FINAL REPORT

NASA Grant NsG 407 to Yale University

20 December 1966

1. Introduction

In the period from March 1957 through May 1966, the Yale University conducted a systematic observing program relating to the decametric radio emission from Jupiter. This program, which was supported by NASA (Grants NsG 73-60 and subsequently NsG 407) and by NSF, is being continued by the Principal Investigator at The University of Texas with the aid of continued NASA (NGR 44-012-055) and NSF support. This final report, covering the Yale phase of the research, is therefore also a kind of status report on the NASA supported parts of the entire program.

Due to the tedious and time consuming hand reduction of records required in polarization and time structure studies, analysis has lagged observation by one to two years. Therefore, this report will in several areas mention data obstained, without results of the analysis and interpretation which is now in progress. These results will appear in progress and final reports for NGR 44-012-055 and its successors.

2. Summary of Characteristic of the Decametric Emission

The complexity of Jupiter's decametric emission is practically without parallel among sources available to radio astronomers:

It is sporadic at frequencies from 15-45 MHz; some evidence for both strong sporadic and weak continuous emission has appeared. The probability of emission occurrence is correlated with the orientation of Jupiter relative to earth, with the position of the innermost Galilean satellite Io relative to Jupiter and to the earth, and also as a possibly periodic variation of roughly 10-12 years, which may reflect solar cycle or orbital correlation.

When present, emission flux varies on time scales of minutes (burst groups), seconds (L-pulses) and hundredths of seconds (S-pulses). A primary discovery of the Yale work was that both L- and S-pulses are propagation phenomena; the nature of L-pulses will be detailed in a later section of this report.

The emitted radiation is directive, with rapid changes in intensity observed over a few degrees of rotation of the planet. Its average directivity properties are systematic function of frequency.

The emission is strongly polarized, with polarization characteristics varying over a wide range, sometimes reversing sense in less than a second. Evidence for systematic variation with orientation of Jupiter and with frequency has been obtained by several observers.

The emission has complex but amazingly systematic spectral properties, with frequency drifts of both senses observed. Dynamic spectrum appearance is characteristic for a given configuration of Jupiter, Io, and earth.

The flux is large, with moderately strong Jupiter storms near 20 MHz having a flux of 5-10 $(10)^{-21}$ Wm^{-2} Hz^{-1}.

The research program carried out under the present grant has been concerned with (1) polarization properties and (2) spaced-receiver observations of time structure of Jupiter's decametric emission; the present status of this work is summarized in subsequent sections.

3. Polarization Studies

A. Instrumentation

Polarization studies were carried out with a six-channel 22.2 MHz polarization analyzer, constructed at Yale with the support of NsG 73-60.

The antenna was a crossed - Yagi array with 16 elements, supported from behind by a fully steerable equatorial mount. This arrangement possessed the desirable trait of full tracking, with no part of the support structure being in the field of any of the elements. The measured imedance of the array varied less than 2% between -4 and +4 hours from the meridian at ecliptic declination. The Yagis were close-spaced, giving the system a 1 MHz bandwidth.

The circularity was excellent; many Jupiter storms observed appeared only in the right circular antenna. Such an observation is a testimony both to the complete circularity of the Jupiter radiation and to the circularity and orthogonality of the right and left circular antenna outputs. A slight elliptical component in the antenna would produce some left circular output for right circularly polarized Jupiter radiation; right elliptical Jupiter polarization just matching the antenna properties would produce no left output for the proper orientation of the ellipse, but terrestrial Faraday rotation would soon remove this favorable orientation, and left output would be visible. The same argument may be used to show that the Jupiter emission must also be nearly circular; if elliptical, the prolonged lack of left output could not be explained even with an elliptical antenna due to Faraday rotation. A conservative upper limit on cross-polarization in the antenna is set at 5%.

The receiver was adapted from a design by M. H. Cohen (Proceedings of the IRE, January 1958). Right (R) and left (L) circular intensity were recorded, together with the amplitude (RL_1) and phase (X_1) of the cross-correlation of right and left circular amplitude. The remaining two channels were the amplitude (RL_2) and phase (X_2) of the cross correlation of right and left circular amplitude at a second frequency which could be offset from 22.2 MHz by a variable amount. R, L, RL_1, and X_1 outputs can be combined to give Stokes parameters at 22.2 MHz, while X_1 and X_2 may be used to produce a Faraday dispersion theory calculation of the total number of Faraday turns along the line of sight to Jupiter.

