HESS – *H*igh *E*nergy *S*tereoscopic *S*ystem of Atmospheric Cherenkov Telescopes

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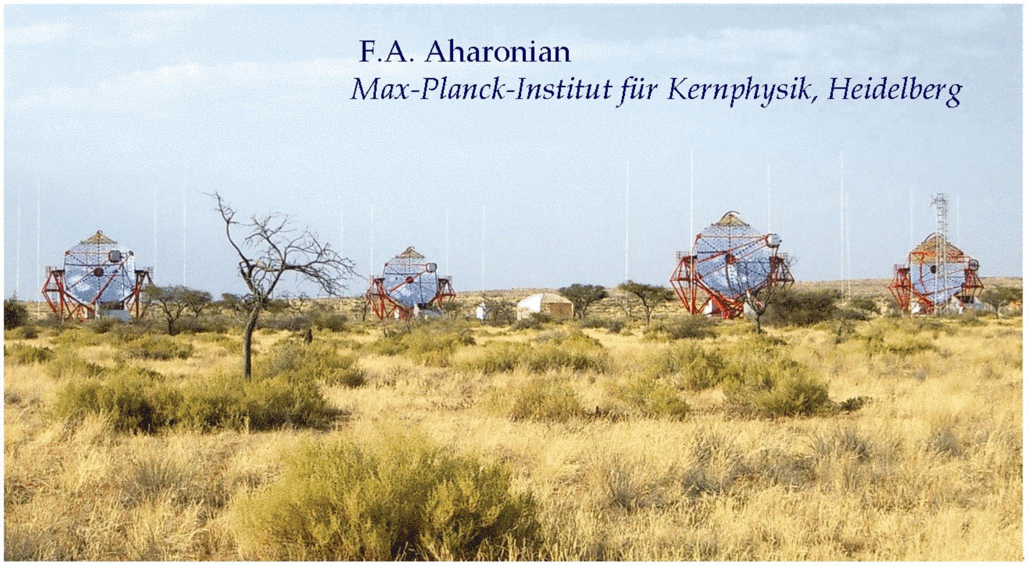


KITP, UHE mini-program, Santa Barbara, May 16 2005

The H.E.S.S. Collaboration:

MPI Kernphysik, Heidelberg
Humboldt Univ. Berlin
Ruhr-Univ. Bochum
Univ. Hamburg
Landessternwarte Heidelberg
Univ. Kiel
Ecole Polytechnique, Palaiseau
College de France, Paris
Univ. Paris VI-VII
Univ. Montpellier II

CEA Saclay
CESR Toulouse
LAOG Grenoble
Paris Observatory
Durham Univ.
Dublin Inst. for Adv. Studies
Charles Univ., Prague
Yerewan Physics Inst.
Univ. Potchefstroom
Univ. of Namibia, Windhoek

Status of the of Gamma Ray Astronomy

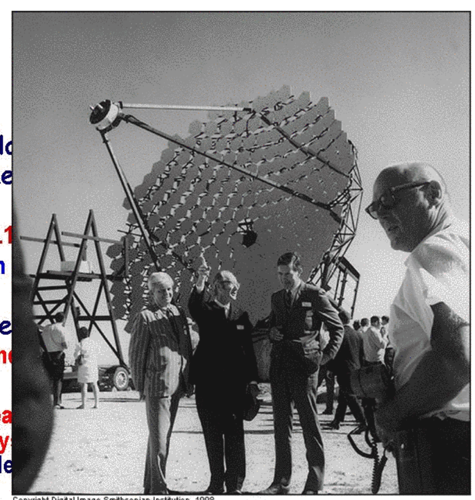
in 1990s, after several decades of struggles and controversial developments ground-based gamma-ray astronomy became an observational discipline and entered the main stream of modern astrophysics and cosmology with:

- **viable detection technique – Imaging Atmospheric Cherenkov Telescope (IACT) arrays - emerged as prime tool for detection of VHE gamma rays**
- **more than 25 reported sources**

all important results are obtained at TeV energies with IACTs !

Brief history:

- 1960s: first pioneers/first efforts (Chudo
  Jelly, Weeke
- 1970s: Crab claimed to be detected 3.1
  (after 3 year observations with Whipple 10m
- 1980s: turbulent years with Cygnus X-3 e
  negative impact - bad reputation of groun
  positive impact - initiated a new resea
  or "Particle Phy
  (more importantly) initiated new de



- 1989: first reliable detection – Crab (Nebula) is a TeV source !
  with Whipple 10 m imaging telescope

Cherenkov Imaging technique and Whipple collaboration
saviours of ground based gamma ray astronomy

1990s – *more sources/more detectors*

- **1992:** **Mkn 421**: a "half TeV source" (Whipple) but soon confirmed as a highly variable object
- **1995:** **Mkn 501**: first gamma-ray source detected in the TeV band (Whipple)

new detectors – CANGAROO, CAT, HEGRA,...

- **1997:** **Mkn 501**: extrordinary strong and long outburst
- **2000s:** new TeV blazaes, as well as **Cas A, M87, an "Unidentified TeV sources"** *detected by HEGRA at < 0.05 Crab level*

2000s – *new generation of IACT systems*

HEGRA – new standards: discovery of γ-ray sources at the level of 10^{-12} erg/cm^2 s with angular resolution of 5 arcmin

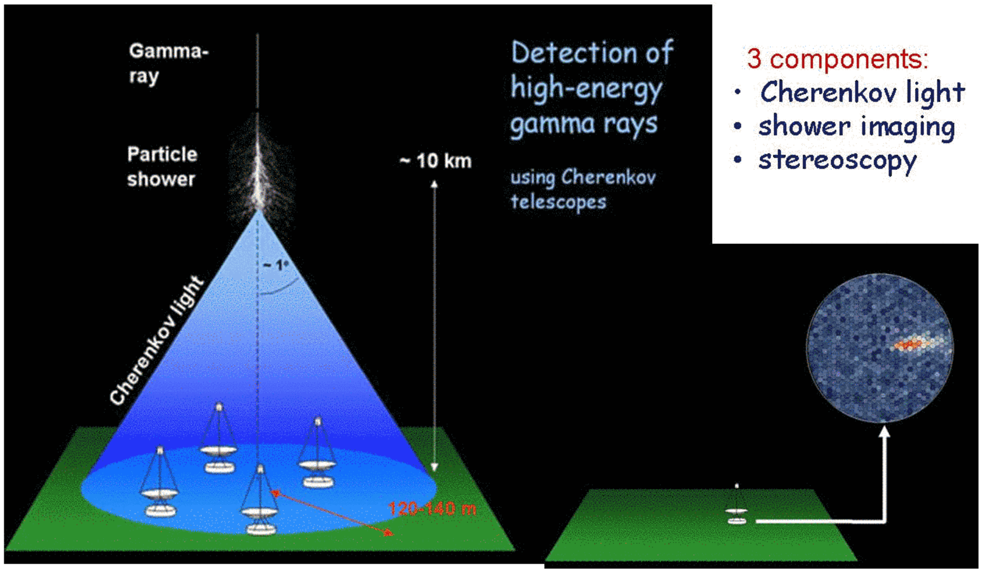
demonstration of the potential of the sterepscopic approach !

HEGRA as a prototype of arrays of "10 m class" (100 GeV threshold) Cherenkov telescopes: **CANGAROO-III, H.E.S.S., VERITAS**

a single 17 m diameter dish MAGIC – a different approach **but MAGIC-2 seems is a move in the same direction**

all curreent proposals/ideas on 4the generation detectors - independent of details - **stereoscopic IACT arrays of different configurations**

Basic tools – Stereoscopic IACT Arrays



Why Cherenkov telescope ?

[= an optical reflector with a PMT in focus + fast (ns) electronics]

- large detection are – typically 0.1 km2,
  potentially up to $10 km^2$
- energy threshold – typically 1 TeV,
  potentially down to a few GeV

but it is a cosmic ray detector

rather than a gamma-ray telescope...

Why Imaging ?

because images allow reconstruction of shower parameters

- (certain) information about arrival direction
- capability to separate gamma and proton induced showers
- larger FoV (larger collection areas)

first result detection of 10 sigma signal from Crab with Whipple 10 m telescope (1989)

a good gamma-ray detector but not yet a telescope ...

Why Stereoscopy ?

✓ better separation of hadronic and E-M showers

✓ angular resolution of about 3 arcmin

→ better sensitivity, source localization, morphology,

✓ energy resolution 10 to 25 per cent

→ better spectrometry

✓ rejection of local muons, better rejection of N.S.B.

→ lower energy threshold, systematics under control

✓ quite large (up to 5 degree) FoV

→ **extended sources, surveys, huge collection areas (at $E>>E_{th}$)**

IACT arrays are perfect gamma-ray telescopes !

Stereoscopic Imaging of Air Showers

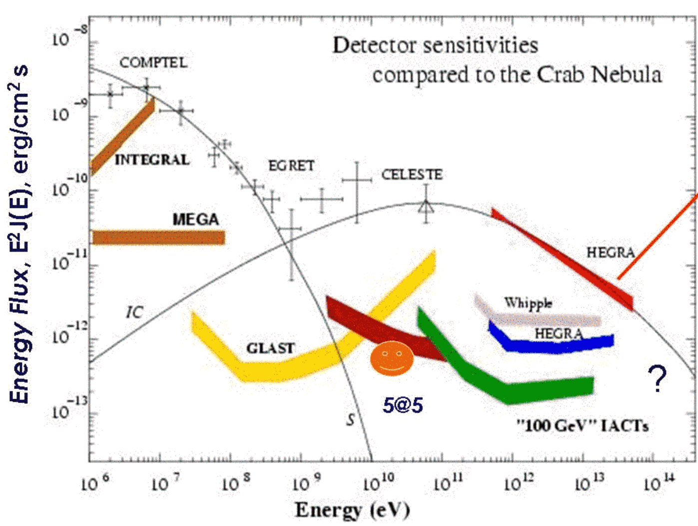
CANGAROO-III, H.E.S.S., VERITAS, MAGIC-2
for TeV astronomy *

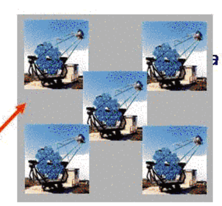
5@5, ECO-1000 …
for multi-GeV astronomy

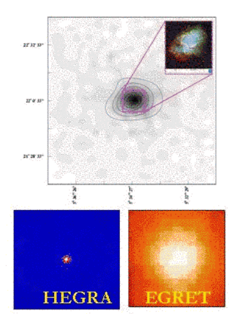
* 100 GeV=0.1 TeV

Potential of IACT Arrays

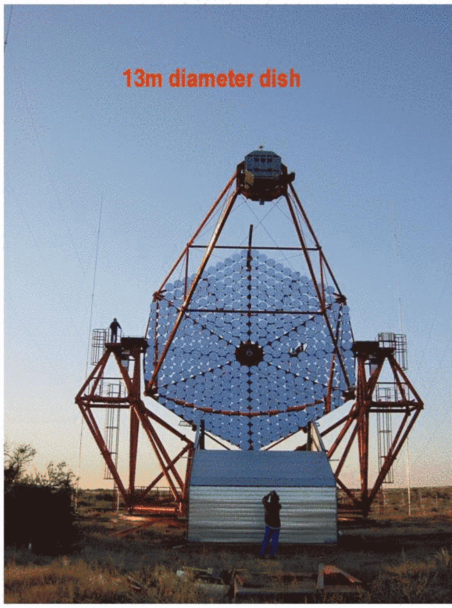
sensitivity down to 10^{-13} erg/cm2s
energy resolution 10 to 20 %
angular resolution a few arcminutes
dynamical range : 3 GeV to 100TeV

