Multi - Frequency Observations of Multiple Nucleus Markarian Galaxies

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SUMMARY.
Multiple nucleus Markarian Galaxies may owe their origin to merging processes among galaxies. They may therefore be key objects for our understanding of galaxy evolution and the origin of nuclear activity. From morphological and multi-spectral data we show that these objects are in an unusually high state of dynamical and nuclear activity (starbursts, Seyfert activity) as would be expected from advanced stages of galaxy mergers.

INTRODUCTION.

Among the Markarian Galaxies many objects are found with double or multiple nuclear structure at their central regions. Often nuclei show starburst or Seyfert characteristics. Some prominent examples of such "multiple nucleus galaxies" are discussed in this contribution. The nuclei of the selected objects are well separated on optical CCD-images, and their linear separation is of the order of a few kpc. The nuclei are surrounded by common envelopes.

An investigation of the origin and the properties of these multiple nucleus galaxies is considered to be of key importance for an understanding of merging processes and the origin of nuclear activity. These objects may represent late stages of galaxy mergers and may owe their nuclear activity to interaction processes among their host galaxies. A detailed study of such mechanisms in closeby objects is promising in view of the evidence that starburst, Seyfert and quasar activity is likely to be triggered and maintained by galaxy interactions.

Recently we have embarked on a systematic investigation of a larger sample of multiple nucleus Markarian galaxies using multispectral data (Kollatschny and Fricke 1984b; Kollatschny et al. 1986b). The objects have been selected for detailed study from the general Markarian lists as well as from Petrosyan's et al. (1978) list of double and multiple nucleus Markarian galaxies. A set of approx. 20 objects is under investigation. Table 1 contains a subsample of four typical objects.

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Table 1: Observed properties of four multiple nucleus galaxies

object	m_V	M_V	V_r [km/s]	separation ["]	[kpc]	Type comp. A	comp. B
Mkn 273	14.5	-21.5	12000	4.5	3.3	Seyfert 2	starburst
Mkn 739	14.1	-21.3	8900	6.7	3.6	Seyfert 1	starburst
Mkn 788	14.3	-20.6	7200	18.5	8.0	starburst	starburst
Mkn 1027	14.2	-21.2	9000	10.5	6.1	starburst	starburst

Systemic velocities are between 5000 and 15000 km/sec. The angular separations of the nuclei are between 4-20 arcsec corresponding to 2.5 - 8.0 kpc. Apparent visual magnitudes of the composite systems range from 13.5-15.5mag implying at their distances absolute luminosities M_V between -20 and -22mag. Hot-spot galaxies and extragalactic HII regions are usually some magnitudes fainter.

In this paper we present and discuss some typical morphological, spectroscopic, and kinematical data on these interesting objects with regard to galaxy evolution and activity.

OBSERVATIONS

Morphological observations of multiple nucleus galaxies have been performed in the radio and in the optical. CCD-imaging through narrowband filters in the redshifted [OIII] - and Hα - lines were done at the 2.2m Calar Alto and ESO telescopes. High-resolution radio maps at 6 and 20cm have been obtained using the VLA in the A-configuration. The following multi-frequency data from the radio to the UV spectral regions were collected:
Optical 2D-spectra from the 2.2m ESO and Calar Alto telescopes, IDS spectra at Kitt Peak, UV spectra with IUE, continuum radio fluxes at 6 and 11cm as well as HI-flux measurements from the 100m Effelsberg telescope, and FIR-fluxes from the IRAS point source catalogue. For details see Kollatschny et al. (1986b) and Netzer et al. (1986).

RESULTS

No exhaustive presentation of our data will be given here. Therefore in the following we describe characteristic results of Mkn 739 and discuss data of some other objects along with them.

a) morphology

A contour plot of Mkn 739 in the light of [OIII]5007 is shown in Fig. 1a. The nuclei are separated by ~6 arcsec corresponding to ~3.5 kpc at the source. The brighter, eastern component is a Seyfert 1 nucleus. In the north-east direction out to 17 kpc a long tidal arm is visible containing at its tip a bright HII region. On the VLA map (Fig. 1b) the Seyfert component A is seen to be much more compact than the starburst component B. Another example of a double nucleus galaxy showing a pronounced tidal arm - indicative of merging - is Mkn 1027. It contains two starburst nuclei. Fig. 2a reproduces the B-band CCD picture and Fig. 2b the VLA map at 20cm of this object.

