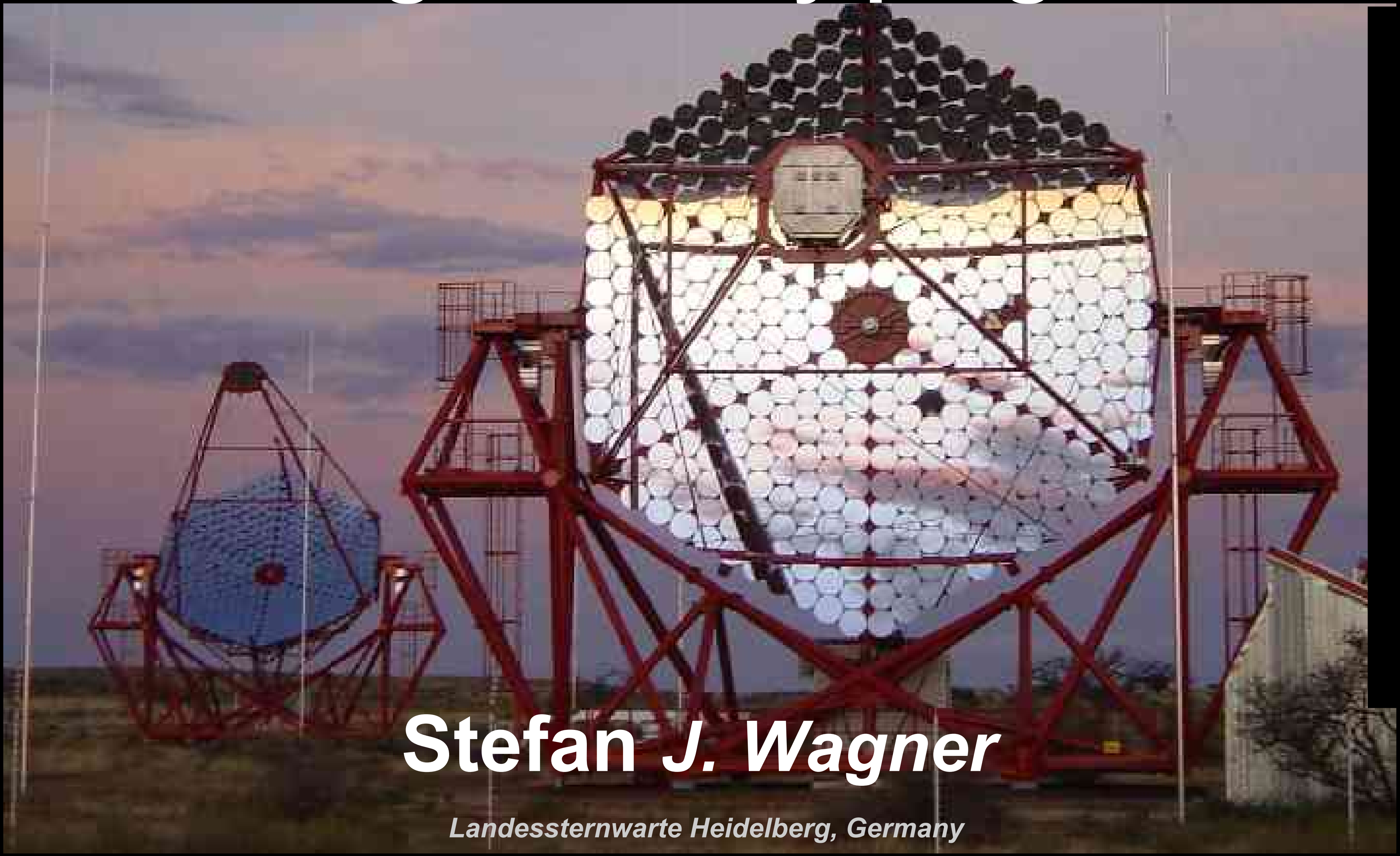
Science with H.E.S.S. and future gamma-ray programs



Stefan *J. Wagner*

Landessternwarte Heidelberg, Germany

Science with H.E.S.S. and future gamma-ray programs

Outline:

H.E.S.S. - the collaboration / the experiment

The High-Energy Galaxy

Extragalactic TeV Astrophysics

Where do we stand? Where will we go?

Possible scenarios for VHE γ-rays in 2010+

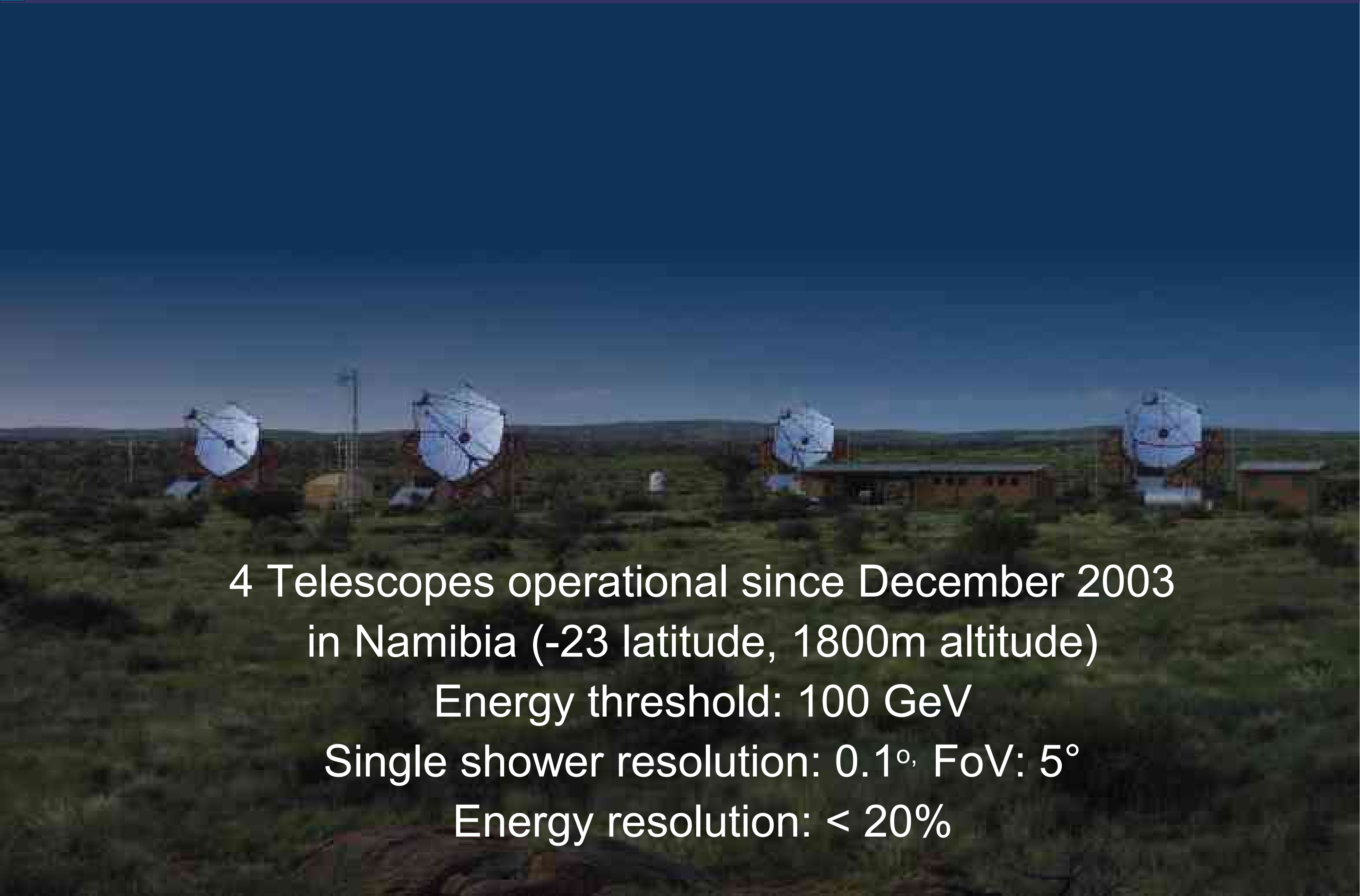
The H.E.S.S. collaboration

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
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
(founding members)

...,developing, building, and operating
the first Cherenkov experiment
of a new generation...

The H.E.S.S. experiment



4 Telescopes operational since December 2003

in Namibia (-23 latitude, 1800m altitude)

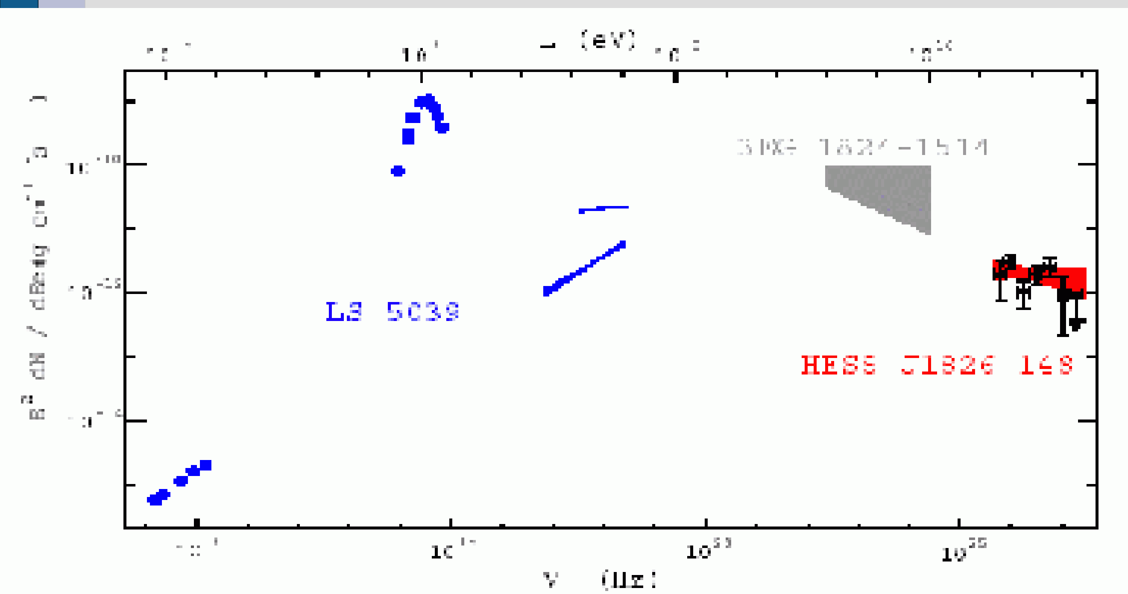
Energy threshold: 100 GeV

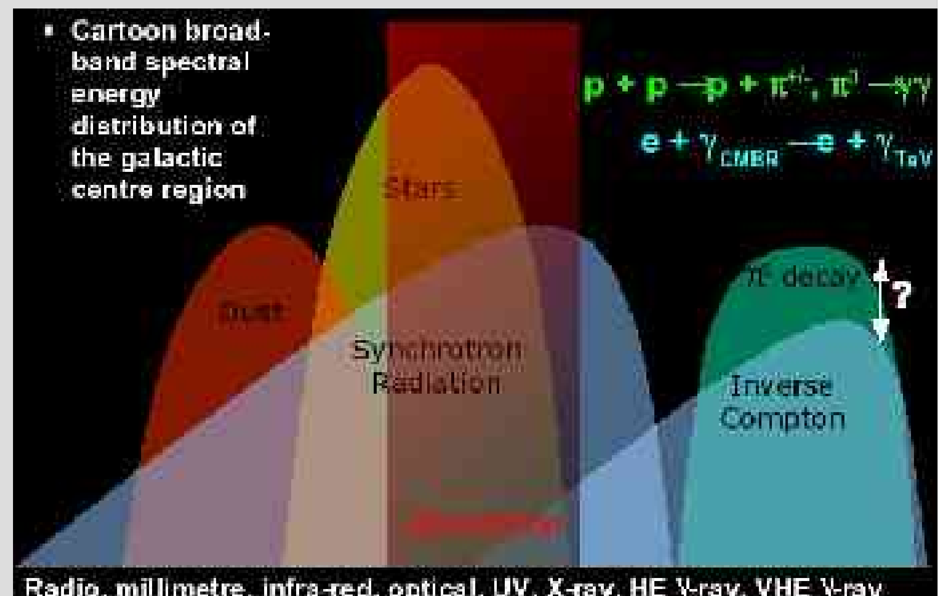
Single shower resolution: 0.1°, FoV: 5°

Energy resolution: < 20%

The H.E.S.S. experiment

TeV Astrophysics in 2006:



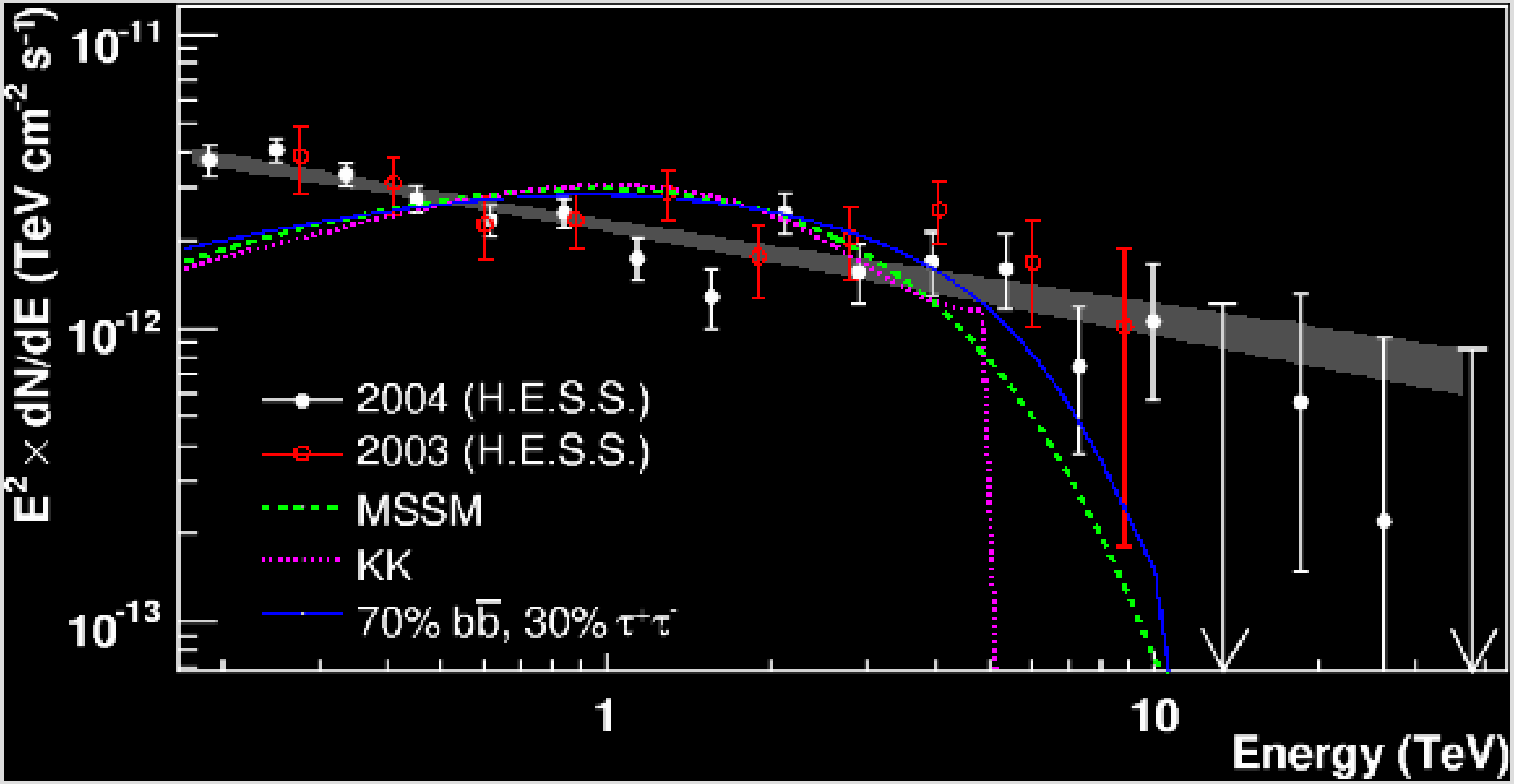


3 “sister“ experiments:

CANGAROO (2000+), similar latitude
MAGIC (2005+), similar longitude
VERITAS (2006+), similar technology

Galactic Centre / Dark Matter

Extended data set, no variability, Sag A*?



Very hard to fit power-law spectra with dark matter annihilation

Possible signals burried underneath other emitters

Aharonian et al. (HESS collaboration), PRL, submitted

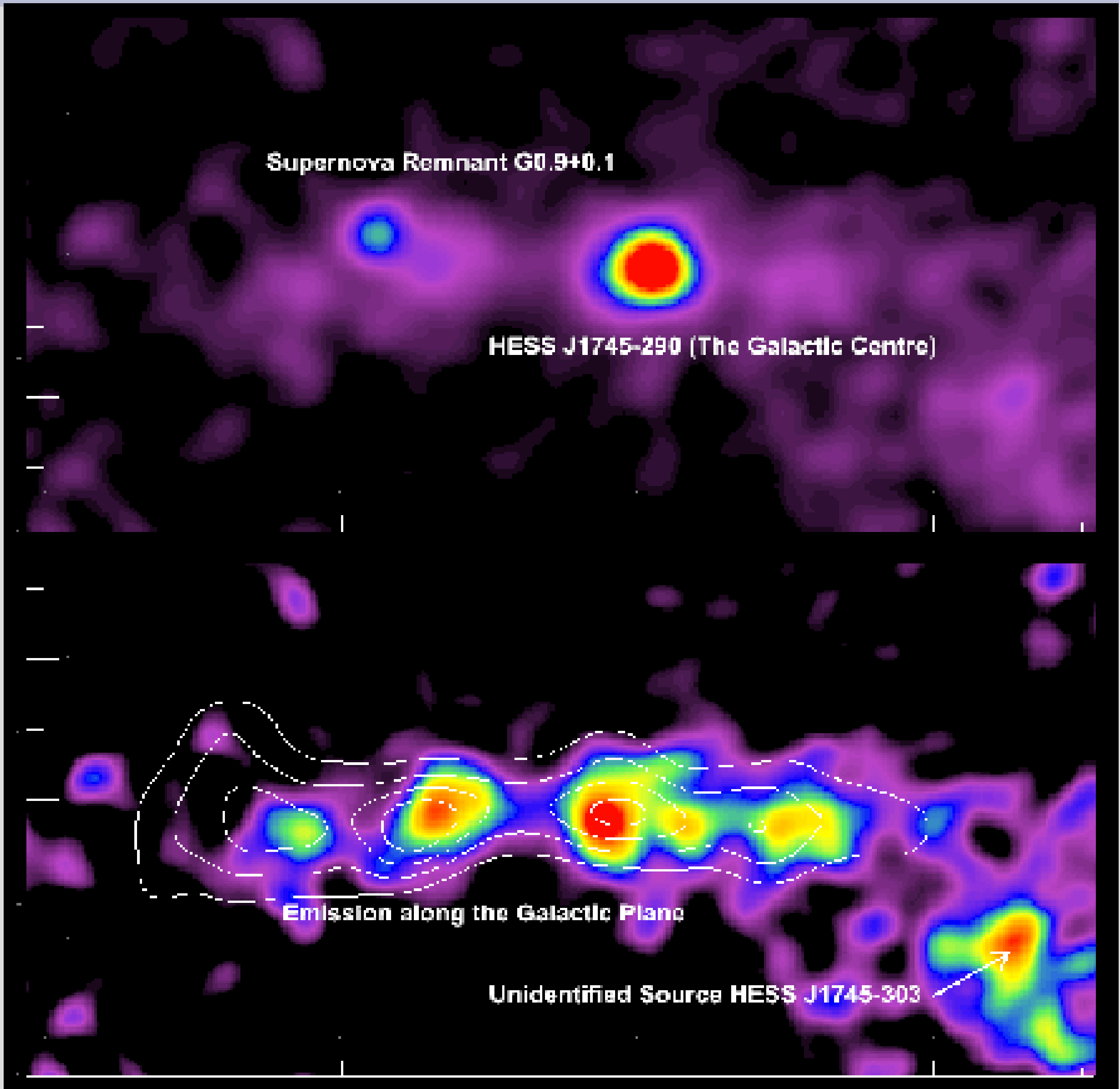
Galactic Centre / Diffuse Emission

VHE emission tracing molecular gas / CR

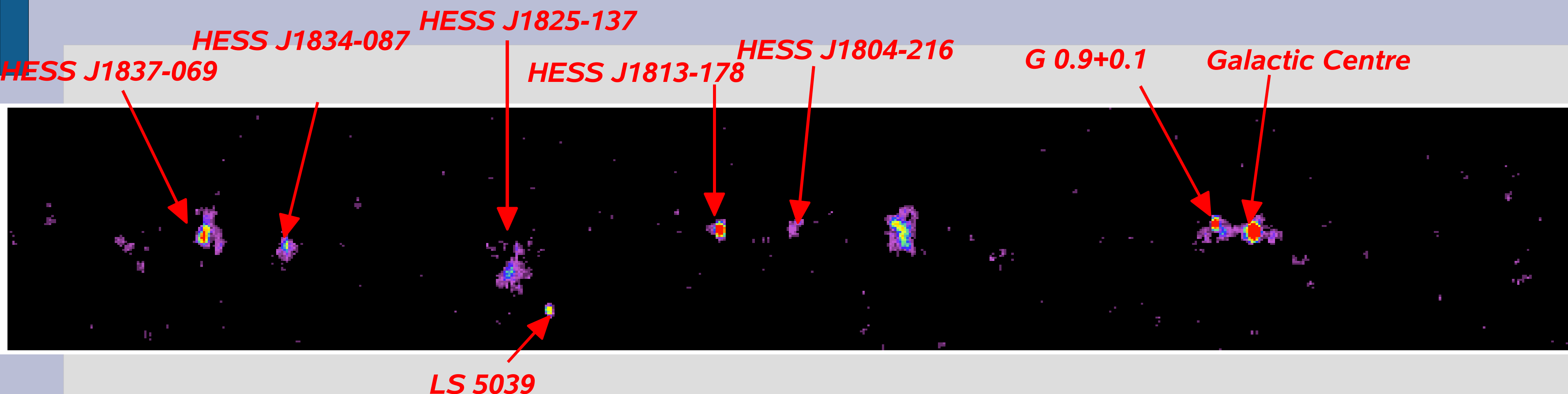
Hard spectrum and morphology suggest recent (10 000 yrs) CR acceleration close to the Galactic Centre

(several new “sources“)

