Dienstagskolloquium,DESY, 29.1.2008

Astrophysics at the Terascale*
Status and Highlights of ground-based Gamma-Ray Observations

*Not related to the Helmholtz-Alliance with similar title

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Collaborative Research Centre 676

Particles, Strings and the Early Universe

- the Structure of Matter and Space-Time -

Bundesministerium für Bildung und Forschung

..or more dramatically..

The last electromagnetic window for astronomical observations: >15 decades

- LE or MeV: 0.1-100 MeV (0.1-10 + 10-100)
- HE or GeV: 0.1-100 GeV (0.1-10, 10-100*)
- VHE or TeV: 0.1-100 TeV (0.1-10, 10-100)
- UHE or PeV: 0.1-100 PeV
- EHE or EeV: 0.1-100 EeV (Top Down?)

Satellites

Ground based

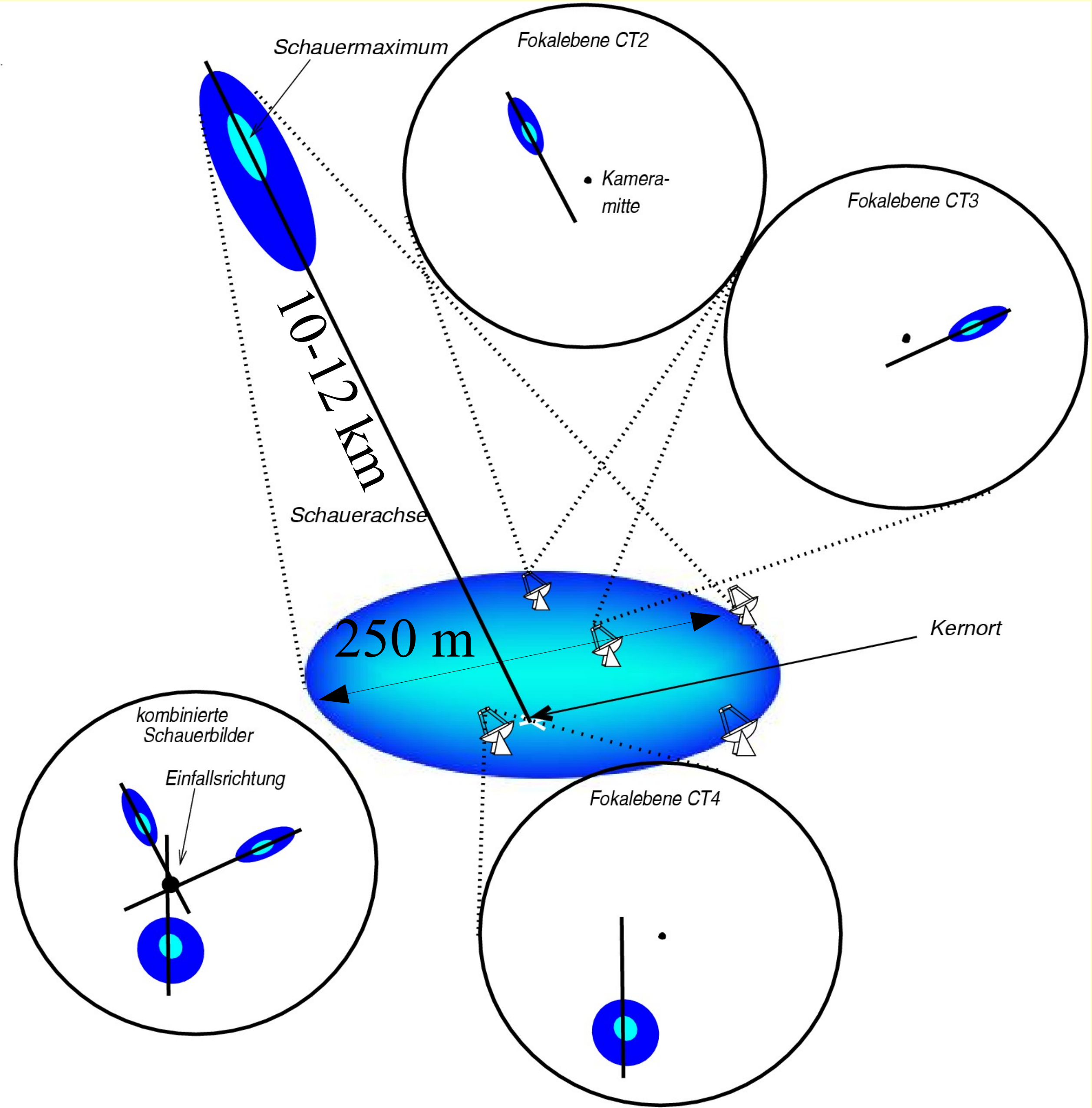
LE, HE: Domain for space based observations

VHE: Domain for ground based observations

10 Gev – 1 PeV: "Cherenkov Astronomy"

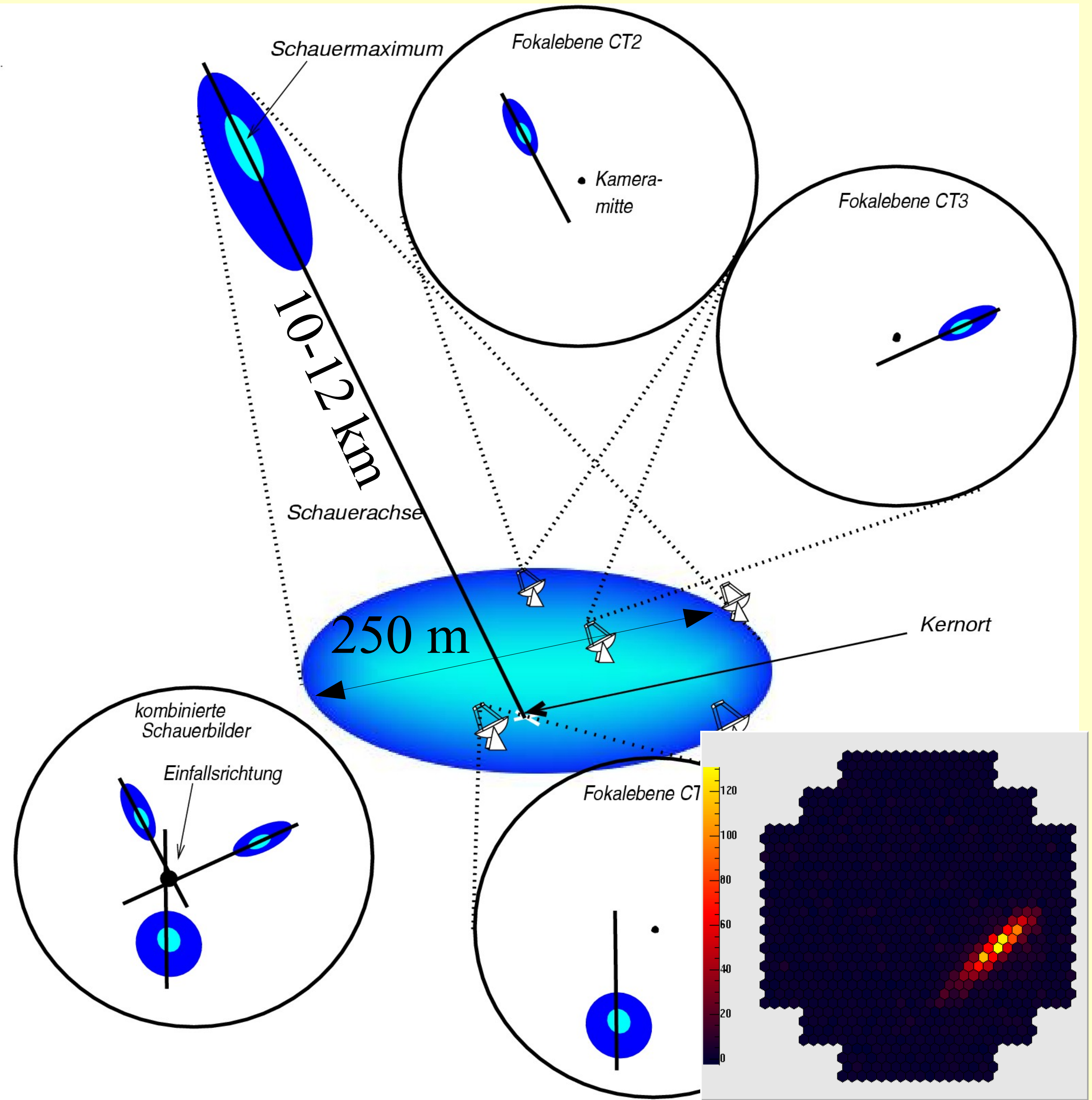
* Presently poorly explored, but in future could become the most advanced energy band

Air Cherenkov imaging technique



- Short (few ns) light flash
- Illuminates ~$5x10^5$ m^2
- Integrated Intensity: 100 ph/m^2/TeV
- Detection with PMTs
- Main background for shower imaging: Night sky light, Cherenkov light from single muons
- Main background for Gamma-ray observations: Cosmic rays

Air Cherenkov imaging technique



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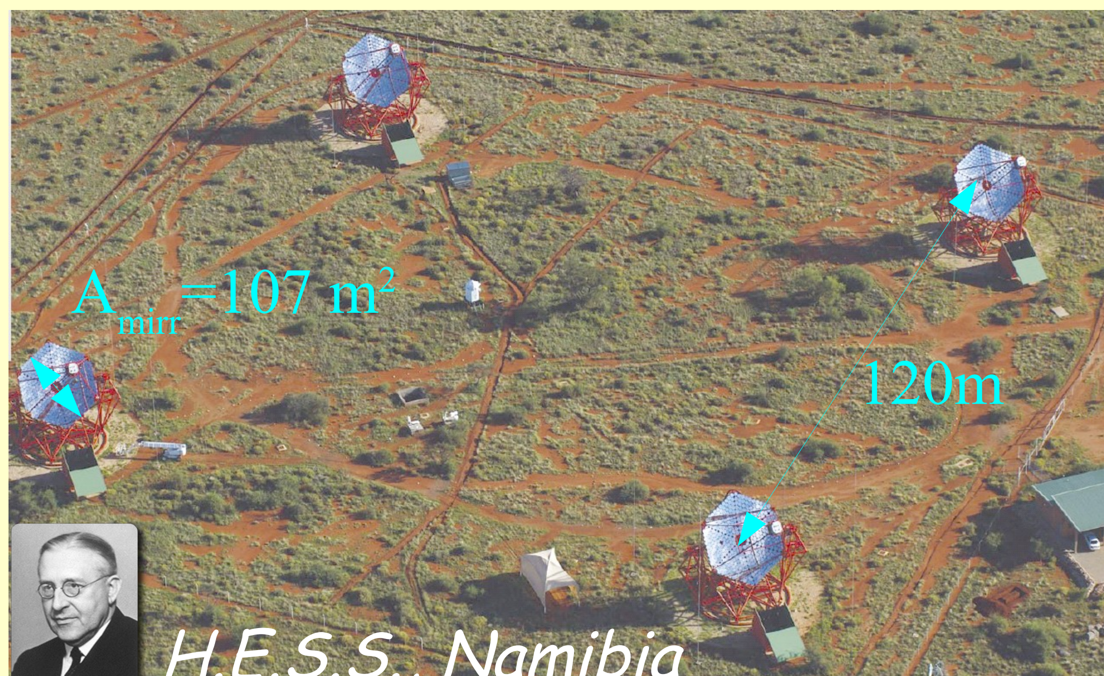
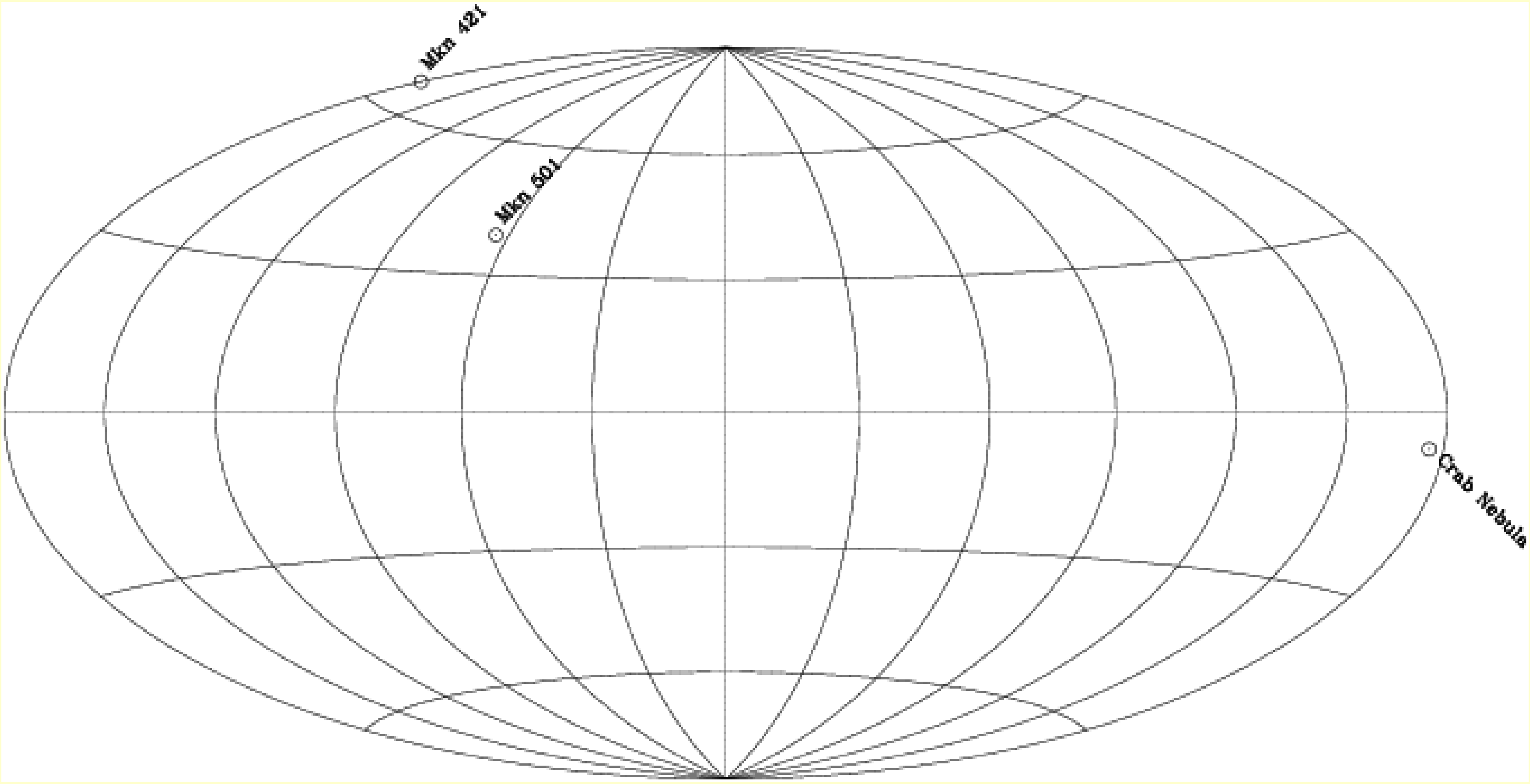
Ground based gamma-ray astronomy

