Cosmic Rays Astrophysics and Very High Energy Gamma-rays Astronomy

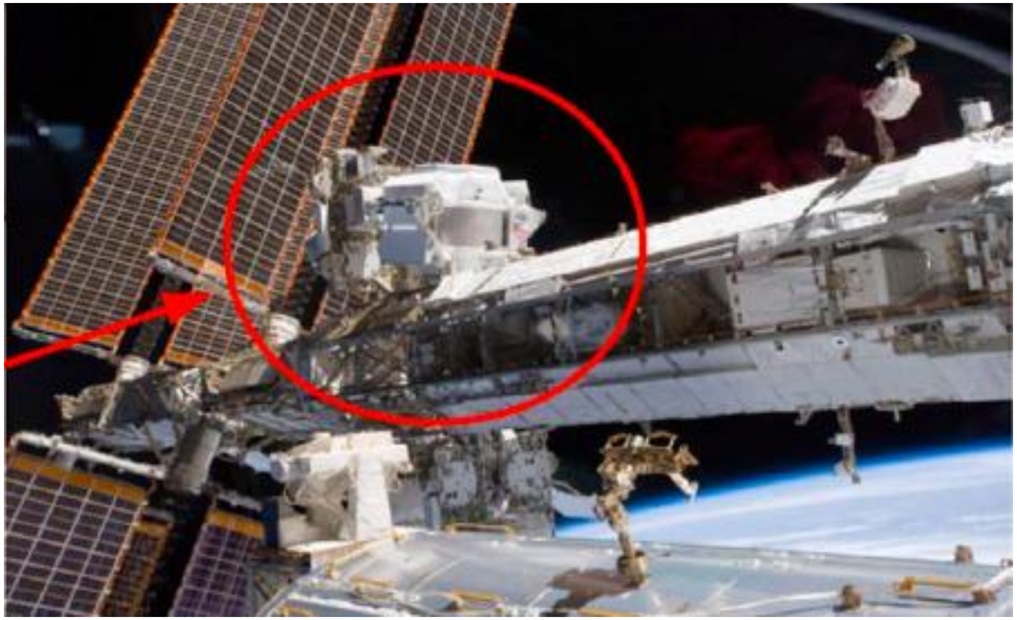
G. LAMANNA

ENIGMASS
12 October 2012

AMS02 on board of the ISS

AMS02 is grappled by the Shuttle Remote Manipulator System (SRMS)

May 19, 2011



May 19:

AMS installation completed on ISS at 5:15 CDT,

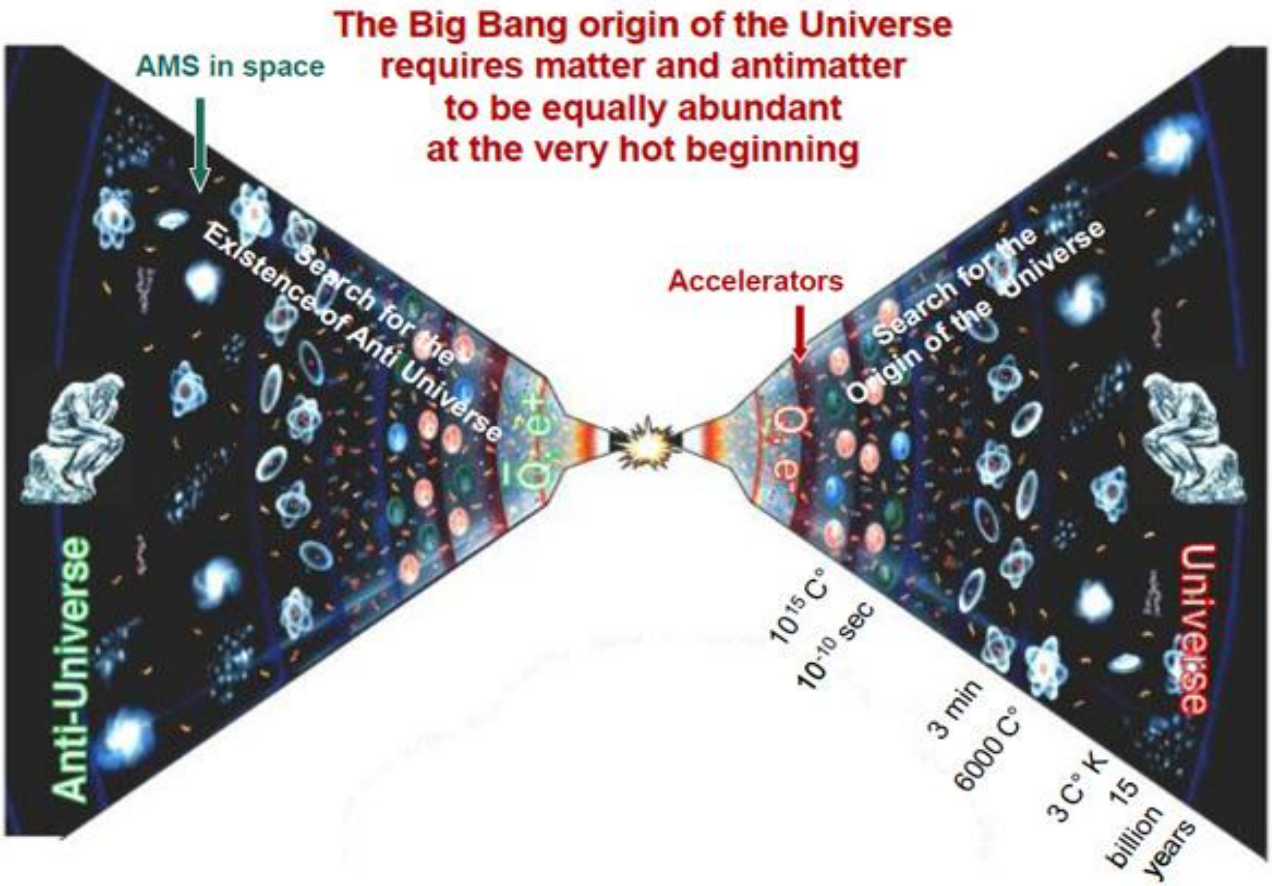
start taking data 9:35 CDT

Until 2020 ….

(CDT Central Daylight Time)

Matter-Antimatter

All evidence currently indicates that the universe is made of matter; however, …



Whether or not there is significant antimatter is one of the fundamental questions of the origin and nature of the universe.

Sakharov's Conditions for Baryogenesis (1967)

1) Baryon number (B) is not conserved.
Otherwise an initially baryon symmetric case could never change.

2) CP is not an exact symmetry.
Otherwise an initially CP-invariant symmetric universe could not evolve into a CP-noninvariant universe.

3) Baryogenesis could have occurred only when the universe was not in thermal equilibrium, e.g. during the GUT era or at the Electroweak phase transition.

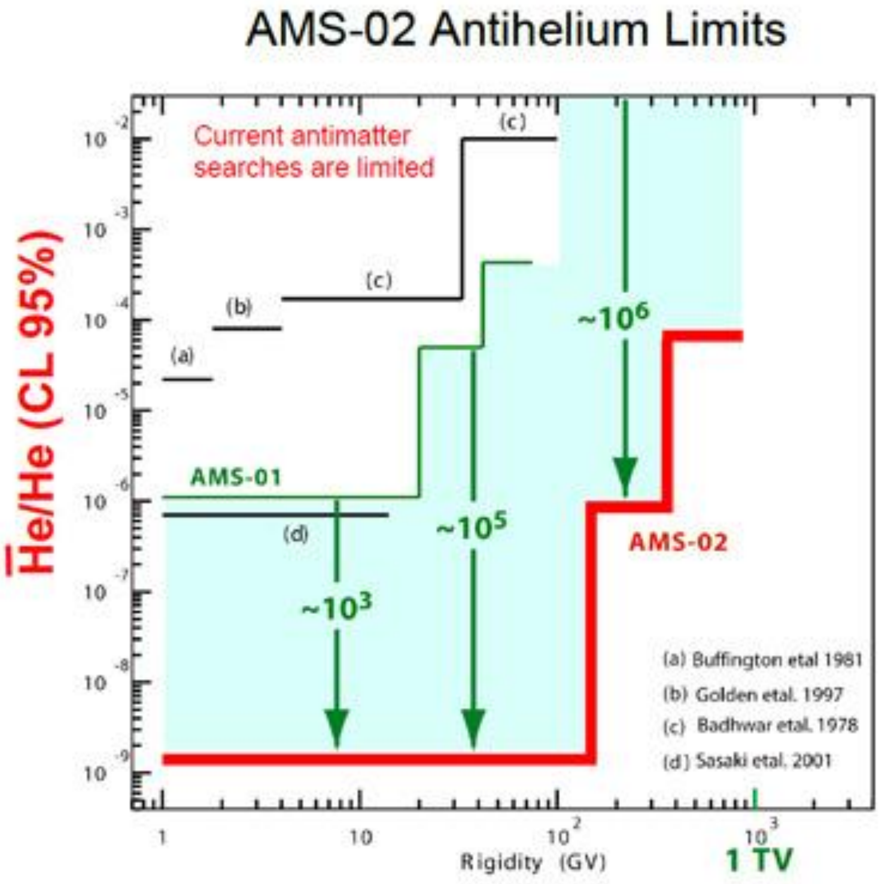
Baryon Number Violation
No data has yet provided evidence for baryon number violation.
Proton Lifetime > 1.6 10^{33} yr ($e^+\pi^0$ mode)

CP Violation
Has been observed in K_L and B only.
Both results are in agreement with the Standard Model.
Need a new type of CP Violation for Baryogenesis.

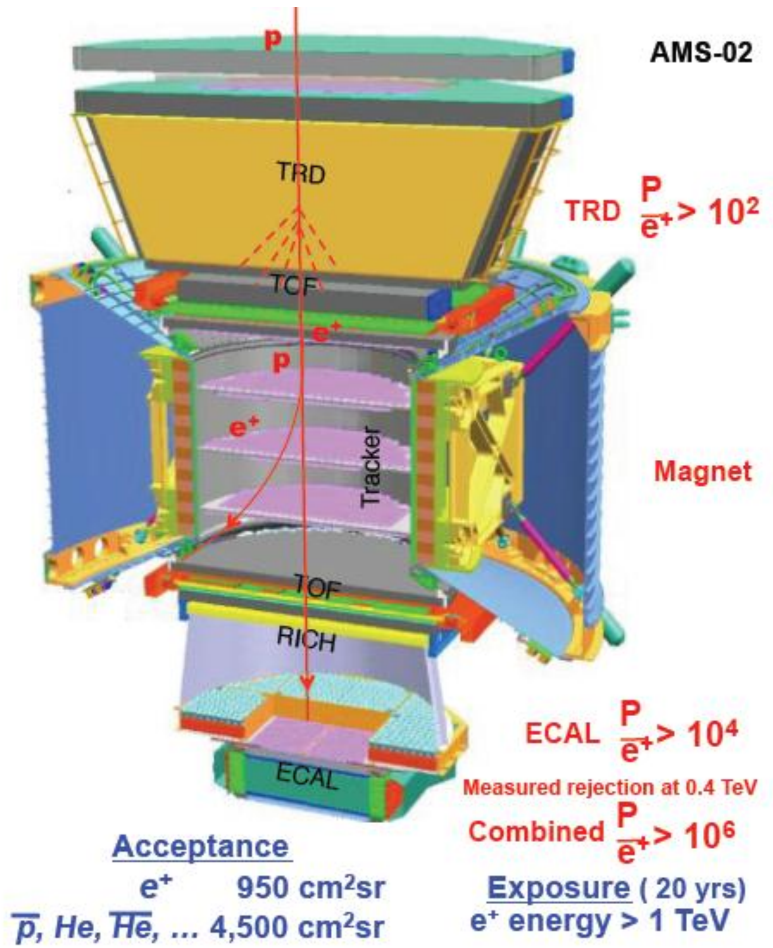
Any observations of an antihelium nucleus would provide strong evidence for the existence of antimatter.

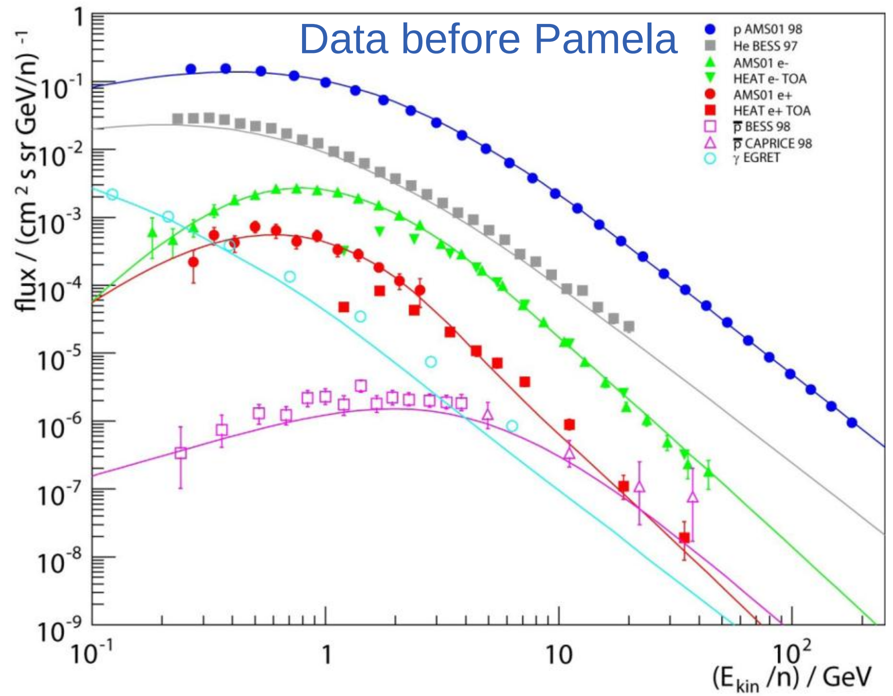
In 1999, AMS-01 established a new upper limit of 10^{-6} for the antihelium/helium flux ratio in the universe.

AMS-02 will search with a sensitivity of 10^{-9}, an improvement of three orders of magnitude, sufficient to reach the edge of the expanding universe and resolve the issue definitively.



