The origin of the slow diffusion around Geminga

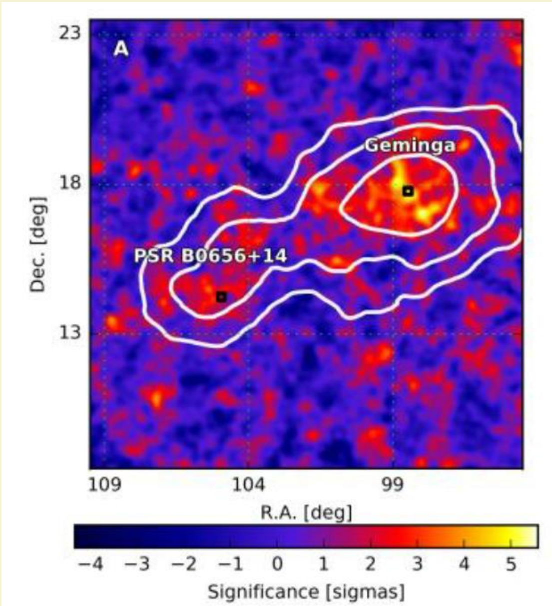
Kun Fang (IHEP)

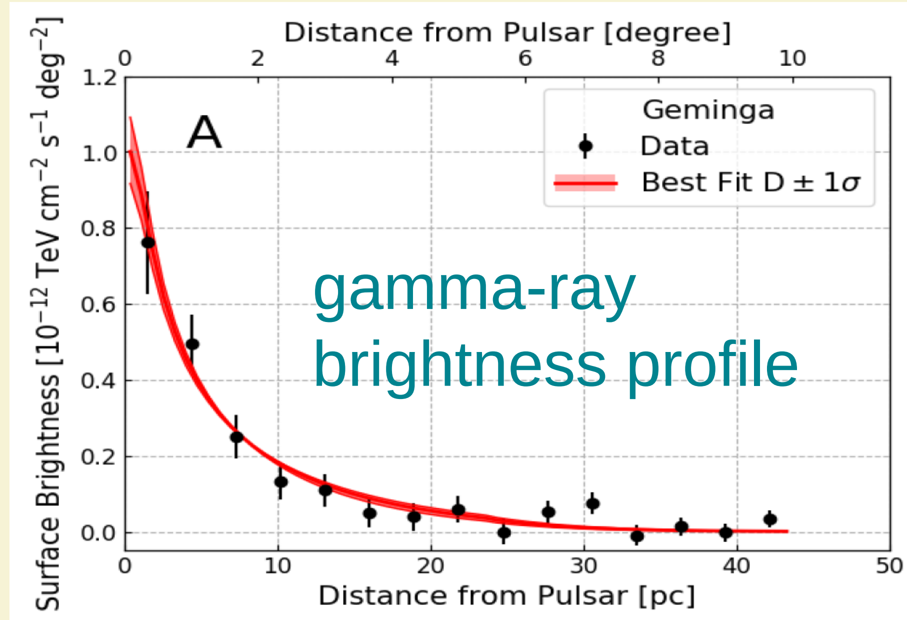
X.J. Bi (IHEP) and P.F. Yin (IHEP)

ICRC2019, Madison

arXiv:1903.06421

The slow-diffusion halo





Abeysekara et al. 2017

- The diffusion coefficient (~100 TeV) is **hundreds times slower** than that derived by B/C!
- The slow diffusion should not be universal in the Galaxy.

Possible origins

- The slow-diffusion region is **self-generated** by the escaping electrons.

  The escaping e-/e+ may induce resonant Alfven waves growth through streaming instability (Skilling 1971, Evoli at al. 2018).

- The slow-diffusion region is **preexisting**.

  The turbulence is not originated by Geminga pulsar (which is what we focus on).

- Anisotropic diffusion.

  No strong turbulence is required. The regular magnetic field is aligned with the line of sight (Liu and Yan 2019).

