High Energy Gamma Rays Sources and Origin of Cosmic Rays

Felix Aharonian
Dublin Institute for Advanced Studies, Dublin
Max-Planck-Institut fuer Kernphysik, Heidelberg

100 years of Cosmic Rays: ***Anniversary of their discovery by V. Hess***
Bad Saarow/Pieskow, Aug 6-8 2013

a general comment:

initiated/motivated in 1950s by cosmic ray studies, high energy gamma-ray astronomy (GRA) has been for decades a (underdeveloped) part of cosmic ray physics. Now it is considered is a discipline in its own right with several topical areas belongs to modern astrophysics, and cosmology, but many of us believe that the combination of topics related to the origin of cosmic rays remains no.1 priority in the list of field' major objectives.

the aim of this talk:

brief overview of the status of GRA in the context of origin of galactic and extragalactic cosmic rays with an emphasis on the VHE domain

Major topics of gamma-ray astronomy related to Astrophysics and Cosmology

(i) Origin of Galactic and Extragalactic Cosmic Rays

SNRs, GMCs, Center of Galaxy, Starburst Galaxies, Active Galactic Nuclei

(ii) Physics and Astrophysics of Relativistic Outflows

Pulsar Winds and Black Hole Jets

(iii) Observational Cosmology

Intergalactic radiation and magnetic fields, Dark Matter

(iv) ……

Origin of Cosmic Rays - after 100yr of the discovery still a mystery

energy range: 10^9 to 10^{20} eV

what do we know about CRs:

- before the knee - galactic
- after the ankle - extragalactc
- between knee and ankle ?

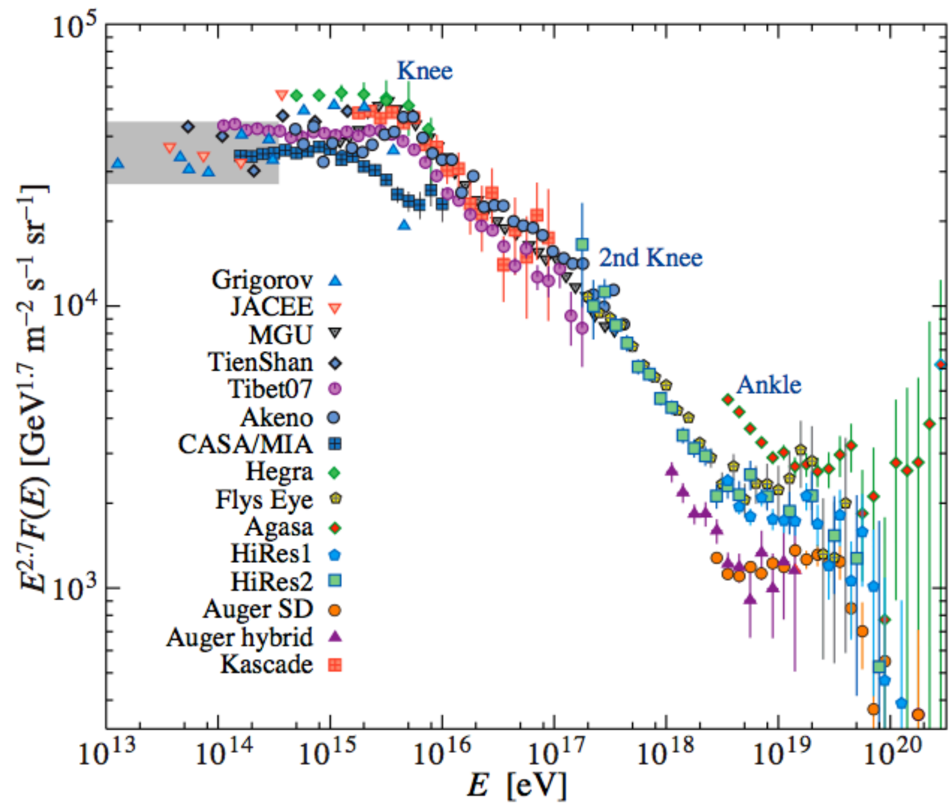


Figure 24.8: The all-particle spectrum from air shower measurements. The shaded area shows the range of the the direct cosmic ray spectrum measurements.

Sources of Galactic Cosmic Rays

- ✓ **SNRs**: up to 10^{15} or even $5x10^{18}$ eV for Fe for type IIb SNe (e.g. Ptuskin et al 2010) but so far we do not have decisive evidence of SNRs operating as CR PeVatrons…

- ✓ collective stellar winds and SNR shocks in clusters and associations massive stars (e.g. Cesarsky and Montmerle 1982, Bykov & Toptygyn 2001) ?

- ✓ other potential sources? Galactic Center (Sgr A*)? "GRB remnants",pulsars?

- ✓ one cannot exclude that the observed CR flux up to 10^{15}eV is contributed by a single or a few local sources (e.g. Erlykin&Wolfendale), i.e. we see a "local fog"; this is the case of TeV electrons (e.g. Aharonian et al 1995)

gamma-rays are expected to give answers to all these questions

Extragalactic Cosmic Rays

EXG origin of CRs? certainly above 10^{19} eV or perhaps even avove 10^{17} eV;

at lower energies? problematic: $t \sim R^2/D$; for any reasonable diffusion coefficient, the propagation time from multi-Mpc distances exceeds Hubble time $\sim 10^{10}$ yr

actually, because of interactions with 2.7 K MBR, the highest energy (10^{20}eV) CRs also represent a "local fog" (nearby universe): <u>R ~ 100 Mpc or less</u>:

"GZK cutoff" is not a cosmological effect!

paradoxically only particles of $E < 10^{18}$ eV can (in principle) carry cosmological information- in the case of extremely weak intergalactic magnetic fields $<10^{-15}$ G

sources ? go to the "Hillas Plot", but don't be mislead - viable options are not many – it implies acceleration of particles at maximum possible rate: $t_{acc} \sim c/R_L$.

GRBs, AGN jets (sub-pc, kpc, radio-lobes)

Cosmic Ray Astrophysics with CRs?

an attempt to extract information from the "smell" (energy spectrum and chemical composition of CRs) of a "soup" (isotropic CRs flux) cooked from different ingredients over huge ($T > 10^7$ yr) timescales…

it is not a big surprise that the origin of CRs is yet a mystery!

origin of CRs can be revealed (only) by *astronomical means;*
the astronomical messengers should be *neutral & stable*:*

gamma-rays and neutrinos, and partly also neutrons

$$d < (E_n/m_n c^2)\, c\, t_o \;\Rightarrow\; E_n > 10^{17}(d/1\ \text{kpc})\ \text{eV}$$

do satisfy fully to these conditions;

*astronomy with protons?: only for $E \sim 10^{20}$ eV if IGMF $B < 10^{-11}$ G

why gamma-rays?

gamma-rays are unique carriers of astrophysical/cosmological information about nonthermal phenomena in many galactic and extragalactic sources

- ✓ are effectively produced in E-M and hadronic interactions
- ✓ are effectively detected by space- and ground-based instruments

but… are fragile - effectively interact with matter, radiation and B-fields

=> *gamma-rays can arrive with significant distorted energy spectra*

VHE gamma-ray astronomy - *a success story*

over last several years the field has bee revolutionized

truly astronomical discipline with characteristic key words:

energy spectra, images, lightcurves, surveys...

with more than 150 reported TeV and multi-TeV sources
representing more than 10 Galactic & Extragalactic populations
over 5 decades of energy extending from 0.1 TeV to 100 TeV

first conclusions from VHE gamma-ray observations:

Universe is full of Extreme Accelerators - TeVatrons (and PeVatrons ?)

this is a great contribution to astrophysics, in fact, beyond the expectations

but do these sources have a relation to "our" cosmic rays

Extreme Accelerators

machines where acceleration proceeds with efficiency close to 100%

(i) fraction of available energy converted to nonthermal particles

in PWNe and perhaps also in SNRs and AGN <u>*can be as large as 50 %*</u>

(ii) maximum (theoretically) possible energy achieved by individual particles

acceleration rate close to the <u>*maximum (theoretically) possible rate*</u> *:*

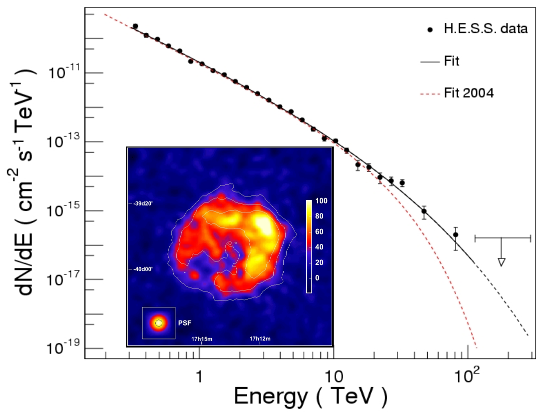
$t_{acc}=\eta(\varepsilon)\, E/ecB = \eta(\varepsilon)\, r_L/c$; $E_{eff}=\eta^{-1} B$ - projection of the electric field on the particle trajectory averaged when particle moves along trajectory; generally $E \ll B$, i.e. $\eta \gg 1$

$\eta=1$ extreme accelerator ($\eta < 1$ => $E > B$ – cannot be excluded)

<u>analogy with X-ray Astronomy:</u>
as cosmic plasmas are easily heated up to keV temperatures - almost everywhere, particles (electrons and protons) can be easily accelerated to TeV energies - almost everywhere, especially in objects containing relativistic outflows -jets & winds

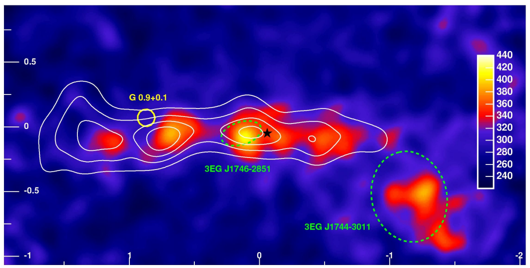
IACTs : good performance* => high quality data

RXJ 1713.7-3946



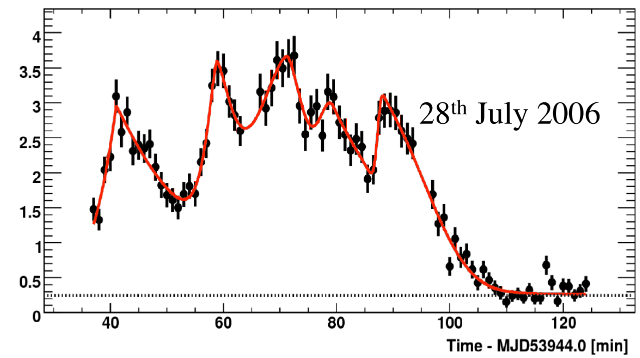
TeV image and energy spectrum of a SNR

Galactic Center



resolving GMCs in the Galactic Center 100pc region

PKS 2155-309



variability of TeV flux of a blazar on minute timescales

multi-functional tools: *spectrometry* *temporal studies* *morphology*

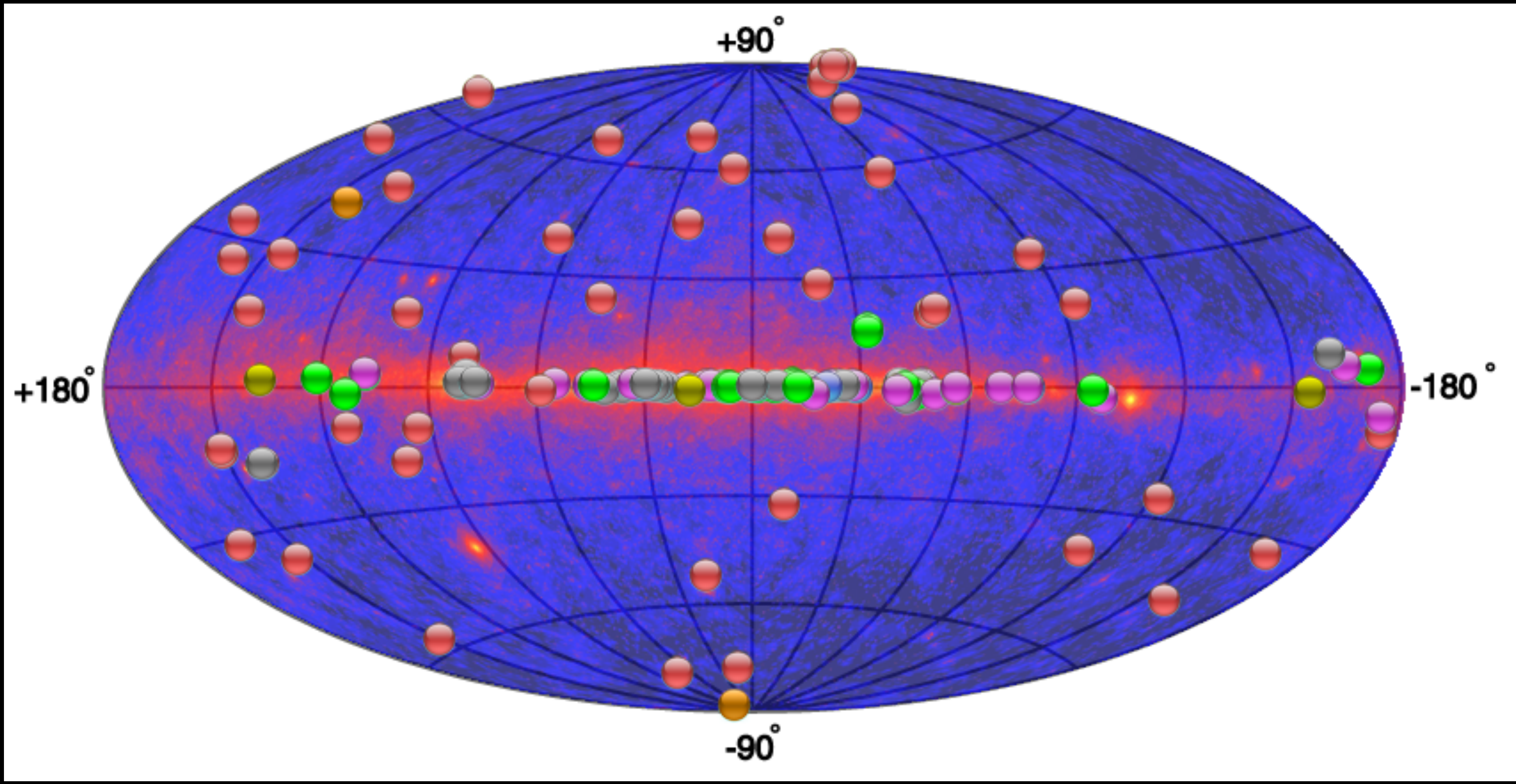
✓ extended sources: *from SNRs to Clusters of Galaxies*

