A Search for Extraterrestrial Beacons at the 22-GHz Frequency of Water Vapour

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This paper reports on an ongoing search for extra-terrestrial radio beacons at the 22.2-GHz (1.35-cm) frequency of water vapour, using the 46-metre radio telescope of the Algonquin Radio Observatory.

The reasons for suggesting that Life As We Know It (LAWKI) could be abundant throughout Population I in our galaxy have been discussed often (e.g. Wald 1964, Shklovskii and Sagan 1966, Ponnamperuma and Cameron 1974) and will therefore not be elaborated here. Although studies of terrestrial life give little insight into the viability of biochemistries other than that of LAWKI, they do demonstrate that the structure of LAWKI is based on some of the more abundant chemical elements found throughout Population I. The thermodynamics of LAWKI is based on obtaining low-entropy energy and matter from sources in its environment and excreting high-entropy energy and matter to suitable sinks. The environments anticipated for many planets around Population I stars should provide the necessary sources and sinks. The organisation of LAWKI is controlled by genetic material whose origin is uncertain and controversial – but we know of no fundamental obstacles to the development of this material in initially abiological environments which are physically and chemically appropriate. The possibility that LAWKI is commonplace throughout the cosmos cannot yet be excluded on the basis of any experimental evidence.

We believe that even the remote possibility that our galaxy is teeming with technically advanced, communicative LAWKI should be investigated as appropriate technology becomes available. In early 1974 we therefore began an exploratory search for "beacon" radio signals at the 22.2-GHz frequency of water vapour. This frequency meets what we consider to be three important criteria for rational selection of a beacon frequency by LAWKI. These criteria are: 1) astronomical anomaly of natural sources emitting at the frequency, 2) biological significance of the frequency for LAWKI, and 3) freedom from natural confusion.

ASTRONOMICAL ANOMALY OF 22.2-GHz LINE SOURCES

The 1.35-cm $6_{16} \rightarrow 5_{23}$ rotation transition of H_2O was first detected in interstellar sources in late 1968 by Cheung et al. (1969). Subsequently this line has been observed in H_2O gas clouds found in association with a number of compact galactic HII regions where stars are believed to be forming. Following the work of Knowles et al. (1974) the water line has also been found associated with certain types of stars: these are typically heavily reddened late-M stars which also exhibit 18-cm OH line and excited-state SiO maser emission. According to Dickinson et al. (1973) all H_2O stars with optical identifications are long-period optical variables, generally Mira variables but sometimes semi-regular variables. Such stars are believed to be in the final stages of stellar life, having evolved from the main sequence of core hydrogen burning onto the giant branch. They possess circumstellar envelopes rich in dust and are believed to be losing mass rapidly. The H_2O emission presumably arises from the oxygen-rich stellar atmosphere of gas and dust.

The natural H_2O emission is characterized by very high intensity (to 10^{32} erg/s in some cases) and confinement to regions of very small physical dimensions ($\leq$1 A.U.). The lines often show rapid time variability and very narrow velocity width (~ 1 km/s). The high brightness temperatures, narrow line widths, and rapid variability are believed to be best explained by a maser mechanism. H_2O is unusual among molecules which have been detected by radio astronomers in that the radiating states lie at 450 cm^{-1} or 0.05 eV above the ground rotational state, a factor of 4 or 5 more excitation than is usually found.

The natural 22-GHz line emitters are thus strikingly unusual systems likely to attract the interest of civilizations interested in astronomy and which have developed radio technology comparable to ours. The water-vapour frequencies should therefore be a distinctive part of the astronomical experience of precisely the class of LAWKI with which recognizable contact may be most achievable – i.e. intelligences interacting with their environment like terrestrial astronomers.

BIOLOGICAL SIGNIFICANCE

Water is the elixir of LAWKI. It is ingested by LAWKI in greater quantities than all other substances combined. The unusual, even extreme, physical and chemical properties of liquid water which underlie its unique significance for LAWKI can be summarised as follows.

Water is an almost universal ionising solvent capable of storing a wide variety of materials in chemically reactive form while being sufficiently inert itself not to be consumed by reactions with the solutes. Its unusually high surface tension further promotes uneven distributions of solute which have important consequences for colloid chemistry.

