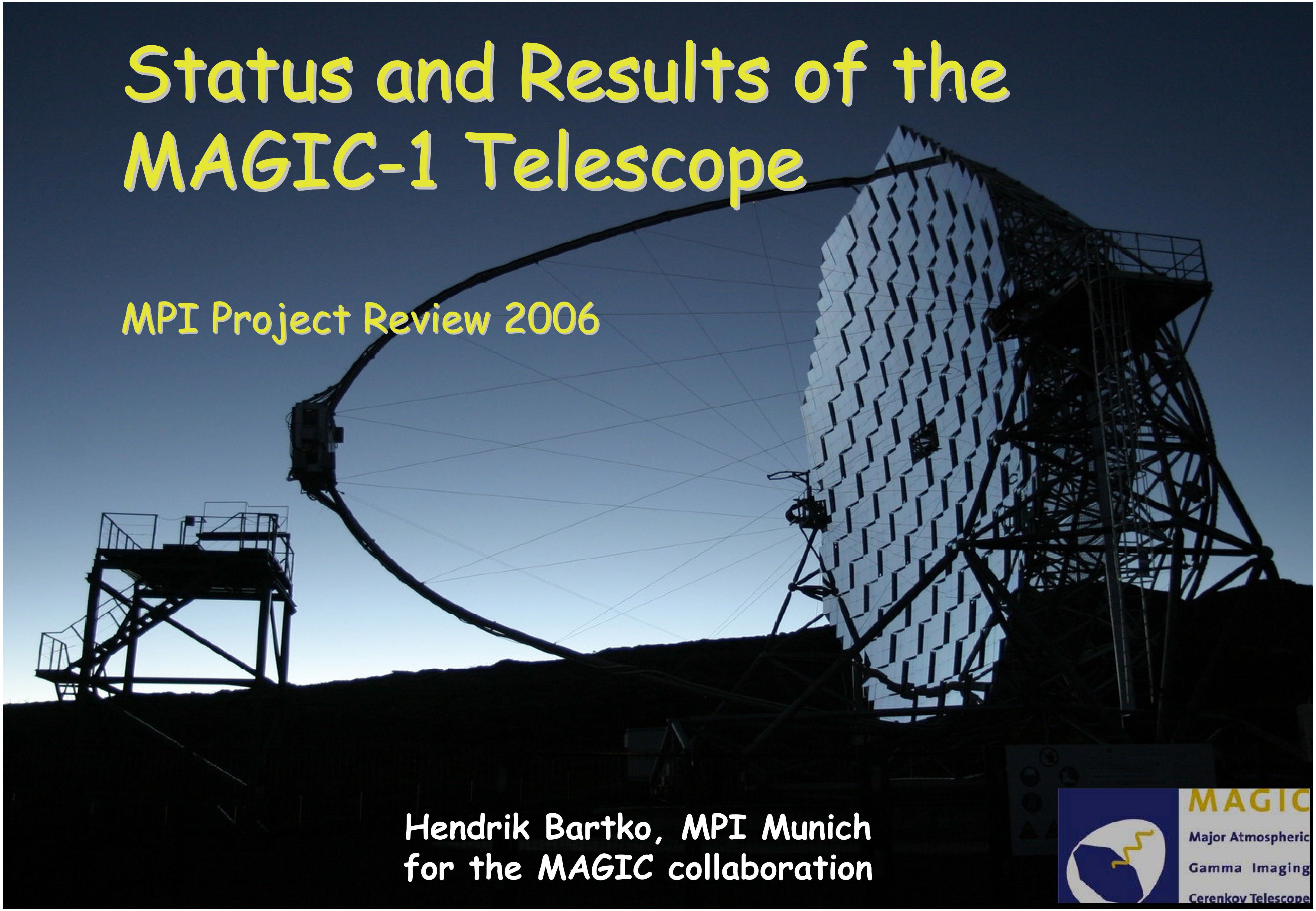
Status and Results of the MAGIC-1 Telescope

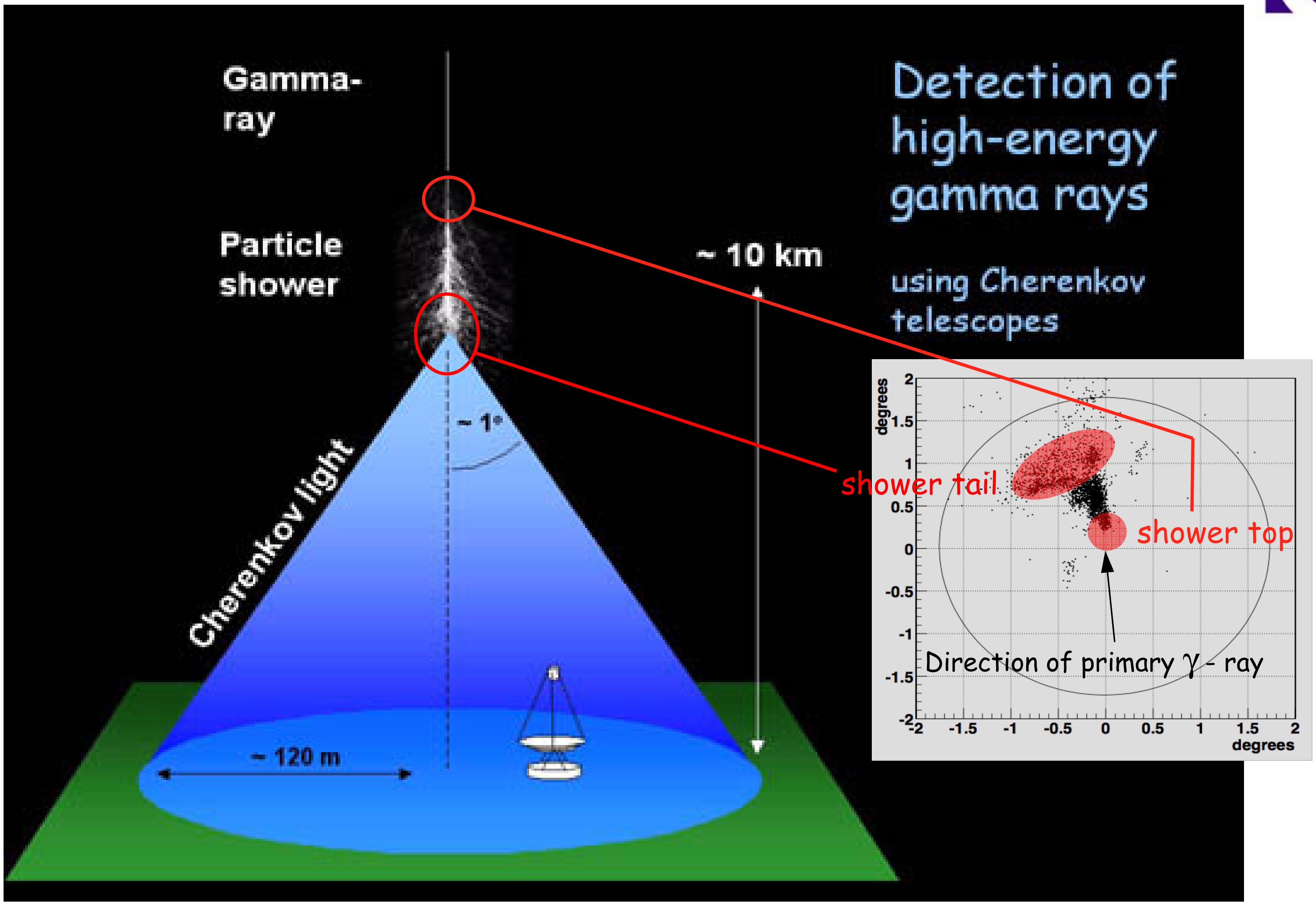
MPI Project Review 2006



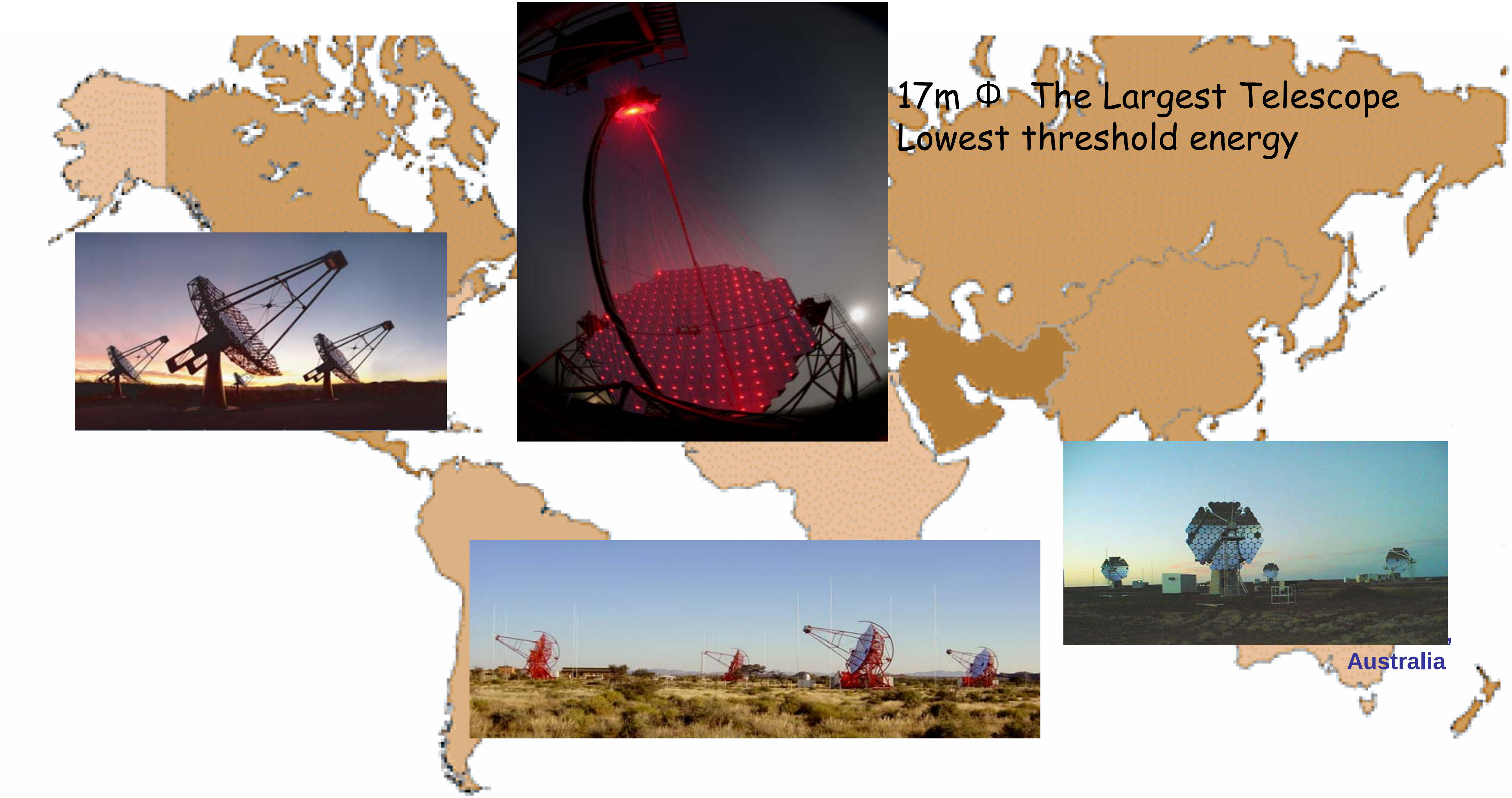
Hendrik Bartko, MPI Munich
for the MAGIC collaboration

MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescope

The IACT principle



Ground Based γ-Ray Instruments



The MAGIC Collaboration

Major Atmospheric Gamma-Ray Imaging Cherenkov Telescope

Collaboration: ~150 physicists & technicians,
19 institutes, 9 countries:

IAA Granada, IFAE Barcelona, UAB Barcelona, U Barcelona, HU Berlin, IAC La Laguna, U.C. Davis, U. Dortmund, U. Lodz, UCM Madrid, MPI München, INFN/ U. Padua, INFN Pisa / U. Siena, INRNE Sofia, INFN Trieste/U. Udine, Obs. Tuorla, U. Würzburg, Yerevan Phys. Institute, ETH Zürich

Project goal: build lowest threshold IACT to observe in the unexplored spectral "gap" between ~30 and 250 GeV.

The MPI MAGIC Group

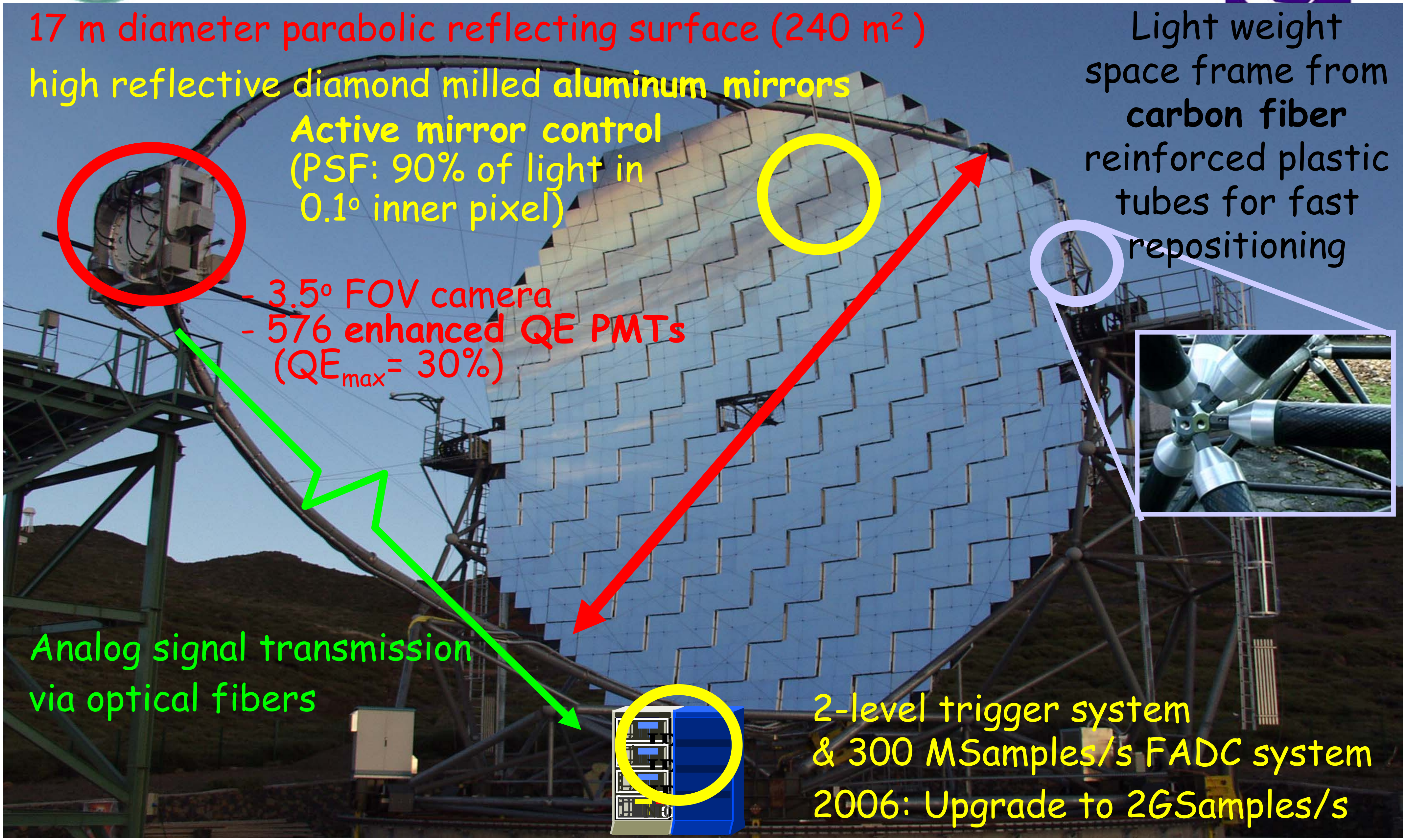
26 Physicists

1 Director: M. Teshima (**Spokesperson of MAGIC**),
6 Senior scientists: F. Goebel (**MAGIC-2 project manager**),
R. Mirzoyan (**Chair Collab. board**),
T. Schweizer (**Technical Coordinator**),
R. Bock, E. Lorenz, W. Wittek (emeriti)
5 Postdocs: E. Carmona, N. Galante, P. Majumdar, J. Ninkovic, K. Shinozaki
11 PhD students: H. Bartko, M. Garczarczyk, M. Hayashida, C. Hsu, T. Jogler,
D. Mazin, C. Merck, S. Mizobuchi, N. Otte, T. Saito, R. Wagner
3 Diploma students: M. Fuchs, R. Kosyra, A. Romaszkiewicz

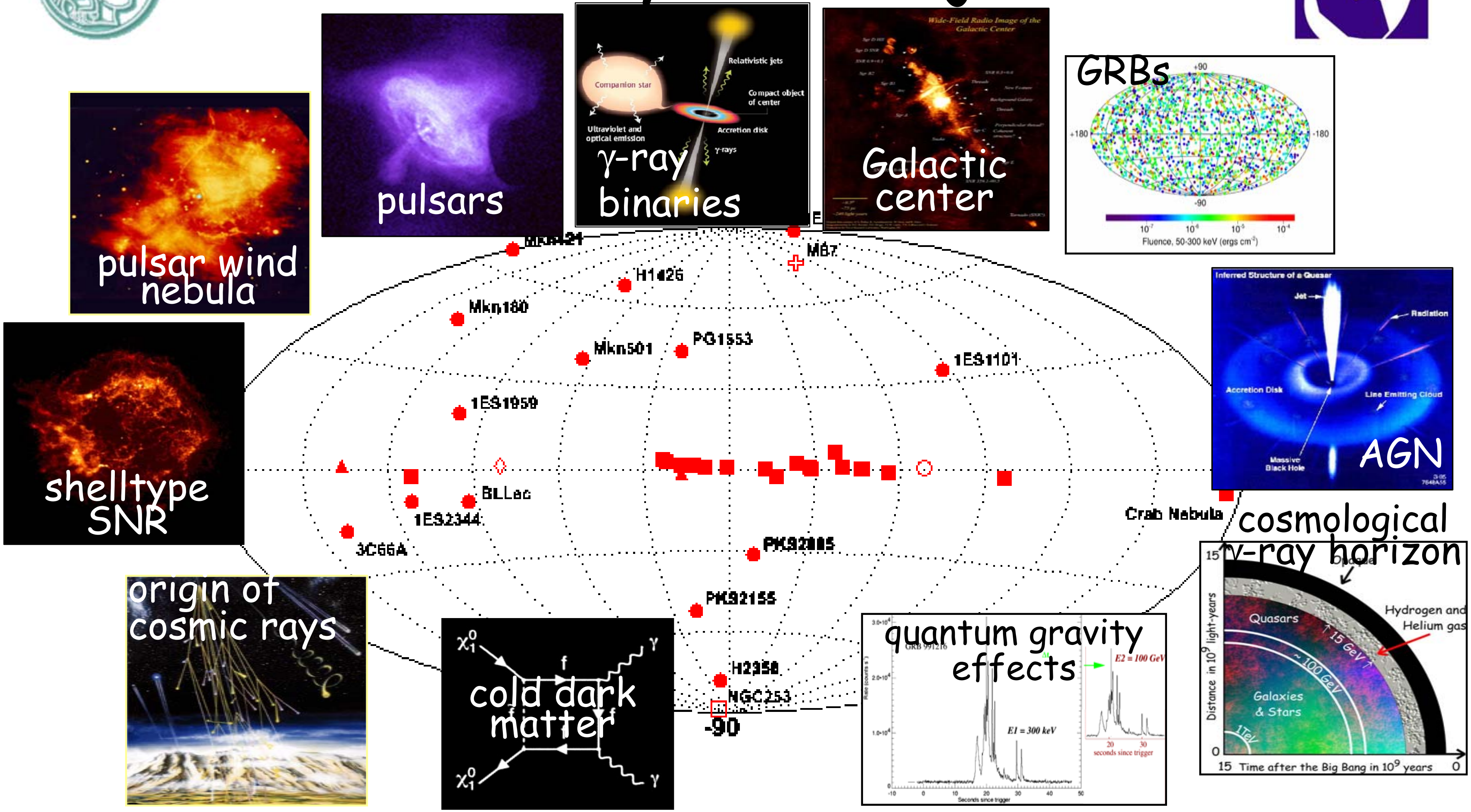
Engineers/Technicians

from electronics/mechanical departments

Subsystems of MAGIC



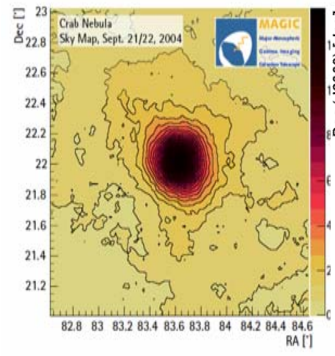
MAGIC Physics Objectives



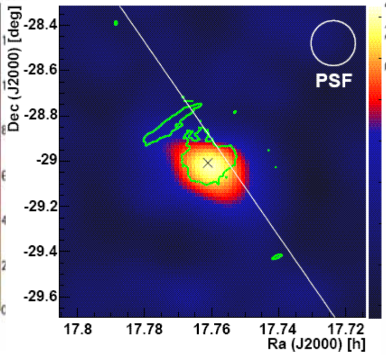
> 30 sources above 100 GeV, rapid growth in recent years

Published Sources of Cycle 1

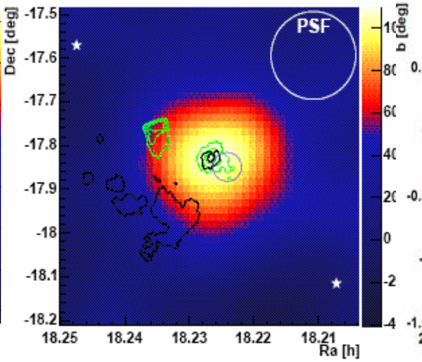
MAGIC catalog was authorized by IAU: "MAGIC JHHMM+DDMM"



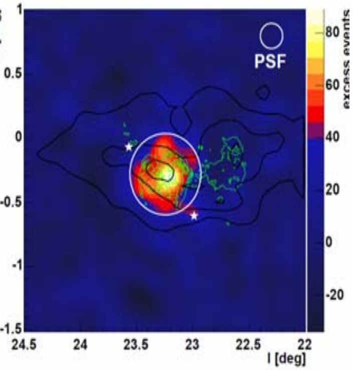
Crab Nebula



Galactic Center

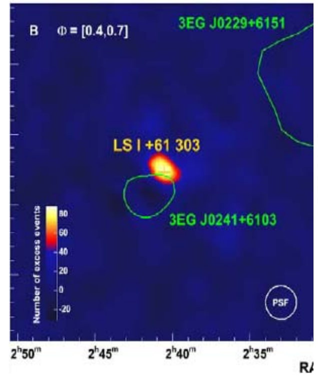


HESS J1813



HESS J1834

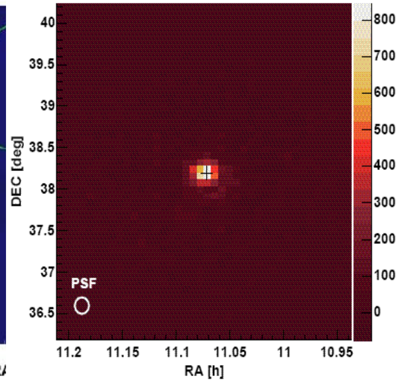
^{13}CO cloud



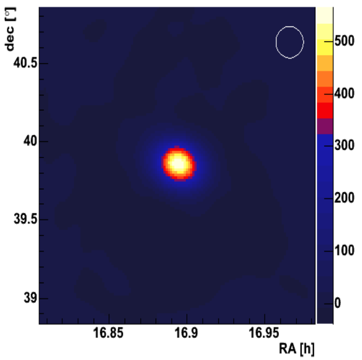
LSI+61 303

γ-ray binary

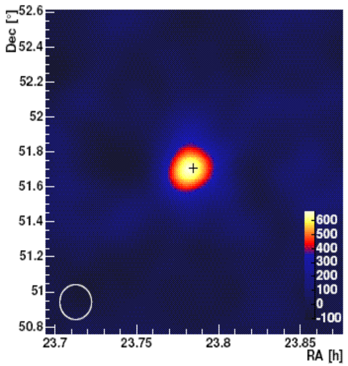
New source



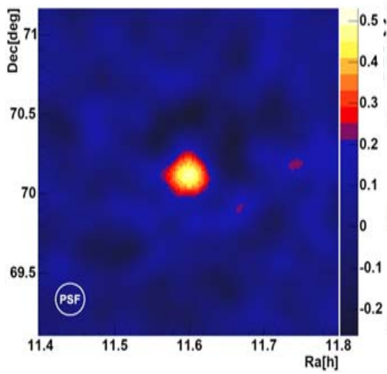
Mrk421 (0.030)



