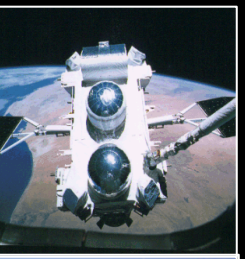
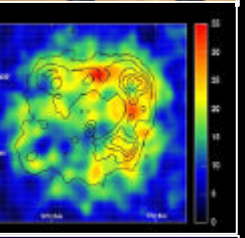
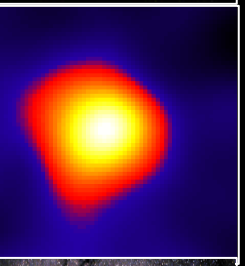
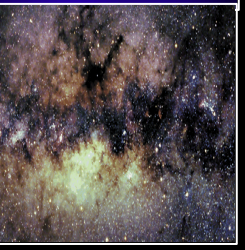
TeV sources in the Galactic plane detected by HESS

Stefan Funk (MPI-K Heidelberg)









- γ-ray Astronomy
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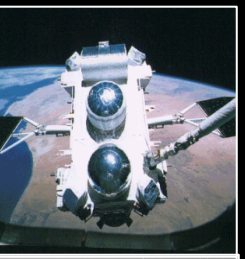

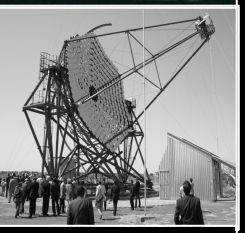

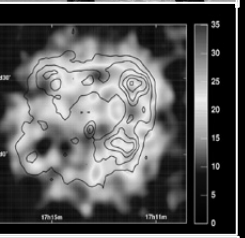

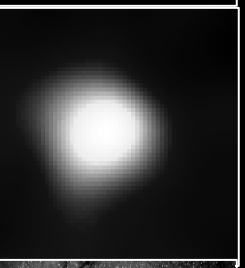

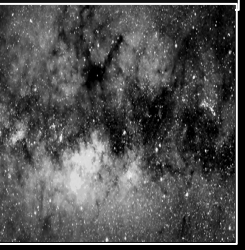

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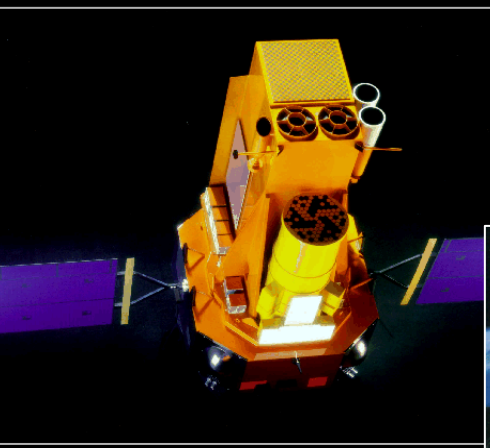
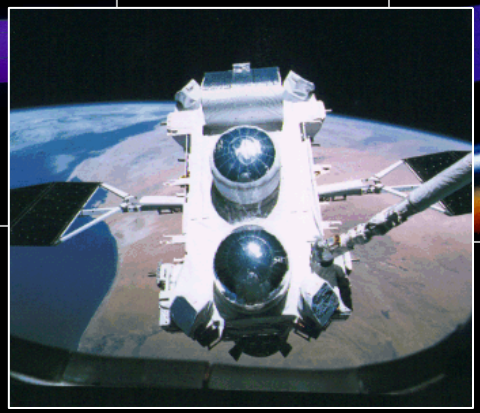
– Soft γ-rays:
  < MeV

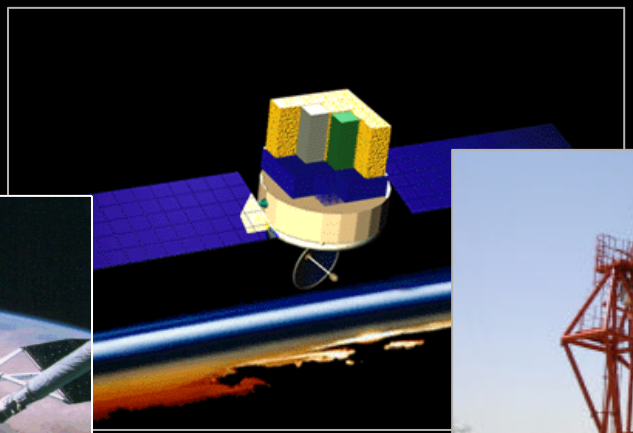
Integral

– High energy γ-rays:
  MeV – 100 GeV
  EGRET, AGILE, GLAST

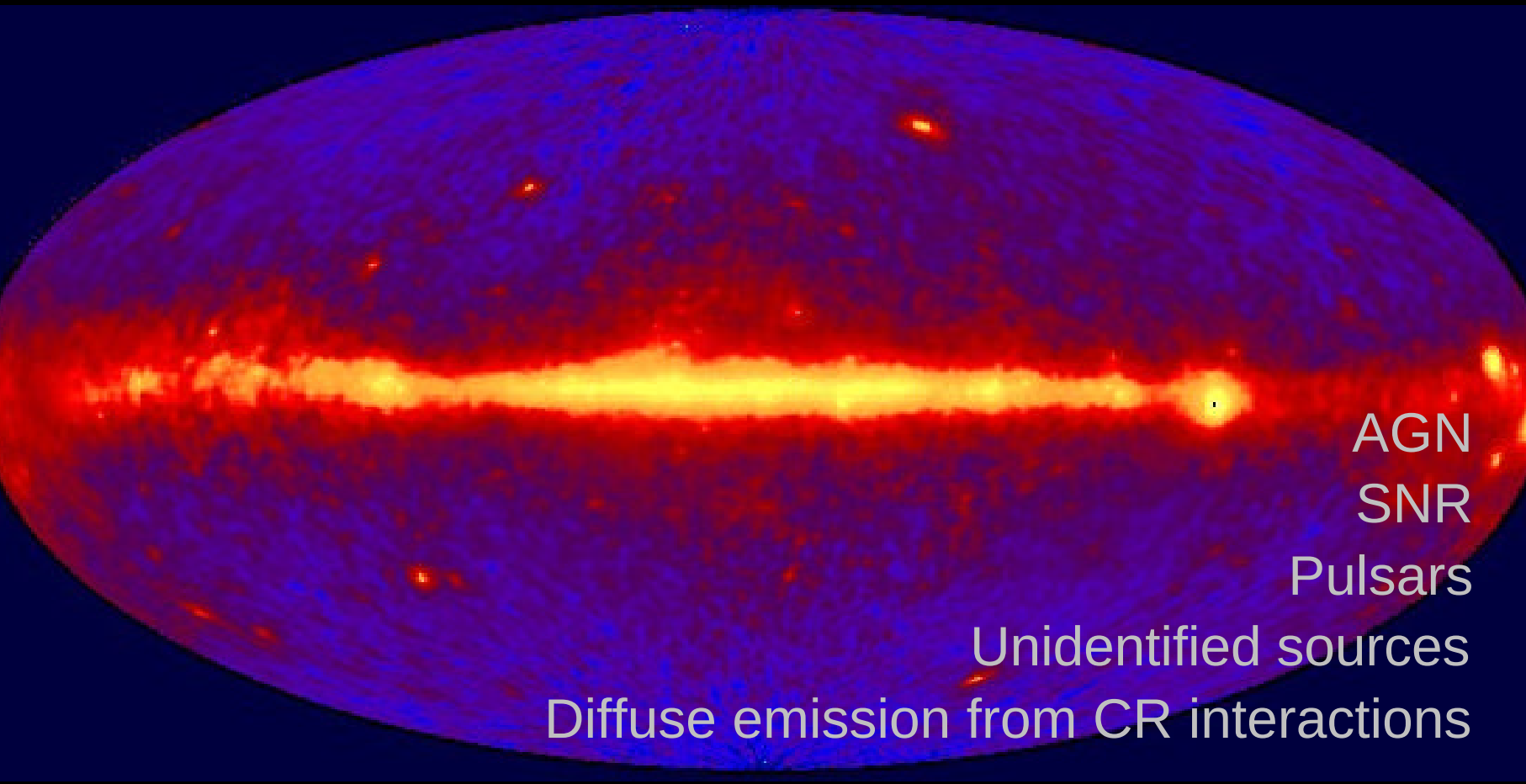
– Very high energy γ-rays:
  > 100 GeV
  Air-Cherenkov Telescopes



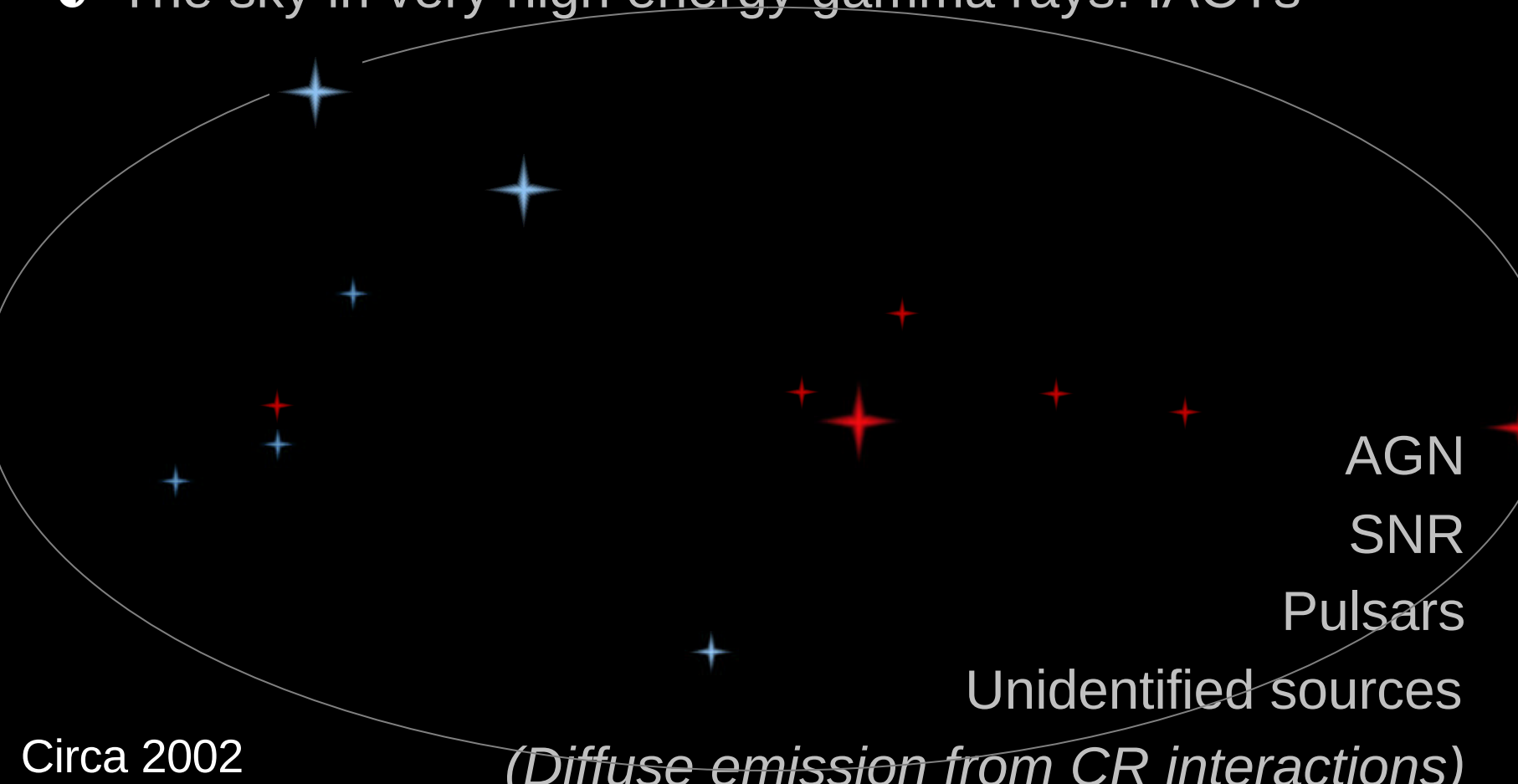




- The sky in high energy gamma-rays: EGRET



- The sky in very high energy gamma-rays: IACTs



AGN

SNR

Pulsars

Unidentified sources

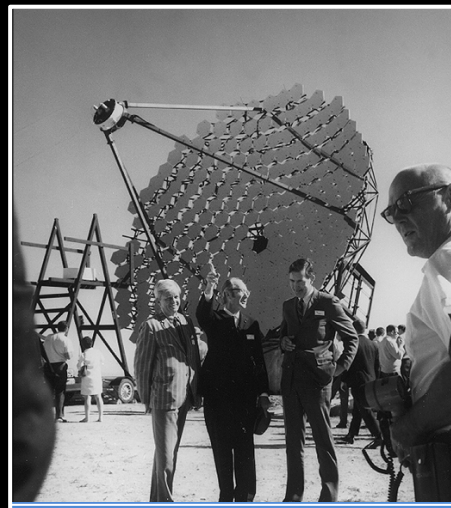
(Diffuse emission from CR interactions)

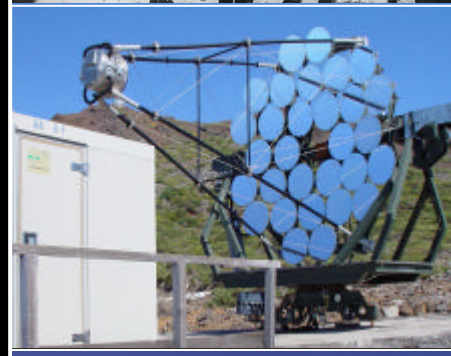
Circa 2002
Only a handful
of sources

- Whipple 1968 - 2004
  - 1989 Detection of Crab Nebula above 1 TeV
  - 1992 First AGN, Mrk 421
- HEGRA 1992 - 2002
  - First telescope system. Cas-A at 1 TeV
  - First Unidentified TeV source
- CANGAROO 1992 -
  - Southern hemisphere. SNR RX J1713

