Gamma-rays from quasi-spherical explosions

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Abstract

Some classes of transient sources can be at first approximation well modelled by quasi-sperical explosions in which the central hot objects are surrounded by fast expanding shells. We assume that processes in the shells can turn to the acceleration of relativistic particles. Electrons mainly comptonize the soft radiation from the central object and hadrons interact with the matter in the shell. We calculate the time dependent gamma-ray emission expected in such model applying parameters observed in the case of Novae.

1. Introduction

GeV gamma-ray emission has been recently discovered from seeveral Novae. In the case of RS Oph its non-thermal emission extends up to TeV energies. The gamma-ray emission is transient (lasting up to a few weeks). It is related to the early phase of thermonuclear eplosion on the surface of the White Dwarf which accreates the matter from the companion star within the compact binary system. During this early phase of the explosion, when the propagation of the ejecta is not strongly influenced by the presence of the matter distributed around the binary system, the propagation of ejected material can be well approximated as quasi-spehrical. We consider such a simple quasi-sperical, but time dependent, model for the evolution of the Nova shell in order to calculate the time dependent spectra of accelerated particles (electrons and protons) and predict the high energy gamma-ray emission at early phase (days time scale) after explosion.

2. Model of quasi-spherical explosion

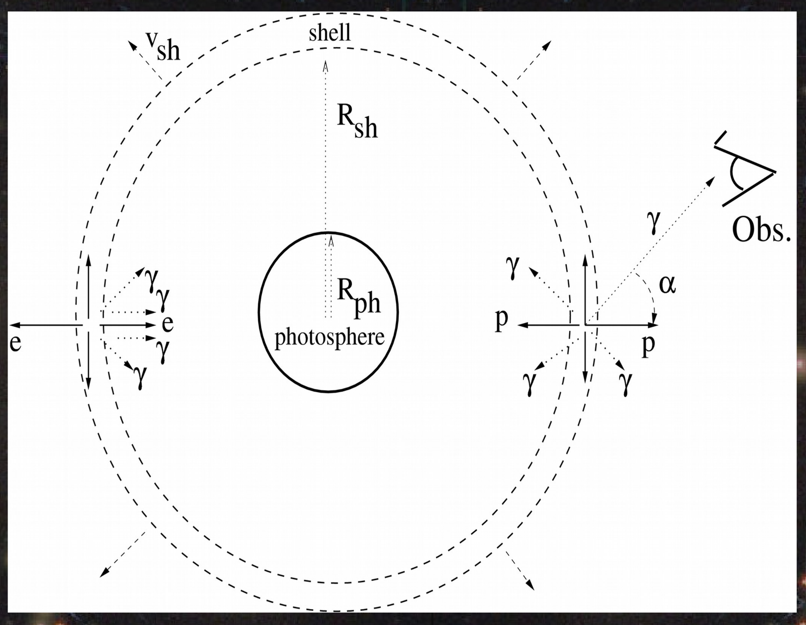

Fig.1: Schematic representation of the model applied for the early phase of the Nova explosion. The shell of material is expelled quasi-spherically with a constant velocity. Particles (electrons, hadrons) are accelerated by the shock in the shell. They reach the power law spectrum extending to the maximum energies determined by their energy losses on different radiation processes or the dynamics of the shell. The inner part of the source (i.e. the WD photopsphere) becomes optically thick. The radiation field from the photosphere is characterised by its temperature. Relativistic electrons in the shell comptonize anisotropic soft radiation from the WD photosphere preferentially towards its centre. Gamma-rays are absorbed in this same soft radiation from the photosphere. Gamma-rays, produced by electrons in the bremsstrahlung process or by hadrons in collisions with the matter, escape to the external observer from the anisotropic radiation field of the photosphere more efficiently.

