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THE RADIO SPECTRUM OF OQ 208 – MARKARIAN 668

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Radio measurements were made at 1.35, 1.93, 2.8 and 3.8 *cm* during April 1978 and at 6 and 11 *cm* during August and November 1977 respectively, supplementing and extending previous work on OQ 208-Markarian 668. The radio source has a curved spectrum with a maximum at centimeter wavelengths. The spectral index $\alpha \approx -1.35$ between 3.8 and 1.35 *cm* and $\alpha \approx +0.65$ between 11 and 6 *cm*. The synchrotron source may be located within a dense ionized medium. It is suggested that OQ 208-Markarian 668 is a Seyfert I-type galaxy.

1. *Introduction.* The radio source OQ 208 has been identified as a Seyfert-type galaxy with a $z = 0.077$ [1]. This galaxy was included by Markarian and Lipovetski [2] in their list of objects manifesting strong UV excess under the number 668. The accurate position of the galaxy ($\alpha = 14^h04^m45^s.9$, $\delta = 28°41'35''$, epoch 1950.0) is given in [3]. The object OQ 208-Markarian 668 has been extensively observed in the radio continuum from 49 *cm* to 2.8 *cm* [4—12]. It has been comprehensively observed for both flux density and possible linear polarization variations by Altschuler and Wardle [8], and for flux density variations by Medd et al. [9], and Dent and Kapitzky [12]. The optical brightness from this galaxy has exhibited variations of about 1^m, and it is suspected of being a long-term optical variable [13].

This paper presents flux density measurements of OQ 208-Markarian 668 obtained during April 1978 at short (1.35, 1.93 and 3.8 *cm*)

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wavelengths at the Haystack Observatory USA (the Haystack Observatory is operated by the Northeast Radio Observatory Corporation (NEROC) with support from the US National Science Foundation), and at 2.8 *cm* at the Algonquin Radio Observatory (the Algonquin Radio Observatory (ARO) is operated by the National Research Council, Ottawa, Canada, as a national radio astronomy facility).

The 6 and 11 *cm* flux density observations were made at the National Radio Astronomy Observatory at Green Bank, West Virginia, USA (the National Radio Astronomy Observatory (NRAO) is operated by the Associated Universities Incorporated under contract with the National Science Foundation) during August and September 1977, respectively. These radio-continuum measurements supplement and extend the past work on this source.

2. *Observations and equipment.* The equipment used at each of the three observatories is summarized in Table 1.

Table 1

OBSERVING SYSTEM PARAMETERS

Frequency (*GHz*)	Antenna used	HPBW (arcminutes)	Bandwidth (*MHz*)	System Temperature (°K)
2.7	NRAO (91.4*m*)	4.7	100	130
5	NRAO (91.4*m*)	2.7	150	125
7.88	Haystack (36.58*m*)	4.4	20	120
10.5	ARO (46*m*)	2.7	100	140
15.5	Haystack (36.58*m*)	2.2	1200	900
22.2	Haystack (36.58*m*)	1.3	20	170

a) *The Haystack Observations.* On-off source cyclings were made at 1.35 *cm* (22.2 *GHz*), 1.93 *cm* (15.5 *GHz*) and 3.8 *cm* (7.88 *GHz*) during April 1978 with the 36.58 *m* paraboloid of the NEROC Haystack Observatory.

The 1.35 *cm* measurements were obtained with a radiometer equipped with a K-band maser preamplifier. System temperature was about 170 °K. The effective bandwidth was 20 *MHz* and the halfpower beamwidth (HPBW) at this frequency is about 1.3.

3C 273 was used as a secondary standard and was calibrated relative to DR 21. The flux density of DR 21 has been carefully measured by Dent [14]. The antenna temperature was corrected for atmospheric absorption and elevation dependent gain effects. The flux error was determined by quadratically combining the noise error and the assumed calibration error.

The method of observation (on-off) and data reduction at 1.93 and 3.8 *cm* has been described in detail elsewhere [15—17].

b) *The NRAO Observations.* Observations were made with the NRAO 91.4 *m* transit telescope at 6 *cm* between August 21 and September 3, 1977 and at 11 *cm* from November 25 through to November 27, 1977. During this period a large sample of Markarian galaxies in Markarian's lists 6 and 7 [18, 2] were observed. Details of the observing method and calibration procedure have been given elsewhere [17, 19—21]. So only a summary is presented here.

The measurements at both wavelengths consisted of right ascension drift scans, three minutes in length, centered on the expected source position and at ± half a beamwidth in declination.

The 6 *cm* beam-switching radiometer system consisted of two feeds aligned in an east-west direction and separated by 7.2. The HPBW for each beam was 2.7. The radiometer system included two cooled parametric amplifiers with system temperatures of about 125 K and bandwidths of about 150 *MHz*.

