HIGH SPATIAL RESOLUTION OBSERVATIONS OF THE QUASAR MR2251-178

F. Macchetto[1,2], M.A.C. Perryman[1] and S. diSerego-Alighieri[1,3]
[1] Affiliated to Astrophysics Division, Space Science Department, European Space Agency
[2] Space Telescope Science Institute, 3700 San Martin Drive, Homewood Campus, Baltimore, MD 21218 USA
[3] Space Telescope-European Coordinating Facility, ESO, Garching, FRG

ABSTRACT. The possibility that quasars are activated by interactions between galaxies has received considerable attention following the discovery of extended emission surrounding many low and moderate red-shift quasars, and the distored morphological appearances of some of these extensions. We have obtained high resolution narrow-band optical images of the field of the low-redshift quasar MR2251-178 which reveal, in addition to nebulosity closely associated with the quasar, diffuse line-emitting regions separated by up to 100 kpc from the nucleus but kinematically associated with it. We attribute these regions to density perturbations of the gaseous envelope or disc now known to rotate about this quasar, caused by a tidal interaction between the quasar and a nearby active galaxy in the same cluster. Limits of between 2-4 x 10^8 years can be placed on the time elapsed since this interaction.

1. INTRODUCTION

The nearby quasar MR2251-178 is at a redshift of z=0.064 and lies within a small cluster of galaxies (Phillips, 1980). The quasar was discovered on the basis of its X-ray emission by Ricker et al. (1978) and was known to have an extended nebulosity surrounding the stellar core.

This prompted Bergeron et al. (1983) to carry out extensive long-slit spectroscopic observations of the quasar, the associated nebulosity and the nearby galaxies in the cluster. These observations resulted in the discovery of a halo of ionized material surrounding the quasar, evidenced by the presence of a weak emmission of [OIII] $_1$4959/5007/, at distances of up to 200 kpc from the quasar (Ho=50 km s^{-1} Mpc^{-1}).

The rotation curve shows a central velocity gradient of 17 km s^{-1} kpc^{-1} out to 6 kpc, a small dip near 10 kpc, rising to a maximum of about 180 km s^{-1} kpc^{-1} at about 120 kpc to the southeast and reaching a value of -60 km s^{-1} kpc^{-1} at distance larger than 25 kpc in

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the northwest. A total mass of $10^{12} M_\odot$ can be inferred to lie within a radius of 200 kpc from the quasar. From energy balance considerations, the gas was postulated to surround the quasar in the form of a disc.

These long-slit observations of the ionized region were, however, only obtained in a few selected directions. Therefore, the mapping of the extent and kinematics of the halo was incomplete. This did not allow Bergeron et al. to clearly attribute the origin of the ionized gas to either the interstellar matter of a galaxy underlying the quasar or to material being accreted by the quasar.

2. EARLY IMAGING OBSERVATIONS

The evident importance of the [OIII] line emission as an indicator of the environment of the active nucleus of the quasar and the uncertain nature of the underlying nebulosity and giant envelope led us to undertake narrow-band imaging observations of the field of MR2251-178 (di Serego-Alighieri, Perryman and Macchetto, 1984). These observations were carried out at the ESO 3.6m telescope at La Silla using the ESA Photon Counting Detector (di Serego-Alighieri, Perryman and Macchetto, 1985) developed as a prototype for the ESA Faint Object Camera on the Space Telescope. Narrow-band interference filters were used to isolate the lines of redshifted H_b, [OIII] and the nearby continuum.

Differential images were constructed to put in evidence the morphology of the line emitting gas. The Hb-Continuum image is quite flat and does not show any evidence for small or large scale structure. Conversely, the [OIII]-Continuum image (Fig. 1) shows the filamentary nebulosity associated with the nucleus along with regions of extended [OIII] emission further from the nucleus.

The emission close to the nucleus shows predominantly a westward elliptical extension up to 13" (≃ 22 kpc) from the nucleus. Additional condensations (K) and filamentary structures are seen to the northwest.

Further from the nucleus, the emission includes three prominent regions (A, B, C) about 25" (40 kpc) to the east of the quasar, forming an arc some 18" (30 kpc) in extent. A more diffuse region (D) extends from 40"(70 kpc) southwest to 60" (100 kpc) to the west while another prominent region (E) is at some 30" (50 kpc) to the northwest.

