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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 extraterrestrial 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.*

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~~The reasons for suggesting that Life As We Know It (LAWKI) could be abundant throughout Population I in our galaxy have been discussed often (Shklovskii and Sagan, Ponnamperuma and Cameron) and will not be elaborated here. Although current understanding of viable biochemical options for life is limited, and still more so the origin of genetically significant material, no fundamental obstacles are known to the development of LAWKI in physically benign but initially abiological environments. The possibility that LAWKI is commonplace throughout the cosmos cannot yet be excluded on the basis of any experimental evidence.~~

We believe that even ~~a~~ 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~~ 22.2-GHz frequency of water vapour. This frequency meets

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*Operated as a National Radio Astronomy Facility by the National Research Council of Canada.

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 hroughout the cosmos cannot yet be *excluded* on the basis of any experimental evidence.

what we consider to be three important ~~our three basic~~ criteria for rational selection of a frequency beacon ~~constructed~~ by [redacted] LAWKI. (   ).

These ~~three selection~~ criteria are: 1) astronomical anomaly of natural sources emitting at the frequency, 2) biological significance of the frequency (for LAWKI), 3) freedom from natural confusion. ~~[illegible]~~

ASTRONOMICAL ANOMALY OF [redacted] 22.2-GHz LINE SOURCES

The 1.35-cm $6_{16} \rightarrow 5_{23}$ rotational transition of H_2O was first detected in interstellar sources in late 1968 ~~by the Berkeley group~~ (Cheung *et al.*). Subsequently this line has been observed in H_2O gas clouds found in association with a number of compact galactic HII regions (~~regions of ionized hydrogen and dust~~) where stars are believed to be forming. Following the work of Knowles *et al*. (   ) 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 emission and excited-state SiO maser emission. According to Dickinson (   ), all H_2O stars with optical identifications are long-period optical variables, generally Mira variables but sometimes semi-regular variables. Such ~~These types of~~ 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 this oxygen-rich stellar atmosphere of gas and dust.

The natural H_2O emission is characterized by very high intensity (to $\sim 10^{32}$ erg/s in some cases), and confinement to ~~It arises from~~ regions of very small physical dimensions ($\lesssim$ 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 ~~1/20~~ 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 our own. 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 ~~astronomers~~ ~~thinking~~ ~~something~~ interacting with their environment like terrestrial ~~ones~~ astronomers.

~~whose guile? ours?~~

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 underly 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 forms 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 equalisation 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°C and 0°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 rôles in non-aqueous organisms, none is likely to do so 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".

Henderson, L.J., "The Fitness of the Environment",
MacMillan (New York) 1913, Beacon Press (Boston) 1958

Wald, G., Proc. Nat. Acad. Sci. 52, 595, 1964

BIOLOGICAL SIGNIFICANCE

Water is ~~very much~~ the elixir of LAWKI. It provides an ionizing fluid solvent for biochemical processes; it facilitates these processes by providing hydrogen bonding between molecules; ~~its large specific heat provides a thermostat for organisms containing it; its expansion on~~ near its ~~freezing~~ point ~~protects (deep water) bodies from freezing through, extending the temperature shelter of aquatic life~~. Although other substances, ~~such as liquid ammonia at suitably low temperatures,~~ could conceivably play these [redacted] and similar rôles, it is ~~not un~~reasonable to expect LAWKI to view radio frequencies emitted by the water molecule itself as being of special significance in the beacon context.

NATURAL CONFUSION AT 22.2GHZ

~~Third,~~ 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. ~~confusion~~. In comparison with the 1.4-GHz neutral hydrogen line, which is ~~seen~~ detected over a wide range of radial velocities in any direction by ~~a~~ reasonably sensitive radio telescopes (ref to ~~other searches,~~ cf P&Z, Dixon Verschuur D&S), ~~the sources~~ natural emitters of the H_2O line are sharply localised discrete sources which ~~are not so abundant as to~~ do not create ~~enormous~~ serious problems of confusion for beacon searches.

