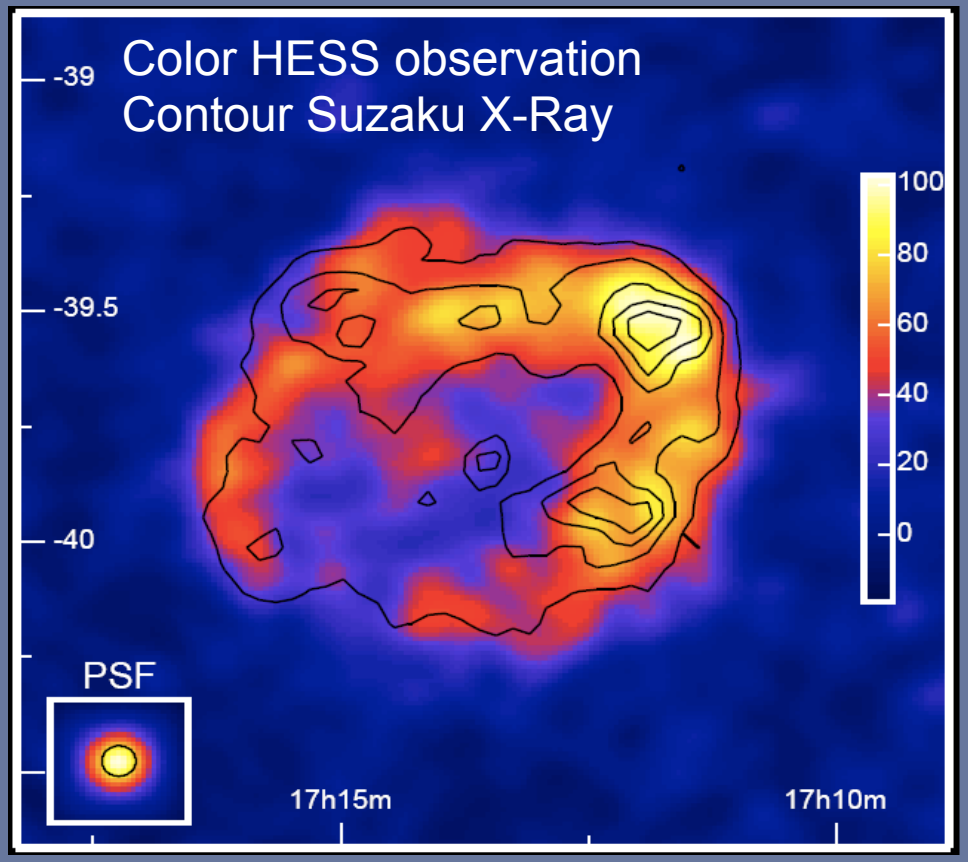
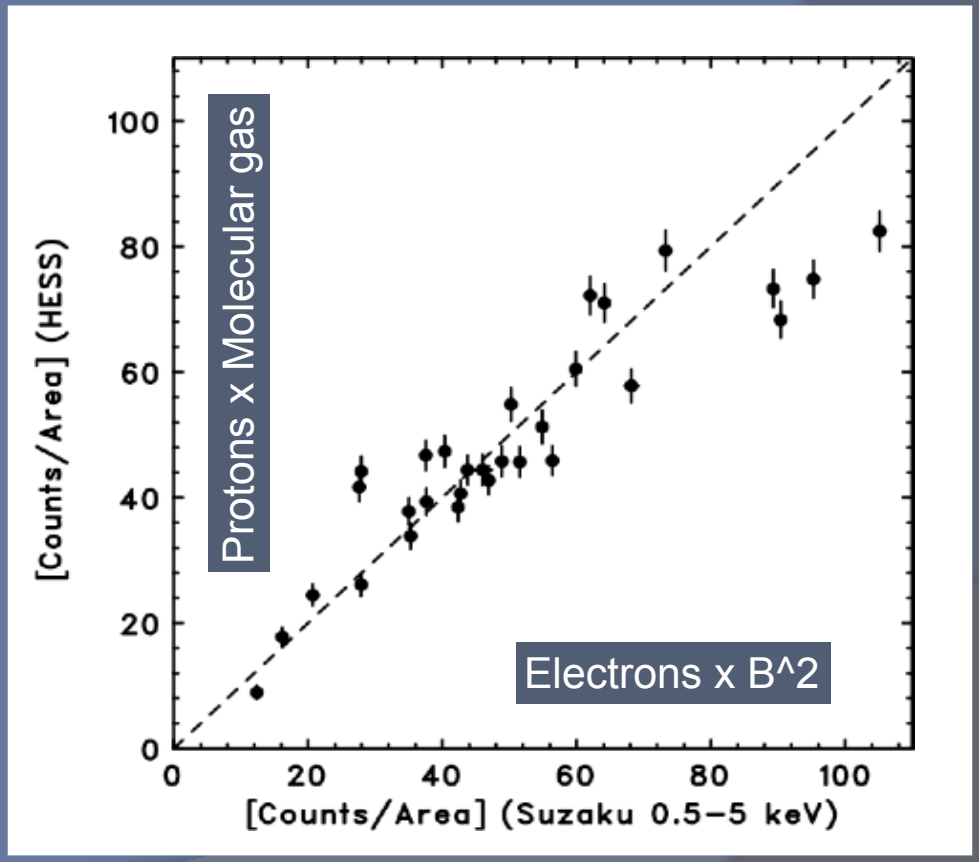


