A low-cost 21 cm horn-antenna radio telescope for education and outreach

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Abstract

Small radio telescopes (1-3m) for observations of the 21 cm hydrogen line are widely used for education and outreach. A pyramid horn was used by Ewen & Purcell (1951) to first detect the 21 cm line at Harvard. Such a horn is simple to design and build, compared to a parabolic antenna which is usually purchased ready-made. Here we present a design of a horn antenna radio telescope that can be built entirely by students, using simple components costing less than $300. The horn has an aperture of 75 cm along the H-plane, 59 cm along the E-plane, and gain of about 20 dB. The receiver system consists of low noise amplifiers, band-pass filters and a software-defined-radio USB receiver that provides digitized samples for spectral processing in a computer. Starting from construction of the horn antenna, and ending with the measurement of the Galactic rotation curve, took about 6 weeks, as part of an undergraduate course at Harvard University. The project can also grow towards building a two-element interferometer for follow-up studies.

Galactic emission from the atomic hydrogen spin-flip transition was first predicted by H. van de Hulst in 1945, and detected by H. Ewen and E. Purcell in 1951 at Harvard. Figures 1 and 2 show these historic results. With modern electronics and powerful digital signal processing techniques, the original HI line detection experiment is made easily feasible at the level of undergraduate education in experimental physics and introductory radio astronomy courses. Here we describe a low-cost horn-antenna radio telescope that is suitable for outreach and education. Figures 3-5 describe the system. Theoretical design considerations are presented in Figures 6-8. Astronomical results made with the horn-antenna are shown in Figures 9 & 10.

Figures 1 and 2: The first detection of the hydrogen spin-flip transition from the Milky Way, obtained on 9 April 1951. The spectrum was obtained in frequency switching mode.

Figures 3-5: Design and construction of the horn-antenna: 1) Cardboard+Al foil horn antenna. 2) Aluminum sheet metal. 3) Mounted on a standard alt-az telescope mount. Dimensions (a, b), which also give the slant length L.

Figures 6-8: The horn antenna's response normalized to an isotropic antenna, calculated using the COMSOL software (http://www.comsol.com), for the parameters shown in Fig. 3 and frequency of 1420 MHz. The FWHM beam size is approximately 20 degrees.

Figures 9-10: Rotation curve of the Milky Way, obtained with the metal horn antenna using spectra shown in Fig. 8. The blue curve is a composite of piece-wise polynomial fits to measured rotation curve from published CO and HI observations (from D. Clemens, 1985, ApJ, 295, 422). Error bars are large along x-axis, mainly due to the large beam size of the horn, smoothing the observations along different longitudes, resulting in blended spectra (contributing to error bars along y-axis). The overall frequency calibration may be in error as suggested by a small negative shift in the measurements compared to the published rotation curve.