Nearby T Tauri Stars as Possible Gamma-Ray Sources

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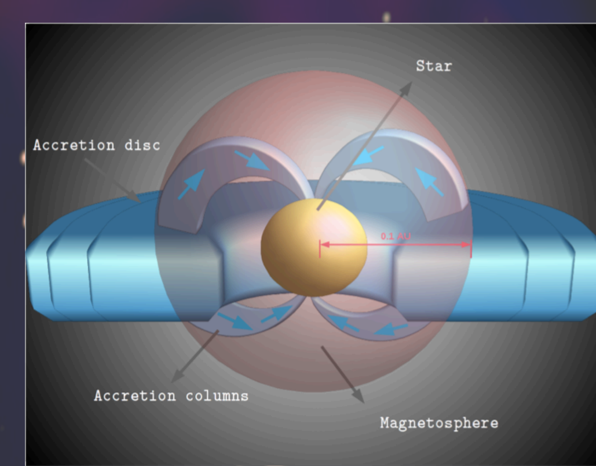
abstract

We consider a possible physical scenario of Fermi mechanism in violent reconnection events taking place in the magnetosphere of T Tauri stars. Such events can accelerate hadrons and leptons up to relativistic energies, which produce non-thermal emission in the surroundings of these low-mass pre-main sequence stars. A simple model is developed to estimate the chances of detection with the current and future gamma-ray telescopes. A comparison of our results with the Fermi source 1FGL J1625.8-2429c is carried out. We tentatively associate it with the collective effect of several T Tauri stars inside its 95% confidence error ellipse. These young objects all belong to the ρ Ophiuchi cloud whose closeness (120 pc) strongly enhances the feasibility of detection through the proposed mechanism.

introduction

The possibility of Young Stellar Objects (YSOs) to play a role in high energy astrophysics has already been considered in previous works. Munar-Adrover, Paredes, & Romero (2011) crossed the Fermi First Year Catalog with databases of known YSOs, in order to identify those protostars that might emit γ-rays. They conclude that 72% of the candidates obtained by spatial correlation should be γ-ray sources with a confidence above 5σ. While massive YSOs have already been claimed to be γ-ray sources (e.g. Araudo et al. 2007, Bosch-Ramon et al 2010, this has not been done yet for low-mass protostars. In this paper we shall argue that these stars, in particular T Tauri stars, can be faint but sometimes detectable γ-ray sources. We will focus our attention on the physical processes that can generate γ-ray emission in T Tauri magnetospheres. Specifically, we shall discuss whether these protostars can be responsible for sources like 1FGL J1625.8–2429c.

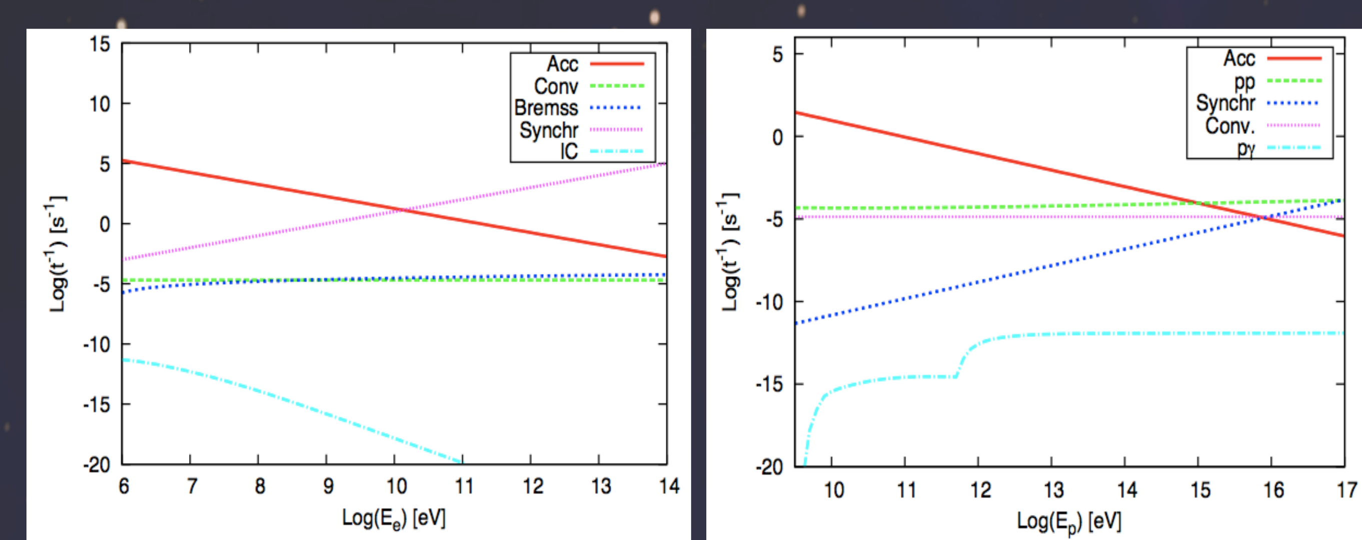


T-Tauri star adapted from Feigelson & Montmerle (1999)

