More Clues on the Structure and Dynamics of Boxy/Peanut Bulges

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Abstract: We investigate here the vertical structure of bars. Our goal is to identify bars within edge-on disk galaxies. The data strongly support a thick bar model for the structure of boxy/ peanut bulges. They also raise questions regarding the unusual behaviour of the emission line ratios in the barred region of these galaxies.

1 Introduction

Boxy/peanut-shaped bulge galaxies constitute an important class of spiral galaxies; they are numerous (20-30% of all spirals) and display interesting dynamics and structure (cylindrical rotation and large deviations from a spheroidal shape). Although accretion can form axisymmetric boxy/peanut systems, the presence of a thick bar in the disk of a spiral is the currently favoured model. N-body simulations show that rotating thick bars are robust, stable configurations, which look peanut-shaped when viewed side-on and boxy-shaped when viewed end-on (e.g. Combes & Sanders 1981).

Although some photometric observations support the barred spirals model, axisymmetric models can not be rejected in most cases because boxy/peanut bulges are only seen in edge-on systems where a bar is very hard to identify. But, Kuijken & Merrifield (1995) have now proposed and tested a spectroscopic method to identify bars in edge-on systems.

We report here on an ongoing project to identify bars in a sample of edge-on spiral galaxies using the Kuijken-Merrifield method. About 3/4 of the sample comprises boxy/peanut bulge systems, the rest of the galaxies being of various morphologies. The primary goal is to determine if a boxy/peanut-shaped bulge necessarily implies the presence of a bar, and vice-versa. This project is part of a larger program on the structure of barred spiral galaxies including near-infrared and optical surface photometry and some HI line-imaging: see Bureau & Freeman (1997).

2 Detecting Bars in Edge-On Disk Galaxies

Kuijken & Merrifield (1995) have shown that the gas in an edge-on barred system has a characteristic two-dimensional line-of-sight velocity distribution (or position-velocity diagram, PVD), markedly different from gas in near-circular motion in an axisymmetric disk. This difference is due to the particular dynamics of a barred disk. The orbits in a non-axisymmetric disk potential are elongated, and resonances occur between circular motions and the bar pattern speed; with increasing radius, the orbits change their orientation at each principal resonance (inner Lindblad resonance, corotation, outer Lindblad resonance). Because the gas is forced on to closed non-overlapping, non-self-intersecting orbits, a region around those resonances will be gas-depleted, creating gaps in the projected gaseous PVD and giving rise to a characteristic "figure-of-eight" (double-peaked) profile. This feature is a signature of the non-axisymmetric potential in the disk. See the bottom diagram of Fig. 1a for a striking example, and Merrifield (1996) for a grid of models.

With simple long-slit spectroscopy, this feature can be used to detect if a bar is present in an edge-on system (whether or not it is thick). If no gas is present, the stellar dynamics should show a similar but weaker signature. We note that it would be difficult to reproduce the level of complexity seen in the spectra by simply adding (or subtracting) a dynamical component to an axisymmetric disk.

3 Relationships Between Bulge Morphology and Bar Presence

We have selected here a few galaxies to illustrate our results. As the data for the whole sample are not analysed yet, these are preliminary results.

Peanut Bulges:

Fig. 1 shows the PVD of the galaxies NGC 5746 (a) and NGC 6722 (b), two prototype peanut bulge galaxies. Both galaxies have large bulges with a clear peanut shape and possess extended disks at a favourable inclination. The spectrum of NGC 5746 is very dramatic. The line splits just outside the steeply rising inner part of the PVD, giving rise to an obvious "figure-of-eight" extending to about twice the peanut length. As we have seen, this probably indicates the presence of an edge-on bar (seen side-on). NGC 6722's PVD is very similar; although the S/N is lower, the line split is still obvious (at least on one side).

These data and those for two other galaxies with large peanut bulges (NGC 128 and IC 4937, not shown) strongly support the hypothesis that peanut-shaped bulge systems are simply edge-on barred spiral galaxies with the bar seen side-on.

Boxy Bulges:

Fig. 2 shows the PVD of the two boxy bulge galaxies NGC 6771 (a) and IC 5096 (b). NGC 6771 represents one extreme of the boxy bulge family, with a large boxy region and almost no disk. The PVD shows a dominant steeply rising inner part followed by a split in the line and an almost flat section. IC 5096 on the other hand possesses an extended disk with a compact boxy bulge. The PVD shows a clear split into two components in the center.

