Constraining positron emission from pulsar populations with AMS-02 data

Based on L. Orusa, S. Manconi, M. Di Mauro, FD 2107.06300, to appear in JCAP

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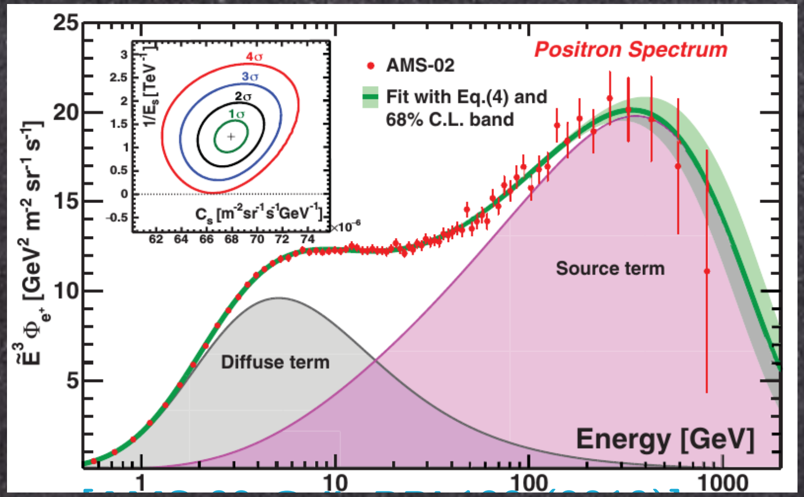
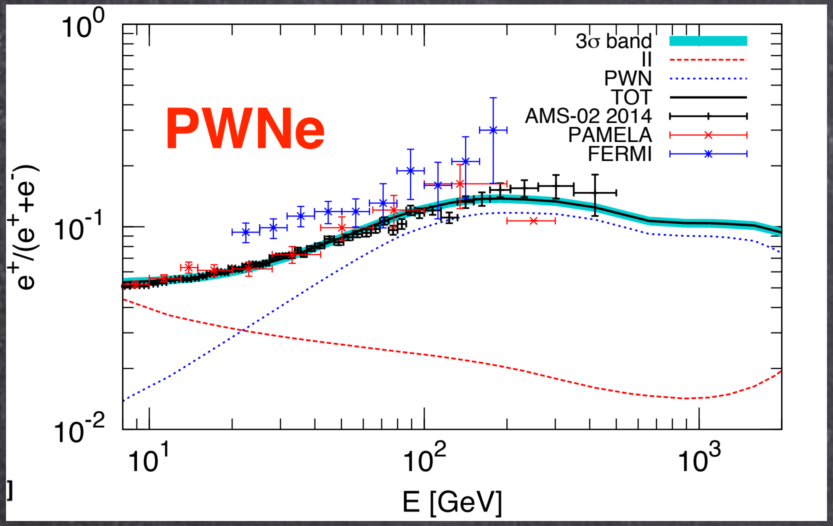
Introduction to the talk

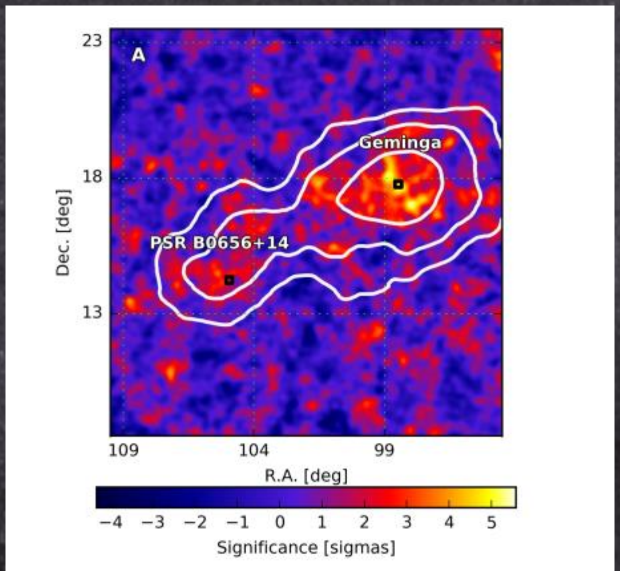
- The positron flux shows (Pamela, AMS data) the need of primary source at high energies. Pulsars could do the job.





Di Mauro+ JCAP 2014

- HAWC has detected a TeV gamma-ray halo around Geminga and Monogem pulsars. Interpreted as
  e+e- accelerated by the pulsar,
  then released in the ISM



HAWC Coll. Science 2017

Sources of $e^{\pm}$ in the Milky Way

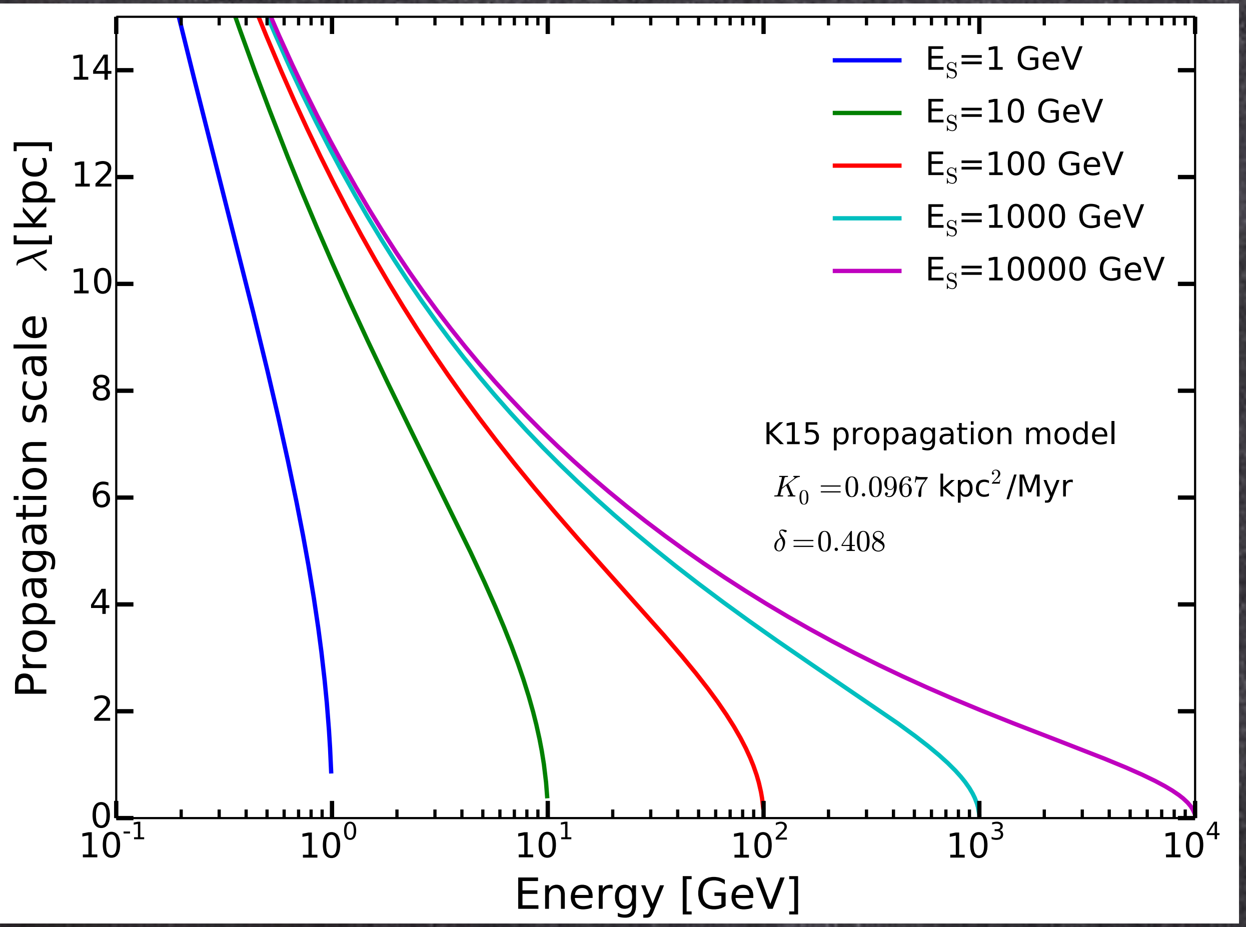
- Inelastic hadronic collisions (asymm.)
- Pulsar wind nebulae (PWN) (symm.)
- Supernova remnants (SNR) (only e+)
- Particle Dark Matter annihilation (e+,e-)?