3. Time dependent, equilibrium spectra of particles

Particles are accelerated in the shell with a constant rate. They obtain the power law spectrum to maximum energies defined by the balance between their acceleration process and energy losses. We obtain the equilibrium spectrum of particles at different moments after the Nova explosion. The energy losses of electrons on the synchrotron, bremsstrahlung and Inverse Compton processes are included. For protons, the energy losses on pion production are considered. The magnetic field strenght at the shell is calculated assuming its equipartition with the kinetic energy of the Nova shell. The evolution of the thermal radiation from the Nova shell is considered as observed in the case of Nova RS Oph. The characteristic time scales for electrons at different moments after explosion are shown in Fig. 2.

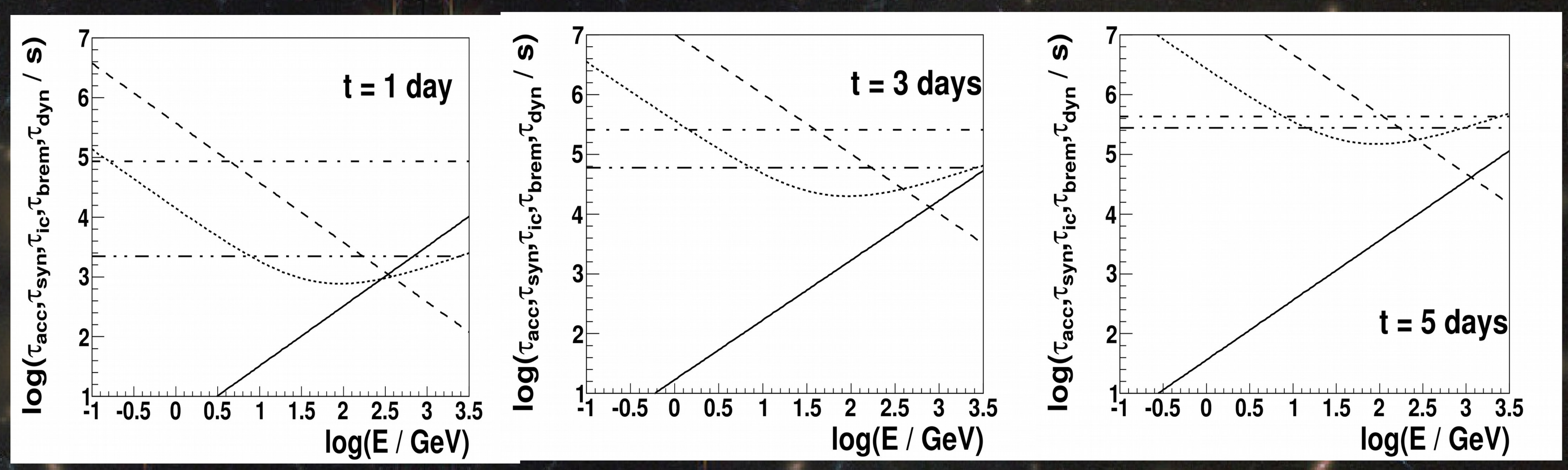

Fig.2: The energy loss time scales and energy gain time scales for electrons at different moments after the Nova explosion equal to: 1 day (on the left), 3 days (in the centre), and 5 days (on the right). The time scales for: acceleration of electrons (solid curve), synchrotron energy losses (dashed), IC losses (dotted), bremsstrahlung (dot-dot-dashed), and dynamical time scale (dot-dashed). The optical light curve of the Nova RS Oph is applied. The parameters of the Nova are: the acceleration coefficient 0.3(v_{sh}/c), magnetization parameter 10^{-6}, thickness of the shell eta = 0.1R_{sh}, mass of the shell 10^{-6} M_{sol}, and the shell velocity 3 x 10^{8} cm/s.