RX J1713

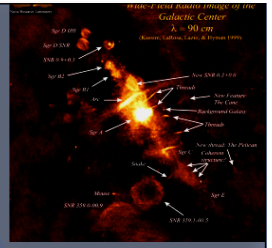
SED and Strong B in the shell suggest Hadronic origin of VHE gammas

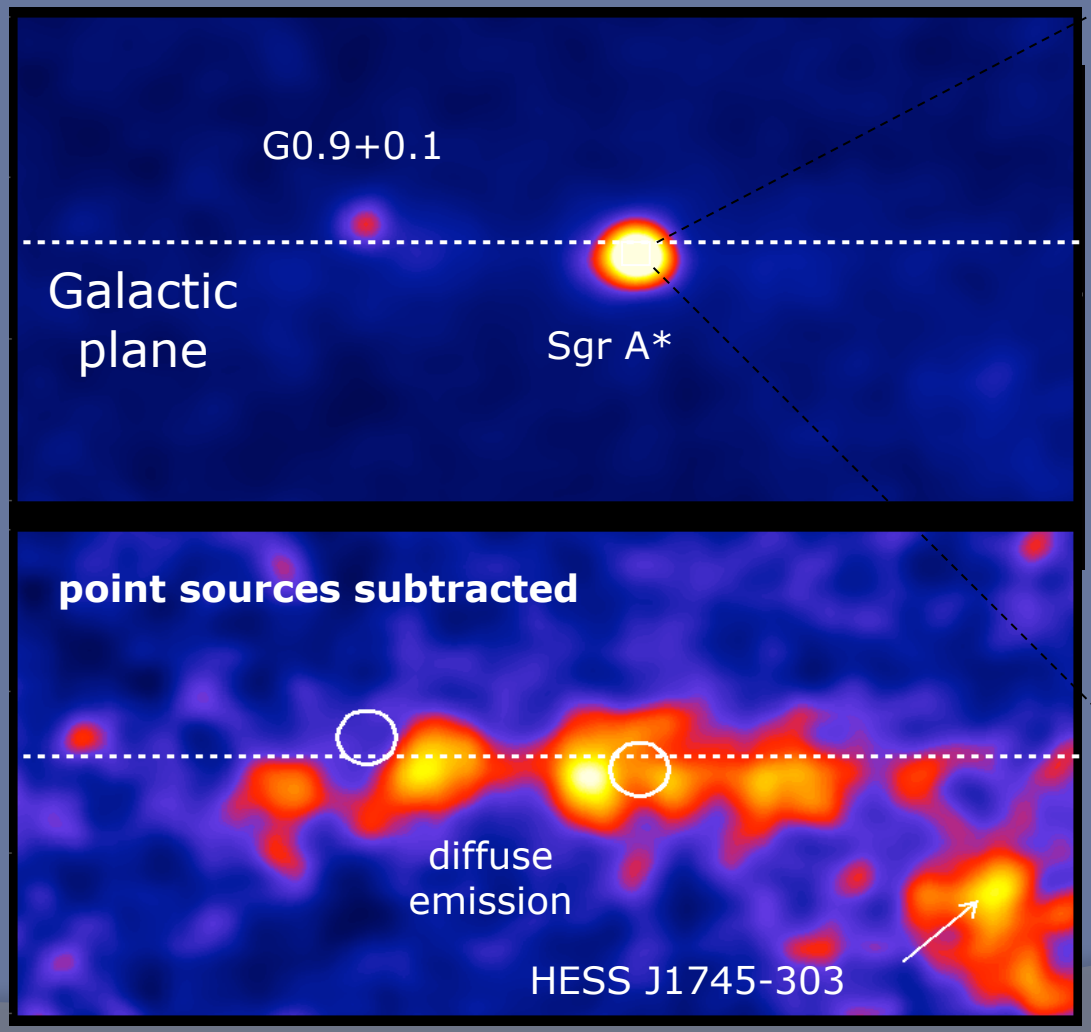


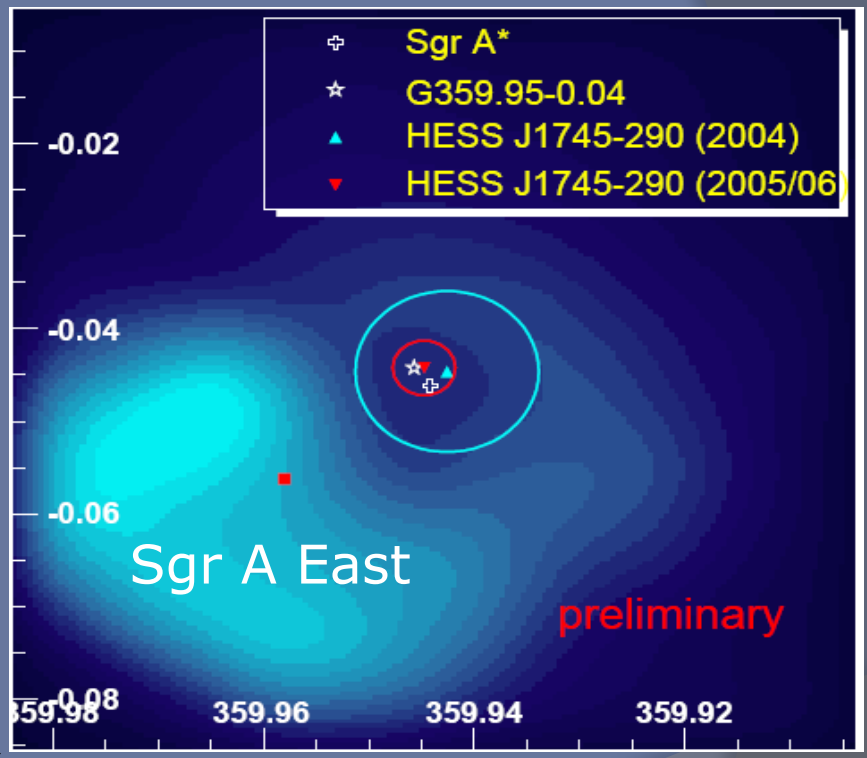


Y. Uchiyama, T. Takahashi
Texas Symp. 2006

Galactic Center







Error on GC source location:
6” stat., 6” syst.
(van Eldik, ICRC07)

EGRET Observation

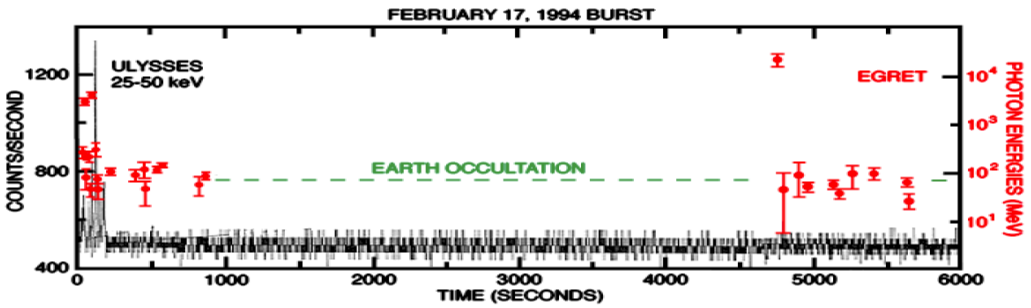
Delayed component at High Energy
It is not easy to explain by electron synchrotron mech.

