

Galactic diffuse gamma-ray spectrum from cosmic-ray proton interactions with gas clouds

Michiko Ohishi, Masaki Mori
Institute for Cosmic Ray Research, University of Tokyo

Mark Walker
School of Physics, University of Sydney

1

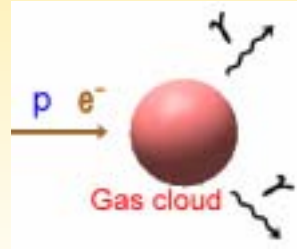
Introduction: gas clouds

- Baryonic dark matter candidate:
a population of self-gravitating clouds of mainly molecular hydrogen [e.g. Pfenninger et al. 1994]
- Typical parameters:
M $\sim 10^{-4}M_{\odot}$, R $\sim 10^{13}$ cm, T ~ 10 K,
Covering fraction $\sim 5 \times 10^{-4}$ [Draine 1998]
- Can survive for billions of years [Walker and Wardle 1999]
- Produce diffuse gamma-ray bombarded by cosmic-rays! [Sciama 2000] *But gamma-ray production in dense matter has not been studied...*

2

Calculation

- Monte Carlo simulation by **Geant4** (detector simulator used in high-energy physics) with “repaired Gheisha”*
 \Rightarrow multiple interaction included
- Cloud radius = 1AU
- Various density
 $5 \times 10^{-16} - 5 \times 10^{-9} \text{ g/cm}^3$
- Cosmic ray proton / electron injection



* improved energy conservation at low energies

3

Cosmic ray flux

- Proton: Mori (median, '97 ApJ)
- Electron: Skibo & Ramaty ('93 A&AS)

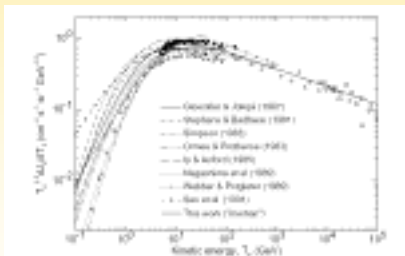


FIG. 5.—Compilation of the demodulated cosmic-ray proton spectra calculated by different authors and the data on the cosmic-ray proton flux at high energies. Lines are the demodulated spectra (Hionkier & Jokipii 1967, Sopher & Badhwar 1981, Simpson 1983, Ormes & Protheroe 1983, Iy & Asford 1985, Nagashima et al. 1989, Webber & Potgieter 1993, See et al. 1991), and symbols are the data at high energies (pluses, open circles, closed circles, squares, crosses, inverted triangles, and triangles are from Buss et al. 1972, Smith et al. 1973, Winkler et al. 1983, Kamataira et al. 1989, See et al. 1990, Anakkinnai et al. 1990, and Sakamoto et al. 1990, respectively.) Also shown by thick solid line is the “median” flux used in this work. See also Fig. 7. Upper and lower dashed lines correspond to the curves BS and Ma of Sopher & Badhwar (1981).

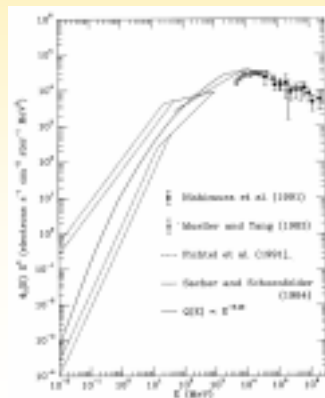
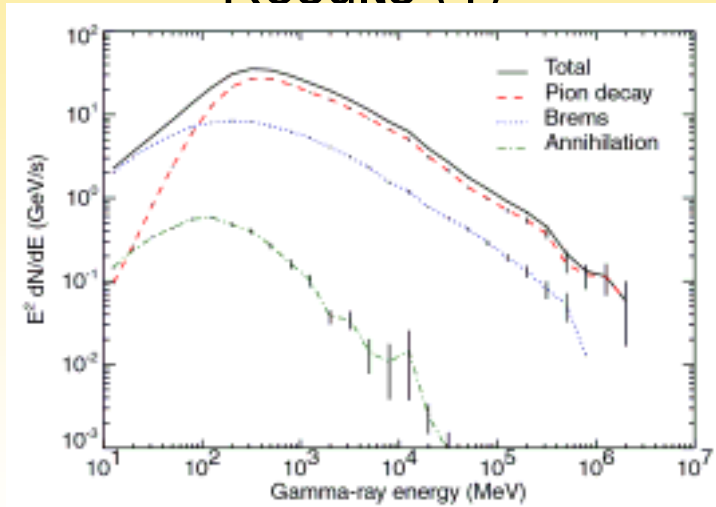


