Recent Results of VHE Cosmic Gamma Ray Searches

Mosè Mariotti, Dip. Fisica and INFN Padova

Outline

- Introduction
- Instruments and techniques
- Scientific highlights and observations
- Summary
- Outlook

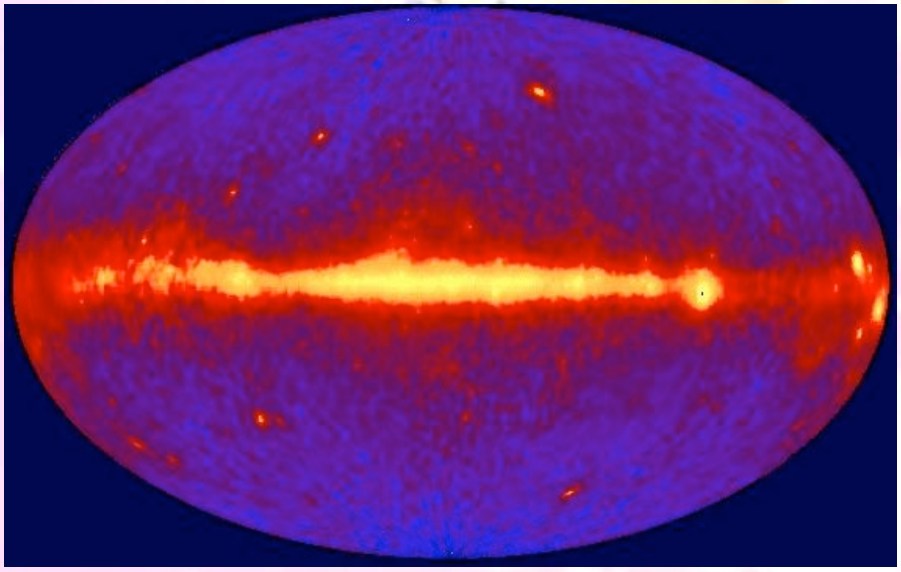
Acknowledgements: Werner Hofman, Jim Hinton, Manel Martinez, Trevor Weeks, J. Cortina,

Apologies: many on-going experiments and developments in HE and VHE cosmic gamma-rays.

Introduction

- Cosmic gamma-ray observation:
  - **directly** from satellites (HE) < O(10 GeV) and
  - **indirectly** from ground-based installations (VHE) > O(100 GeV)

- Satellites: EGRET -> HE gamma-ray astronomy already consolidated.



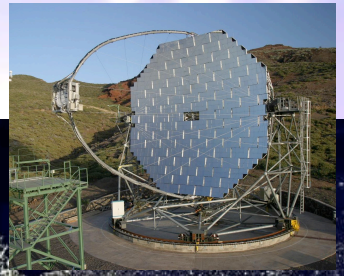
EGRET: Around 350 sources (250 unidentified)

VHE Experimental World

MILAGRO

STACEE

MAGIC



TIBET

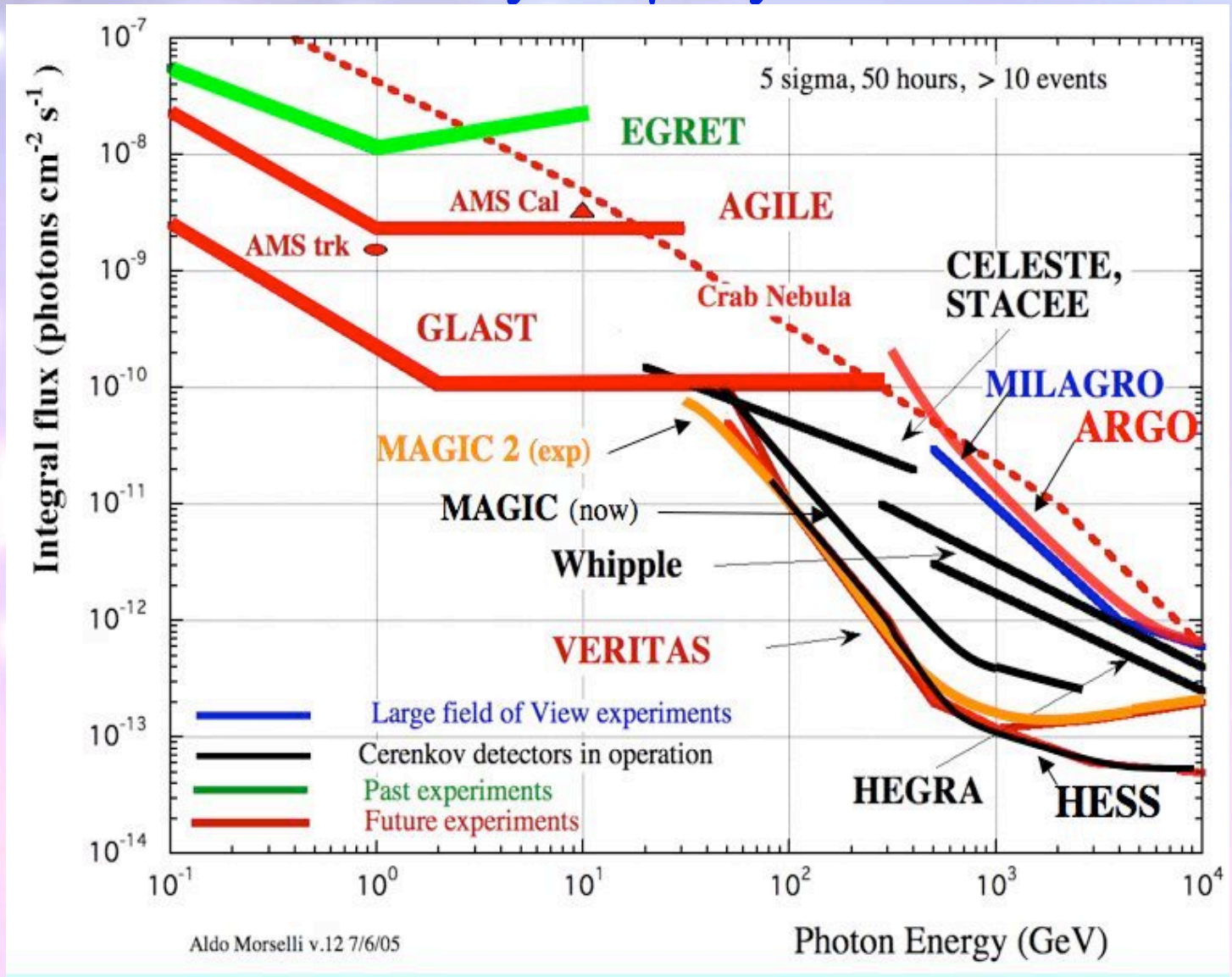
VERITAS

TACTIC

HESS

CANGAROO

Sensitivity of γ-ray detectors



High galactic latitudes(Φ_b=2 10^{-5} γ cm^{-2} s^{-1} sr $^{-1}$ (100 MeV/E)$^{1.1}$). Cerenkov telescopes sensitivities (Veritas, MAGIC, Whipple, Hess, Celeste, Stacee, Hegra) are for 50 hours of observations.Large field of view detectors sensitivities (AGILE, GLAST, Milagro, ARGO, AMS) are for 1 year of observation.

Ground based detectors: Cherenkov Telescopes

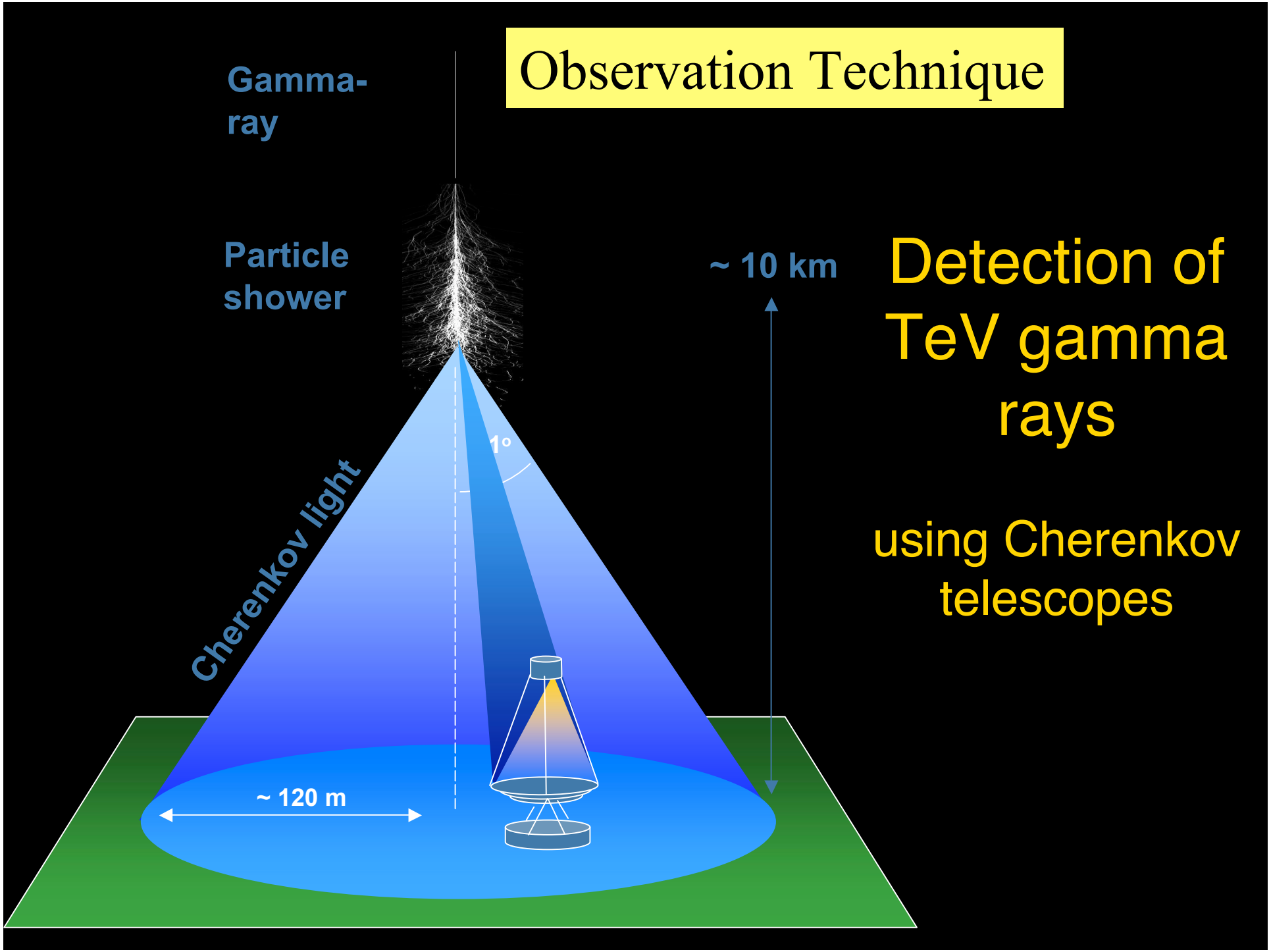
- Very special moment in VHE Cosmic gamma-ray observation:
  real revolution in consolidation of Cherenkov telescopes as astronomical instruments
  => transition from "HE experiments" to "telescopic installations"
  --> exploding interest in the astronomical community… !

- Big observational step within the last year:
  - **quantitative** (tripling number of detected sources)
  - **qualitative** (extremely high quality => unprecedented detailed studies).

=> DOWN OF A GOLDEN AGE FOR CHERENKOV TELESCOPES !

--> concentrate on Gamma-ray astronomy with Cherenkov telescopes

Observation Technique



Detection of TeV gamma rays

using Cherenkov telescopes

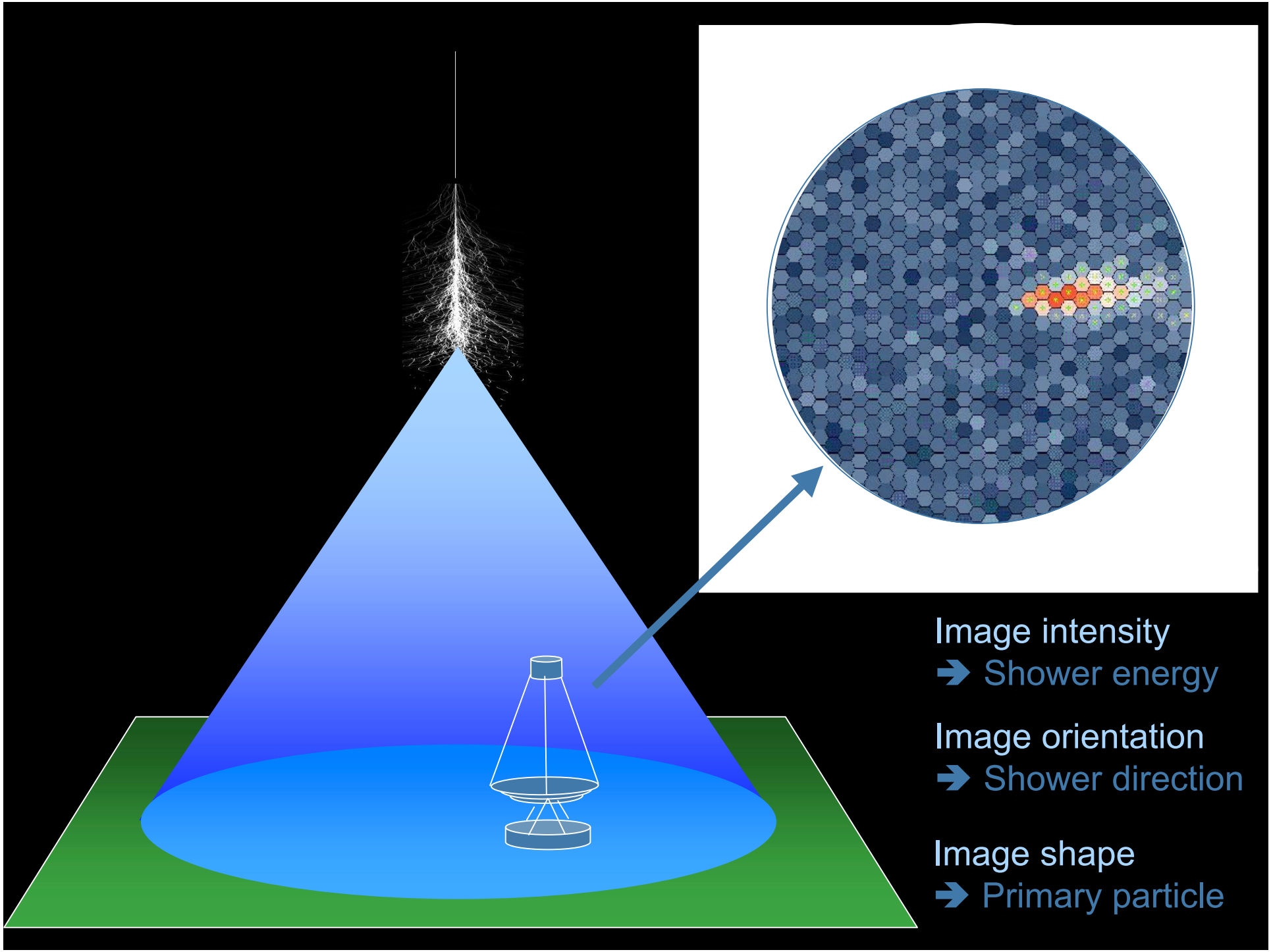
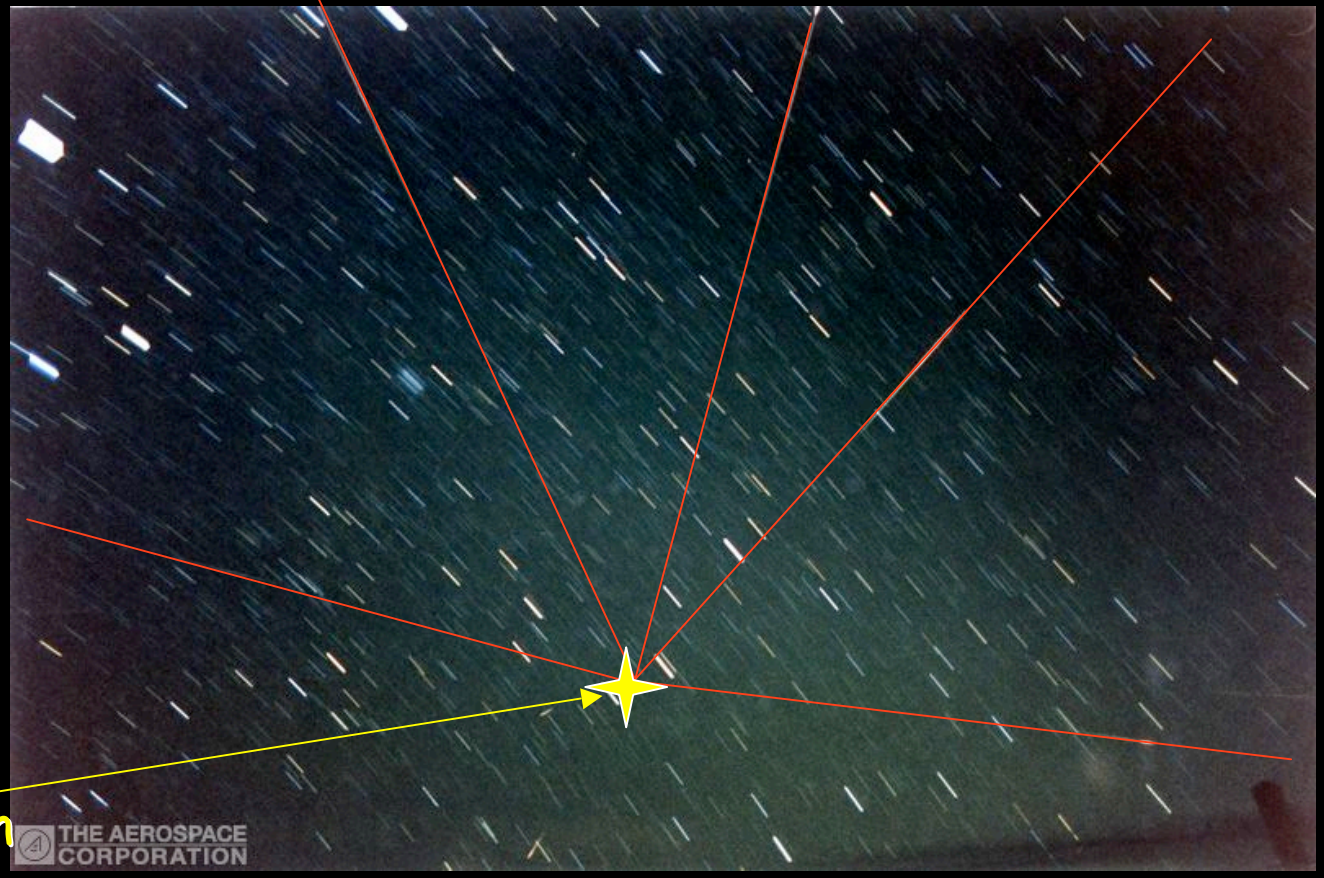


Image intensity
➔ Shower energy
Image orientation
➔ Shower direction
Image shape
➔ Primary particle

Gamma showers from a point source

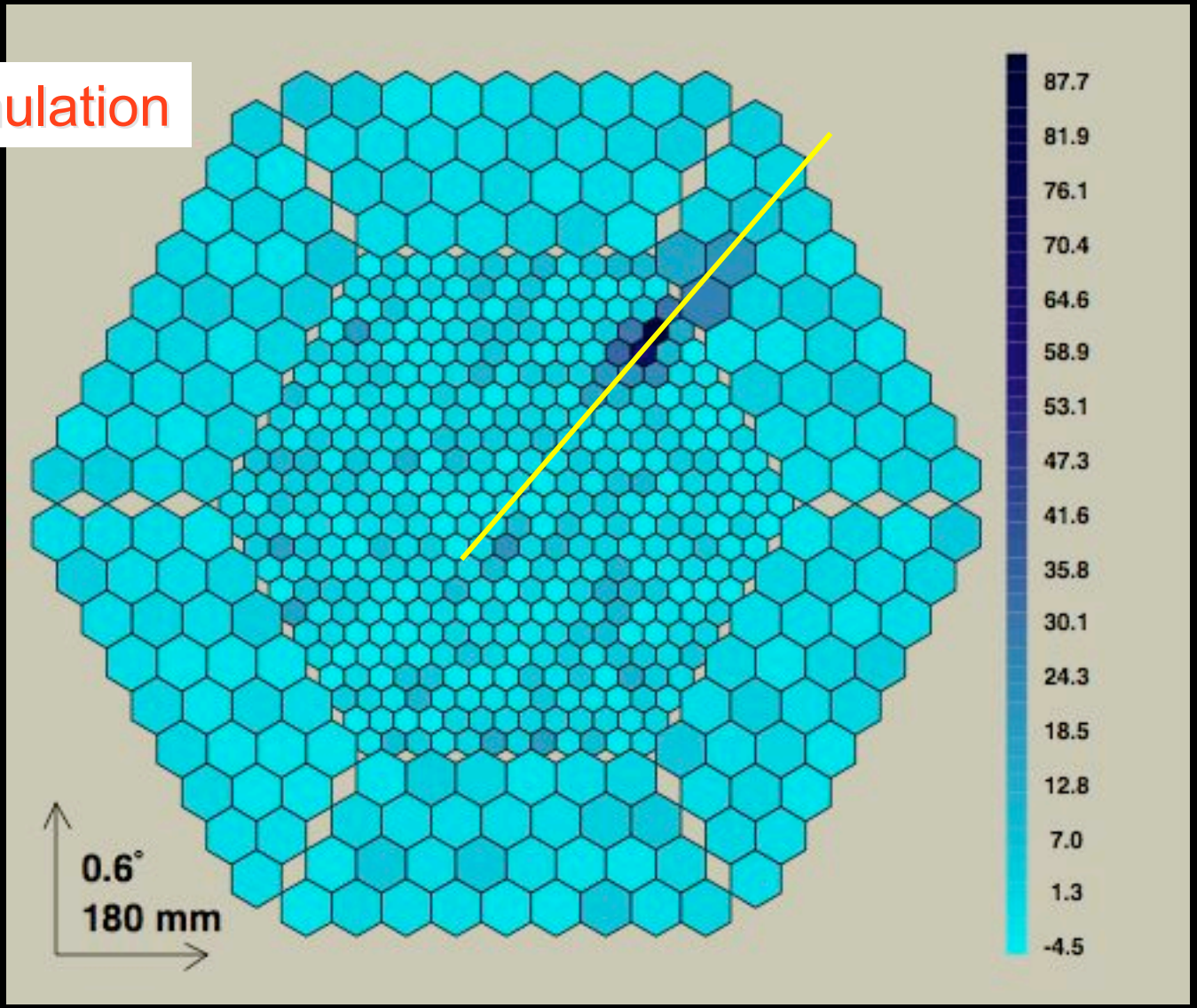
Imaging Air Cherenkov Telescopes are detecting a gamma source finding superimpositions on many shower axes of Cherenkov images

Like in some meteor showers, the apparent movement direction of the Earth can be seen as the radial point of meteor axis



