ACTIVITY IN NEAR-NORMAL GALAXIES

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ABSTRACT. Modern detectors permit astronomers to examine galaxies at very low light levels, at very high velocity resolution, and for nearby objects, at very high spatial resolution. Such observations will lead to phenomenon not previously detected, and offer new insights into the phenomena we presently lump under the heading of "activity."

1. INTRODUCTION

Activity in galaxies manifests itself in many ways. Galaxies are enormously varied, and their variety offers clues to the processes which have influenced their past history and which will determine their future evolution. However, new observational techniques are forcing astronomers to revise ideas of what constitutes a galaxy and to recognize that knowledge of galaxies is a function of the techniques of observation. We are all familiar with the peculiar galaxies which Arp (1965) and others continually show us. But what are we to make of a normal Sa galaxy (Fig. 1) which developes envelopes and jets and tails on deep images?

At a minimum, such images cause us to remember that the Hubble classification is based on moderate photographic exposures and such a classification scheme may not be applicable to deep CCD images. Thus new techniques advance astronomy by producing observations which do not fit our preconceptions. Surely this is not a novel idea at the Byurakan Observatory, where the technique exploited by Markarian and his colleagues led to a new class of object, "Markarian galaxies."

With such considerations in mind, I wish to show you some very recent observations, all taken with CCD detectors, and all of which reveal information which was not detected by earlier photographic observations. These observations, and similar ones being made at observatories all over the world, teach us a little more about galaxies. The connection of some of my comments with galaxy "activity" may be slight, yet the connection is important, for it illustrates how minor is the distinction between normal and active galaxies. Perhaps all normal galaxies are active galaxies. Perhaps inactive galaxies do not exist. Perhaps activity is a requisite for galaxy life.

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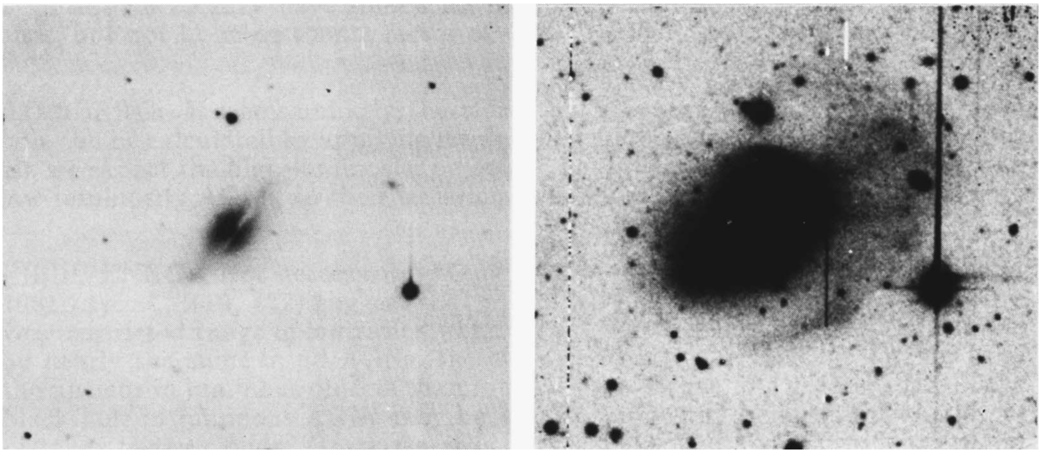

Figure 1. UGC 10205, an Sa galaxy, from a broad-band red CCD frame. Note the low light level streamers and extensions, at an intensity level of a few percent of the sky.

My illustrations come from the following 3 sets of observations:

1) Very high velocity resolution spectra, taken with the Kitt Peak echelle spectrograph in the Hα order, and with a long slit. The velocity resolution is better than 1 km/s, but my present measuring techniques are probably no better than 2 or 3 km/s. Galaxies chosen for study are galaxies observed previously at lower dispersion for rotation curves, whose emission line spectra indicated that higher resolution spectra might reveal interesting nuclear velocity structure in Hα.

