RADIO SOURCE INTERFEROMETRY AT 1427 Mc/s

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[*Manuscript received February* 23, 1962]

Summary

Interferometer measurements at 1427 Mc/s of amplitudes and phase angles are tabulated for eight radio sources. The interferometer spacing, orientation, and polarization were all varied.

I. Introduction

This paper tabulates some interferometer measurements made at 1427 Mc/s on the radio sources Taurus A, Virgo A, Centaurus A, Hercules A, Sagittarius A, Cygnus A, and the Omega and Orion nebulae. The methods used and some preliminary results on four sources have already been briefly described (Paper 1) by Twiss, Carter, and Little (1960), but the present paper lists the results for all sources in detail.

The aim of these measurements was twofold. The first objective was to determine if the brightness distribution over several sources, especially Taurus A, varied with polarization. The second was to study the brightness distributions over several sources for their own intrinsic interest.

The limitations of current techniques do not allow us to consider the first objective, the search for polarization effects, as merely a special case of the second, the measurement of brightness distributions. In practice, it is not possible to measure brightness distributions over small sources with sufficient accuracy to detect small variations with polarization. Brightness distributions constructed from interferometer observations are not accurate enough to detect small variations with polarization, and pencil-beam antennas are not available with sufficient resolution to resolve small diameter sources. There is, however, an alternative method of detecting polarization differences. It is to compare directly a few Fourier components of the brightness distributions, each component being measured with two or more different polarizations. By studying the individual Fourier components, instead of the brightness distribution synthesized from them, two advantages are gained. Firstly, we avoid the cumulative errors involved in reconstructing the source brightness distribution. Secondly, fewer observations are needed, as it is not necessary to measure the wide range of Fourier components required to construct a definitive brightness distribution.

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TABLE 1

FOURIER COMPONENTS FOR SOURCE TAURUS A

Orientation	Spacing	Polarization	Amplitude	Phase	Remarks
East-west	58	Any	1·00	0°	Assumed
	116	N.-S.	0·94±0·02	—14°±4°	
		E.-W.	0·99±0·02	—7°±4°	
		N.-S.	0·91		0·01 relative accuracy
		E.-W.	0·91		
	174	N.-S.	0·88±0·03	—22°±5°	Amplitude 0·01 relative accuracy
		E.-W.	0·90±0·03	—10°±5°	
	232	N.-S.	0·96±0·03	—26°±7°	
		E.-W.	0·86±0·03	—1°±7°	
	290	N.-S.	0·76±0·03	—24°±8°	Amplitude 0·01 relative accuracy
		E.-W.	0·74±0·03	+3°±8°	
	348	N.-S.	0·76±0·03	—25°±8°	
		E.-W.	0·69±0·03	—3°±8°	
	406	N.-S.		—22°±9°	
		E.-W.		—1°±9°	
	464	N.-S.	0·48±0·02	—22°±10°	
		E.-W.	0·52±0·02	+1°±10°	
		N.-S.	0·49		0·01 relative accuracy
		E.-W.	0·48		
	522	N.-S.		—33°±10°	
		E.-W.		0°±10°	
	580	N.-S.	0·34±0·02	—52°±10°	
		E.-W.	0·38±0·02	+2°±10°	
		N.-S.	0·35	—3°±3°	Amplitudes 0·01 relative accuracy. These angles are $\chi(580)-2\chi(290)$
		E.-W.	0·36	0°±3°	
		NE.-SW.	0·37	+3°±3°	
	754	N.-S.	0·16±0·03	—9°±9°	These angles are $\chi(754)-\chi(696)$
		E.-W.	0·19±0·03	—13°±9°	
	870	N.-S.	0·09±0·03		
	1045	N.-S.	0·04±0·03		
		E.-W.	0·03±0·03		
	1161	N.-S.	0·03±0·03		
	1393	N.-S.	0·06±0·03		0·01 relative accuracy
		E.-W.	0·05±0·03		
	1509	N.-S.	0·04±0·03		
North-south	33	Any	1·00		Assumed
	391	E.-W.	0·69±0·02		
	586	E.-W.	0·39±0·02		
	782	E.-W.	0·17±0·02		
Northeast-southwest	41	Any	1·00		Assumed
	574	N.-S.	0·55±0·03		
	1067	N.-S.	0·12±0·03		