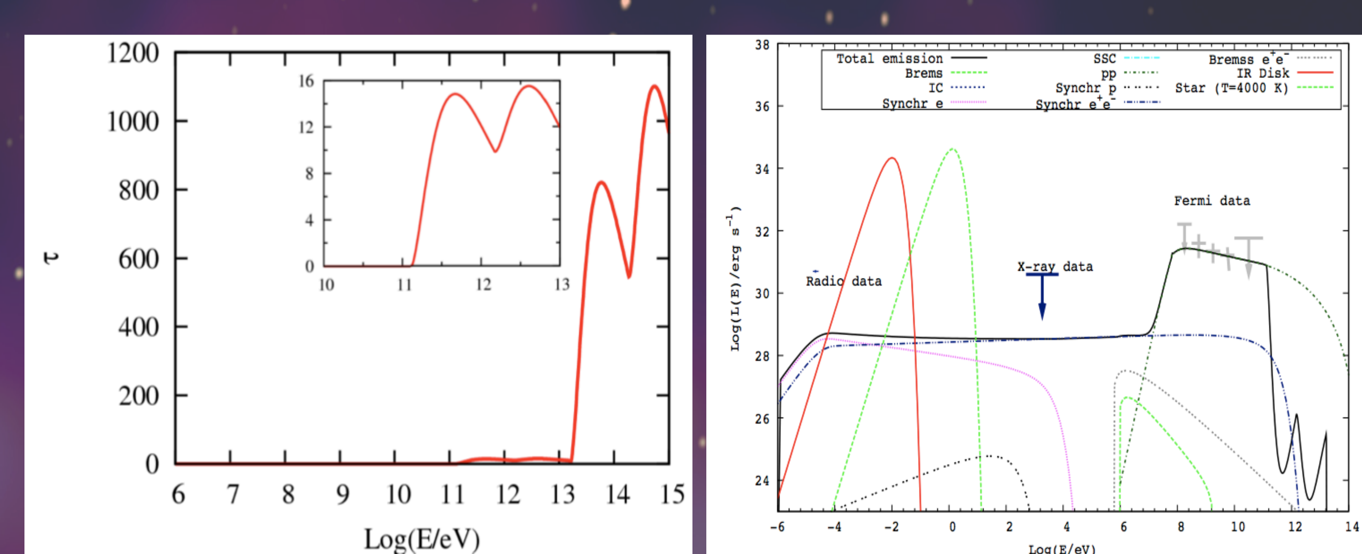
theoretical model

The details of our T Tauri model will be given in del Valle et al. (2011). In short, we assume that shock acceleration occurs in the outflow regions of coronal magnetic reconnection sites, where the first-order Fermi mechanism is believed to operate at an standing fast shock (Aschwanden 2008). Shocks are expected to accelerate charged particles up to high energies by a Fermi-like diffussive process (e.g. Drury 1983). The total power available in a flux tube with area A and magnetic field B is estimated as $L = (B^2/8\pi) A\, v_A$, where v_A is the local Alfven speed. We consider that only about 1% of this power goes finally into relativistic particles. Once such non-thermal relativistic electrons and protons are injected into the T Tauri magnetosphere, we calculate the expected spectral energy distribution (SED) by solving their steady state transport equation. Different particle energy losses are considered but the dominant ones are synchrotron radiation and inellastic proton-proton collisions for electrons and protons, respectively. In addition, internal absorption due to photon annihilation is found to be an important process in T Tauri stars.

In the figures shown, we summarize the most important results of our work. These plots have been computed adopting the following values for the most relevant parameters (that are conceivable for a T Tauri system): flux tube length 10^{11} cm, Alfven speed 600 km s^{-1}, acceleration efficienciy 10^{-4}, fractional content of relativistic particles 0.1, particle injection index 2.2, stellar wind velocity 200 km s^{-1}, magnetic field 200 G and particle density 5×10^{11} cm^{-3}.



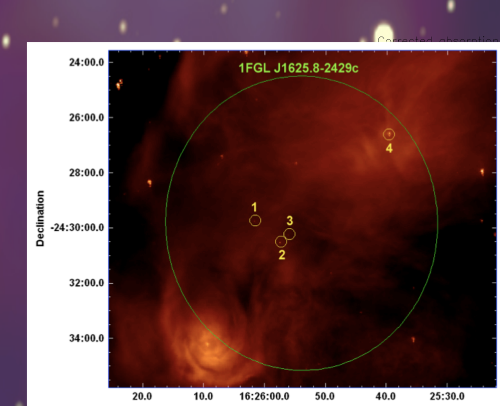
Acceleration and cooling rates for electrons (left) and protons (right).

