The Peculiar Spiral Galaxy NGC 3310

I. General Properties; Far Ultraviolet and Radio Continuum Observations

P. C. van der Kruit

Kapteyn Astronomical Institute, University of Groningen, The Netherlands and Hale Observatories, Carnegie Institution of Washington, California Institute of Technology, Pasadena, California

A. G. de Bruyn

Sterrewacht, Leiden

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Summary. This paper is the first in a series on the peculiar spiral galaxy NGC 3310 (Arp 217). Here we give a discussion of the general properties, present far-UV observations made with the Astronomical Netherlands Satellite and radio continuum observations at $\lambda 49, 21$ and $6 \text{ cm}$ made with the Westerbork Synthesis Radio Telescope. In the inner part of the disk there is a symmetrical, open spiral structure with many bright H II-regions. The high luminosity in optical emission lines, early spectral type and the optical colours indicate a relatively high content of early type stars. This is confirmed by observations in the far UV. NGC 3310 is possibly a member of a loose group of galaxies. Whether this is the case or whether it is a field galaxy, the distance is about 20.5 Mpc if the Hubble constant is 55 km s$^{-1}$ Mpc$^{-1}$. The severe disturbances in the outer parts are probably not due to an encounter with another galaxy. The radio emission has a spectral index of $-0.69$ between 0.6 and 6.6 GHz. The Westerbork map at $\lambda 6 \text{ cm}$, which has the best resolution ($7'' \times 9''$ or $0.7 \times 0.9 \text{ kpc}$), shows intense emission from the inner edge of the north-eastern spiral arm. This is indicative of density wave compression. No radio emission has been detected from the disturbed outer parts of the galaxy. A large, bright H II-region in the southern arm has dimensions and a 6 cm luminosity comparable to the giant complex NGC 5461 in M 101. No emission is detected from SN 1974d in NGC 3310. The disk has an unusually high average brightness temperature; at 1415 MHz it is about an order of magnitude higher than that of M 51.

Key words: spiral galaxy — peculiar galaxy — far UV emission — radio continuum emission

1. Introduction

NGC 3310 (= Arp 217) is a bright, peculiar galaxy, which due to its relative proximity ($V_{|\phi|} \sim 1000 \text{ km s}^{-1}$), and its high declination (+54°) is a suitable system for detailed radio and optical studies with telescopes in the northern hemisphere. Its interest is based on a number of notable features, of which the most striking are: (1) a disturbed structure in the outer parts, which Walker and Chincarini (1967, hereafter referred to as WC) describe as a “bow-and-arrow” structure; (2) a very symmetric spiral structure in the inner part of the disk, which is especially clear in plates exposed through an Hz-filter; (3) its high luminosity in optical emission lines (see Humason et al., 1956; Arp, 1966); (4) its rather high radio continuum emission (van der Kruit, 1971). Especially the combination of a highly disturbed outer part and a very well-defined spiral structure in the inner disk would warrant a detailed study, because it might throw light on questions regarding the possible relation of spiral structure and density waves to proposed excitation mechanisms such as nuclear activity (van der Kruit et al., 1972) and encounters between galaxies (Toomre and Toomre, 1972). Also NGC 3310 is the brightest disturbed system in Arp’s Atlas (Arp, 1966).

This paper is the first in a series, in which the various aspects of the galaxy will be studied. Here a summary of previous observations will be given as a general introduction to the series. Furthermore far ultraviolet observations with A.N.S. and radio continuum observations at $\lambda 6, 21$ and 49 cm with the Westerbork Synthesis Radio Telescope (WSRT) will be presented. Further papers will deal with the determination of the velocity field using optical emission lines, observations of the distribution and velocity field of the neutral hydrogen and analysis and interpretation of these results.
2. General Characteristics of NGC 3310

a) Optical Appearance and Classifications

The appearance of NGC 3310 has been described previously by WC with the use of a collection of blue (103a–0+GG 13) 5 s to 10 min exposures at the Lick 120-inch (3 m) telescope. It has a bright nucleus and at a distance of about 10" either some tightly-wound bright spiral arms or a ring-like structure. They describe the main part of the disk as containing "many fainter arms with numerous condensations in them". However, this description is not confirmed by a plate in the light of Hα taken by Dr. Arp with the Hale Telescope, and reproduced in Fig. 1. In that figure we see that two bright arms emerge from the central region forming a very regular, open spiral structure. The arms appear to contain many bright, large H II-regions; the brightest one is at the point where the southern arm emerges from the central region.