Cosmic rays propagation





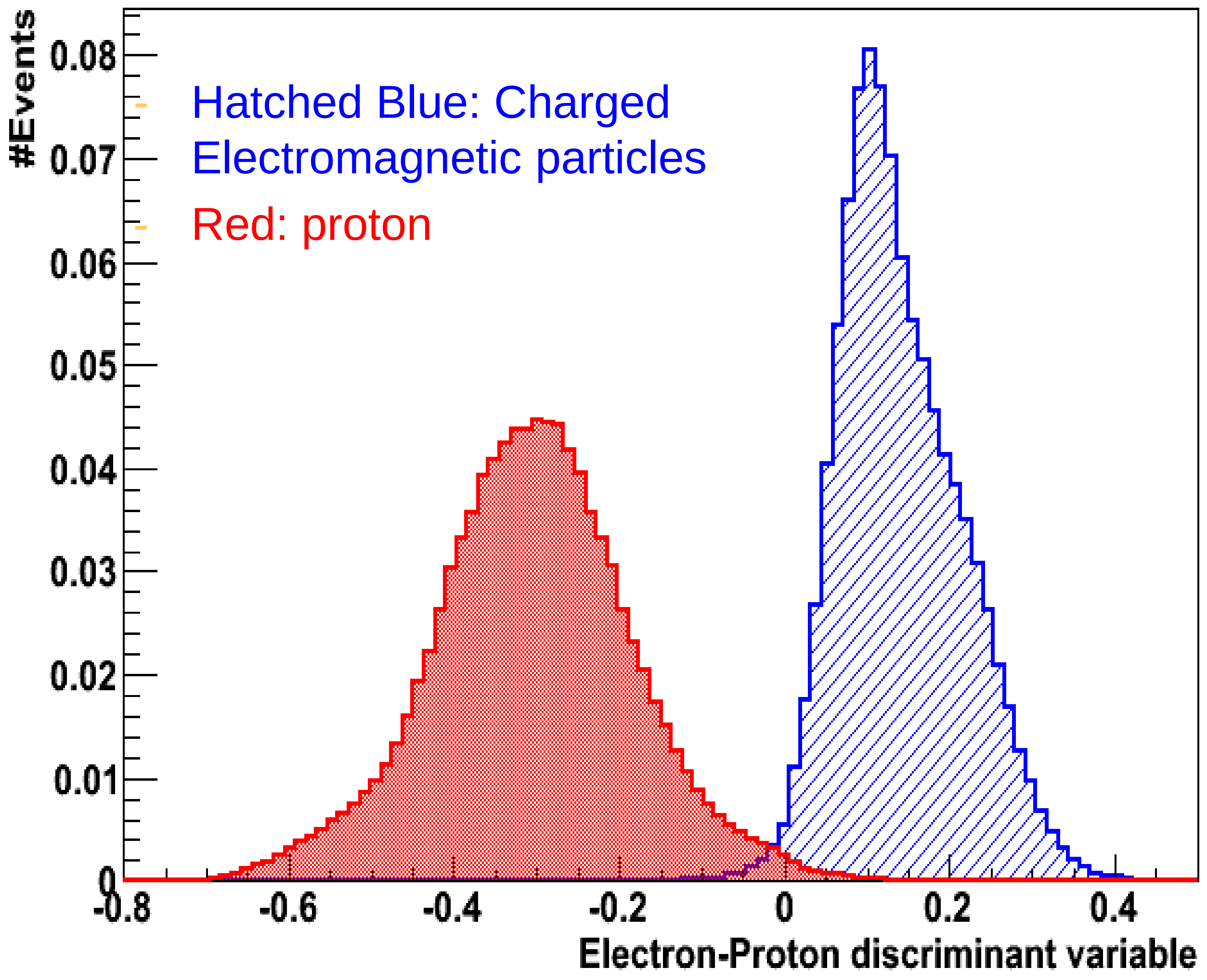
@ 10 GeV

88%	**Protons**
10%	**Helium**
++1%	**Electrons**
++0.1%	**Positrons**
++0.01%	**Gamma rays**
0.001%	**Antiprotons**

AMS: e-/p rejection with ECAL

- Ecal Standalone Estimator + E/P matching: Rejection greater than 4000 for an efficiency of 90 %
- Combined to other detector (TRD) an overall rejection factor of $\mathbf{10^6}$ is achieved .
- Based on data only.

ISS Data – ECAL Boost Decision Tree

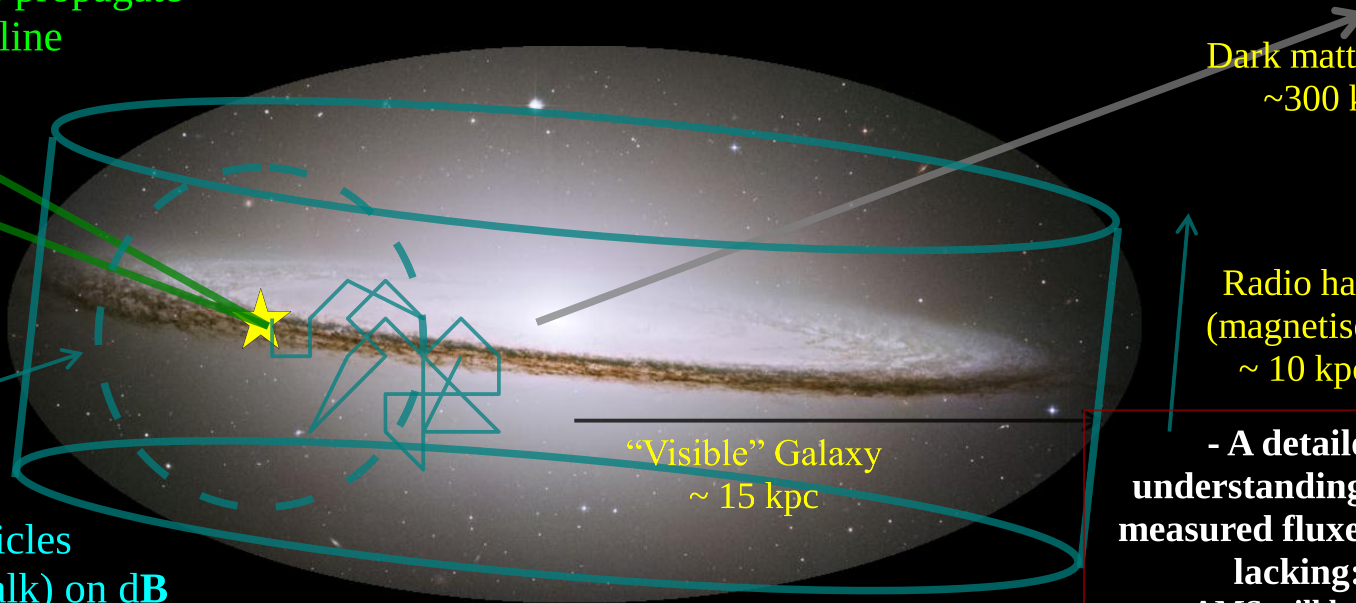


Cosmic-ray propagation

- Neutral particles propagate in straight line

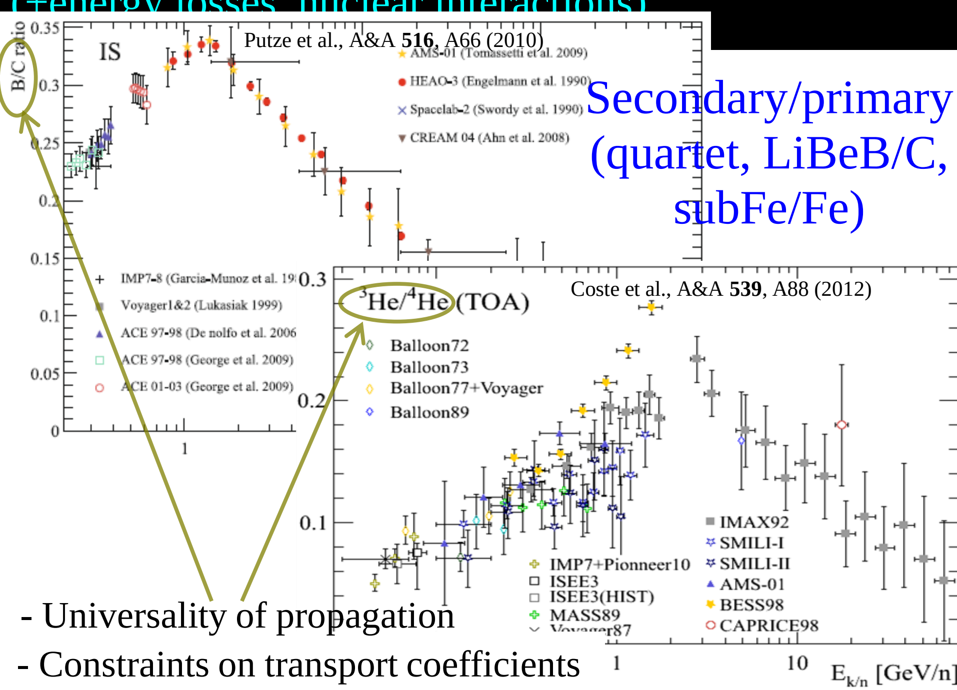
DW

"Effective" volume of contributing sources



- Charge particles diffuse (random walk) on d**B** (+energy losses, nuclear interactions)

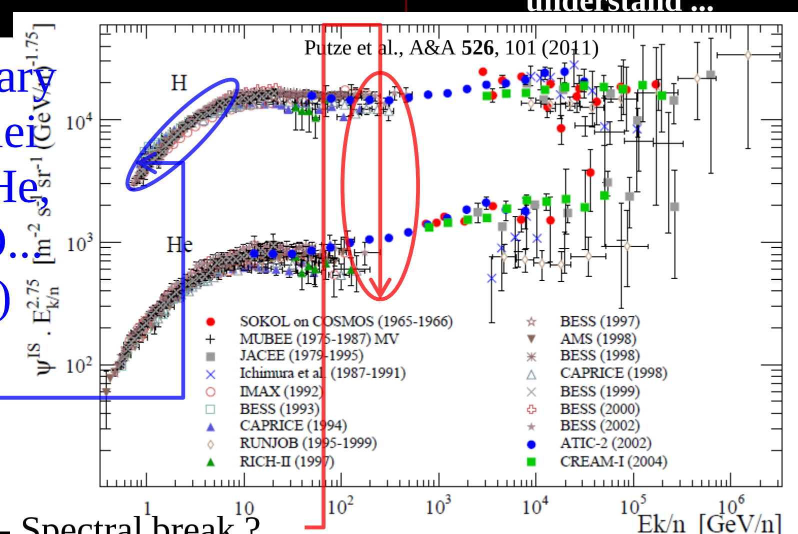
- **A detailed understanding of the measured fluxes is still lacking:**
  - **AMS will help to understand ...**



Secondary/primary (quartet, LiBeB/C, subFe/Fe)

- Universality of propagation
- Constraints on transport coefficients

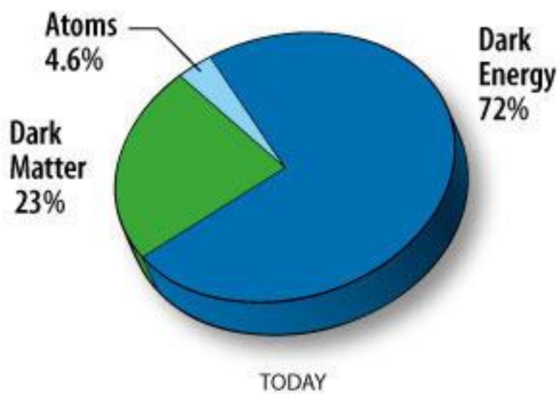
Primary nuclei (H, He, C, O… Fe)

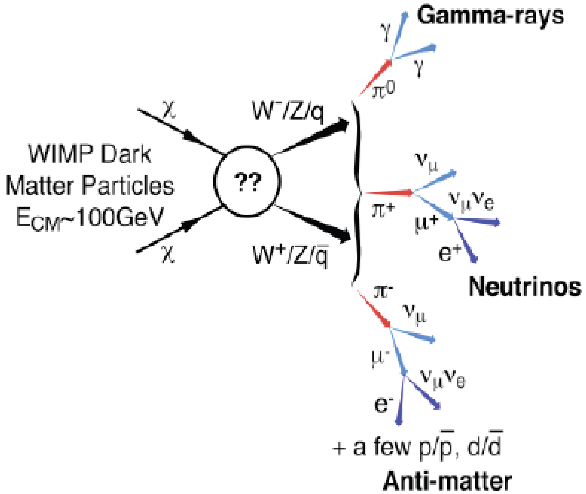


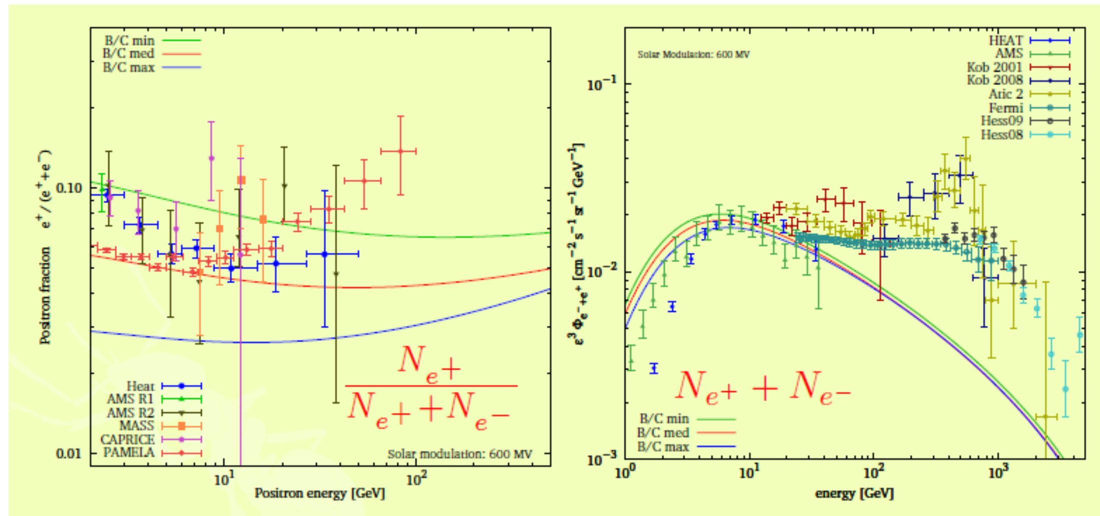
- Spectral break ?
- Constraints on CR src (spectrum, abundances)
- Solar modulation monitoring