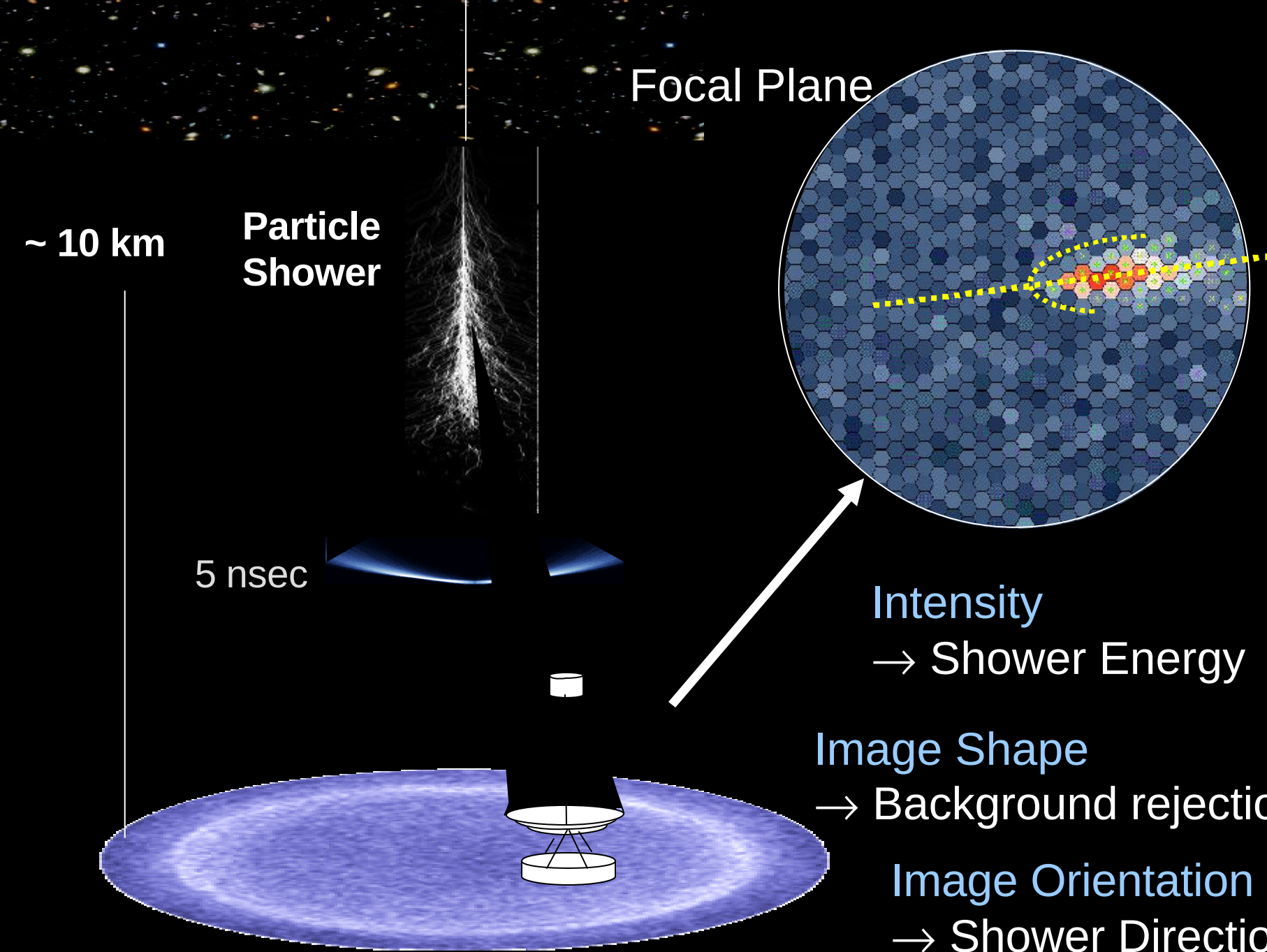
Also Durham Mrk 6, CAT... + non-imaging expts.

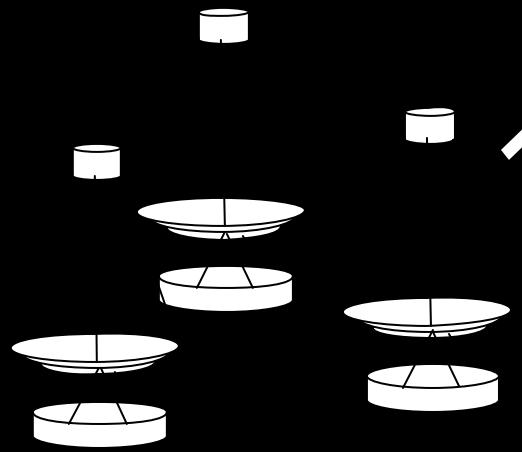
- And now 3rd Generation instruments:
  - HESS, MAGIC, VERITAS, CANGAROO-III






Veritas
Start 10.2006
photomontage
MAGIC
Start 8.2004
H.E.S.S. Start 12.2003
CANGAROO III
Start 3.2004


Focal Plane
~ 10 km
Particle Shower
5 nsec
Intensity
→ Shower Energy
Image Shape
→ Background rejectio
Image Orientation
→ Shower Directio



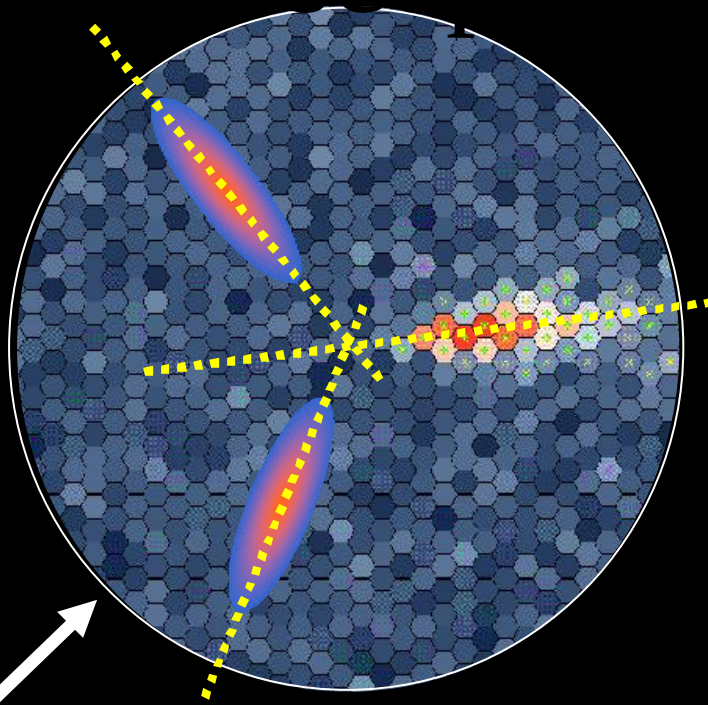
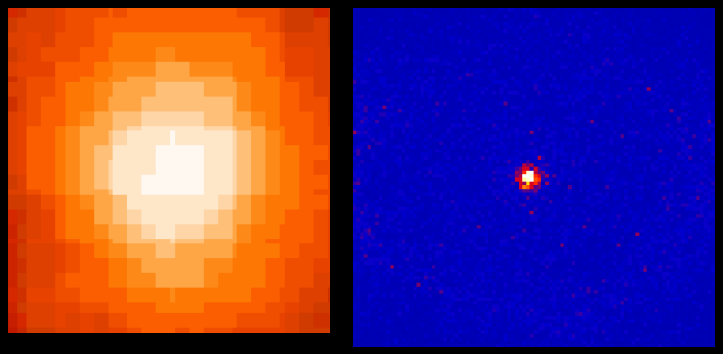


Image of source is somewhere on the image axis …

Need several views to get precice shower direction

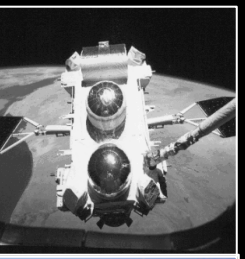
- Angular resolution (with stereo) is a few arcminutes
  - Not good compared with radio (or Chandra) but much better than EGRET:

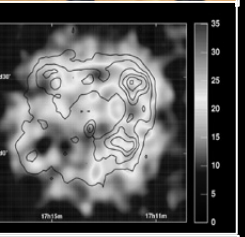
The Crab Nebula

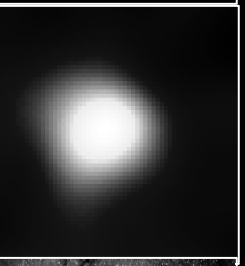


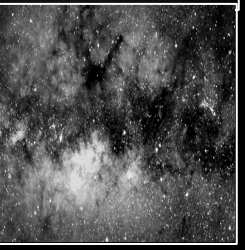
EGRET H.E.S.S

- And collection area: 50000 m^2 *vs* a O(m^2)
- BUT: lower duty time (need clear, moonless nights)
  AND smaller field of view (few degrees)
  AND higher background









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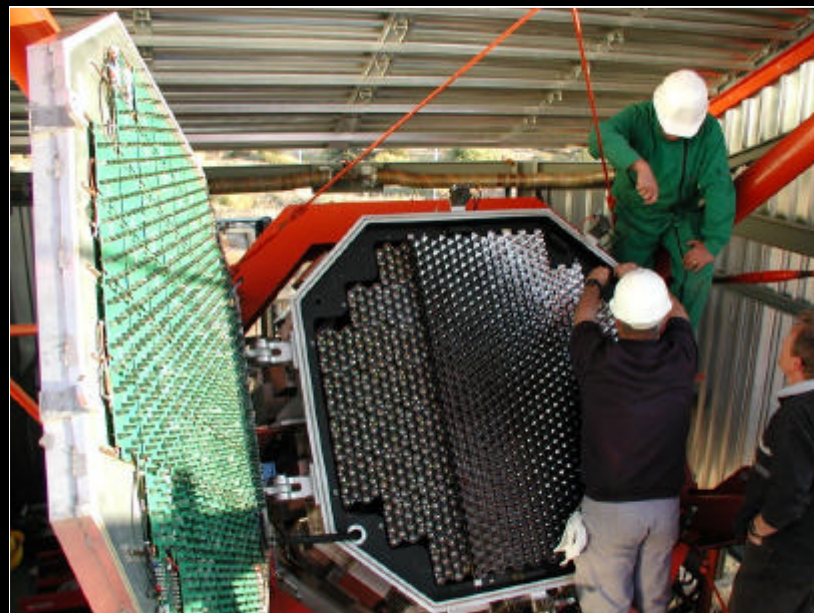
- Array of 4 Imaging Cherenkov Telescopes
- In Namibia, 1800 m a.s.l.
  - Good optical site - dry, high and clear
  - Location perfect for central part of our galaxy
- Telescopes arranged in a 120 m square
- **System completed December 2003**

- 107 m^2 mirror area
  - 380 individual facets
- 15 m focal length
- 60 t structure
- Alt-Az mount

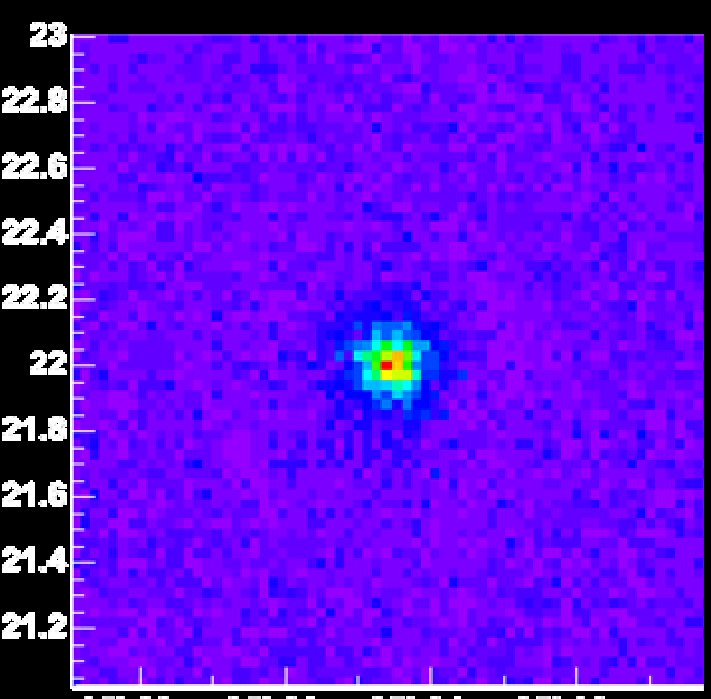


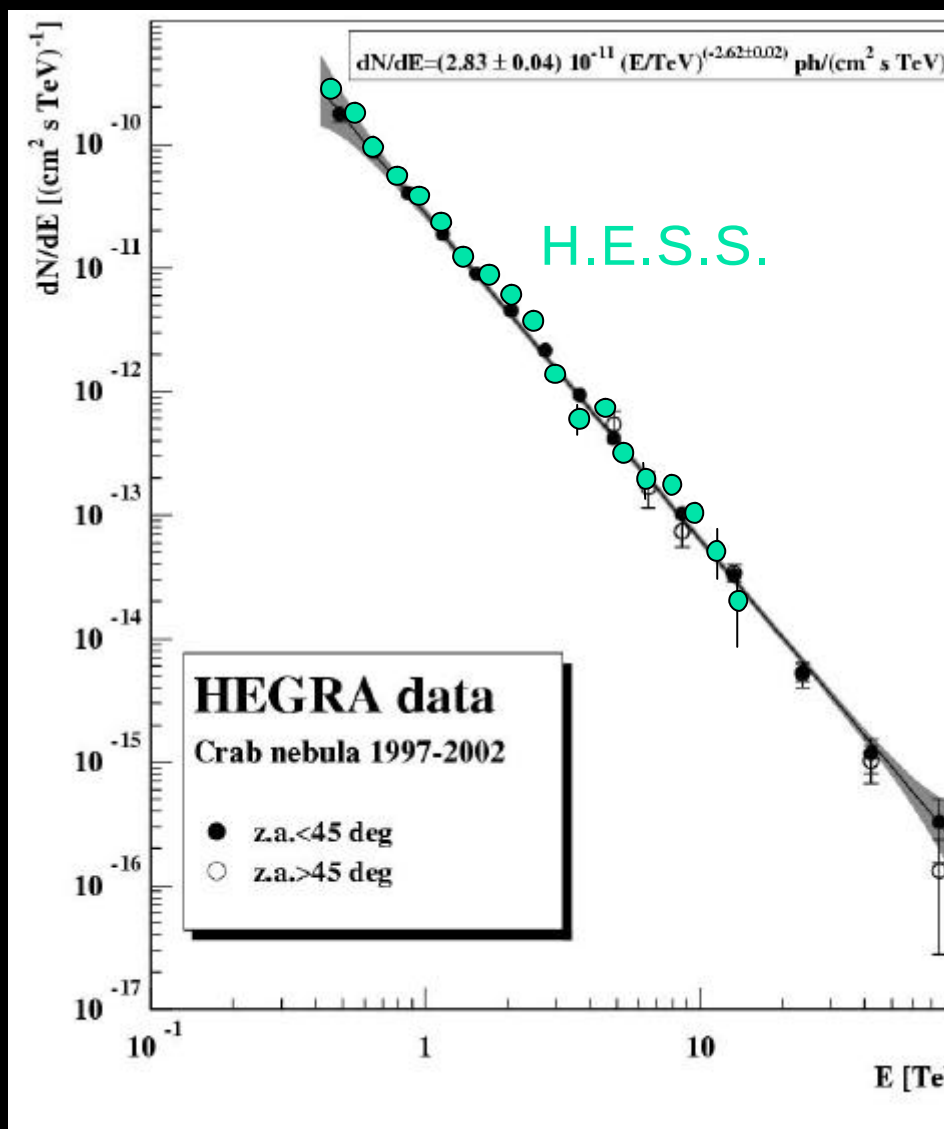
- 960 photomultiplier pixels each 0.16^o

