

Multi messenger constraints to the emission of cosmic ray electrons

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A multi-wavelength, multi-messenger analysis

S. Manconi, M. Di Mauro, FD JCAP 2019

We build a model for the production and propagation of e^- and e^+ in the Galaxy and test it against 3 observables:

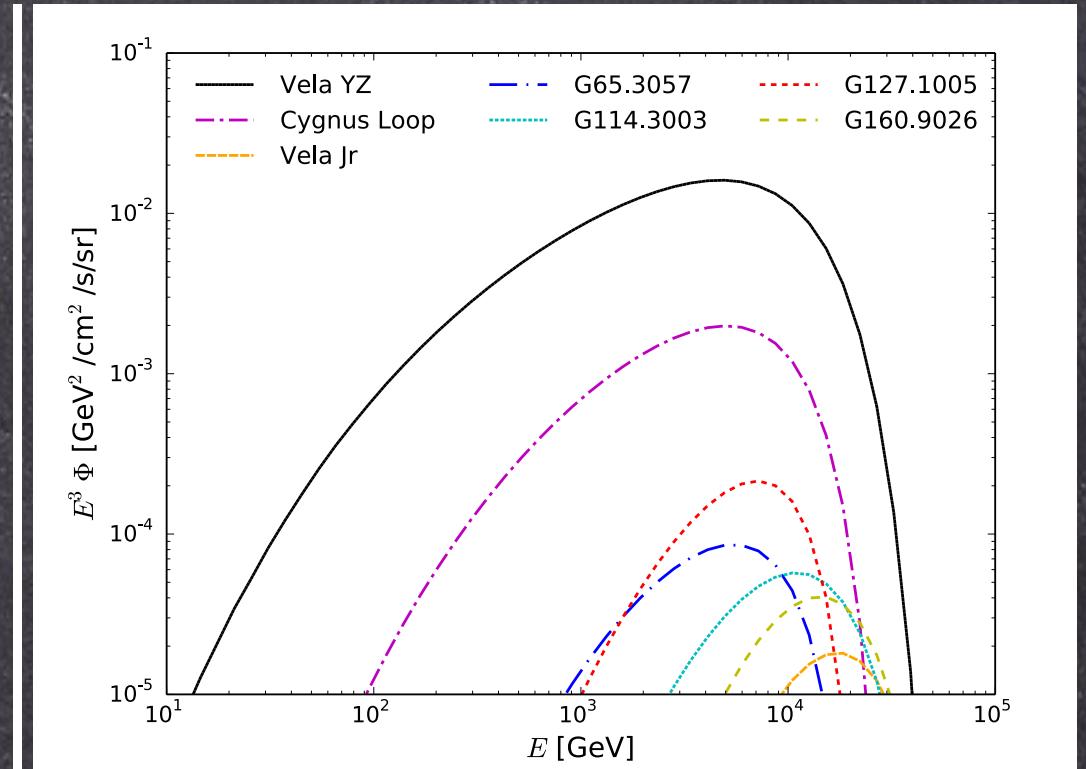
1. Radio brightness data from Vela YZ and Cygnus Loop SNRs at all frequencies.
The radio emission is all synchrotron from e^- accelerated by the source.
2. e^+e^- flux. Data from 5 experiments, e^+ flux from AMS-02
Contributors: Far and near SNRs, near SNRs and PWNe, secondaries for e^+e^- .
The e^+ flux constrains the PWN emission.
 e^+e^- data taken with their uncertainty on the energy scale.
3. e^+e^- dipole anisotropy upper bounds from Fermi-LAT
Test on the power of this observable on the closest SNRs.