lapp

Antimatter - Dark Matter

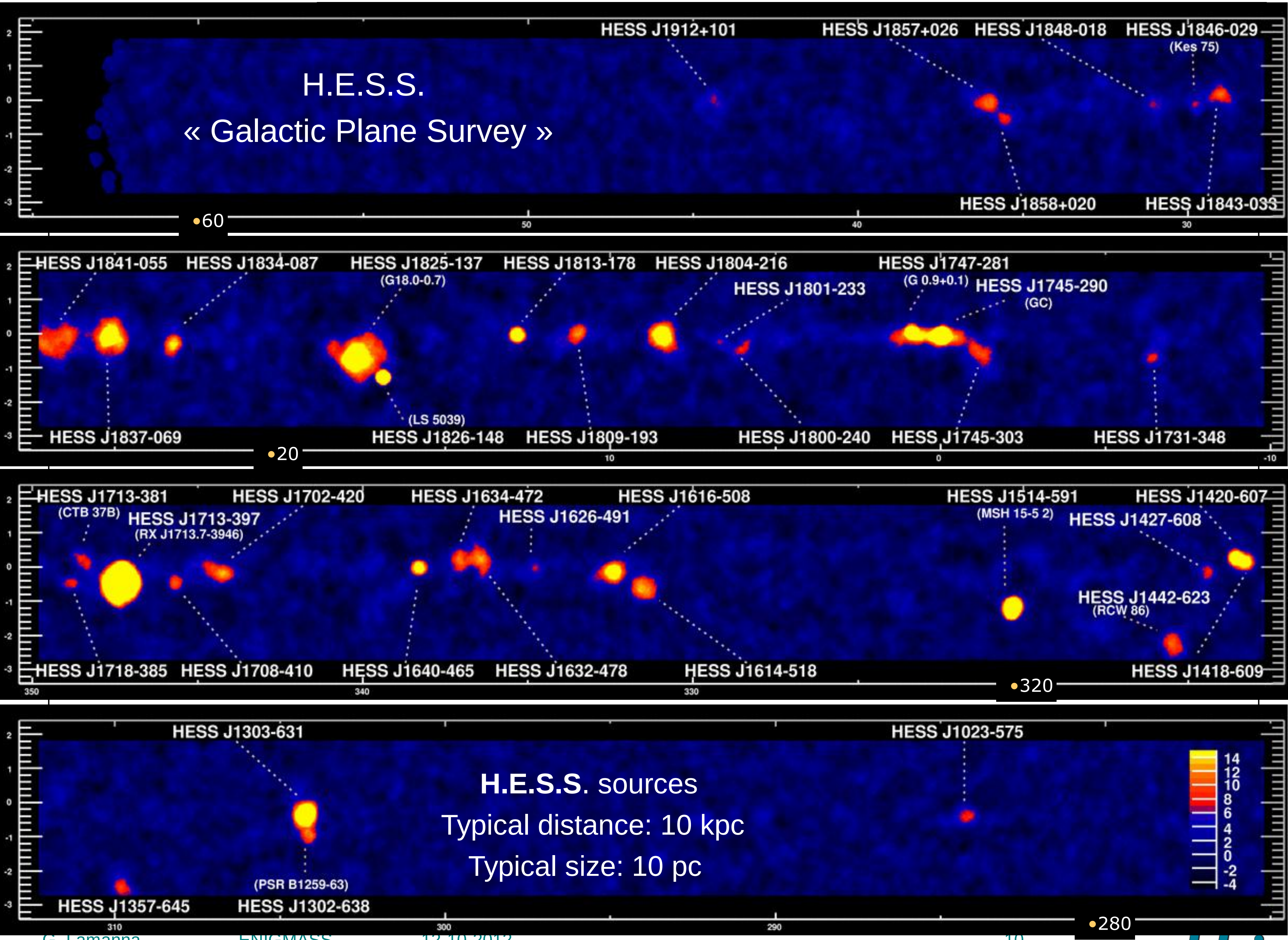




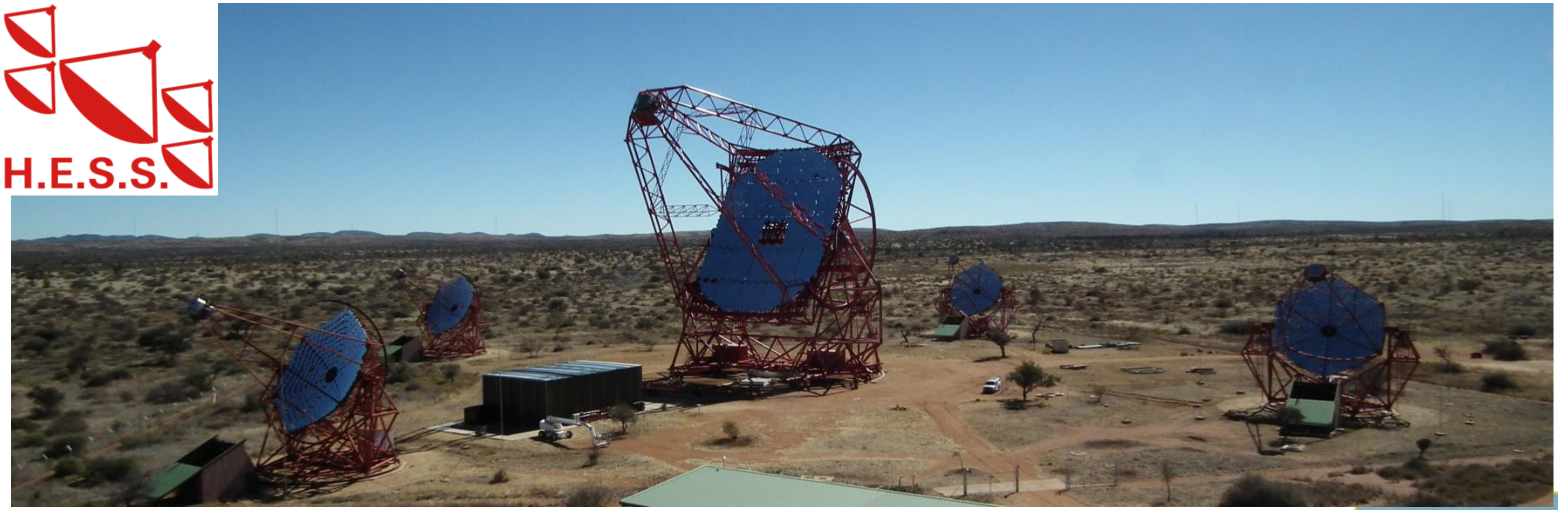


$$Q_{charged} = \frac{dN}{dE}\frac{<\sigma v>}{2m_\chi^2}\rho_\chi^2$$

- Pamela positrons excess opens exotic interpretations…
- AMS results are expected *vs* the Pamela (<100 GeV) and (partially) Fermi &HESS (0.02-1TeV) e+ e- spectra
- BUT: ..Supernova remnants and Pulsars are objects capable to produce electrons and positrons.


H.E.S.S.
« Galactic Plane Survey »
HESS J1912+101
HESS J1857+026
HESS J1848-018
HESS J1846-029
(Kes 75)
HESS J1858+020
HESS J1843-033
60
HESS J1841-055
HESS J1834-087
HESS J1825-137
(G18.0-0.7)
HESS J1813-178
HESS J1804-216
HESS J1801-233
HESS J1747-281
(G 0.9+0.1)
HESS J1745-290
(GC)
(LS 5039)
HESS J1837-069
HESS J1826-148
HESS J1809-193
HESS J1800-240
HESS J1745-303
HESS J1731-348
20
HESS J1713-381
(CTB 37B)
HESS J1713-397
(RX J1713.7-3946)
HESS J1702-420
HESS J1634-472
HESS J1626-491
HESS J1616-508
HESS J1514-591
(MSH 15-5 2)
HESS J1420-607
HESS J1427-608
HESS J1442-623
(RCW 86)
HESS J1718-385
HESS J1708-410
HESS J1640-465
HESS J1632-478
HESS J1614-518
HESS J1418-609
320
HESS J1303-631
HESS J1023-575
H.E.S.S. sources
Typical distance: 10 kpc
Typical size: 10 pc
(PSR B1259-63)
HESS J1357-645
HESS J1302-638
280

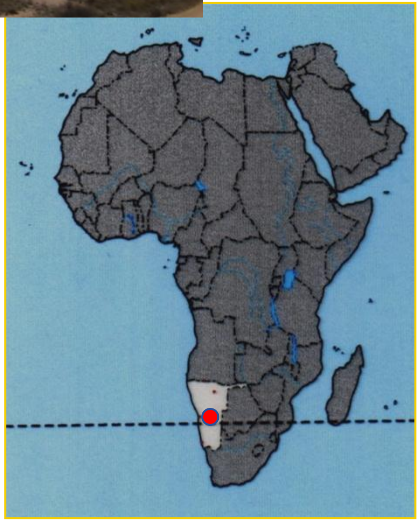
H.E.S.S.: High Energy Stereoscopic System



A system of 4 (13 m diameter dish) telescopes (since 10 years)

