Motivation

- Some Observational evidence
  - Can explain ESE (extreme scattering events) in the radio observation
- Dense gas irradiated by high-energy cosmic rays produce gamma-rays—could be a part of galactic diffuse gamma-ray emission
- Lack of detailed calculation of gamma-ray production from interaction in dense gas

Monte-Carlo calculation of interaction process using modern high-energy simulator—GEANT4 (Ver. 4.5.1)

Gamma-ray production in dense matter

Examples of 10 GeV proton injection

- In addition to $\pi^0$ decay, Bremsstrahlung by secondary electrons becomes major component, especially in the lower energy range.
- Generated gamma-rays also suffer from secondary interaction (and absorption) with matter.

Emissivity versus column density

Proton injection

Electron injection

Calculation of diffuse gamma-rays

Flux of diffuse gamma-rays from gas clouds

$$I_0 = \frac{1}{\pi} \int d\Omega \rho(s)J_{\gamma}(s) \frac{dN_\gamma}{dE} \frac{dE}{dE}$$


$$\rho(R,z) = \frac{\sigma^2}{2 \pi \rho R^2 (z^2 + r_z^2)}$$


$$J_{\gamma}(R,z) = \left( \frac{R}{R_0} \right)^2 \exp \left[ \frac{R_0 - R}{L} \right]$$

Discussion

Comparison with EGRET data

- High Galactic latitudes (Kniffen et al. 1996, A&AS 120, 615)
  - Observed $I > 1.5 \times 10^{-5}$ ph/(cm$^2$ sr)
  - Unmodeled emission $< 10^{-5}$ ph/(cm$^2$ sr)
  - Low $\Sigma$ gas: $\leq 20\%$ of the total Galactic dark halo
  - Observed $I > 3 \times 10^{-8}$ ph/(cm$^2$ s MeV) at 1 GeV ($|l| < 60^\circ$, $|b| < 10^\circ$)
  - Galactic dark halo must be $\leq 4.6 \times 10^5$ ph/(s g MeV)
  - Low $\Sigma$ gas: $\leq 30\%$ of the total Galactic dark halo
  - Galactic dark halo to be made of dense gas, $\Sigma \geq 100$ g/cm$^2$

Summary

- Gamma-ray emissivity of dense gas declines substantially for $E > 100$ MeV photons for $\Sigma > 200$ g/cm$^2$.
- EGRET data do not exclude purely baryonic models for the Galactic dark halo for $\Sigma > 200$ g/cm$^2$.