Self-generated scenario

Propagation of electrons:

$$\frac{\partial N}{\partial t} - \nabla \cdot (D \nabla N) - \frac{\partial}{\partial E}(bN) = Q$$

$$D(E_{\rm res}) = \frac{1}{3} r_g c \cdot \frac{1}{kW(k)}$$

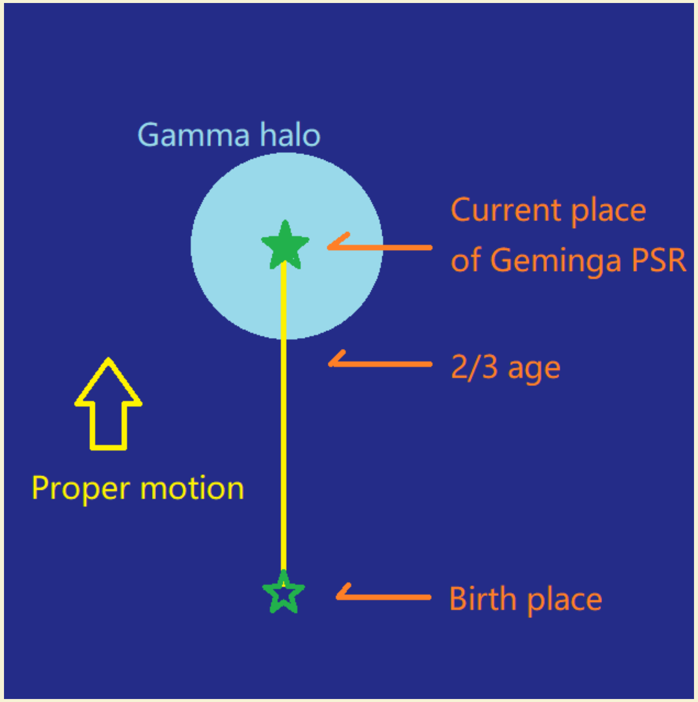
radiative cooling is omitted

Evolution of Alfven waves:

$$\frac{\partial W}{\partial t} + v_A \nabla W = (\Gamma_{\rm cr} - \Gamma_{\rm dis})W$$

wave damping is omitted

Optimistic for wave growth!



Wave growth through streaming instability:

$$\Gamma_{\rm cr} = -4\pi v_A E_{\rm res}^2 / (3 B_0^2 k W) \nabla N(E_{\rm res})$$

Faherty et al. 2007

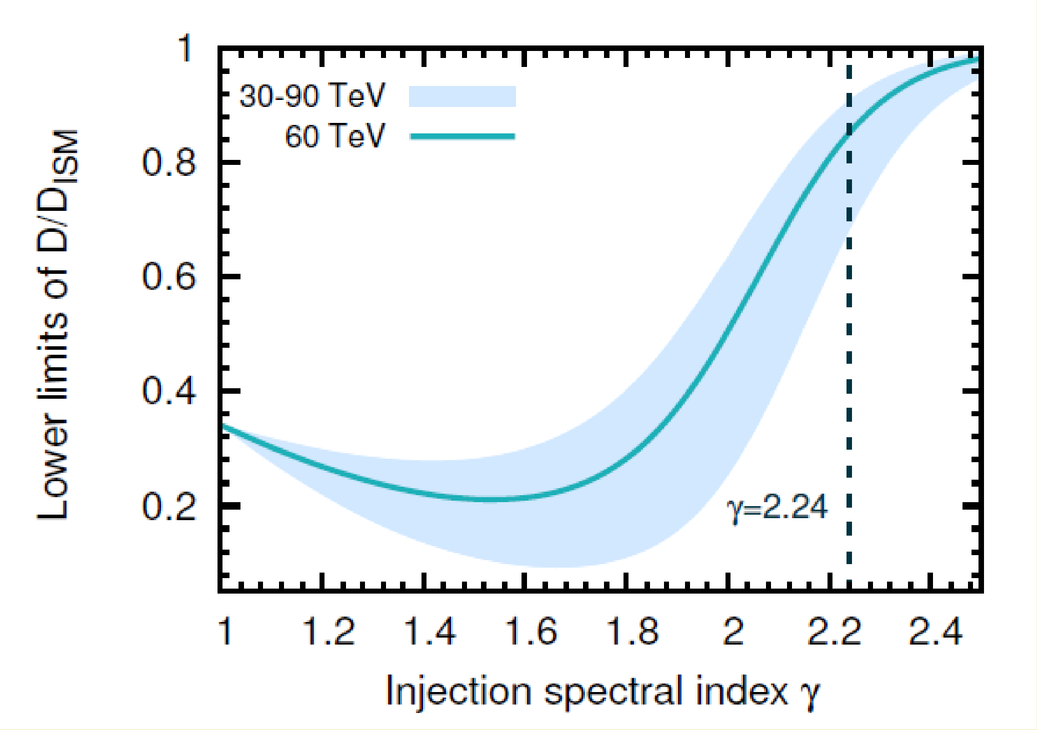
The movement of ~70 pc must be considered!