A comparison with Merrifield's (1996) models shows that both galaxies are probably edge-on barred spirals, with the bar at an intermediate angle to the line-of-sight in the case of NGC 6771, and almost end-on for IC 5096. Again, the thick bar hypothesis is supported.

Other Bulges:

Fig. 3 shows the PVD for the galaxies ESO 597-G36 (a) and NGC 1032 (b). ESO 597-G36 is a so-called X-shaped galaxy and is part of a small interacting group. No sign of structure is visible in the spectrum which indicates the galaxy is unlikely to be barred. The usually postulated mechanism to form X-shaped systems, accretion of material from a satellite galaxy, seems more plausible here (although the interaction with the satellite could also excite strong bar modes). NGC 1032 is an isolated galaxy with a large "normal" ellipsoidal bulge. The PVD shows no splitting or structure, with only the broadening expected from the edge-on projection of a typical disk, indicating that the galaxy is axisymmetric.

These data and those for other galaxies in our sample support the view that galaxies with bulges that are not boxy or peanut-shaped do not possess a bar.

4 Comments

The data shown here represents a small fraction (≈20%) of the data from our sample galaxies. But, even at this point, we can see a picture emerging, confirming the view arising from N-body models that boxy/peanut-shaped bulges are simply bars seen edge-on. Although it remains to be confirmed, it also seems that thin bars do not exist.

An unexpected result of this work is the unusual spatial behaviour of the Hα/[NII] line ratio in our sample galaxies. Many galaxies show evidence of LINER activity in their bulge. More interesting, in the galaxies with strong "figure-of-eight", the line ratios correlate with the PVD structure: inside the *entire* line-splitting region, [NII] is much stronger than Hα, while outside that region, a typical HII-region line ratio is seen. In other galaxies, the line ratios for the two PVD components are completely different (one component being absent from one line is some cases). The origin of this behaviour is not fully understood at this point, but it is likely that shocks associated with the bar play an essential role. We are beginning hydrodynamical simulations to understand the physical conditions and excitation mechanisms of the gas in the boxy/peanut (barred) bulges. These simulations will also yield a better grid of models to relate the shape of the PVD with the characteristics of the bar (strength, orientation, ...). Care should be taken when determining rotation curves of highly inclined galaxies as the result might be significantly different depending on which line is used.

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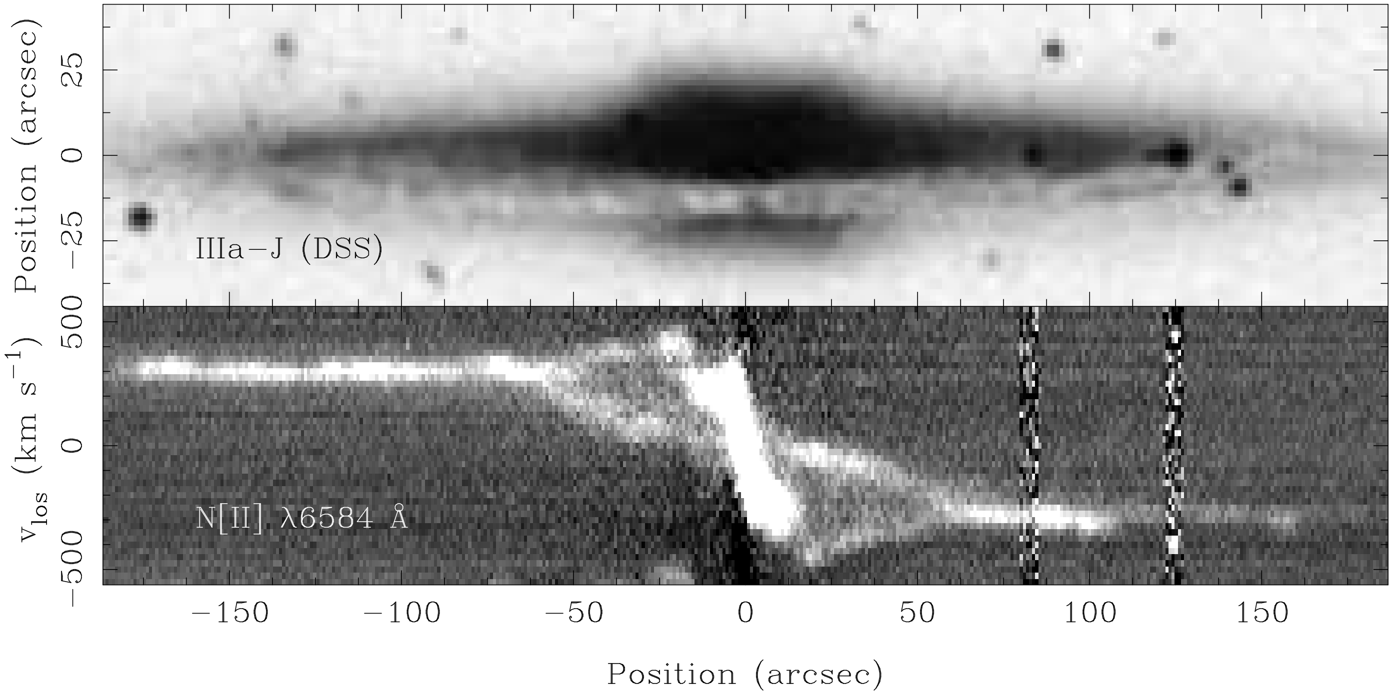
Figure 1. Structure and kinematics of a) NGC 5746, b) NGC 6722.