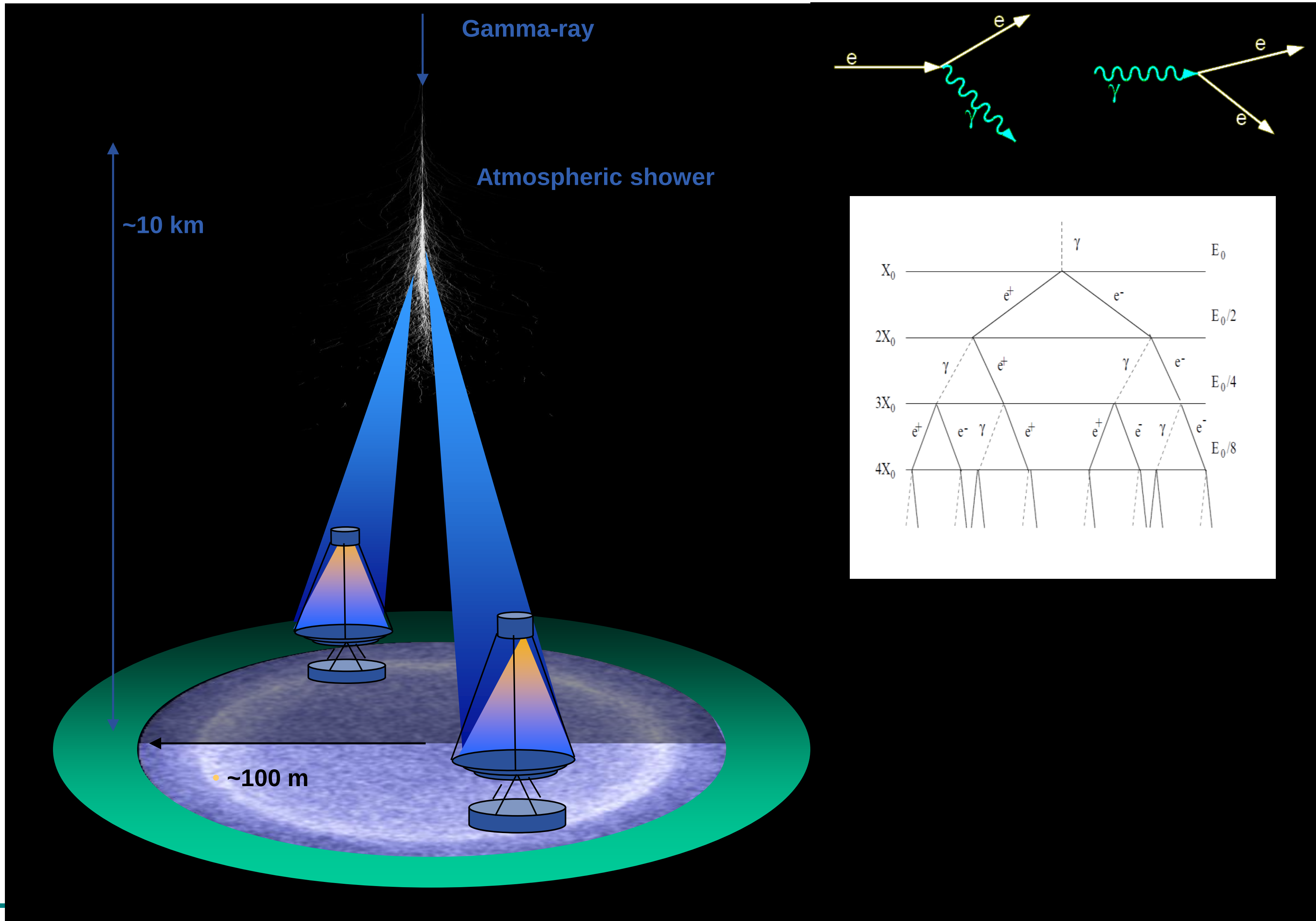
and

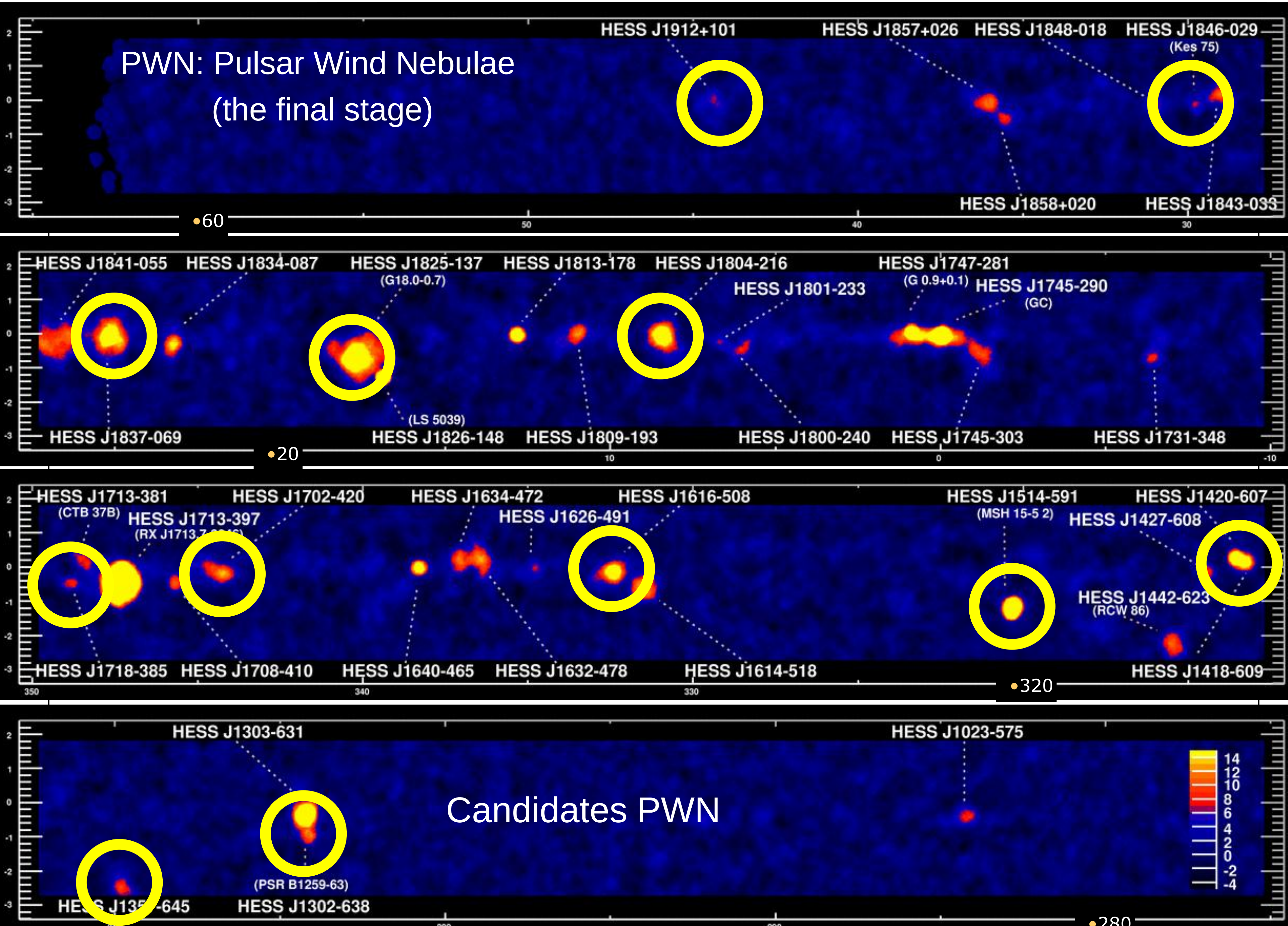
1 (30 m diameter dish) telescope (since September 2012)



In Namibia (1800 m)

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





PWN: Pulsar Wind Nebulae
(the final stage)
HESS J1912+101
HESS J1857+026
HESS J1848-018
HESS J1846-029
(Kes 75)
HESS J1858+020
HESS J1843-033
60
HESS J1841-055
HESS J1834-087
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HESS J1713-397
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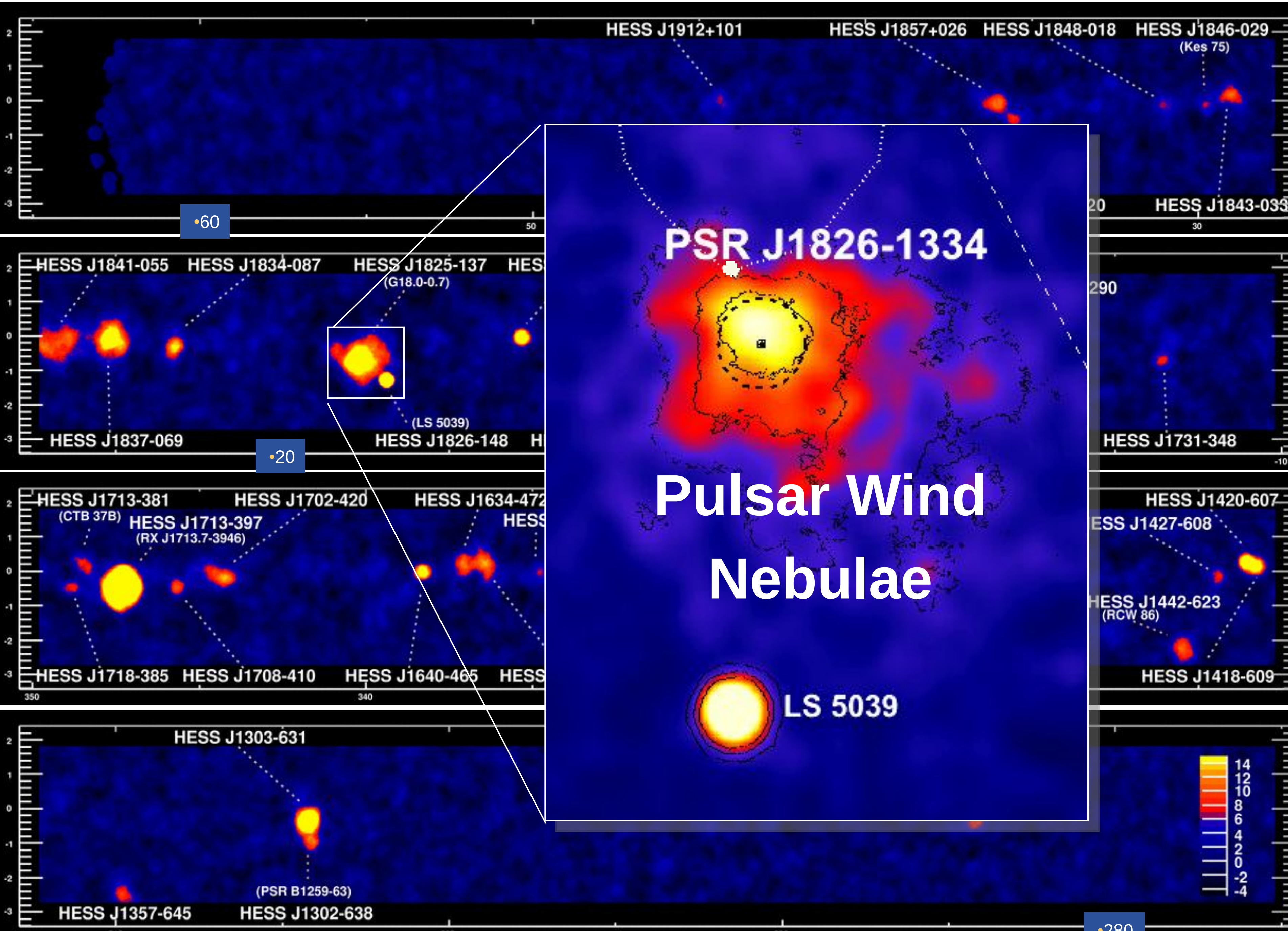
HESS J1640-465
HESS J1632-478
HESS J1614-518
HESS J1418-609
320
HESS J1303-631
HESS J1023-575
Candidates PWN
(PSR B1259-63)
HE S J135 -645
HESS J1302-638
280


PSR J1826-1334
Pulsar Wind
Nebulae
LS 5039
HESS J1912+101
HESS J1857+026
HESS J1848-018
HESS J1846-029
(Kes 75)
HESS J1843-033
HESS J1841-055
HESS J1834-087
HESS J1825-137
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(PSR B1259-63)
HESS J1357-645
HESS J1302-638
•60
•20
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14
12
10
8
6
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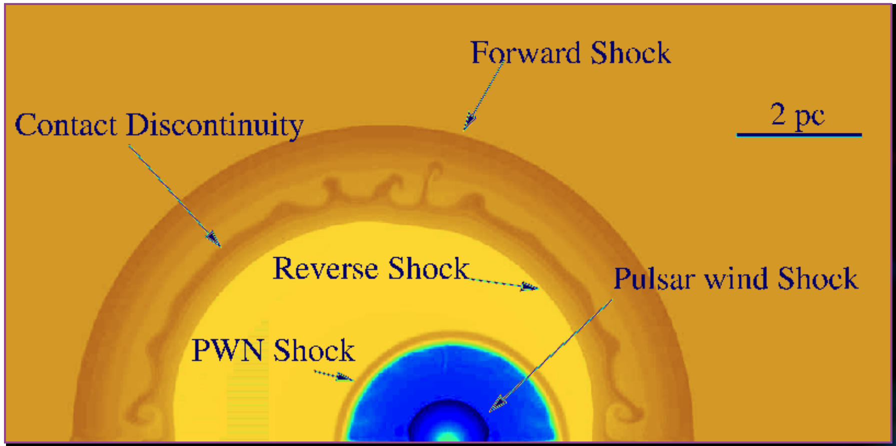
2
0
-2
-4

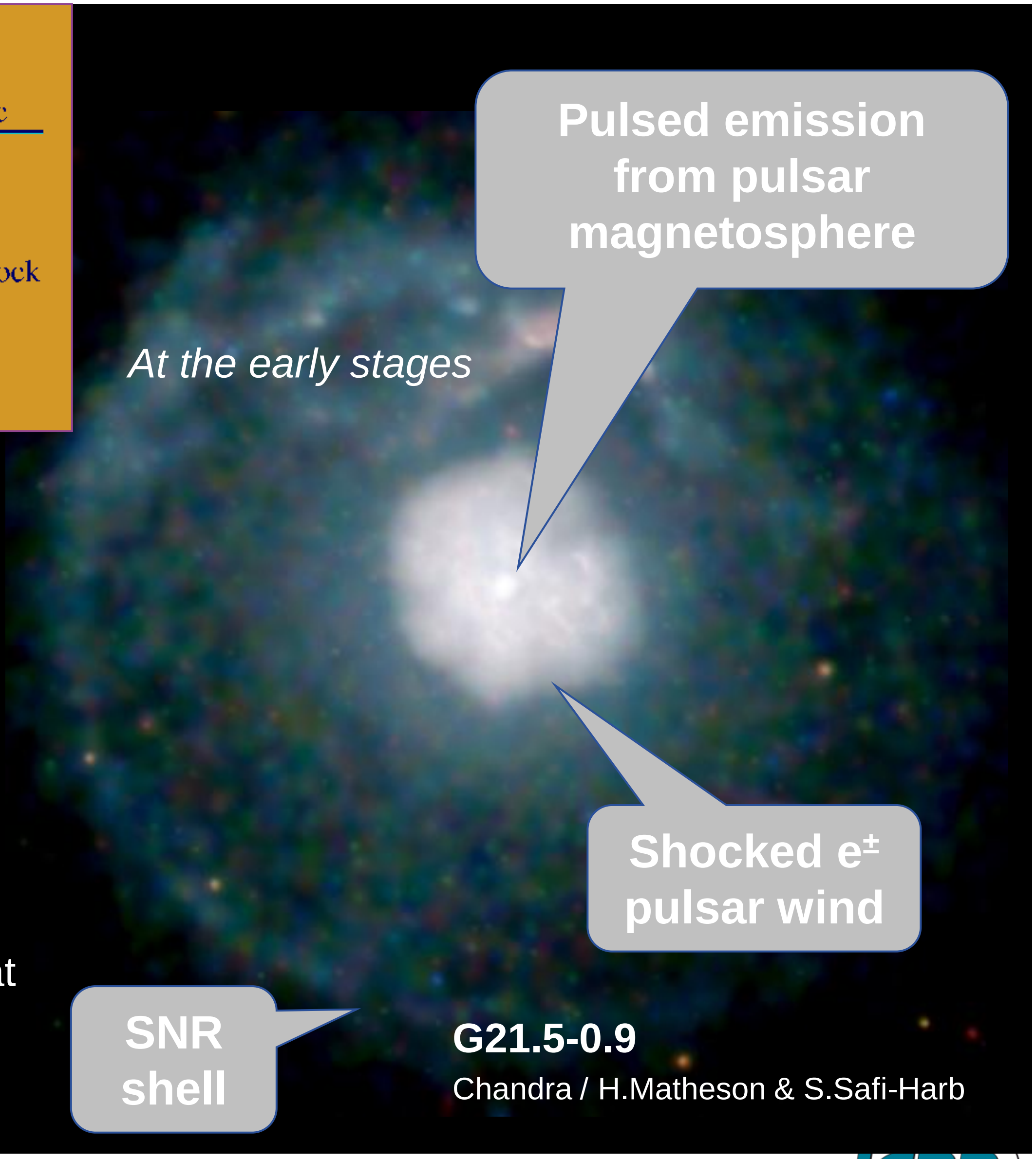
Pulsar Wind Nebulae (PWN)