slow-diffusion region should be formed in late age of Geminga.

Self-generated scenario

$$D(x) = D_{\rm ISM} \exp\left(-\frac{4\pi e v_A E}{B_0 c}\int_x^\infty N dx'\right)$$

where $2S\int_x^\infty N dx' < \iint Q dt dx$ the injection power in the late age is small



Fang et al. arXiv:1903.06421

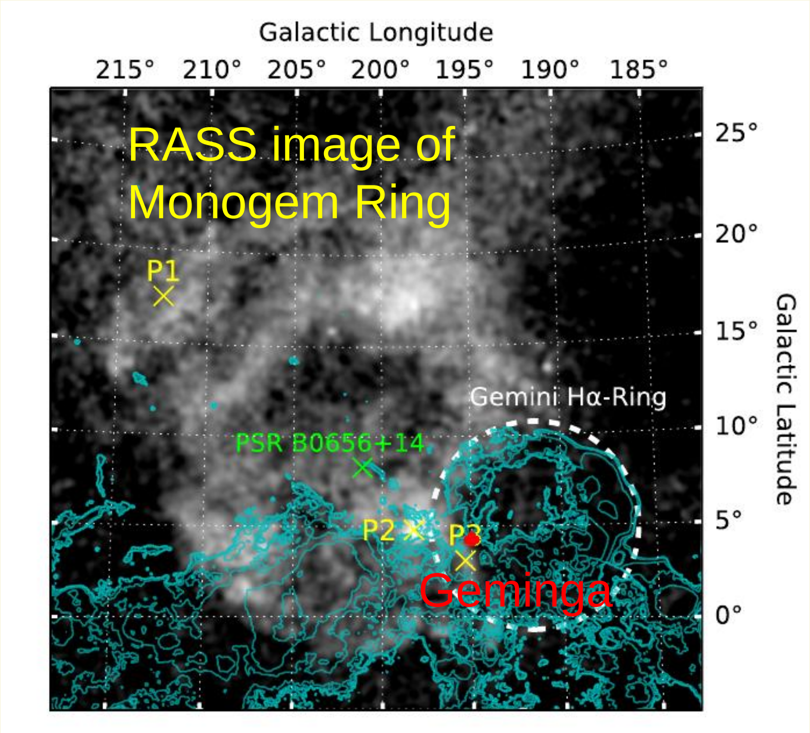
Lower limit of the diffusion coefficient for varying gamma

At most ~0.2 times reduced!

This scenario cannot suppress the diffusion coefficient to the observed level.

Slow-diffusion inside SNR

- Geminga may still be inside its (invisible) host SNR.
  The size of the SNR should be large.
- The interior of the SNR can be more turbulent than the ISM.



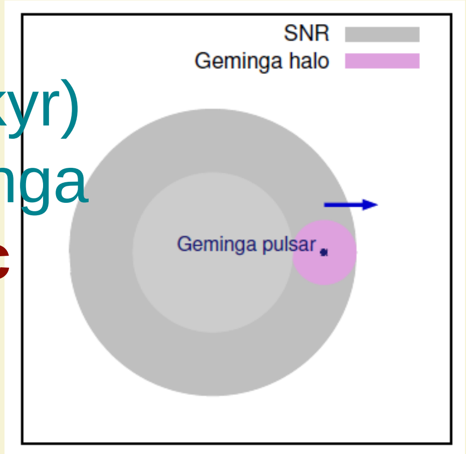
Knies et al. 2018

south of Monogem Ring

ambient density: $0.034\ \mathrm{cm}^{-3}$

initial energy: 10^{51} erg (typical) injecta mass: $1.4M_{\odot}$ (typical)

