ICRC 2005
Rapporteur OG 1

γ-ray
Science and Techniques

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SESSIONS & PAPERS

Session	Topics	Oral	Poster	Total
OG 2.1	Diffuse X-rays, γ-rays	10	10	20
OG 2.2	Galactic Sources (SNRs, pulsars, etc.)	29	21	50
OG 2.3	Extragalactic Sources (AGN, clusters, etc.)	23	18	41
OG 2.4	Gamma-Ray Bursts	6	7	13
OG 2.7	New expts. & instrumentation	33	44	77
Total		101	100	201

Can choose:

- **Say "nothing about everything".**
- **Say "something about something". ← try this.**

Caveats & Acknowledgements

- **Large number of papers … all received quite late …**
  so this summary:
  - concentrates on highlights from this meeting,
  - is subjective and condensed.

  Write-up will contain more information.

- **Relatively little from outside VHE γ-rays, and mostly observational results.**

- **Papers (results) are referenced by presenting author.**

- **Considerable thanks to:**
  - Organizers.
  - Experimental groups with results (5 or more papers):
    AGRO-YBJ, CANGAROO, HESS, MAGIC, Milagro,
    STACEE, TACTIC, Tibet, VERITAS.

OUTLINE

- **Instruments and Techniques**
- **Scientific Highlights**
- **Source Count & Map**
  - Where are we relative to 1995 (Hillas), 2003 (Mori)?
- **Science Results**
  - Arranged session by session.
- **New Experiments and Instrumentation**
- **Conclusions**

Instruments (Past and Present)

- **X-ray:**

  RXTE, ASCA, Chandra, XMM-Newton

- **Gamma-ray (Satellite, 100 keV-20 GeV):**

  EGRET, INTEGRAL*, Swift

- **Gamma-ray (Cherenkov, E > 50 GeV):**

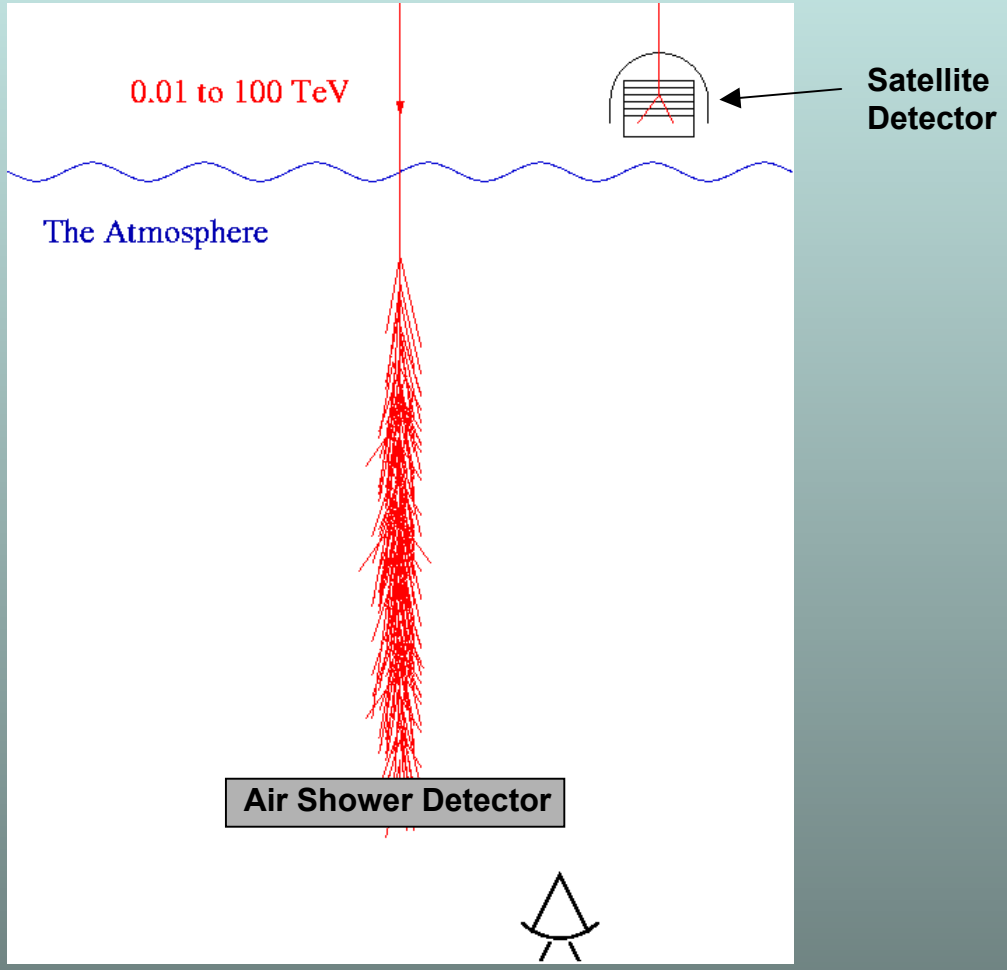
  Whipple, PACT, STACEE, TACTIC, Shalon, CANGAROO, HESS, MAGIC, VERITAS

- **Gamma-ray (Air Shower, E > 100 GeV):**

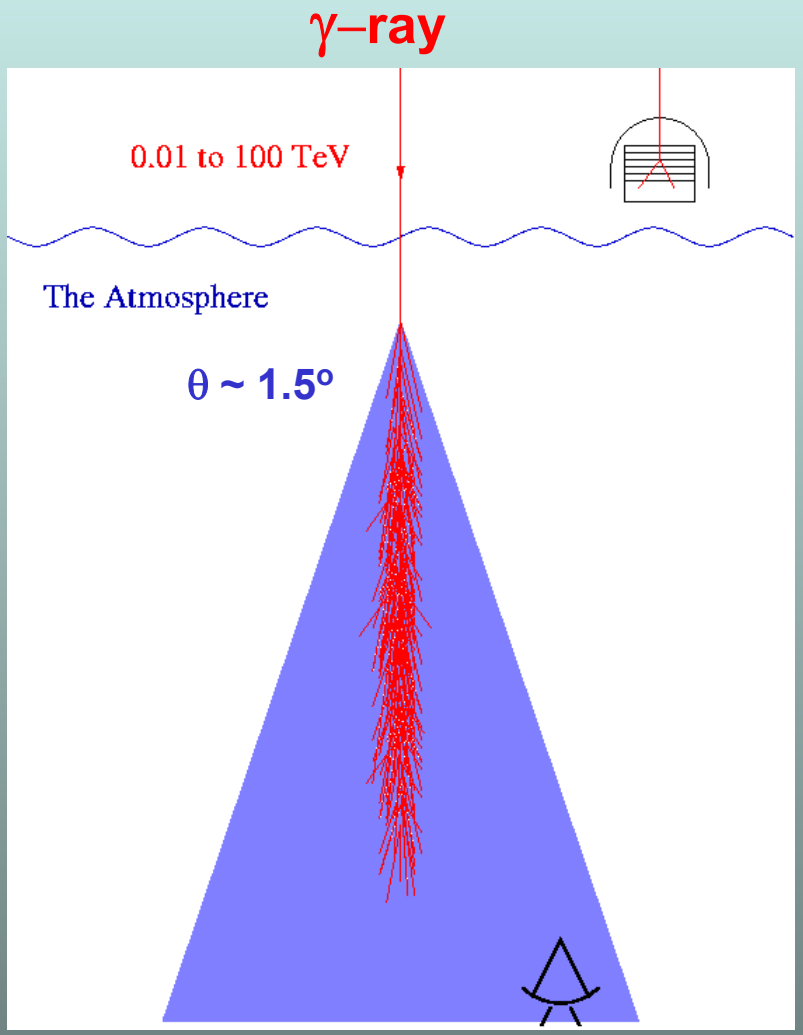
  Tibet, Milagro, GRAPES-3, ARGO-YBJ

*Science summary by Produit (OG 2.2).

Air Shower Detectors



Cherenkov Telescopes



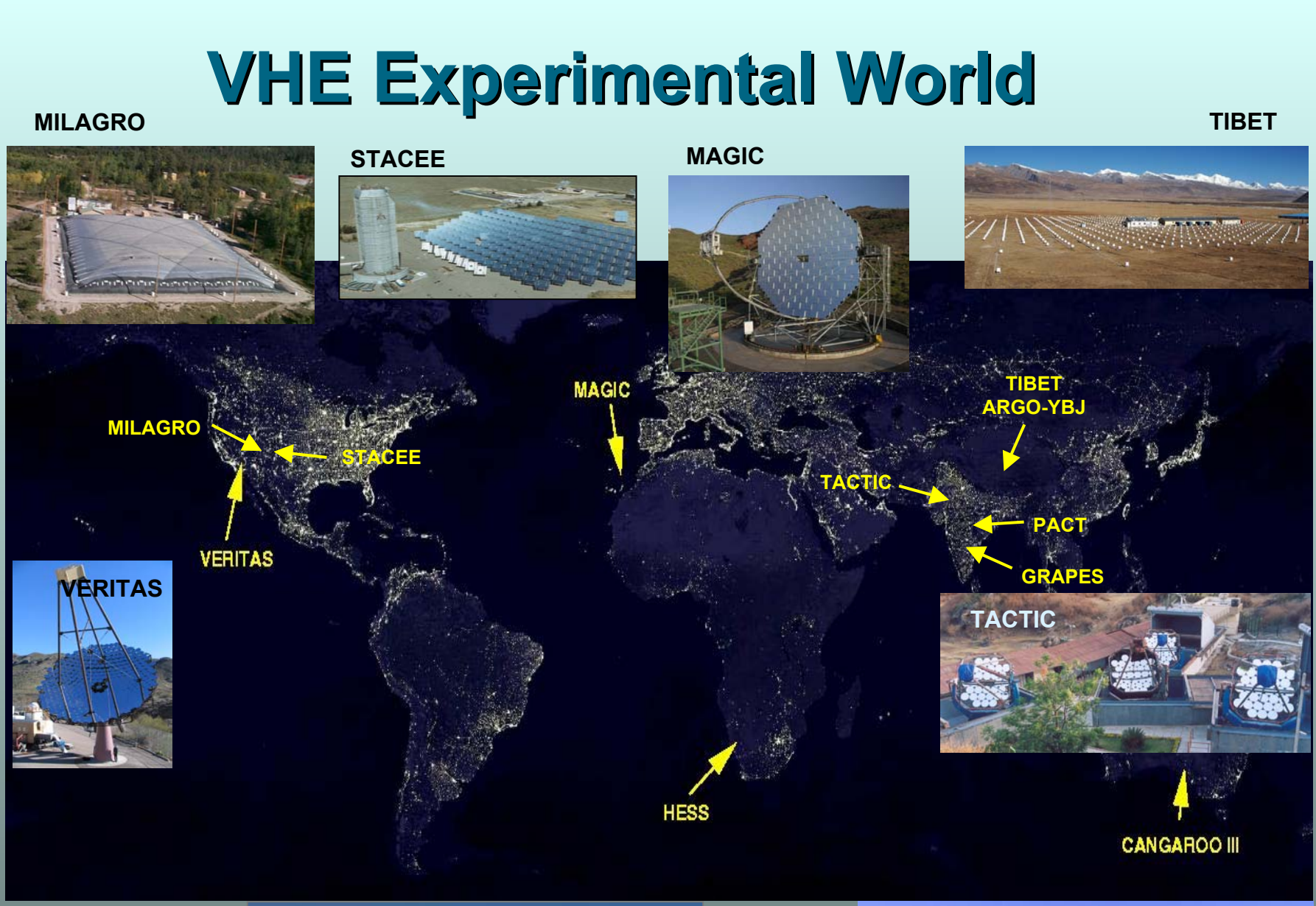
VHE Experimental World

MILAGRO

STACEE

MAGIC

TIBET



VERITAS

TACTIC

HESS

CANGAROO

Scientific Highlights

I. Discovery of many new Galactic sources by HESS:

- HESS GP Survey & targeted observations.

II. Detailed studies of Galactic sources:

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

III. Discovery of 4 new AGN by HESS and MAGIC.

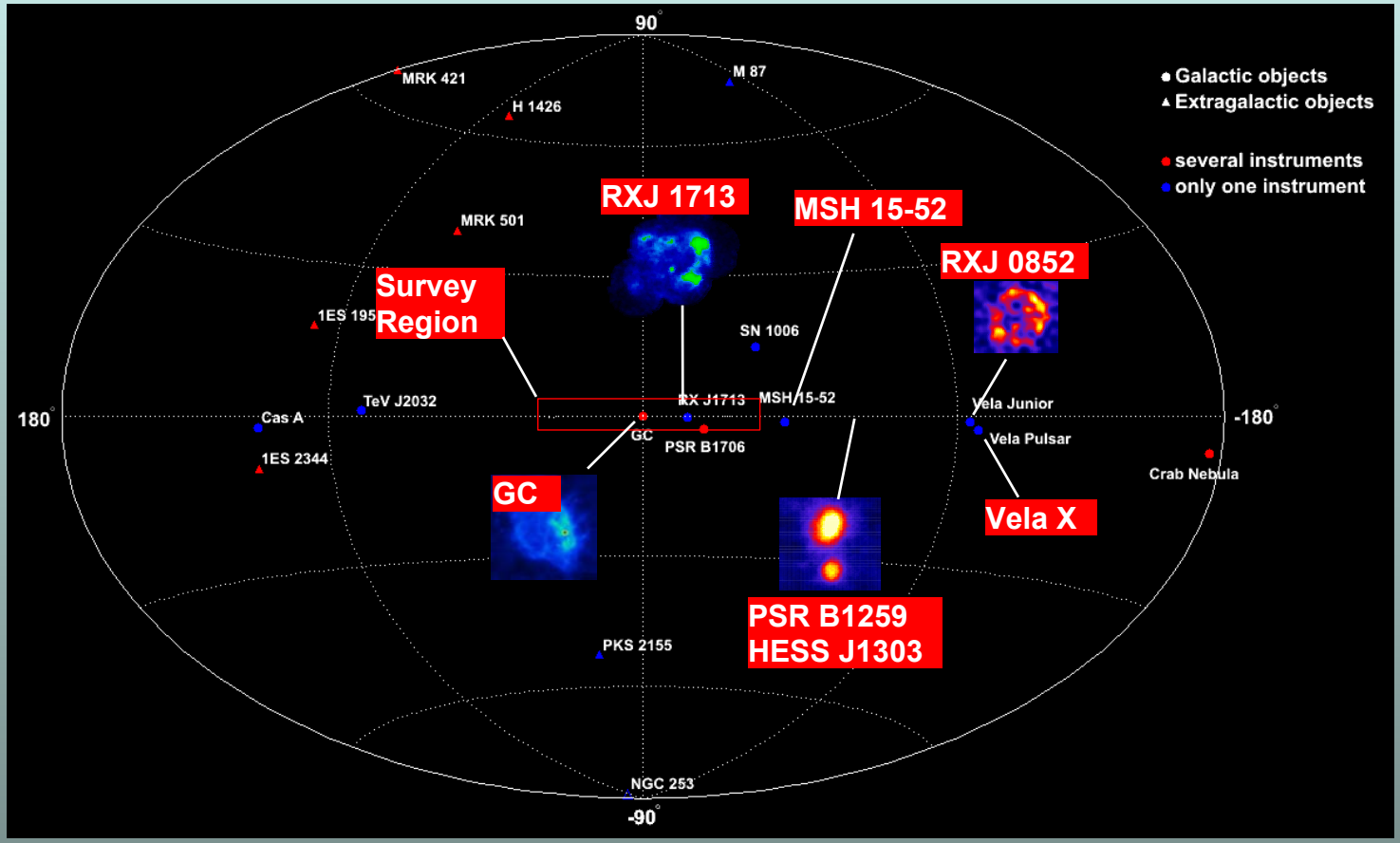
- Measurements of AGN properties and multi-λ studies.

IV. Other new observations:

- Detection of diffuse emission in Cygnus by Milagro.
- Searches for new galactic and extragalactic sources.