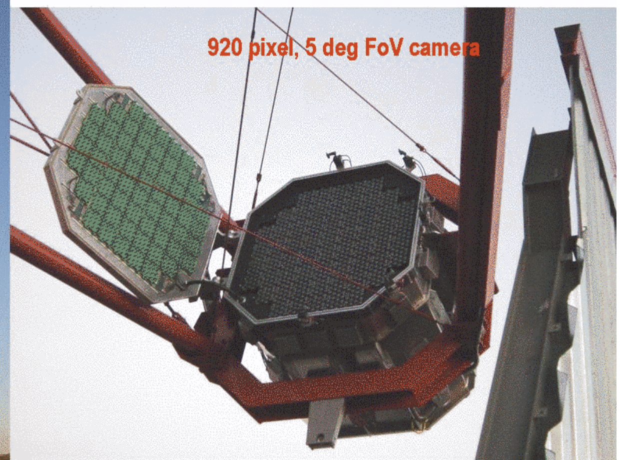






H.E.S.S. - High Energy Stereoscopic System

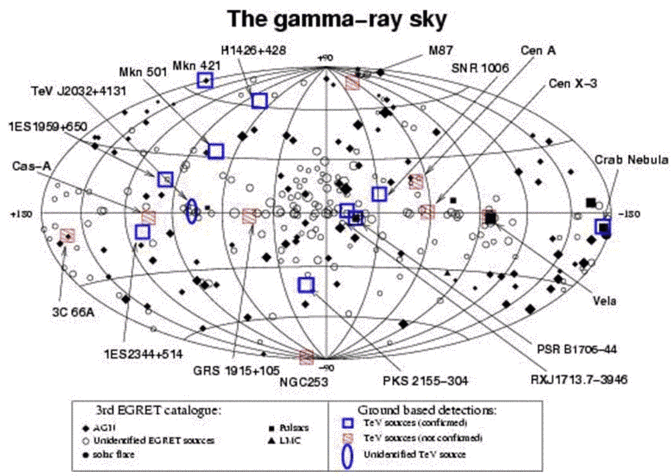




Reported TeV Sources before 2004

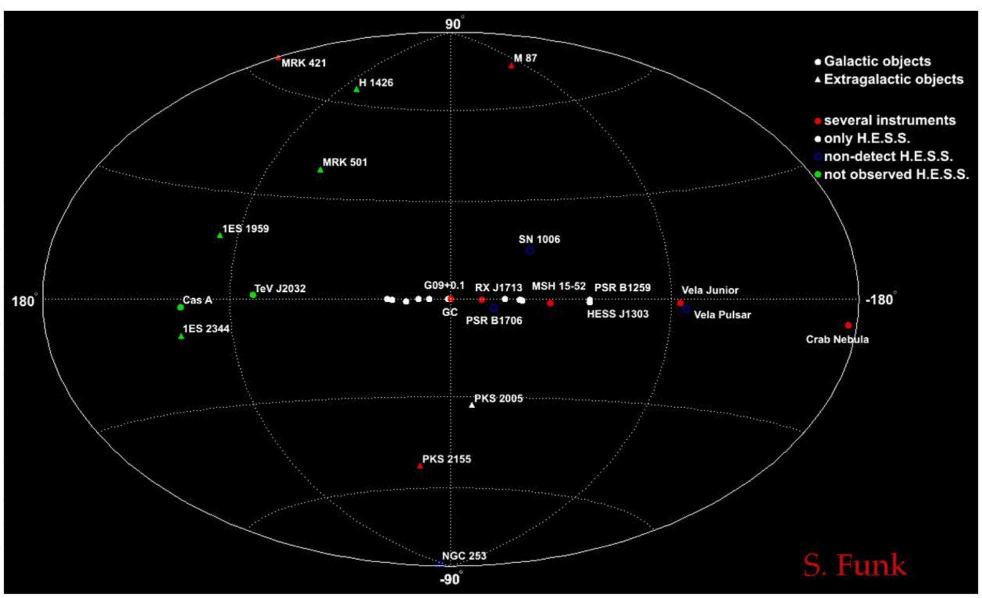
- *Blazars* — Markarian 421, Markarian 501, 1es2344+514, 1es1959+650, 1es1426+428, PKS 2155-304
- *Plerions* — Crab Nebula, PSR 1706-44
- *SNRs* — Cas A, SN 1006, RX1713.7-394
- *Radiogalaxies* — M87, Cen A
- *X-ray binaries* — GRS1915+105, Cen X-3,...
- *Starburst Galaxies* — NGC 253
- *First Uniden.source* — TeV J2032+4131

TeV Sky before 2004



TeV sources - not many, but represented by several populations

HESS reported – published (public available) results



- Energy range
  100 GeV - 10 TeV
- Energy resolution
  15 - 20%
- Angular resolution
  3 - 6 arcmin
- Sensitivity:

1 Crab	30 sec
0.1 Crab	20min
0.01 Crab	25 hours
10 Crab	1 sec

- Field of View 5°

1 Crab = 3×10^{-11} erg/cm^2 s

✓ 0.1 Crab - min detection time for Whipple – 50-100 hour

✓ 0.003 Crab requires 200 h
10^{-13} erg/cm^2 s level
better than Chandra/XMM for >0.1 deg objects !

✓ 10 Crab (i) strong flares of Mkn 421/501
(ii) energy flux sensitivity of EGRET
(iii) several orders of magnitude less than typical GRB fluxes

✓ 3 arcmin - angular resolution of ASCA

✓ 5° FoV plus 0.1 Crab for < 1 h –
sufficient for effective surveys !

Expectations from the Foreseeable Future

- GLAST — large source statistics !
  "Era of gamma-ray astronomy with thausand sources" (0.1-10 GeV)
  also: a few objects and G- & EXG- backgrounds in 10-100 GeV range
- Stereoscopic IACT Arrays — large photon statistics !
  (H.E.S.S./CANGAROO-III/MAGIC-2/VERITAS)

High quality **morphological, spectrometric, and variability** studies in 0.1-10 TeV range of a reasonable number of several source populations based on data sets consisting of more than 10,000 gamma-ray photons

Also exploration of a few (or many ?) objects in 10-100 TeV domain

Major scientific objectives of HESS

- Origin of Galactic Cosmic Rays
  SNRs, Molecular clouds, Diffuse radiation of the Galactic Disk, ...
- Galactic and Extragalactic Sources with relativistic flows
  Pulsar Winds, Microquasars, Small and Large Scale jets of AGN, GRBs...
- Observational Gamma Ray Cosmology
  Large Scale Structures (Clusters of Galaxies), Dark Matter Halos,
  Diffuse Extragalactic Background radiation, Pair Halos

....
....

first H.E.S.S results

Galactic Sources

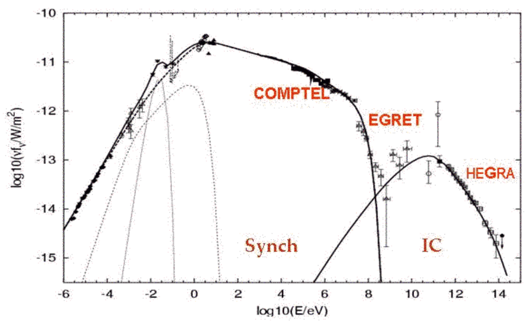
- morphology/spectrometry of shell type SNRs
- TeV gamma-rays from plerions
  and from binary pulsar PRB 1259-63
- new (unidentified) galactic TeV sources

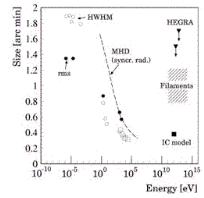
- Galactic Center

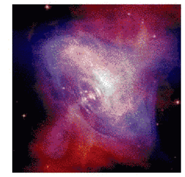
Extra-Galactic Sources

- M87
- TeV Blazars - PKS 2155-304, PKS 2005-489, ...

Crab Nebula – not only a "standard candle"







Standard MHD theory (model)
Kennel and Coroniti 1984

cold ultrarelativistc pulsar wind terminates by reverse shock resulting in acceleration of electrons up to 10^{16} eV ⇒ Synchrotron radiation => nonthermal optica and X-ray nebula
Inverse Compton scattering => high energy gamma-ray nebula

Crab Nebula – a very powerful $W = L_{rot} = 5 \times 10^{38}$ ergs

and an "extreme" accelerator $h\nu_{cut} = 0.1 h\nu_{max} \sim 0.1 m_e c^2/\alpha_f \sim 10$ MeV

Acceleration takes place at 10 % of the maximum possible rate c/r_g !

PeV electrons are responsible for MeV synchrotron and for >30 TeV IC components

Challenges

A. Localization of the gamma-ray production region
(within the Kennel-Koroniti type models)

B. Probing possible hadronic component
spectrum is explained nicely from 500 GeV to 80 TeV energies by IC scattering within the MHD theory of shock termination of ultrarelativistic pulsar wind

additional hadronic component with narrow energy spectrum with characteristic energy 10^{15} eV is not excluded at the level of the the nergy content of ions in the wind of about 10-20 %

> 1 TeV neutrinos (marginally) detectable by km^3 class detectors

C. Probing the site of creation and the Lorentz factor of the kinetic-energy dominated wind through inverse Compton scatering of wind electrons

cold wind is not a "dark matter", but can be visible/detectable in gamma-rays with energy $E = m_e c^2$ x wind Lorentz factor (because of K-N effect)

unique feature of VHE gamma-ray astronomy - detection *of ultrarelativistic flows through bulk motion Comptonzation*

TeV gamm-rays from other Plerions ?

Crab Nebula is a very effective accelerator
but not an effective IC γ-ray emitter

We see TeV gamma-rays from the Crab Nebula because of very large spin-down luminosity: $f_{rot} = L_{rot}/4\pi d^2$

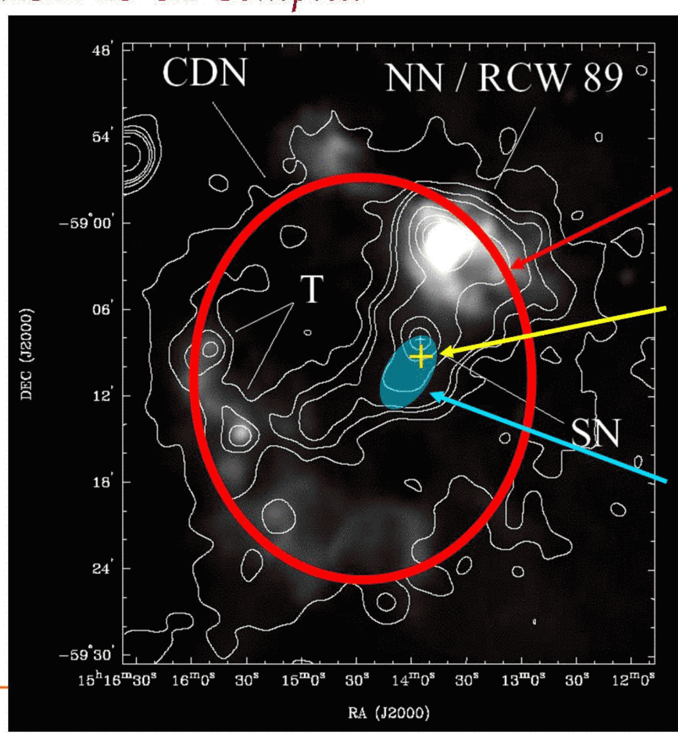
but gamma-ray flux << "spin-down flux"
because of large magnetic field

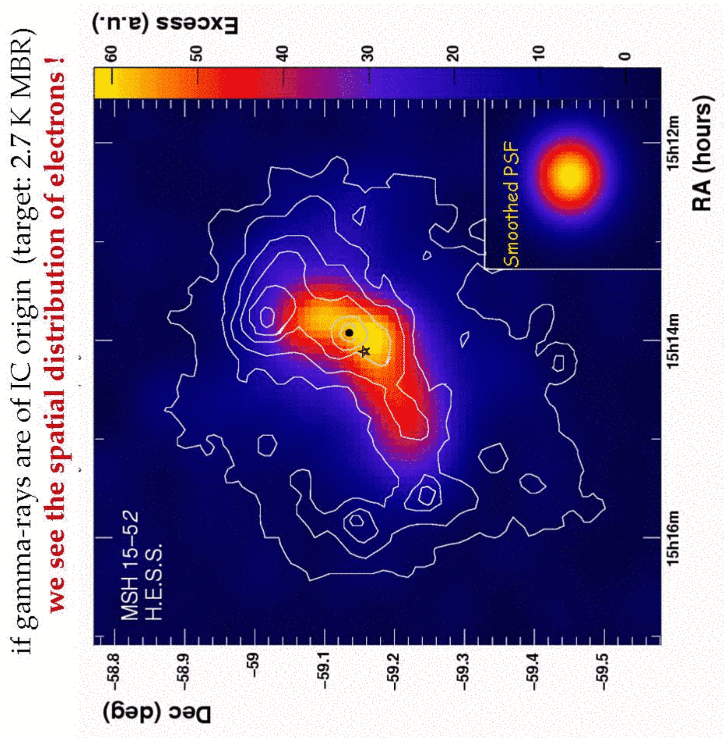
$\dot{W}_e \approx L_{rot}$ but the strength of B-field also depends on L_{rot}

