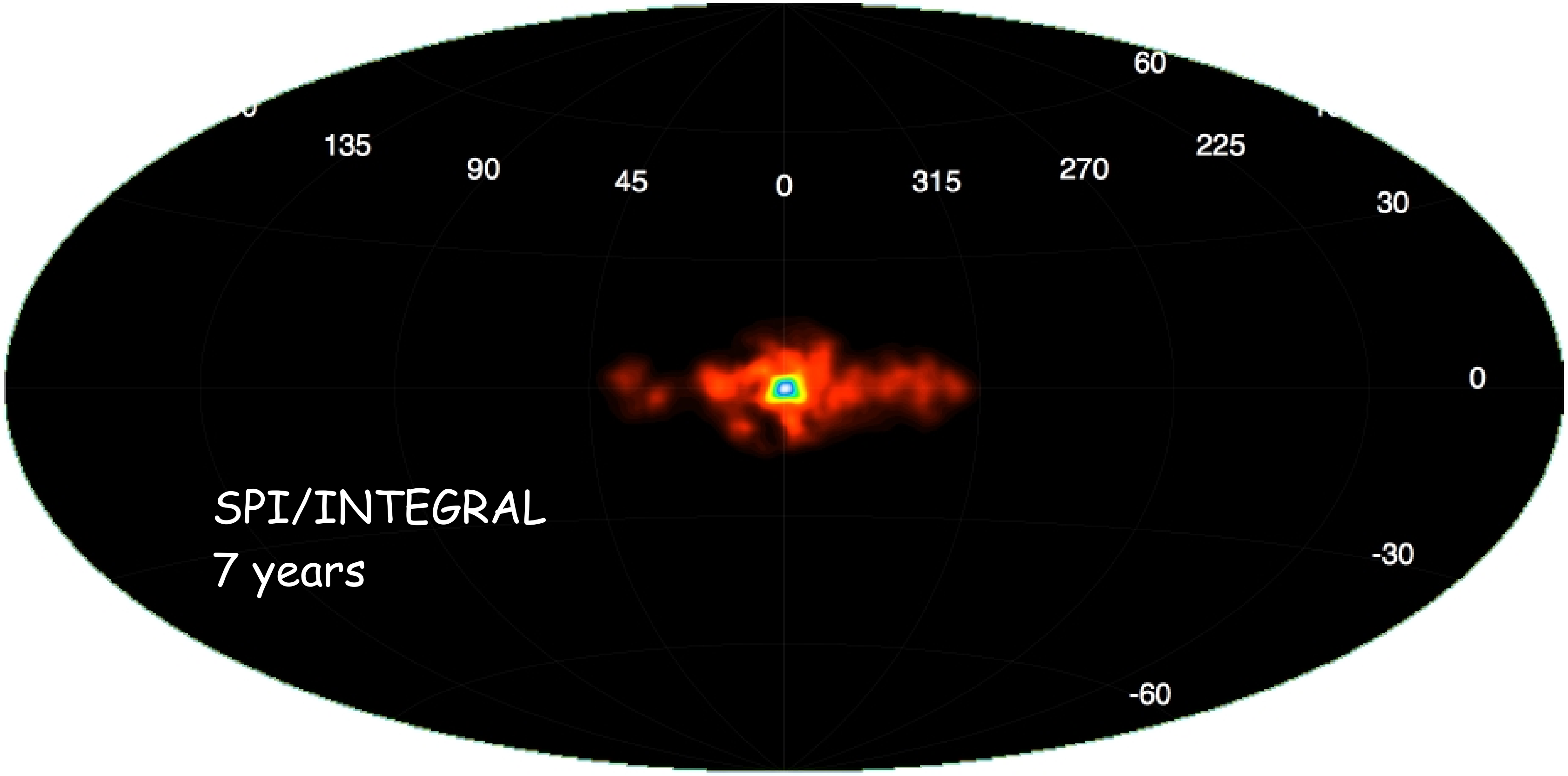
Can positrons from Sgr A* produce the 511 keV emission in the galactic bulge ?



P. Jean, N. Guessoum & K. Ferrière

- Analysis of the spatial distribution

- Uncertainties in the morphology

  2 bulges (~3° & ~10° FWHM) & thick disk

  or extended halo & thin disk

- Annihilation rates :

  (1 - 3) × 10^{43} s^{-1} in the bulge

  ~ 2 × 10^{42} s^{-1} in the inner bulge (~3°)

  ~ 8 × 10^{42} s^{-1} in the outer bulge (~10°)

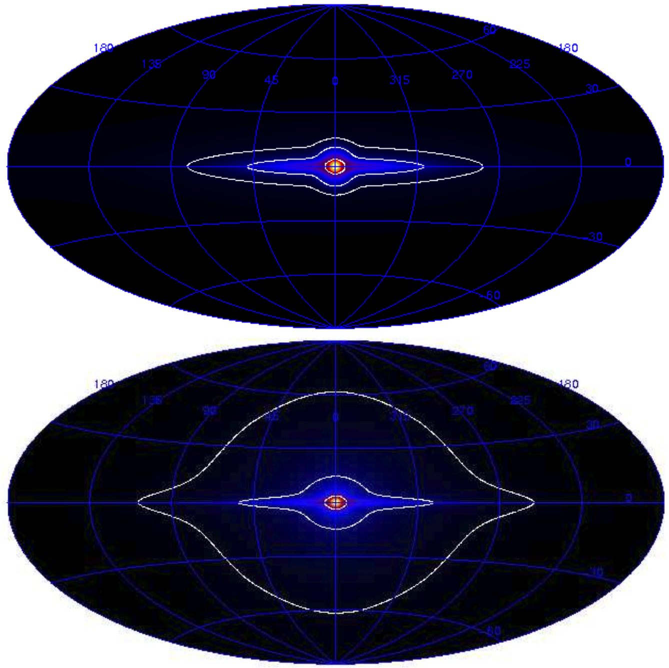
- No point sources detected at the Sgr A* position