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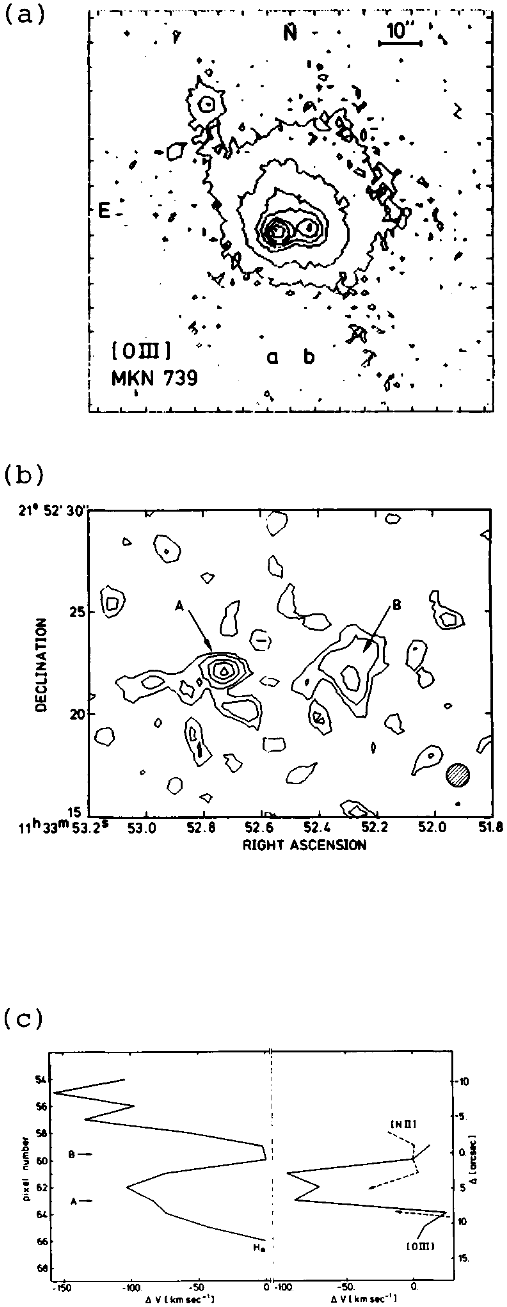

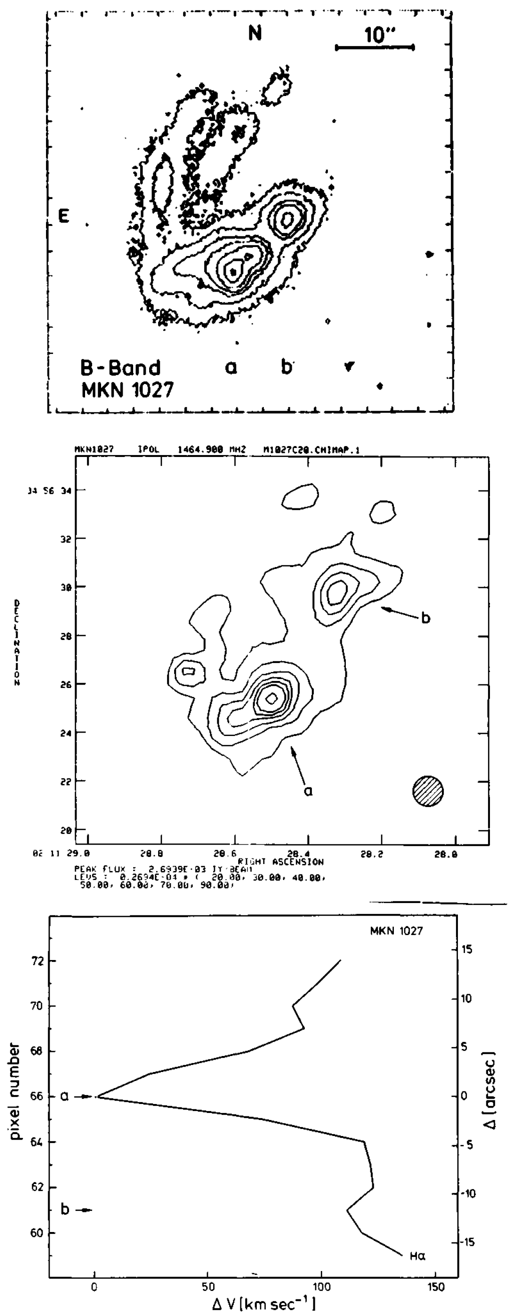

Fig.1.Mkn739:a)CCD image in [OIII]5007, b)20cm VLA map, c)velocity curves through the nuclei A and B in Hα, [OIII], and [NII].

Fig.2.Mkn1027:a)CCD image in the B-band, b)20cm VLA map, c)velocity curve through the nuclei A and B in Hα .