~~This is not to say, however, that~~ Observers, however, in the 22.~~35~~-GHz line [redacted] may occasionally have to deal with natural H_2O emissions which could masquerade as pseudo-intelligent signals.

Figure 1 shows a spectrum obtained at the Algonquin radio telescope of ~~VY CMa, an~~ the irregular red variable VY CMa. There is evidence for a symmetric structure in its H_2O emission spectrum, with 2 pairs of variable features separated by approximately equal radial velocity displacements from a central velocity where a strong central feature may be present. ~~(Slide 7)~~ [illegible] ~~The figure~~ Figure 2 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 H II region W49 that come and go on time scales of less than 10 days. ~~(Slide 6)~~ If ~~we~~ he did not ~~see~~ detect the lower-level emission which is spread over a wide range of velocity. The W49 source might look rather interesting to an over-eager observer seeking 'intelligent' signals.

~~It will be seen~~ These examples demonstrate that although the ~~water~~ 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 ~~H_2O-line~~ 22-GHz beacons by some designers of search strategies.

Figure ~~3~~ 3 appears in the Project Cyclops report (~~Slide~~ 3) (ref) 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 located at ground level ~~in some place like San Francisco during a heavy~~ ~~dense~~ ~~fog~~ under a ~~warm~~ humid atmosphere, and grossly exaggerates the ~~terrestrial~~ atmospheric noise contribution ~~in a radio-telescope system~~ due to water-vapour ~~in the atmosphere~~ over a typical terrestrial radio observatory ~~has been grossly exaggerated in this figure~~ ~~work~~. In fact, as Figure ~~3~~ 4 shows, the absorption due to atmospheric water (~~Slide~~ ~~4~~) vapour (and O_2) at 22 GHz is typically 0.1 db or about 2% at the zenith for much of the ~~"nine-month winter" we have~~ year "not typical"! at the Algonquin Radio Observatory. This in turn amounts to only about 6° K of atmospheric ~~noise~~ emission at the zenith~~, which makes the water-line frequency quite comparable at most (?)~~ during most of the ~~certain times of year to the so-called "water hole" as a region of low background noise in the radio frequency band.~~

L.D. To see.

~~natural~~ ~~The background noise of~~ ~~22 GHz~~ ~~is therefore~~ ~~that at~~ (Cyclops)

Moreover, there are astronomical sites on earth such as the 14,000 ft. summit of Mauna Kea in Hawaii above which there is ~~only~~ typically only ~1 mm of precipitable water (~~for most of the year~~) ~~And what prevents us from observing in space, at least in the supposedly logical minds of hypothetical technologically advanced communicants?~~ The ~~fundamental~~ irreducible noise limits to the appropriate range of beacon frequencies are those imposed by the non-thermal galactic background, the 3K cosmogonical radiation and quantum noise. ~~The "minimum-noise~~ (10°K business) window" is ~~then~~ approximately 1 to 30 GHz ~~between its 3 dB~~ ~~and the natural background noise at 22 GHz is quite comparable to that of~~ ~~points~~ ~~and~~ ~~the "water-hole" frequencies near 1.5~~ (1.4-1.7 GHz) are ~~zero for~~ ~~terrestrial observatories under most prevailing conditions.~~

~~not so clearly advantageous as is often claimed.~~ ( ). If we attach importance to the biological significance of water when evaluating beacon strategies, then the 22-GHz water line is ~~equally~~ as promising as the "water hole" frequencies between 1.4 and 1.7 GHz, unless we visualise all communicants living in environments resembling San Francisco in a heavy fog.

