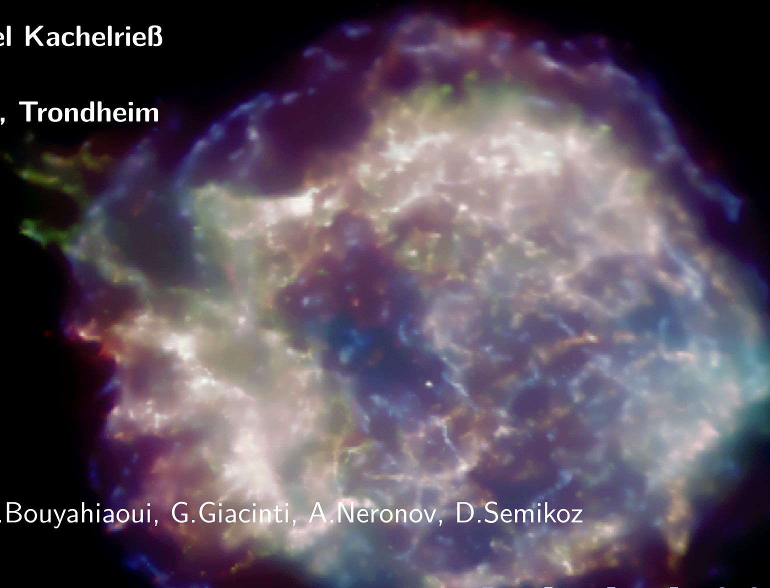
Local Cosmic Ray Sources and the Local Bubble

Michael Kachelrieß

NTNU, Trondheim

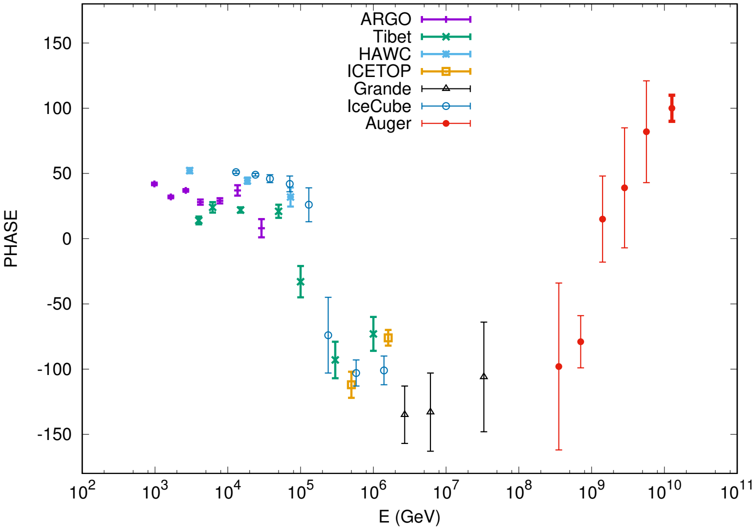


with M.Bouyahiaoui, G.Giacinti, A.Neronov, D.Semikoz

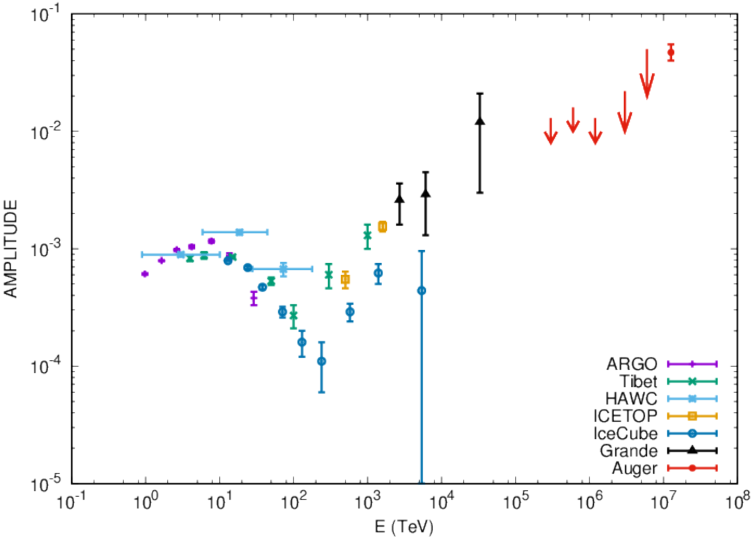
Outline of the talk

1. Introduction
   - Dipole anisotropy: evidence for 2 local sources
2. 2–3 Myr local SN
   - Primaries: breaks, non-universality
   - Secondaries: positron excess, antiprotons, B/C
3. Vela and the CR knee
   - Living in the Local Bubble
   - CR fluxes
   - Neutrinos
4. Conclusions

