Observations of the 327 MHz line of Deuterium using an array with multiple electronically steered beams.

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INTRODUCTION

An array which operates at 327 MHz has been constructed to observe spin-flip transition line of Deuterium analogous to the hydrogen line at 1420 MHz. A search for this line was made by Weinreb [1] in 1962 and more recently by others [2,3,4,5,6] setting limits on the D/H abundance to constrain the photon to baryon ratio based upon the theory of Big Bang nucleosynthesis [7]. After about one year of continuous operating we have obtained a significant detection of the line with a strength consistent with the D/H ratio from the ultraviolet Lyman alpha lines [8].

INSTRUMENT DESCIRPTION

The array, which is located near Haystack Observatory, Westford, Massachusetts, consists of 24 stations covering about 1 hectare. Each station is an array of 24 active crossed Yagi antennas mounted on a 4.4×4.4 m ground plane. A 48 channel receiver, consisting of analog down conversion followed by digital downconversion and filtering is mounted below the ground plane of each station. The receiver data is transferred to a PC mother board via 12 USB 2.0 paths each carrying 4 receiver channels. Multiple station beams are formed in software and the spectra from the stations are periodically transferred via fiber optic Ethernet to a central processor. The array design is optimized for the expected diffuse nature of the Deuterium line emission. The stations are spaced far enough apart to make the signals at each station uncorrelated. The use of multiple stations provides a means of acquiring an equivalent amount of single station data in one year that would take 24 years with a single station. Special care has been taken to limit the self-generated RFI by enclosing the receivers in well shielded boxes and double filtering the A.C. power line entering each receiver. The effects of external RFI have been minimized by adding resonant directors which to make Yagi elements that have 10 dB less gain at the horizon than dipole elements. In addition the software at the central processor performs excision of RFI transients and exclusion [9] of sources of CW RFI which are present for extended periods. Fig. 1 shows one of the array stations in the foreground with a RFI monitoring trailer and other stations in the background.

Fig. 1 "Deuterium" array. Crossed active Yagi elements of one station in the foreground. RFI trailer with active Yagi antenna pointed at the horizon with 30 degree spacing in azimuth for the detection of RFI are shown in background. Some of the other stations are seen in the background.

ARRAY CHARACTERISTICS

Table 1 The key parameters of the array are given.

The array characteristics are:	
Number of elements per station	24
Number of stations	24
Receiver noise temperature	40K
Station beamwidth	14 degrees
Number of simultaneous beams processed	4
Receiver bandwidth	250 kHz
Receiver resolution	244 Hz
Polarization	Dual linear
Maximum scan angle for less than 30% loss	30 deg
Beam efficiency	75%

Multiple simultaneous stations are formed in software and can be used to track regions of the sky. Fig. 2 shows the measured scan loss as a function of the scan angle.

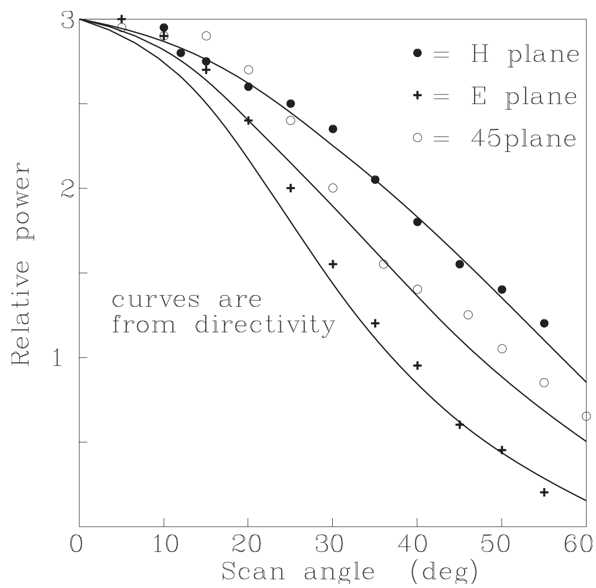

Fig. 2 Scan loss vs. scan angle for the 3 principal planes measured on the Sun.

OBSERVATIONS

The array has been in operation since the end of June 2004. Multiple beams are used to simultaneously observe regions in the Galactic plane at longitudes 171, 183 and 195 degrees and at least one reference position out of the Galactic plane. In addition the Pulsar 0329+54, the Sun, Cygnus and a fixed beam pointed at the zenith are observed to calibrate the array and check the performance and phasing of the individual elements. The system temperature is measured by comparing the sidereal variation of zenith beam power with that expected from a sky brightness model [10] obtained from surveys [11]. The regions of the sky are tracked electronically and observed for scan angles up to a maximum of 40 degrees.

The results of 11 months of observing the anticenter (183˚) where the 327 MHz deuterium line is expected to be the strongest due to the velocity crowding and the adjacent region at 171˚ are shown in Fig. 3 along with the average spectrum for the reference regions out of the plane. An equivalent single station polarization integration of 7.6 years on the region of the anticenter at 183˚ shows a 5.6 sigma detection of the 327 MHz line of Deuterium with a signal strength of 3±1 ppm of the system noise.

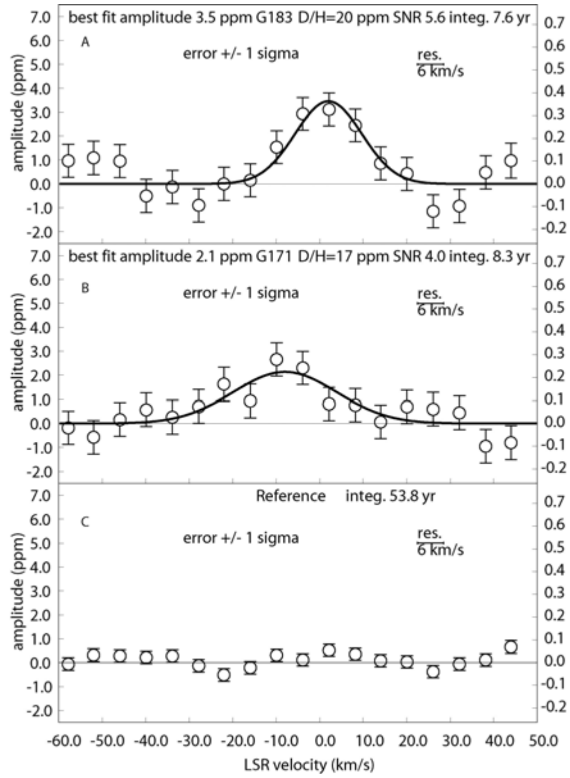

Fig. 3 (A) The average spectrum for (*l, b*) = (183˚, 0˚) A SNR of 5.6 was calculated for the best fit deuterium line profile of width 18 km/s and LSR of 2 km/s based on the hydrogen line data [11]. (B) Average spectrum for (*l*,*b*) = (171˚, 0˚) with best fit profile based on a width of 28 km/s and velocity -8 km/s. (C) Average spectrum on reference regions. An amplitude scale, which is the ratio of the signal to the system noise, and antenna temperature scale, based on an average system noise of 105 K, are shown.

The D/H ratio from the measurement of the line shown in Fig. 3 is estimated to be 20±10 ppm (3 sigma) based on the relative line strengths and the convolution of the array station beam with the distribution of hydrogen opacity from the H1 surveys [12], the distribution of continuum brightness, and an assumed 130 K spin temperature. More details and discussion of this result are given by Rogers et al [13].

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