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Ne II EMISSION AND GALACTIC DYNAMICS IN NGC 253*

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ABSTRACT

The 12.8 μm fine-structure line of Ne II has been mapped in the central 25″ of NGC 253 with a 6″ beam and 0.1–0.15 cm^{-1} spectral resolution. As in visible studies, both circular and non-circular motions were observed. However, there are major differences between the Ne II velocities and those measured in the optical and radio regions.

Subject headings: galaxies: individual — galaxies: internal motions — radio sources: galaxies

I. INTRODUCTION

NGC 253 is a bright, nearby Sc galaxy. It is a strong infrared and radio source (Becklin, Fomalont, and Neugebauer 1973). Its optical emission lines show large-scale departures from circular motion (Burbidge, Burbidge, and Prendergast 1962; Demoulin and Burbidge 1970) and in some areas are actually doubled, indicating motion out of the plane of the galaxy (Ulrich 1978). The overall behavior of NGC 253 is typical of the active extreme of "normal" galaxies rather than Seyferts.

Gillett *et al.* (1975) studied the 8–13 μm spectrum of NGC 253 and detected the 12.8 μm line of Ne II fine-structure emission. This paper describes a map obtained with a high spatial and spectral resolution infrared spectrometer of the same ionic fine-structure line for the purpose of determining the velocity field in the center of the galaxy. The data were taken at the 2.5 m du Pont telescope at Las Campanas Observatory, Chile, in 1977 June–July. The spectrometer is described in Beck *et al.* (1978). Spectra were measured in 11 positions with a 6″ beam and are displayed in Figure 2. Spectra in positions 2, 5, 6, 9, and 10 were measured with 0.1 cm^{-1} resolution and the rest with 0.15 cm^{-1} resolution.

II. NEON ABUNDANCE

Radiation features at 12.8 μm with intensity of 3 σ or greater were detected in seven of the 11 positions. The total flux of Ne II observed is $8 \pm 2.4 \times 10^{-18}$ W cm^{-2} and the flux within a 6″ beam in the central position is $2.4 \pm 0.8 \times 10^{-18}$ W cm^{-2}, where the uncertainties quoted are primarily systematic errors due to the lack of well-known infrared fluxes for the calibration star (α Sco). The total flux is consistent with that observed by Gillett *et al.* If Seaquist and Bell's (1977) figure of 1 Jy thermal continuum flux at 6.1 GHz is used, the calculated Ne II flux in the central 4′, assuming the "cosmic" abundance of neon and $[Ne^+/Ne] = [H^+/H]$, is $\sim 3 \times 10^{-17}$ W cm^{-2}, about 4 times that observed. Thus, either the neon abundance is considerably less than "cosmic," not all the neon is singly ionized, the thermal continuum flux is less than that reported by Seaquist and Bell, or substantial radio emission comes from outside of the region observed here.

III. VELOCITY FIELD

Figure 1 shows the peak velocity in each beam, and in Figure 2 the spectrum in each position is displayed on a flux versus velocity scale. Points in the spectra are separated by 0.015 cm^{-1} or 5.77 km s^{-1}. The rms noise on a single point is 0.54×10^{-18} W (cm^2 cm^{-1})$^{-1}$ in positions 2, 9, and 10, 0.4×10^{-18} W (cm^2 cm^{-1})$^{-1}$ in positions 3 and 5, 0.35×10^{-18} W (cm^2 cm^{-1})$^{-1}$ in position 7, and 0.5×10^{-18} W (cm^2 cm^{-1})$^{-1}$ in the rest. It may be seen that in beam positions 4–7, 9, and 10 rotation is observed. The emission in position 6 is very broad, with a strong wing of low-velocity material. There is no evidence for an infrared continuum in NGC 253 strong enough to produce the observed wing. Due to an H_2O absorption line in the atmosphere we were not able to observe velocities redder than 450 km s^{-1}, so it is not certain whether there is a similar wing on the high-velocity side of the line. The velocity in position 3 does not appear to be due to rotation.

