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# Galactic Cosmic Ray PeVatrons

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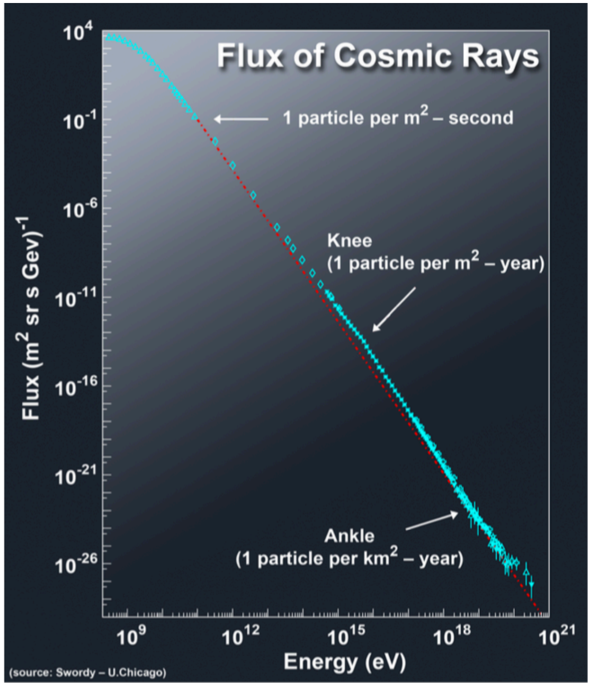
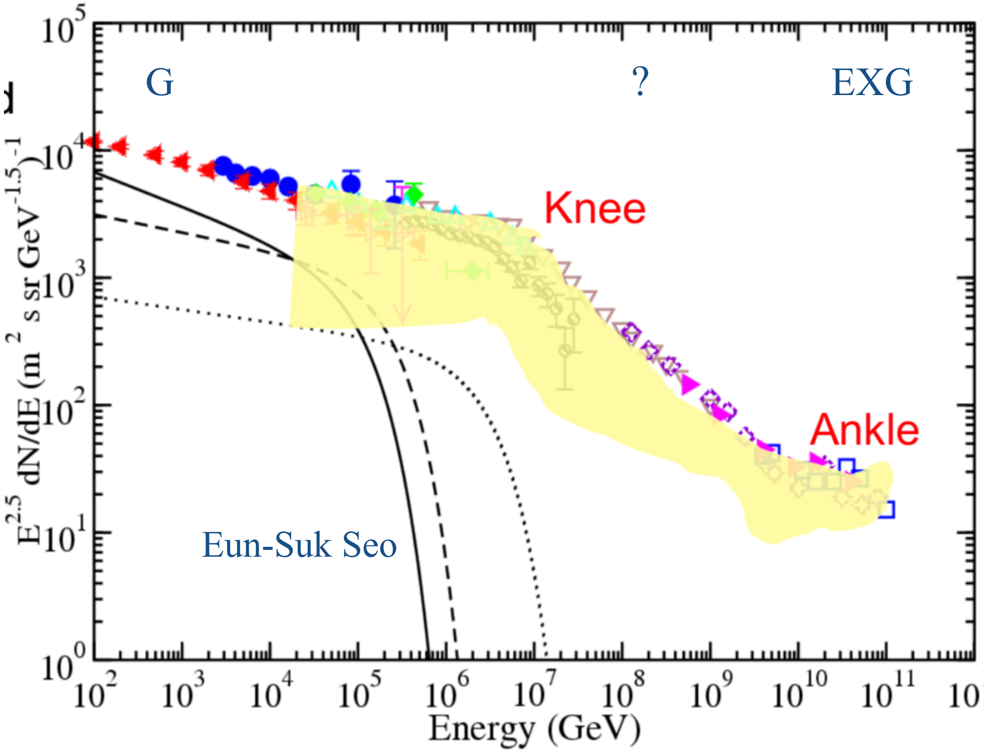
# Cosmic Rays from sub-GeV to 100 EeV energies




below $10^{15}$ eV - Galactic; beyond $10^{18}$ eV - Extragalactic;

$10^{15}$-$10^{18}$ eV ? Galactic rather Extragalactic

Origin of Galactic Cosmic Rays ?

what does mean "Origin of Cosmic Rays" ?

*term "Cosmic Rays" itself has two meanings:*

- *locally* detected relativistic particles - "local fog"
- nonthermal/relativistic particles produced throughout the Milky Way - they may/may-not contribute to the "local fog"

"origin of CRs" generally is reduced to the identification of the major contributors (SNRs, pulsars, GC, etc.) to the 'local fog'

this question cannot be solved by observations of only charged CRs

CR accelerators can be identified only by neutral stable messengers: photons and neutrinos *hundreds of GeV and/or TeV gamma-ray emitters have been discovered representing 10+ source populations:*

- SNRs, Stellar Clusters, GMCs
- Pulsars, PWNe
- Binaries (Binary Pulsars, Microquasars)
- Galaxies, Starburst Galaxies,
- Radiogalaxies,
- AGN, GRBs

**analogy with X-rays:**
as cosmic plasmas are easily heated up to keV temperatures - almost everywhere, particles (electrons and protons/nuclei) can be easily accelerated to TeV energies - almost everywhere!

not all of them contribute to local CR flux but all are CR accelerators - *factories* of relativistic matter

many questions beyond the origin of local CRs,
for example the physics of 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* *can be as large as 50 %*

(ii) maximum possible energy achieved by individual particles

*acceleration rate close to the* *maximum (theoretically) possible rate*

# Rescaling the Hillas Plot for Galactic PeVatrons

acceleration time:

$$t_{acc} = \eta \frac{E}{eBc} = \eta \frac{r_L}{c}$$

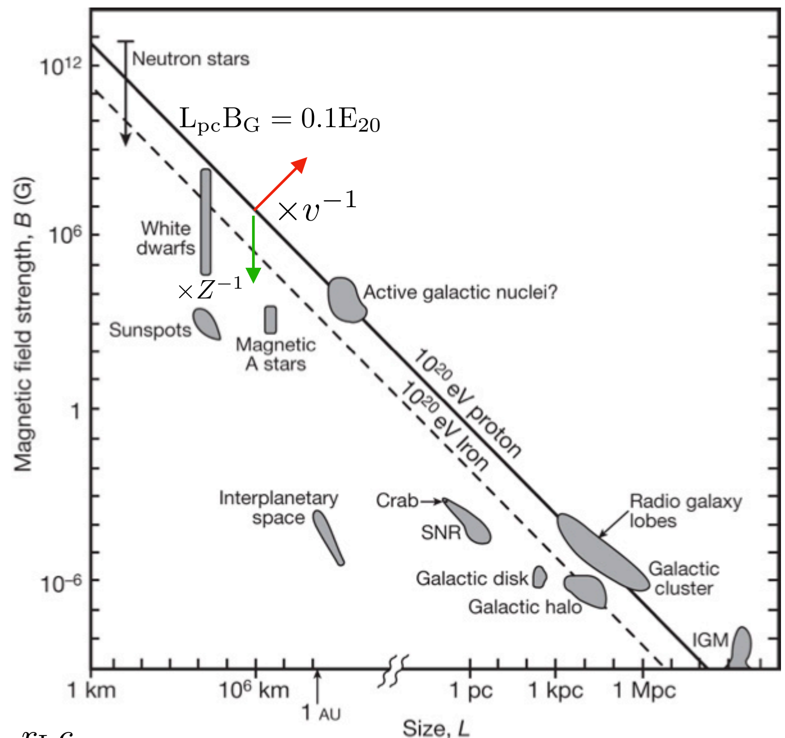
$\eta^{-1}B = \mathcal{E}_{eff}$ projection of electric field on particle trajectory averaged as particle moves along the trajectory

$\eta = 1$ absolute minimum set by classical ED => absolute extreme accelerator

DSA in Bohm regime: $\eta = (1-10)(c/v)^2$

e.g. in young SNRs $\eta \approx 10^5$

still can be called extreme accelerator




effective accelerator : $t_{conf} \geq t_{ac}$

best confinement – in Bohm Diffusion regime with $D = \frac{r_L c}{3}$

$$t_{conf} = \frac{L^2}{3D} = \frac{L^2}{r_L c} \Rightarrow L \geq \eta^{1/2} r_L$$

$L = r_L$ condition implies an absolute extreme accelerator

trivial condition - non-trivial solutions!

maximum energy of accelerated protons $E_{15} \leq 3 \times 10^{-3} L_{pc} B_{\mu G} (v/0.01c)$

# PeVatrons in our Galaxy?

Electron PeVatrons - *related to the pulsar winds in PWNe (Crab Nebulae) or Pulsar Binaries*

Proton PeVatrons - in young individual SNRs and Stellar Winds with v > 0.01c, and provided B > 0.01 G

Large Scale structures - *Superbubbles, Fermi Bubbles, …*

Galactic Center *magnetosphere of SMBH (Sgr A*)*

$$E_{15} \sim eBR \approx 10^3 (B/10^4 \mathrm{G})(\mathrm{M}/3 \times 10^6 \mathrm{M}_\odot)$$

relativistic (barionic) outflows

*wind in GC or the jet in SS 433*

## Proton PeVatrons in the Milky Way are extreme accelerators

### definition of the term **“PeVatron”**

*particle accelerators boosting energy of protons to the PeV domain without a sharp cutoff/break to 0.1 PeV*

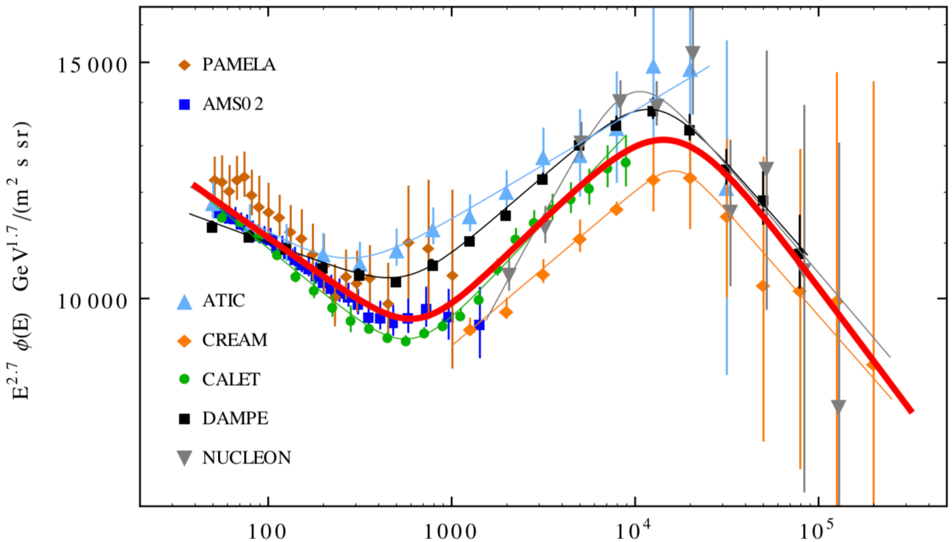
until recently:

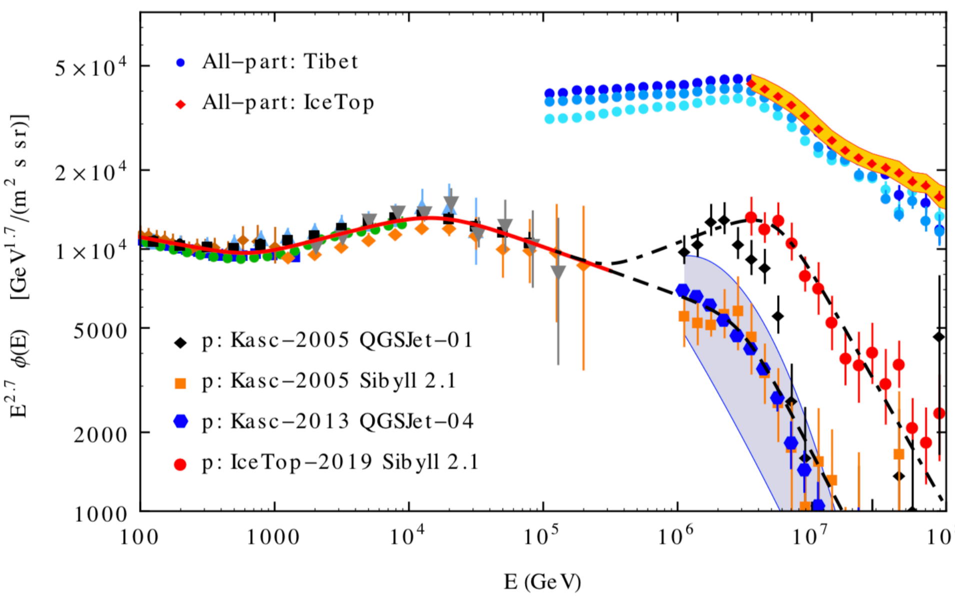
(i) featureless power-law spectrum up to the “knee” around 1 PeV has been interpreted as the dominance of a single CR component supported by a single source population

(ii) SNRs as the major contributors to GCRs until the “knee” should operate as “PeVatrons” ... despite all theoretical challenges !