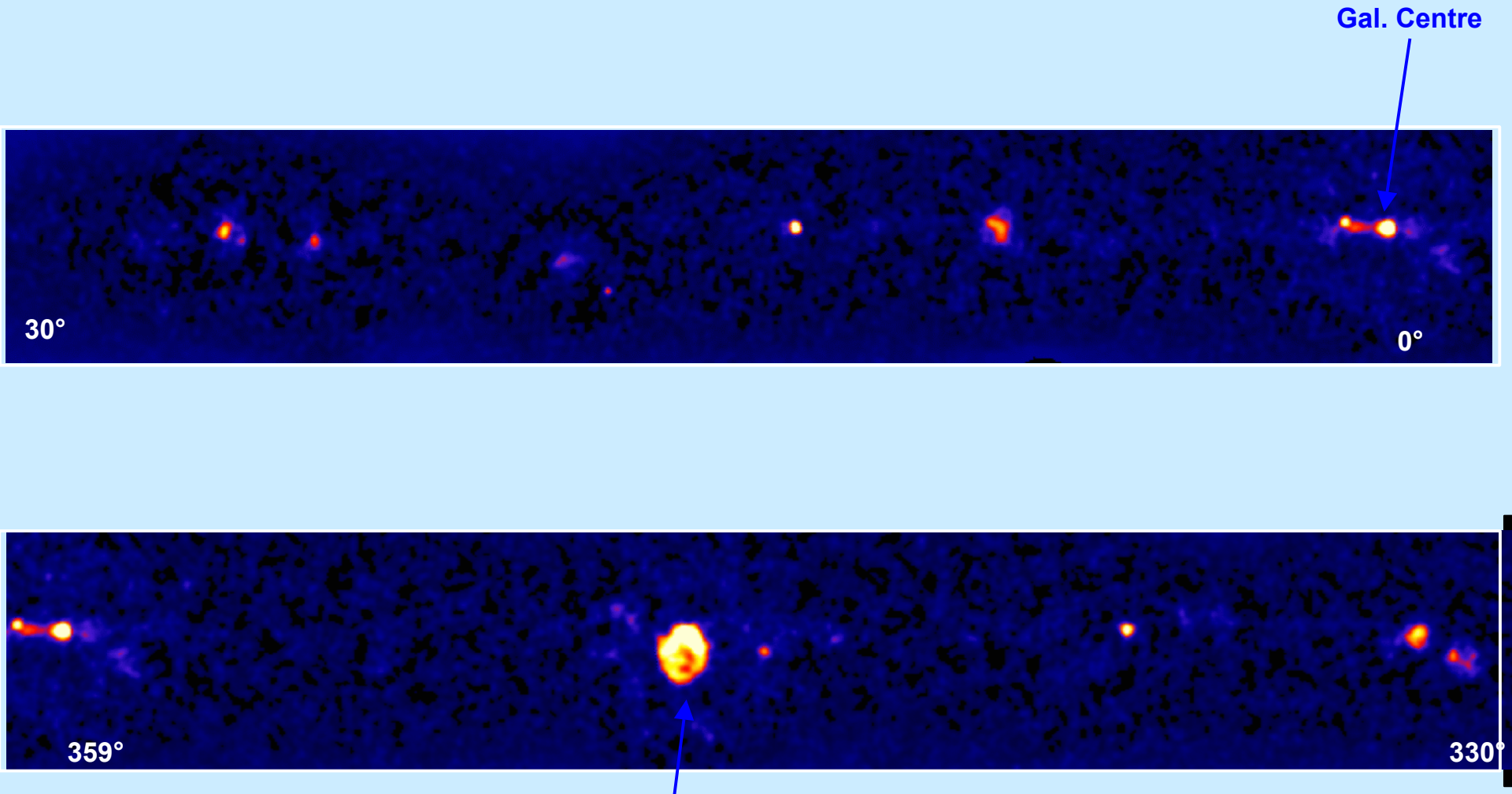
HESS Galactic Plane Survey

[Funk, Lemiere]

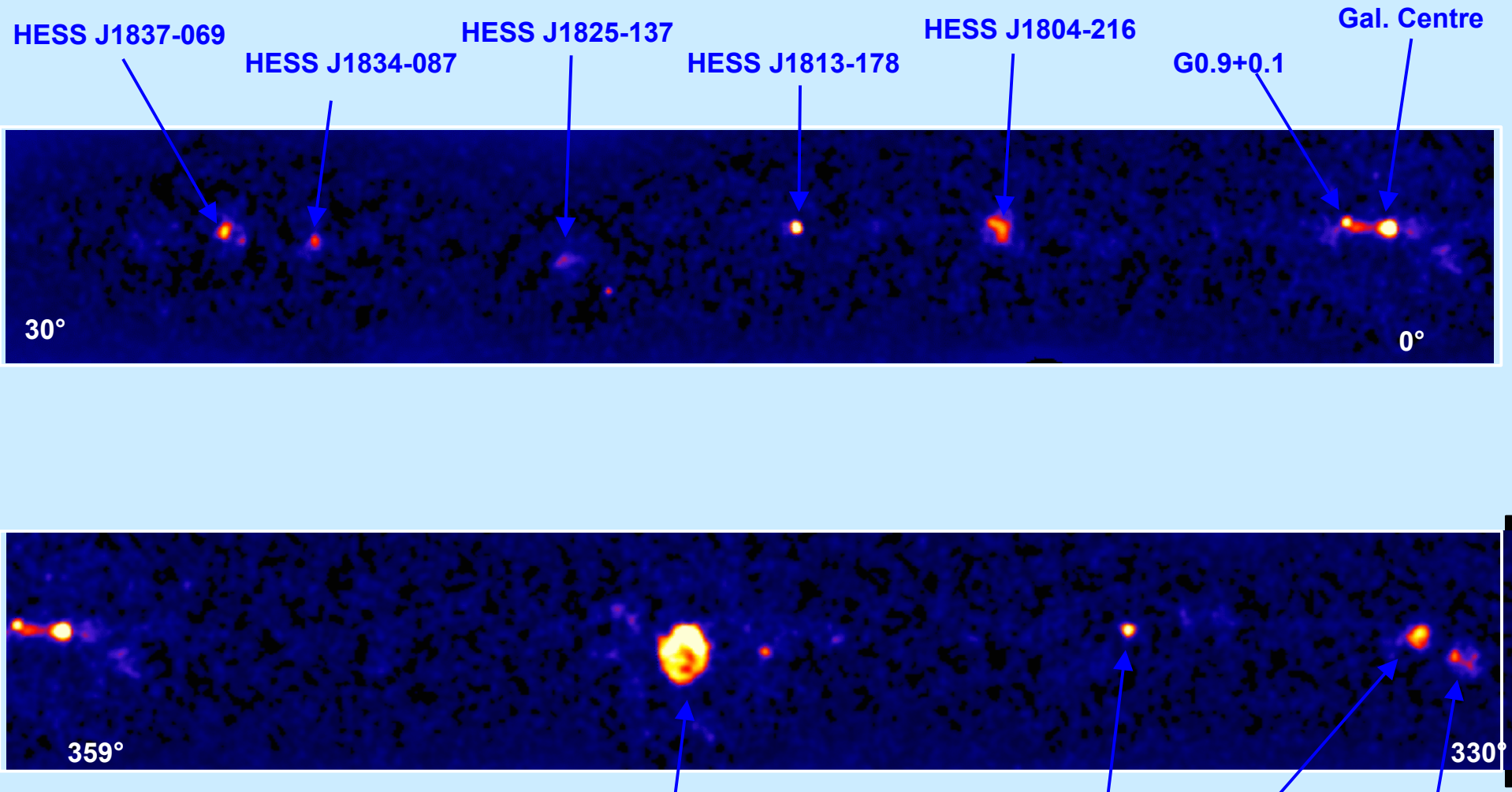


- 60° in longitude, ± 3° in latitude
- 112 hrs scanning + follow-up observations

HESS GP Survey

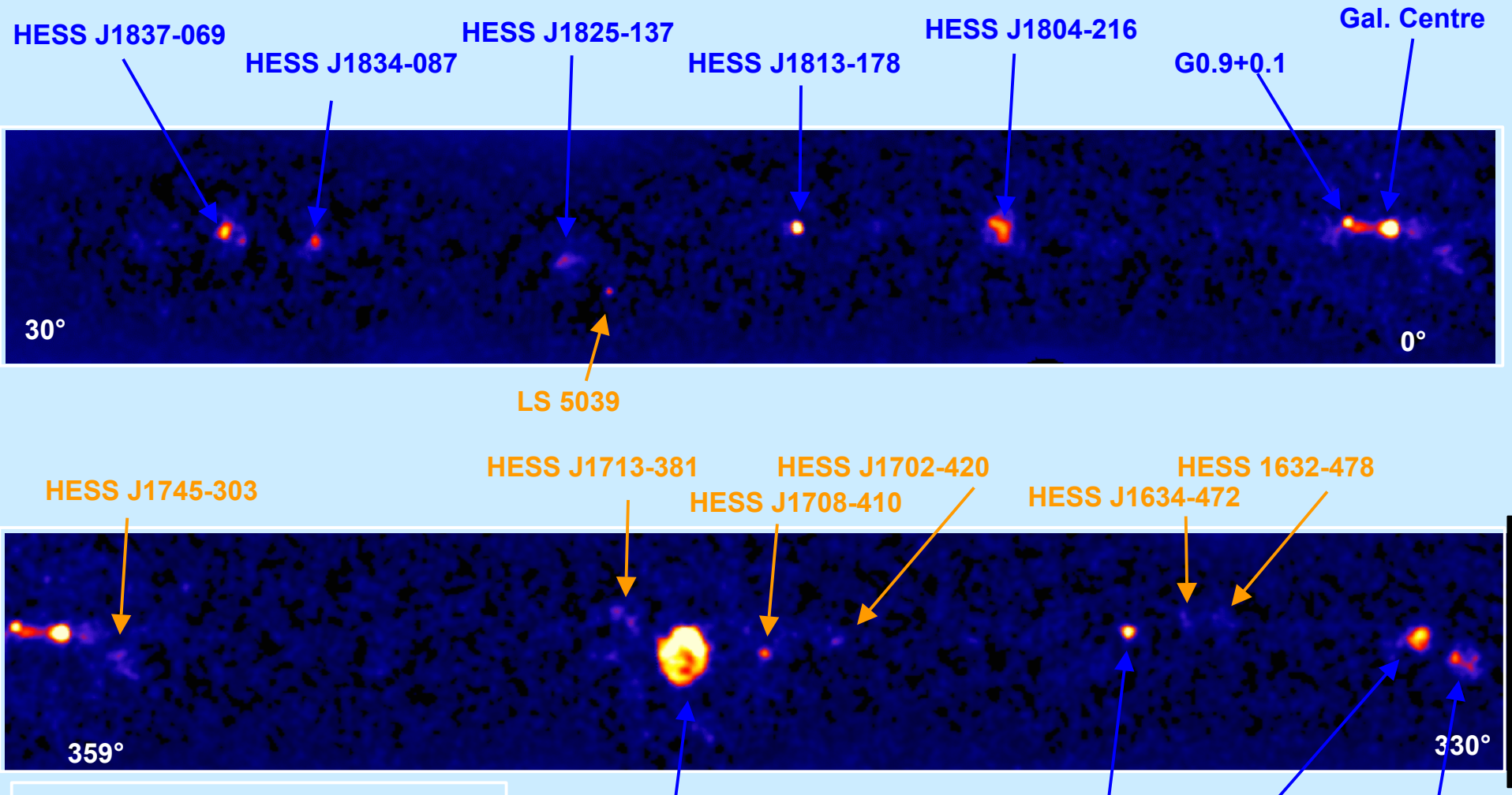


HESS Survey: New sources



Sources > 6 sigma (9 new, 11 total)

HESS Survey: New Sources



Sources > 6 sigma (9 new, 11 total)

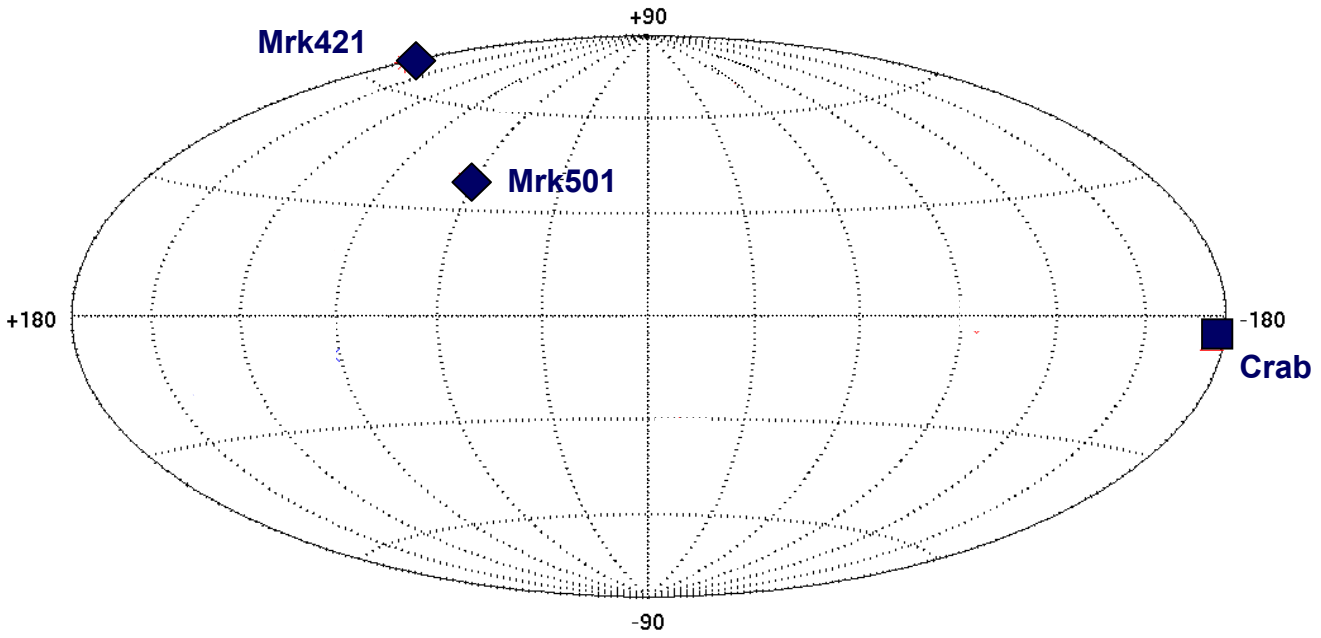
Sources > 4 sigma (7 new)

HESS GP Source Associations

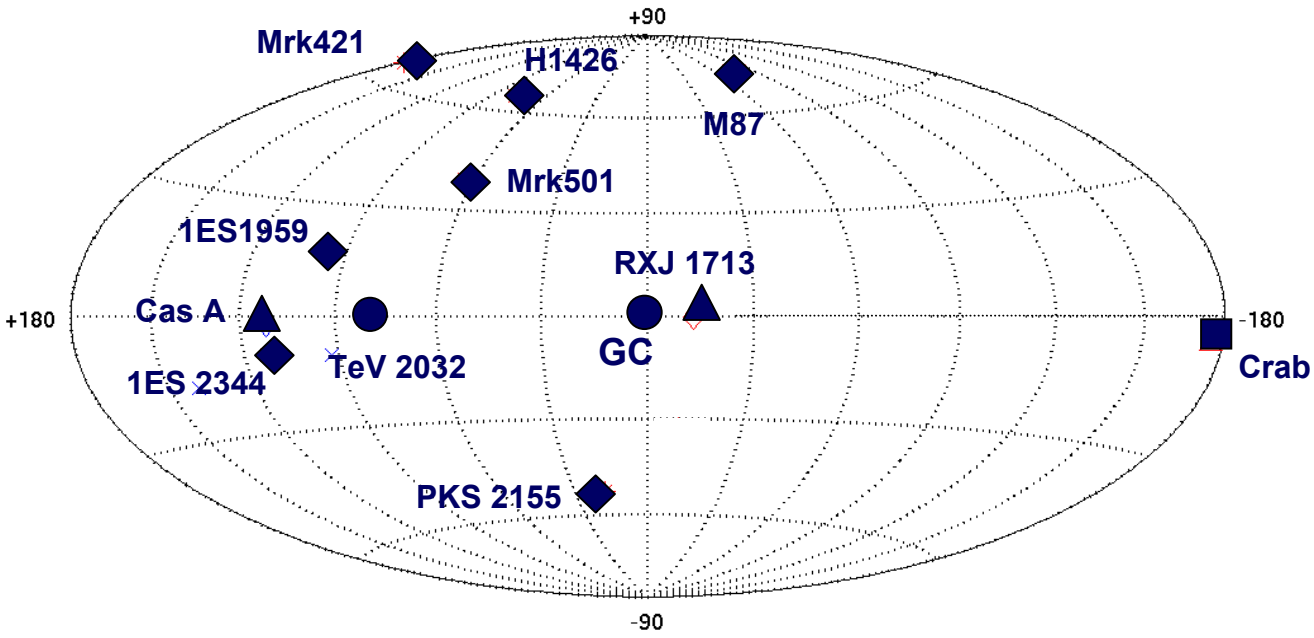
Source	Possible Association	Comments
G0.9+0.1	PWN/SNR	Firm Association
LS 5039	Micro-Quasar	Firm Association
J1616-508	PWN ?	Tentative
J1614-518		Unid ?
J1640-465	SNR ? (G338.3)	Tentative
J1804-216		Unid ?
J1813-178	SNR ? (G12.8-0.0, Integral)	Tentative
J1825-137	PWN ? (PSR J1826)	Tentative
J1834-087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

Study spatial association and correlation with HI/CO maps [Lemiere].

The VHE Sky - 1995



The VHE Sky - 2003



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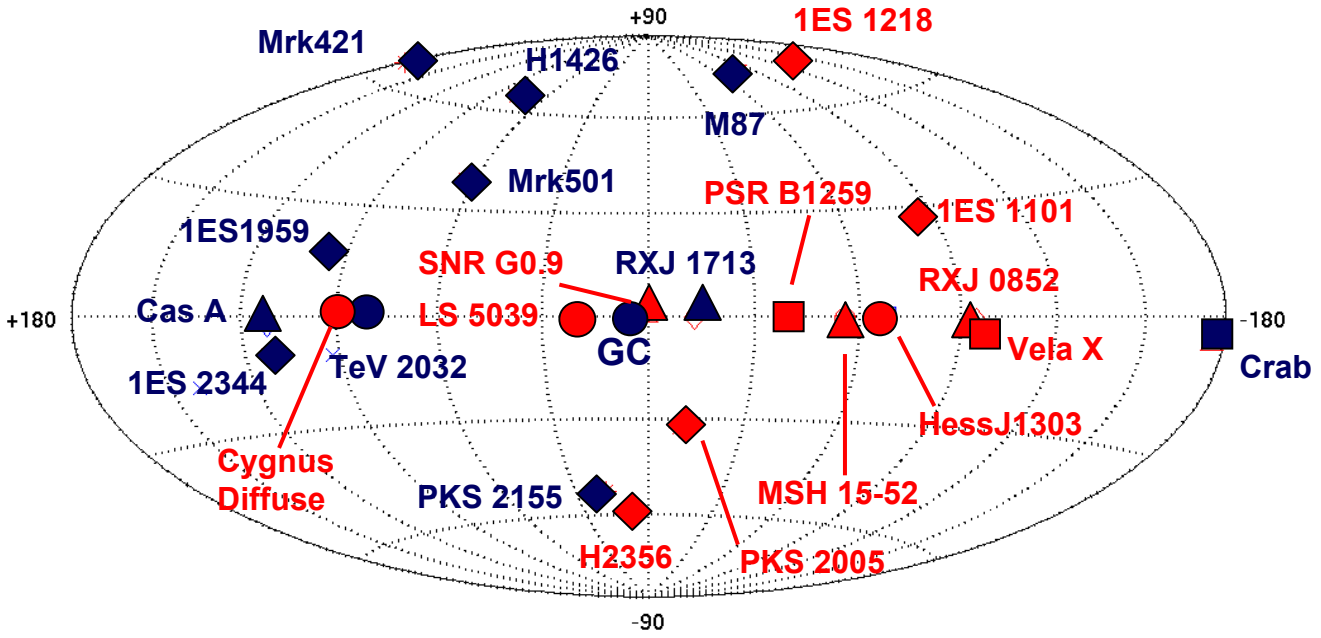
Aug 2005

The VHE Sky - 2005

+ 8-15 add. sources in galactic plane.