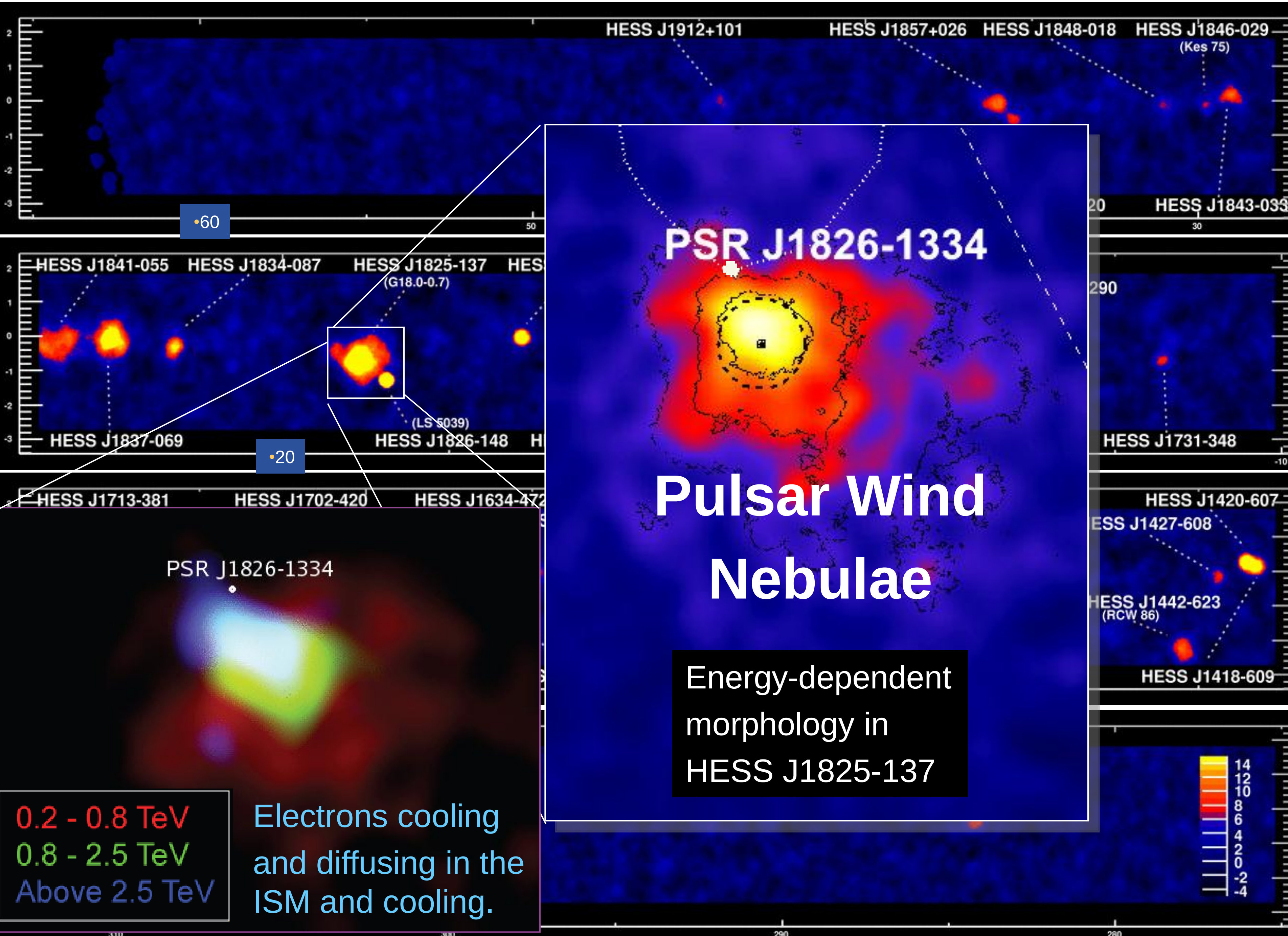


- The relativistic e+e- wind from the pulsar terminates in a shock where the ram pressure of the wind is balanced by the pressure of the surrounding nebula.

- At the shock, the kinetic energy of the wind is transformed into random motion.

- Outside the shock, the resulting relativistic e+e- gas convects outwards at subsonic speeds forming an expanding PWN visible in synchrotron radiation (kyrs) and IC gamma-rays (10^5y)





Pulsar Wind Nebulae

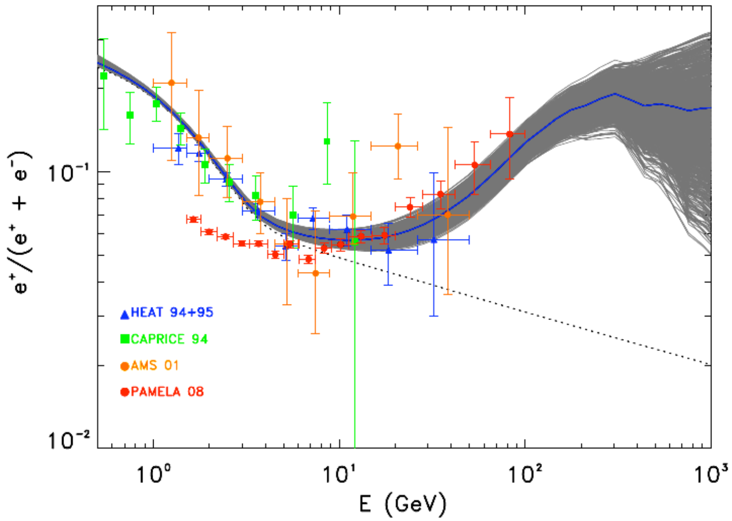
Energy-dependent morphology in HESS J1825-137

0.2 - 0.8 TeV
0.8 - 2.5 TeV
Above 2.5 TeV

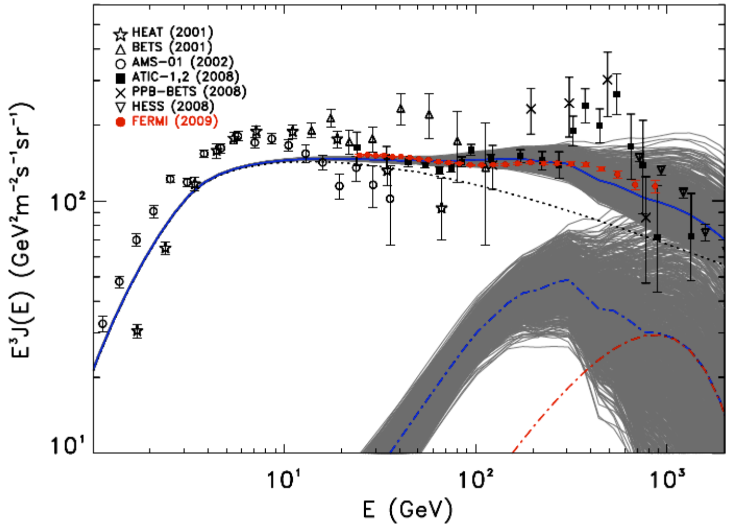
Electrons cooling and diffusing in the ISM and cooling.

Pulsar, PWN and e+ e- spectra

S.Profumo



S.Profumo

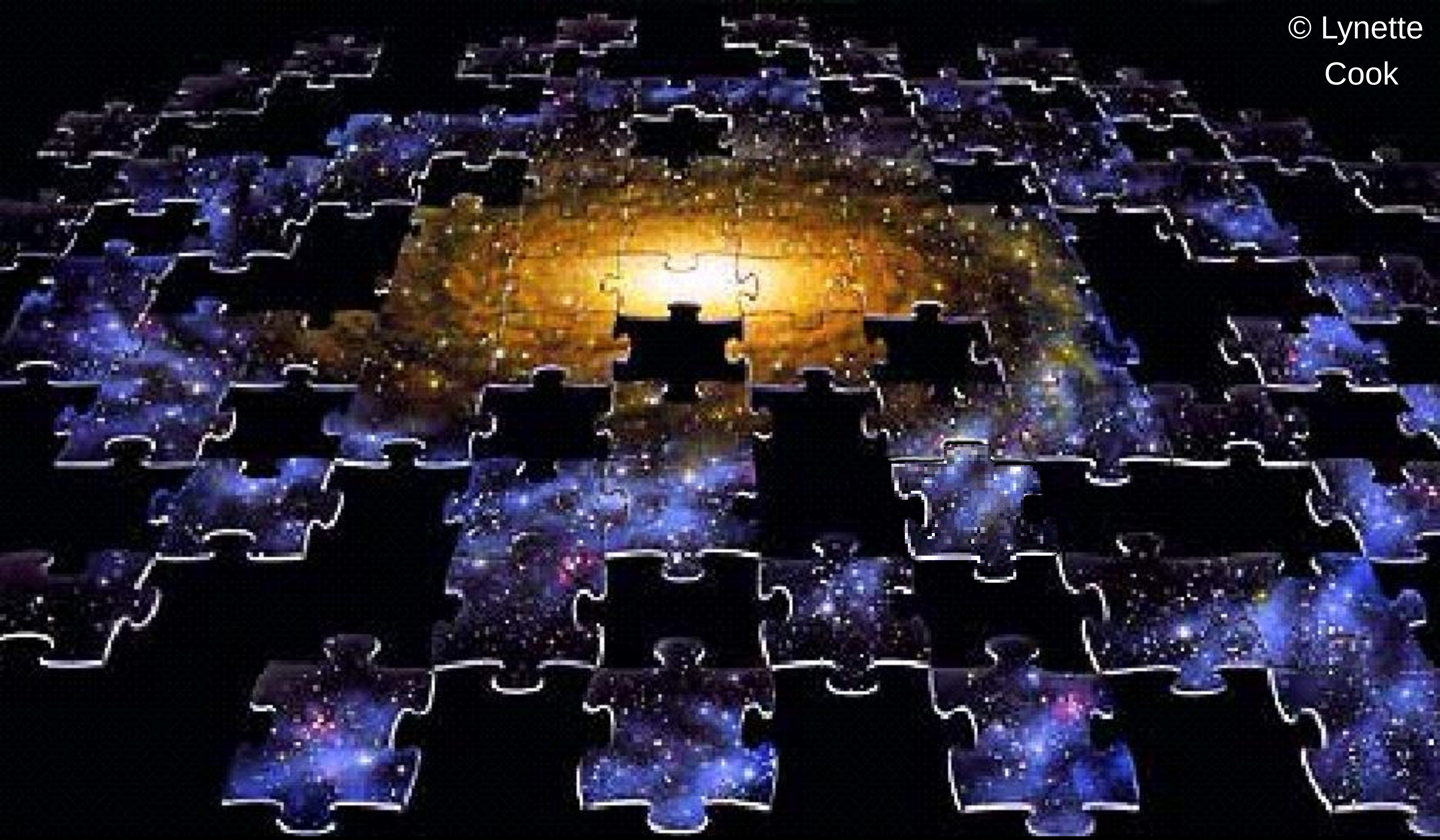


Contribution of Pulsars to the e± flux depends on three observational inputs: the pulsar age, its distance and its spin-down power.

1) The local spectrum of e± from mature pulsars (T is much larger than the trapping time of e± before they diffuse in the ISM)

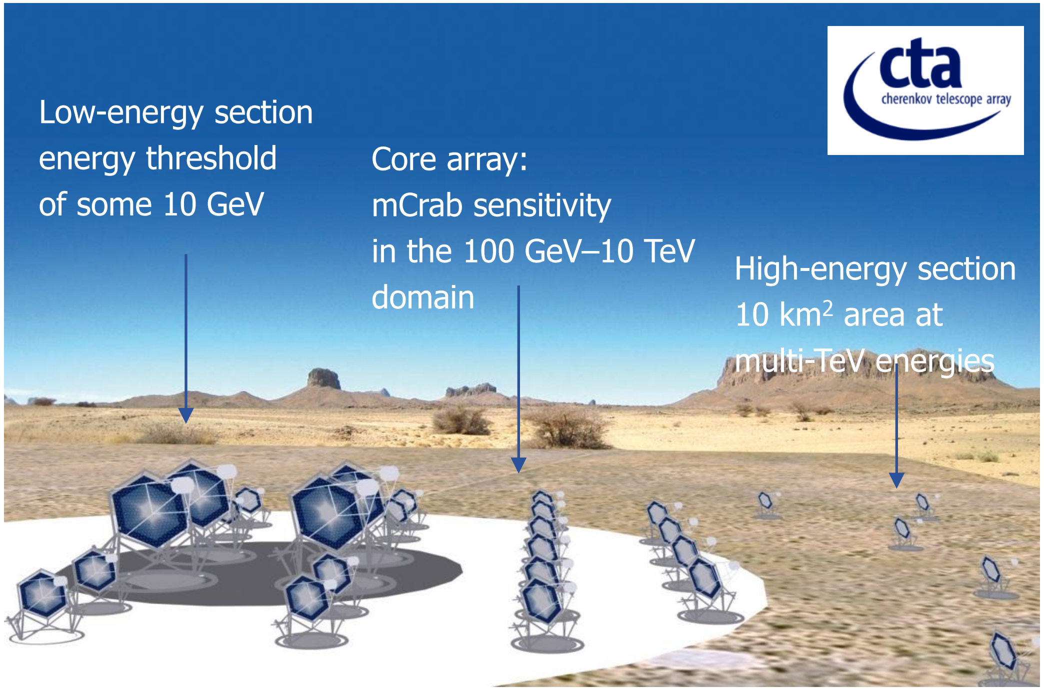
2) Nearby Geminga pulsar-like, (D=200 pc; T ~ 2 − 3 × 100 kyrs), (<u>and other dark sources</u>) can very naturally be the dominant positron sources to explain the PAMELA data. (Vela X too young, too much energy)

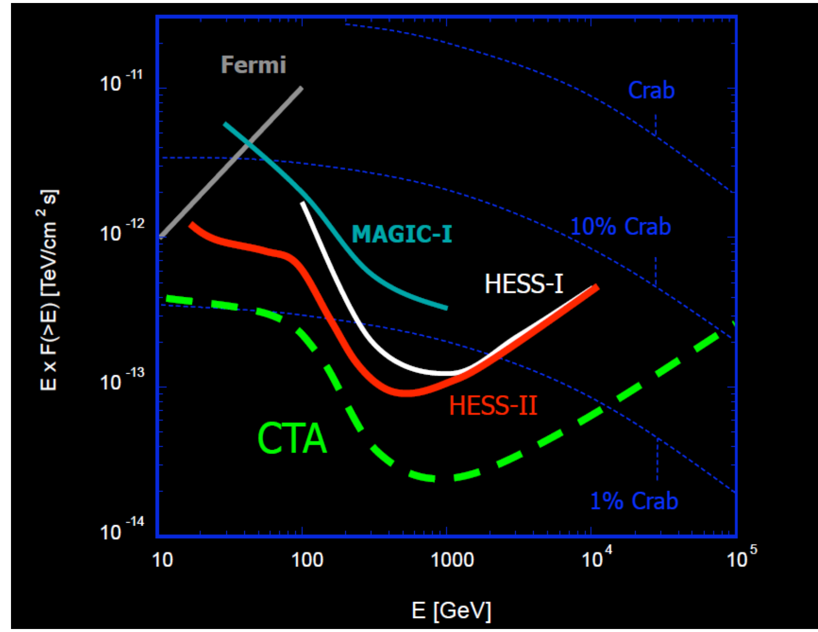
3) Many observational uncertainties needing PWN **<u>population study.</u>**



The age of real VHE gamma ray astronomy has started

Cherenkov Telescope Array – CTA





- **Higher sensitivity at TeV energies (x 10)**
  more sources, details in extended sources
- **Lower threshold (some 10 GeV)**
  pulsars, distant AGN, source mechanisms
- **Higher energy reach (100s of TeV)**
  cutoff region of Galactic accelerators
- **Wider field of view**
  extended sources, surveys
- **Improved angular resolution**
  structure of extended sources
- **Higher detection rates**
  transient phenomena