# Do we need CR PeVatrons in our Galaxty?

# CR proton spectrum




Lipari and Vernetto 2019

the spectrum is not single power-law; it contains (at least) two spectral features:

- hardening above a few 100 GeV
- steepening above 10 TeV
- hardening above 100 TeV ?

we do need **PeVatrons**

- either **quasi-PeVatrons** up to 0.1 PeV and more

- or **nominal -PeVatrons** up to 1 PeV

- or **super-PeVatrons** up to 10 PeV

# Galactic Cosmic Rays: sources ?

SNRs as prime candidates - over decades the conviction has been based on phenomenological arguments and theoretical meditations

- as early as 1933 W. Baade and Zwicky recognized the comparable energetics characterizing SN explosions and CRs and envisaged a link between

  $E_{SN} \sim 10^{51}$ erg, $R \sim 0.03$ yr$^{-1}$, $P_{SN} \sim 10^{42}$ erg/s => 10 % to CRs ?

- DSA theory applied to SNRs - viable mechanism for acceleration of particles with hard proton spectrum in young SNRs. Up to 1 PeV ? Difficult but possible; requires amplification of the magnetic field in upstream is a critical issue

- direct prove - detection of gamma-rays, neutrinos

# Probing SNRs with gamma-rays

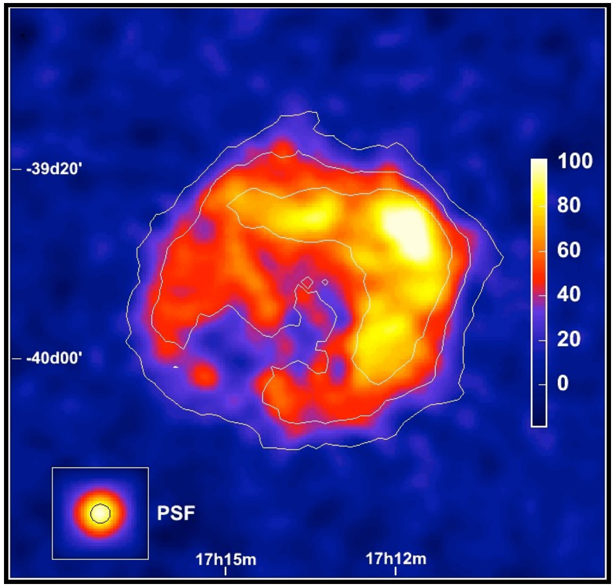
SNRs as the most likely sources

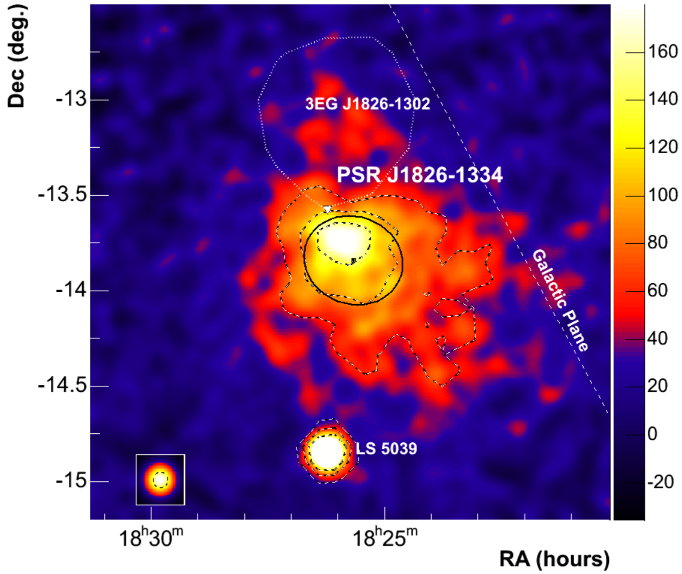
of galactic cosmic rays up to 1 PeV?

main hope is related to gamma-ray observations:

- detect VHE gamma-rays from SNRs
- demonstrate that they have hadronic origin
- demonstrate that proton spectra continue up to 1 PeV

# Gamma Ray images of Galactic TeVatrons




## Supernova Remnant

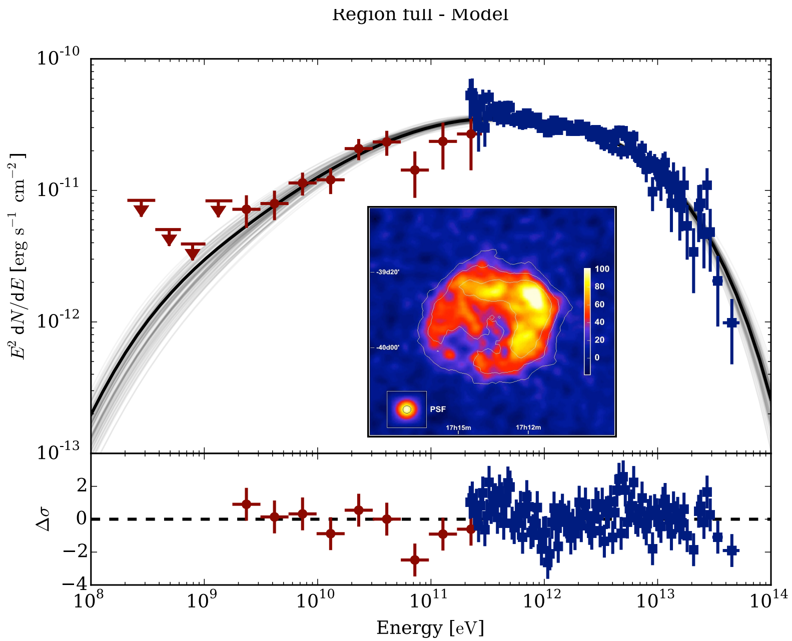
(the) major contributors to galactic cosmic rays:

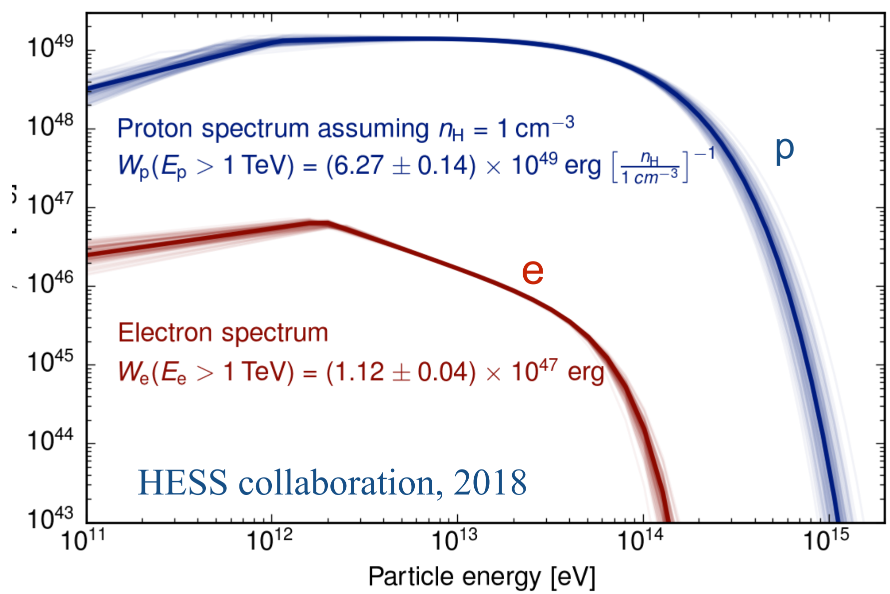
## Pulsar Wind Nebula

contributors to cosmic ray electrons and positrons

# Probing the distributions of accelerated particles in SNRs

Fermi+HESS measurements **RXJ 1713** derived spectra of e and p

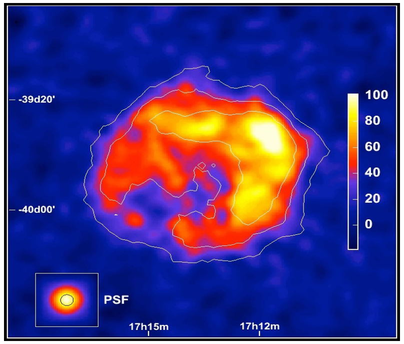


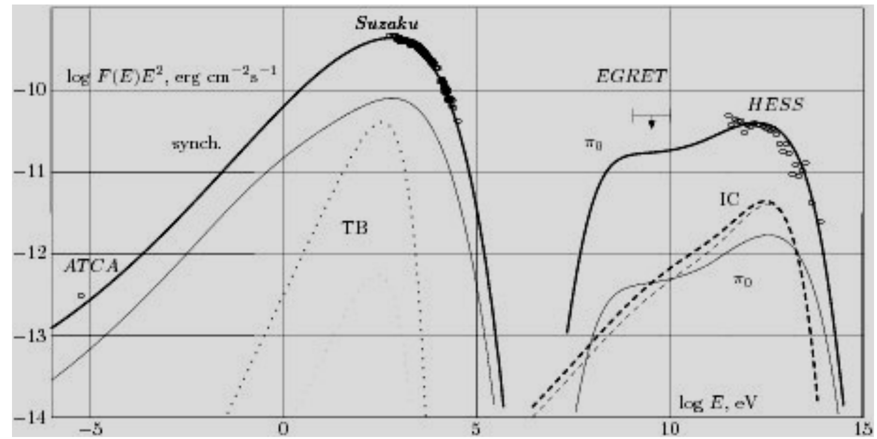

cutoff /break in the proton spectrum at 100 TeV

RXJ 1713.7-4639

# *modeling of broad-band SEDs:*

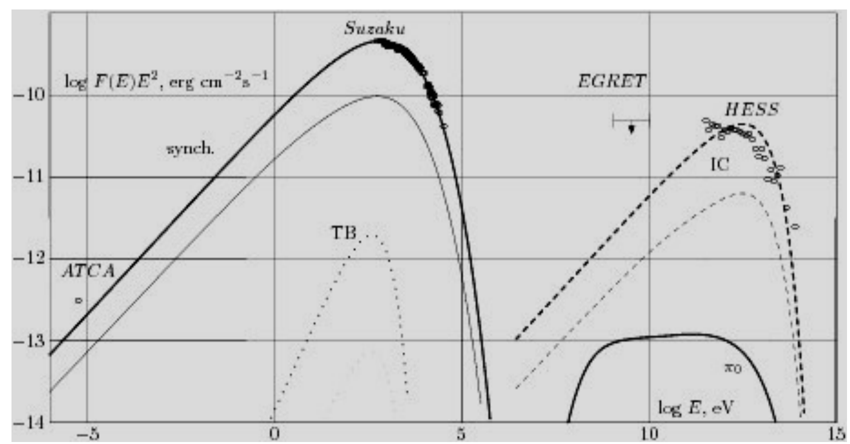



hadronic model




good spectral fit, reasonable radial profile, but …
(1) lack of thermal emission - possible explanation?
>70% energy is released in acceleration of protons!
(2) very high p/e ratio ($10^4$)

leptonic model



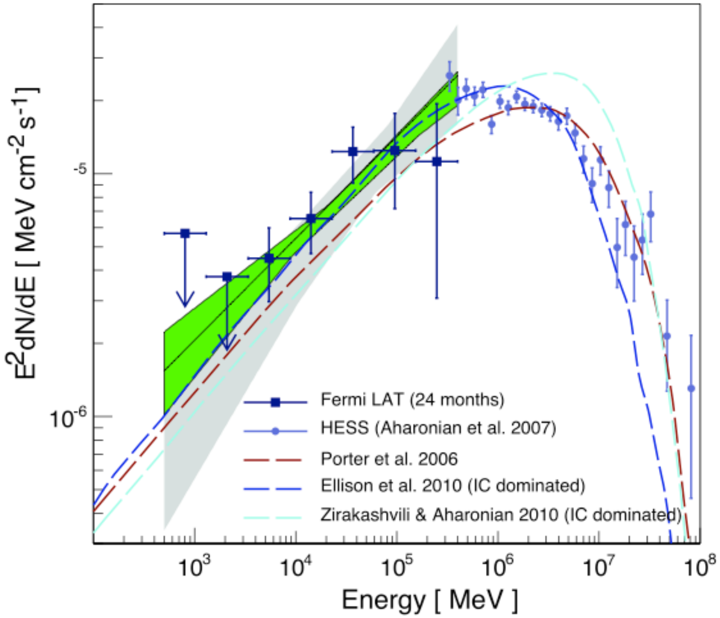

not perfect, but still acceptable, fits for spectral and spatial distributions of IC gamma-rays; suppressed thermal emission, comfortable p/e ratio ($\sim 10^2$);small large-scale B-field ($\sim$ 10 μG)

