6th Rencontres du Vietnam: Particle Astrophysics

Very High Energy (VHE) γ-ray Astronomy: Status & Future

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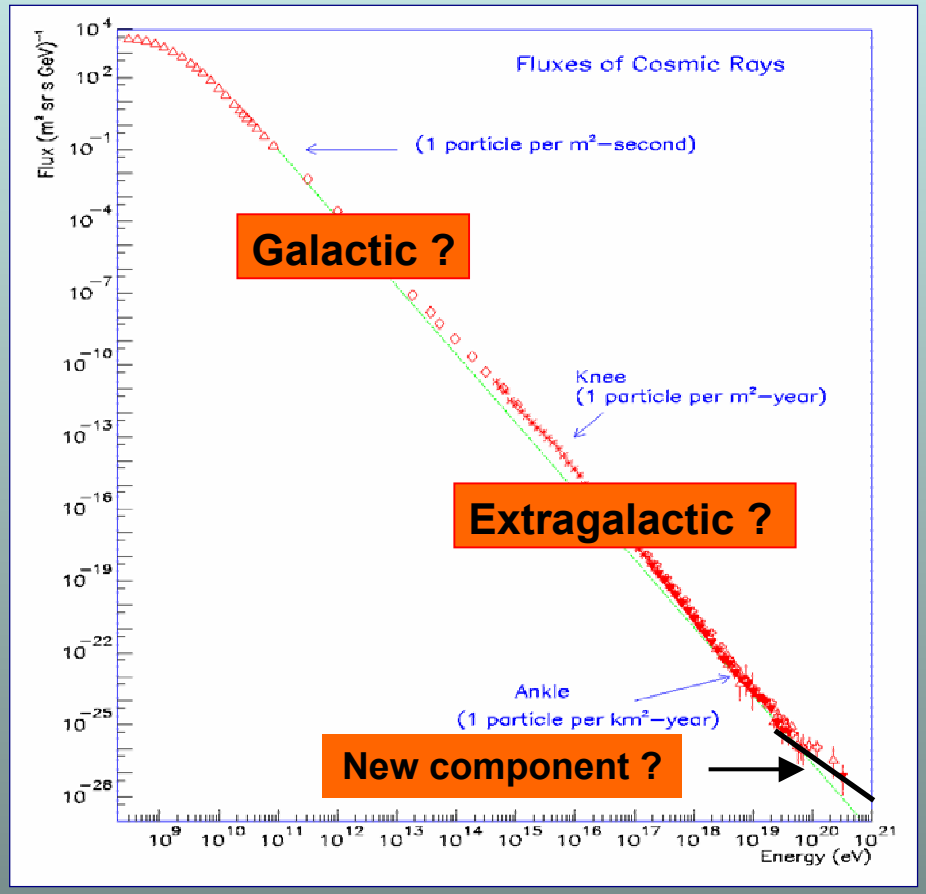
OUTLINE

- **Scientific Motivation**
  - Origin of cosmic rays
  - A new Astronomy
  - Beyond Standard Models.
- **Experimental Technique**
- **Latest results from around the world**
- **Where do we go now?**
  - Next few years.
  - Next decade.
- **Conclusions**

Cosmic Ray Origin



Diffuse, all particle spectrum

90 year old mystery !

- Enormous E range
- Mostly charged particles
- E density ~ 1 eV/cm^3

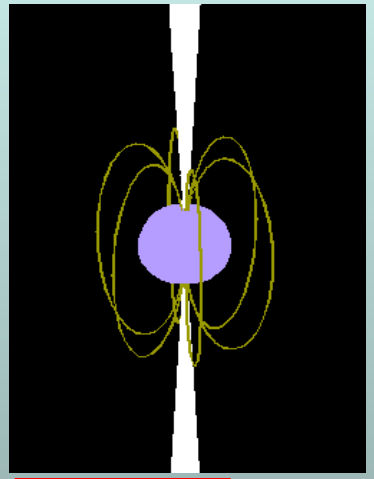
Neutral messengers

γ, ν

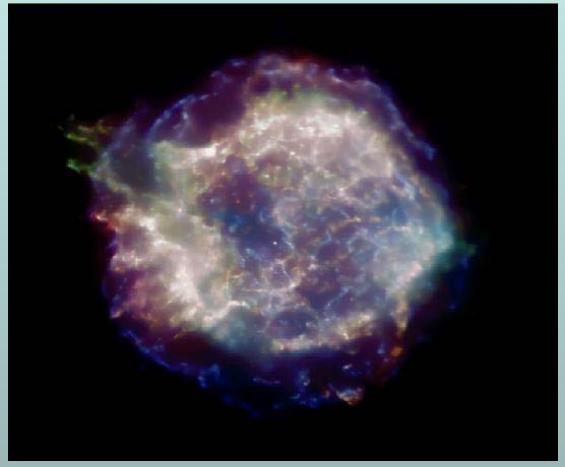
required to directly observe cosmic accelerators.

(ν astronomy: DeYoung, Hoffman, Vernin, Weiler)

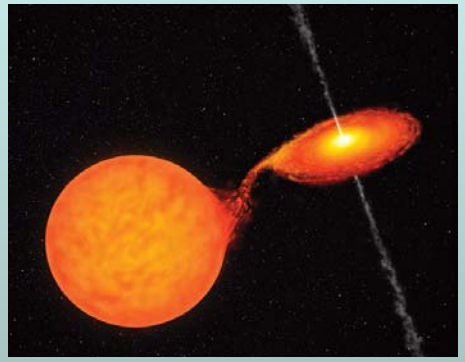
Galactic TeVatrons and PeVatrons



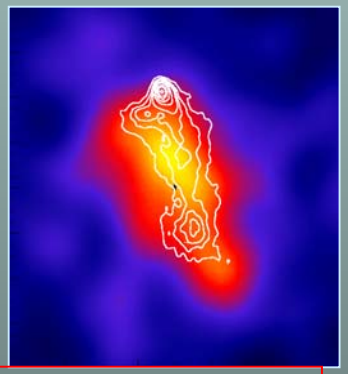
Pulsars



Supernova Remnants (SNRs)



Microquasars

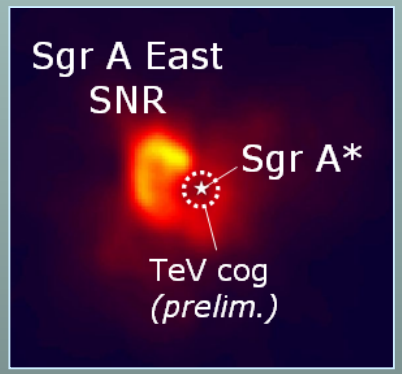


Pulsar Nebulae

Standard picture of SNRs:

- SN explodes into ISM.
- Diffusive shock acceleration.
- E, power-law form satisfied.

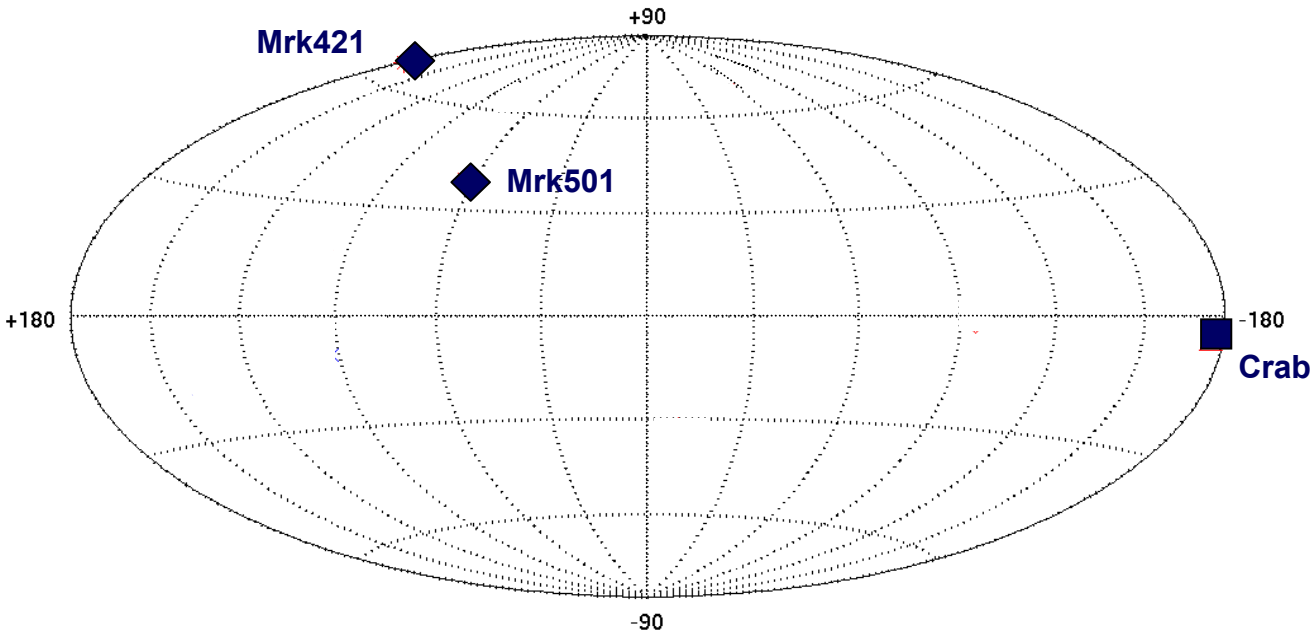
But, no unambiguous evidence so far.



Galactic Center

The VHE Sky 1995

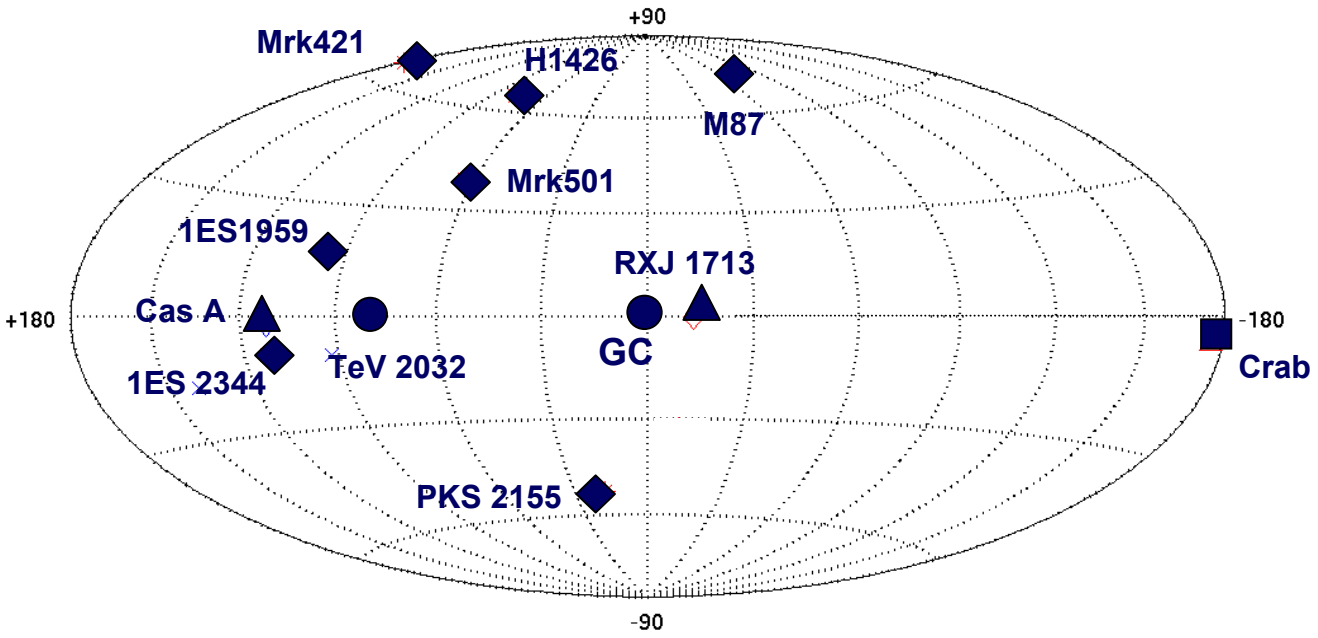
3 sources



R.A.Ong
Aug 2005

The VHE Sky - 2003

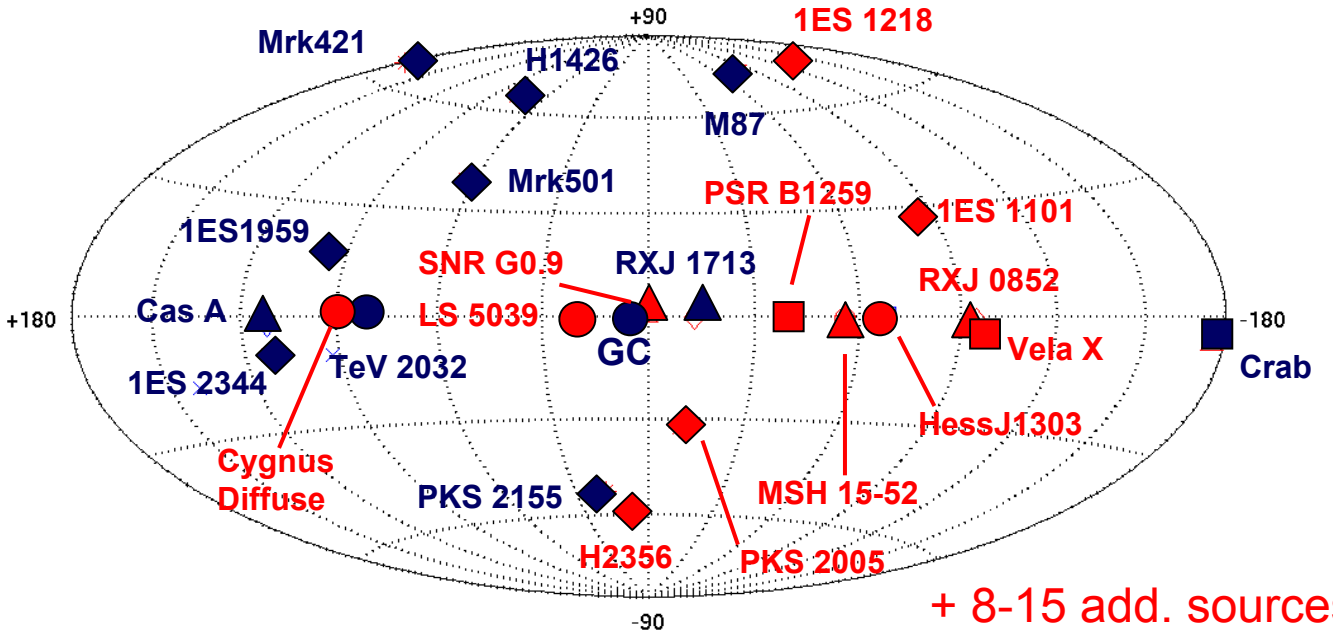
12 sources



R.A.Ong
Aug 2005

The VHE Sky - 2005

30 sources



+ 8-15 add. sources in galactic plane.