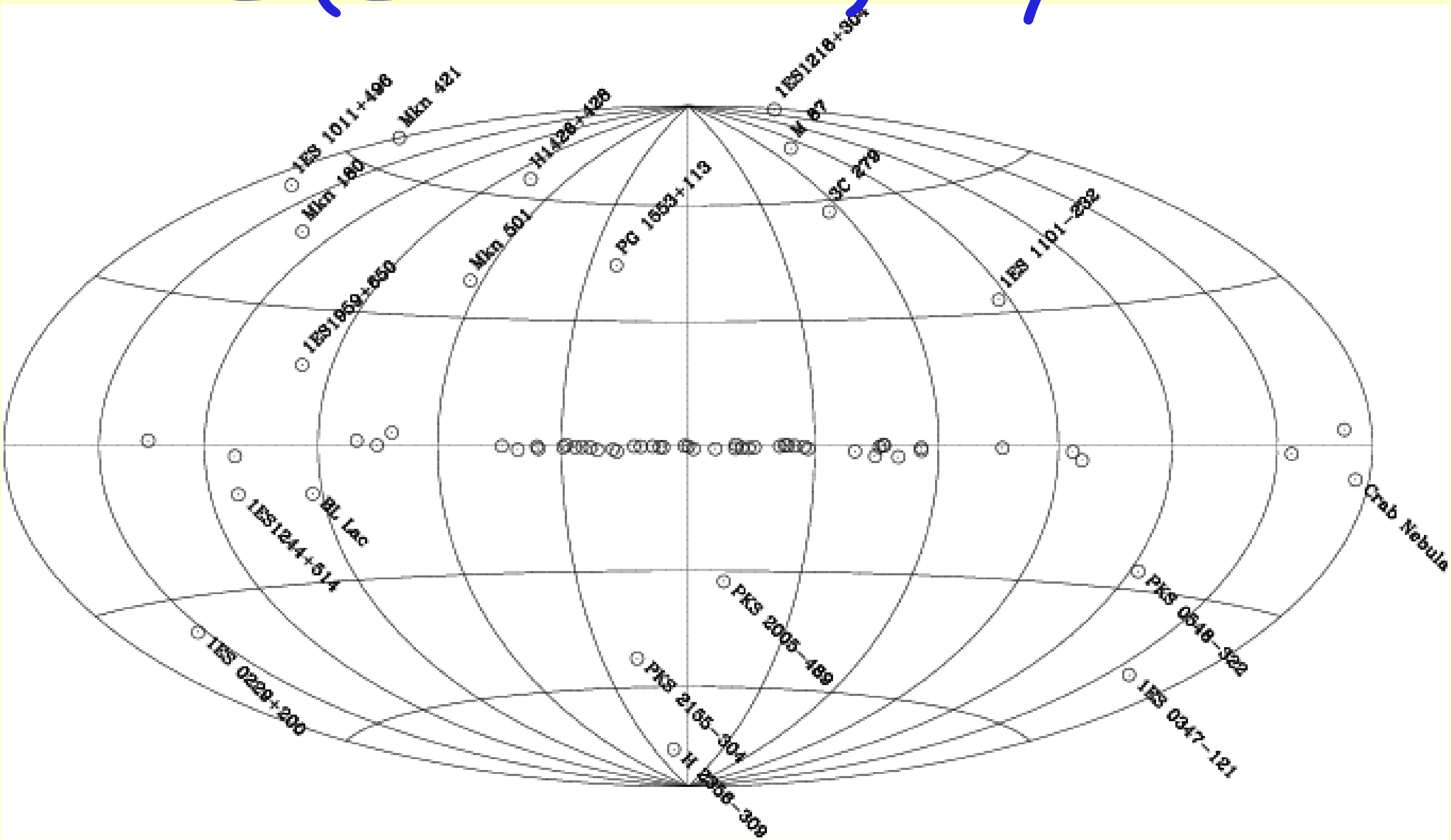
- Performance of Air Cherenkov imaging:
  - Energy range covered: ~60 GeV-60 TeV
  - Field of view: 3-5°
  - Angular resolution (per event): ~5 arc min
  - Source location: ~5 arc sec ... arc min
  - Sensitivity: $L_\gamma \sim 10^{32}$ ergs/s $(d/1\ kpc)^2$ (for a 50 h exposure)



"TeV" sky 1997



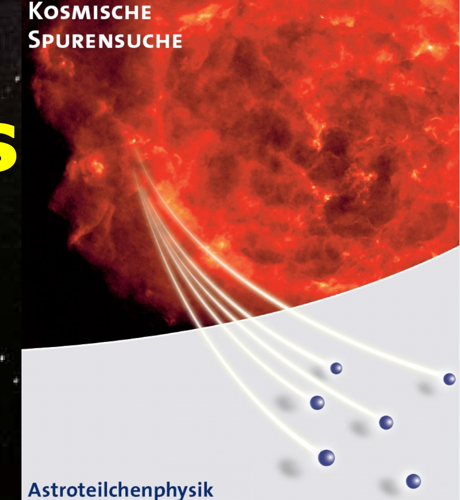
VHE (E>100 GeV) sky 2007

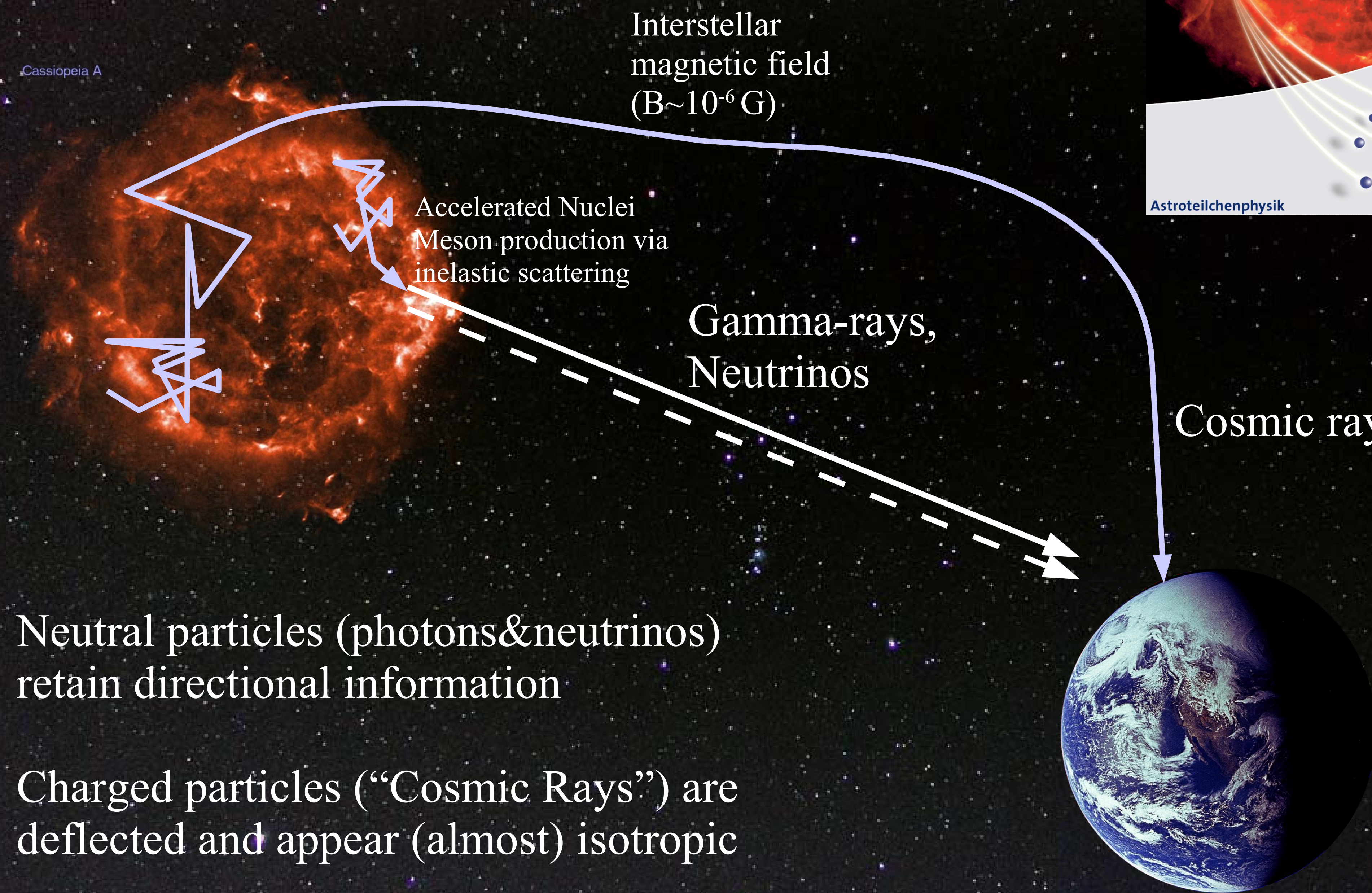


A total of 70+ sources

Why gamma-rays?
Three reasons..

Unveiling Cosmic Ray accelerators

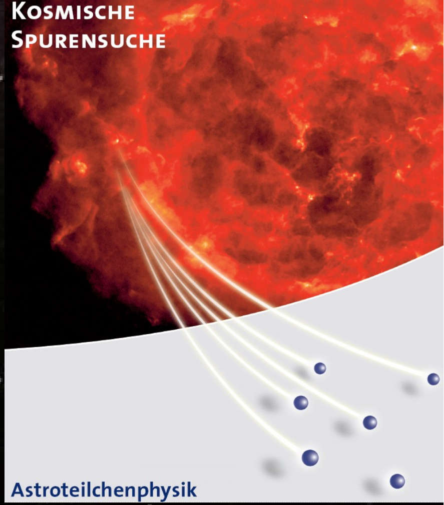




Neutral particles (photons&neutrinos) retain directional information

Charged particles ("Cosmic Rays") are deflected and appear (almost) isotropic

Unveiling Ultra-high energy Cosmic Ray accelerators:

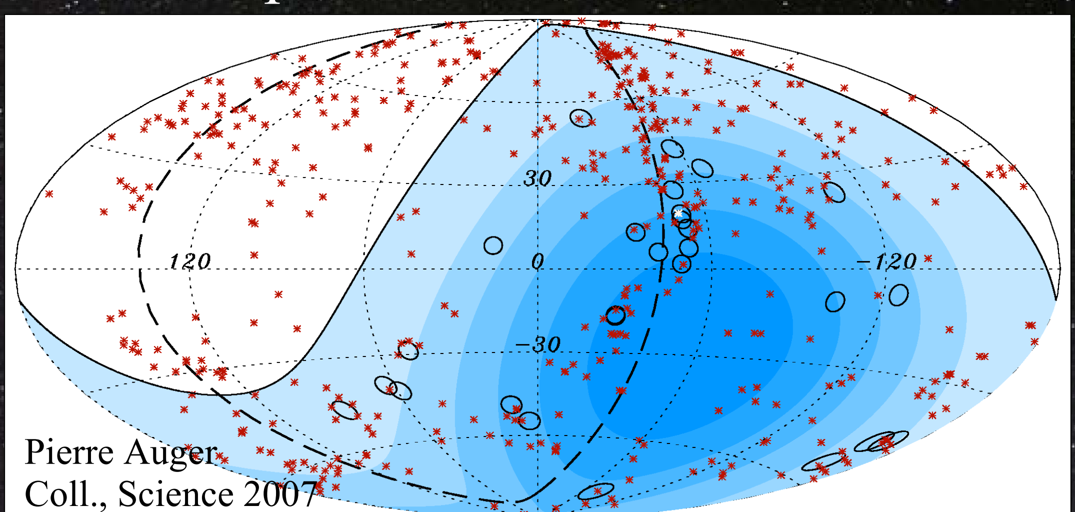


Intergalactic magnetic field (B??)

Accelerated Nuclei
Meson production via inelastic scattering

Gamma-rays, Neutrinos, Ultra-high energy cosmic rays

Ultra-high energy cosmic rays at energies $E > 10^{19.5}$ point back to sources - AGN?



Pierre Auger Coll., Science 2007

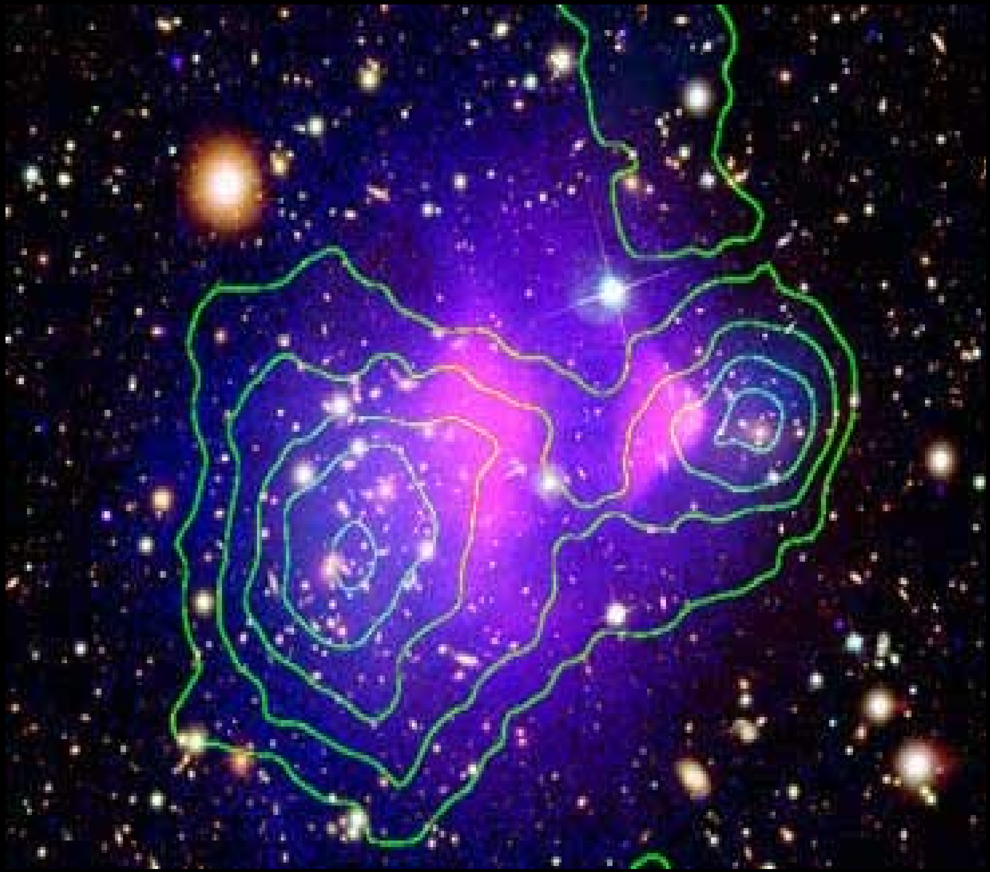
Propagation VHE γ:

$\gamma_{VHE}\gamma_{EBL} \rightarrow e^+e^-$

Dispersion (QG)

Axion convers.