The unusually high specific heat of water provides a thermostat for organisms containing it or surrounded by it. Its high latent heat of vaporisation further allows organisms to eliminate waste heat effectively by evaporation of water from their surfaces. Its high thermal conductivity (relative to other liquids of similar atomic content) promotes temperature equalization throughout the microstructure of LAWKI, whose cellular organisation tends to inhibit such alternative temperature-smoothing mechanisms as convection.

Hydrogen-bonding in water facilitates biochemical processes by holding large molecules in proximity while they enter into chemical reactions. It is also responsible for the anomalous expansion of liquid water between $4^{o}C$ and $0^{o}C$ and the consequent buoyancy of ice which protects deep bodies of water from freezing through in winter, directly extending the temperature shelter of aquatic life (and indirectly of all terrestrial life) by prolonging the participation of water vapour and ocean currents in global meteorological cycles.

Although other substances could play some of these roles in non-aqueous organisms, none is likely to do so as effectively as water does in LAWKI (e.g.

Henderson 1913, Wald 1964). It therefore seems reasonable to consider that LAWKI may view radio frequencies emitted by the water molecule itself to be of special significance in the context of interstellar “beacons”.

NATURAL CONFUSION AT 22 GHz

Although the anomalous natural water sources could focus attention on the 22.2-GHz water line as a possible beacon frequency, they are not so abundant as to create a strong confusing background. In comparison with the 1.4-GHz neutral hydrogen line, which is detected over a wide range of radial velocities in any direction by reasonably sensitive radio telescopes, natural emitters of the H_2O line are sharply localised discrete sources which do not create serious problems of confusion for beacon searches.

Observers in the 22.2-GHz line may however occasionally have to deal with natural H_2O emissions which could masquerade as pseudo-intelligent signals. Figure 1 shows a spectrum of the irregular red variable VY Can Maj. There is evidence for a symmetric structure in its H_2O emission, with two pairs of variable features separated by approximately equal radial velocity displacements from a central velocity where a strong feature may be present. Figure 2 (from Sullivan 1973) also shows very narrow, extremely high intensity features of H_2O emission at -3.5, +6.5 and -2.0 km/s in the giant HII region W49 that come and go on time scales of less than 10 days. The W49 source might look rather interesting to an over-eager observer seeking “intelligent” signals if he did not detect the lower-level emission which is spread over a wide range of velocity.

These examples demonstrate that although the 22.2-GHz water line is free of confusion in most directions, one still has to be cautious in looking for so-called intelligent signals at this frequency. This possible confusion with natural galactic sources should however be distinguished from an entirely illusory problem associated with 22.2-GHz beacons by some designers of search strategies.

Figure 3 appears in the Project Cyclops report (1971) and in many subsequent papers dealing with the frequency-selection problem. It shows the various contributions that are expected to the noise in a radio receiver at ground level under a warm humid atmosphere and grossly exaggerates the noise contribution due to atmospheric water vapour over a typical terrestrial radio observatory. In fact, as Figure 4 shows, the absorption due to atmospheric water vapour (and O_2) at 22 GHz is typically 0.1 db or about 3% at the zenith for much of the year at the Algonquin Radio Observatory. This in turn amounts to only about 6^{o}K of atmospheric emission at the zenith. However, there are astronomical sites on Earth such as the 14,000-ft summit of Mauna Kea above which there is only ~1 mm of precipitable water. The irreducible noise limits to the appropriate range of beacon frequencies are those imposed by the non-thermal galactic background, the 3^{o}K cosmogonical radiation and quantum noise. The "minimum-noise" (10^{o}K) window is approximately from 1 to 30 GHz. If we attach importance to the biological significance of the water line when evaluating beacon strategies, then the 22-GHz water line is as promising as the "water hole" frequencies between 1.4 and 1.7 GHz unless we visualize all communicants living in environments resembling San Francisco in a heavy fog.