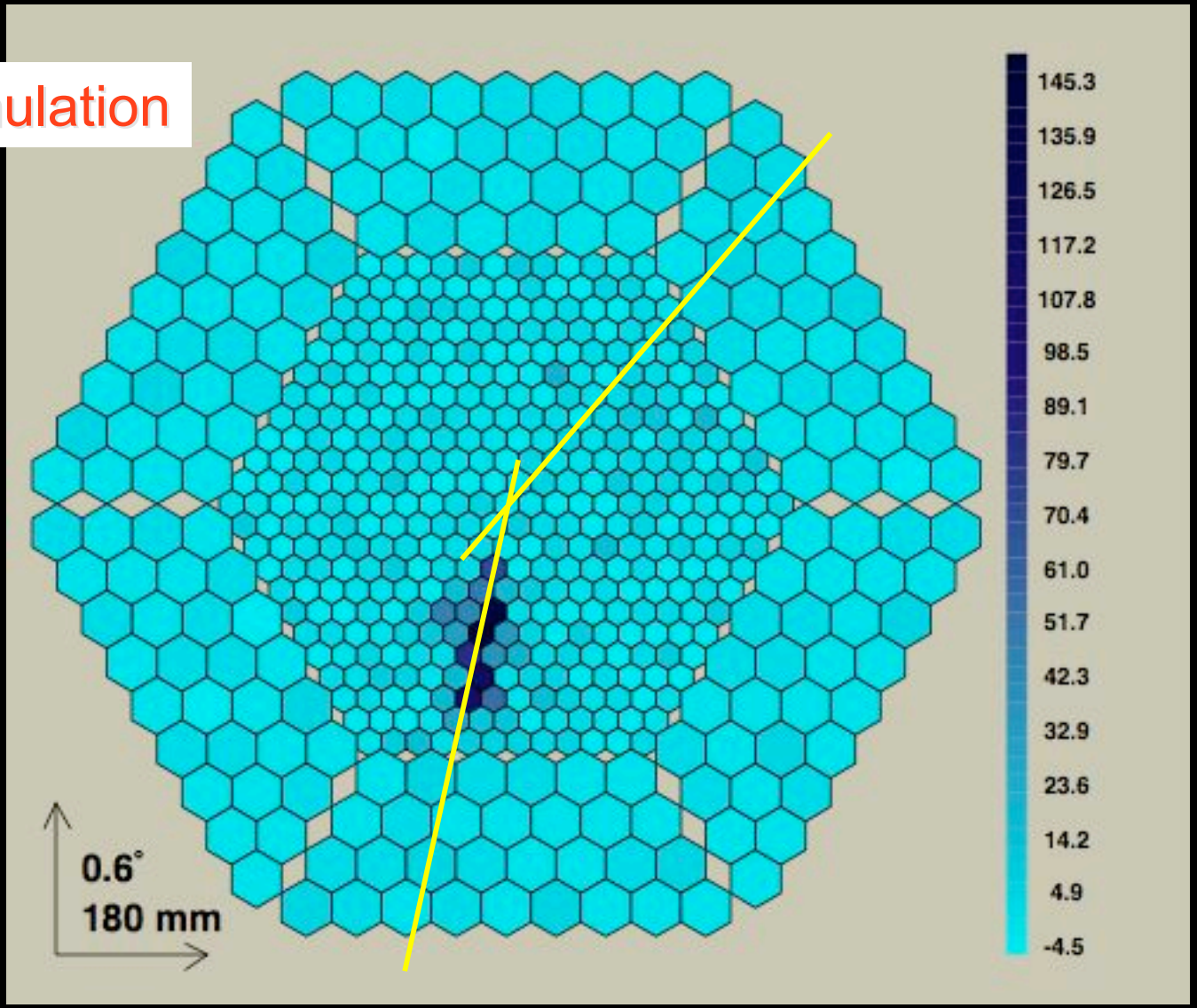
E = 38 GeV, b = 130 m

MC simulation



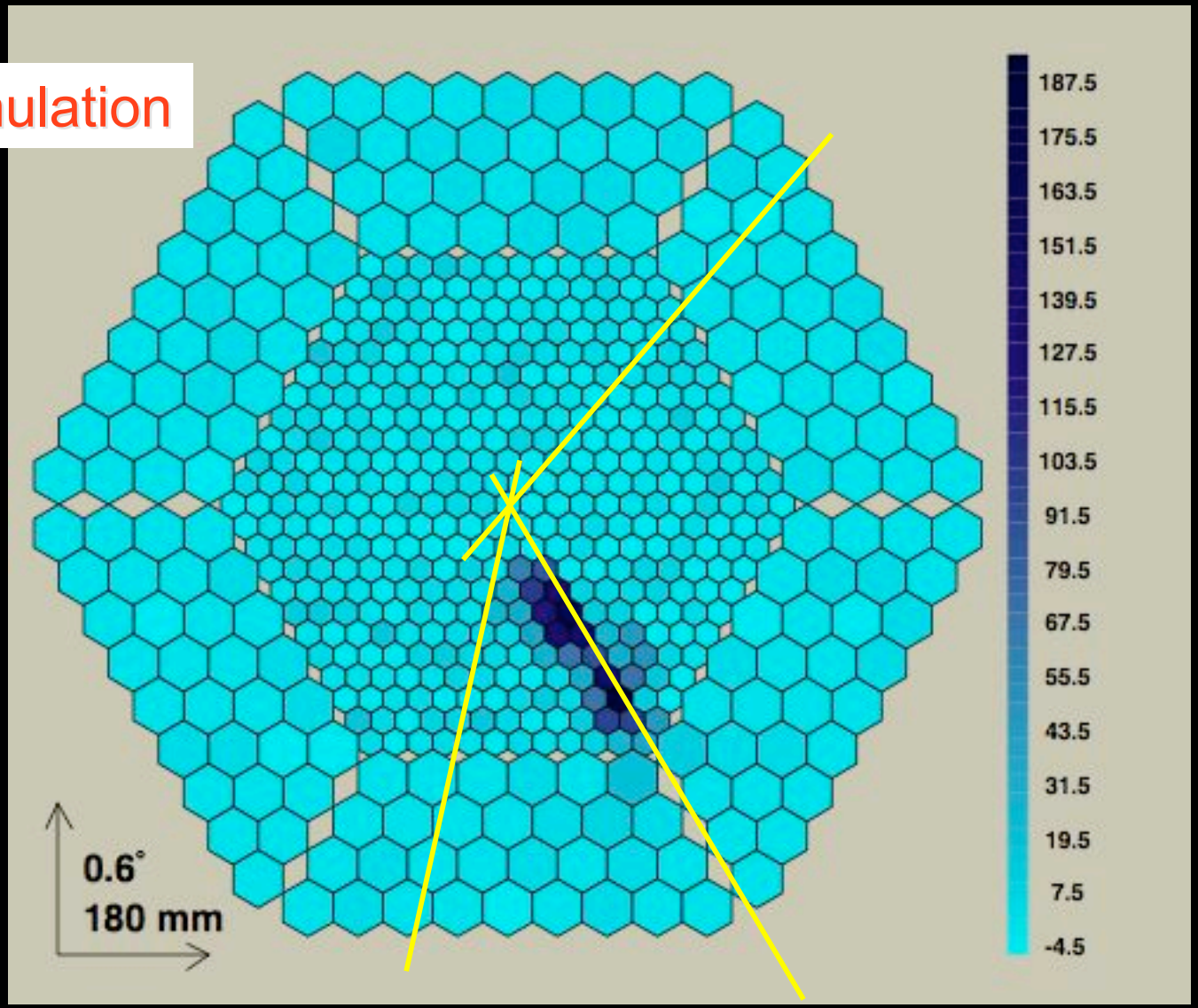
E = 76 GeV, b = 100 m

MC simulation



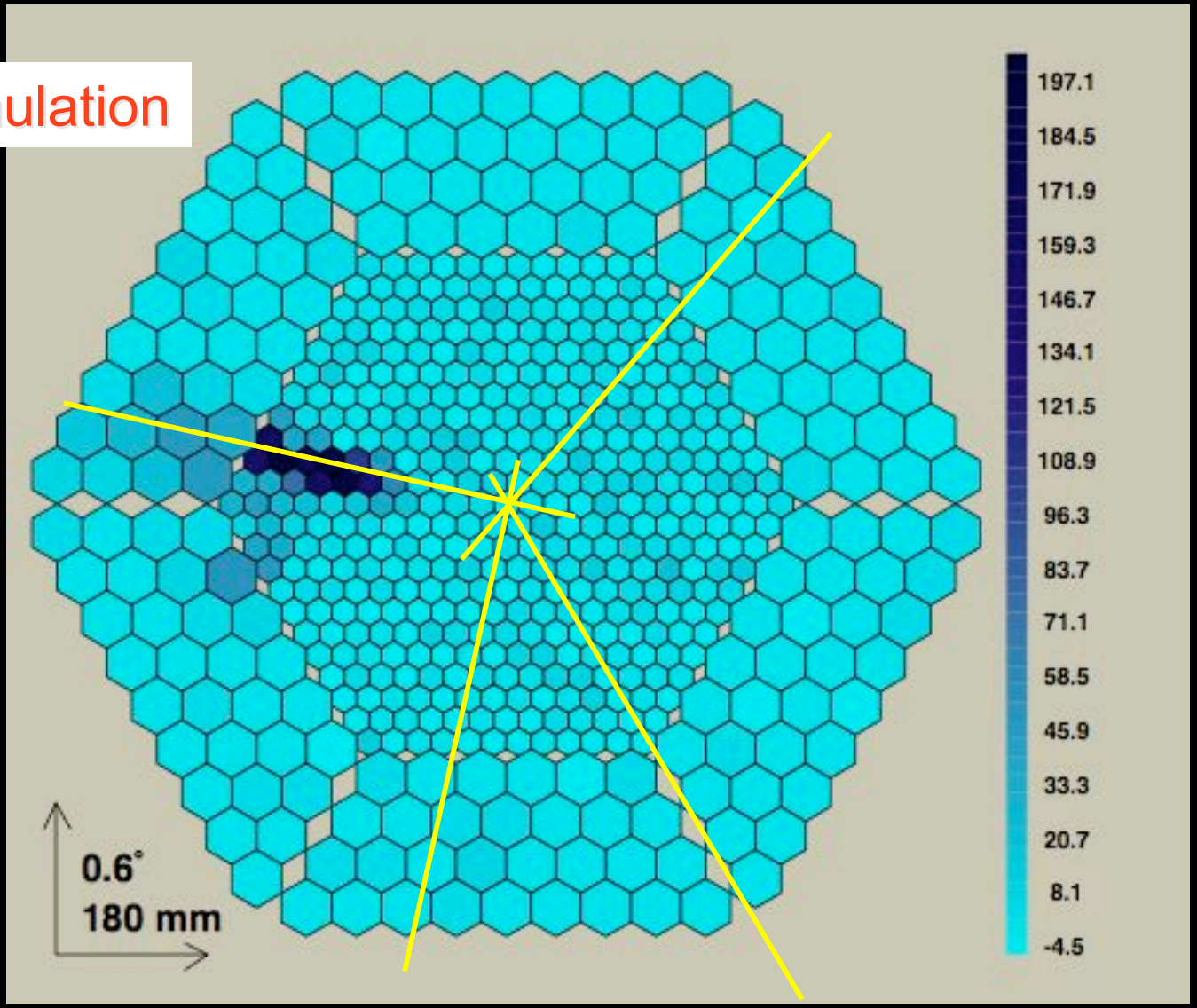
E =120 GeV, b = 107 m

MC simulation

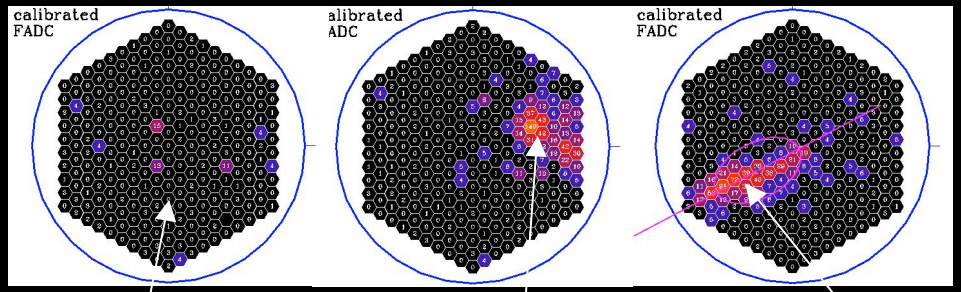


E =286 GeV, b = 119 m

MC simulation



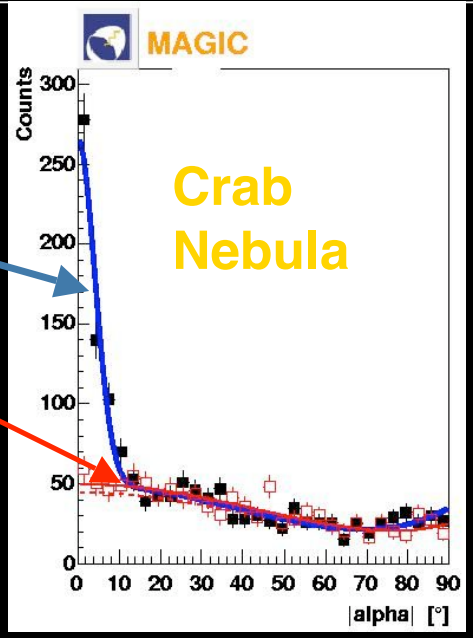
γ/HA Separation



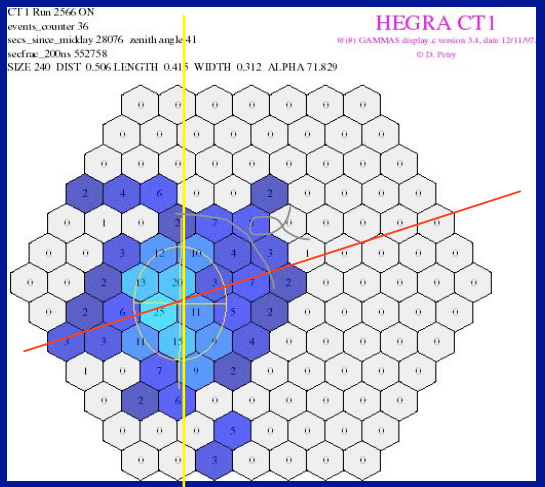
NSB event Hadronic shower Gamma shower

ON: Pointing to source

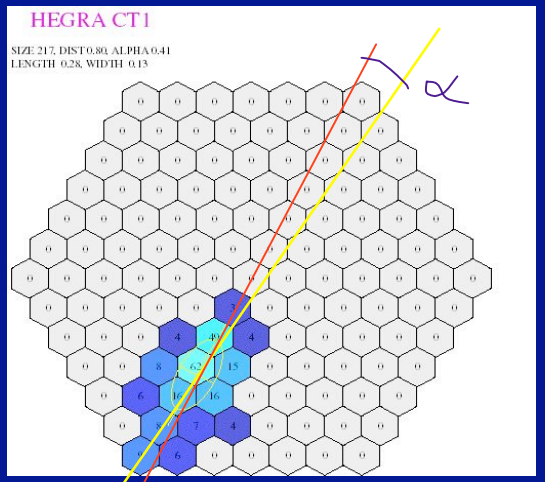
OFF: Pointing somewhere else



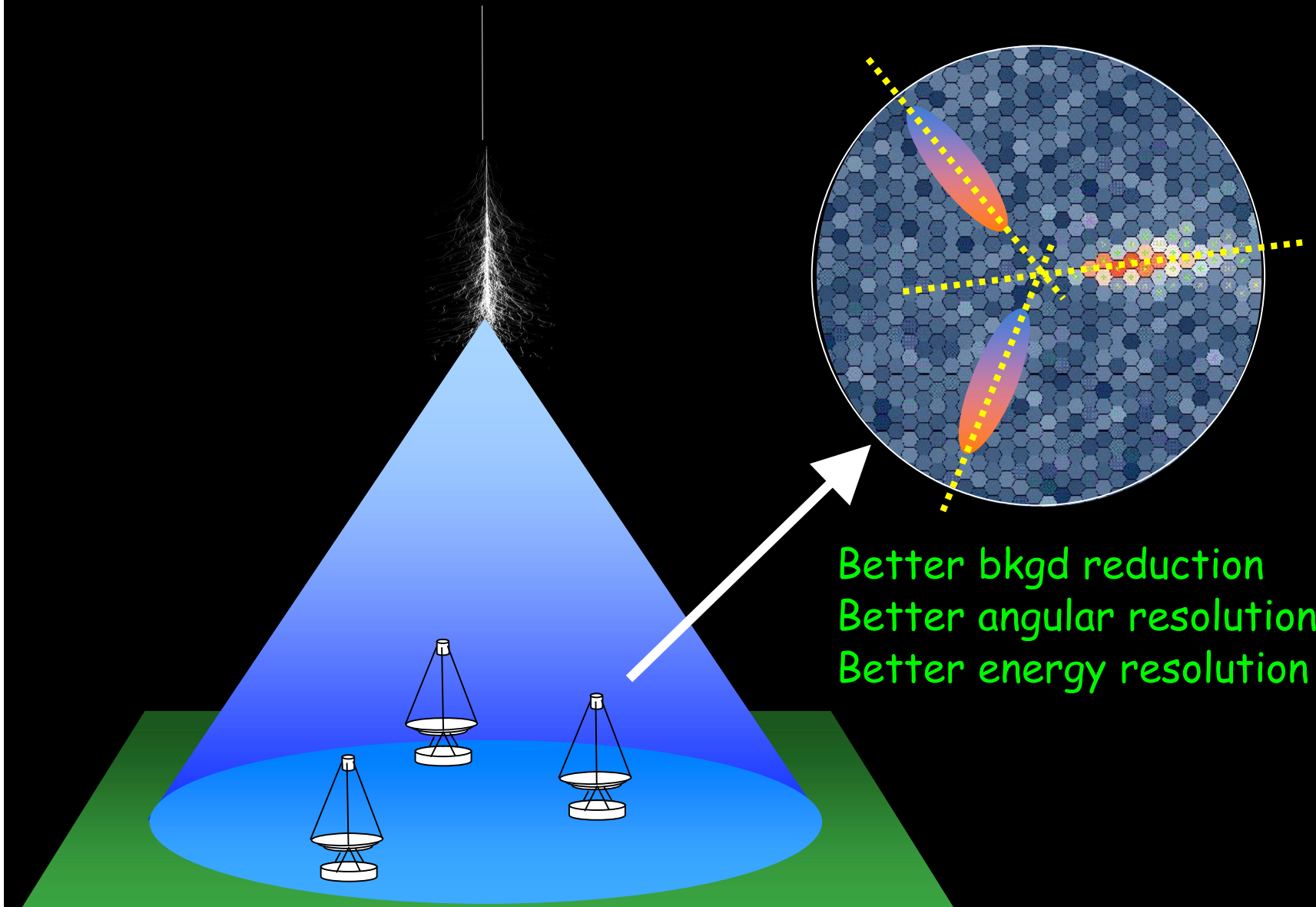
Proton shower



Gamma shower



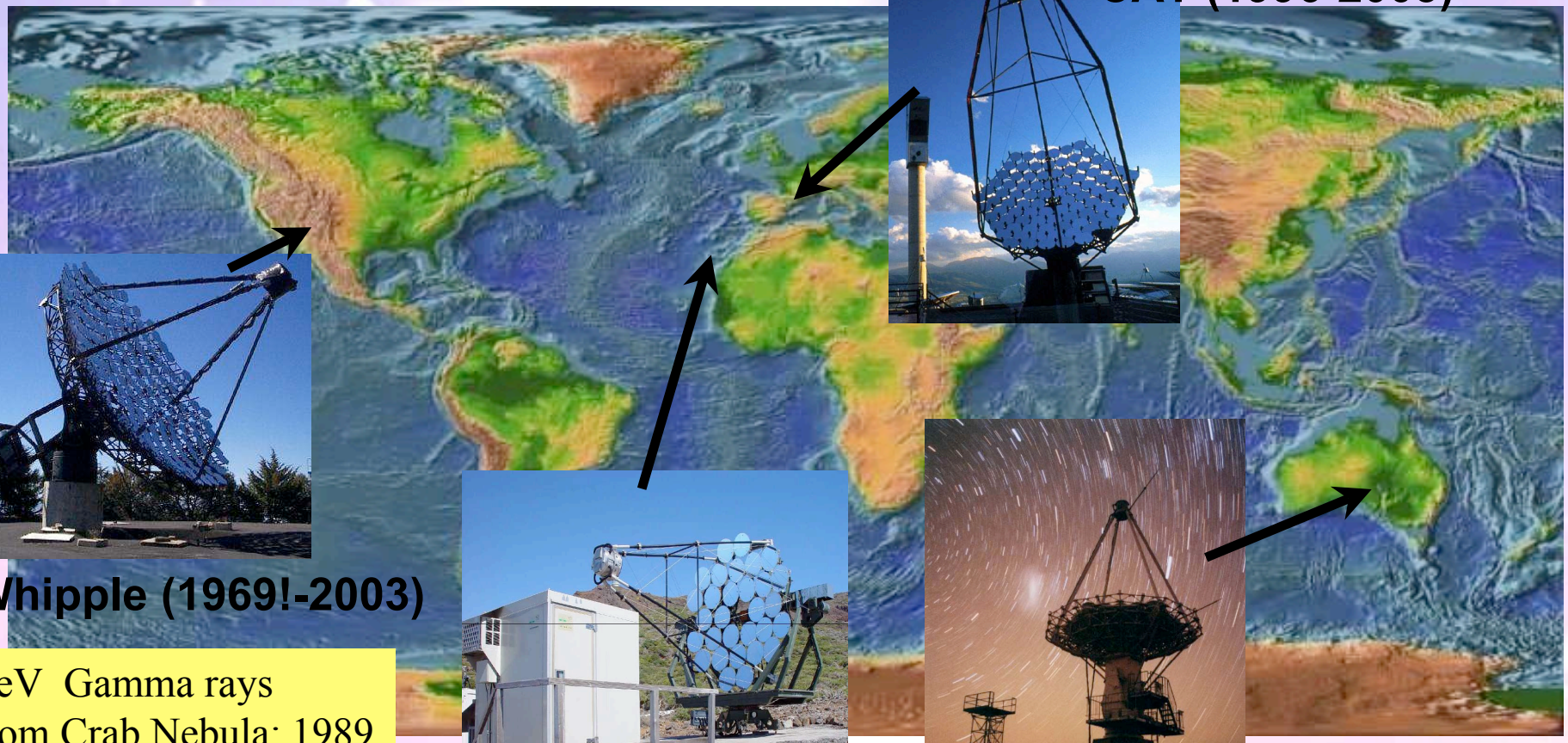
Systems of Cherenkov telescopes



Better bkgd reduction
Better angular resolution
Better energy resolution

Slide fro Pr W. Hofmann

First generation telescopes



CAT (1996-2003)

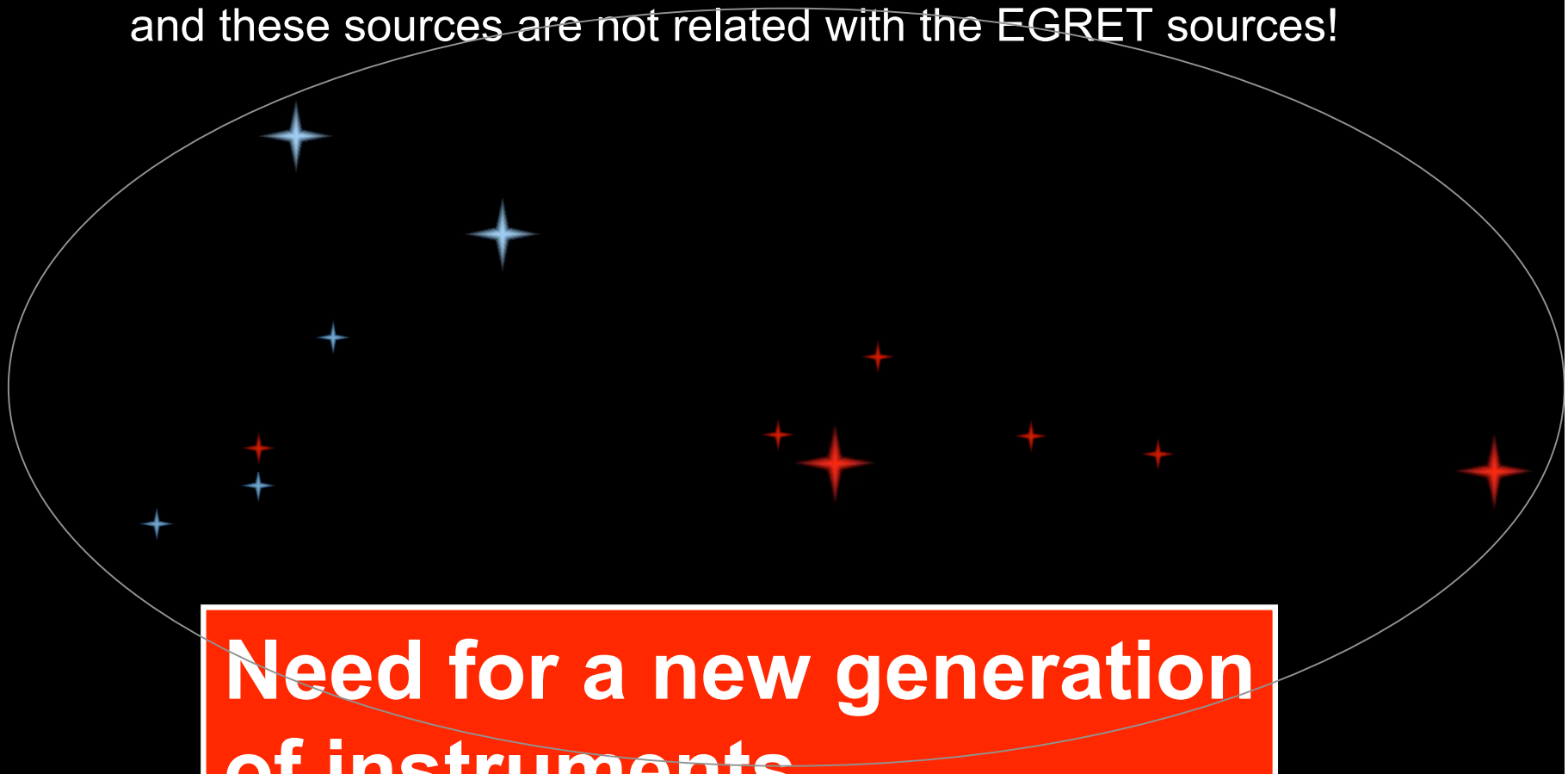
Whipple (1969!-2003)

TeV Gamma rays
from Crab Nebula: 1989

HEGRA (1993-2002)

CANGAROO (1992-2001)

Even if TeV instruments have much better sensitivities than EGRET, they've only detected this handful of sources... and these sources are not related with the EGRET sources!



