mines critically whether the ray paths to the spacecraft intercept the torus.

Extraordinary arc structures continue to dominate the Voyager 2 high-frequency data as they did the data from Voyager 1. Figures 1 and 5 show the great arcs (extending to high frequencies) as they invariably appear in connection with Io-controlled early (Fig. 5) and main (Fig. 1) source emission. The great arcs in the early source have vertices early (that is, the arcs open toward increasing times) while those in the main (and late) sources have vertices late (arcs open toward decreasing times). This pattern is identical in sense to what was observed by Voyager 1 [figure 1 of (2)]. It argues strongly for a geometric origin of the arc shapes.

The systematics of the arc shapes is as remarkable as the longitudinal pattern of vertex-early and vertex-late great arcs. The arcs often occur in nested sets whose frequency range and curvature progressively change over times several hours long. In some of these nested sets (Fig 6) the arcs are homologous, in the sense that when they are plotted on normalized time and frequency coordinates they have virtually the same shape. Our study is still preliminary. Clearly, however, there exist homologous arc families, including arcs that extend from 1 MHz to well above 30 MHz, to those lying totally below 10 MHz. Individual arcs persist from less than 10 minutes to more than 1/2 hour. The description in terms of normalized coordinates (Fig. 6) can qualitatively be summarized by two facts: (i) arcs of longer duration extend to higher frequencies; and (ii) the higher the maximum frequency, the higher the vertex frequency.

We conclude that all decametric emission occurs when its instantaneous source lies in a single special geometrical relation to the observer; otherwise the very special shape is difficult to understand. Its sources lie at all longitudes because we see these arcs everywhere as Jupiter rotates, but each arc corresponds to a single source. Finally, the homologous members of a single family of arcs occur in sequences extending over 40 or more degrees of Jupiter longitude.

One simple model immediately suggests itself for these arcs. If (i) the radio sources produce emission in hollow conical sheets centered on a given line of force and (ii) the emission occurs at the local electron gyrofrequency, then, because the line of force is curved, different frequencies correspond to cones pointing in different directions. As Jupiter rotates, these cones, fixed relative to one another, rotate past the direction of the spacecraft. Simple geometrical considerations show how an arc will be formed for ad hoc choices of emission angle and the active line.

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References and Notes

1. J. W. Warwick, J. B. Pearce, R. G. Peltzer, A. C. Riddle, *Space Sci. Rev.* **21**, 309 (1977).
2. J. W. Warwick, J. B. Pearce, A. C. Riddle, J. K. Alexander, M. D. Desch, M. L. Kaiser, J. R. Thieman, T. D. Carr, S. Gulkis, A. Boischot, C. C. Harvey, B. M. Pedersen, *Science* **204**, 995 (1979).
3. Voyager ultraviolet experiment [B. R. Sandel *et al.*, *ibid.* **206**, 962 (1979)].
4. Voyager magnetometer experiment (N. F. Ness *et al.*, *ibid.*, p. 966).
5. Voyager plasma wave experiment (D. A. Gurnett, W. S. Kurth, F. L. Scarf, *ibid.*, p. 987).
6. M. A. Gordon and J. W. Warwick, *Astrophys. J.* **148**, 511 (1967). Many of our records show fringes in the spectrum of total intensity. Figure 4 does not and, therefore, represents the extreme case in support of the interpretation of this paragraph.
7. V. V. Zheleznyakov, *Radio Emission of the Sun and the Planets* (Pergamon, Oxford, 1970), p. 332.
8. We again thank the Voyager Magnetometer team and Plasma Wave team for use of their data prior to publication. We also thank R. G. Peltzer, C. C. Harvey, F. T. Haddock, W. E. Brown, Jr., and R. J. Phillips who participated as our coinvestigators in various phases of this experiment; our experiment representative, R. L. Poynter, for his continued help in the operation of our receiver on Voyager 2. Our data analysts, Andy Gaynor and Pearl Harper, have given us invaluable support. This receiver, like the identical one on Voyager 1, was built by by Martin Marietta Corporation, and also like it has operated essentially faultlessly. Our French investigators acknowledge support by Centre National d'Etudes Spatiales. Supported in part by the Jet Propulsion Laboratory under NASA contract NAS 7-100.
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26 September 1979

Jupiter's Cloud Distribution Between the Voyager 1 and 2 Encounters: Results from 5-Micrometer Imaging