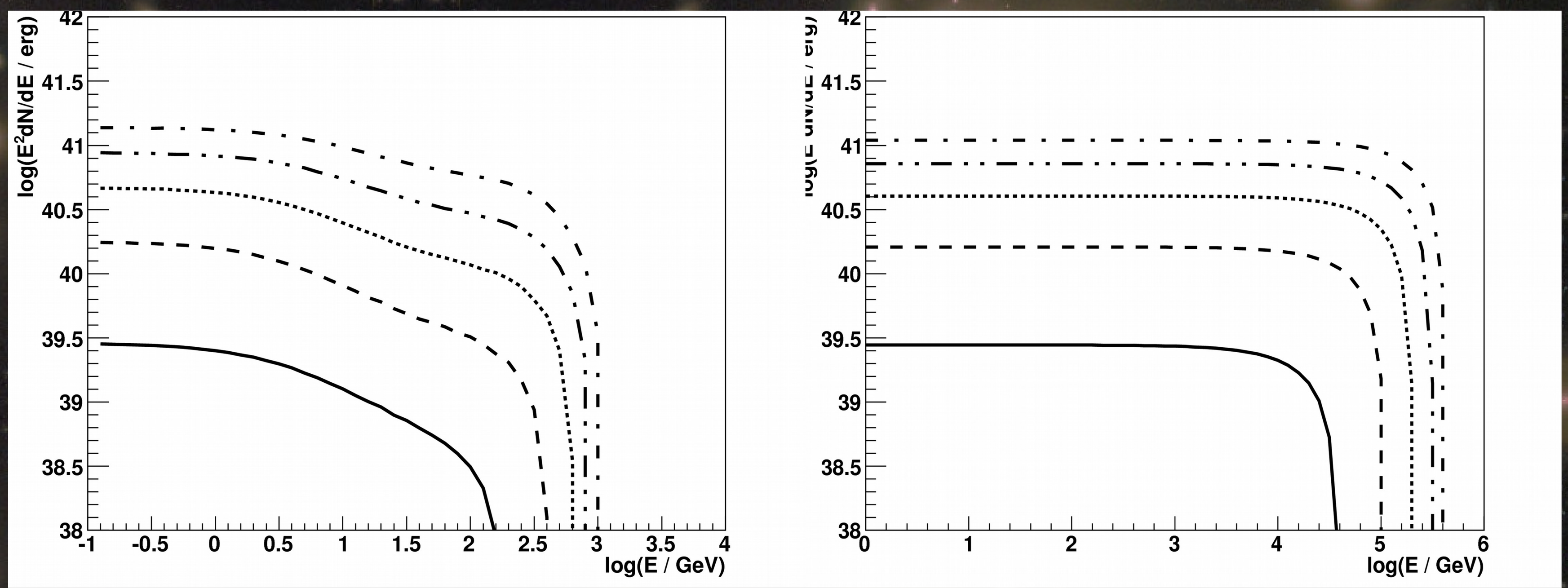

Fig.3: The equilibrium spectra of electrons (on the left) and protons (on the right) within the Niova shell (parameters of the Nova RS Oph are applied) shown at different moments after the Nova explosion, 1 day (solid curve), 2 days (dashed), 3 days (dotted), 4 days (dot-dot-dashed), and 5 days (dot-dahsed). It is assmed that particles are accelerated at a constant rate during the first 5 days after the Nova explosion with the power law spectrum up to the maximum energies detrmined from the balance between acceleration time scale and the energy loss time scales.

References.

Bednarek, W. 2006 MNRAS 368, 579
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4. Gamma-ray production

In principle, up to TeV gamma-rays can be produced by electrons and protons accelerated in the shell. We have shown that electrons can obtain ~TeV energies already for the magnetization of the shell of the order of 10^{-6} (see Fig. 2). In the case of protons magnetization of the shell has to be much stronger of the order of 10^{-3}. Therefore, we consider two models for the gamma-ray production: leptonic (weak magnetization) and hadronic (strong magnetization). In leptonic model gamma-rays are produced in the anisotropic IC scattering process of the soft radiation from the expending Nova photosphere. In the case of hadronic model gamma-rays are produced via neutral pion decay which are produced in collisions of protons with the matter of the shell. The angular distribution of of gamma-rays (produced in both models) is different. Electrons produce gamma-rays preferentially towards the photosphere due to the anisotropic distribution of soft radiation (see Fig. 1). On the other hand, protons produce gamma-rays isotropically in collisions with the matter of the shell since the velocity of the shell is sub-relativistic.