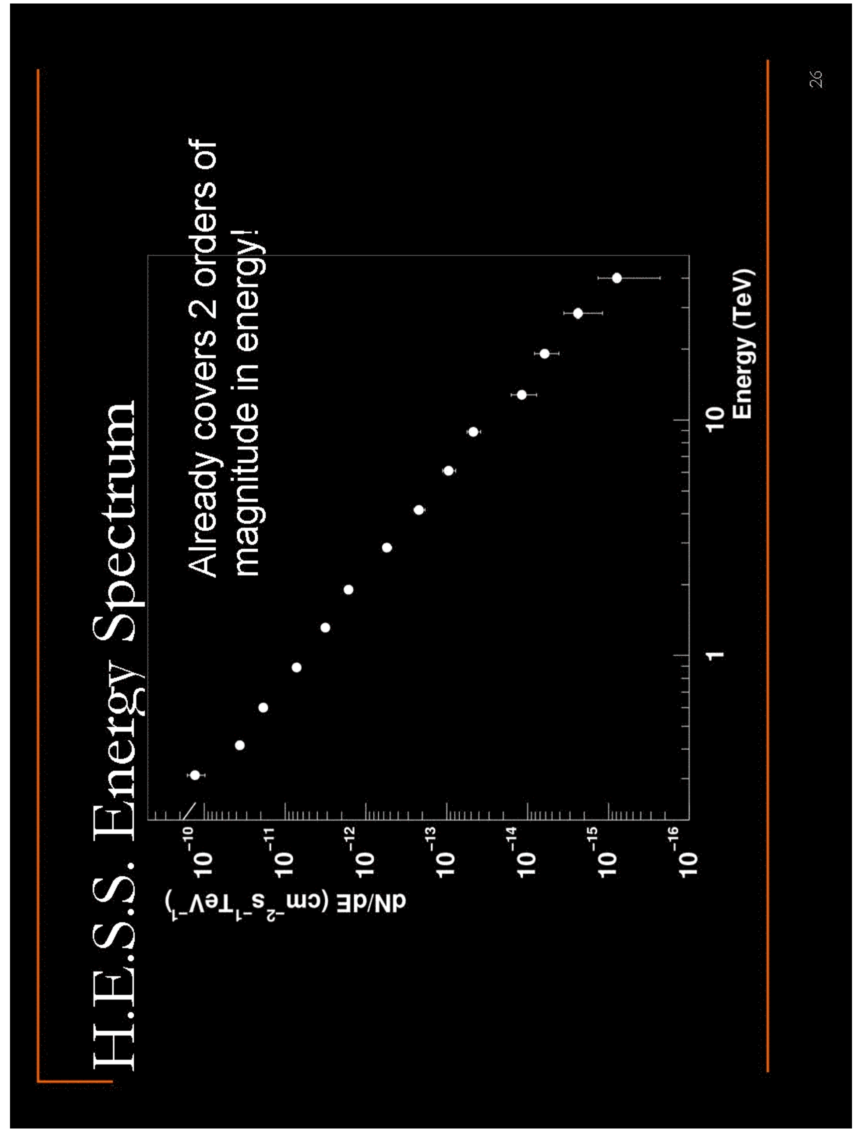
less powerful pulsar ➡ weaker magnetic field
➡ higher gamma-ray efficiency
➡ detectable gamma-ray fluxes from other plerions

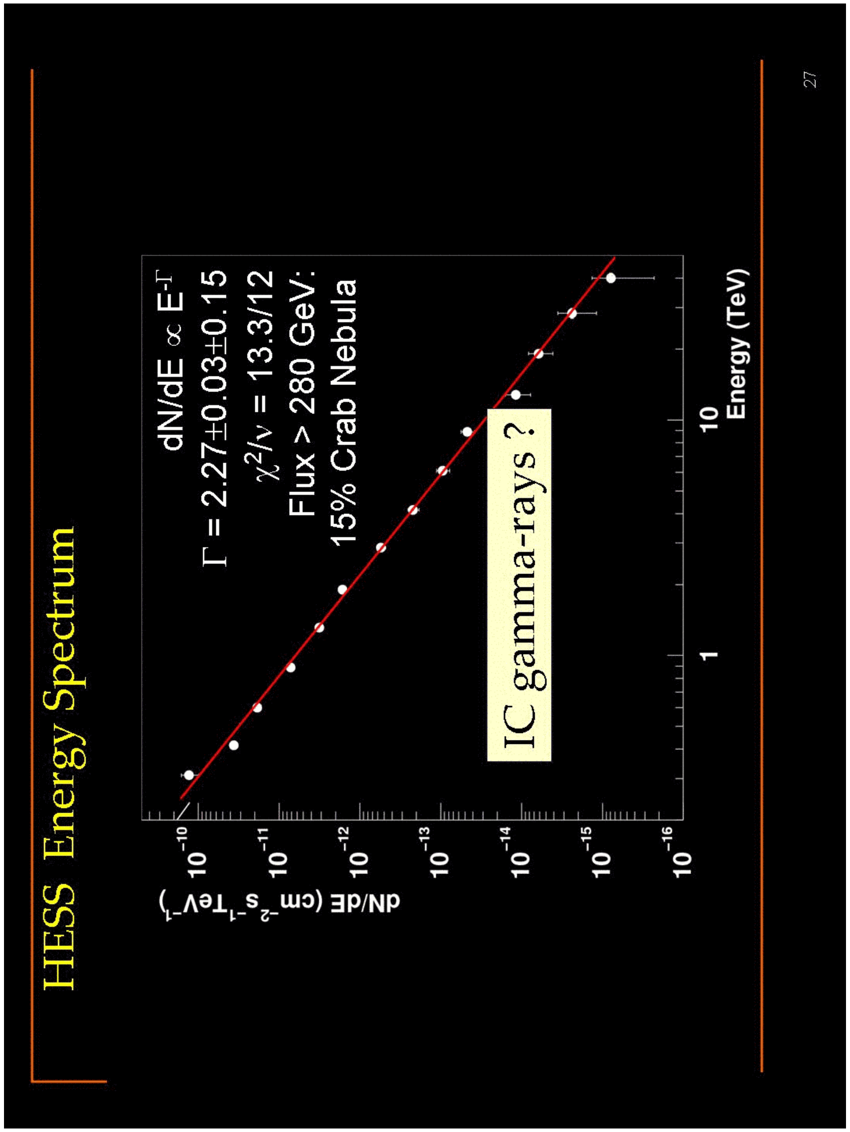
* Plerions – Pulsar Driven Nebulae

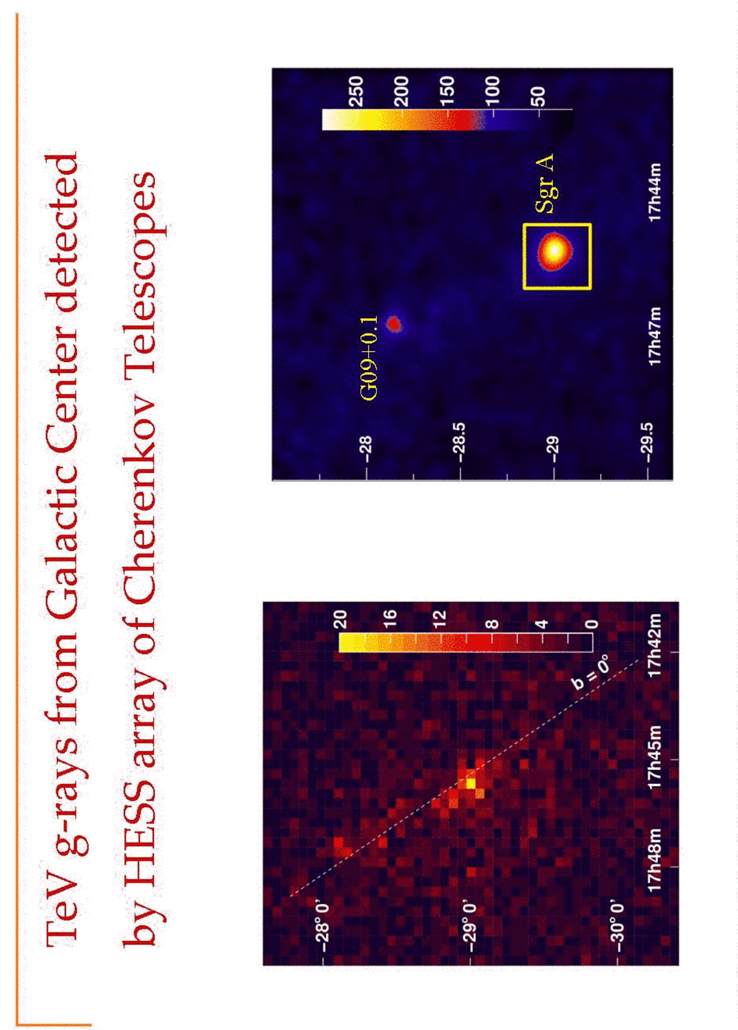
MSH 15-52 Complex

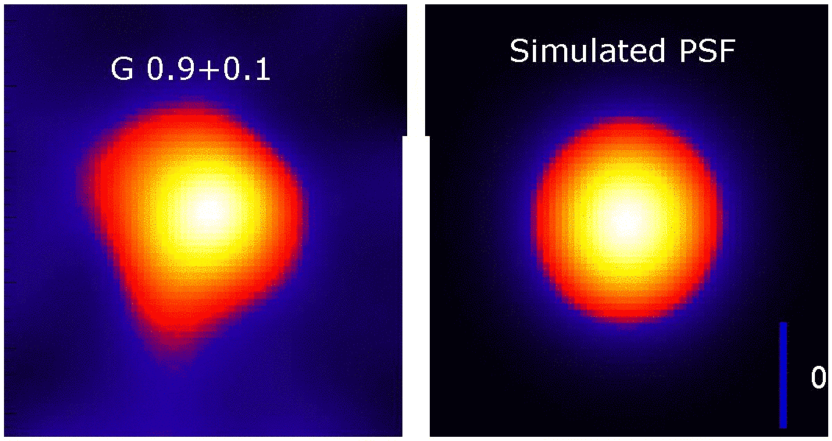



if gamma-rays are of IC origin (target: 2.7 K MBR)
we see the spatial distribution of electrons !
MSH 15-52
H.E.S.S.
Smoothed PSF
Excess (a.u.)
60
50
40
30
20
10
0
Dec (deg)
-58.8
-58.9
-59
-59.1
-59.2
-59.3
-59.4
-59.5
RA (hours)
15h16m
15h14m
15h12m


H.E.S.S. Energy Spectrum
Already covers 2 orders of magnitude in energy!
dN/dE (cm^-2 s^-1 TeV^-1)
10^-10
10^-11
10^-12
10^-13
10^-14
10^-15
10^-16
Energy (TeV)
1
10
26


HESS Energy Spectrum
dN/dE ∝ E^-Γ
Γ = 2.27±0.03±0.15
χ²/ν = 13.3/12
Flux > 280 GeV:
15% Crab Nebula
IC gamma-rays ?
dN/dE (cm^-2 s^-1 TeV^-1)
Energy (TeV)
27


TeV g-rays from Galactic Center detected
by HESS array of Cherenkov Telescopes
b = 0°
Sgr A
G09+0.1



- TeV gamma-ray luminosity: ~2×10^{34} ergs/s *(200 GeV and 10 TeV)* about half that of the Crab Nebula !
- In PWN electrons accelerated in termination shock of pulsar wind
- Origin of g-rays via Inverse Compton scattering of these electrons on 2.7 MBR (and perhaps also IR and starlight seed photons) (B field 10-20 μG)

PSR1259-63 - a unique high energy laboratory

binary pulsars - a special case with strong effects associated with the optical star on both the dynamics of the pulsar wind and the radiation before and after its termination

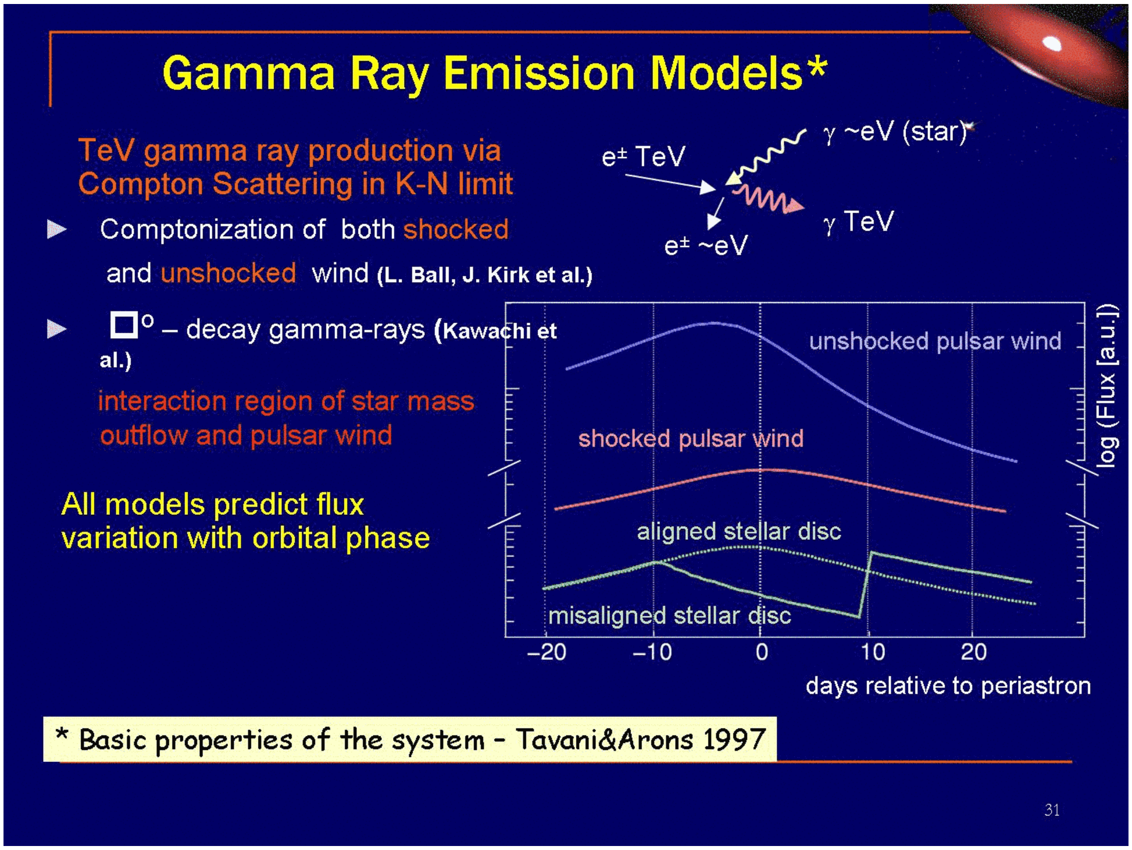
the same 3 components - *Pulsar/Pulsar/Wind/Synch.Nebula* - as in plerions*
but the cold wind and the shocked accelerated electrons are illuminated by optical radiation from the companion star ➡ detectable IC gamma-ray emission