both forward and reverse shocks contribute to γ-rays

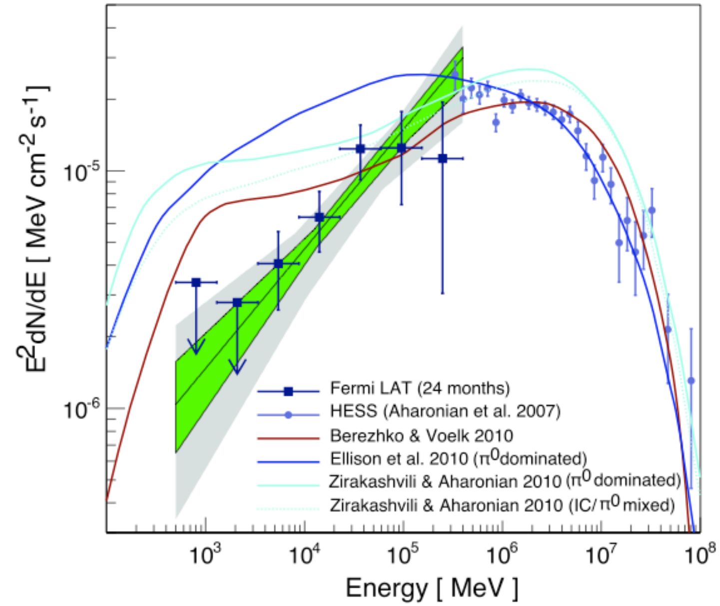
Zirakashvili, FA 2010

gamma-rays detected by Fermi? very important… but not decisive

# Fermi:  GeV data contradict hadaronic origin of γ-rays  (?)




leptonic models




hadronic models

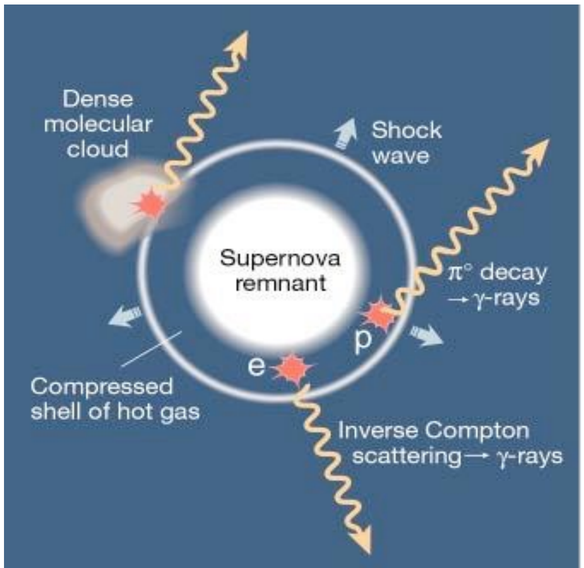
questions:   (i)  can we compare GeV and TeV fluxes within one-zone models?

*they could come from quite  different regions*

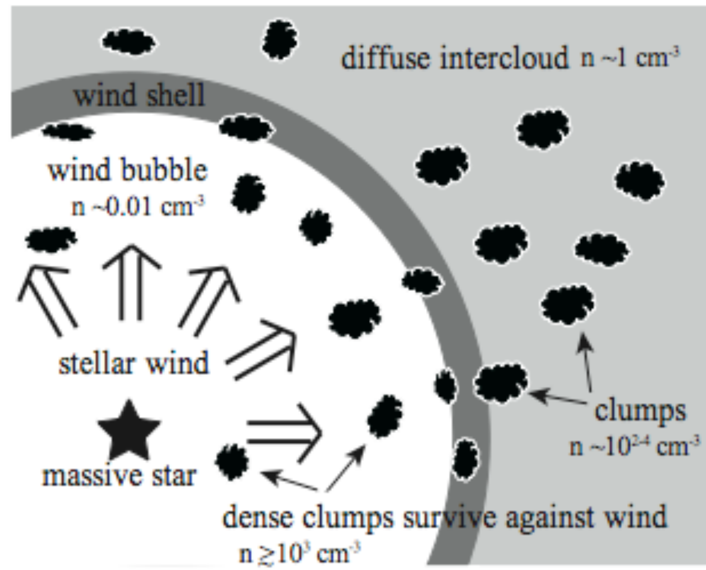
(ii)  cannot we assume hard proton spectra ?

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

GeV γ-rays can be suppressed because low energy protons cannot reach the dense target (Malkov et al. 2005) or cannot penetrate deep into the dense clouds/clumps Zirakashvili&FA 2010)




FA 2002, Nature 416,797

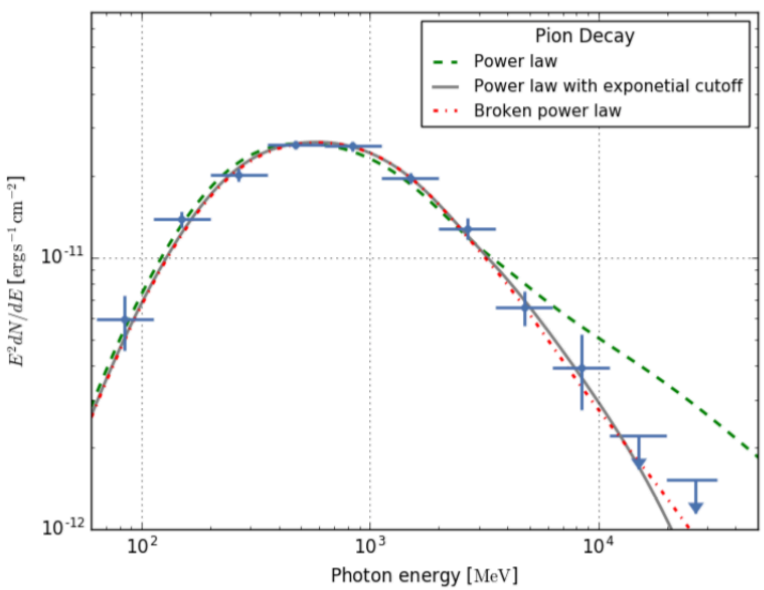


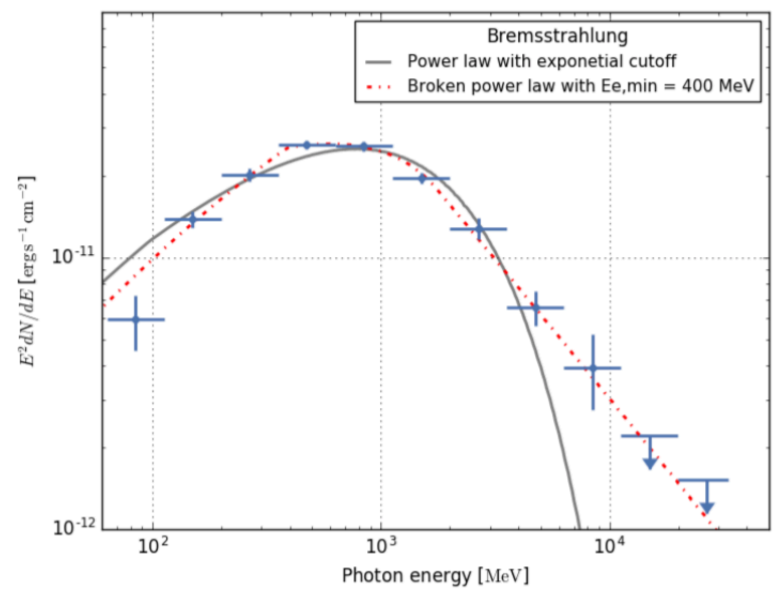

Inoue et al. 2011, ApJ

Fermi LAT - important, but only neutrinos, ultra-high energy gamma-rays and hard synchrotron X-rays from secondary electrons can provide decisive conclusions *detection of '$\pi^0$' bump in middle-aged SNRs?*

- 'pi-0' bump in SED can be reproduced also by bremsstrahlung of electrons with broken power-law spectrum close to the one observed in the interstellar medium, unless the differential spectrum below the bump is not flatter than $dN/dE \sim E^{-1}$

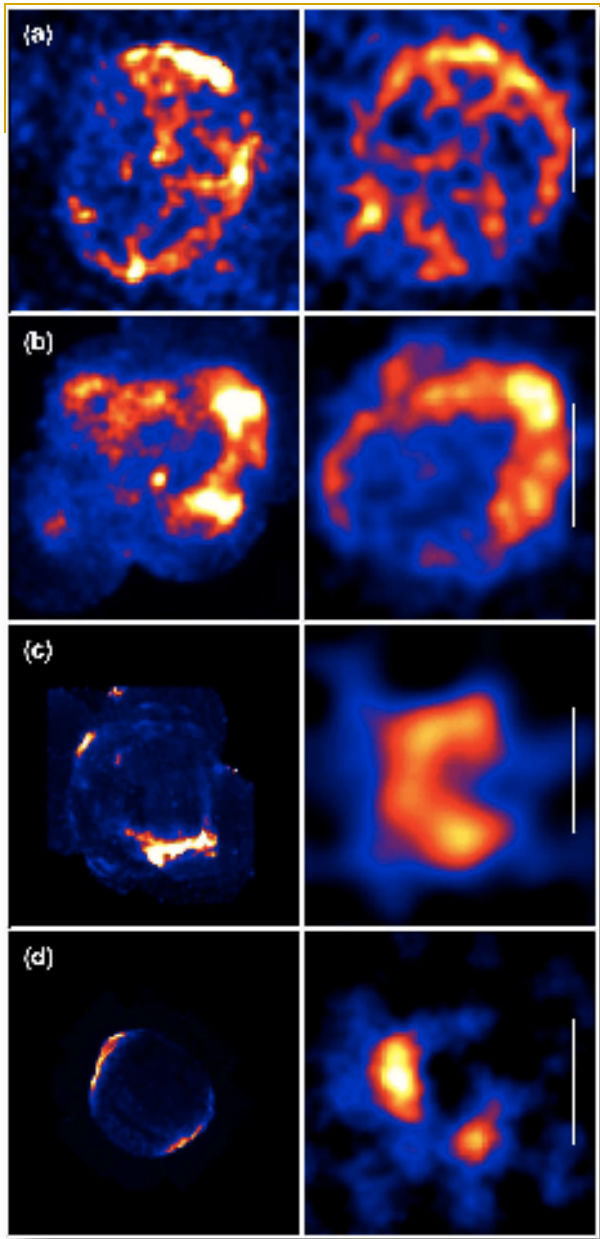
- $\pi^0$ origin of the bump is important for estimates of the content of low-energy CR protons and nuclei, but it is not a critical issue for the origin of Galactic CRs