Two almost identical starbursts are present in Mkn 788. The narrow-band [OIII]CCD image of this example is shown in Fig. 3a.

b) spectroscopy

The optical spectrum of Mkn 739A is typical for Seyfert 1 galaxies with strong FeII lines while Mkn 739B shows a typical starburst spectrum (Fig. 1e). In the Seyfert spectrum the Balmer decrement is found to be extremely steep. The "blue bump" shortward of 4000 Å, which is usually present in Seyfert 1 galaxies and low-redshift quasars, is completely absent in Mkn 739A. The interpretation of the steep Balmer decrement with the presence of much dust is supported by the observation of a strong FIR bump (cf. Fig. 1f) which is most likely due to dust reradiation. Further evidence for strong dust obscuration is provided by a very weak UV continuum as shown in Fig. 1d and recorded after a 7 hrs IUE exposure. The upper limit for the Lyα/Hβ ratio as obtained from this spectrum is ~50 times less than in isolated Seyfert 1 galaxies.

A similar and even more extreme influence of a large amount of dust on the spectral properties is observed in Mkn 273 which shows a far-infrared flux stronger than in Arp 220 (Kollatschny et al. 1986a, Fricke and Kollatschny 1986). A common feature of the double nucleus galaxies is a high colour excess E(B-V) between 0.5 and 1.2 There are only a few exceptions having low E(B-V) like Mkn 266 and 463. In these cases the UV spectra are strong and the Lyα line is perfectly measurable (Kollatschny and Fricke 1985a,b).

c) star formation rates

The Lyman continuum photon rate, N_C, of hot stars - or an upper limit to it in the case of Seyfert nuclei - has been determined using three different pieces of information (Kollatschny et al. 1986b):
(i) the 6cm VLA radio flux interpreted as the free-free emission from the HII regions around the young stars,
(ii) the Hα luminosity assumed to measure directly the Lyman continuum photons absorbed by the gas, and
(iii) the far-infrared luminosity L_{IR} assumed to be due to dust reradiation the energy of which is supplied by young stars.

The starburst parameters of four double nucleus galaxies are compiled in Table 2. All the nuclei contain an extremely high number of OB stars (6-60$M_\odot$ stars) of the order $N_{OB}=10^5$ - 10^6. In most cases the stationary star formation rates Ψ(assuming a Salpeter initial mass function between 0.1 and 60$M_\odot$) exceed the star formation rate of the prototype starburst galaxy M82 by a large factor.

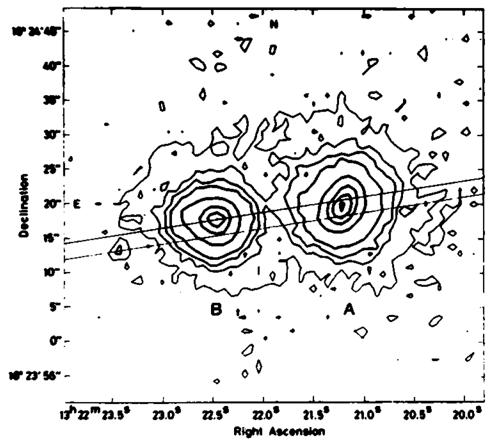

Fig.3.Mkn788: a)CCD image in [OIII]5007.

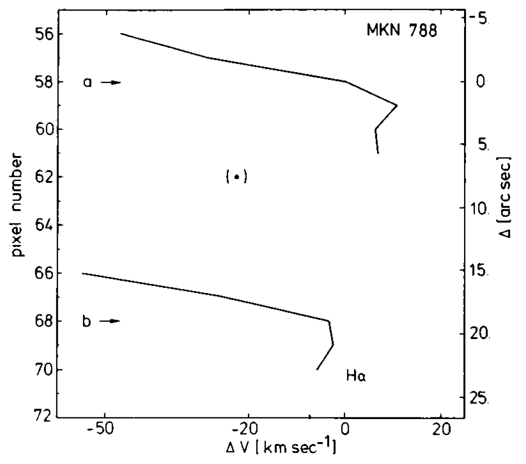

Fig.3.Mkn788: b)velocity curve through the nuclei A and B in Hα .

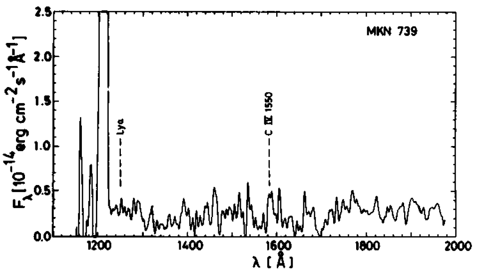

Fig.1.Mkn739: d)the short-wavelength UV spectrum.

