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THE LIEGE-BALLOON PROGRAM

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ABSTRACT

The Liège-balloon program is intended to make high-spectral resolution observations of the sun in the near- and intermediate infrared regions not accessible from the ground. A description of the equipment, followed by a summary of the data obtained till now is presented.

INTRODUCTION

Since over 20 years, Professor M. Migeotte's group of the Institute of Astrophysics of the University of Liège, has been involved in spectroscopic observations of the sun with a spectral resolution as high as possible. Most of these observations have been done at the International Scientific Station of the Jungfraujoch, located in the Swiss Alps, at 3580 m altitude.

Despite high-mountain advantages, the solar spectrum above 1.0 micron, is only partially accessible to ground observations. This situation is mainly due to the absorption of radiation by minor atmospheric constituents such as water vapor, carbon dioxide, methane, ozone, ..., which only allow extraterrestrial infrared radiation to reach the ground in the well known atmospheric windows (1.65 ; 2.30 ; 4.6 ; 10.5 microns). Except for ozone whose maximum of concentration lies near 25 Km altitude, the residual mass distribution of the other mentioned molecules decreases with altitude. This is a self-explanatory argument for carrying out spectroscopic observations from platforms transcending the densest layers of the earth's atmosphere.

The Liège balloon equipment is primarily intented for very high-resolution solar observations from about 27-30 Km altitude, in all spectral regions between 1.5 and 15.0 microns, not accessible from the ground.

THE EQUIPMENT

Figure 1 represents the optical layout of the system.

The gimbaled plane mirror Ml directs the solar radiation within the 38.5 cm-aperture telescope of the Ritchey-Chrétien type, having an effective focal length of 6 meters ; a solar image of 56 mm diameter is produced in the focal plane S of the telescope. The central part of that image is then transferred and focussed onto the entrance slit E of the spectrometer by the mirrors M5 and M6.

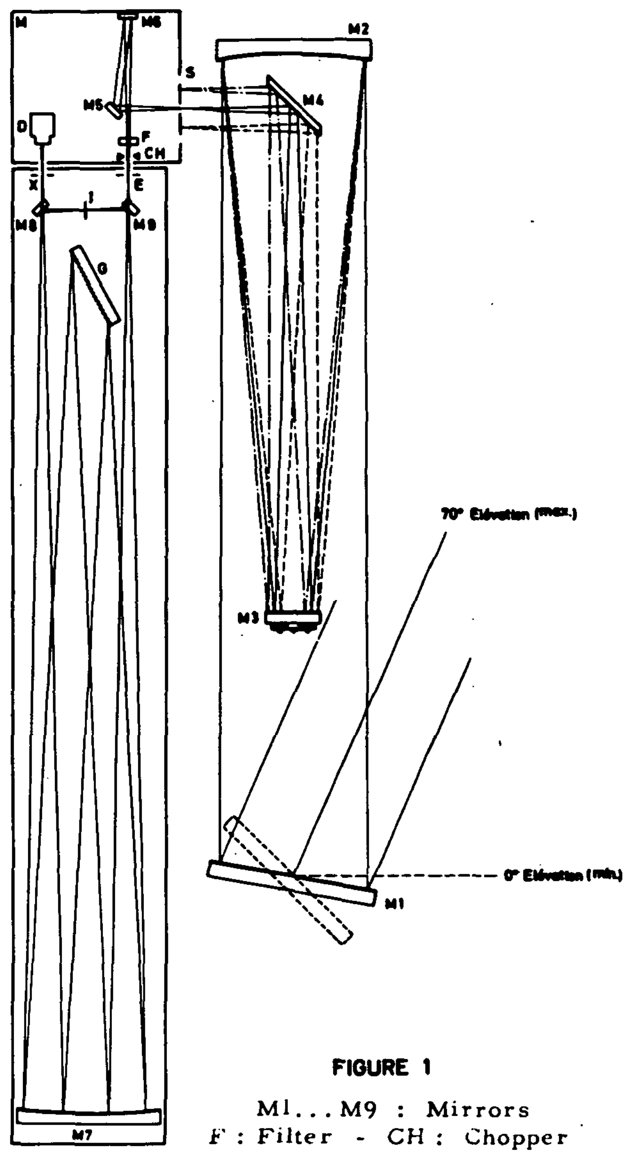

FIGURE 1

M1...M9 : Mirrors
F : Filter - CH : Chopper
E, I, X : Slits
G : Grating
D : Detector
S : Telescope Focal Plane

Figure 1. Optical layout of the balloon equipment.

