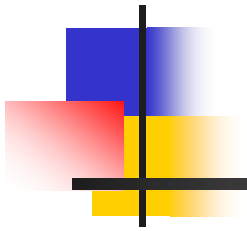
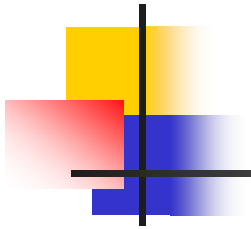


Galactic sources of VHE gamma rays

Werner Hofmann
MPI Kernphysik
Heidelberg



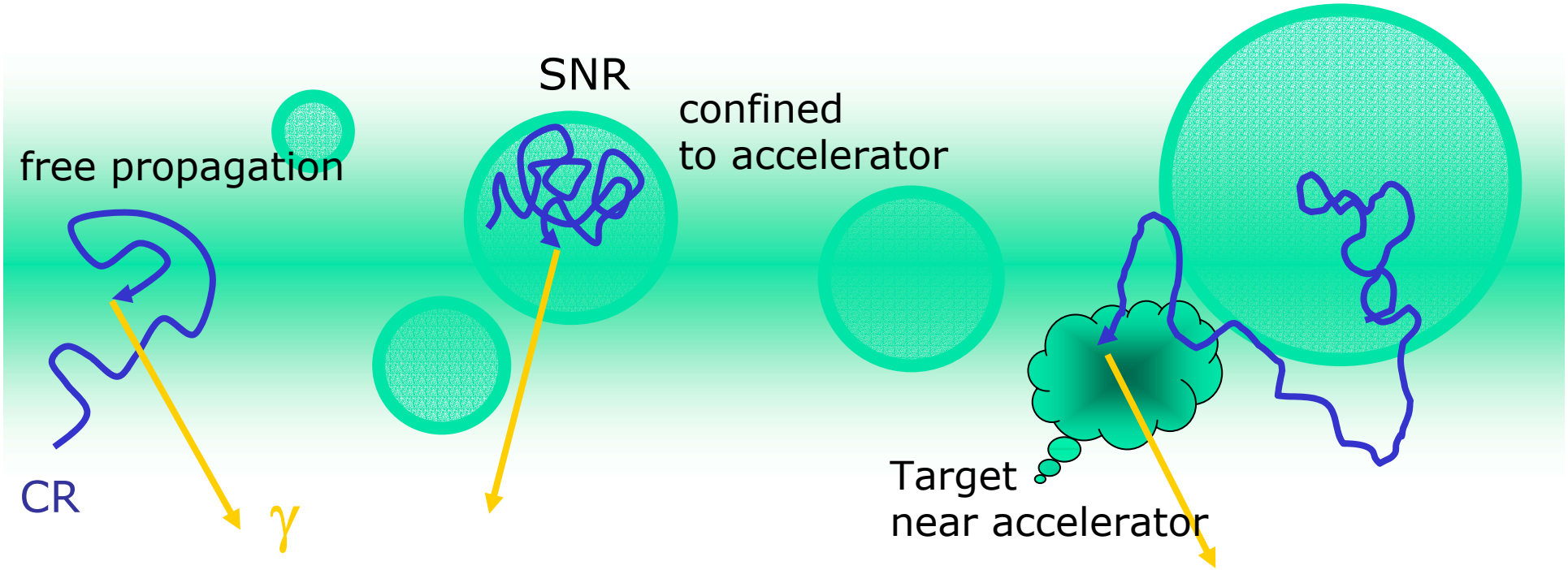
Outline

Concentrate on highlights during last year

- Introduction: instruments, physics
- TeV sky surveys
- Standard candle: Crab Nebula
- Other pulsars & nebulae
- Supernova remnants & CR
- ~~Diffuse TeV emission~~
- Unidentified TeV source
- Galactic center
- Exotics

Apologies for many omissions …

Issues ⏩
CR origin and propagation



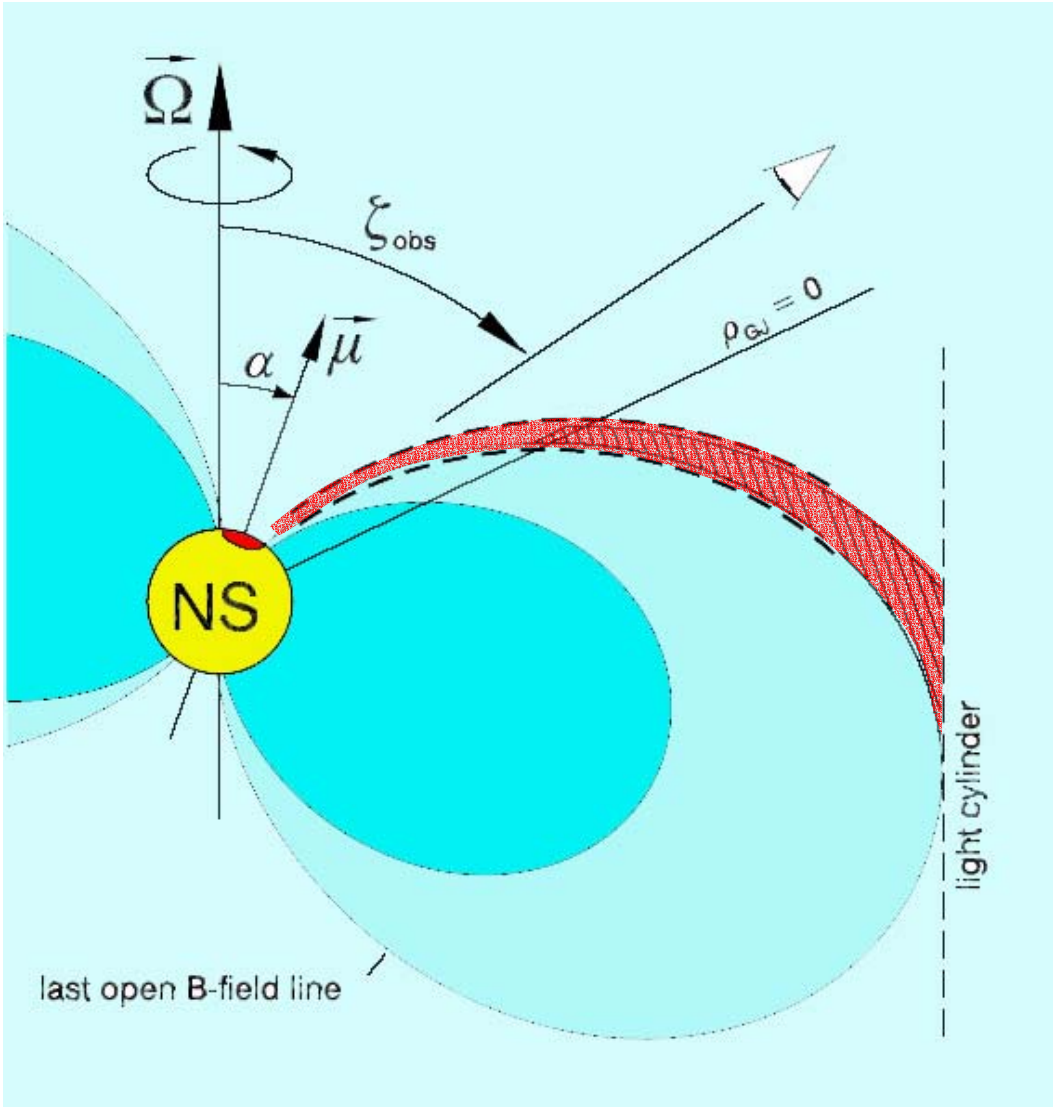
VHE gamma rays from secondary interactions:

p: π^o production and decay

e: Inverse Compton scattering and Bremsstrahlung

Trace beam density x target density

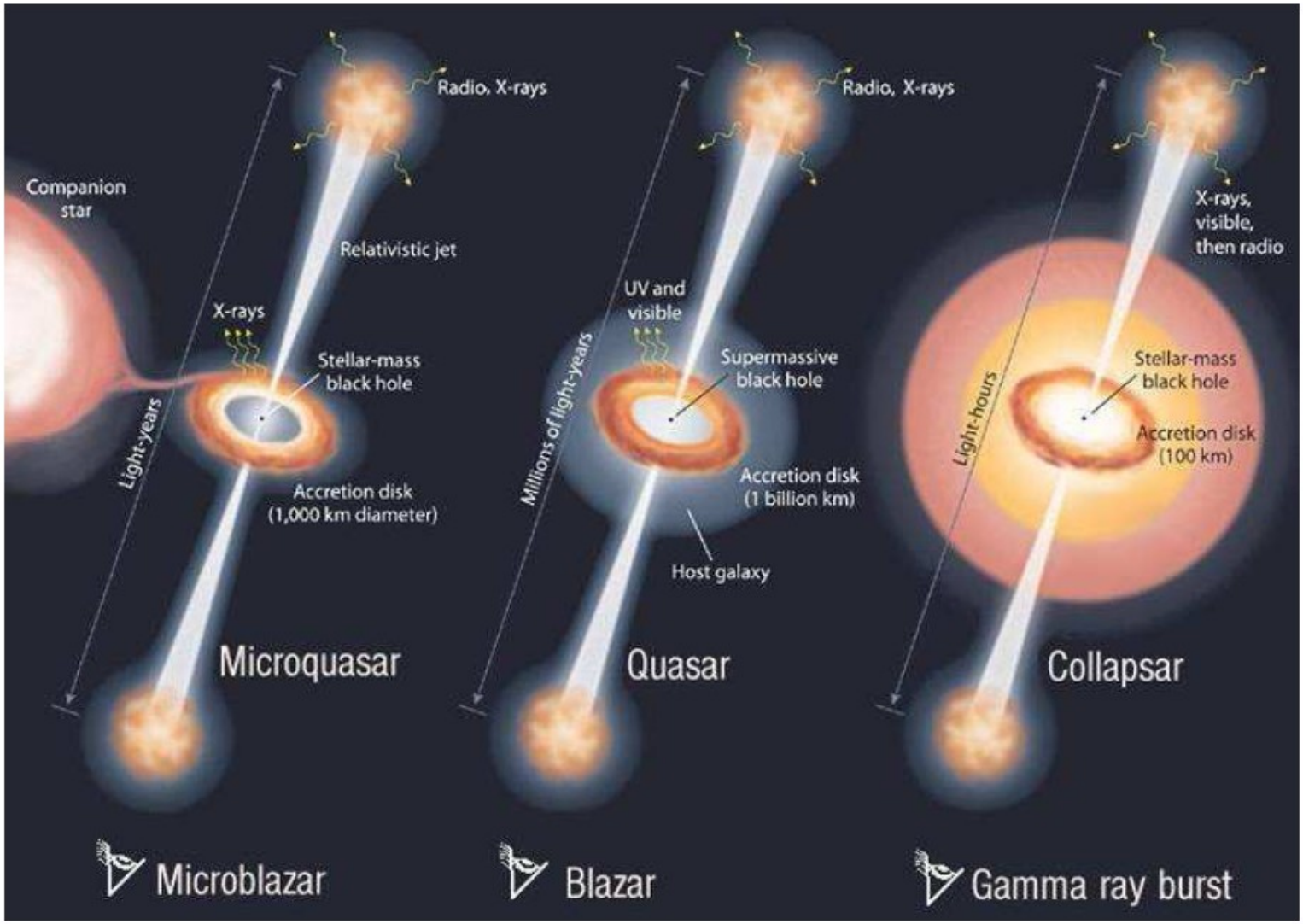
Issues ⏩
Pulsars: GR & Electrodynamics



from J. Dyks et al.

Issues ⏩
Microquasars: Mini-AGNs / GRBs

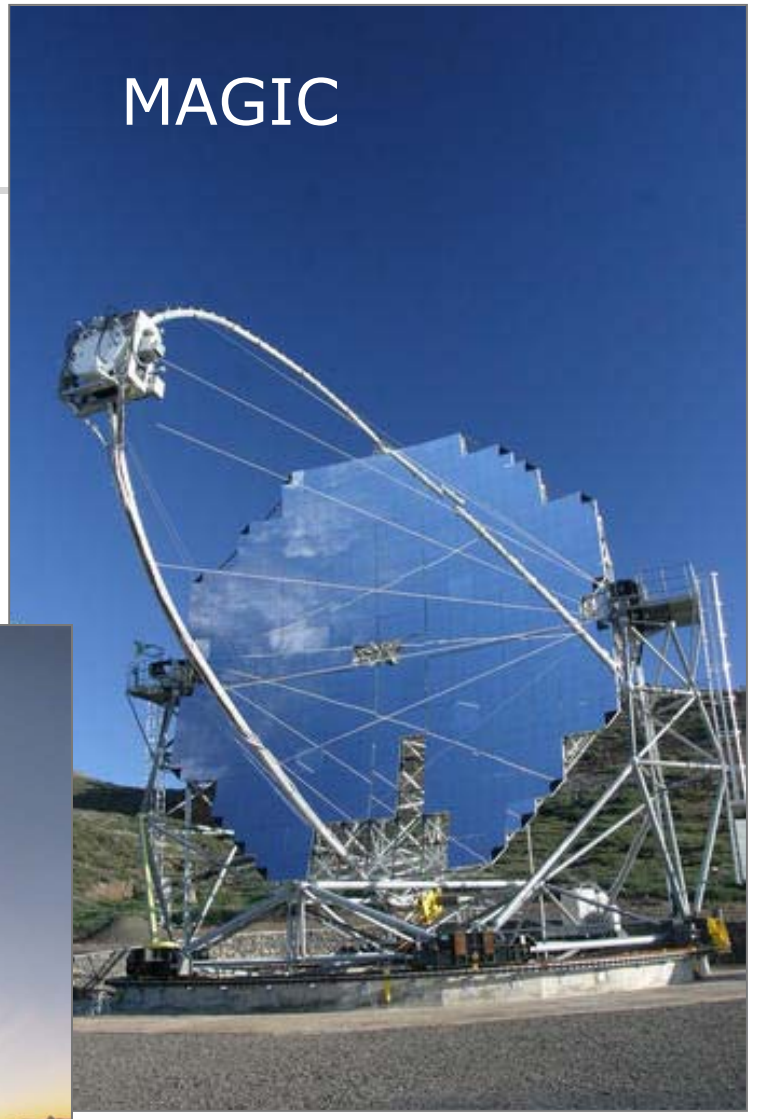
Mirabel



Galactic TeV sources

Source	Type	Distance (kpc)	Year	Flux (CU)	Grade	Group
Crab Nebula	**Plerion**	**~ 1.7**	**1989**	**1**	**A**	**Whipple, ...**
PSR 1706-44	**Plerion**	**~ 1.8**	**1995**	**~ 0.5**	**A**	**CANG., Durh.**
Vela	Plerion	~ 0.5	1997	~ 0.5	B	CANG.
SN 1006	**Shell SNR**	**~ 1.8**	**1997**	**~ 0.5**	**B ?**	**CANG., HE**
RXJ 1713.7-3946	Shell SNR	1 – 6	1999	~ 0.7	B	CANG.
Cassiopeia A	Shell SNR	~ 3.5	1999	~ 0.03	C	HEGRA
RCW 86	**Shell SNR**	**~ 2.5 ?**	**2003**	**~ 0.2**	**C**	**CANG. prel**
RXJ 0852.0-4622	**Shell SNR**	**< 0.5**	**2003**	**?**	**C**	**CANG. prel**
Centaurus X-3	Binary	> 5	1999	~ 0.4	C	Durham
TeV J2032+4130	**?**	**?**	**2002**	**~ 0.03**	**B**	**HEGRA, Whi.**
Galactic center	**?**	**~ 8**	**2003**	**0.1-0.4**	**B+**	**CANG.,Whi.**

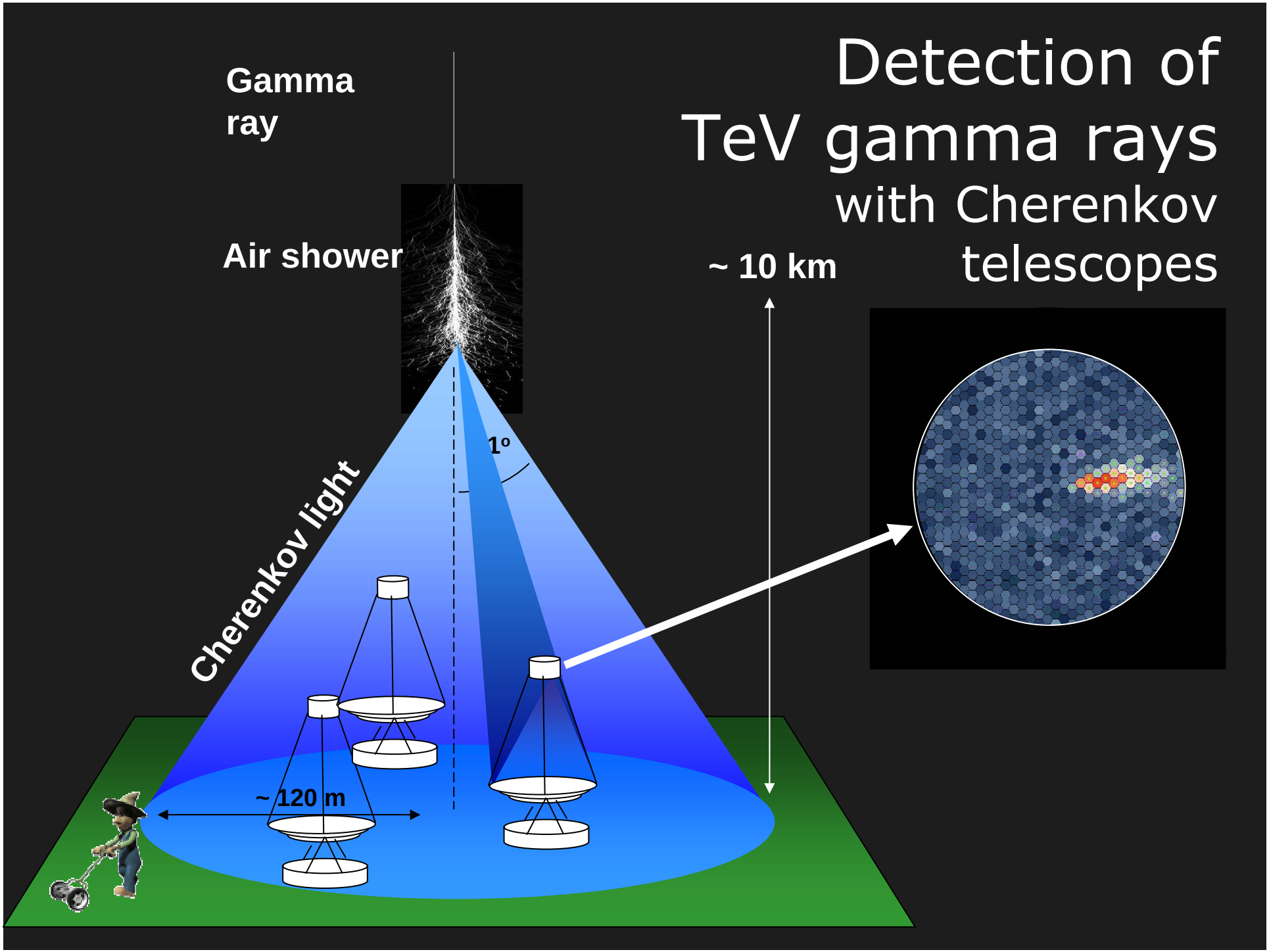
New instruments coming online


MAGIC

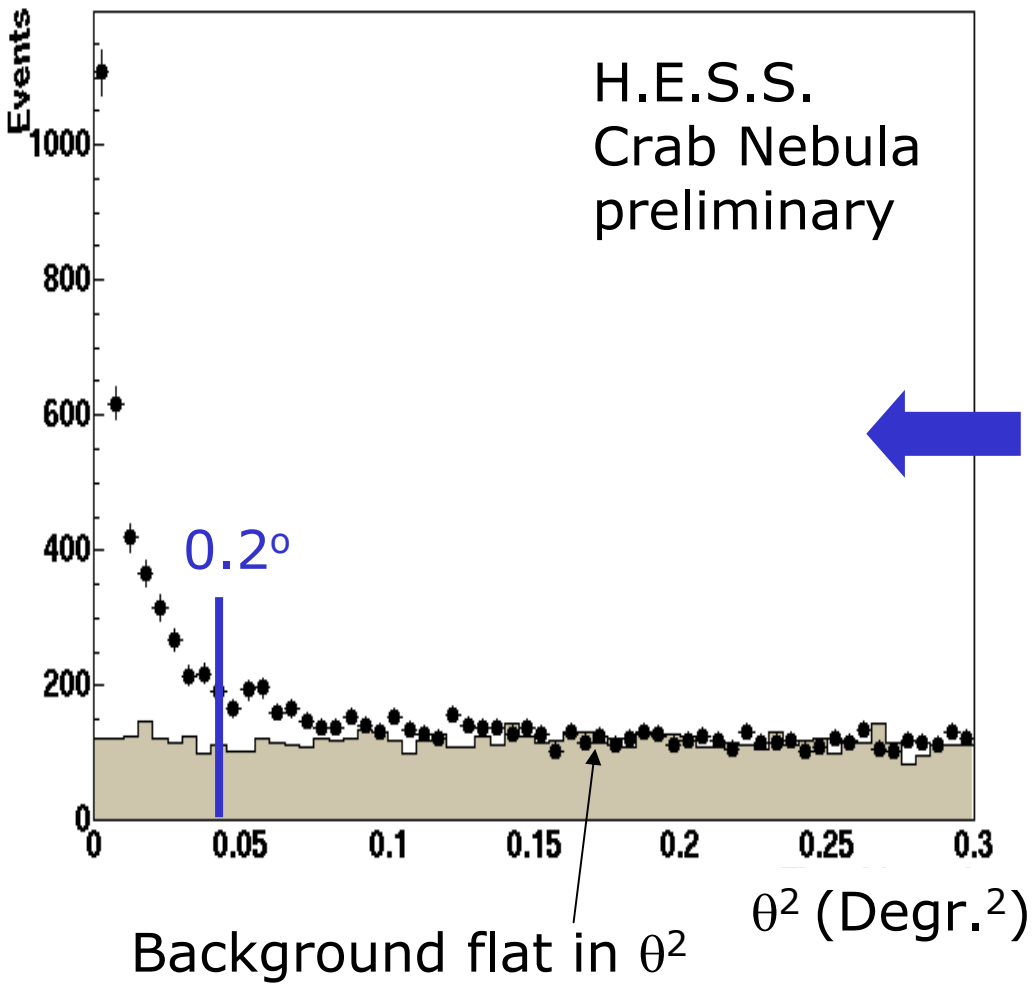

VERITAS
(photomontage)

R.I.P.

