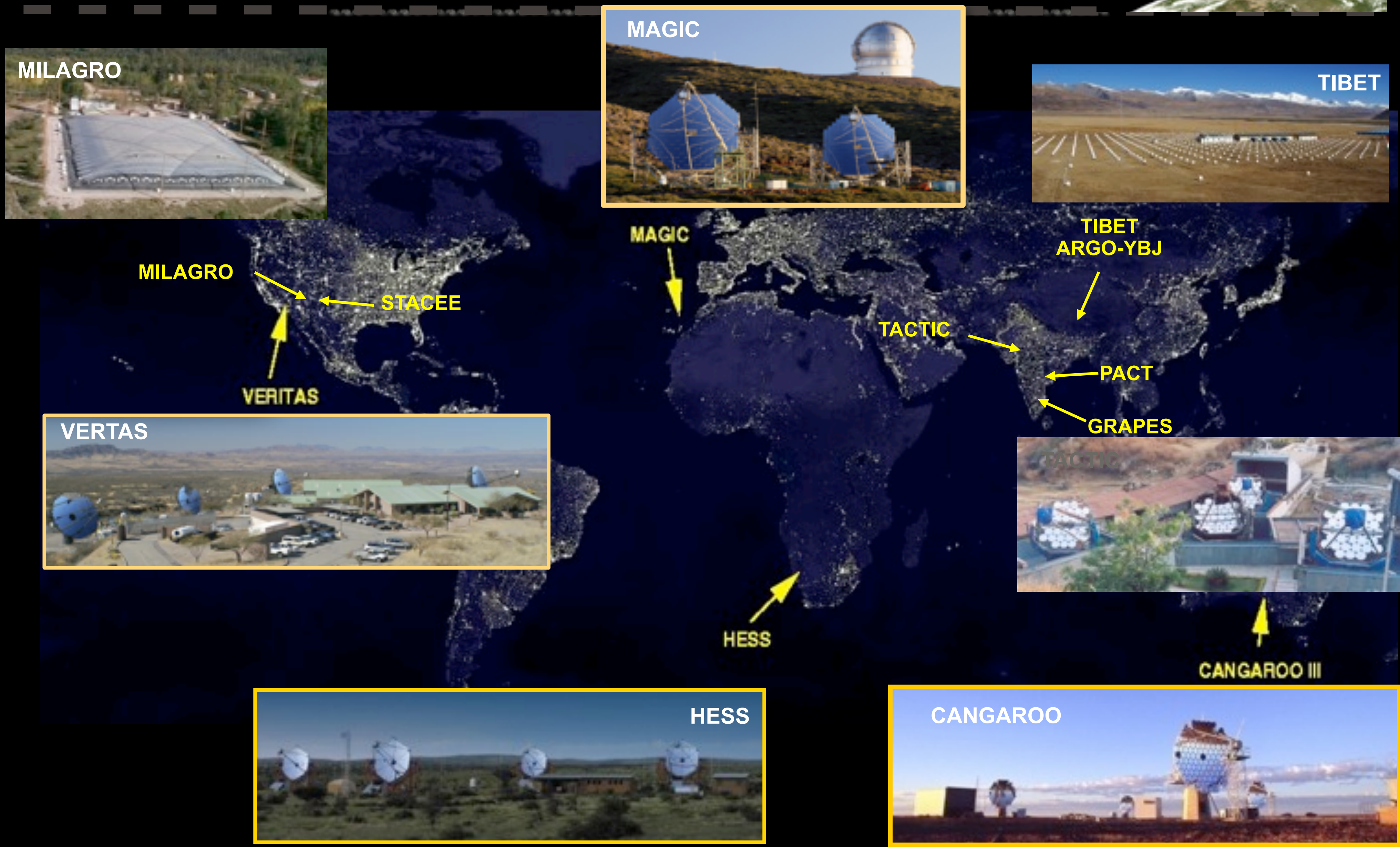
Gamma-Ray Astronomy with MAGIC and CTA

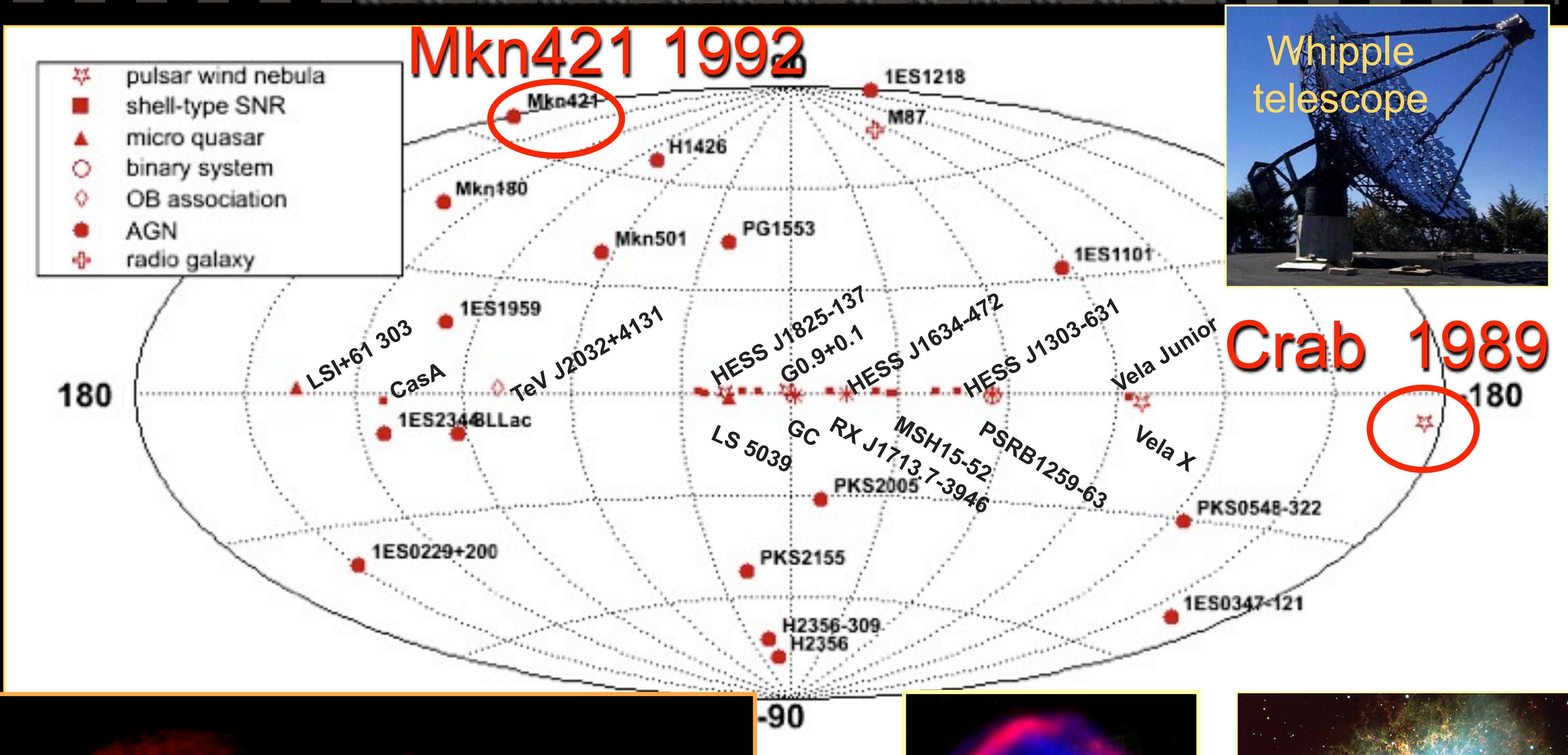
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Thomas Schweizer
Max-Planck-Institut Munich

Current gamma-ray Telescopes

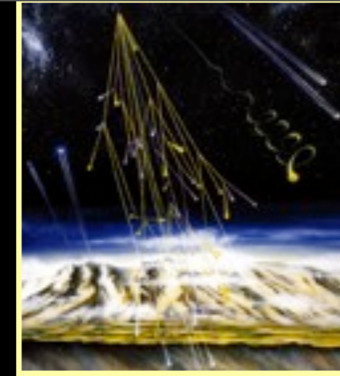


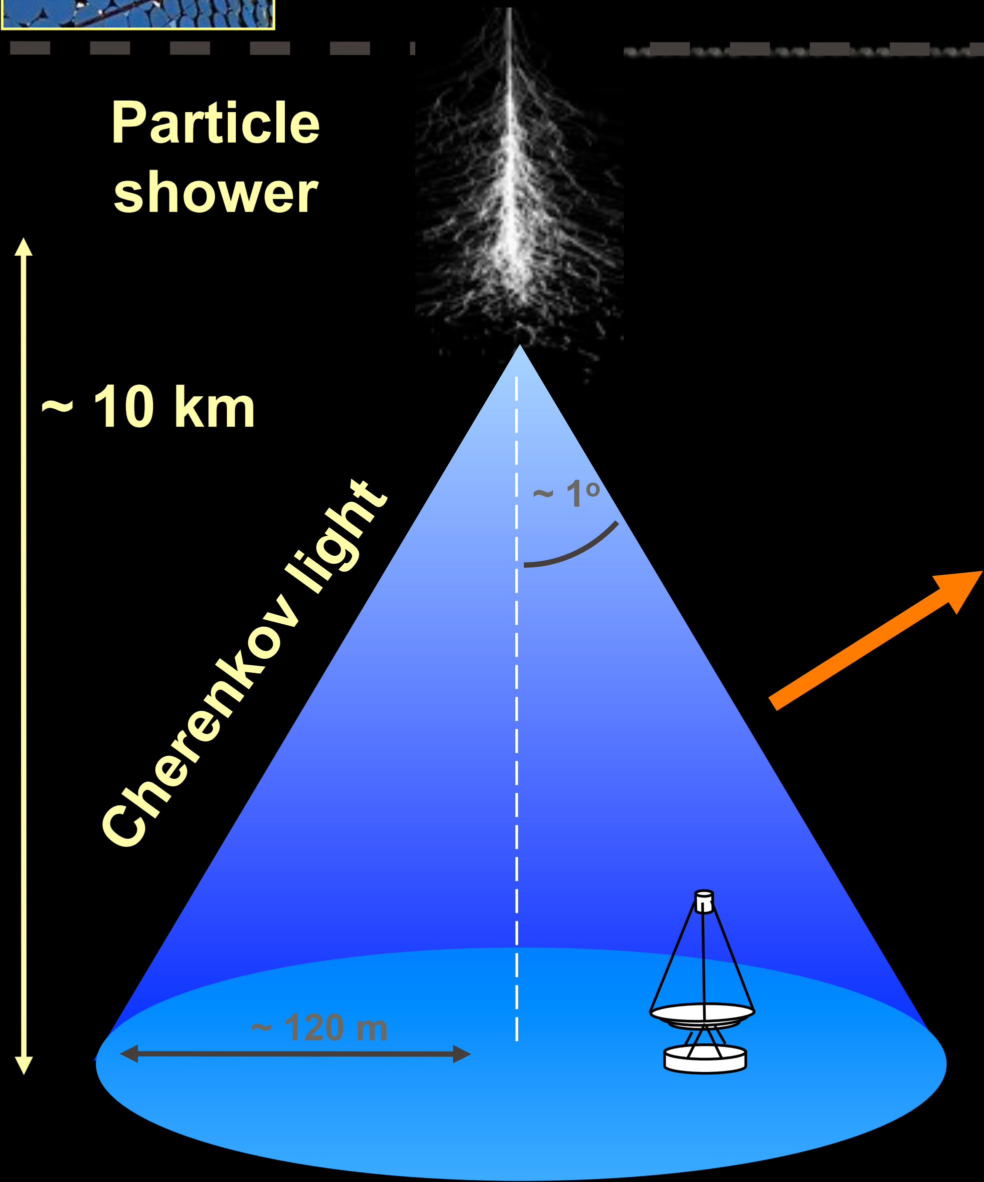
HE Gamma ray astronomy
today: around 100 sources



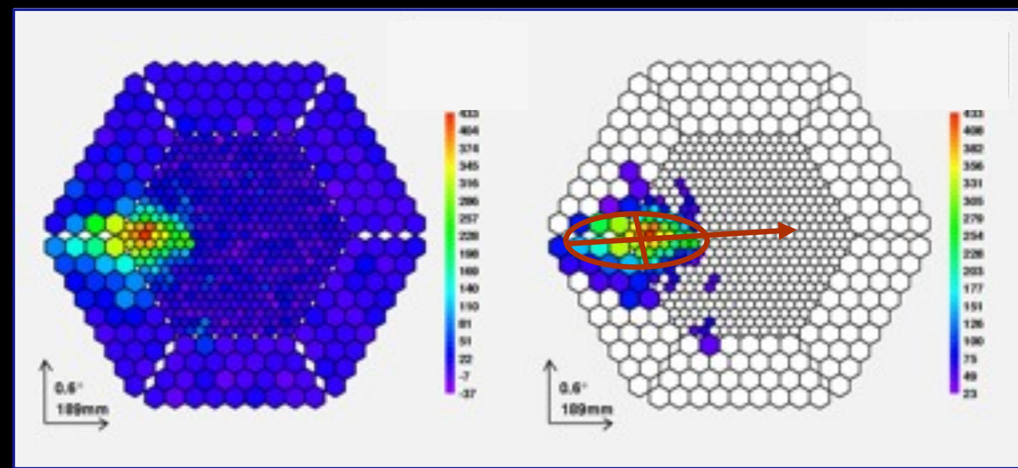
Imaging Cherenkov Technique

The Imaging Cherenkov Technique

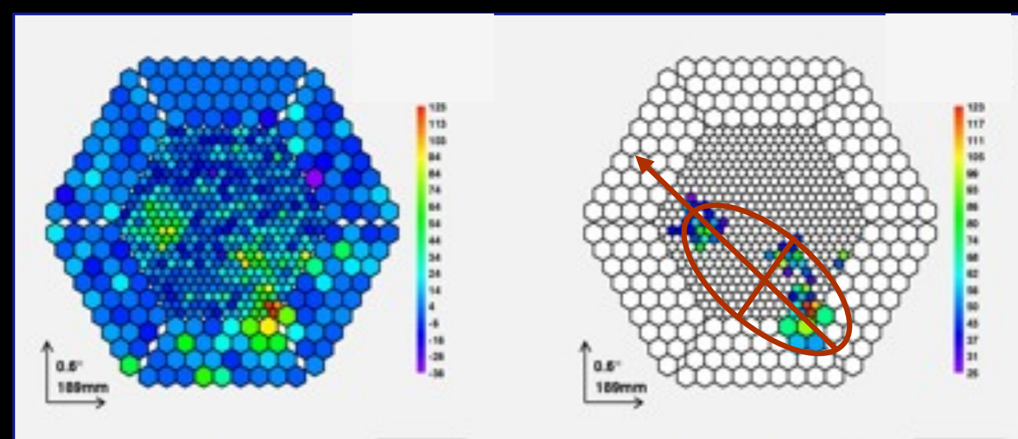




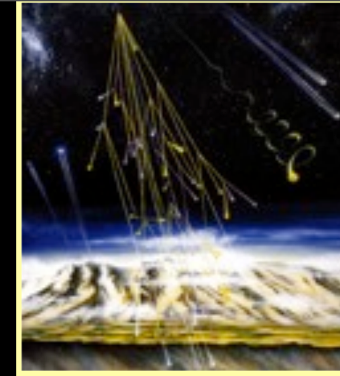
Gamma event: Signal

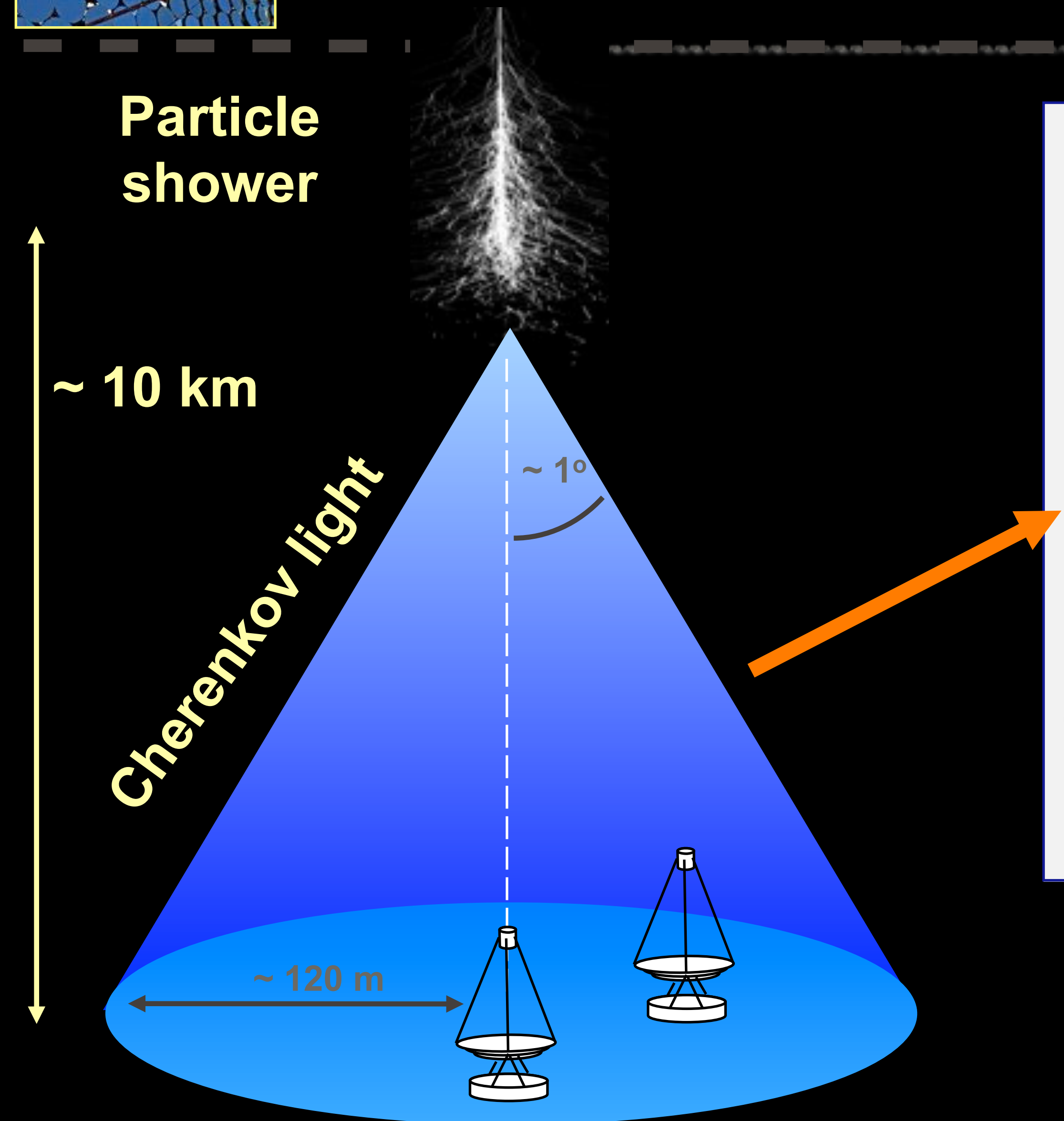


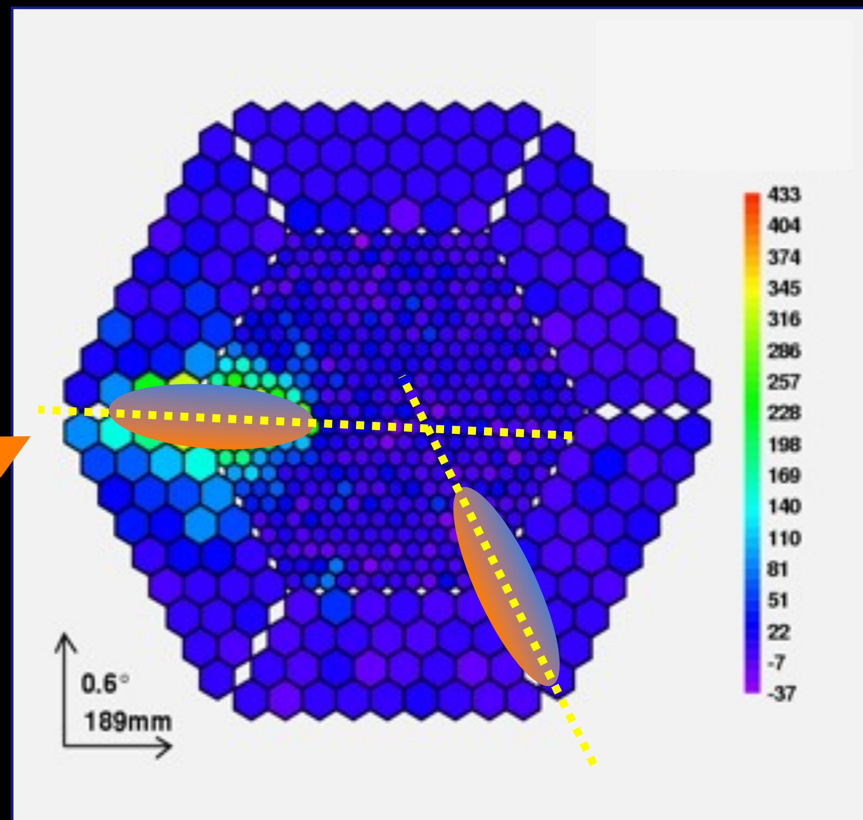
Hadronic event: Background



The Imaging Cherenkov Technique







Better background reduction
Better angular resolution
Better energy resolution

MAGIC Telescopes

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

- 17 m Ø reflector, Al mirrors
- CF frame, fast rotation
  Upgrade !! <180°/20s
- Active mirror control
- Analogue signal transport via 162m long optical fibres
- 2 GSample/s readout,...
- MAGIC I: 1.6 % Crab/50h
  MAGIC stereo: <1% C./50h
- Trigger threshold: 60 GeV
- With sumtrigger: 25-30 GeV

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Sensitivity curve of MAGIC

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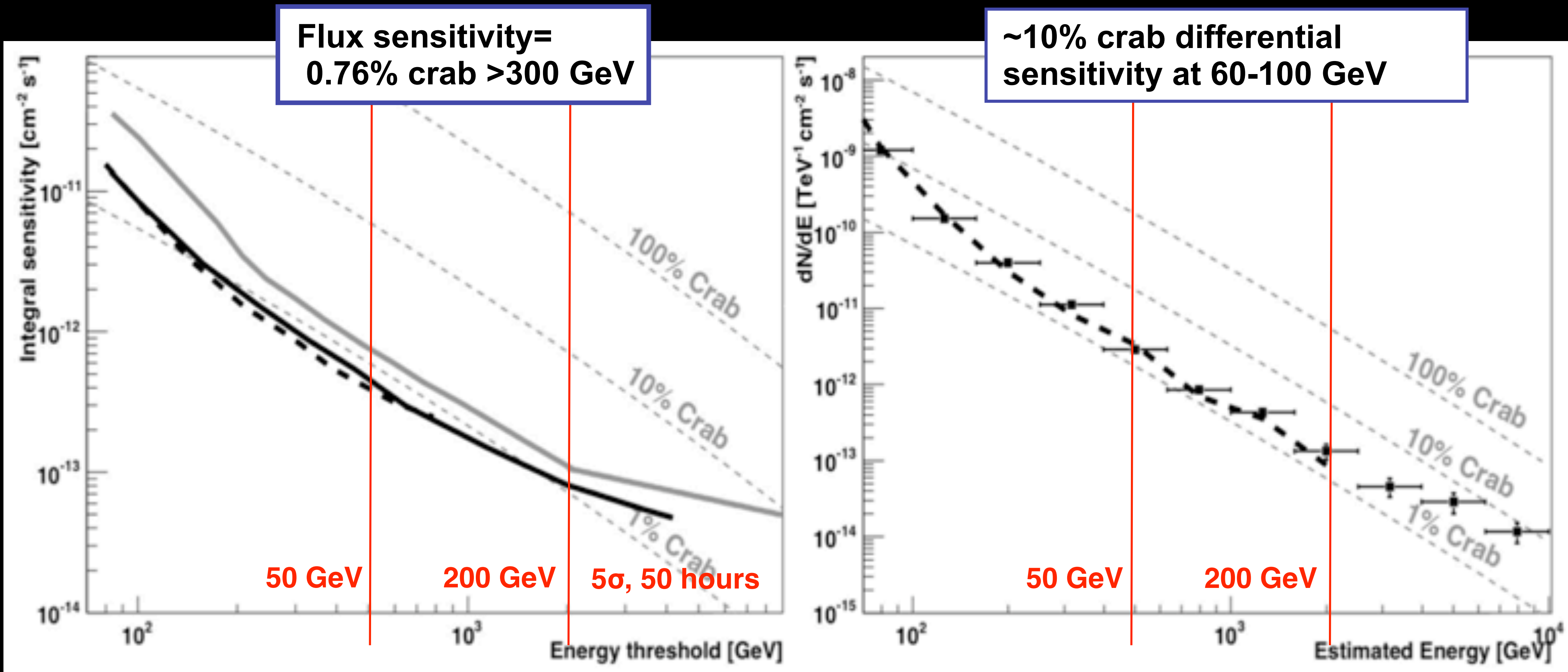

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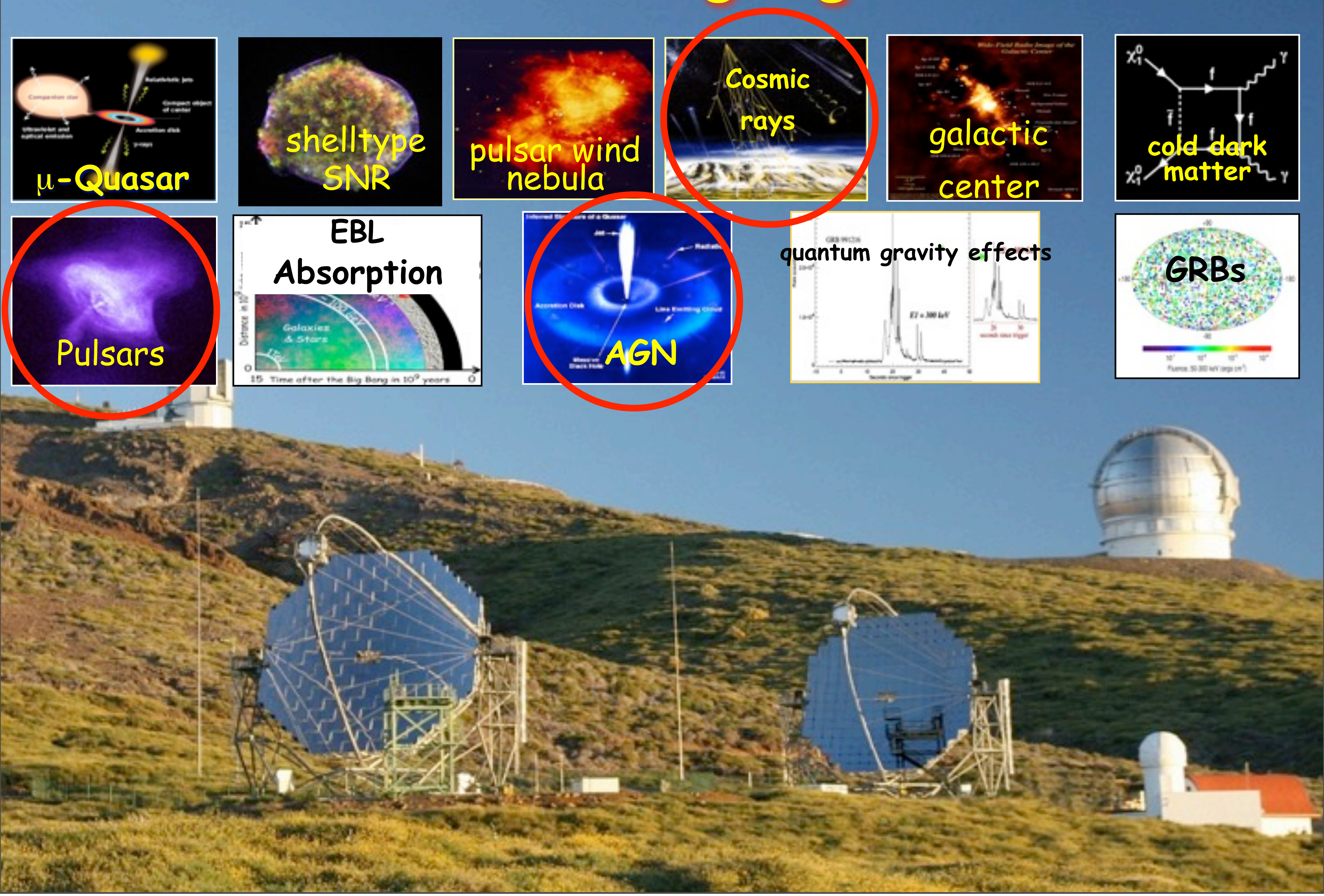
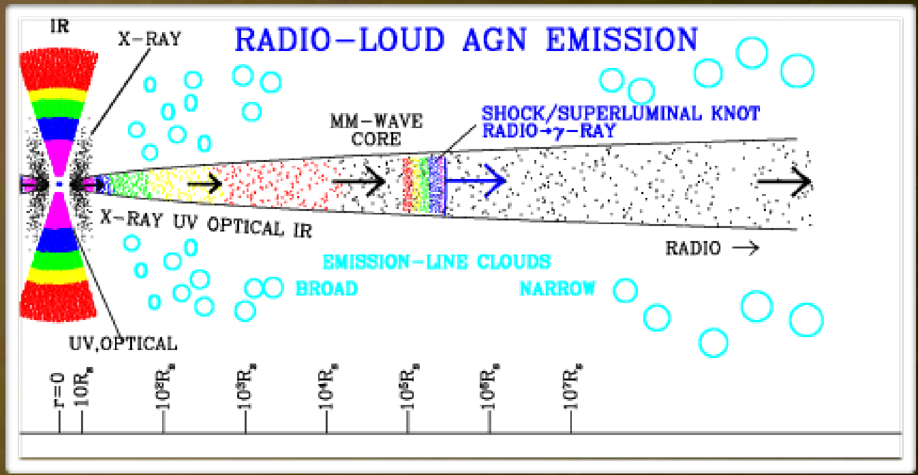
Some MAGIC highlight results



Giant radio galaxy M87: A Unique Astrophysical Laboratory



- VERITAS/MAGIC/H.E.S.S. monitoring 120 h of observation
- Simultanous VLBA radio imaging and Chandra monitoring

From which location originates the gamma radiation ?

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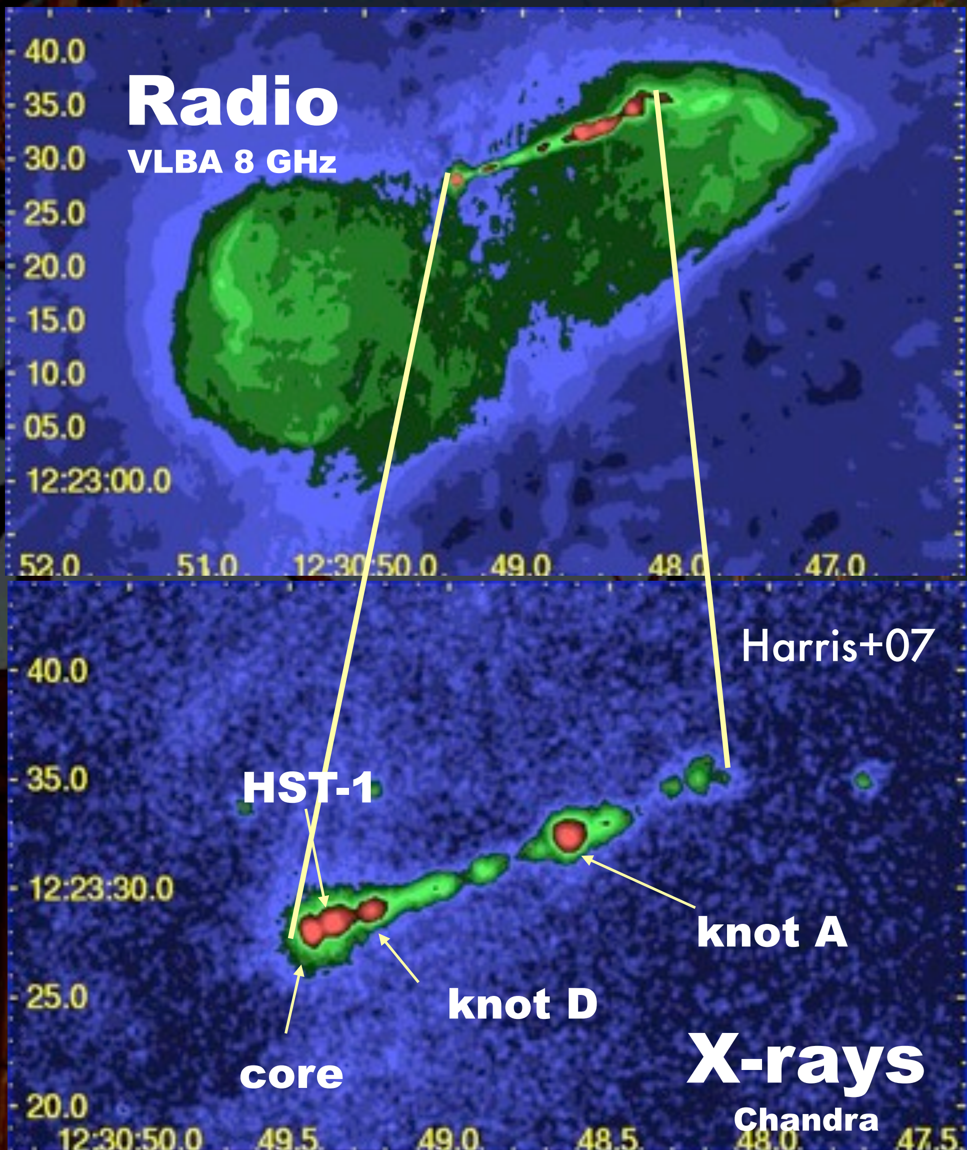

- **X-rays: HST-1 sometimes brighter than nucleus**
- **Nature of the TeV emission?**
  - Leptonic or hadronic acceleration?
  - Proton-induced cascades (Mannheim 93)
  - synchrotron proton radiation (Mücke+Protheroe 01; Aharonian 00)
  - Might also account for parts of the UHECR (Protheroe+03)

- **Location of TeV emission? Core, HST-1, Knot A?**
  - close to the core (Georganopoulos+05; Ghisellini+05; Lenain+08; Tavecchio+Ghisellini+08)
  - large-scale jet (Stawarz+03; Honda07),
  - in the vicinity of BH (Neronov+Aharonian 07; Rieger+Aharonian 08)

Beilicke, Mazin, Raue, RMW et al. 2008
Colin, RMW, Beilicke et al. 2008

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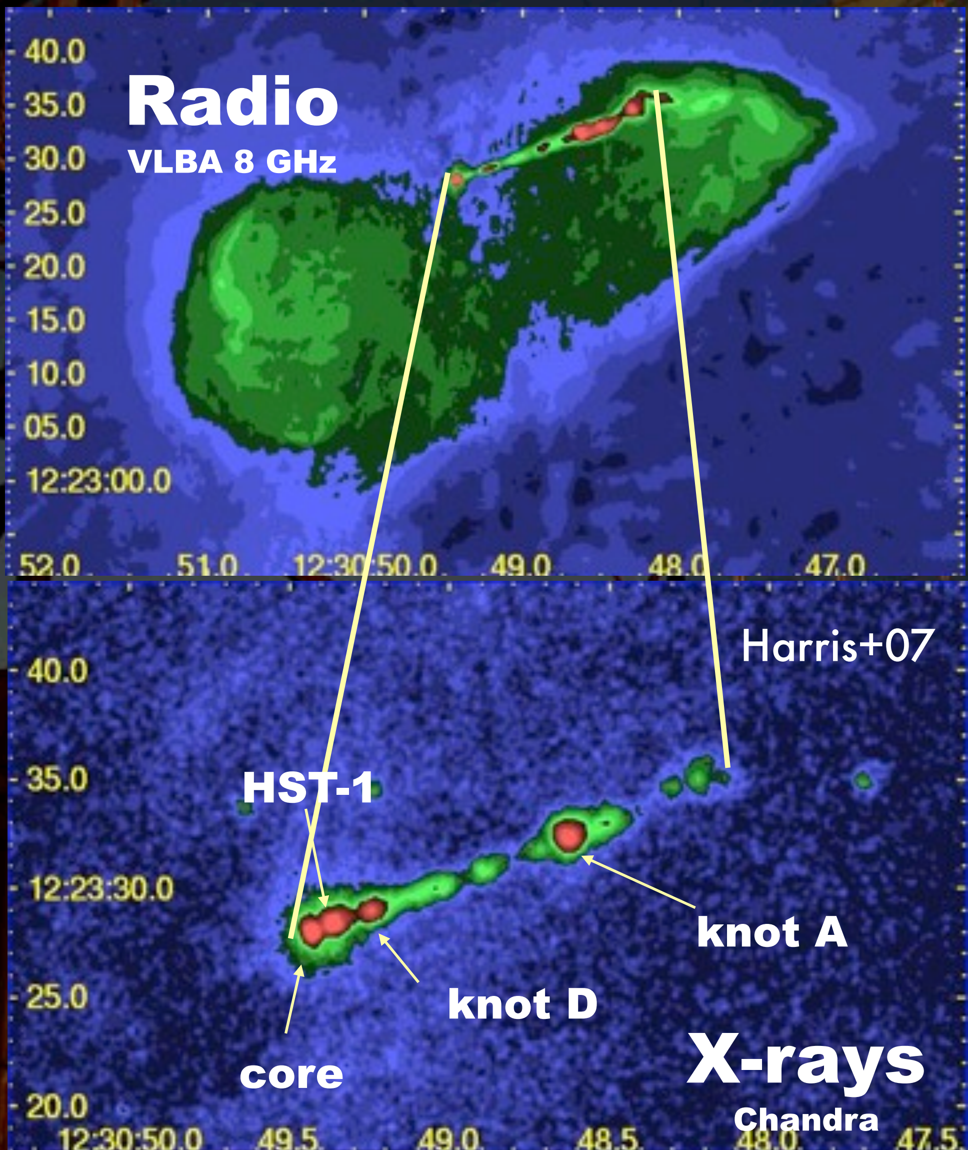
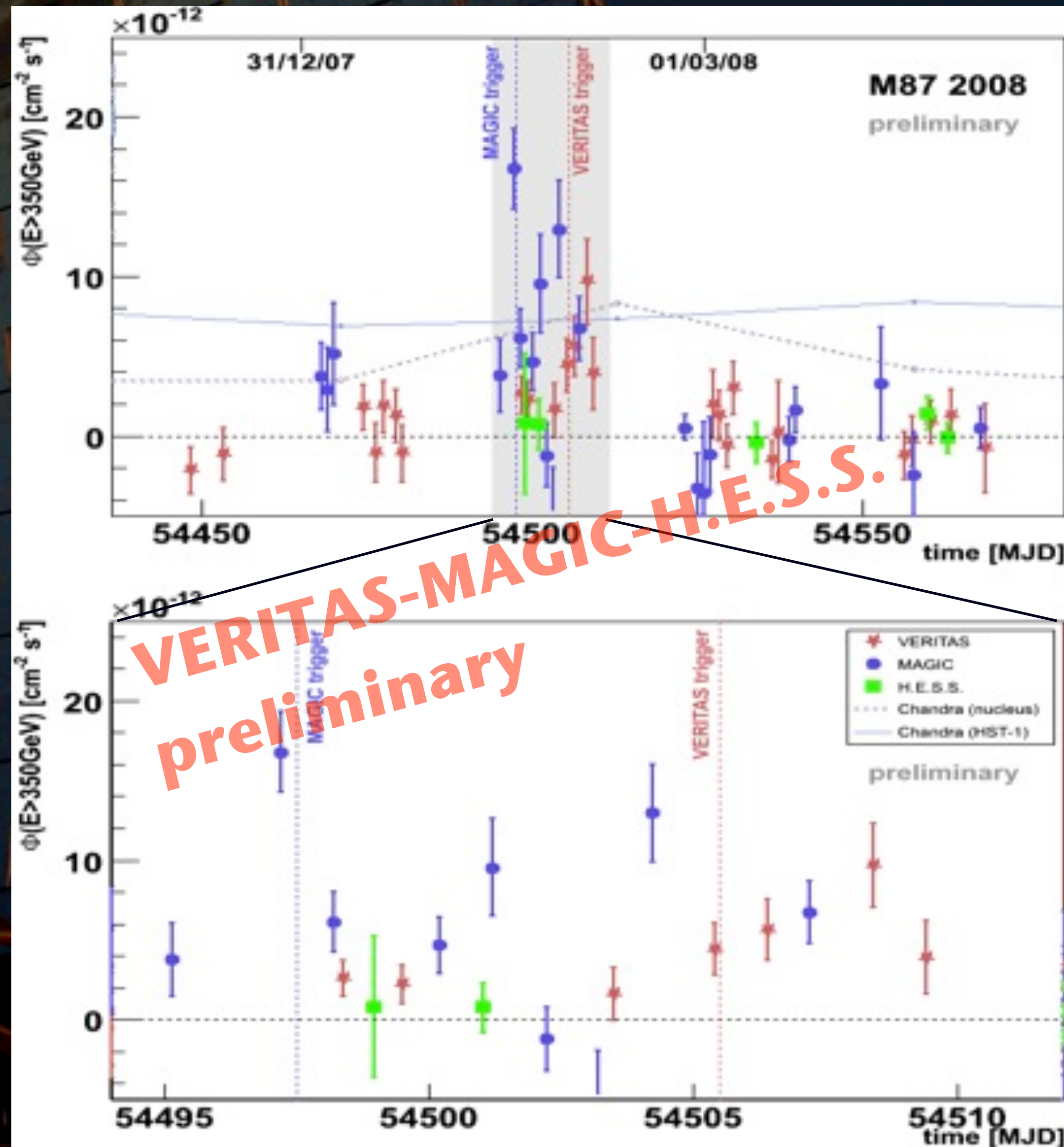
VERITAS-MAGIC-HESS monitoring





Beilicke, Mazin, Raue, RMW et al. 2008
Colin, RMW, Beilicke et al. 2008

MAGIC

Increased radio activity at core during gamma ray high state

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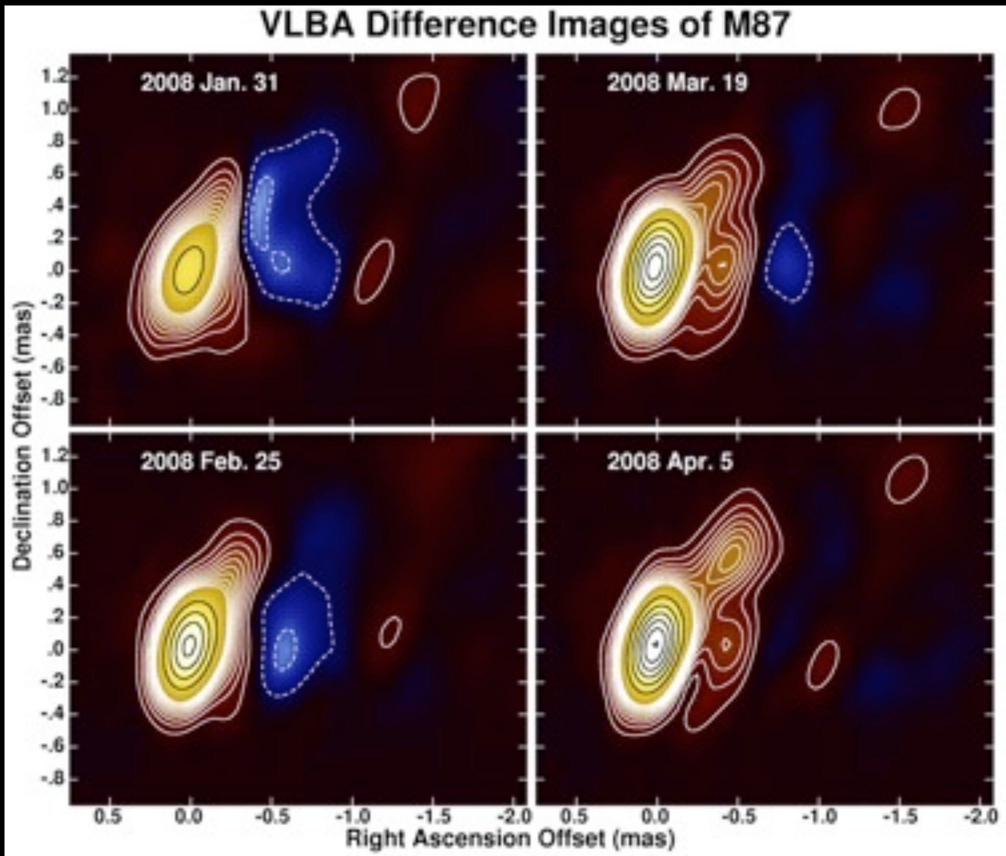

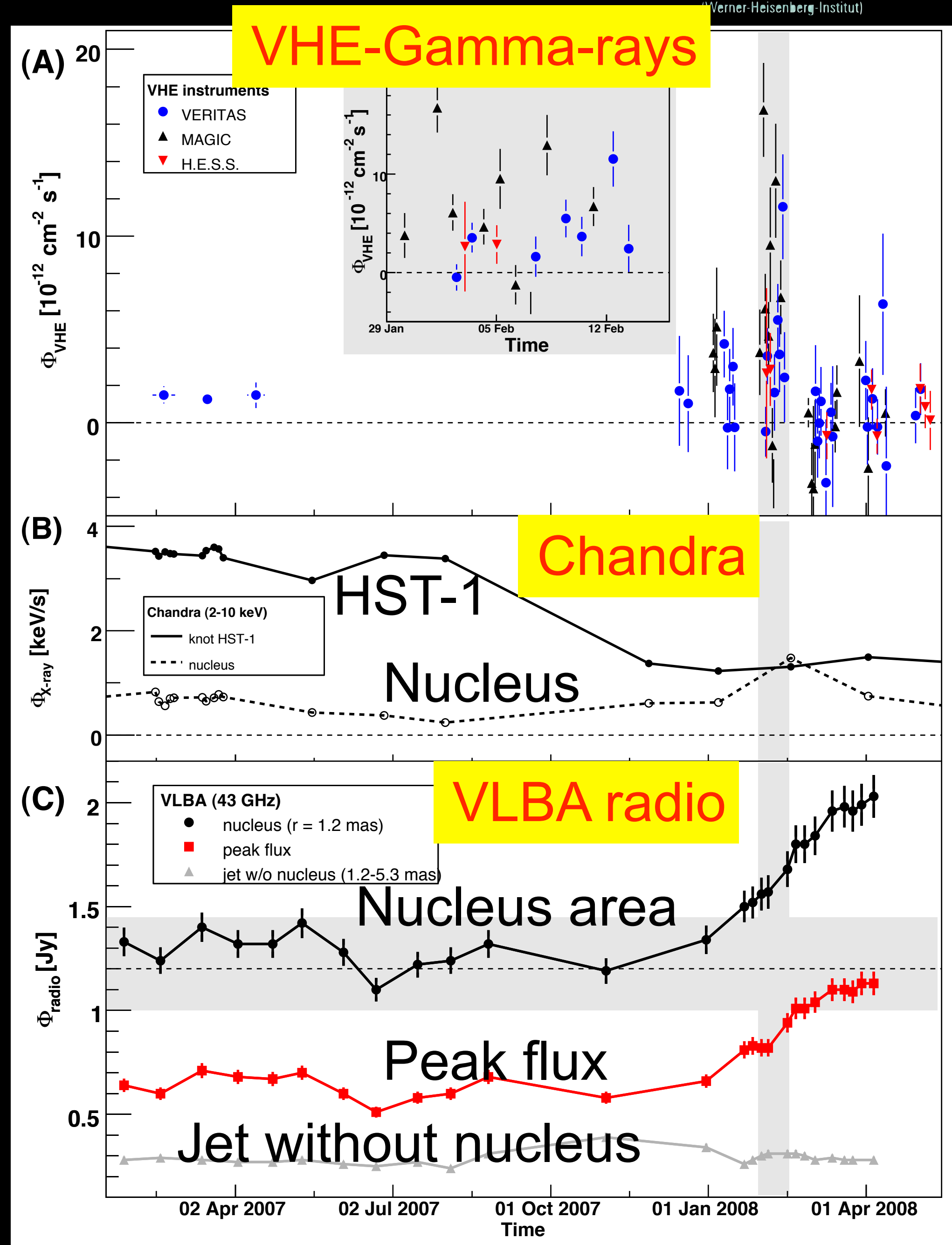

- Gamma emission originates from region close to the core of M87
- Science express, July 2, 2009
  DOI: 10.1126/science.1175406

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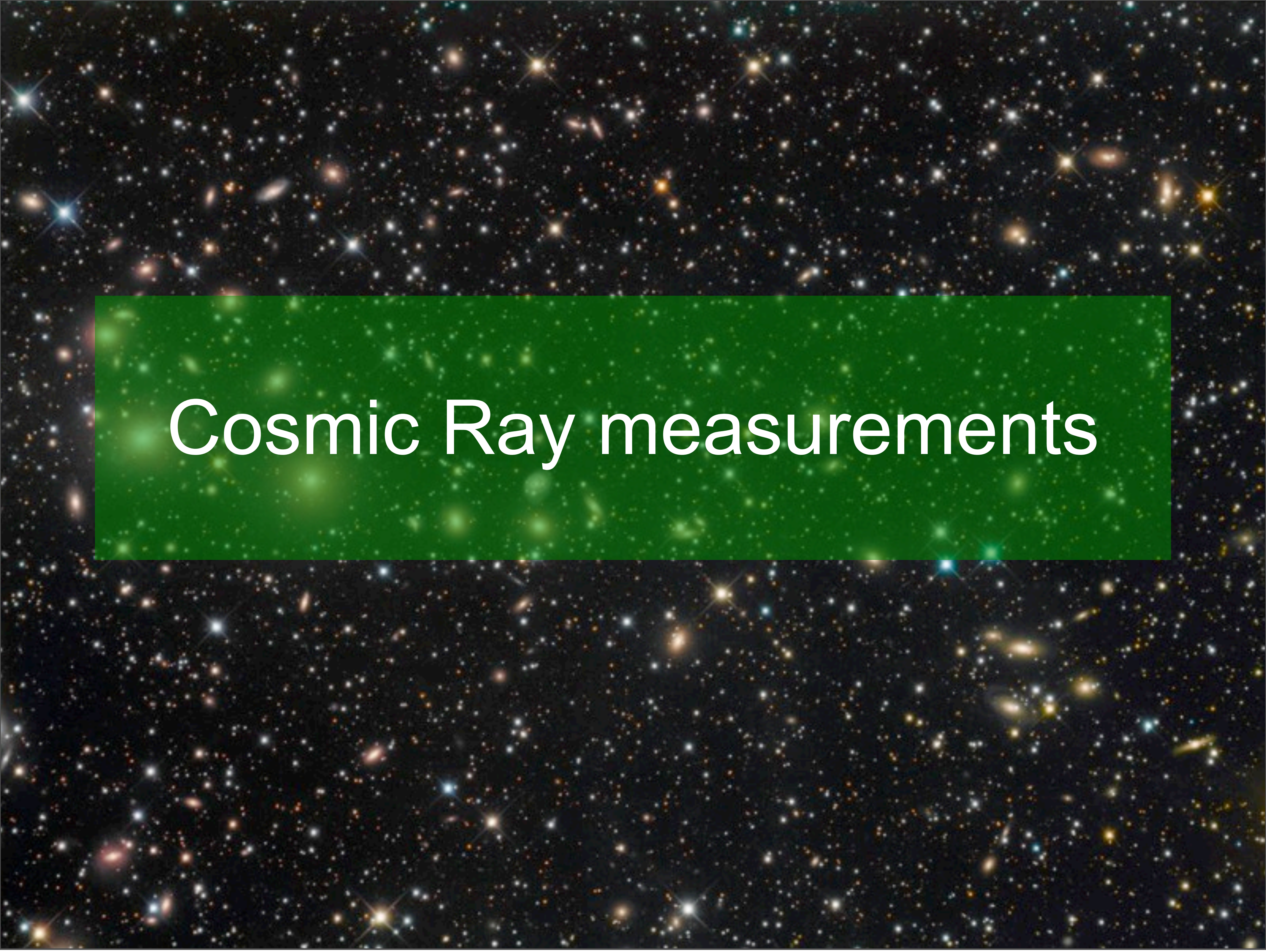
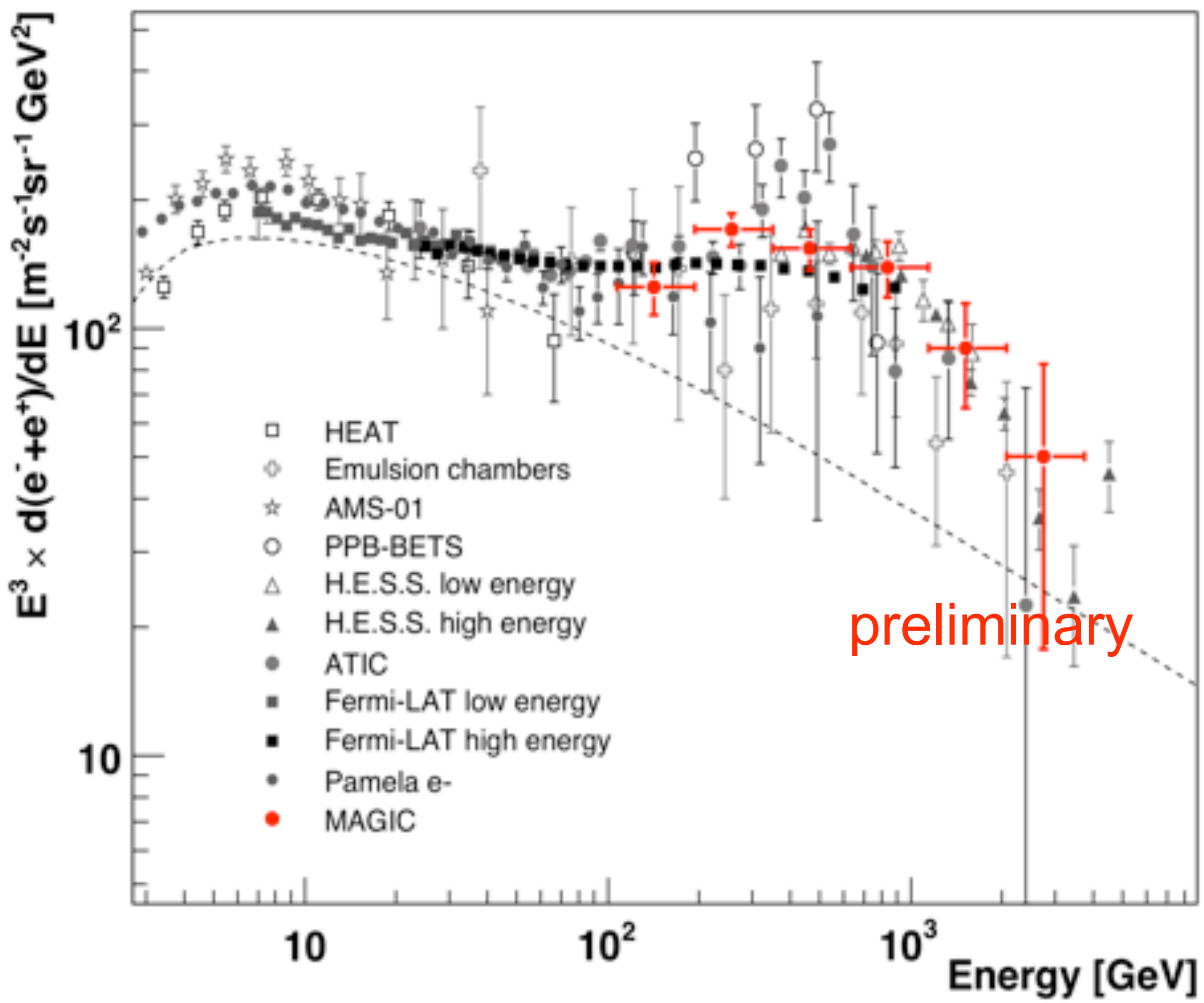

Cosmic Ray measurements

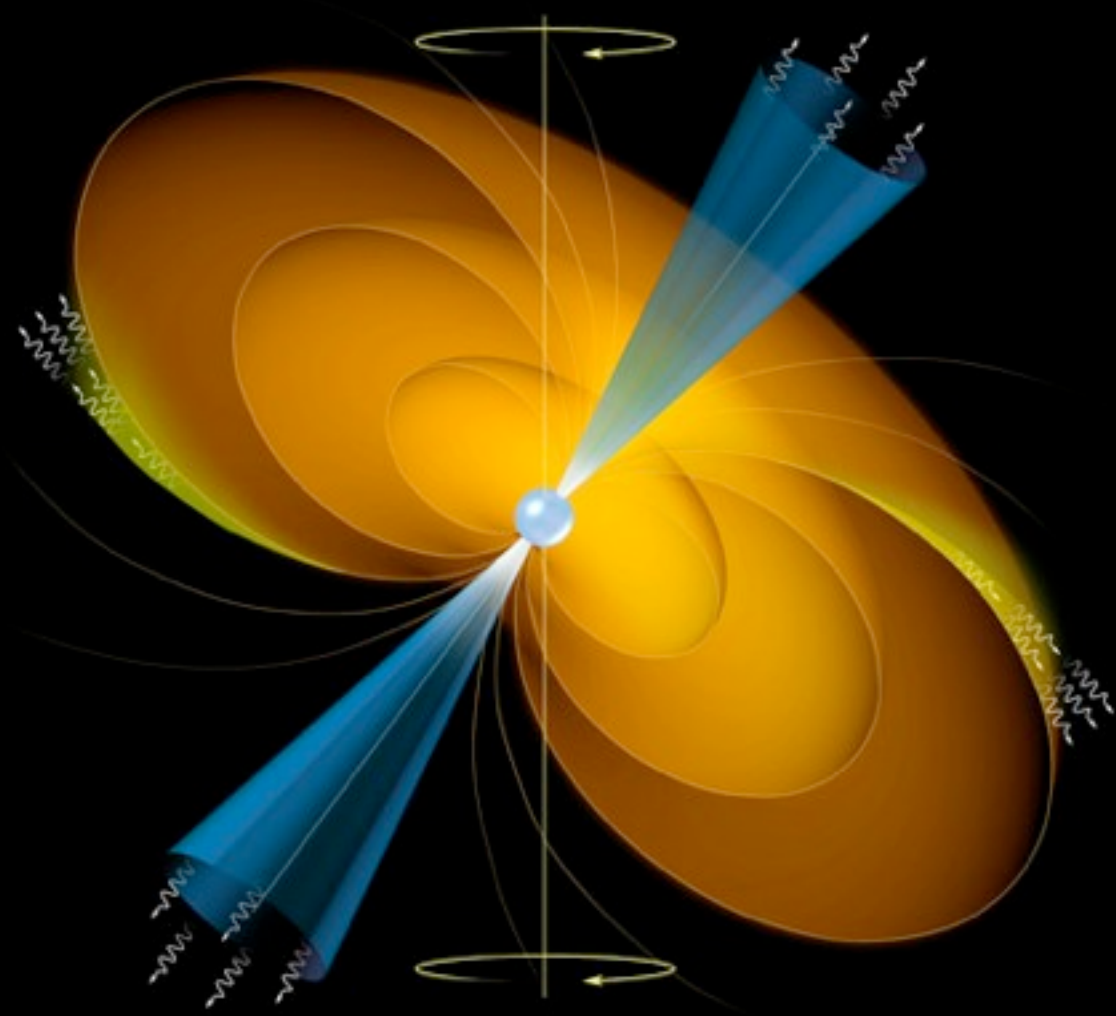
CR $e^- + e^+$ spectrum

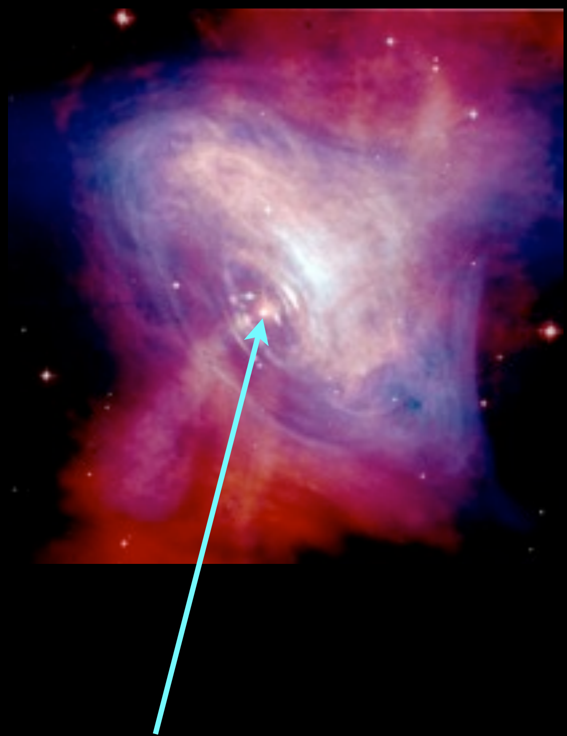
Borla Tridon et al. arXiv:1110.4008

- First result based on only 14h of observations: measured $e^{\pm}$ spectrum in the energy range between **100 GeV and 3 TeV.**
- Preliminary results fitted by a power-law with index Γ= **$-3.16\pm0.06_{stat}\pm0.15_{sys}$.**
- Spectrum in good agreement with previous measurements (bump observed by ATIC cannot be excluded or confirmed).



Pulsar observations with MAGIC

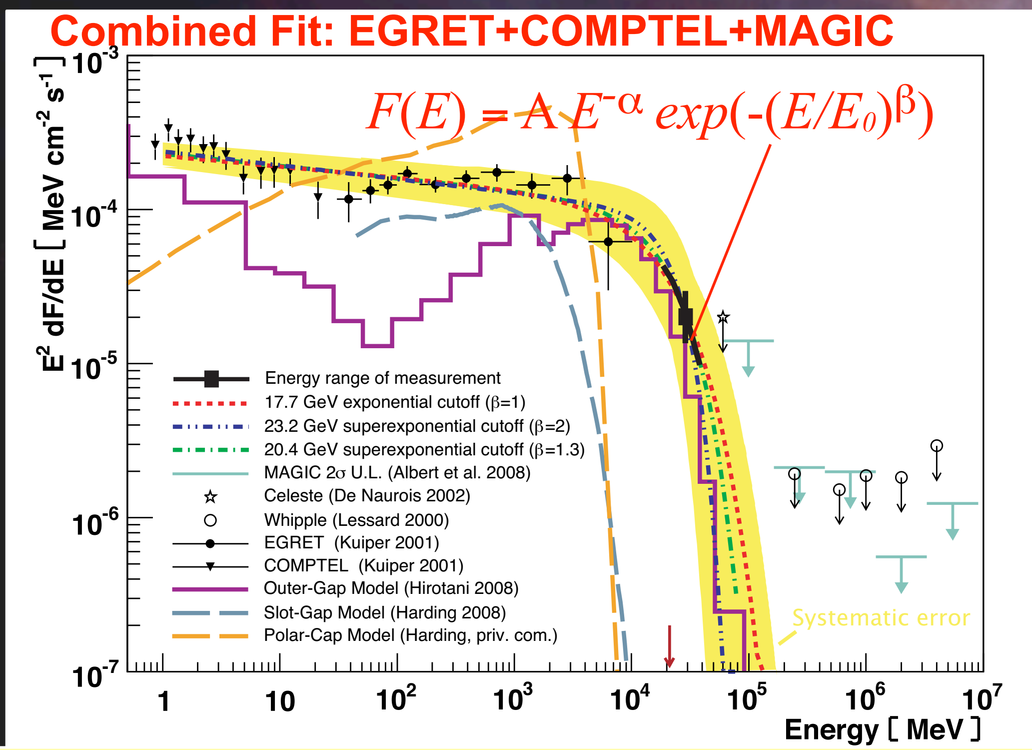




- Huge magnetic field of 10^8T
- Absorption of gamma rays through magnetic pair production
- Polar cap model, outer gap model & slot gap model

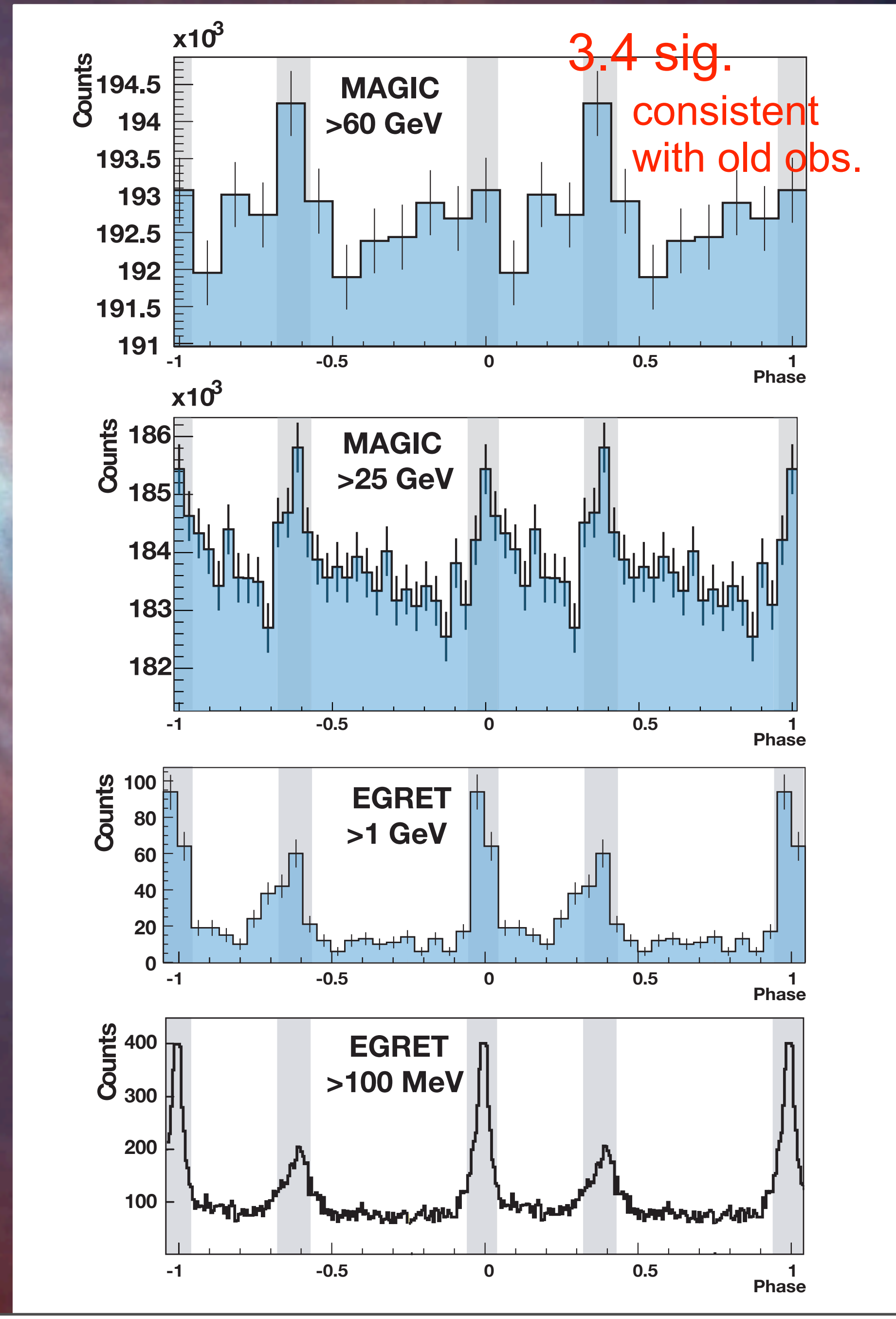
Detection of the Crab pulsar above 25 GeV at 6.4 sigma !