The grating spectrometer is of the Ebert-Fastie type; the main mirror M7 is spherically shaped to a radius of curvature of 5 meters. Two different gratings G are actually available for covering the 1.5 to 15 microns region; they are Bausch and Lomb "echelle" replicas with a ruled area of 102 mm x 208 mm; their principal other characterisitics are given in the following table.

	Grating No. 1 for 1.5 to 3.2 microns region	Grating No. 2 for 3.0 to 15 microns region
Rulings/mm	79.0	31.6
Blaze angle	63°26'	63°26'
Working Orders	14 to 7	18 to 4

The working order selection is obtained with a set of interference filters mounted on a filter-wheel.

All mirrors and mounts are made from light aluminium alloy, kanigen-coated to a depth of about 0.12 mm; the optical surfaces worked in this last layer are aluminized.

In the classical single-pass configuration of a grating spectrometer, the spectrum corresponding to the radiation admitted through the entrance slit E, is formed in the focal plane of M7, after only one dispersion by the grating. The adopted double-pass configuration only requires the addition of two plane mirrors M8 and M9 and of an intermediate slit I; the real and fictitious entrance and exit slits of both passes, all lie on a circle of Fastie (Fastie and Sinton, 1954) of 11.0 cm radius. The advantages of the double-pass configuration with a narrow intermediate slit have been given elsewhere (Zander, 1970). For the 1.5 to 3.0 microns region, the double passed radiation traversing the exit slit X is focussed onto a lead sulfide cell, cooled down to -70°C by thermoelectrical effect; a second PbS detector located near and parallel to the intermediate slit I, allows to record simultaneously the spectrum in single pass. For the 3-15 microns region, a galium doped germanium detector cooled with liquid helium, is being integrated now to our equipment.

During the scanning of a spectrum through continuous rotation of the grating, the signals detected by the cells are synchroneously amplified and recorded on an on-board magnetic tape recorder; they are also transmitted to the ground by telemetry for real-time monitoring and subsequent optimisation of the equipment by telecommand.

A tungsten lamp, which can be placed temporarily in the optical path at S, is used for in-flight realignment of the spectrometer; it also allows to determine spectroscopically, the amount of water vapor inside of the equipment.

Figure 2 represents the 4.75 m-high balloon gondola which contains the optics shown in Figure 1 and all components, necessary to render the equipment automatic.

The gondola, as well as the telescope and spectrometer frames are made out of aluminium honeycomb; a crash-pad (not shown) fixed under the instrument, dissipates the energy of the vertical impact shock, when the equipment returns to the ground by parachute.

The acquisition of and guidance on the sun are reached in two steps. The first one consists to direct the aperture seen on Figure 2, towards the sun, in order for solar radiation to fall onto M1. This coarse azimuth orientation is realized to + or - 2 degrees of arc by using coarse silicon solar sensors, installed on the top of the gondola and which control the rotation of the 24 Kgs inertial wheel located in the upper part of the equipment. The second step which follows the first one with a lag time of 10 seconds, is accomplished by the mirror M1, mounted in a two-axis gimbaled system, positioned by torque motors servo-controlled by two pairs of fine solar sensors located under M3. The fine guidance accuracy is better than + or - 3 minutes of arc in azimuth and in elevation.

The total weight of the balloon equipment is approximately 1100 Kgs.

RESULTS

a. - New solar lines identifications.

Up to now, the spectral regions from 1.81 to 1.89 and from 2.46 to 2.83 microns have been recorded with a resolving power better than 0.04 cm^{-1}. H_2O in the first interval, H_2O and CO_2 in the second one, are the molecules responsible for almost all the telluric absorption observed in these regions.