THE A.R.O. BEACON SEARCH

We have begun to implement a two-level search program at the Algonquin Radio Observatory: (1) sensitive and repeated observations of ~15 nearby stars for which there is some evidence, albeit controversial, for unseen planetary companions, and (2) brief (~ 30-min) observations of a fairly complete list of several hundred single stars out to a given limiting distance (~45 L.Y.). A guiding principle of the experiment is that it utilizes equipment which already exists for normal astronomical investigations and requires only a small portion of the observing time available on the telescope.

The 46-metre telescope has a sensitivity of 15 Jy/^{o}K at 22 GHz and a half-power beamwidth of 1.4 arc min. The receiver is a cooled parametric amplifier with system temperature T ~ 250 °K. Spectral information is provided by a dual-bank 100-channel spectrometer. We have used 100-kHz and 30-kHz banks simultaneously so that the total bandwidth covered in a single spectrum is equivalent to ±65 km/s centered on the stellar radial velocity relative to the local standard of rest. Observations are made in the total-power mode, each individual scan consisting of 10 min integration on source followed by 10 min off source at the same declination and over the same range of hour angles. Typically, a single 10-min observation results in a noise level of 60 m°K , or slightly less than 1 Jy.

In May 1974 we carried out an exploratory experiment in which 13 stars of particular interest were observed for times up to an hour. The list of these stars is shown in Table 1. RMS noise levels of 25 m°K were achieved so we might have been able to detect an isotropic beacon of $\sim 10^{14}$ W from one of these nearby (10-15 L.Y.) stars . Equivalently, we would have been able to detect ~10 MW of directed emission from a hypothetical twin of the Algonquin telescope at these relatively close interstellar distances. Radar powers of this order are within the present capacity of terrestrial transmitters.

We resumed observations in January and April 1976, observing over fifty additional stars in what is the start of the second stage of this program. Initially we are concentrating on stellar systems most likely to have planets which might nurture LAWKI: single, non-variable, non-degenerate stars out to a distance of 45 L.Y. at declinations above -20°, and we are excluding known spectroscopic binaries, regular optical variables, and white-dwarf stars. There are several hundred such stars so the project will probably take a few years to complete.

The sensitivity which we intend to achieve is comparable to the upper limits being set in searches for natural H_2O emission from likely stellar candidates from IR and OH star lists. A useful scientific by-product of our work will be a much less biased survey for H_2O emission from main-sequence stars than other workers have so far attempted.

No unambiguously intelligent signals have yet been detected during our search, so it is clear that quick successes are not to be expected and that our Galaxy is not teeming with LAWKI whose beacon philosophy exactly matches that of the present authors. We concur with Cocconi and Morrison (1959), however, that the probability of success in such experiments is zero only if they are not tried, and we urge other radio astronomers to consider the possibilities of similar modest explorations.