  Upper limit for a point source at the GC :

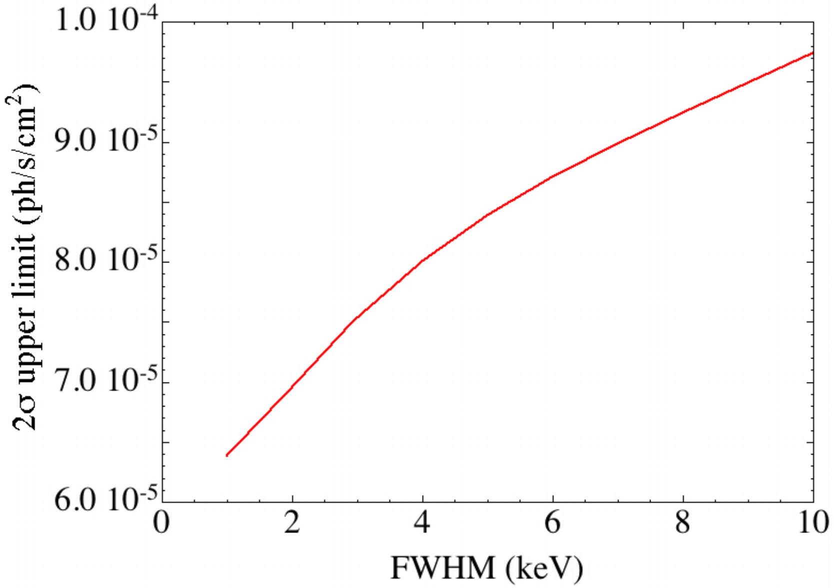
  < 1.6 x 10^{-4} ph/s/cm^2 with ISGRI (Cesare et al.)

  < ~0.7-1 x 10^{-4} ph/s/cm^2 with SPI

  < ~ 10^{42} s^{-1}



Weidenspointner et al. (2008)



• Sgr A* as the source of bulge e^+ ?

Supermassive black hole ($M \sim 2\text{-}4 \times 10^6\ M_\odot$)

- Cheng et al. (2006 & 2007)

Disruption of stars in the vicinity of the supermassive black hole every $10^{4\text{-}5}$ yrs.

pp collisions produced π^+ that decay in e^+

- Totani (2006)

Steady state production of e^+ in the accretion disk (RIAF). Accretion interrupted by the expansion of the Sgr A East SNR 300 yr ago.

However, these authors :

- underestimated the amount of gas enclosing Sgr A* (10 pc radius)
- assumed particular/simplistic positron propagation

• Sgr A* as the source of bulge e^+ ?

Goal of our study:

- Determine the fate of positrons produced by Sgr A* taking into account:

  - a physical propagation model (Jean et al. 2009)

  - a realistic description of the gas in the inner 10 pc radius

- Method:

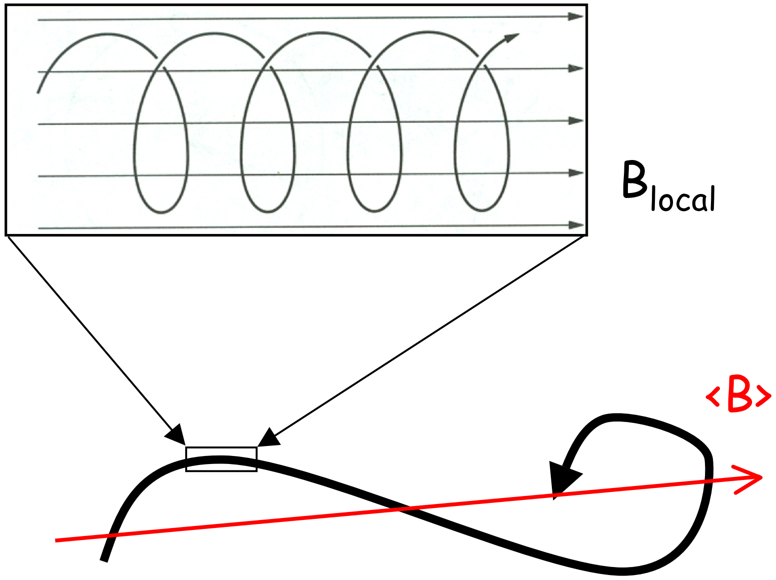
  - calculate probabilities that positrons annihilate or escape the Sgr A* region as a function of their initial kinetic energy with Monte Carlo simulations

  - estimate the rate & spectrum of positrons escaping the 10 pc radius by convolving the probabilities with spectro-temporal distribution of source models

- Transport of positrons

Positrons do not scatter magnetohydrodynamic waves when their Larmor radius is lower than the scalelength of turbulences in the interstellar medium ($r_L \ll \lambda$).