2) Very high spatial resolution spectra, taken of the central region of M33 with the Palomar 5-m double spectrograph and two CCD detectors, one centered near Hα and one centered near λ = 5000A. At a nominal distance of 600,000 pc, 1" = 3 pc along the major axis. This is the highest spatial resolution available for a late-type spiral galaxy.

3) Deep CCD images, taken with the Kitt Peak 0.9-m telescope, generally one frame through a narrow Hα filter and one frame through a broad-band (~ 1000A) red filter. Galaxies observed are field galaxies previously studied for rotation curves, or galaxies in compact groups (Hickson 1982) presently being studied for rotation.

These will now be discussed in turn.

2. HIGH VELOCITY RESOLUTION SPECTRA

In our earlier photographic spectra (Rubin et al. 1985), nuclear regions were generally overexposed and emission was often lost in the bulge continuum spectrum, especially in early type galaxies. In those earlier spectra, our aim was to detect faint emission at large radial distances, r. In order to examine the nuclear spectra in greater detail, we have now obtained echelle spectrograms of about a dozen spirals.

I show in Fig. 2a and 2b echelle spectra of NGC 2742 and NGC 5676;

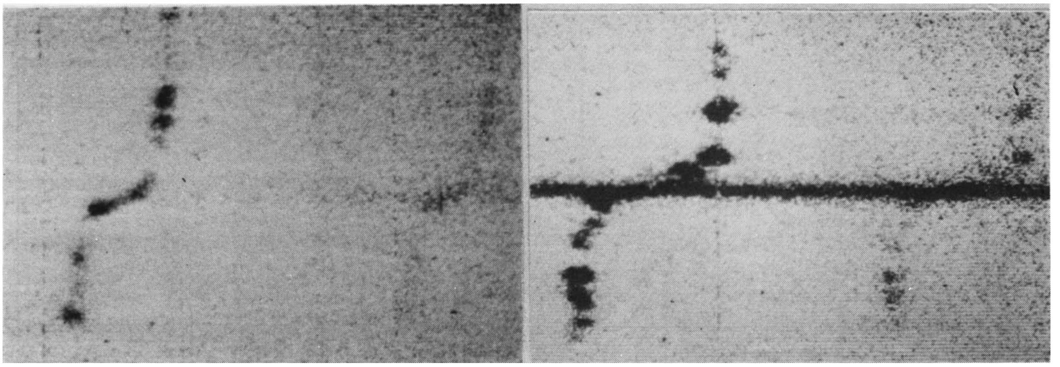

Figure 2. Kitt Peak 4-m echelle spectra of NGC 2742 (left) and NGC 5676 (right). Hα is the strong emission line, with [NII] to its right.

in each frame Hα is the strongest line, with a weaker [NII] λ6583 line to the right. (Note that a bad column falls on the high velocity side of Hα in NGC 5676). For these observations, the cross disperser is replaced by a silvered flat and a (properly redshifted) Hα filter selects the single Hα order. The detector is a low readout noise Texas Instruments (TI) CCD; spectra are recorded at 0.125A/pix along the dispersion and 0.68"/pix along the galaxy. The slit length is 2'.

Examination of the major axis spectra, and the measured velocities (Fig. 3), reveal that velocities do not increase smoothly from 0 at the nucleus, but that a small but significant rotation velocity exists at the first measured points. A region of nearly-constant velocity at very small r is a feature of several of the echelle spectra. Minor axis spectra show no velocity gradient. I think that some of the scatter in the velocities is due to the techniques of curve fitting to the emission line intensity profile at the computer terminal. The eye and brain combination used previously to measure velocities from photographic spectra obviously introduced significant smoothing.