✓ transient phenomena *μQSOs, AGN, GRBs, ...*

Galactic Astronomy | Extragalactic Astronomy | Observational Cosmology

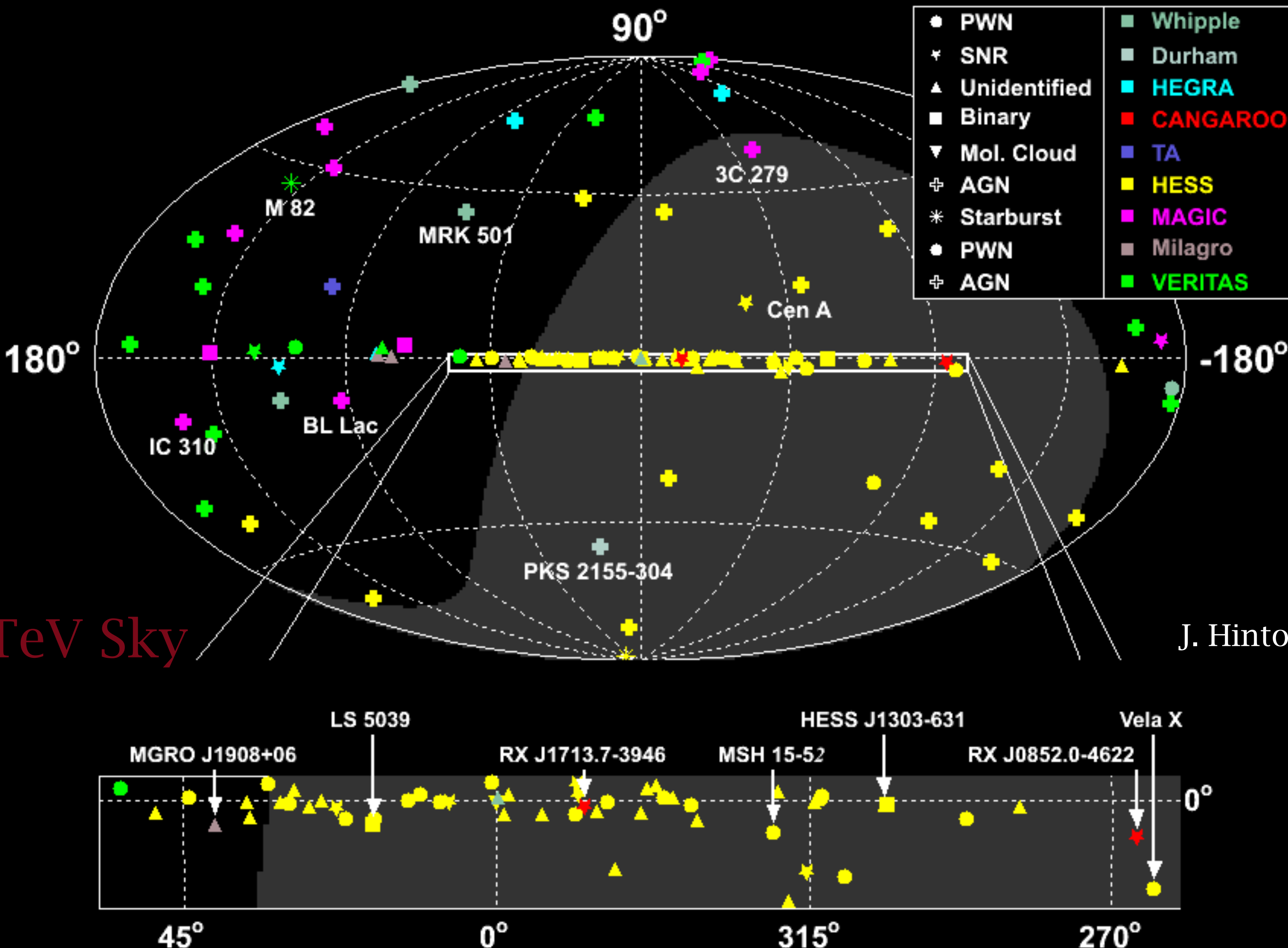
* ΔE: 0.1-100 TeV, δφ - a few arcmin, ΔE/E ~15-20%, F_{min} ~ 10^{-13} erg/cm^{2}s

TeV Sky



blue-to-red colors – > 0.1 GeV – Fermi gamma-ray sky

TeV Sky



J. Hinton

VHE gamma-ray source populations

Extended Galactic Objects

- ✓ Shell Type SNRs
- ✓ Giant Molecular Clouds
- ✓ Star formation regions
- ✓ Pulsar Wind Nebulae

Compact Galactic Sources

- ✓ Binary pulsar PRB 1259-63
- ✓ LS5039, LSI 61 303 – microquasars?
- ✓ Cyg X-1 ? (a BH candidate)

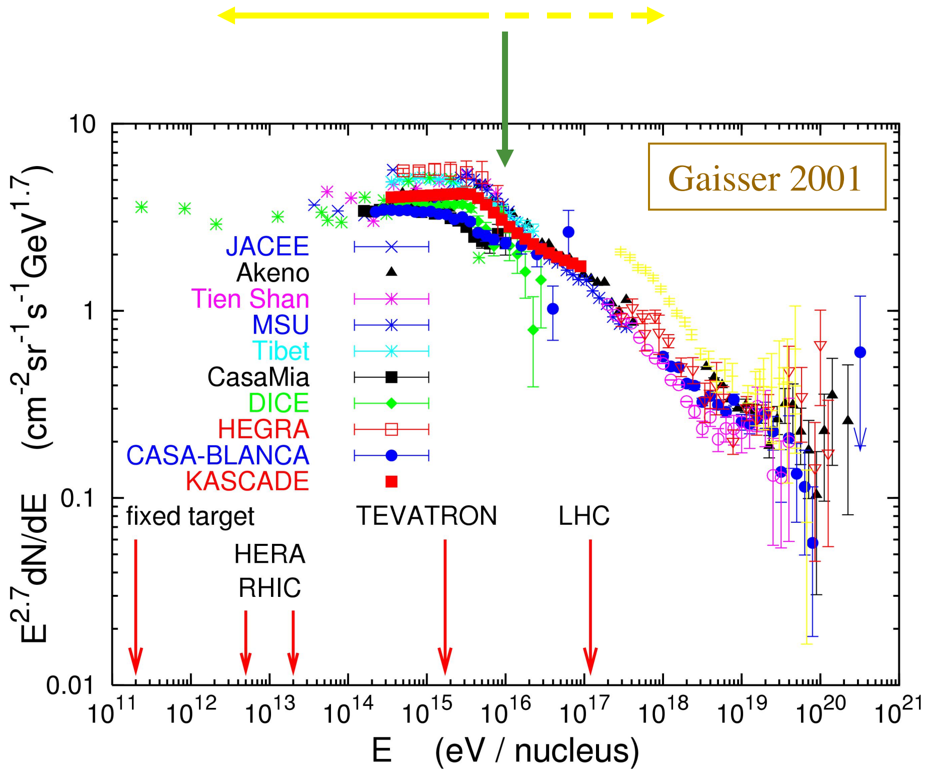
Galactic Center

Extragalactic objects

- ✓ M87, Cen A - radiogalaxy
- ✓ TeV Blazars – with redshift from 0.03 to 0.18
- ✓ NGC 253 and M82 - starburst galaxies
- ✓ GRBs (Fermi LAT; photons of tens of GeVs at $z > 1$)

and a large number of yet unidentified TeV sources …

Galactic TeVatrons and PeVatrons - particle accelerators responsible for cosmic rays up to the "knee" around 1 PeV



SNRs ?

one of the key objectives of the high energy gamma-ray astronomy: confirmation that SNRs operate as PeVatrons, and can provide the bulk of Galactic CRs up to $E \sim 10^{15}$ eV

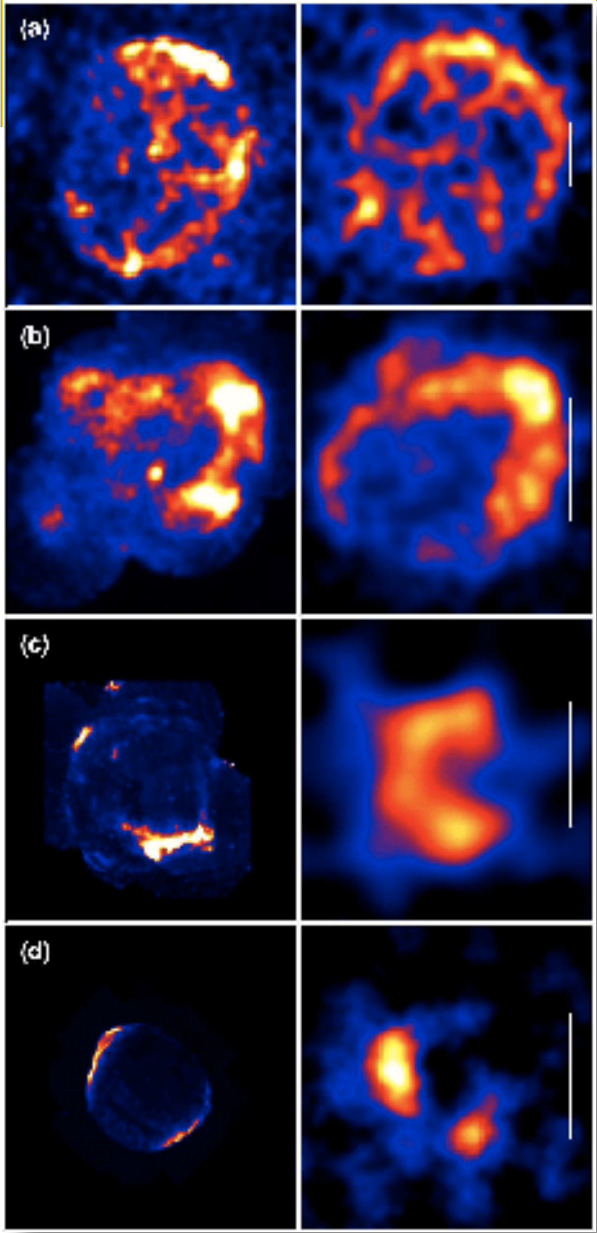
other possible sources?

Pulsars/Plerions

OB, W-R Stars

"microquasars"

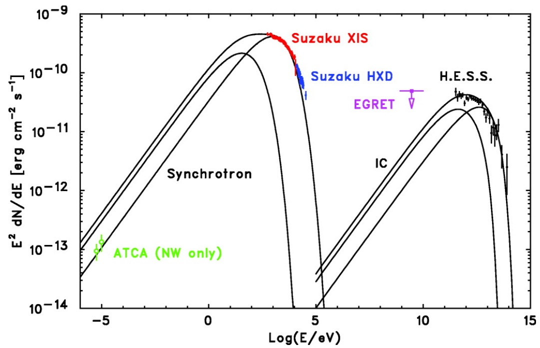
Galactic Center

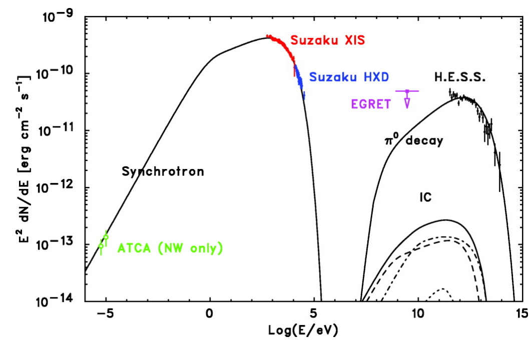


acceleration of protons and/or electrons in SNR shells to energies up to 100TeV

leptonic or hadronic?

=>





RXJ1713.7-4639

inverse Compton scattering of electrons on 2.7K CMBR

B=15μG

We ≈3.4 10^{47} erg/cm^3

γ-rays from pp ->π^o ->2γ

$dN/dE=A\ E^{-\alpha} \exp(-E/Eo)$

with α=1.7, Eo ≈ 25 TeV,

B=200μG

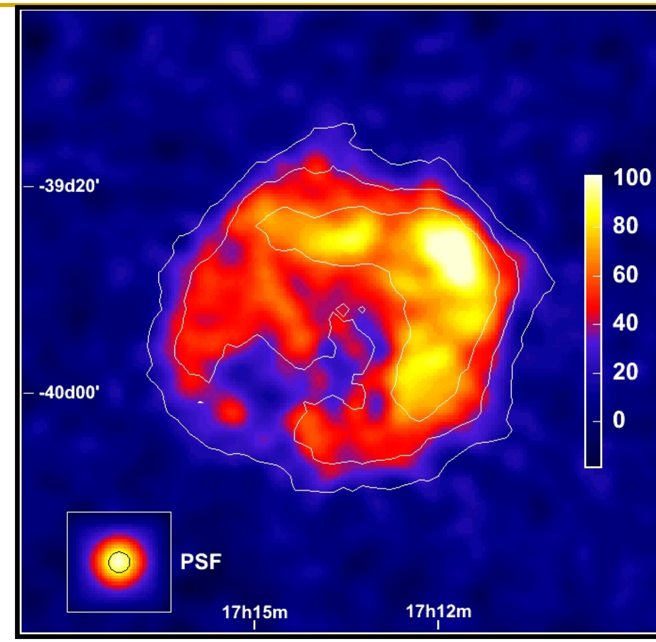
Wp ≈2 $10^{50}(n/1cm^{-3})^{-1}$erg/cm^3

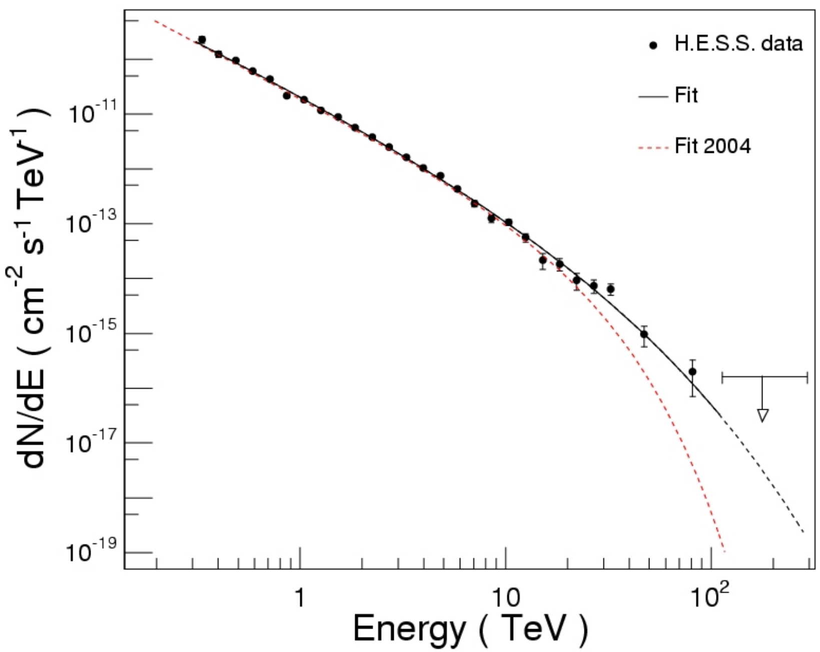
unfortunately we cannot give preference to hadronic or leptonic models - both have attractive features but also serious problems

solution? detection of more sources, broader energy coverage, and search for neutrinos

RXJ1713.7-4639

TeV γ-rays and shell type morphology: acceleration of p or e in the shell to energies exceeding 100TeV





can be explained by γ-rays from pp $\to \pi^0 \to 2\gamma$

HESS: $dN/dE = K\,E^{-\alpha} \exp[-(E/E_o)^{\beta}]$

$\alpha=2.0$ $E_o=17.9$ TeV $\beta=1$

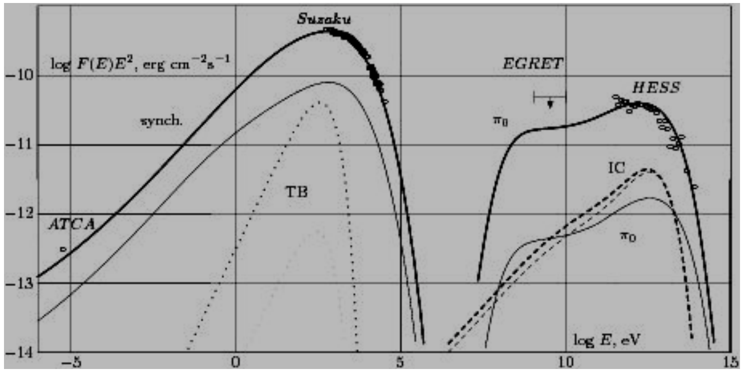
$\alpha=1.79$ $E_o=3.7$ TeV $\beta=0.5$

and with just "right" energetics
$W_p=10^{50}\,(n/1\,cm^{-3})^{-1}$ erg/cm^3

but IC canot be immediately excluded…

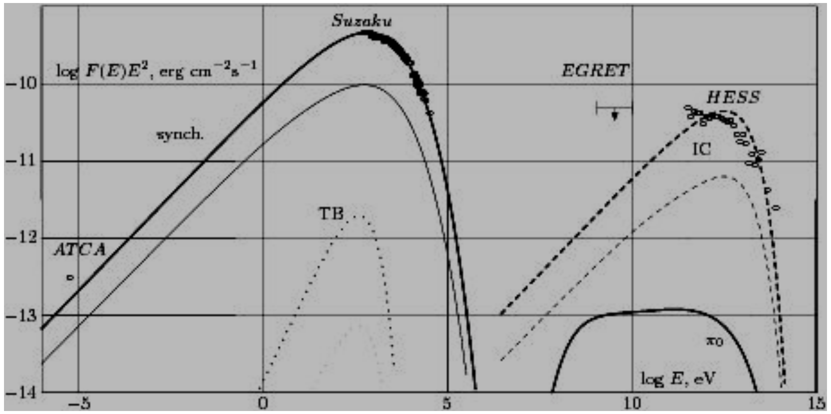
broad-band SEDs

hadronic model



good spectral fit, reasonable radial profile,
support for amplification of B-field
but … (1) lack of thermal emission - possible explanation?
>70% energy is released in acceleration of protons!
or gamma-rays are produced in clumps
(2) very high p/e ratio (10^4)
Emax ~ 100 TeV (not 1 PeV) – escape ?