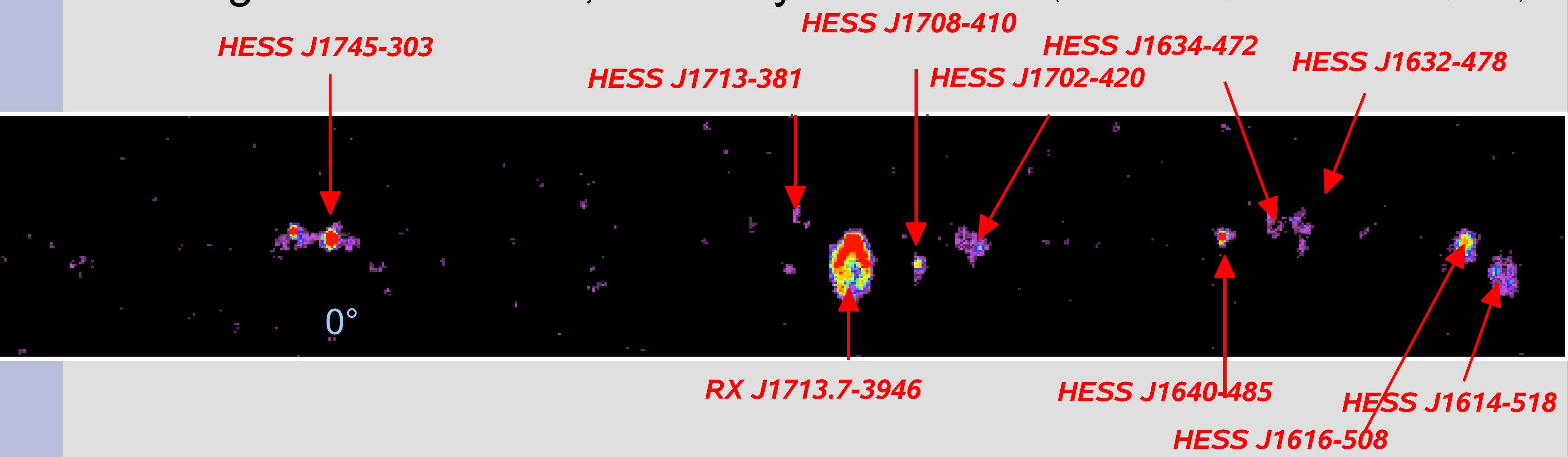
Aharonian et al. (HESS Collaboration, 2006, Nature)



The High-Energy Galaxy



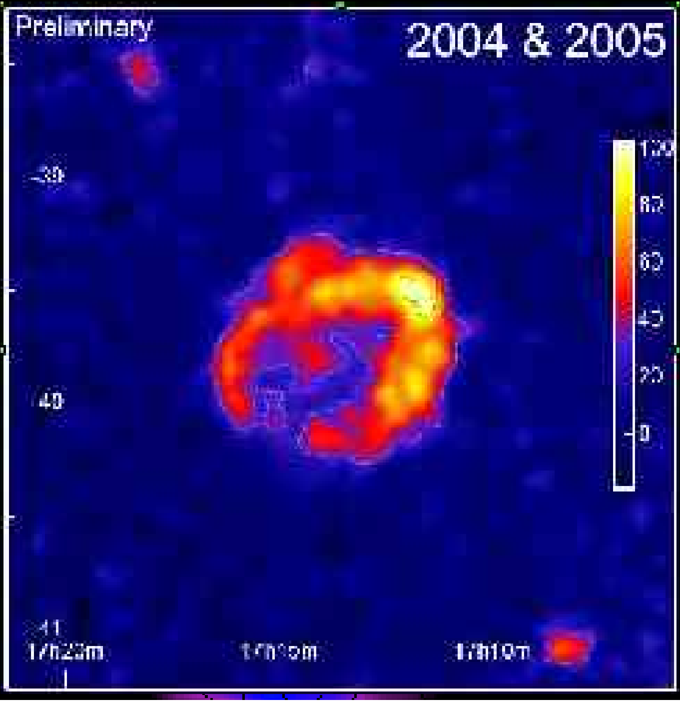
18 significant sources, 16 newly discovered (Aharonian et al., HESS collaboration, 2006)

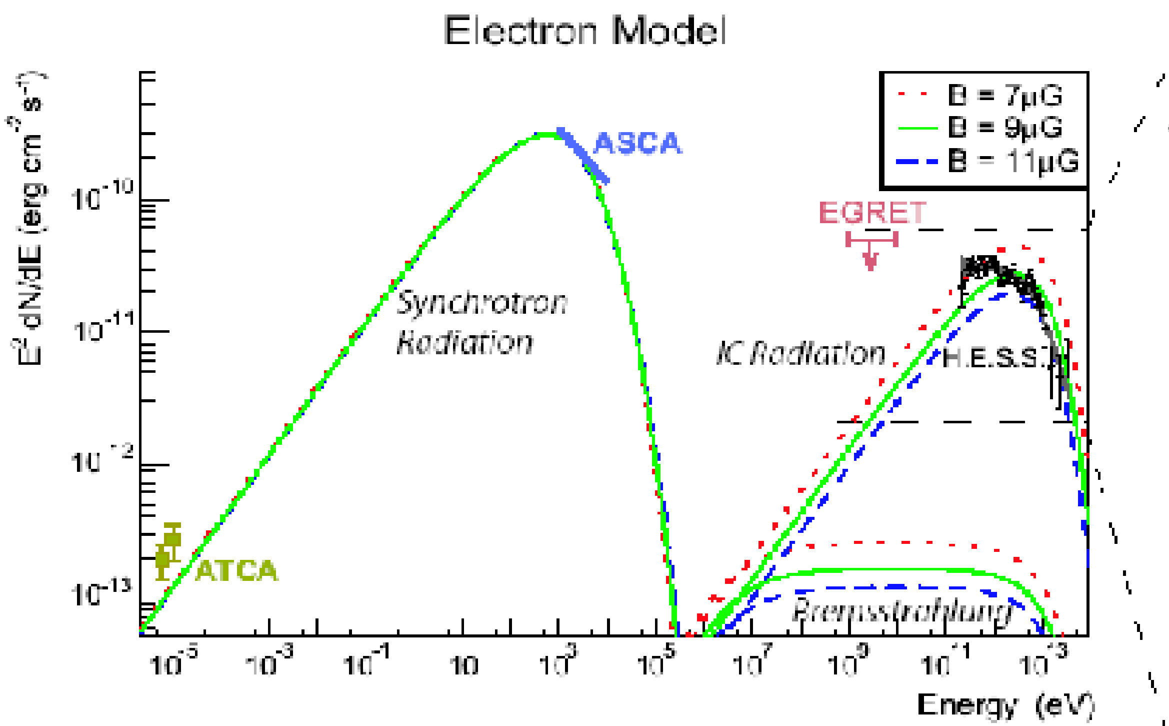


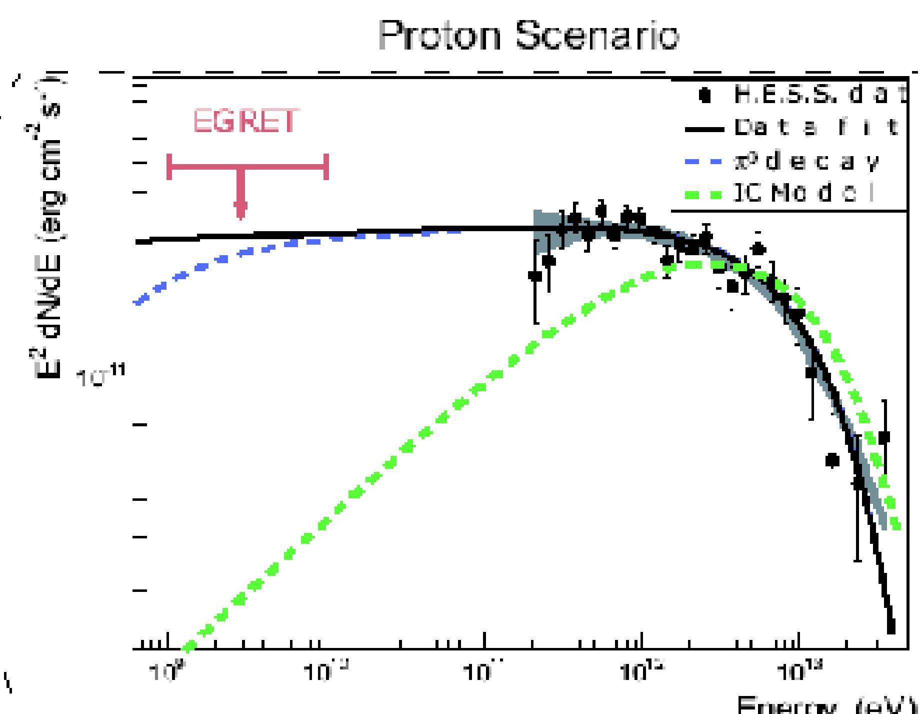
Shell type SNR

Aharonian et al 2004, Nature 432, 75
2006, A&A 449, 223

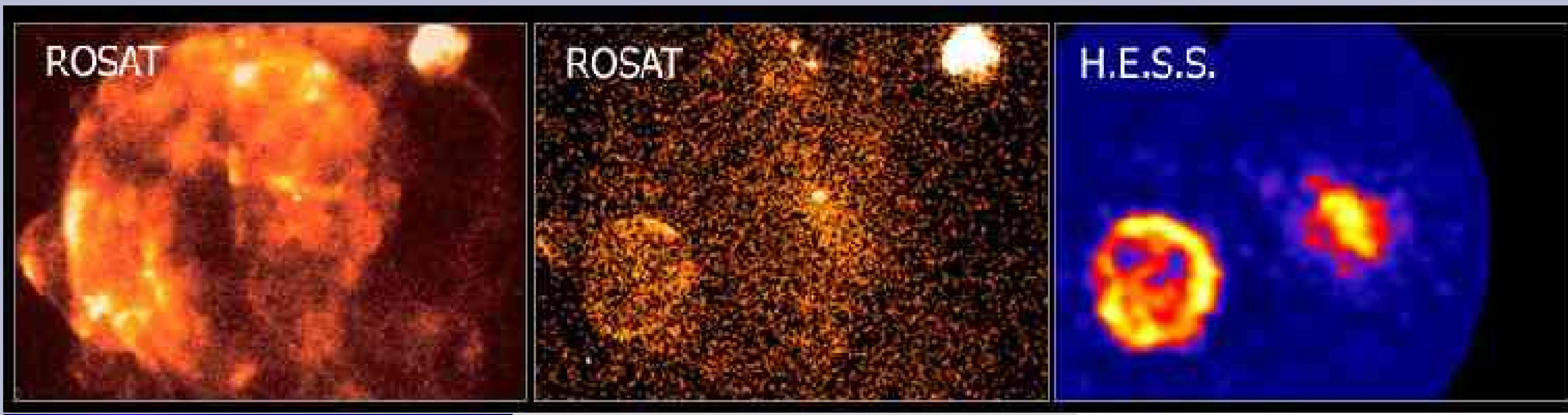
- **RX J1713.7-3946**
  - **D ~ 1 kpc , Age ~ 1000 years**
  - **Close (but not perfect) correlation between γ-rays and (hard) X-rays**
  - **IC Scenario seems less likely**
  - **Spectral shape hard to fit**
  - **Required low B fields contradict thin X-ray filaments**