It can also be seen in Fig. 1 that throughout the disk there are quite a few H II-regions, which in their spatial distribution do not seem to follow any pattern of large scale organization, but especially in the southern part they tend to form chains parallel to the spiral arm. This
might be connected to the strong disturbances in the outer parts. It is in the north-western part that a straight line of luminous material starts (the arrow in WC’s bow-and-arrow structure), running out almost exactly along a line through the nucleus. This structure is shown in more detail in the Atlas of Peculiar Galaxies (Arp, 1966), where a 200-inch (5 m) 103a-O plate is reproduced. It is seen there that the “bow” actually extends over the whole western side as half an outer ring. This is more clearly seen in Fig. 2. This plate even shows part of a second ring in the north-western quadrant at twice the distance from the centre. The outer rings are not visible on the H\alpha-plate, but condensations in the jet-like feature (the “arrow”) can be recognized on the original plate from which Fig. 1 is reproduced. They are very faint, so that it is possible that we only see continuum emission there. If these condensations are H II-regions, they are then very much less luminous in optical emission lines than those in the spiral arms. In view of these peculiar structures of the outer part, the regularity and symmetry of the spiral structure is truly remarkable. De Vaucouleurs and de Vaucouleurs (1964) have classified NGC 3310 as SAB(r)bc, while van den Bergh (1960), who bases his classification mainly on the Sky Survey prints, uses it as an illustration of his class Ir II. Clearly, the fact that the inner portion of the galaxy has been over-exposed on these plates puts it erroneously in the class of irregular galaxies.

b) Integral Properties

The high-luminosity observed in the optical emission lines and the presence of many large, bright H II-regions are consistent with some of the integral properties of NGC 3310, which will now be discussed. De Vaucouleurs and de Vaucouleurs (1964) give a \((B-V)\) of 0.28 when corrected for absorption and redshift. In their largest diaphragm (128") WC give \((B-V)=+0.29\);
$$U - B = -0.48.$$ Since they find the same colours in four smaller diaphragms (down to 11") these colours apply to the disk and there is no large radial dependance for them. Unlike Seyfert galaxies the nucleus is not dominating the optical light and the blue colours are therefore not due to peculiarities of the nucleus. These numbers indicate that NGC 3310 is one of the bluest spiral galaxies observed. The disk therefore has a relatively large content of early type stars\(^1\). Assuming that its age is \(10^{10}\) years, the calculations of Searle et al. (1973) indicate that either the initial luminosity function contains a larger percentage of luminous stars than usual, that the rate of star formation has not or hardly been declining during its life-time or that there has been a more recent burst of star formation.

Its early type spectrum (A 8; Humason et al., 1956) is also in agreement with the presence of many early type stars. We also note that the average surface brightness \(B'(0) = 13.14\) mag (arcmin)\(^{-2}\) (de Vaucouleurs and de Vaucouleurs, 1964) is among the brightest in their sample.

We will turn now to the mass-to-light ratio and the hydrogen content. The values we quote will be normalized to the distance of 20.5 Mpc (see Section 3) and to an inclination of 30\(^\circ\), which has been found dynamically from optical velocity measurements (paper II; van der Kruit, 1976).