Indirect Search for Dark Matter



“Bullet” cluster: merging of 2 Galaxy clusters, Composite of X-rays, Optical, and Grav. lensing

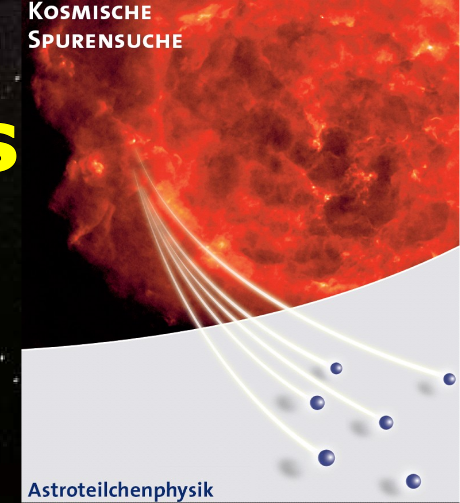
Self-annihilating Dark Matter Particles:

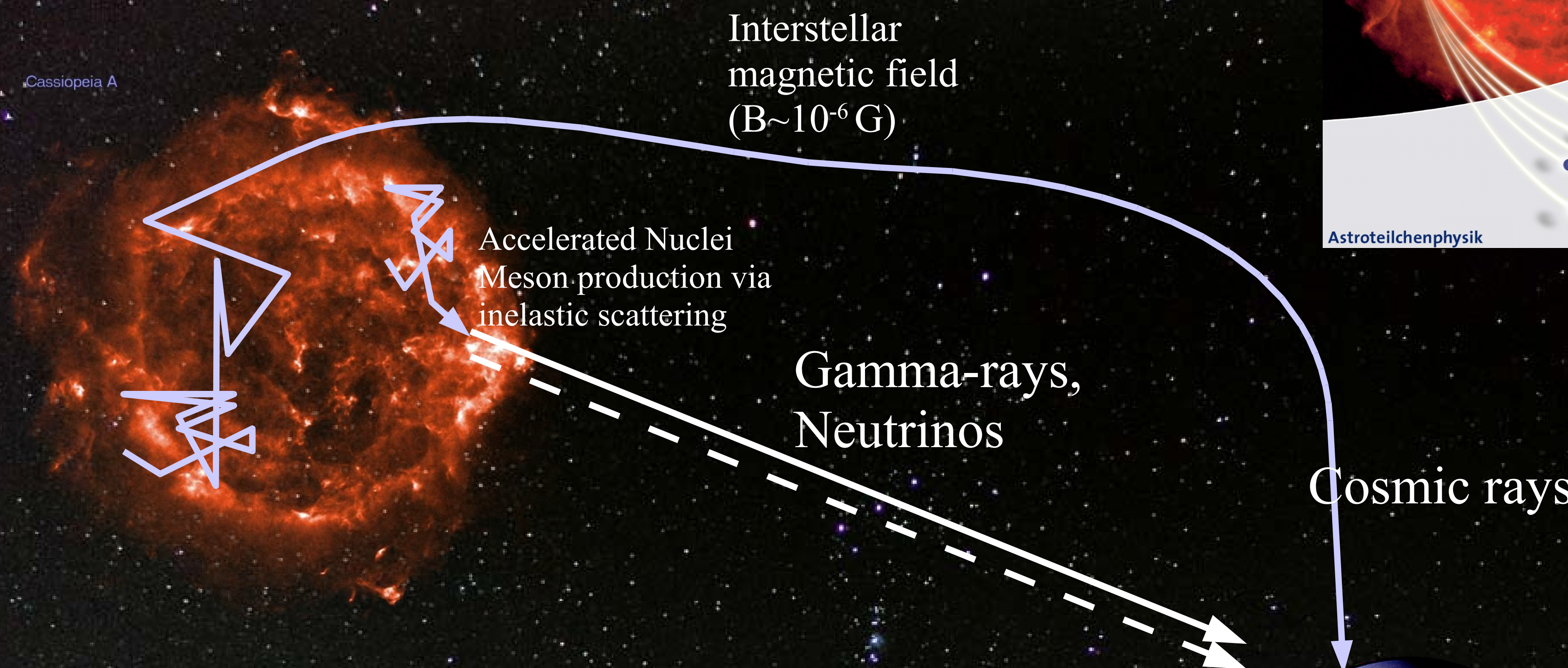
X+X -> Standard model particles

Detection via:

- **Gamma-rays**
- Neutrinos
- Anti-Protons
- Positrons

Unveiling Cosmic Ray accelerators





Neutral particles (photons&neutrinos) retain directional information

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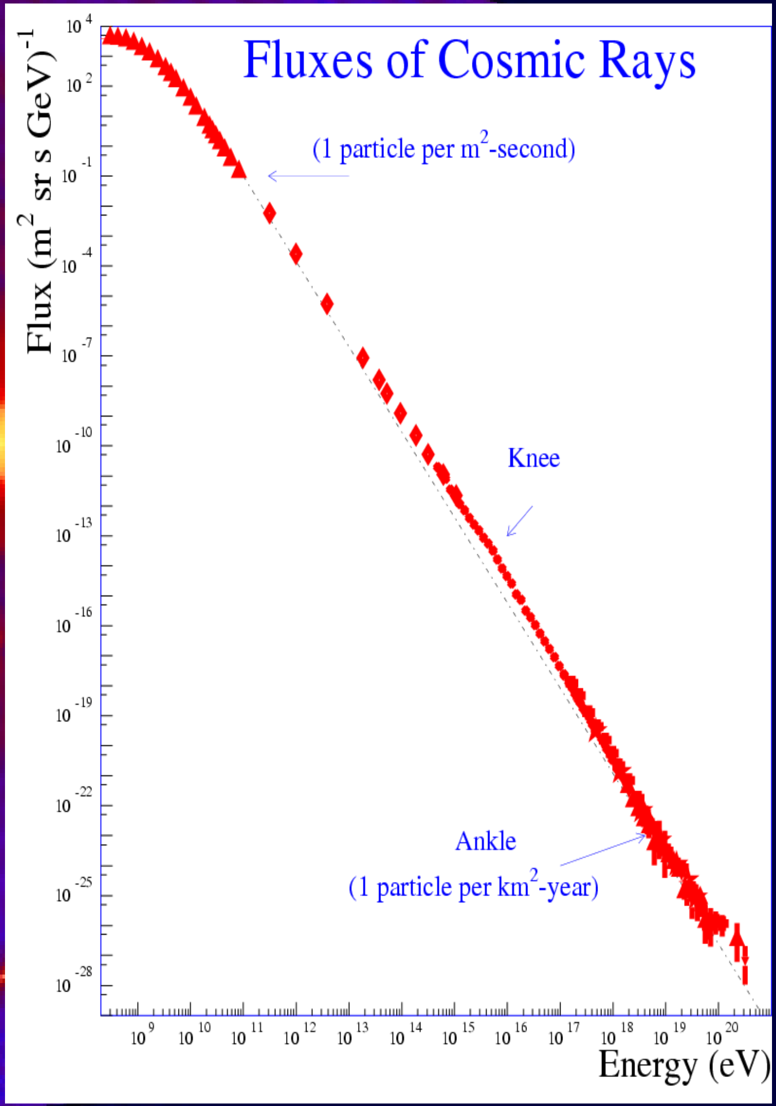
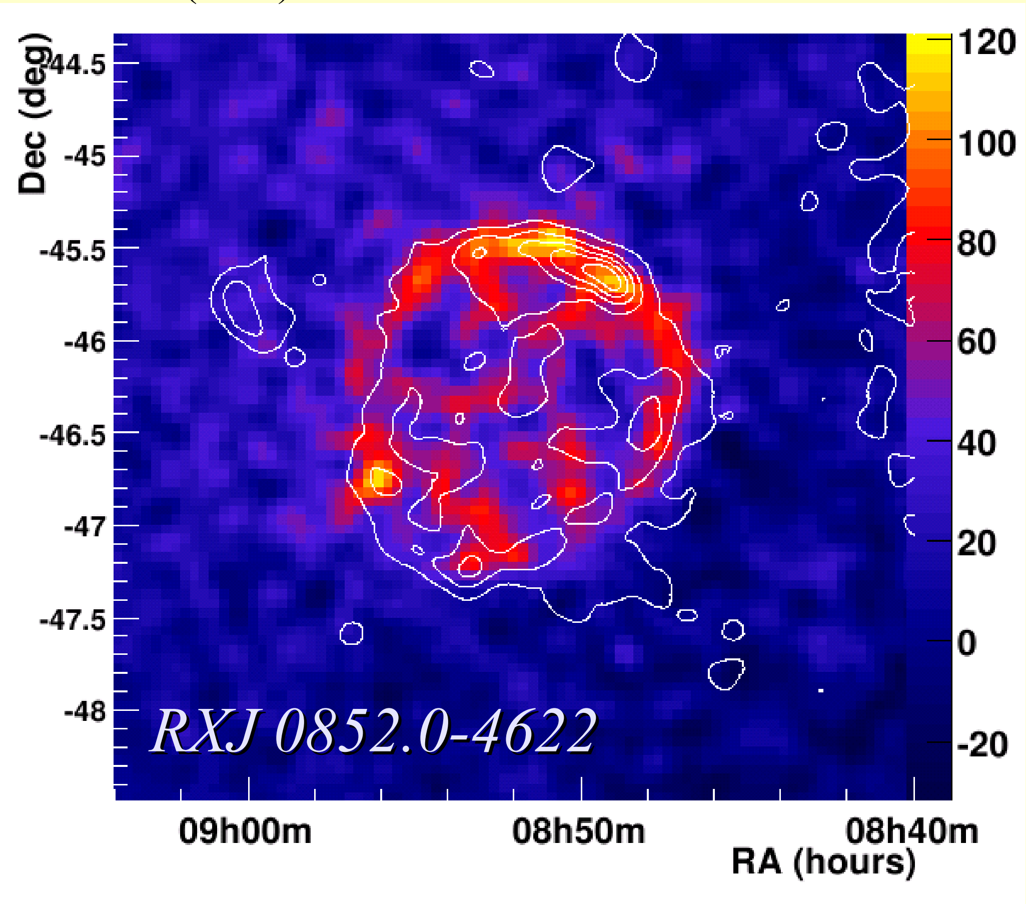
SNR Origin of Cosmic Rays

- Measurements:
  - Spatially homogeneous in the Galaxy
  - $\rho_{CR} \approx \rho_{*} \approx \rho_{B} \approx 1$ eV/cm^3 constant in time
  - Residence time of ~10^7 yrs $(E/GeV)^{-0.3}$
  - Spectrum: $d\rho_{cr}/dE \sim E^{-2.7}$
- Implications:
  - Cosmic ray loss balanced by injection
  - Power-law injection by sources
  - Power: $L=10^{40}-10^{41}$ ergs/s $\approx 10^7 L_{\odot}$
- Origin of Cosmic Rays (paradigm):
  - Shock acceleration in expanding Supernova remnants up to a few 10^{15} eV
  - Efficient (10%) conversion of kinetic energy of the blast wave ($E_{kin}=10^{51}$ erg)



HESS coll. (2006)



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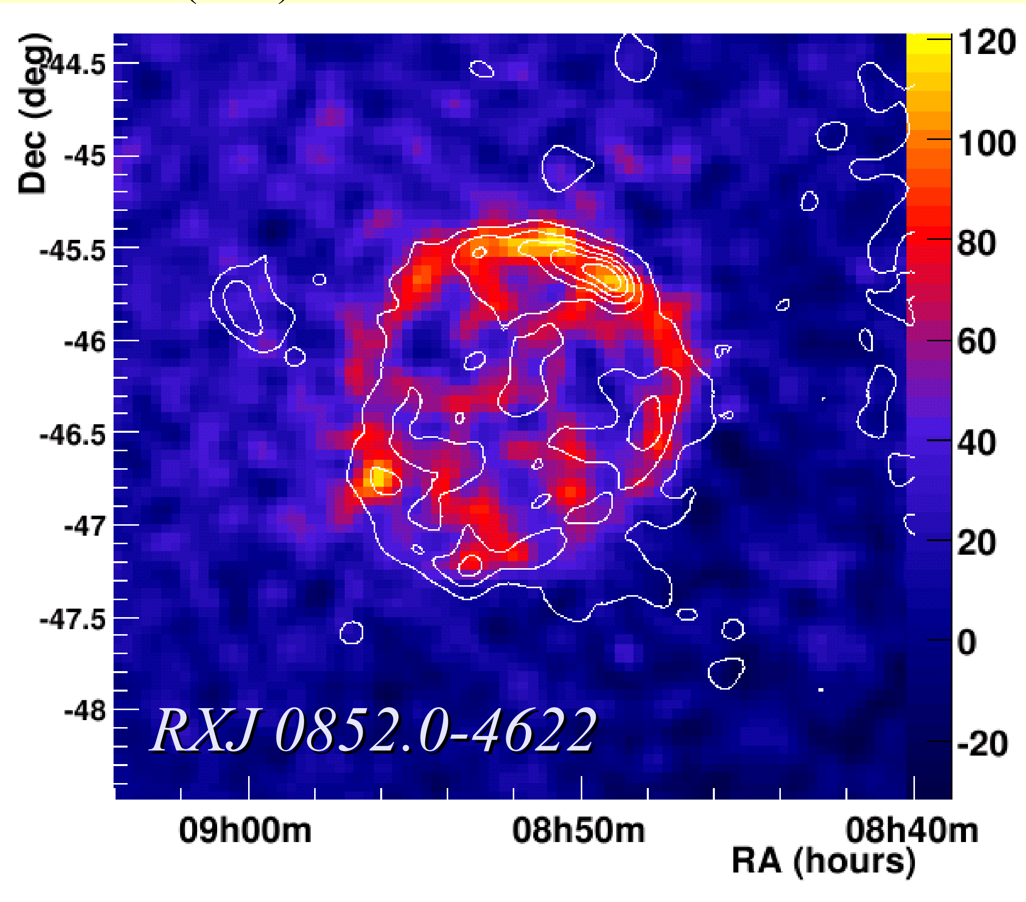

