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Damping of self-generated Alfvén waves in a partially ionized medium and the grammage of cosmic rays in the proximity of supernova remnants

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Overview

- CRs escaping from SNRs

- excitation of Alfvén waves by resonant streaming instability
  - suppression of diffusion coefficient in the source region
  - self-confinement

- damping of Alfvén waves
  - ion-neutral friction
  - turbulent damping
  - non-linear Landau damping

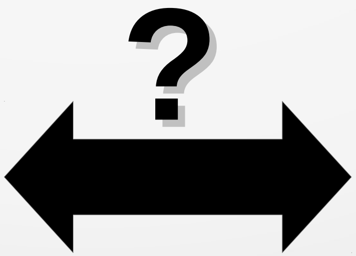
- CR grammage accumulated in the source region?
- Need a revision of the standard picture of CR Galactic propagation?

CR escape from SNRs: a challenge

- a self consistent theory of acceleration and escape of CRs is still missing
  - time-dependent problem
  - active role of CRs - non linearity
  - broad range of spatial scales and propagation regimes involved
  - difficult with simulations

SOURCE

- strong B amplif. $\delta B \sim B_0$
- Bohm diffusion $\lambda \sim R_L$
- $P_{CR} > P_B$

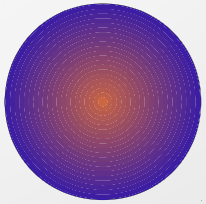


ISM

- $\delta B \ll B_0$
- $\lambda \gg R_L$
- $P_{CR} \sim P_B$

CR resonant streaming instability

- CR density gradient
  - streaming CRs transfer momentum to waves
  - generate resonant waves $k \sim 1/R_L$
  - CRs scatter on self-generated waves, more effective diffusion
- Geometry of CR propagation
  - 1D flux-tube
  - 3D isotropic
  - ...
  - affects the CR gradient



Wave damping

- Ion-neutral friction
  - ionization fraction of the ISM
  - species of the colliding ion and neutral
- Turbulent damping
  - interaction with counter-propagating Alfvén waves
  - per-existing Alfvénic turbulence
- Non-linear Landau damping
  - interaction of background thermal ions with the beat of two Interfering Alfvén waves