Figure 2. Structure and kinematics of a) NGC 6771, b) IC 5096.

Figure 3. Structure and kinematics of a) ESO 597-G36, b) NGC 1032.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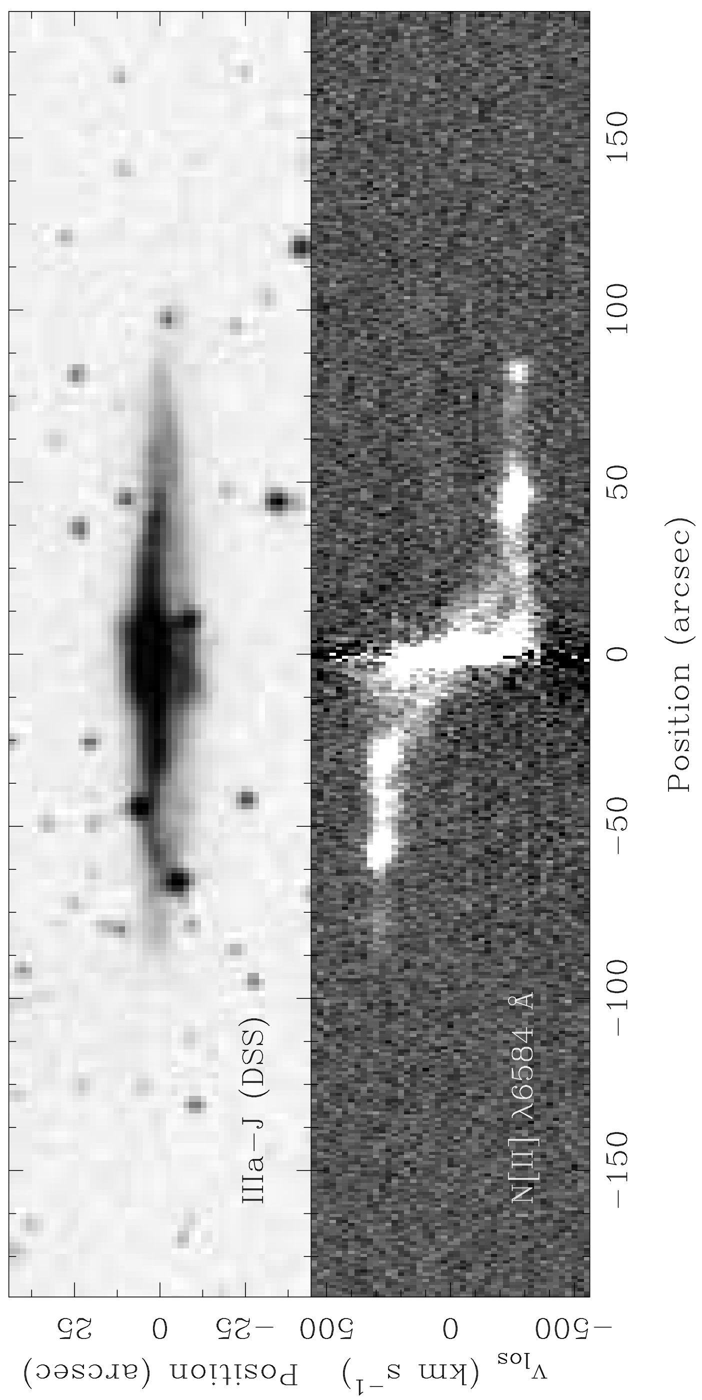
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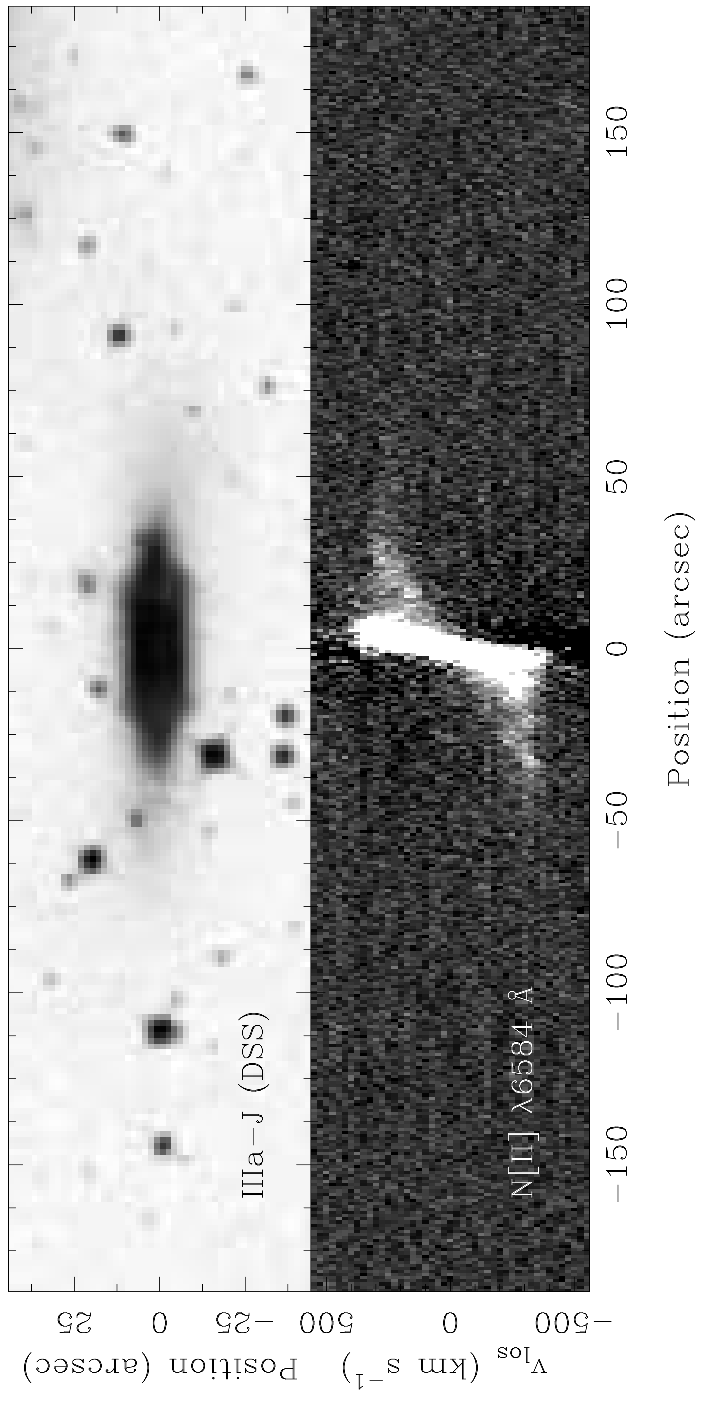