WC find \(M/L\) to be 1.0–2.0 (in solar units) in the inner disk. A similar value is found from the analysis in paper II. With lower reliability this ratio can also be derived from observations of the total H\(_i\) 21-cm line profile. Balkowski (1973) then gives \(M/L\) \approx 10, while Peterson and Shostak (1974) find \(M/L\) \approx 4. These values are not abnormal, but are slightly low compared to galaxies of similar type (say Sbc), when it is derived by similar means. The difference between the optical and radio values is not disturbing because the second refers to a much larger region. We may conclude that the mass-to-light ratio for the inner region is in agreement with the presence of many luminous stars there.

From Balkowski and from Peterson and Shostak we get a hydrogen mass of \(9.1 \times 10^9\) and \(5.6 \times 10^9\) \(M_\odot\) respectively.

c) Velocity Structure

The only published velocity measurements are those by WC, who took spectra in p.a. 0\(^\circ\) and 90\(^\circ\), recording the \([\text{O} ii] \lambda \lambda 3726–3729\) doublet, \([\text{Ne} iii] \lambda 3869\) and various Balmer lines starting at H\(\beta\). They find that the apparent nucleus is displaced from the rotation centre and indicate possible non-circular motions. From their rotation curve they derive a somewhat detailed mass-model, but it will be shown in paper II that the motions are probably affected by a field of large scale non-circular streamings, so that this mass-model is not very realistic.

3. Group Membership and Distance

The possible membership of NGC 3310 of a group of galaxies is important for the papers in this series, not only for determining the distance, but also for finding possible candidates for a recent encounter, which might have produced at least the outer disturbances. To investigate the group membership we have plotted in Fig. 3 all galaxies brighter than \(m = 13.9\) from the Zwicky catalogue (Zwicky and Herzog, 1966, 1968) in a box of \(16^\circ \times 14^\circ\) centered on NGC 3310. De Vaucouleurs (1966) defines two groups in this area; Ursa Major X—consisting of NGC 3310, 3445, 3448, 3548 and 3549—and Ursa Major Y—consisting of NGC 3583, 3726 and more systems beyond the lower-left-hand corner of the figure. The magnitude of NGC 3310 itself is 11.0 on Zwicky’s scale.

We have examined each individual system by comparing its redshift to others in the field and in particular to NGC 3310. If no redshift is available we used the van den Bergh (1960) classification together with apparent magnitudes and the calibration of the absolute magnitudes of the various classes by Sandage and Tammann (1974) to decide whether it might be at a distance similar to that of NGC 3310. The only system which we reasonably believe to be a foreground galaxy is NGC 3556, based on its redshift \(+760\) km s\(^{-1}\), corrected for galactic rotation, as will be all redshifts quoted here), which is far from any redshift observed in the area, and its angular size (8'). Secondly, the group around R.A. 11\(^h\) 20\(^m\), Dec. +59\(^\circ\) almost certainly is a background group at a mean redshift of \(+1870\) km s\(^{-1}\) (from four members). Five systems (NGC 3079, 3448, 3631, 3718 and 3726) have redshifts comparable to NGC 3310, while from arguments like indicated above and angular size six more (NGC 3206, 3445, 3549, 3729, 3738 and 3756) are likely to be at roughly the same distance. It is also probable that NGC 3353, 3458 and 3583 are at a similar distance.

It seems therefore that all the brighter galaxies in Fig. 3, except for the small group in the upper-left-hand corner, are at about the same distance. The mean redshift is \(+1170\) km s\(^{-1}\) (for de Vaucouleur’s Ursa Major X group this is \(+1270\) km s\(^{-1}\)). Using a Hubble constant of \(55\) km s\(^{-1}\) Mpc\(^{-1}\) the distance of the group is 21.3 Mpc (23.1 Mpc for Ursa Major X). If NGC 3310 is treated as an isolated galaxy, the distance can according to Sandage and Tammann (1975) be derived to a reasonable accuracy from the redshift. Since this is \(+1084\) km s\(^{-1}\) (see paper II), the distance would then be 19.7 Mpc. Since the distances are nearly the same, we will use the average value from these two methods and assume that the distance is 20.5 Mpc in the following.

