VHE γ-Ray Astronomy

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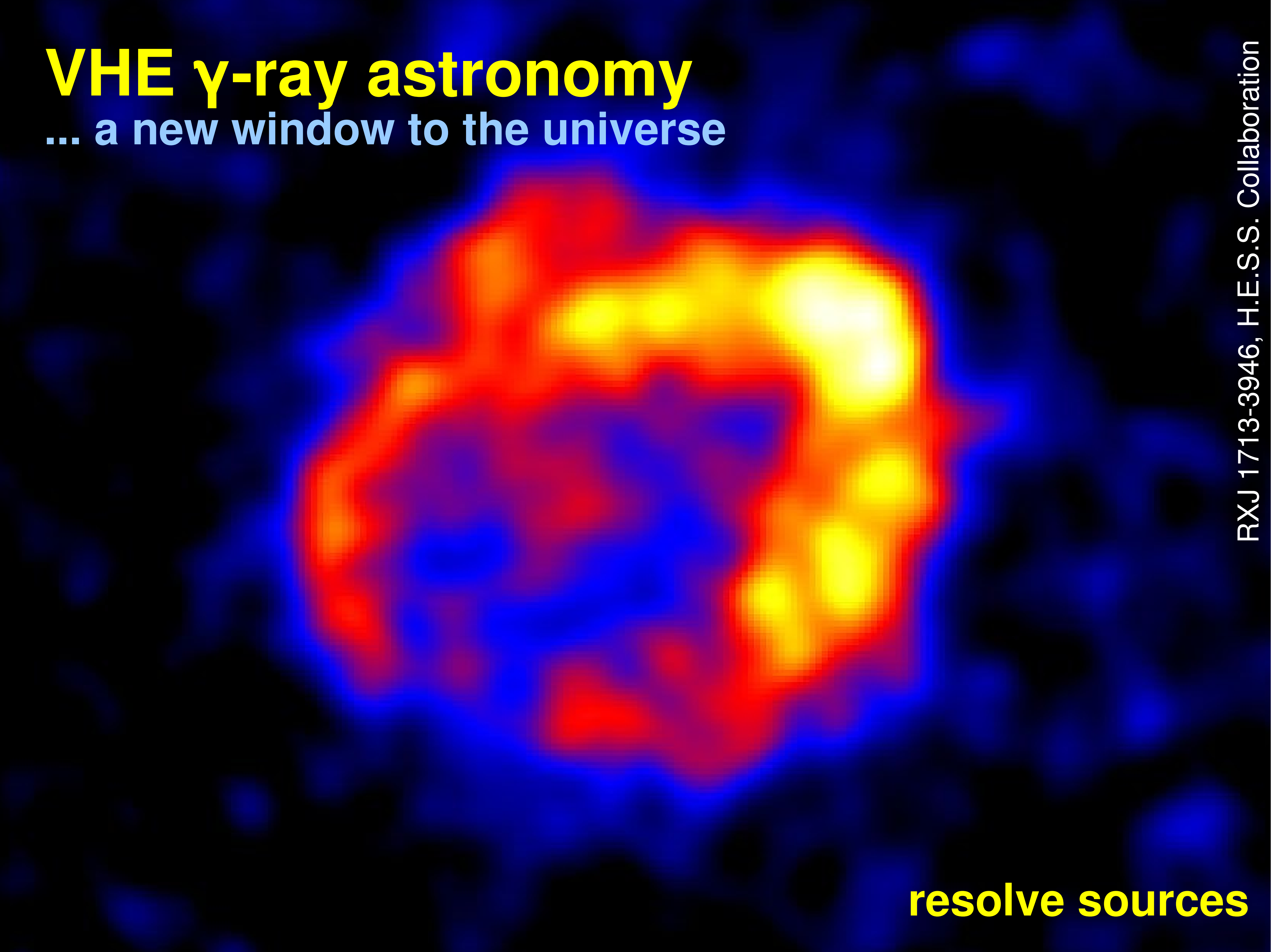
VHE γ-ray astronomy

... a new window to the universe


VHE γ-ray astronomy
... a new window to the universe
RXJ 1713-3946, H.E.S.S. Collaboration
resolve sources

VHE γ-ray astronomy

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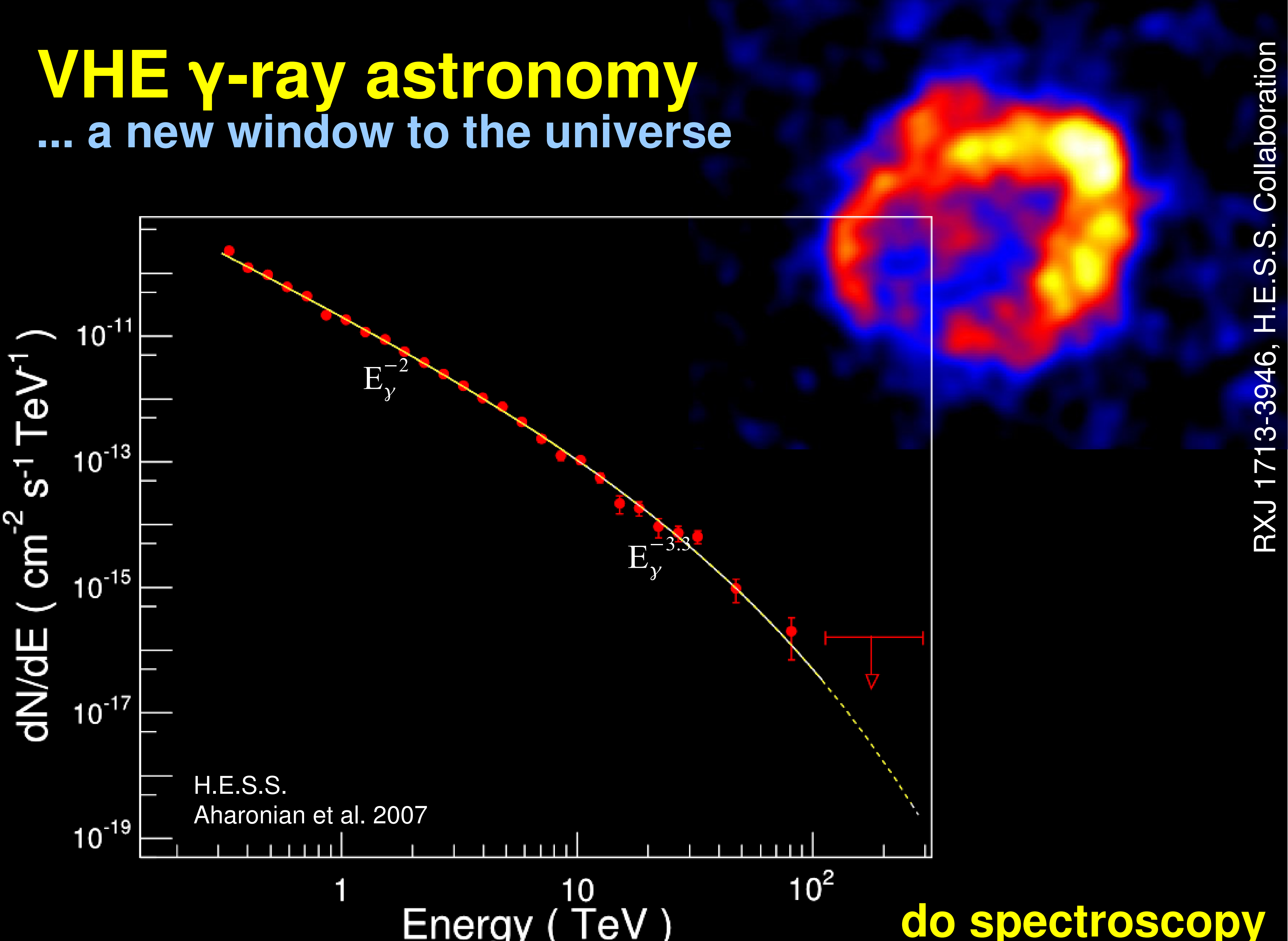

do spectroscopy

VHE γ-ray astronomy

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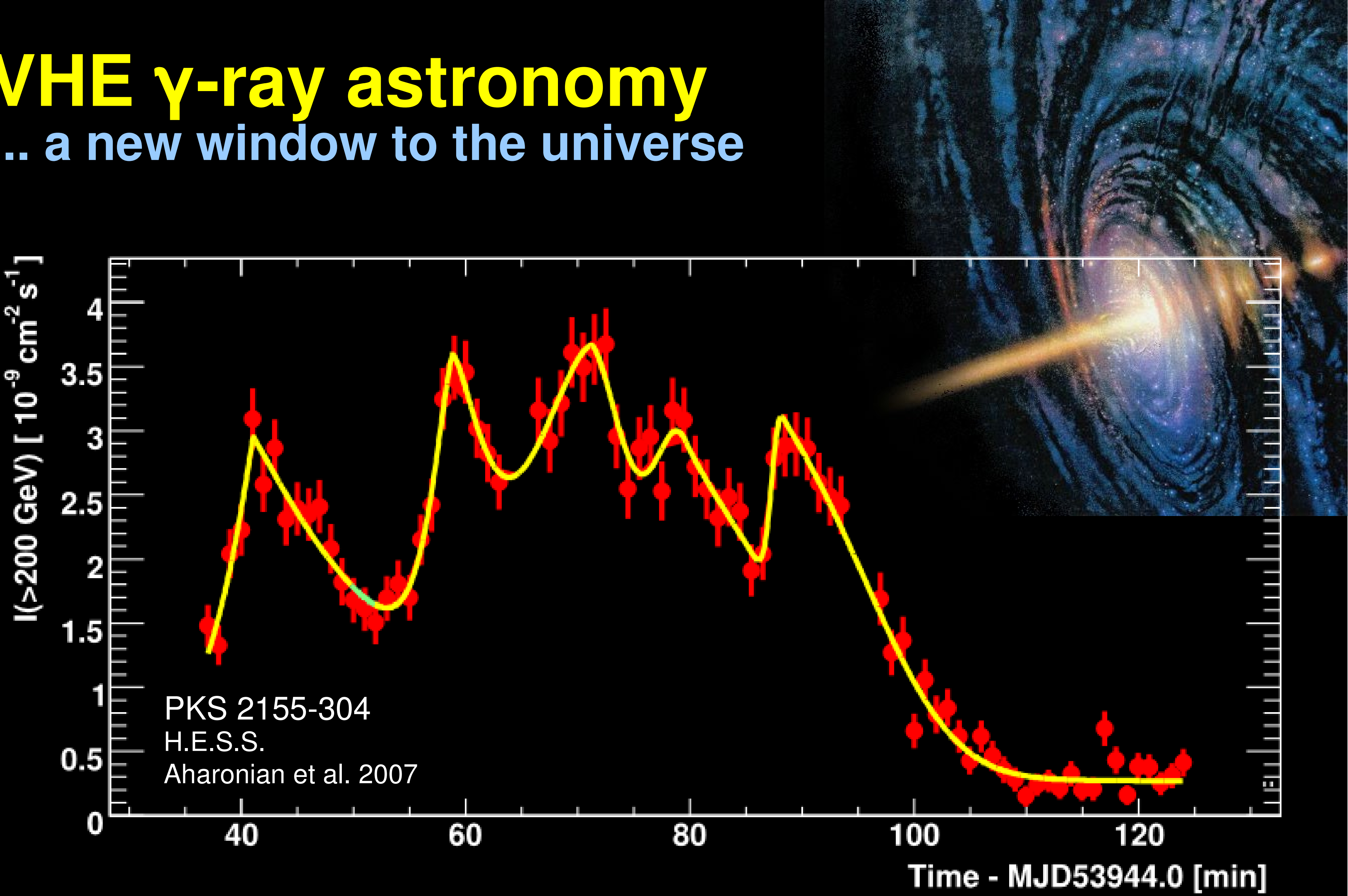
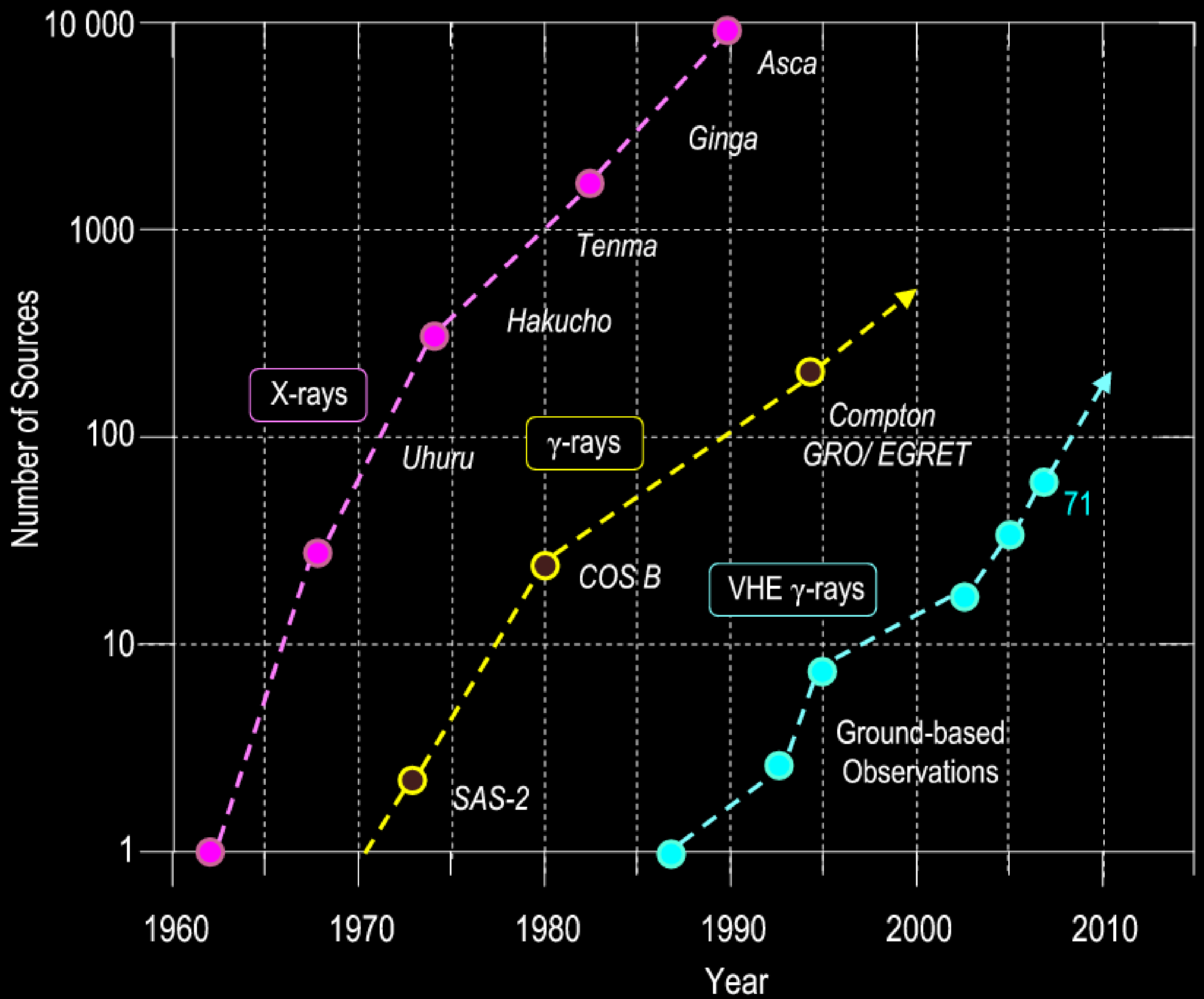


measure flux variability

VHE γ-ray sky in 2009

... more than 75 sources known



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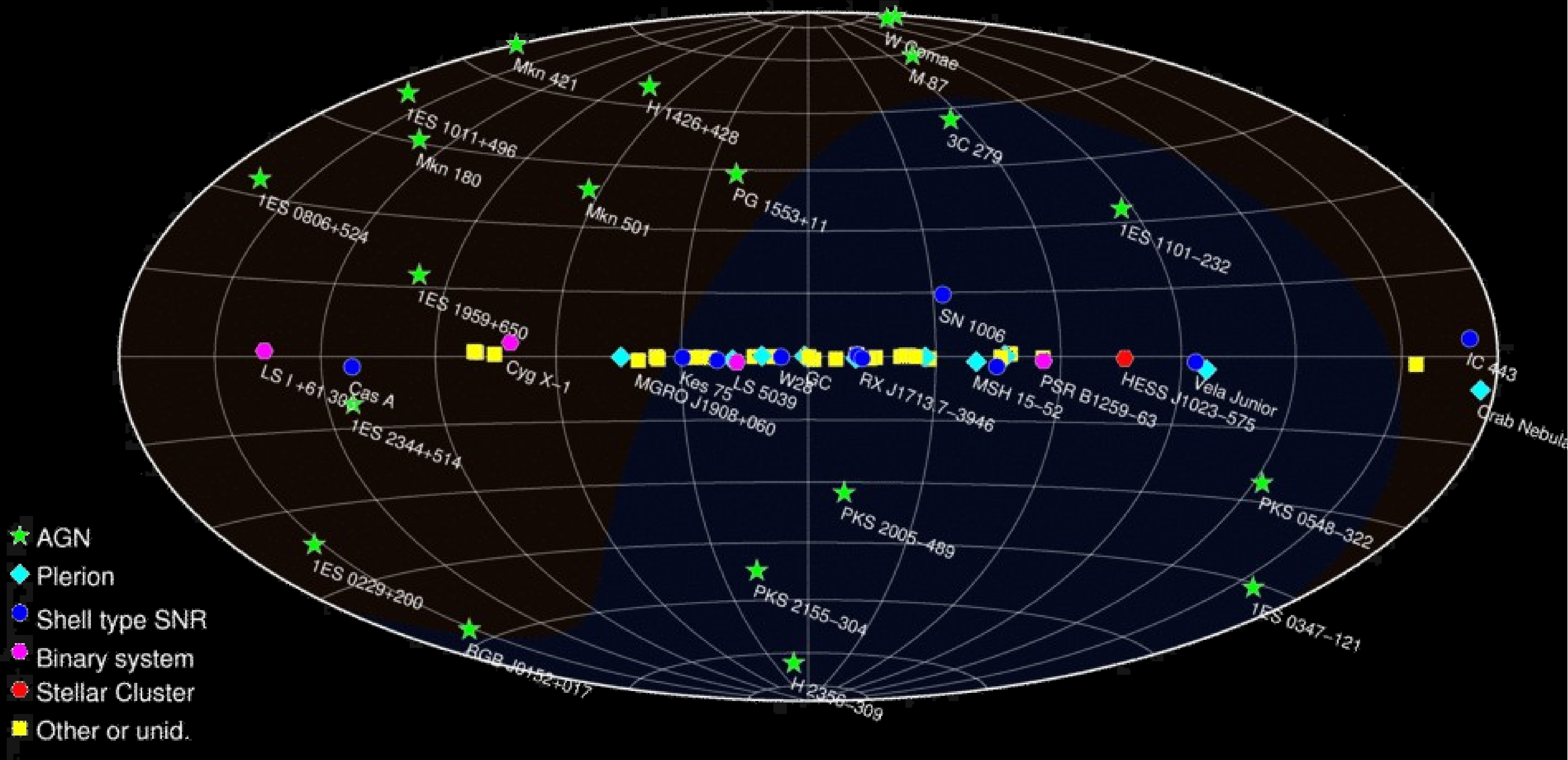
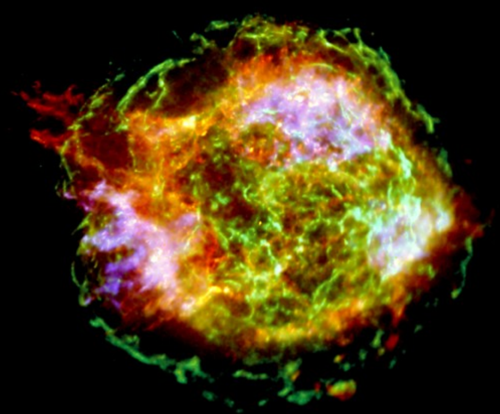