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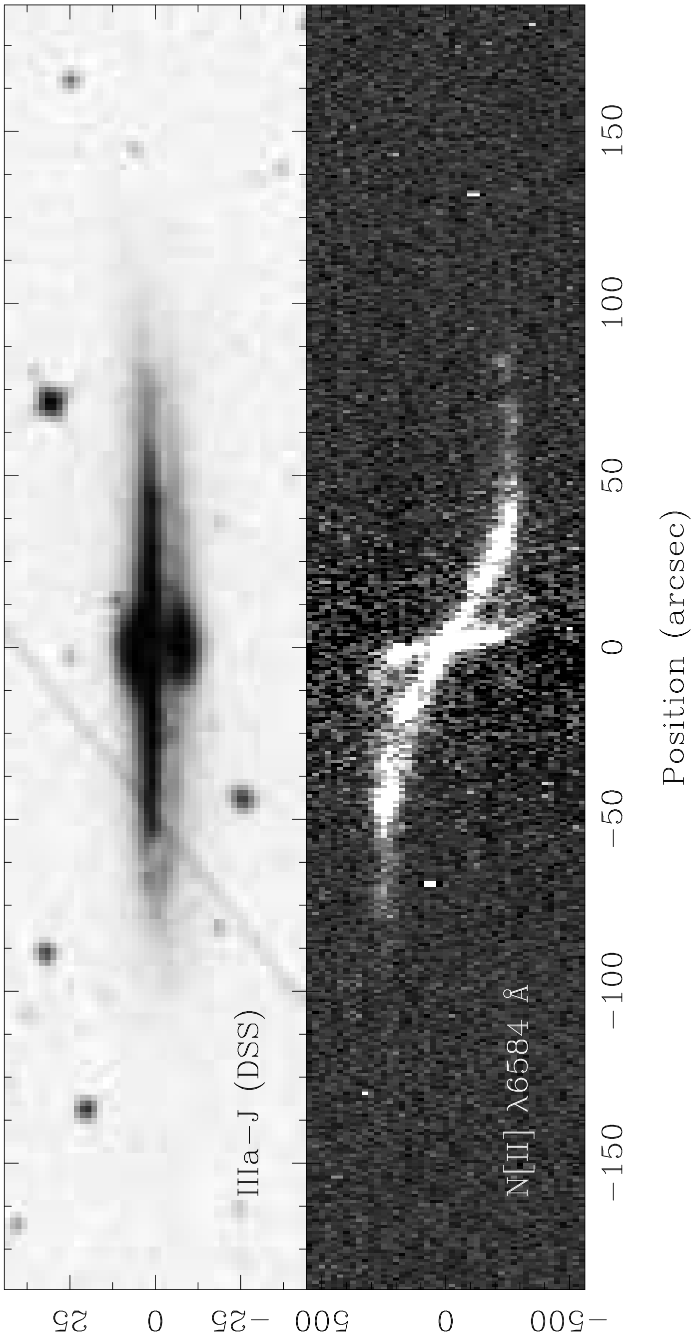
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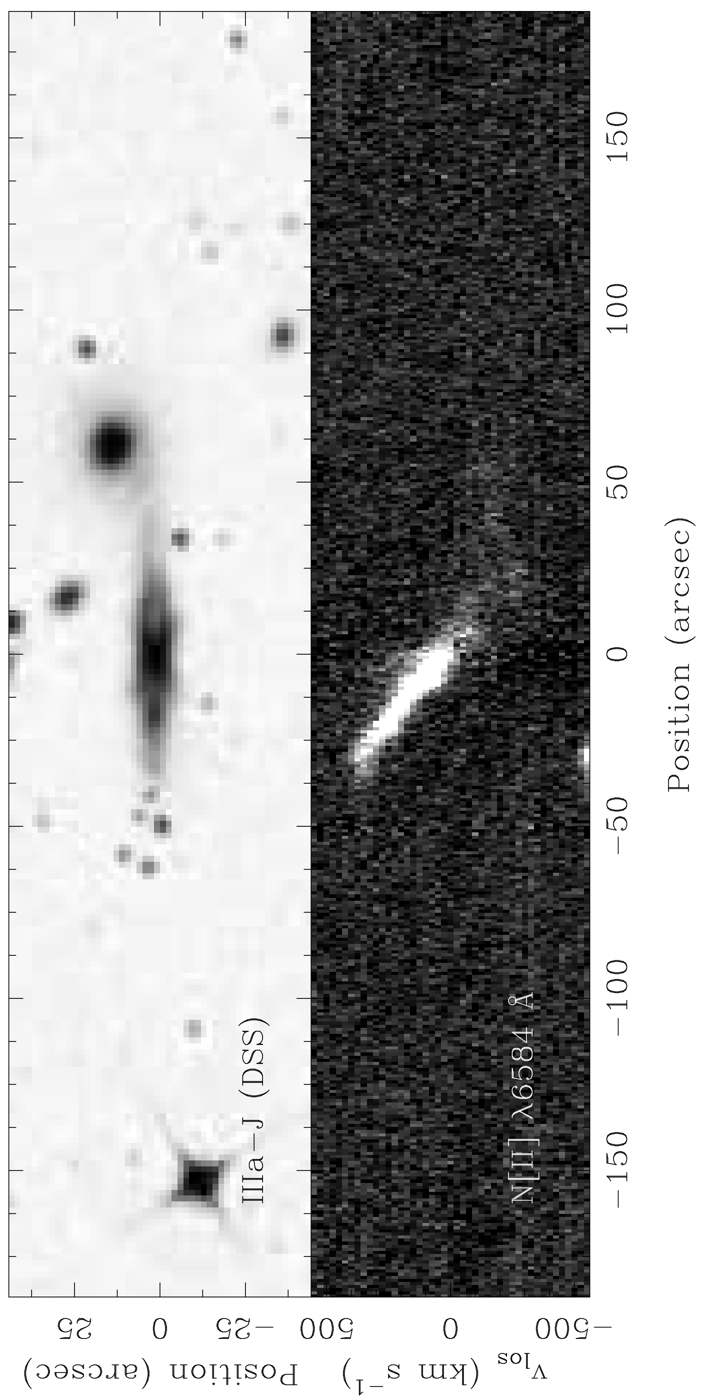