Indirect search for DM: where to look for…

Galaxy clusters:

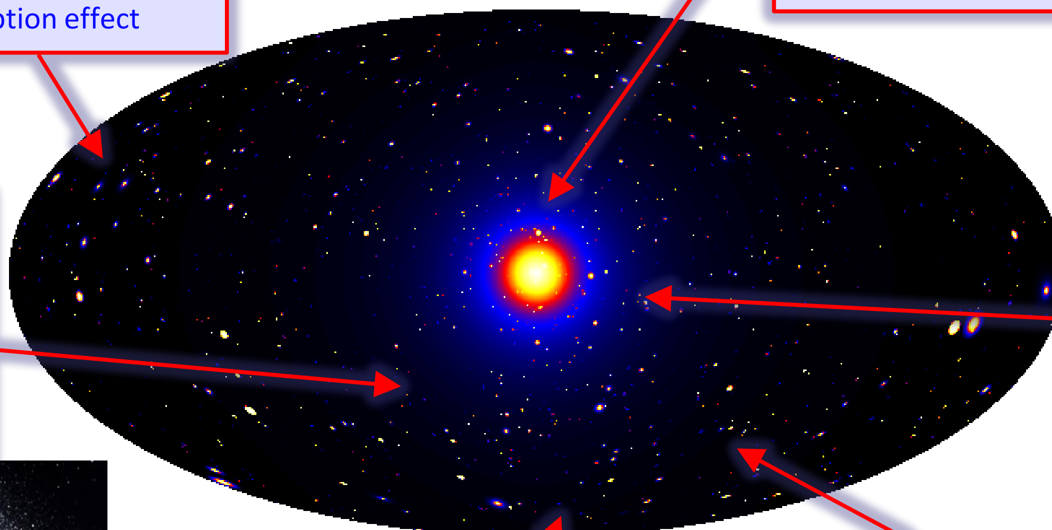
\+ low background, astronomical data

\- distance, low statistics, EBL absorption effect

Galactic center:

\+ close and good statistics

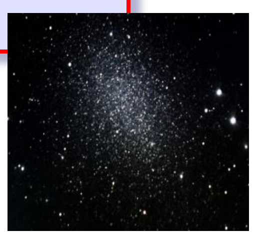
\- astrophysics source confusion and diffuse γ-background



Dwarf Spheroidal Galaxies:

\+ off galactic plane (low background), astro. data

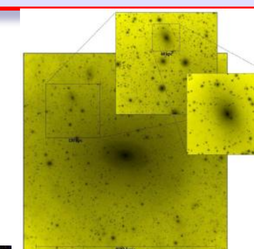
\- low statistics, tidal disruption



Galactic halo, sub-halos, clumps:

\+ (may be) close and good statistics

\- number and position unknown, diffuse γ-bg., large uncertainties



Extragalactic:

\+ large statistics

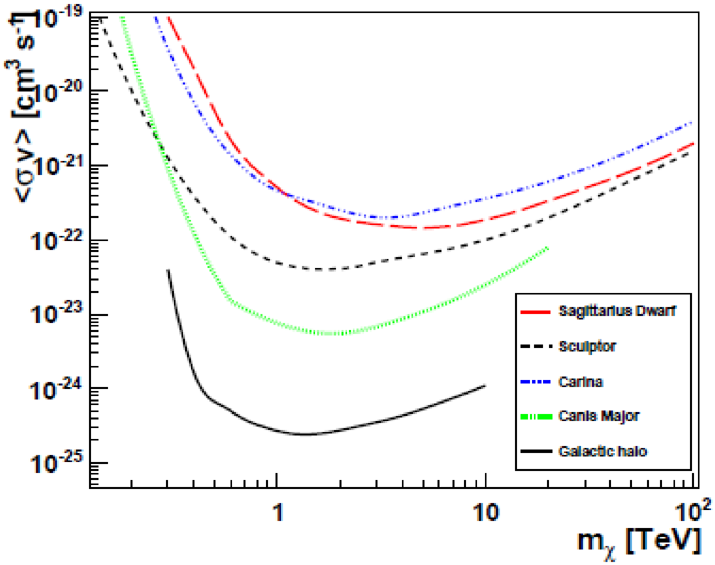
\- Astrophysics and diffuse background

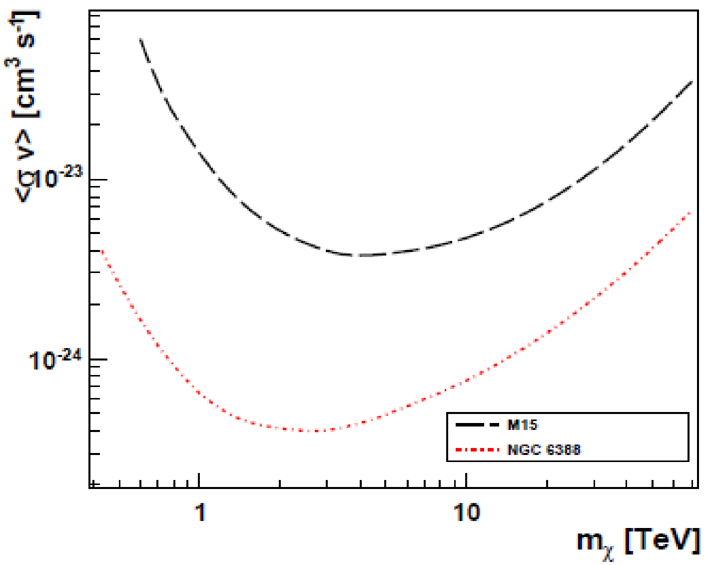
IMBH:

\+ Survey-mode obs. time

\- Astrophysics, distribution and location uncertainties

G.Lamanna





- Compilation of H.E.S.S. constraints in the DM search: 95% CL upper limits on <σv> as a function of the WIMP mass. Dwarf galaxies have a reduced astrophysical back-ground since they have little or no recent star formation activity.

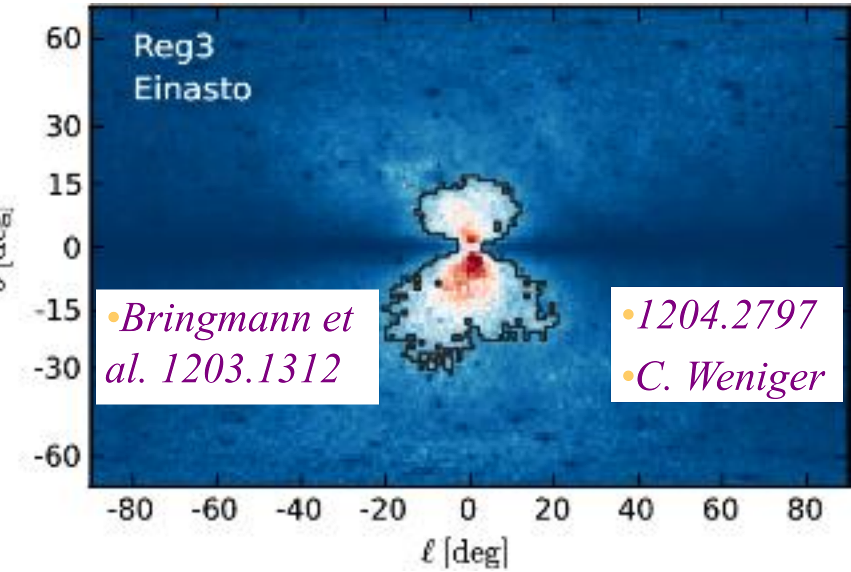
Globular Clusters in the primordial formation scenario could have been formed in DM minihalos, before or during the reionization, before formation of galaxies and WIMPs could still be present in their environment.

$$\Phi_\gamma(E) \cong \frac{dN_\gamma}{dE\, dS\, dt\, d\Omega} = \frac{1}{4\pi} \frac{<\sigma v>}{m_\chi^2} \frac{dN_\gamma}{dE}(E) \;<J>$$

$$\langle \sigma v \rangle_{min}^{95\%\, C.L.} = \frac{4\pi}{T_{\rm obs}} \frac{m_{DM}^2}{\bar{J}(\Delta\Omega)\Delta\Omega} \frac{N_\gamma^{95\%\, C.L.}}{\int_0^{m_{DM}} A_{\rm eff}(E_\gamma)\frac{dN_\gamma}{dE_\gamma} dE_\gamma}$$

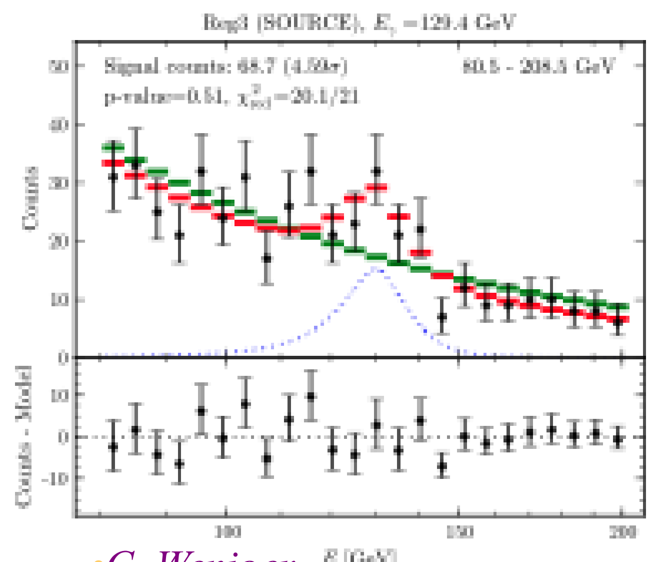
Dark Matter: Fermi gamma-lines from GC

By using a S/N "optimized" search strategy (dependent on background and signal morphology), Weniger et al. claim observation of a line-like ~130 GeV corresponding to a cross section around ~10^{-27} cm^3/s in the Fermi public data.



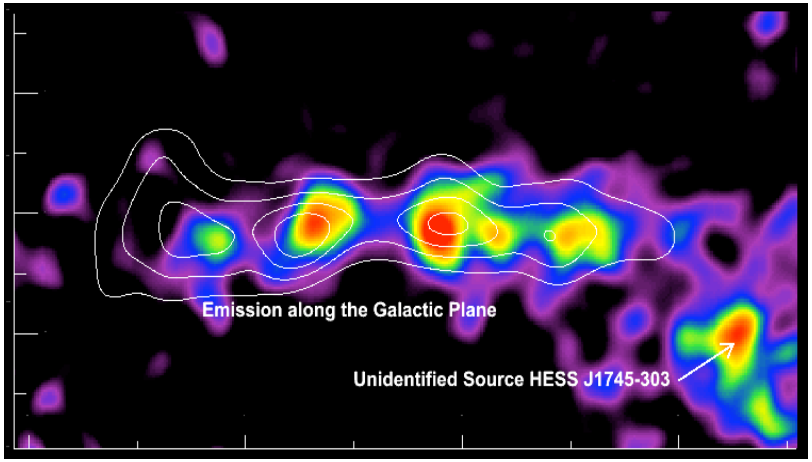
- Bringmann et al. 1203.1312
- 1204.2797
- C. Weniger

- Is this a statistical fluke?
- Is it instrumental? (but why only towards GC?)
- Is it astrophysical (but of what sort)?
- Is it the first glimpse of dark matter?



- C. Weniger
- 1204.2797

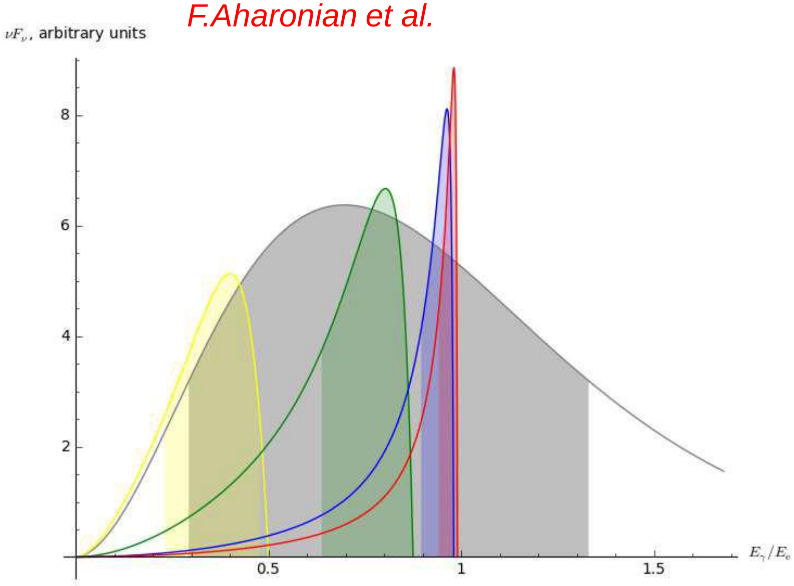
Dark Matter: Fermi gamma-lines from GC



Galactic Center:

- 10 % of galactic interstellar medium
- [giant molecular clouds]
- Host the nearest [hypothetical] super-massive BH
- Variety of VHE emitters: SNRs, Molecular Clouds, non-thermal arcs...

F.Aharonian et al.



- Comptonization of a cold ultrarelativistic (large Lorentz factor) electron-positron pulsar wind in the deep Klein-Nishina regime

$$b = \varepsilon E_e / m_e^2 c^4 \geq 1$$

can readily provide very narrow ($\Delta E/E \leq 0.2$) distinct gamma-ray line features.

- An experimental challenge for HESS 2 and a potential science case for all pulsars and binary system at E<100 GeV.