The current (342 kyr) scale of the Geminga SNR can be **90 pc**



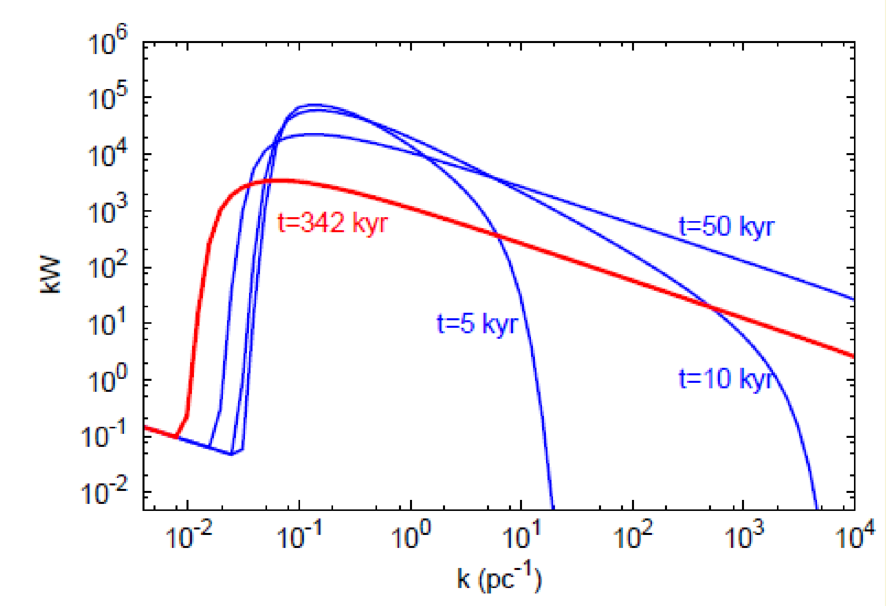
Slow-diffusion inside SNR

$$\begin{cases} \frac{\partial W}{\partial t} = \frac{\partial}{\partial k}\left(D_{kk}\frac{\partial W}{\partial k}\right) \\ W(0,k) = Q_W\delta(t)\delta(k-k_0) + W_{\rm ISM} \end{cases}$$