4a. Absorption of gamma-rays

Gamma-rays, produced in both models, can be additionally absorbed in the soft radiation from the Nova photosphere. The absorption process is anisotropic (Fig. 1). It is clearly stronger in the case of leptonic model since TeV gamma-rays are preferentially produced towards the Nova photosphere. However, in the case of the Novae, the gamma-ray absorption is important only at a relatively short period after the Nova explosion (see optical depths on Fig. 4).

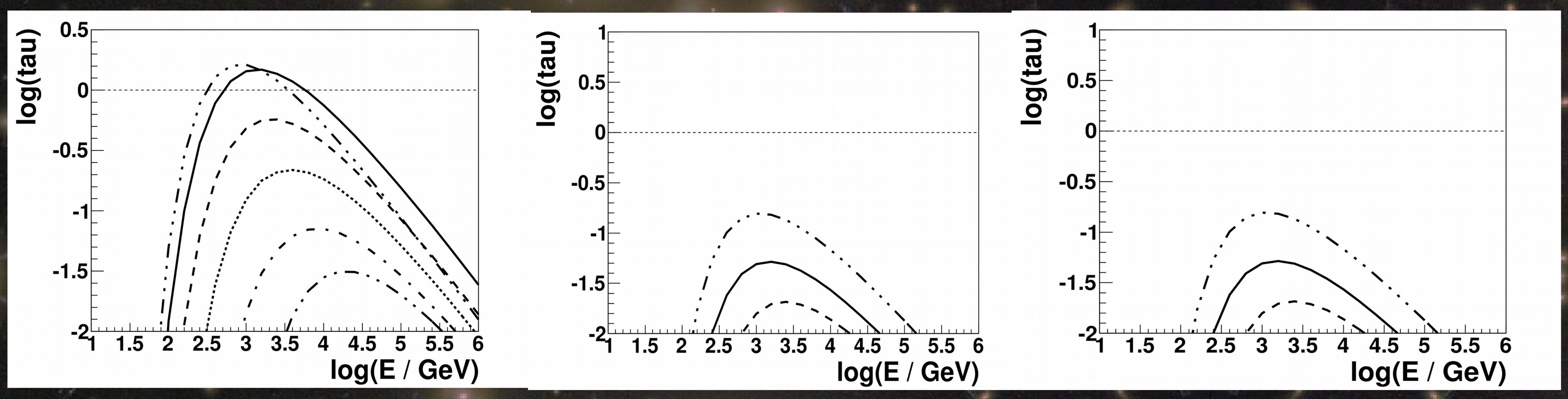

Fig.4: The optical depths for gamma-rays in the radiation field as observed in the Nova RS Oph at 1 day after explosion (on the left), 3 days (middle), and 5 days (on the right). The gamma-rays propagate at the injection angle 0^o(i.e. the outward direction from the centre of the Nova, dot-dot-dot-dashed curve), 30^o (dot-dashed), 60^o (dotted), 90^o (dashed), 120^o (solid), and 150^o (dot-dot-dot-dashed),

The time dependent gamma-ray spectra, calculated in terms of both models, leptonic (on the left) and hadronic (on the right), are shown in Fig. 5. For the assumed parameters of the acceleration scenario, both models are able to explain the sub-TeV gamma-ray emission from the Novae already during a few days after explosion, assuming that particles are accelerated at a constant rate, and they reach the power law spectrum with the spectral index close to -2. The efficiency of the gamma-ray emission in terms of the leptonic model is clearly larger than the efficiency of the hadronic model. The hadronic model also requires much stronger magnetization of the Nova shell.