  $\rightarrow 5^o$ field of view
- Integrated readout electronics

Strong detection

- Angular resolution: <0.1°
- Energy resolution: 15%
- Excellent agreement with simulations
  - Flux, spectrum consistent with previous measurements



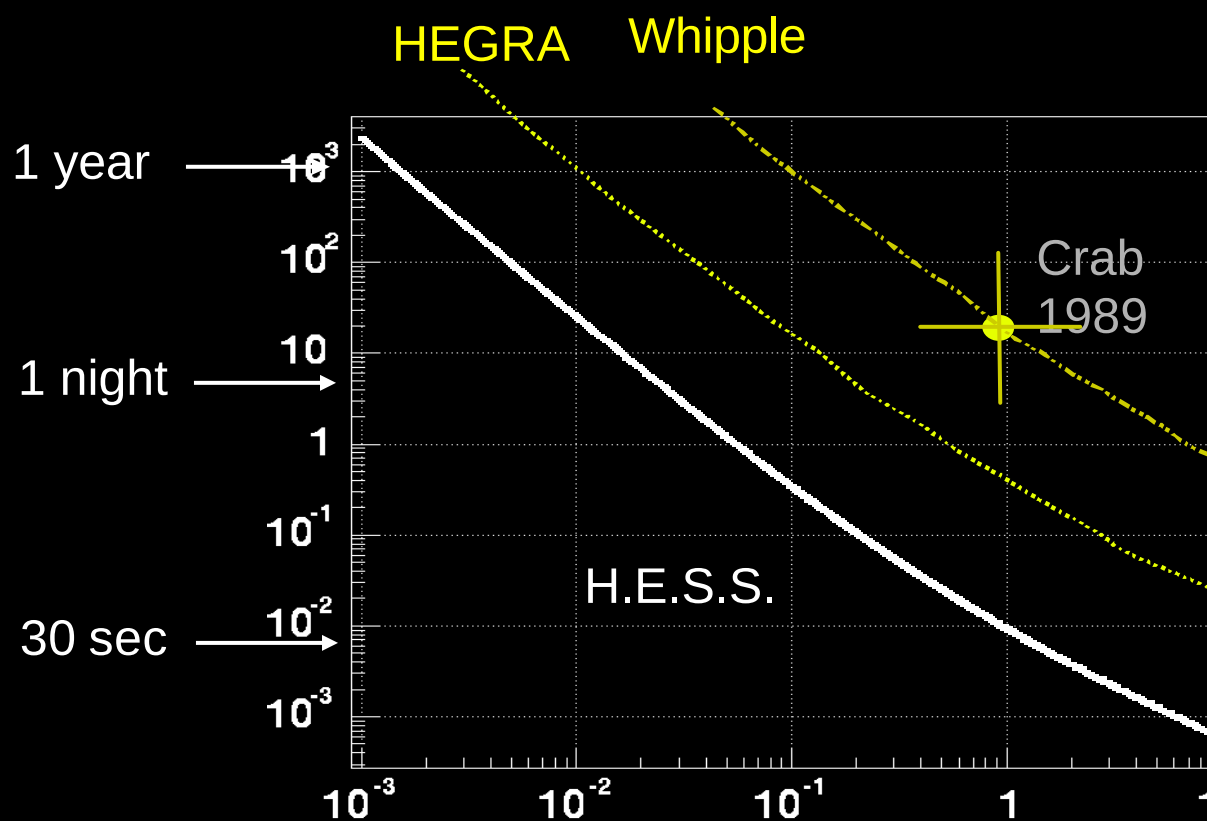


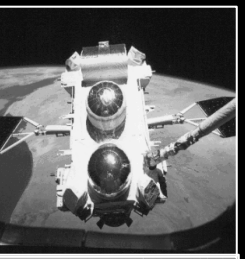
HEGRA

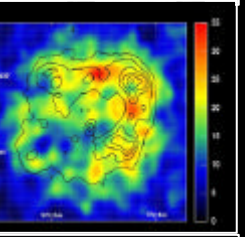
- 5% of Crab flux in 100 hours
- 500 GeV Threshold

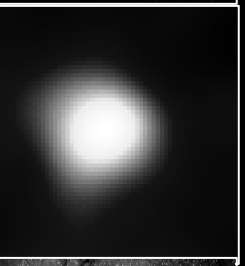
H.E.S.S.

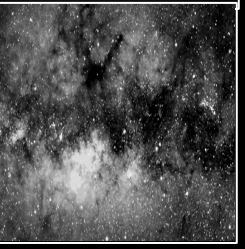
- 5% of Crab in 1 hour
- 0.5% in 100 hours
- 100 GeV Threshold











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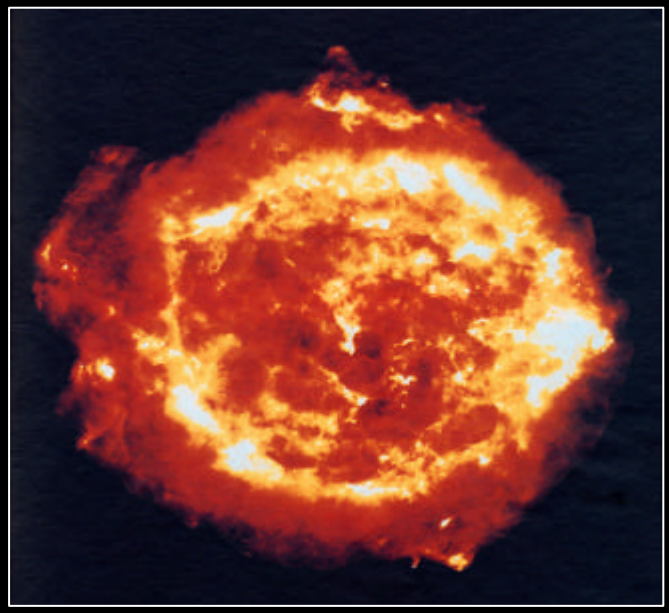
- Could be sources of cosmic rays
  - Good candidates because they provide enough energy
  - Solid modelling exists (first order Fermi acceleration) in expanding shock wave
- Not unambiguously detected with EGRET
- In interaction with molecular clouds could produce VHE γ-rays



- **What do we see in VHE gamma-rays?**

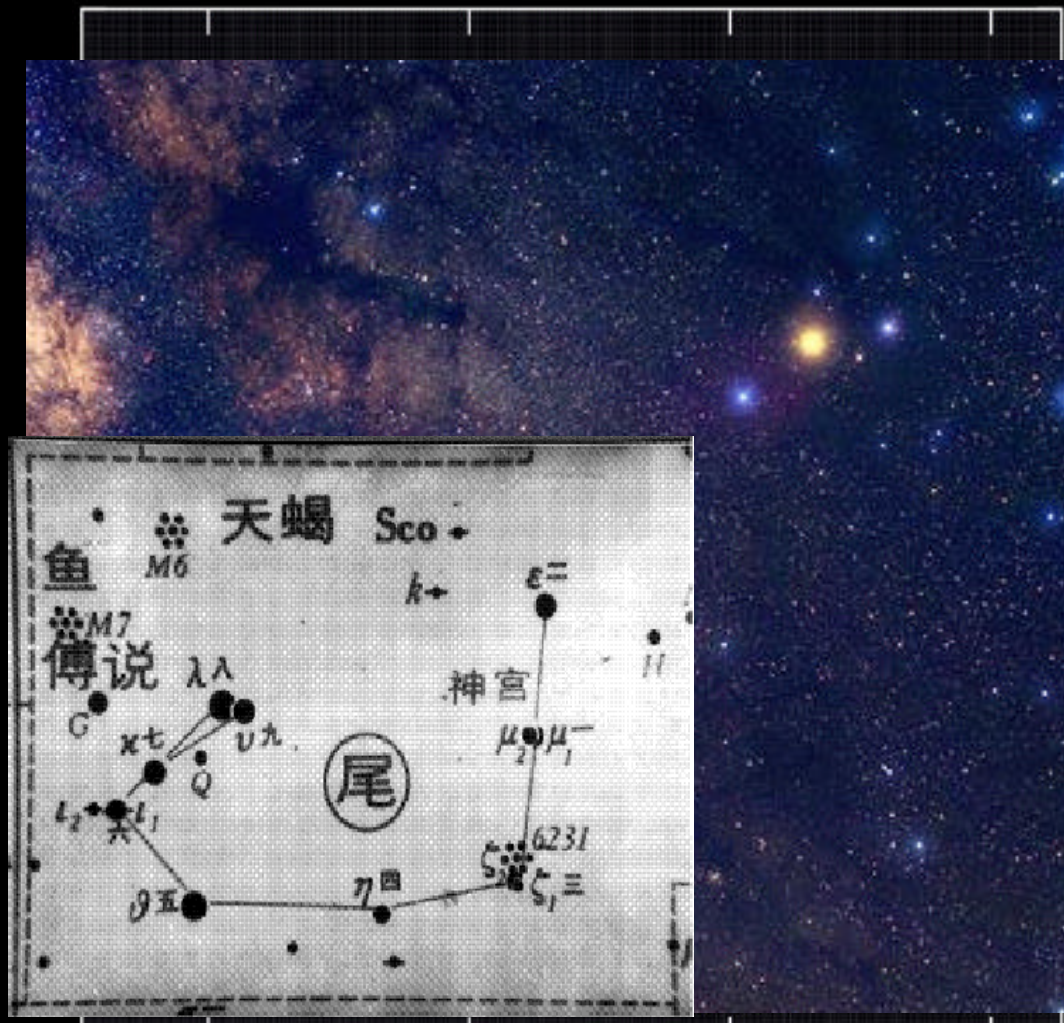
Discovery: ROSAT All-Sky Survey

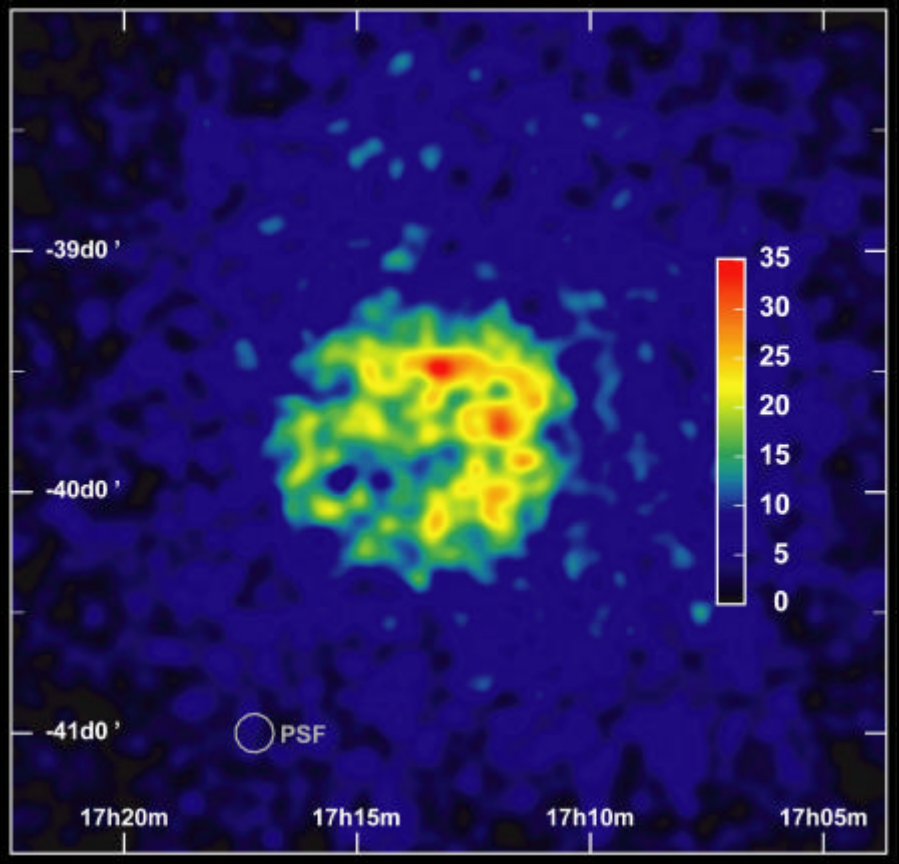
X-ray emission mostly non-thermal

CANGAROO: TeV excess from western rim

Recent CO data:

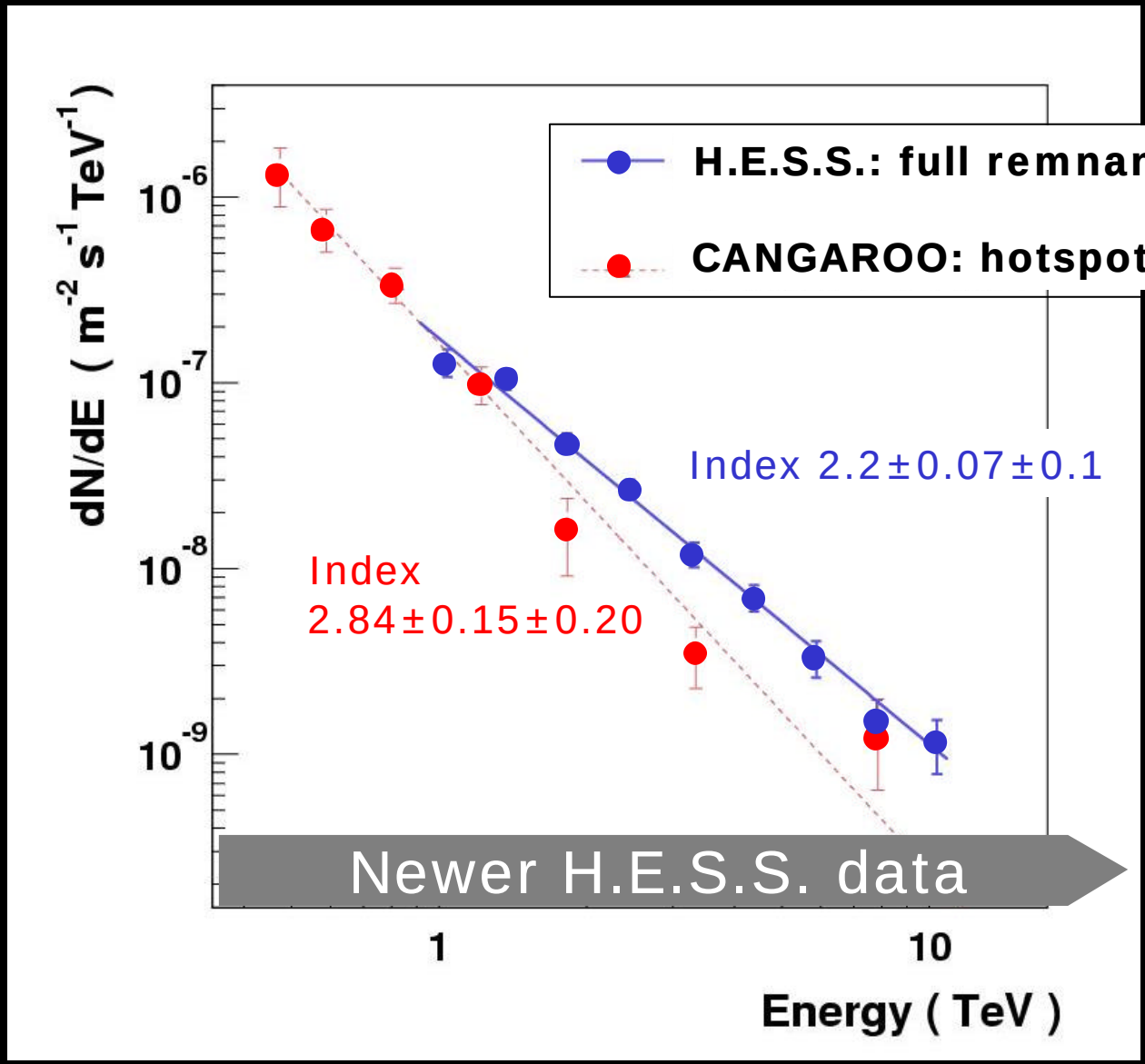
- Interaction with MoC
- distance of 1kpc, age compatible with Chinese records (393 a.d.)





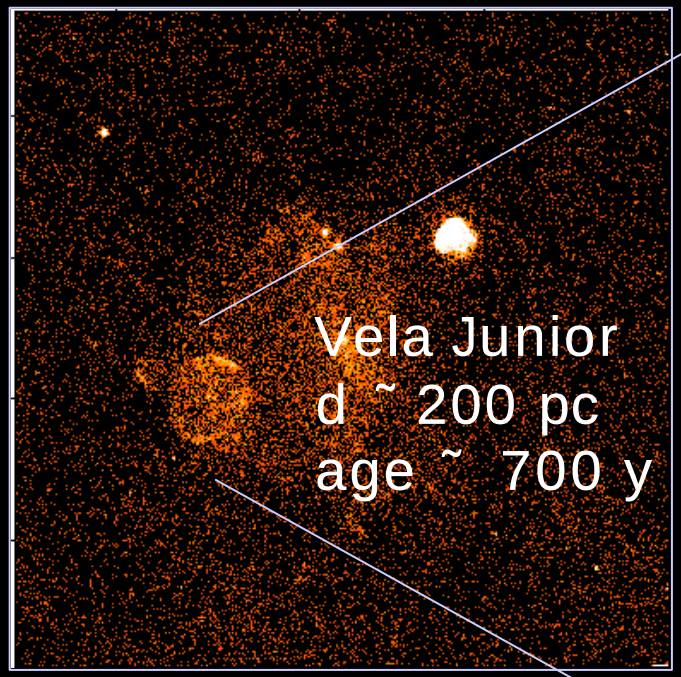
- 18 hours of data taken with 2 telescopes in 2003
  $\rightarrow$ Nature **432**, 75 (2004)

First TeV source with resolved morphology

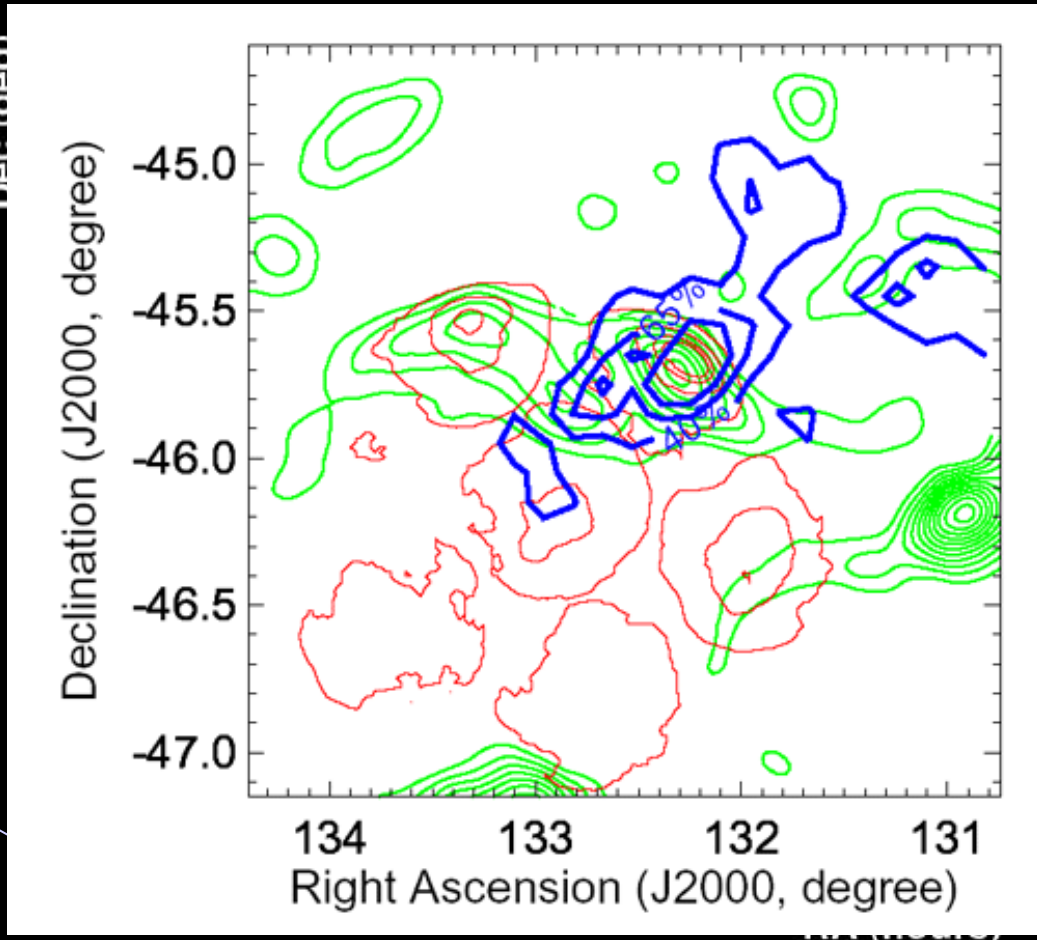


Spectrum as expected for cosmic ray acceleration

H.E.S.S. 2004 – 3.2 h obs. time



Vela (Rosat)



Detected by CANGAROO
Katagiri et al., astro-ph/0412623

Spectral index 2.2±0.1±0.2

Unambiguous proof that
supernova shock waves are cosmic accelerators;
they accelerate particles to O(100 TeV)

Big step forward in cosmic ray problem,
but are they really the sources of (nucleonic) cosmic rays

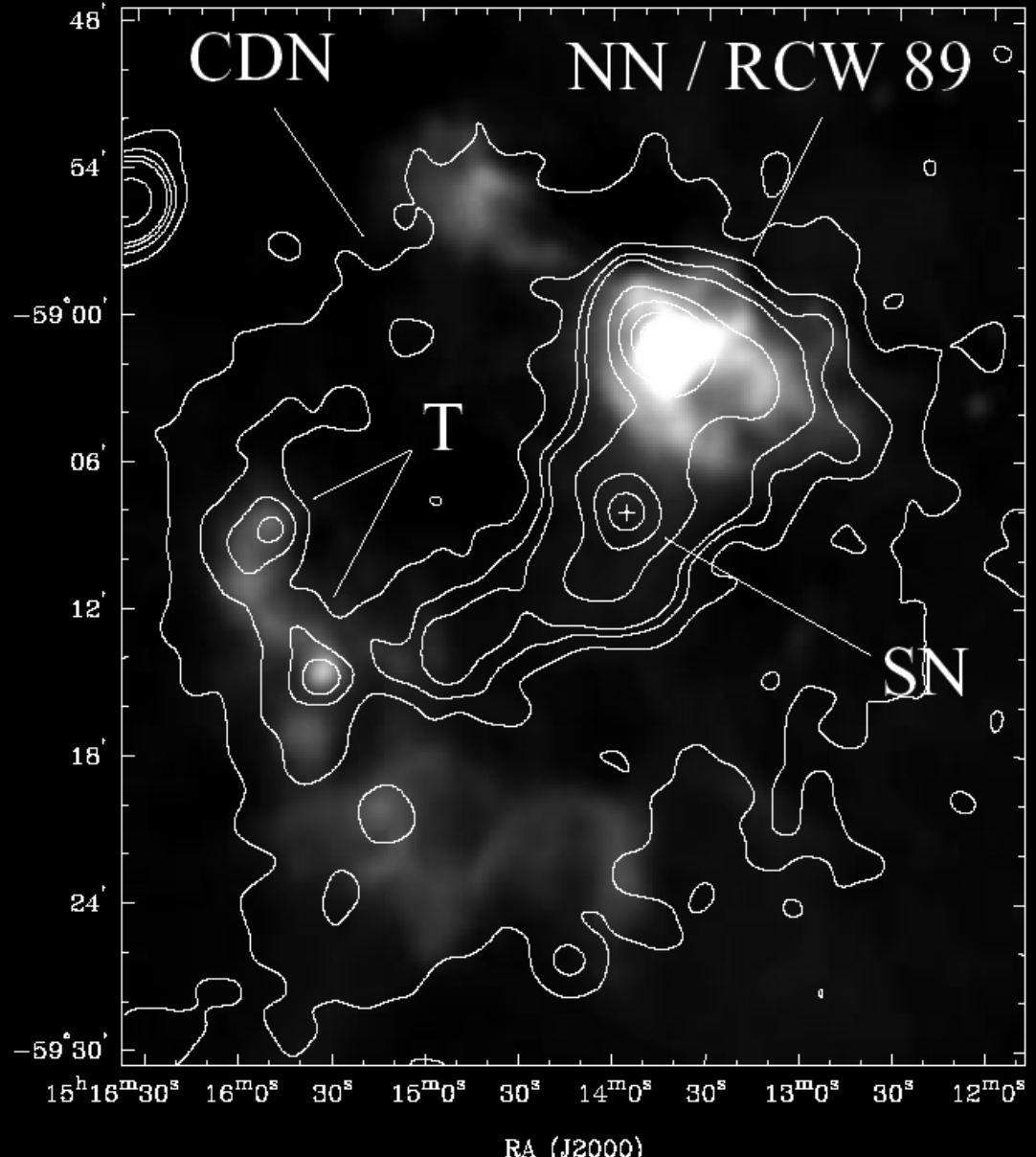
Need wide multiwave band coverage (especially in MeV-GeV) to answer this question

- Crab Nebula as well studied example
- PWN electrons accelerated in termination shock of pulsar wind
- Inverse Compton scattering of these electrons on background photons could produce γ-rays