Pulsar Nebula

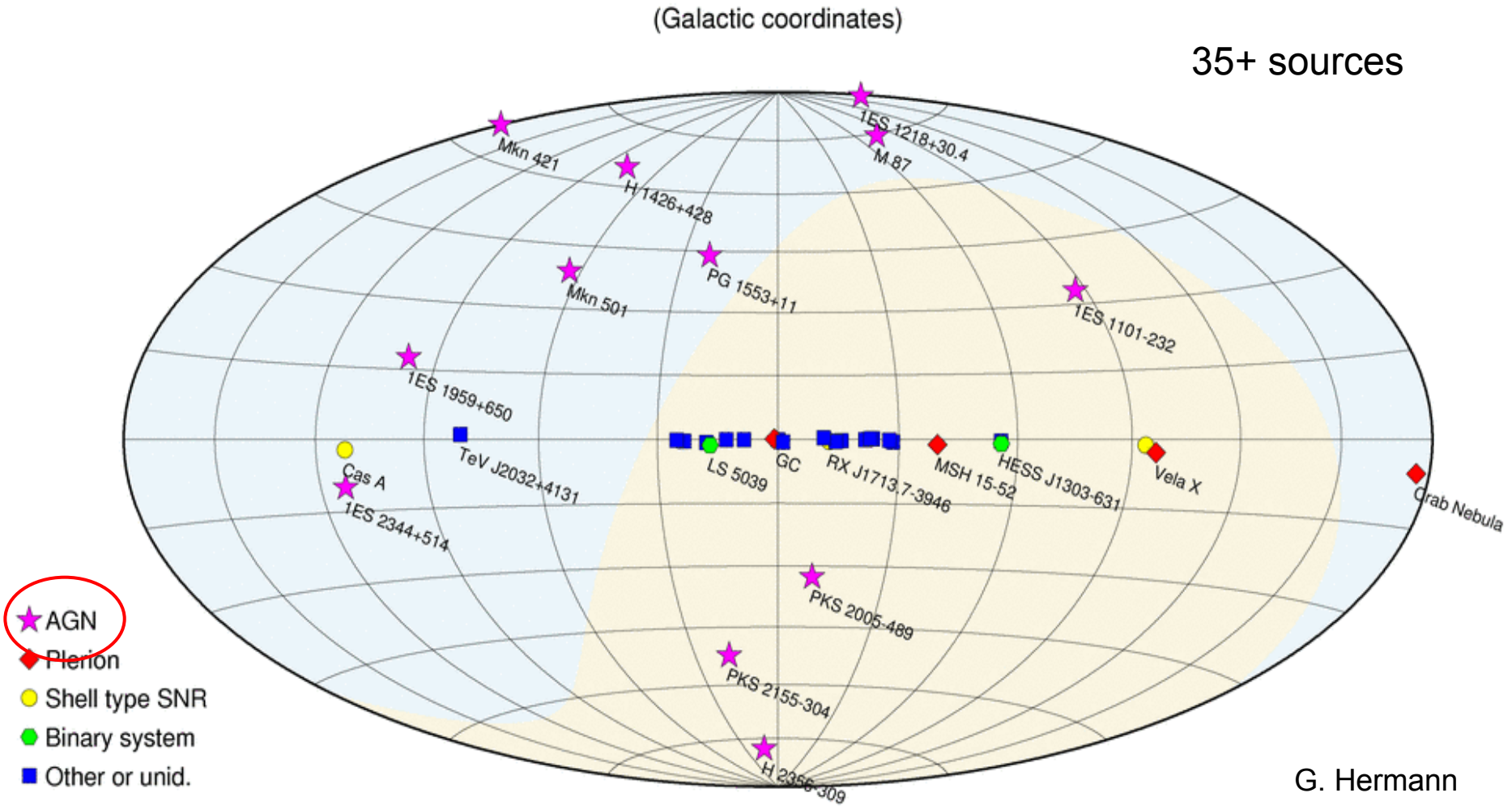
AGN

SNR

Other, UNID

R.A.Ong
Aug 2005

Present Time: August 2006



G. Hermann

Source Counts

Source Type*	2003	2006
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, LSI +61 303)	0	2
Diffuse (Cygnus region)	0	1
AGN (e.g. Mkn 421, PKS 2155 …)	7	13
Unidentified	2	6
TOTAL	**12**	**35**

* Includes likely associations of HESS unid sources.

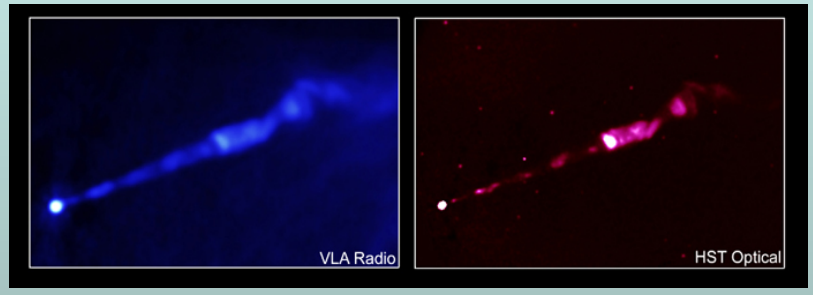
→ **Explosion in the number of VHE sources.**

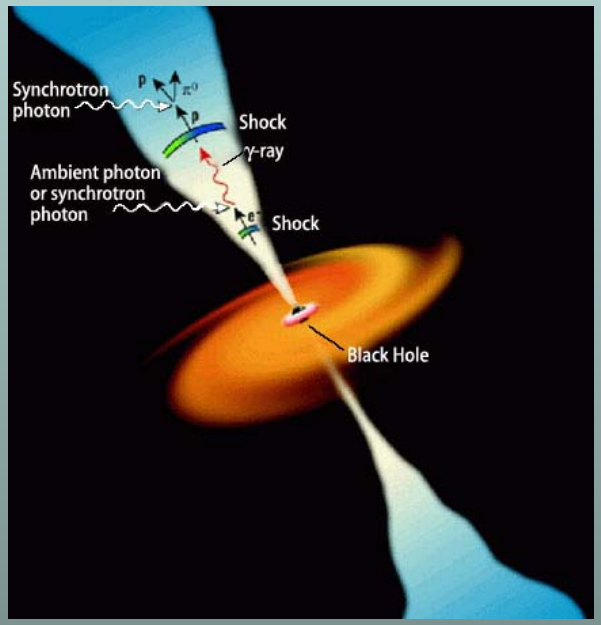
A New Astronomy

New view of the Universe → Many Surprises

One example: Active Galactic Nuclei

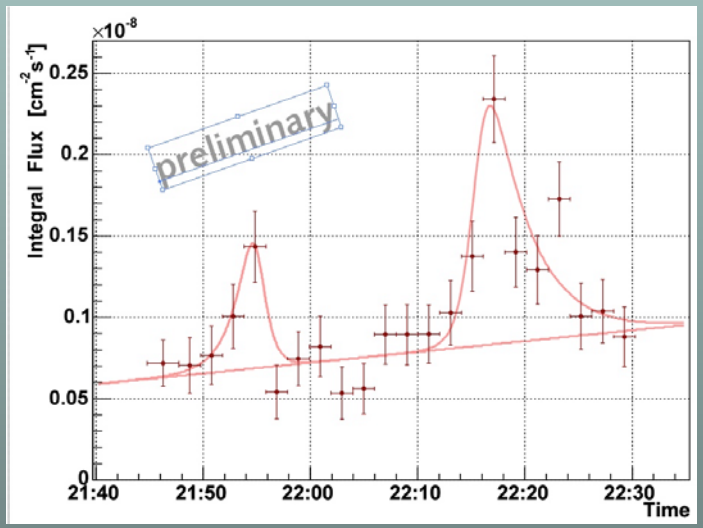
M87 Jet





Supermassive BHs
Jets beamed towards us

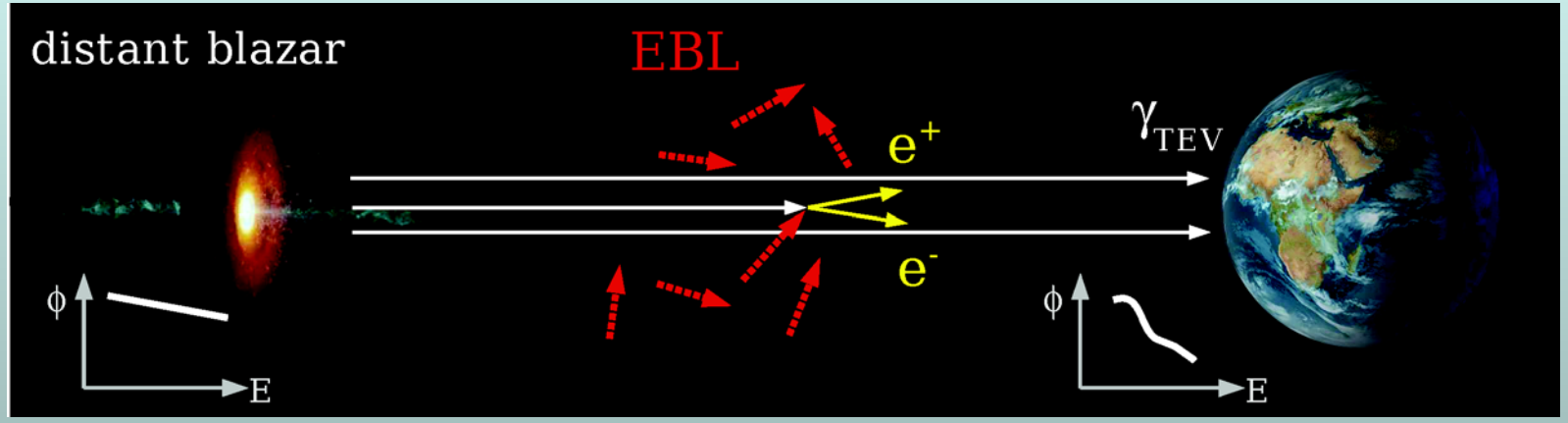
MAGIC Mrk 501

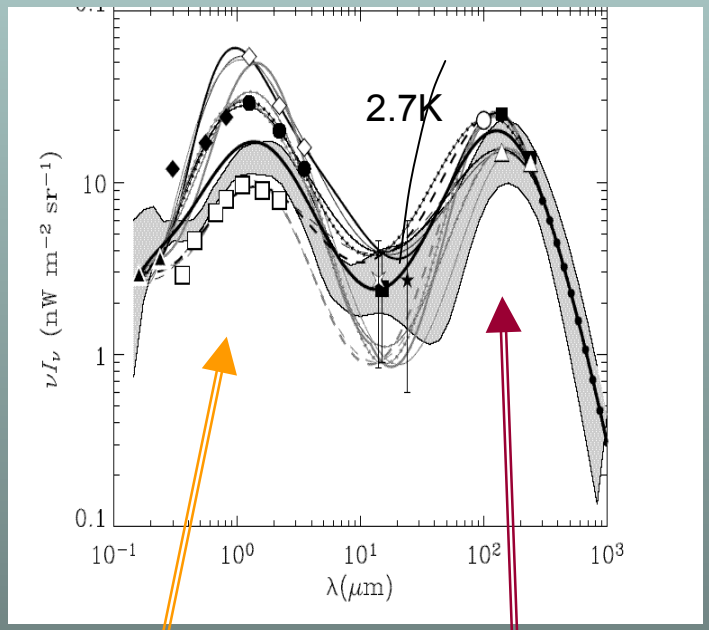


Remarkable variability

Central BH

Extragalactic Background Light (EBL)





