1-3-DAY VARIATIONS OF THE BROAD EMISSION LINES OF SEYFERT NUCLEI

Nikolay G. Bochkarev
Sternberg State Astronomical Institute
Moscow
USSR

ABSTRACT. One of the principal problems of investigation of AGNs is to understand the nature of the central objects and the physical processes which yield their gigantic luminosities. This requires us to consider the innermost parts of AGNs (3-30 gravitational radii, i.e. $\lesssim 10^{16}$ cm: angular size less than 1 milliarcsecond).

$1\text{-}3^d$ variations of the relative shape of broad emission line profiles of active galactic nuclei (AGN) are perhaps the most informative probe of the innermost parts of AGNs ($r = 10^{15-16}$ cm from the centre). Optimal objects for these observations are Sy 1.5 with strong variations of the non-thermal continuum (e.g. NGC 4151). The expected amplitude of the variations ranges from a few percent to 10-20%. The optimal spectral resolution is 0.5-5 Å. It is very desirable to complement spectral observations with photometric data. The results of the first set of such observations with the 6-meter telescope are reported.

1. SELECTION OF THE SPECTRAL RANGE

Radio observations give proper angular resolution but free-free absorption does not permit to see regions with $\int n_e^2 dl > 10^{28}$ cm^{-5} (n_e - electron column density), which corresponds to obscuration of radiation with $\lambda > 1$ cm. For $n_e > 10^9$ cm this gives an upper limit to the column density $N < 10^{19}$ cm^{-2}. Gamma-rays permit to search matter with $N \lesssim 10^{26}$ cm^{-2}, but AGNs emit a very small quantity of such photons. Moreover, high energy gamma rays with $N = 10^{26}$ cm^{-2} have a continuum spectrum which gives very poor information in comparison with spectral lines. This is also the case for X-ray spectra of AGNs which have almost no prominent spectral lines. BL Lac objects may give a chance to see the innermost parts of nuclei, but the absence of spectrum lines does not allow us to understand their spatial structure. Thus, the most informative ranges are the optical and the UV, where it is possible to reach regions with $N = 10^{24}$ cm^{-2} and where numerous spectral lines are present.

E. Ye. Khachikian et al. (eds.), Observational Evidence of Activity in Galaxies, 219–222.

2. DIAGNOSTIC POSSIBILITY OF EMISSION LINE PROFILES

Until now clear observational data are absent on geometry and kinematics of gas in AGN's. So we do not know how matter inflows into the central object, nor do we know the behaviour of matter around this object. Therefore we do not know how the "machine" giving the huge luminosities of AGNs operates and what acts as "food" for it. Jets give information only about a part of the outflowing gas. The main reason for the absence of a definite picture is the difficulty with the interpretation of the profiles of emission lines. This is so because the nuclear gas is sufficiently transparent and it is difficult to distinguish cases of inflow and outflow of the matter.

Variations of profiles of lines can permit to distinguish at least these two cases and the cases of accelerated and decelerated motions. Thus the study of variability can provide solid observational foundations for a theory of AGN's (Fabrika, 1980; Bochkarev and Antokhin, 1982; Antokhin and Bochkarev, 1983).

The reason for such powerful diagnostic properties of profile variability is the following. Strong and fast variations of AGN X-ray flux show that variations of intensities of broad lines on timescales from days to months are responses of the gas envelope to the X-ray bursts. During the first moments after the X-ray bursts only the line-of-sight gas "senses" the changes of the X-ray flux. But the average gas density increases strongly to the centre, so the earliest variations of UV/optical line profiles are a result of a reaction of the innermost parts of the gas, namely the gas clouds at distances of 10^{15} - 10^{16} cm from the centre (Bochkarev and Antokhin, 1982; Antokhin and Bochkarev, 1983).

One to two months after an X-ray flare all the matter in the broad line region (BLR) changes emissivity and we can find the initial shape of the line profile with the same or changed intensity. Thus, it is necessary to search broad line profile variations on a timescale $t \ll t_c = r/c \approx 30^d$ that is with $t \lesssim 3\text{-}10^d$. The timescale t_c is obtained from the observations of Cherepashchuk and Lyutyi (1973), and Lyutyi and Cherepashchuk (1974) of the delay of broad line variations after the optical continuum changes. Variations with timescales less than $0.3\text{-}1^d$ are expected to be negligible (Bochkarev and Antokhin, 1982; Antokhin and Bochkarev, 1983) because only a very small volume of BLR matter changes emissivity (see details in Bochkarev, 1986). Thus, the best timescale is $1\text{-}3^d$.

3. SELECTION OF OBJECTS FOR OBSERVATIONS

The best type of objects for investigating $1\text{-}3^d$ line profile variability are Sy 1.5. This is because QSOs and most Sy 1's have large, optically thick BLRs with $t_c \gg \tau$, where τ is the time between X-ray bursts. During $t \ll \tau$ only a very small part of the gas can change emissivity and the profile variations will be negligibly small. The least active nuclei (LINERs and Sy 2) probably have a small quantity of gas around the central object. Therefore we can see the innermost

https://doi.org/10.1017/S0074180900155172 Published online by Cambridge University Press

parts of the nuclei, but variations of the X-ray fluxes from these types of AGN's occur very seldom (if at all). Until now these variations have not been found (Elvis and Lawrence, 1985). As a result we cannot recognize kinematics or structure of the gas envelopes. BL Lac objects are also not adequate because of absence of measurable spectral lines.