Dipole anisotropy: phase



Dipole anisotropy: amplitude



Anisotropy of a single source

- if only turbulent field:
  diffusion = isotropic random walk = free quantum particle
- number density is Gaussian with $\sigma^2 = 2DT$

$$\delta_i = \frac{3D_{ij}}{c}\frac{\nabla_j n}{n} = \frac{3R}{2T} = 5 \times 10^{-4}\frac{R}{200\text{pc}}\frac{2\text{Myr}}{T}$$

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- 2 options:
  - old nearby source dominating flux
  - young nearby source (not dominating) flux, suppression:

$$D_{ij} = D_{\|}\, b_i b_j + D_{\perp}(\delta_{ij} - b_i b_j) + \varepsilon_{ijk} e_k D_A \simeq D_{\|}\, b_i b_j$$

    not aligned to ∇n

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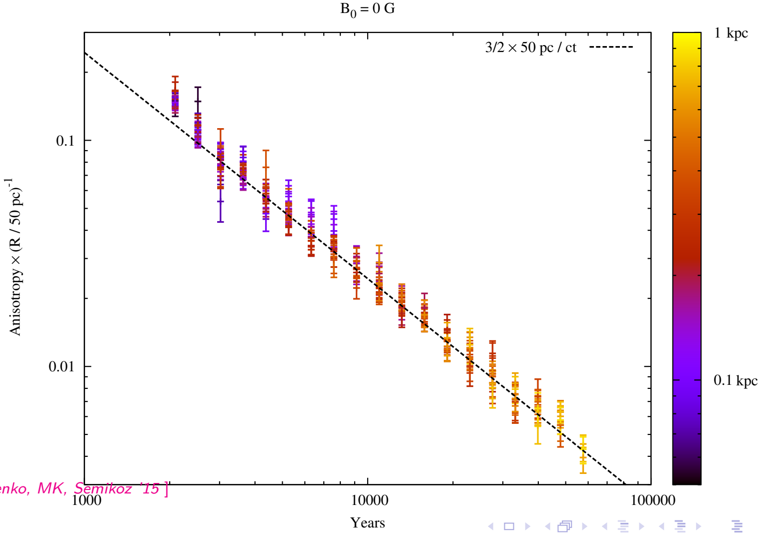
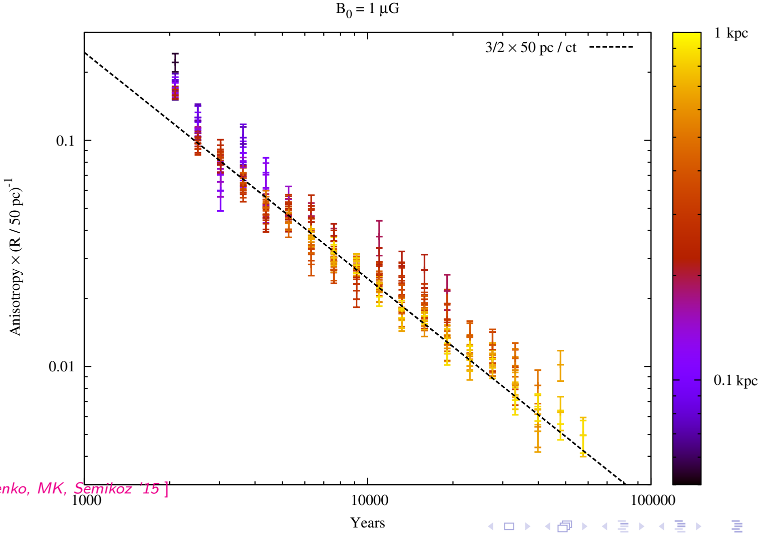
- what happens for general fields?

Anisotropy of a single source: only turbulent field



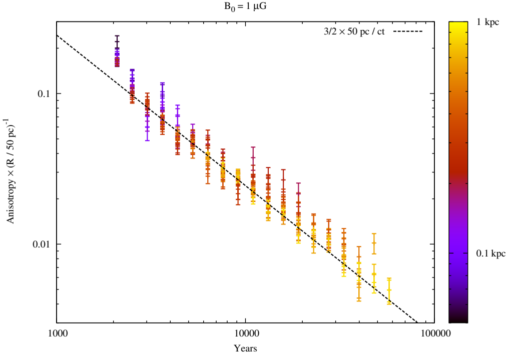
[Savchenko, MK, Semikoz '15]

Anisotropy of a single source: plus regular



[Savchenko, MK, Semikoz '15]

Anisotropy of a single source:

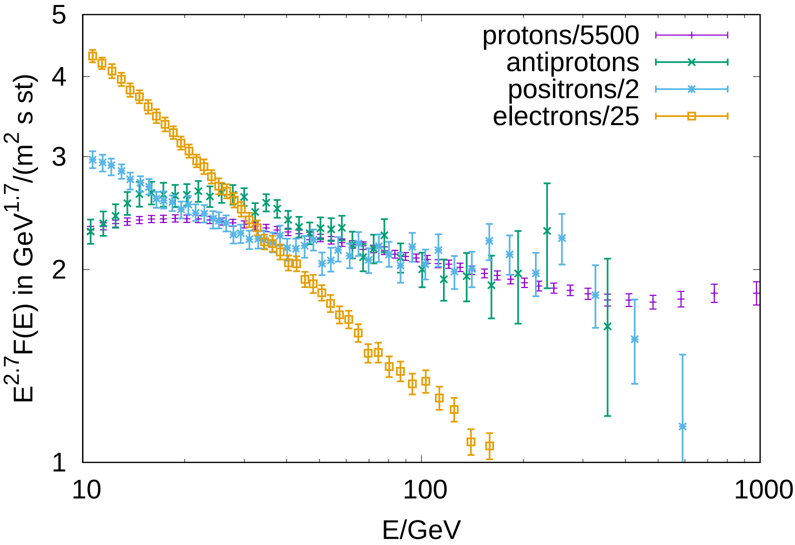


- regular field changes $n(\boldsymbol{x})$, but keeps it Gaussian

  $\Rightarrow$ no suppression because of misalignement of ∇n and $D_{\|}$

  $\Rightarrow$ no change in δ

The p, $\bar{p}$, e^+, e^- fluxes:



Signatures of a young, local single source:

- secondary $\bar{p}$ and e^+ flux have same shape as p
  - $\bar{p}$ diffuse as $p \Rightarrow$ leads to constant $\bar{p}/p$ ratio for fixed grammage
  - $\bar{p}/p$ ratio fixed by source age $\Rightarrow$ age is predicted
  - e^+ flux is fixed, break should be consistent with age
  - relative ratio of $\bar{p}$ and e^+ depends only on their Z factors: $R = F_{e^+}/F_{\bar{p}} \simeq 1.8$ for $\alpha = 2.6$

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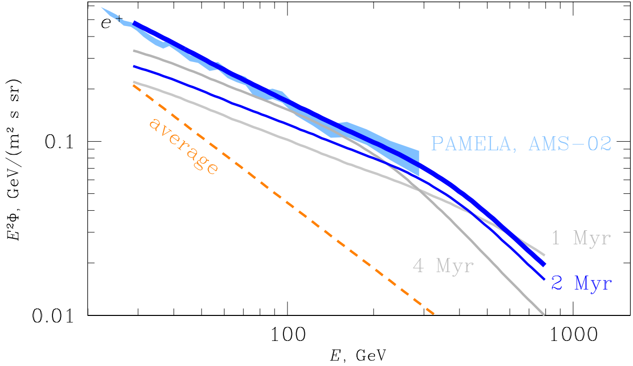

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- 2-3 Myr SN explains anomalous ^{60}Fe sediments [*Ellis+ '96,...*]
- SNe connected to Local Bubble [*Schulreich '17,...*]

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- SNe connected to Local Bubble [*Schulreich '17,... *]
- what about other CR puzzles?
  - breaks? rigidity dependence?
- B/C consistent?
- anisotropy?

Local source: nuclei fluxes

- same shape of rigidity spectra $F_A(\mathcal{R})$ for all nuclei A

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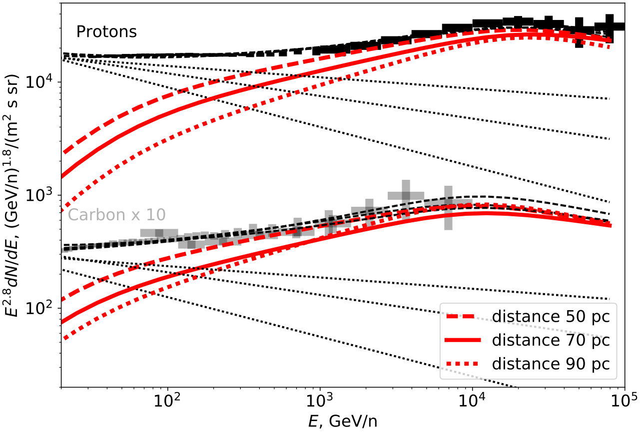
- relative normalisation of "local source" $F^{(1)}(\mathcal{R})$ and "average" $F^{(2)}(\mathcal{R})$ varies,

$$F_A(\mathcal{R}) = C_A^{(1)} F^{(1)}(\mathcal{R}) + C_A^{(2)} F^{(2)}(\mathcal{R})$$

Local source: nuclei fluxes

⇒ explains breaks and variation of rigidity spectra



[MK, Neronov, Semikoz '17]