- Crab observation from October 2007 until Febrary 2007:
  22.3h good hours/40 hours: 8500+-1330 Excess events
- Pulses in phase with EGRET
- P1 = P2 !! at 25 GeV



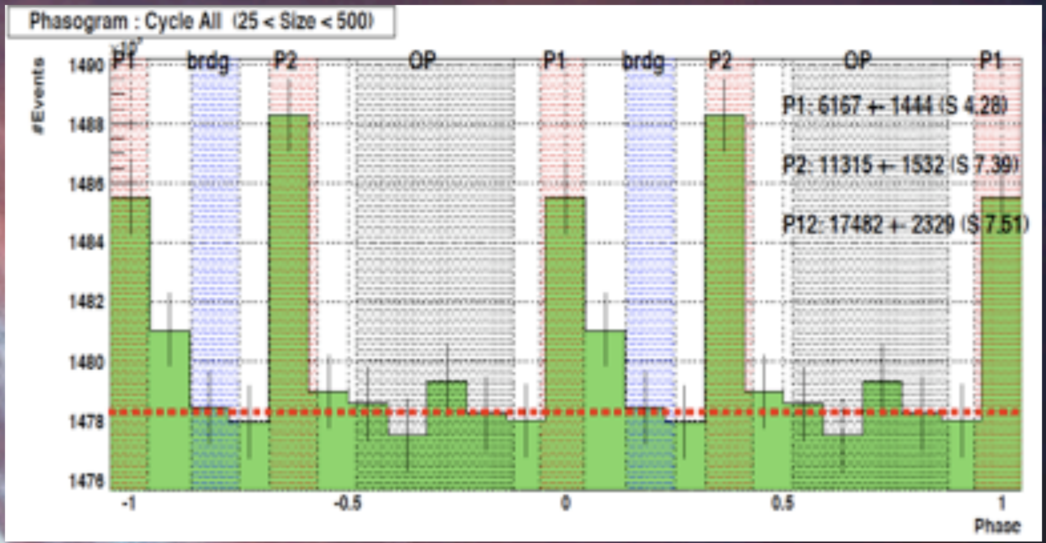
$E0=17.7 \pm 2.8_{stat} \pm 5.0_{syst}$ GeV for $\beta = 1$ (exp.)

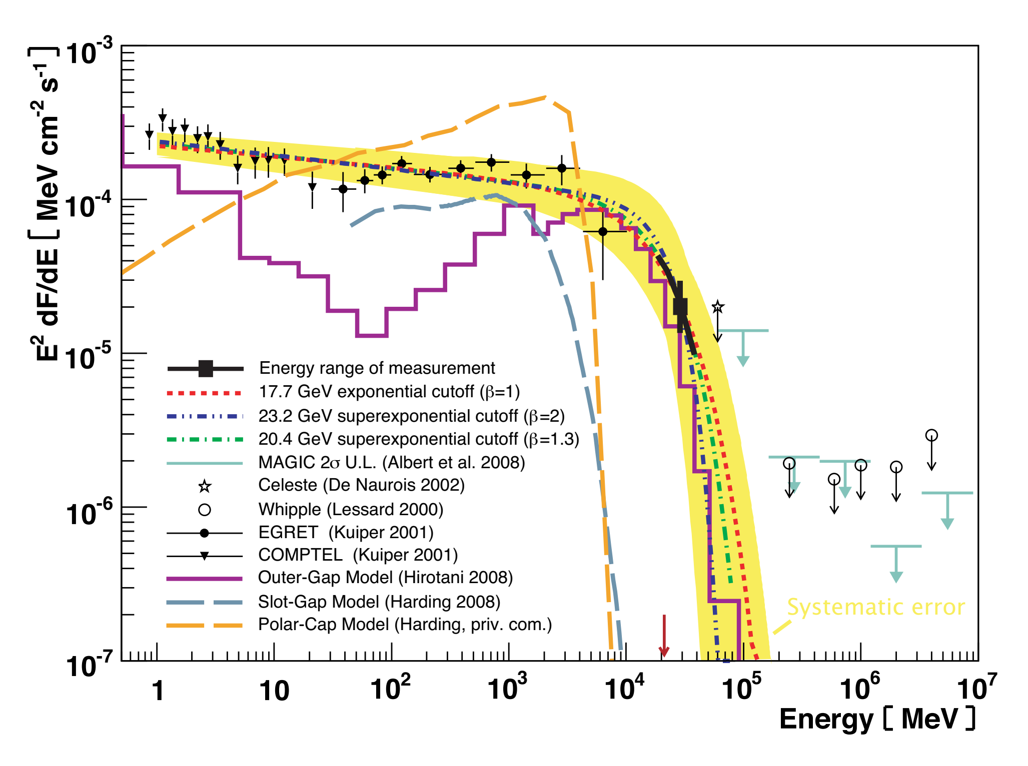
$E0=23.2 \pm 2.9_{stat} \pm 6.6_{syst}$ GeV for $\beta = 2$ (super-exp.)



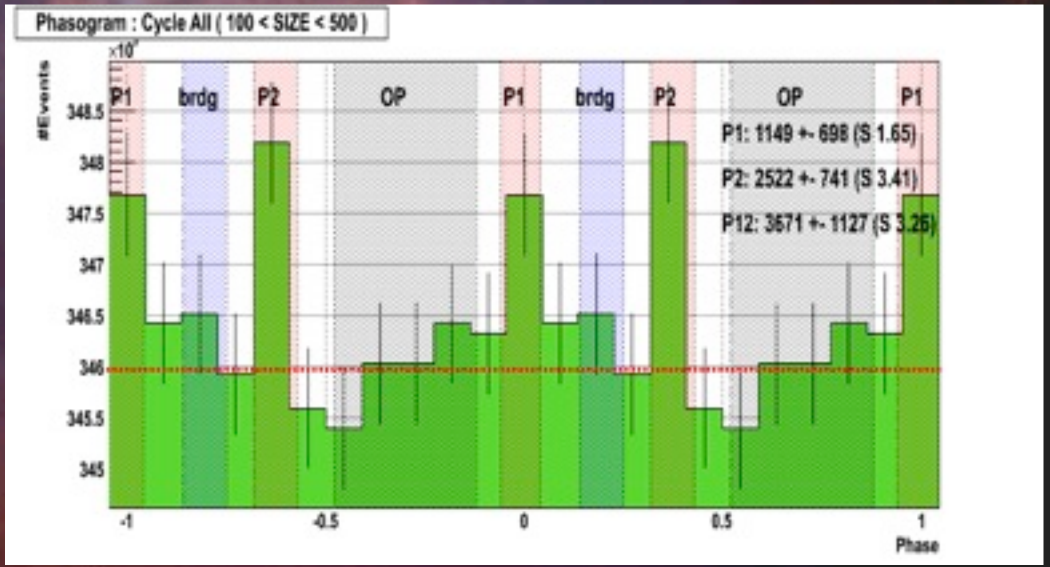
2007+2008: 7.5 Sigma above 25 GeV

**High cutoff excludes emission close to the neutron star !!
(polar cap model)**





Emission above 60 GeV ?



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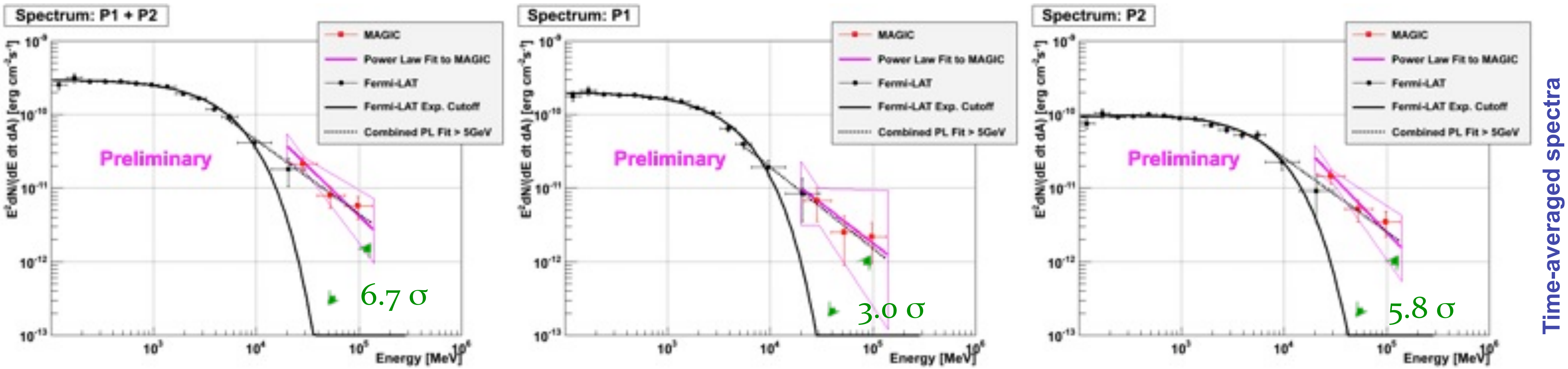
Mono observations 2007-09

MAGIC, ApJ, 742, 43 (2011)

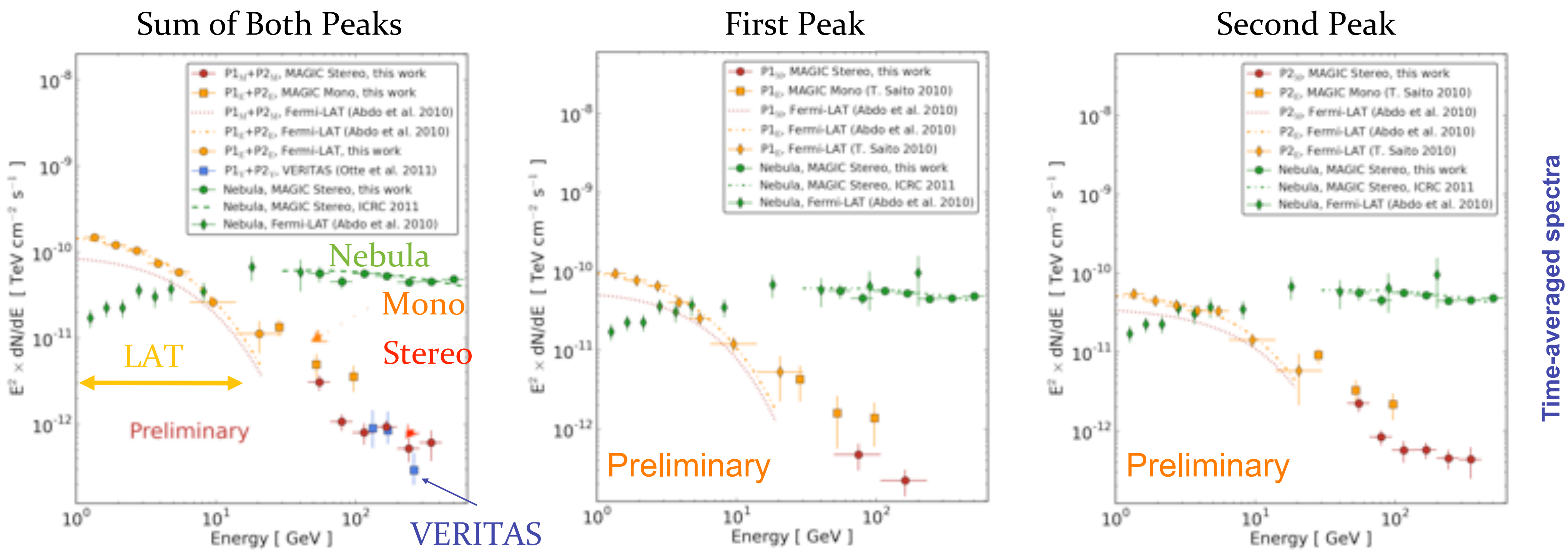
- From Oct. 2007 to Feb. 2009, 59 hours
- Sum Trigger, E >25 GeV



- **Inconsistent** with the extrapolation of the exponential cutoff (>5 σ).
- Spectra between 25 GeV and 100 GeV show a **power law**.

HOT NEWS: after 73 hours of stereo data

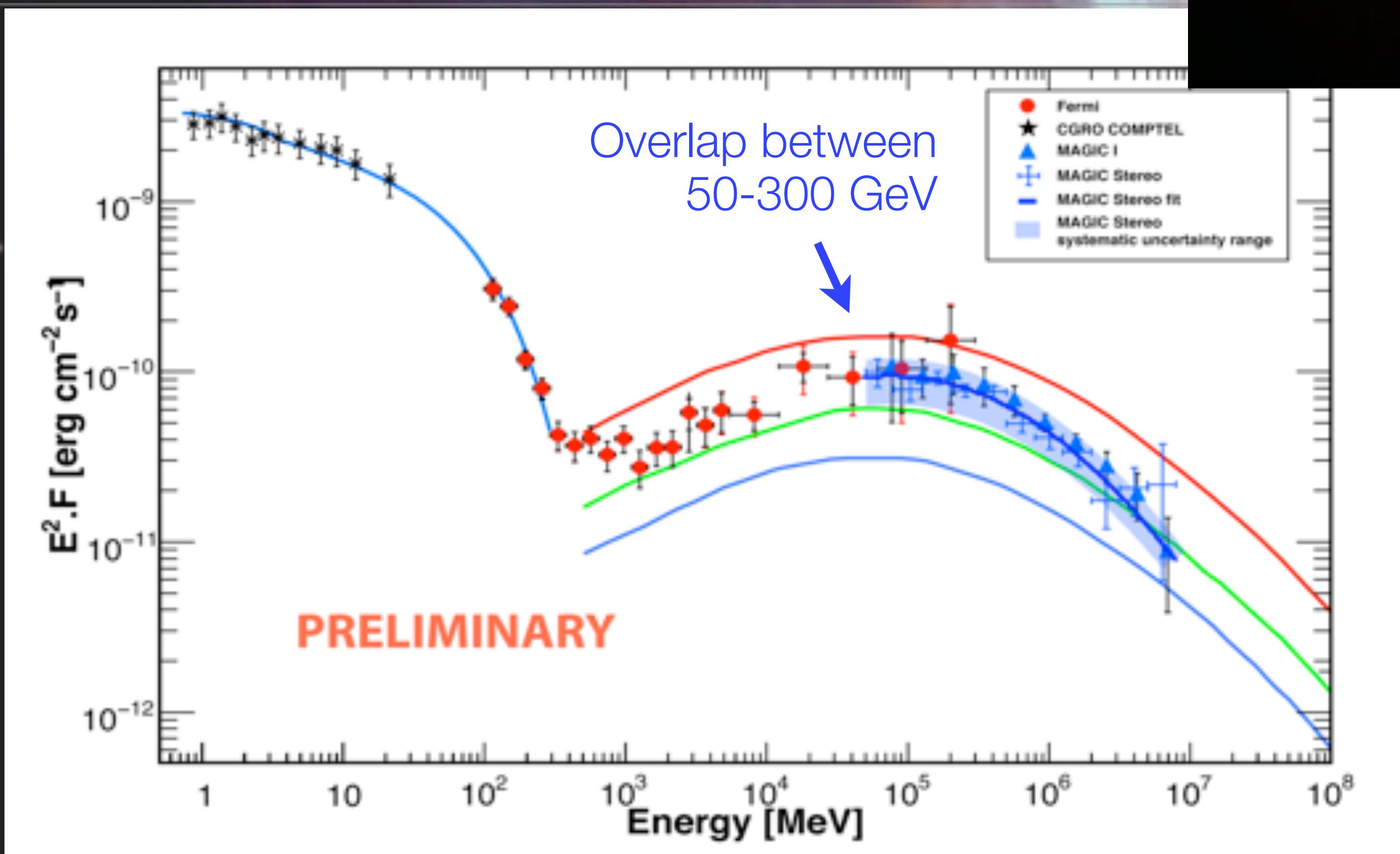
MAGIC, published in A&A (2011)



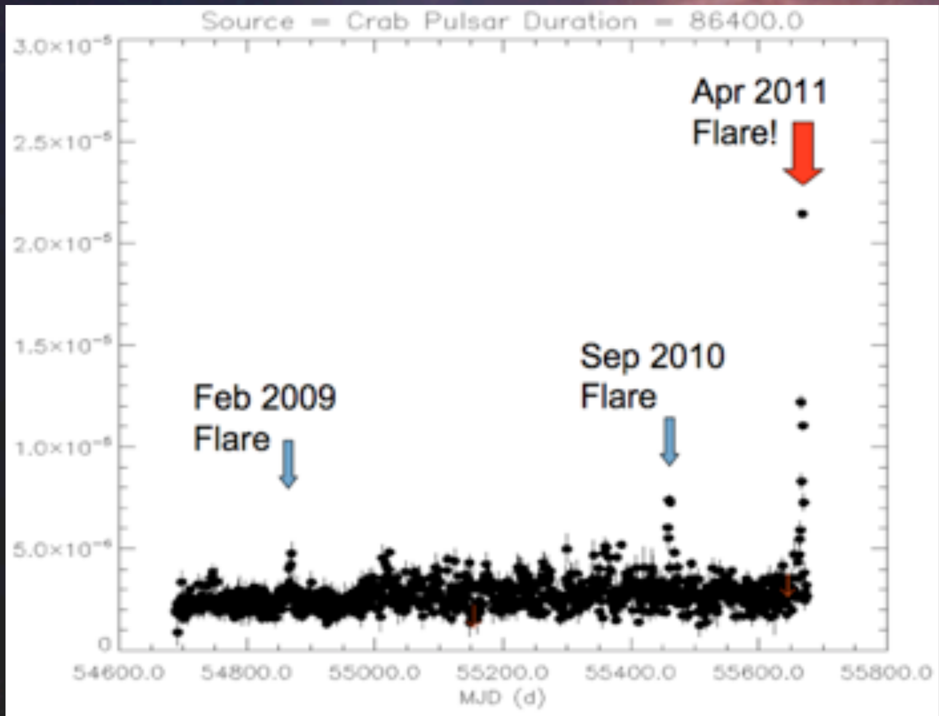
- Stereo data provides precise spectra up to 400 GeV.
- No gap between Fermi and MAGIC.
- We can even produce spectra for both peaks separately.
- Mono/stereo spectra agree… and go well beyond a cutoff at few GeV!

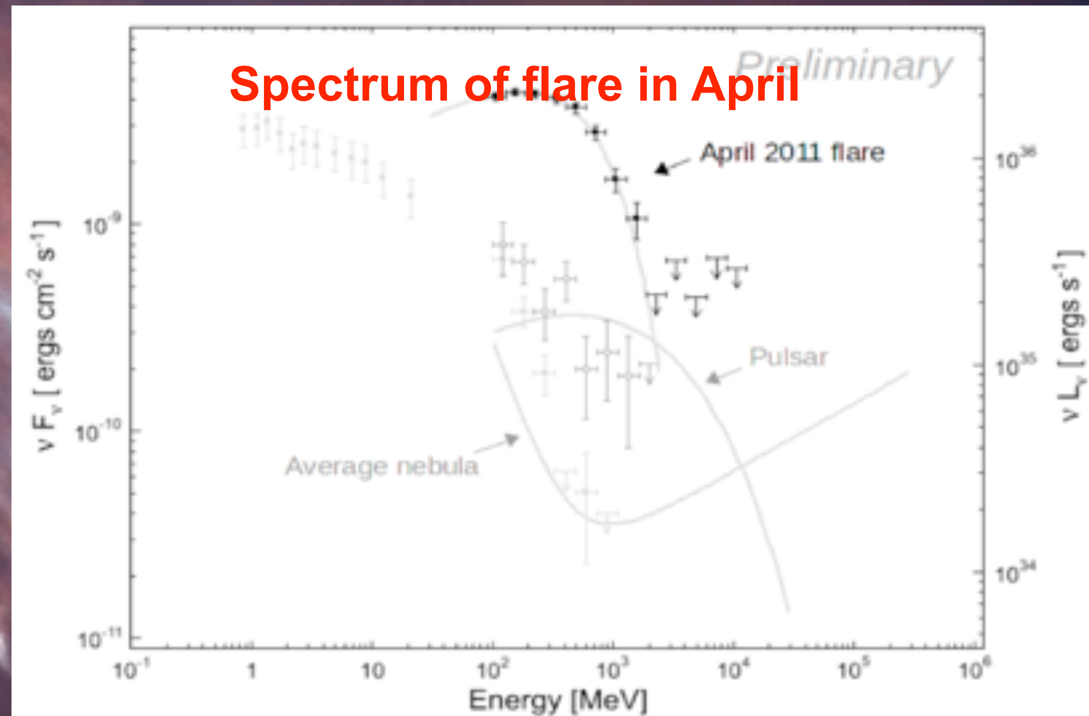
The Nebula Emission

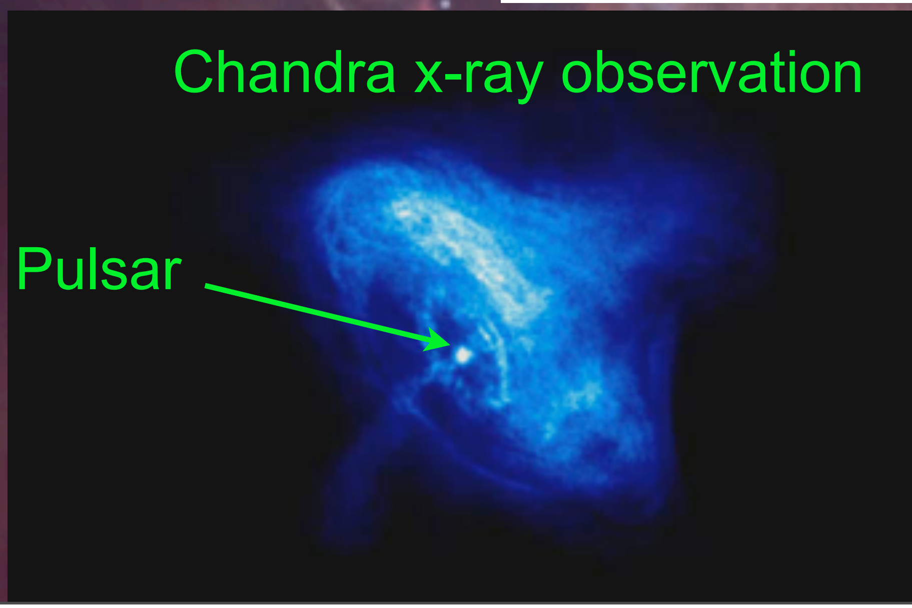
- MAGIC measures the nebula spectrum down to 50 GeV with a good overlap with FERMI between 50-300 GeV
- The IC peak can be very clearly seen now.



Flares from Crab nebula >100MeV seen by FERMI





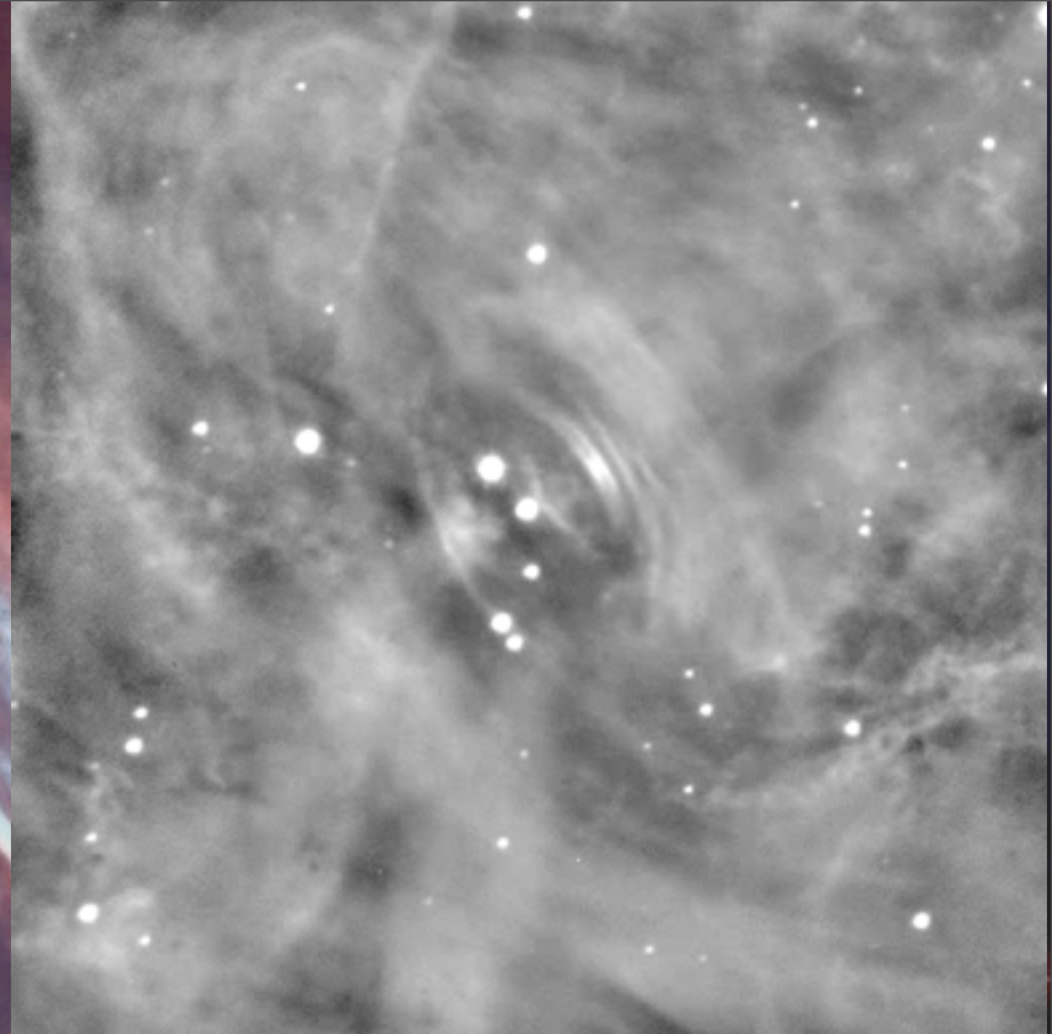


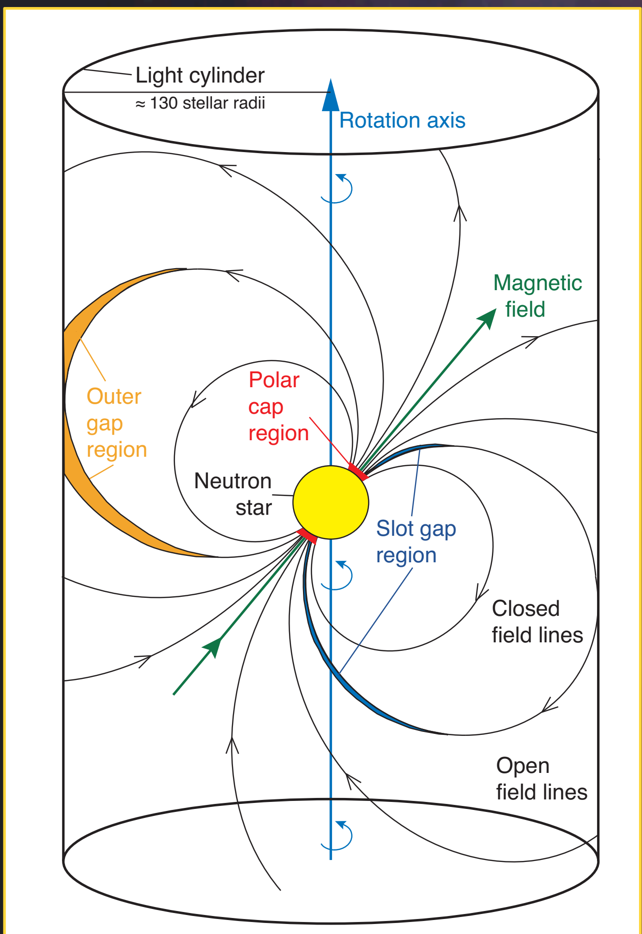
Thomas Schweizer

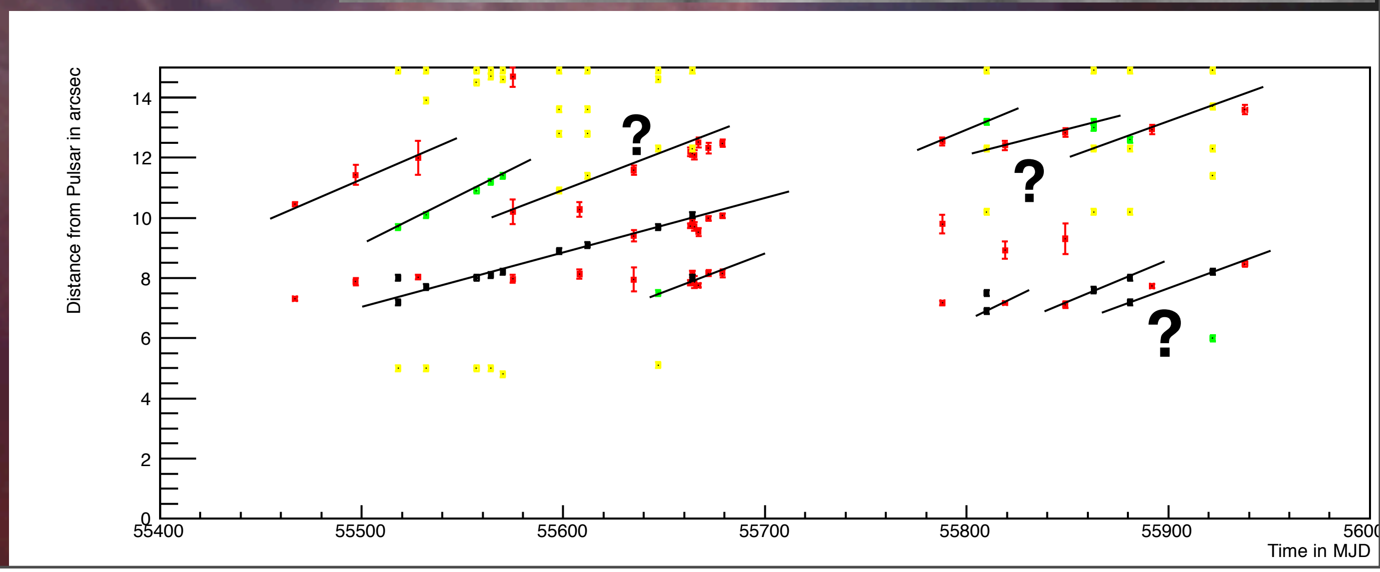

Nordic Optical Telescope
La Palma

Observations in optical with NOT

- Study of variability in inner nebula
- Study of movements of wisps
- Study of correlation with FERMI, MAGIC, Chandra, timing noise







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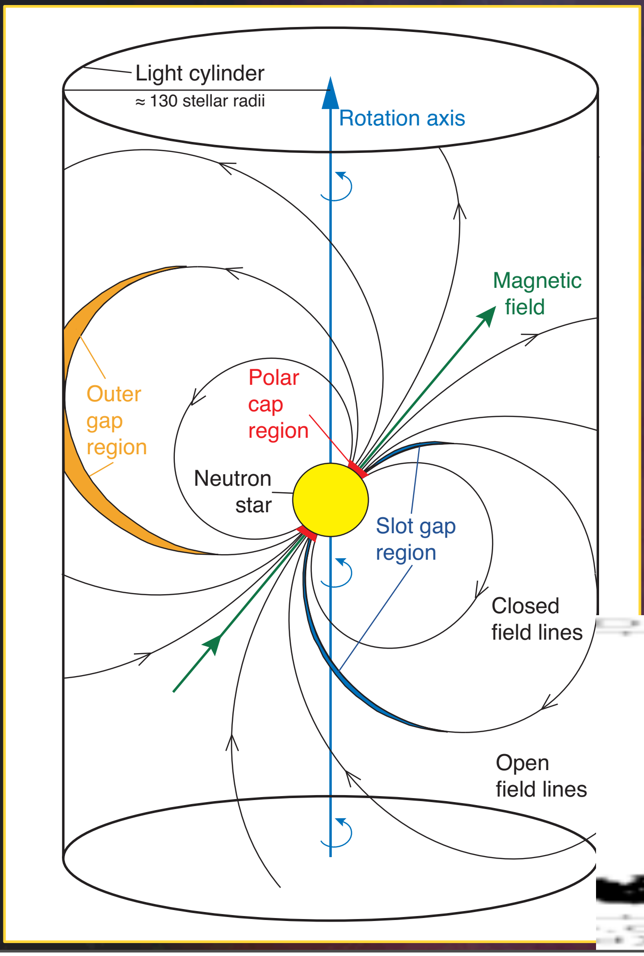
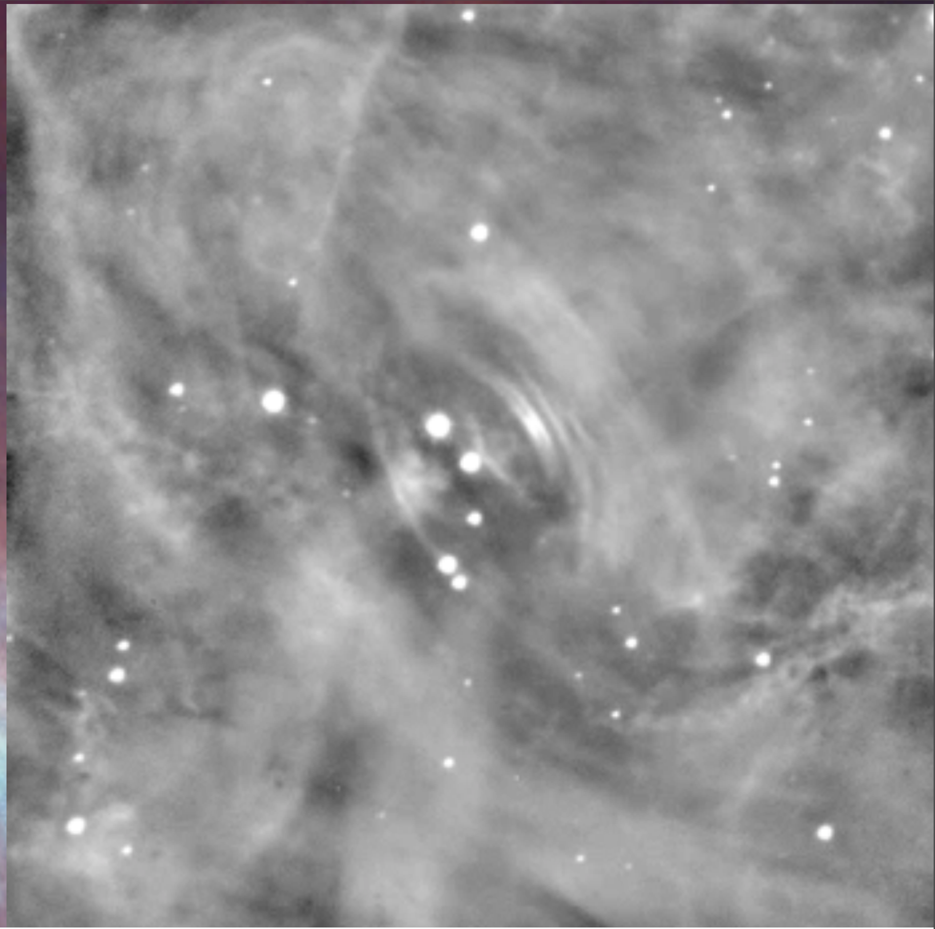
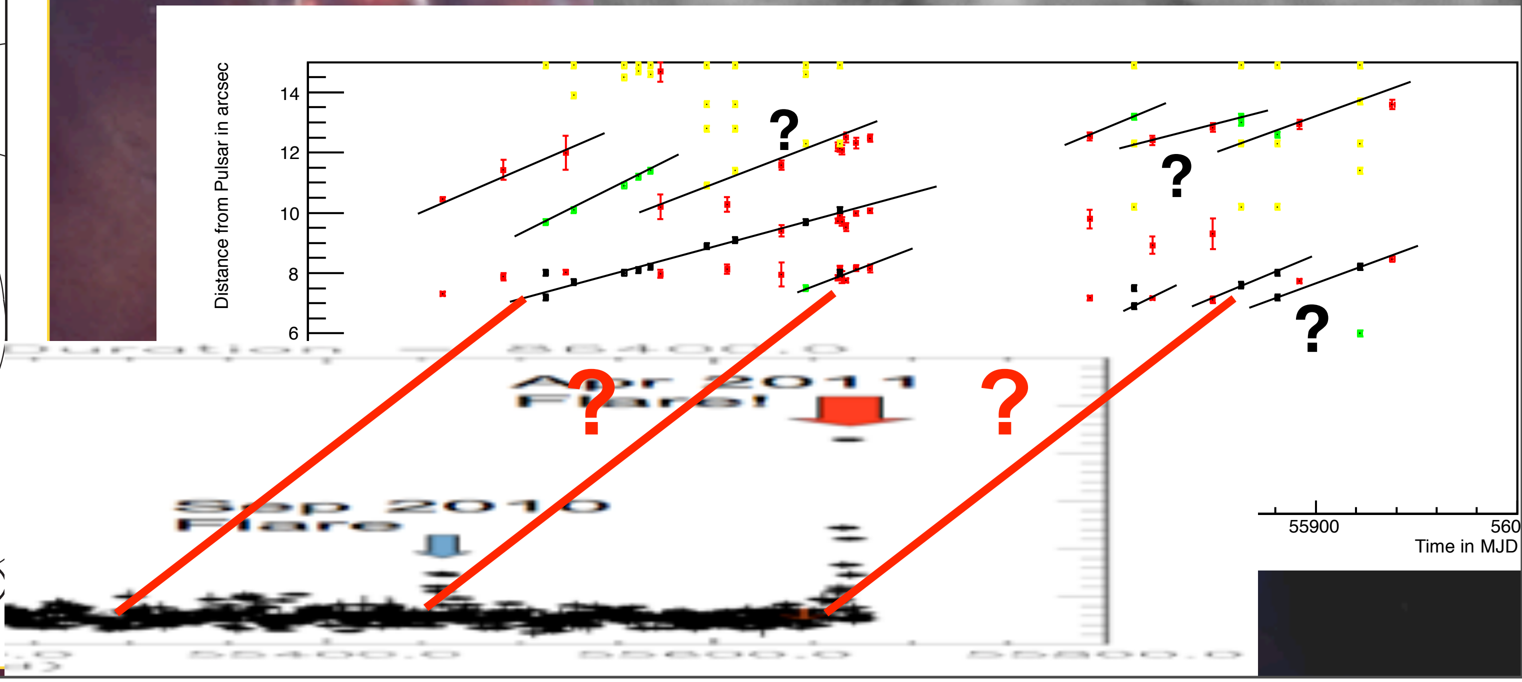






The Cherenkov Telescope Array (CTA)

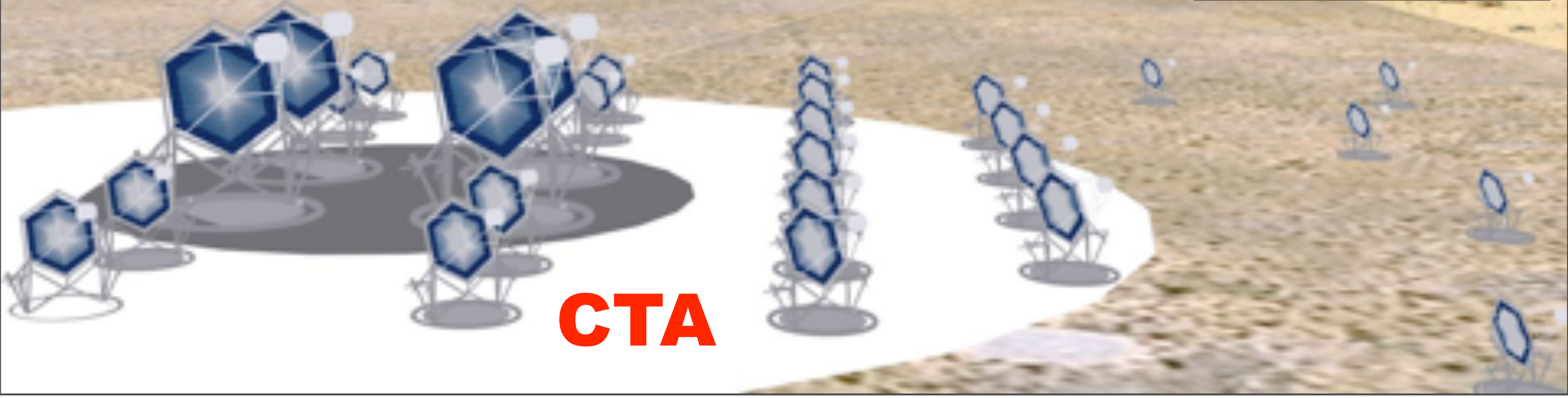
1000 members
from ~90 institutions

- MAGIC collaboration
- HESS collaboration
- VERITAS/AGIS collaboration
- Astronomers from EU, Japan, US

MAGIC

HESS

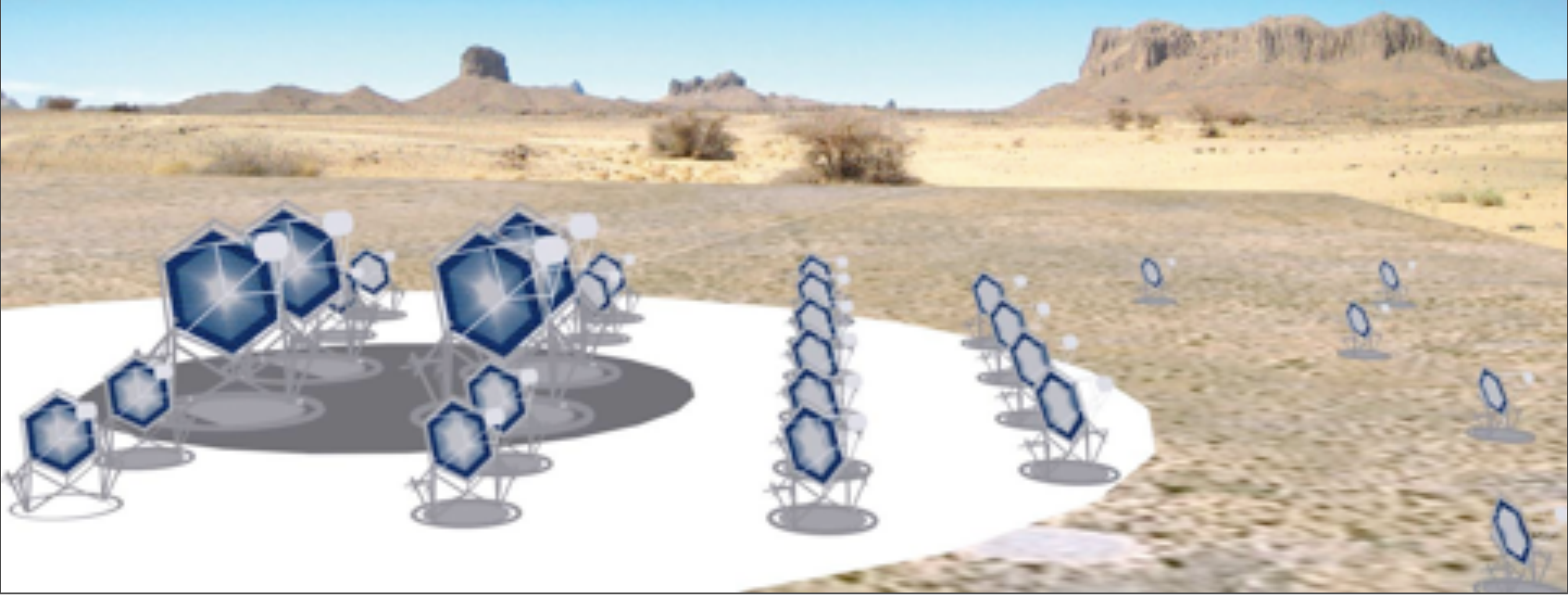
AGIS



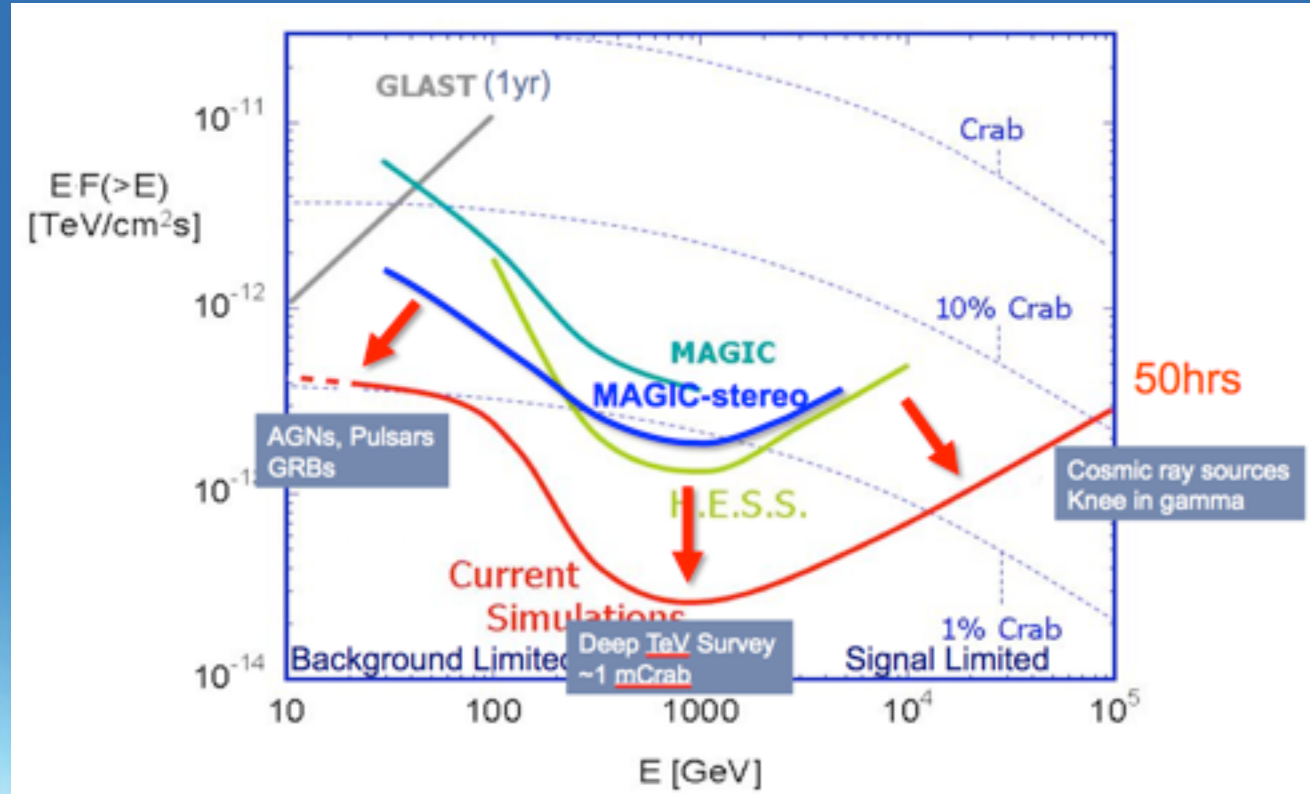
CTA

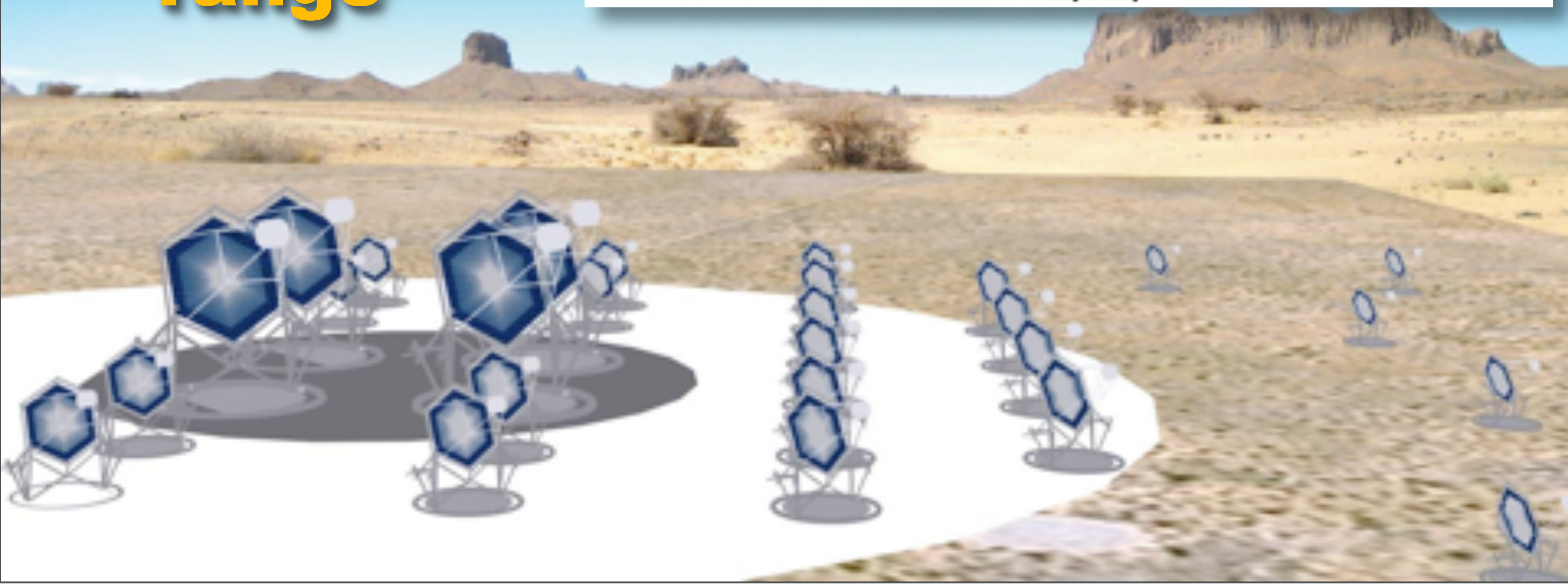
CTA specifications

- Boost sensitivity to 1 mCrab
- Expand energy range ~10-20 GeV to 100 TeV
- Improved angular resolution
- Full sky coverage (two installations)
- Observatory open to external astronomers
- Budget 150 Mio Euro
- Lots of new physics



Three telescope sizes for large dynamic range





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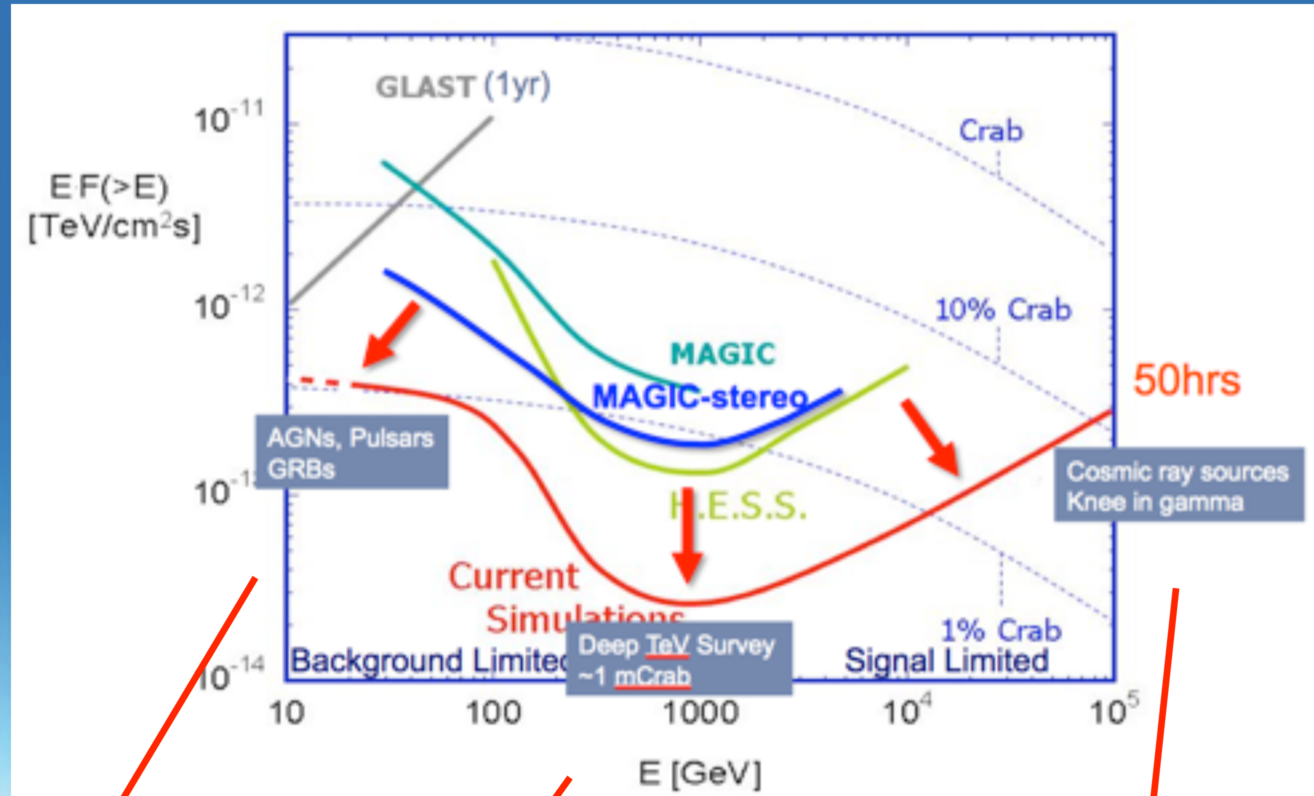
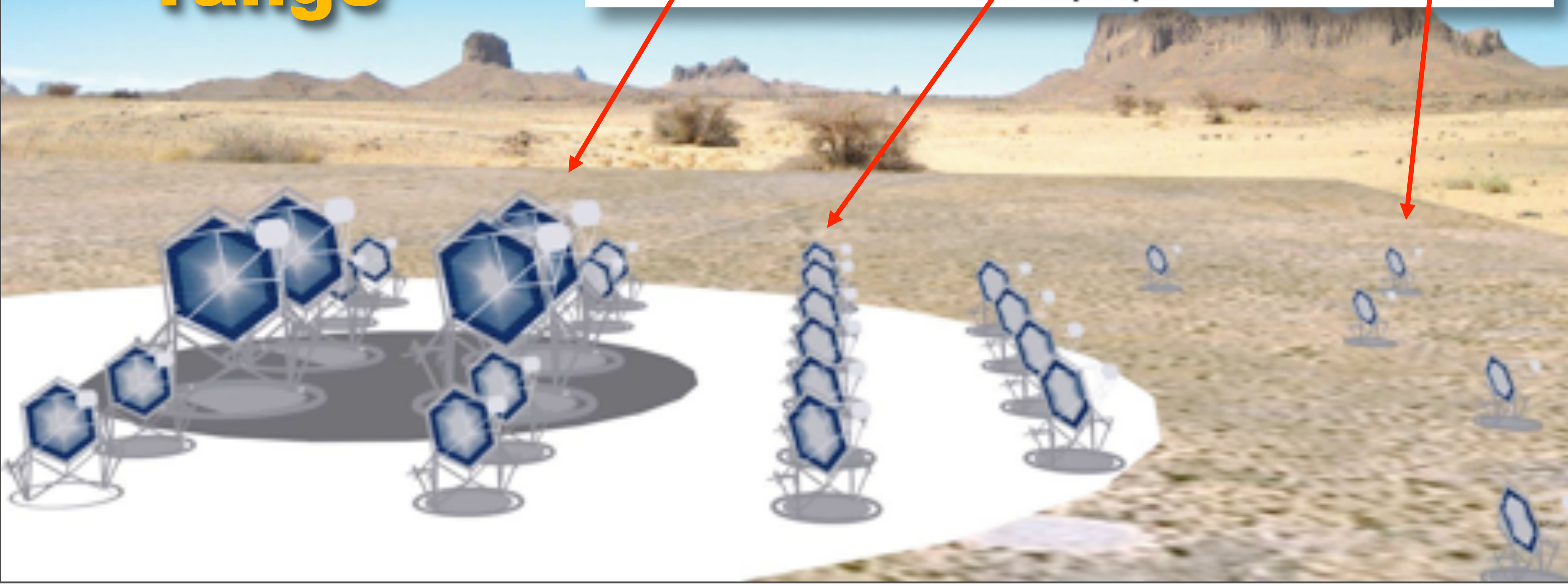
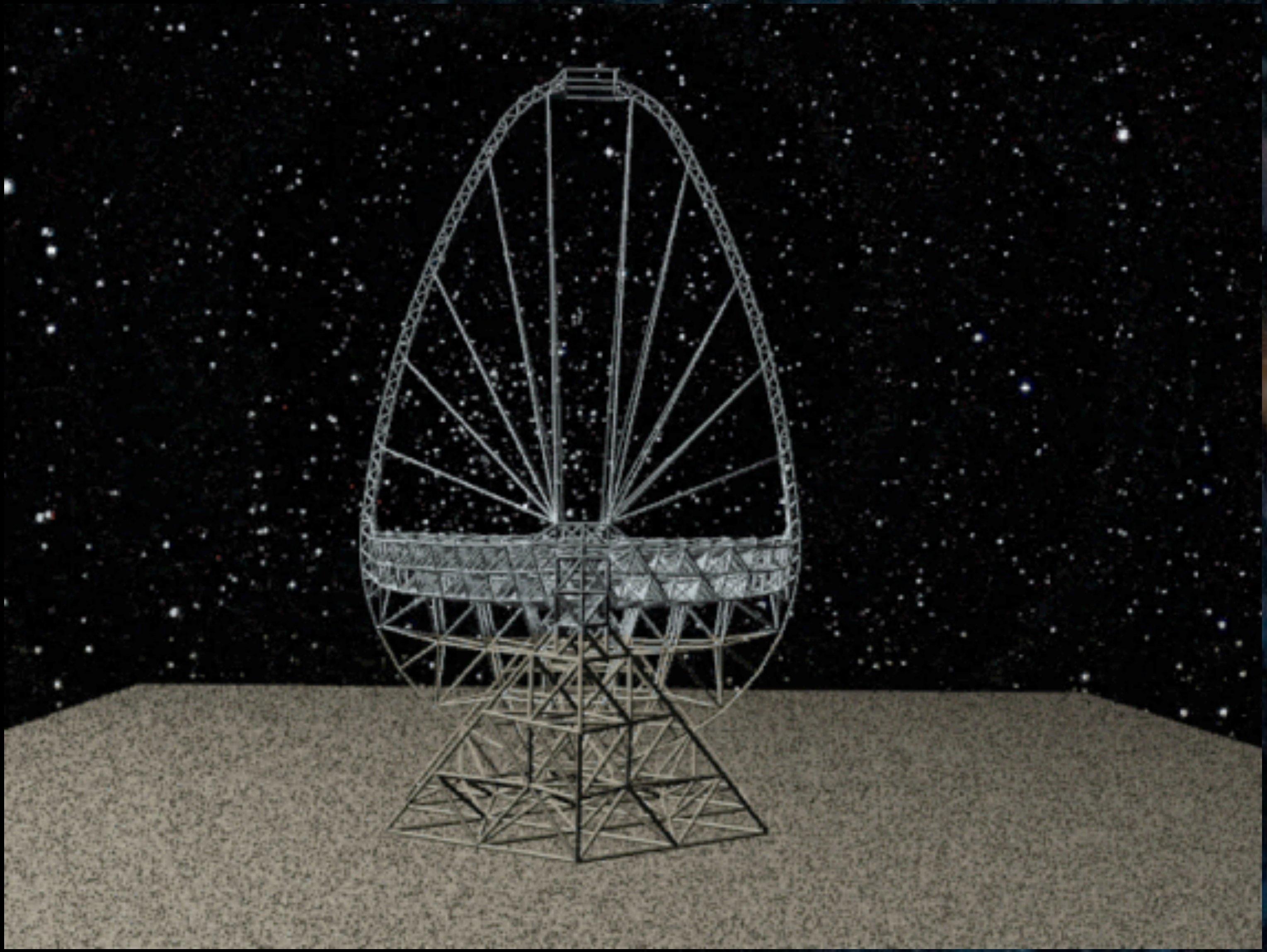
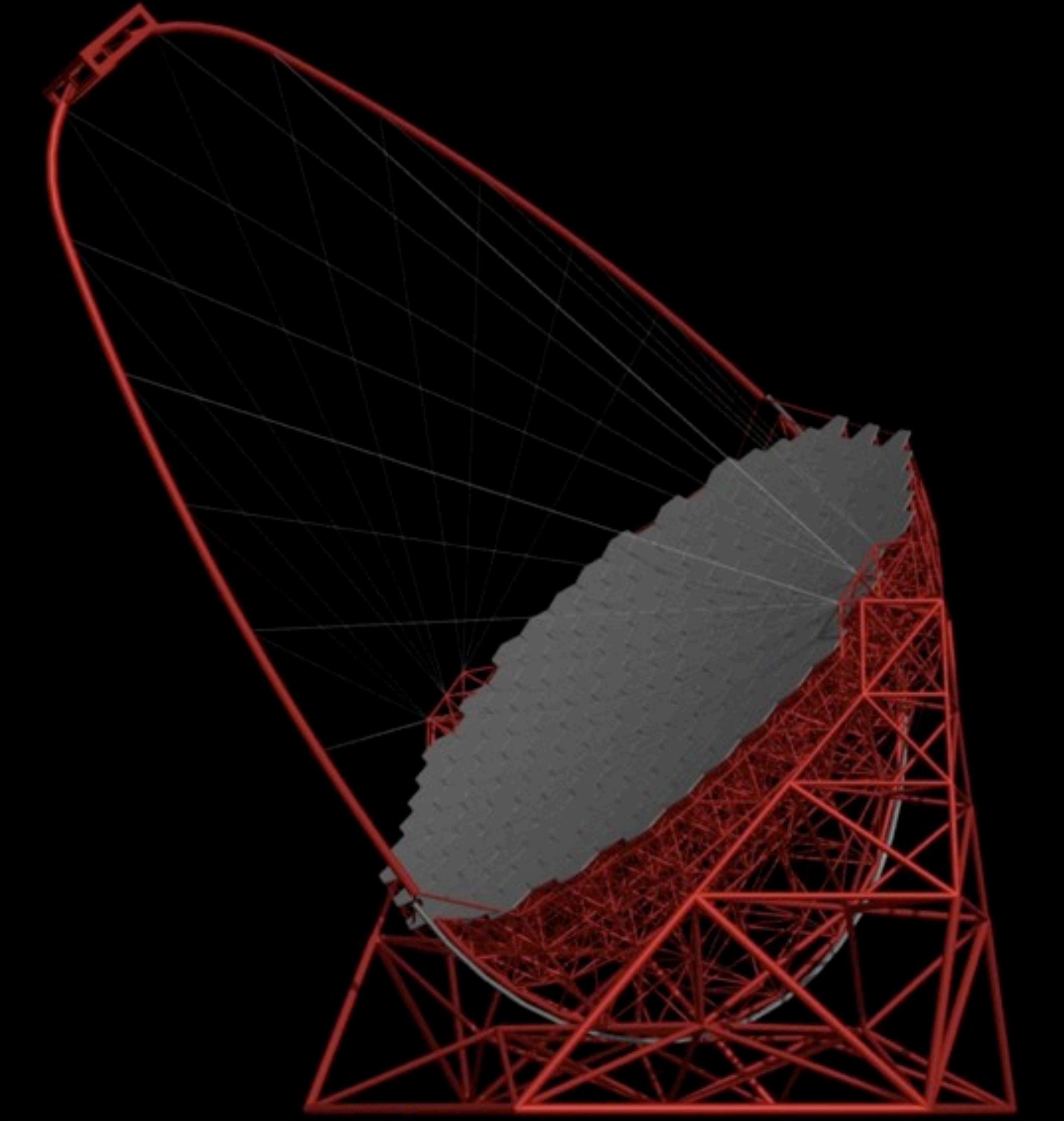




MPI
The Large Size Telescope





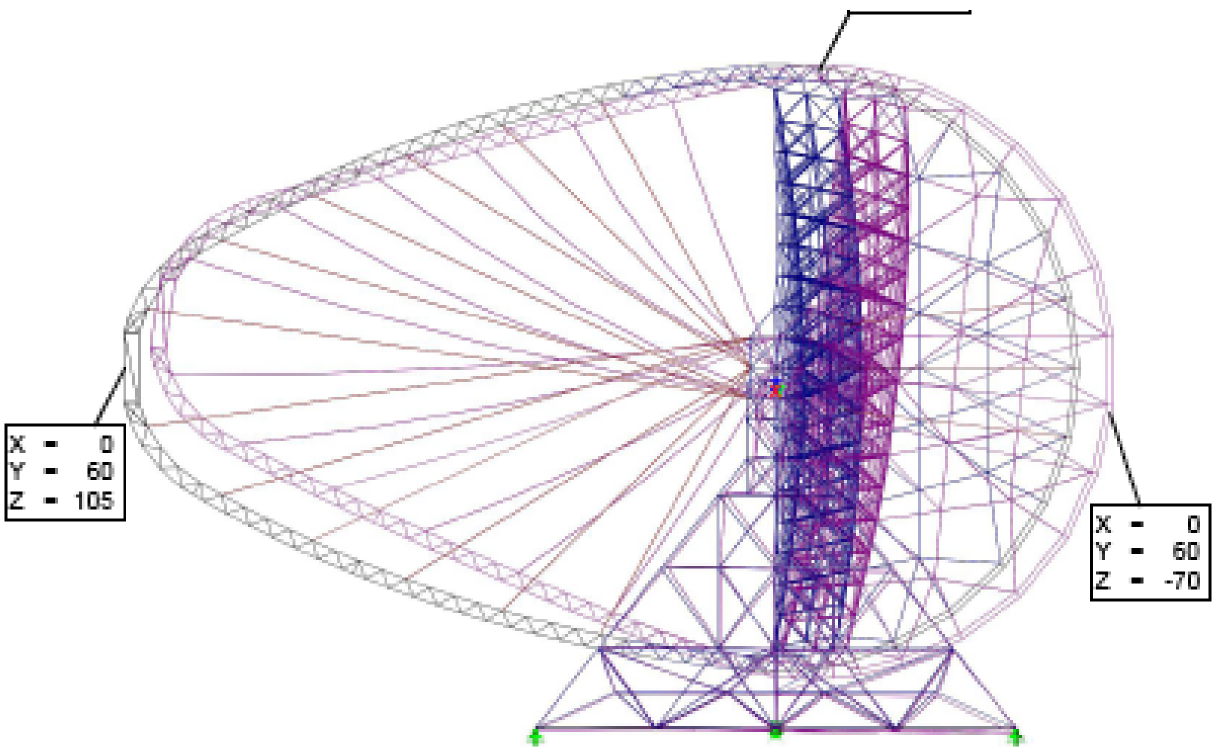
Extremely robust structure

Withstand storm (200 km/h)

- Wind load at the order of 60-70 t on dish
and from the side on the space frame

--> Pressure on boggies
(up to 75t and about 25t uplift) !

