Thermal and Viscous Instability of Accretion Disc in AGN

A. Janiuk 1, B. Czerny 1

1) N. Copernicus Astronomical Centre, Bartycka 18, 00-716, Warsaw, Poland

Abstract

The observed optical/UV spectra of most Seyfert galaxies are much redder than expected from a stationary accretion disk. Two explanations of this effect are probable: (i) the observed spectrum is strongly contaminated by starlight (ii) the accretion disk is not stationary in these objects.

The standard accretion discs are known to be thermally and viscously unstable over a certain range of temperatures. In the inner disc regions there may develop radiation pressure driven instability, which is possibly related to the rapid variability detected in AGNs in the UV range. In the outer disc develops the ionization instability, similar to that in the cataclysmic variables, but operating on much longer timescales. Due to this process the spectrum of the accretion disc differs from that of a stationary one.

We examine the accretion disc vertical structure model in order to determine the range of the ionization instability. We derive the radial dependence of the accretion rate in a non-stationary disc between outbursts, and we calculate the effective temperature profile and the corresponding spectral slope.

The predicted shape of the spectrum is different from a stationary case but it does not seem to reproduce the observed spectra of Seyfert galaxies. We therefore suggest that the starlight contribution is most probably responsible for the spectral shape in red Seyfert galaxies and its contribution extends to shorter wavelengths than usually adopted.

1 Introduction

Accretion disc in Active Galactic Nuclei are subject to thermal - viscous instabilities which operate in the inner disc regions. The radiation pressure driven instability (Lightman & Eardley 1974) is developed in the models, which assume the viscous torque proportional to the total pressure. It operates in the innermost disc part, while further away, where the disc is gas pressure dominated, there exists a partial ionization zone. Therefore these regions are unstable due to the same mechanism as in cataclysmic variables (e.g. Smak 1984, Lasota et al. 1995), but in much
longer time scales. Finally, the outer parts of the disc may be gravitation-
ally unstable (Hure 1998).

Here we consider only the ionization instability. Its radial extension de-
pends on several parameters, like the mass of a central black hole, viscosity
parameter $\alpha$ and external accretion rate $M_{ext}$. Using the parametrization
given in Siemiginowska et al. (1996) we estimate for the inner and outer
radii of the unstable zone that $R_{in} \sim 250R_{schw}$ and $R_{out} \sim 1500R_{schw}$
for $M = 10^8M_\odot$, $\alpha = 0.03$ and $M_{ext} = 0.1M_{Edd}$.

At any given radius the local thermal equilibrium may be represented
by the characteristic shape of the S curve on the $T_{eff} - \Sigma$ (or $M - \Sigma$)
plane. The upper and lower branches of the positive slope describe the
stable configurations and the middle part of the S curve describes the
unstable solution. When the external accretion rate corresponds to the
unstable branch the disk undergoes oscillations between the upper hot and
the lower cold branch. Faint phase corresponds to the slow accumulation
of the material and increase of the disk surface density; the accretion rate
and surface density corresponding to the upper end of the low branch are
characteristic for this phase.

2 Vertical structure model

The basic equations that describe the disc vertical structure are the equa-
tion of viscous energy dissipation, the hydrostatic equilibrium, and equa-
tion of energy transfer. The last equation takes into account the pres-
ence of convection which carries non-negligible fraction of energy. The
frequency-averaged opacity $\kappa$ (Rosseland mean) includes the electron scattering as well as the required free-free and bound-free transitions. The tables are from Alexander, Johnson & Rypma (1983) for $\log T < 3.8$, from Seaton et al. (1994) for $\log T > 4.0$ and the value of opacity is interpolated between these two tables for intermediate values of the temperature, as in Róžańska et al. (1999).

The temperature dependence of the Rosseland mean opacity changes
for different temperature ranges: for $T < 10^3$ K the power law function is: $\kappa \sim \rho T^{-5}$, for $T > 10^4$ K the power law index is equal to -3.5, while at the intermediate temperature range, corresponding to partial hydrogen ionization, the trend is opposite and power law index is about 5 - 10 (see Kato et al. 1999). The opacity changes affect the cooling rate in the disc, which is important in determining the equilibrium solutions. Moreover, the presence of $H^-$ ions causes a large reduction of radiative transport efficiency and therefore excited convection results in higher opacity.