Detection of TeV gamma rays with Cherenkov telescopes



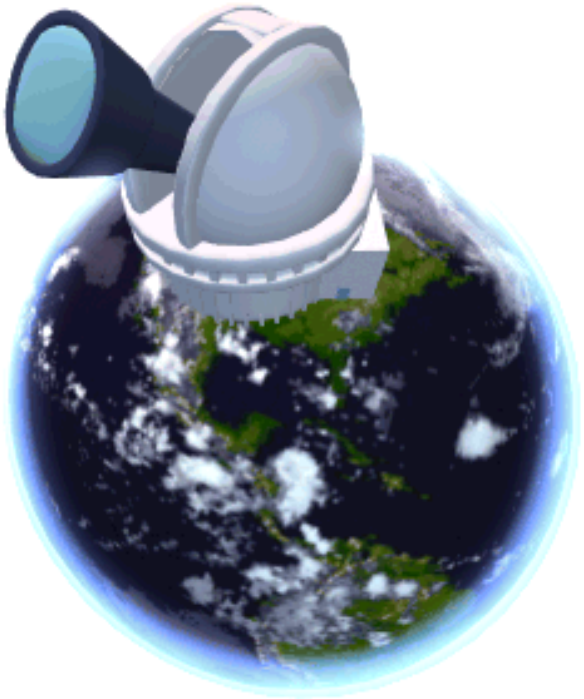
Two ways to present data



Angle α between image axis and source image; signal has a < 10-20°

Sky plot or angle θ between shower axis and direction to source; signal has θ < 0.1-0.2°

Sky surveys



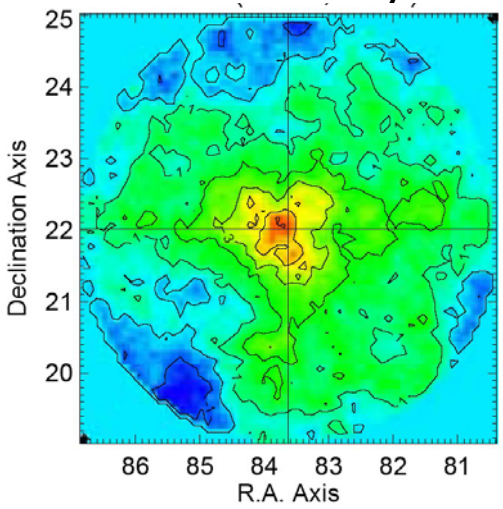
Survey capability

Wide-angle instruments surveying ~ 2-3π

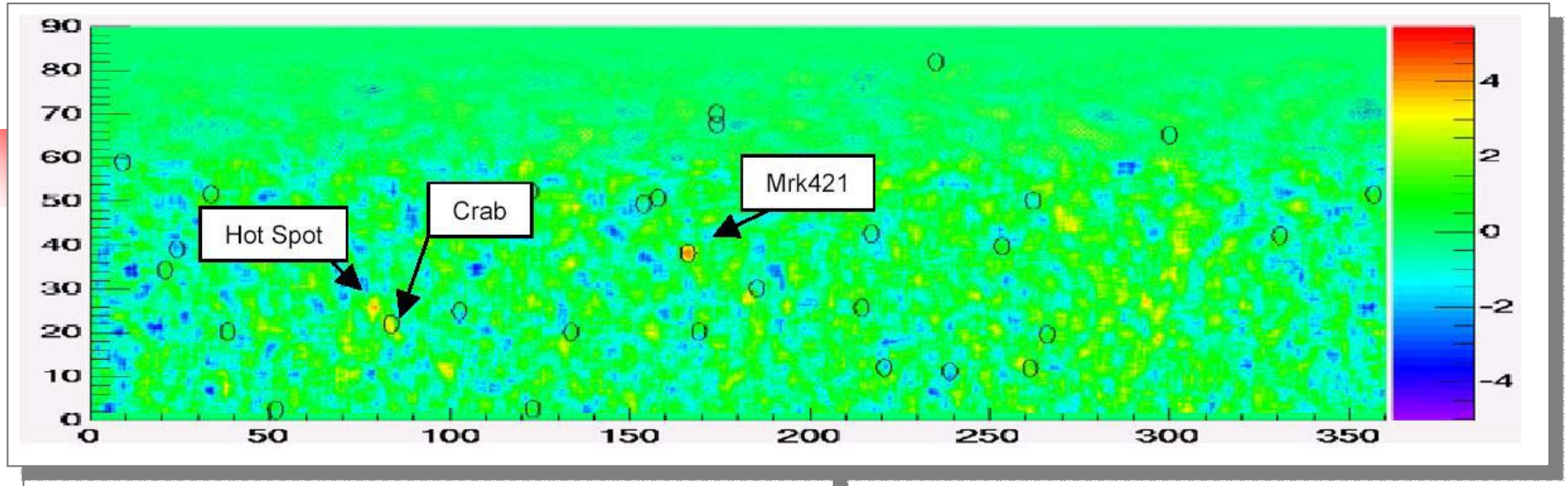
	"Threshold"	Sens. (1 y)
Milagro	~ 2 TeV	~ 0.5 Crab
Tibet III shower array	~ 3 TeV	~ 1 Crab
ARGO YBJ	0.5 – 1 TeV	~ 0.5 Crab

Milagro

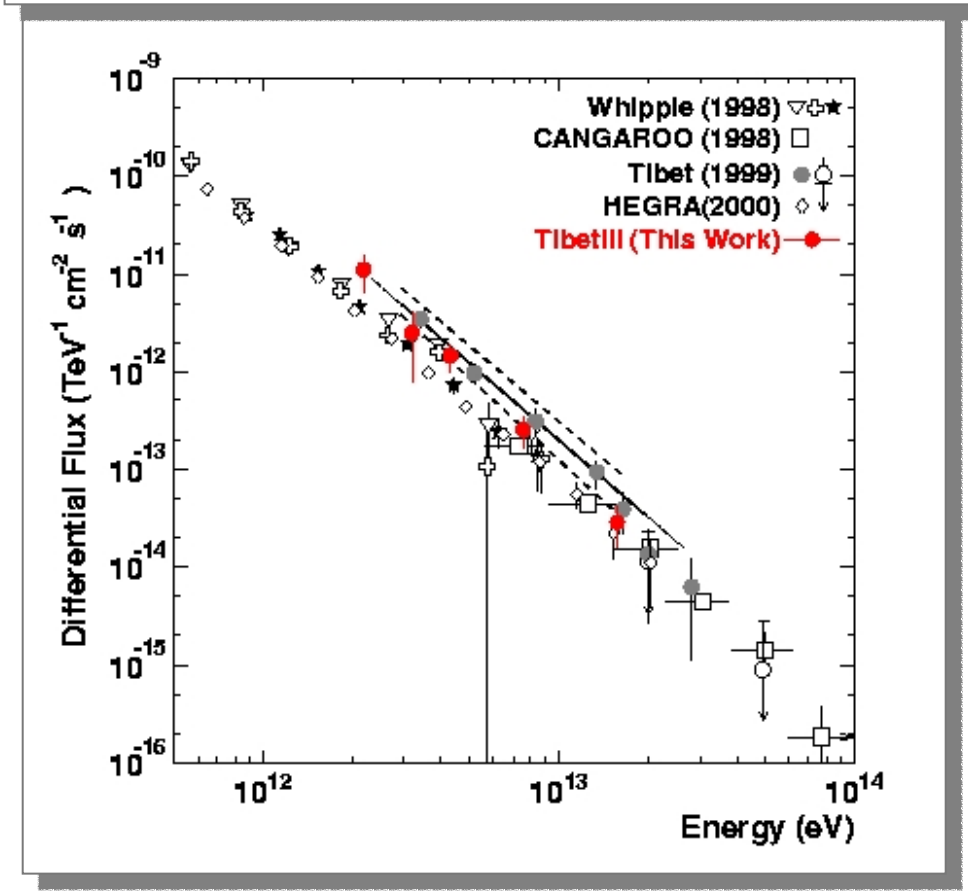
Crab signal
Tibet array



ARGO



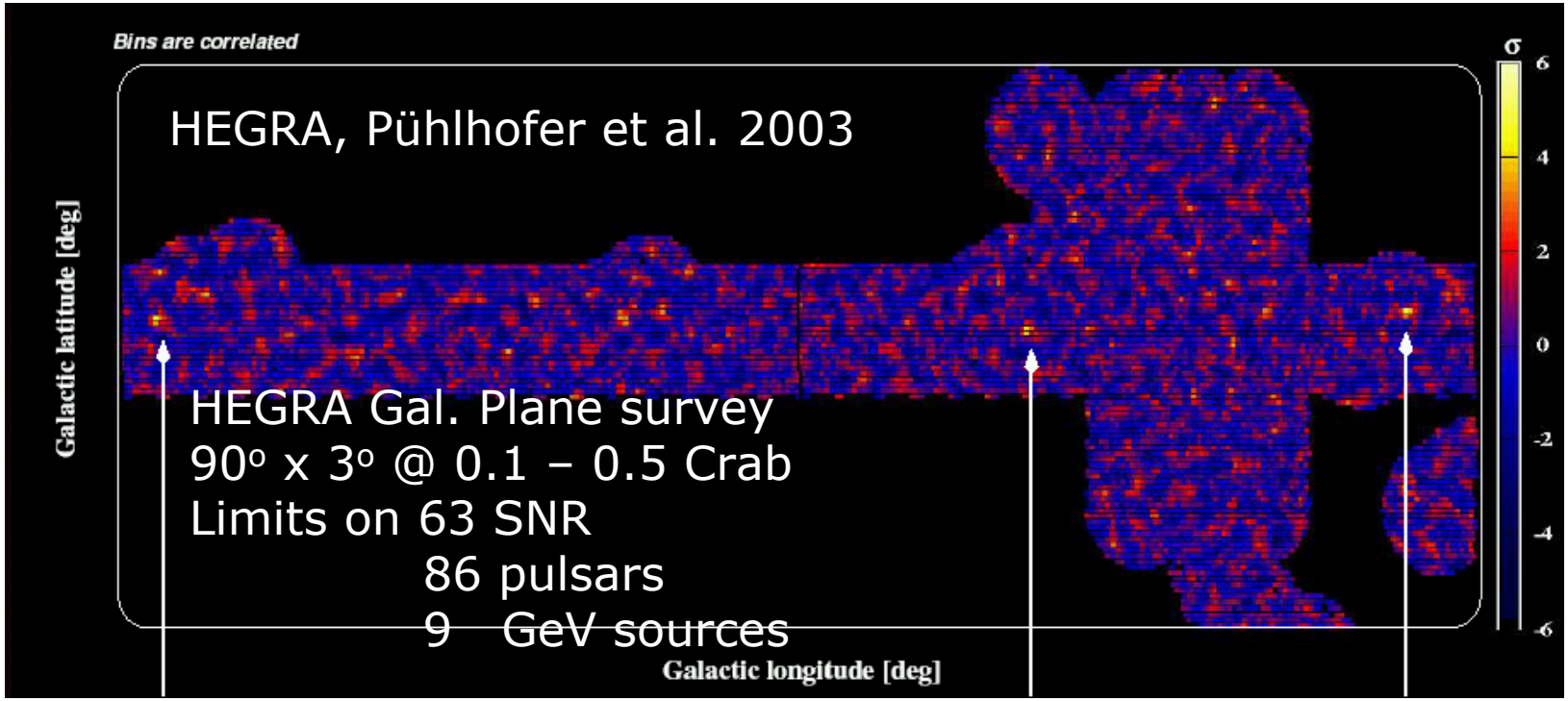
Milagro sky survey



Tibet array
Crab spectrum

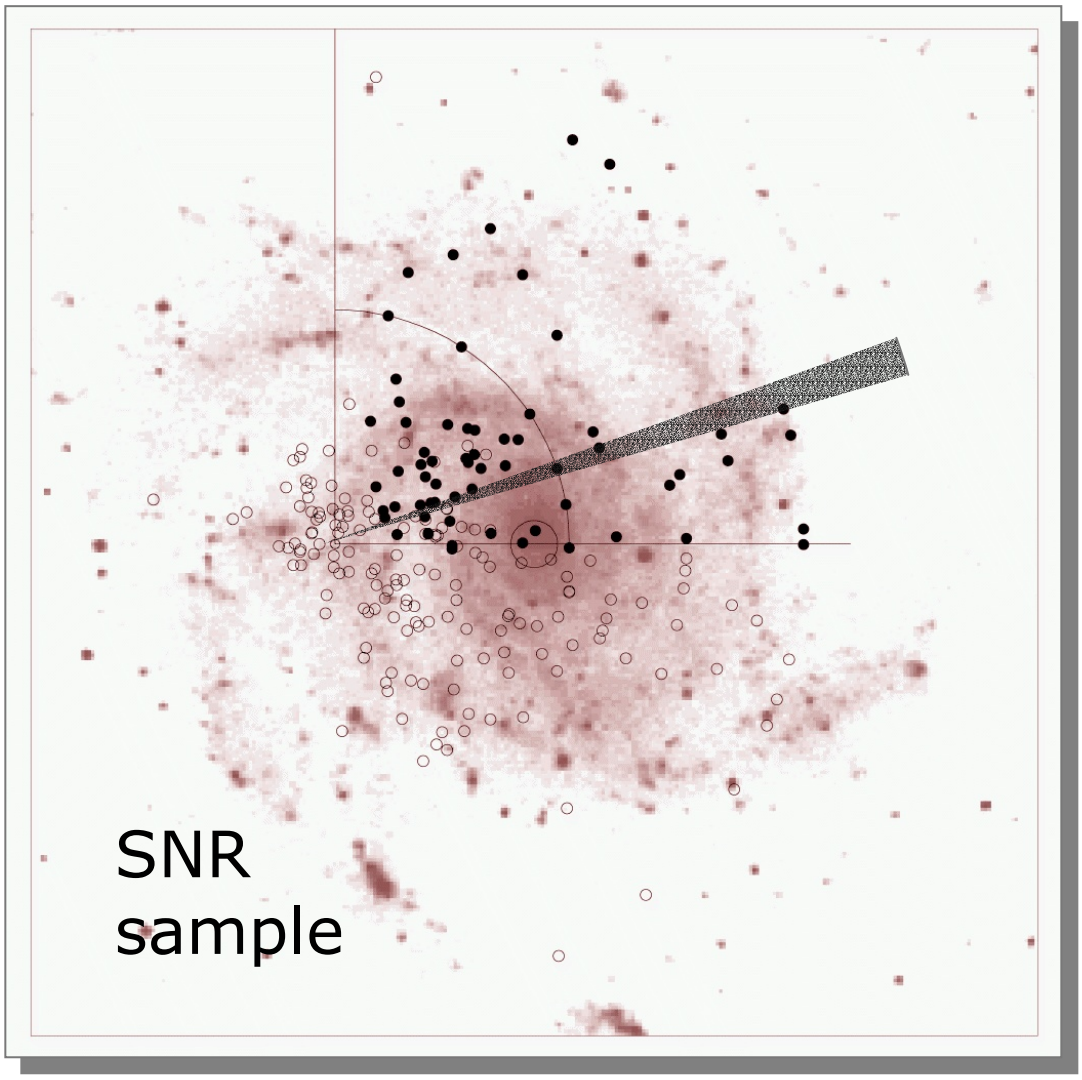
Survey capability

Small-angle instruments



H.E.S.S.: ~ 300 deg.^{2} in 100 h @ 0.03 Crab
2π in 7 years

HEGRA Galactic Plane survey

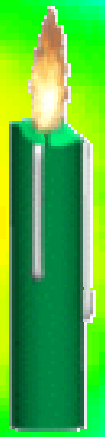


HEGRA
Aharonian et al. 2002

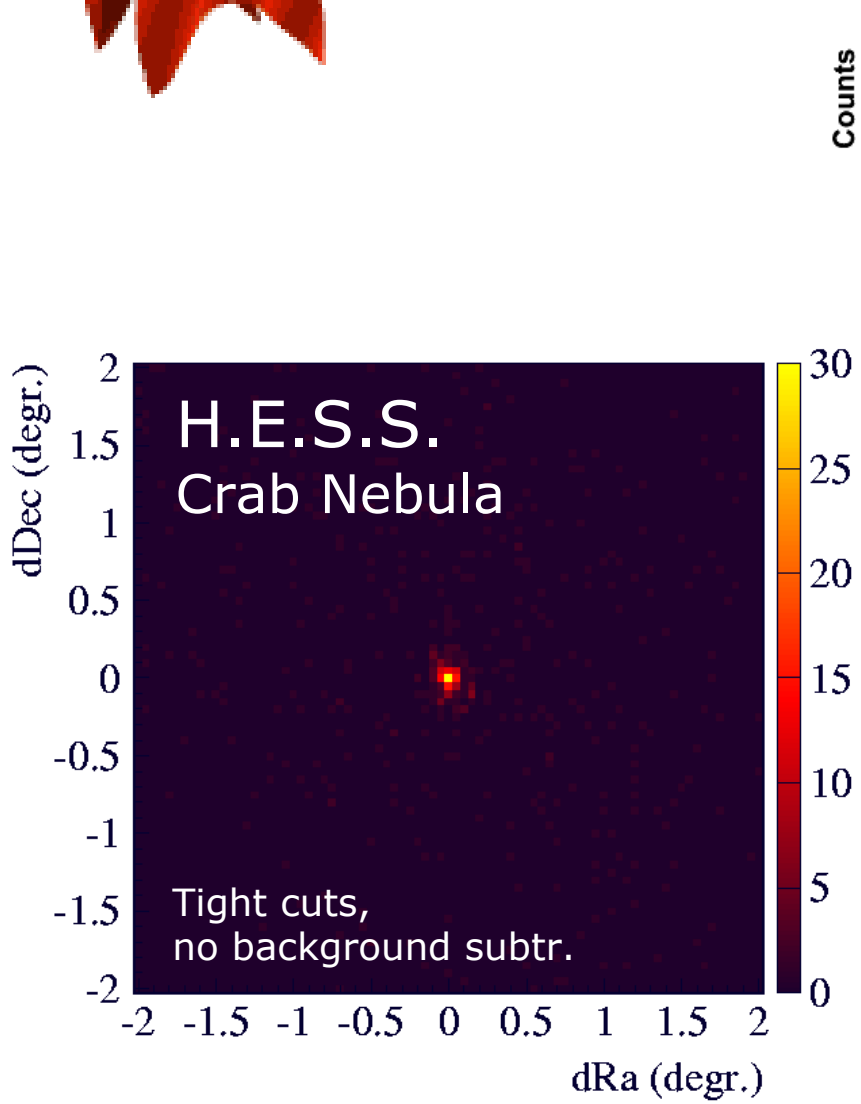
Covered
- 63 SNR
- 86 pulsars
- 9 GeV sources

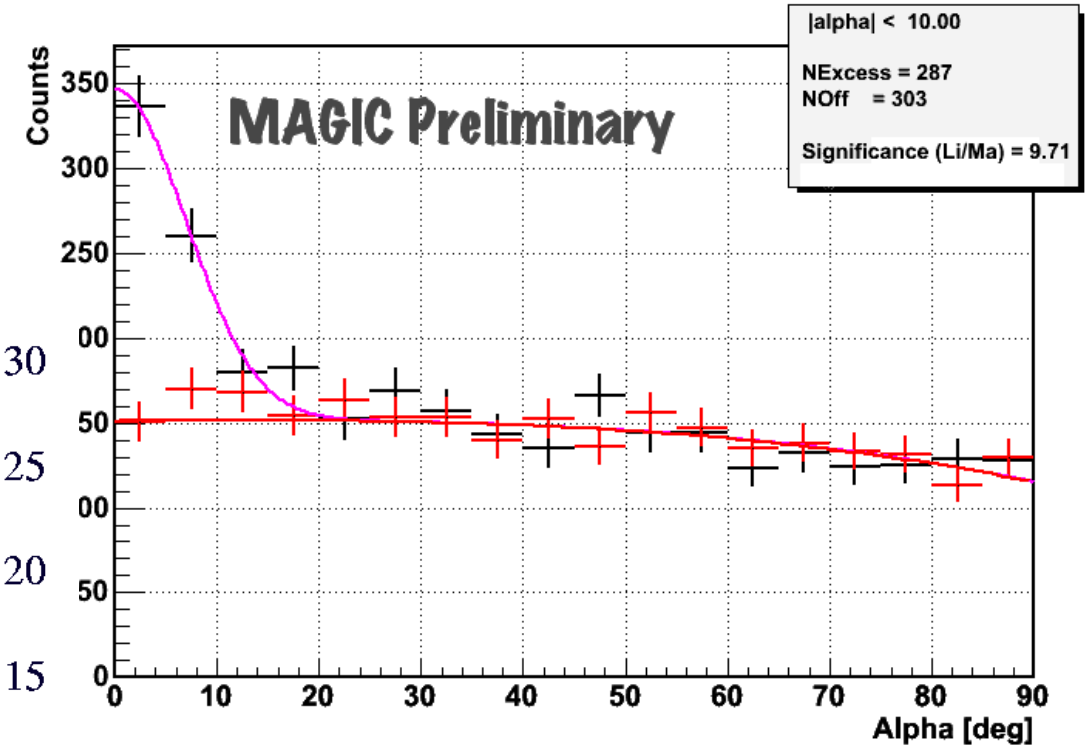
No detection;
typical limits
0.1 – 0.5 Crab

