What Radio Astronomy Tells Us About Jupiter

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Imke de Pater is a Professor at the University of California in Berkeley. She is well known for her work on Jupiter's synchrotron radiation, for which she received the URSI John Howard Dellinger Gold Medal in Aug. 1984. She led a worldwide campaign observing Jupiter's radio emissions during the impact of comet D/Shoemaker-Levy 9 with Jupiter in 1994. This work has lead to a detailed investigation of the effects of impacts on the magnetospheric environment of the planet. Together with Jack J. Lissauer she wrote a textbook at the upper level undergraduate/graduate student level: "Planetary Sciences" (Cambridge University Press).

Since we can see planets like Jupiter in the sky even without a telescope, we don't often think of the radio waves they emit, but radio signals from Jupiter were first detected in 1955 at a frequency of 22.2 MHz. This emission was sporadic in character and confined to frequencies less than 40 MHz. This type of radiation is commonly referred to as decametric radiation, and originates near Jupiter's iono-sphere in the auroral regions. In subsequent years the planet's thermal emission was detected at short centimeter wavelengths, and its synchrotron radiation at wavelengths between about 2 cm and a few meters. Thermal radiation is basically the planet's blackbody radiation, a continuous spectrum of electromagnetic radiation, emitted by all "objects" with a temperature above absolute zero. Relativistic electrons (approaching the speed of light) produce synchrotron radiation, spiraling around magnetic field lines. This radiation is strongly beamed in the direction in which the particle is moving. The Very Large Array (VLA) has detected thermal and synchrotron emission from Jupiter and both are discussed below.

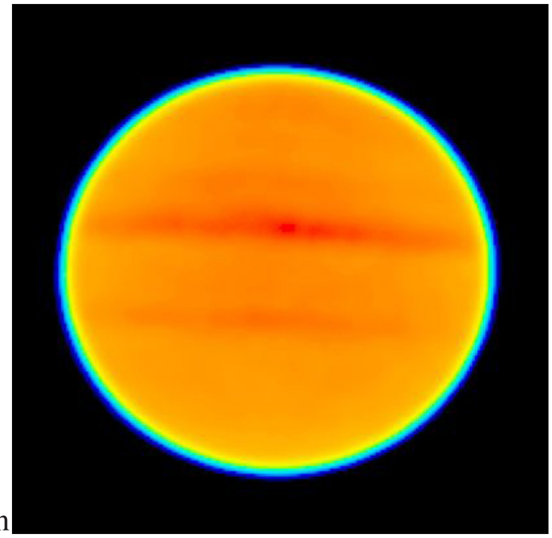

Figure 1. VLA image of Jupiter at a wavelength of 2 cm, taken 25 Jan. 1996. The observations are averaged over time. The relatively bright North and South Equatorial belts are clearly visible on either side of the Equatorial zone (image credit: Imke de Pater).

Thermal Emission

Radio wavelengths in the millimeter to centimeter range probe into and below Jupiter's ammonia-ice cloud layer. Most of the opacity1 is from ammonia gas, which has a broad absorption feature near 1.3 cm. Near the center of the absorption line, one is detecting the ammonia-ice cloud. Away from the center of the absorption line, the opacity decreases. Because the lines are broadened by high pressure in the environment where they arise, there still is opacity at much longer and shorter wavelengths, so that deeper warmer layers of the planet are probed. Observations at both visible and infrared as well as radio wavelengths provide complementary information on Jupiter's atmosphere: at radio wavelengths one is detecting gas from which the clouds condense, while at visible and infrared wavelengths one is detecting the cloud particles. Thus the base level of the clouds is determined through radio observations, whereas the altitude of the cloud tops is defined by measurements at optical and infrared wavelengths. The location of the base level is needed to develop dynamical models of Jupiter's atmosphere.

A false color radio image of the planet, taken January 25, 1996 at 2 cm wavelength, is shown in Fig. 1. The resolution is about 1.2", and the disk diameter was 32" at the time of the observations. The data have been integrated for several hours, so because of the atmospheric rotation, no longitudinal structure is visible. The image