(Some) topics of VHE γ-ray astronomy

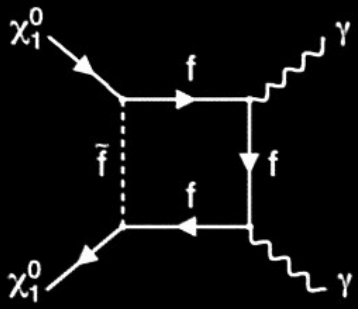


Astrophysics

- Which are the cosmic PeVatrons?
- How do they work?
- Acceleration, emission, propagation

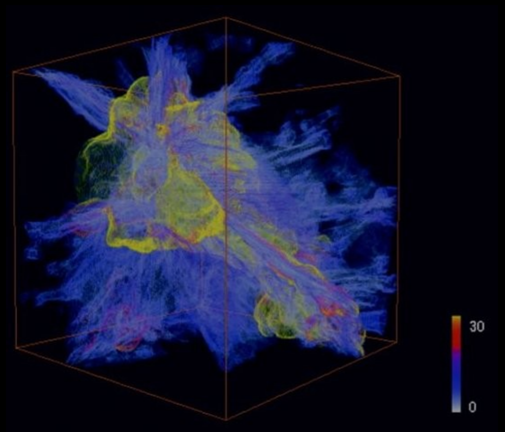
Fundamental Physics

- Indirect Dark Matter searches
- Energy dependence of speed of light



Cosmology

- Extragalactic Background Light
  $\rightarrow$ star formation in the early universe
- Galaxy clusters as storehouses of cosmic rays



Cosmic Ray Spectrum

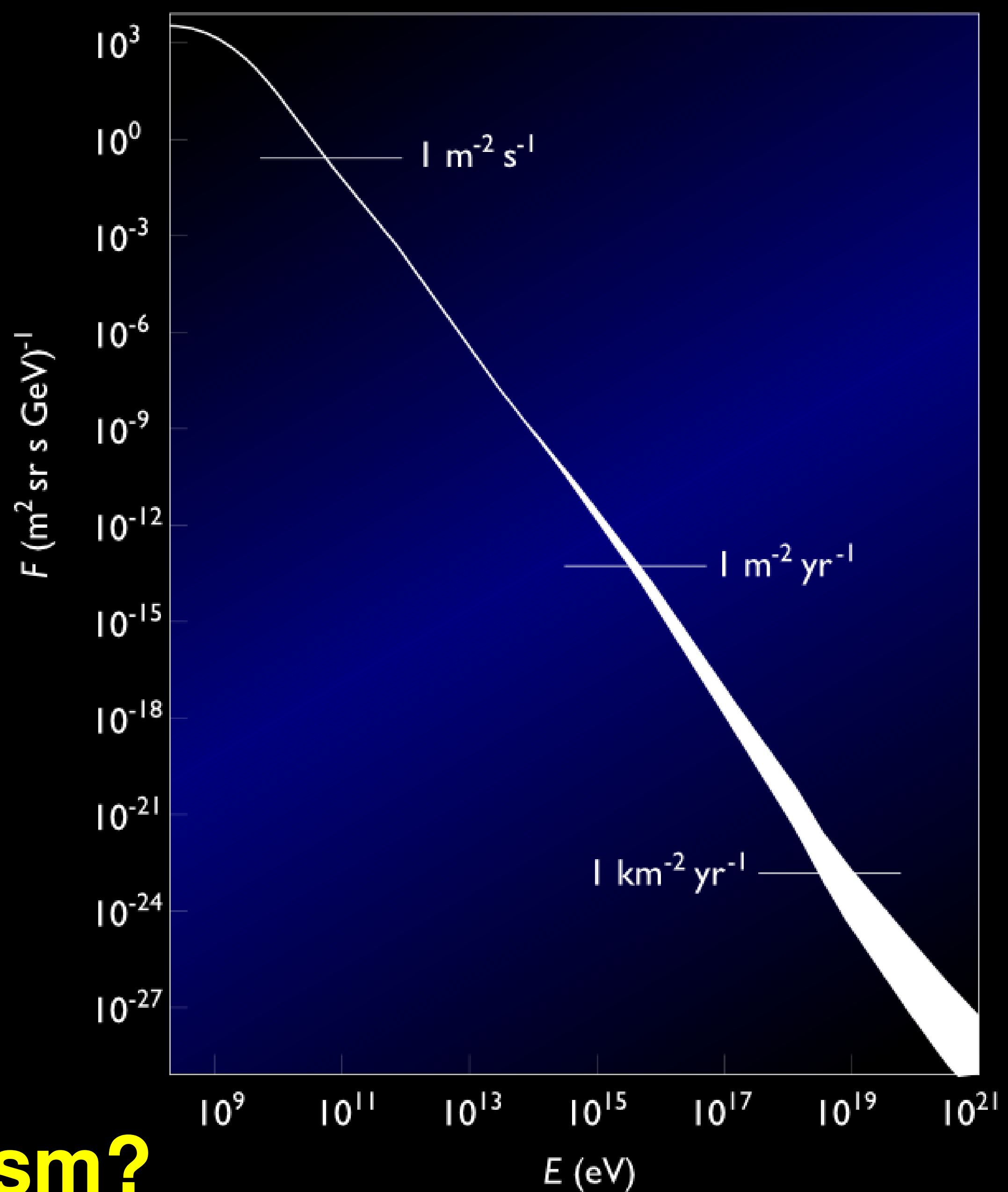
- power-law: $F \sim E^{-2.7}$
- non-thermal
- energy density $\approx$ 1 eV/cm^3

Composition

- Protons 87%
- Helium 12%
- heavier nuclei 1%
- few electrons & gammas

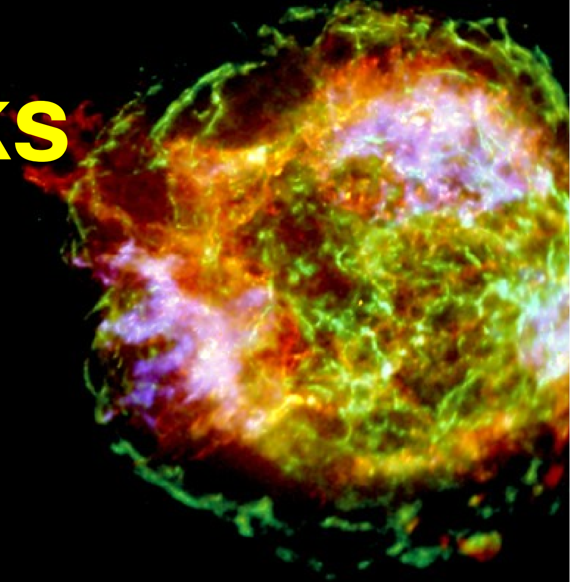
Propagation

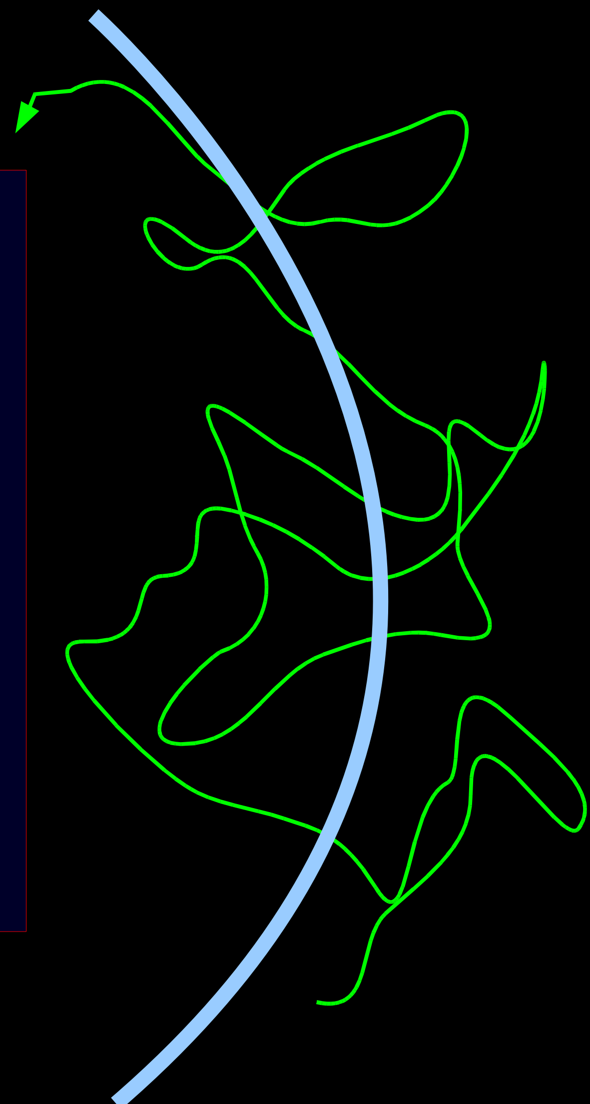
- stay 10^7 years in Galaxy
  $\rightarrow$ have to sustain $3 \cdot 10^{40}$ erg/s
- energy-dependent escape
  $\rightarrow$ source spectra $\sim E^{-2}$



Sources?
Acceleration mechanism?

Acceleration in Strong Shocks





- Astrophysical strong shock

- Particles cross shock forward and backward
- Head-on collisions
  $\rightarrow$ energy gain

- Particles get lost downstream

$\rightarrow$ unique spectral index of ~2

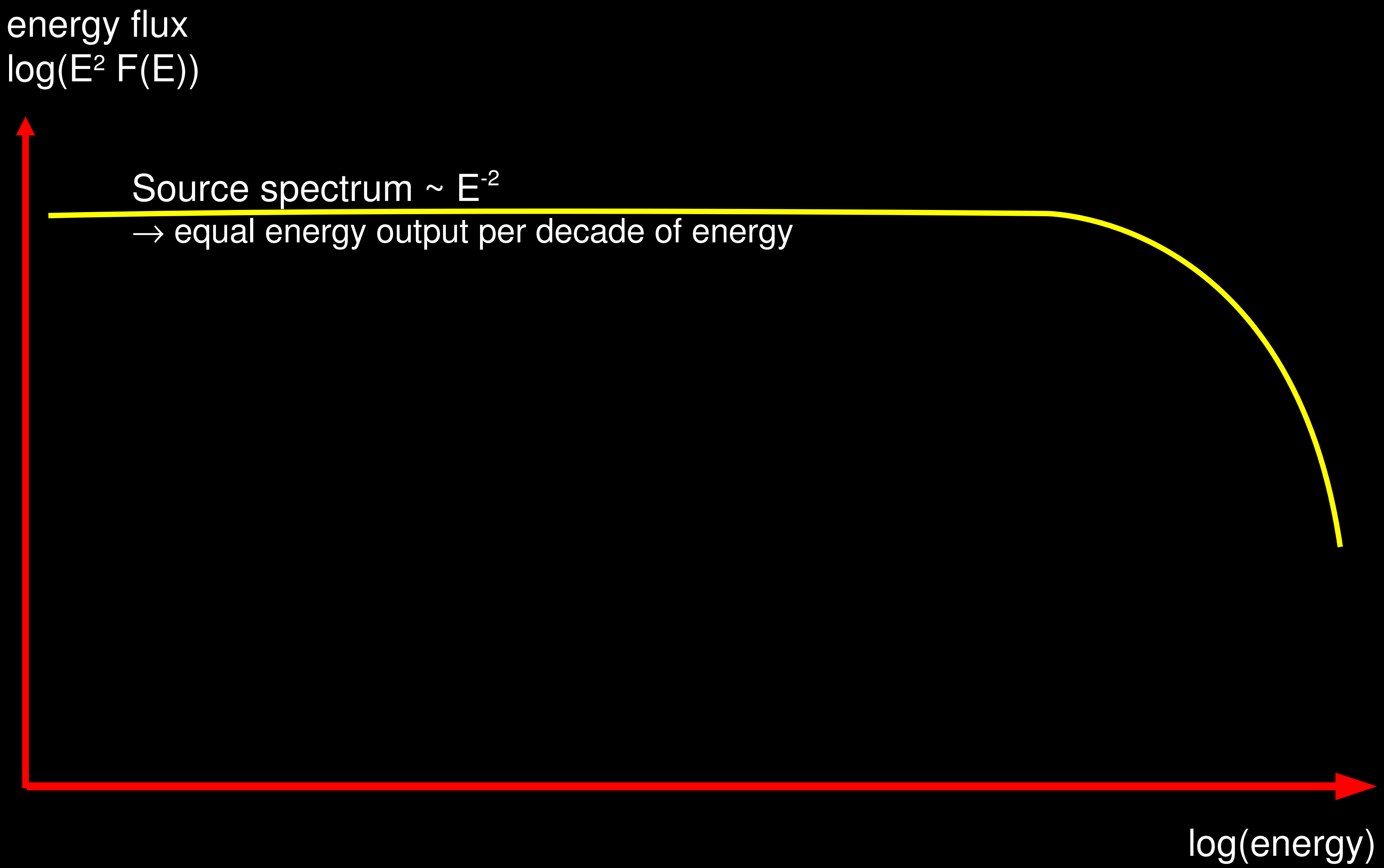
$$\frac{dN(E)}{dE} = aE$$

$$\frac{dN}{dt} = -bN$$

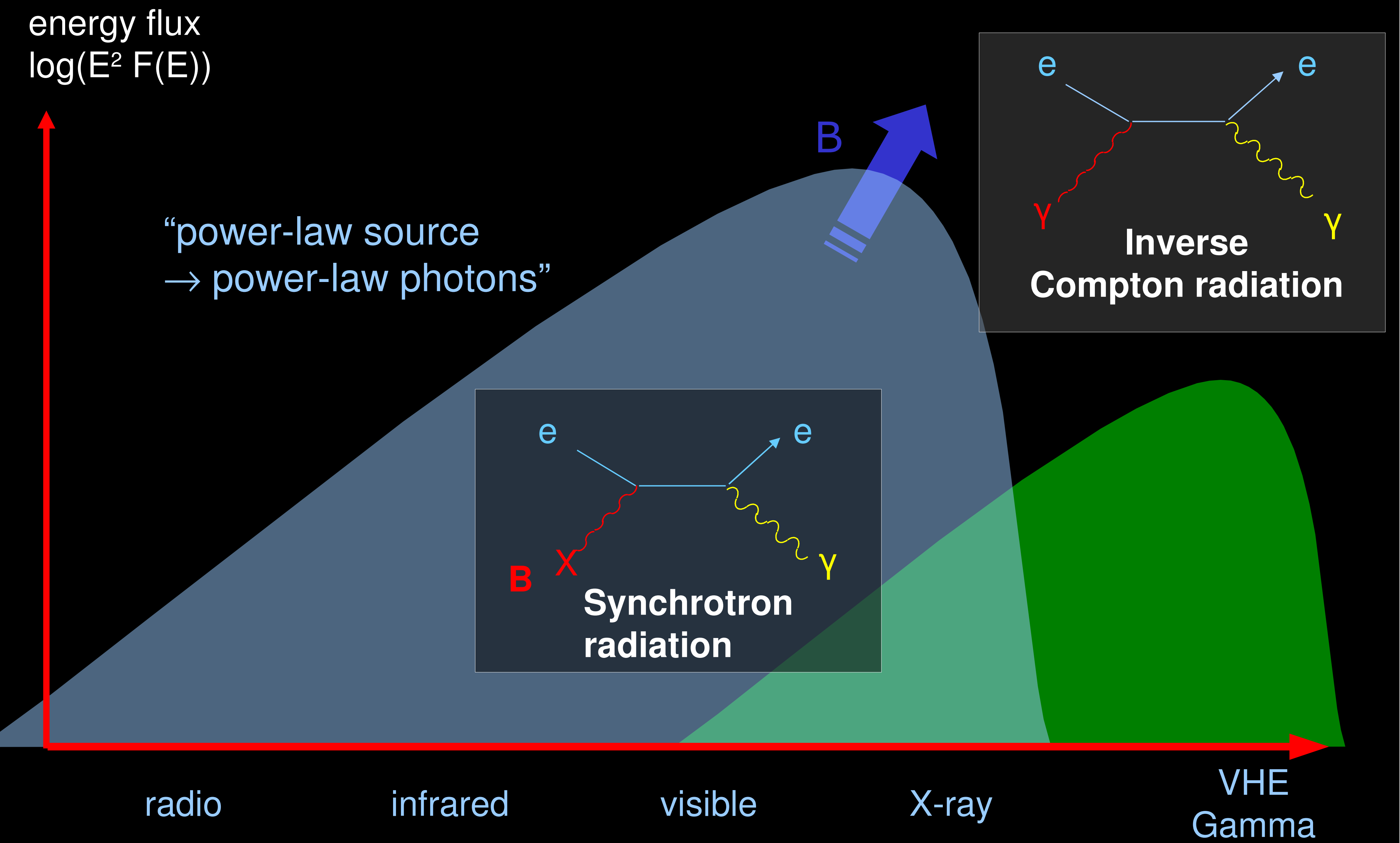
$$\rightarrow \frac{dN}{dE} = -\frac{b}{a}\frac{N}{E}$$

