Evolution of the accretion disk in the nucleus of NGC 1097

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Abstract.

We discuss the long-term evolution of the broad double-peaked Hα profile of the LINER/Seyfert 1 nucleus of NGC 1097. Besides the previously known variation of the relative intensities of the blue and red peaks, the profile has recently shown an increasing separation between the two peaks, at the same time as the integrated flux has decreased. We successfully model these variations using a precessing asymmetric accretion disk with a varying emissivity law. We interpret the emissivity variation as due to the fact that the source of ionization is getting dimmer, causing the region of maximum emission to drift inwards (and thus to regions of higher velocities). In addition, in the last 3 yrs of observations, the central wavelength of the double-peaked line has shifted to bluer wavelengths, which may be due to a wind from the disk. It is the first time that such evolution is observed so clearly, giving additional support for an accretion disk as the origin of the double-peaked profile in NGC 1097.

1. Introduction

The recent developments in the study of the stellar kinematics around the nuclei of nearby galaxies (e.g. Ferrarese & Merrit 2000) and in our own support the presence of supermassive blackholes (hereafter SMBH) in the bulges of most present day galaxies. And if the SMBH are there, they will eventually accrete mass, e.g. via capture of a star passing close enough to the SMBH. If the SMBH has a mass smaller than \(10^8\) \(M_\odot\), a solar-type star will be tidally disrupted, leading to the formation of an accretion disk or ring (Rees, 1988).

We believe that such ring could be the source of the broad (\(\sim 10,000\) km s\(^{-1}\)) double-peaked Hα emission which we first observed in a spectrum of the nucleus of NGC 1097 obtained in 1991 (Storchi-Bergmann et al. 1993). Previous observations of the nucleus of this galaxy had only shown narrow emission-lines typical of a LINER. We have since then followed the variation of the double-peaked profile and discuss, in this work, the results of 10 yrs of monitoring. A more detailed study of these observations, including modeling of the ring (or disk) will be presented elsewhere.
2. Observed variations, interpretation and modeling

We have observed the nucleus of NGC 1097 using mostly long-slit spectroscopy at the CTIO Blanco telescope, approximately once a year. We show in Fig. 1 the broad double-peaked Hα profile in 4 epochs, which illustrate the main variations observed in the profiles.

In order to quantify the variations, we have measured the wavelengths of the blue and red peaks (λ_B and λ_R), their peak fluxes (F_B and F_R) and the total flux of the broad line (F_{broad}). Fig. 2 shows the variations of these quantities as a function of time: the wavelength of the blue peak decreases while that of the red peak increases, the flux ratio between the blue and red peaks varies between 0.5 to 1.5 and the total flux of the line decreases.

The variation of F_B/F_R supports the origin of the profile on an asymmetric disk or ring, which could be the elliptical accretion disk proposed by Eracleous et al. (1995) or a circular disk with a disturbance like a spot or spiral arm (Gilbert et al. 1999). The precession of the elliptical disk or of the disturbance in the circular disk would be the origin of the variation of F_B/F_R.

2.1. Are we witnessing the matter falling into the SMBH?

We have used the elliptical ring model described in Storchi-Bergmann et al. (1995, 1997) to try to reproduce the variations observed from 1991 to 2001, by changing only the orientation of the major axis of the ring relative to the line of sight Φ_0. Nevertheless, the observed shifts of the blue and red peaks could only be reproduced by decreasing the inner radius of the ring from 1300 gravitational radii (hereafter R_g) to 450 R_g. This result could suggest that this radius has decreased during the ten years of observations, and that we are witnessing the matter from the disk falling towards the SMBH! However, such a decrease should occur in the viscous time scale, which is about 10^3 yrs (Frank et al. 1992) in
An alternative possibility is that the ring has always had a smaller inner radius of 450 R_g (and can now most properly be called a disk), but the emissivity is changing, such that in more recent epochs it is favoring the inner regions of the disk relative to the outer ones. This picture is also in agreement with the observational result that the flux of the broad line is decreasing, as shown in Fig. 2. The emissivity law which best reproduces the observations is a double power-law as a function of the radius, such that the emissivity increases from the inner radius until a radius \( \xi_q \) and then decreases beyond \( \xi_q \). The increasing separation between the blue and red peaks in an elliptical disk with the above emissivity law is due to the fact that the region of maximum emission is getting closer to the source.

The fit of this model to the profiles is shown together with the data in Fig. 1. These fits have evidenced another change in the profiles beginning by 1997: we had to introduce a blueshift of the lines of \(-500\, \text{km s}^{-1}\) in order to reproduce the most recent profiles. This is illustrated in Fig. 2, which shows the fit to the Sep. 2001 profile before (dotted lines) and after the blueshift.

3. Conclusions

The variation of \( F_B/F_R \) supports the origin of the profile on an asymmetric disk. The increasing separation of the blue and red peaks indicates that the broad-line emission is coming from regions of successively larger velocities and thus smaller radii, at the same time as the broad line flux is decreasing. The
favored interpretation is that the ionizing source is getting dimmer, causing the region of maximum emission to drift inwards (Dumont & Collin-Souffrin 1990). We have successfully modelled this evolution using an elliptical disk model, with a varying emissivity law, as illustrated in Fig. 3. The blueshift of the line which has appeared by 1997, suggests that we are witnessing the formation of a wind, with velocity consistent with those observed for Fe II absorption lines in an HST UV spectrum of NGC 1097 (Eracleous 2002) and with absorption systems in general observed in the spectra of active galaxies.

Our observations and consistent modeling show that the double-peaked emission in NGC 1097 present many ingredients predicted by accretion disk models (Elvis 2000), giving stronger support yet for its presence around a nuclear SMBH in this galaxy.

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