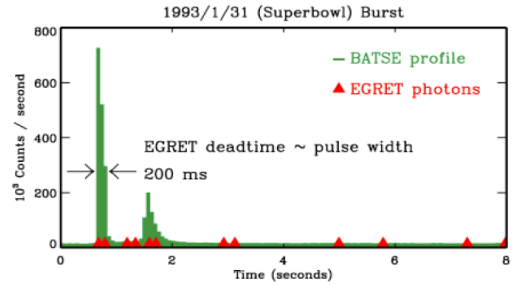
Evidence of P synchrotron?

2 GeV photons

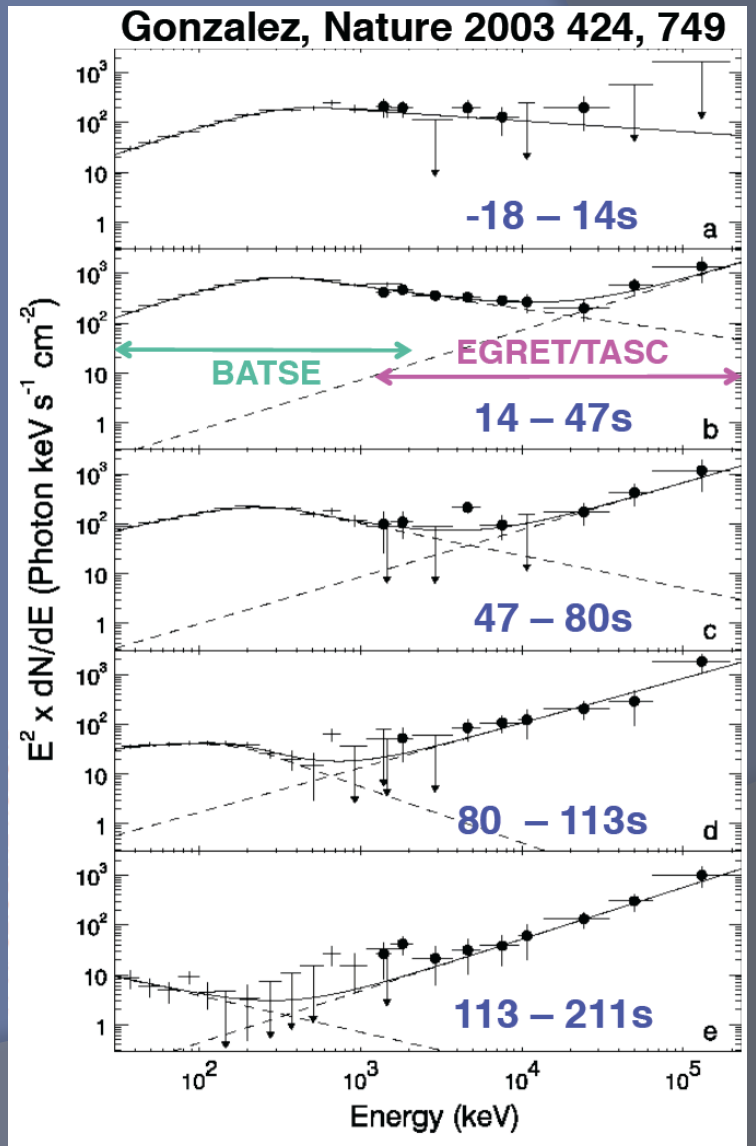
18GeV at T0+75mins

Two EGRET Bursts





- >10 GeV photons can last for > 1 hr, start w. MeV trigger
- Considerable energy at 100 MeV-10 GeV