Need for a new generation of instruments...

Towards a second generation:

- Reduce threshold: larger fluxes (power law spectra) -> larger Cherenkov light collector -> **large telescopes**

- Improve sensitivity: larger discovery potential -> better gamma-hadron separation -> **telescope arrays**

AND

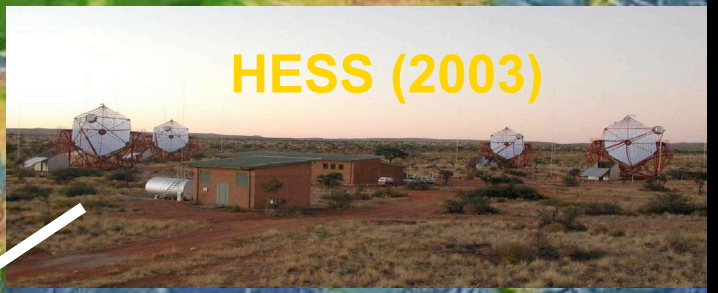
- wide-field camera: survey capability, serendipitous discoveries, source morphology studies (HESS: 5 degree FoV)

- isochronous mirror and fast digitization : possibility of using Cherenkov photon arrival time for gamma-hadron separation (MAGIC: sub-ns timing)

- light structure: fast GRB followup (MAGIC: <20s repositioning)

Second generation telescopes

MAGIC (2004)



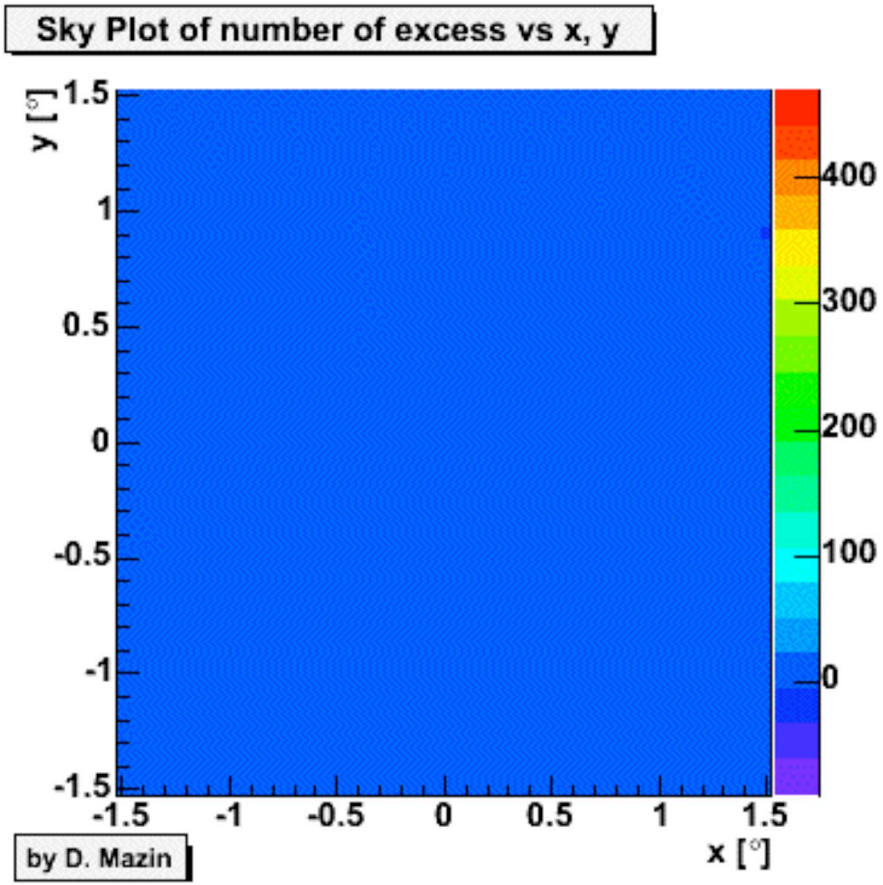
HESS (2003)

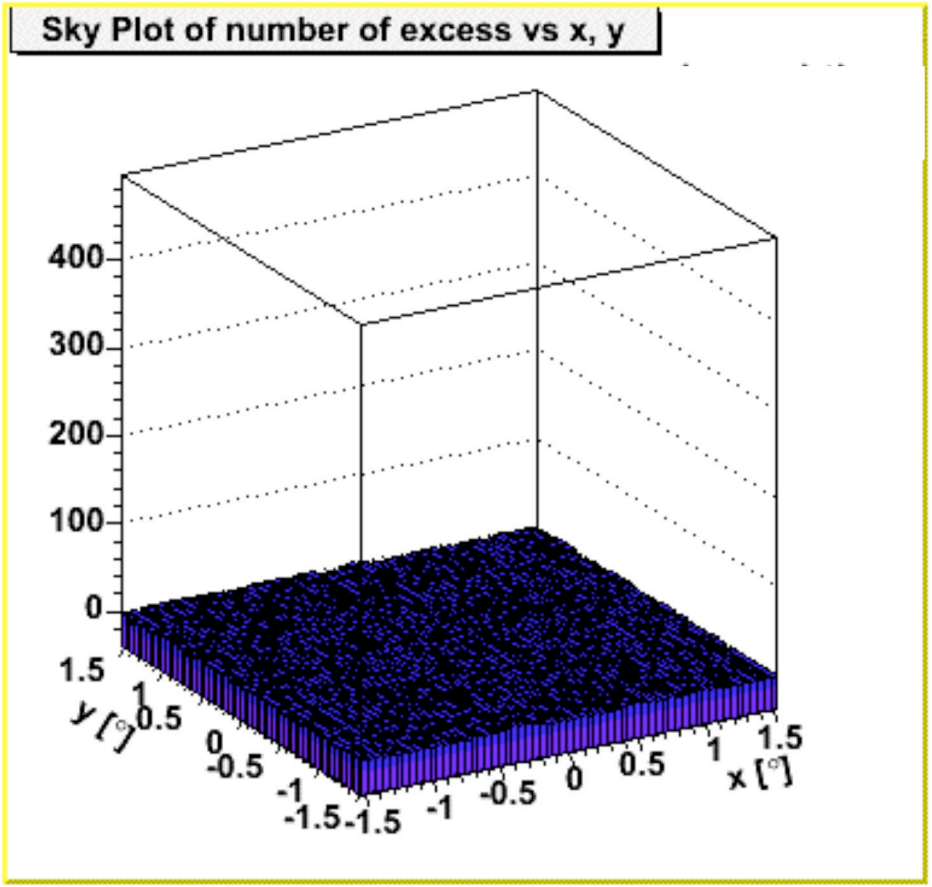
VERITAS (2006)

CANGAROO-III (2004)

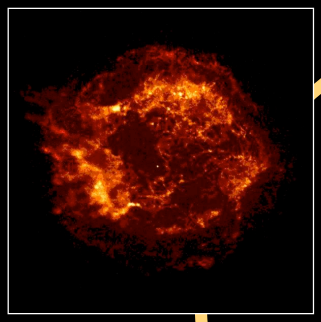
Crab signal in 1 hour of MAGIC data

Gamma ray event rate ~1Hz
After hadron rejection ~0.5Hz
For Crab ~20 σ / hr$^{1/2}$



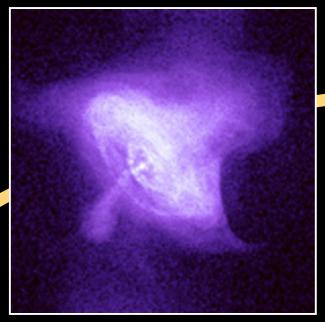


The Physics Program for HE-VHE γ–ray astronomy

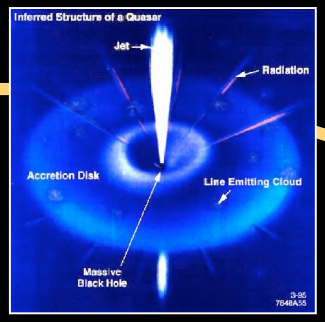


SNRs

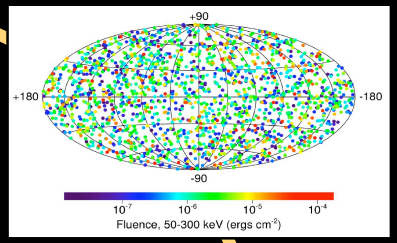
Origin of Cosmic Rays



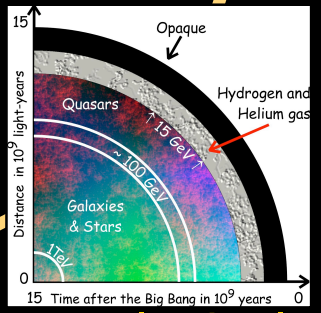
Pulsars



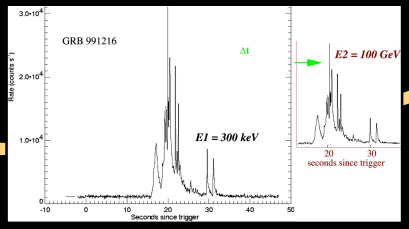
AGNs



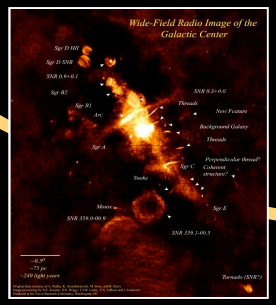
GRBs



cosmological γ-Ray Horizon



Quantum Gravity effects



Cold Dark Matter

Scientific Highlights (Feb.2006)

Galactic observations:

I. Discovery of many new Galactic sources by HESS:

- ***HESS GP Survey* & *targeted observations.***

II. Detailed studies of Galactic sources by HESS:

- ***Precision measurements (spectra, morphology, etc.).***
- ***Theoretical models and understanding.***

III. Discovery of new classes of VHE gamma-ray emitters by HESS:

- ***First variable galactic source: Binary pulsar (B1259-63)***
- ***Microquasar (LS 5039)***

IV. Detailed study of the Galactic Center by HESS and MAGIC:

- ***Search for DM annihilation signal***
- ***Morpholigical studies of digffuse Gamma emission after subtractions of localized sources (HESS)***

Scientific Highlights (Feb.2006)

Extragalactic observations:

V. Discovery of 6 new AGN by HESS and MAGIC:

- *Measurements of AGN properties and multi-λ studies.*
- *Constraints on cosmological EBL density from absorption spectrum.*

VI. Observation of AGN with orphan flares by MAGIC:

- *Connexion to neutrino and UHECR astronomy ?.*

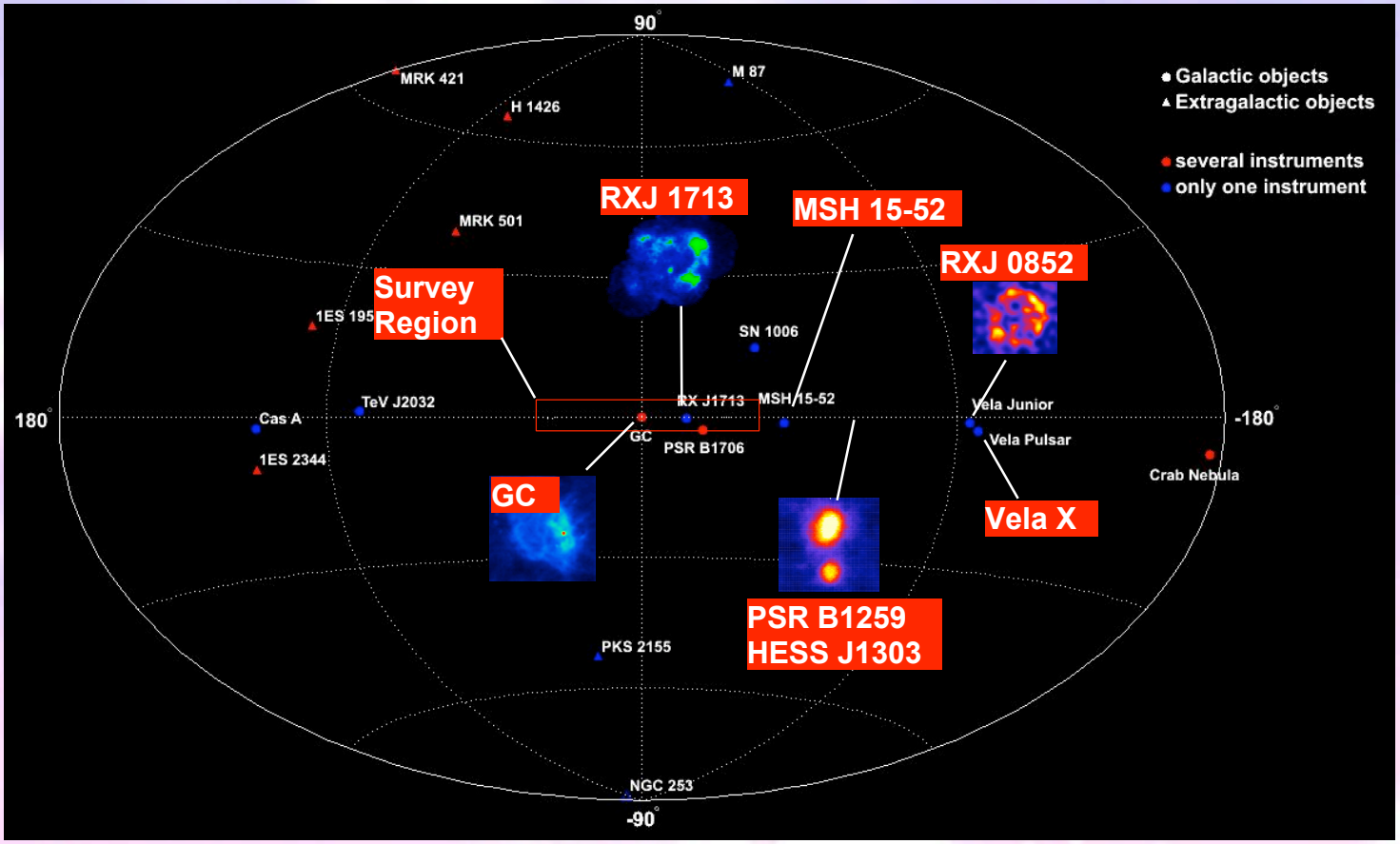
VII. High time-resolution study of AGN flares by MAGIC:

- *New constraints on emission mechanisms and light speed dispersion relations.*

VIII. Prompt GRB follow-up by MAGIC:

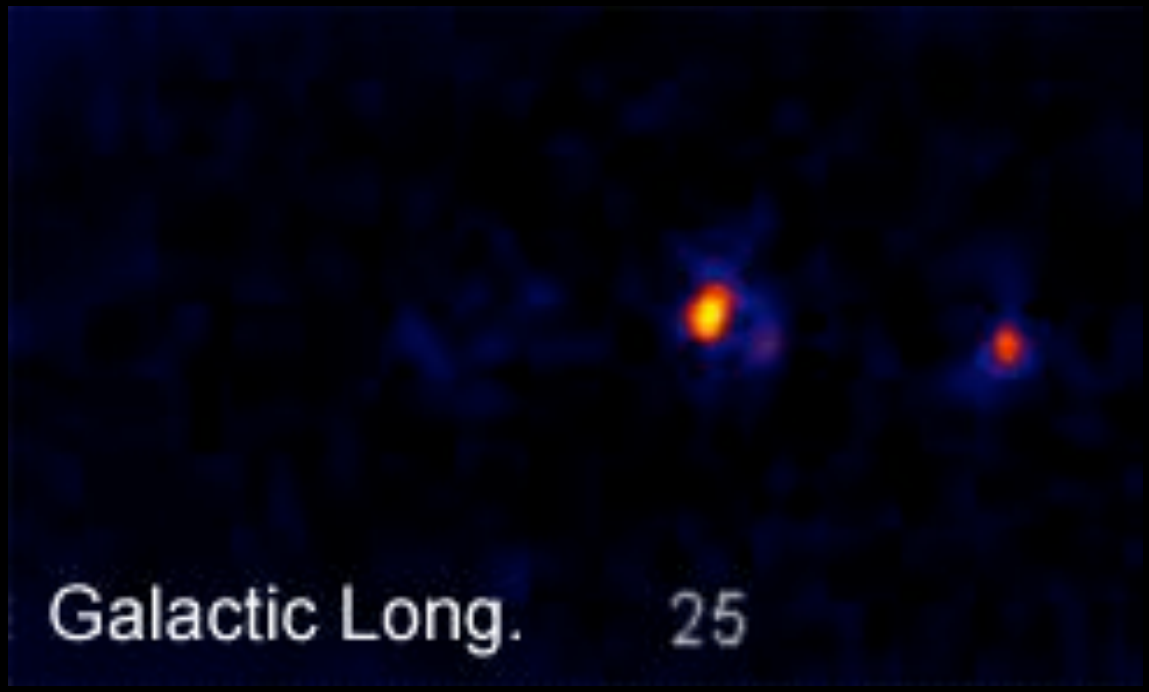
- *GRB follow-up in coincidence with observation in the X-ray domain.*

HESS Galactic Plane Survey



- ***60° in longitude,*** ± 3° in latitude
- 112 hrs scanning + follow-up observations