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\(^1\) Andrillat and Collin-Souffrin (private communication) find evidence for a high content of O and B stars in the nucleus, derived from spectrophotometry.
Between $m = 11.0$ and $m = 12.9$ we find in Fig. 3 that of the systems at roughly the same distance ten are to the east and two to the west of NGC 3310. This reflects the well-known crowding of bright galaxies towards R.A. about $12^h$, which constitutes the northern extension of the Virgo cluster. However, between $m = 13.0$ and $m = 13.9$ these values are more comparable (nine versus sixteen), indicating that the majority of these systems are at a distance greater than 20 Mpc.

At a distance of 20.5 Mpc, $1^\circ$ corresponds to 99 pc. The spiral structure then extends to about 4 kpc from the centre, while the outer rings are at projected distances of 7.5 and 13 kpc from the nucleus. So, even at 20.5 Mpc distance NGC 3310 comes out as a fairly small galaxy.

In connection with the possibility of encounter it seems worthwhile to examine the systems closest in the sky in somewhat more detail. These are a system at $10^h29^m4.4, +54^\circ38^\prime$ of magnitude 13.2, NGC 3353 and NGC 3448. The first is at a projected distance of 0.5 Mpc, but its smaller angular size ($\sim 1^\circ$) suggests that it is a background galaxy. Moreover, it appears undisturbed at the Sky Survey prints. NGC 3353 is of magnitude 12.9 and also has a diameter of $1^\circ$. The projected distance is 0.9 Mpc and it is also undisturbed on the Sky Survey prints. NGC 3448, however, is a disturbed system; it is shown in Arp's Atlas as $\neq 205$ and is at a projected distance of 0.9 Mpc from NGC 3310. The systemic velocity is $+1420$ km s$^{-1}$ (Peterson and Shostak, 1974; Bottinelli et al., 1975), which is 340 km s$^{-1}$ higher than that of NGC 3310. The separation and relative velocity are large; a possible encounter, which has a very low probability, must have occurred several billion years ago. Furthermore, the study of Bottinelli et al. (1975) indicates that NGC 3448 is almost certainly an interacting pair in itself, the bright blob to the west being a companion dwarf system. This argument makes the encounter hypothesis even more unlikely.

4. Far-ultraviolet Observations

NGC 3310 has been observed on several occasions in 1975 with the ANS (Astronomical Netherlands Satellite; for a brief description see van Duinen et al., 1975). The spectral regime covered runs from 1500 Å to 3300 Å in five discrete bands. The greater part of the galaxy is included in the $2.5 \times 2.5$ entrance aperture. The ANS photon count rates and the conversion to monochromatic intensities are given in Table 1. The errors have been calculated from the internal spread in the four observations and are consistent with those calculated from counting-statistics.

Unfortunately, no narrow band optical or infrared photometry is available for comparison with the far-
UV data. The sharp upturn in the far-UV is similar to that found for the lm-galaxy NGC 4449 (Code et al., 1972) and the late-type spiral M 101. Since NGC 3310 does not have an intense starlike nucleus with an UV-excess as observed in Seyfert nuclei (the blue optical colours are due to the disk and not to the nucleus; see Section 2), the far UV-excess is most likely related to the numerous H II-regions (see Fig. 1) and then must come from the emission of OB stars.

In principle the slope of the far-UV spectrum can be used to synthesize the population of early-type stars in NGC 3310. Because of the uncertain reddening and extinction we will not attempt to do this here. However, comparing the far-UV emission with that of giant H II-regions and H II-complexes in external galaxies also observed by ANS leads to some interesting results. Such a comparison shows that the distribution of the ANS count rates for NGC 3310 over the five channels is similar to those of the H II-region NGC 604 in M 33 and the giant H II-complex NGC 5447 in M 101 (Israel, 1976). When we take the difference in distance of the galaxies into account, we find that the far-UV emission from NGC 3310 is equivalent to 30 and 700 H II-regions of the type of NGC 5447 and NGC 604 respectively!