Mrk501 (0.034)

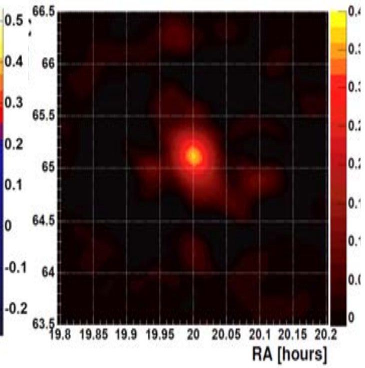


1ES2344 (0.044)

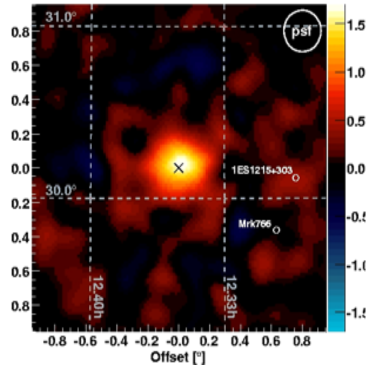


Mrk180 (0.045)

New source

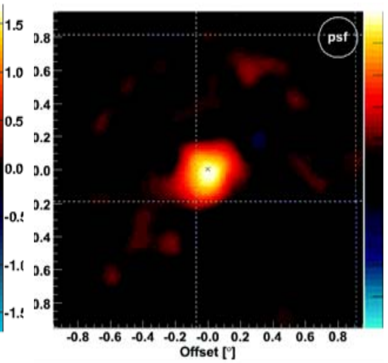


1ES1959 (0.047)



1ES1218 (0.182)

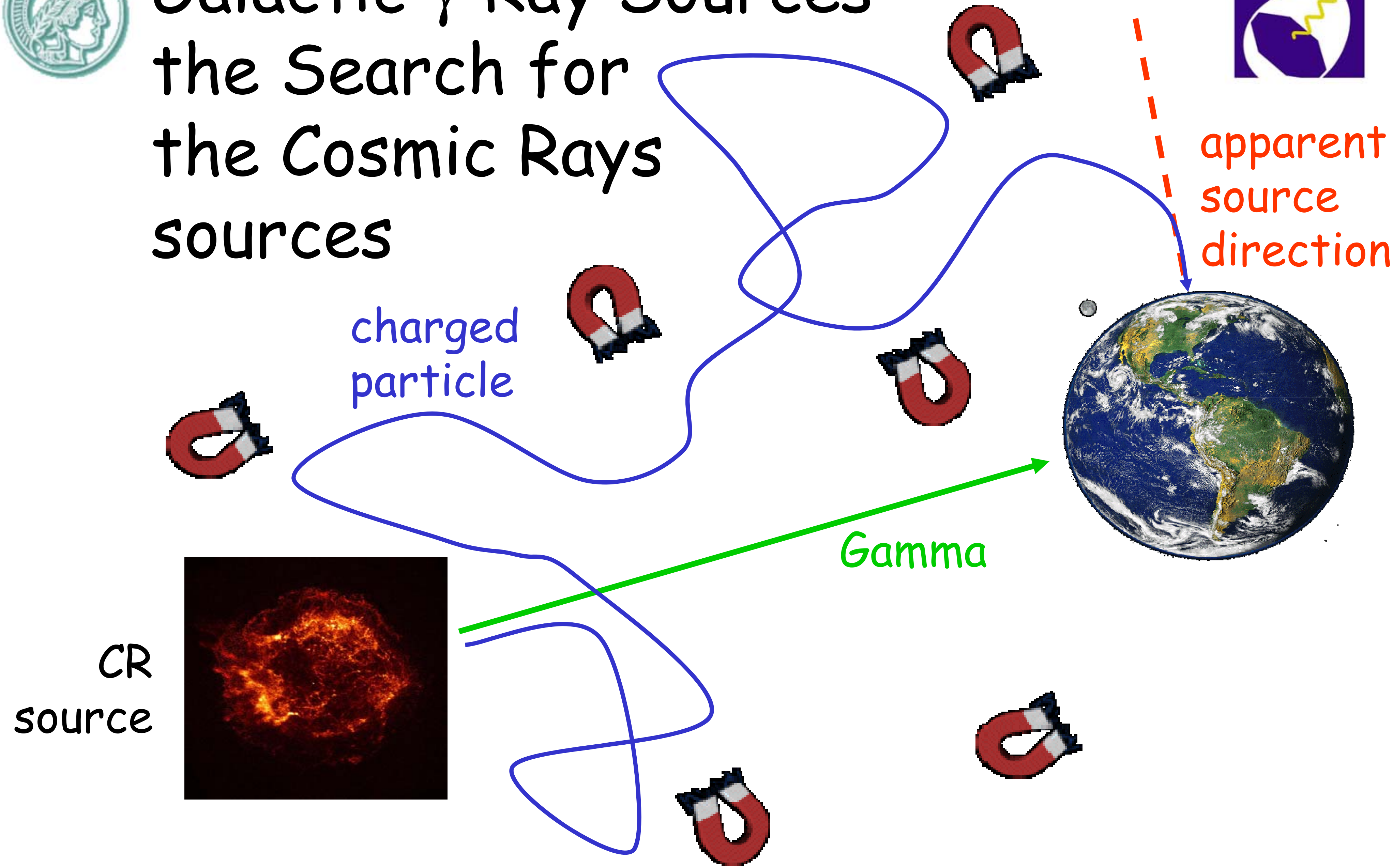
New Source



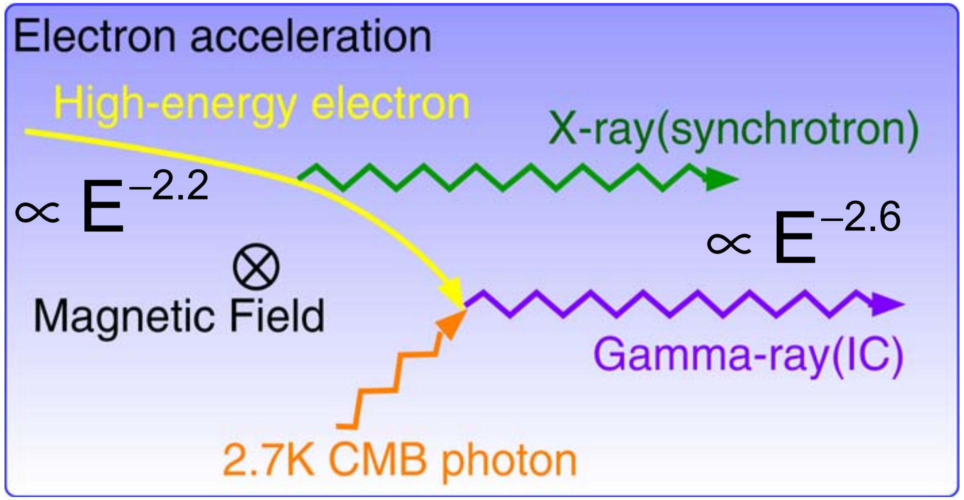
PG 1553 (>0.25)

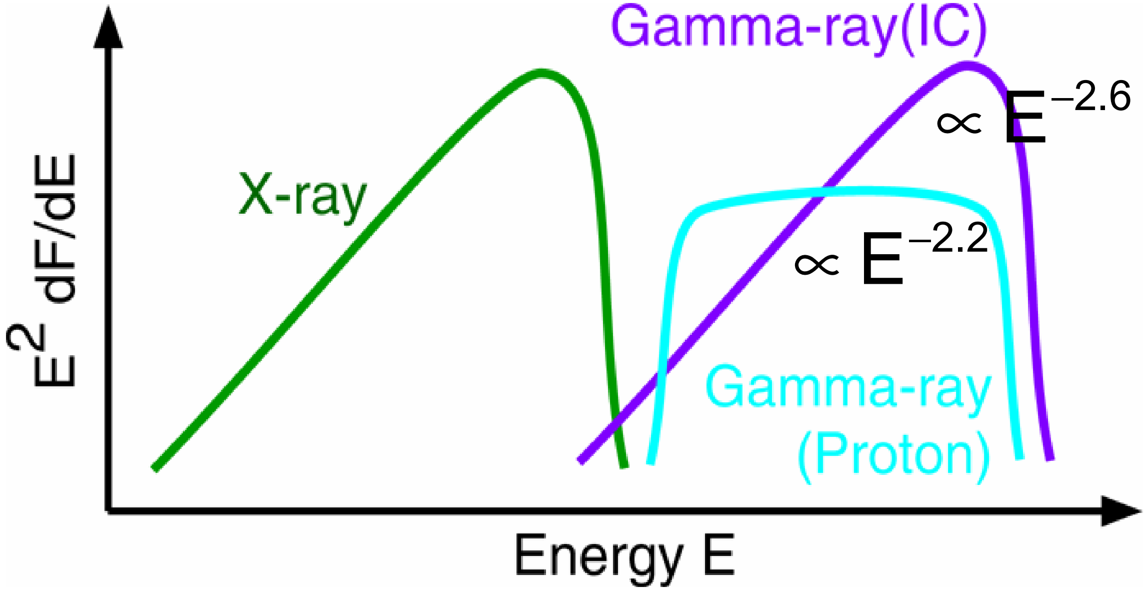
New source

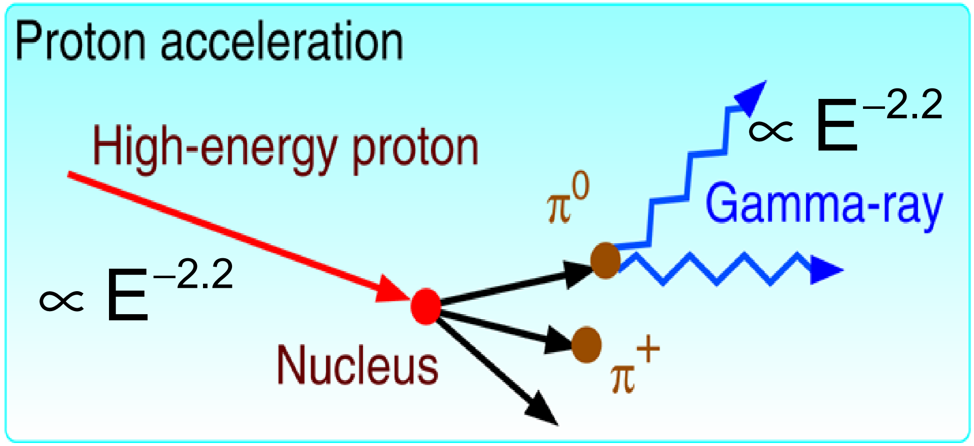
Galactic γ-Ray Sources - the Search for the Cosmic Rays sources



γ-Ray Emission Processes



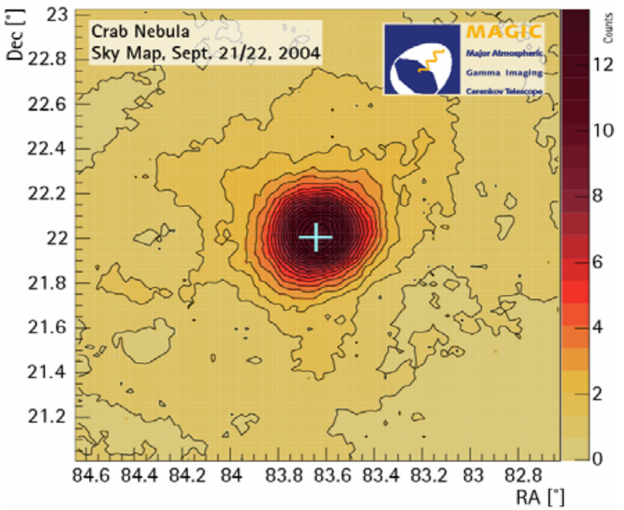


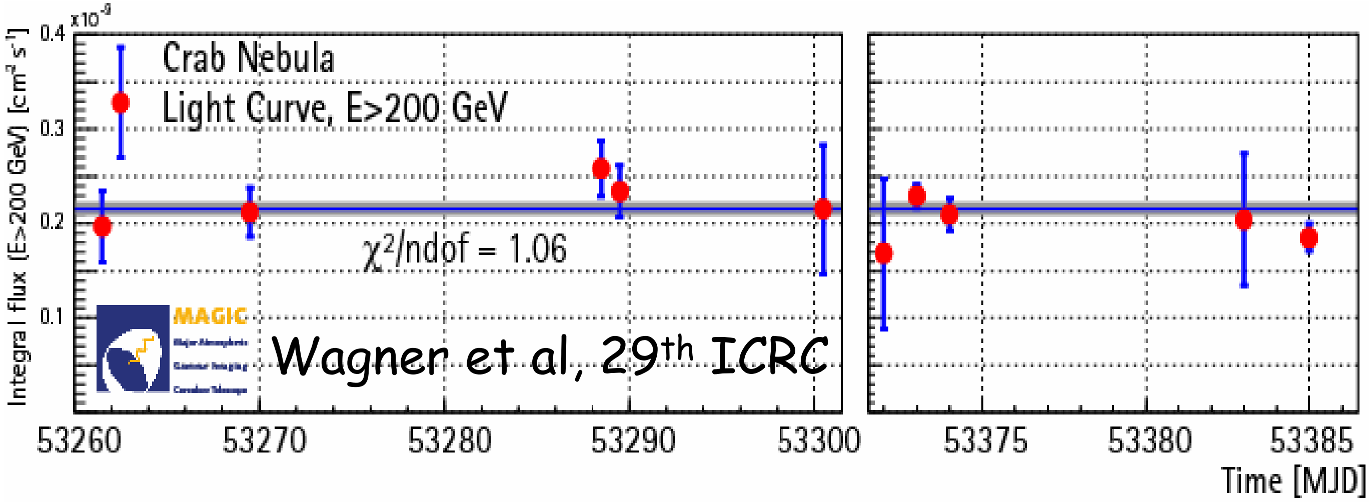


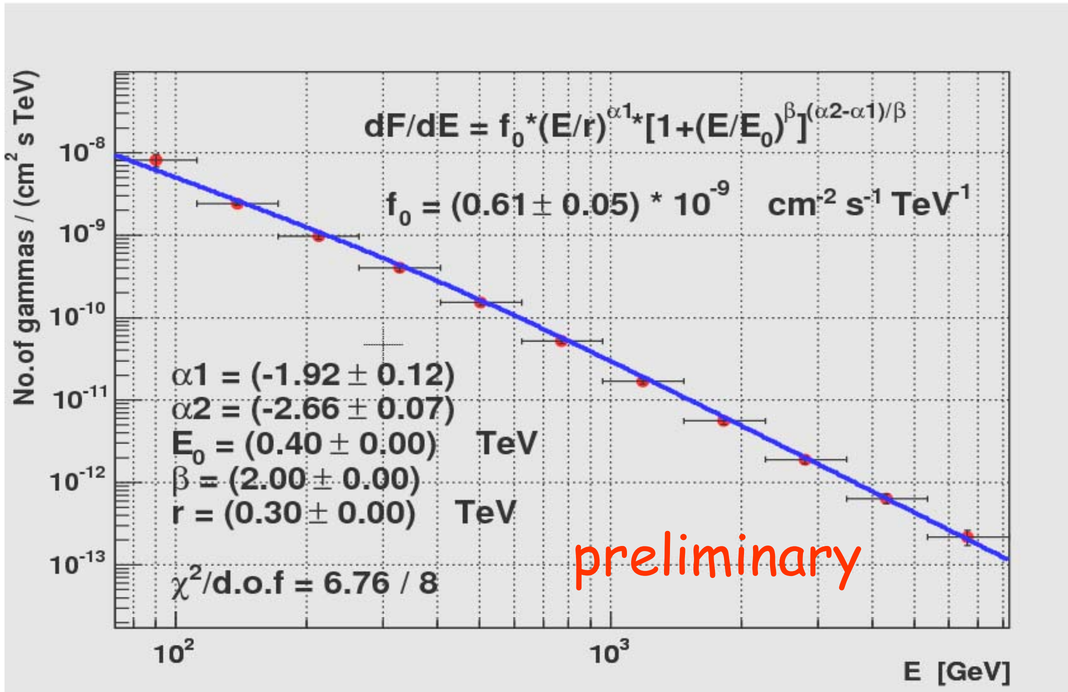
$$\left(\frac{dE}{dt}\right)_{\mathrm{I.C.}} = \frac{4}{3}\sigma_{\mathrm{T}}\, c\, \gamma_{\max}^{2}\, \mathrm{U}_{\mathrm{photon}}$$