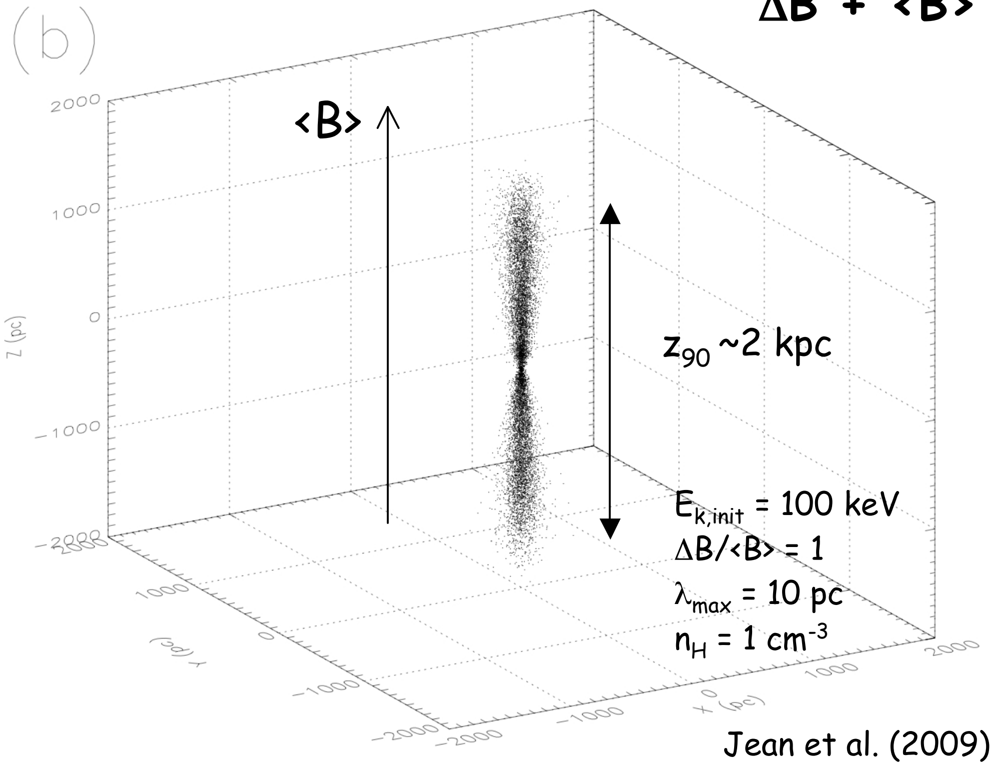
⇒ « collisionnal » transport (Jean et al. 2009)



→ ballistic trajectory along the magnetic field

→ pitch angle variations due to collisions

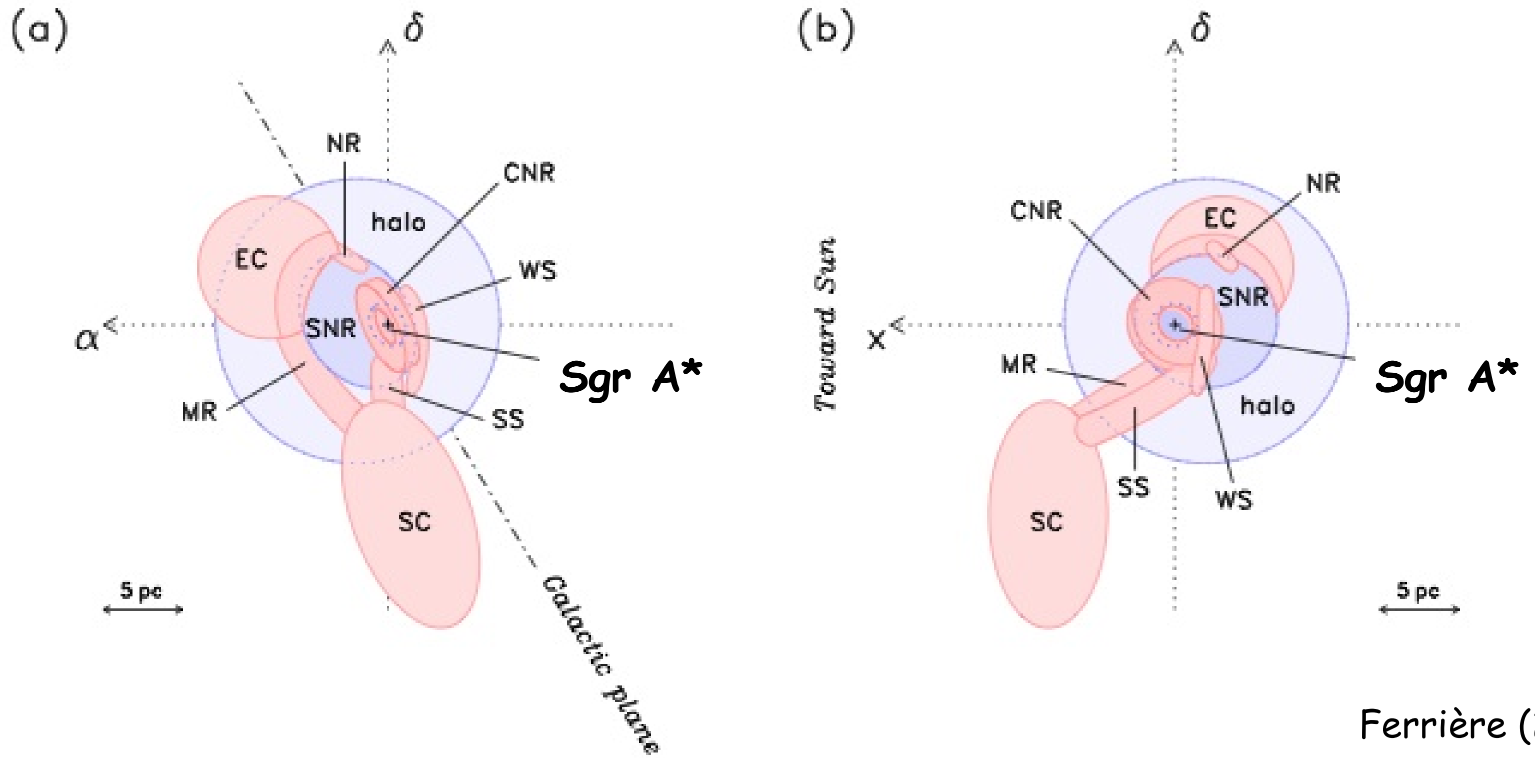
See Alexis et al. poster (e^+ in the Galactic disk)



Jean et al. (2009)

• Physical description of the interstellar medium around Sgr A*

- *Gas distribution*



Ferrière (2011)

