

Galactic Cosmic Rays from Supernova Remnants?

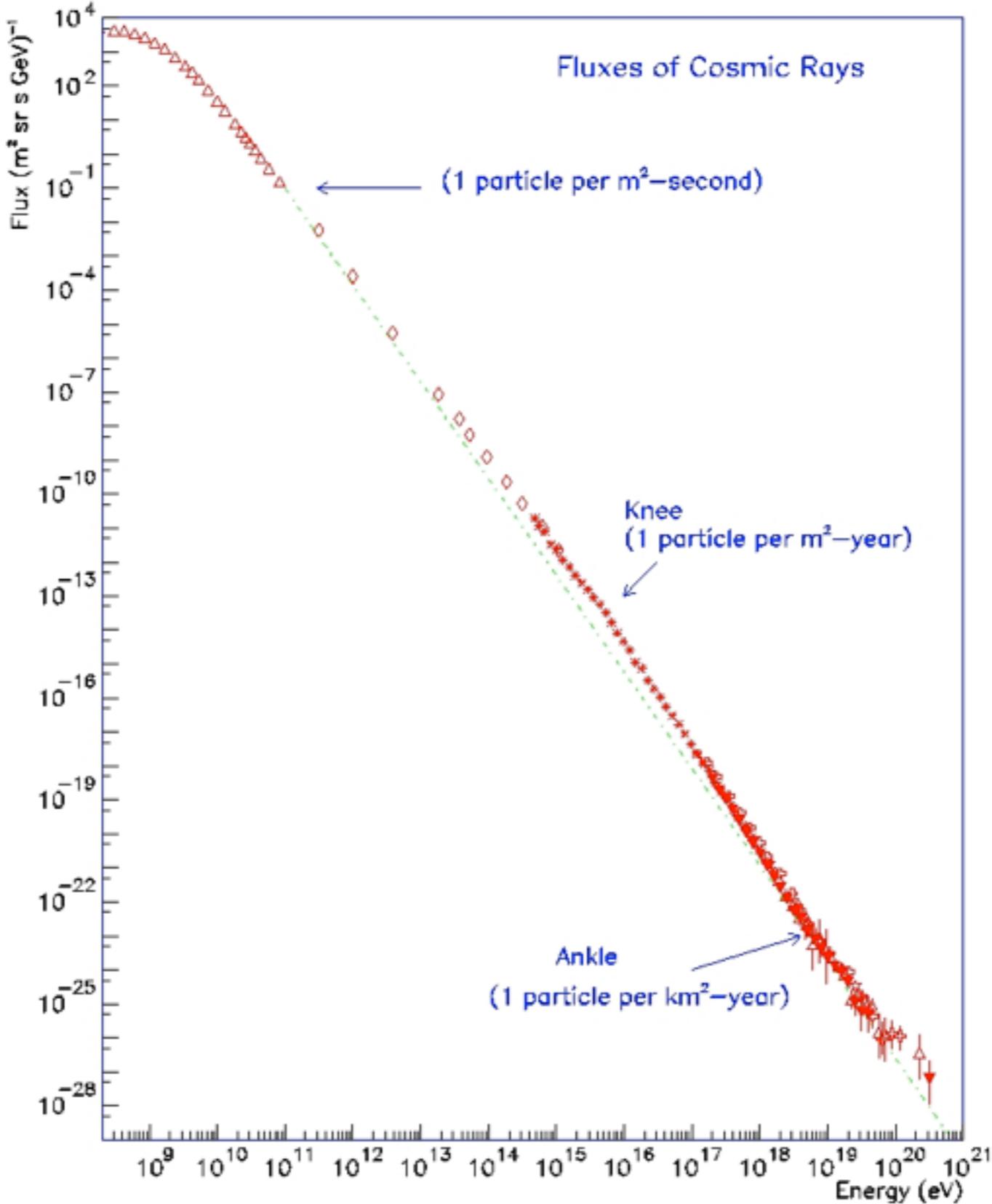


Stefano Gabici
APC, Paris

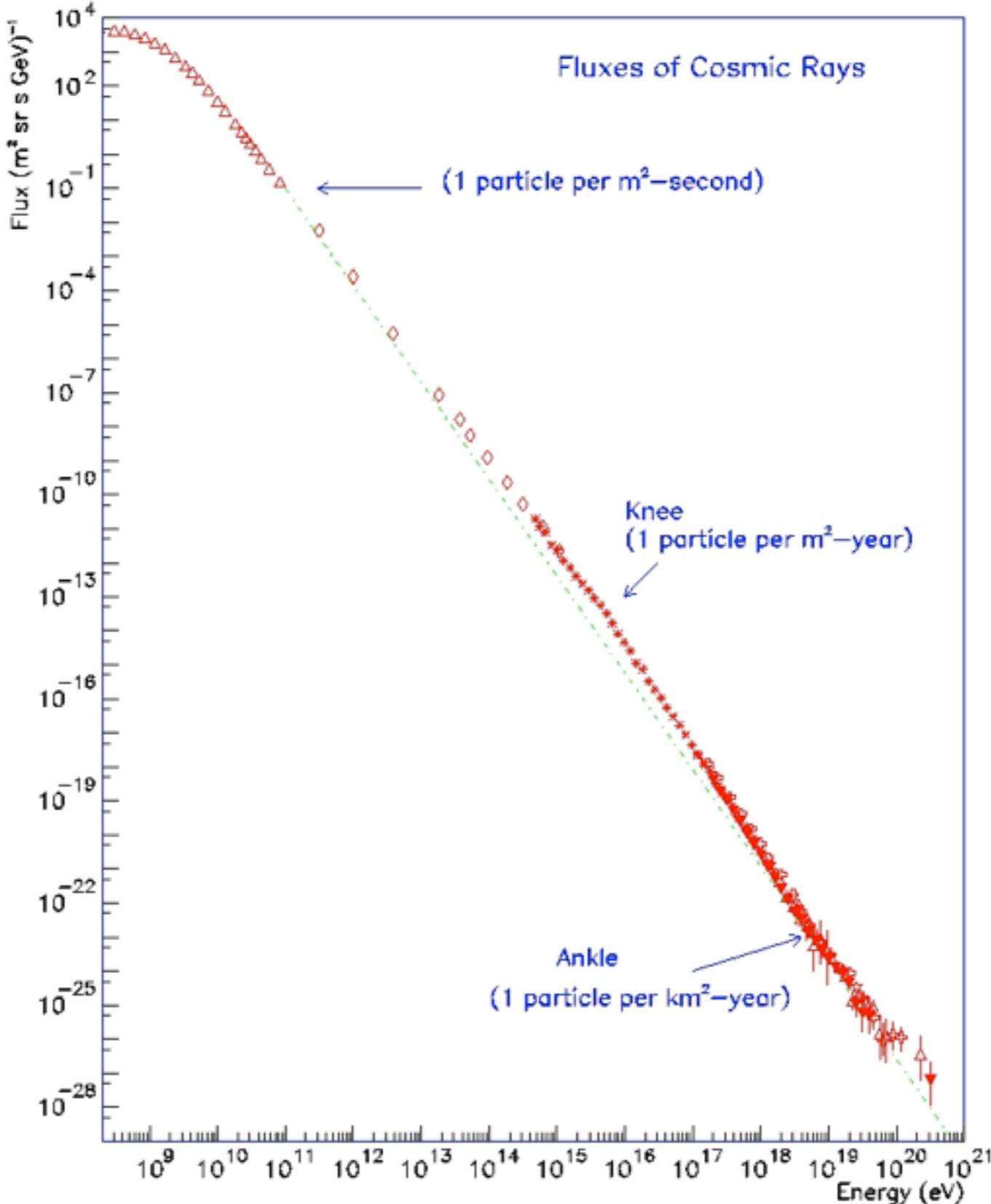


www.cnrs.fr

The Cosmic Ray spectrum



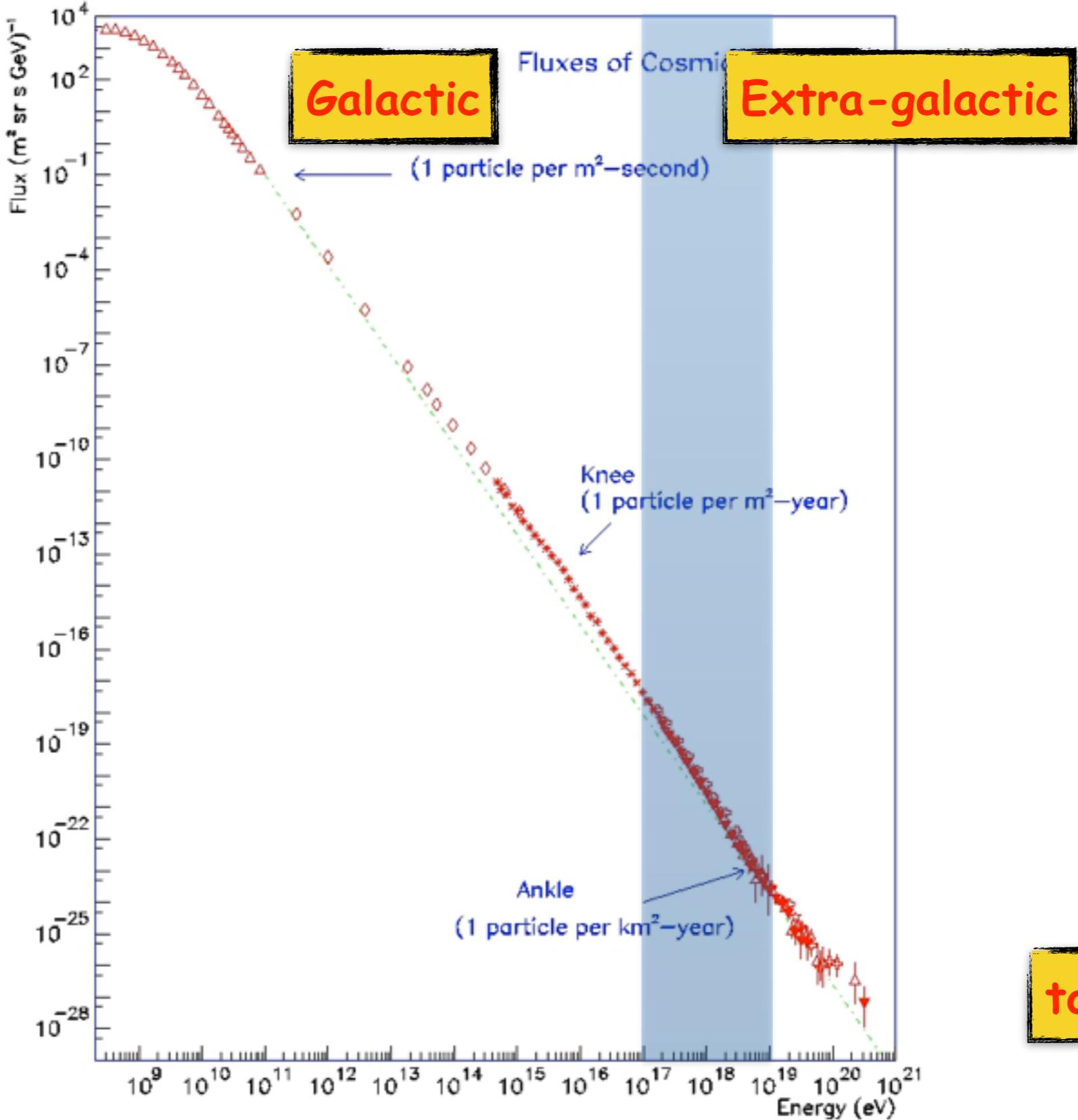
The Cosmic Ray spectrum



from sub-GeV

to ~EeV

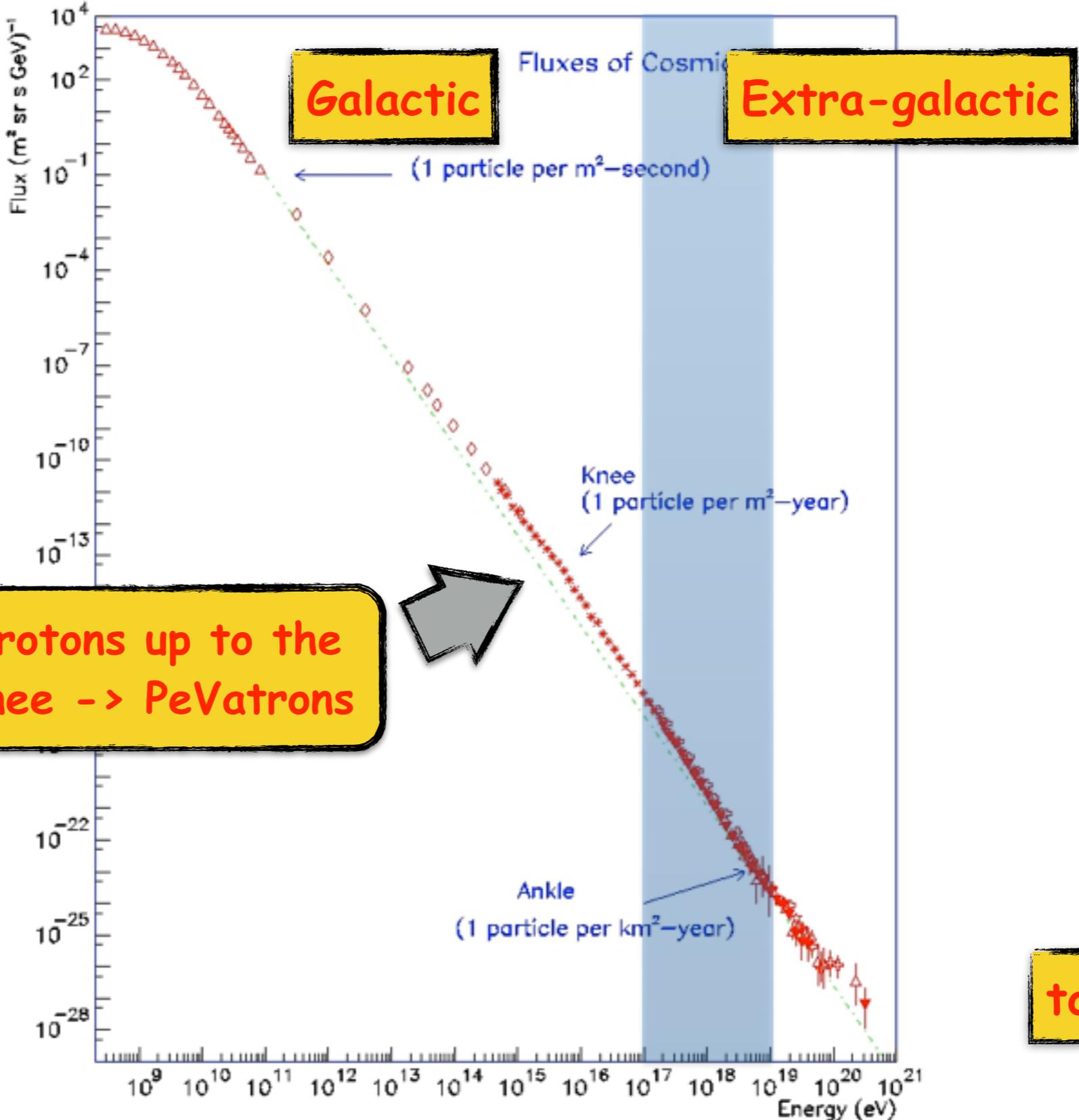
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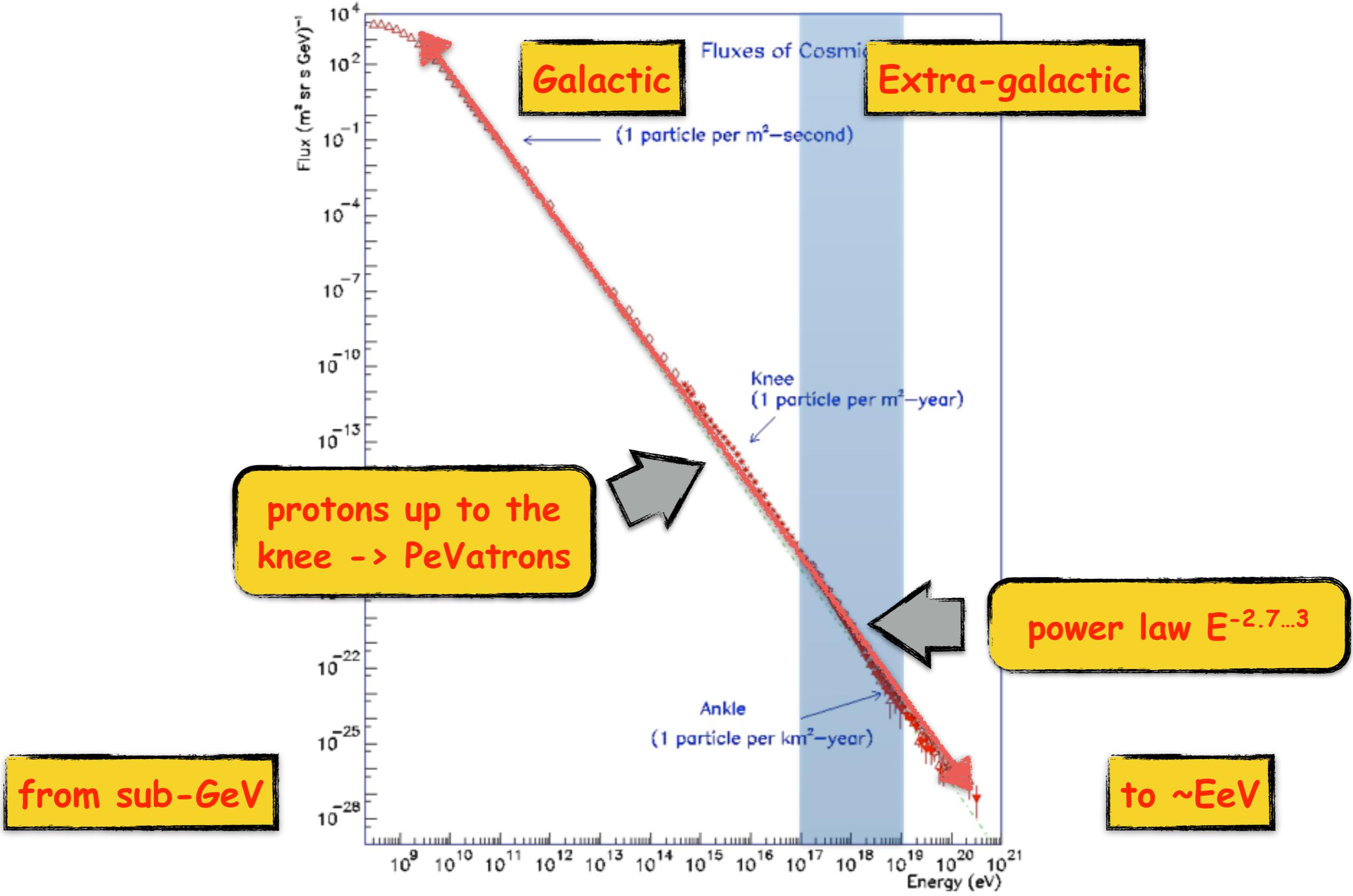


protons up to the knee -> PeVatrons

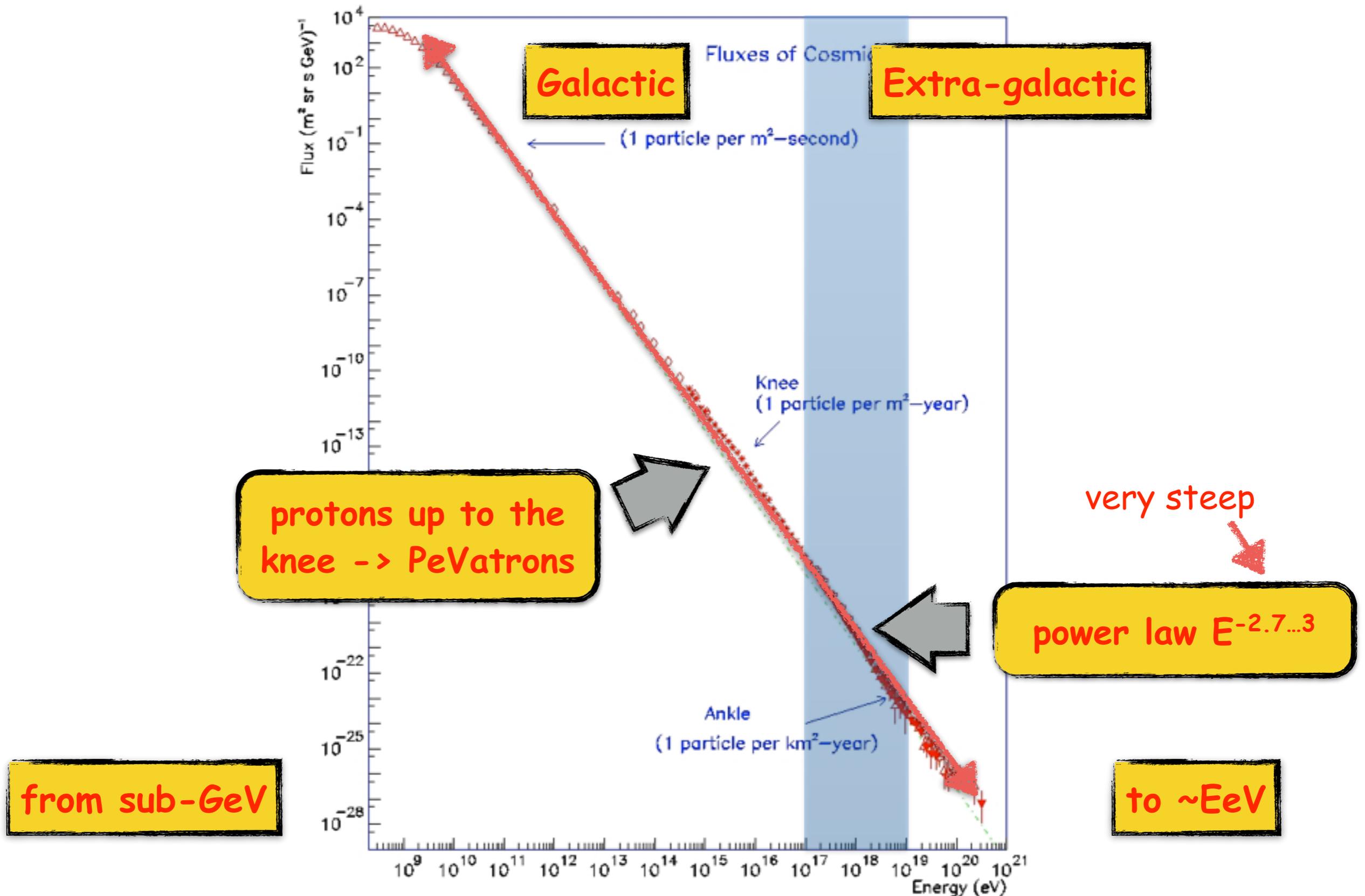
from sub-GeV

to $\sim \text{EeV}$

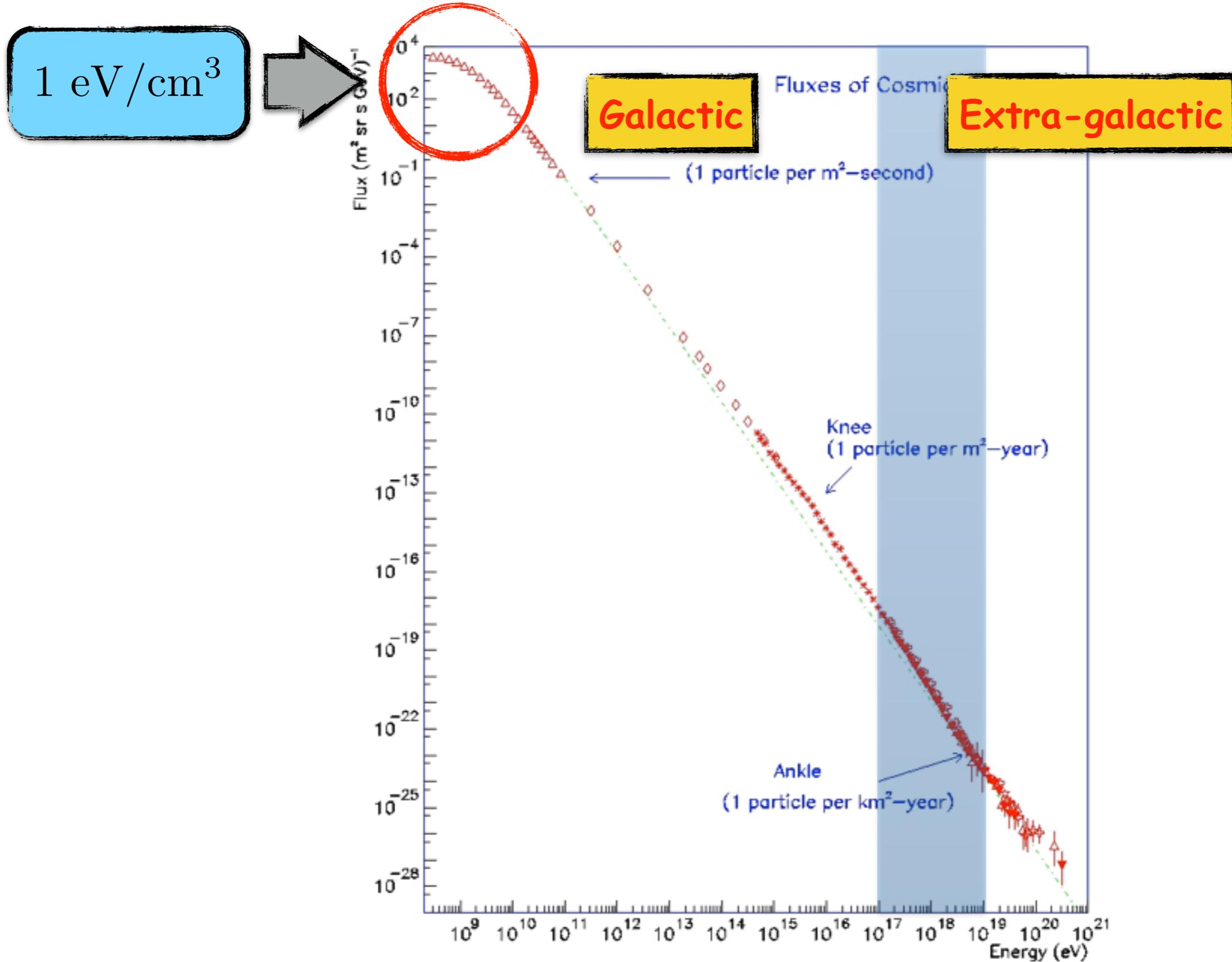
The Cosmic Ray spectrum



The Cosmic Ray spectrum

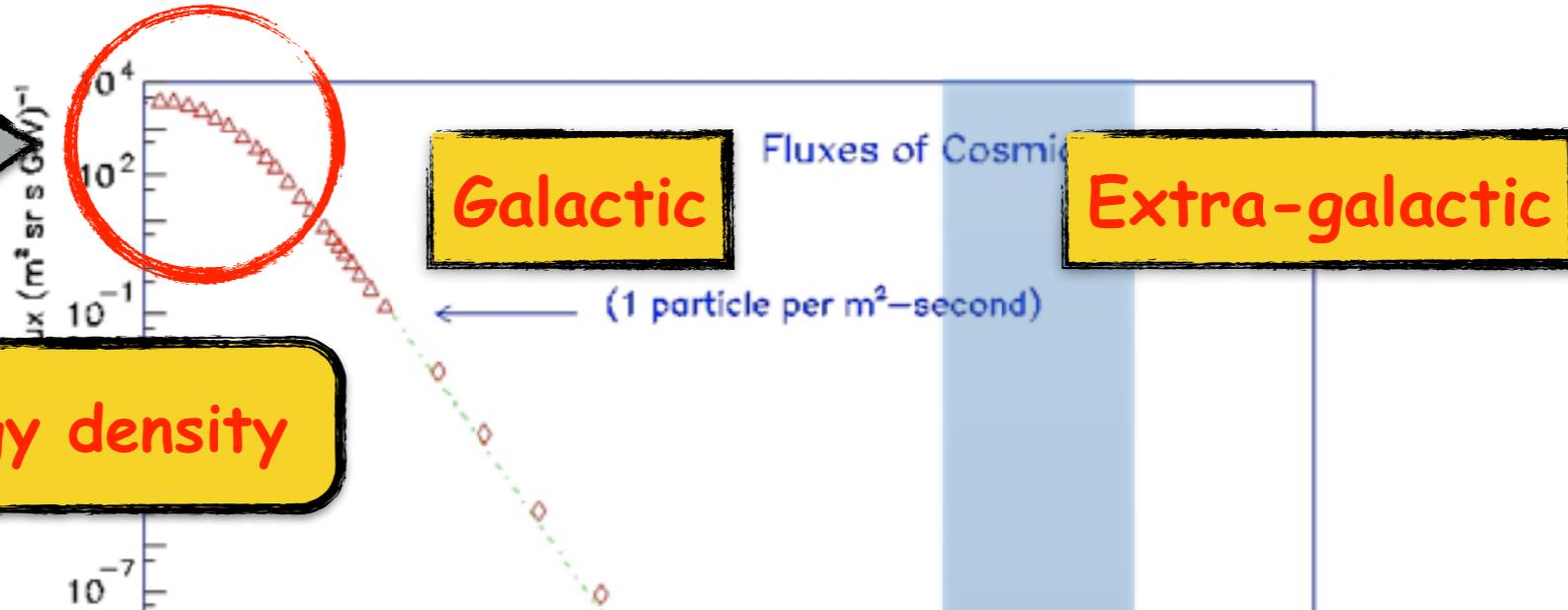


The origin of CRs: energy requirements



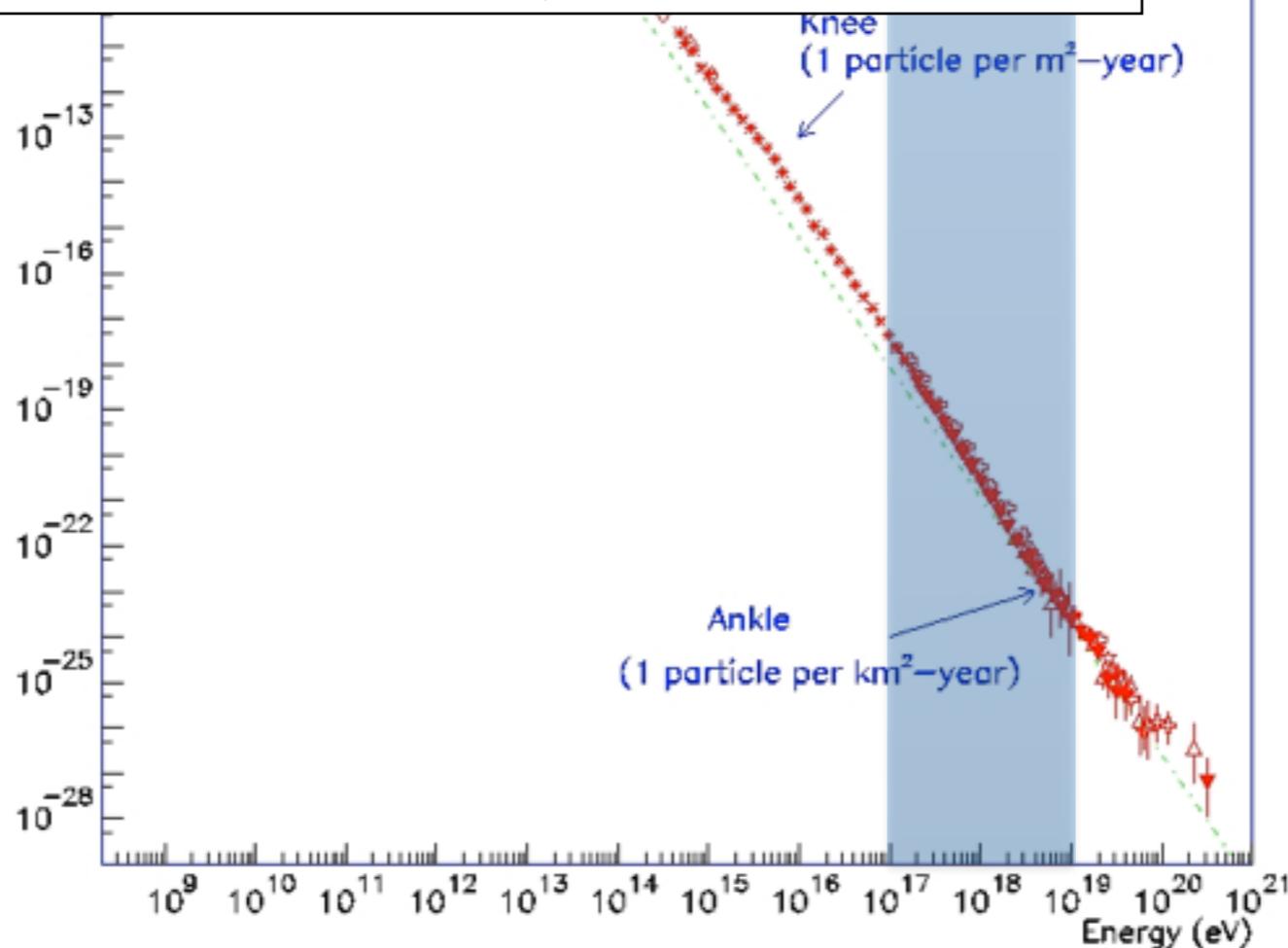
The origin of CRs: energy requirements

1 eV/cm³



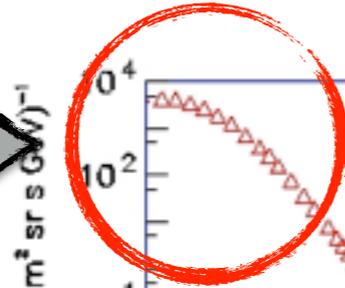
Quite large energy density

Energy equipartition -> cosmic rays = B-field = gas



The origin of Cosmic Rays: sources

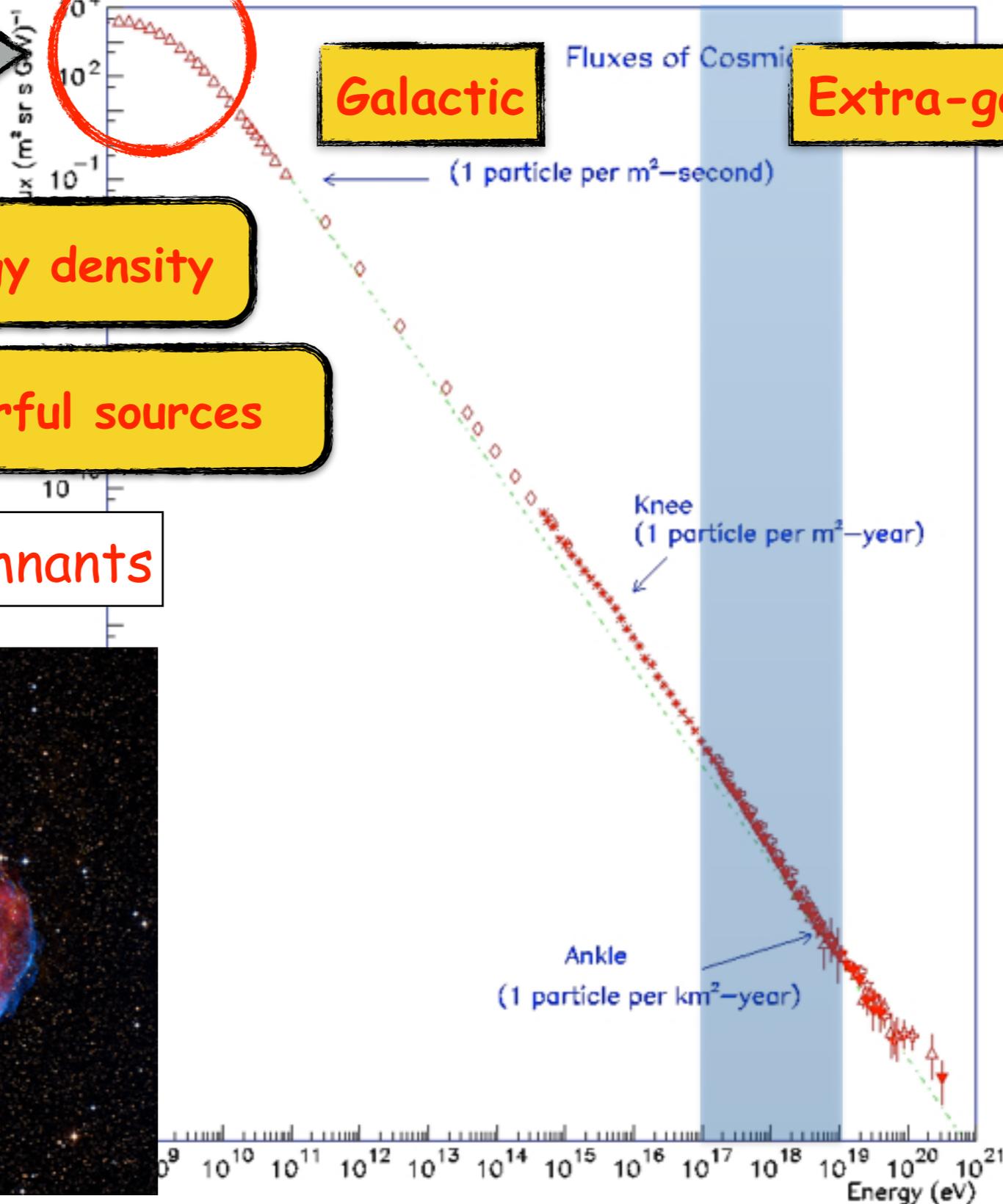
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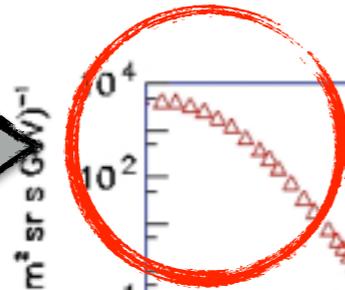
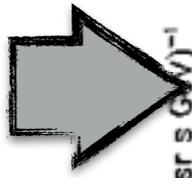
Powerful sources

SuperNova Remnants



The origin of Cosmic Rays: sources

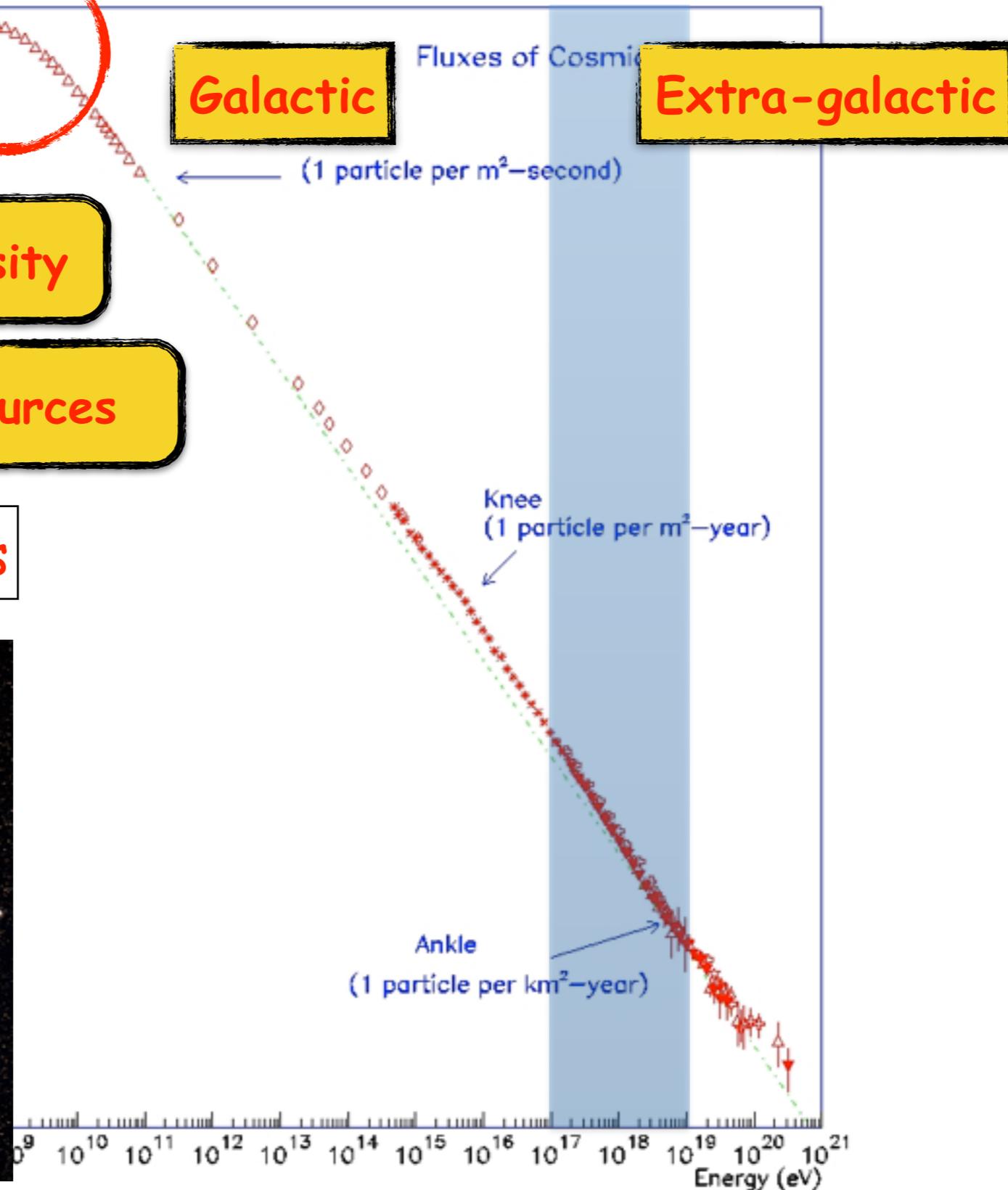
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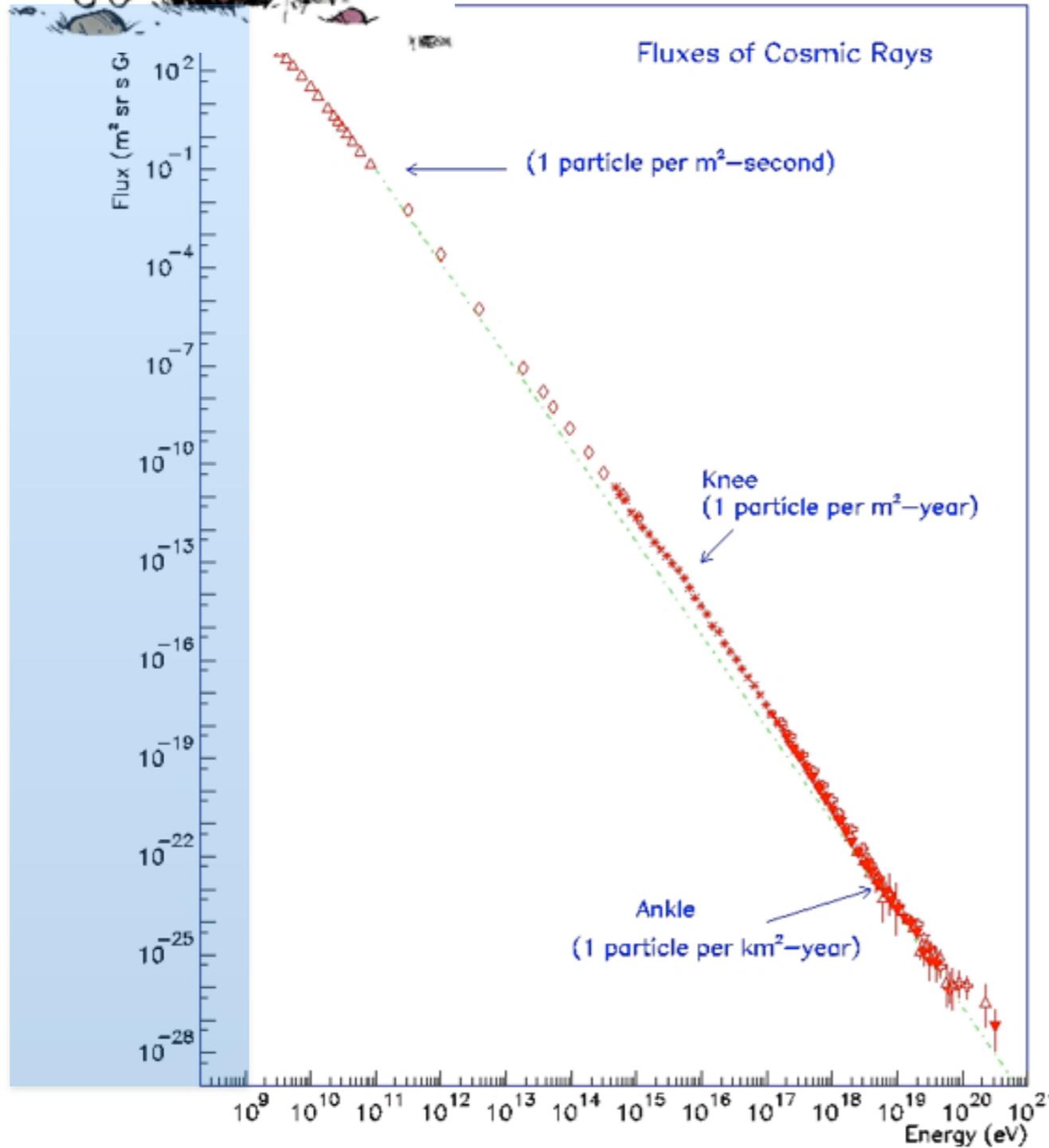
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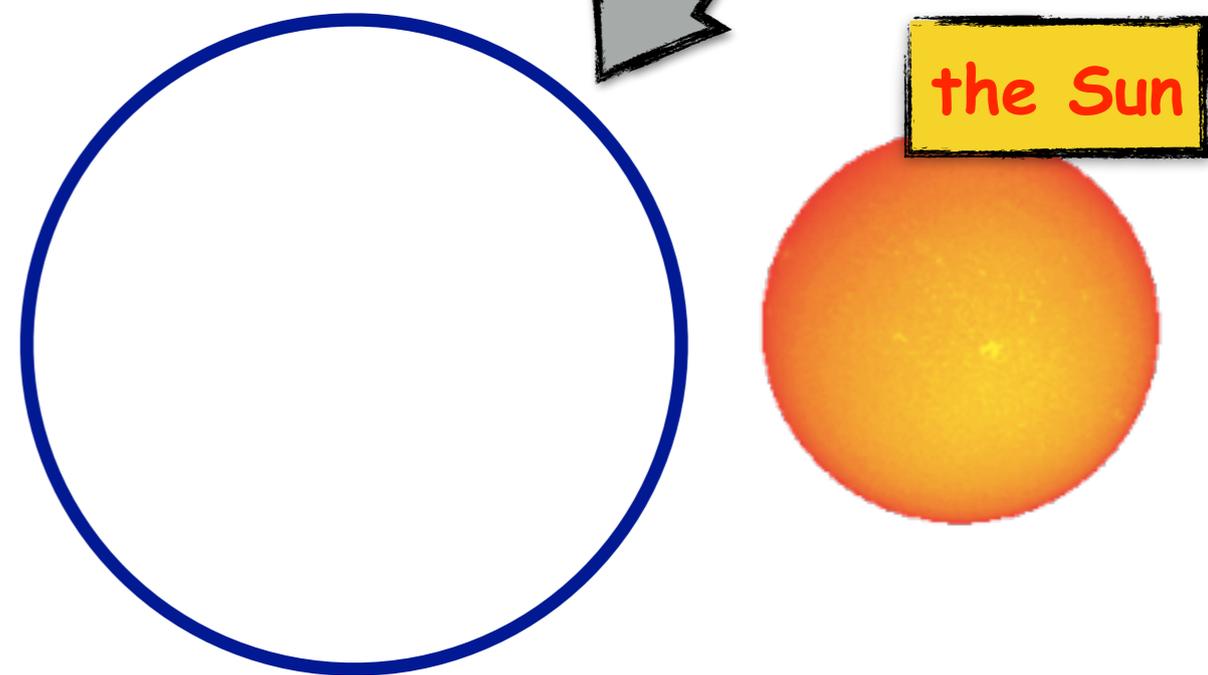
SuperNova Remnants



The MeV domain (MeV...~1 GeV)



$$R_L(1 \text{ MeV}) \sim 5 \times 10^{10} \text{ cm}$$



the Sun

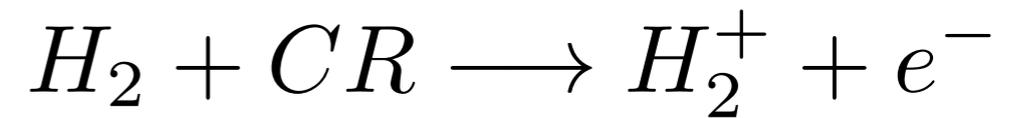
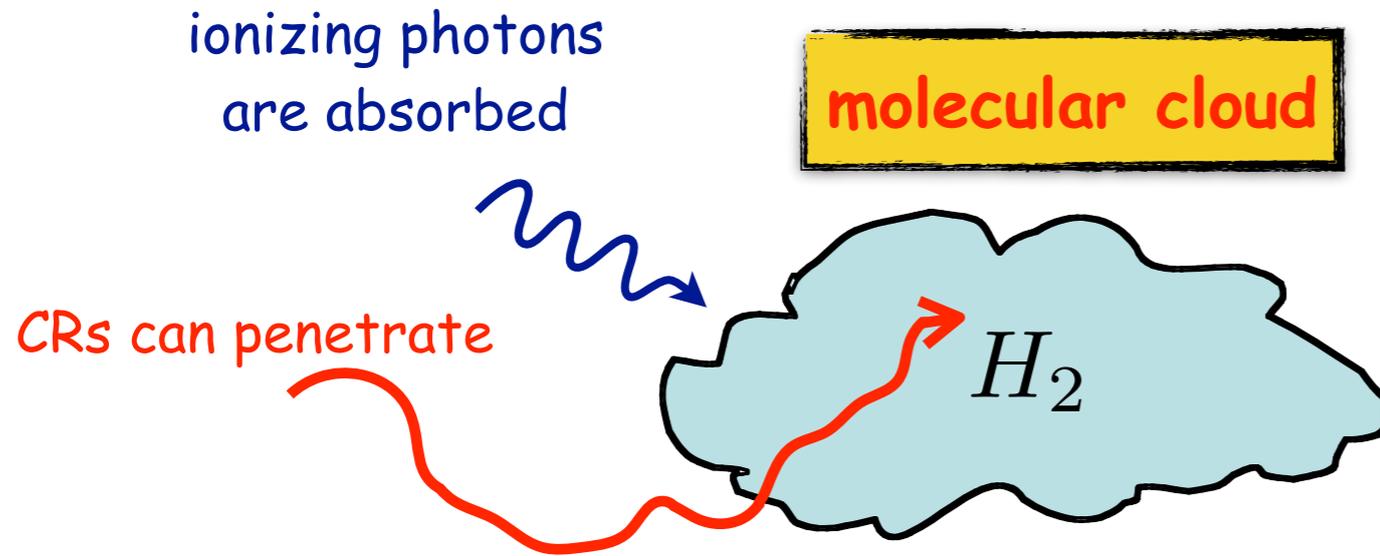
Solar modulation

CR spectrum known with very large uncertainties in the MeV range
 -> but see recent Voyager results

MeV GeV TeV PeV EeV ZeV

The MeV domain: CR ionization

(see Padovani et al. 2009 for a recent review)



MeV

GeV

TeV

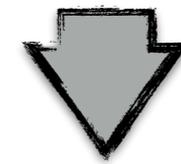
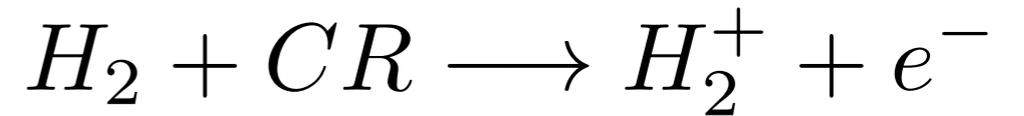
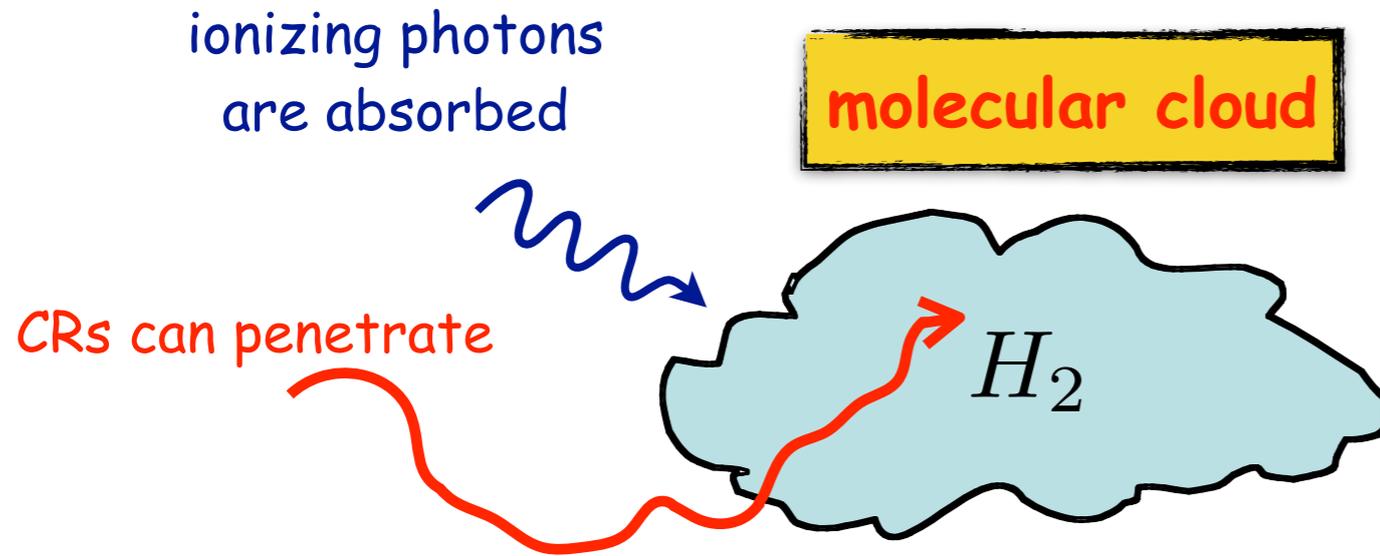
PeV

EeV

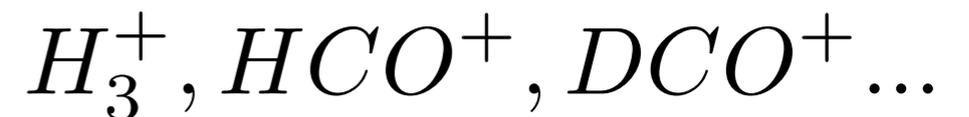
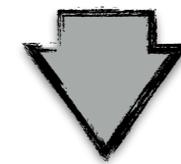
ZeV

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chemistry



see papers by McCall, Indriolo,
Ceccarelli, Vaupré ...

