Dark matter annihilations in the Large Magellanic Cloud*

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I examine the possibility of detecting high energy $\gamma$-rays from non-baryonic dark matter annihilations in the central region of the Large Magellanic Cloud.

1. LMC ROTATION CURVE

The study of the kinematics of globular clusters in the outer regions of the Large Magellanic Cloud by Schommer et al. [1] suggested a flat rotation curve, perhaps out to 15 kpc: the LMC might have a dark matter halo. Here, from a composite $\text{H} \, \text{i}$ and star cluster rotation curve (fig. 1), I want to estimate the parameters of an isothermal halo added to a 'maximum disk.'

Luks and Rohlfs [2], in the analysis of their extended 21-cm line survey of the LMC, showed that the $\text{H} \, \text{i}$ kinematics can be modeled by that of a flat disk in differential rotation. The rotation curve they obtained considering data within a $\pm 5^\circ$ sector of the major axis is shown by crosses in fig. 1. The geometrical and kinematical parameters they assumed for the LMC are as follows: distance 50 kpc; inclination 33$^\circ$; position angle of the major axis 162$^\circ$; $\text{H} \, \text{i}$ kinematic center ($\alpha_0, \delta_0$) = ($5^h12^m48^s$, $-69^\circ03'03''$); heliocentric velocity of the $\text{H} \, \text{i}$ kinematic center 282.4 km/s radially and 483 km/s tangentially towards 87$^\circ$ position angle.

Using for consistency the same geometrical and kinematical parameters as in ref. [2], I have redetermined the star cluster rotation curve in Schommer et al. [1], reading the heliocentric velocities and the positions of the 83 star clusters from their tables 1 and 2. To render the cluster rotation curve symmetric, the radial systemic velocity was adjusted by 6.9 km/s. The points shown as circles in fig. 1 were obtained using the clusters lying within $\pm 30^\circ$ of the major axis and beyond 3 kpc of the center. The velocities have been binned in 1 kpc bins. The error bars represent the standard deviation of the mean of velocities, while circles without error bars are single objects.

The rotation curve cannot be firmly determined from these data points. Nevertheless let us try to compare models with and without a dark matter halo.

The most recent surface photometry of the LMC is provided by the CCD observations of Bothun and Thompson [3] with a camera set up in a parking lot. An exponential disk with central brightness $\mu_0 = 21.17$ mag/arcsec$^2$ and scale length 1.677 (1.46 kpc) fits the surface-brightness profile well in the innermost 3$^\circ$ (2.6 kpc). (Values in parentheses are for the assumed LMC distance of 50 kpc.) I use the parameters of this fit plus a constant mass-to-luminosity ratio to derive the rotation curve due to the exponential disk. Since signs of truncation are present beyond 2.6 kpc, this choice somewhat overestimates the disk contribution in the outer regions. The dashed curve in fig. 1 corresponds to a disk $M/L = 3.3$ in solar units. Higher mass-to-luminosity ratios would give curves overshooting the radio data points.

I now add a halo with canonical density profile $\rho(r) = \rho_0 a^2/(r^2 + a^2)$, where $a$ is the core radius and $\rho_0$ is the central dark matter density. Imposing that the disk+halo rotation curve passes close to the outermost points, the combination $\rho_0 a^2$, which corresponds to the asymptotic rotation velocity, is constrained to be $\approx 5 \times 10^{-24}$ g/cm$^3$·kpc$^2$. Unfortunately, a determination of the two halo parameters separately cannot be achieved with the present data. The core radius is presumably $\ll 10$ kpc and will be kept as a parameter. For sake of illustration, a rotation curve with $a = 1$ kpc and $\rho_0 = 5 \times 10^{-24}$ g/cm$^3$ is plotted as a solid line in fig. 1.

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2. GAMMA-RAYS FROM WIMP ANNIHILATION

In this section, I entertain the possibility that weakly interacting massive particles (WIMPs) constitute an LMC dark matter halo with \( a \ll 10 \) kpc. An indirect signature of their presence would be the \( \gamma \)-ray flux produced after their self-annihilation.