Local source: Secondary nuclei and B/C

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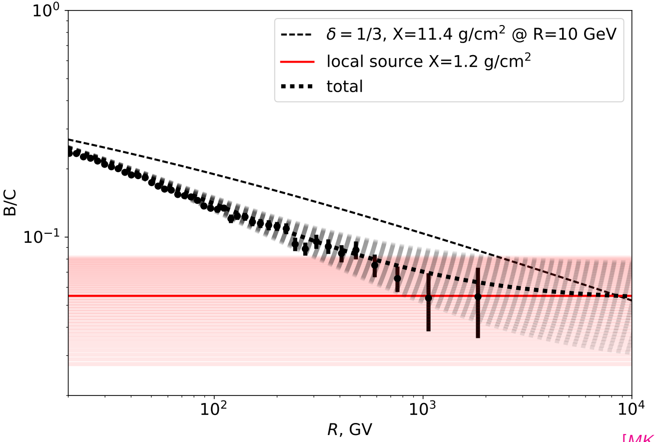
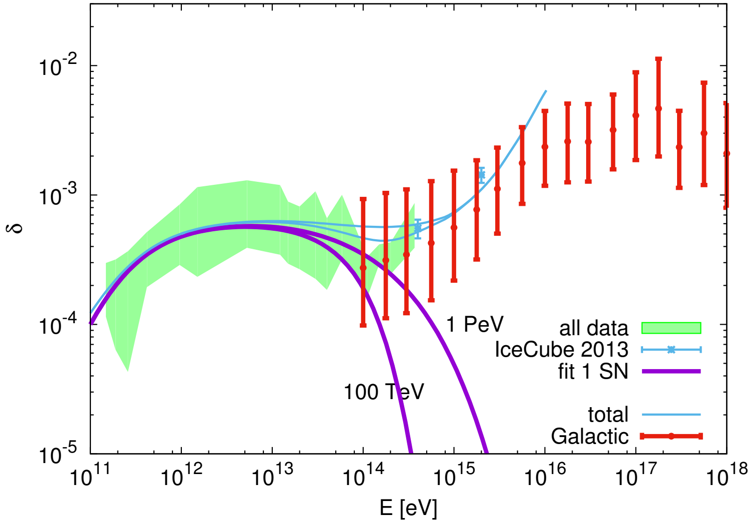


[MK, Neronov, Semikoz ’17]

Dipole anisotropy



[Savchenko, MK, Semikoz '15]

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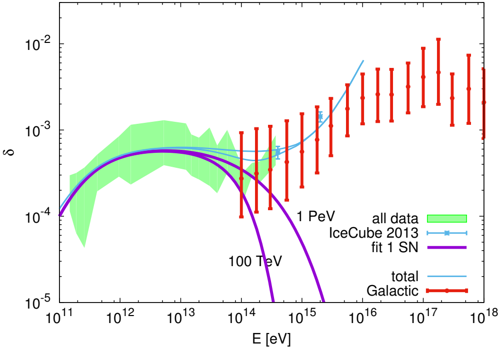
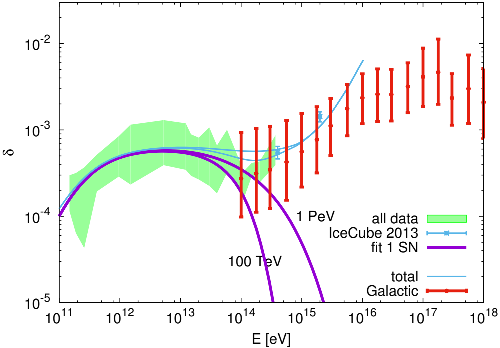


[*Savchenko, MK, Semikoz '15*]

- suggests low-energy cutoff ⇒ source is off-set
- same cutoff responsible for breaks in spectra

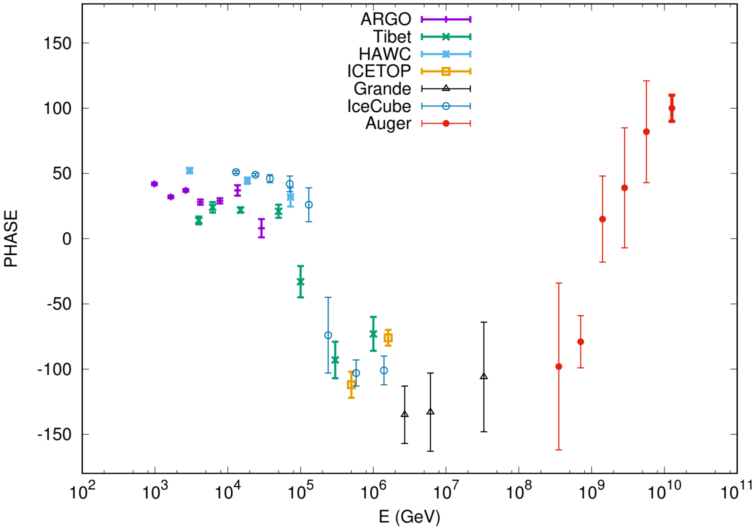
Dipole anisotropy



[*Savchenko, MK, Semikoz '15*]