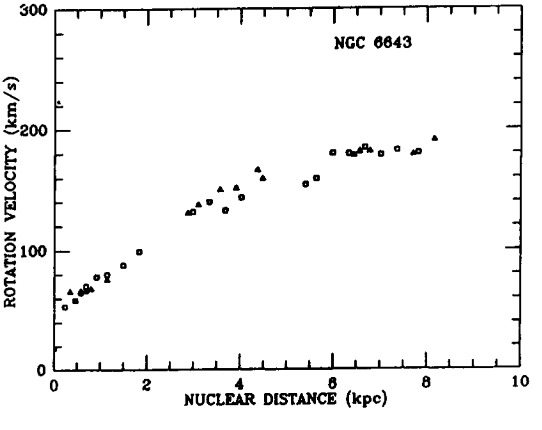

Figure 3. Rotation velocities in NGC 6643; different symbols refer to the two sides of the major axis. Note that the rotation velocity is significant even at very small r, as it is also in NGC 2742 and NGC 5676.

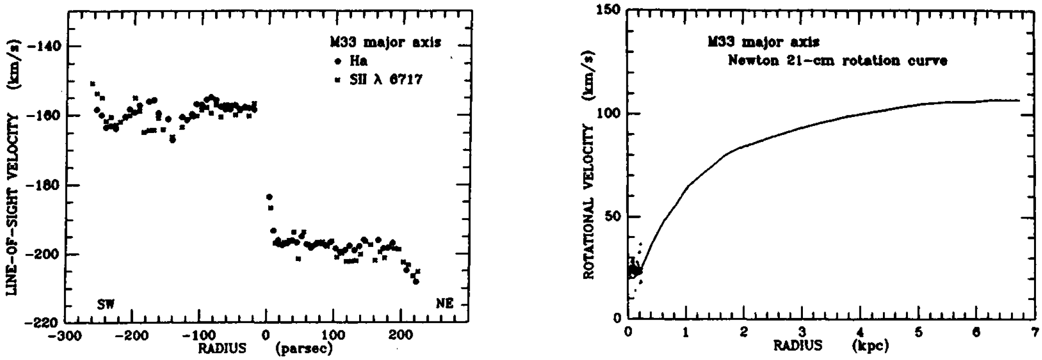

Figure 4. (left) Line-of-sight velocities along the major axis of M33, from a spectrum with the Palomar 5-m double spectrograph and CCD. (right) Rotation velocities in M33 from 21-cm observations by Newton (1980). The optical velocities (Fig. 4, left) are all located in the small blur at r< 0.3 kpc (Fig. 4, right).

It is virtually certain that higher spatial resolution will show even additional velocity features at small r. But even at this spatial resolution we may have to modify our ideas concerning the distribution of mass in nuclei of galaxies. We return to this point in Section 3 below.

3. HIGH SPATIAL RESOLUTION SPECTRA

Although M33, at a nominal distance of 600,000 pc is the closest late-type spiral, there is no recent optical spectrographic study. From a spectrum taken with the Palomar double spectrograph, line-of-sight Hα velocities along the major axis (Fig. 4, left) show a steep velocity gradient across the nucleus, with relatively constant velocities beyond. However, these velocities cover only the inner 60" of the galaxy radius. A recent Newton (1980) 21-cm rotation curve for M33 is shown in Fig. 4 (right). Note that the spatial resolution of this study is about 60" = 180pc, so the inner velocities are schematic only. A comparison of the 21-cm and the optical velocities shows that (a) these new optical velocities cover only about 4% of the galaxy major axis, and (b) the low velocities, only a small fraction of the final rotation velocity, are virtually constant and do not decrease smoothly to zero at the origin. This charateristic is much like that seen in the more distant spirals (Fig. 3 and Section 2 above) observed at very high velocity resolution.

If we model the M33 nuclear regions as a spheroid, then the flat rotation curve implies that local density within the inner ~100 pc is falling as $1/r^2$. Thus the contribution to the density from a peaked central mass with sharply falling density must exceed the contribution from a disk of increasing density. Yet the semi-stellar nucleus of M33, as well as the more extended nuclear regions, are notable for being so undistinguished and small. Even for this nearest of spirals, surprises concerning the distribution of mass must still be in store, and can now be studied with the available instrumentation.