The 11 *cm* system consisted of a 3-feed, 4-receiver system arranged in line. When the central horn is located on the telescope's electrical axis, the other two horns provide beams ten arcminutes off axis, in opposite directions. The system temperatures and RF bandwidths of the 4 load-switched radiometers were about 130 K and 100 *MHz*, respectively.

Observations of point sources from Kellermann et al. [22] and Kellermann et al. [23] were used for the conversion of source antenna temperatures to flux densities at 6 and 11 *cm*, respectively.

c) *The Algonquin Observations.* The 2.8 *cm* observations were made on the 46-meter antenna at ARO utilizing the on-off technique. The system employed a Dicke-switched dual feed, parametric amplifier radiometer with an effective bandwidth of about 100 *MHz* and system noise temperature of about 120°K. The horns are mounted azimuthally, eliminating the effects of differential emission. Details regarding the observing technique and calibration procedure are given elsewhere [17].

3. *Results and discussion.* The results of our observations of OQ 208-Markarian 668 are presented in Table 2.

The radio spectrum of OQ 208-Markarian 668 is well defined between wavelengths $\lambda = 1.35$ *cm* (22.2 *GHz*) and $\lambda = 49$ *cm* (606 *MHz*) due to many investigators at several observatories.

Table 2

OQ 208-MARKARIAN 668 FLUX DENSITIES

Frequency *GHz*	Wavelength *cm*	Flux $(mJy)^*$
2.7	11	1870 ± 410
5	6	2766 ± 460
7.88	3.8	3420 ± 690
10.6	2.8	2290 ± 150
15.5	1.93	1440 ± 216
22.2	1.35	850 ± 140

* $mJy = 10^{-29}\, Wm^{-2}Hz^{-1}$

Figure 1 is a summary of recently measured spectral data by the authors and previously published measurements by other investigators. Ryle and Pooley [10] have already stated that the spectrum is peaked with a maximum flux density at a frequency close to 5 *GHz* ($\lambda = 6$ *cm*). Medd et al. [9] have also indicated that this radio source has a curved spectrum with a single maximum at centimeter wavelengths; they further characterize this galaxy as a weak variable at 2.8 *cm* (10.6 *GHz*) and at 4.5 *cm* (6.6 *GHz*).

Our measurements confirm the curved form of the spectrum. It appears broadly peaked near $\lambda = 3.8$ *cm* (7.88 *GHz*) and falls off rapidly above this frequency and decreases with decreasing frequency. The spectral index at wavelengths shorter than the peak wavelength is $\alpha \approx -1.35$ ($S \sim \nu^{\alpha}$), manifesting the non-thermal nature of this radio source. The source has a positive spectral index $\alpha \approx +0.65$, between 6 and 11 *cm*. The spectral index at the shorter wavelengths was determined by measurements obtained during April 1978, and the positive index at the longer wavelengths was calculated from flux density measurements made during August and November 1977.

The segment of the spectrum shown in Figure 1 between $\lambda = 11$ *cm* (2.7 *GHz*) and 6 *cm* (5 *GHz*) appears to follow the form $S \sim \nu^{(\alpha+2)}$ [24], suggesting that the synchrotron source may be embedded in a medium consisting of ionized hydrogen. Under these physical conditions free-free absorption may take place within the enviroment of the synchrotron radiation source, thus altering the synchrotron spectrum. OQ 208 was amongst the radio sources monitored by Altschuler and Wardle [8] for linear polarization. Their results indicate that the degree of linear polarization in the emission from OQ 208 is unspectacular, thus lending some support for the concept that a dense HII-like region is contributing to the alteration of the synchrotron spectrum. A source of high density thermal electrons would tend to depolarize radiation from a synchrotron source through the influence of Faraday rotation. The synchrotron emitter associated with OQ 208-Markarian 668 may be located within an ionized medium consisting of a dense source of thermal electrons. Epstein and Petrosian [25] indicate that the observed radio spectrum of OQ 208 can be reproduced by either small pitch-angle or thermal absorption model.

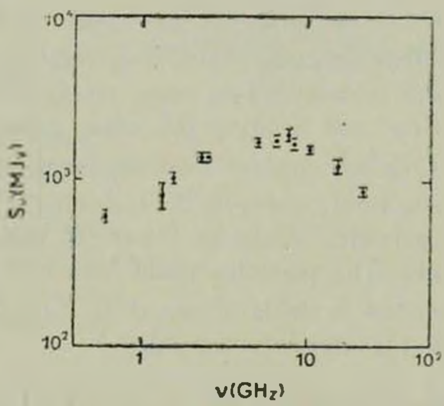

Fig. 1*. The spectrum of OQ 208-Markarian 668. Additional data points are from the following references: 8.085 *GHz* [8], 6.6 *GHz* [9], 2.7 *GHz* [8], 2.296 *GHz* [7], 1.67 *GHz* [6], 1.4 *GHz* [5] and 606 *MHz* [4].