H.E.S.S. Highlight: Galactic Plane Survey



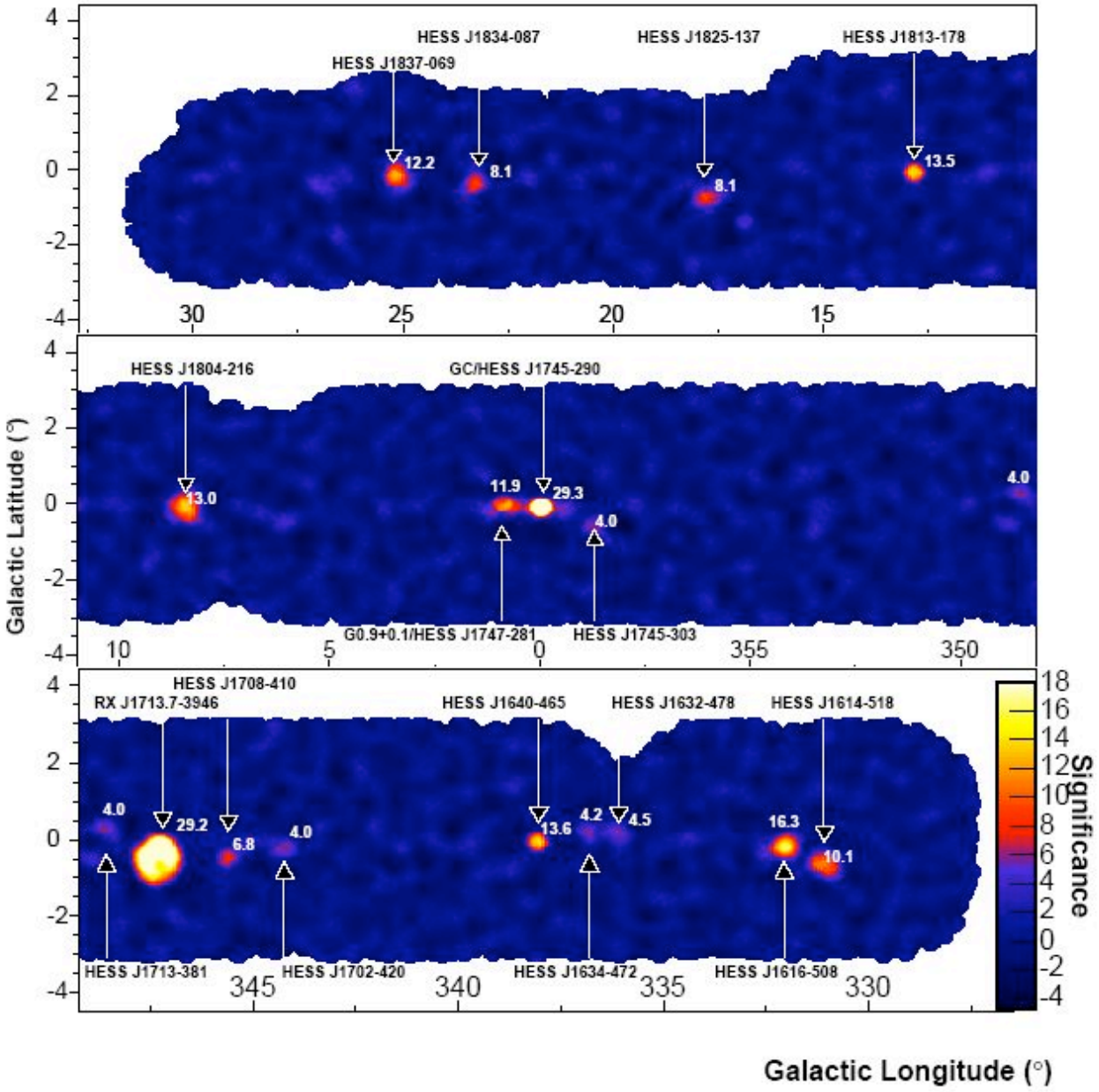
HESS Galactic Plane Survey

Sources > 6 sigma:
9 new, 11 total

Sources > 4 sigma:
7 new

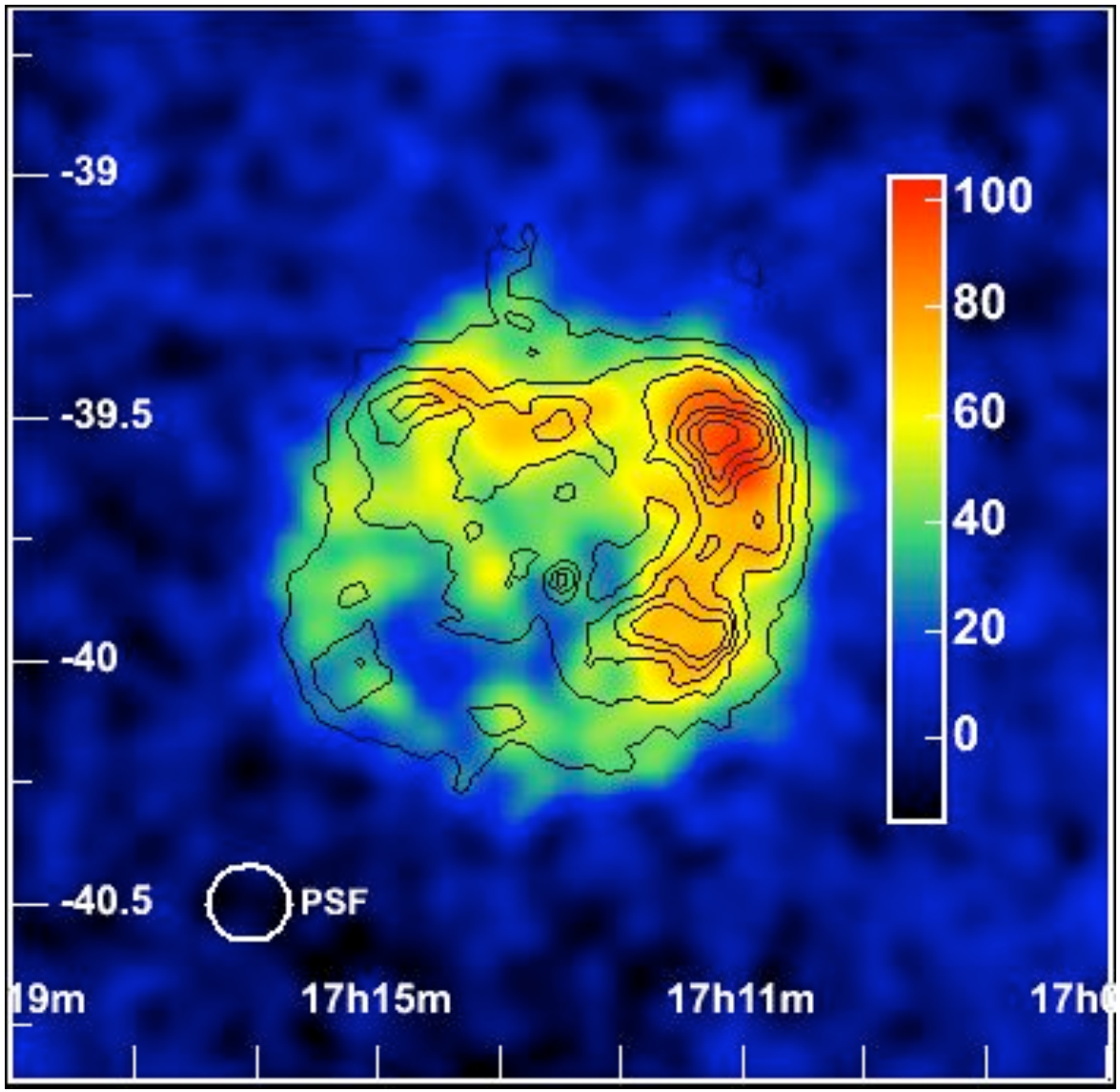
Most sources:

- Shell-type SNR
- Pulsar-Wind-Nebulae
- Unidentified
- New objects

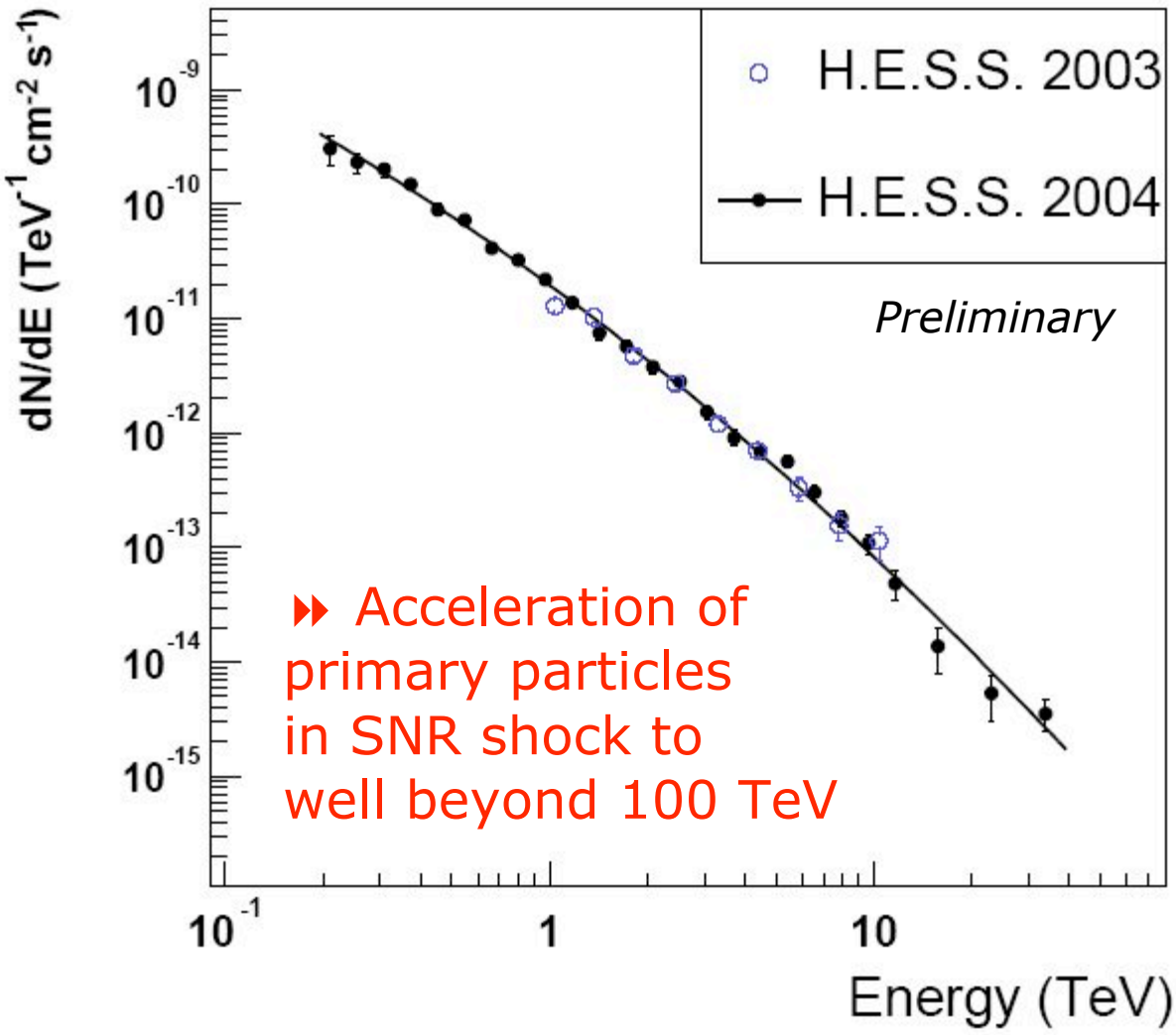


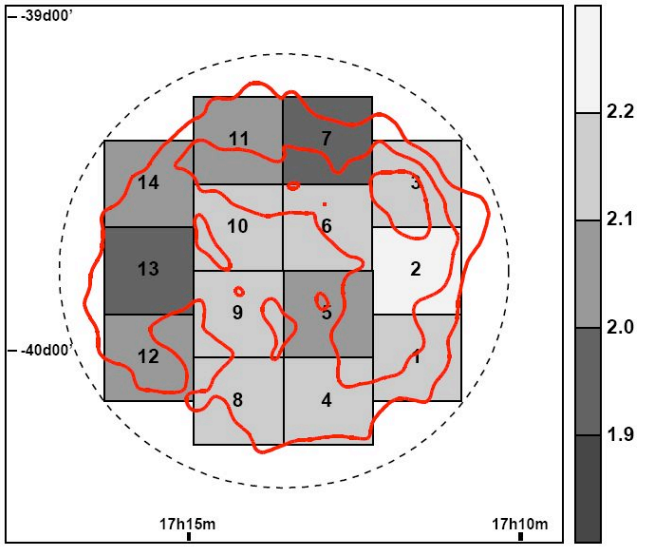
H.E.S.S. Highlight: Resolved Supernova-Remnants

RX J1713-3946



Spectra

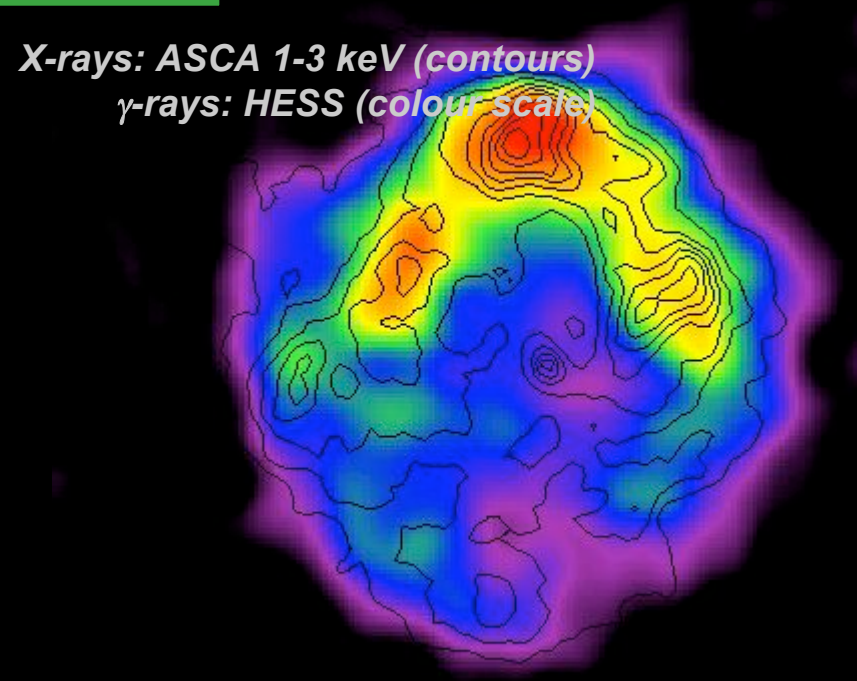


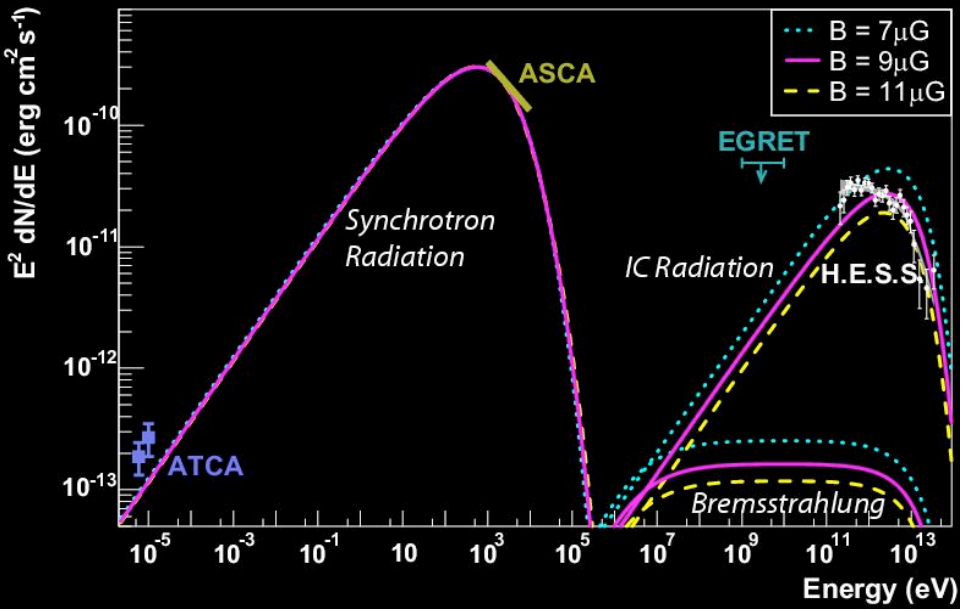


- Index ~ 2.1 – 2.2
- Little variation across SNR
- No evidence of cutoff or break at high energy

The SNR RX J1713.7-3946

- Unambiguous evidence for particle acceleration in an SNR shell
  - Resolved shell in VHE γ-rays
  - Close correlation between X-rays and γ-rays - could the VHE emission be IC?
    - Hard to explain spectral shape and implied B-field is low...





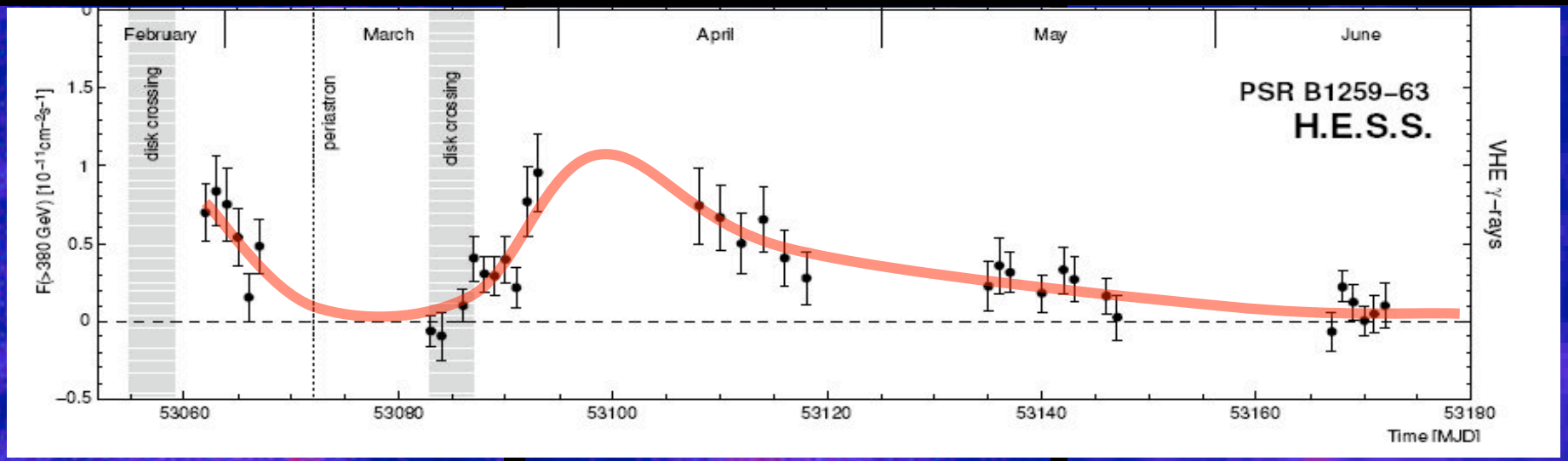
What are they ?

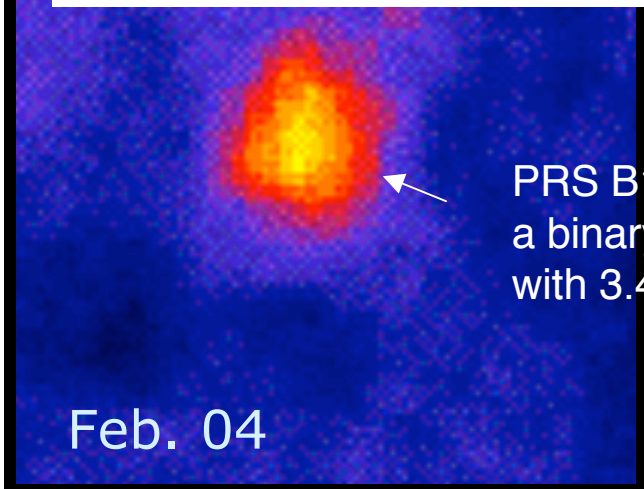
Source	Possible Association	Comments
G0.9+0.1	PWN/SNR	Firm Association
LS 5039	Micro-Quasar	Firm Association
J1616-508	PWN ?	Tentative
J1614-518		Unid ?
J1640-465	SNR ? (G338.3)	Tentative
J1804-216		Unid ?
J1813-178	SNR ? (G12.8-0.0, Integral)	Tentative
J1825-137	PWN ? (PSR J1826)	Tentative
J1834-087	SNR ? (G23.3)	Tentative
J1837-069	(Integral)	Unid ?

Study spatial association and correlation with HI/CO map.

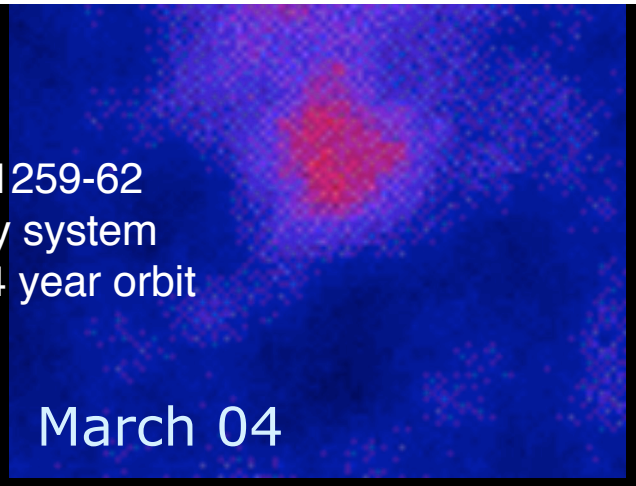
Mysterious “dark accelerators”

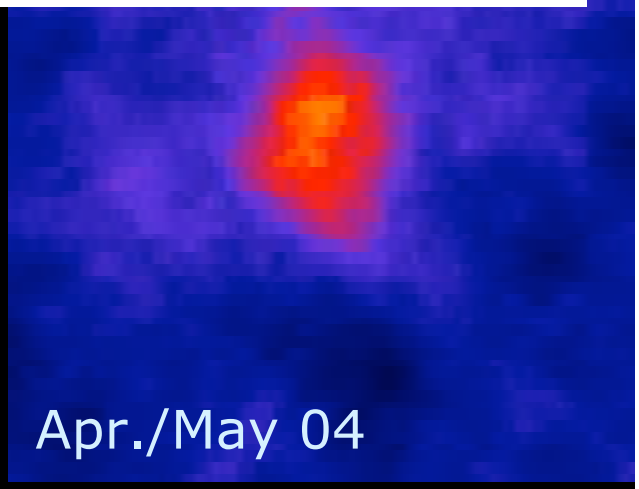
first variable galactic TeV source





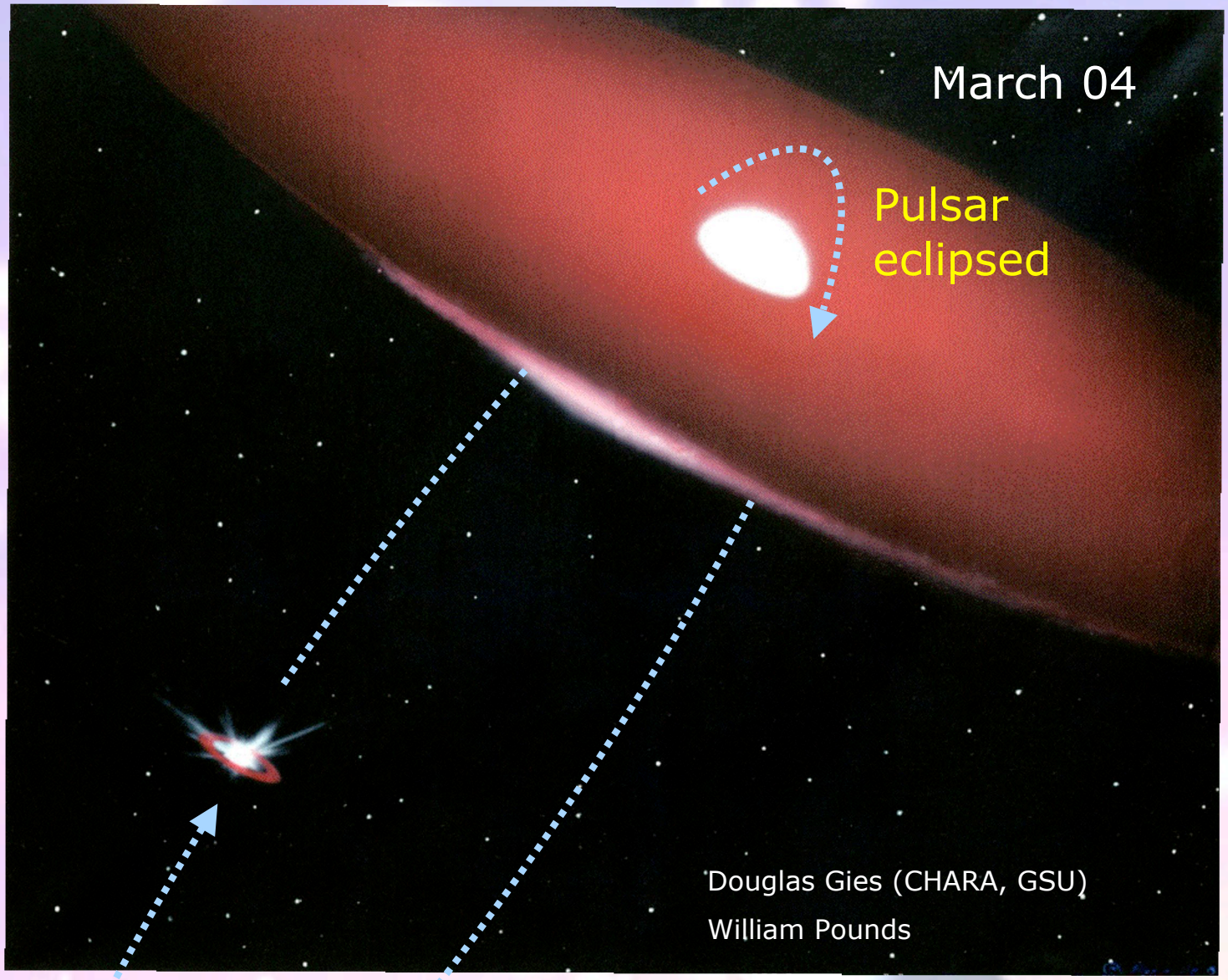
PRS B1259-62
a binary system
with 3.4 year orbit