TABLE 2

FOURIER COMPONENTS FOR SOURCE VIRGO A

Orientation	Spacing	Polarization	Amplitude	Phase	Remarks
East-west	58	Any	1·00	0°	Assumed
	116	N.-S.	0·97±0·03	+1°±5°	
	174	N.-S.	0·75±0·05	+1°±8°	
	232	N.-S.	0·78±0·04	+7°±11°	
		E.-W.	0·76±0·05		
	290	N.-S.	0·78±0·05		
	348	N.-S.	0·70±0·04	+17°±13°	
		E.-W.	0·61±0·05		
	406	N.-S.	0·80±0·05		
	464	N.-S.	0·61±0·04	—3°±23°	
	696	N.-S.	0·64±0·04		
	812	N.-S.	0·52±0·05		From ratio A(812)/A(116)

TABLE 3

FOURIER COMPONENTS FOR SOURCE CENTAURUS A

Orientation	Spacing	Polarization	Amplitude	Phase	Remarks
East-west	58	Any	1·00	0°	Assumed
	116	N.-S.	0·79±0·01	—12°±3°	
	174	N.-S.	0·71±0·02	—24°±5°	
	232	N.-S.	0·46±0·02	—11°±5°	
		E.-W.	0·44±0·02		
	290	N.-S.	0·28±0·02	—7°±7°	From product A(290)×A(174)
		E.-W.	0·36±0·05		
	348	N.-S.	0·13±0·02	+29°±7°	
		E.-W.	0·16±0·02		
	406	N.-S.	0·28±0·05		
	464	N.-S.	0·41±0·02	+73°±10°	This phase angle was incorrectly given in Paper 1
	696	N.-S.	0·54±0·02		

TABLE 4

FOURIER COMPONENTS FOR SOURCE HERCULES A

Orientation	Spacing	Polarization	Amplitude	Phase	Remarks
East-west	58	Any	1·0		Assumed
	116	N.-S.	1·3±0·2		
	232	N.-S.	0·8±0·2		
		E.-W.	0·7±0·2		
	464	N.-S.	0·8±0·2		
	696	N.-S.	0·7±0·2		

II. The Measurements

For most sources we measured the amplitude and phase of the Fourier components at a regular series of aerial spacings. Many measurements were repeated for greater reliability and some measurements were repeated at least once with a different polarization.

Polarization effects in Taurus A have been reported at higher frequencies so a separate group of observations were made on this source with very high relative accuracy in the comparison of different polarizations. Each observation in this group consisted of two measurements made in quick succession with different polarizations. The change was made within a few minutes of transit to give two successive measurements, symmetrical about transit, and with the same receiver calibrations. This method allows differences between Fourier components to be found although each individual component may be inaccurate through calibration errors.

Phase measurements were made using Jennison's (1958) method. This method does not give absolute phase angles, i.e. it does not give the position of an interference pattern in relation to a known position in the sky. Instead it gives the difference in position from one Fourier component to another. To simplify the tabulation of these angles we have therefore arbitrarily taken the phase angle at our closest aerial spacing of 58 wavelengths as zero, and used this as a datum for all other phase angles.

Table 5

Fourier components for source Sagittarius A

Orientation	Spacing	Polarization	Amplitude	Phase	Remarks
East-west	58	Any	$1 \cdot 00$	$0°$	Assumed
	116	N.-S.	$0 \cdot 50 \pm 0 \cdot 02$	$-26° \pm 4°$	
	174	N.-S.	$0 \cdot 58 \pm 0 \cdot 02$	$-40° \pm 5°$	
	232	N.-S.	$0 \cdot 35 \pm 0 \cdot 03$	$-84° \pm 9°$	
		E.-W.	$0 \cdot 41 \pm 0 \cdot 03$		
	290	N.-S.	$0 \cdot 59 \pm 0 \cdot 06$	$-107° \pm 11°$	
	348	N.-S.	$0 \cdot 38 \pm 0 \cdot 03$	$-88° \pm 12°$	
	406	N.-S.	$0 \cdot 20 \pm 0 \cdot 08$		From product A(406) × A(290)
	464	N.-S.	$0 \cdot 26 \pm 0 \cdot 03$	$-188° \pm 20°$	
	580	N.-S.	$0 \cdot 16 \pm 0 \cdot 03$		
	696	N.-S.	$0 \cdot 10 \pm 0 \cdot 03$		
	928	N.-S.	$0 \cdot 04 \pm 0 \cdot 03$		
North-south	58	Any	$1 \cdot 00$		Assumed
	173	N.-S.	$0 \cdot 32 \pm 0 \cdot 03$		
	231	N.-S.	$0 \cdot 39 \pm 0 \cdot 03$		
	289	N.-S.	$0 \cdot 42 \pm 0 \cdot 03$		
	347	N.-S.	$0 \cdot 28 \pm 0 \cdot 03$		
	463	N.-S.	$0 \cdot 33 \pm 0 \cdot 03$		
	578	N.-S.	$0 \cdot 21 \pm 0 \cdot 03$		
	694	N.-S.	$0 \cdot 13 \pm 0 \cdot 03$		
	809	N.-S.	$0 \cdot 19 \pm 0 \cdot 03$		