Dark Matter: Fermi gamma-lines from GC

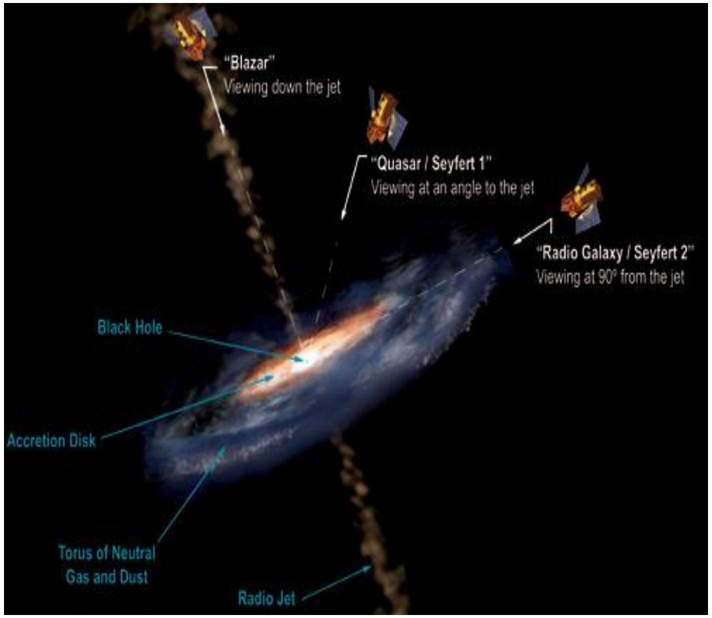
- Claimed line-like emission at ~130 GeV towards the Galactic Center detected in Fermi-LAT data: *Bringmann et al. 1203.1312, C. Weniger 1204.2797*
- HESS-II can *at least* check if it is an instrumental effect (completely different systematics) *L. Bergstrom et al."Investigating Gamma-Ray Lines from Dark Matter with Future Observatories," arXiv:1207.6773*
- Further morphological studies are possible which may help discriminating among models.
- Is there a new type of astrophysical emission of which this represents the "first of its kind", just due to lack of sensitivity till now? *F. Aharonian, D. Khangulyan and D. Malyshev, "Cold ultrarelativistic pulsar winds as potential sources of galactic gamma-ray lines above 100 GeV," arXiv:1207.0458*

HESS 2 with ~50 hrs observation of the GC at E>30 GeV in spring/summer 2013 will enable and independent check

Active Galactic Nuclei (AGN), TeV Blazars

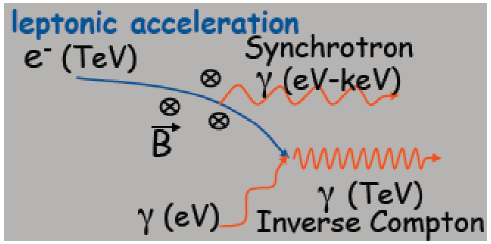
More than 30 extragalactic sources seen in VHE γ-rays

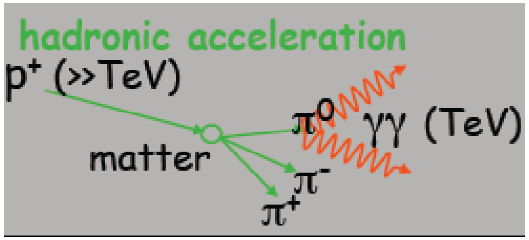
- Four classes of sources but the same object: AGN
- A supermassive black hole with a matter accretion disk
- Factories of broad band non-thermal radiation
- Relativistic jest observed at different view angles
- Particle acceleration in the jets
  (Leptonic or hadronic?)

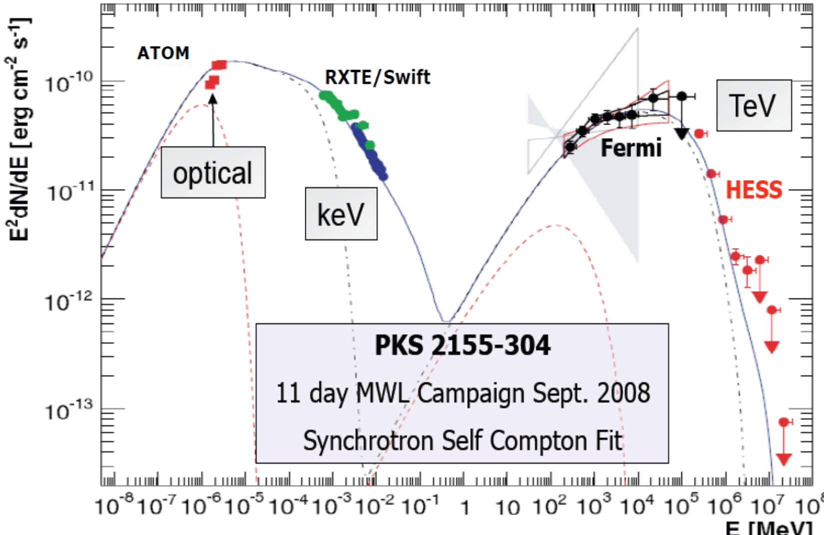


More than 25 Blazars

- Aligned with the observer view relativistic plasma jets
- Large spectral emission (radio-TeV)
- High variability (i.e. flares)

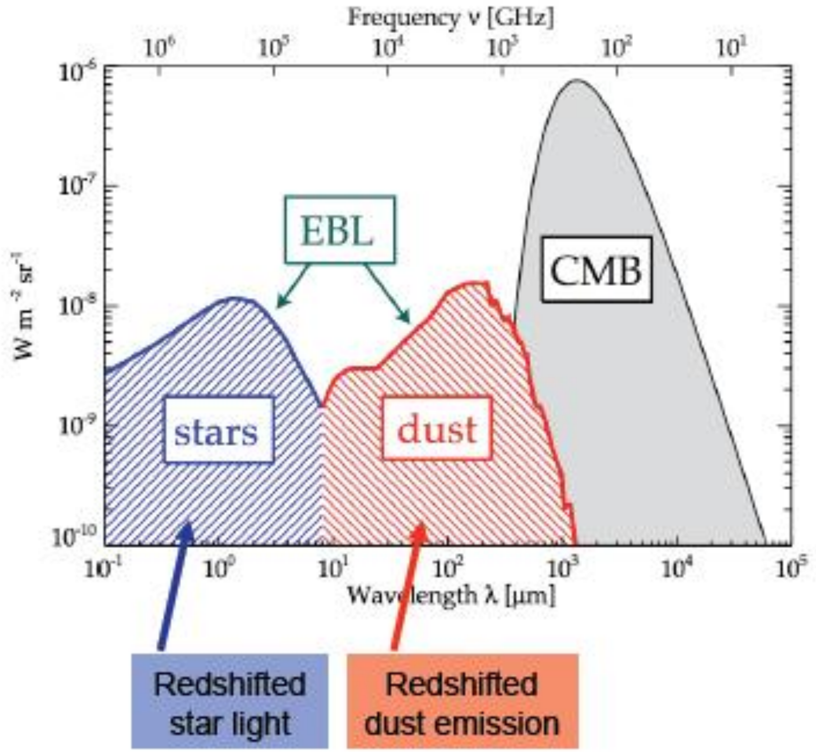






EBL

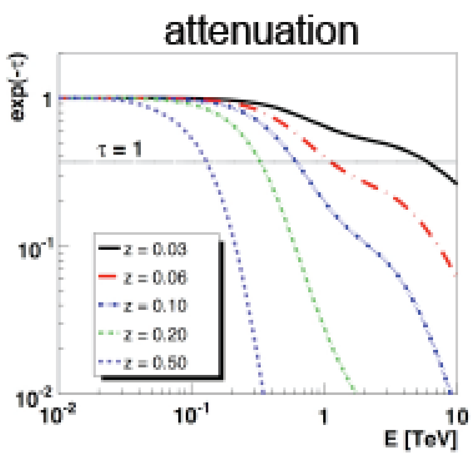
- The diffuse **Extragalactic Background Light** (EBL) is all the accumulated radiation in the Universe.
- It covers the ultraviolet, optical, and infrared wavelength range (between ~ 0.1-1000 microns).
- After the CMB, the EBL produces the second-most energetic diffuse background, thus being essential for understanding the full energy balance of the universe.

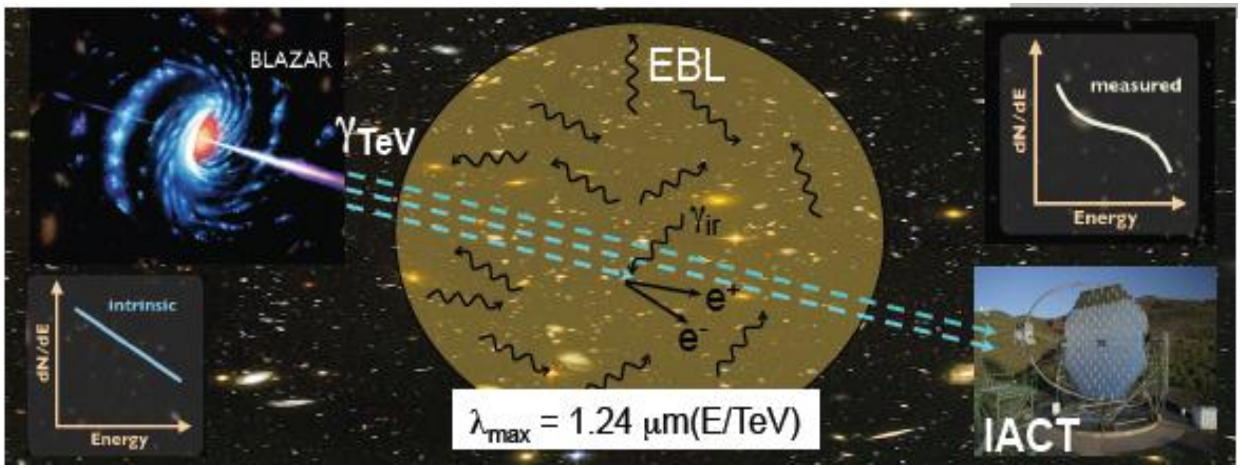


- Unique imprint of the history of the universe.
- Test of star formation and galaxy evolution models
- Cosmological evolution models have to explain the current EBL

TeV AGNs vs EBL

- The understanding of the EBL is fundamental for extragalactic very-high-energy (VHE, 30 GeV-30 TeV) astronomy: VHE photons coming from cosmological distances are attenuated by pair production with EBL photons. This interaction is dependent on the spectral energy distribution of the EBL.





$\Phi_{obs}(E)=\Phi_{intr}(E)^{*}\, e^{-\tau(E,z)}$

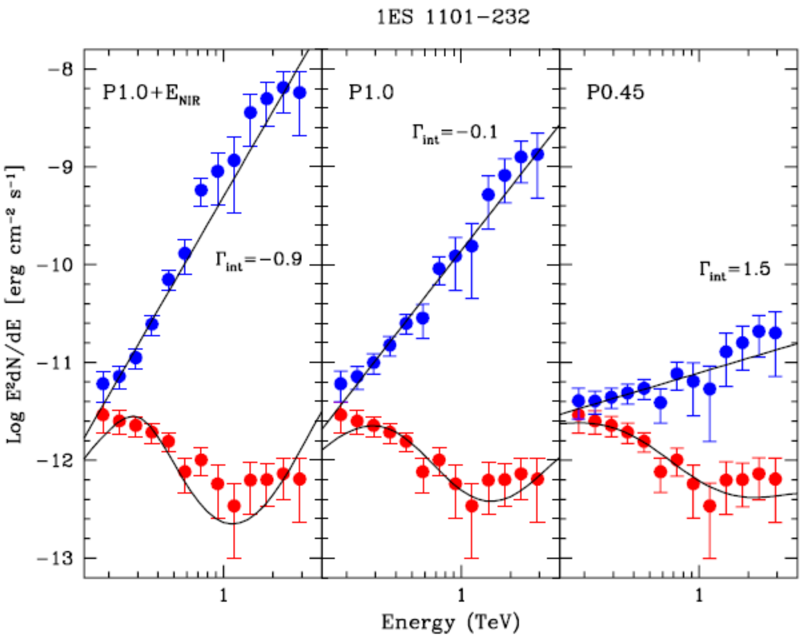
τ, attenuation coefficient

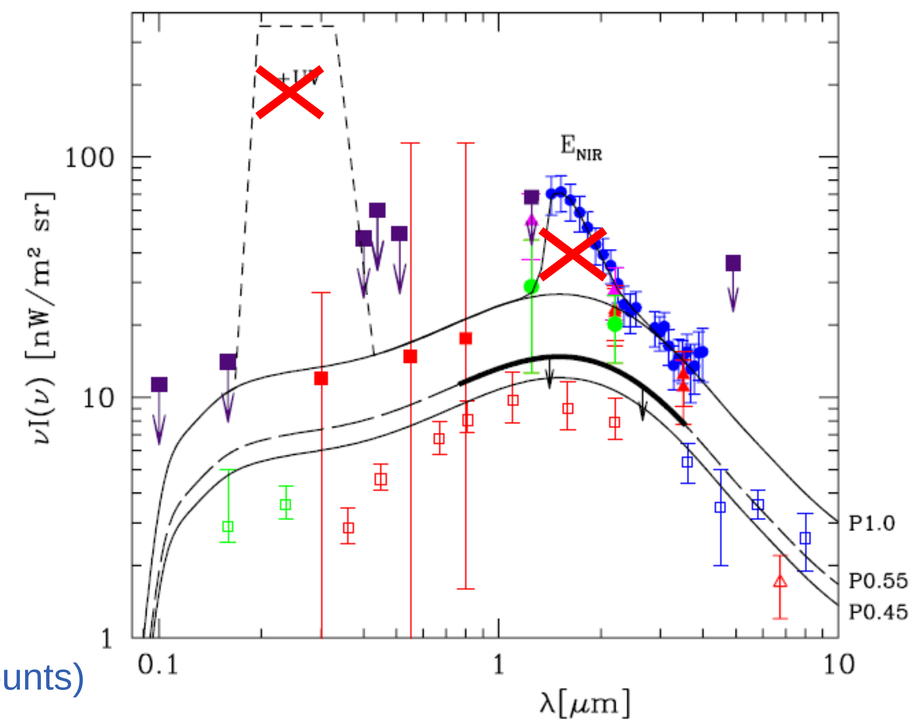
τ =1, « optical depth »

$$\tau(E) = \int_0^z \mathrm{d}l(z) \int_{\epsilon_{\mathrm{thr}}}^{\infty} n(\epsilon)\sigma(E,\epsilon)\mathrm{d}\epsilon$$

- Direct measurements of the EBL in UV to IR are difficult (foregrounds)
- Imprint of the EBL density and shape in the measured GeV-TeV spectra
- GeV-TeV spectra used to test EBL density under assumptions about the intrinsic spectra