- for flip in phase: 2.nd source

Dipole anisotropy: phase flip



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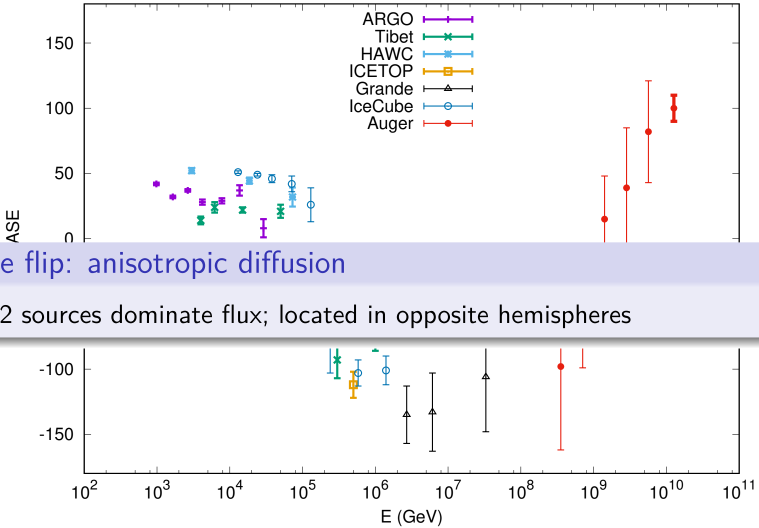

phase flip: anisotropic diffusion

- 2 sources dominate flux; located in opposite hemispheres

Vela SNR

- SNR with $T = 11.000\,\text{yr}$ and $R = 270\,\text{pc}$
- Erlykin & Wolfendale: Vela $E_{\max} \leftrightarrow$ CR knee

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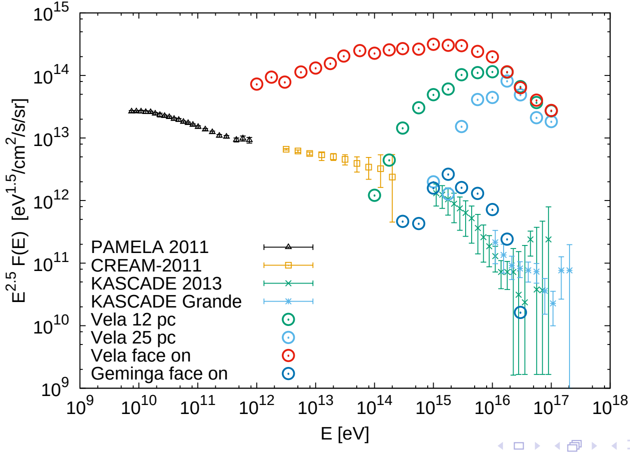
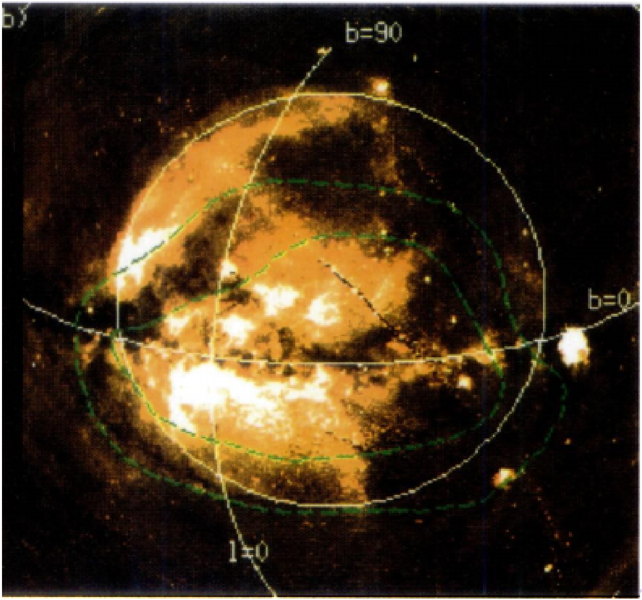
- SNR with $T = 11.000\,\mathrm{yr}$ and $R = 270\,\mathrm{pc}$
- Erlykin & Wolfendale: Vela $E_{\max} \leftrightarrow$ CR knee
- anisotropic diffusion: Sun & Vela connected by field line