Summary

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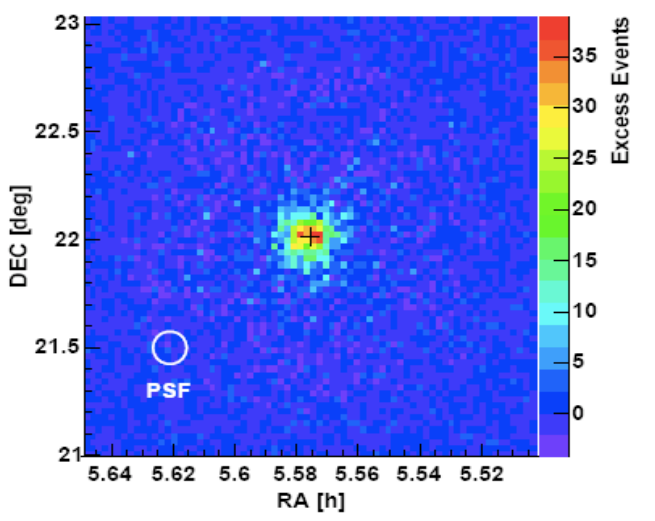
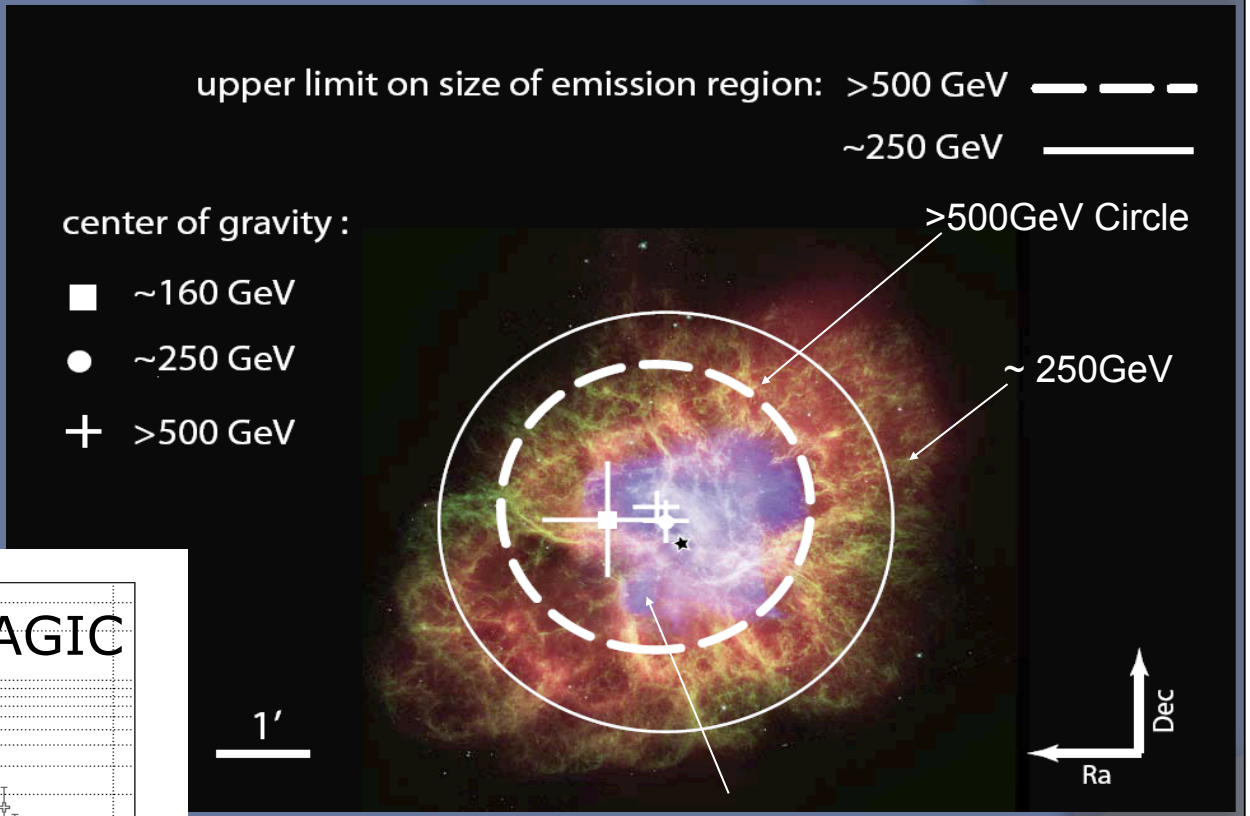
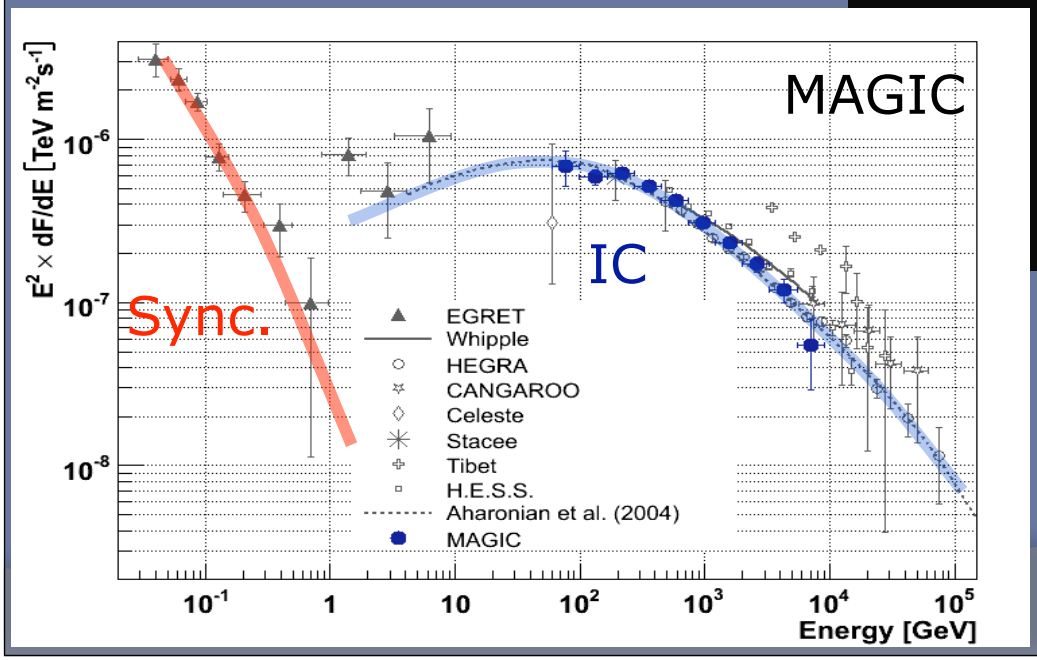
- タイムスケジュール