Thus, the best objects are those with a moderate to small quantity of gas in the central regions (BLR) but with observed fast and strong X-ray variability (and fast and strong variations of the emission line intensities). Several Sy 1.5 are very adequate objects for such observations (e.g. NGC 4151 and NGC 3516).

4. EXPECTED AMPLITUDE OF THE VARIATIONS

Bochkarev and Antokhin (1982), Antokhin and Bochkarev (1983) calculated variations of Hβ profiles on timescales from 8 hours to several days for a model nucleus having 1000 clouds with typical parameters in the BLR. 1000 clouds is a small quantity for a typical BLR, but the best periods for observations correspond to moments of deep minima of AGN brightness. In these periods the BLR has a very small quantity of gas (temporal change of an AGN from Sy 1 to Sy 2, see e.g. Lyutyi et al., 1984) and the non-thermal continuum is weak. Therefore in these periods the predicted effect is expected to have the largest contrast. Our calculations with 10^3 clouds correspond to an intermediate case and predict relative profile variations of 2-5% during $\sim 1^d$ for a spectral resolution 10 Å and a variation of X-ray flux by a factor of 2.

The optimal spectral resolution in the optical is $\Delta\lambda \approx 0.5$ Å because it is approximately the $\Delta\lambda$ of radiation of an individual cloud ($\Delta V \approx$ 50-60 km/sec = 2-3 c_s; c_s is sound speed). The expected amplitude of profile variations increases with spectral resolution and can probably reach 10-20%. The upper limit is determined by variations of the volume emissivity of the BLR cloud gas (~ 40-50% for Hβ after a variation of X-ray flux by a factor of 2, Bochkarev and Pudenko, 1975).

5. OPTIMAL PROGRAM FOR OBSERVATIONS. THE FIRST OBSERVATIONAL SETS

The expected amplitude of the variations is so small that it is very desirable to have simultaneous observations of several lines. This requires a wide spectral range: ideally in the optical and in the UV at the same time, e.g. HeII λλ1640 and 4686 Å. The UV range is preferable because of small continuum opacity and because of the presence of broad lines with collisional excitation (CIV 1550 Å and others). Therefore it is not surprising that the most spectacular line profile changes have been observed in NGC 4151 in the UV range (Ulrich et al., 1985).

Bochkarev (1984) has initiated a program of research of night-to-night variations of optical broad lines. The first two sets of observations of NGC 4151 (six-night and five-night intervals) were made with the 6-meter telescope in 1983. A 700 Å range of spectra near Hβ and HeII λ4686 Å was observed with the TV spectral scanner and a spectral resolution 1.4 Å per channel. There are some apparent changes (10-20%) near the wavelength 4740 Å between Hβ and 4686 Å. Qualitatively these changes are very similar to a variable component of the UV CIV line from Ulrich et al. (1985), but only one variable component was found and its velocity does not correspond to the data of Ulrich et al. The absence of simultaneous photometrical data does not allow to distinguish between real line profile changes and apparent changes of the ArIV line during a variation of the continuum.

One month of observations of NGC 4151 and NGC 3516 has been made with the 6-meter TV spectral scanner during March and April 1986 (Bochkarev and Shapovalova, in preparation). A 900 Å range of spectra between Hβ and Hδ was observed with spectral resolution 0.9 Å. The Hβ profile of NGC 4151 was very asymmetrical in March of 1986. This asymmetry was present during the whole period of the observations. Episodic photometric observations show that both galaxies have had non-active behaviour and NGC 4151 had low brightness.

6. CONCLUSIONS

1-3^d variations of broad emission line profiles are presently the only method to "penetrate" into AGN's down to $r = 10^{15} - 10^{16}$ cm and to investigate this region. The optimal type of objects for these observations are the nuclei of Sy 1.5 galaxies, especially in periods of minima of brightness when a small quantity of gas near the centre can permit to investigate the deepest parts of the nucleus.

The Hubble Space Telescope is the best instrument for this purpose because it has high S/N spectrographs and conditions for simultaneous observations in optical and UV ranges.

REFERENCES

Antokhin, I.I., and Bochkarev, N.G.: 1983, Sov. Astron., **60**, 261.
Bochkarev, N.G.: 1984, Sov. Astron. Lett., **10**, 239.
Bochkarev, N.G.: 1986, in Active Nuclei and Stellar Cosmogony, eds. Martynov, D.Ya. et al., Moscow University Press.
Bochkarev, N.G., and Antokhin, I.I.: 1982, Sov. Astron. Circ., **1238**, 1.
Bochkarev, N.G., and Pudenko, S.P.: 1975, Sov. Astron. Lett., **1**, 51.
Cherepashchuk, A.M., and Lyutyi, V.M.: 1973, Astrophys. Lett., **13**, 165.
Elvis, M., and Lawrence, A.: 1985, in Astrophysics of Active Galaxies and Quasi-Stellar Objects, ed. Miller, J.S., Univ. Sci. Books, p. 289.
Fabrika, S.N.: 1980, Sov. Astron. Circ., No. **1109**, 1.
Lyutyi, V.M., and Cherepashchuk, A.M.: 1974, Sov. Astron. Circ., No. **831**, 1.
Lyutyi, V.M., Oknyanskij, V.L., and Chuvaev, K.K.: 1984, Sov. Astron. Lett., **10**, No. 11.
Ulrich, M.-H., et al.: 1985, Nature, **313**, 747.