Most of the H II-regions visible in NGC 3310 (Fig. 1) have linear sizes intermediate between those of NGC 604 and NGC 5447 and it seems therefore that the comparison has astrophysical significance. We then find that there must be of the order of $10^9 M_\odot$ of ionized gas in NGC 3310 ($\sim 1/8$ of the H I mass) and about $2 \times 10^4$ stars of spectral type O 5 (or their equivalent) are needed to keep that gas ionized. These numbers are scaled from the calculated quantities for NGC 604 (Israel and van der Kruit, 1974) and NGC 5447 (Israel et al., 1975). The very large number of OB stars, which is consistent with the optical colours (Section 2), also suggests a very high rate of type II supernovae. Most of these will unfortunately be difficult to detect, since the bright disk of NGC 3310 is overexposed on types of plates taken in current supernova searches (a supernova was detected in 1974, but not in a search program; see Section 5).

The thermal emission of NGC 3310 based on a comparison with the observed radio flux densities of NGC 604 and NGC 5447 (Israel and van der Kruit, 1974; Israel et al., 1975) is 50 and 30 mJy respectively (at 1.4 GHz).

5. The Distribution of Radio Continuum Emission

We have observed the radio continuum emission from NGC 3310 with the Westerbork Synthesis Radio Telescope (see Baars and Hooghoudt, 1974; Casse and Muller, 1974; and Högbom and Brouw, 1974) at the three available wavelengths of 49, 21 and 6 cm. The relevant characteristics of the telescope and the observations are summarized in Table 2.

The observation at $\lambda$ 21 cm is the one that was reported earlier (van der Kruit, 1971). Those measurements were hampered by two serious effects. The shortest baseline in the observations was 180 m (see Table 2), causing a serious attenuation of all structure larger than an angular size of 1'–2'. Secondly, the galaxy was exactly on a grating ring of an intense background source. The flux density given in that paper refers approximately to the peak flux density, since the source then looked unresolved. Now that clean techniques (Högobm, 1974) have become available, we have re-analysed the map. By an iterative procedure the effects of the confusing source could be removed; furthermore, a large fraction of the total flux density, which was buried in the negative "bowl" created by the missing short spacings, could be recovered by the clean technique. However, since not all the flux could be recovered (still $\sim 20\%$ missing) and some contribution from 21-cm line radiation must be present in the 4 MHz band, we have decided not to publish the $\lambda$ 21-cm contour map. We now derive a total flux density around 0.4 Jy in good agreement with other determinations at this frequency.

Figure 4 shows the map at $\lambda$ 6 cm superposed on the Hα photograph. In the map there clearly is emission from the region of the spiral arms. Certainly along the northern arm this is displaced inward from the optical arm and therefore provides evidence for the presence of density wave compression (Mathewson et al., 1972). Sequist (private communication) has mapped NGC 3310 with the NRAO-interferometer at 2.7 and 8.1 GHz (11 and 3.7 cm) and also found the arm emission; his data imply it to be largely non-thermal with a spectral index similar to the overall spectral index.

Figure 4 shows a peak in the emission at the position of the very large H II-region at R.A. = $10^h35^m39^s$ and Dec. = $53^\circ 45' 42''$. The flux density as estimated for a point source from the excess above the surrounding

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region is $\sim 6$ mJy. Part or all of this might be thermal emission. If it is all thermal, the source is about 2.5 times more luminous than NGC 5461 in M 101 (Israel et al., 1975). The size ($\sim 5''$) of about 0.5 kpc is also comparable to NGC 5461.