Figure 3 shows a sample of the original unfiltered data, as recorded between 1.841 (5431 cm^{-1}) and 1.847 microns (5413 cm^{-1}), in single pass (trace A, resolving power $\sim$ 30,000) and in double pass (trace B, resolving power $\sim$ 150,000).

The distinction between telluric and Fraunhofer lines is only possible on trace B, the atmospheric lines being, in our case, narrower than the solar ones. This first discrimination is very important in the regions of telluric absorption where, until recently, only very scarce informations were available for the identification of new observed solar features.

Biémont and Grevesse (1973) have undertaken systematic theoretical calculations of the wavelengths and transition probabilities of atomic lines, between 1 and 25 microns; their already published results concern the following elements : LiI, BeI and BeII, BI, CI, NI, OI, NaI, MgI and MgII, AlI and AlII, SiI and SiII, PI and PII, SI, KI, CaI and CaII ; more than 100 new solar lines have already been identified.

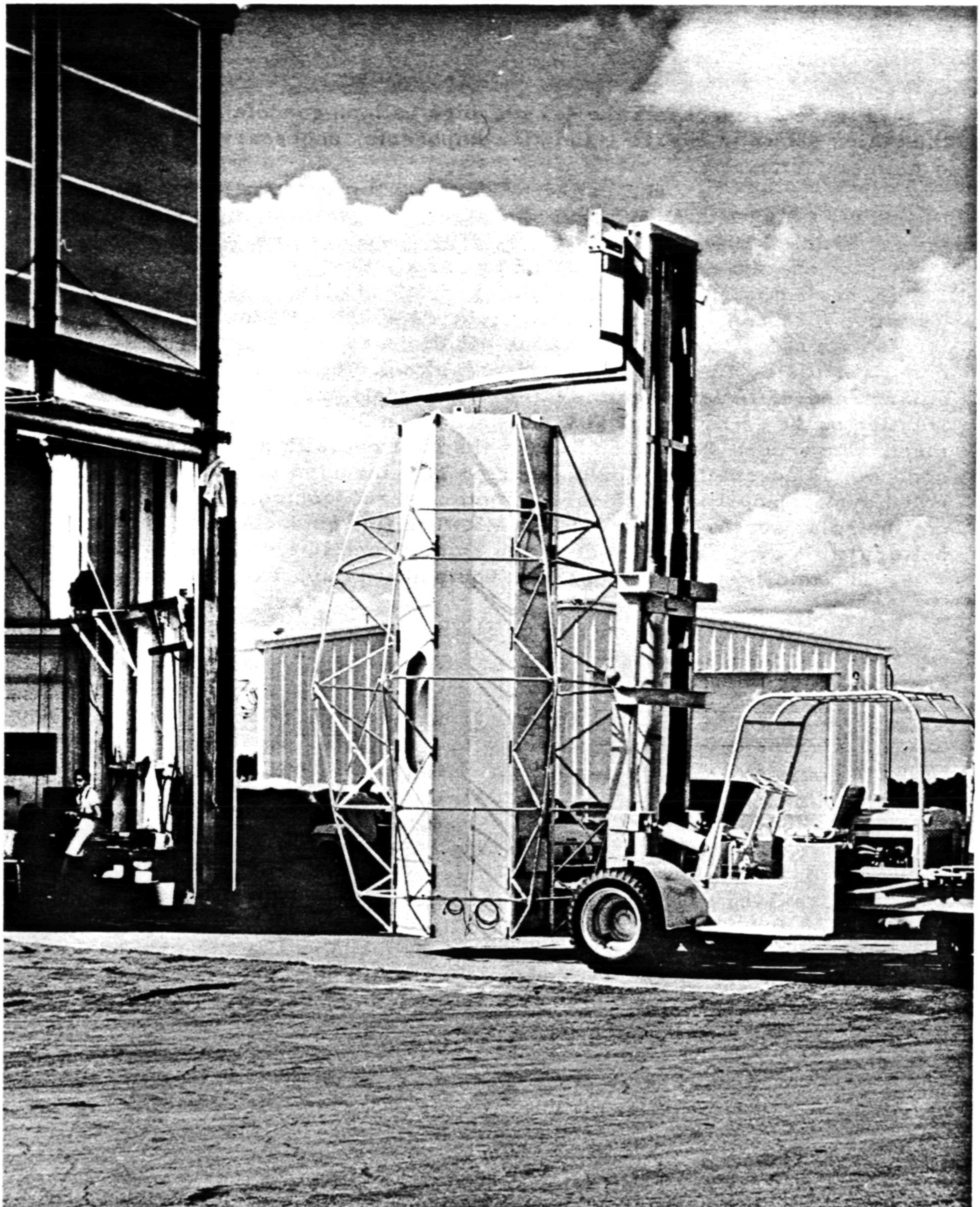

Figure 2. Balloon gondola with protective frames

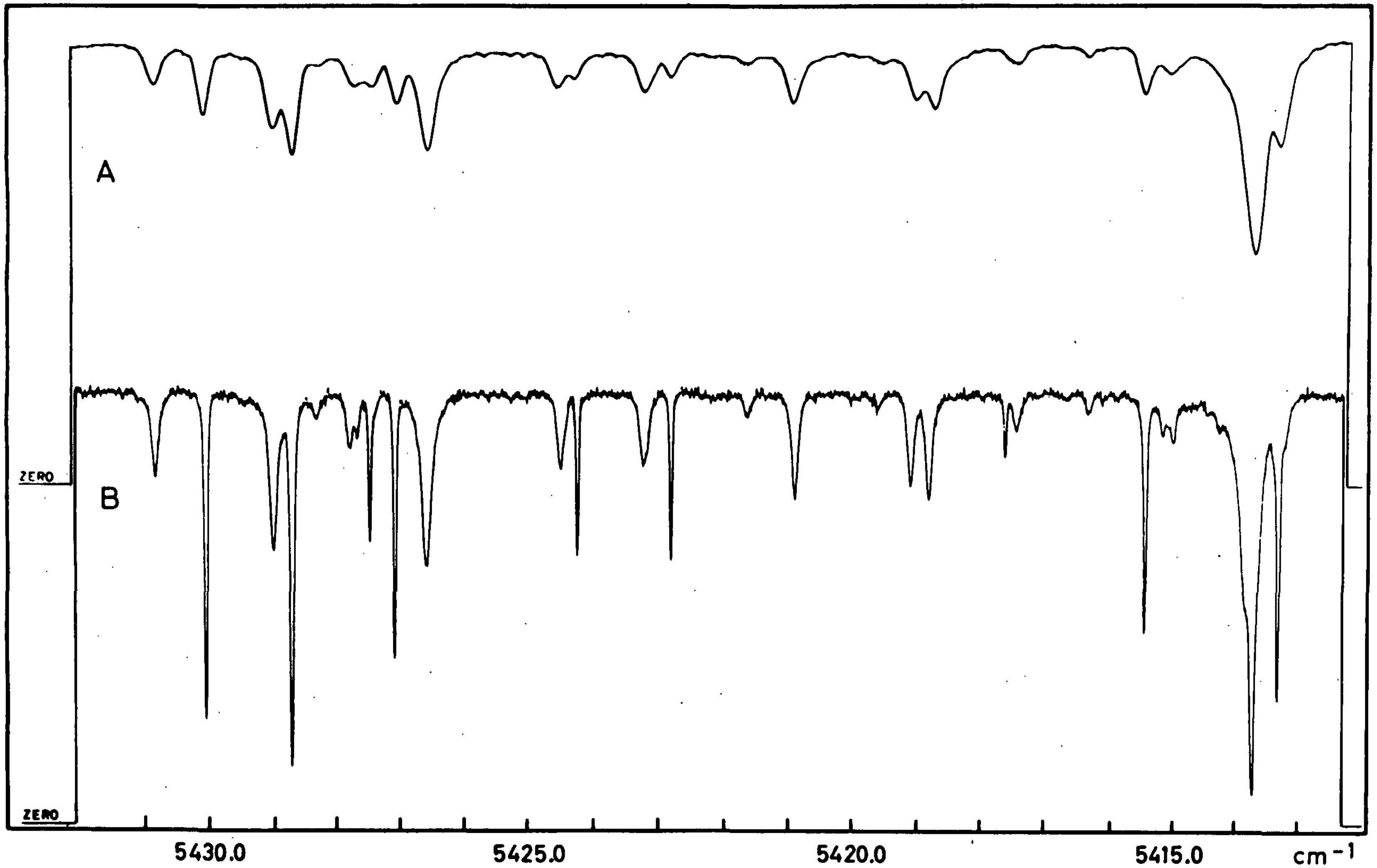

Figure 3. Sample data recorded in single pass (trace A) and in double pass (trace B).

