Diffuse Gamma-Ray Observations of the Orion Molecular Clouds

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Abstract

We report on the analysis of the Orion A & B molecular clouds using the first 12 months data obtained by the Large Area Telescope (LAT) onboard the *Fermi Gamma-ray Space Telescope*. Their gamma-ray emission in the energy range of 200 MeV - 20 GeV is well explained by the hadronic and electromagnetic interactions between the Galactic cosmic rays and the interstellar medium. Therefore the emission is thought to be proportional to the gas column density $N(H_2)$ which has long been estimated using radio emission from CO molecules and an empirical conversion factor $X_{CO} \equiv N(H_2)/W_{CO}$ [1][2]. On a ~50 pc scale of the Orion region, however, we found that the gamma-ray intensity is not proportional to the CO line intensity (W_{CO}).

Motivations

- The LAT observations are able to study ≲1° scale structure of molecular clouds without being affected by the condition of the gas (CO excitation, temperature and star light).
- What is the mechanism of the diffuse gamma-ray emission above 1 GeV?
- What is the total mass of the Orion A and B?
- Is the conversion factor X_{CO} constant on a ~50 pc scale?

Results

- The Orion A and B clouds are clearly seen in the GeV range (Fig. 1). It is possible to analyze three separated regions which could not be fully resolved by EGRET [3][4].
- The energy spectra are explained by a combination of hadronic (π^0 gamma rays) and electromagnetic (electron bremsstrahlung) components (Fig. 2).
- We obtained their mass assuming the GALPROP-predicted cosmic-ray intensity and 400 pc distance to the clouds.

$$M_A = (80.6 \pm 7.5_{stat} \pm 4.8_{HI}) \times 10^3 M_\odot$$
$$M_B = (39.5 \pm 5.2_{stat} \pm 2.6_{HI}) \times 10^3 M_\odot$$

- We obtained different correlation slopes in the two clouds. Corresponding conversion factors are:

$$X_{CO} = 1.76 \pm 0.04_{stat} \pm 0.02_{HI} \quad \text{(Orion A)}$$
$$X_{CO} = 1.27 \pm 0.06_{stat} \pm 0.01_{HI} \quad \text{(Orion B)}$$

We need to rethink the simple assumption of a constant X_{CO} on ~50 pc scales.

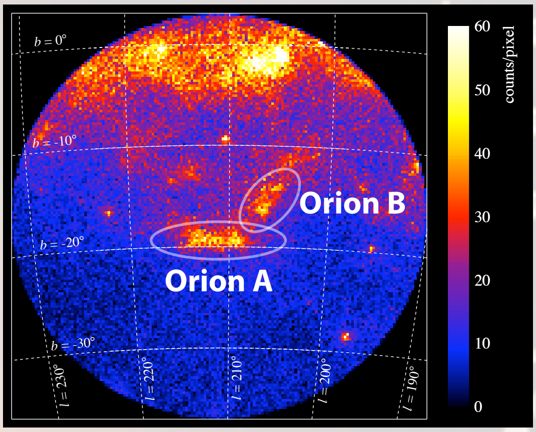

Fig. 1 *Fermi*/LAT Count Map (200 MeV ~ 20 GeV)

The *Fermi*/LAT Gamma-ray count map in a 20° radius region centered at (l=211°, b=-17°). The Orion A and B clouds are marked with white ellipses.

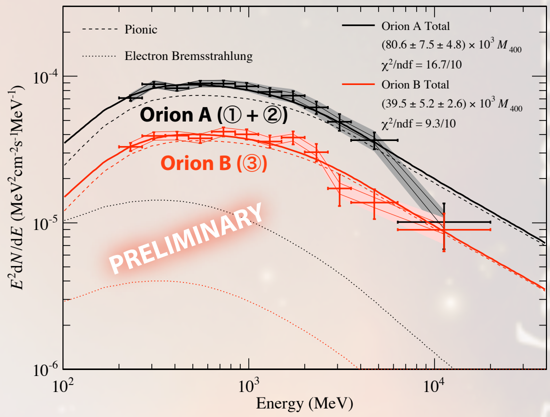

Fig. 2 Energy spectra of the Orion A and B

The energy spectra of the gamma-ray emission associated with the Orion A (region ① + ② in Fig. 3) and B (③). The Dashed and dotted lines are pionic (hadronic) and electron-bremsstrahlung (electromagnetic) components, respectively. Error bars show statistical errors. Shaded ribbons and polygons show the systematic errors of the LAT and our HI subtraction process, respectively.

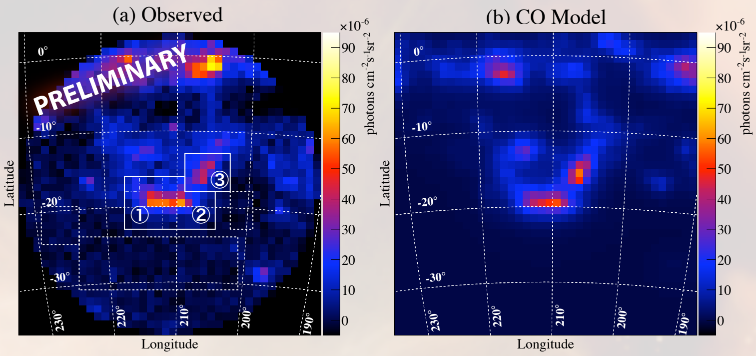

Fig. 3 (a) Observed gamma-ray intensity (b) CO based model

(a) Observed gamma-ray intensity map rebinned into 1° × 1° pixels. Contributions from HI gas, IC emission and residual background are already subtracted. (b) A modeled gamma-ray intensity map based on 115 GHz radio emission from CO molecules [1]. We assumed a constant X_{CO} of 1.5×10^{20} cm^{-1} (K km s^{-1})$^{-1}$, the LAT response function, and the CR distribution predicted by GALPROP.

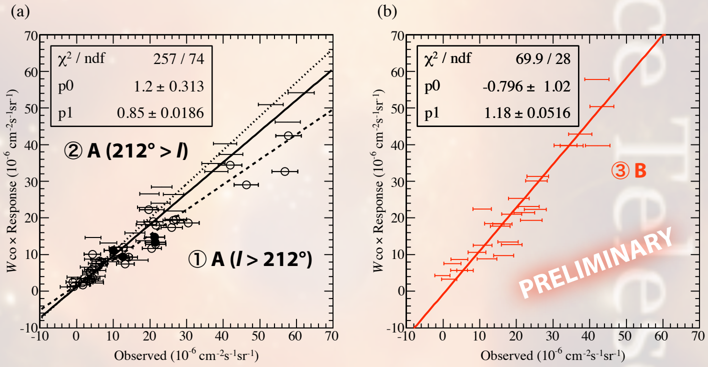

Fig. 4 Pixel-by-pixel (1°×1°) correlation between the observed gamma-ray intensity and a CO based intensity model

(a) Correlation in the region ① and ② (see Fig. 3). Solid, dashed, and dotted lines are the best-fit line of ①+②, ① and ②, respectively. Pixels of ② are marked with open circles. (b) region ③. Error bars show statistical errors only.

References

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