

FINAL
IN-93-CR
OCT. 64705

CAL-2350

National Aeronautics and Space Administration

P.6

FINAL TECHNICAL REPORT FOR NAG 5-2017

Submitted to: National Aeronautics and Space Administration
300 E. Street, SW
Washington, DC 20546

Prepared by: Columbia Astrophysics Laboratory
Departments of Astronomy and Physics
Columbia University
538 West 120th Street
New York, New York 10027

Submitted by: The Trustees of Columbia University
in the City of New York
Box 20, Low Memorial Library
New York, NY 10027

N96-10855

Unclas

G3/93 0064705

Title of Research: GRO: Black Hole Models for
Gamma-Ray Bursts

Principal Investigator: Malvin Ruderman
Columbia University

Report Period: 15 July 1994 - 14 July 1995

(NASA-CR-199243) GRO: BLACK HOLE
MODELS FOR GAMMA-RAY BURSTS Final
Technical Report, 15 Jul. 1994 - 14
Jul. 1995 (Columbia Univ.) 6 p

September 1995

Final Technical Report for NAG 5-2017

The Burst and Transient Source Experiment (BATSE) on board the Compton Gamma Ray Observatory (CGRO) has established that the distribution of gamma-ray bursts (GRBs) is isotropic but is bound radially (Meegan et al. 1992). This finding suggests that the bursts are either cosmological (Hartmann 1992; Paczyński 1994) or they originate from an extended Galactic halo (Eichler & Silk 1992; Li & Dermer 1992). The implied luminosities and the observed variability of the GRBs on time scales as short as one millisecond suggest that they originate from compact objects.

We are presently studying black hole models for GRBs. Any such model must produce a non-thermal photon spectrum to agree with the observed properties. For a wide range of burst parameters the assumed bursting source consists of a non-thermal electron-positron-photon plasma of very high density. It seems possible to produce such a plasma in accretion onto black holes (Gunnlaugur & Svensson 1992).

Early attempts to understand the physical properties of pair plasmas were restricted to the case where the pairs were assumed to be in thermodynamic equilibrium. Bisnovatyi-Kogan, Zel'dovich, & Sunyaev (1971) analyzed pair plasmas, with negligible photon concentration, at extreme relativistic temperatures. Their work was generalized and enlarged by Lightman & Band (1981), Lightman (1982), and Svensson (1982), who considered thermal pair plasmas in equilibrium with photons. These latter papers contain results for a wide range of temperatures and include many novel photon and particle reactions, which were comprehensively tackled for the first time. They identify various parameters of a thermal

pair-photon plasma and give a detailed portrait of plasma equilibria in the parameter space. All these papers assume that the plasma is stationary and homogeneous. Guilbert & Stepney (1985) and Kusunose (1987) analyzed the time evolution and radiative-transfer problems in a thermal pair plasma with the aid of kinetic equations. Investigation of the physics of non-equilibrium pair plasmas and their time evolution is a relatively recent undertaking. Nonetheless, several important results have been obtained already. Those studies, in general, have employed two different methods: Monte-Carlo method (e.g., Stern et al. 1995 and references therein) and solving the kinetic equations (e.g., Coppi 1992; Lightman & Zdziarski 1987; Svensson 1987; Zdziarski, Coppi, & Lamb 1990).

In our on-going work, we are developing the kinetic theory for a non-equilibrium pair plasma. For such a plasma, containing arbitrary concentrations of pairs and energetic photons, we derive the expressions for the emission and absorption coefficients, for particles as well as photons, starting from a single general equation. The processes we consider are Compton scattering, pair annihilation and creation, and bremsstrahlung. The kinetic kernels for all these processes are given in terms of arbitrary distribution functions, for pairs as well as photons. We then use this formalism to compute the luminosities, cooling rates, opacities, and the relaxation times for such a plasma.

The main new features of our work are as follows. (1) We do not assume the presence of a thermal electron bath. (2) Non-thermal, high-energy pairs are allowed to have an arbitrary concentration and energy distribution. This means that the kernels for processes such as Coulomb collisions are not linear functionals of the distribution function any more.