PSR B1259-63:

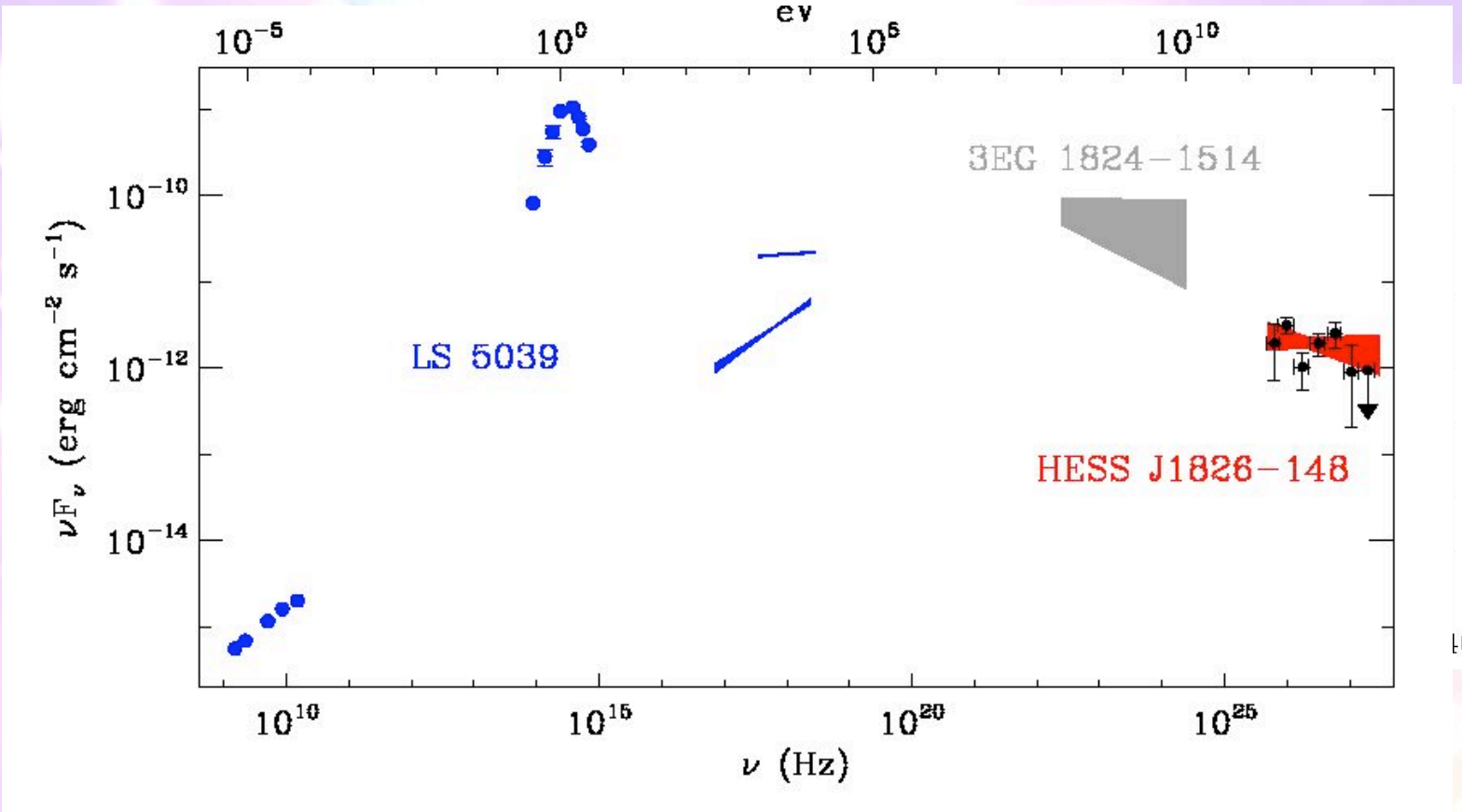
3.4 year highly eccentric orbit around ~10 $M_\odot$ star closest approach ~20 stellar radii (Kirk)



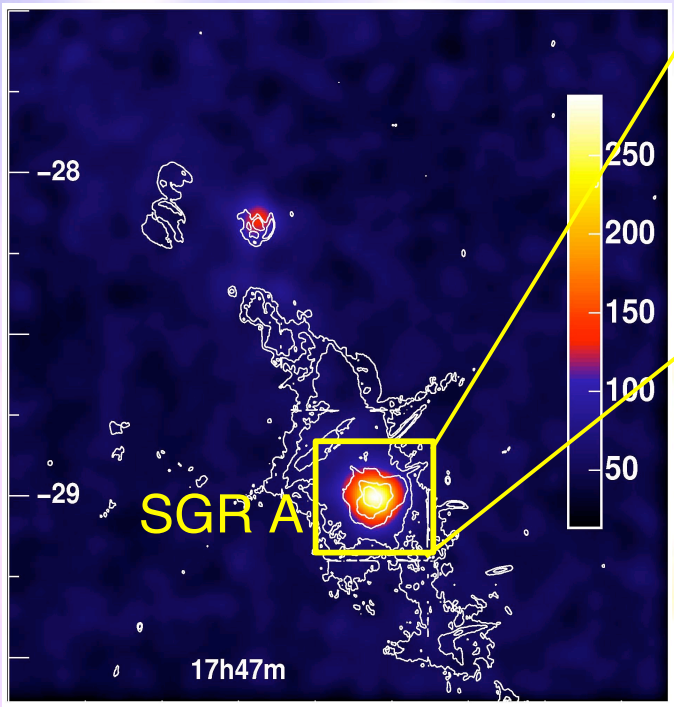
Microquasar LS 5039

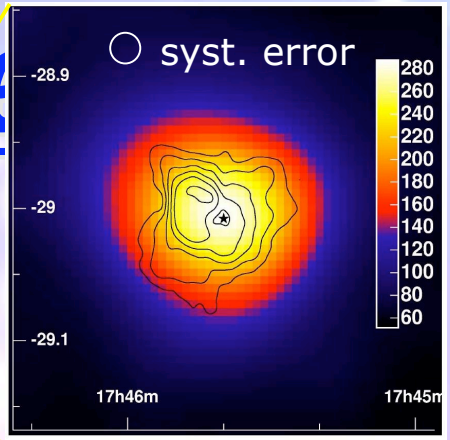
first detection of TeV emission from a microquasar

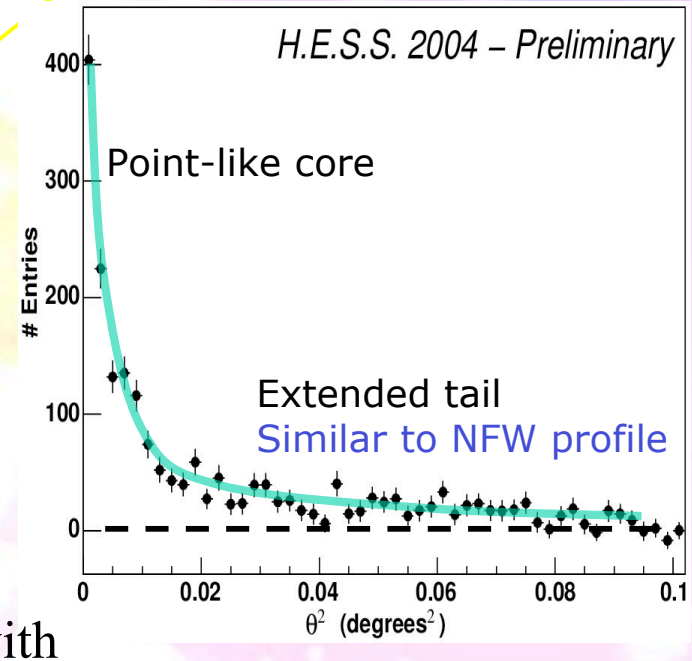
- compact ~ 4 $M_\odot$ object in eccentric 4 day orbit around 20-30 $M_\odot$ star
- closest approach ~2 stellar radii
- fueled by wind accretion (?)



Galactic Cente



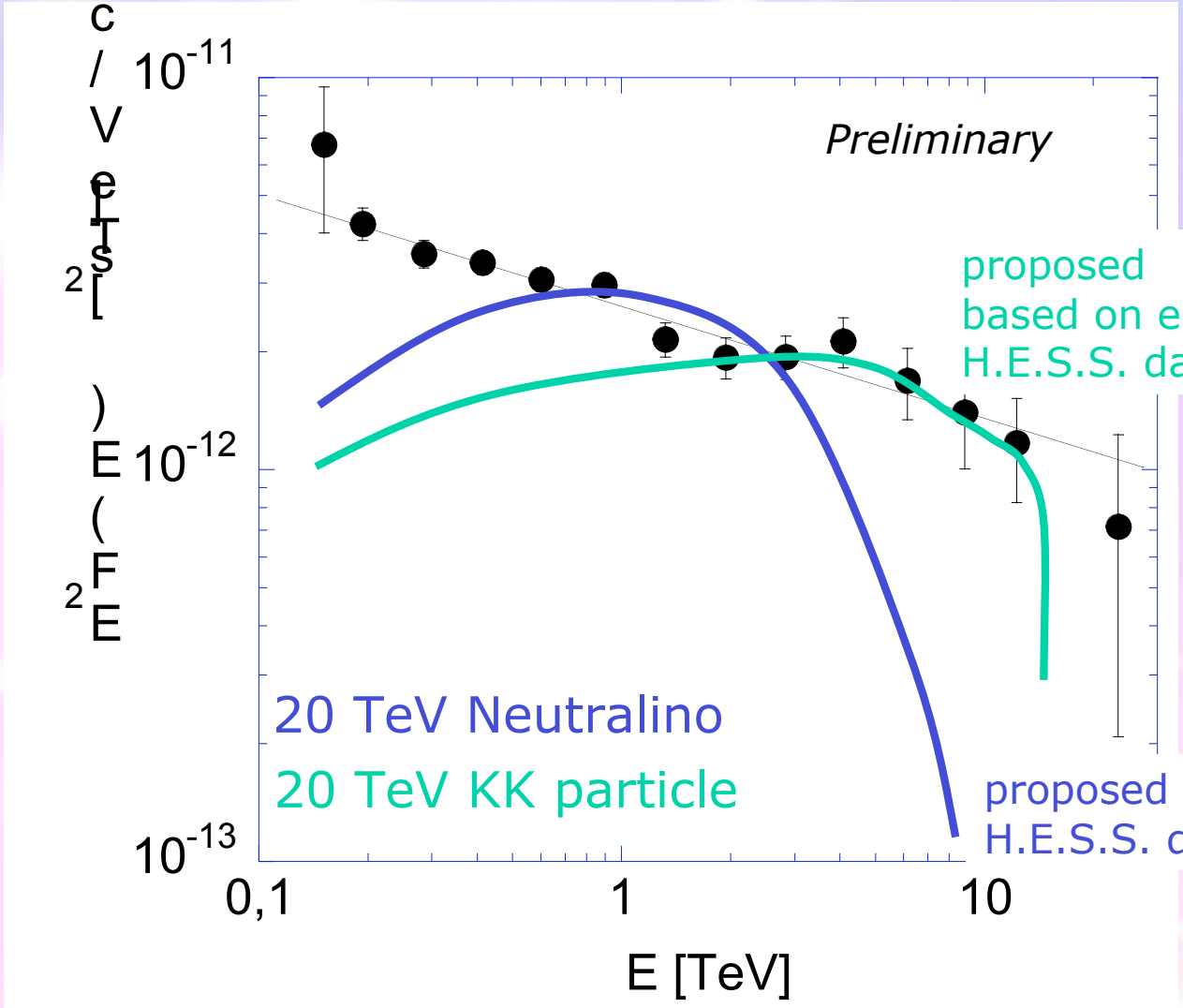




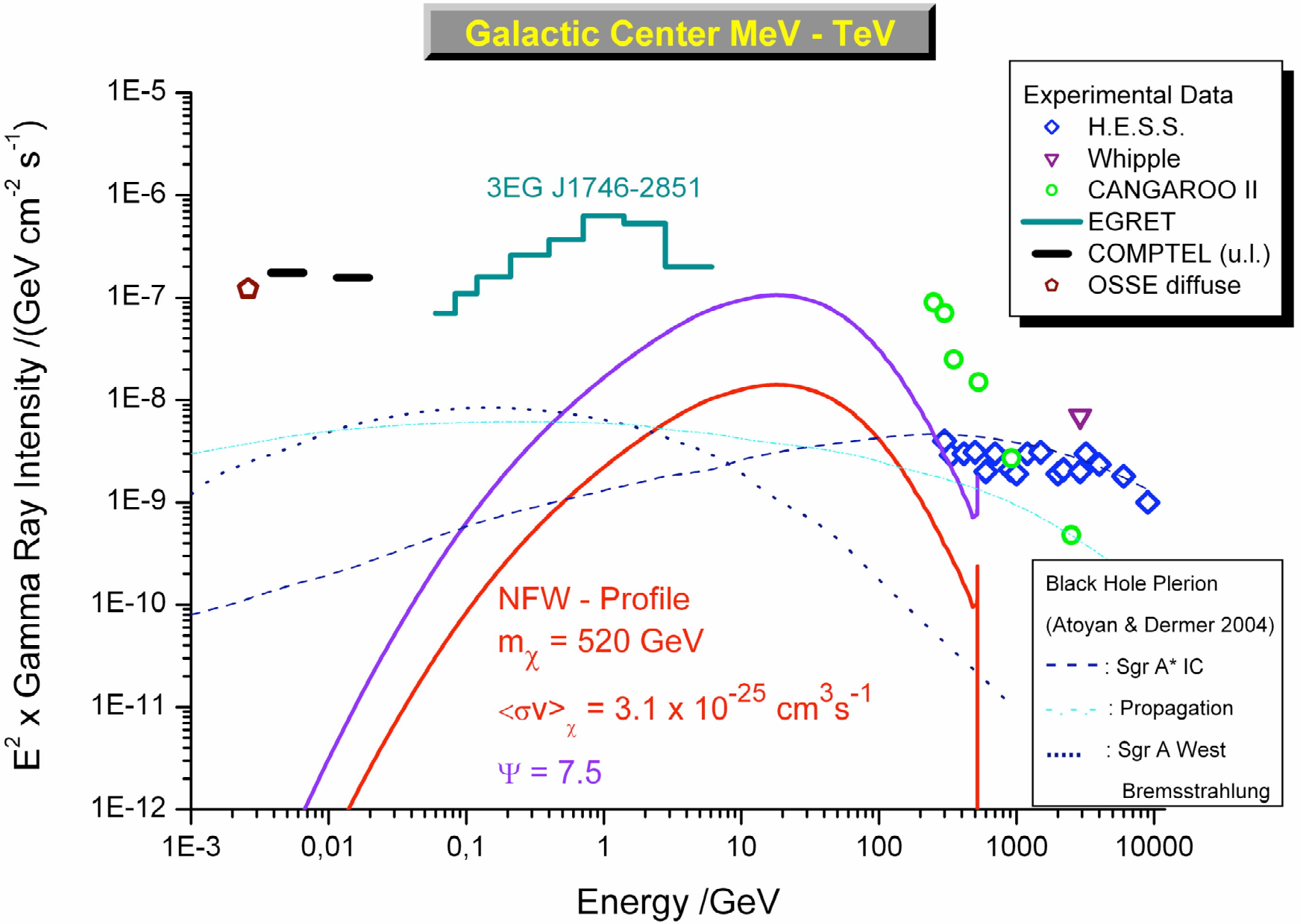
-> Consistent with SGR A* to 6'' and slightly extended.

-> No significant variability from year to minute scales (in ~40 h obs. time distributed over 2 years)

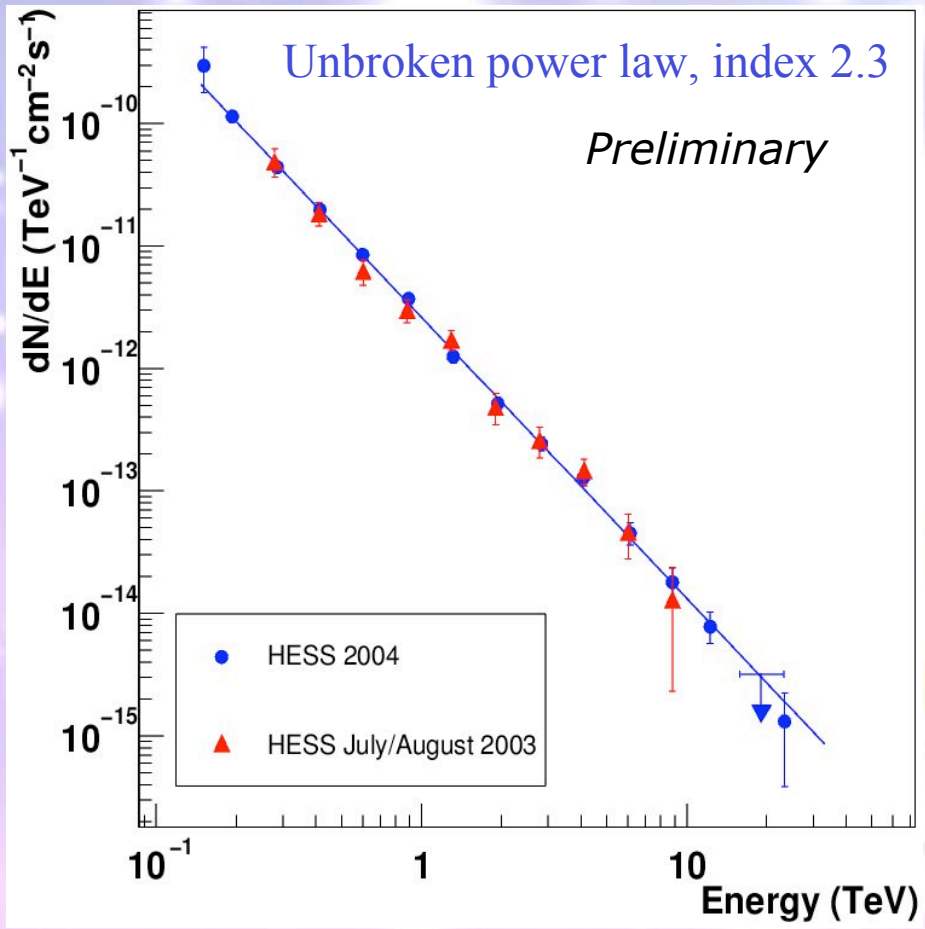
Dark matter annihilation ?



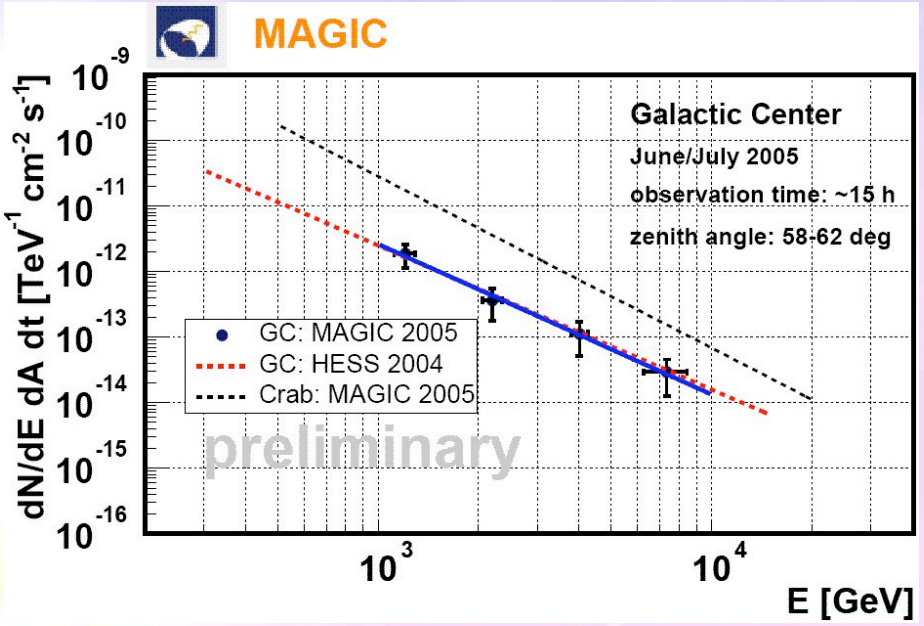
- J. Ripken ICRC 2005


Galactic Center MeV - TeV
Experimental Data
H.E.S.S.
Whipple
CANGAROO II
EGRET
COMPTEL (u.l.)
OSSE diffuse
3EG J1746-2851
NFW - Profile
m_χ = 520 GeV
$\langle\sigma v\rangle_\chi$ = 3.1 x 10^{-25} $cm^3 s^{-1}$
Ψ = 7.5
Black Hole Plerion
(Atoyan & Dermer 2004)
: Sgr A* IC
: Propagation
: Sgr A West
Bremsstrahlung
E^2 x Gamma Ray Intensity /(GeV cm^{-2} s^{-1})
1E-5
1E-6
1E-7
1E-8
1E-9
1E-10
1E-11
1E-12
1E-3
0,01
0,1
1
10
100
1000
10000
Energy /GeV

Gamma ray spectrum



Preliminary



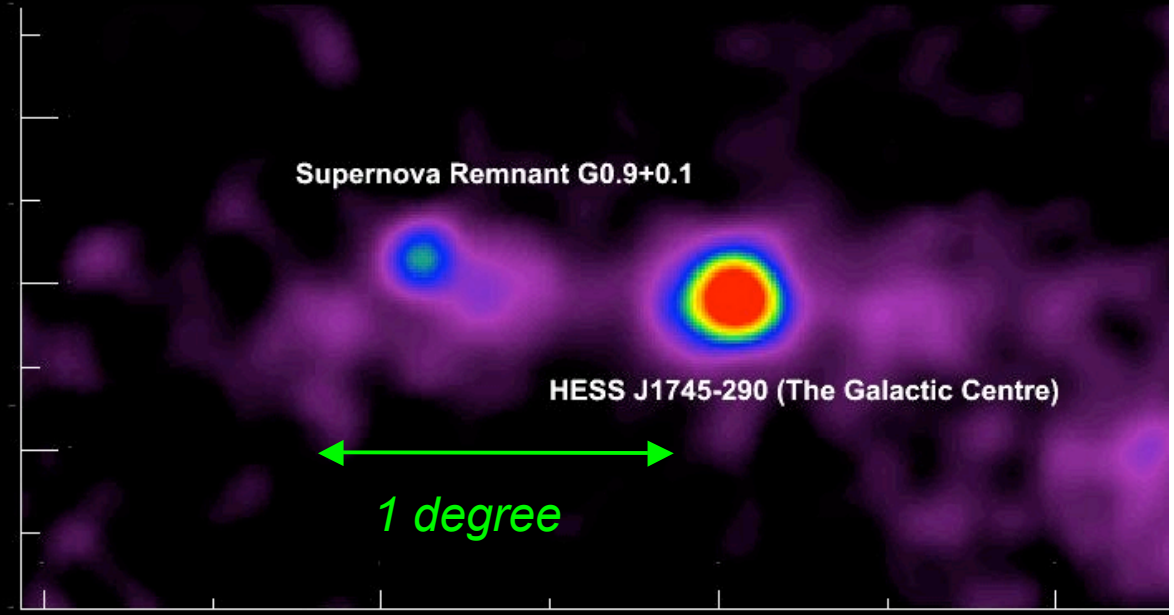
Good agreement between HESS and MAGIC (large zenith angle observation).