MeV

GeV

TeV

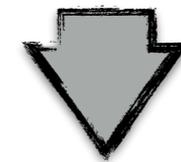
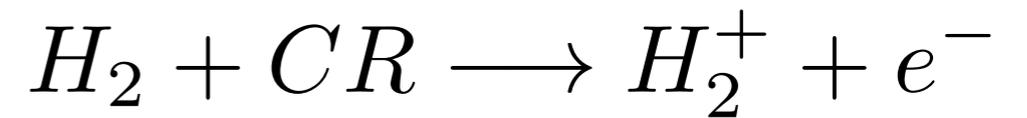
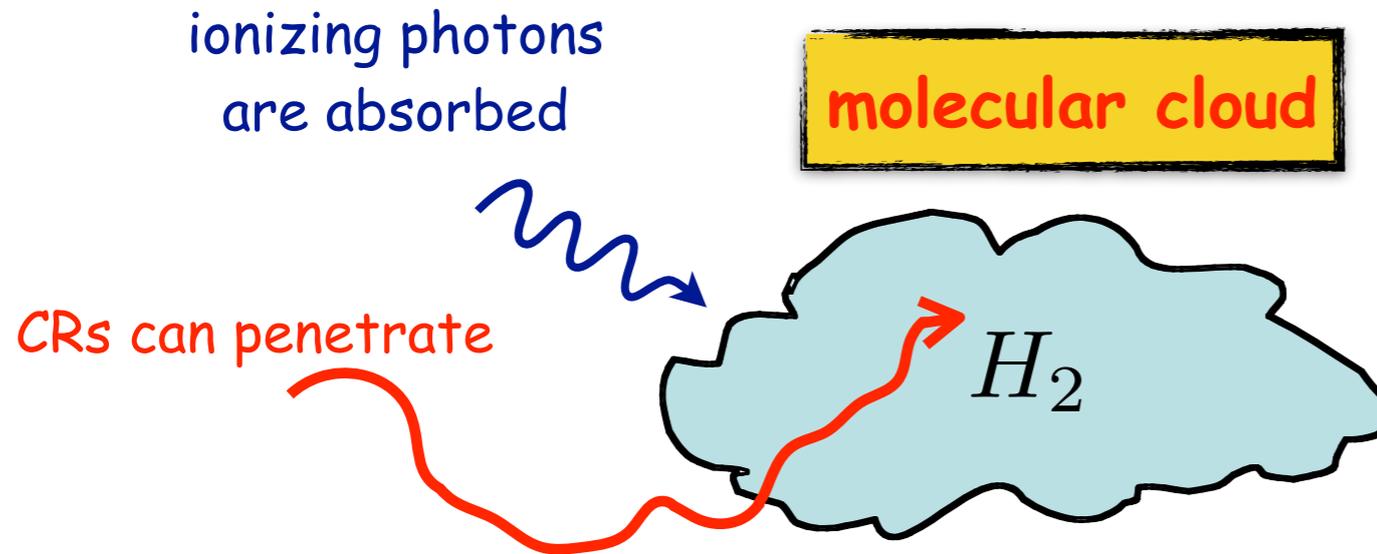
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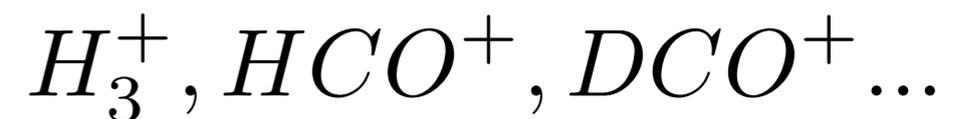
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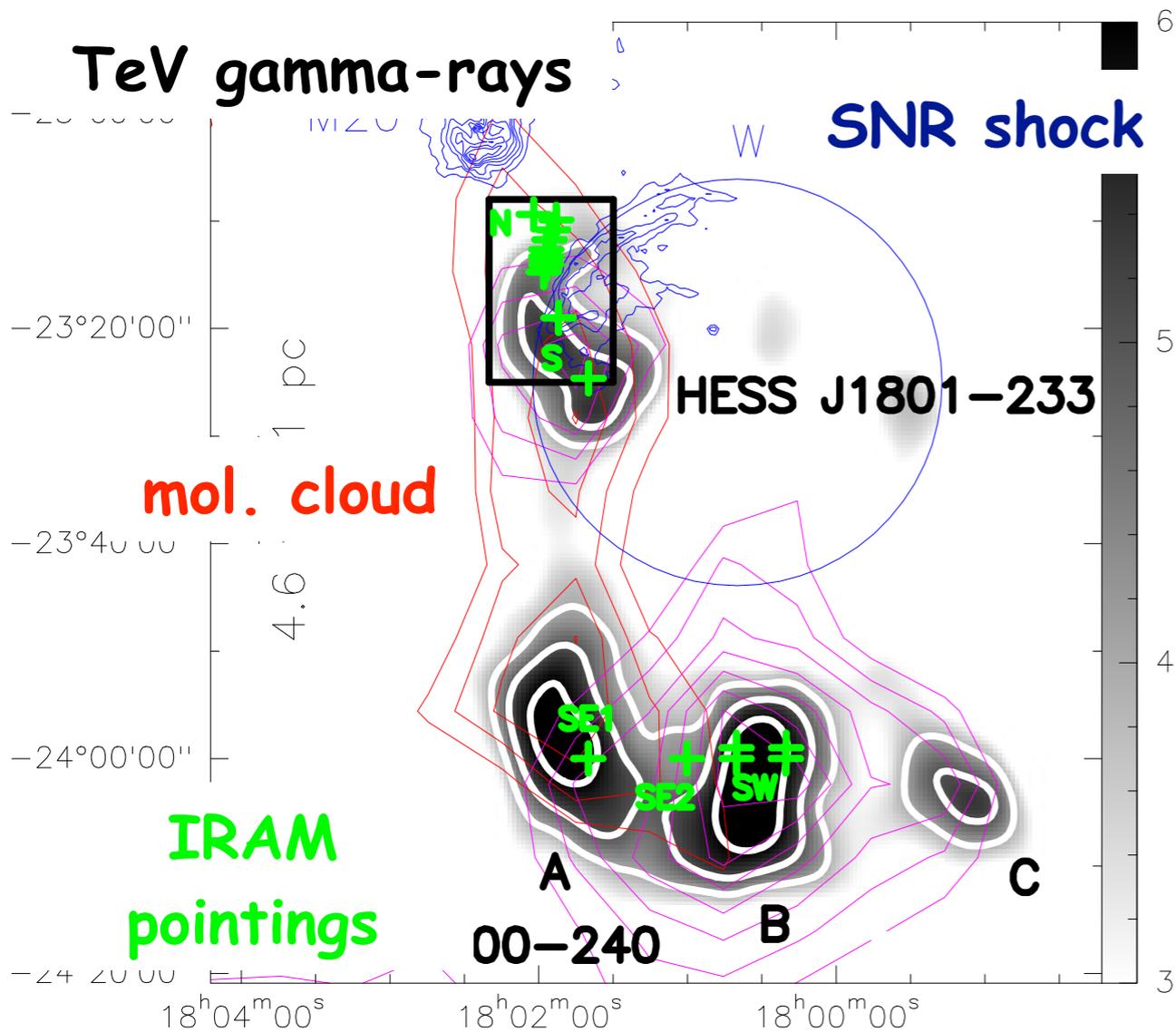
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The MeV domain: the SNR W28

Vaupré, Hily-Blant, Ceccarelli, Dubus, SG, Montmerle (to appear soon on arXiv)



TeV + **gas** -> multi-TeV CR protons

MeV

GeV

TeV

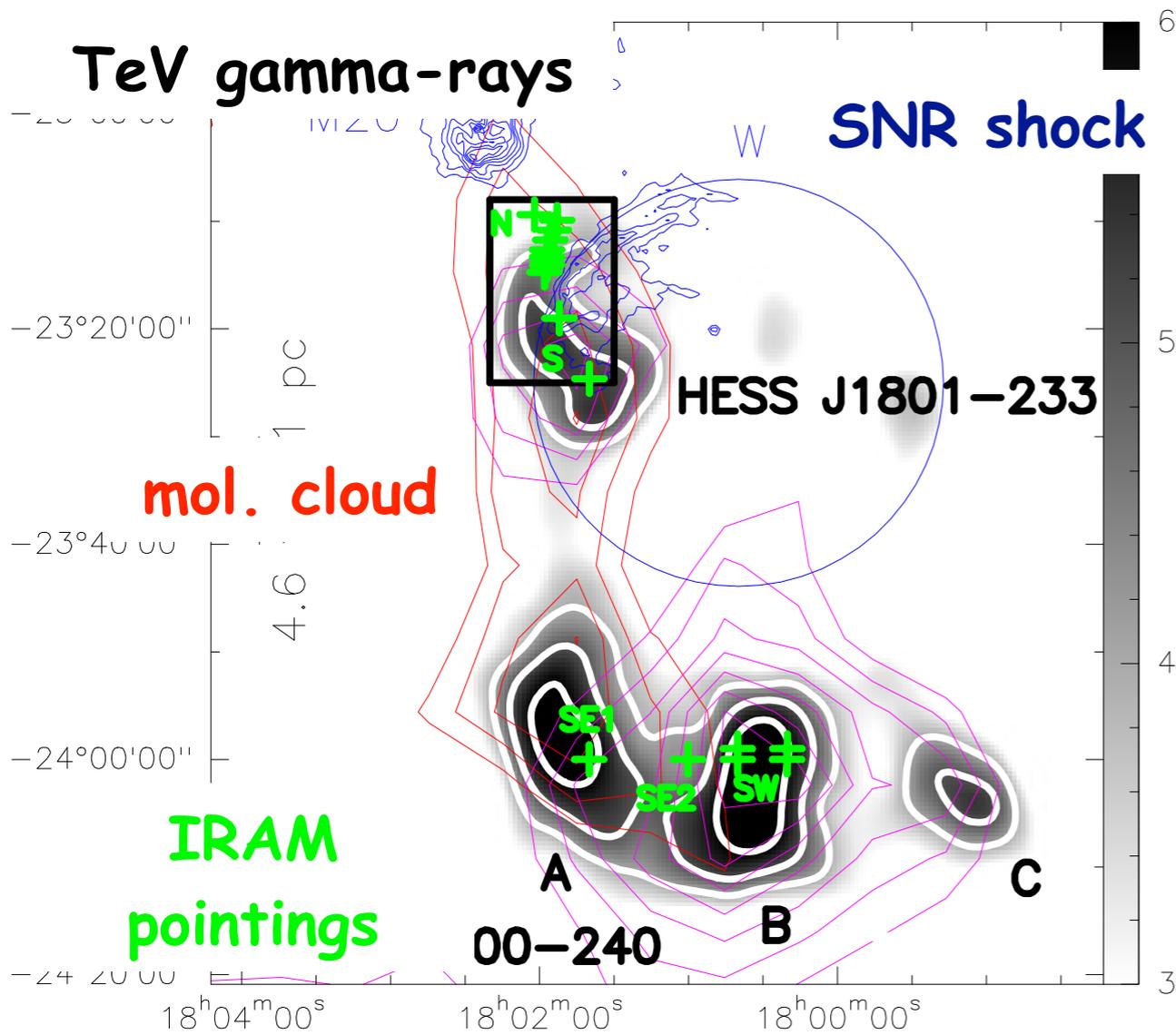
PeV

EeV

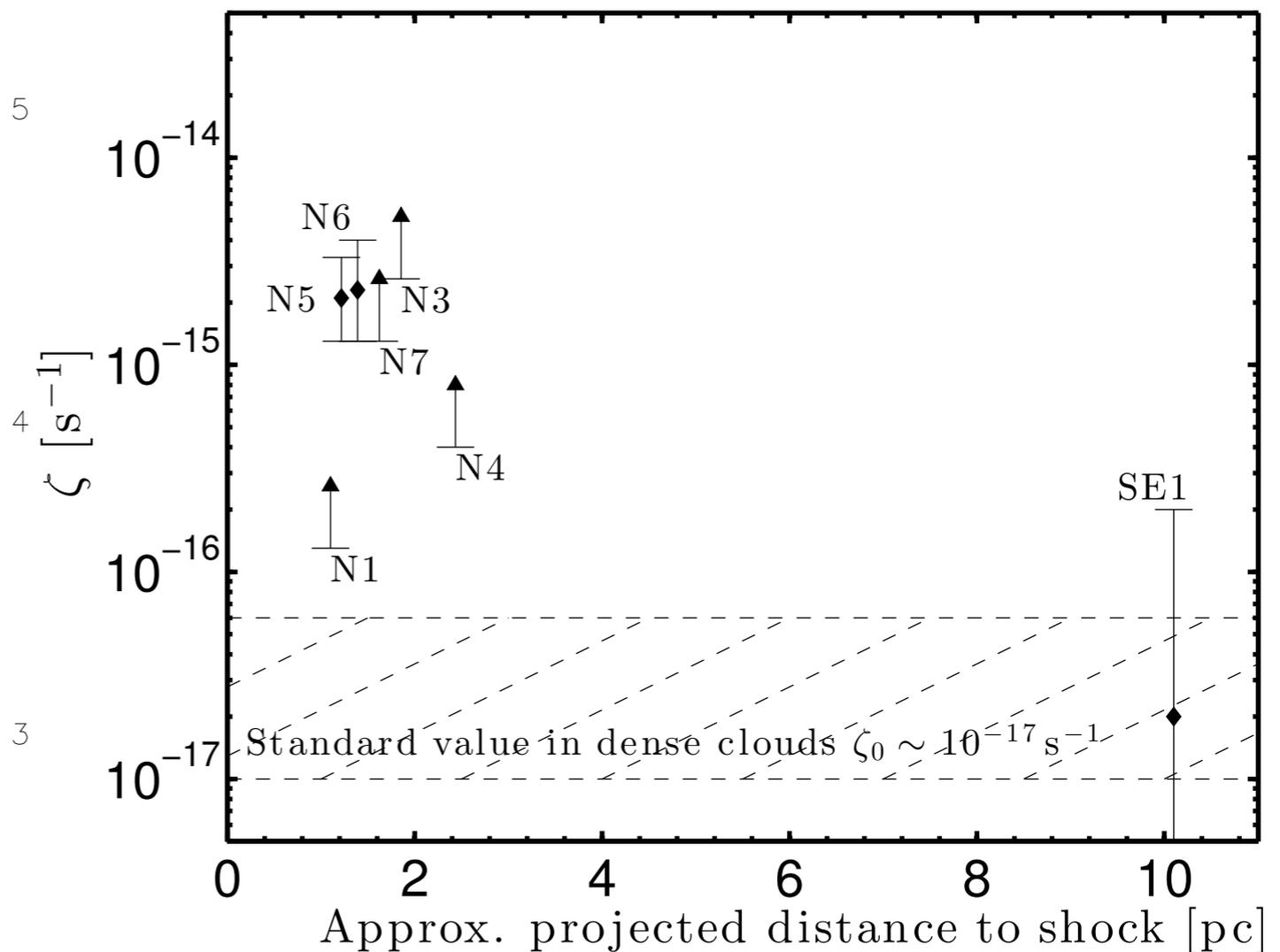
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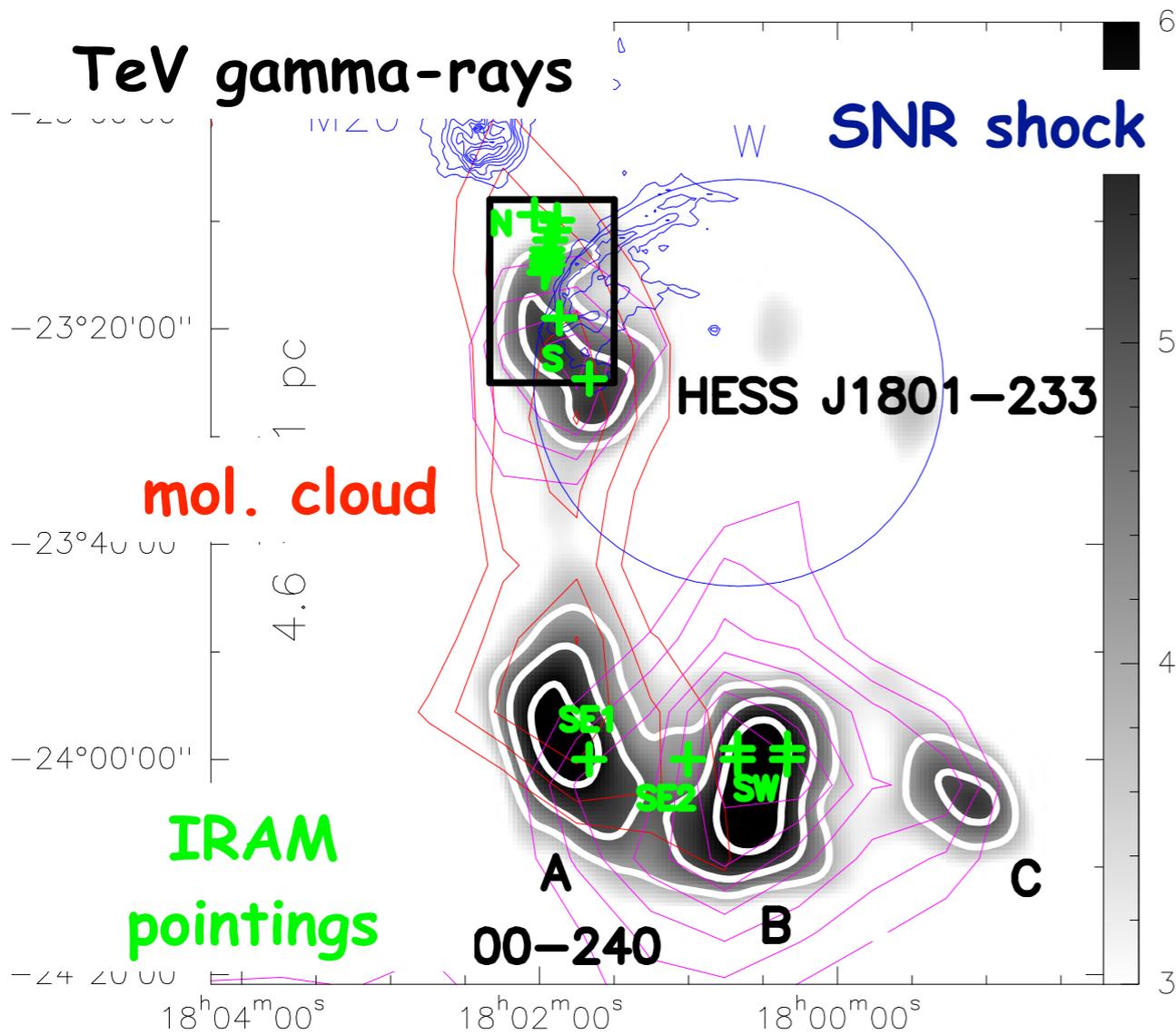
PeV

EeV

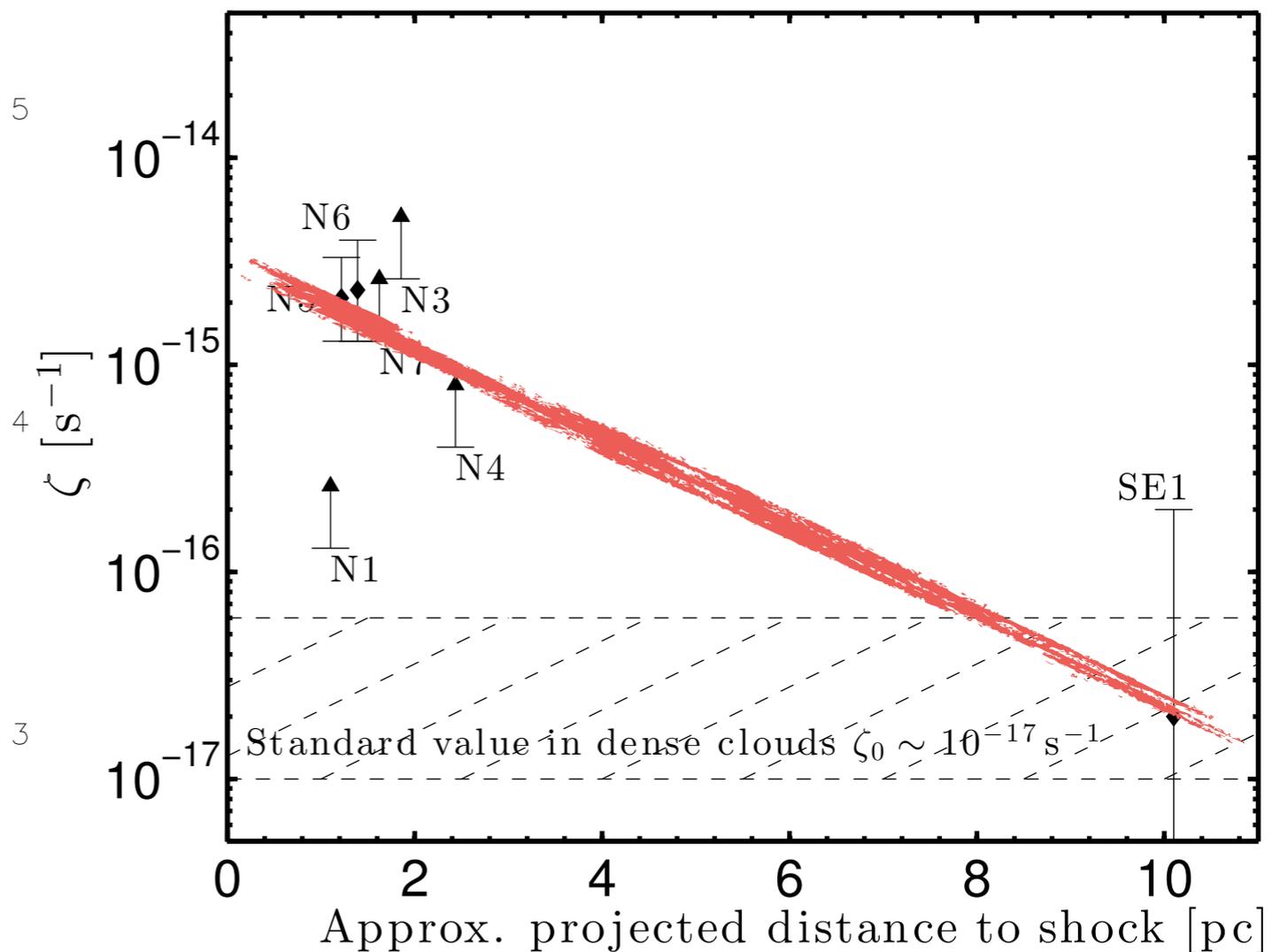
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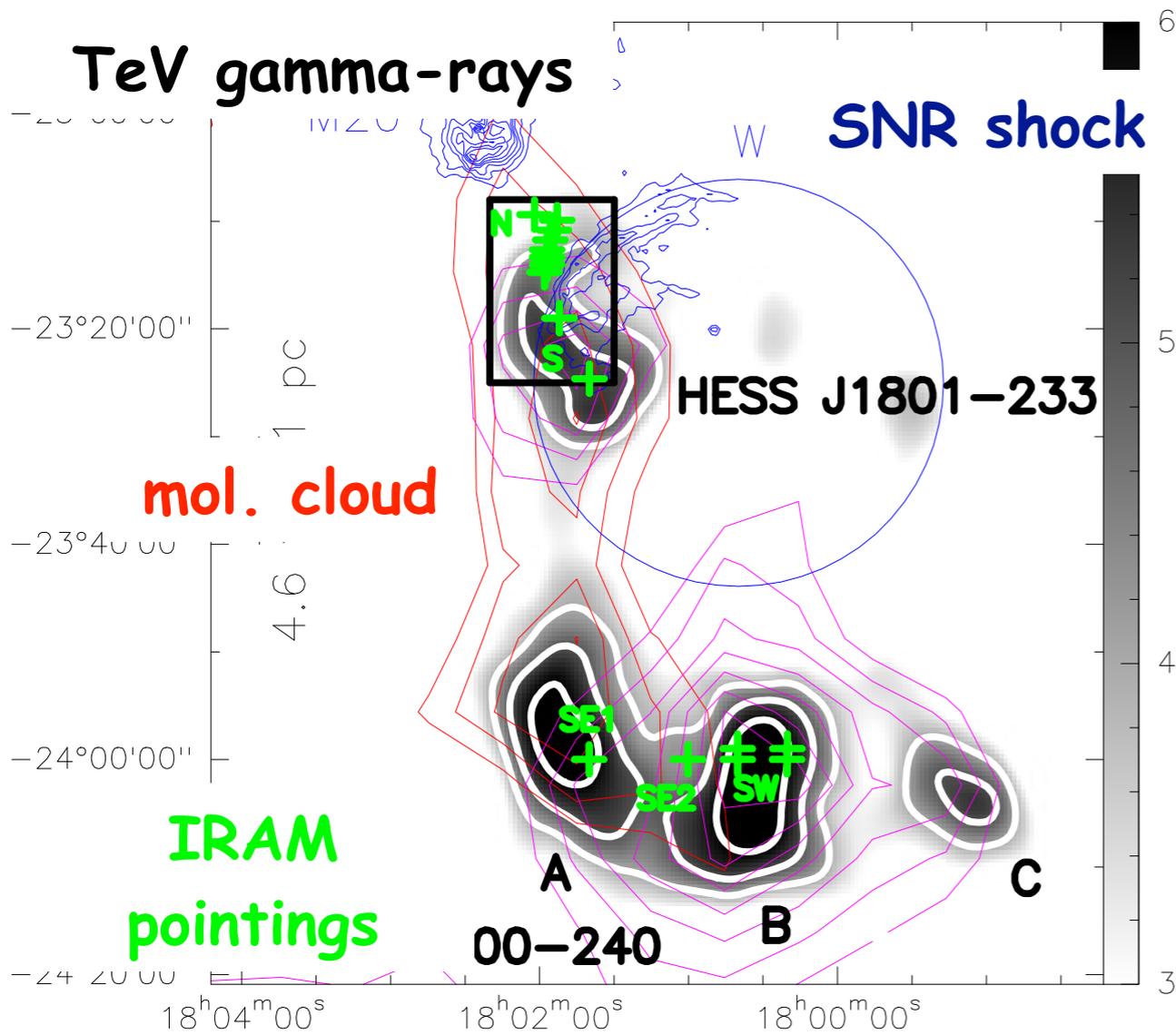
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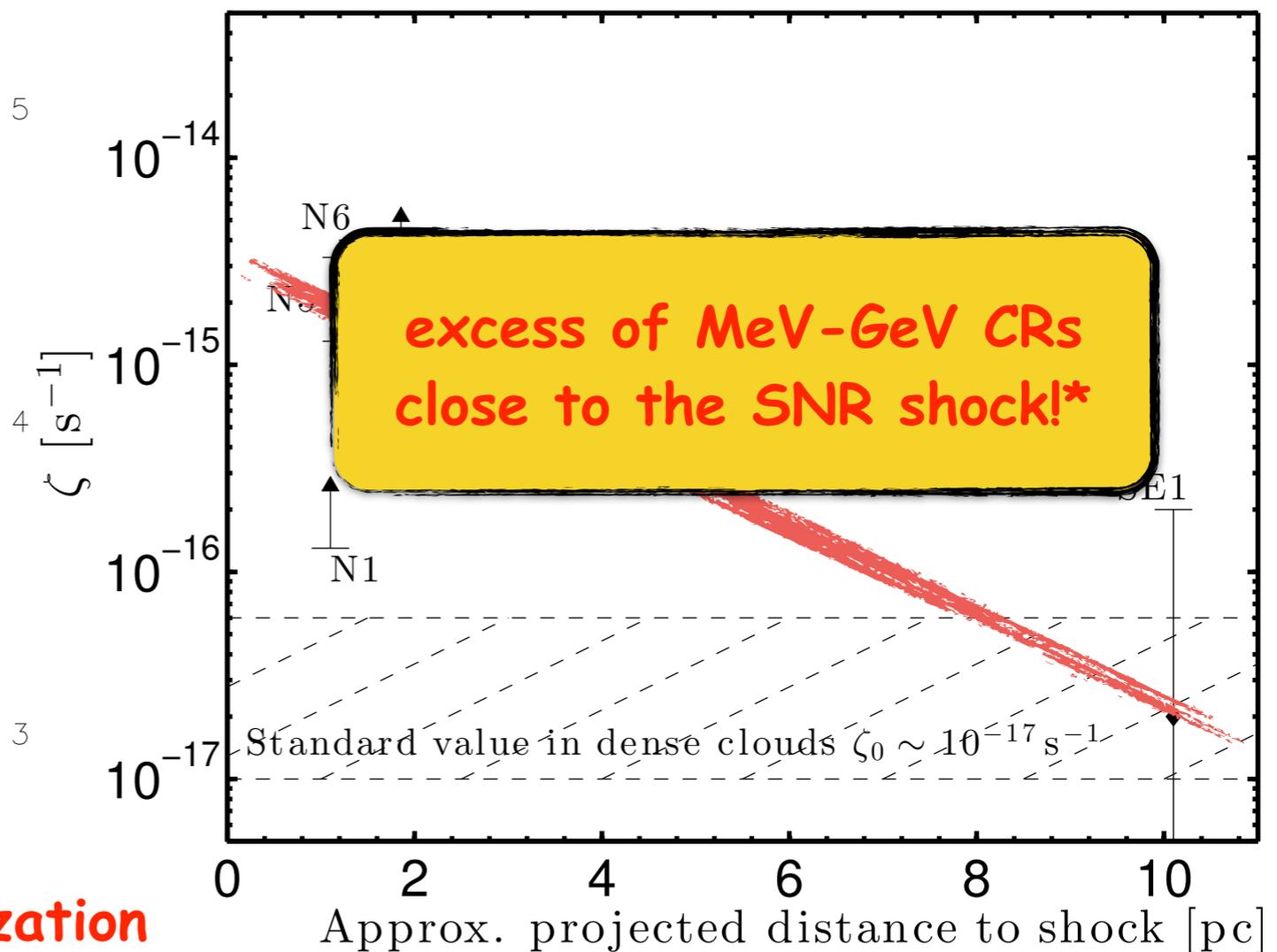
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* also CR electrons contribute to ionization

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GeV

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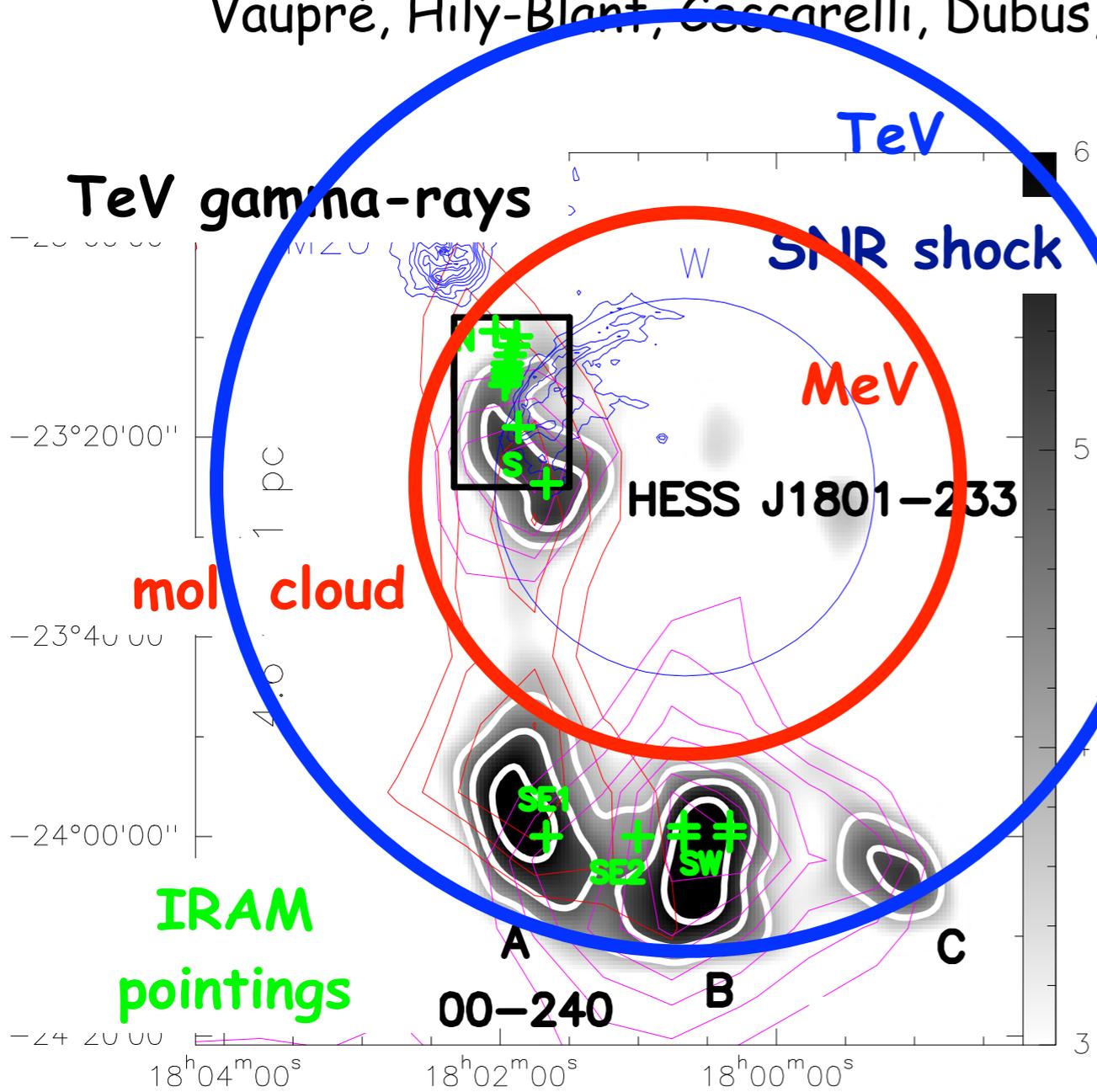
PeV

EeV

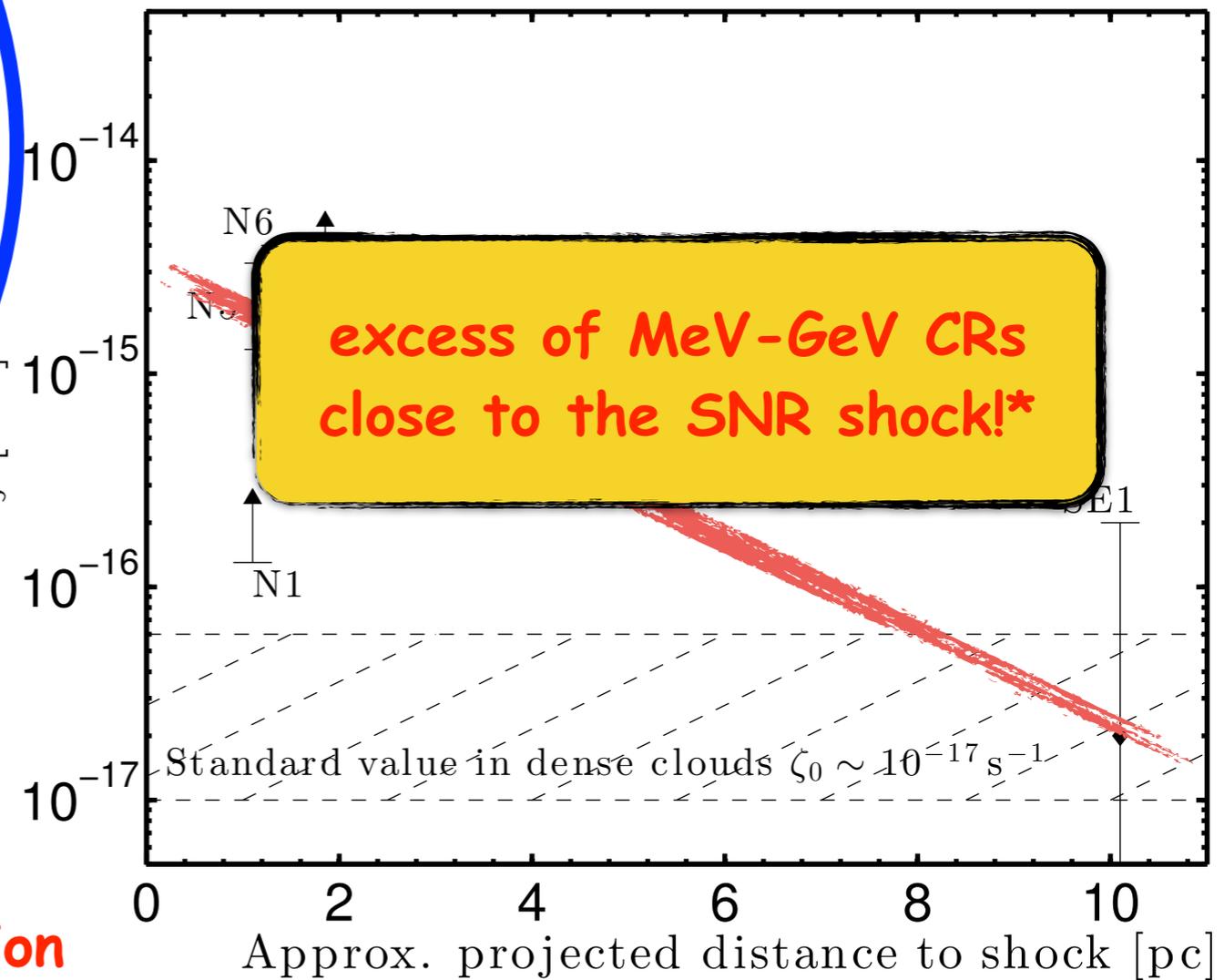
ZeV

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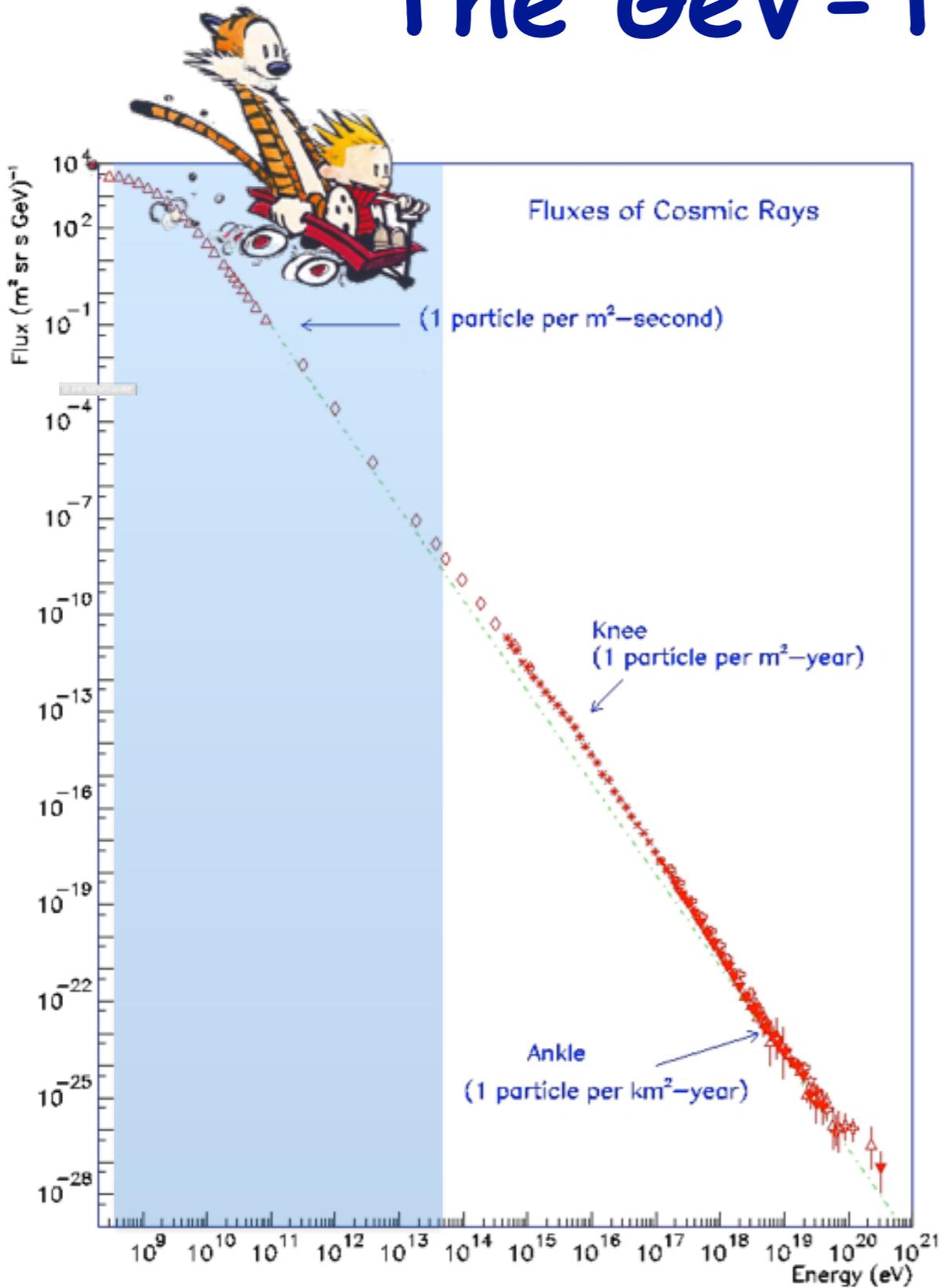
TeV

PeV

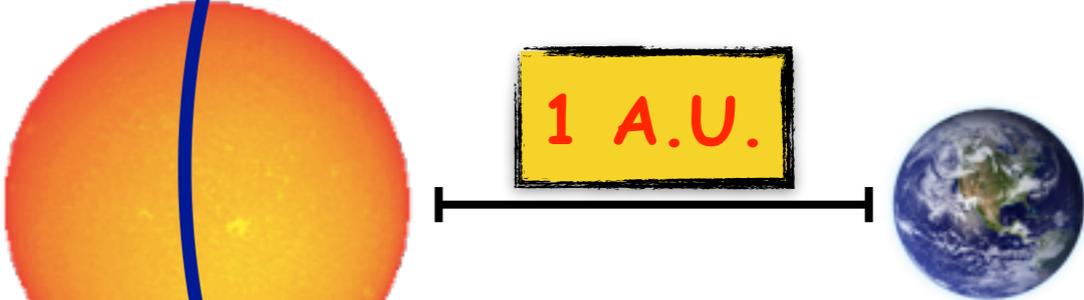
EeV

ZeV

The GeV-TeV domain



$$R_L(10 \text{ GeV}) \sim 1.2 \times 10^{13} \text{ cm}$$

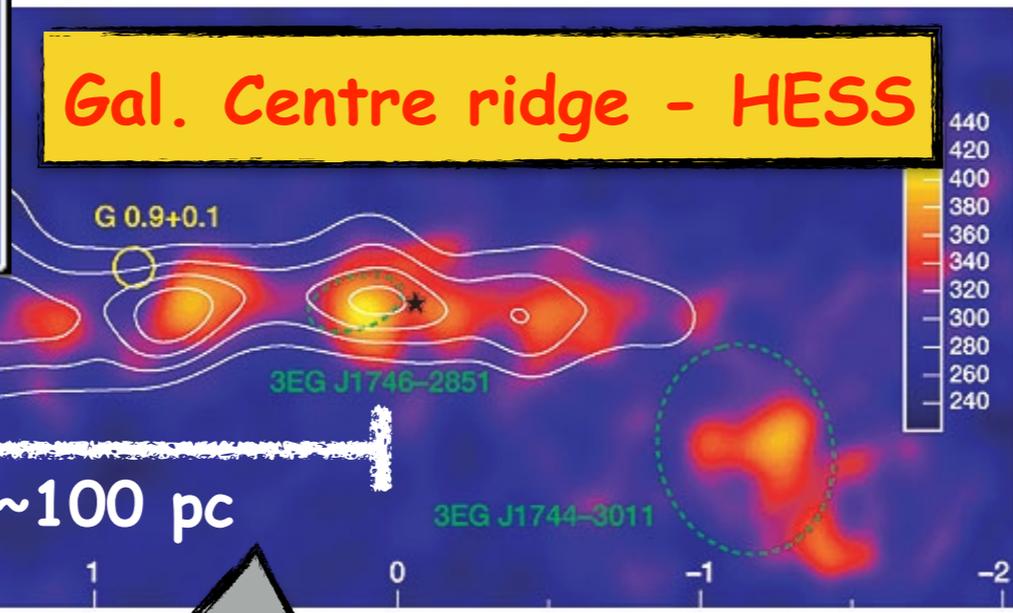
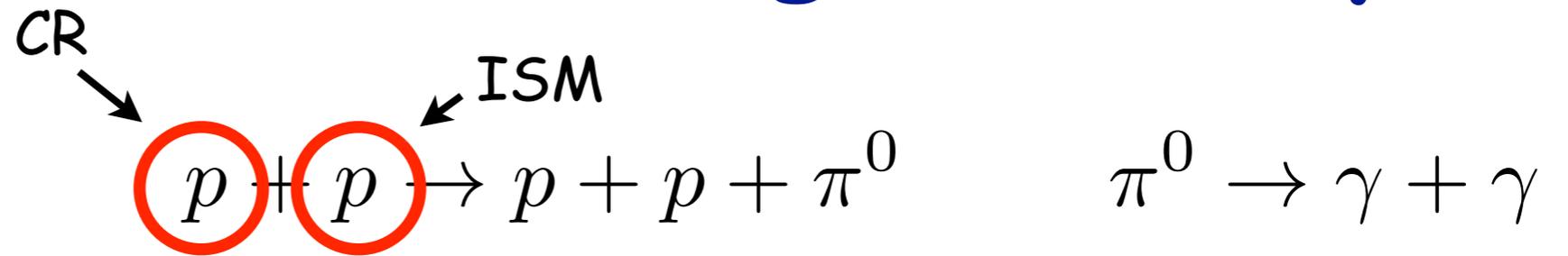
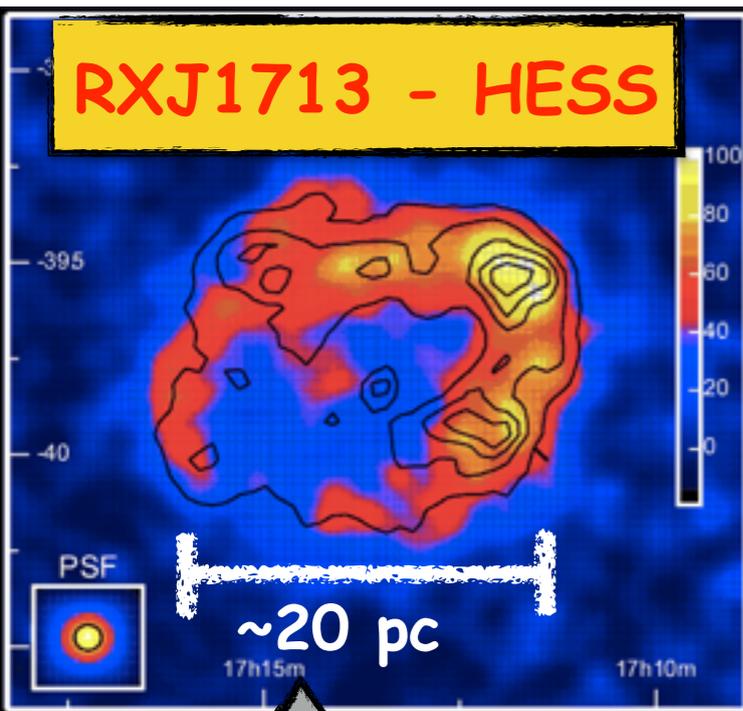


Galactic cosmic rays

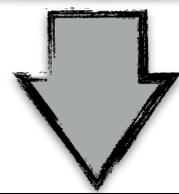
bulk of the energy

MeV GeV TeV PeV EeV ZeV

The GeV-TeV domain: gamma rays

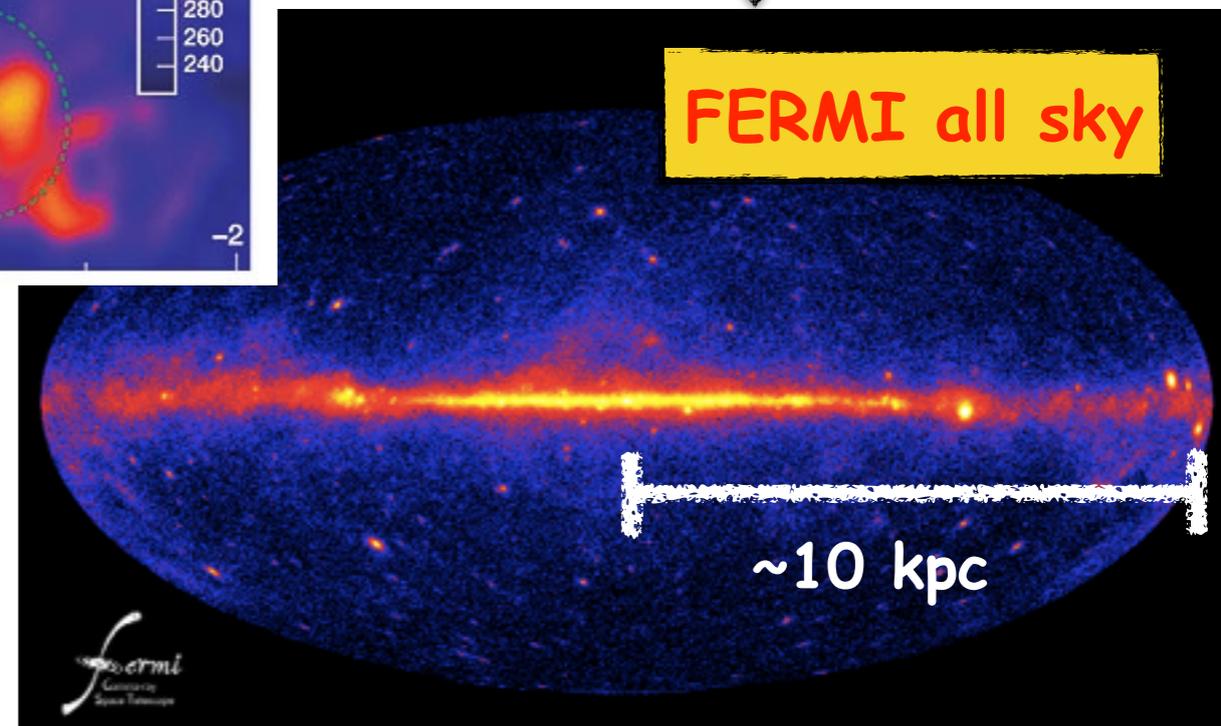


CR transport on Galactic scale



diffusive shock acceleration

CR transport close to sources



see plenary talks by Jim Hinton and Rolf Bühler + parallel sessions on gamma rays

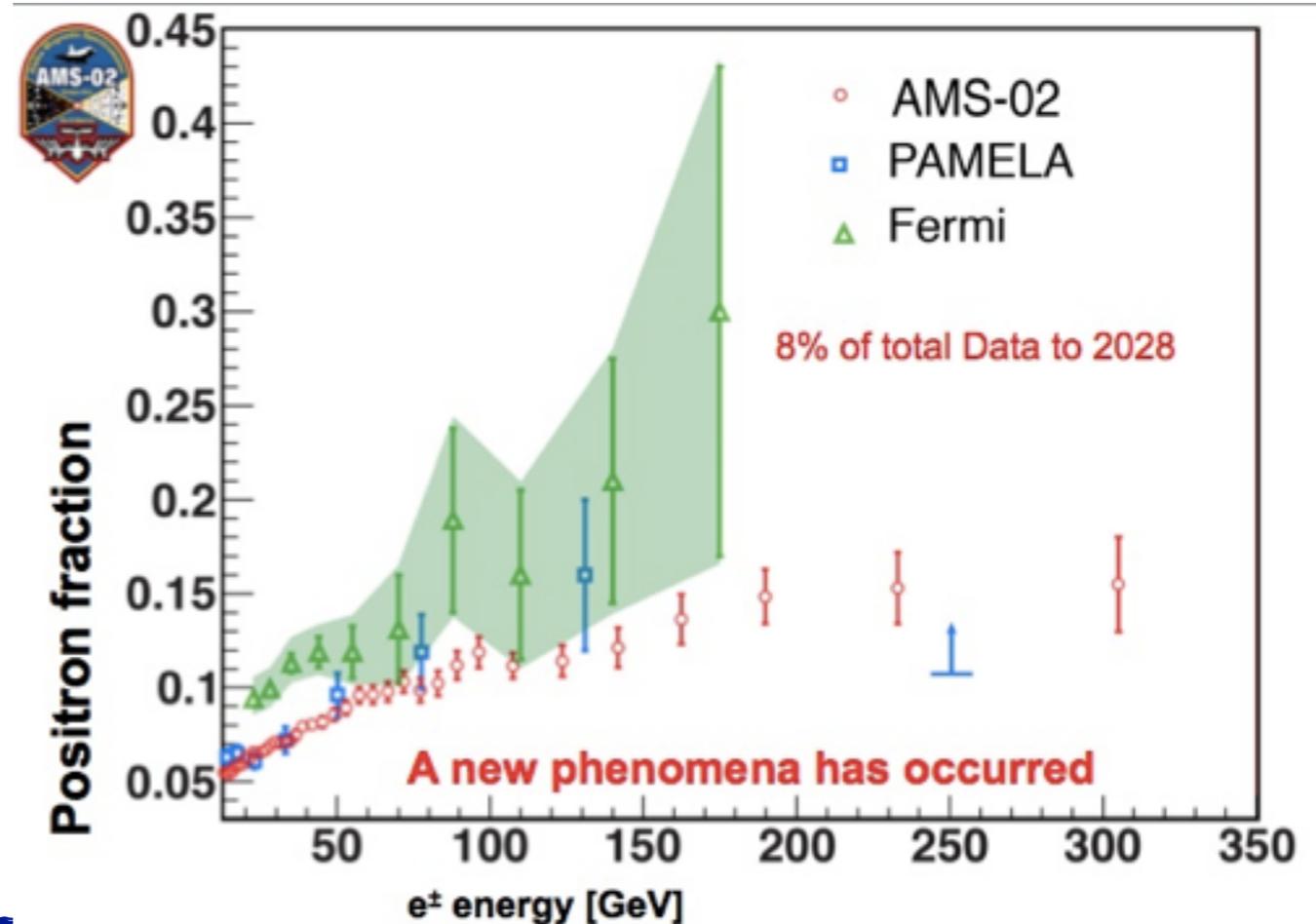
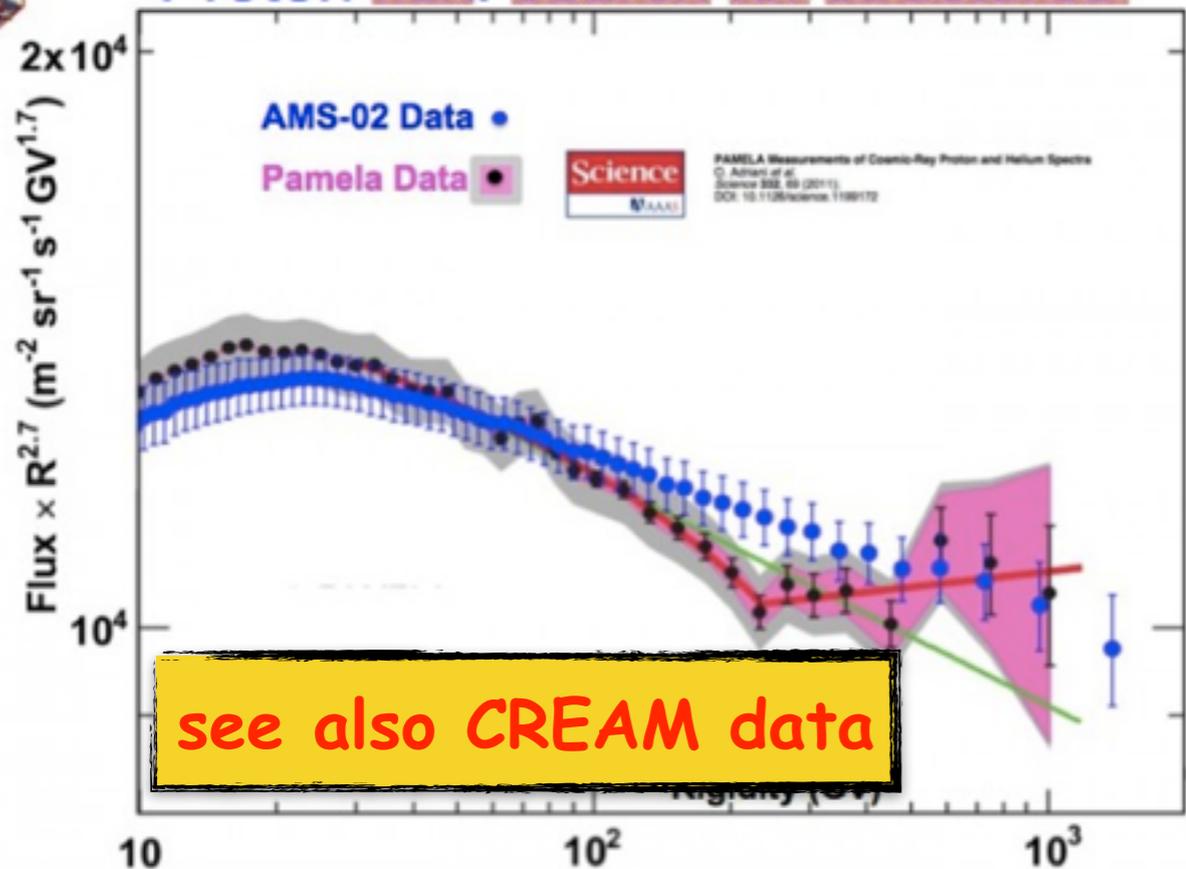


The GeV-TeV domain: cosmic rays

breaks in p and He spectra?

rise in the positron fraction

Proton flux: search for structures



if real, breaks tell us something about the acceleration and/or propagation of CRs

need for a nearby e^+e^- TeVatron

see talks by Sparvoli, Seo, Vagelli, Grasso, Oliva, Mori, Bernardini, Thoudam, Mertsch, Taoso...