The galactic population of SNRs

Selection of sources by catalog parameters

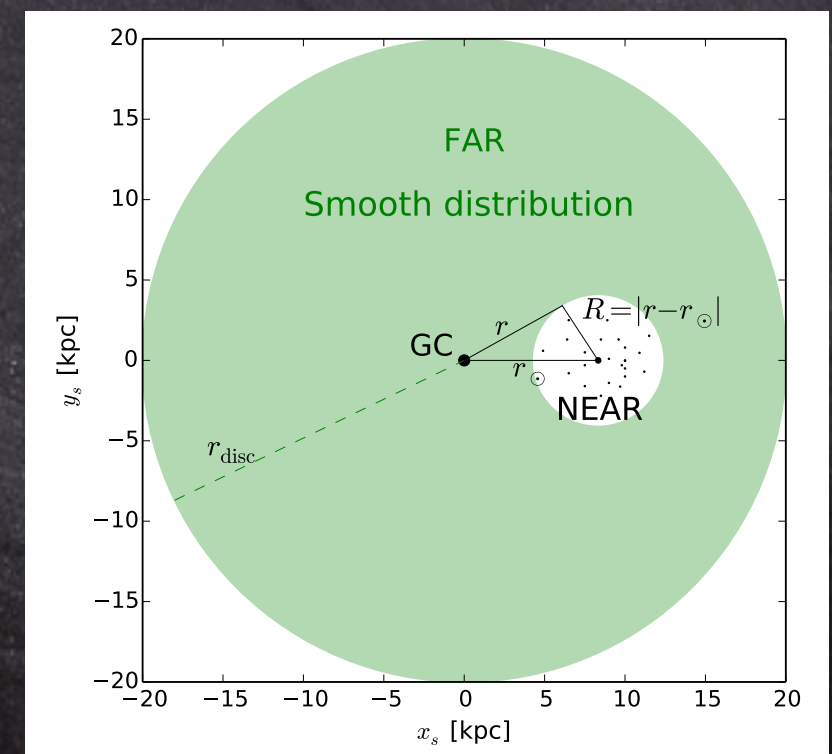
Vela YX and Cygnus Loop have highest flux

Source	other name	d [kpc]	t_{obs} [kyr]	α_r
G263.9-3.3	Vela YZ	0.295 ± 0.075	11.4	0.5
G74.0-8.5	Cygnus Loop	$0.54^{+0.10}_{-0.08}$	20	0.4
G266.2-1.2	Vela Jr	0.75	[2.7,4.3]	0.3
G65.3+5.7	-	1.0 ± 0.4	26 ± 1	0.58
G114.4+03	-	0.7	7.7	-0.49
G127.1+05	R5	1.0 ± 0.1	25 ± 5	0.43
G160.9-2.6	HB9	0.8 ± 0.4	3	0.59



We consider a FAR population at $R > R_D$, with smooth radial distribution (Green 2015).

In the very local Galaxy ($R_D < 0.7$ kpc), sources are set from catalog



Injection of e^+e^- from SNR into the ISM

Burst like model: all the e^- are injected at $t=T_{\text{SNR}}$ ($T_{\text{Vela}} = 11.3 \text{ kyr}$, $T_{\text{Cygnus}} = 20 \text{ kyr}$)

$$Q(E) = Q_0 \left(\frac{E}{E_0} \right)^{-\gamma} \exp \left(-\frac{E}{E_c} \right)$$

$$E_{\text{tot}} = \int_{E_1}^{\infty} dE E Q(E)$$

Evolutionary model (Ohira+ MNRAS 2012): of the SNR radius and velocity.

The maximum E of accelerated e^- is limited by SNR age, cooling by synchrotron emission or escape (Bohm-like).

$$E_{\text{m,esc}}(t) = E_{\text{knee}} \left(\frac{T}{t_{\text{Sedov}}} \right)^{-\alpha}$$

$$E_{\text{m,esc,Vela}} = 88 \text{ GeV}$$

$$E_{\text{m,esc,Cygnus}} = 17 \text{ GeV}$$

below which e^- are still trapped in the SNR:

$$Q_{\text{trap}}(E, T) = Q_{0,\text{trap}}(T) \left(\frac{E}{E_0} \right)^{-\gamma} \exp \left(-\frac{E}{E_c} \right)$$

while the runaway e^- follow:

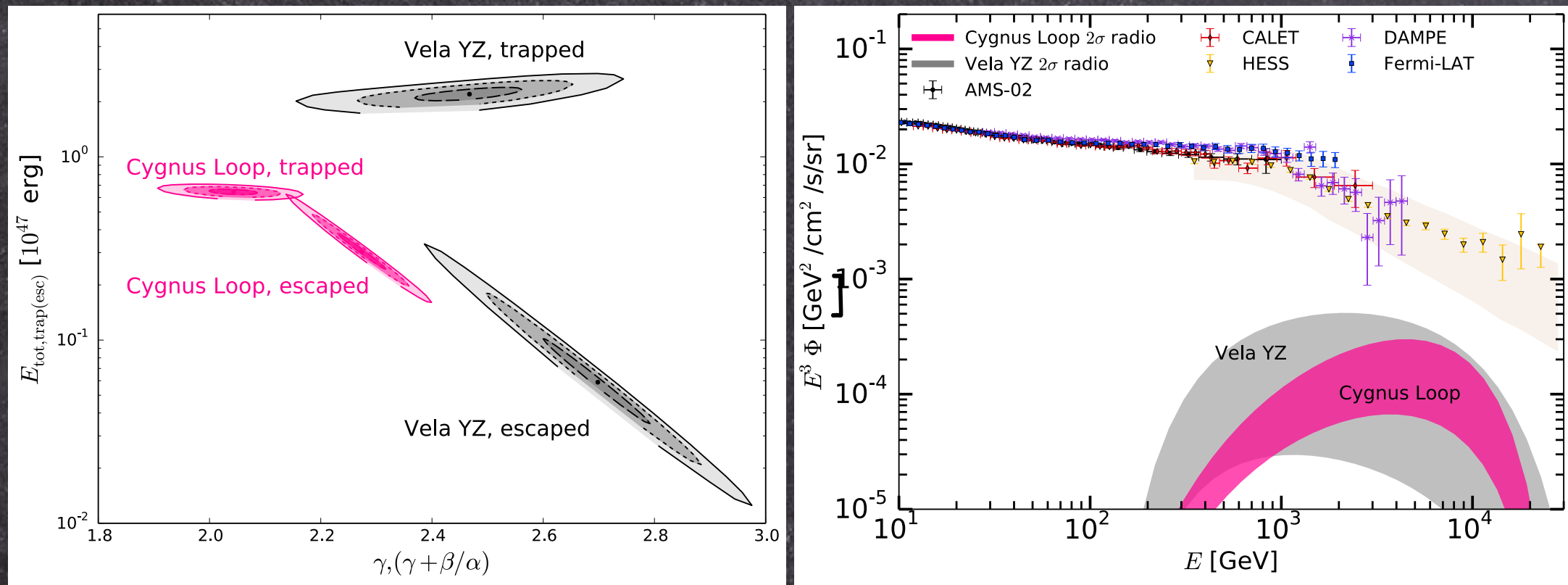
$$Q_{\text{esc}}(E) = A \left(\frac{E}{E_0} \right)^{-(\gamma+\beta/\alpha)} \exp \left(-\frac{E}{E_c} \right)$$

I - Bounds from radio emission

Hyp.: Radio flux is due to synchrotron emission from accelerated e^- in the SNR

$$Q_{0,\text{SNR}} = 1.2 \cdot 10^{47} \text{GeV}^{-1} (0.79)^\gamma \frac{B_r^\nu(\nu)}{\text{Jy}} \left[\frac{d}{\text{kpc}} \right]^2 \left[\frac{\nu}{\text{GHz}} \right]^{\frac{\gamma-1}{2}} \left[\frac{B}{100 \mu\text{G}} \right]^{-\frac{\gamma+1}{2}}$$

Evolutionary model



We fit all the available radio data fixing $B_{\text{Vela}} = 36 \mu\text{G}$ and $C_{\text{Cygnus}} = 60 \mu\text{G}$.

