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

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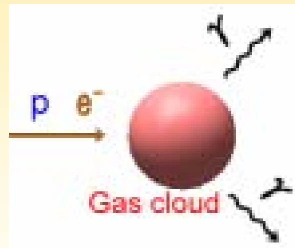
Introduction: gas clouds

- 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, $T \sim 10$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…*

Calculation

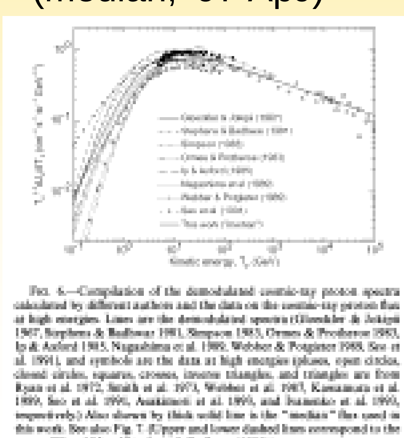
- Monte Carlo simulation by
  Geant4
  (detector simulator used in high-energy physics) with "repaired Gheisha"*
  ⇒ *multiple interaction included*
- Cloud radius = 1AU
- Various density
  $5\times10^{-16} – 5\times10^{-9}$ g/cm^3
- Cosmic ray proton / electron injection

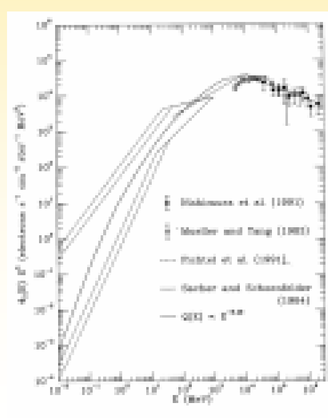


* improved energy conservation at low energies

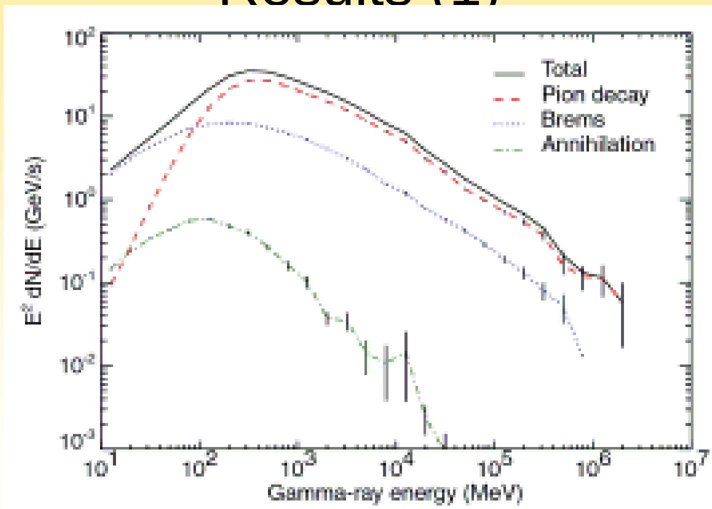
Cosmic ray flux

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



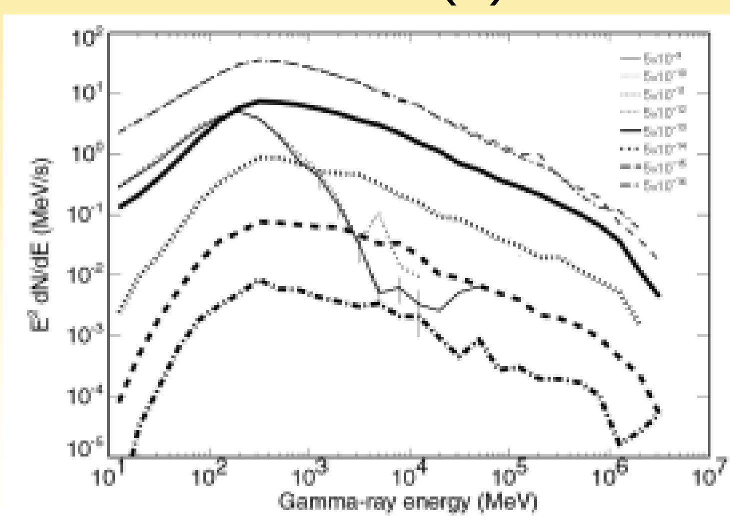


Results (1)