MeV

GeV

TeV

PeV

EeV

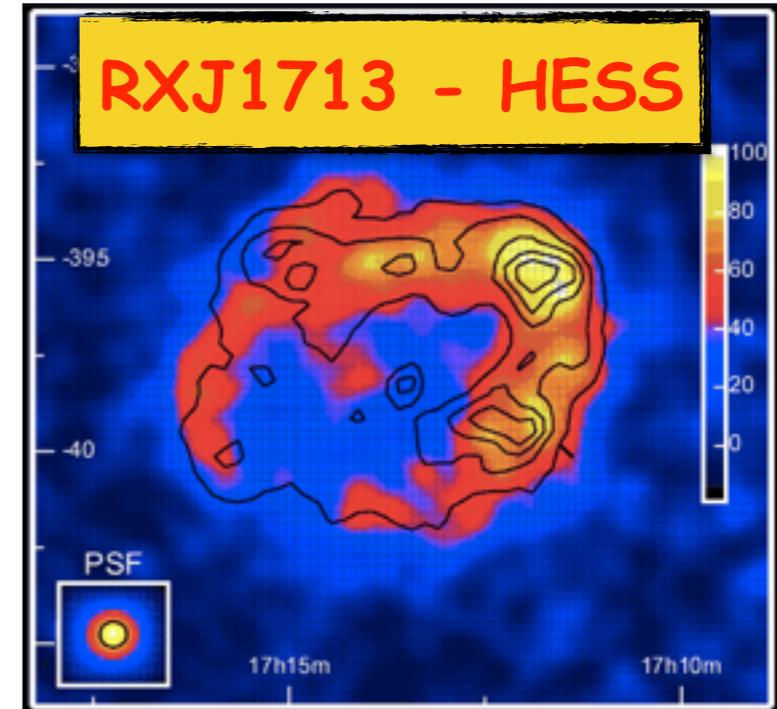
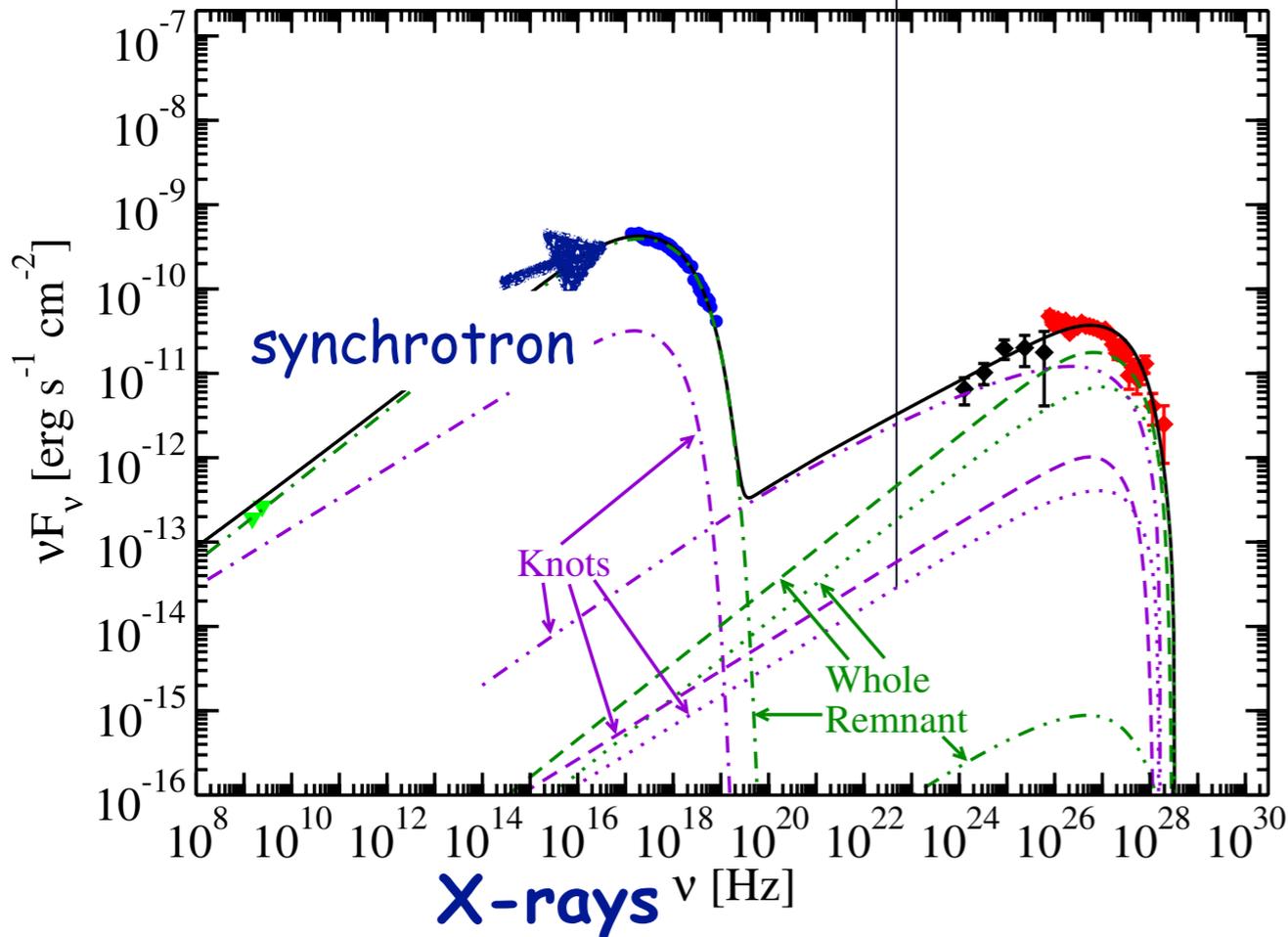
ZeV

Do SNRs accelerate the bulk of CRs?

Leptonic...

RXJ 1713

RXJ1713 - HESS



MeV

GeV

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PeV

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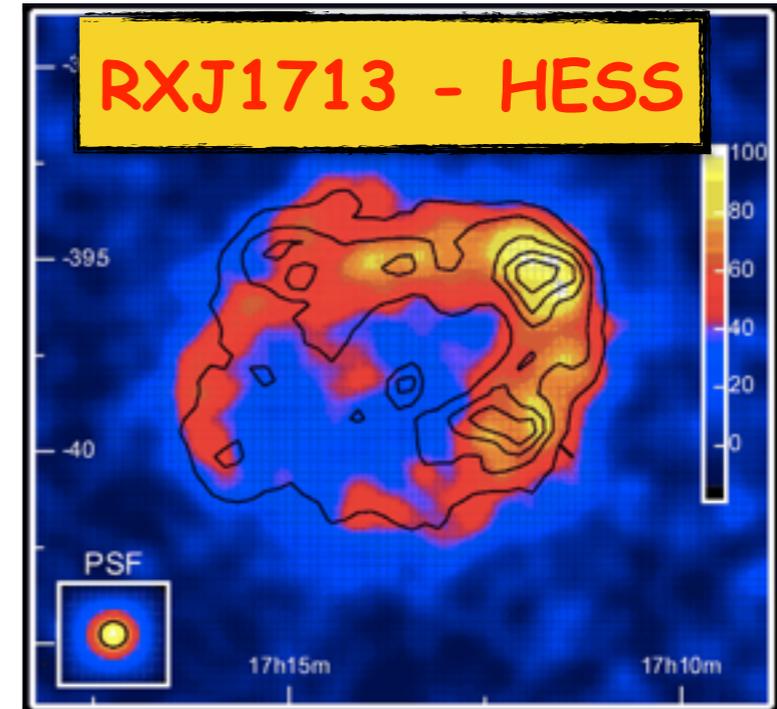
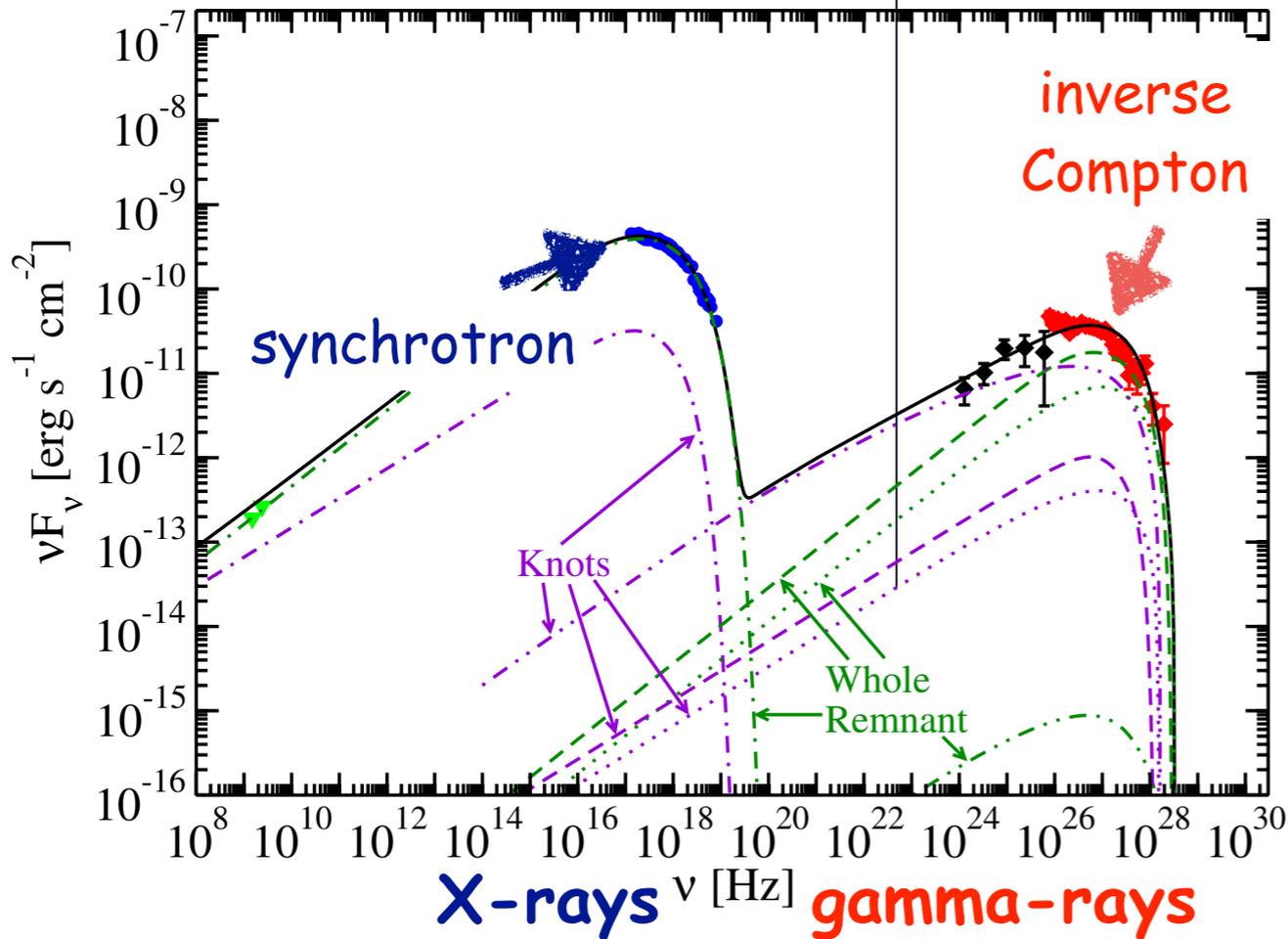
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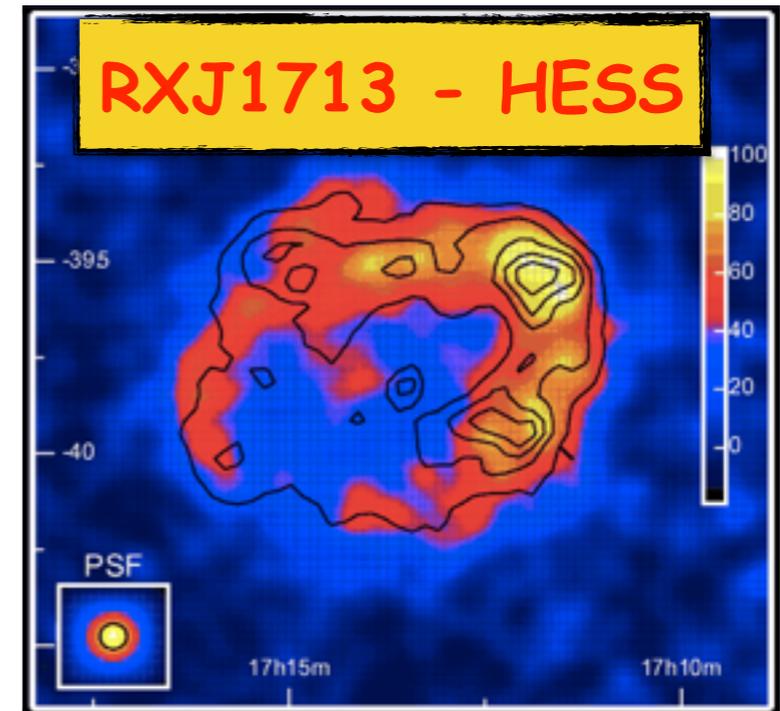
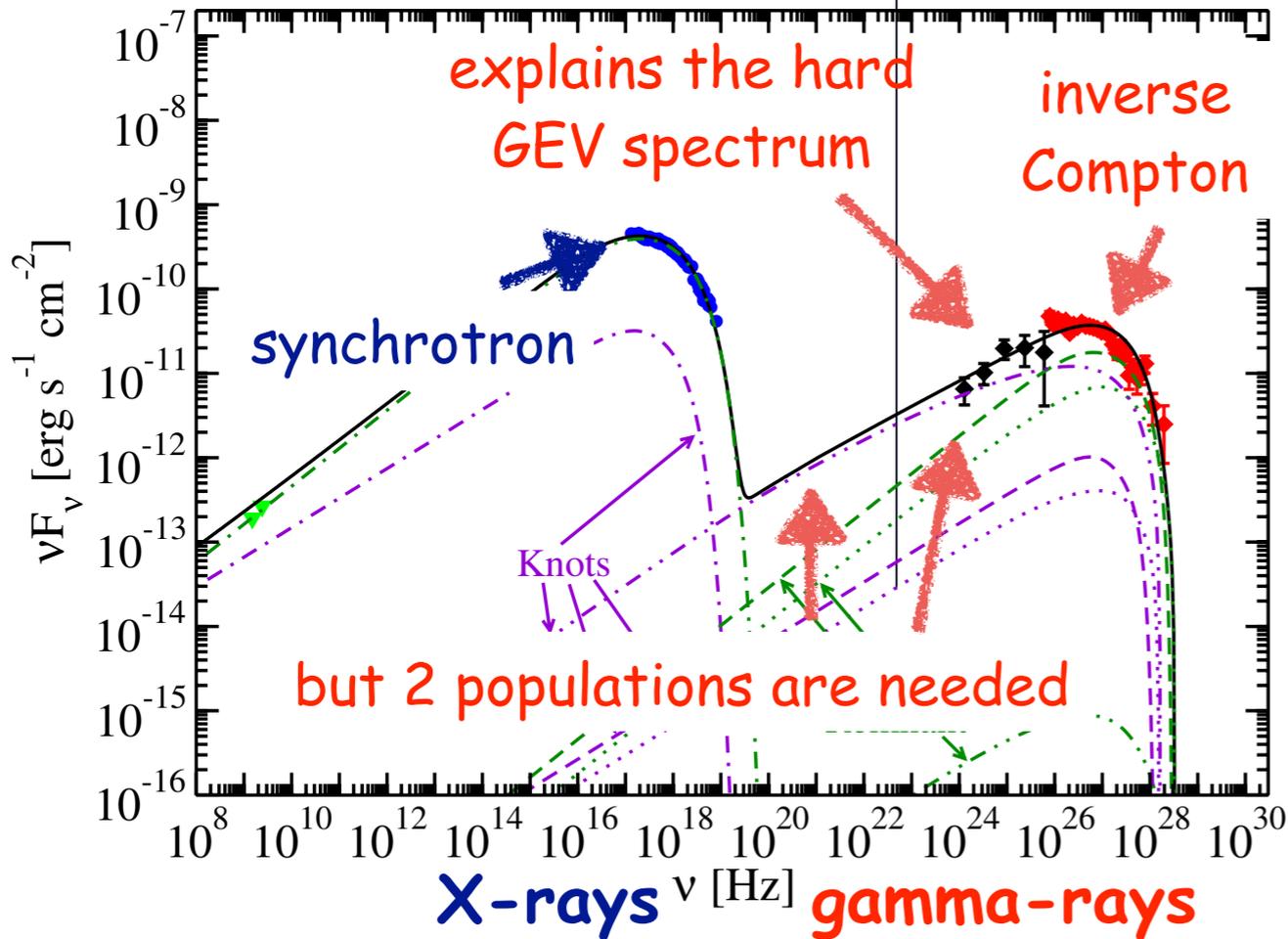
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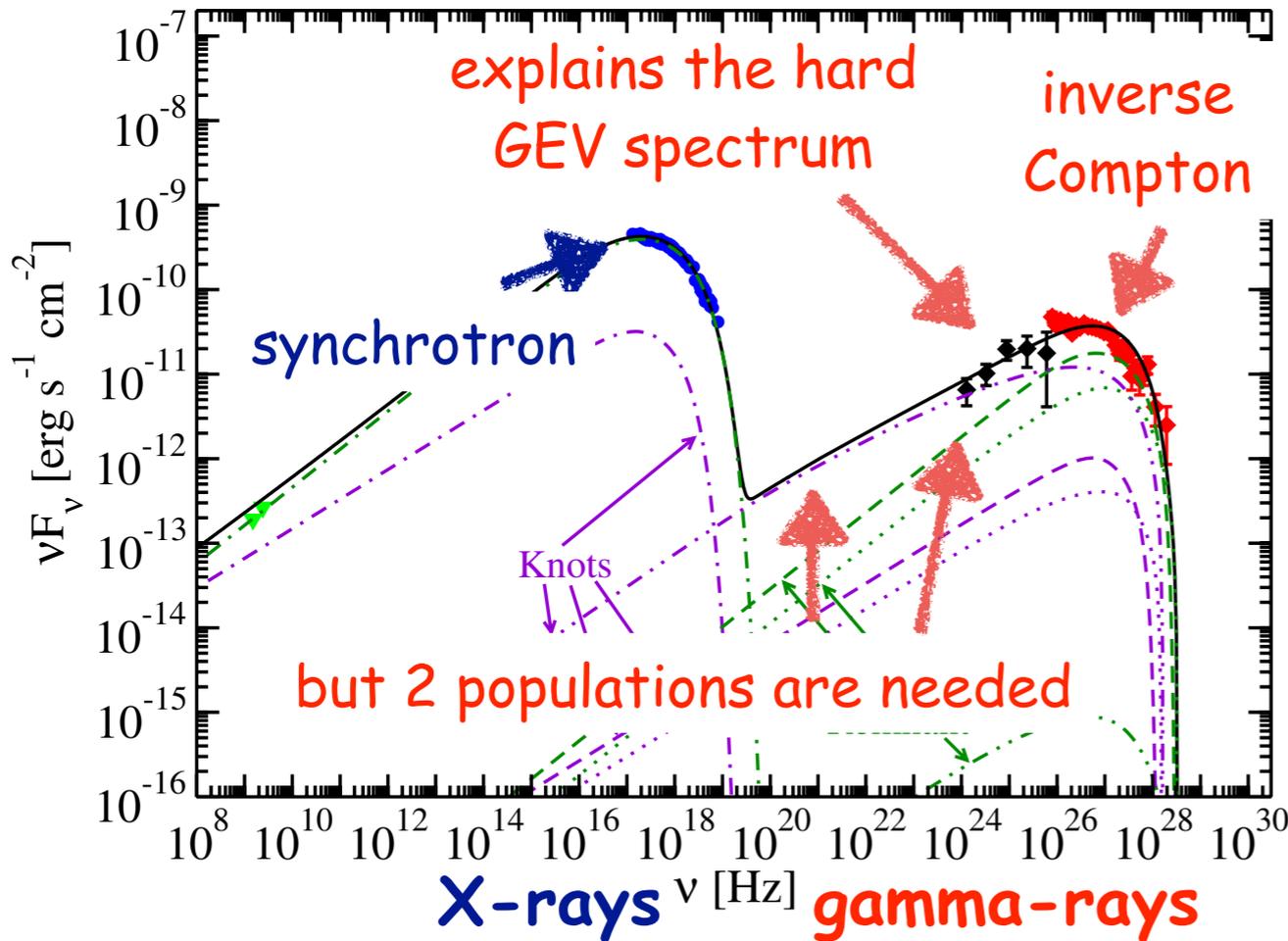
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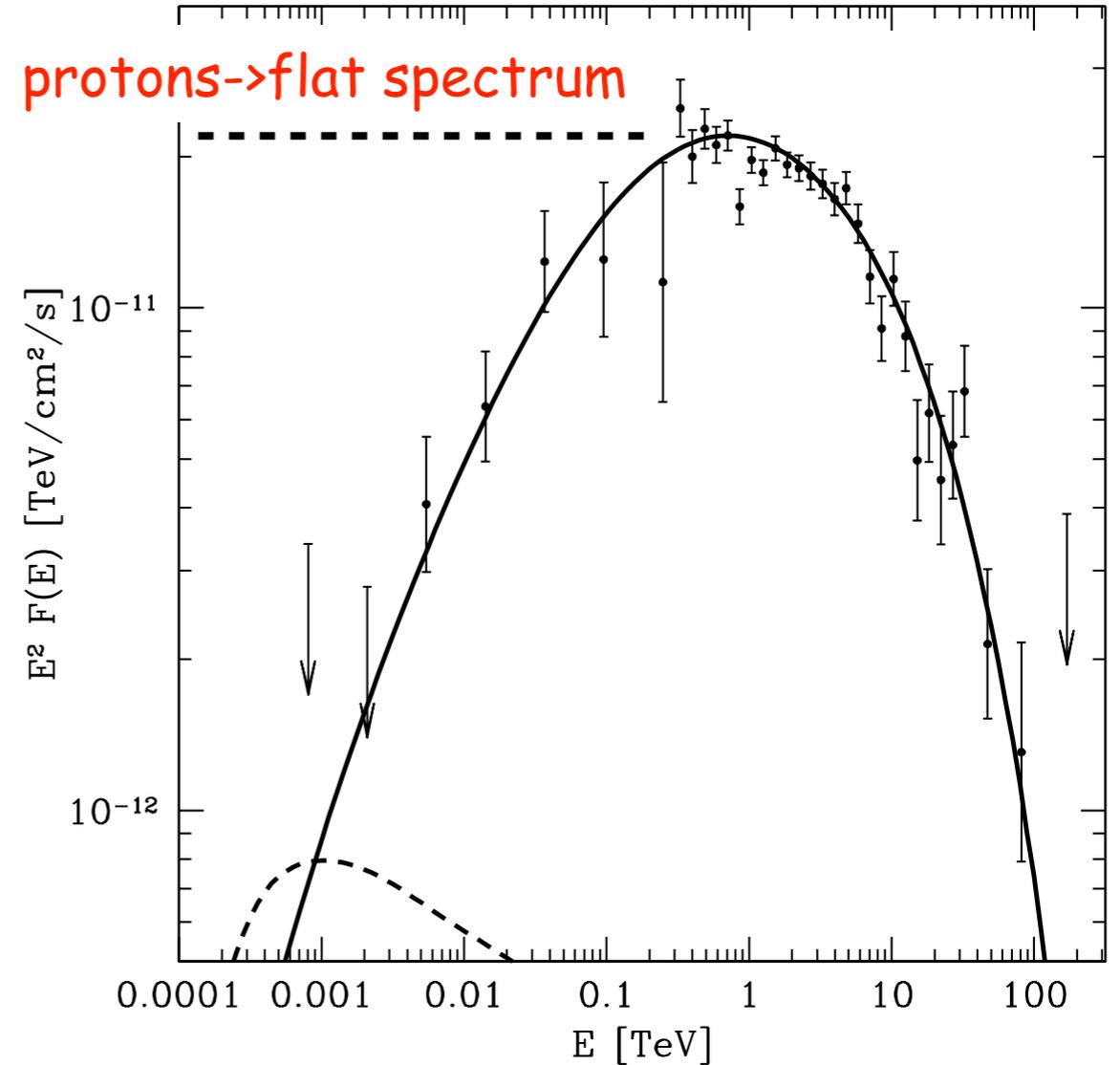
RXJ 1713

...or hadronic?

Finke&Dermer2012



protons->flat spectrum



Gabici&Aharonian2014

MeV

GeV

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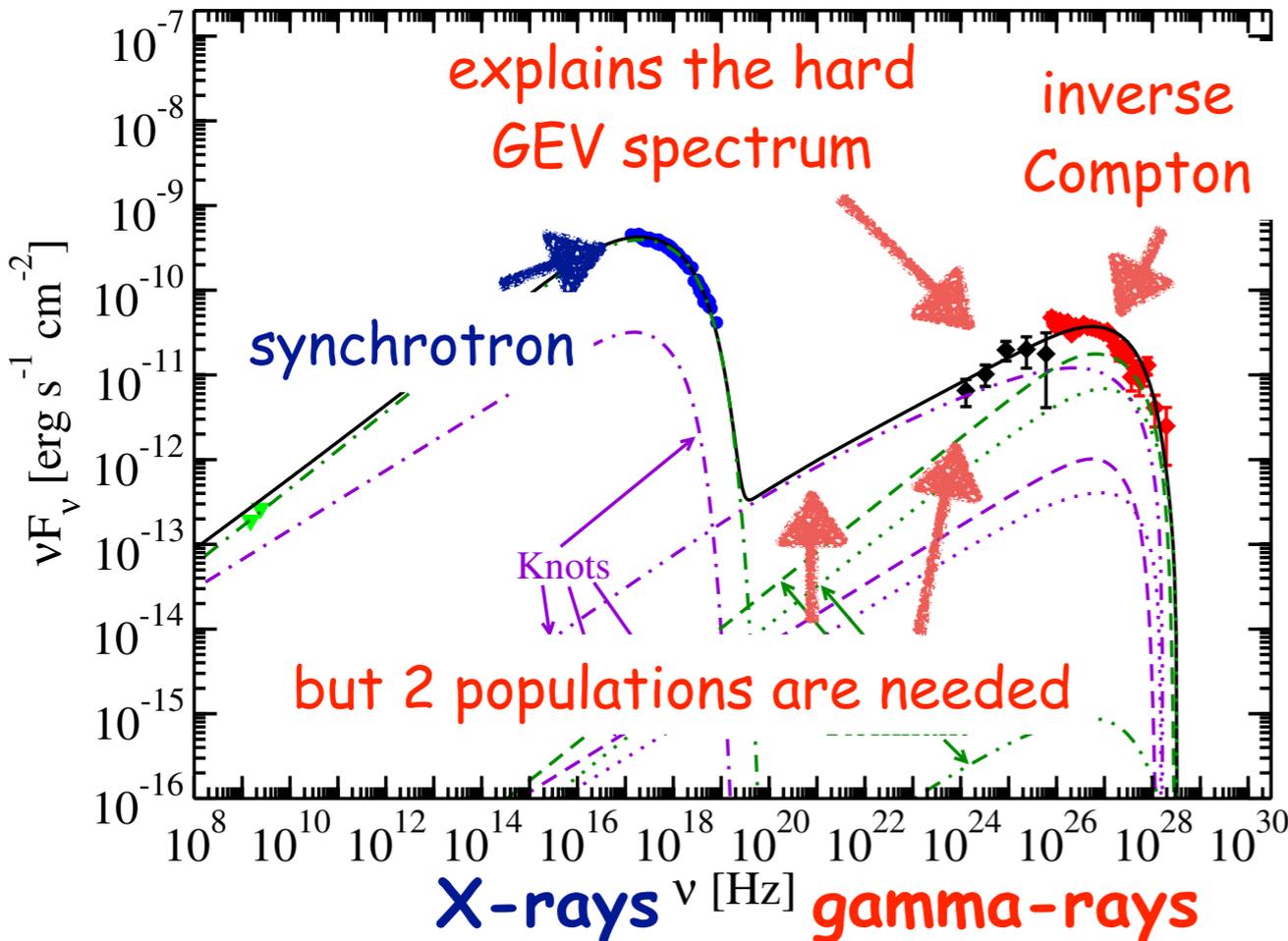
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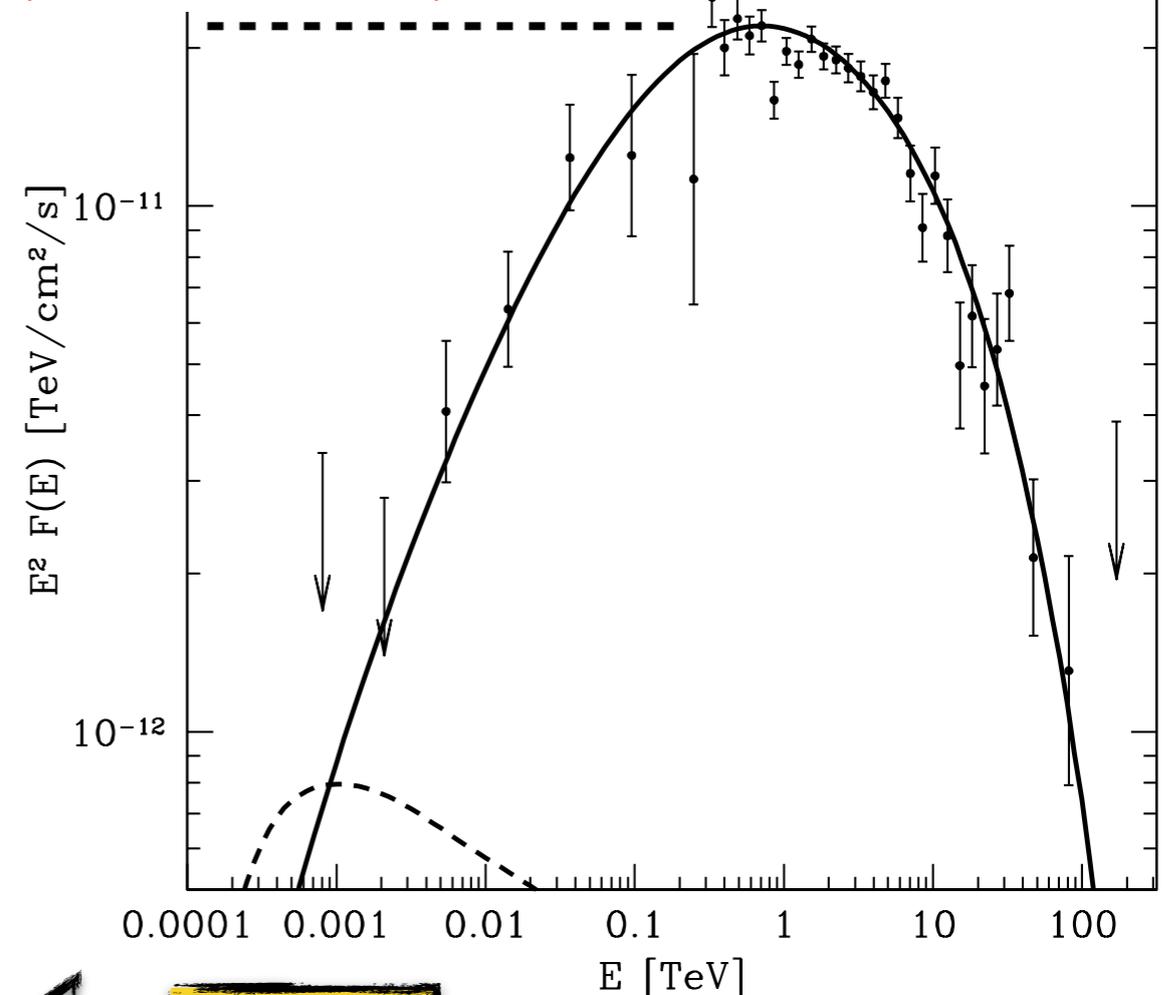
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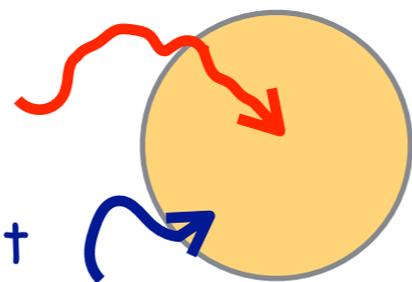
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Gabici&Aharonian2014

high energy CRs penetrate

low energy CRs don't



← clumps!

MeV

GeV

TeV

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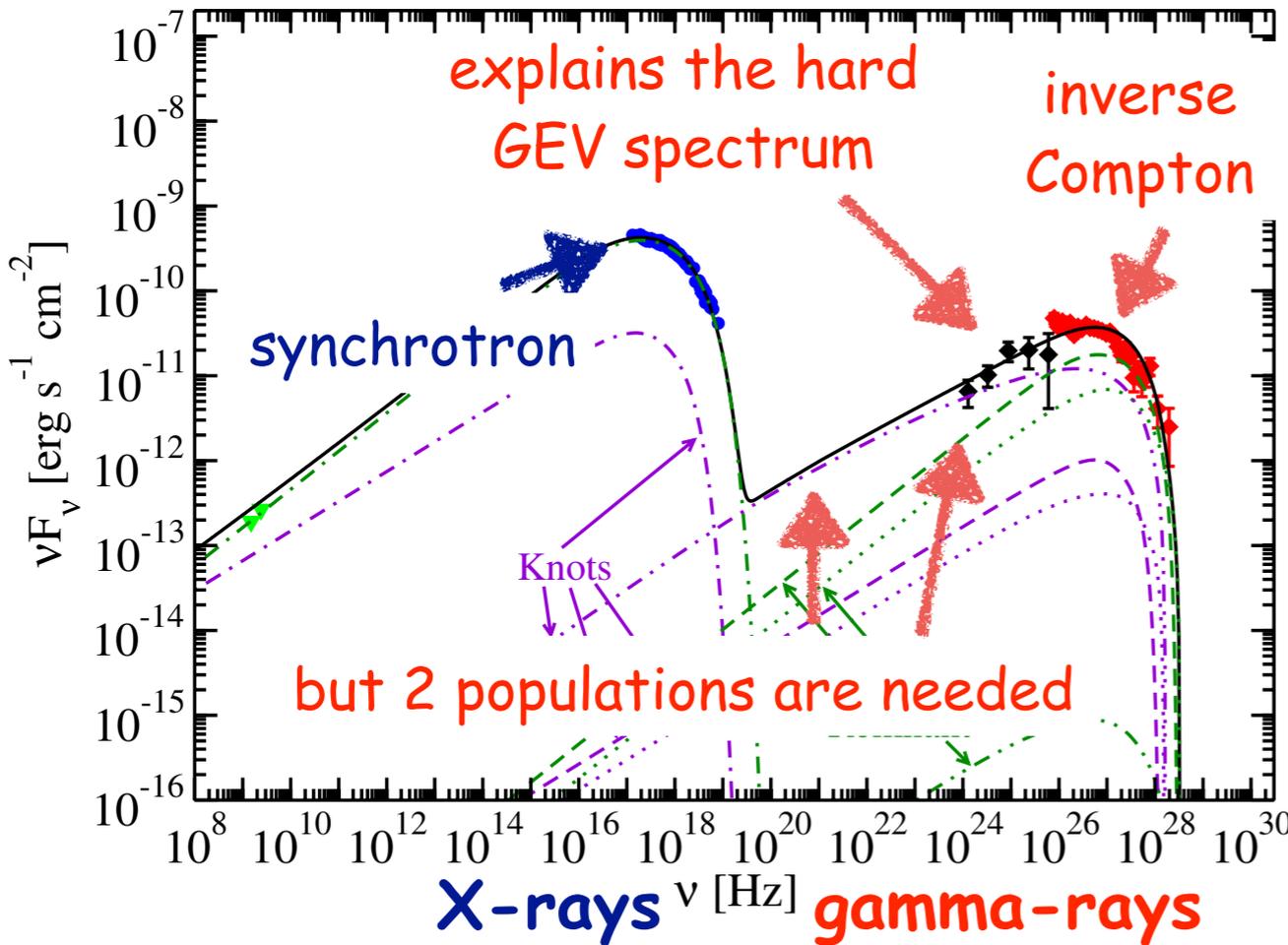
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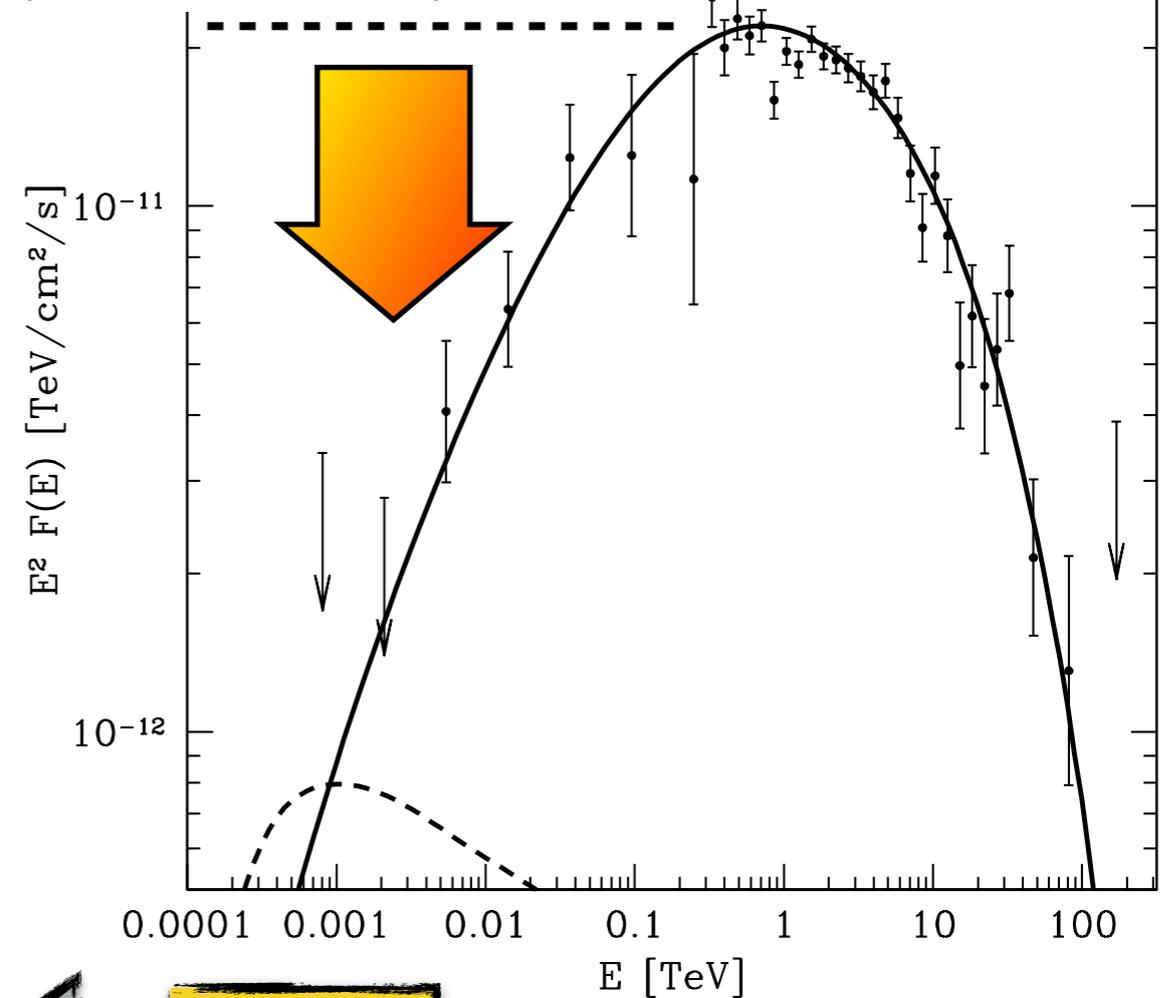
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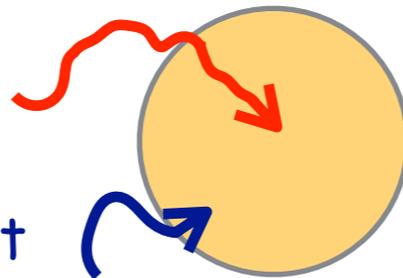
protons → flat spectrum



Gabici&Aharonian2014

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clumps!

see also Ellison+ 2010 for leptonic, Zirakashvili+ 2010, Fukui+2012 for hadronic

MeV

GeV

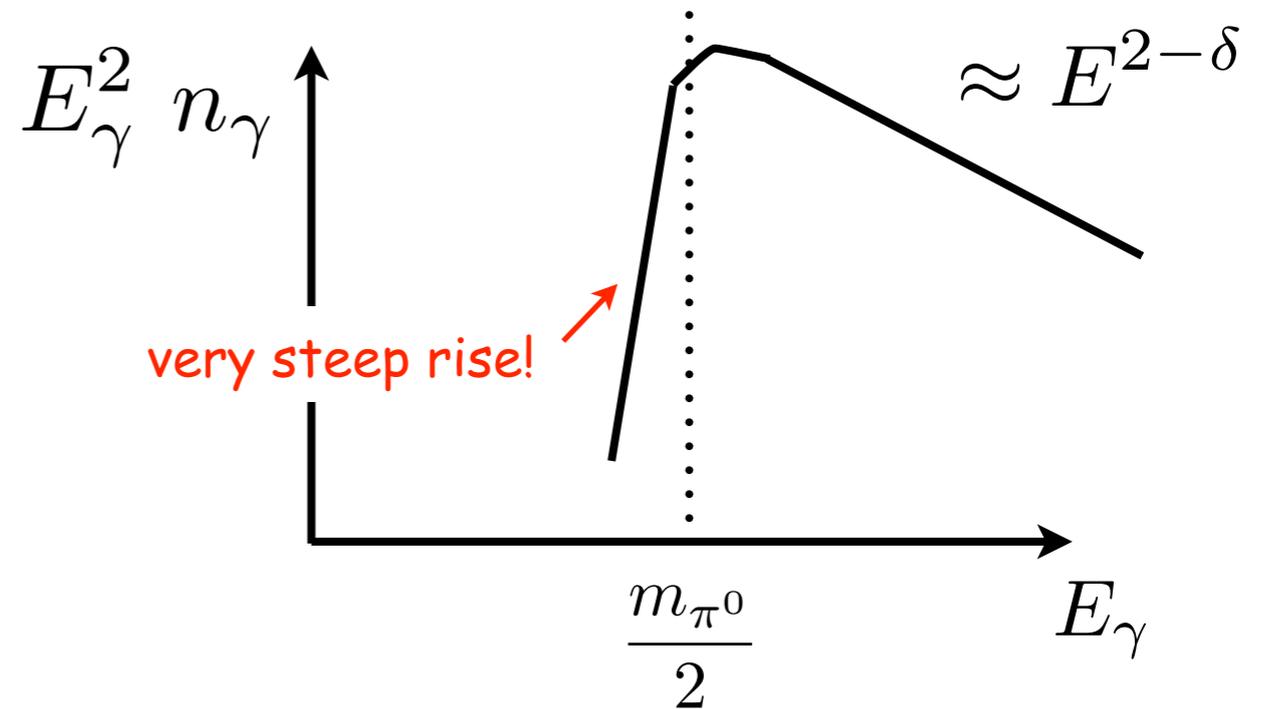
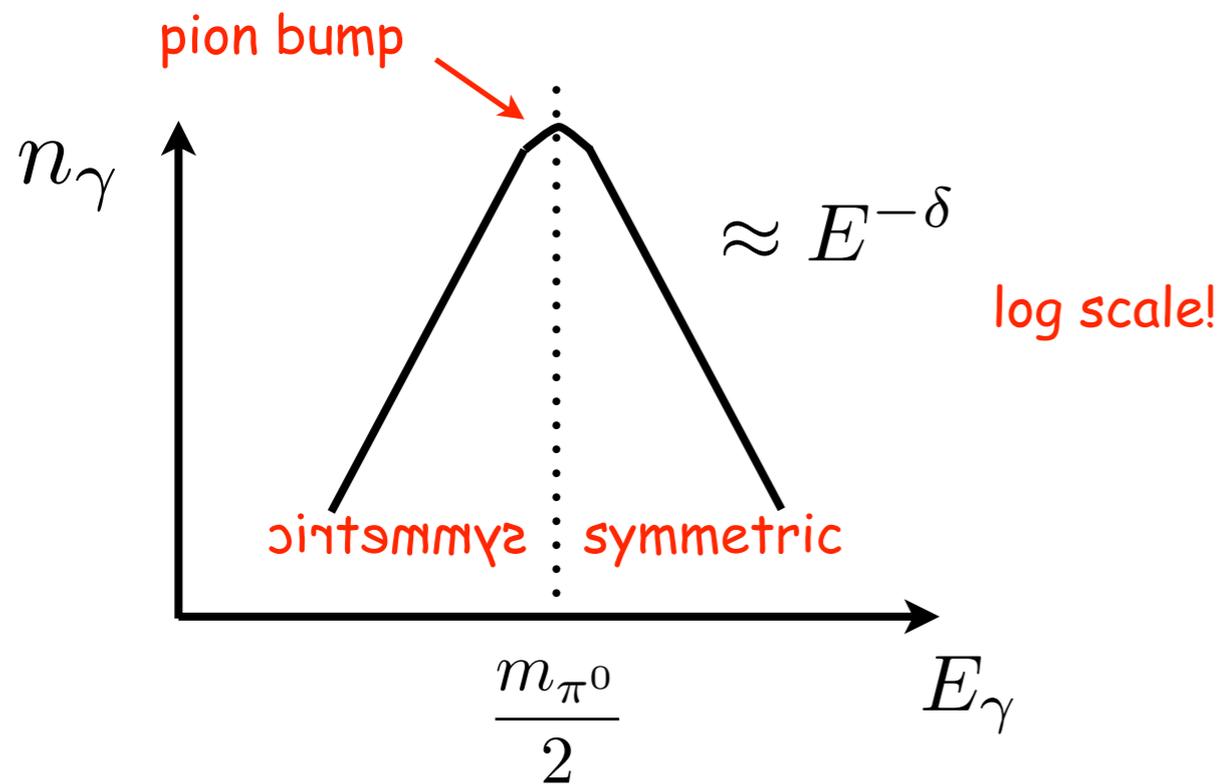
TeV

PeV

EeV

ZeV

Do SNRs accelerate protons?



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GeV

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Do SNRs accelerate protons?

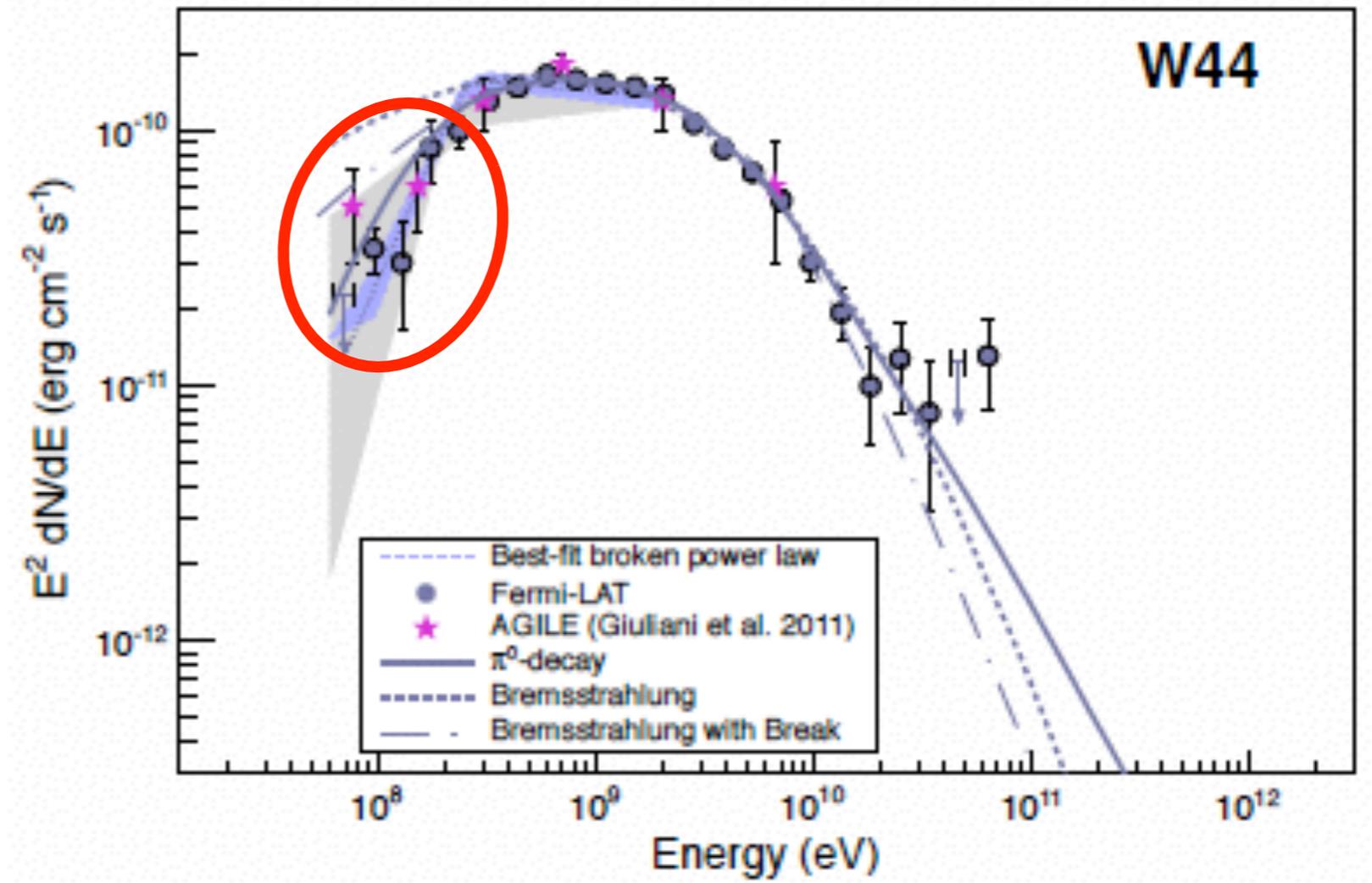
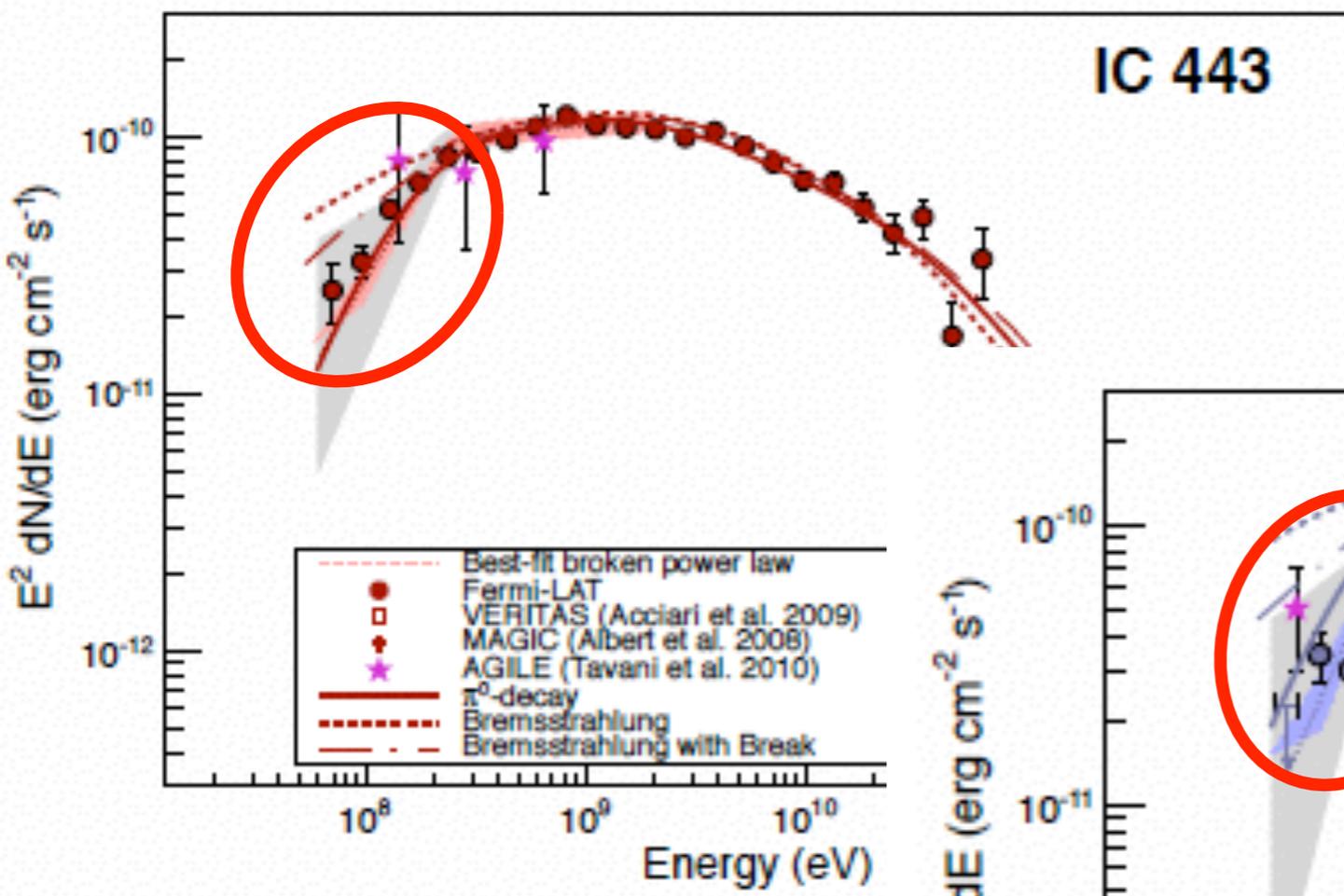
(Ackermann et al 2013)

FERMI (and **AGILE**)