- **What do we see in VHE gamma-rays?**

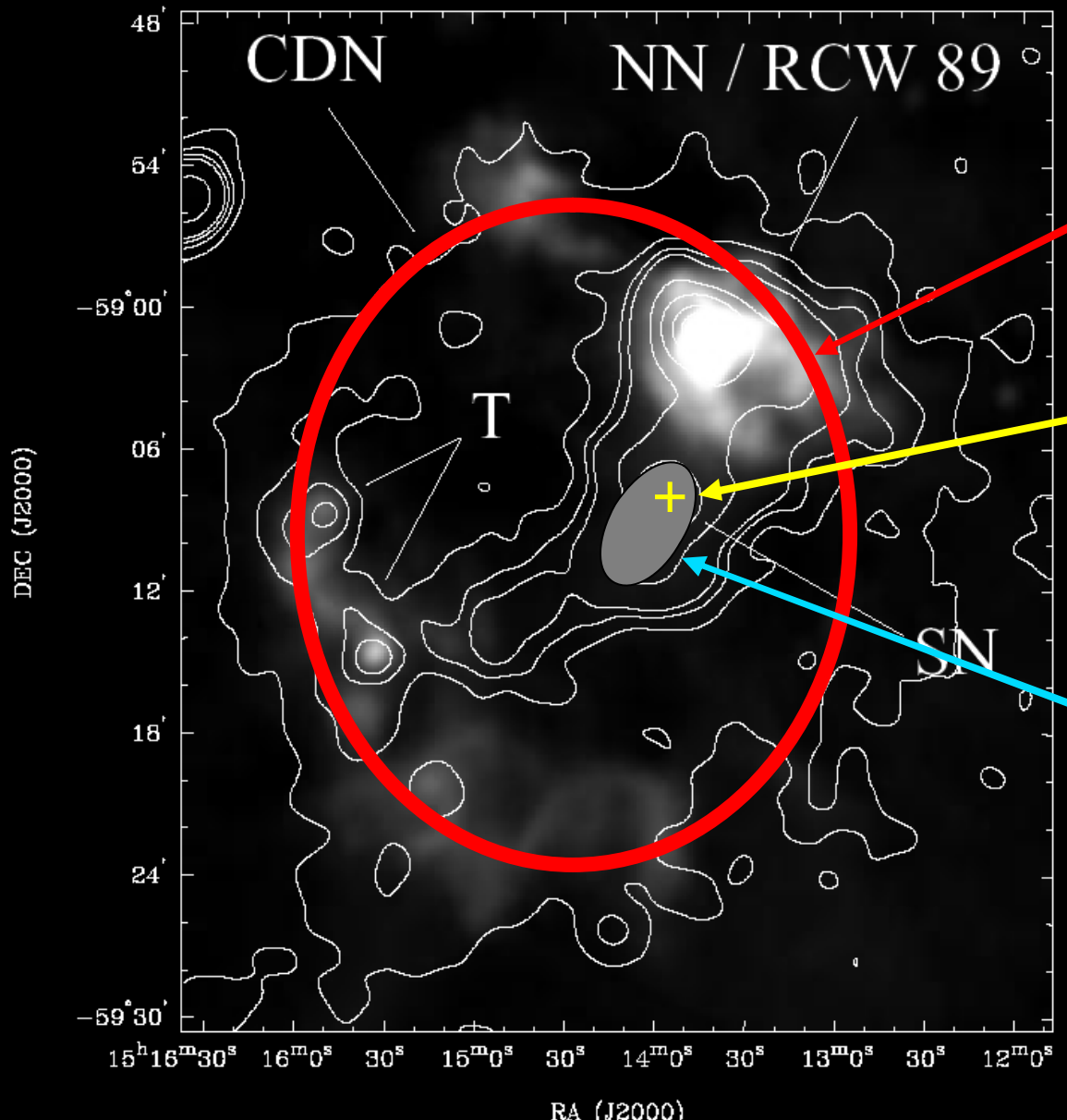
ontours:
OSAT
oft X-ray

reyscale:
IOST
340 Hz)



Age:
1.7- 20 kyr

Distance:
5.2 ± 1.4 kpc



SNR Shell

G320.4-1.2: ∅=

Pulsar

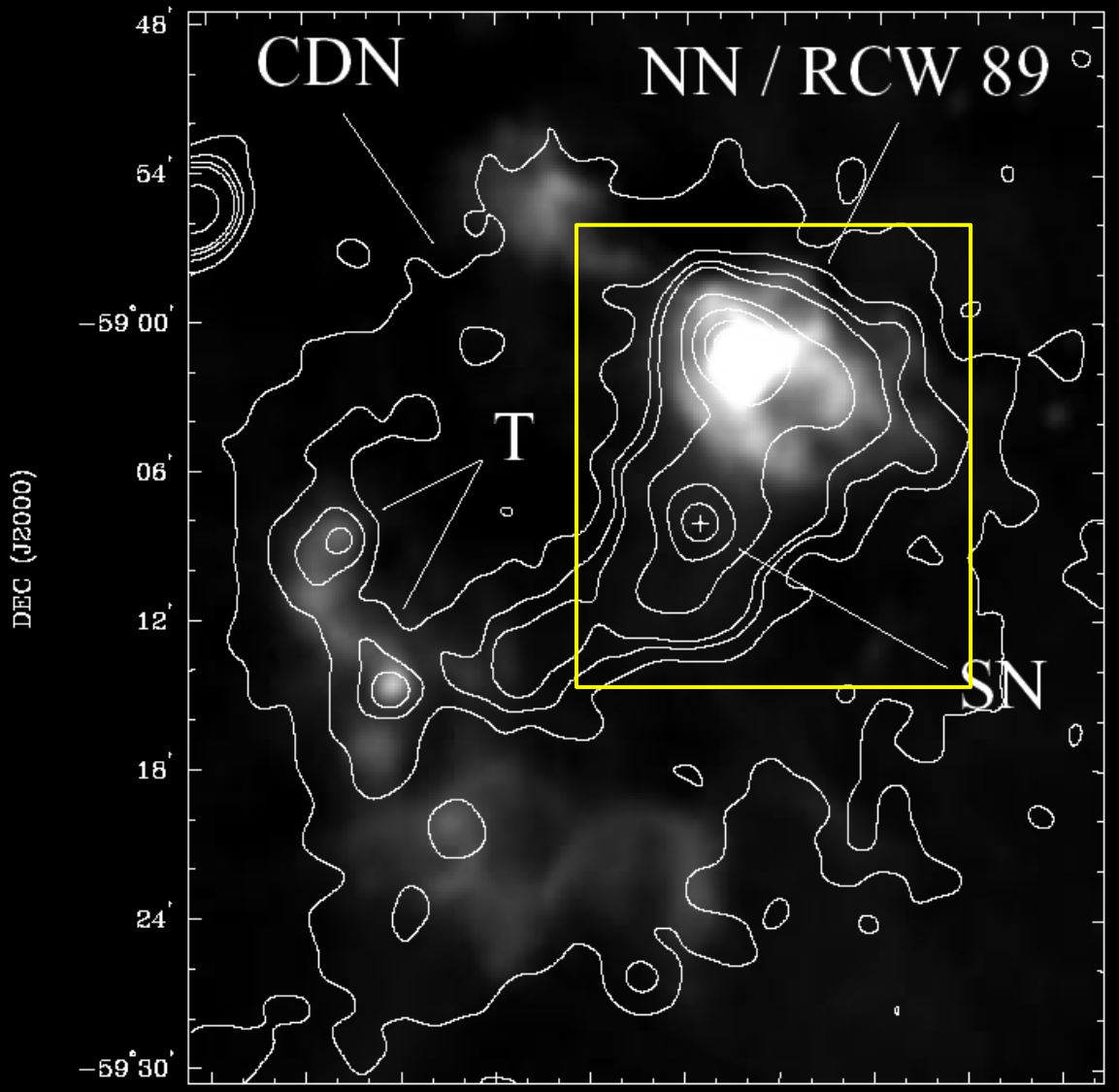
PSR B1509-5

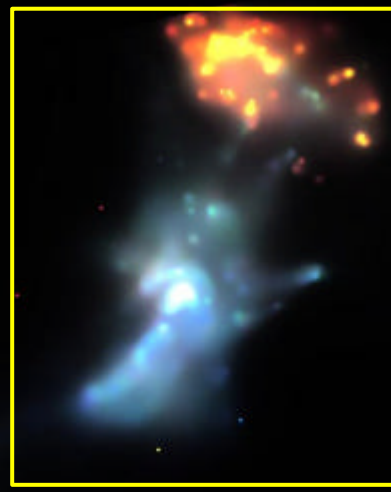
Period 150ms

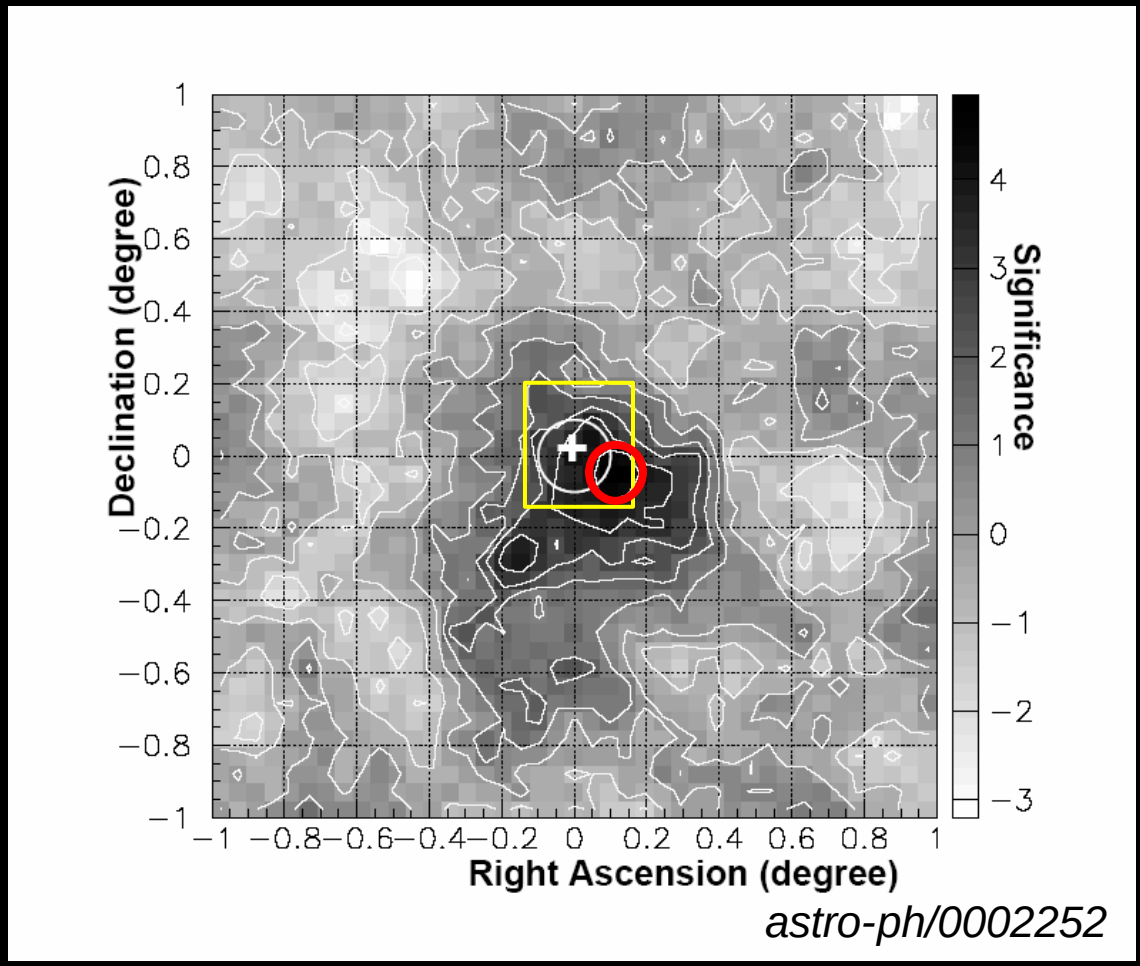
Pulsar

Wind

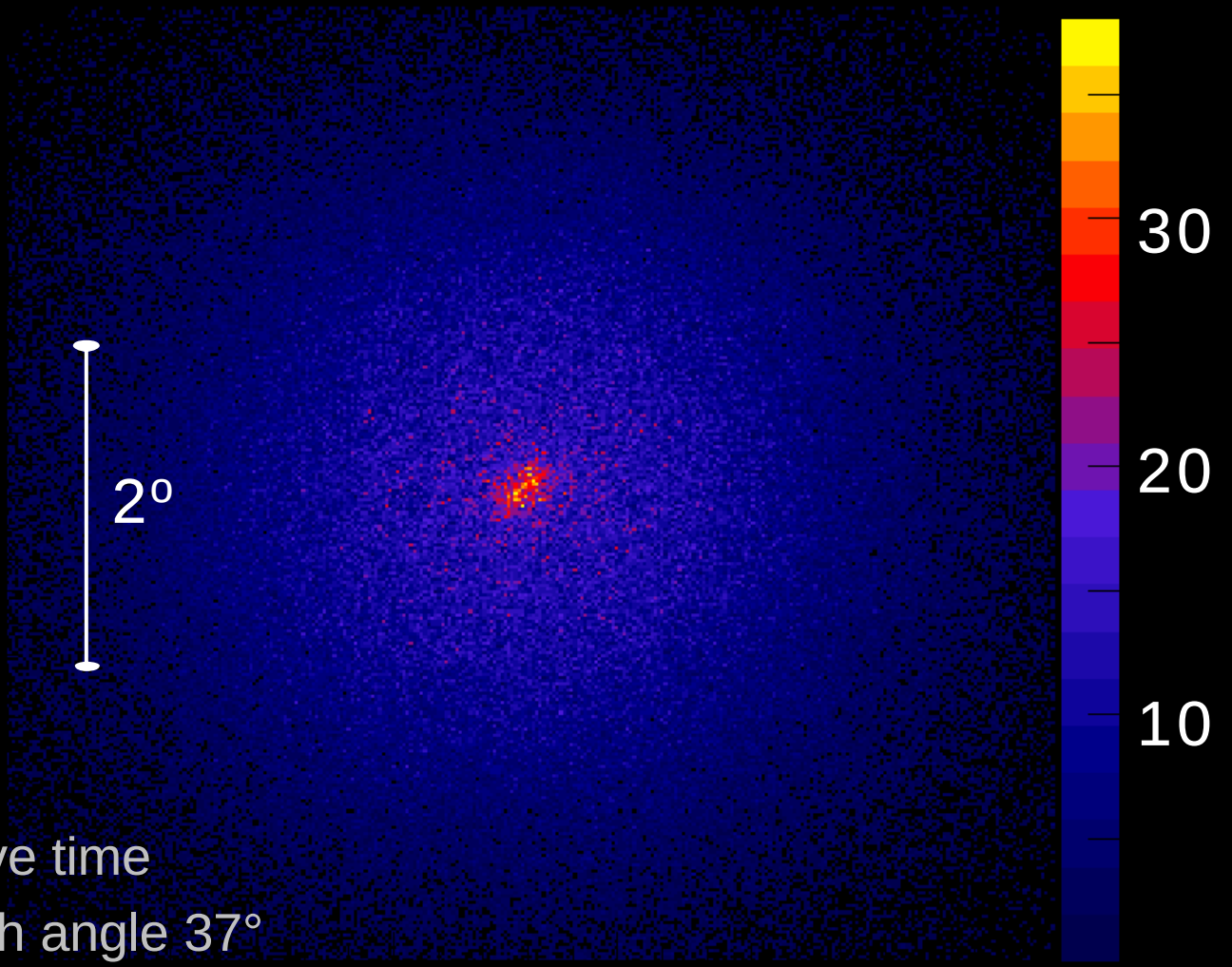
Nebula


CDN
NN / RCW 89
T
SN
48'
54'
−59°00'
06'
12'
18'
24'
−59°30'
DEC (J2000)
15h16m30s
16m0s
30s
15m0s
30s
14m0s
30s
13m0s
30s
12m0s
RA (J2000)