H.E.S.S. results





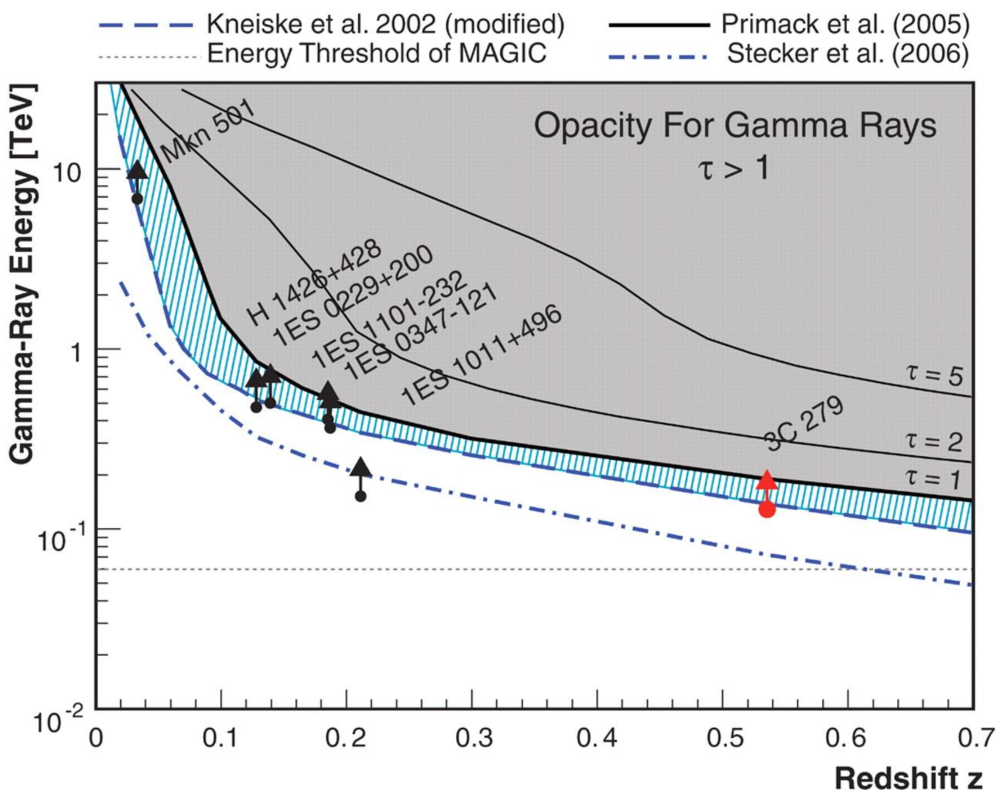
- EBL spectrum compatible with P0.45
  (close to the lowest experimental limit from galaxy counts)

- Strong upper limit from H.E.S.S. in the range from 0.8 μm to 3.5 μm (excluding the NIR satellites measurements and their cosmological origin from Pop3 stars)

- Excluding UV over-abundant density to reproduce an acceptable intrinsic spectrum (not too hard spectrum; index close to 1.5)

- The results is that EBL is less dense than expected.

Compiling IACT results



- **J Albert et al. Science 2008;320:1752-1754**

In the future with HESS 2 and CTA:

- Blazars spectra up to z~2 ("stars formation epoch")

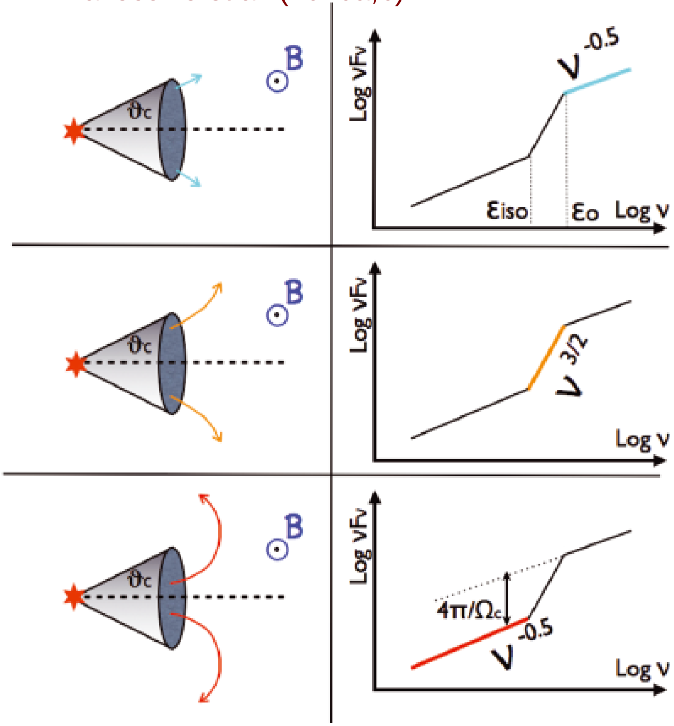
- Indirect constraint on EBL UV, *mid*- and *far*- IR: to understand the galaxies formation history *(« dust contents ? how many galaxy populations ? ..»)*

- At E> 30 GeV (with Fermi) precision study of Blazars « time-resolved » spectra;

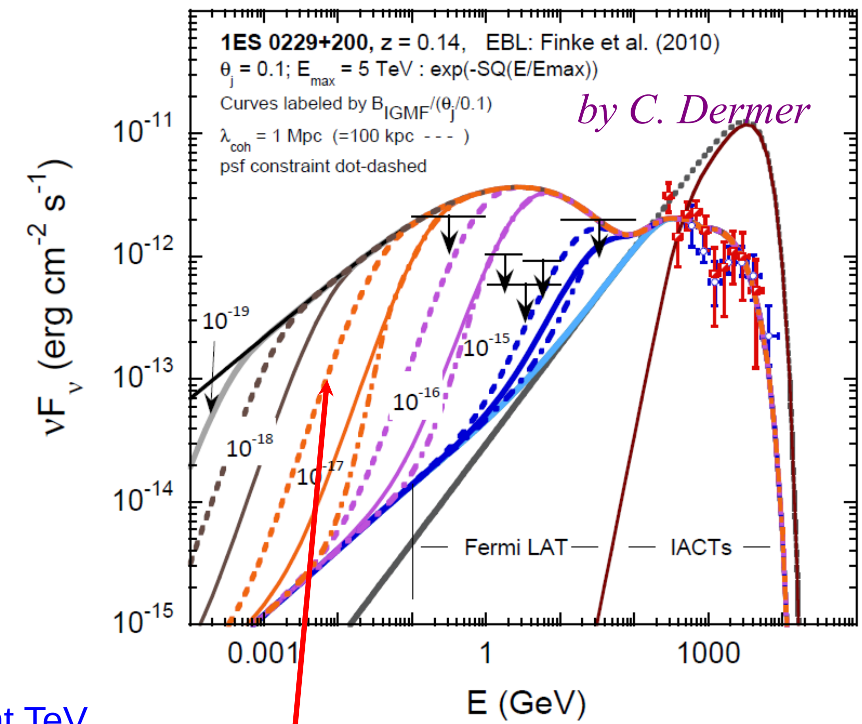
- Population study and constraints on cosmological paramteres.

γ re-emission and Extragalactic Magnetic Fields

Tavecchio et al. (2010a,b)



- Subsequent re-emission of gamma-rays by e^+e^- pairs leads to appearance of extended and time delayed gamma-ray emission around extragalactic very-high-energy gamma-ray sources.



- Non-detection of cascade emission from several bright TeV extragalactic sources implies existence of non-zero magnetic field in the IGM (which deflects and cools electrons). Combination of IACTs (HESS2 + CTA) and Fermi-LAT data is crucial.

spectra as function of the B-field intensity (for fixed domain size...)

Fundamental Physics: Lorentz Invariance Violation tests

- **LI**: speed of light identical in any reference system and for all energies.

- Potential violation of LI in the primordial Universe at the energy Planck scale
  (E ~O(E_P = 1.2 x 10^{19} GeV)).

- LIV is suggested by several extensions of standard model:
- *(e.g. Quantum Gravity - QG, Doubly-Special Relativity-DSR,..)*

- The Space-Time assumes discrete structures of the order of the Planck scale (10^{-35} m)
- -> perturbation of gamma-ray propagation which increases with the energy E << E_P.

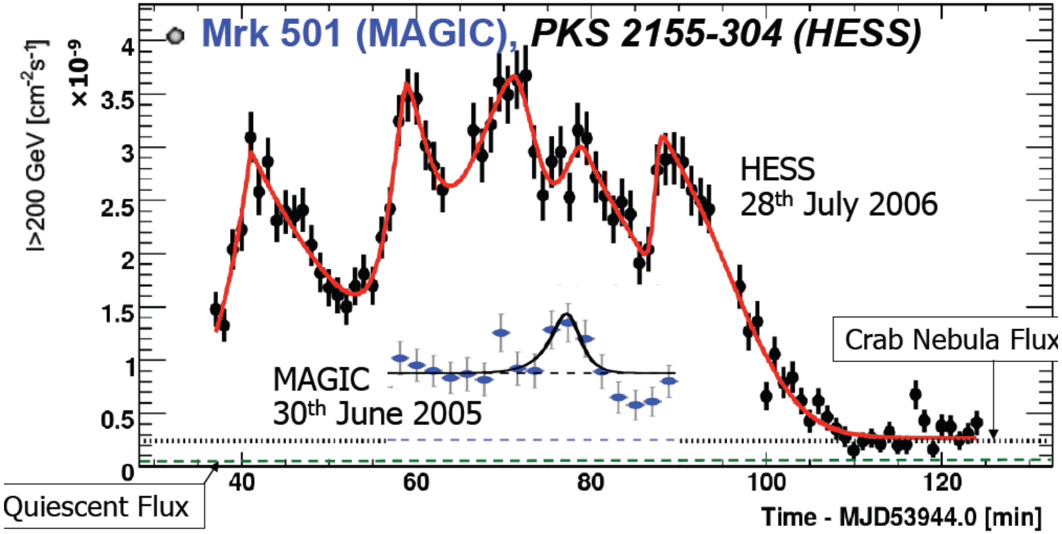
- Modifications of the dispersion relation linear or quadratic

$$m^2 = E^2 - p^2 + \lambda E p^2 \qquad m^2 = E^2 - p^2 + \lambda^2 E^2 p^2$$

-
- Photon speed dependency on the energy:

$$v = c(1 - \xi(E / E_P))$$
$$v = c(1 - \zeta(E / E_P)^2)$$

•Données H.E.S.S. de PKS2155-304



A unique test of LIV with the 2006 flare of Blazar PKS 2155-304 detected by H.E.S.S.

The best quadratic limit achieved with AGNs

$$\frac{\Delta t}{\Delta E} \approx \frac{\xi}{\mathrm{E_P H_0}} \int_0^z \frac{(1+z')\,dz'}{\sqrt{\Omega_m(1+z')^3+\Omega_\Lambda}}$$

→ $M^{l}_{LIV(QG)} > 2.1 \times 10^{18}$ GeV

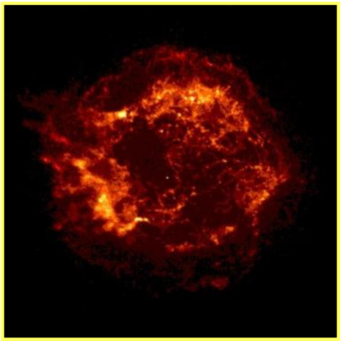
$$\frac{\Delta t}{\Delta E^2} \approx \frac{3\zeta}{2\mathrm{E_P^2 H_0}} \int_0^z \frac{(1+z')^2\,dz'}{\sqrt{\Omega_m(1+z')^3+\Omega_\Lambda}}$$

→ $M^{q}_{LIV(QG)} > 0.6 \times 10^{11}$ GeV

Enormous potential with HESS2 and CTA by using AGNs, GRBs but also Pulsars (lower distance but larger statistics) with a larger lever-arm in energy…

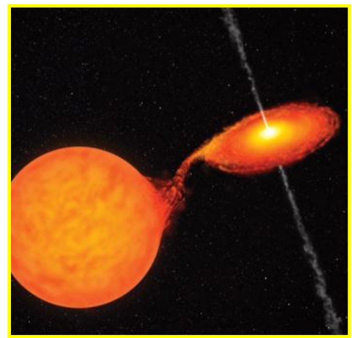
Scientific Objectives

We hope to succeed in doing all this and even more within ENIGMASS

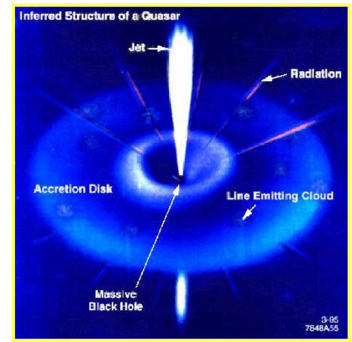


SNRs

Pulsars and PWN



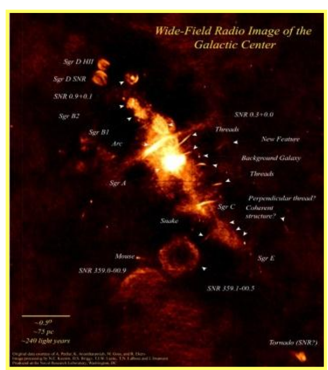
Micro quasars X-ray binaries



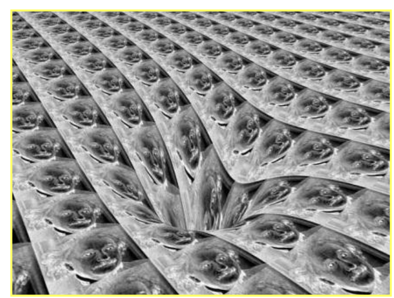
AGNs

GRBs

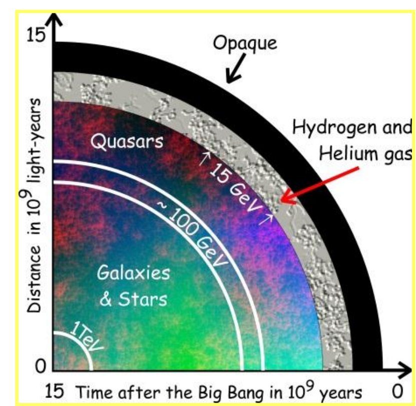
Origin of cosmic rays



Dark matter



Space-time & relativity



Cosmology