(Giuliani+, Cardillo+)

n_γ ↑

$\approx E^{2-\delta}$



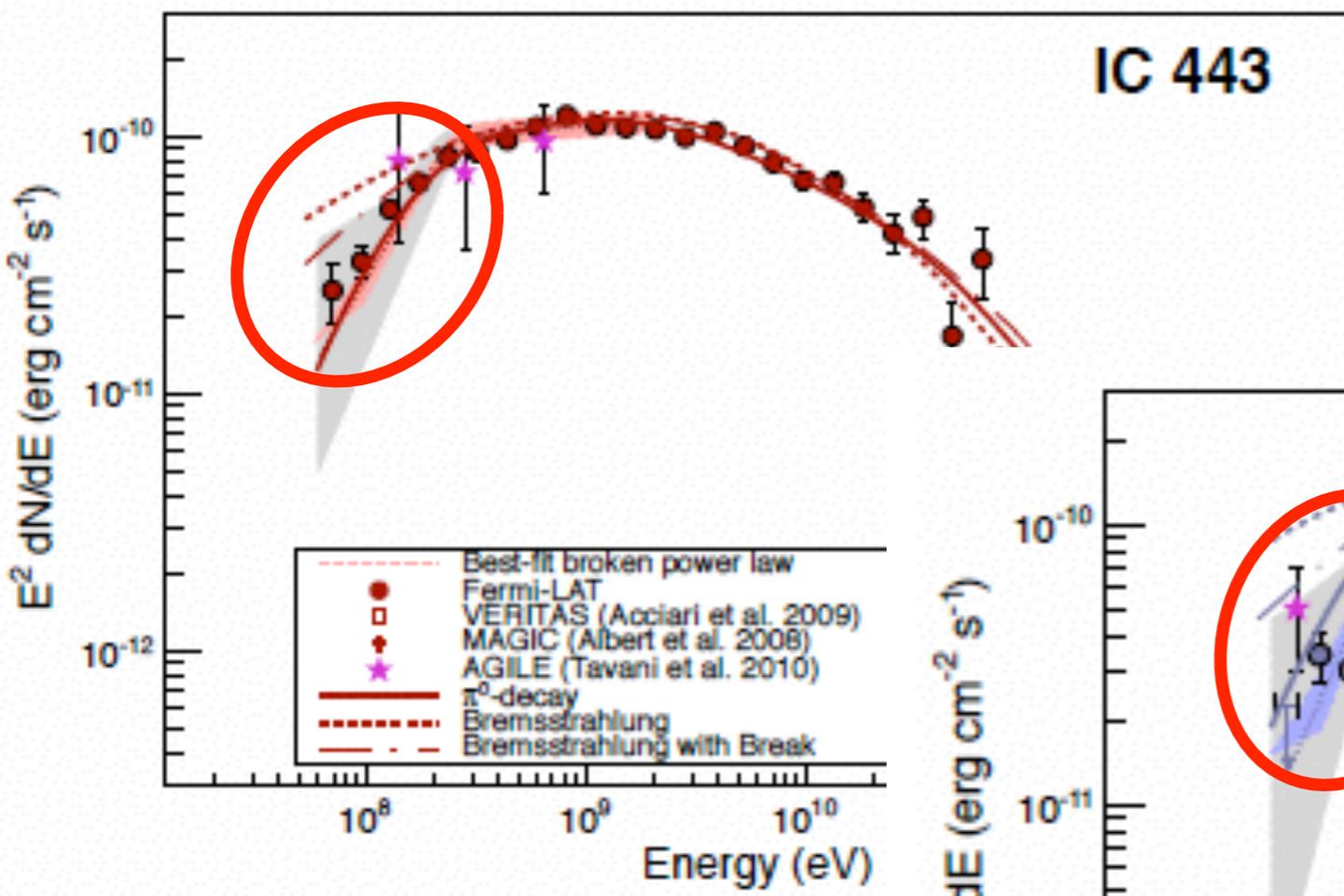
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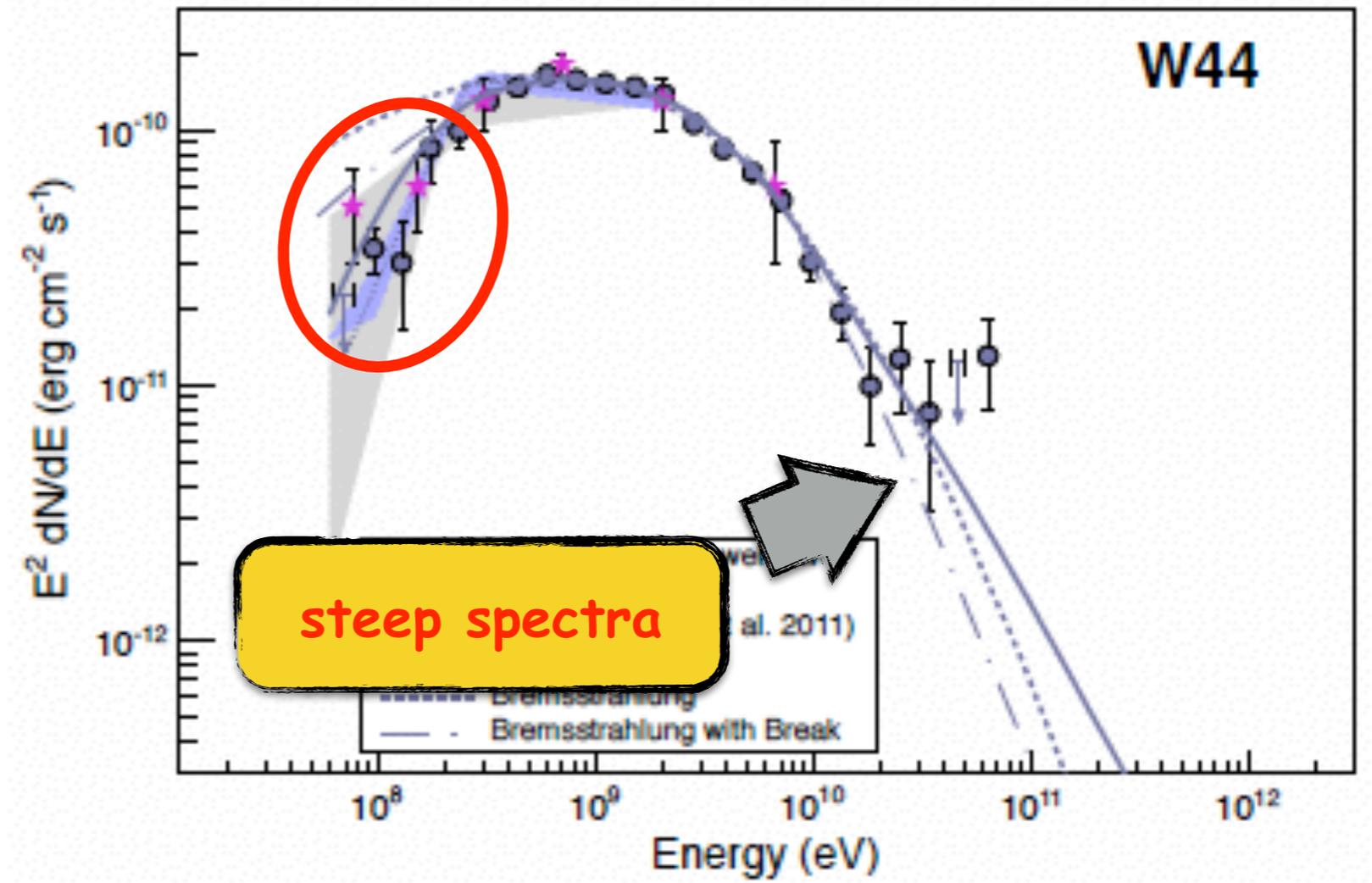
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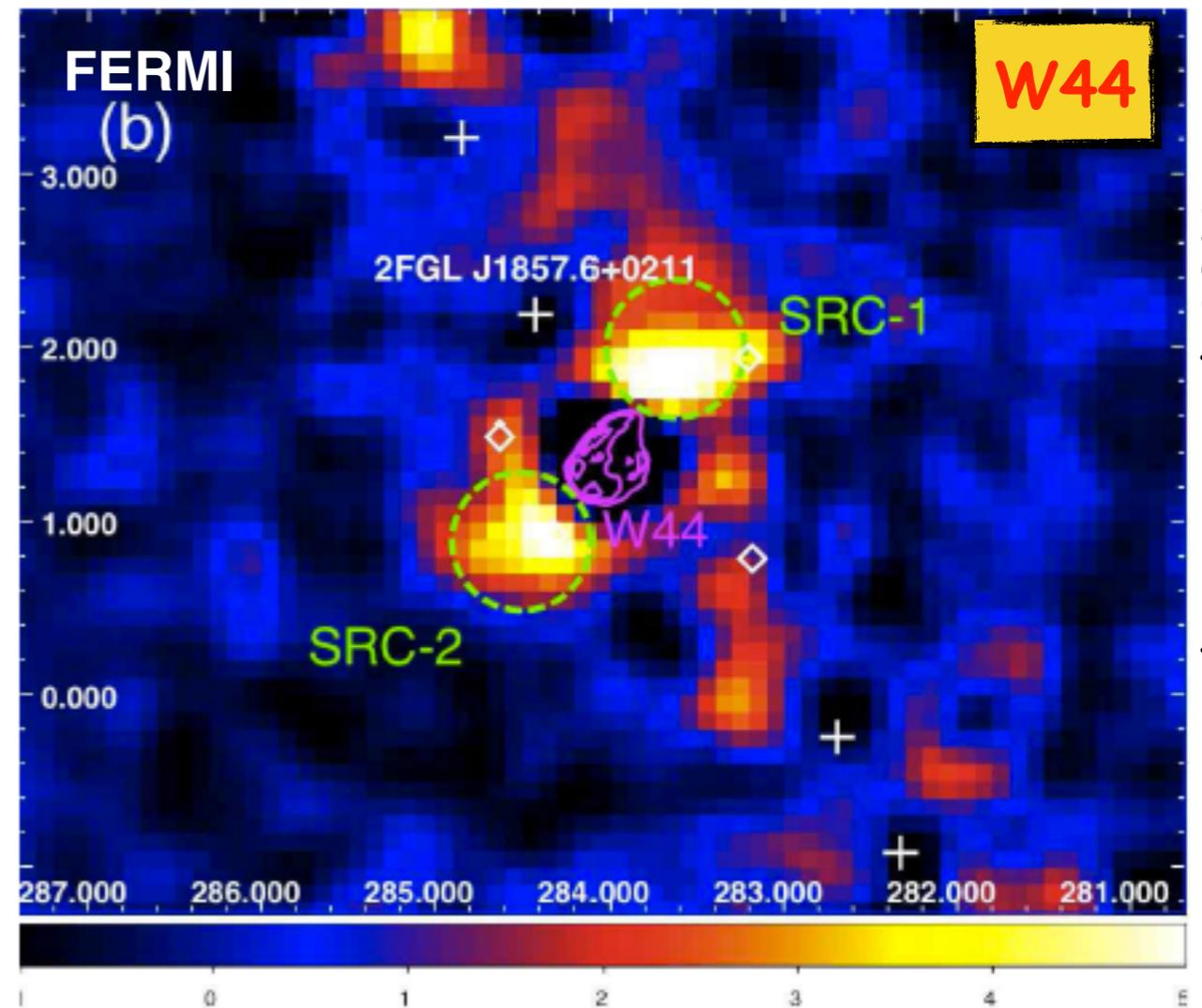
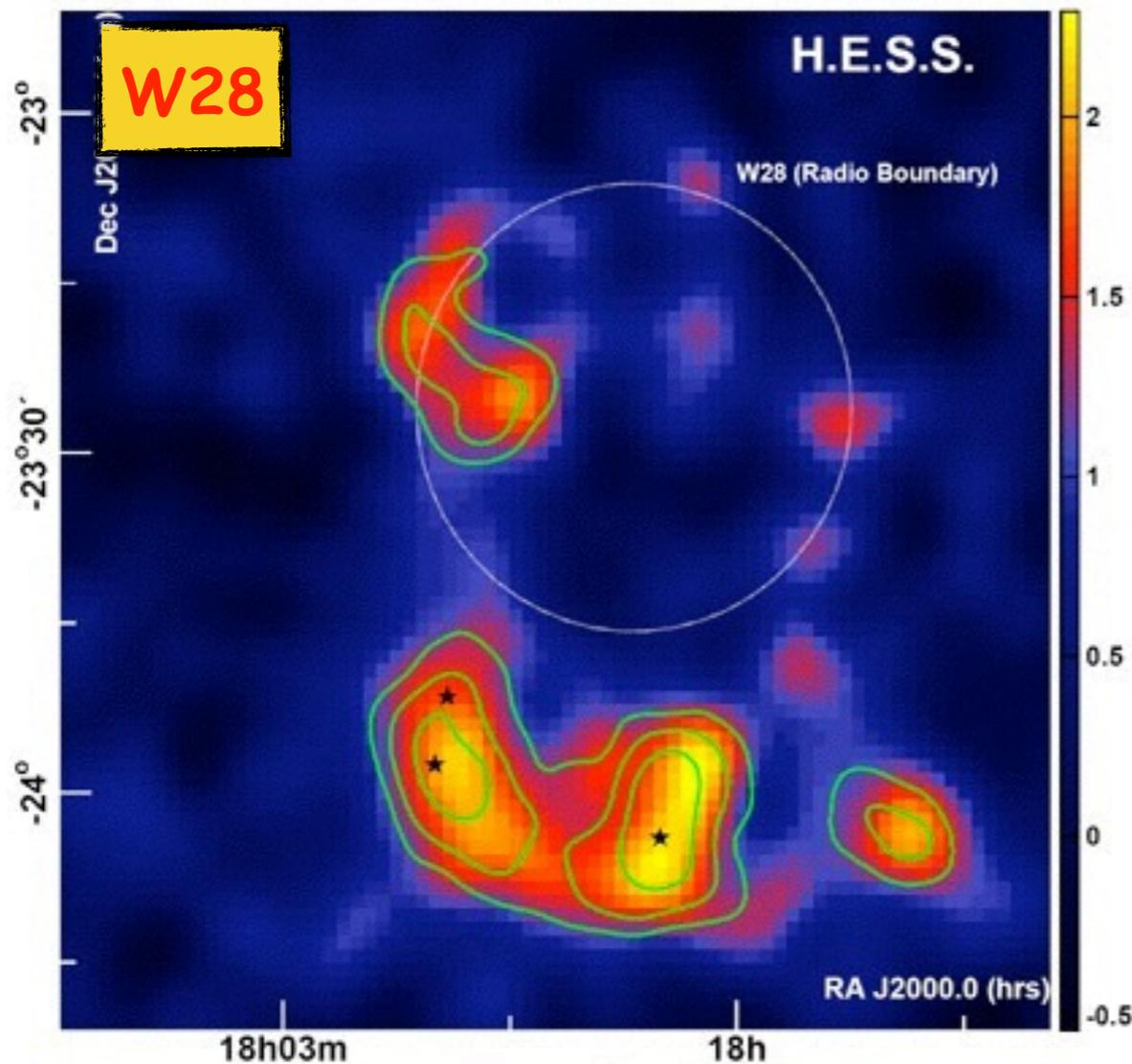
GeV CR are present
 -> we want SNR to be **PeVatrons** -> additional evidence required



MeV GeV TeV PeV EeV ZeV

Indirect evidence for protons: clouds

Aharonian et al. 2008



Uchiyama et al. 2012

MeV

GeV

TeV

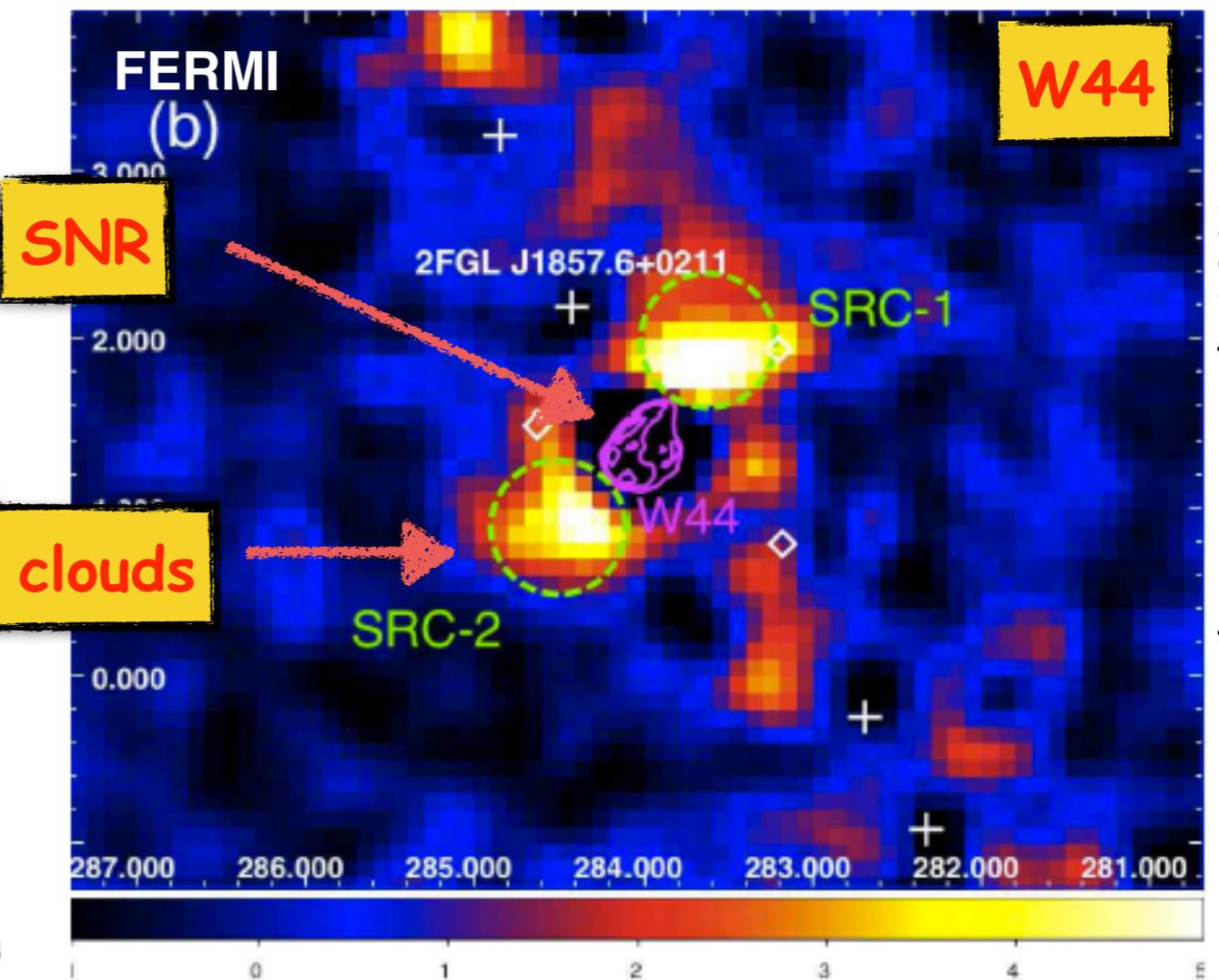
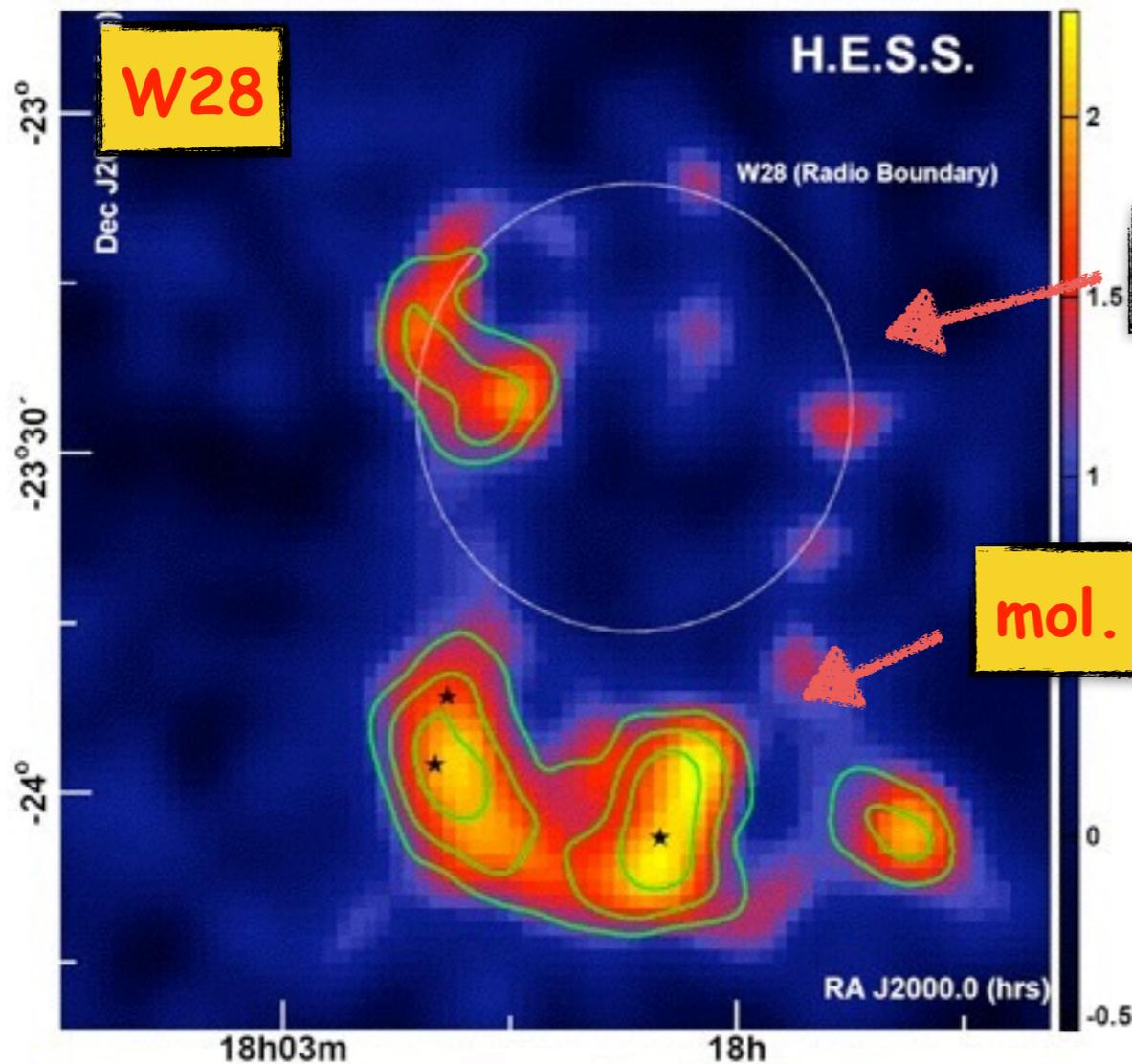
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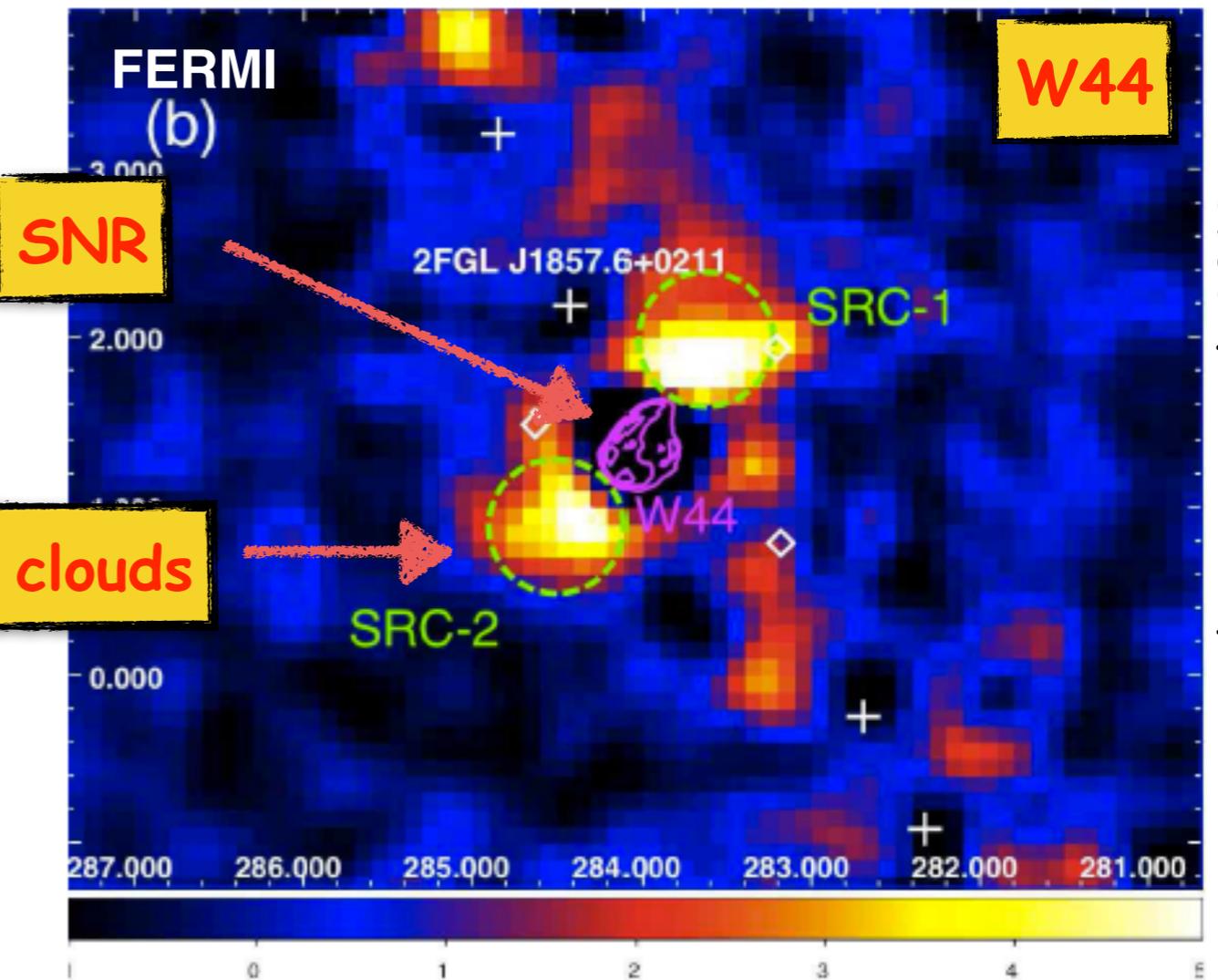
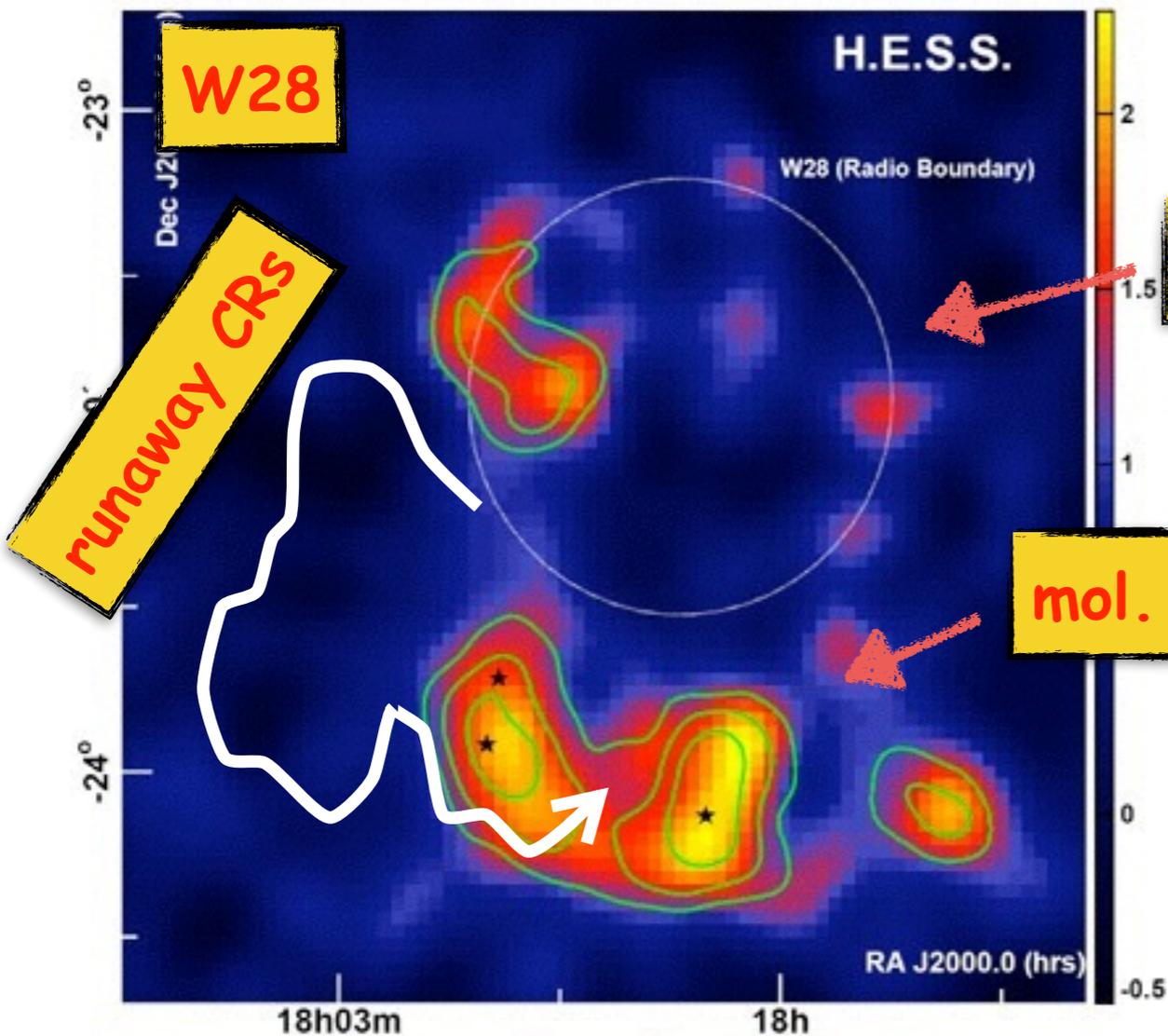
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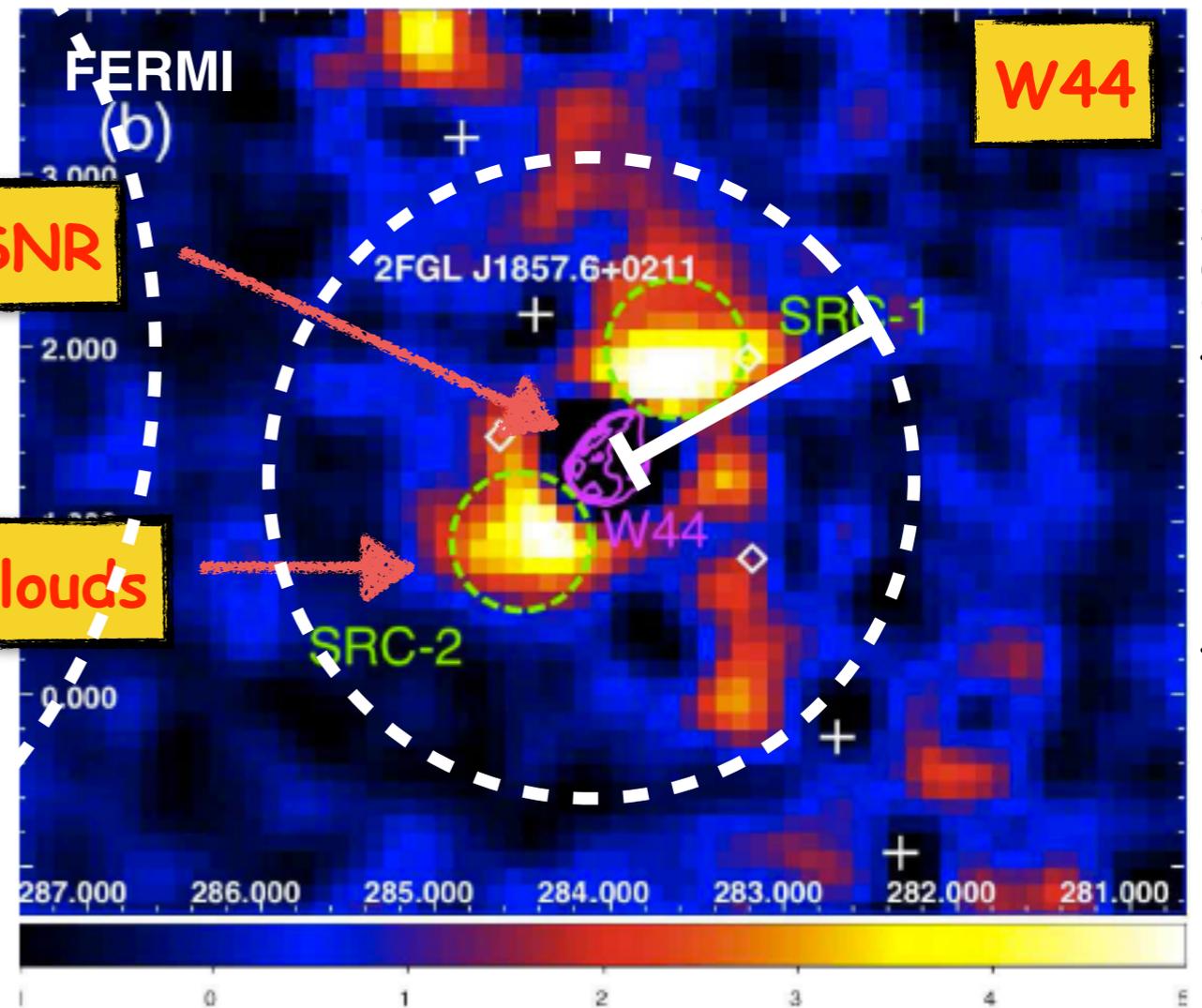
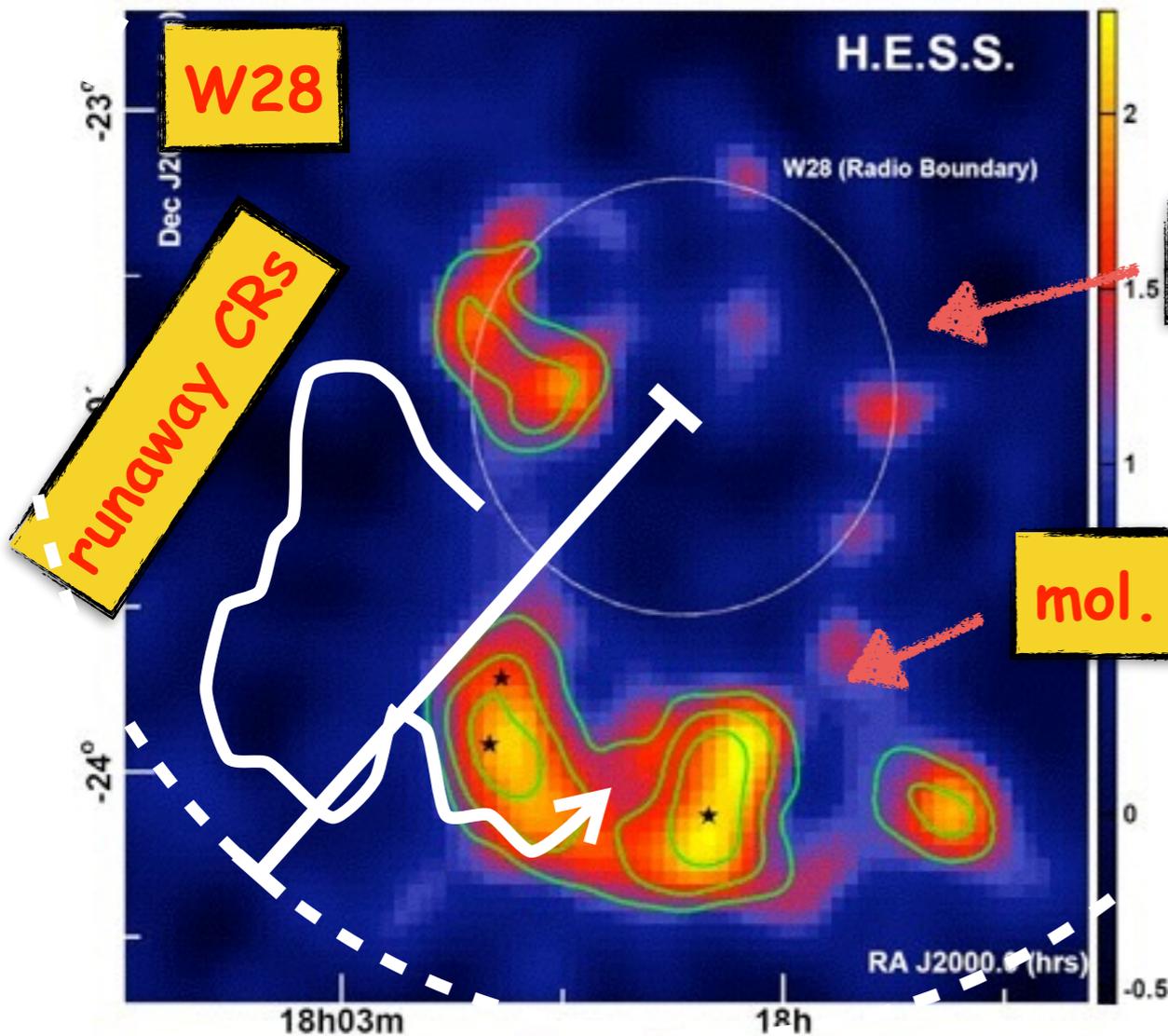
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Aharonian et al. 2008



Uchiyama et al. 2012

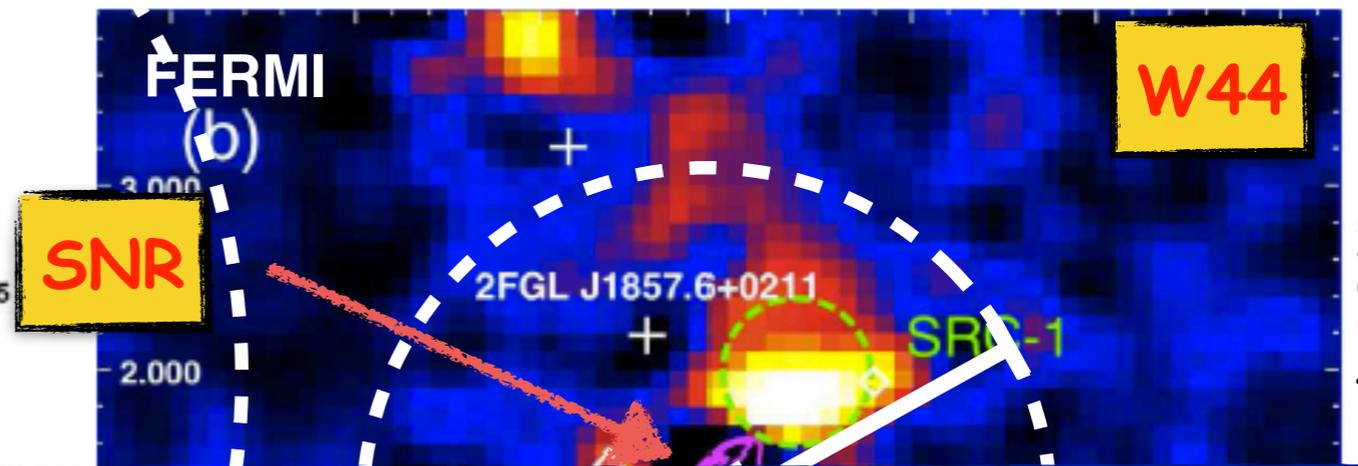
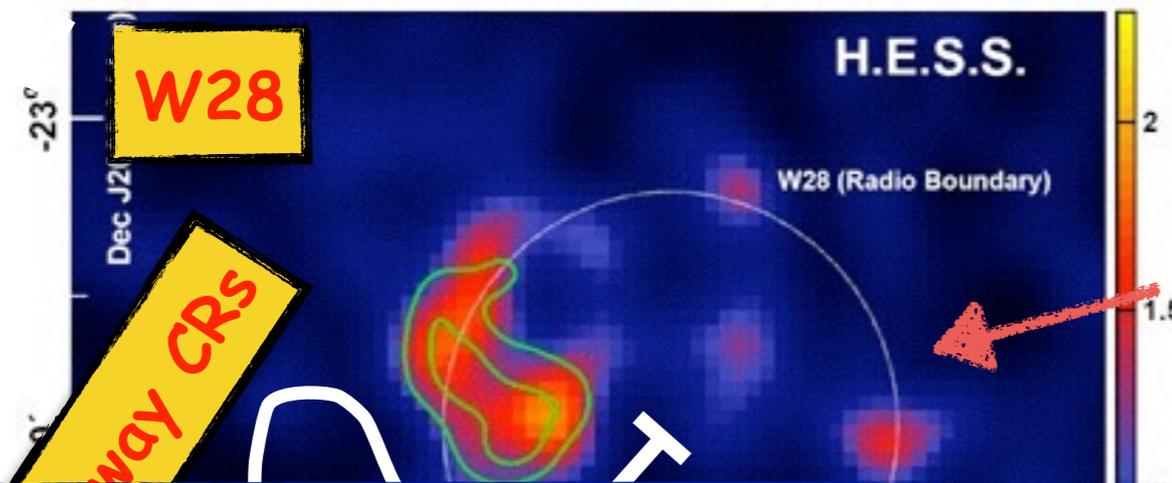
$$R_{diff} = \sqrt{6 D t}$$

for theoretical modeling see Aharonian & Atoyan, Gabici+, Casanova+, Nava & Gabici, Torres+, Li & Chen, Ohira+, Fujita+, Ellison&Bykov ...



Indirect evidence for protons: clouds

et al. 2008



et al. 2012

Direct (pion bump seen by FERMI&AGILE) and indirect (illuminated molecular clouds) evidence/hint for the acceleration of CR protons in SNRs.

Do SNRs accelerate ENOUGH protons?
Do they accelerate protons up to the knee?

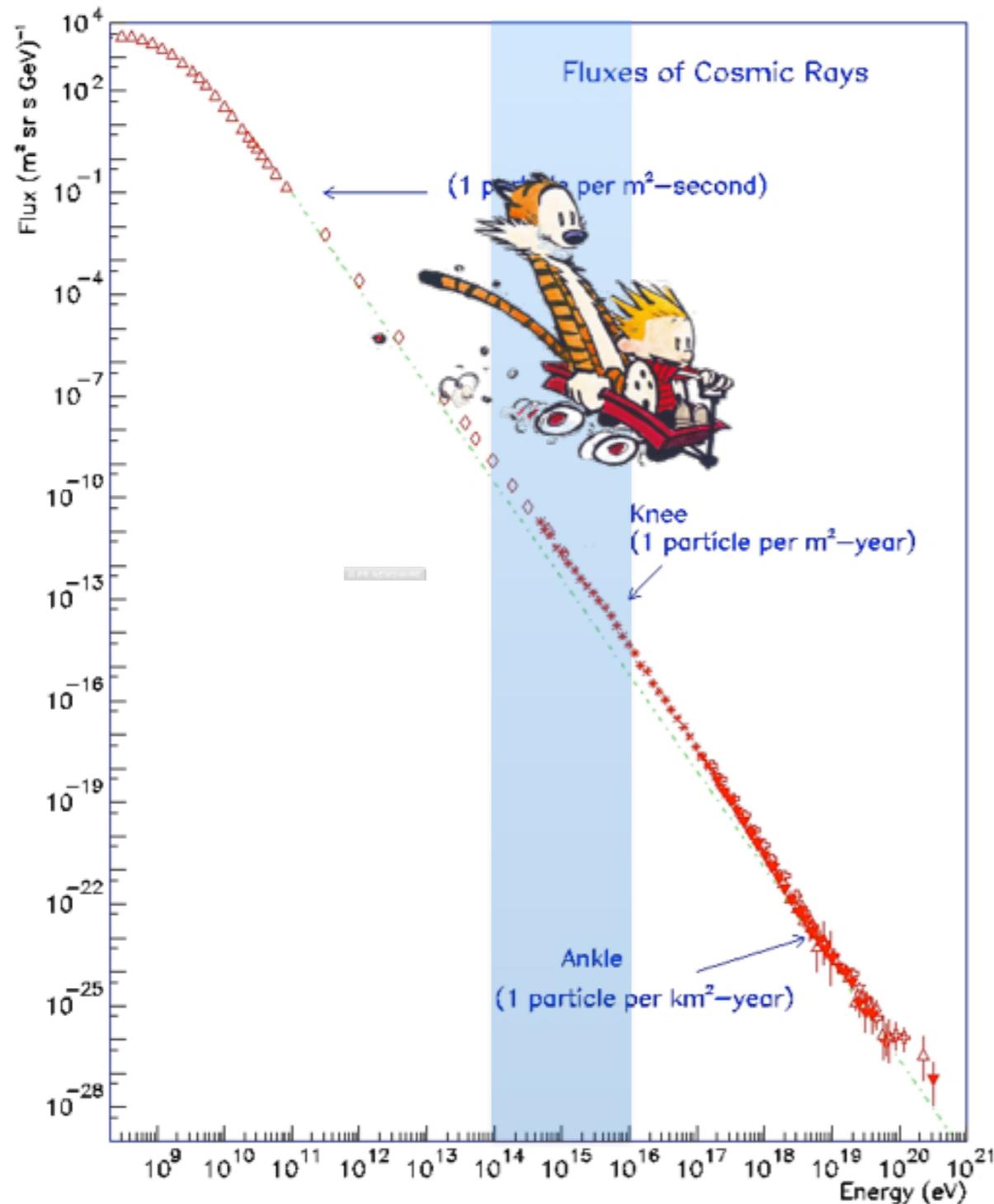


$$R_{diff} = \sqrt{6 D t}$$

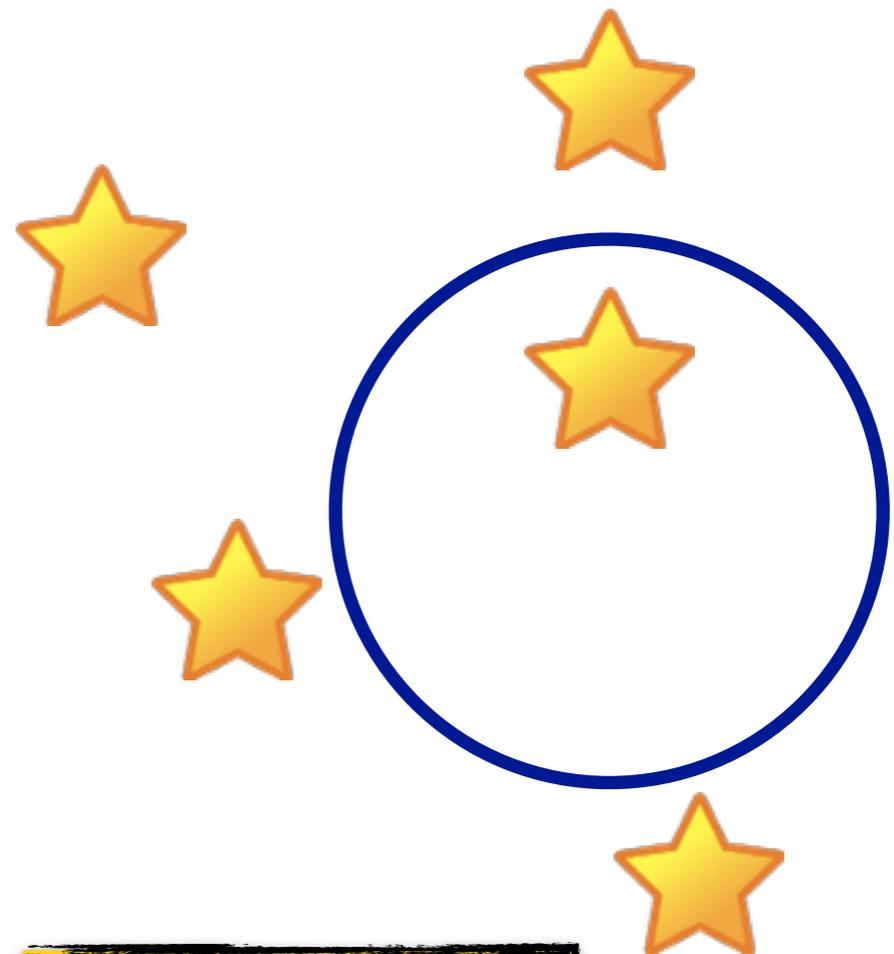
for theoretical modeling see Aharonian & Atoyan, Gabici+, Casanova+, Nava & Gabici, Torres+, Li & Chen, Ohira+, Fujita+, Ellison&Bykov ...



The PeV domain (100 TeV-10 PeV)



$$R_L(1 \text{ PeV}) \sim 0.36 \text{ pc}$$



still Galactic...

MeV

GeV

TeV

PeV

EeV

ZeV

The PeV domain: can we get to the knee?

Observations

Let's assume SNRs do accelerate up to the knee

p-p interactions -> $E_{max}^p \approx 4 \times 10^{15} \text{eV} \longrightarrow E_{max}^\gamma \approx 400 \text{TeV}$

inverse Compton -> suppressed above several tens of TeV (Klein-Nishina effect)

MeV

GeV

TeV

PeV

EeV

ZeV

The PeV domain: can we get to the knee?

Observations

Let's assume SNRs do accelerate up to

p-p interactions $\rightarrow E^p$

$$E^p \rightarrow E_{max}^\gamma \approx 400 \text{ TeV}$$

inverse

suppressed above several tens of TeV (Klein-Nishina effect)

testable with future gamma ray facilities: CTA, HAWC, HiSCORE, LHAASO

MeV

GeV

TeV

PeV

EeV

ZeV

The PeV domain: can we get to the knee?

Observations

Let's assume SNRs do accelerate up to 10^6 eV

p-p interactions $\rightarrow E^p$

$$E_{\text{TeV}} \rightarrow E_{\text{max}}^{\gamma} \approx 400 \text{ TeV}$$

inverse

testable with future gamma ray facilities: CTA, HAWC, HiSCORE, LHAASO
 suppressed above several tens of TeV (Klein-Nishina effect)

Theory

Hillas criterium \rightarrow

$$E_{\text{max}} \approx u R B$$

velocity \rightarrow u size \rightarrow R magnetic field \rightarrow B

MeV

GeV

TeV

PeV

EeV

ZeV

The PeV domain: can we get to the knee?

Observations

Let's assume SNRs do accelerate up to 10^6 eV

p-p interactions $\rightarrow E^p_{\text{TeV}} \rightarrow E_{\text{max}}^\gamma \approx 400 \text{ TeV}$

inverse Compton suppressed above several tens of TeV (Klein-Nishina effect)

testable with future gamma ray facilities: CTA, HAWC, HiSCORE, LHAASO

Theory

Hillas criterium \rightarrow

$$E_{\text{max}} \approx u R B$$

velocity
size
magnetic field

In numbers...

$$E_{\text{max}} \approx 1 \left(\frac{u}{1000 \text{ km/s}} \right) \left(\frac{R}{\text{pc}} \right) \left(\frac{B}{\mu\text{G}} \right) \text{ TeV}$$

MeV

GeV

TeV

PeV

EeV

ZeV

The PeV domain: can we get to the knee?

Observations

Let's assume SNRs do accelerate up to 10^6 eV

p-p interactions $\rightarrow E^p$ $\rightarrow E_{max}^\gamma \approx 400 \text{ TeV}$

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In numbers...

$$E_{max} \approx 1 \left(\frac{u}{1000 \text{ km/s}} \right) \left(\frac{R}{\text{pc}} \right) \left(\frac{B}{\mu\text{G}} \right) \text{ TeV}$$

~ 10
 ~ 3
 ~ 3

Lagage & Cesarsky 1983 $\rightarrow E_{max} \approx 100 \text{ TeV}$

well below the knee

MeV

GeV

TeV

PeV

EeV

ZeV

The PeV domain: can we get to the knee?

Observations

Let's assume SNRs do accelerate up to 10^6 eV

p-p interactions $\rightarrow E^p_{\text{TeV}} \rightarrow E^{\gamma}_{\text{max}} \approx 400 \text{ TeV}$

inverse Compton suppressed above several tens of TeV (Klein-Nishina effect)

inverse

testable with future gamma ray facilities: CTA, HAWC, HiSCORE, LHAASO

Theory

Hillas criterium \rightarrow

$$E_{\text{max}} \approx u R B$$

velocity \rightarrow
size \rightarrow
magnetic field \rightarrow

In numbers...

B is the only parameter we can play with

$$\left(\frac{B}{\mu\text{G}} \right) \text{ TeV}$$

~3

Lagage & Cesarsky 1983 $\rightarrow E_{\text{max}} \approx 100 \text{ TeV}$

well below the knee

MeV

GeV

TeV

PeV

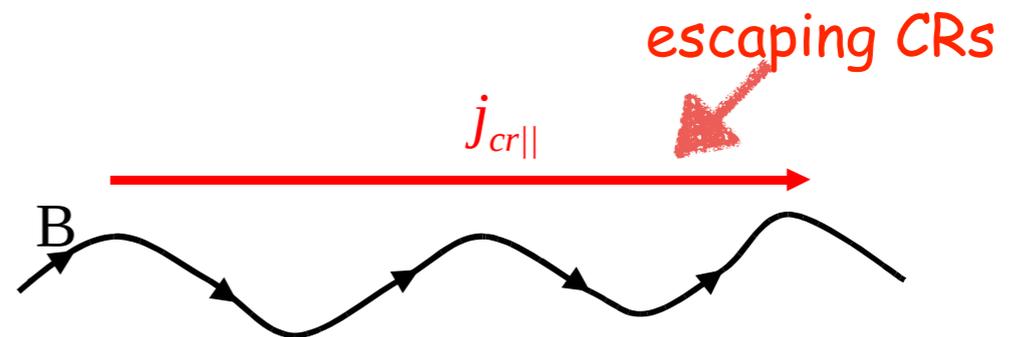
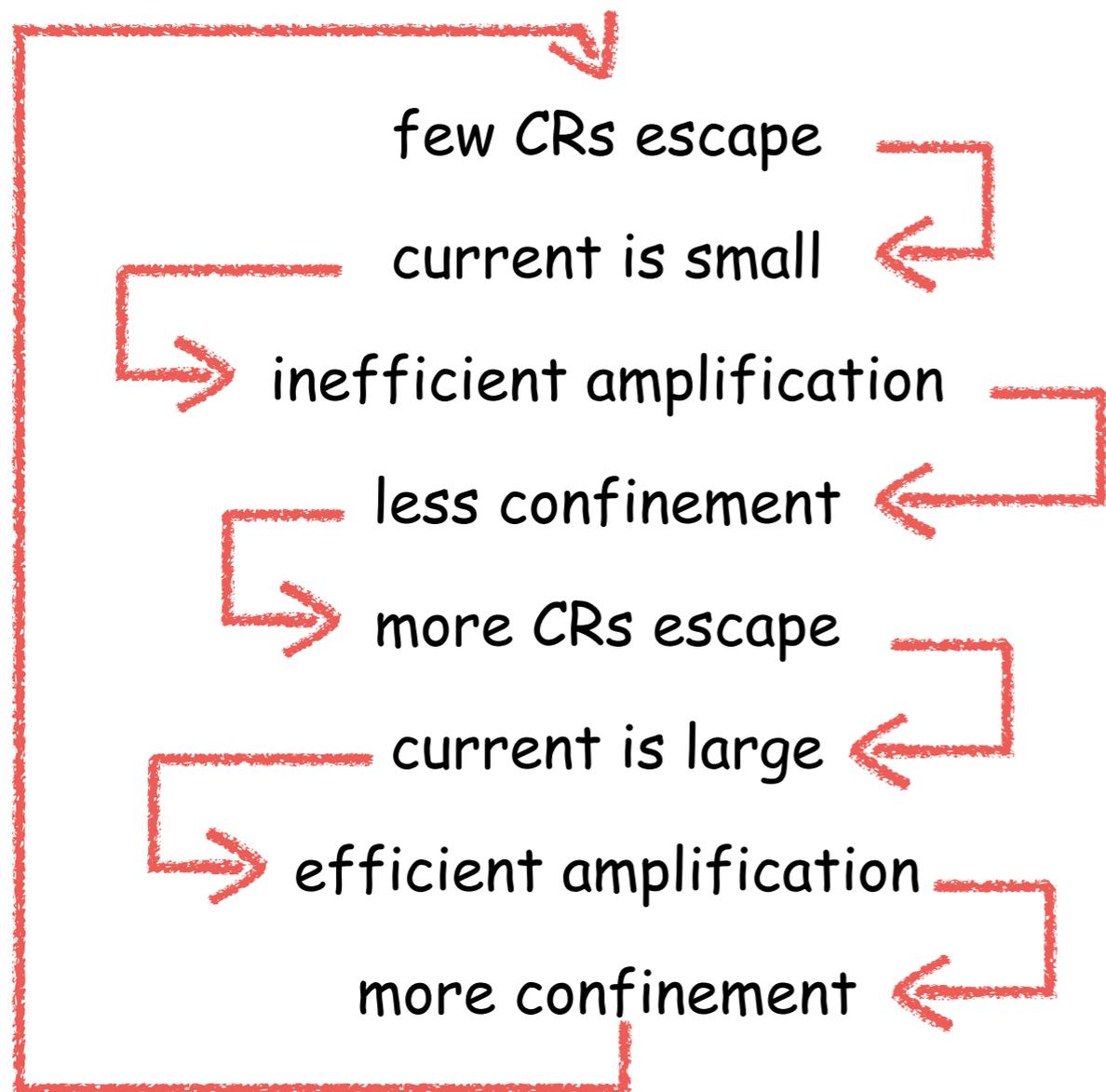
EeV

ZeV

The PeV domain: can we get to the knee?

CR current-driven instability: a self-regulating mechanism

Bell 2004



Bell et al. 2013

see also Caprioli&Spitkovski,Ptuskin&Zirakashvili,Amato&Blasi, Bykov+, ...

MeV

GeV

TeV

PeV

EeV

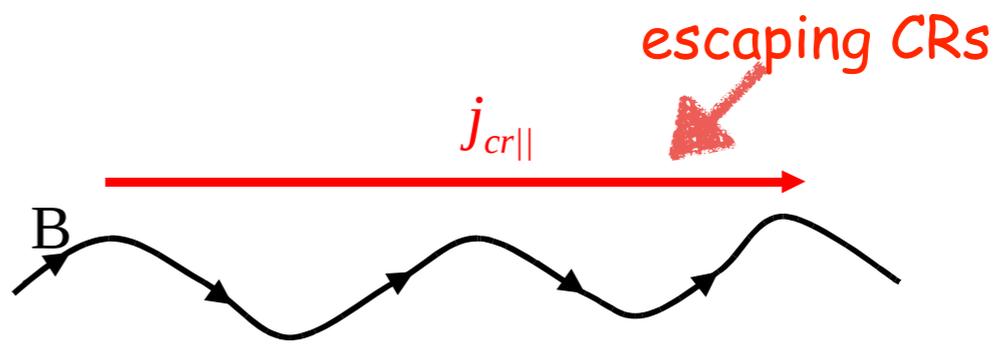
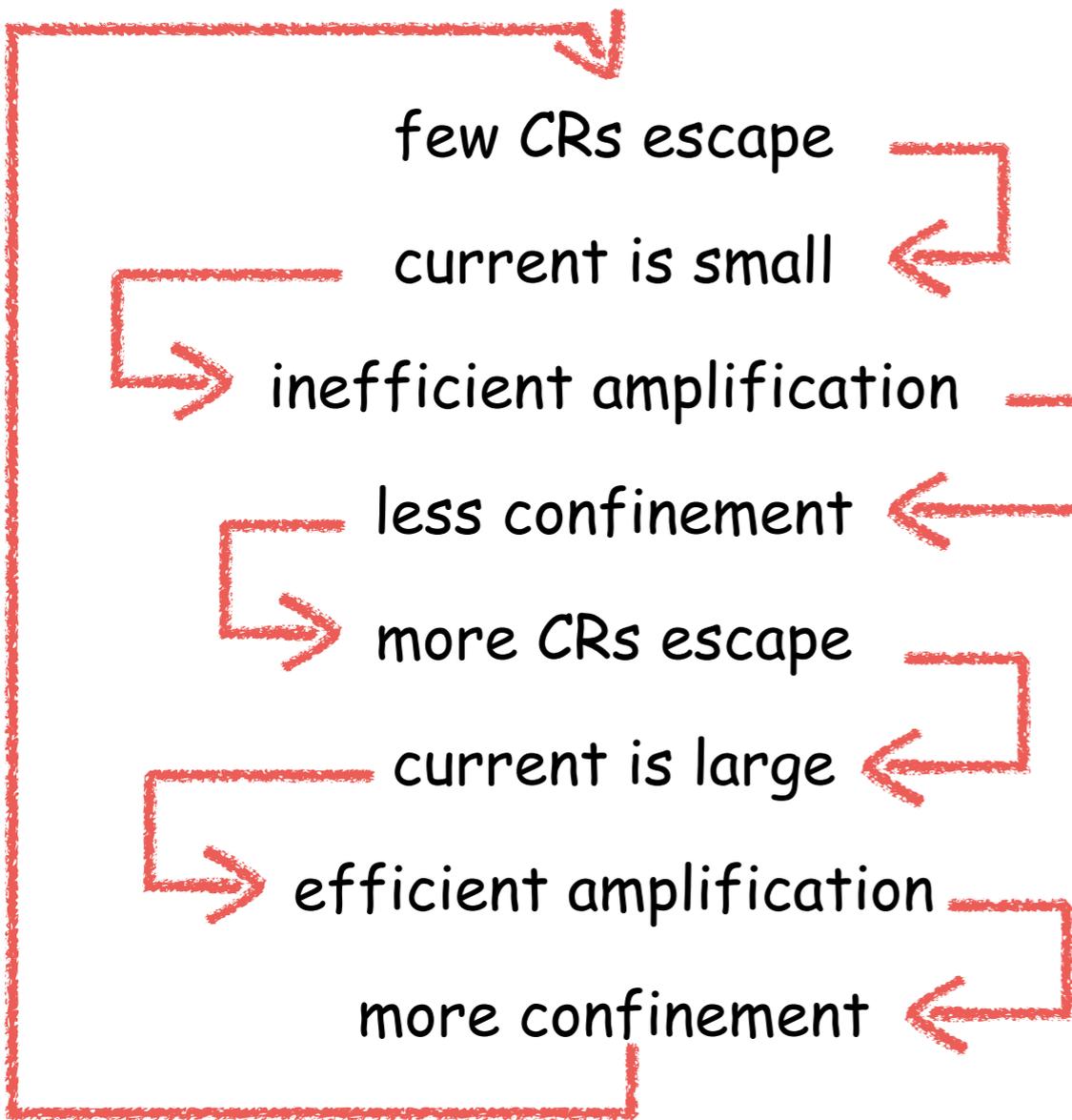
ZeV

The PeV domain: can we get to the knee?