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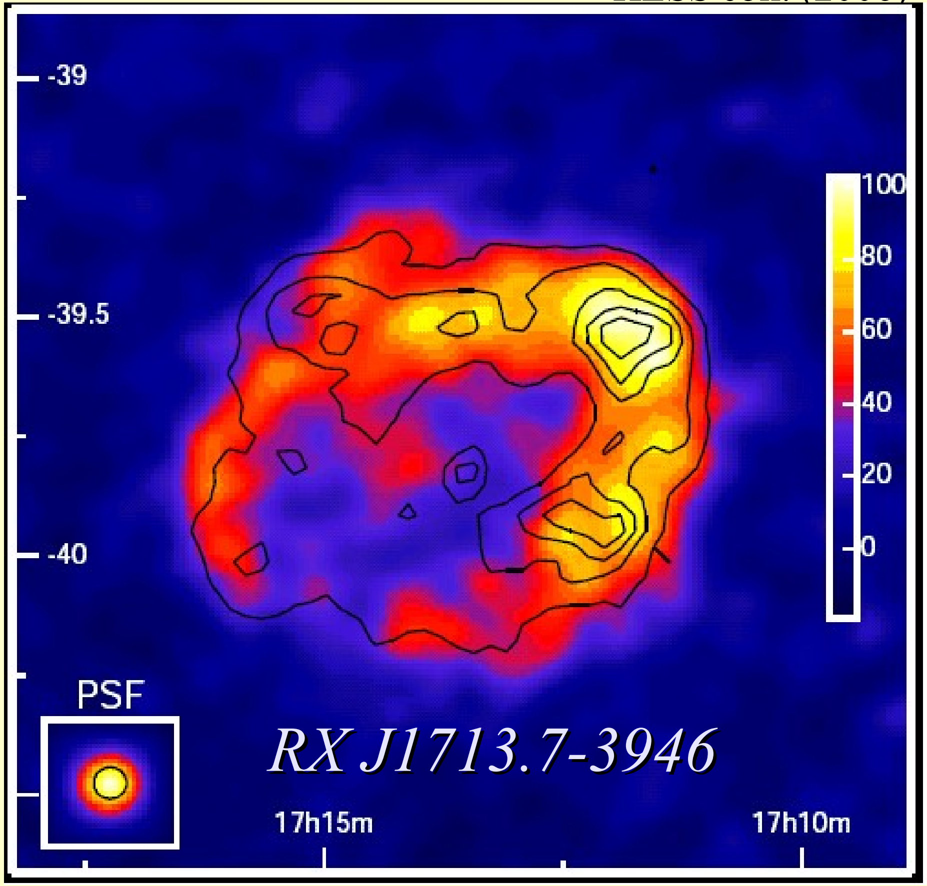

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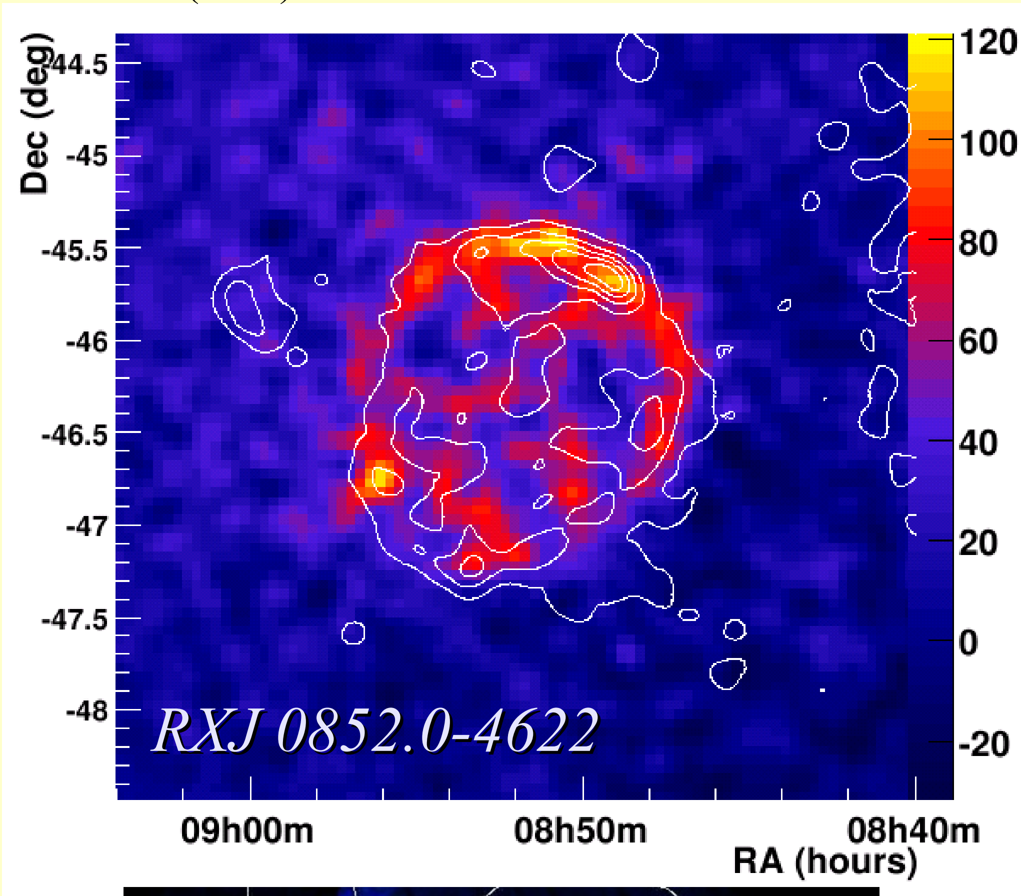

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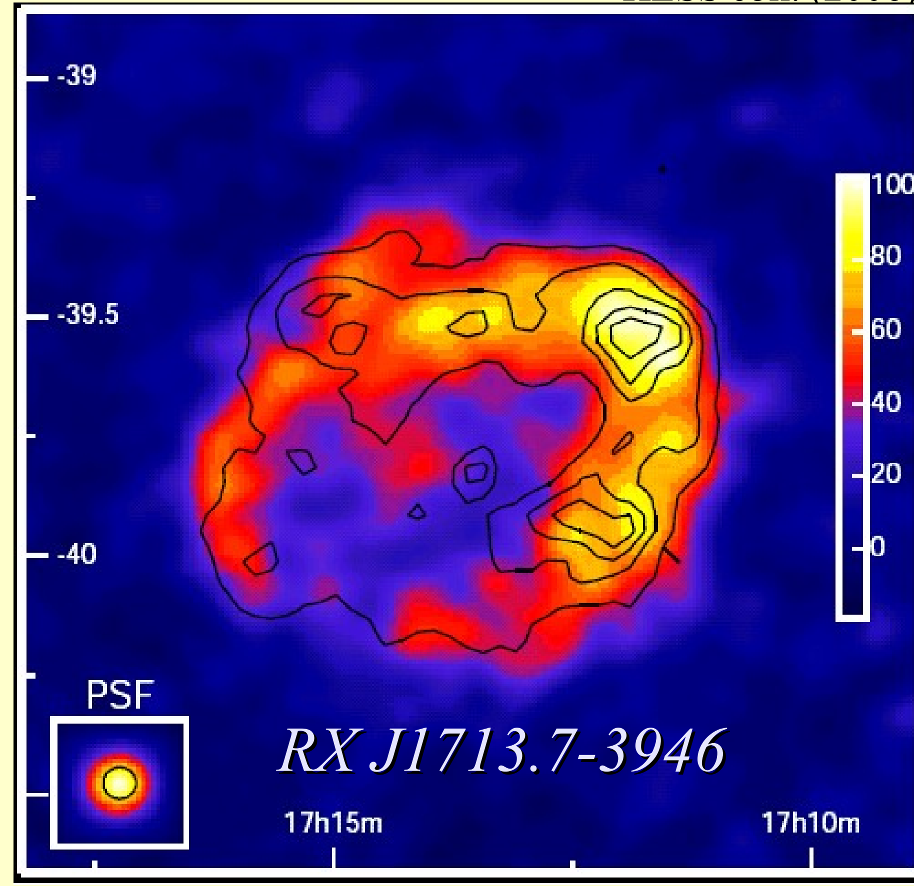
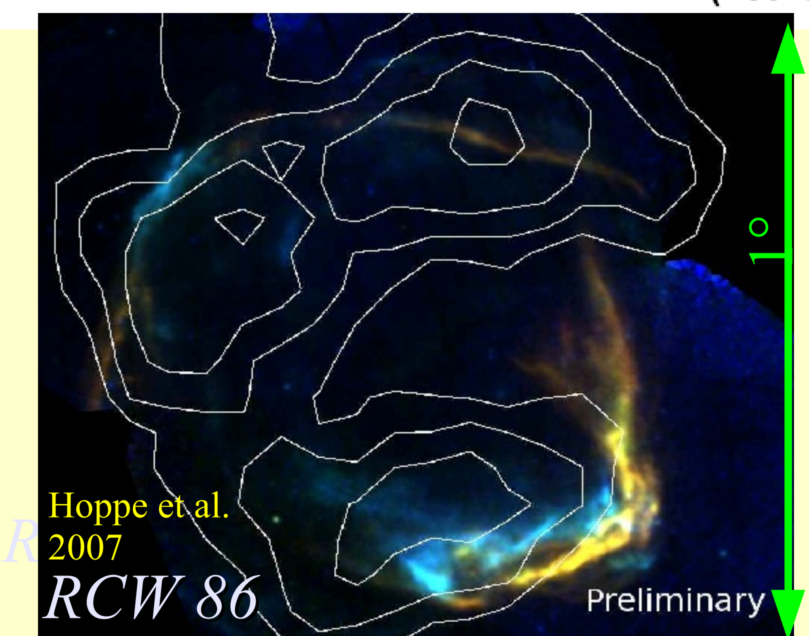




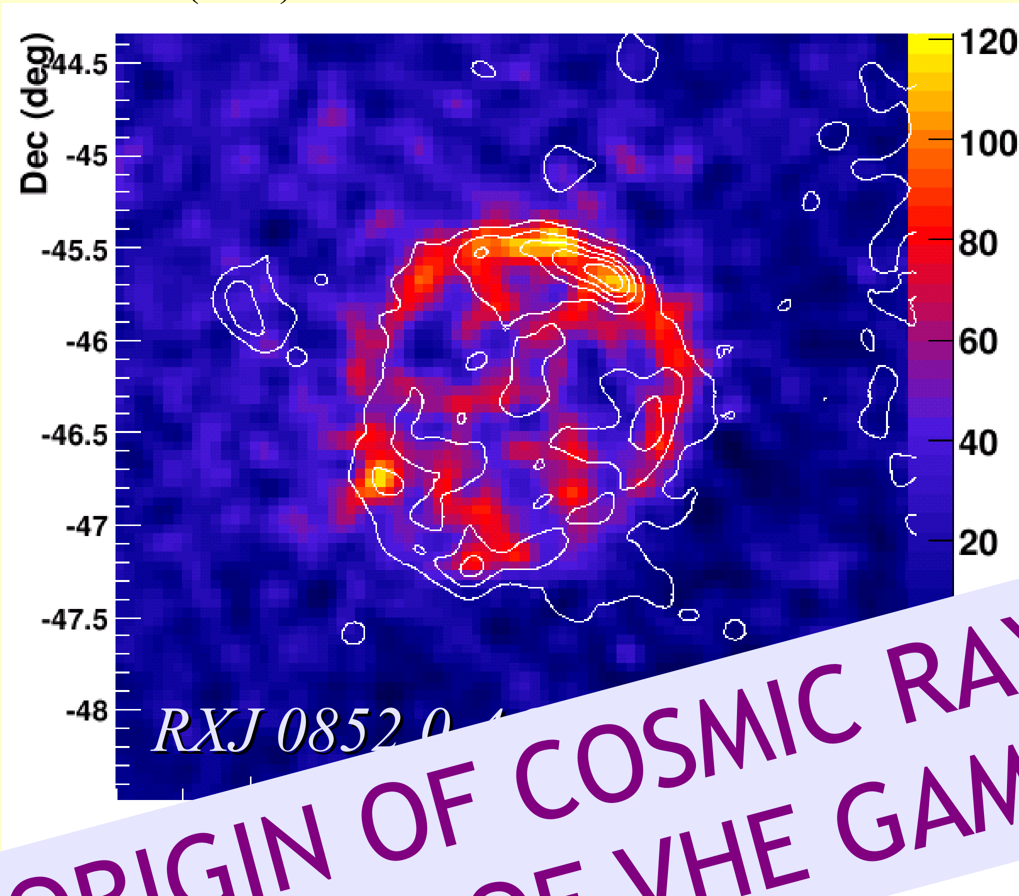
Detection from

- W28 (Aharonian et al. 2007)
- Cas A (Aharonian et al. 2003, Albert et al. 2007)
- IC 443 (Albert et al. 2007)

Upper limits from historical supernova remnants:

- Tycho (Aharonian et al. 2003)
- SN1006 (Aharonian et al. 2005)

HESS coll. (2006)