Abstract. *As part of a continuing effort of ground-based support for Voyager target selection, infrared images in the 5-micrometer wavelength region were acquired in preparation for the Voyager 2 flyby of Jupiter. Observations were made during May 1979 from the Palomar 5-meter telescope and the new 3-meter NASA Infrared Telescope Facility at Mauna Kea and are compared to previous observations. Variations seen in the 5-micrometer flux distribution suggest global patterns of clouding over of some Jovian belts and clearing of others. These data were used to predict the Jovian cloud distribution at the time of the Voyager 2 encounter in order to target the imaging and infrared experiments to areas free of high obscuring clouds.*

Over the past year a coordinated program of high spatial resolution infrared imaging of Jupiter was undertaken in order to support target selection for Voyager imaging and infrared experiments (*1*). The 5-μm wavelength region was used for this imaging because it is relatively free from Jovian gaseous spectral absorption lines and offers a view of the deepest observationally accessible layers of Jupiter's atmosphere (*2*). These deep holes in the atmosphere appear as isolated bright regions at 5 μm and are found to vary in position and spatial distribution with time (*3, 4*). Infrared observations leading up to the Voyager 1 encounter in March have already been reported by Terrile *et al.* (*1*) who discussed the changes observed between October 1978 and March 1979. We now describe the observations obtained after March as part of the target selection for the Voyager 2 encounter in July 1979.

Voyager 2 has a capability similar to that of Voyager 1 for retargeting observations to areas of high scientific interest. Voyager 1 imaging and infrared experiments (*5, 6*) were successfully targeted to observe some of the hottest infrared regions and thus the deepest areas in the Jovian clouds even though sequencing considerations required that targeting be established 1 month before encounter. This month-long time constraint was also present in the Voyager 2 planning and necessitated our making predictions of 5-μm activity and position at the time of encounter.

Observations were made from the Hale 5-m telescope at Palomar, Califor-

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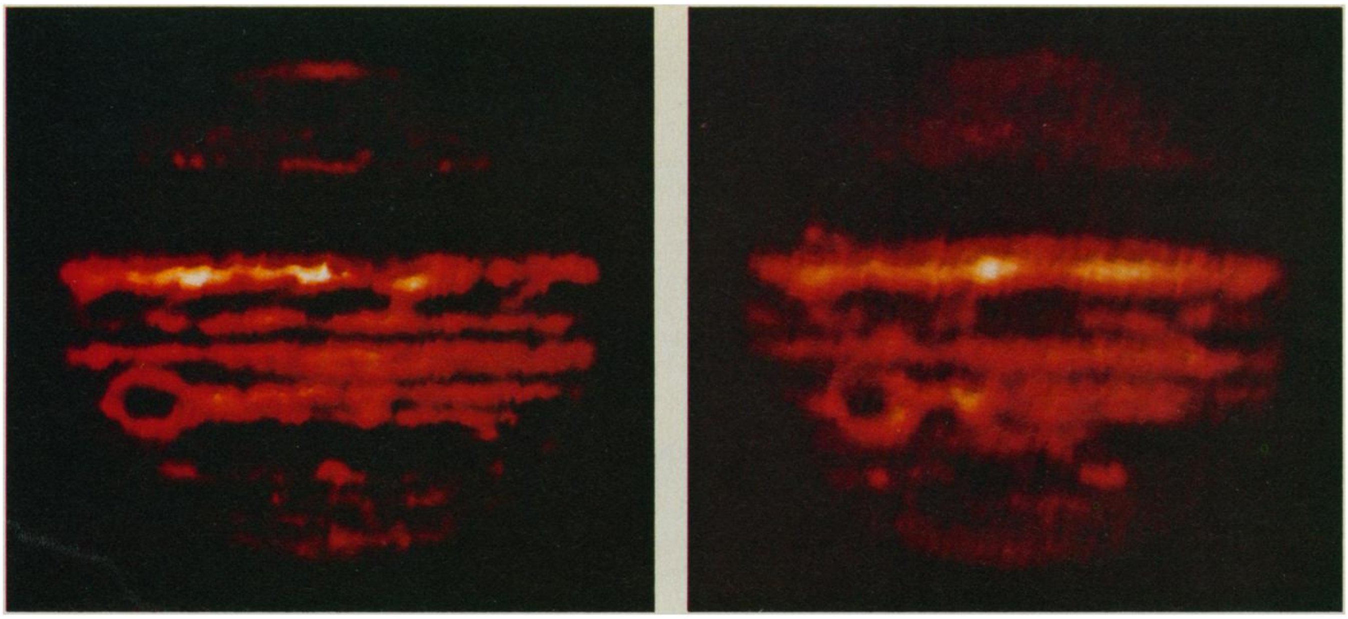

