Anisotropy and antiparticles from a local source

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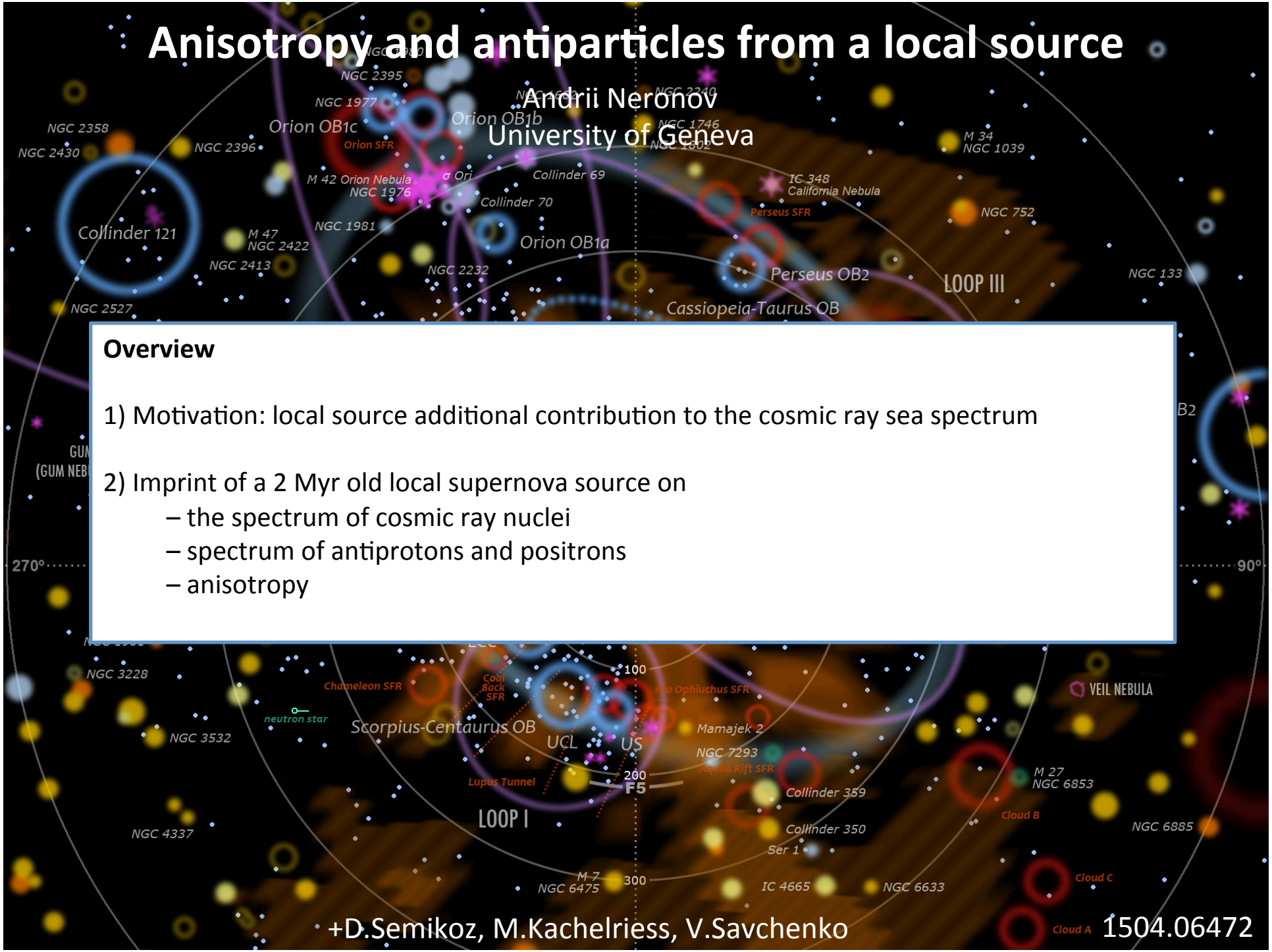


Overview

1) Motivation: local source additional contribution to the cosmic ray sea spectrum

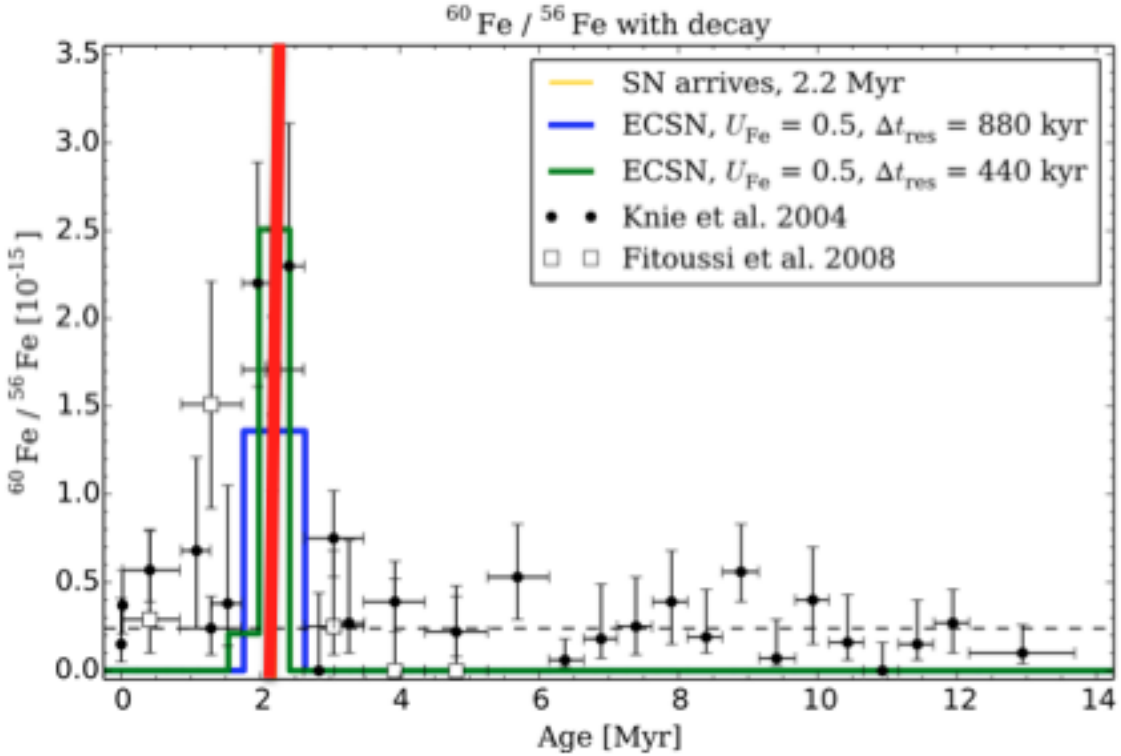
2) Imprint of a 2 Myr old local supernova source on
   – the spectrum of cosmic ray nuclei
   – spectrum of antiprotons and positrons
   – anisotropy

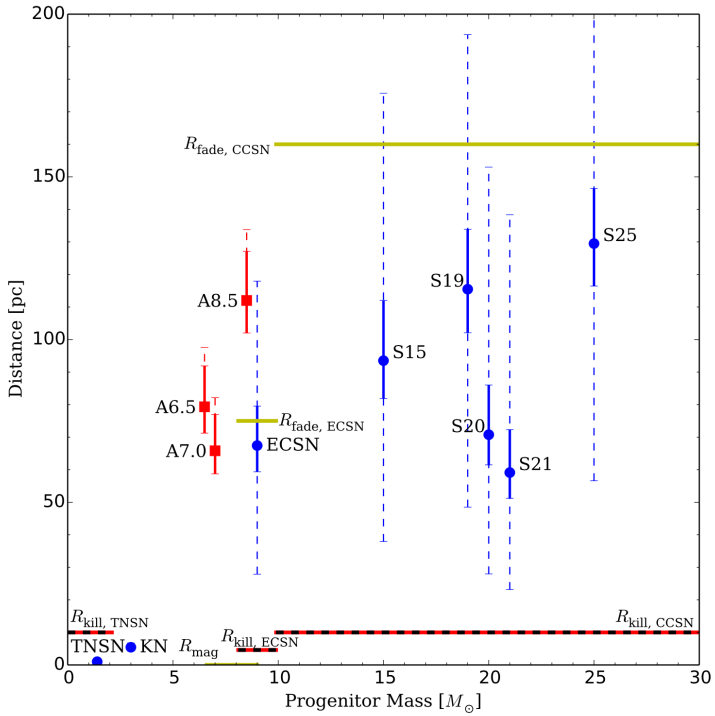
+D.Semikoz, M.Kachelriess, V.Savchenko 1504.06472