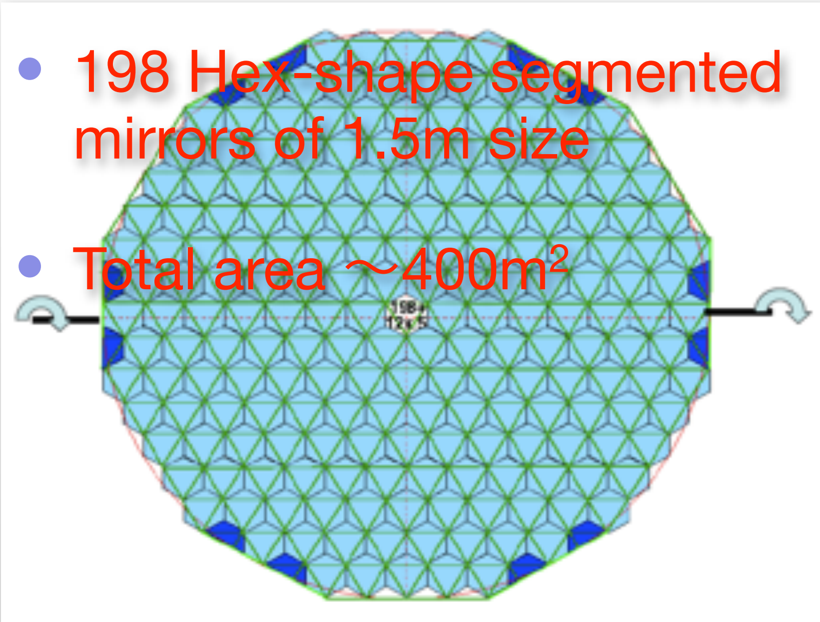
--> Windshield

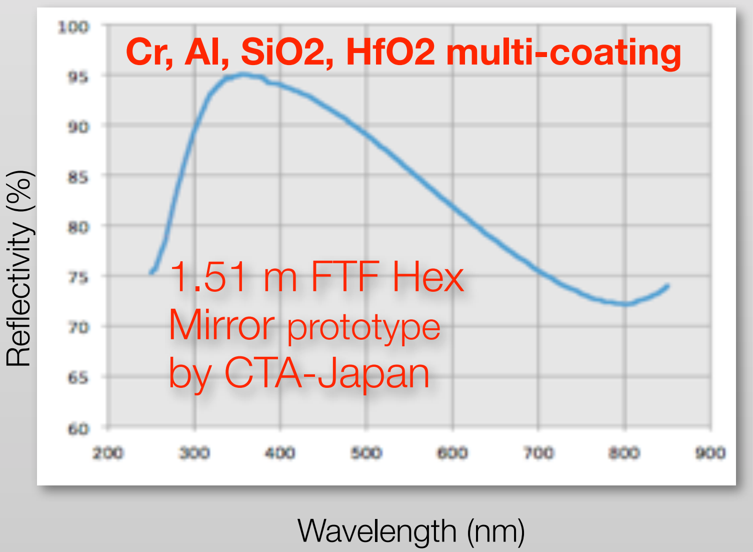


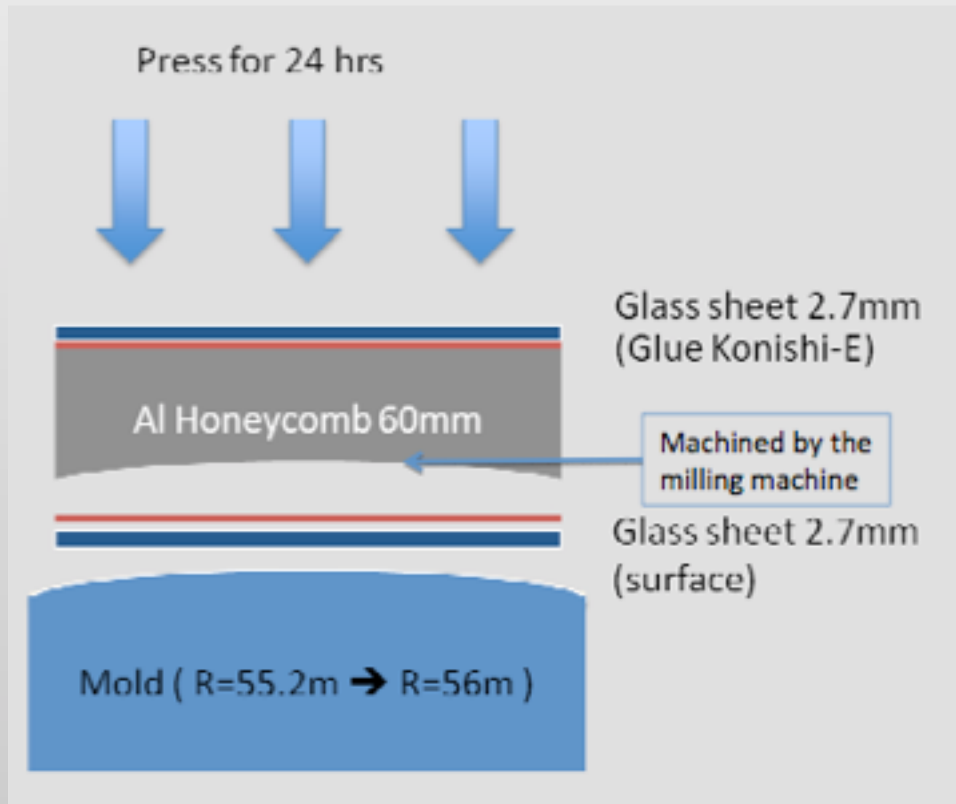
Windshield

LST 23m size mirror reflector: Masahiro Teshima

- 198 Hex-shape segmented mirrors of 1.5m size
- Total area ~400m^2

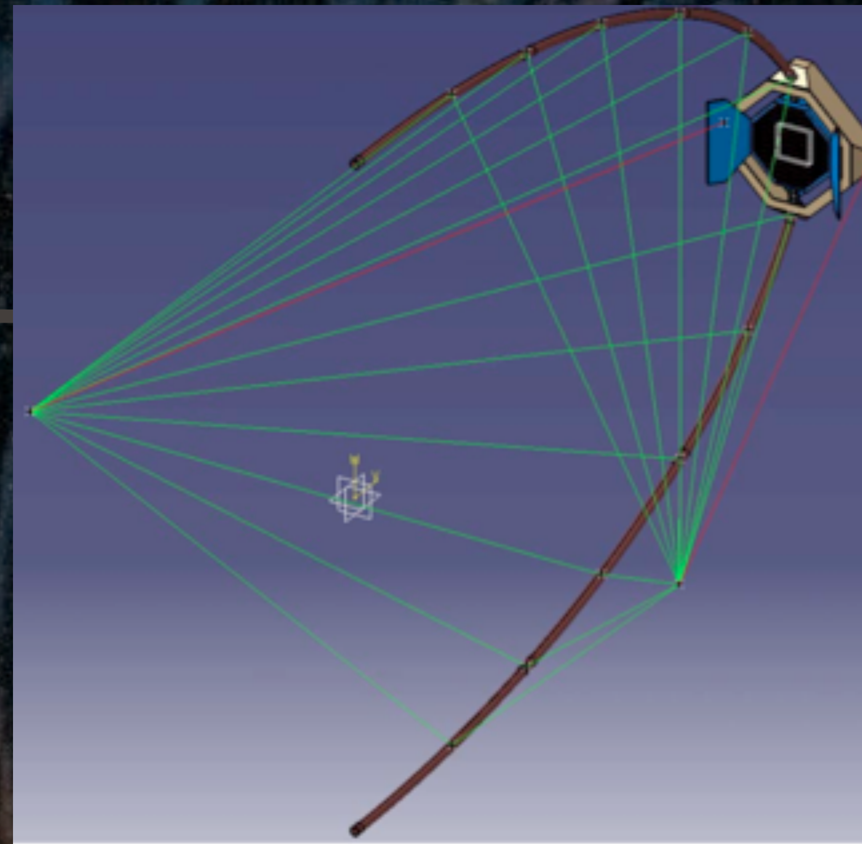


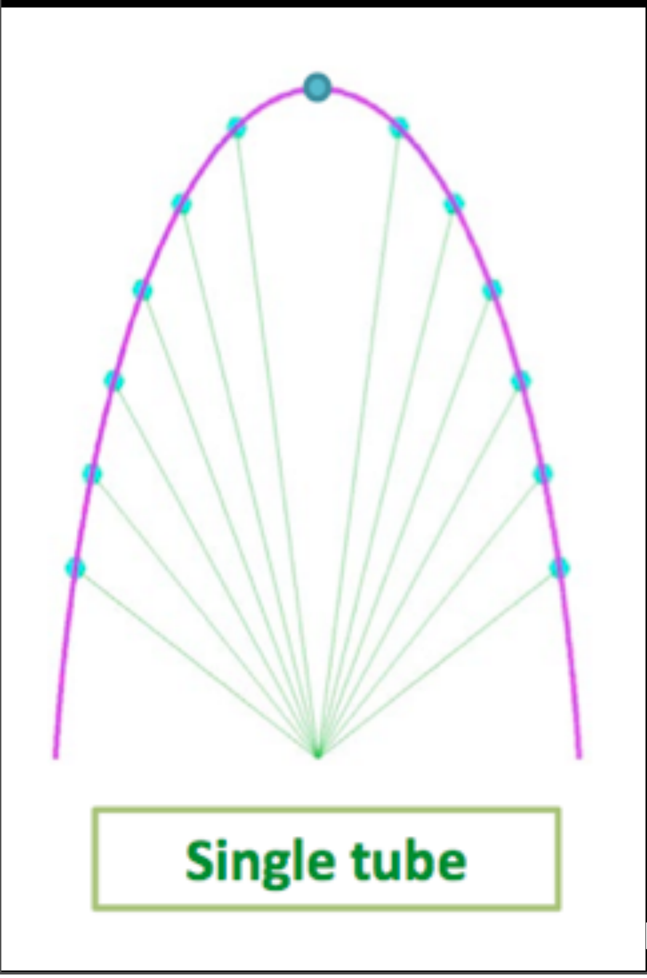


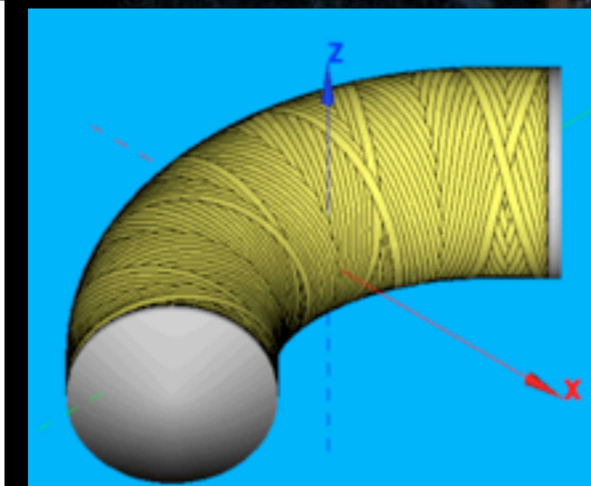


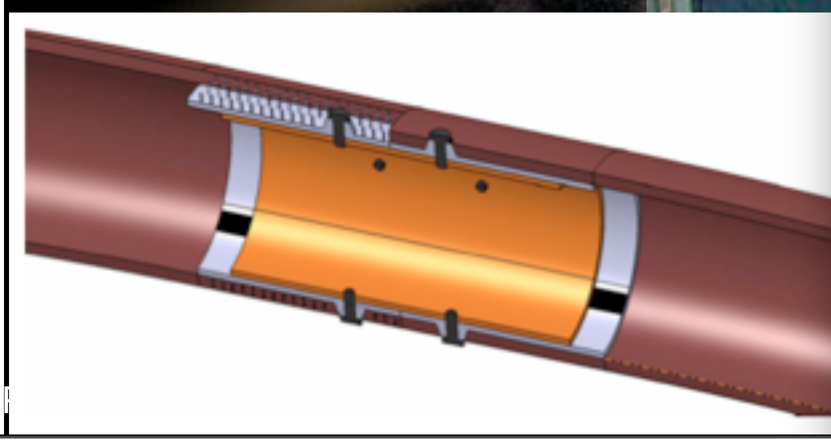
Arc design (LAPP) (+ camera frame)

- Single curves CF tubes
  3-4 sections each side
- Stiff light weight CF cables

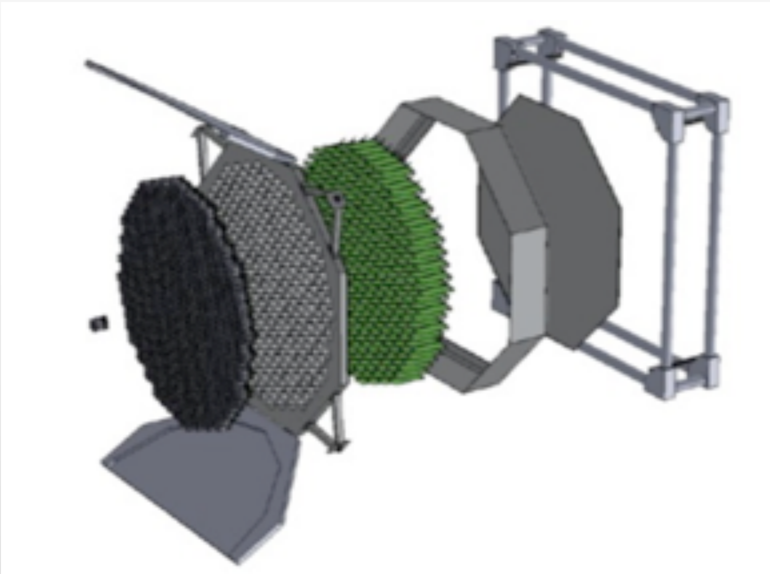








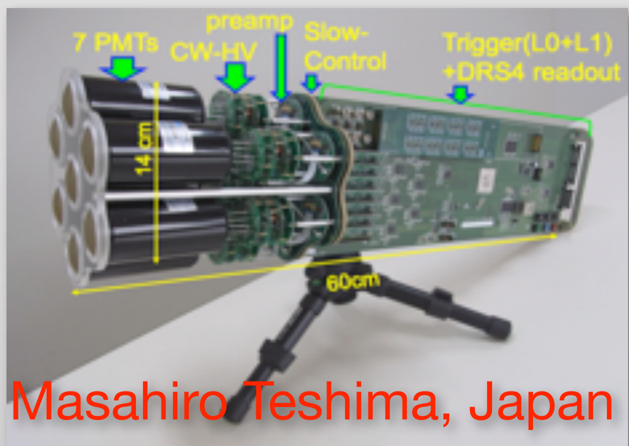
Camera design, camera body and Cooling: Project lead: IFAE Barcelona, several institutes in Spain



Sealed Camera
(MAGIC-II camera)

CTA Camera
Size: 2.5 m
Weight: 2 tons
# of Ch: 1855 ch
Heat: ~ 5kWatt

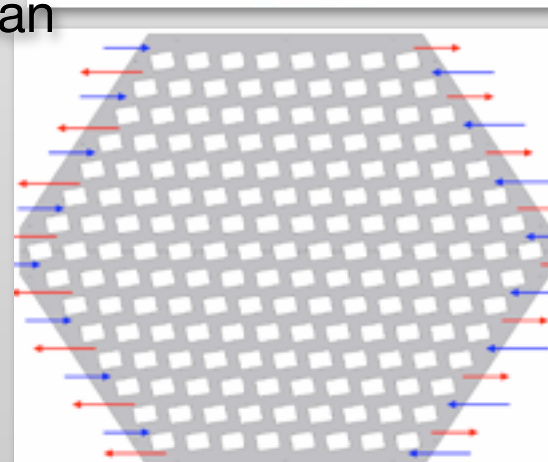
Water cooling System
MPI Munich



Masahiro Teshima, Japan

Cluster Prototype by CTA-Japan
(R.Orito: #1091)

7PMTs
CW HV system
Pre-Amplifier
DRS-4 readout system (4μsec)
G-bit ethernet



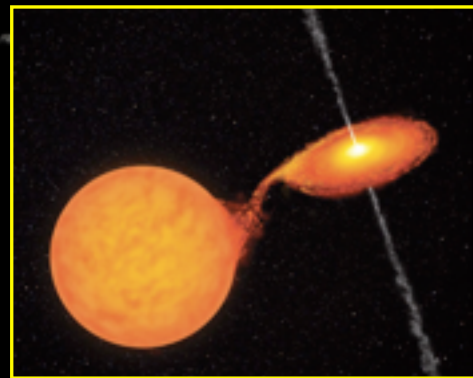
Rich Physics is waiting for CTA !

--> 1000 sources

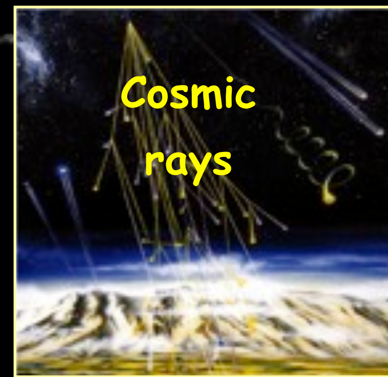
Galactic & Extragalactic sources

AGN

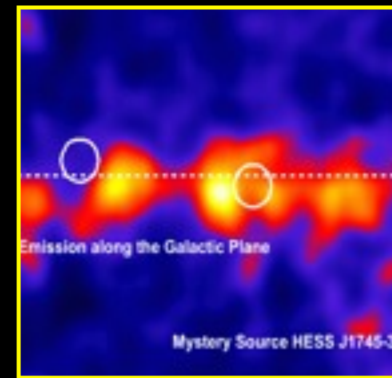
SNR & PWNe



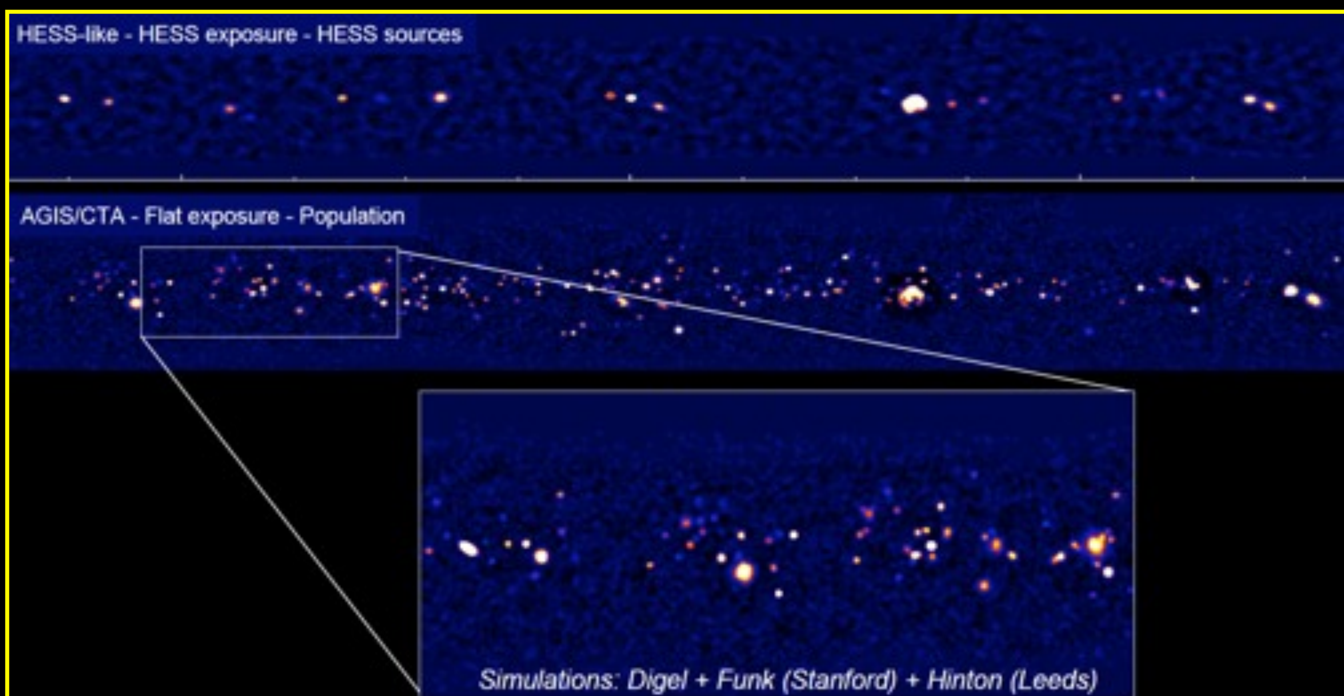
Micro quasars
X-ray binaries



Cosmic rays



Diffuse gamma radiation



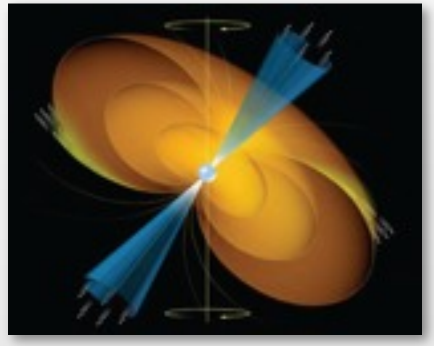
Galactic sources
200~400 sources with CTA

- CTA sensitivity (1 mCrab)
- CTA angular resolution -> needed for morphology and separation

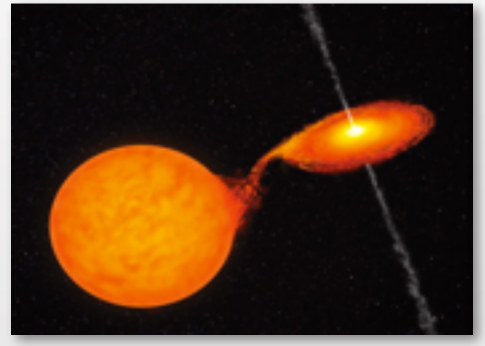
Science case of LST

High redshift AGNs (z<3)

GRBs (z<10)



Pulsars



Binaries and transients

- LST is optimized in the energy range between 20 - 200 GeV
- Low energy threshold
  - Trigger threshold: 15-20 GeV
  - Analysis threshold: 20-30 GeV

- Key physics cases:
  - High-redshift AGNs and GRBs
  - Binaries, Pulsars and other type of transients at low energy

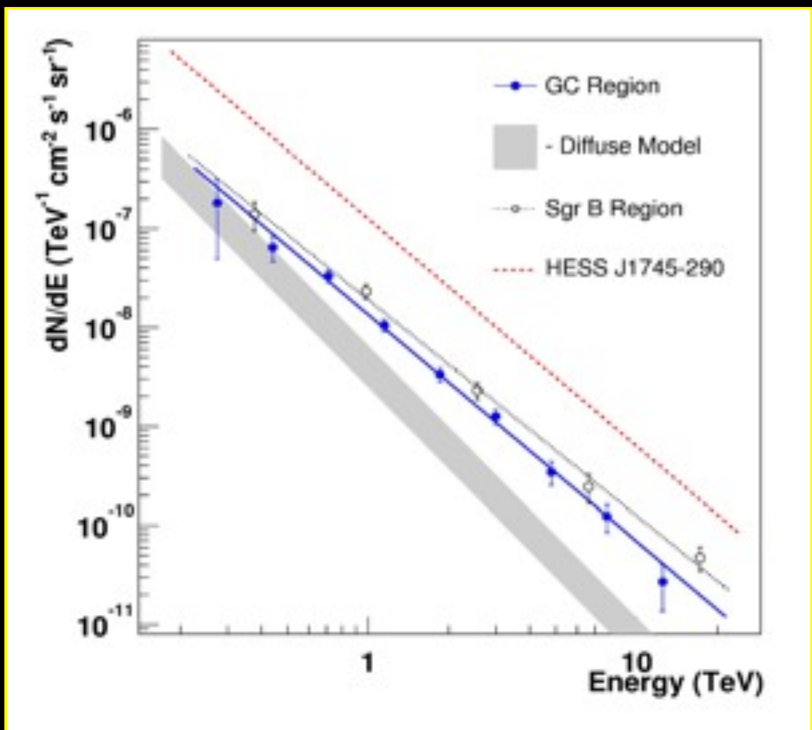
The end

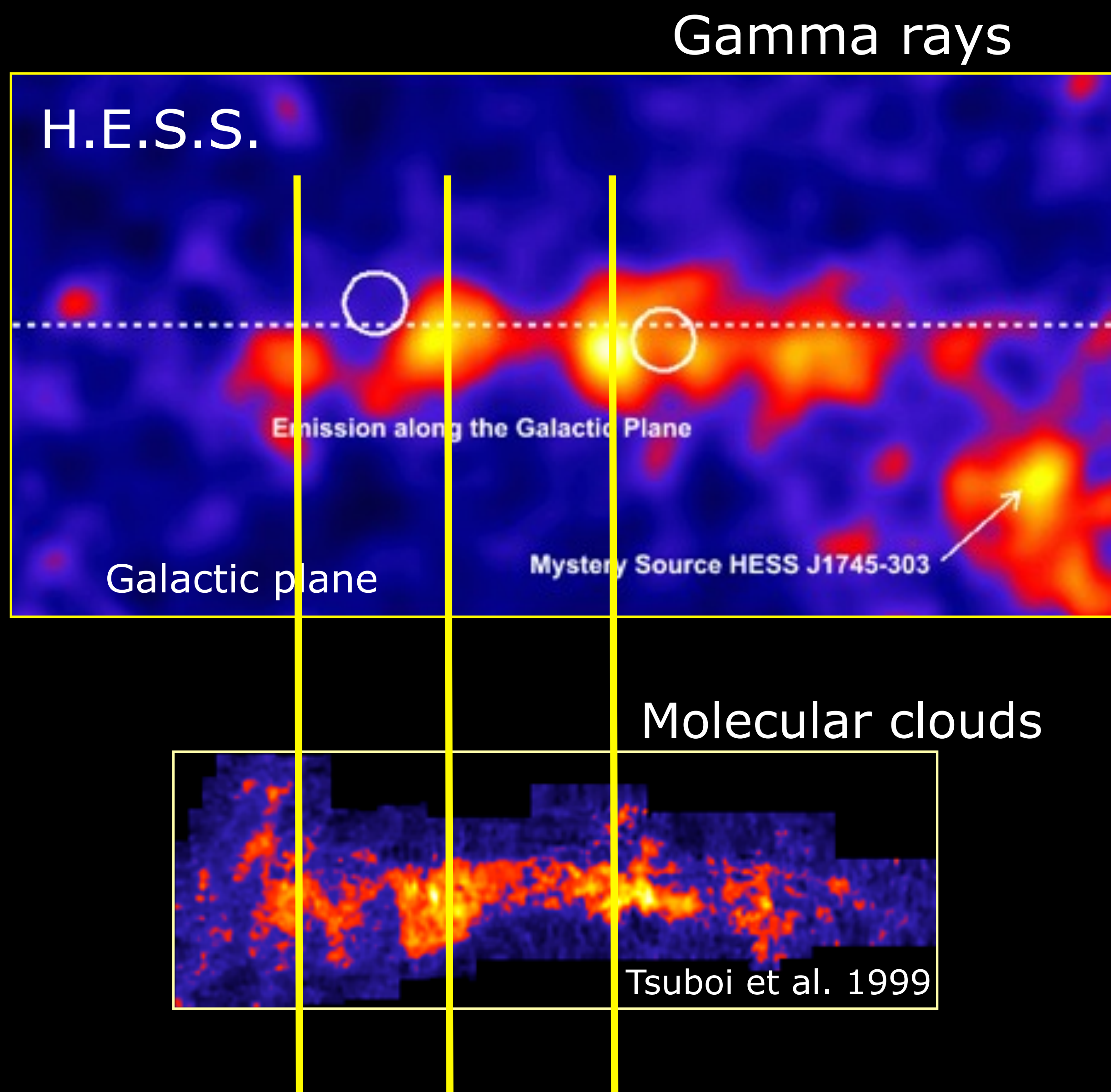
Friday, April 20, 2012

Friday, April 20, 2012

Probing Cosmic rays in the Galaxy using molecular clouds

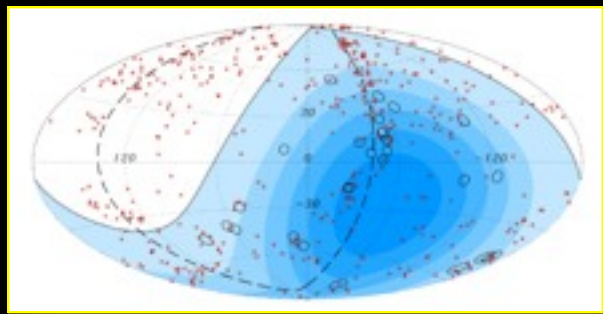
Gamma Spectrum from diffuse radiation



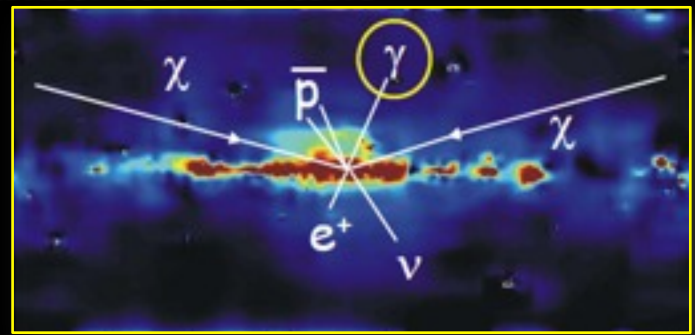


Rich physics in low energy range (>10-20 GeV): Unexplored physics !!

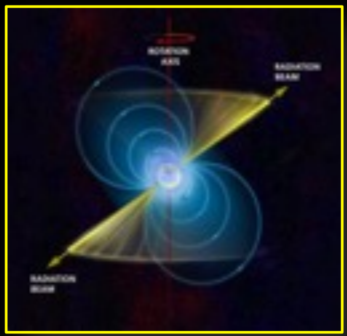
GRBs



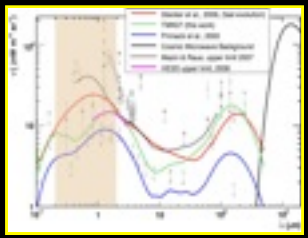
AGN & UHECR Sources



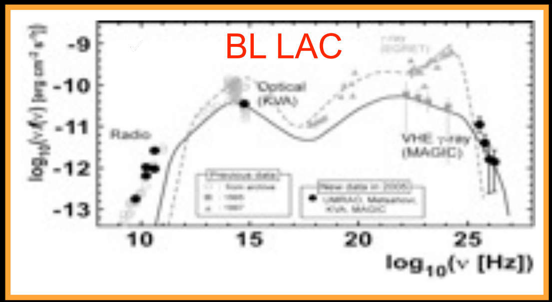
Dark Matter Annihilation



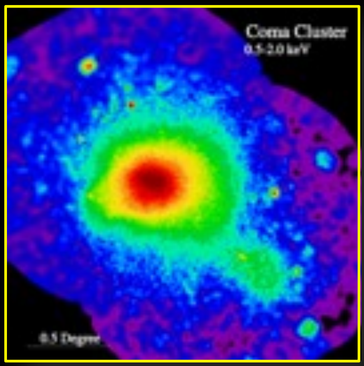
Pulsars



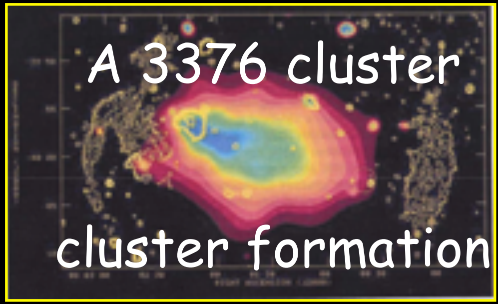
high redshift BL BLAC & EBL



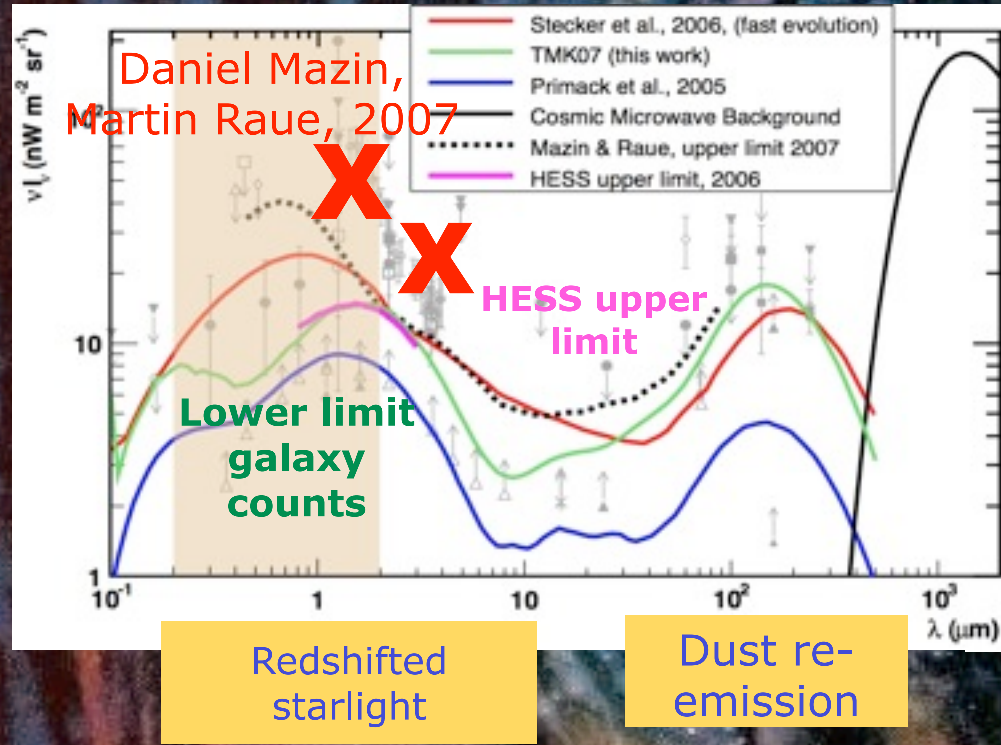
LBLs

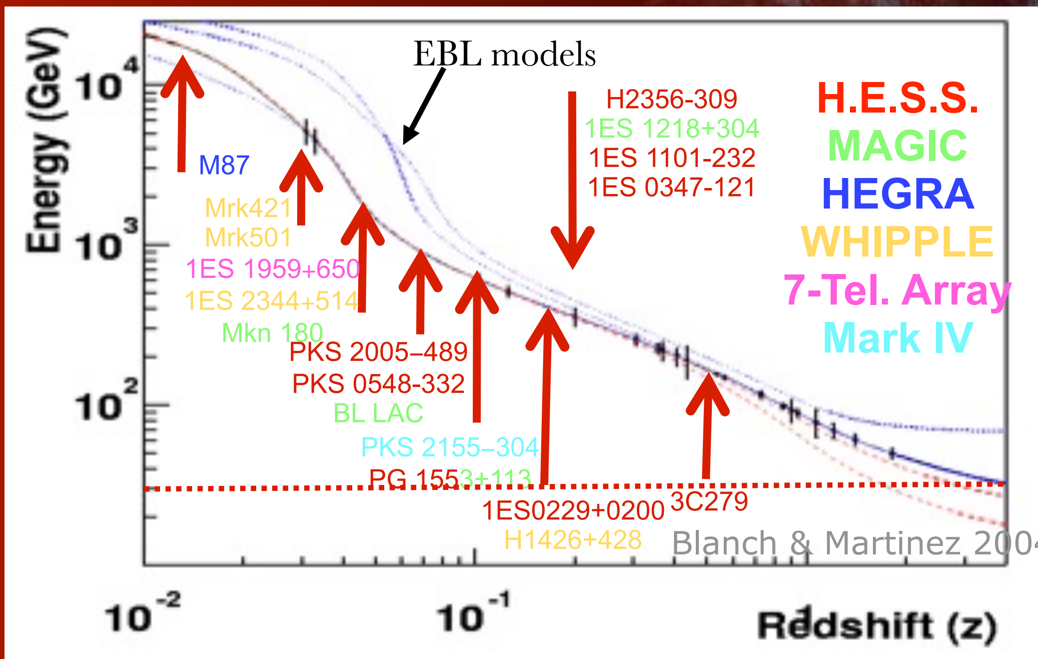


Clusters of galaxies



Nail down gamma ray horizon up to z=2



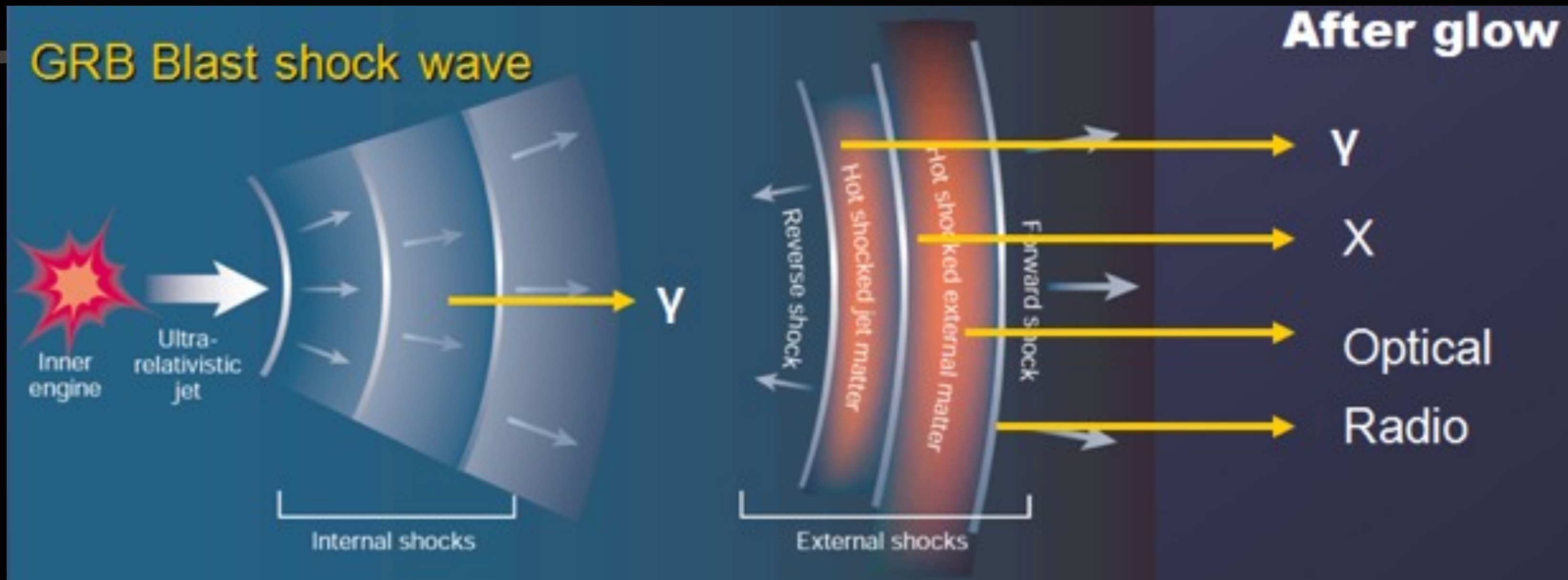


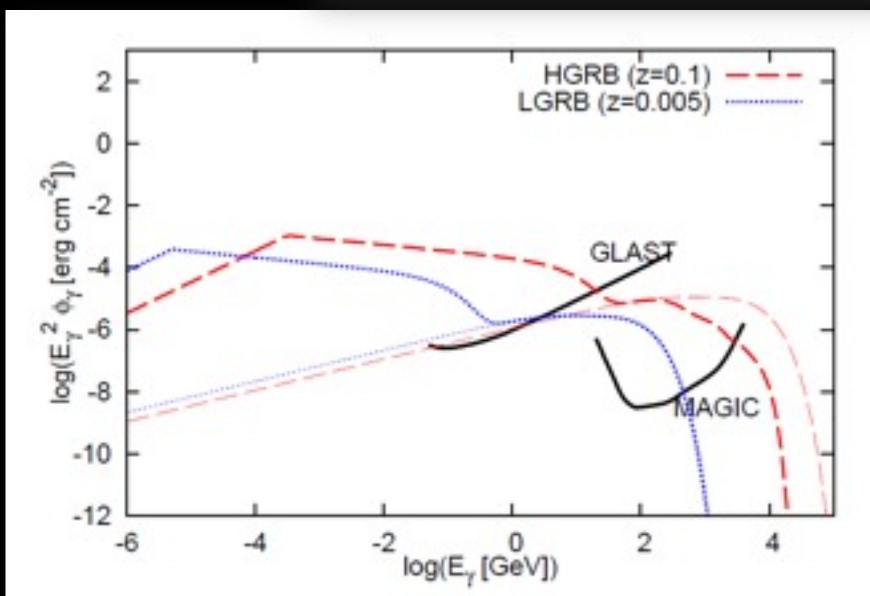
$\gamma_{VHE}\gamma_{EBL} \rightarrow e^{+}e^{-}$

Constrain the model for the star formation in the universe

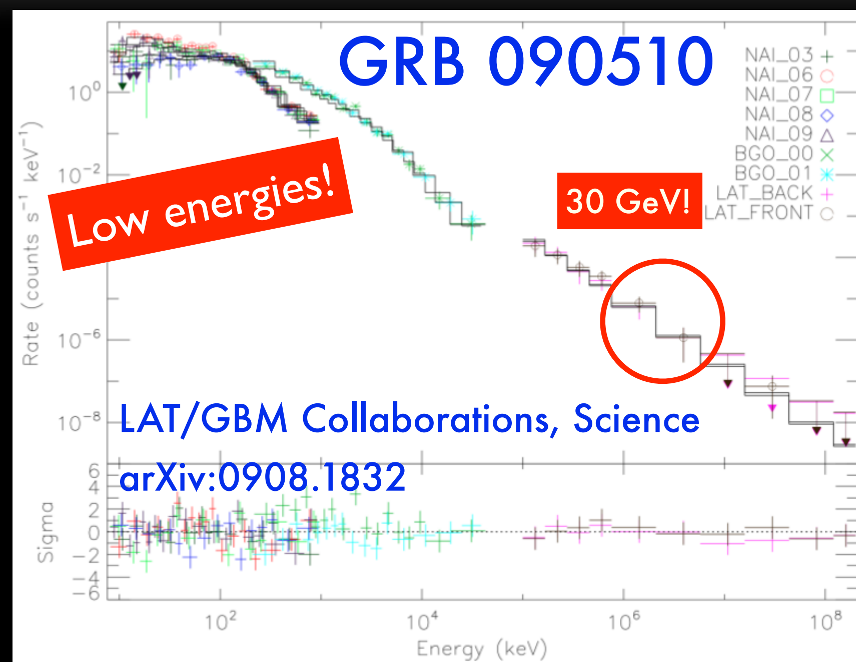
CTA will nail down the EBL measurement using AGN up to z=2.0 !!

Gammas from GRBs:
Fermi has seen two GRBs up to 30 GeV

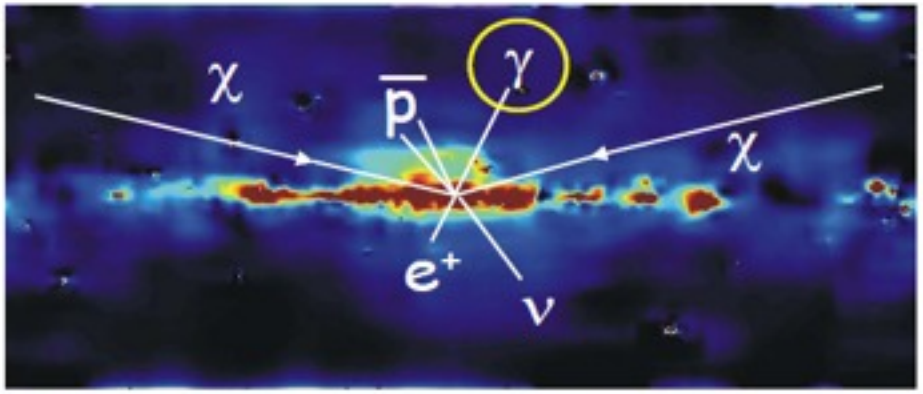




Murase et al. 2008



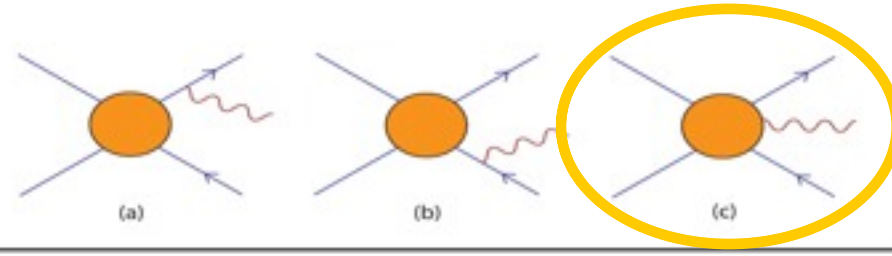
Neutralino anihilation signal: Complementary with direct searches

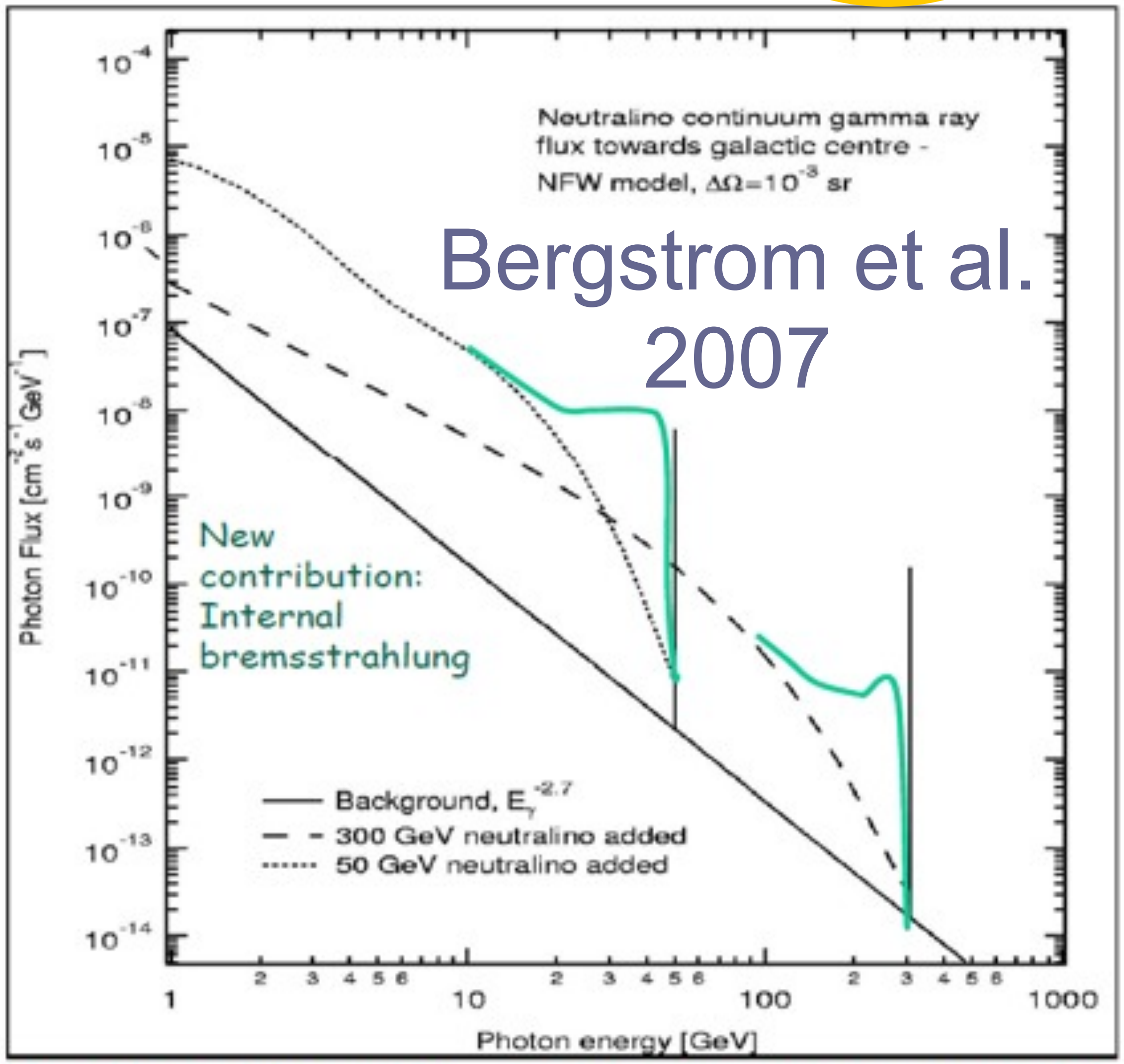


Indirect detection through γ-rays.
Three types of signal:

- Continuous from π^0, K^0, … decays and
- Monoenergetic line and
- Internal bremsstrahlung from QED process.

Enhanced flux possible thanks to halo density profile and substructure (as predicted by CDM)
Good spectral signatures!
Unfortunately, large uncertainties in the predictions of absolute rates

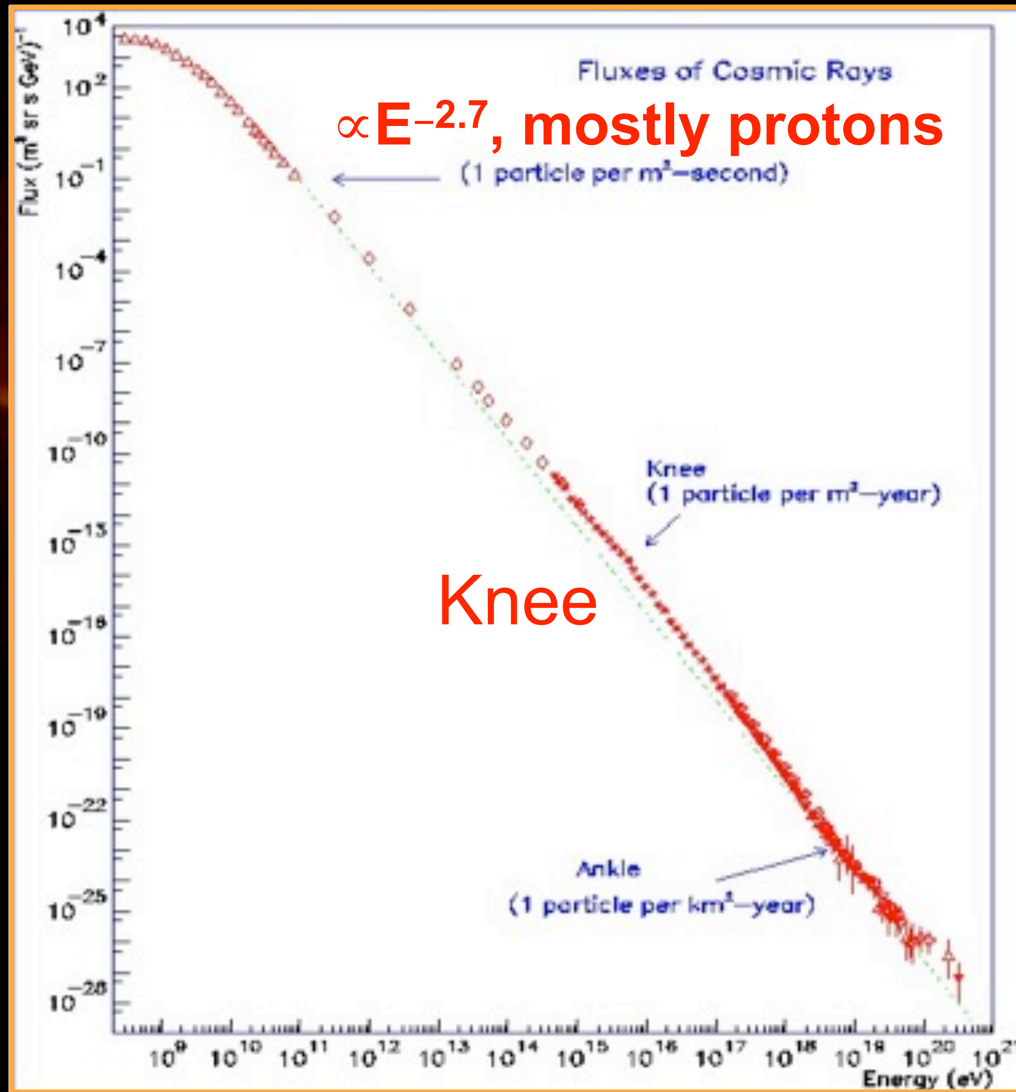




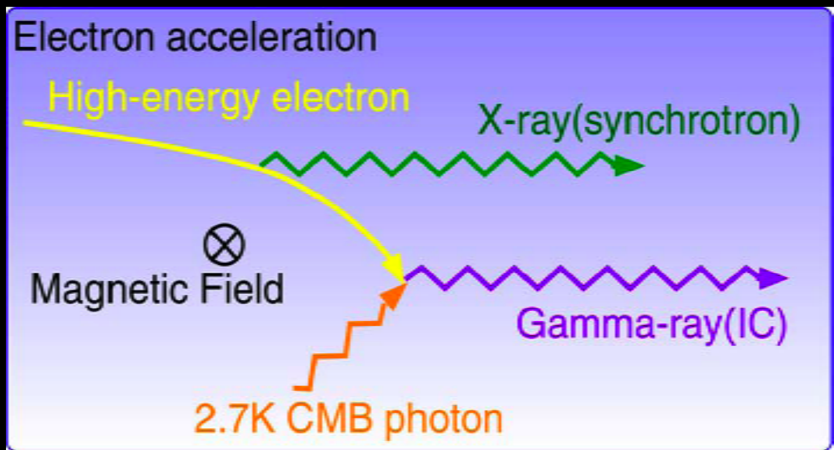
L.B., P.Ullio & J. Buckley 1998 T. Bringmann, L.B., J. Edsjö, 2007

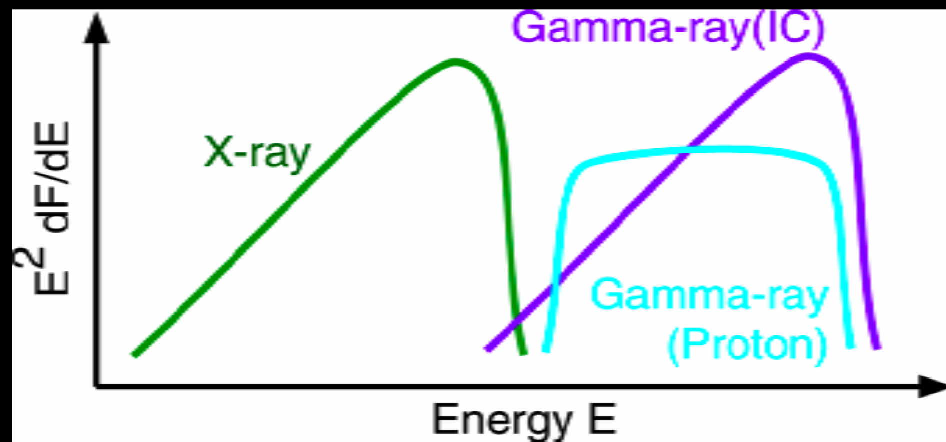
Which are the sources of the cosmic rays ?

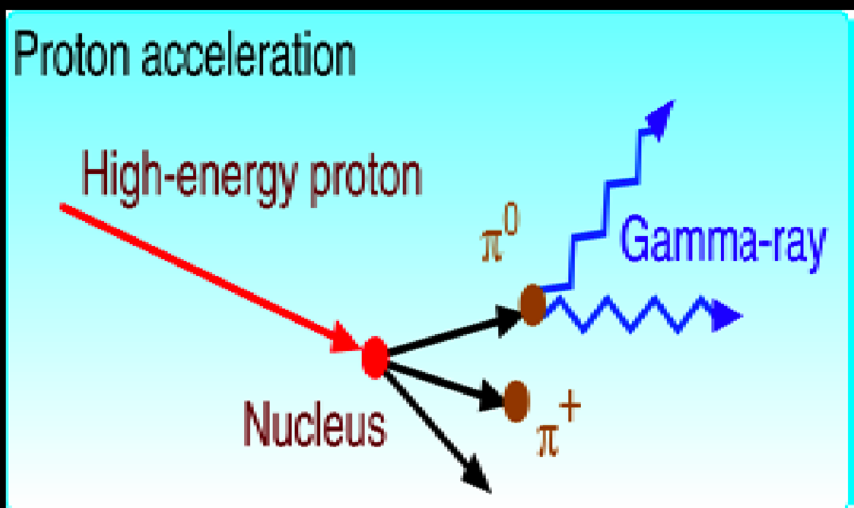
Victor HESS 1912



Sources of cosmic rays:
Which sources have hadronic acceleration ?

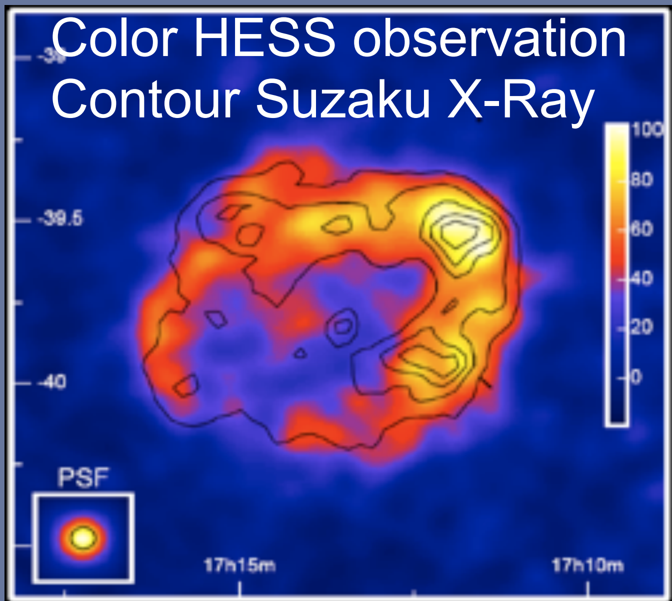


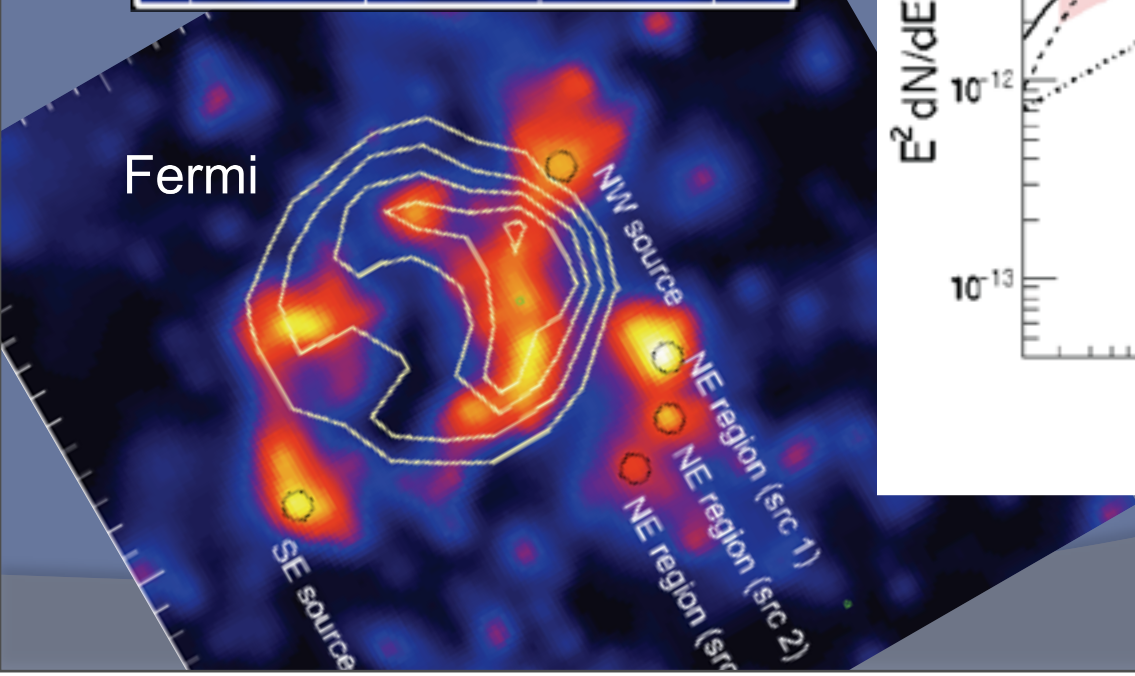




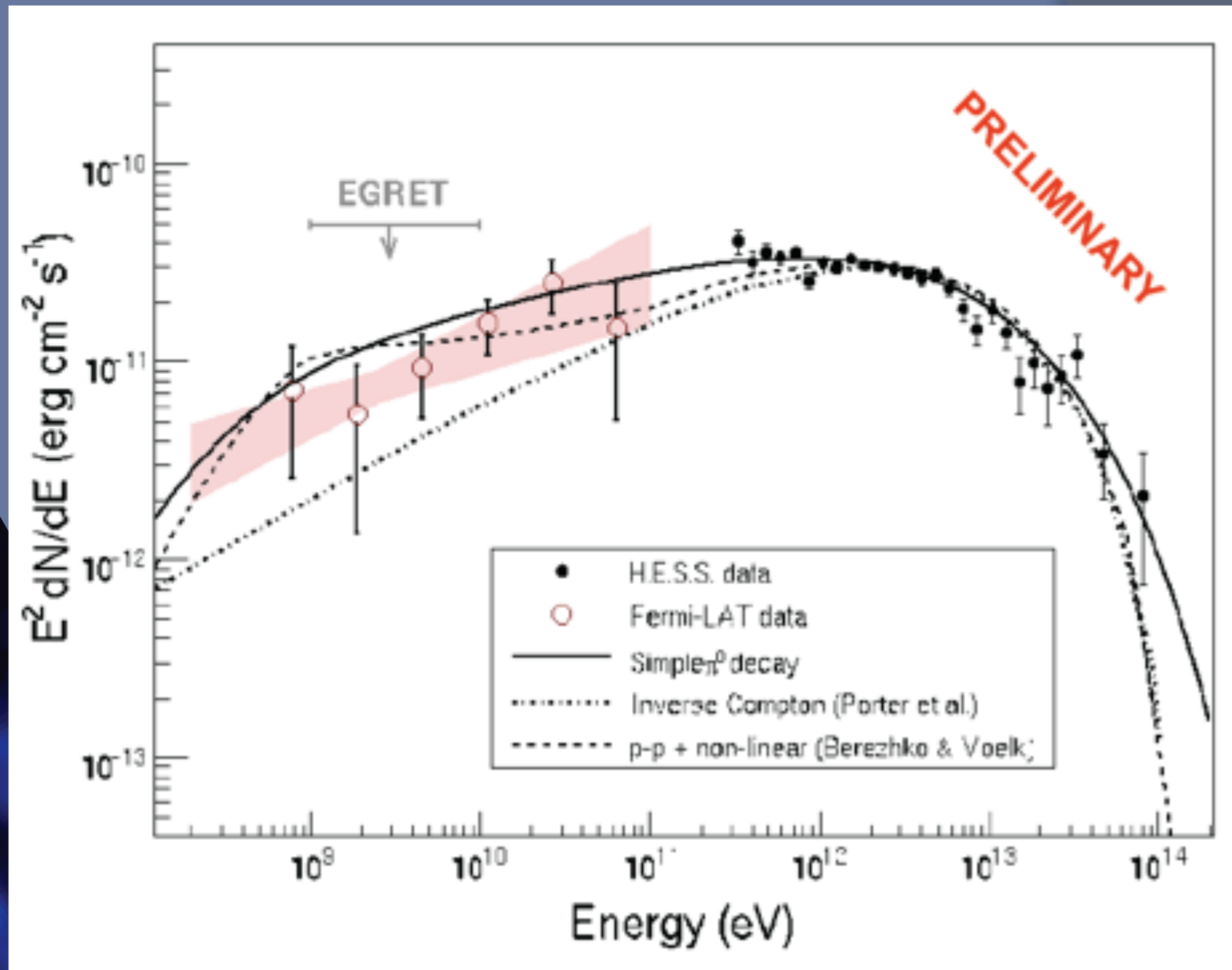
- SSC model: leptonic acceleration
  - High energy gamma rays
  - Strong synchrotron emission
- π^0-decay: hadronic acceleration
  - High energy gamma rays
  - High energy hadrons --> CR
  - 10 TeV proton -> 1 TeV gamma

Wide energy range of CTA
RX J1713 HESS + Fermi

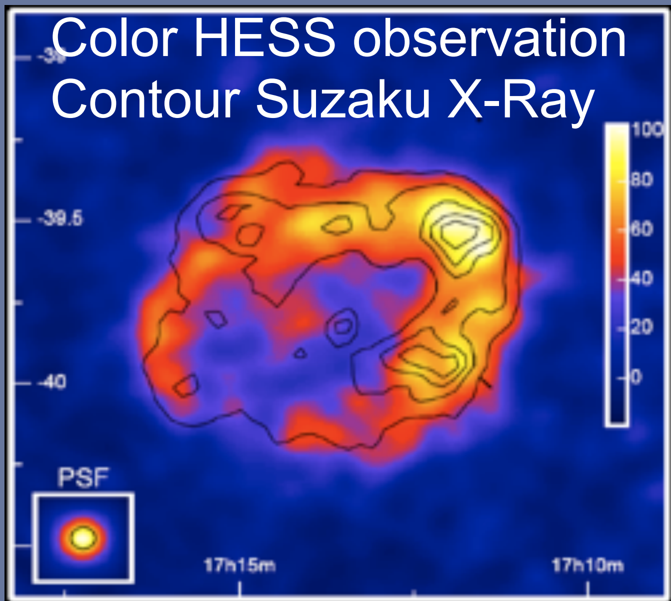


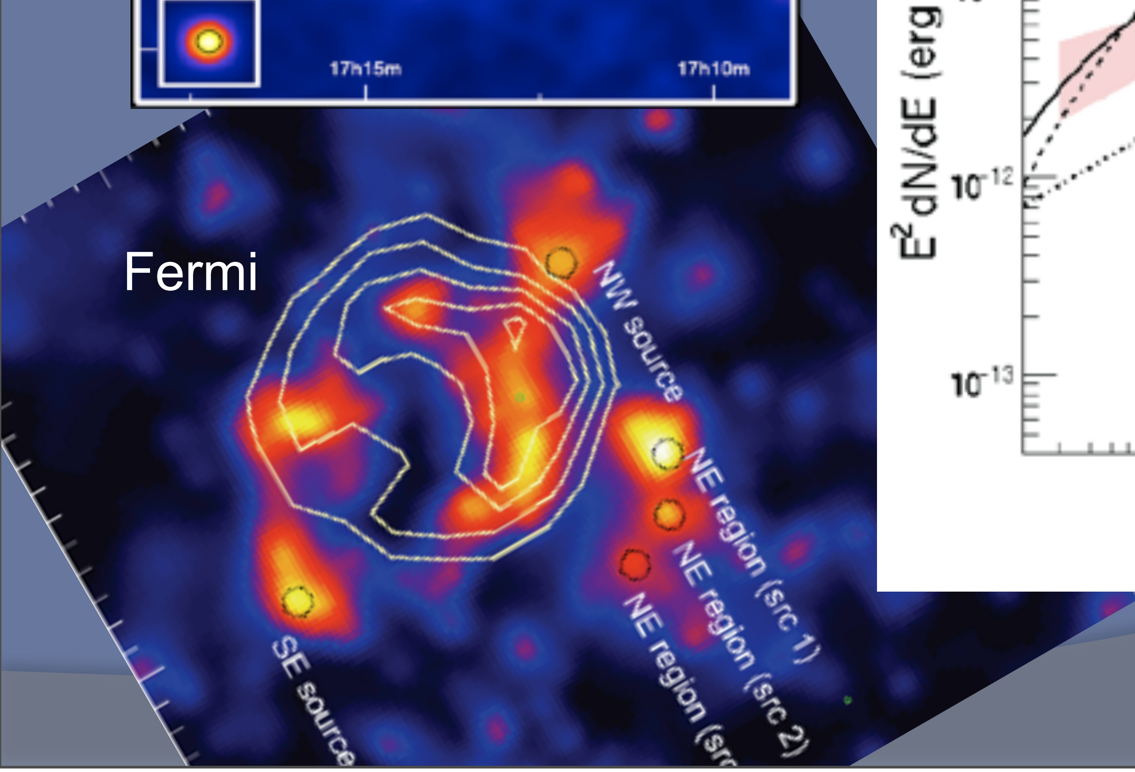


Concaved spectrum (non-linear effect)??

