PROCEEDINGS OF SCIENCE

The Solar System

Imke de Pater
Dept. of Astronomy, 501 Campbell Hall, University of California at Berkeley, Berkely, CA 94720-3411, USA
E-mail: imke@berkeley.edu

Jaap Bregman
ASTRON
Oude Hoogeveensedijk 4, 7991 PD Dwingeloo, The Netherlands
E-mail: bregman@astron.nl

PoS(westerbork)015

50 Years Westerbork Radio Observatory, A Continuing Journey to Discoveries and Innovations
Richard Strom, Arnold van Ardenne, Steve Torchinsky (eds)

The Solar System

Chapter 14.1 1980: Jupiter's Radiation belts

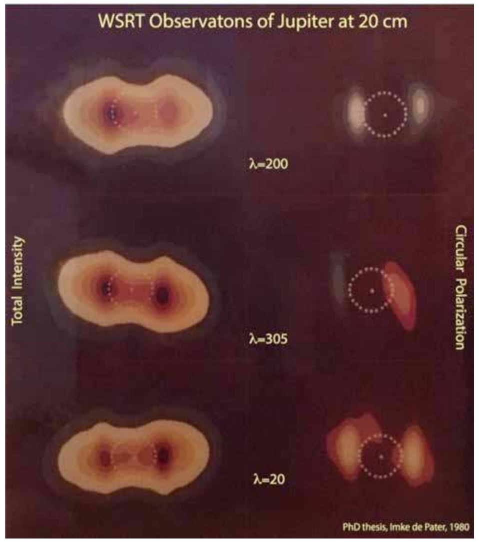
Imke de Pater*

* University of California, USA

In 1977, a few days before Christmas, graduate student Imke de Pater spent 5 consecutive 12-hour nights at the Westerbork telescope, anxiously watching the red flickering lights in the dark operating room. She was observing Jupiter, and the telescope array had to work smoothly without any interruptions for 5 nights straight, since she wanted to map every rotational aspect of a planet that rotates in 10 hrs. With Westerbork's east-west array you need to observe an object for 12 hours to build-up a 2-dimensional map, since one short ½ hour observation would give you in essence only a scan through the planet, i.e., shows structure (resolution) only in one direction. The rotation of the Earth during a 12-hour observation provides resolution in both east-west and north-south directions. Using five 12-hour observations, de Pater combined six 25-min snapshots at each rotational aspect of the planet (every 15 deg.) to construct 24 maps to get a full picture of the planet from all viewing angles.

She was not focused on the planet itself, but observed the synchrotron radiation at a wavelength of 20 cm, emitted by energetic electrons trapped in Jupiter's radiation belts (analogous to the Earth's van Allen belts). She used the emission from these electrons to derive the structure of Jupiter's magnetic field and the electron distribution within it, and developed full radial diffusion models for the electrons in a multipole magnetic field for this work. In order to best map out the magnetic field structure, she arranged the dipoles at the telescope in the parallel configuration to optimize sensitivity to circular polarization. This was an innovation at the time! The combination of linearly and circularly polarized emission was optimal to derive the magnetic field structure in Jupiter's radiation belts.

Maps of Jupiter's total and circularly polarized flux density at three rotational aspects of the planet are shown in Figure 1. Most emission comes from electrons near Jupiter's magnetic equatorial plane. In the top figure, the magnetic north pole was directed towards us (longitude 200 deg), and the bottom one away from us (longitude 20 deg), and the middle figure shows a map at an aspect in between (305 deg). The orientation of the magnetic dipole field can be derived from the maps of the circularly polarized flux density (figures on the



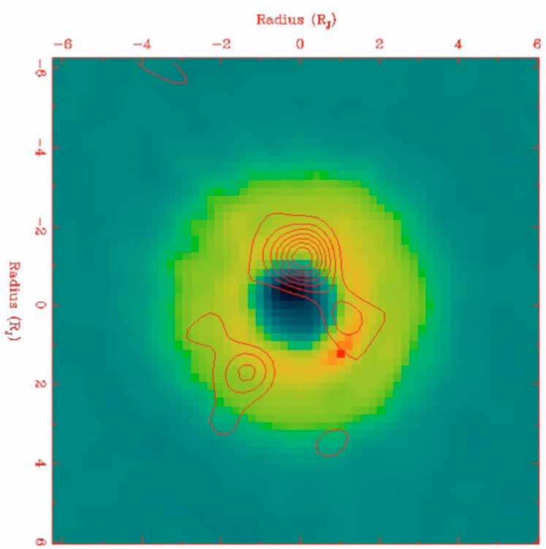


Figure 1. Maps of Jupiter's synchrotron radiation at three rotational aspects, from top to bottom: 200 deg, 305 deg, and 20 deg. The magnetic north pole is facing earth in the top figure. On the left side the total intensity is shown, and on the right side the circularly polarized flux density.

Figure 2. Observations taken with the WSRT telescope on 20 July 1994 during the week that comet ShoemakerLevy 9, a string of 2 dozen comet fragments, crashed into Jupiter. In this figure we look down onto the magnetic equator. The magnetic pole is in the center. The coloured background shows the emissions about 2 weeks before the impact, while the contours show the excess in emission after several fragments had impacted the plan

right side). The simultaneous red and blue colors at the rotational aspect of 305 deg is a clear indication that Jupiter's field is not a simple dipole magnetic field, like that of a bar magnet, but has a multipole character, such that the magnetic equatorial plane, where most radiating electrons reside, is warped like a potato chip. These circularly polarized maps are still now, 40 years later, the best maps ever produced from Earth!