$$\rightarrow N(E) = N_0 E^{-b/a}$$

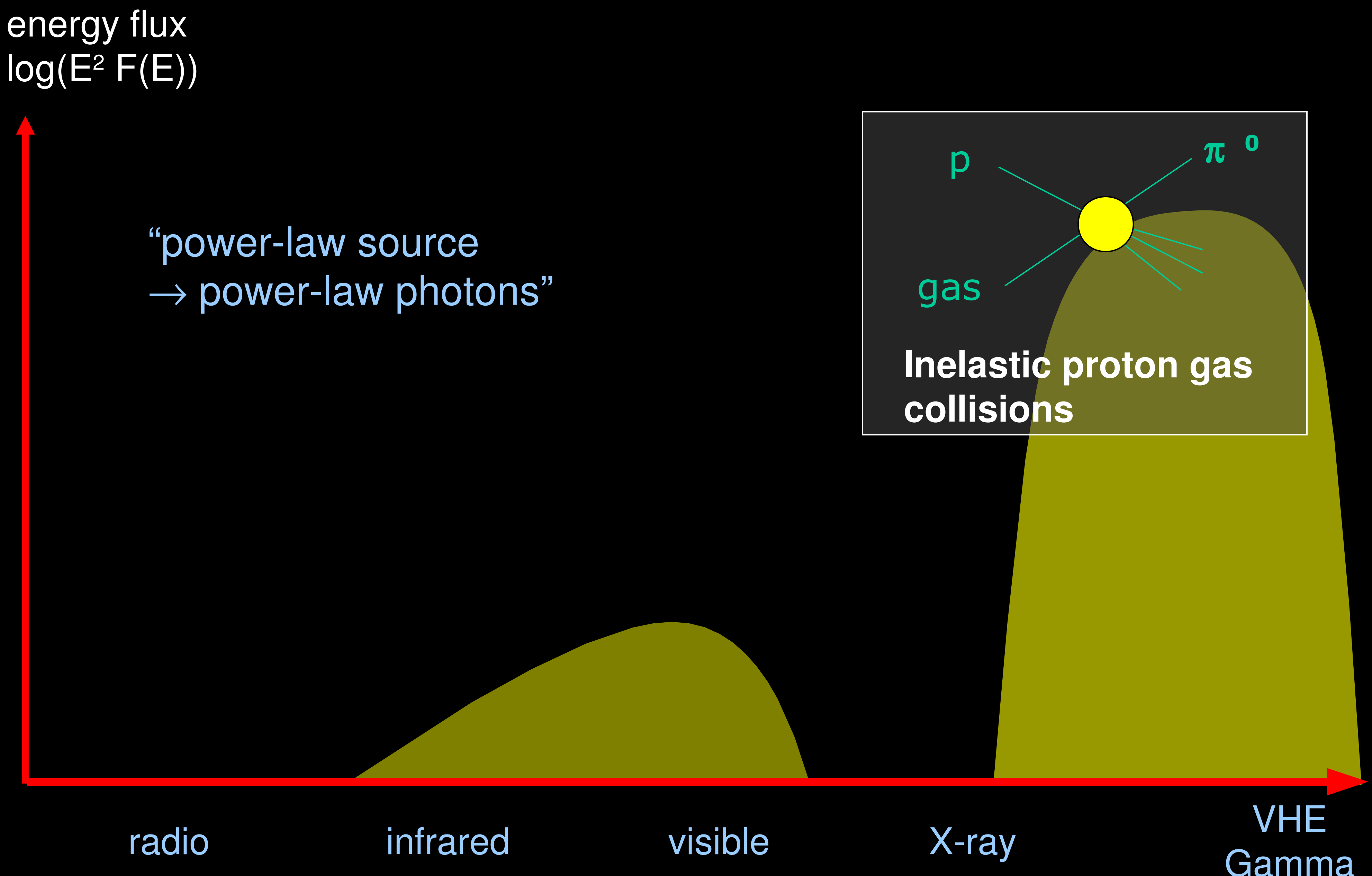
From particles to radiation



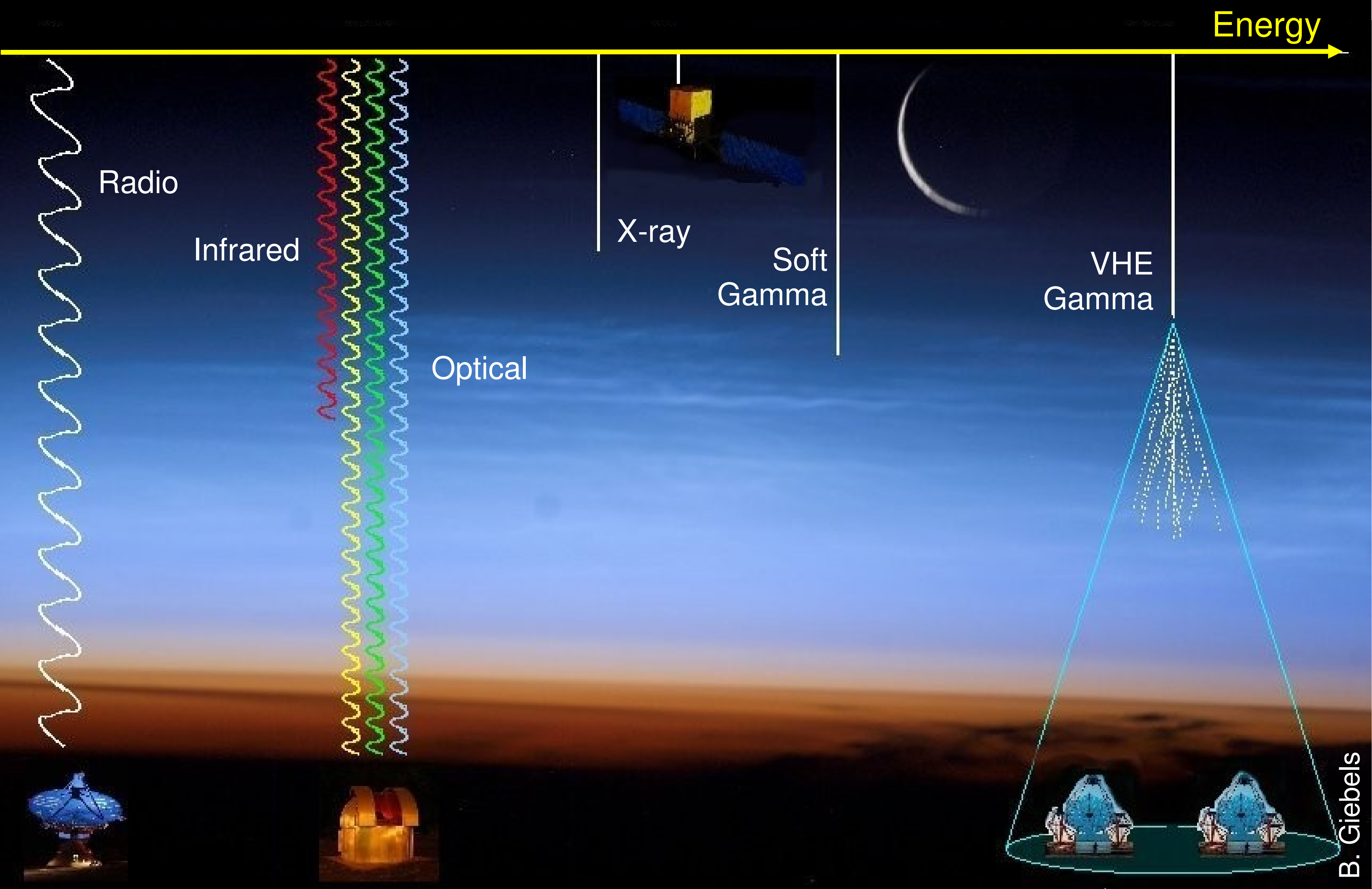
From particles to radiation - electrons



From particles to radiation - protons



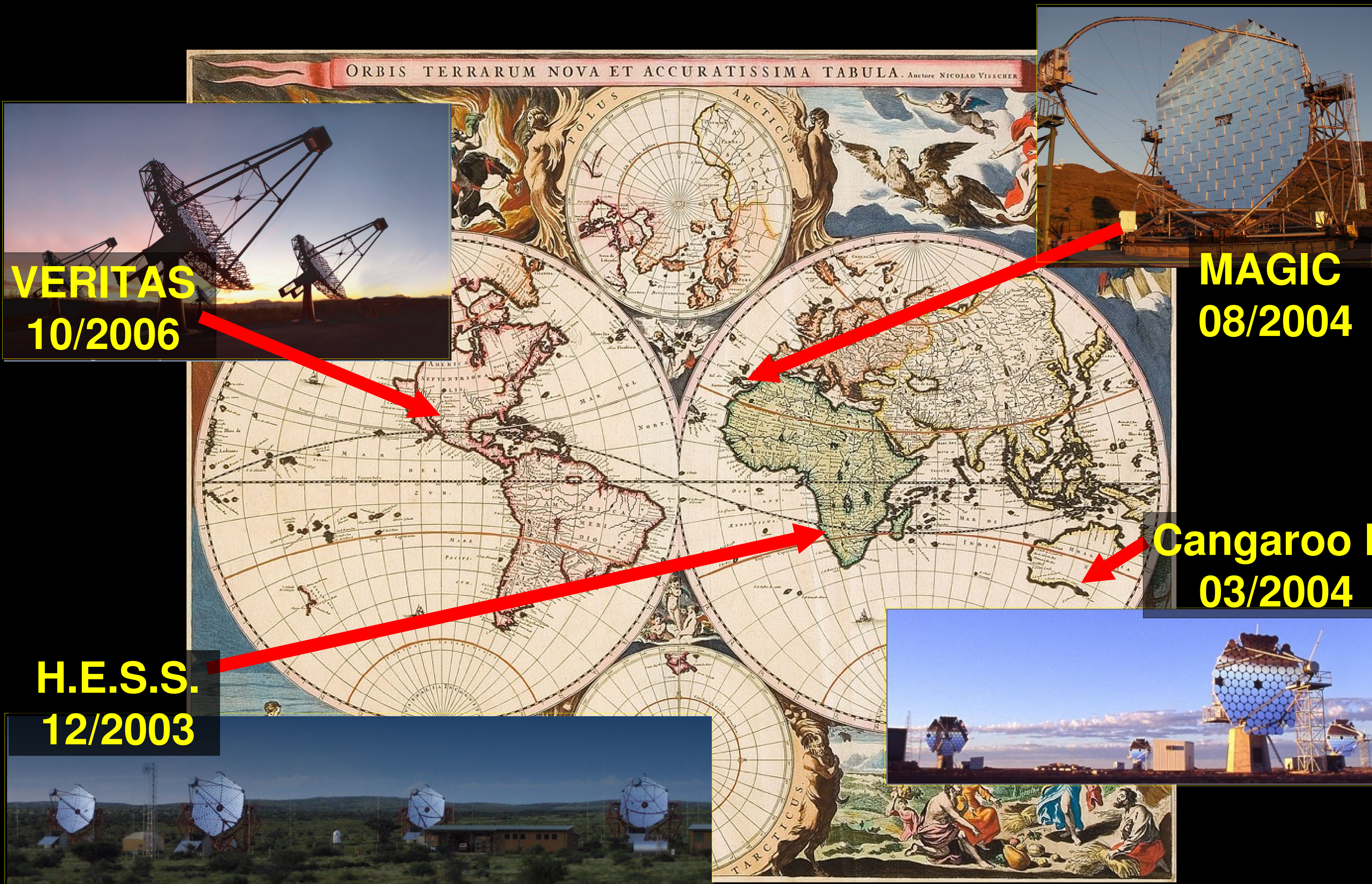
Windows for Astronomy



A typical instrument - H.E.S.S.

- 4 telescopes
  120 m spacing
  107 m^2 mirror surface each
- 960 PMT pixels
  5 deg field of view
- energy threshold ~100 GeV
  energy resolution < 15 %
- angular resolution ~0.1°
  pointing accuracy < 20''
- sensitivity (5σ):
  5% of Crab in 1 h
  1% of Crab in 25 h
  HEGRA: 5% of Crab in 100 h
- 1000 h of observations / year
  during moonless nights

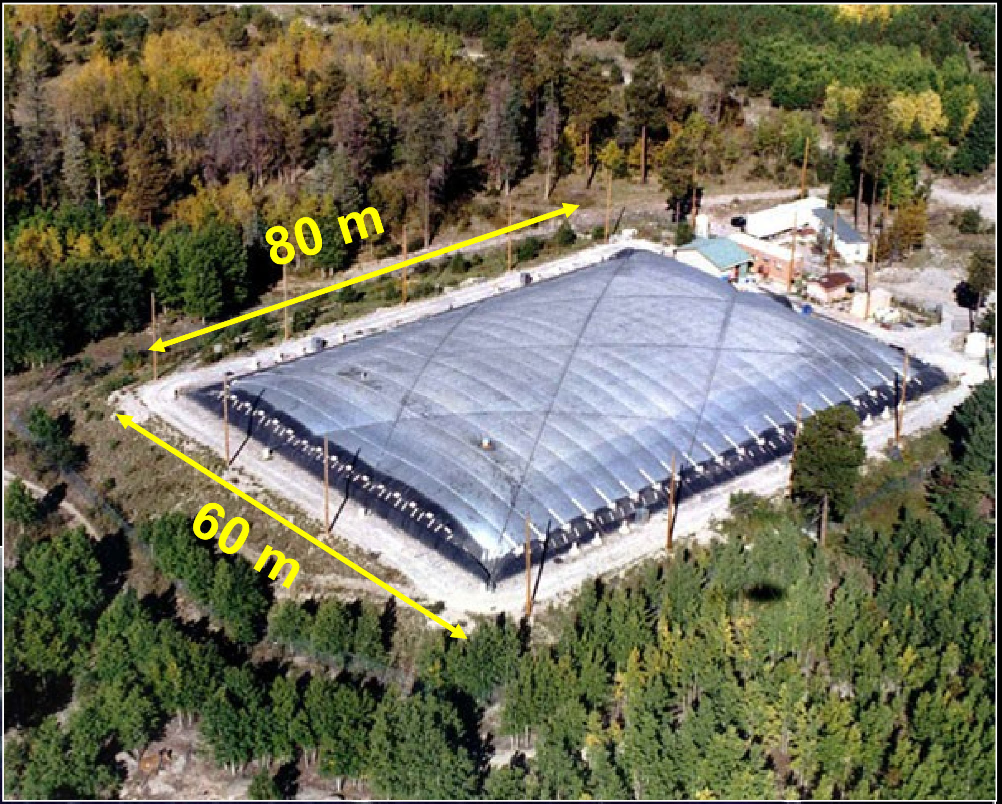
Cherenkov Telescopes World Map

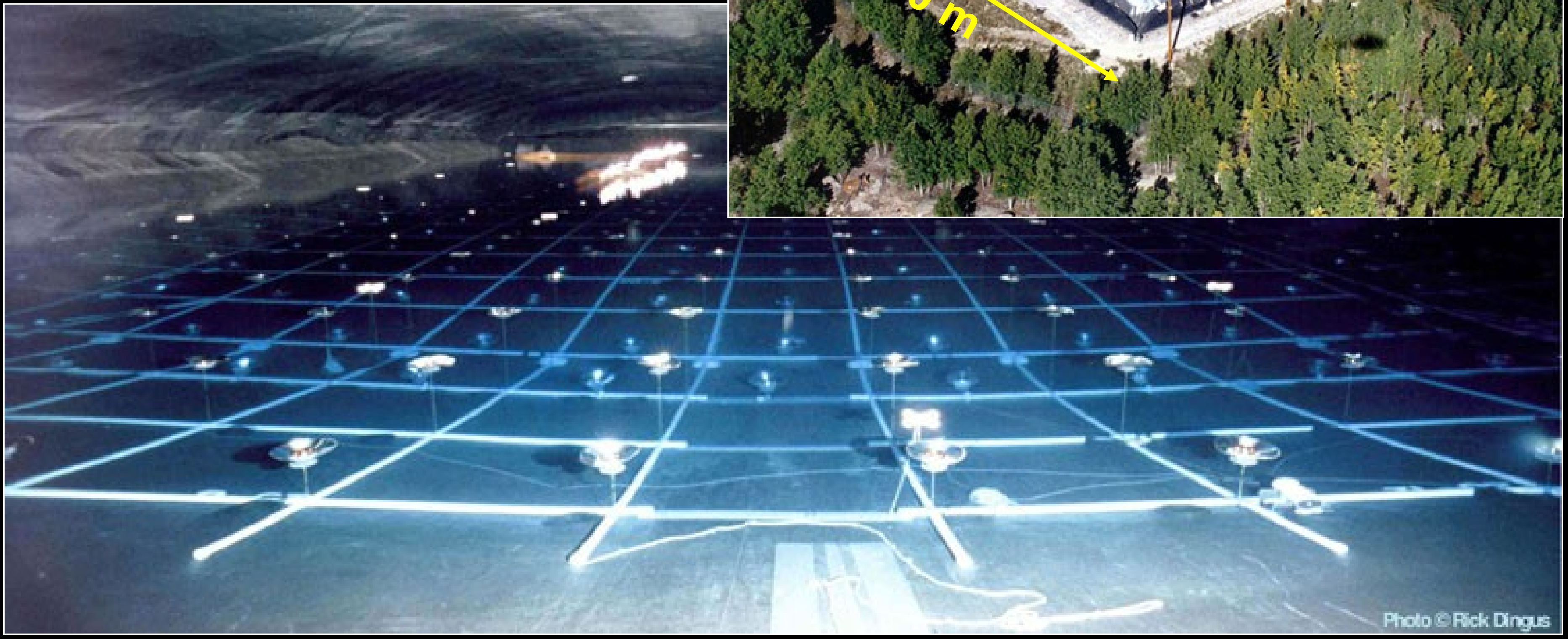


Milagro – Water Cherenkov

- instrumented water pond
- several water tanks around

- record Cherenkov light with two layers of PMTs
  → energy, γ/h separation
- arrival time: shower direction