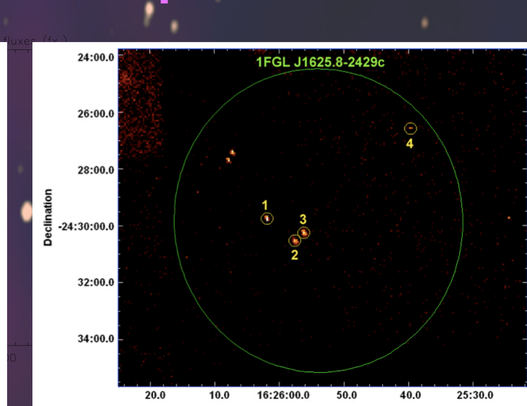


Opacity curve (left) and theoretical SED (right).

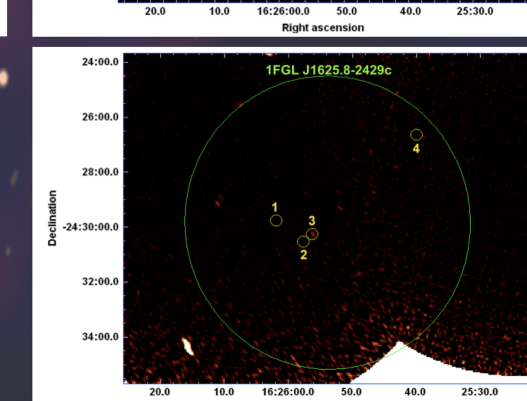
observations: the case of ρ-Ophiuchi

After performing several catalog cross-correlations, a new possible association of a gamma-ray source with nearby T Tauri stars inside the well-known ρ Ophiuchi star forming region clearly emerges for 1FGL J1625.8–2429c. Indeed, inside the 95% confidence error ellipse of this Fermi source we find four known T Tauri stars: 2MASS J16260160–2429449, 2MASS J16255752–2430317, JCMTSF J162556.8–243014 and 2MASS J16253958–2426349. In the accompanying figures, we show this field (l =353◦.0, b =17◦.0) as observed in the infrared, X-ray and radio wavelengths with these objects labeled from 1 to 4, respectively. The images have been produced using public data retrieved (and calibrated when necessary) from the Spitzer-GLIMPSE, Chandra and NRAO Very Large Array (VLA) archives, respectively. As discussed below, we tentatively suggest that this Fermi source might be the result of the emission of at least these four T Tauri stars that lay inside the location error box of 1FGL J1625.8 –2429c. The SED in previous box has been presented with the main goal of assessing the feasibility of this idea.





Infrared, X-ray and radio view of 1FGL J1625.8-2429c. Numbers indicate different T-Tauri stars



discussion and conclusions

Under a reasonable set of physical parameters for T Tauri stars, a relatively weak γ ray source can be produced. The intrinsic luminosity is not high (Lγ ~ 1031 erg s−1 at ~ 1 GeV), but for very nearby stars the flux may be significant. If such an association is confirmed for 1FGL J1625.8–2429c, the ρ Ophiuchi T Tauri stars would be the nearest γ-ray sources to the solar system detected so far. However, the complex environment of this source made difficult the background subtraction in the first Fermi catalog, and so the cosmic ray origin of the observed gamma rays cannot be excluded. In this case, 1FGL J1625.8–2429c would be the nearest passive γ-ray source detected outside the solar system.

To conclude, we have found that under some assumptions T Tauri stars might be responsible for some nearby Fermi sources. We have presented a simplified model for the high-energy emission of this type of stars, that agrees with the available multiwavelength observations. T Tauri stars might be a new class of galactic γ-ray sources in the Galatic plane. Based on this new scenario, 1FGL J1625.8-2429c is the first candidate for collective γ-ray emission from low-mass protostars. If the association with the ρ Ophiuchi cloud is confirmed, it would be the closest γ-ray source to the Solar System. This statement still holds even in the alternative case where the detected γ-rays were simply due to cosmic rays interacting with the cloud ambient gas.

References

Araudo, A., et al. 2007, A&A, 476, 1289
Aschwanden, M. J., 2008, IAU Symposium 247, p. 257
Bosch-Ramon, V., et al. 2010, A&A, 511, A8
Del Valle, M., et al. 2001, ApJ (submitted)
Drury, L. O., 1983, Rep. Prog. Phys., 46, 973
Munar-Adrover, P., Paredes, J. M., Romero, G. E., 2011, IAU Symposium 275, p.406

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