From Fig. 4 we can put an upper limit of 7 mJy on a pointsource at the nucleus, so that the luminosity at this wavelength is less than $3 \times 10^{19}$ W Hz$^{-1}$ sterad$^{-1}$. If we assume a spectral index of $-0.7$ (see Section 6) it corresponds to less than $7 \times 10^{19}$ W Hz$^{-1}$ sterad$^{-1}$ at 1415 MHz, which is still bright for normal spiral nuclei (van der Kruit, 1973).

The total flux density at $\lambda$ 6 cm (Table 3) was derived from extrapolating the visibility curve to zero spacing. This procedure is valid if the source is smaller than 3', which is corroborated by our $\lambda$ 49 cm result.

Our $\lambda$ 49 cm results are shown in Fig. 5. The map has been cleaned and restored with a Gaussian beam of $42'' \times 52''$, which is slightly narrower than the synthesized beam. Our resolution is insufficient to map the
Table 3. Total radio flux densities from NGC 3310

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Flux density S (Jy)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.178</td>
<td>&lt;2.0</td>
<td>4C-Gower et al. (1967)</td>
</tr>
<tr>
<td>0.610</td>
<td>0.65 ± 0.05</td>
<td>WSRT</td>
</tr>
<tr>
<td>0.750</td>
<td>0.60 ± 0.10</td>
<td>Heeschen and Wade (1964)</td>
</tr>
<tr>
<td>1.400</td>
<td>0.60 ± 0.10</td>
<td>Heeschen and Wade (1964)</td>
</tr>
<tr>
<td>1.415</td>
<td>0.40 ± 0.10</td>
<td>de la Beaujardière et al. (1968)</td>
</tr>
<tr>
<td>1.420</td>
<td>0.31 ± 0.03</td>
<td>Lequeux (1971)</td>
</tr>
<tr>
<td>2.695</td>
<td>0.30 ± 0.025</td>
<td>De Jong (1967)</td>
</tr>
<tr>
<td>2.695</td>
<td>0.30 ± 0.04</td>
<td>Kazés et al. (1970)</td>
</tr>
<tr>
<td>2.695</td>
<td>0.24 ± 0.03</td>
<td>Pfeiderer (private communication)</td>
</tr>
<tr>
<td>4.850</td>
<td>0.15 ± 0.02</td>
<td>Le Squeren and Crovisier (1974)</td>
</tr>
<tr>
<td>4.990</td>
<td>0.14 ± 0.015</td>
<td>WSRT</td>
</tr>
<tr>
<td>5.000</td>
<td>0.129 ± 0.017</td>
<td>Sramek (1975)</td>
</tr>
<tr>
<td>6.630</td>
<td>0.15 ± 0.02</td>
<td>McCutcheon (1973)</td>
</tr>
</tbody>
</table>

*) 1 Jy = 1 Jansky = 10^{-26} W m^{-2} Hz^{-1}.

Spiral structure. There is some evidence of a weak extension of the source in the direction of the jet (north-west) and the first outer ring.

The total flux density at $\lambda$ 49 cm (Table 3) was determined by summing the delta-functions found in the clean-process in an area $2' \times 2'$ centered on the galaxy. It agrees within the errors with the extrapolation to zero spacing of the interferometer visibility amplitudes.

In February 1974 a supernova was discovered in NGC 3310 (van der Kruit and Arp, 1974) during a spectroscopic program. At the time of discovery it was of magnitude $\sim 16.5$ (visual) and it decreased very little in brightness in the next two months, when spectroscopic observations continued. A spectrum showed that it presumably was of type II and that at the time of discovery it was at least a few months, but maybe as

Fig. 5. Radio contour map of the $\lambda$ 49 cm emission from NGC 3310, superposed on the IIIa-J photograph (Fig. 2). The contour levels are $-3$, $3$, $6$, $9$, $15$, $30$, $60$, $120$ and $240$ mJy per beam. Note that the contour levels are highly non-linear. The shaded ellipse indicates the half-power of the Gaussian beam with which the cleaned map was restored. The r.m.s. noise is 2 mJy per beam.
much as half a year, after it reached its maximum brightness. The supernova event therefore probably occurred before the $\lambda 49$ and 6 cm observations were done. Its position, which was later determined more accurately to be 17” south and 12° east of the nucleus, has been indicated in Fig. 4. No radio emission was detected at $\lambda 6$ cm, while no useful upper limit can be established at $\lambda 49$ cm. This is not unexpected since de Bruyn (1975) detected no emission from other supernovae at a similar age. Emission at the level of supernova 1970g in M 101 (Goss et al., 1973) would be of the order of one mJy at the distance of NGC 3310 and therefore go unnoticed in our maps.