Pointed vs all-sky

Water Cherenkov offers:

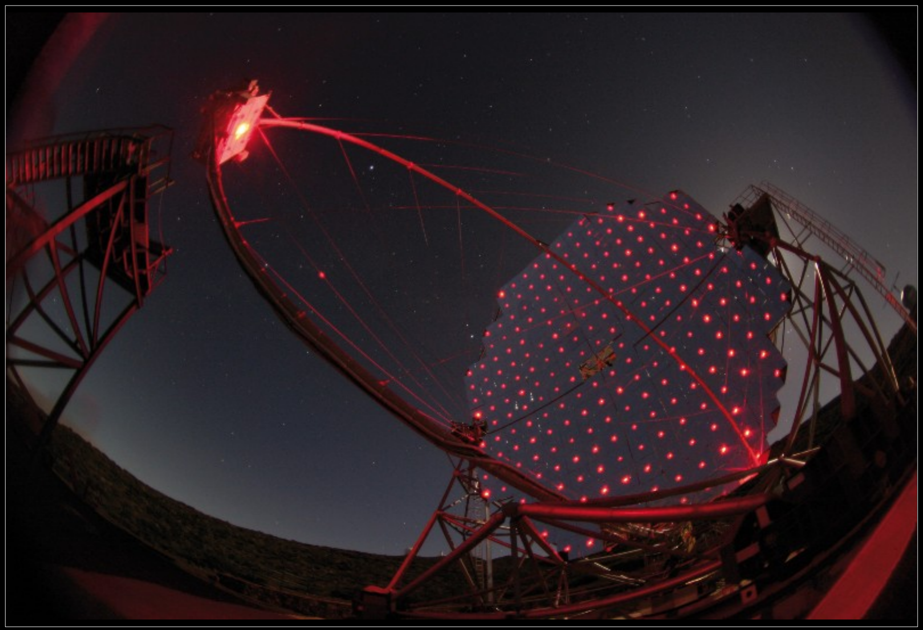
- ✔ Large sky coverage
- ✔ Uniform exposure
- ✔ Operation 24h/day
- ✔ Reliable and cheap setup

→ long-term monitoring
→ discovery potential

Cherenkov Telescopes have:

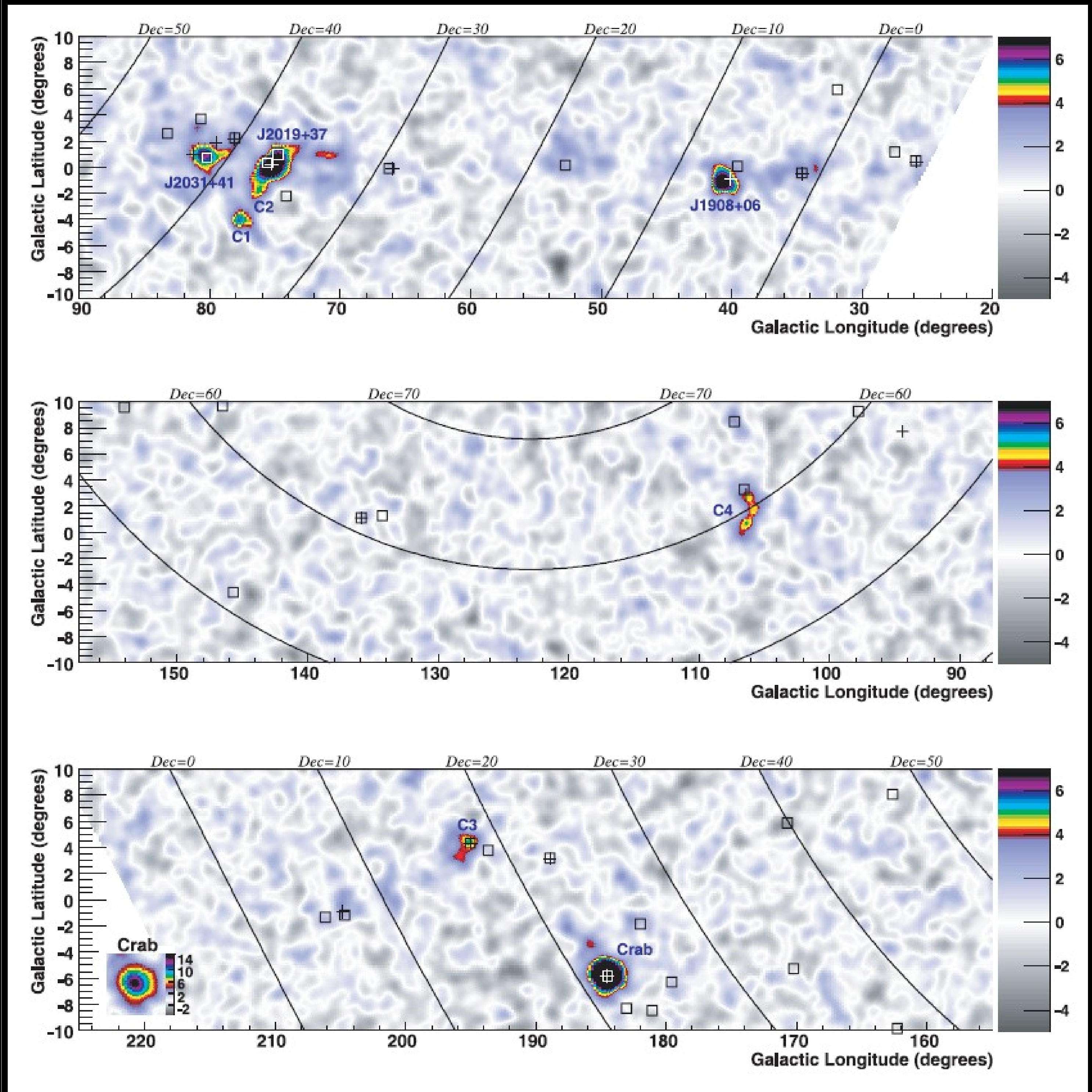
- ✔ Good angular resolution
- ✔ Small energy threshold
- ✔ Energy reconstruction
- ✔ Better γ/h separation
- ✔ Better point-source sensitivity

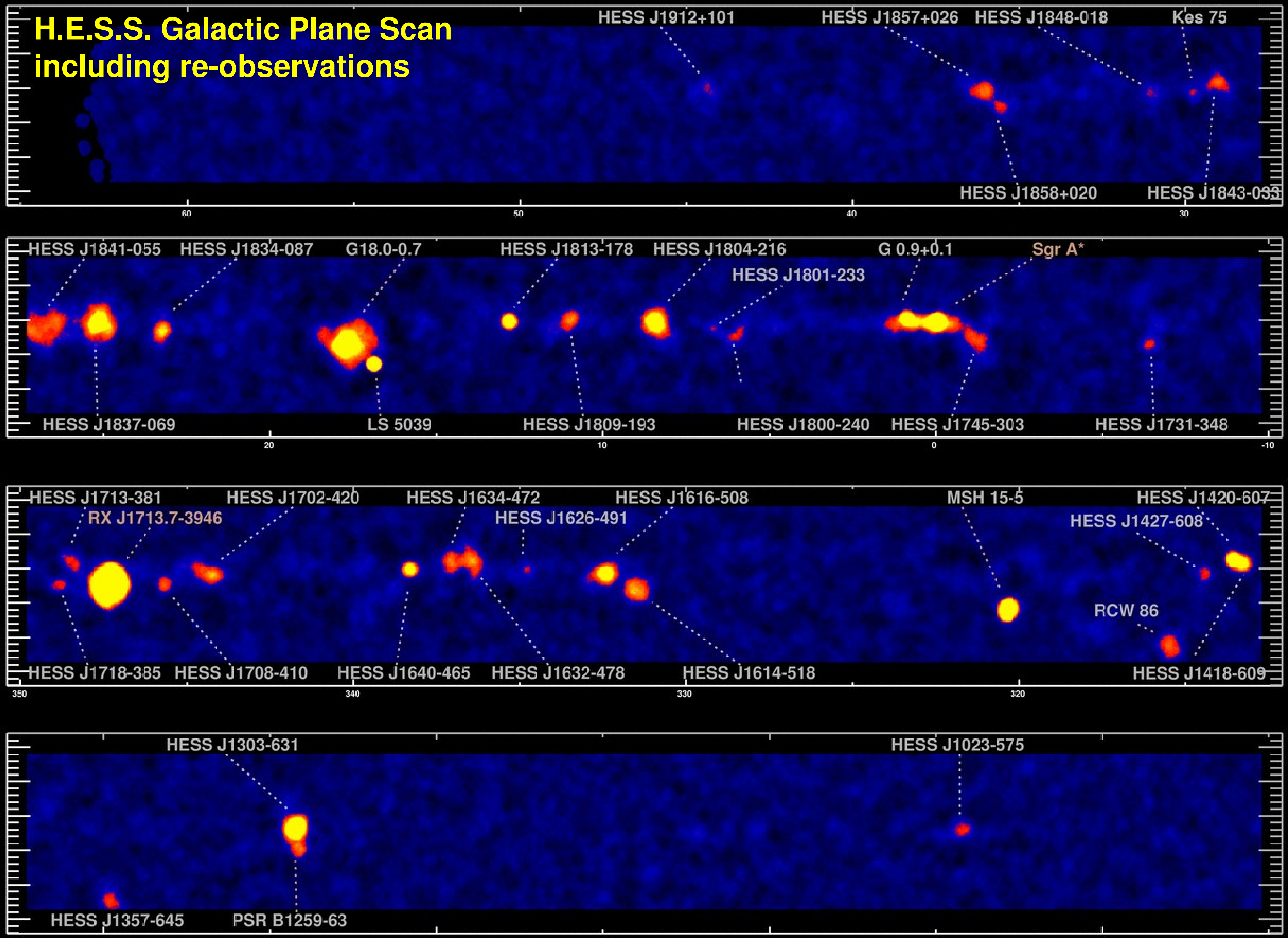
→ detailed source analyses
→ faint sources

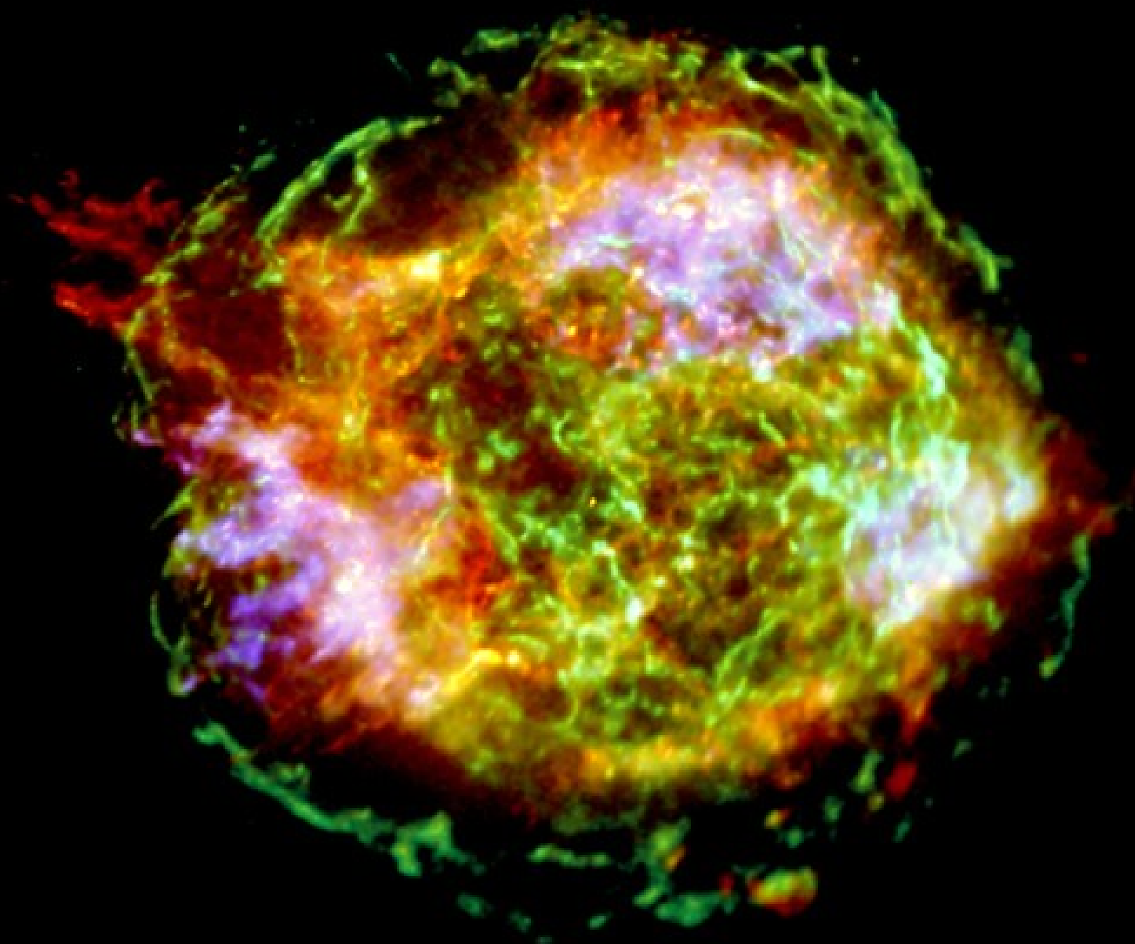


Source hunting

- MILAGRO 7yr Galactic Map
- Median energy ≈ 20 TeV
- 2 new detections
- 4 hotspots

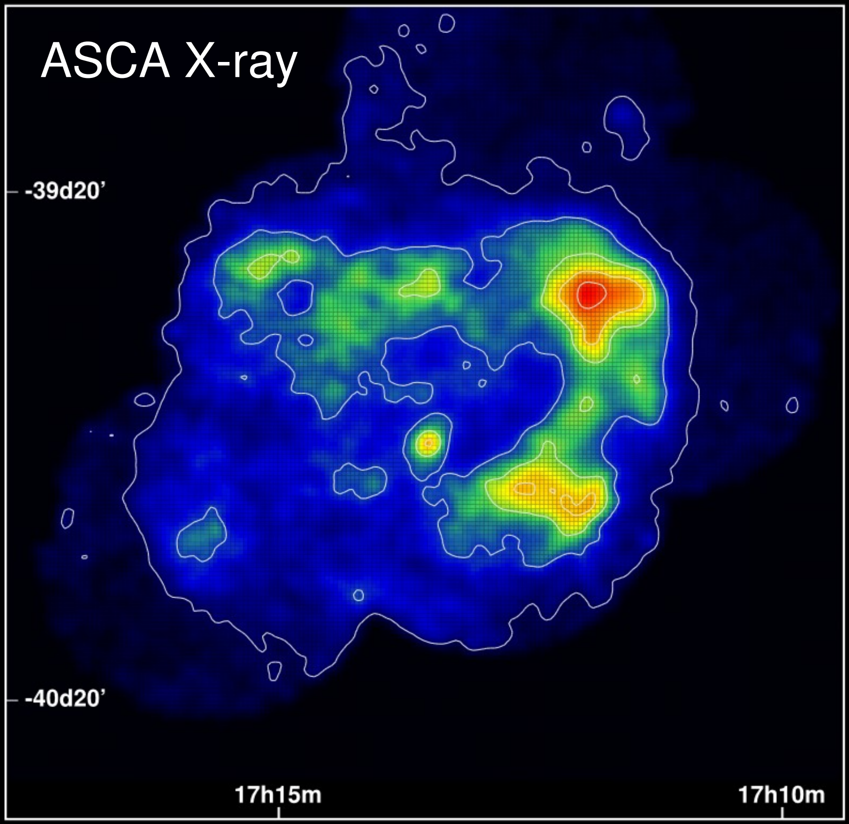



H.E.S.S. Galactic Plane Scan
including re-observations
HESS J1912+101
HESS J1857+026
HESS J1848-018
Kes 75
HESS J1858+020
HESS J1843-033
HESS J1841-055
HESS J1834-087
G18.0-0.7
HESS J1813-178
HESS J1804-216
HESS J1801-233
G 0.9+0.1
Sgr A*
HESS J1837-069
LS 5039
HESS J1809-193
HESS J1800-240
HESS J1745-303
HESS J1731-348
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
HESS J1303-631
HESS J1023-575
HESS J1357-645
PSR B1259-63