- Magnetic field : $\mathbf{B}_T = \mathbf{B}_{reg} + \mathbf{B}_{turb}$

Regular: perpendicular to the Galactic plane everywhere except in molecular clouds

Turbulent: Kolmogorov spectrum with $B_{turb}/B_{regular} = 1$ (Giacalone & Jokipii 1994)

- Simulation method

For a given initial energy E_i at $t = 0$:

Monte Carlo

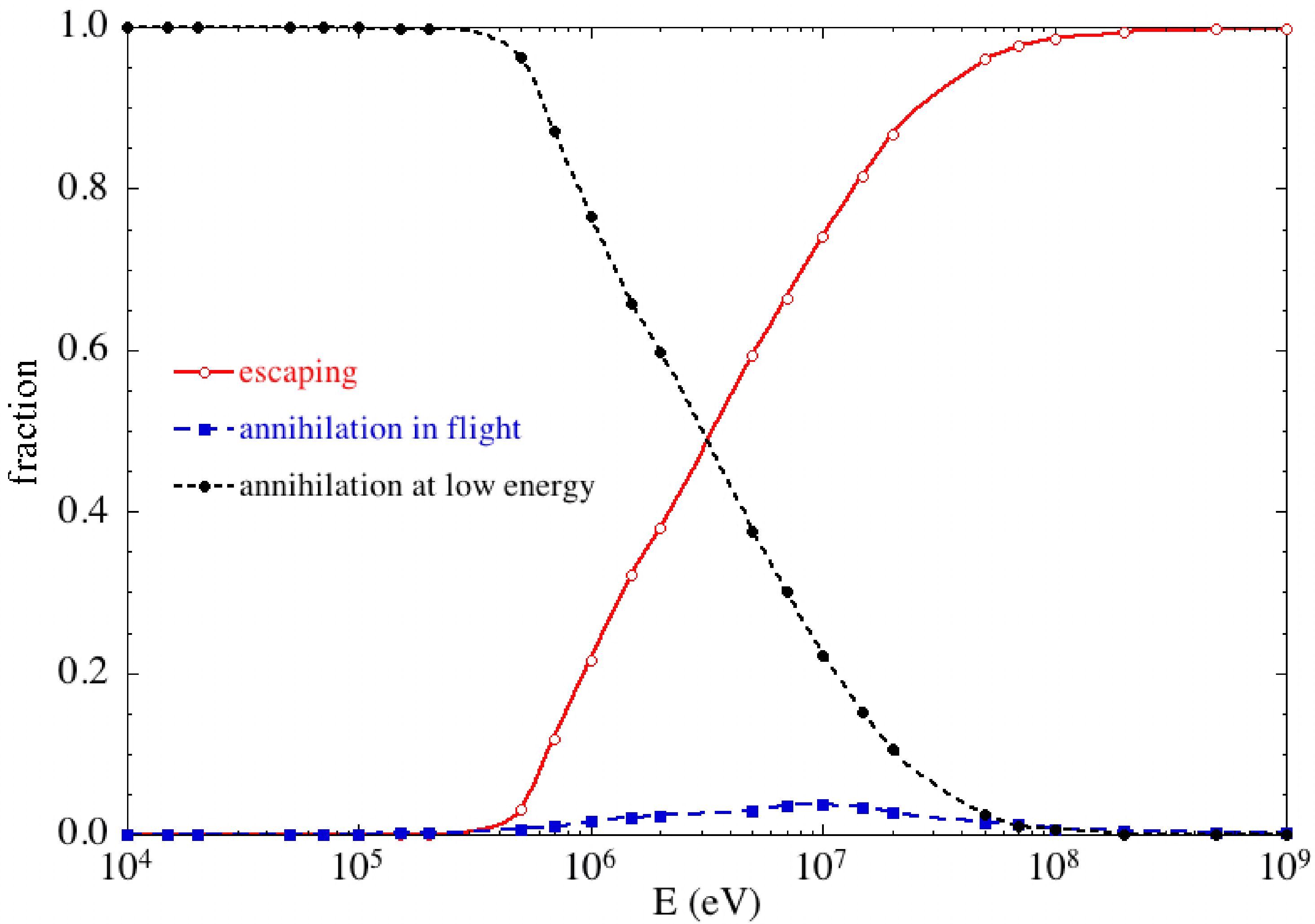
- Initial momentum direction chosen randomly
- Track the positron taking into account
    - energy losses
    - interactions
    - transport
- Stop tracking and store (E, x, y, z, t) when :
    - E < 100 eV → Annihilation computed with local medium properties → $p_{511}(t, E_i)$
    - escape the simulated volume → $p_{esc}(t,E_i,E)$
    - annihilation in flight → Annihilation computed with the positron energy → $p_{aif}(t,E_i,\varepsilon_\gamma)$

Analysis

Production of response functions $\mathbf{p_k}(E_i,t)$ based on output of the Monte Carlo simulation with E_i and the physic of annihilation (Ps fraction, annihilation rate as functions of T and abundances).

