Venus, Meteorology
and the Jacobus Kapteyn Telescope

Some years ago one of us (JT) was approached by the other with the following problem:

"You've seen the 22° halo? Well, its inner edge is strongly polarised and I've found out why; the hexagonal ice crystals causing it are birefringent. I'd like to use that fact to see whether the Venusian upper atmosphere contains ice crystals, as predicted by some people. That would be important for the dynamics of the Venus atmosphere, because of the latent heat such crystals would represent. The test involves polarimetry when Venus is 10° to 15° from the Sun. Do you think that can be done?"

JT had his doubts, but was willing to try, so the other persisted. Six years, two observing runs (at ESO and La Palma) and much "valuable experience" later, we were on La Palma doing what we consider is the ultimate experiment of this kind from an earthbound platform. Once our results have been reduced, the next worthwhile step will be an orbiter for Venus or other planet or satellite with an atmosphere. Meanwhile, let us try to entertain you with an explanation of what we were trying to do (as we entertained and mystified the UK/NL Joint Steering Committee and others watching us at work — in comfortable sunshine with a telescope decked out like a Christmas tree).

The terrestrial 22° halo is polarised because the 22° angle depends not only on crystal geometry but also on the refractive index. That's why the halo is coloured and, hexagonal ice being birefringent, the halo is in a slightly different position (0.1°) for one polarisation than for the other. This fact does not depend on crystal orientation. What crystal orientation does is to determine whether you see a halo, a mock sun or a tangent arc (*Können, 1985, Polarised Light in Nature, CUP*); the halo is caused by crystals in random orientation, as might be expected from its circular symmetry. To convince yourself that these features are indeed polarised, examine their inner edges through a rotating Polaroid next time. This polarisation is the basis for the Venus experiment.

When the Sun-Venus-Earth lines of sight make an angle of 22° (twice in quick succession every 18 months), the "halo condition" is fulfilled. Any ice crystals present should show up as a polarisation variation as Venus passes through 22°. This moment should be slightly different, in a well-defined way, for different wavelengths. Furthermore, the position angle of this variation of polarisation can be predicted. Therefore several diagnostic tests can be applied to the observations — and indeed they must, since the observations are not at all easy:

1) Venus is not far from the Sun, so one observes in daylight. Light scattered off the telescope and dome is polarised.

2) The relative positions of sky, dome and telescope change during the observations, so the scattered component varies, both in strength and in polarisation.

3) The blue sky background is polarised

Years before, Dollfus and Coffeen (*1970, Astron Astrophys 8, 251*) had performed Venus polarimetry down to a separation from the Sun of 1.5°, so we were not demanding the impossible *a priori*; all would depend on the level of disturbance by scattered light. Dollfus and Coffeen reported that they rigorously kept sunlight off the primary mirror. In fact, the only part of the primary they actually used was that covered by the solar shadow of the secondary. We decided to be equally rigorous and brave all supercilious smiles. We blanked off half the aperture at the top end of the telescope tube and covered the tube by a homemade sandwich of plastic survival blanket (aluminised foil) and computer paper. We painted the computer paper black on the inside with kindergarten finger paint, and used wrapping paper — also painted black — and photographic masking tape to cover all remaining structure exposed to direct sunlight. The photograph shows the result of our efforts to optimise JKT; as you can see, the telescope is bearing up rather well under the weight of our baffling.