Crab Nebula: The standard candle



New kids on the block





Old hand: HEGRA

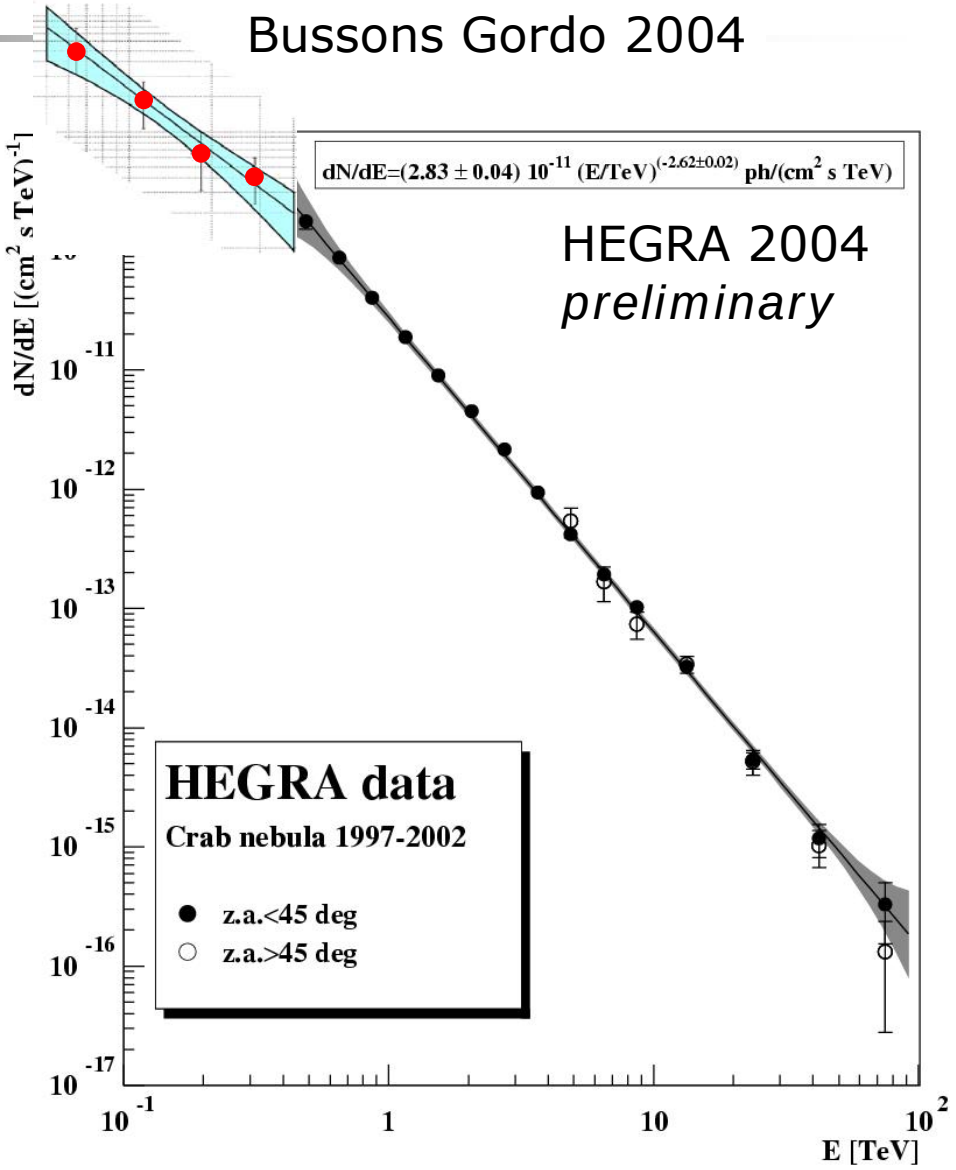
400 h data, 1997-02

Study energy dependence of position, size

< 10% ionic component

see talk by D. Horns

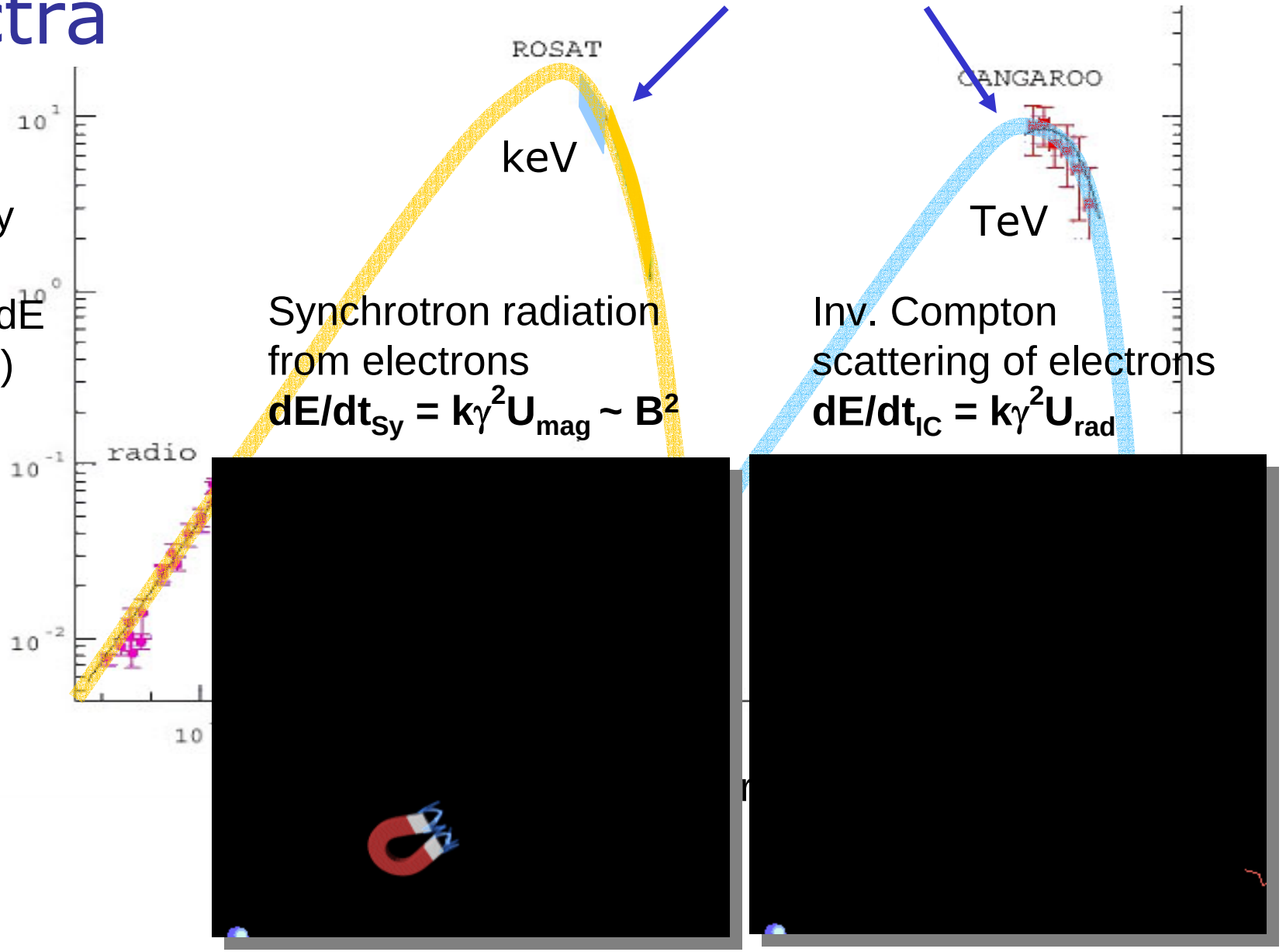
CELESTE
Bussons Gordo 2004



Multiwavelength spectra

For typical ISM $U_{mag} \sim U_{rad}$
⏩ Peaks have equal height

Energy flux
$E^2\, dn/dE \sim \nu F(\nu)$

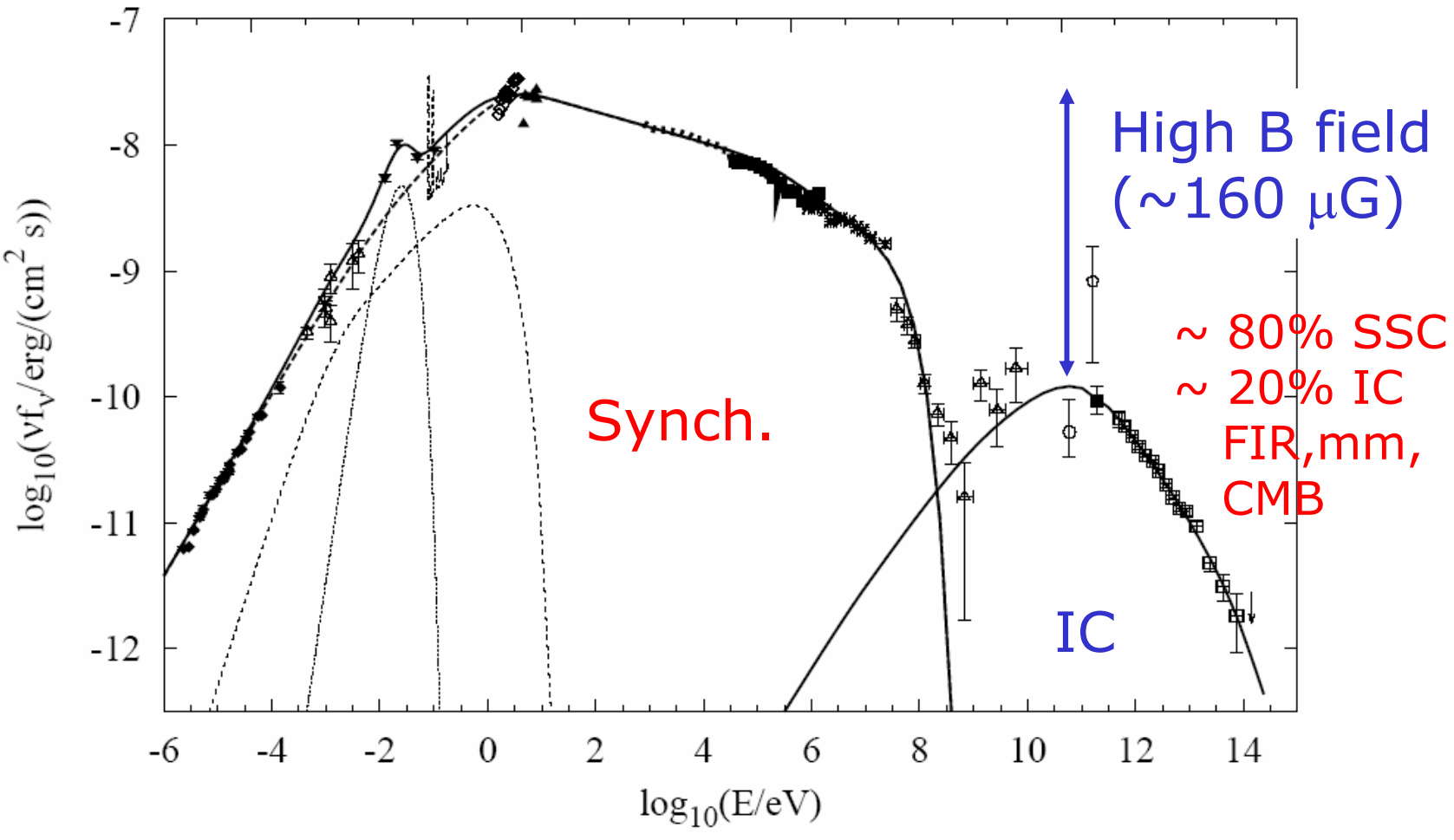


Synchrotron radiation from electrons
$dE/dt_{Sy} = k\gamma^2 U_{mag} \sim B^2$

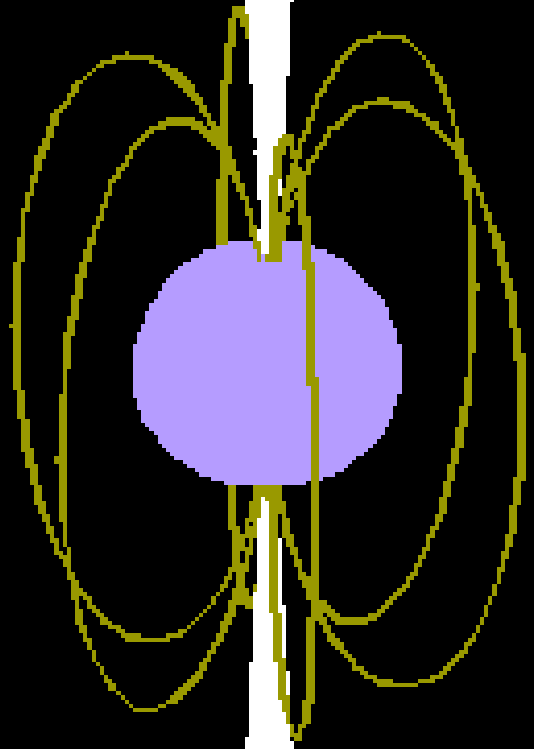
Inv. Compton scattering of electrons
$dE/dt_{IC} = k\gamma^2 U_{rad}$

Multiwavelength spectra

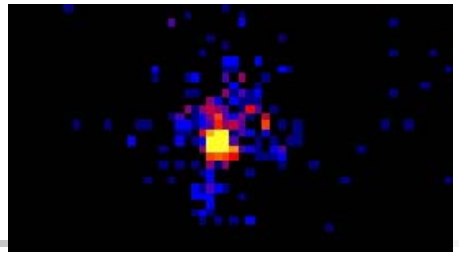
Aharonian et al. 2004



Other pulsars & nebulae



PSR 1706-44



Chandra

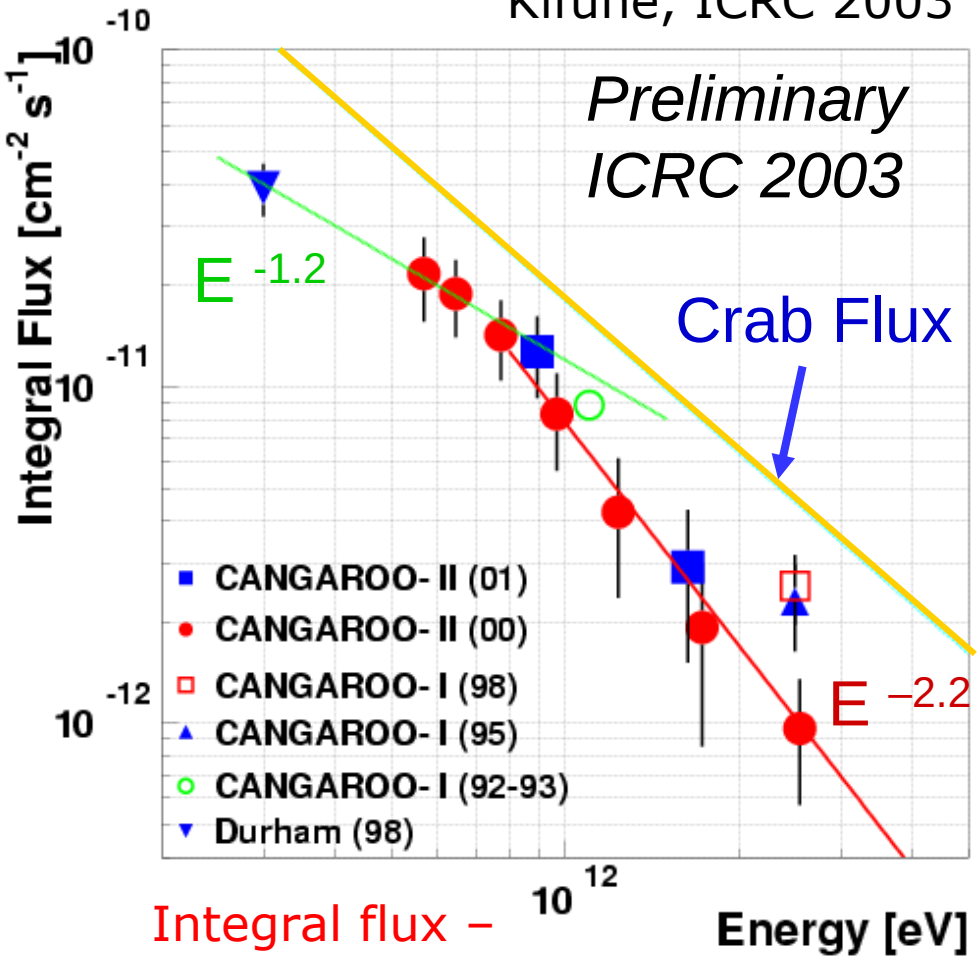
- P=102 ms
- Spindown lum. about 1% of Crab
- X-ray lum. about 0.01% of Crab
- TeV emission detected with Durham and CANGAROO-I

  Kifune et al. 1995

  Chadwick et al. 1998
- Observed with CANGAROO-II in 2000 and 2001

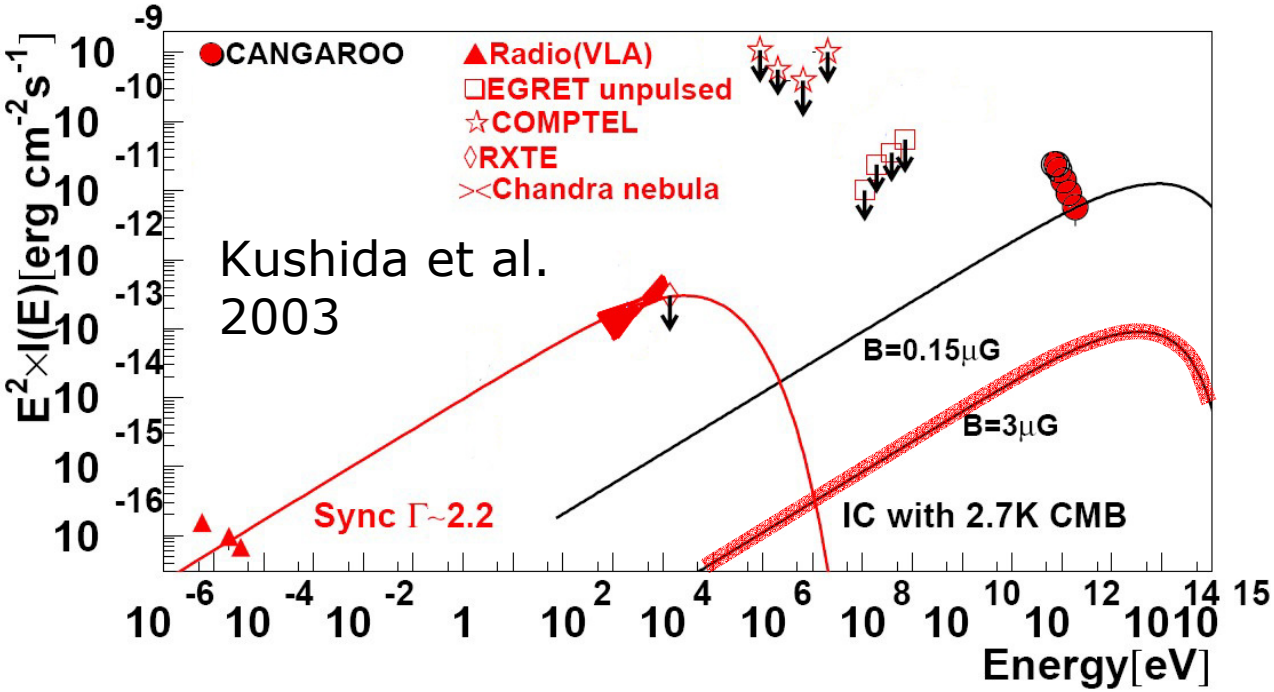
  Kushida et al., ICRC 2003

Kifune, ICRC 2003



Integral flux – Correlated points!

PSR 1706 interpretation



Difficult to make IC work!

Aharonian,Atoyan, Kifune 1997

Kushida et al. 2003, …

Sefako & de Jager 2003, 2004

Chandra data ⏩ expect ~ 0.001 Crab !