In di Serego, Perryman and Macchetto (1984), SPM, we argued that the inclination angle of the disc structure is likely to lie in the range i = 30°-50°, based upon subjective measurements of the axial ratio of the extended emitting regions assuming circular outer structure. The rotation curve derived by Bergeron et al. and corrected for in this way bears a quantitative similarity to the rotation curves for spiral galaxies. The maximum diameter of theemitting structure would be some 140 kpc from region C to the westernmost extension of region D. This is very large compared with the optical diameters of normal spiral

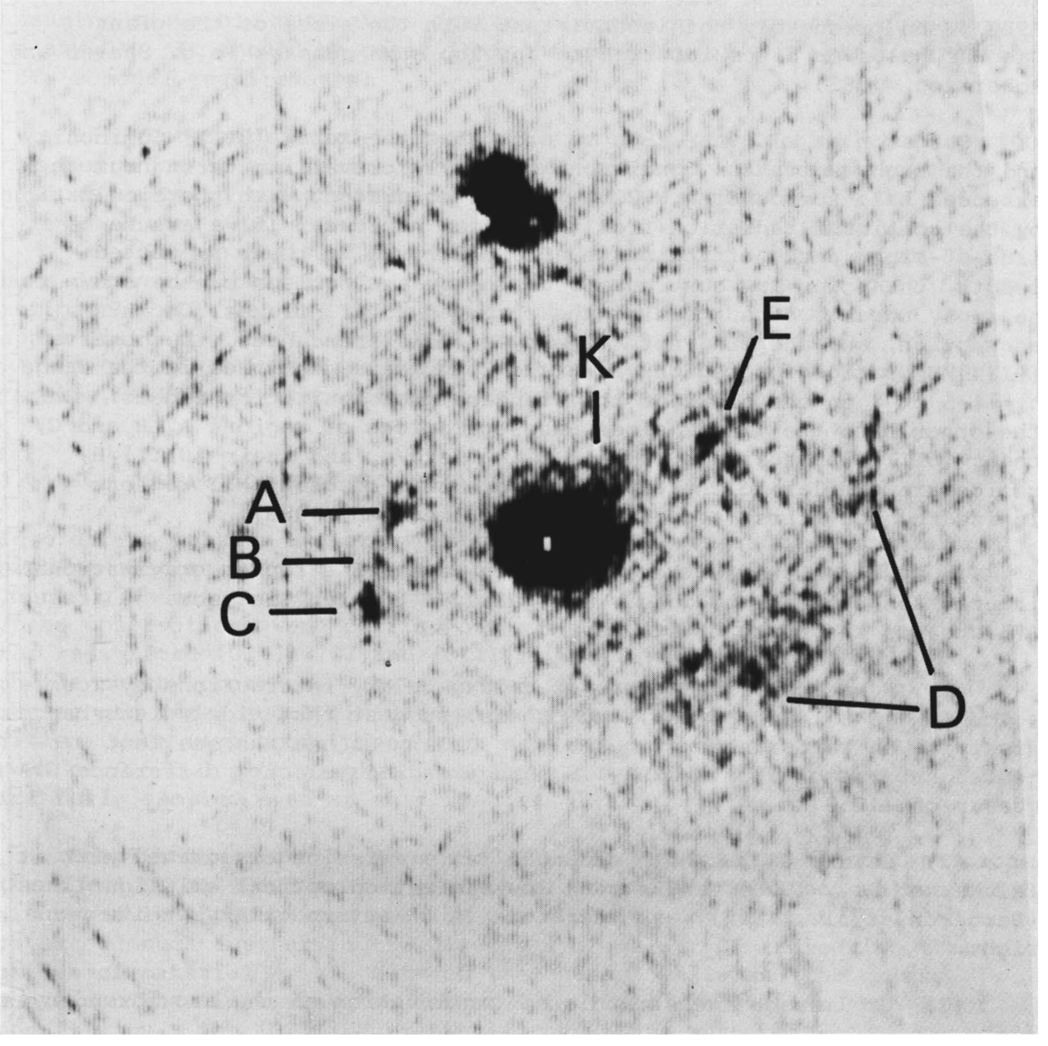

Figure 1 - Narrow-band [OIII] image of the field surrounding the quasar MR2251-178. This was obtained by subtracting an image of the nearby continuum from the [OIII] emission image. North is at the top and east is on the left.