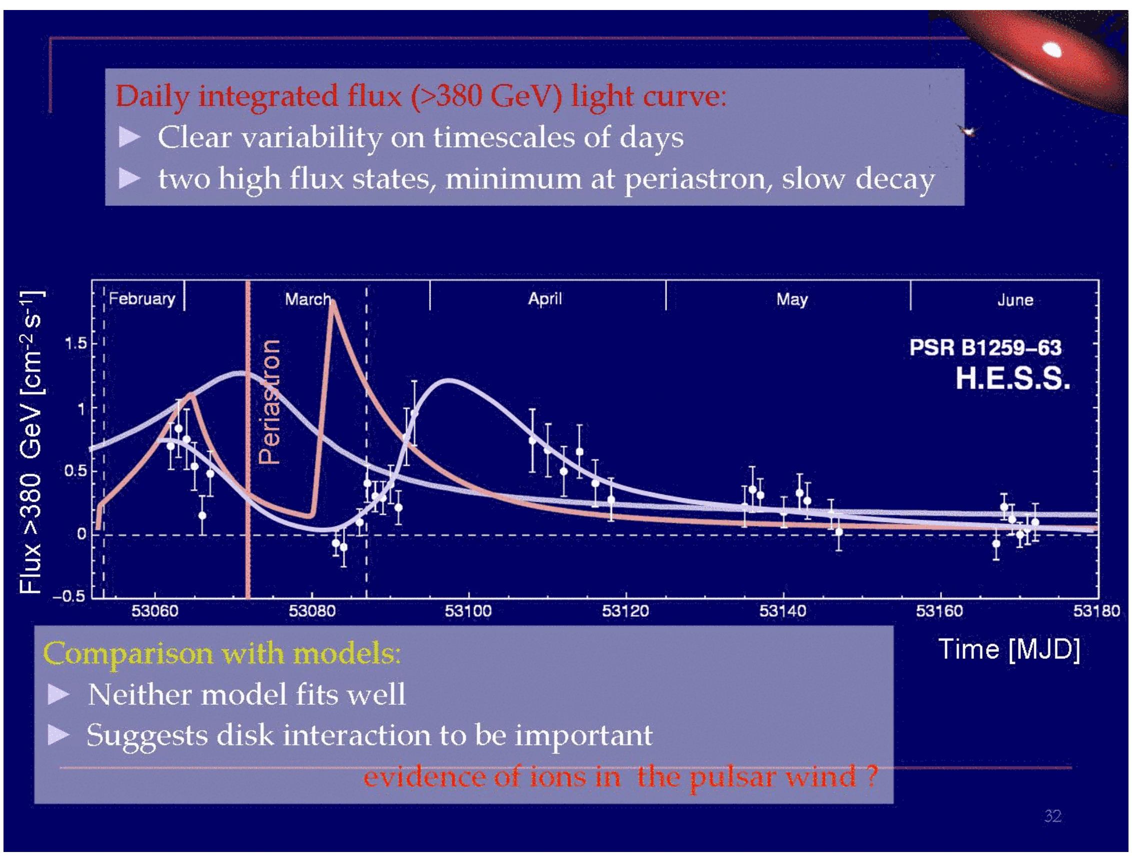
> new ! detection of TeV gamma-rays from PSR1259-63 at < 0.1Crab level by H.E.S.S. several days before the periastron (March 7)

the photon field is a strong function of time, thus the only unknown parameter is B-field:
TeV electrons are cooled and and radiate in deep Klein-Nishina regime with very interesting effects on both synchrotron X-ray and IC γ-rays

time evolution of energy spectra of X- and gamma-rays, and the f_X/f_γ ratio contain unique information about the shock dynamics, electron acceleration, B(r), ...

* but with characteristic timescales much shorter - less than 1 h !!!


Gamma Ray Emission Models*
TeV gamma ray production via Compton Scattering in K-N limit
▶ Comptonization of both shocked and unshocked wind (L. Ball, J. Kirk et al.)
▶ □° – decay gamma-rays (Kawachi et al.)
interaction region of star mass outflow and pulsar wind
All models predict flux variation with orbital phase
e± TeV
γ ~eV (star)
γ TeV
e± ~eV
unshocked pulsar wind
shocked pulsar wind
aligned stellar disc
misaligned stellar disc
log (Flux [a.u.])
–20
–10
0
10
20
days relative to periastron
* Basic properties of the system - Tavani&Arons 1997
31


Daily integrated flux (>380 GeV) light curve:
▶ Clear variability on timescales of days
▶ two high flux states, minimum at periastron, slow decay
February
March
April
May
June
Periastron
PSR B1259–63
H.E.S.S.
Flux >380 GeV [cm⁻² s⁻¹]
1.5
1
0.5
0
–0.5
53060
53080
53100
53120
53140
53160
53180
Time [MJD]
Comparison with models:
▶ Neither model fits well
▶ Suggests disk interaction to be important
evidence of ions in the pulsar wind ?
32

Origin of Cosmic Rays:

a mystery since the discovery in 1912 by V.Hess ...

but now we are quite close (hopefully) to the solution of the (galactic) component below the energy 1PeV (10^{15}eV)

thanks to the new generation of IACT arrays (HESS et al.) and space-based gamma-ray detectors (GLAST)

33

Cosmic Ray Studies with Cosmic Rays

what do we know about Cosmic Rays ?

- energy spectrum $dN/dE=kE^{-2.6-2.7}$ up to the "knee" (10^{15} eV)
- chemical composition ➡ ●=5 $(E/10GeV)^{-0.6}$ g/cm^2

little doubt that up to (at least) 10^{15} eV they have Galactic Origin*

➡ source spectrum close to $E^{-2.0-2.1}$
production rate 3 x 10^{40} erg/s

* CRs above 10^{19} eV most likely of extrargalactic origin,
CRs between 10^{15} eV and 10^{19} eV ? both G- and EXG are possible

34

γ-rays as tracers of CRs

what we <u>do not</u> know about Galactic Cosmic Rays ?

acceleration sites, source populations, acceleration mechanisms

reason ? *deflection (diffusion) of CRs in interstellar B-fields*

solution ? ***probing CRs with high energy gamma-rays:***

discrete γ-ray sources – productions sites oF CRs
diffuse γ-ray emission – propagation of CRs in ISM

the major (historical) motivation of gamma-ray astronomy
(P. Morrison, V. Ginzburg, S. Hayakawa, ...)

35

SNRs – the most probable factories of GCRs ?

(almost) common belief based two arguments:

- necessary amount of available energy – 10^{51} erg
- Diffusive Shock Acceleration – **10% efficiency and E^{-2} type spectrum up to ? <u>at least 10^{15} eV</u>**

<u>Straightforward proof:</u> detection of gamma-rays (and neutrinos) from pp interactions (as products of decays of secondary pions)

<u>Objective:</u> to probe the content of nucleonic component of CRs in SNRs within 10 kpc at the level 10^{49} -10^{50} erg

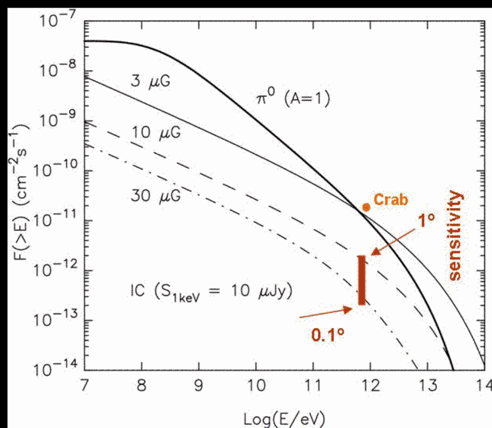
<u>Realiztion:</u> *sensitivity of detectors* - down to 10^{-13} erg/cm^2 s

crucial energy domain - VHE/UHE (up to 100 TeV)

36

Visibility of SNRs in high energy gamma-rays

for CR spectrum with 𝔊=2



$F_\gamma(>E)=10^{-11}$ A $(E/1TeV)^{-1}$ ph/cm^{2}s

A=$(W_{cr}/10^{50}$erg)(n/1cm^{-3})(d/1kpc)$^{-2}$

1000 yr old SNRs (in Sedov phase)

Detectability ? compromise between angle ❑ (r/d) and flux F_γ (1/d^2)

typically A: 0.1-0.01 ❑ : 0.1°

TeV γ-rays – detectable if A > 0.1

❑° component dominates if A > [illegible]

γ's

nucleonic component of CRs - "visible" through TeV (and GeV) gamma-rays !

main target photon field 2.7 K: $F_{\gamma,IC}/F_{x,sinch}$=0.1 (B/10○G)$^{-2}$

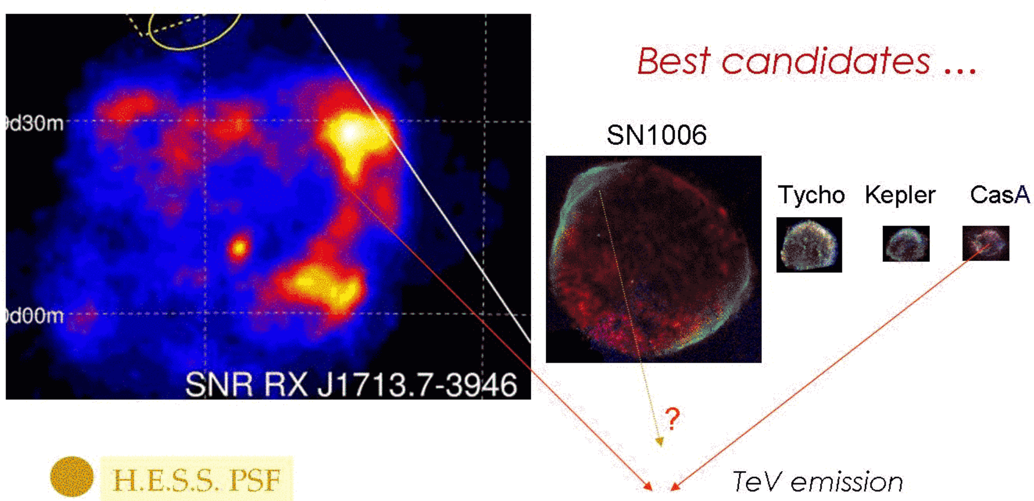
37

Cosmic Ray Accelerators ?

SNRs in our Galaxy: 231(Green et al. 2001

with nonthermal X-ray emission - 10 or so

Best candidates ...



J.Hiraga

SN 1006 - *a good candidate for particle source acceleration*

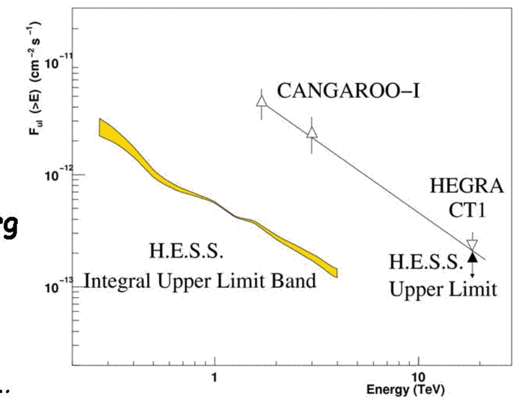
H.E.S.S. upper limits - an order of magnitude below the flux reported by CANGAROO

a trouble ? not at all ...

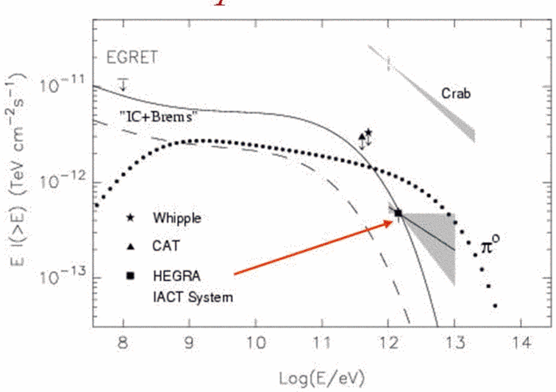
HESS upper limits imply

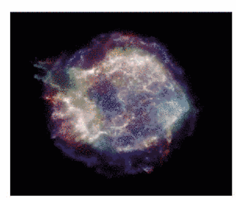
IC : B > 25 OG
□ ° : W_p<(0.2-2) x 10^{50} erg

no problem for the hypothesis of SNR origin of Galactic CRs ...