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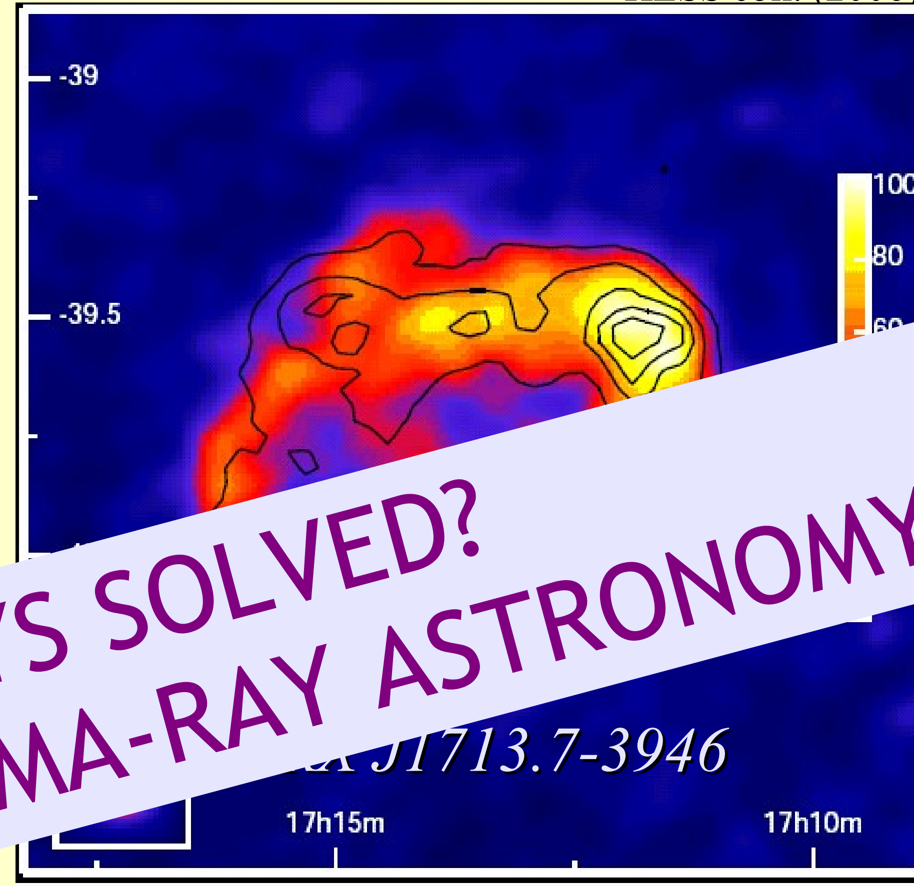


ORIGIN OF COSMIC RAYS SOLVED?
THE END OF VHE GAMMA-RAY ASTRONOMY?

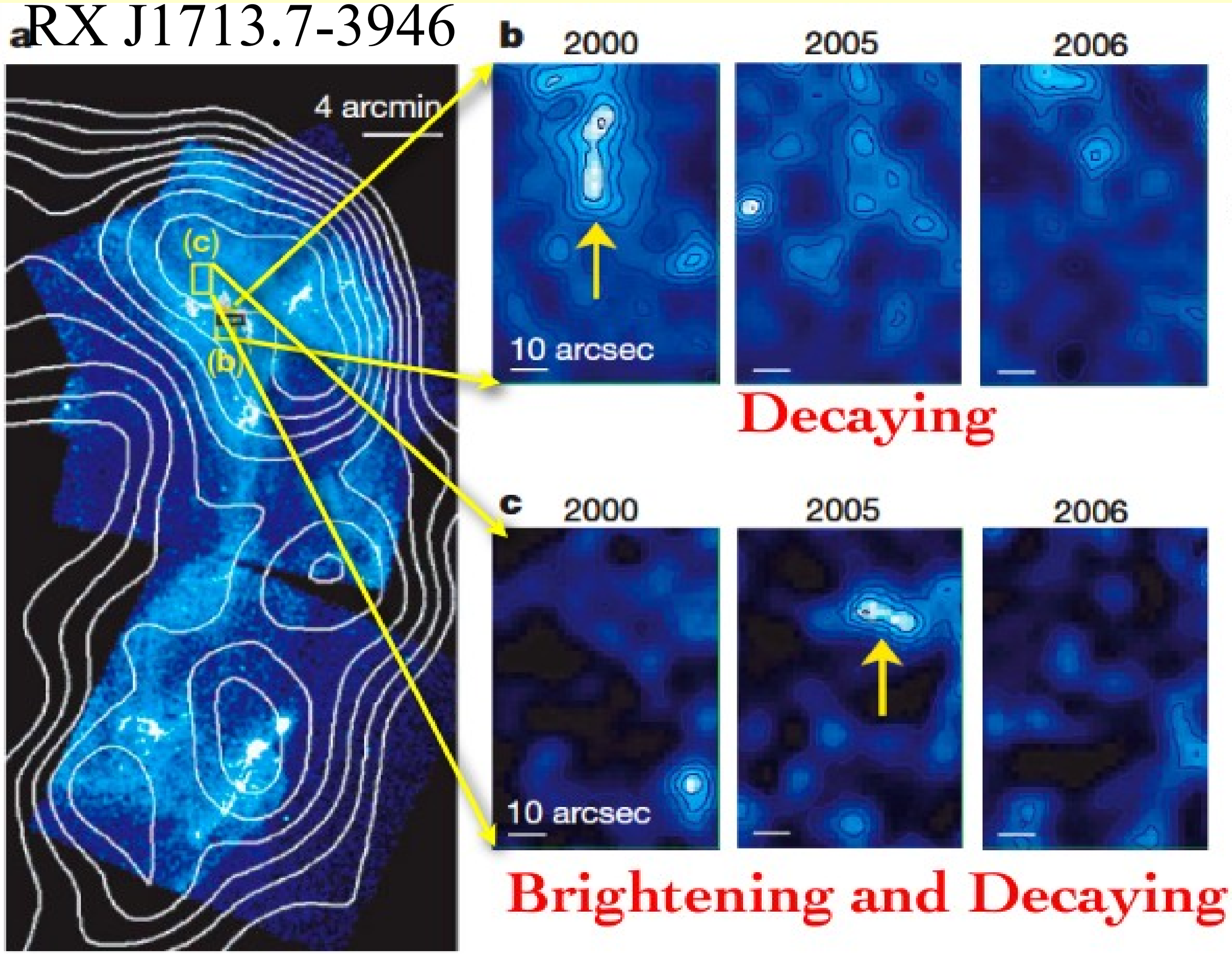
Detection from
- W28 (Aharonian et al. 2007)
- Cas A (Aharonian et al. 2003, Albert et al. 2007)
- IC 443 (Albert et al. 2007)

Upper limits from historical supernova remnants:
- Tycho (Aharonian et al. 2003)
- SN1006 (Aharonian et al. 2005)

Open questions related to SNR origin of GCR

- Gamma-rays from electrons or nuclei (correlation of X-ray / VHE morphology)?
- Maximum energy consistent with “Knee” energy?
- Acceleration efficiency – should be >10% (non-linear shock acceleration)?

Magnetic field amplification due to efficient cosmic ray acceleration



Most filaments (spatially extended) are variable in time!!

Timescale ~ 1 year

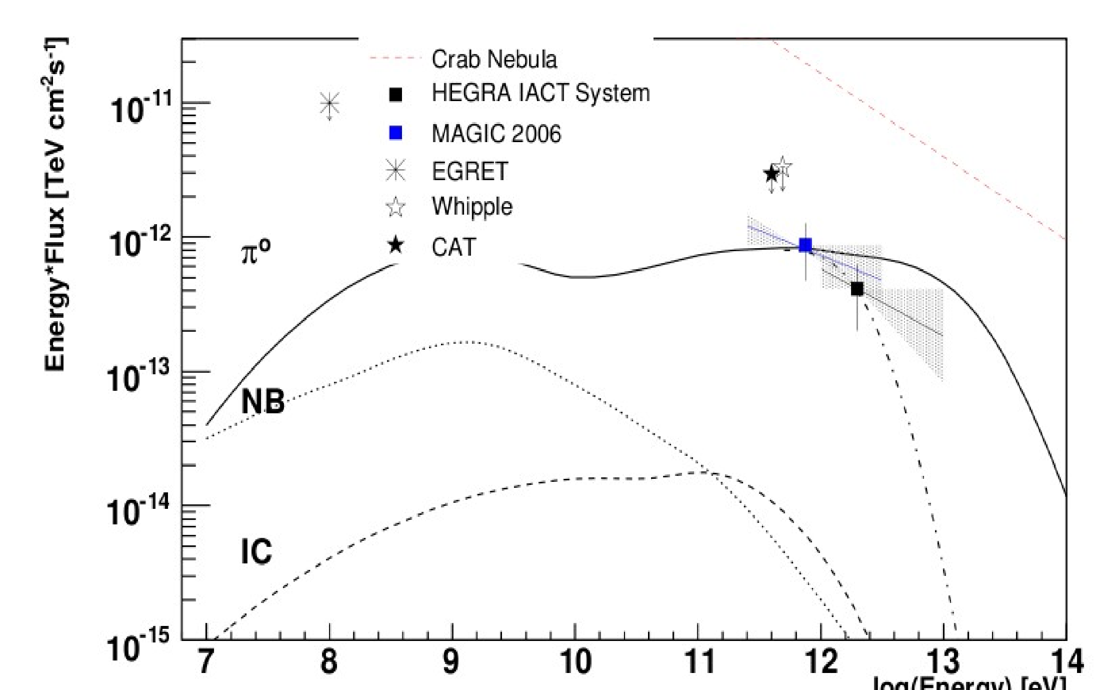
X-ray spectra:
a power law
with photon index ~2

Chandra (color)
HESS (contours)

Uchiyama et al. (2007)

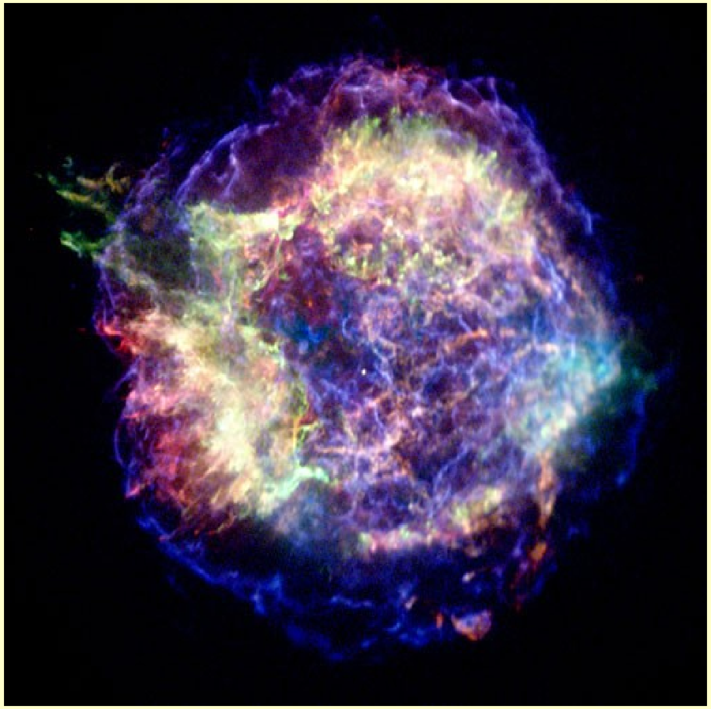
SNR come in different ages

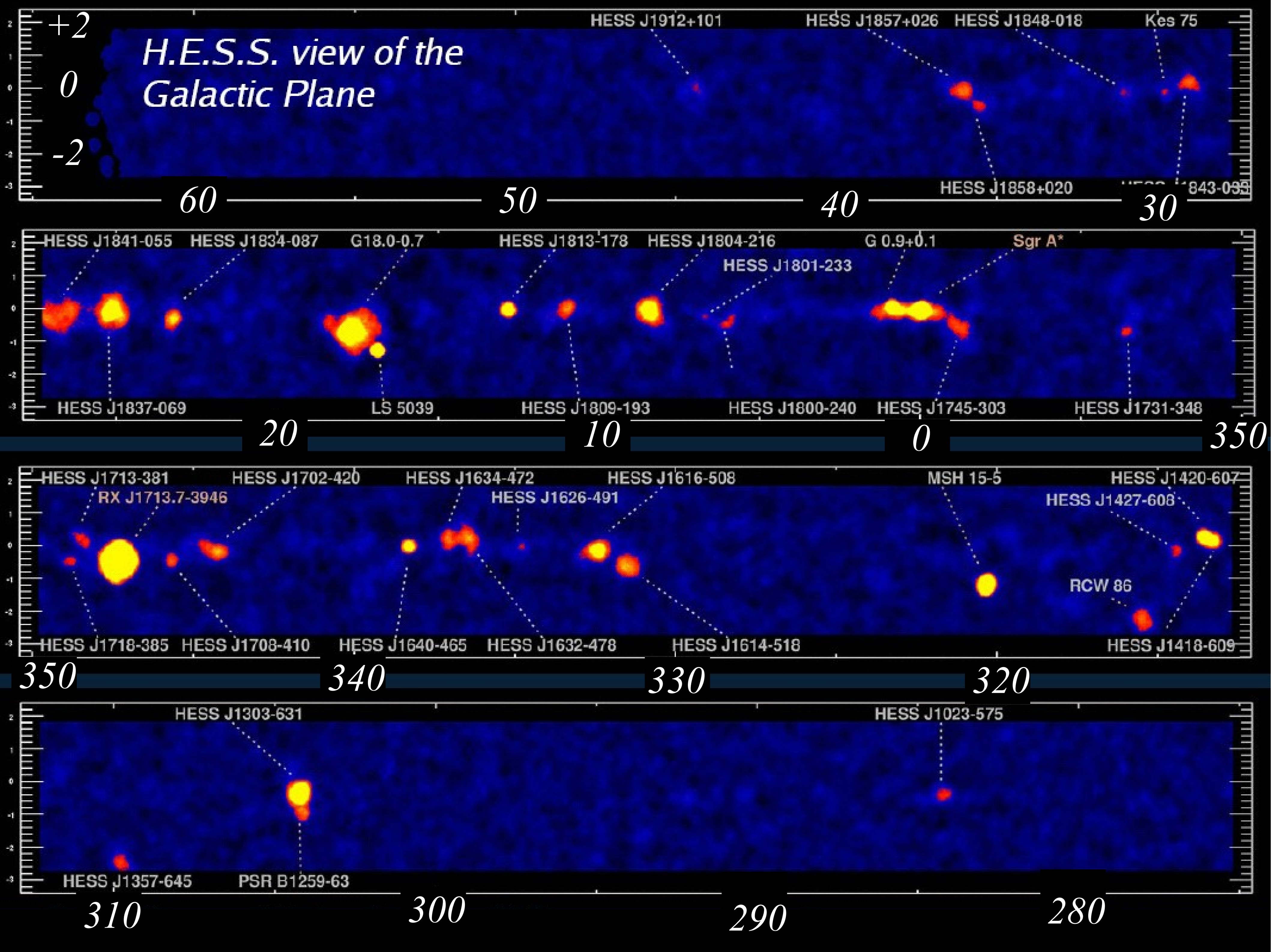
- Maximum energy ~ $t^{-1/5}$
  - Young SNR best candidates for PeV-acceleration
- Historical Supernova: Cas A (~300 yrs)
  - Low efficiency (10^{48} erg), low maximum energy, soft spectrum
  - Trouble?? or just a very special case?
  - More observations needed..