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galaxies, althought comparable to the scales of extended HI envelopes known to exist around some nearby spirals (e.g. Huchtmeier & Richter, 1982), and presumably not inconsistent with the sizes of the giant gaseous halos or discs inferred to envelop some quasars (e.g. Shaver and Robertson, 1983).

Bergeron et al. were able to show that the total [OIII] luminosity and the high-excitation conditions generally prevailing throughout the extended halo surrounding MR2251-178 are consistent with photoionization by the continuum radiation from the active nucleus. If we assume a line-of-sight depth of regions A, B and C equal to their projected length, the power-law continuum from the quasar nucleus can be shown to be amply capable of supporting the observed [OIII] fluxes. On this assumption, and adopting normal heavy-element abundances, the observed [OIII]/H_β ratios for regions A, B and C indicate densities in the range $n = 1$-$5\ cm^{-3}$ on the basis of the standard photoionization models. On the other hand the linear sizes and separations of regions A, B and C, their [OIII] luminosities of 5-11 x 10^{40} erg/s, and their [OIII]/H_β ratios are similar to the expected properties of giant HII regions ionized by hot stars (e.g. Elmegreen & Elmegreen, 1983).

In SPM we stressed the evidence in favor of a recent gravitational interaction between the quasar and galaxy G1, which lies some 40 arcsec (75 kpc) to the north of it, having occured:

(1) Numerical simulations of galaxy-galaxy interactions by Toomre & Toomre (1973), Icke (1984) and others, suggest that tidal disturbances dissipate on rather short timescales. Galaxy G1 has the smallest projected separation from MR2251-178, and a radial velocity difference G1-quasar of +1250 km s^{-1};

(2) Galaxy G1 has both extended ratio emission associated with it (Ricker et al., 1978), and strong low-ionization optical emission lines (Bergeron et al., 1983), and therefore is an active galaxy in its own right;

(3) G1 lies on an extrapolated continuation of the arc formed by regions A, B and C;

(4) The models of Icke (1984) allowed us to extimate velocity perturbations in the gaseous quasar envelope induced by a prograde, coplanar interaction between a disc system and a galaxy of comparable mass, in an attempt to predict the effects of such an encounter. In these models the perturbations in the gaseous envelope are approximated by:

$$v(pert) = 4\pi g v\ (R/b)^3$$

where v is the circular velocity in the perturbed galaxy, b is the impact parameter, R is the characteristic radius of the galaxy at which $M(R) = 0.5\ M(\infty)$, and the dimensionless constant $g = 0.39$. We have taken a lower limit of R = 20 kpc, V = 200 km s^{-1}, and arbitrarily taken B = 50 kpc, giving v(pert) = 60 km s^{-1}, considerably larger than the

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expected local sound speed. We have no satisfactory way of estimating b, but we conclude that shocks may have occured in the gaseous disc assuming plausible parameters for an interaction between the quasar and galaxy G1. It should be noted that the geometry of the system satisfies Icke's model requirements;

(5) Interaction models frequently predict countertidal features on the far sides of the interacting nuclei, and this could explain the diffuse emitting regions seen to the SW of the nucleus;

(6) On the basis of the ionization conditions within galaxy G1 we have derived a lower limit to the time elapsed since the proposed interaction of 2×10^{8} yr, and on the basis of the assumed cluster size an upper limit to this time of 4×10^{8} yr. A recent burst of star formation within galaxy G1 associated with the tidal encounter (e.g. Larson and Tinsley, 1978) may be consistent with this elapsed time.

3. HIGH RESOLUTION IMAGING OBSERVATIONS

In order to further explore this gravitational interaction scenario, high-resolution imaging observations were obtained with the ESA Photon Counting Detector at the Cassegrain focus of the 3.6m CFH Telescope. These observations were carried out with 40/ wide filters centered on the redshifted [OII]g3727 and [OIII]g5007 as well as 100/ wide filters on the nearby continua. The standard PCD format gave a scale of 0.155 arcsec per pixel and a field of view of about 80 arcsec. Seeing conditions were very good indeed with measured stellar profiles having a FWHM of 0.5-0.7 arcsec; given the above pixel size the stellar profiles are fully sampled even at this high resolution.