The systemic velocity of the galaxy was determined by taking a weighted average of the neon velocities in the beam positions along the apparent major axis (positions 4–7). This method was chosen in preference to attempting to measure the velocity at a previously chosen nucleus because of the uncertainty in the

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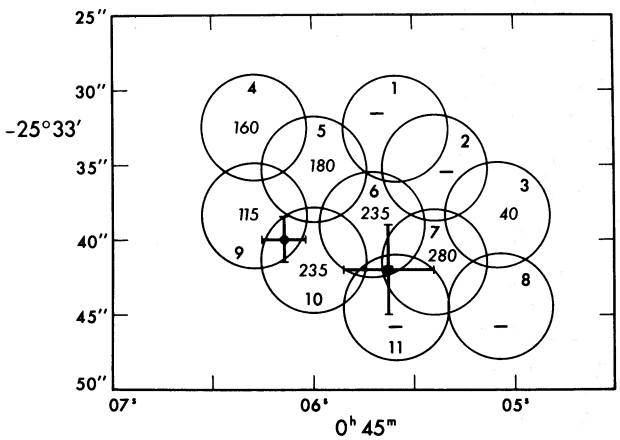

FIG. 1.—Beam positions for Ne II observations of NGC 253. Boldface numbers label the beam positions and lightface numbers give the peak velocities in those positions. The square marks the position Ulrich called the nucleus and the circle the position Demoulin and Burbidge called the center.

position of the dynamical center of the galaxy. The systemic velocity thus calculated is 245 km s^{-1} (LSR), in good agreement with the optical results. This central velocity indicates that the dynamical center of the galaxy is in the region denoted by beam position 6 (which also has almost one-third of the neon emission). This beam position is roughly centered on Becklin, Fomalont, and Neugebauer's (1973) 2 μm nucleus and is consistent with Ulrich's position for the nucleus, but is approximately 6″ west and 1″ north of the optically brightest spot used as the center by Burbidge, Burbidge, and Prendergast and by Demoulin and Burbidge. (The radio and optical centers are shown in Fig. 1.) There is, of course, no reason to expect the center of mass to coincide with the optically brightest point in such an obscured galaxy.

The rotation curve of NGC 253 near the center is difficult to discuss in detail due to the probable noncircular motions. The Ne II motions along the major axis are roughly similar to the velocities observed in the optical, with a slope of 0.4 km s^{-1} pc^{-1} compared with an optical slope (Burbidge, Burbidge, and Prendergast) of 0.3 km s^{-1} pc^{-1} (1″ = 15 pc). Neither slope agrees well with Gottesman *et al.*'s (1976) H I result of 1.7 km s^{-1} pc^{-1}. The observed velocity gradient of 0.4 km s^{-1} pc^{-1} implies an average density in the central 300 pc (diameter) of 9 $M_\odot$ pc^{-3} (assuming a spherical mass distribution.) For comparison, the average density in the central 300 pc of the Galaxy is 120 $M_\odot$ pc^{-3} (Oort 1977).

The most noticeable differences between the 12.8 μm data and those observed at other wavelengths are in the presence or absence of the very high- or low-velocity features. Demoulin and Burbidge found optical emission lines with velocities of both 130 km s^{-1} and 245 km s^{-1} near the center, and Seaquist and Bell detected a broad H102α recombination line centered at 132 km s^{-1} only. This is an approach velocity of roughly 120 km s^{-1} toward the observer relative to the galaxy as a whole. The only Ne II spectrum with a comparable velocity is that in position 9. However, that velocity (115 km s^{-1}) is only 65 km s^{-1} lower than what would be expected from the rotation curve, not 120 km s^{-1} lower, and the line there is fairly weak. It is unlikely that flux from that beam position would contribute notably to the recombination-line spectra.

Two extremely low-velocity components are evident in the neon spectra that are not seen in the radio: the 40 km s^{-1} feature in position 3 and the strong low-velocity plateau in position 6. The only previous mention of such low velocities in NGC 253 was in Deharveng's (1971) thesis, where two groups of velocities were found toward the center of the galaxy, one clustered around the systemic velocity and one that ranged from -20 to $+120$ km s^{-1}. The width of the line in position 6 is consistent with either the presence of a slightly active nucleus emitting material or high rotational velocities within a few arcseconds of the nucleus. The 40 km s^{-1} line in position 3, where a velocity at least 200 km s^{-1} higher would be expected from the rotation curve, is harder to understand. It may be a bright component on the near side of the cone of outflowing gas, as proposed by Ulrich, or a strong H II region with an anomalous proper motion through the galaxy. The line in position 3 is the clearest evidence we have found for noncircular motions in NGC 253.

Following Ulrich's model of gas flowing out from the center at an angle to the plane of the galaxy, one would expect to see high velocities coming from the other side of the cone. We do in fact see peaks at 430 km s^{-1} in positions 1 and 10 which are stronger than 3 σ, but which are too narrow to be thoroughly convincing as lines. It would be of great interest to take longer integrations at higher spectral resolution and determine whether these high-velocity features are real.

