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COSMIC RAYS FROM REGIONS OF STAR FORMATION
III. The role of T-Tauri stars in the Rho Oph cloud

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1. The Rho Oph cloud as a cosmic-ray source

It has long been expected that gamma-ray astronomy will visualize the mysterious cosmic-ray (CR) sources. Indeed, on the basis of COS-B observations (Wills, 1980), it has been proposed that CR acceleration within the Rho Oph cloud complex (ROCC) is required to account for its gamma-ray luminosity (Cassé and Paul, 1980, herein after CP, Bignami and Morfill, 1980). However, Issa et al. (1980) have suggested that the size of the ROCC has been underestimated by a factor ≈ 2, and that the cloud mass is a factor ≈ 4 higher than given by Myers et al. (1978), making unnecessary CR acceleration and trapping in the cloud interior.

Counter arguments are presented in the following. The radial density distribution from the center of the cloud to a distance $r = 2.1$ pc can be parametrized as $n(r) \sim r^{-\alpha}$ (1) (Myers et al., 1978). Let us define the cloud boundary radius, R, as the radius at which relation (1) ceases to be valid. Assuming perfect spherical symmetry and taking $\alpha = 1$ for simplicity (still compatible with star counts, Myers et al., 1978), the column density depends on the radial distance r through $N_H = 1.7\ 10^{22}\ \mathrm{Ln}\ (R/r + ((R/r)^2 - 1)^{1/2})$ H-atom cm^{-2} (2). The constant corresponds to an integrated mass of 1800 $M_\odot$ within a radius of 2.1 pc (Myers et al., 1978). R can be determined from the column density on the line of sight towards stars observed in the direction of the ROCC. Take, for instance, HD 148605 located at a distance of ≈ 217 pc from the Sun, i.e. ≈ 57 pc behind the ROCC. Its line of sight intercepts the ROCC region at 2.2 pc from the cloud center. The total column density toward this star is estimated to be $9.1\ 10^{20}$ H-atom cm^{-2} (Bohlin et al., 1978). This value is much lower than expected from (2) with $R > 2.1$ pc. Other examples lead to the same conclusion. Consequently, it does not seem that the radius of the dense part of the ROCC has been underestimated, and we confirm the picture depicted by Myers et al. (1978) and hence the necessity of CR acceleration in the cloud.

2. The role of T-Tauri stars

The gamma-ray emission of the ROCC likely results from CR interactions with the cloud material. CR would be accelerated at the boundary between supersonic stellar winds and the circumstellar medium, as suggested by CP. In CP it was proposed that the wind from the B1 III star HD 148165 was the main accelerating agent, but Copernicus measurements (Snow, private communication) tend to show that the mass-loss rate of this star is actually much less than expected on the basis of its spectral type. However, the contribution of T-Tauri stars (TTS) may in fact account for a substantial release of mechanical power. In the survey of Cohen and Kuhi (1979), 13 TTS are apparently associated to the ROCC. For these 13 TTS the visual absorption A_V never exceeds 5 mag (mean value ~ 1.8). Since A_V up to 15 mag are noticed in the densest part of the ROCC, only the brightest and/or less obscured stars are visible (Cohen and Kuhi, 1979). Assuming a cloud of uniform density, ~ 40 TTS would be obscured by the cloud material. This crude estimate is sufficient since the wind parameters from TTS are still debated. Typical values as $\dot{M} = 10^{-7}\ M_\odot\ yr^{-1}$ and wind velocity $\sim 200\ km\ s^{-1}$ have been proposed, leading to a mechanical power injected in the cloud $\sim 10^{33}$ erg. s^{-1}, per TTS. Including hidden TTS, the whole T-association would release $\sim 10^{34}$ erg. s^{-1}, to be compared with the gamma-ray luminosity ($\sim 8\ 10^{32}$ erg. s^{-1}) of the ROCC. This power has to be considered as a lower limit since it is expected that the mass-loss rate is higher for younger TTS, supposed to be in the densest part of the cloud (Cohen and Kuhi, 1979). It is worth noting that most of the mechanical power released by TTS is not used to accelerate CR, but remain available, for instance, to excite the nebula (Schwartz and Dopita, 1980).

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