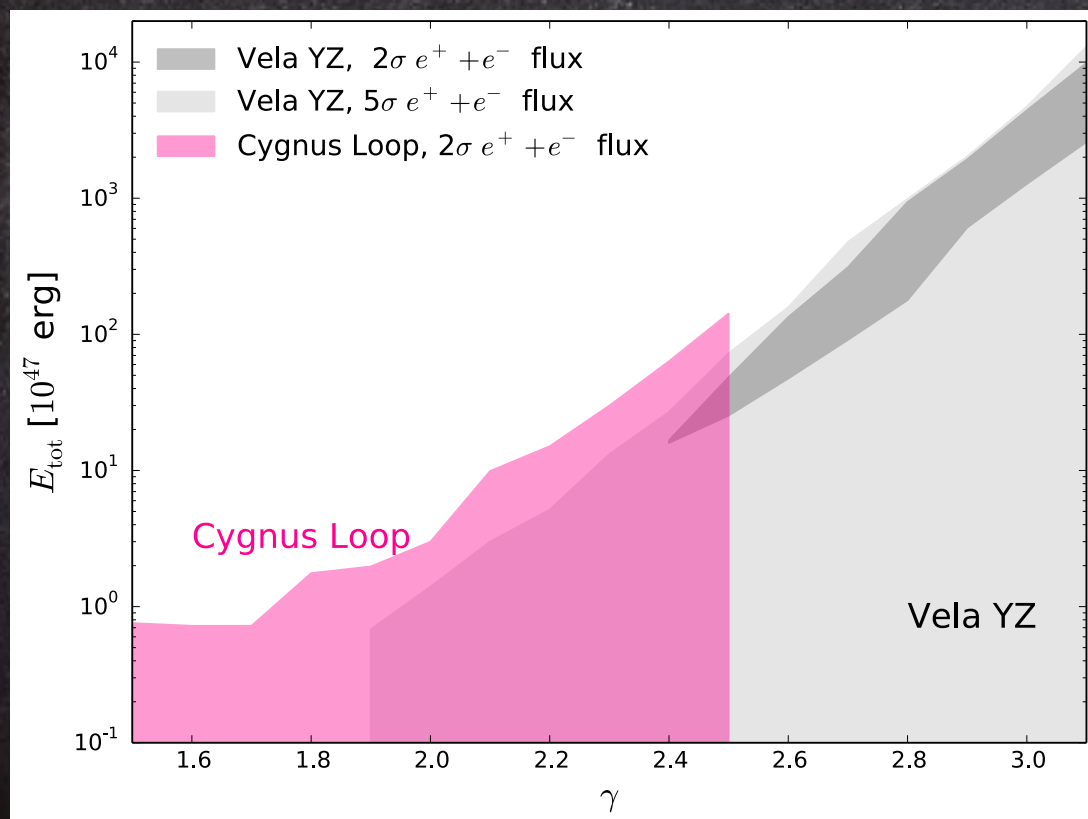
Vela has more energetic trapped e^- , and only $E > 88 \text{ GeV}$ have escaped (17 GeV for Cygnus).

The flux of electrons as constrained by radio data contribute few % to the (e^+e^-) data

II - Bounds from e^+e^- flux

Hyp: e^+e^- data are explained by:

- emission from smooth far SNR (e^-)
- emission from catalog near SNR (e^-)
- secondary production from spallation of CRs on the ISM (asymmetric e^+e^-)
- emission from ATNF catalog PWN (symmetric e^+e^-)



Fit to data:

- e^+e^- CALET, HESS, AMS-02, Fermi-LAT, DAMPE
- e^+ AMS-02

At 2sigma, Vela parameters selected by a fit to flux data do not overlap radio fit.

Full agreement at 2 sigma is reached for a fit to DAMPE data alone, or to AMS-02, HESS and CALET.