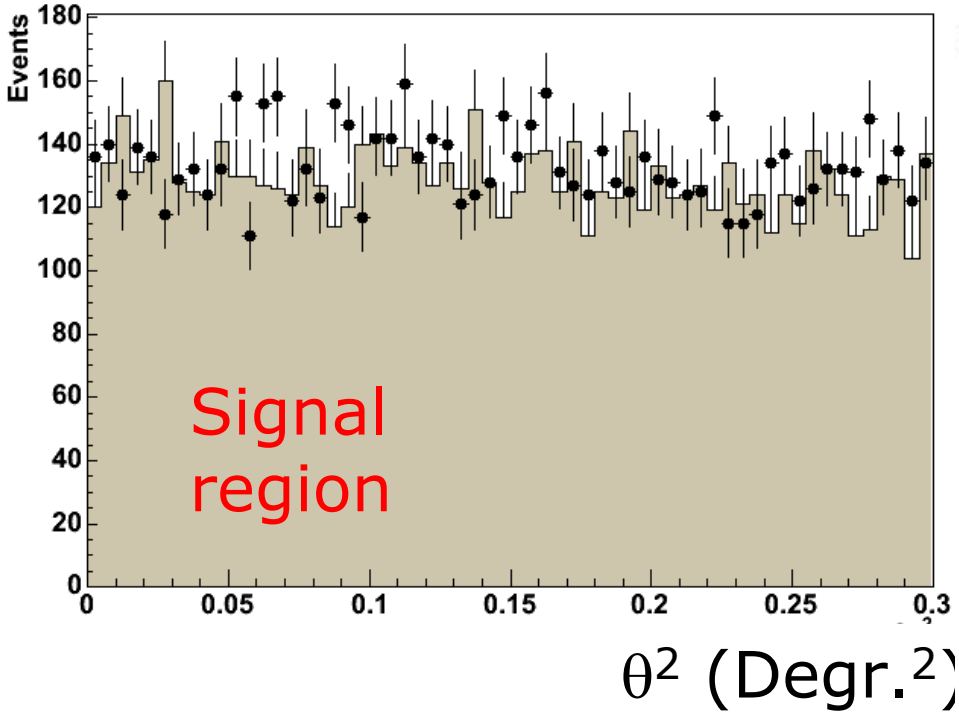
Bednarek, Bartosik 2003

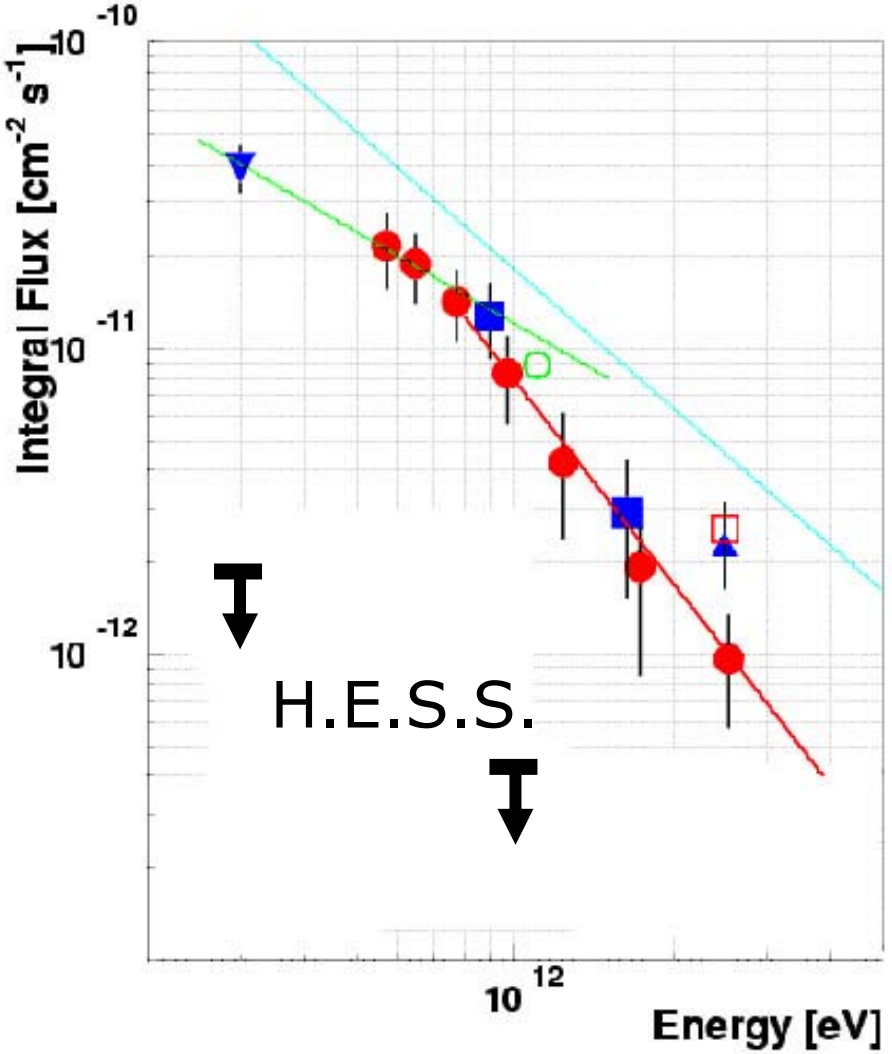
Amato et al. 2003, …

VHE proton or Fe component ?

New H.E.S.S. data on 1706-44

preliminary

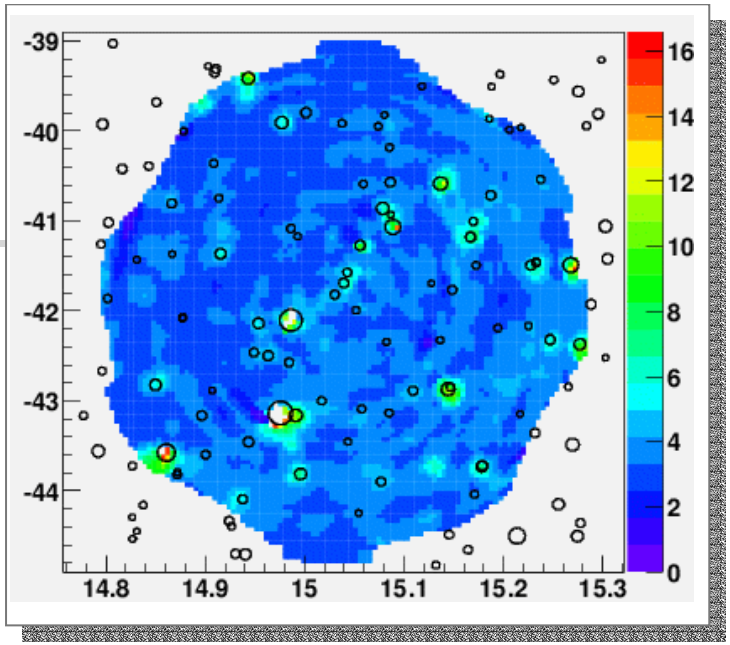




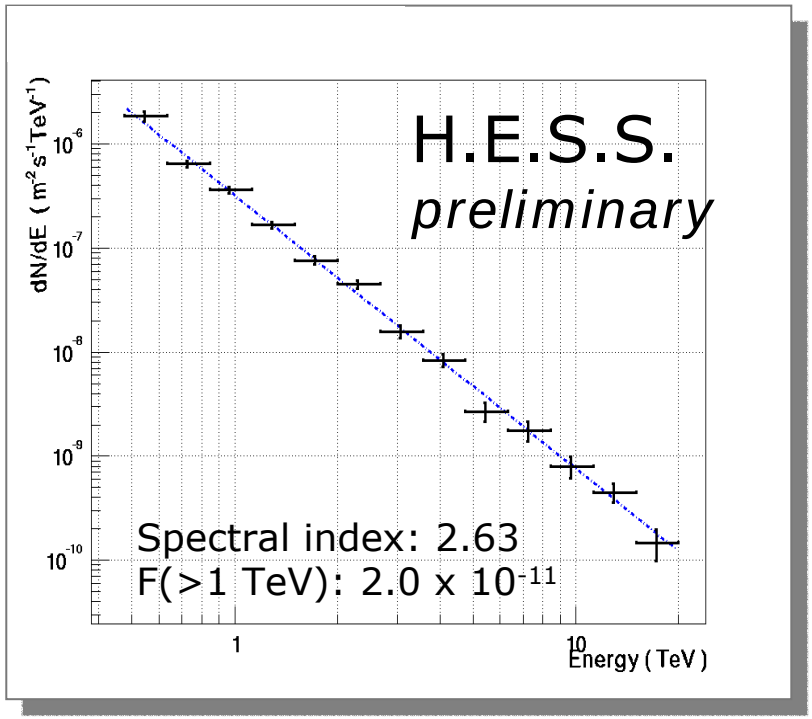
14 h 2-telescope data
taken during commissioning phase

H.E.S.S. data quality

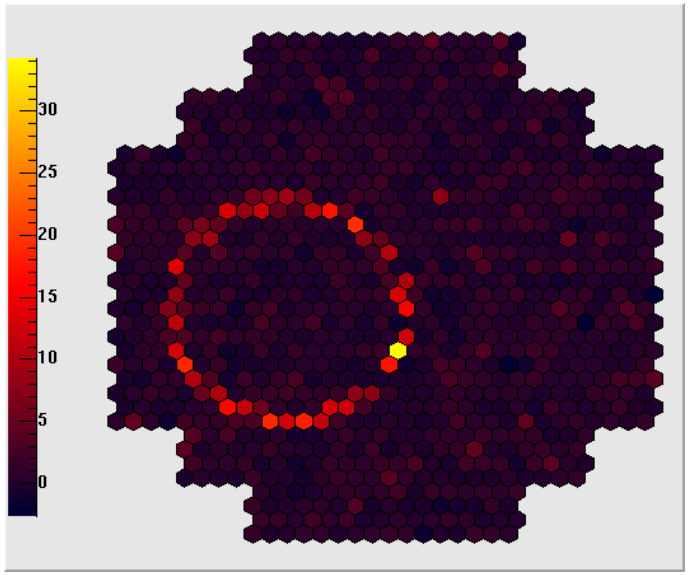
Pointing: stars & pixel currents; good to 20”



Energy & flux determination: Crab spectrum

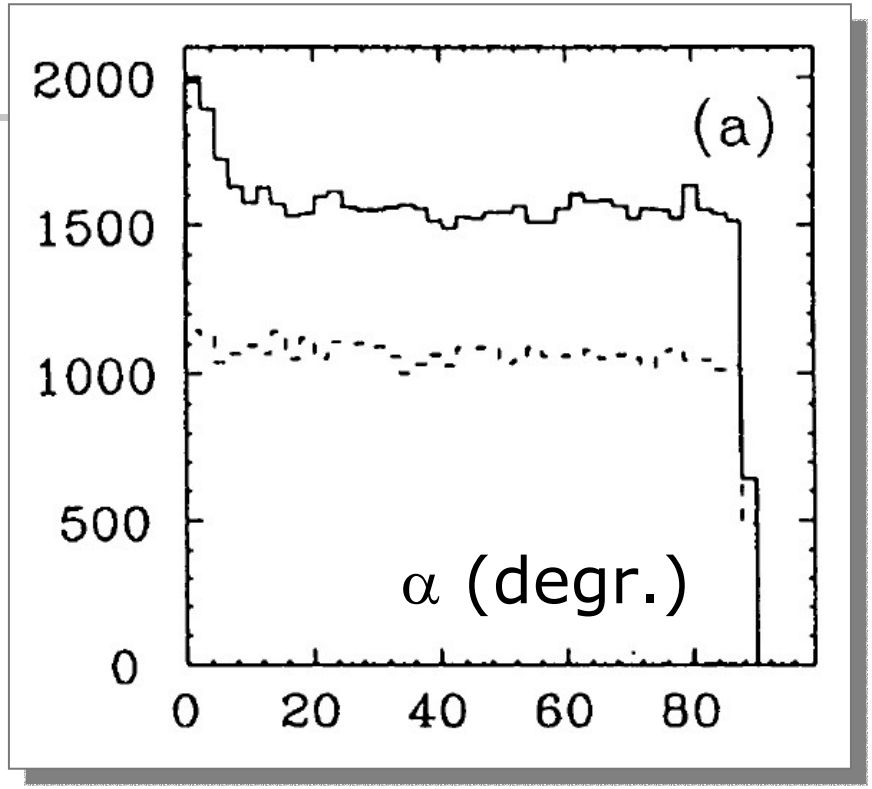


Imaging & calibration: muon rings



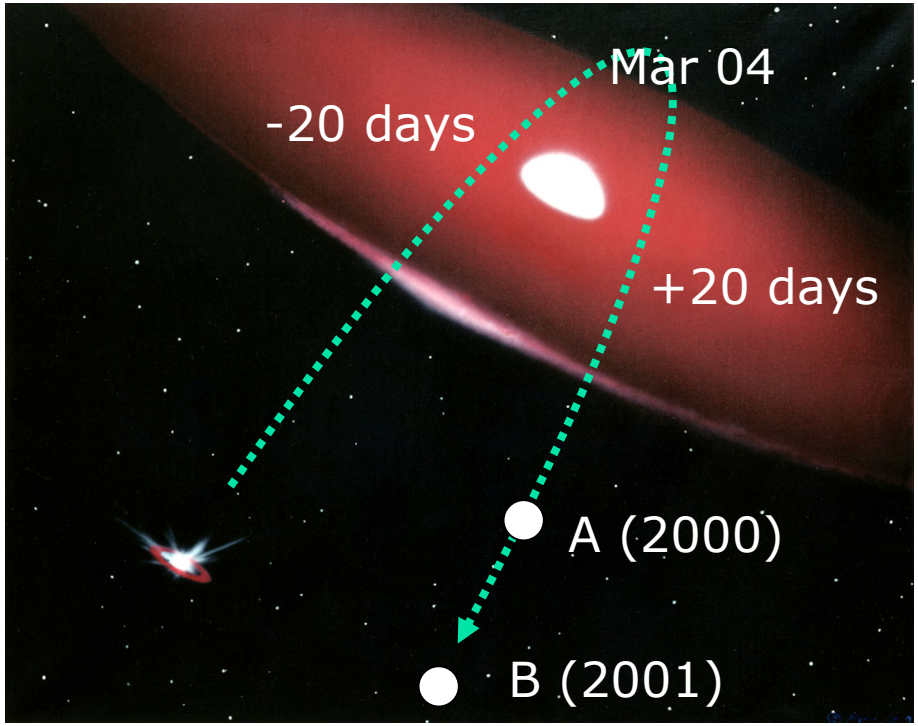
Interpretation

CANGAROO
Kifune et al.
1995



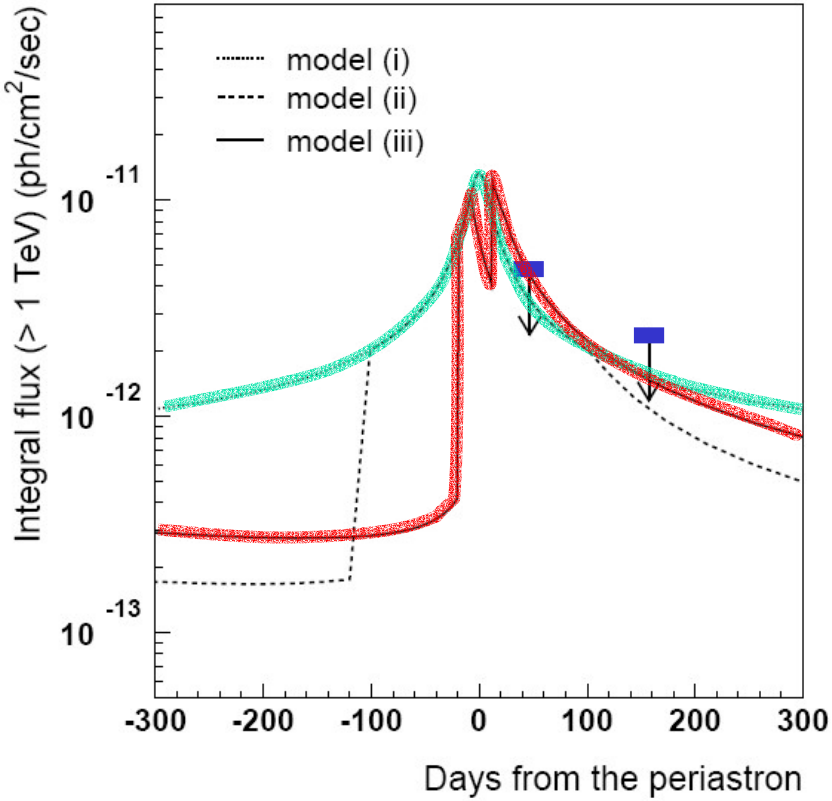
- CANGAROO signal very solid
- Time dependence of gamma rays from pulsar nebula ? Size ~ 0.1 pc
- Time-dependent background source ?

PSR B1259-63



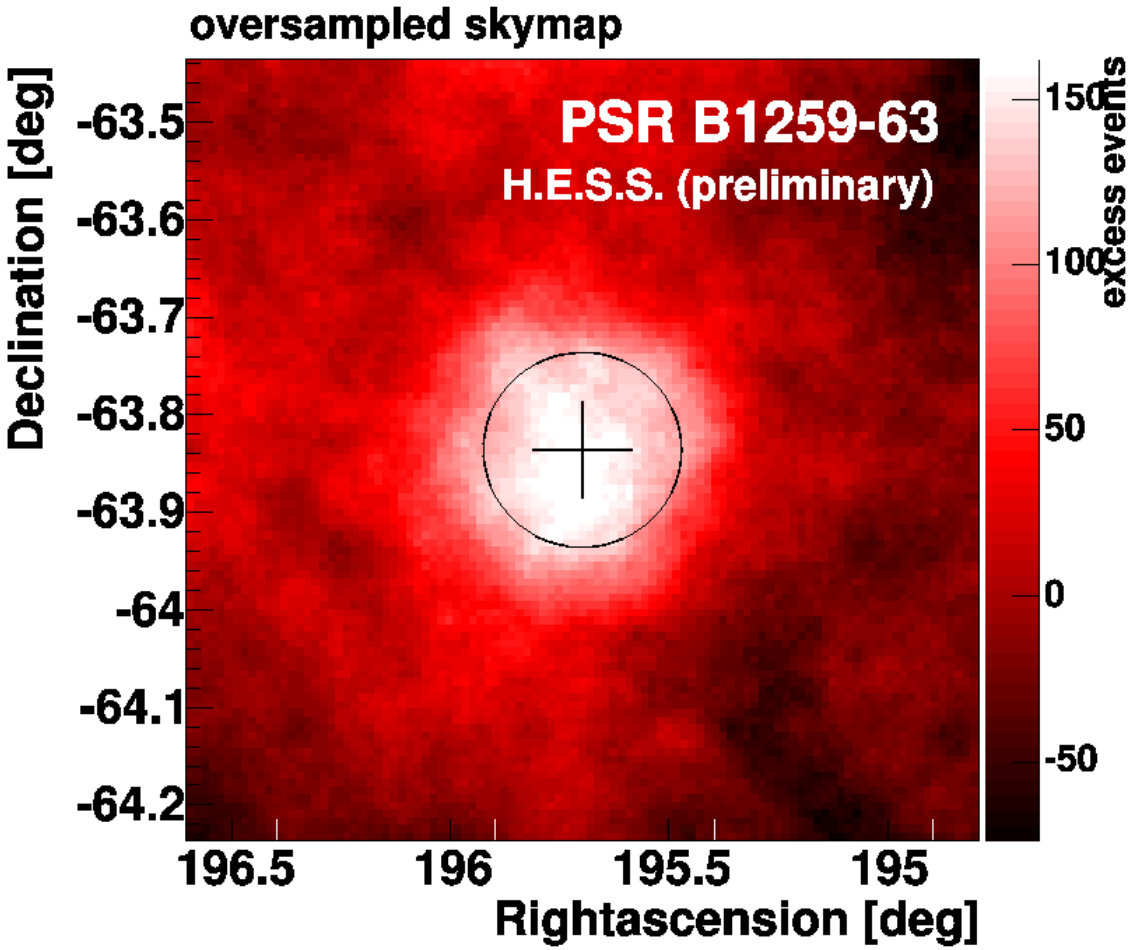
Model: Ball & Kirk 2000

CANGAROO
Kawachi et al. 2004



Complex structure depending on alignment of pulsar and stellar wind

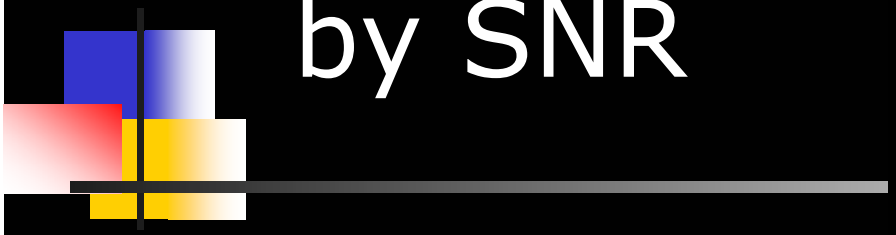
PSR B1259-63

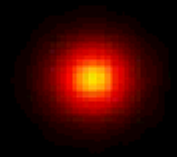


H.E.S.S.
See talk by M. Beilicke

~ 10 days before periastron (Feb./March)