M. Beilicke

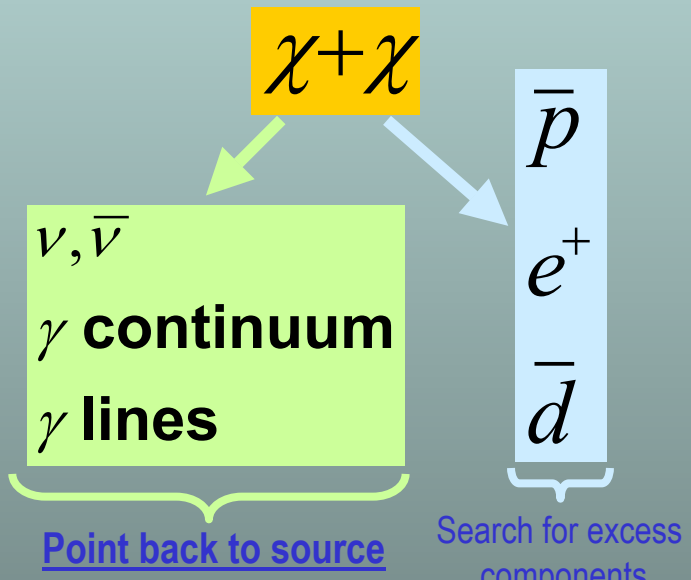
Determine cosmic IR/UV background

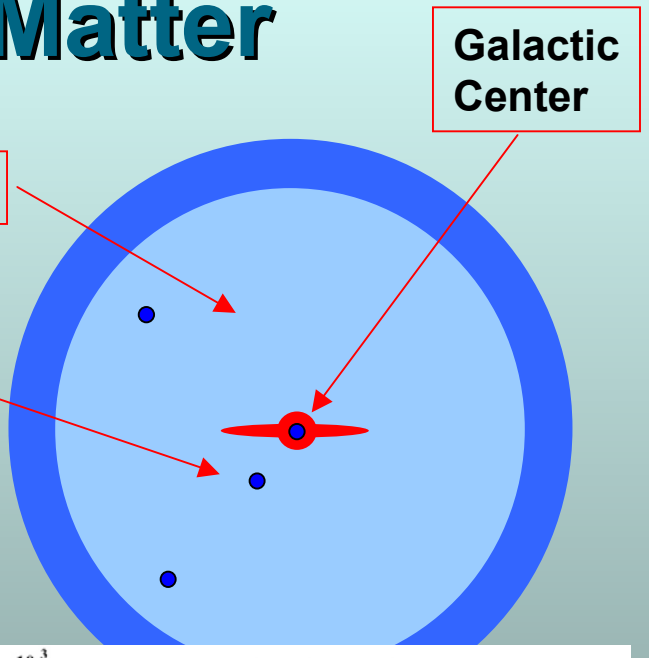
Red shifted stellar light

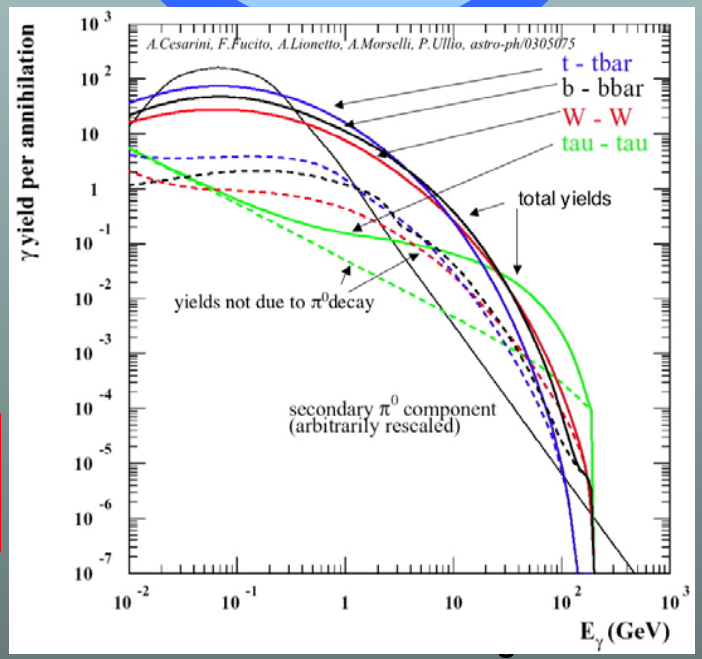
Red shifted dust light

Searching for Dark Matter

- Enhanced WIMP density in certain locations.
- WIMP annihilation → γ, ν



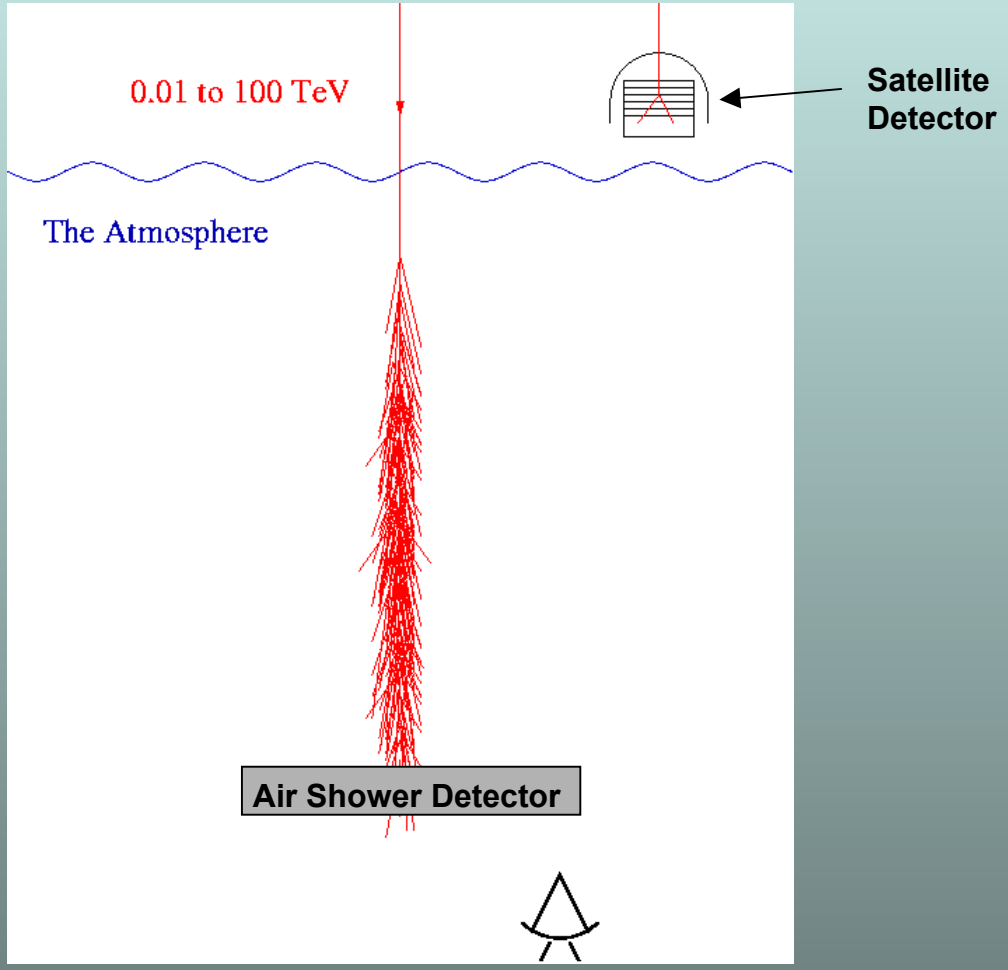




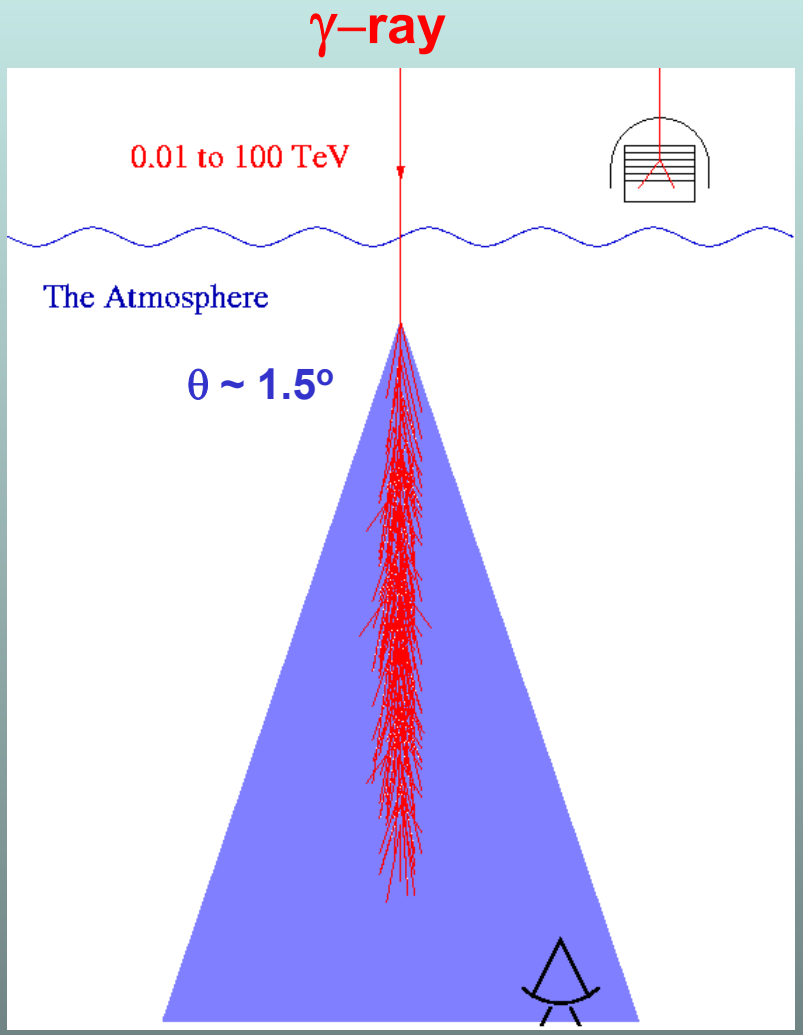
γ-ray yields

Experimental Technique

HE and VHE γ-ray Detectors



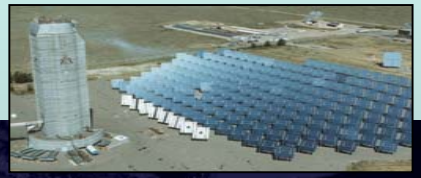
Cherenkov Telescopes



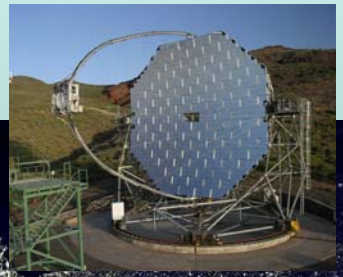
Experimental World

MILAGRO

STACEE



MAGIC



TIBET

CACTUS

VERITAS

TACTIC

HESS

CANGAROO III

Rene A. Ong (U

Scientific Highlights

I. HESS Galactic Plane survey.

- Discovery of many new sources, many unidentified.

II. Detailed studies of Galactic sources:

- Supernova remnants.
- Pulsars and pulsar wind nebulae.
- Binary systems – microquasars.
- Diffuse sources.

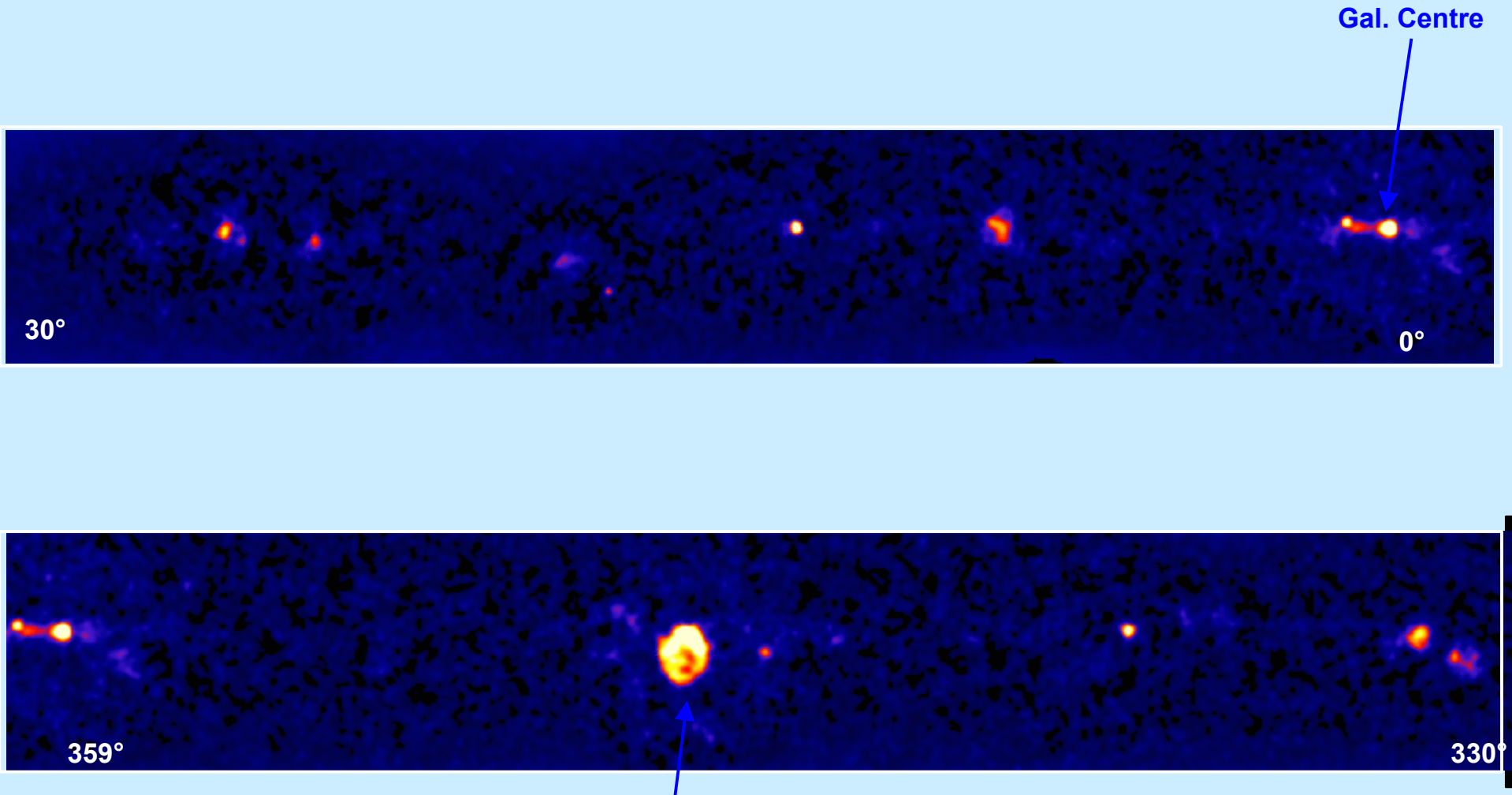
III. Extragalactic Sources.