Astrophysics

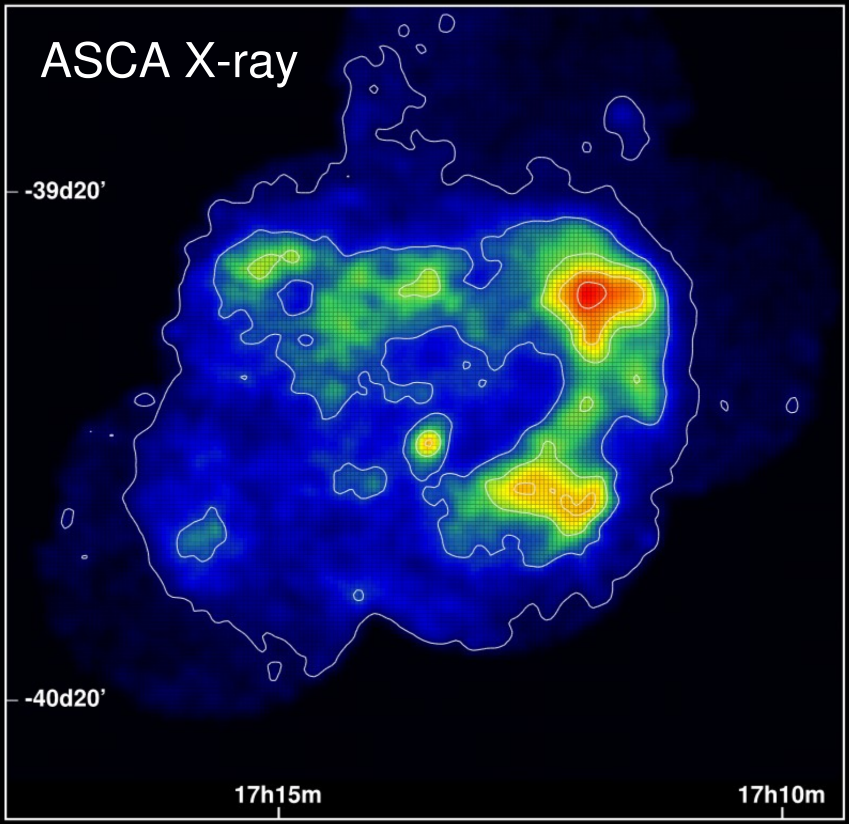
SNR RX J1713.7-3946

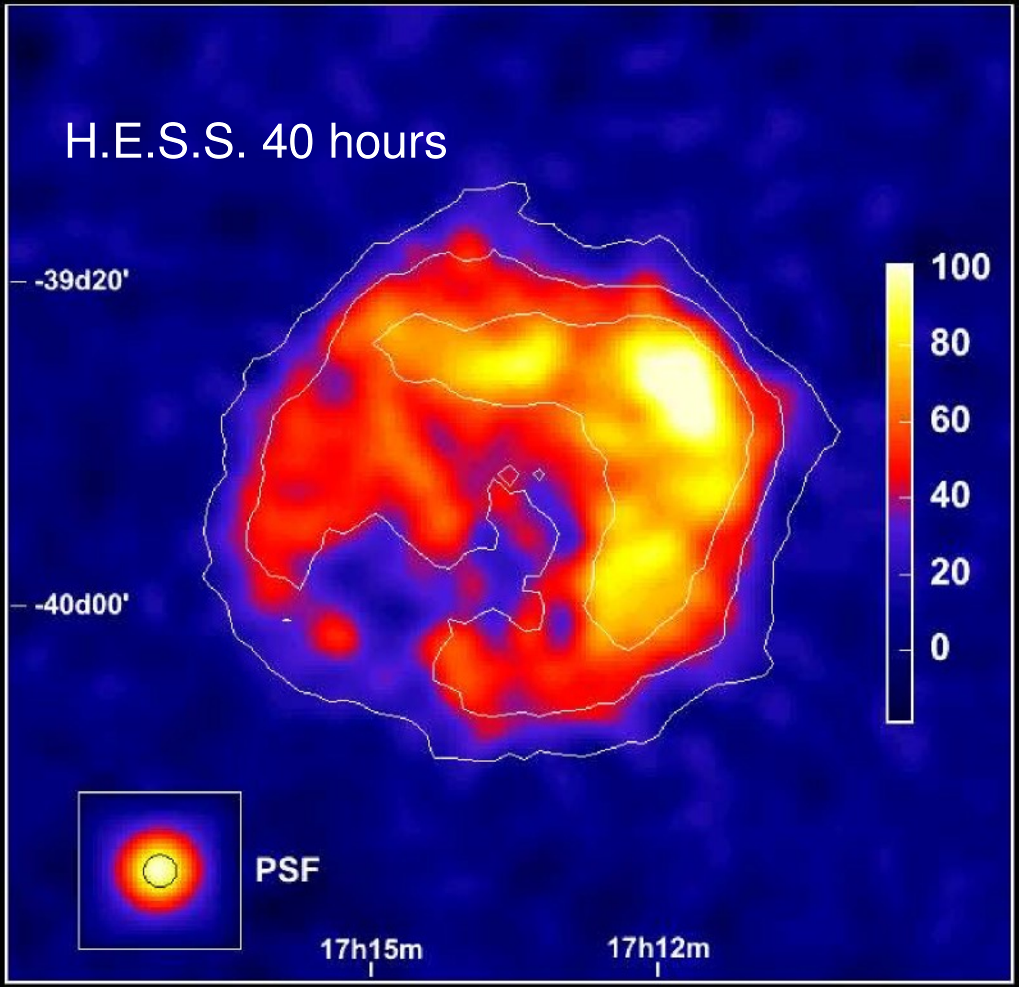


- discovered 1996 in ROSAT all-sky survey
- 1° diameter
- distance: probably 1 kpc
  $\rightarrow$ age: ~1000 years

- pure non-thermal X-ray continuum emission
- almost no radio emission

SNR RX J1713.7-3946





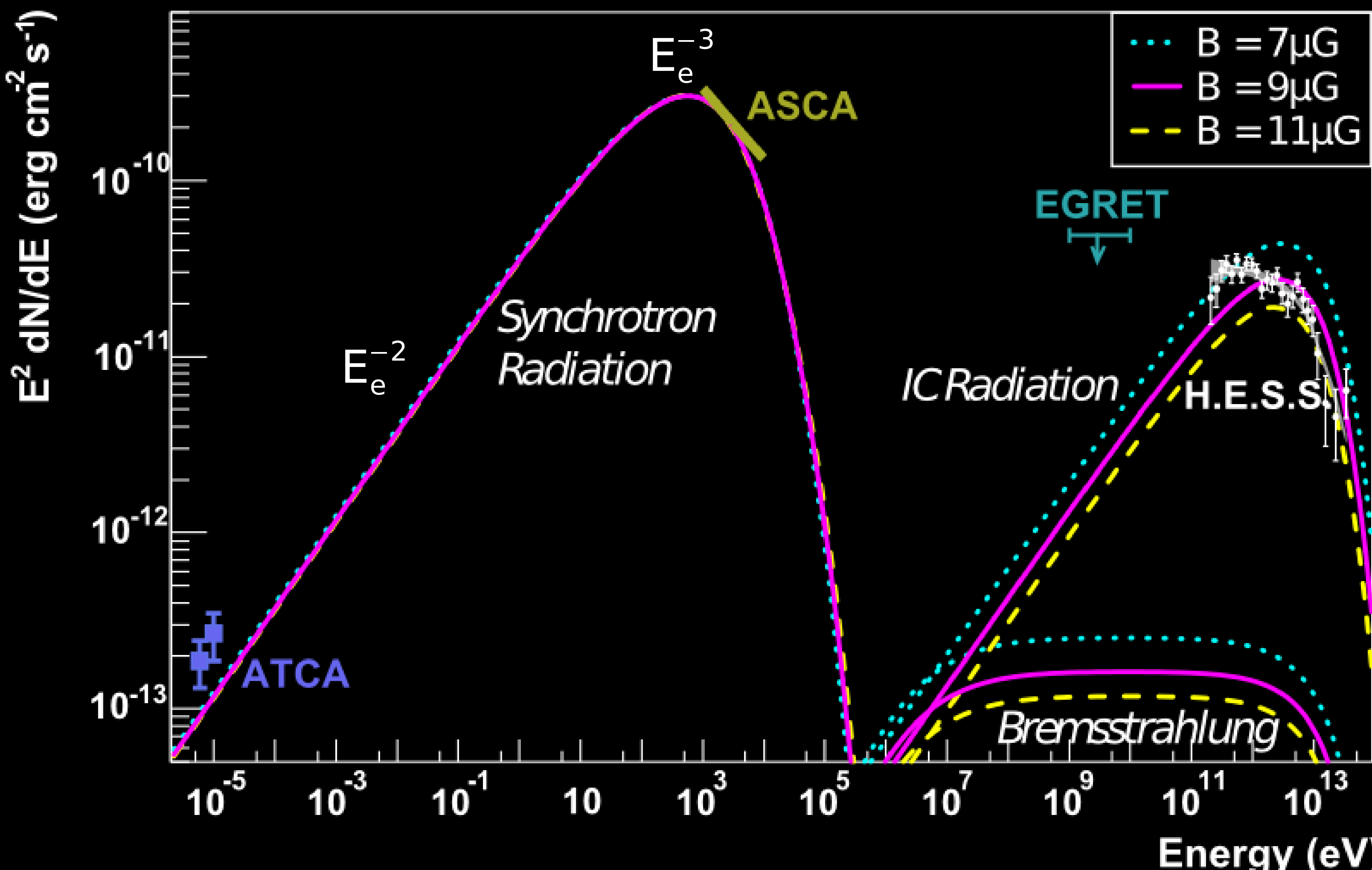
Aharonian et al. 2006

- first resolved VHE image of an SNR
- excellent correlation with X-ray morphology

→ common origin of X-rays and γ-rays?

SNR RX J1713.7-3946

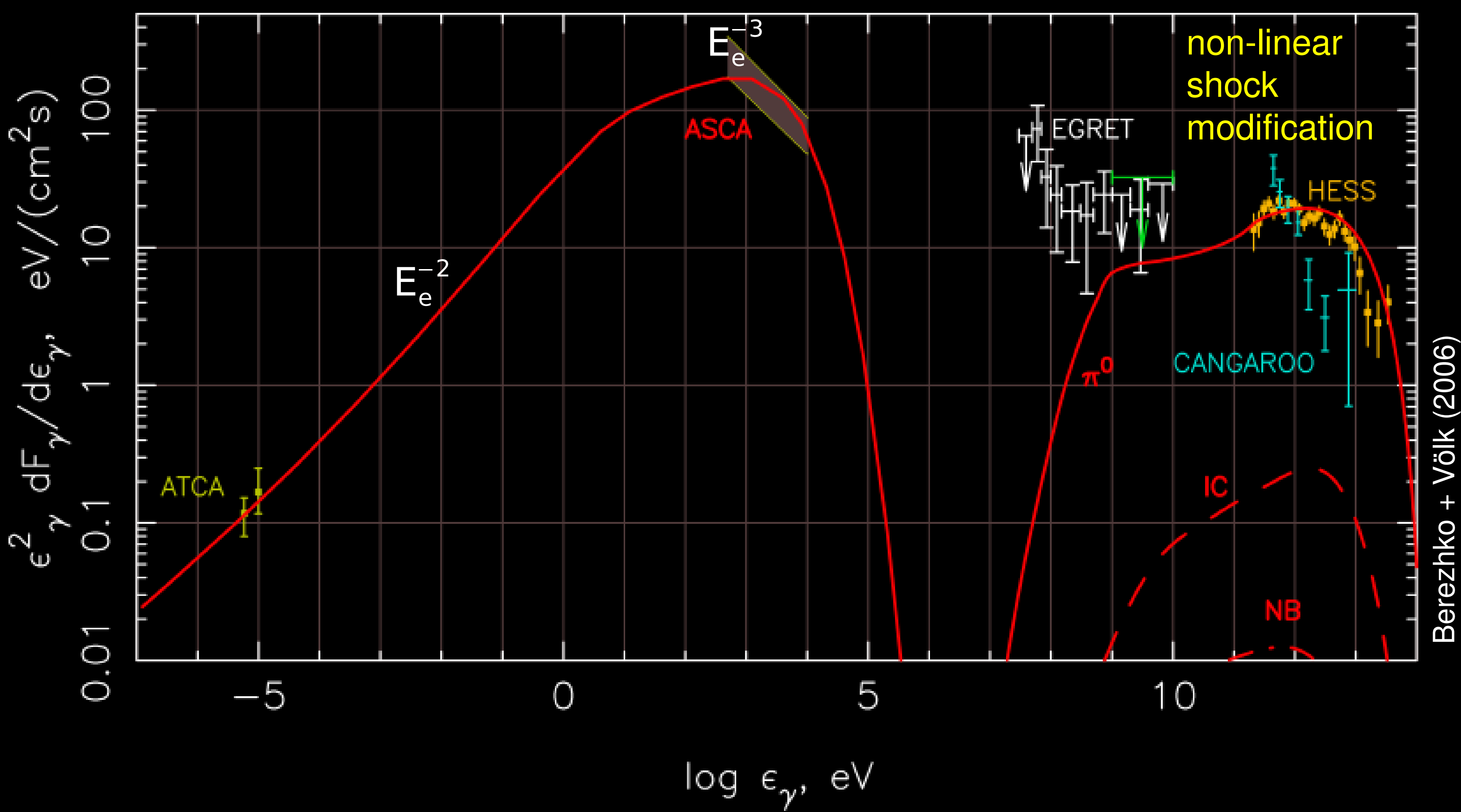
... leptonic scenario



...can in principle explain VHE emission by electrons, but...

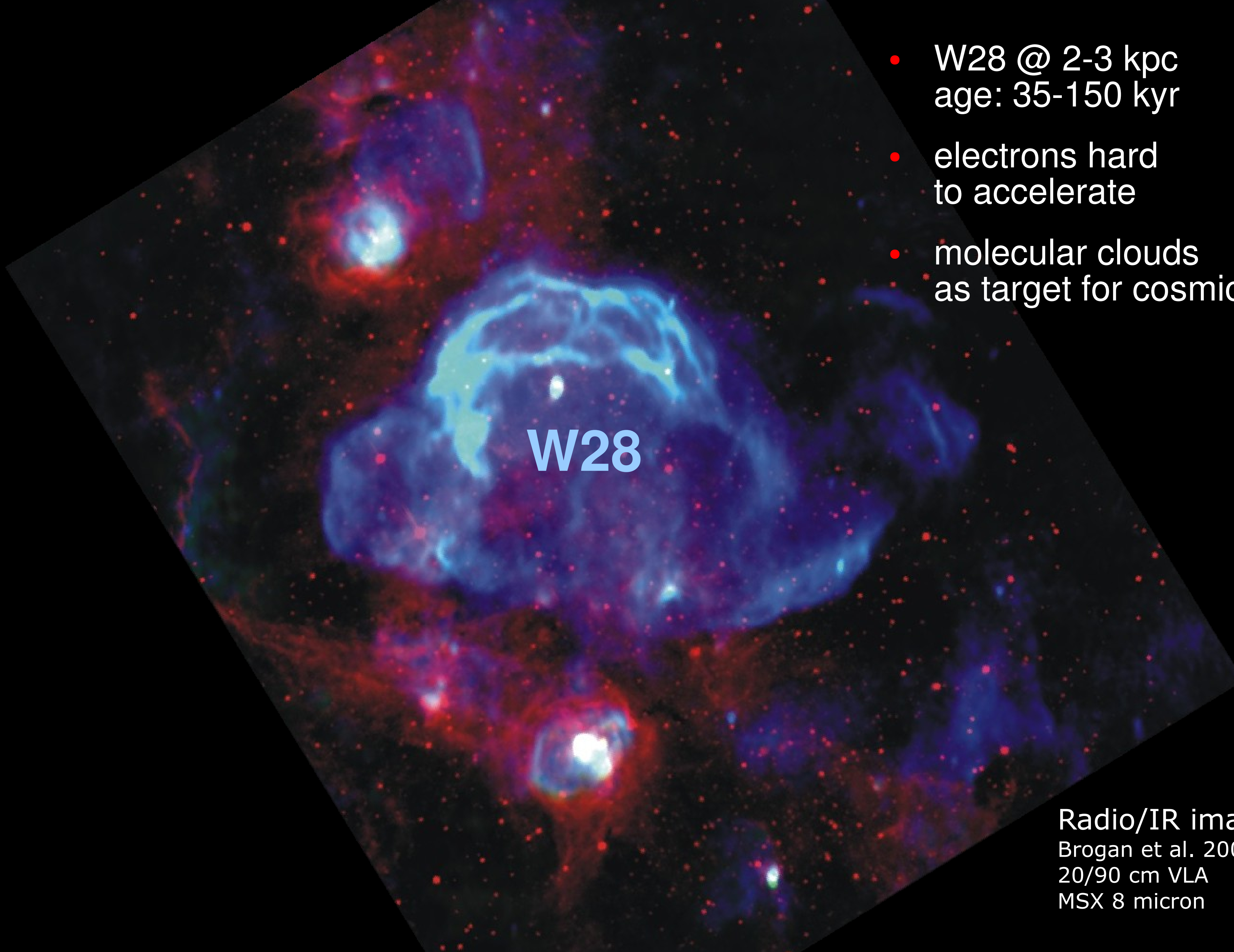
SNR RX J1713.7-3946

... hadronic scenario



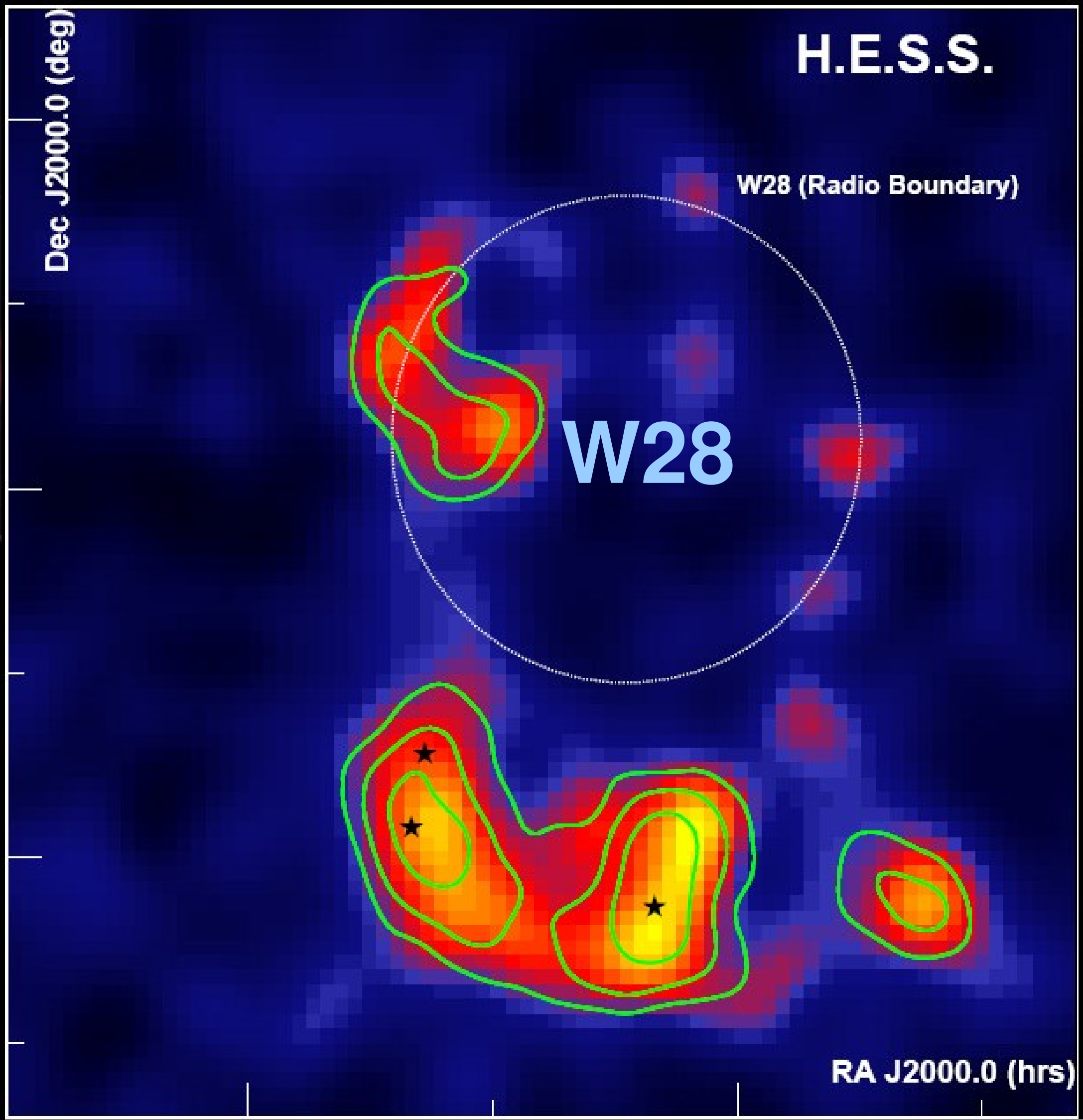
Old SNRs & cloud interaction

- W28 @ 2-3 kpc
  age: 35-150 kyr
- electrons hard
  to accelerate
- molecular clouds
  as target for cosmic rays