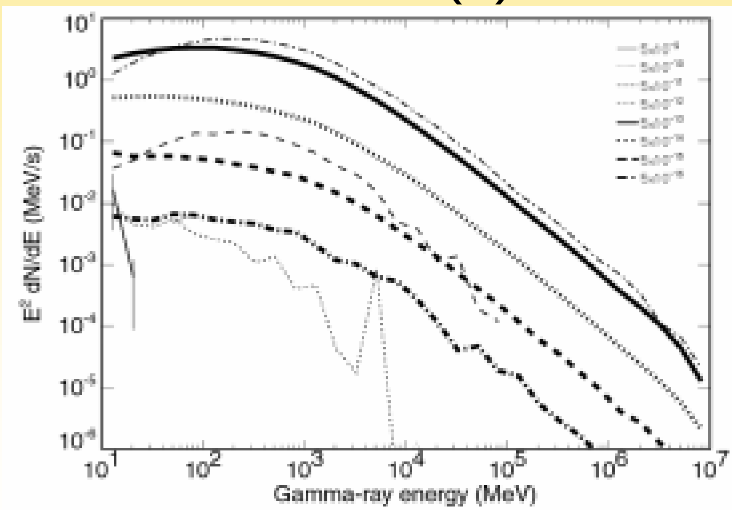
Gamma-ray yield from a cloud irradiated by cosmic-ray protons, assuming the cloud density of 5×10^{-12} g/cm^3.
Note the Brems component!

Results (2)



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

Results (3)



Gamma-ray yield from a cloud irradiated by cosmic-ray electrons, for various cloud densities (unit: g/cm³)

Gamma-ray flux from cloud halo

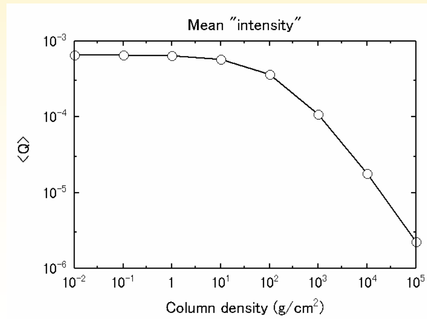
- $F_{\mathrm{cloud}}(E)\mathrm{d}E = \mathrm{d}N(E)/\mathrm{d}E\ F_{\mathrm{CR}}(E)\ \langle Q(\sigma)\rangle$

d*N*/d*E*: gamma-ray flux from a single cloud

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

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

σ: column density of cloud



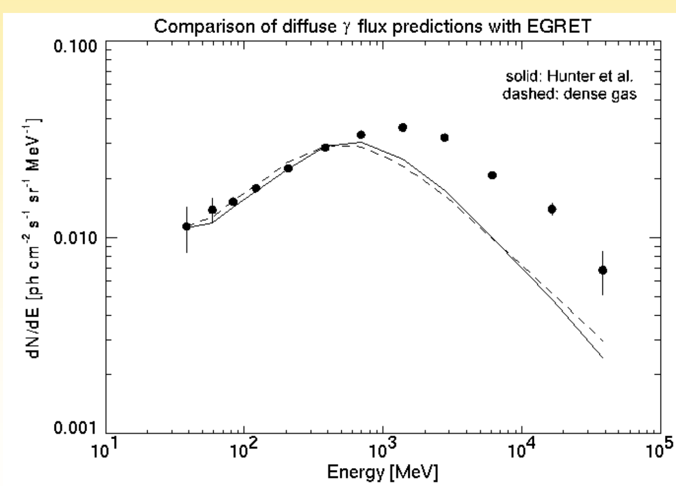
<Q> based on collisional dark halo model (Walker 1999 MNRAS 308, 551)

Diffuse flux prediction

- Diffuse gamma-ray flux calculation (Hunter et al. 1997) :
  $F = (q_{pp\Rightarrow\pi^0}+q_{brems})(N_{HI}+N_{HII}+N_{H_2})+F_{IC}+F_{EG}$
  where q is the gamma-ray source function.
- Assuming all H_2 are in the form of clouds,
  $F = F_{p/e+cloud} +$
  $(q_{pp\Rightarrow\pi^0}+q_{brems})(N_{HI}+N_{HII})+F_{IC}+F_{EG}$

  $F_{p/e+cloud}$ for $\rho\sim 8\times10^{-12}$ g/cm^3 gives the best fit (see next figure).

Comparison with EGRET data



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.

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