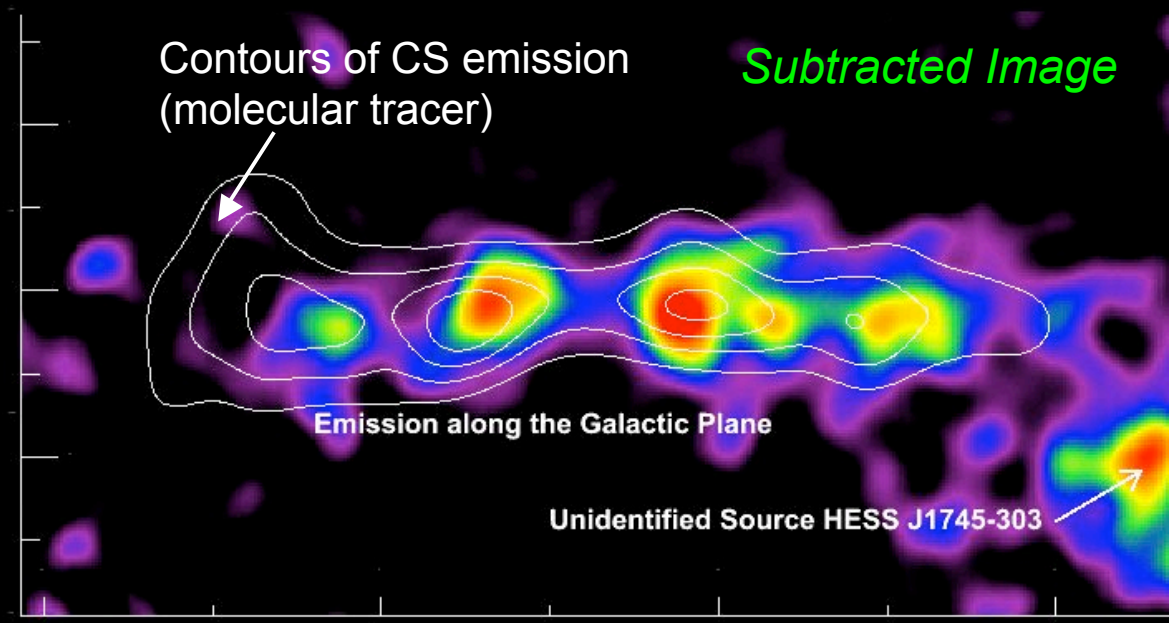
⇒Very unlikely to be dark matter.

⇒Presence of a strong gamma-ray source outshines any possible DM signal -> more detailed studies on the way…

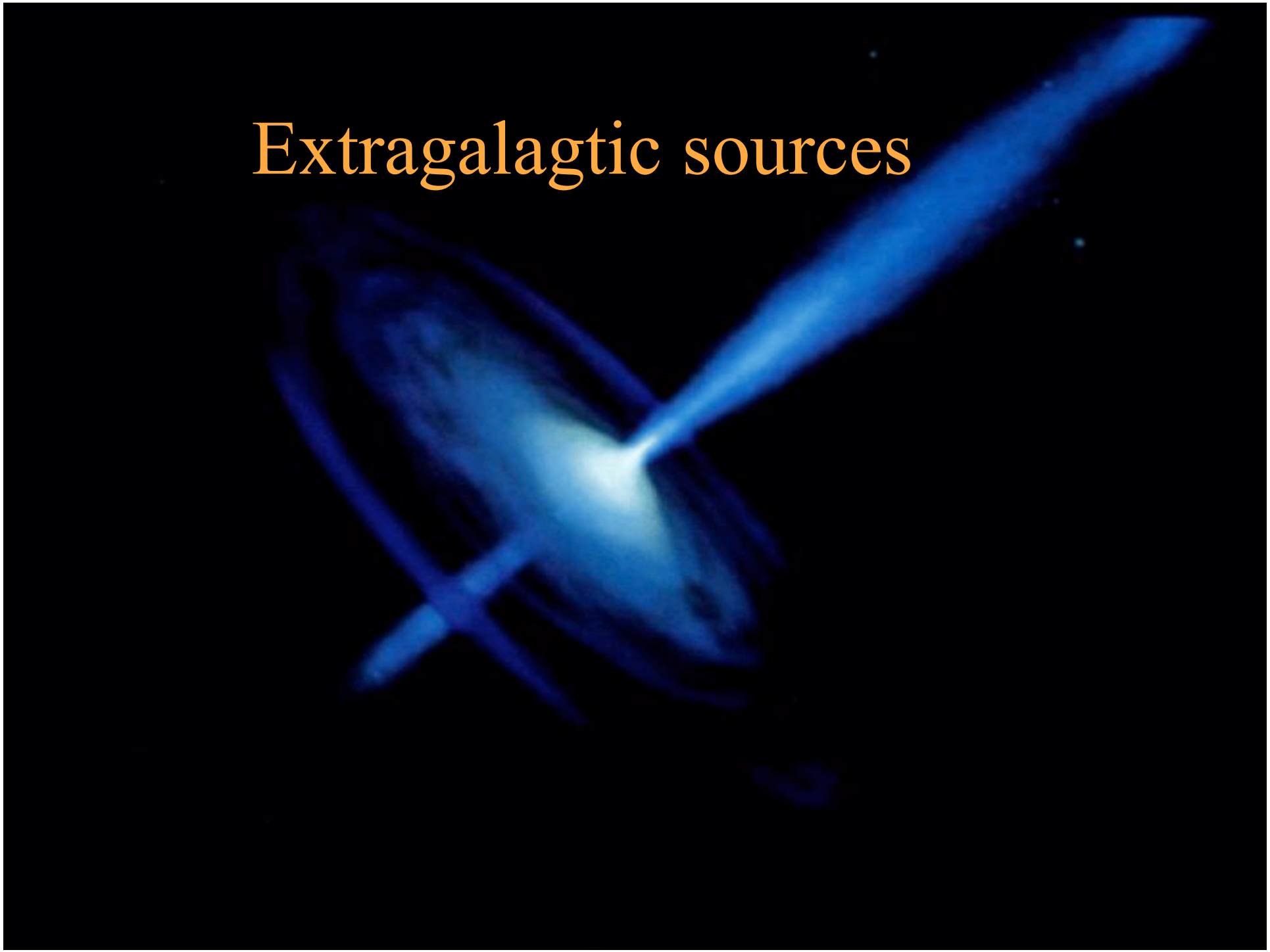
The Galactic Centrer

- Source coincident with supermassive black hole Sgr A*
- ***Diffuse Emission***
  - Emission along the plane is revealed by subtraction of strong sources...
  - Correlation with molecular material
    - Cosmic rays interacting with molecular clouds
  - Nature, Feb. 9th 2006



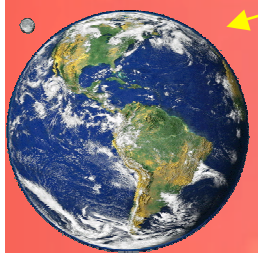


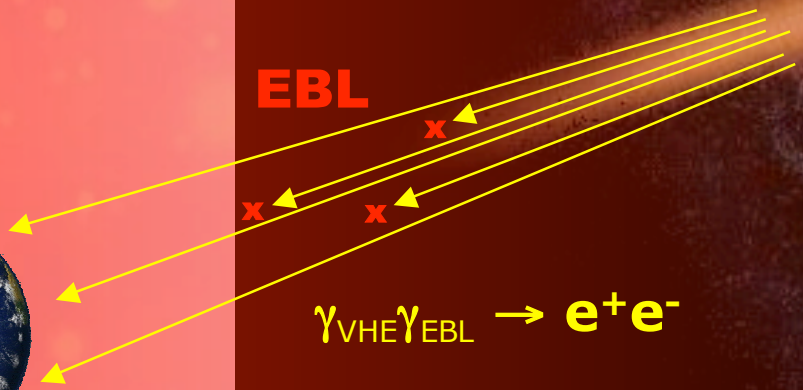
Extragalagtic sources



Extragalactic VHE γ astronomy

- Physics of AGN jets
- Density of cosmological extragalactic background light (EBL)

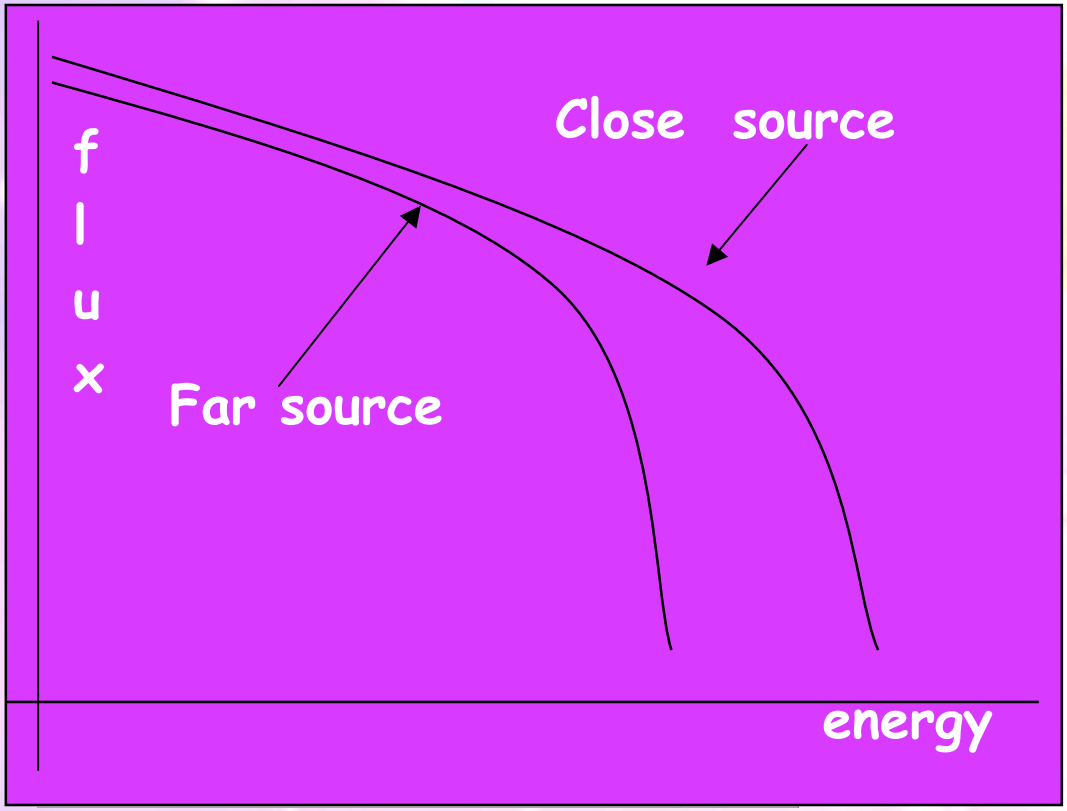


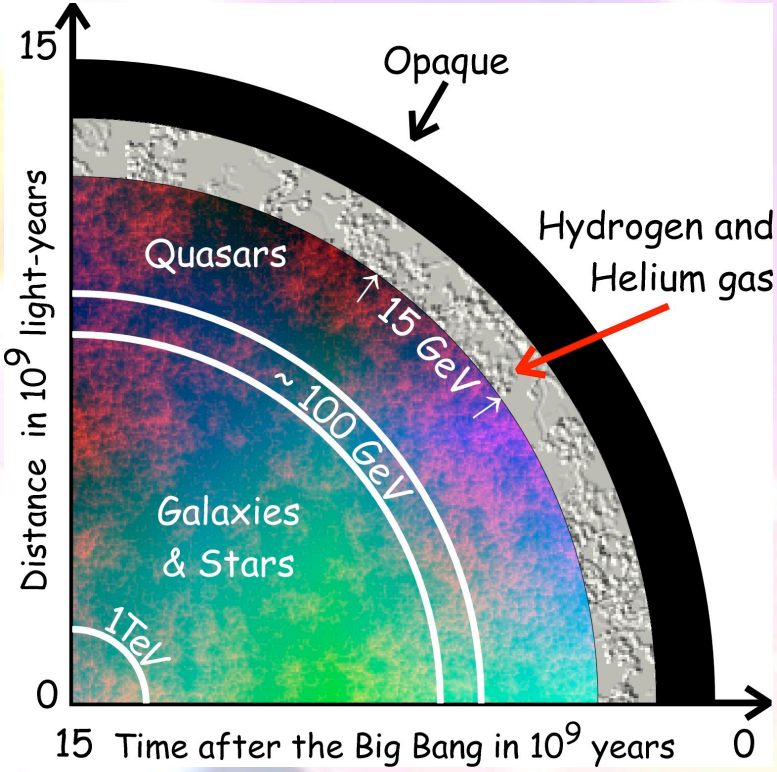


Optical Depth & GRH

Any γ that crosses cosmological distances through the universe **interacts with the E**xtragalactic **B**ackground **L**ight.

$$\gamma_{HE}\,\gamma_{EBL} \rightarrow e^{+}\,e^{-}$$





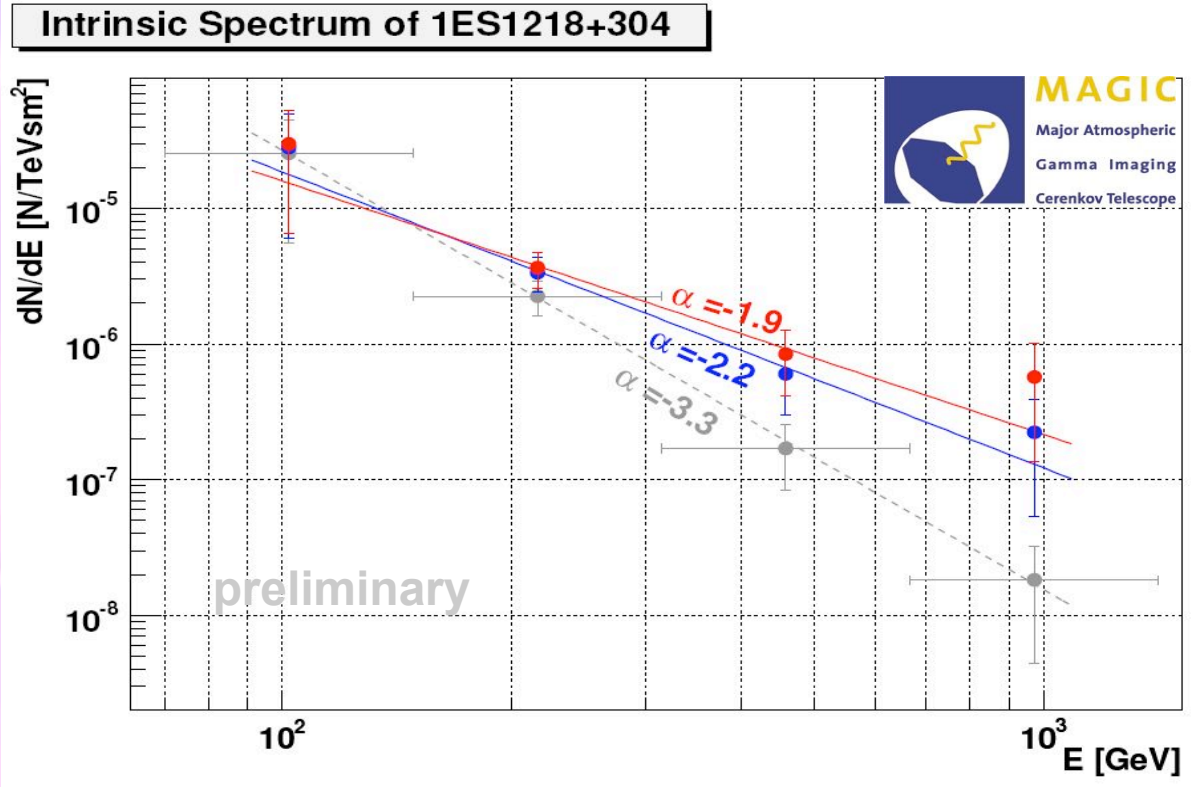
Extragalactic sources: AGN Summary

Source	Redshift	Type	First Detection	Confimation
M87	0.004	FR I	HEGRA	HESS
Mkn 421	0.031	BL Lac	Whipple	Many
Mkn 501	0.034	BL Lac	Whipple	Many
1ES 2344+514	0.044	BL Lac	Whipple	HEGRA
1ES 1959+650	0.047	BL Lac	Tel. Array	Many
PKS 2005-489	0.071	BL Lac	HESS	
PKS 2155-304	0.116	BL Lac	Mark VI	HESS
H1426+428	0.129	BL Lac	Whipple	Many
H2356-309	0.165	BL Lac	HESS	
1ES 1218+304	0.182	BL Lac	MAGIC	
1ES 1101-232	0.186	BL Lac	HESS	

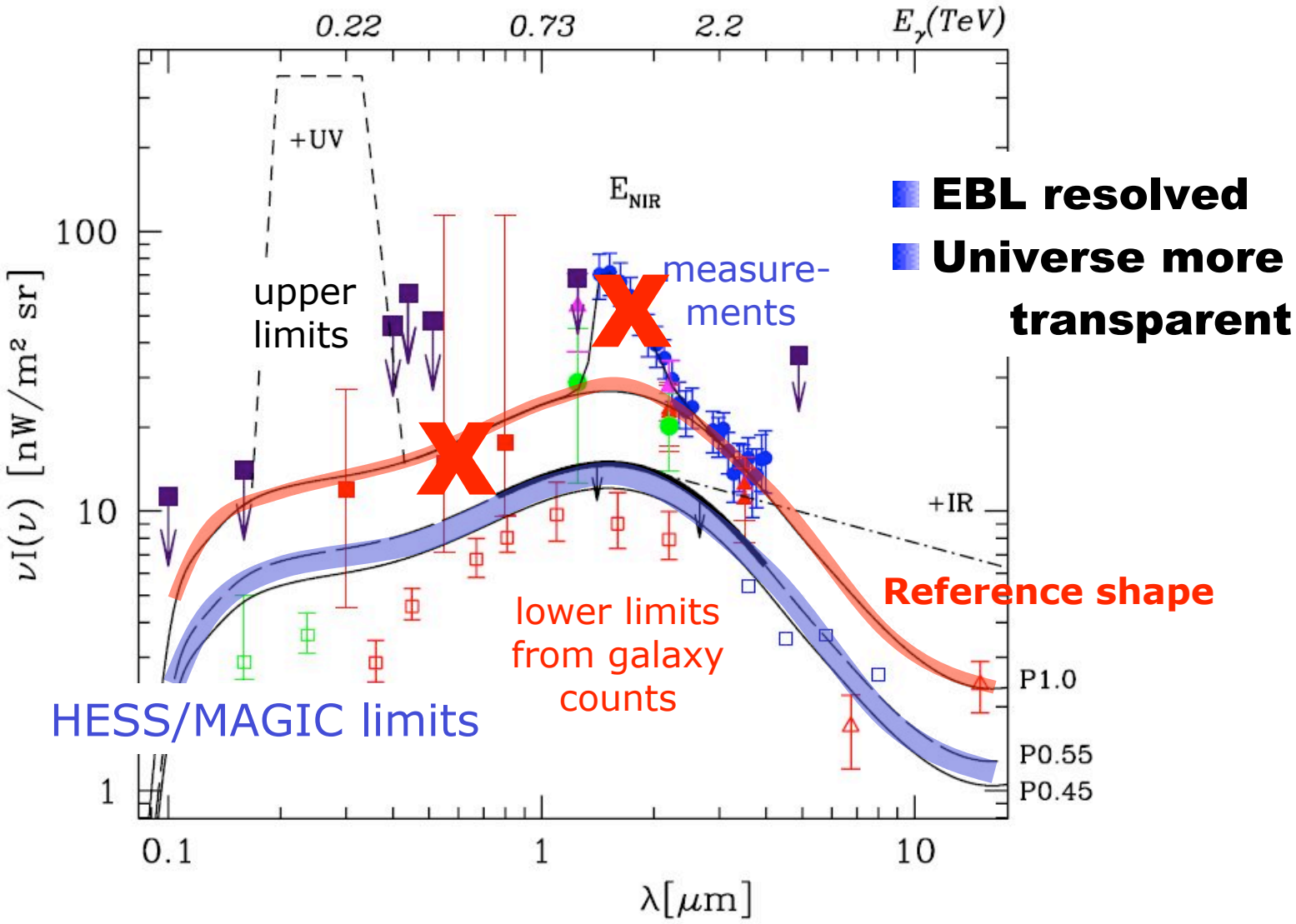
→ Reaching further out in redshift.

Extragalactic Background Light (EBL)

- Cosmological radiation from star formation and evolution.
- Spectral signature from γγ absorption for Eγ ~ 50-2000 GeV.
- Use measured AGN spectra to constrain EBL.