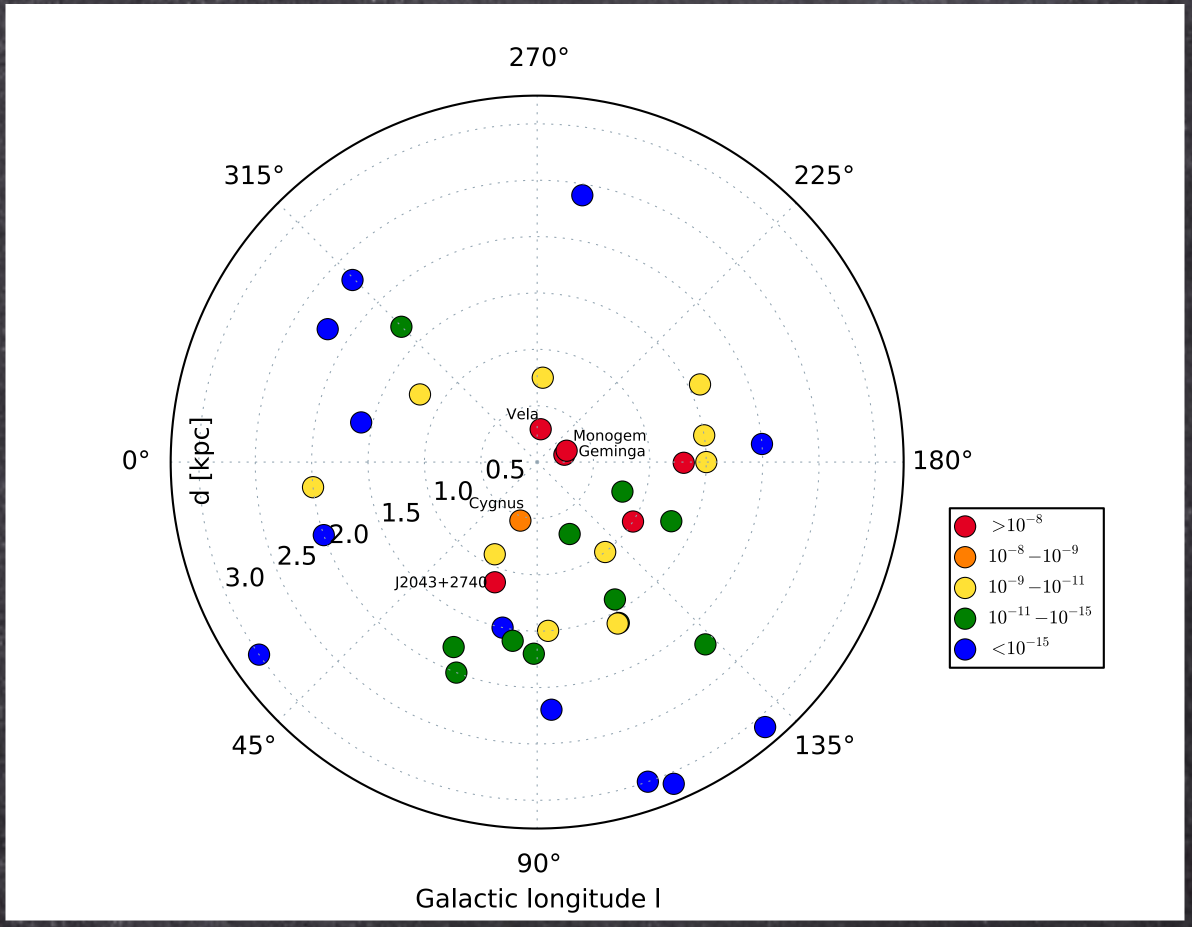
Detected e+ and e- are Local

$$\lambda^2(E, E_S) = 4\int_E^{E_S} dE' \, \frac{D(E')}{b_{\rm loss}(E')}$$

Typical propagation length in the Galaxy

Manconi, Di Mauro, FD JCAP 2017





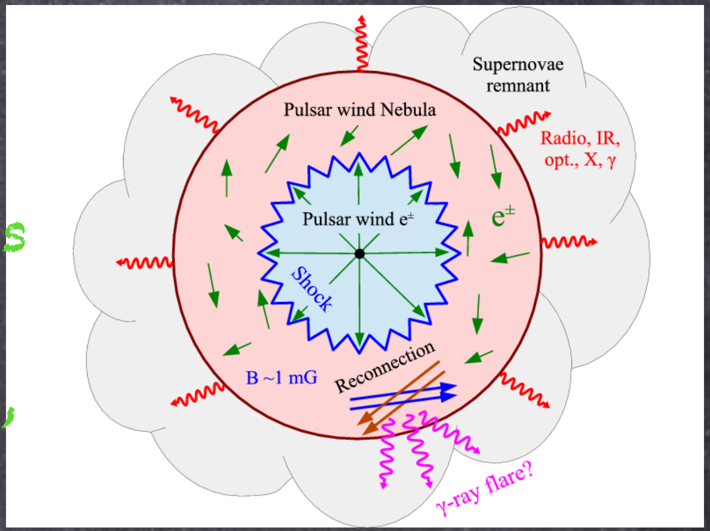
e-, e+ have strong radiative cooling and arrive at Earth if produced within few kpc around it

Most powerful sources within 3 kpc from the Sun.
SNRs (e-) and PWN (e+e-)

