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CAN T TAURI STARS PRODUCE HIGH-ENERGY RADIATION?

M. V. del Valle[1,2] and G. E. Romero[1,2]

RESUMEN

Las estrellas T Tauri son estrellas de baja masa de pre-secuencia principal. Estos objetos están rodeados por un disco de acreción y presentan una poderosa actividad magnética. Las estrellas T Tauri son copiosas emisoras de rayos X. Los rayos X se generan en eventos intensos de reconexión magnética. Ondas de choque fuertes pueden estar asociadas con la reconexión masiva del campo magnético. Estas ondas o la propia reconexión pueden acelerar partículas hasta energías relativistas, como se ha observado en el sol. Presentamos un modelo para la radiación de muy alta energía producida en la magnetósfera de las estrellas T Tauri. Discutimos si esta emisión es detectable o no con los telescopios de rayos gamma existentes.

ABSTRACT

T Tauri stars are low mass, pre-main sequence stars. These objects are surrounded by an accretion disk and present strong magnetic activity. T Tauri stars are copious X-rays emitters. The X-rays are likely generated by powerful magnetic reconnection events. Strong shocks can be produced by massive reconnection in the stellar magnetosphere. These shocks or the reconnection of the field might accelerate particles up to relativistic energies, as observed in the Sun. We present a model for the high-energy radiation produced in the magnetosphere of T Tauri stars. We discuss whether this emission is detectable with the existing gamma-ray telescopes.

Key Words: gamma rays: stars — radiation mechanisms: non-thermal — stars: pre-main sequence

1. GENERAL

The aim of this work is to determine whether T Tauri stars can emit high-energy radiation and to establish whether the high-energy emission is detectable. T Tauri stars are low-mass pre-main sequence stars. These objects have accretion disks. The accretion of plasma occurs through magnetically confined columns. These stars drive strong winds and the youngest ones produce jets. T Tauri stars emit thermal X-ray radiation. This radiation corresponds to a plasma of typical temperature of $\sim 10^7$ K. This emission is variable and produces flares that are thought to be related to strong magnetic reconnection events (see Feigelson & Montmerle 1999).

The reconnection processes move the magnetospheric plasma producing shock waves. These shocks can accelerate particles up to relativistic energies (e.g., Schopper, Lesch, & Birk 1998; de Gouveia Dal Pino, Piovezan, & Kadowaki 2010). High-energy particles interact with the fields in the source: the magnetic field, the matter field and the radiation field. These interactions can give rise to gamma-ray radiation.

2. CALCULATIONS

We consider a spherical magnetosphere of radius $R = 0.1$ AU. The magnetic field is $B \sim 5 \times 10^2$ G and the maximum plasma density is $n \sim 10^{11}$ cm^{-1}. An estimate of the power available in the system is

$$L \sim \frac{B^2}{8\pi} Ac, \tag{1}$$

where A is the magnetosphere area. We assume that 10% of this power is release in the reconnection process, and 0.01% of the latter is transformed into relativistic particles.

We assume besides that the relativistic particles (electrons and protons) are injected in the magnetosphere with a power law distribution with power-law index $\alpha = 2$. These particles lose energy through the interactions with the fields in the magnetosphere. The electrons lose energy mainly through synchrotron mechanism, relativistic Bremsstrahlung, and inverse Compton radiation. The protons lose energy through synchrotron and (mainly) proton-proton inelastic collisions. Figure 1 shows the radiative looses and the acceleration rate for electrons and protons.

The particles distribution is calculated solving the corresponding transport equation (e.g., Ginzburg & Syrovatskii 1964):

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[1] Instituto Argentino de Radioastronomía, CCT La Plata (CONICET), C.C.5, (1894) Villa Elisa, Buenos Aires, Argentina (maria@iar-conicet.gov.ar).

[2] Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, Paseo del Bosque s/n, 1900, La Plata, Argentina.