~~Figure 4 is an exaggeration, but it indicates (Slide 5) what really does constitute inclement observing conditions at the water line, and these conditions are rarely prevalent at our observatory.~~

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. ~~We hope to be able to observe these stars for a total of 1 day per star.~~ (2) ~~less assiduous~~ brief (~15 min) observations of a fairly complete list of several hundred single stars out to a given limiting distance (~45 l.y.). ~~Here we envision only about 30 min per star.~~

The 46-m telescope has a sensitivity of 15 Jy/~~degree of antenna temperature~~ °K at 22 GHz and a half-power beam-width of 1.4' arc at that frequency. The receiver is a cooled parametric amplifier with $T_s \approx 250$°K. ~~Improvements are now being made to the system which are expected to lower the system temperature by ≈ 50°K.~~ Spectral information is provided by a dual-bank 100-channel spectrometer ( ) ~~10 kHz, 30 kHz, 100 kHz, 300 kHz, and 900 kHz filter banks are currently available.~~ We have ~~been using~~ used ~~the~~ 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^{m} minutes integration on source followed by 10^{m} minutes off source at the same declination and over the same range of hour angles. Typically, a single 10^{m} minute observation results in an rms noise level of 60 m°K or slightly less than 1 Jy.

Single-channel [illegible] limit is much higher than this, and is more relevant

600mK ≈ 10Jy

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 levels of 25 m°K were achieved, (Slide 8) so we might have been able to detect an <u>isotropic</u> beacon of ~10^{14} W from one of these nearby stars (10-15 l.y.). Equivalently, we would have been able to detect ~ 10 MW of directed emission from a hypothetical twin of the Algonquin telescope ~~telescope similar to our own~~ at these relatively close interstellar distances. Radar powers of this order are within ~~our~~ the present ~~technical~~ 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 our program. Initially, we are concentrating on stellar systems most likely to have planets which might nurture LAWKI: and are ~~initially~~ ~~therefore~~ excluding known spectroscopic binaries, regular optical variables, and white-dwarf stars. ~~The~~ ~~larger~~ target ~~stars are~~ ~~chosen to be~~ single, non-variable, non-degenerate stars

flare stars?

Reworded by PAF to show # stars → limits?

out to a distance of 45 l.y. at declinations above -20°. There are several hundred such stars, so ~~and~~ the project will probably take a few years to complete.

The sensitivity ~~level to~~ which we intend to achieve ~~observe~~ is comparable to the upper limits being set in searches for natural [redacted] H_2O emission from likely stellar candidates [redacted] 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.

To para. 1 of AROBS section

A ~~The~~ guiding principle of the experiment is that it utilizes equipment which already exists for normal nominal ~~astrophysical~~ investigations, and requires ~~consumes~~ only a small portion of the observing time available on the telescope. [redacted] no unambiguously intelligent signals have yet been detected, during our search, So it is clear already that quick successes are not to be expected ~~in such a search~~, and that our Galaxy is not teaming with LAWKI whose beacon philosophy exactly matches that of the present authors. We concur with Cocconi and Morrison (1959) ~~feel~~, however, that the probability of success in such experiments is zero only if they are not tried, and urge ~~with~~ other radio astronomers to consider the possibilities of similar modest explorations.

Project Cyclops
p. 41
CETI (ed. Sagan)
p. 234
etc. etc.

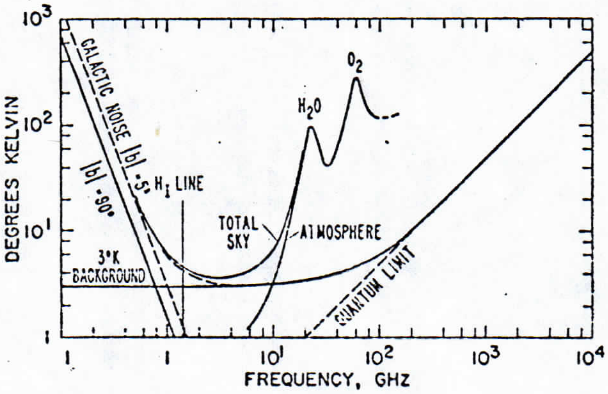


Figure 5-2. *Sky noise temperature for coherent receivers.*

Slide 2.