Results are shown in Figures 2,3 and 4. The chain of condensations (A, B and C) at 20-25 arcsec (f 40 kpc) to the east of the nucleus and discussed in the previous section are shown in the current [OIII] data to extend much further in the direction of galaxy G1 indicating that a bridge of material exists between the quasar's halo and the galaxy G1. These condensations are also detected in [OII] albeit with much lower sensitivity. The [OIII]/H_b ratio is compatible with that of an extended HII region. Star formation can therefore be taking place locally in these condensations although as already remarked the overall envelope can easily be ionized by the quasar's power spectrum.

In addition to confirm and expand the earlier observations in the extended halo, these data are of such high resolution that they allow us to explore in detail the central filamentary region around the quasar.

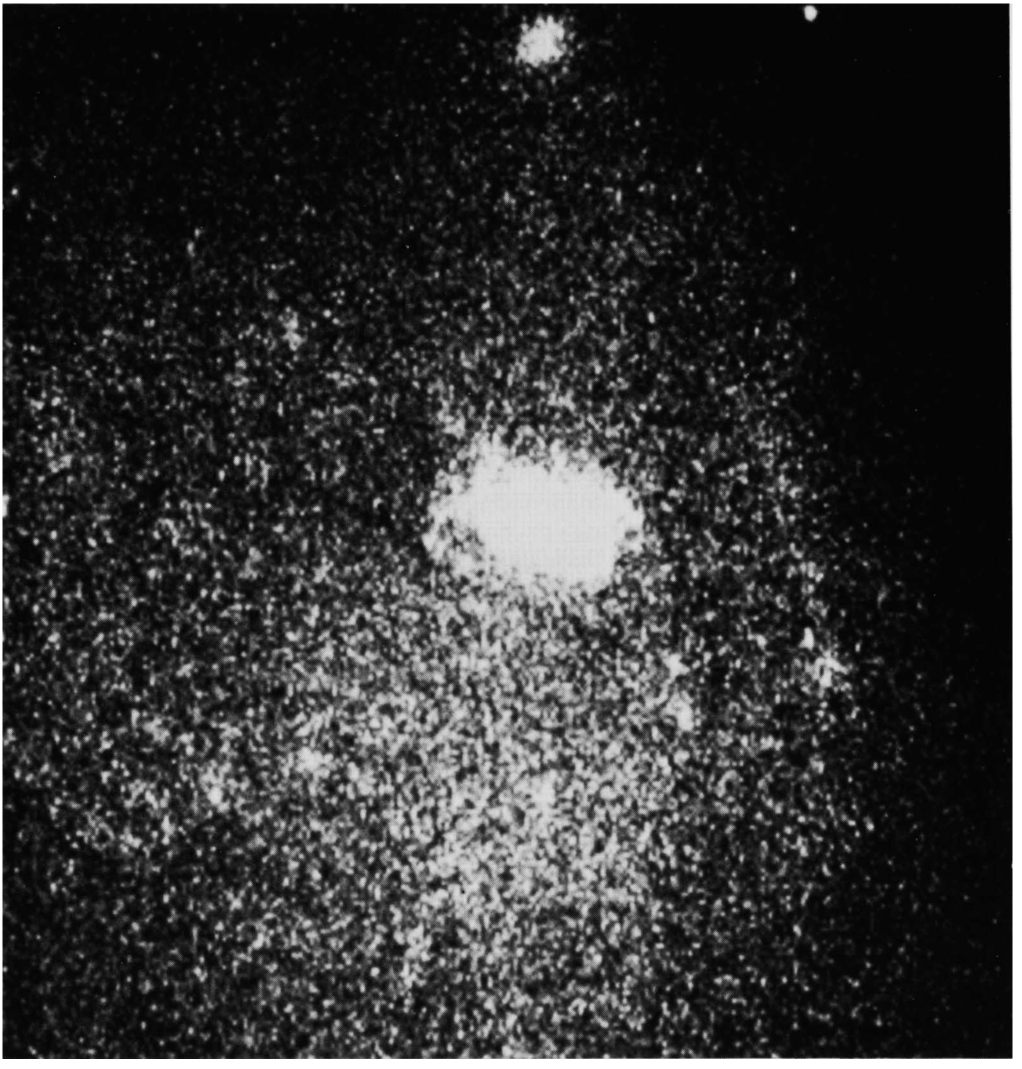

Figure 2 - High-resolution [OIII] line emission in the extended halo surrounding MR2251-178. Chain of condensations to the right (east in this photograph), point to galaxy G1 at the north (up). Condensations are also seen south, and south west of the quasar. Filamentary structure surrounds the inner region of the quasar.