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Aug 2005

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.**

SCIENCE RESULTS
Session by Session

OG 2.2 – Galactic Source
OG 2.1 – Diffuse Sources
OG 2.4 – Gamma-Ray Bursts
OG 2.3 – Extragalactic Sources

OG 2.2
Galactic Sources

OG 2.2: Galactic Sources

1a. Pulsar Nebulae (PWN)

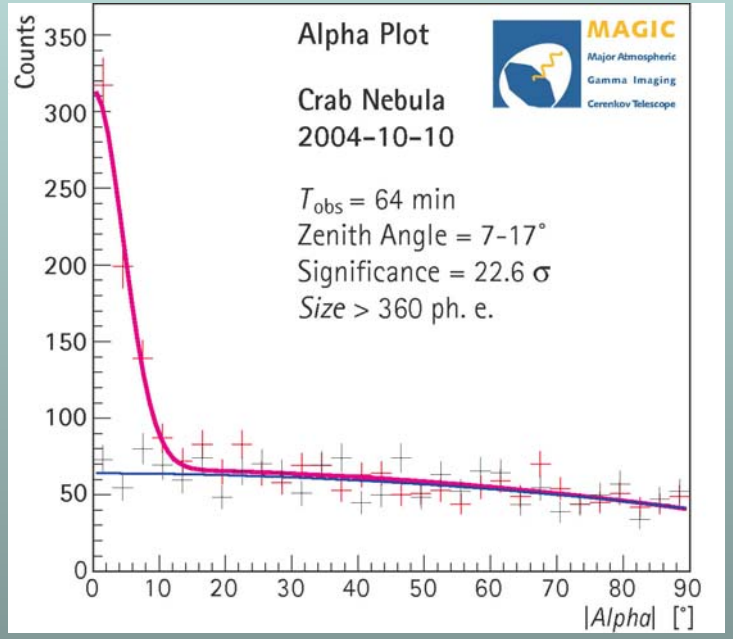
- Pulsar wind powered. Known e^- accelerators (synch and IC).
- "Standard Candle" (Crab).

Known (2003):	**Crab**	**HESS [Masterson], MAGIC [Wagner], STACEE [Kildea], TACTIC [DHAR], CANGAROO [Nakamori]**
New Sources:	**MSH 15-52**	**HESS [Khelifi]**
	G0.9+0.1	**" "**
	Vela X	**" "**
	J1616-508	**HESS association [Funk]**
	J1825-137	**HESS association [de Jager]**

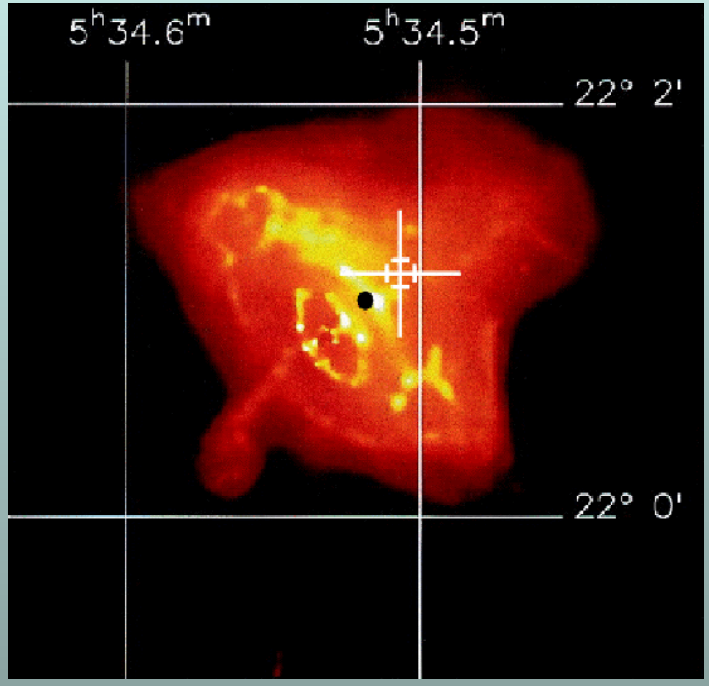
6 established VHE pulsar nebulae.

OG 2.2: Galactic Sources

CRAB



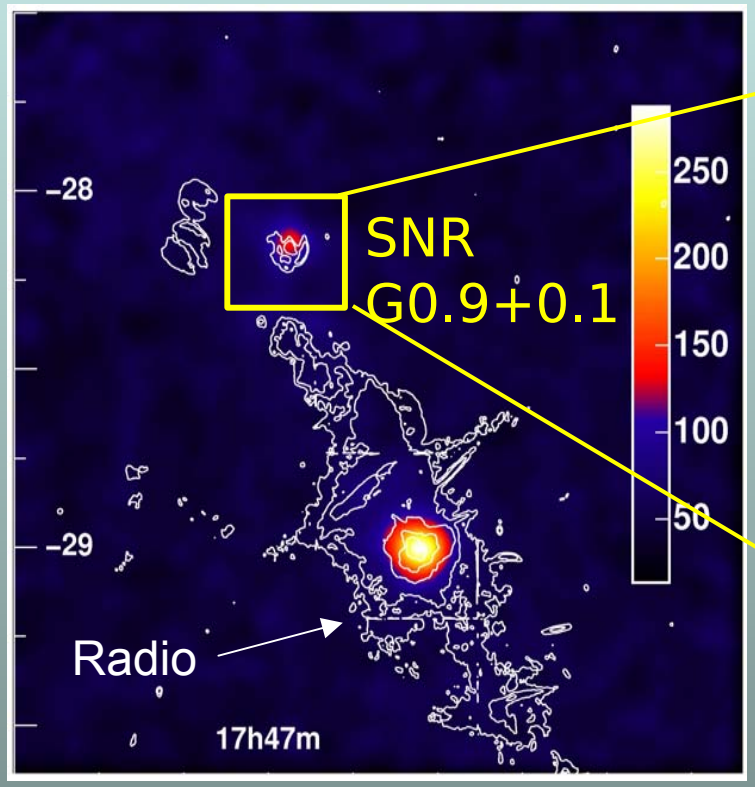
MAGIC [Wagner]:
22.6 σ/hour
Spectrum from 300-3000 GeV

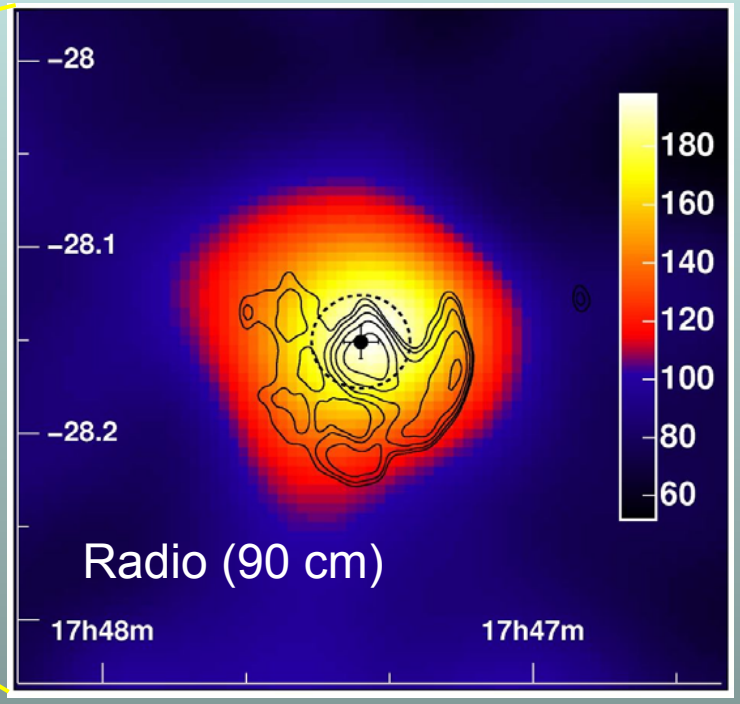


HESS [Masterson]:
Consistent with pt. source,
< 2′ and X-ray center.

OG 2.2: Galactic Sources

G0.9+0.1





HESS [Khelifi]:
2004: 50 hrs, 4 Telescopes
13 σ

Consistent with pt. source
at position of pulsar wind.
(but not SN shell).
2% Crab flux (50% luminosity).

OG 2.2: Galactic Sources

1b. Pulsars

- 8 pulsars detected by EGRET, but none at VHE.
- Pulsed emission mechanism not known.

Limits:	**Crab**	**HESS [Konopelko], MAGIC [Lopez], STACEE [Kildea], PACT [Singh]**
	Vela, 1706-44	**HESS [Konopelko]**
	msec pulsars	**MAGIC [Ona-Wilhelmi]**
Unconfirmed:	**Geminga**	**Shalon [Sinitsyna] PACT [Vishwanath]**

→ **No convincing pulsar detections at VHE.**

OG 2.2: Galactic Sources

2. Supernova Remnants (SNRs)

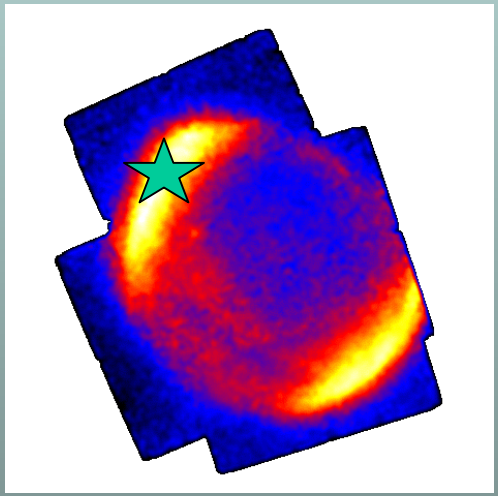
- Origin of CR's ? Based on energetics & spectrum.
- Known to accelerate TeV electrons (synchrotron).
- 2003: situation is unclear (especially SN1006).

Known (2003):	**RXJ 1713**	**HESS [Berge]**
	Cas-A	
New Sources:	**RXJ 0852**	**CANGAROO [Tanimori], HESS [Komin]**
	J1813-178	**HESS [Funk], MAGIC [Bartko]**
	J1834-087	**HESS association [Funk]**
	J1640-465	**HESS association [Funk]**
Limits:	**SN 1006**	**CANGAROO [Tanimori], HESS [Rowell]**
	5 SNRs	**HESS [Rowell]**
	Monogem Loop	**TIBET [Saito]**
	G40.5-0.5	**TIBET [Zhang]**

OG 2.2: Galactic Sources

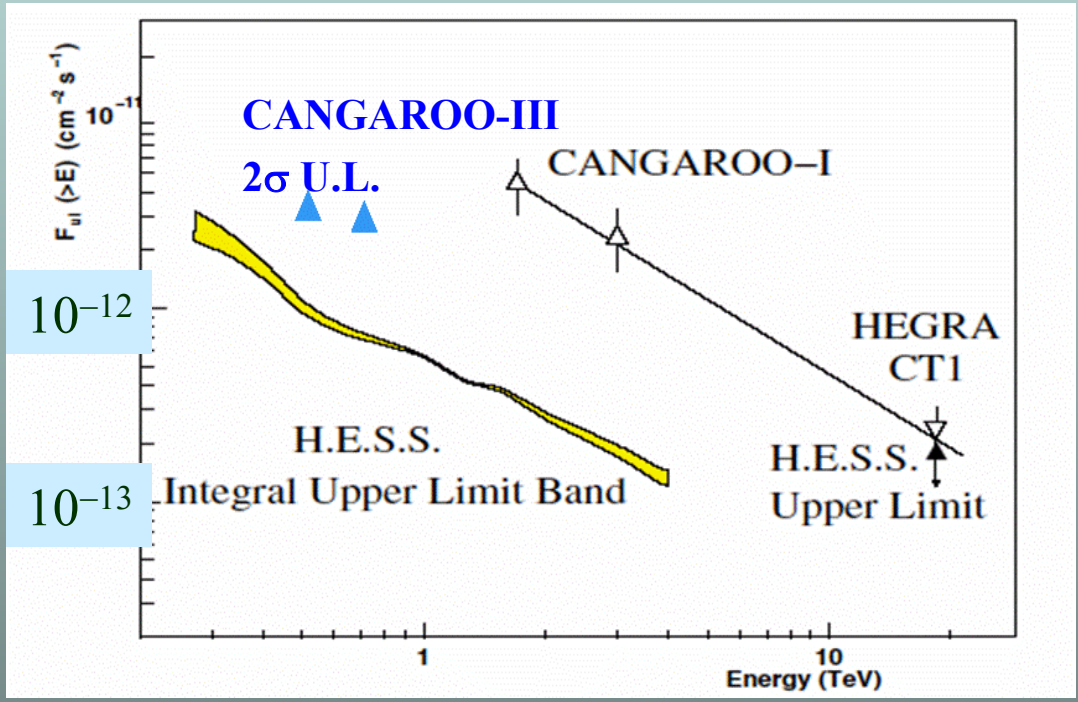
SN 1006

Earlier detection by CANGAROO-I from NE rim. Also HEGRA CT1.



2004: HESS Upper limit.

New data from CANGAROO-III [Tanimori].
~ 25 hrs, 3 telescopes

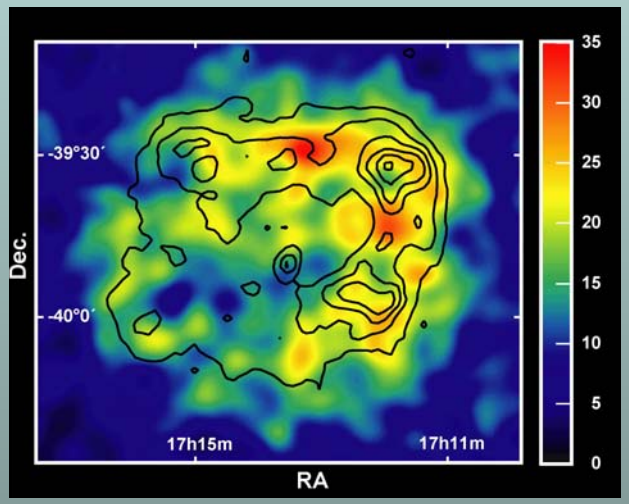


→ **SN1006 not detected at previous levels.**

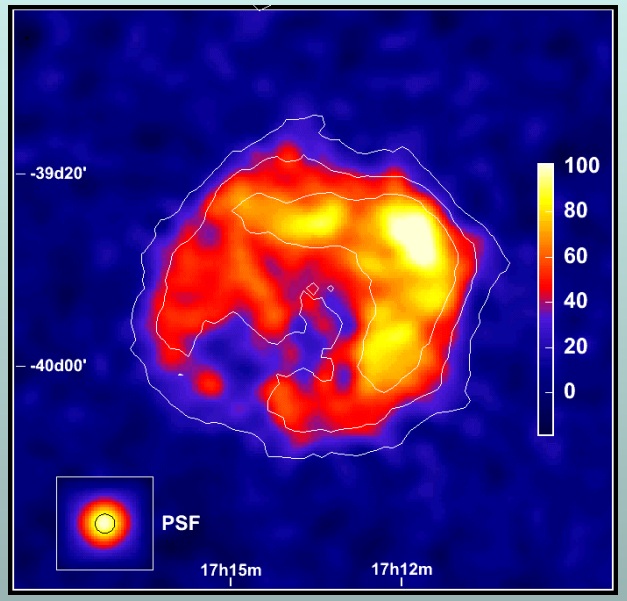
OG 2.2: Galactic Sources

RXJ 1713-394

2003: CANGAROO
detection ~7σ.