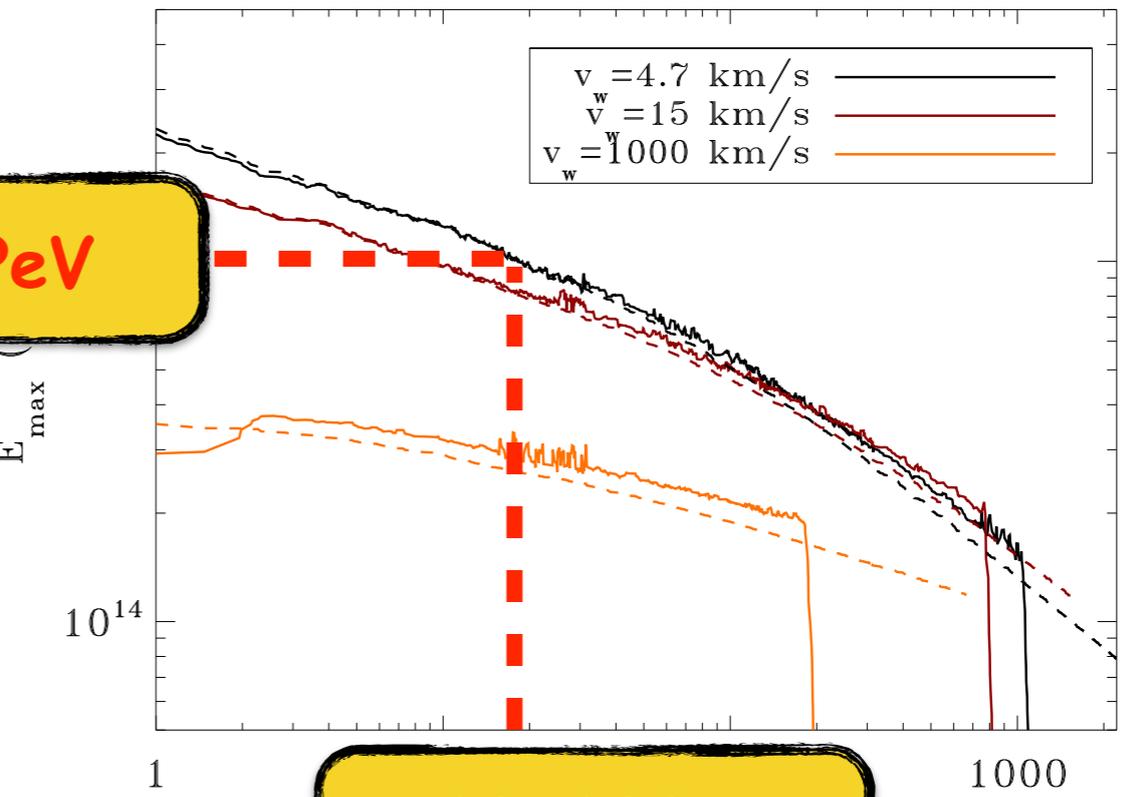
CR current-driven instability: a self-regulating mechanism

Bell 2004

Schure & Bell 2013/2014



PeV



~10-100 yr

age of the SNR

Bell et al. 2013

see also Caprioli&Spitkovski, Ptuskin&Zirakashvili, Amato&Blasi, Bykov+, ...

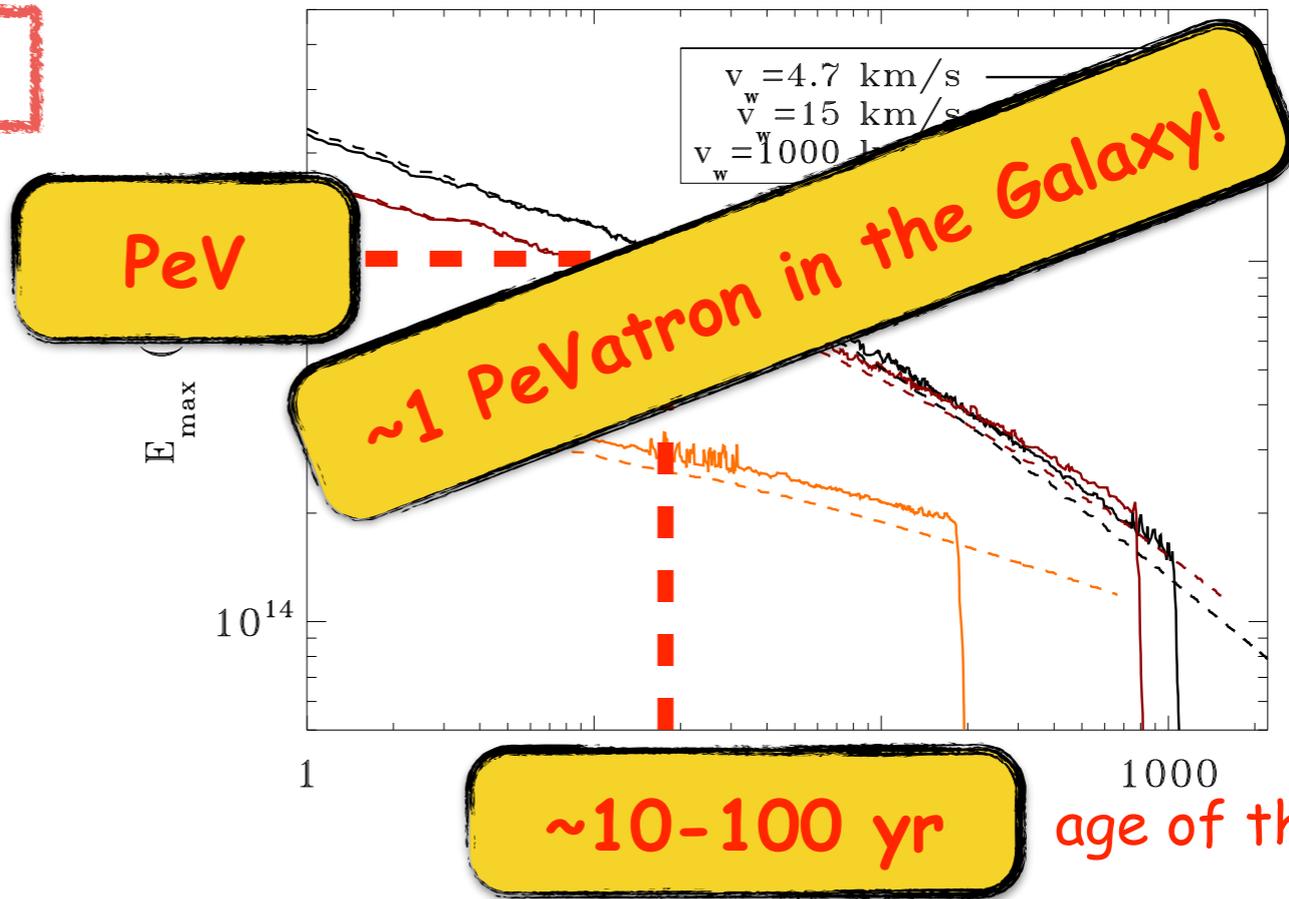
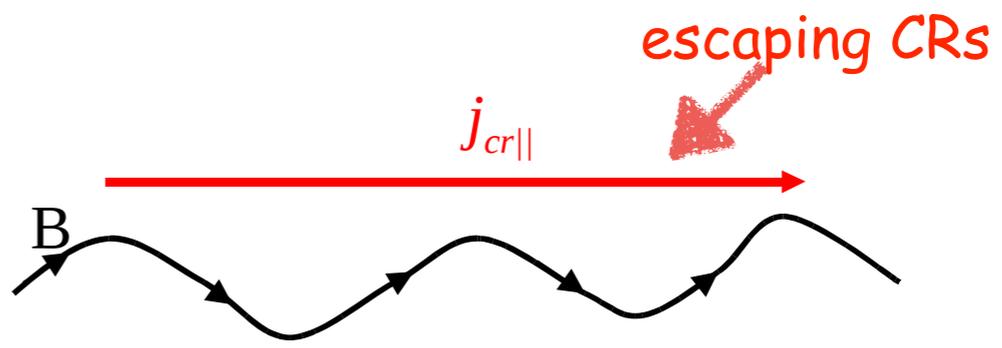
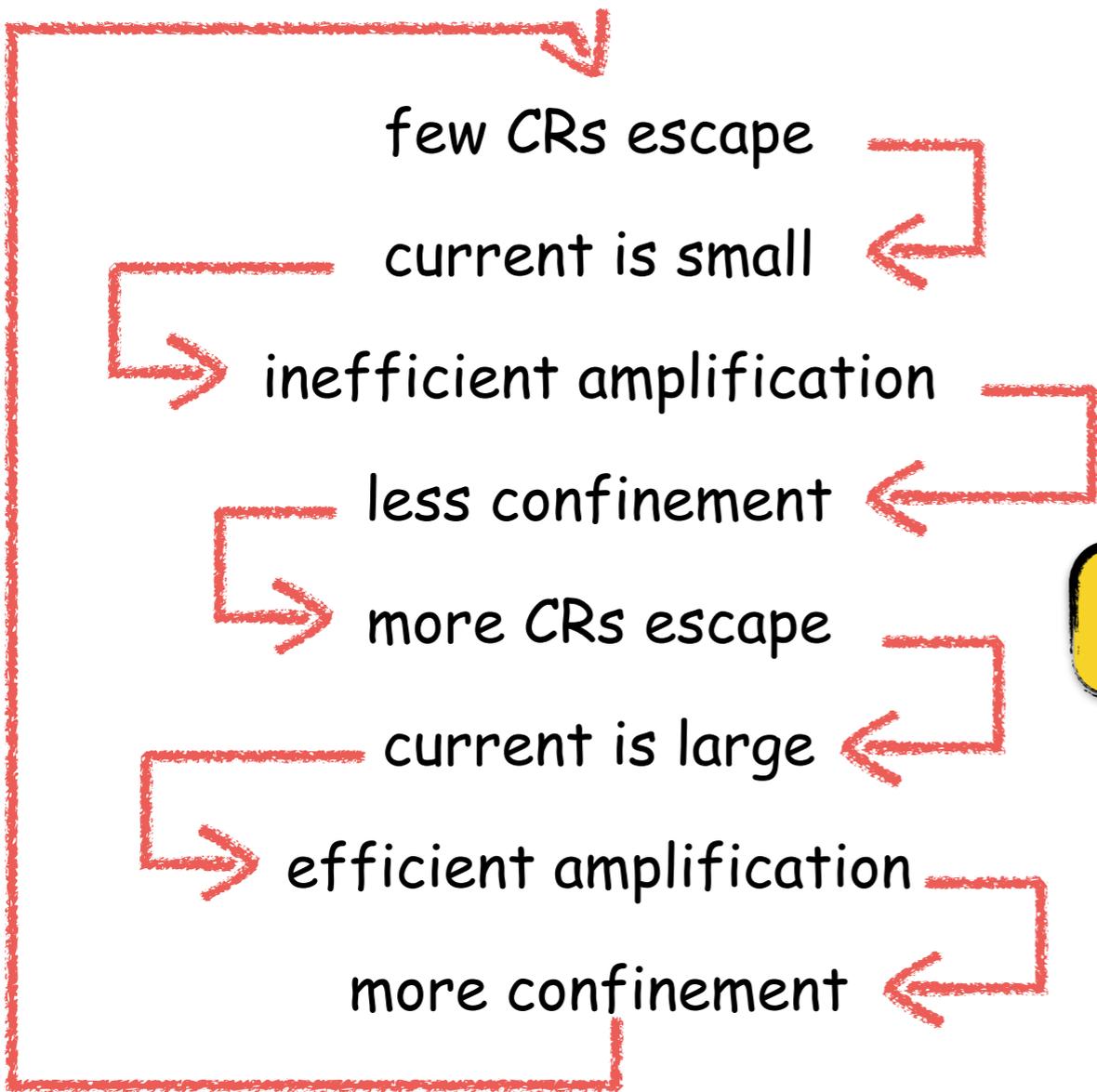


The PeV domain: can we get to the knee?

CR current-driven instability: a self-regulating mechanism

Bell 2004

Schure & Bell 2013/2014



Bell et al. 2013

see also Caprioli&Spitkovski, Ptuskin&Zirakashvili, Amato&Blasi, Bykov+, ...



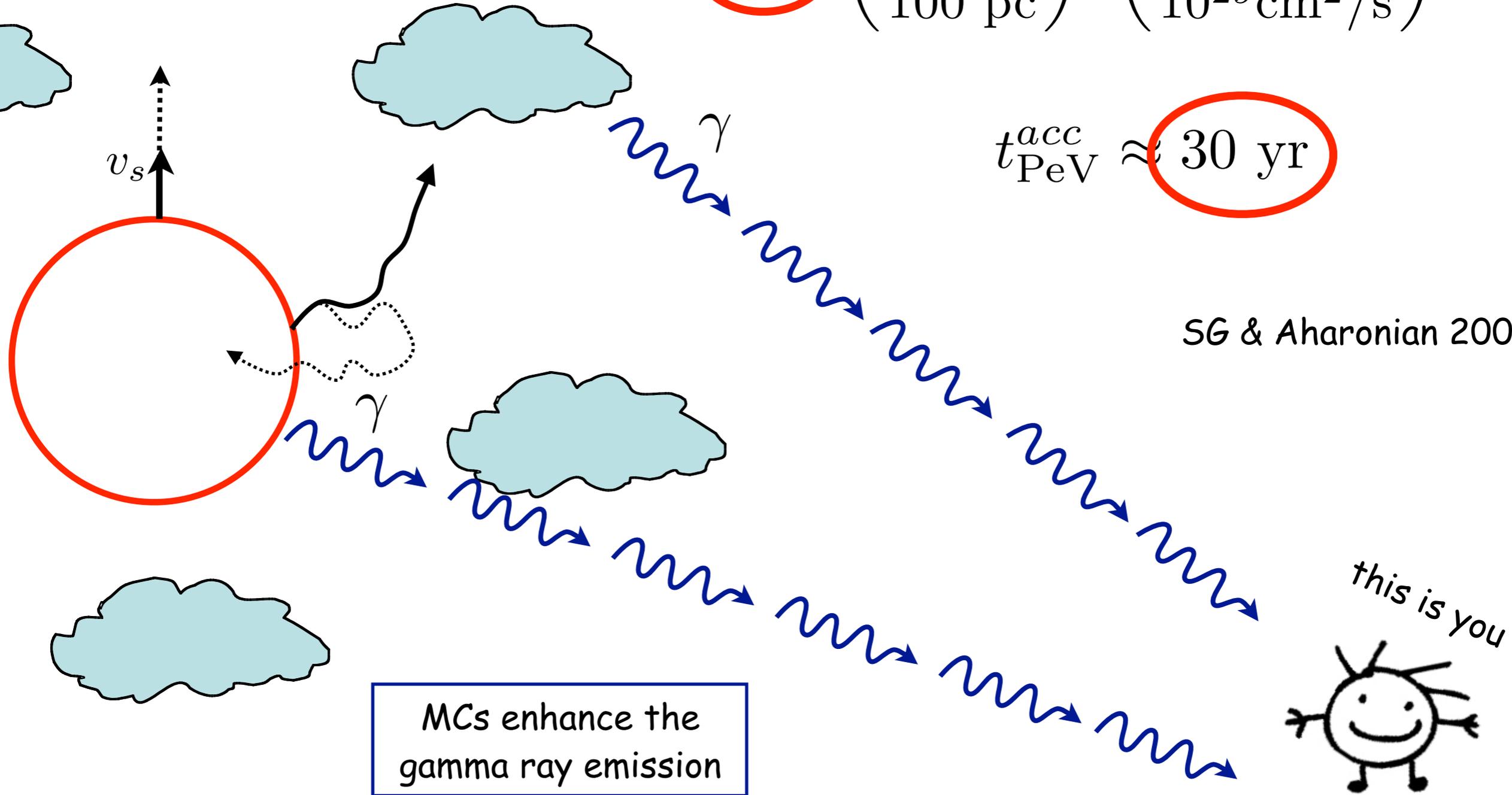
Indirect detection of PeVatrons?

CRs escape the SNR

$$t_{\text{PeV}}^{\text{diff}} \approx 5000 \left(\frac{d}{100 \text{ pc}} \right)^2 \left(\frac{D_{\text{PeV}}}{10^{29} \text{ cm}^2/\text{s}} \right)^{-1} \text{ yr}$$

$$t_{\text{PeV}}^{\text{acc}} \approx 30 \text{ yr}$$

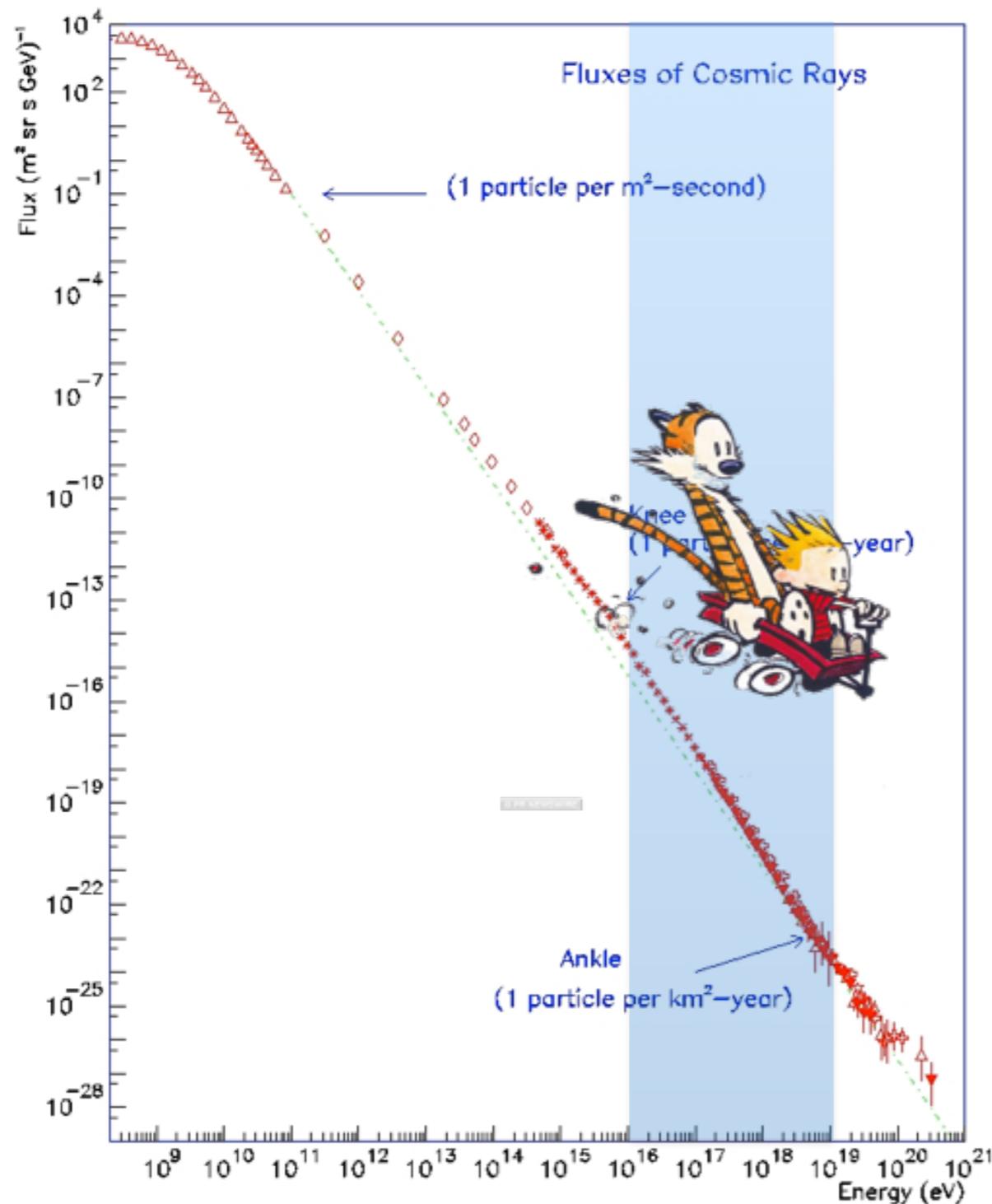
SG & Aharonian 2007



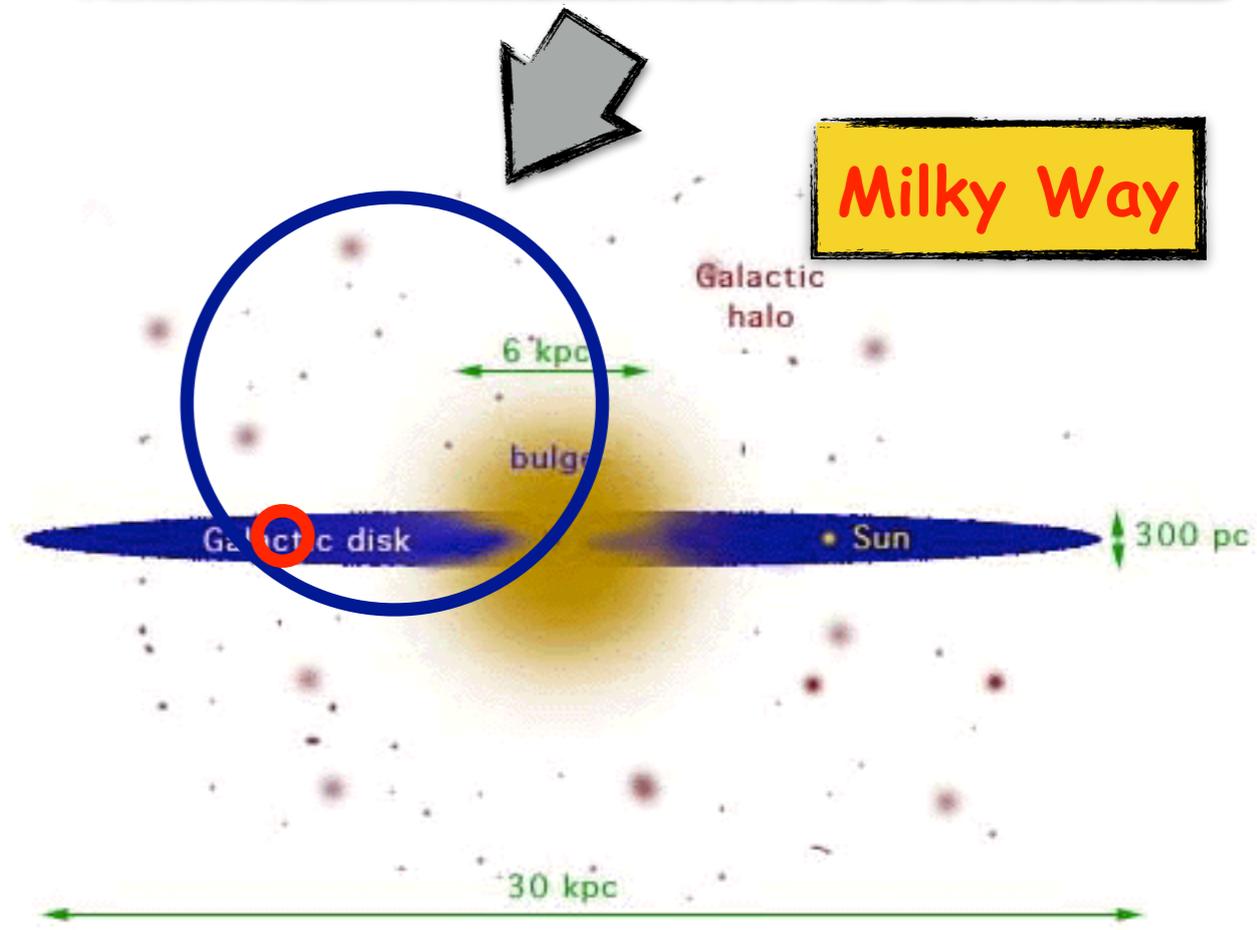
MCs enhance the gamma ray emission



The EeV domain (10^{16} eV - 10^{19} eV)



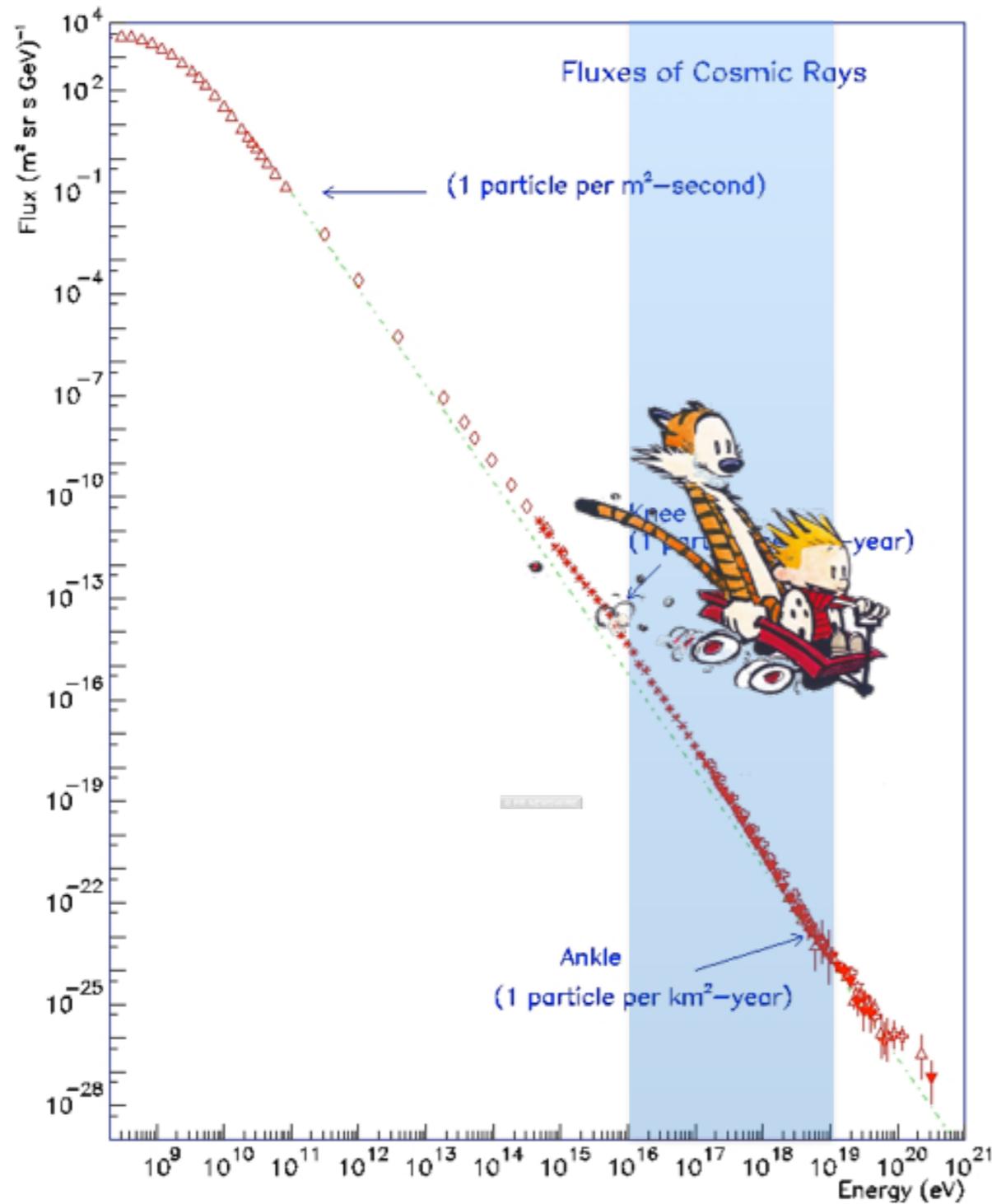
$$R_L(10^{19} \text{ eV}) \sim 3.6 \text{ kpc}$$



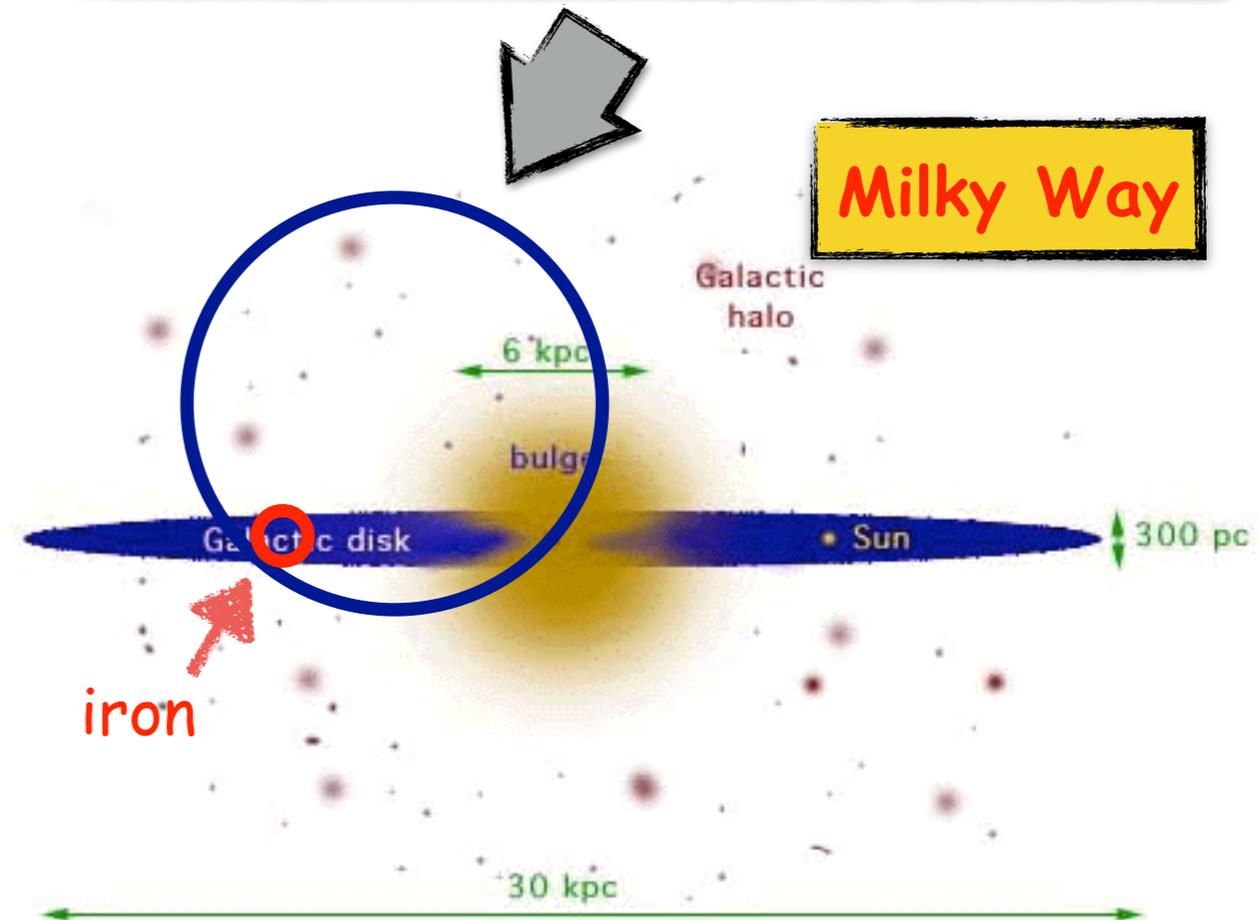
Transition from Galactic to extra-galactic Cosmic Rays

MeV GeV TeV PeV **EeV** ZeV

The EeV domain (10^{16} eV - 10^{19} eV)



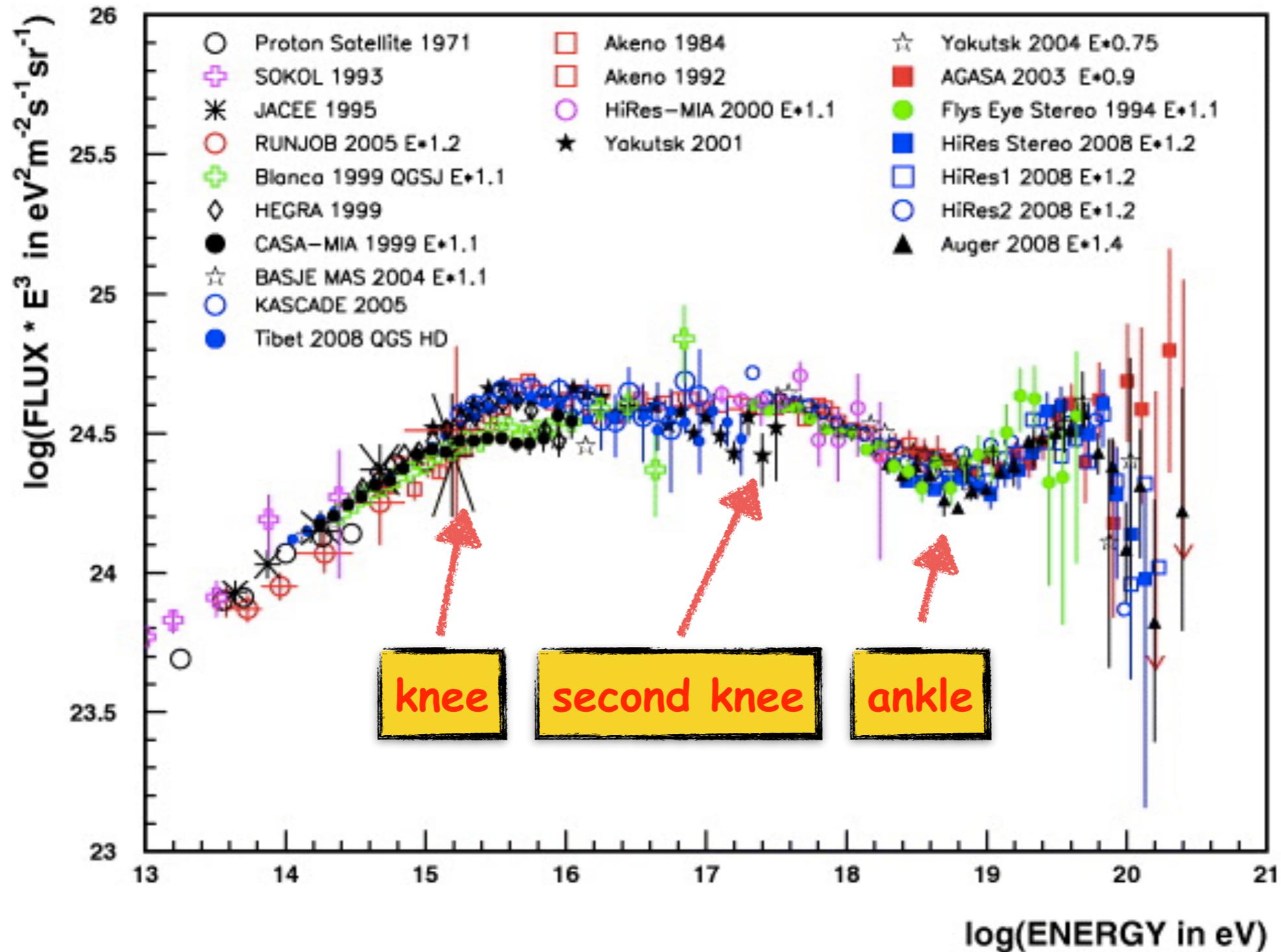
$$R_L(10^{19} \text{ eV}) \sim 3.6 \text{ kpc}$$



Transition from Galactic to extra-galactic Cosmic Rays

MeV GeV TeV PeV **EeV** ZeV

The EeV domain: Galactic-Extragalactic



MeV

GeV

TeV

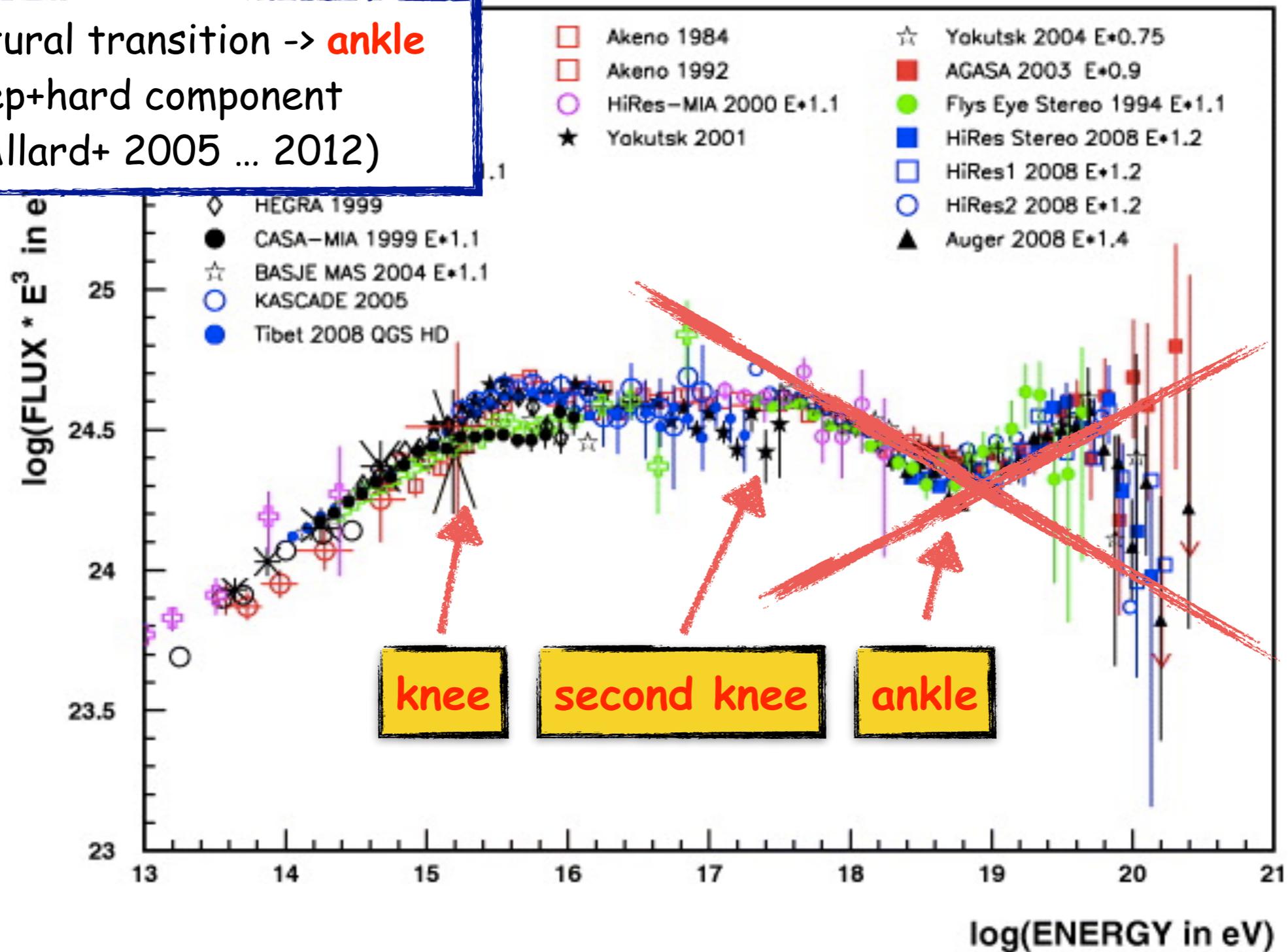
PeV

EeV

ZeV

The EeV domain: Galactic-Extragalactic

most natural transition -> **ankle**
 steep+hard component
 (e.g. Allard+ 2005 ... 2012)



MeV

GeV

TeV

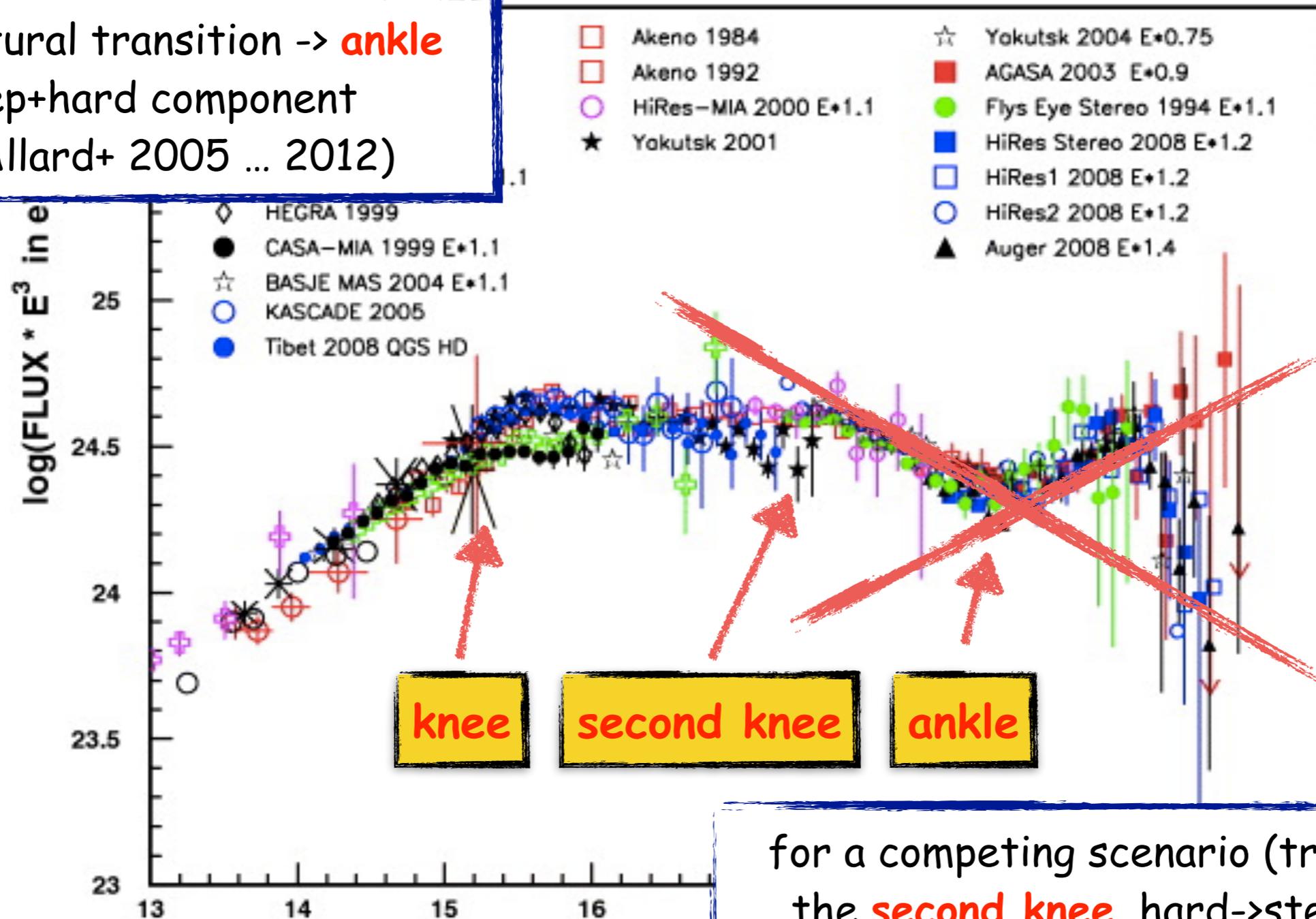
PeV

EeV

ZeV

The EeV domain: Galactic-Extragalactic

most natural transition -> **ankle**
 steep+hard component
 (e.g. Allard+ 2005 ... 2012)



for a competing scenario (transition at the **second knee**, hard->steep?) see several papers by Aloisio+, Berezhinsky+ ...