Local supernova in the local cosmic ray « sea »

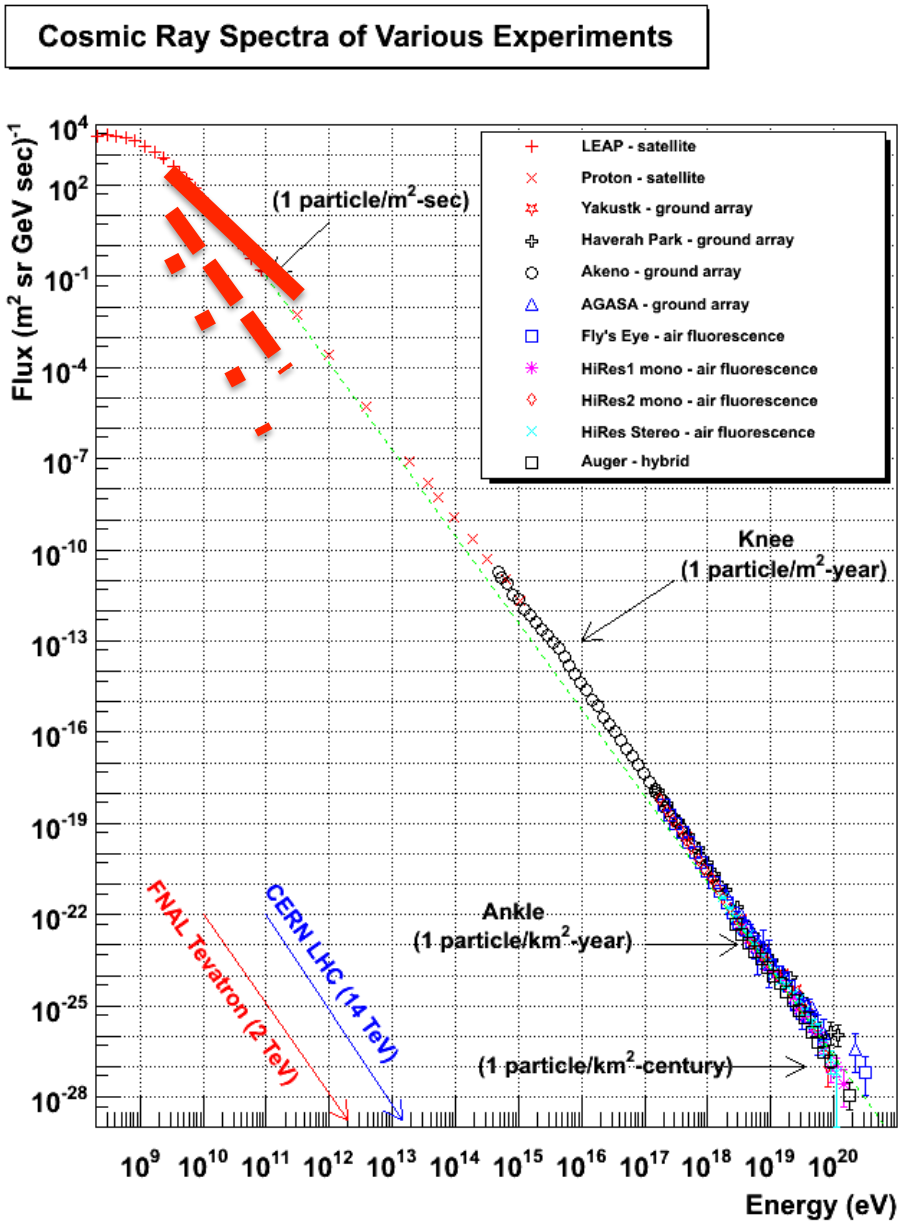
The ejecta from the local supernova explosion at the distance ~100 pc have apparently reached the Earth some 2 Myr ago and deposited ^{60}Fe isotope found in the deep ocean crust.

1 supernova exploding evey 30 yr within the Galactic disk of radius 10 kpc implies
1 supernova within 100 pc distance every Myr.





Local supernova in the local cosmic ray « sea »



1 supernova exploding evey 30 yr within the Galactic disk of radius 10 kpc implies **1 supernova within 100 pc distance every Myr**.

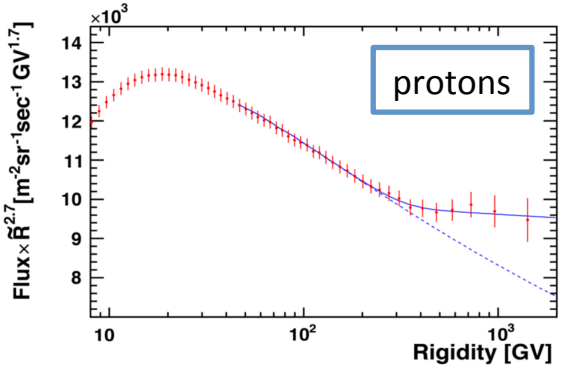
A supernova which occurred within the last T Myr within 100 pc distance has spread some $E_{CR} \sim 10^{50}$ erg of cosmic rays over the distance $R \sim (D(E)T)^{1/2}$ produces a flux comparable to the locally observed cosmic ray spectrum in the TeV range if

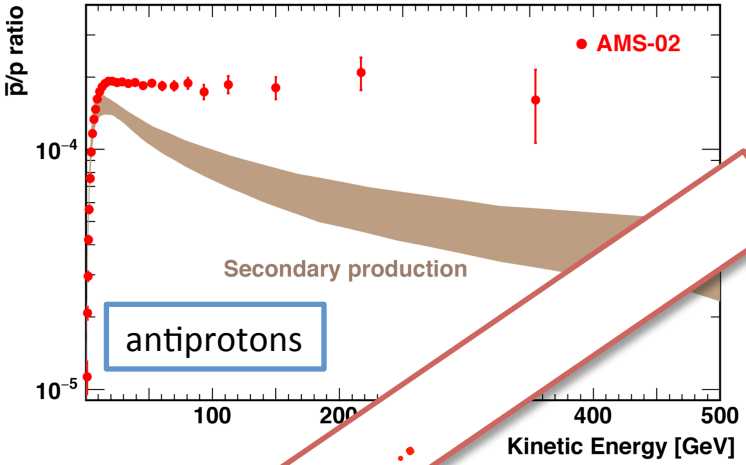
$$(E_{CR}/T^{3/2}) > (10^{50} \text{ erg} / [1 \text{ Myr}]^{3/2})$$

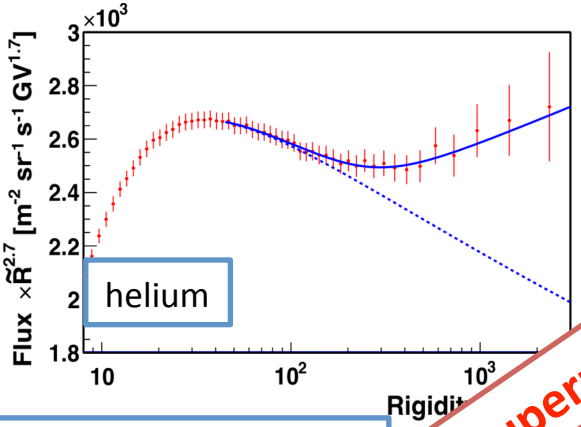
Did the last nearby supernova leave an imprint on the observed cosmic ray spectrum?