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

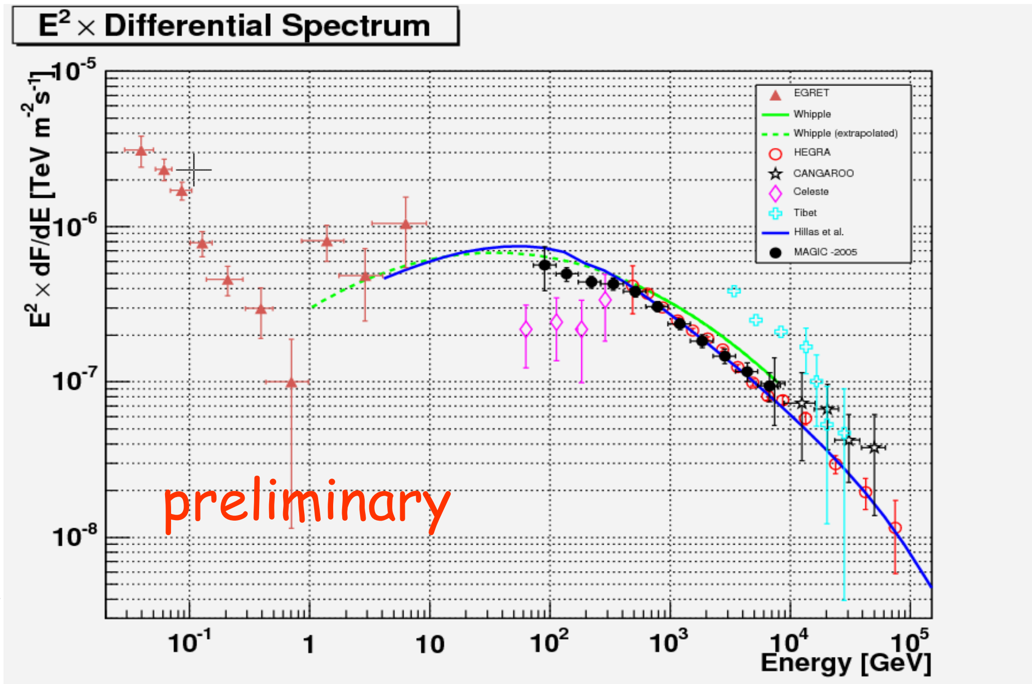
Crab - The Standard Candle



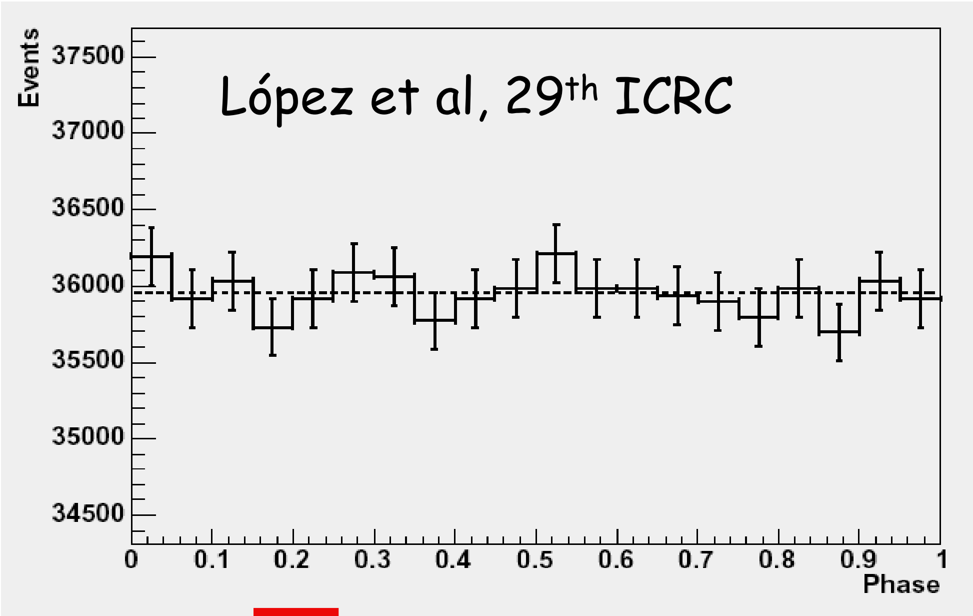




MPI

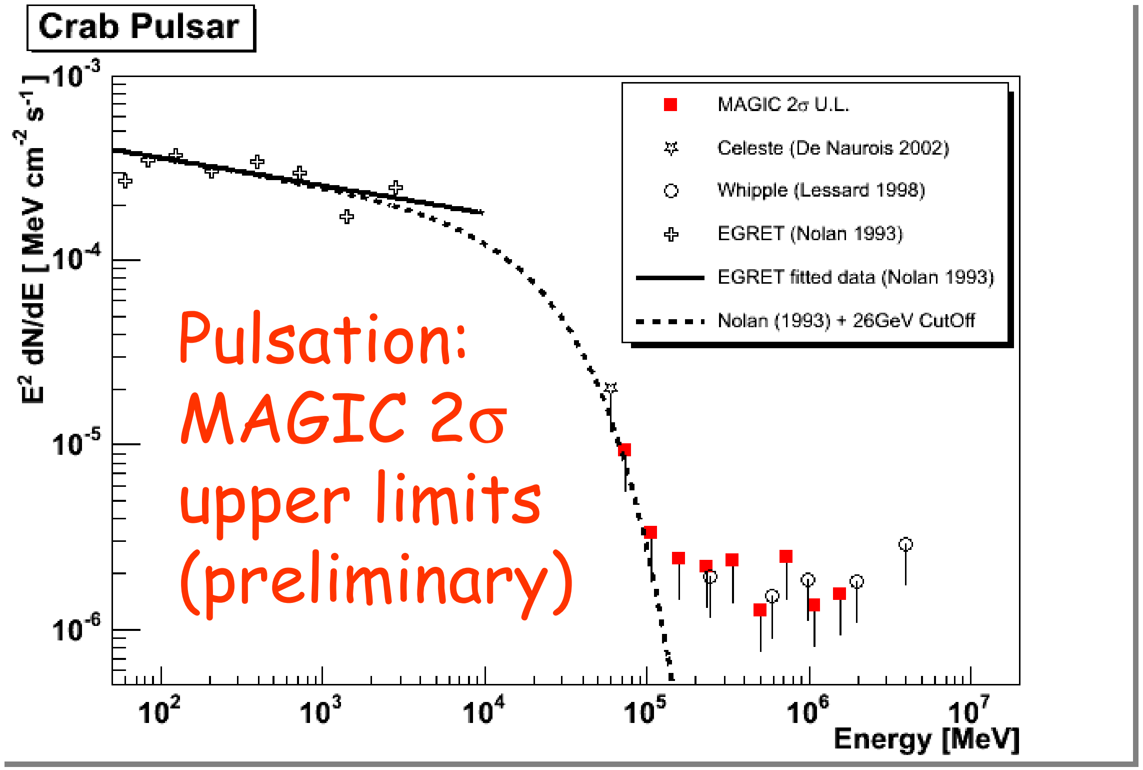


Crab Pulsar



No pulsation detected at energies > 60 GeV

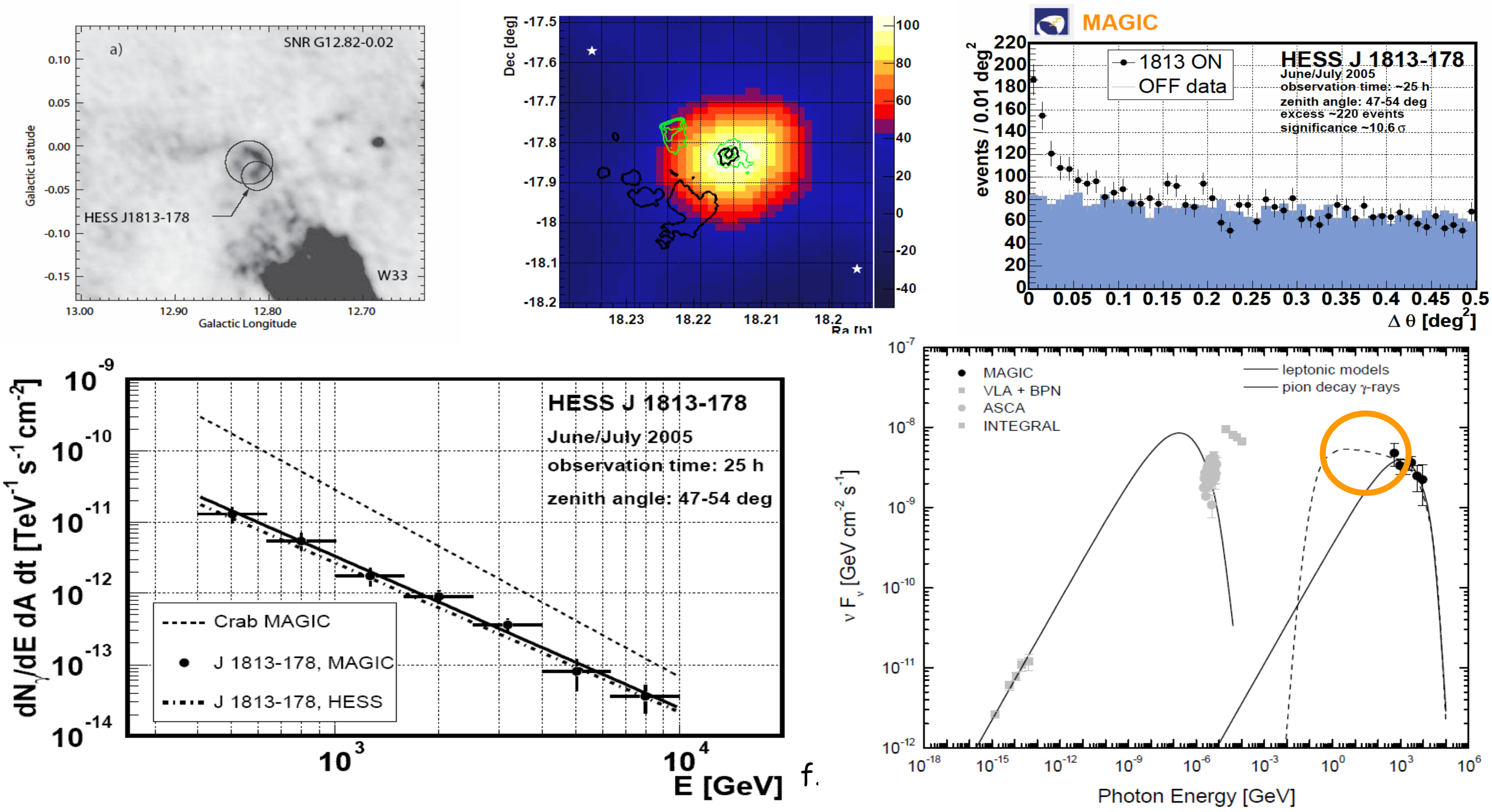
Limit to exponential cut-off: E_{cut} < 30 GeV



HESS J1813-178

Shell-type or Composite SNR?

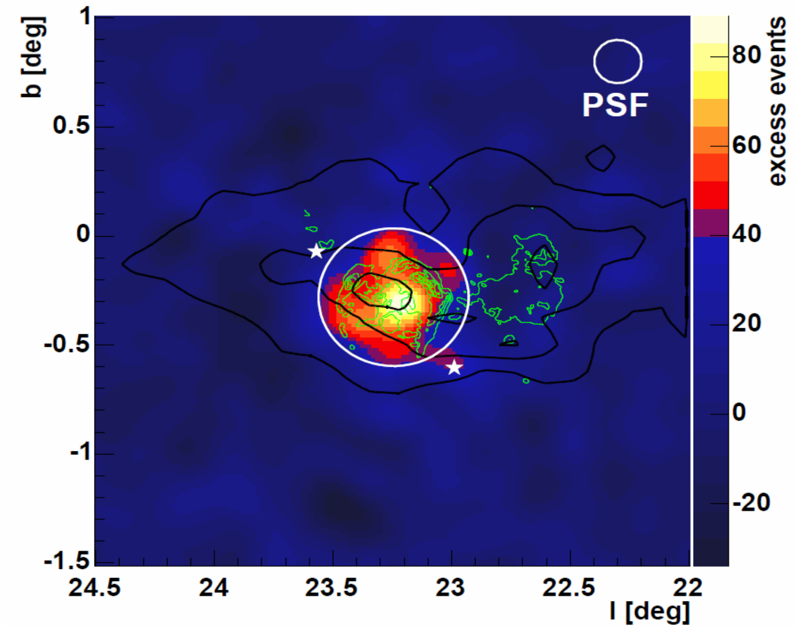
Published: ApJL 637 (2006) 41

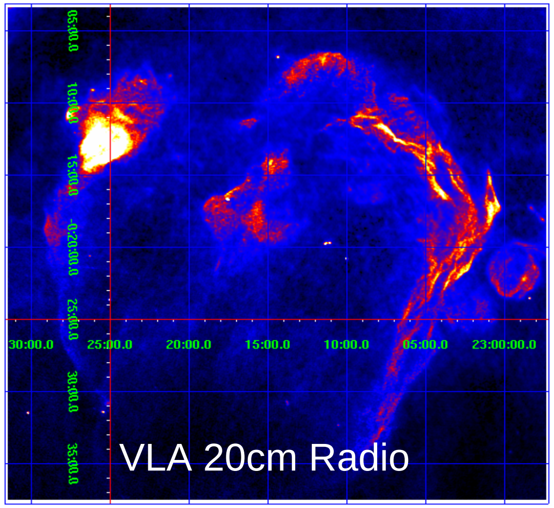


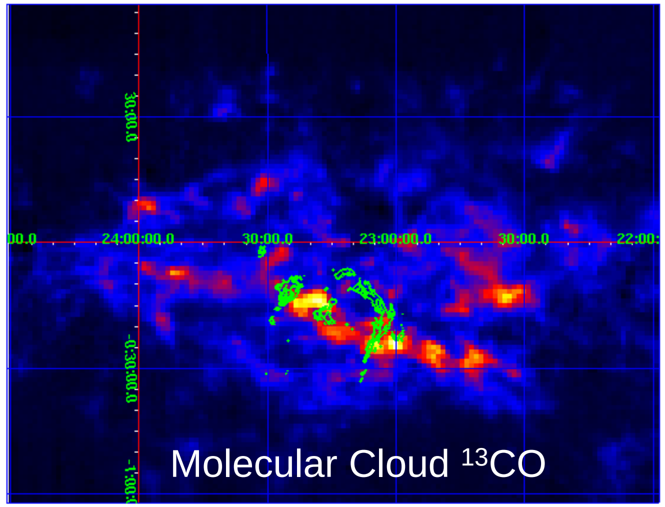
HESS J1834-087

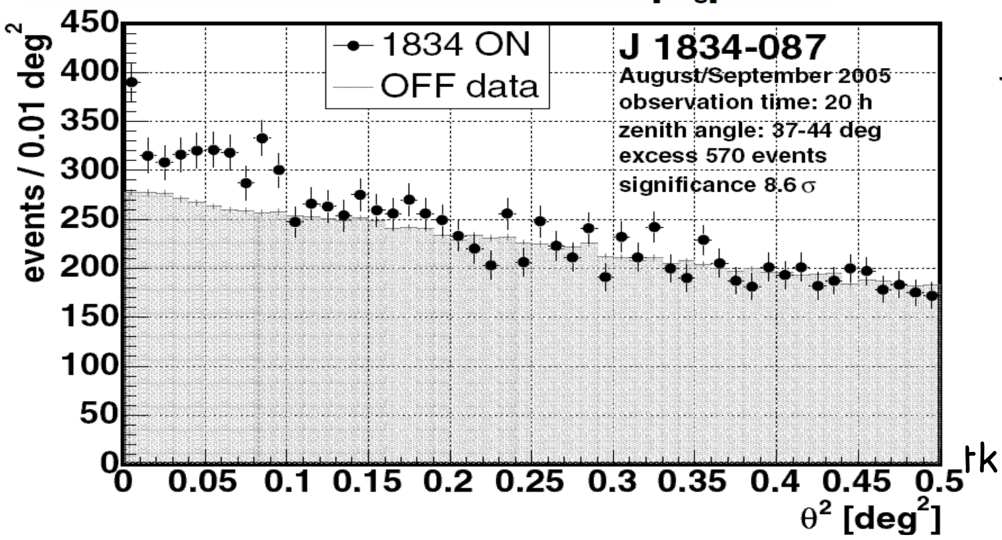
extended source -- SNR molecular cloud interaction

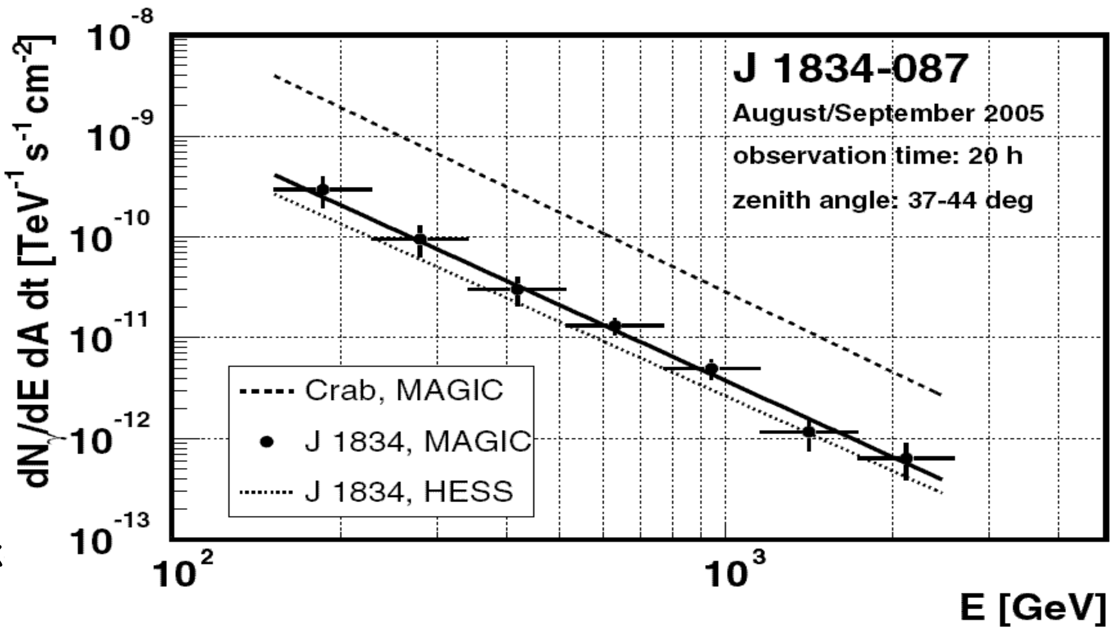
Published: ApJL 643 (2006) 53







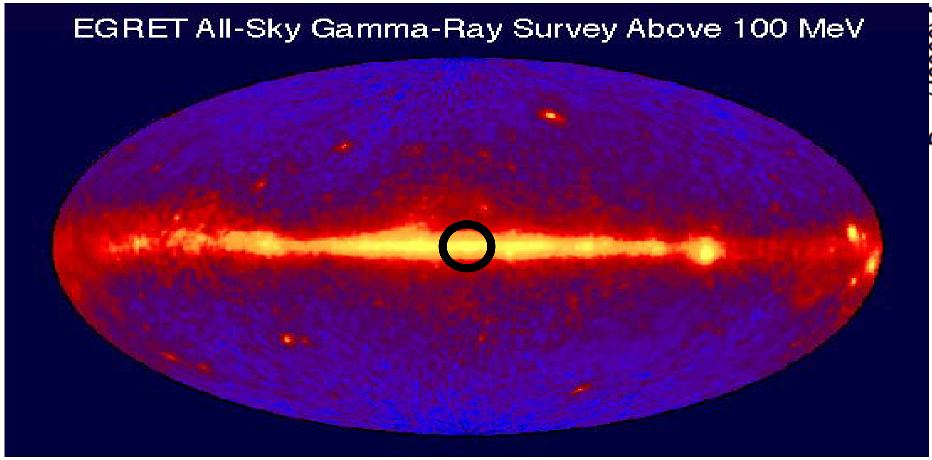


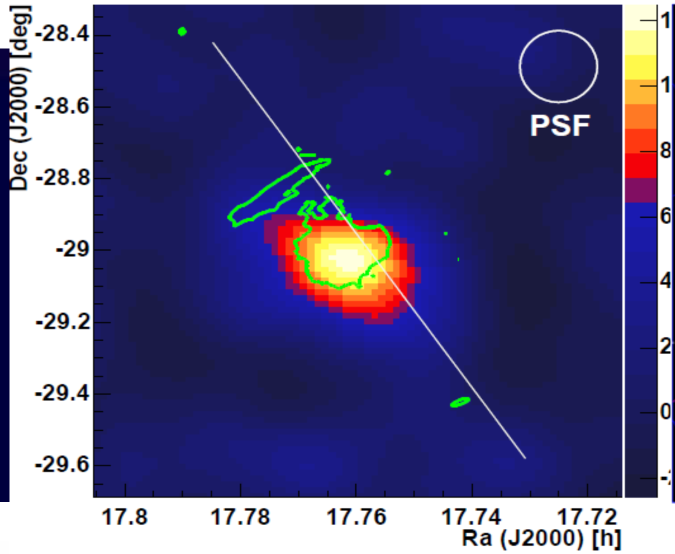


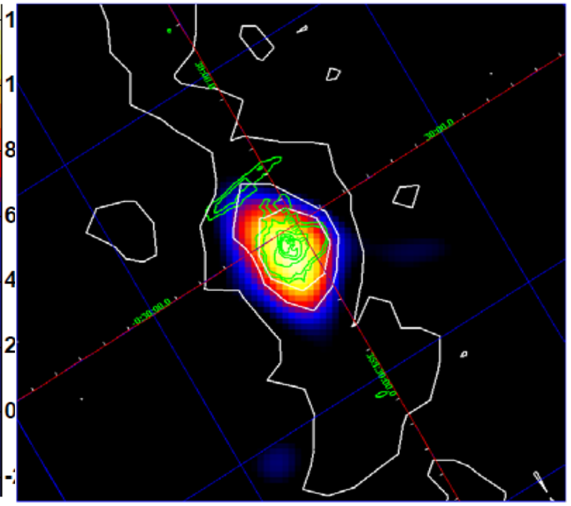
Galactic Center

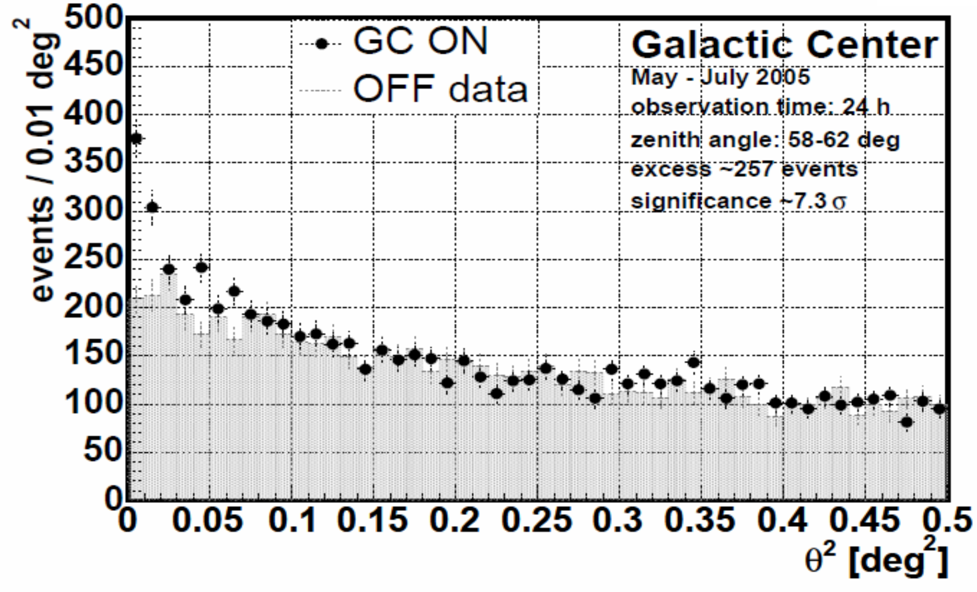
source unknown – black hole? SNR? PWN?

Published: ApJL 638 (2006) 101

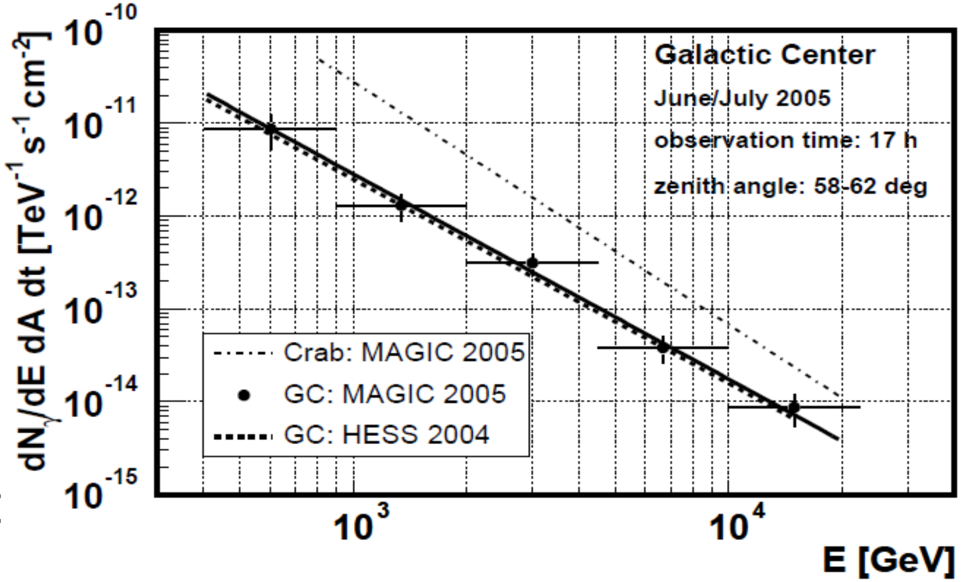








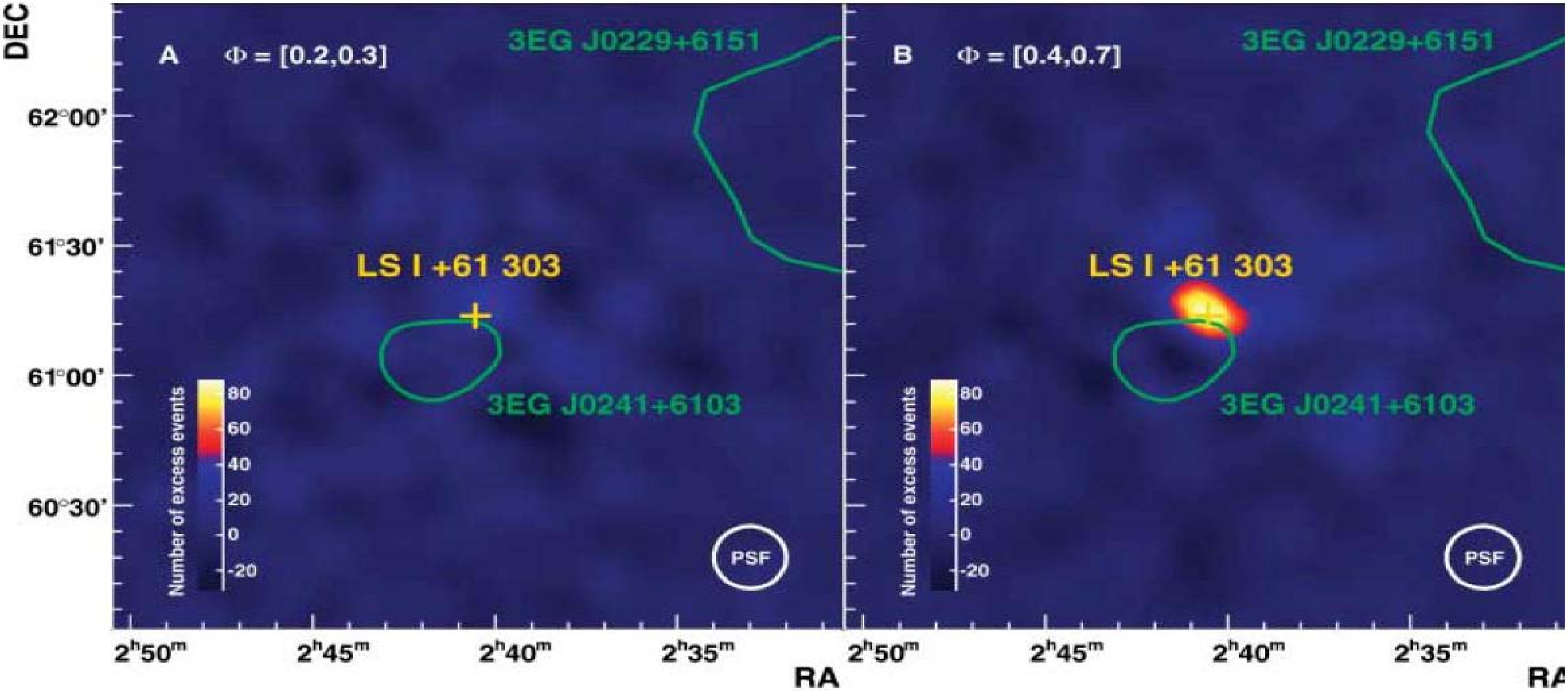
MP:



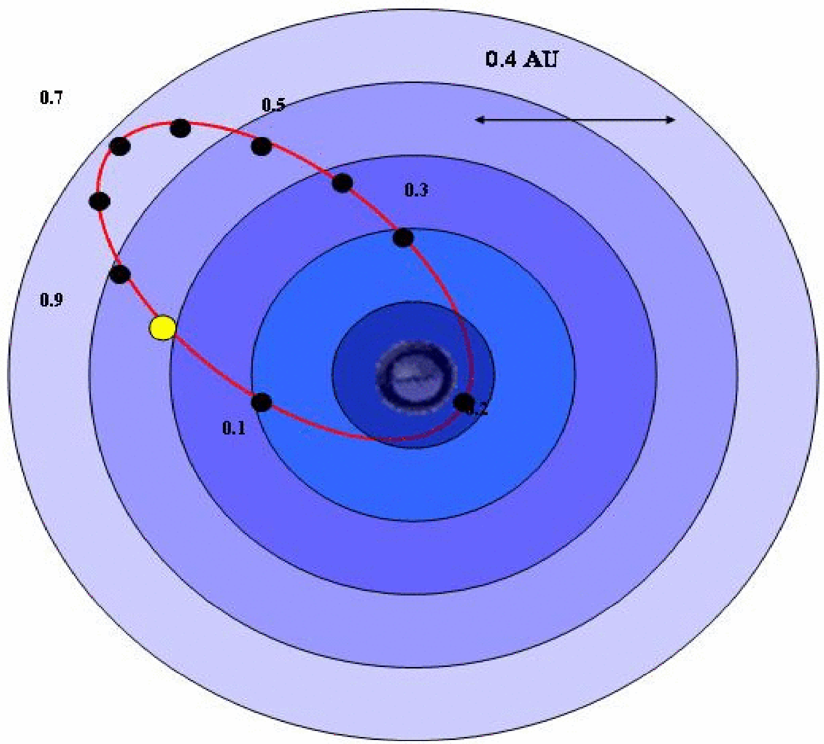
LS I +61 303

Discovery of variable γ-Ray Emission

Published: Science 312 (2006) 1771



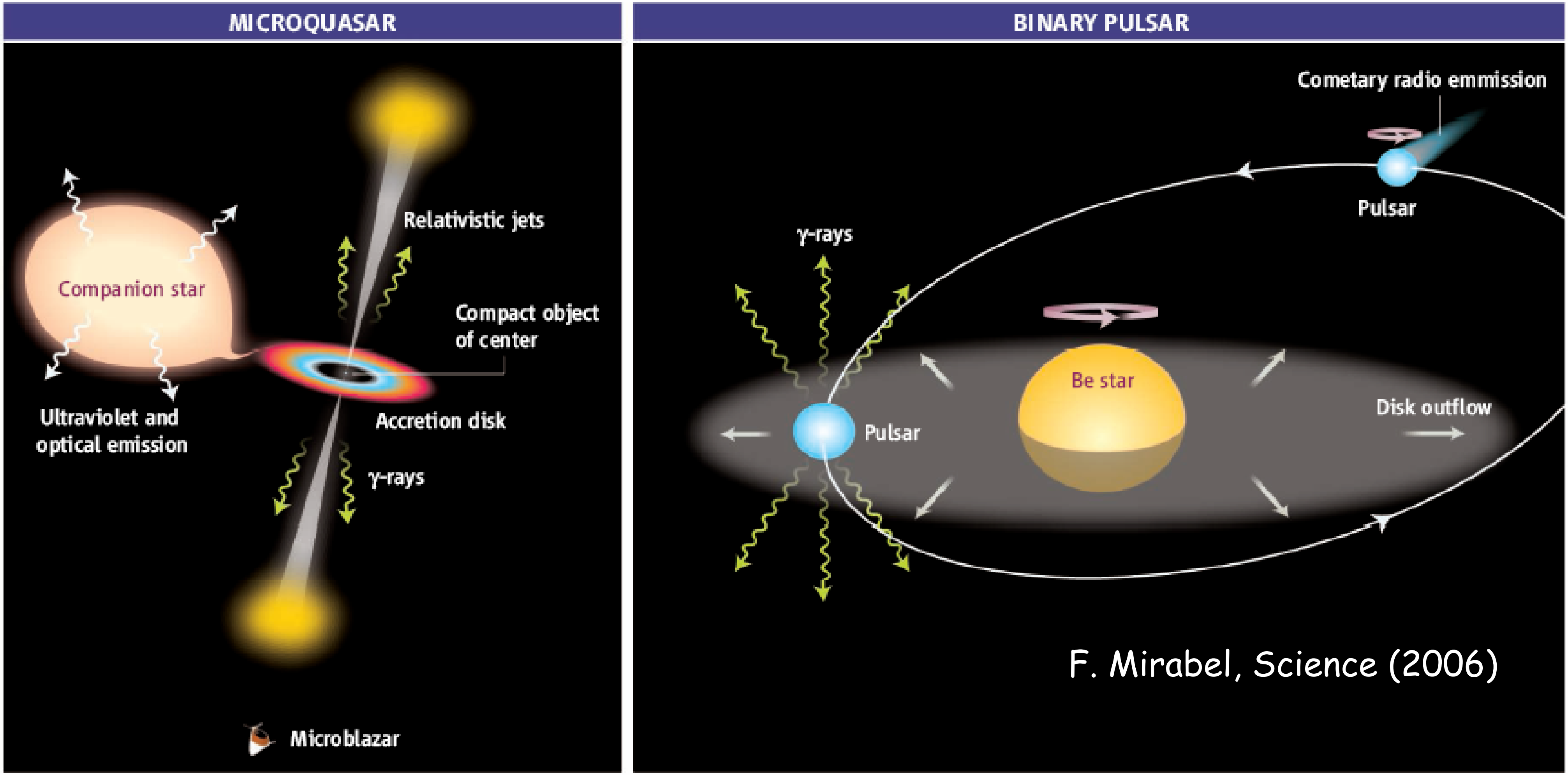
Variable γ-Ray Emission from LS I +61 303



X-Ray binary system of Be star and black hole/neutron star
26.5 days orbital period
distance ~2kpc

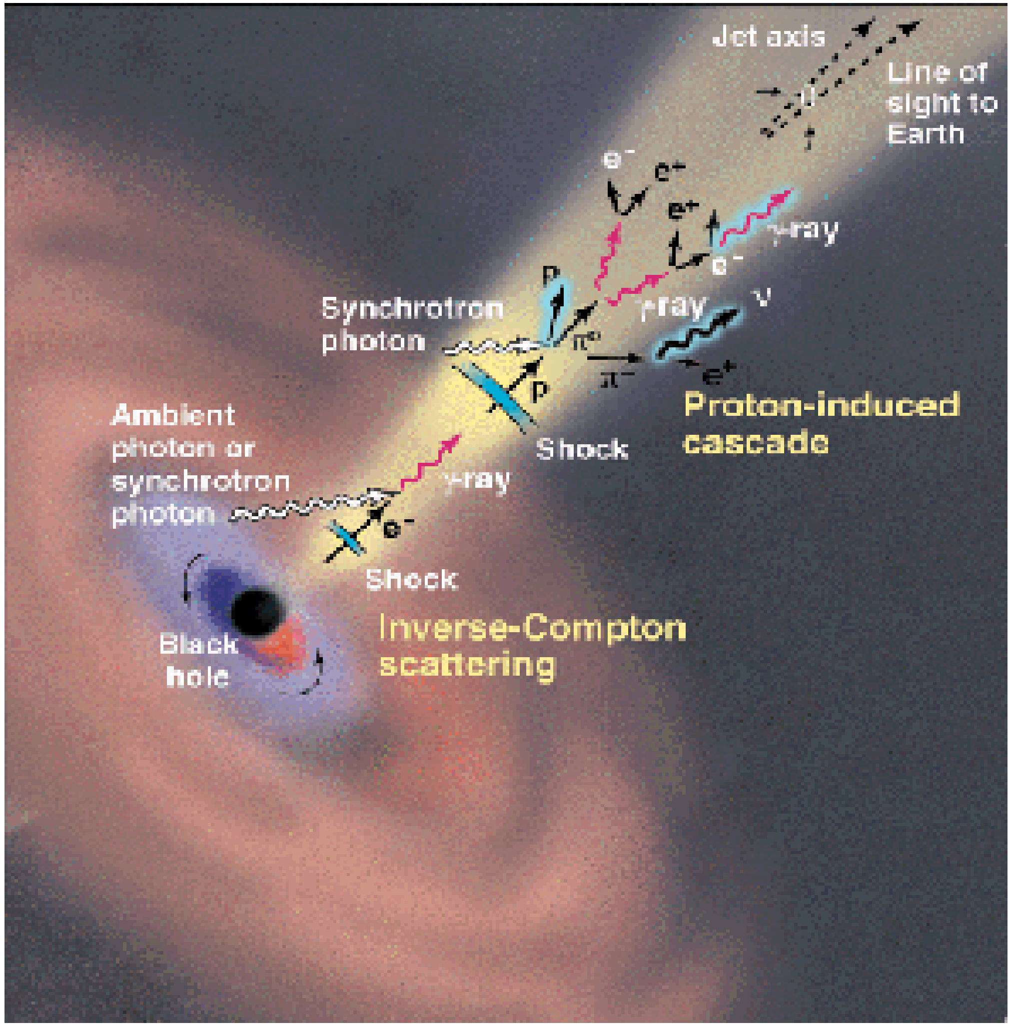
LSI+61 303: Models

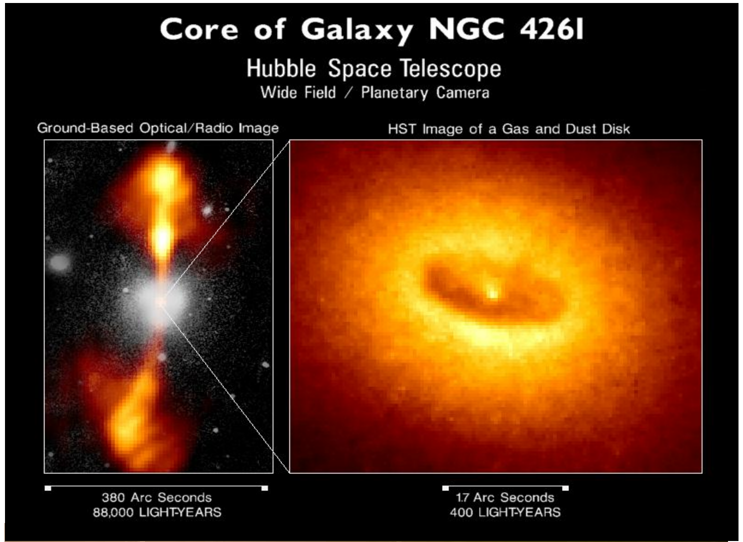
- Microquasar: rel. electrons (& hadrons) from accretion powered jets
- Binary Pulsar: Interaction between outflow disk and pulsar winds

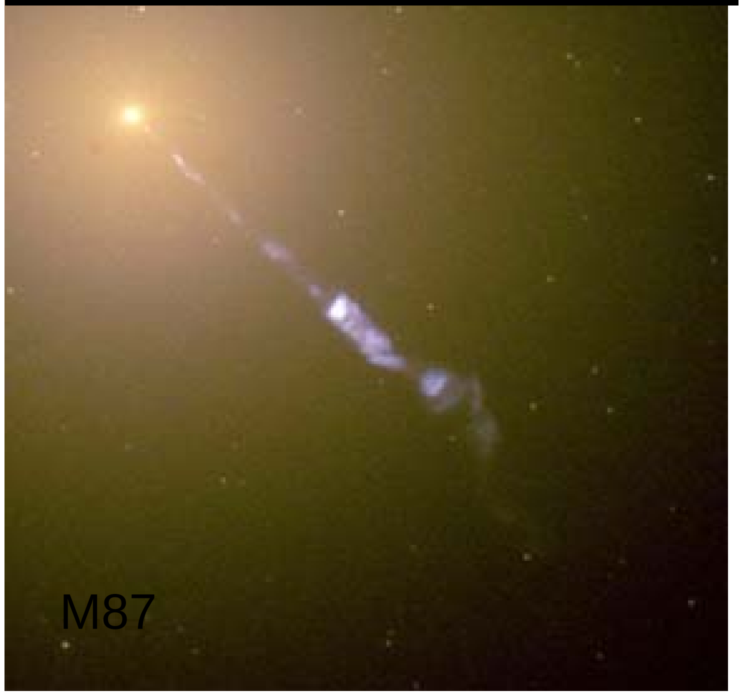


F. Mirabel, Science (2006)

Extra Galactic Sources: AGNs



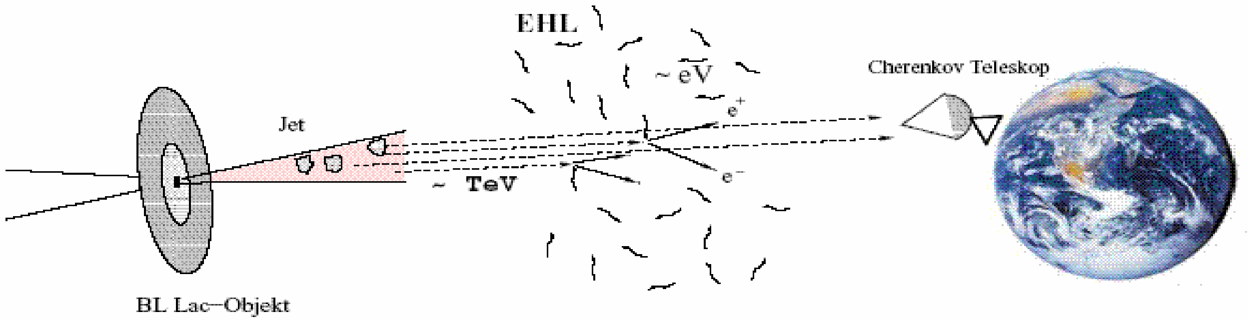


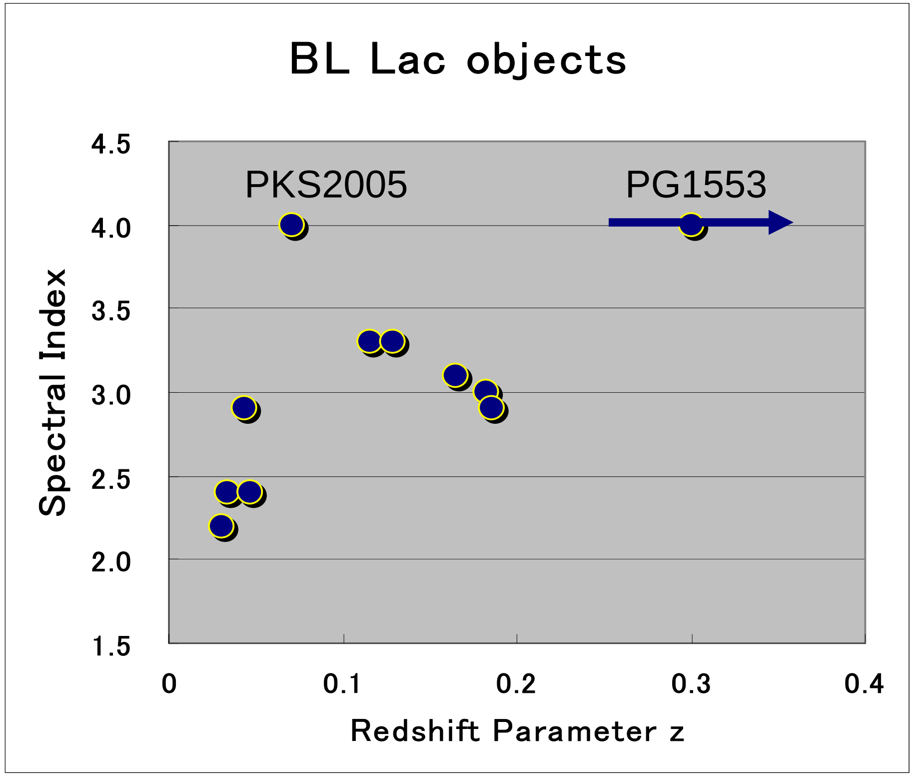


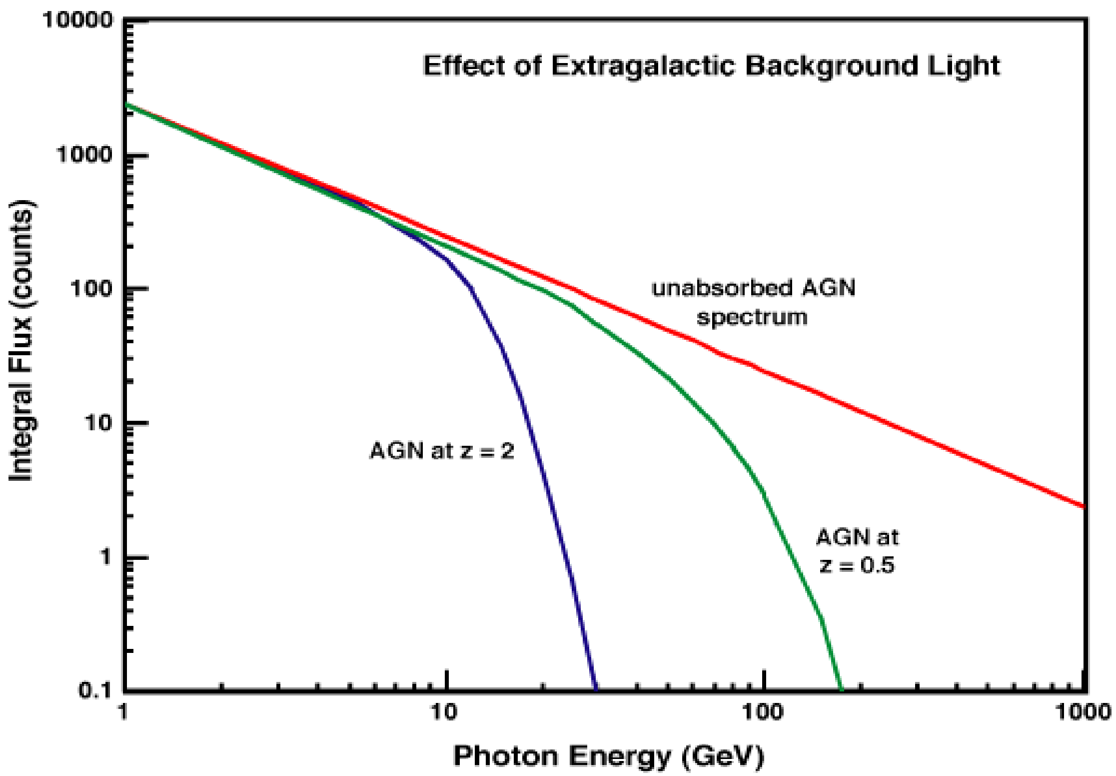
Absorption of γ-Rays in the Universe

Pair creation:

$\gamma + \gamma \rightarrow e^+ + e^-$

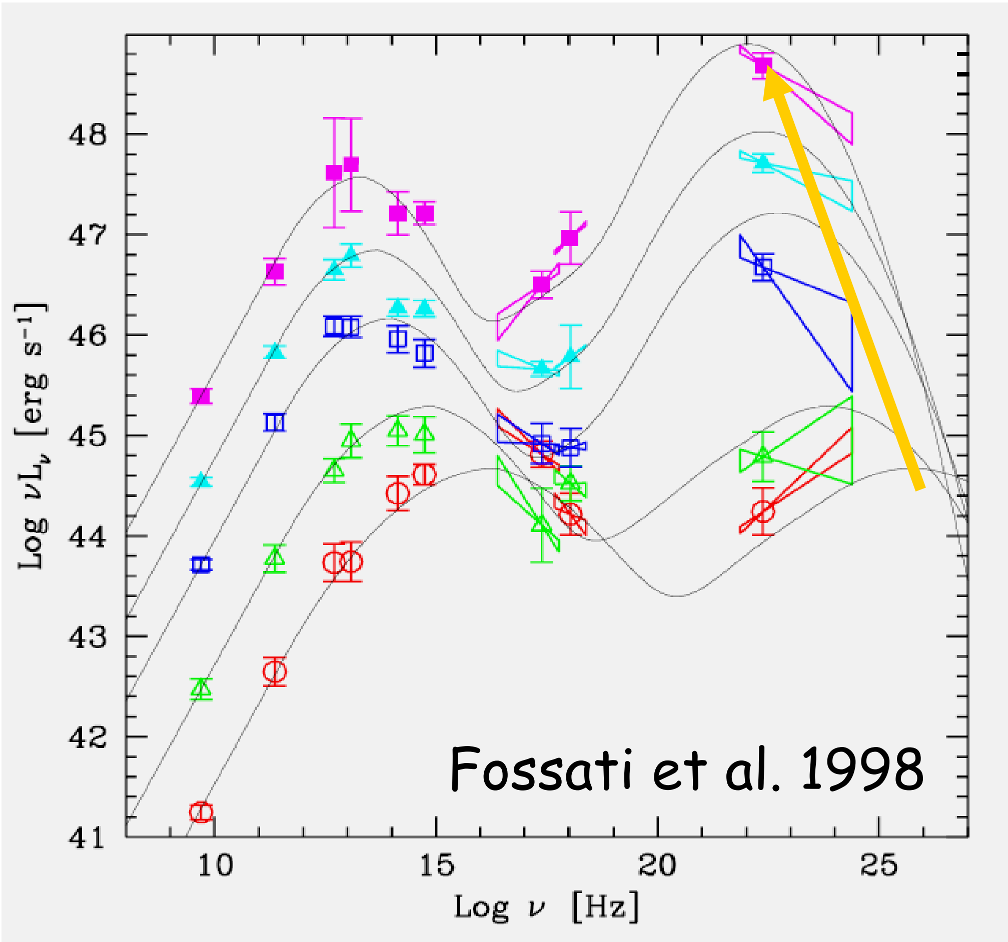






The SSC Framework

Higher z ➔ Higher source luminosity ➔ Lower IC peak ➔ softer spectrum



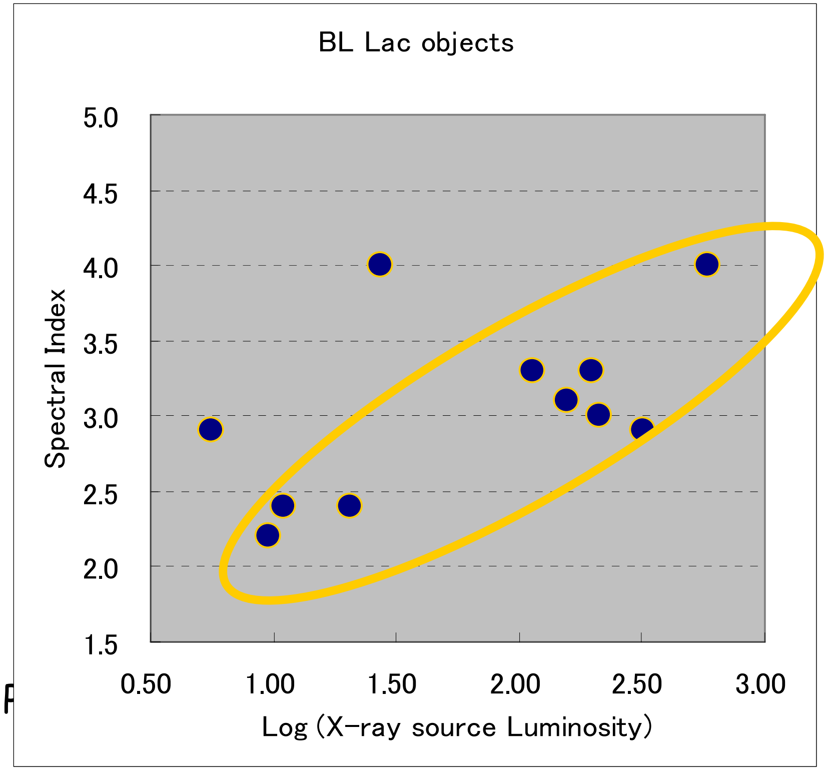
X-ray intensity at 1keV

PG 1553 6.5 μ Jy z~0.3

Mrk421 9.9 μ Jy z=0.03

Mrk501 9.4 μ Jy z=0.03

PG1553's source luminosity ~100 x Mrk



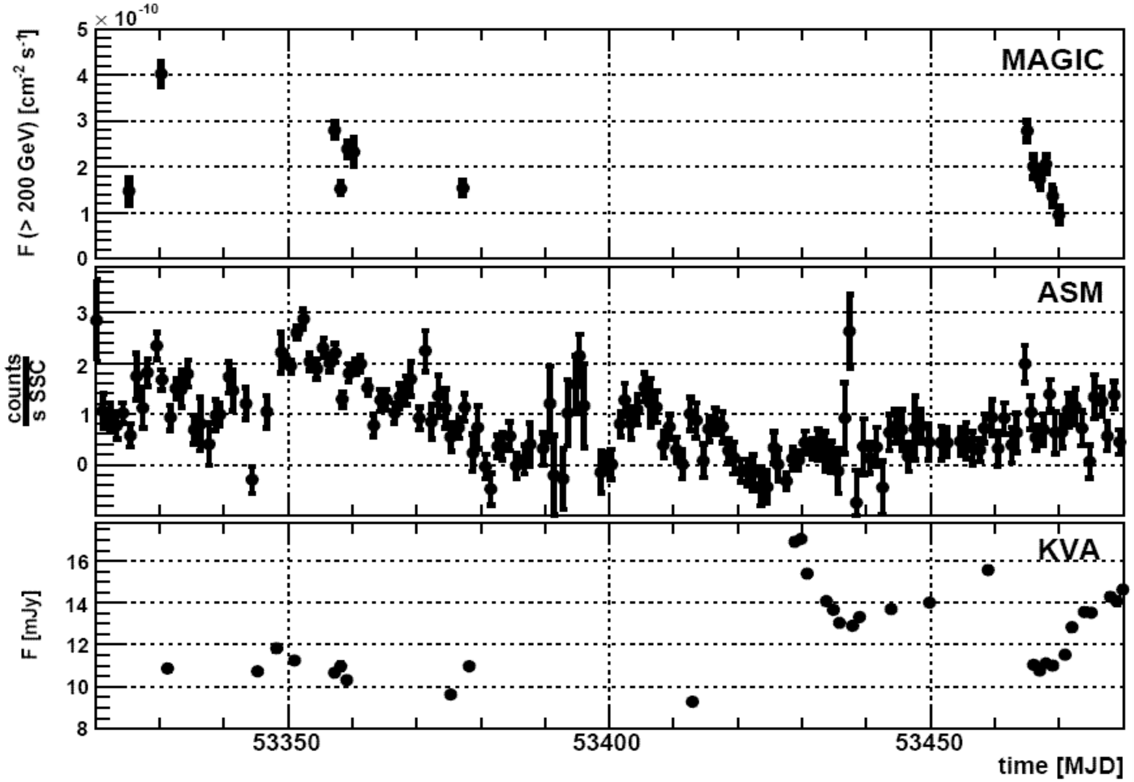
AGN Mrk421 (z=0.031)

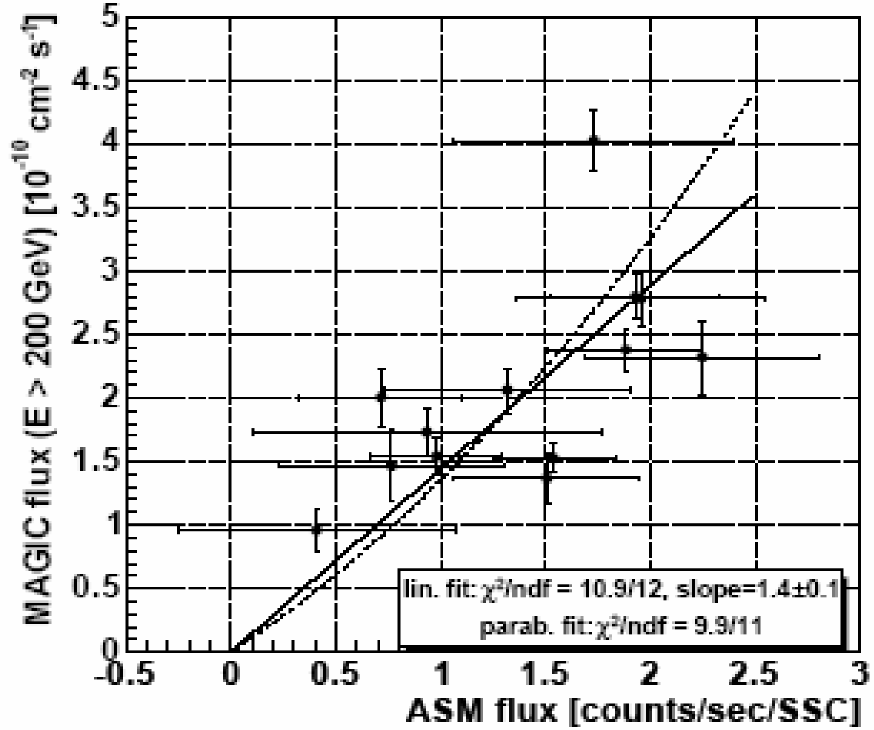
ApJ submitted, astro-ph/0603478

Long exposure: Dec 2004 – Apr 2005

- 25.6 h, over 7000 excess events
- medium flux state (0.5-2 Crab)

good VHE / X-ray (RXTE) correlation





AGN Mrk421 (z=0.031)

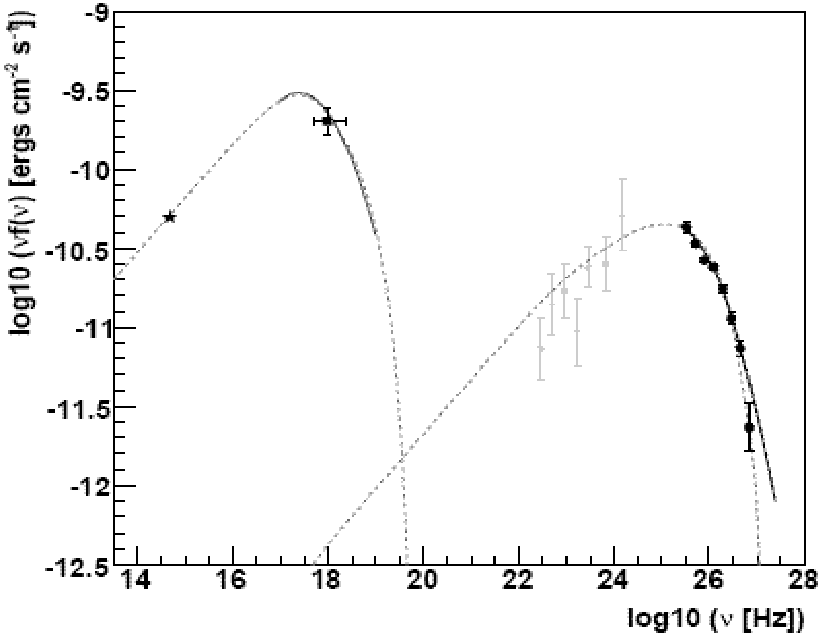
Self Synchrotron Compton Model

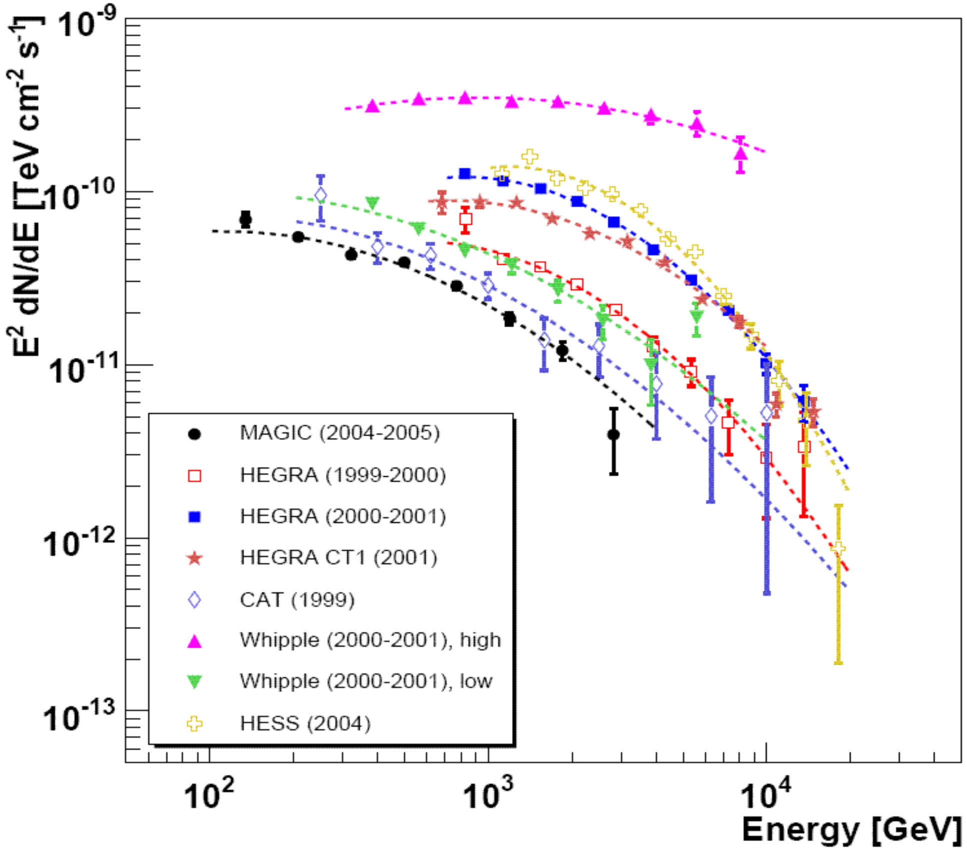
high energy electrons & magn. fields

- X-rays: synchrotron radiation
- VHE γ-rays: inverse Compton scattering off synchrotron photons

➔ X-ray / VHE correlation

flares ➔ varying electron spectrum



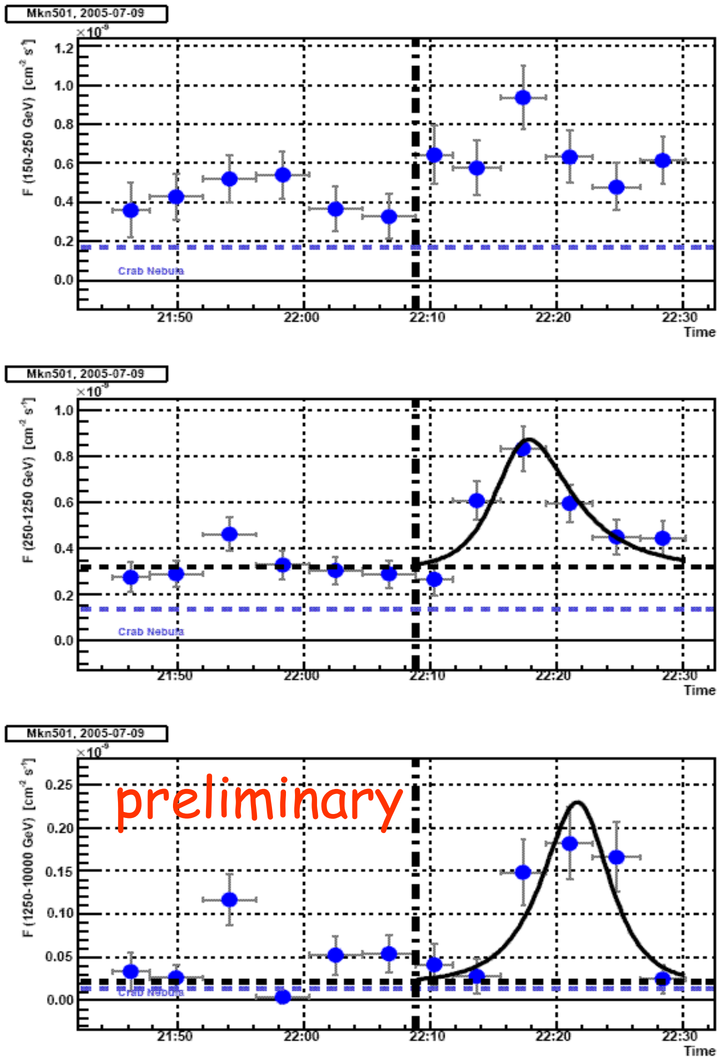


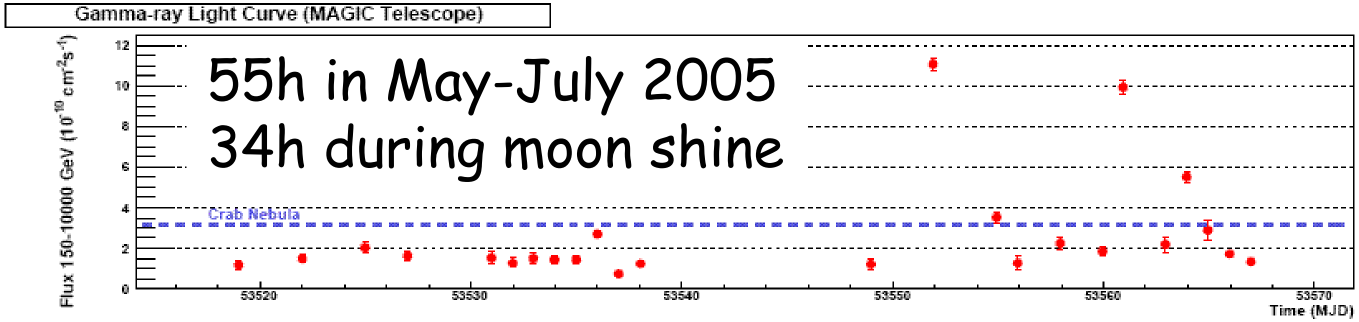
AGN Mrk501 (z=0.034)

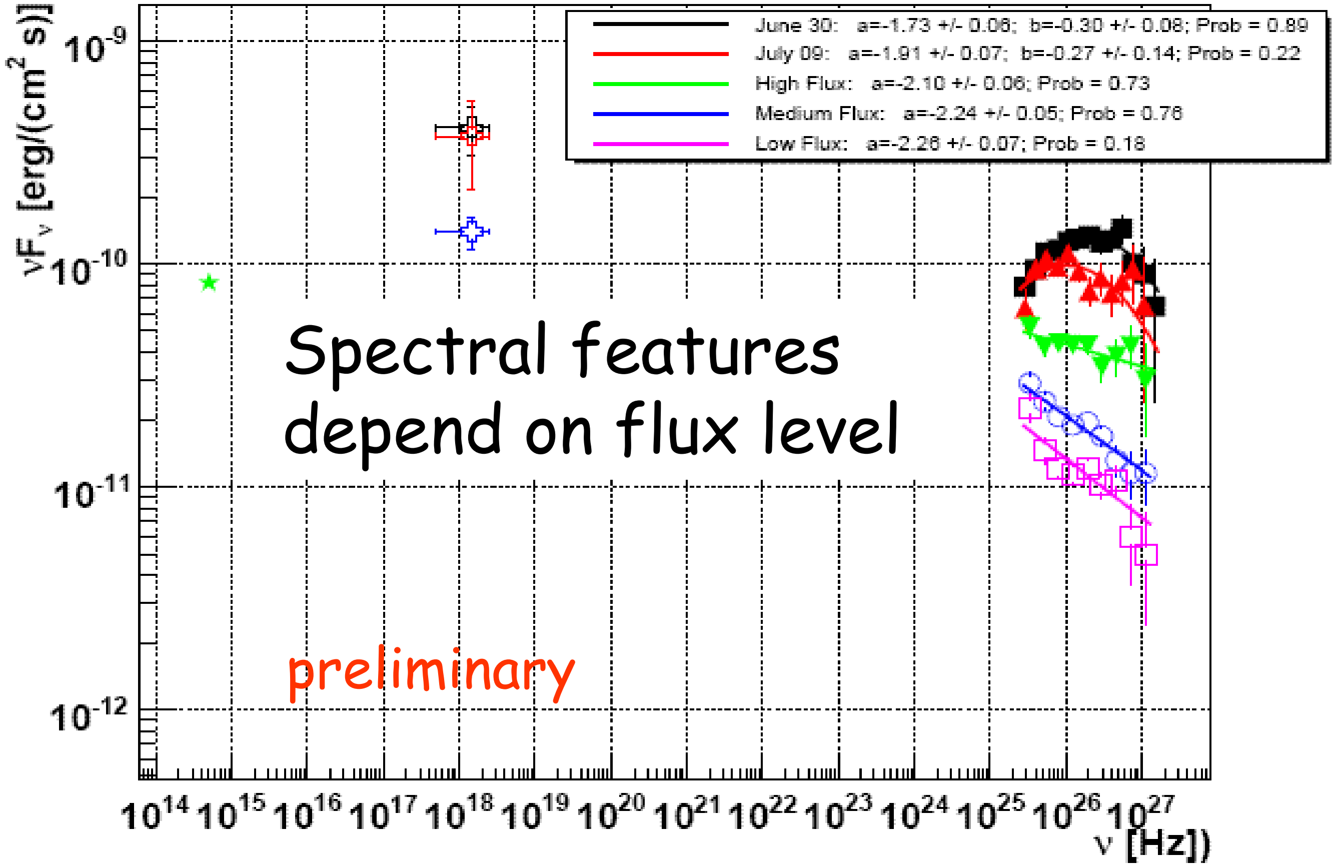
Giant Flares in July 2005

Immediate IAU Circular

Flux doubling time <3 min





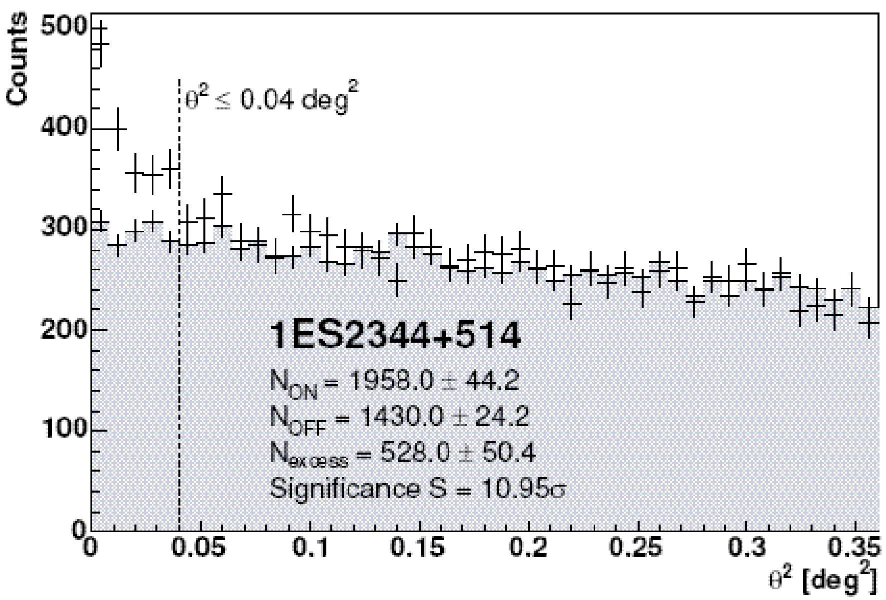


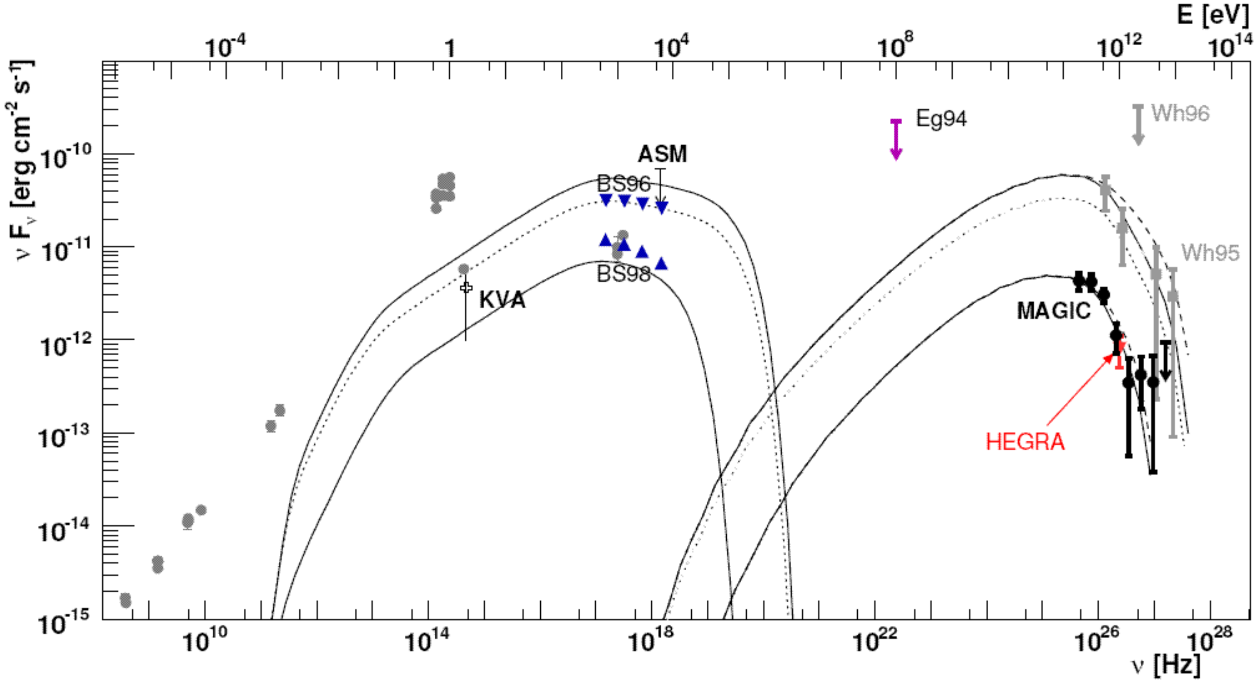
AGN 1ES 2344+514 (z=0.044)

high significance observation in non-flaring state

Submitted: ApJ (2006)

AGN marginally detected by previous IACTs
either in short flaring episode (Whipple)
or in long exposure observation (HEGRA)
MAGIC: steady state emission with high significance observed





AGN Mrk180 (z=0.046)