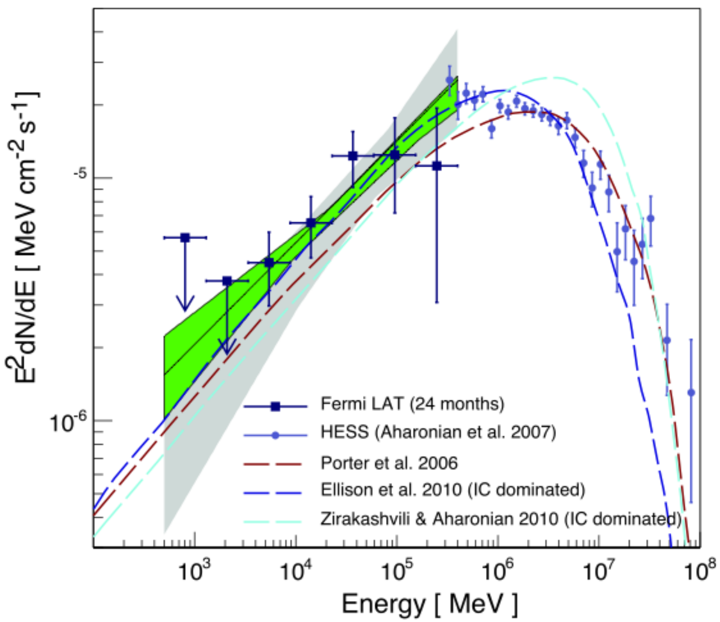
leptonic model

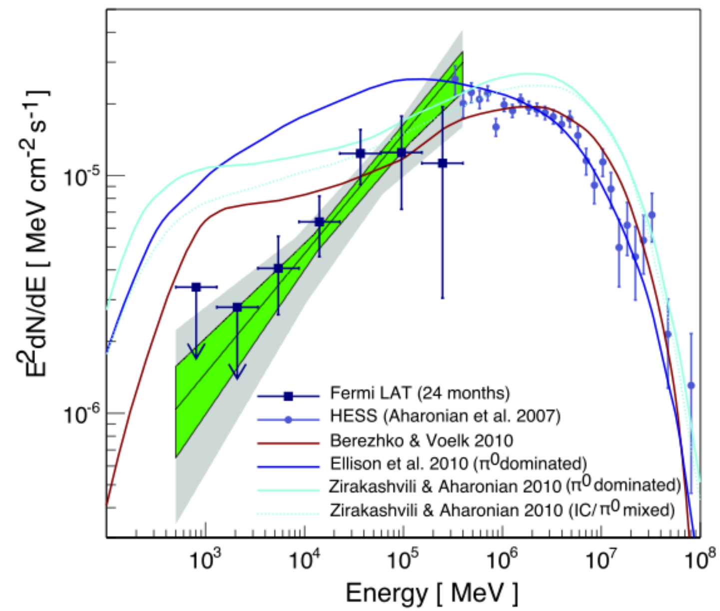


not perfect, but still acceptable, fits for spectral and spatial distributions of IC gamma-rays; suppressed thermal emission, comfortable p/e ratio (~10^2);small large-scale B-field (~ 10 μG)
2zone-model?: IC gamma-rays in reverse shock,
Syncrotron X-rays – forward shock

Zirakashvili, FA 2010

Fermi: GeV data contradict daronic origin of γ-rays ! (?)





leptonic models

hadronic models

Questions: (i) can we compare GeV and TeV fluxes within one-zone models?

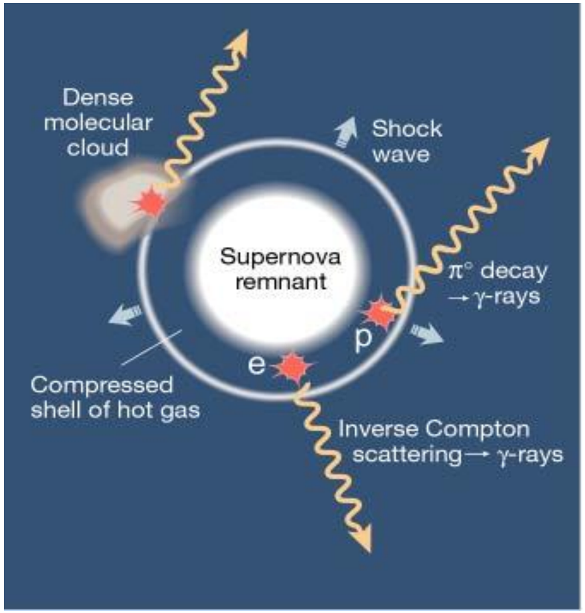
they could come from quite different regions

(ii) cannot we assume hard proton spectra ?

nonlinear theories do predict very hard spectra with α -> 1.5

the "composite" model

IC gamma-rays from (i) the entire shell with average small B-field and (ii) π^0 -decay gamma-rays from dense clouds inside the shell



not strong correlation is expected between GeV and with TeV gamma-ray images

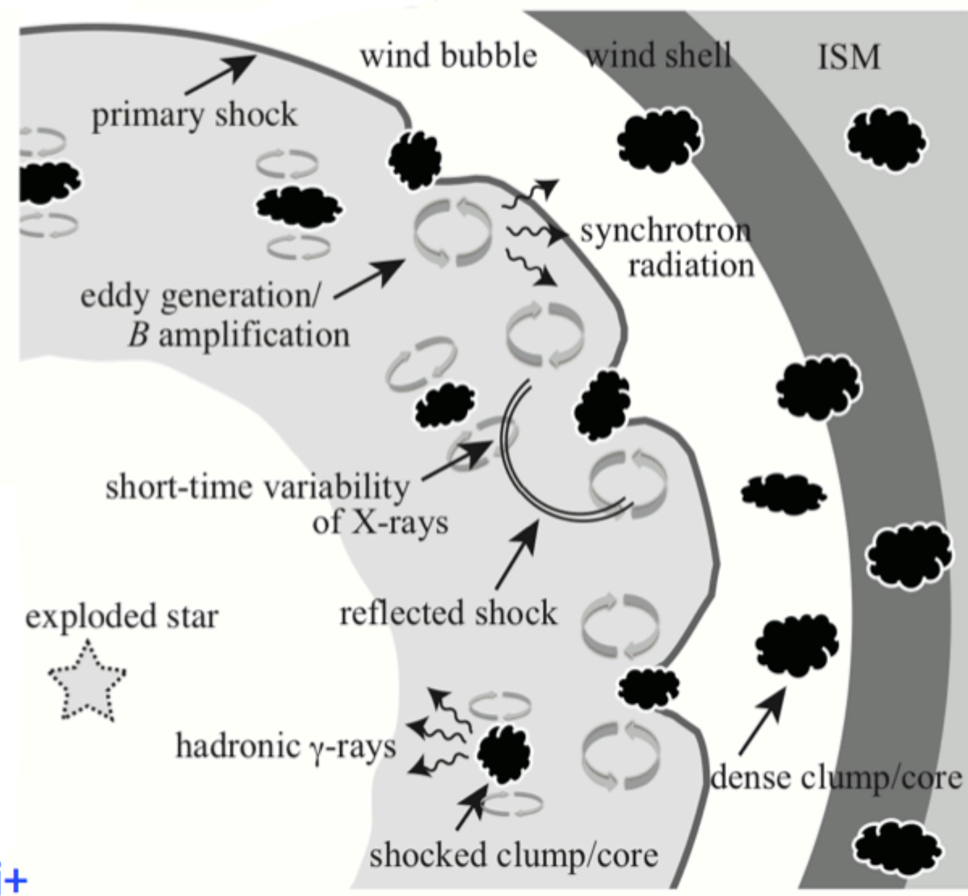
<10 GeV and E >10 TeV gamma-rays should correlate with dense CO clouds

GeV gamma-rays can be suppressed because low energy protons cannot penetrate deep into the dense clouds

(Zirakashvili&FA 2010)

Fermi LAT - important, but only neutrinos, ultra-high energy gamma-rays and hard synchrotron X-rays from secondary electrons can provide decisive conclusions

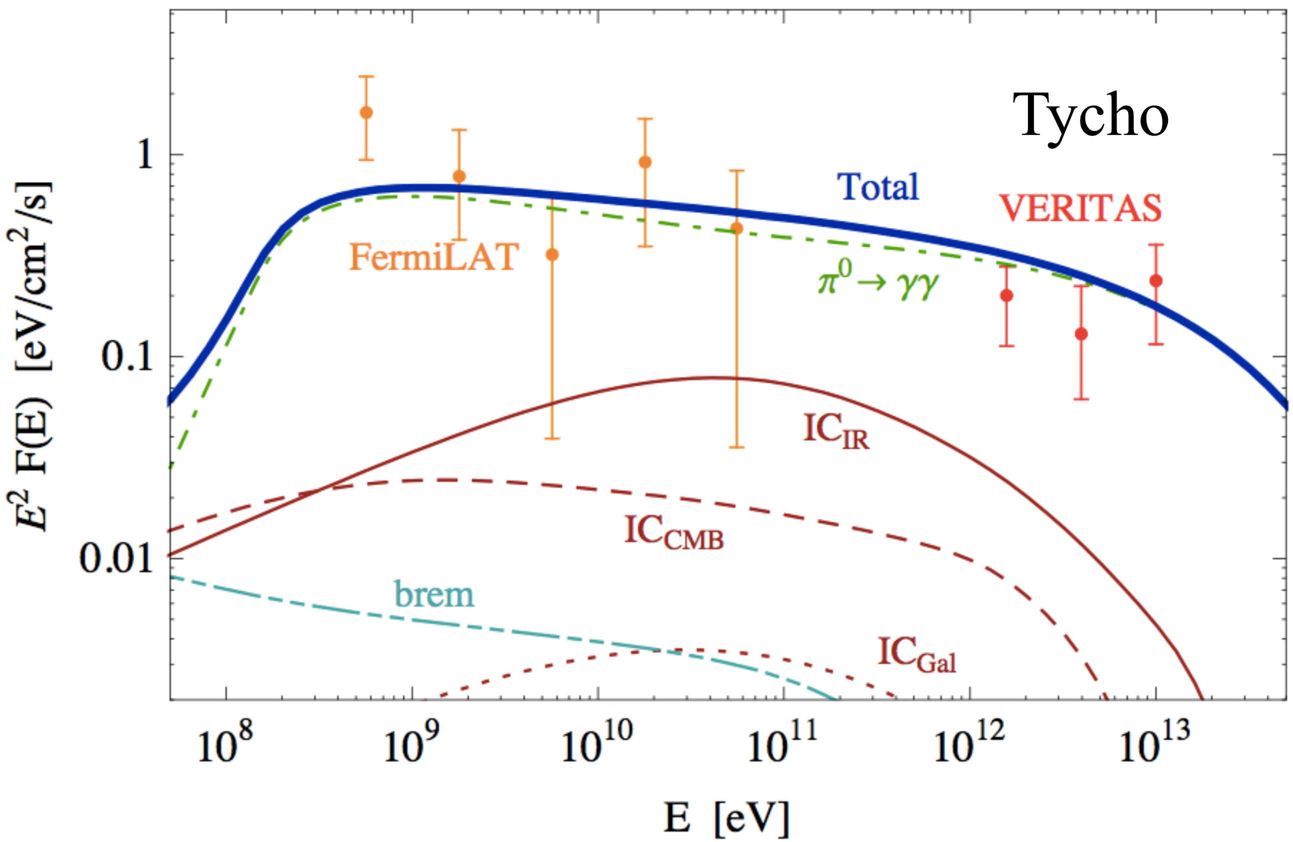
a natural way of suppression of GeV γ-rays



Poster
P5-2
Yamazaki+

Inoue, Yamazaki, Inutsuka, Fukui 2012, ApJ, 744, 71

Tycho: better candidate for a PeVatron ?