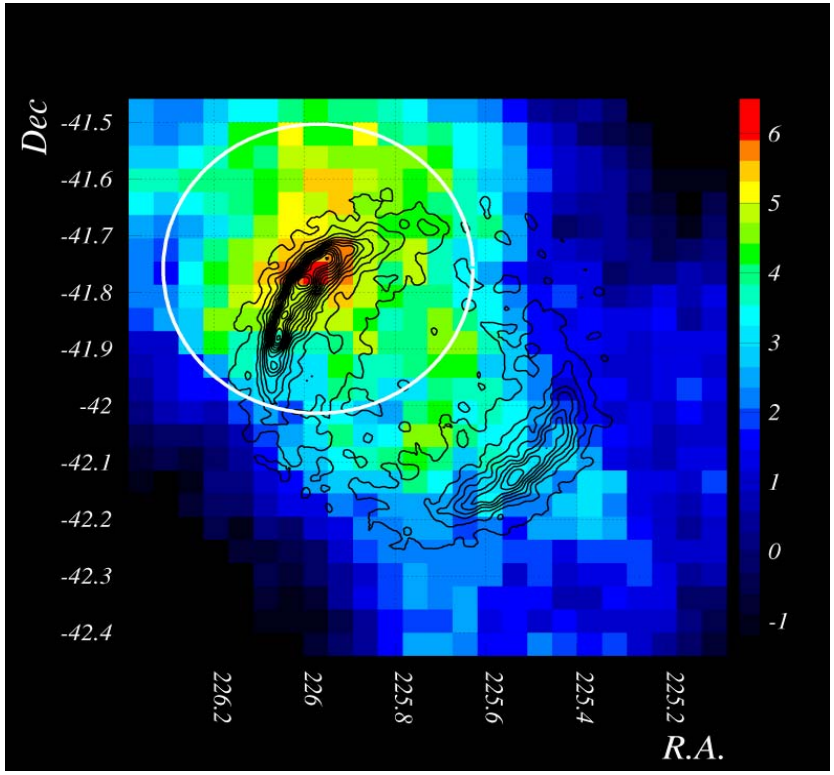
Gamma emission by SNR



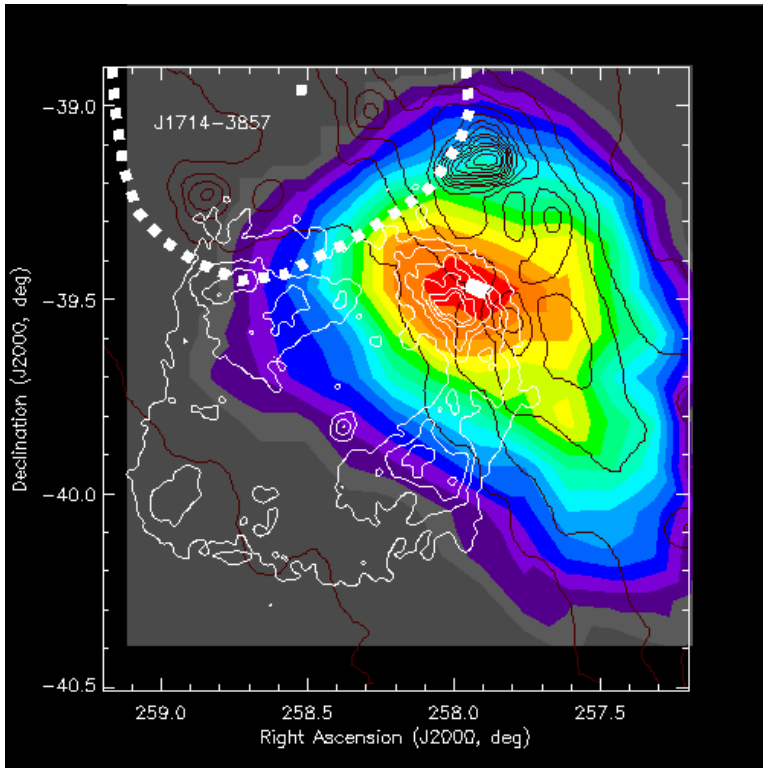


SNR established as VHE gamma-ray sources

CANGAROO SN 1006



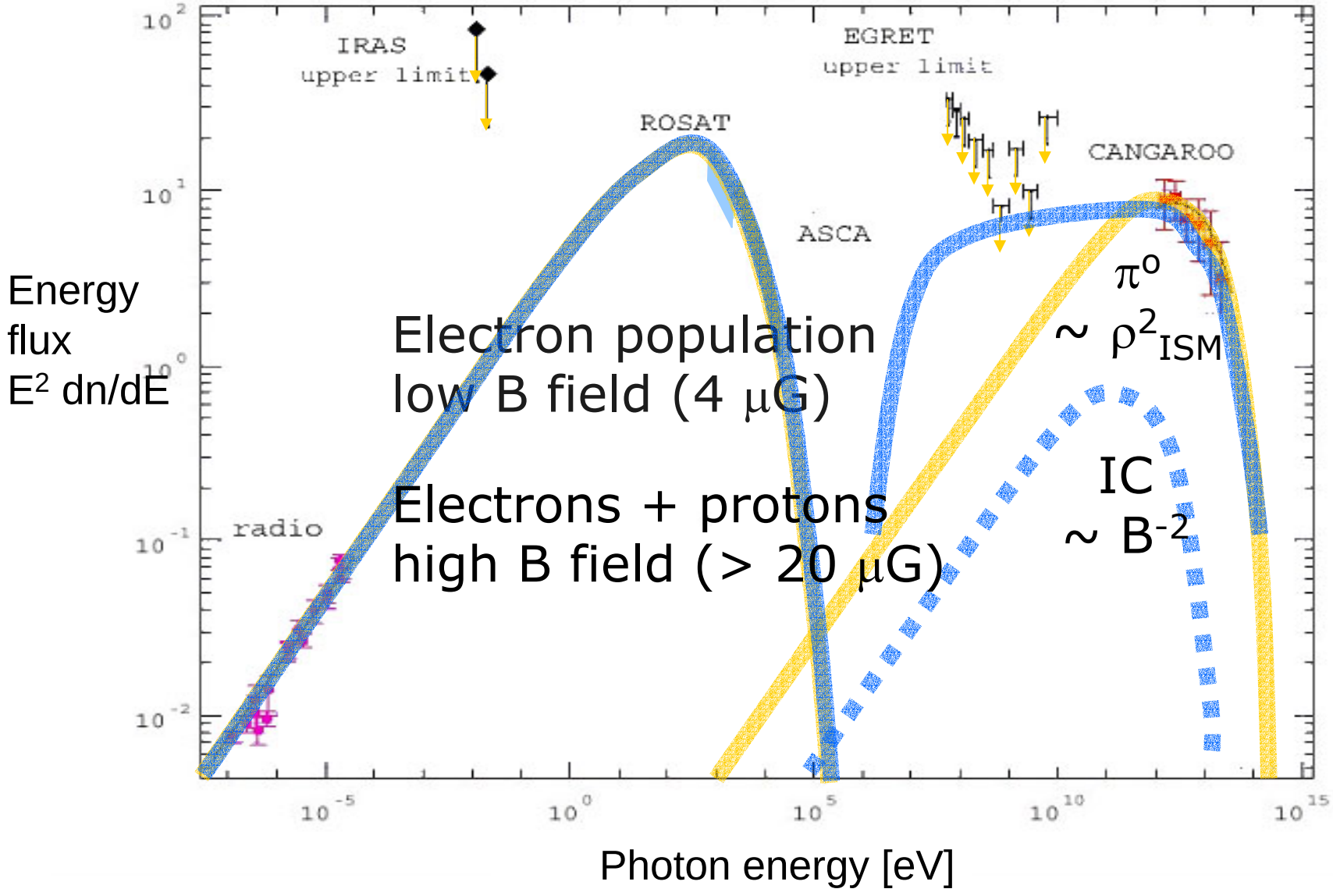
CANGAROO RXJ1713.7-3946



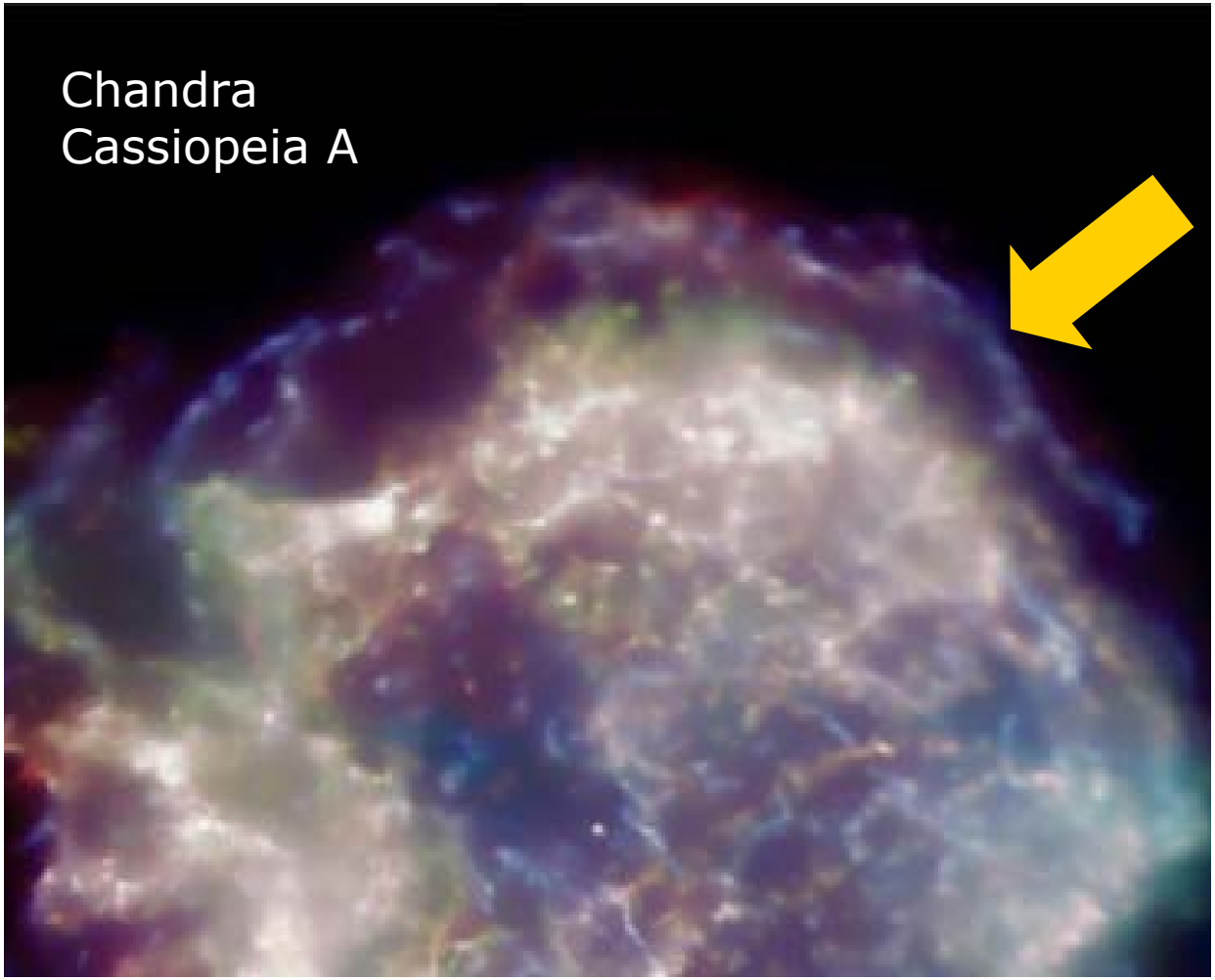
Kifune ICRC 2003

and HEGRA Cas A,
CANGAROO RXJ0852, CANGAROO RCW 86

Big issue: Interpretation



Key issue: magnetic field



Short electron lifetimes!

- Large post-shock magnetic fields

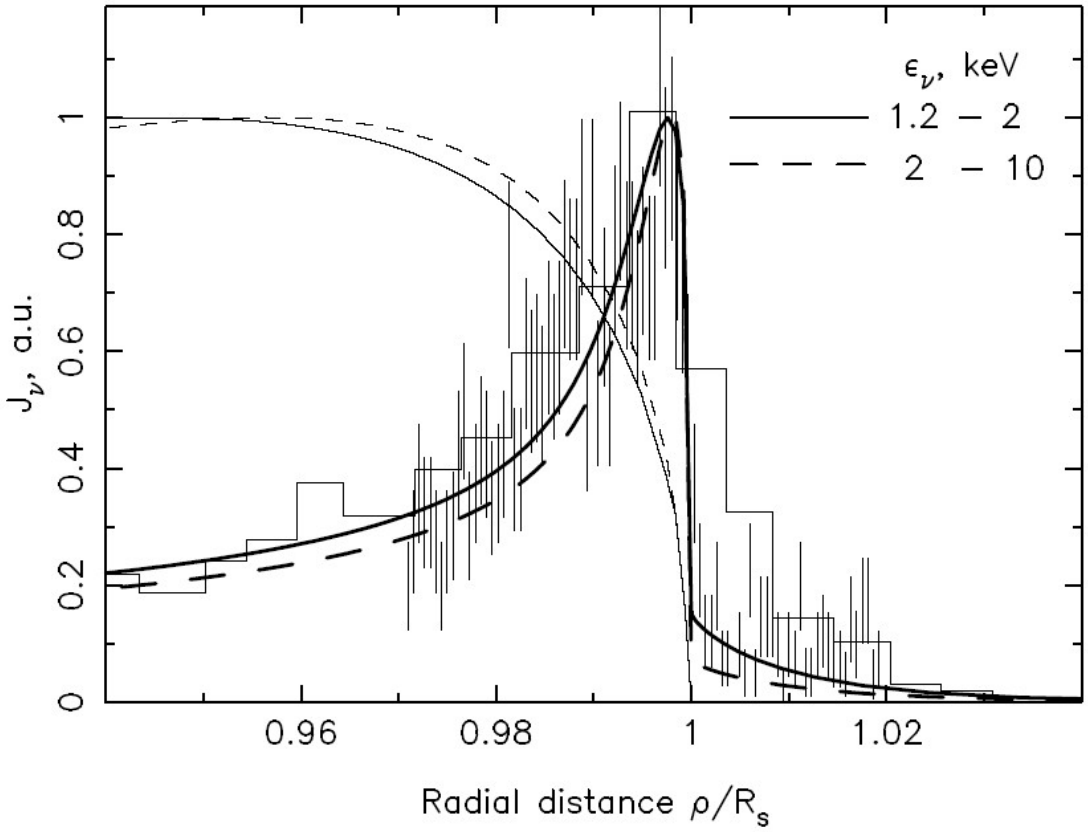
Cas A

Berezhko & Völk, 2004
~ 500 μG
Vink, Laming, 2002
~ 80-160 μG

SN 1006

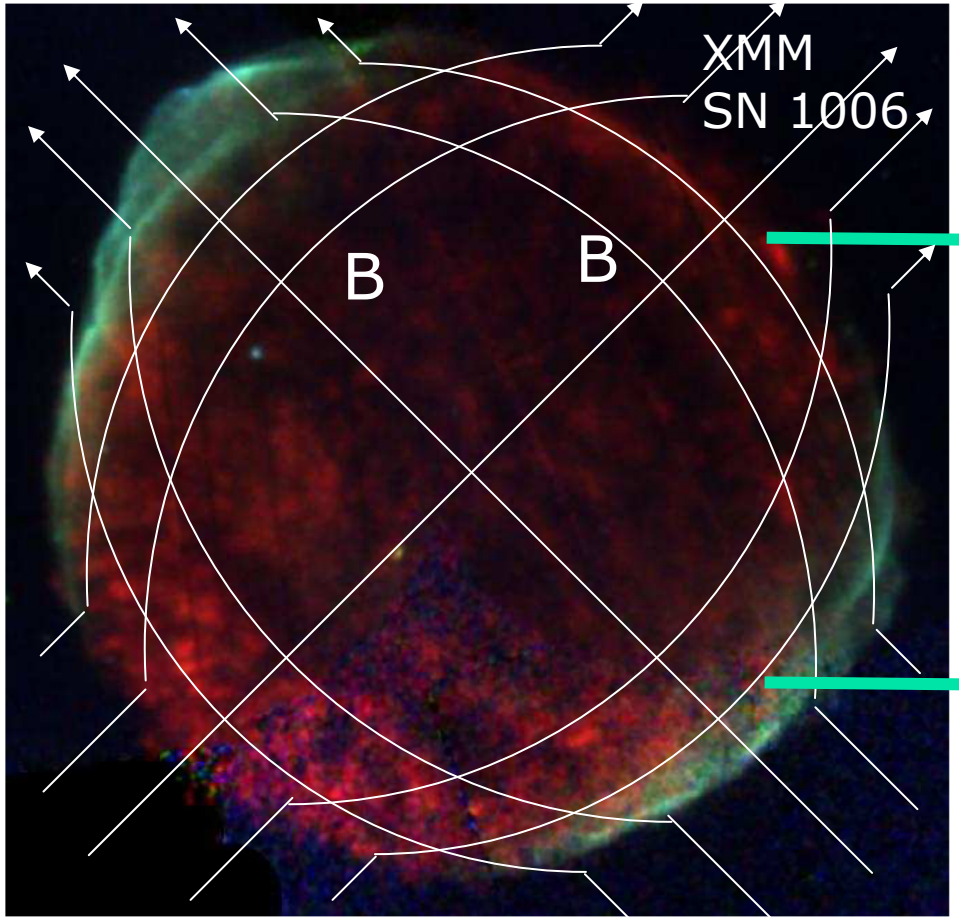
Berezhko, Ksenofontov, Völk, 2003
~ 100 μG
Bamba et al. 2003
~ 14-85 μG

SN 1006 (Berezhko, Ksenofontov, Völk 2003)



Need hadronic component to explain TeV flux !

Why X-ray lobes … and what do they mean for TeV gammas ?