FIGURE 1. The local Galactic equilibrium electron spectrum.

4

Results (1)

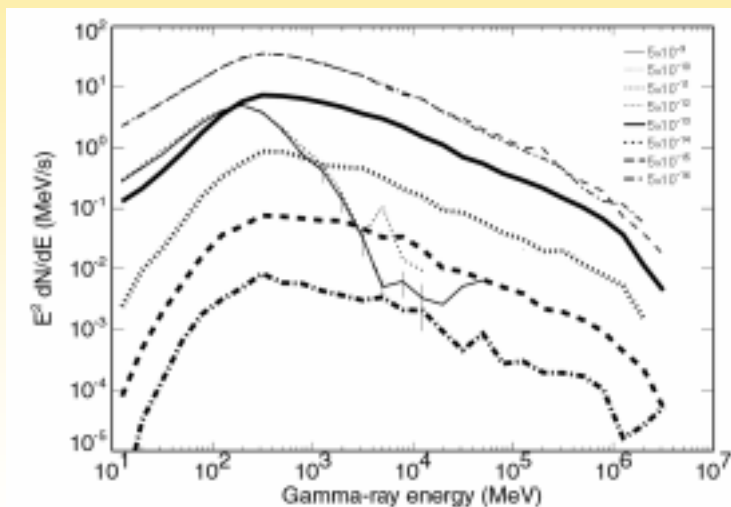


Gamma-ray yield from a cloud irradiated by cosmic-ray protons, assuming the cloud density of $5 \times 10^{-12} \text{ g/cm}^3$.

Note the Brems component!

5

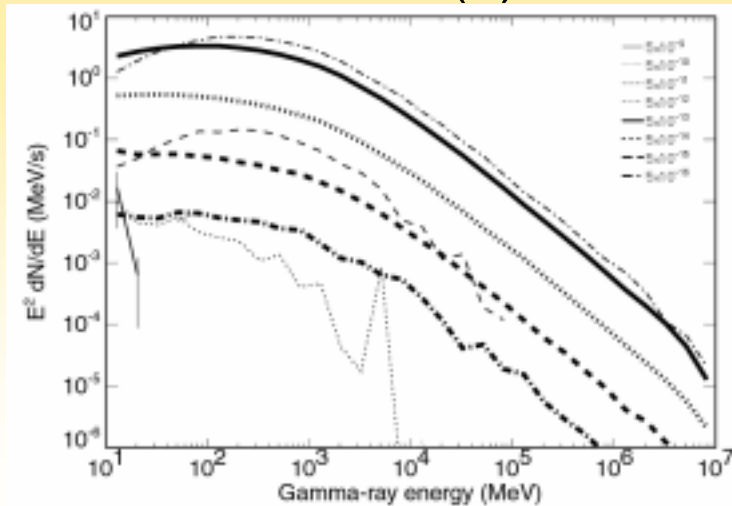
Results (2)



Gamma-ray yield from a cloud irradiated by cosmic-ray protons, for various cloud densities (unit: g/cm^3)

6

Results (3)



Gamma-ray yield from a cloud irradiated by cosmic-ray electrons, for various cloud densities (unit: g/cm^3)