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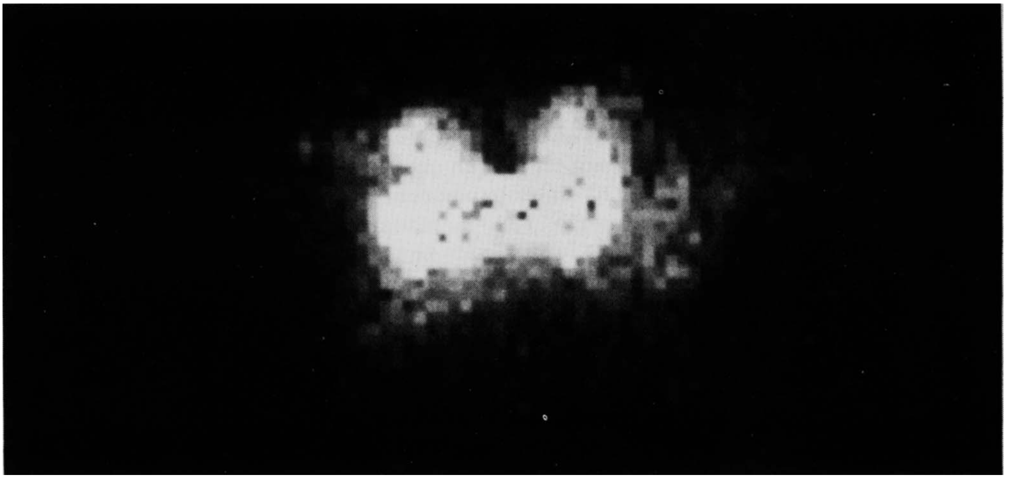

Figure 3 - High resolution [OIII] line emission surrounding the quasar MR2251-178. North is at the top and east to the left. Condensations and filaments extend to about 6 arcsec (10 kpc) to the west and 5 arcsec to the east.

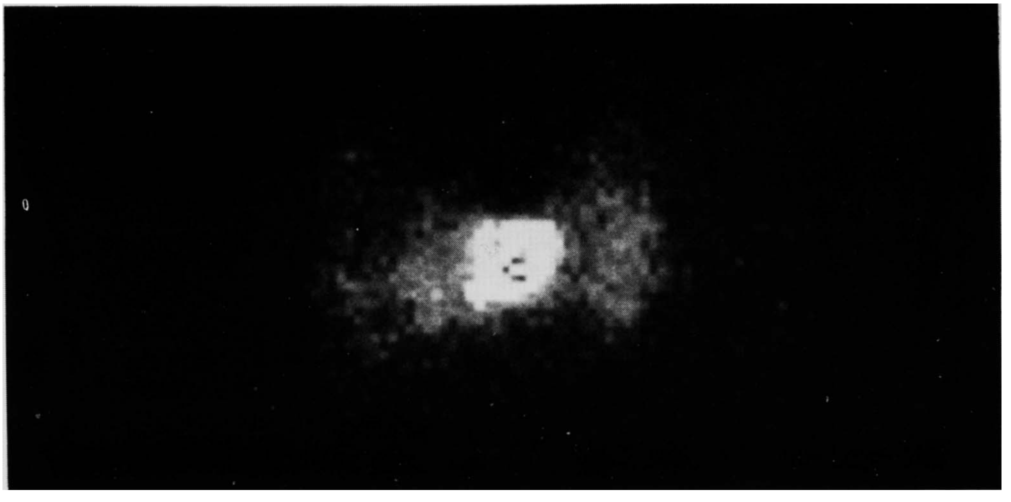

Figure 4 - As Fig. 3. The inner nebulosity is now seen to have two regions of enhanced emission at about 2.0 arcsec from the nucleus. The gas emission can also be traced all the way to the nucleus.