Pulsars (PWN) as CR e+e- sources

Pulsar wind nebulae (PWNe) as engines of e±

- High magnetic fields (10^9–10^{12} G) extract wind of e- from the pulsar surface, e± pairs produced in EM cascades
- Pulsar spin-down energy (W_0) is transferred to e± pairs, accelerated to very high energy with $Q \sim E^{-\gamma}$.
- After several kyrs e± can be released in the ISM
- These e± pairs radiate by IC and synch., and shine at many frequencies



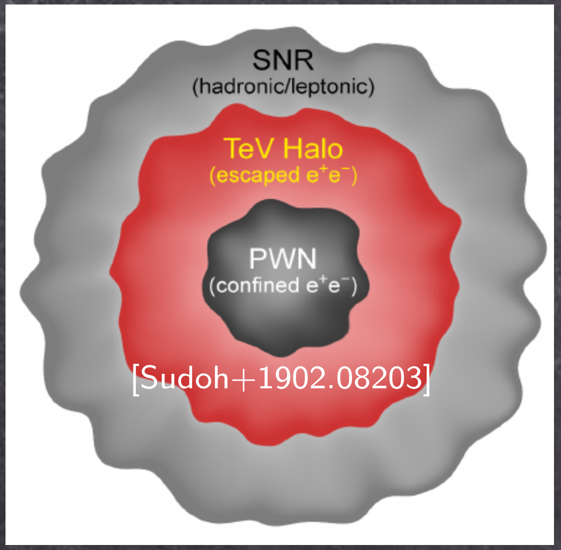
$$E_{\rm tot} = \eta W_0 = \int_0^T dt \int_{E_1}^{\infty} dE E Q(E,t)$$

The total energy E_{tot} emitted in e± by a PWN is a fraction η (efficiency conversion) of the spin-down energy W_0. Relevant parameters: γ and η

Multi-wavelength emission from Pulsars

- $e^{\pm}$ pairs accelerated by Pulsar Wind Nebulae (PWN) loose energy by inverse Compton scattering (ICS) on background photons (CMB, IR, VIS) and by synchrotron emission -> photon PRODUCTION

A cascade of photons, in a broad E range. Now also in γ rays

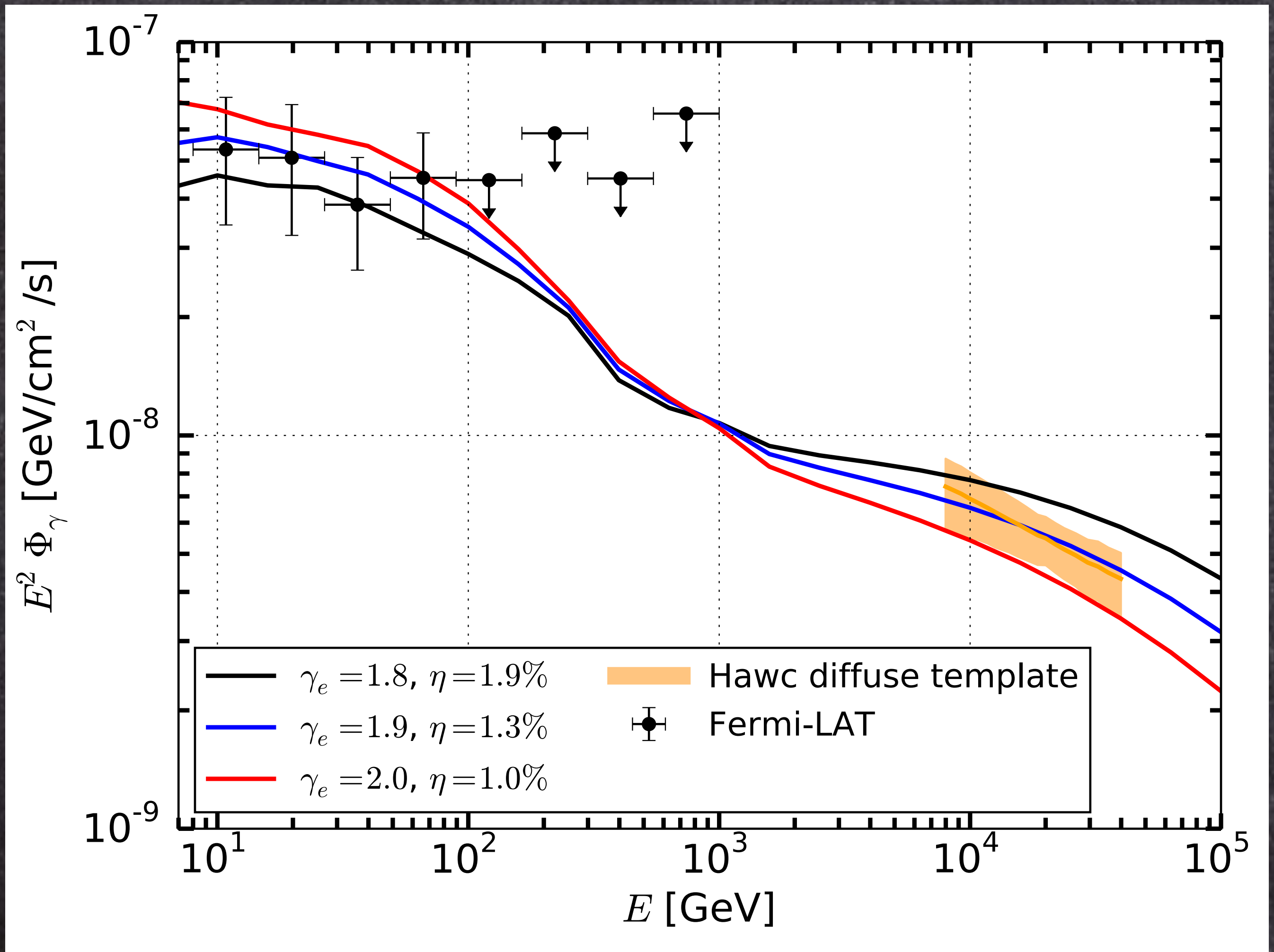


- $e^{\pm}$ suffer strong radiative cooling -> they probe LOCAL Galaxy, typically < 5 kpc for E > 10 GeV

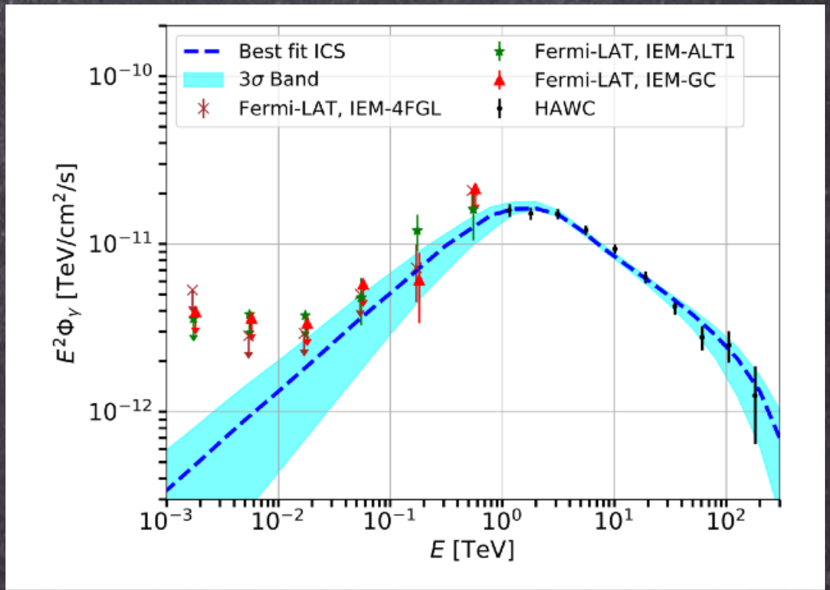
Discovers of γ-ray halos in Fermi-LAT data