The most difficult discrepancy to understand is that between the neon data and the H102α results of Seaquist and Bell. The observed H102α emission is centered at 132 km s^{-1} with a full width of nearly 400 km s^{-1}. Their model for the line-emitting region gives a Ne II flux in one of our beams of 6×10^{-18} W cm^{-2} and, as mentioned above, a total flux of 3×10^{-17} W cm^{-2}, about 4 times that observed. If the Ne II and H102α emission were produced in the same region, the discrepancy between the fluxes could be due to either underabundant neon or overestimated radio continuum, and in either case the line velocities of Ne II and H102α should be the same. Yet the weighted average of neon velocities along the major axis which is to an excellent approximation the weighted average of all observed neon velocities is 245 km s^{-1}, and the lowest-velocity strong line observed near the center is peaked at 160 km s^{-1}. We must therefore conclude that the majority of the recombination-line emission comes from outside of the central 25″ which we observed. The hypothesized source of radio radiation could be, for example, a superluminous, highly reddened giant star cluster such as van den Bergh (1971) found in M82.

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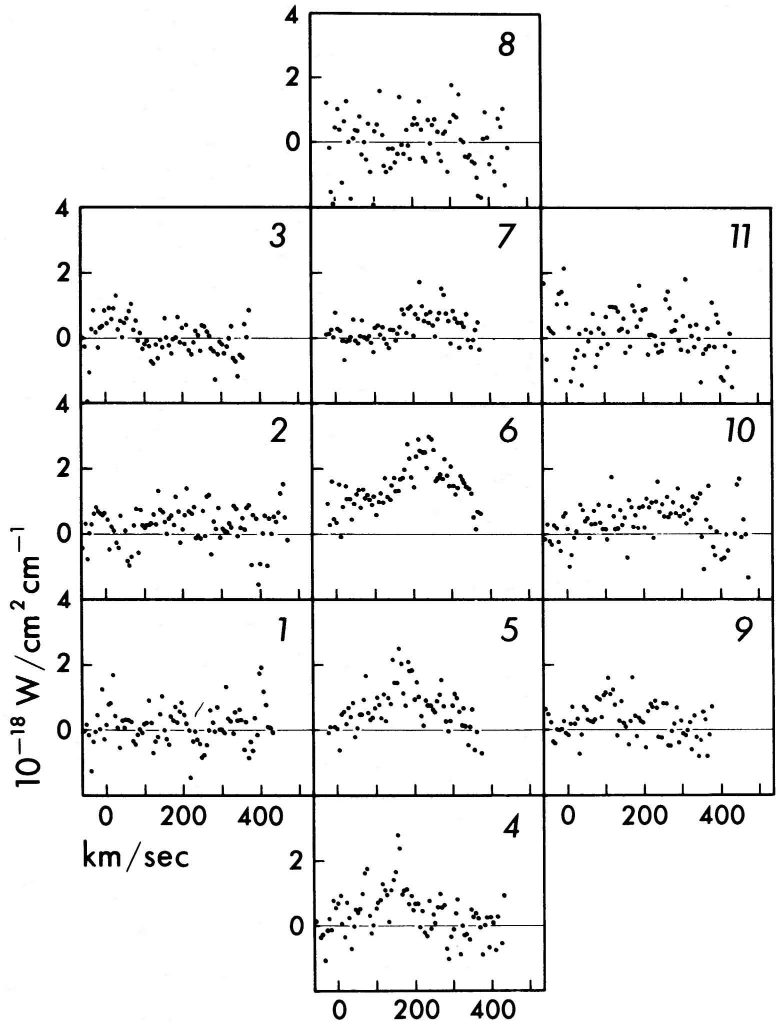

FIG. 2.—Ne II flux versus velocity in NGC 253. The spectrum numbers refer to the beam positions of Fig. 1. The noise in each spectrum is discussed in § III.

IV. SUMMARY

The Ne II line spectra show a mixture of rotation and noncircular motions in the center of NGC 253. The emission is rather strongly localized, with almost one-third in the central 6″. The width of the line in that position suggests that some unusual, although not violently explosive, activity is occurring there. The H102α results and the Ne II data are apparently contradictory. It would be of great value in resolving this question to have high resolution maps in the radio, and infrared observations of a larger area of the galaxy than the inner 25″, since it is possible that strong neon and radio fluxes are generated outside of the nuclear region.

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Note added in manuscript.—Recent radio recombination line observations of NGC 253 by Mebold *et al.* (1979) have caused these workers to revise the estimated thermal continuum flux downward to 0.15 Jy at 85 GHz. This flux is consistent with all neon present in H II regions in NGC 253 being singly ionized and a neon abundance close to or slightly greater than "cosmic."

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