Focus on WIM and WNM, which have a total filling factor in the ISM ~ 50%

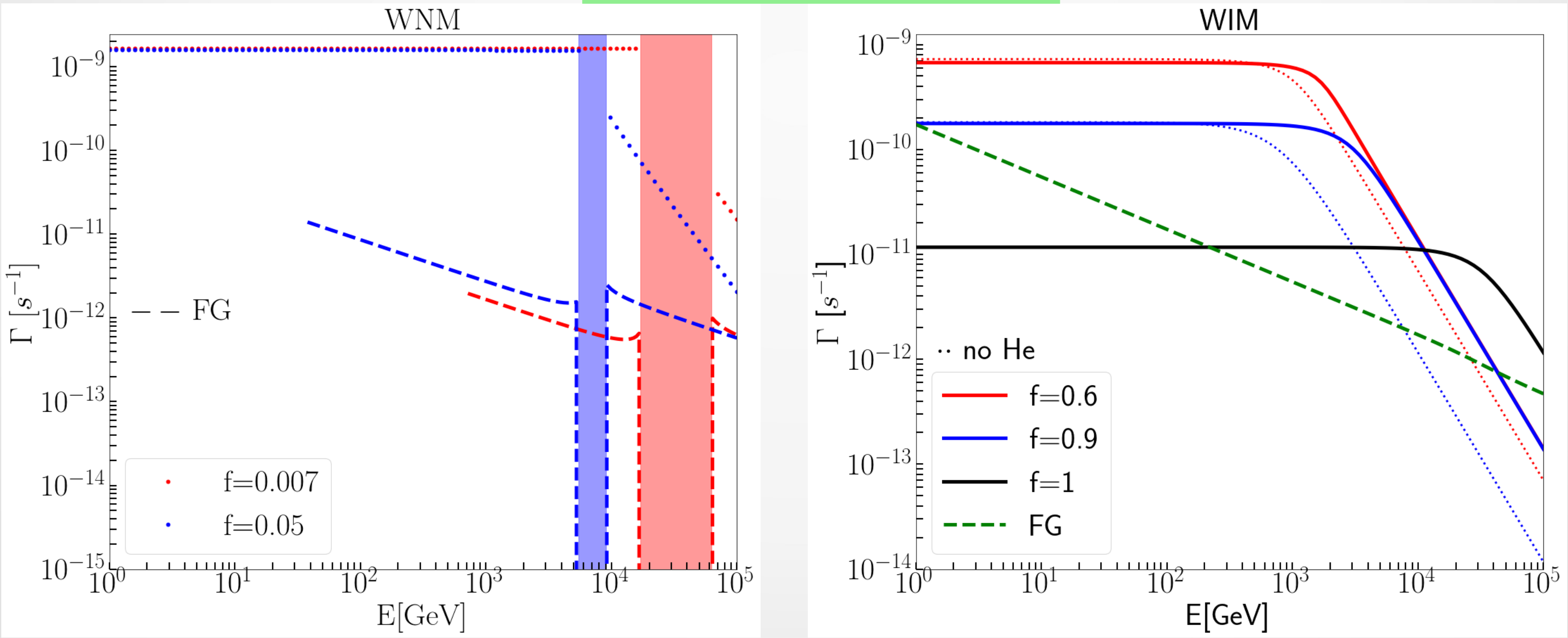
Wave damping

WIM and WNM: H ions and H, He neutrals

$$f = ionization\ fraction$$

$$\chi = He\ fraction$$

ion-neutral damping
turbulent damping (FG)



Escape radius and age

- Half-time of the CR cloud
  - cloud of initial radius *R*
  - $t_{1/2}$ is the time after which half of the CRs has escaped the initial cloud of radius *R*
  - t_a is the age of a SNR of a given radius
  - the escape radius is taken such that $t_{1/2}(R) = t_a(R)$
- $\mathbf{t_{1/2} > t_a}$ **:** SNR expansion is faster that CR cloud expansion
- $\mathbf{t_{1/2} < t_a}$ **:** SNR expansion is slower that CR cloud expansion
- $R_{esc}(E)$, $T_{esc}(E)$ are typically decreasing functions of the particle energy

Suppression of D

- $t \sim t_{1/2}$: CR overdensity at small radii
- $t >> t_{1/2}$: solutions approaches test particle
- $t_{1/2}$: timescale over which waves can grow, CRs confined
- CR overdensity for $t >> t_{1/2}$
- important suppression of the CR diffusion coefficient
- $R_{esc}(E)$ and $T_{esc}(E)$ decrease with energy
- high energy particles are less confined and escape/diffuse faster