Extensive molecular lines studies have been undertaken by A. Sauval (1972) and predictions are available for the intermediate infrared domain. The interest of infrared solar observations towards longer wavelengths λ arises from the fact that the opacity increases roughly as λ^2, which means that the continuum will originate from higher and higher layers in the solar atmosphere.

We expect to have soon good quality solar spectra in the 5 - 15 microns region (and later on up to 25 microns) in order to determine, whether or not, weak absorption lines are still present at such wavelengths. If they could be detected, these lines would allow to determine physical conditions in the upper layers of the solar photosphere.

b. - H_2O and CO_2 in the upper stratosphere.

The telluric absorption features present on the solar tracings are useful by-products of our observations.

There remains, indeed, a need for qualitative informations about the chemical composition of the upper stratosphere; concentrations and distributions, above 25 Km, of minor constituents such as H_2O, CO_2, CH_4, NO_2, N_2O, HNO_3, ..., remain one exploratory aspect of our balloon program.

The major difficulty encountered when studying the telluric H_2O concentration in the stratosphere is a consequence of the desorption at altitude, of the humidity adsorbed by the equipment during the launch preparation (Mastenbrook, 1964 ; Zander, 1966).

At the occasion of our last flights, using the on-board tungsten lamp as a source of radiation, sample spectra have been recorded regularly and H_2O amounts present in the equipment were then deduced. Subtracting these amounts from the quantities of H_2O derived from water vapor absorption lines present on the solar recordings, has allowed us to deduce data concerning telluric H_2O above float level. The results have already been given elsewhere (Zander, 1973); important conclusions are :

1. - the rate of water vapor desorption by the equipment varies approximately as the inverse of the square root of the local pressure.

2. - the H_2O concentration above 25 Km altitude lies in the range $(3.5 \pm 1.5) \times 10^{-6}$ gg^{-1}. All our data as well as those obtained by other investigators having taken the contamination effect into consideration, can be "bracketed" as shown in Figure 4 ; they are in favor of a "dry" stratosphere.

3. - the amount of moisture per meter optical path inside of the equipment, is approximately equal to 0.25 microns ppt H_2O at 25 Km altitude.