…. The imprint should be encoded in the features of the spectra of cosmic ray components

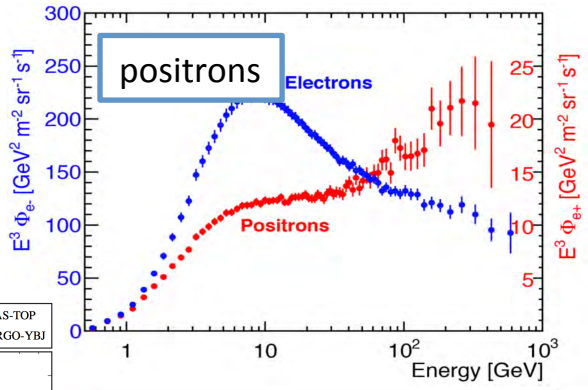
Features in the cosmic ray spectrum components



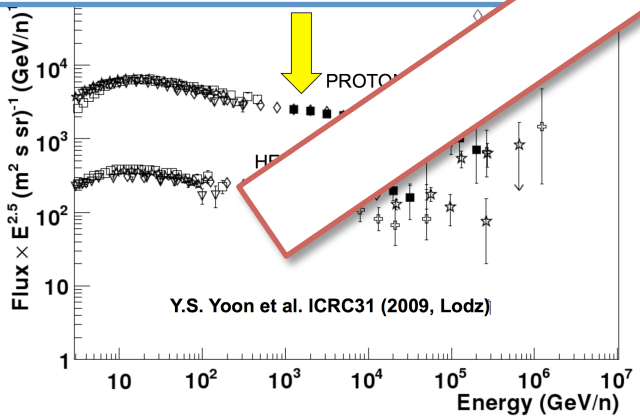


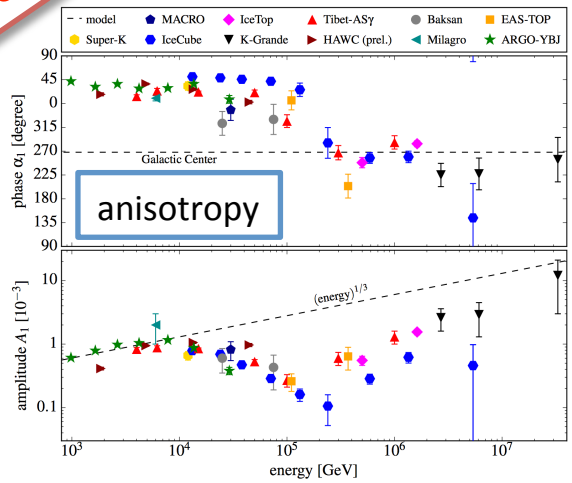


Supernova signal hides here….