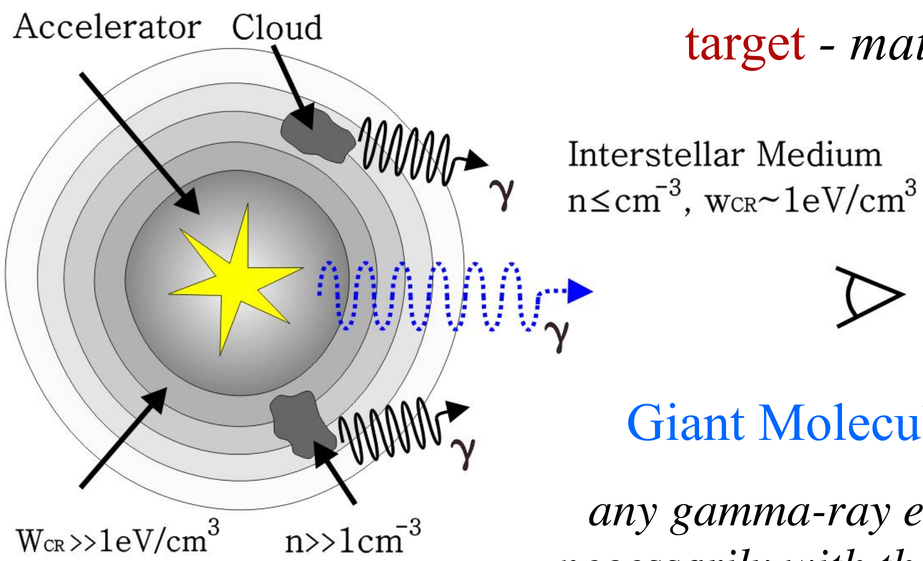


Morlino & Caprioli 2011

because of flat spectrum up to 10 TeV, but the quality of data is not adequate…

gamma-ray production: particle accelerator + target

existence of a powerful particle accelerator by itself is not sufficient for γ-radiation; an additional component – a dense target - is required



target - *matter, radiation, magnetic field*

Giant Molecular Clouds as barometers of CRs

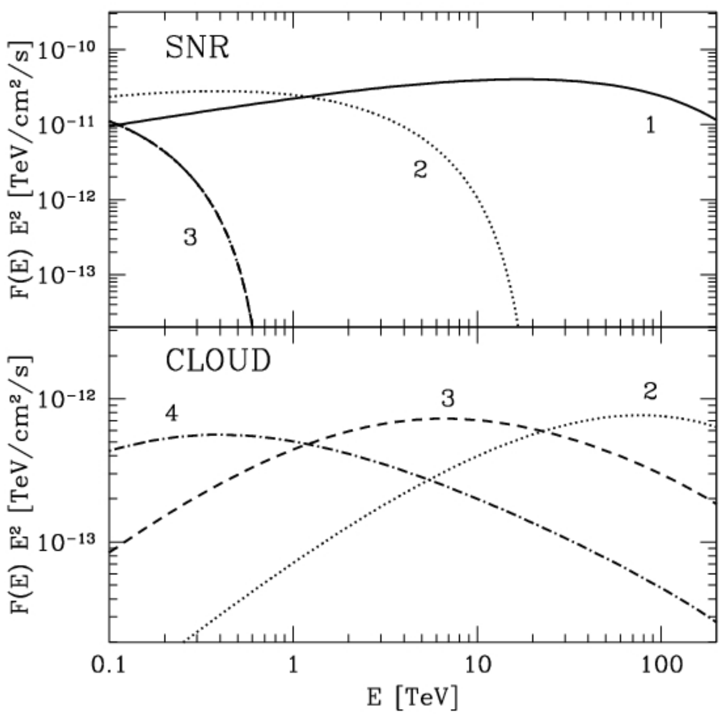
any gamma-ray emitter coincides with the target, but not necessarily with the "primary" source/particle-accelerator

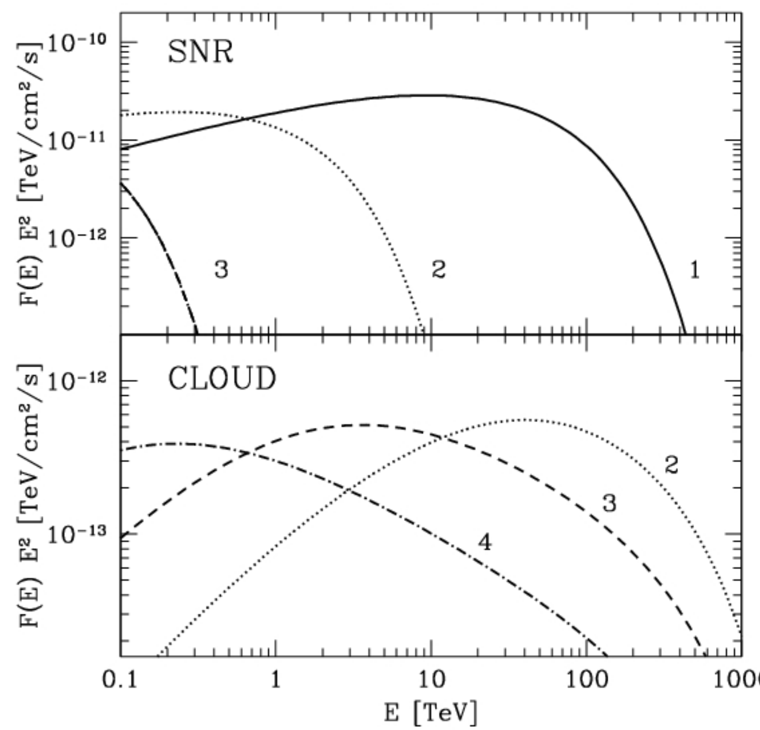
"passive" GMCs - level of the sea of GCRs

"active" GMCs – nearby accelerators – history, escape, propagation, etc…

Gamma-rays and neutrinos inside and outside of SNRs

1 - 400yr, 2 - 2000yr, 3 - 8000yr, 4 - 32,000 yr





SNR: $W_{51}=n_1=u_9=1$ d=1 kpc GMC: M=10^4 M_o d=100pc

ISM: $D(E)=3x10^{28}(E/10TeV)^{1/2}$ cm^2/s

[S. Gabici, FA 2007]

how to find the “missing PeV protons in SNRs?

highest energy particles, E > 100 TeV, are confined in the shell only during a few 100 years => most promising search for PeVatrons? multi-TeV γ-rays from dense gas clouds in the near neighborhood

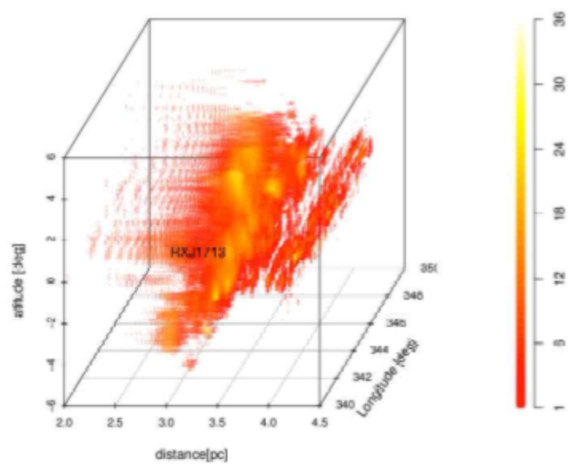
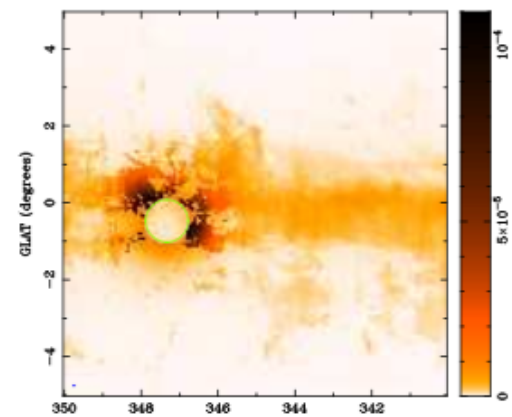


Fig. 1. The gas distribution in the region which spans Galactic longitude 340° < l < 350°, Galactic latitude −5° < b < 5° and heliocentric distance 50 pc < l_d < 30 kpc, as observed by the NANTEN and LAB surveys, expressed in protons cm^{-3}. The distance axis is logaritmic in base 10. A value for the gas density is given every 50 pc in distance, which is reflected in the apparent slicy structure for distances below 100 pc. For sake of clarity only densities above 1 protons cm^{-3} are shown. Also indicated the position of the historical SNR, RX J1713.7-3946.

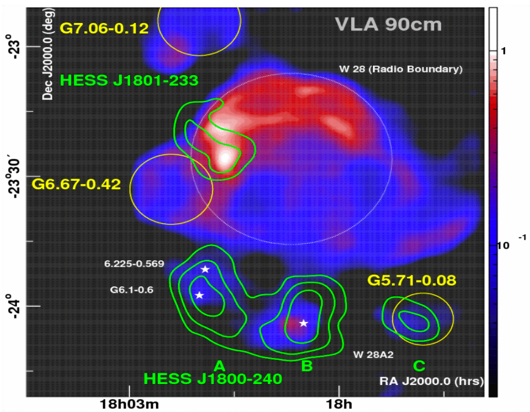


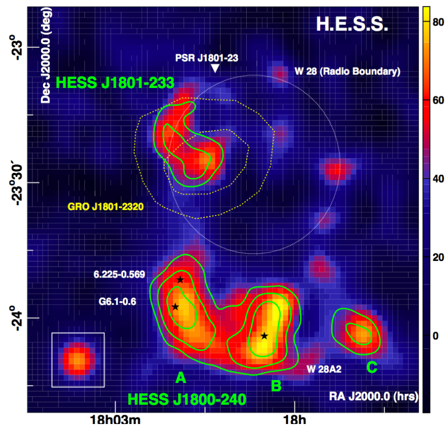
surrounding gas density:
NANTEN data
age:
1600 yr
escape of protons:
model of Zirakashvili&Ptuskin 2008
diffusion coefficient outside SNR:
$D=10^{26}\,(E/10GeV)^{0.5}\ cm^2/s$

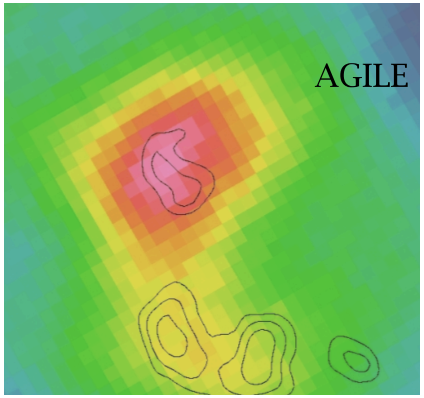
required angular resolution as good as 1-2 arcmin can be achieved at 10 TeV !

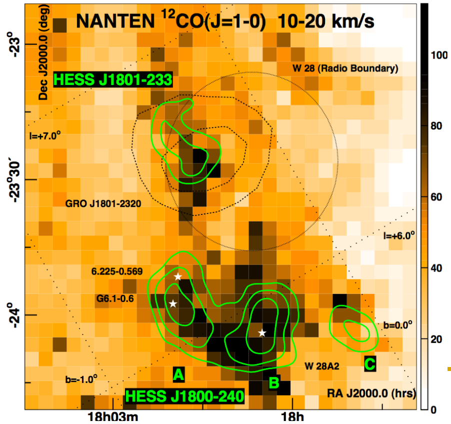
GeV TeV gamma-ray sources around mid age W28:

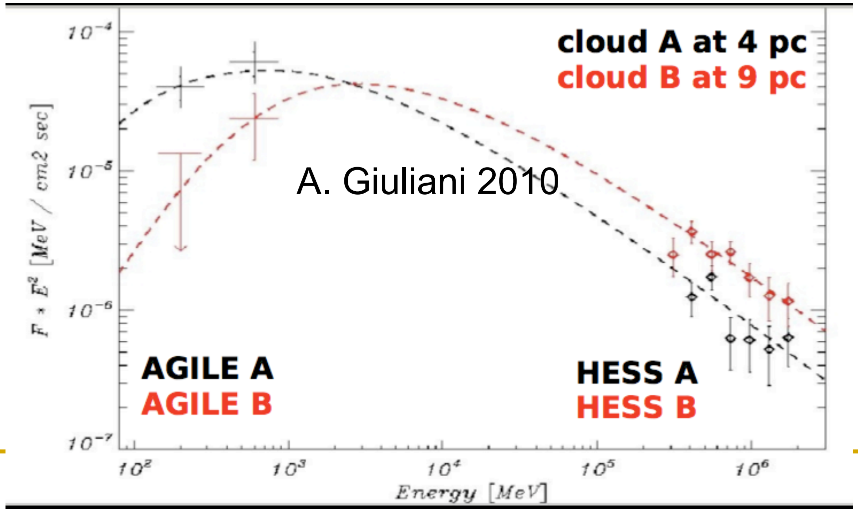
CRs from an old SNR interacting with nearby clouds?





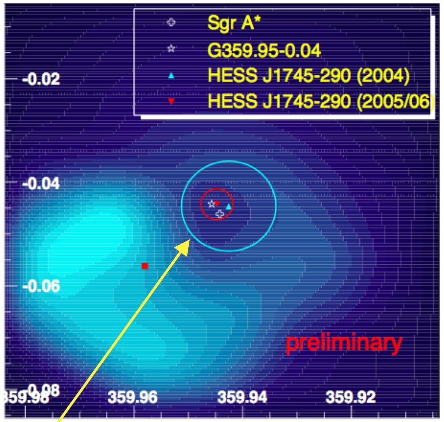






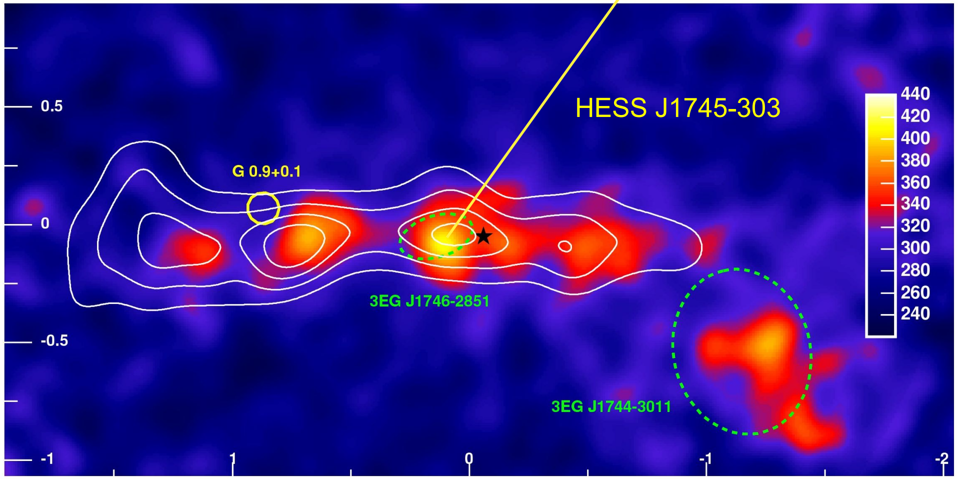
Galactic Center

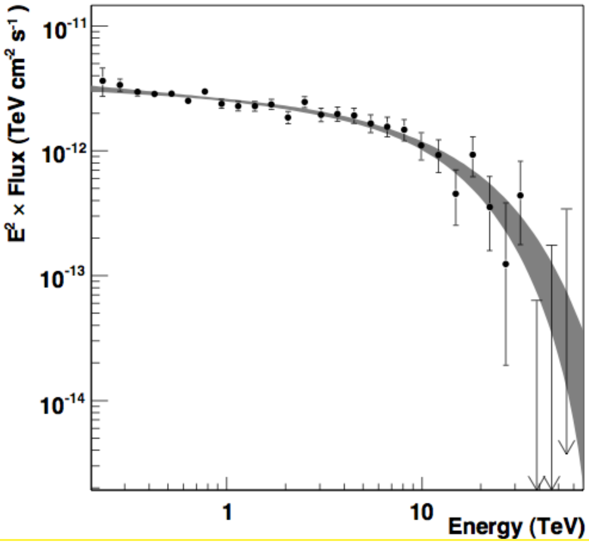
90 cm VLA radio image



Sgr A* or the central diffuse < 10pc region or a plerion? [no indication for variation]

γ-ray emitting clouds





Energy spectrum:

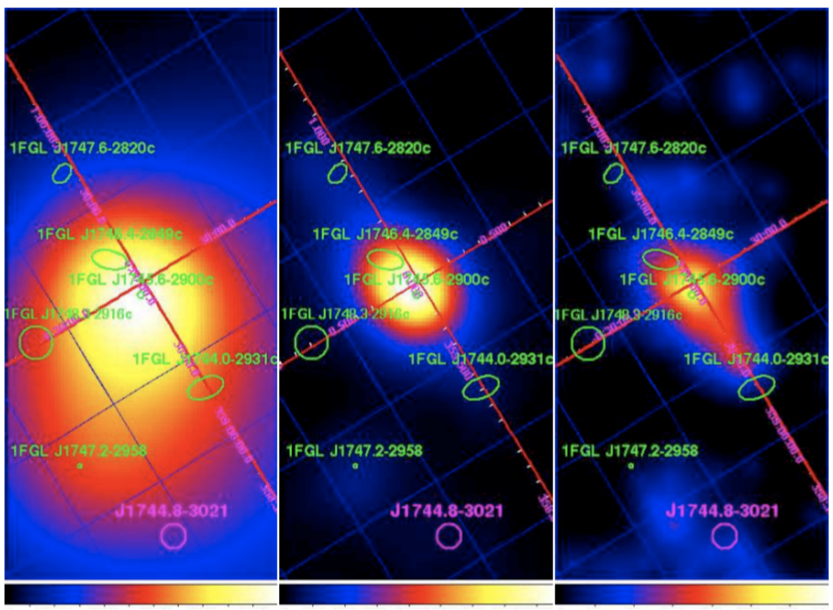
$dN/dE = AE^{-\Gamma} \exp[(-E/E_{0)})^{\beta}]$

β=1	Γ=2.1; E_0=15.7 TeV
β=1/2	Γ=1.9 E0=4.0 TeV

γ-rays from GMCs in GC: a result of an active phase in Sgr A* with acceleration of CRs some 10^4yr ago?