All the east–west scans were analysed by correlating the recorded data with a sine wave having a period appropriate to the aerial spacing in wavelengths and the declination of the source. The calculations were done by an electronic computer which multiplied the recorded data, term by term, with both a sine wave and a cosine wave, and summed the products of each group. The amplitude and phase of the interference pattern were then easily found from the two sums. The observation times were made as near as possible to a whole number of fringes and small approximate corrections applied for any residual end effects.

Many east–west scans of particular interest have subsequently been re-analysed by fitting a sine wave using the least-squares criterion. This recomputation was intended as a check on human errors in the original data processing and not as a check on either the original computer program or the numerical technique. In this connection it should be noted that the correlation method becomes identical to the least-squares method if suitable corrections are made for the unknown zero level, and for the end effects which arise when the observation time is not exactly one sample period less than a whole number of fringes. These corrections are time-consuming to calculate, so for the original analysis of

TABLE 6

FOURIER COMPONENTS FOR THE OMEGA NEBULA

Orientation	Spacing	Polarization	Amplitude	Phase	Remarks
East-west	58	Any	$1\cdot00$	0°	Assumed
	116	N.-S.	$0\cdot85\pm0\cdot03$	—6° ± 2°	
		E.-W.	$0\cdot76\pm0\cdot04$		
	174	N.-S.	$0\cdot65\pm0\cdot03$	—17° ± 3°	
	232	N.-S.	$0\cdot48\pm0\cdot04$	—33° ± 5°	
		E.-W.	$0\cdot60\pm0\cdot04$		
	290	N.-S.	$0\cdot48\pm0\cdot03$	—40° ± 7°	
		E.-W.	$0\cdot36\pm0\cdot08$		From product $A(290)\times A(174)$
	348	N.-S.	$0\cdot35\pm0\cdot04$	—48° ± 8°	
	406	N.-S.	$0\cdot22\pm0\cdot04$		
	464	N.-S.	$0\cdot20\pm0\cdot04$	—89° ± 12°	
		E.-W.	$0\cdot19\pm0\cdot04$		
	580	N.-S.	$0\cdot16\pm0\cdot04$		
	696	N.-S.	$0\cdot10\pm0\cdot04$		
	928	N.-S.	$0\cdot06\pm0\cdot04$		
North-south	55	Any	$1\cdot00$		Assumed
	111	N.-S.	$0\cdot76\pm0\cdot04$		
	166	N.-S.	$0\cdot52\pm0\cdot03$		
	221	N.-S.	$0\cdot37\pm0\cdot04$		
	277	N.-S.	$0\cdot22\pm0\cdot04$		
	332	N.-S.	$0\cdot19\pm0\cdot04$		
	442	N.-S.	$0\cdot10\pm0\cdot04$		
	553	N.-S.	$0\cdot06\pm0\cdot03$		
	664	N.-S.	$0\cdot01\pm0\cdot04$		

the east–west scans we made the observation time close to a whole number of fringes and used approximate corrections only. Errors due to the numerical technique are expected to be negligible. When recomputing the selected east–west scans by the least-squares method we went back to the raw data and put it into digital form in a different way as an additional safeguard against error. One error inadvertently published in Paper 1 for Centaurus A was found, and the corrected value is given here.

The declination of these sources is known with high accuracy but in principle we could have treated each declination as another variable and computed the least-squares solution for it. In practice we considered the extra computation time was not justified.