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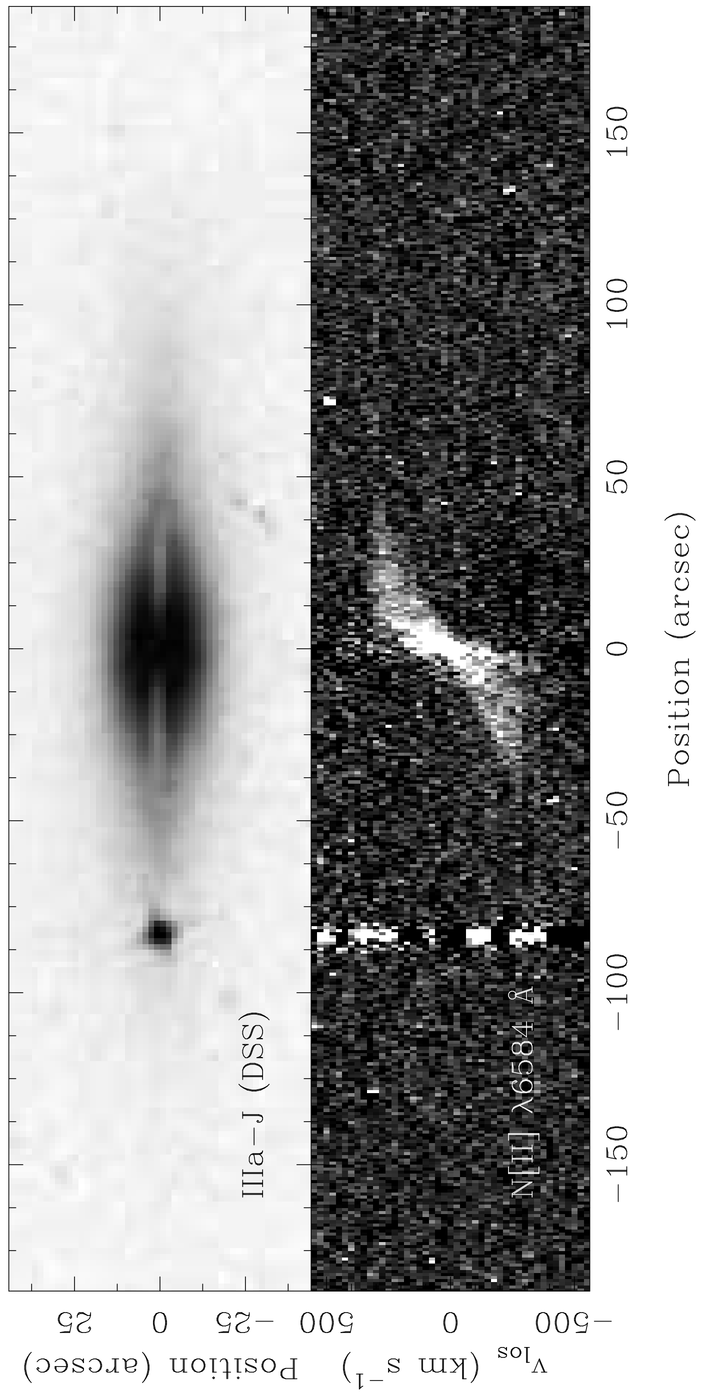
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