Standard Colour Slide of ARO,
supplied by N.R.C.

Slide 7.

Knowles & Batchelor
(CSIRO preprint)

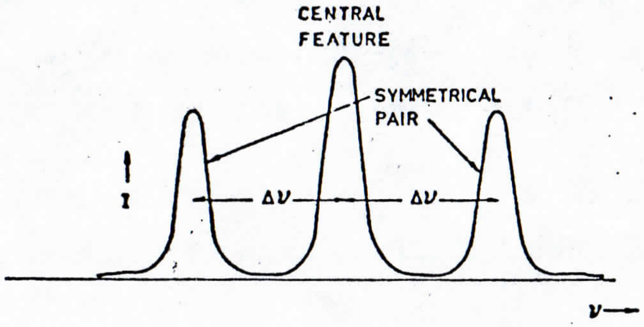
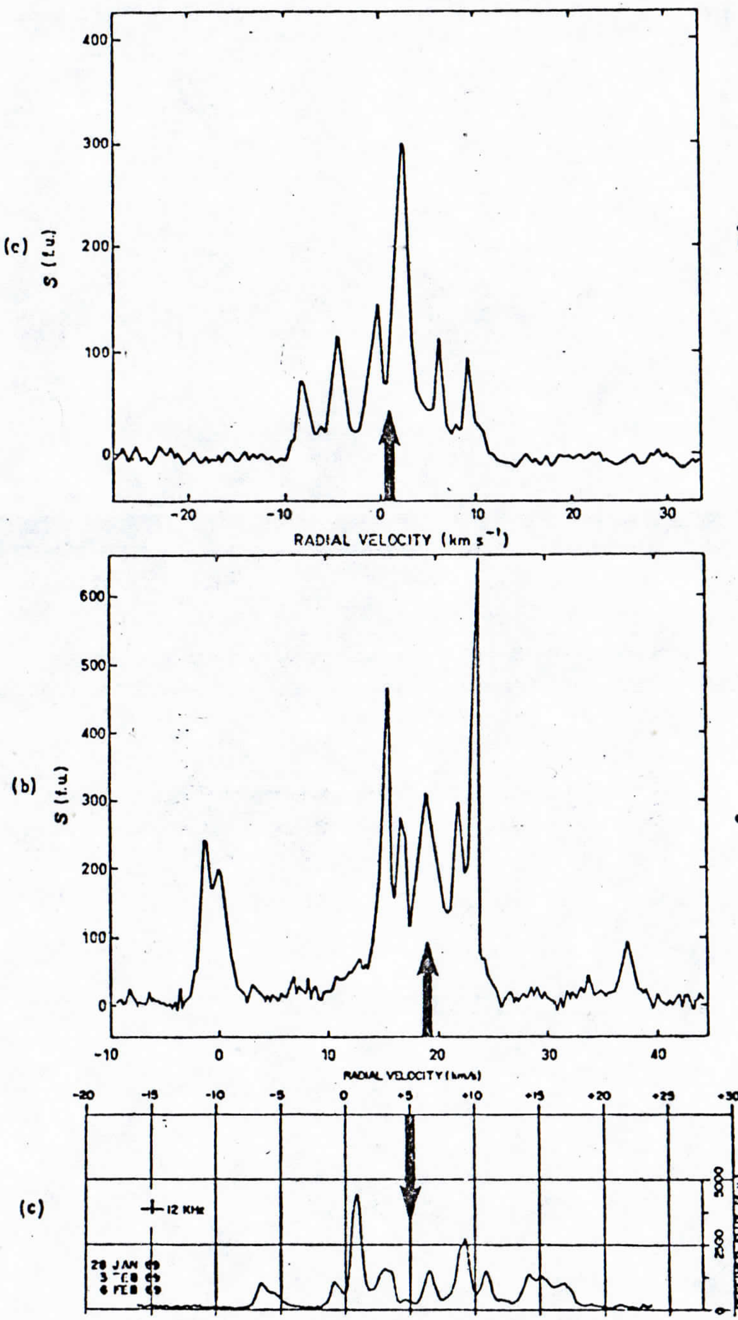