Galactic Center at high energies

0.3-3 GeV 3-30 GeV 30-300 GeV



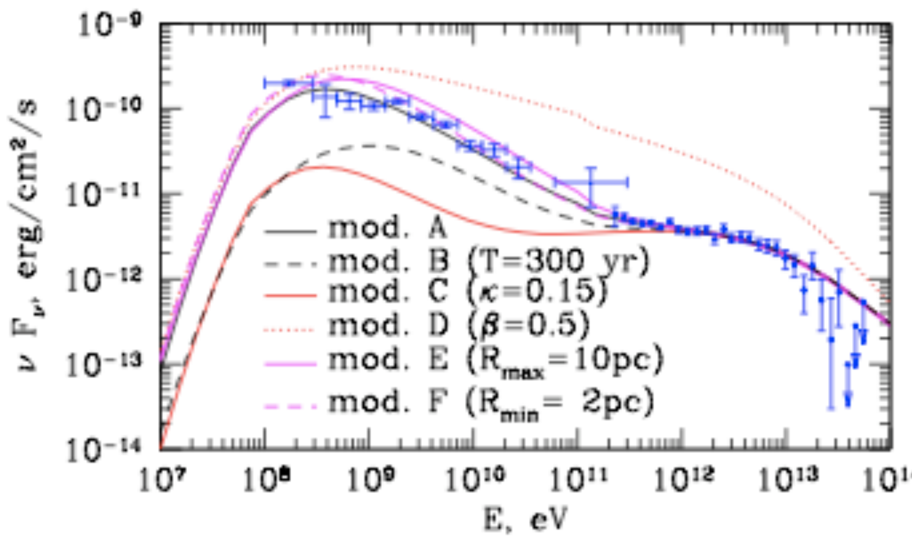
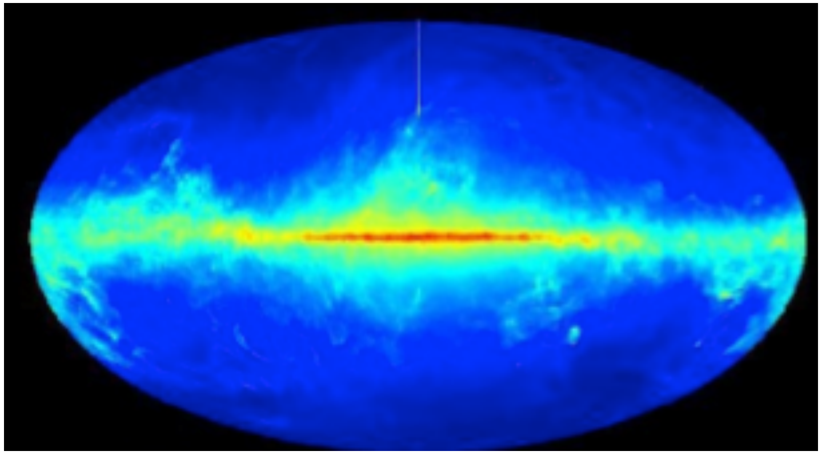


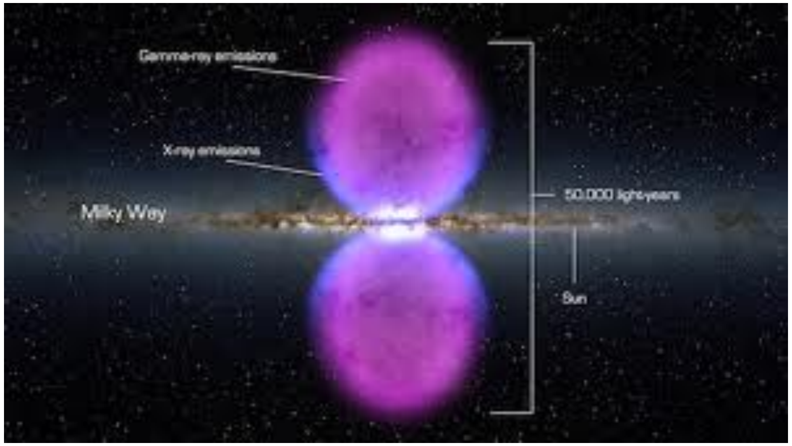
FIG. 5.— Spectral energy distribution of gamma-rays expected from a region filled with relativistic and non-relativistic protons within different assumptions concerning the injection, diffusion and the region geometry (see text for a discussion of parameters for each specific model). The data points have been derived from the Fermi and HESS data

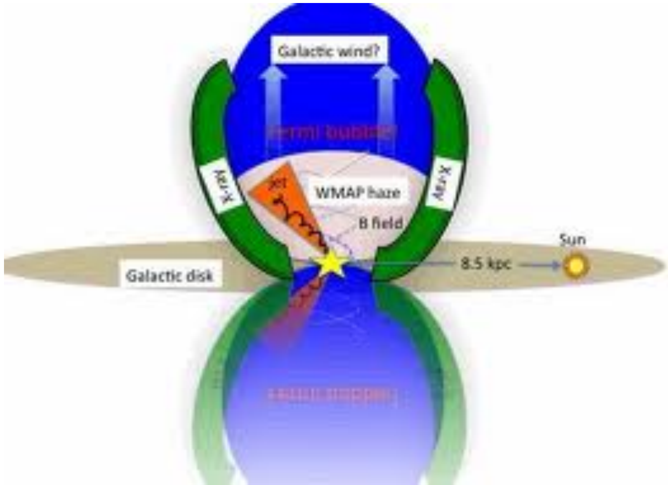
$L_p \approx 10^{39}$ erg/s

Chernyakova et al 2010

Fermi Bubbles !







Finkbeiner and collaborators 2010

Fermi Bubbles - result of pp interactions of CRs produced in the GC and accumulated in R ~10 kpc regions over 10Gyr comparable to the age of the Galaxy? (Crocker&FA 2011)

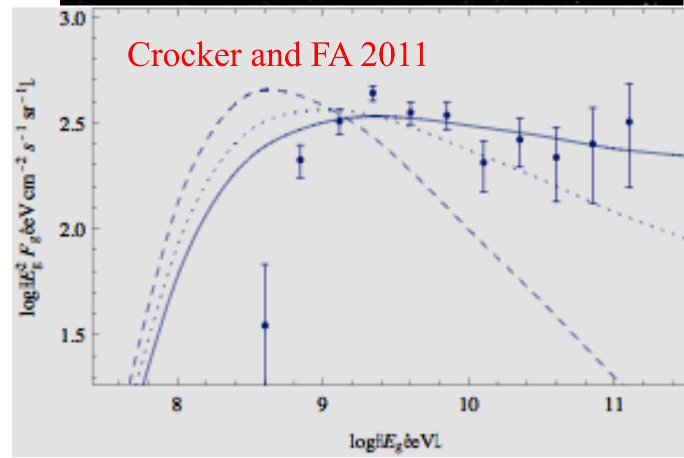
Size - because of slow diffusion in turbulent environment (10 times slower than in the Galactic Disk)

plasma density: $n \sim 0.01\ cm^{-3}$ timescale: $t_{pp} \sim 5$ Gyr $< t_{Galaxy}$

saturation (calorimetric) regime can explains:

generally homogeneous distribution of gamma-rays (local γ-ray production rate does not depend on density), unless possible gradients in the CR spatial distribution, e.g. due to propagation effects ; if the sharp edges tentatively found in the Fermi images is a real effect, they can be naturally explained by higher turbulence introduced by shocks => slower diffusion => accumulation of CRs close to the edges

modest requirements to CR rate : $L_p \sim 10^{39}$ erg/s



Fermi Bubbles as a ν-source ?
if γ-ray spectrum extends to 100 TeV, Km3NeT should be able to detect neutrinos after few years of operation (P Sa-pienza and R.Coniglione 2011)

Fermi Bubbles - alternative explanation:

IC scattering of electrons:

age: 10^7 yr, electron inj. rate $10^{38\text{-}39}$ erg/s

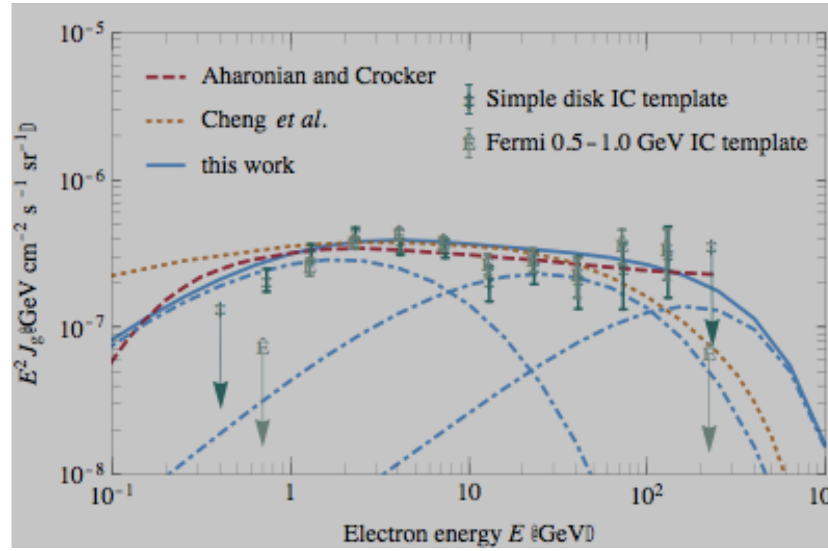
Problem: how transport E >1 TeV electrons to distances 10 kpc - in situ acceleration?

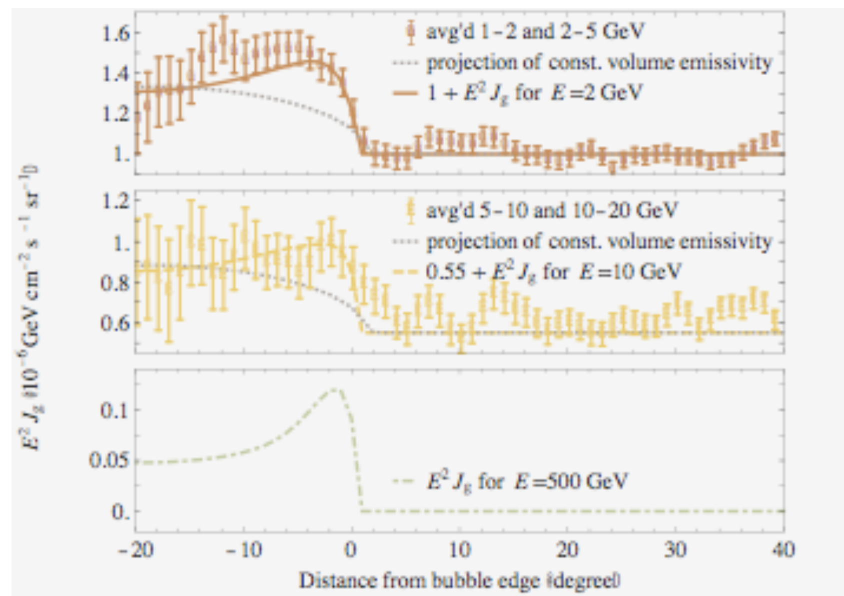
stochastic (2nd order Fermi) most viable option (Mertsch& Sarkar 2011)

shock fronts at Bubble edges (ROSAT) => higher turbulence - concentration of electrons close to the edges => sharp γ-ray edges

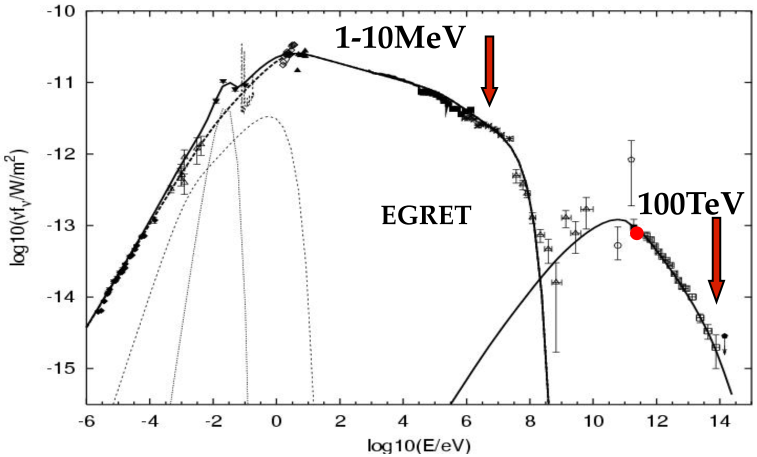
narrow electron distribution+limited E_{max}~1TeV only 2.7K MBR as a target cannot for IC explain the 1-100 GeV γ-radiation: galactic FIR/O target field helps to explain the average 1-100 GeV E^{-2} type flat gamma-ray spectrum .

distinct feature of the model - much steaper spectrum at the "top" of bubbles compared to region close to the galactic plain. Can be checked very soon …





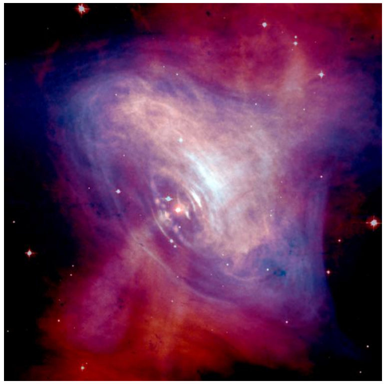
Crab Nebula – *a perfect electron PeVatron*



standard MHD theory (Kennel&Coroniti)

cold ultrarelativistc pulsar wind terminates by reverse shock resulting in acceleration of multi-TeV electrons

synchrotron radiation => nonthermal optical/X nebula
Inverse Compton => high energy gamma-ray nebula

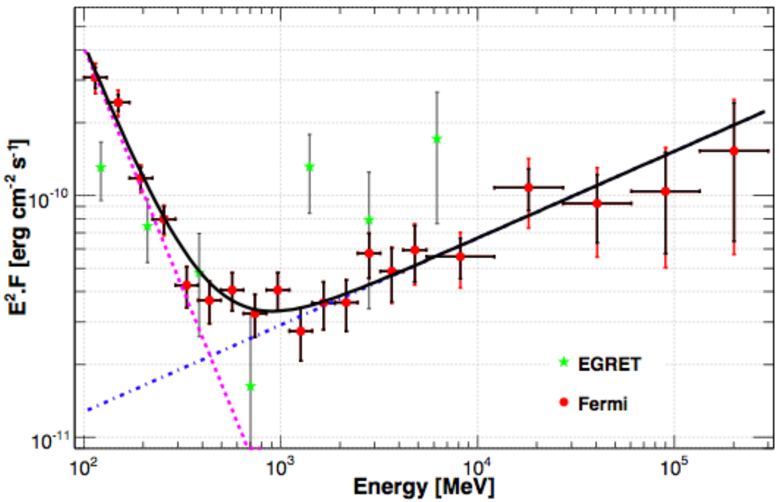


Crab Nebula – a powerful $L_e = 1/5 L_{rot} \sim 10^{38}$ erg/s
and extreme accelerator: Ee >> 100 TeV

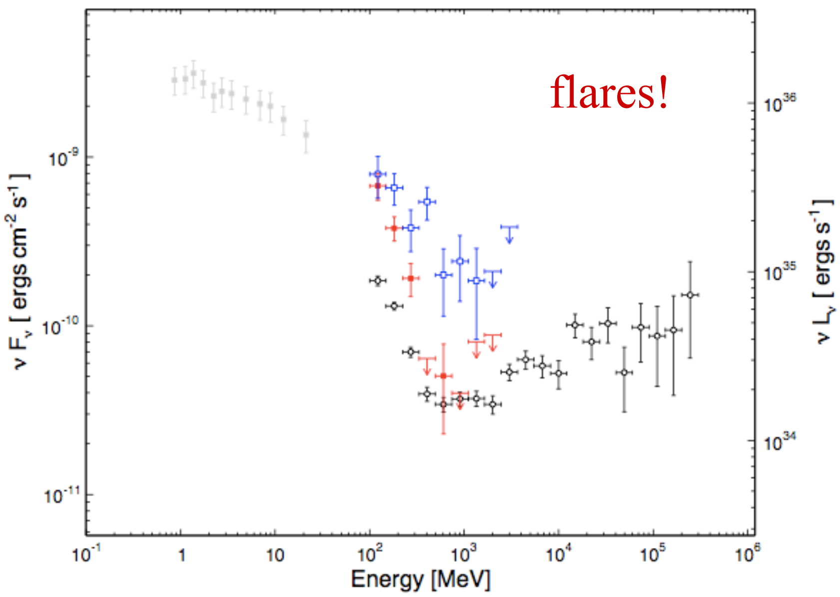
$E_{max} = 60\ (B/1G)^{-1/2}\ \eta^{-1/2}$ TeV and $h\nu_{cut} \sim 150\eta^{-1}$ MeV

Cutoff at $h\nu_{cut} > 10$ => $\eta < 10$ - acceleration at 10 % of the maximum rate
γ-rays: $E_\gamma \sim 50$ TeV (HEGRA, HESS) => $E_e > 200$ TeV
B-field ~100 mG => $\eta \sim 10$ - independent and more robust estimate
1 mG => $\eta \sim 1$?