Berezhko, Völk, 2003

Inefficient injection if B || shock front

⏩ no gammas from these regions

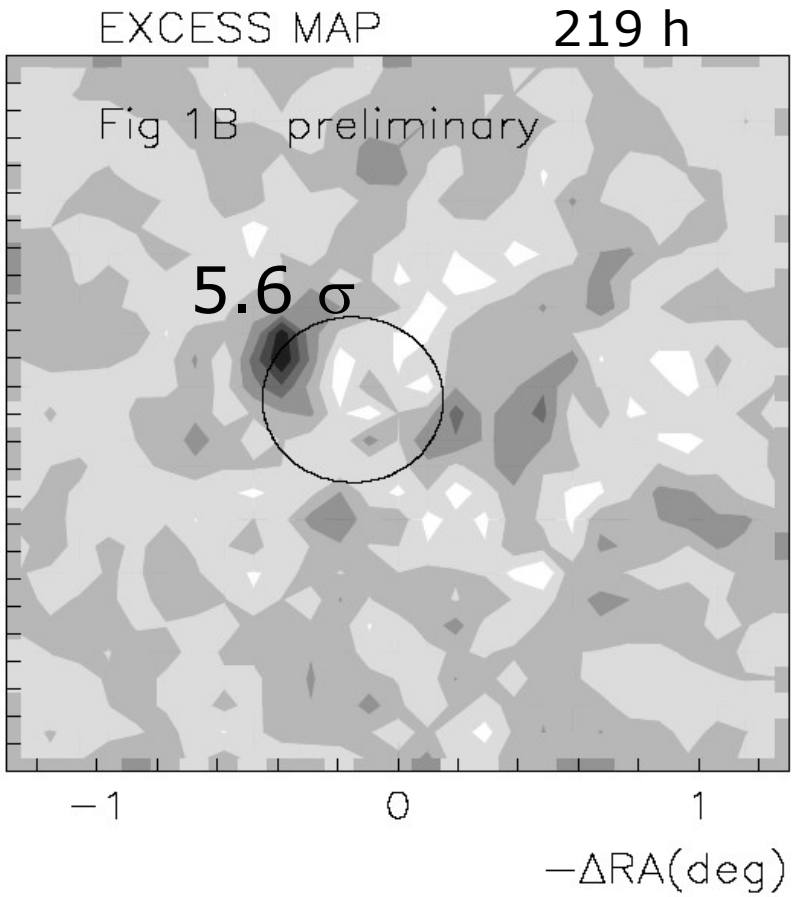
Reynolds, 1998

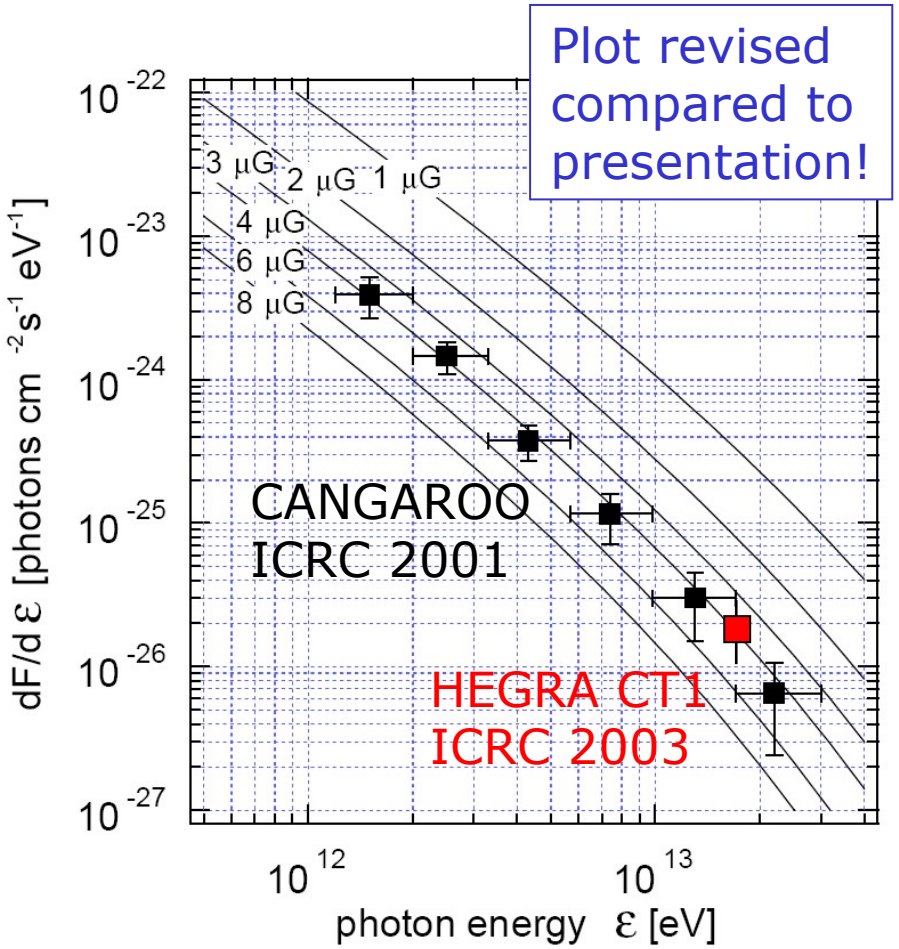
Compressed field

⏩ enhanced synch. radiation

⏩ softer gamma spectrum

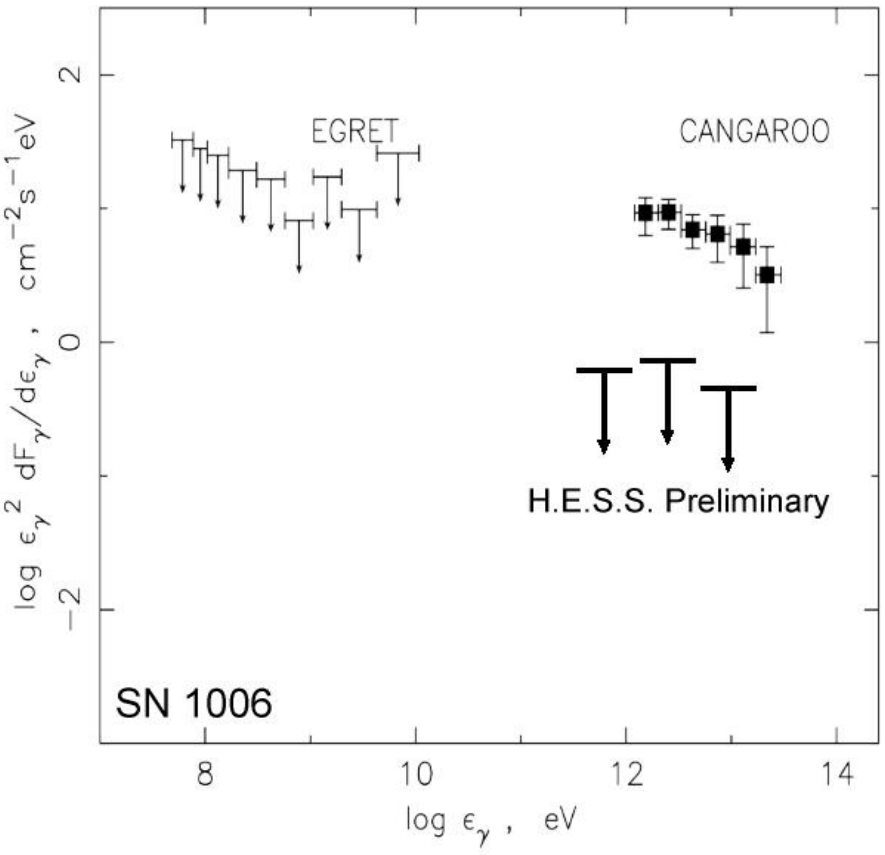
SN 1006: HEGRA CT1 Data

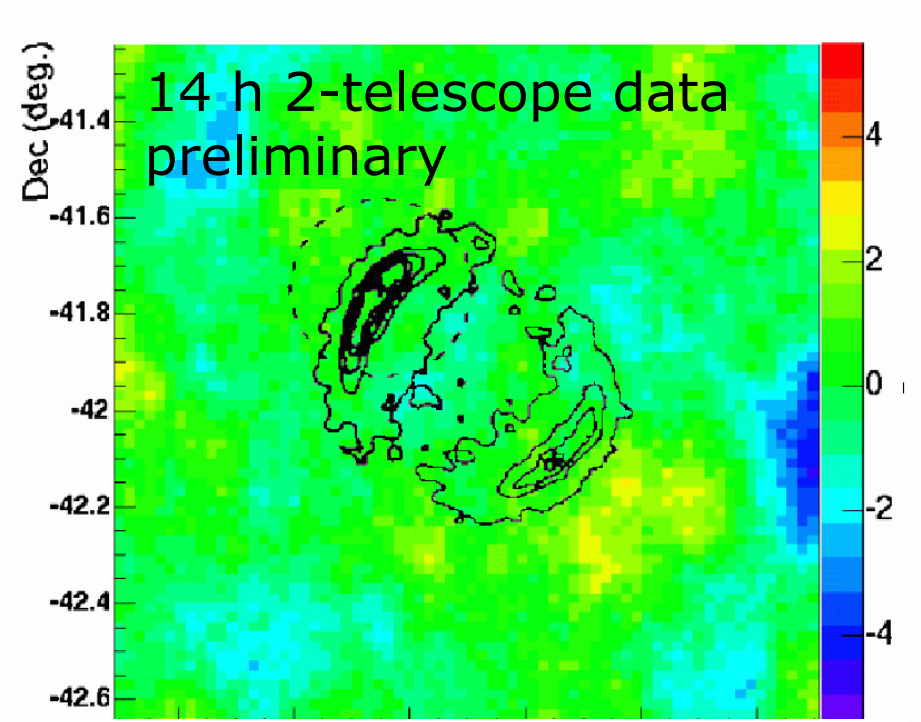


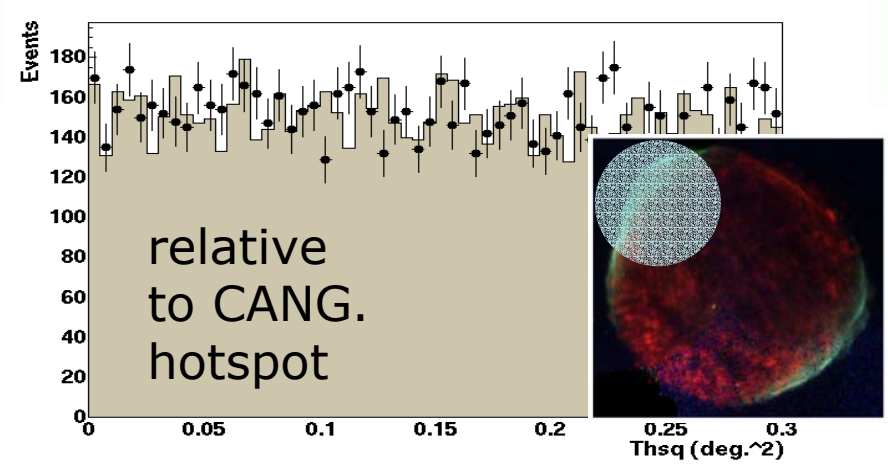


Vitale, ICRC 2003
Preliminary

SN 1006: Problem with H.E.S.S. data

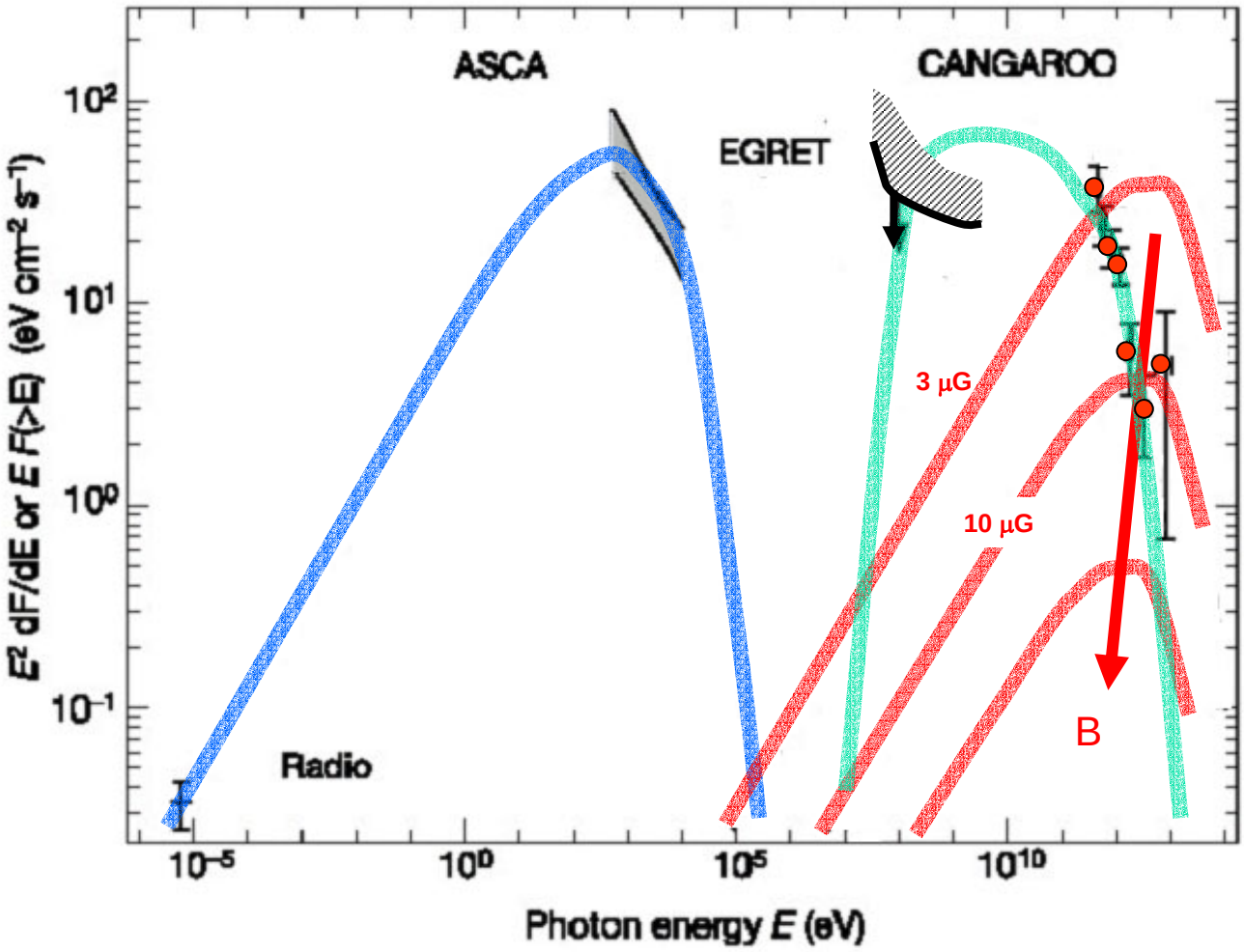






CANGAROO RXJ 1713

Muraishi et al. 2000
Enomoto et al. 2002



Fit electron spectrum assuming B field

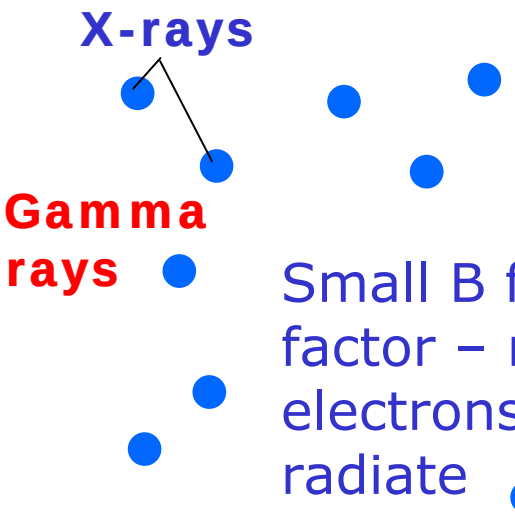
Predict IC spectrum

Gammas from proton inter-actions

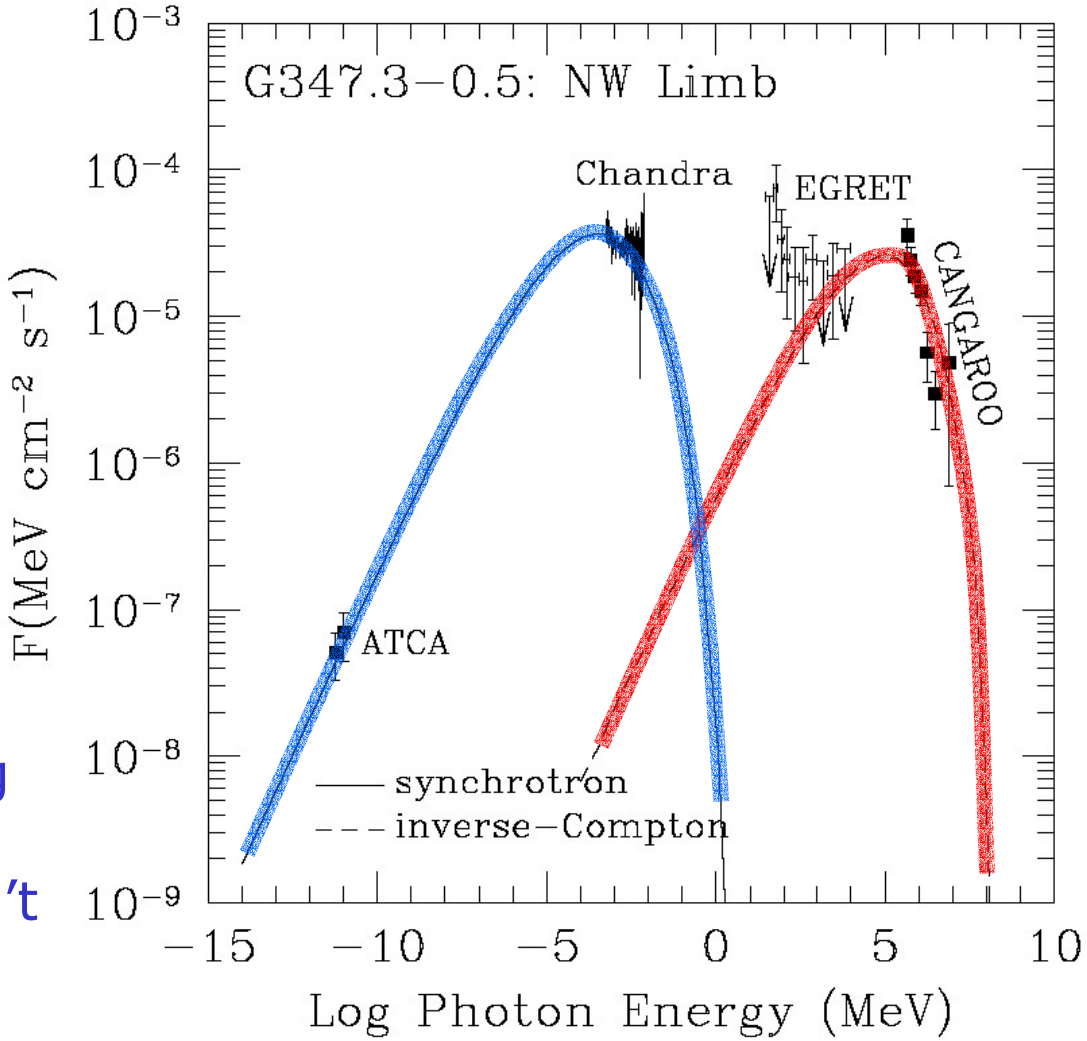
Problems?
EGRET Limit (Reimer & Pohl 2002, Butt et al. 2002)

Alternative explanations

Other option: inhomogeneous B field (15 μG in 1%)
Lazendic 2004



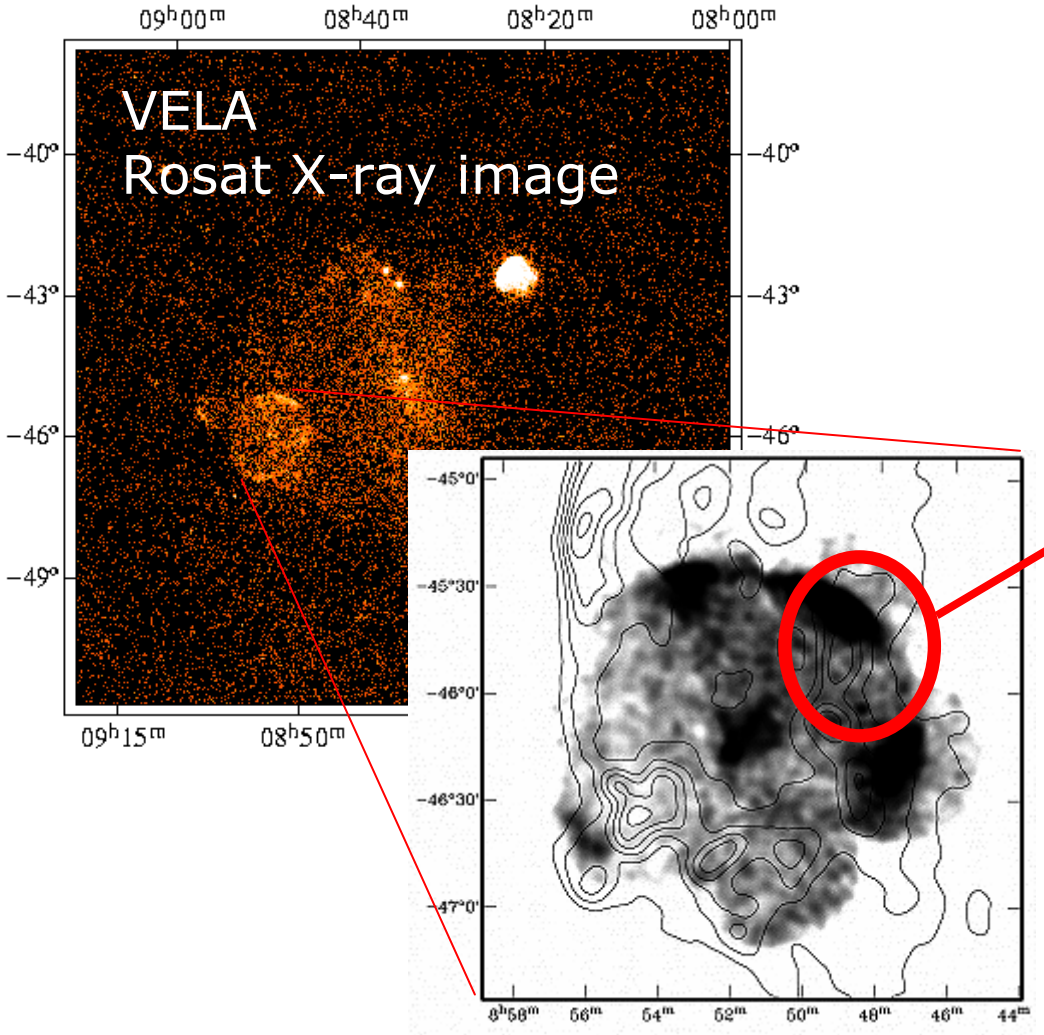
Small B filling factor – most electrons don't radiate

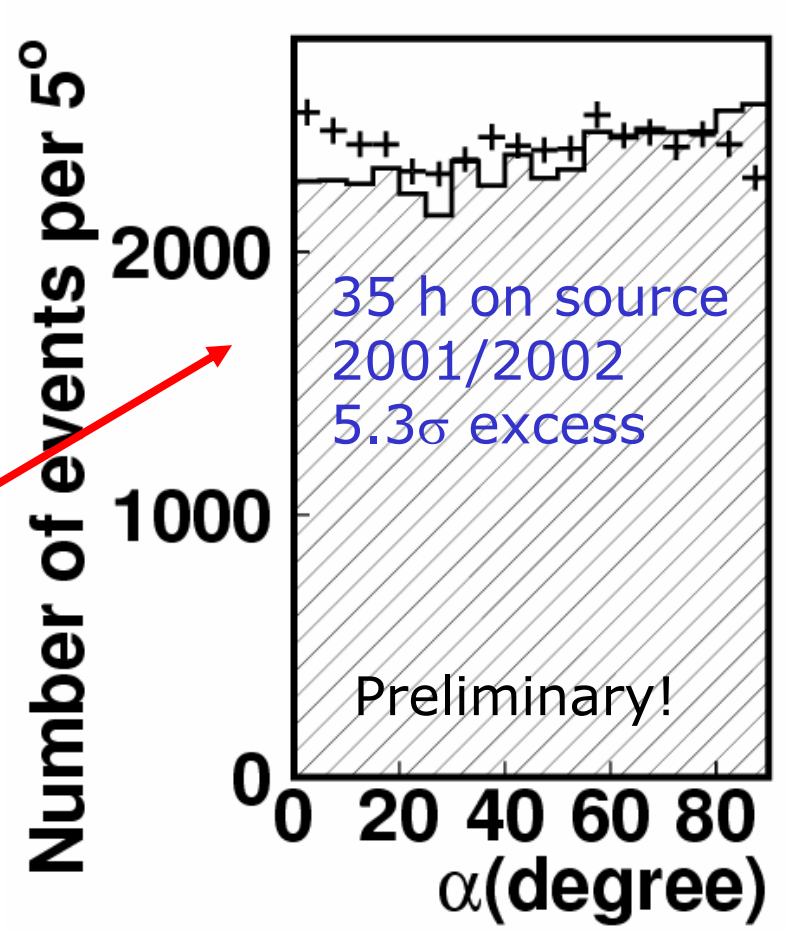


SNR RX J0852.0-4622

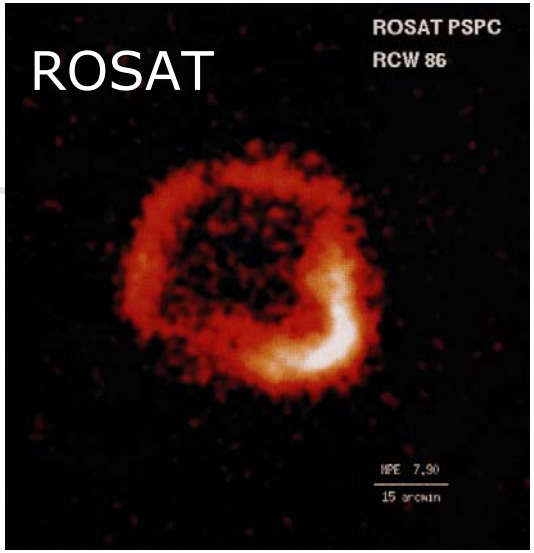
"Vela junior"