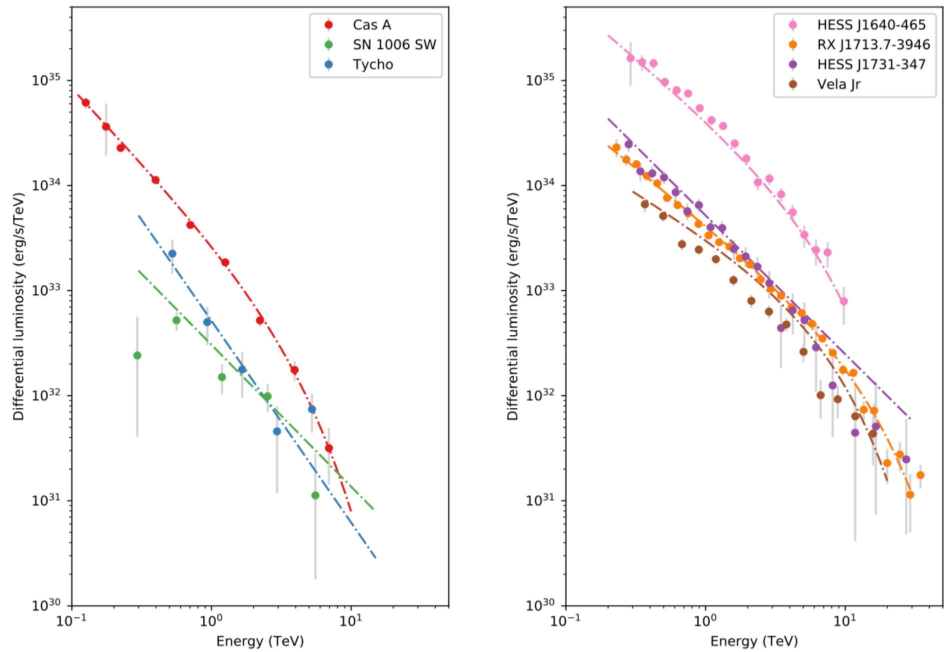



detection of hard gamma-ray spectra above 10 TeV would be a distinct signature of hadronic origin of radiation *as robust as the detection of neutrinos* !

more importantly, it would be the indication of effective continuation of the spectrum of the parent protons well beyond 100 TeV (0.1 PeV)




TeV gamma-rays from from >10 young SNRs:
support to the SNR origin of galactic CRs,
but it is not yet clear whether SNRs alone can
provide the CR flux up to the *knee* ( ~1 PeV)




steep spectra or 'early' cutoffs ?

spectra of young SNRs above 1 TeV - steep with Γ= 2.3-2.6

slope or intrinsic power-low index?

formally the spectra can be presented in the form:

$$\mathrm{dN/dE} \propto \mathrm{E}^{-\Gamma} \exp[-(\mathrm{E}/\mathrm{E}_0)^{\beta}]$$

with reasonable combination of $E_0$ and $\beta$, $\Gamma=2$ could be an option

price?

Eo < 10 TeV => Ep < 100 TeV is not a PeVatron

Eo > 10 TeV => Ep > 100 TeV and $\Gamma > 2.3$ can be a PeVatron

?

## two options

- large power-law indices

  it is more realistic than $\Gamma$=2 of the "standard" DSA (M. Malkov, T. Bell, …)

  no constrains on the proton maximum energy from gamma-ray data

- "early cutoff"

  standard DSA but low-energy cutoff

  should we relax and accept that SNRs are main contributors to CRs but at TeV energies are overtaken by other source population ("PeVatrons") responsible for the knee region? (Laggage and Cesarsky 1983) ?

  or

  relate it to the much early "PeVatron Phase" - first 10 to 100 years after the SN explosion (Bell+, Zirakashvili+) and the escape of highest energy (>100 TeV) particles from the remnant energy particles

"large $\Gamma$ or small Eo ?" - extension of observations to 10 TeV

## searching for proton PeVatrons through their "echos":

*multi-TeV radiation from dense clouds located outside the accelerator*

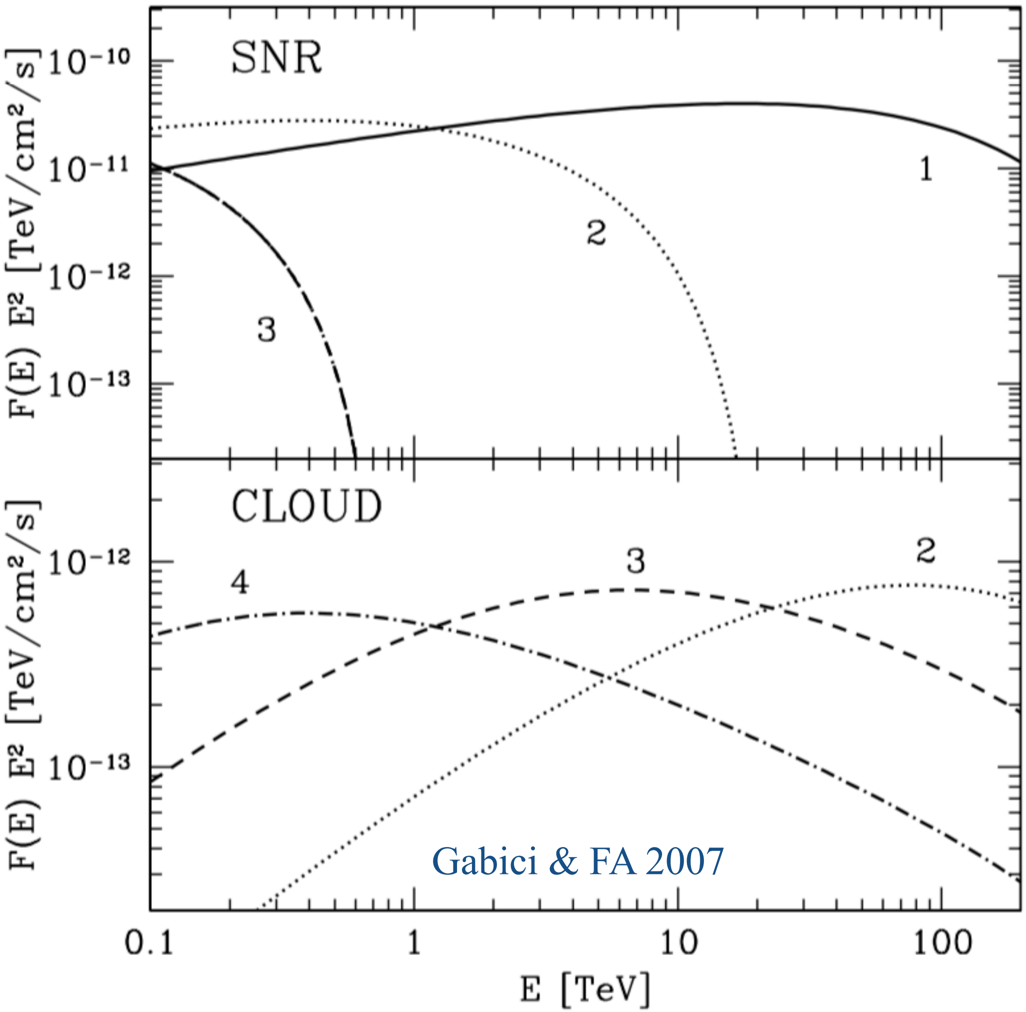
– protons of energy exceeding 100 TeV are accelerated and leave the shell at $T<1000$ yr or, more likely, <100 year, epochs

– $\gamma$-rays extending to energies beyond 10 TeV expected only from very young SNRs - the chance of their detection is small

– if by a chance a massive gas cloud appears in the 100 pc vicinity of the remnant, "delayed" multi-TeV $\gamma$-rays signals arise when run-away partices reach the cloud

– detection of such delayed emission of multi-TeV $\gamma$-rays allows indirect but robust identification of the SNR as a proton PeVatron

# gamma-rays from SNR and nearby molecular cloud




**d=1 kpc**

**SNR:**
$W=10^{51}$ erg
$n= 1$ cm$^{-3}$
$f(p)\sim p^{-4}$
$p_{max}=5$ PeV
$p_{max}\sim t^{-2.4}$

**Cloud:**
$R=100$ pc
$M=10^{4}$Mo
$D(E)=3\times10^{29}(E/1\mathrm{PeV})^{0.5}$ cm$^2$/s

1 - 400 yr; 2 - 2000 yr; 3 - 8000 yr; 4 - 32000 yr after the explosion

# warning: don't be tricked by propagation effects!

## transition from rectilinear to diffusive regime of propagation

$$f(r,\mu) = \frac{Q}{4\pi c}\left(\frac{1}{r^2} + \frac{c}{rD}\right)\frac{1}{2\pi Z}\exp\left(-\frac{3D(1-\mu)}{rc}\right)$$

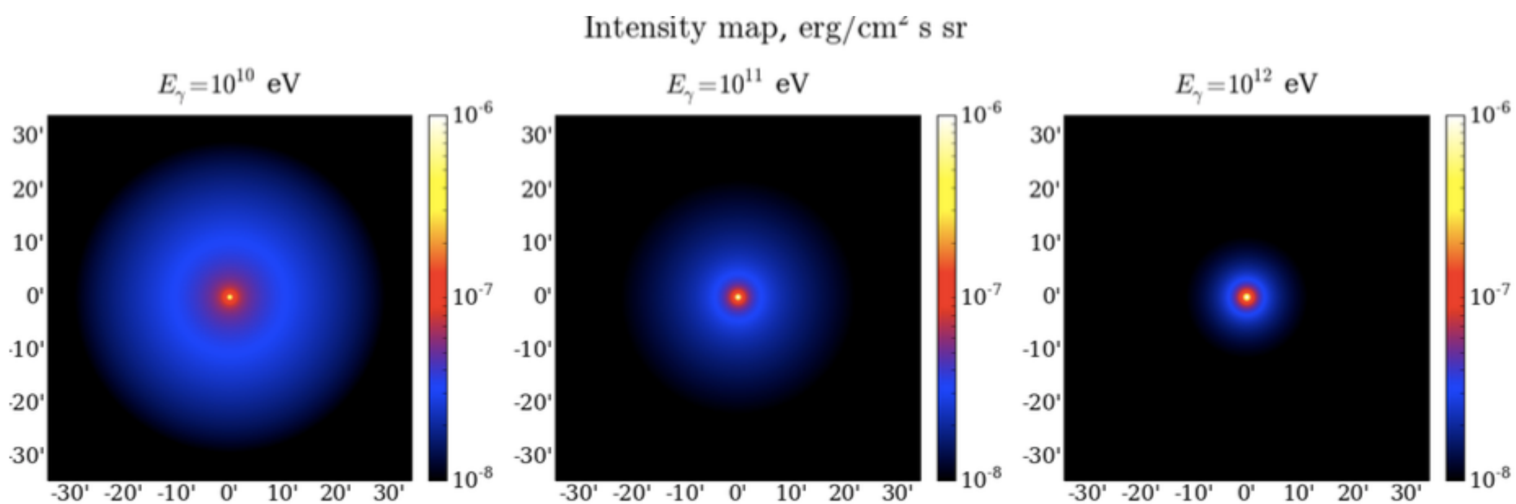
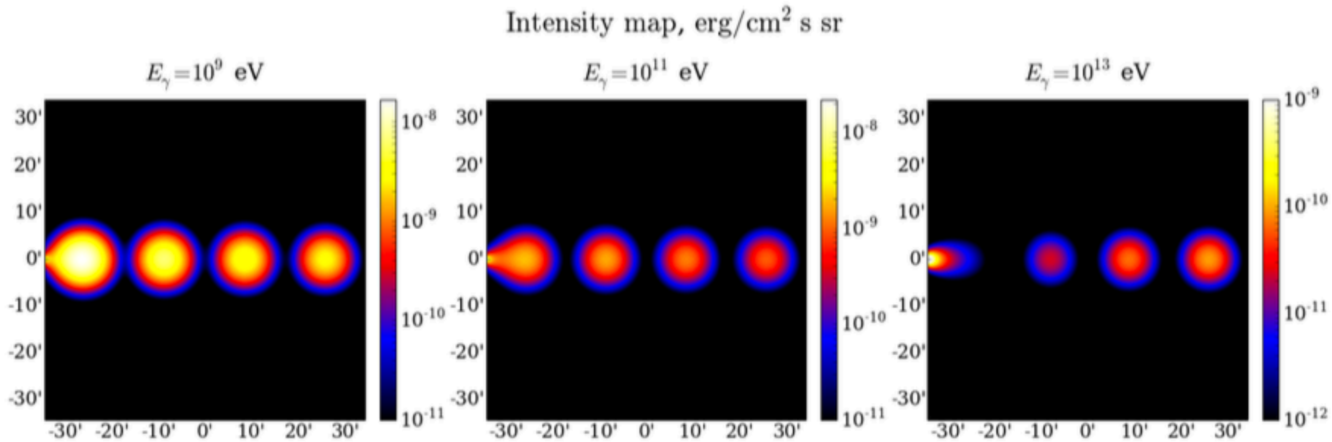



Figure 2: The intensity maps of gamma-ray emission at different energies. The spherical cloud with homogeneous density distribution is irradiated by the cosmic-ray source located in its centre. The gas density inside the accelerator is assumed very low, so the contribution of the accelerator to the gamma-ray emission is negligible. The maps are produced for the case of small diffusion coefficient (for details, see the text). For the distance to the source $d = 1$ kpc, the region of $\sim 1^\circ \times 1^\circ$ corresponds to the area $\sim 20 \times 20$ pc$^2$.