All the north–south scans were analysed by the least-squares method. In principle the analysis was similar to that for the east–west scans, the main difference being that a fringe-swinging receiver system was used. Allowance

TABLE 7

FOURIER COMPONENTS FOR CYGNUS A

Orientation	Spacing	Polarization	Amplitude	Phase	Remarks
East-west	58	Any	$1\cdot00$	$0°$	Assumed
	116	N.-S.	$0\cdot96\pm0\cdot01$	$-3°\pm1°$	
		E.-W.	$0\cdot94\pm0\cdot02$		
	174	N.-S.	$0\cdot95\pm0\cdot02$	$-4°\pm1°$	
	232	N.-S.	$0\cdot91\pm0\cdot02$	$-11°\pm1°$	
		E.-W.	$0\cdot94\pm0\cdot02$		
	290	N.-S.	$0\cdot89\pm0\cdot02$		
	348	N.-S.	$0\cdot86\pm0\cdot02$	$-10°\pm2°$	
	464	N.-S.	$0\cdot80\pm0\cdot01$	$-25°\pm3°$	
		E.-W.	$0\cdot81\pm0\cdot01$		
	580	N.-S.	$0\cdot71\pm0\cdot01$		
	696	N.-S.	$0\cdot54\pm0\cdot01$	$-22°\pm4°$	
	812	N.-S.	$0\cdot42\pm0\cdot01$		From ratio A(812)/A(116)
	928	N.-S.	$0\cdot27\pm0\cdot01$	$-19°\pm4°$	From ratio A(928)/A(116)
	1045	N.-S.	$0\cdot15\pm0\cdot01$	$-10°\pm4°$	From ratio A(1045)/A(116)
		R.H. Circ.	$0\cdot13\pm0\cdot01$		
	1161	N.-S.	$0\cdot08\pm0\cdot01$		From ratio A(1161)/A(116)
	1277	N.-S.	$0\cdot17\pm0\cdot01$	$+93°\pm4°$	Amplitude from A(1277)/A(116)
	1393	N.-S.	$0\cdot29\pm0\cdot01$	$+104°\pm4°$	Amplitude from A(1393)/A(116)
	1509	N.-S.	$0\cdot39\pm0\cdot01$	$+124°\pm5°$	Amplitude from A(1509)/A(116)
	1625	N.-S.	$0\cdot52\pm0\cdot01$	$+127°\pm5°$	Amplitude from A(1625)/A(116)
	1741	N.-S.	$0\cdot61\pm0\cdot01$		From ratio A(1741)/A(116)

TABLE 8

FOURIER COMPONENTS FOR THE ORION NEBULA

Orientation	Spacing	Polarization	Amplitude	Phase	Remarks
East-west	58	Any	$1\cdot00$	$0°$	Assumed
	116	N.-S.	$0\cdot82\pm0\cdot05$	$+5°\pm4°$	
	174	N.-S.	$0\cdot71\pm0\cdot05$	$+17°\pm6°$	
	232	N.-S.	$0\cdot66\pm0\cdot05$	$+14°\pm9°$	
	290	N.-S.	$0\cdot47\pm0\cdot04$		
	348	N.-S.	$0\cdot41\pm0\cdot12$	$+24°\pm11°$	From product A(348) × A(232)
	464	N.-S.	$0\cdot28\pm0\cdot05$	$+18°\pm24°$	
	580	N.-S.	$0\cdot20\pm0\cdot05$		
	696	N.-S.	$0\cdot20\pm0\cdot05$	$+18\pm29°$	
	928	N.-S.	$0\cdot08\pm0\cdot05$		
	1161	N.-S.	$0\cdot03\pm0\cdot05$		
	1509	N.-S.	$0\cdot04\pm0\cdot05$		

was made for the fringe-swinging period and for the variation with time of the direction cosine between the source and the interferometer base line.

The results are tabulated in Tables 1–8 for the sources Taurus A, Virgo A, Centaurus A, Hercules A, Sagittarius A, the Omega nebula, Cygnus A, and the Orion nebula in that order. As a guide to the general features of these measurements they are also plotted in Figure 1. If the same Fourier component was measured several times the average value is listed in the tables. The separate group of high accuracy polarization measurements made on Taurus A is also listed in Table 1, and can be identified by the phrase " 0·01 relative accuracy " in the remarks column. These measurements have been included in the average values also listed in Table 1.

In the tables the term " orientation " refers to the direction in which the source was scanned, which is not necessarily the same as the azimuth of the aerial base line. Aerial spacing is given in wavelengths and refers to the effective spacing allowing for projection effects, polarization refers to the electric vector, and amplitudes are given as ratios to the intensity of the source at our closest spacing. This was 58·03 wavelengths in a horizontal plane at latitude 33° 51′ S. The convention for phase angles has already been described.