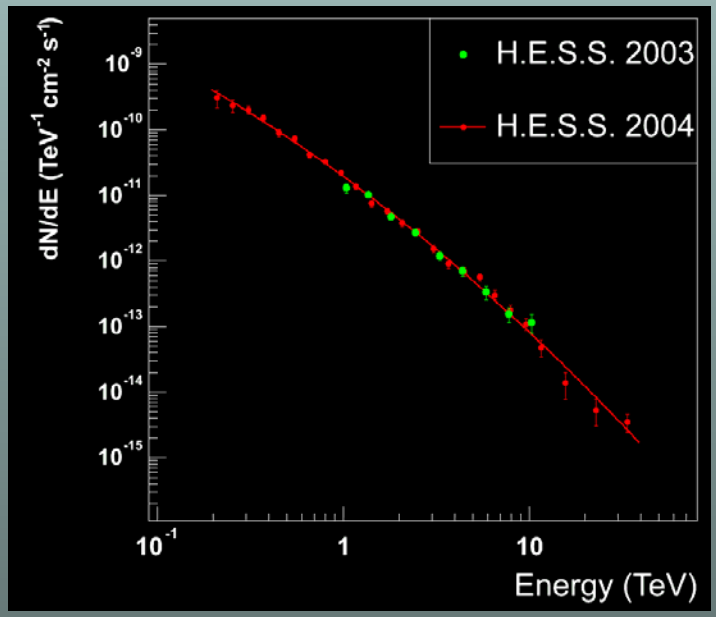
HESS [Berge]:
2003 data: 2 tels,



HESS [Berge]:
2004 data:
4 telescopes
33 hrs
> 40σ

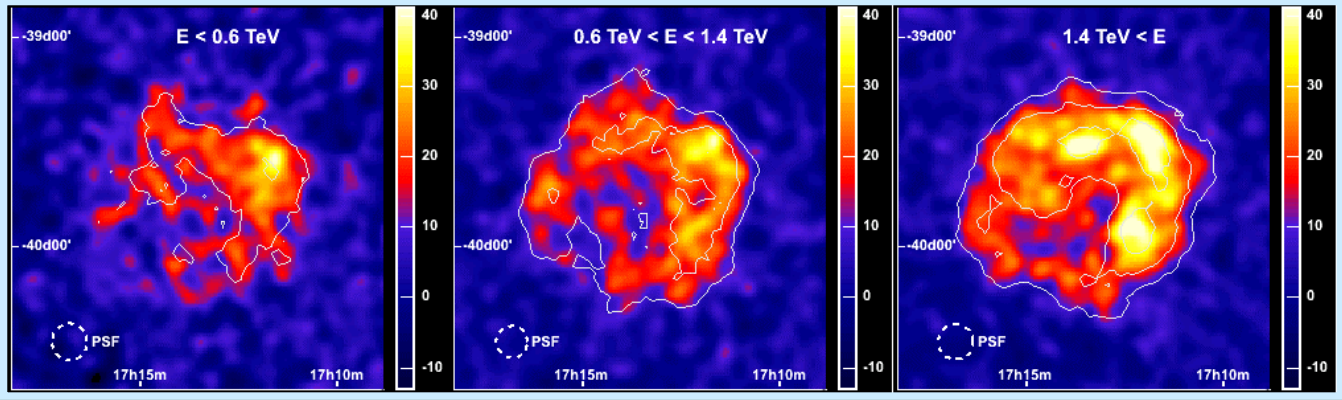
Shell structure
clearly resolved.

Hard spectrum $\Gamma \sim 2$
Not a simple power-law.



OG 2.2: Galactic Sources

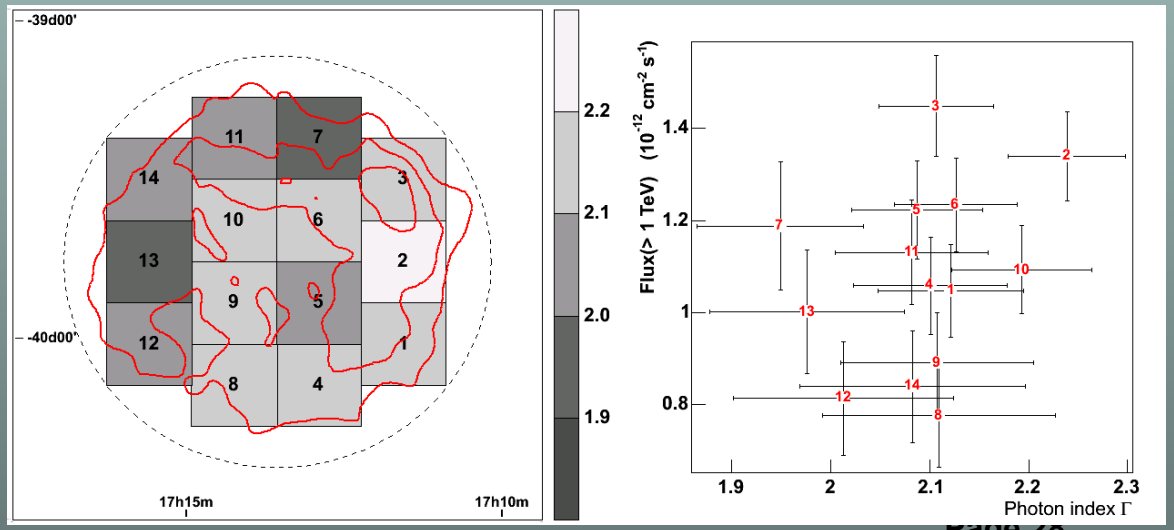
RXJ 1713-394



HESS: Morphology does not change with energy.

Spatially resolved spectra:

Spectra do not appreciably change over remnant !



We are now confident of VHE emission from numerous shell-type SNRs.

We have much more precise VHE data on SNRs than previously.

OG 2.2: Galactic Sources

SNR Theory

- SNRs clearly accelerate particles to > 10 TeV. Are they electrons or protons?
- Detailed diffusive shock models designed to explain broad-band emission from SNRs.

Ksenofontov:

Non-linear model for SN1006, key importance of gas density.
Dominant γ-ray emission from π^o decays.
HESS result requires $N_H < 0.1$ cm^{-3}.

Ellison:

CR ions efficiently accelerated to beyond knee. Large compression ratio required – evidence in Kepler, Tycho.

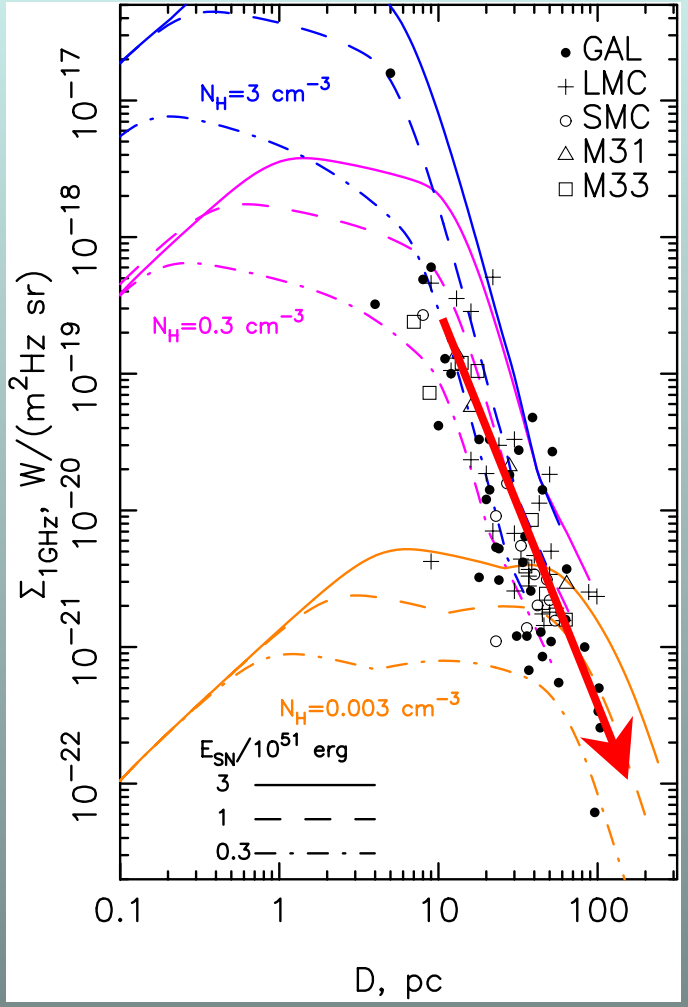
OG 2.2: Galactic Sources

SNR Theory

Berezkho:

Evidence for B field amplification in young SNR – steep synchr. spectra and sharp X-ray features.

Surface brightness fall rapidly shell diameter – in Sedov phase?



Q: Are SNRs the origin of HE CR's ?

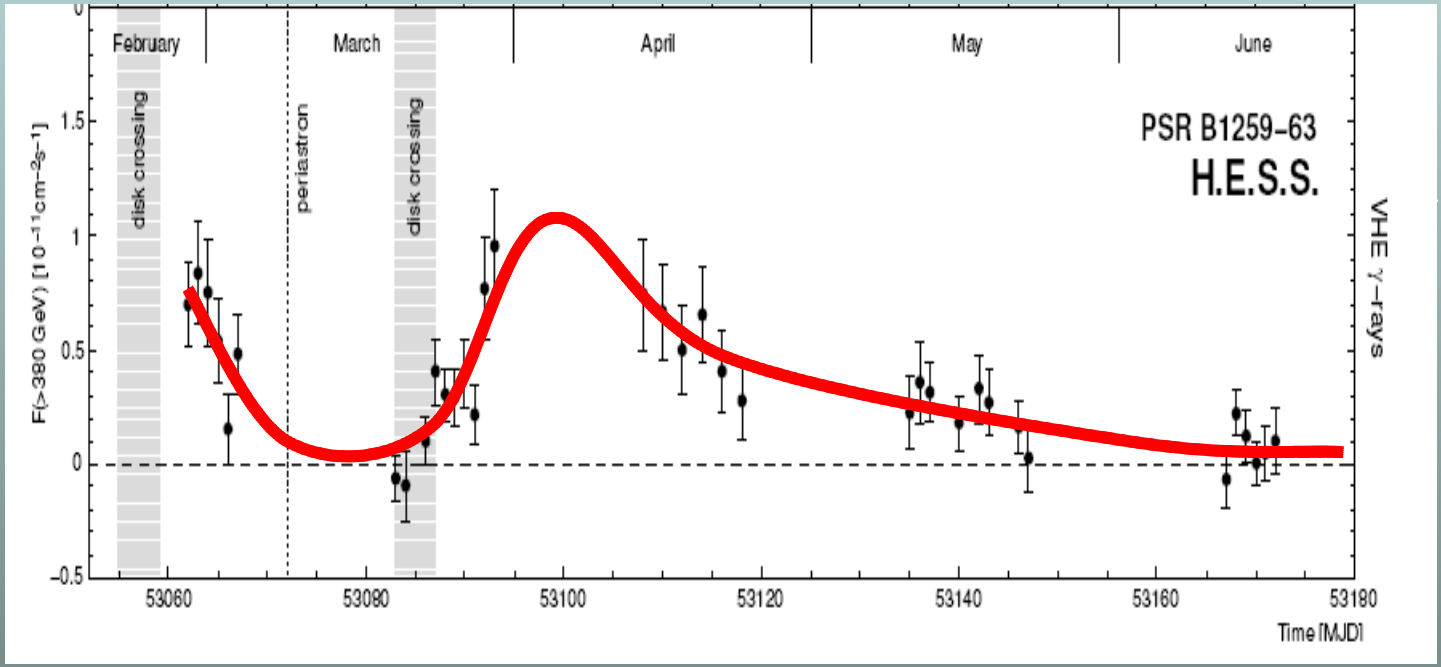
$e^{+/-}$ could be source of TeV γ-ray emission in SNRs, but would require low B fields – not generally supported by data and models.

OG 2.2: Galactic Sources

C. Binary Pulsar B1259-63

HESS [Schlenker]

Theory [Kirk]



Variable light curve on daily timescale.
Complex interaction of pulsar wind and disk.
→ First variable galactic source !

OG 2.2: Galactic Sources

D. Unidentified Sources

Known (2003):

TeV 2032	
Galactic Center	HESS [Rolland], MAGIC [Bartko]

New Sources:

J1303-631	HESS [Raue]
J1614-518	HESS [Funk]
J1804-216,	" "
J1804-216	" "

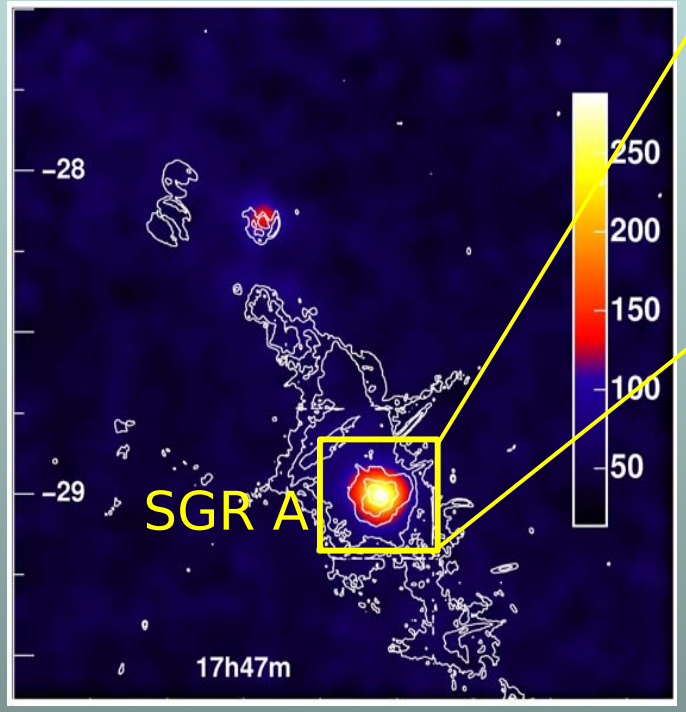
Unconfirmed:

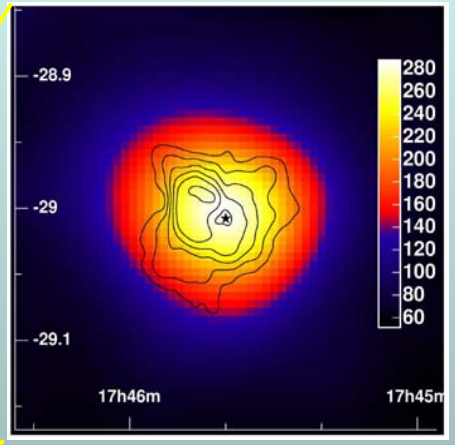
3EG J0520+2556	Milagro [Dingus]

Q: Is there are new population of "dark" TeV emitters ??

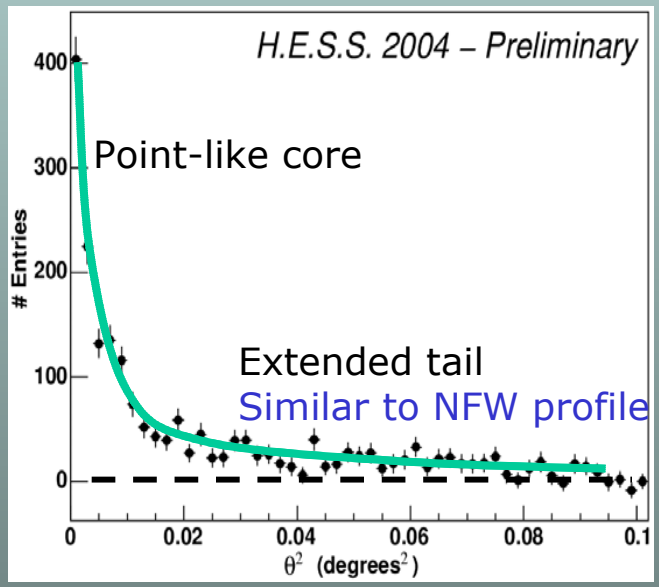
OG 2.2: Galactic Sources

Galactic Center





HESS [Rolland]



Consistent with SGR A* to 6″ and slightly extended.

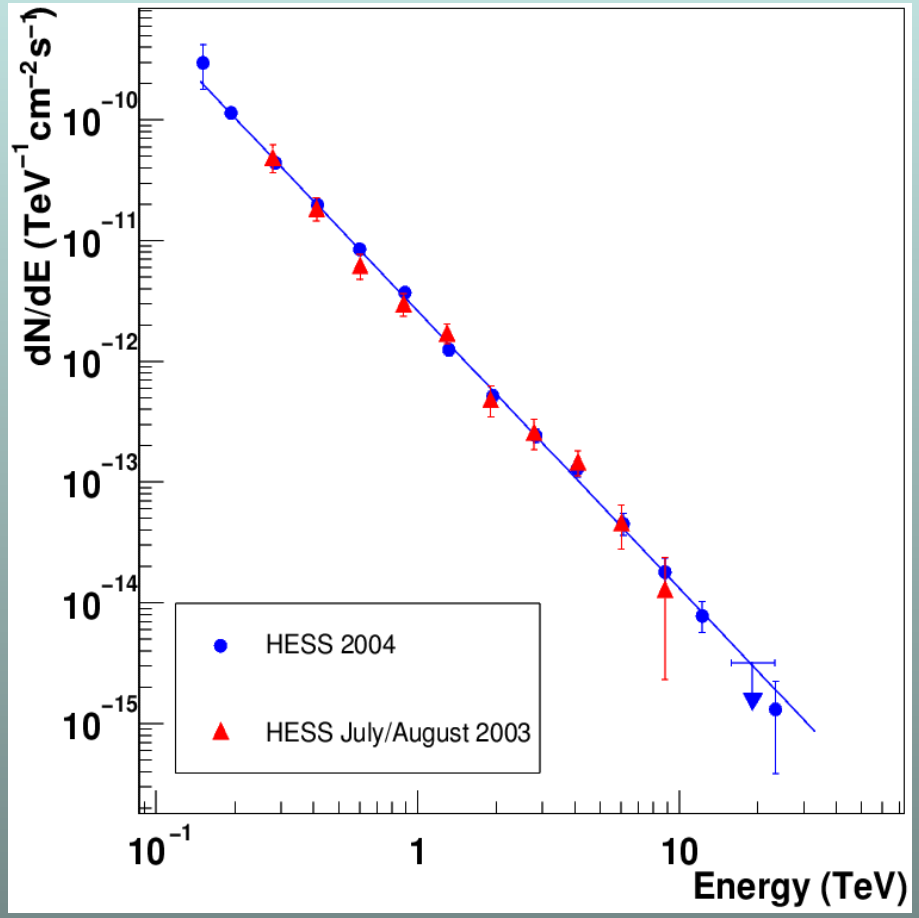
OG 2.2: Galactic Sources

Galactic Center

HESS Spectrum

- Unbroken power-law.
- Hard spectrum $\Gamma = 2.2$.
- No evidence for variability on a variety of time scales.