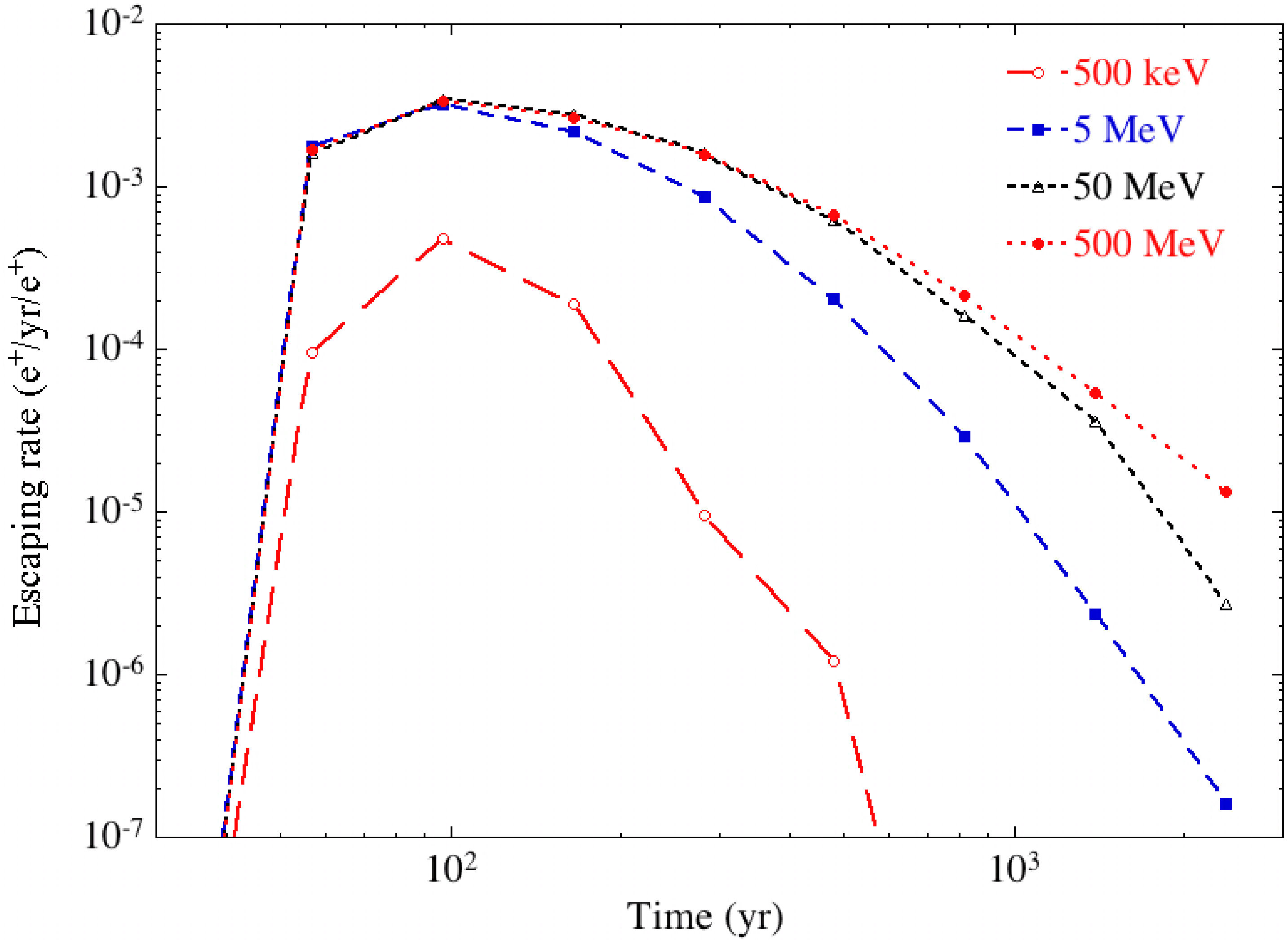
• Response functions

$$\text{fraction}(E_i) = \int p_k(t, E_i)\, dt$$



• Response functions

$$R_{esc}(t, E_i) = \int p_{esc}(t, E_i, E)\, dE$$



- Convolution with positron source model

The spectro-temporal distribution of source positrons is convolved with the « escaping » response function to obtain the spectrum of positron that escape the Sgr A* region (10 pc radius).

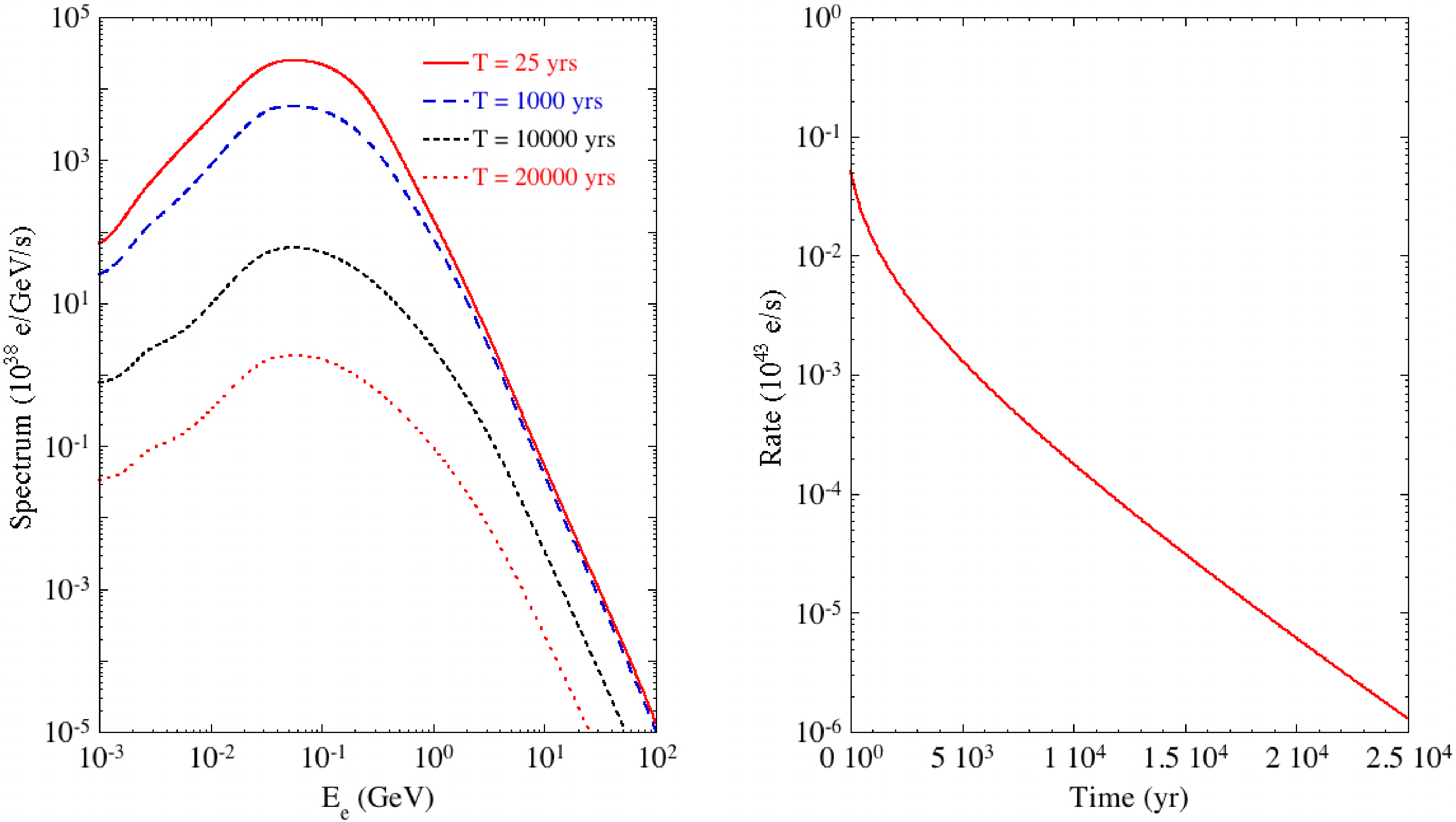
$$\frac{d\dot{N}_{esc}}{dE_{esc}}(t, E_{esc}) = \int_E \int_t \frac{d\dot{N}_+}{dE}(t', E)\, \mathrm{p}_{esc}(t - t', E, E_{esc})\, dE\, dt'$$