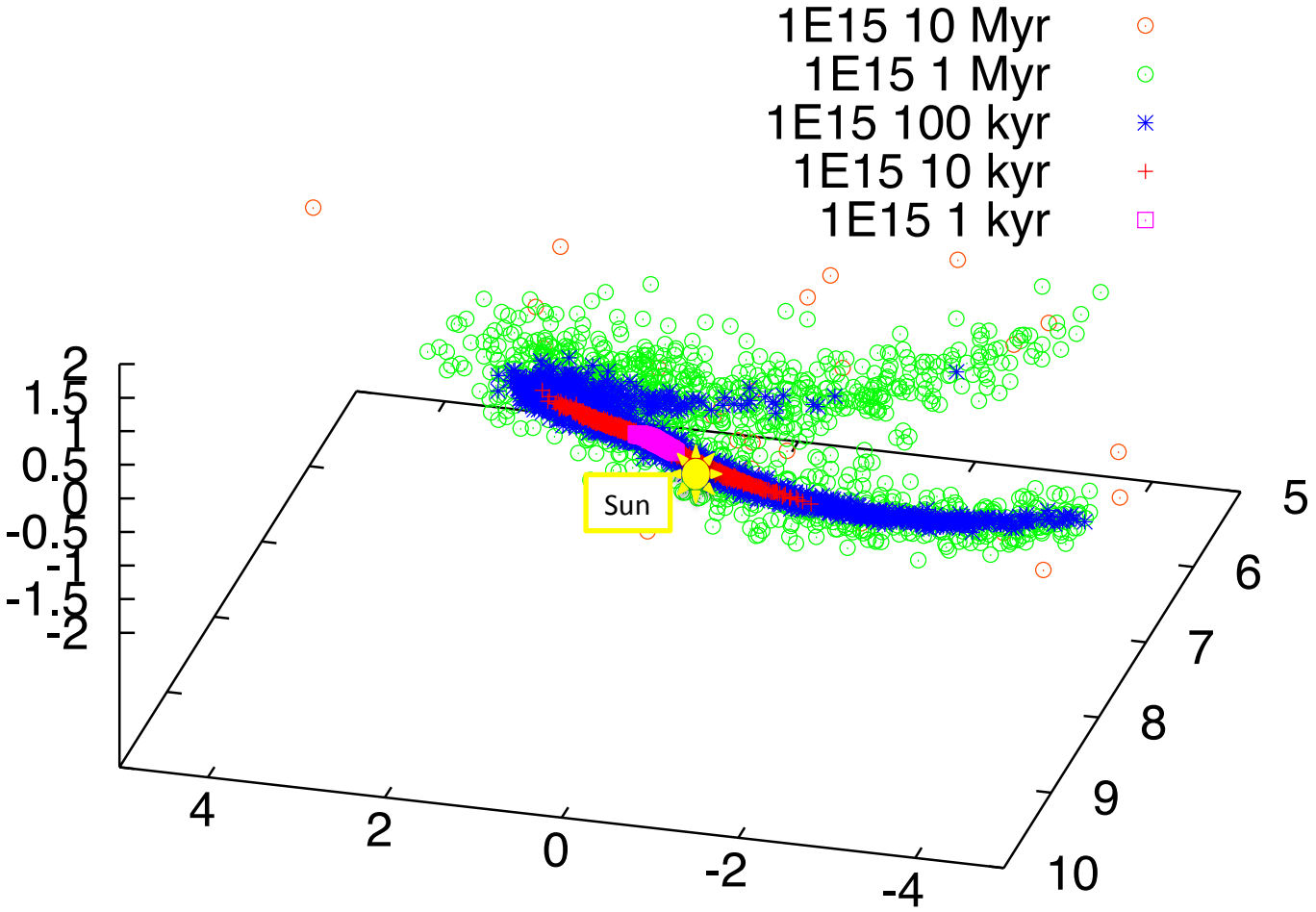
Proton / helium / heavier elements





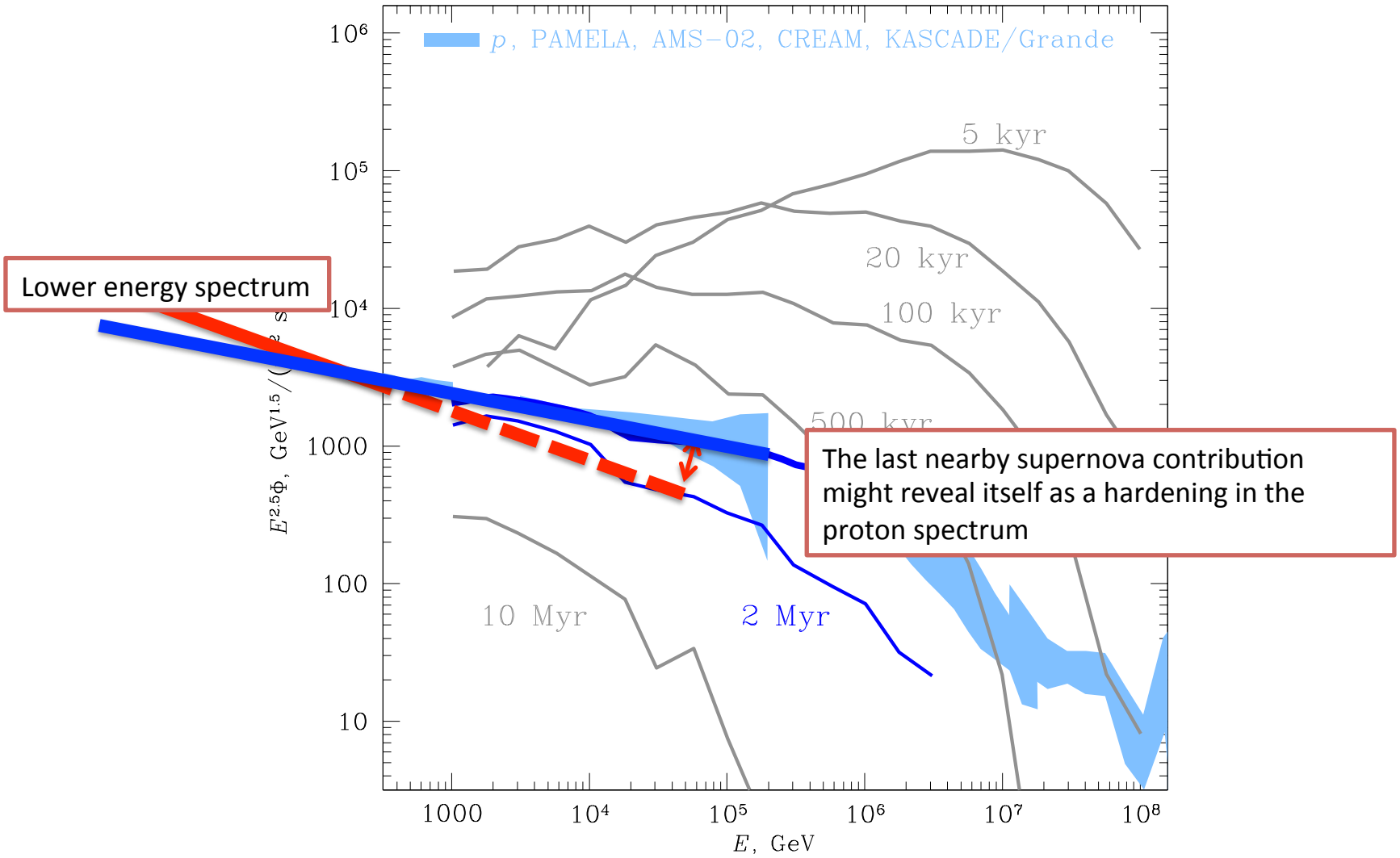
Pamela, AMS-02, CREAM, …

Spread of cosmic rays from single source



Monte-Carlo code simulating trajectories of individual particles through the Jensson-Farrar ‘12 model of Galactic magnetic field including regular and turbulent (Kolmogorov spectrum) components.

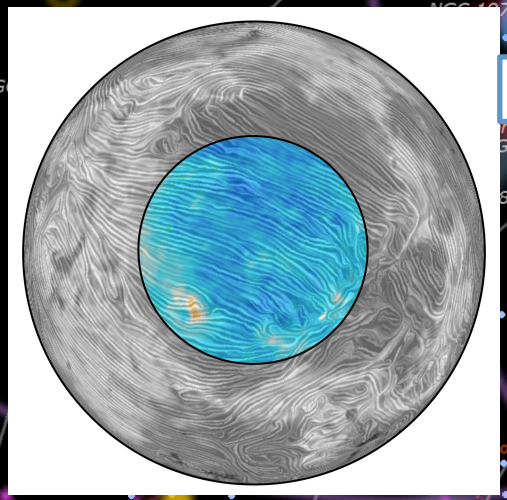
Local supernova imprint on the spectra of protons



A supernova with cosmic ray injection energy 10^{50} erg exploding some ~100 pc away along the ordered Galactic magnetic field line passing at ~50 pc from the Solar system

Kachelriess et al. '15

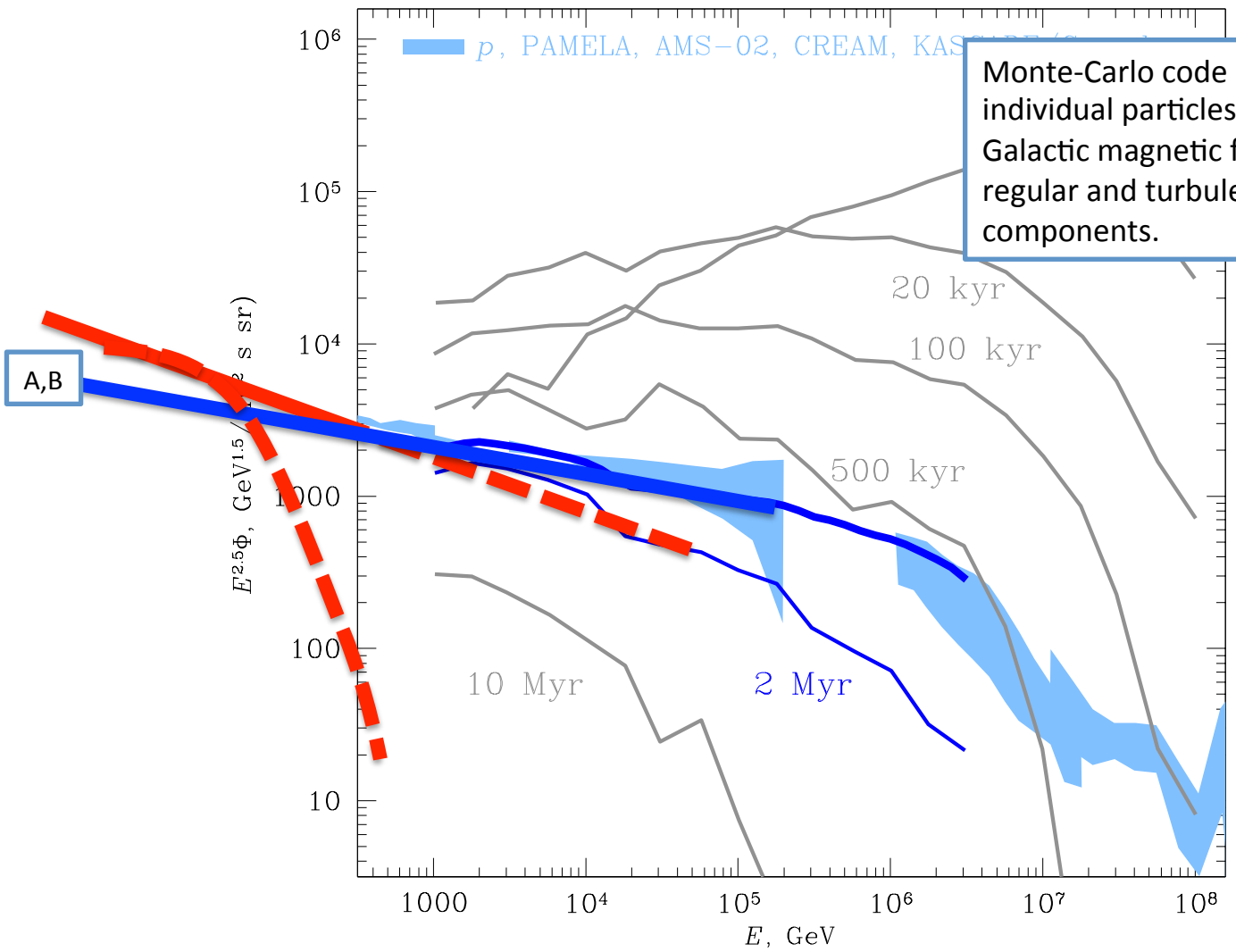
Local Galactic magnetic field and the source position