Radio/IR image
Brogan et al. 2006
20/90 cm VLA
MSX 8 micron

Old SNRs & cloud interaction



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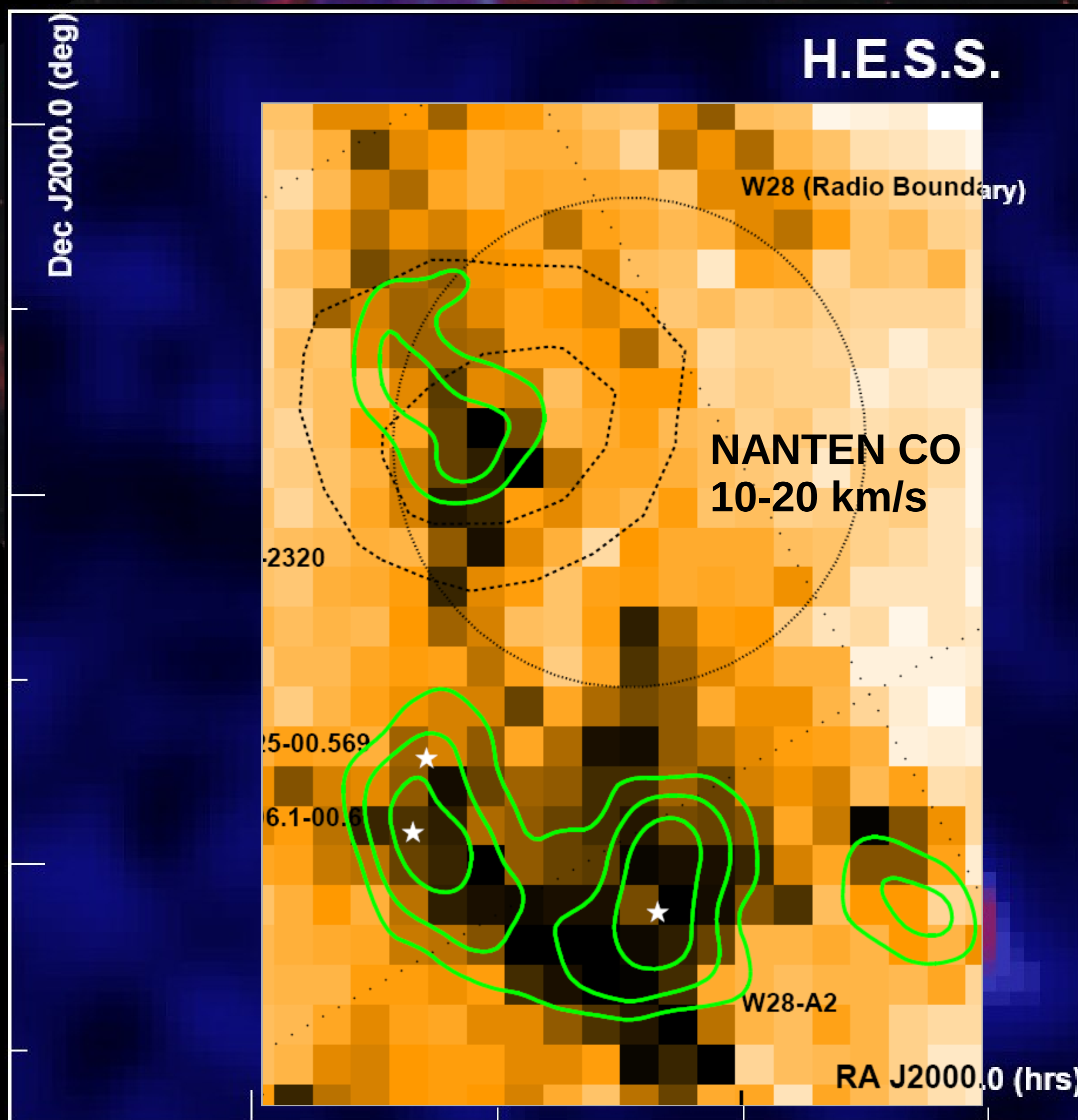

Aharonian et al. 2008

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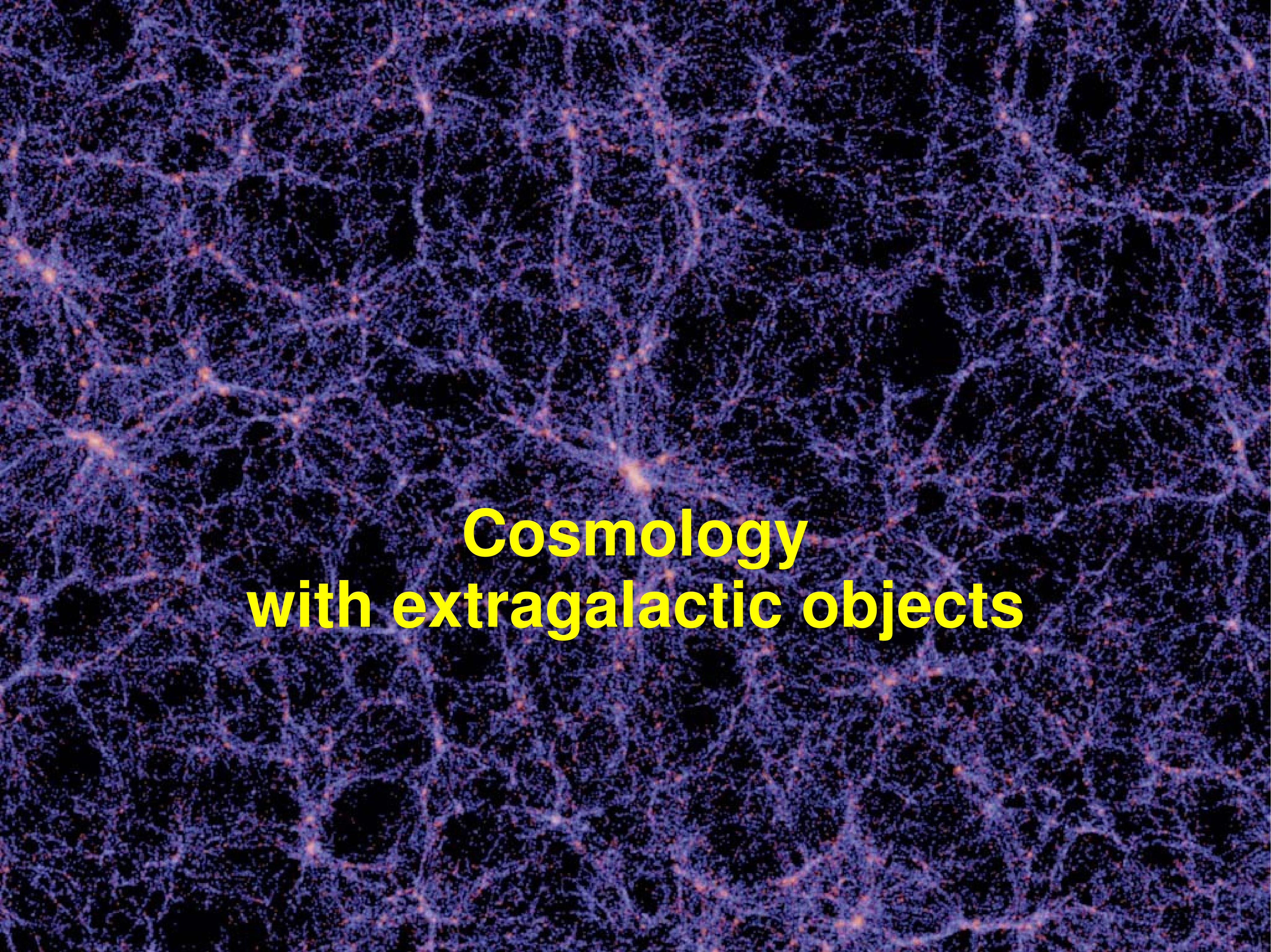
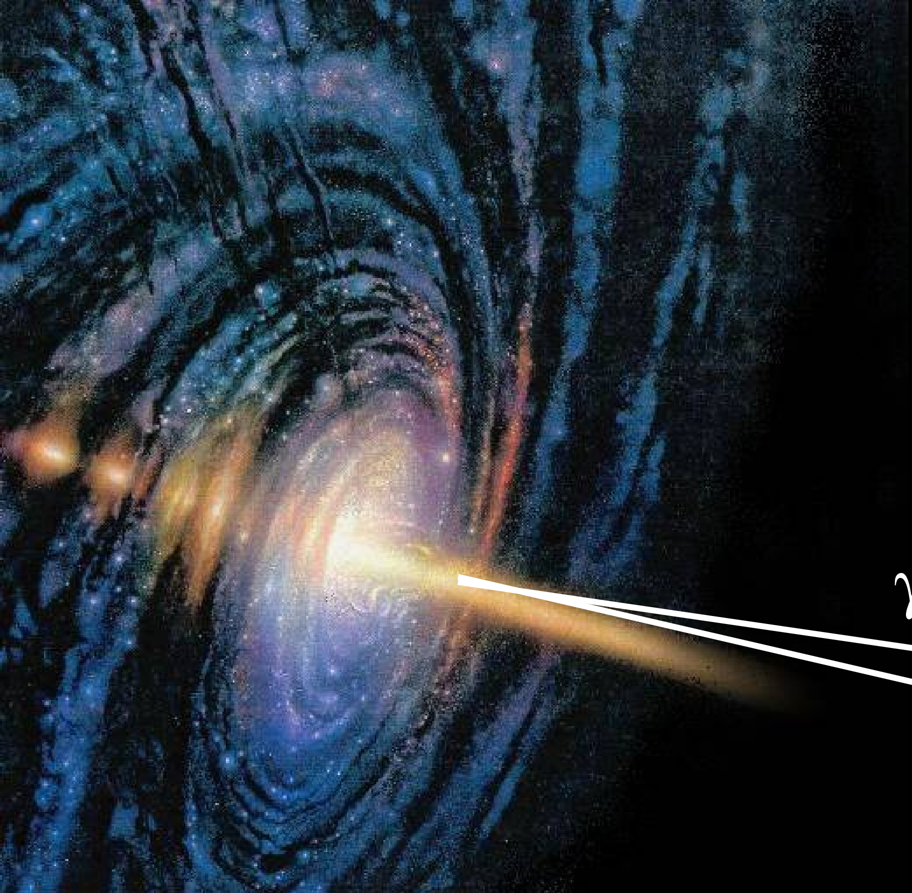


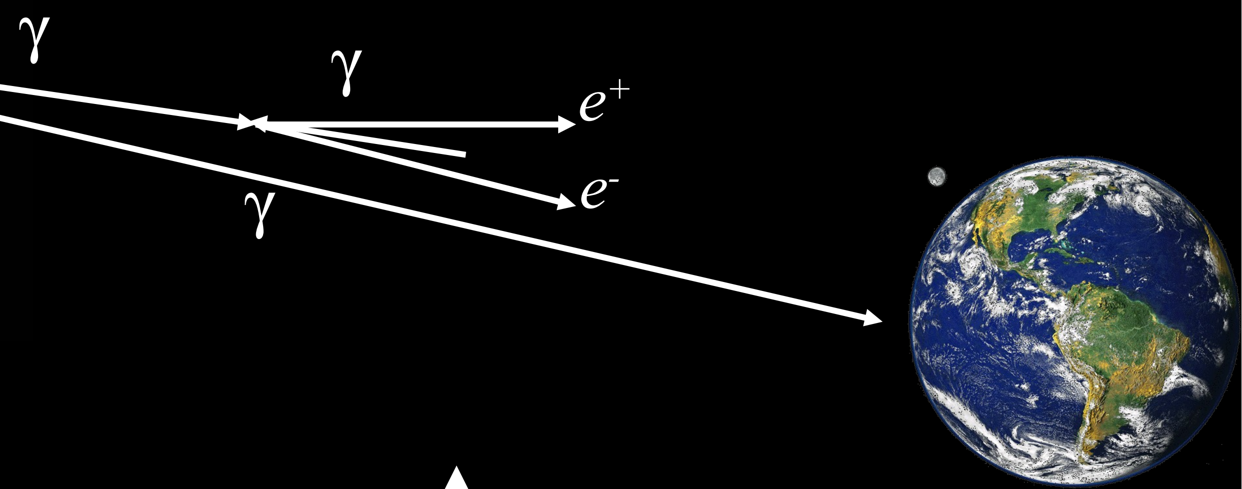
Cosmology
with extragalactic objects

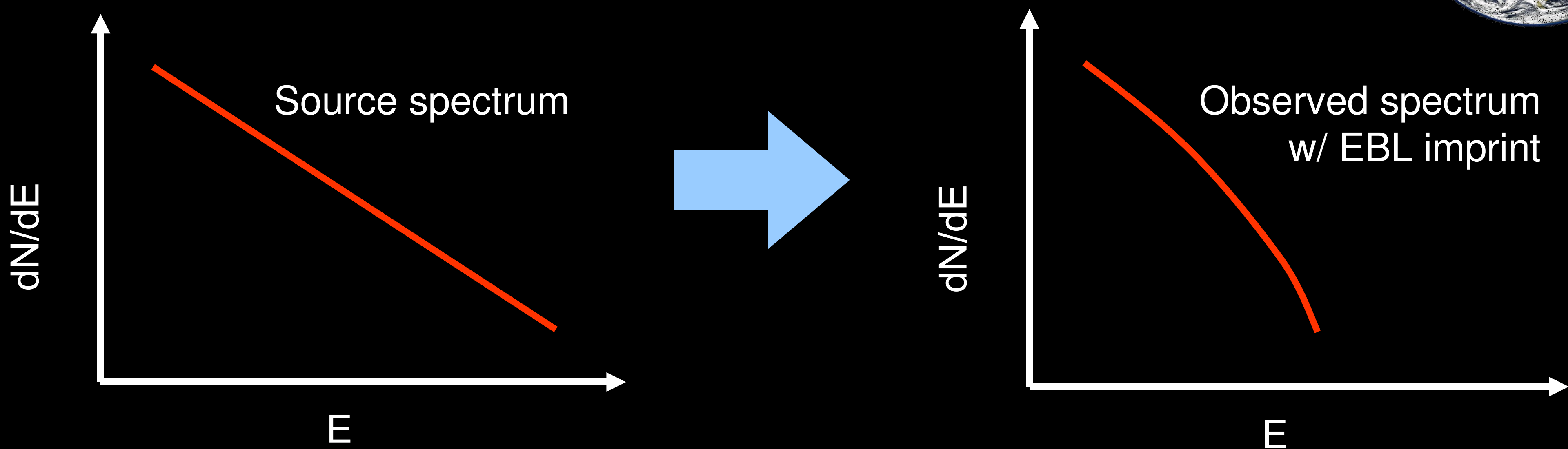
The γ-ray horizon

- γ-rays get absorbed by extragalactic background light
- Direct measurements of EBL difficult

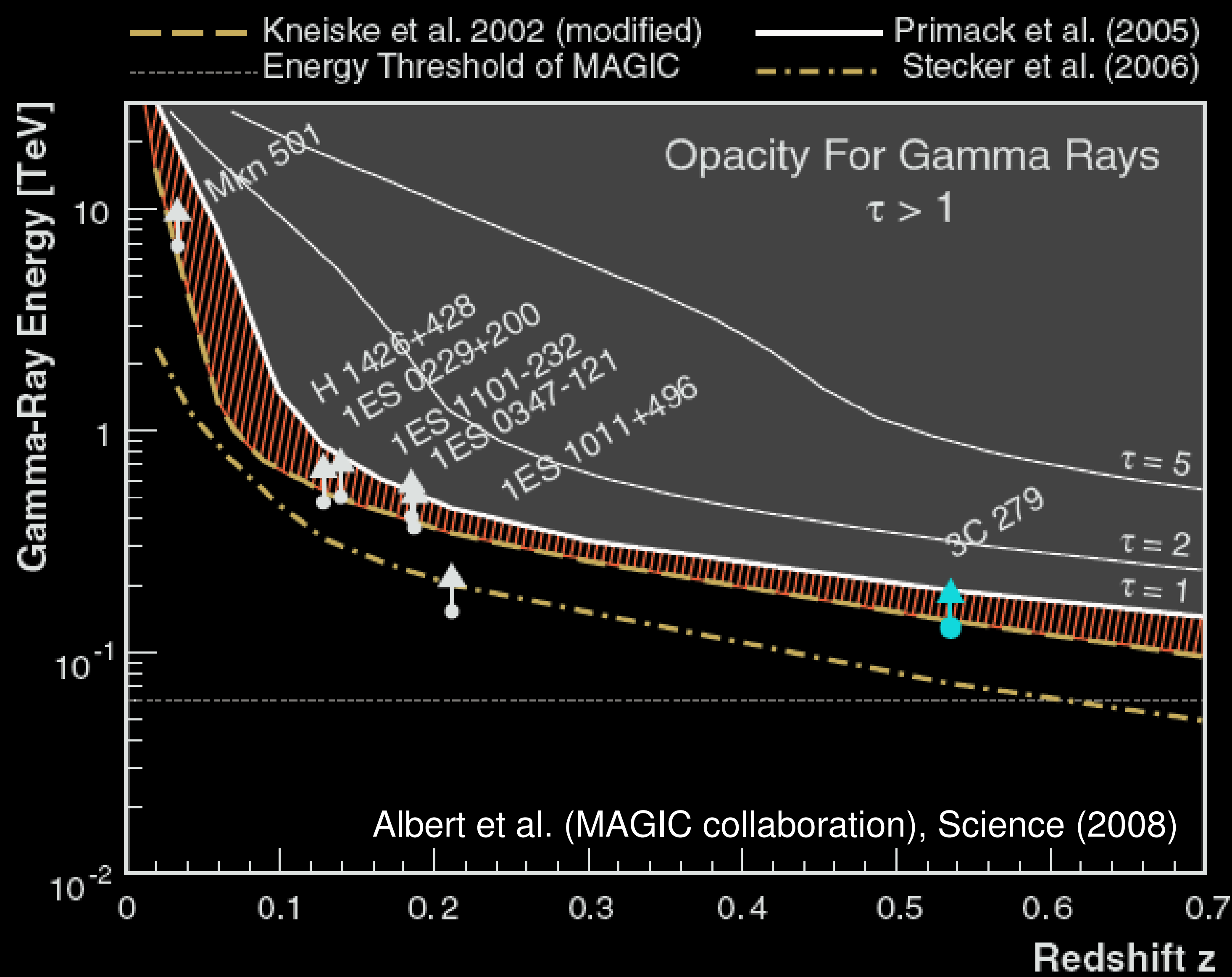
- Upper limit on EBL density
- Study of cosmology