3 Results

In Figure 1, we plot local stability curves for several different radii. The
critical turning points on each curve, indicated as $a_1$, $a_2$ and $a_3$, represent
the maximum surface densities achieved during the faint phase of the
ionization instability cycle. The critical mass transfer rate is \( \dot{M}_{\text{crit}}(r) \equiv \dot{M}(\Sigma_{\text{max}}(r)) \).

In Figure 2, we show the radial dependence of accretion rate in the faint phase, derived from our vertical structure model. The accretion rate is in Eddington units and the radius is in Schwarzschild radii. This dependence is well fitted with the power law function: \( \dot{m}(r) \sim r^{-2.3} \).

The effective temperature of the accretion disc scales with radius as \( T(r) \sim (\dot{M}(r)/r^3) \) and for the stationary accretion disc this relation gives \( T(r) \sim r^{-0.75} \), while in our model we obtain \( T(r) \sim r^{-0.175} \). The approximate spectral slope is given by the formula \( F_\nu \sim \nu^{3-p} \), where \( p \) is the index in the radial dependence of the temperature (Kato et al. 1999). In the first case it results in \( F_\nu \sim \nu^{1/3} \). In the latter case it becomes \( F_\nu \sim \nu^{-8.4} \), however as the outer disc temperature is not very much smaller than the inner disc temperature, the resulting spectrum looks practically like a single black body. None of these, however, is observed in the Seyfert galaxies, for which the optical/UV spectral indices are in the range from -1.9 to -1.2 (e.g. Edelson & Malkan 1986). For NGC 7469 the spectral slope in the optical band is \( \sim -1.69 \) (see also Nandra et al. 1998), while for the faint state of NGC 4151 it is \( \sim -1.7 \) (Lyutyi & Doroshkevich, 2000).

Therefore our conclusion is, that even if the instability processes may affect the emitted optical spectral slope, nevertheless the non-negligible effect of starlight component should be taken into account.

In Figure 3, we show the example of the starlight spectrum, taken to
FIGURE 2. The radial dependence of accretion rate (vertical structure model parameters: \( M = 10^8 M_\odot, \alpha = 0.03 \)). The accretion rate is given in Eddington units. The dashed line represents the power law function \( \dot{m}(r) \sim r^{2.3} \).

be the spectrum of the nuclear bulge of M31 galaxy, as in Kuraszkiewicz et al. (1997). It is compared with the power law spectrum of the index -1.9 (e.g. NGC 4051, NGC 3516, Mkn 231). We conclude, that the starlight contribution may be responsible for this spectral slope, however it must extend to shorter wavelengths. Clearly more young, blue stars are needed in this case to account for this shape of the spectrum.

REFERENCES

Alexander D.R., Johnson H.R., Rypma R.L., 1983, ApJ, 272, 773
Done C., et al., 1990, MNRAS 243, 713
Edelson R.A., Malkan M.A., 1986, ApJ, 308, 59
Hure J.M., 1998, A&A, 337, 625
Kato S., Fukue J., Mineshige S., “Black hole accretion discs”, 1999, Kyoto Univ. Press
Kuraszkiewicz J., Loska Z., Czerny B., 1997, Acta Astron., 47, 263
Lasota J.P., Hameury J.M., Hure J.M., A&A, 1995, 302, L29
Lightman A.P., Eardley D.M., 1974, ApJ, 187, L1
Lyutyi & Doroshkevich, 2000, JENAM Conf., Moscow
Nandra K., et al., 1998, ApJ, 505, 594
Różańska A., Czerny B., Życki P.T., Pojmański G., 1999, MNRAS, 305, 481
Seaton M.J., Yan Y., Mihalas D., Pradhan A.K., 1994, MNRAS, 266, 805
FIGURE 3. The starlight spectrum (solid line) compared with the power law $\nu F_\nu \sim \nu^{-0.9}$ (dashed line).

Siemiginowska A., Czerny B., Kostyunin V., 1996, ApJ, 458, 491
Smak J.I., 1984, Acta Astron., 34, 161