CANGAROO, Katagiri et al., ICRC 2003
Mori, ICRC 2003



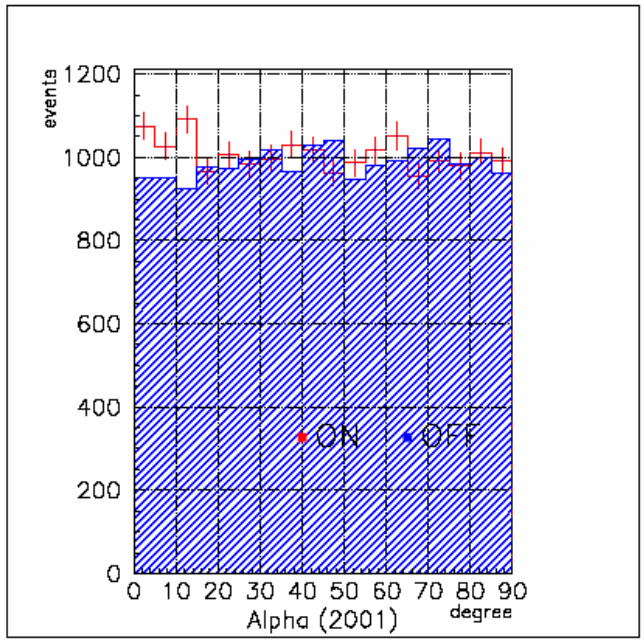


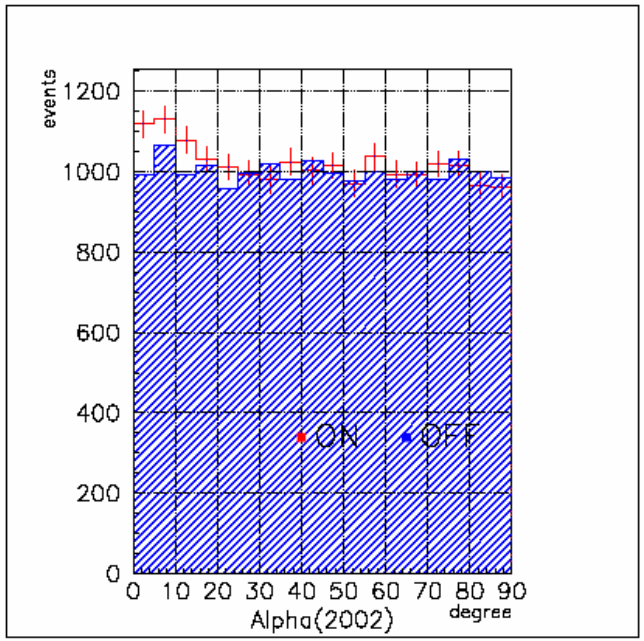
RCW 86



CANGAROO, Watanabe et al., ICRC 2003

79 h on source
2001/2002
~4 σ each year





Flux
~ 20% Crab

consistent
with IC for
B ~ 10 μG

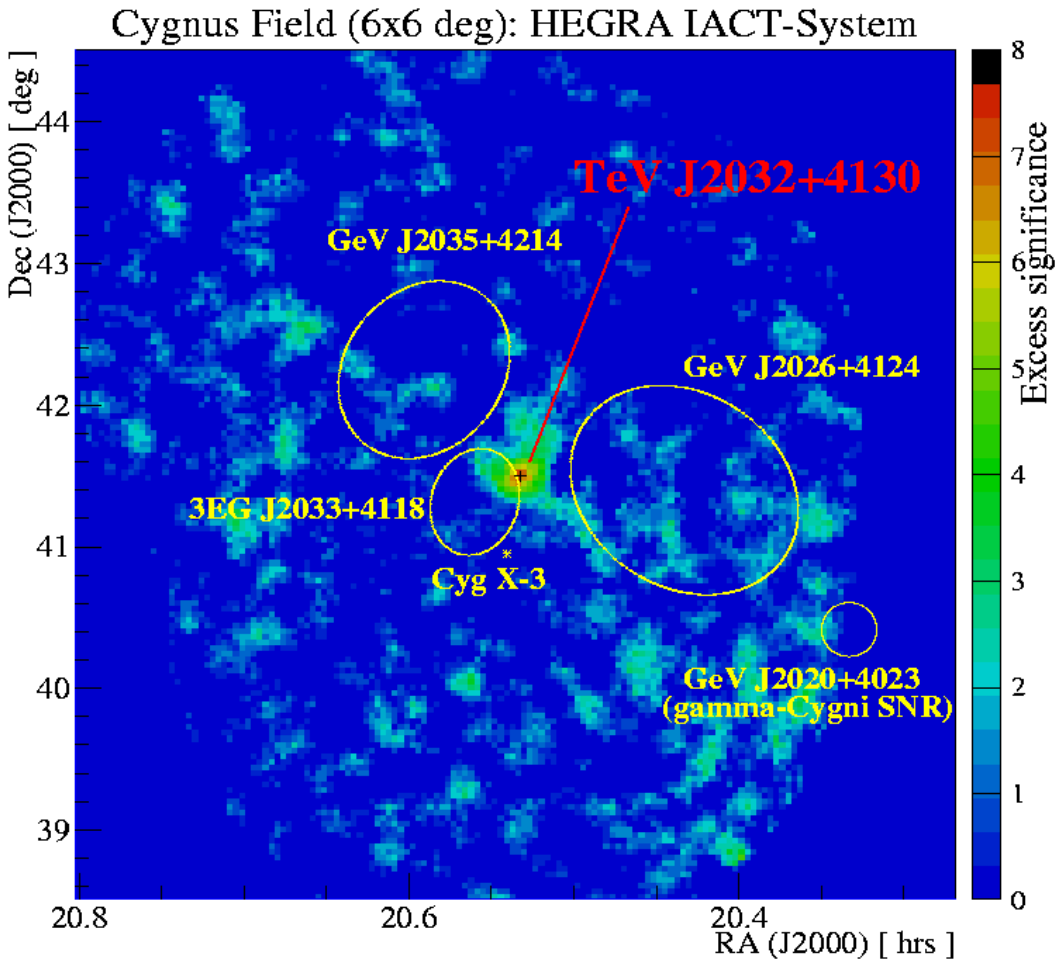
Conclusion on SNR

- Even if original 1006 results are questioned by H.E.S.S. data, SNR are clearly sources of O(100) TeV electrons
- High VHE gamma-ray flux (≈ X-ray flux) must be of hadronic origin, if B fields are >> B_{ISM}
- High B fields are naturally expected due to shock compression and nonlinear feedback, and indicated by short electron scale lengths
- Need better TeV data to understand details, morphology

(Still) Unidentified Cygnus TeV source

HEGRA final results

Aharonian et al. 2002, 2004



Flux (> 1 TeV)
~5% of Crab

Hard spectrum
Index 1.9±0.1±0.3

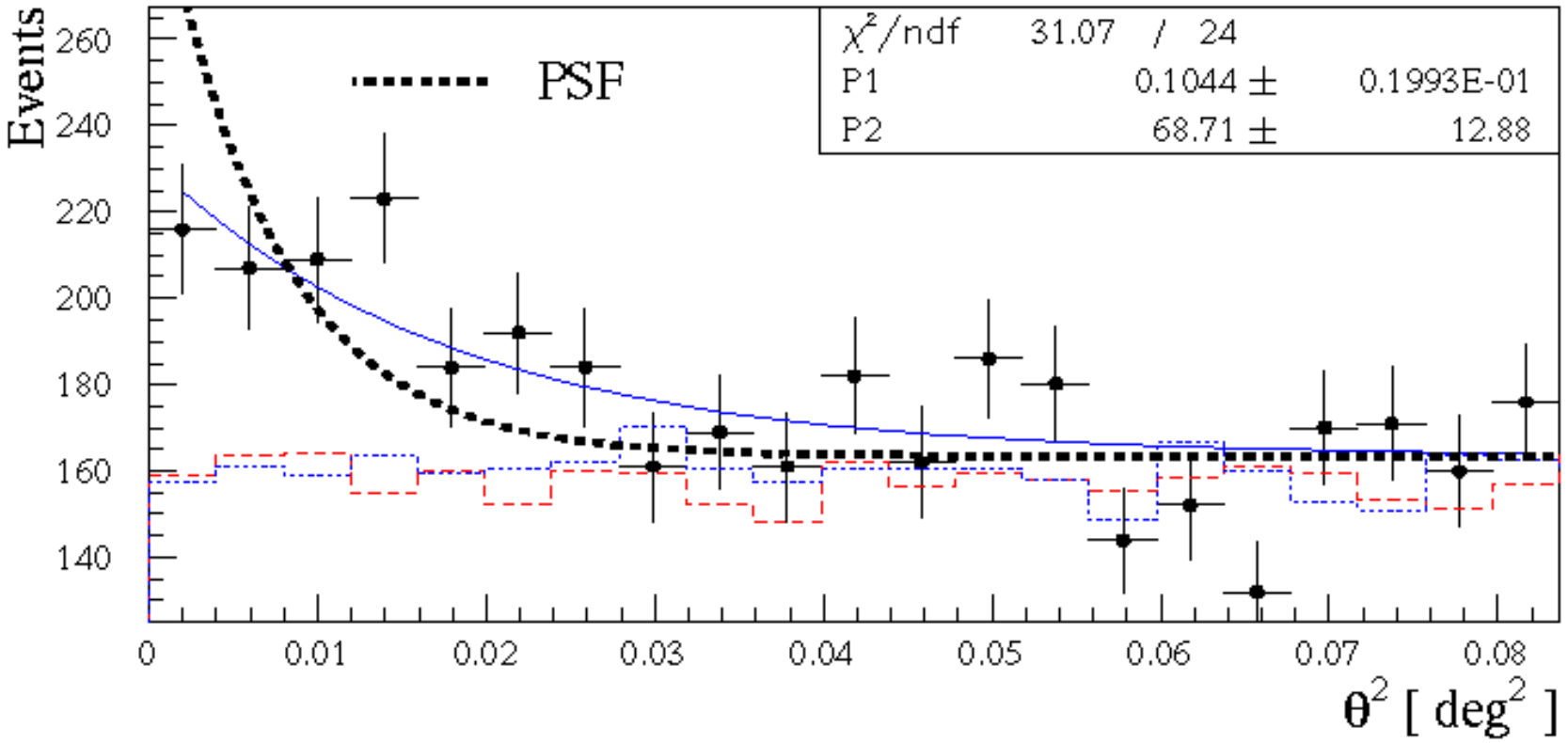
Extended
6.2’±1.2’±0.9’

No obvious radio,
X-ray counterpart
Butt et al. 2003
Mukherjee et al. 2003

Near Cygnus OB2

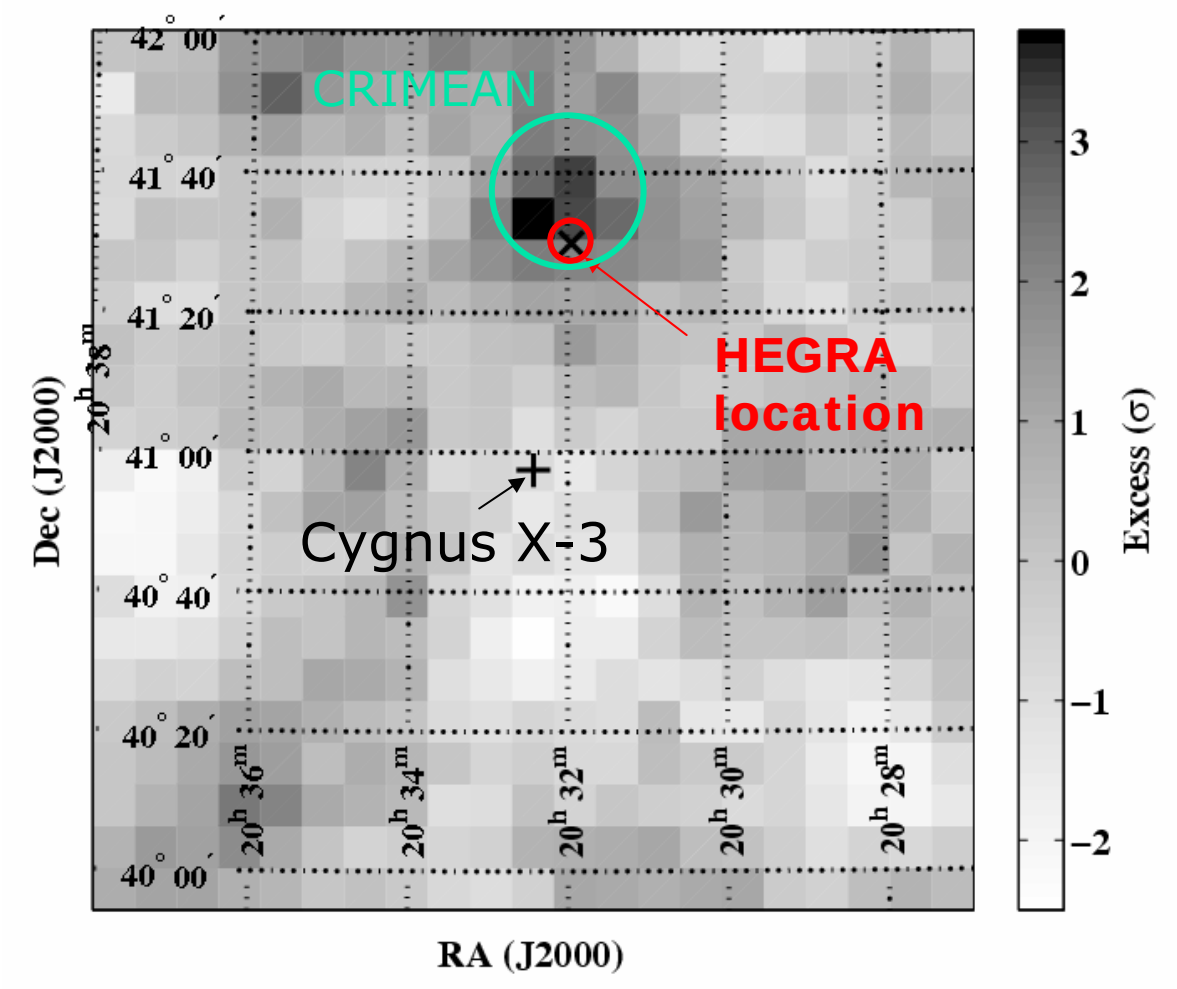
Source size

Aharonian et al. 2004



Whipple 1988-90 archival data

Lang et al. 2004



3.3 – 3.8 σ signal
Flux ~ 12% Crab

CRIMEAN:
6 σ signal
Neshpor et al.
ICRC 1995
Flux ~ 1-2 Crab ?

Interpretation

(Almost) inconsistent with electron source

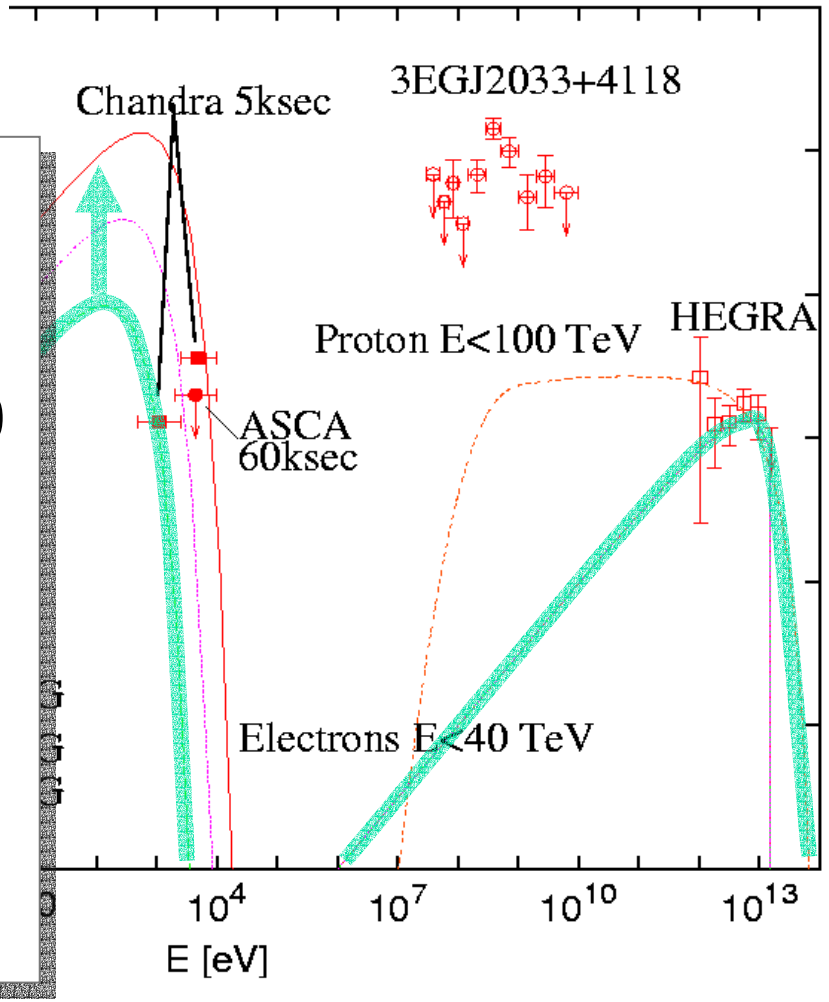
OB winds
as CR source ?

Cygnus OB2 has 2600 OB stars

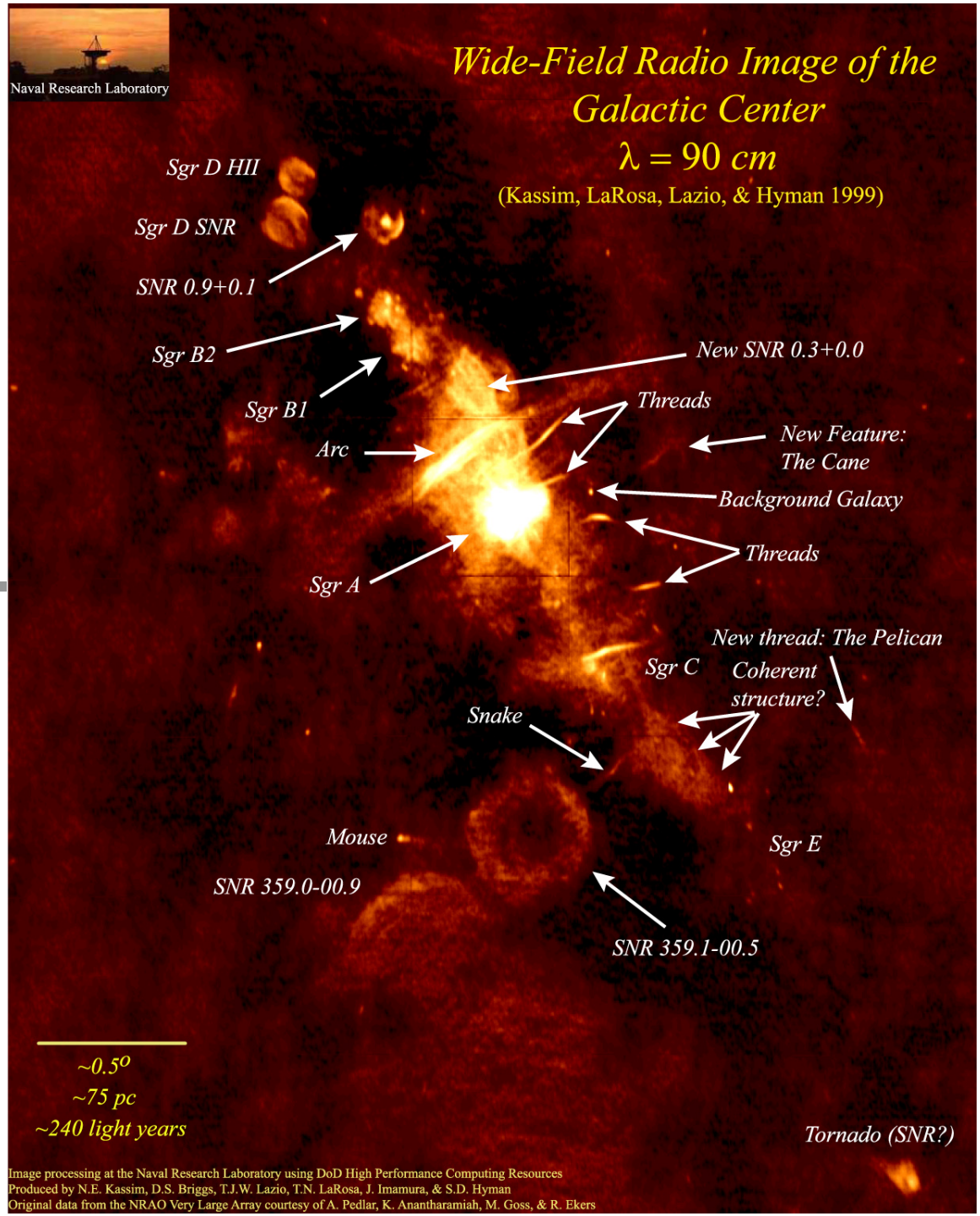
Wind energy release
~ 10^{51} ergs/10^4 years
~ SNR

Butt et al. 2003

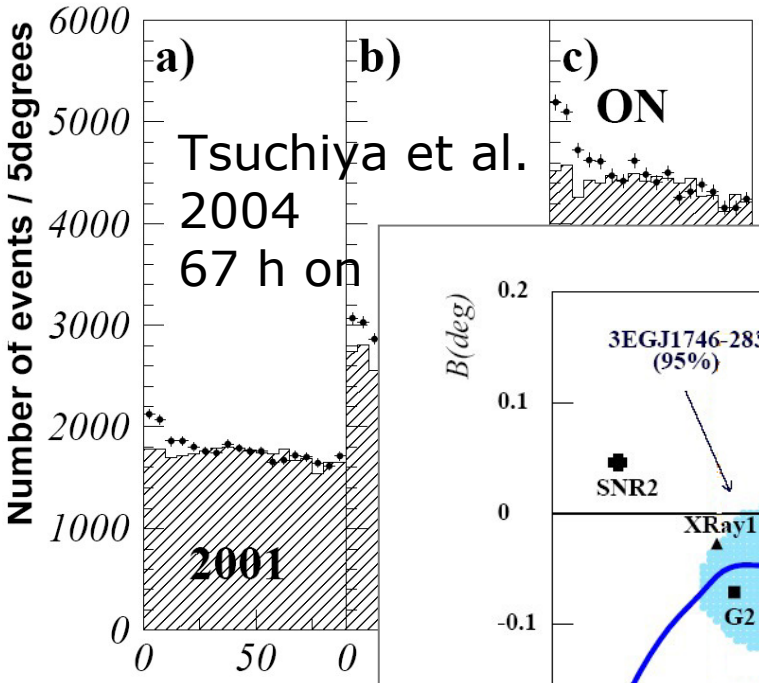
Aharonian et al. 2004,
also Butt et al. 2003