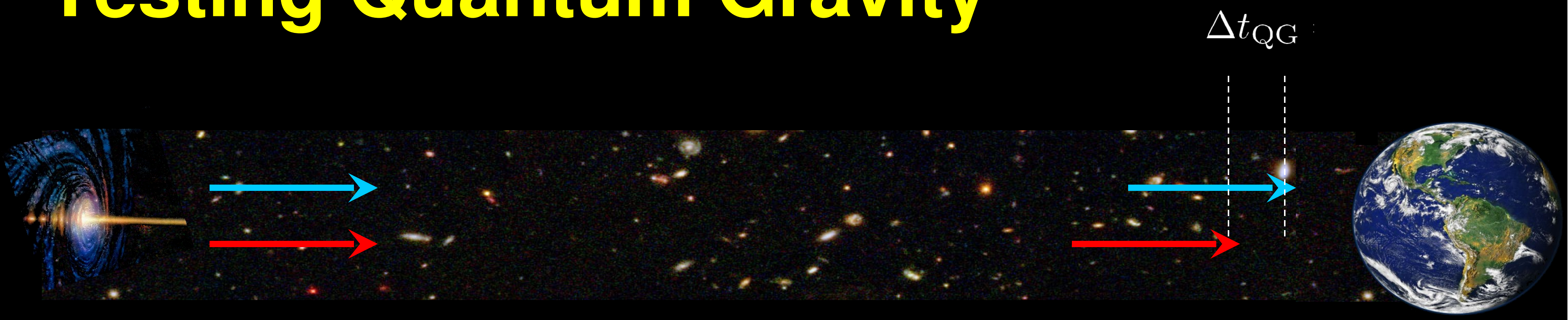
The γ-ray horizon



- Big step forward: γ-rays from 5 billion lyr distance
- Constraints models of EBL, hence cosmic evolution

Fundamental Physics

Testing Quantum Gravity



- Some QG model predict c(E) ≠ c(E'):

$$c' = c\ (1 \pm \frac{E}{k \cdot M_{\mathrm{p}}} \pm \frac{E^2}{p^2 \cdot M_{\mathrm{p}}^2})$$

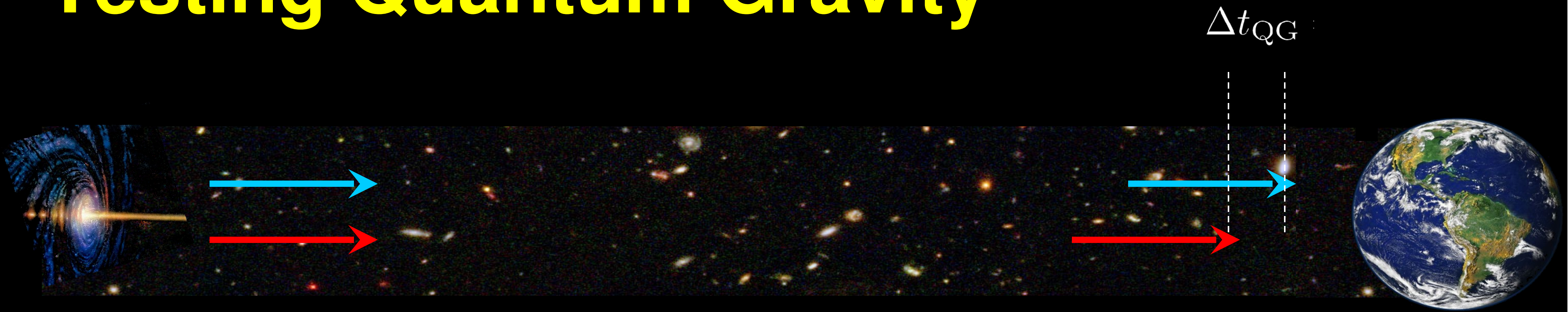
- Arrival time for photons of different energy:

$$\Delta t_{\mathrm{QG}} = L\ (\frac{1}{c_1} - \frac{1}{c_2}) \approx \frac{\Delta E \cdot L}{k \cdot M_{\mathrm{p}} \cdot c}$$

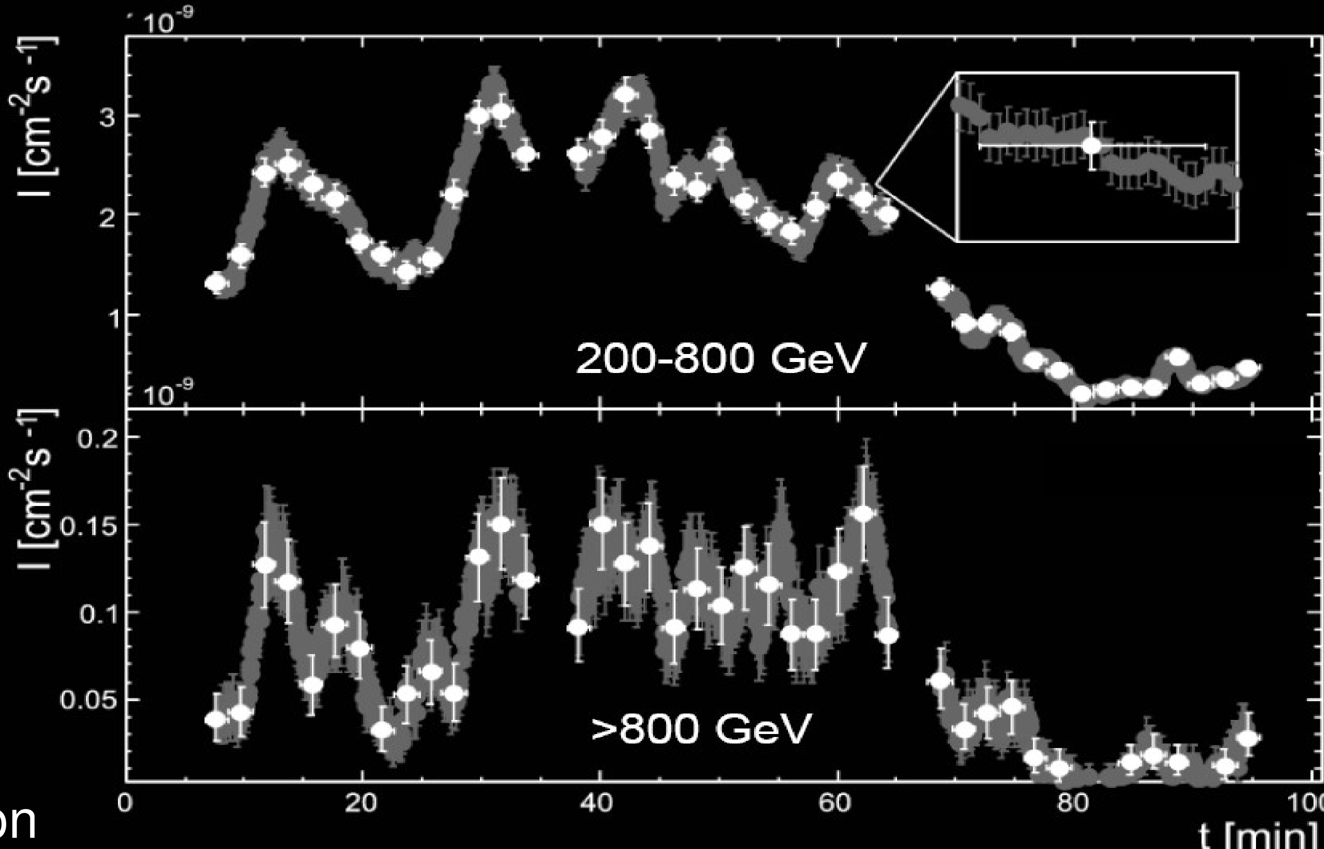
- Need:
  - high energies
  - large distances

- Use variable emission from extragalactic sources

Testing Quantum Gravity

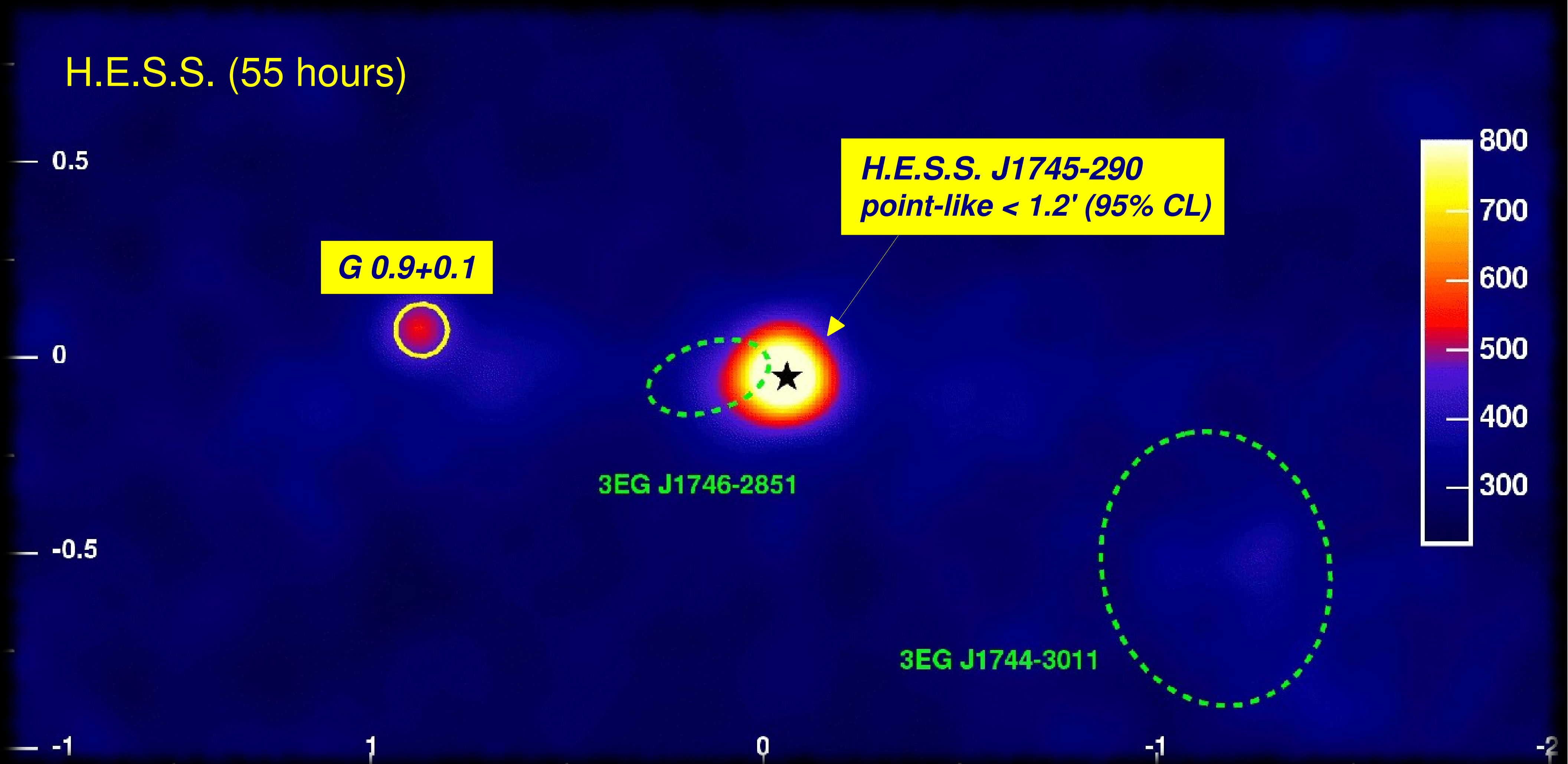


- Test for time lag between high-energy and low-energy lightcurves
- Insignificant lag: $\Delta t = (20 \pm 30)$ s
- Compare to light travelling time: $t \approx 2$ billion years
- Most constraining limit on speed of light modification to date



Indirect Dark Matter Searches

The Centre of the Milky Way

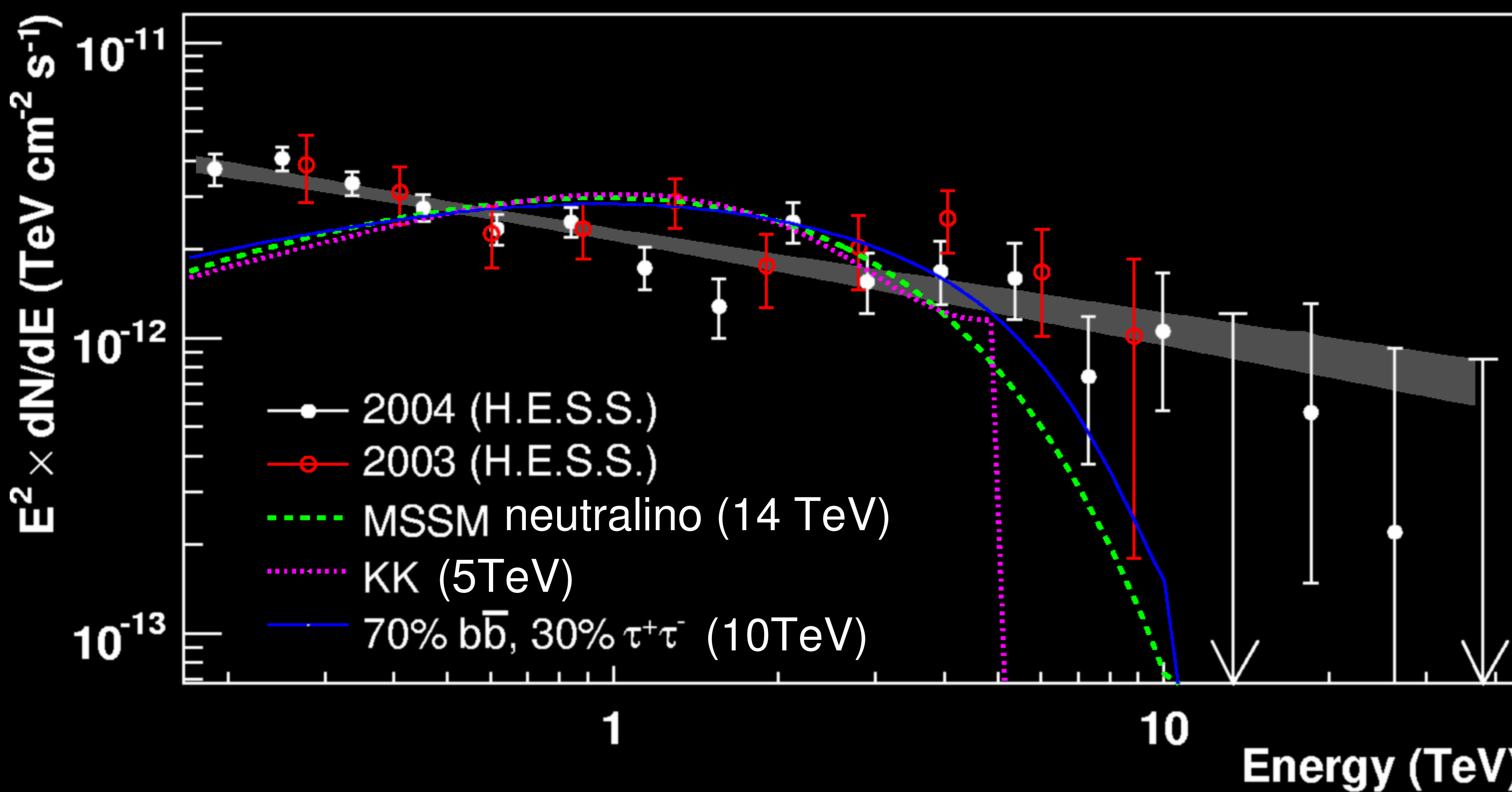


Aharonian et al. (2006)