- AGN and Radio Galaxies (M87).
- New constraints on EBL.

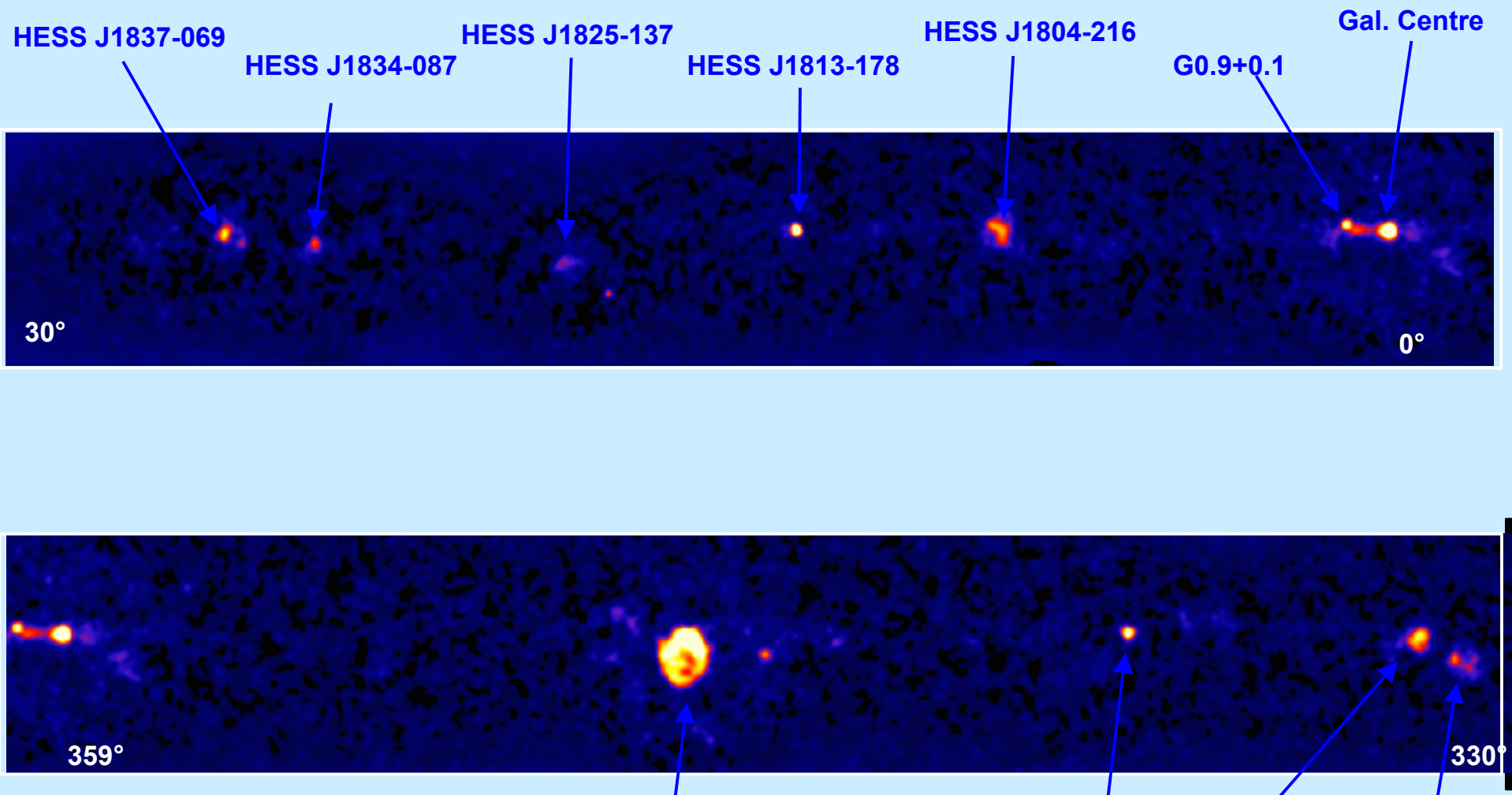
IV. Dark Matter Searches:

- Galactic Center and dwarf satellites.

HESS Survey

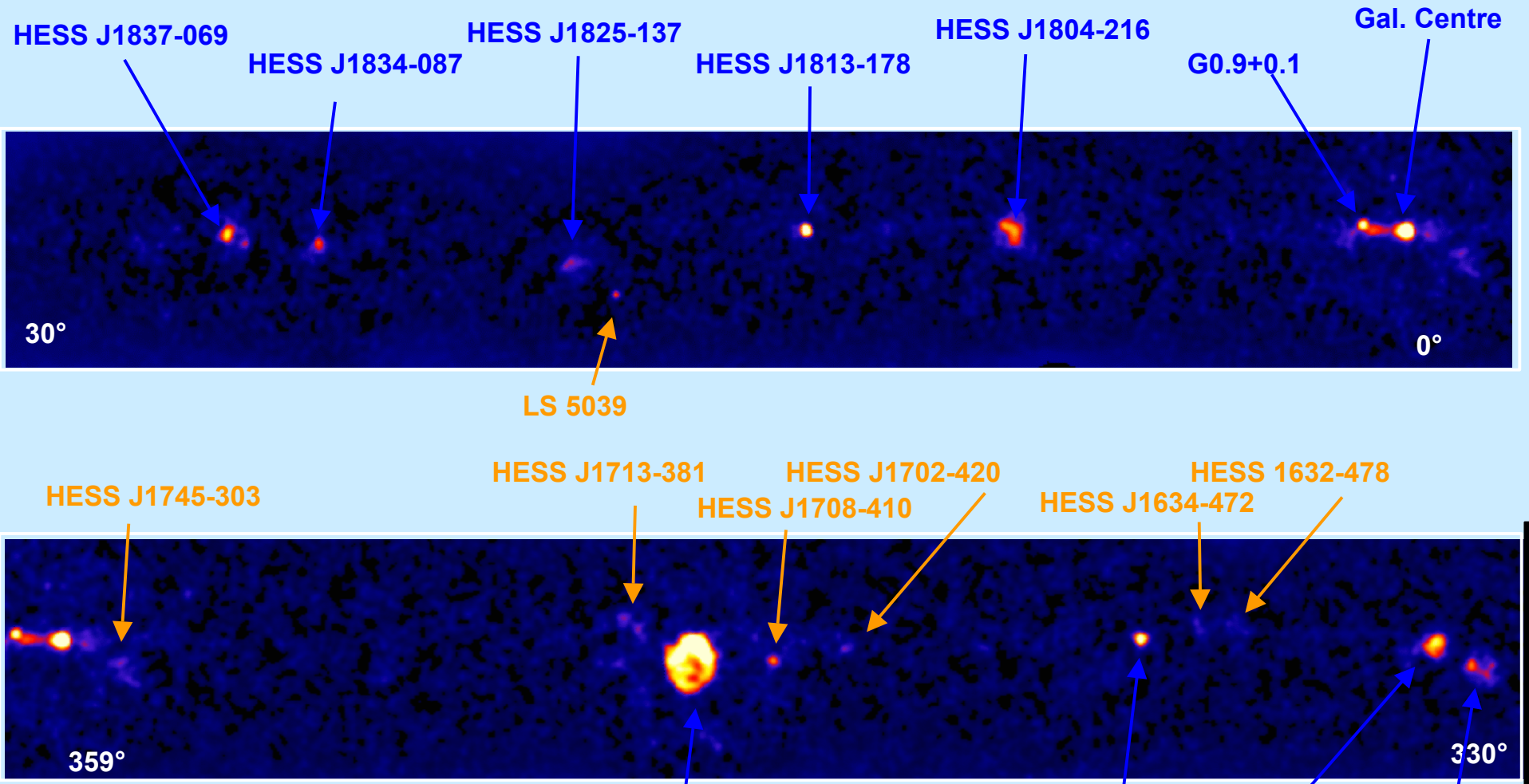


HESS Survey: New Sources



Sources > 6 sigma (9 new, 11 total)

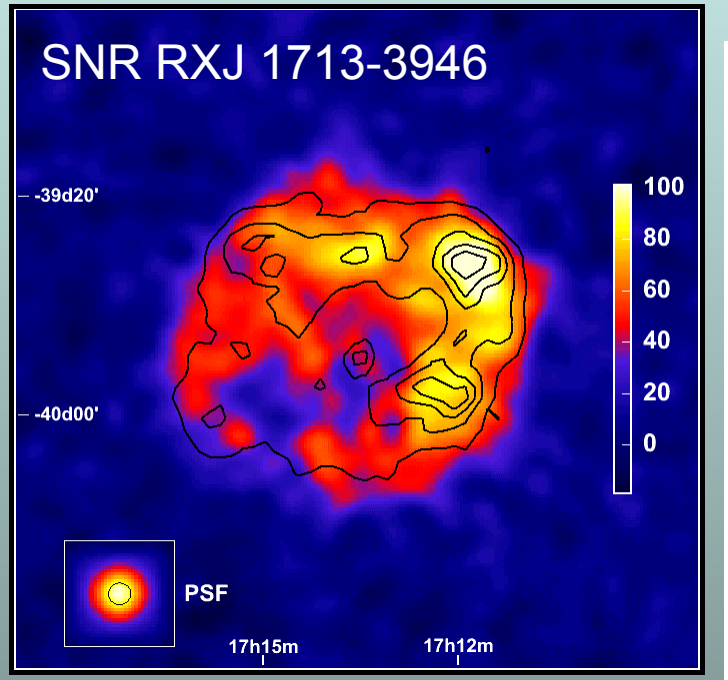
HESS Survey: New Sources



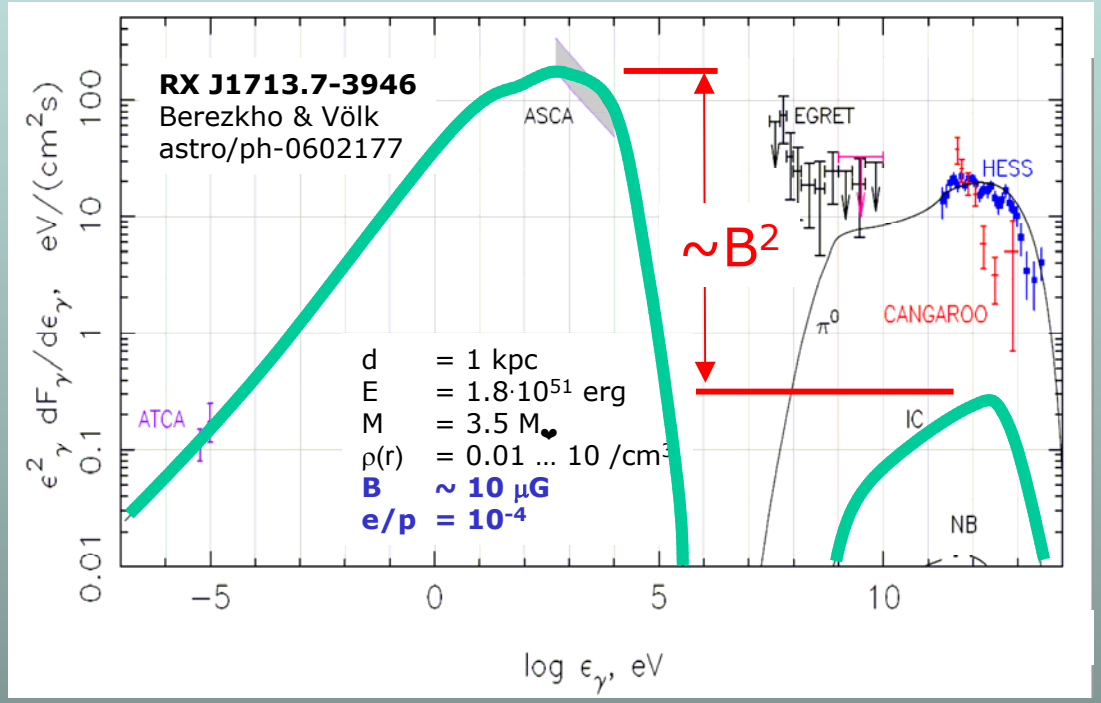
Sources > 6 sigma (9 new, 11 total)

Sources > 4 sigma (7 new)

