ON THE COMPUTATION OF ACCRETION DISK SPECTRA

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ABSTRACT. Spectra of accretion disks in dwarf novae and some nova-like stars have been computed. Many simplifications to the general model of the nature of a cataclysmic variable are needed to make the system numerically tractable. The necessity, justification, and implications of such simplifications are discussed together with the influences of some system parameters on the disk radiation.

1. INTRODUCTION

Spectra of accretion disks in dwarf novae have been computed by different authors in various degrees of sophistication and the influence of various parameters on the outgoing radiation has been investigated. There is a very wide span between simple black body disks and very elaborate three-dimensional NLTE computations taking into account various interactions within the cataclysmic system. Clearly however simplifications to the most general model are necessary. Thesy imply limitations on the type of observed spectra the synthetic ones may reasonably be compared with. The necessity, justification and consequences of some such simplifications has been investigated together with a very general discussion of the influence of system parameters on the radiation and of the possibility of deriving system parameters from the comparison between observed and computed spectra.

2. THE RADIAL TEMPERATURE LAW

Energy generation in an accretion disk is due to viscous interaction of matter contained in the disk that leads to the liberation of gravitational energy and a corresponding spiralling of the matter towards the white dwarf. The temperature at any point in the disk is determined by the total amount of energy set free in a volume element. This quantity is in turn determined by the nature of the viscosity at work. This is entirely unknown. If a spectrum is to be computed, some

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assumptions about the properties of the viscosity have to be made.

The approach for all spectral computations published so far has been to postulate a stationary accretion disk, i.e. a steady throughput of matter throughout the disk at constant rate. Together with some further assumptions this leads to the well known temperature distribution:

$$T_{eff}^4(r) = \frac{3\,\gamma\,M_{WD}\,M}{8\,\pi\,\sigma\,r^3}\left(1 - \frac{\sqrt{R_{WD}}}{\sqrt{r}}\right) \qquad (1)$$

It must be emphazised that this law does not hold if the disk is not stationary, if energy is generated within the atmosphere, or if the disk is convective at the bottom of the atmosphere, nor does such a simple expression hold in these cases.

Assuming that eq. (1) is valid for the disk, to a first approximation the slope of the continuum can be computed by assuming that locally the disk radiates as a black body. For very large disks, i.e. for disks that cover a very large temperature range, the spectral index $\alpha_\lambda = -2.33$ is to be expected over a wide wavelength range. However, the accretion disks in dwarf novae and nova-like systems are much too small for this spectral index ever to be realized over more than a very small wavelength range. A non-stationary accretion disk is the explanation for observed spectra with this spectral index.

3. NUMERICAL TREATMENT OF RADIALLY VARIABLE PHYSICAL CONDITIONS

Physical conditions such as temperature and gravitational acceleration vary appreciably radially in the disk. For practical reasons homogeneous conditions have to be assumed for geometrically larger areas. As a very first step the disk can be regarded as consisting of a series of concentric homogeneous "rings".

Investigation of the vertical and radial gradients of models of the central disk by Meyer and Meyer-Hofmeister (1983, private communication) combined with LTE atmosphere computations demonstrate that in the inner disk ($\tau \gg 1$) the assumption of no interaction between adjacent "rings" is well justified. In the atmosphere this is by no means the case. The strength of the interaction there is strongly dependent on the geometrical shape of the disk's surface. This can only be determined by further computations which again involve many assumptions, in particular about the nature of the viscosity.

4. THE ATMOSPHERE

Many authors have published synthetic absorption spectra and have investigated some of their properties. However, different authors have covered different parameter ranges. So no clear picture emerges. In addition, some very important questions have never been addressed.

The assumption that the entire disk is in hydrostatic equilibrium locally is already implicit in the simplifications imposed on the full hydrodynamic equations in order to arrive at the $T_{eff}(r)$ dependence.

In the cool outer parts, the disk is expected to be convective. It can be shown that as long as the central disk is optically thick, the radiation from of the outer disk is neglegible so that neither the use of eq (1) nor a total neglect of any convection in the disk has any serious consequences.