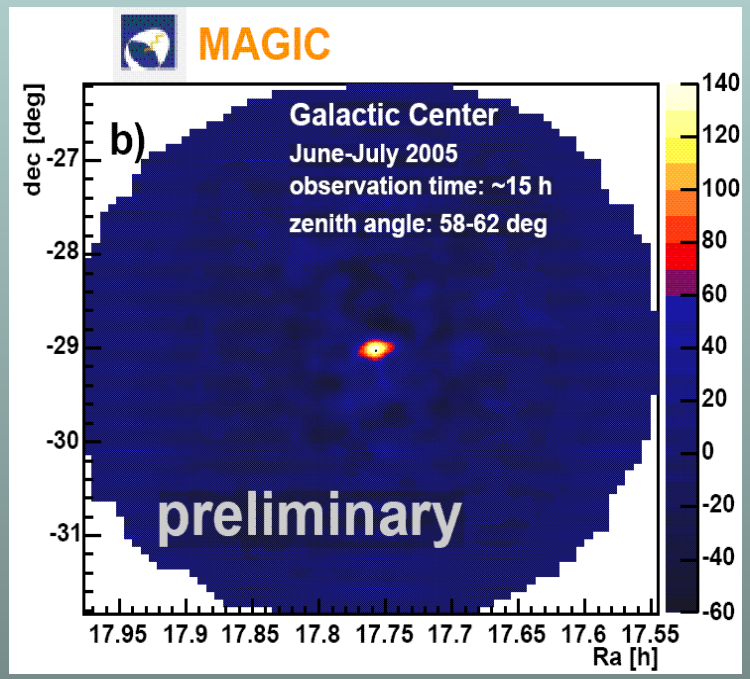
Very unlikely to be dark matter [Ripken]. Presence of strong γ-ray source makes this region difficult area to search for DM.



OG 2.2: Galactic Sources

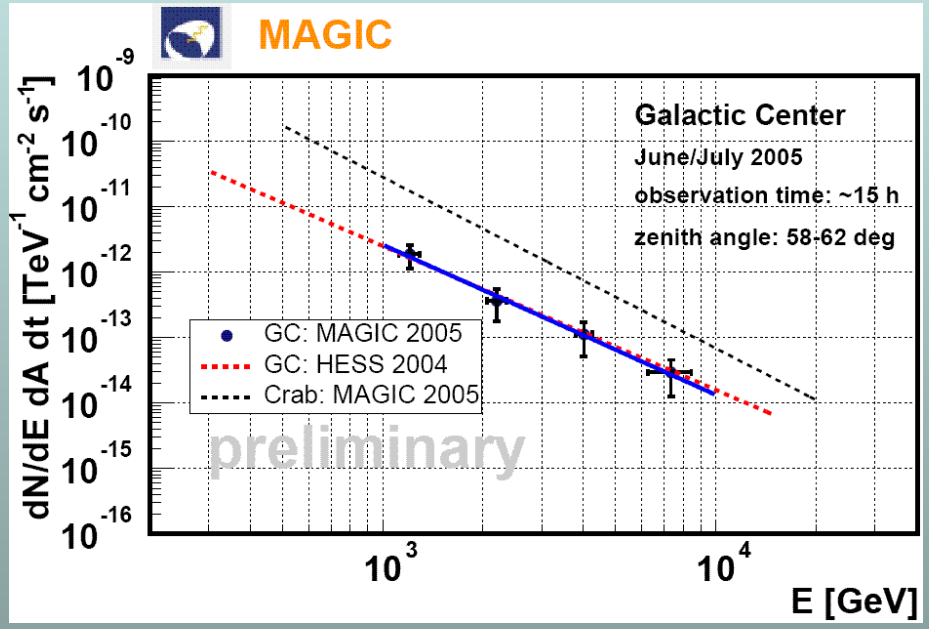
Galactic Center

Also seen clearly by MAGIC.



MAGIC (Bartko)

Spectrum

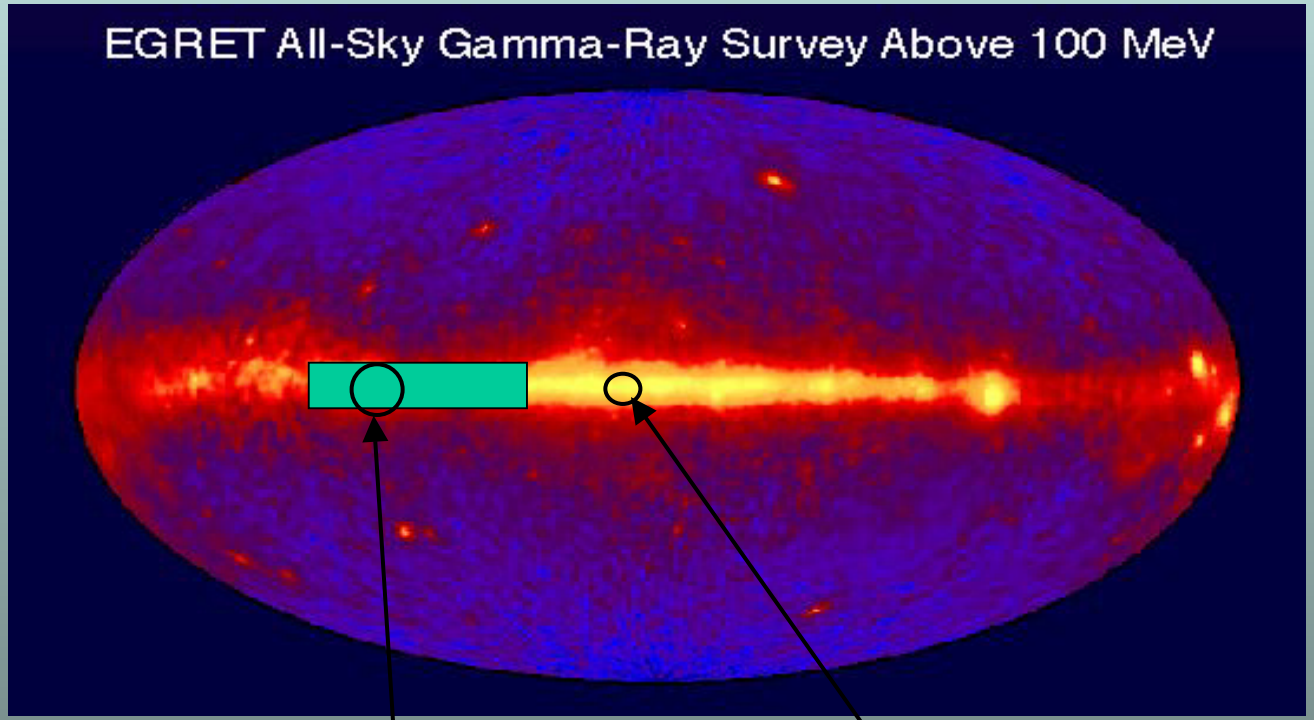


Good agrement between HESS and MAGIC.

OG 2.1
Diffuse γ-ray Sources

OG 2.1: Diffuse γ-ray Sources

Galactic Diffuse Emission



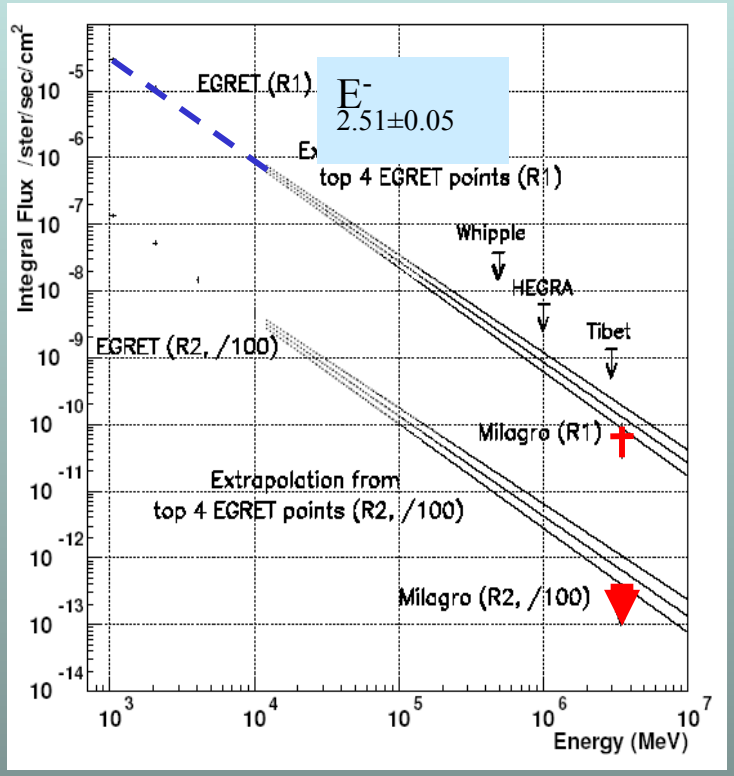
Gal. Plane Emission (Milagro)

Cygnus Region (Milagro)

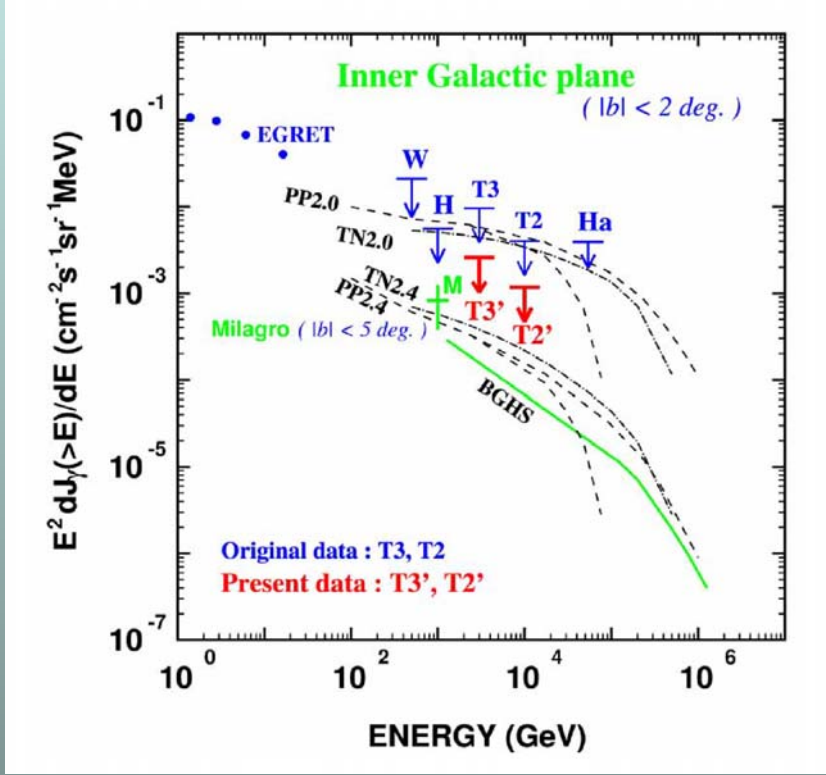
Galactic Center Region (HESS)

OG 2.1: Diffuse γ-ray Sources

1. Galactic Plane



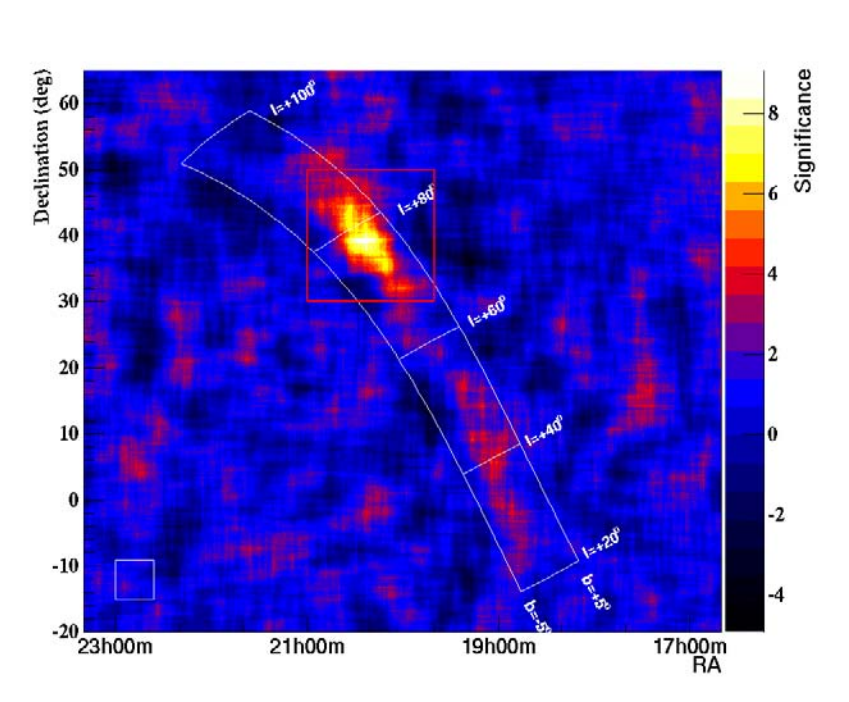
Milagro [Sinnis]
~ 4.5σ detection in 3 yr data set.
Inner region:
40-100° in longitude, ± 5° in latitude



Tibet [Ohnishi]
Flux upper limit, consistent with Milagro detection.

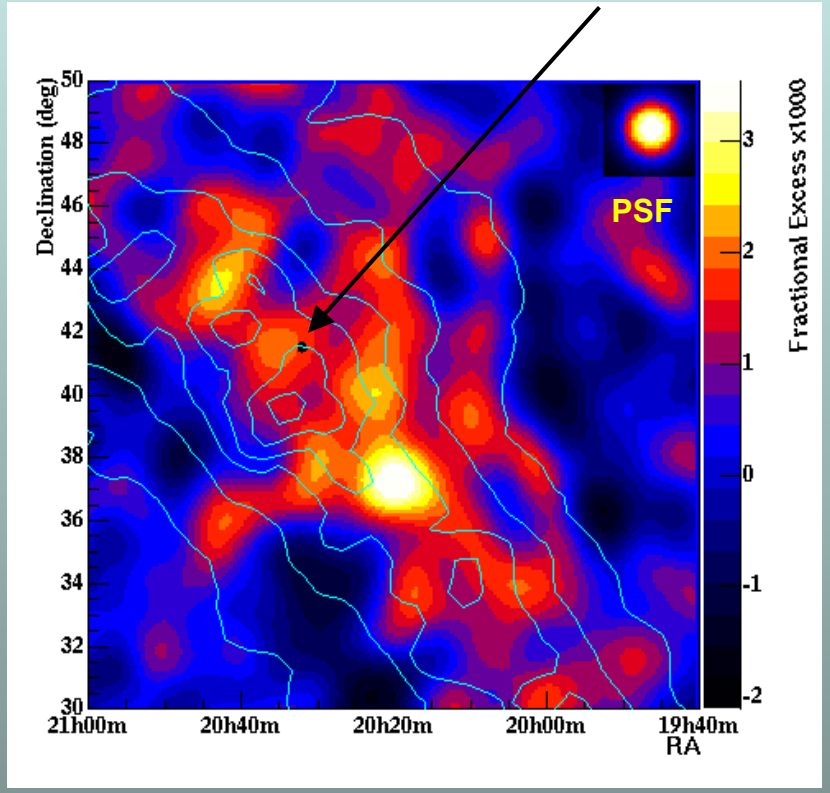
OG 2.1: Diffuse γ-ray Sources

2. Cygnus Region



Milagro [Smith]
All-sky survey – for extended sources.
Cygnus region: most luminous in N. sky.
Significance ~ 7σ.

HEGRA
TeV 2032+4130



Milagro excess (color).
EGRET diffuse model (contours).