Fig. 1. Comparison of two 5-μm images of Jupiter recorded at the Hale 5-m telescope at Palomar, California, on 6 March 1979 (left) and 20 May 1979 (right). These images are shown in false color in order to bring out the large contrasts. The hottest areas at 5 μm (bright) indicate regions clear of overlying clouds. Obscuring clouds are present at an intermediate level in the warm areas (red) and at a level high up in the atmosphere in the coldest regions (black). Both images are oriented with north at the top, east at the right, and the Great Red Spot near the left limb. The most notable changes visible in these images are a clouding over of the equatorial area and the northern portion of the ring encircling the Red Spot and a clearing (brightening) of the area north of the North Equatorial Belt.

nia, and the new 3-m NASA Infrared Telescope Facility (IRTF) at Mauna Kea, Hawaii. Images were recorded on 8, 9, and 10 May 1979 (universal time) from the IRTF (these were the first data collected with this new NASA instrument) and on 20, 21, and 22 May 1979 from Palomar. These data, combined with earlier observations, were used to extrapolate Jovian cloud distributions. Weather problems and the close proximity of Jupiter to the sun prevented our acquiring data at the time of the Voyager 2 encounter on 9 July.

Figure 1 shows a comparison of two 5-μm images of Jupiter recorded at Palomar on 6 March 1979 and 20 May 1979. The images were selected so that the Great Red Spot (GRS) is visible near the left limb of each image. Terrile *et al.* (*1*) described the changes that occurred between October 1978 and March 1979 (*1*) which included a narrowing of the bright North Equatorial Belt (NEB) and the formation of a ring of warm emission encircling the GRS. During the May observations a general clouding trend was seen in the equatorward portion of the NEB, the Equatorial Belt, and the northern portion of the GRS ring. Regions east of the equatorial plumes, which were bright at 5 μm in March and appeared as a chain of nearly equally spaced features, have also clouded over. Clearing was observed in the northern component of the NEB [including the area where the dark brown clouds were seen (*7*)] and in about half of the South Equatorial Belt (SEB).

Targeting for Voyager 2 was more difficult than Voyager 1 because of limited observations and because the large patches of bright 5-μm regions (cloud-free areas) were no longer present in the equatorward portion of the NEB. Furthermore, only certain Jovian longitudes were available for Voyager near-encounter observations because of sequence design constraints. It was predicted that the bright 5-μm regions in the SEB would not coincide with these available longitudes. As a result, the hot spot observations from the infrared interferometer spectrometer (IRIS) were targeted for the brightest 5-μm regions in the NEB. Details of the success of this targeting will have to await further reduction of the IRIS spectral data. We plan to continue 5-μm imaging as soon as Jupiter is far enough away from conjunction to allow observations.

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References and Notes

1. R. J. Terrile *et al.*, *Science* **204**, 1007 (1979).
F. C. Gillett, F. J. Low, W. A. Stein, *Astrophys. J.* **157**, 925 (1969).
3. R. J. Terrile and J. A. Westphal, *Icarus* **30**, 274 (1977).
4. R. J. Terrile, thesis, California Institute of Technology (1978).
5. B. A. Smith *et al.*, *Science* **204**, 951 (1979).
6. R. Hanel *et al.*, *ibid.*, p. 972.
7. B. A. Smith *et al.*, *ibid.* **206**, 927 (1979).
8. We thank D. Backman, C. Beichman, R. Brown, P. Muller, D. Pieri, C. Telesco, and D. Wenkert for help with observations and data processing, and we appreciate the help of G. Garneau and the Imaging Processing Laboratory at JPL in processing the color images. We also thank G. Smith, H. Boesgaard, E. Irwin, and J. Harwood for their special effort in making the IRTF operational for this program. This report presents the results of one phase of research carried out at the JPL, California Institute of Technology, under contract NAS 7-100, sponsored by NASA. Work at the University of Hawaii was also supported by NASA under contract NASW 3159 and NGL 12-001-057.

26 September 1979