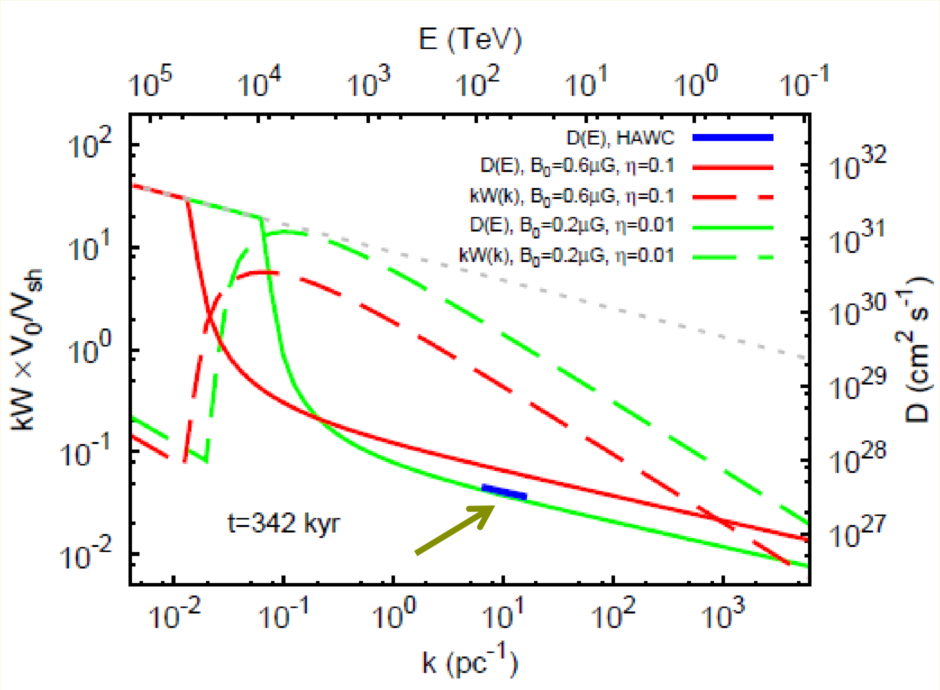
Komogorov type **turbulence cascading**

Burst-like injection, k0=0.1 pc^-1

since the shock speed declines quickly



Time evolution of turbulence wave spectrum

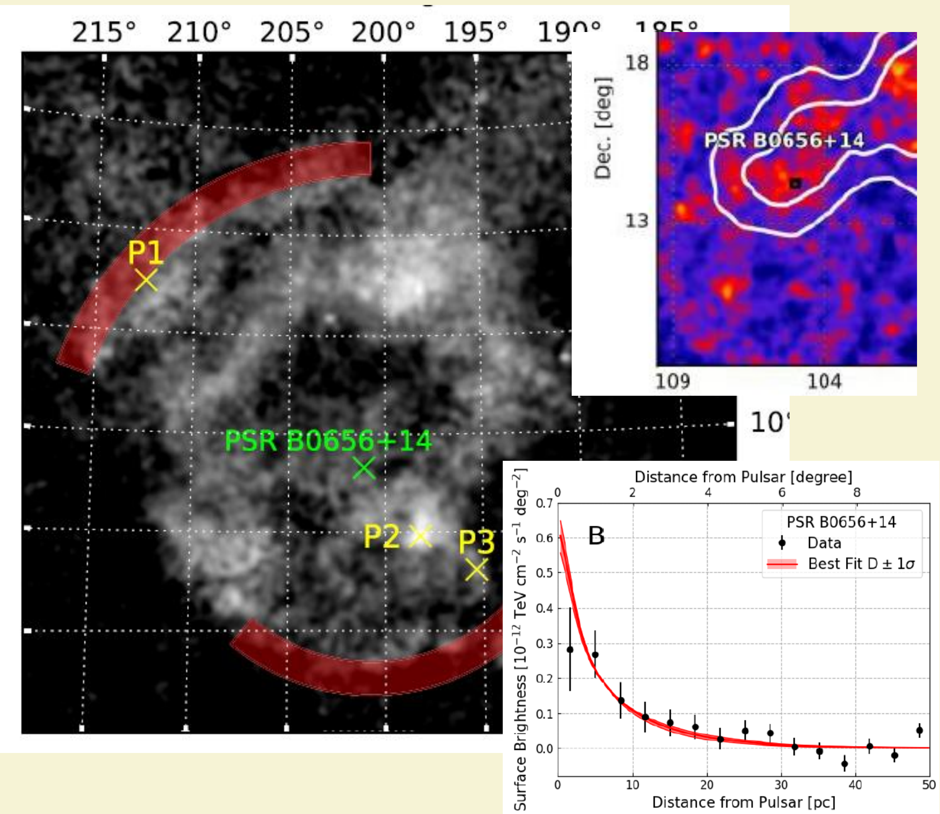


The required conversion efficiency of magnetic turbulence is **1%** to explain the observation