M. Di Mauro, S. Manconi, FD, PRD 2019; M. Di Mauro, S. Manconi, M. Negro, FD, PRD 2021

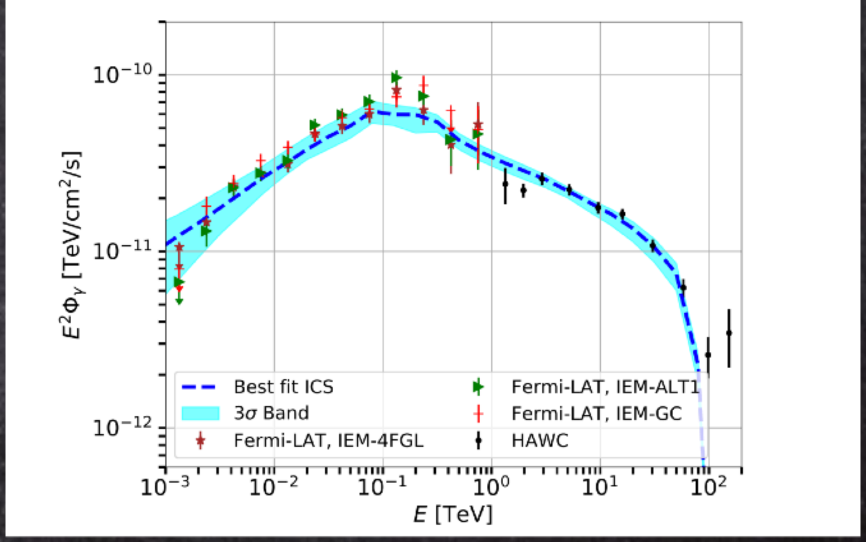
Geminga



eHWC J1907+63



eHWC J1825-134

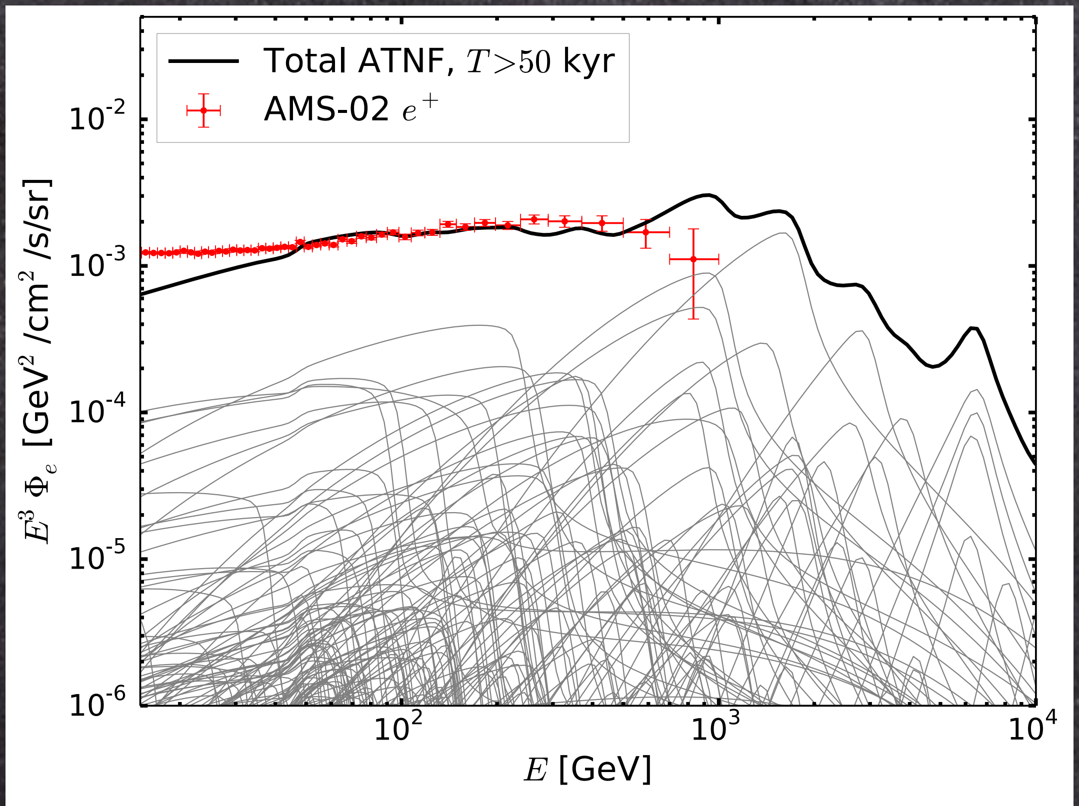


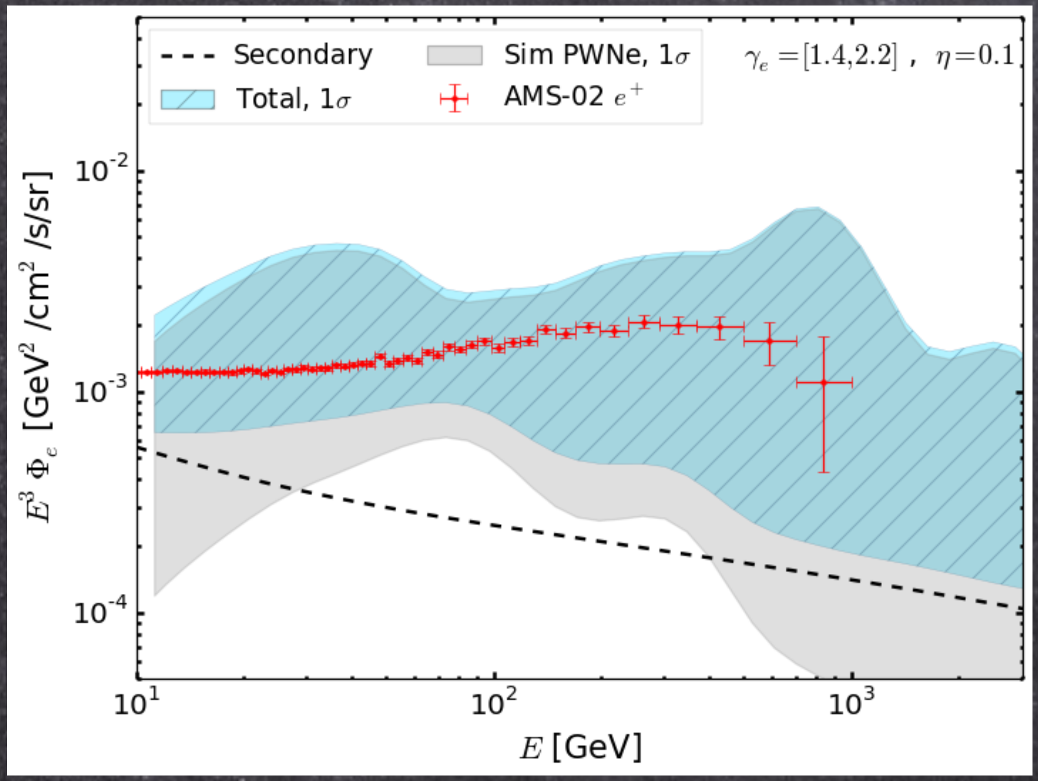
γ-rays from Inverse Compton scattering

Simulating Galactic pulsar populations

Manconi, Di Mauro, FD PRD 2020

We predict e+ from pulsar ATNF catalog & from synthetic populations
Within a 2-zones diffusion around pulsars
compatible with HAWC data interpretation





From ATNF catalog

From simulations

There is a lower limit on PWN contribution.

Pair emission from pulsars

We assume continuous injection :