Flares of Crab (Nebula) :



IC emission consistent with average nebular B-field: B ~ 100μG-150μG



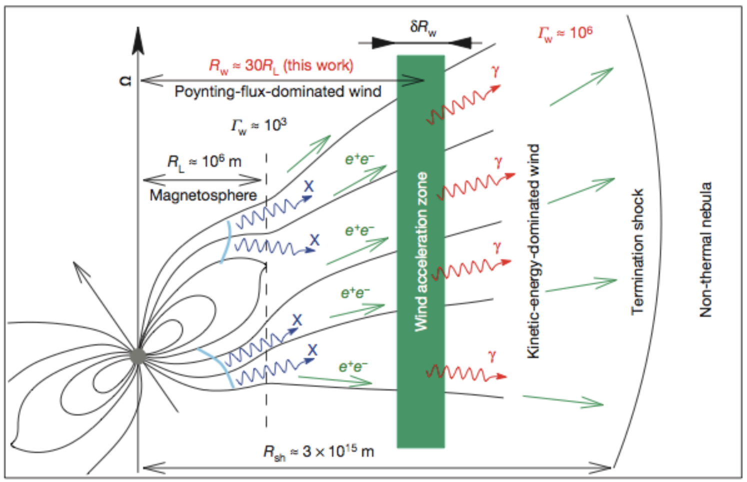
seems to be in agreements with the standard PWN picture, but … MeV/GeV flares!!

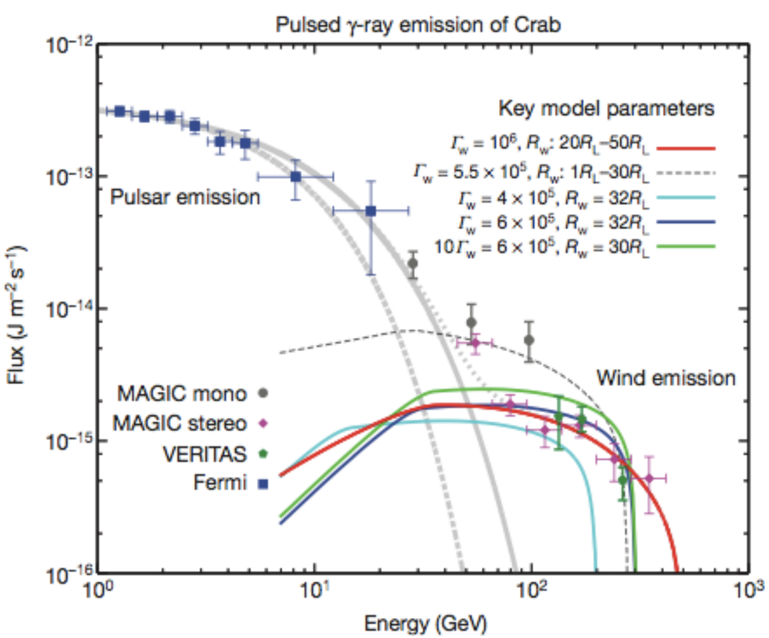
although the reported flares perhaps can be explained within the standard picture - no simple answers to several principal questions - extension to GeV energies, B>1mG, etc.

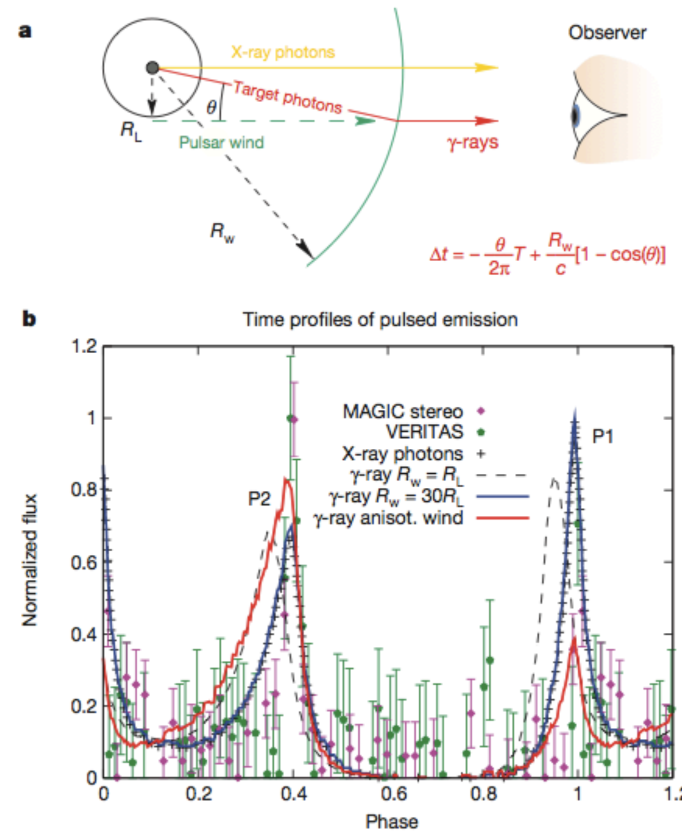
<u>observations of 100TeV gamma-rays</u> - IC photons produced by electrons responsible for synchrotron flares - a key towards understanding of the nature of MeV/GeV flares

Previous talk by Marco Tavani

Pulsed VHE gamma-rays from the Crab – Comptonization of the cold ultrarelativistic pulsar wind?







$\Gamma \sim 10^6$; R ~ 30 L

Crab Nebula is a very <u>effective accelerator</u>

but <u>not an effective IC γ-ray emitter</u>

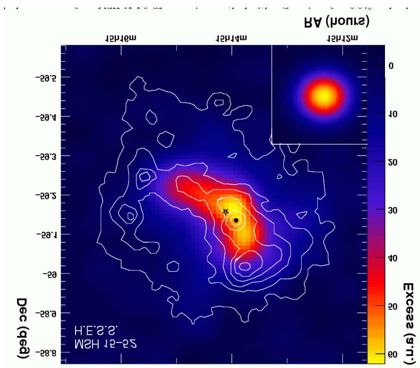
we do see TeV γ-rays from the Crab Nebula because of very large spin-down flux: $f_{rot}=L_{rot}/4\pi d^2=3\times10^{-7}$ erg/cm^2 s

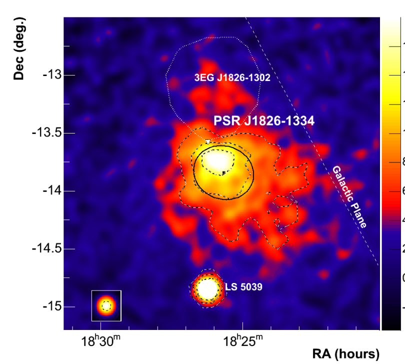
gamma-ray flux << "spin-down flux" *because of large B-field*

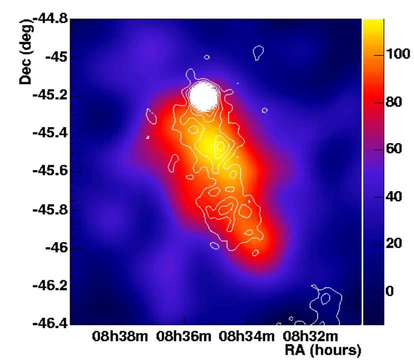
if the B-field is small (environments with small external gas presure)

higher γ-ray efficiency ➡ detectable γ-ray fluxes from other plerions

HESS confirms this prediction – many (20+) candidates associated with PWNe; firm detections - MSH 15-52, PSR 1825, Vela X, ...



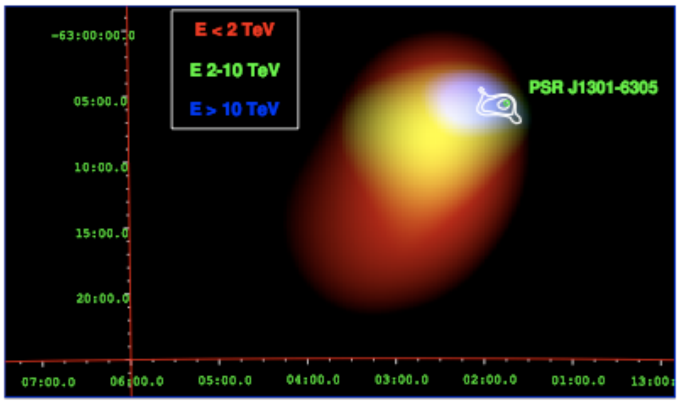


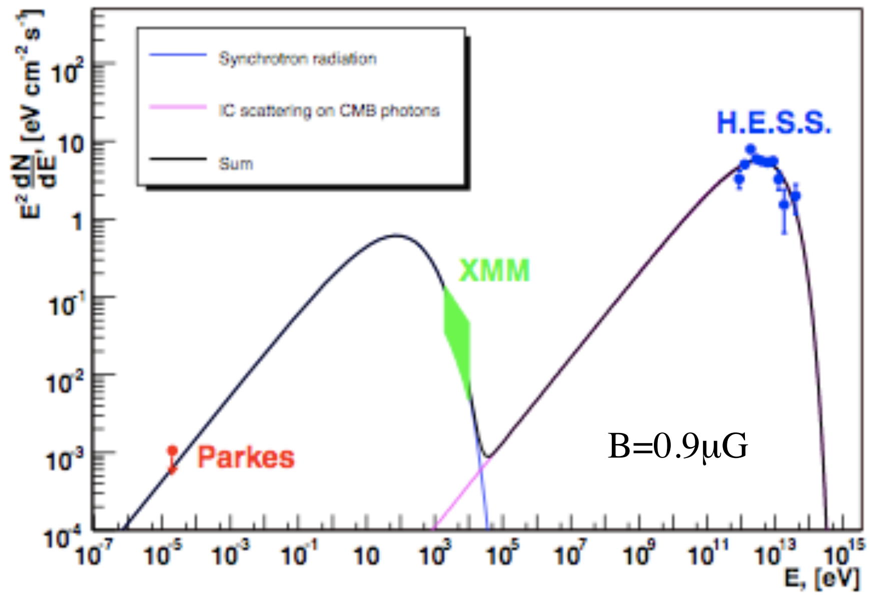


PWNe - *perfect electron accelerators and perfect γ-ray emitters!*

(1) rot. energy => (2) Poynting flux => (3) cold ultrarelativistic wind =>
(4) termination of the wind/acceleration of electrons => gamma-radiation:
efficiency at each stage >50% !

HESS J 13030-62 = PSR J1301-6305?





dramatic reduction of the angular size with energy:strong argument in favor of the IC origin of the γ-ray nebula

very small average B-field; for d=12.6kpc
$L_\gamma/L_{SD} = 0.07$; 3arcmin ~ 10 pc

because of small B-field we see "relic" electrons produced at early epochs of the pulsar

binary systems - unique high energy laboratories

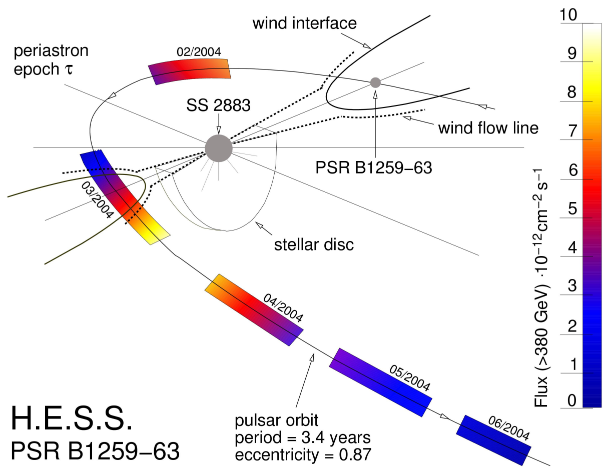
binary pulsars - a special case with strong effects associated with the optical star on both the dynamics of the pulsar wind and and the radiation before and after its termination

the same 3 components - *Pulsar/Pulsar Wind/Synch.Nebula* - as in PWNe both the electrons of the cold wind and shocke-accelerated electrons are illuminated by optical radiation from the companion star detectable IC γ-rays

''on-line watch'' of the MHD processes of creation and termination of the ultrarelativistic pulsar wind, as well as particle acceleration by relativistic shock waves, through spectral and temporal studies of γ-ray emission

(characteristic timescales 1 h or shorter !)

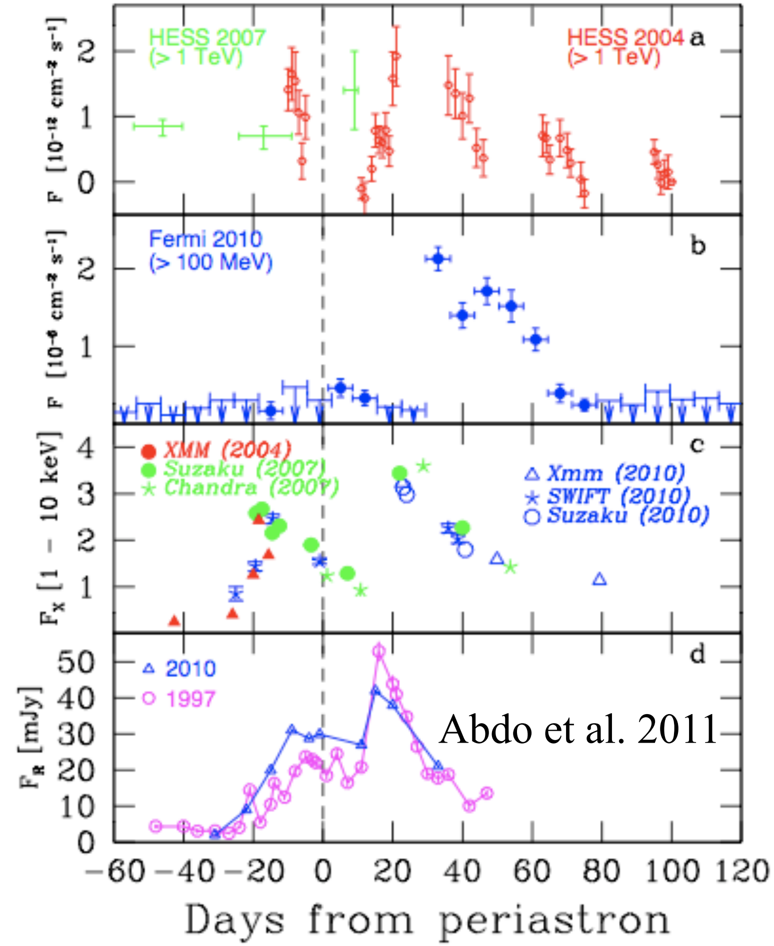
the target photon field is function of time, thus the only unknown parameter is B-field => predictable gamma-ray emission?