The general expression of the \( \gamma \)-ray brightness from WIMP annihilation in a canonical halo can be found in refs. [4,5]. For a typical annihilation rate \( \sigma v \) of \( 10^{-27} \) cm\(^3\)/s and the above-mentioned LMC halo parameters, the WIMP-generated \( \gamma \)-ray brightness from the LMC center amounts to

\[
I_\gamma = 3.0 \times 10^{-7} N_\gamma(E_\gamma) \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} m_{10}^{-1} a_{\text{kpc}}^{-3},
\]

where \( N_\gamma(E_\gamma) \) is the number of photons of energy \( E_\gamma \) generated per annihilation, \( a_{\text{kpc}} \) is the core radius in kpc, and \( m_{10} \) is the WIMP mass in units of 10 GeV. This brightness is \( \sim 9/a_{\text{kpc}}^3 \) times bigger than the \( \gamma \)-ray flux used by Bengtsson et al. [5] in their discussion of \( \gamma \)-ray signals from annihilation of galactic WIMPs in the direction of the galactic pole. By adopting their Lund Monte Carlo estimates of \( N_\gamma(E_\gamma) \), I can simply rescale their \( \gamma \)-ray spectra up by a factor of \( 9/a_{\text{kpc}}^3 \).

A possible foreground to the LMC WIMP-annihilation signal is the \( \gamma \)-ray flux from annihilation of galactic WIMPs in the direction of the LMC. Using the galactic parameters of ref. [5], the latter is a factor \( 0.043 a_{\text{kpc}}^3 \) lower than the former, and will be neglected in the following.

For interesting WIMP masses, \( 10 - 1000 \) GeV, the background to the annihilation signal is simply not known. At lower energies, \( \gamma \)-ray emission from the LMC has been detected by EGRET aboard the Compton Gamma Ray Observatory [6]. After subtraction of the galactic and extragalactic components from the contour map in ref. [6], the LMC emission in the central region is \( \sim 4 \times 10^{-6} \) cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\) \((E_\gamma > 100 \text{ MeV})\). This is at the level predicted for \( \gamma \)-ray production by collisions of cosmic rays with the interstellar matter in the LMC. Using the expected spectral index to extrapolate to higher energies, this background is a factor of \( \sim 4 \) lower than the background adopted as a comparison in ref. [5]. If non-LMC emission would be included in the background, the last factor would reduce to \( \sim 2 \).

The total gain in signal-to-background ratio with respect to the galactic case examined in ref. [5] is therefore of \( \sim 30/a_{\text{kpc}}^3 \). This allows the signal-to-background ratio to exceed unity in the most favorable cases if \( a \lesssim \) few kpc. Since the background is expected to have spectral index -1.7 above 300 MeV, the signal-to-noise ratio would be almost independent of the WIMP mass if the analysis would be carried out on the \( \gamma \)-ray spectrum itself. Knowledge of the latter is presently prevented by the limited number of photons detected by EGRET.

3. CONCLUSIONS

If the Large Magellanic Cloud has a non-baryonic dark matter halo with core radius \( a \lesssim \) few kpc, it would be more promising to search for \( \gamma \)-rays from dark matter annihilations in the central regions of the LMC than in our galaxy. Detection of such annihilation signals would be indirect evidence for the presence of exotic matter in the LMC. Further observations of the \( \gamma \)-ray emission from the LMC central region could therefore have profound cosmological implications.

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REFERENCES

[1] R A Schommer, E W Olszewski, N B Suntzeff and H C Harris, Astron J 103 (1992) 447.
[2] Th Luks and K Rolffs, Astron Astrophys 263 (1992) 41.
[3] G D Bothun and I B Thompson, Astron J 96 (1988) 877.
[4] J E Gunn et al., Astrophys J 223 (1978) 1015; M Turner, Phys Rev D34 (1986) 1921.
[5] H-U Bengtsson, P Salati and J Silk, Nucl Phys B346 (1990) 129.
[6] P Sreekumar et al., Ap J 400 (1992) L67.