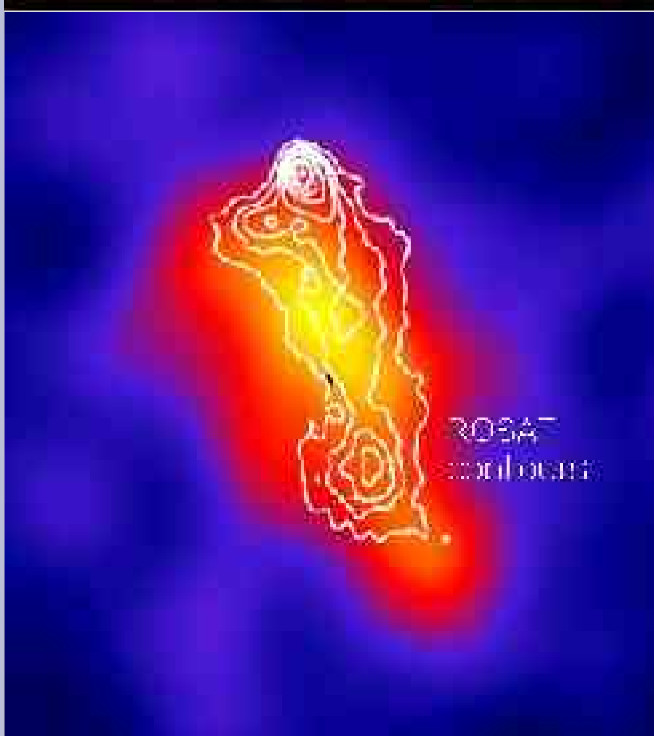






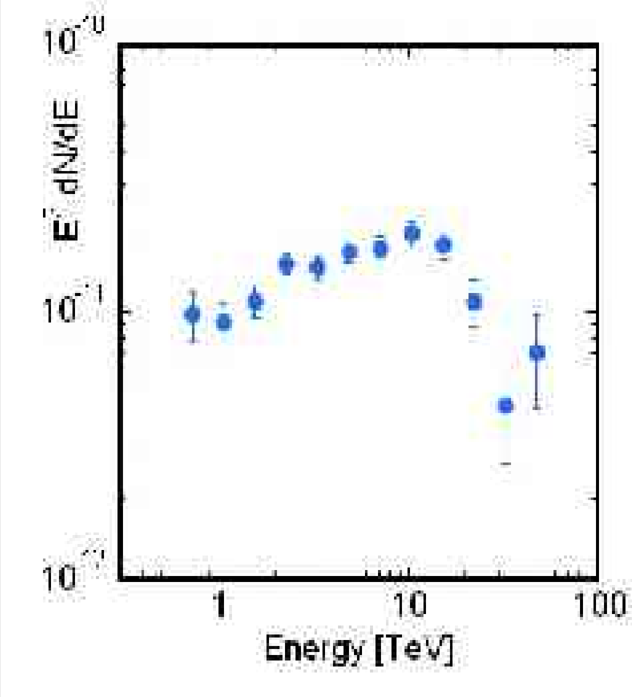
Supernova Remnants



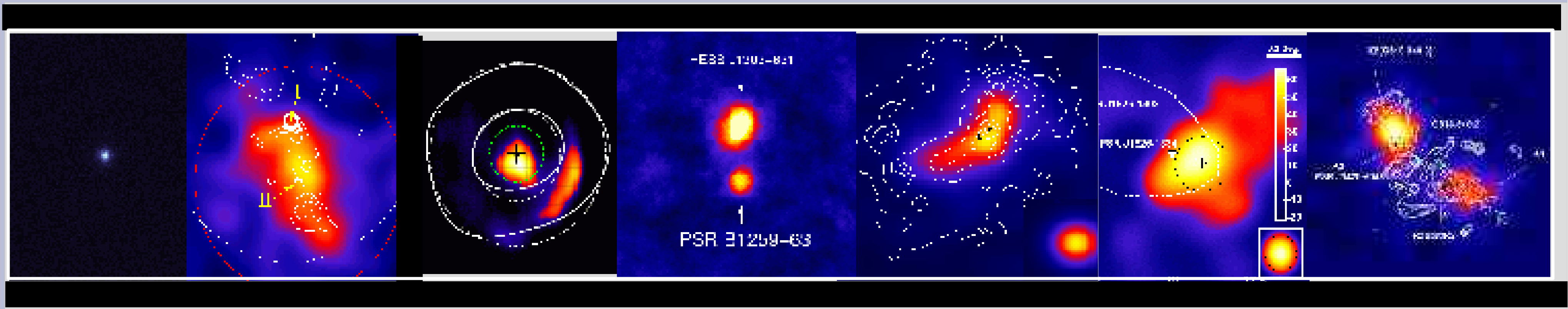


Vela and Vela Junior

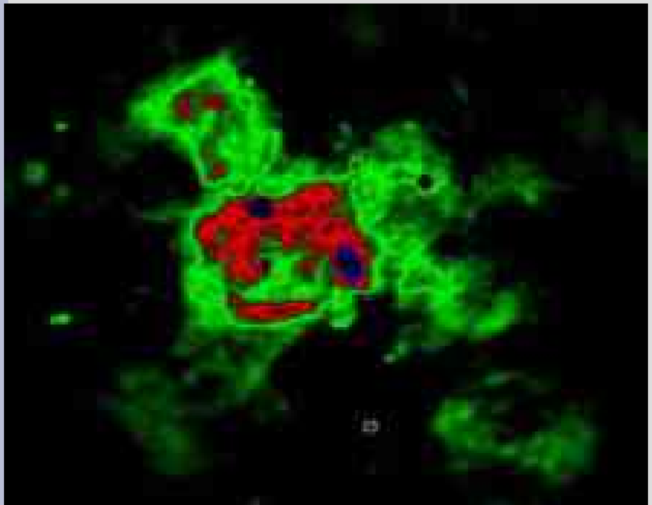
Aharonian et al., (HESS collaboration), 2006

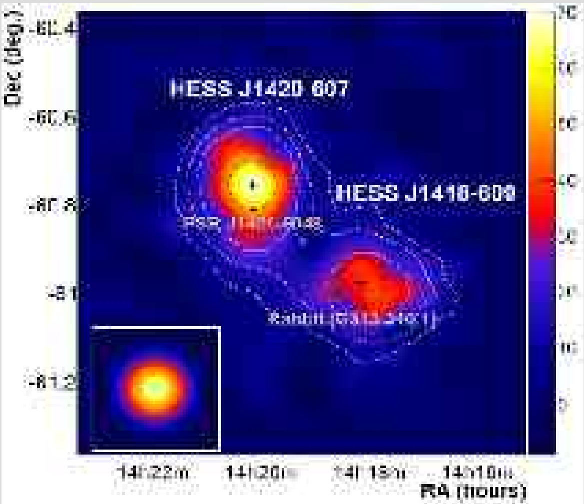


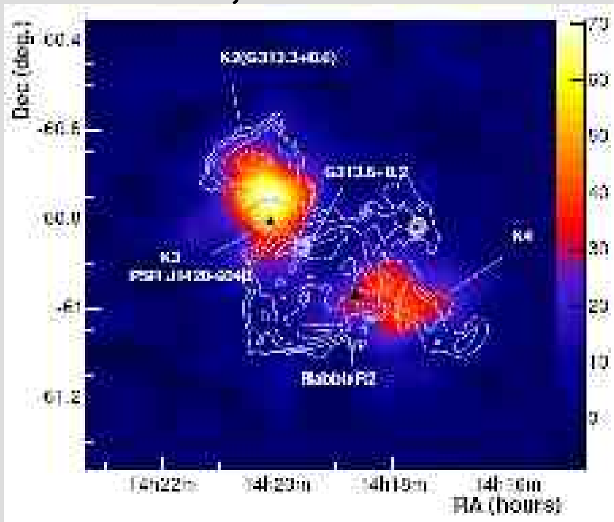
Pulsar Wind Nebulae



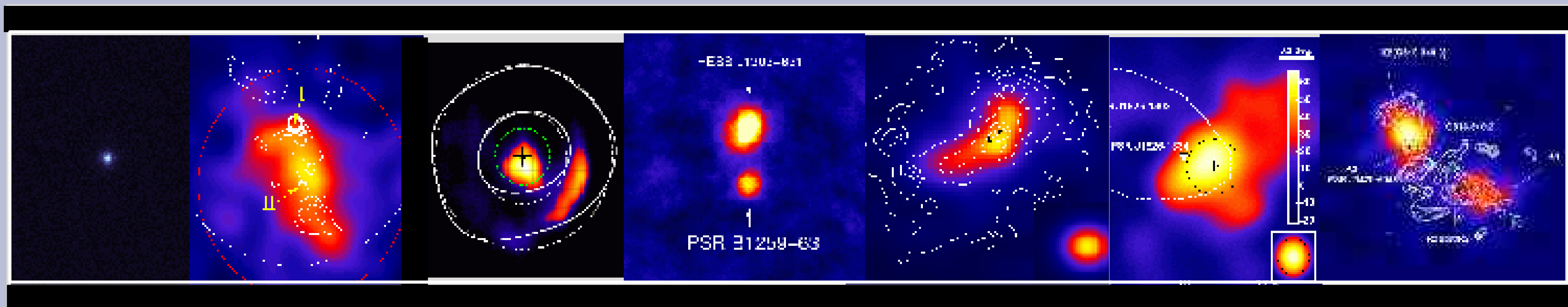
Eight known TeV PWNe: Whipple (1989): Crab,
HESS (04,05): Vela X, G09+01, PSRB 1259- 63, MSH 15-52,
PSRB 1823-13,PSR J 1420-6048, The Rabbit, ...







Pulsar Wind Nebulae



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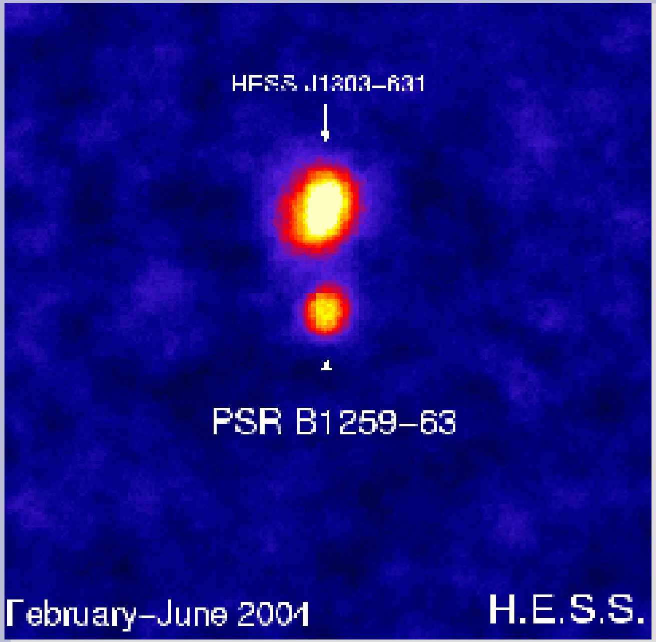
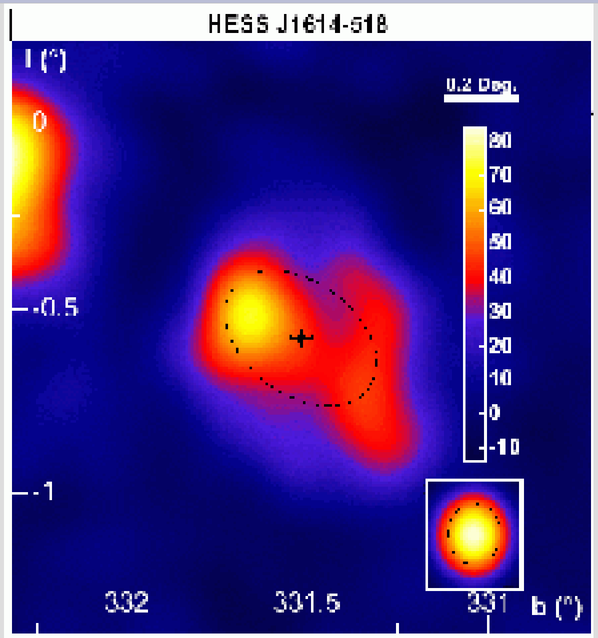
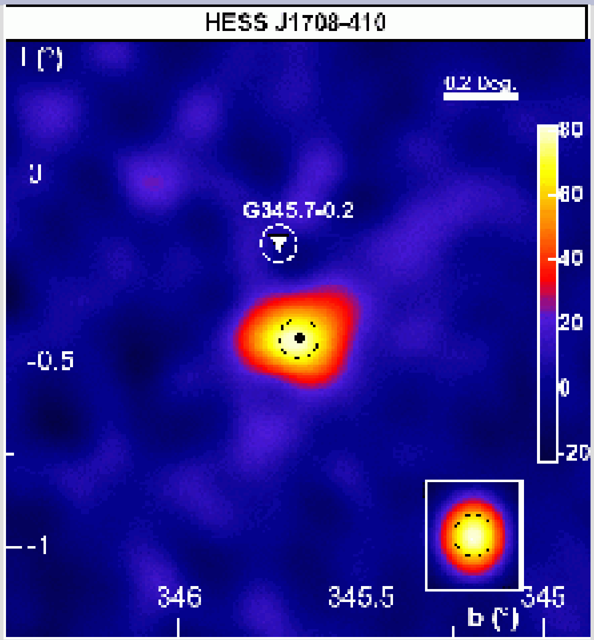
The first population of Galactic VHE sources.
TeV emission from nebulae of energetic young pulsars is ubiquitous
All X-ray / VHE sources: IC scenario favoured
Combination gives spatial and spectral distribution of e and B