$$Q(E,t) = L(t)\left(\frac{E}{E_0}\right)^{-\gamma_e}\exp\left(-\frac{E}{E_c}\right)$$

$$L(t) = \frac{L_0}{\left(1+\frac{t}{\tau_0}\right)^{\frac{n+1}{n-1}}}$$

Normalized to:

$$E_{tot} = \eta W_0 = \int_0^T dt \int_{E_1}^{\infty} dE\, E\, Q(E,t)$$

Having:

$$\dot{E} = \frac{dE_{\rm rot}}{dt} = I\Omega\dot{\Omega} = -4\pi^2 I\frac{\dot{P}}{P^3}\,.$$

We can derive a relation for:

$$\tau_0 = \frac{P_0}{(n-1)\dot{P}_0}.$$

Constraining positron emission from pulsar populations with AMS-02 data

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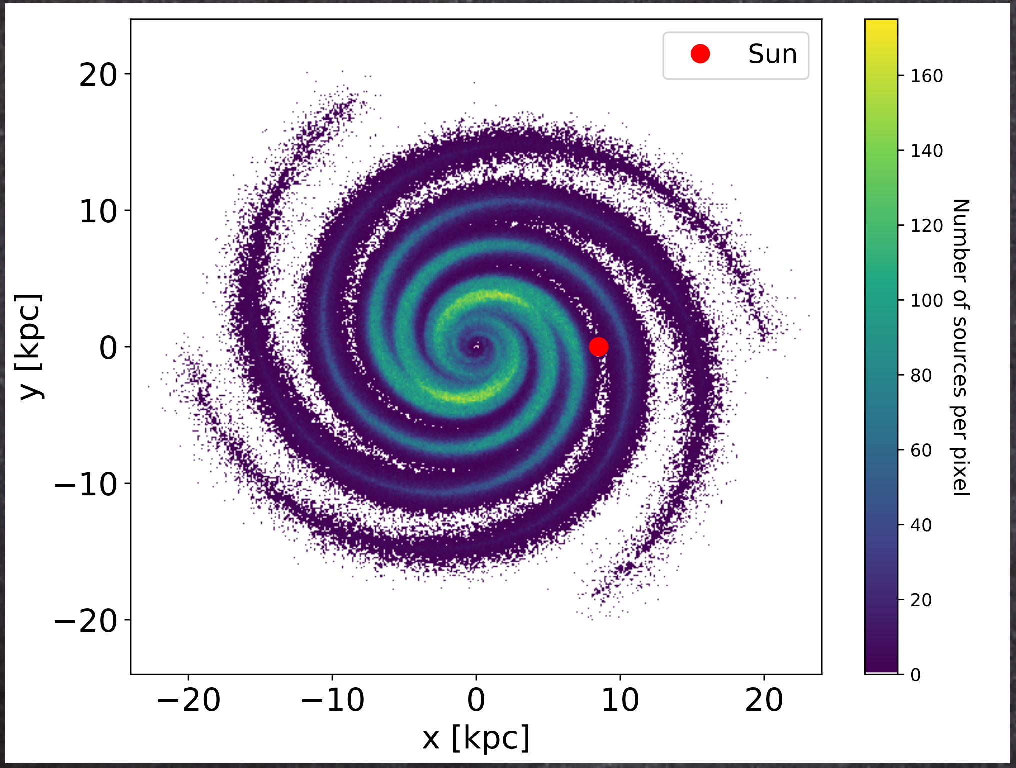
We simulate Galactic pulsar populations