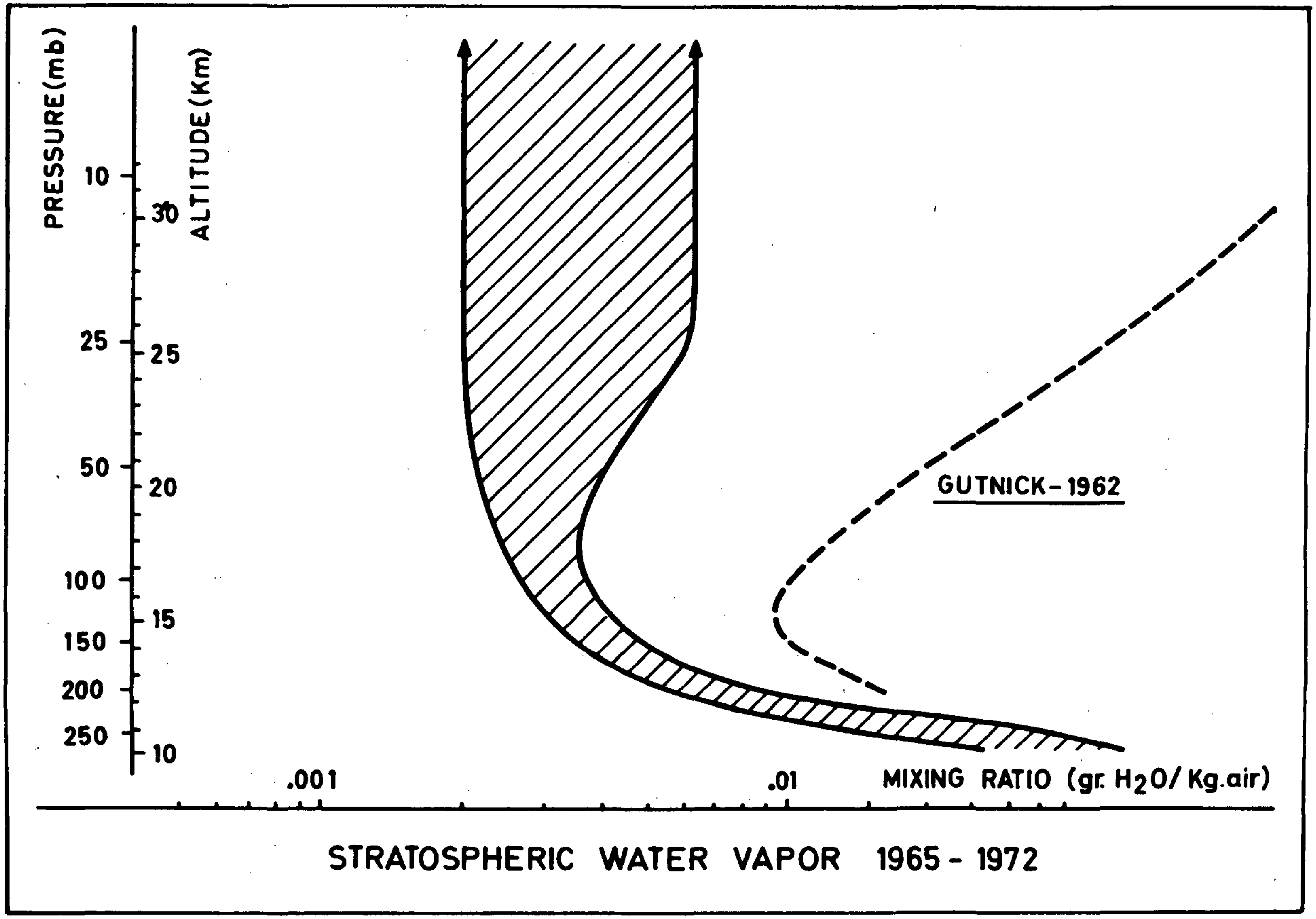

Figure 4. Most realistic range of H_2O-mixing ratio.

The telluric absorption between 2.65 and 2.80 microns is mainly due to CO_2. A line by line analysis of the P and R branches of the strong $00°0 \rightarrow 10°1$ band of CO_2 has been carried out for values of the quantum number J between 0 and 60. Using the line intensities given by Gates and Benedict (1966), we have deduced the relative variations of the line half-widths γ_0 versus J, assuming γ_0 to be equal to 0.075 cm^{-1} for $20 < J < 35$; the results are given in Figure 5. If one assumes the telluric CO_2-mixing ratio to be constant throughout the stratosphere, and equal to 330 ppmv, then the γ_0-values for $J > 20$ have to be much smaller, of the order of 0.050 cm^{-1}; such low values have never been reported in earlier CO_2 investigations.

A final conclusion concerning the carbon dioxide concentration in the upper stratosphere has to await further laboratory measurements on CO_2 line half-widths.

