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MODELS RELATING THE RADIO EMISSION AND IONISED GAS IN SEYFERT NUCLEI

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SUMMARY

We discuss possible models in which the radio emitting components in Seyfert II nuclei can compress and accelerate the ambient nuclear medium to produce the characteristics of the narrow line region. A first order model (Pedlar, Dyson & Unger 1985), which considers only the expansion of the radio components, is briefly described. However, in many Seyfert nuclei it appears that the linear motion of the radio components is also important. This can result in shock heating of the ambient medium, and if the cooling time is long enough, can lead to a displacement between the radio component and the associated [OIII] emission lines. This effect may be present in NGC1068 (Meaburn & Pedlar 1986), and NGC5929 (Whittle et al. 1986) and by considering ram pressure balance and the cooling length it is possible to estimate lobe velocities and ambient densities.

i) INTRODUCTION

The relationship between the radio continuum and the optical forbidden line regions (FLR) was first investigated by de Bruyn and Wilson (1978) who showed that a correlation existed between the 21cm radio continuum power and the luminosity of the 5007A [OIII] line. High resolution studies using MERLIN and the VLA have confirmed that the two regions are physically associated as not only do they have similar linear extent (100-1000pc), but also there appears to be approximate pressure balance (~10^{-9} dynes cm-2) between the relativistic electrons/magnetic fields and the thermal electrons in the FLR gas.

Many Seyfert nuclei show elongated or double radio structure which strongly suggests that collimated ejection from the optical nucleus is taking place. By analogy with classical radio sources this has lead to the suggestion that a collimated beam is responsible for the radio emission. Hence, models involving the interaction of such beams with FLR clouds (Wilson 1983, Booler, Pedlar & Davies 1982) have been used to account for the relationship between the radio continuum emission and the FLR. There are, however, theoretical difficulties with such models, as the FLR clouds are unlikely to remain coherent entities whilst being accelerated to velocities many times their internal sound speed (Nittman et. al. 1982). Furthermore, in those cases where the [OIII] lines are well resolved (eg NGC1068 Meaburn & Pedlar 1986), there seems little evidence to support such a model.

As the very existence of such beams is in doubt, their parameters are, of course, highly uncertain. As the masses and sizes of the FLR clouds are also unknown, the combination of these two phenomena leads to somewhat unconstrained series of models. Unlike the proposed beams, the properties of the radio emitting components are reasonably well defined (Unger et. al. 1986) and it seems much more reasonable to consider initially the interaction of these components with the nuclear environment.

ii) RADIAL EXPANSION OF THE RADIO COMPONENTS

The pressure of the relativistic gas in some of the radio emitting components appears to be greater than the thermal pressure of the ionised gas in the forbidden line region (Unger et. al. 1986). This led us to develop a simple model (Fig. 1) in which the radio components expand radially in a stationary medium, and in doing so shock heat and compress the ambient medium in the nuclear vicinity (see Pedlar, Dyson and Unger 1985). When the gas cools to $\sim 10^4$K it will be ionised by photons from the optical nucleus. This model readily explains the close physical connection between the radio emission and the FLR gas and can account for a number of global FLR properties such as linewidths, filling factors and densities. Also, as the gas is compressed by shocks rather than existing as individual clouds, it does not require a confining medium.

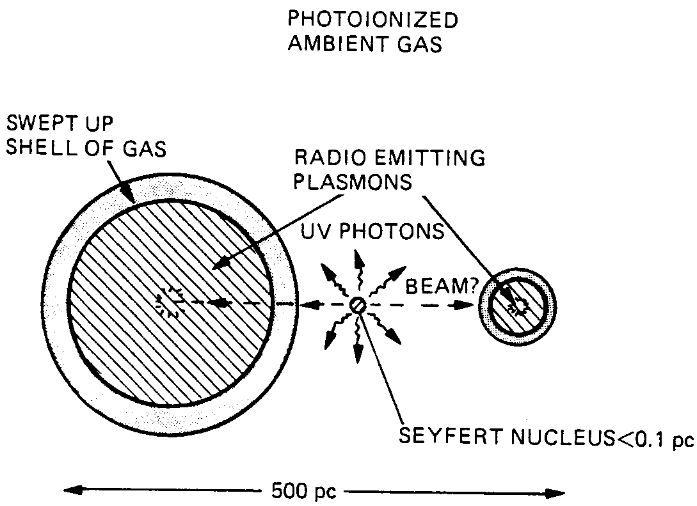

Fig. 1 Schematic diagram for the expanding radio component model. See Pedlar et. al. (1985) for a full discussion of this model.

