Inverse Compton scattering in high energy astrophysics.

A thesis submitted for the degree of
Doctor of Philosophy

by

Jason Cullen

Research Centre for Theoretical Astrophysics
& Theoretical Physics Group
School of Physics
University of Sydney
Australia

August 2001

Declaration of originality

To the best of my knowledge, this thesis contains no copy or paraphrase of work published by another person, except where duly acknowledged in the text. This thesis contains no material which has been presented for a degree at the University of Sydney or any other university.

Jason Cullen

Acknowledgements

I wish to thank Zdenka Kuncic and Kinwah Wu for important suggestions regarding the work in Chapter 4.

I also wish to thank Chris Rennie for advice on the IDL routine used in Chapter 5.

Thanks also to Roberto Soria for suggesting I work on bulk rotational motion Comptonization.

My grateful thanks to my principle supervisor for this thesis, Kinwah Wu.

Abstract

This thesis investigates some aspects of the inverse Compton scattering process within various physical contexts in high energy astrophysics. Initially an introduction to the key results of Comptonization theory for the case of scattering in optically thick plasmas is given, using a diffusion approach, since these results are required for the interpretation of Comptonized spectra.

Since Comptonization in astrophysical systems is frequently treated using numerical techniques, an introduction to these is then presented. Such linear Monte Carlo photon transport codes are typically applied to scattering in plasmas without temperature and density gradients. Additionally, treating bulk motion can be difficult even for simple cases.

It is demonstrated that these problems can be made tractable numerically with the use of algorithms associated with non-linear Monte Carlo codes. Such codes can already treat scattering within arbitrary velocity structures in a plasma, and an extension of the algorithm is proposed that enables the easy calculation of photon transport in plasmas with non-constant density as well as non-constant temperature and/or bulk motion. This algorithm and code has been developed to treat scattering in astrophysical situations where bulk motion, temperature gradients and density gradients are simultaneously present in a plasma.

Both a semi-analytic approach and the numerical approach are then used to treat Comptonization problems of current interest. Firstly, the standard two-phase disk–corona model for the high-energy spectra of Active Galactic Nuclei is modified to include an an outflow or wind which may provide an additional source of disk cooling. Earlier slab disk–corona models predict a spectral index which is consistent with observations only if all the accretion power is dissipated in the corona. For the models investigated here, energy spectral indices that are consistent with observations can be obtained with less accretion power being dissipated in the corona, as a result of an outflow/wind. However, it is required that the wind extract large amounts of power from the disk, and it it yet to be seen if this is a plausible scenario.

Secondly, the linear numerical technique is then applied to a study of the time delay or lag of high energy photons due to the inverse Compton process, for cases where the scattering plasma is characterised by more than one temperature. Such a model has been proposed for Cyg X-1, and the spectral and temporal behaviour of such a model is investigated. Predictions are made regarding the form that the time lag curve should take if this particular geometry is a realistic model for the material surrounding Galactic black hole candidates.

The extended non-linear algorithm is then applied to the study of scattering in bulk motion accretion flows in both one and two dimensions. The 1-D case is that of line photon scattering in the accretion column of a magnetised white dwarf star, and the resulting spectra are presented for various inclination angles, accretion rates, and Cyclotron cooling rates in the post-shock region. Spectra as a function of inclination angle are also obtained and beaming of photons by the inhomogeneous column is investigated.

The 2-D case is that of Comptonization in a rotating torus geometry, which is a first attempt at considering scattering in an orbiting accretion disk-like structure. Different photon injection spectra are investigated for different values of the electron momentum within the torus. It is found that for a reasonable optical depth and electron momentum, lines can be significantly broadened by rotational Compton scattering.

Contents

List of Figures