see also talk by G. Giacinti

MeV

GeV

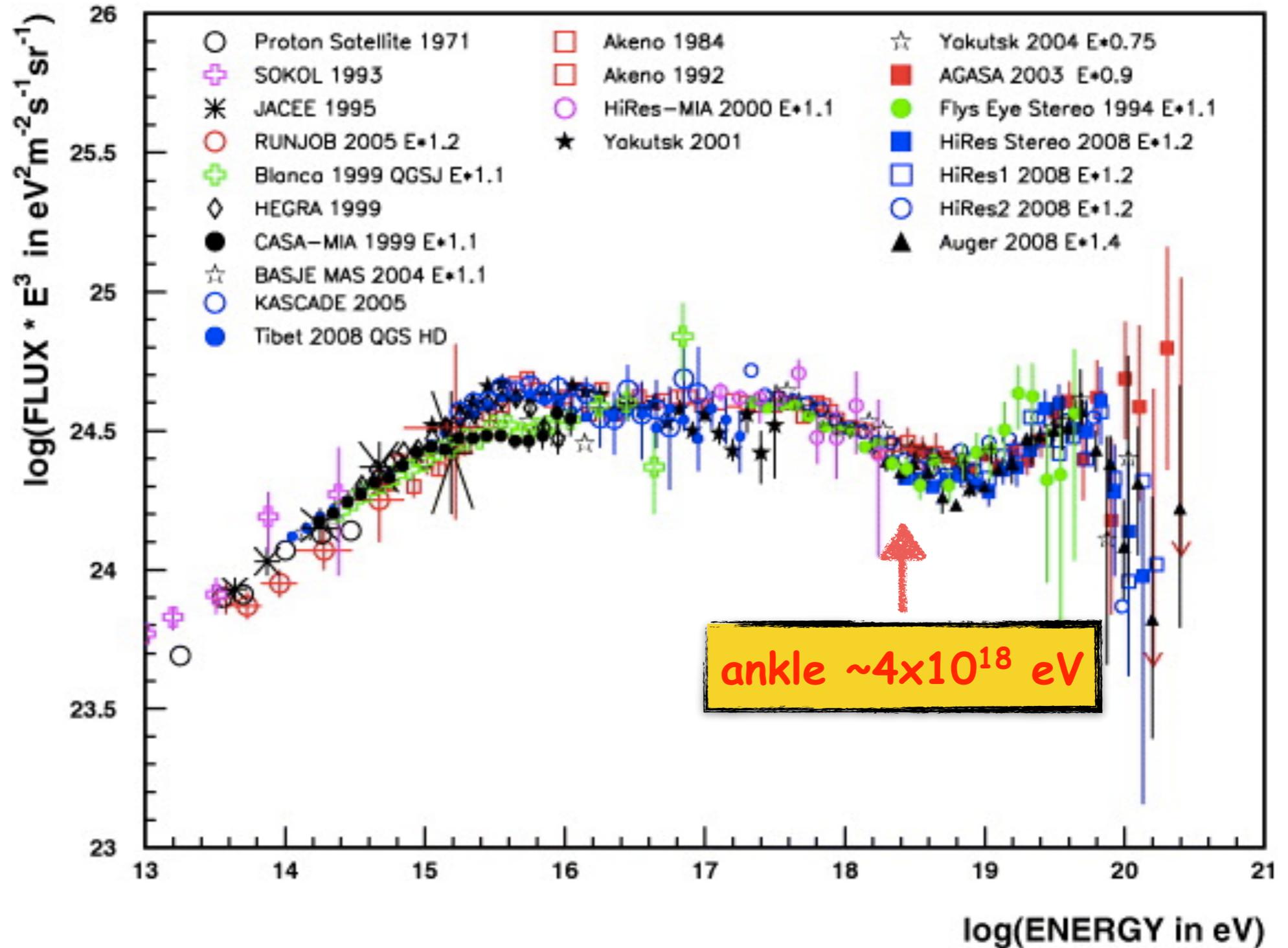
TeV

PeV

EeV

ZeV

The EeV domain: Galactic-Extragalactic



MeV

GeV

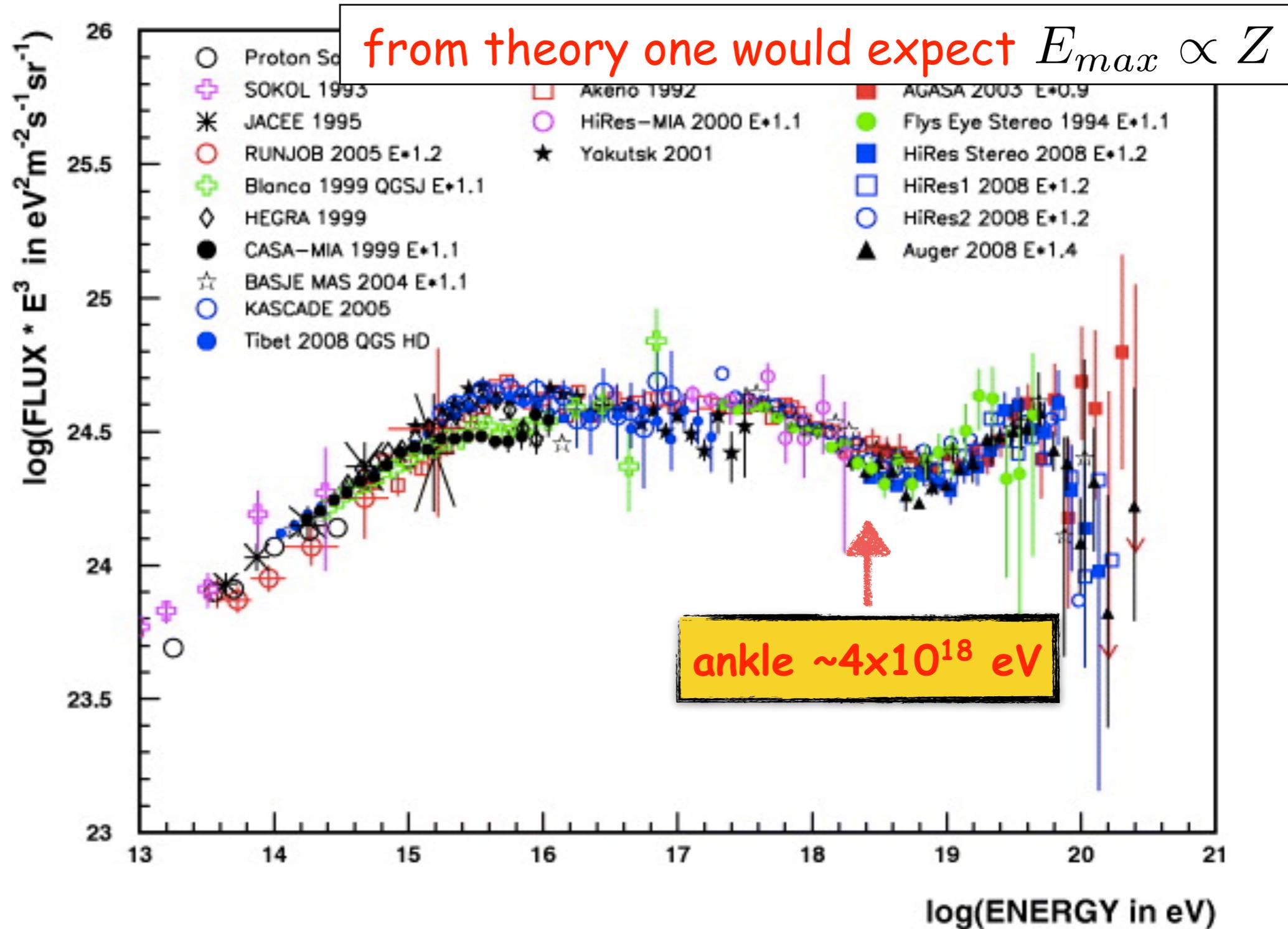
TeV

PeV

EeV

ZeV

The EeV domain: Galactic-Extragalactic



MeV

GeV

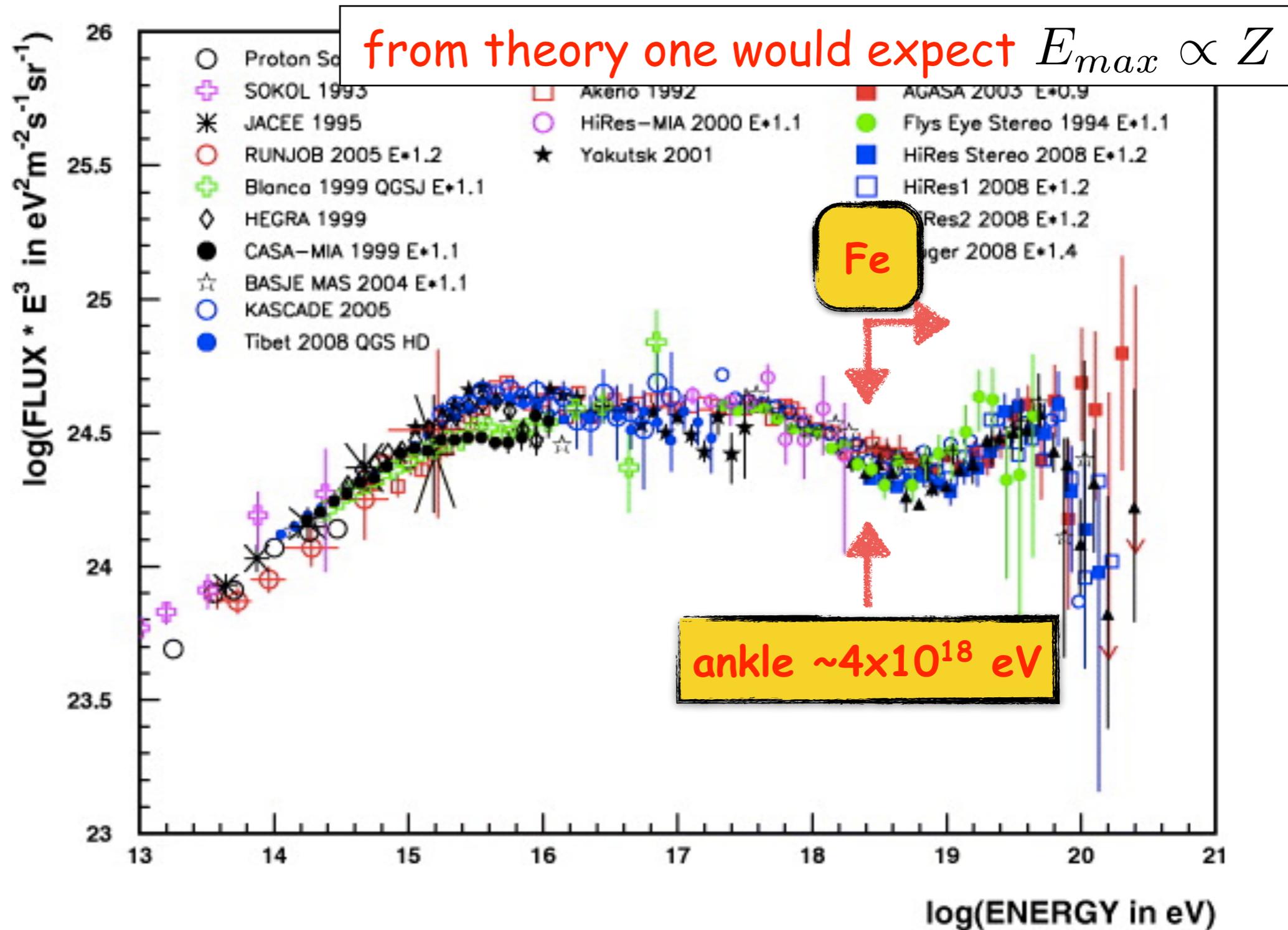
TeV

PeV

EeV

ZeV

The EeV domain: Galactic-Extragalactic



MeV

GeV

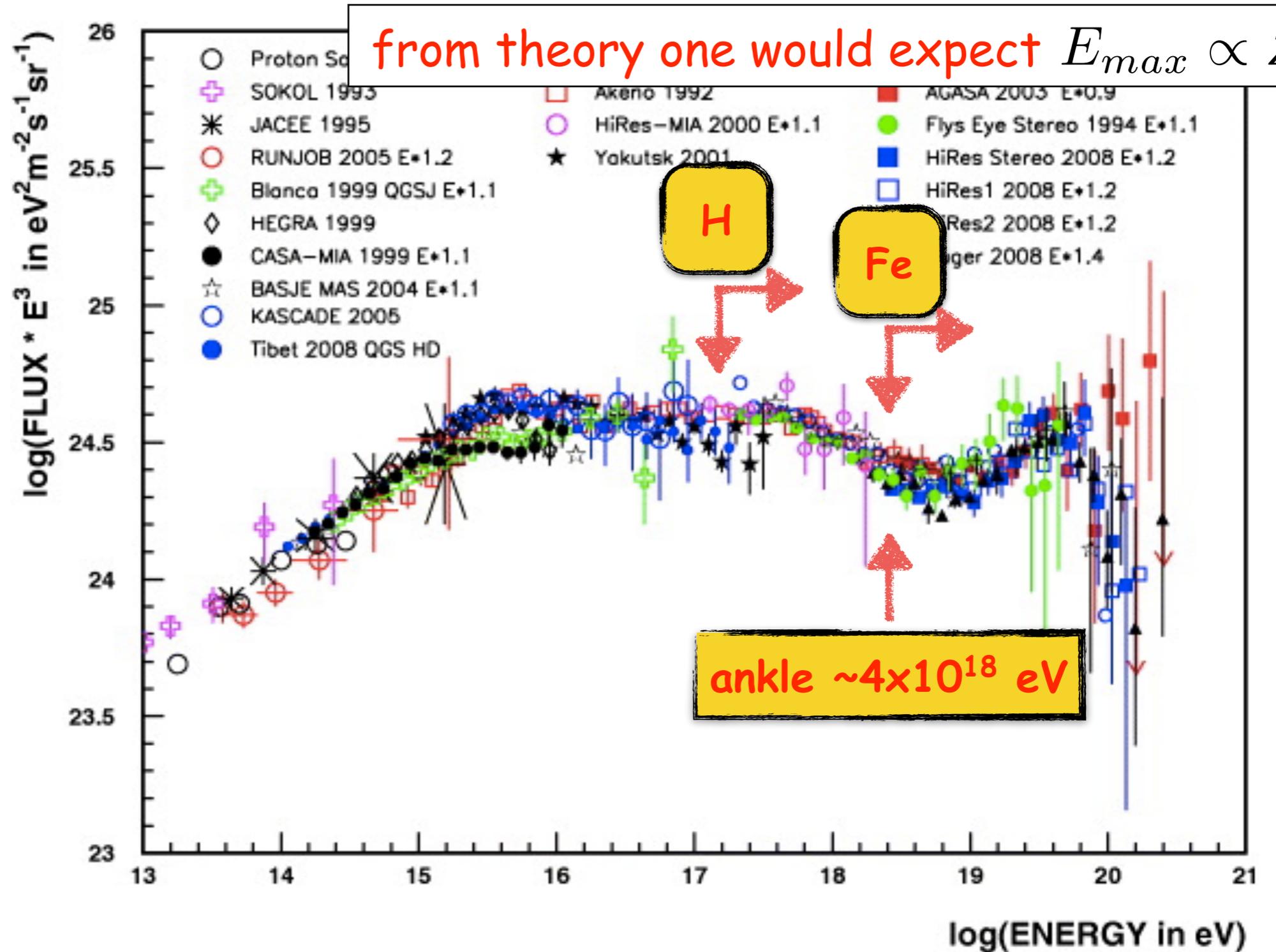
TeV

PeV

EeV

ZeV

The EeV domain: Galactic-Extragalactic



MeV

GeV

TeV

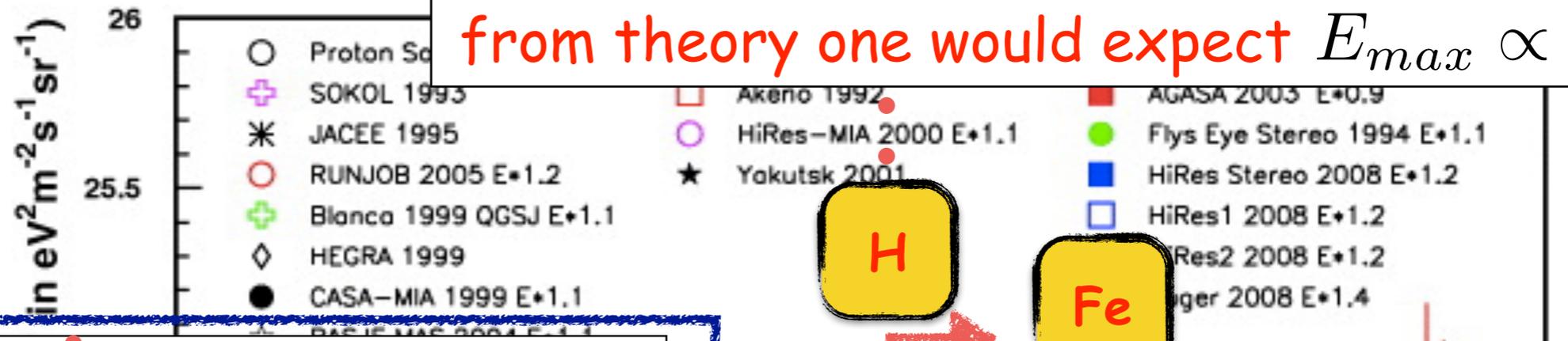
PeV

EeV

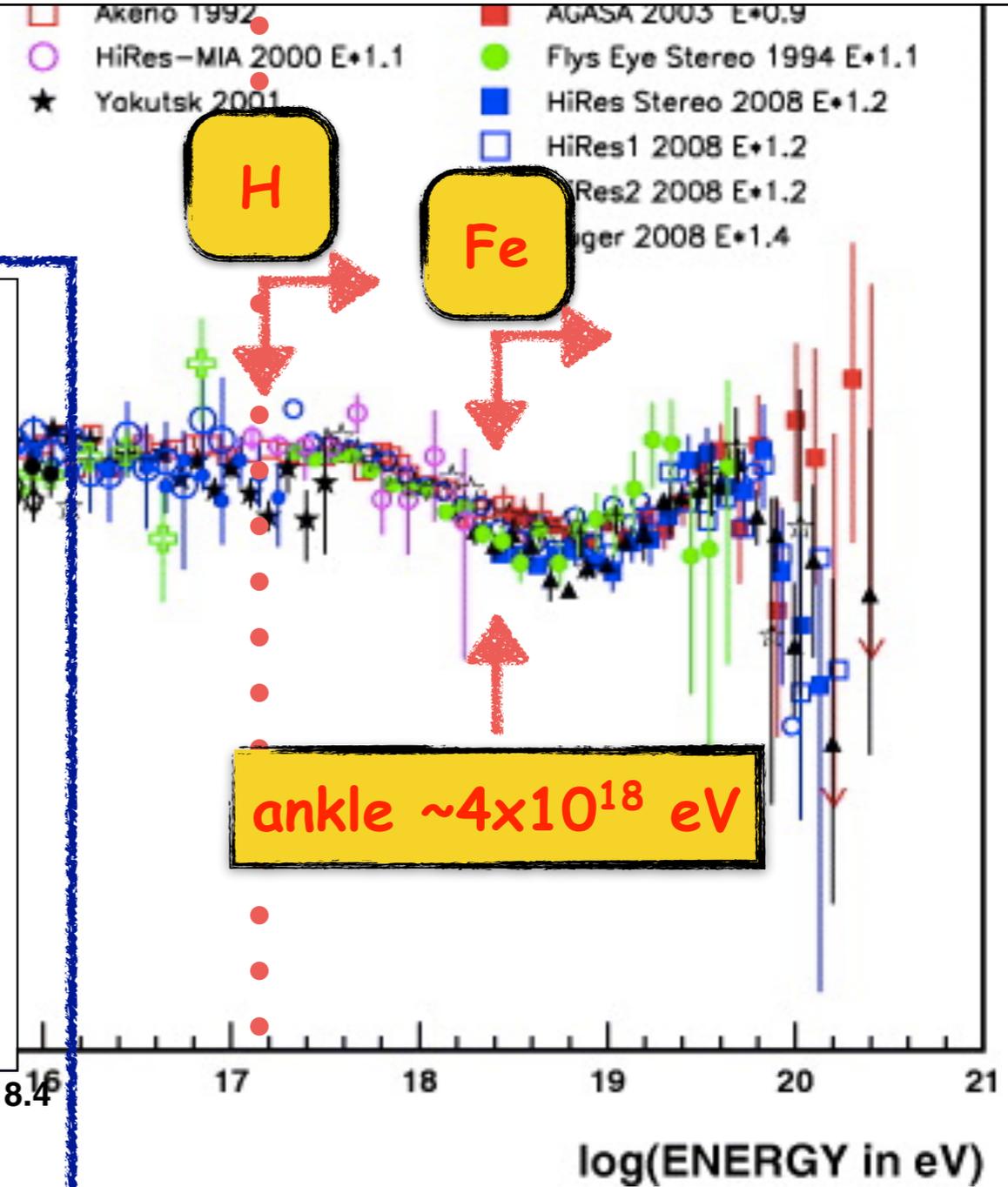
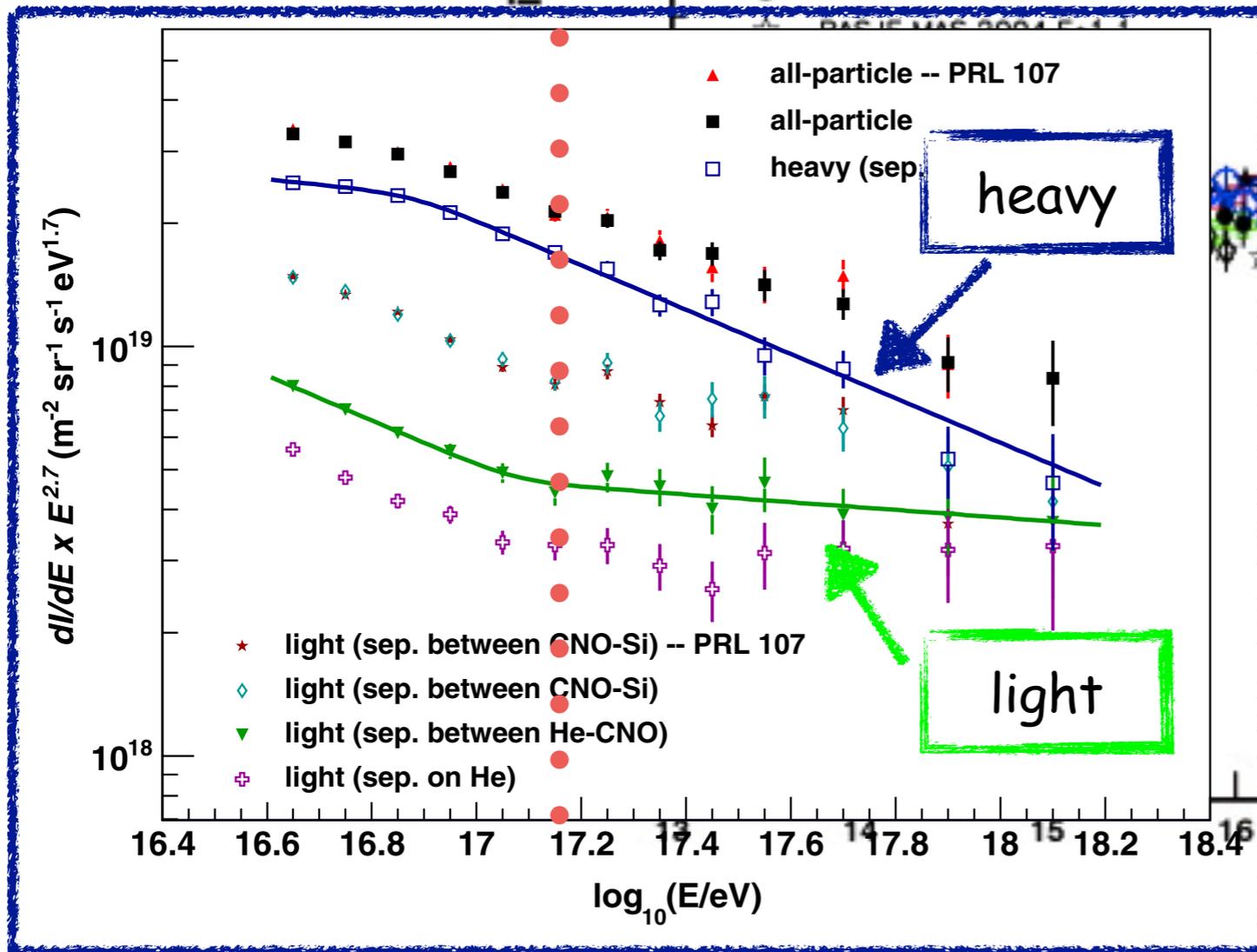
ZeV

The EeV domain: Galactic-Extragalactic

from theory one would expect $E_{max} \propto Z$



KASCADE-Grande coll. 2013



MeV

GeV

TeV

PeV

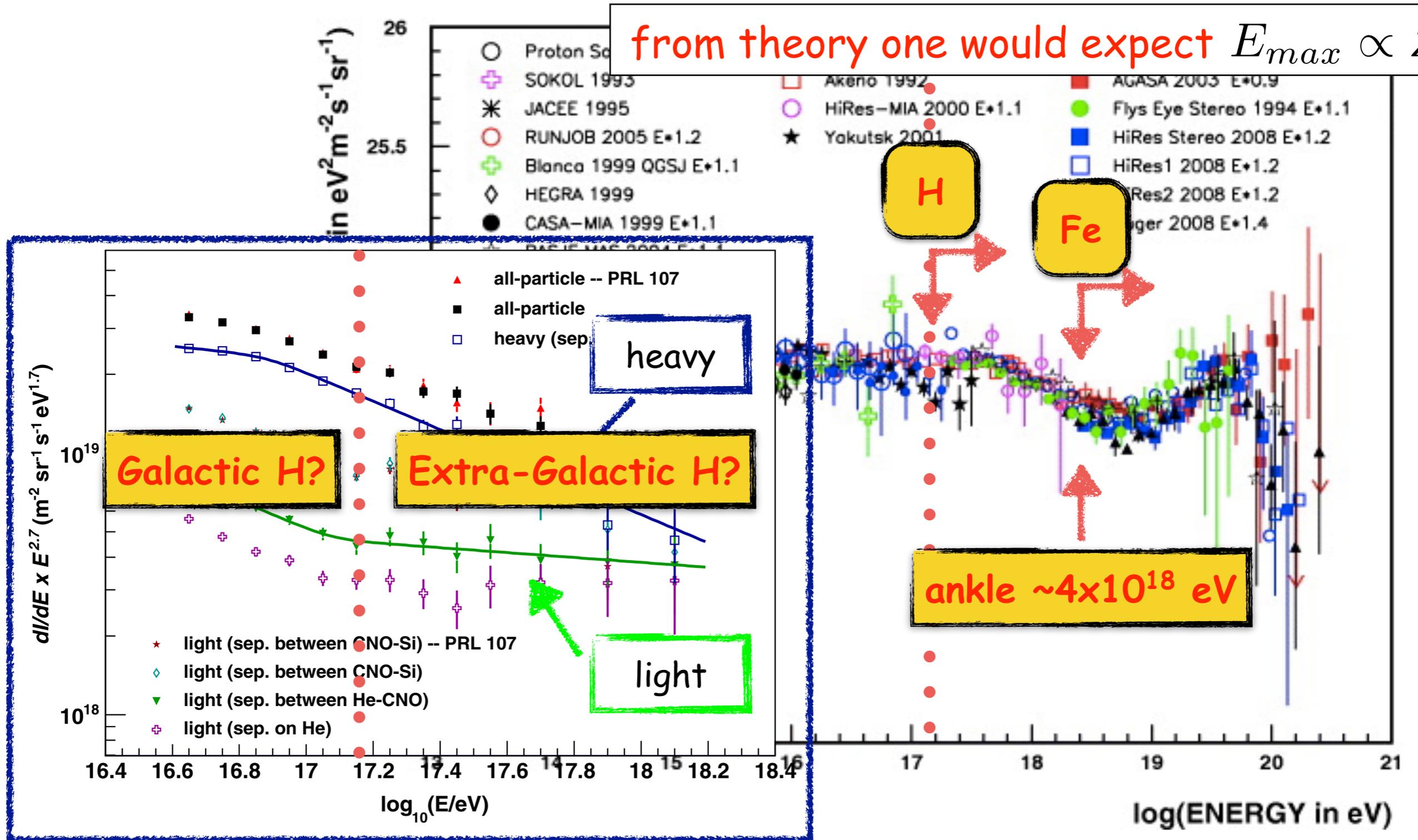
EeV

ZeV

The EeV domain: Galactic-Extragalactic

from theory one would expect $E_{max} \propto Z$

KASCADE-Grande coll. 2013



MeV

GeV

TeV

PeV

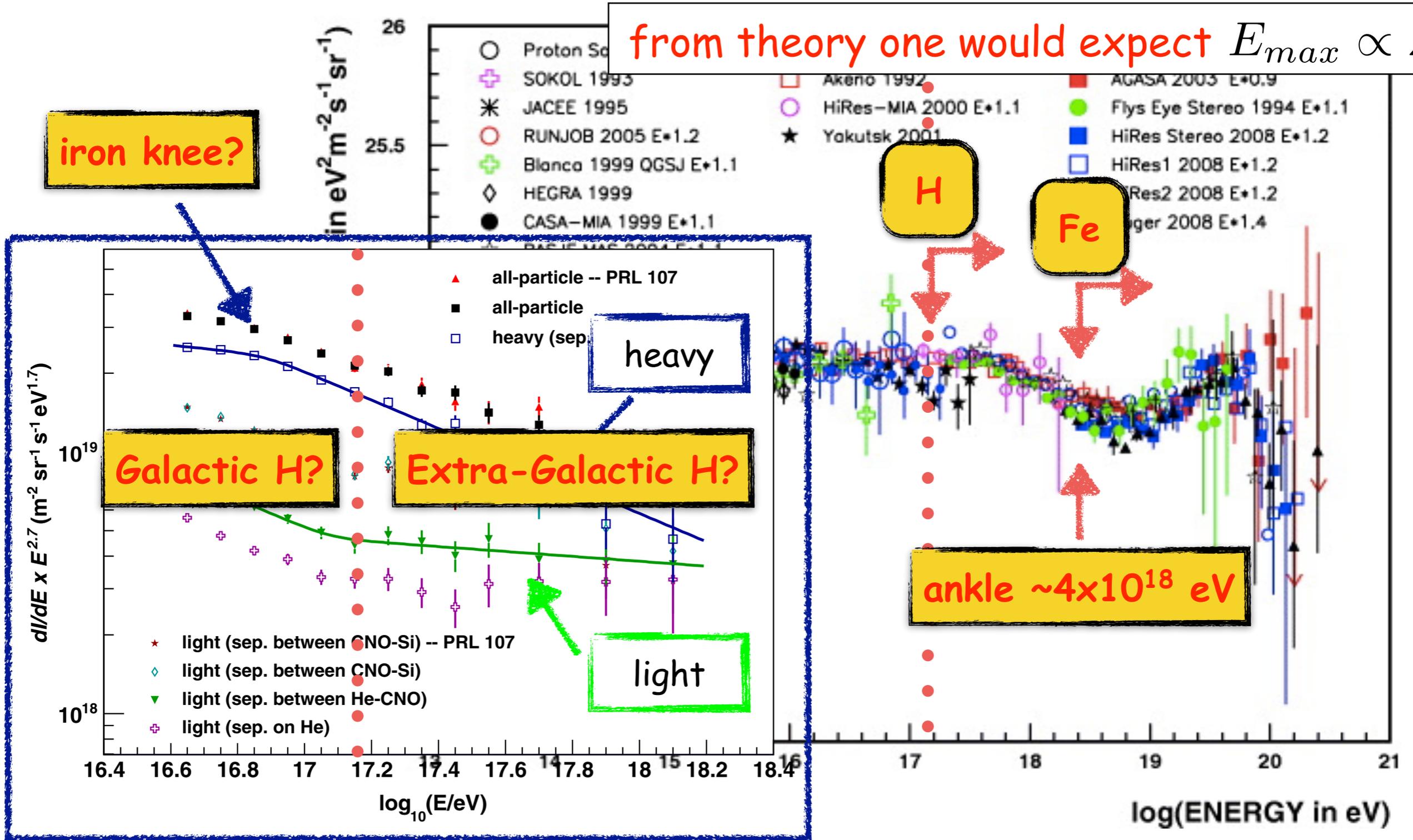
EeV

ZeV

The EeV domain: Galactic-Extragalactic

from theory one would expect $E_{max} \propto Z$

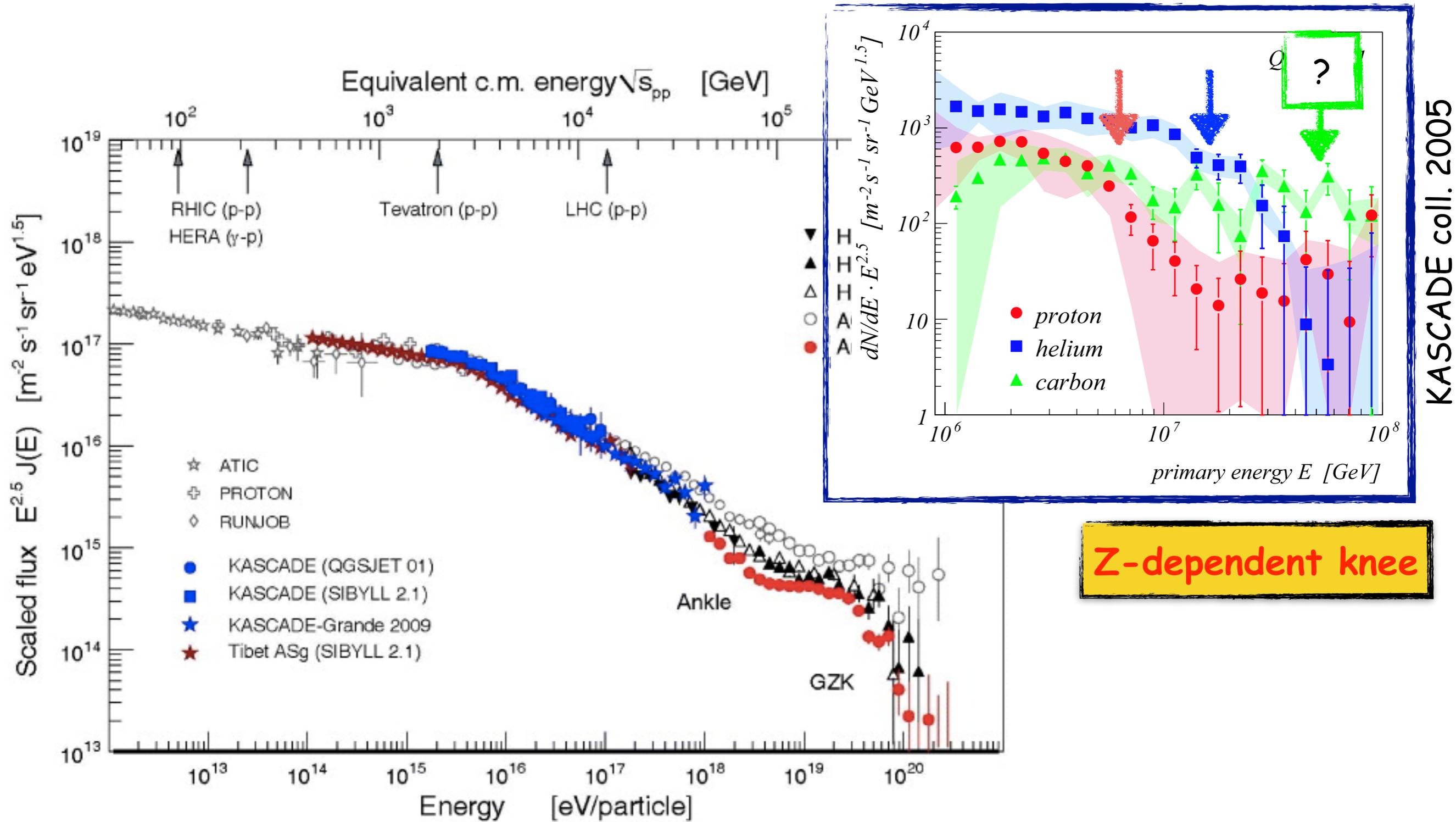
iron knee?



KASCADE-Grande coll. 2013

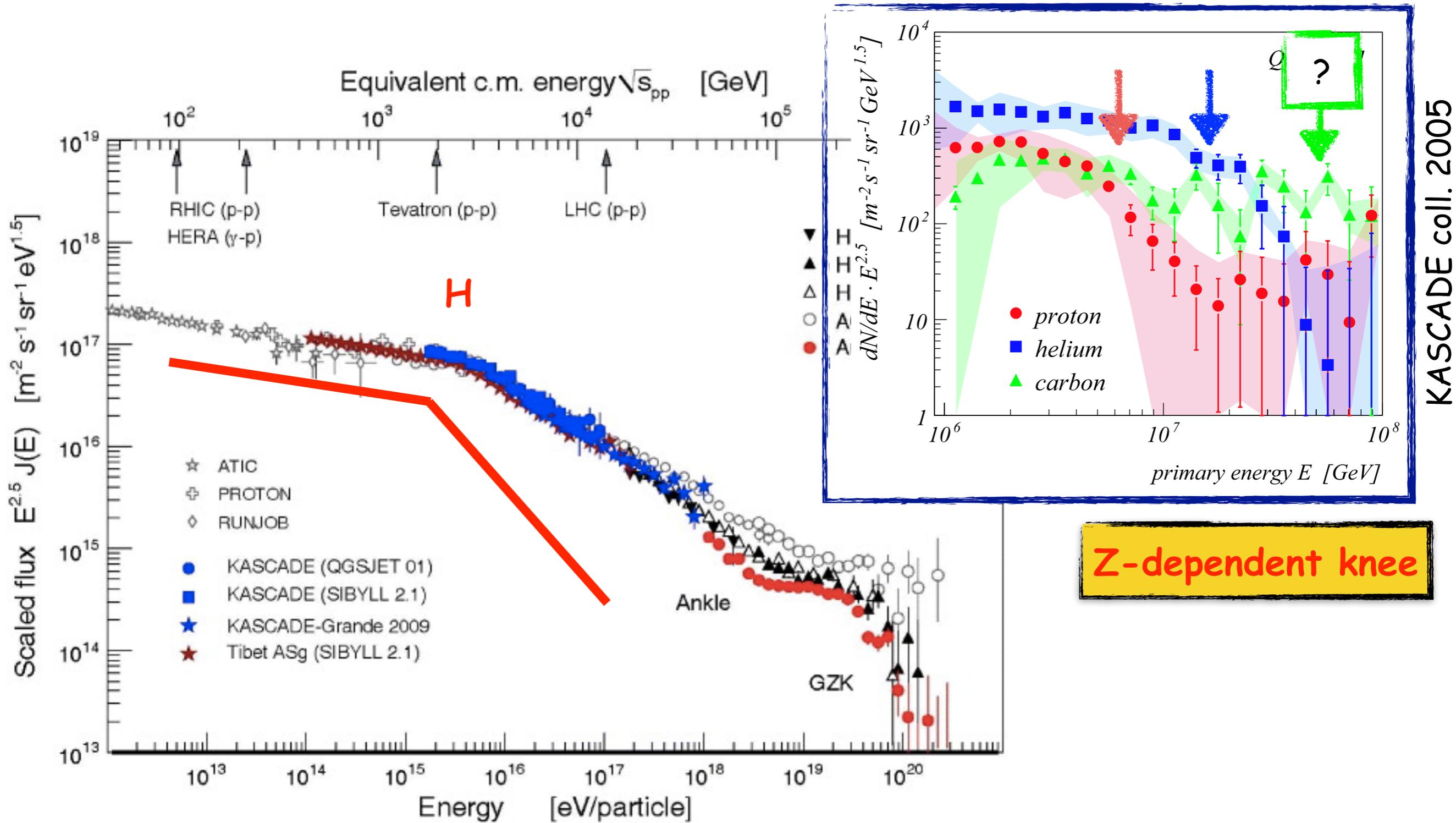
MeV GeV TeV PeV **EeV** ZeV

The EeV domain: Galactic-Extragalactic



Z-dependent knee

The EeV domain: Galactic-Extragalactic

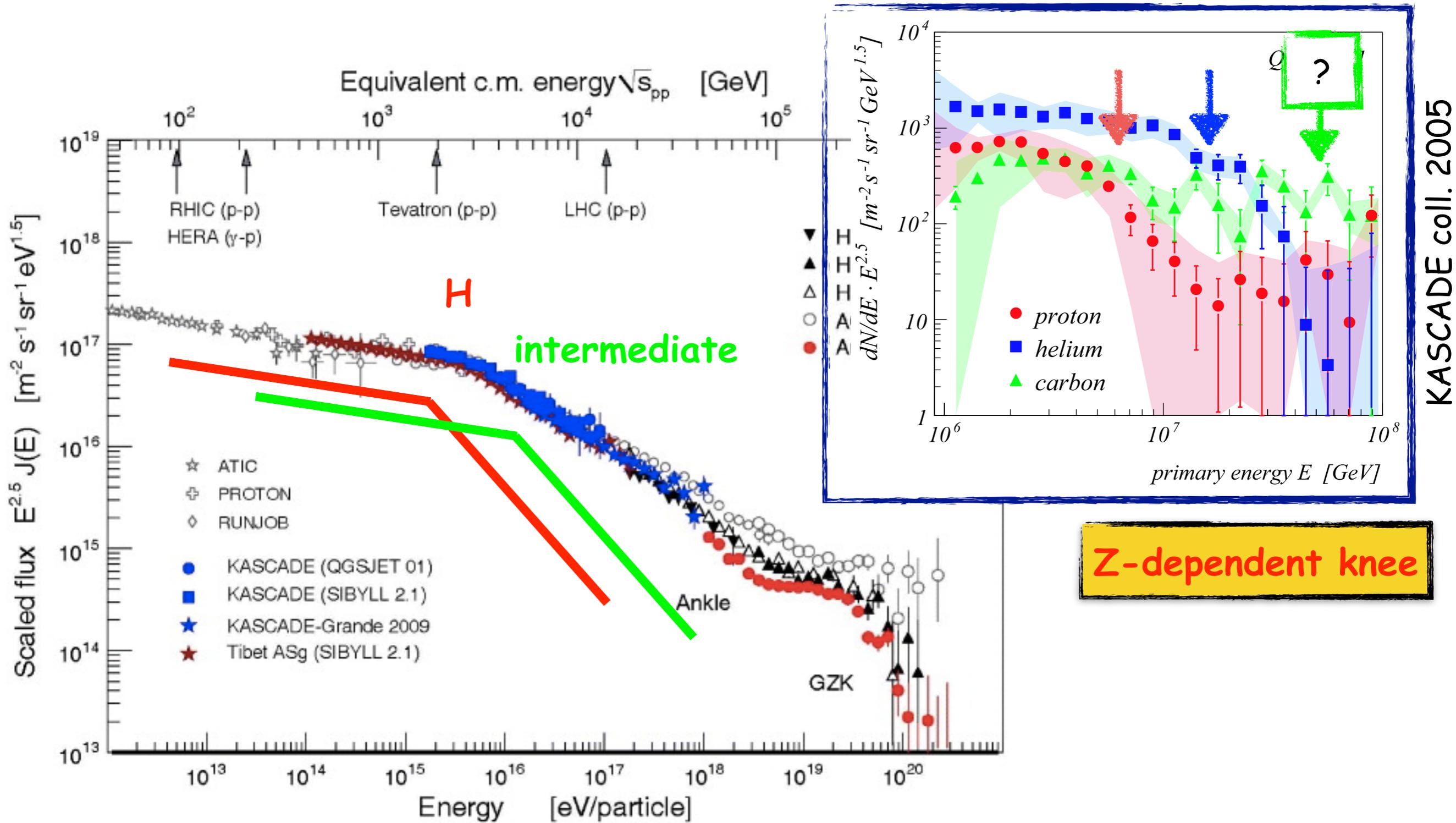


KASCADE coll. 2005

Z-dependent knee

MeV GeV TeV PeV **EeV** ZeV

The EeV domain: Galactic-Extragalactic

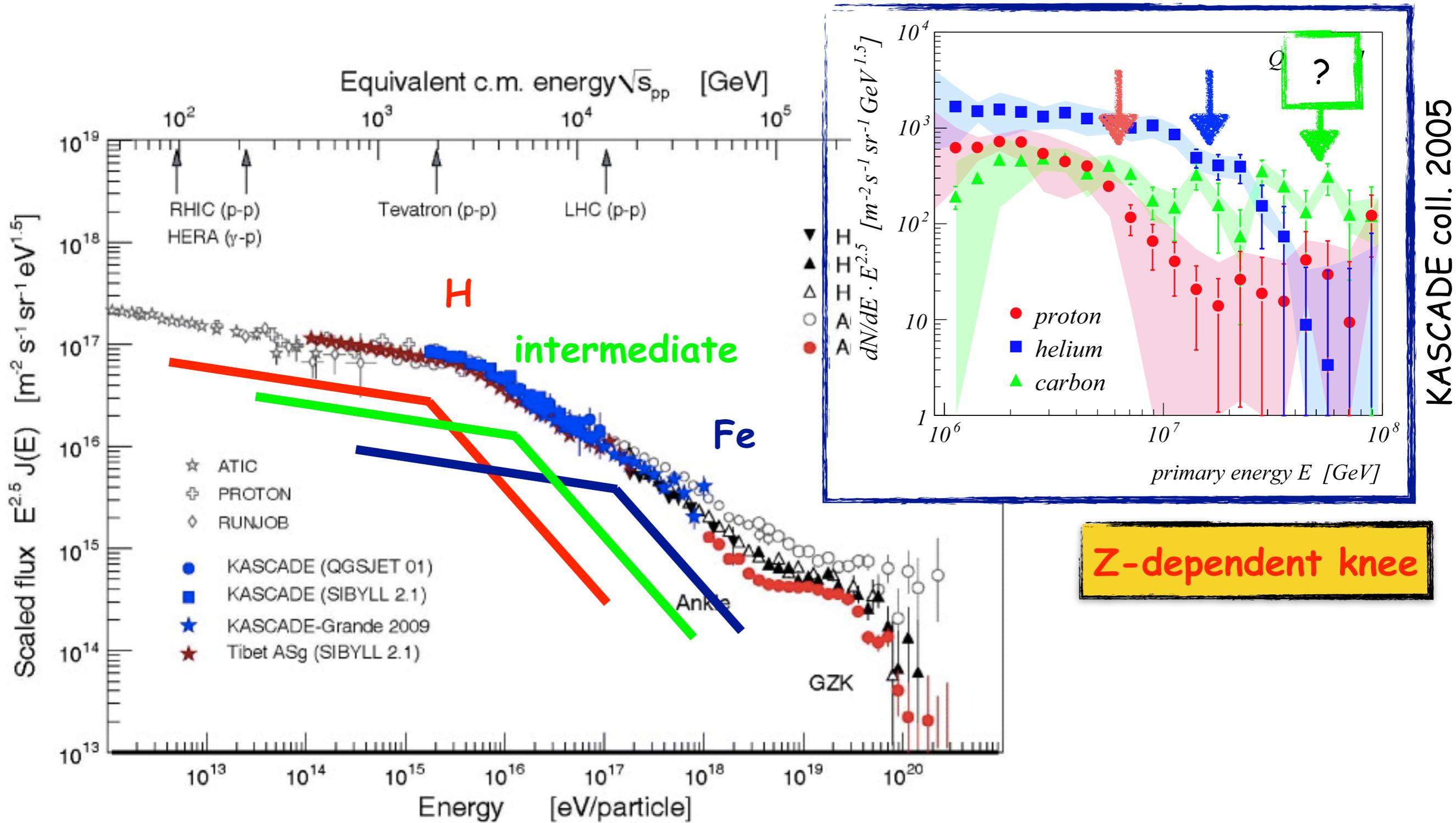


KASCADE coll. 2005

Z-dependent knee

MeV
GeV
TeV
PeV
EeV
ZeV

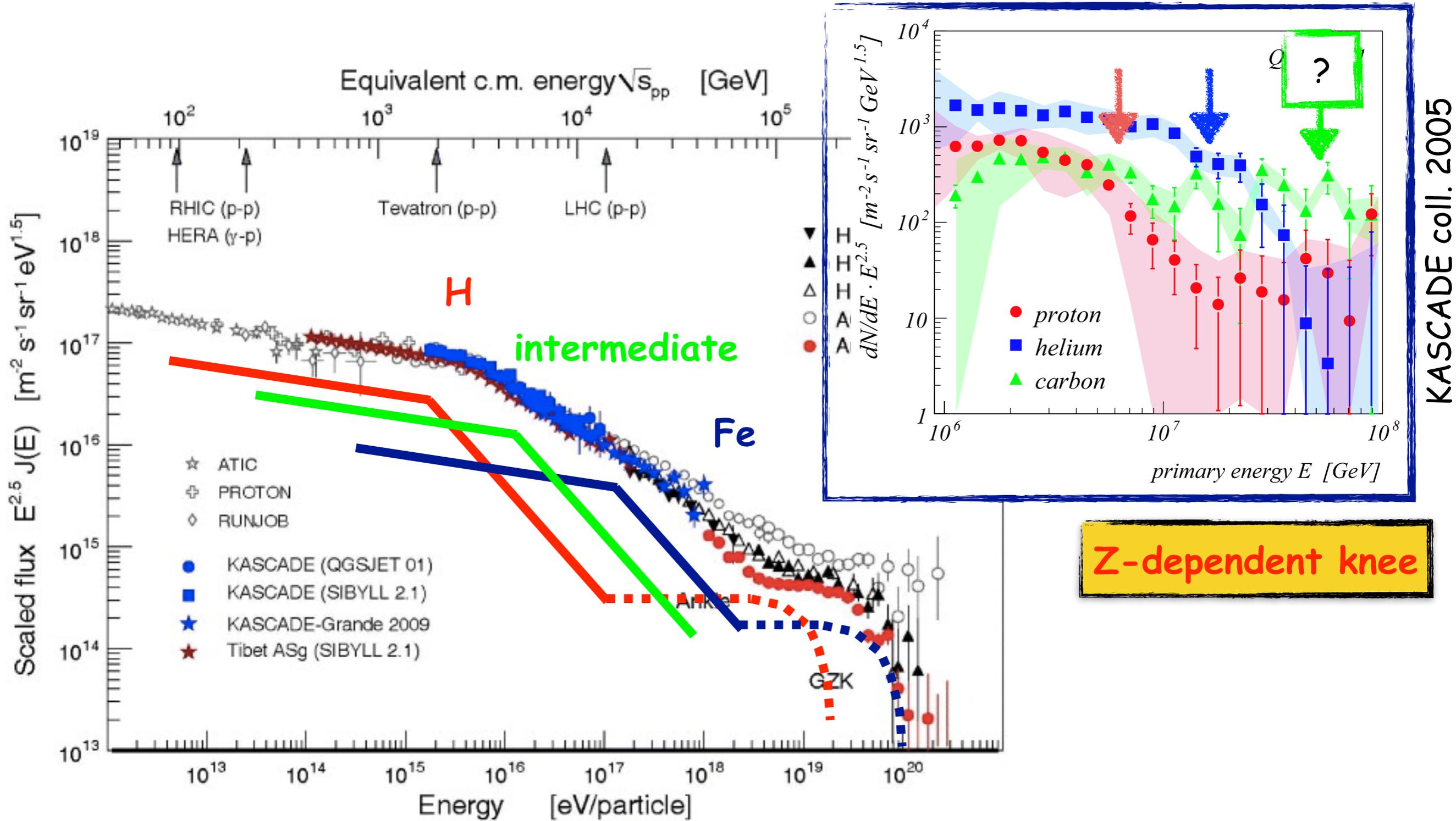
The EeV domain: Galactic-Extragalactic



KASCADE coll. 2005

MeV GeV TeV PeV **EeV** ZeV

The EeV domain: Galactic-Extragalactic

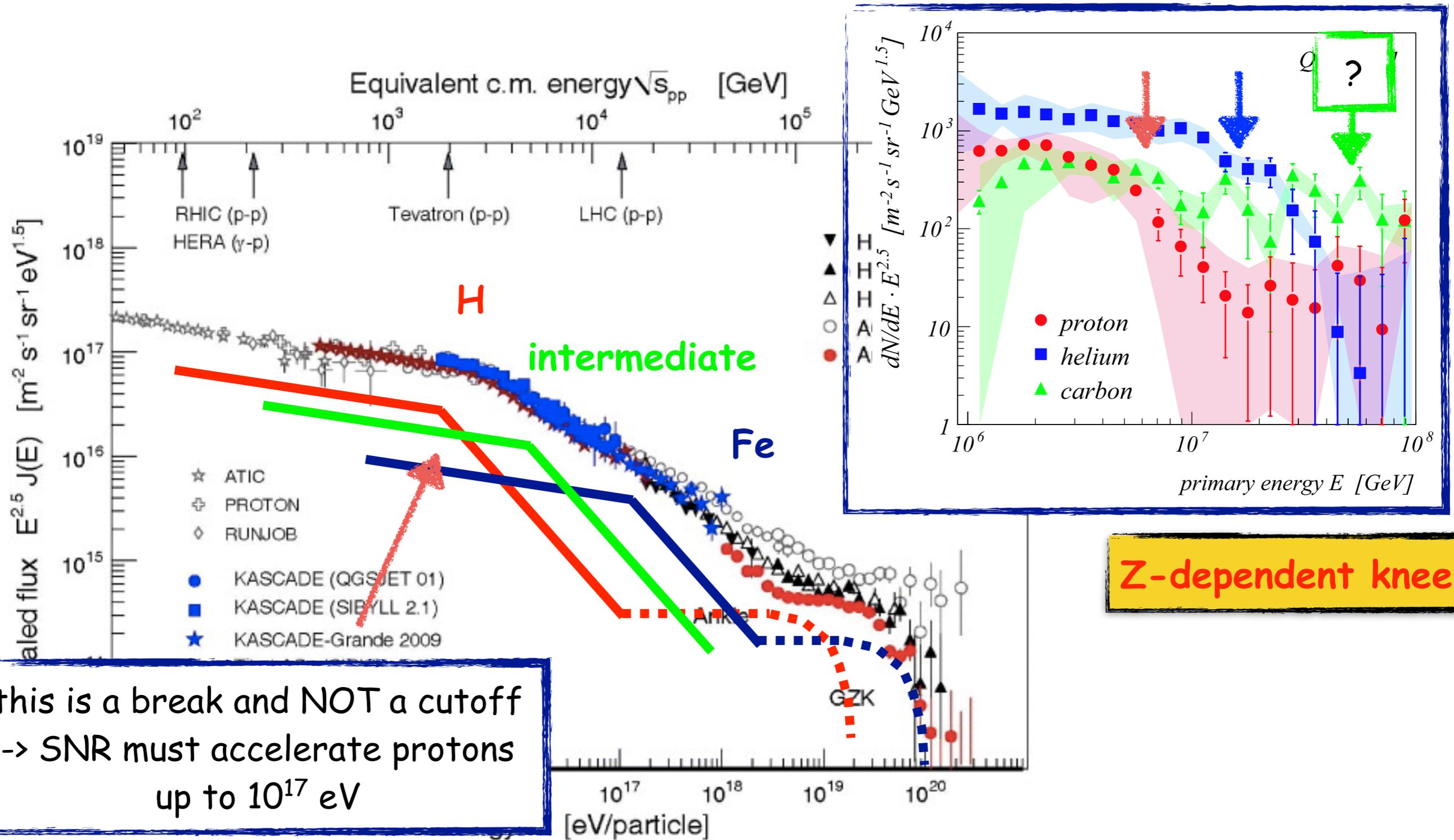


KASCADE coll. 2005

Z-dependent knee

MeV
GeV
TeV
PeV
EeV
ZeV

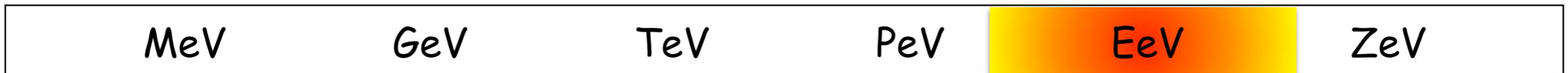
The EeV domain: Galactic-Extragalactic



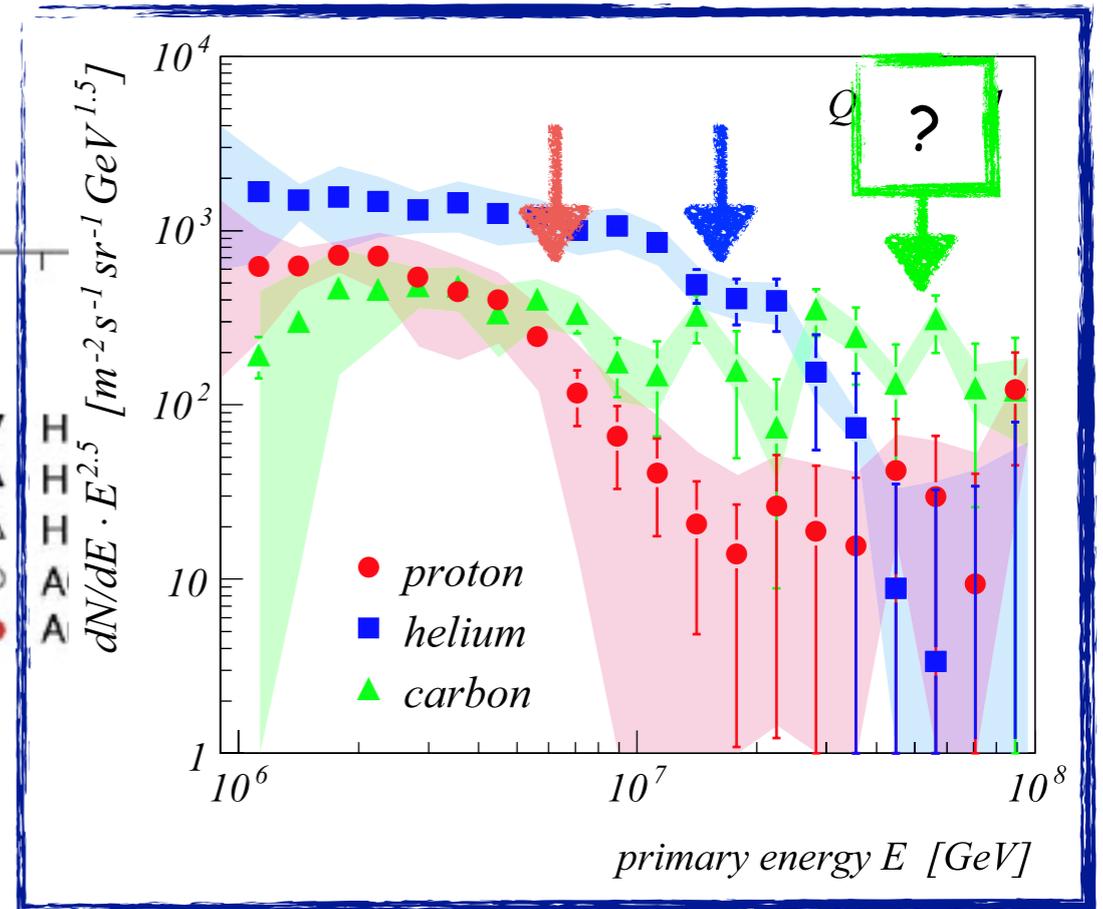
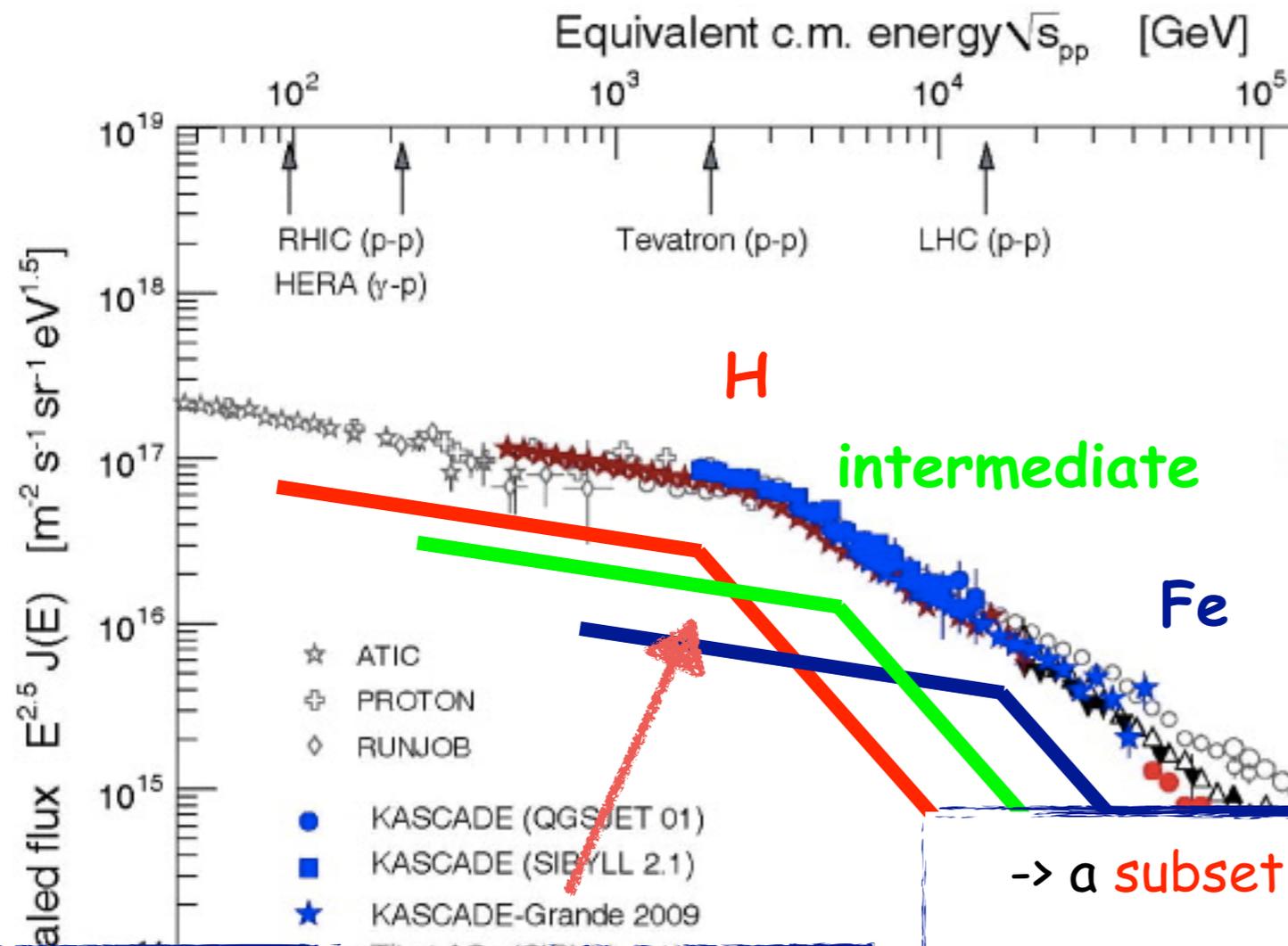
KASCADE coll. 2005

this is a break and NOT a cutoff
-> SNR must accelerate protons
up to 10^{17} eV

Z-dependent knee



The EeV domain: Galactic-Extragalactic



KASCADE coll. 2005

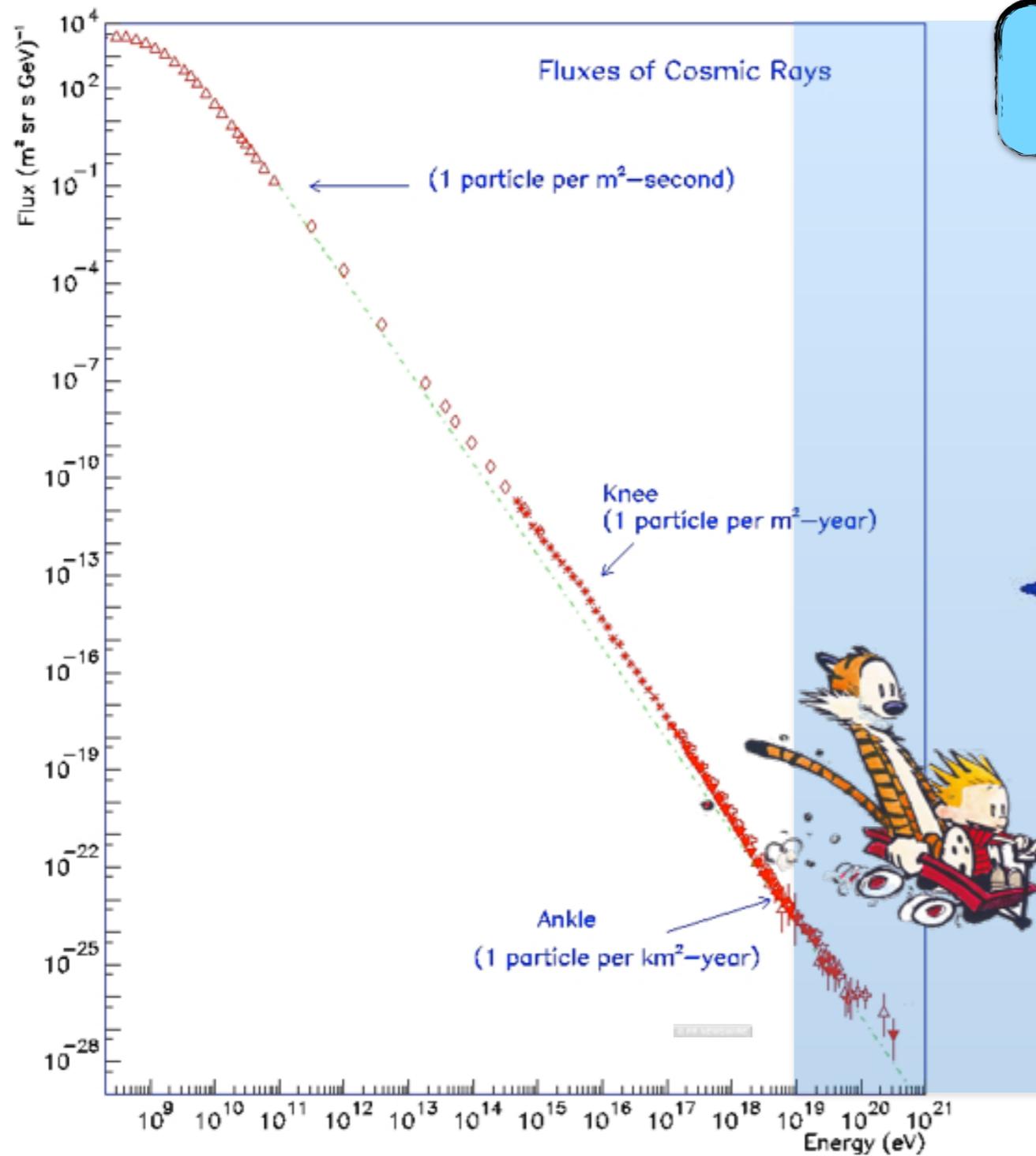
this is a break and NOT a cutoff
 -> SNR must accelerate protons up to 10^{17} eV

-> a subset of SNRs accelerate H up to $>10^{17}$ eV? (Ptuskin&Zirakashvili)
 -> SNRs are NOT the sources of CRs? (superbubbles? Bykov+, Parizot+)
 -> $E_{max} = Z$ only if iron is FULLY ionized. Is that true? (Morlino)

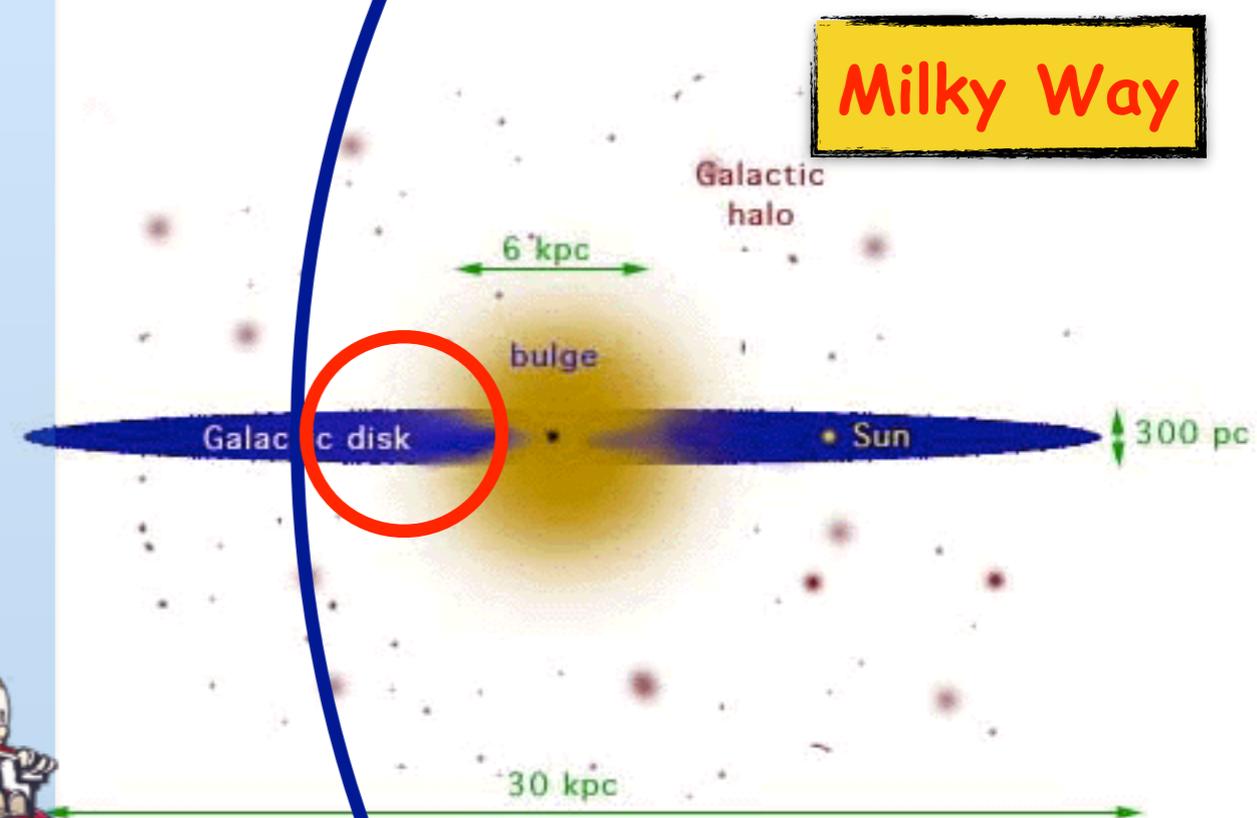
MeV GeV TeV PeV EeV ZeV

The ZeV domain ($> 10^{19}$ eV)

see plenary talk by E. Roulet + parallel session



$R_L(10^{20} \text{ eV}) \sim 36 \text{ kpc}$



Milky Way

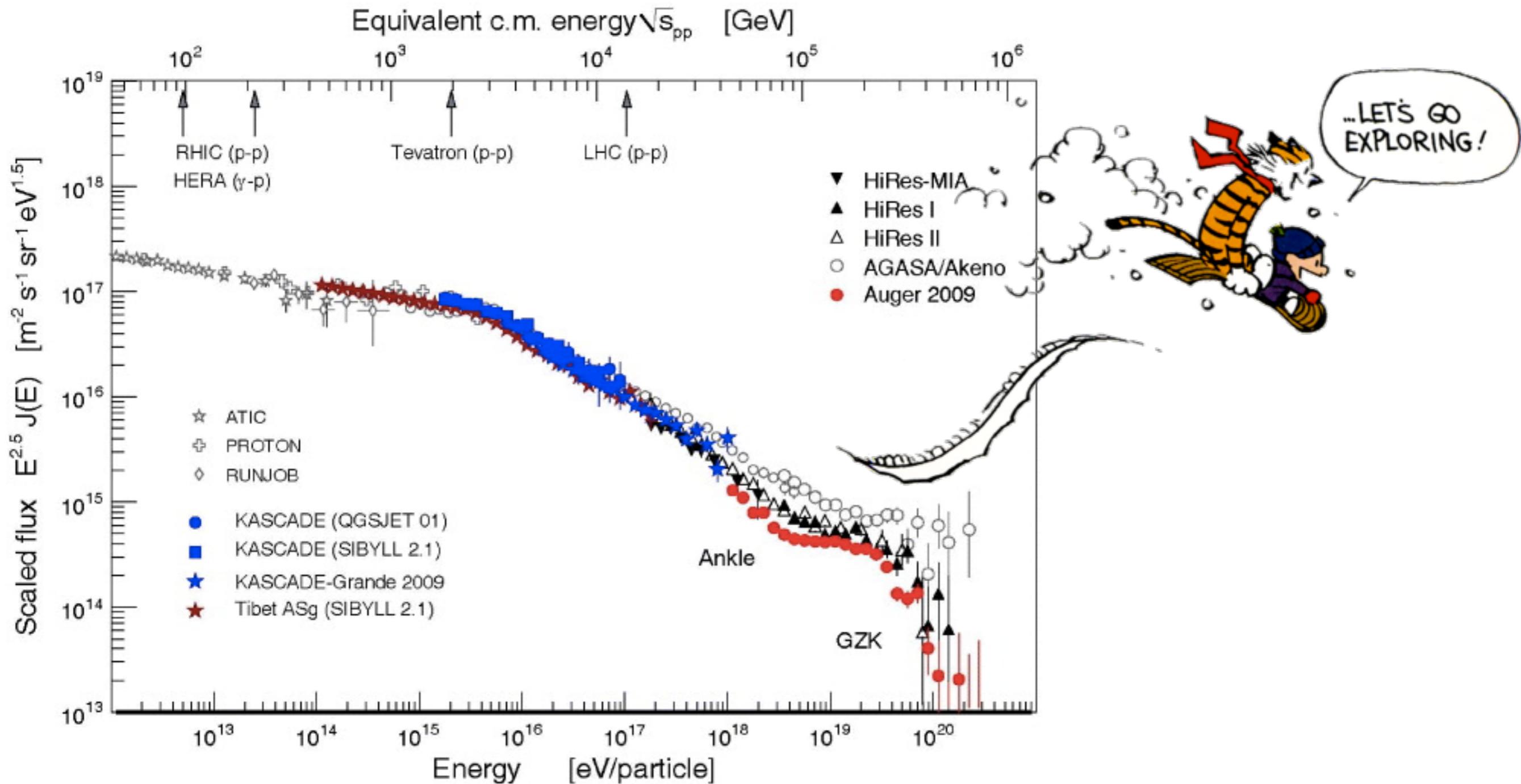
extragalactic CRs

MeV GeV TeV PeV EeV ZeV

~~Conclusions~~ Questions

- Are SNRs the sources of Galactic CRs? (no, we don't have the answer yet)
- Can diffusive shock acceleration explain the features observed in the CR spectrum? Are they real, by the way?
- When do CRs escape from SNRs? How? And how many? or, do SNRs accelerate particles up to the knee?
- Which sources produce the positrons we observe in the CR spectrum? Which are the sources of CR electrons?
- Do we understand CR transport in turbulent fields (or, the propagation of CRs in the Galaxy)?
- Is the Galactic/extragalactic transition at the ankle?
- What is going on at the transition? Is there another Galactic component? Should we search for an alternative (or complement) to SNRs?