The escaping rate is:

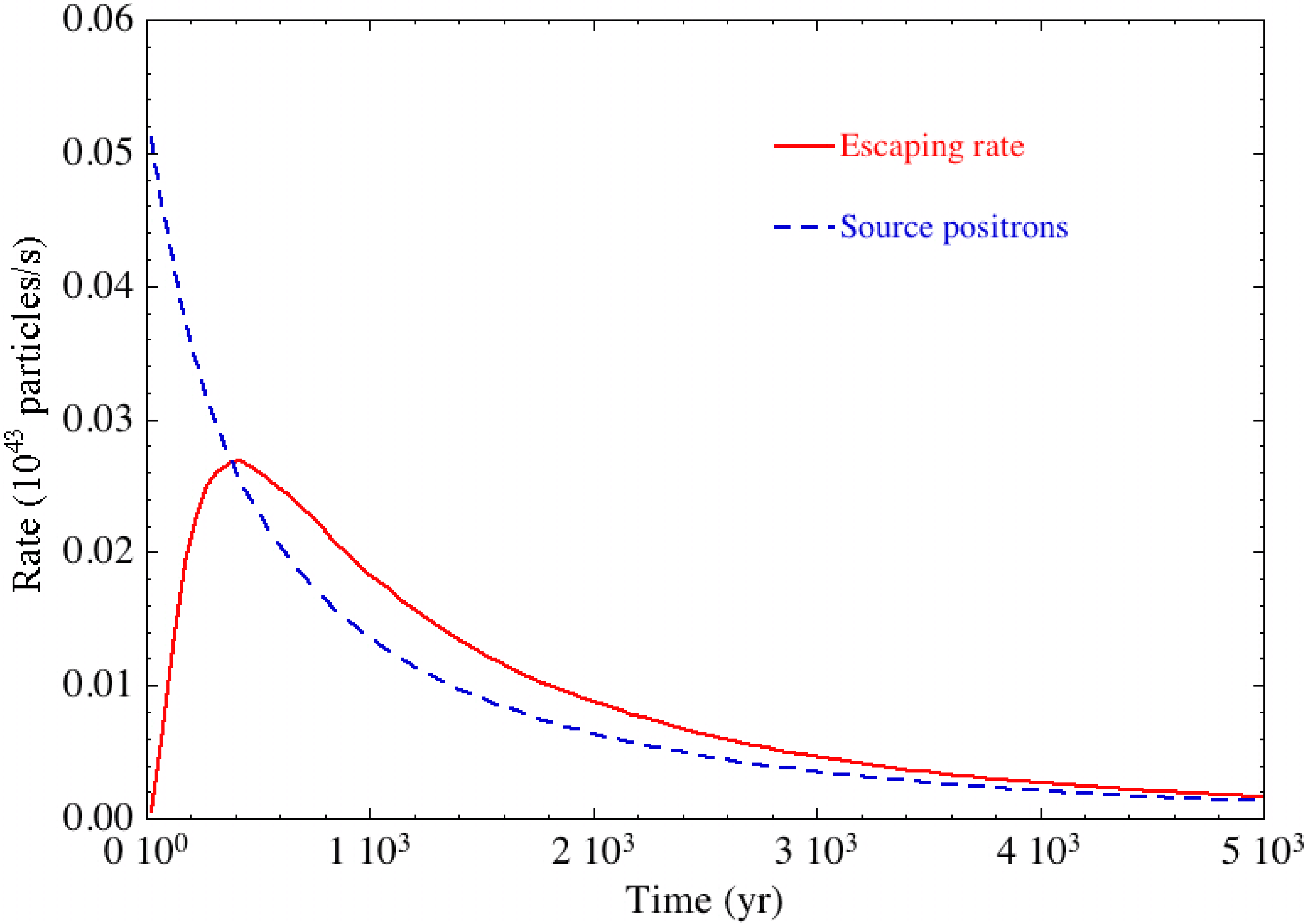
$$\dot{N}_{esc}(t) = \int_{E_{esc}} \frac{d\dot{N}_{esc}}{dE_{esc}}(t, E_{esc})\, dE_{esc}$$

• Model of Cheng et al. (2006) - calculated with new interstellar medium densities

Positrons results from decays of π^+ produced by pp collisions. The amount of accelerated protons is scaled with the γ emission induced by π^0 decays as measured by EGRET. With the new gas model the time scale of π emissions is ~10^3 yr instead of ~10^5 yr and accelerated protons do not escape Sgr A* region.