HESS J1745-290

... not much room for Dark Matter

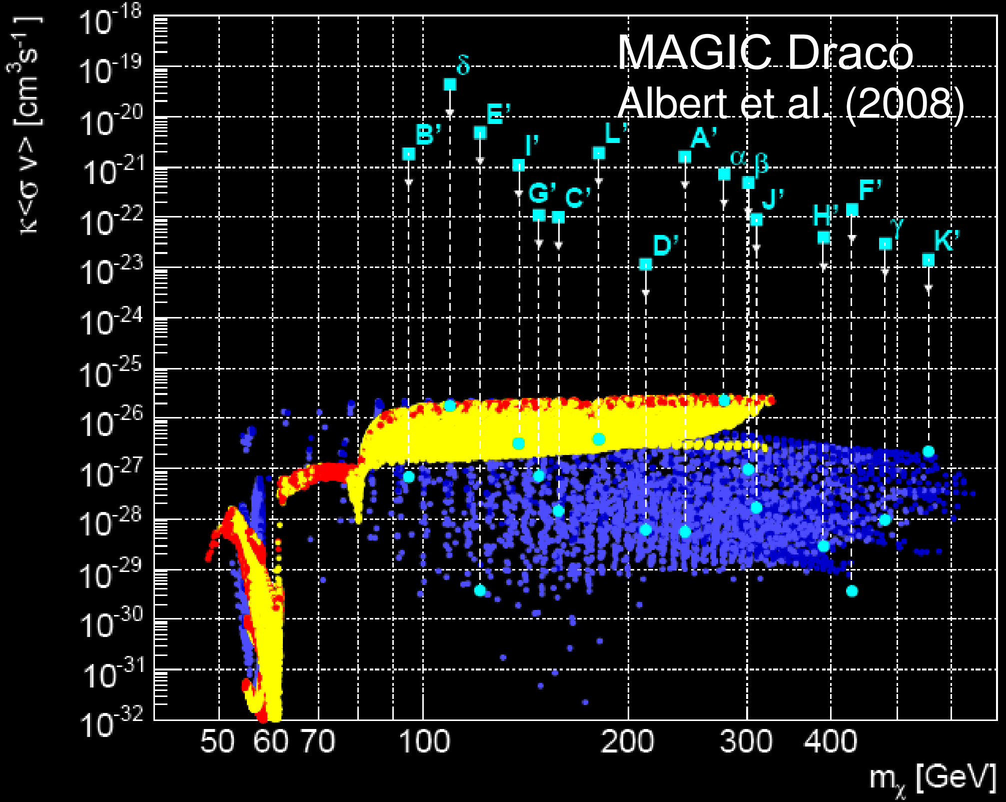
- energy spectrum: straight powerlaw
  exponential cutoff: E_C > 9 TeV @ 95% CL
- curved annihilation spectra
  + “uncomfortably large” masses in MSSM
- 10% DM contribution not ruled out
  → derived limits on <σv> do not constrain models

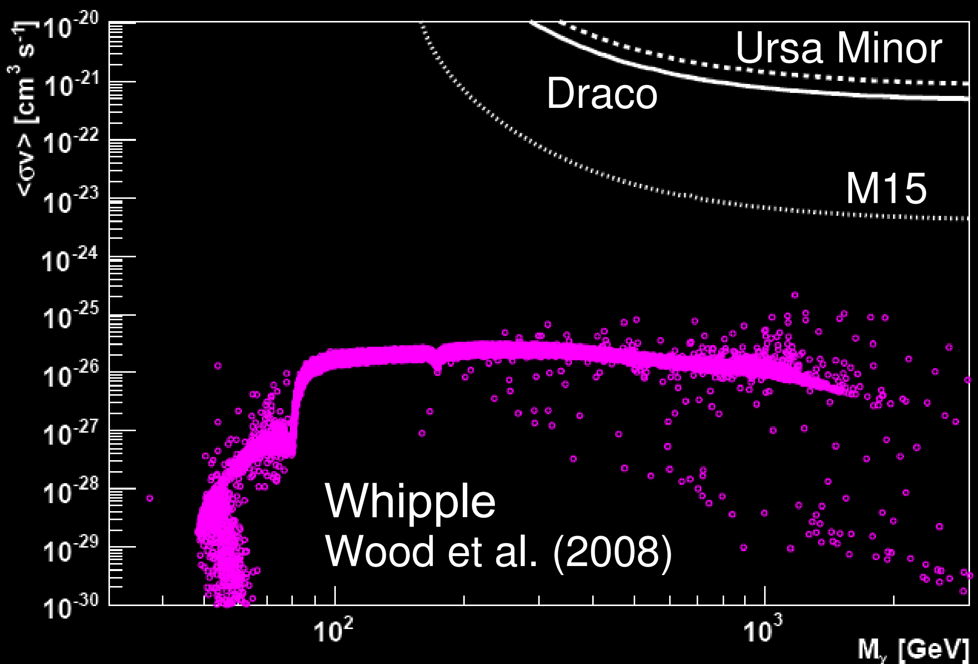


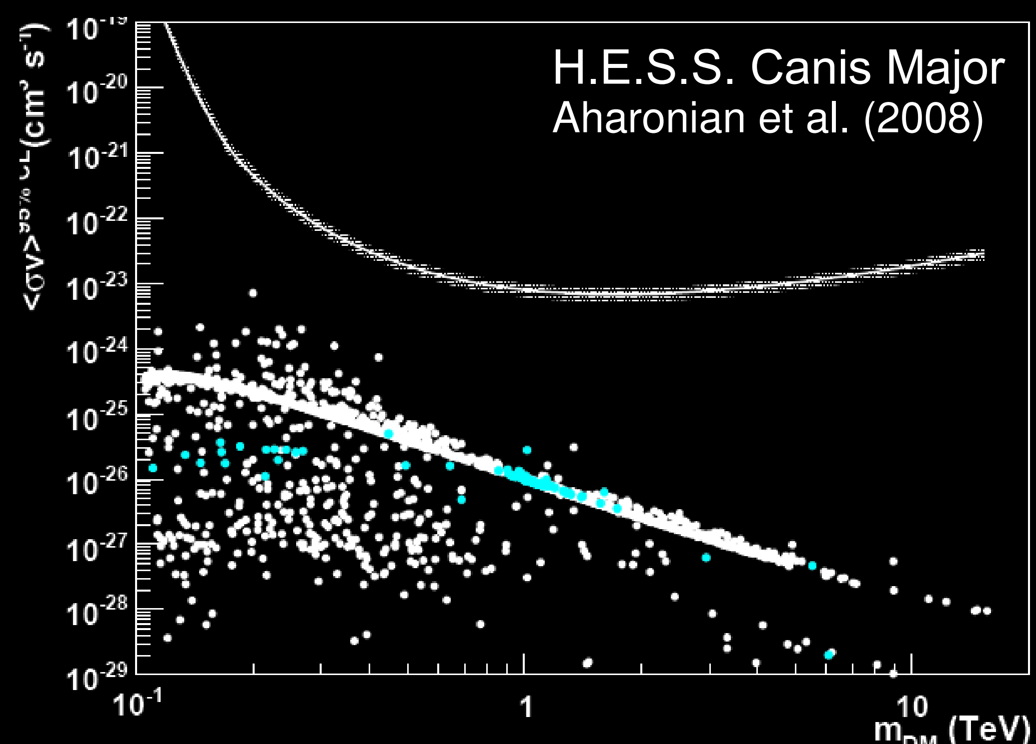
Aharonian et al. 2006

Dwarf Galaxies

- High mass/luminosity ration
- Most extreme DM dominated environments
- Only upper limits on γ-ray flux
  → derive upper limits on
  annihilation cross section
- ULs do not yet constrain models

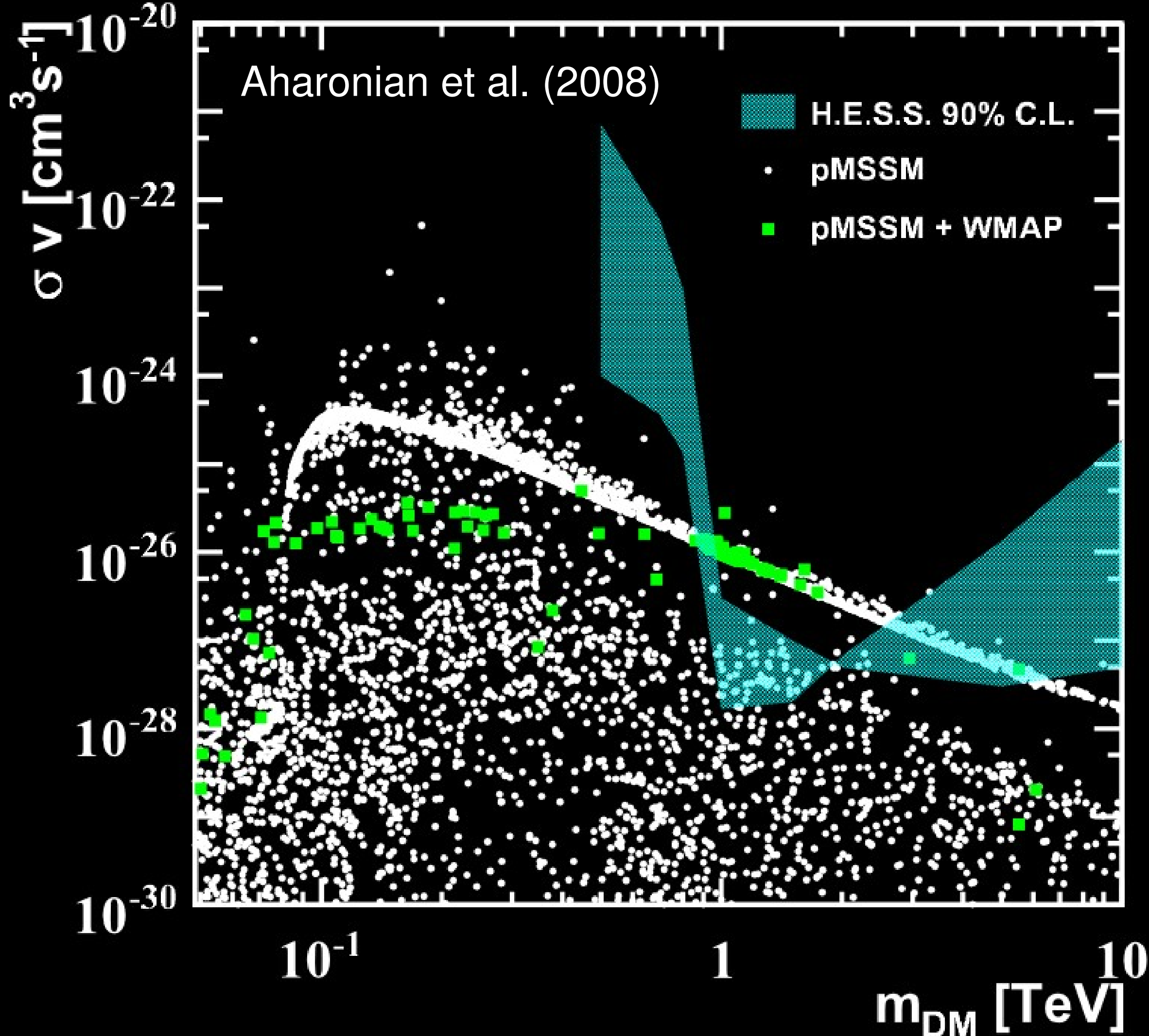






Dark Matter from IMBHs

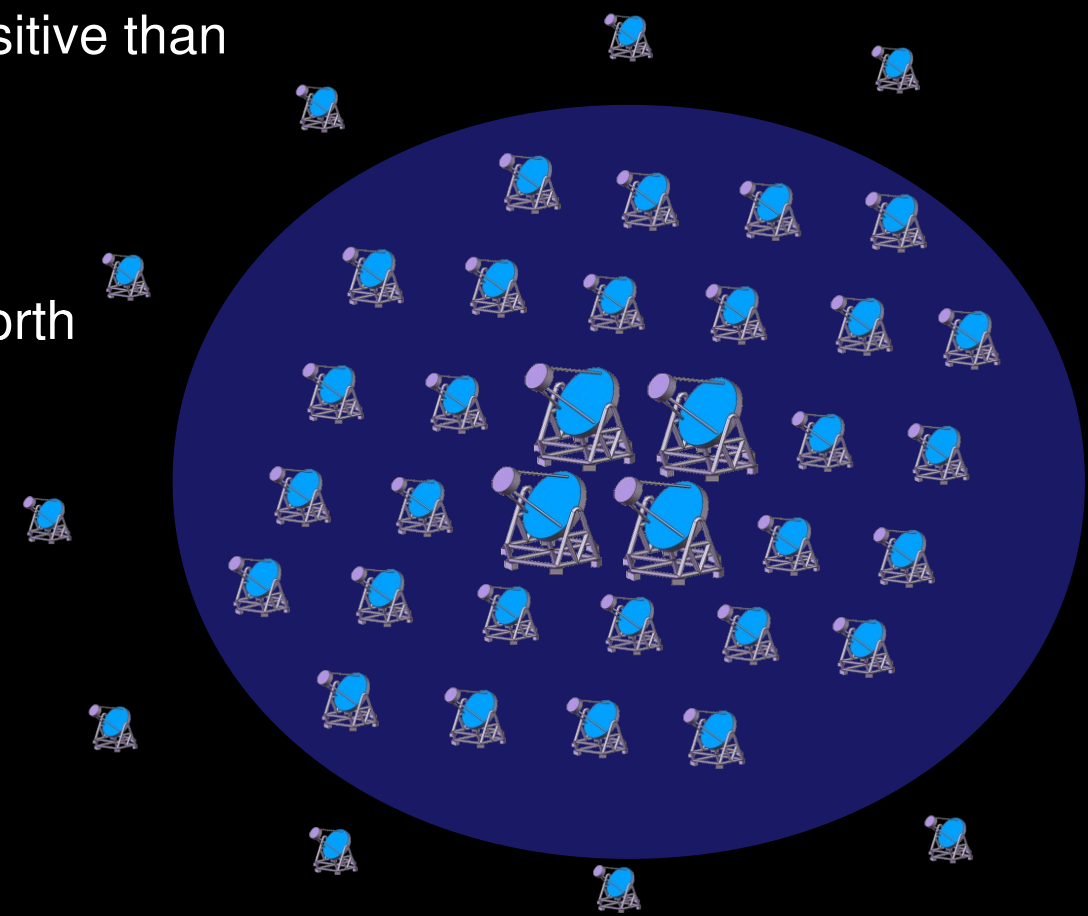
- black holes of mass ($100\ M_{sun} < M_{BH} < 10^6\ M_{sun}$)
- may power ultra-luminous X-ray sources
- formation procedure highly debated but leads to formation of DM overdensities
- search in H.E.S.S. scan data for point-like sources
- Depending on IMBH formation models there seems to be some potential



The Future: CTA

Jim Hinton (Gamma 2008)

- **Concept**
  - an IACT array *observatory*
  - an order of magnitude more sensitive than HESS: 1 mCrab
  - wide energy coverage: O(10) GeV - O(100) TeV
  - possibly sites in the south and north
- **Consortium**
  - largely European
  - HESS + MAGIC + many others
  - 15 countries currently involved
- **Currently in design phase**
  - Prototype construction in 2-3 years
- **High priority in European road maps:**



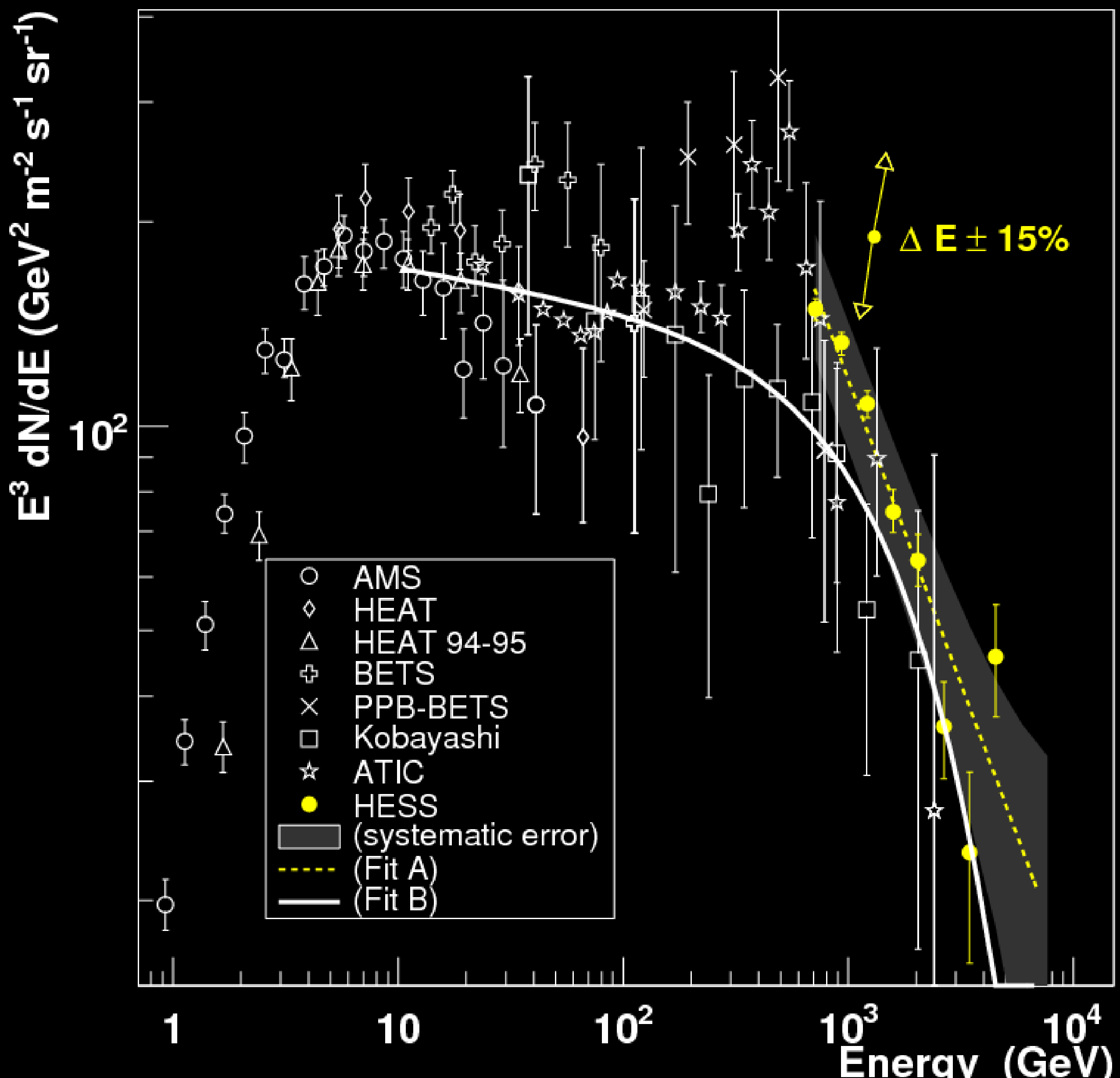
Summary

- VHE γ-ray instruments reach critical sensitivity to do real astronomy
- Significant progress on solving the problem of cosmic ray origin
- Expect to see 10x more sources with CTA
- VHE γ-ray astronomy has entered a golden era

Electrons (+positions)

- Search for electrons in data from extragalactic empty fields
- Extragalactic gamma component small @ TeV energies
- Spectral index 3.05 cut-off @ 2 TeV
- Existence of TeV electrons implies local electron source → PWN? DM?

Aharonian et al. 2008



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