Fang et al. arXiv:1903.06421

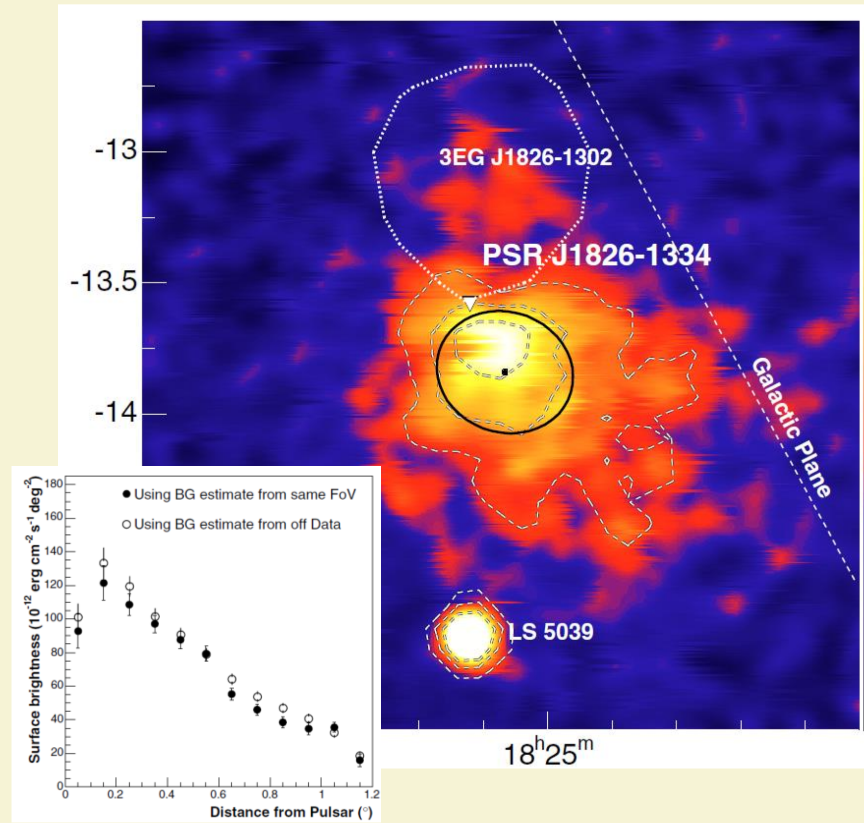
Other TeV halos

PSR B0656+14



Knies et al. 2018,
Abeysekara et al. 2017

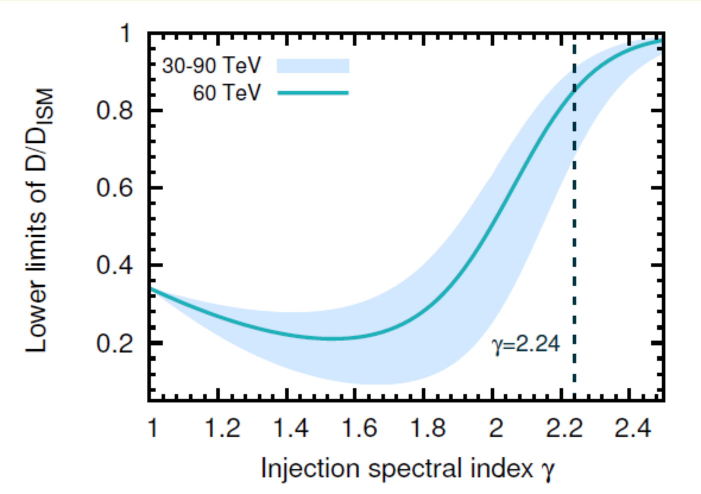
HESS J1825-137

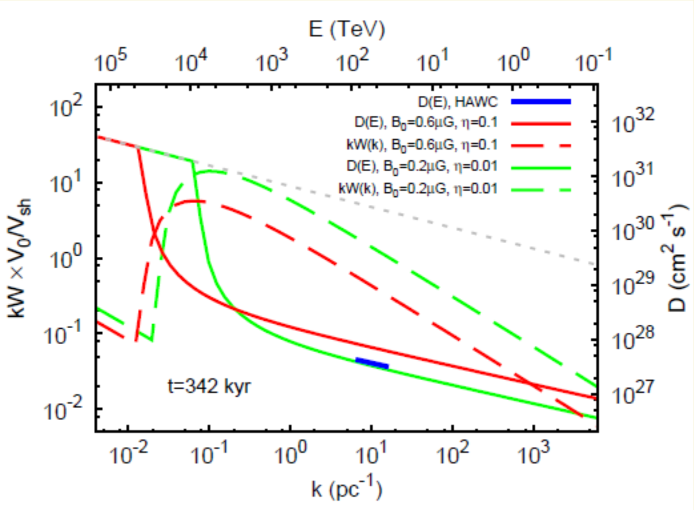


Aharonian et al. 2006

Summary

- The Geminga slow-dffusion halo cannot be self-generated by the escaping electrons considering the proper motion of Geminga.
- Geminga may still be inside its host SNR. The SNR could be energetic enough to generate a turbulent environment for Geminga.





Thank you !