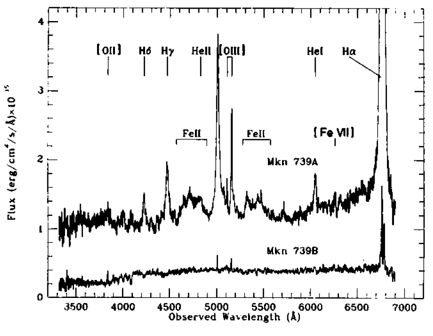

Fig.1.Mkn739: e)the optical IDS spectra of the two nuclei A and B.

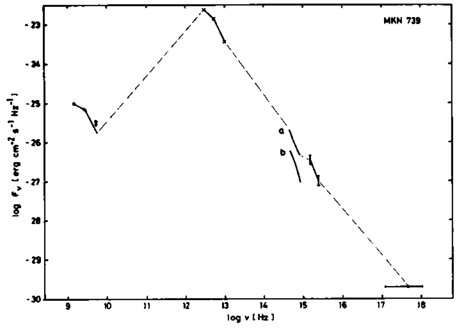

Fig.1.Mkn739: f)the overall continuum spectrum from the radio through the X-ray range.

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Table 2: Starburst parameters of four multiple nucleus galaxies

object	$\frac{L_{IR}}{10^{10} L_{\odot}}$	$\frac{N_c(IR)}{10^{54} s^{-1}}$	$\frac{N_c(6cm)}{10^{54} s^{-1}}$	$\frac{N_c(H\ )}{10^{54} s^{-1}}$	$\frac{N_{OB}}{10^5}$	$\frac{\psi(H\alpha)}{M_{\odot} yr^{-1}}$
Mkn 273a	9.7	18.	310.	2.1	11.	38.
Mkn 739b	≦ .6	≦1.	2.0	0.3	1.5	5.4
Mkn 788a				0.3	1.4	5.1
	0.4	0.7	<0.9			
b				0.1	0.4	1.5
Mkn 1027a			7.2	1.8	9.5	33.
	2.1	3.8				
b			4.1	0.5	2.9	10.

d) nuclear abundances

We determined the oxygen and nitrogen abundances in the individual nuclei of our objects using methods described by Edmunds and Pagel (1984) and by McCall et al. (1985). These methods employ the [OIII], [OII], [NII], and Hα line intensities. The O-and N-abundances of the nuclei range from low values typical for BCDG's up to solar values. Sometimes significant abundance differences between the component nuclei of a multiple nucleus galaxy have been encountered (e.g. Mkn 266, 480, 673).

e) kinematics

For Mkn 739 the radial velocity curve has been measured along the line joining the two nuclei from various emission lines (Fig. 1c). The line centres and the resulting line shifts have been evaluated by fitting a Gaussian profile through each line. The estimated errors are ~10 km/sec near the positions of the nuclei and ~30 km/sec in the outer regions. From this "rotation curve" the dynamical centre of the system cannot be identified. The velocity difference between these nuclei is 80±20 km/sec implying a virial mass 5.2 $10^9 M_{\odot}$. For comparison, the upper limit to the HI mass from our Effelsberg line observations amounts to 2 $10^9 M_{\odot}$. The velocity curve of Mkn 739 is consistent with the picture that one of the nuclei is crossing the rotating plane of the other at a rather large angle. Another example for a disturbed velocity curve is that of Mkn 1027 (Fig. 2c). In contrast to most of the multiple nucleus objects Mkn 788 shows a very regular pattern: the two - almost identical - nuclei rotate in the same sense and at virtually the same rate (cf. Fig. 3b).

CONCLUSIONS

The detailed morphological and spectroscopic analysis of the multiple nucleus objects reveals violent activity in three respects: (i) the internal state of activity within the individual nuclei manifests itself as strong starbursts or even Seyfert 1 activity, (ii) the nuclei are in rapid orbital and spinning motion, in many cases apparently decoupled from the background rotation field of the system, and (iii) the host system has a peculiar appearance often accompanied by a long tidal arm.

It has been demonstrated earlier (Kollatschny et al. 1986a) that the emission line excitation of the nuclei in our sample is on average higher than in interacting Arp galaxies. In the latter the typical spacing of the nuclei is between 8 and 80 kpc.

Our observations seem to imply that the dynamical activity of the multiple systems (rotation curves, tidal arms) provides evidence for advanced stages of merging. The observed nuclear activity in these systems is then regarded as a result of very close interaction processes taking place at the centres of these systems.

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DISCUSSION

RUBIN: Do you know the statistics of tidal tails in Markarian galaxies which show only a single nucleus? Tidal tails might remain as an indication of a previous merger, even after the two separate nuclei could no longer be resolved.

KOLLATSCHNY: At the beginning of our investigation we have only looked for objects with clear double nuclei. For the future we intend to observe further objects with tidal arms but we have not yet checked the statistics.