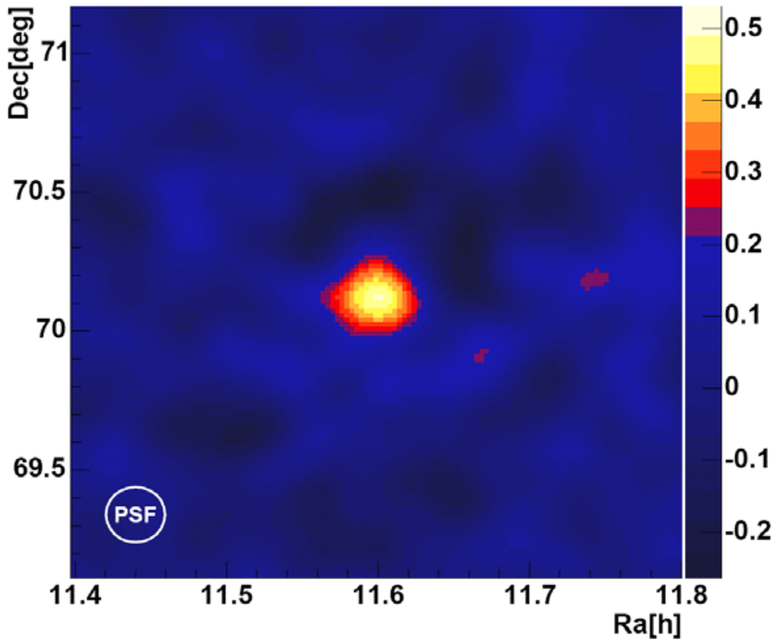
discovered during optical flare

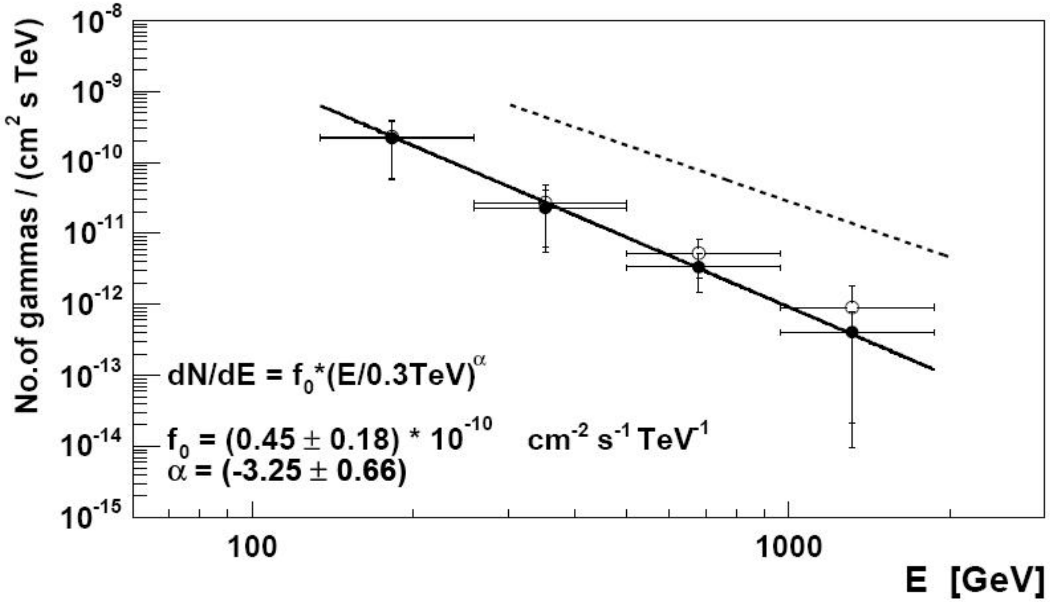
Published: ApJL 648 (2006) 105

Nearby AGN at z = 0.045

MAGIC: DISCOVERY

- April 2006, ~11 h
- triggered by optical & X-ray flare
- important: KVA telescope
- 5.5 σ detection
- $F_{(E>200GeV)}$ = 11% Crab
- spectral index: -3.3 ± 0.7

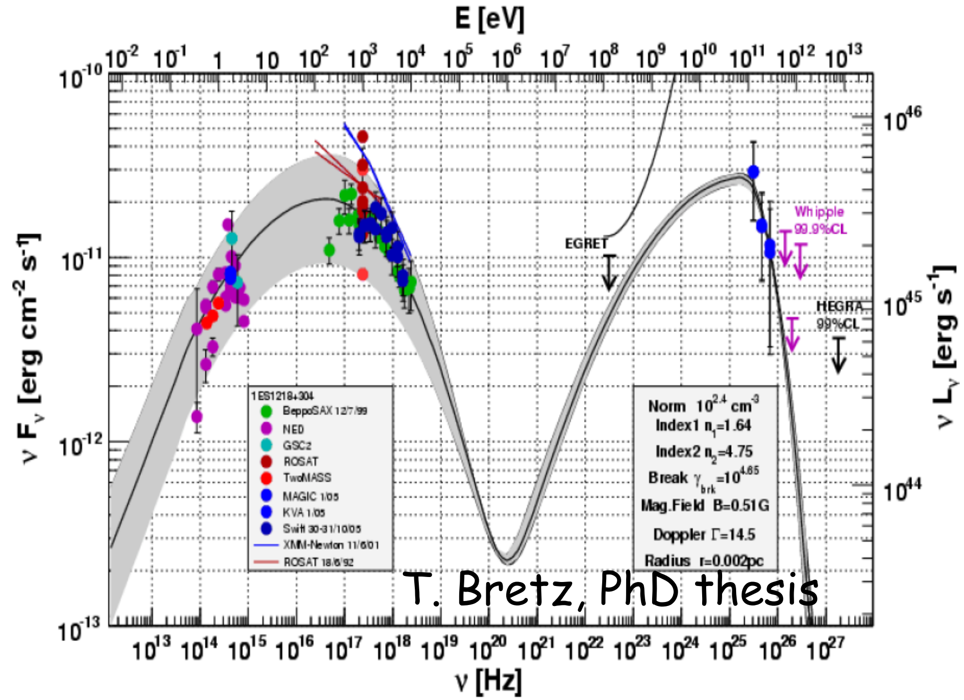




AGN 1ES1218+304 (z=0.182)

First new source discovered with MAGIC

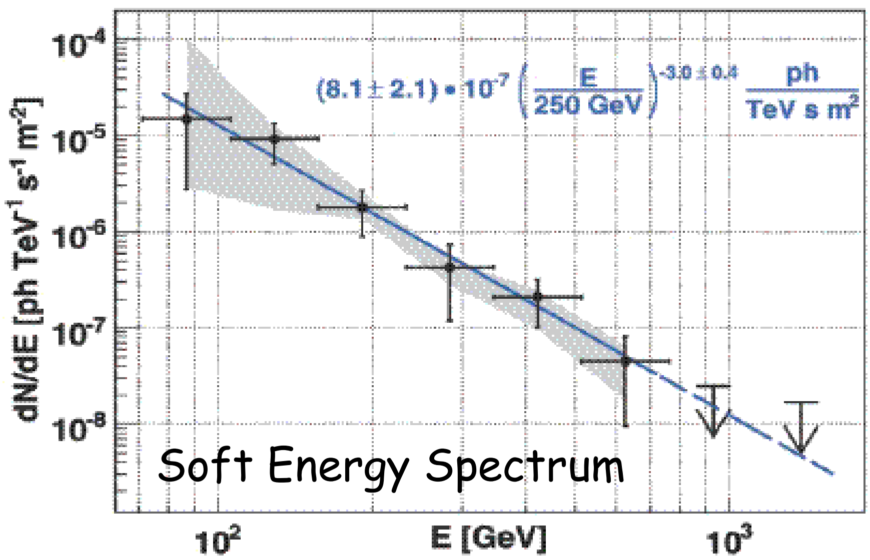
Published: ApJL 642 (2006) 119



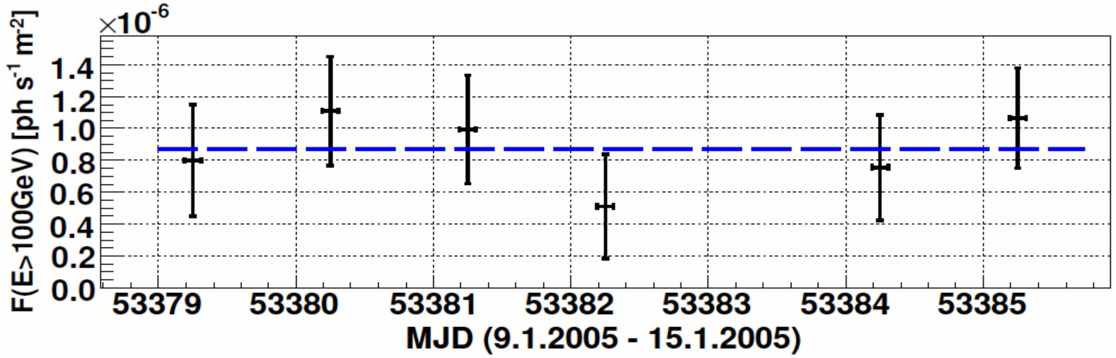
T. Bretz, PhD thesis

First MAGIC DISCOVERY

- Jan 2005, 8.2 h
- 6.4 σ significance
- F(>120GeV) = 13% Crab
- spectral index: -3.0 ± 0.4



Soft Energy Spectrum



AGN PG 1553+113 (z uncertain)

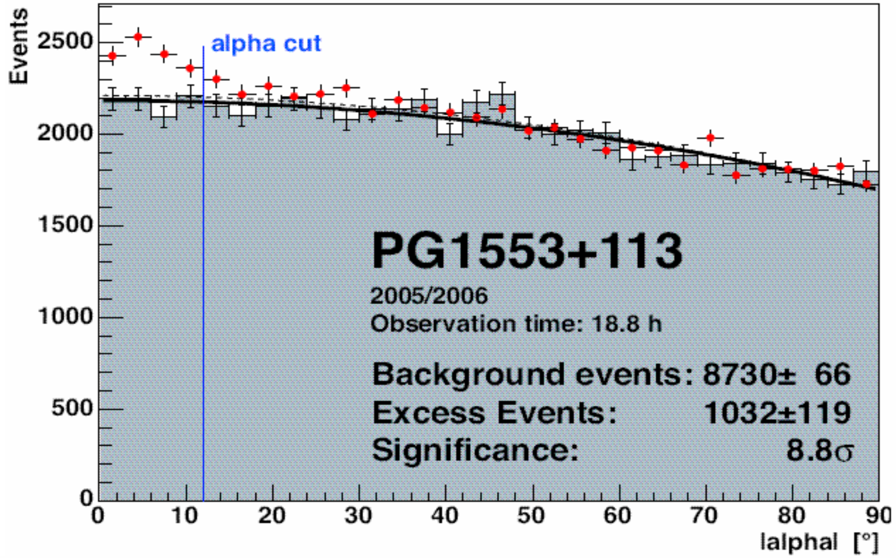
simultaneous discovery by HESS/MAGIC

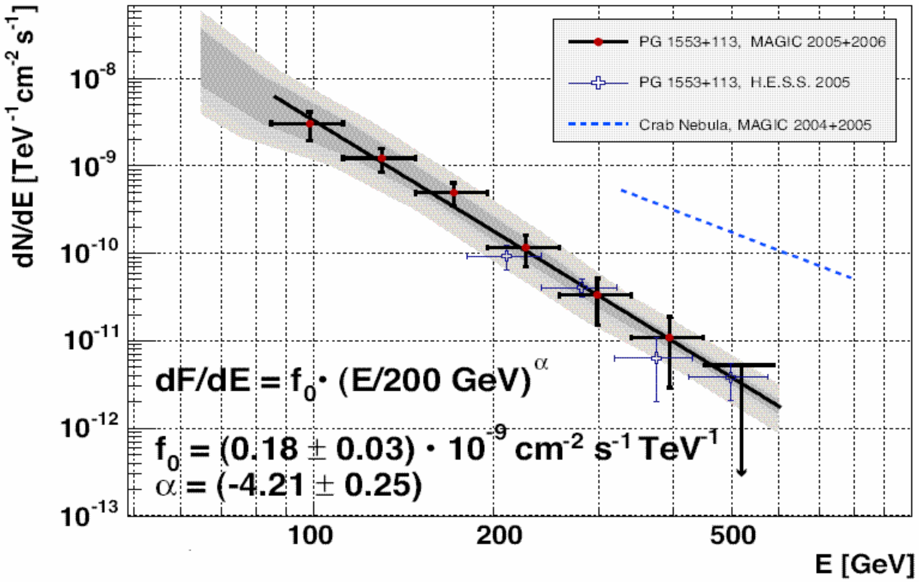
ApJ accepted, astro-ph/0606161

H.E.S.S.: 4σ evidence

MAGIC observation:

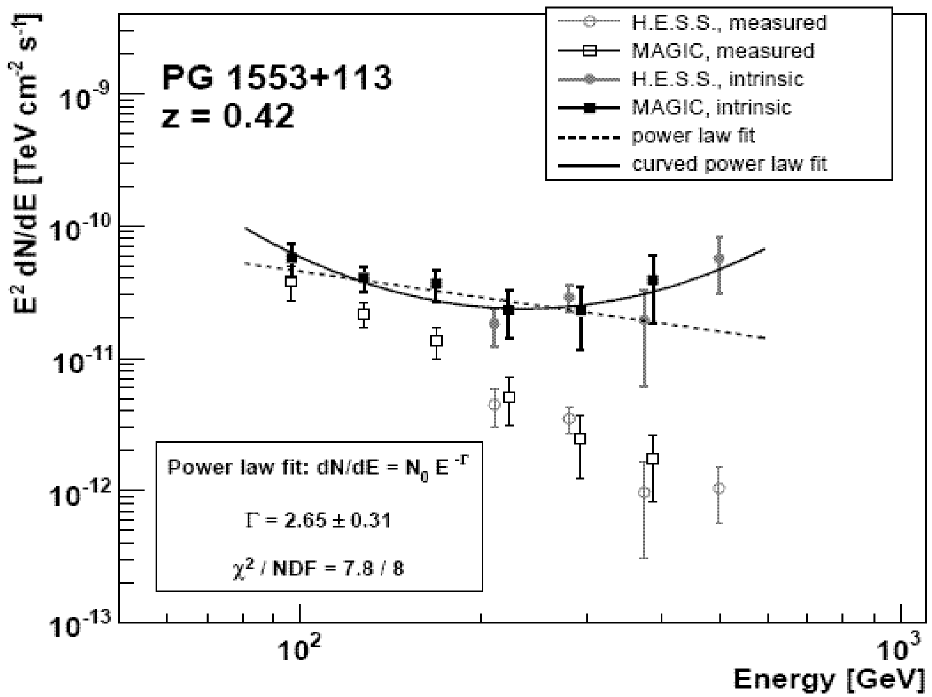
- 2005-06, ~19h
- 8.8σ, firm detection
- flux level in 2006 reduced by factor 3
- spectral index: -4.2 ± 0.3
- very soft spectrum due to: attenuation by e^+e^- pair creation
  or nature of SSC mechanism

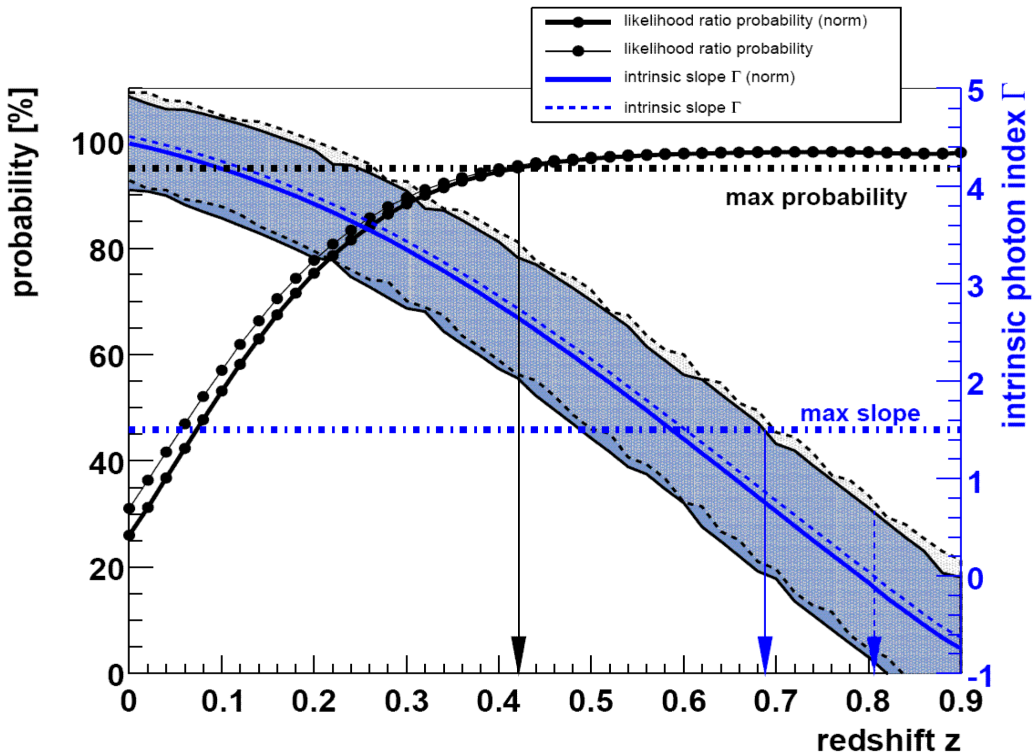




Distance of PG 1553+113

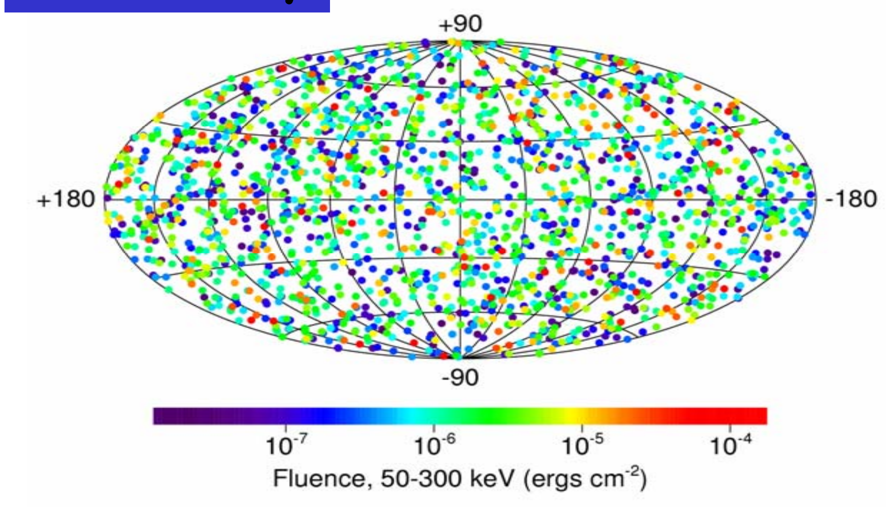
- no spectral line found → only lower limit: $z > 0.09$
- assume: EBL (conservative) + z
- require: $dN/dE \sim E^{-\Gamma}$, $\Gamma > 1.5$ → upper limit on z
  MAGIC +HESS data: $z < 0.74$
- improved method (Mazin&Goebel, astro-ph/0611817): $z < 0.42$



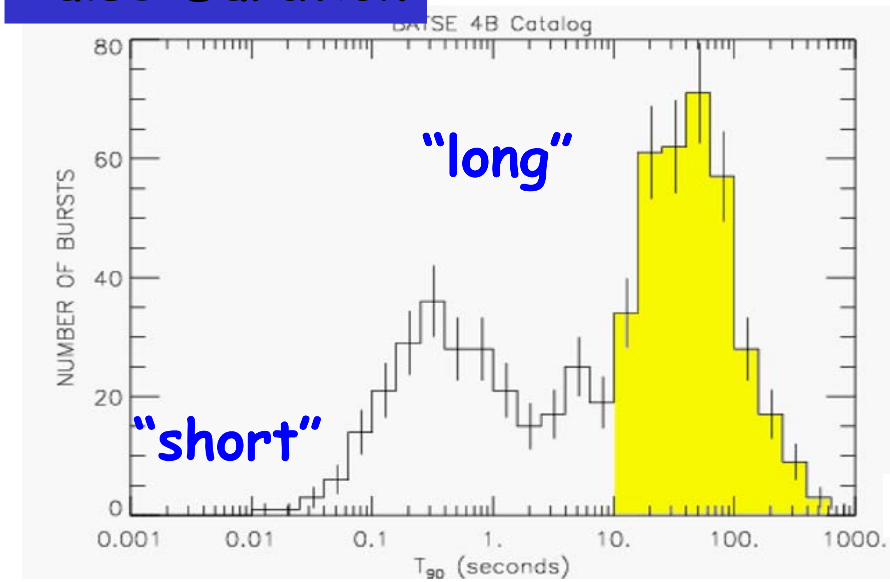


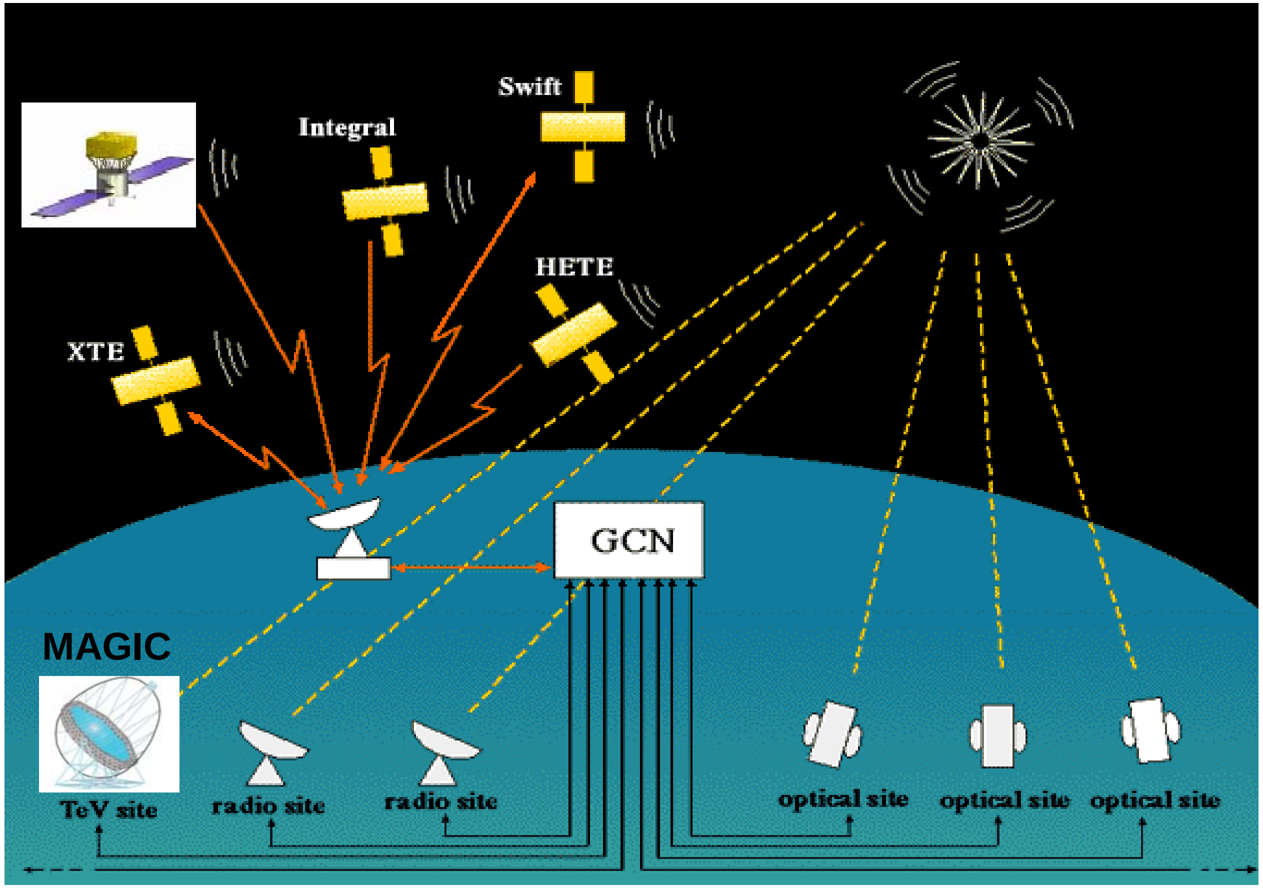
GRB observation by MAGIC

Uniformity



Pulse Duration





~10sec GRB trigger Satellite to MAGIC

~50sec/180° MAGIC slewing time

future: ~39sec/180°

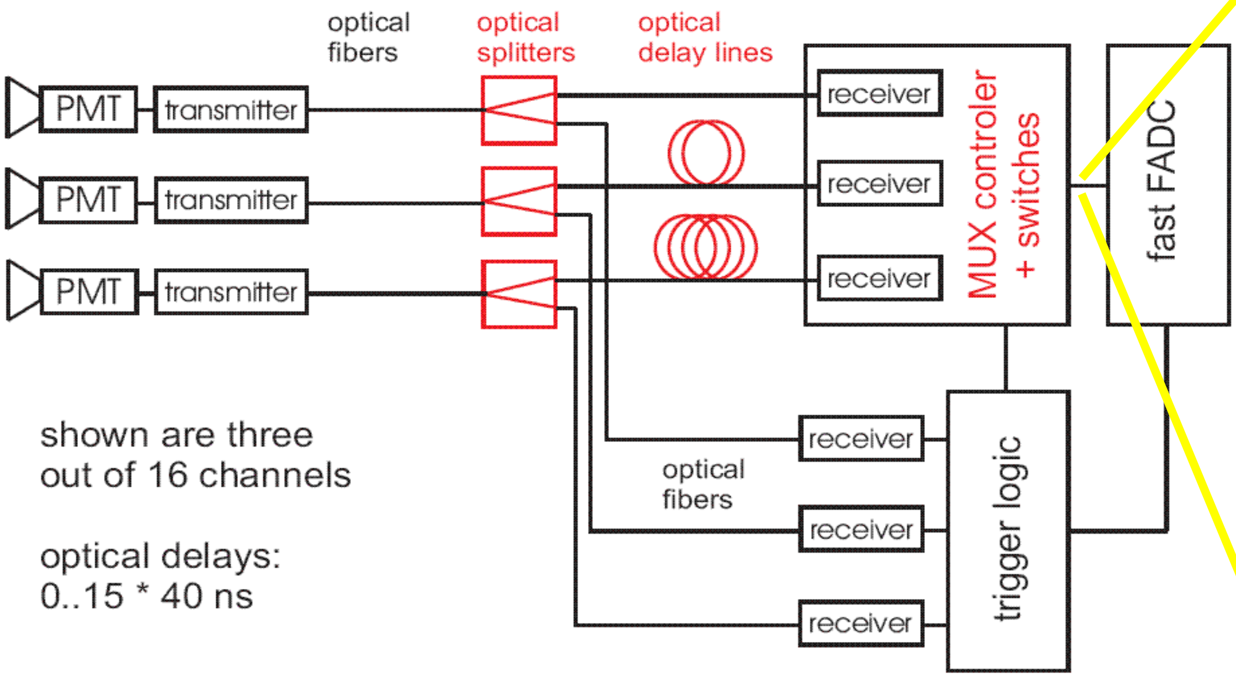
Upper limits for 9 GRBs in VHE γ-rays

- fast response of MAGIC
  no gamma-ray emission seen
- wait for stronger GRB
- GRB 050713a published:
  ApJL 638 (2006) 101