Albert et al. 2007, Berezhko et al. 2003

X-ray image of Cas-A (Chandra CXO)





H.E.S.S. view of the Galactic Plane
+2
0
-2
HESS J1912+101
HESS J1857+026
HESS J1848-018
Kes 75
HESS J1858+020
60
50
40
30
HESS J1841-055
HESS J1834-087
G18.0-0.7
HESS J1813-178
HESS J1804-216
HESS J1801-233
G 0.9+0.1
Sgr A*
HESS J1837-069
LS 5039
HESS J1809-193
HESS J1800-240
HESS J1745-303
HESS J1731-348
20
10
0
350
HESS J1713-381
RX J1713.7-3946
HESS J1702-420
HESS J1634-472
HESS J1626-491
HESS J1616-508
MSH 15-5
HESS J1420-607
HESS J1427-608
RCW 86
HESS J1718-385
HESS J1708-410
HESS J1640-465
HESS J1632-478
HESS J1614-518
HESS J1418-609
350
340
330
320
HESS J1303-631
HESS J1023-575
HESS J1357-645
PSR B1259-63
310
300
290
280

The Galaxy is (almost) crowded!

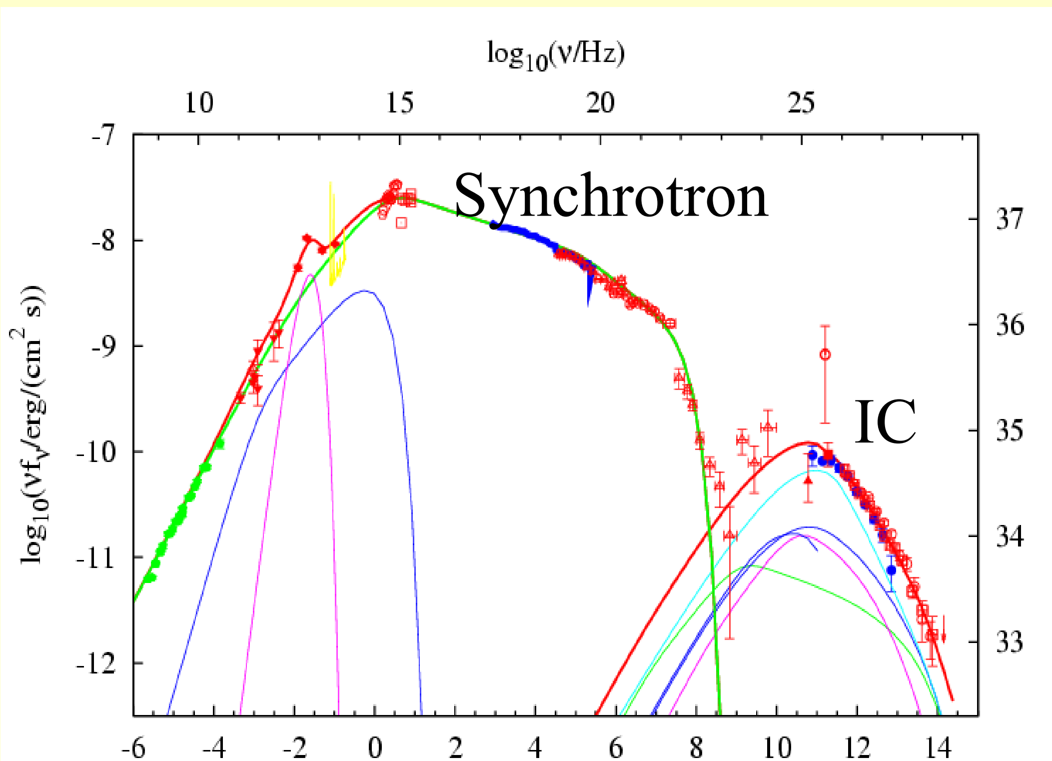
- VHE gamma-ray detection from ~50 Galactic sources
  - Shell type supernova remnants (~6)
  - Pulsar wind nebulae (~18)
  - X-ray binaries (4)
  - Young and massive stellar associations (2-3)
  - Unidentified objects (~21)
  - Molecular clouds (1-3)

Very different object types!

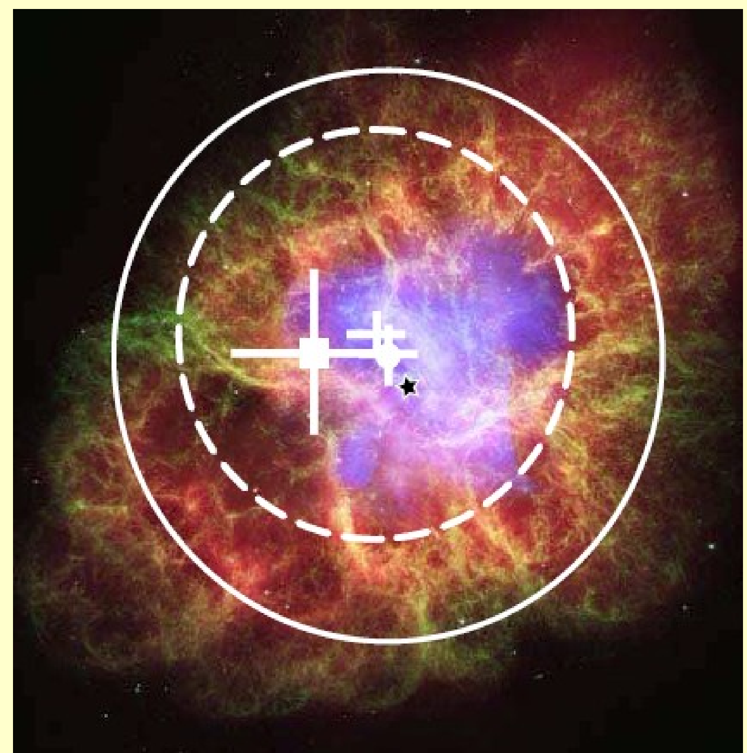
Pulsar wind nebula systems

Crab Nebula : the “standard candle” of VHE observatories

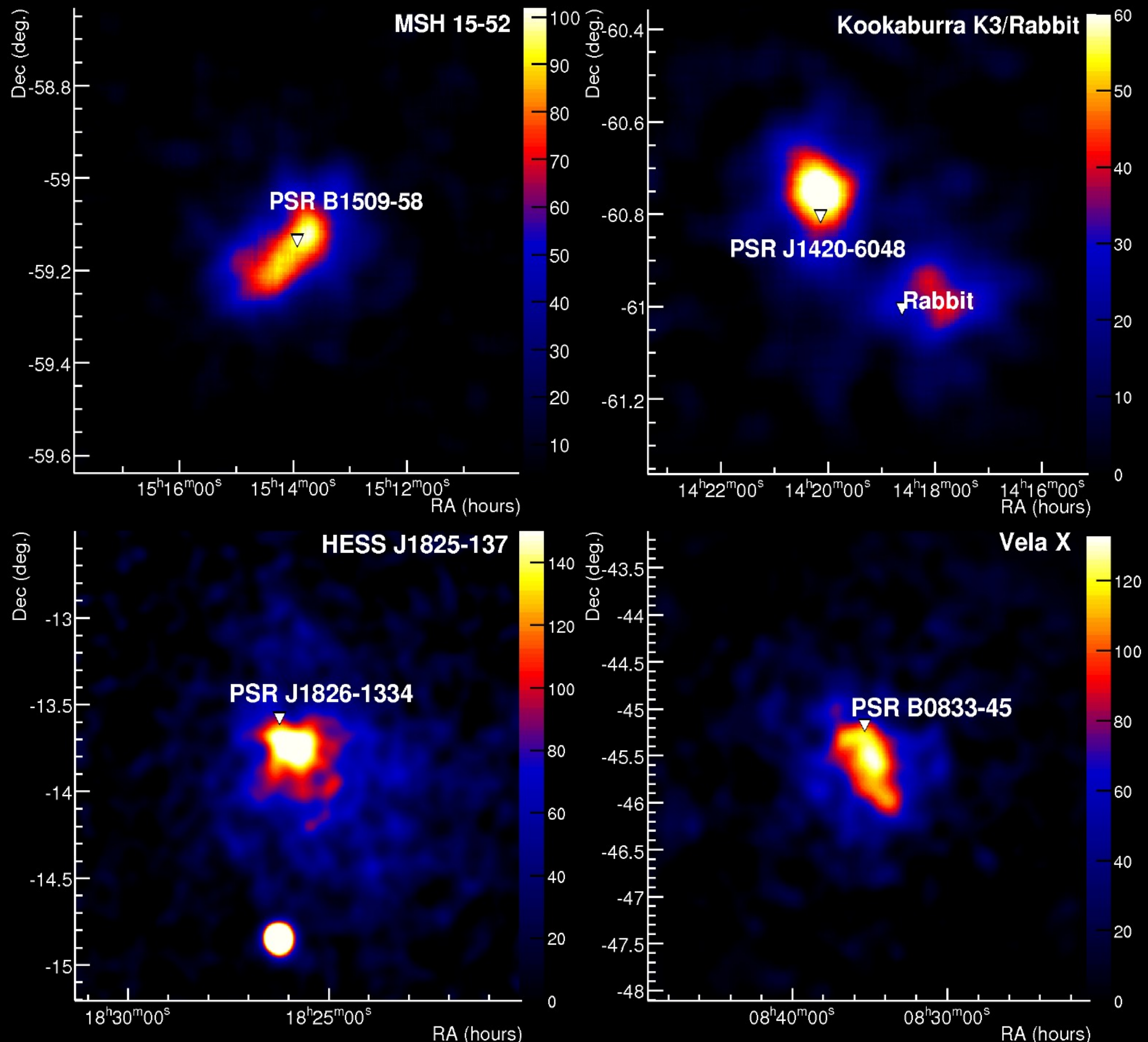
- Brightest and most inefficient “TeV Plerion”
- VHE source extension < 1.5 pc
- radio-to X-rays: Synchrotron emission from relativistic electrons
- HE to VHE gamma-rays: Inverse Compton emission from the same electrons



DH (2007)