The frequencies at which OQ 208 was extensively monitored are displayed with a dot and two horizontal dashes representing the extent of the uncertainty in the measurements. The monitored densities presented are the averages of the published maximum and minimum values. The corresponding error bars were established by adding the published error to the maximum and subtracting it from the mininum flux density.

At a magnetic field strength B of about 10^{-2} *gauss*, the total energy contained in the magnetic field and in the form of relativistic particles is minimized and is of the order of 10^{52} *ergs*.

The Razin-Tsytovich [26, 27] effect may probably further contribute to the alteration of the synchrotron spectrum at the lower frequencies. For a magnetic field of 10^{-2} *gauss* the density of thermal electrons needed to affect the spectrum below 2 *GHz* is about 10^{6} cm^{-3}.

* Note added in proof: the scalo of the oordinate of the Figure is wrong.

This value for the electron density of the ionized region in which the synchrotron source is embedded, is characteristic of Seyfert I-type galaxies [28—30]. G. T. Petrov [31], using spectrophotometry data accumulated by Osterbrock [32], has obtained a mean value of about $5 \cdot 10^6$ cm^{-3} for the electron density of Seyfert I-type galaxies.

The form of the radio spectrum discussed herein which has a broad peak near 3.8 *cm* and falls off rapidly at short wavelengths and decreases with increasing wavelengths, appears to be supportive of a suggestion made by Sramek and Tovmassian [19] that the absence of detectable emission at 6 *cm* from some of the observed Seyfert I-type galaxies may be due to the compactness of their nuclei.

If the synchrotron model with its assumptions are invoked [33—36] and a magnetic field of the order of 10^{-2} *gauss* is assumed, the angular size of the synchrotron emitting region is calculated to be about $0\overset{''}{.}0002$. The related linear size is about 0.4 *pc*, when taking $H = 75$ $km\ sec^{-1} Mpc^{-1}$ and $z = 0.077$. Shaffer and Schilizzi [6] have indicated that the total flux density from OQ 208 appears to come from components $\lesssim 0\overset{''}{.}001$.

For a magnetic field strength B of about 10^{-3} *gauss*, the energy of the relativistic particles would be about 10^6 times greater than that stored in the B field. The particles could not be contained under conditions which permitted B fields of about 10^{-3} *gauss* or less, and the radio source would then tend to expand.

4. *Conclusion.* We confirm the turnover in the spectrum of OQ 208 indicated by Ryle and Pooley [10] and also by Medd et al. [9]. Our measurements show that the turnover is in the neighborhood of 3.8 *cm* (7.88 *GHz*). The non-thermal nature of the radio source associated with the Seyfert galaxy OQ 208-Markarian 668 is evident from the spectral data exhibited in Figure 1. This source has a spectral index $\alpha \simeq -1.35$ between 3.8 *cm* (7.88 *GHz*) and 1.35 *cm* (22.2 *GHz*). The segment of the spectrum between 6 *cm* (5 *GHz*) and 11 *cm* (2.7 *GHz*) manifests a positive spectral index $\alpha \simeq +0.65$.

We suggest, that the apparent alteration of the synchrotron spectrum may be attributed to a dense region of thermal electrons within the enviroment of the synchrotron emitter, and that OQ 208-Markarian 668 is probably a Seyfert I-type galaxy.

Optical studies, and radio measurements which supplement and extend this and previous work on the radio properties, may further help to clarify the relationship between the synchrotron source and its enviroment.

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РАДИОСПЕКТР OQ 208 — МАРКАРЯН 668

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Представлены результаты наблюдений радиоизлучения сейфертовской галактики OQ 208 — Маркарян 668, выполненных на длинах волн 1.35, 1.93, 2.8, и 3.8 *см* в апреле 1978 г., и на 6 и 11 *см* в августе и ноябре 1977 г., соответственно. Спектр радиоисточника выпуклый, с максимумом на сантиметровых волнах. Спектральный индекс $\alpha \approx -1.35$ между длинами волн 3.8 и 1.35 *см* и $\alpha \approx +0.65$ между 11 и 6 *см*. Предполагается, что источник синхротронного радиоизлучения расположен внутри плотной ионизованной среды. Предполагается, что OQ 208 — Маркарян 668 является галактикой типа Сейферт I.

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