HESS: detection of γ-rays at < 0.1Crab level - tendency of minimum flux close to periastron;

Several possible explanations, but many things uncertain and confusing.

Special expectations/hopes from Fermi related to the periastron passage in Dec 2010



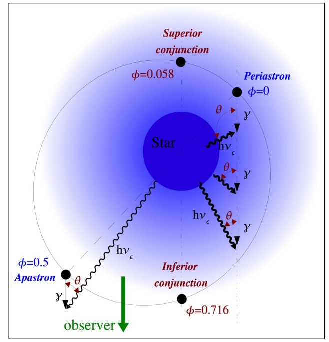
Fermi LAT - weak signal faround periastron, but flares after 1 month!

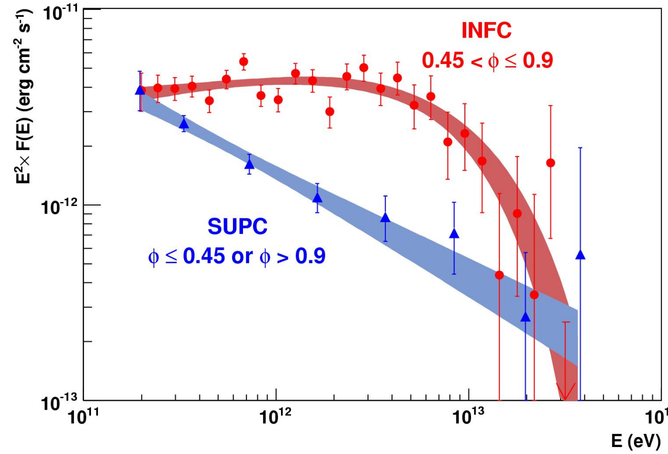
IC emission of unshocked wind with Lorentz factor 10^4 ? (Khangulyan et al 2011)

LS 5039

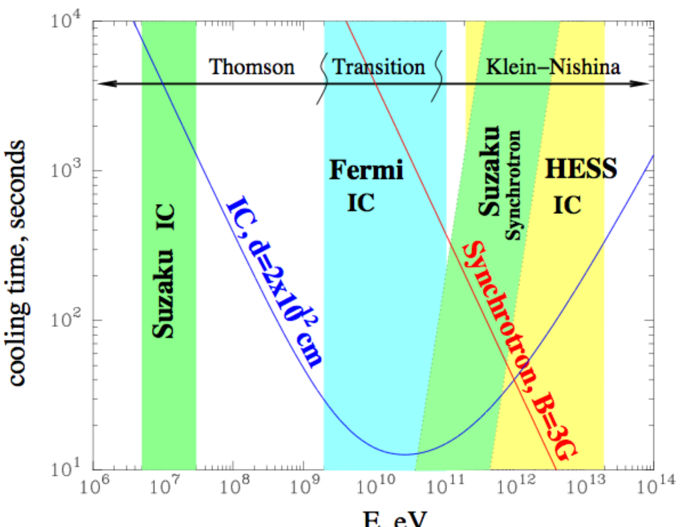
works as a perfect TeV clock
and an extreme accelerator

close to inferior conjuction - maximum
close to superior conjuction – minimum





modulation of the gamma-ray signal? *a quite natural reason (because of $\gamma-\gamma$ absorption), but we see a different picture… anisotropic IC scattering? yes, but perhaps some additional factors (adiabatic losses, modest Doppler boosting) also play a non-negligible role*



can electrons be accelerated to energies up to 20 TeV in presence of dense radiation? *yes, but accelerator should not be located deep inside binary system; even at the edge of the system $\eta < 10$ => although* the origin of the compact object is not yet known (pulsar or a BH) and we do not understand many details, it is clear that this binary system works as an extreme accelerator

10^{20} eV proton sources – almost for sure – extreme accelerators

suspected sites of 10^{20} eV cosmic rays based on the condition: source size > Larmor radious

$(R/1pc)(B/1G) > 0.1\ (E/10^{20}eV)$

necessary but not sufficient condition:
it implies

(1) minimum acceleration time

$t_{acc}=R_L/c=E/eBc$

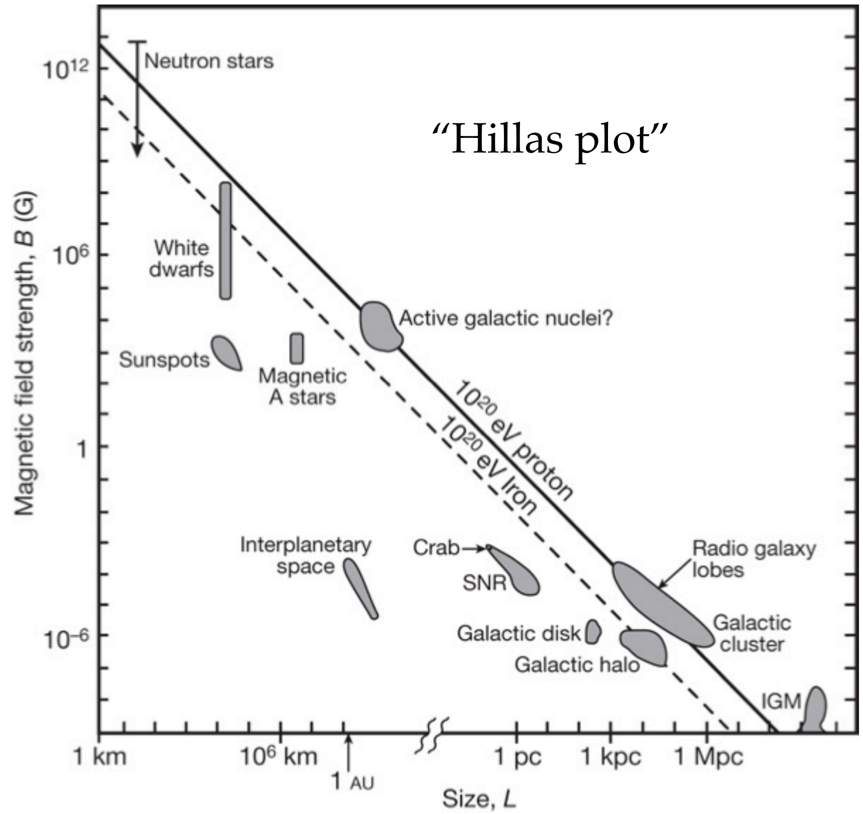
acceleration in fact is slower:

$t_{acc}=(1\text{-}10)\eta\ R_L/c\ (c/v)^2$

with $\eta>1$ and shock/bulk-motion speed $v<c$ ($\eta=1$ - Bohm diffusion)

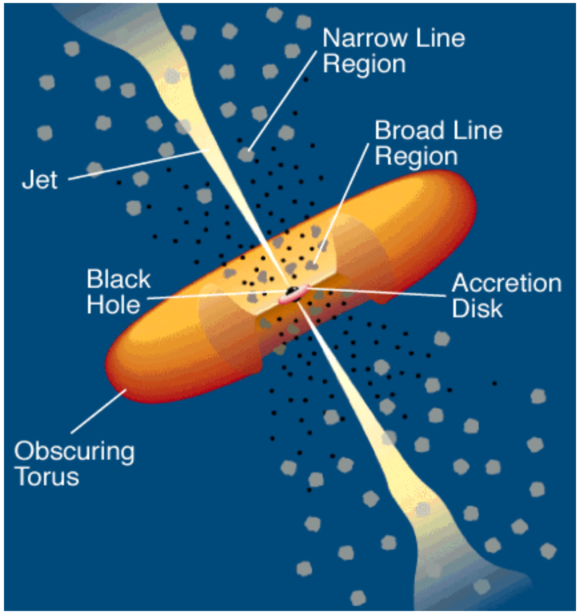
Compact objects like AGN and GRBs
the best candidates

(2) no energy losses but synchrotron/ curvature losses in compact objects become severe limiting factor



PM Bauleo & JR Martino Nature 458, 847-851 (2009

Blazars - sub-class of AGN dominated by nonthermal/variable broad band (from R to γ) radiation produced in relativistic jets close to the line of sight, with massive Black Holes as central engines



before 2004:

detection of 6 TeV Blazars, extraordinary outbursts of Mkn 501 in 1999, variations on <1h timescales;

=> initiated huge interest in AGN and EBL communities

today:

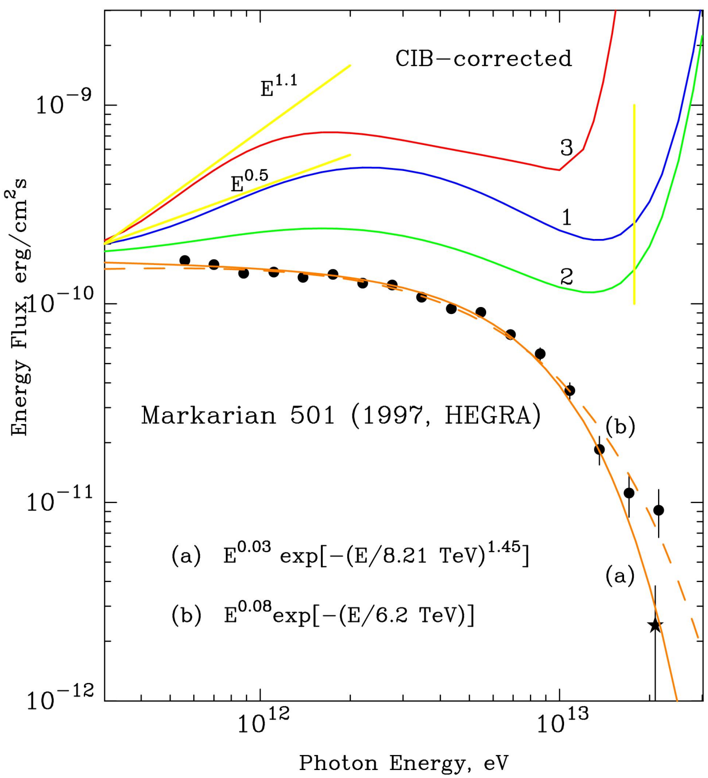
more than three dozens TeV blazars; quite unexpectedly TeV γ-rays from distant blazars; $z > 0.5$

=> strong impact on both blazar physics and on the Diffuse Extragalactic Background (EBL) models

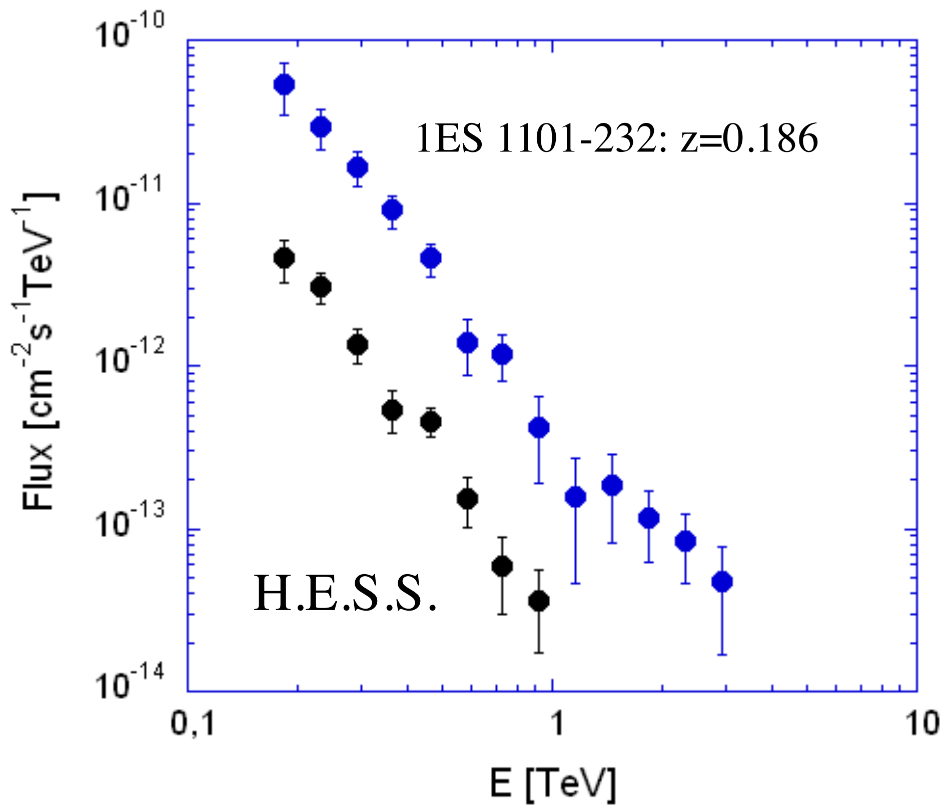
most exciting results - variability on 2-3 min timescales
unusually hard gamma-ray spectra

Blazars and EBL

Mkn 501: z=0.031: an “infrared crisis”, but with a happy end…



TeV blazars detected by HESS at z> 0.15 !