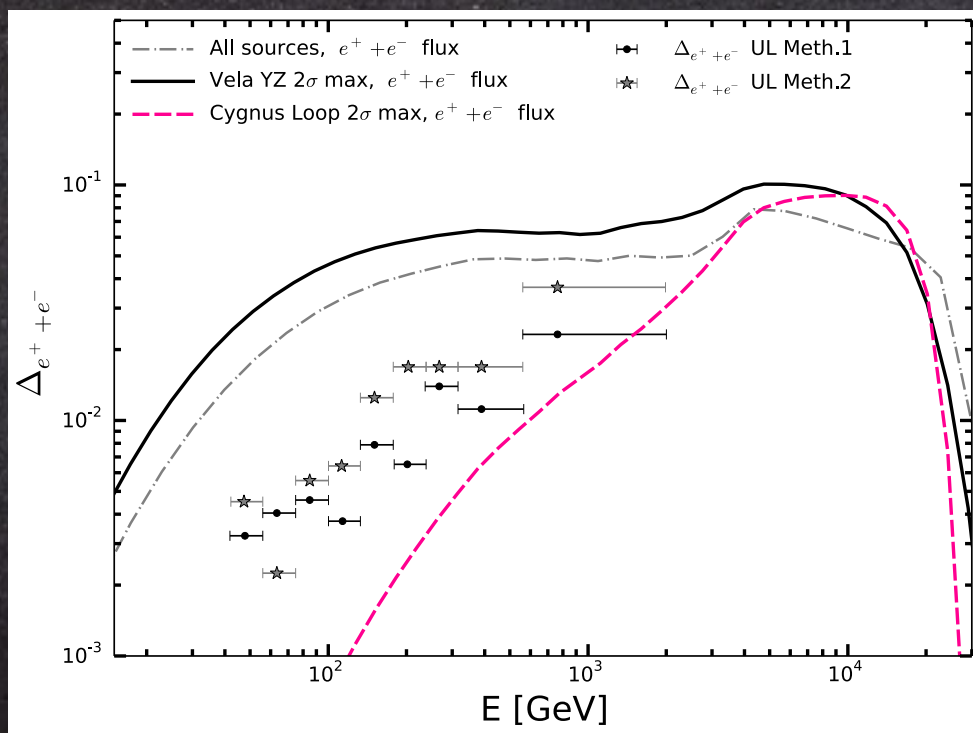
p.s.: Galactic propagation treated and in Manconi, Di Mauro, FD JCAP 2017

III - Bounds from dipole anisotropy

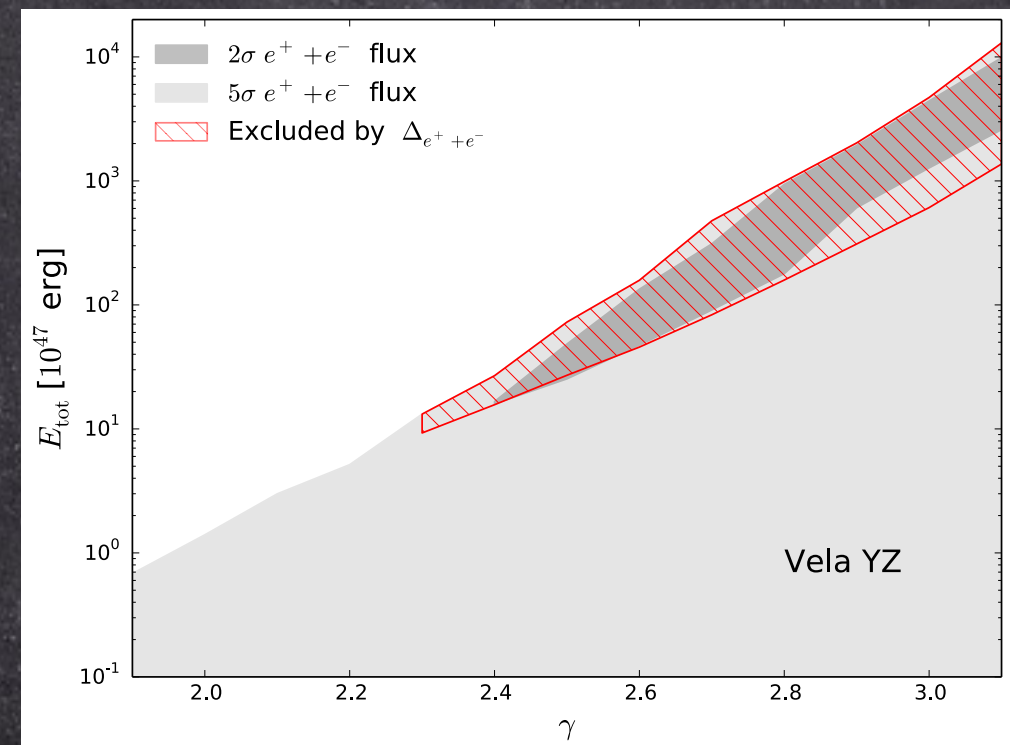
Data from e^+e^- dipole anisotropy are upper bounds vs E - Fermi-LAT (Abdollahi+ PRL 2017)