l=70°±5°, b=24°±5°

Planck intermediate results XLIV

Local supernova imprint on the spectra of protons

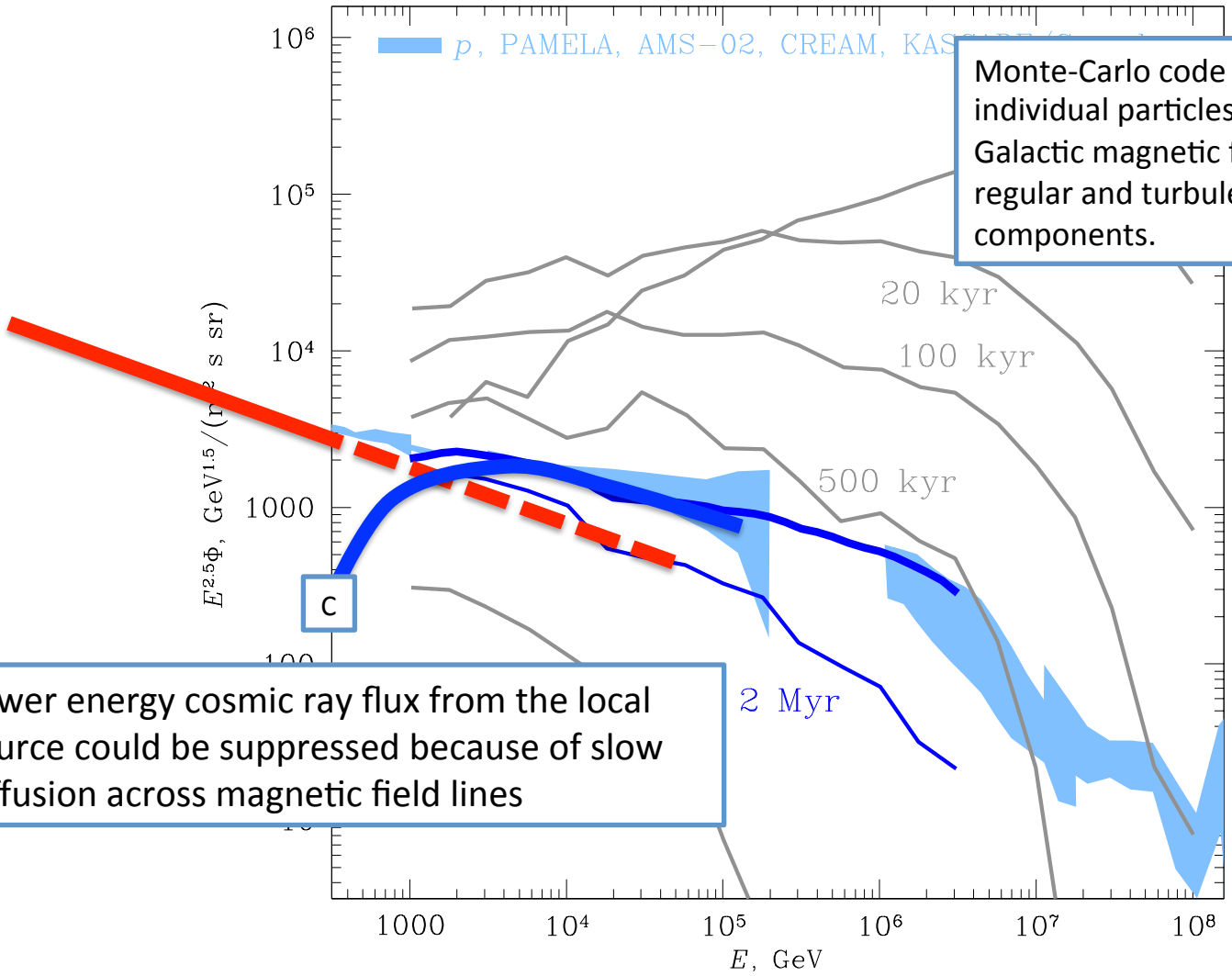


Monte-Carlo code simulating trajectories of individual particles through the realistic Galactic magnetic field which includes regular and turbulent (Kolmogorov) components.

A supernova with cosmic ray injection energy 10^{50} erg exploding some ~100 pc away along the ordered Galactic magnetic field line passing at ~50 pc from the Solar system

Kachelriess et al. '15

Local supernova imprint on the spectra of protons



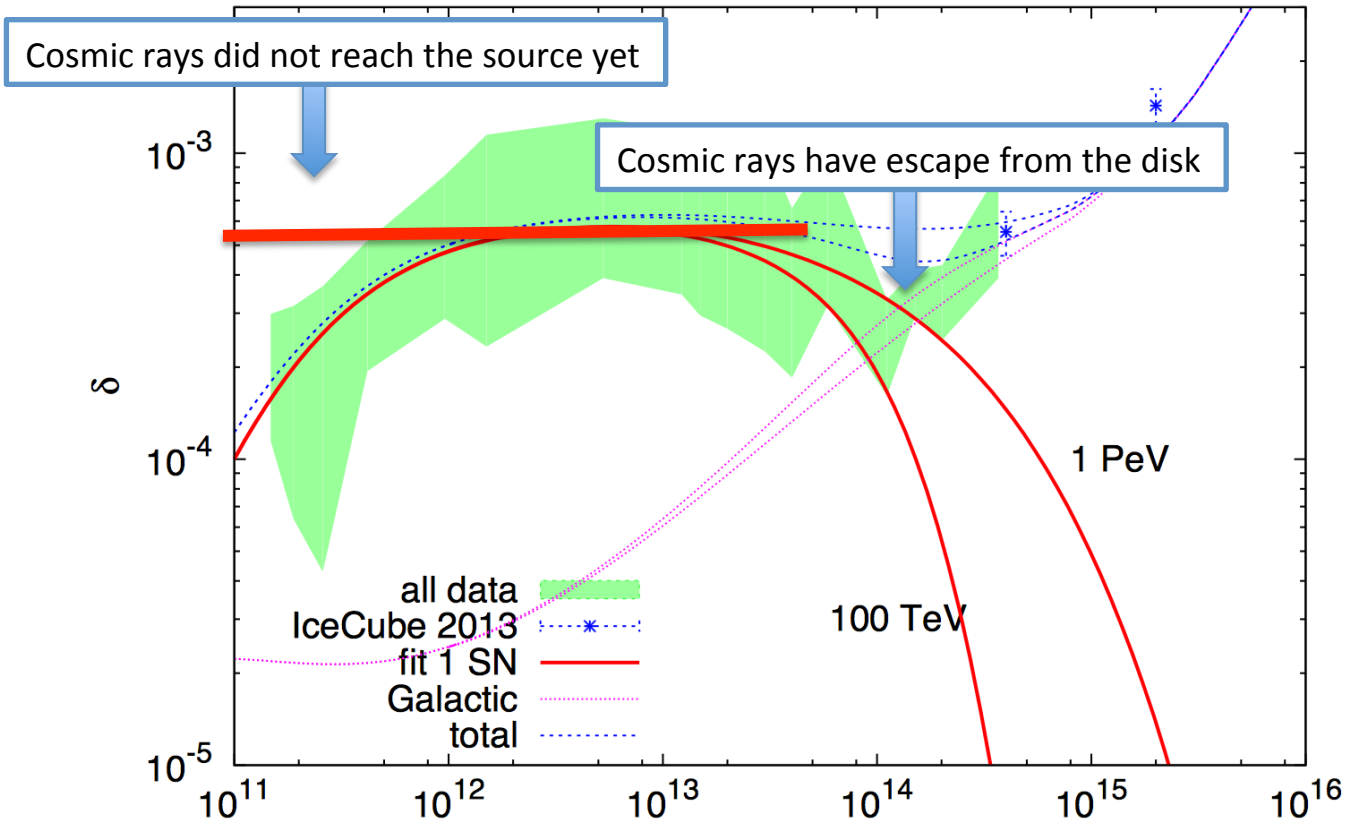
Monte-Carlo code simulating trajectories of individual particles through the realistic Galactic magnetic field which includes regular and turbulent (Kolmogorov) components.