Thank you.



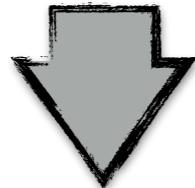
Backup slides

GeV/TeV domain: CR transport in the MW

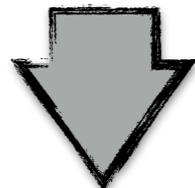
the "other half" of the problem: after acceleration CRs somehow reach us

bottom-up approach

compute the spectrum of magnetic turbulence in the ISM (Goldreich & Shridhar ...)



compute the CR diffusion coefficient in the turbulent field (Lazarian+, Yan+, Schlickeiser+, Shalchi+ ...)



fast magnetosonic waves are now believed to be the most effective in scattering CRs

MeV

GeV

TeV

PeV

EeV

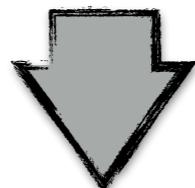
ZeV

GeV/TeV domain: CR transport in the MW

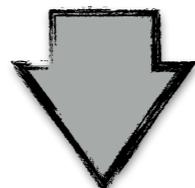
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fast magnetosonic waves are now believed to be the most effective in scattering CRs

top-down approach

parametrize the diffusion coefficient D



solve the diffusion equation for a given distribution of sources in the Galaxy (Ginzburg and many many many others...)

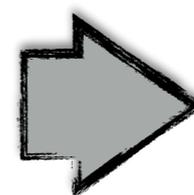


reproduce observables such as local CR spectrum, B/C, diffuse gamma rays ...



GALPROP = standard approach

homogeneous & isotropic D often assumed



$$D \sim D_0 E^{0.3...0.6}$$

MeV

GeV

TeV

PeV

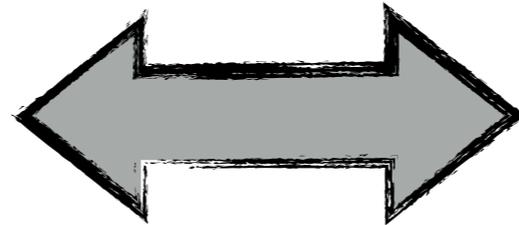
EeV

ZeV

GeV/TeV domain: CR transport in the MW

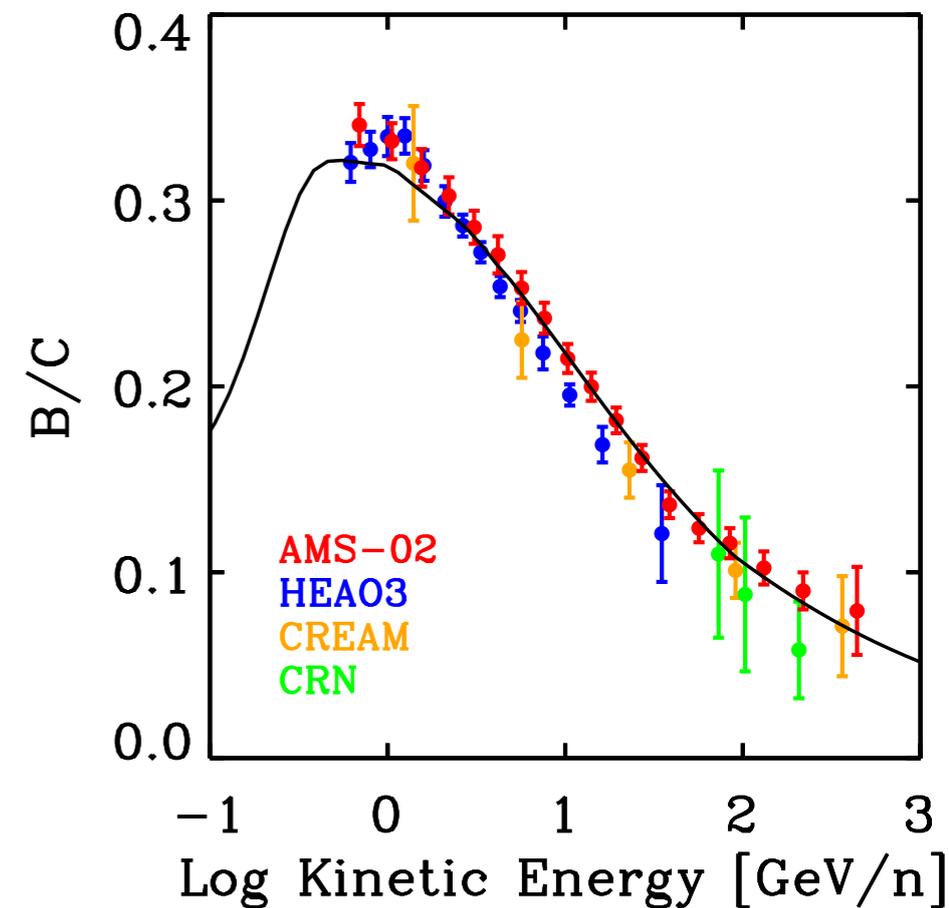
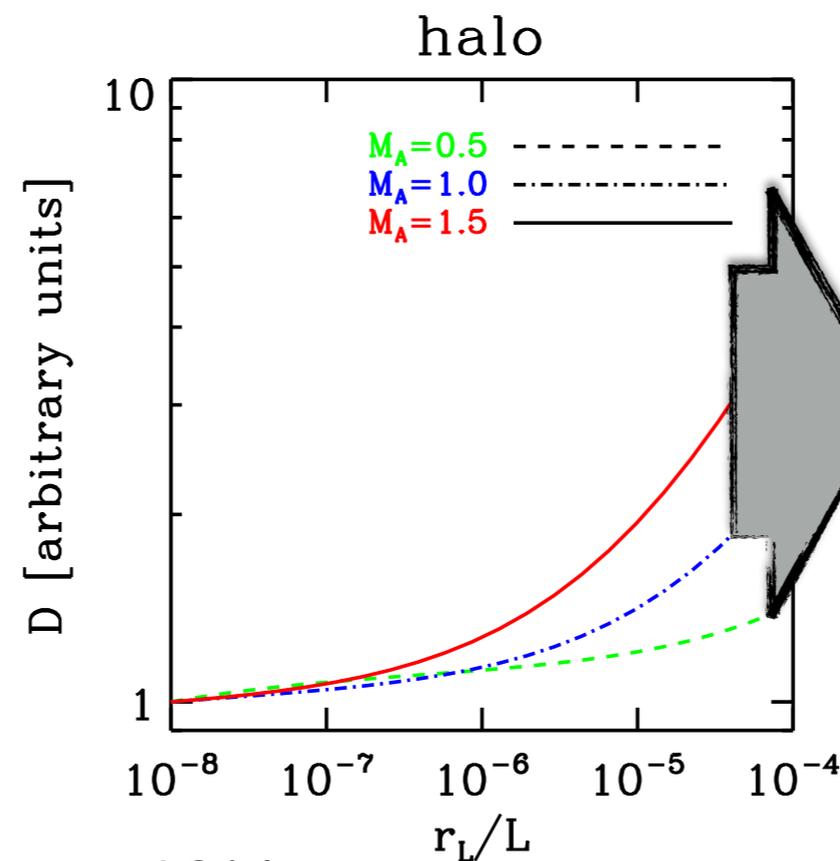
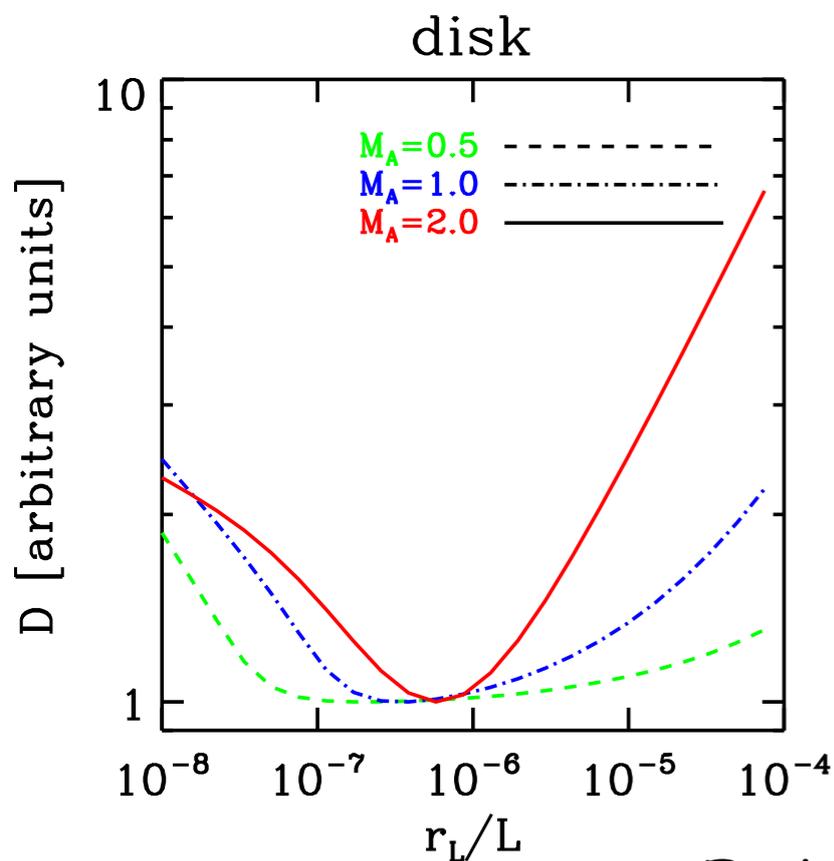
the "other half" of the problem: after acceleration CRs somehow reach us

bottom-up approach



top-down approach

DRAGON code -> user implemented D , can be inhomogeneous, anisotropic ...
(Evoli+ 2008, Gaggero+ 2013)



Evoli & Yan 2014

MeV

GeV

TeV

PeV

EeV

ZeV

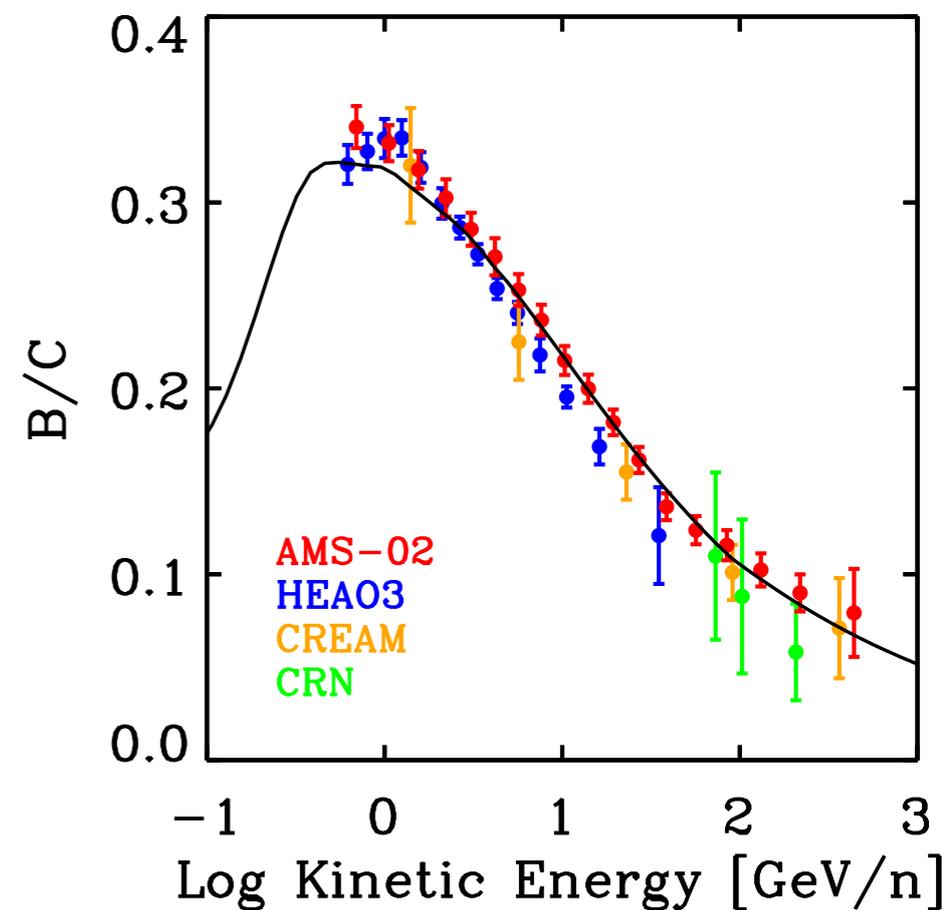
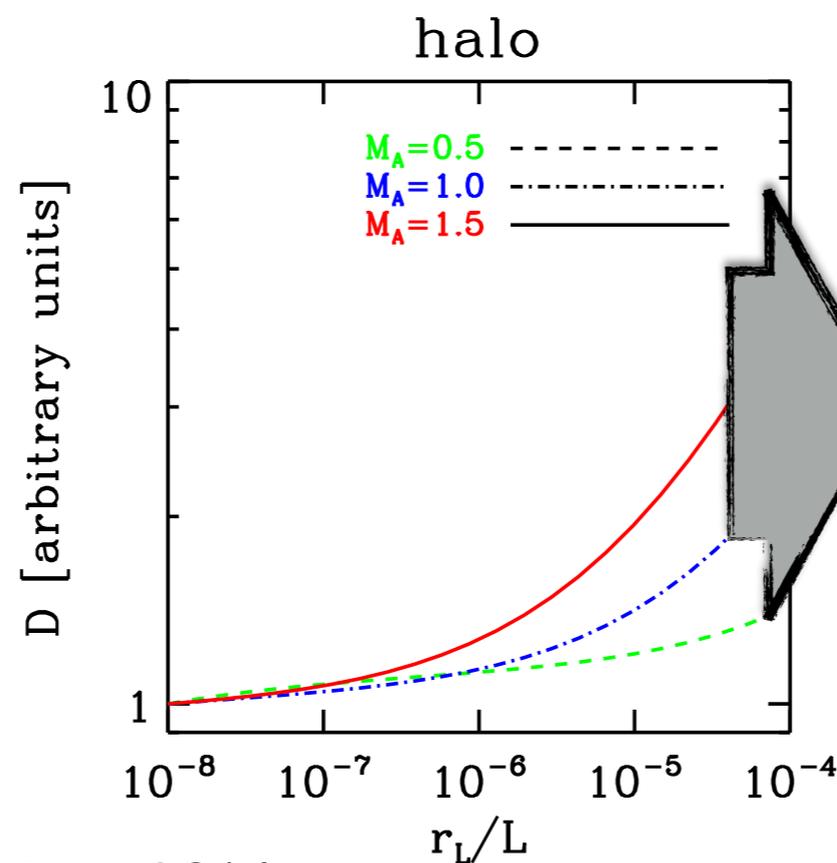
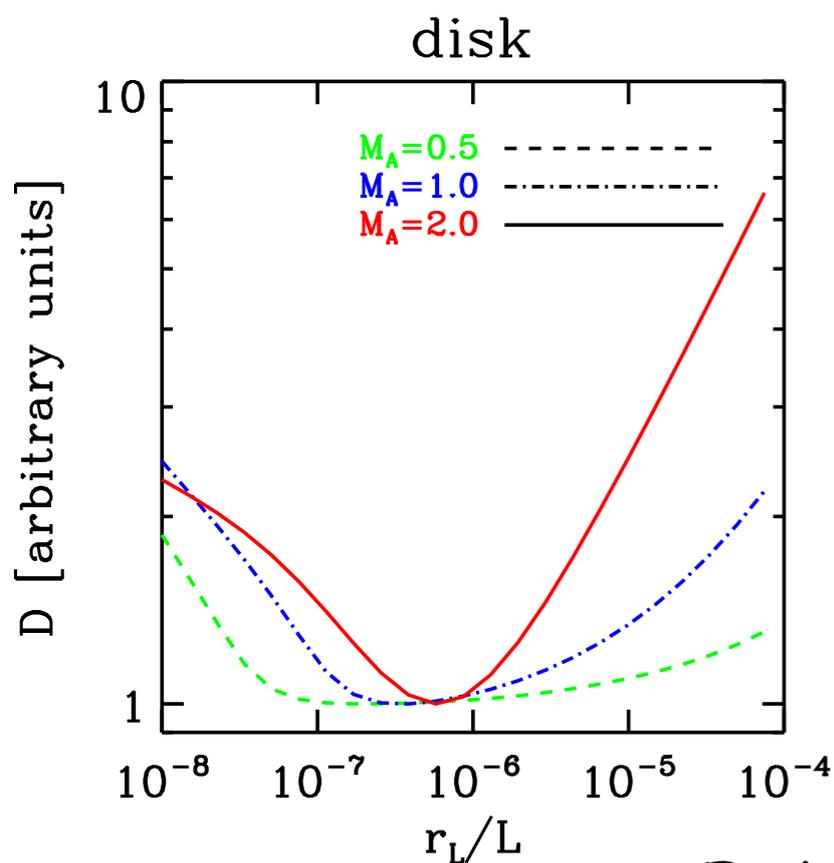
GeV/TeV domain: CR transport in the MW

the "other half" of the problem: after acceleration CRs somehow reach us



top-down approach

DRAGON code -> user implemented D , can be inhomogeneous, anisotropic ...
(Evoli+ 2008, Gaggero+ 2013)



Evoli & Yan 2014

MeV

GeV

TeV

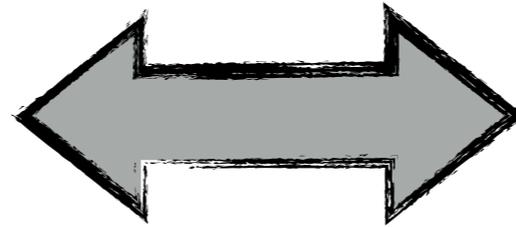
PeV

EeV

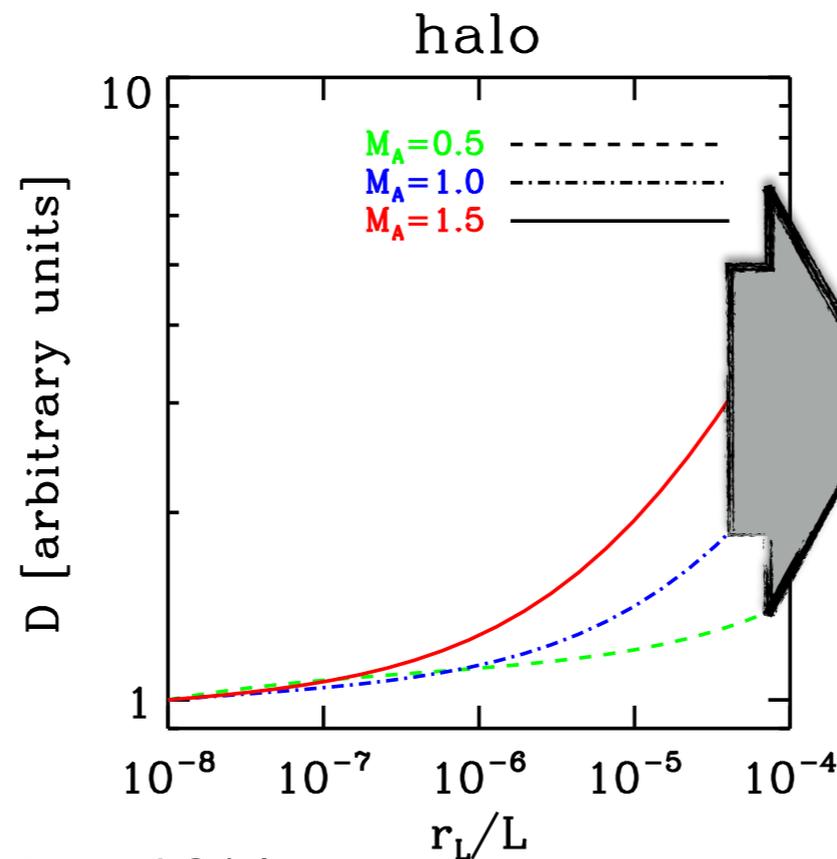
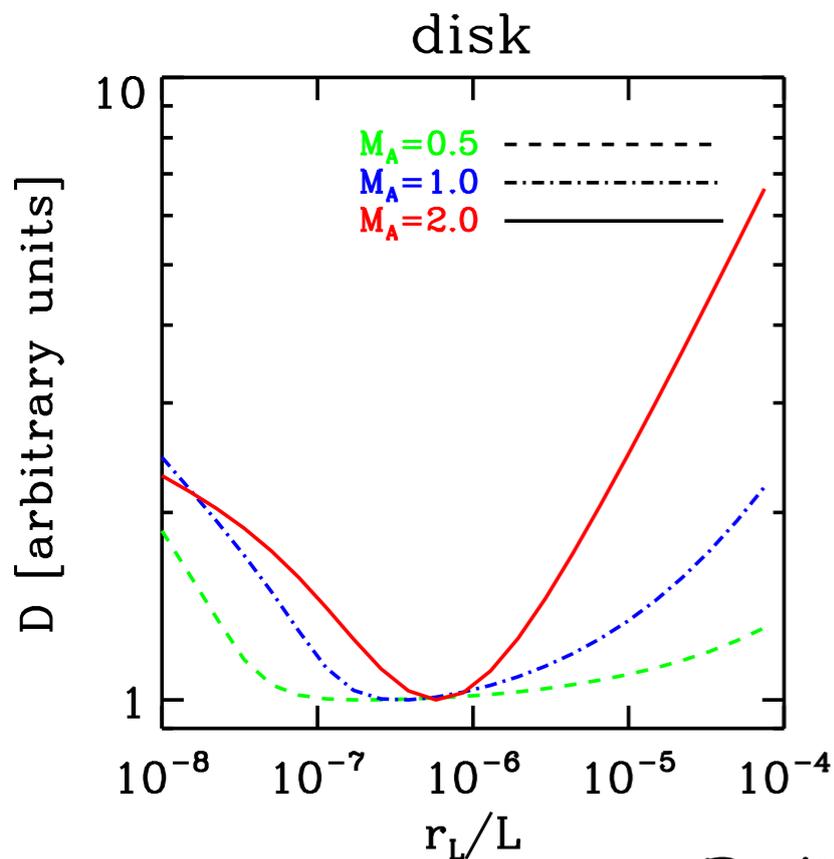
ZeV

GeV/TeV domain: CR transport in the MW

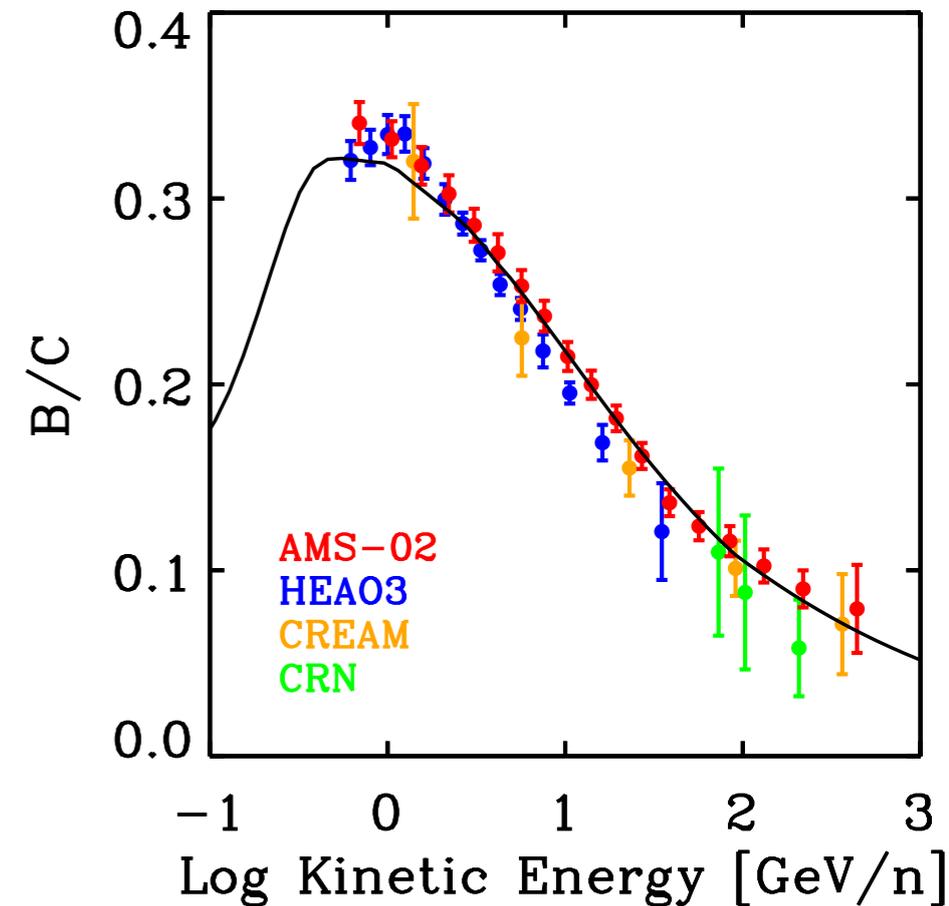
the "other half" of the problem: after acceleration CRs somehow reach us



DRAGON code -> user implemented D , can be inhomogeneous, anisotropic ...
(Evoli+ 2008, Gaggero+ 2013)



Evoli & Yan 2014



MeV

GeV

TeV

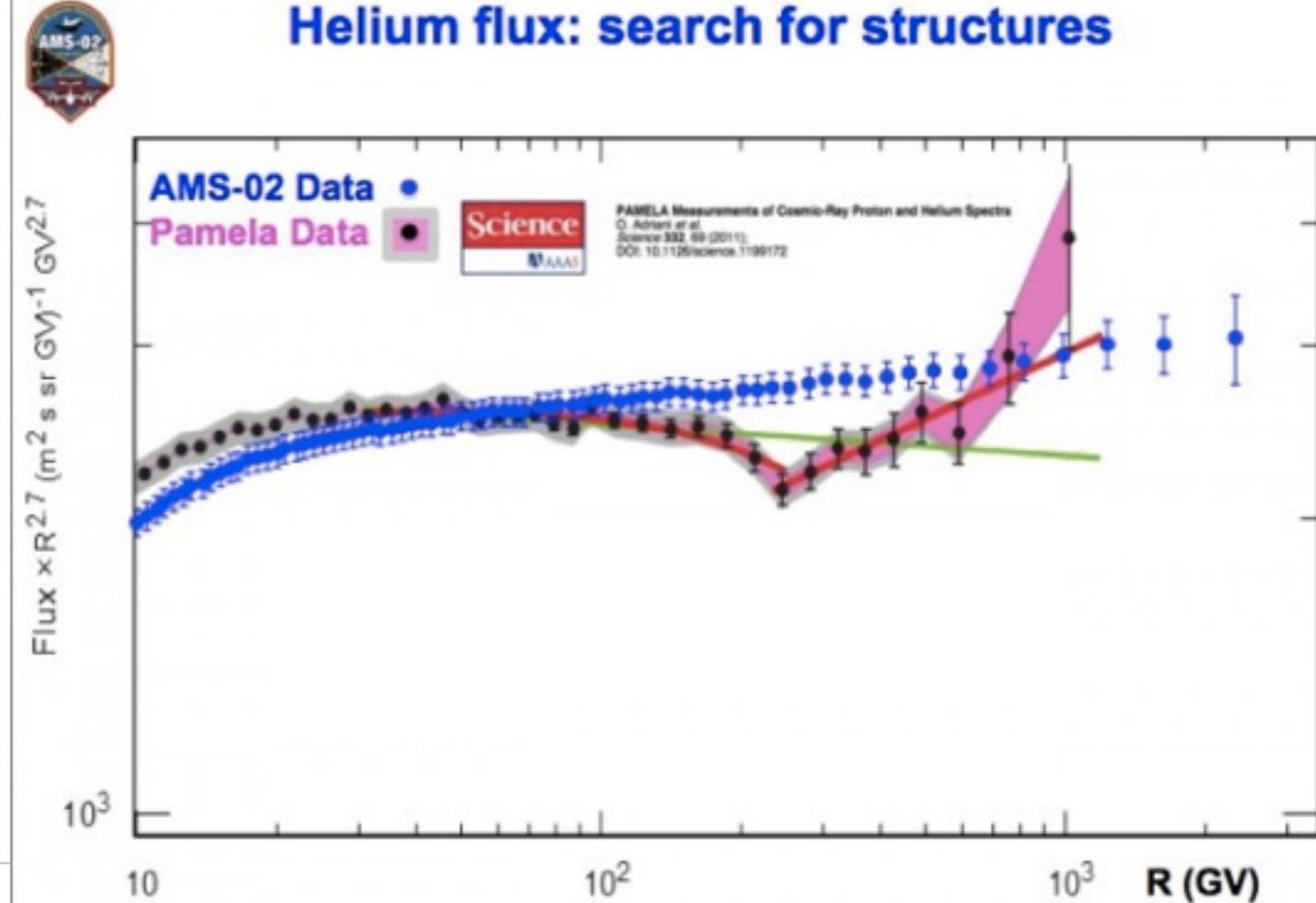
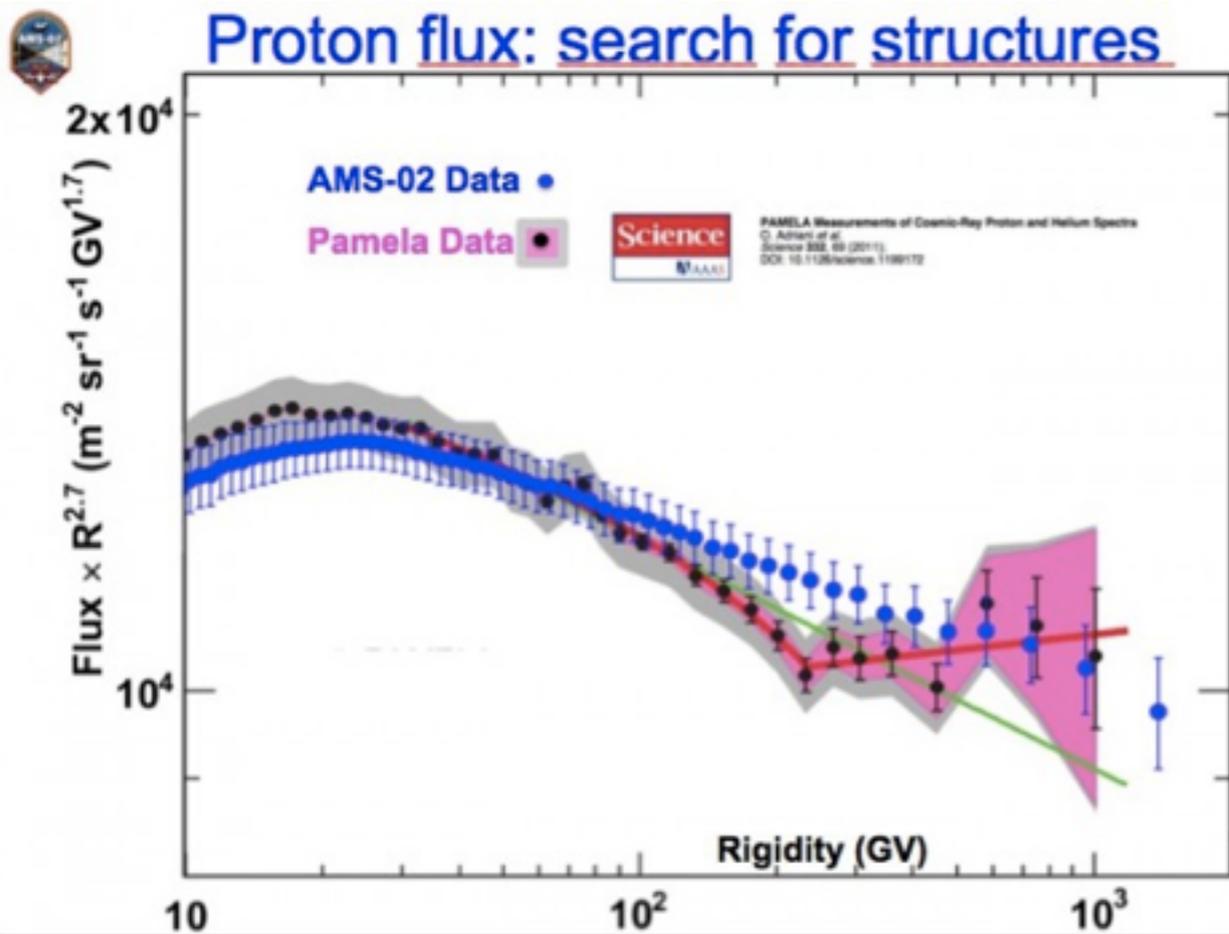
PeV

EeV

ZeV

The GeV-TeV domain: spectral features

1 - Protons/Helium nuclei



disagreement between PAMELA and AMS-02

...many theoretical interpretations in term of acceleration or propagation...

MeV

GeV

TeV

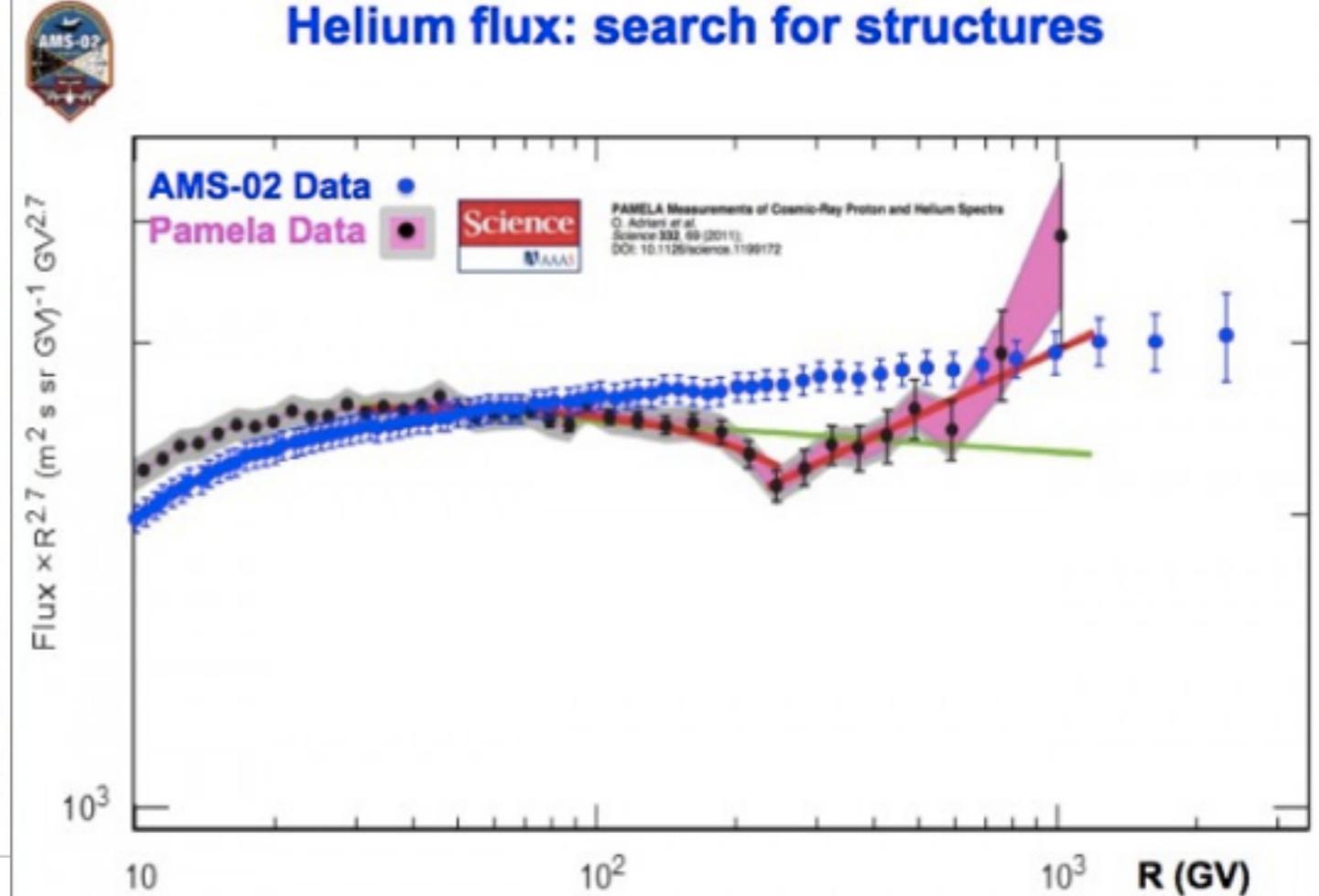
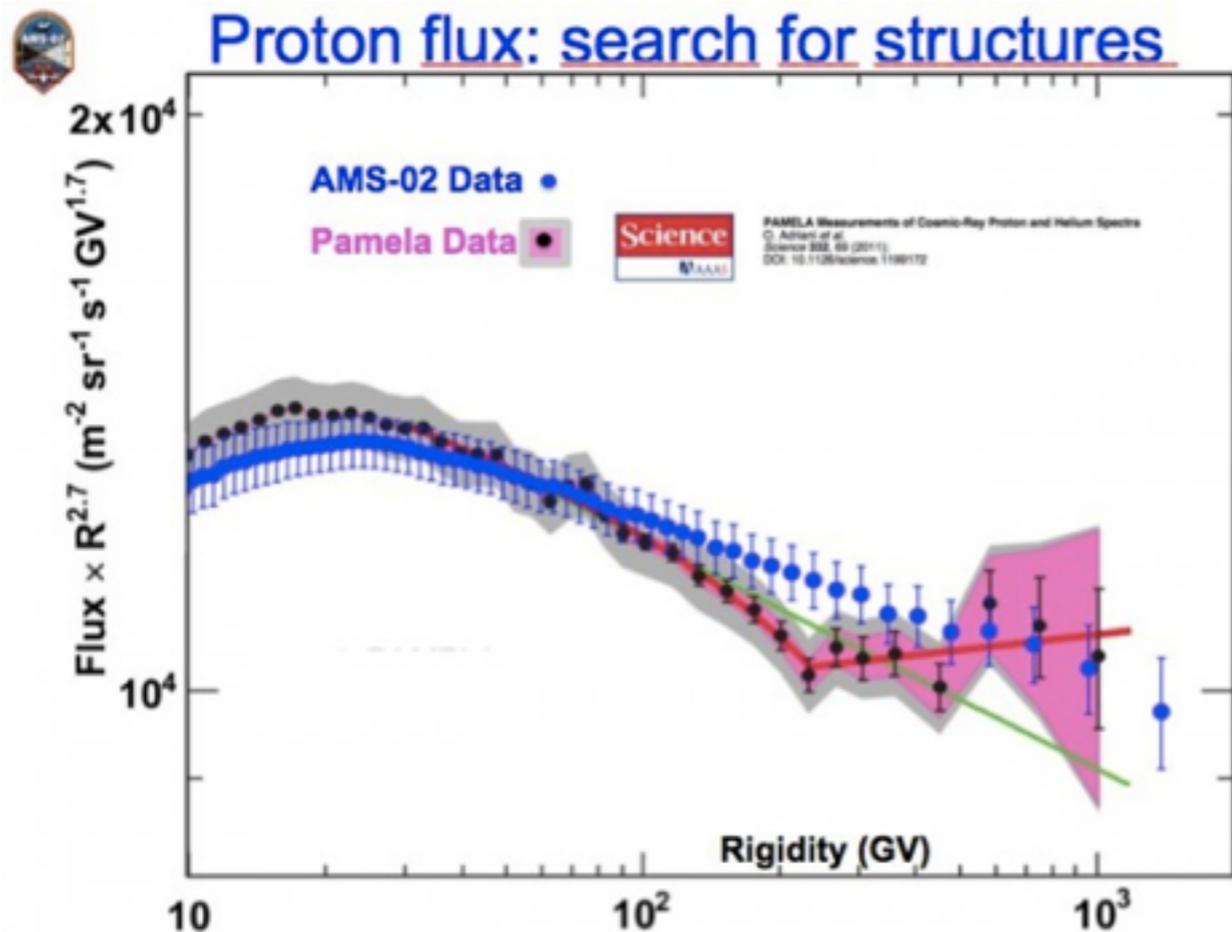
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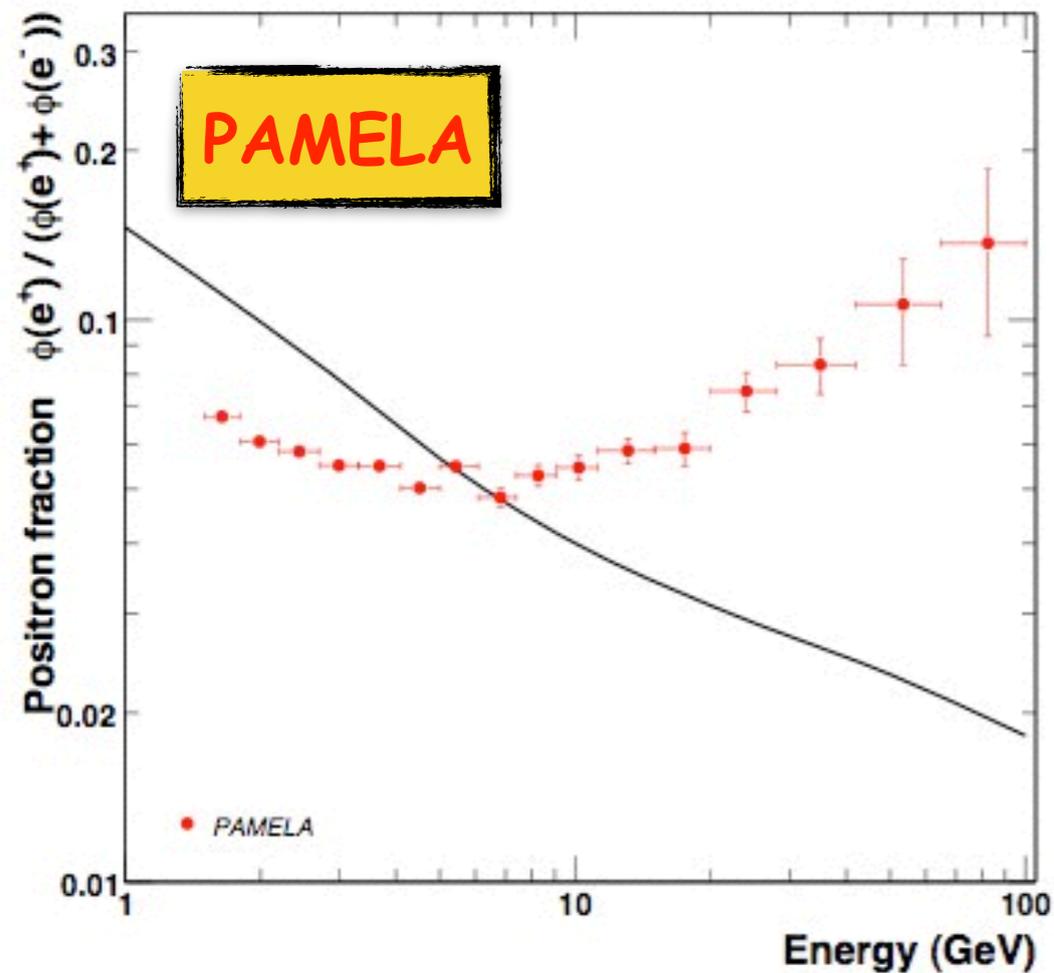
PeV

EeV

ZeV

The GeV-TeV domain: spectral features

2 - Electrons/Positrons



MeV

GeV

TeV

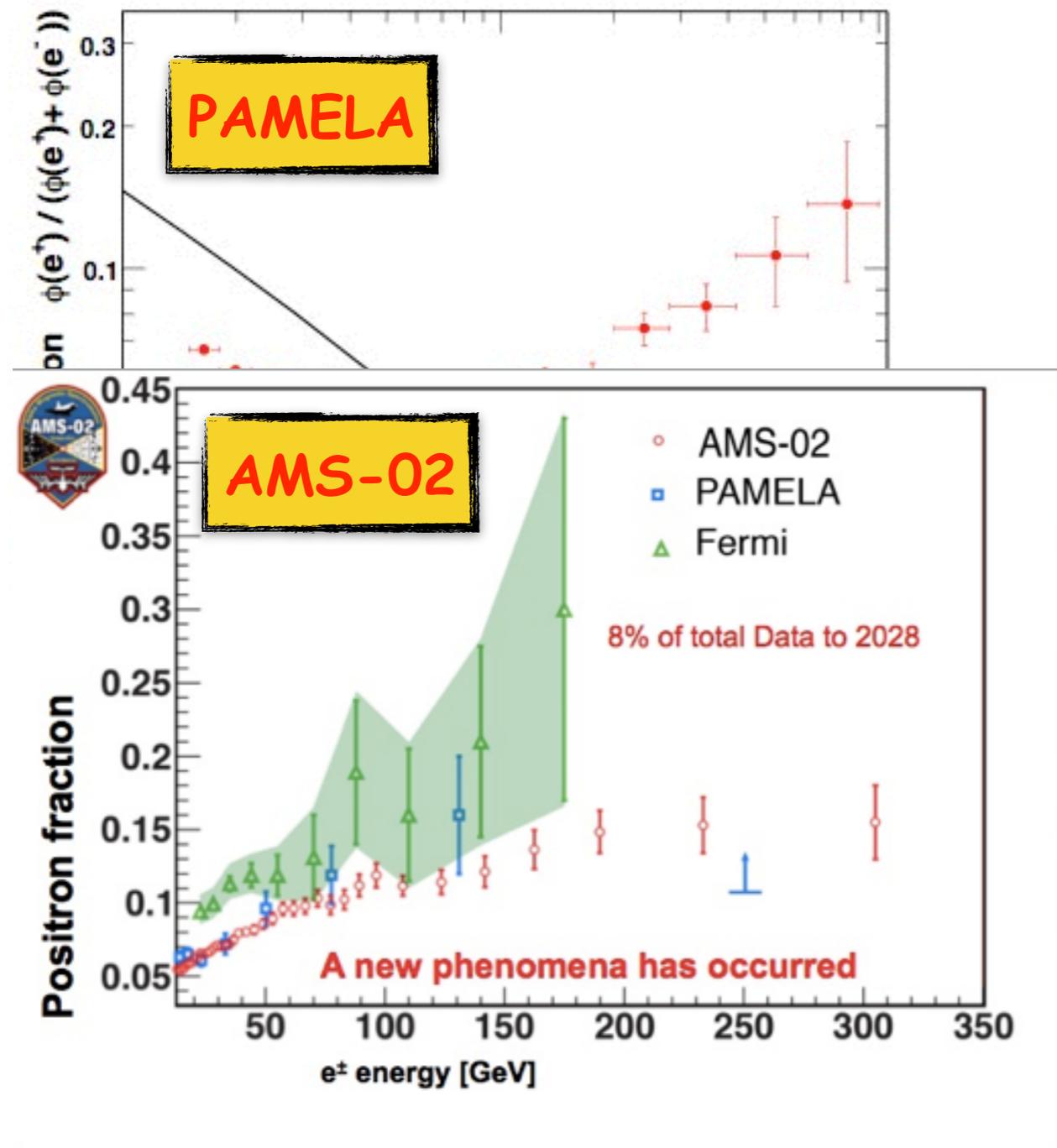
PeV

EeV

ZeV

The GeV-TeV domain: spectral features

2 - Electrons/Positrons



MeV

GeV

TeV

PeV

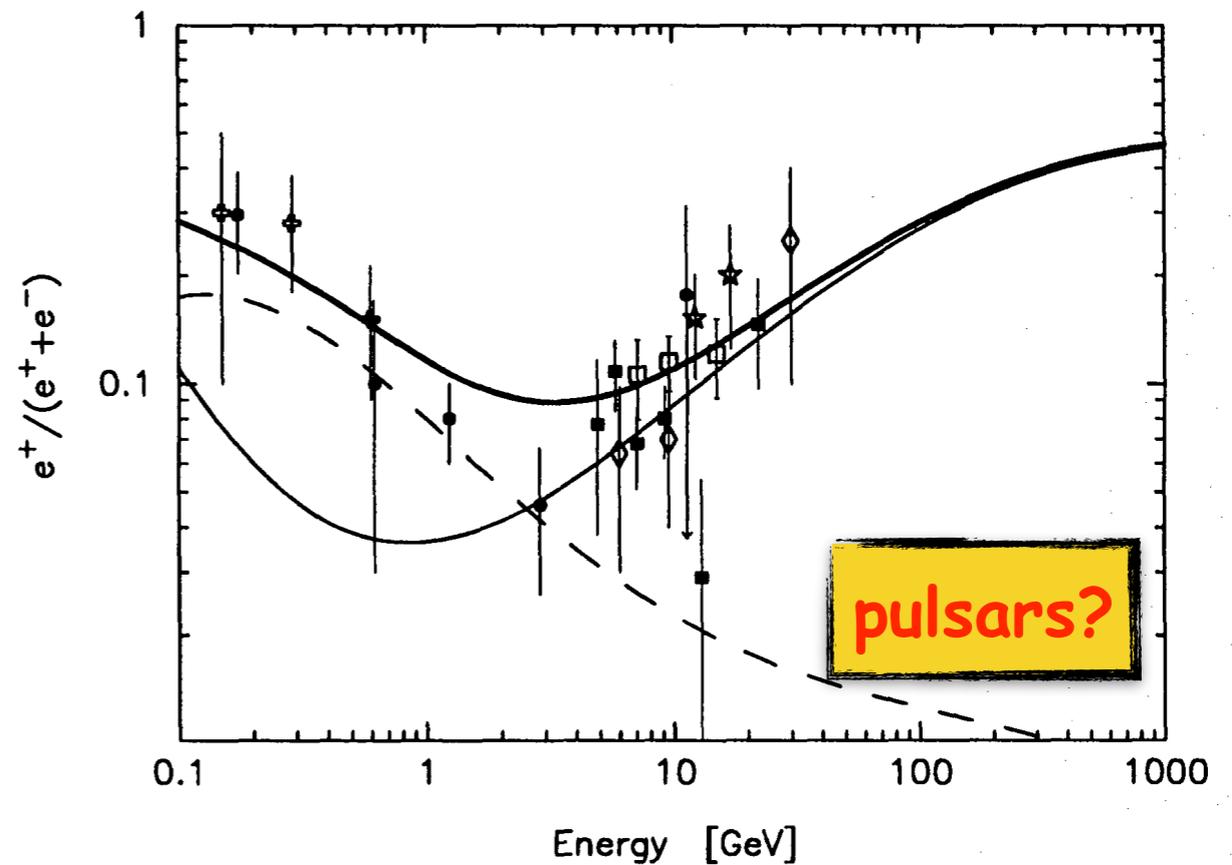
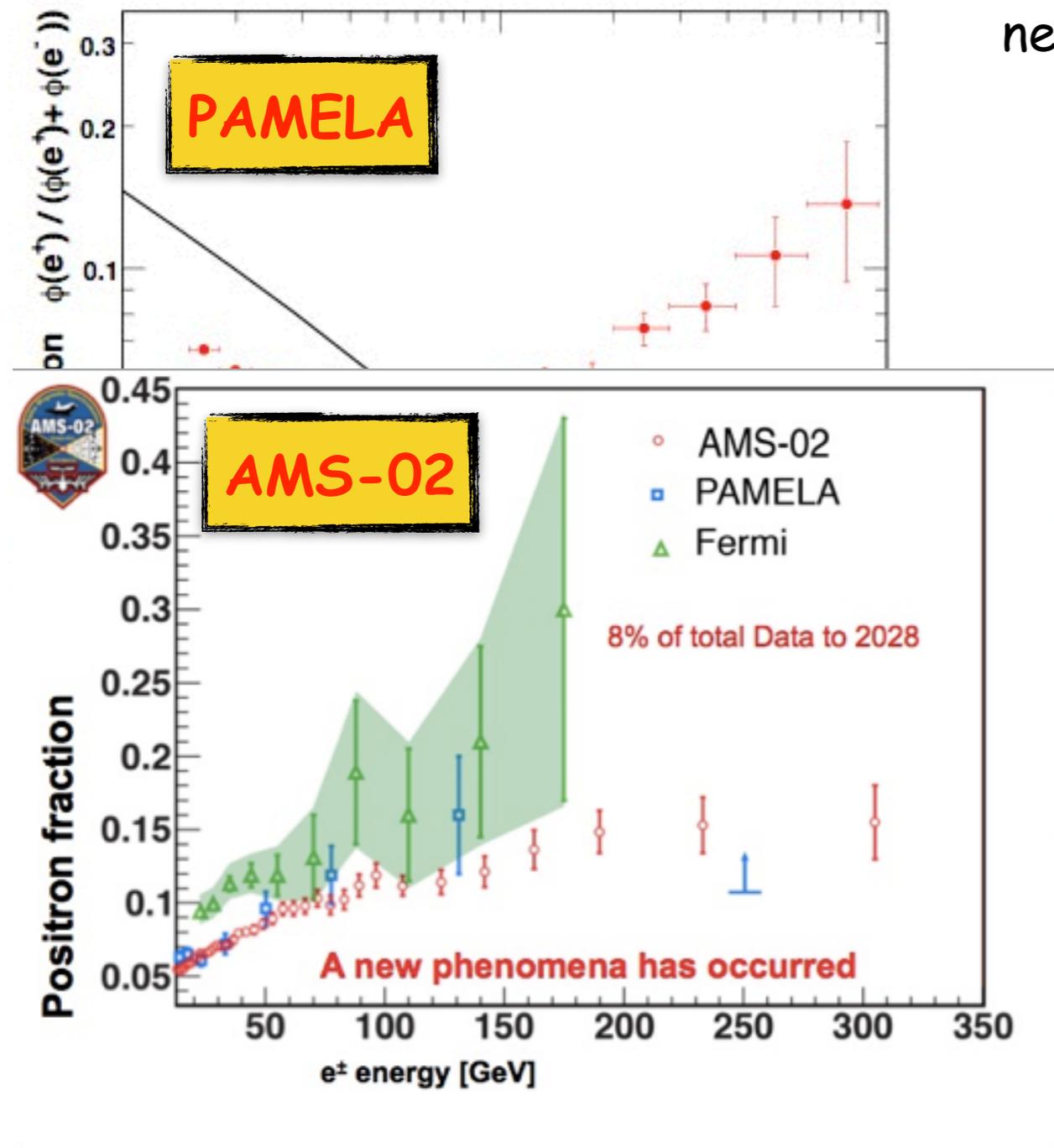
EeV

ZeV

The GeV-TeV domain: spectral features

2 - Electrons/Positrons

need for a nearby source of e^+e^- (Boulares 1989...)