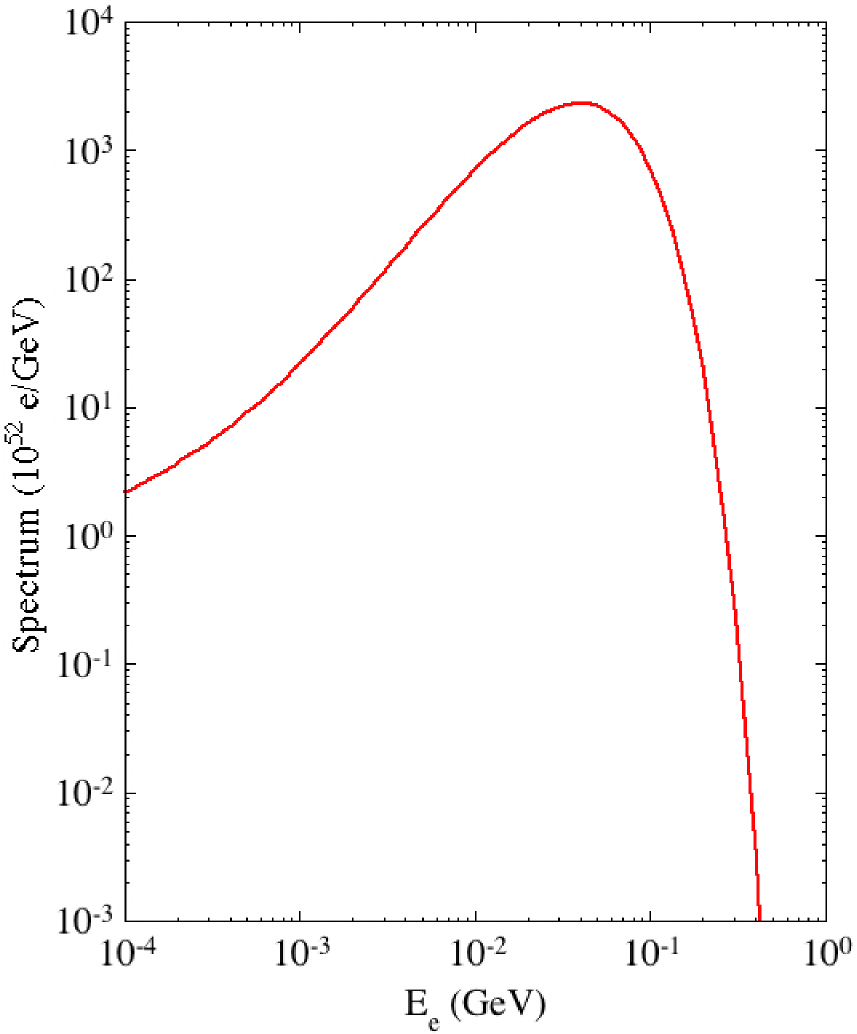


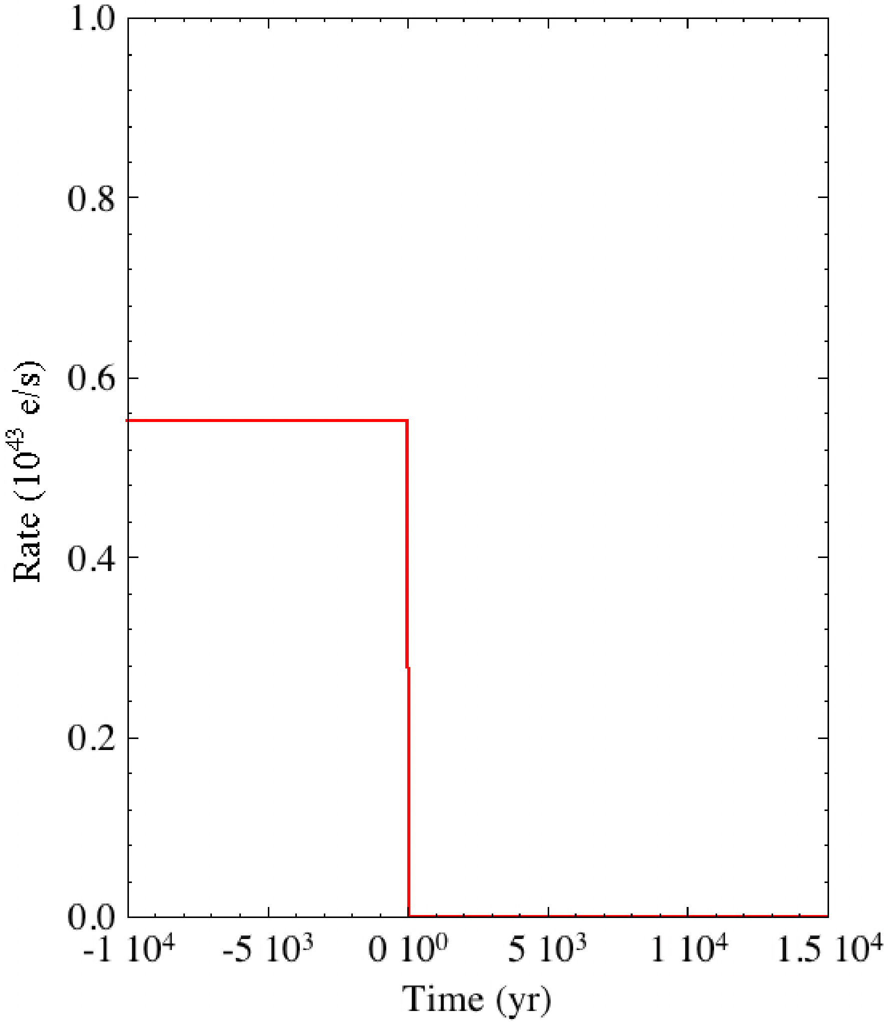
• Model of Cheng et al. (2006) - calculated with new interstellar medium densities