Lower energy cosmic ray flux from the local source could be suppressed because of slow diffusion across magnetic field lines

A supernova with cosmic ray injection energy 10^{50} erg exploding some ~100 pc away along the ordered Galactic Magnetic field line passing at ~50 pc from the Solar system

Kachelriess et al. '15

Local supernova imprint on the CR anisotropy

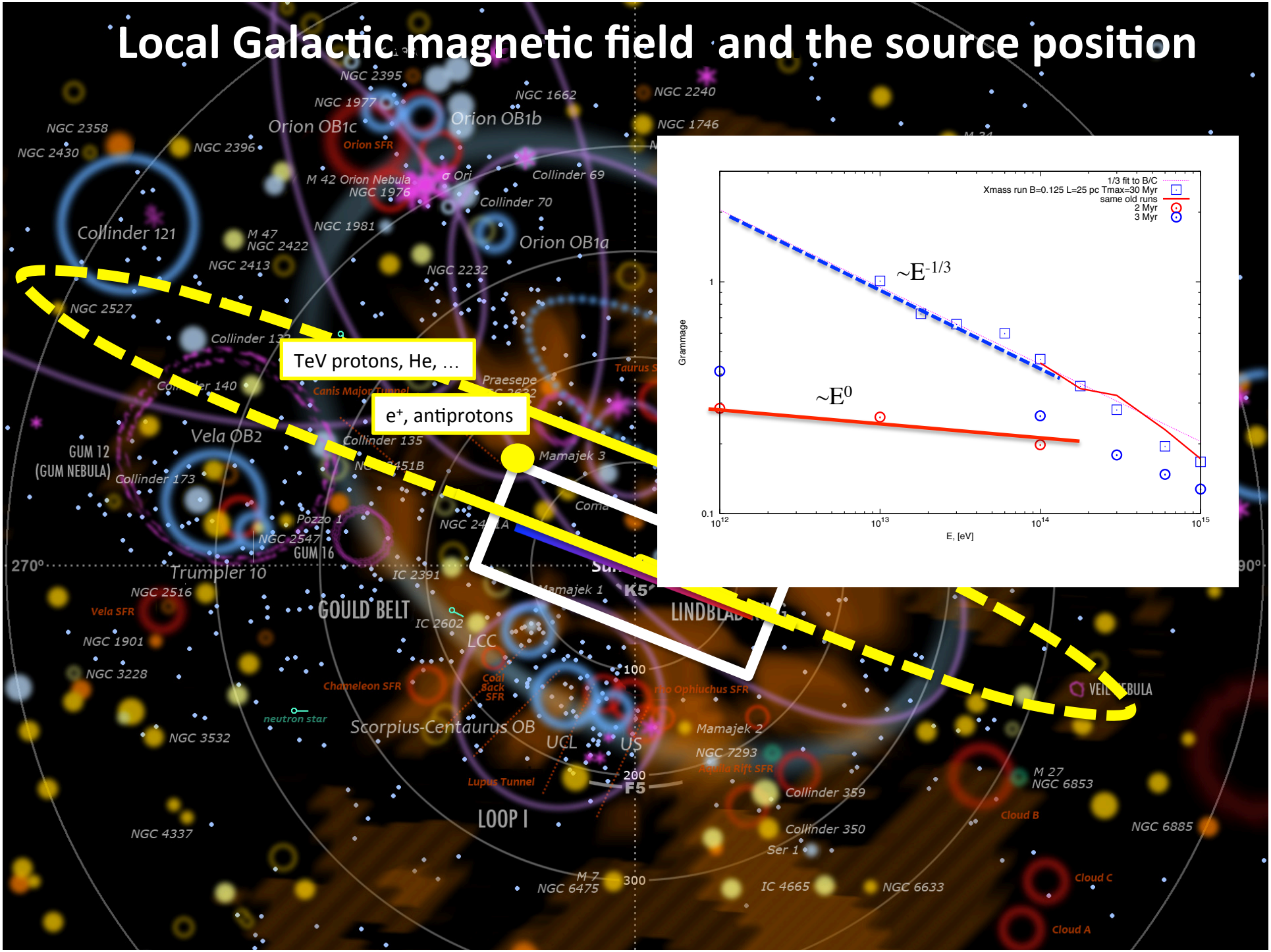


$$\delta = f\frac{3R}{T} \sim 10^{-3}\left[\frac{R}{200\ \mathrm{pc}}\right]\left[\frac{T}{2\ \mathrm{Myr}}\right]^{-1}$$

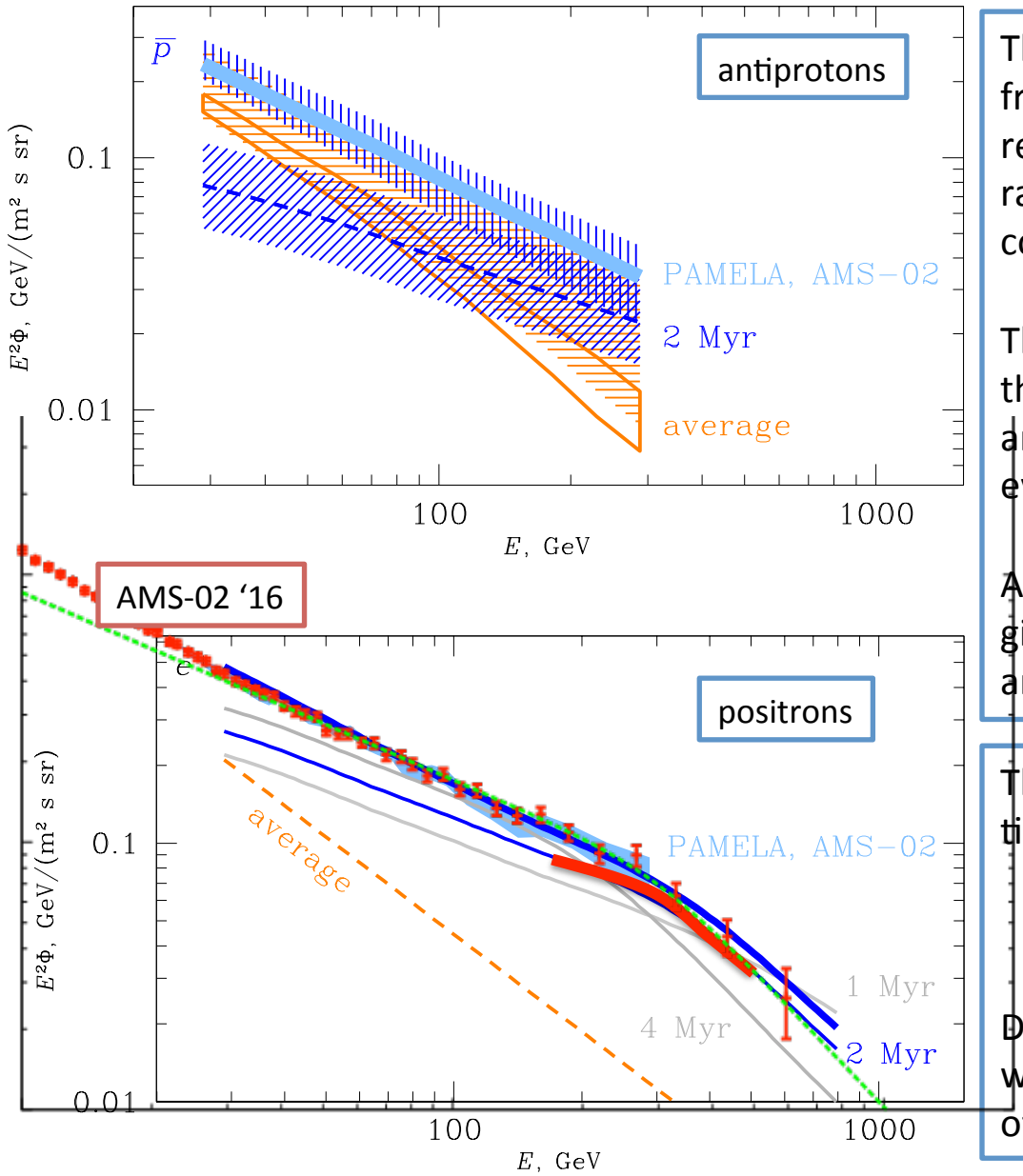
A supernova with cosmic ray injection energy 10^{50} erg exploding some ~100 pc away along the ordered Galactic Magnetic field line passing at ~50 pc from the Solar system

Savchenko et al. '15

Local Galactic magnetic field and the source position



Local supernova imprint on antiprotons and positrons



Kachelriess et al. '15

The spectrum of positrons and antiprotons from the local supernova approximately repeats the spectrum of the source cosmic rays, because the matter column crossed by cosmic rays is energy-independent.