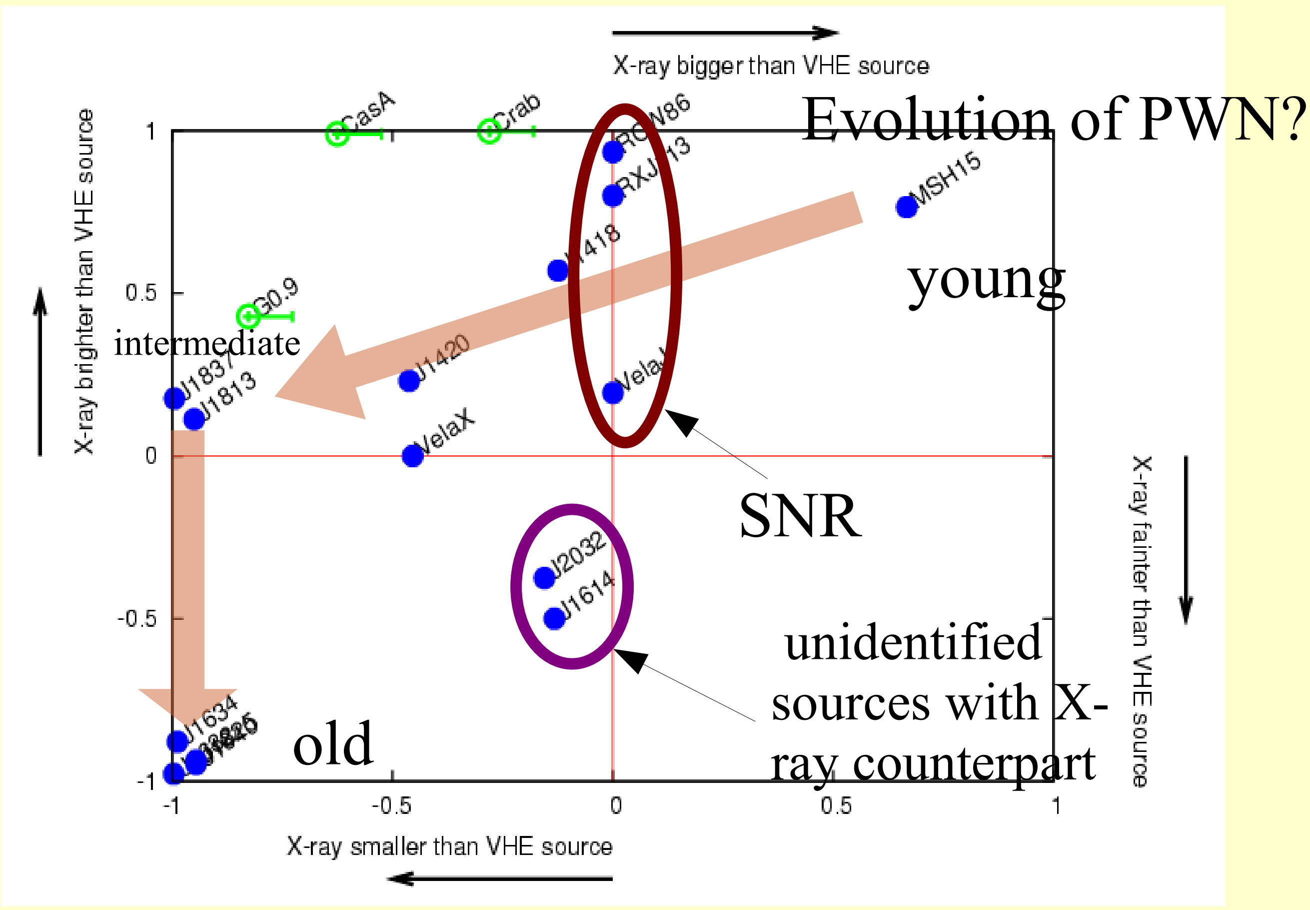


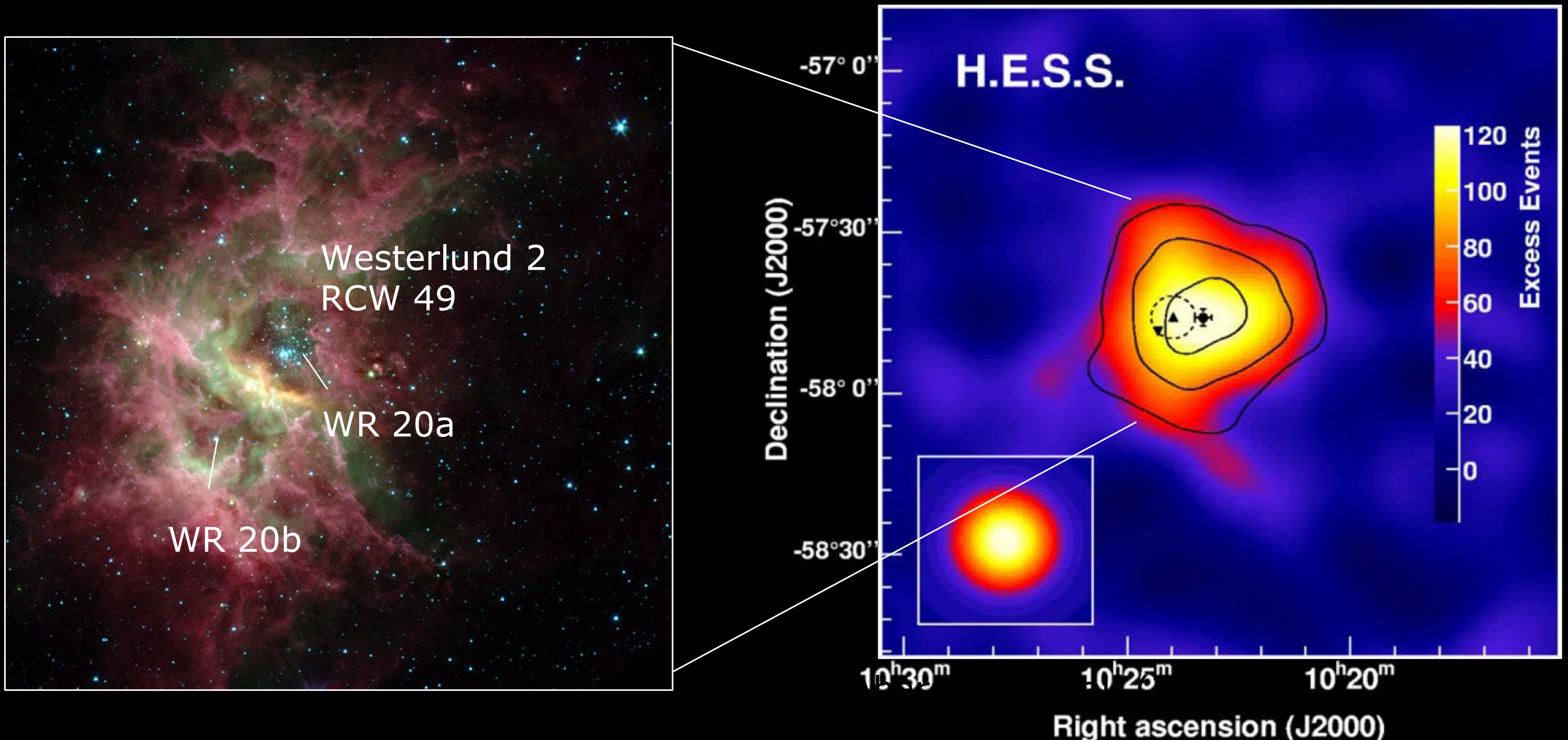
Example for offset TeV Plerions



Counterparts-Study

- Pulsar-Wind-Nebulae and shell-type supernova-remnants have X-ray counterparts





Open stellar association *Westerlund 2*: too young to have SNR

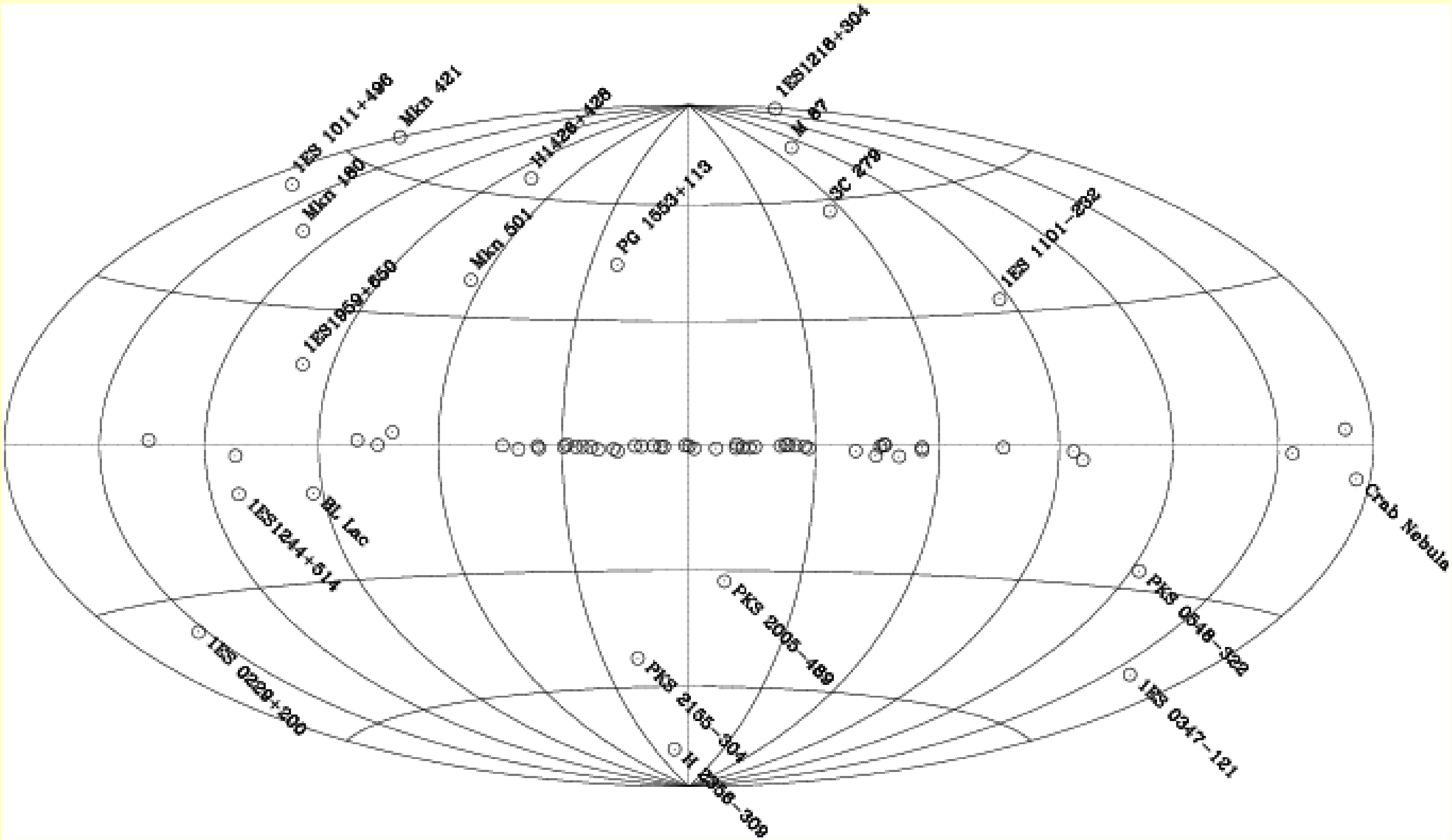
Emission from binary W-R stars?

Total power ~10^{37} erg/s in stellar winds, integrated kinetic energy~10^{50}-10^{51} ergs (similar to SNR)

Acceleration in Wind-Wind interaction, cumulative wind driven shocks or combination?

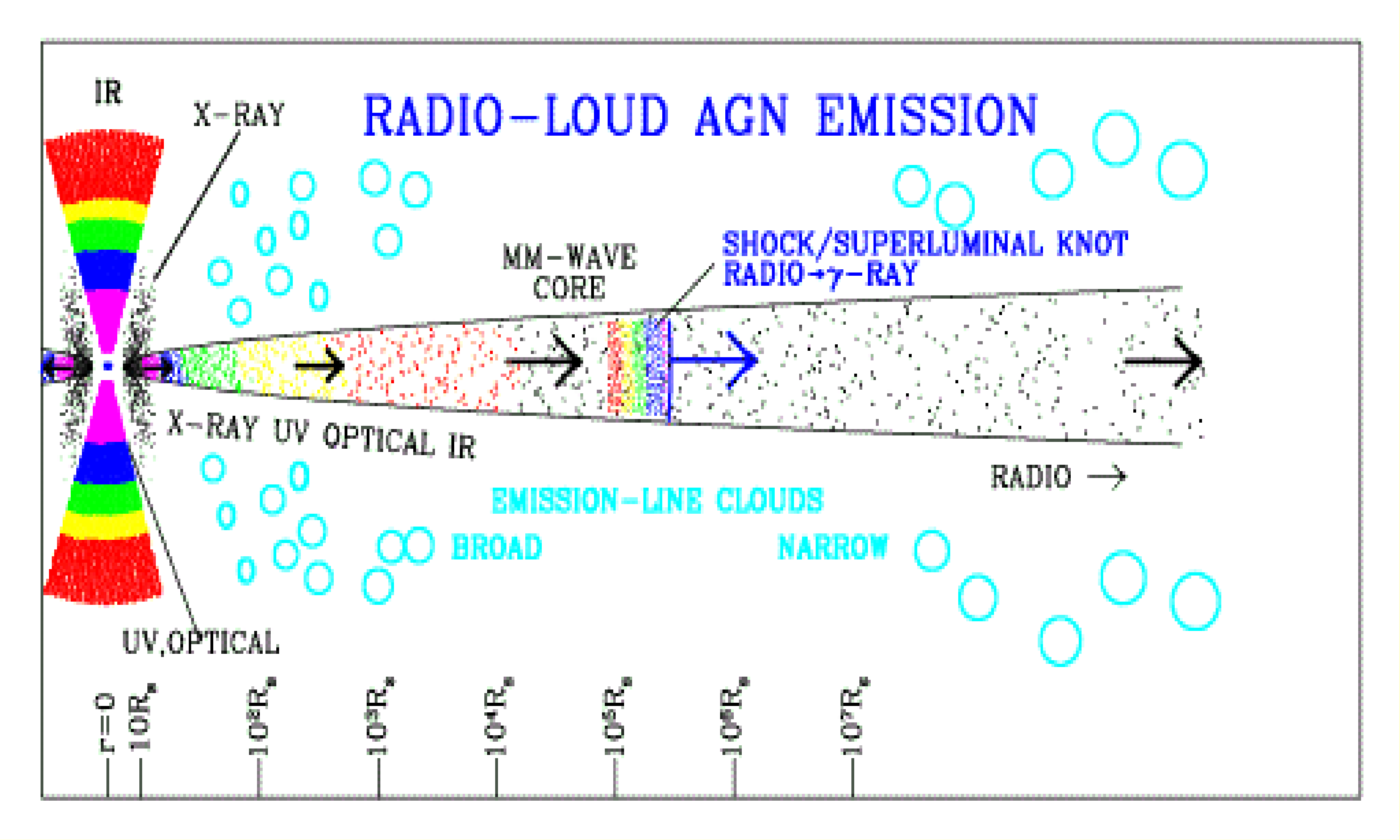
More stellar associations with VHE counterparts: Cyg OB2, Berk 87?

What are these telephone numbers?



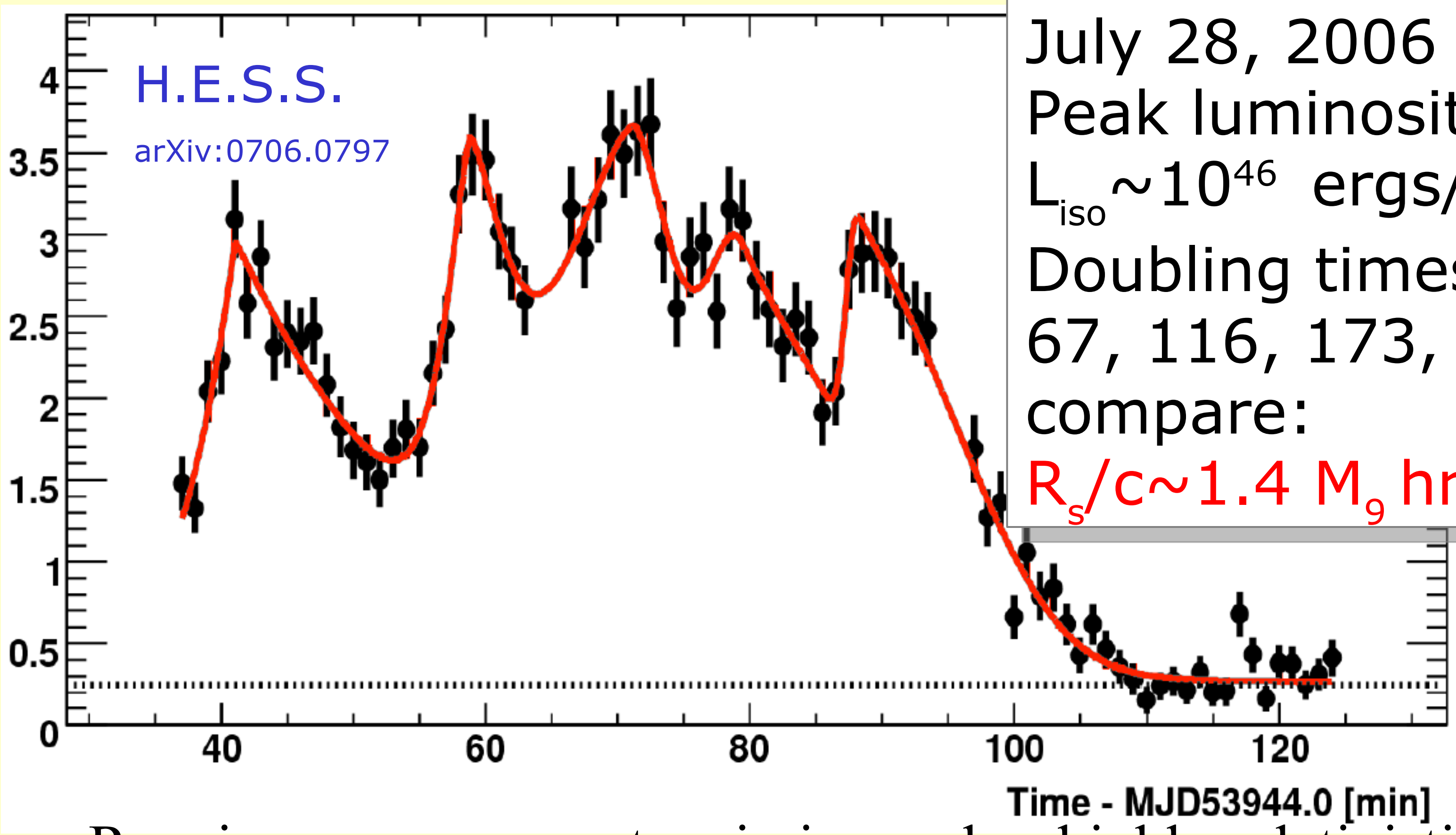
17 Blazars, 1 Radio galaxy, 1 Flat-spectrum radio Quasar
max. red-shift: 0.5

TeV Blazars: Extreme Active Galactic nuclei



Schwarzschild Radius $R_s = 2GM/c^2 = 3\times10^{14}$ cm M_9, $M = M_9 \cdot 10^9\ M_\odot$

(Ultra) fast variability



PKS 2155−304
z = 0.116

July 28, 2006
Peak luminosity
$L_{iso} \sim 10^{46}$ ergs/s ($\sim 10^{12}\ L_{\odot}$)
Doubling times
67, 116, 173, 178 ±50 s
compare:
$R_s/c \sim 1.4\ M_9$ hrs!