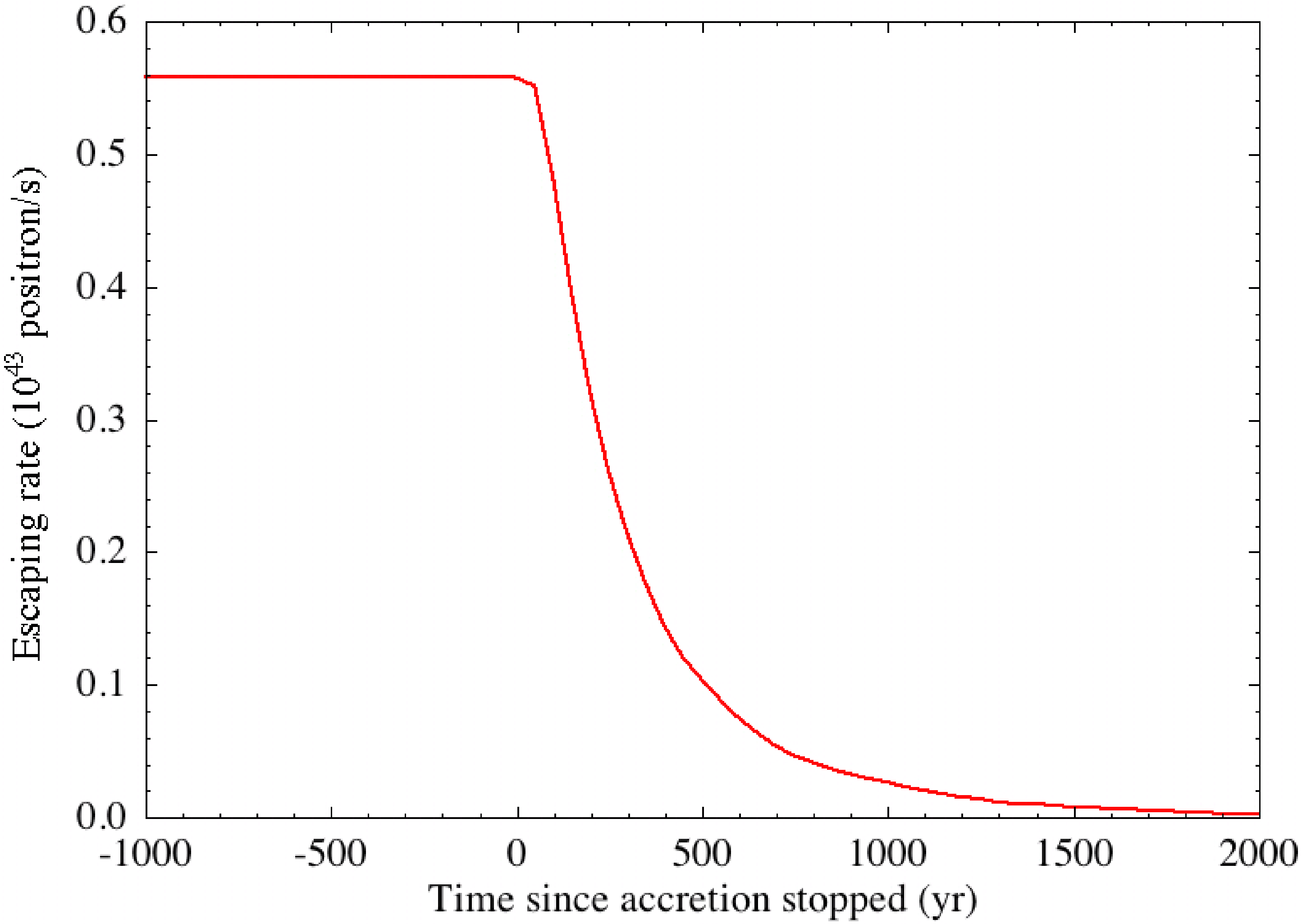
- Model of Totani (2006)

Positrons were produced in the accretion process at thermal energy (kT ~ 20 MeV). They were blowed out by winds. Accretion dropped ~300 years ago because of the shell passage of the supernova remnant Sgr A East.





- Model of Totani (2006)



Conclusions

- The annihilation emission from the bulge cannot be due to e^+ produced by Sgr A* with $E_i < 1$ MeV

- Sgr A* region acts as a filter: the spectro-temporal distribution of positrons from Sgr A* is modified

- Model Cheng et al. (2006): positron rate too low to explain the observed flux in the bulge.

- Model Totani (2006):
  - positron rate is close but too low to explain the total annihilation rate observed in the bulge
  - may explain the flux in the inner part of the bulge (~2×10^{42} s^{-1}).

- Next steps
  - add transport & annihilation of e^+ in the bulge $\Rightarrow$ need model of gas and magnetic fields
  - investigation of other models for Sgr A* or candidate sources

  e.g. Cheng et al. (2007), Fatuzzo et al. (2001), AGN like jets, diffuse sources …

  - need for more investigation on the transport of positrons in the ISM & in sources
  - need for a better imaging gamma-ray spectrometer