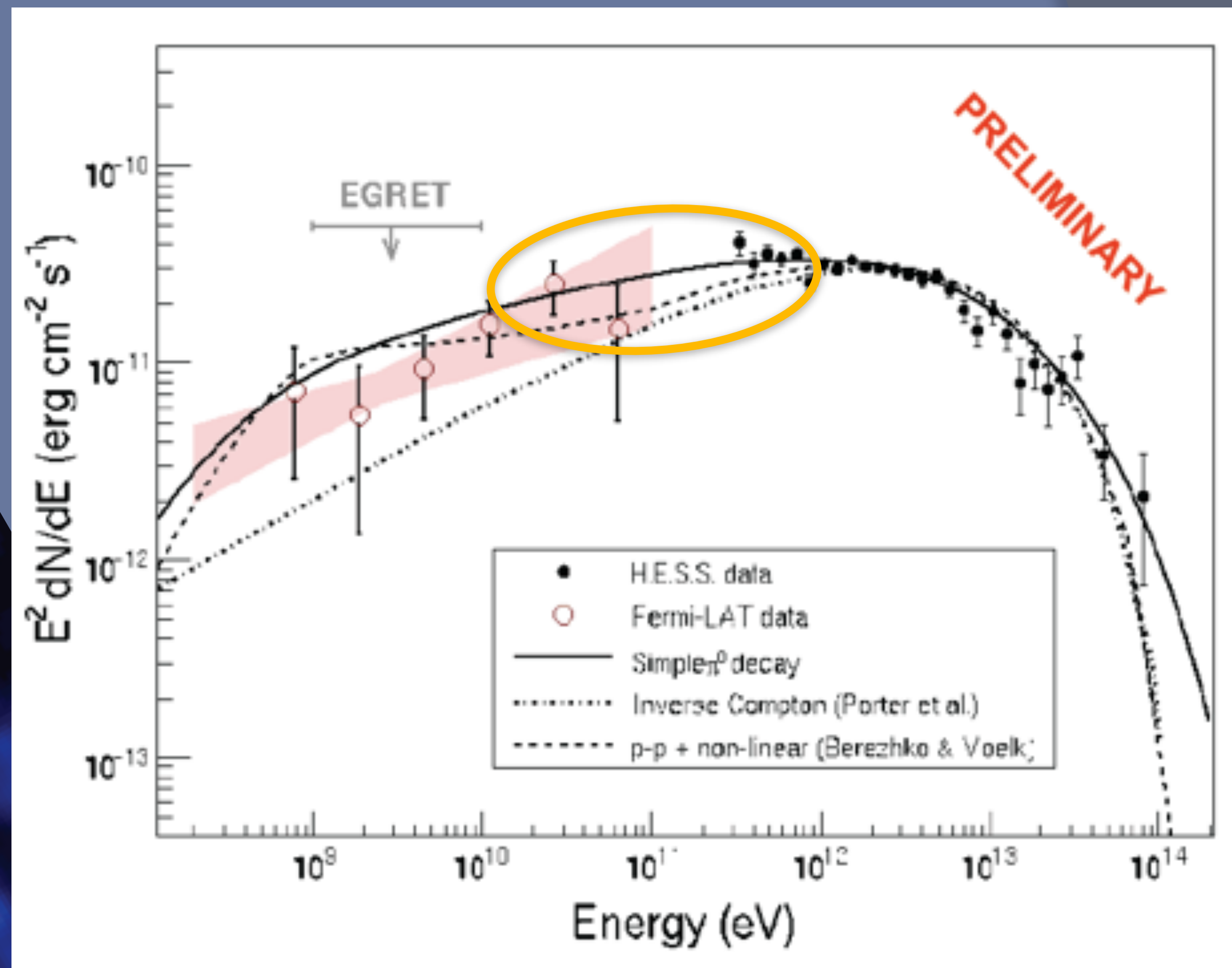


Wide energy range of CTA
RX J1713 HESS + Fermi

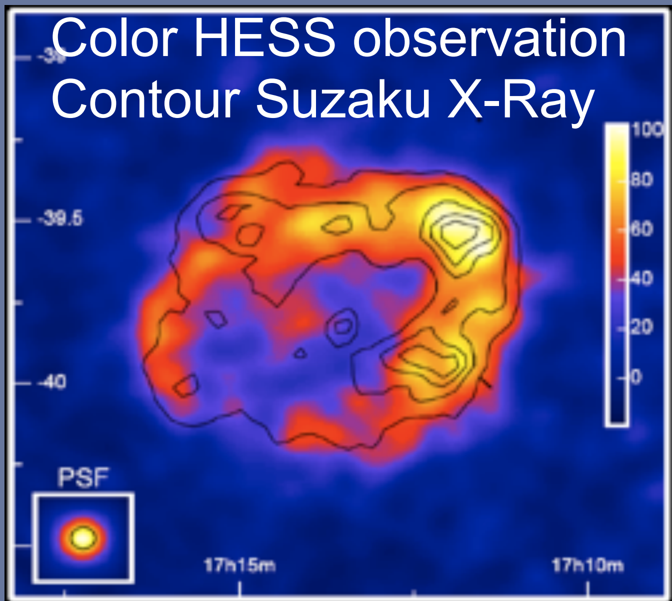


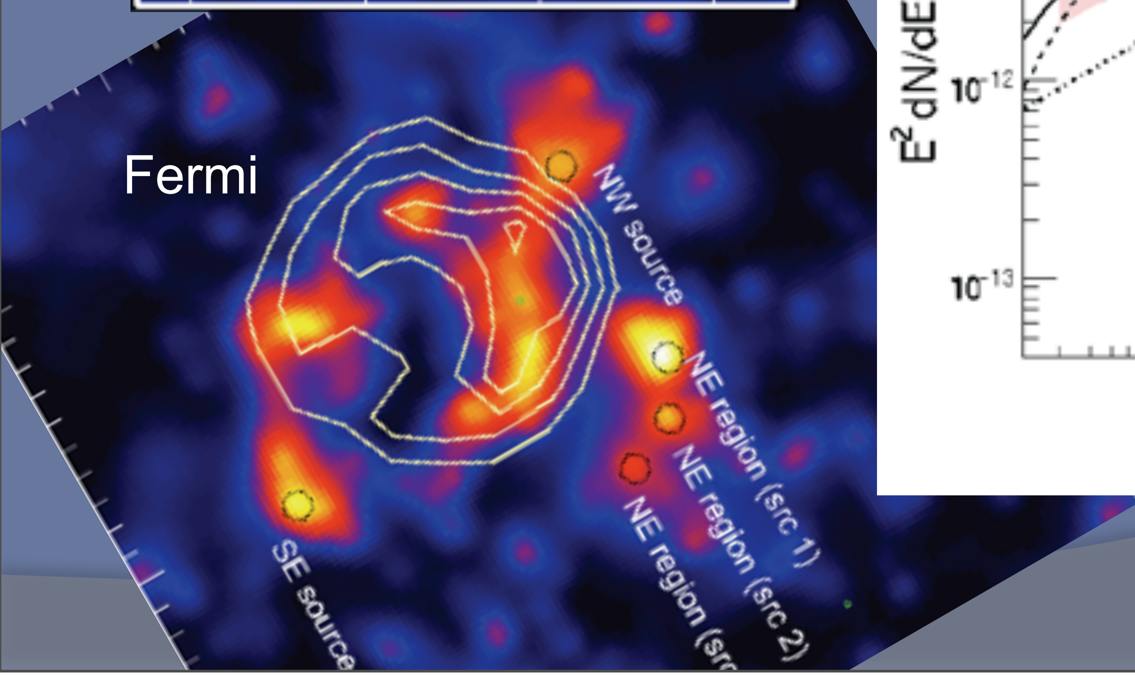


Concaved spectrum (non-linear effect)??

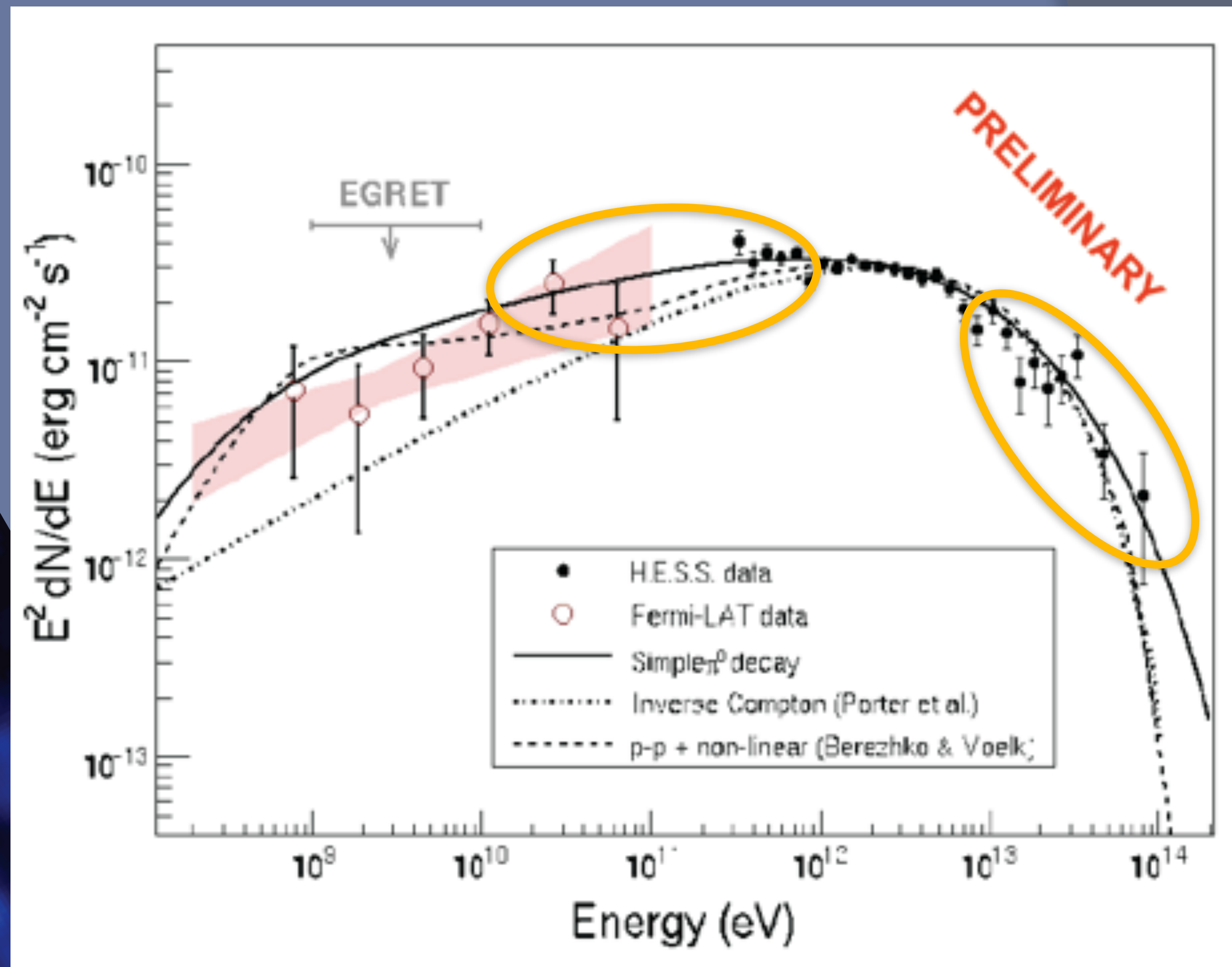


Wide energy range of CTA
RX J1713 HESS + Fermi



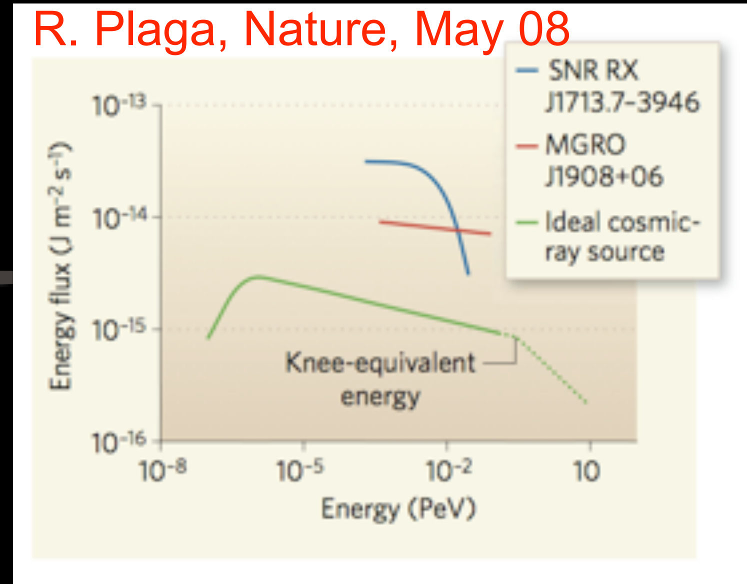


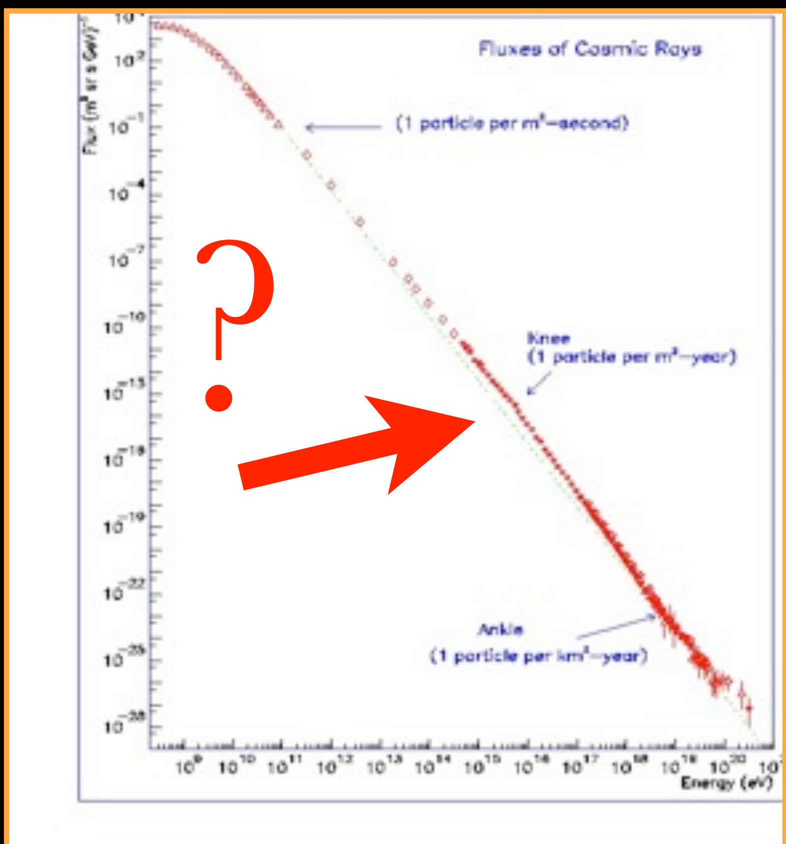
Concaved spectrum (non-linear effect)??

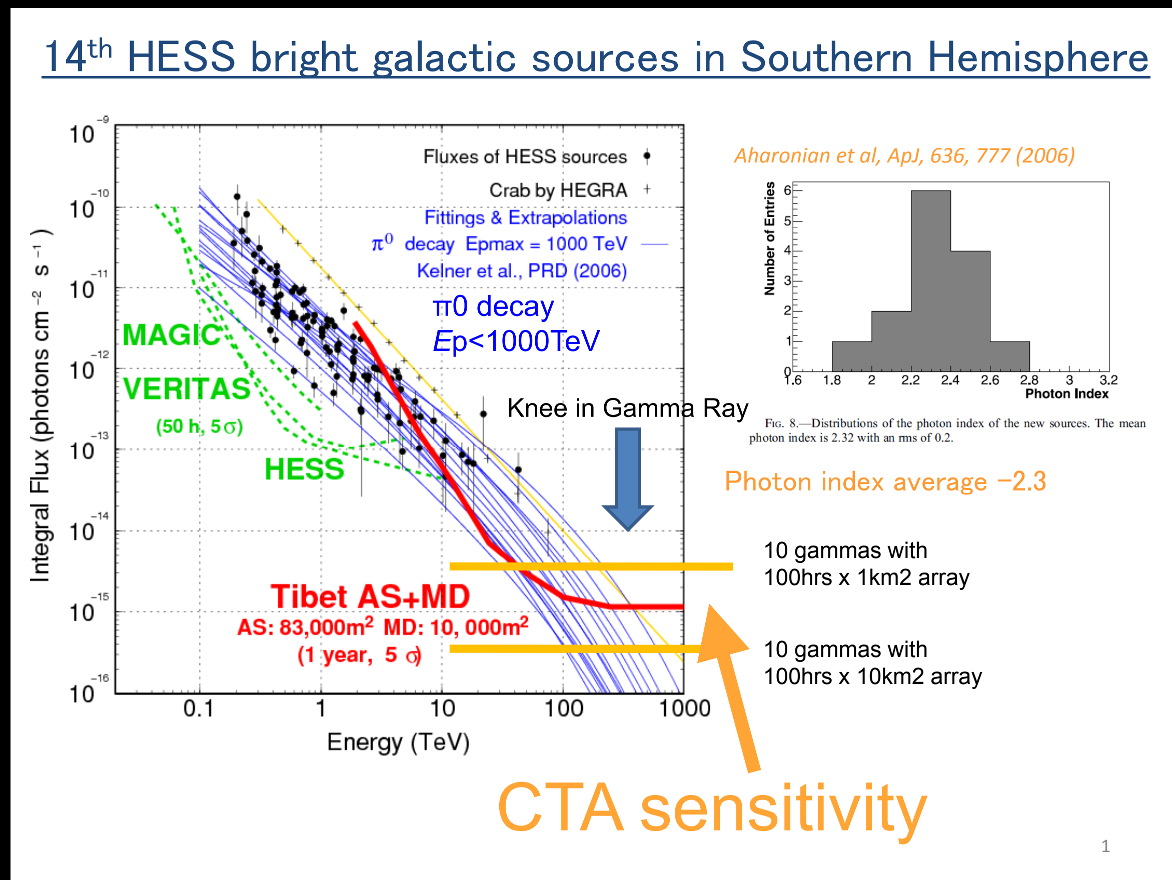


High energies >300 TeV
Long standing question: Origin of the knee

- Probing the knee in gamma rays
- Knee due to diffusion in galaxy ?
- Finding the Pevatron source !

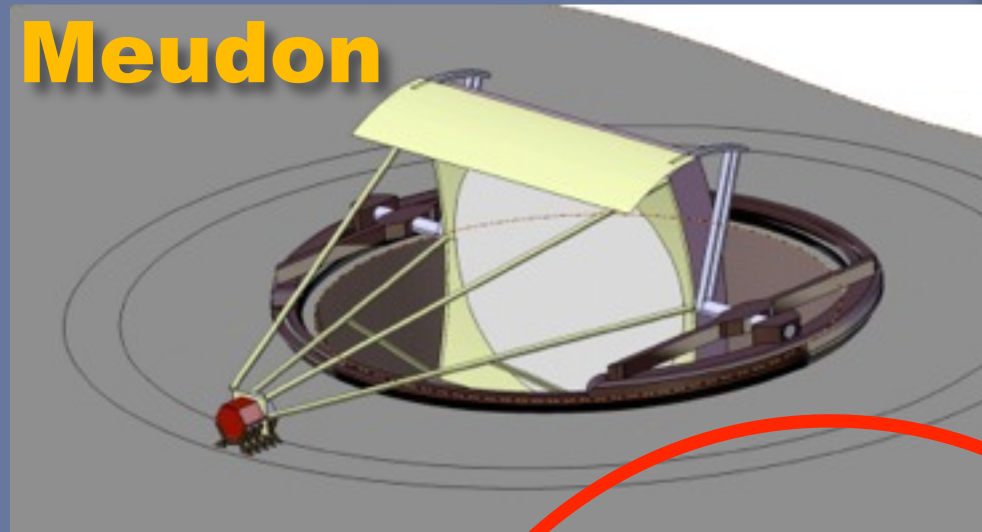






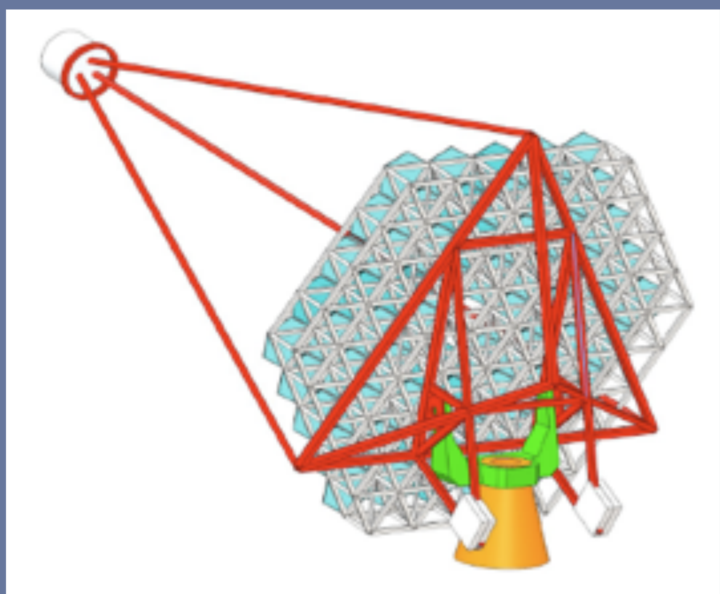
Technology and design study

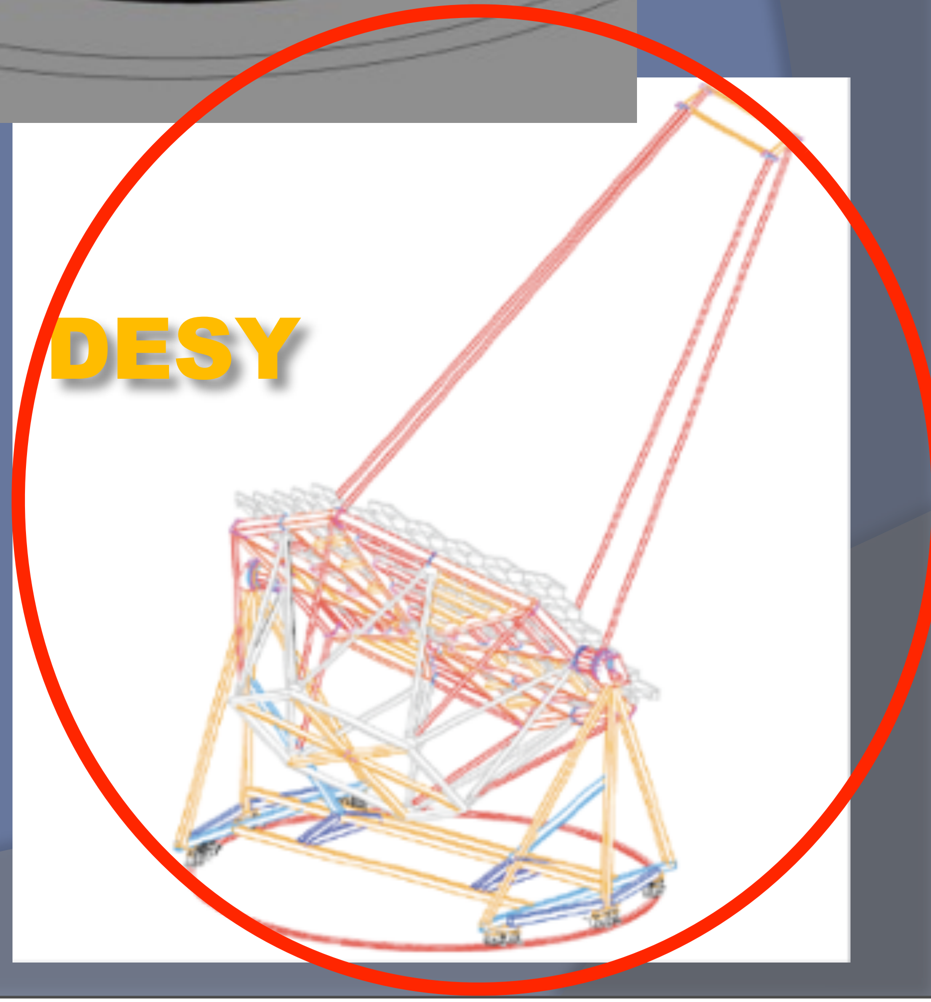
Midsize telescope (12m) designs



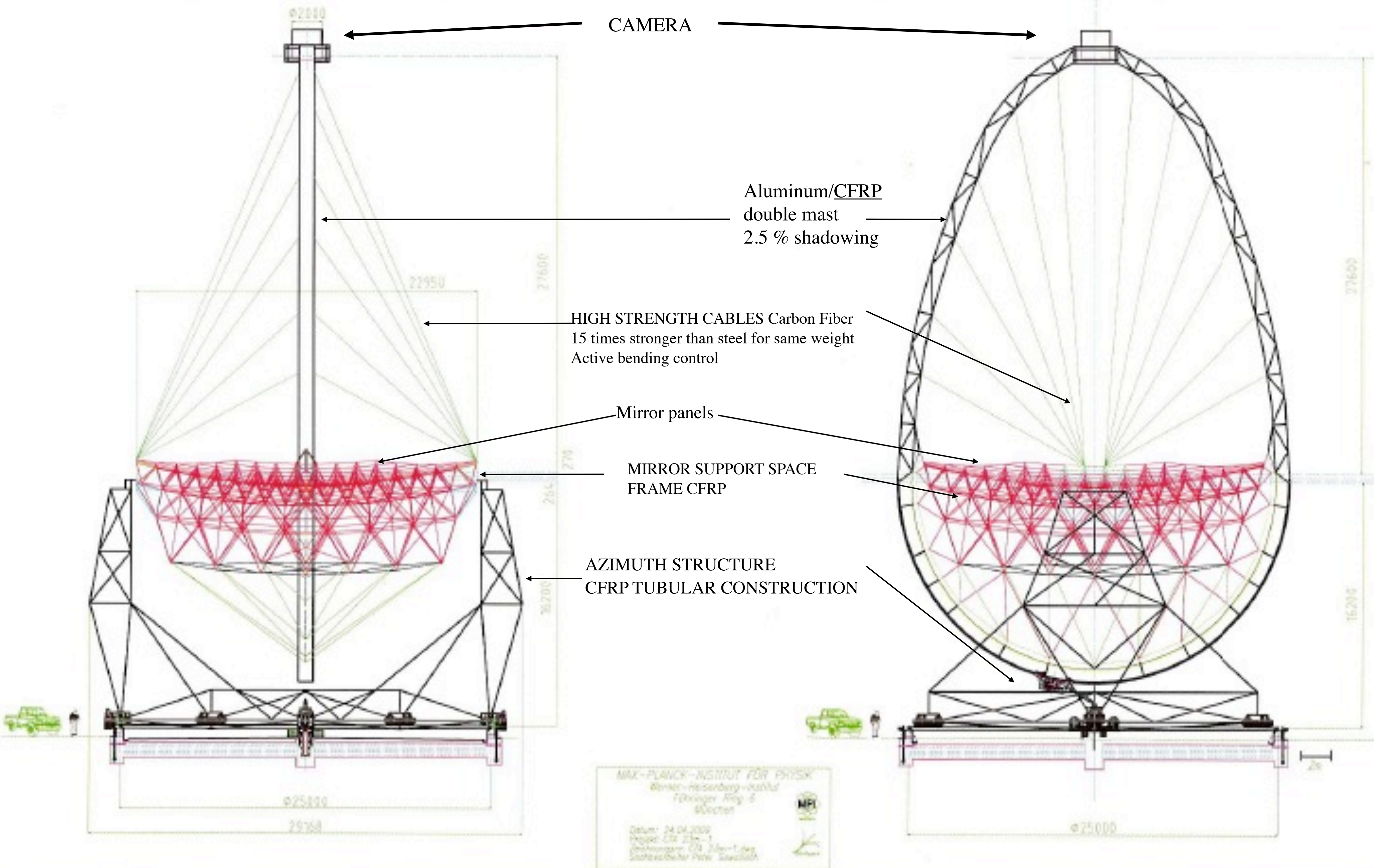
MPI

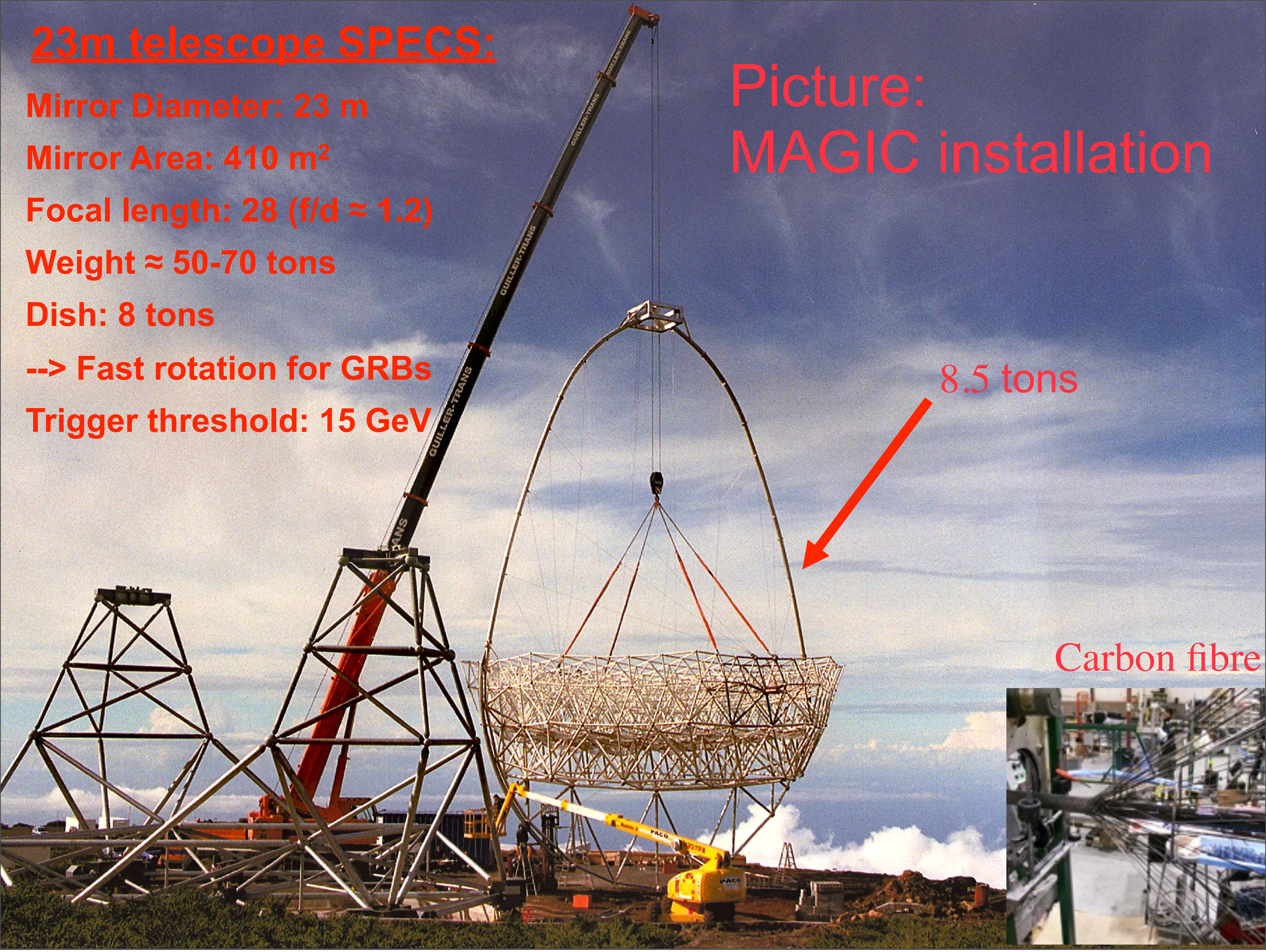
Heidelberg





23m telescope design MPI Munich (50 tons, fast rotation, F/D=1.2)





23m telescope SPECS:

Mirror Diameter: 23 m

Mirror Area: 410 m^2

Focal length: 28 (f/d ≈ 1.2)

Weight ≈ 50-70 tons

Dish: 8 tons

--> Fast rotation for GRBs

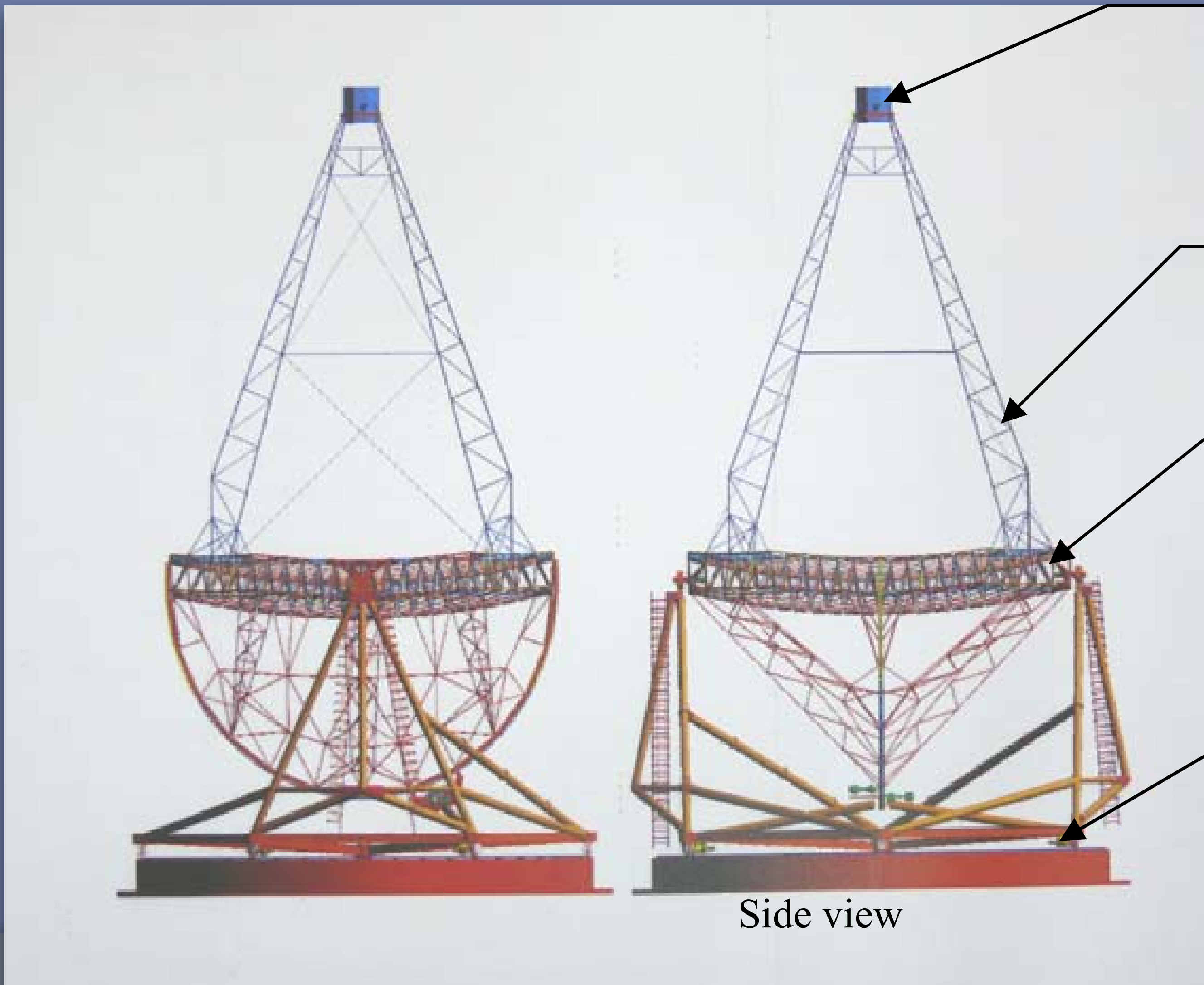
Trigger threshold: 15 GeV

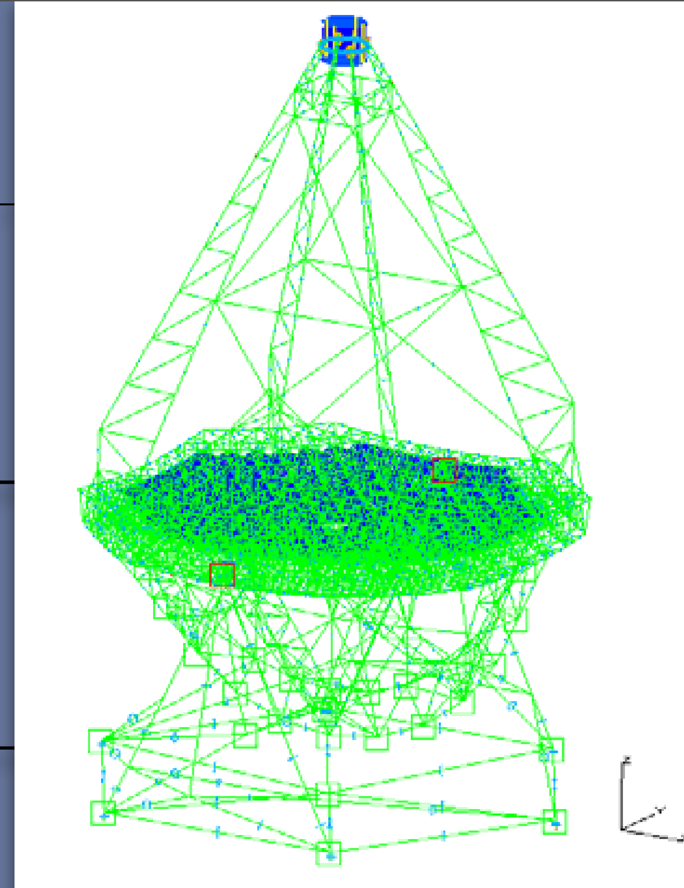
Picture:
MAGIC installation

8.5 tons

Carbon fibre

Indian Maze telescope (21m)

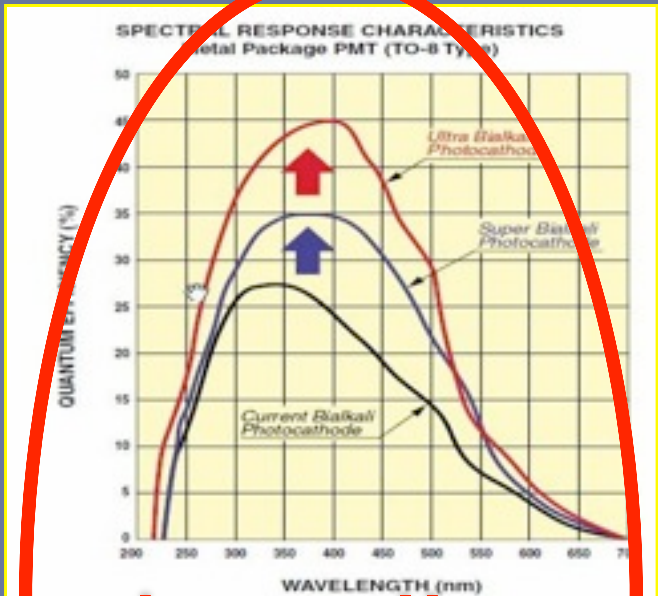




Basket Assembly

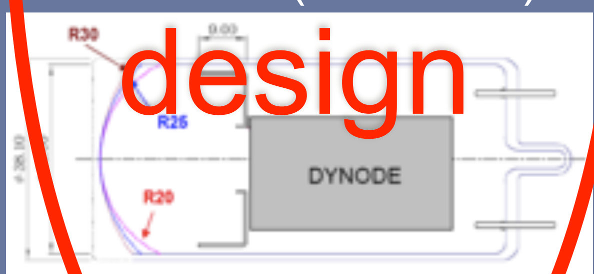
Rail assembly

High QE photosensors we need 200K PMs

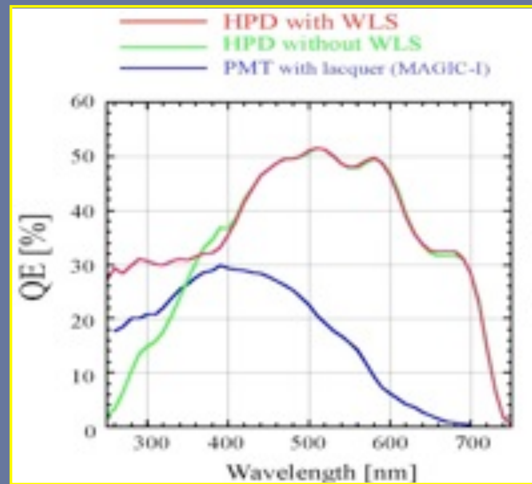


baseline design

R9420 (QE=34%)

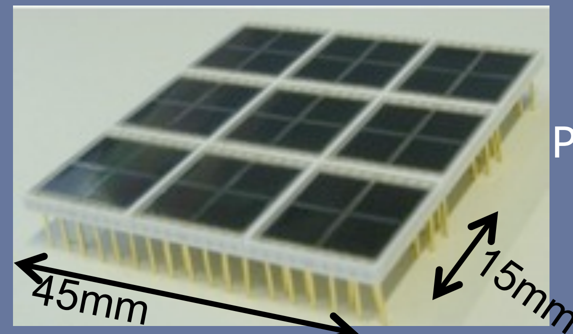


Hamamatsu SBA 34% QE ==> 30% PDE



GaAsP HPD (MPI & Hamamatsu): 50% PDE

Hamamatsu &MPI MPPC Array



PDE~30-40%

Size 5x5 mm^2

PDE~50-60%

MPI-HLL SiMPL

PDE~60%(target)

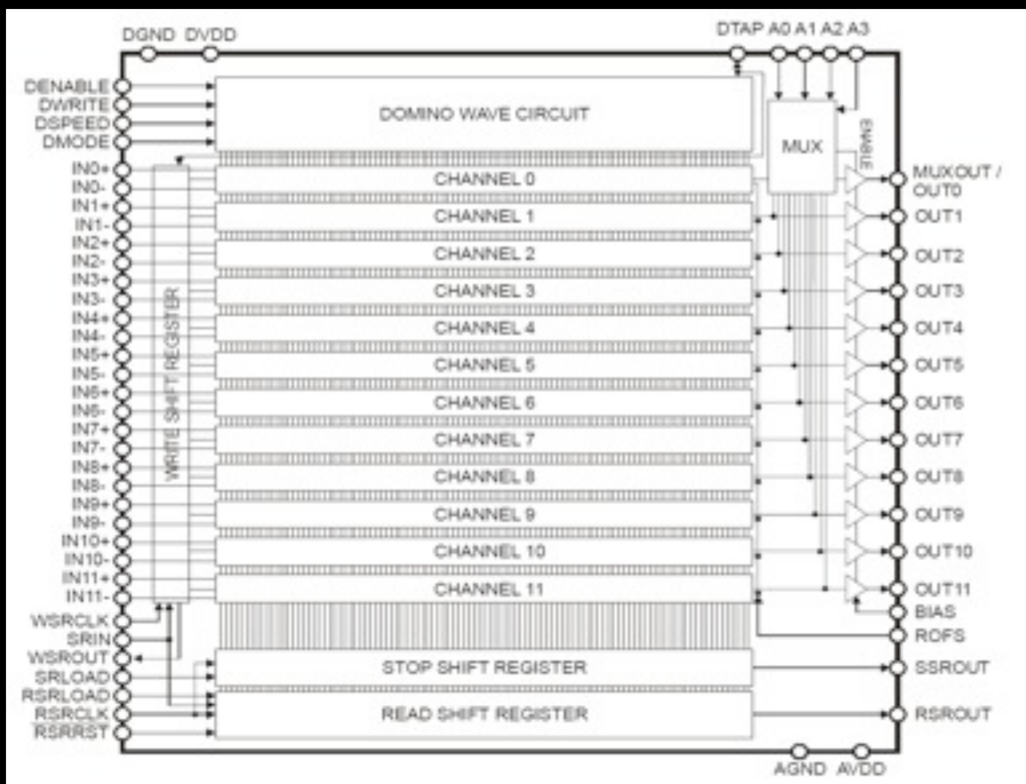
SiPM

About 60% effective PDE will be realistic

Readout electronics: Analog pipelines

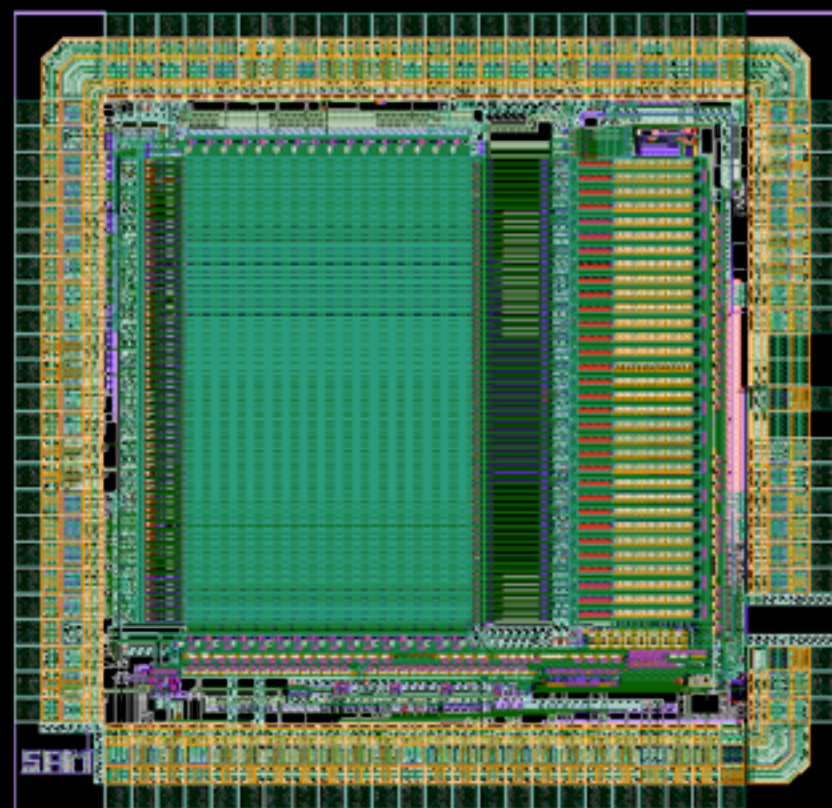
Domino Ring Sampler 4

12 x 1024 samples
up to 5 Gsamples/s
11.5 bit effective range
450 MHz bandwidth
25 mm^2



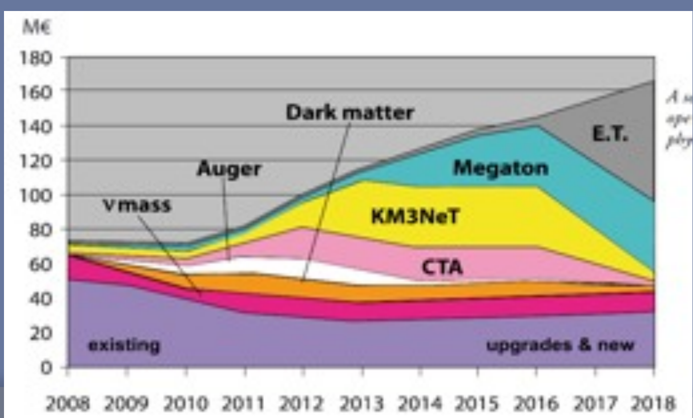
SAM/SAMOSO

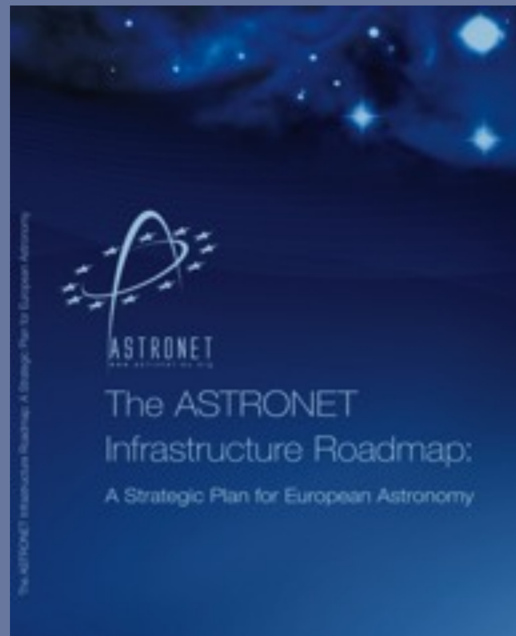
2 x 256 samples
up to 2 Gsamples/s
12 bit effective range
350 MHz bandwidth
11 mm^2



Recommendations and supports

ASPERA Roadmap
Magnificent Seven



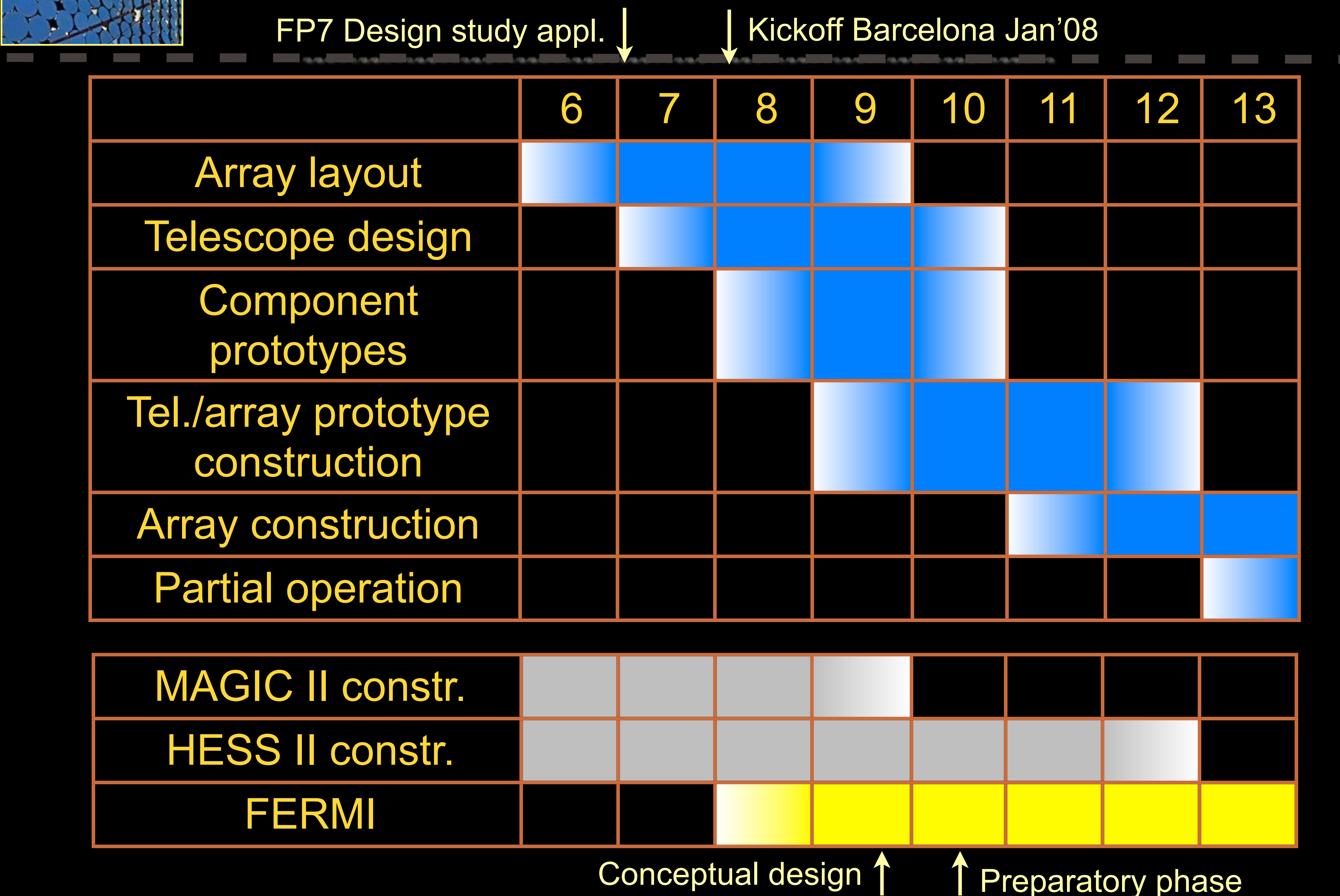


ASTRONET Roadmap
High Priority project
Ground based projects

CTA is newly added in 2008 update

8 Infrastructures from Physics and eng

Preliminary time line

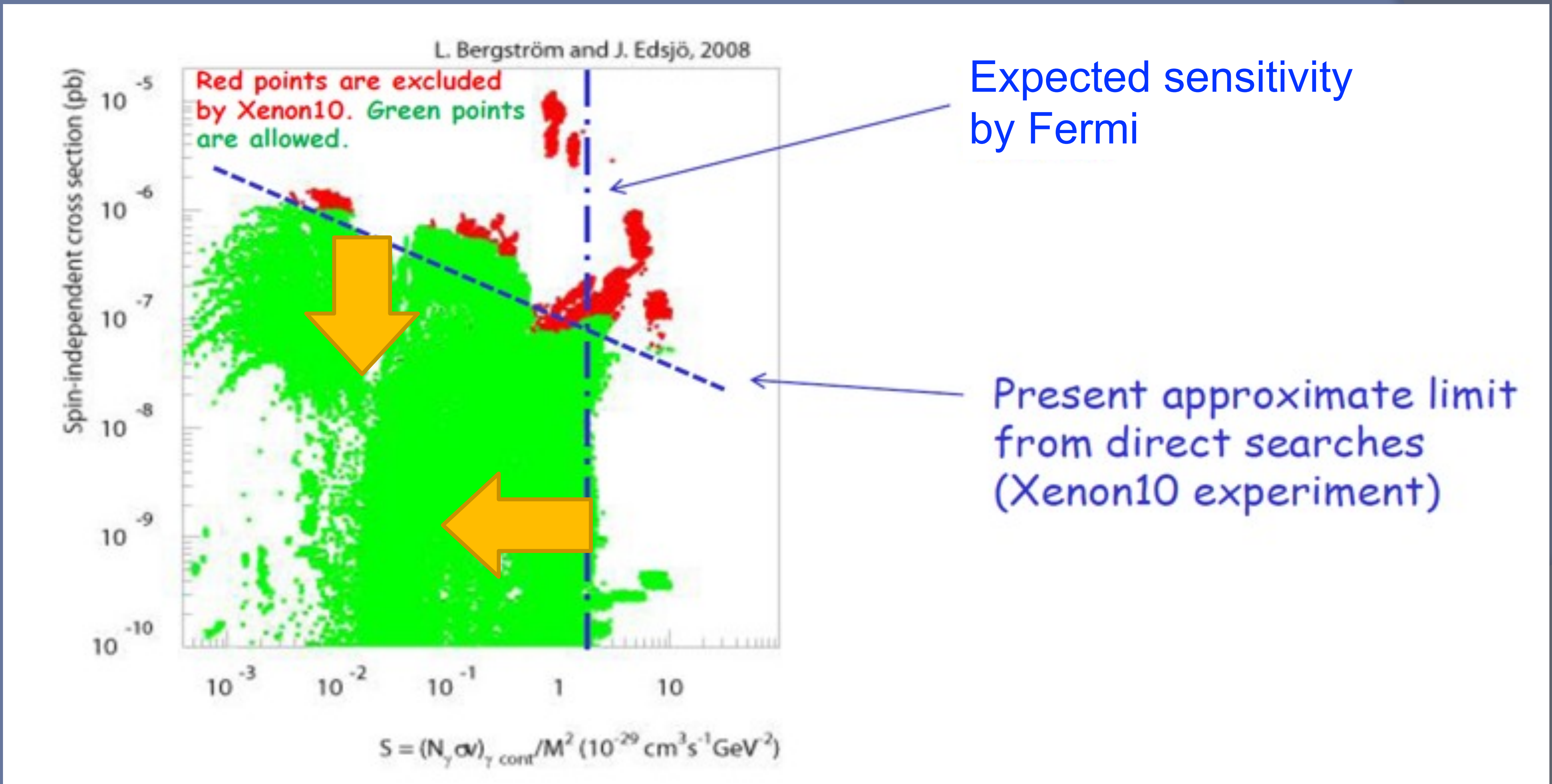


AGIS Advanced Gamma Imaging System

CTA Conclusions

- CTA is a next generation gamma ray observatory with one order of magnitude better sensitivity, larger FOV and an improved angular resolution
- There will be one station in the North and one in the South
- European initiative but collaboration with institutions from all over the world such as USA and Japan
- It will be run as an observatory, open to external astronomers
- CTA is already now a very large project with around 70 institutions and 500 physicists
- CTA is a large project, aiming for a budget of 150 Mio Euros
- We expect rich physics with CTA

Complimentary with the direct search experiment

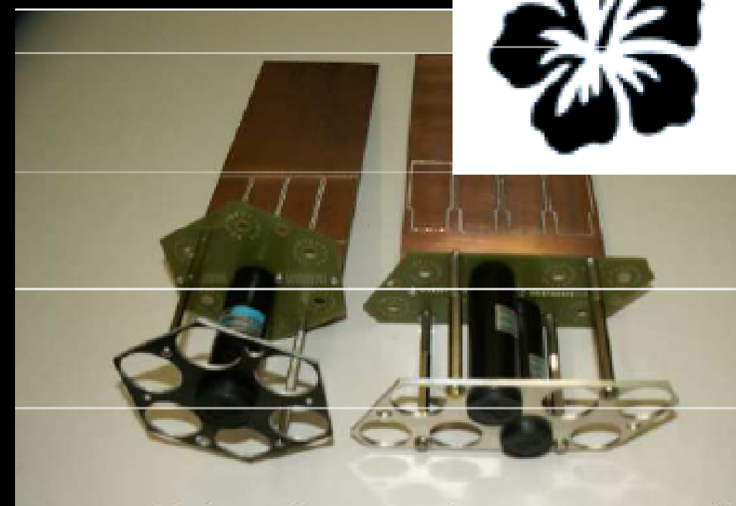


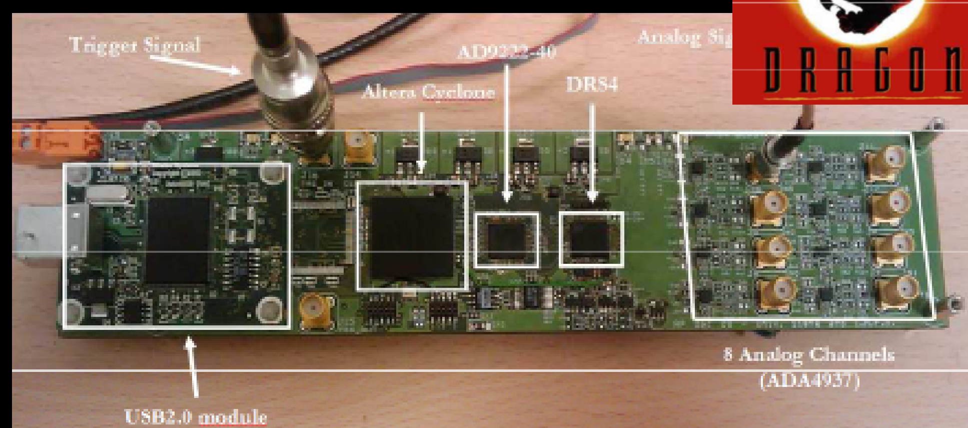
CTA readout Electronics

- NECTAr project (SAMOSO chip)
(development of new
analog capacitor array)