MAGIC Crab Nebula (PWN)



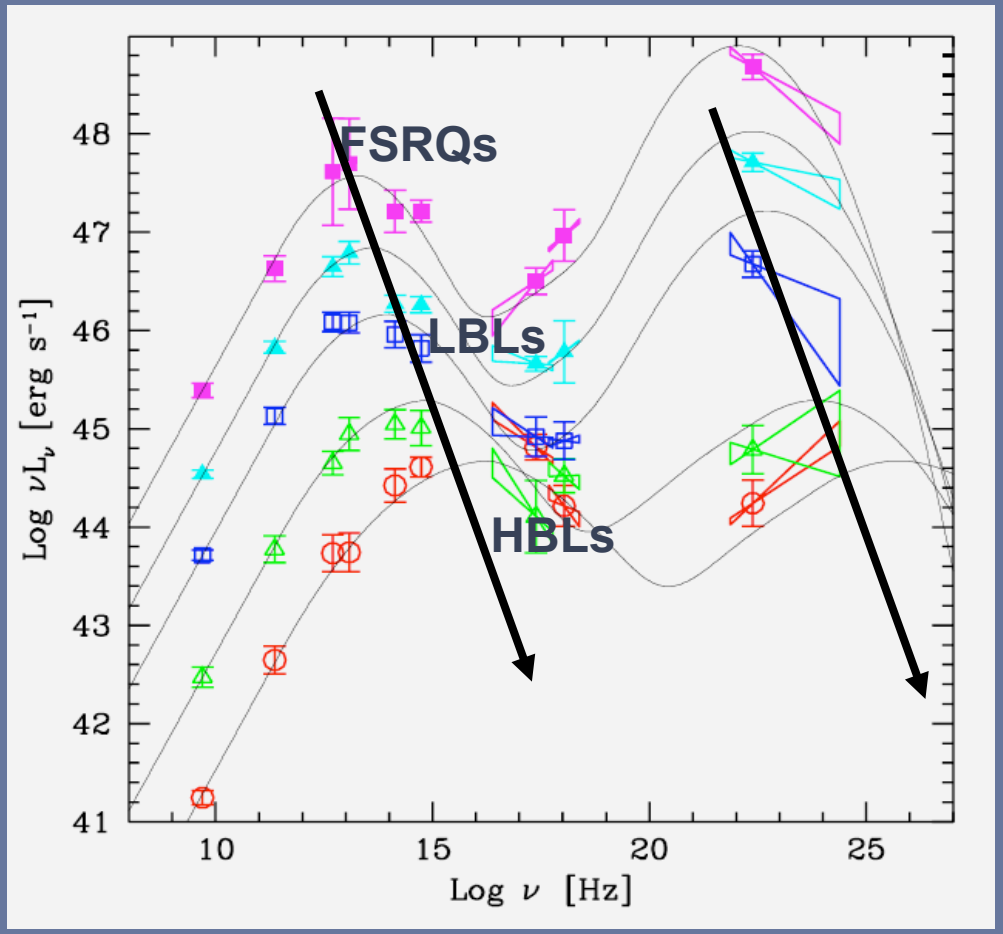




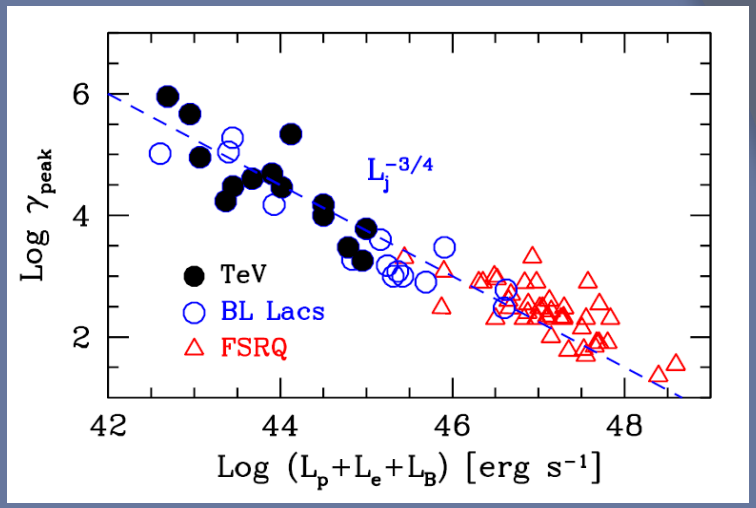
IC peak is estimated to be

IC_peak = 77 ± 35 GeV

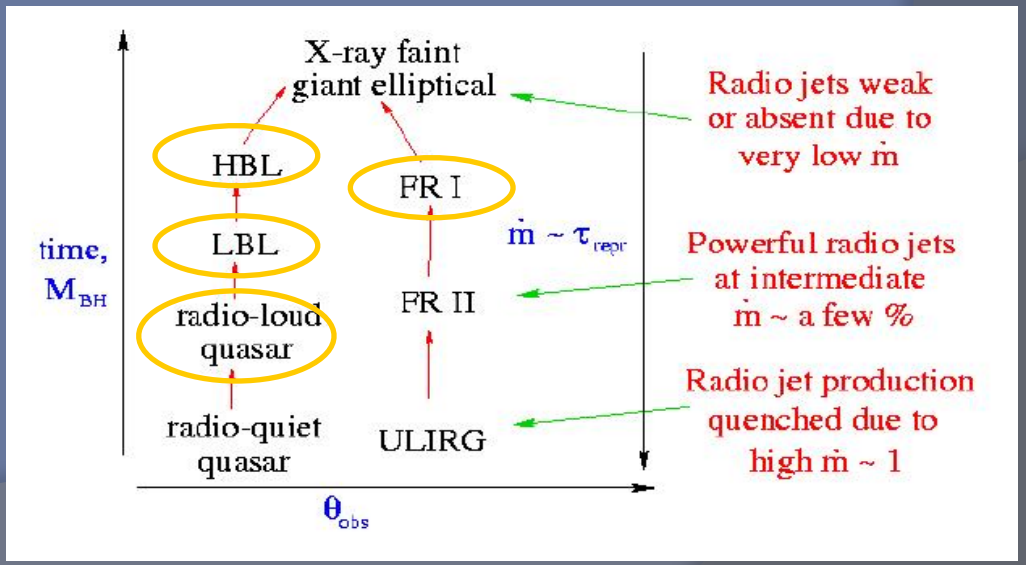
Blazar's Sequence