Cas A – *a proton accelerator*





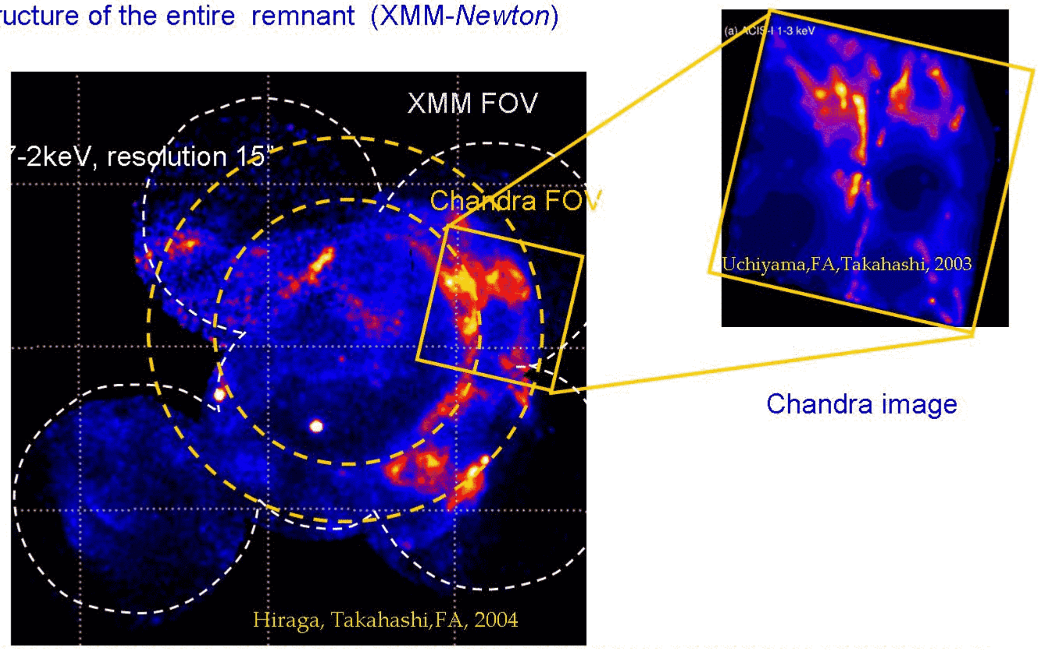
B > 0.1 mG ➡ IC origin is unlikely
TeV gamma rays of hadronic origin ?
but note that Wp =10^{49}erg (only)

Cas A is well designed for acceleration of protons to 10^{15} eV !
can be checked with >10 TeV γ -ray and neutrino (?) and X-ray detectors
?

in principle yes, but expected fluxes are quite low (less than 10^{-12} erg/cm^2 s)
therefore significant efforts are required to detect TeV neutrinos and extract 10-100 keV fluxes with next generation hard X-ray detectors (ASTRO-E2, NeXT)

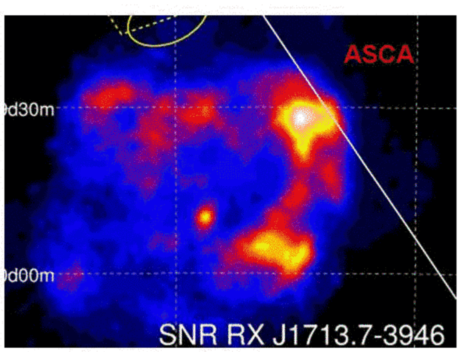
RX J1713.7-3946

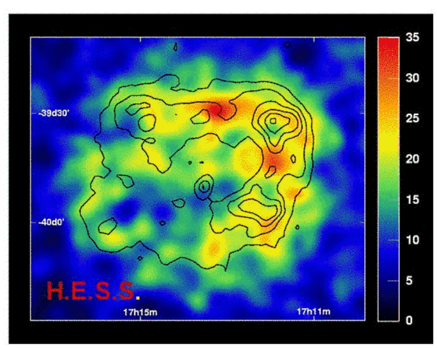
structure of the entire remnant (XMM-*Newton*)



Chandra image

Nonthermal X-rays and TeV gamma-rays from RXJ1713.7-3946



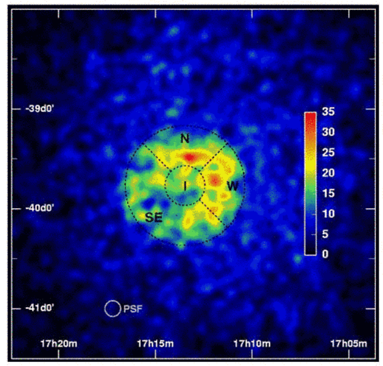


Direct evidence of high energy particle acceleration in the shell of RXJ 1713.7-3946*

F. Aharonian
on behalf of H.E.S.S collaboration

first image of an astronomical object obtained in γ-rays on arcmin scales

Nature, Nov 4, 2004



COSPAR 2004, Paris, July 22

RX J1317.7-3946

discovered during the ROSAT all sky survey
(Pfefferman & Ashebach 1996)

1 degree diameter remnant with very large, 5×10^{-10} erg/cm^{2}s flux consisting of only nonthermal (synchrotron) component - ASCA
(Koyama et al., 1997, Slane et al. 1999)

no convincing evidence yet for a thermal component !

distance to the source - around 1 kpc (no anymore 6 kpc) - from CO observations of the interacting cloud - NANTEN *(Fukui et al. 2003)*

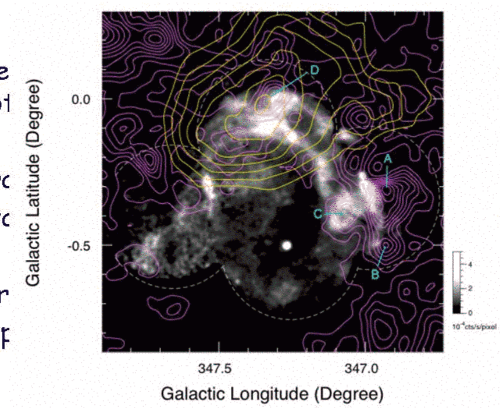
age - s 1 kyr - 1611 yr as the remnant of the AD 393 SN event ?

X-ray properties

Chandra – striking small – scale ... ıe
forms of filaments and hotspot

sites of electron accelerc
Chandra - noticeable spatial vc ... 's

XMM - surprising positive corr
N_H along the western p



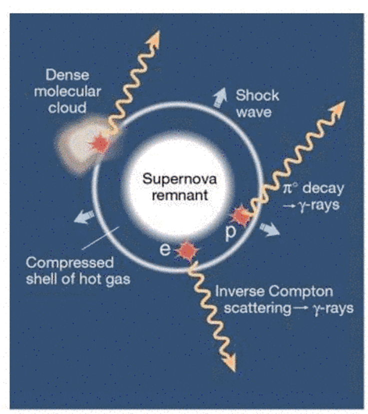
Reason ? massive molecular cloud(s) interacting with the shell of SNR

Origin of radiation ?

- hadronic origin seems preferable given
  the high density environment:

W_p (above 10 TeV) = 3×10^{49} (n/1 cm^{-3})$^{-1}$ erg

- IC origin is not excluded, but this model
  requires B – field less than 10-20 OG

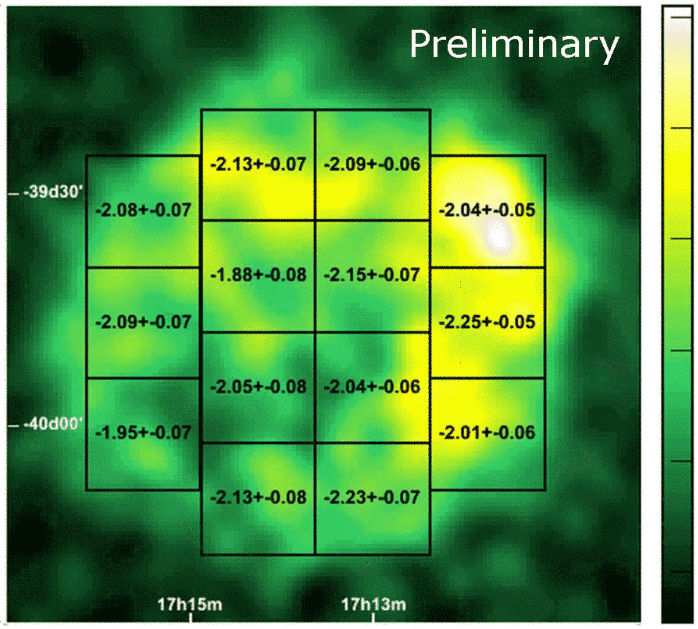


More complex scenario, e.g. γ-rays from NW+SW are contributed by protons while gamma-rays from remaining parts are due to IC γ-rays, cannot be excluded

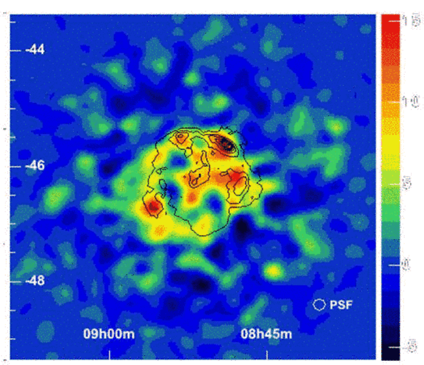
HESS observations with 4 telescope in 2004
provides higher quality data but not certain answers…

Spatially resolved spectra

- Spectral shape doesn't change significantly!
- Flux varies up to a factor of 2



Vela Junior - a 2° diameter remnant



CANGAROO - 5 sigma (or so) 2003

HESS - 12 sigma after 4.5 h obs. time in 2004!

Flux - 1 Crab at 1 TeV

H.E.S.S. will observe the source for ca 50 h, so one should expect perfect data to estimate energy in p and/or e

uncertainty in **d** as large as factor of 3, n – poorly known
nevertheless if no nearby clouds - Wp could be as large as 10^{50} erg

IC ? – very small magnetic field at the level of 3-4 OG

Searching for Cosmic PeVatrons

searching for galactic PeVatrons ...

TeV gamma-rays from *Cas A* and RX1713.7-3946 and Vela Jr
- a proof that SNRs are responsible for the bulk of *GCRs* ?

not yet ! The hunt for galactic PeVatrons continues

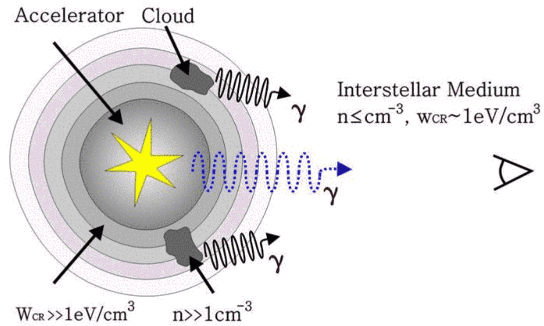
unbiased approach – deep survey of the *Galactic Plane* - not to miss any recent (or currently active) acceleration site:

SNRs, Pulsars/Plerions, Microquasars...

not only from accelerators, but also from nearby dense regions

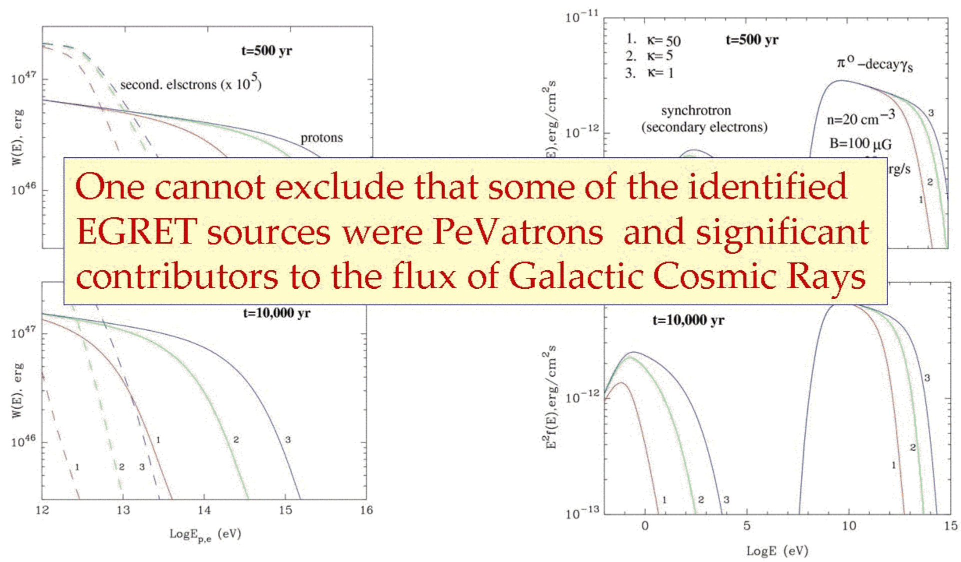
Gamm-rays/X-rays from dense regions surrounding accelerators

the existence of a powerful accelerator by itself is not sufficenrt for gamma radiation; an additional component – a dense gas target - is required



gamma-rays from surrounding regions add much to our knowledge about highest energy protons which quickly escape the accelerator and therefotr do not significantly contribute to gamma-ray production inside the proton accelerator-PeVatron (especially in old sources)

older source – steeper gamma-ray spectrum



One cannot exclude that some of the identified EGRET sources were PeVatrons and significant contributors to the flux of Galactic Cosmic Rays

$t_{esc} = 4 \times 10^5 (E/1TeV)^{-1} \kappa^{-1} yr$ (R = 1 pc) $\kappa = 1$ – Bohm Difussion

$\dot{Q}_p \propto E^{-2.1} \exp(-E/1PeV)$ $L_p = 10^{38}(1 + t/1{,}000yr)^{-1}$ erg/s

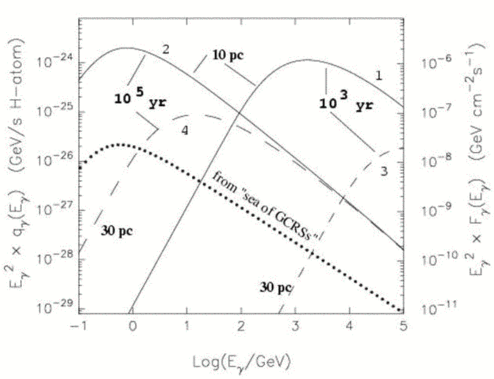
Giant Molecular Clouds (GMCs) as tracers of Galactic Coismic Rays

GMCs - 10^3 to 10^5 solar masses clouds physically connected with *star formation regions* the likely sites of CR accelerators (with or without SNRs) - perfect objects to play the role of targets !