Local & Loop I superbubble



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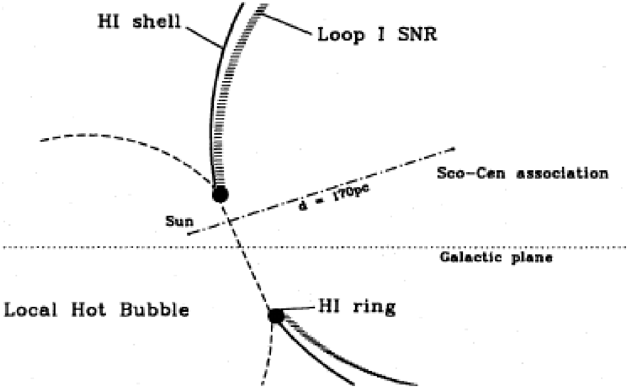
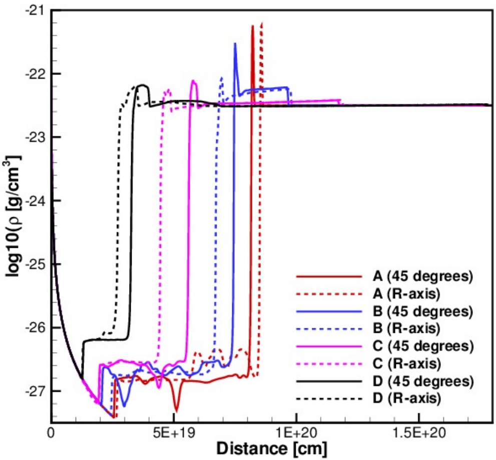


Local & Loop I superbubble

[van Marle, Meliani, Marcowith '15]



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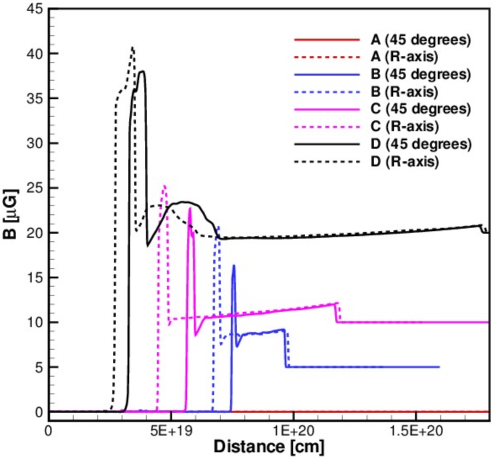
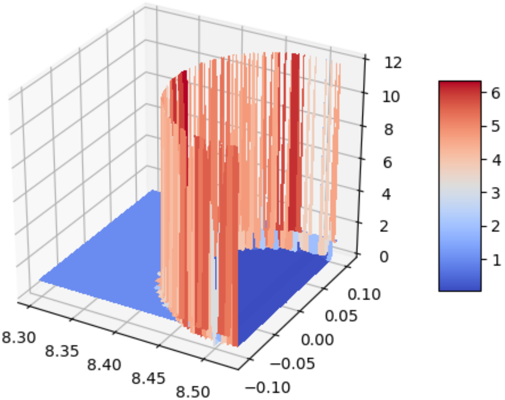


- wall traps particles; acts as a screen

Our toy model

[M.Bouyahiaoui, MK, D.Semikoz '18]



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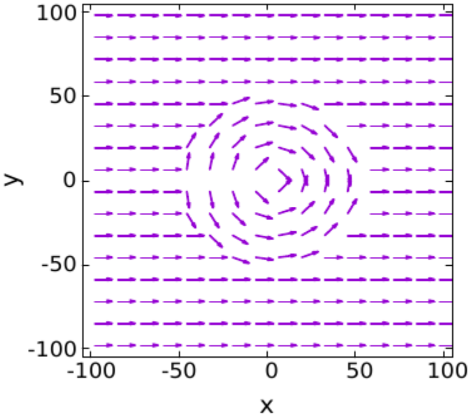
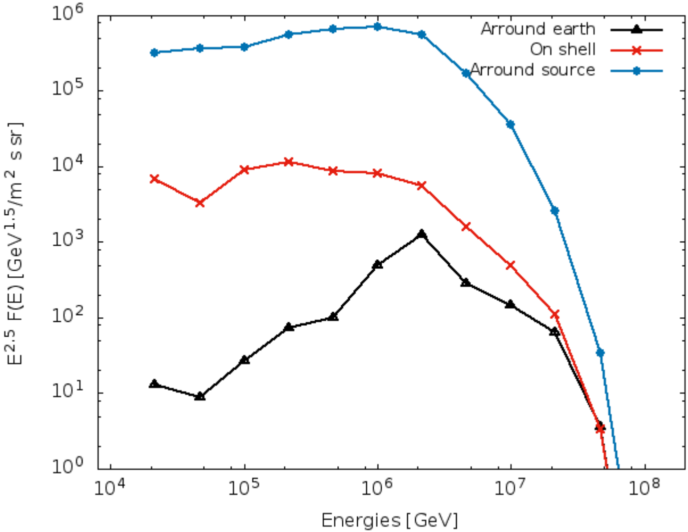