FIG. 1



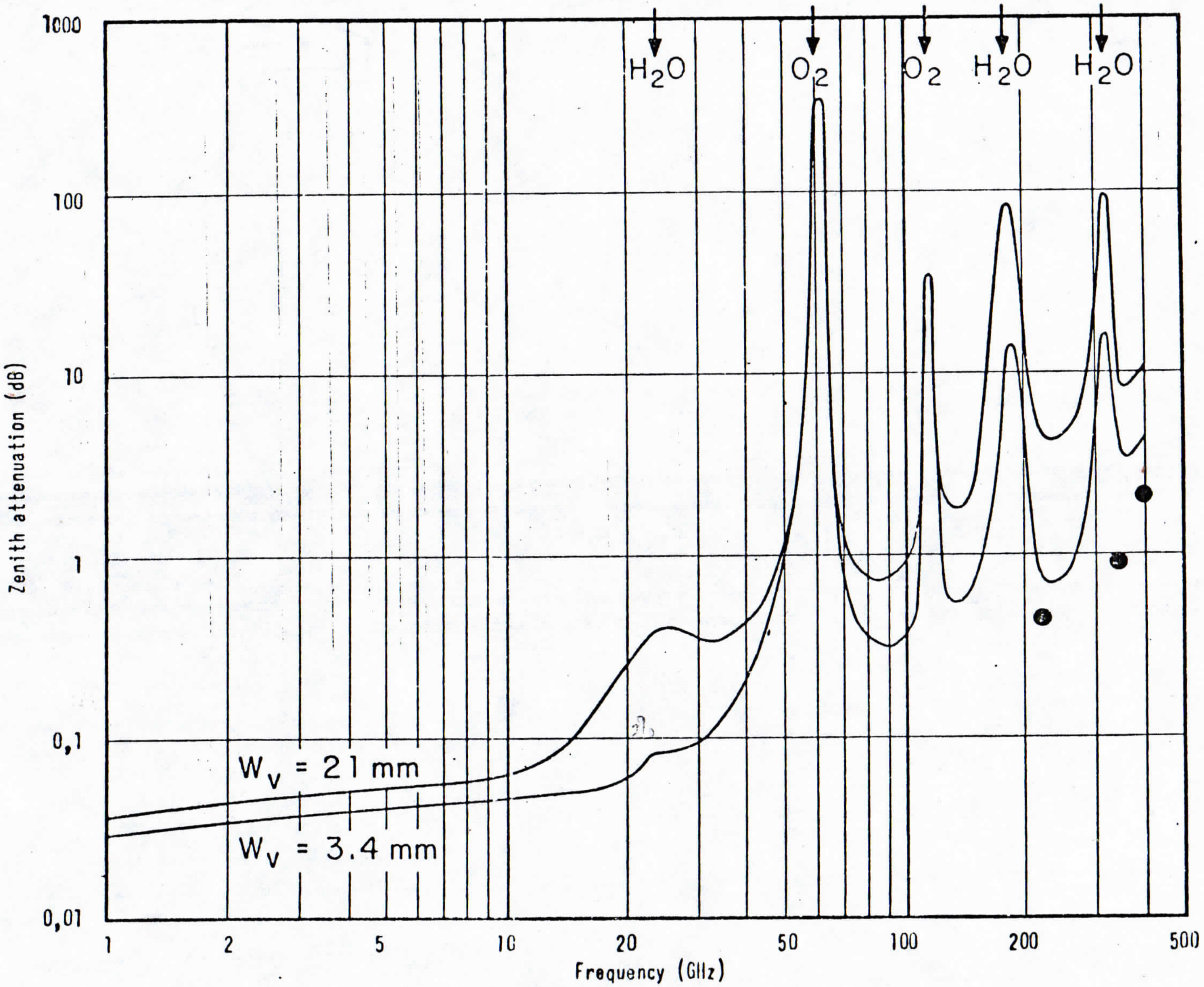
H_2O 285.3-0

VY CMa

Orion A
(Sullivan 1973

FIG. 2

Slide 4.