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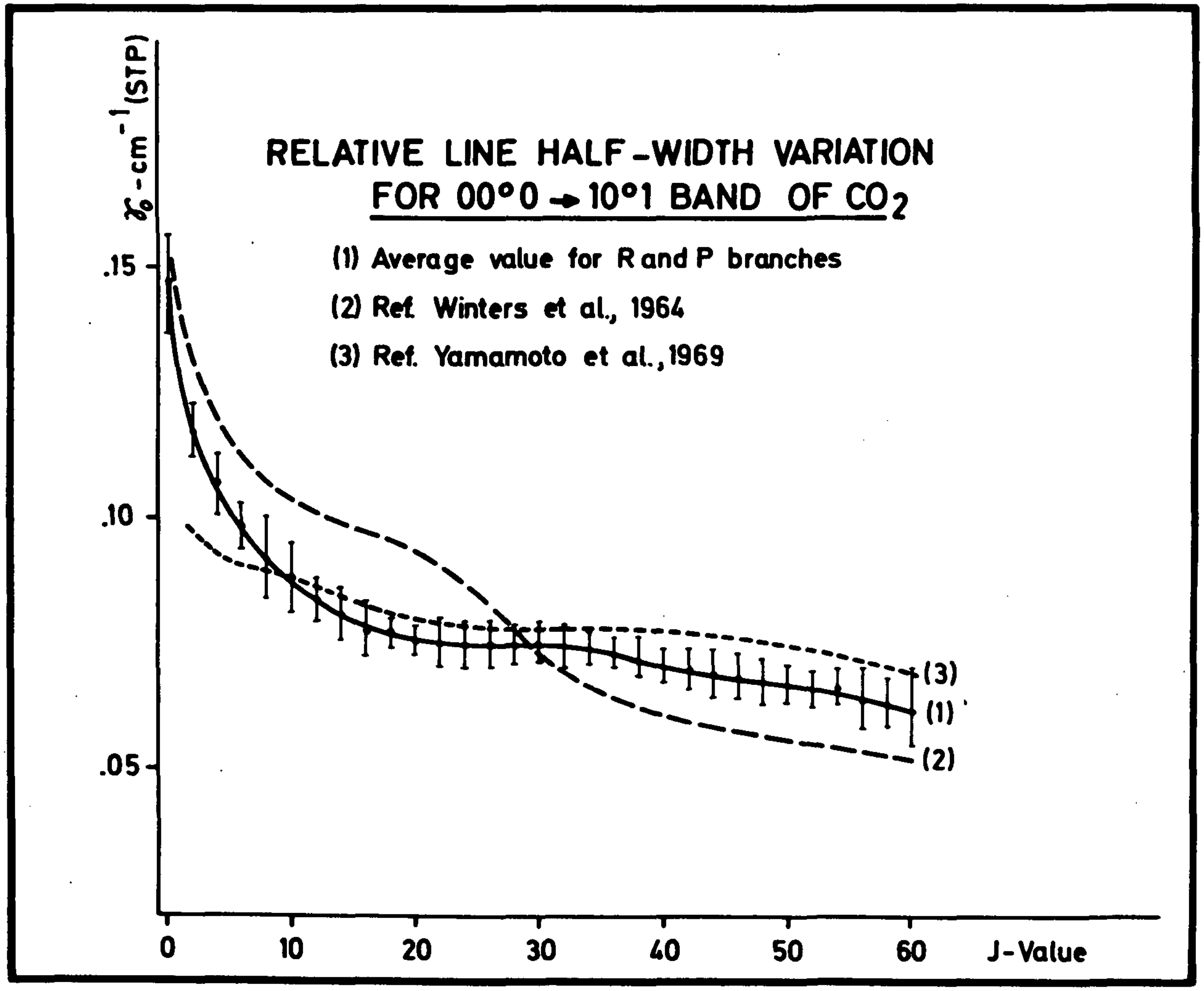

Figure 5. Relative line half-width variation of carbon dioxide.

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DISCUSSION SUMMARY — PAPER 1.4

This system weighs a thousand kilograms. It is stabilized in azimuth to plus or minus two degrees using signals from silicon solar cells. Reaction is provided by a 24-kilogram fly wheel. Final pointing accuracy of plus or minus two arcminutes is achieved using a heliostat at the entrance to the telescope.

Two gratings are used in this system. Each is 102 mm by 208 mm, and has a blaze angle of 63°26'. There are 72.25 rulings per millimeter on the grating used for the 1.5 to 3 micron range. For the 3 to 15 micron range a grating with 31.6 rulings per millimeter is used. Observations have been made between 1.81 and 1.89 microns and between 2.46 and 2.83 microns.

Observations are planned for the 2.3 to 3.3 micron range and for the 5 to 10 micron range. This will allow solar observations to reach higher levels in the photosphere. In addition observations of HNO_3, CH_4, and N_2O in the telluric atmosphere will be possible.