$$\Delta(E)_{e^++e^-} = \frac{3K(E)}{c} \frac{2d}{\lambda^2(E, E_s)} \frac{\psi_{e^++e^-}^s(E)}{\psi_{e^++e^-}^{tot}(E)}$$

Manconi, Di Mauro, FD JCAP 2017



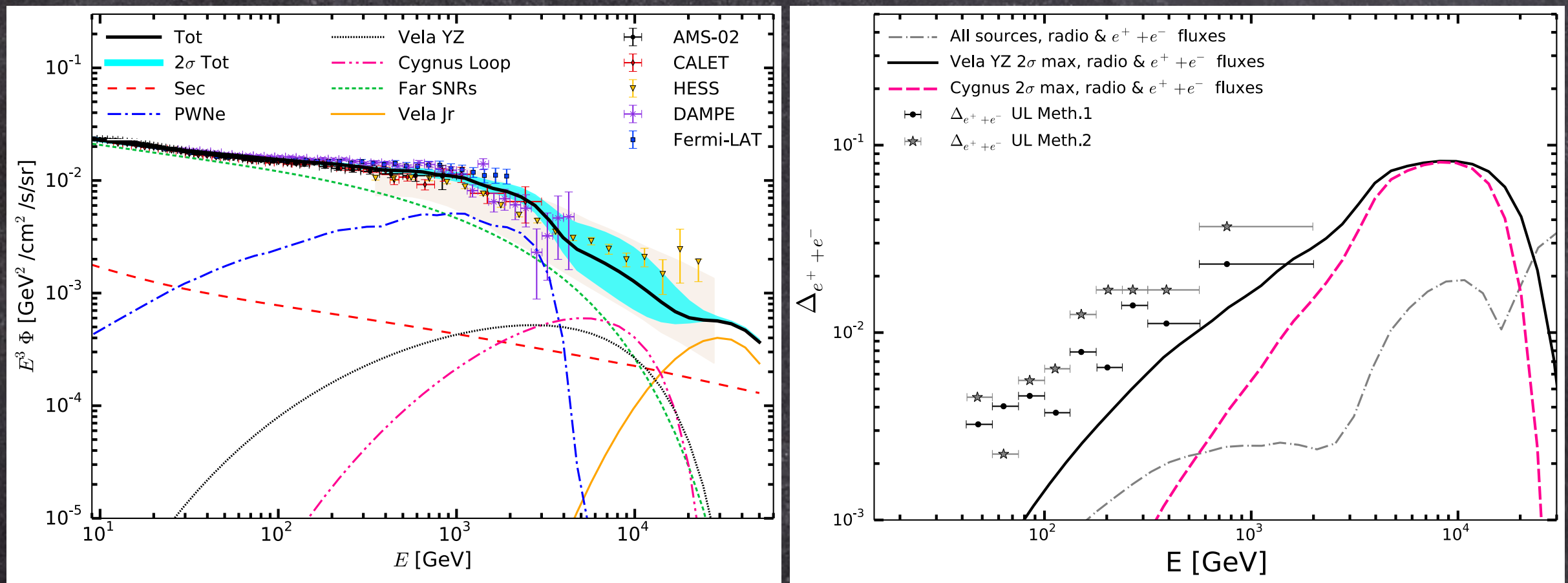
Maximal anisotropy from e^+e^- flux
selected configurations