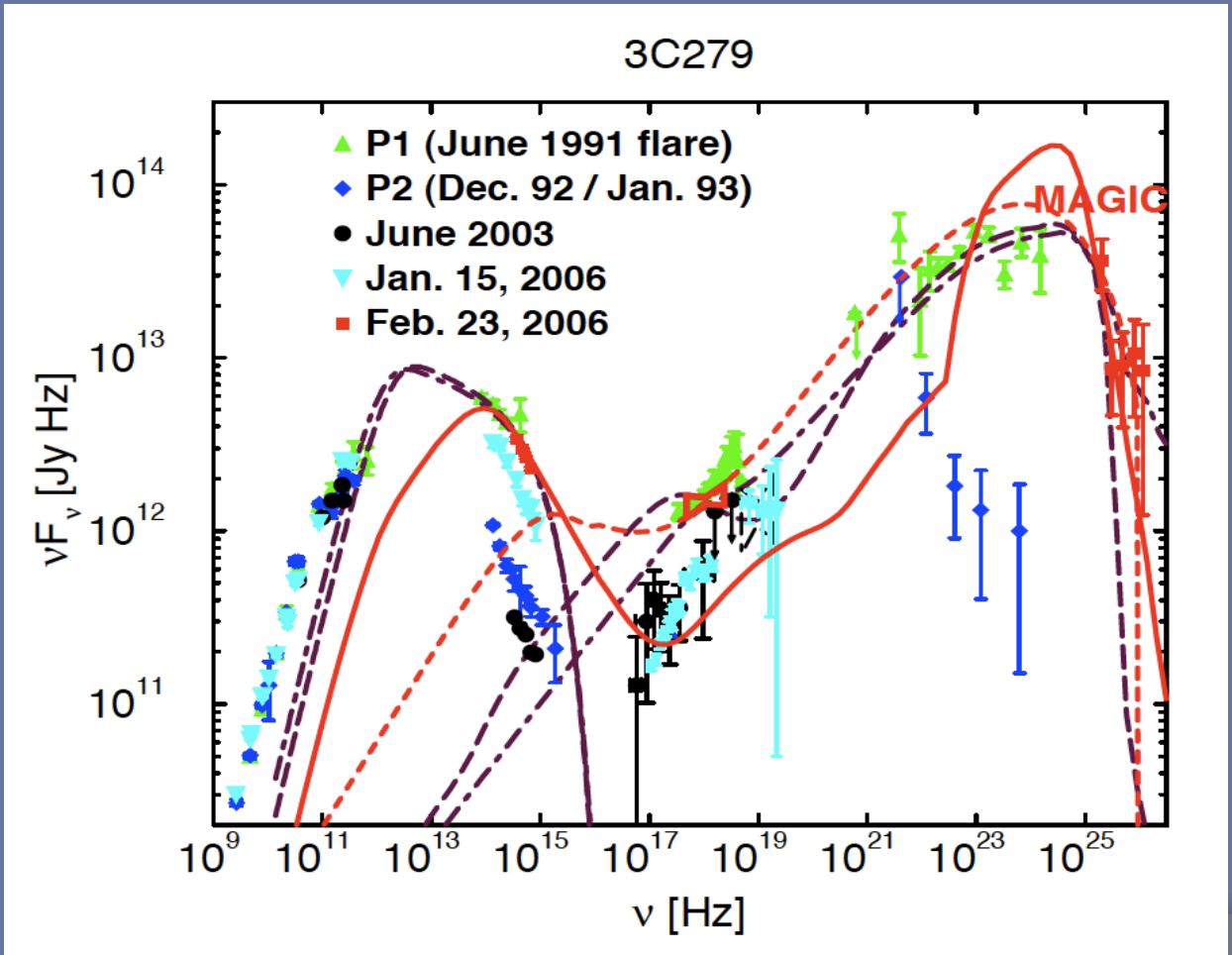
Fosatti et al. 1998



Celotti & Ghisellini 2007



Source modeling



Leptonic EC
B is too weak

Leptonic SSC
B is too weak

SPB +Sync Pγ
Jet energy 10^{49}erg/s

SPB + Sync, BLR Pγ