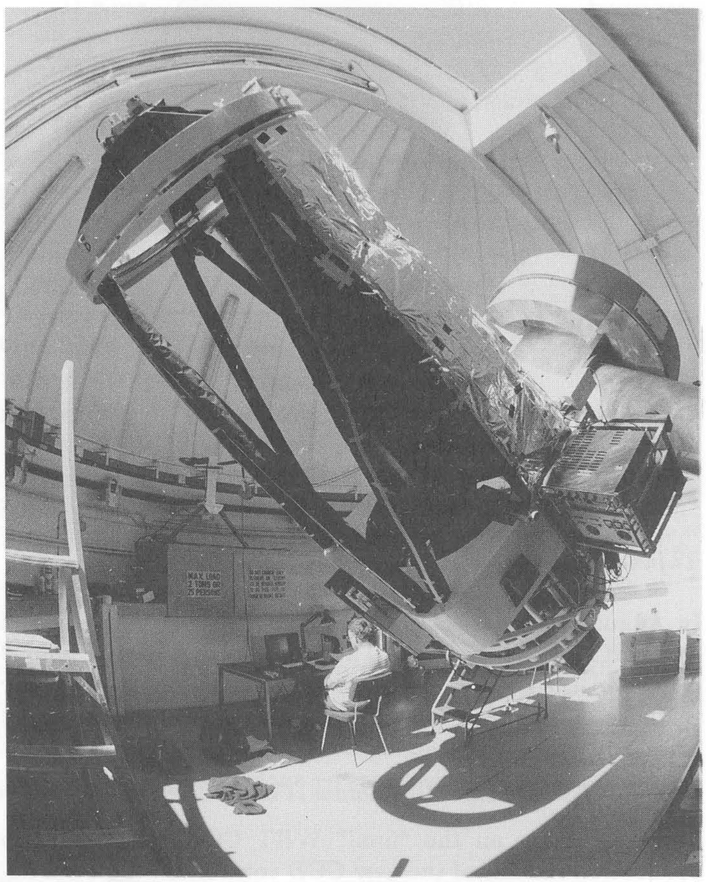

Figure 1 — Jacobus Kristmas Tree and friends

These precautions reduced the background to principally direct light from the sky around Venus. The asymmetric telescope would introduce instrumental polarisation, but this could be calibrated by observing zero-polarisation standards at night (cold work, that). To remove the sky contribution, we alternated between it and Venus in series of short exposures, starting and ending each series with sky. We only moved the dome between series. The result was that the sky signal varied smoothly (both in strength and in polarisation), so that it could be interpolated and used to correct the Venus data. To be able to detect the wavelength variation, we observed at 8 different wavelengths simultaneously, 4 of them duplicated for redundancy. We had to scrounge around internationally for the funds to buy 100-Angstrom interference filters, but using the "now or never, timing astronomically-determined" argument, we did succeed (or nearly, anyway; donations still welcome).

To accommodate 12 filters within MPF is kids' stuff. In fact, we also carried filters for the nighttime observers. Linear polarimetry in 12 channels with sky interpolation is one of MPF's standard modes (*Tinbergen, 1987, La Palma Manual XIV: MPF Users' Manual, RGO*), so we were all set. We had been scheduled nearly optimally, by a combination of a clearly brilliant proposal, an excellent referee, PATT ("no adverse scientific comments were made"), some lobbying, Bill Martin, and a reluctance on the part of overworked island staff to consider an instrument change at the weekend. The weather rose to the occasion, more or less. The only serious setback during our 15 days of observing was a violent power failure on one of the two critical days, whereupon the data disc forgot where it had put our crucial data and the MPF went dead. Repairs to MPF took a full day, while Chris Mayer and Marion Fisher (M.P.F.! what's in a name?) performed miracles of drudgery to locate, save and dump most of the submerged data. (In case you are interested how that was done, they decided to forget.)

