PROCEEDINGS OF SCIENCE

High-energy radiation from T Tauri stars

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T Tauri stars are young, low mass, pre-main sequence stars surrounded by an accretion disk. These objects present strong magnetic activity and powerful magnetic reconnection events. Strong shocks are likely produced in the stellar magnetosphere by such events and charged particles accelerated up to relativistic energies.

We present a simple model for the non-thermal radiation generated by high-energy particles in T Tauri stars. We discuss whether this emission is detectable at high energies with the available gamma-ray telescopes.

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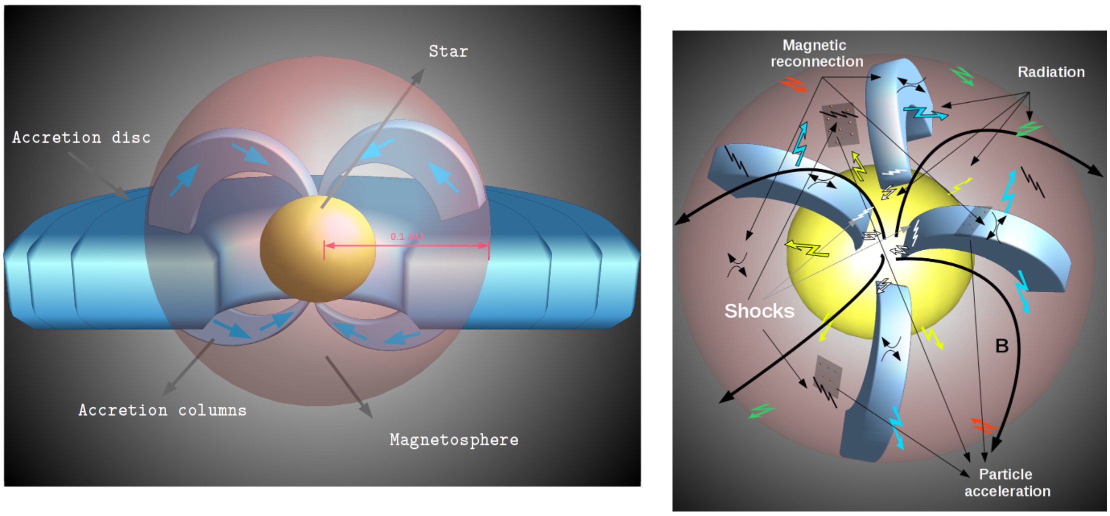

Figure 1: T Tauri star scheme (not to scale)

1. Introduction

T Tauri stars are low-mass stars ($M < 3\ M_{\odot}$) in their early stages of evolution. They are progenitors of solar-like stars. They are surrounded by an accretion disk. The youngest objects drive bipolar outflows (see [1]). The accretion is thought to be magnetically confined and to proceed via infall along magnetic flux tubes threading the inner disk, leading to shocks and hot spots on the surface (e.g. [2]). Figure 1 shows a simplified scheme of the physical scenario and a scheme of the physical processes which take place in the magnetosphere, viewed from the pole.

Variable thermal keV X-ray emission is detected from T Tauri stars. This emission comes from a high density plasma at a typical temperature of $\sim 10^7$ K. X-ray flares are considered as upscaled versions of solar flares, related to magnetic reconnection. Several works have been done on particle acceleration in magnetic reconnection (e.g. [3], [4]). Non-thermal radio emission have being detected from these stars, therefore a population of non-thermal particles must exist in the system (e.g. [5], [6]).

The most likely acceleration region is the magnetosphere, where violent magnetic reconnection episodes take place. Plasma collisions might produce strong shocks which can accelerate particles up to relativistic energies through difussive Fermi-like mechanism. These particles can produce the non-thermal radio emission through synchrotron losses. In this work we calculate the output of all losses of a lepto-hadronic particle population in the magnetosphere of T Tauri stars.

2. The model

We consider that a power-law population of relativistic particles (electrons and protons) is injected in the magnetosphere. For simplicity we consider a spherical magnetosphere of radius $R_{\rm m}$. These particles interact with the magnetic field, with the various radiation fields, and with the magnetosphere plasma.