The disk emission in NGC 3310 is enormously intense. For example, the peak brightness in the north-eastern spiral arm is about 7 K at $\lambda 6$ cm, which corresponds to about 200 K at $\lambda 21$ cm. This is more than an order of magnitude higher than the spiral arms in M 51, which is already quite high (van der Kruit, 1973). The average brightness temperature of the disk, assuming a diameter of 1.5, is 40 K at $\lambda 21$ cm; again this is unusually high. Illovasisky and Lequeux (1972) estimate a power at 1 GHz for the disk of our Galaxy of $1.8 \times 10^{-11}$ W Hz$^{-1}$, which corresponds to 36 mJy at 20.5 Mpc. This is a factor 13 weaker than NGC 3310 at this frequency. If we also take into account that the diameters of the radio disks are different by a factor 3 to 4 this corresponds to more than two orders of magnitude in the volume emissivities. If supernovae are the source of relativistic electrons in disks of spiral galaxies, this high volume emissivity is consistent with the inferred high supernova rate (see Section 4).

6. The Overall Radio Spectrum of NGC 3310

Measurements of the radio continuum flux density from NGC 3310 have been made from 0.610 GHz to 6.630 GHz. The flux densities and their errors as quoted by the observers have been listed in Table 3. The measurements indicated by WSRT are those made by us. The values by Heessen and Wade include some background sources; the effect however is probably within the errors. The data are plotted in Fig. 6. A least-square fit of a straight line to the data with every point weighted by its error gives $S(\text{Jy}) = (0.48 \pm 0.01) \times \{\nu(\text{GHz})\}^{-0.69 \pm 0.02}$ and is indicated in Fig. 6. This gives a satisfactory fit to the data and is still consistent with the upper limit at 0.178 GHz. It should also be pointed out that the absence of measureable thermal radio emission is not in contradiction with the earlier mentioned strong Hz emission and the large number of O and B stars. The thermal flux density was estimated to be about 40 mJy from the far-UV observations (see Section 4). Furthermore, it would take 60 giant H II complexes like NGC 5461 in M 101 (Israel et al., 1975) to produce 0.15 Jy (the upper limit to the thermal emission) and there certainly are not that many such objects in NGC 3310.

If the radio emission from NGC 3310 contains a thermal (spectral index $-0.1$) component with a flux density of about 40 mJy at 1.4 GHz, the non-thermal part of the emission must have a spectral index of about $-0.79$.

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References

Balkowski, C. 1973, Astron. & Astrophys. 29, 43
Heeschen, D. S., Wade, C. M. 1964, Astron. J. 64, 77
Högbohm, J. A. 1975, Astron. & Astrophys. Suppl. 15, 147
Israel, F. P. 1976, in preparation
Kruit, P. C. van der. 1971, Astron. & Astrophys. 15, 110
Kruit, P. C. van der, Arp, H. C. 1974, I.A.U. Circular No. 2641
Lequeux, J. 1971, Astron. & Astrophys. 15, 30
McCutcheon, W. M. 1973, Astron. J. 178, 18

Sramek, R. 1975, Astron. J. 80, 771

P. C. van der Kruit,
Kapteyn Astronomical Institute
P. O. Box 800
Groningen-8002, The Netherlands

A. G. de Bruyn
Hale Observatories
613 Santa Barbara street
Pasadena, CA 91101, USA