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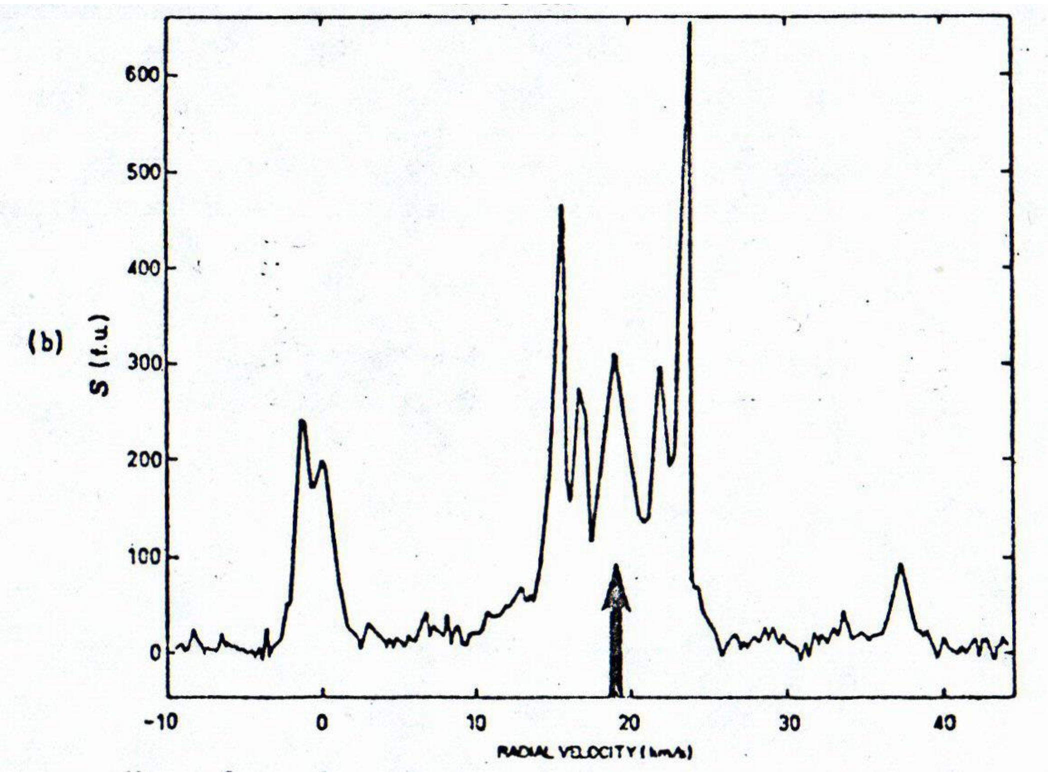
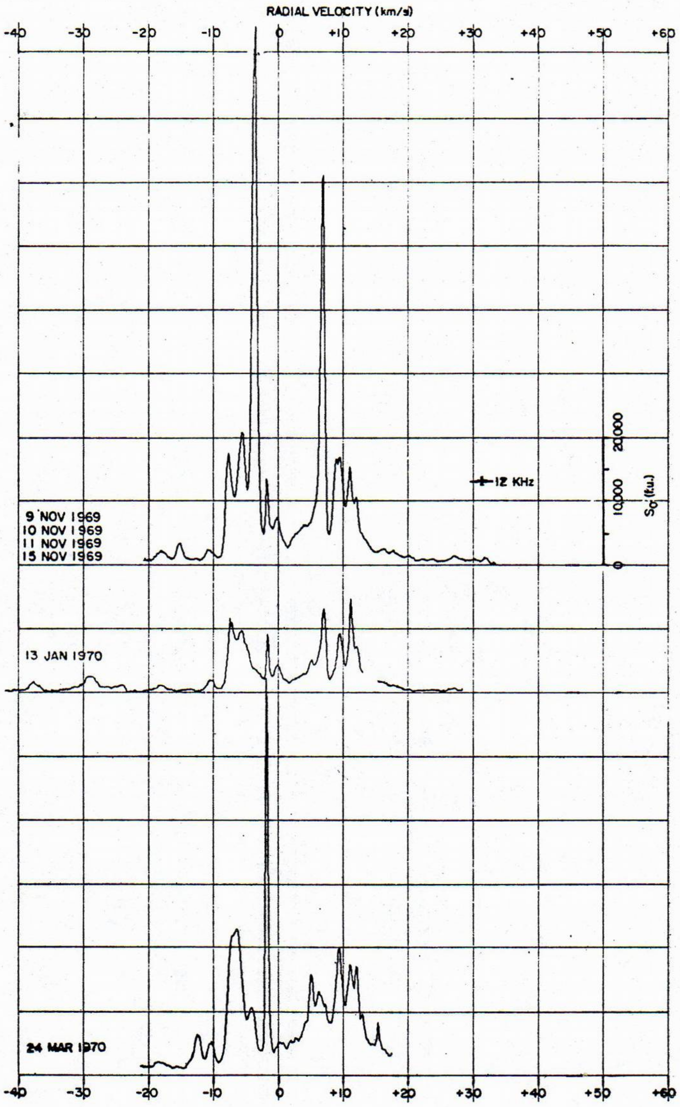
TABLE 1. STARS OBSERVED IN MAY 1974 RUN

BD +5°1668
Epsilon Eridani
Tau Ceti
BD +43°4305
61 Cygni
Barnard's Star
Lalonde 21185
Tau Bootis
BD +20°2465
Groombridge 1618
Lalonde 25372
Luyten 726-8
AOe 17415-6



<u>Figure 1.</u> Spectrum of 22.25-GHz water line emission from the star VY Can Maj (from Knowles and Batchelor preprint, Monthly Norices of Royal Astronomical Society, 1976)