- cylinder symmmetry in z, Vela outside

Flux from Vela in Local Superbubble: suppression



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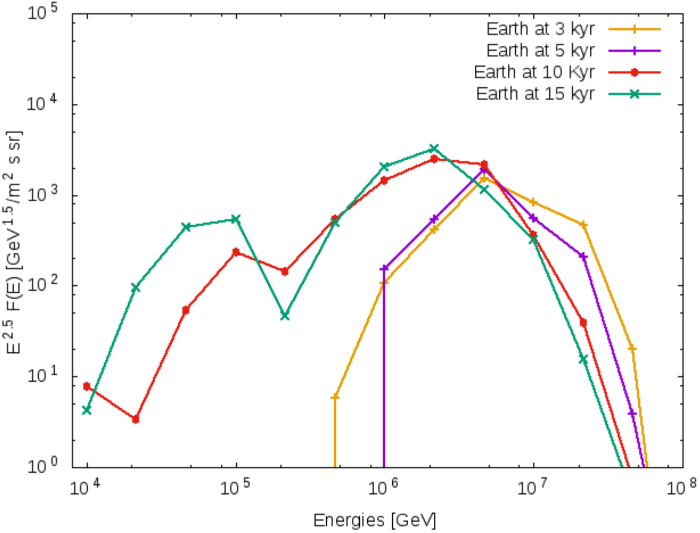

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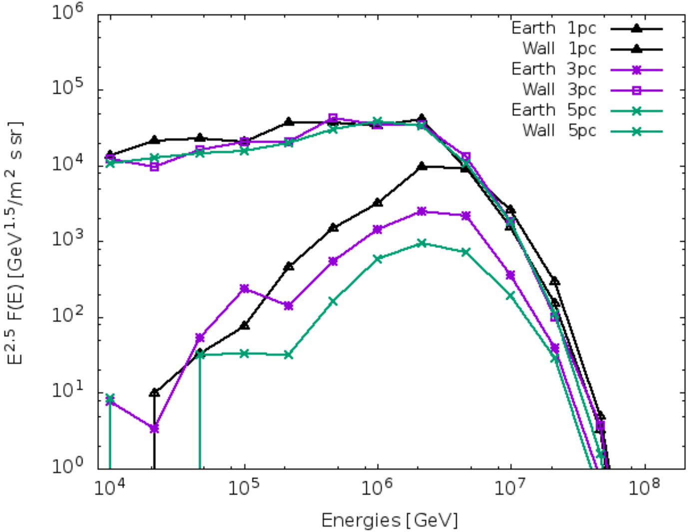
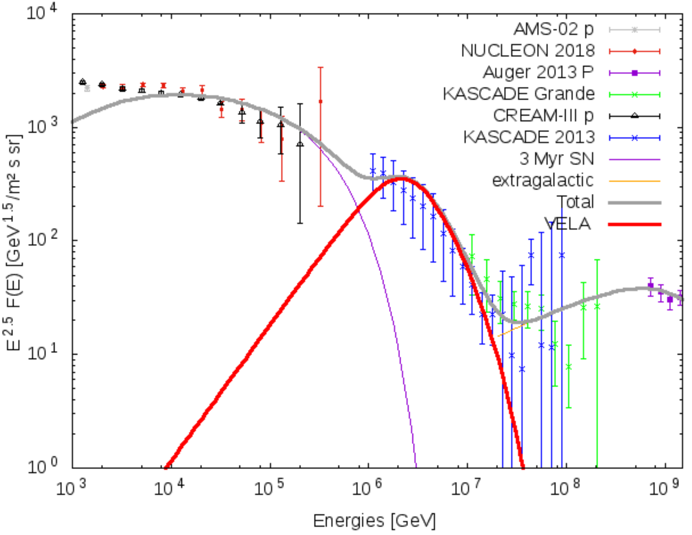
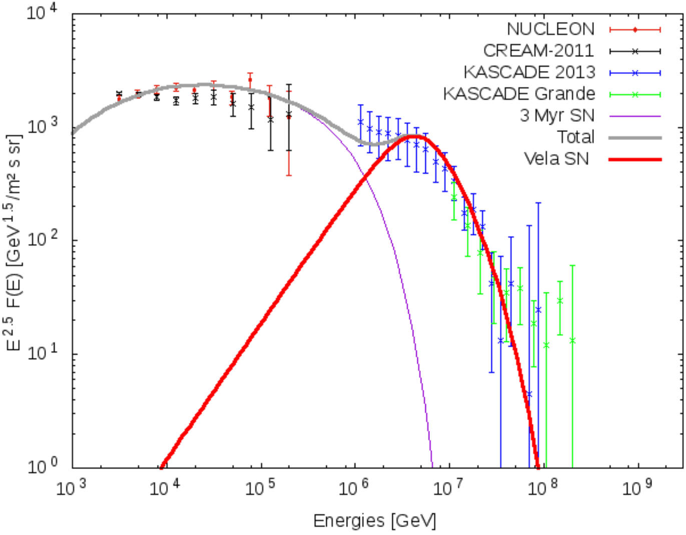