III. ACCURACY

The accuracy of the measurements on the strongest source Cygnus A was expected to be better than one per cent in amplitude and one degree in phase. Errors for other sources were expected to be inversely proportional to their flux densities. In practice, however, we found the day-to-day reproducibility of results for the stronger sources such as Cygnus A or Taurus A was about two or three times larger than expected, with occasional very large deviations from the mean values (these we discarded). This lack of reproducibility mainly affects the observations on Taurus A. These were the first observations made and were probably affected by minor receiver faults. However, later measurements on the stronger sources, made when the receivers appeared to be very stable, still did not show the reproducibility originally expected. Weaker sources showed about the expected degree of reproducibility.

We cannot explain this discrepancy with certainty but suspect that it was partly due to errors in our calibration procedure and partly to drifts in the receiver gains between calibrations (especially in the gains of the linear multipliers which were exceptionally sensitive to changes of supply voltage). These possi-

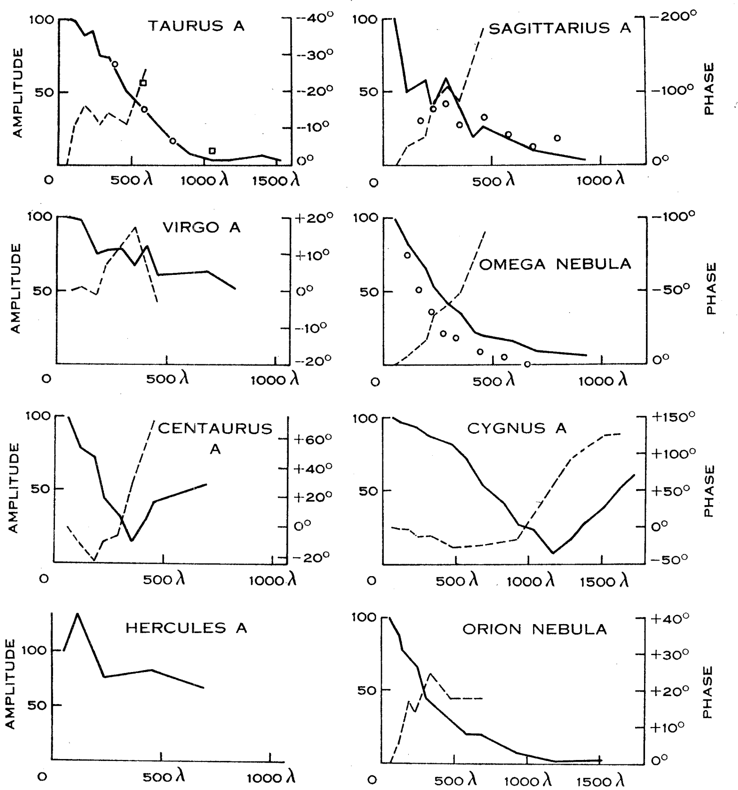

Fig. 1.—Interferometer measurements at 1427 Mc/s. The full line represents amplitude as a function of aerial spacing in wavelengths when the source is scanned E.-W. The dashed line represents phase angles when scanned E.-W., the circles amplitude scanned N.-S., and the squares amplitude scanned NE.-SW.

bilities are given some weight by an analysis of the signal-to-noise ratios of individual receiver outputs. The computation of this quantity is easily combined with the least-squares method of analysis, and this was done for several north–south scans and several of the recomputed observations with east–west scans. In all cases, for both strong and weak sources, the signal-to-noise ratios were as expected. This result suggests a calibration uncertainty or gain variation which would affect the expected high accuracy of the strong source measurements more than the expected lower accuracy measurements on the weaker sources. The errors given in the tables are based on the day-to-day reproducibility of the measurements and not on the observed signal-to-noise ratio.

IV. Conclusion

The main conclusions to be drawn from this work have already been described in Paper 1. These include (i) the discovery that the central bright region in Centaurus A is a double source, (ii) the demonstration that there is no detectable polarization in Taurus A at 1427 Mc/s when measured with a signal-to-noise ratio of 100 : 1, and (iii) the demonstration that the two bright regions in Cygnus A are smaller and further apart at 1427 Mc/s than at metre wavelengths. We do not propose to discuss the remaining measurements and our purpose in publishing them is to make them available in numerical form for comparison with measurements at other frequencies by later workers.

V. References

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