	Energy [GeV]	Fluence Upper Limit [ph cm^{-2} keV^{-1}]	Fluence Upper Limit [erg cm^{-2}]	C.U.
GRB060121	151.3	2.64×10^{-15}	9.67×10^{-8}	0.41
	212.8	6.57×10^{-16}	4.76×10^{-8}	0.25
	273.7	2.13×10^{-16}	2.56×10^{-8}	0.15
	367.7	4.47×10^{-16}	9.66×10^{-8}	0.69
	636.4	4.84×10^{-17}	3.14×10^{-8}	0.31
GRB060203	151.5	1.10×10^{-14}	4.03×10^{-7}	1.71
	219.5	5.07×10^{-16}	3.91×10^{-8}	0.21
	274.0	1.57×10^{-16}	1.88×10^{-8}	0.11
	365.3	3.54×10^{-16}	7.56×10^{-8}	0.54
	639.5	4.45×10^{-17}	2.91×10^{-8}	0.29
GRB060206	85.5	1.23×10^{-14}	1.44×10^{-7}	0.44
	139.9	9.83×10^{-16}	3.08×10^{-8}	0.13
	210.3	5.50×10^{-16}	3.89×10^{-8}	0.20
	269.2	3.65×10^{-16}	4.23×10^{-8}	0.25
	355.4	6.47×10^{-16}	1.31×10^{-7}	0.91
	614.0	2.88×10^{-17}	1.74×10^{-8}	0.17

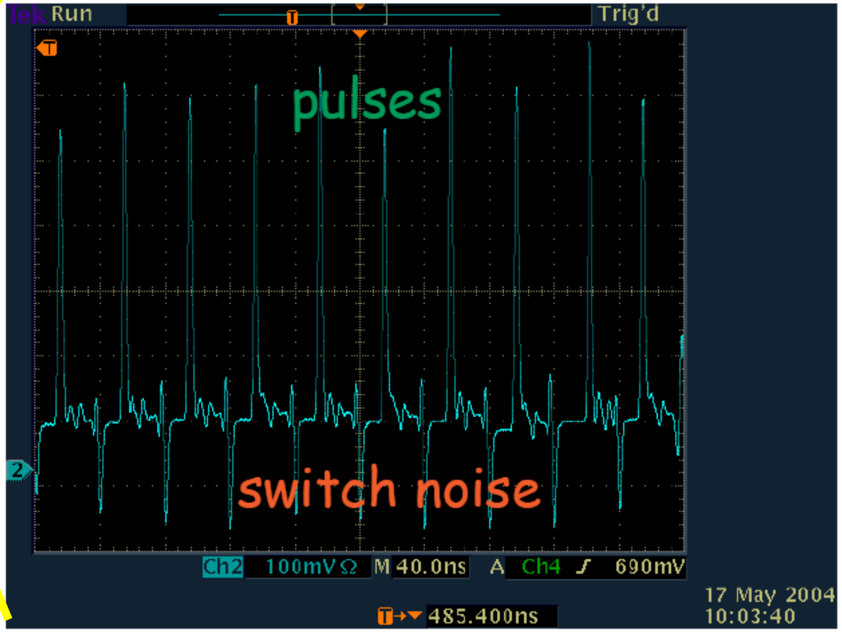
	Energy [GeV]	Fluence Upper Limit [ph cm^{-2} keV^{-1}]	Fluence Upper Limit [erg cm^{-2}]	C.U.
GRB050421	212.5	5.26×10^{-16}	3.80×10^{-8}	0.20
	275.8	3.64×10^{-16}	4.43×10^{-8}	0.27
	366.4	5.21×10^{-17}	1.12×10^{-8}	0.08
	658.7	2.07×10^{-17}	1.41×10^{-8}	0.14
GRB050502	152.3	1.67×10^{-15}	6.21×10^{-8}	0.27
	219.3	2.83×10^{-15}	2.18×10^{-7}	1.15
	275.8	1.13×10^{-15}	1.37×10^{-7}	0.83
	360.8	7.57×10^{-17}	1.58×10^{-8}	0.11
	629.1	5.62×10^{-17}	3.56×10^{-8}	0.35
GRB050505	212.9	2.03×10^{-15}	1.48×10^{-7}	0.76
	275.1	2.66×10^{-15}	3.22×10^{-7}	1.94
	363.6	5.28×10^{-16}	1.11×10^{-7}	0.79
	704.1	1.85×10^{-17}	1.46×10^{-8}	0.15
GRB050509a	215.1	1.04×10^{-15}	7.69×10^{-8}	0.40
	273.4	1.39×10^{-15}	1.67×10^{-7}	1.00
	362.8	7.74×10^{-16}	1.63×10^{-7}	1.15
	668.5	1.69×10^{-16}	1.21×10^{-7}	1.22
GRB050713a	169.9	3.63×10^{-15}	1.68×10^{-7}	0.76
	212.5	1.12×10^{-15}	8.08×10^{-8}	0.42
	275.8	2.07×10^{-15}	2.52×10^{-7}	1.52
	366.4	3.33×10^{-16}	7.16×10^{-8}	0.51
	658.7	2.24×10^{-17}	1.55×10^{-8}	0.15
GRB050904	85.5	9.06×10^{-15}	1.06×10^{-7}	0.32
	140.1	3.00×10^{-15}	9.42×10^{-8}	0.38
	209.9	2.18×10^{-15}	1.53×10^{-7}	0.79
	268.9	5.82×10^{-16}	6.74×10^{-8}	0.40
	355.2	5.01×10^{-16}	1.11×10^{-7}	0.71
	614.9	1.26×10^{-16}	7.63×10^{-8}	0.73

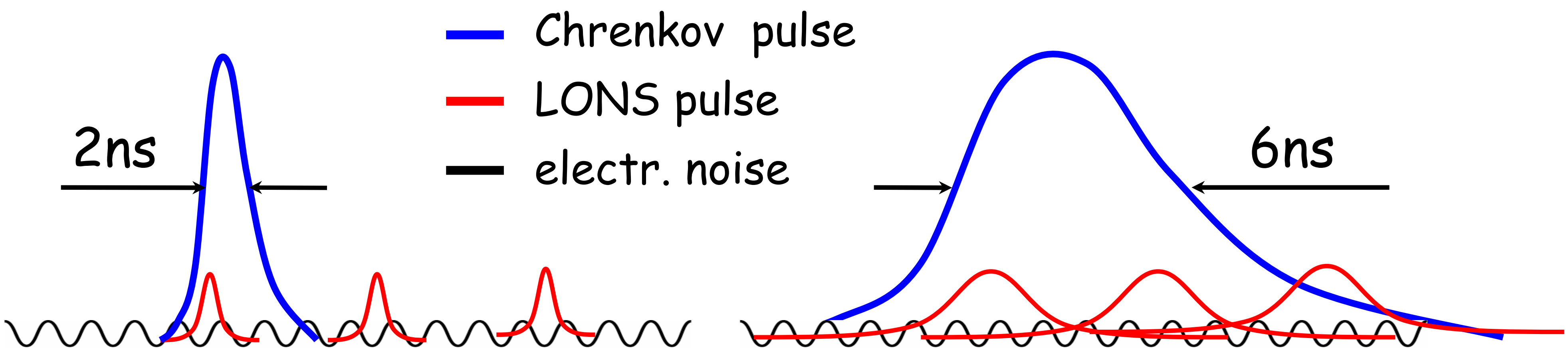
DAQ Upgrade: MUX-FADCs



shown are three out of 16 channels

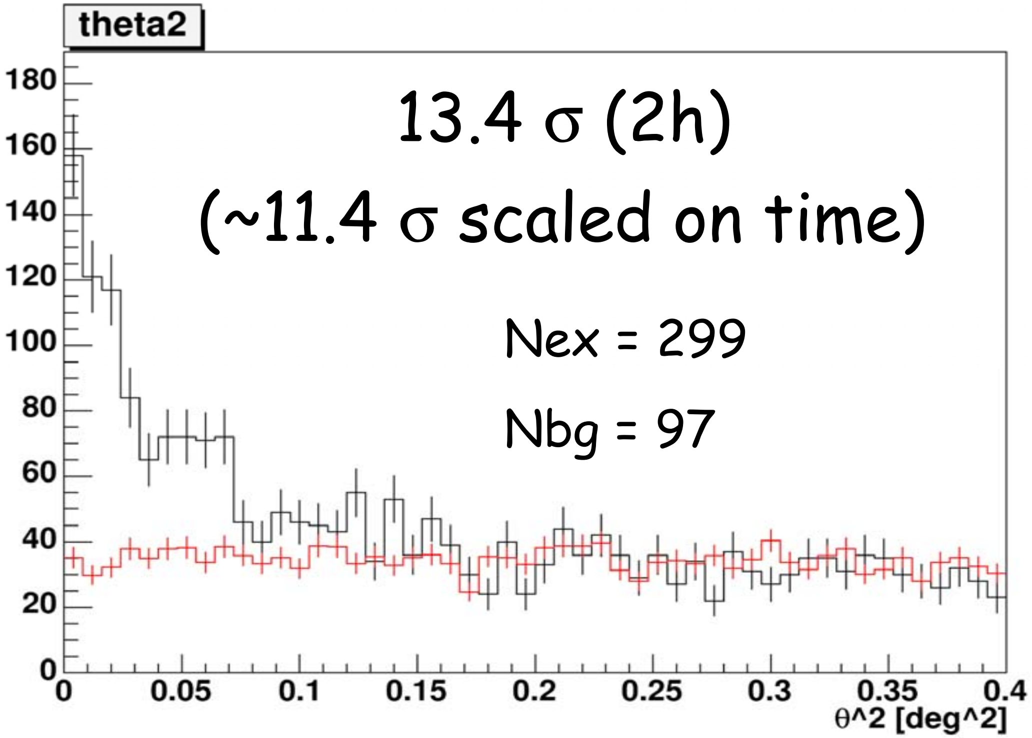
optical delays: 0..15 * 40 ns



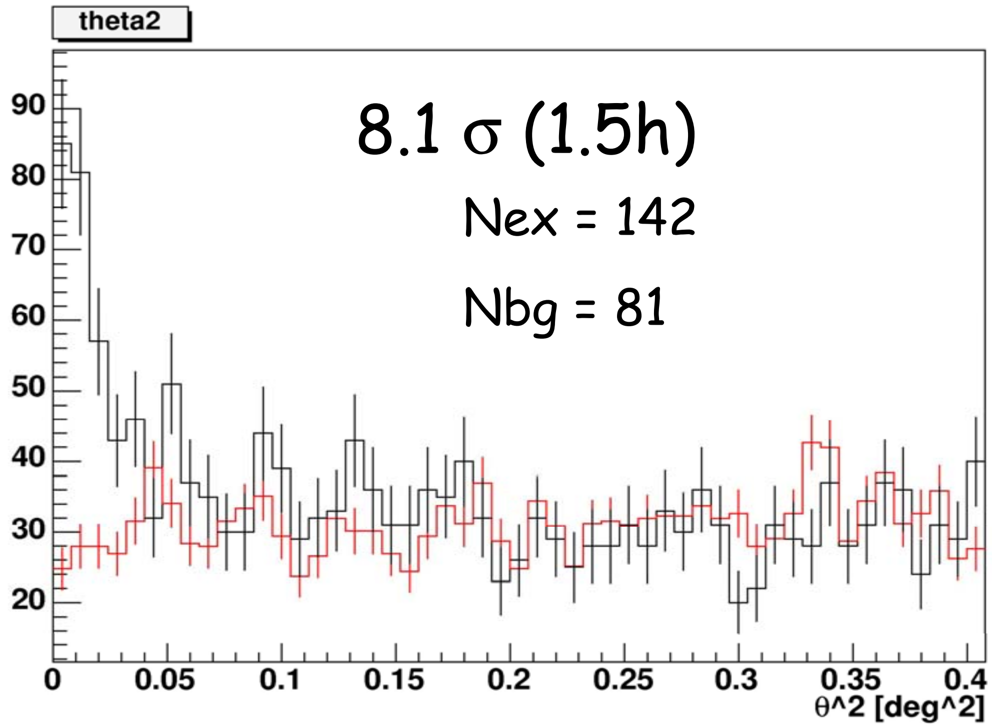


First Data: Crab Nebula

300 MSamples/s FADCs

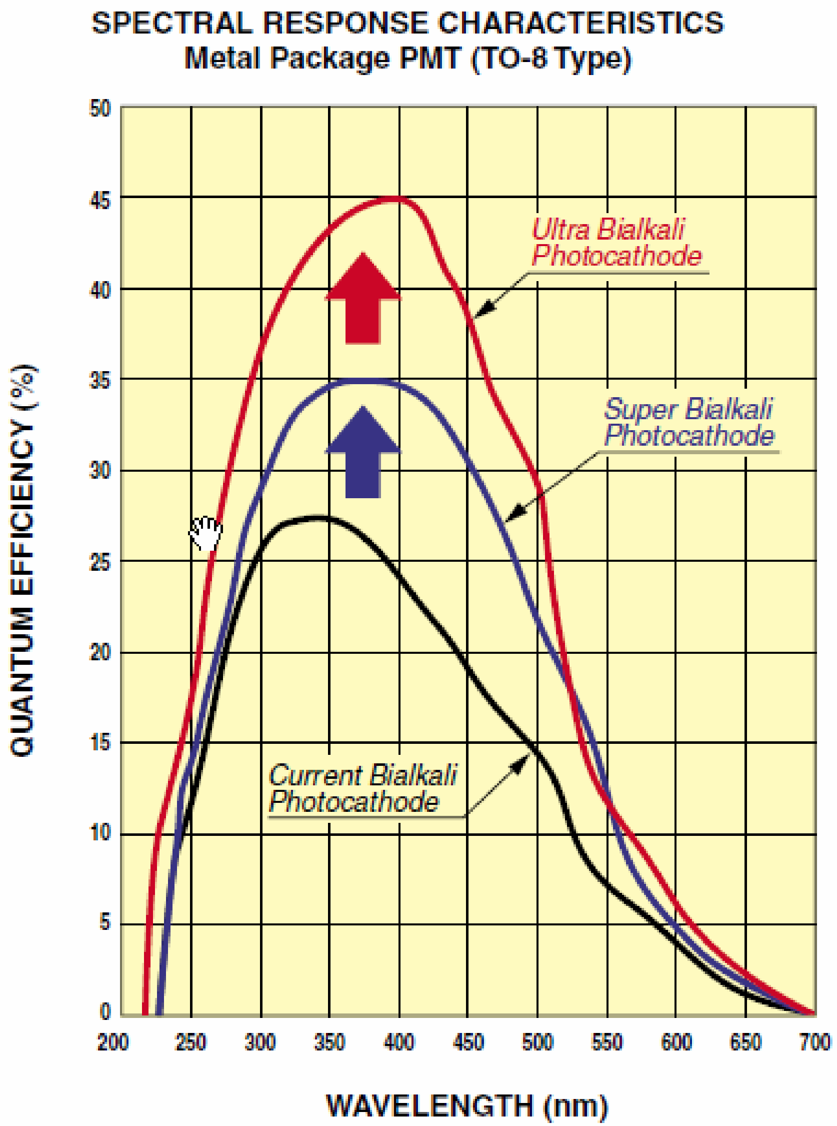


2 GSamples/s MUX-FADCs



gamma/hadron separation optimized for old system

New High QE PMTs



- Hamamatsu has announced PMTs with peak QE of 43 % !
- stimulated by requirements of MAGIC
- chance to replace MAGIC PMTs?

Photocathode	QE at peak wavelength		Type Availability
	Min.	Typ.	
Ultra Bialkali (UBA)	38 %	43 %	Metal Package PMT (TO-8 Type, □28 mm Type PMT)
Super Bialkali (SBA)	32 %	35 %	Metal Package PMT (TO-8 Type, □28 mm Type PMT) ϕ28 mm to ϕ76 mm Head-on PMT (Glass Bulb Type)

Conclusions

- First MAGIC telescope is taking data regularly since fall 2004
- 5 galactic sources are observed,
  variable emission from a γ-ray binary discovered
- 7 extragalactic sources are observed
  2 discoveries by MAGIC
- distant sources -> study the gamma attenuation by e^+/e^- pair creation (extragalactic background light)
- rapid flux variations -> study quantum gravity effects
- GRBs: 9 fast follow-up observations are carried out
  no detection of signals so far
- several publications + more data to be analyzed

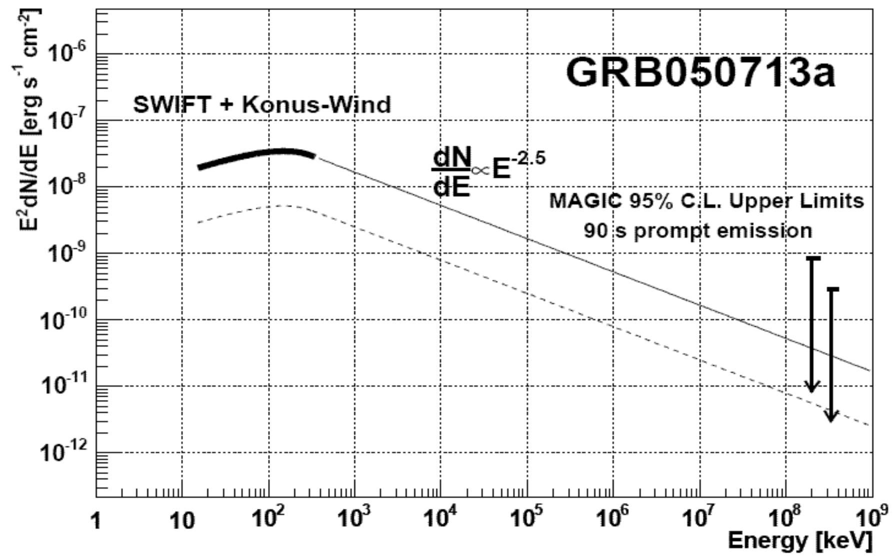
- DAQ upgrade with ultra-fast MUX-FADC system
- second MAGIC telescope under construction
  (talk by F. Goebel)