Prosekin, Kelner, FA 2015

warning:

transition from rectilinear to diffusive regime of propagation




d=1 kpc

intensity map of gamma-rays at different energies from a group of clouds located at different distances from the accelerator

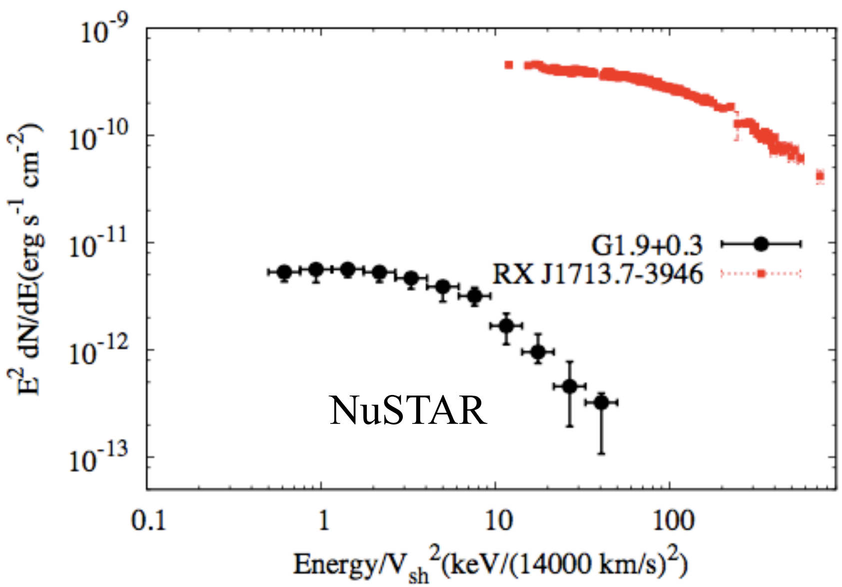
Prosekin, Kelner, FA 2015

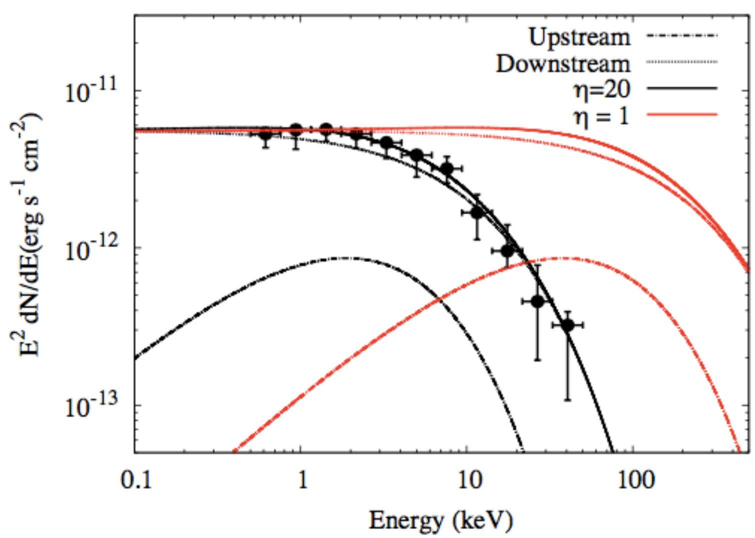
# Very young SNRs as PeVatrons?

G1.9+0.3 - youngest (100yr-old) known SNR in Galaxy with the current shock speed v=14,000 km/s

$$h\nu_{\max} \approx 1(\mathrm{v_{sh}}/3000\ \mathrm{km/s})^2\ \mathrm{keV}$$

in the Bohm diffusion limit the peak should be around 20 keV but is detected at at 1 keV




Presently G1.9+0.3 does not operate as a PeVatron!

PeV protons have been accelerated at earlier epochs, but, because of the particle escape, the remnant is already emptied =>

early acceleration and escape reduce the chances of finding PeVatrons ?

in very young (SN 1987a and G1.9+0.3) SNRs, multi-TeV particles cannot run far away, thus the current upper limits can be applied to the "escape regions"

G1.9+0.3 in GC region:

propagation of **R > 10 TeV** protons cannot exceed 30 pc (for **D ~ $10^{30}$ cm$^2$/s** )

for **d=8.5 kpc** the angular sized less than **10 arcmin**

HESS upper limit on the γ-ray luminosity $L_\gamma(\geq 1\ \mathrm{TeV}) \leq 2 \times 10^{32}$ erg/s

can be applied to the content of >10 TeV protons within R=30 pc region

for n~100 $\mathrm{cm}^{-3}$ $W_p(\geq 10E)=L_\gamma(\geq E)t_\pi$ or **Wp < $10^{45}$ erg**

=> G1.9+0.3 was not an effective PeVatron also in the past !

# Realization of PeVatrons

by SNRs in magnetized bubbles produced by winds of SN progenitors?

one of the key condition for acceleration of protons to PeV energies :
large magnetic field exceeding 100 μG

"preprepared" B-field in cavities produced by winds of O or WR stars?
Voelk&Bierman 1988, Berezhko&Voelk 2000

recently Zirakashvili&Ptuskin 2018 :
*acceleration takes place in a highly magnetised and turbulent environment* with gas density as small as $0.01 cm^{-3}$

$E_{max}$ well beyond 1 PeV in for Ib/c SN in WR wind cavity
$E_{max}$ slightly below 1 PeV in Type IIP SN in O star wind cavity

Several Galactic SNRs/PeVatrons of age ~1,000 yr

low γ-ray flux: $F_E \sim 10^{-13}$ $(n/0.01\ cm^{-3})$ $(W_p/10^{50}\ erg)$ $(d/10\ kpc)^{-2}$ $erg/cm^2$

# alternative CR factories?

- ✓ collective stellar winds and SNR shocks in clusters and of massive stars, superbubbles speeds off stellar winds - several 1000 km/s - comparable to young SNR shock speeds $10^{41}$ erg/s (comparable or a factor of 2 less than mechanical power of SN) acceleration efficiency should be at least 10 % - much less is needed for the knee region

- ✓ Galactic Center - significant contribution could come only from the Supermassive Black Hole (Sgr A*) . $5 \times 10^6$ solar masses can formally provide a power as large as $10^{43}$ erg/s (assuming 10 % acceleration efficiency). But presently the accretion rate does not exceed $10^{39}$ erg/s (bolometric luminosity of Sgr A* is less than $10^{36}$ erg/s)

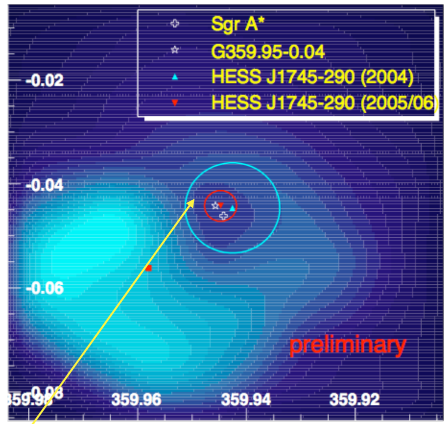
- ✓ pulsars/pulsar wind nebulae? prolific accelerators of electrons and positrons; potential, but, most likely, not the major contributors to CR electrons

one cannot exclude that the observed (local) CR flux up to $10^{15}$eV is contributed essentially by a single (or a few) local sources. This is the case of TeV electrons

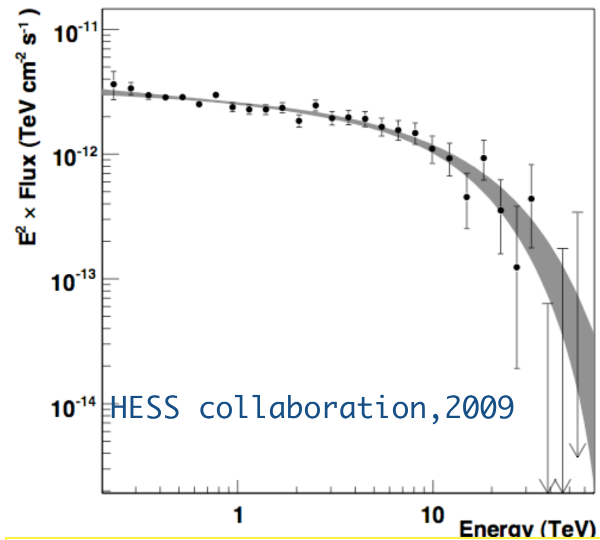
# PeVatron(s) in the Galactic Center!

# TeV gamma-rays from GC

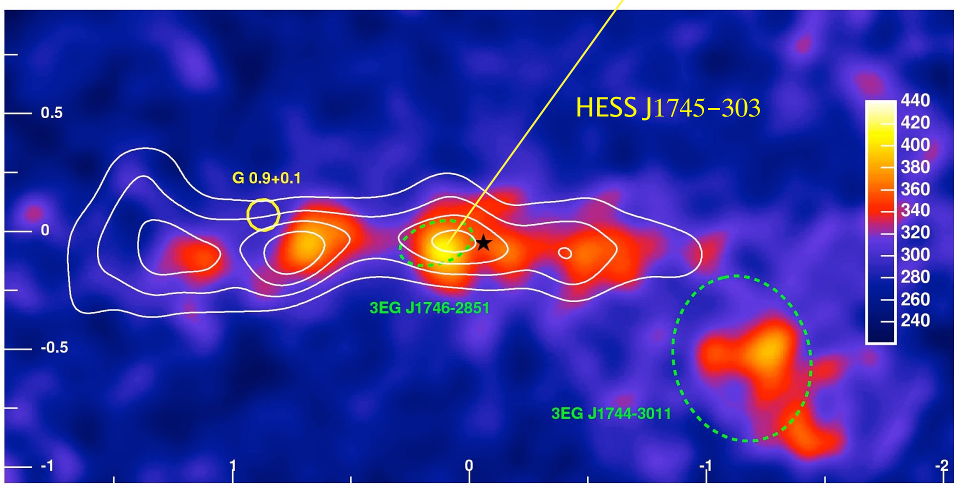
90 cm VLA radio image




Sgr A* or the central diffuse < 10pc region or a plerion?




γ-ray emitting clouds




HESS collaboration,2006

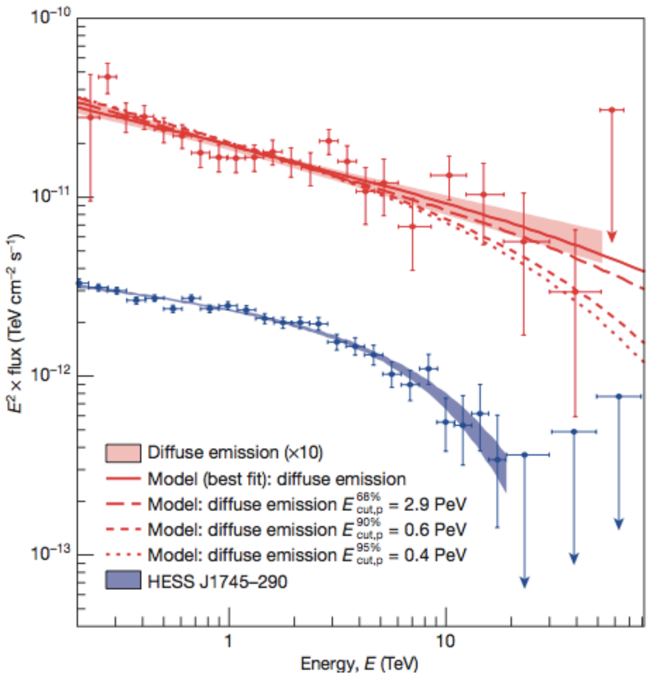
Energy spectrum:

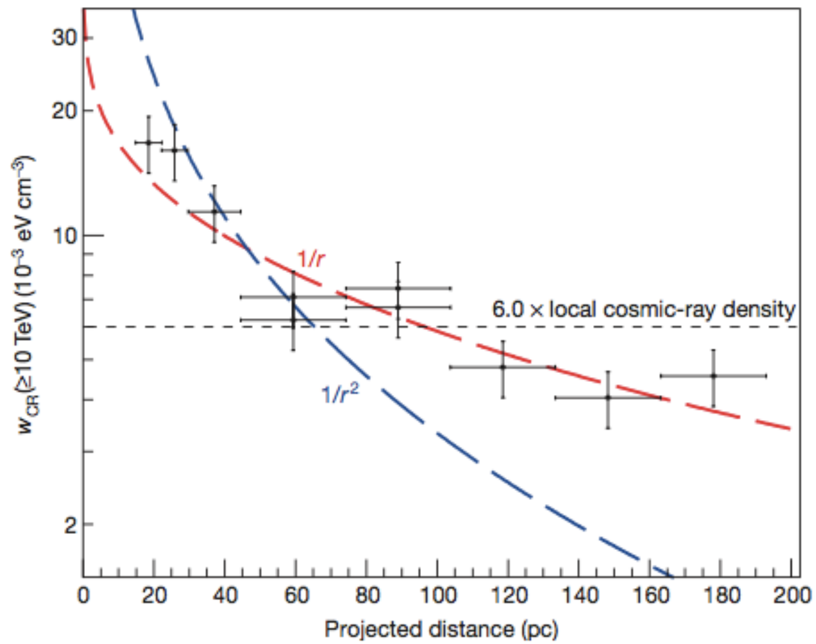
$dN/dE = AE^{-\Gamma} \exp[(-E/E_0)^{\beta}]$

$\beta=1$ $\Gamma=2.1$; $E_0=15.7$ TeV

$\beta=1/2$ $\Gamma=1.9$ E0=4.0 TeV

# PeVatron located within R<10 pc and operating continuously over > $10^3$ yr




*no-cutoff* in the gamma-ray spectrum up to **25 TeV**
=> *no-cutoff* in the proton spectrum up to ~ **1 PeV**

*what do we expect?*

1/r continuous source
1/r$^2$ wind or ballistic motion
constant burst like source

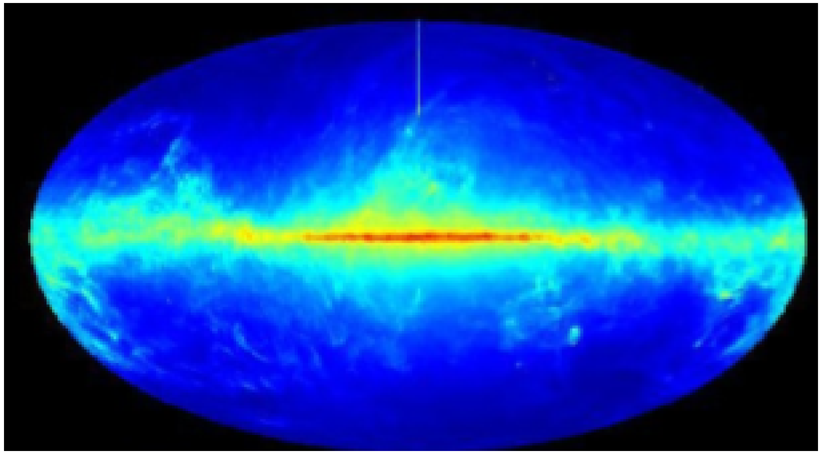
*derived*: **1/r** distribution
**=> continuous acceleration !**

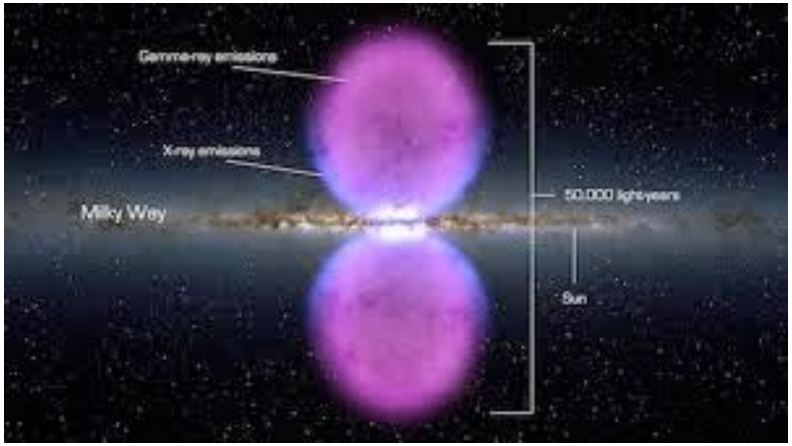
## implications?

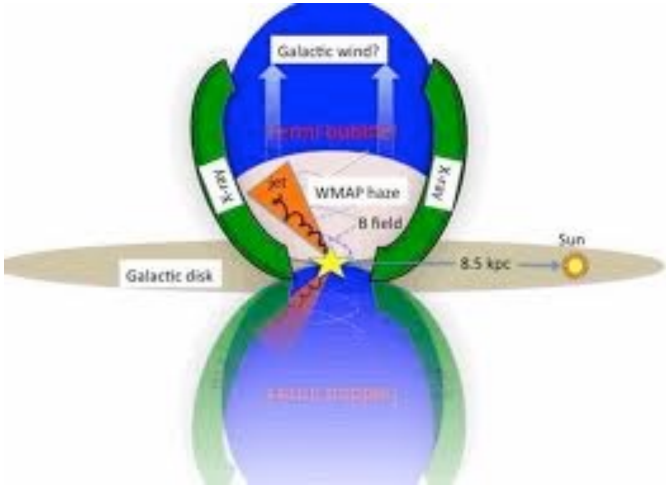
- Galactic Center (GC) harbors a hadronic PeVatron within a few pc region around Sgr A* (a SMBH in GC)
- 1/r type distribution of the CR density implies (quasi)continuous regime of operation of the accelerator with a power $10^{38}$ erg/s (on timescales 1 to 10 kyr) - a non negligible fraction of the current accretion power
- this accelerator alone can account for most of the flux of Galactic CRs around the “knee” if its power over the last $10^{6}$ years or so, has been maintained at average level of $10^{39}$ erg/s
- escape of particles into the Galactic halo and their subsequent interactions with the surrounding gas, can be responsible for the sub-PeV neutrinos recently reported by the IceCube collaboration

SMBH or young massive-star clusters?

# CRs from GC responsible for Fermi Bubbles?






and "IceCube Neutrinos" from a larger >>10 kpc halo ?

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)

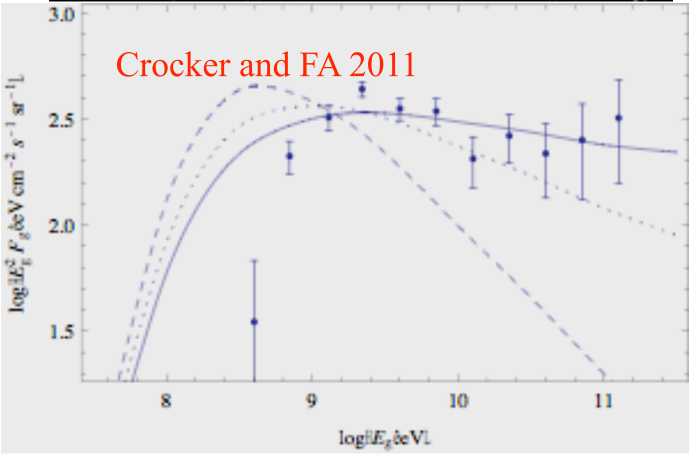
*Size - because of slow diffusion in turbulent environment (10 times slower than in the Galactic Disk)*

plasma density: $n \sim 0.01\ \mathrm{cm}^{-3}$ 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 : $L_p \sim 10^{39-40}$ erg/s




Fermi Bubbles
as a VHE neutrino source?

Clusters of Young Massive Stars
as major sources of CRs?

# Extended Regions surrounding Clusters of Young Massive Stars sources of GeV and TeV gamma-rays

*Westerlund 1*, *Westerlund 2*, *30 Dor C* (in LMC)

*CygnusOB2*, *Westerlund 2*, *NGC3603*

*Arches*, *Quintuplet* and *Nuclear* ultracompact clusters in GC

- collective power in stellar wind $10^{38}$ - $10^{39}$ erg/s
- typical speeds of stellar winds several 1000 km/s

continuous injections of CRs into ISM over (2-5) x $10^6$ yrs formation of ~ 1/r radial distribution of CRs up to 200 pc; diffuse (typically irregular) gamma-ray morphology

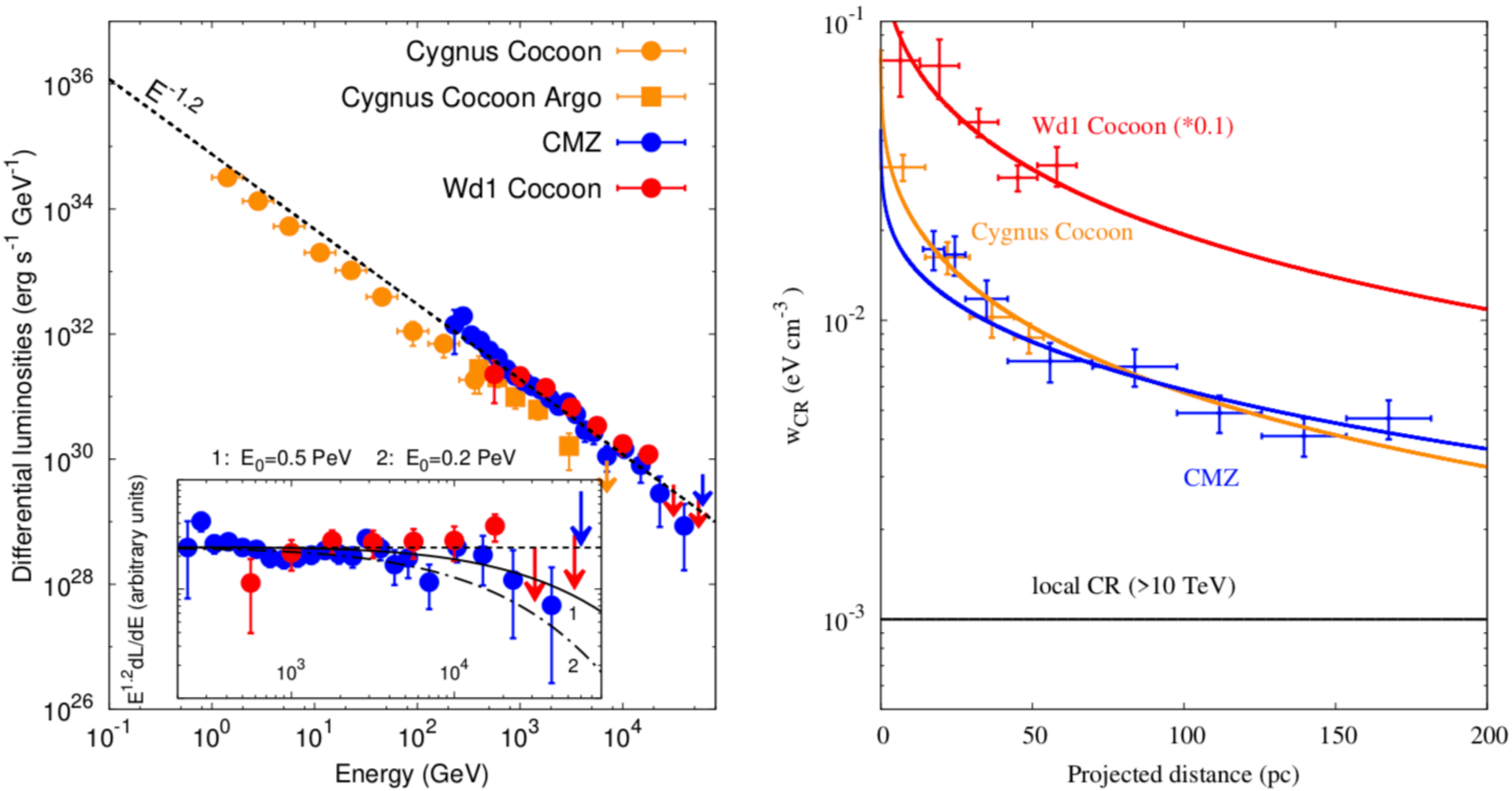



Figure 1: Gamma-ray luminosities and CR proton radial distributions in extended regions around the star clusters Cyg OB2 (Cygnus Cocoon) and Westerlund 1 (Wd 1 Cocoon), as well as in the Central Molecular Zone (CMZ) of the Galactic Centre assuming that CMZ is powered by CRs accelerated in *Arches*, *Quintuplet* and *Nuclear* clusters.