OG 2.1: Diffuse γ-ray Sources

Galactic Diffuse Emission

New Sources:

Galactic Center	HESS [Hinton]
Galactic Plane	Milagro [Sinnis]
Cygnus Region	Milagro [Smith]

Limits:

Galactic Plane	CANGAROO [Ohishi]
	TIBET [Ohnishi]
Cygnus Region	Whipple [Atkins]
Dwarf (M32,M33, etc.)	Whipple [Hall], MAGIC [Bartko]

OG 2.4
Gamma-Ray Bursts

OG 2.4: Gamma-Ray Bursts

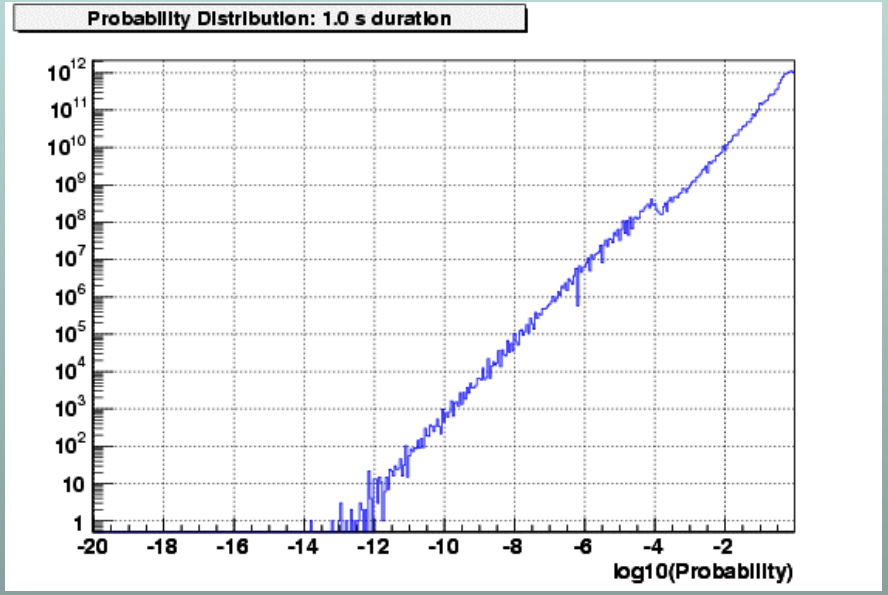
→ **No evidence for VHE emission from GRB's.**

Limits:

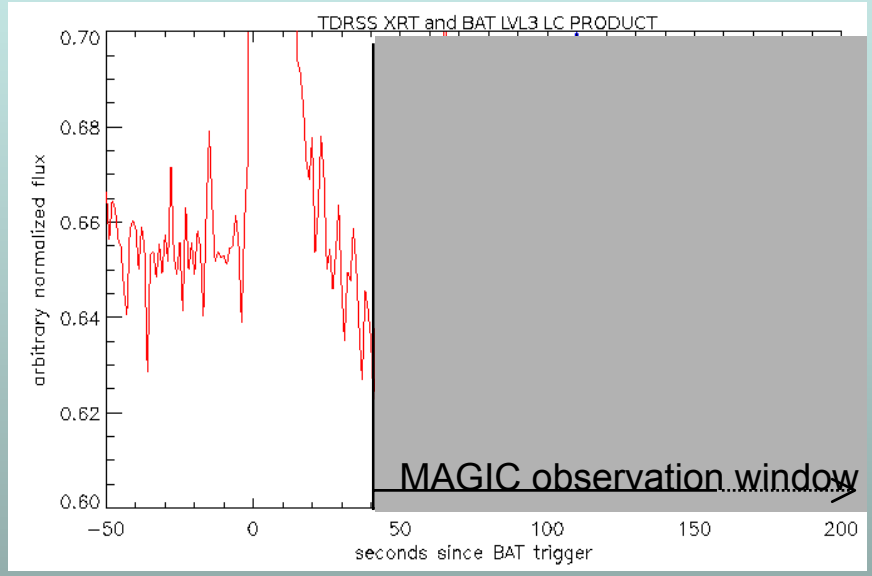
Cherenkov	**STACEE [Jarvis]**
	MAGIC [Bastieri]
Air Shower	**Milagro [Parkinson] – satellite triggered GRBs.**
	Milagro [Noyes] – short duration events.
	ARGO-YBJ [Girolamo]
	Andyrchy, Baksan [Smirnov]
	Sierra la Negra [Alvarez]
	Auger Observatory [Allard]

OG 2.4: Gamma-Ray Bursts

GRB Observations



Milagro [Noyes]
Untriggered GRB search.
Search at all times/positions/durations.
No bursts detected.



MAGIC [Bastieri]
GRB050713A: data-taking started 40s after burst.
Preliminary analysis: no signal.

STACEE [Jarvis] will similarly reach bursts in < 2 min.

OG 2.3
Extragalactic Sources

OG 2.3: Extragalactic Sources

Active Galactic Nuclei (AGN)

- Blazars – wideband non-thermal spectra, highly variable.
- VHE sources of the HBL ("extreme BL Lac") type and one radio galaxy (M87).
- Models: Leptonic versus Hadronic cascades.

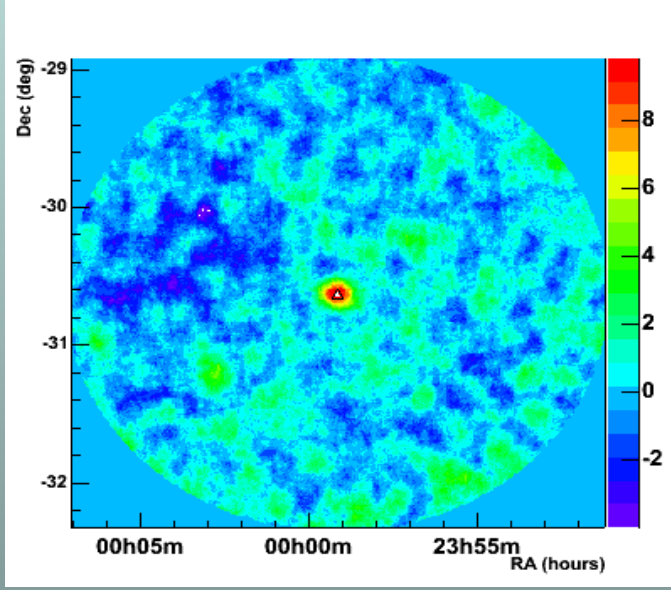
NEW SOURCES:

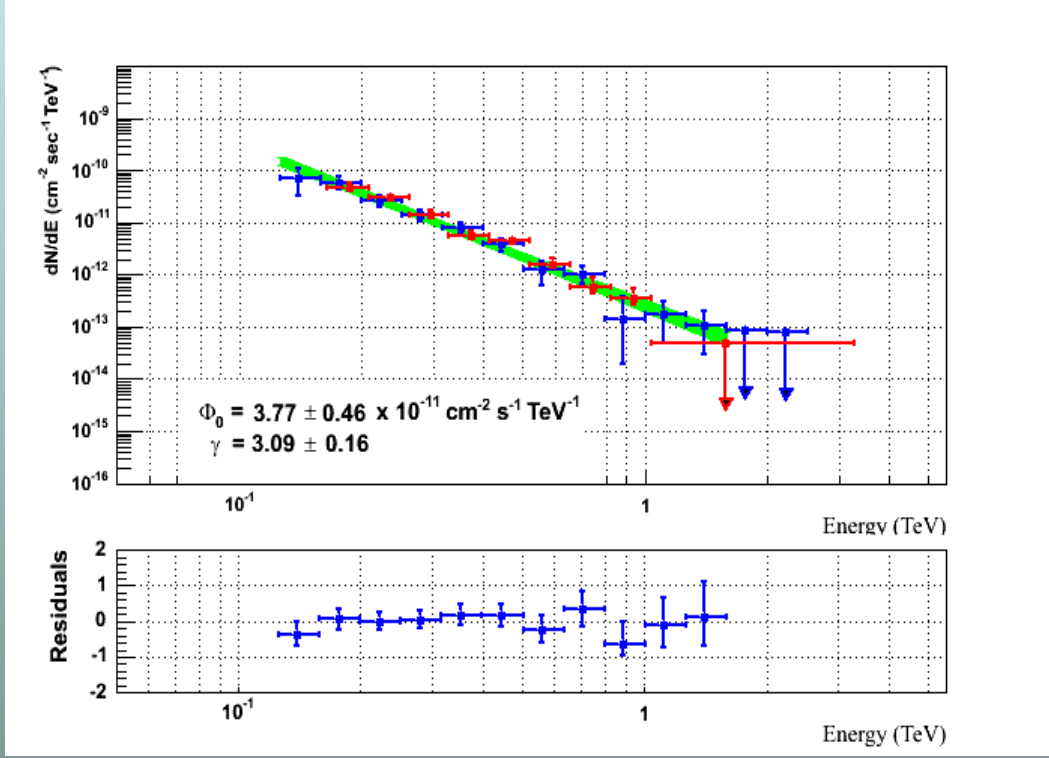
PKS 2005-489	**z=0.071**	**HESS [Benbow]**
H2356-309	**z=0.165**	**HESS [Pita]**
1ES1218+304	**z=0.182**	**MAGIC [Meyer]**
1ES1101-232	**z=0.186**	**HESS [Tluczykont]**

OG 2.3: Extragalactic Sources

H2356-309

(z=0.165)





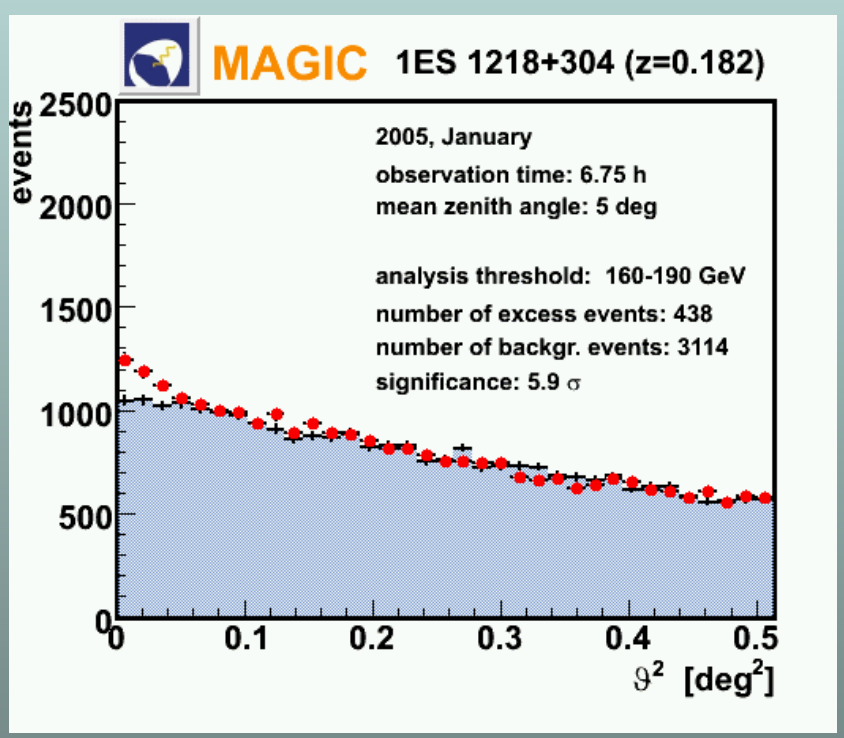
HESS [Pita]:
2004 data:
~39 hrs, 9σ, pt. source

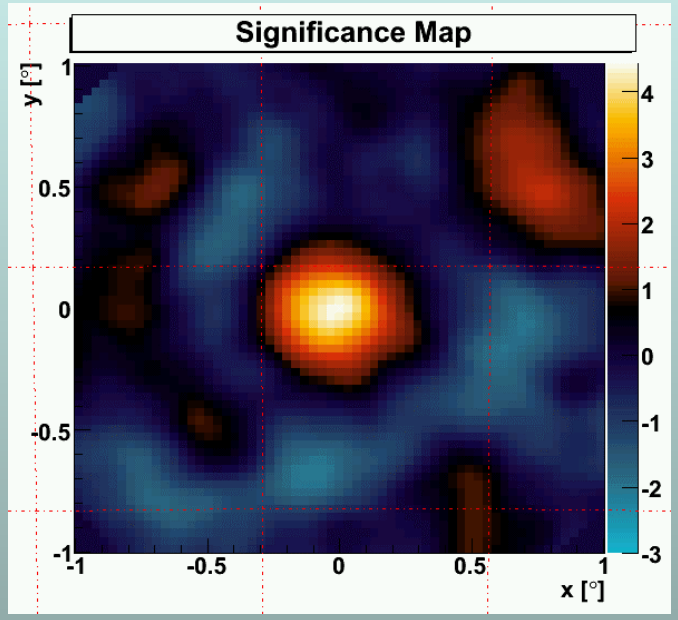
Spectrum:
Good power-law fit, Γ ~ 3.1
Flux ~ 3% Crab.

OG 2.3: Extragalactic Sources

1ES1218+304

(z=0.182)





MAGIC [Meyer]:
2005 data:
~7 hrs, 6σ
no spectrum yet.

OG 2.3: 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.**

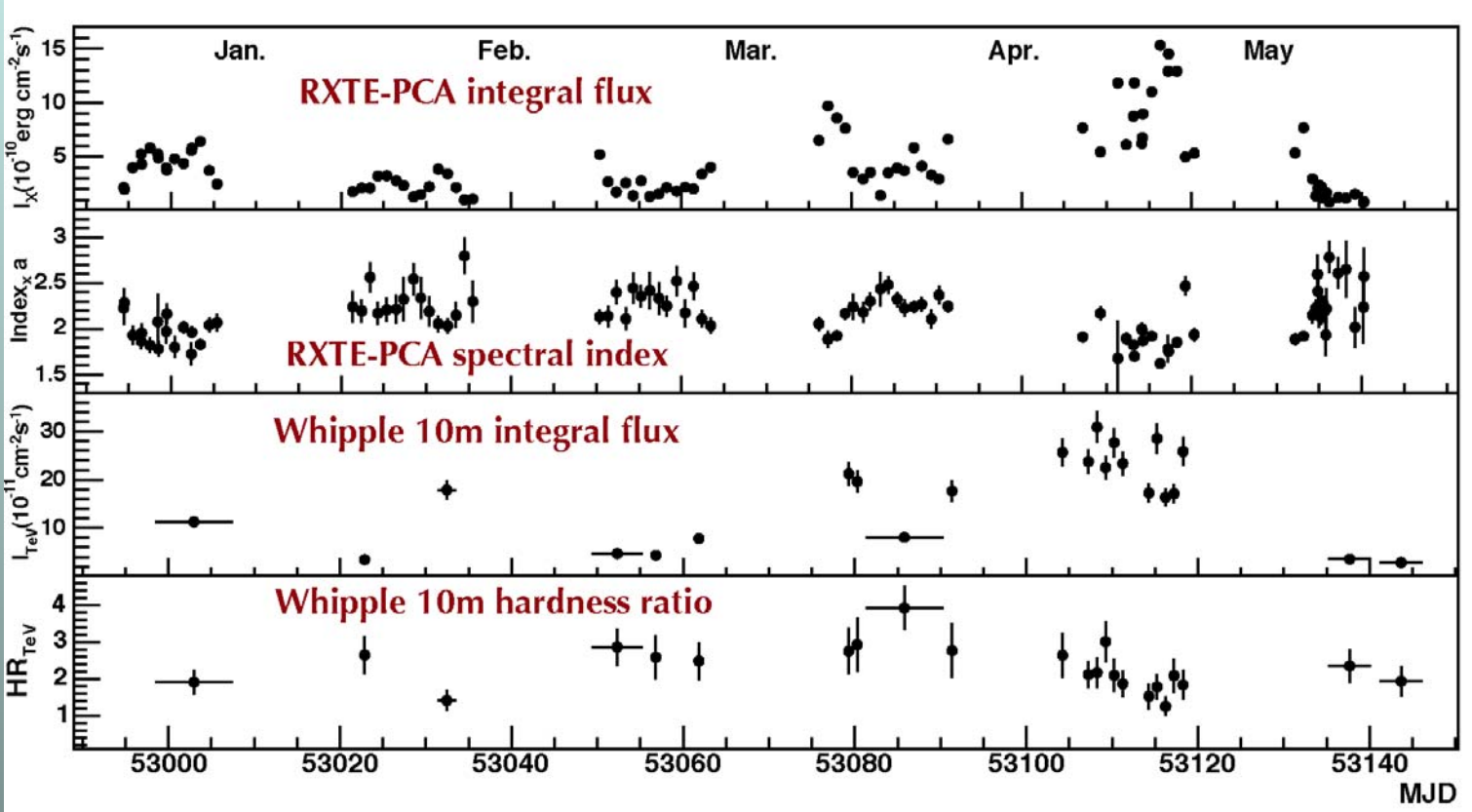
OG 2.3: Extragalactic Sources

- Detailed studies of established AGNs.

Mkn 421	**Whipple [Grube], STACEE [Carson], MAGIC [Mazin], CANGAROO [Sakamoto], HESS [Horns], PACT [Bose], VERITAS [Cogan], TACTIC (Rannot[**
Mkn 501	**MAGIC [Mirzoyan]**
PKS 2155-304	**HESS [Fontaine], CANGAROO [Sakamoto]**
1ES1959+650	**MAGIC Tonello]**
M87	**HESS [Beilicke], MAGIC [Albert]**

OG 2.3: Extragalactic Sources

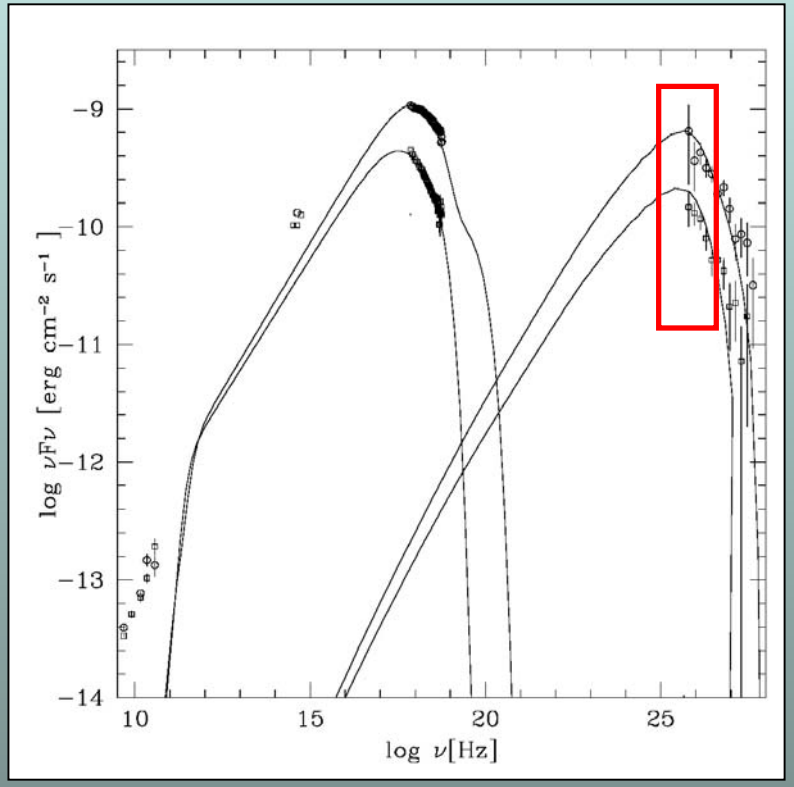
Mkn 421



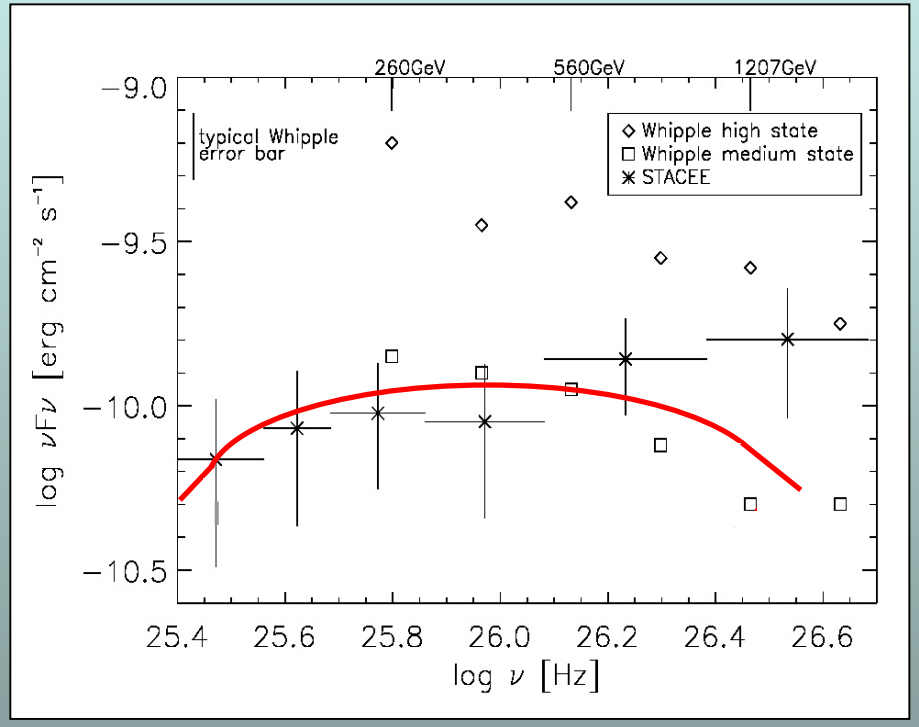
Whipple [Grube]:
2004: Five month multi-λ campaign: X-ray, TeV γ-ray.