Supernova Remnants
RXJ 1713-3946



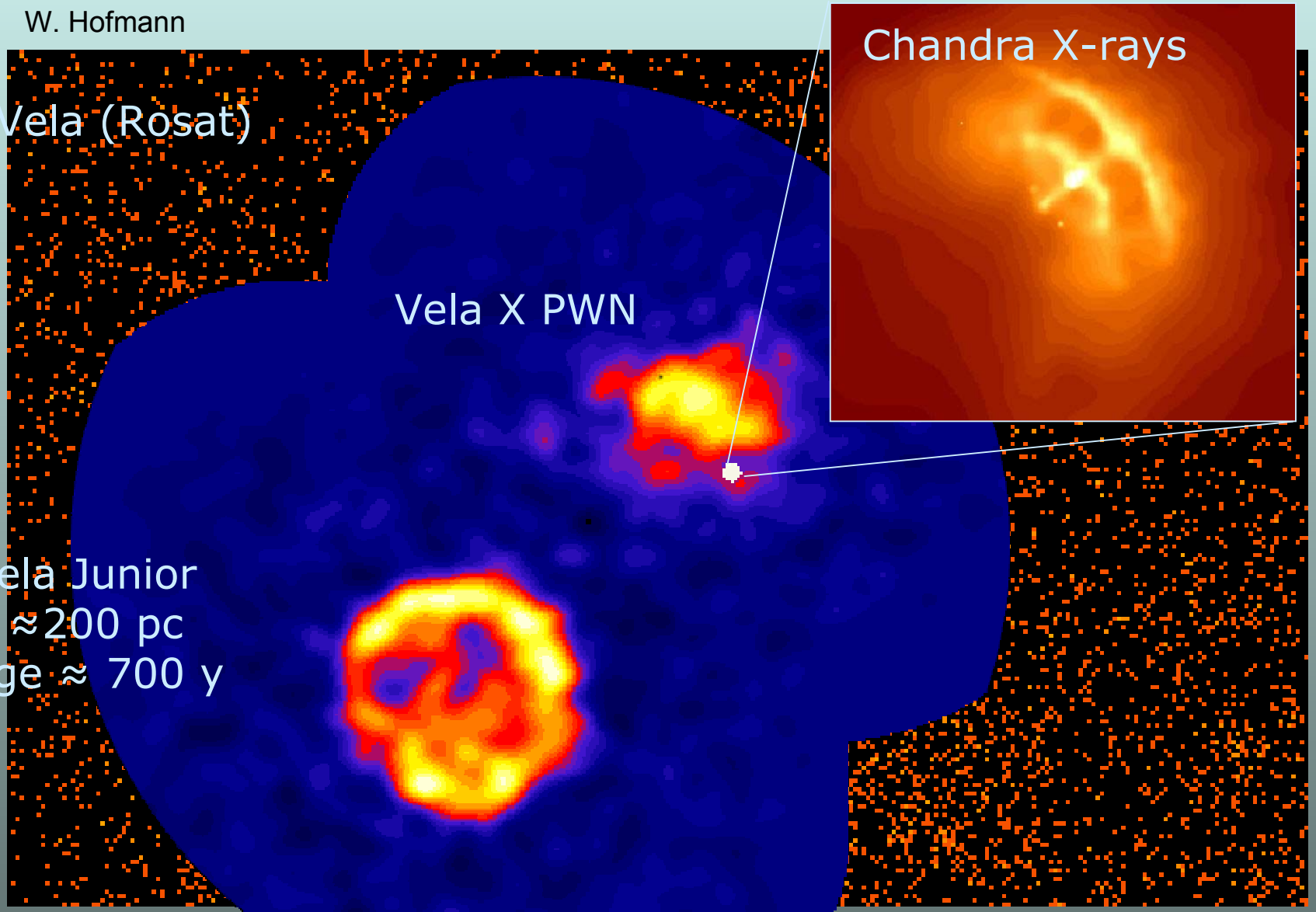
HESS Image
ASCA (X-ray) contours



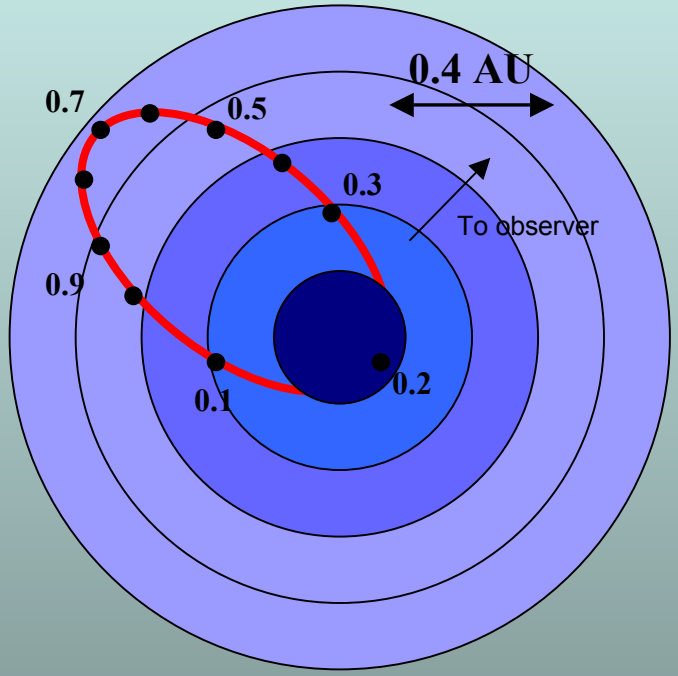
Good fit for this proton model – but electron models are still possible.

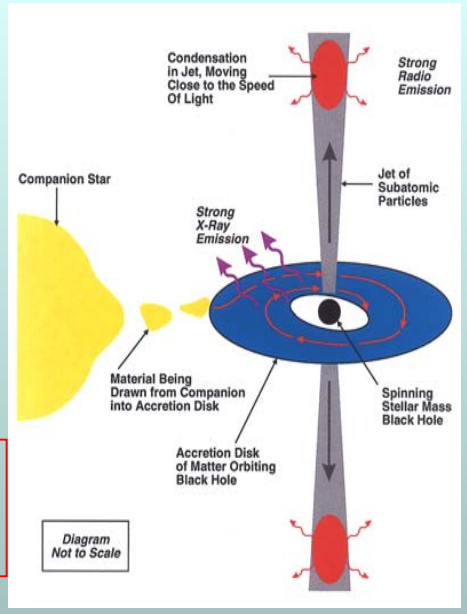
(U. Schwanke, parallel sessions)

Pulsar Wind Nebulae: Vela Region



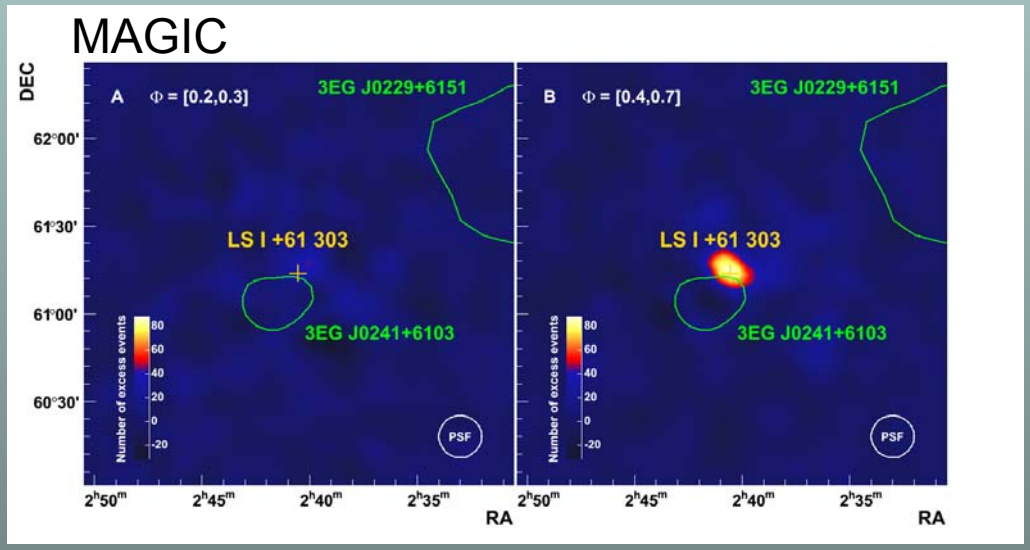
μ–Quasars: LSI +61 303





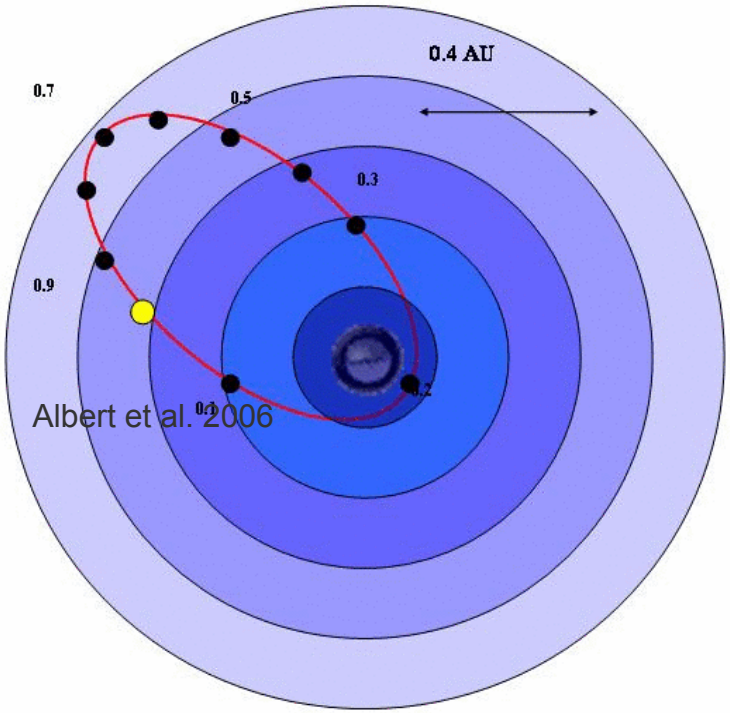
μ-quasar model

- High mass XRB @ 2kpc.
- Eccentric orbit, probably NS.
- Radio, X-rays modulated by orbital period of 26.5d.
- Compact jets resolved.



MAGIC:
Pt-like source, bright at phase [0.5,0.7].

LS I +61 303: the movie



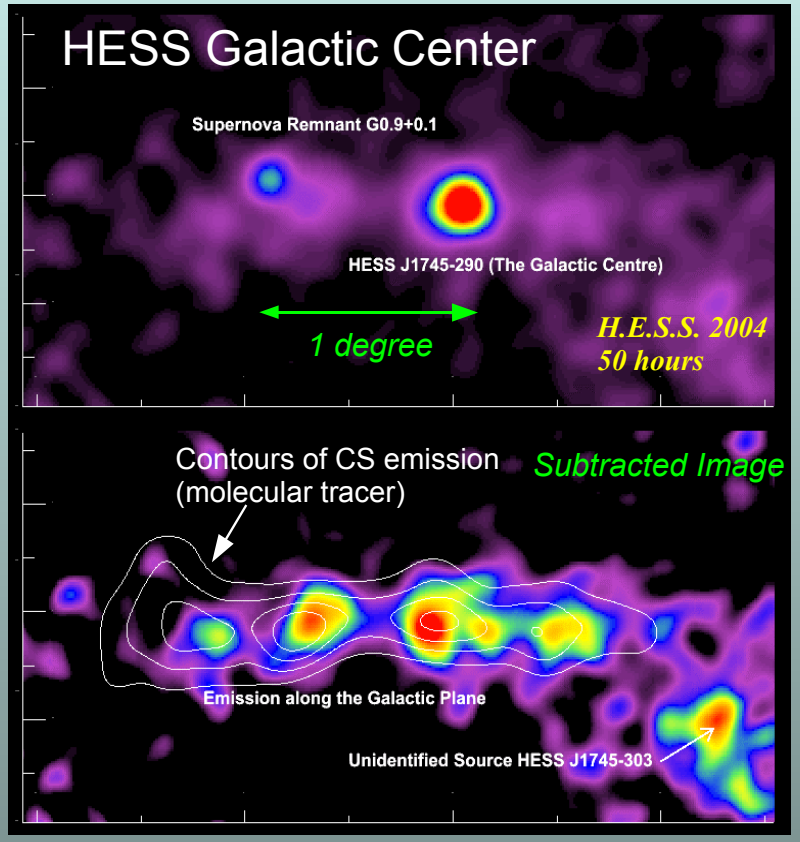
Albert et al. 2006

Q: Are we seeing the jet or the disk ?

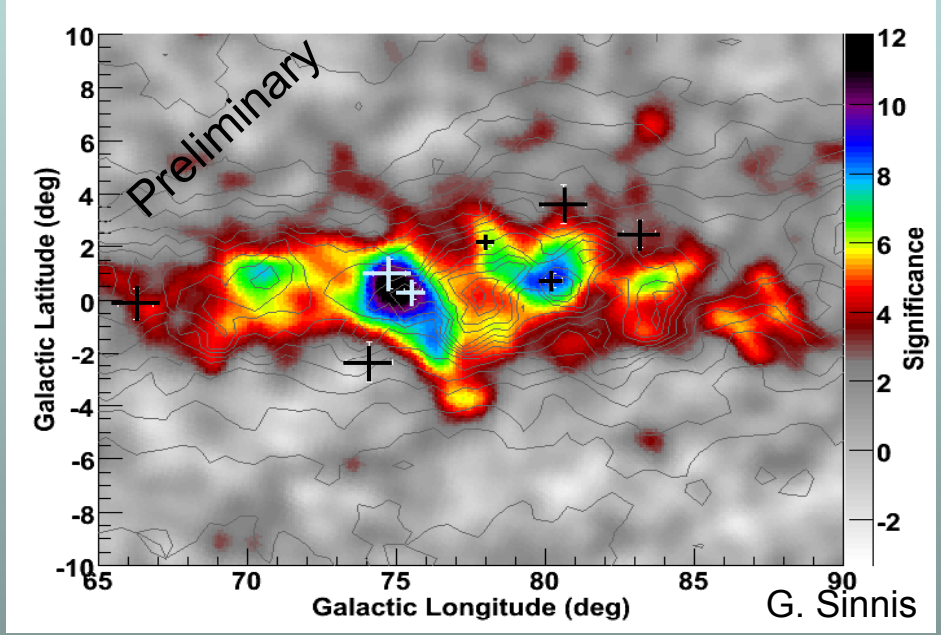
J. Rico

Diffuse VHE Sources
Galactic Center and Cygnus

J. Hinton



Milagro Cygnus Region
EGRET GeV Map underlay



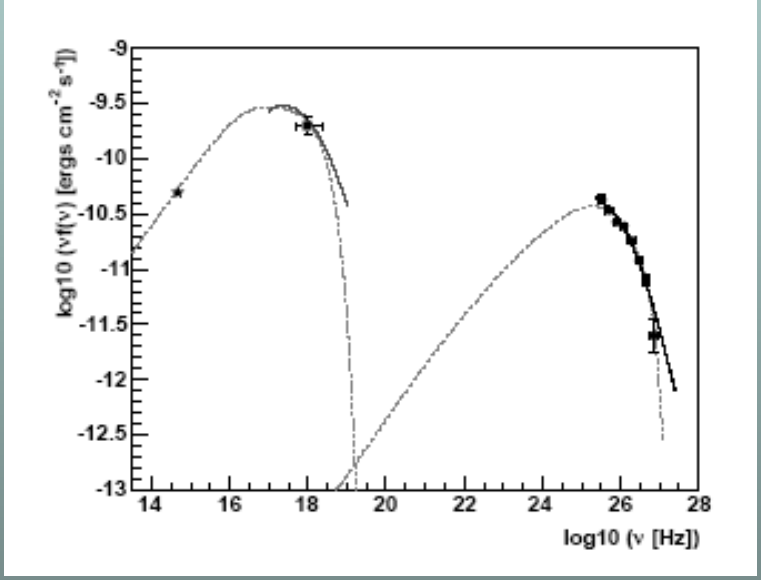
TeV emission along Gal. plane.
CRs interacting with molecular clouds.