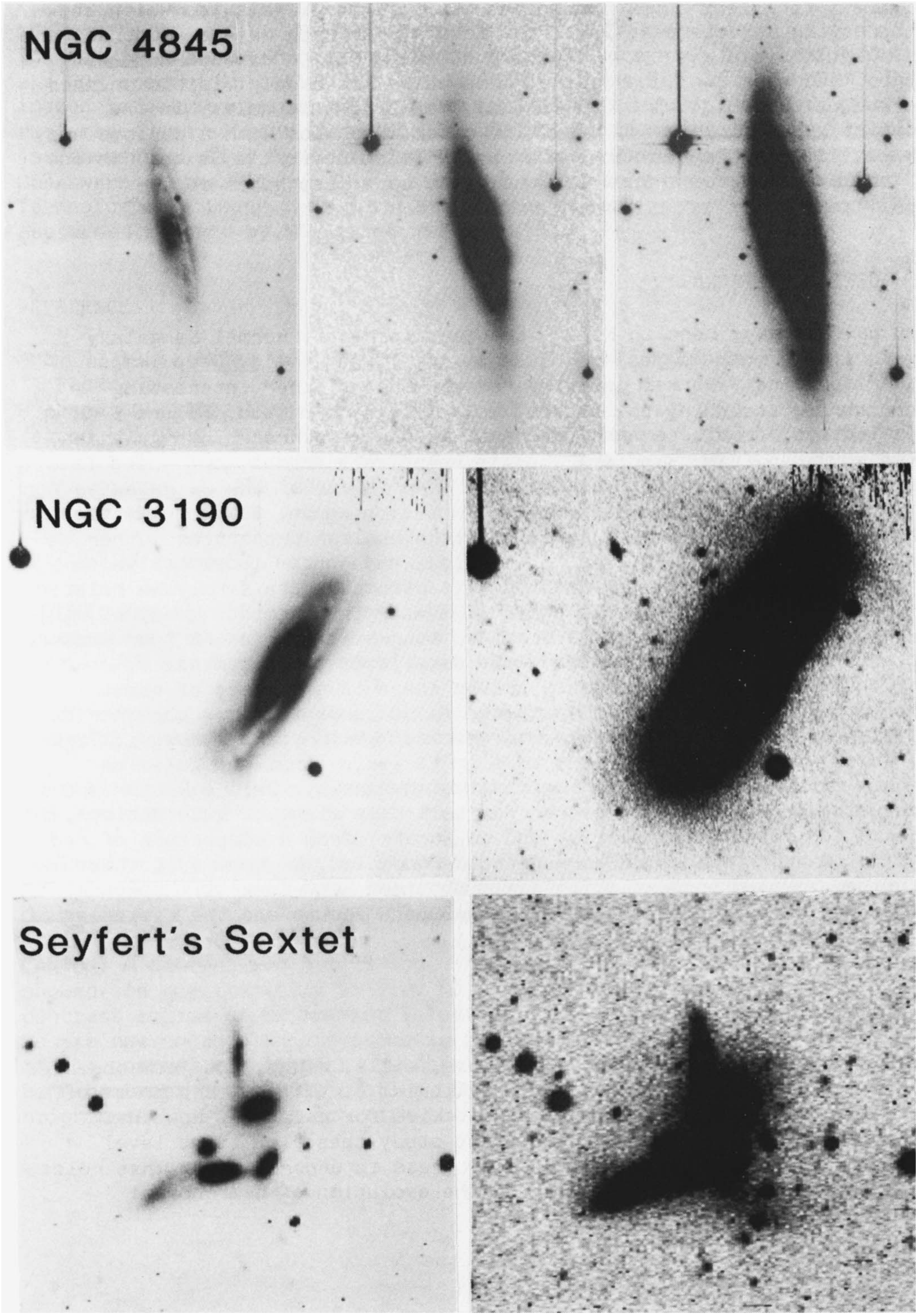

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Figure 5 (previous page). Broad-band CCD images of galaxies which show interesting structure at low light levels. For each object, moderate and low light levels are shown. (upper) NGC 4845 (Sa), develops a peanut shape, and then two outer spiral arms which are barely visible on this reproduction. (middle) NGC 3190 (Sa), the brightest galaxy in the compact group Hickson 44, has faint outer isophotes with a curious boxy shape. (lower) Compact Hickson group 79 (also Seyfert's Sextet) is one of the Hickson groups in which the faint outer isophotes of the individual galaxies merge.