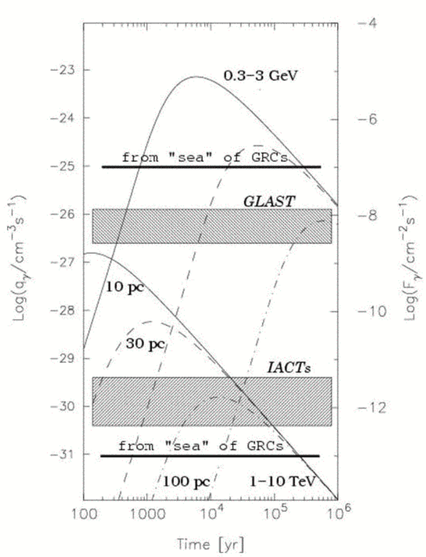
While travelling from the accelerator to the cloud the spectrum of CRs is a strong function of time t distance to the source R, and the (energy-dependent) Diffusion Coefficient D(E)

➡ depending on t, R, D(E) we may expect any proton, and therefore gamma-ray spectrum - very hard, very soft, without TeV tail, without GeV counterpart ...

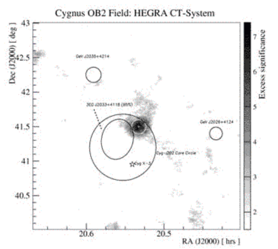
Propagation Effects on the spectrum of Gamma Rays

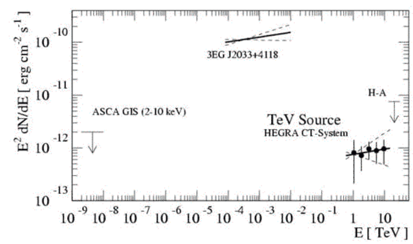


emissivities and fluxes (M_5/d^2_{kpc}) of gamma rays from a cloud at different times and distances from an impulsive accelerater with $W=10^{50}$ erg [$D(E)=10^{26}$ $(E/10GeV)^{0.5}$ cm^2/s]



First Unidentified TeV source TeV J2032+4130 *





Found by HEGRA seredipiously (6 sigma signal accumulated 100h from the Cygnus region and confirmed in 2002 by pointing observations (130 h)

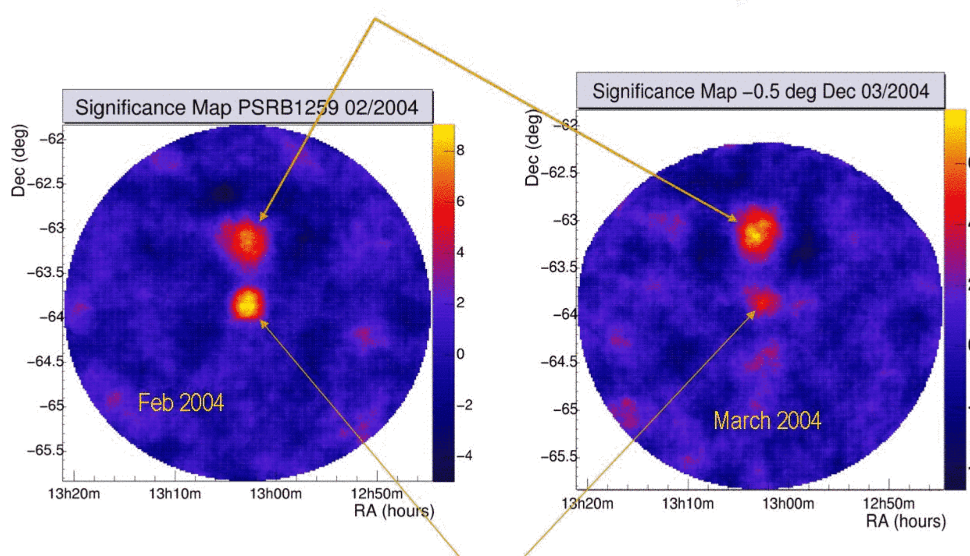
Basic features – hard power-law spectrum (photon index 1.9), constant flux and slightly extended (about 5 arcmin) source

Origin ? leptonic (IC) origin is almost excluded, possibly dense gas cloud(s) illuminated by protons arriving from a recent nearby Pevatron ?

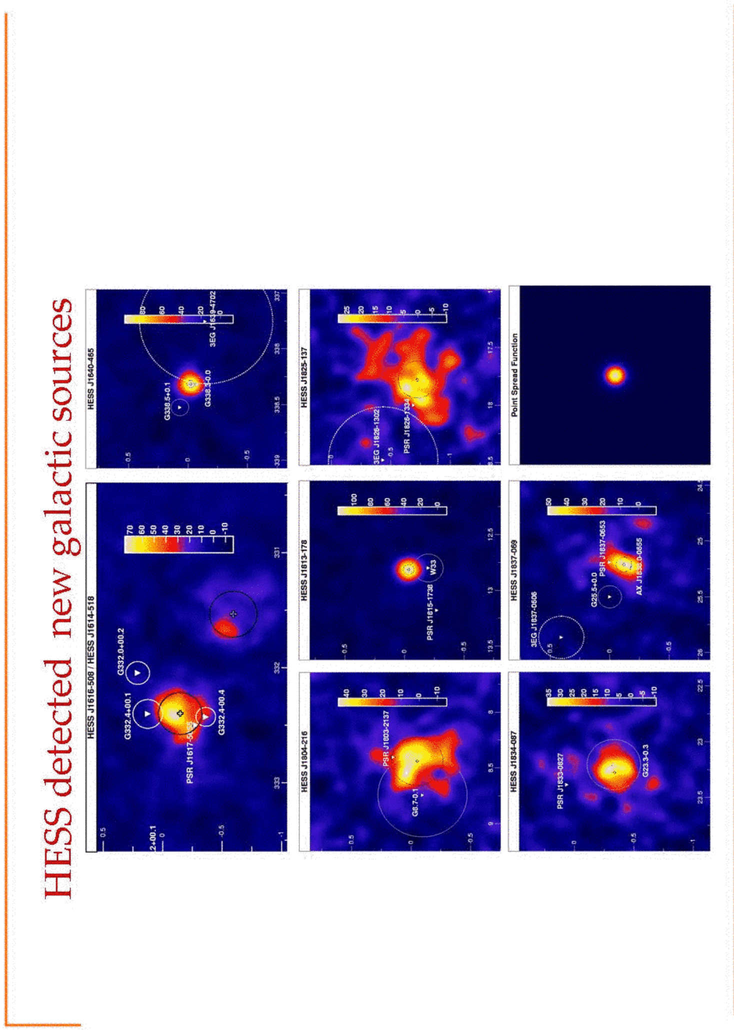
if this object is a representative of a large source population, the planned surve of the Galactic Disk by H.E.S.S. will reveal (many ?) more new hot spots

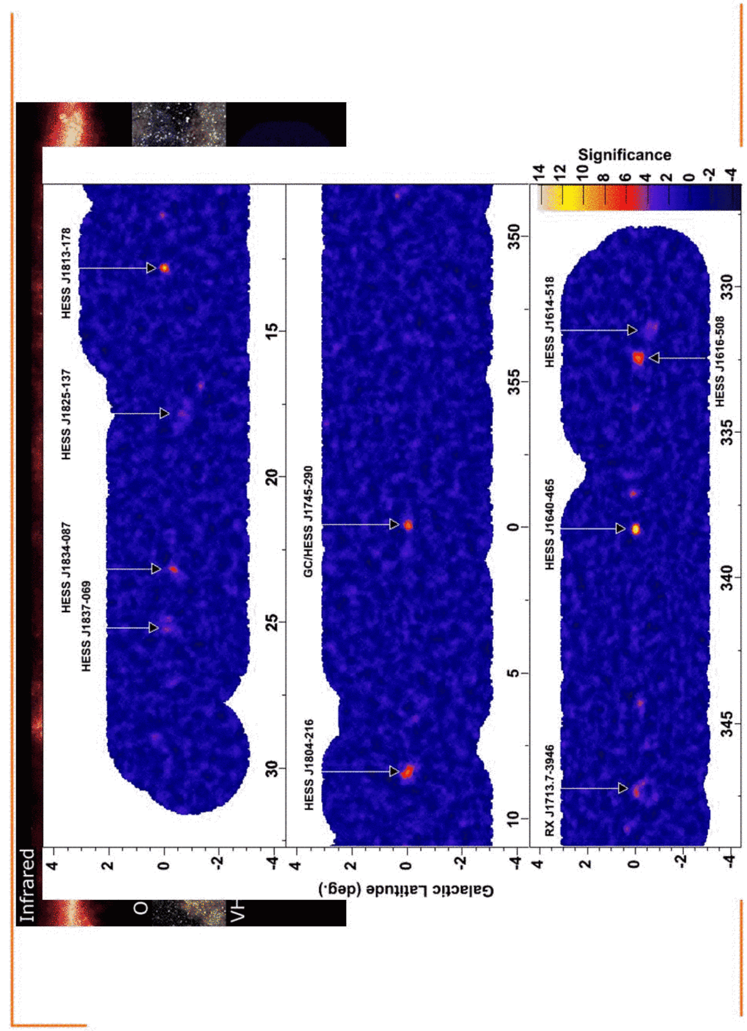
*detected earlier by the HEGRA array and Crimean and "recently" by Whipple groups(?)

A new unidentified sources is found by HESS !



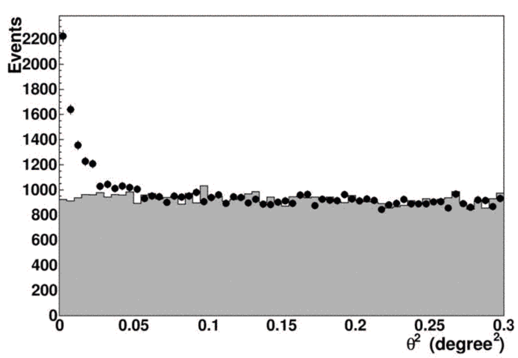
PSR1259-63


HESS detected new galactic sources
HESS J1616-508 / HESS J1614-518
HESS J1640-465
HESS J1804-216
HESS J1813-178
HESS J1825-137
HESS J1834-087
HESS J1837-069
Point Spread Function


Infrared
Significance
Galactic Longitude (deg.)
Galactic Latitude (deg.)
HESS J1813-178
HESS J1825-137
HESS J1834-087
HESS J1837-069
GC/HESS J1745-290
HESS J1804-216
HESS J1614-518
HESS J1616-508
HESS J1640-465
RX J1713.7-3946

TeV Blazars

H.E.S.S. Detection of PKS 2155-304



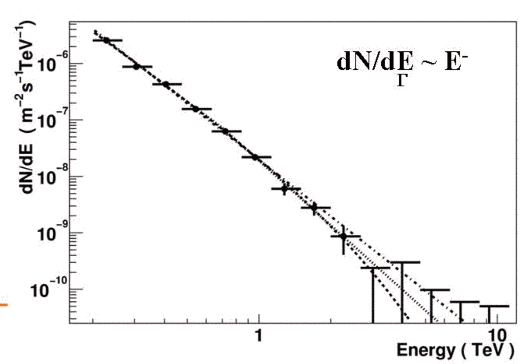
VHE (>160 GeV) emission is clearly detected (>4500 γ-rays; ~45 σ)

- 63 hrs (live time) of observations made during detector construction

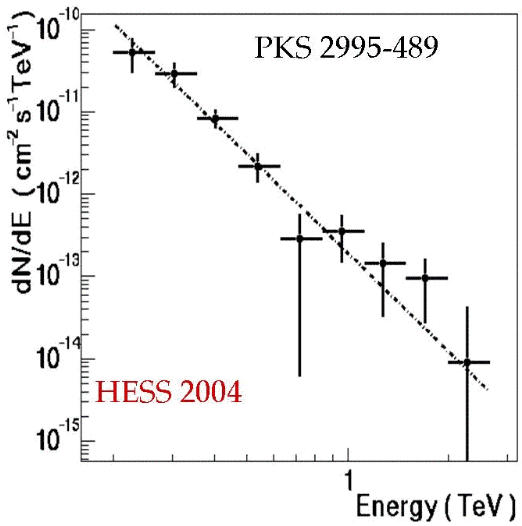
Confirms previous detection of 2nd furthest known VHE AGN (z=0.116)

Time-average spectrum is soft:
Γ = 3.32 +/- 0.06 +/- 0.1

Fits of curved spectra show improved χ^2, but the improvement is marginal (~2 σ)



PKS 2005-489 Spectrum & Flux



2004 data (24.3 h)

dN/dE ~ $E^{-\Gamma}$ Γ = 4.0 +/- 0.4

χ^2/ν = 0.8 (5.6/7), $P(\chi^2)$ = 0.