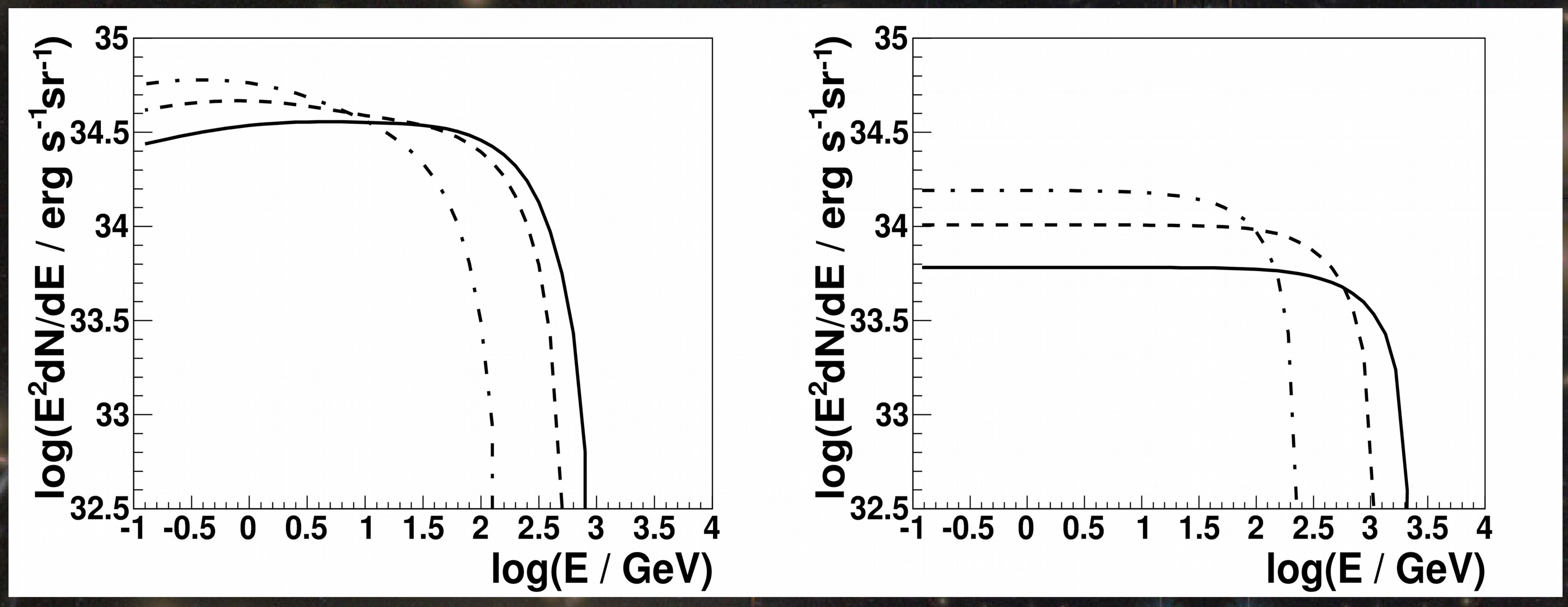

Fig.6. The gamma-ray spectra, produced in terms of the leptonic (on the left) and hadronic model (on the right) as a function of time after the Nova explosion: 1 day (dot-dahsed curves), 3 days (dashed), and 5 days (solid). The absorption of gamma-rays is included. Gamma-rays are produced by leptons in the IC and bremstrahlung processes and by protons in the decay of neutral pions from hadronic interactions.

Preliminary R_s=7 x 10^{10} cm

5. Conclusion

We developed time dependent leptonic and hadronic models for the quasi-sperical explosions with the application to Novae. Both, leptonic and hadronic, models can explain the GeV-TeV gamma-ray emission from the Novae (RS Oph). Hadronic model is more energetically demanding than leptonic model since the efficiency for the gamma-ray production in terms of leptonic model is larger than in the case of hadronic model. Both models predict similar tendency in dependence of the GeV and TeV gamma-ray emission, i.e. decrease of GeV emission and increase of TeV emission with time. In the case of the Nova RS Oph, GeV emission drops in time and TeV emission is close to constant during a few days after explosion. Therefore, we conclude that the efficiency of particle acceleration in RS Oph has to drop during the first few days after explosion. The absorption of gamma-rays (in the radiation from the Nova) can be important only at very early moment after explosion (day time scale). Moreover, hadronic model requires clearly stronger magnetization of the Nova shell (in respect to leptonic model) in order to explain TeV gamma-ray emission from Novae.

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