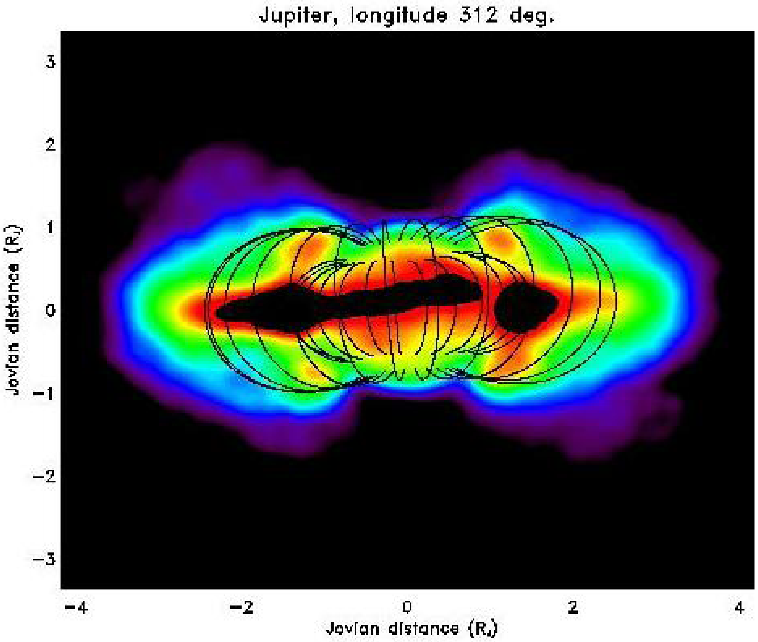

Figure 2. 20 cm radio image of Jupiter's decimetric emission at a central meridian longitude of 312 deg. Jupiter's thermal emission is visible at the center. Several magnetic field lines of a multipolar (O6) magnetic field model are superimposed. The image was taken with the VLA in June 1994. The resolution is roughly the size of the high latitude emission regions (image credit: Imke de Pater).

shows bright horizontal bands across the disk, which coincide with the brown belts seen at visible wavelengths. These bands are brighter, most likely due to a lower ammonia abundance in the belts relative to what is called the zonal regions; deeper, warmer layers are probed in the belts. This phenomenon is suggestive of gas rising up in the zones. When the temperature drops below 140 K, ammonia gas will condense out. In the belts, the "dry air," now depleted in ammonia gas, descends. This general picture is in agreement with that suggested by studies of visible and infrared data.

Synchrotron Radiation

Synchrotron radiation is emitted by high energy (relativistic) electrons in a Jovian Van Allen (radiation) belt. The emission is strongly beamed in the direction of motion during the electron's helical path around Jupiter's magnetic field lines. Because of a periodic (sinusoidal) variation in the radio emission intensity during a full rotation around the planet's axis, researchers have concluded that most of the electrons are confined to the planet's magnetic equatorial plane. VLA radio images clearly show this phenomenon visually. Fig. 2 shows a radio image of Jupiter at a wavelength of 20 cm: at the center the thermal emission from Jupiter's disk is visible, while the "salamander-like" pattern is produced by synchrotron radiation. Overlaid on this image are black magnetic field lines. Figure 3 shows a 3D-image of the synchrotron radiation. The latter image clearly shows the main "ring" of emission to coincide with the magnetic equatorial "plane" (note that the plane is warped). Two similar rings of emission are seen at higher latitudes: these are produced by electrons at their mirror (turning) points. The fact that these electrons are not confined to the magnetic equatorial plane may be caused by a complicated interaction of these particles with the moon Amalthea and/or its dusty ring.

Radio astronomy and radio telescopes also contributed to our understanding of one of the largest solar system "collisions" in the last few decades. In July 1994, comet D/Shoemaker-Levy 9 crashed into Jupiter, an event observed by many astronomers all over the world, at many different wavelengths. At radio wavelengths the synchrotron emission of Jupiter increased about 20% during the collisions, and the brightness distribution changed drastically. The impact of comet D/Shoemaker-Levy 9 also strongly affected the high-energy electron population in Jupiter's radiation belts.

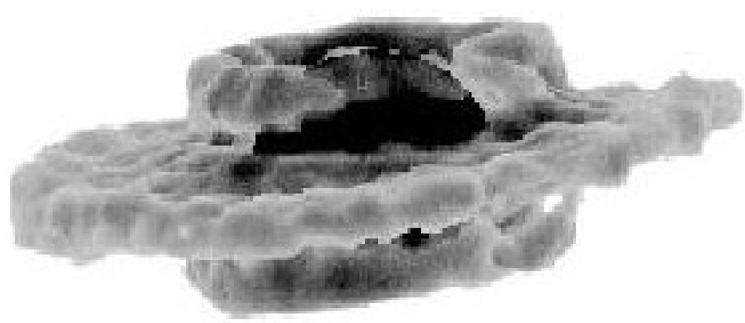

Figure 3. Three-dimensional reconstruction of Jupiter's synchrotron radio emissivity, as seen from Earth at a central meridian longitude of 140 deg. This reconstruction is obtained from the same data as displayed in Fig. 2. The planet is added as a black sphere in this visualization (image credit: Imke de Pater and R.J. Sault).

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