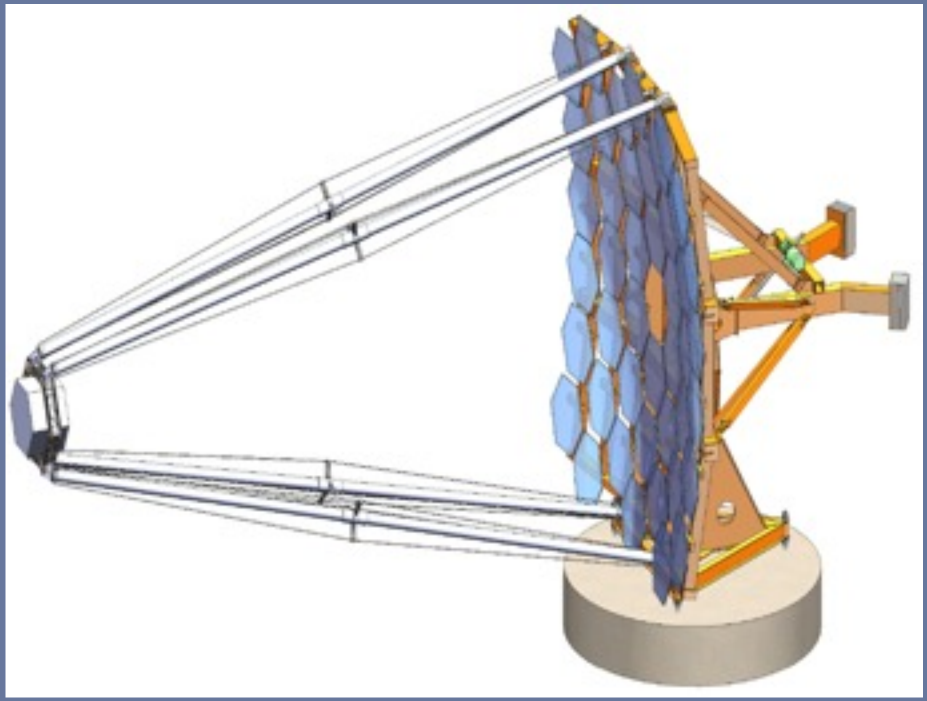
- Dragon project
(Domino Ringsampler 4
700 Mhz bandwidth,
Ethernet output)

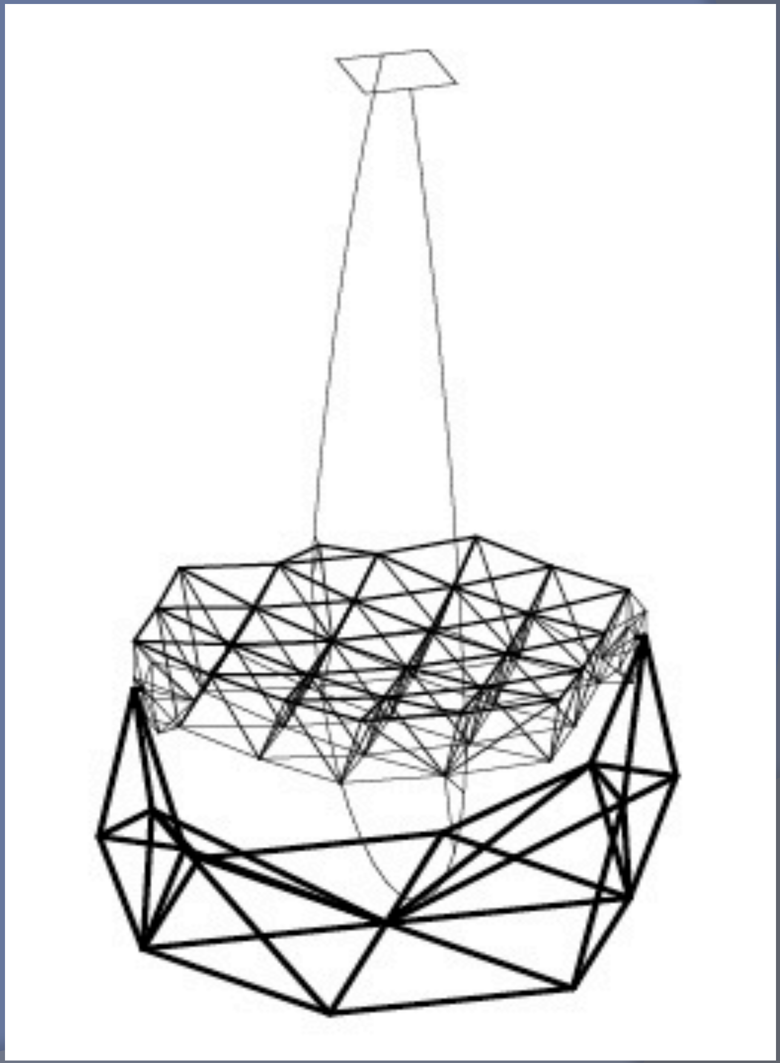
- Fully digital camera (sampling
the signal with commercial
60-200 Mhz FADC
and processing with FPGAs,
including the trigger)

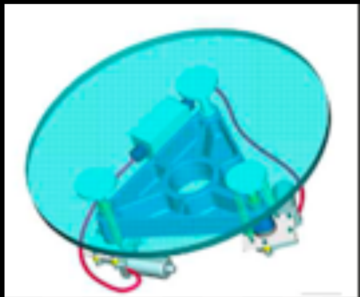

Possible layout for NECTAr (courtesy F.Toussenel)
Only 1 PCB/ 7, 8 or 16 channels



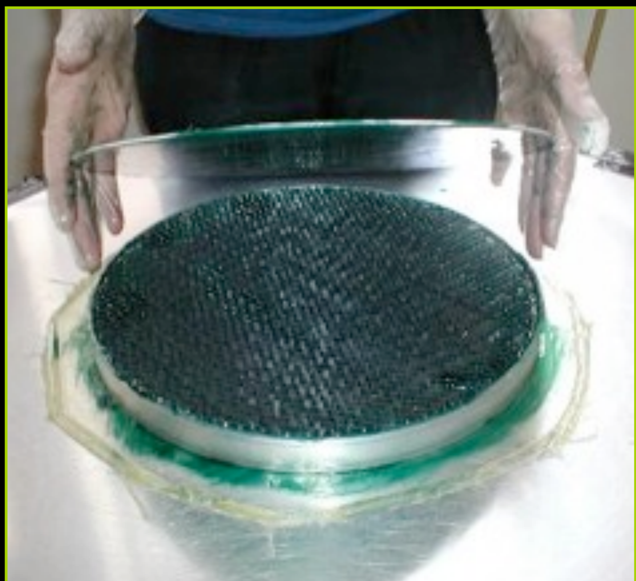
Small Size Telescope designs (6m diameter)

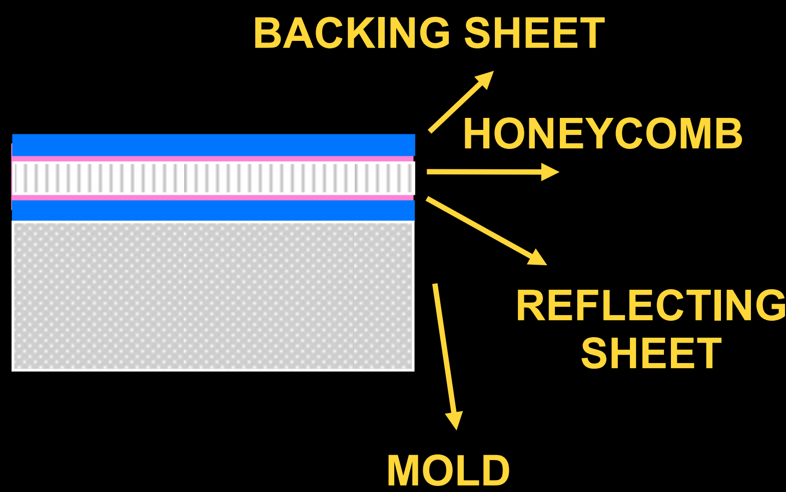




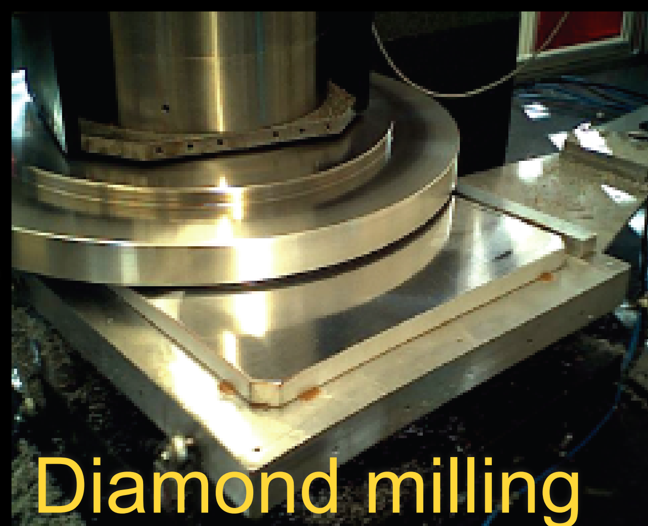


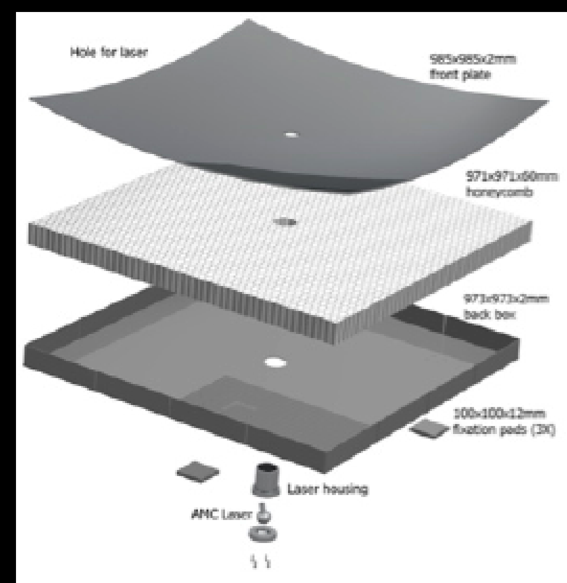
Mirrors must be cheap and good quality/ high reflectivity





Replica techniques
(thin glas sheet on honeycomb structure with aluminized surface), are a cheap possibility, while diamond milled surfaces have a longer life time

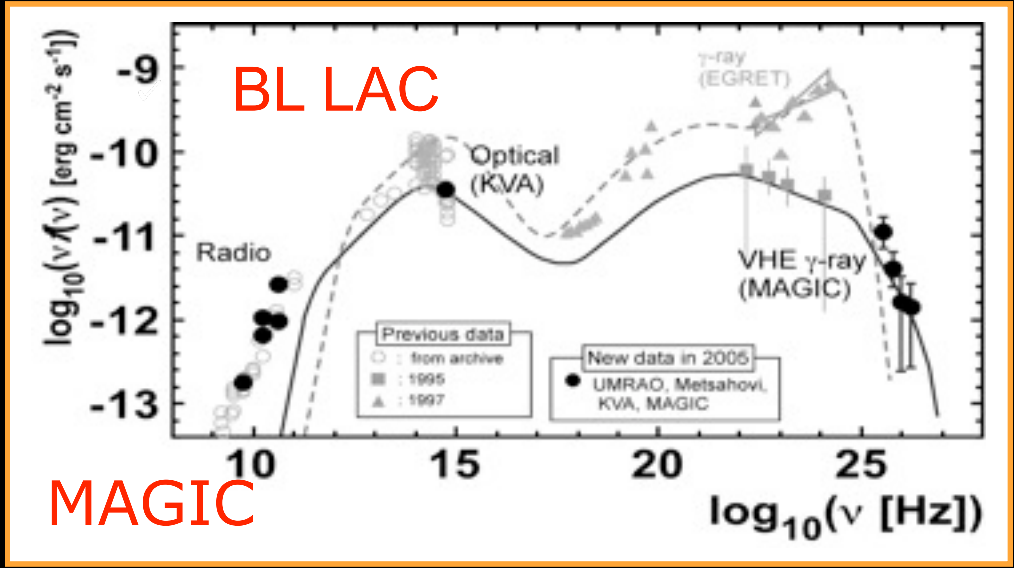


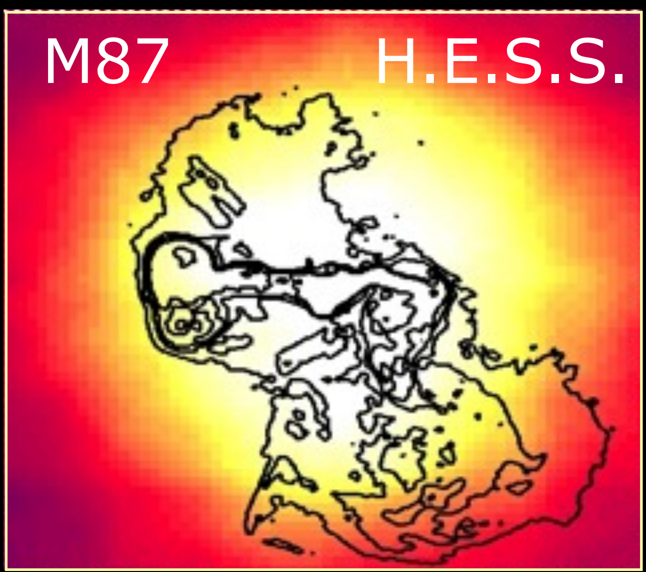


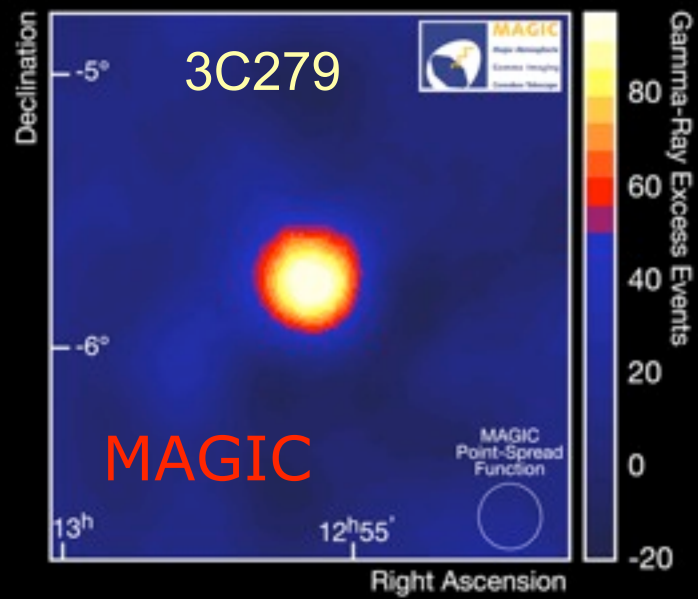
Steep spectra AGN: LBL, FSRQ & high redshift (z<2.0) AGN

- The extension of CTA to low energies will uncover many soft and steep spectrum AGN

- ~200 AGN (z<2.0) with CTA
  Threshold energy some 10 GeV to be free from EBL absorption

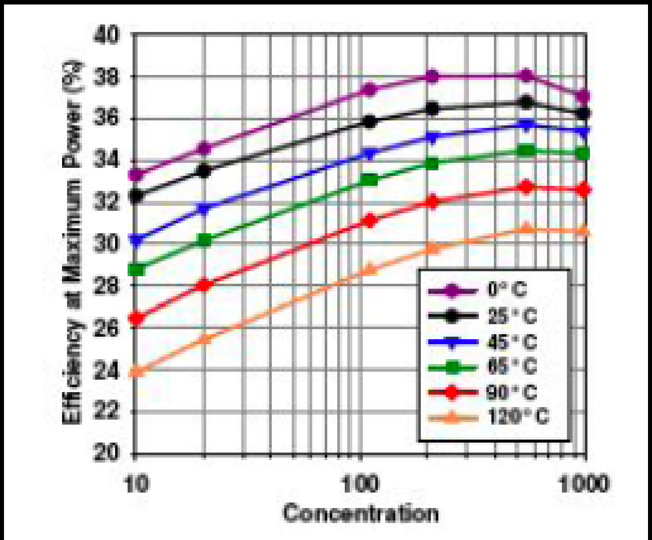


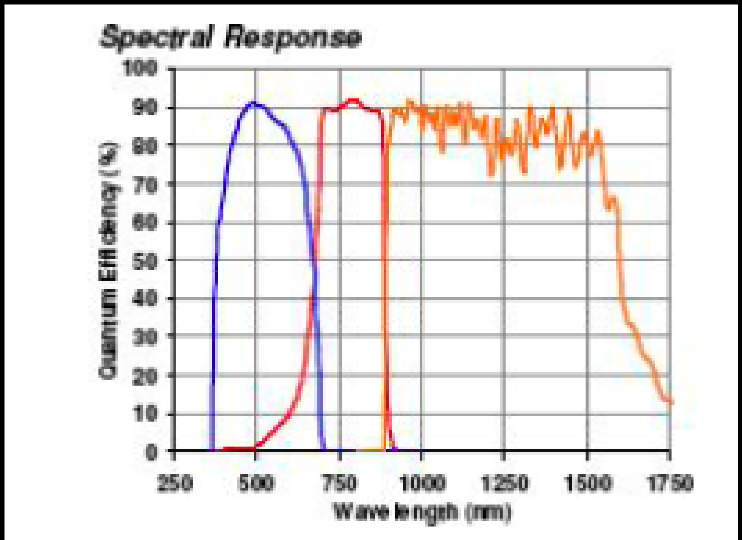


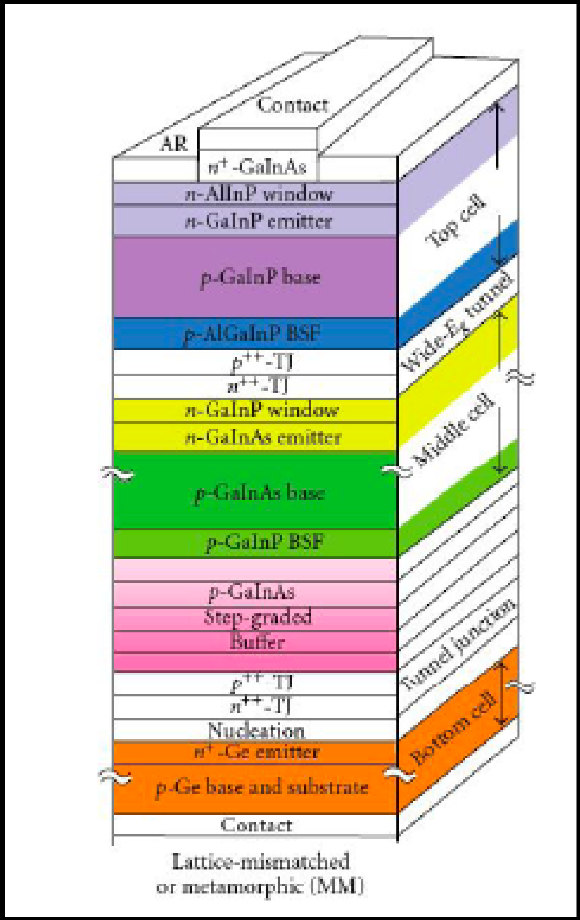


CTA, a green experiment ?

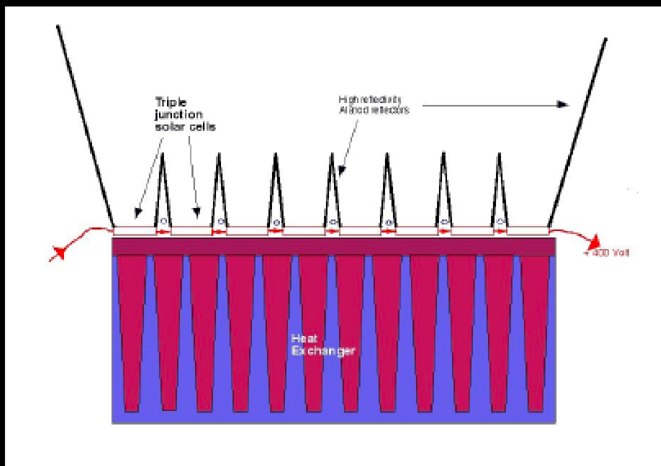
Commercially available multi-junction solar cells reach a QE of 41% now.
They cost between 10-30 Euros for a power of 50Watt (2.5 cm^2)
One could use small telescopes to concentrate light and produce the power needed to run CTA.

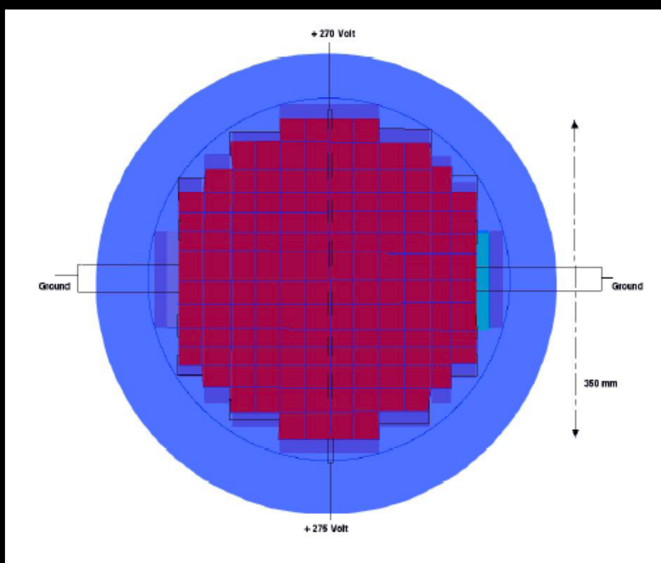


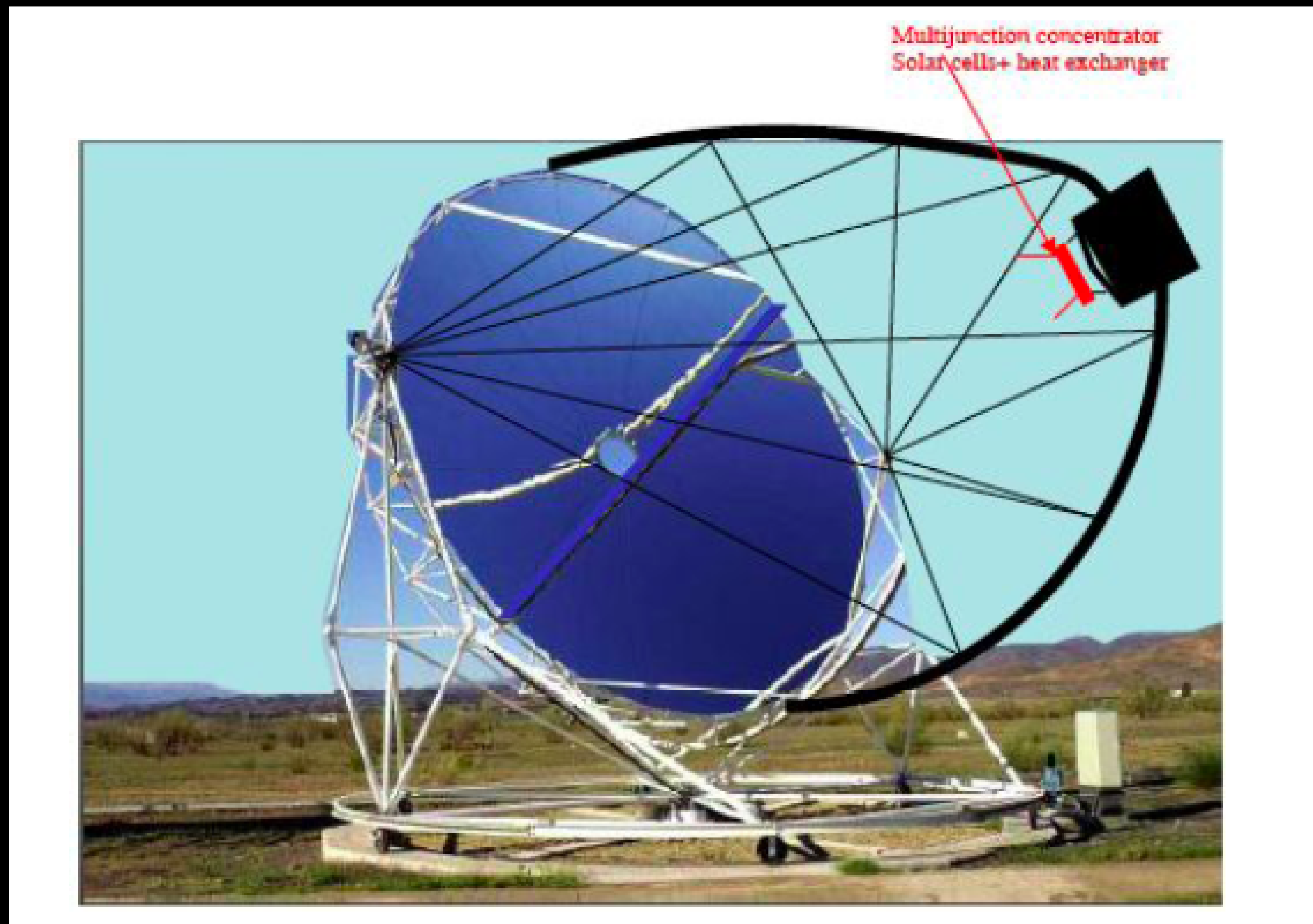




Dual-use of SST for electrical power

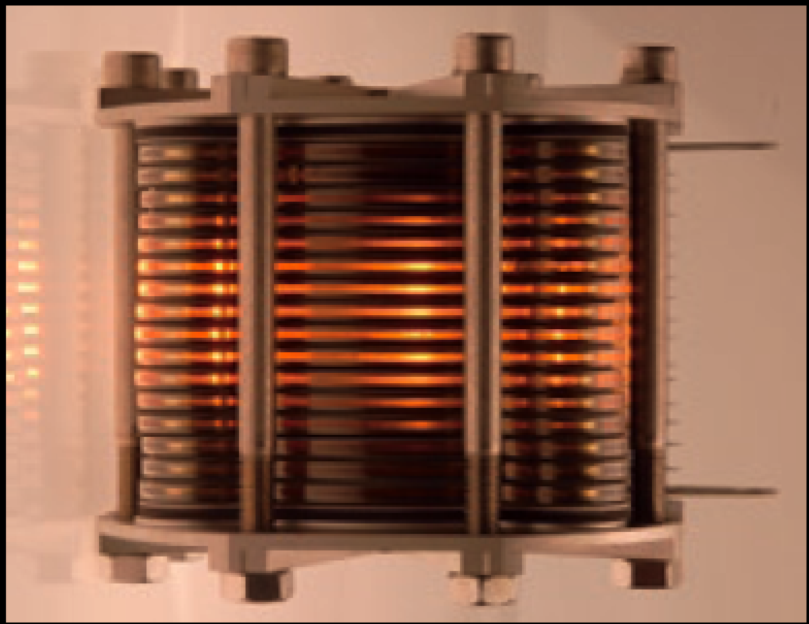






Emergy must be stored

- Combination of Li-Ion batteries
(short term, 90% efficiency) and
- hydrogen storage (long term:
40-50% efficiency) by usage of electrolysis cells, fuel cells
and high pressure metal-hydrid-storage



Solar power plant

Datacenter and operations center for CTA

- Challenges:
  - ✓ Huge data rates (0.5 PBytes/Year)
  - ✓ Observatory: Automatic calibration and analysis for users
- Organisatorial structure:
  - ✓ Array operation center
  - ✓ Data handling and analysis center
  - ✓ Science operation center
  - ✓ Maybe array control center and data handling in different locations
- Lots of personal (local technicians, operation crew, professional data analyzers for science operation)

Specs of large size telescope design

- Optimized for high light detection efficiency
  - ✓ High QE: PMTs, HPDs or SiPm (60% QE)
  - ✓ Trigger threshold at 10 GeV
  - ✓ Analysis threshold at 20 GeV
  - ✓ Optimized for physics at lowest energies
  - ✓ Fast rotation for GRBs (20s/180deg)

11 GRBs observed by LAT

GRB	duration	# of events > 100 MeV	# of events > 1 GeV	Highest Energy (arrival time)	Delayed HE onset	Long-lived HE emission	Extra component	Redshift
080825C	long	~10	0	~0.6 GeV (~T_0+28 s)	✔	✔	?	
080916C	long	>100	>10	~13 GeV (~T_0+17 s)	✔	✔	hint	4.35
081024B	short	~10	2	~3 GeV (~T_0+0.6 s)	✔	✔	?	
081215A	long	–	–	–	–	–	–	
90217	long	~10	0	~1 GeV (~T_0+15 s)	X	X	?	
90323	long	~20	>0	–	–	✔	–	3.57
90328	long	~20	>0	–	–	✔	–	0.736
90510	short	>150	>20	~31 GeV (~T_0+0.8 s)	✔	✔	✔	0.903
90626	long	~20	>0	–	–	✔	–	
090902B	long	>200	>30	~33 GeV (~T_0+82 s)	✔	✔	✔	1.822
90926A	long	>150	>50	~20 GeV (~T_0+25 s)	✔	✔	✔	2.106

→ 71GeV (16.54s)

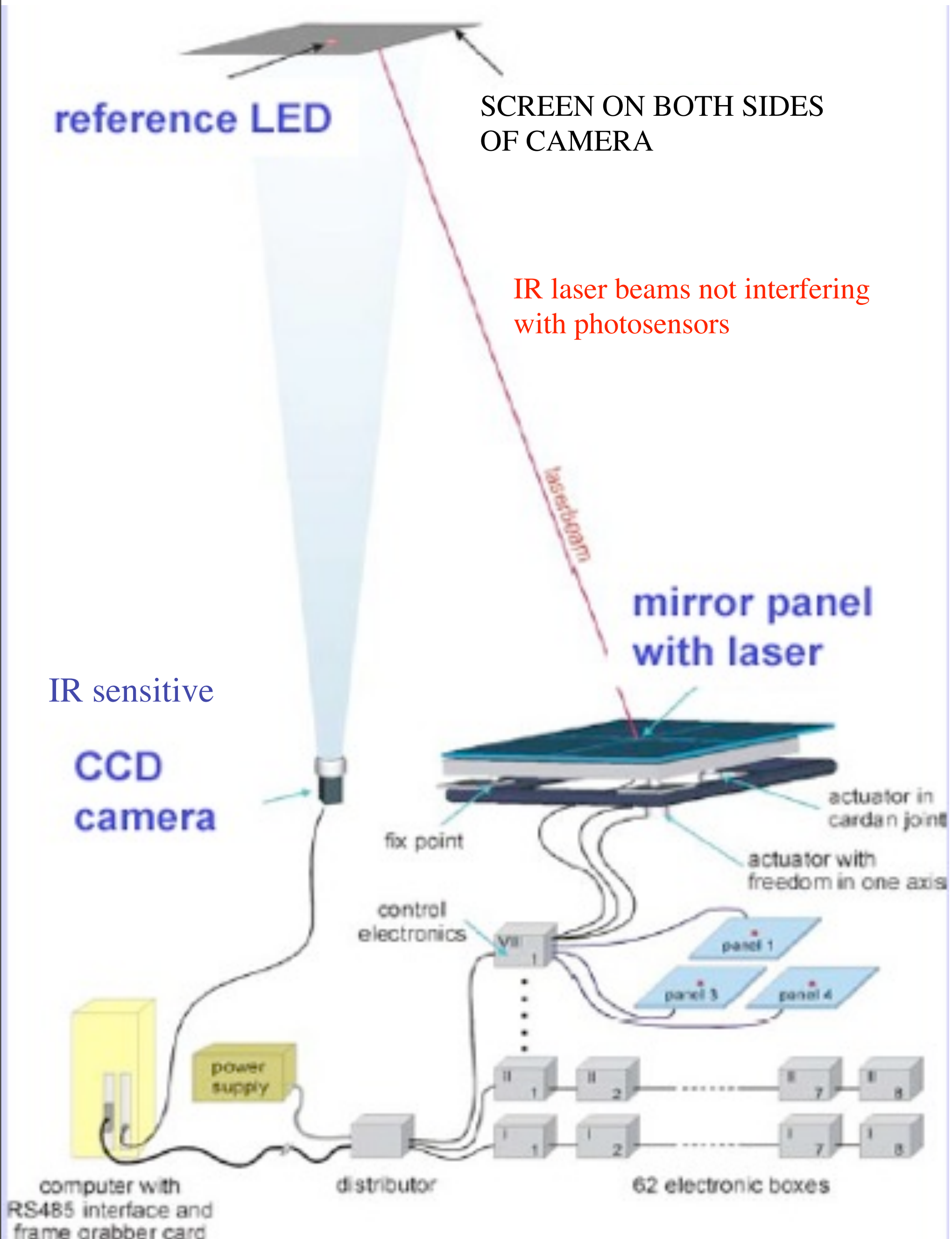
→ 59GeV (0.829s)

→ 93GeV (82s)

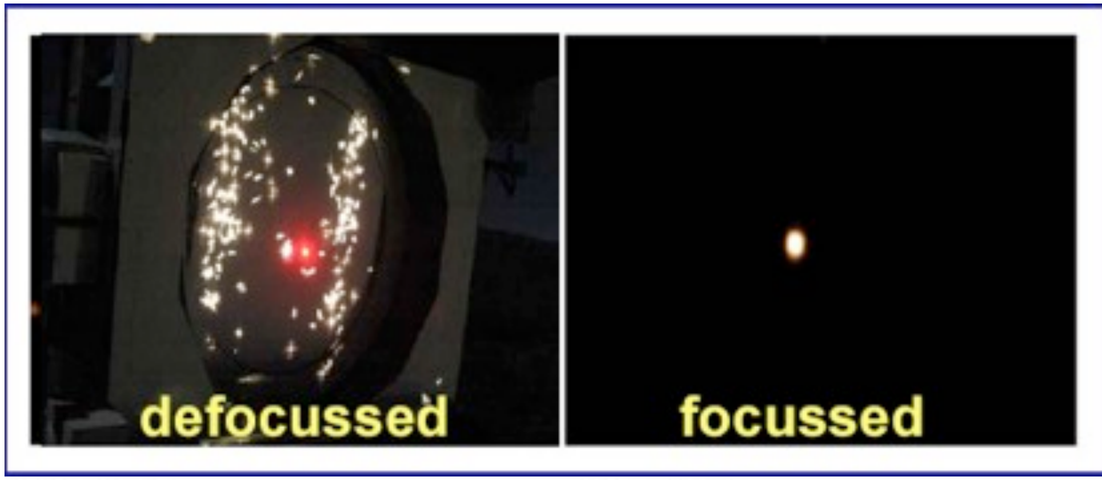
→ 62GeV (s)

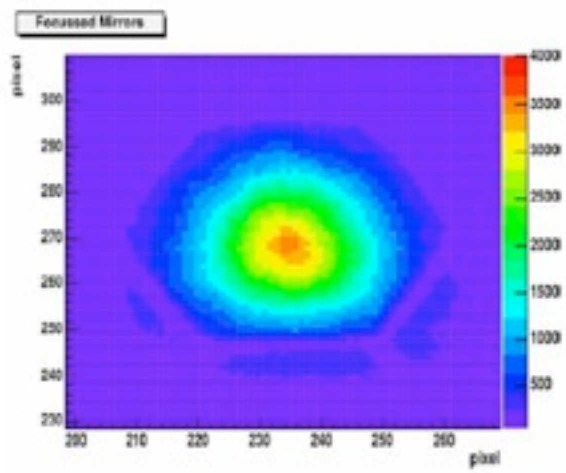
THE ACTIVE MIRROR CONTROL

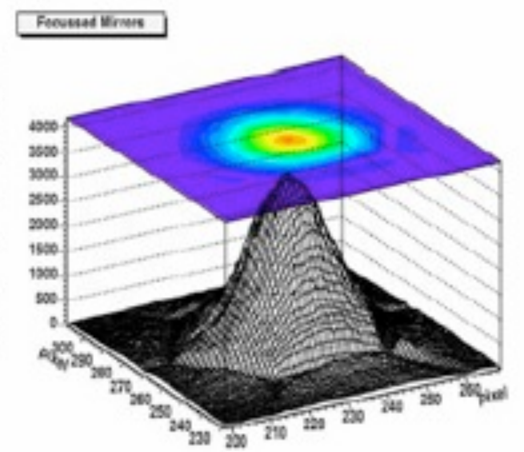
COUNTERACTS SOME SMALL DEFORMATIONS
OF MIRROR SUPPORT FRAME

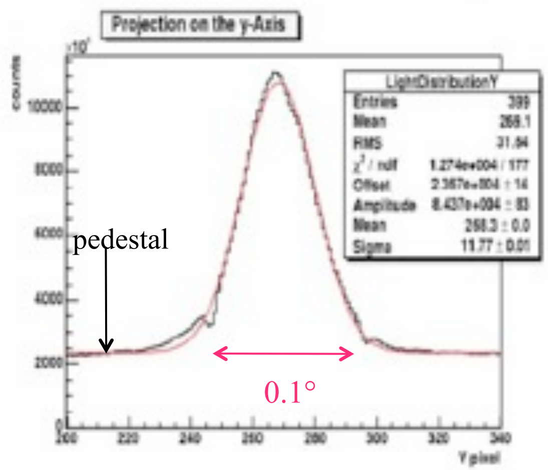


EXAMPLE OF MIRROR FOCUSSED TO A LIGHT SOURCE 1000mtr AWAY



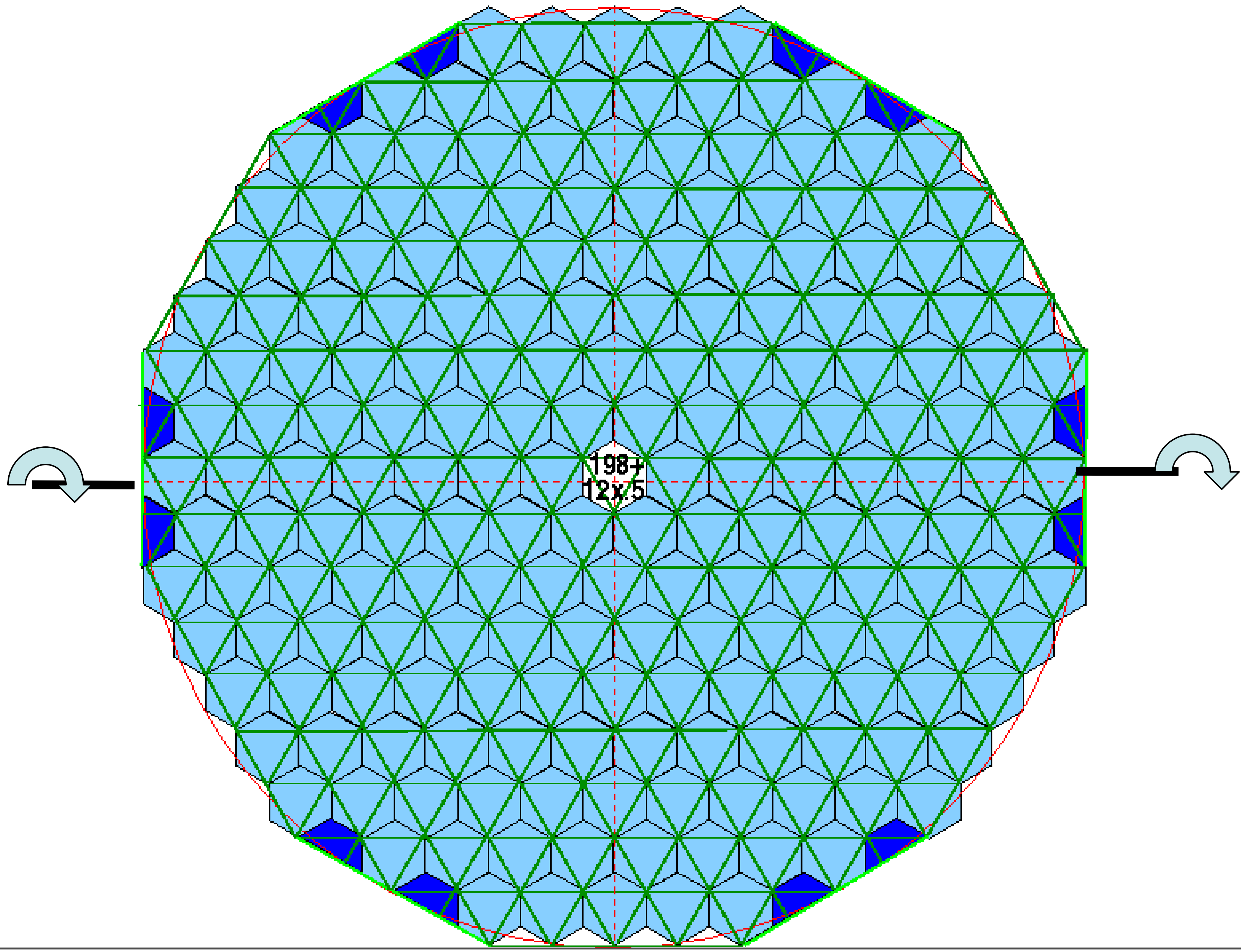






PSF 0.03° AFTER MANUAL ADJUST. (0.02° AUTOMATIC) WILL DEGRADE DURING RUNS IF NOT FREQUENTLY READJUSTED

LAYOUT OF MIRROR SEGMENTS

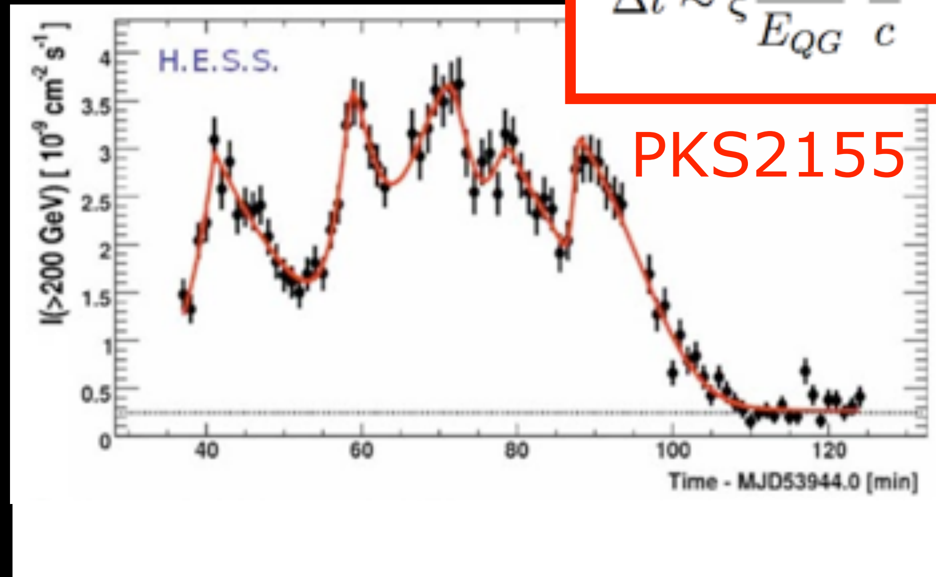


Increased statistics (incr. coll. area) Test on Lorentz Invariance Violation

CTA has not only an increased sensitivity but also an increased collection area which results in an increased statistics by a factor of ten and for lower energy threshold even more

$$\Delta t \sim \xi \frac{E}{E_{QG}} \frac{L}{c}$$

PKS2155



The best limits on LIV are now:

HESS: 0.04 M_p
MAGIC: 0.02 M_p

--> CTA: O(0.1 M_p)

Mkn421

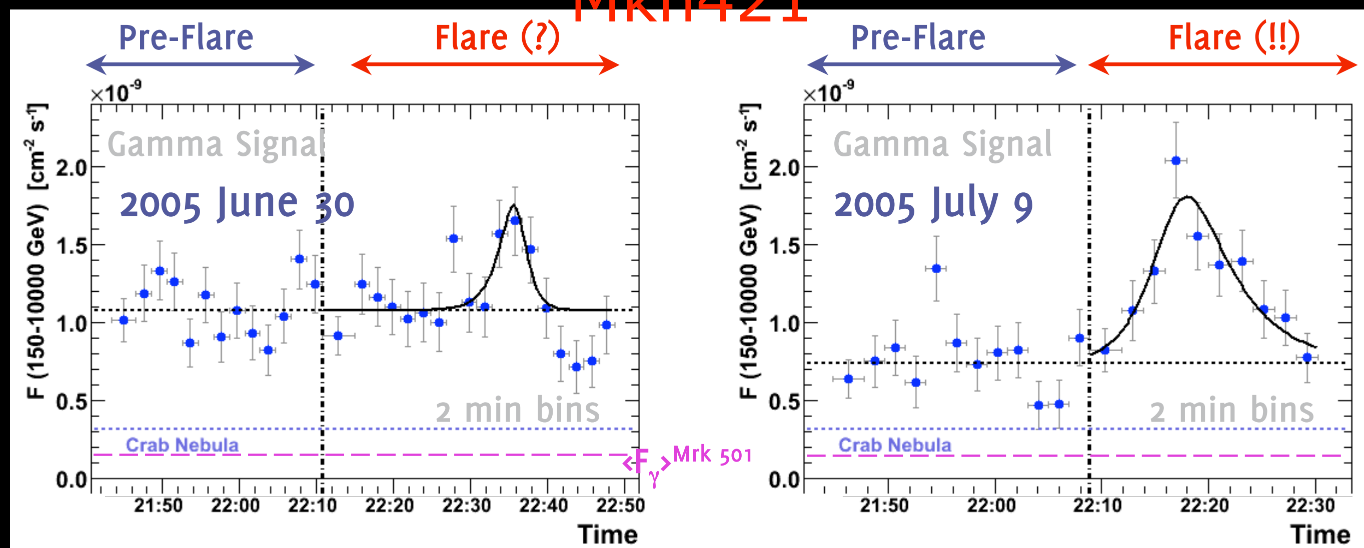


Image quality and F/D

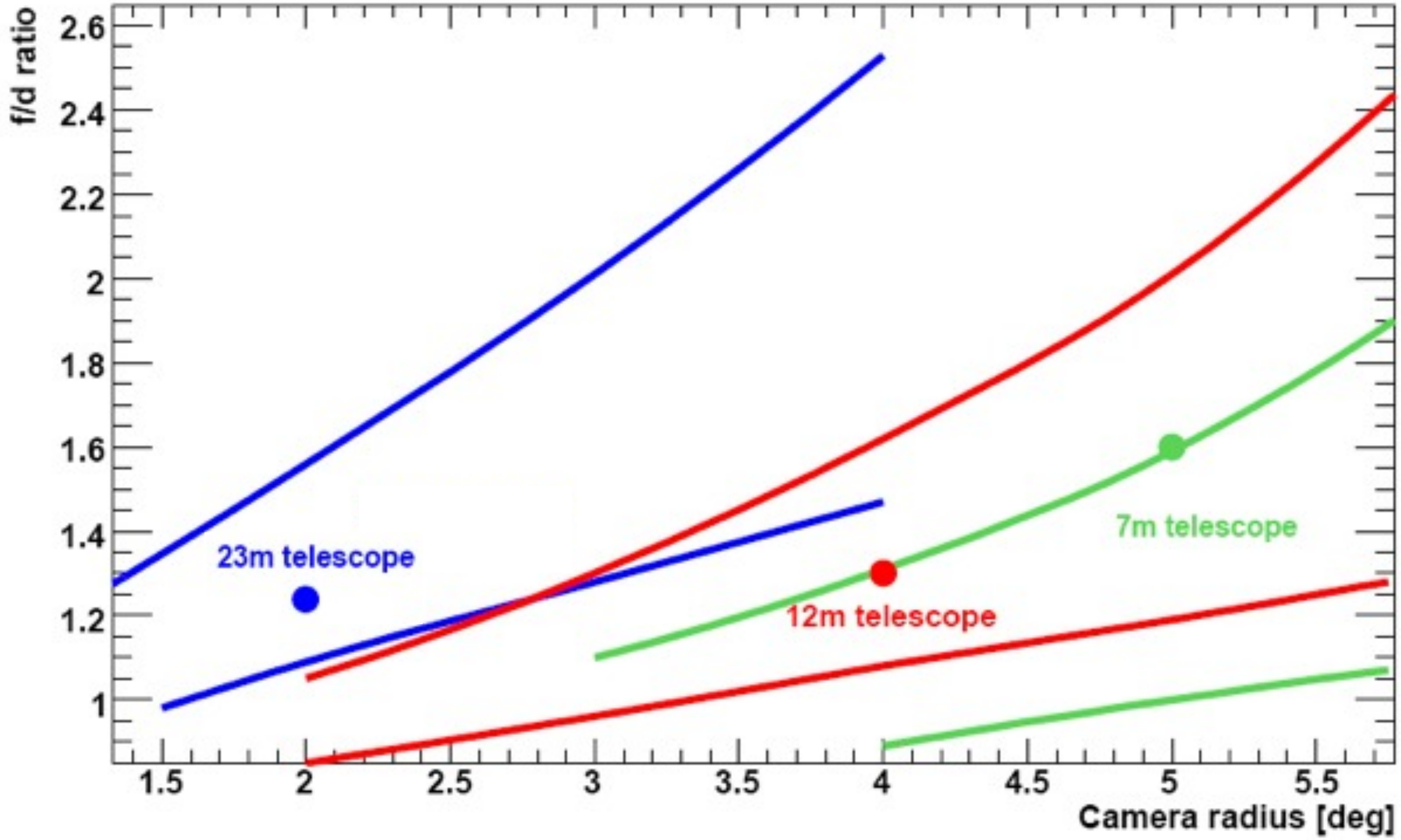
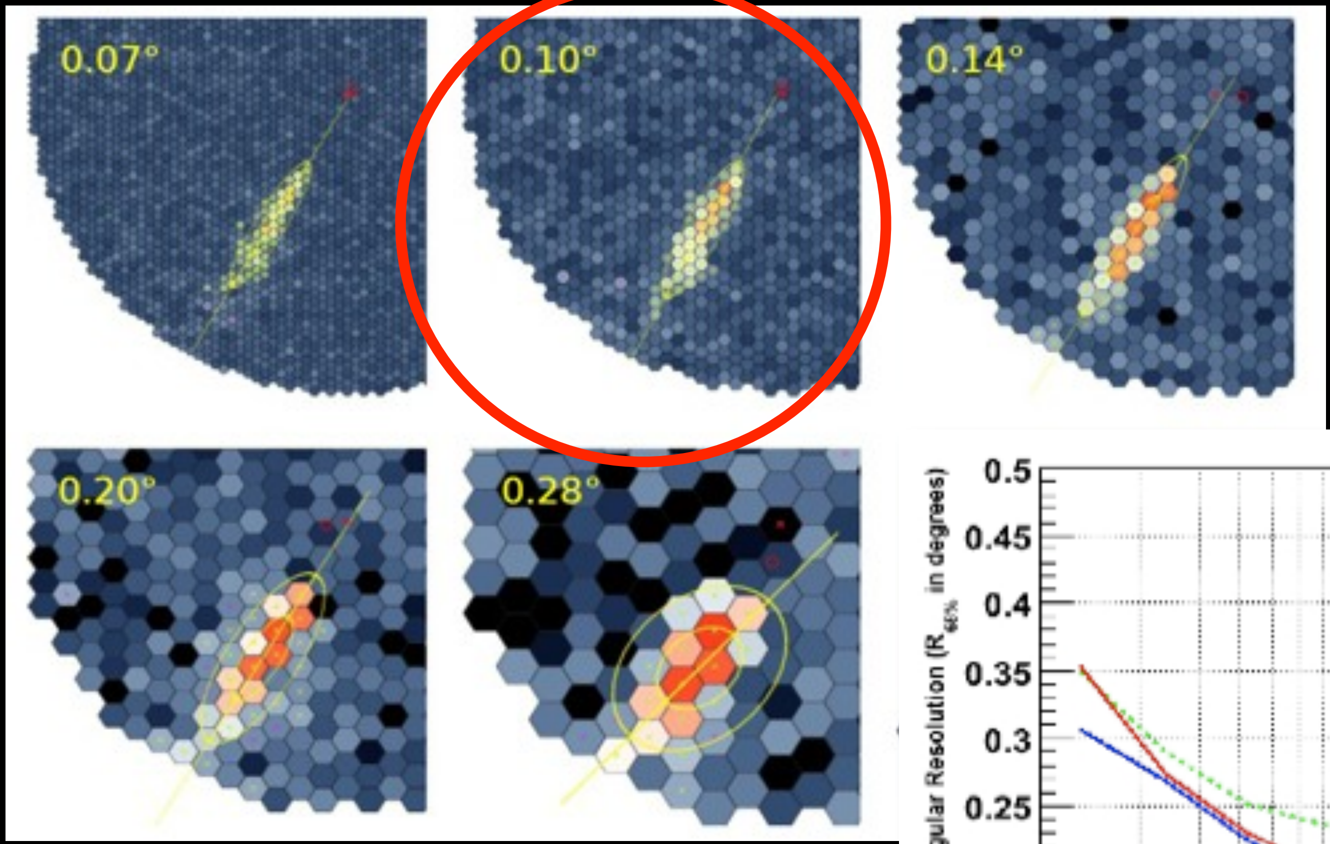
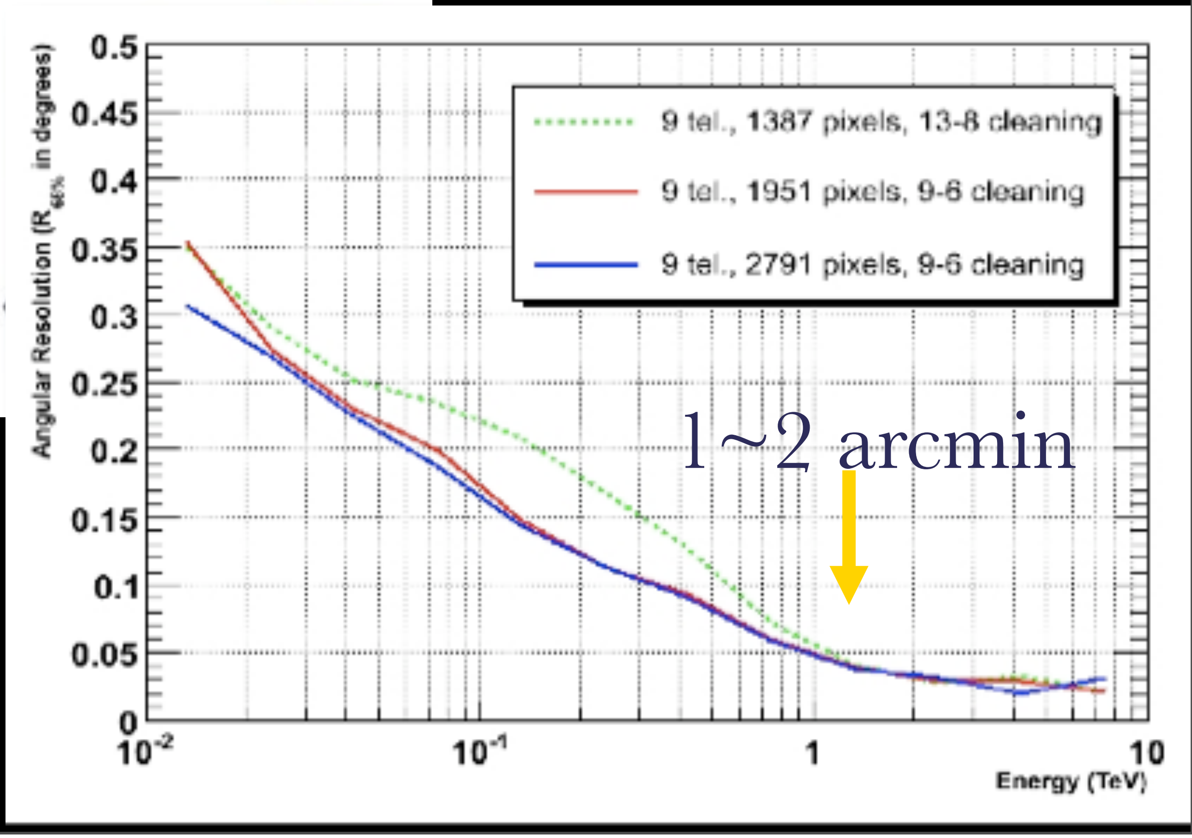


Figure 7: Range of reasonable f/d ratio for a given FOV for 23 m parabolic telescopes (blue), 12 m Davies-Cotton telescopes (red) and 7 m Davies-Cotton telescopes (green). The telescopes used in the MC productions are shown with circles.

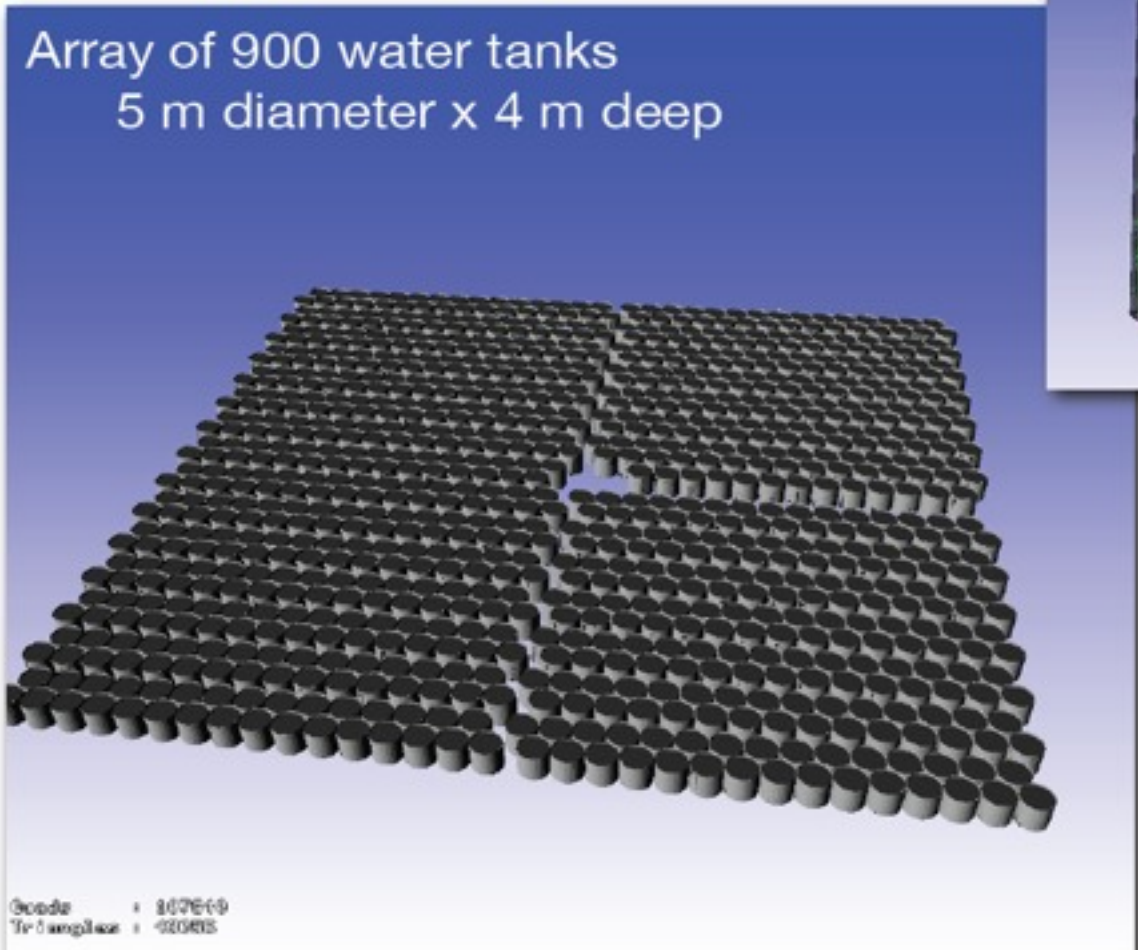
Impact of Pixel size to the Angular resolution