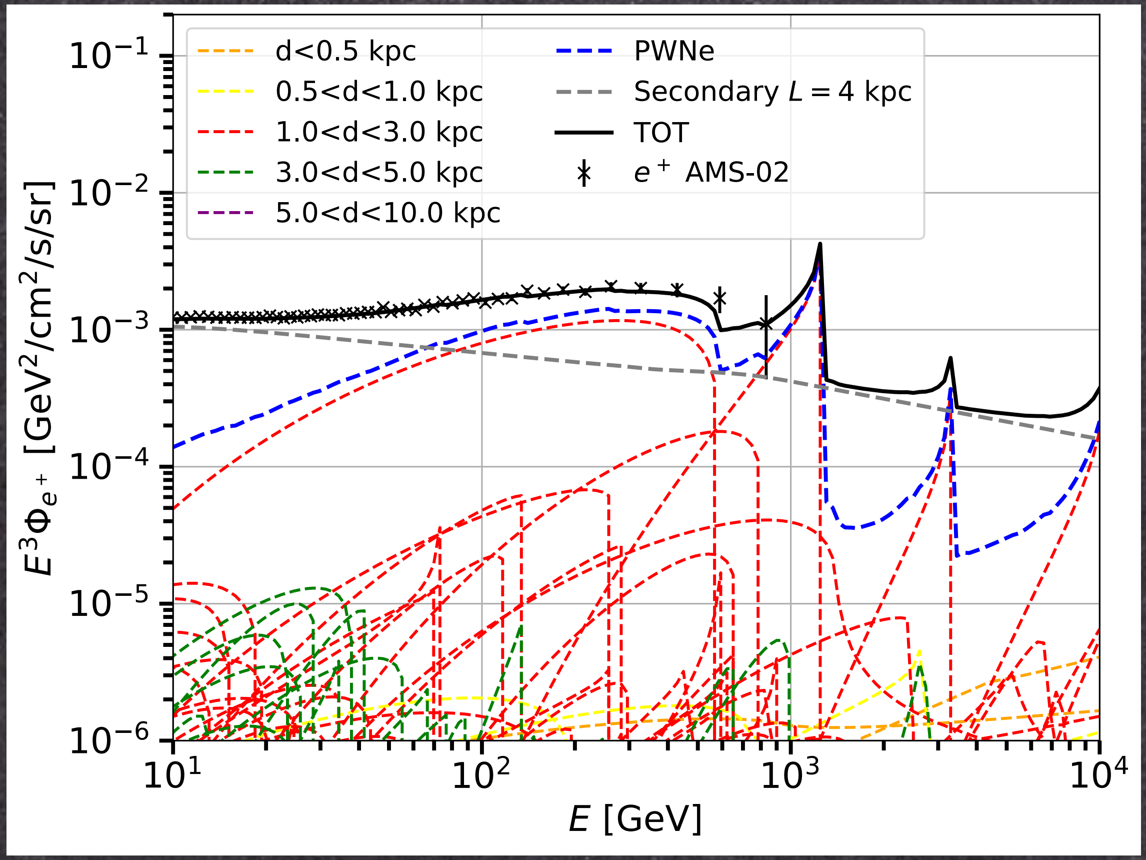
1000 simulations for 4 setups

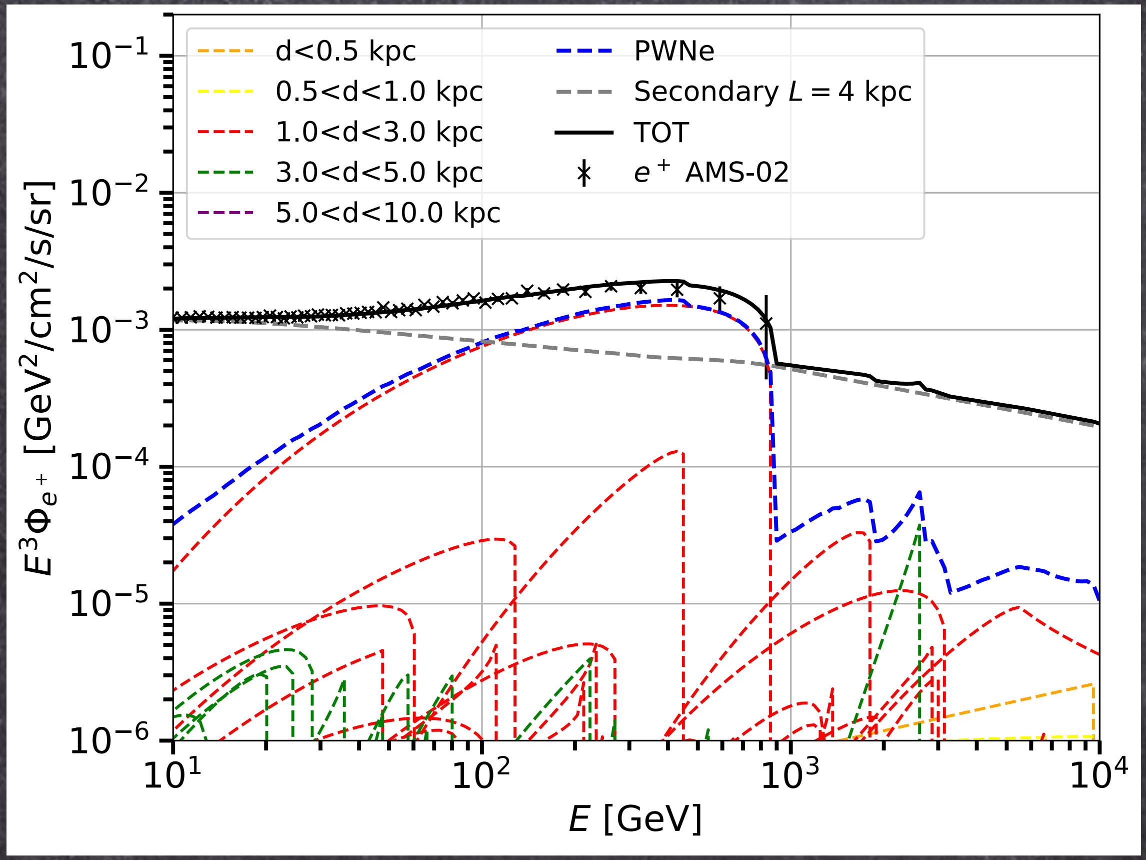


Pulsar property	Simulated quantity	Benchmark	Variations
Age	T	Uniform $[0, t_{max}]$	-
Spin-down		CB20[39]	FK06[54]
	P_0	Gaussian [0.3s; 0.15s]	-
	$\log_{10}(B)$	Gaussian [12.85G; 0.55G]	Gaussian [12.65G; 0.55G]
	n	Uniform [2.5-3]	Constant [3]
	$\cos\alpha$	Uniform [0-1]	Constant [0]
$e^{\pm}$ injection	γ_e	Uniform [1.4-2.2]	-
	η	Uniform [0.01-0.1]	-
Radial distribution	$\mathbf{r}$	$\rho_L(r)$ [38]	$\rho_F(r)$[54]
Kick velocity	v_k	-	FK06VB [54]