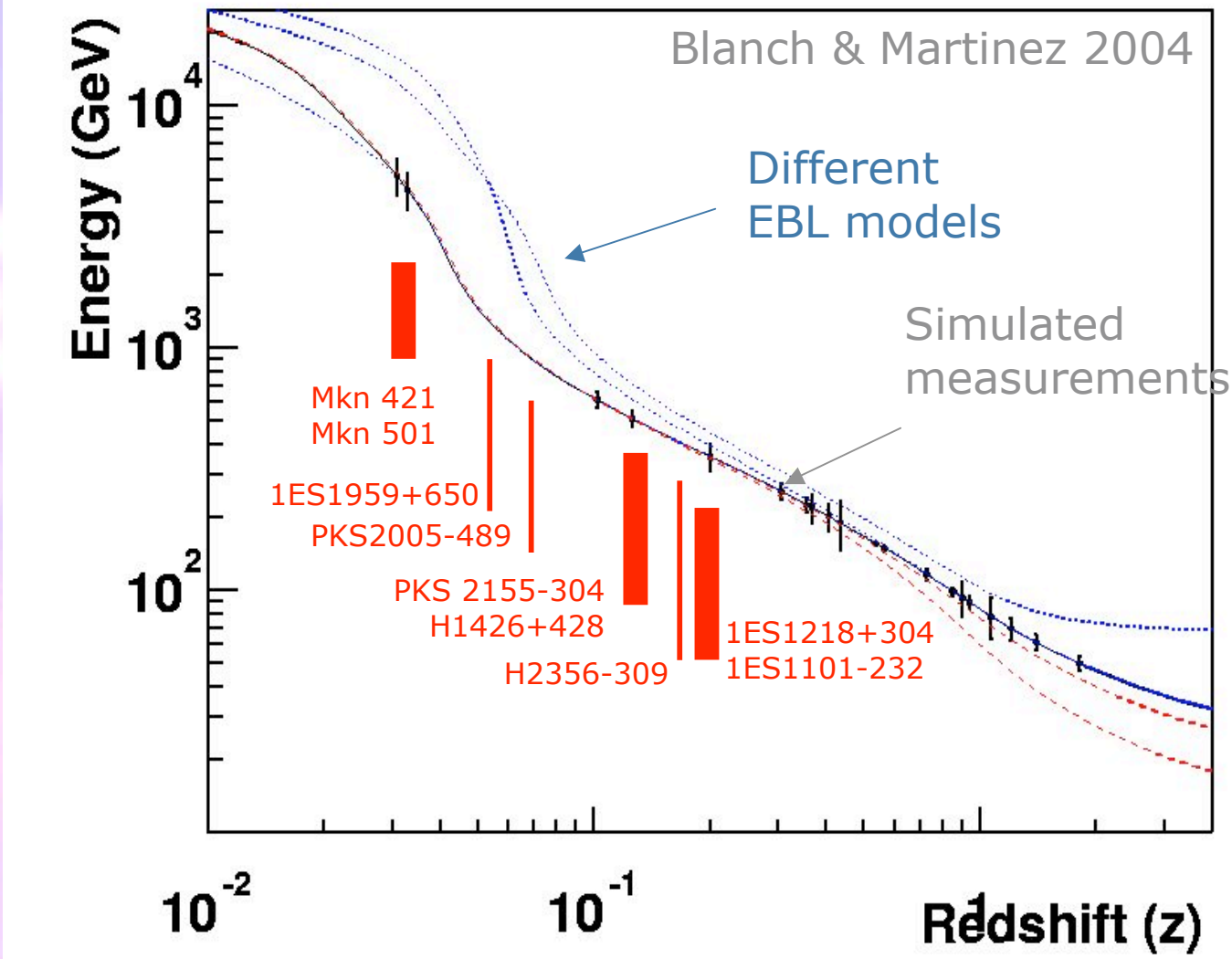


Spectra & Extragalactic Background Light

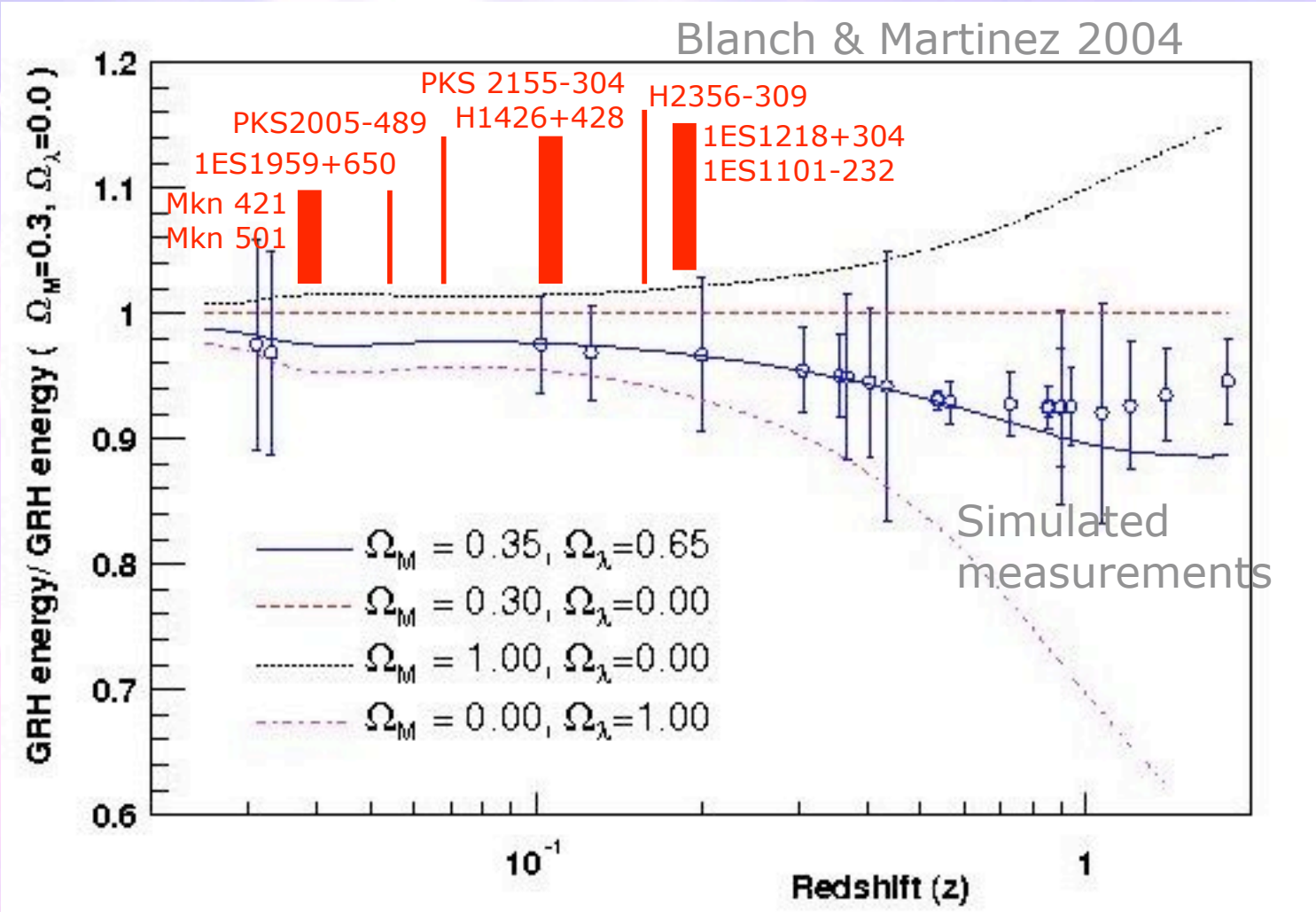


- **EBL resolved**
- **Universe more transparent**

GRH measurement is constraining the EBL density and…



… paving the way for the use of AGNs to fit Ω_M and Ω_Λ …

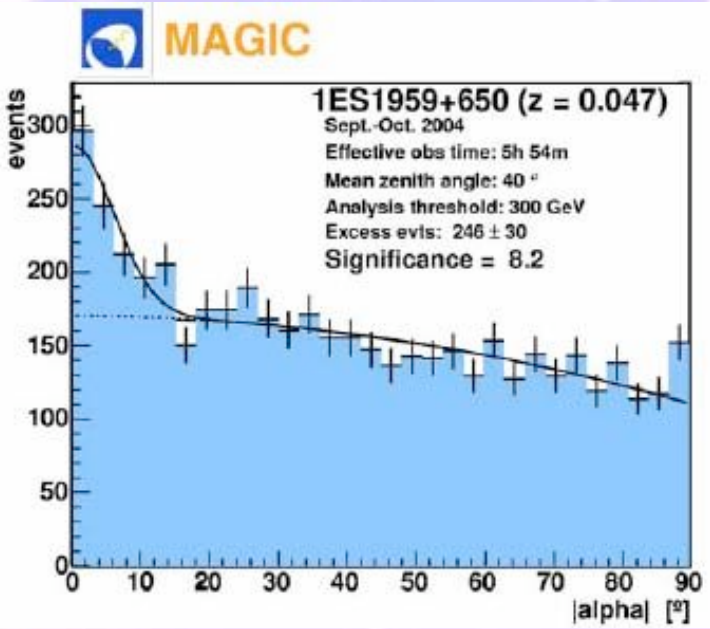


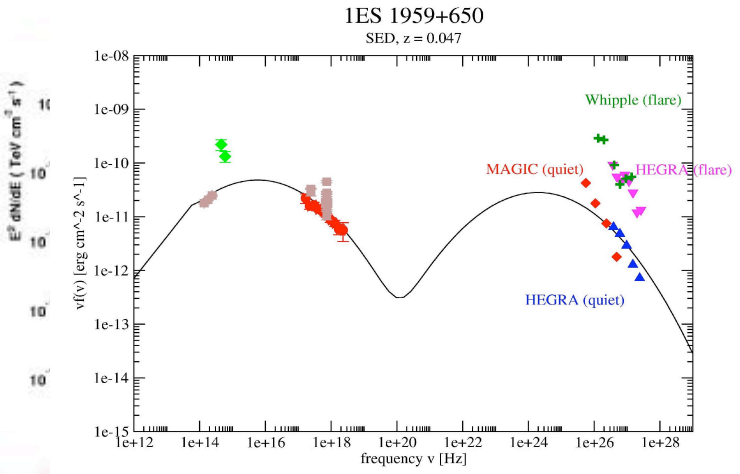
AGN with orphan flares

- Source observed already by Whipple and HEGRA in flaring state.
- Orphan flares (hadronic origin ?)
- MAGIC observation: low threshold and low flux (low state).

- Two neutrinos in AMANDA data ?.
- Two HiRes stereo events ?.

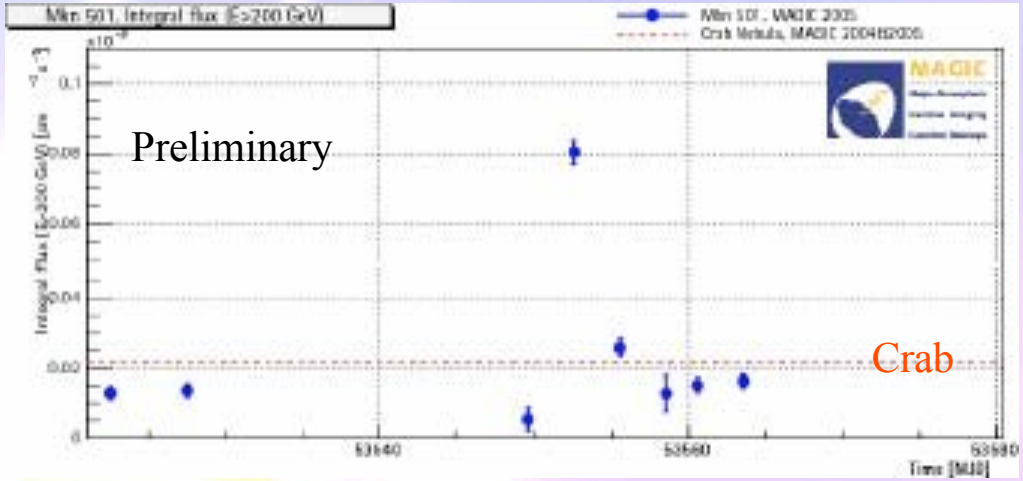
=> Connexion btw. Gamma-ray astronomy and neutrino/UHECR astronomy ?.

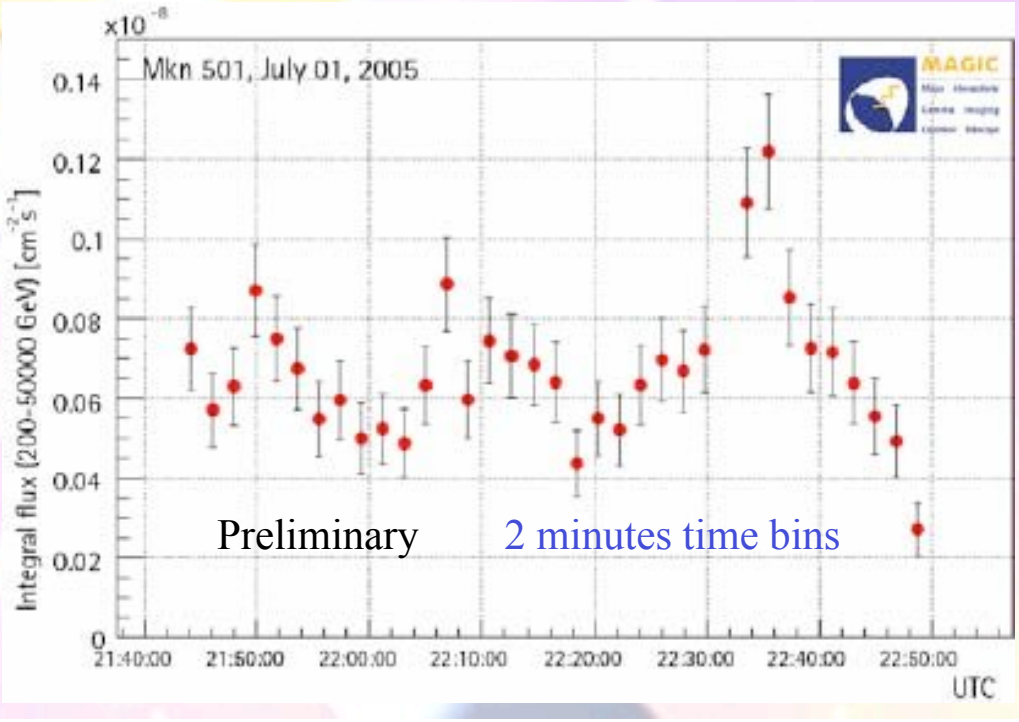




High time-resolution study of AGN flare

- Huge Mkn 501 flare on 1st July 2005 -> 4 Crab intensity.
- Intensity variation in 2 minute bins -> new, much stronger, constraints on emission mechanism and light-speed dispersion relations (effective quantum gravity scale).





Tests of Quantum Gravity effects.

- From a phenomenological point of view, the effect can be studied with a perturbative expansion. In first order, the arrival delay of γ–rays emitted simultaneously from a distant source should be proportional to their energy difference ΔE and the path L to the source:

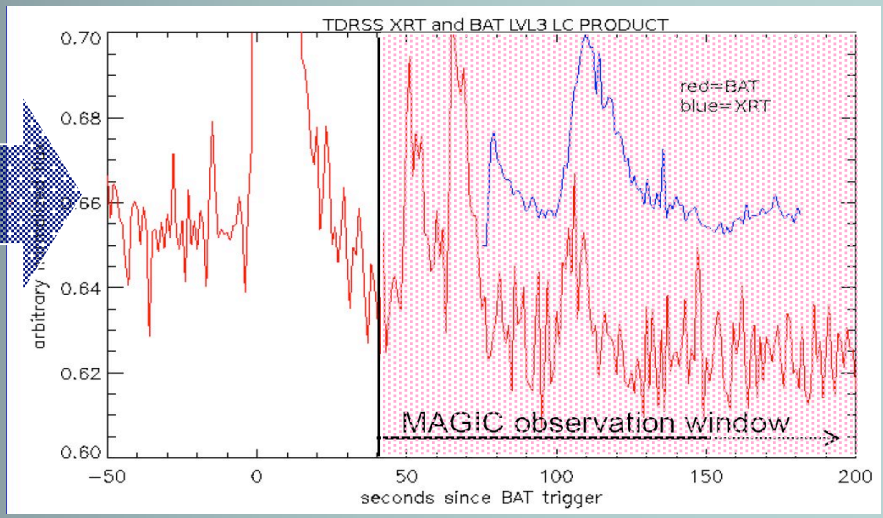
$$\Delta t \sim \frac{\Delta E}{E_{QG}} \frac{L}{c}$$

- The expected delay is very small and to make it measurable one needs to observe very high energy γ-rays coming from sources at cosmological distances.

Gamma Ray Bursts

#	GRB Event	Satellite	Onset [UTC]	Δt alert [sec]	Δt obs. [sec]	θ [deg]	z
1	GRB050408	HETE	16:22:50	14	3138	48	1.23
2	GRB050421	SWIFT	04:11:52	58	112	52	
3	GRB050502	SWIFT	02:14:18	18	990	33	3.79
4	GRB050505	SWIFT	23:22:21	540	793	50	4.27
5	GRB050509A	SWIFT	01:46:29	16	115	57	
6	GRB050509B	SWIFT	04:00:19	15	368	69	0.23
7	GRB050528	SWIFT	04:06:45	43	77	52	
8	**GRB050713A**	**SWIFT**	**04:29:02**	**13**	**40**	**49**	

- On 13 July 2005 MAGIC has observed a GRB with only 40 s delay
- Preliminary analysis shows no signal > 270 GeV
- Constrain models on prompt emission



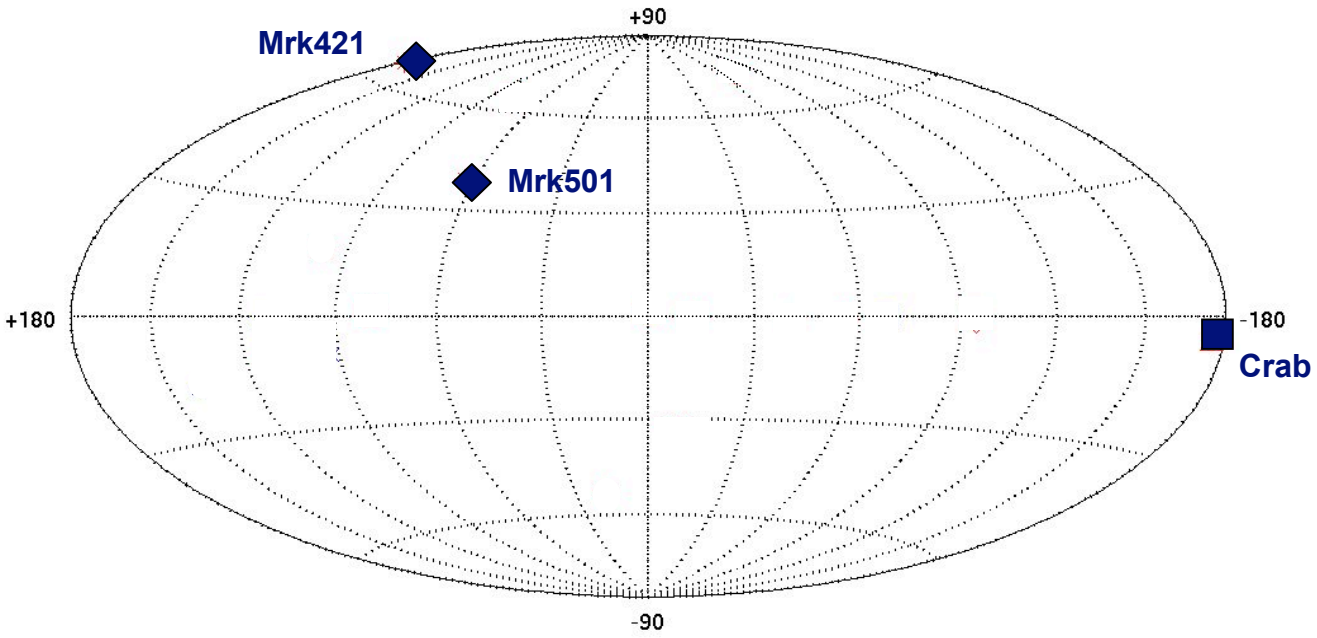
Summary: Status

- **A big revolution is occurring in VHE gamma-ray astronomy: the new generation of Cherenkov telescopes is yielding outstanding results, even beyond expectations.**

- **VHE gamma-ray installations are establishing themselves as astronomical observatories rather than as experiments: VHE gamma-ray is now emerging as a solid new astronomy.**

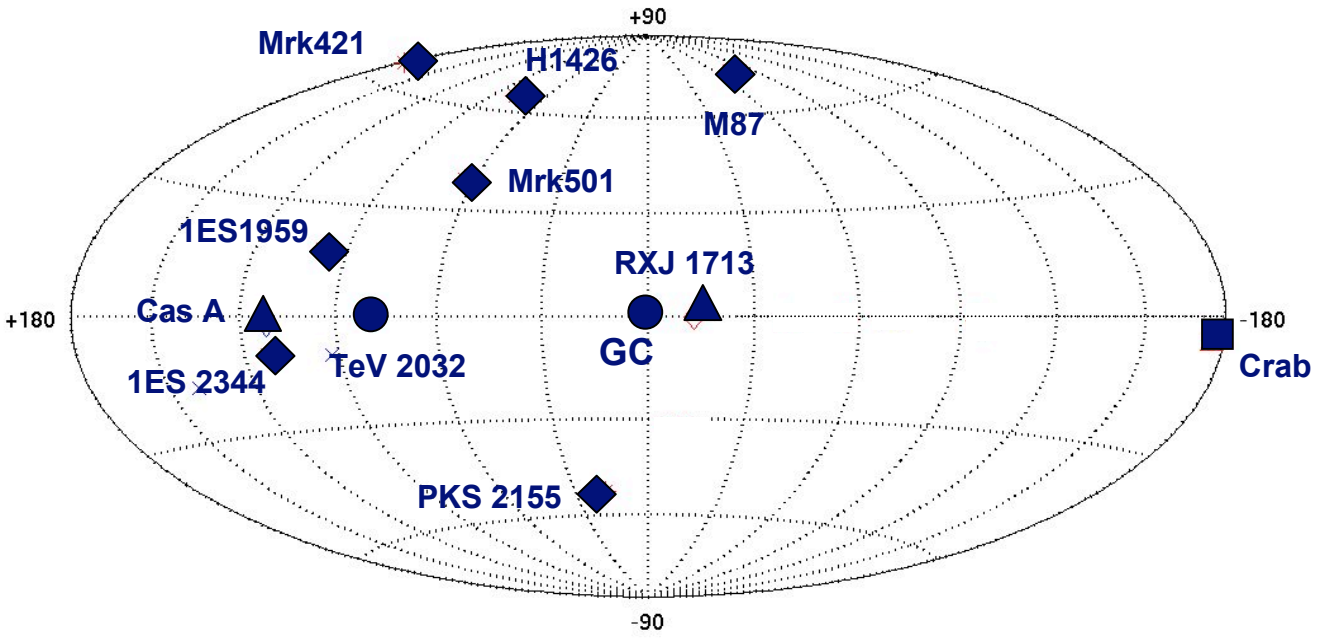
- **As many new VHE sources discovered in the last year as in the last 20 years… and likely many more coming !.**

The VHE Sky - 1995



R.A.Ong
Aug 2005

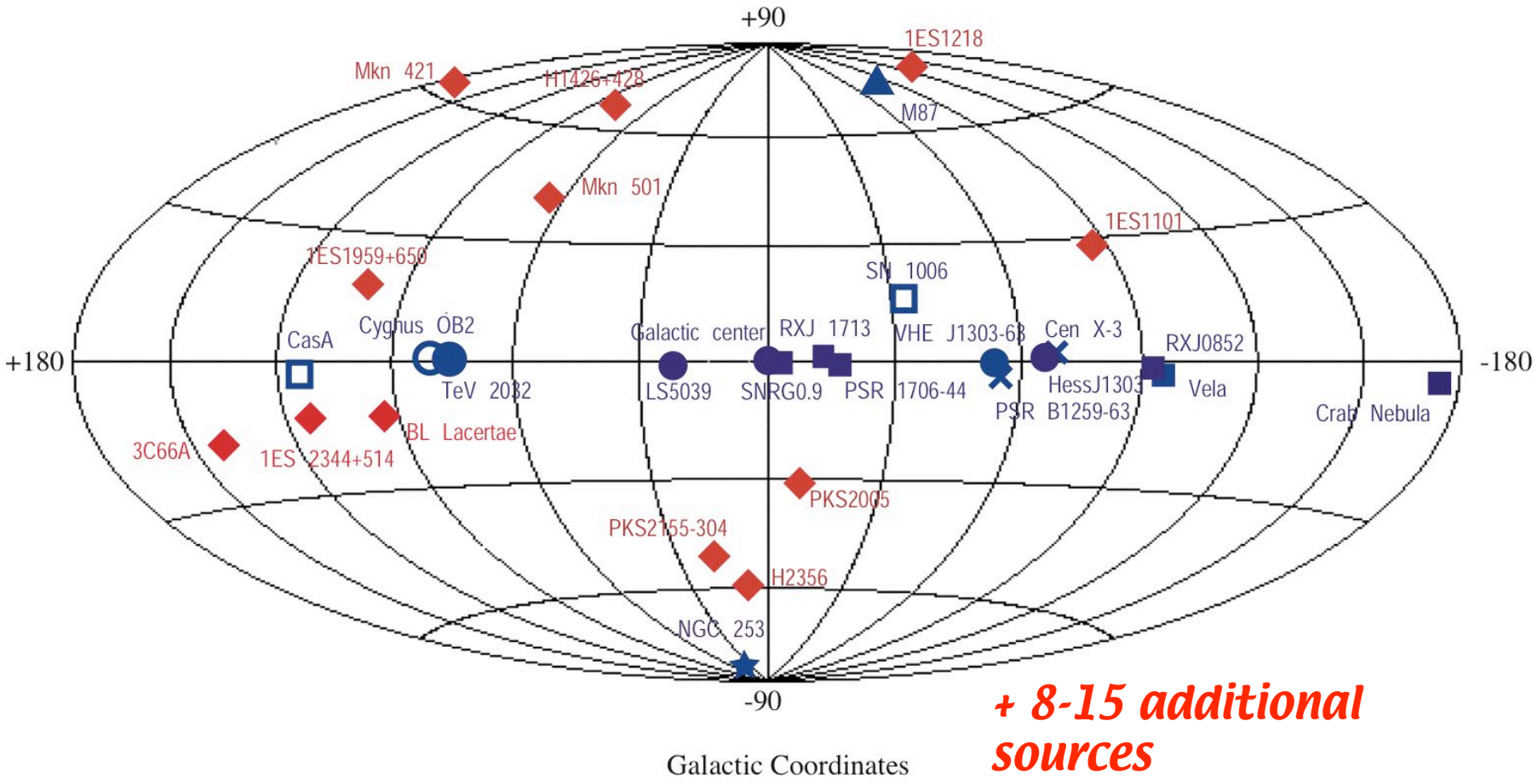
The VHE Sky - 2003



R.A.Ong
Aug 2005

VHE Gamma Sources (E > 100 GeV)

(Status August 2005)



+ 8-15 additional sources in galactic plane.