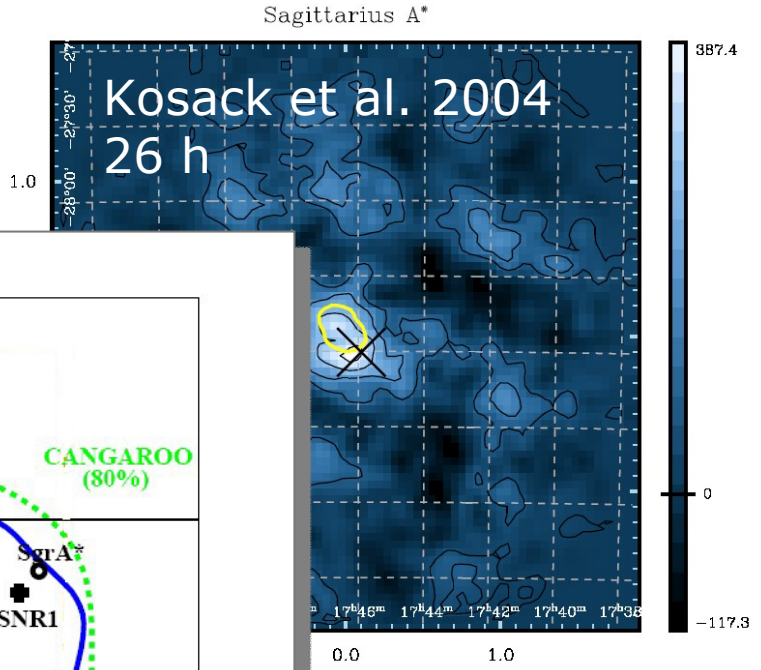
Galactic center



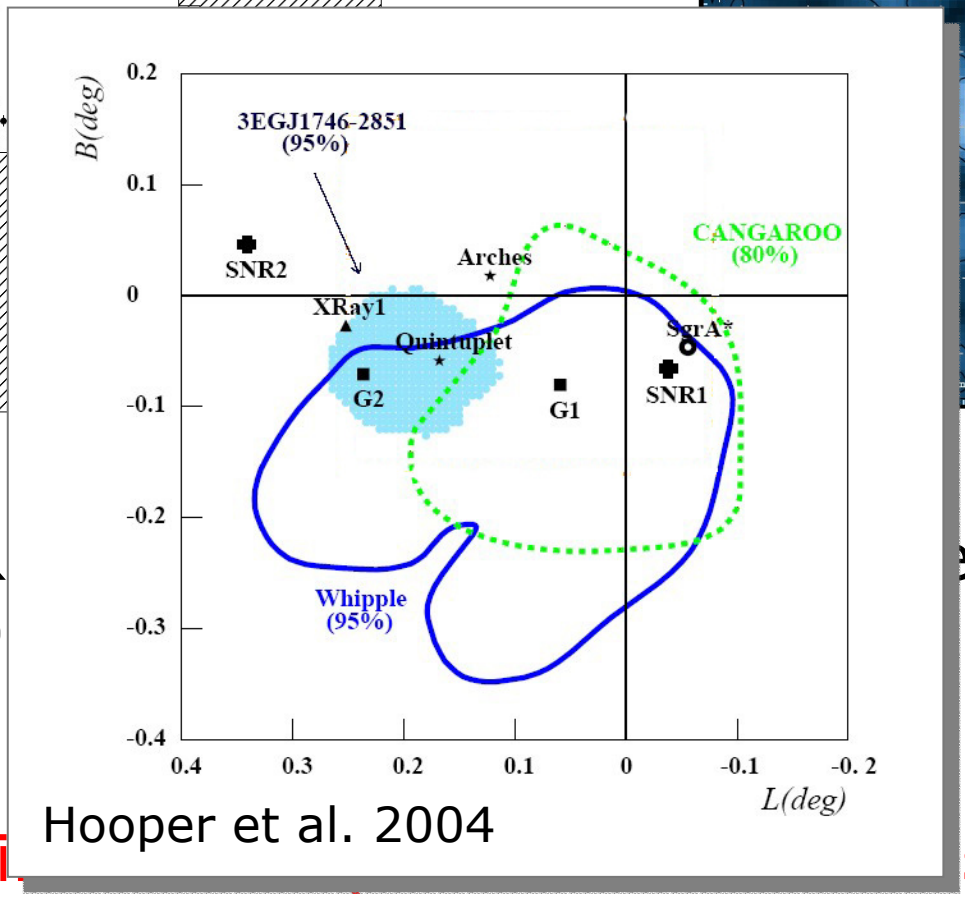
TeV gamma rays from GC



Tsuchiya et al. 2004
67 h on



Kosack et al. 2004
26 h



Hooper et al. 2004

CANGAR

2001/20

> 10 σ

2003

Poi

scale)

Possible origins

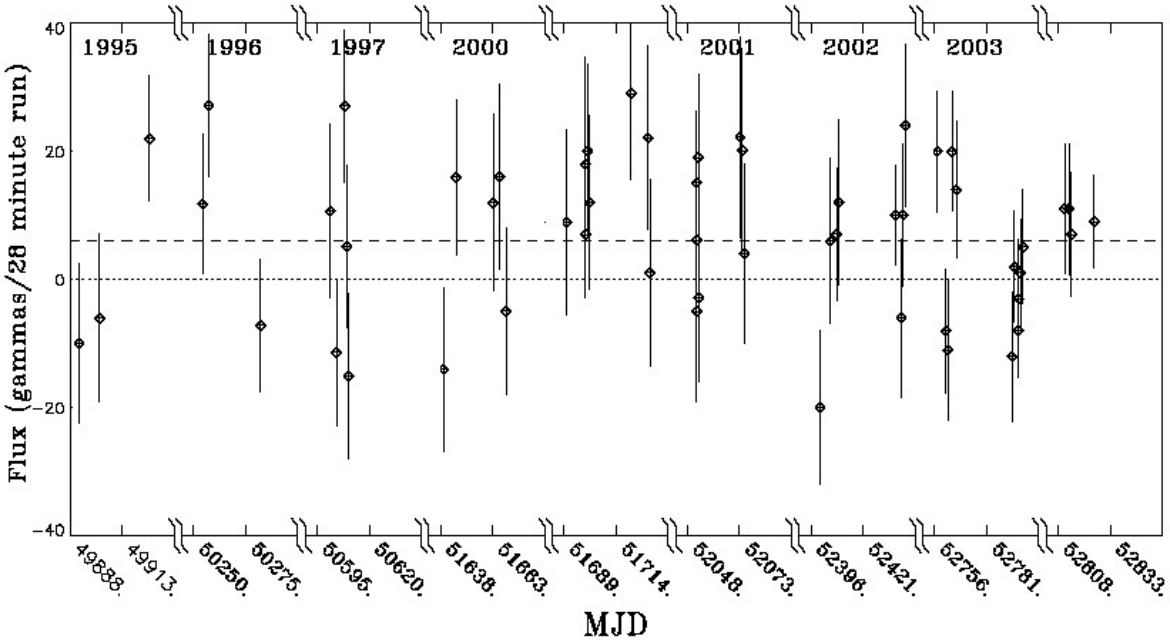
- Shocks in Sgr A* accretion flow or jet
- Acceleration in stellar winds from OB clusters
- Acceleration in Supernova shocks (Sgr A East)
- Diffuse CR interacting with gas ($\rho \sim 10^3$/cm)
- Proton acceleration near event horizon and curvature radiation
- Neutralino / Wimp annihilation
- ...

Source location, source size
Time variability
Energy spectrum

Variability

CANGAROO: 2001/2 = 1.60 ±0.34

Consistent within systematics



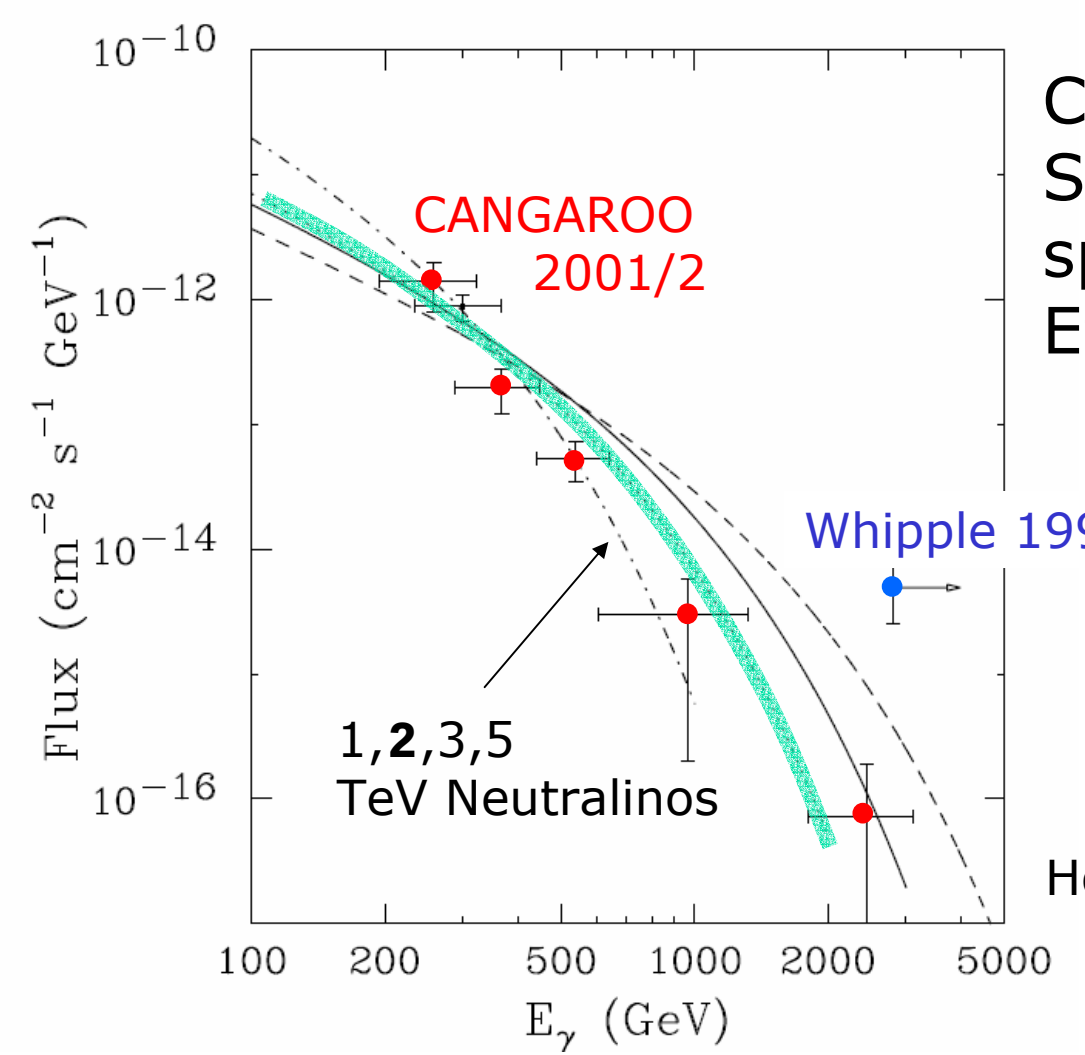
Whipple

Kosack et al. 2004

Steady “excess”

No dramatic bursts

Spectrum: could it be DM ?



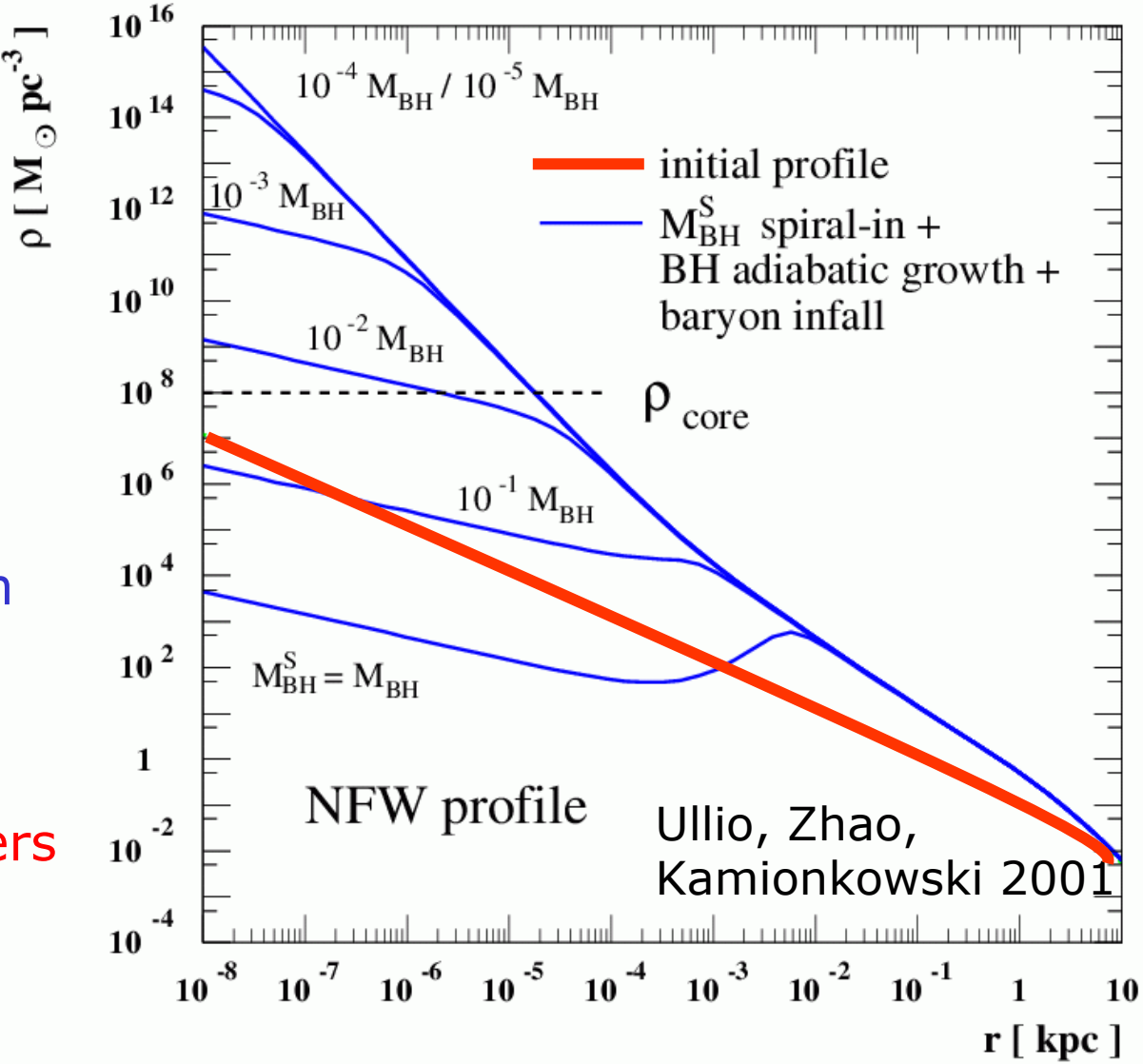
CANGAROO: Steep energy spectrum $E^{-4.6\pm0.5}$

Hooper et al. 2004

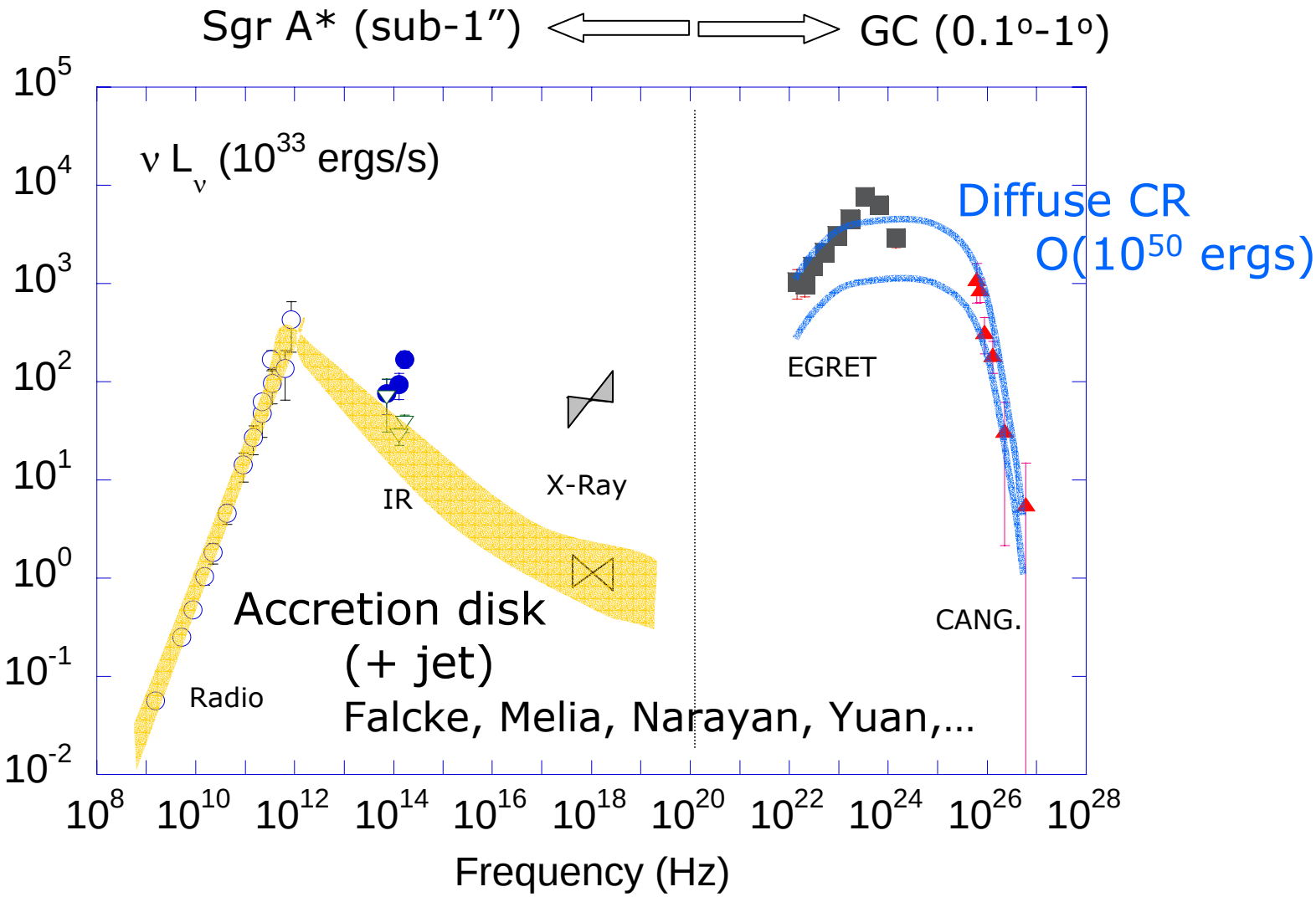
Could it be DM ?

Need spiky profile and large annihilation cross-section

- Moore profile
- adiabatic accretion
- baryon cooling
- NFW profile
- hierarchical mergers
- stellar encounters
- baryon heating

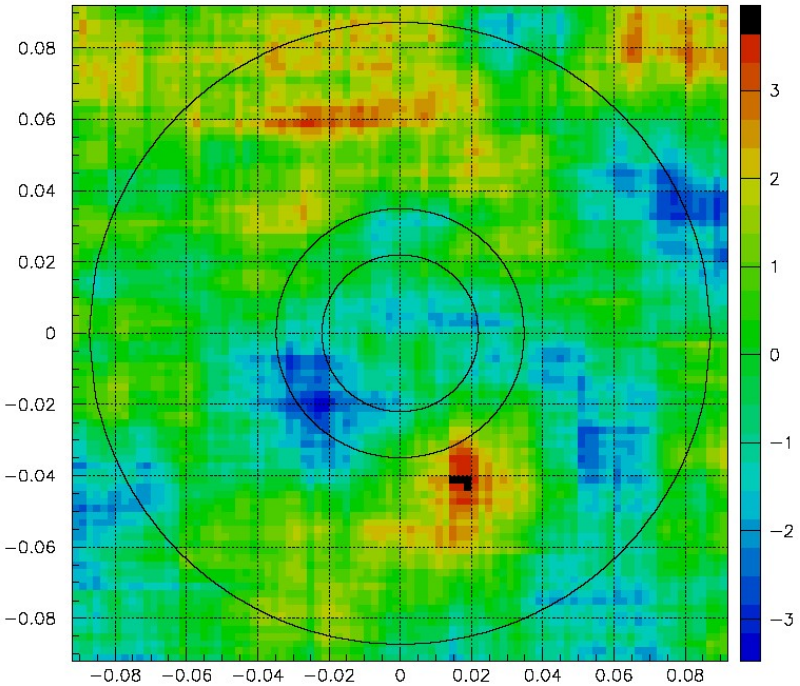


Wide-band spectra



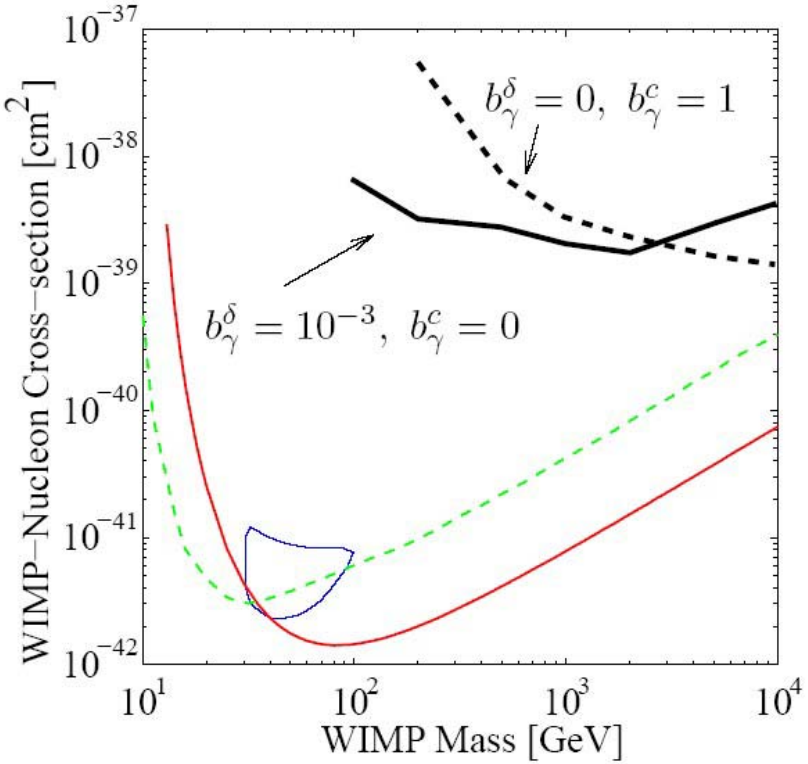
Fun & exotics

Fun & exotics



Atkins et al. 2004

Milagro:
searching for neutralino annihilation near the sun



Progress

Detection of TeV gamma rays from the Crab Nebula
Whipple 1989: 50 h observation time

HEGRA 1997:
15 min

HESS 2004:
30 sec