This model predicts that much of the FLR gas will be associated with individual radio components, and that line splitting up to ~1000km/s could be observed. Unfortunately, although the radio structure is well resolved, conventional optical techniques do not have the angular resolution to determine whether the FLR components of most Seyfert II nuclei are associated with the radio components. One exception is the nucleus of NGC1068, which has an angular extent of ~8 arcsec. In this case it appears that the NE east radio component is associated with Walker's (1968) clouds I and III and exhibits line splitting of order 1000km/s (Meaburn & Pedlar 1986). The radio structure of this component (Wilson & Ulvestad 1983), however, suggests that linear motion, as well as radial expansion is taking place which should be taken into account. We have surveyed a number of Seyfert nuclei using long slit spectroscopy and in a number of cases we have found evidence that FLR components are associated with individual radio components. The clearest example is NGC5929 (see Fig. 2) in which the FLR structure closely matches the radio double, showing two distinct velocity components.

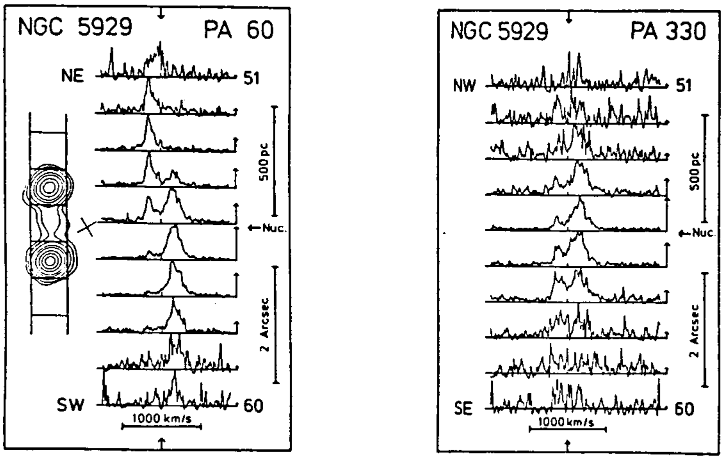

Fig. 2 [OIII] 5007A profiles along and orthogonal to the radio axis of NGC5929. See Whittle et. al. (1986) for further details.

These components lie in the same position angle as the radio components but lie slightly inside them. These observations are described in full by Whittle et. al. (1986). The linewidths of the individual FLR are relatively narrow and much smaller than would be expected to be produced by the radial expansion of stationary radio components. We suggest that the radial expansion is reduced by ram pressure due to their linear motion through the ambient gas, which, as we shall show below, can also account for the displacement between the radio and FLR components.

iii) LINEAR MOTIONS OF THE RADIO COMPONENTS

The model described by Pedlar, Dyson, and Unger assumes that the radio components expand into a stationary ambient medium. If the radio components bave been ejected from the nucleus then this approximation will only be valid after they have been braked by ram pressure of the ambient medium. Hence, in the early stages they are ram pressure confined and their linear velocity will be greater than their expansion velocity. We shall, therefore, consider the effects on the nuclear environment of linear, supersonic motions of the radio emitting components. As in the previous model we will assume that there are sufficient UV photons from the optical nucleus to ensure

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that gas in the vicinity of the radio components is completely photoionised. Hence, as the emission line intensity increases as the square of the density, compression of the ambient medium due to interaction with the radio lobes will result in a local enhancement of [OIII] emission (Fig. 3).