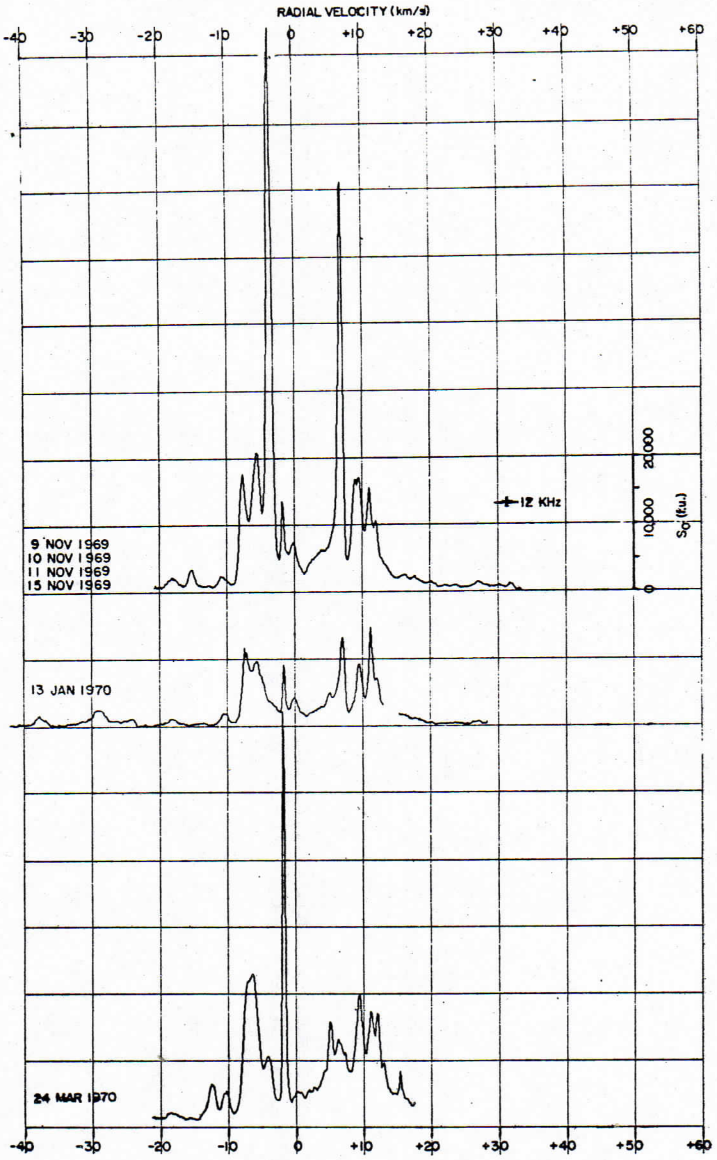
● Measured points with W_v = 1,0mm

FIGURE 1

Zenith attenuation for a very dry and a normal atmosphere

W_v : Total vertical precipitable water in mm

Slide 6.



clearly visible or only inferred to exist from the presence of asymmetry, are individually not shifting significantly in velocity. Figure 12 shows that when the -2 km s^{-1} feature flared up sometime between 1970 January and March, its width changed less than 0.1 km s^{-1}. On the other hand, the width of the $+6.5$ km s^{-1} feature (fig. 3*b* in Paper I) decreased by 0.6 km s^{-1} when it flared up between 1969 September and November, and subsequently increased by 0.2 km s^{-1} when the intensity dropped again. It should be noted that while the intense phases of the -3.5 and $+6.5$ km s^{-1} features were ephemeral, lasting less than 4 months, the -2 km s^{-1} feature remained quite intense

STARS OBSERVED IN MAY 1974 RUN

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