OG 2.3: Extragalactic Sources

Mkn 421



Whipple and RXTE:
Spectral Energy Distribution.
"Low" and "high" flux states.

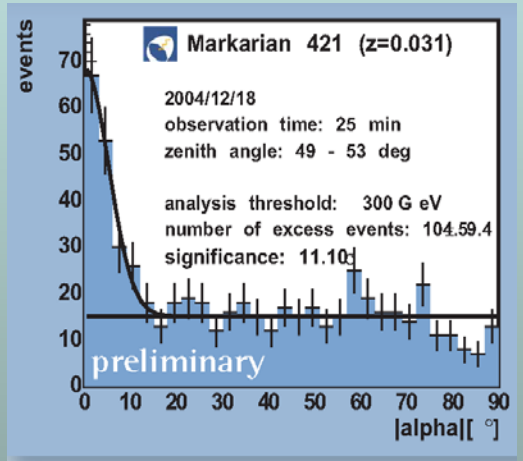


STACEE [Carson]:
Spectrum extends down to 100 GeV.
See peak of IC component ?

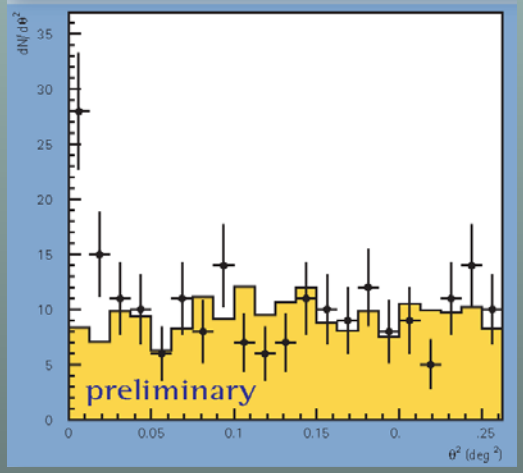
OG 2.3: Extragalactic Sources

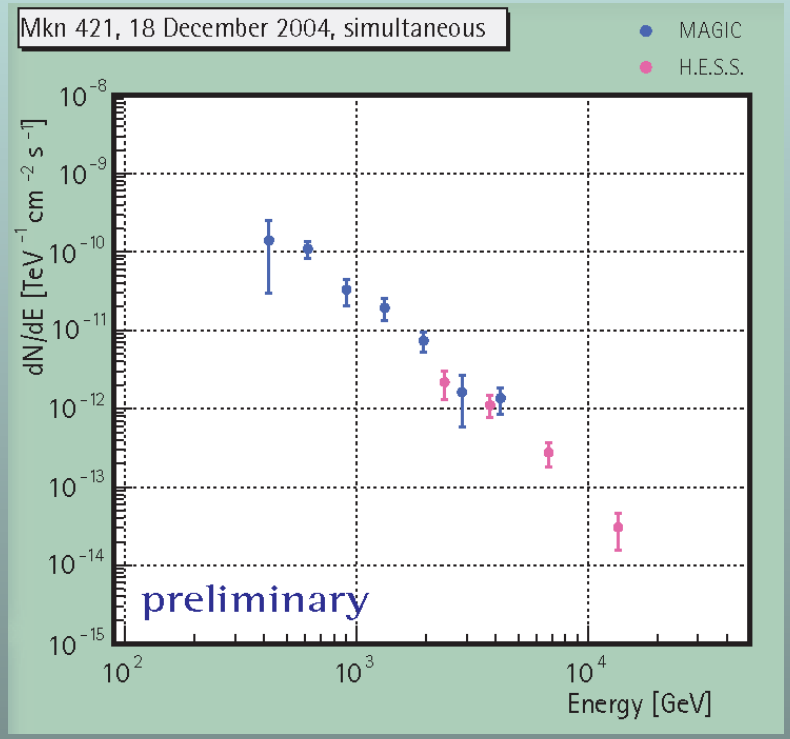
Mkn 421: Simultaneous Observations [Mazin]

MAGIC



HESS



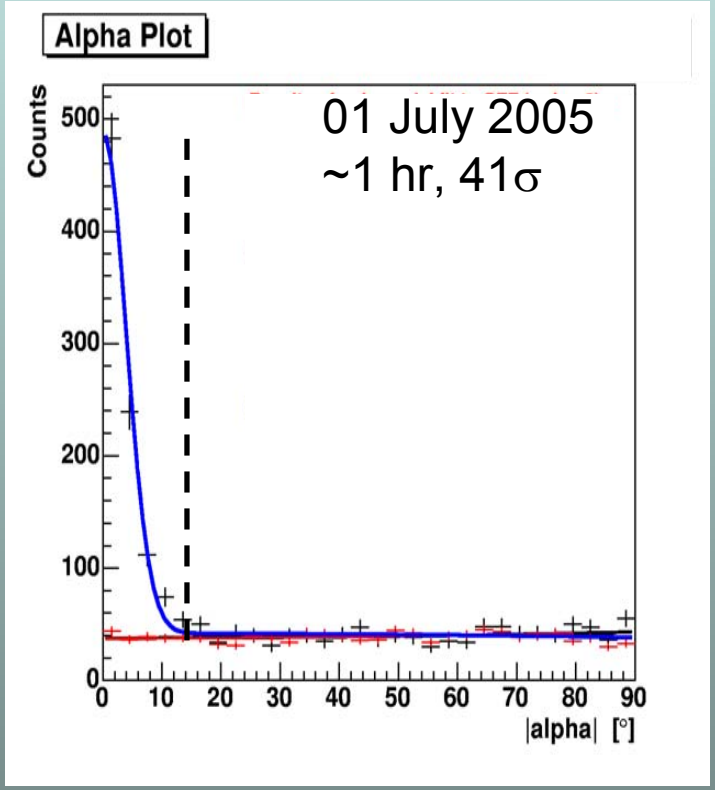


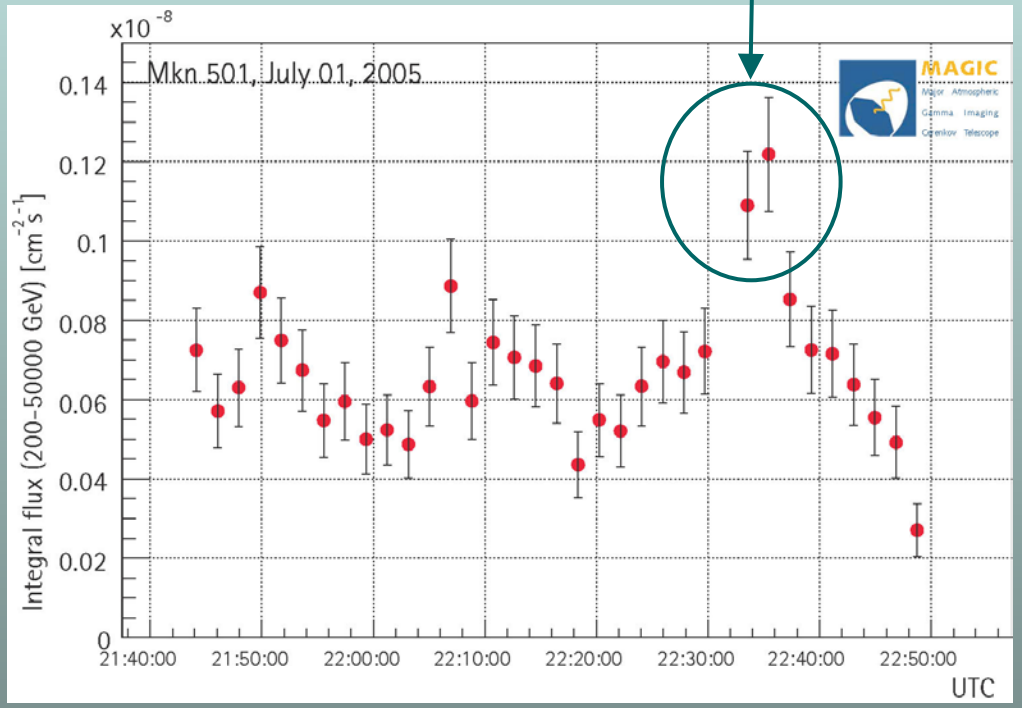
Combined spectrum – agreement !

OG 2.3: Extragalactic Sources

Mkn 501: Giant flare July 2005

V. rapid variation
(< 4 min)



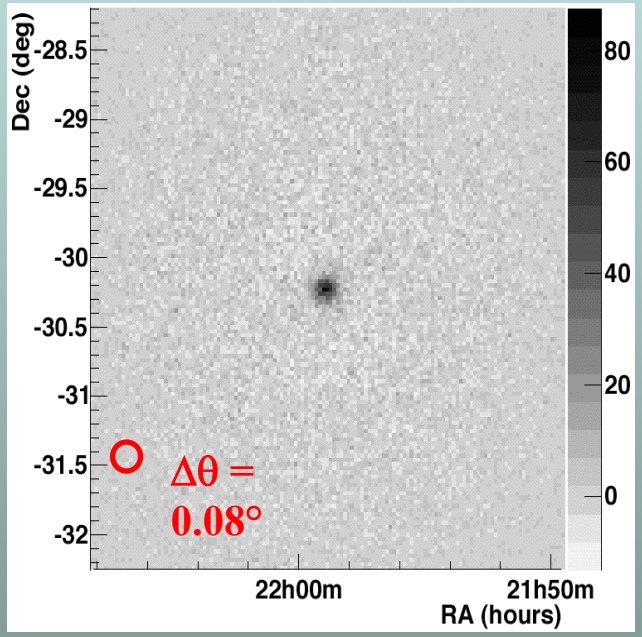


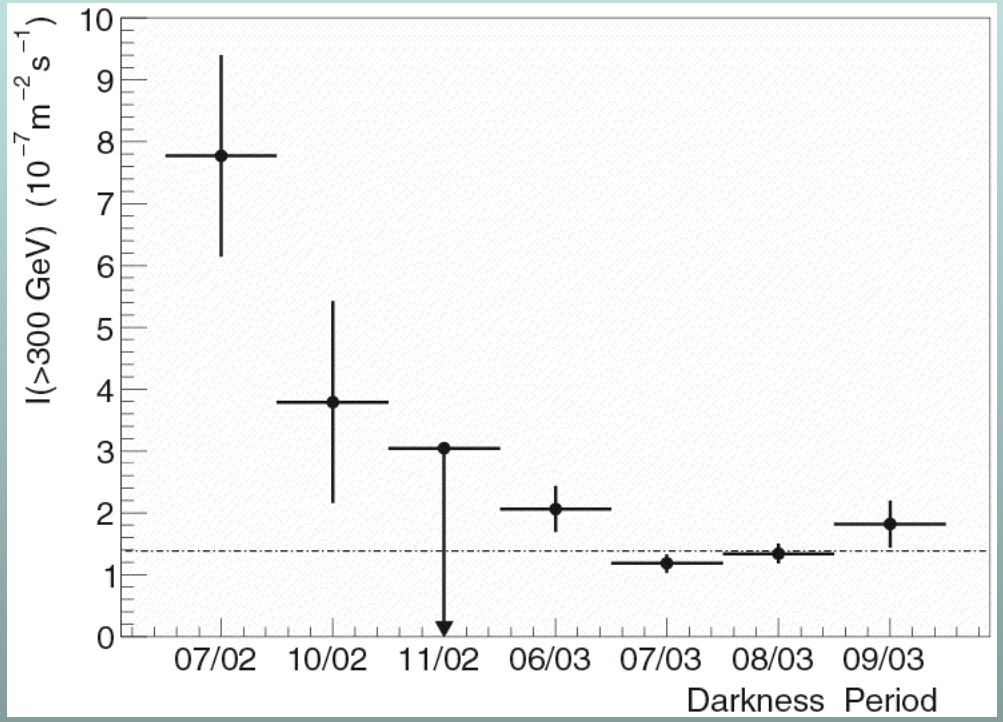
MAGIC [Mirzoyan]:

Light Curve: 2 min time bins.

OG 2.3: Extragalactic Sources

PKS 2155-304





HESS [Fontaine]:
2003 data: 34σ

Flux steadily decreasing.
Spectral index does not vary with flux level.

Reached quiescent level ?

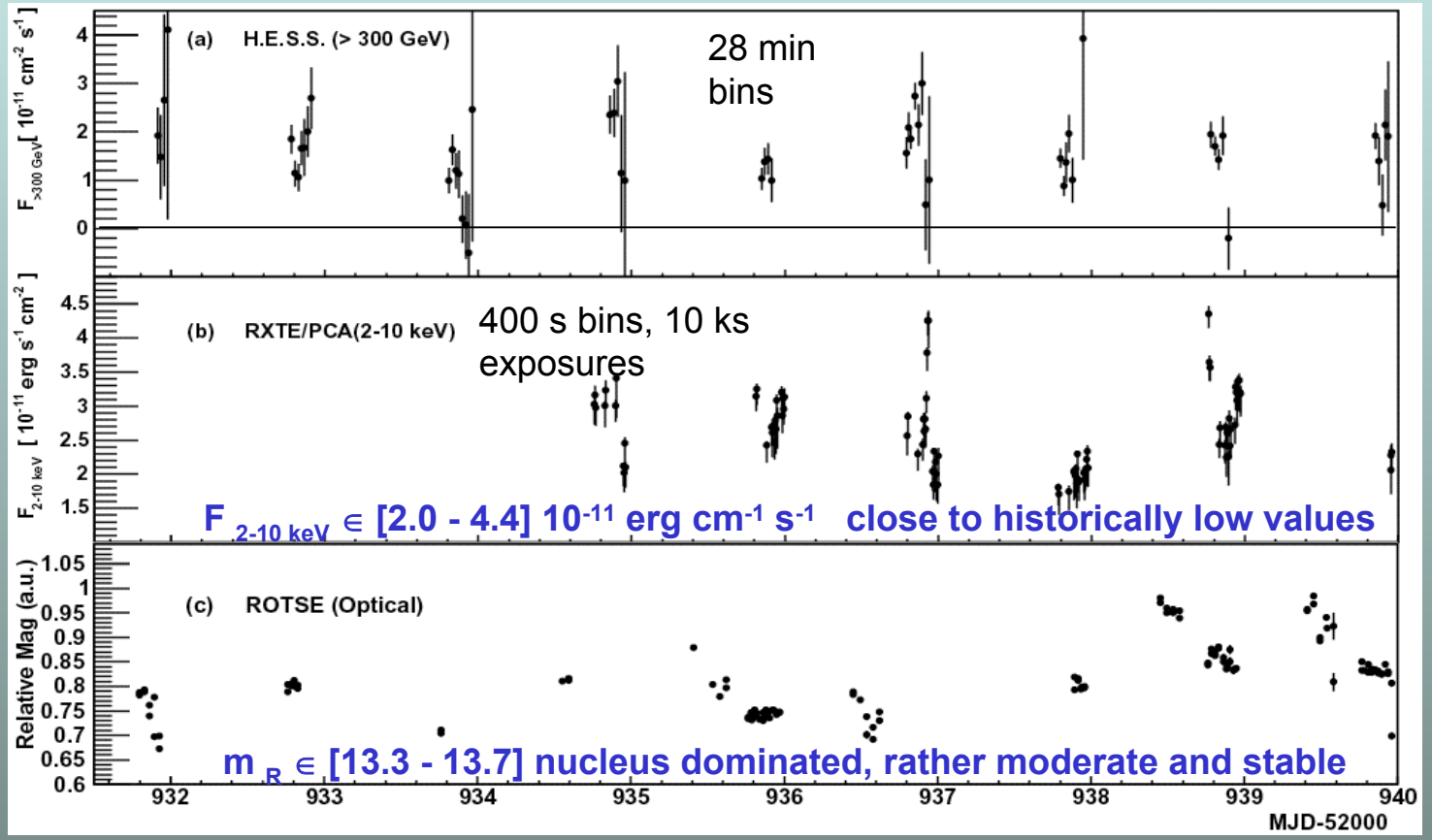
OG 2.3: Extragalactic Sources

PKS 2155-304

VHE γ-rays (HESS)

X-rays

Optical



→ **Low state detected in γ-rays ?**

OG 2.3: Extragalactic Sources

- Limits from new extragalactic observations.

