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:
  \[ M \sim 10^{-4} M_{\odot}, \quad R \sim 10^{13} \text{cm}, \quad T \sim 10^K, \]
  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 $5 \times 10^{-16} - 5 \times 10^{-9}$ 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 $5 \times 10^{-12}$ 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

• \( F_{\text{cloud}}(E) dE = \frac{dN(E)}{dE} F_{\text{CR}}(E) <Q(\sigma)> \)

\( dN/dE \): gamma-ray flux from a single cloud
\( F_{\text{CR}}(E) \): cosmic-ray proton/electron flux
\( <Q(\sigma)> \): mean “intensity” over the inner Galactic disk
\( \sigma \): 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):
  \[ F = (q_{pp\to\pi^0} + q_{\text{brems}})(N_{\text{HI}} + N_{\text{HII}} + N_{\text{H}_2}) + F_{\text{IC}} + F_{\text{EG}} \]
  where \( q \) is the gamma-ray source function.

- Assuming all \( \text{H}_2 \) are in the form of clouds,
  \[ F = F_{p/e+\text{cloud}} + (q_{pp\to\pi^0} + q_{\text{brems}})(N_{\text{HI}} + N_{\text{HII}}) + F_{\text{IC}} + F_{\text{EG}} \]
  \( F_{p/e+\text{cloud}} \) for \( \rho \sim 8 \times 10^{-12} \text{g/cm}^3 \) 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