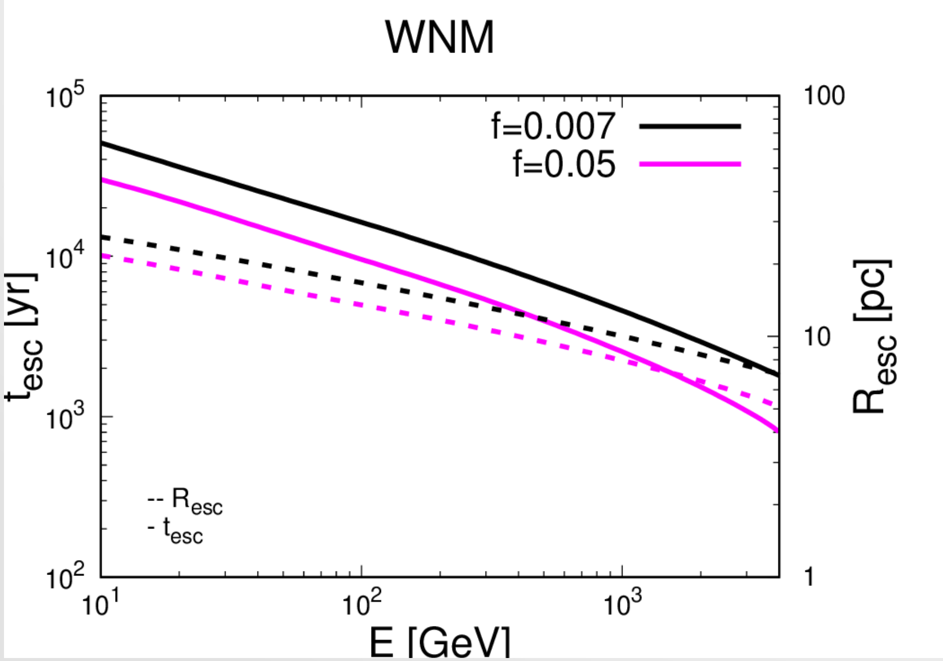
Results: escape time and radius

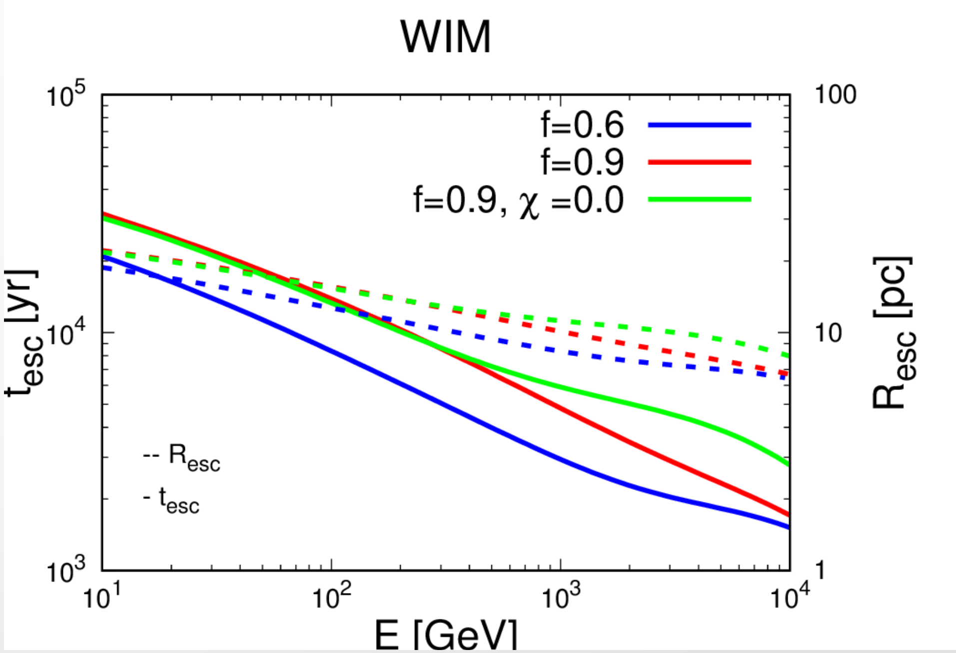
Strong dependence on the ISM phase due to ion-neutral damping