Both low and high speed analog outputs were obtained; the necessity for subsequent reduction to digital form has made large scale data analysis slow and laborious.

B. Results

(i) Percentage of Polarization

Prior to the Yale work, interpretation of polarization observations depended upon the assumption that the radiation was completely polarized, i.e. no randomly polarized component present. The R, L and RL outputs of the 22.2 MHz polarimeter, appropriately combined, yield estimates of the percentage of polarized flux, M.

During the early part of the present grant period, polarization observations made during the 1961 apparation of Jupiter were analyzed. Particular attention was paid to a period in July and August of 1961. The results obtained during this period are summarized in Table 1.

Table 1

Date (EST)	Γ_{III} Range	Axial Ratio	Percentage of Polarize Flux
18 July 1961	187-241	$\approx$ .05	100% ± 20%
20 July 1961	151-167	$\approx$0.5	90% ± 20%
26 July 1961	197-231	$\approx$ .05	100% ± 20%
28 July 1961	117-155	0.6	90% ± 20%
2 Aug 1961	222-236	.07	100% ± 10%
4 Aug 1961	229-248	.3	100% ± 20%
	184-222	.2	80% ± 20%

The errors quoted in M are due to receiver and reduction noise errors; systematic errors in M, particularly correlated with r, may remain. It is interesting to note that in no case is a significant fraction of randomly polarized radiation definitely present.

More extensive reduction for M are not yet underway; analysis time has been primarily assigned to the basic question of understanding the way in which polarization and flux vary on a rapid time scale. This issue is fundamental to the interpretation of time-averaged data such as the results of Table 1.

(ii) Time-averaged Axial Ratio

Although usually nearly completely right-circularly polarized, a number of cases of more elliptical polarizations are noted. In addition, complete polarization renewals to left-hand circular are occasionally observed. Analysis of the 1961 data showed an intriguing correlation with System III longitude. Storms were classified according to the region producing them, Region 1 = early source, Region 2 = main source, and Region 3 = late source. Average axial ratios were divided into ranges and Table 2 prepared.

Table 2

Number of Nights with:

	$0.0 < r < 0.2$	$0.2 < r < 1$	Left Hand Polarization
Region 1	1	6	0
Region 2	11	0	3
Region 3	2	0	0
Totals	14	6	3

The early source is seen to be the most prolific contributor of highly elliptical polarization. Later and more extensive results now being prepared for publication bear this out. Dowden, Barrow, Sherrill and Smith and Carr all report similar phenomena, becoming more marked at lower frequency.

(iii) High-speed Axial Ratio Studies

A number of Jupiter storms recorded on a high-speed oscillograph have been measured manually every $0\overset{s}{.}25$, calibration applied and axial ratios calculated. A summary of one such reduction was included in a previous status report. The data available now suggest that while r is usually constant through amplitude fluctuations of 10/1, occasional periods of rapid r fluctuation in times of 1 second are seen. The polarization sense may even reverse and return in times of this order. If intrinsic to Jupiter, these polarization fluctuations pose intriguing problems. A spaced receiver polarization experiment now in preparation will help settle the question of where such behavior originates: ionosphere, interplanetary medium, or Jupiter. In any event, the fast-changing polarization behavior make interpretation of time-averaged data difficult, and future reduction will concentrate on point-by-point analysis.

(iv) Faraday Rotation

Reduction of 20 nights show that the total Faraday rotation present in the Jupiter radiation is entirely consistent with the behavior of the terrestrial ionosphere. Any effect due to Jupiter's ionosphere and the interplanetary medium must be less than the terrestrial Faraday effect.

4. Time Structure Studies

A. Two Station Observation

These results are fully described in the preprint of the paper "Interplanetary Scintillation in Jovian Decametric Radiation", which forms a part of this report.

B. Three Station Observation

The attached in-house progress report prepared by Louis P. Pataki summarizes the current state of the analysis of three station observations.

5. Decameter Monitoring Station

The decameter monitoring station for Kodaikanal, India has been fabricated; antenna, driver and computers are to be shipped shortly.

The radiometer itself requires further check-out and calibration operations; it has been transferred to The University of Texas where this work will be completed. Support for shipping this part of the instrument to Kodaikanal will be requested in a future proposal, so that the Kodaikanal Station may join the other Decameter Monitoring Stations (operated by Goddard Space Flight Center) in the synoptic Jupiter-Solar monitoring program.

James N. Douglas
Principal Investigator