7

Gamma-ray flux from cloud halo

- $F_{\text{cloud}}(E)dE = dN(E)/dE F_{\text{CR}}(E) \langle Q(\sigma) \rangle$

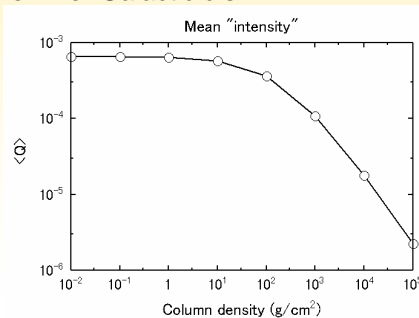
dN/dE : gamma-ray flux from a single cloud

$F_{\text{CR}}(E)$: cosmic-ray proton/electron flux

$\langle Q(\sigma) \rangle$: mean "intensity" over the inner Galactic disk

σ : column density of cloud

$\langle Q \rangle$ based on collisional dark halo model (Walker 1999 MNRAS 308, 551)



8

Diffuse flux prediction

- Diffuse gamma-ray flux calculation (Hunter et al. 1997) :

$$F = (q_{pp \rightarrow \pi^0} + q_{\text{brems}})(N_{\text{HI}} + N_{\text{HII}} + N_{\text{H}_2}) + F_{\text{IC}} + F_{\text{EG}}$$

where q is the gamma-ray source function.

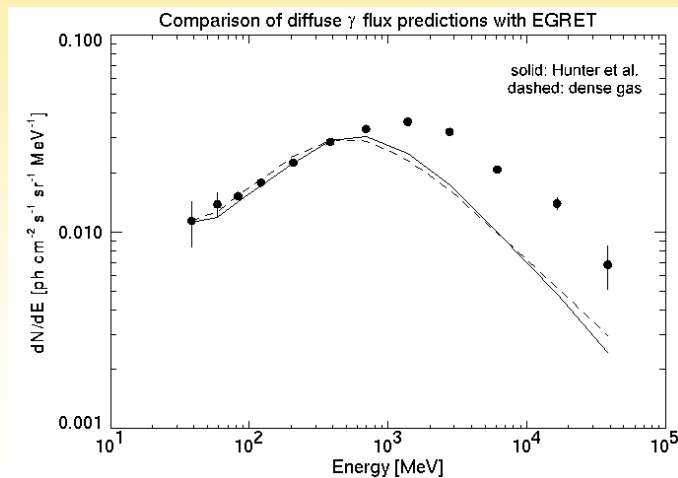
- Assuming all H_2 are in the form of clouds,

$$F = F_{\text{p/e+cloud}} + (q_{pp \rightarrow \pi^0} + q_{\text{brems}})(N_{\text{HI}} + N_{\text{HII}}) + F_{\text{IC}} + F_{\text{EG}}$$

$F_{\text{p/e+cloud}}$ for $\rho \sim 8 \times 10^{-12} \text{g/cm}^3$ gives the best fit (see next figure).

9

Comparison with EGRET data



10

Conclusion

- Gamma-ray spectrum from cosmic-ray interactions with dense gas has been calculated using a Monte Carlo simulator, Geant4.
- Within reasonable range of parameters of gas cloud as a dark matter candidate, galactic diffuse gamma-ray spectrum can be reproduced, except the “GeV excess” reported by EGRET.

11

References

- D. Pfenniger et al. 1994, A&A, 285, 79
- B.T. Draine, 1998, ApJ 509, L41
- M. Wardle and M. Walker, 1999, ApJ 527, L109
- D.W. Sciama 2000, MNRAS 312, 33; *ibid.* 319, 1001
- Geant4: <http://wwwinfo.cern.ch/asd/geant4/geant4.html>
- M. Mori, 1997, ApJ, 478, 225
- J.G. Skibo and R. Ramaty, 1993, A&Ap Suppl. 97, 145
- S.D. Hunter et al., 1997, ApJ 481, 205
- M. Walker, 1999, MNRAS 308, 551

12