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Several filaments are seen to extend up to 17 arcsec (32 kpc) from the nucleus. The two main filaments point to the west and to the northwest, where emission was seen further out (SPM), and can be followed as close as 3 arcsec from the nucleus, where they merge with the inner nebulosity. The latter is resolved into two main regions: one centered at 2.0 arcsec (3.8 kpc) to the west of the nucleus, but well separated from it, and elongated in the north-south direction, and a second one to the east, more diffuse and with an enhancement at 1.6 arcsec (2 kpc) from the nucleus in position angle 120°. These regions in the inner nebulosity are seen also in [OII] but not in the continuum images.

In the framework of the gravitational interaction proposed by SPM, we suggest the following interpretation of this data. The recent passage of galaxy G1 near MR2251-178 produced a number of effects in the gaseous envelope surrounding the quasar: in the outer regions ($R > 35$ kpc) it created density enhancements, which appear largely unaltered since the time of the encounter, because of their long dynamical timescale. Star formation is likely to be taking place in these regions. However, the overall envelope is ionized by the quasar power spectrum. In the intermediate region ($5 < R < 35$ kpc) the filamentary structure is evidence of radial motions - possibly inward - of the gas left in unbound orbits after the encounter. In the inner region ($R < 5$ kpc), where a few rotation times have elapsed since the encounter, the gas is settling into a disc or annulus around the quasar, possibly warped by precession. The gas from this inner region may well be responsible for powering the quasar activity.

4. CONCLUSIONS

The current high resolution observations confirm our earlier suggestion that MR2251-178 is an example of tidal interaction. The outer halo extended condensations which point to galaxy G1 and the counter tidal features to the southwest can be ionized by the quasar's power spectrum, but can also be the place of current star formation.

A model for the flow of material into the nuclear region of barred spiral galaxies has been proposed by Tubbs (1982). In this model, gas is channeled into the galactic center along the bar following tidal interactions and distortions in the outer regions. The inner filaments and condensations show that gas is falling into the central region and settling into a disc around the quasar with the scenario of quasar activity being triggered by gas funneled into the core.

Our observations of MR2251-178 are in agreement with this scenario.

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DISCUSSION

WARD: Is there any evidence for extended X-ray emission co-spatial with the extended optical line emission?

MACCHETTO: No; the X-ray emission seems to be confined to the 3-5kpc region around the central QSO.

RUBIN: Is there any velocity information in the earlier [OIII] spectra? The spectra appeared to cover larger regions, and it would be interesting to know what they reveal.

MACCHETTO: The spectra of Bergerson et al., show a rotation curve derived from the [OIII] lines. It has a velocity gradient of 17 km s^{-1} kpc^{-1}, it shows a dip at ~10kpc and it has a maximum of 180 km s^{-1} at ~120 kpc. (Ho=50 km $s^{-1}kpc^{-1}$). This rotation curve is similar to that of a Sb or Sc galaxy.

YEE: Do you have an estimate of the richness of the cluster or group associated with the quasars?

MACCHETTO: The total number of galaxies in this group is of the order of 12.

HUTCHINGS: Gower and I have published a VLA map of 2251-178. It is compact and one-sided, and I do not recall any correspondence with the optical features.

MACCHETTO: Yes, I have read your paper and agree.

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TOVMASSIAN: Is this interaction scenario not the recovery of the hypothesis of collision proposed by Ambartsumian 30 years ago?

MACCHETTO: The scenario of activity triggered by tidal stripping has been given new impetus by both new observational evidence and models of galaxy/ galaxy encounters (Icke, 1984, Toomre and Toomre 1983). In the particular case of MR2251-178 the evidence points strongly to a tidal stripping which then sends matter towards the nuclear region. This may or may not be the cause of the QSO phenomenon but it is the cause for the condensation, both for (~70kpc) and close (1-3kpc) to the nucleus.

DULTZIN-HACYAN: I am somewhat afraid to make a nonorthodox comment, but all these last papers make me think that I've read that there was a time when all the astronomical establishment (except Ambartsumian) was convinced that the phenomenon of extended radiogalaxies (extended double lobes) was the result of collision of galaxies. At least in this form of activity we now know that Ambartsumian was right in pointing out the importance of outflowsof matter from the nucleus. Shouldn't we be more open minded towards the possibility of ejections of knots and splitting (of nucleus) and so on?

MACCHETTO: I agree that we should be open minded about the true interpretation of the mechanism in each case. However, in the case of MR2251-178 all the evidence at hand points towards matter falling towards the nucleus and perhaps feeding the QSO itself. This does not exclude a different scenario for other objects.

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