Table 1: Parameters

Parameter		value
$R_{\rm m}$	Magnetosphere radius	0.1 AU
η	Acceleration efficiency	10^{-4}
a	Hadron-to-lepton energy ratio	100
$q_{\rm rel}$	Content of relativistic particles	10^{-3}
α	Particle injection index	2.2
$v_{\rm w}$	Wind velocity	2×10^{8} cm s^{-1}
B	Magnetic field [G]	10^{2}
n	Maximum magnetospheric density	10^{11} cm^{-3}
$r_{\rm D}$	Disk radius	100 AU
$T_{\rm IR}$	Disk temperature	30 K
$T_{\star}$	Star temperature	4×10^{3} K
$R_{\star}$	Star radius	$2\ R_{\odot}$
$L_{\rm x}$	X-ray luminosity	10^{30} erg s^{-1}

The values adopted for the different parameters in our model are listed in Table 1. We estimate the available power as $L = B^2/8\pi Ac$ where A is the magnetosphere area. We assume that 10% of this power is release in the reconnection process. The efficiency of non-thermal acceleration is estimated in the Bohm limit by $\eta \sim (v_{\rm s}/c)^2$, where $v_{\rm s}$ is the shock velocity. For solar-like values we obtain $\eta \sim 10^{-4}$. The relativistic electrons lose energy mainly through synchrotron emission, inverse Compton (IC) scattering with the star radiation field and the X-ray radiation field, and through relativistic Bremsstrahlung with the magnetospheric plasma. The relativistic protons lose energy mainly through synchrotron emission and pp inelastic collisions with ambient matter. Particles can escape from the acceleration region by wind convection. The maximum energy for both types of particles is obtained equating the cooling rates with the acceleration rate $t_{\rm acc}^{-1} = \eta ecB/E$. Figure 2 shows the different rates.

The particles steady state distribution is calculated using the standard transport equation (see [7]). We also consider the population of secondary $e^{\pm}$ pairs injected by charge pion decay (e.g. [8]).

We take into account four processes of interaction of the relativistic particles with the fields in the magnetosphere: synchrotron radiation of protons and electrons, pp inelastic collisions, IC scattering and relativistic Bremsstrahlung (e.g. [9]). The particles will collide with the accretion plasma columns. These columns occupy a non well-established volume of the magnetosphere. We adopt a small filling factor $f \sim 10^{-4}$.

We also calculate the opacity from internal and external photon-photon absorption (e.g. [10]). The external fields considered are the radiation fields from the disk and from the star, and the X-ray thermal emission. The internal fields are the fields generated within the system by non-thermal processes. Fig. 3 shows the opacity curve as a function of energy. The absorption is relevant for energies greater than 10 TeV.

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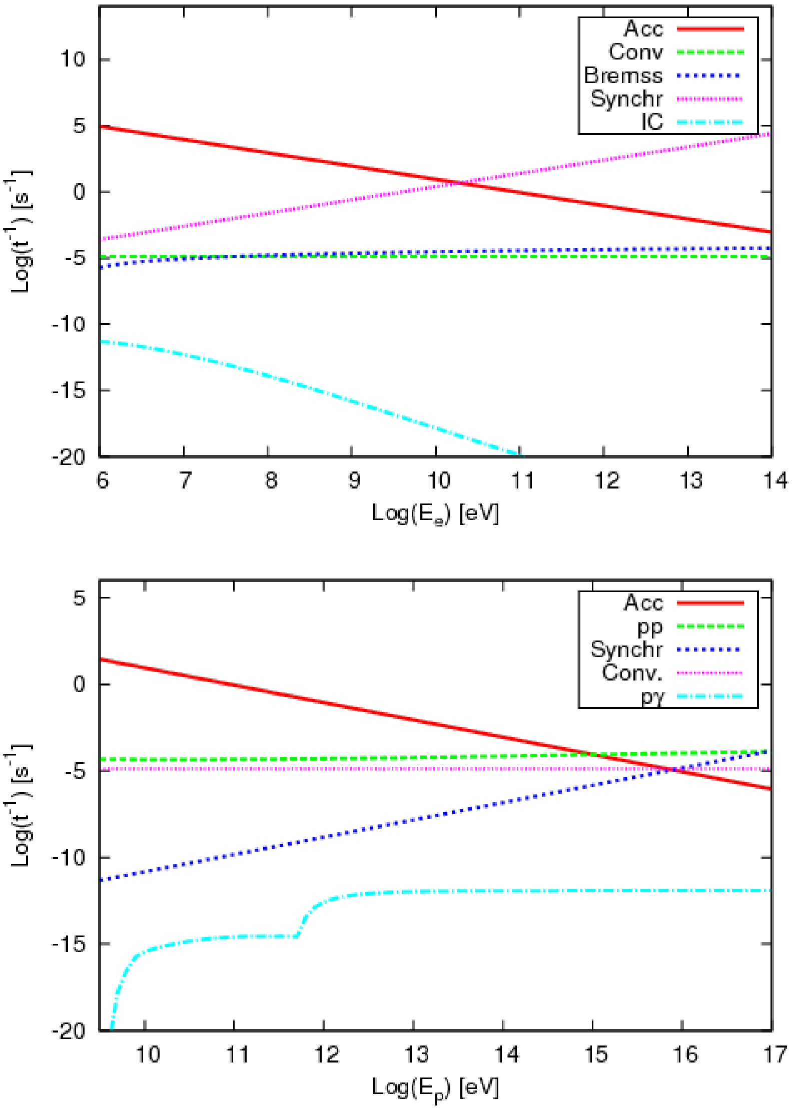

Figure 2: Electron and proton losses and acceleration rates.