Evidence for new source of diffuse TeV radiation.
CR interactions !

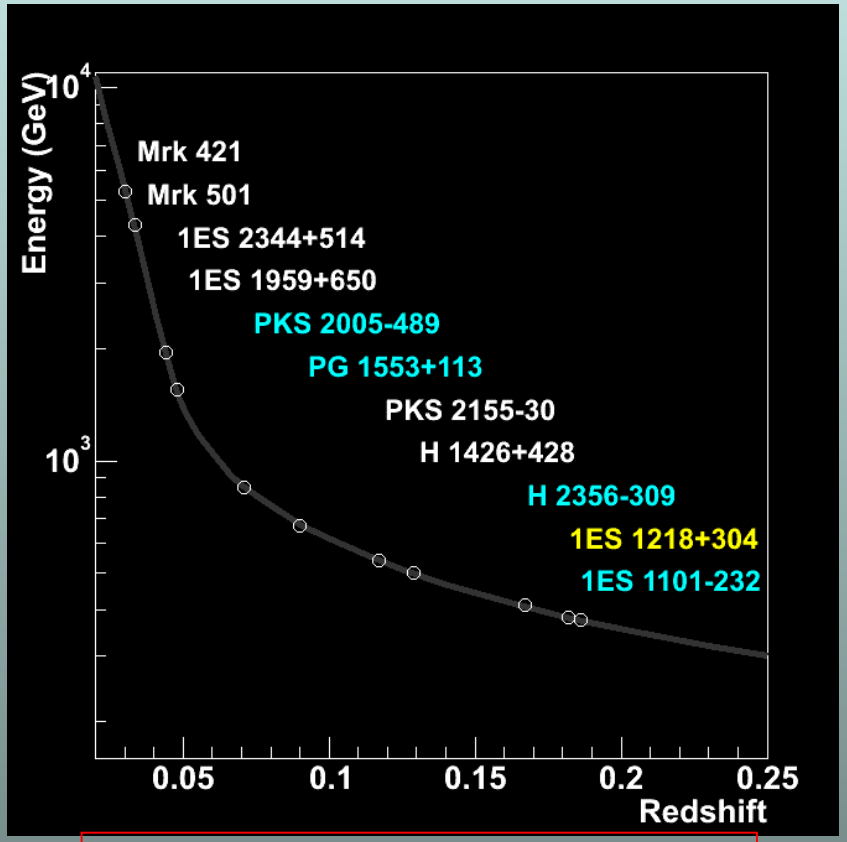
Extragalactic TeV Sources

Now 12 known AGN (& M87)

- AGN are Blazars – relativistic jet beamed to us
- 2 peak spectra
- Highly variable !

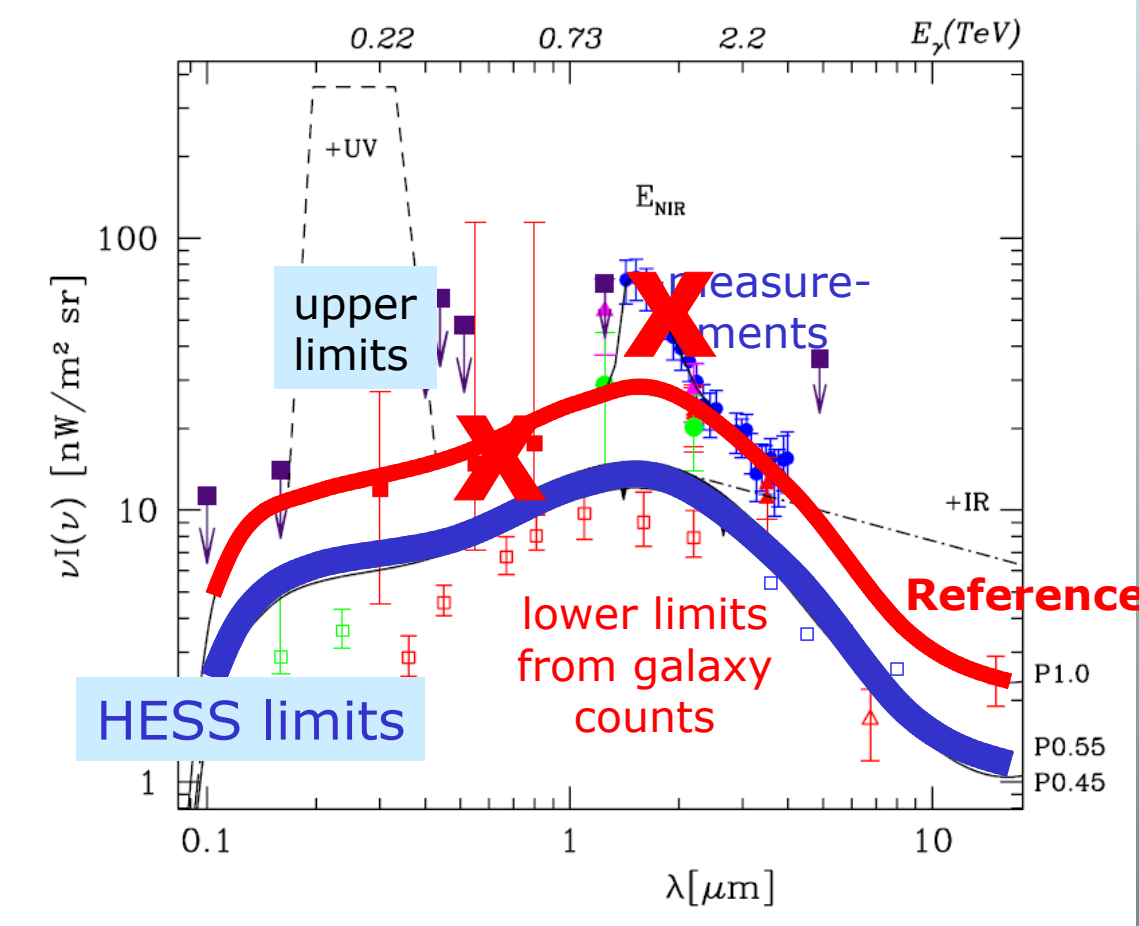


MAGIC – Mrk 421 and model fit.



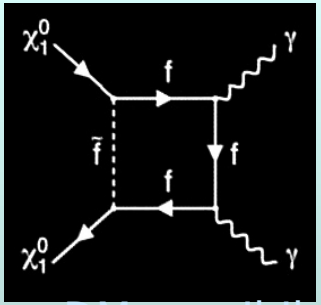
Looking out further in redshift.

Extragalactic Background Light



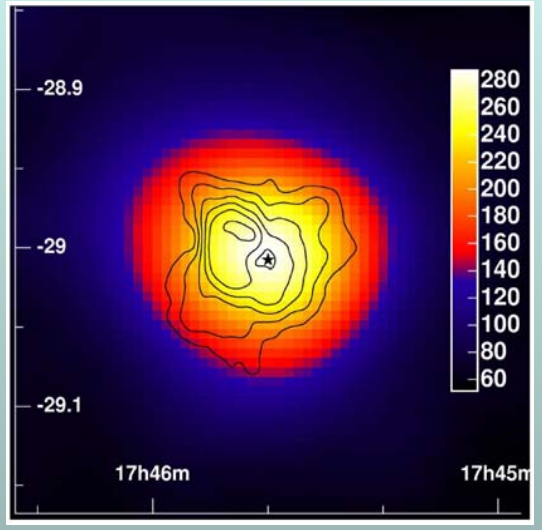
Universe is more transparent !

Dark Matter I



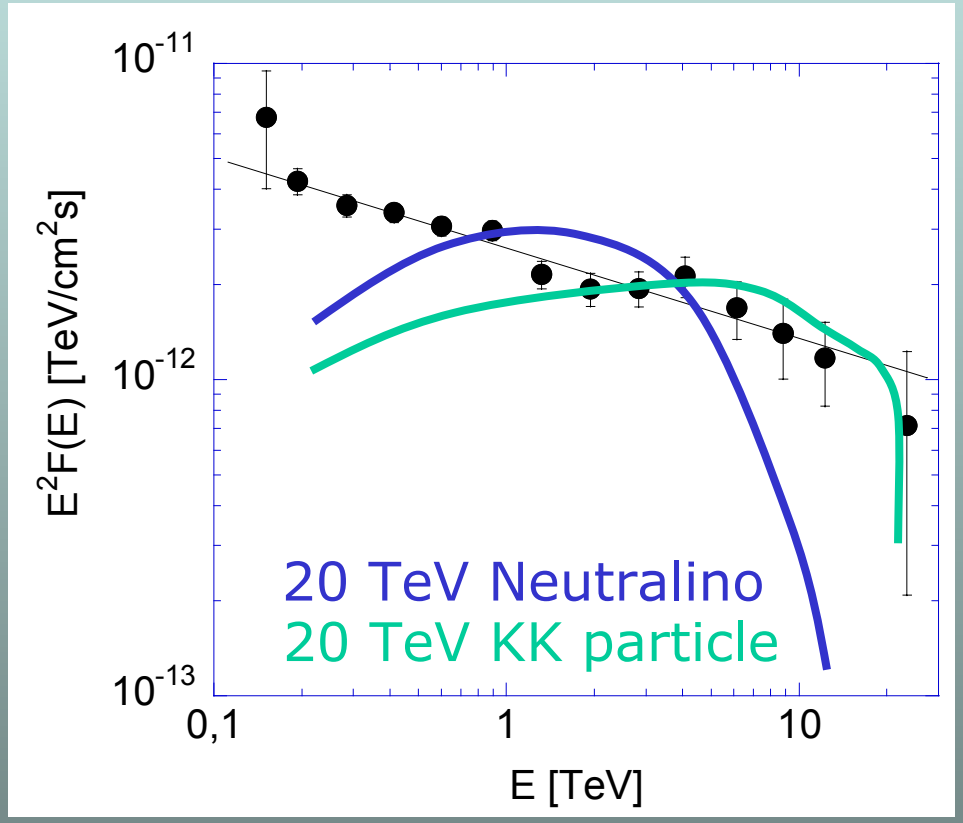
?

DM annihilation



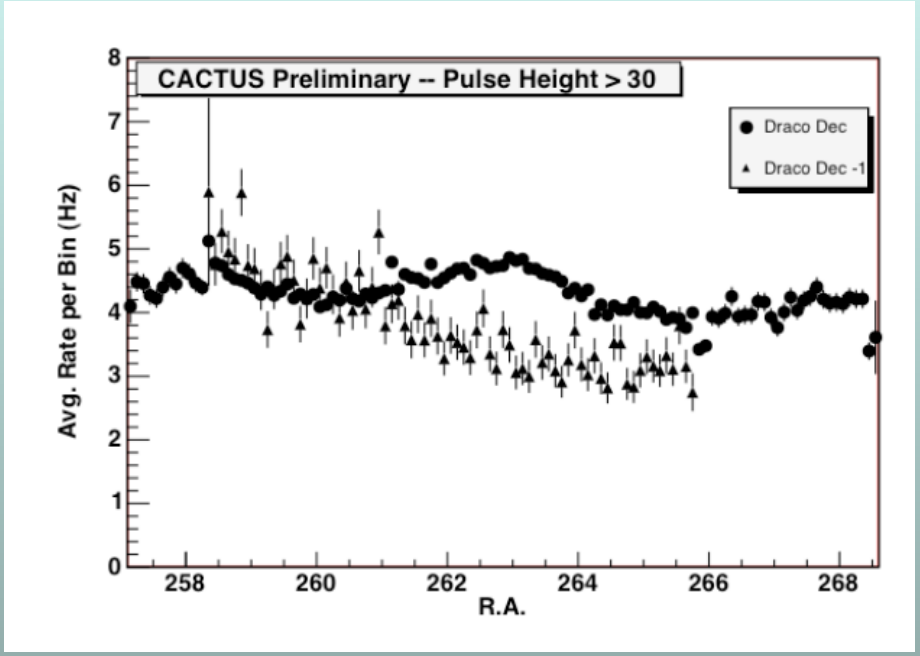
HESS – Galactic Center.

Results also from MAGIC.



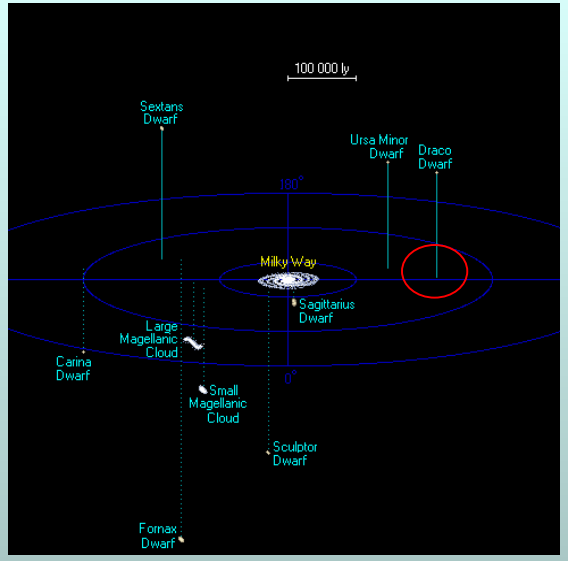
Astrophysics dominates –
but we don't know what it is !