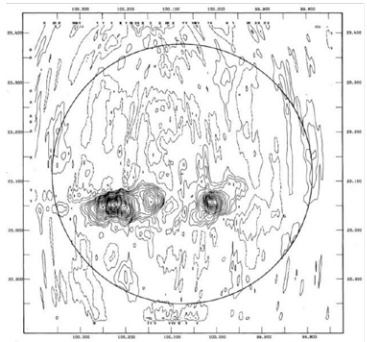
Follow-up observations of Jupiter's synchrotron radiation in 1994, when comet ShoemakerLevy 9 crashed into the planet, reveal a quite distorted view of the radiation belts. Figure 2 shows a view of the magnetic equator seen from above: The colour view shows the emission before the impact took place, while the superposed contours show the excess emission caused by impacts of various comet fragments.

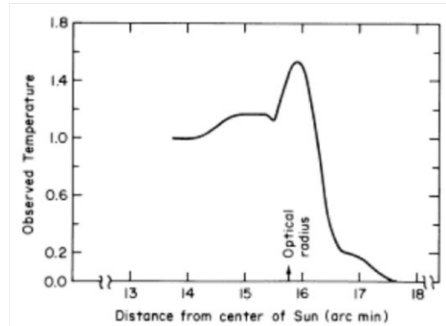
The Solar System

Chapter 14.2 Participating in Solar Maximum Year 1980

Jaap Bregman*

The first solar observations with the WSRT at 21 cm and 6 cm wavelength date back to 1974 and suffered from saturation effects in the receiver chain, for which reason it was necessary to implement a 20 dB solar attenuator in (potentially all) later frontend upgrades. The first solar image with the WSRT by Bregman and Felli published in 1976 is shown in the left figure. The circle marks the white light disk of the Sun with ~0.52° diameter that fills the 21 cm beam of ~0.6° FWHM.





In 1976 Kundu et al observed the quiet Sun at 6 cm with 6 arcsec resolution. The right figure from the 1979 paper shows the limb brightening obtained by model fitting. Auto correlation of a 10 arcmin x 10 arcmin field indicated the first radio supergranulation "network" width ~11,000 km and a radio "cell" spacing of 32,000 km. The brightness temperature of typical network elements is ~2.5 x 10^4 K, while that of the radio cells is 1.5 x 10^4 K.

The solar astronomy group at Utrecht University participated through SRON in the HXIS experiment aboard the Solar Maximum Mission Satellite. This X-ray imager would provide data that needed complementary radio data. Therefore, ASTRON was approached in 1978 whether the new Digital Line Backend (DLB) would be suitable to provide one-dimensional snapshot images at timescales shorter than one second at 6 cm and 50 cm wavelength. A fast readout cycle of 0.1 s was feasible only when one data block with zero time lag cross-correlations was read. In practice it meant that only a single polarization output of the

* ASTRON, The Netherlands

fixed telescope receivers could be used which had to be duplicated to the other polarization input at the DLB to receive there an additional 90 degree phase shift. Then, every fixed movable combination got a sine and a cosine channel for a complex output, just as in the old analogue backend.

Radio emission from the Sun has hardly any linear polarization, so only one orthonormal and one orthogonal linear cross-polarization is sufficient to provide the total intensity and the circular polarization state. Digital cross-correlation in 1bit mode can handle high correlated fractions as could occur when radio bursts provide more power than the background of the quiet Sun. Apart from additional software for fast data block reading and sorting of the data, special calibration procedures provided accurate amplitude, phase and polarization settings for on-line imaging.

In addition to Utrecht University, solar physicists at Maryland University in the USA and Arcetri Astrophysical Observatory in Florence expressed interest in using the WSRT in its new solar mode. Three observing sessions of respectively 8, 10 and 6 days were allocated, mainly at 6 cm, and some observation switching between 6 cm and 50 cm. Utrecht received the 0.1 s data and the other institutes received data integrated longer to 10 s for synthesis imaging.
The Real-time Display System (RDS) provided by Utrecht used an HP 21MX computer that shared the hard disk controller with the 21MXE for data sorting and control of all WSRT subsystems, and the 21MXF for monitoring and tape writing. The RDS Fourier transformed every 0.1 s the total intensity and the circular polarization correlations from the 40 interferometers into fan beam patterns and put them on three display screens, with one for recording on film and two for real time monitoring. This real-time monitoring was essential to prolong an observation when bursting activity had started.

In the figure, we just see time markers at the top and two time series: The top one for total intensity and the other for circular polarization. At meridian transit, each band extends 11.5 arcmin in East West direction and its brightness gives the strength relative to a running mean. Each signal spot on the sun gives four tracks, one being the main lobe of the point spread function, and the other three give the grating lobes each with a different shape (in vertical direction).

Kattenberg et al observed a particular sub-flare on June 13 1980 with the Hard X-ray Imaging Spectrometer (HXIS) and the WSRT in 0.1 s mode at 6 cm and with 3 arcsec highest resolution. A full synthesis image of the flaring region was compared with optical images for proper position alignment. Citing the important scientific result from their paper summary is as follows. “The fast electrons causing the X-ray and microwave impulsive bursts had a common acceleration source, but the bursts were produced at the opposite foot points of the loops involved, with microwaves emitted above a sunspot penumbra.”