Unidentified TeV sources







Many extended sources without counterpart at other wavebands

MWL campaigns underway (X-rays, Radio, ...)
Possibly compound sources
Large VHE/X-ray ratios may suggest hadronic origin

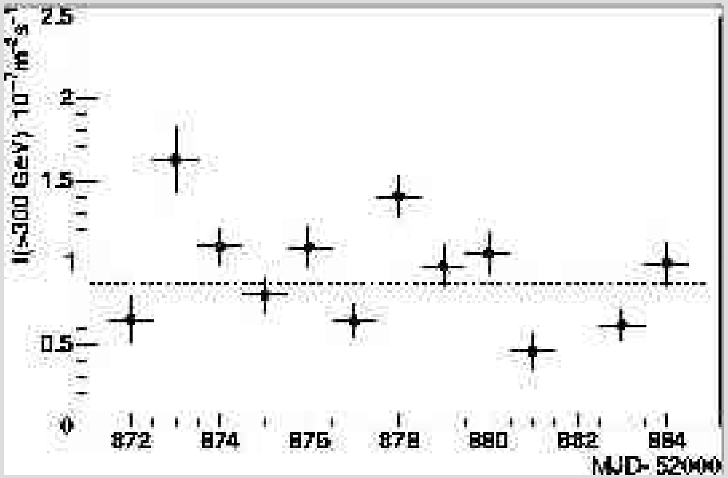
VHE Emission from AGN

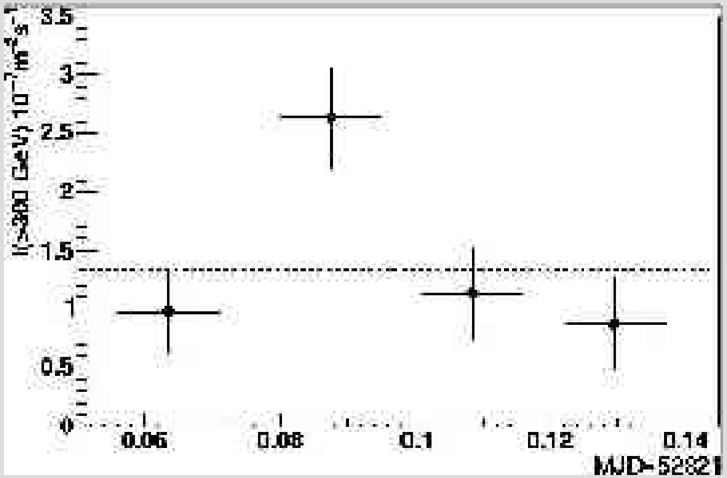
Increasing the number of and distances to TeV emitting Blazars:

Mrk 421	0.031	
Mrk 501	0.033	
1426+428	0.129	
1959+650	0.047	
2344+514	0.044	
1218+304	0.182	no spectrum
2155-304	0.116	
2005-489	0.071	softest spectrum
1101-232	0.186	hardest spectrum
2356-309	0.165	
1553+113	?	

Observational constraints

e.g. variability on time-scales of 1000 sec.



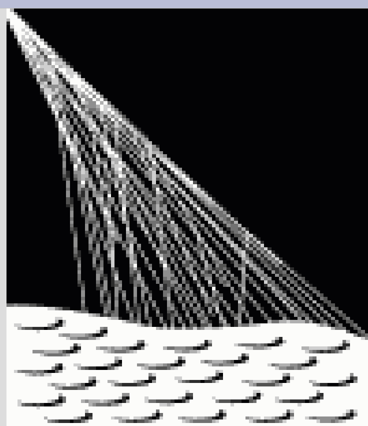


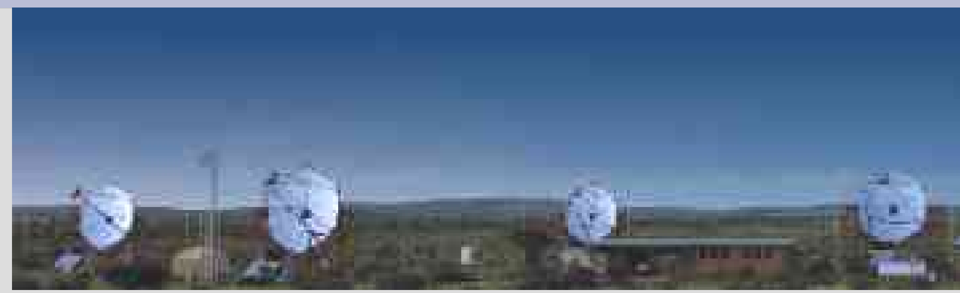
PKS 2155-304, observed with HESS

Rapid variations suggest small volume and large relativistic corrections (radius R ~ $\mathcal{D}$ 2 AU)

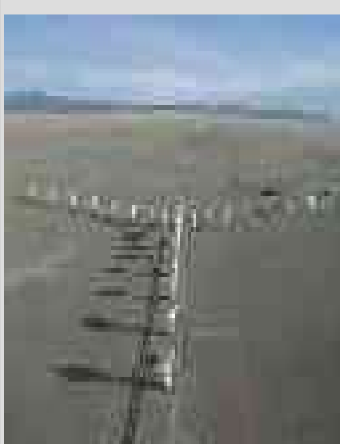
SSC modeles suggest $\mathcal{D}$ ~ 50

Astrophysics at all wavelengths

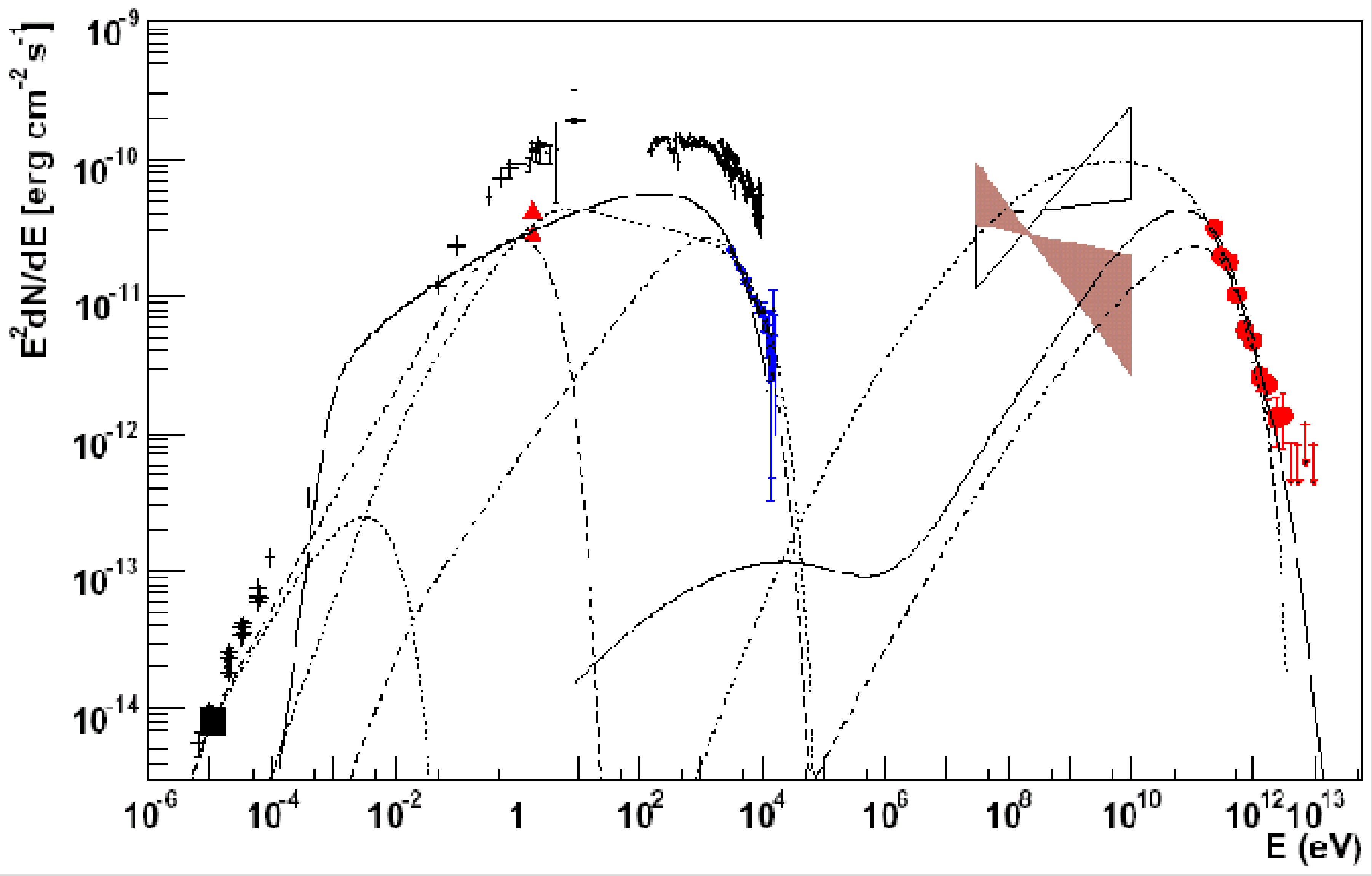




The quest for broad-band studies



Modelling PKS 2155-304



TeV opacity of the Universe

$$\tau(E) = \int_0^{z_{em}} dz \frac{dl}{dz} \int_{-1}^{1} dx \, \frac{(1-x)}{2} \int_{\epsilon_{th}}^{\infty} d\epsilon \, n(\epsilon) \, \sigma(\epsilon, E, x)$$

with cross-section and

$$\sigma(\epsilon, E, x) = \frac{3\,\sigma_T}{16}(1-\beta^2)\left[2\,\beta(\beta^2-2) + (3-\beta^4)\ln\left(\frac{1+\beta}{1-\beta}\right)\right] \quad \beta = \left[1 - \frac{2\,m_e^2\,c^4}{E\,\epsilon\,(1-x)}\right]^{1/2}$$

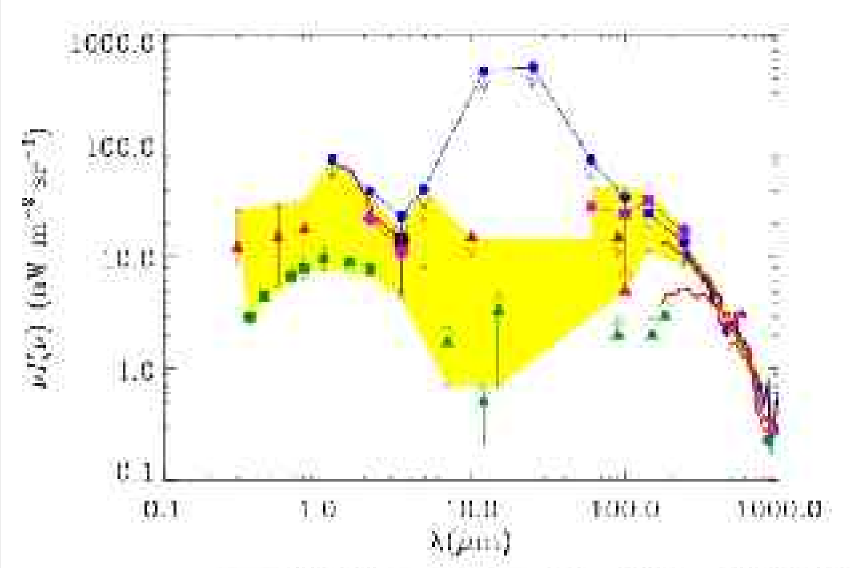
Pair-absorption within sources can generally be neglected.