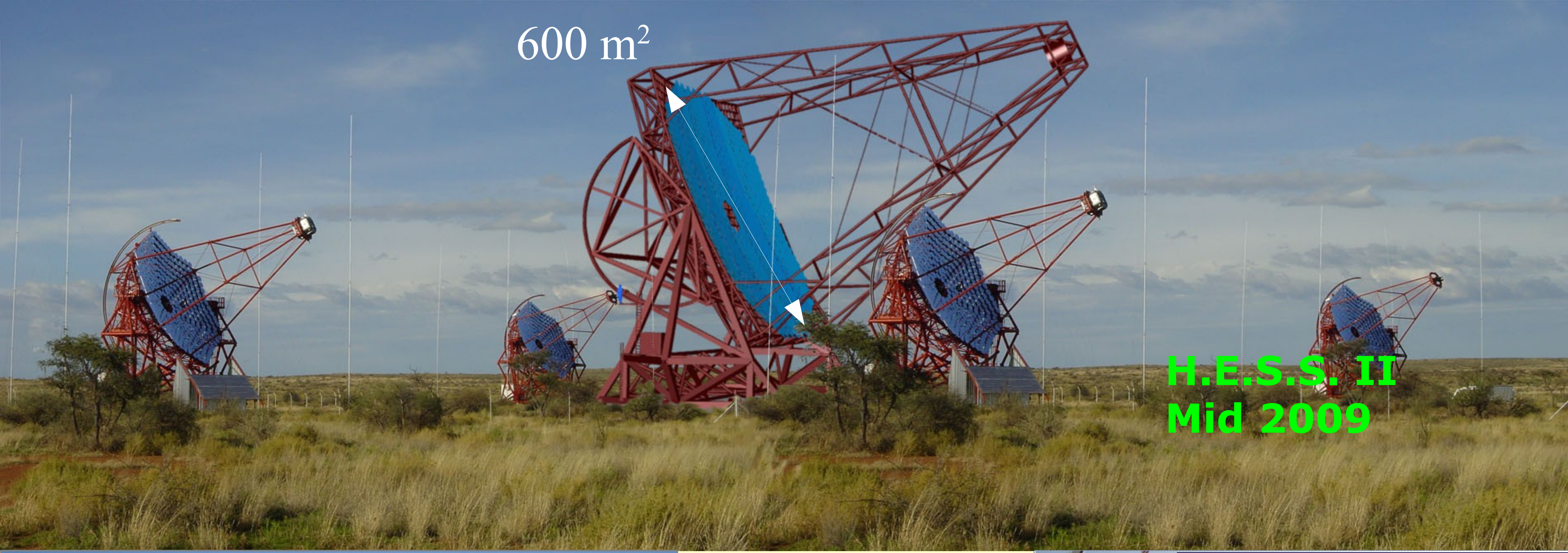
Requires very compact emission and or highly relativistic motion region. Optically thick? High Doppler boost similar to GRB (~100)

Waiting for detection?

- Galaxy clusters (too extended, too faint)
- Starburst Galaxies (too faint)
- Pulsars (spectra cuts off before VHE energies)
- Gamma-Ray Bursts (too short? Too far away?)

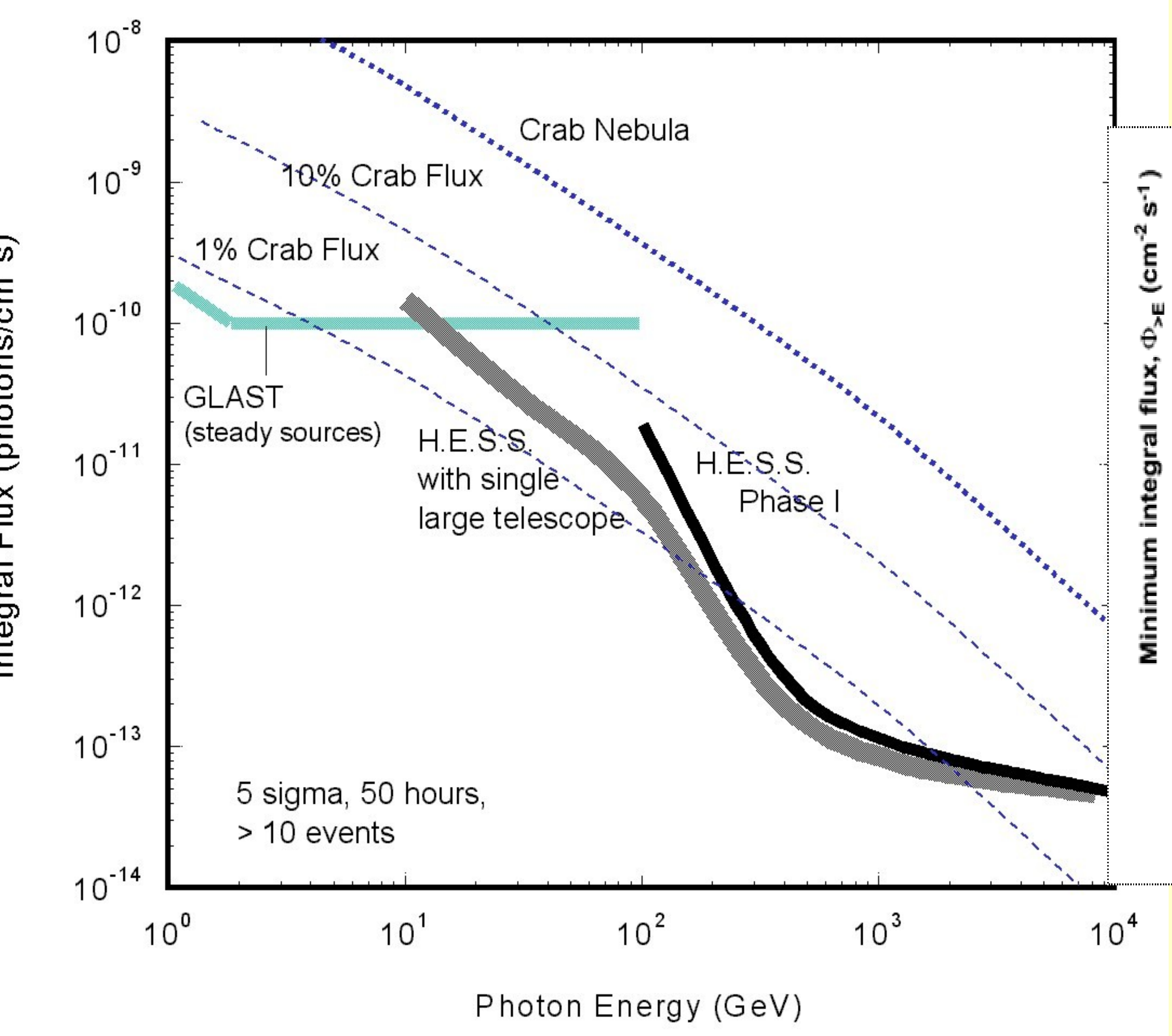
Future experiments:
Scientific motivations (subjective list)

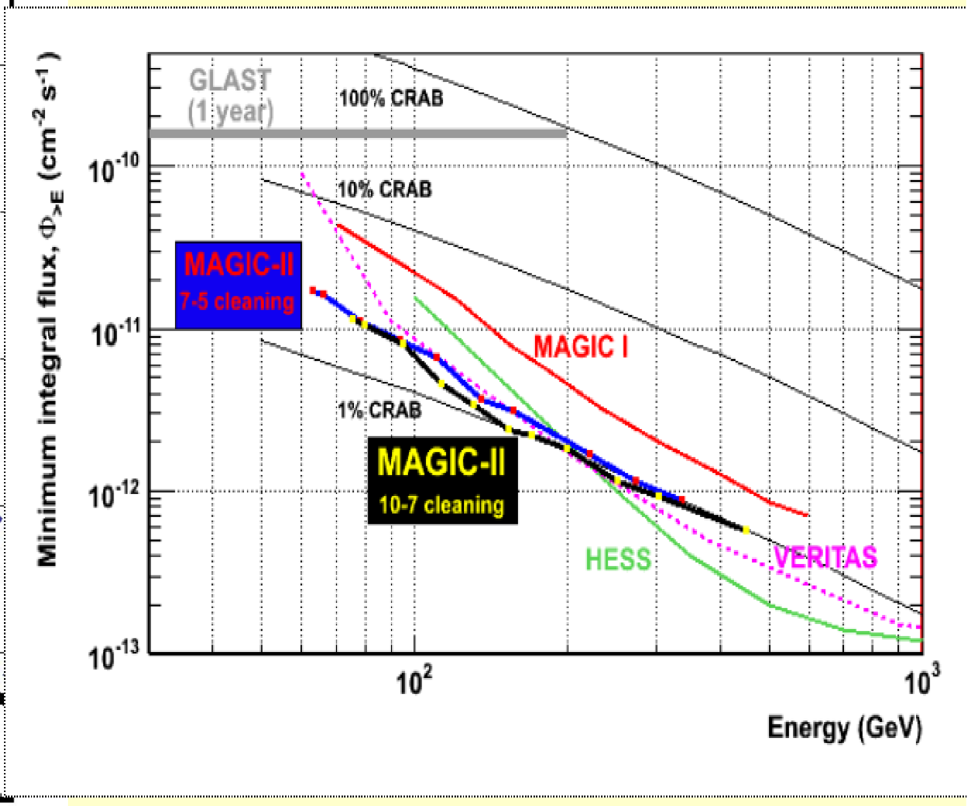
- Particle acceleration:
  - Complete census of Cosmic Ray accelerators ->Improved Sensitivity, energy coverage
  - Acceleration in ultra-relativistic outflows (AGN, Pulsar-Wind-Nebula): ->Improved collection area, lower energy threshold, improved angular resolution
- Fundamental science:
  - Indirect search for Dark Matter annihilation (improved energy resolution, low energy threshold)
  - Search for violation of Lorentz Invariance (absorption, dispersion of photons)-> large collection area, low energy threshold



Extensions of Existing Instruments

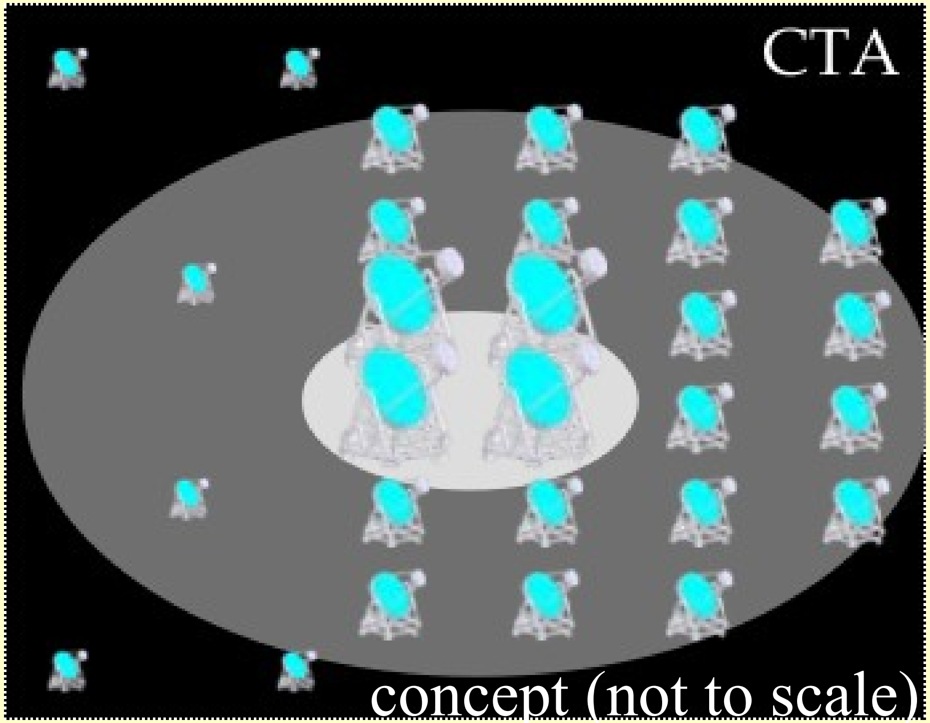
Improved sensitivity and energy reach HESS II, MAGIC II





The long-term future (>2015, >100 M€)

- European project: Cherenkov telescope array (CTA)
- US-American project: Advanced Gamma-ray imaging System (AGIS)



The future is bright and promising, because of

- energy coverage from 20 MeV to 200 TeV
- first time observations between 10 GeV and 100 GeV ->discovery potential
- LHC results that will guide the indirect search for Dark matter in the Universe
- new X-ray missions (eg. SIMBOL-X) that will help us understand in depth the physics of gamma-ray sources
- exciting interplay of particle physics, Astrophysics, Plasma Physics, Cosmology

..thank you for your attention