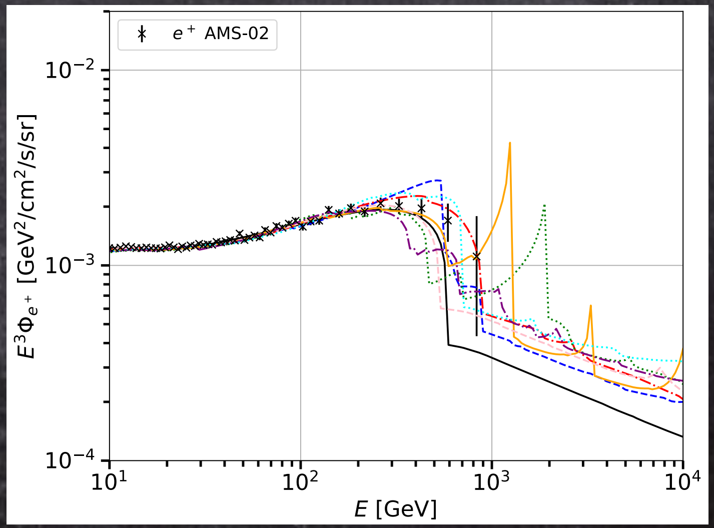
+ diffusion schemes

Fit of Galactic pulsar populations to AMS-02 e+ data



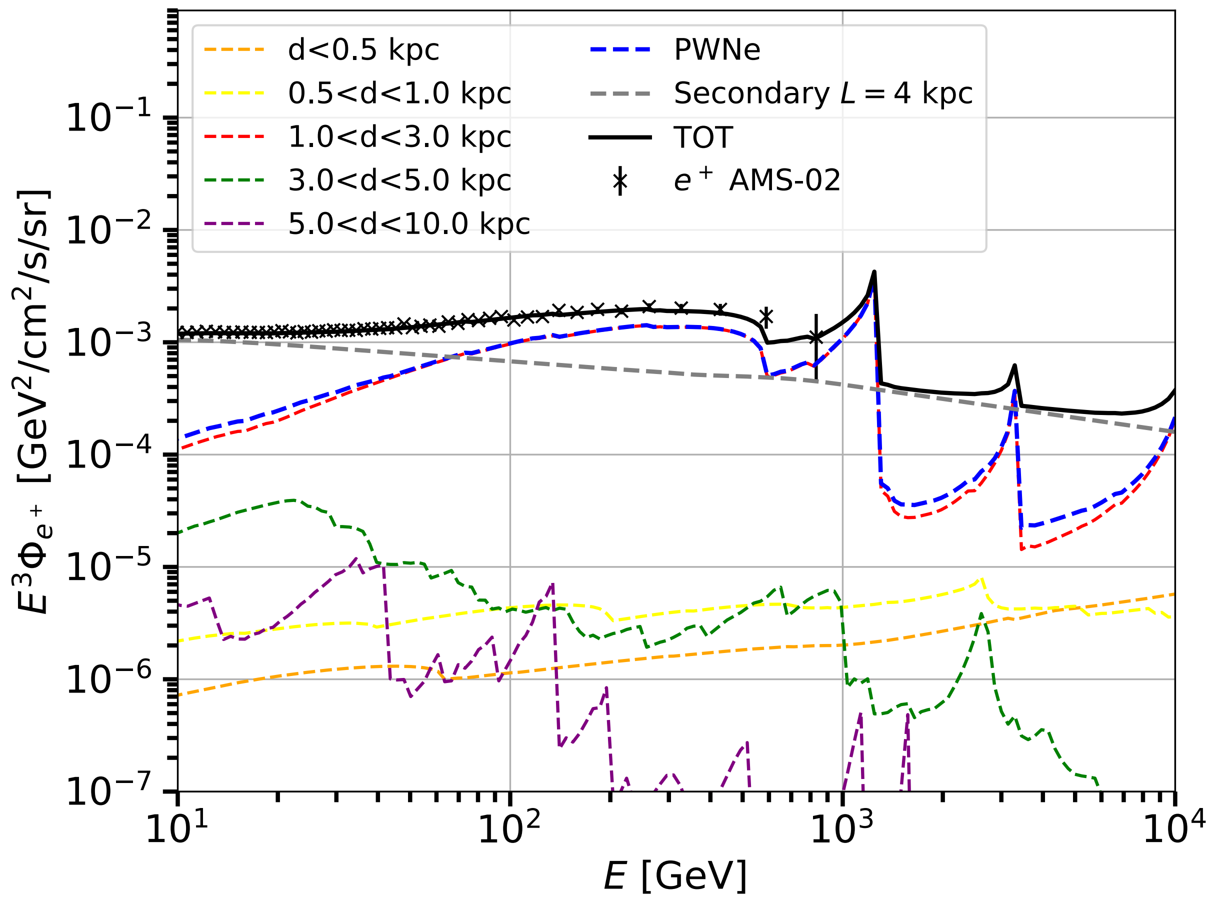


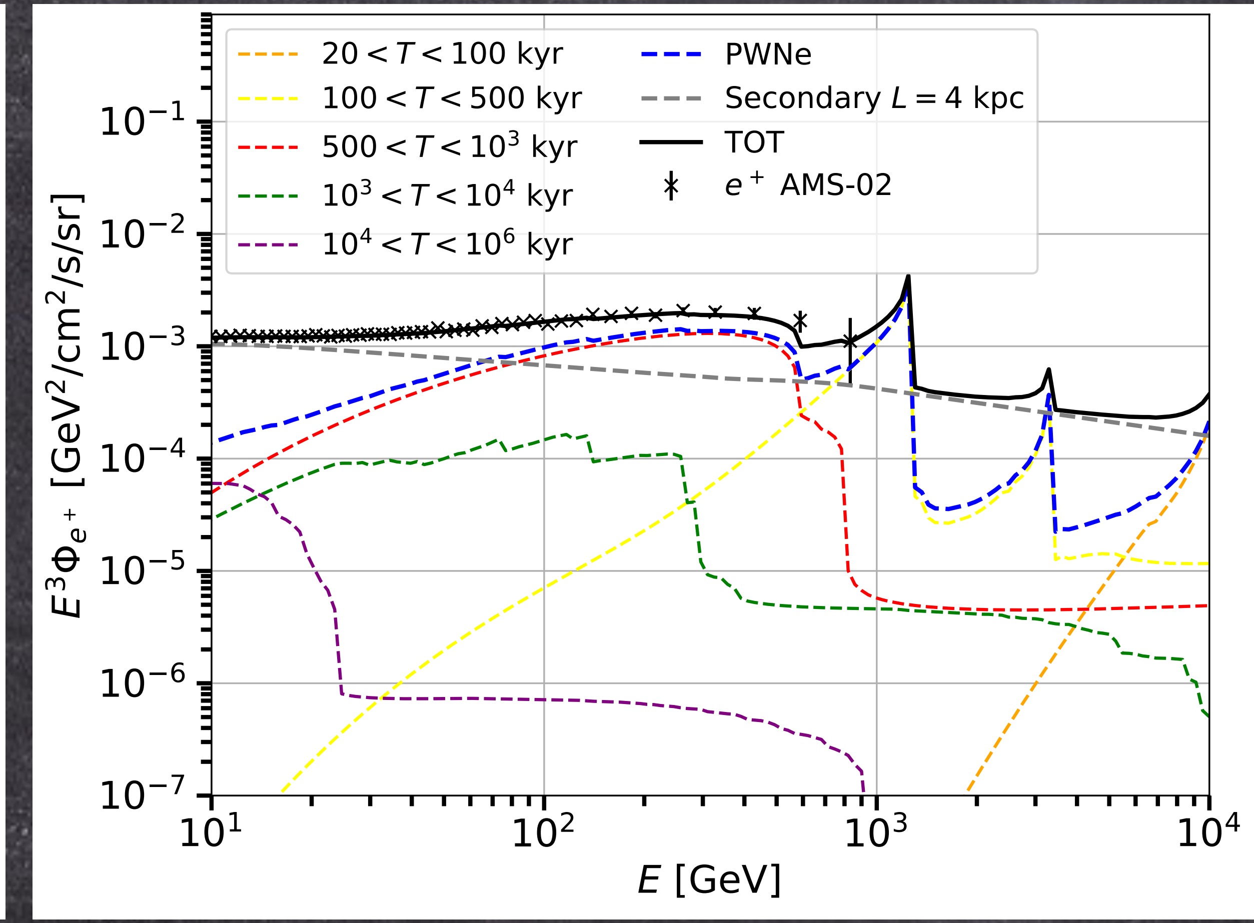
The contribution of pulsars to e+ is dominant above 100 GeV and may have different features.
For E>1 TeV: unconstrained by data.
Secondaries forbid evidence of sharp cut-off