This situation affects the photon distribution also, in a non-trivial way, because the kinetic equations are coupled and are non-linear. (3) There is no soft photon source in our model. Initially all the photons in the plasma are either energetic X-rays or γ -rays. Therefore most of the photons are initially very near or above the pair-creation threshold energy. Also, there are no cold electrons in the plasma. (4) The initial energy distribution of the pairs as well as photons is arbitrary. Also, the pair and photon concentrations may be comparable to each other in the beginning. (5) We collect the analytical expressions for the kinetic kernels for all relevant processes. Several of these are evaluated through a method that is different from those that are available now. Where possible, we compare our results with previous ones. (6) We present a different approach to finding the time-evolution of pair and photon spectra, which is a combination of the kinetic-theory and the non-linear-Monte-Carlo schemes.

We have developed many Monte-Carlo programs to model various processes, to take into account the time evolution, and to incorporate various physical effects which are unique to non-thermal plasmas. We have tested our programs by comparing our results with those of the existing ones for the special case of equilibrium distributions and they are in very good agreement. All results pertaining to this study, in full detail, are in a paper (Pilla and Shaham 1995) in the final stages of preparation.

Fireballs are a generic feature of many gamma-ray-burst models. The hydrodynamics of fireballs in GRBs was studied before (e.g., Shemi & Piran 1990; Piran, Shemi, & Narayan 1993; Mészáros, Laguna, & Rees 1993; Mészáros & Rees 1993). Applying results from kinetic theory will improve our understanding of these systems. While the full understanding of the

nature of non-thermal radiation from various compact sources, especially GRBs, requires the solution to the radiative transfer equations which incorporate Comptonization, pair processes, and bremsstrahlung in a self-consistent manner, the analysis carried out so far serves as a preliminary to such studies. In a forthcoming paper (Pilla 1995) we will apply the formalism of the present study to the fireballs in GRBs.

The research described above has been carried out by R. Pilla with the late Jacob Shaham.

References

- Bisnovatyi-Kogan, G. S., Zel'dovich, Ya. B., & Sunyaev, R. A. 1971, *Sv. Astr. AJ*, **15**, 17
- Coppi, P. S. 1992, *MNRAS*, **258**, 657
- Eichler, D. & Silk, J. 1992, *Nature*, **257**, 937
- Guilbert, P. W. & Stepney, S. 1985, *MNRAS*, **212**, 523
- Gunnlaugur, B. & Svensson, R. 1992, *ApJ*, **394**, 500
- Hartmann, D. 1992, *Comm. Astrophys.*, **16**, 231
- Kusunose, M. 1987, *ApJ*, **321**, 186
- Li, H. & Dermer, C. D. 1992, *Nature*, **359** 14
- Lightman, A. P. 1982, *ApJ*, **253**, 842
- Lightman, A. P. & Band, D. L. 1981, *ApJ*, **251**, 713
- Lightman, A. P. & Zdziarski, A. A. 1987, *ApJ*, **319**, 643
- Meegan, C. A. et al. 1992, *Nature*, **355**, 43
- Mészáros, P., Laguna, P., & Rees, M. J. 1993, *ApJ*, **415**, 181
- Mészáros, P. & Rees, M. J. 1993, *ApJ*, **405**, 278

- Paczynski, B. in *Proc. Huntsville GRB Workshop*, ed. Fishman, G. et al. (AIP, New York, 1994)
- Pilla, R. P. & Shaham, J. 1995, in preparation
- Pilla, R. P. 1995, in preparation
- Piran, T., Shemi, A., & Narayan, R. 1993 *MNRAS*, **263**, 861
- Shemi, A. & Piran, T. 1990, *ApJ*, **365**, L55
- Stern, B. E., Begelman, M. C., Sikora, M., & Svensson, R. 1995, *MNRAS*, **272**, 291
- Svensson, R. 1982, *ApJ*, **258**, 321 (S82a)
- Svensson, R. 1987, *MNRAS*, **227**, 403
- Zdziarski, A. A., Coppi, P. S., & Lamb, D. Q. 1990, *ApJ*, **357**, 149