- Marginal (4.1 σ) signal, offset from PSR B1509 (>1.9 TeV)
- But no signal seen in 1996 or 1998…



22 hours live time

Mean zenith angle 37°

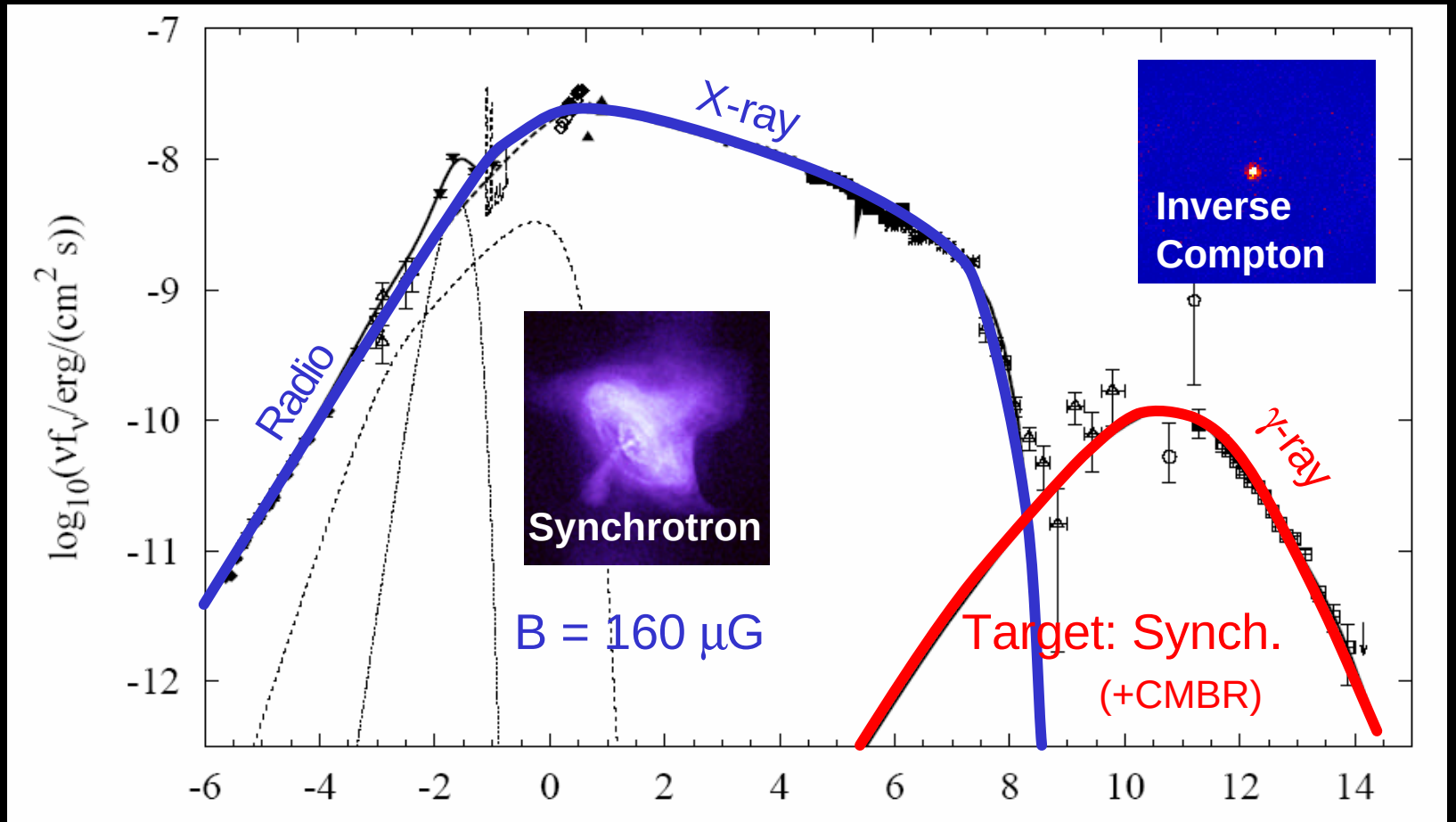
– Energy threshold 280 GeV

25 s signal (for a point source at position of PSR B1509-58)

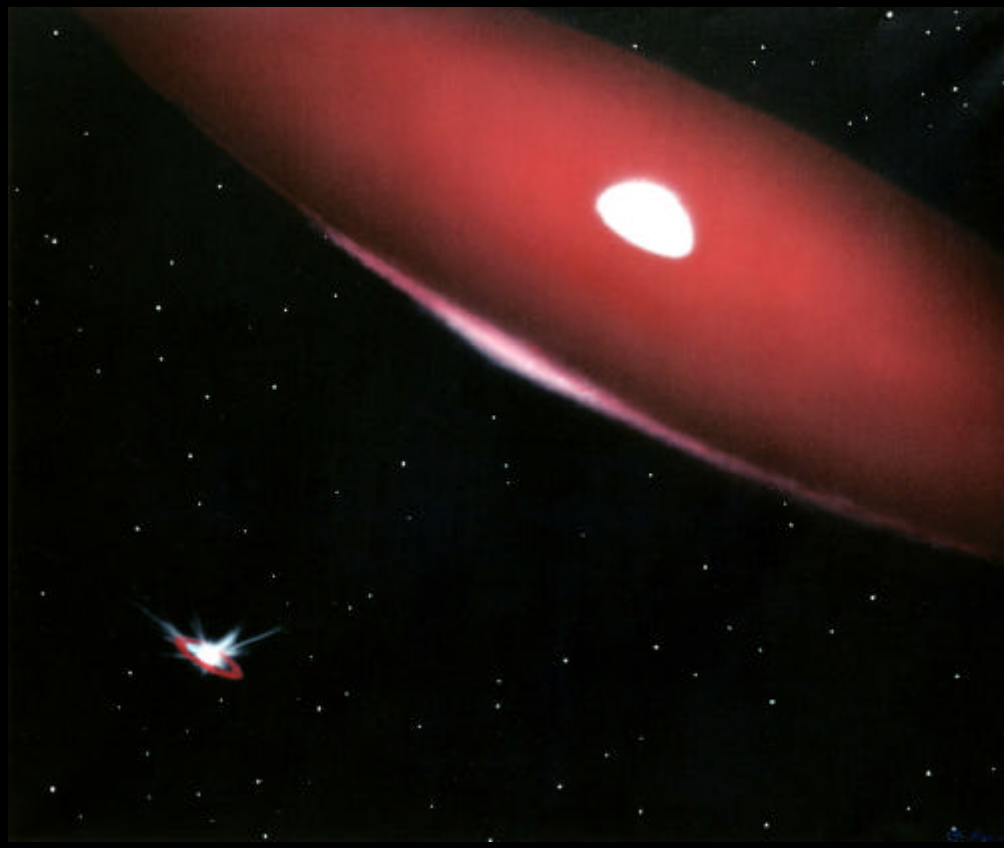
Total excess events: 3481 +- 129

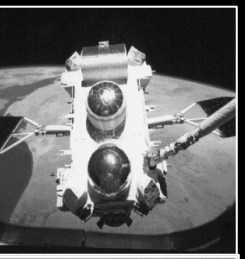
- Accelerated electrons + B-field → synchrotron
- Accelerated electrons + photon field → IC

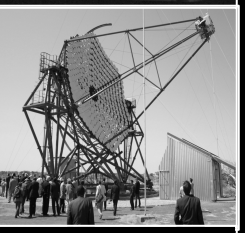
➲ Best known example – the Crab

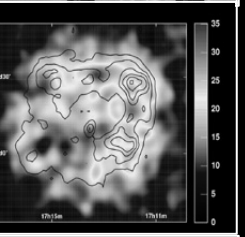


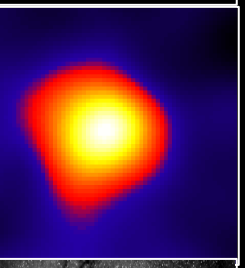
- 48 ms pulsar orbiting a 10 solar mass Be-star with outflow.
- At closest approach expect complex interaction between the pulsar wind and the massive star
- 3.4 year orbital period. Last periastron - 7th March 2004

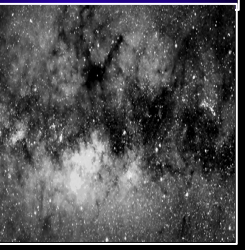






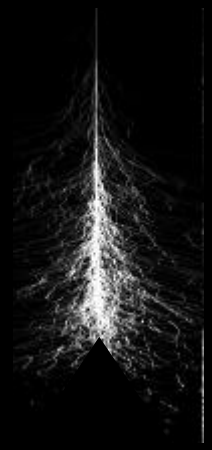




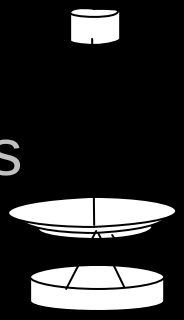


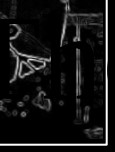
- γ-ray Astronomy
- The H.E.S.S. Telescope Array
- H.E.S.S. Galactic sources
- γ-rays from the Galactic Centre
- The Galactic Plane Survey

- Many potential sources of very high energy γ-rays
  - Standard:
    - Supernova remnants
    - Pulsar wind nebulae
    - Cosmic rays interacting with molecular clouds
  - More exotic:
    - 'Quiet' Supermassive Black Hole
      - Particle acceleration near event horizon
      - Shocks in the accretion flow
    - Dark matter
      - WIMP annihilation



- 3 Detections at TeV energies
  - all published in 2004!
- CANGAROO-II – single 10 m telescope
  - 250 GeV threshold
- Whipple – single 10 m telescope
  - 2.8 TeV (large zenith angles)
- and H.E.S.S. with two 13 m telescopes
  - 160 GeV threshold