Dark Matter II



CACTUS (2005) –
Claim evidence for 100 GeV γ-rays from Draco.

2.4 hr data. Large γ-ray excess.



Draco Dwarf Satellite

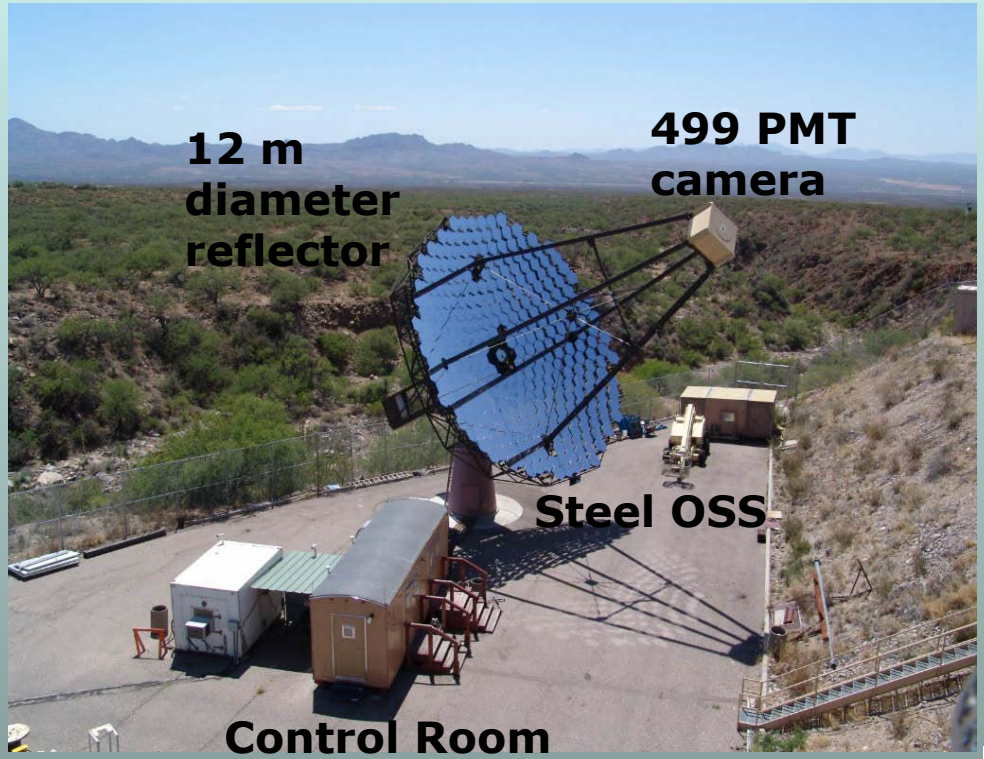
New result from STACEE (preliminary)

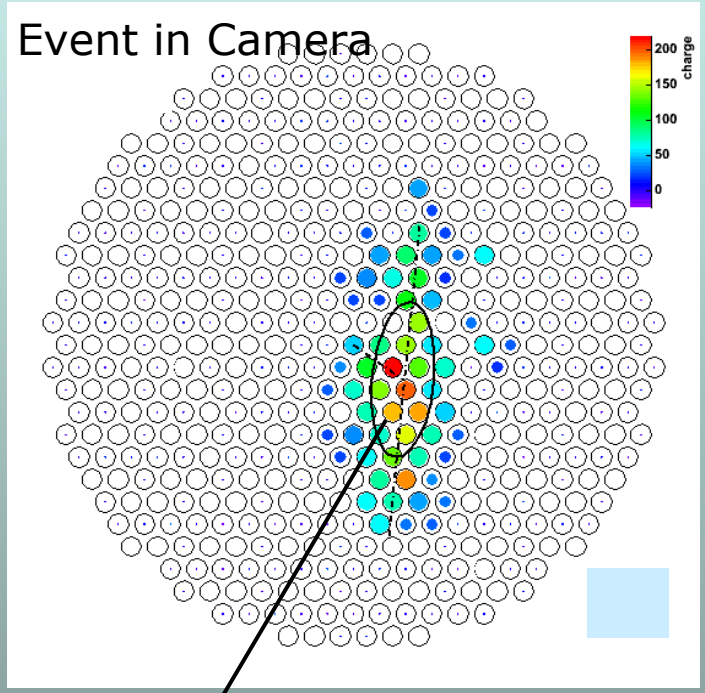
- 10.2 hr data, Apr-Jun 2006.
- No γ-ray signal.
- Rate, R < 0.085 γ/min (95%).
- Flux (>200 GeV) < 1.9 x 10^{-11} /cm^2/s

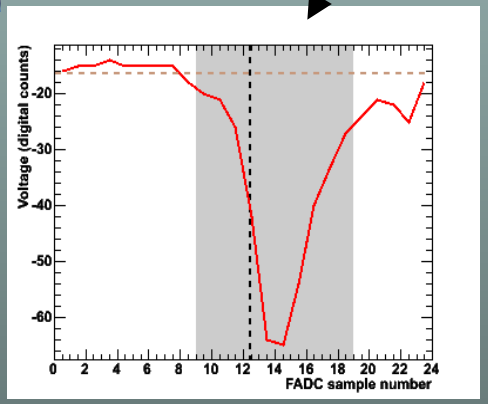
CACTUS also now sees no signal. (Tripathi, ICHEP 2006)

Upcoming Projects

VERITAS





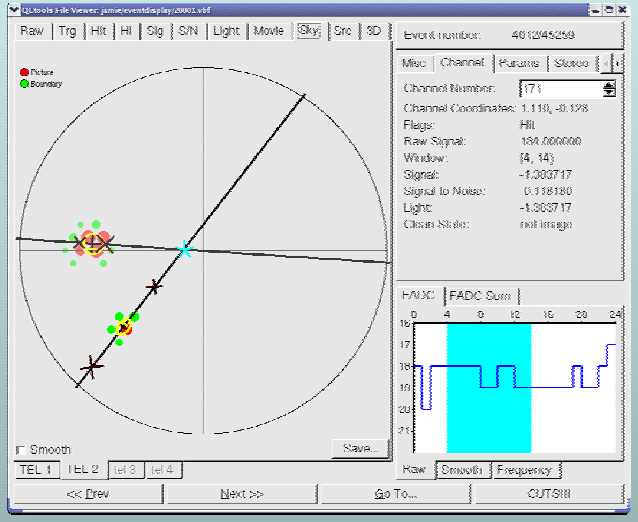


VERITAS – Arizona, USA

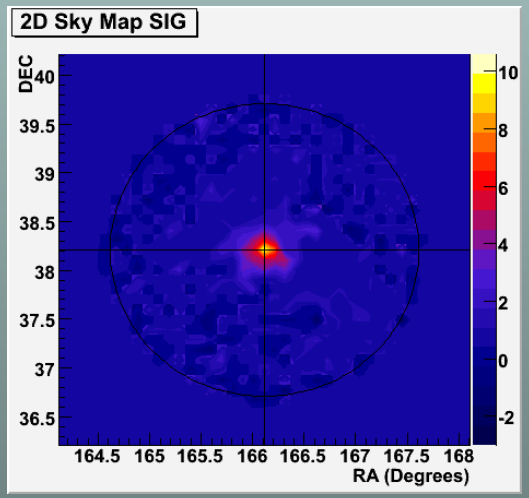
Similar to HESS:
4 x 12m Telescopes
500 element cameras, 3.5^{o}

500 MHz FADC on each pixel.

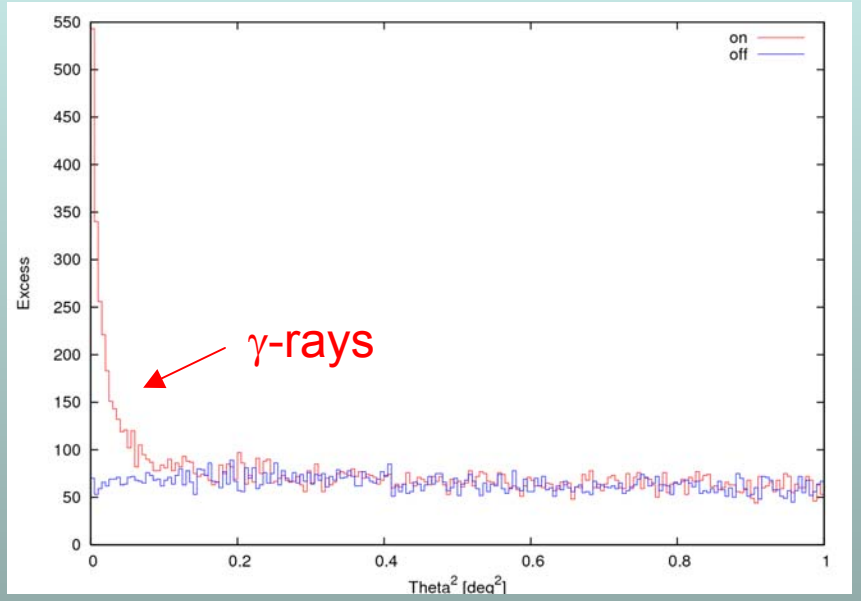
VERITAS: 2 Telescope Operation



VERITAS Event
April 2006



Mrk 421 Image



Strong γ-ray signal:
Mrk 421, 4 hr data,
30 σ, ~6 γ/min (not optimized)

(Whipple 10m: 1.8 γ/min)

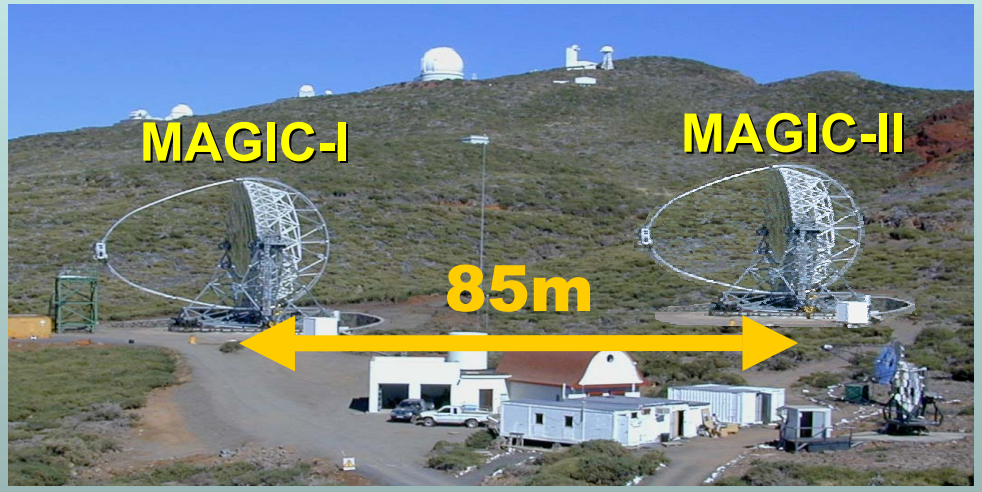
VERITAS: Array Completion

Whipple Base Camp
July 2006
1350m, dark site

Telescope 4
July 2006

- **Oct 2006: 3 Telescope operation:**
  Science observations begin.
- **Feb 2007: 4 Telescopes !**

MAGIC II and HESS II



MAGIC-II (2007)

- Second 17m telescope.
- High-QE camera.

(F. Goebel, parallel session)

HESS-II (2008)

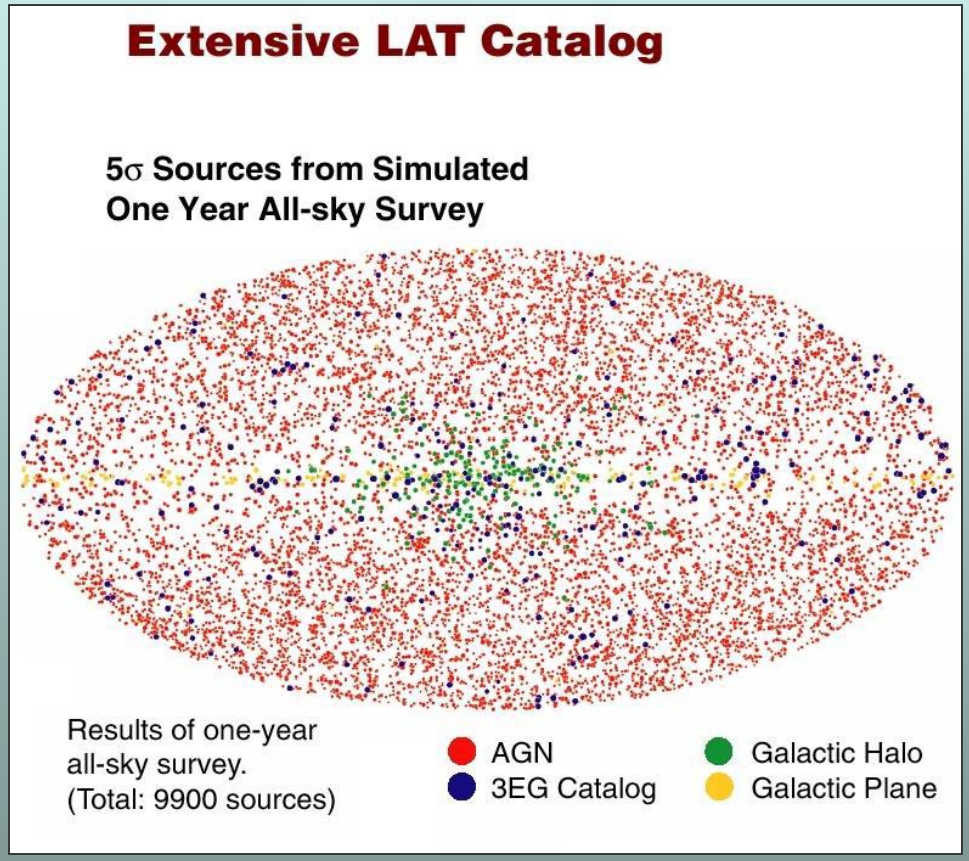
- New 28m telescope.
- 2048 pixel camera.
- Lower energy ~50 GeV.