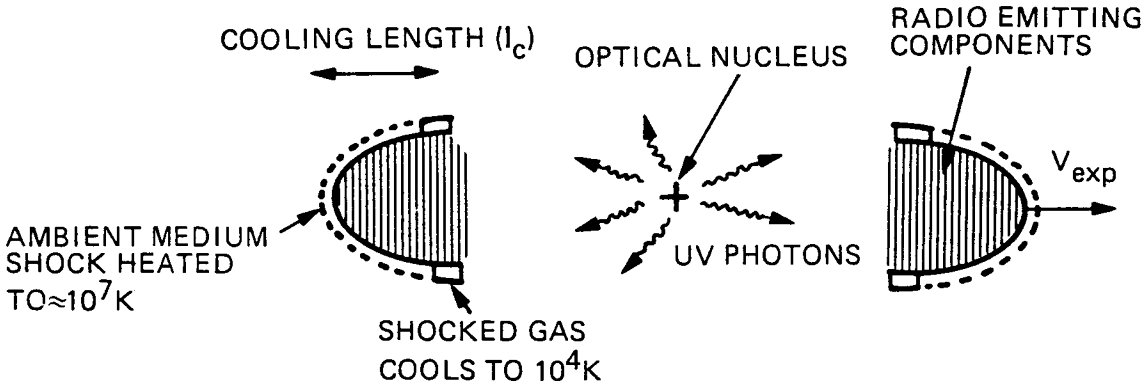

Fig. 3 Schematic diagram for the moving radio component model. The ambient medium is shock heated and compressed into a shell, and cools downstream to ~10^4 K after which it is photoionised by UV photons from the continuum nucleus.

In order to confine the radio components the pressure of the relativistic particles in the lobe (Prel) must be approximately balanced by ram pressure of the lobe moving through the ambient medium. Hence,

$$\mathrm{Prel} = \rho v^2 = 1.7 \times 10^{-14} n_a V_s^{\,2} \text{ dynes cm-2} \qquad (1)$$

Where n_a is the ambient proton density in cm^{-3} and Vs is the lobe velocity in km/s. As the lobe velocity will, in most cases, be supersonic it will drive a shock into the ambient medium. This will shock heat the medium in the vicinity of the lobe to

$$T_s \sim 14\, V_s^{\,2} \text{ K} \qquad (2)$$

with an associated cooling time

$$t_c \sim 3.2 \times 10^3\, n_s^{\,-1}\, T_s^{\,3/2} \qquad (3)$$

Where $n_s = 4n_a$ is the immediate post shock density. Thus, if the lobe velocity exceeds 270km/s the gas will be shock heated to >10^6K and will have relatively long cooling times. Even in the presence of a strong UV field such gas will not emit significant optical lines until it cools. During this cooling period the radio component will move a distance ~tcVs and, consequently, there will be a linear displacement between the radio lobe and the gas which has cooled sufficiently to emit optical spectra. This cooling length will be approximately given by

$$l_c \sim t_c V_s \sim 1.4 \times 10^{-9} n_a^{\,-1} V_s^{\,4} \text{pc} \qquad (4)$$

From the displacement between the [OIII] and radio components in NGC5929 we can estimate the cooling length to be ~50pc, and, hence, from equations 1 and 4 and the value of Prel derived from the radio continuum parameters we can estimate Vs to be ~700km/s and Na to be 7 cm-3. If we interpret the 200pc displacement between the front of the radio lobe and FLR gas in NGC1068 (Meaburn & Pedlar 1986) also as a cooling length then using Prel from Pedlar et. al. (1983) we can derive a lobe velocity of 600km/s and an ambient density of 0.7 cm-3. Note that for lobe velocities of this magnitude, even components of the interstellar medium with temperatures as high as 10^6K (ie sound speed ~150 km/s) will be compressed by a strong shock.

More detailed modeling of the ram pressure confined radio lobe and its interaction with the ambient medium are required to predict the detailed velocities and line profiles of the [OIII] emitting gas.

iv) ACKNOWLEDGEMENTS

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