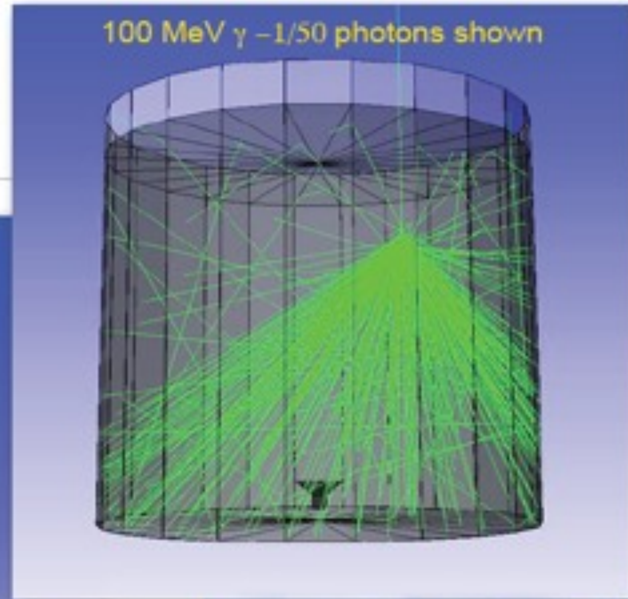




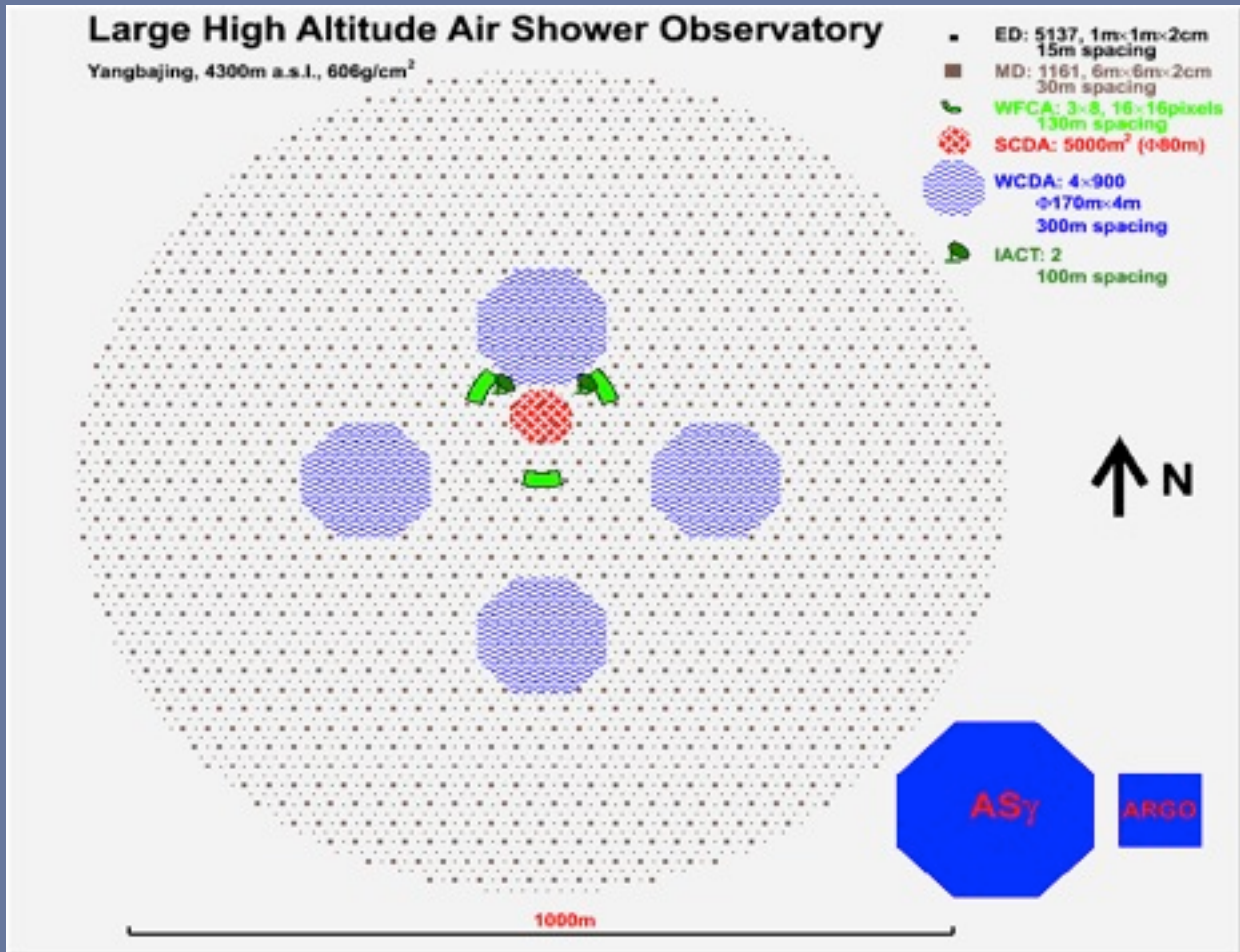
Competing high energy telescopes:HAWC

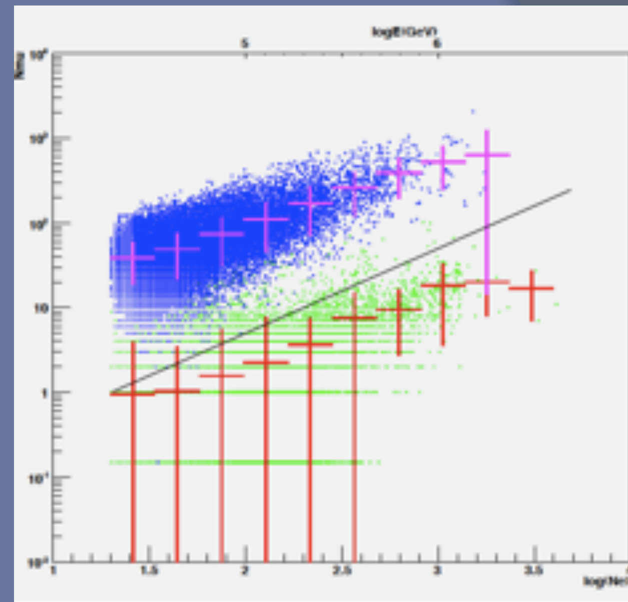
HAWC Design

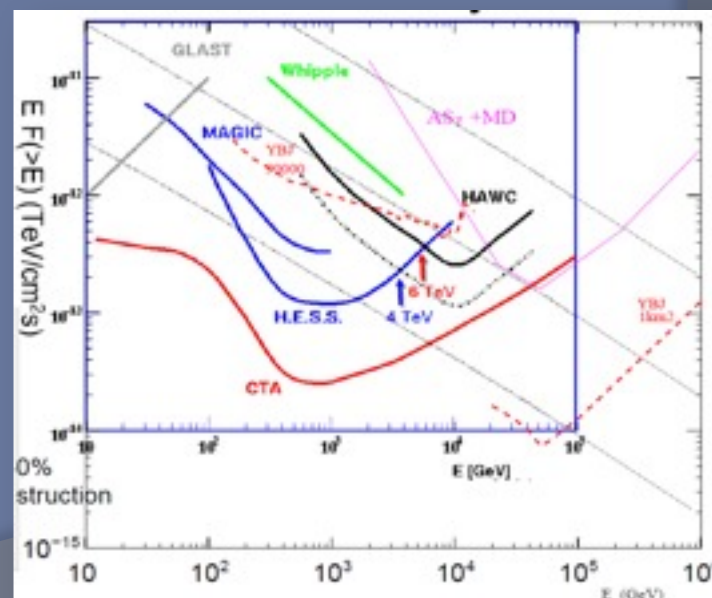




Competing high energy telescopes: LHAASO







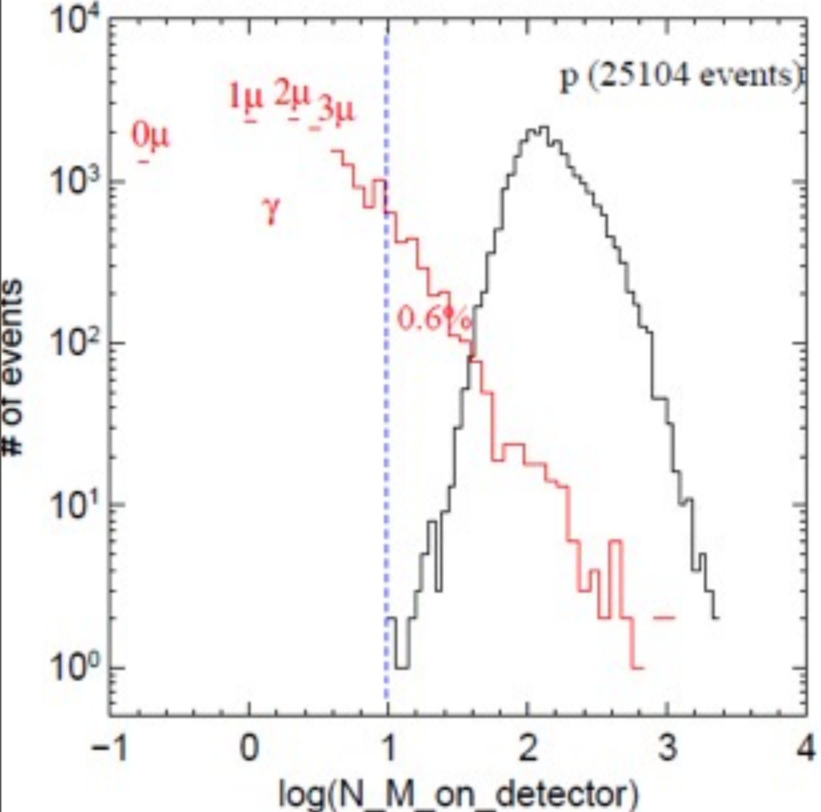
Friday, April 20, 2012

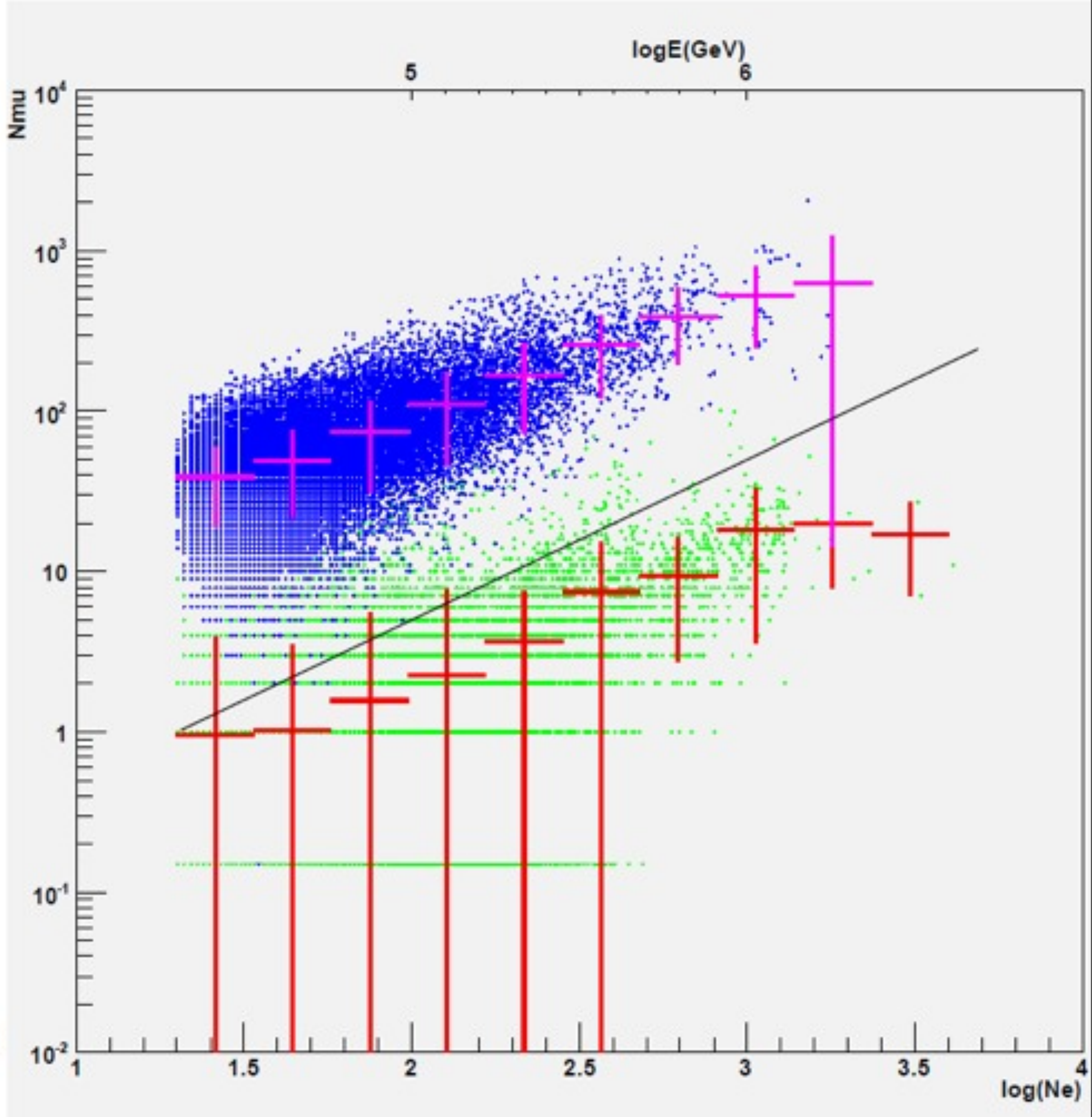
γ /p discrimination

- Above 60TeV

CR BG-free(10^{-5})

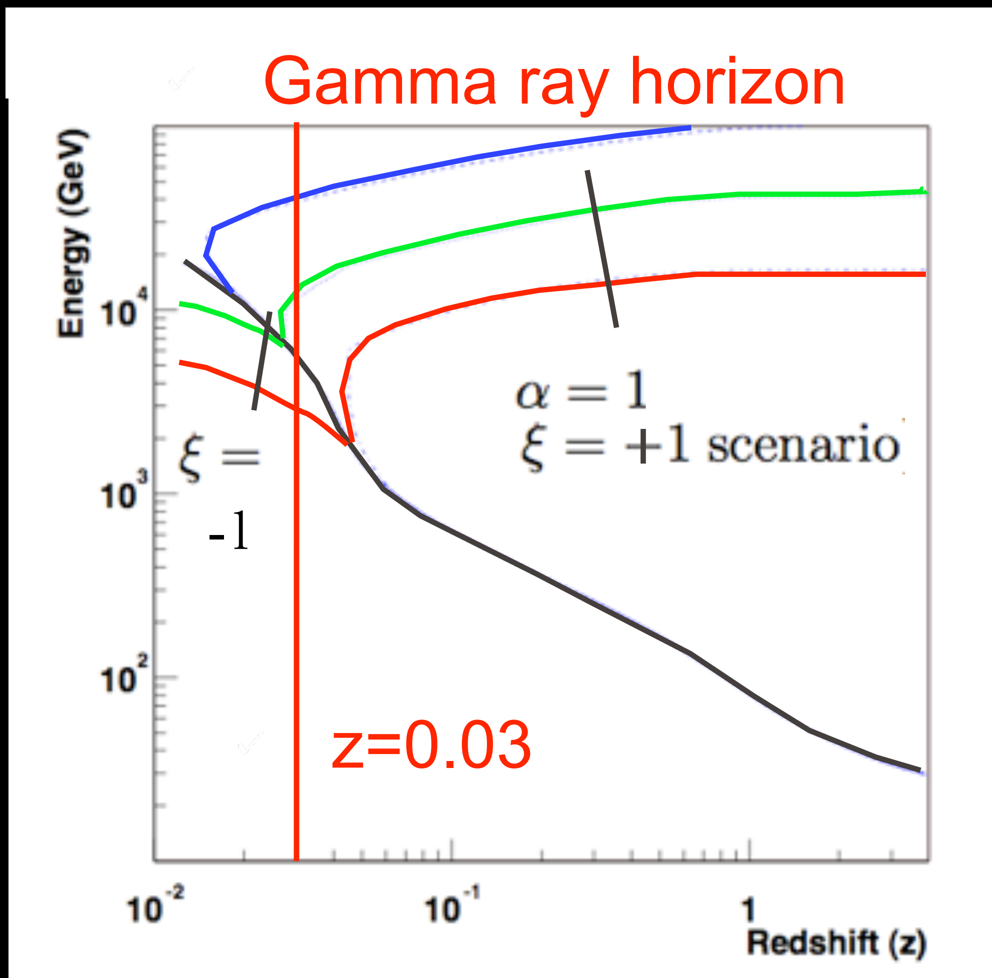
- γ survival rate ~99%
- Angular resolution 0.5°

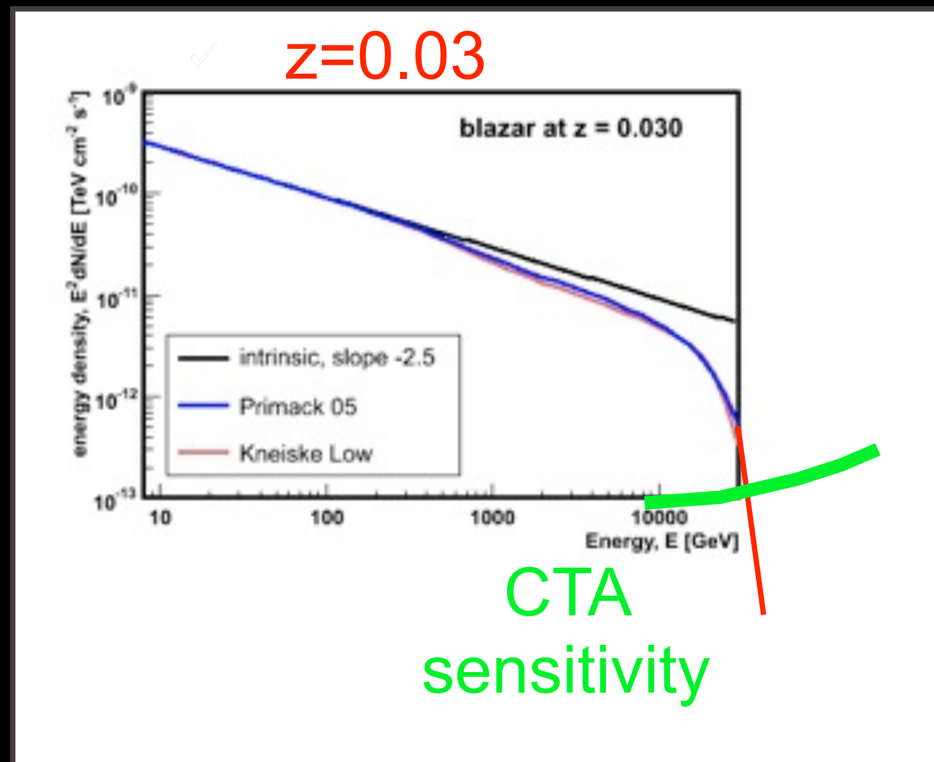




Lorentz invariance violation
Modification of gamma ray horizon

✓ Gamma ray horizon for $E_{QC} = E_P$, $0.1E_P$, $0.01E_P$





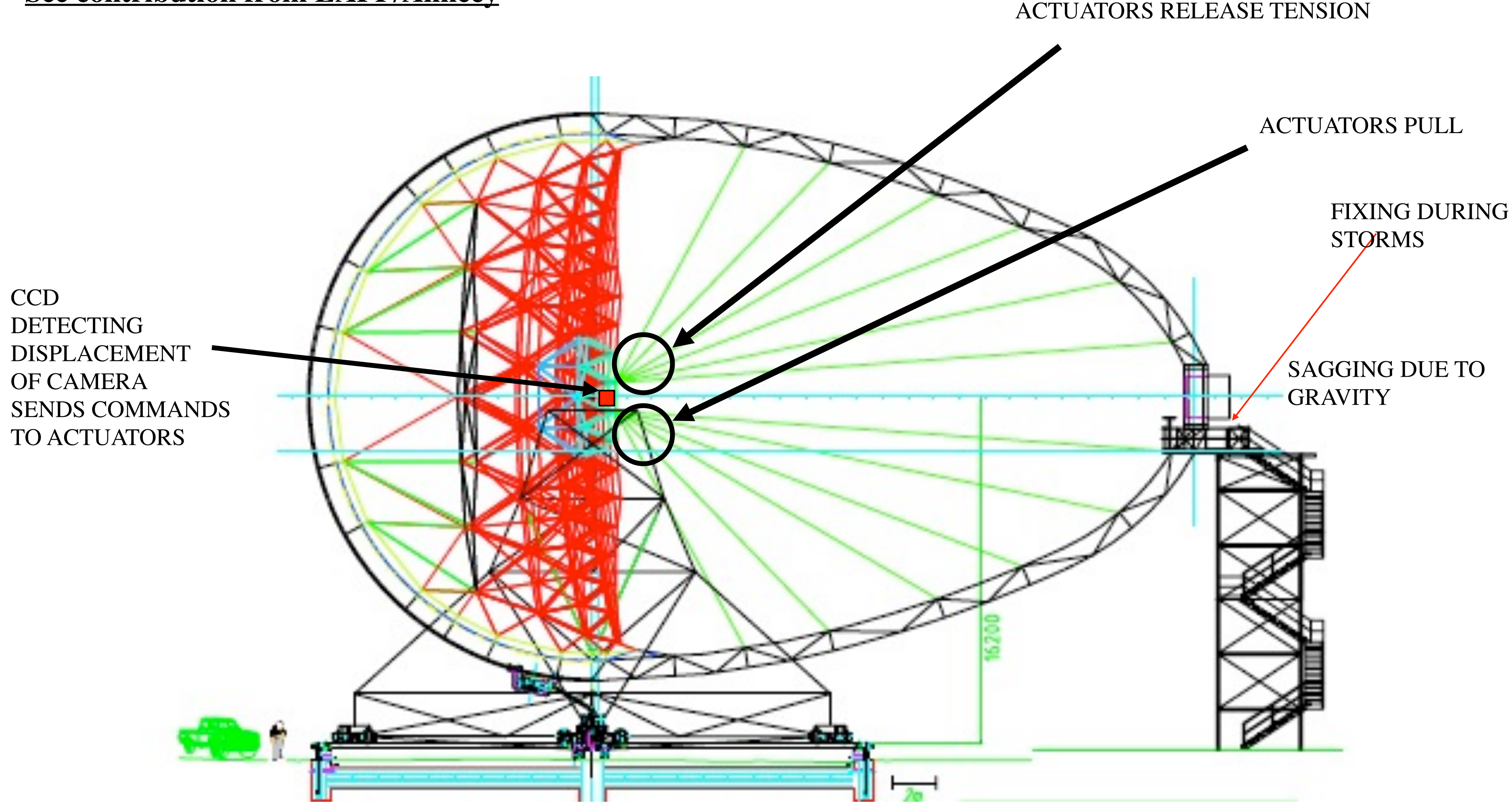
Very hard limits on
LIV possible !!
Theory extremly difficult...
(LIV breaks gauge invariance)


4.5 TONS, EXTRA HEAVY FOR PREVENTING
TELESCOPE LIFTOFF DURING STRONG WINDS
MPI
MPI

I-BEAM EXAMPLE FOR THE AZIMUTH RAIL OFFER ALREADY AVAILABLE

POSSIBLE USE OF ACTIVE BENDING CORRECTION

See contribution from LAPP/Annecy



23m telescope SPECS:

- Mirror Diameter: 23 m
- Mirror Area: 410 m^2
- Focal length: 28 (f/d ≈ 1.2)
- Weight ≈ 50 tons (needed for GRB studies), 50 tons possible for CFRP
- Foundation: Concrete ring with steel I-Beam ring with protection against wind lift-up of telescopes during storms
- Bogeys: 6 (4 wheels each, similar to version of PETAL)
- Substructure: similar like HESS/MAGIC, but CFRP frame with some steel components
- Dish spaceframe: 3 layer space frame, with tetraeders as basic elements
- Space frame material: CFRP (high strength fibers) + Al knots
- Reduction of wind resistance: cover of space frame by panels as in radio telescopes
- Tetraeder elements: rods of 153-155 cm, detailed length following mirror profile
- Mirror profile: main curvature: parabolic, locally with deviations up to 2-3 cm
- Gross mirror shape: hexagonal
- Mirror elements: hexagonal, 152-153 cm width (width across flats)
- Production technique similar to MAGIC 1x1 m^2, central hole
- allow for a small zone of imperfection (change of diamond)
- individual mirror elements: ≈ 2 m^2

•Area of individual mirrors: ≈ 2 m^2

•# of mirrors: ≈ 220, weight < 30(40) kg/ mirror

•Mirrors with dielectric coating for high reflectivity ??

R> 95% between 300 and 550 nm,

R > 85% between 550-650 nm

•PSF: < 1cm FWHM, > 90% of light within 1 cm radius

•Active mirror control: permanent, fast response. IR lasers (not disturbing PMTs)

project a spot on a screen outside camera, viewed by IR CCD

alternatively: 1 CCD camera per mirror

viewing an LED at the camera position.Inclinometer?

AMC will be a key element to cut costs (allows a softer frame, cheaper)

SEE TALK A. GADOLA, U. ZURICH

•Camera support by 2 CF-masts like in MAGIC.

•**SEE TALK G. DELEGILSE, LAPP ANNECY**

•Reasonable limit of camera weight: 2 tons (1 ton preferred)

•Motors: 2 for azimuth (10 KW /motor), 1 for declination (10 KW/motor),like for MAGIC

First estimate of weight of moving part

Bogeys and wheels (8-12t)		12 t
Substructure (CF+ Steel)(10-14 t)	12 t	
Support dish (7-9t)		8 t
Mirrors and AMC		10 t
Camera masts, declination drive ring camera support frame	6 t	
Camera		2 t
Auxiliary stuff		?? ?
		50 ± x tons

HESS I (12 mØ) : 68 tons
MAGIC (17mØ) : 70 tons
HESS II (28mØ) : 560 tons

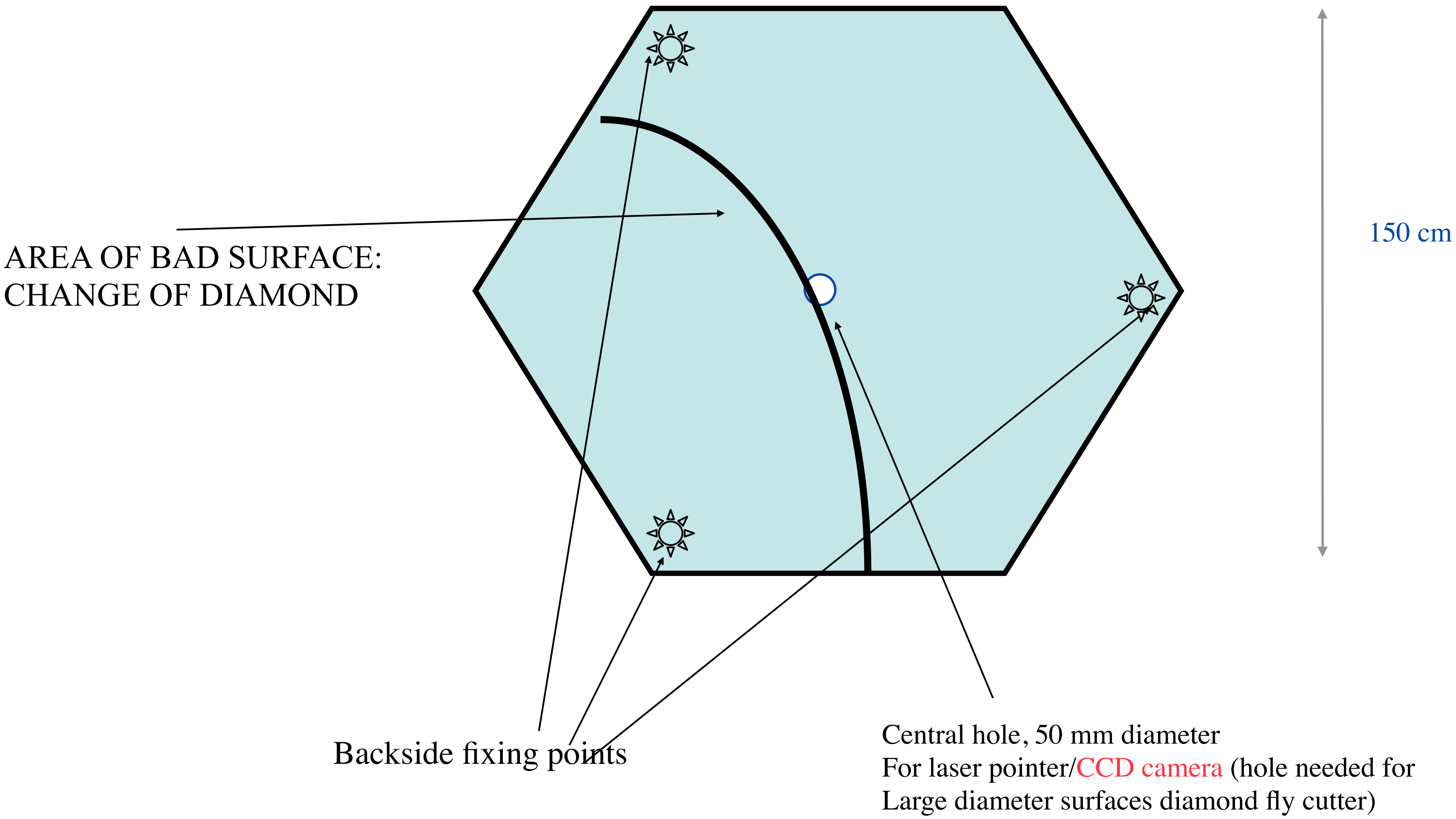
Raw costs for CF tubes for dish ≈ 250 k€
Raw costs for CF tubes for substructure ≈ 270 k€
Mirror costs /m**2 ≈ 3000€ / m**2

MIRROR

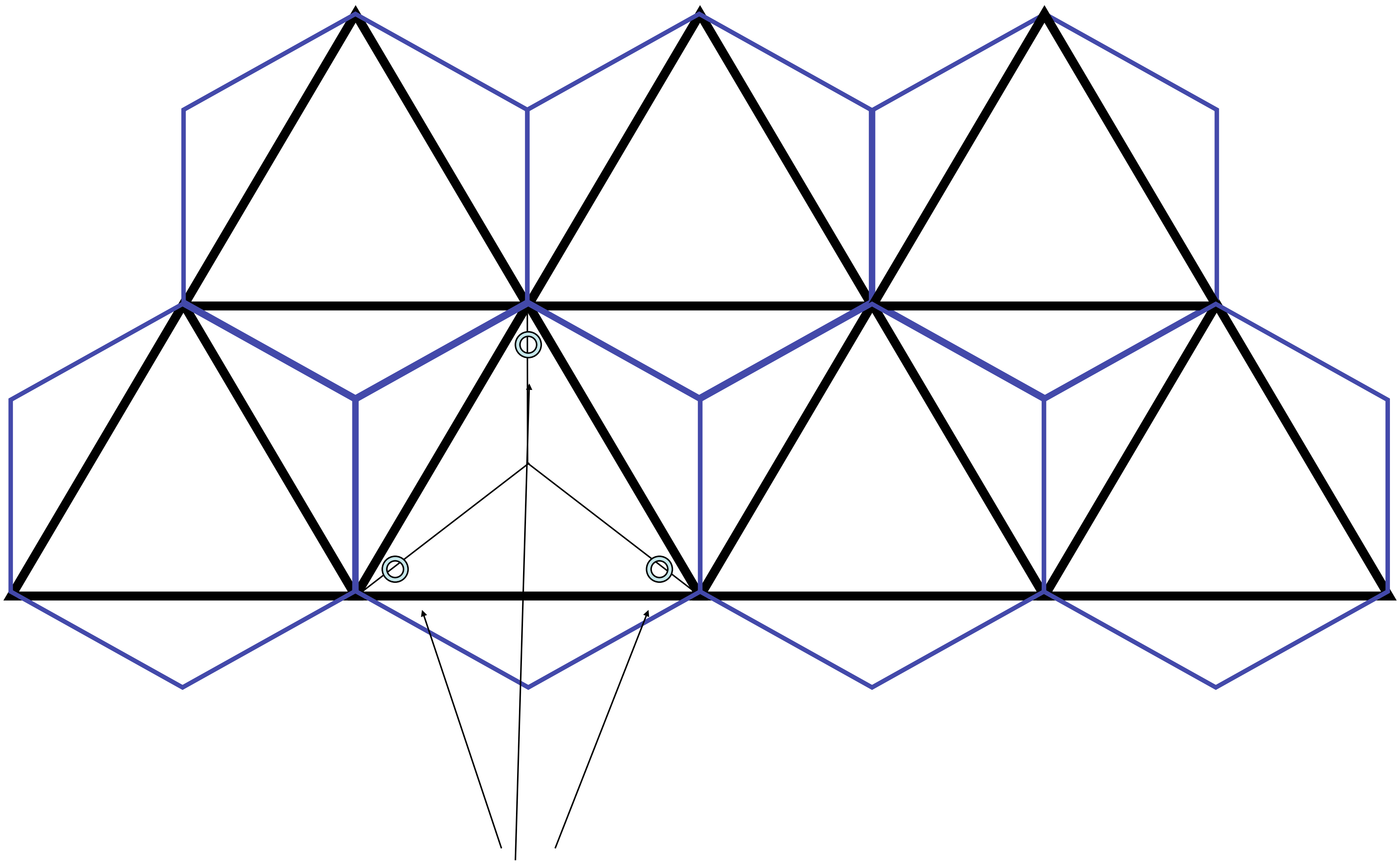
Parabolic mirror profile
220 (240) elements
400 (420) m^2 area
Obscuration < 3%
Mirror elements: hexagonal, lightweight sandwich construction
either all aluminum diamond turned ≈ 18-20kg/m**2 (PADOVA,MPI DEV.)
or cold slumped glass sandwich mirrors ≈ 12-15 kg/m**2(INAF DEV.)
Diamond turned mirrors: at least 30% more expensive but little aging
Test of MAGIC prototype mirrors: drop in reflectivity ≤ 1 %/year

Total weight of mirror surface including AMC and link elements ≈ 10 tons ??

A MIRROR ELEMENT
2 m^2 area
80-100 mm HEXCELL
3-4 mm FRONT/BACKPLATE
ALUMINIUM DIAMOND TURNED, (ELECTRO POLISHED to remove small rims ?),
DIELECTRIC COATING
< 30 KG WEIGHT/unit



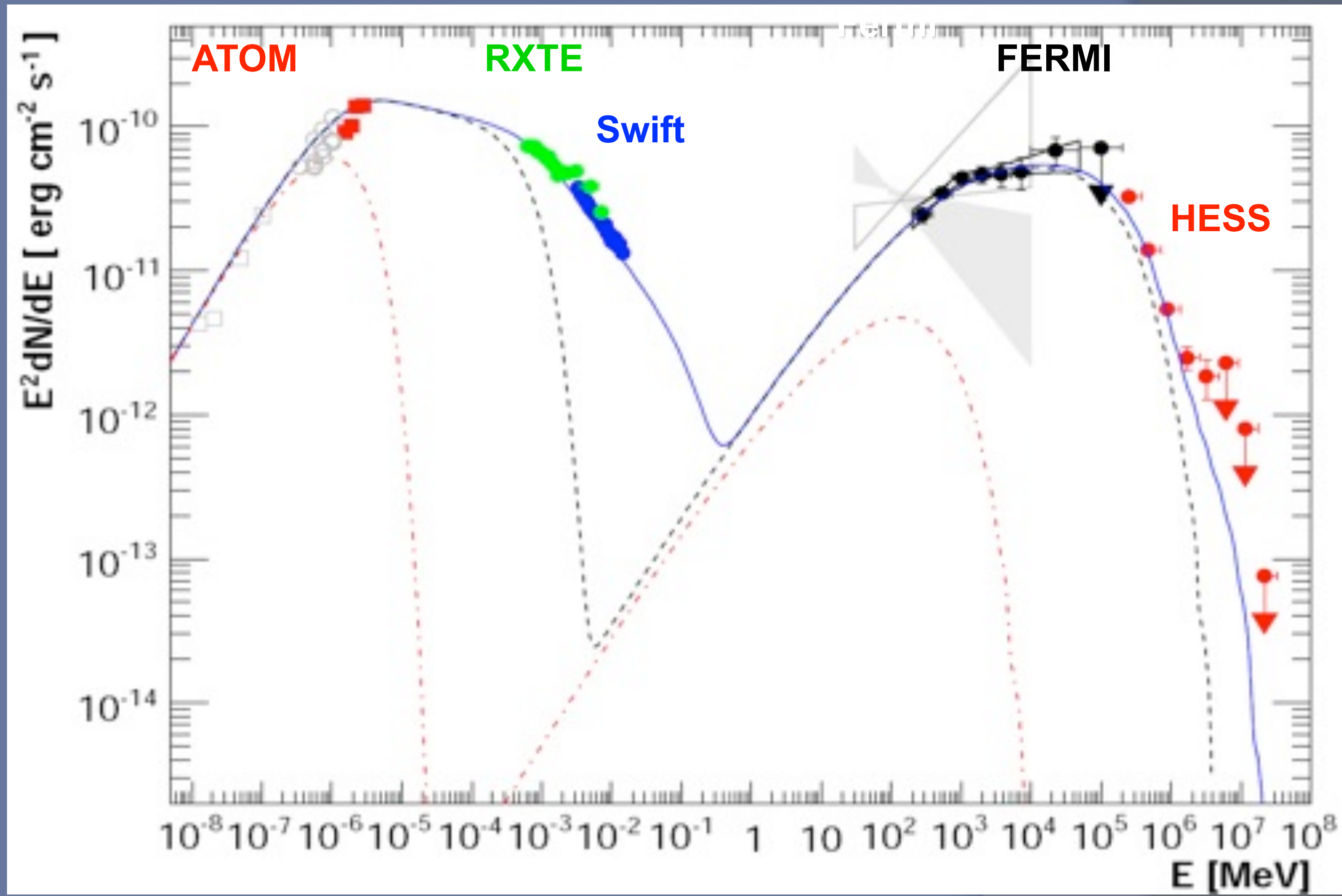
MIRROR (BLUE) AND TOP LAYER SECTION OF SPACE FRAME (BLACK)



MIRROR FIXING POINTS, CLOSE TO IDEAL POSITION, 2 ACTUATORS

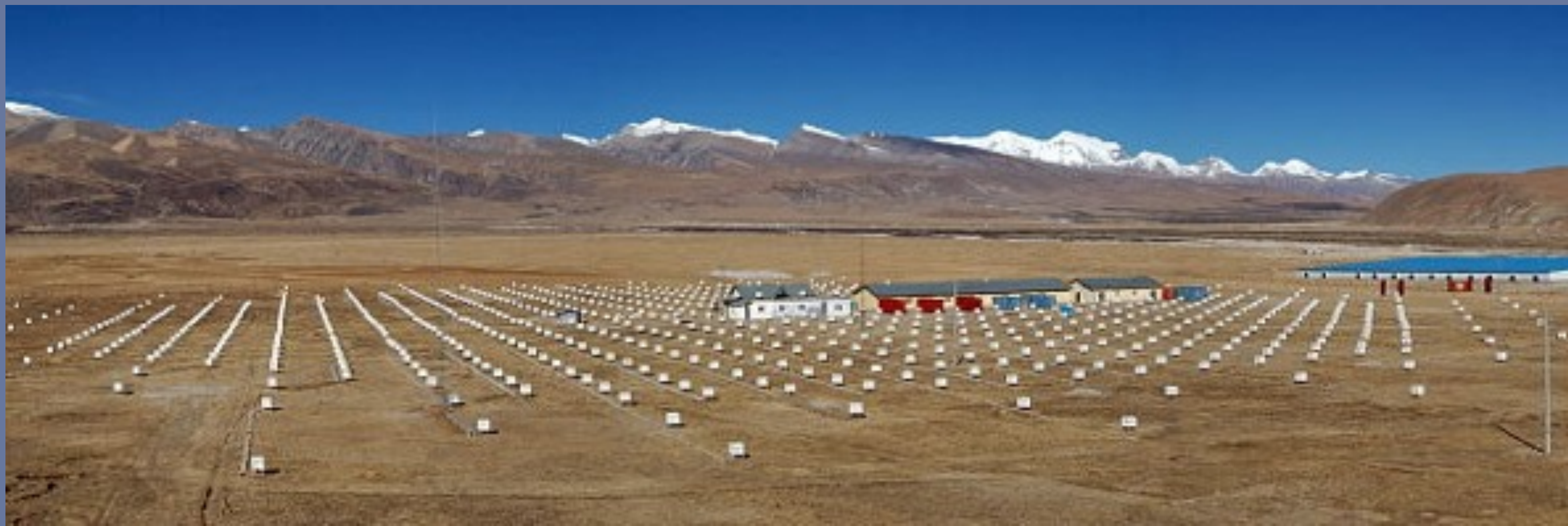
PKS 2155–304
Spectral Energy Distribution

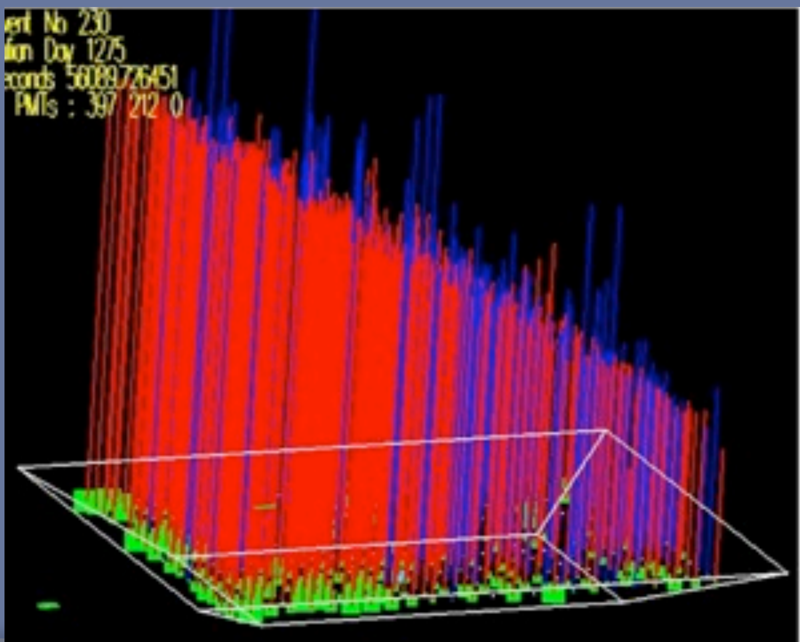
- Time-averaged SED is well described by a single zone SSC model:

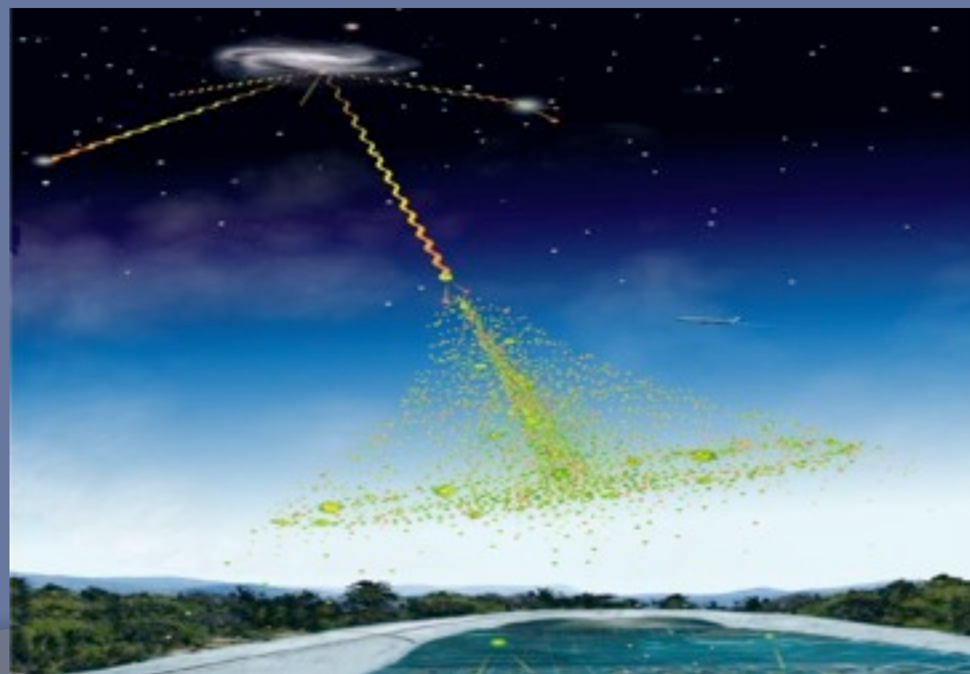


Highest energy electrons ($\gamma_e > 2\times10^5$) produce the X-ray emission, but contribute relatively little above 0.2 TeV

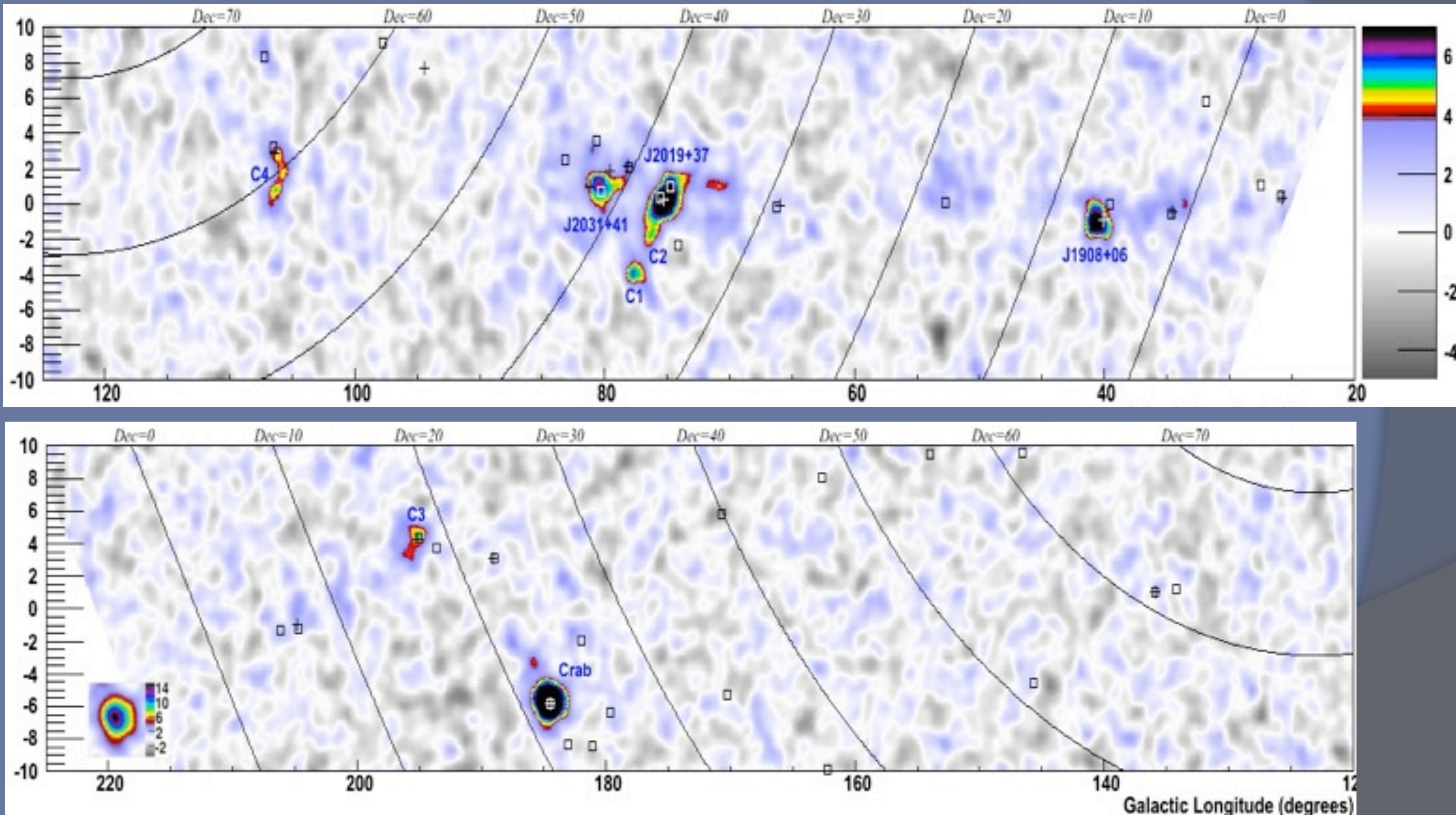
Water C-pool and AS array at high altitude



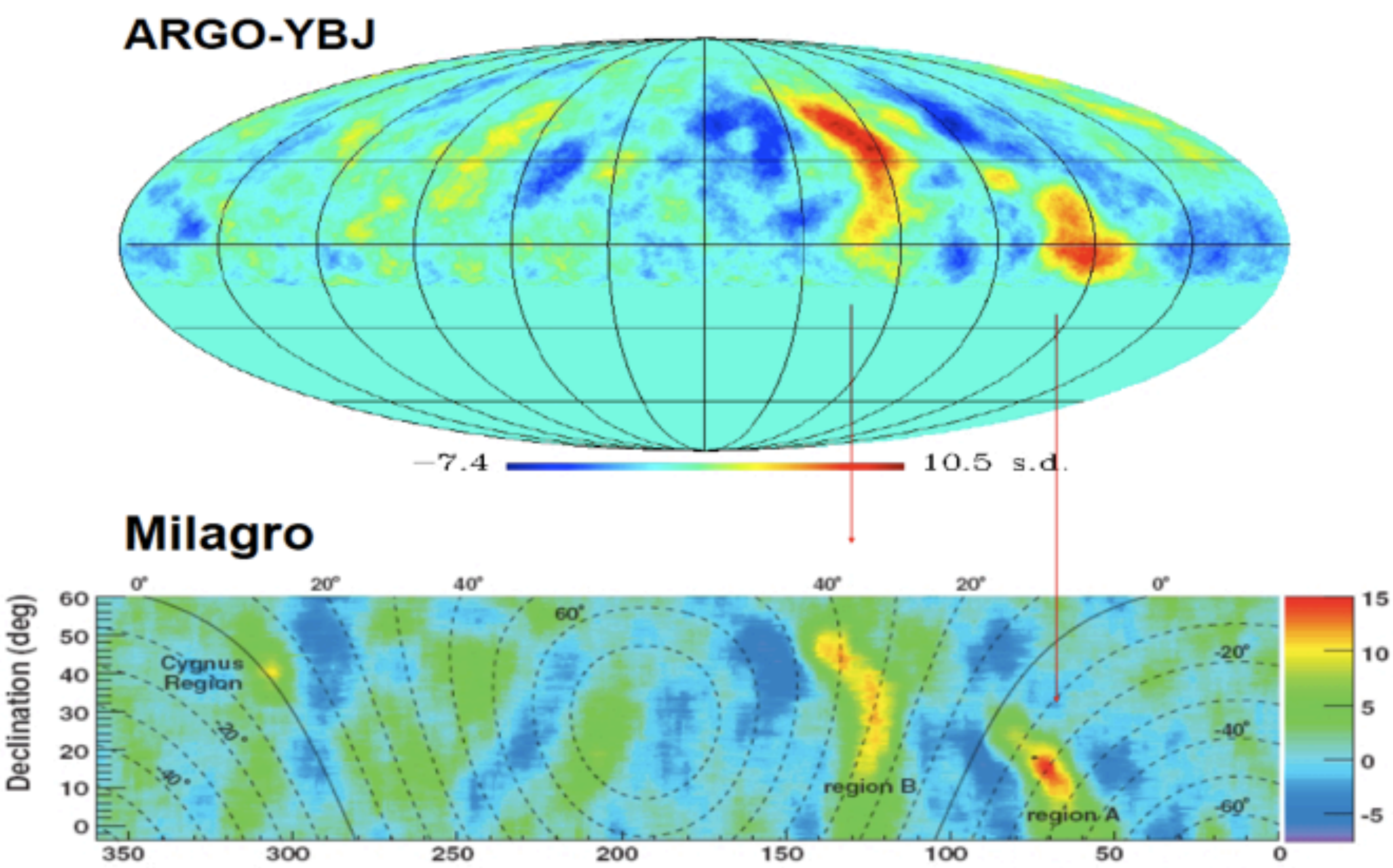




MILAGRO Galactic plane



Anisotropy pattern

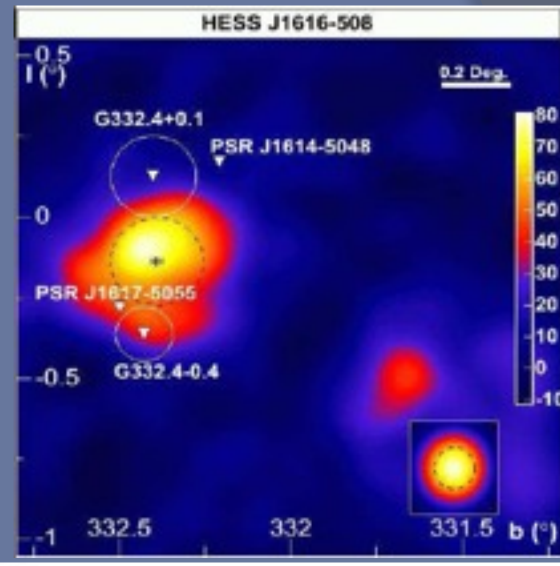


Abdo et al., Phys Rev. Lett, 101, 221101, 2008

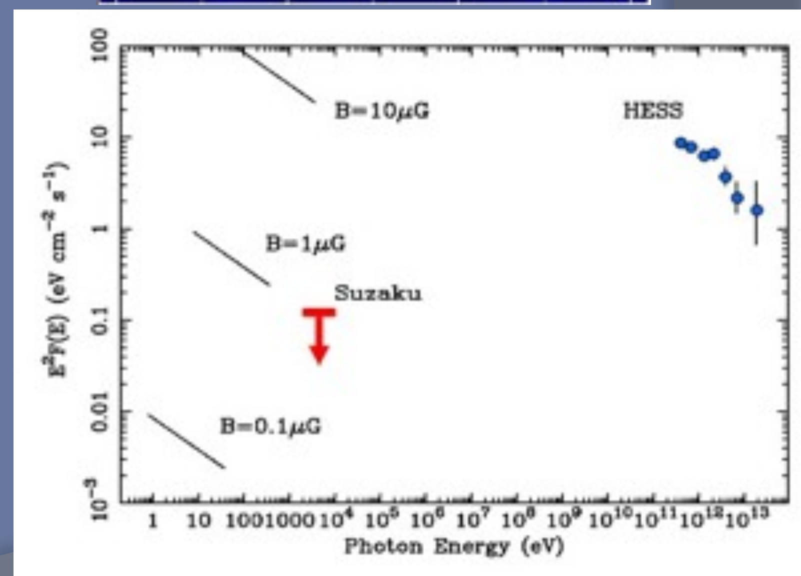
Un-IDs (Dark Sources)

?

Category	Source	Discovery	Observation
Un-ID	TeV J2032+4130	HEGRA	
Un-ID	HESS J1303-631	HESS	
Un-ID	HESS J1614-518	HESS	
Un-ID	HESS J1702-420	HESS	
Un-ID	HESS J1708-410	HESS	
Un-ID	3EG J1744-3011 ?	HESS J1745-303	



Name	Possible counterpart	Type[a]	Γ^b_{TeV}	f^c_{TeV}	N^d_H	Γ^e_X	f^f_X	f_{TeV}/f_X	Reference[g]
HESS J0852-463	RX J0852-4622	SNR	2.1	6.9	4	2.6	~10	~0.7	1, 2, 3
HESS J1303-631	—	?	2.4	1.0	20	2.0	<0.64	>1.6	4, 5
HESS J1514-591	PSR B1509-58	PWN	2.3	1.6	8.6	2.0	3.2	0.5	6, 7
HESS J1632-478	AX J1631.9-4752	HMXB?	2.1	1.7	210	1.6	1.7	1.0	8, 9
HESS J1640-465	G338.3-0.0	SNR	2.4	0.71	96	3.0	0.30	2.4	8, 10
HESS J1713-397	RX J1713.7-3946	SNR	2.2	3.5	8	2.4	54	0.065	11, 12
HESS J1804-216	Suzaku J1804-2142	?	2.7	0.48	2	-0.3	0.025	19	8, 13
HESS J1804-216	Suzaku J1804-2140	?	2.7	0.48	110	1.7	0.043	11	8, 13
HESS J1813-178	AX J1813-178	?	2.1	0.89	110	1.8	0.70	1.3	8, 14
HESS J1837-069	AX J1838.0-0655	?	2.3	1.4	40	0.8	1.3	1.1	8, 15
TeV J2032+4130	—	?	1.9	0.20	?	?	<0.20	>1.0	16
HESS J1616-508	—	?	2.4	1.7	4.1	2.0	<0.031	>55	This work

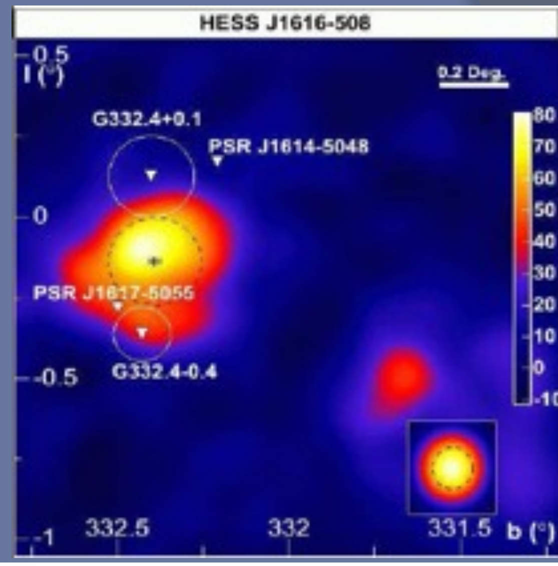


Suzaku (Matsumoto et al. 1996)

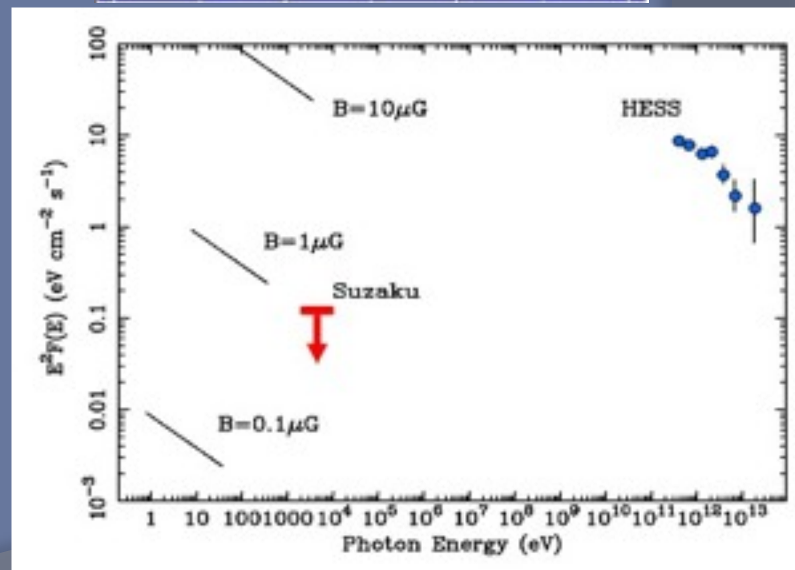
Un-IDs (Dark Sources)

?

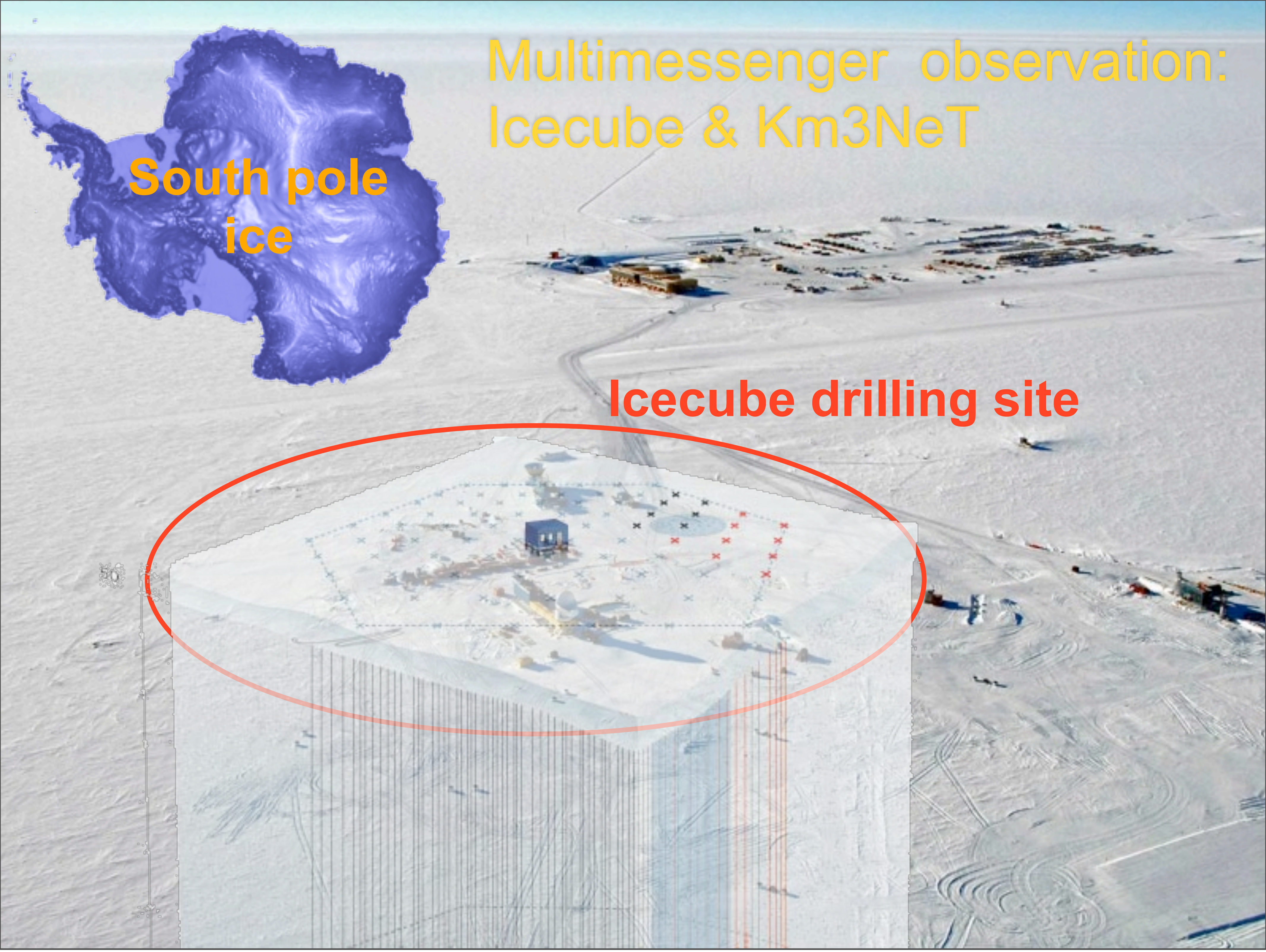
Category	Source	Discovery	Observation
Un-ID	TeV J2032+4130	HEGRA	
Un-ID	HESS J1303-631	HESS	
Un-ID	HESS J1614-518	HESS	
Un-ID	HESS J1702-420	HESS	
Un-ID	HESS J1708-410	HESS	
Un-ID	3EG J1744-3011 ?	HESS J1745-303	



Name	Possible counterpart	Type[a]	Γ^{b}_{TeV}	f^{c}_{TeV}	N^{d}_{H}	Γ^{e}_{X}	f^{f}_{X}	f_{TeV}/f_X	Reference[g]
HESS J0852−463	RX J0852−4622	SNR	2.1	6.9	4	2.6	~10	~ 0.7	1, 2, 3
HESS J1303−631	—	?	2.4	1.0	20	2.0	<0.64	> 1.6	4, 5
HESS J1514−591	PSR B1509−58	PWN	2.3	1.6	8.6	2.0	3.2	0.5	6, 7
HESS J1632−478	AX J1631.9−4752	HMXB?	2.1	1.7	210	1.6	1.7	1.0	8, 9
HESS J1640−465	G338.3−0.0	SNR	2.4	0.71	96	3.0	0.30	2.4	8, 10
HESS J1713−397	RX J1713.7−3946	SNR	2.2	3.5	8	2.4	54	0.065	11, 12
HESS J1804−216	Suzaku J1804-2142	?	2.7	0.48	2	-0.3	0.025	19	8, 13
HESS J1804−216	Suzaku J1804-2140	?	2.7	0.48	110	1.7	0.043	11	8, 13
HESS J1813−178	AX J1813−178	?	2.1	0.89	110	1.8	0.70	1.3	8, 14
HESS J1837−069	AX J1838.0−0655	?	2.3	1.4	40	0.8	1.3	1.1	8, 15
TeV J2032+4130	—	?	1.9	0.20	?	?	<0.20	>1.0	16
HESS J1616−508	—	?	2.4	1.7	4.1	2.0	<0.031	>55	This work



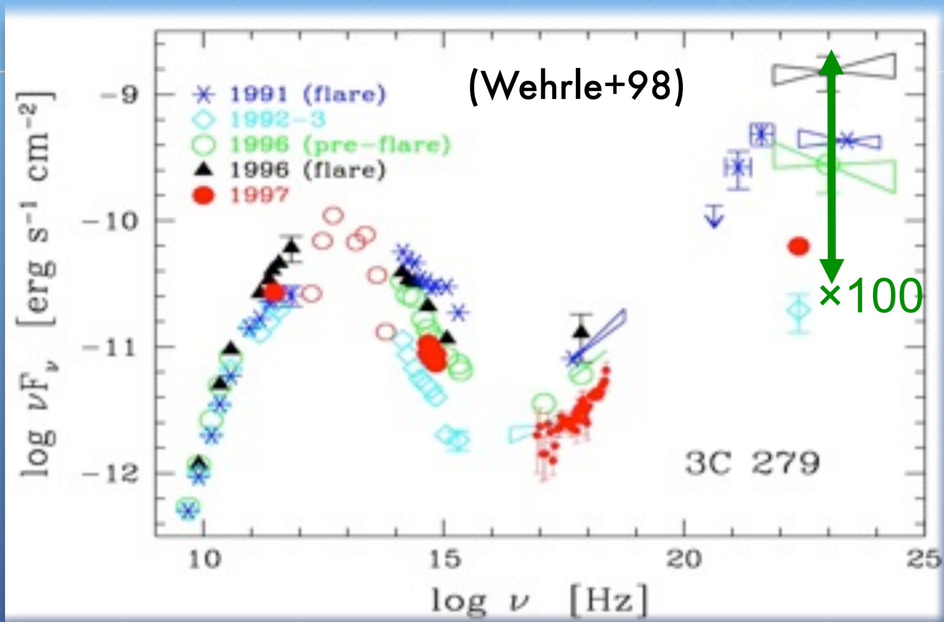
Suzaku (Matsumoto et al. 1996)


Multimessenger observation:
Icecube & Km3NeT
South pole
ice
Icecube drilling site

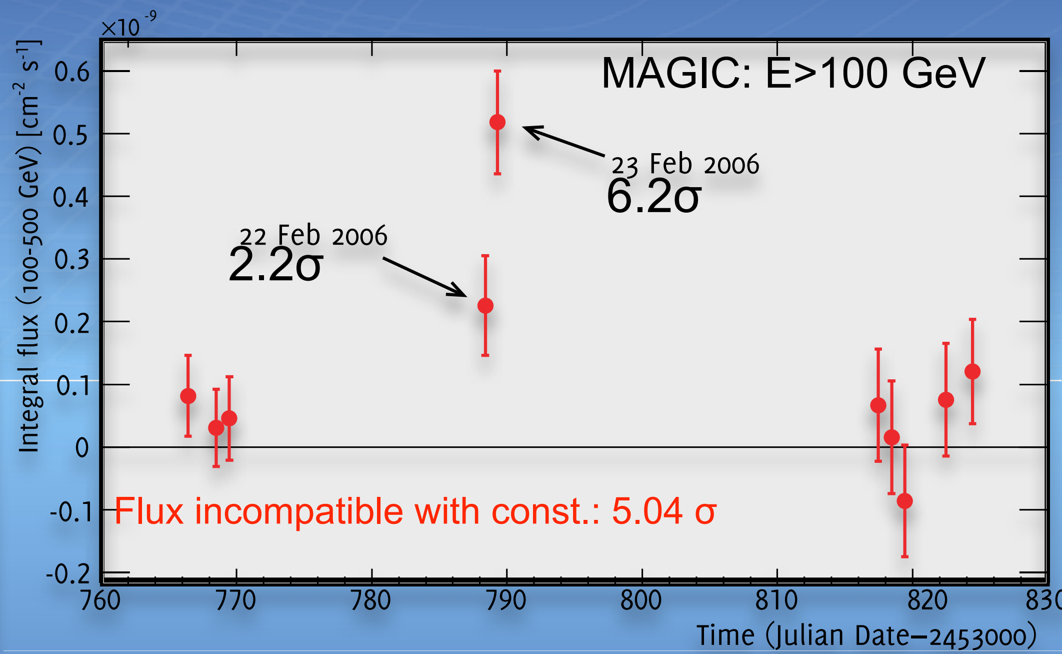
3C 279: A Famous Blazar

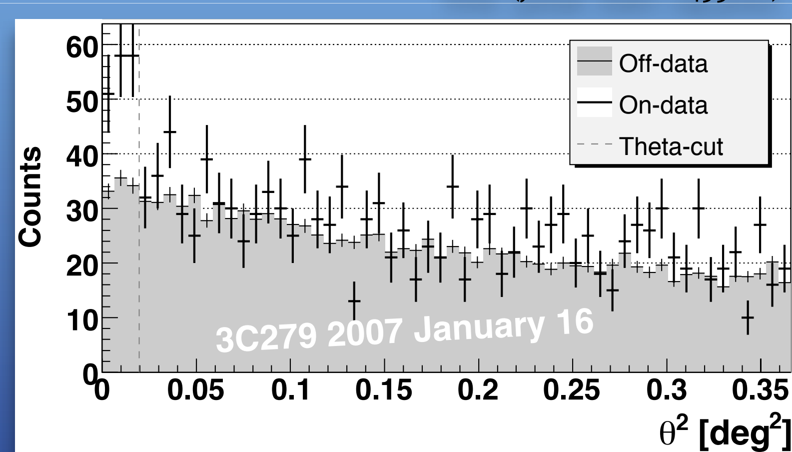
MAGIC Coll., Science 320 (2008) 1752

- Flat Spectrum Radio Quasar at z=0.536
- Apparent luminosity ≈ 10^{48} erg/s
- Brightest EGRET AGN (Wehrle+97,98)
- Gamma-ray flares in 1991 and 1996: High dynamical range in EGRET data
- Fast time variation: ΔT ~ 6hr in 1996 flare



- MAGIC observations: 2006 January–April during WEBT campaign (Böttcher+08)





Update: Have seen it again in January 2007!