3. Results

Figure 4 shows the computed spectral energy distribution (SED) and the sensitivity curves from the gamma-ray detectors CTA, MAGIC, and Fermi. We consider a source at a distance $d \sim$ 120 pc, similar to the distance of the nearest T Tauri stars in the ρ Ophiuchus star forming region.

4. Conclusions

Some of the existing gamma-ray instruments should be able of detecting T Tauri stars with the characteristic adopted in this work.

T Tauri stars might be the counterpart of some Fermi galactic sources (e.g. del Valle et al. in prep.) published in the first Fermi LAT catalog ([11]). Also Munar-Adrover, Paredes & Romero

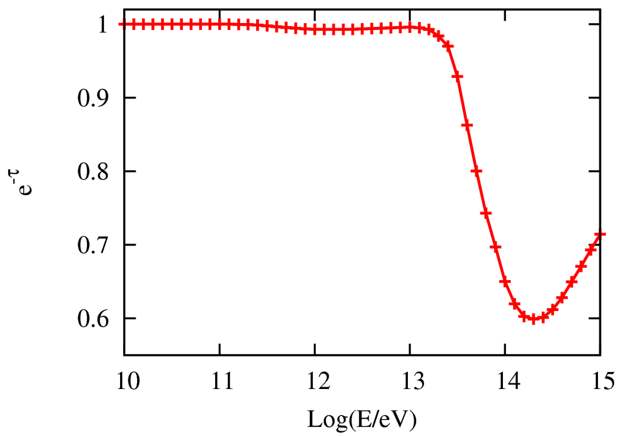

Figure 3: Opacity curve.

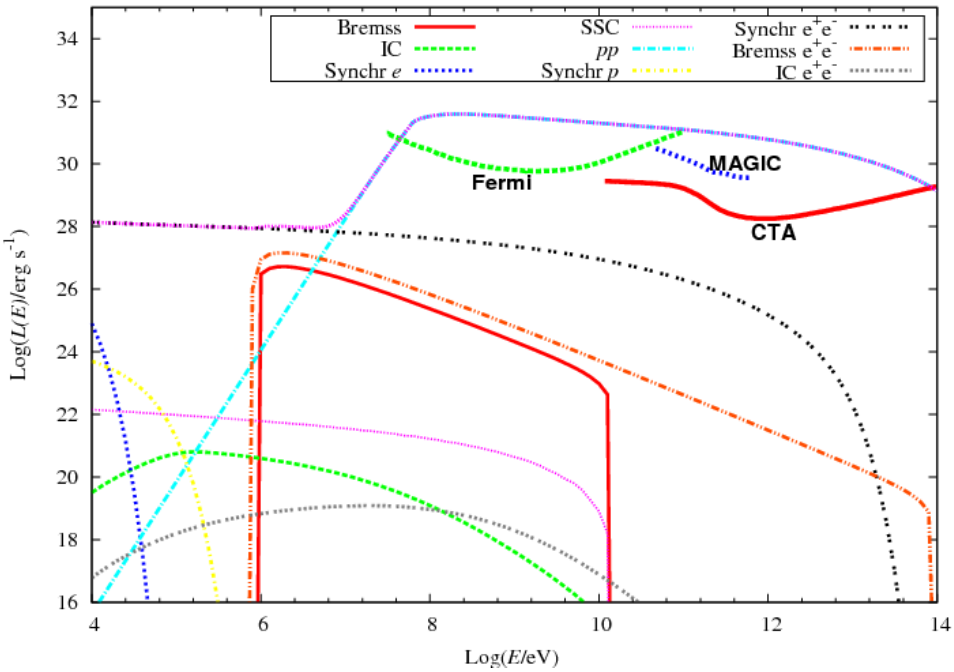

Figure 4: Computed high-energy SED for a source at d $\sim$ 120 pc and the sensitivity curves for CTA, Fermi and MAGIC.

2011 ([12]) have crossed the Fermi catalog with catalogs of YSOs obtaining a set of candidates by spatial correlation. aproximately, 72% of these candidates should be gamma-ray sources with a confidence level above 5σ.

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