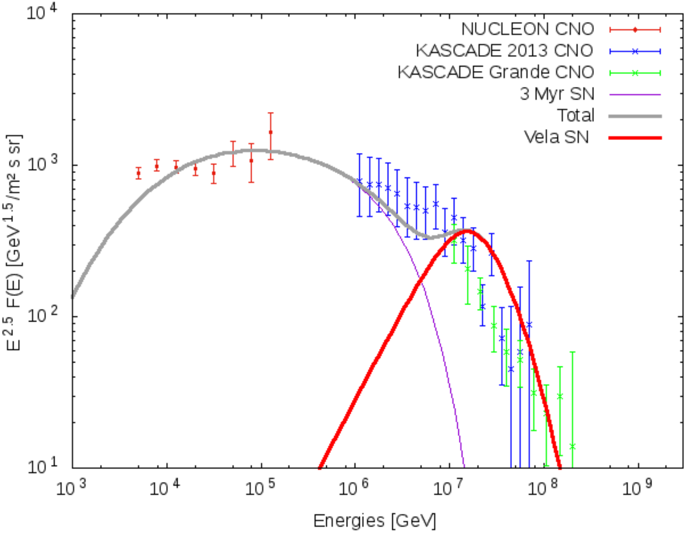
Flux from Vela in Local Superbubble:protons



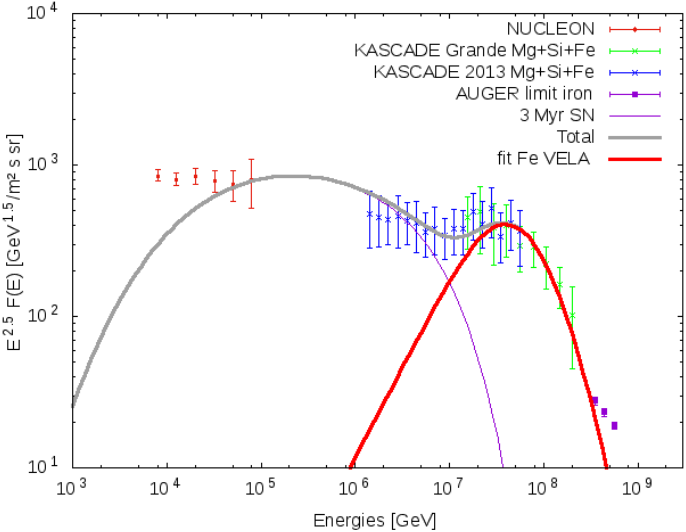
Flux from Vela in Local Superbubble: He



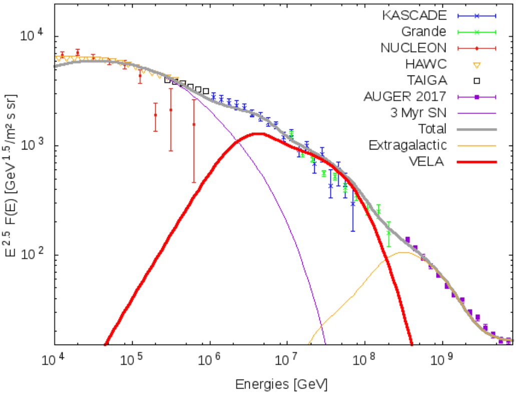
Flux from Vela in Local Superbubble: CNO



Flux from Vela in Local Superbubble: Fe+Mg+Si



Flux from Vela in Local Superbubble: total



⇒ two local sources dominate Galactic CR flux above 200 GeV

Conclusions

1. Single source: anisotropy
   - dipole formula $\delta = 3R/2T$ holds universally in quasi-gaussian regime
   - plateau of δ and phase flip point to dominance of 2 single sources
2. Source with $T \sim 2 - 3$ Myr and $R \sim 200$ pc:
   - consistent explanation of $\bar{p}$ and e^+ fluxes, breaks and B/C
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