H.E.S.S. 2003 data

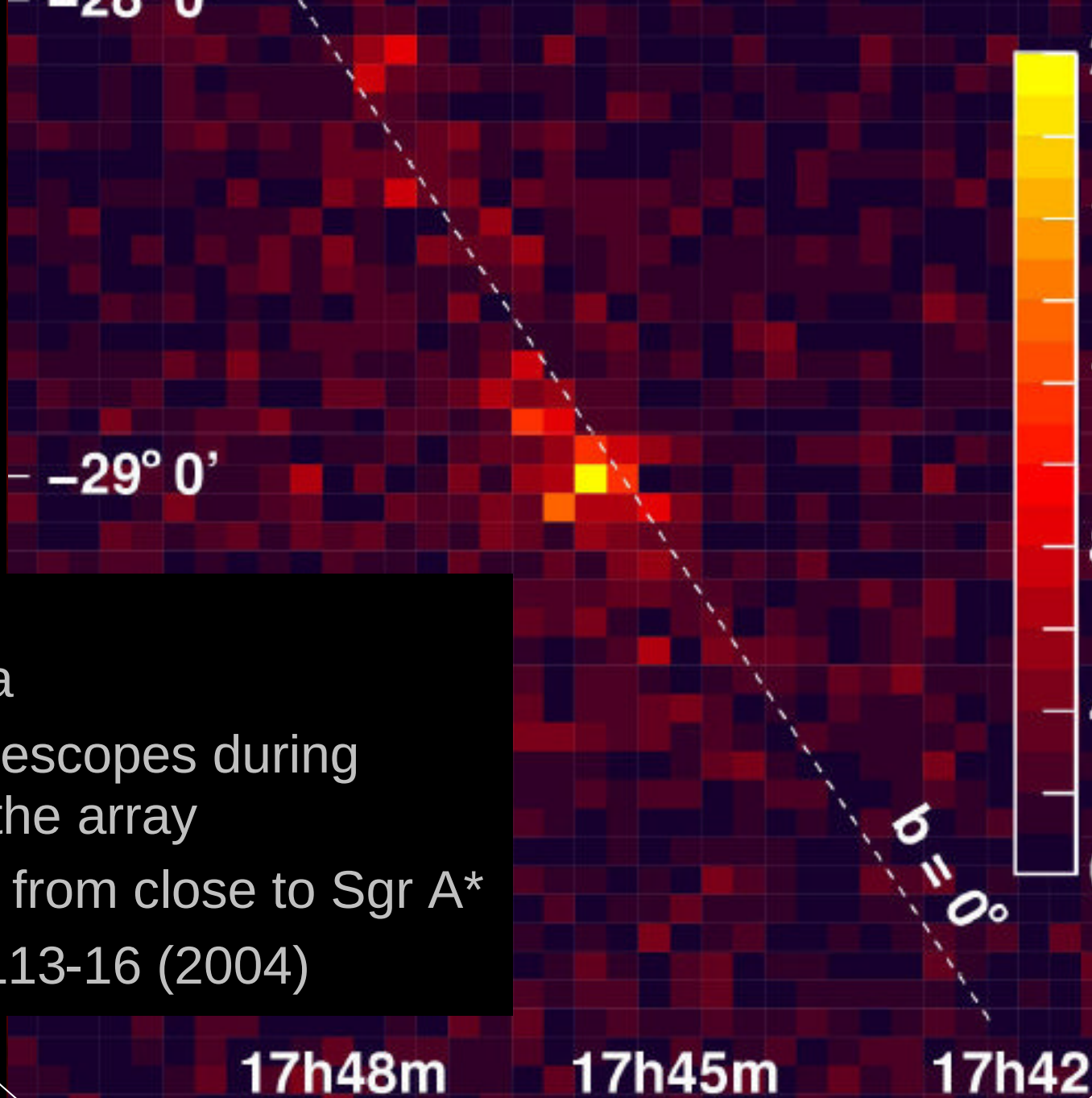
17 hours of data

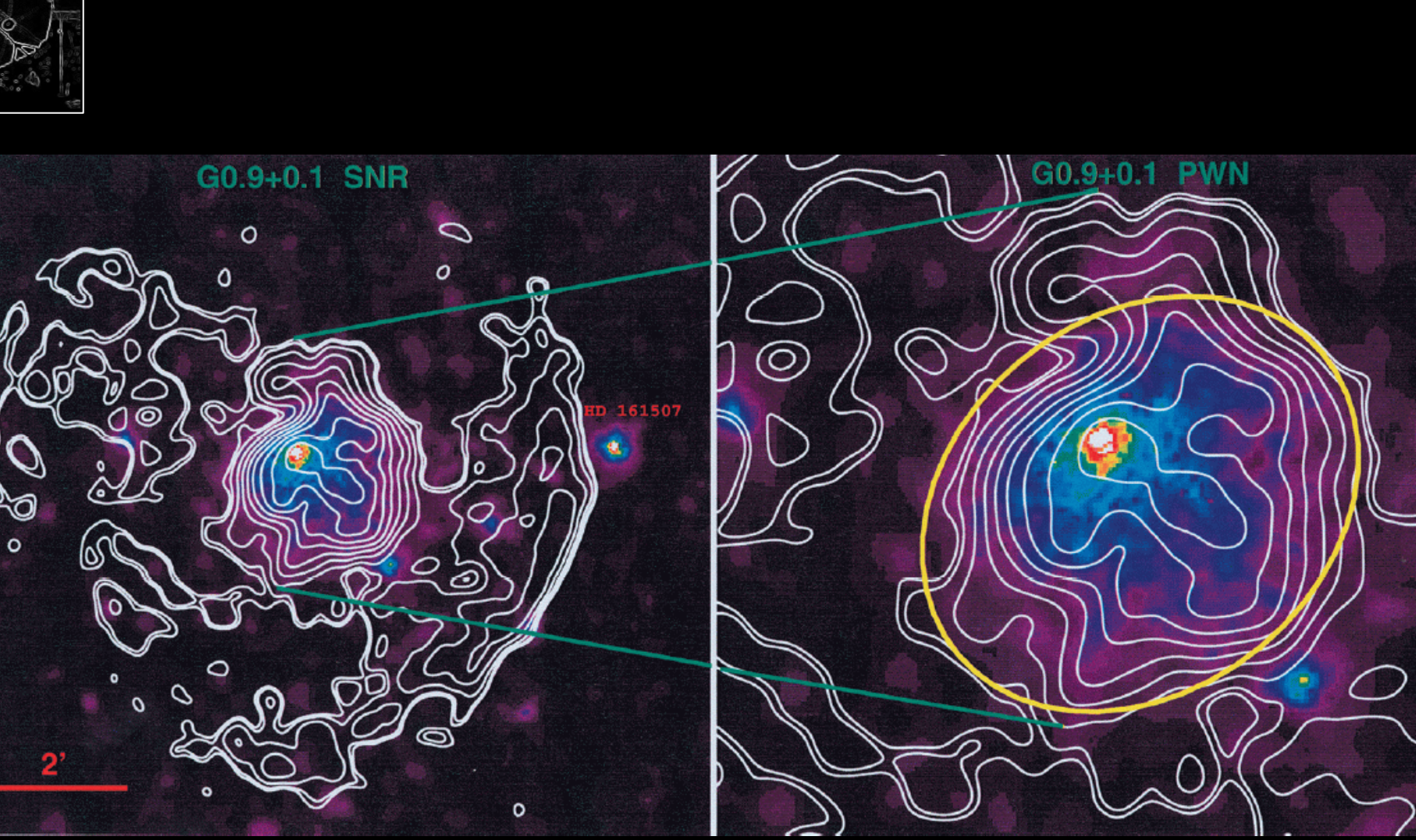
Taken with 2 telescopes during construction of the array

11 sigma signal from close to Sgr A*

See A&A 425, L13-16 (2004)

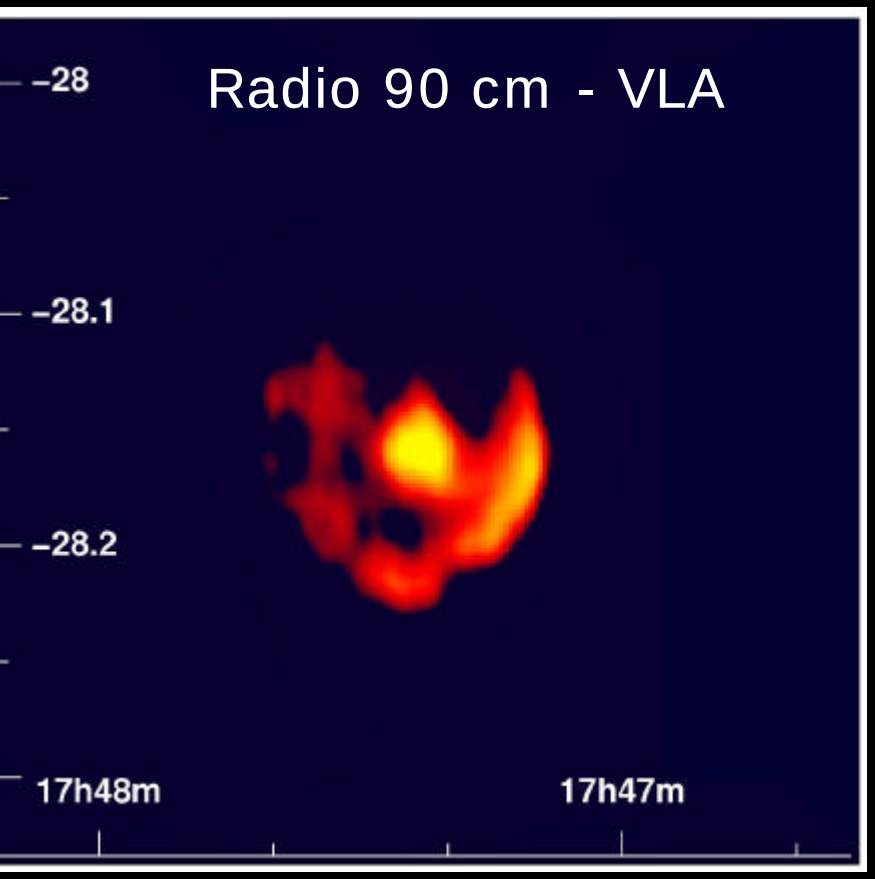
H.E.S.S. Field of View

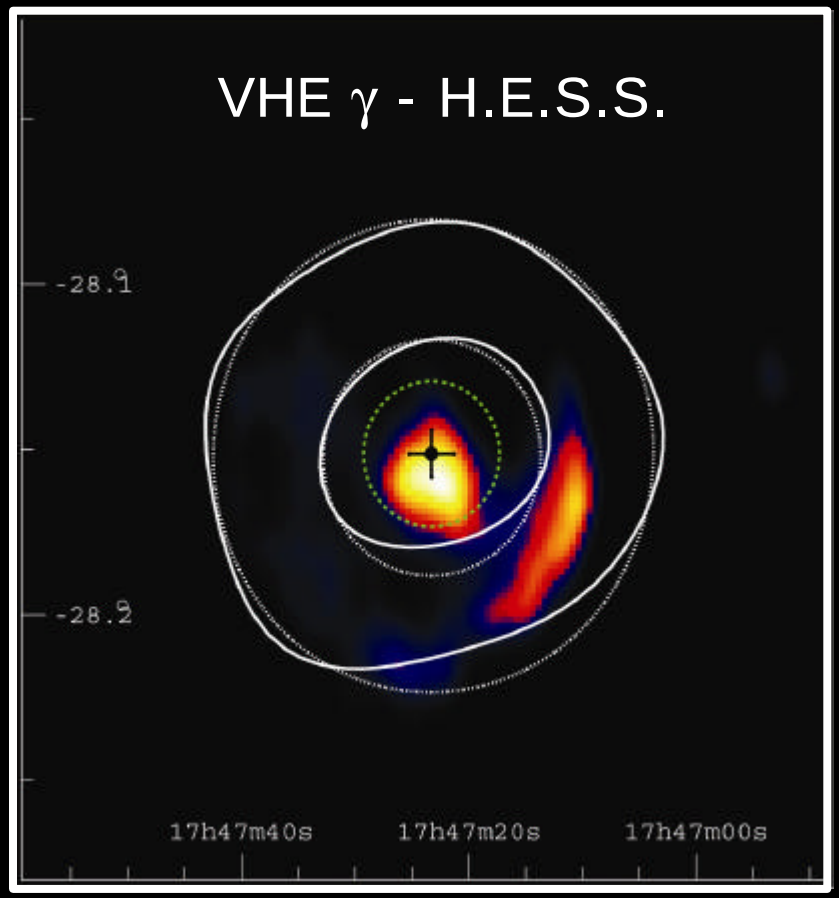




XMM - A&A 401, 19

- In X-rays the shell is very weak, compact central source is bright - power 5×10^{34} ergs/s





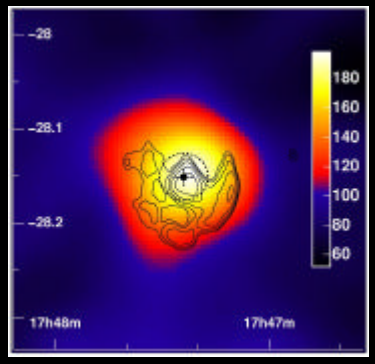
- 13 sigma signal in 2004 data, was ~4 sigma in 2003
- A new source of VHE gamma-rays!

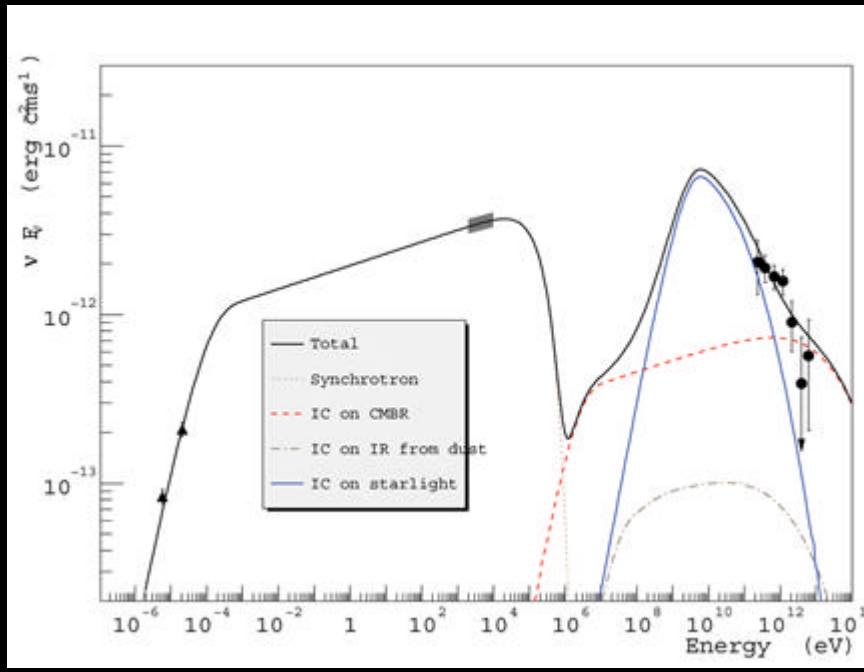
Flux is 2% of the Crab Nebula – *faintest source ever detected in very high energy γ-rays*

Power is ~2×10^{34} ergs/s *(200 GeV and 10 TeV)* – about half that of the Crab Nebula

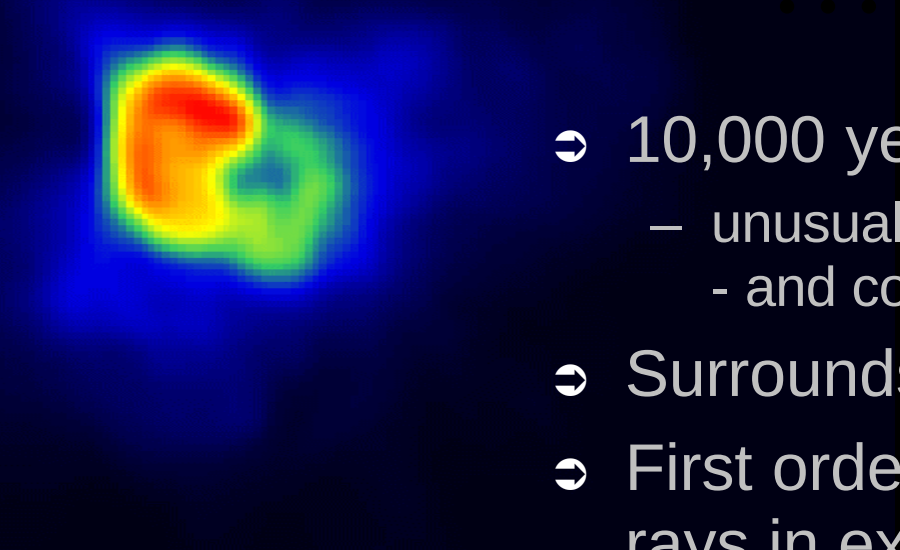
Origin of γ-rays via Inverse Compton scattering of electrons on CMBR, IR and starlight seed photons seems plausible….