$$f = ionization\ fraction$$

$$\chi = He\ fraction$$

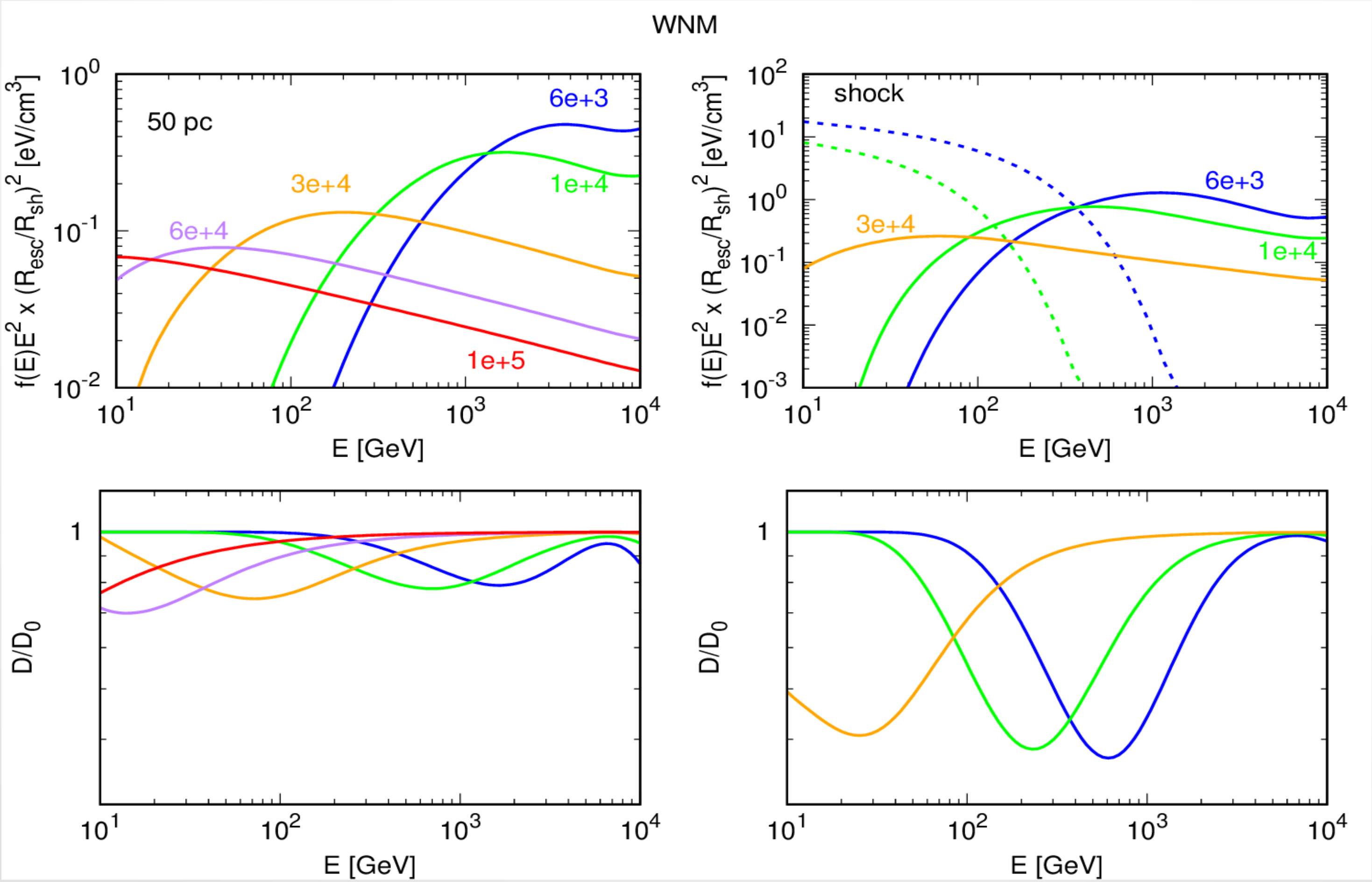
High energy particles are less confined…





Results: suppression of D

WNM: spectrum and D suppression at the shock and at 50pc from the SNR at different ages