<u>Figure 2.</u> Time variation of 22.25-GHz water vapour lines from W49 (from Sullivan 1975)

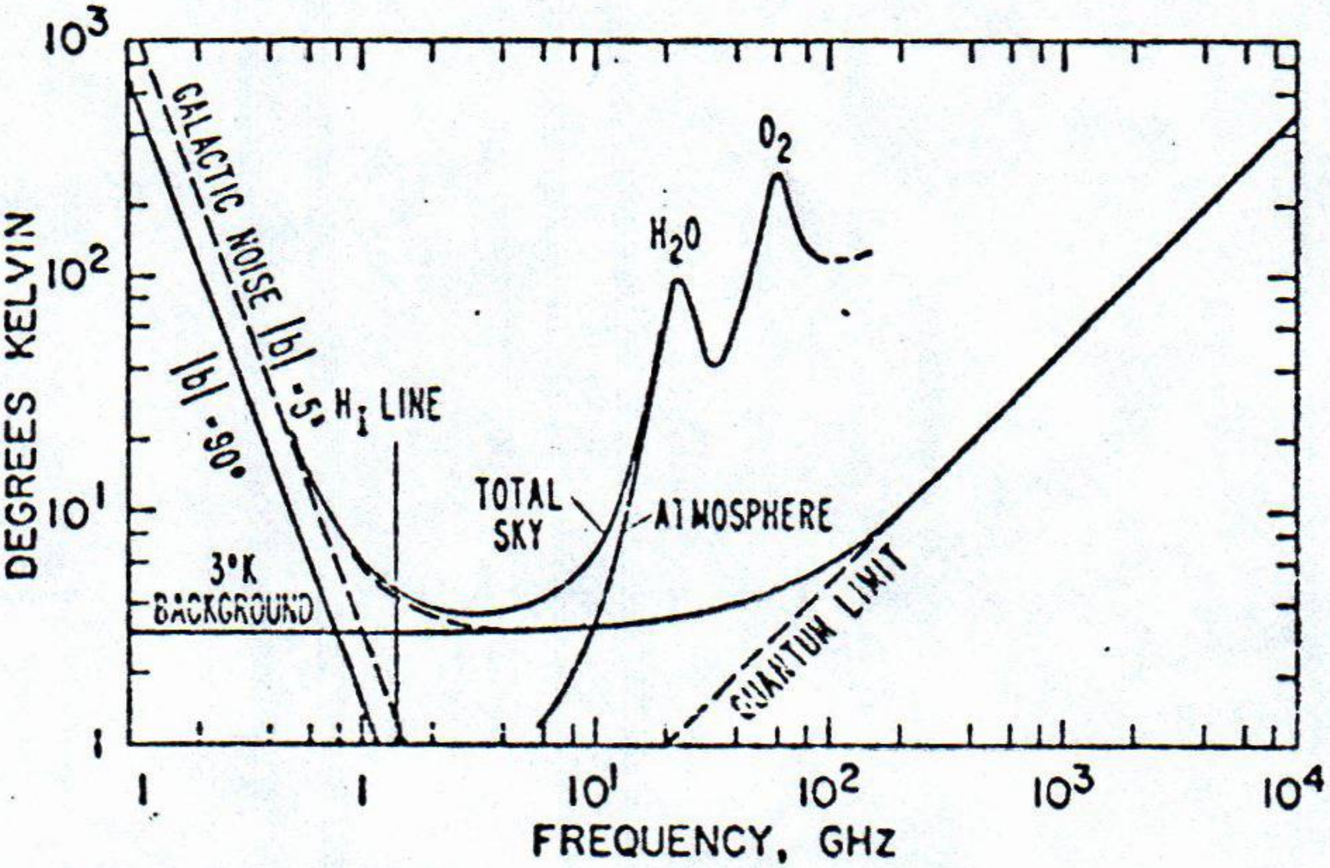


Figure 3. Chart from “Project Cyclops” report (p.42) showing large atmospheric noise contribution (from a warm humid atmosphere) at 22 GHz.