(J.P. Tavernet, next talk)

GLAST – Satellite Telescope

GLAST LAT:

- **Si strip tracker.**
- **CsI calorimeter.**
- **Energy range 0.03-300 GeV**



Simulated sky map from 1 year survey.
Scheduled launch: Sept. 2007.

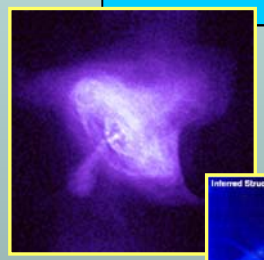
GLAST will have a huge impact on the field.

Future Directions

GLAST

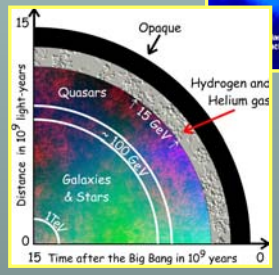
A. Konopeloko

10 - 100 GeV	100 GeV – 10 TeV	10 – 100 TeV



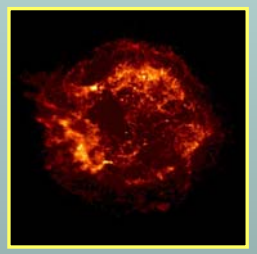
Pulsars & PWN

AGNs



Cosmology

HESS, VERITAS CANGAROO III MAGIC



SNRs

Origin of cosmic rays

Dark matter

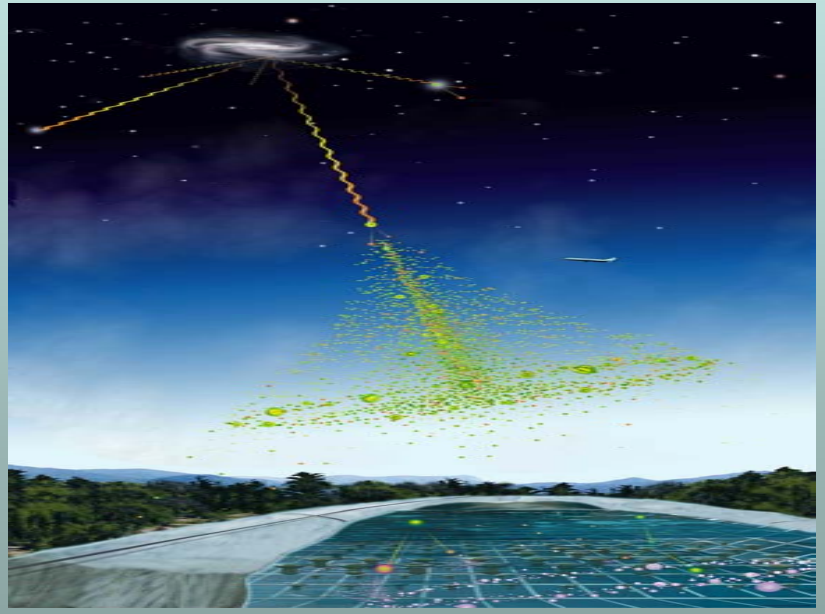
Ong (UCLA)

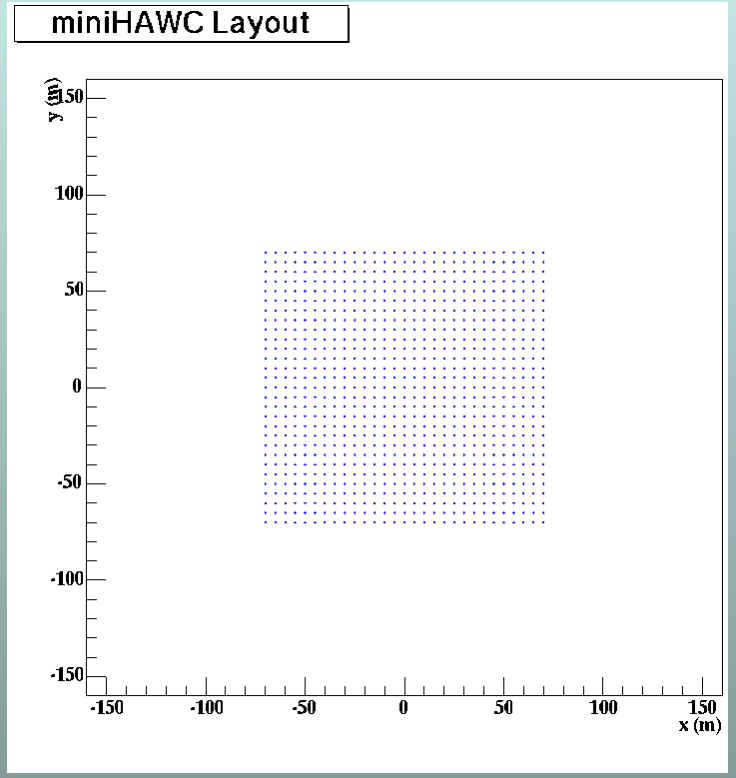
Better sensitivity!
Wider FOV

GRBs

There is a wide variety of opinion on what direction(s) to pursue.

Future Concepts
mini-HAWC





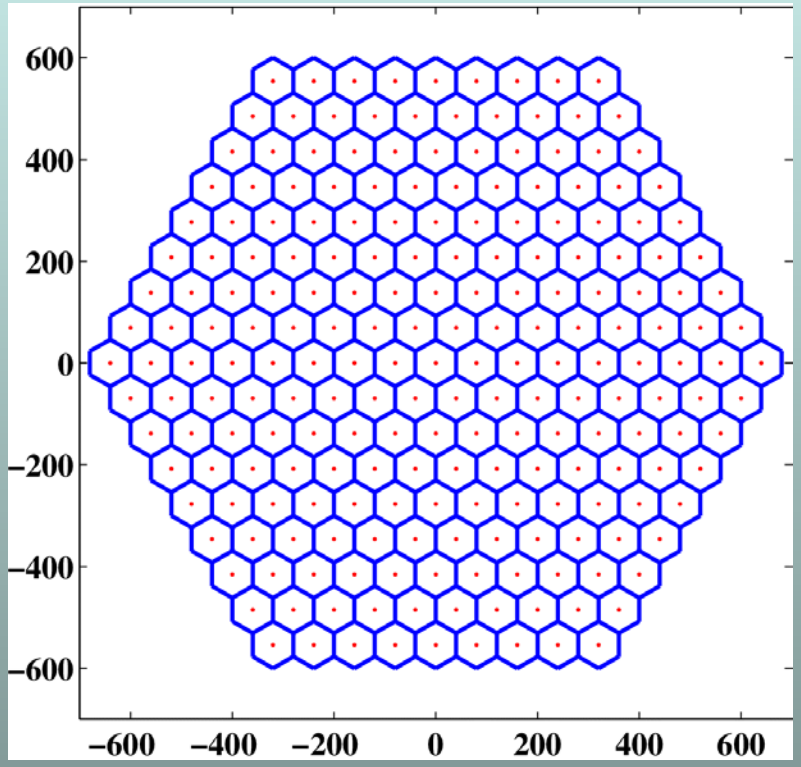
mini-HAWC:

- **Air shower detector:**
  wide FOV and good duty cycle.
- **Moderate sensitivity & resolution.**
- **Energy E > 500 GeV.**

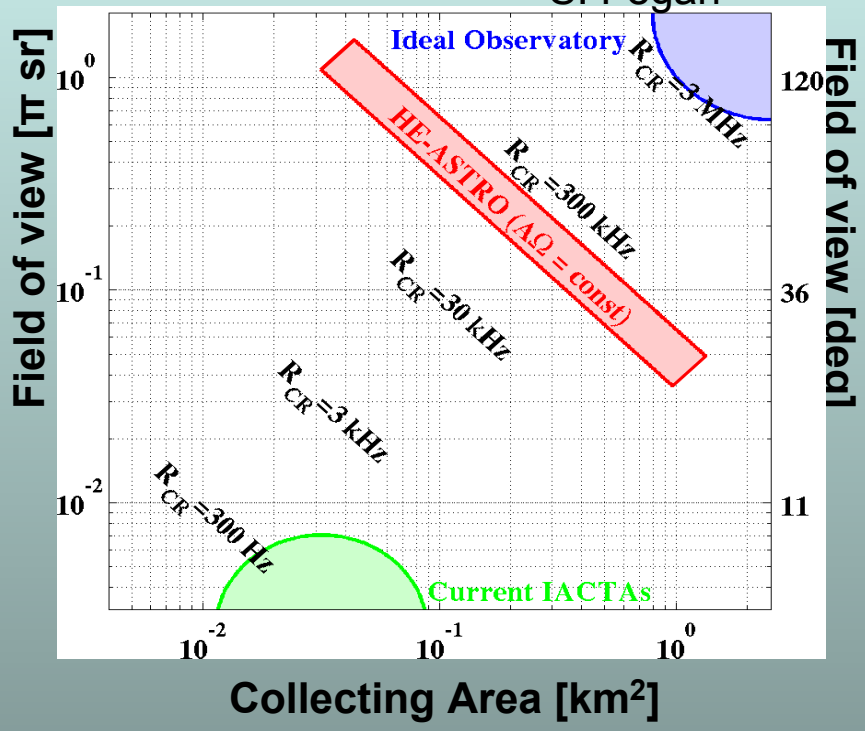
miniHAWC:
841 PMTs (29x29)
5.0 m spacing
Single layer with 4m depth

Instrumented Area:	**22,500 m^2**
PMT spacing:	**5.0 m**

Future Concepts
Large Cherenkov Tel. Arrays



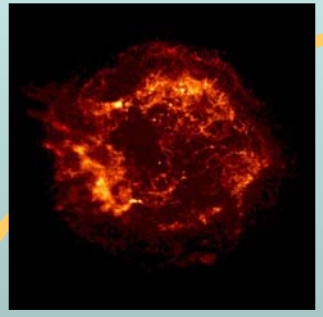
S. Fegan



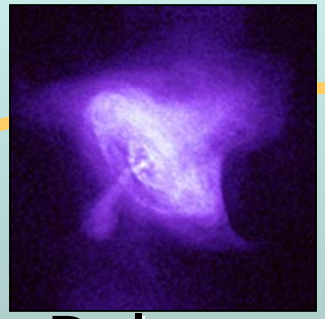
HE-ASTRO:
217 Telescopes (ø10m), 80m separation.
1.1 km^2 collection area & 12^o FOV.
Challenging !

Also, detailed work in Europe and Japan. Cherenkov Telescope Array (CTA) concept well underway.

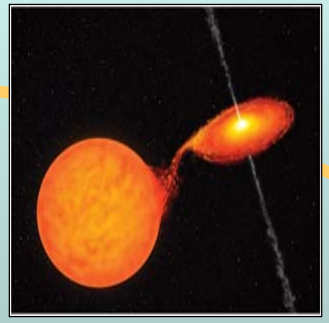
The VHE γ-ray Science Program



SNRs
Origin of
Cosmic Rays

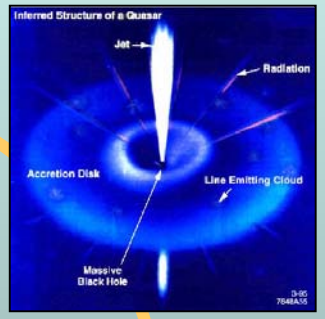


Pulsars



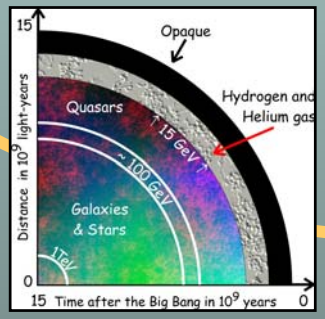
Microquasars

M. Martinez

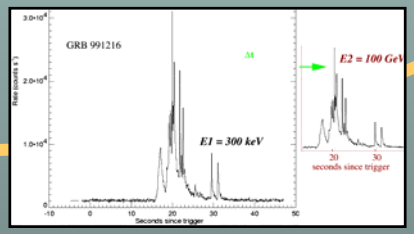


AGNs

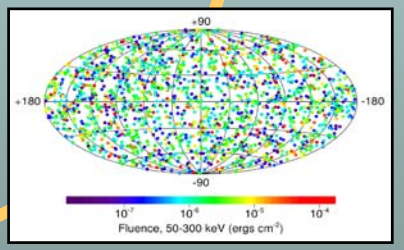
Cold Dark
Matter



cosmological
γ-Ray Horizon



Test of the speed
of light
invariance



GRBs

SUMMARY

- New generation of Cherenkov telescopes has yielded outstanding results – many new sources discovered in last two years – an unprecedented increase.
- Galactic Plane is rich in the number and type of VHE sources. Pulsar nebulae and SNRs are both firmly established in the TeV band. Origin of CR's is still an important question.
- New discoveries increase the number of known TeV blazars and push further out in redshift. Universe is more transparent than expected.
- No real evidence for DM from TeV γ-ray measurements, but technique is a key complement to direct and LHC.
- Upcoming experiments on ground (VERITAS) and in space (GLAST) should continue the rapid development of VHE astrophysics. Others will follow… !

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