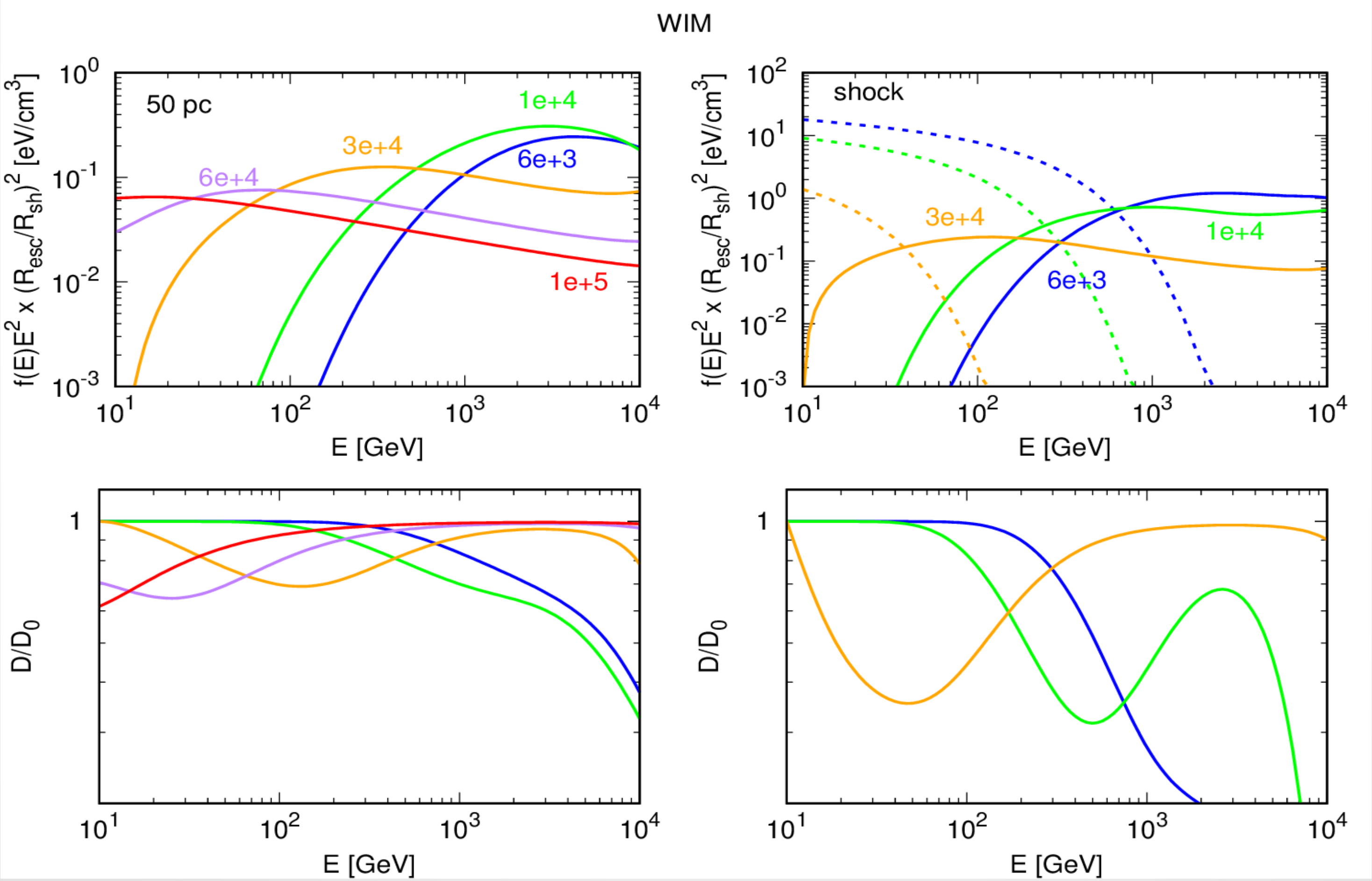


$$f = 0.05$$

$$\chi = 0.1$$

Results: suppression of D

WIM: spectrum and D suppression at the shock and at 50pc from the SNR at different ages