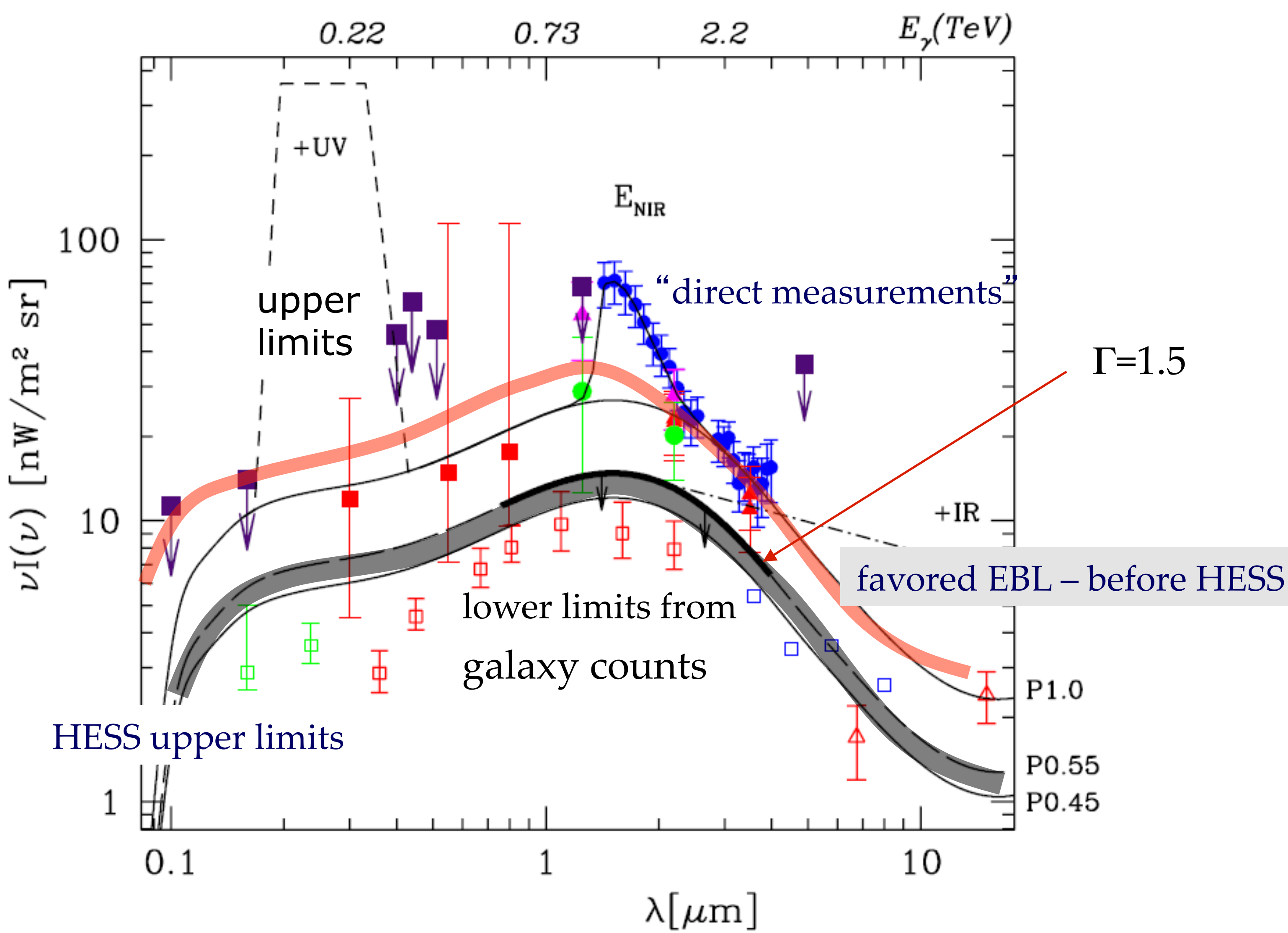


reported EBL flux at FIR have not been confirmed

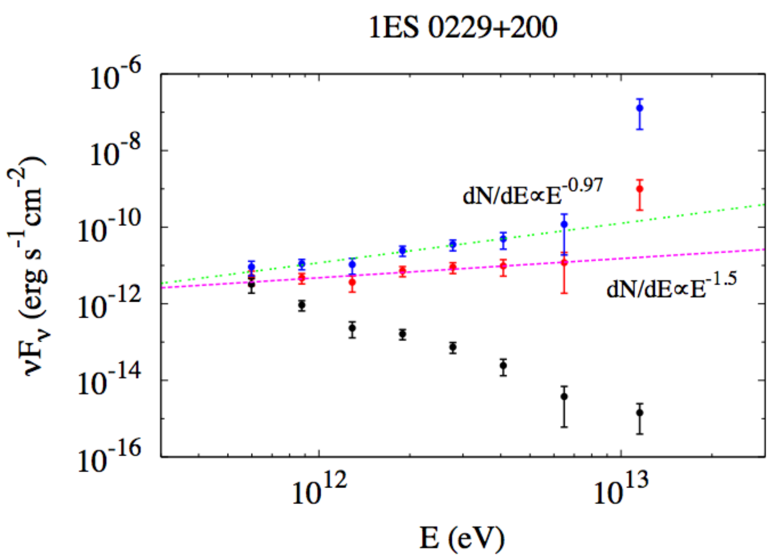
corrected for EBL absorption γ-ray spectrum not harder than $E^{-\Gamma}$ (Γ=1.5) => **u.l. EBL**

HESS upper limits on EBL - good agreement with recent EBL studies

EBL (almost) resolved at NIR ?



1ES 0229+200 - *a new "trouble-maker"*



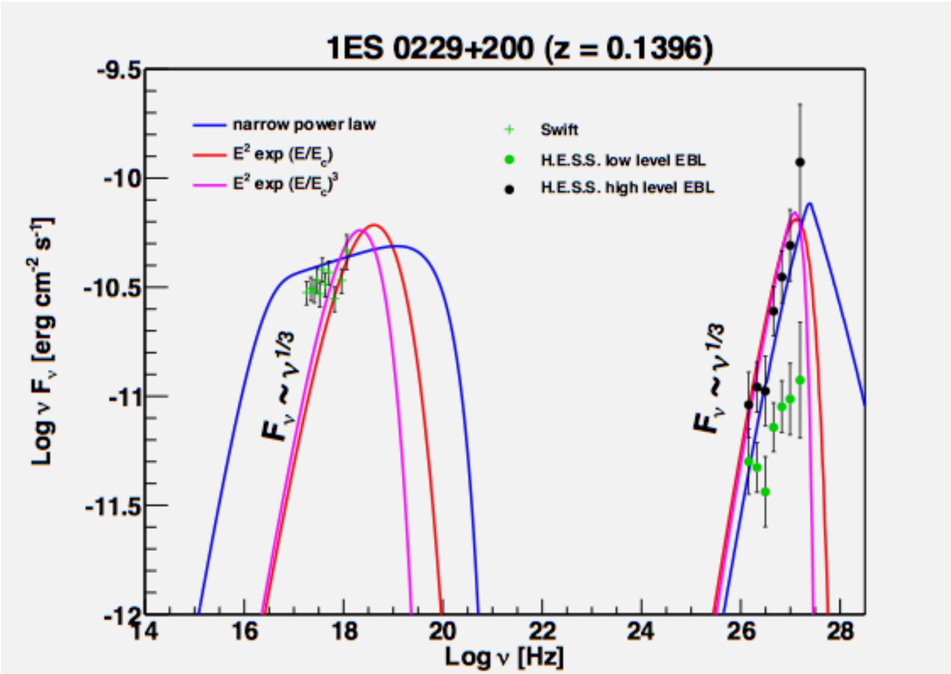
z= 0.14, but spectrum extends to >5 TeV !
even slight deviation from the "standard" EBL
=> extremely hard γ-ray spectra with Γ < 1

possible explanations:

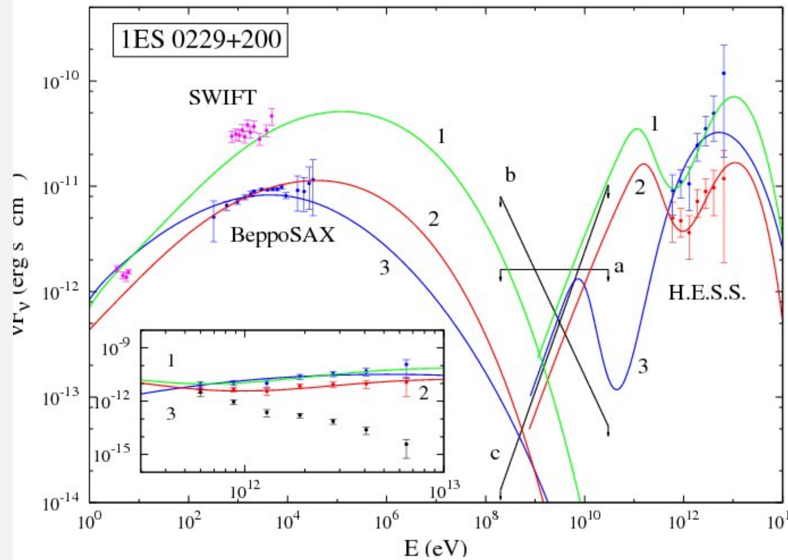
- very narrow electron distribution - no significant radiative energy losses =>
  typically very small B-field: 0.001G
  mechanism: External IC or SSC
- cold ultrarelativistic electron wind?
  mechanism: External IC
- internal γ−γ absorption =>
  very strong magnetic field, B >10 G
  mechanism: proton synchrotron

Synchrotron Self Compton

Proton synchrotron plus internal γ−γ absorption



E. Lefa

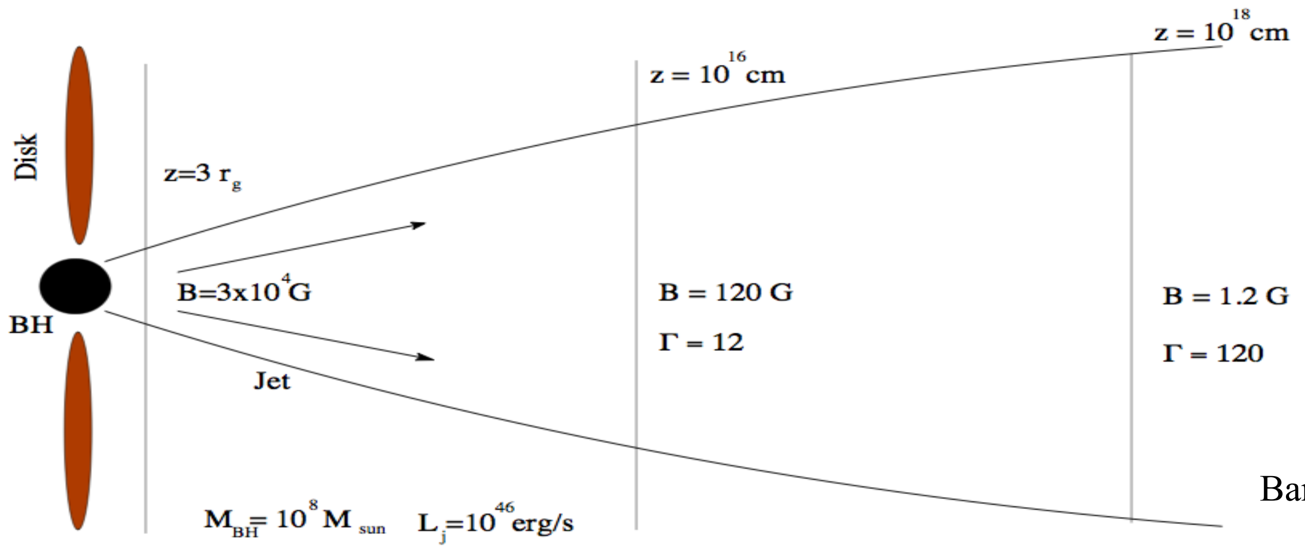


O. Zacharopoulou

narrow electron distribution
plus weak magnetic field
B < 0.1 G

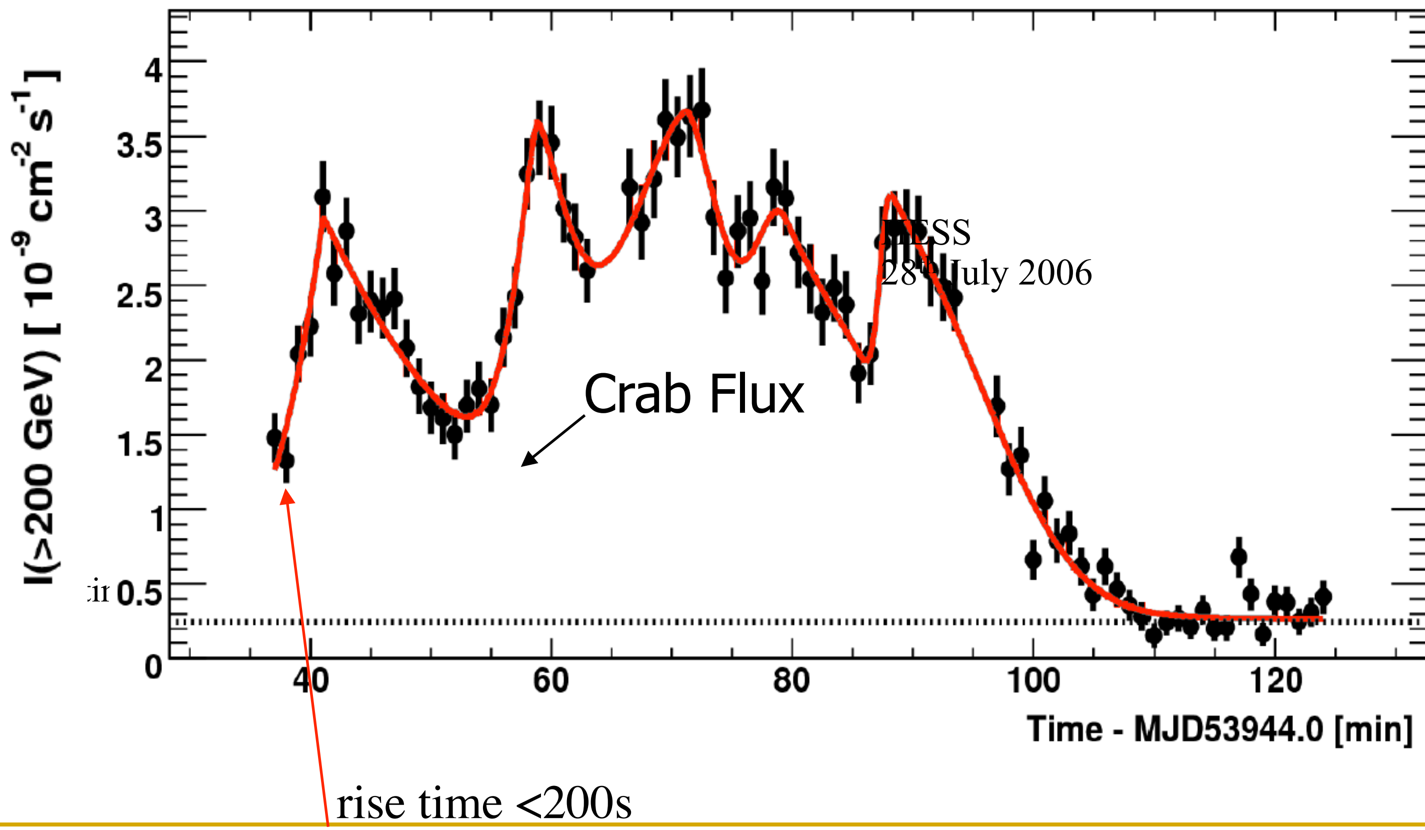
strong magnetic field:
B > 10 G

B-field: very large or very small?



Barkov et al 2010

in powerful blazars at subparsec scales B-field cannot be smaller than 1G, a serious constraint for the simplified one-zone "leptonic models, several min (200s) variabiliry timescale => $R = c\,\Delta t_{var}\,\delta_j = 10^{14}\delta_{10}$ cm for a 10^9Mo BH with 3Rg = 10^{15} cm => δj > 100, i.e. close to the accretion disk (the base of the jet), the bulk motion Γ > 100



on the Doppler boosting and mass of BH in PKS2155-309

- several min variability timescale => $R=ct_{var}\delta_j \sim 10^{13}\delta_j$ cm for a 10^9Mo BH with 3Rg ~ 10^{15} cm => $\delta j > 100$, i.e. close to the accretion disk (the base of the jet), the Lorenz factor of the jet $\Gamma > 50$ - this hardly can be realized close to Rg!

- the (internal) shock scenario: shock would develop at $R=Rg\,\Gamma^2$, i.e. minimum γ-ray variability would be $R_g/c=10^4(M/10^9Mo)$ sec, although the γ-ray production region is located at $R_g \sim ct_{var}\Gamma^2$ (e.g. Chelotti, Fabian, Rees 1998) - this is true for any other scenario with a "signal-pertubaution" originating from the central BH

- thus for the observed $t_{var} < 200$ s, the mass of BH cannot significantly exceed 10^7Mo. On the other hand the "BH mass–host galaxy bulge luminosity" relation for PKS2155-304 gives $M > 10^9$Mo.

Solution? perturbations are cased by external sources, e.g. by magnetized condensations ("blobs") that do not have direct links to the central BH;

do we deal with the scenario "star crosses the relativistic e^+e^- jet" ?

Summary:

gamma-rays are the best carriers of information about the sites and processes of extreme particle acceleration on both galactic and extragalactic scales

they will help us to identified the major contributors to "our" cosmic rays with the current detectors Fermi/AGILE and HESS/MAGIC/VERITAS

CR related studies – perhaps will still be the highest priority task for the new generation of ground-based gamma-ray detectors, first of all CTA