FA, Yang, Ona de Wilhelmi, 2018

Total energy in CRs within the size of radius Ro

$$W_{\rm p} = 4\pi \int_0^{R_0} w(r) r^2 \, {\rm d}r \approx 2.7 \times 10^{47} (w_0/1 \ {\rm eV/cm^3})({\rm R_0}/10 \ {\rm pc})^2 \ {\rm erg}$$

Size of emission region - depends on D and To

$$R_{\rm D} = 2\sqrt{T_0 D(E)} \approx 3.6 \times 10^3 (D_{30} T_6)^{1/2} \ \ {\rm pc}$$

Efficiency of conversion of the wind kinetic energy to CRs

$$f(\geq 10 \ {\rm TeV}) \approx 1 w_0 D_{30} L_{39}^{-1}$$

for $E^{-2.3}$ proton spectrum, f(>10TeV) does not significantly exceed 1%
the diffusion coefficient $D_{30}$ cannot be larger than 0.01; $R_D \sim 300$ pc

γ-rays from individual clouds - unique information about D(E)

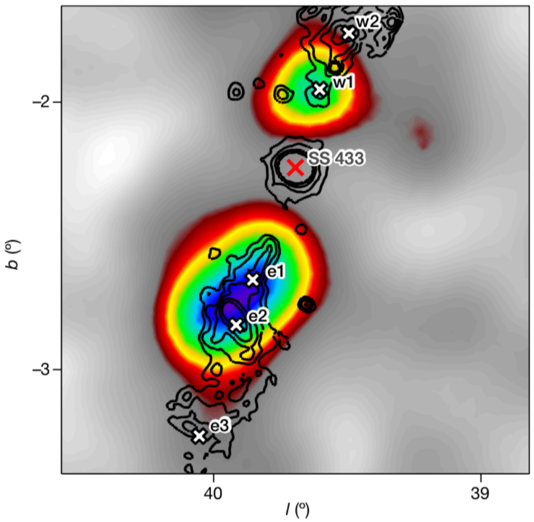
effective acceleration of particles by fast stellar winds was predicted by Cesarsky and Montmerle as early as 1983; for recent developments regarding particle acceleration in SCs - see A. Bykov and collaborators

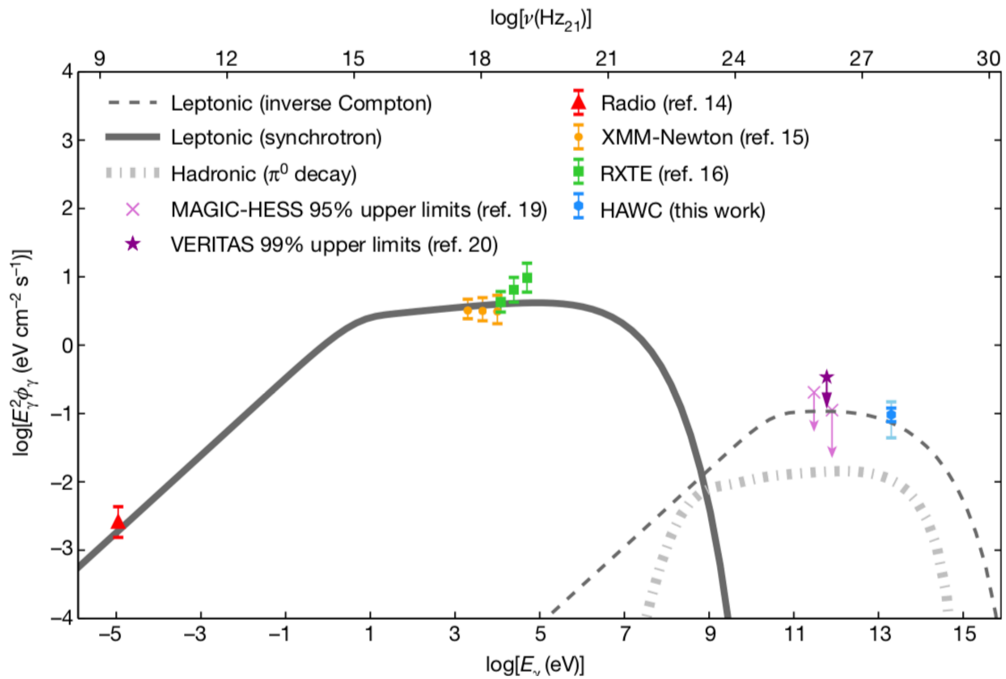
# Other PeVatron candidates

# detection of >10 TeV hard spectrum gamma-rays from SS 433

HAWC - HESS/MAGIC upper limits

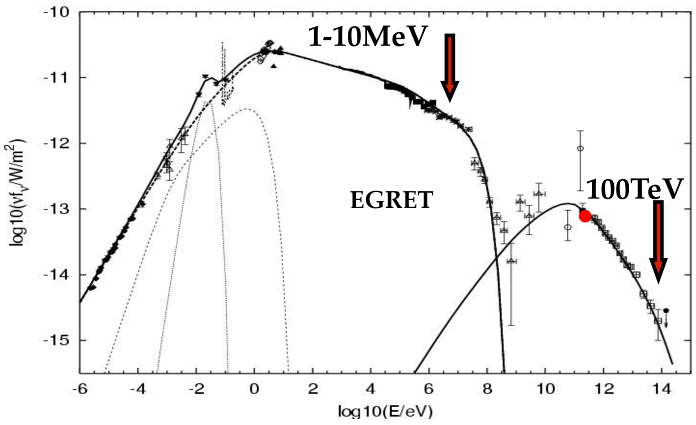
spectrum as flat as $E^{-2}$ extending 20 TeV




- $E^{-2}$ electron spectrum with Eo=2 PeV
- gas density - not sufficient?

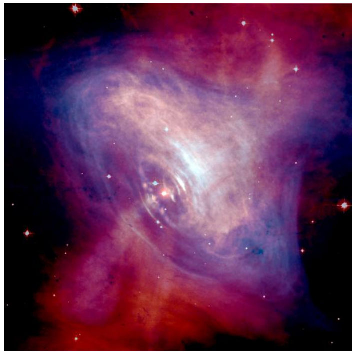
# Crab Nebula – *a perfect electron PeVatron*




**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 $L_e=1/5L_{rot} \sim 10^{38}$ 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 => $\eta \sim 1$ ?

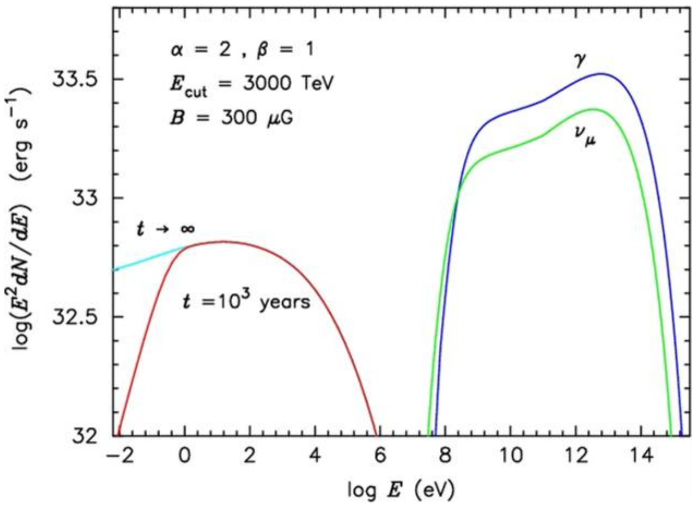
## Detecting Pevatrons at other wavelengths?

*a Galactic PeVatron:* E~$10^{15}$eV

*three channels of information about cosmic PeVatrons:*

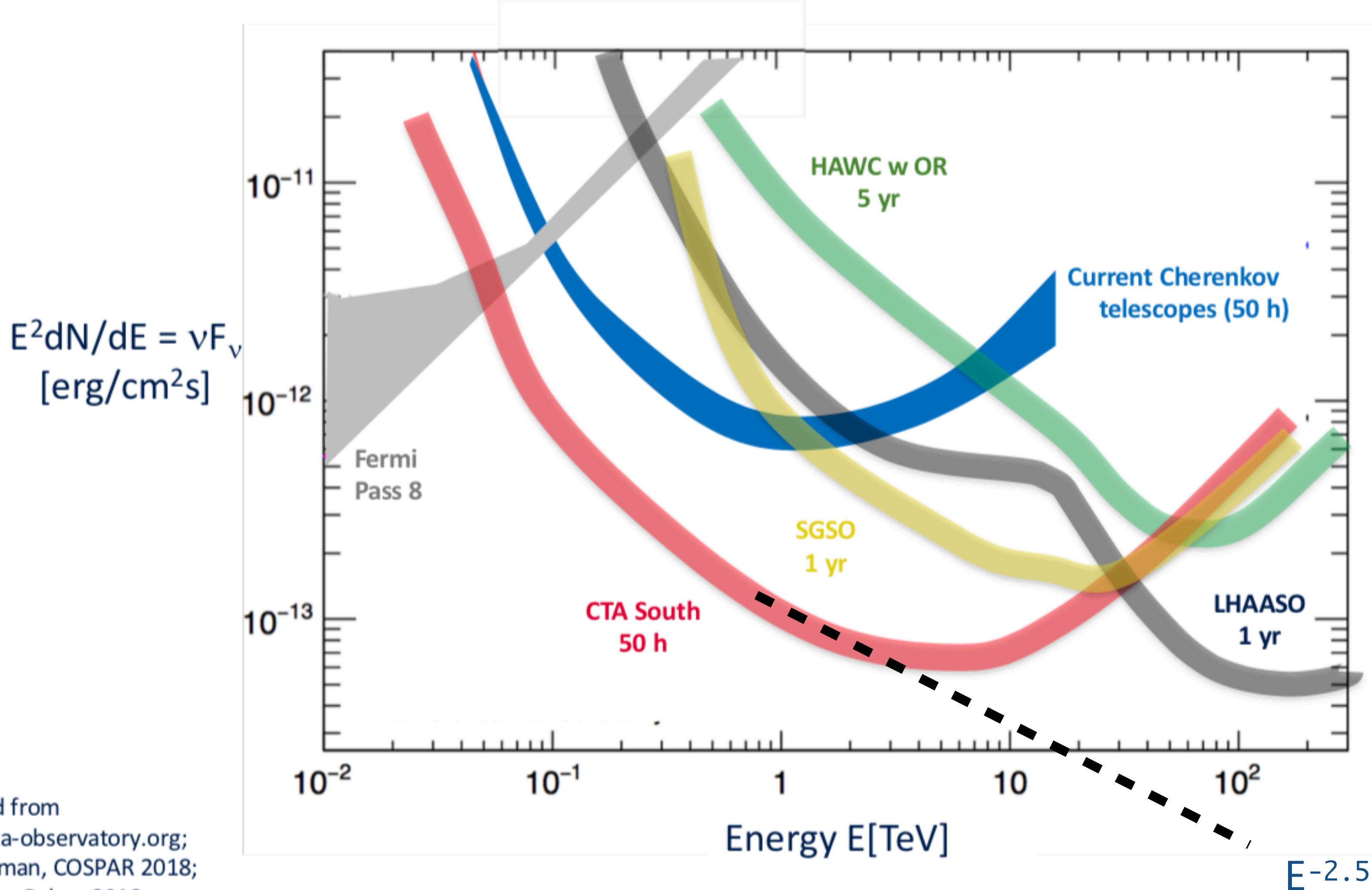
10-1000 TeV gamma-rays
10-1000 TeV neutrinos