The flux of positrons is at the level of excess in the positron spectrum observed by PAMELA and AMS-02 if the the cosmic ray injeciton event happened ~2 Myr ago.

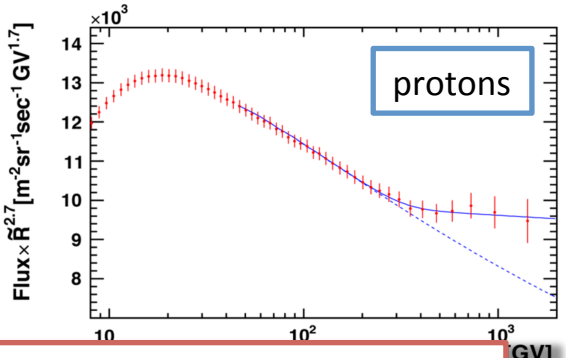
Antiprotons produced on the same time scale give sizable contribution to the observed antiproton flux.

The synchrotron / inverse Compton cooling time for positrons is

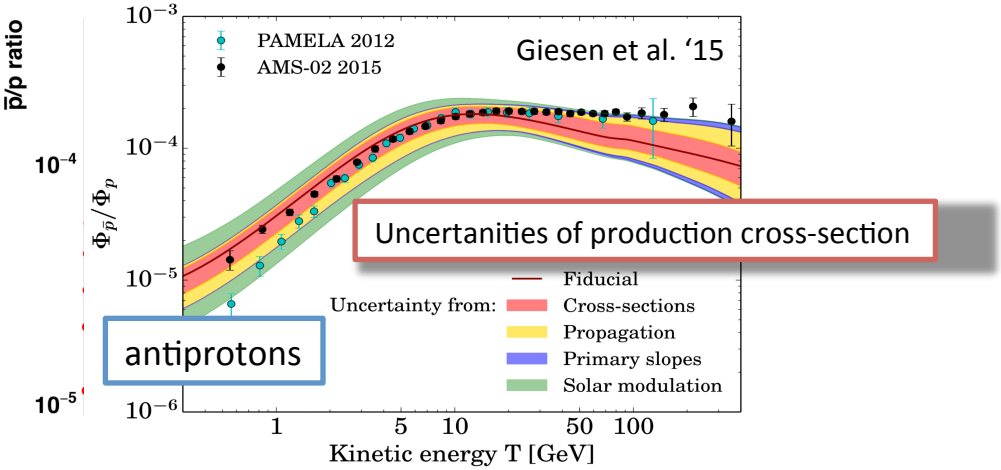
$$t_{cool} \simeq 2\left[\frac{E}{300\ \mathrm{GeV}}\right]^{-1}\left[\frac{U}{0.5\ \mathrm{eV/cm^3}}\right]^{-1}\ \mathrm{Myr}$$

Detection of a break in the positron spectrum would provide an independent measurement of time elapsed from CR injection moment.

Local supernova vs. alternative models of spectral features

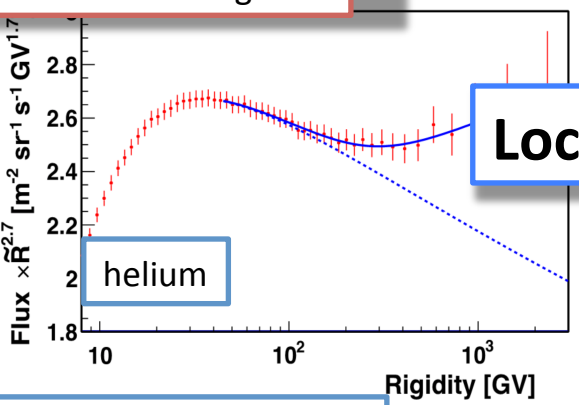


Change in the diffusion regime?

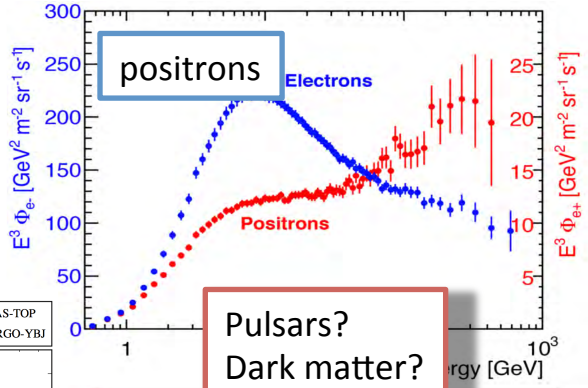


Uncertainties of production cross-section

antiprotons

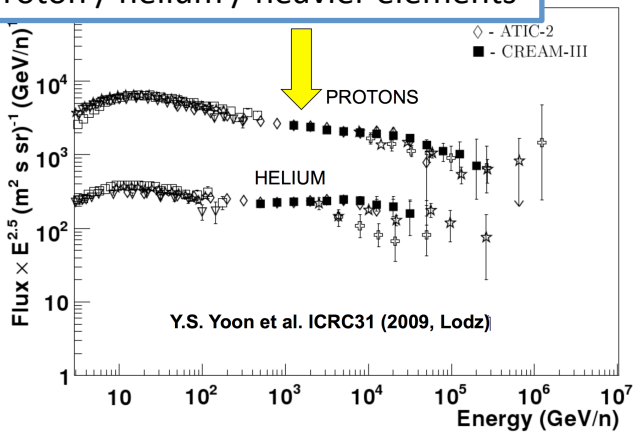


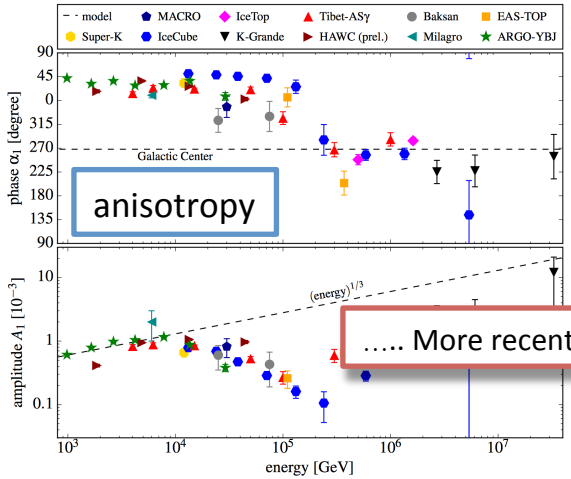
Local supernova



Pulsars?
Dark matter?