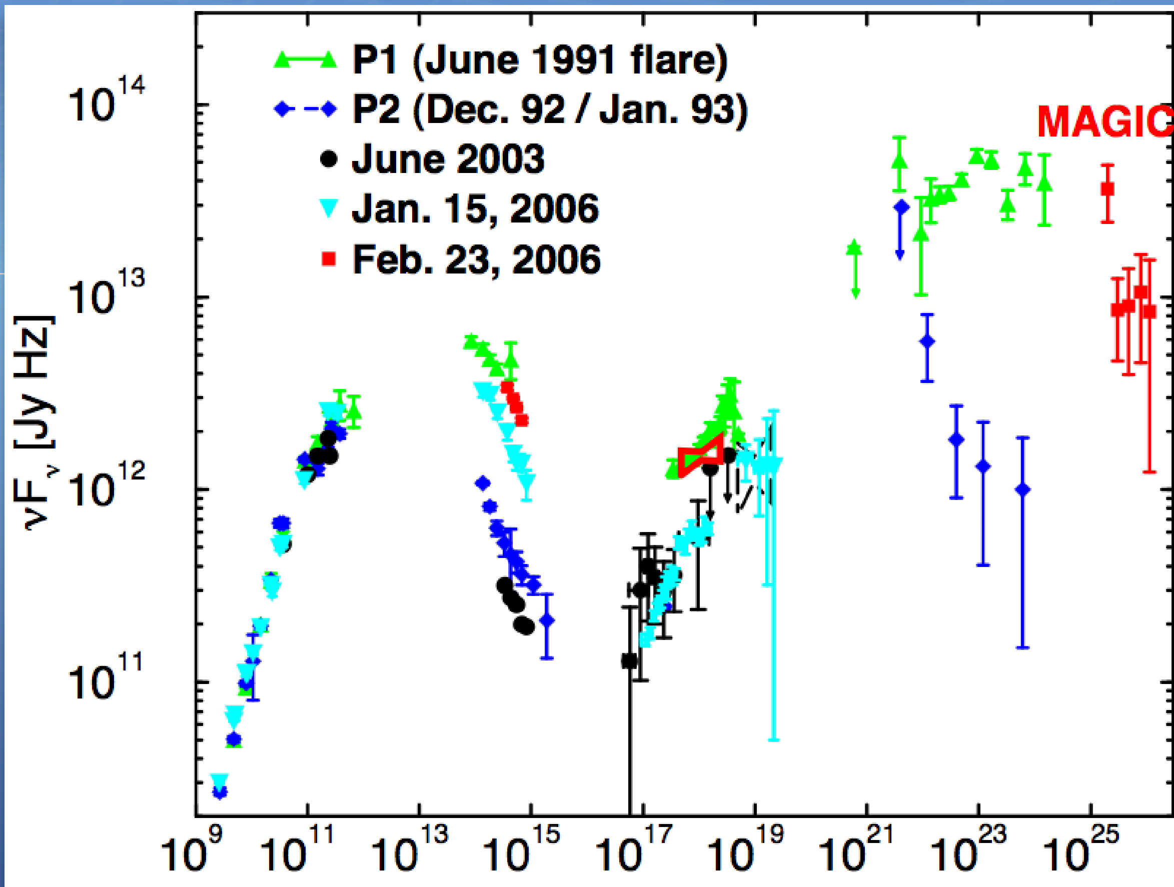
Friday, April 20, 2012

3C 279: What's the Relevance?

MAGIC Coll.,
Science 320 (2008) 1752

- z=0.536! Major jump in redshift of VHE sources
- First FSRQ in TeV gamma-rays: All source classes of the „blazar sequence“ detected in VHE

- Modeling of 3C 279 non-trivial:
  - FSRQ → bright emission lines: External photon fields important (Dermer+93, Sikora+94)
  - External-Inverse Compton Modeling required, more free parameters
  - VHE provides vital input!
  - Follow-up models & papers... Böttcher 08, Chatterjee+08, Marscher+08, Tavecchio+Mazin 08 Sitarek+Bednarek08...



Böttcher, Reimer, Marscher 08

3C 279: What's the Relevance?

MAGIC Coll., Science 320 (2008) 1752

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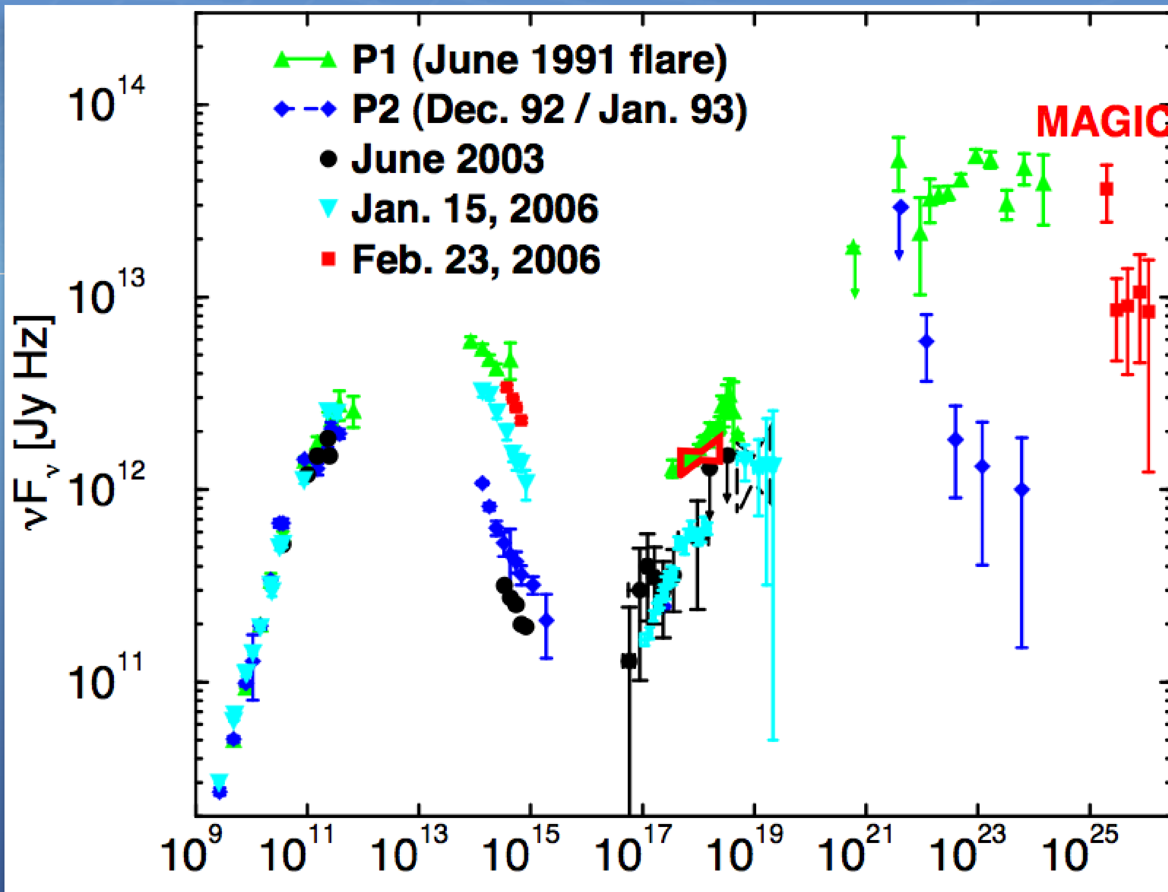
  - Follow-up models & papers... Böttcher 08, Chatterjee+08, Marscher+08, Tavecchio+Mazin 08 Sitarek+Bednarek08...

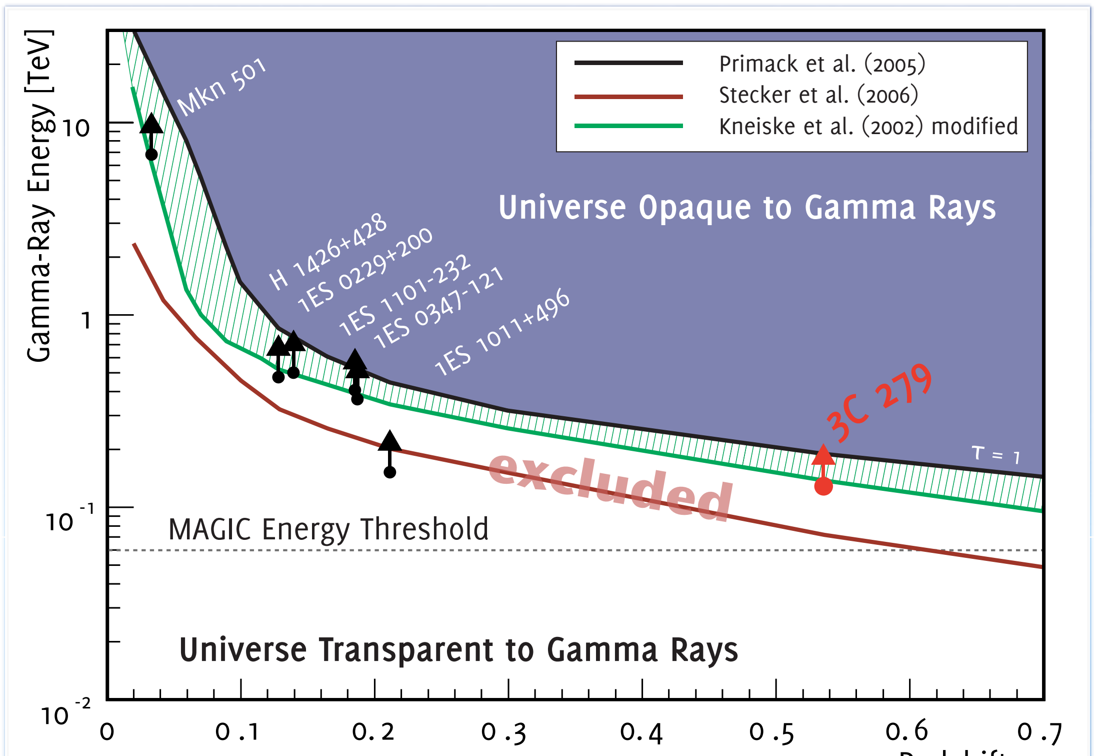
- Can be used to limit EBL models
  - Stecker fast evolution excluded MAGIC 2008; Tavecchio+Mazin 08
  - Complications may arise from lines (strong absorption Aharonian+08, Sitarek+Bednarek 08, Liu+08



Böttcher, Reimer, Marscher 08

Friday, April 20, 2012

EBL Studies with TeV Gamma-Rays

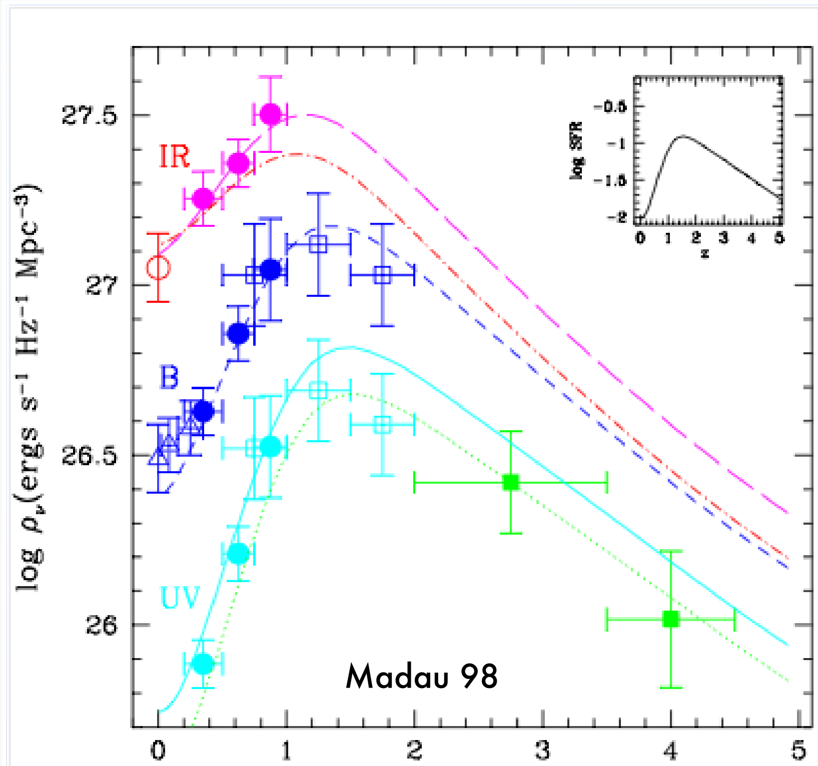


Science 320 (2008) 1752

- Determine spectral cut-offs at different redshifts
- Approaching maximum of star forming rate
- Beacons before max SFR at z<2: future instruments

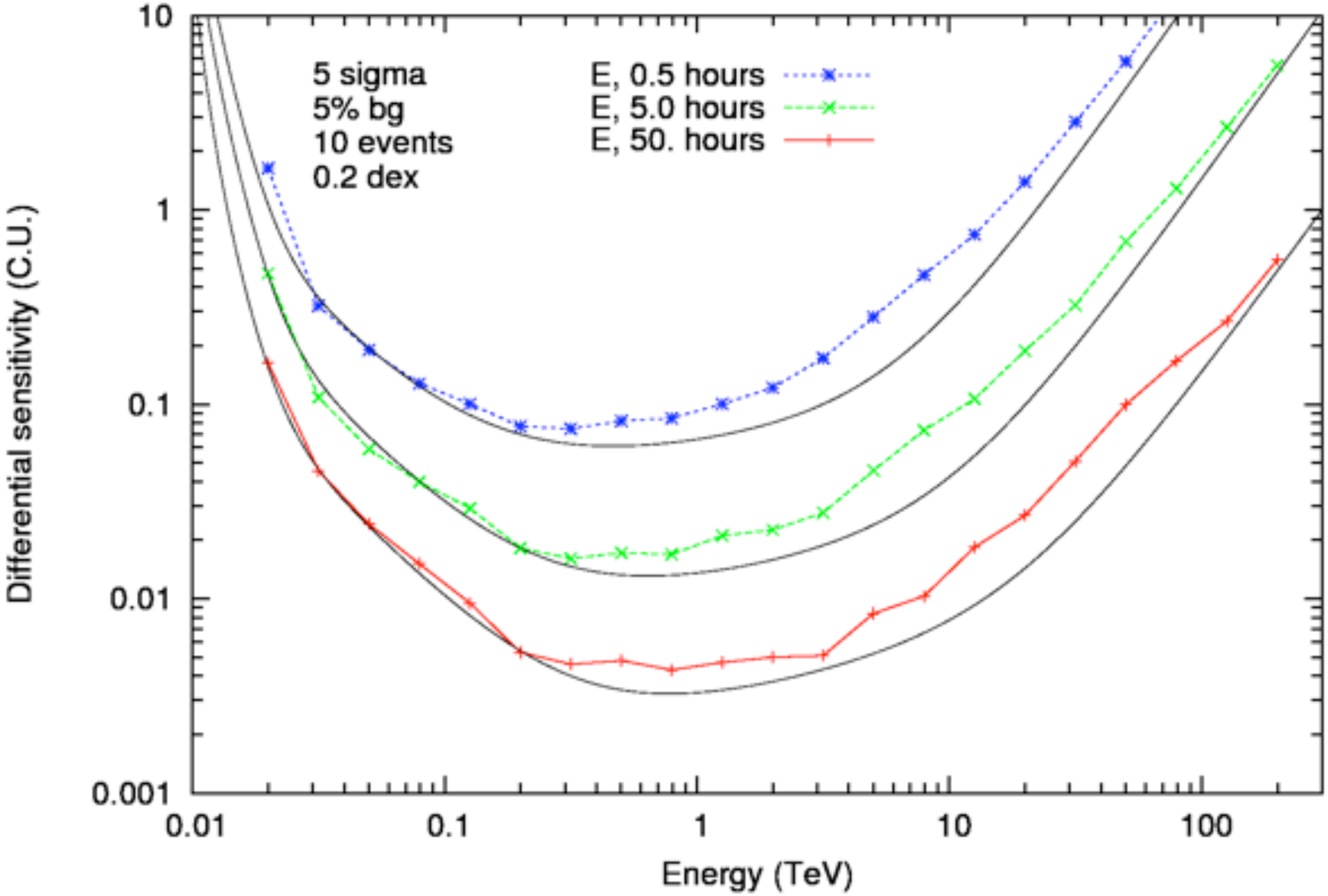
➡Infer **gamma-ray horizon**

- Maximum visibility for given TeV energy
- Probe evolution of EBL
- Star and galaxy evolution largely unknown



How many telescope sizes?

- Array with no mid-sized telescopes performance worse 0.1-1 TeV
  - E.g. K (more studies needed with optimised layout)

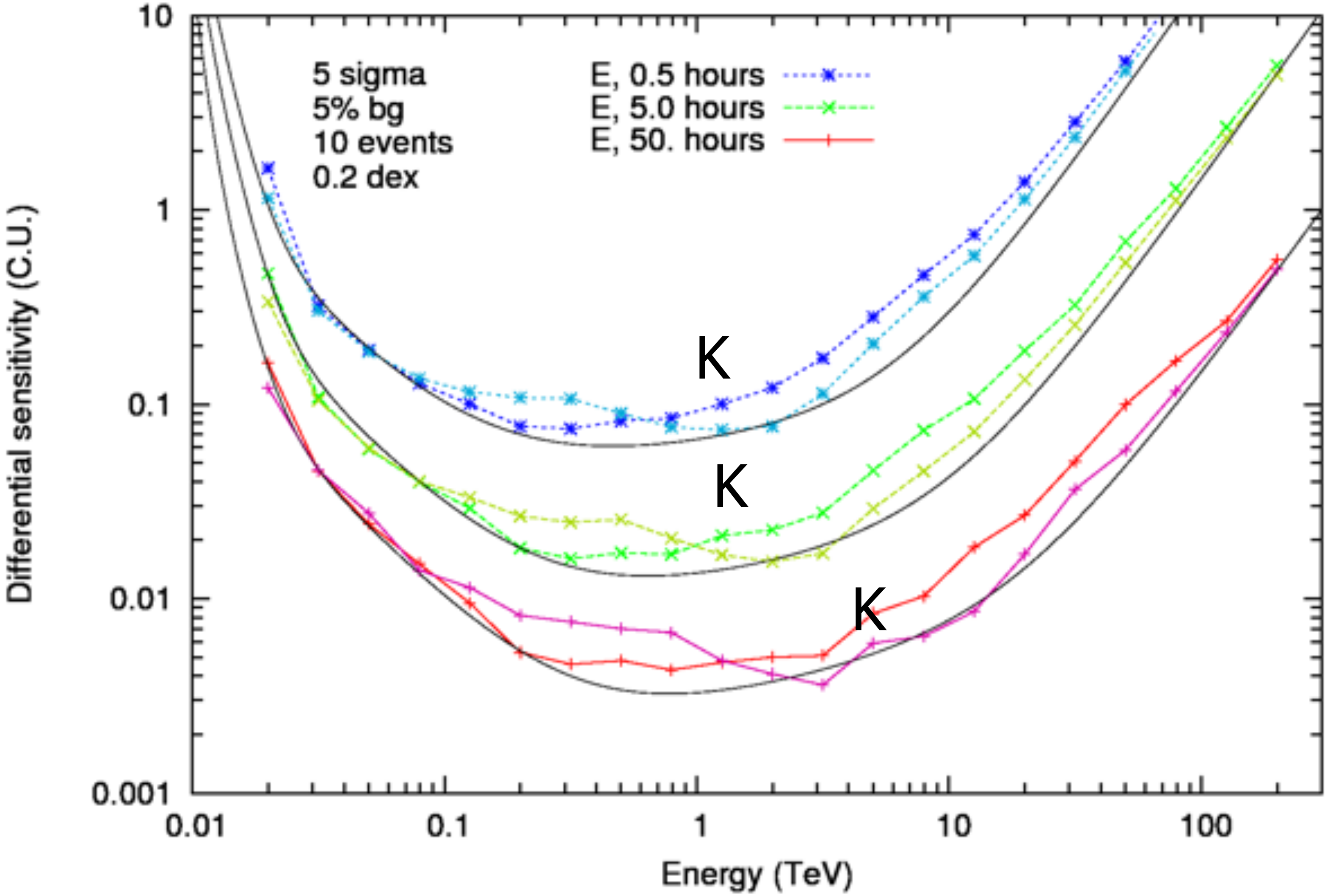


Compare with E

How many telescope sizes?

- Array with no mid-sized telescopes performance worse 0.1-1 TeV
  - E.g. K (more studies needed with optimised layout)

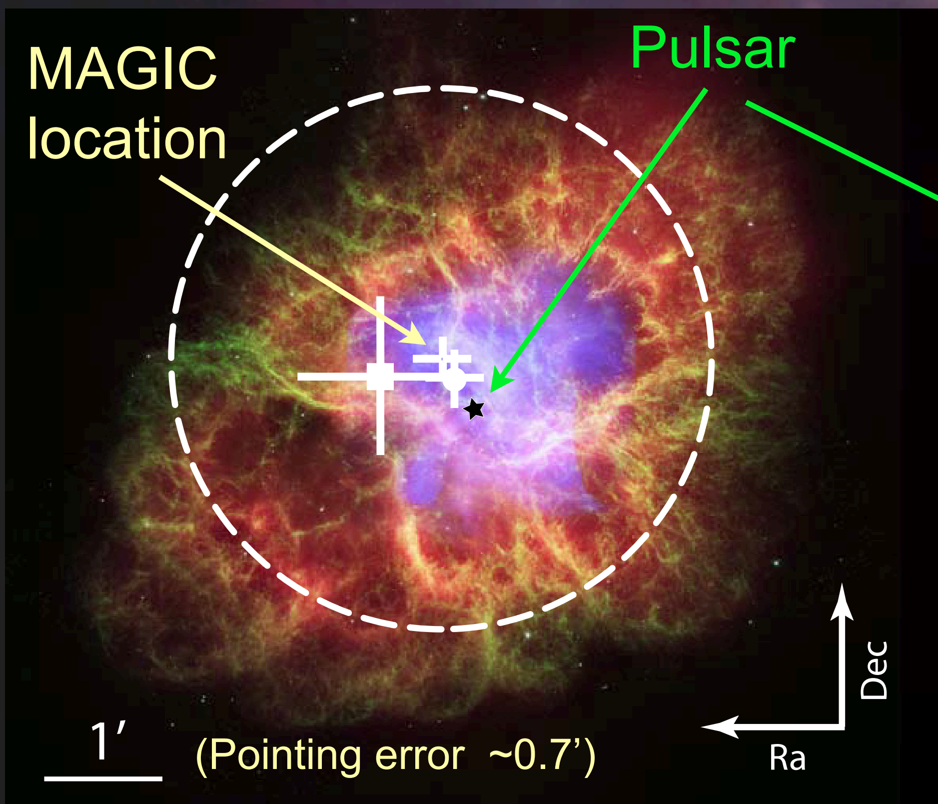
NOTE: EMPTY RING BET.
100-300 m (no telelcopes)

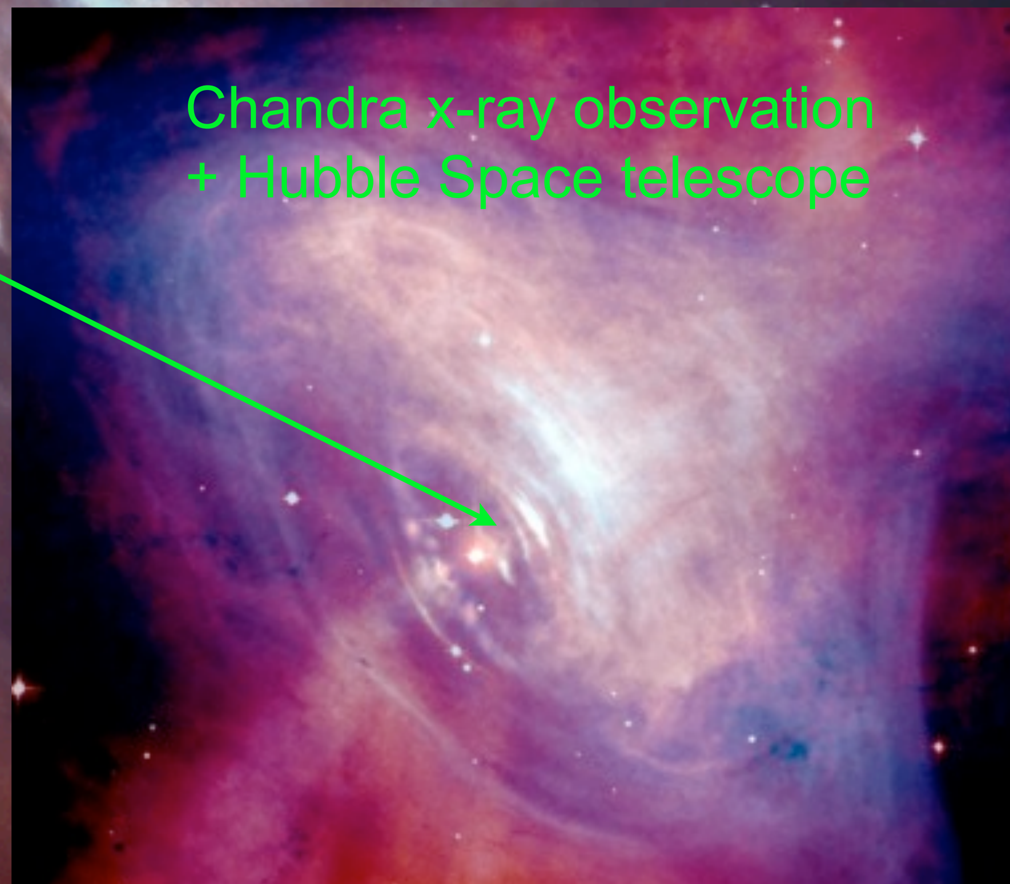


PHYS input needed to decide

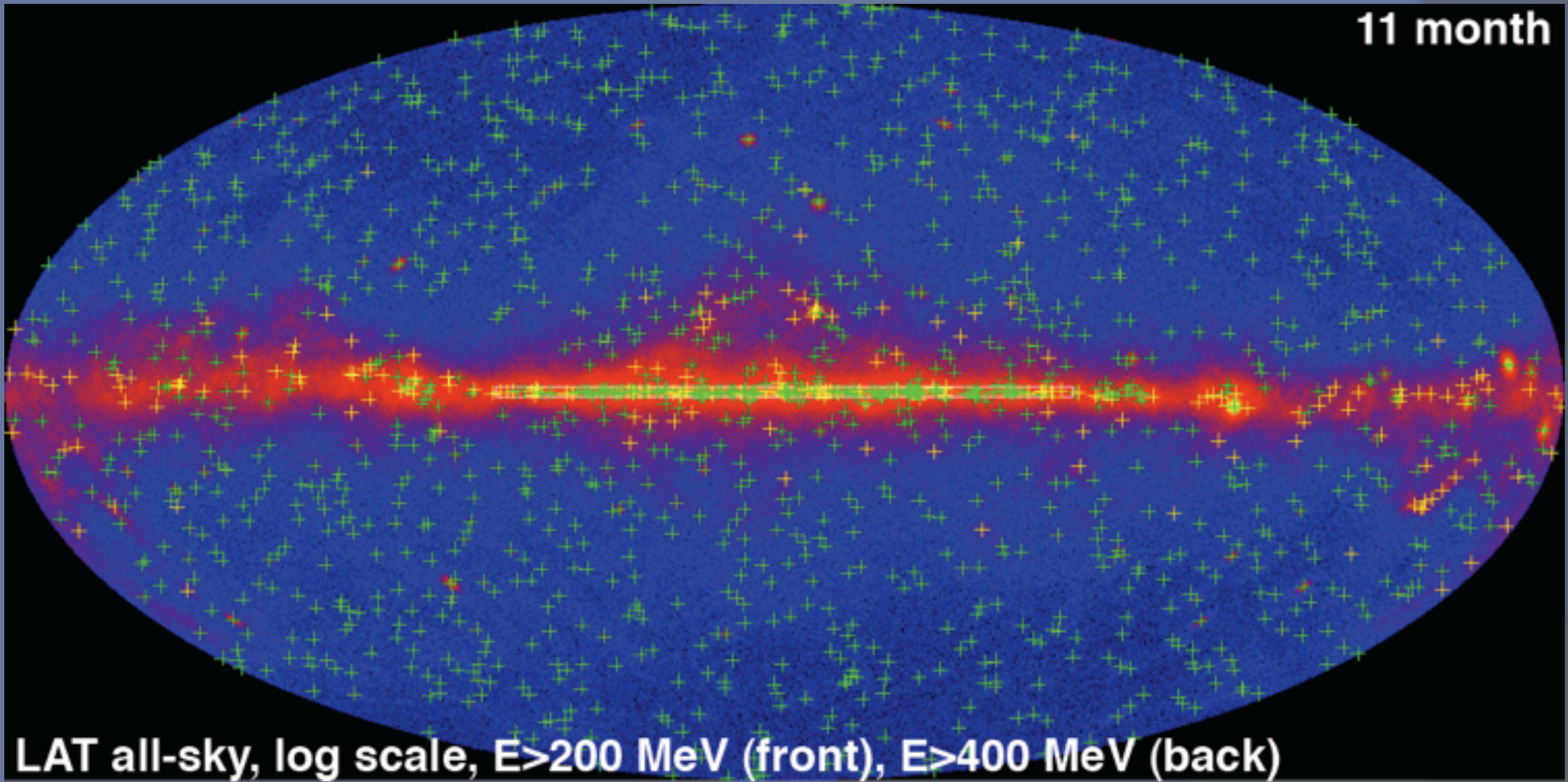
What is the connection between pulsar and nebula ?

- Exact location of VHE gamma nebula emission ? Emission point-like!
- Variability in pulsar wind
- Pulsar spectrum variable ? Spectrum of nebula (slightly) variable ?
- Pulsar spectrum to high energies might give clues



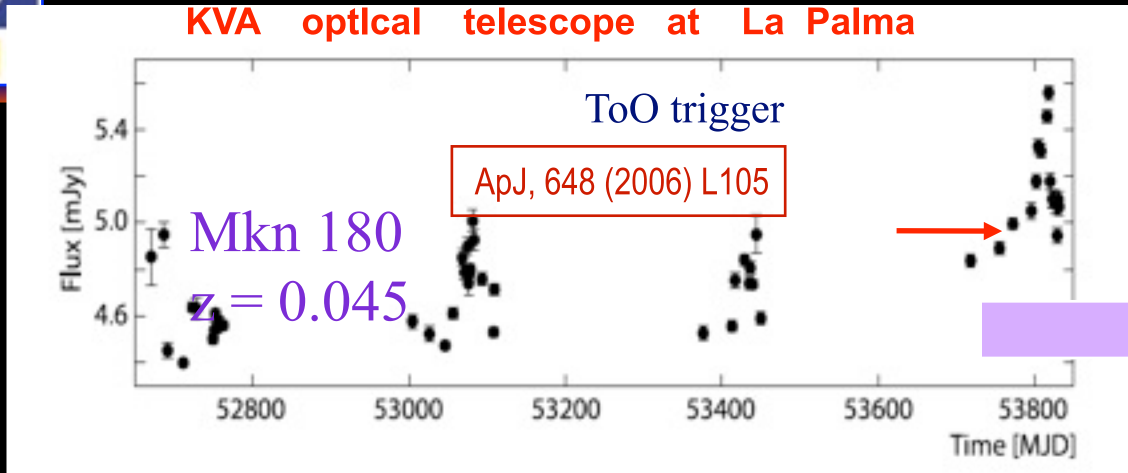


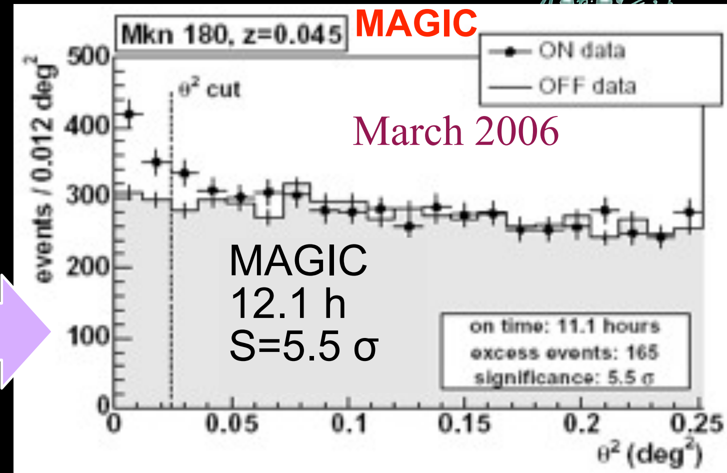
The first LAT catalog (1FGL) Fermi 11 month data

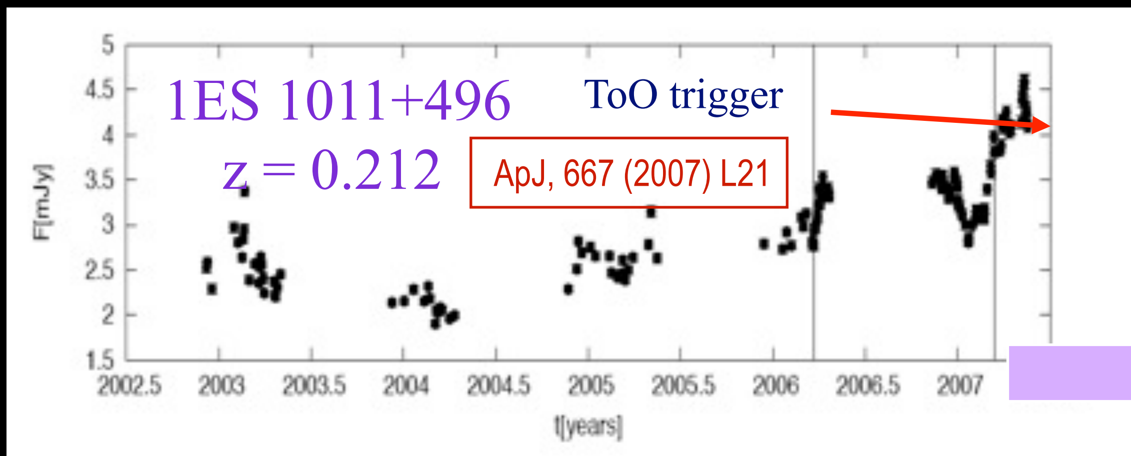


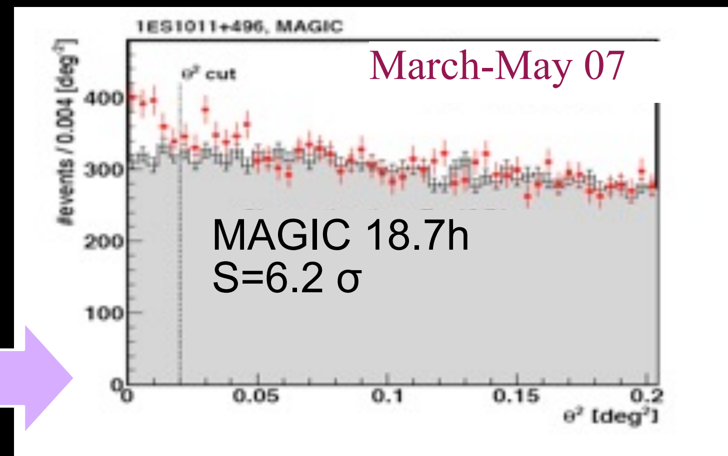
- >1000 sources for TS = 2 Δlog(likelihood) > 25 (~4σ for 4 D.o.F.)
- Typical 95% error radius is 10’. Absolute accuracy is better than 1’

Do optical triggers work ?









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• ?

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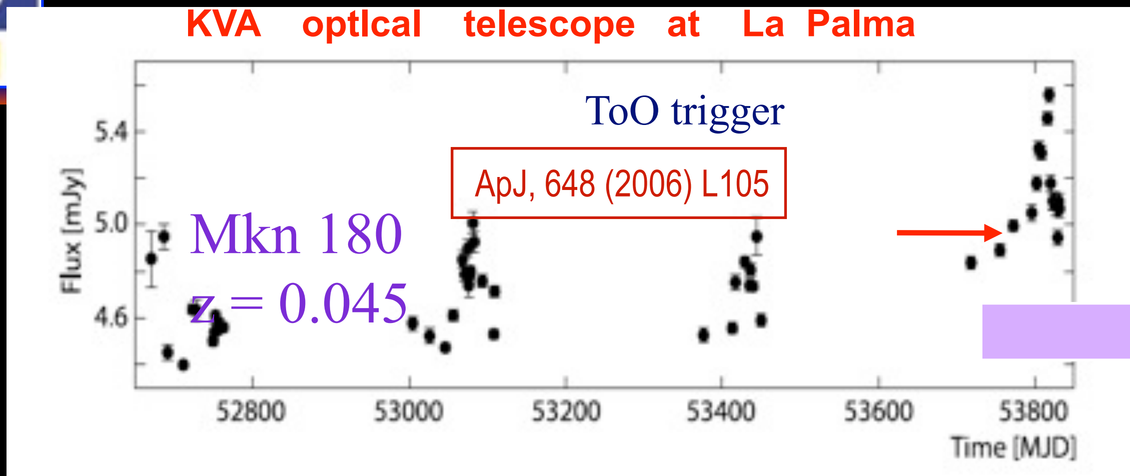
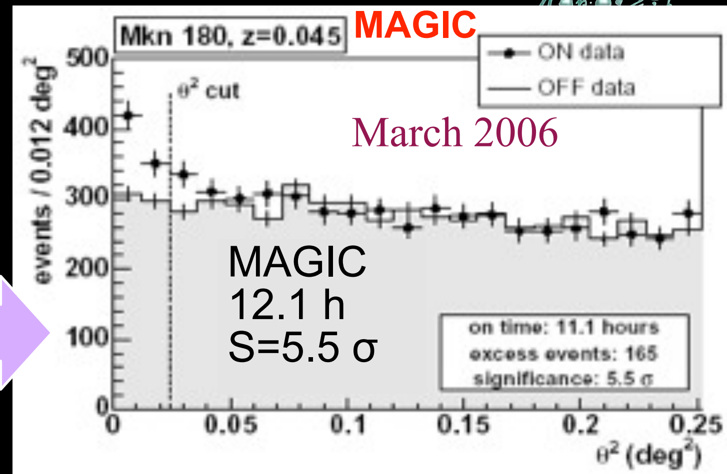
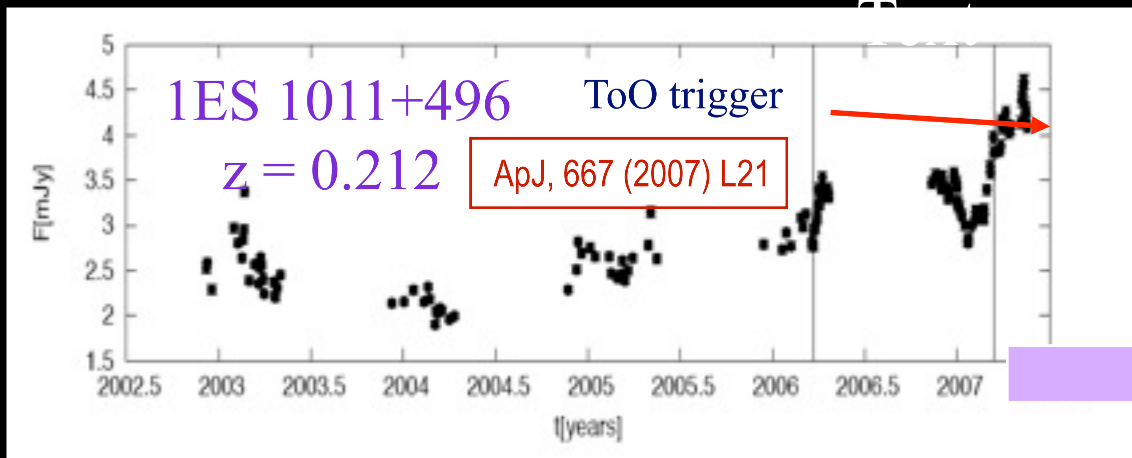
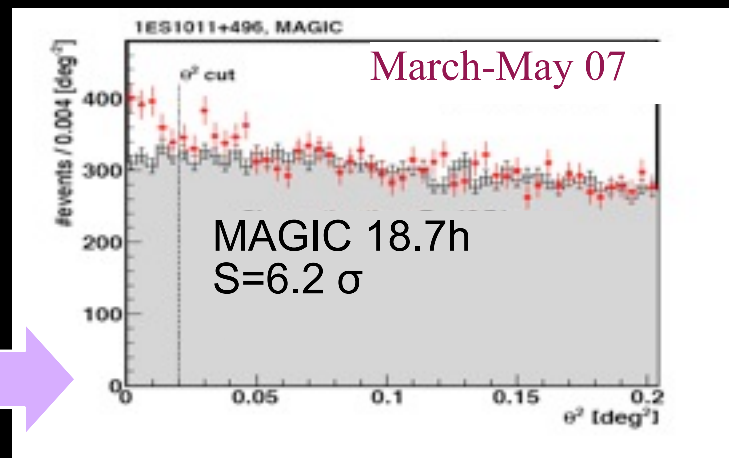
Thomas Schweizer

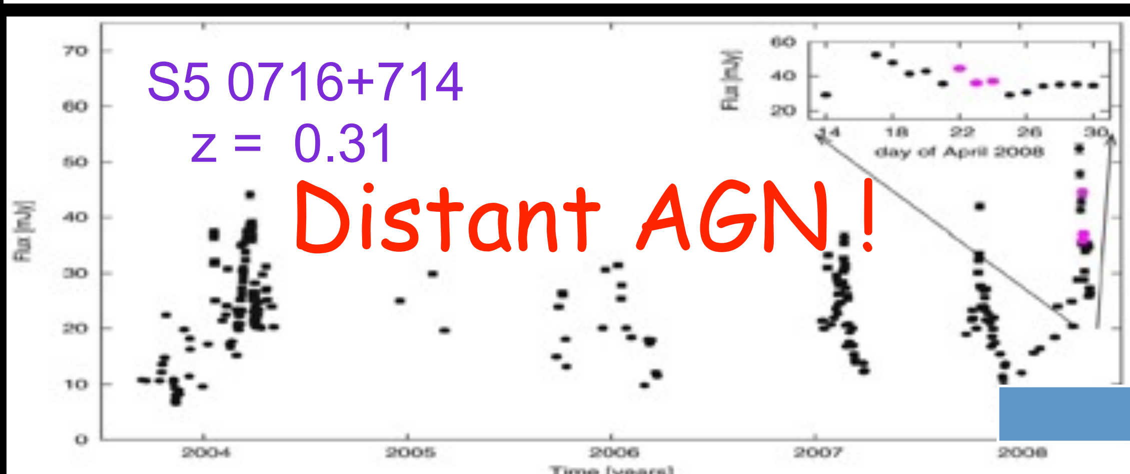
Discovery !!

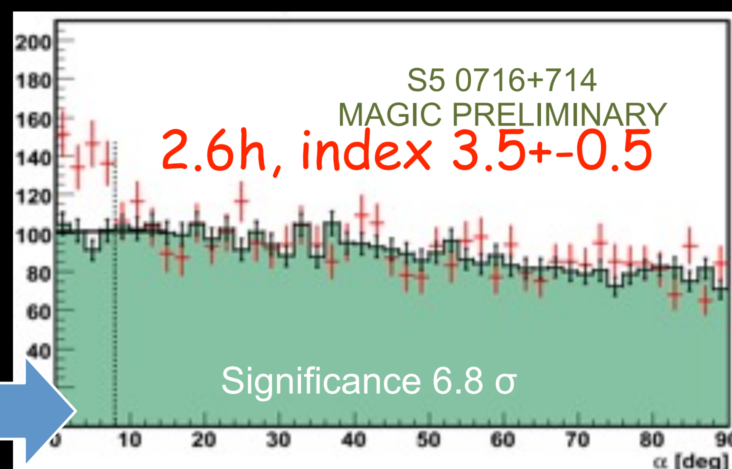

KVA optical telescope at La Palma
ToO trigger
ApJ, 648 (2006) L105
Mkn 180
z = 0.045
Flux [mJy]
Time [MJD]


Mkn 180, z=0.045
MAGIC
ON data
OFF data
March 2006
MAGIC
12.1 h
S=5.5 σ
on time: 11.1 hours
excess events: 165
significance: 5.5 σ
events / 0.012 deg²
θ² (deg²)


1ES 1011+496
z = 0.212
ToO trigger
ApJ, 667 (2007) L21
F[mJy]
t[years]


1ES1011+496, MAGIC
March-May 07
MAGIC 18.7h
S=6.2 σ
θ² [deg²]

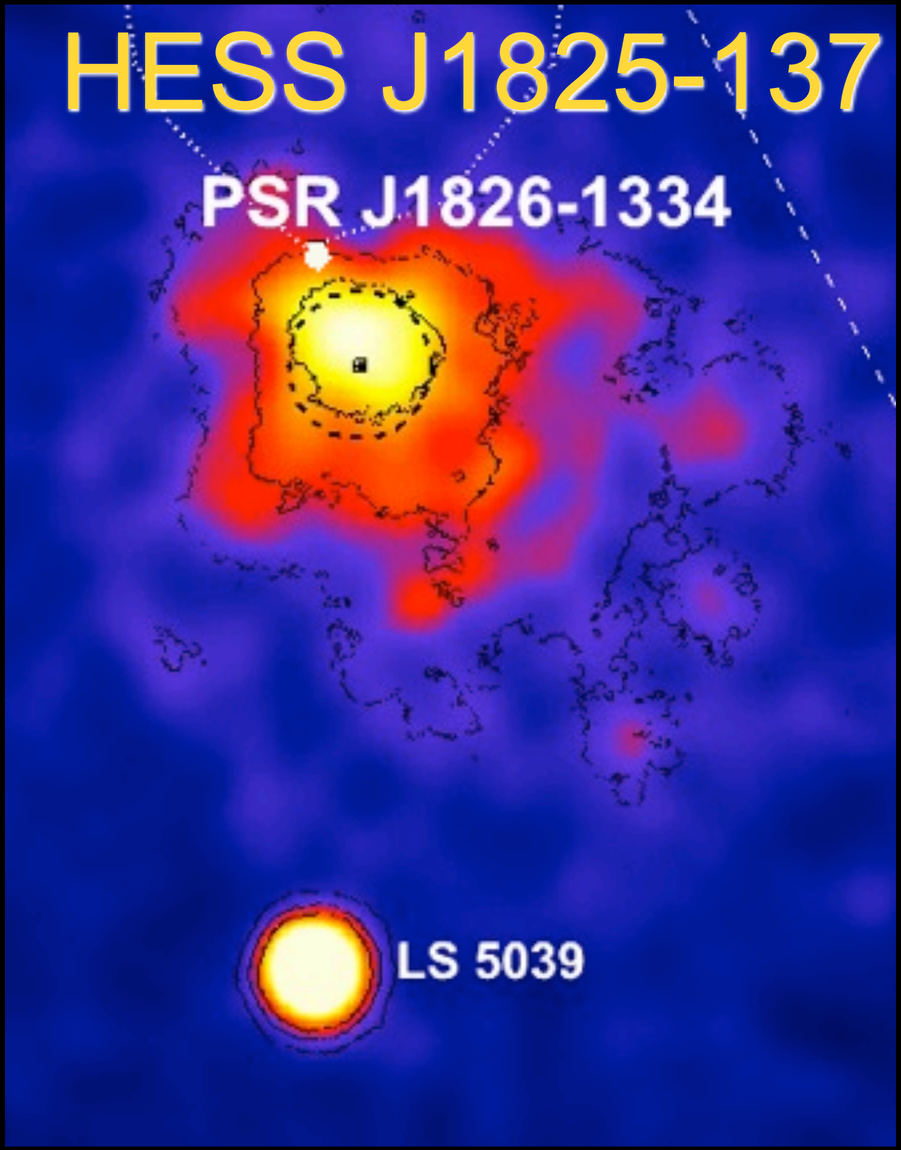

S5 0716+714
z = 0.31
Distant AGN !
day of April 2008
Time [years]


S5 0716+714
MAGIC PRELIMINARY
2.6h, index 3.5+-0.5
Significance 6.8 σ
α [deg]

Seminal discoveries since 2003

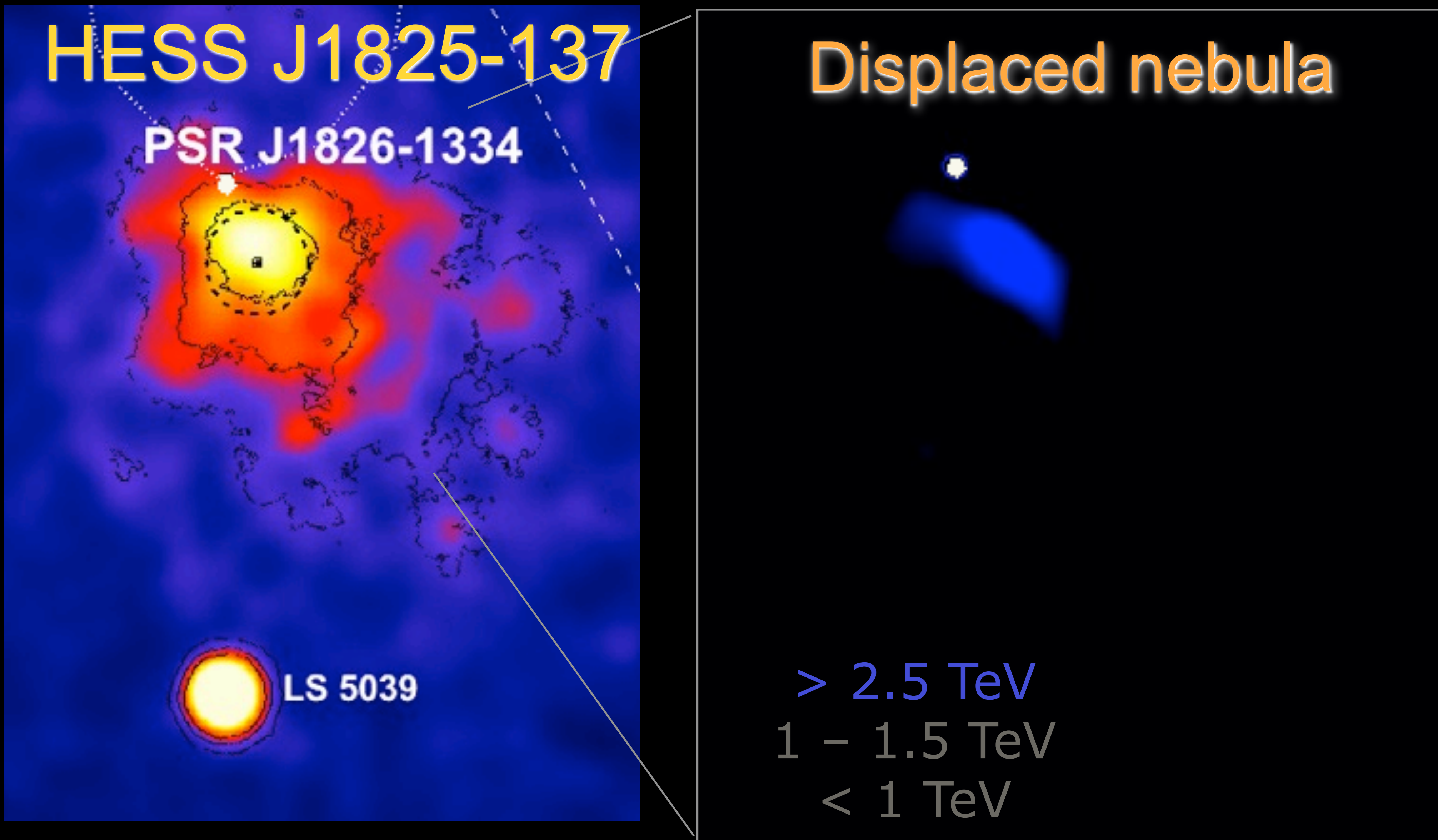
- Massive flares of Active Galactic Nuclei! Low energies!
- Imaged supernova remnant shells!
- Galaxy is full of VHE pulsar-wind-nebulae!
- Pulsed VHE emission in Pulsars! Very low energies!
- Galactic Center Source: possible accreting SMBH!
- Binary Systems: VHE modulation!
- Diffuse gamma rays from interacting molecular clouds and star-forming regions!
- Starburst Galaxies! Steep spectra: Low energies!
- Dark Accelerators!
- Extra-galactic background light constraints! Low energies!
- Cosmic Ray Electron and Iron spectra!

Morphology studies with CTA
High angular resolution

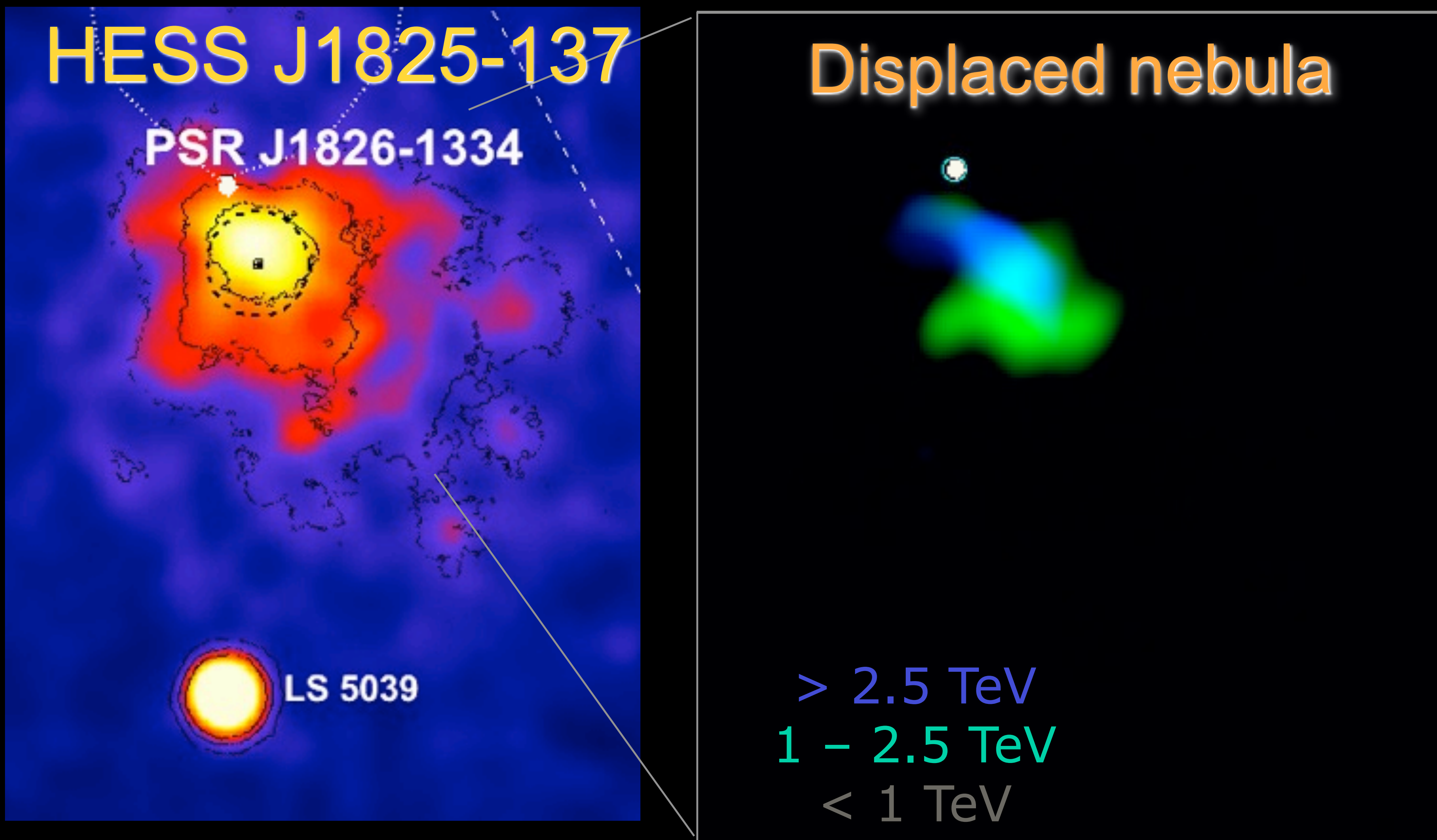


Displaced nebula

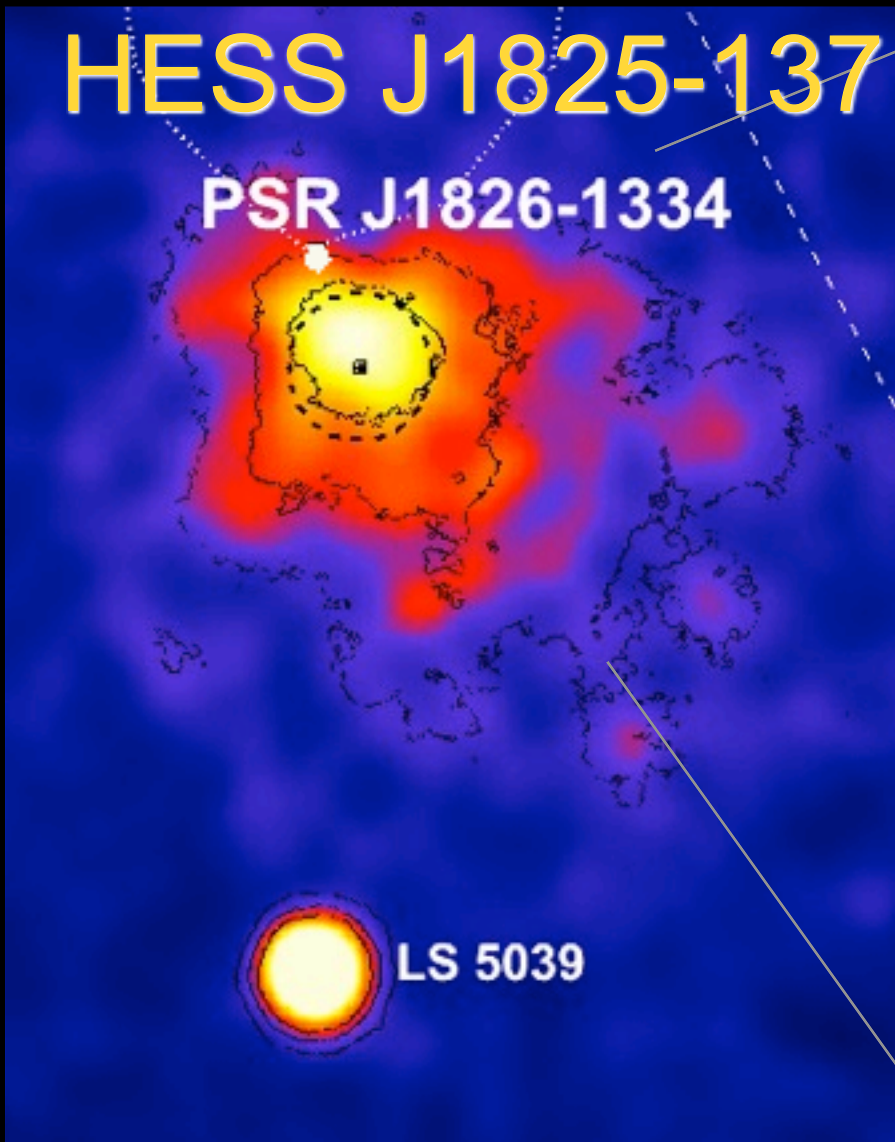
Morphology studies with CTA
High angular resolution