Effect of age and distance

on mock galaxies as selected by e+ AMS-02 data

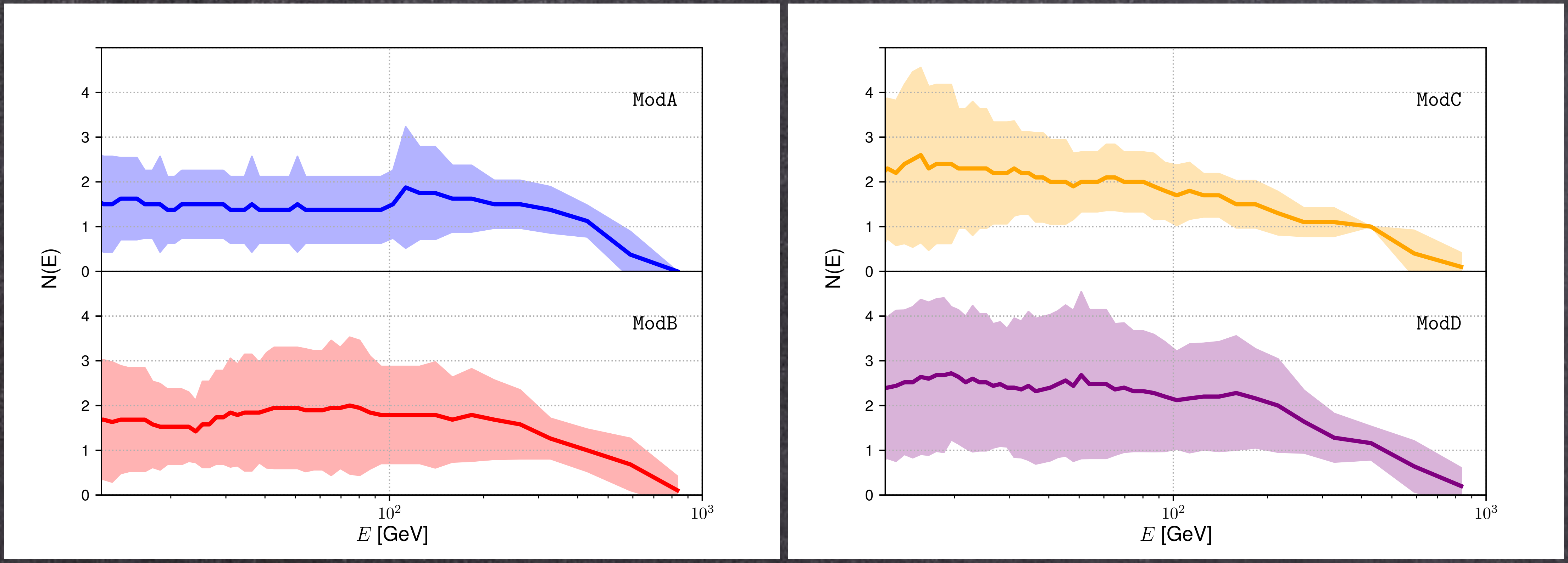




1-3 kpc ring is the most fruitful in terms of e+
Interplay between spiral arms and propagation length

Few pulsars suffice

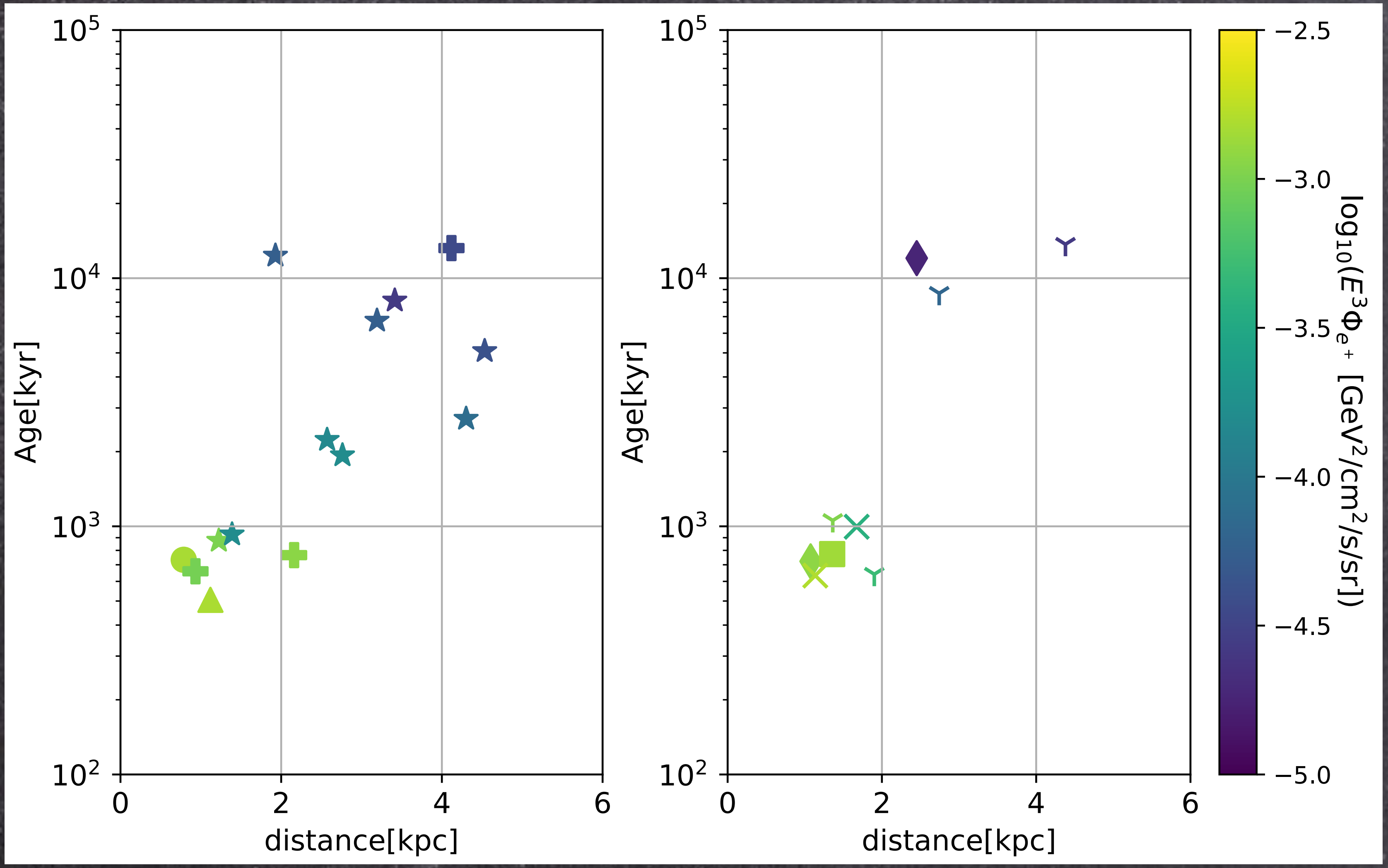
Very few ones, indeed



N(E) is the mean number of PWNe that produce a flux higher than the experimental flux error in at least one energy between above 10 GeV.

Typically 2-3 sources explain most of the measured flux (+ secs)

Characteristics of the (few) pulsars dominanti the AMS-02 flux



A Galaxy with 1-2 very powerful sources, with ages between 400 and 2000 kyr, located within 3 kpc from the Earth

Conclusions

We use AMS-02 data from charged CRs to put constraints on the properties of a Galactic population of pulsars

Simulations are based on catalog data

Few, bright middle-aged pulsars can explain all the positrons we Observe above 100 GeV