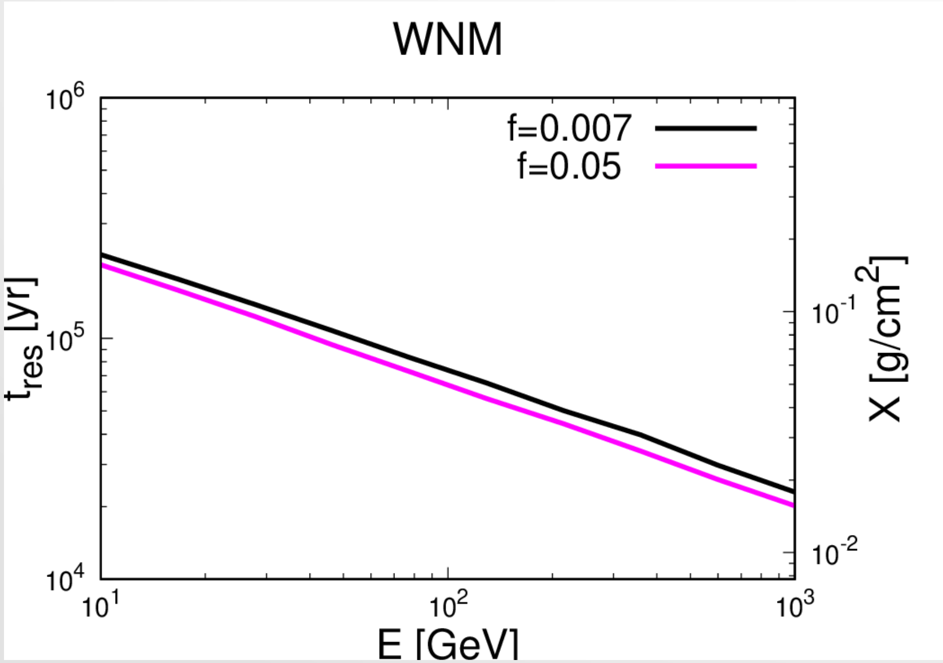


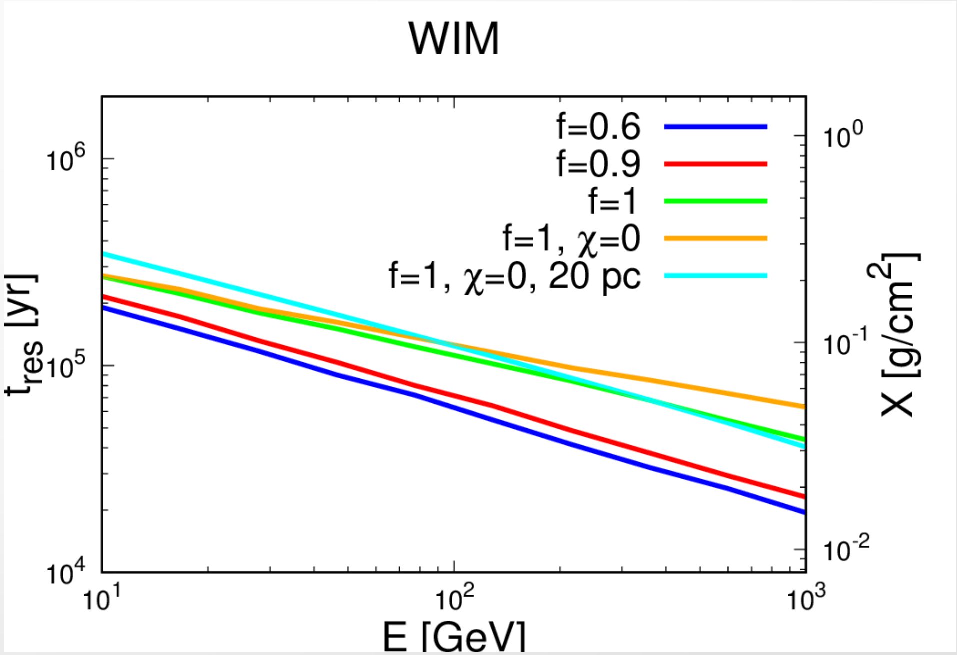
$$f = 0.9$$

$$\chi = 0.1$$

Results: residence time and grammage

- damping processes, especially ion-neutral damping
  - there is an effect of self-generated waves on the confinement time
  - but the resulting source grammage is found to be negligible compared to observations
  - region of ~ 100pc around the source





Conclusions

- the escape of CRs from sources is still an open issue
- CR propagation in the source region can be highly non-linear
  - Streaming instability and suppression of D
  - Limitations due to damping mechanisms
  - dependence on the ISM phase in which the SNR is embedded
- CR source grammage
- possibility of producing secondaries in the source region
- implications for the observed CR spectrum
- interpretation of gamma-ray data...

We find a negligible source grammage in the WNM and WIM