I(>200 GeV) = (6.9 +/- 1.0) e-12 cm^{-2} s^{-1}

2.5% of Crab Nebula Flux

2003 data (27.3 h, non-detection):

99% Flux upper limit (assume Γ = 4.0)

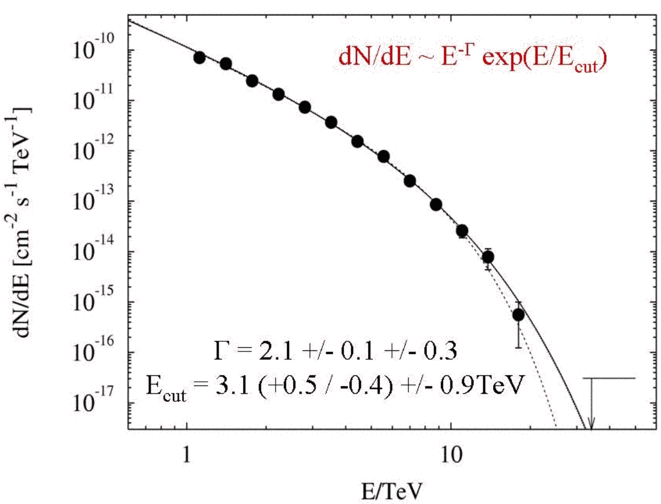
I(>200 GeV) < 5.2 e-12 cm^{-2} s^{-1}

no evidence for variability on monthly, nightly, or intra-nightly time scales

Lowest flux & steepest spectrum ever detect from a VHE AGN!

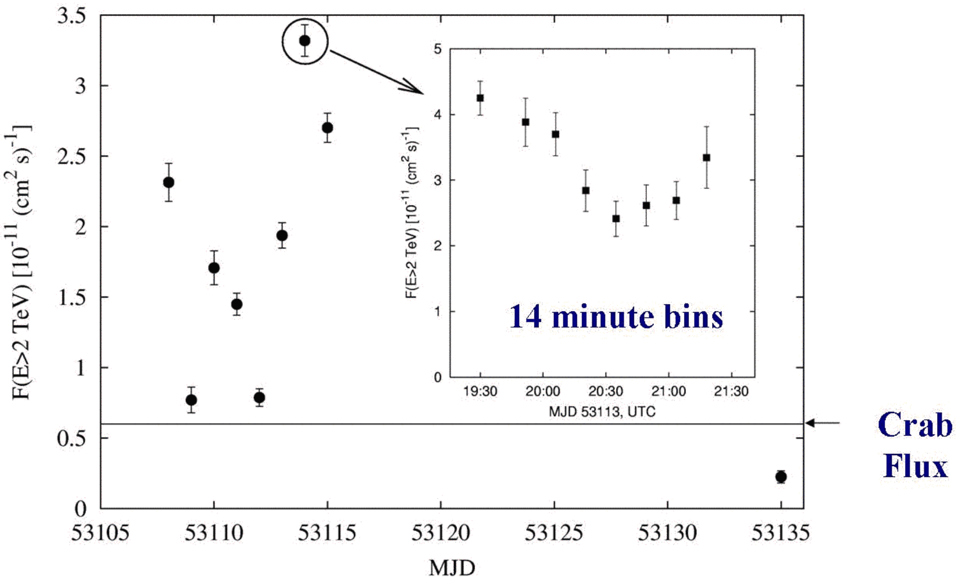
H.E.S.S. Observations of Mkn 421

9 nights in April & May 2004; Zenith angle range 60-65°; E_{th} ~1.5 TeV



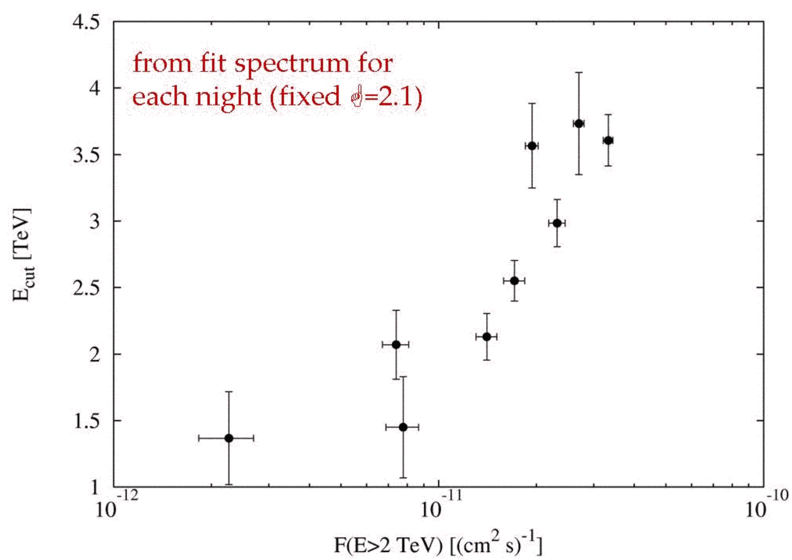
7000 photons in ~15 hrs; 8 γ/min; >100 σ Spectrum clearly curved!

Mkn 421 Flux Variability



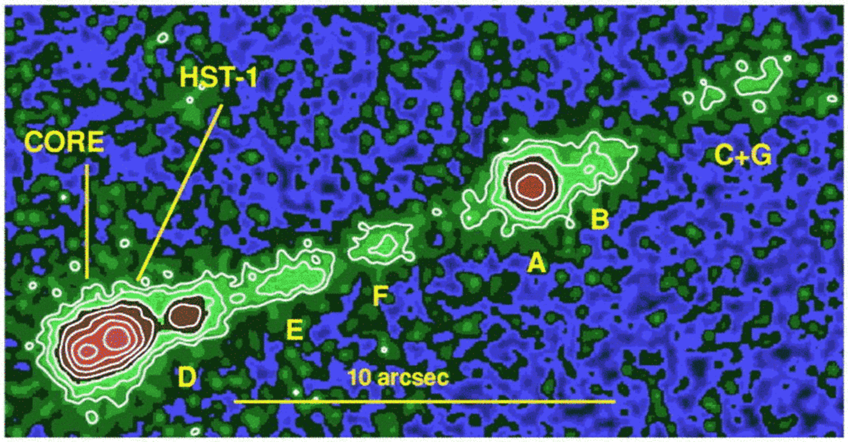
Flux (>2 TeV) varies by factor of >5; Average value ~3 Crab
Doubling time-scale less than 1 hour

Mkn 421 Spectral Hardening

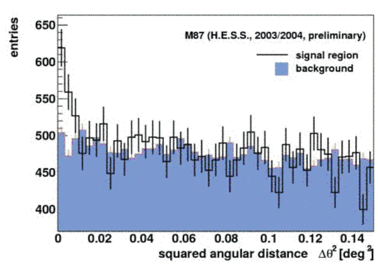


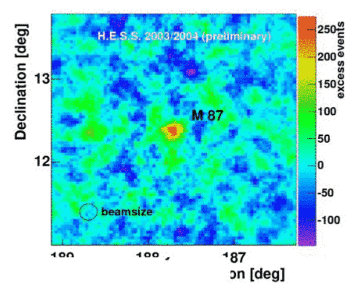
evidence for spectral hardening with increase of flux !

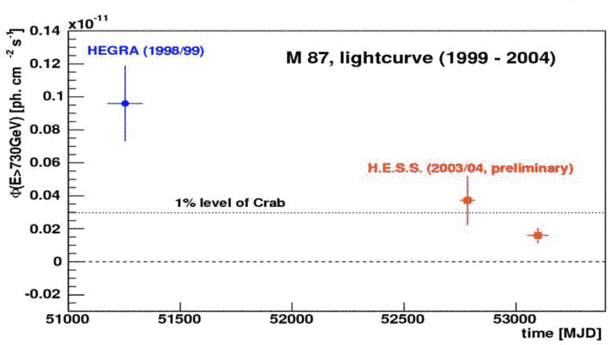
M 87



M87 – detected by HEGRA and HESS

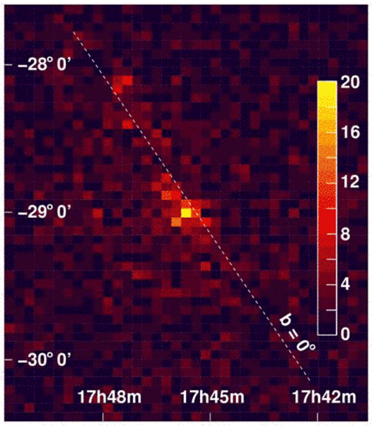


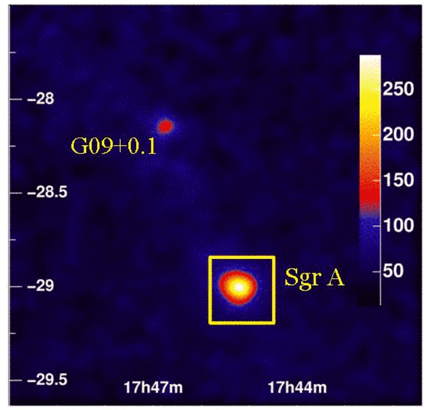


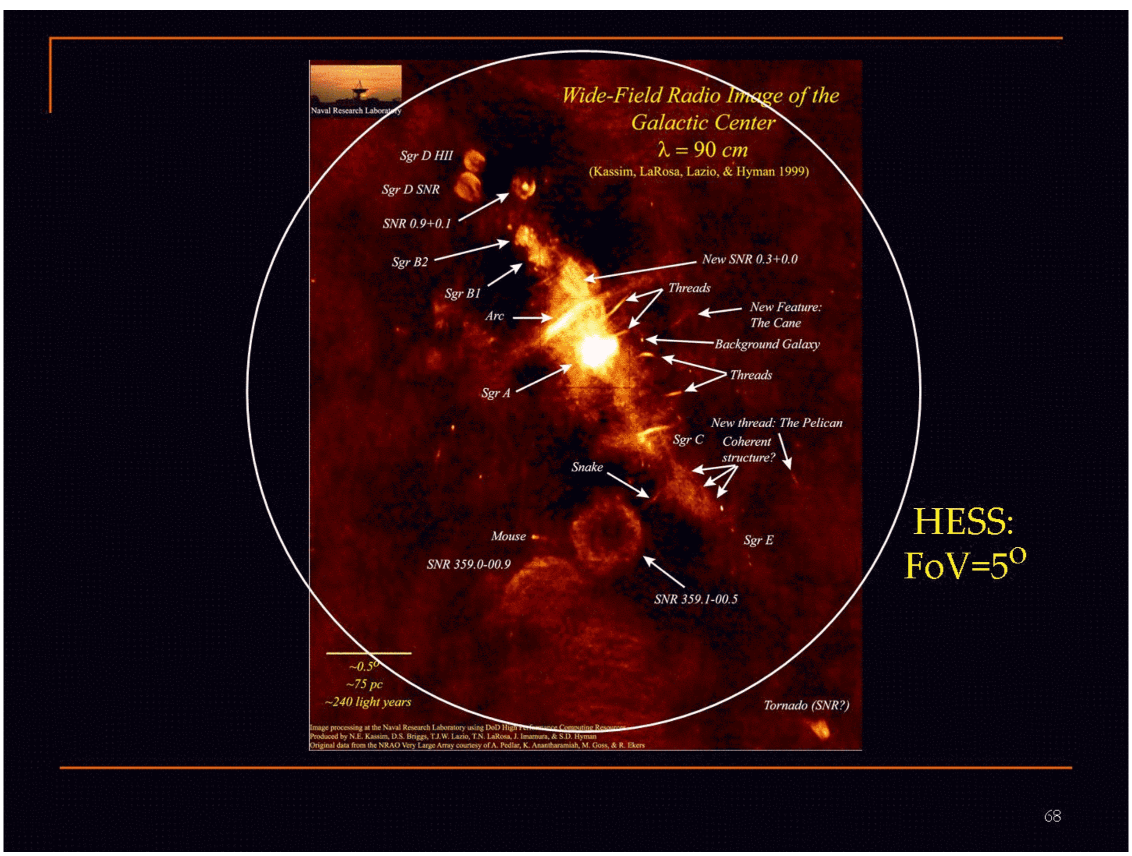


TeV γ-rays from Galactic Center detected by HESS

in 2003 and 2004



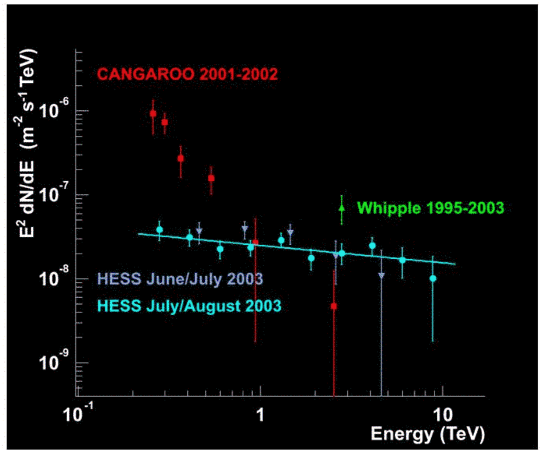




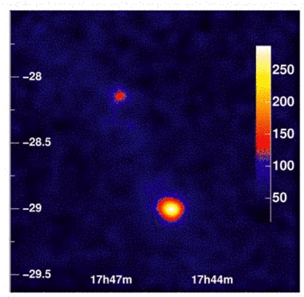
Energy Spectrum

- HESS:
  dN/dE $\propto E^{-2.2}$
- Flux > 160 GeV:
  $1.8 \pm 0.2 \times 10^{-11}$ cm^{-2} s^{-1}
  (5 % of Crab flux)