4. DEEP CCD IMAGES

You have already seen in Fig. 1 that an apparently normal Sa galaxy turns into a pathological specimen at low light levels. Deep images of other apparently normal galaxies reveal various other interesting structures, including box shapes, polar rings, and jets. Figure 5 shows a selection of objects with interesting faint features. Some galaxies, like NGC 4845 (Fig. 5 upper), remain relatively normal, but there is a significant morphological change. NGC 4845 is one of the Sa galaxies for which we had previously determined a rotation curve. New echelle spectra in several position angles reveal curious nuclear properties. Other galaxies, like NGC 3190 (Fig. 5, middle), have outer isophotes which grow in an "almost" normal fashion. Its structure can surely be related to "activity", for it is the dominant member in a compact group of other interesting galaxies. We have obtained long-slit spectra of four members of this group, in order to study the details of the dynamics.

Among the Hickson compact groups there is a sub-set of about one-third of the groups, in which the faint isophotes grow together to envelop the entire set of galaxies. Hickson 79 (Seyfert's Sextet; Figure 5, lower) is such a group, and thus it is likley that the galaxies within it have evolved in a region of high density. Deidre Hunter and I are using these images to search for tell-tale signs of interactions, to search for faint tidal debris, and to locate (from a comparison of red and Hα images) regions of current star formation. We hope that these studies, coupled with velocity field obtained with long-slit spectra, will lead to an understanding of the compact groups and the evolution of galaxies within them.

5. CONCLUSIONS

Most of the faint envelopes, extensions, tails, rings, and jets observed around galaxies appear to be non-equilibrium structures, and hence offer evidence for complex evolutionary histories for galaxies. Now that astronomers can more easily detect and study these low light level phenomenon, we can look forward to progress in understanding what role these evidences of activity play in the evolution of near-normal galaxies.

ACKNOWLEDGMENTS

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DISCUSSION

FRICKE: You have shown us deep images of groups as manifestations of tidal interactions. What do you estimate are the largest distances over which evidence for tidal interaction can be seen?

RUBIN: The objects we have observed show extensions of order 100 kpc. I am not certain that these are all tidal phenomena.

TSVETANOV: What is the spatial resolution on the pretty images of M33 you have just shown to us?

RUBIN: The M33 reproduction is from a photographic plate taken by Malcolm Smith at the Cerro Tololo Interamerican Observatory (Chile), using an $H\alpha$ filter. The scale is about 16"/mm.

CANNON: A comment and a question. The beautiful deep CCD pictures you showed are qualitatively similar to what we find by making very high contrast copies of UK Schmidt Telescope IIIa-J Sky Survey photographs. We are now engaged in a systematic programme of looking at about 300 of the nearest and largest southern galaxies and plan to make a special high-contrast photographic atlas. Can you tell me what surface brightness limit you reach with the deep CCD frames?

RUBIN: I am pleased that you are conducting such a survey, for we have picked a curious selection for study: those galaxies for which we have rotation curves. We reach about 2 or 3% of the sky, for we have made no special efforts to go even fainter.

PASTORIZA: Have you studied the luminosity distribution of the envelope of the group?

RUBIN: These observations are very recent, so we have done little toward a sophisticated reduction. We have made single cuts across the envelope in an effort to see if the surface brightness distribution was disk like or bulge like. However, the irregularities within the light distribution are large, so we have reached no conclusion yet.

MELNICK: Do you see [OI] 6300Å in the central region of M33?

RUBIN: Because the spectra are at high resolution, only a small wavelenth region is recorded, and we do not see the 6300Å region.

FILIPPENKO: Regarding your statement that M33 is the only disk galaxy you know of, whose nucleus has Hα in absorption, with no emission: Wal Sargent and I have found several other cases, although we agree they are rare.

KOMBERG: Do you have any deep photographs of radiogalaxies? It seems to me, that there is a resemblance between their radio - and optical images.

RUBIN: I have not.

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