Absorption due to extragalactic background light EBL

Very important in cosmological context
(integrated light resulting from fusion, i.e. Star-formation history),
but very difficult to measure.

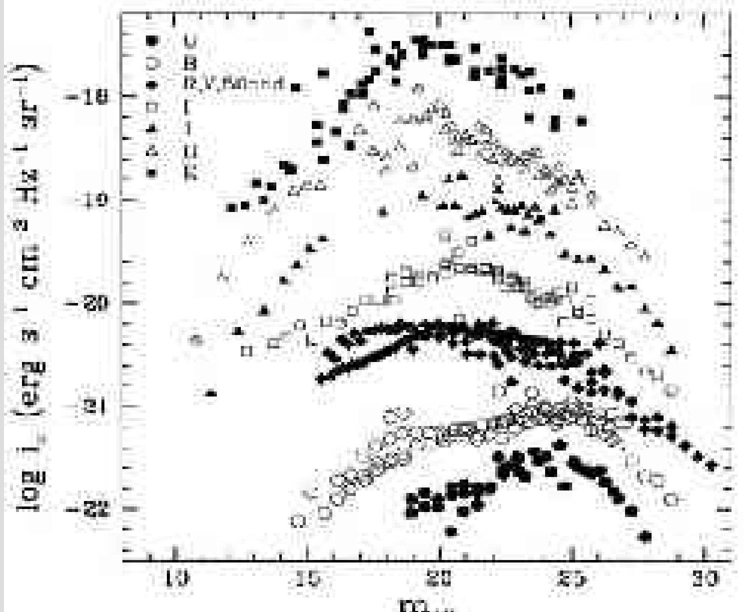
Extragalactic Background Light

Direct measurements:
Difficult due to strong,
variable, and inhomogeneous
foreground (solar system, Galaxy)



M.G. Hauser, E. Dwek
Ann.Rev. Astron. Astrophys. 39, 249

Upper limits from extrapolation of
discrete source counts:
Convergence and extrapolations?
Diffuse contributions (clusters)?
LSBGs?



P. Madau, E. Pozetti, 2000

Measuring EBL in situ with VHE

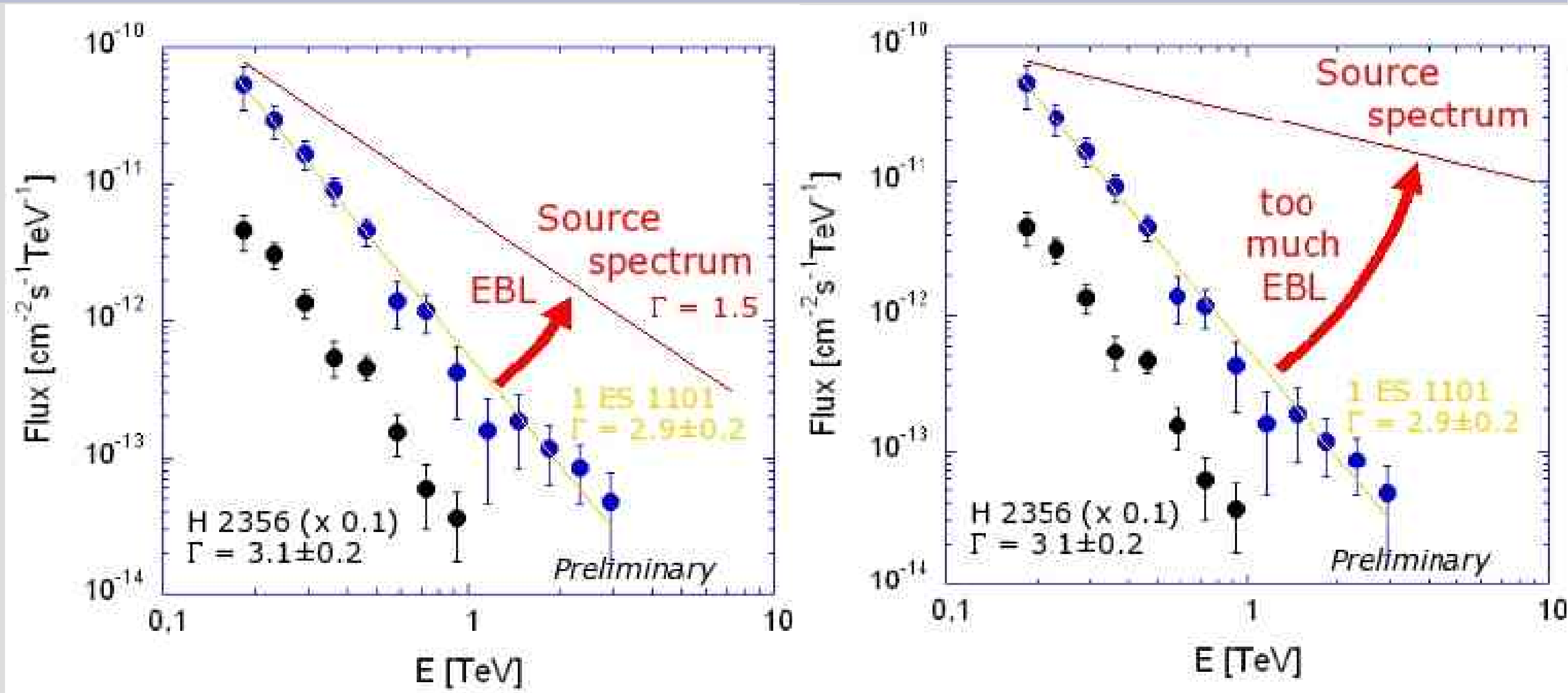
Procedure: Predict intrinsic spectrum (using SED), measure observed spectrum, derive , compute n .

Predictions involve $_{min}$, $_{max}$, B, ⃠, $\mathcal{D}$

Problems: Spectral coverage, variability of sources, complex sources, emission mechanisms

Conservative approach:
Assume EBL shape, derive upper limit from spectral model
Diffusive Acceleration, p<1.5 (log n ~ p log E)

Constraints on diffuse EBL



shock acceleration: s=1.5 Protons: =1.5

IC: > 1.5 unless no radiative cooling and IC fully in Thomson limit [= (s+1)/2 =1.25]

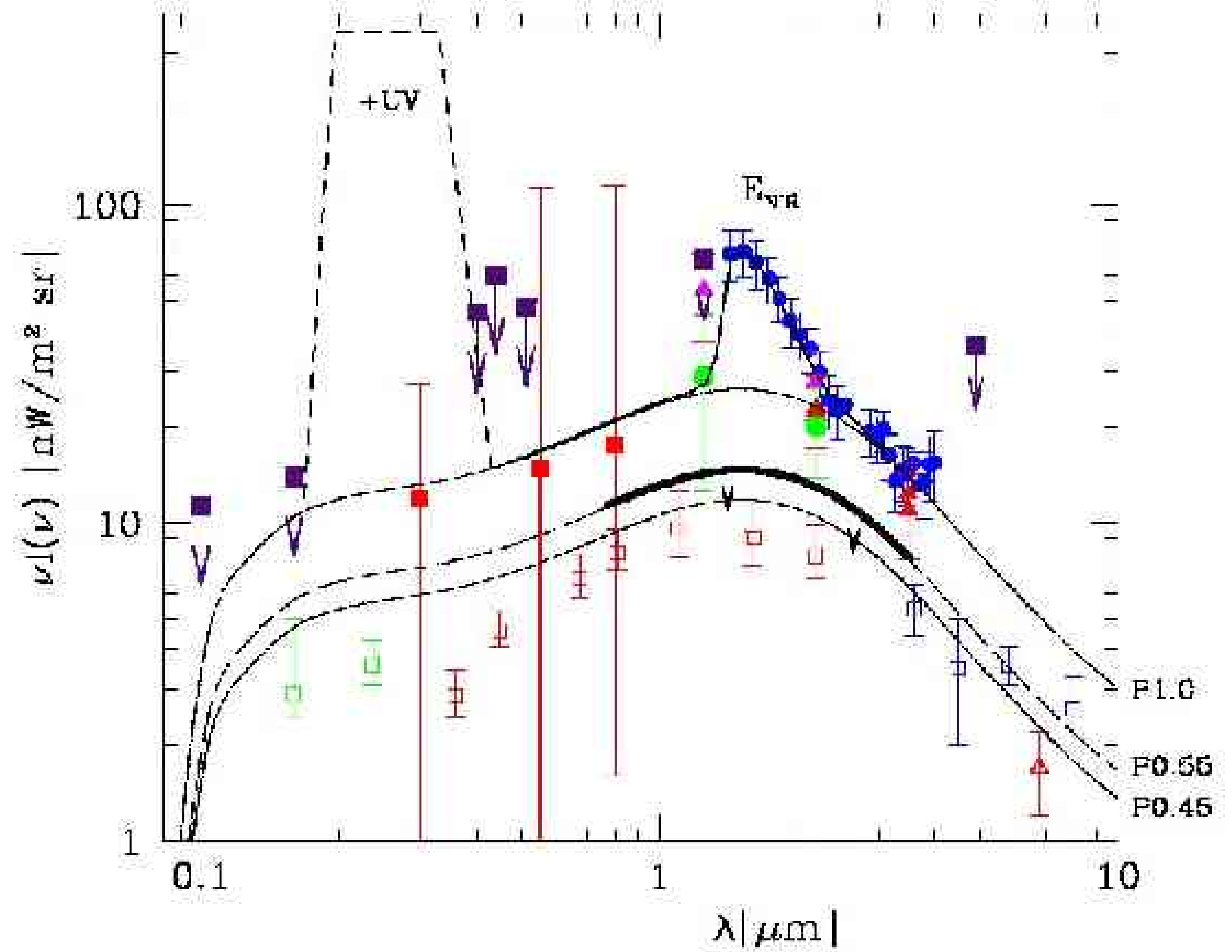
A model of the diffuse EBL

Data and upper limits compiled by Hauser

Lower limits (counts) from HST, Spitzer, ISO

P1.0 SAM by Primack
P0.55 and P0.45 are multiplicative versions thereof.