For details: A&A 432, L25

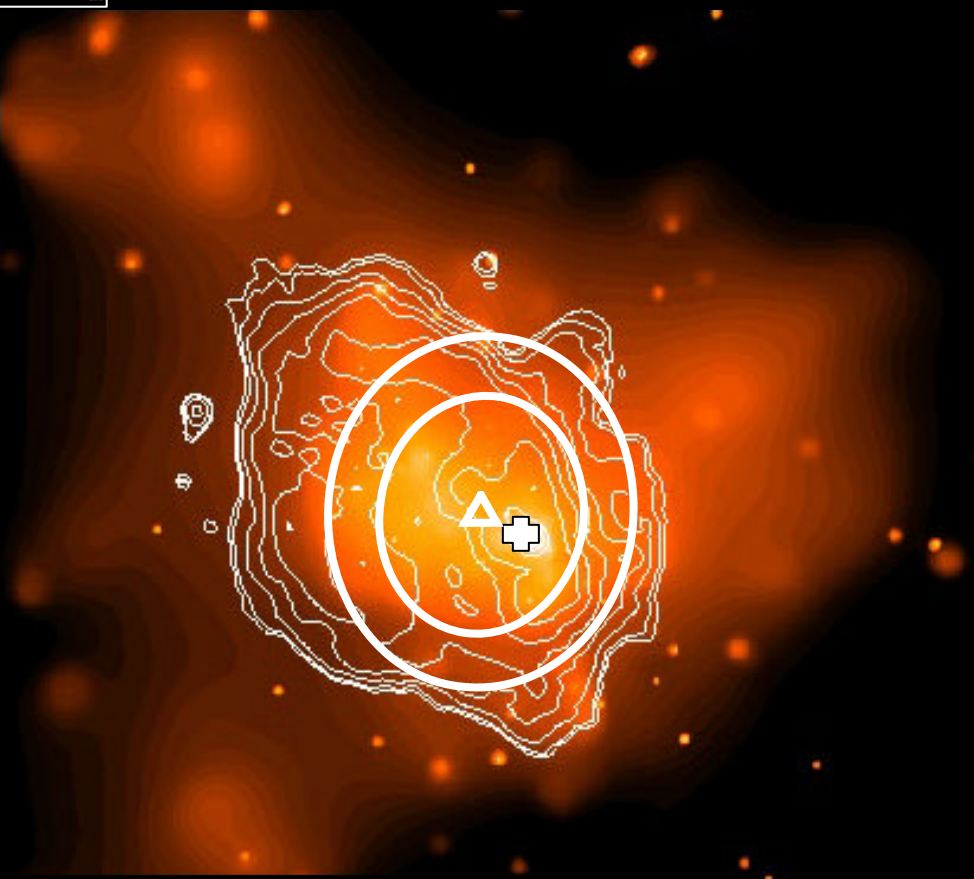




- 3×10^6 solar mass black hole
- Fast rotating supermassive black hole embedded in a magnetic field produces a huge emf
  - could accelerate protons to 10^{18} eV ($\pi^0 \rightarrow \gamma\gamma$)
  - Or accelerate electrons (γ–rays via IC)
- Or acceleration at shocks in the accretion disk



- 10,000 year old supernova explosion
  - unusually powerful - 4 x 10^{52} ergs
    - and compact (3 arcmin)
- Surrounds Sgr A* !
- First order fermi acceleration of cosmic rays in expanding shock

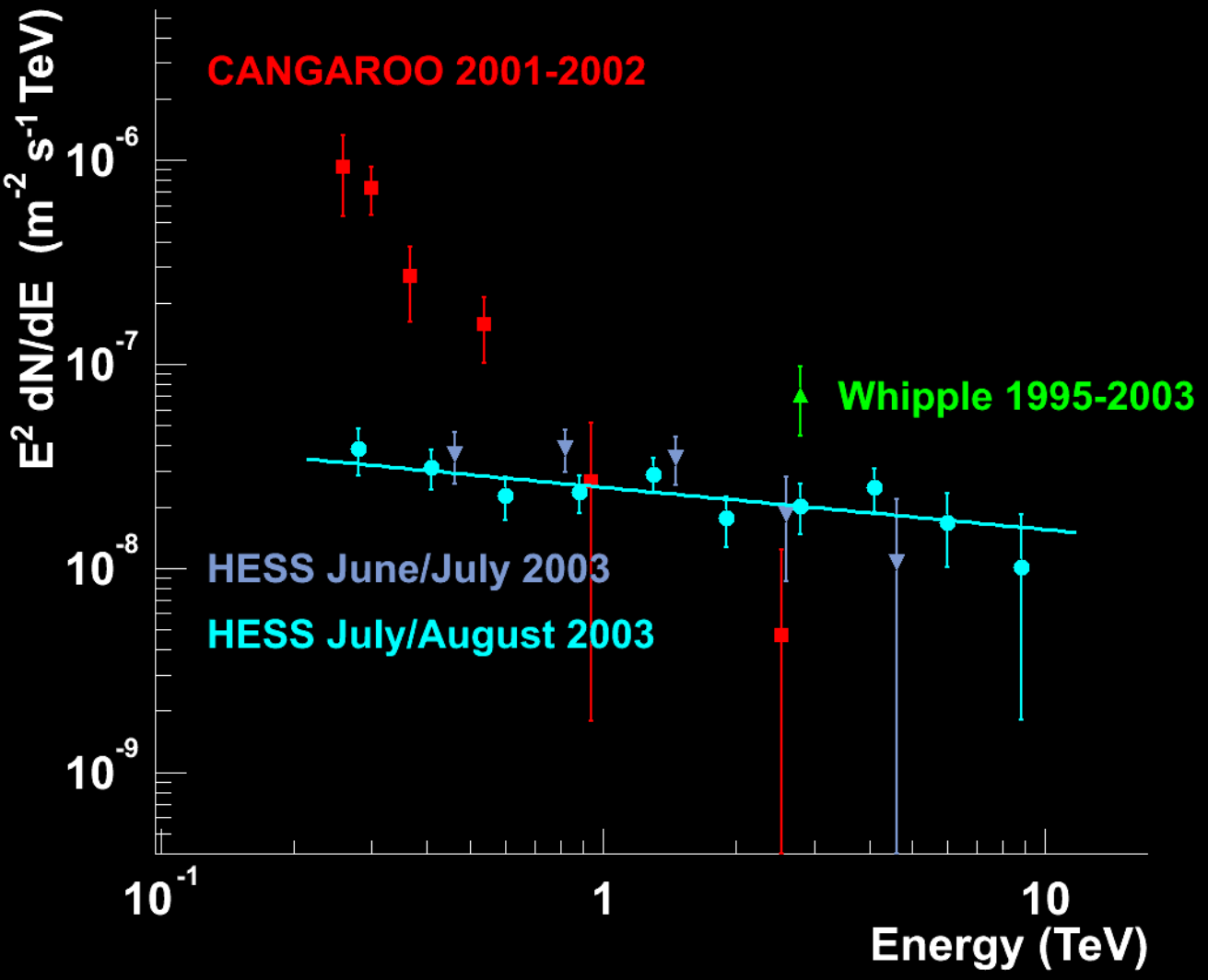


Sgr A East
Chandra & Radio
NASA/G.Garmire (PSU)
F.Baganoff (MIT)
Yusef-Zadeh (NWU)

Distance to Sgr A*:
14'' +- 30'' in Longitude
12'' +- 30'' in Latitude

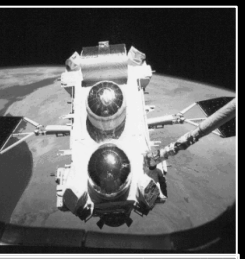
But: Sgr A East
not ruled out

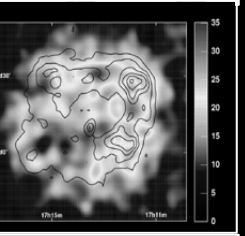
Call γ-ray source
HESS J1745-290

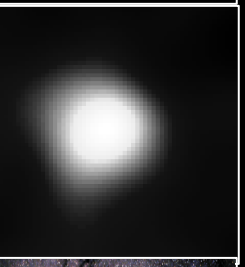


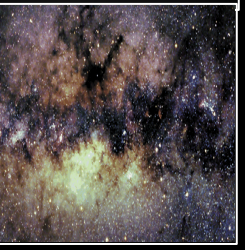
® *HESS data consistent with constant flux and spectrum*

- Firm identification of VHE source with Sgr A* requires
  - Detection of correlated variability
  - Or careful work on pointing systematics and long exposure for good statistics. The limit for H.E.S.S. is ~ 3 arcseconds…
- Identification of the emission mechanism needs
  - Simultaneous multi-wavelength observations
  - Or detection of neutrino source by KM3Net et al.
- But on the bright side
  - If Sgr A East is the culprit we should soon know
    - Better statistics should allow us to explore morphology









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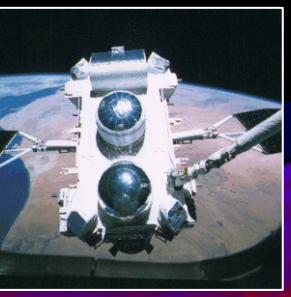
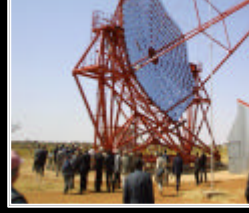
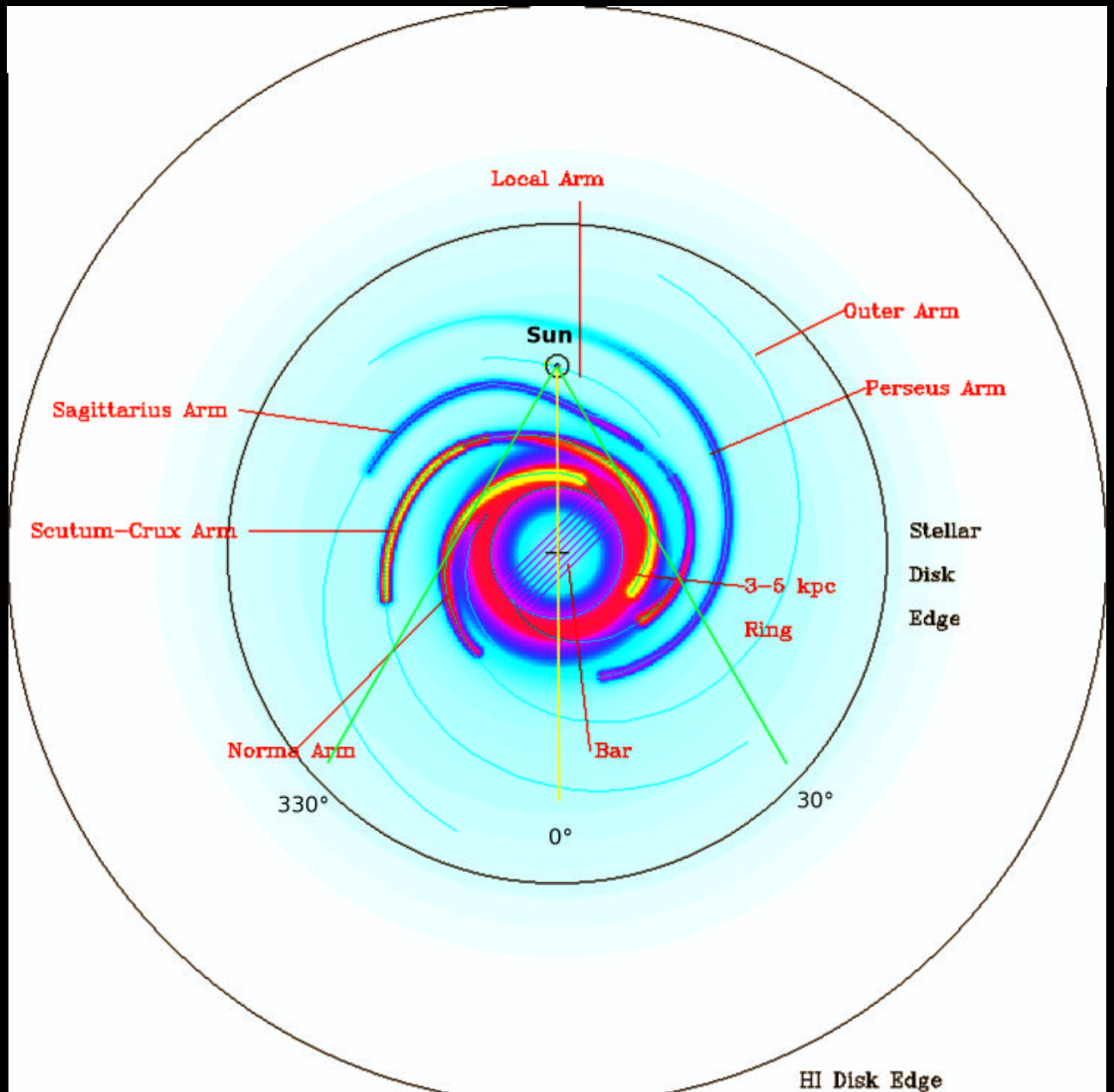
- EGRET high energy gamma rays
- HEGRA VHE energy survey (nothern sky), found no sources (average sensitivity 15%-30% Crab)
- Known VHE sources in this region: RX J1713.7 and GC






Local Arm
Outer Arm
Sun
Perseus Arm
Sagittarius Arm
Scutum–Crux Arm
Stellar
Disk
Edge
3–5 kpc
Ring
Norma Arm
Bar
330°
30°
0°
HI Disk Edge

- H.E.S.S. has had a good start
  - and expect lots more results soon!
- We have big plans for the future