Anisotropy excludes configurations
selected by e^+e^- flux

A multi-wavelength / multi-messenger analysis

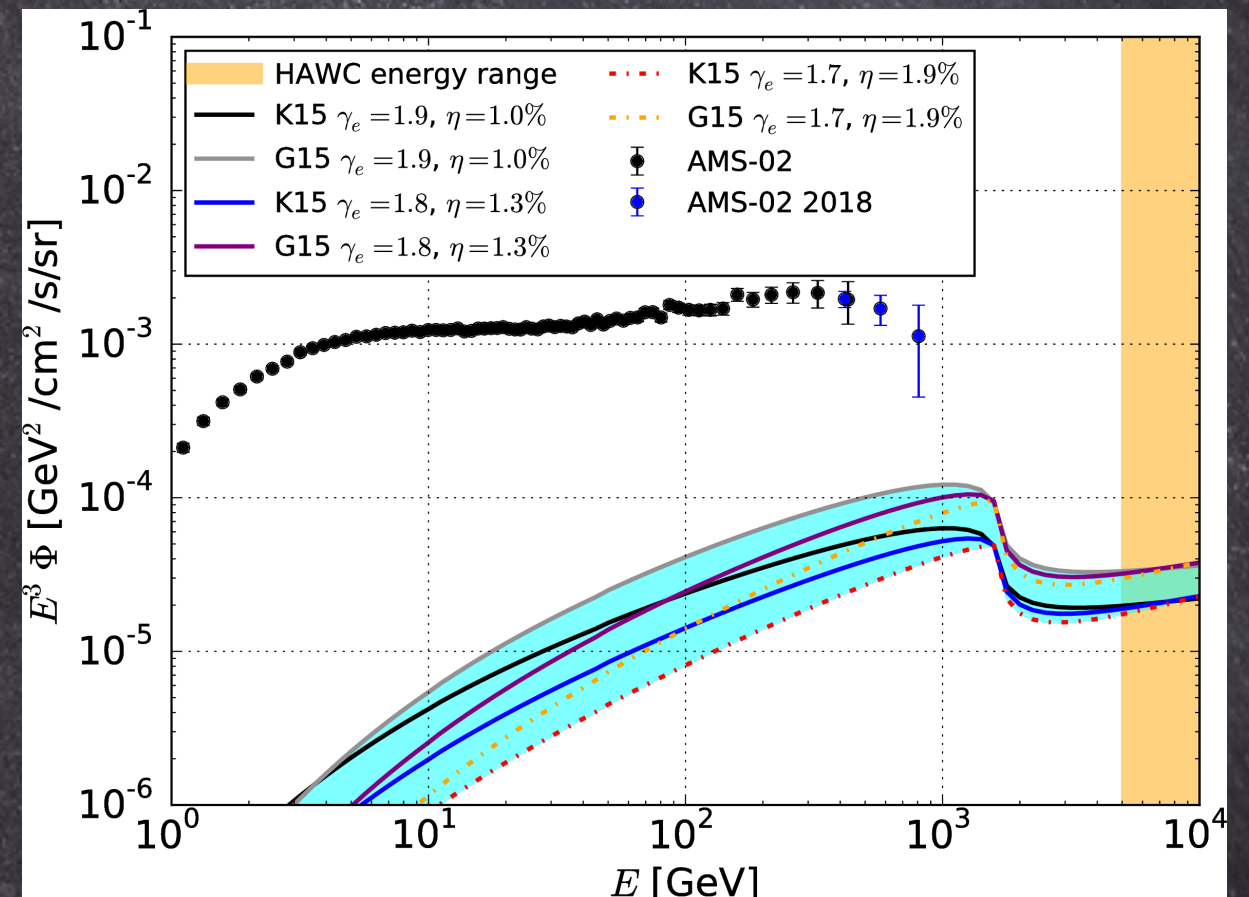
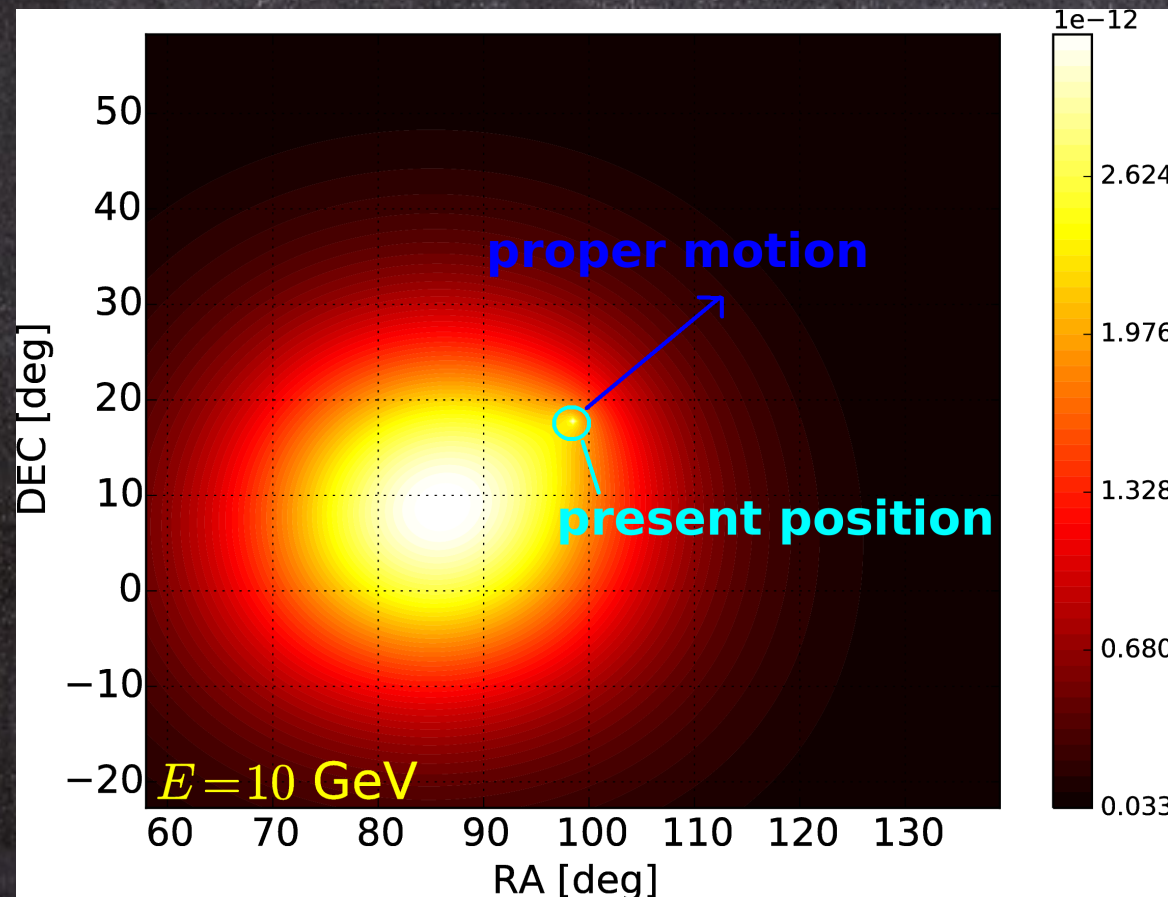
We now fit the parameters selected by radio and e^+e^- flux data and check against dipole anisotropy data



We find models compatible with the three independent observables (here burst model - similarly for evolutionary model)

Contributions to e^+e^- from Geminga PWN

Di Mauro, Manconi, FD 1903.05647, sub PRD



Discovery of a gamma-ray Inverse Compton halo around Geminga in Hawc data

(Abeysekara, Science 2017) and in Fermi-LAT data (Di Mauro, Manconi, FD 1903.05647)

The contribution of Geminga to the e^+ is 20% at most of AMS-02 data

See talk by S. Manconi GAD4b, July 31st

Conclusions

Leptons at Earth have a composite origin: e^- from far smooth and near catalog SNR, e^+e^- from PWN, e^+e^- as secondaries in the ISM

We compare our model with **three observables**:

1. The radio flux from Vela YZ and Cygnus Loop
2. The CR e^+e^- , e^+ flux
3. The e^+e^- dipole anisotropy upper bounds

- Radio data are strong constraints
- Dipole anisotropy is bounding when no other priors are set
- A multi-wavelength and multi-messenger combined analysis finds models compatible with data from all observables
- IC gamma rays around PWN can size the e^+ flux at Earth