10 -100 keV hard X-rays



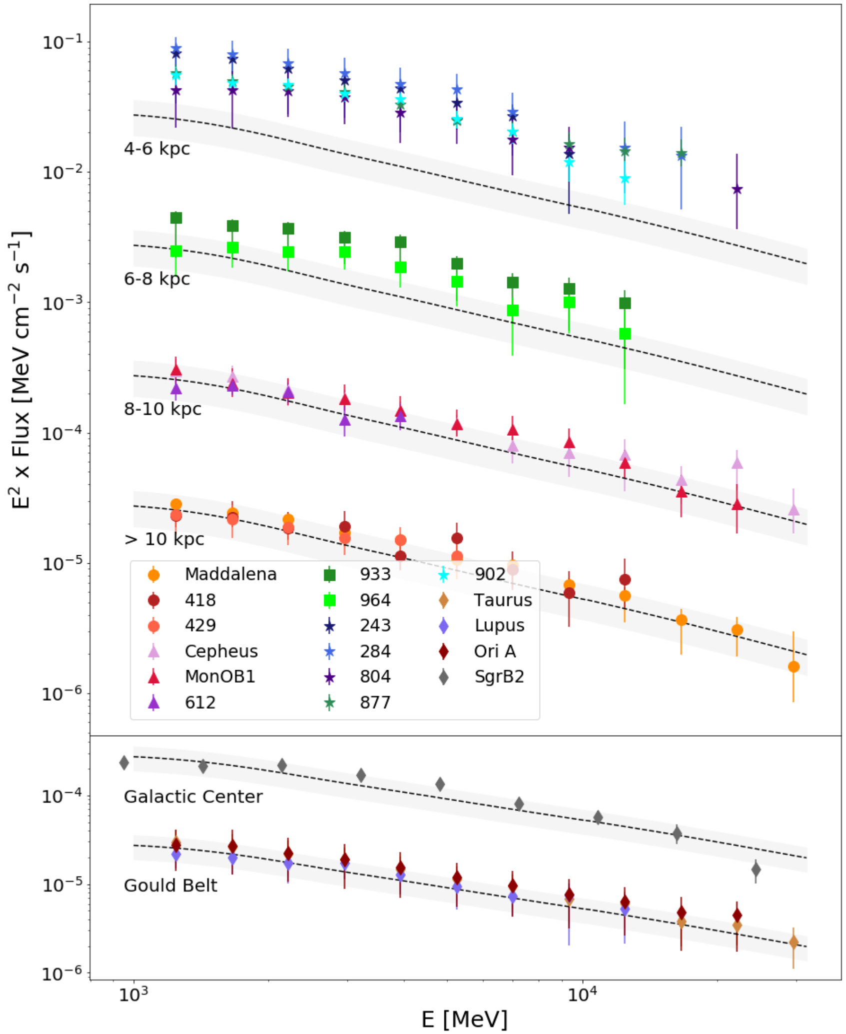

- γ-rays: difficult, but possible with future "10km$^2$" area multi-TeV IACT arrays
- neutrinos: marginally detectable by IceCube, Km3NeT - don't expect spectrometry, morphology; uniqueness - unambiguous signatute!
- "prompt" synchrotron X-rays: smooth spectrum a very promising channel - quality!

$\sim \varepsilon^{-(\alpha/2+1)} \exp[-(\varepsilon/\varepsilon_0)^{1/5}]$



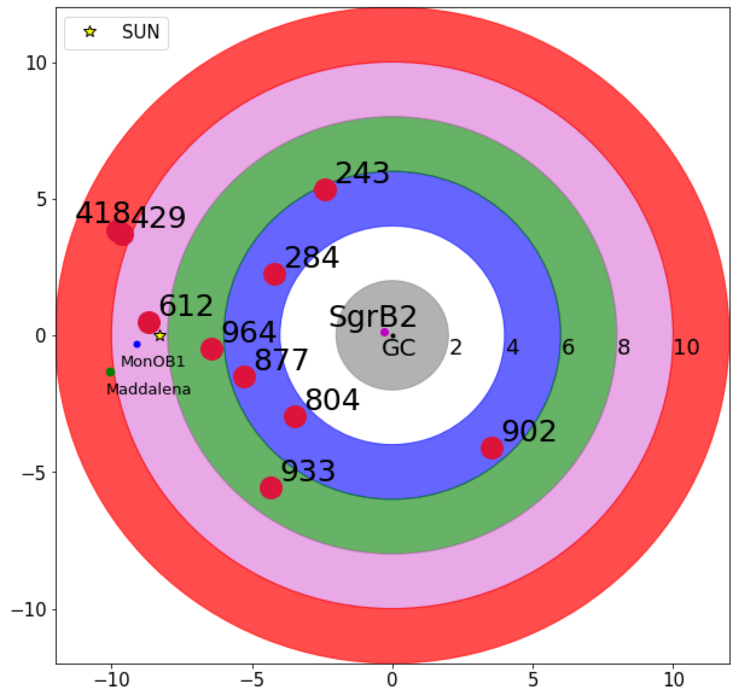

adapted from
www.cta-observatory.org;
J. Goodman, COSPAR 2018;
Z. Cao, La Palma 2018

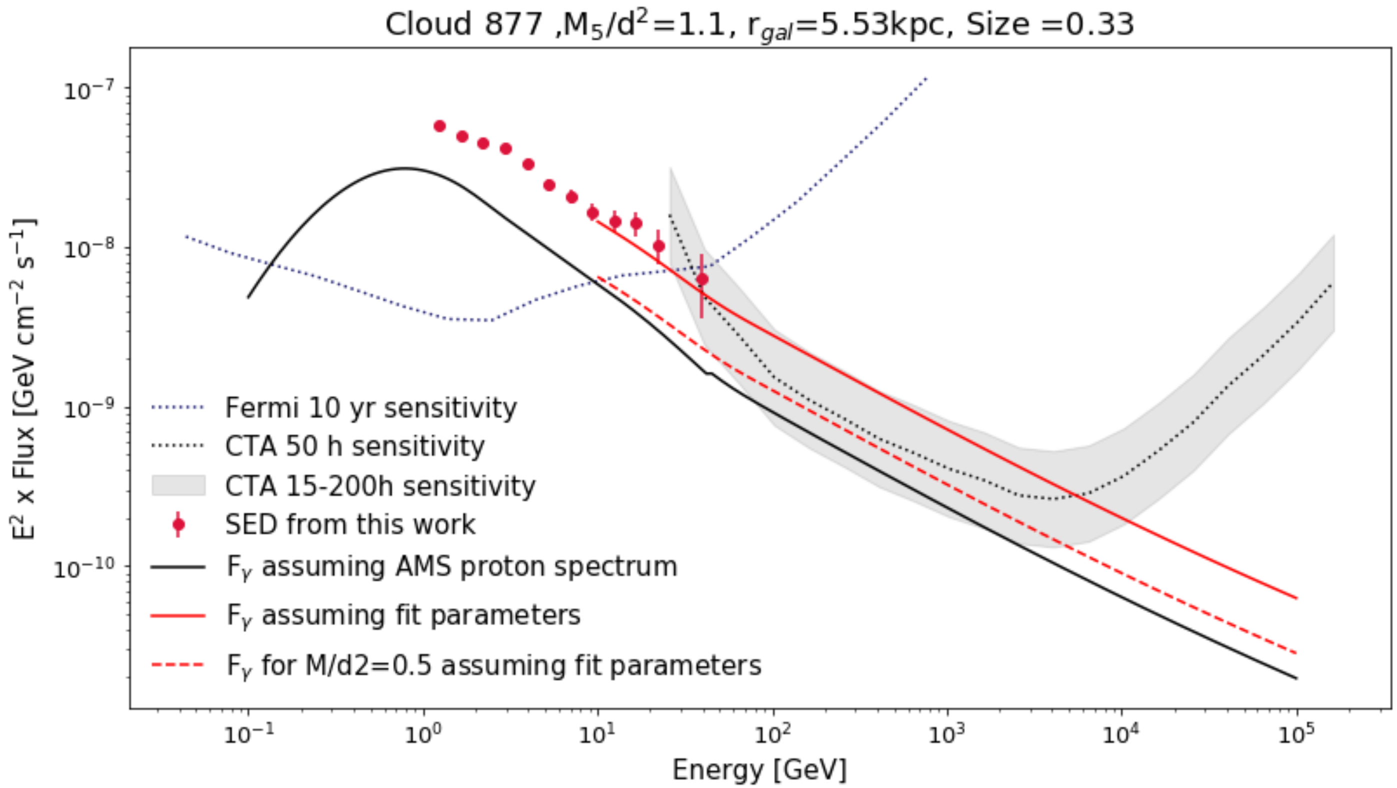
The CR sea is resolved; everywhere is the same and coincides with the AMS 02 spectrum except perhaps the 4-6 ring (?)




clouds detectable by Fermi

$$\frac{M_5}{d^2} > 0.4; \quad M_5 = M/10^5 M_\odot; \; d_{kpc} = d/1\mathrm{kpc}$$



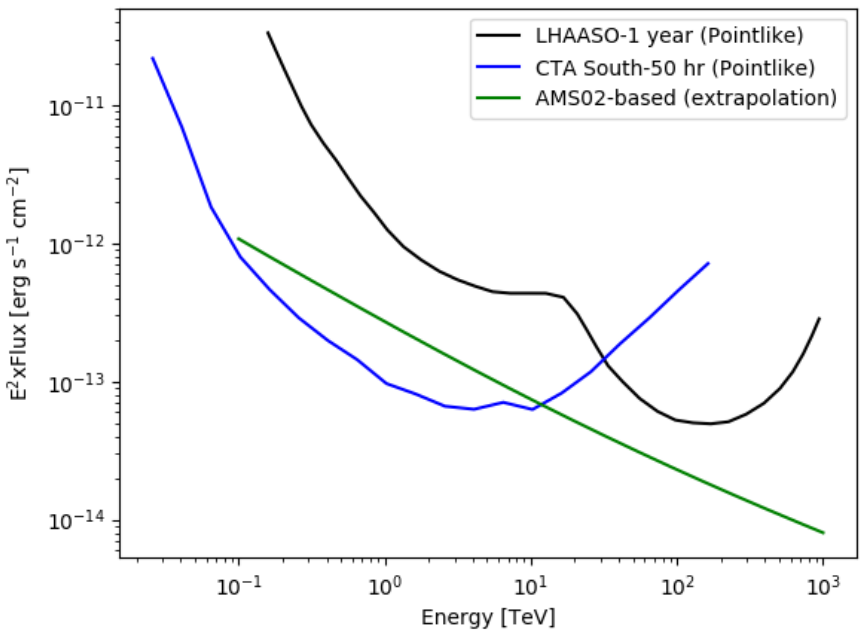


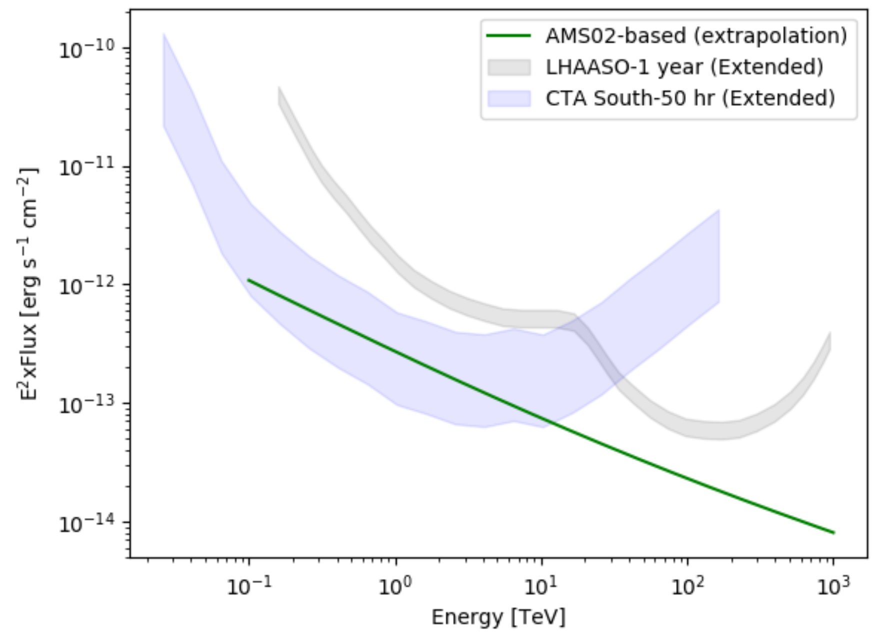

# future ?

would be great to have a gamma-ray space telescope:
more sensitive than Fermi LAT by an order of magnitude:

measurements of CR pressure in hundreds locations of the Galactic Disk - a real barometer

CTA - can marginally detect the CR sea at TeV energies !


LHAASO-1 year (Pointlike)
CTA South-50 hr (Pointlike)
AMS02-based (extrapolation)
E$^2$xFlux [erg s$^{-1}$ cm$^{-2}$]
Energy [TeV]


AMS02-based (extrapolation)
LHAASO-1 year (Extended)
CTA South-50 hr (Extended)
E$^2$xFlux [erg s$^{-1}$ cm$^{-2}$]
Energy [TeV]

# Summary:

Recent CR and γ-ray measurements

=> GCRs consists of (at least) two major components

- First component dominates until 1 TeV or so SNRs (!?)
- Second component has harder spectrum and dominates above 1 TeV - production rate ~$10^{39}$ erg/s. 'Proton PeVatrons' ?

sources? Central BH - Sgr A* or young stellar clusters?

prospects for "Pevatron studies"

CTA , multi-km-cube scale neutrino detectors, hard X-ray imagers,

and especially LHAASO