Absorption of 1101-232

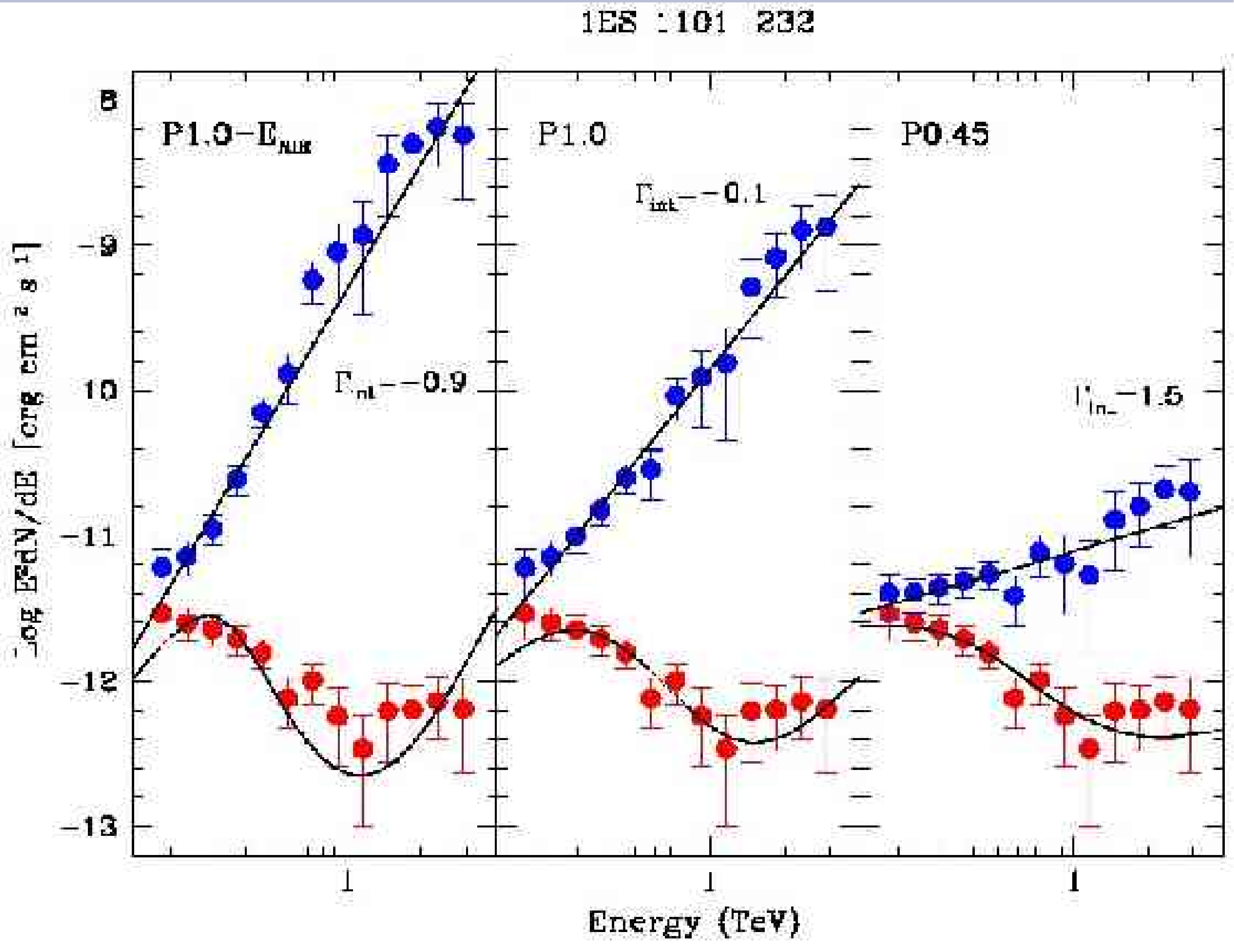


Constraints on intrinsic spectra

Measured and **computed intrinsic** spectra of 1101-232

Only an EBL level of 0.45 P1.0 = “P0.45“ is compatible with spectral constraints

Aharonian et al.
(HESS collaboration),
Nature, 2006



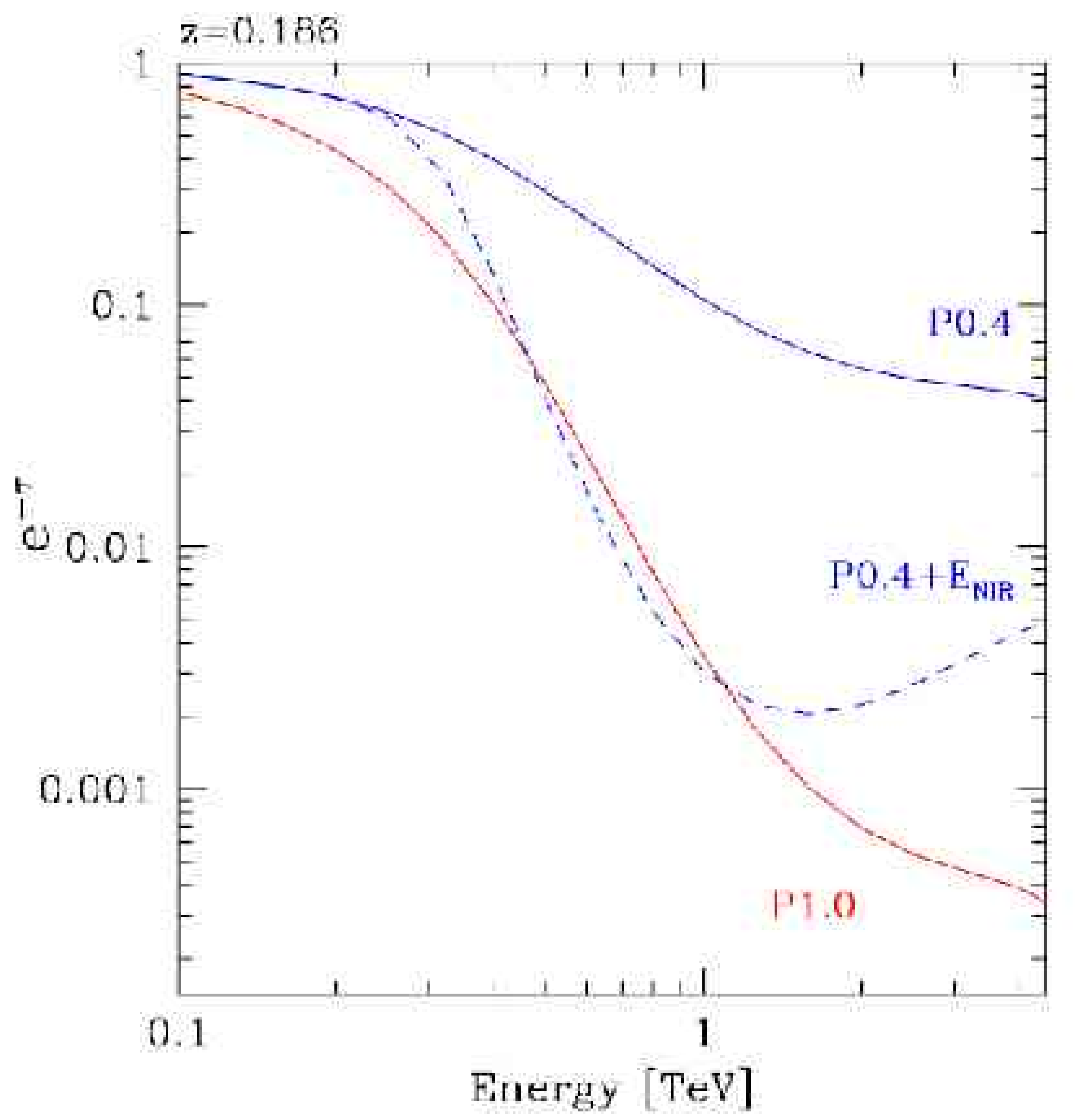
Why TeV?

Absorption is very sensitive:

60% changes cannot be probed otherwise.

No problems with cosmic variance

in-situ capabilities allow studies of EBL evolution.



Conclusions on EBL

Any plausible AGN emission model suggests that EBL in optical-NIR range ~ deep counts

EBL (1 micron) < 10 nW / m^2 sr

NIR excess (Pop III signature) ruled out

No room left for significant distributions from LSBG, intergalactic/-cluster stars, subluminous CF stars, .. (WYSIWYG star formation history)

TeV universe is big (studies of EBL evolution)

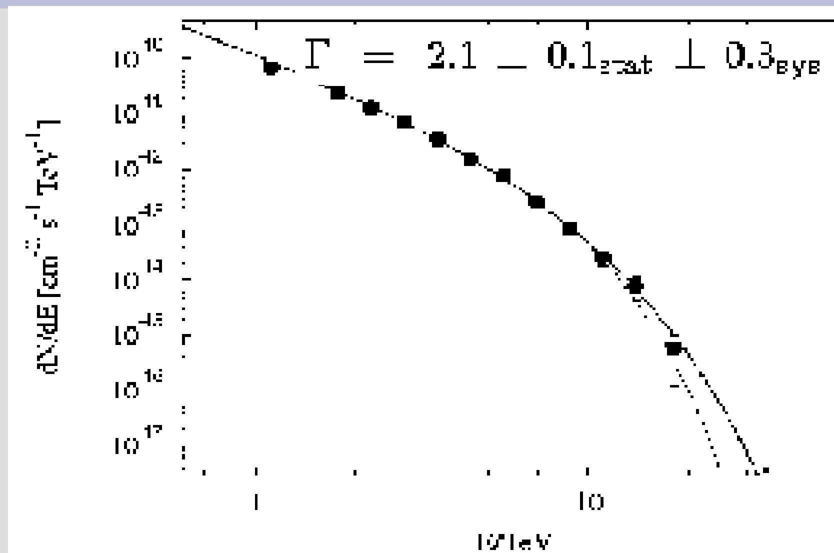
Challenges: Cosmology, Fundamental physics

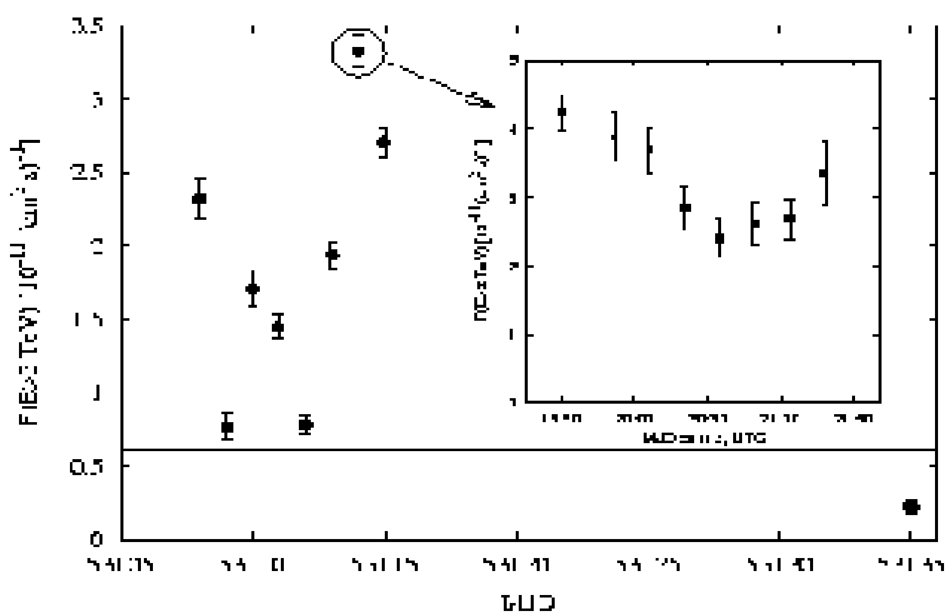
Mrk 421 (Variability)

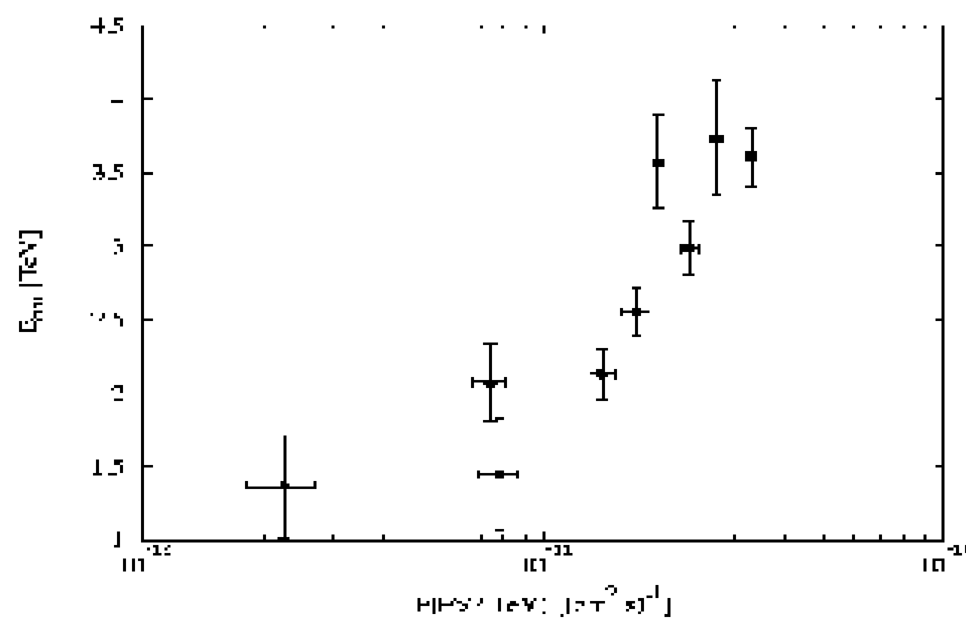
$E_c = 3.1(+0.5 - 0.4)_{stat} \pm 0.9_{sys}$ TeV

Cut-off not due to absorption

Variability on all time-scales.
Power-law index and cut-off correlated in nightly averages
Flux correlates with cut-off energy







Where do we stand?
Where will we go?