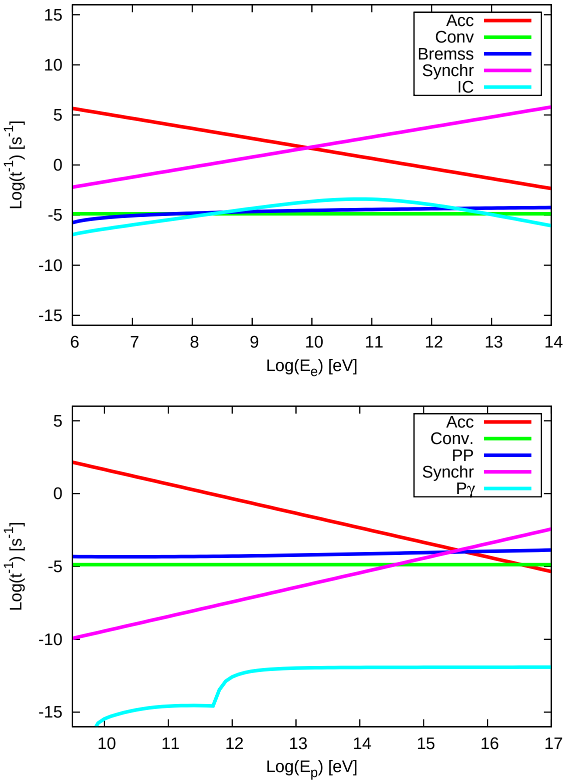

Fig. 1. Radiative looses and acceleration rate.

$$\frac{\partial}{\partial E}\left[\left.\frac{\mathrm{d}E}{\mathrm{d}t}\right|_{\mathrm{loss}} N(E)\right]+\frac{N(E)}{t_{\mathrm{esc}}}=Q(E), \tag{2}$$

where $Q(E)$ is the injection function in steady state. The particles can escape from the acceleration region through wind convection:

$$t_{\mathrm{esc}} \sim R/v_{\mathrm{w}}, \tag{3}$$

here v_{w} is the wind terminal velocity.

The solution to the equation is

$$N(E)=\left|\frac{\mathrm{d}E}{\mathrm{d}t}\right|_{\mathrm{loss}}^{-1}\int_{E}^{E^{\max}} \mathrm{d}E' \\ Q(E')\exp\left(-\frac{\tau(E,E')}{t_{\mathrm{esc}}}\right), \tag{4}$$

where

$$\tau(E,E')=\int_{E}^{E'} \mathrm{d}E'' \left|\frac{\mathrm{d}E''}{\mathrm{d}t}\right|_{\mathrm{loss}}^{-1}. \tag{5}$$

The dominant radiative processes are: proton-proton interactions with the magnetosphere material; synchrotron emission for protons, electrons and for secondary pairs from the proton-proton interactions (Orellana et al. 2007); relativistic bremsstrahlung and inverse Compton scattering for electrons and secondary pairs (e.g., Vila & Aharonian 2009). We assume that interaction volume with matter is a small fraction, $\sim 10^{-4}$ of the total magnetosphere volume.

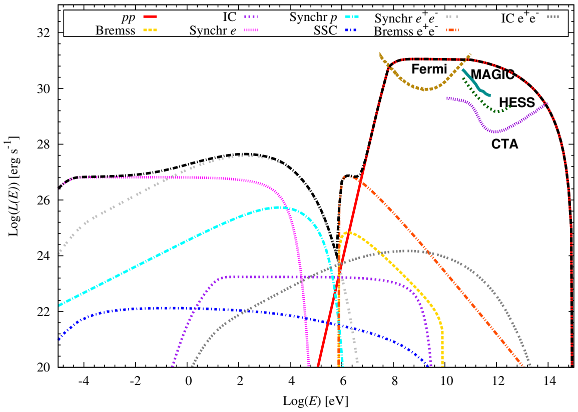

Fig. 2. Computed non-thermal spectral energy distribution.

The nearest T Tauri stars are localized in low-mass star forming regions. We consider a standard source at $d \sim 150$ pc. The high-energy radiation produced in the source can be absorbed through photon-photon interaction (Gould & Schréreder 1967). Figure 2 shows the computed non-thermal emission corrected by photon absorption. We also show the sensitivity curves, for a source at 150 pc, of the high-energy detectors Fermi, Magic, HESS and CTA.

3. CONCLUSIONS

T Tauri stars can produced high-energy radiation. Nearby sources might be detectable. These stars can be the counterparts of some of the unidentified galactic gamma-ray sources.

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