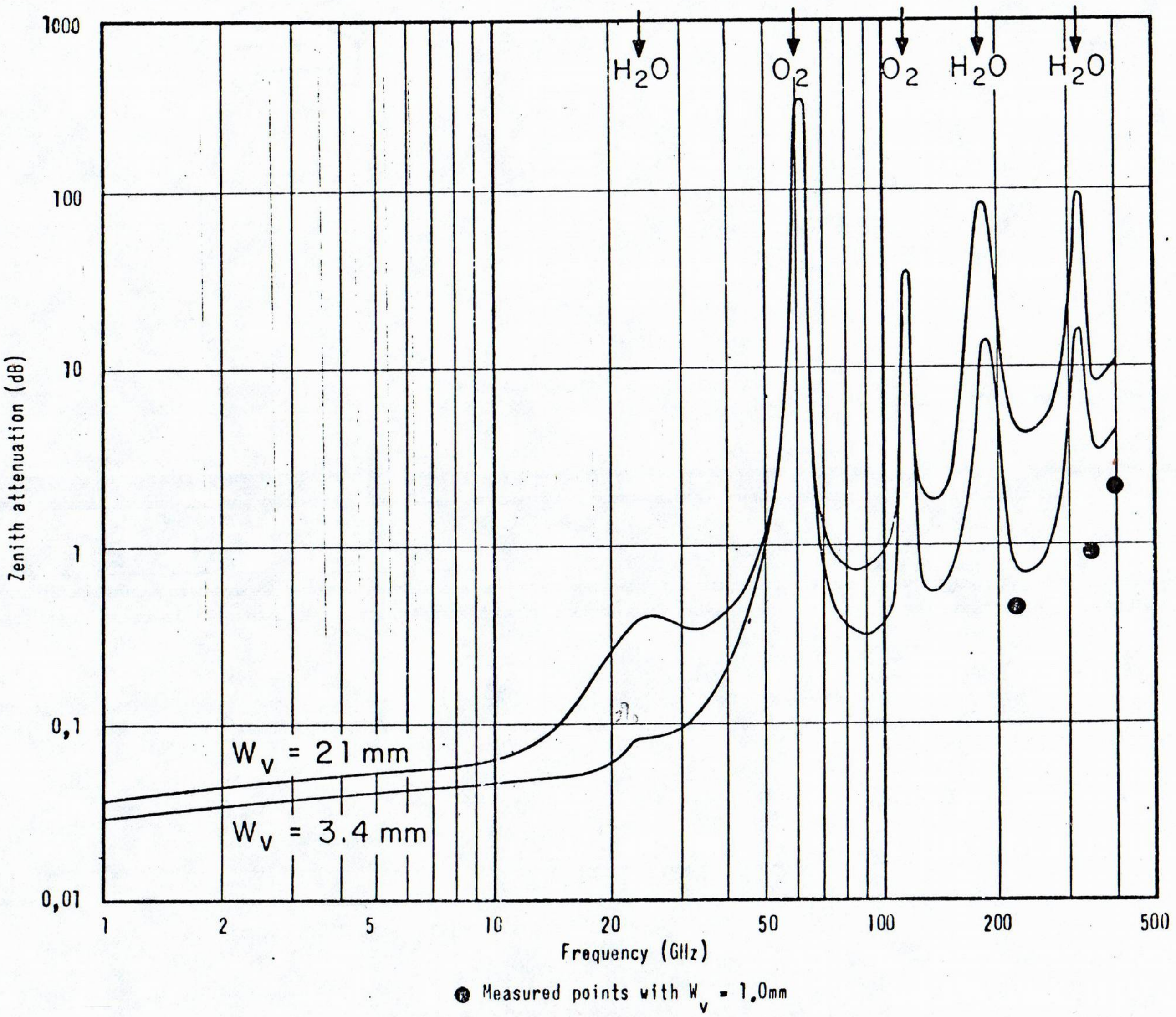


FIGURE 1

Zenith attenuation for a very dry and a normal atmosphere

W_v : Total vertical precipitable water in mm

Figure 4. Zenith attenuation expected for atmospheric conditions at a cold dry observing site such as the Algonquin Radio Observatory. (NRC of Canada)