From 2 years of 4-telescope data
(2000h worth of observations (all quality)):

35 H.E.S.S. Sources
6 previously known, 29 newly detected
7 extragalactic, 28 Galactic (most likely)
23 extended, 12 unresolved
19 found in surveys/serendipitously, 16 targeted

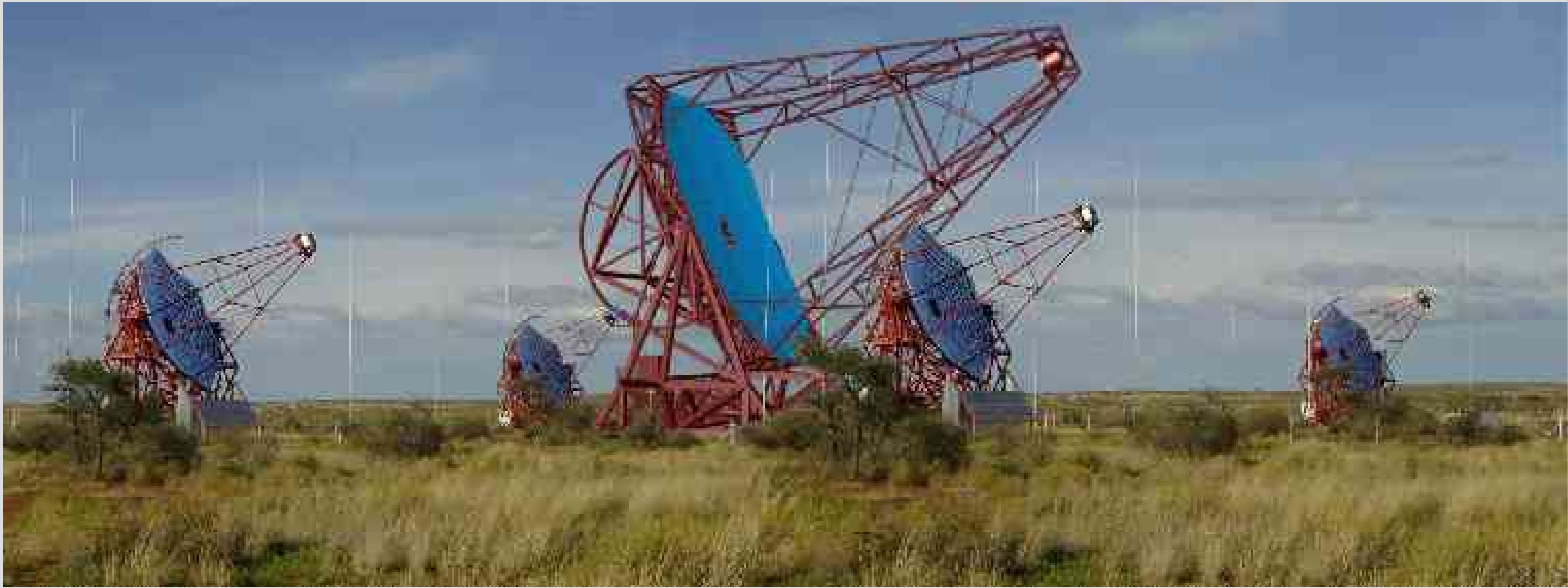
many new source classes, populations,
studies extreme non-thermal universe (mechanisms)
VHE probes photon fields, gas, B (in-situ): MWL astrophysics

Step 1: HESS II

HESS II

An additional large (30 m diameter equivalent) telescope in the centre of the array

Aims: more² light (lower energies)



Where should we go?

Discussions on status and future of VHE astronomy:

2005/2006 2 meetings each on either side of atlantic ocean
“The future of TeV astrophysics“ .

New facilities (beyond 2010+) may require new collaborations.
They are likely to be more expensive.
They should happen while GLAST is still up.

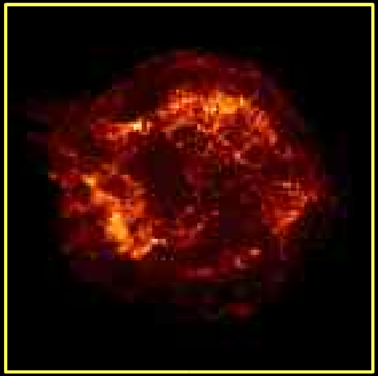
European efforts currently organized within CTA planning:

CTA

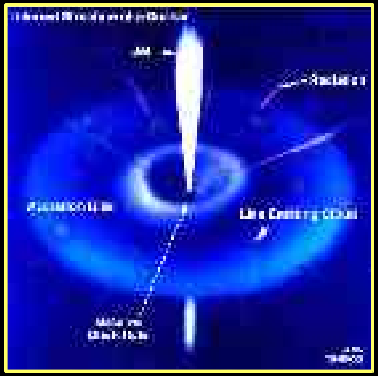
Science topics

An advanced facility for ground-based high-energy gamma ray astronomy

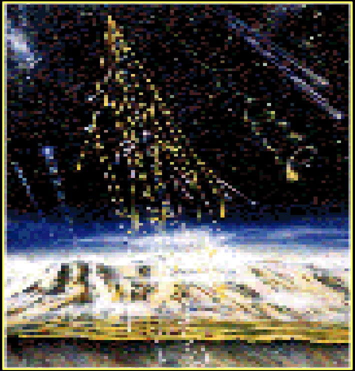
Pulsars and PWN



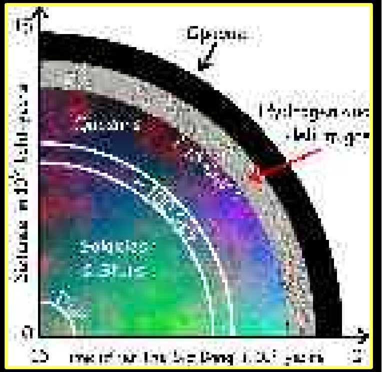
SNRs



AGNs

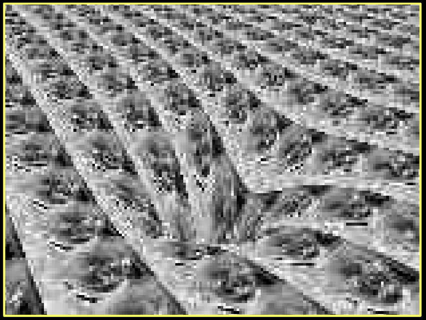


Origin of cosmic rays



Cosmology

Space-time & relativity

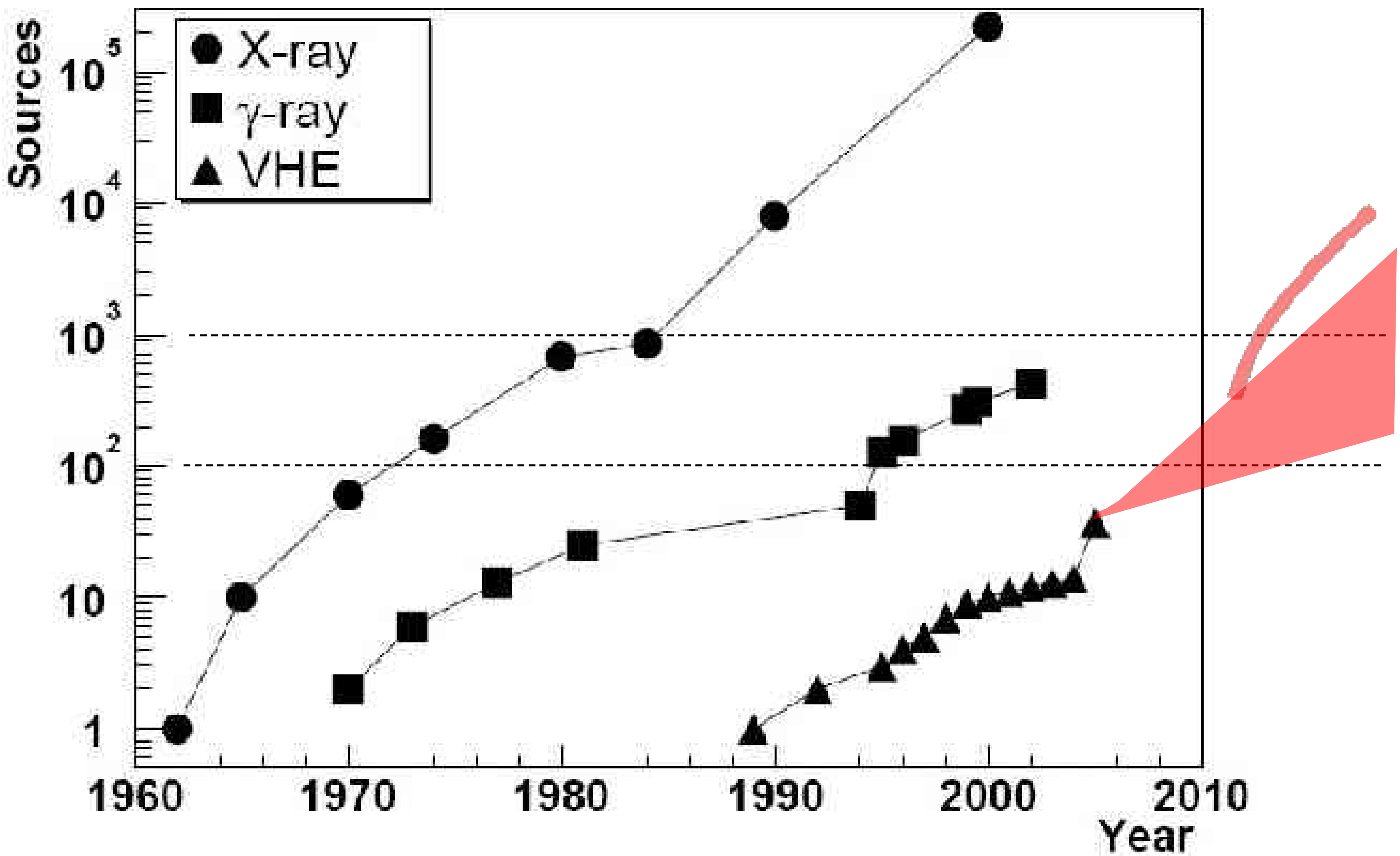


Dark matter

GRBs

Science potential

An advanced facility for ground-based high-energy gamma ray astronomy



Possible CTA sensitivity

An advanced facility for ground-based high-energy gamma ray astronomy