Aharonian et al. 1995

MeV

GeV

TeV

PeV

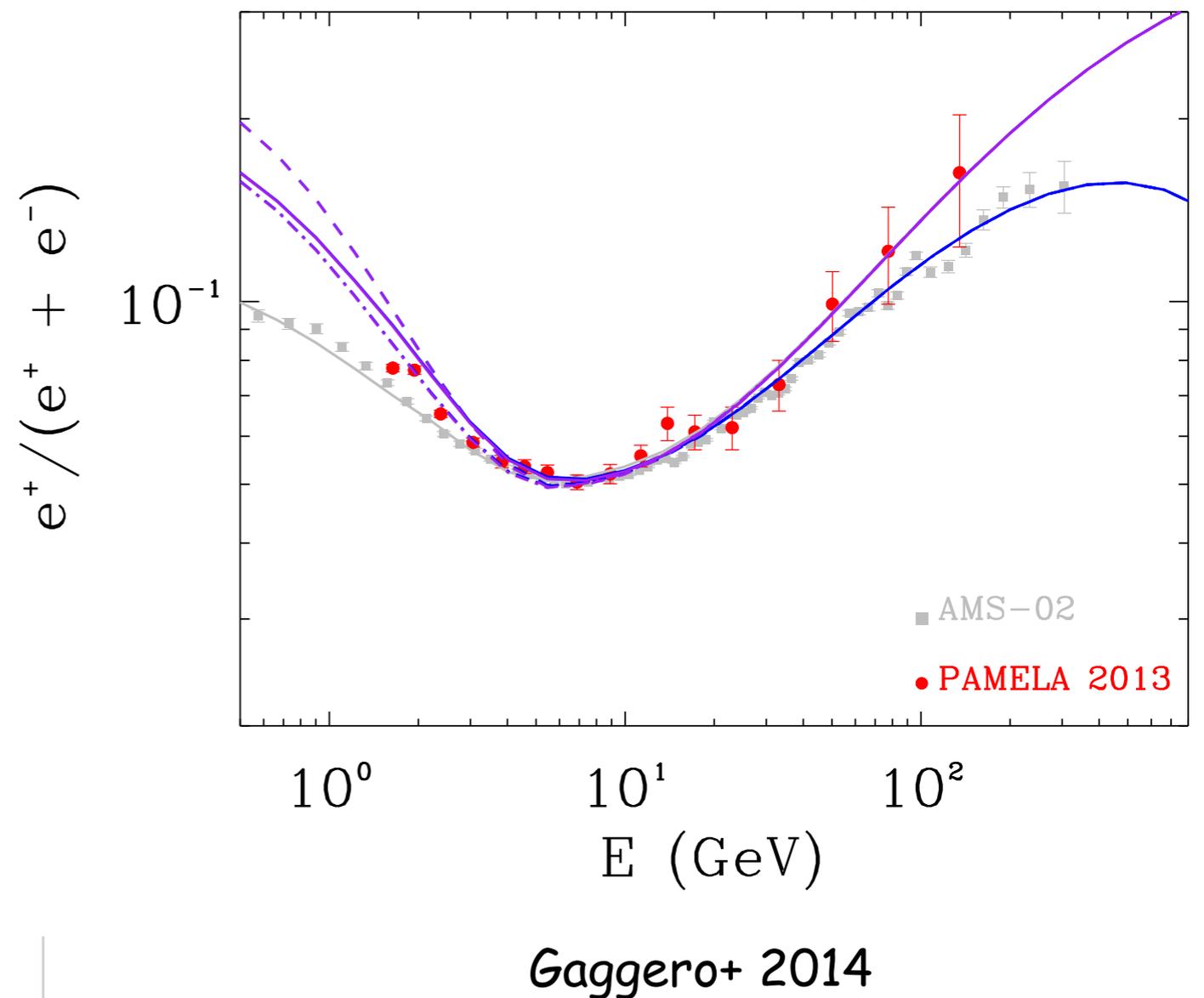
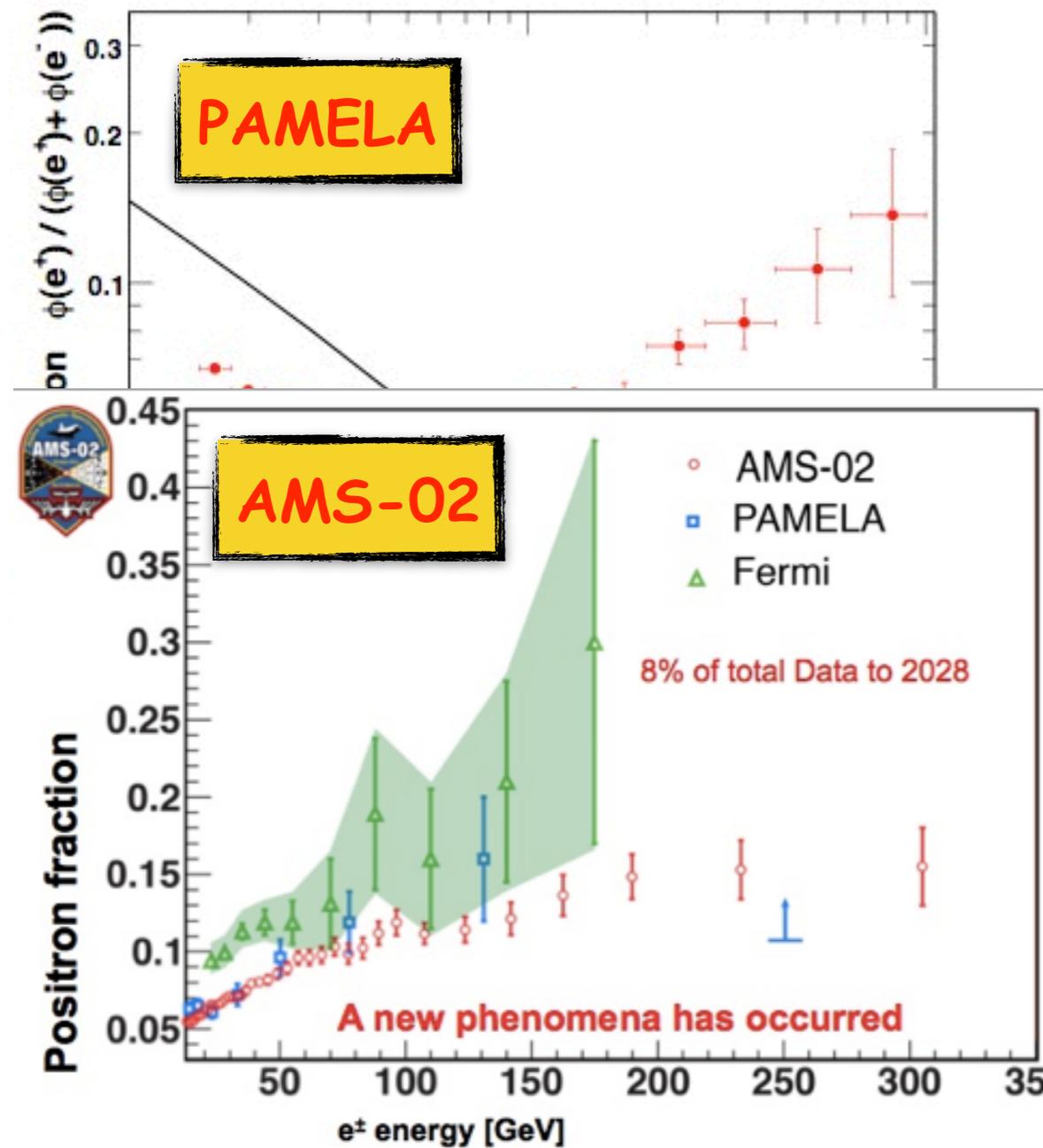
EeV

ZeV

The GeV-TeV domain: spectral features

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MeV

GeV

TeV

PeV

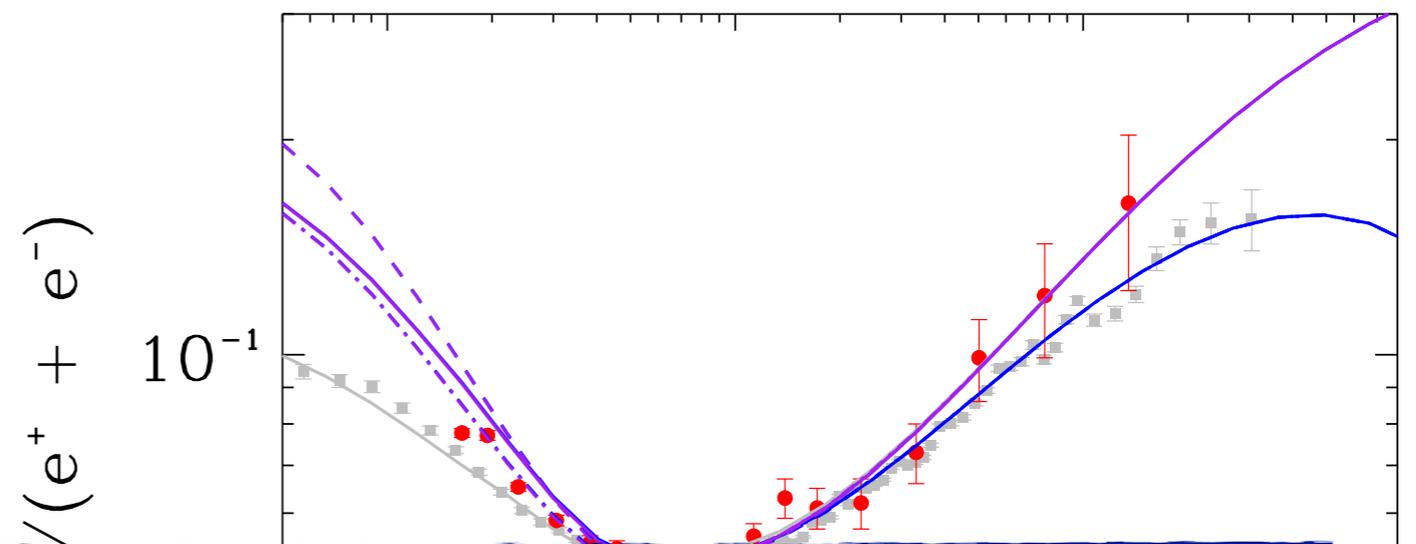
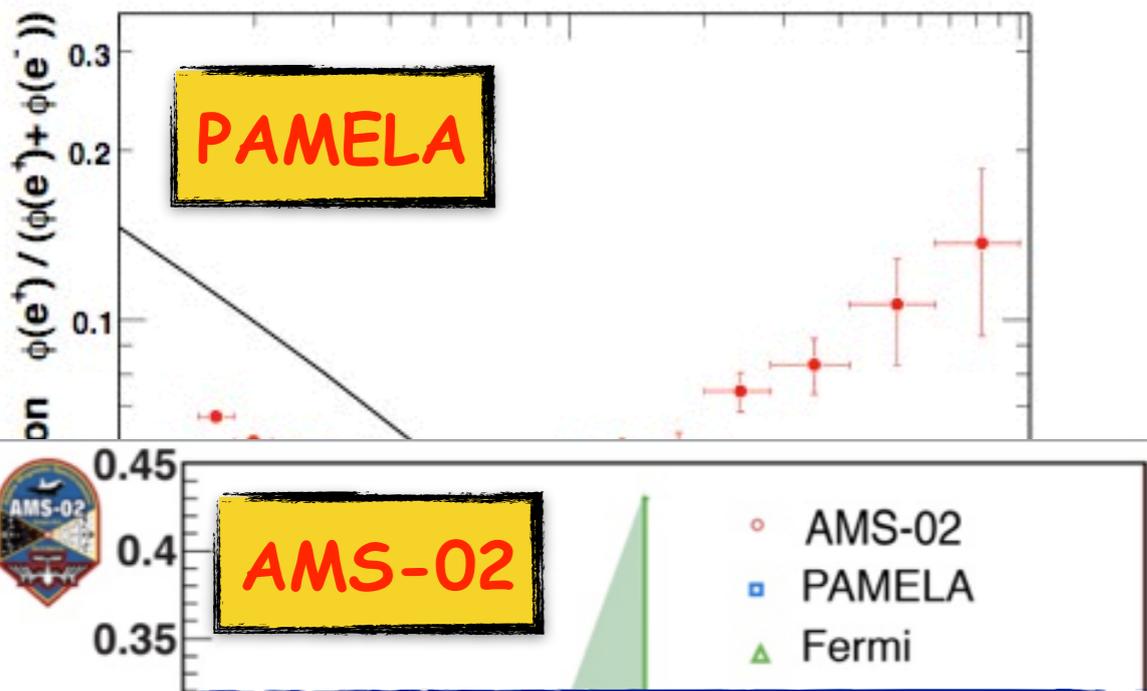
EeV

ZeV

The GeV-TeV domain: spectral features

2 - Electrons/Positrons

need for a nearby source of e^+e^- (Boulares 1989...)



Positron fraction

nearby known pulsars (Hooper+ 2009)
 nearby SNRs (Blasi 2009)
 sources in the nearby spiral arm + 3D diffusion (Gaggero+ 2014)
 dark matter (see parallel session at this conference)

for a review see Profumo (2009) and references therein

MeV

GeV

TeV

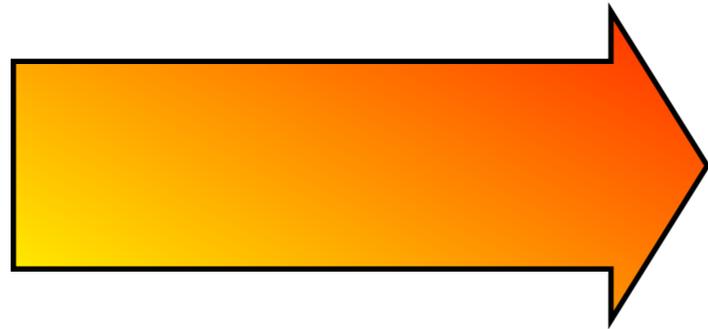
PeV

EeV

ZeV

The PeV domain: can we get to the knee?

escaping CR current



these are fixed for a given SNR

$$\text{Hillas criterium } E_{max} \sim u B R$$

field amplification is needed

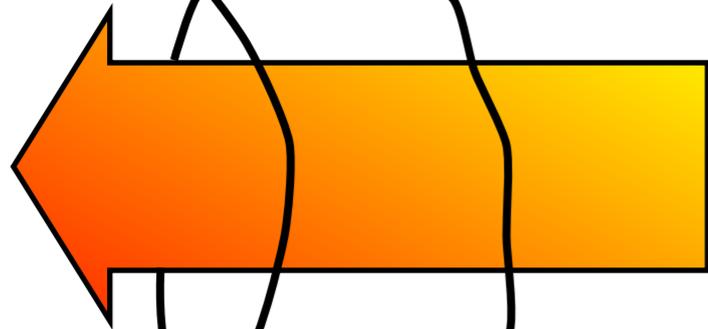
current driven instability

interaction between return current and B-field sets the background plasma in motion and drives the instability (Bell 2004)

for observational evidences in X-rays see Vink2013

$$\vec{j} \times \vec{B}$$

return current (carried by the thermal plasma)



$$\vec{j} \times \vec{B}$$

B-field line (frozen into the thermal plasma)

down-shock-up

MeV

GeV

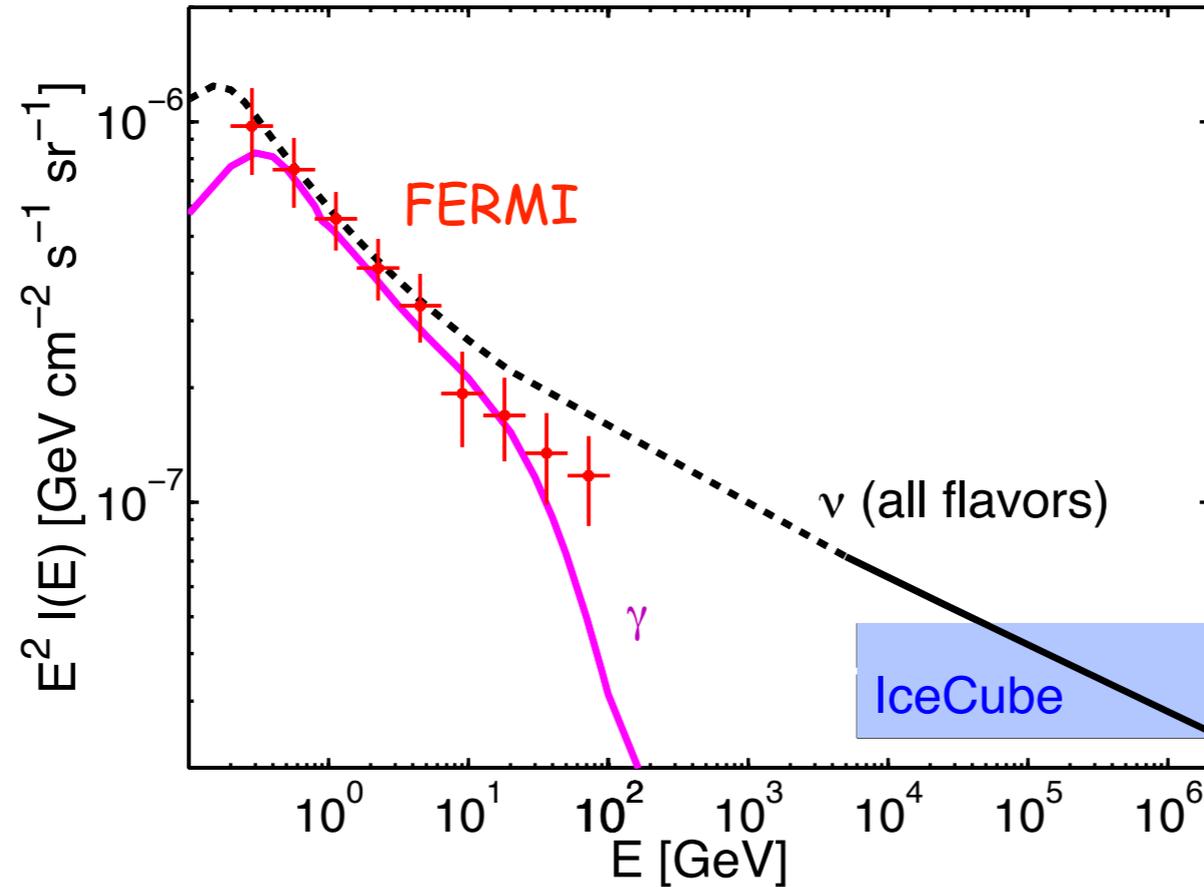
TeV

PeV

EeV

ZeV

The PeV domain: IceCube neutrinos



see plenary talks by Elisa Resconi and John Beacom + parallel sessions on neutrinos

MeV

GeV

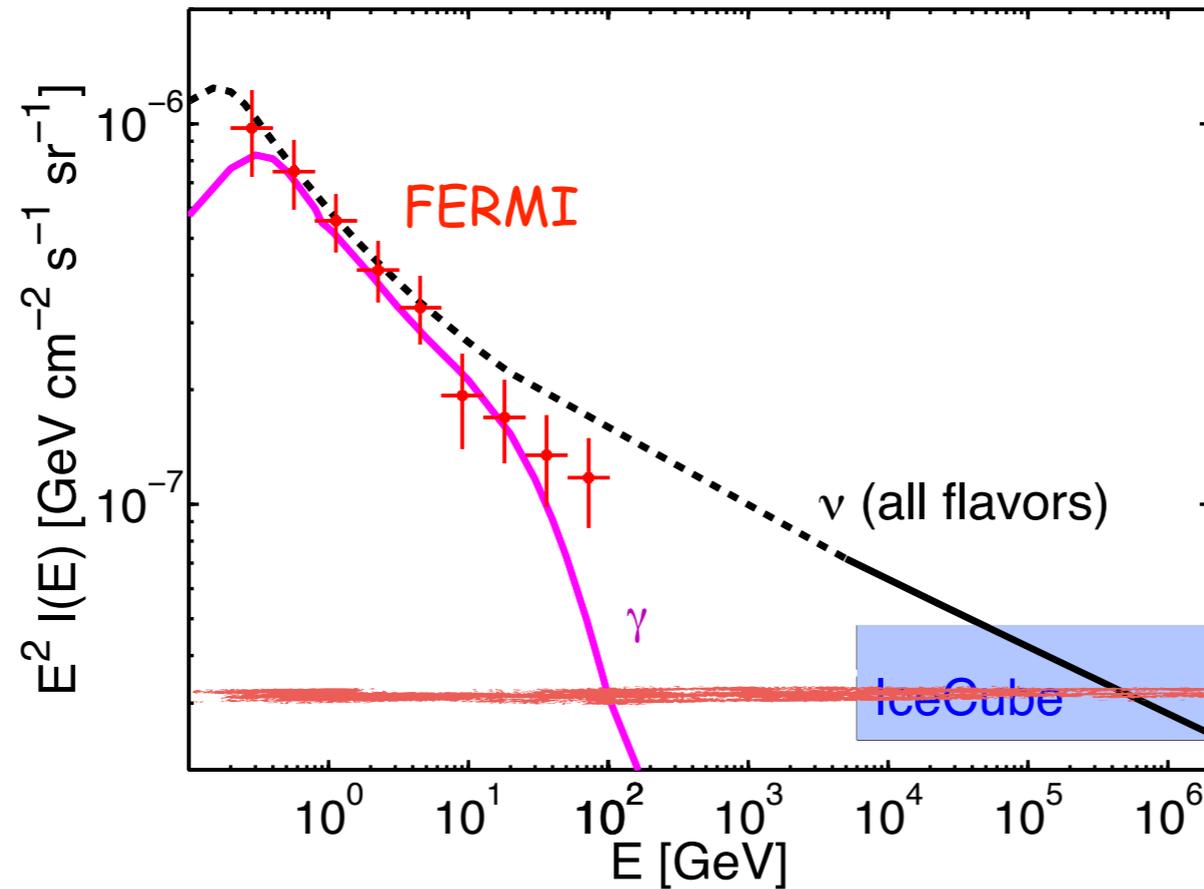
TeV

PeV

EeV

ZeV

The PeV domain: IceCube neutrinos



30 eV/cm²/s/sr

see plenary talks by Elisa Resconi and John Beacom + parallel sessions on neutrinos

MeV

GeV

TeV

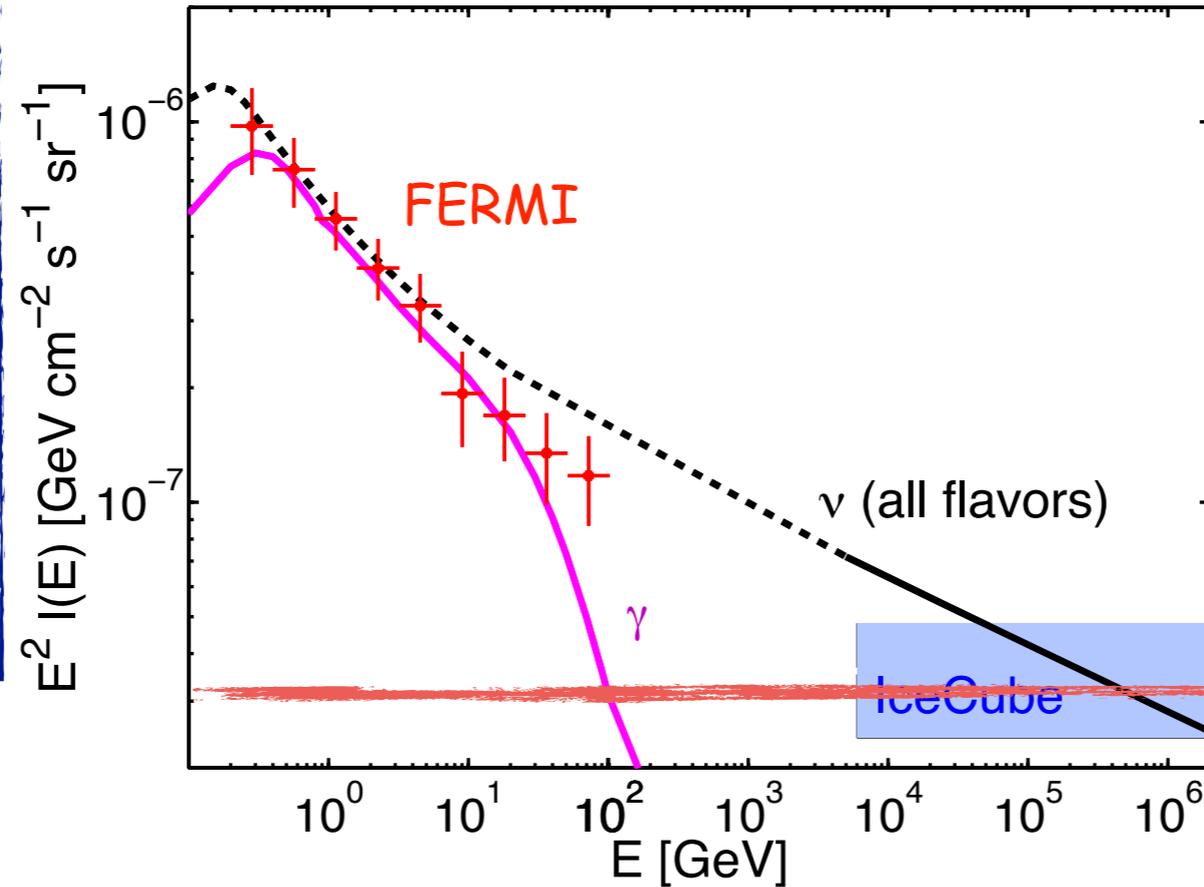
PeV

EeV

ZeV

The PeV domain: IceCube neutrinos

if p-p interactions spectrum cannot be too steep (e.g. Murase+ 2013) for p-gamma interactions -> Winter2013, Kalashev+2013 ...



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see plenary talks by Elisa Resconi and John Beacom + parallel sessions on neutrinos

MeV

GeV

TeV

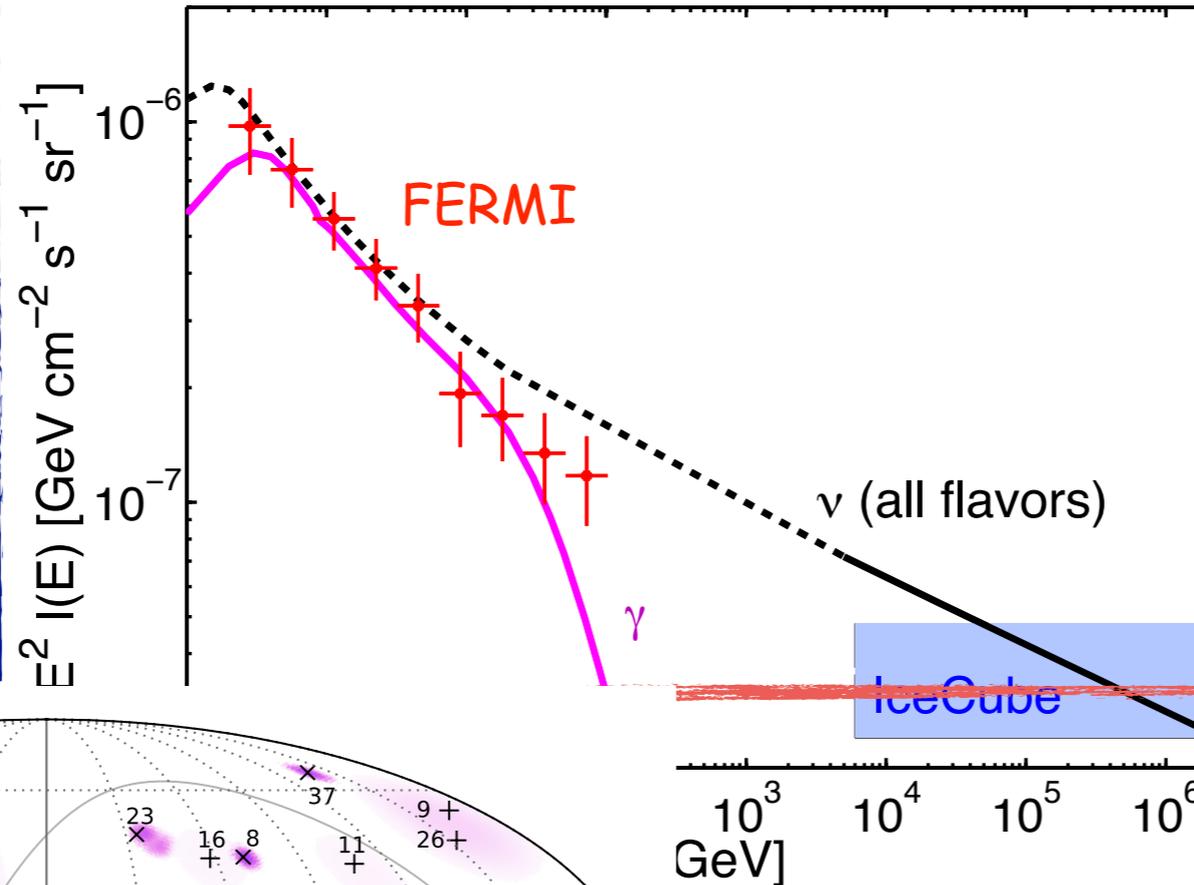
PeV

EeV

ZeV

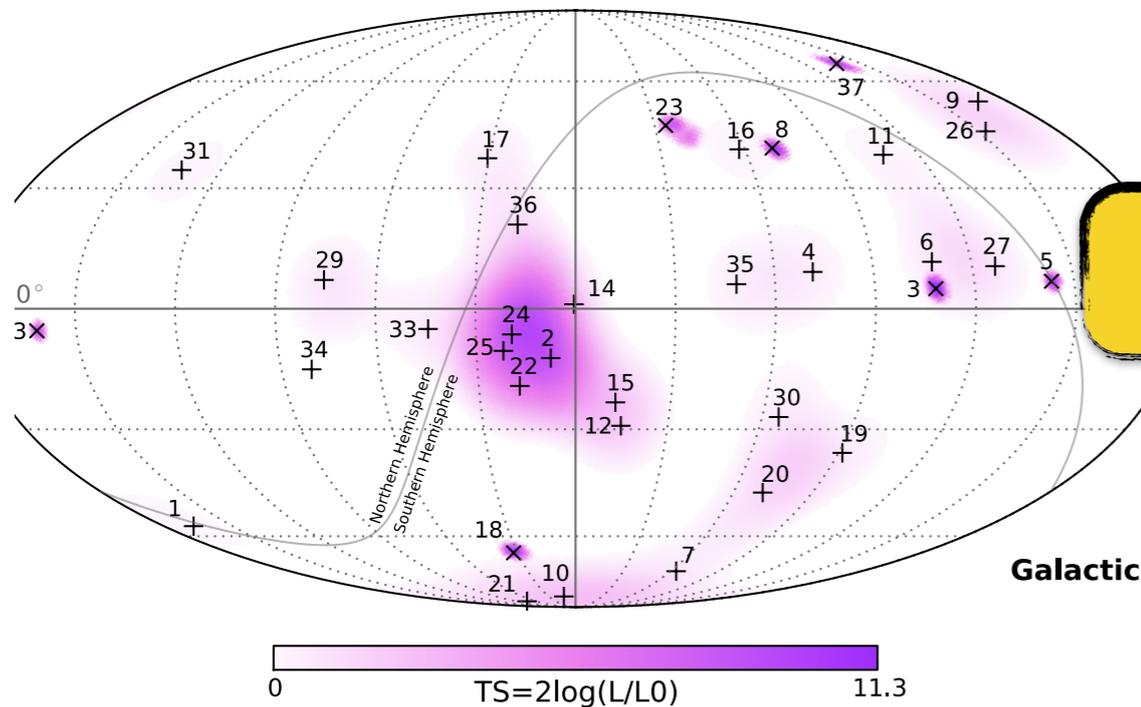
The PeV domain: IceCube neutrinos

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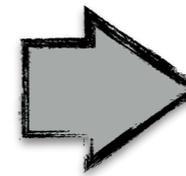


30 eV/cm²/s/sr

Aartsen et al. 2014



isotropy?



extragalactic?

see plenary talks by Elisa Resconi and John Beacom + parallel sessions on neutrinos

MeV

GeV

TeV

PeV

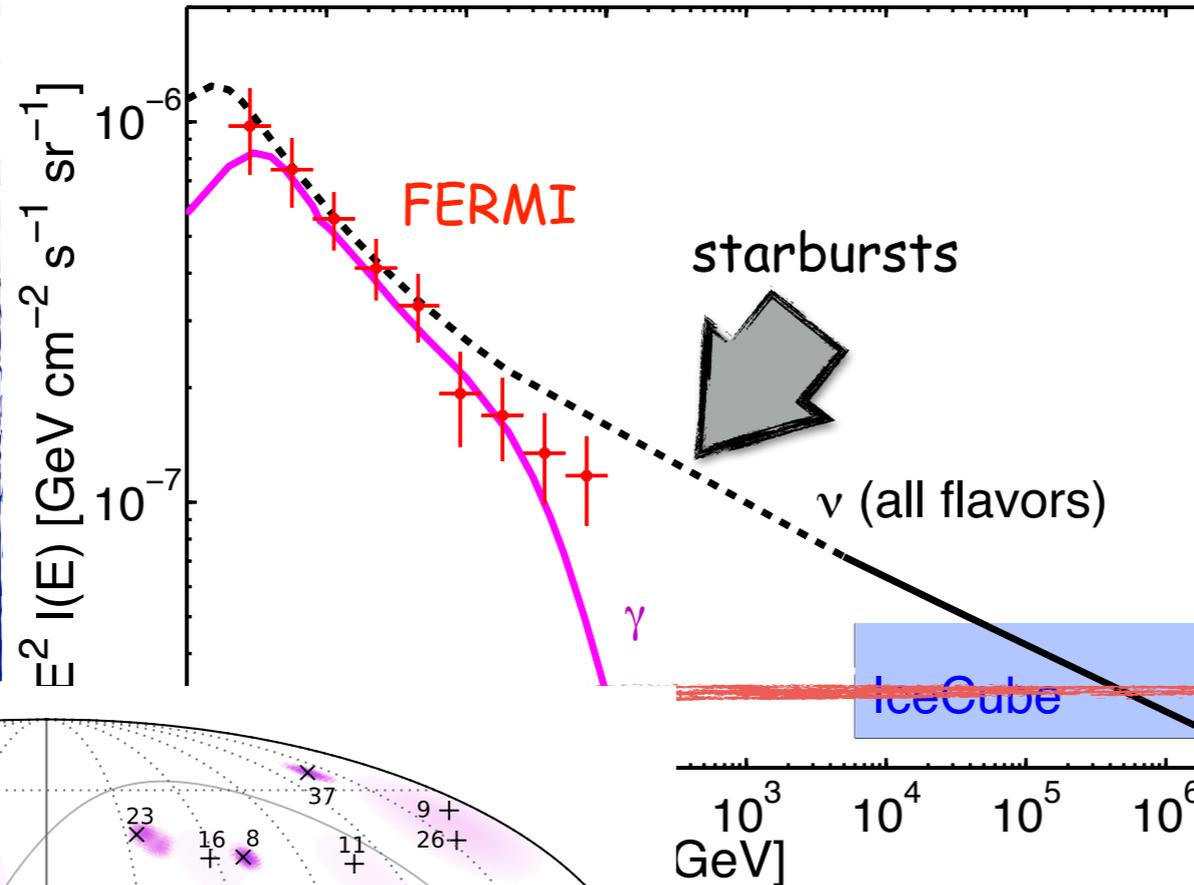
EeV

ZeV

The PeV domain: IceCube neutrinos

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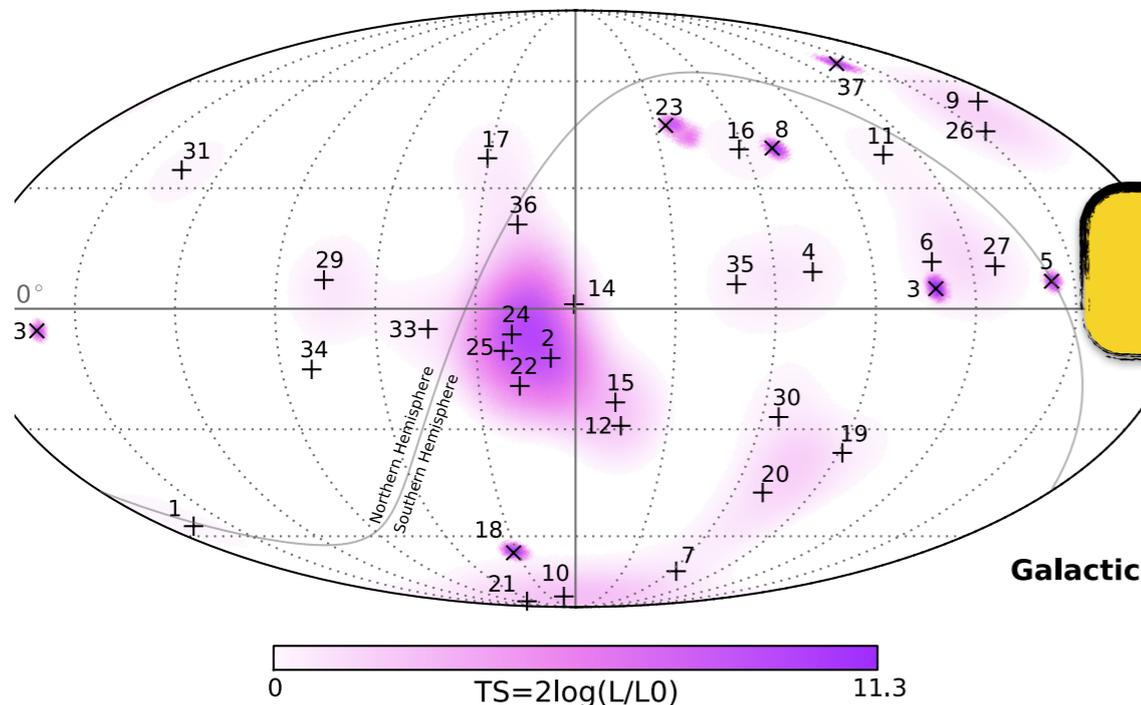
Tamborra et al. 2014



but also Murase et al., Anchordoqui et al., Chang & Wang, Liu et al. ...

30 eV/cm²/s/sr

Aartsen et al. 2014



isotropy?

extragalactic?

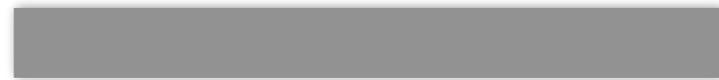
starburst galaxies are amongst the most popular sources according to arXiv

see plenary talks by Elisa Resconi and John Beacom + parallel sessions on neutrinos



IceCube neutrinos: a huge Galactic halo?

of neutrinos



Galactic plane

≈ 1

Taylor, SG, Aharonian 2014

MeV

GeV

TeV

PeV

EeV

ZeV

IceCube neutrinos: a huge Galactic halo?



Galactic halo
(homogeneous CRs)

≈ 0

Galactic plane

≈ 1

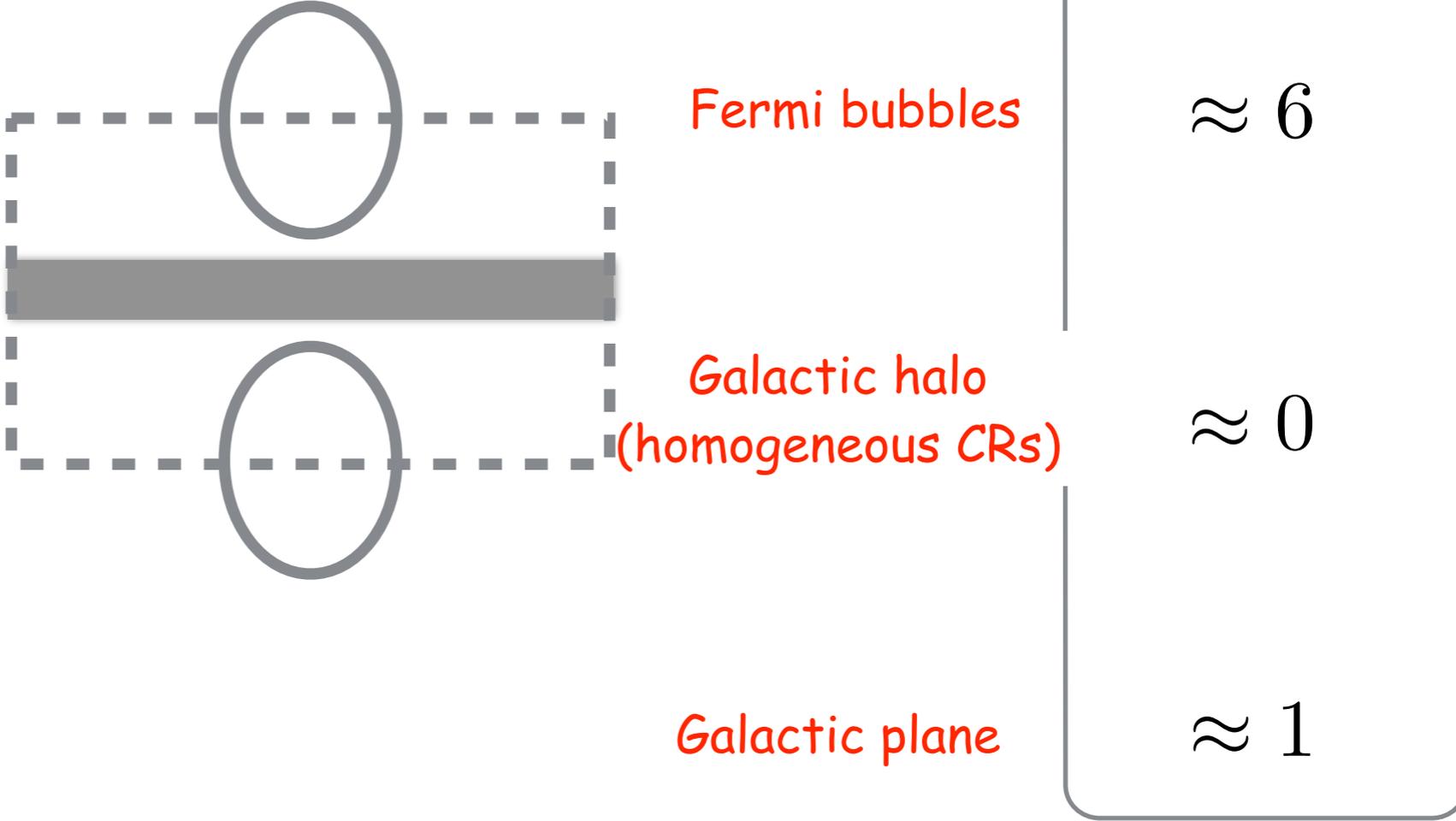
of neutrinos

Galactic halo (homogeneous CRs)	≈ 0
Galactic plane	≈ 1

Taylor, SG, Aharonian 2014

MeV	GeV	TeV	PeV	EeV	ZeV
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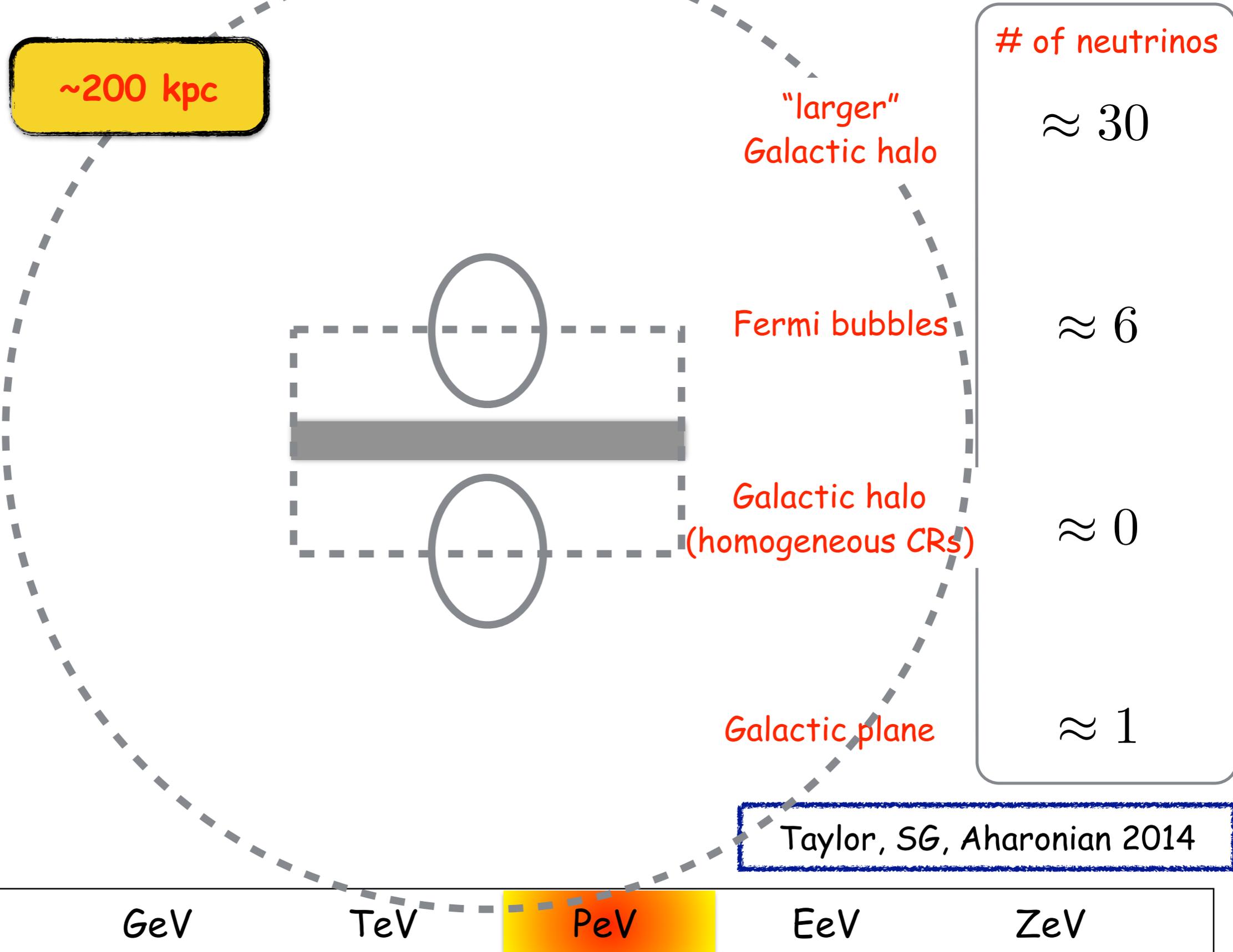
IceCube neutrinos: a huge Galactic halo?



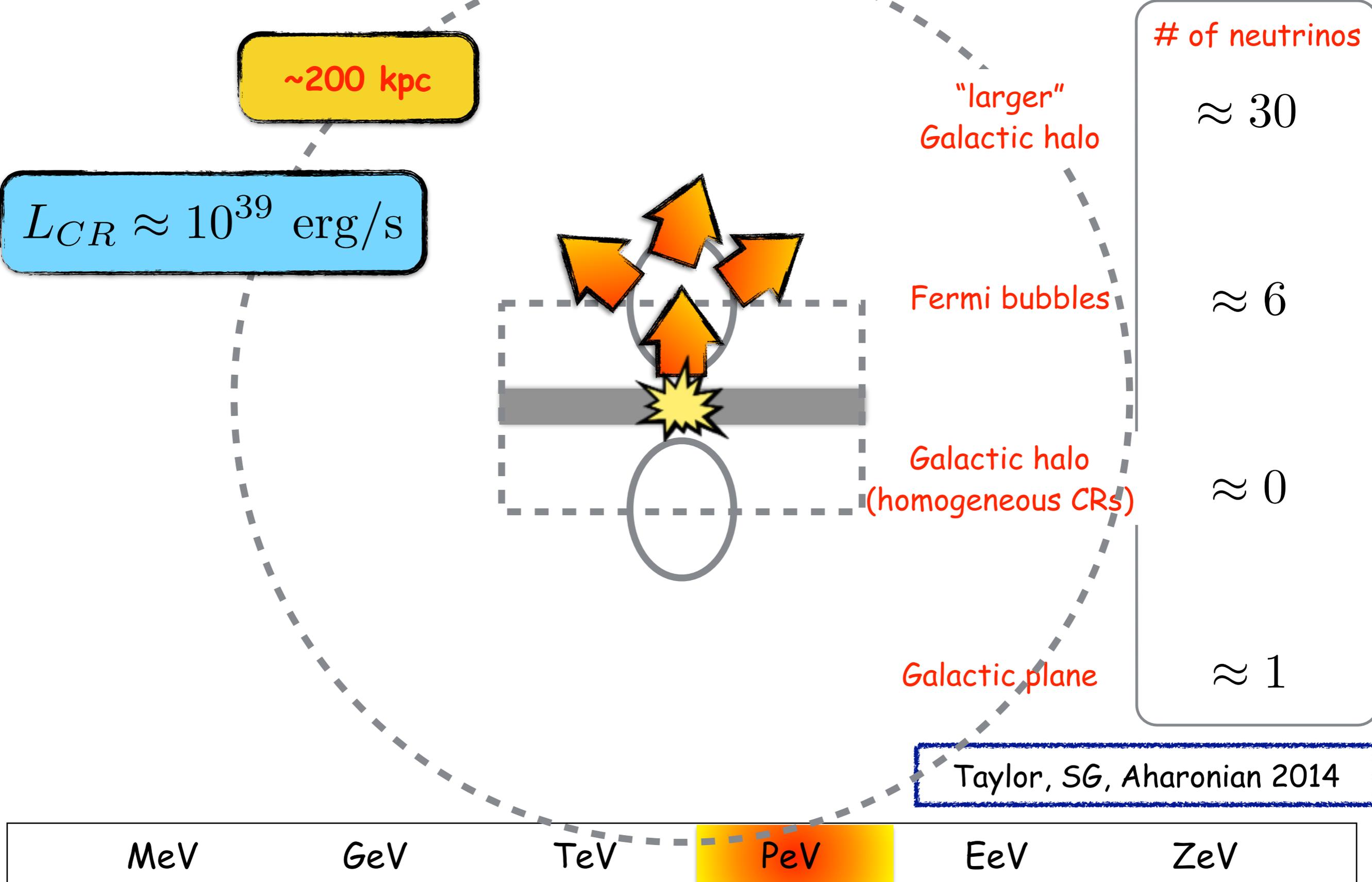
Taylor, SG, Aharonian 2014



IceCube neutrinos: a huge Galactic halo?



IceCube neutrinos: a huge Galactic halo?

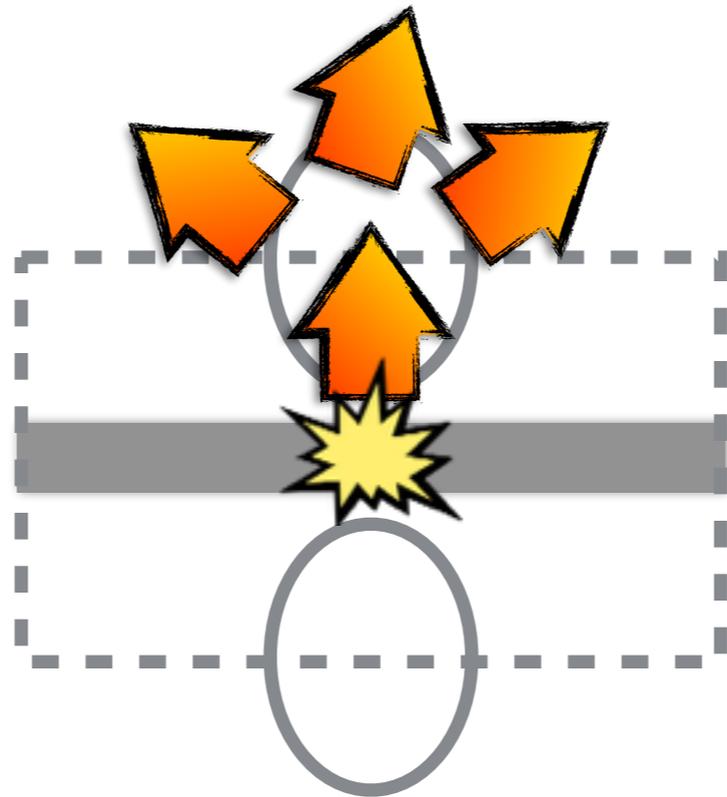


IceCube neutrinos: a huge Galactic halo?

~200 kpc

$L_{CR} \approx 10^{39}$ erg/s

is this big or small?
 -> of the same order of the power required to explain the CRs above the knee



"larger" Galactic halo

Fermi bubbles

Galactic halo (homogeneous CRs)

Galactic plane

of neutrinos
≈ 30
≈ 6
≈ 0
≈ 1

Taylor, SG, Aharonian 2014



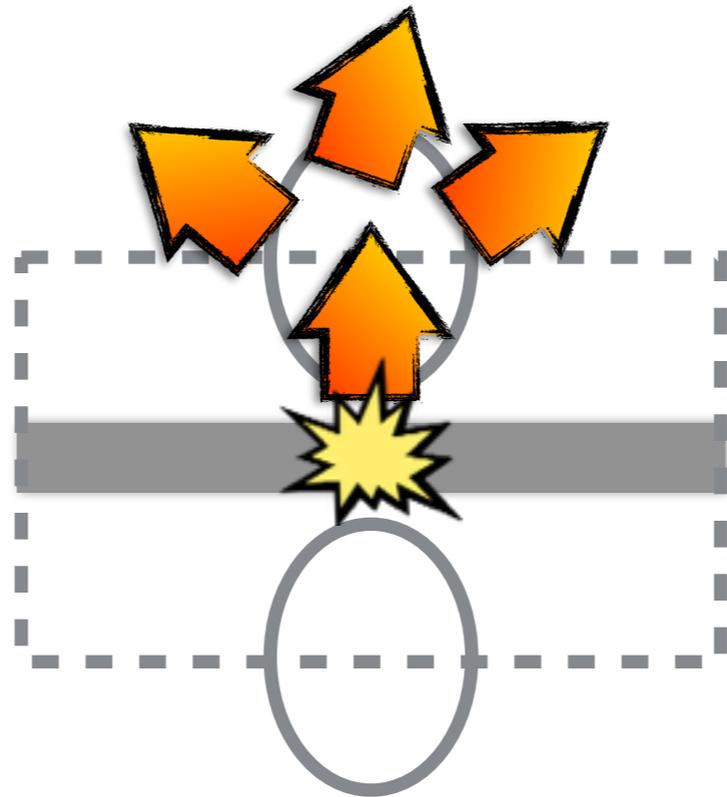
IceCube neutrinos: a huge Galactic halo?

~200 kpc

$L_{CR} \approx 10^{39}$ erg/s

is this big or small?
 -> of the same order of the power required to explain the CRs above the knee

evidence for a huge reservoir of ionized gas ($> 10^{10} M_{sun}$) in the halo from X-ray observations (Gupta+ 2012)



"larger" Galactic halo

Fermi bubbles

Galactic halo (homogeneous CRs)

Galactic plane

of neutrinos
≈ 30
≈ 6
≈ 0
≈ 1

Taylor, SG, Aharonian 2014