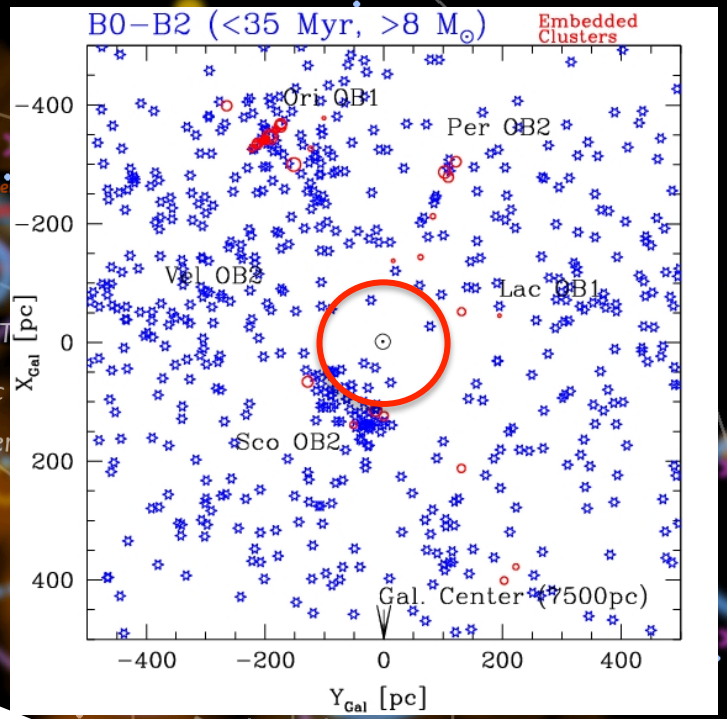
Proton / helium / heavier elements



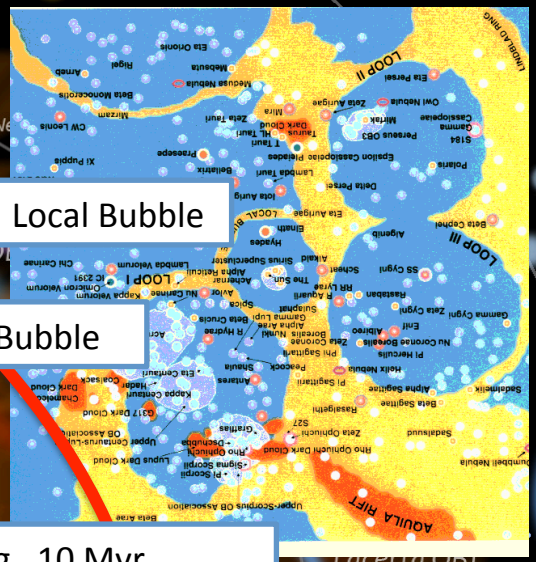


….. More recent supernova?

Superova location

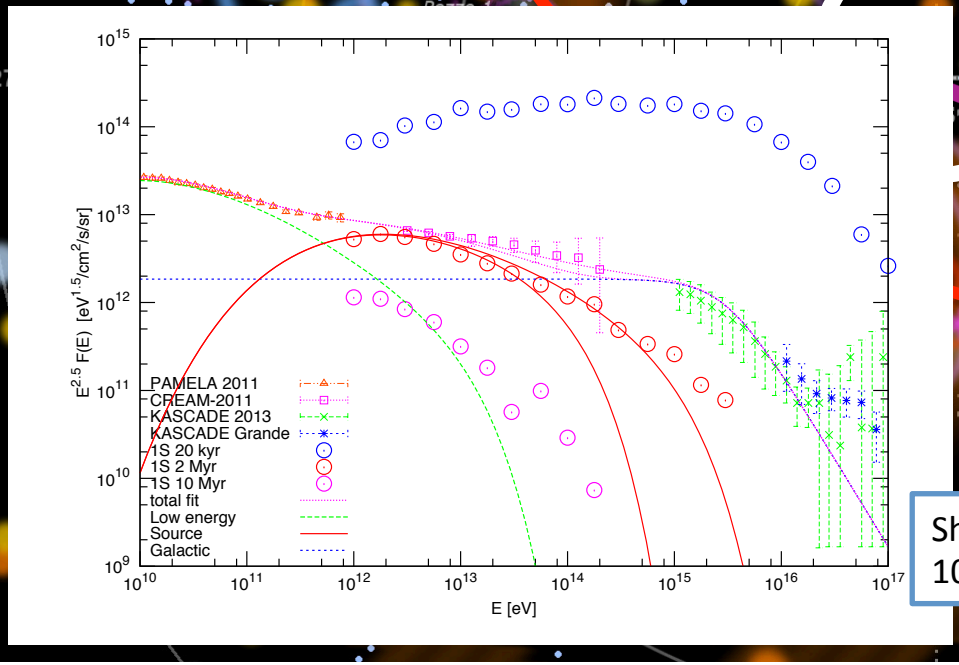


Local supernova, Sco-Cen association, Local Bubble, . . .

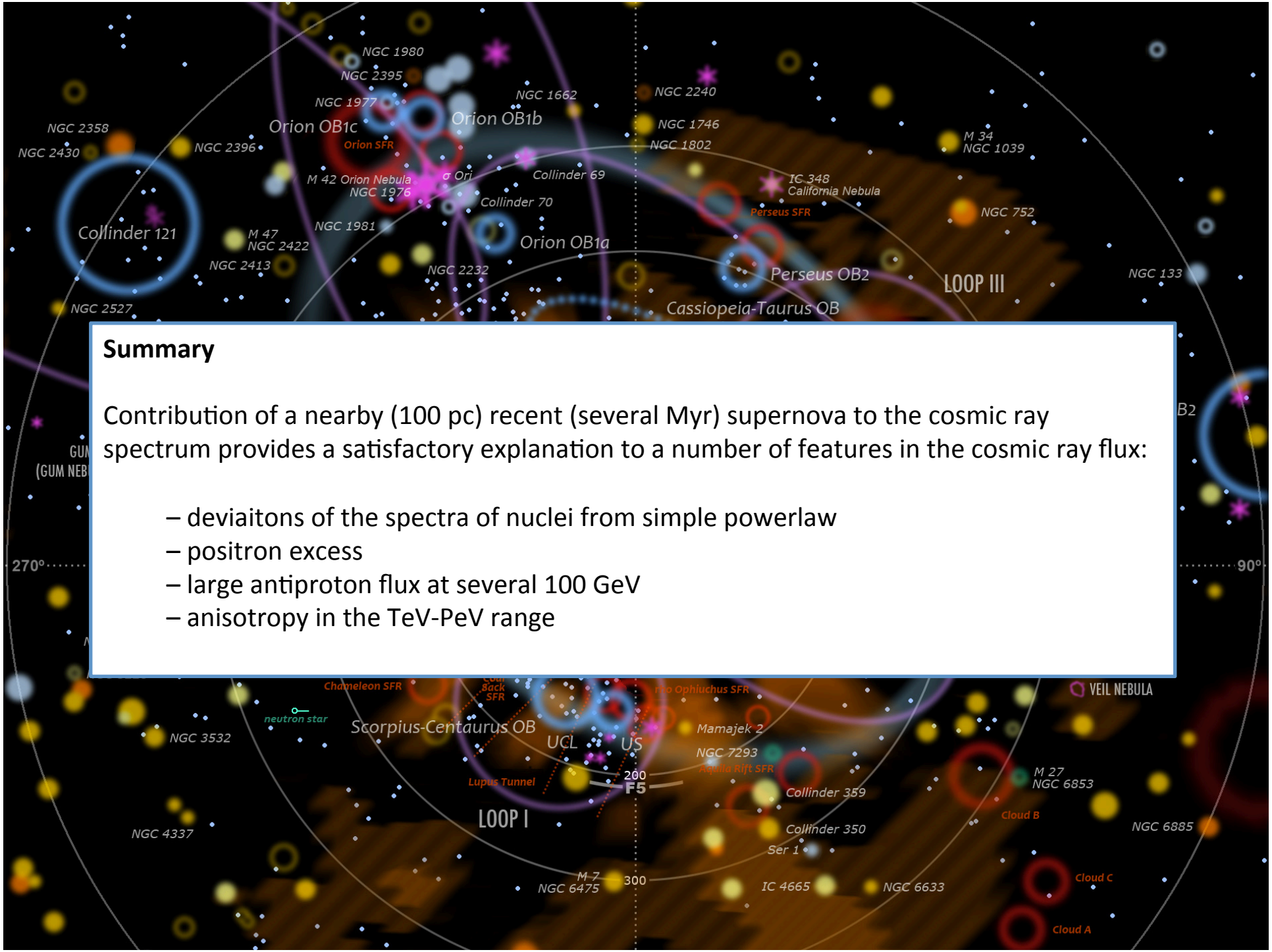


10^{52} erg , 10 Myr

Gould Belt
10^{52} erg, 30 Myr



Should variaitons of local star formation rate on 10 Myr scale leave imprint on the CR spectrum?



Summary

Contribution of a nearby (100 pc) recent (several Myr) supernova to the cosmic ray spectrum provides a satisfactory explanation to a number of features in the cosmic ray flux:

– deviaitons of the spectra of nuclei from simple powerlaw
– positron excess
– large antiproton flux at several 100 GeV
– anisotropy in the TeV-PeV range