AGN:

Surveys	**HESS [Benbow], MAGIC [Meyer]**
W Comae,3C 66A	**STACEE [Mukherjee]**
1ES2344+514	**TACTIC [Godambe]**
H1426+428	**TACTIC [Thoudam)**
Cen-A	**CANGAROO [Kabuki]**

Non-AGN:

NGC 253 (starburst)	**HESS [Lemoine-Goumand]**
Galaxy Clusters	**Whipple [Perkins]**

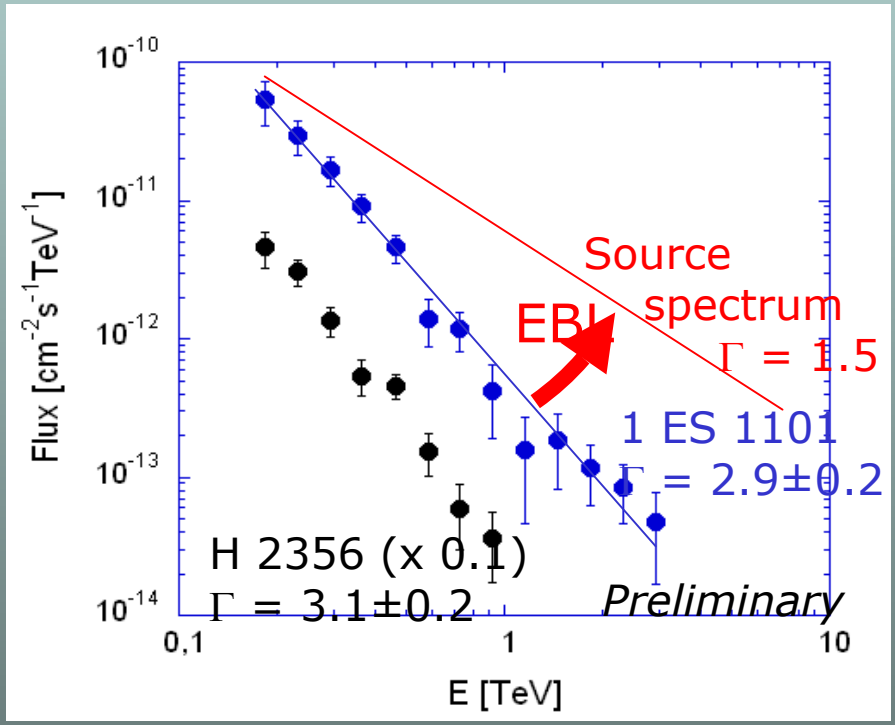
OG 2.3: Extragalactic Sources

Extragalactic Background Light (EBL)

- Sdiffuse O/IR radiation from star formation and evolution.
- Spectral signature from $\gamma\gamma$ absorption for $E\gamma$ ~ 50-2000 GeV.
- Use measured AGN spectra to constrain EBL.

HESS [Tluczykont]

H2356 and 1ES 1101



Appears to be less EBL than expected.

Close to lower bound from galaxy counts.

OG 2.7
New Experiments and Instrumentation

Will say very little regarding instrumentation: many papers on detectors, techniques, and simulations.

See also Cherenkov Workshop in Palaiseau (May 2005).

OG 2.7: New Experiments

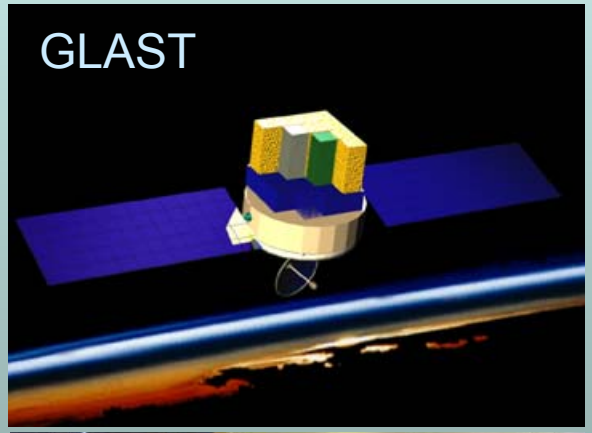
Satellite

1. ASTROSAT [Agrawal]

- UV/X-ray mission.
- 5 instruments: 0.3-100 keV range.
- Scheduled for 2007.

2. GLAST [Moiseev]

- New, major HE g-ray mission.
- LAT: coverage from 20 – 300 GeV.
- Scheduled for 2007.



LAT construction at SLAC June 2005.

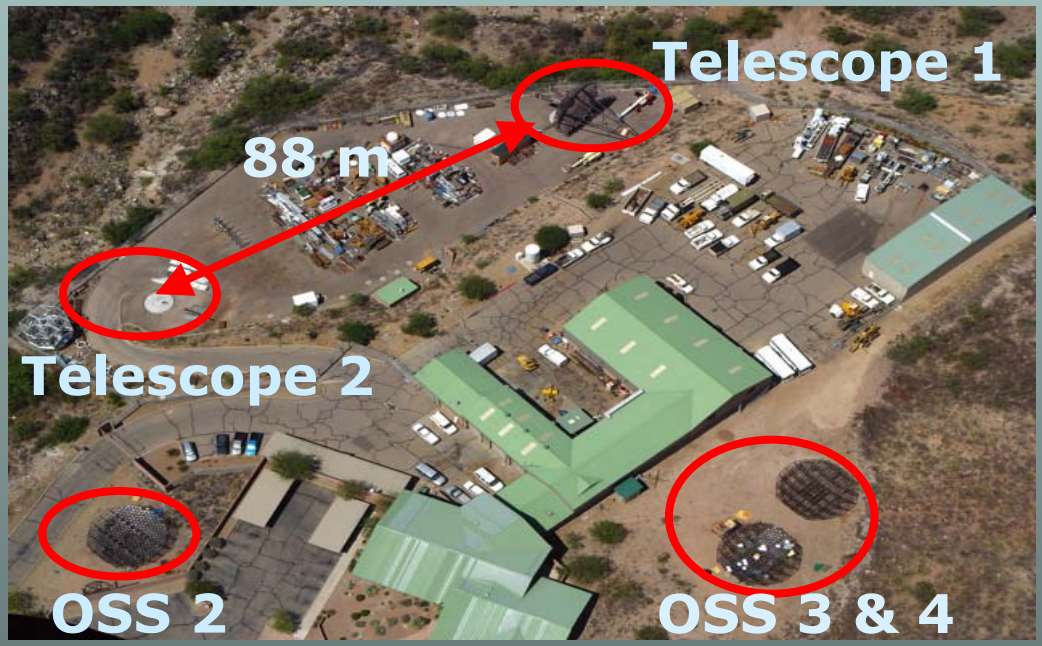
OG 2.7: New Experiments

Cherenkov Telescopes

1. VERITAS [Holder]

- 4x12m telescopes for Kitt Peak site (2006). →
- 2 telescopes operated this fall at Whipple Base Camp.

VERITAS Telescope 1

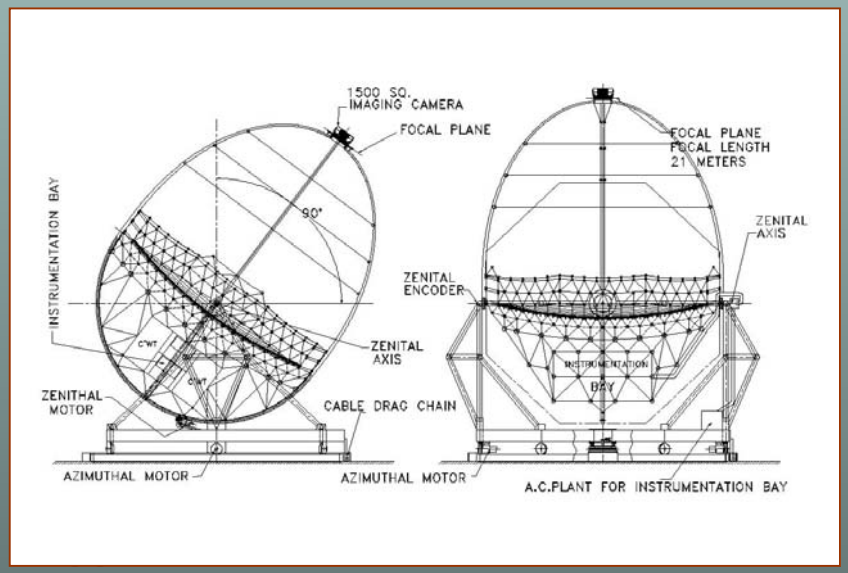


OG 2.7: New Experiments

Cherenkov Telescopes

2. HAGAR [Chitnis]

- 7 telescopes by late 2006.
- Hanle site, 4200m a.s.l.



3. Mace [Koul]

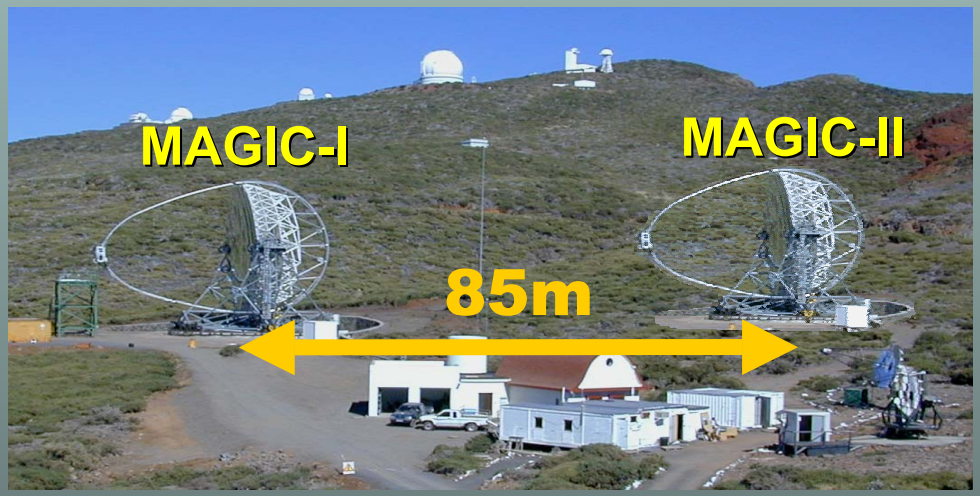
- 2 x 21m imaging telescopes.
- 4º x 4º camera.
- Hanle site.

OG 2.7: New Experiments

Cherenkov Telescopes

4. HESS-II [Vincent]

- New 28m telescope.
- 2048 pixel camera.
- Lower energy 40-50 GeV.



5. MAGIC-II [Teshima]

- New 17m telescope.
- Possible high-QE camera.
- 2007 schedule.

OG 2.7: New Experiments

Air Shower Experiments

1. ARGO-YBJ [Girolamo[

4300m ASL
6,000 m^2 RPC detector
Scalers sensitive ~GeV energies.

2. Pierre Auger [Allard]

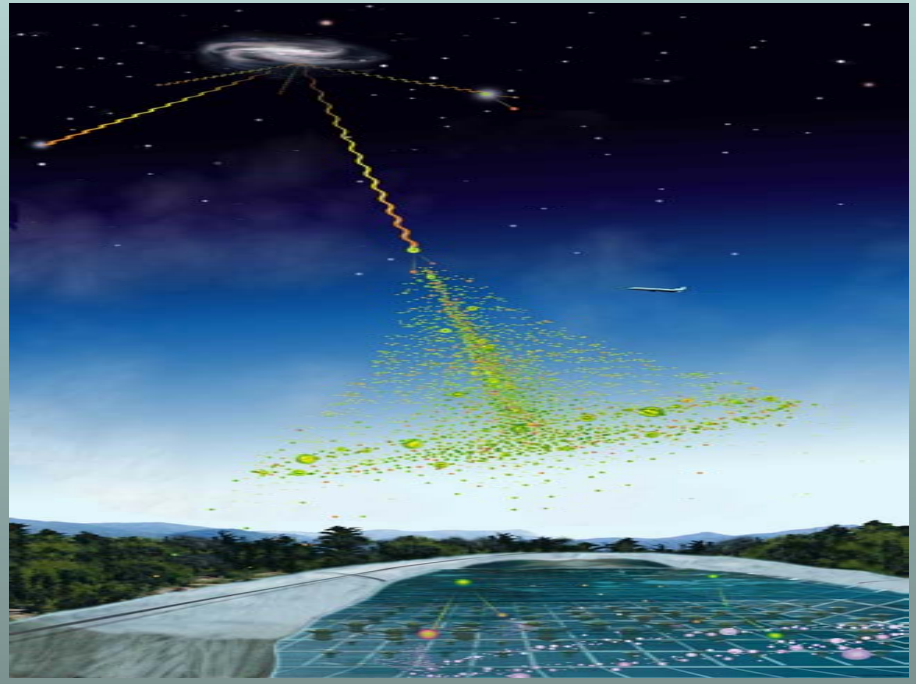
Single particles in Auger water tanks sensitive to GRBs.
A ~1600 x 10 m^2.

OG 2.7: New Experiments

Air Shower Experiments

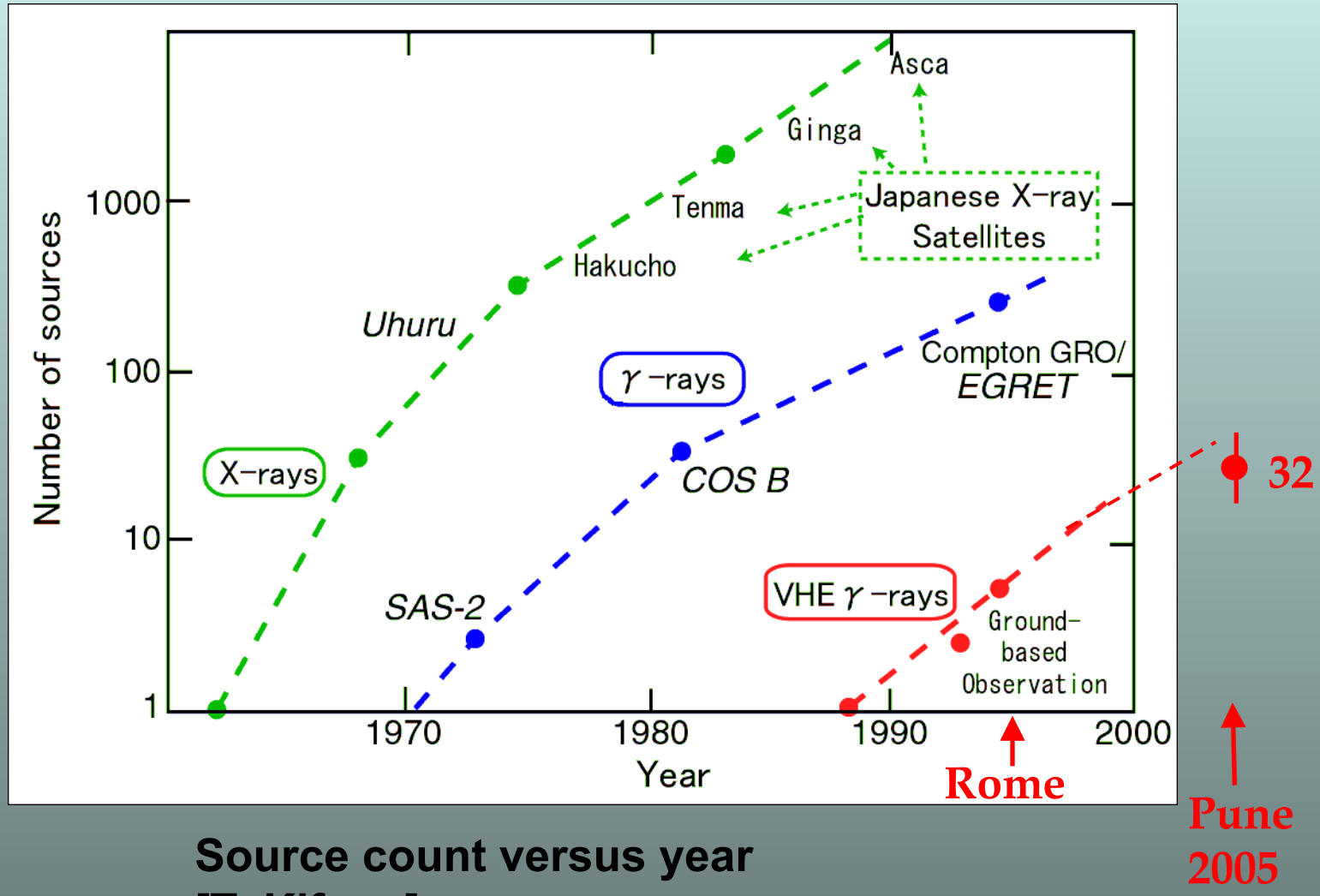
3. HAWC [Sinnis]

- 300m x 300m pond.
- Wide FOV ~ 2 SR.
- High altitude site to go lower in energy.
- In R&D phase.



HAWC Concept

"Kifune Plot"



Source count versus year [T. Kifune]

SUMMARY

- New generation of Cherenkov telescopes has yielded outstanding results.
- Many new VHE sources discovered in last two years … an almost unprecedented increase.
- Galactic Plane is rich in the number and type of VHE emitter. Pulsar nebulae and SNRs are both firmly established in the TeV band.
- New discoveries increase the number of known TeV blazars and push further out in redshift.
- Future experiments on ground and in space should continue the rapid development of VHE astrophysics.