■ = Pulsar/Plerion □ = SNR ★ = Starburst galaxy ○ = OB association

◆ = AGN (BL Lac) ▲ = Radio galaxy ✕ = XRB ● = Undetermined

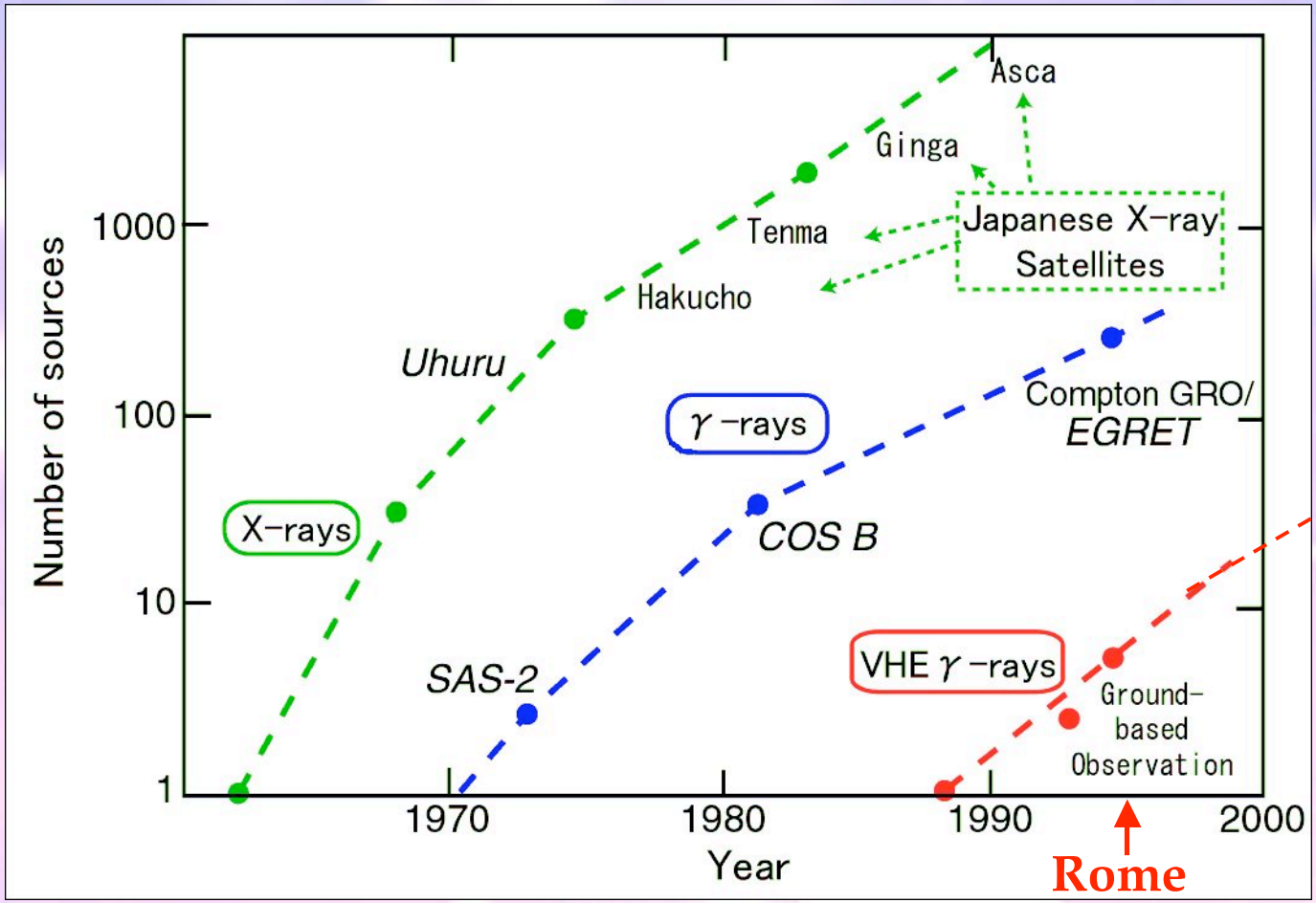
Source Counts

Source Type*	2003	2005
Pulsar Wind Nebula (e.g. Crab, MSH 15-52 …)	1	6
Supernova Remnants (e.g. Cas-A, RXJ 1713 …)	2	6
Binary Pulsar (B1259-63)	0	1
Micro-quasar (LS 5039)	0	1
Diffuse (Cygnus region)	0	1
AGN (e.g. Mkn 421, PKS 2155 …)	7	11
Unidentified	2	6
TOTAL	**12**	**32**

**** Includes likely associations of HESS unid sources.***

→ ***Explosion in the number of VHE sources.***

"Kifune Plot"



Source count versus year [T. Kifune]

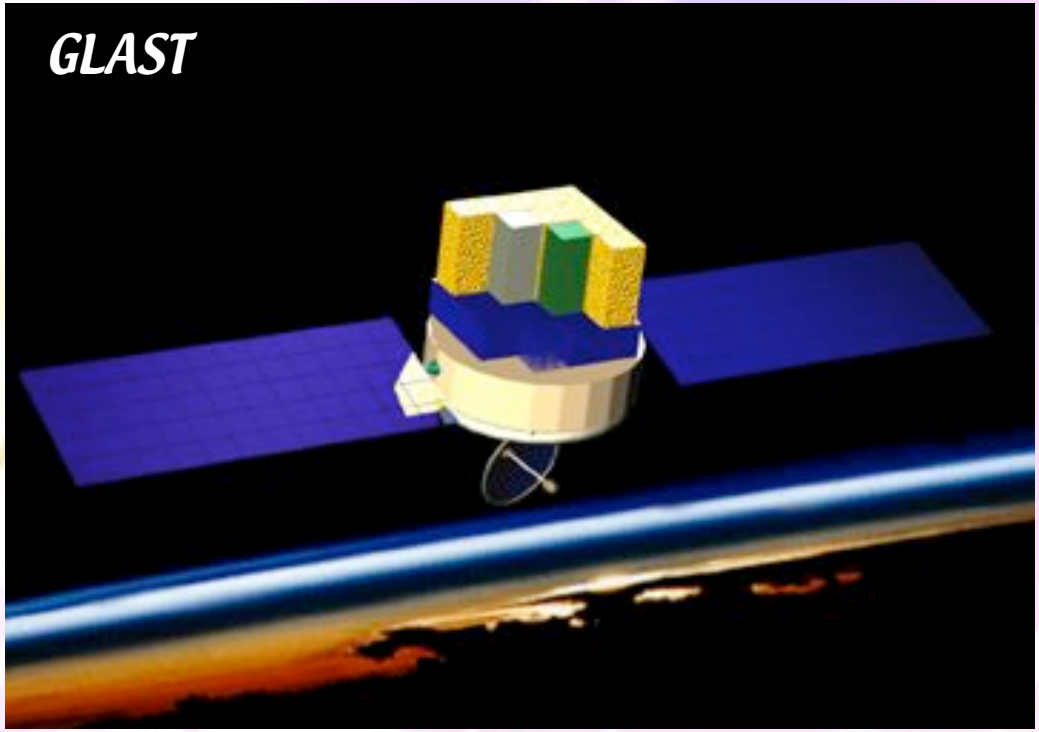
R.Ong ICRC2005

Outlook: coming installations

Satellites

GLAST

- *Major HE gamma-ray instrument.*
- *Thousands of new HE sources expected.*
- *LAT: coverage from 20 - 300 GeV.*
- *Scheduled for 2007.*




GLAST @ SLAC
12/16 Towers in the GRID on 7/10/05


GLAST @ SLAC
16/16 Towers in the GRID on 20/10/05

ARGO - YBJ

High Altitude Cosmic Ray Laboratory in Tibet

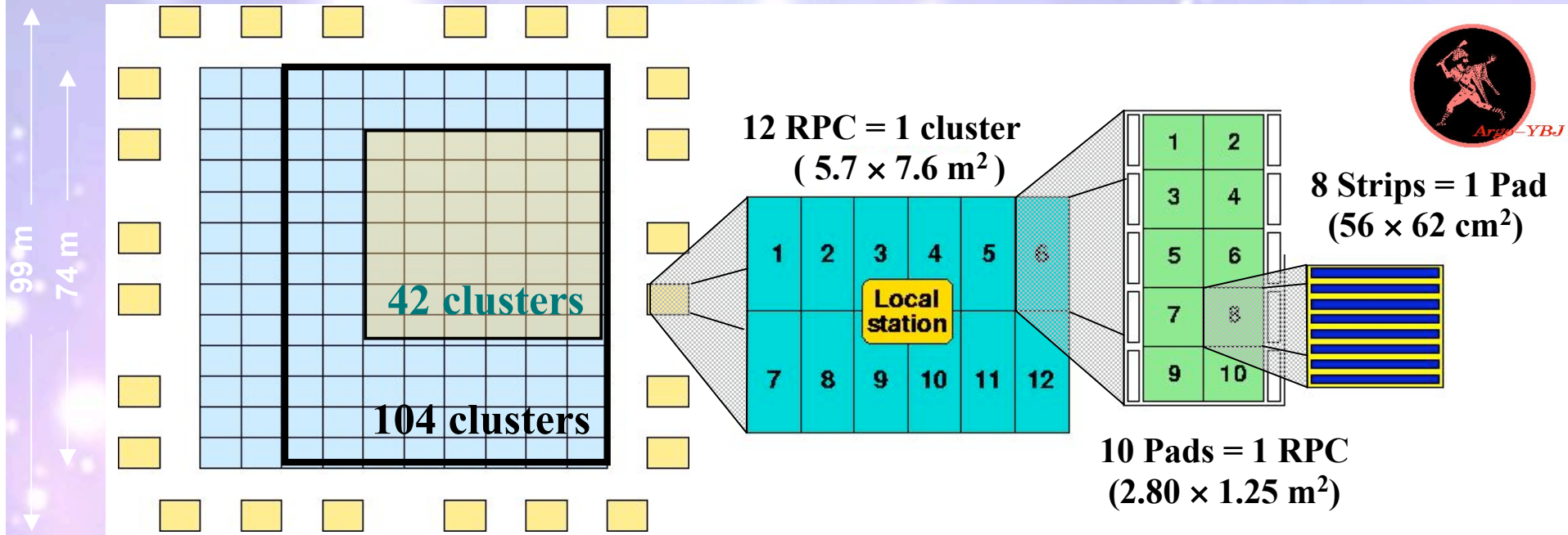
Longitude 90° 31' 50" East
Latitude 30° 06' 38" North

4300 m above the sea level

Astrophysical Radiation Ground-based Observatory

- ✓ γ-ray astronomy
- ✓ Gamma Ray Burst physics
- ✓ Cosmic Ray physics
- ✓ Sun and Eliosphere physics

Detector layout



Data taking started in December 2004 with 42 clusters

Now in data taking with 104 clusters

Outlook: What next ?

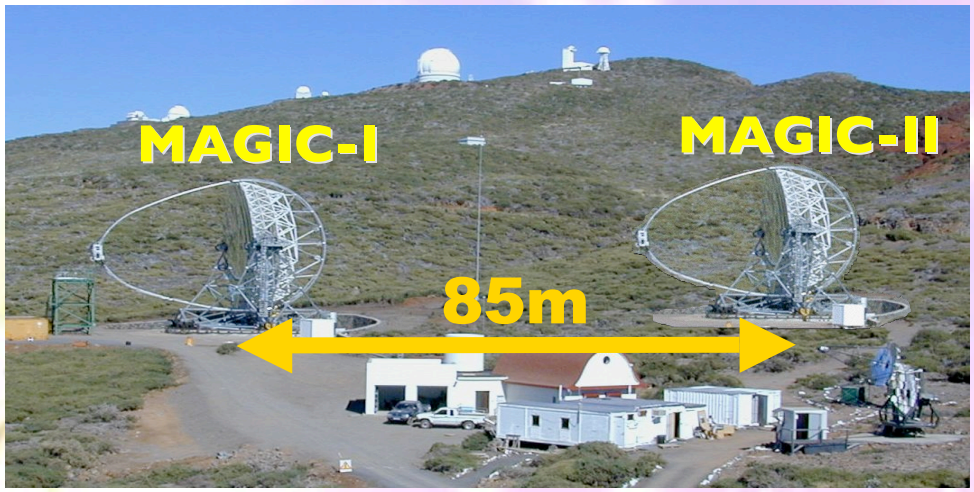
Cherenkov Telescopes

VERITAS

- 4x 12m telescopes at Kitt-Peak in 2006.

MAGIC-II

- Improved 17m telescope.
- Faster FADCs and a high-QE camera.
- First light in 2007.



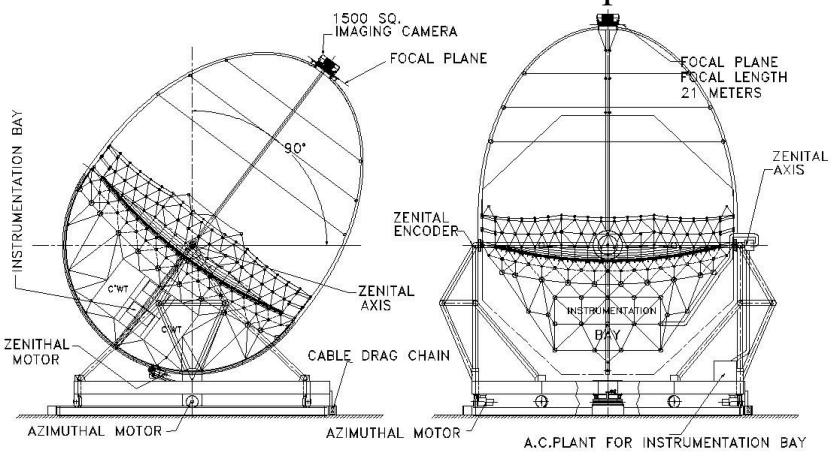
HESS-II

- New 28m telescope.
- 2048 pixel camera.
- Lower energy 40-50 GeV
- First light in 2008.

Outlook: What next ?

Still open directions for development:

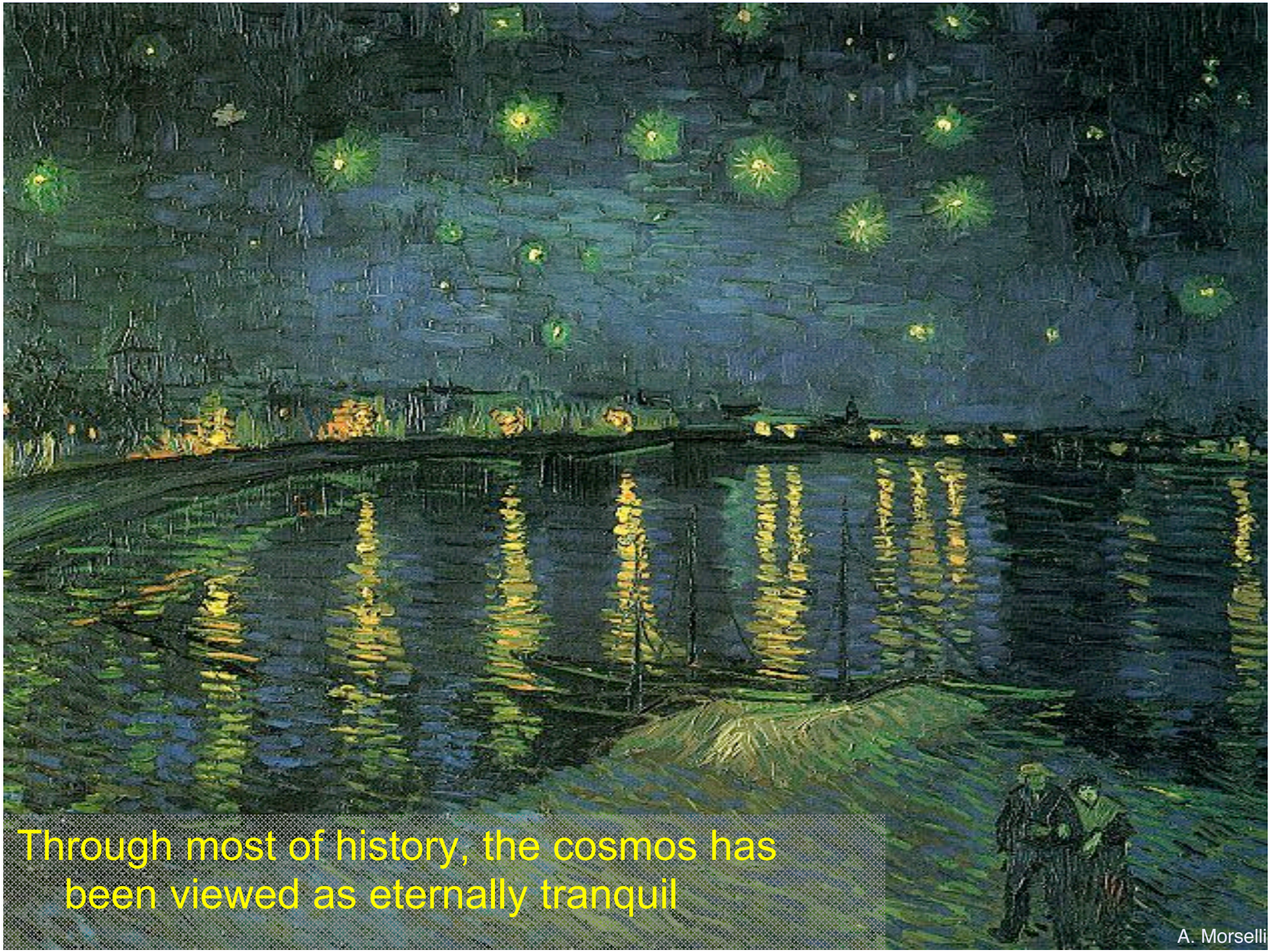
MACE: MAGIC-like 21m telescope at 4300 m

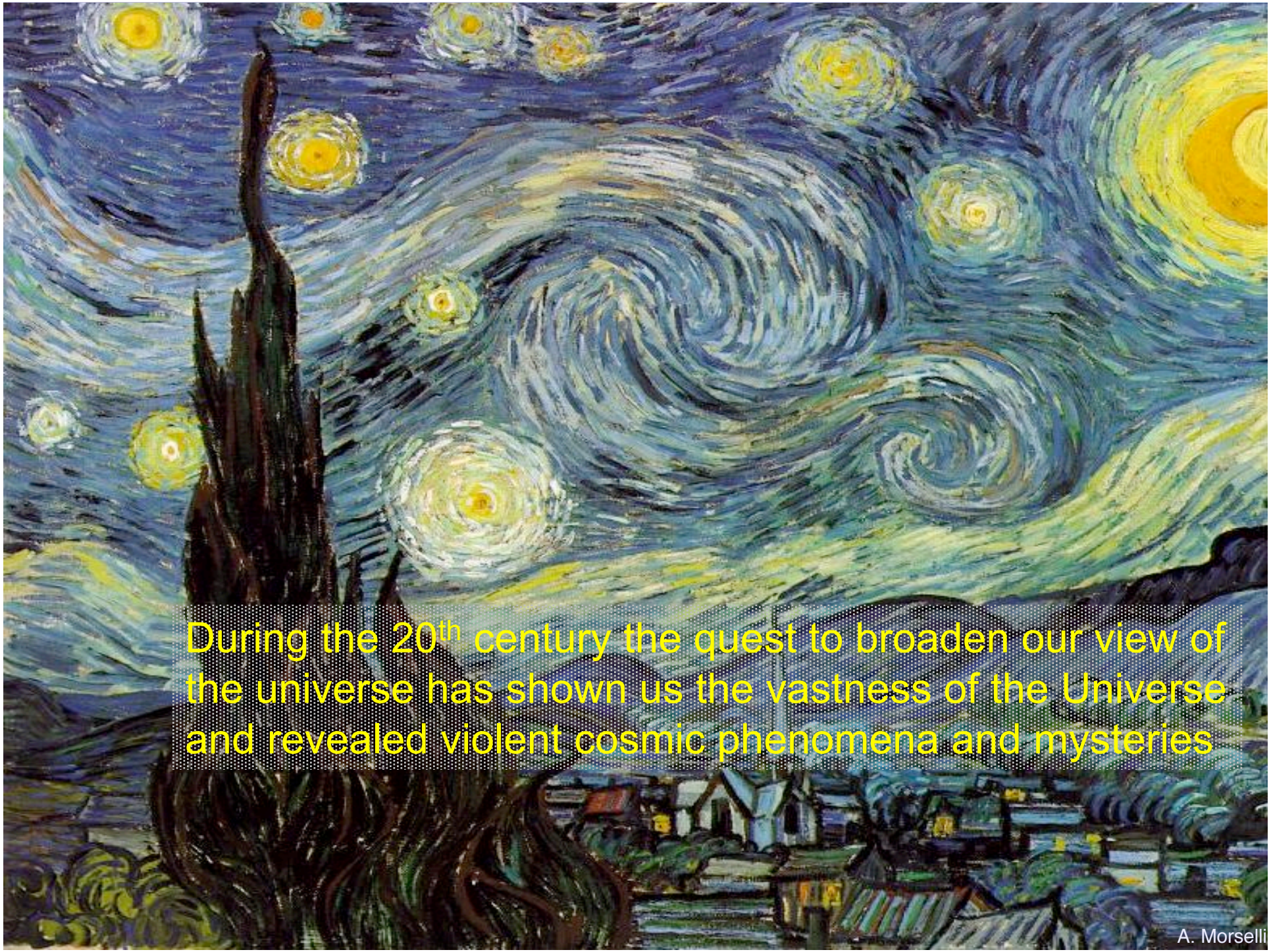


- Further threshold reduction:
  - Array of large telescopes…?
  - High QE cameras…?
  - High altitude…?
  - Further use of timing…?
  - New analysis concepts…?

- Wider angle observations:
  - surveys with multiple telescopes and wider angle cameras…?
  - new concepts of wide-angle Cherenkov telescopes -> GAW
  - improved shower detectors -> ARGO-YBJ

-> an exciting open opportunity for new ideas and developments


Through most of history, the cosmos has been viewed as eternally tranquil
A. Morselli


During the 20th century the quest to broaden our view of the universe has shown us the vastness of the Universe and revealed violent cosmic phenomena and mysteries
A. Morselli

Exploring Nature's Highest Energy Processes

- AGILE
  2006 Launch
- MAGIC II 2007
- VERITAS 2007/8
- HESS II 2008
- GLAST:
  August 2007 launch
- AMS:
  2008 launch