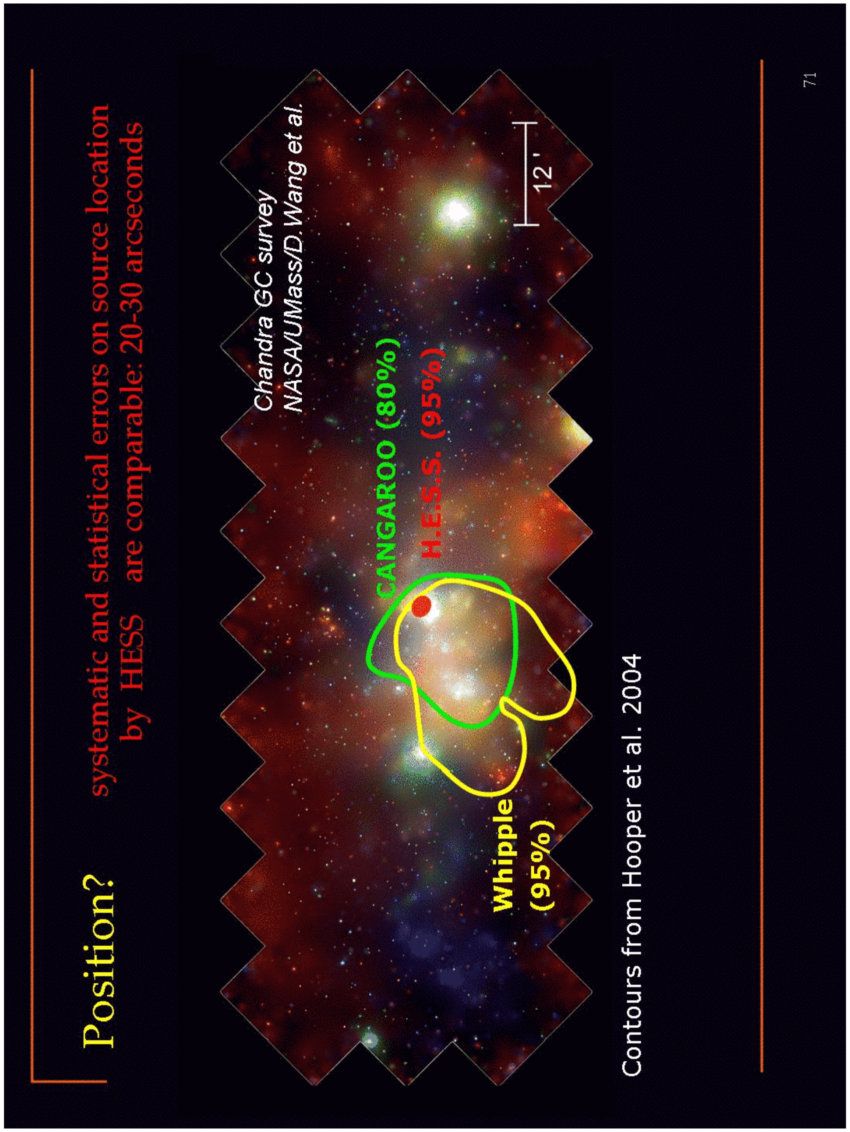
- CANGAROO:
  dN/dE $\propto E^{-4.6}$
  Flux > 160 GeV:
  ~ 1 Crab

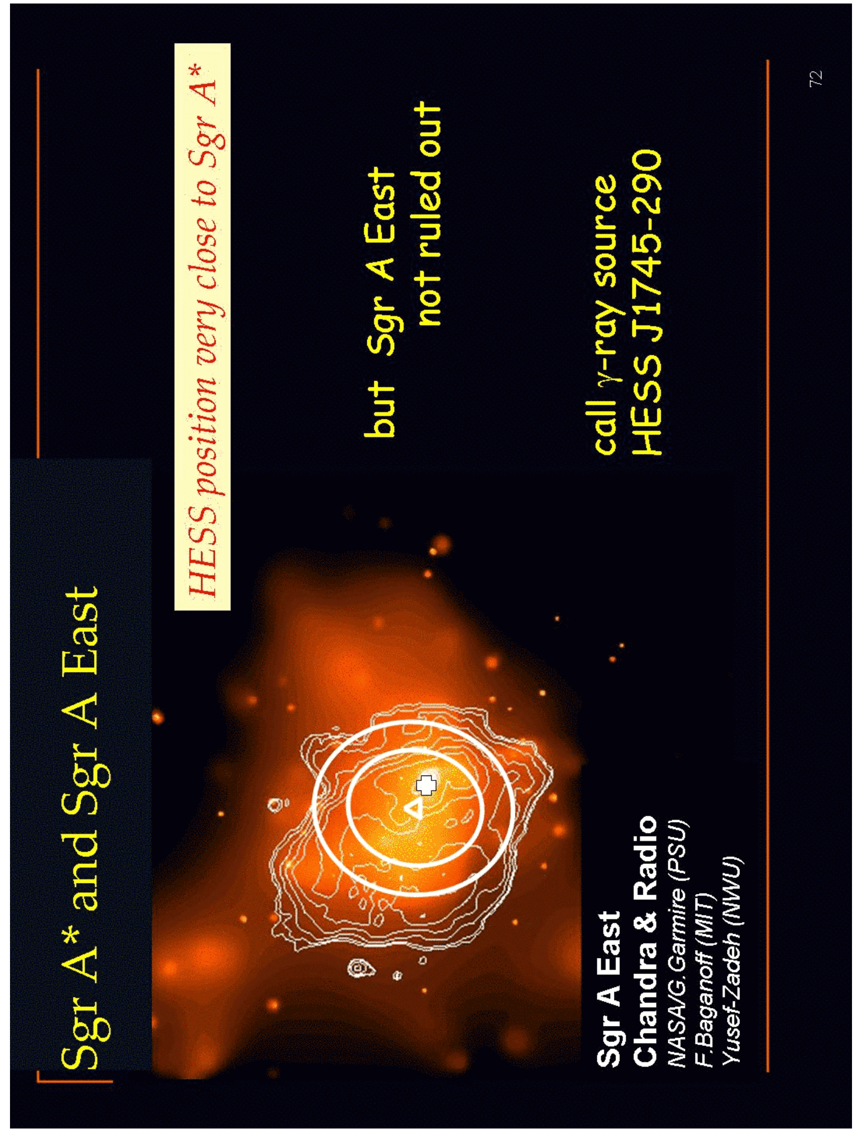


HESS : 2004 data



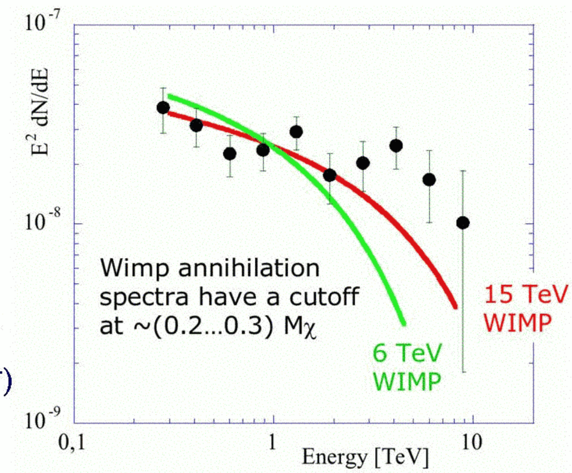
- 50 hours of data
  with full 4 telescope array
- Significance of HESS J1745-290 is 35 sigma
  5 s/√(hour) at quiescent level ➡ HESS has
  a power to resolve flares on 1 h timescales
- *Flux and Spectrum compatible*
  no details yet – paper in preparation
- New source detected in the same field of view


Position?
systematic and statistical errors on source location
by HESS are comparable: 20-30 arcseconds
Chandra GC survey
NASA/UMass/D.Wang et al.
12 '
CANGAROO (80%)
H.E.S.S. (95%)
Whipple
(95%)
Contours from Hooper et al. 2004
71


Sgr A* and Sgr A East
HESS position very close to Sgr A*
but Sgr A East
not ruled out
call γ-ray source
HESS J1745-290
Sgr A East
Chandra & Radio
NASA/G.Garmire (PSU)
F.Baganoff (MIT)
Yusef-Zadeh (NWU)
72

DM Annihilation?

- HESS Spectrum requires a > 10 TeV DM particles
- most WIMPs models favour a < 2 TeV mass neutralinos
-
  - GMSB: *Gauge mediated Supersymmetry Breaking*
  - Kalusa-Klein Dark Matter
- also a rather cuspy profile and a high density of DM in the very central part (around SBH/Sgr A*)



TeV γ-rays from central <10 pc region of GC *

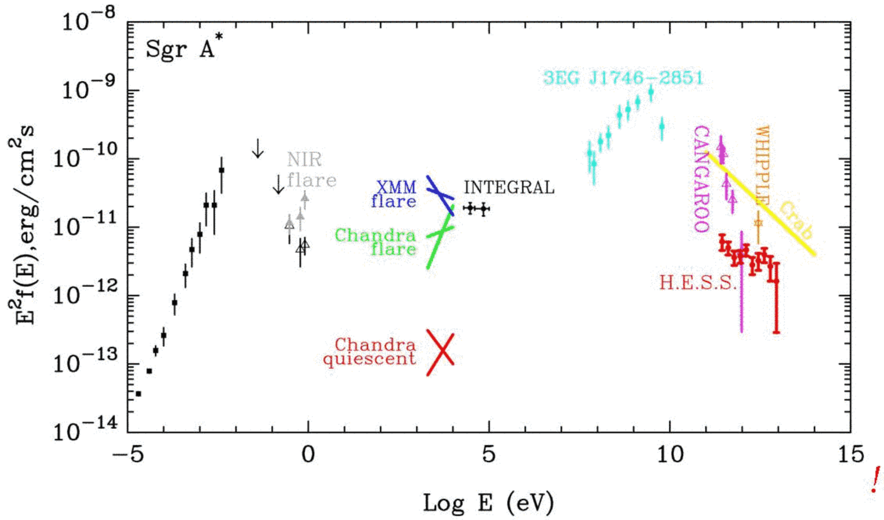
- Annihilation of DM ? *mass of DM particles > 12 TeV ?*
- *Sgr A* :* 3 10^6 M_o BH ? *somewhat speculative but possible*

  SNR Sgr A East ? *why not ?*

  Plerionic (IC) source(s) *why not ?*

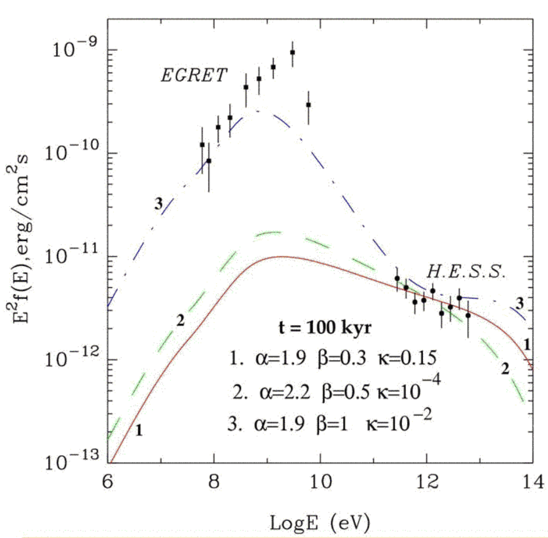
- Interaction of CRs with dense molecular gas (clouds) ? *easily*

a nice present for (gamma-ray) astronomers …



pp gamma-rays in the central 10 pc region

$Q_p(E)=Q_o E^{-\alpha}$ exp(-E/1 PeV), $D(E)=10^{28}(E/1GeV)^{\delta}\ \kappa$ cm²/s; κ =1, δ=0.5-0.6 -diffusion in GD



if $t_{pp} < t_{esc}$ => π^o-decay γ-ray production in "saturated" regime => $L\gamma$ =1/3 Lp, otherwise the flux and spectrum of γs depend not only on CR injection power and spectrum, but also on the (energy dependent) propagation of CRs in ISM

1. fast diffusion : →
   Lp=7.5 x 10^{37} erg/s
2. slow diffusion: →
   Lp=6.9
3. Diffusion-to-rectlinear prop.
   → → α=δ
   Lp=