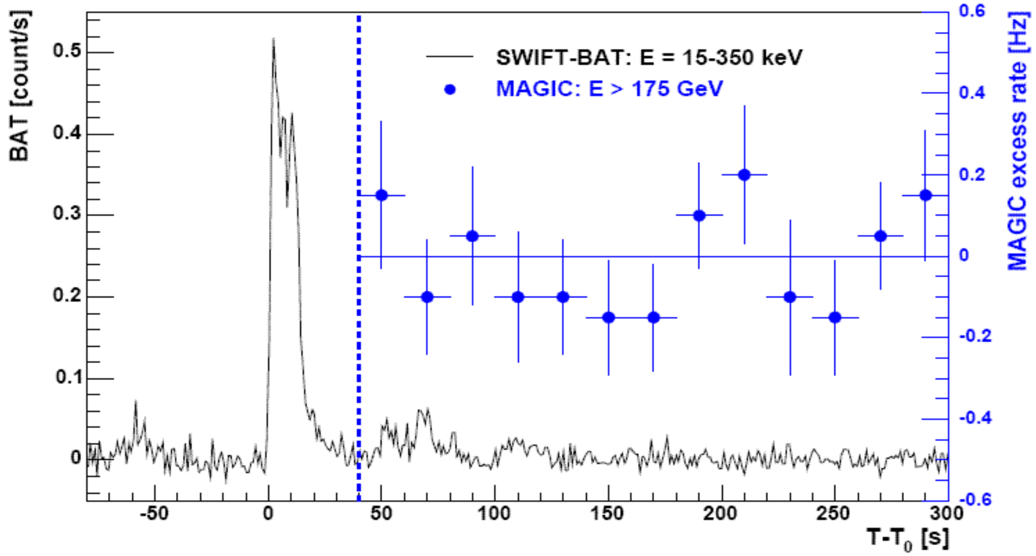
Backup

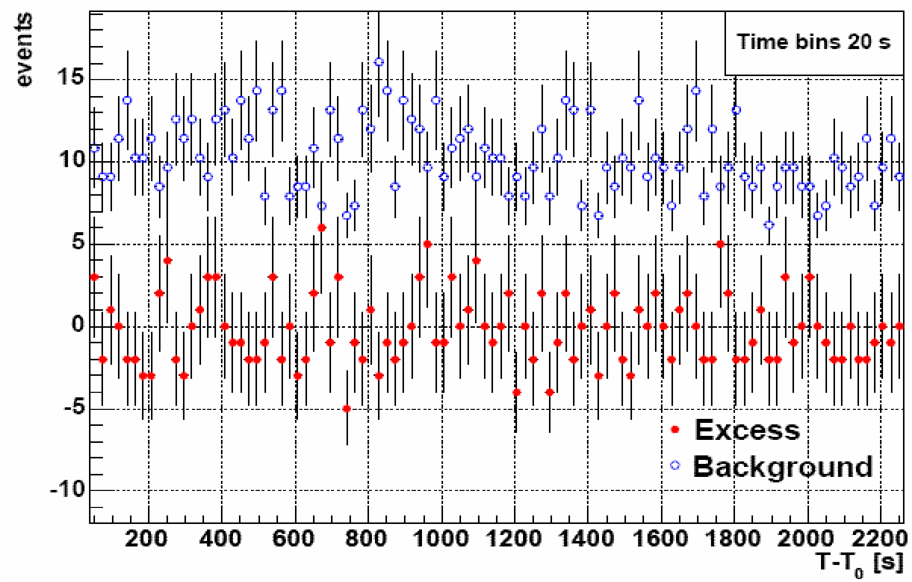
GRB 050713a

Published: ApJL 638 (2006) 101

fast response of MAGIC
no gamma-ray emission seen







The MAGIC Telescope at the Roque de los Muchachos Observatory

Status of MAGIC

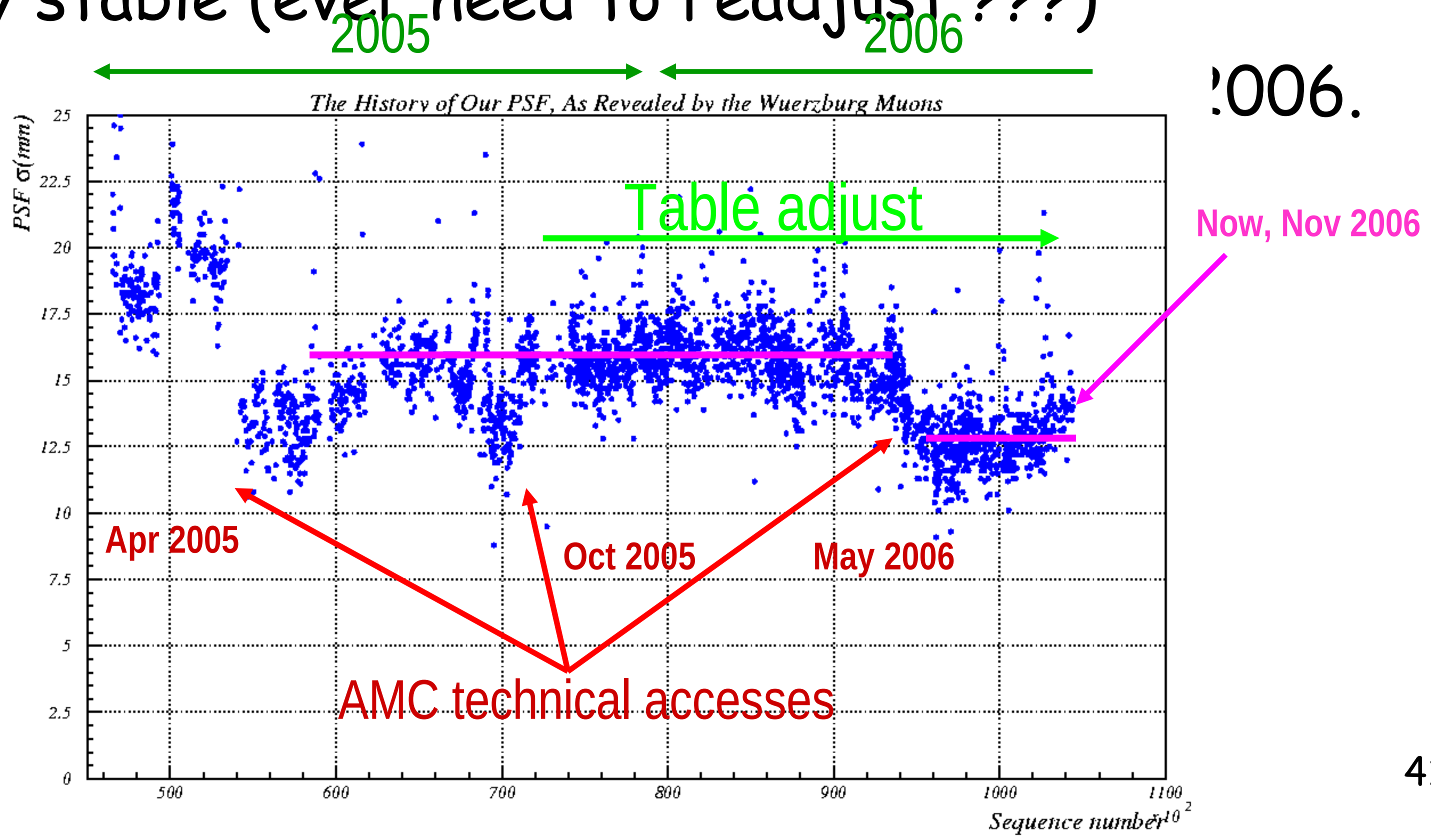
- October 2003: Inauguration
- until August 2004: Commissioning
- July 2004: Installation of last Mirrors
- September 2004: Start of regular data-taking
- June 2005: start of cycle 1 observations
- data-taking efficiency gradually improving, reaching 80-90%
- in 2005 some weather hazards
- 2006 good weather conditions
- Dec 2006: 12 sources published more results in pipeline

Infrastructure Updates in 2006

- fire protection:
  - cleared the bushes around the telescopes and around cable tray
  - plan to install a water tank close to upper road, water pipe and probably hydrant for firemen
- road paving: will pave the path to control house with asphalt allows snow plough to clean the house area
- humidity protection: paint the house soon with special protective paint
- power line: installed cable channel from ORM main power line plus a transformation center

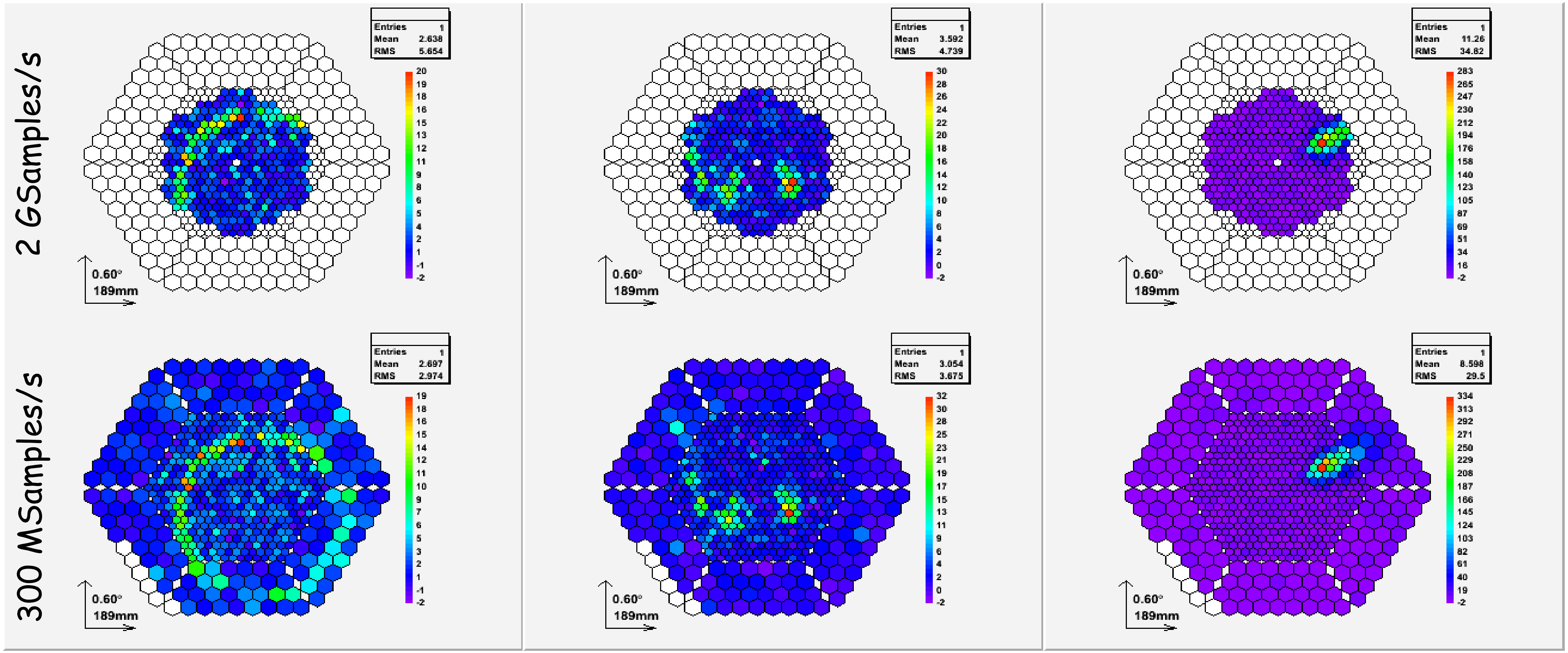
Active Mirror Control

- Since May 2006: significantly improved optical PSF
- single mirror facet reflections under full control
  (trivial to change position and focal length of whole mirror)
- full mirror recalibration in ~15 min using a bright star
- MAGIC very stable (ever need to readjust ???)
- Stable at 15 2006.
- Reduces to



New vs. Old FADCs

Parallel read-out of new and old FADC systems
-> cross-checks, performance validation, software adaptation



Status of Observations

Observation cycle 1: June 2005 - June 2006
• dark night: 955 h observed / 1595 h available
  = 60 % efficiency (bad weather, technical problems)
• moon shine: 205 h observed

Observation cycle 2: June 2006 – May 2007 (numbers till Nov.)
• dark night: 409 h observed / 653 h available
  = 63 % efficiency (bad weather, technical problems)
• moon shine: 122 h observed

-> 1000 h dark night observation time per year + moon time
= 50 sources * 20 h / source, for min. fluxes of 3.2% Crab

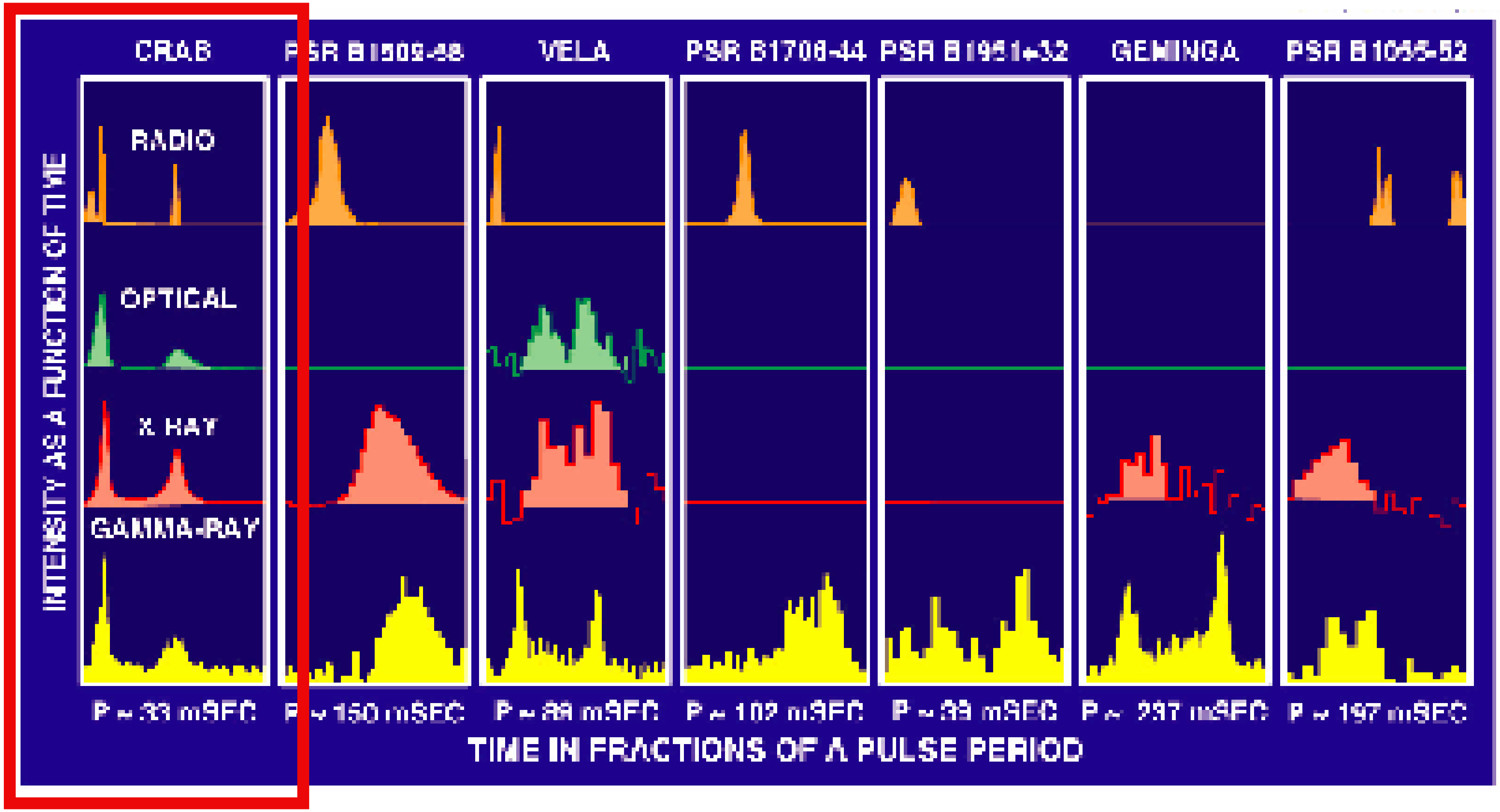
MAGIC Source Catalogue (December 2006)

MAGIC catalog was authorized by IAU: "MAGIC JHHMM+DDMM"

MAGIC Source	R.A. J2000	Dec J2000	feature/z	Other Name	Status	Cit.
MAGIC J0240+6113	02 40 31.7	+61 13 41	γ–ray binary	LSI+61 303	Science 312, 1771 (2006)	27
MAGIC J0534+2201	05 34 31	+22 01	PWN	Crab Nebula	in analysis	
MAGIC J1745-2902	17 45 20	-29 02	???	G.C.	ApJ Letters 638, 101 (2006)	23
MAGIC J1813-1748	18 13 27	-17 48 20	SNR/PWN?	HESS J1813-178	ApJ Letters 613, 41 (2006)	18
MAGIC J1834-0842	18 34 27	-08 42 40	SNR/PWN?	HESS J1834-087	ApJ Letters 643, 53 (2006)	7
MAGIC J1101+3828	11 01 40.3	+38 28 34	HBL (0.0308)	Mrk421	astro-ph/0603478	5
MAGIC J1133+7026	11 33 32.7	+70 26 00	HBL (0.0458)	Mrk180	ApJ Letters 648, 105 (2006)	4
MAGIC J1221+3010	12 21 21.9	+30 10 37	HBL (0.182)	1ES1218+30.4	ApJ Letters 642, 119 (2006)	3
MAGIC J1555+1111	15 55 43.1	+11 11 24	HBL (>0.2)	1ES1553+113	astro-ph/0606161	5
MAGIC J1652+3950	16 52 11.7	+39 50 07	HBL (0.0337)	Mrk501	in analysis	
MAGIC J1959+6508	19 59 59.9	+65 08 55	HBL (0.047)	1ES1959+650	ApJ 639, 761 (2006)	6
MAGIC J2347+5142	23 47 04.8	+51 42 18	HBL (0.044)	1ES2344+514	in analysis	
MAGIC J1534+2330	15 34 57.21	+23 30 09	flux u.l.	Apr 220	astro-ph/0611786	
MAGIC J2122+7704	21 22 09.53	+77 04 29	flux u.l.	GRB050713A	ApJ Letters 641, 9 (2006)	4
MAGIC J ...					in analysis	

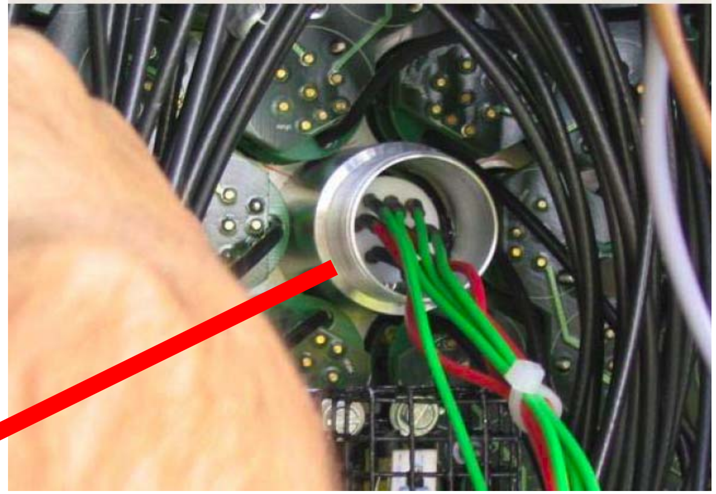
Crab pulsar

- most energetic pulsar ($L_m = 5\times10^{38}$ erg s^{-1})
- only pulsar whose pulse phase is the same in all wavelengths.

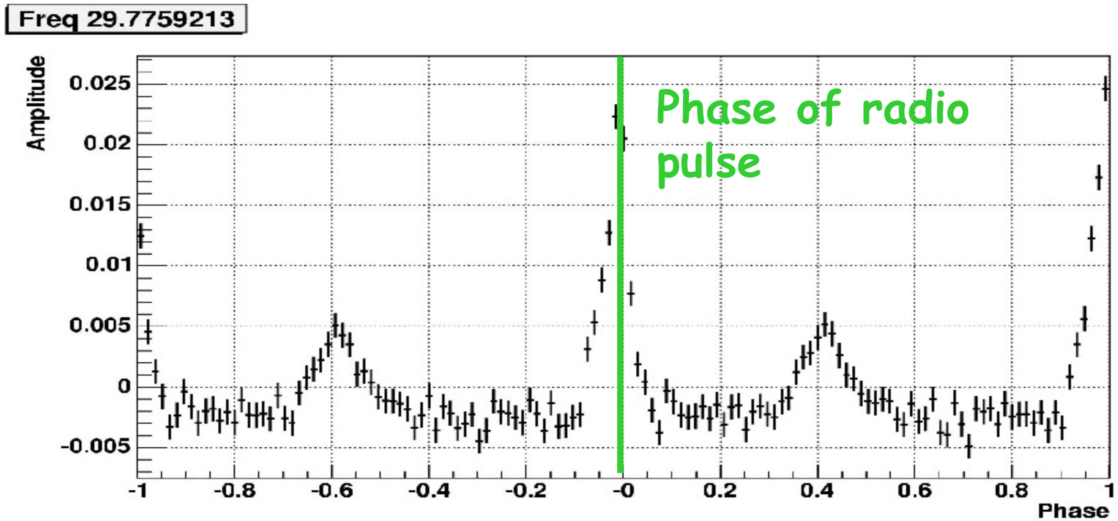


Central Pixel: Optical Pulse

- modified central pixel for optical DC-light measurements
- simultaneous phase measurement of optical pulse
- assess MAGIC clock



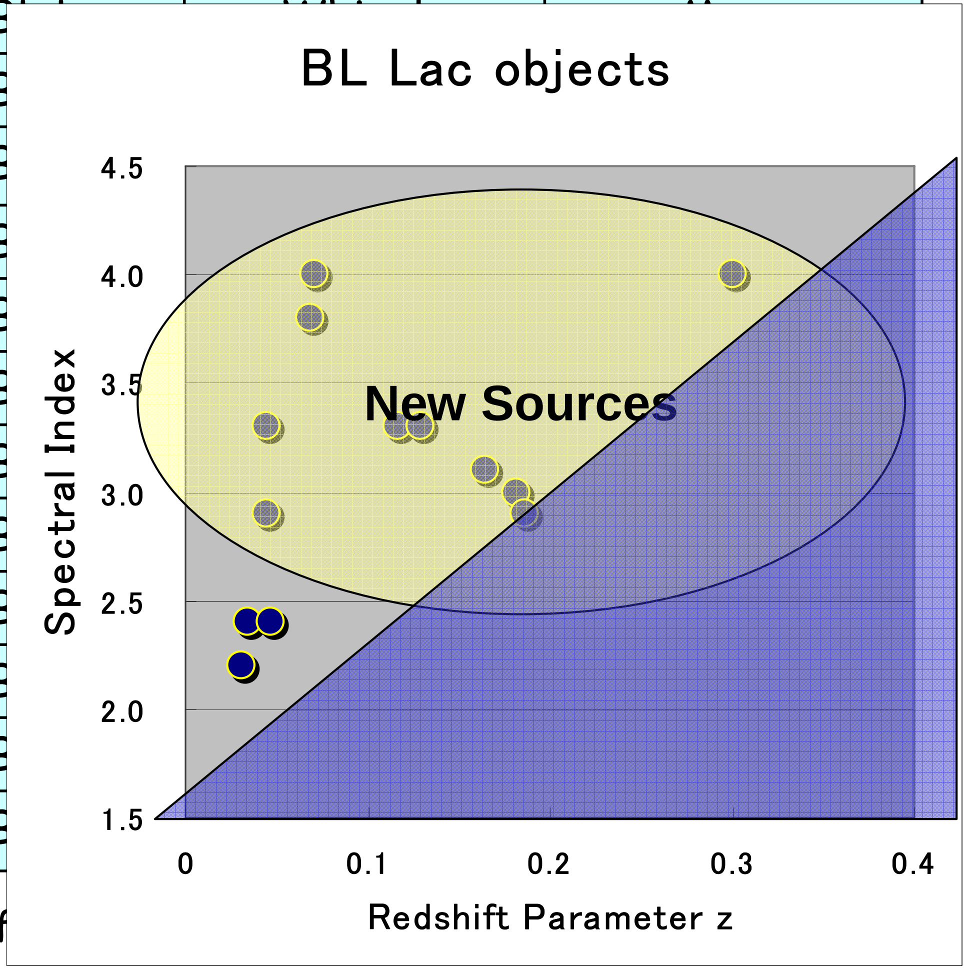
installed and tested with Crab-Pulsar in March '05.



Extragalactic sources

Spectral indices of new sources range 3~4

Source	Redshift	Spectral Index	Type	First Detection	Confimation
M87	0.004	2.9	FR I	HEGRA	HESS
Mkn 421	0.031	2.2	B		
Mkn 501	0.034	2.4	B		
1ES 2344+514	0.044	2.9	B		
Mkn 180	0.045	3.3	B		
1ES 1959+650	0.047	2.4	B		
PKS 2005-489	0.071	4.0	B		
PKS 2155-304	0.116	3.3	B		
H1426+428	0.129	3.3	B		
H2356-309	0.165	3.1	B		
1ES 1218+304	0.182	3.0	B		
1ES 1101-232	0.186	2.9	B		
PG 1553+113	0.3	4.0	B		



MUX Performance Tests

- successful test of 32 MUX-FADC channels in September 2004: H. Bartko et al., 2005, NIM, A548, 464.
- commissioning of the full MUX-FADC system in progress

reduced pulse width | less integrated noise | better timing res.