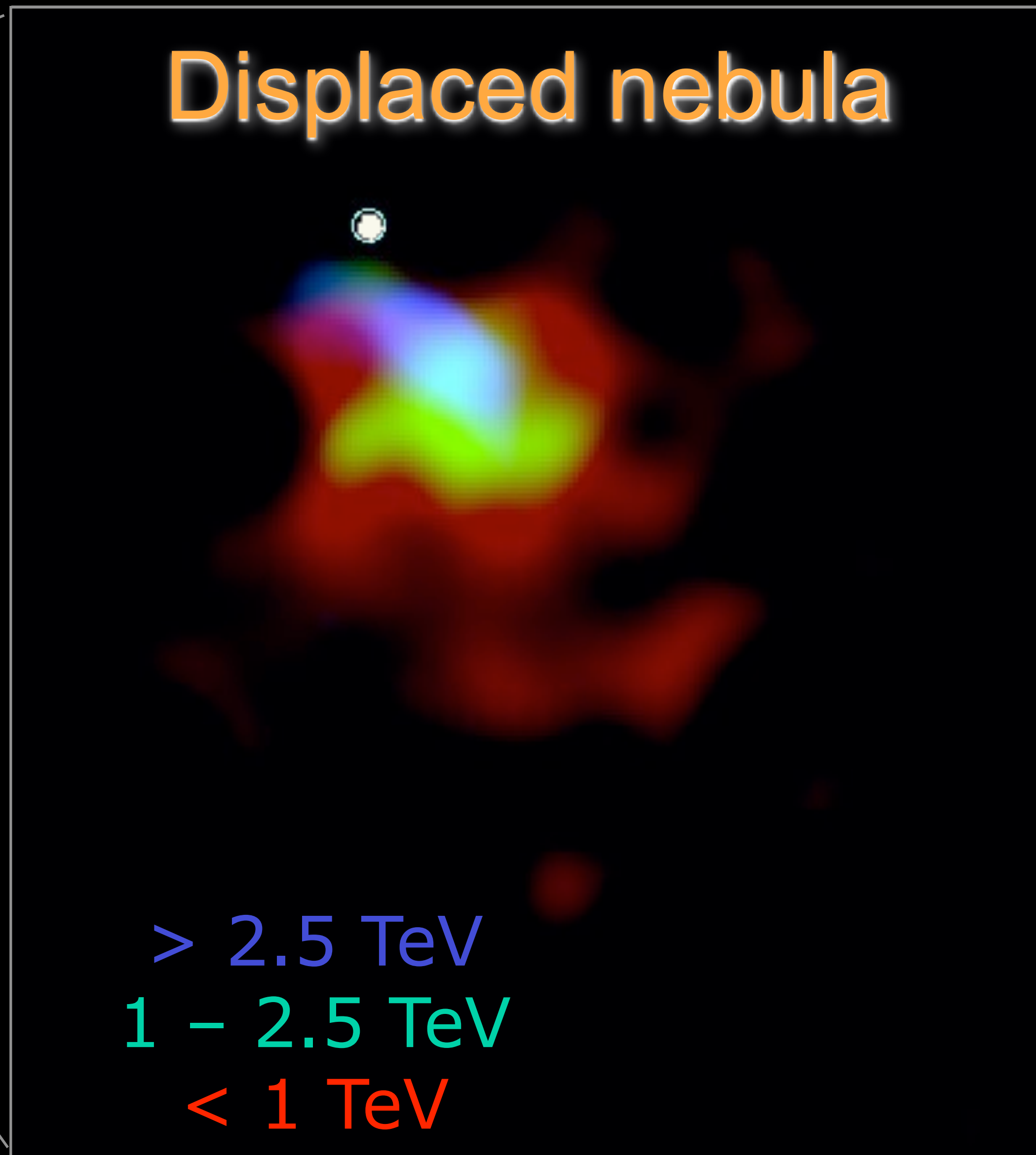


Morphology studies with CTA
High angular resolution

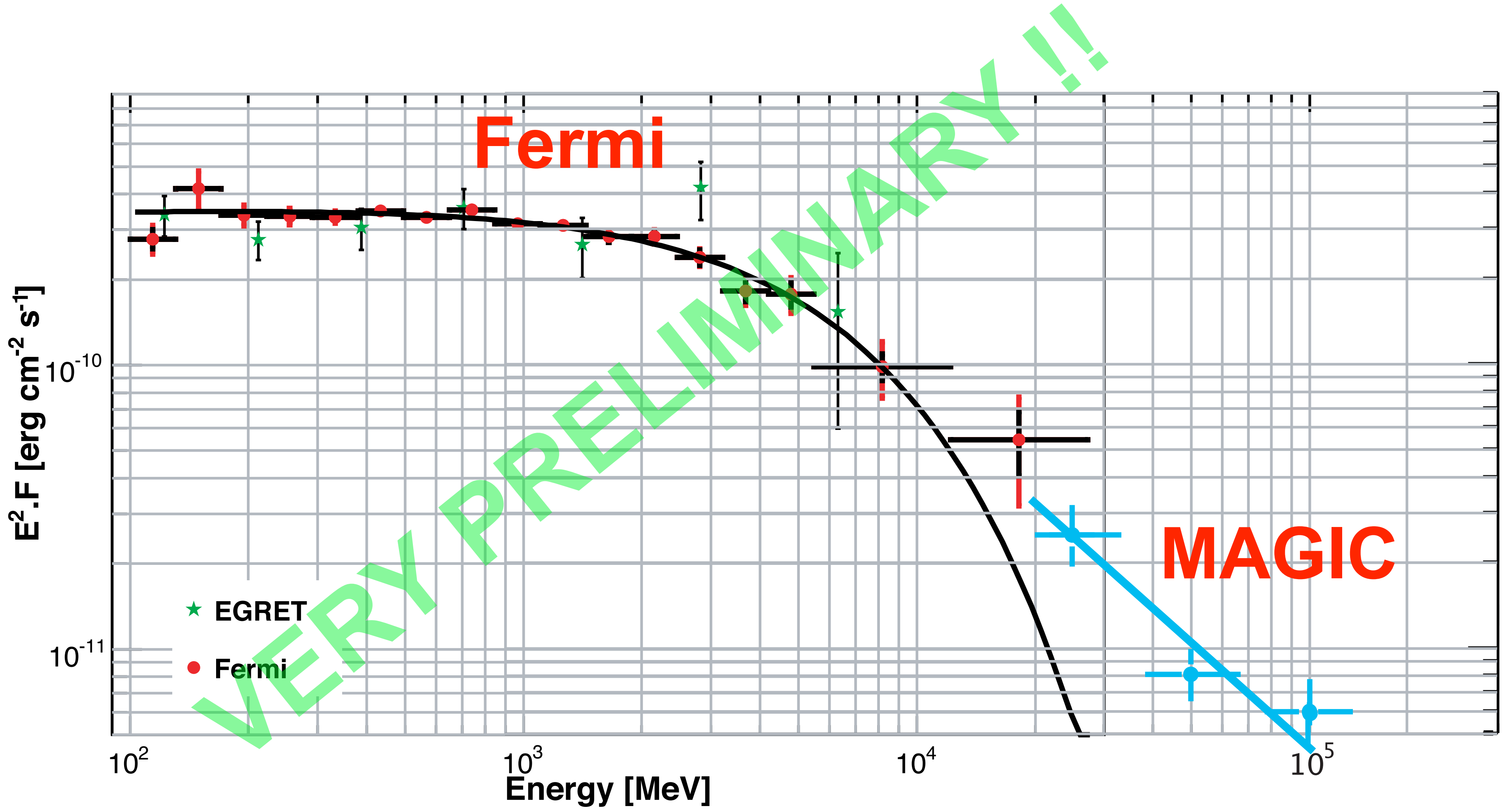


Morphology studies with CTA
High angular resolution





FERMI+ MAGIC Crab pulsar spectrum

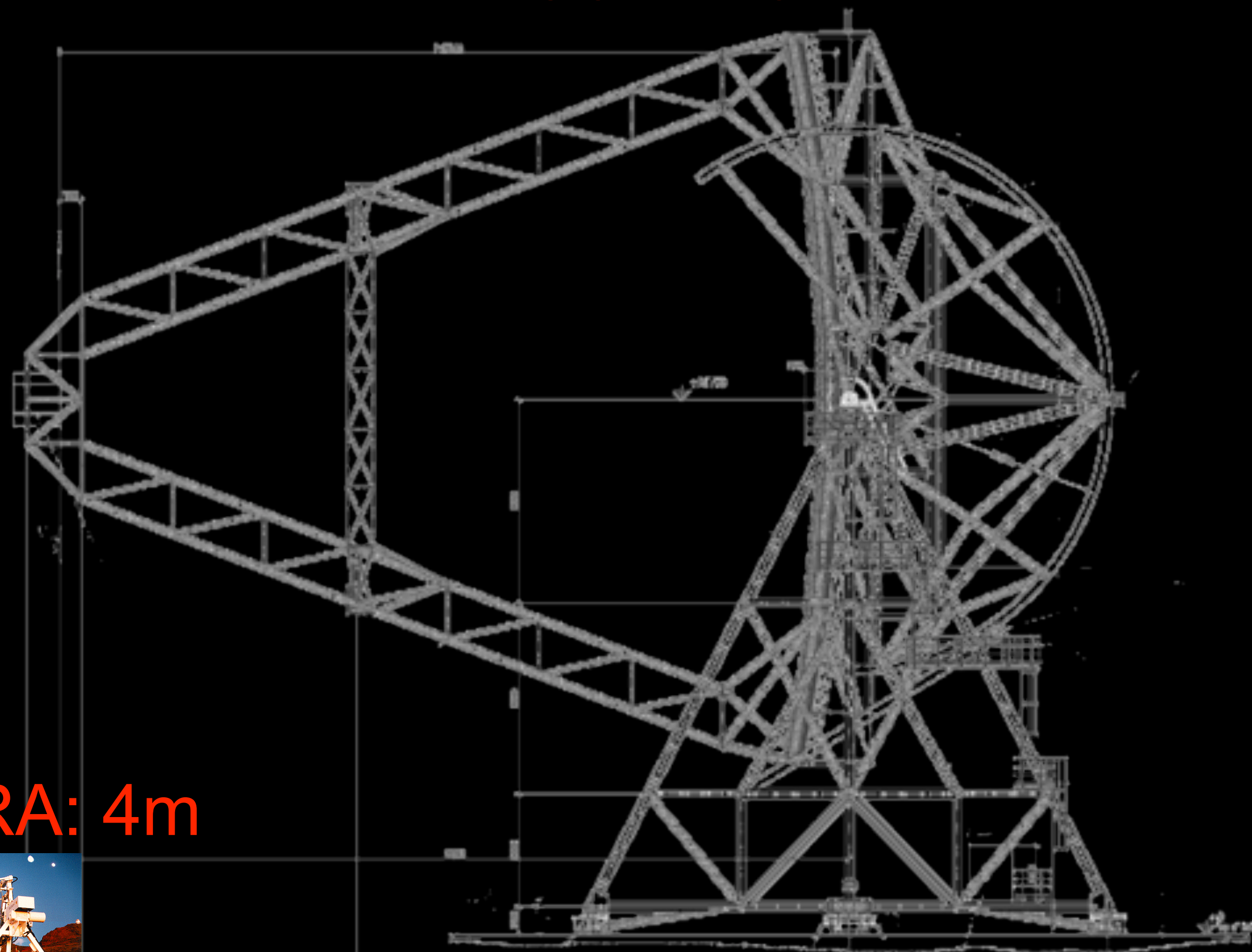


Lots of past experience

HESS / MAGIC / HEGRA as prototypes

MAGIC: 17 m

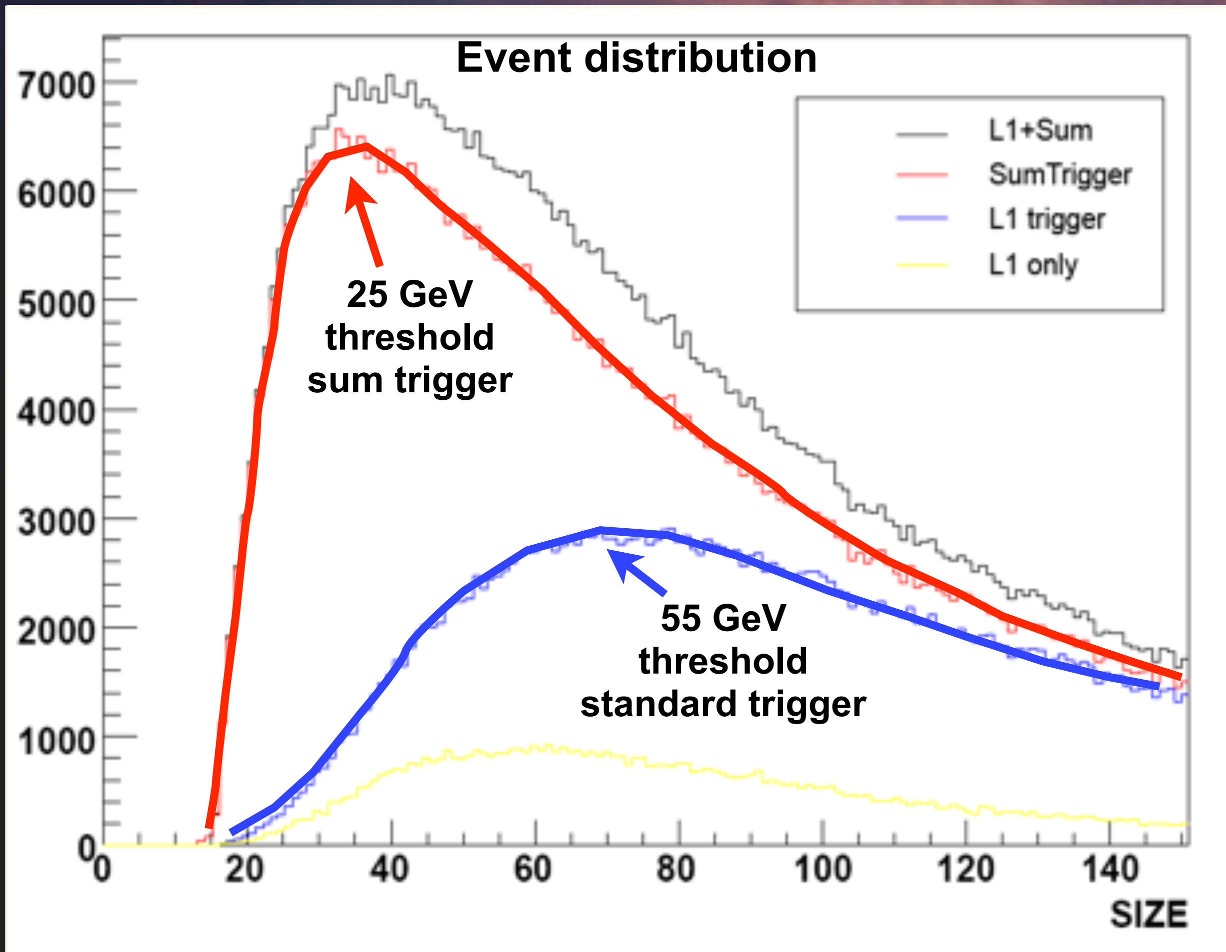
HESS II: 28m

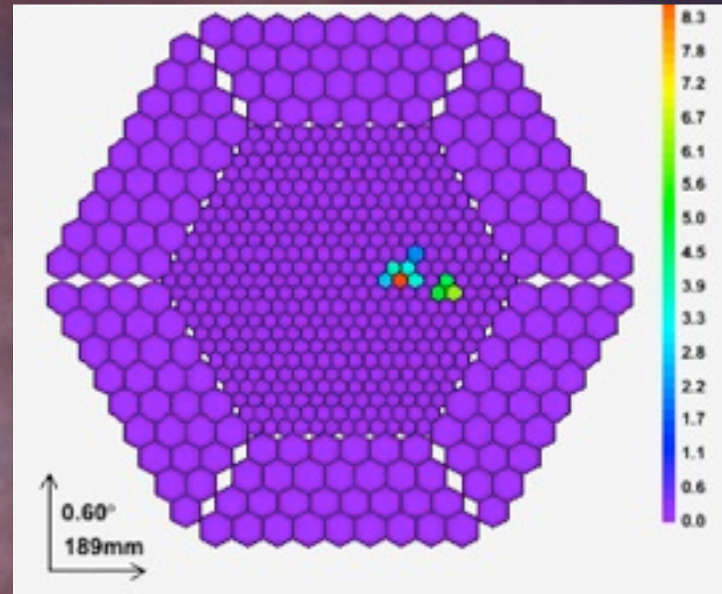


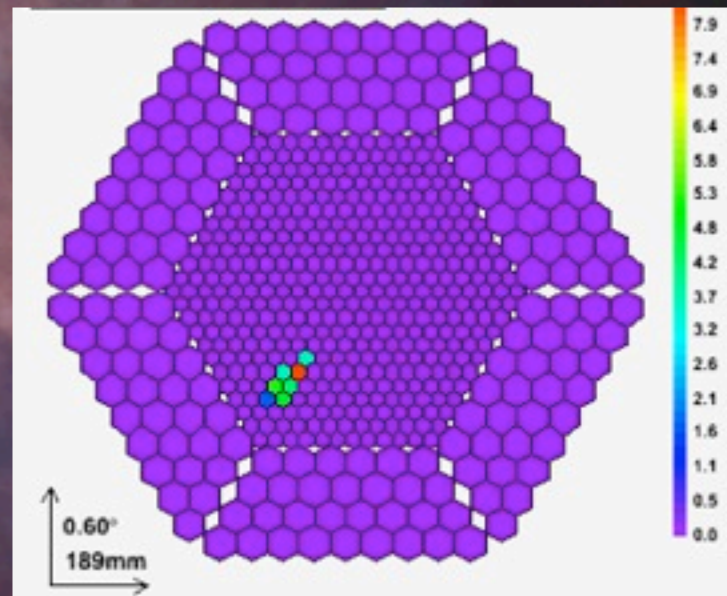
H.E.S.S. 12 m

HEGRA: 4m

--> Lower trigger threshold 25 GeV !!

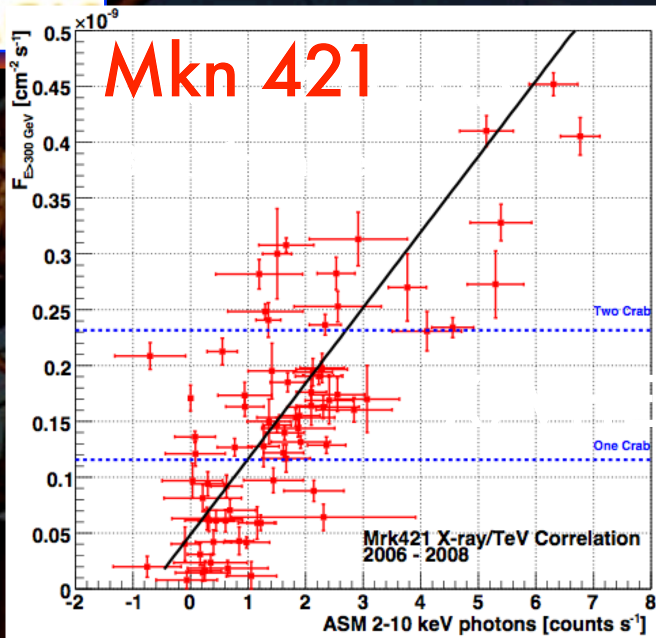


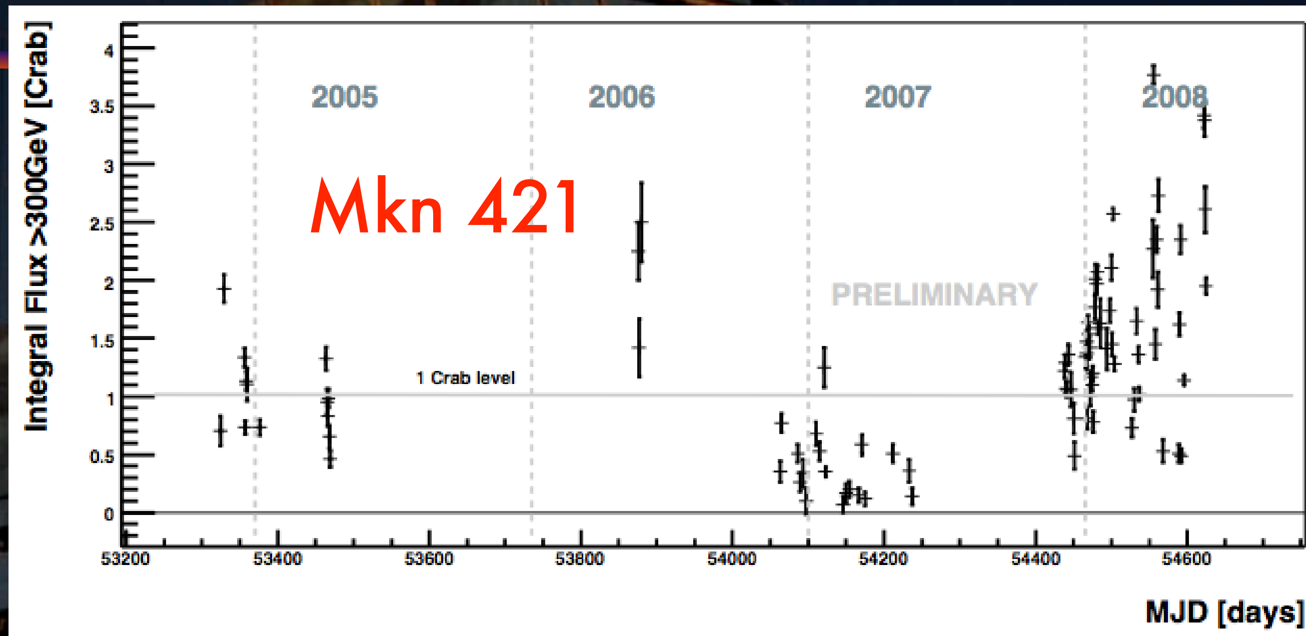


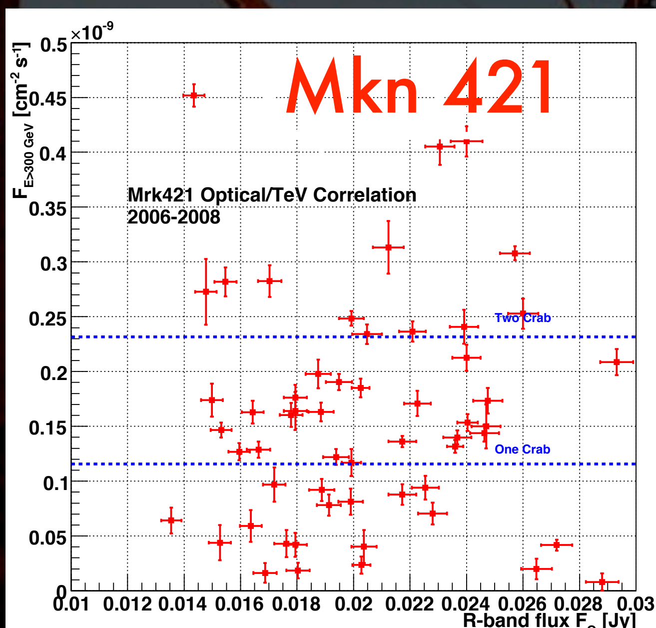


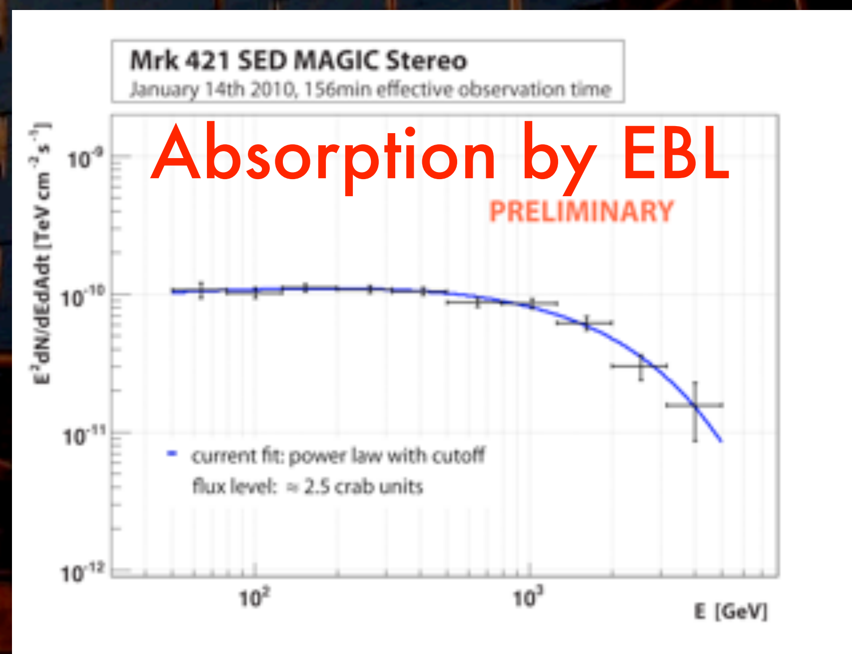
- Examples of 30 GeV showers

Monitoring of Mkn421





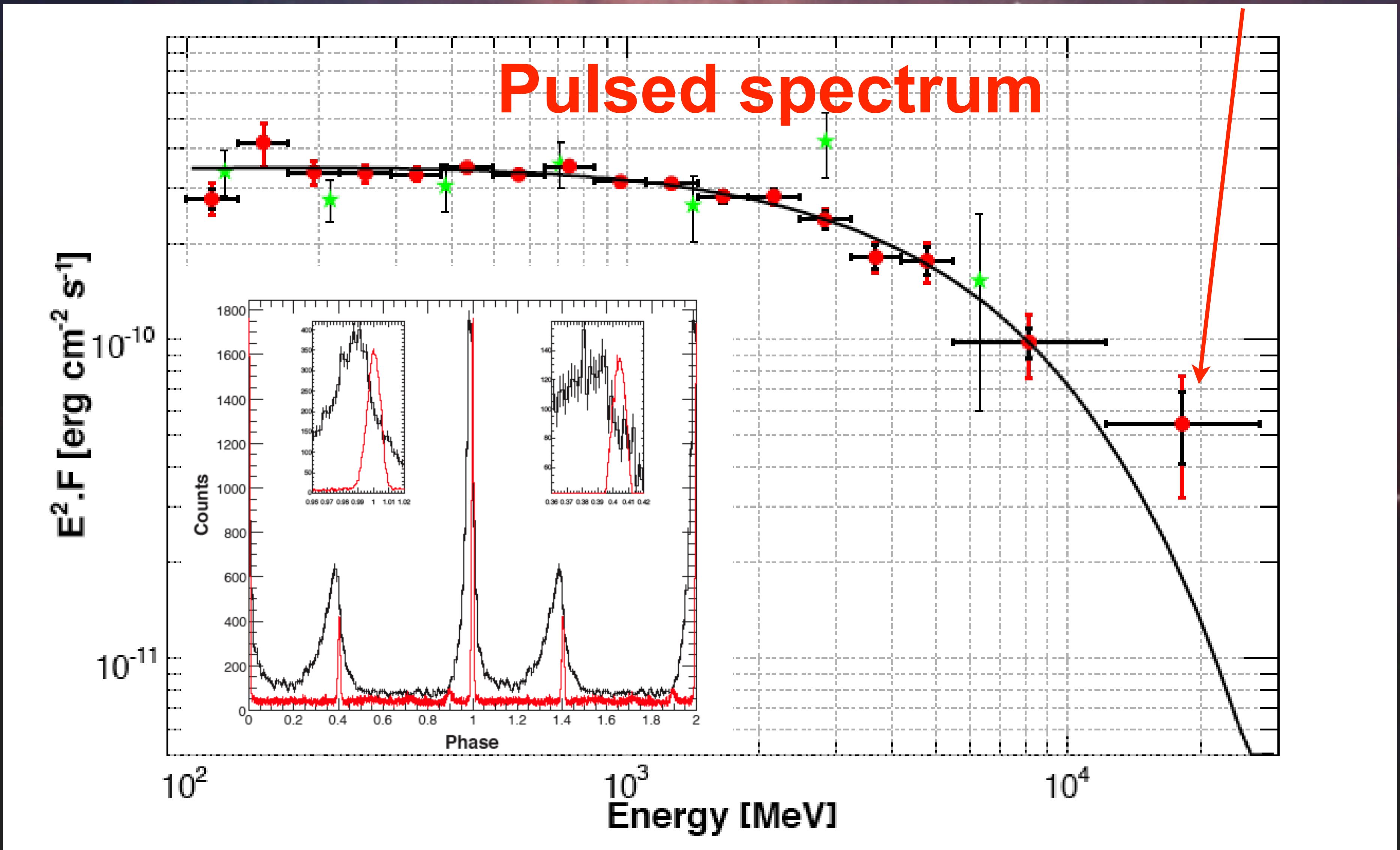




Thomas Schweizer

Fermi observation of Crab pulsar

- Exponential cutoff at E_c = (5.8 ± 0.5 ± 1.2 GeV) (neglecting the last point)



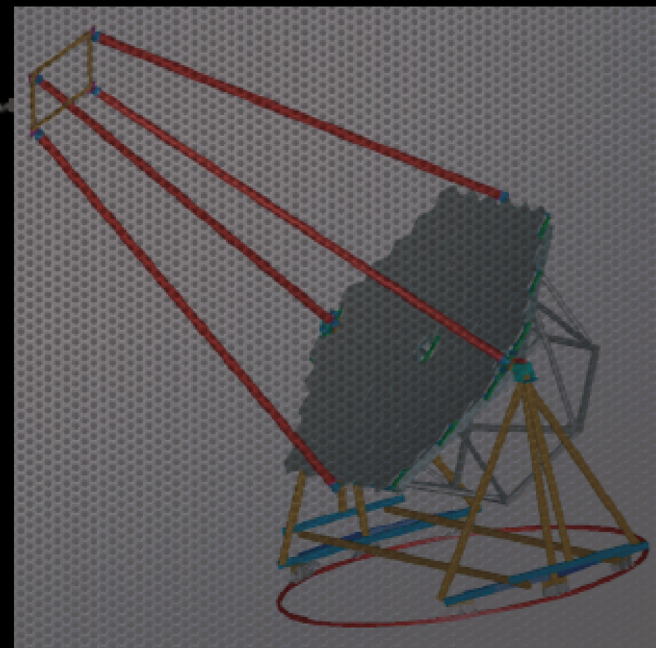
Favored:12m telescope design from DESY

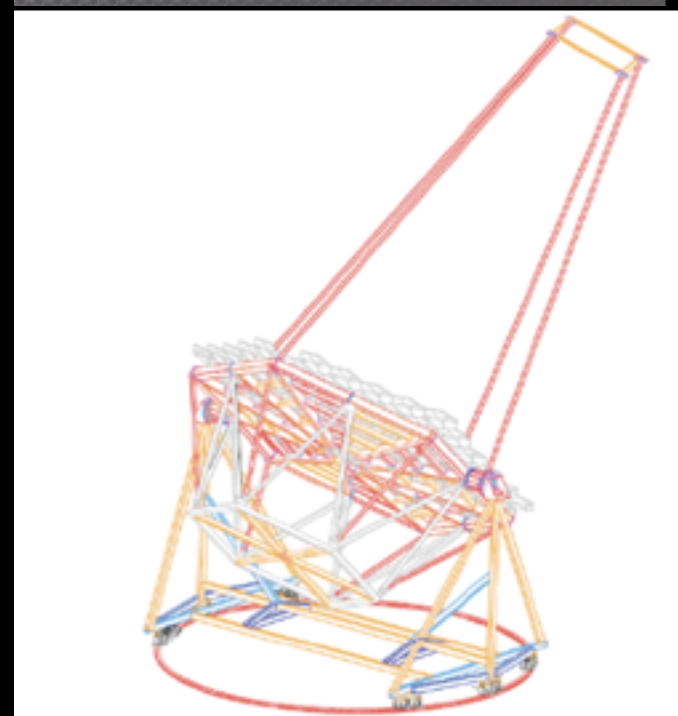
F/D 1.5
Hexagonal mirrors 1.2 m
Camera weight 1.5 t
Camera size 1x1 m^2
Mirror weight 1.5 ... 5 t

➡OSS 20 t

➡Counter weight 5 t

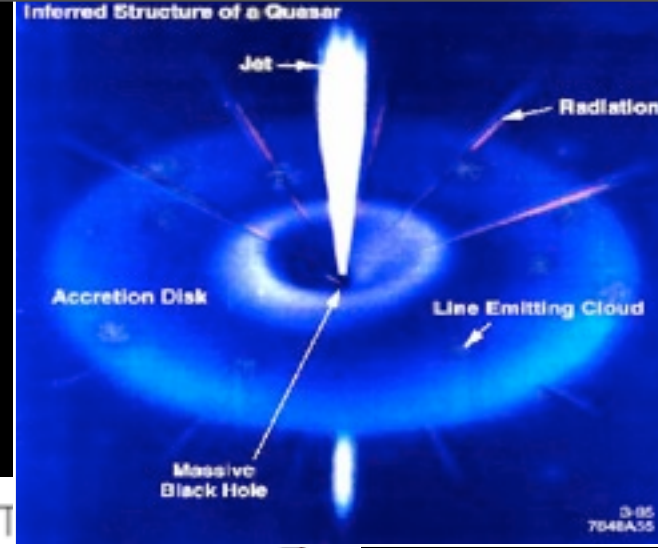
➡Positioning system 20 t

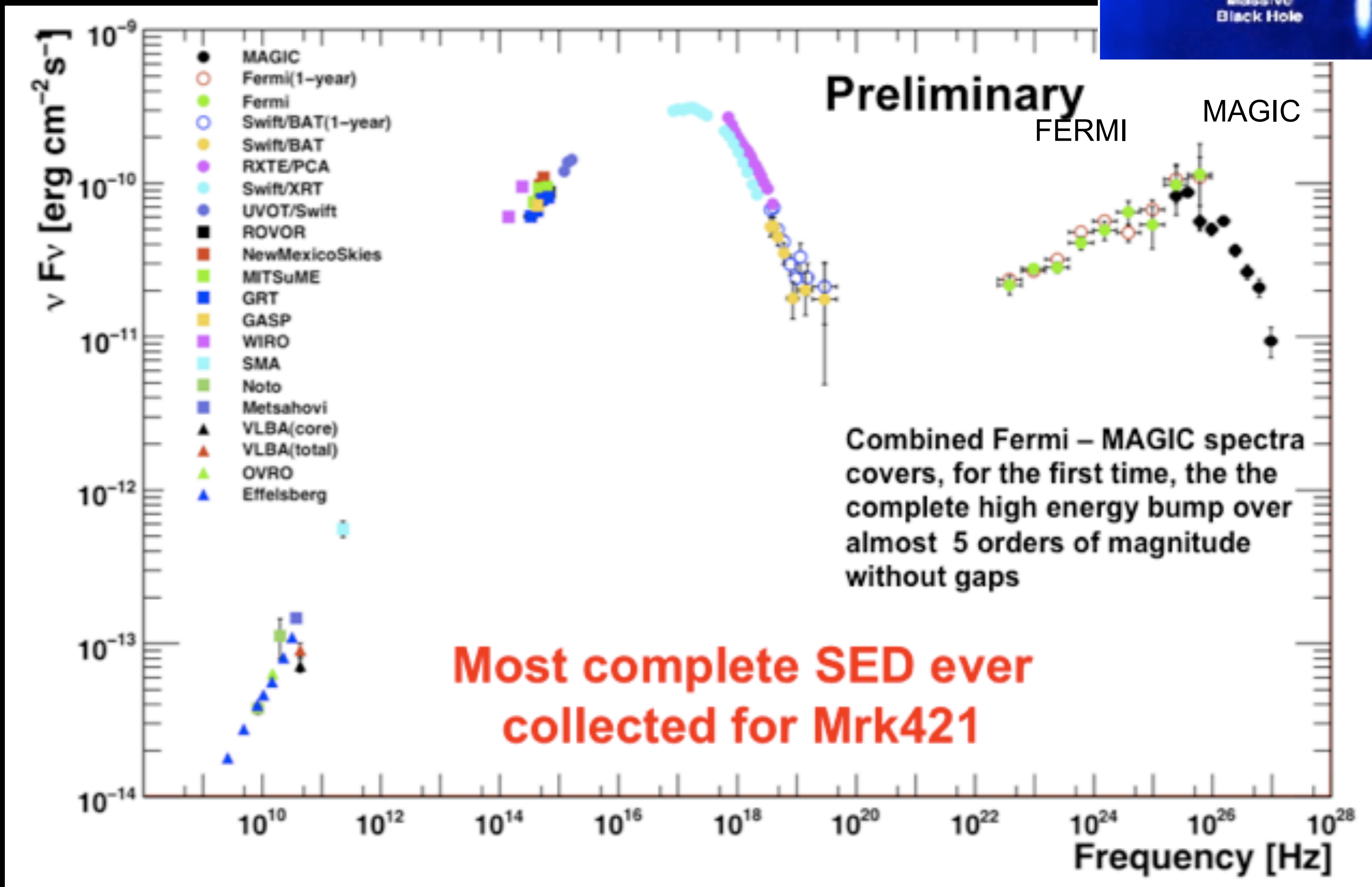




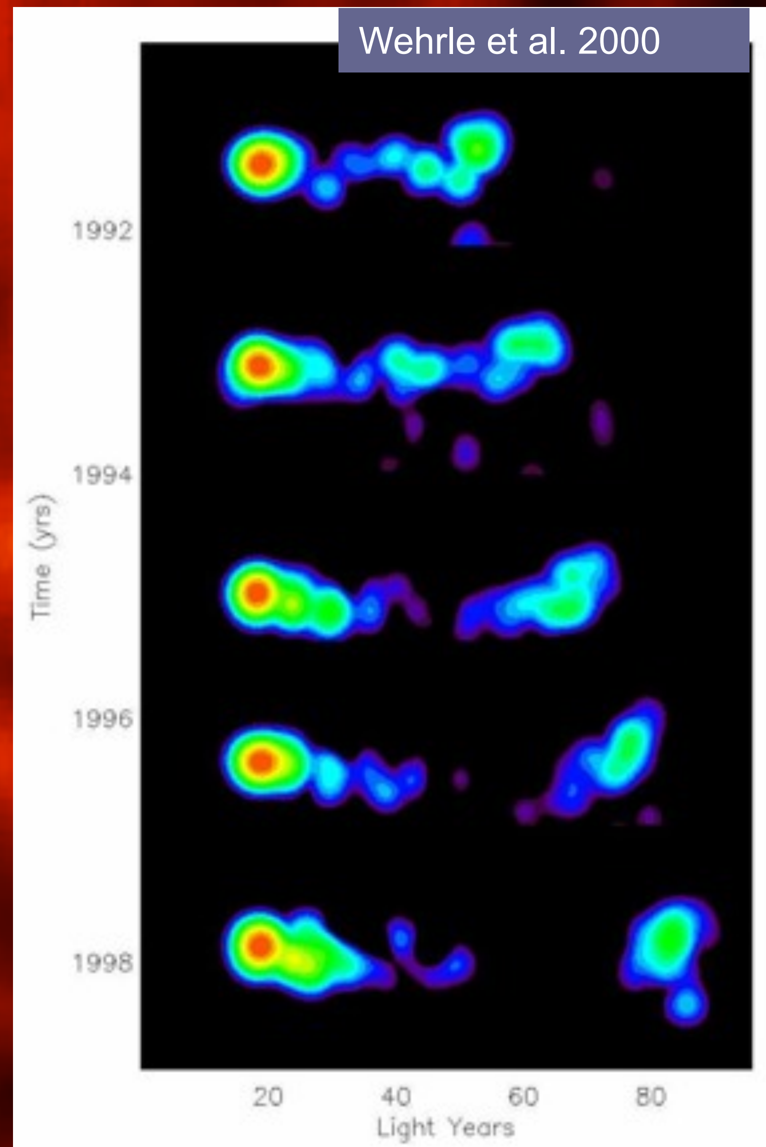
Mkn 421: First combined spectrum: Fermi and MAGIC

- 10 day multiwavelength campain
  Jan 20 - May 31, 2009



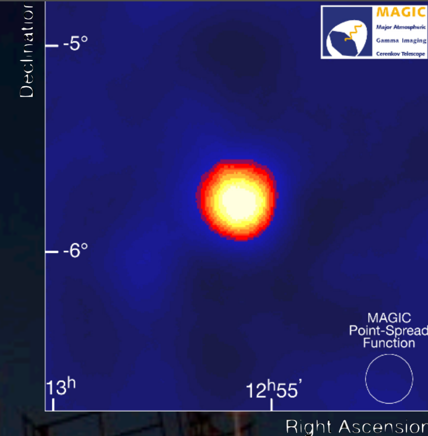


High-z Observations: Need low energy sensitivity 3C 279



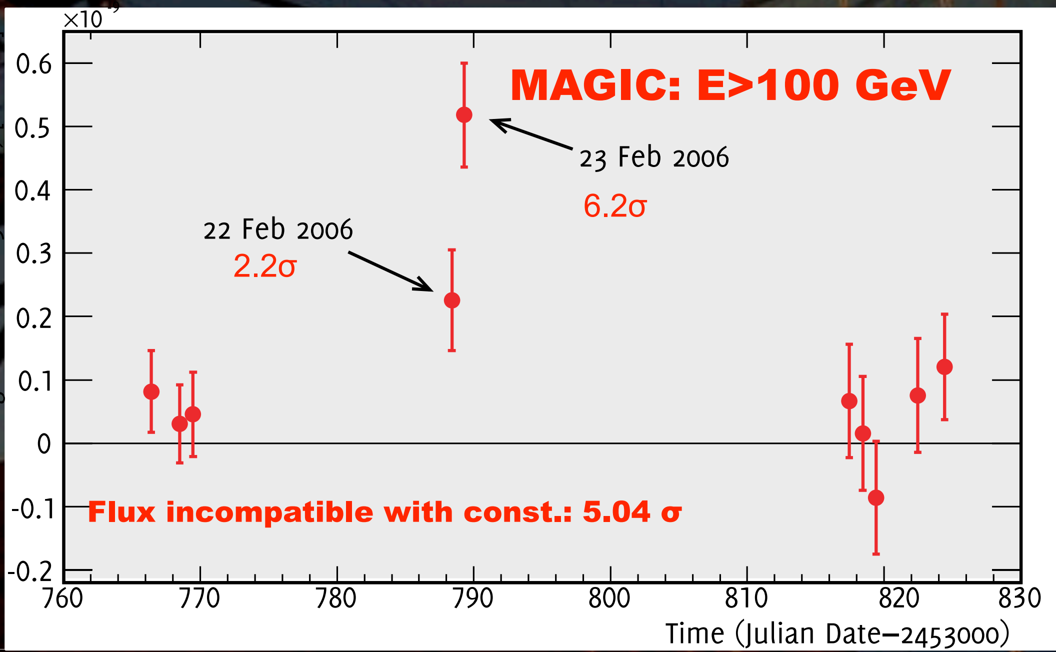
- First Flat Spectrum Radio Quasar !!
- Redshift z=0.536
- Apparent luminosity ≈ 10^{48} erg/s
- Brightest EGRET AGN (Wehrle+97,98)
- Gamma-ray flares in 1991 and 1996: High dynamical range in EGRET data
- Fast time variation: ΔT ~ 6hr in 1996 flare

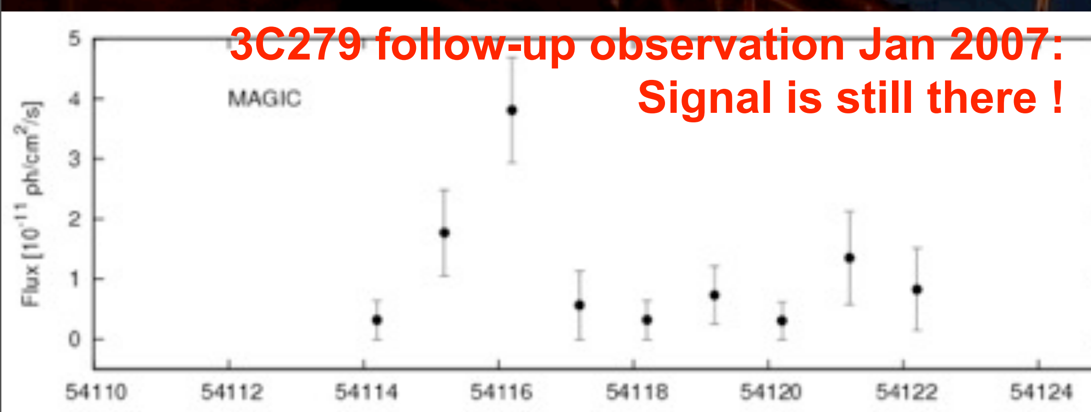
3C 279 MAGIC observations Jan -April 2006

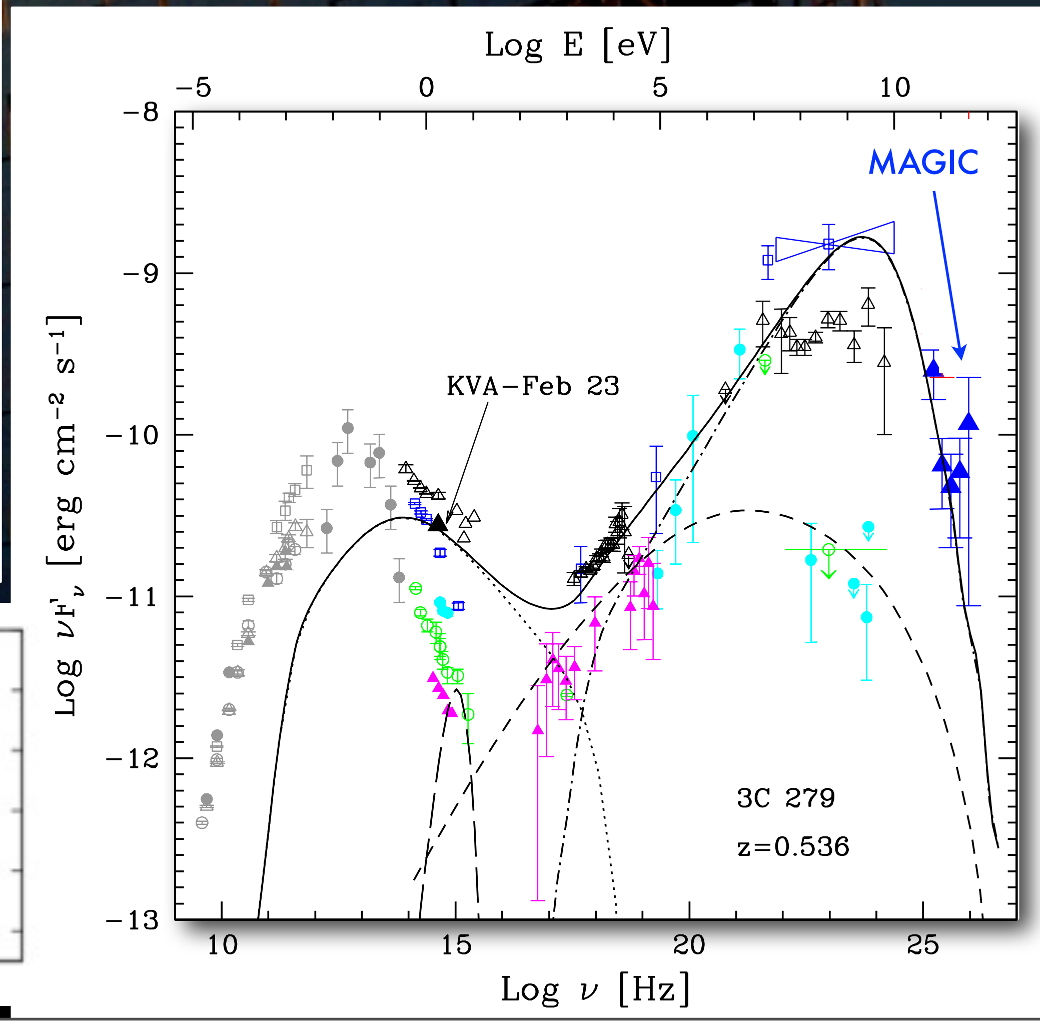


- Modeling of 3C 279 non-trivial:
  - External-Inverse Compton Modeling required, more free parameters

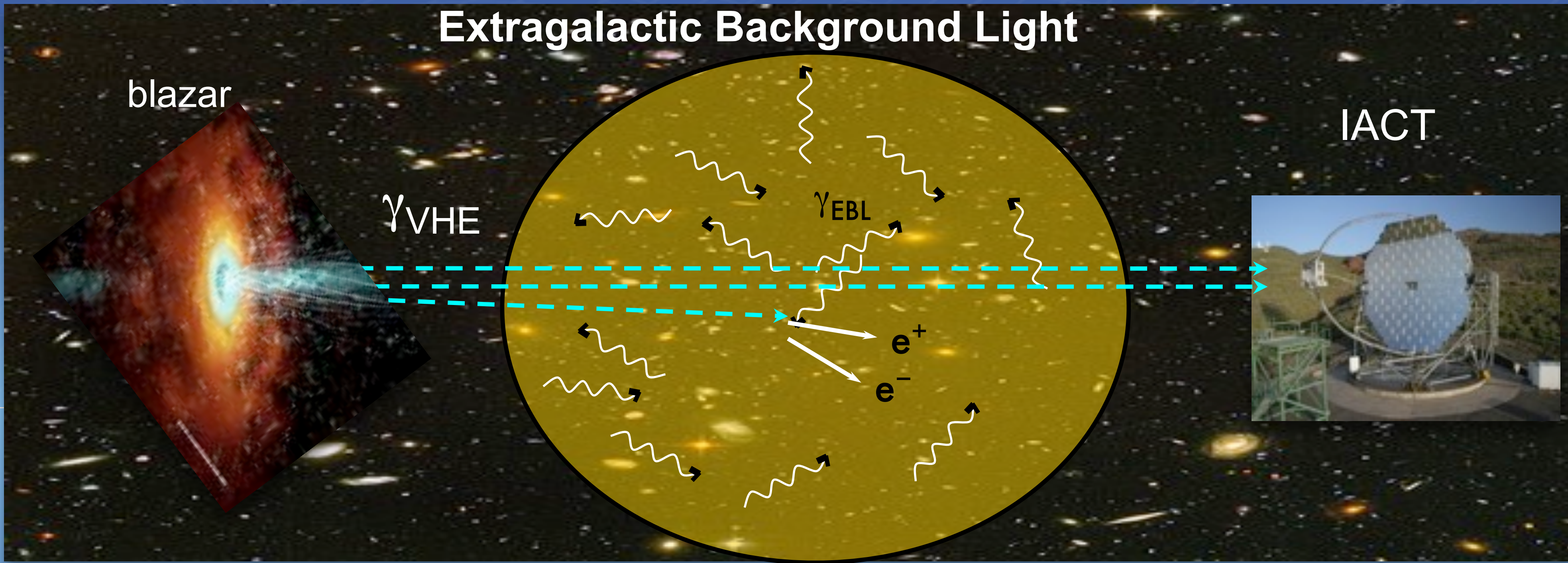
MAGIC Coll., Science 320 (2008) 1752

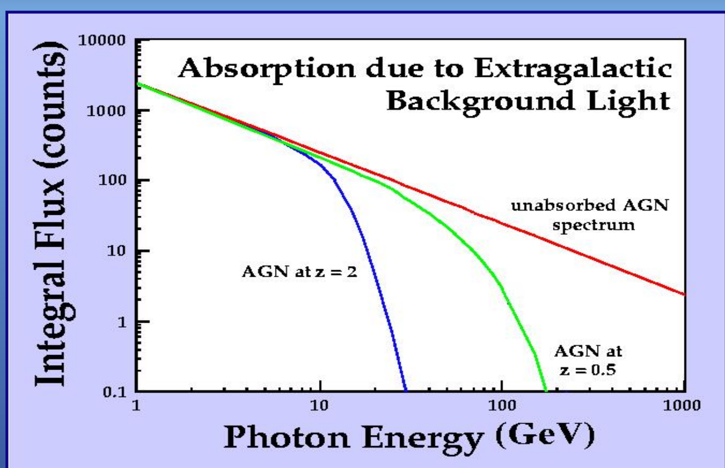


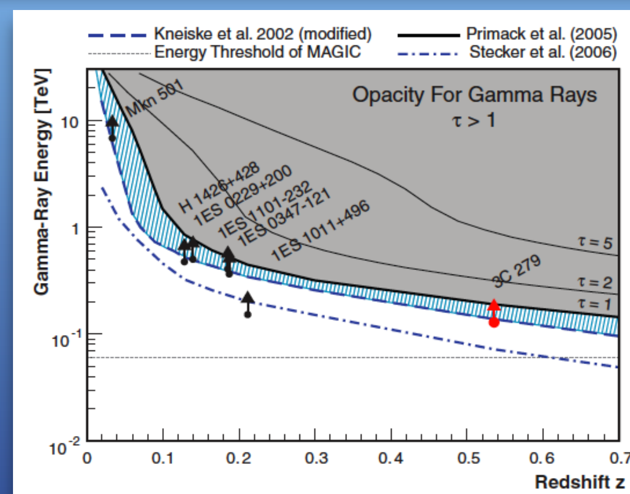




The gamma ray horizon





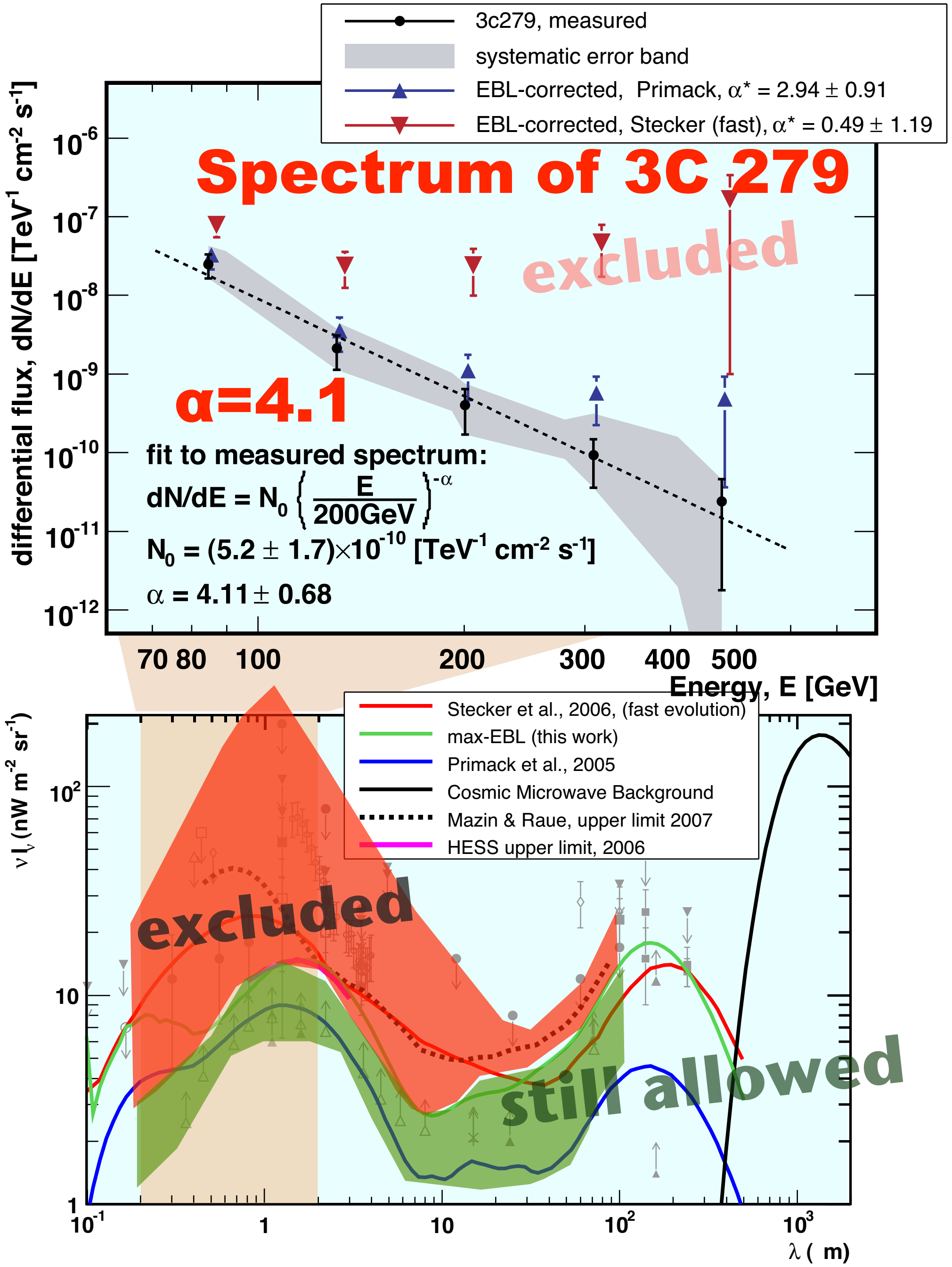


Measuring the EBL

- Reconstruct intrinsic spectrum using state-of-the-art EBL models:
  - Stecker fast-evol. → $\alpha^*=0.5\pm1.2$
  - Primack: → $\alpha^*=2.9\pm0.9$
- Generic acceleration mechanism arguments, e.g. Aharonian+06: Assume $\alpha^*<1.5$ unreasonable
- Formation of hard spectra possible Aharonian+08, Sitarek+Bednarek 08, Liu+08
- Internal absorption in 3C279 does not produce important hardening Tavecchio+Mazin 08

➡ Infer maximum tolerable EBL

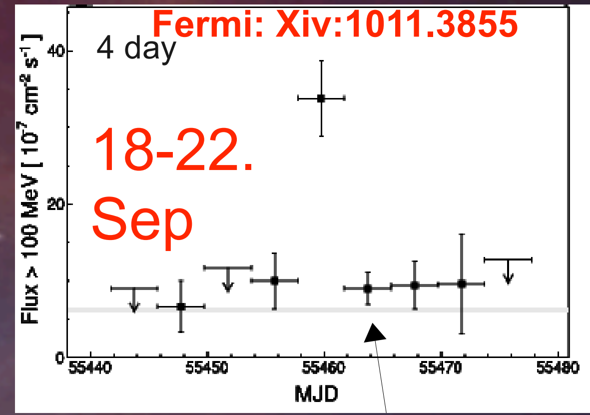
➡ Gamma-ray horizon



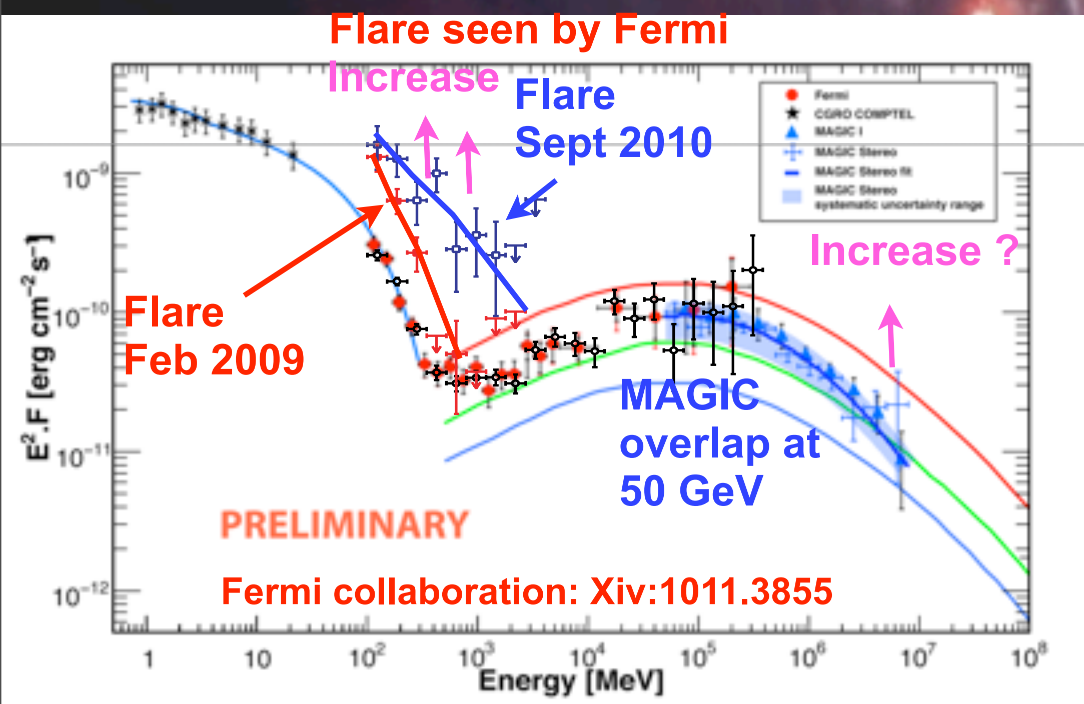
MAGIC Coll., Science 320 (2008) 1752

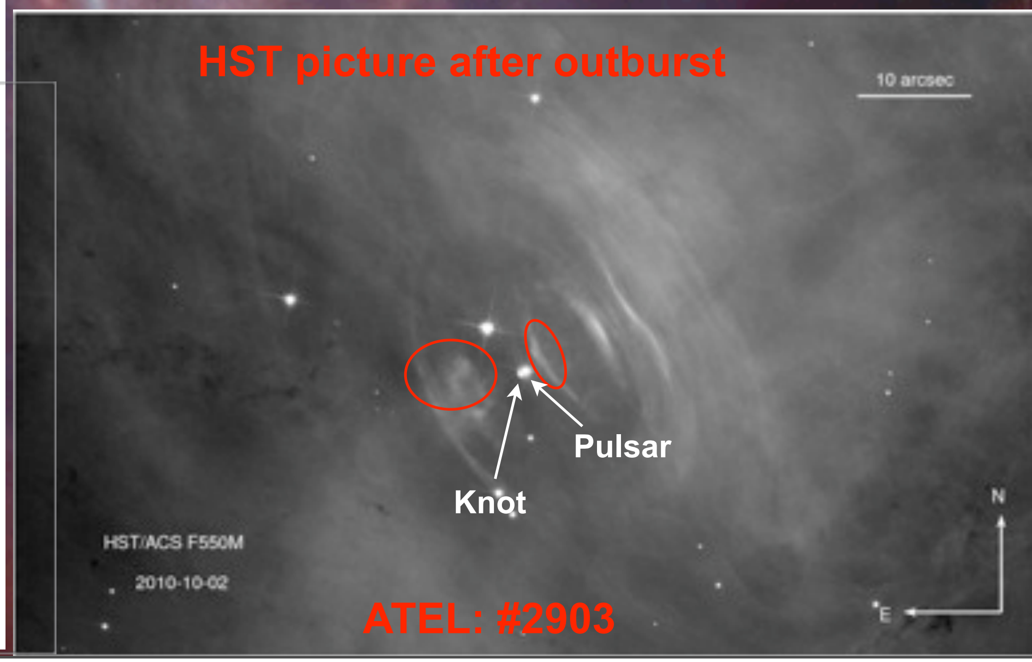
Thomas Schweizer

Short term variability in the Crab nebula ?



- Fermi and AGILE reported an enhanced gamma emission from the Crab nebula (Agile: 4.4 sigma 19.Sep. 2010, ATEL:2855, Fermi: double flux, 9 sigma, 18-22. Sept, >100MeV, ATEL:2861)
- Integral (20keV-400keV), BAT (15-150keV) and SWIFT/XRT (0.2-10 keV) see no FLUX increase --> no evidence for AGN, ATEL: 2856, 2868, 2893
- Chandra sees previously bright knot at 6 arc sec south-east extends to 3 arc-sec south-east, not clear if correlated with flare. Structure south-east has changed significantly to one year ago. (2882)
- HST sees an increased emission 3 arcsec east of pulsar, wisps north-west appear bright, ATEL 2903
- ARGO-YBJ: Hint: 3-4 time increased flux at TeV energies (Sept 17-22), median energy 1 TeV (2921)
- MAGIC & VERITAS see no flux increase (ATEL: 2967, 2968)

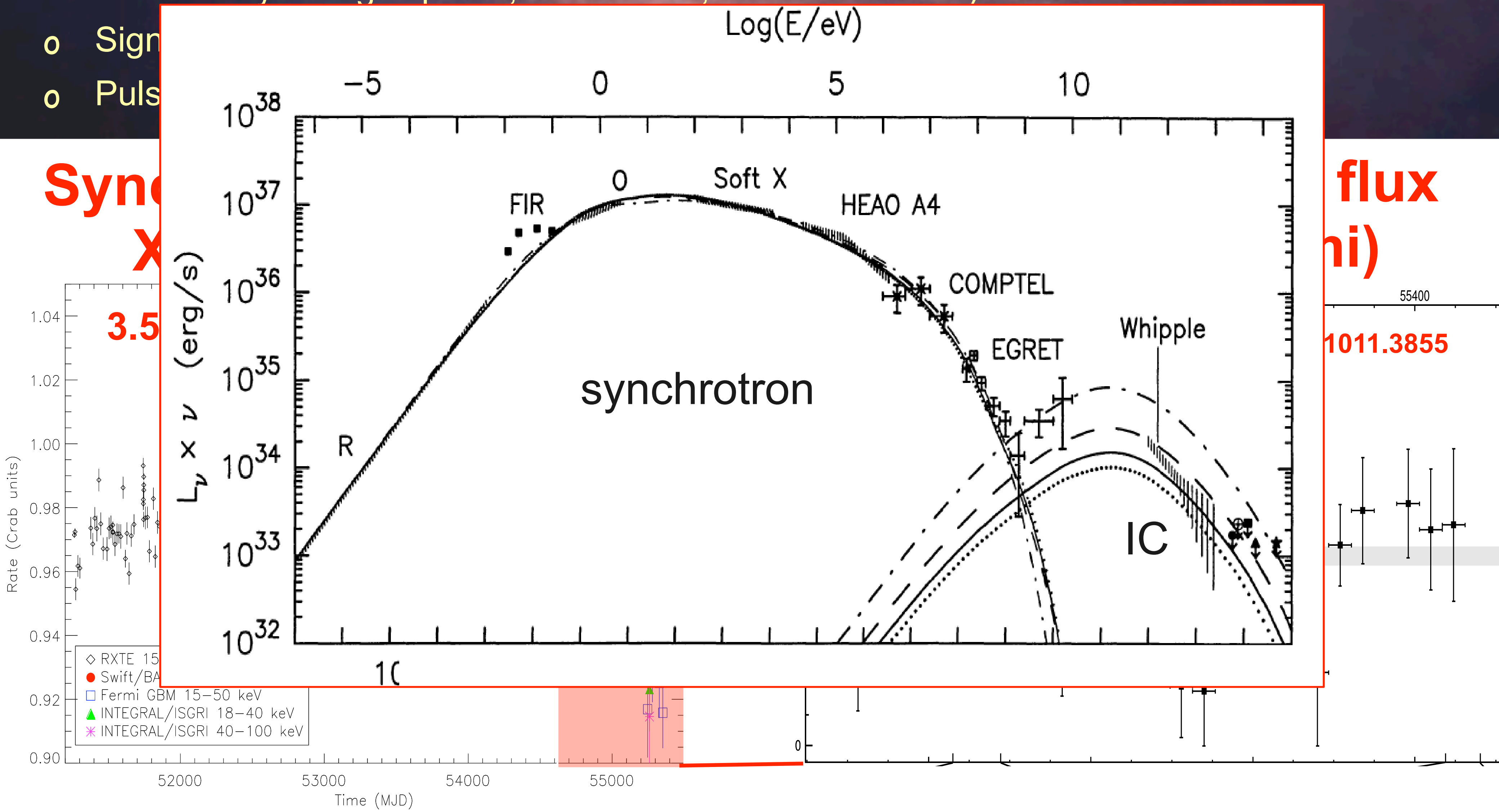




Is Crab really a standard candle ?
How stable is Crab in IC-gamma rays ?

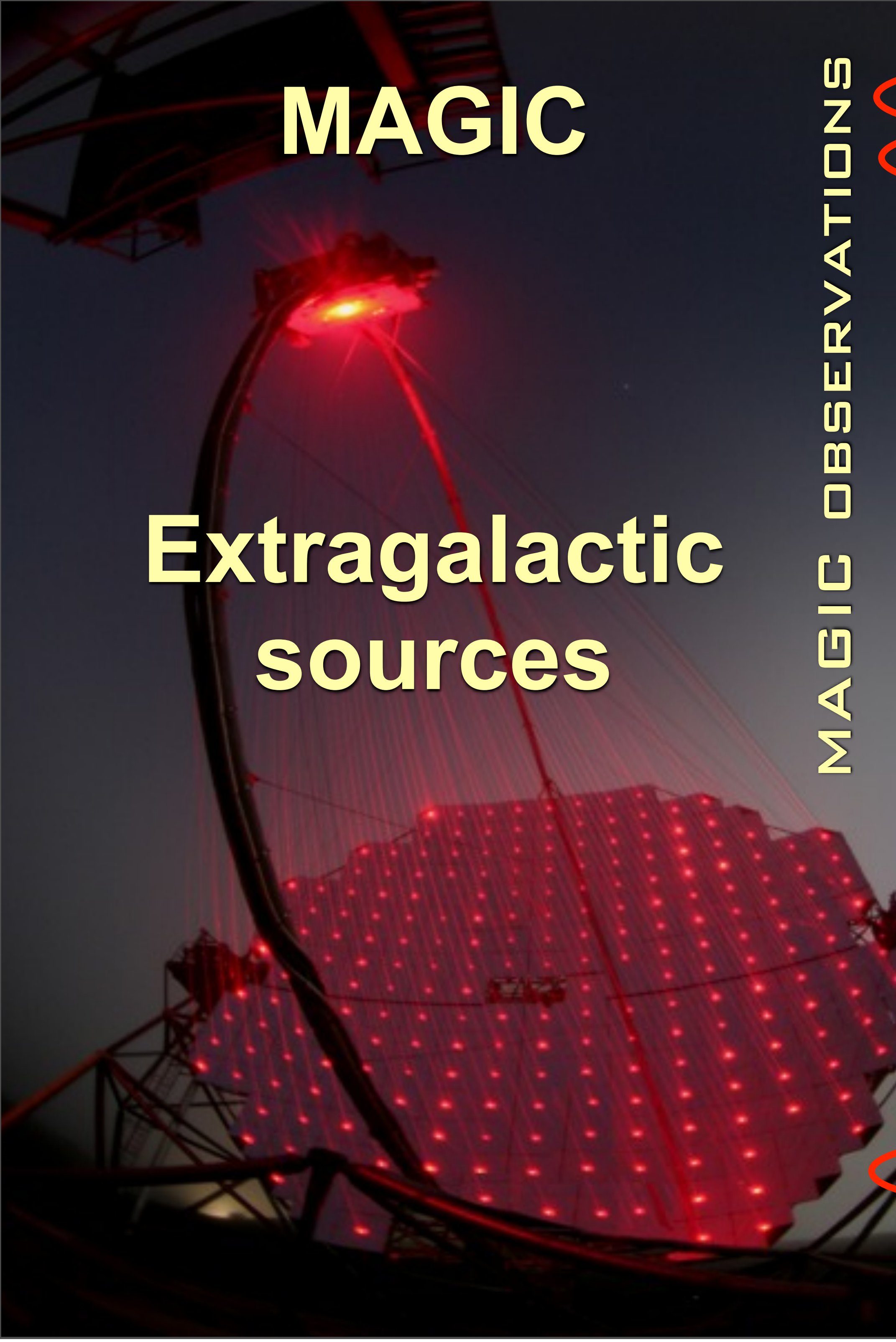
- Decreasing and variable Crab flux in Fermi Gamma ray burst monitor (10-50 keV) by 7% from August 2008 to August 2010 (confirmed by similar measurements with SWIFT/BAT, Rossi X-ray timing explorer, RXTE/PCA, INTEGRAL/IBIS).
- Sign
- Puls

Sync … flux
X … ni)



MAGIC

Extragalactic sources



MAGIC OBSERVATIONS

Source	z	Sp.	Type	Discovery
M 87	0.004	2.9	FR-I	HEGRA
Mkn 421	0.031	2.2	HBL	Whipple
Mkn 501	0.034	2.4	HBL	Whipple
1ES 2344+514	0.044	2.9	HBL	Whipple
Mkn 180	0.045	3.3	HBL	MAGIC
1ES 1959+650	0.047	2.4	HBL	7TA
PKS 0548-322	0.069		HBL	HESS
BL Lac	0.069	3.6	LBL	MAGIC
PKS 2005-489	0.071	4.0	HBL	HESS
PG 1553	>0.09	4.0	HBL	HESS/MAGIC
PKS 2155-304	0.116	3.3	HBL	Durham
1ES 1426+428	0.129	3.3	HBL	Whipple
1ES 0229+200	0.139		HBL	HESS
H 2356-309	0.165	3.1	HBL	HESS
1ES 1218+304	0.182	3.0	HBL	MAGIC
1ES 1101-232	0.186	2.9	HBL	HESS
1ES 0347-121	0.188		HBL	HESS
1ES 1011+496	0.212	4.0	HBL	MAGIC
3C 279	0.538	4.1	FSRQ	MAGIC
3C 66A/B	?		?	MAGIC
S5 0716+714	0.31	3.5	HBL	MAGIC