To a first approximation it seems justified to assume that the entire disk is in radiative equilibrium. In order to be able to compute a spectrum at any point r in the disk the chemical composition, the effective temperature $T_{eff}(r)$ and the gravitational acceleration $g_z(r)$ at optical depth $\tau = 2/3$ must be given. A solar composition of the disk material is in agreement with the observations as well as with theoretical concepts about the evolutionary state of cataclycmic variables. If it is supposed that all viscous energy is liberated well below $\tau = 2/3$ eq. (1) provides a value for $T_{eff}(r)$. The local value of $g_z(r)$ depends on the local height $z_o(r)$ of the disk at the point r which is not known. Tests using a wide range of values for $z_o(r)$ (keeping all other parameters constant) demonstrated that different geometrical heights do make themselves felt in the integrated radiation, but that the effects are neglegible to those of variables in the problem.

Most published disk spectra have been computed assuming that the gravitational acceleration in the atmosphere is constant. It is by no means clear that this assumption is justified in all cases. The question of course is by how much does $g_z(r)$ change between $\tau = 2/3$ and $\tau = 0$? Tests for different values of $z_o(r)$ and both variable and constant $g_z(r)$ lead to the conclusion that the variability can be neglected (in LTE atmospheres) provided that the disk is really, and not only marginally, optically thick in the central plane.

The boundary between the LTE and NLTE regimes in log g-T_{eff} has been determined by Kudritzki (1976, 1979). With the exception of the very central areas of either very thin or very hot disks, accretion disks in dwarf novae and nova-like stars fall well within the LTE regime implying that this approximation is a good one.

It is obvious that due to the high gravitational accelerations which prevail in the disk, radiation pressure can be entirely neglected.

The importance of electron scattering σ_e can be estimated if the ratio $\sigma_e(\nu)/(\sigma_e(\nu)+\kappa_{Ross}(\nu))$ is regarded as a function of pressure and temperature. It turns out that for the physical conditions found in accretion disks, electron scattering can become very important.

5. SYSTEM PARAMETERS

The mass of the central star and the mass accretion rate enter the radial temperature law (eq. 1.) (and only there) with the same exponent. Possible masses have a range of a factor of three at most, while possible mass accretion rates can vary by a factor of 10^5. Consequently, although it does have a slight effect on the spectrum, any reasonable value may be adopted for the mass of the central star. However, changes in the mass transfer rate can change the character of the entire spectrum.

The inner one, two, or three percent of the disk area dominate the UV radiation entirely, whereas the outer 70 to 90 percent of the area of an average-sized accretion disk are totally irrelevant for the UV as well as the optical radiation. Variations in the outer disk radius have practically no effect on the optical and even less on the UV radiation. Variations of the inner disk radius can change the character of the spectrum to a much greater extent than variations in the mass-transfer rate. In a stationary accretion disk the inner radius should be identical with the radius of the white dwarf if the star does not possess a magnetic field and if the boundary layer is not taken into account. But it cannot be taken for granted that the white dwarf has no magnetic field. Moderately strong fields, though unobservable can give Alfven radii that are significantly larger than the radius of the white dwarf. In particular if the stellar mass and the mass transfer rate are small. Variations in the mass transfer rate can lead to appreciable variations in the inner disk radius and corresponding large changes in the UV radiation.

6. APPLICABILITY OF THE COMPUTATIONS

Statistical properties such as the spectral indices, the size of the Balmer jump and to some degree even the line spectra of dwarf novae during outburst and of some nova-like stars can be reproduced by computations of LTE spectra of optically thick accretion disks. This should, however, not lead to an attempt to derive system parameters from a comparison between observed and computed spectra. It must be kept in mind that contributions from the secondary star and the hot spot have been neglected. The boundary layer may become important for UV radiation, if not directly then indirectly by irradiation processes. More realistic computations are clearly needed but lead to serious problems because important physical effects such as magnetic fields and the structure and radiation of the boundary layer are ill-understood, and since three-dimensional computations are needed in order to deal with anisotropic irradiation or radial interaction.

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