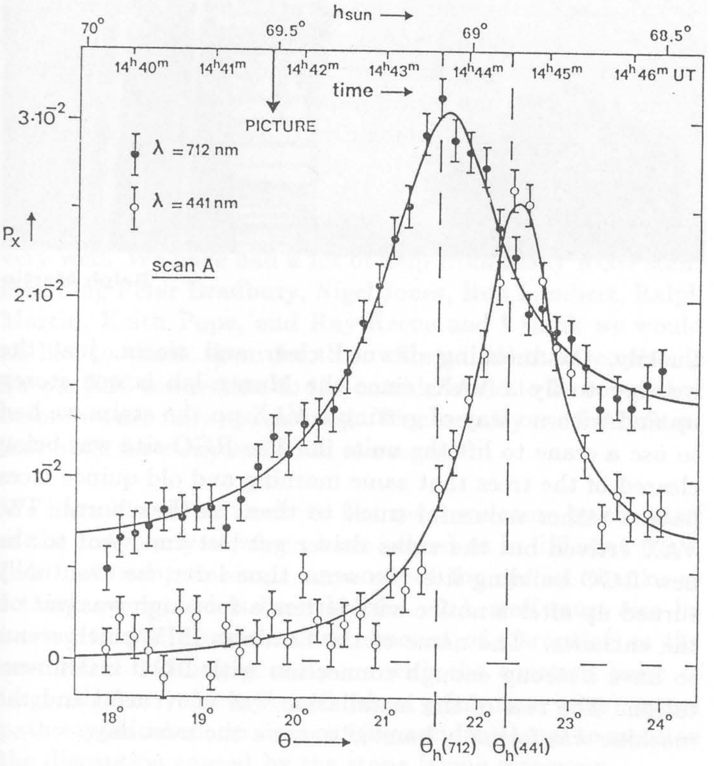

Figure 2 — Polarisation of the terrestrial 22° halo for 2 wavelengths (curves for 5 more wavelengths available). $P_x = Q/I$ is the second Stokes parameter, expressed in degree of polarisation; θ is the scattering angle. The plane of reference of the Stokes vector is the scattering plane. θ_h is the halo angle. The solid lines represent a best-fit birefringence/diffraction halo model. Time of observation and solar elevation, h_{sun}, are indicated at the top. At the time labelled PICTURE, we recorded the halo geometry with the fourshooter camera.

One of our days was marred by cirrus, which fortunately caused a display of the terrestrial halo. We took advantage of the fact that the telescope was almost optimally baffled, improvised with the differential tracking rate facilities and obtained 2 good (out of 4 attempted) radial cuts of the terrestrial halo in 12-channel polarimetry. A fourshooter photographic camera with Polaroid filters was also used to record the geometry of that particular halo. This is the first time that the polarisation of the terrestrial halo has been properly quantified, and has provided us with a never-expected terrestrial calibration of the effect we are looking for in Venus. The figure shows a narrow birefringence peak in the polarisation of the halo for 2 wavelengths, obtained in 6 minutes during the last and most successful scan. Ten minutes after this scan, the sky was clear again and we proceeded with the Venus observations.

Since we have given priority to reduction of the terrestrial halo, the Venus data are still awaiting treatment, but during the campaign we used a desk calculator to reduce 4 channels roughly; our impression from this is that we reach a precision of around 0.03% for a half-hour average and that significant variations near the predicted days are indeed present. The effects need not be perfectly repeatable; the Venus atmospheric rotation period is only 4 days and UV photographs show the top of the atmosphere as highly structured, so that cloud features crossing the crescent terminator can cause variations on a timescale of hours (the terrestrial halo, of course, is also subject to variations). After complete reduction we expect to be able to quantify the amount of ice, or at least put a significant upper limit on it. In the former case, we may be able to pronounce on the level of sulphuric acid contamination in the crystals, which would show up through changes in the refractive index of the ice and thus in timing changes of any polarisation feature.

It was all very hectic and we did feel bad at times asking for funds and special treatment for something so vulnerable to cloud or malfunctions. However, one has to be selfish at times and it all worked out. We feel we managed to stretch "the system" to its limits, which is a very satisfying feeling. The weather cooperated by being imperfect in a perfect way. We hope we've been able to transmit some of the flavour of the enterprise and possibly persuade you that MPF can do some things very well. At present, postdoc Rene Rutten at Roden is implementing a 10-millisecond 12-channel photometry option, which should lead to an optimised variable-star mode including automatic telescope offsets to sky and comparison star. We expect this to become operational in 1989, first on the JKT, later on the INT as well. If you are interested, ask RGO for La Palma Manual XIV and contact Rene at Roden .

Obviously, various members of on-site staff contributed very significantly to the success of our work. Thanks be to them, even if they remain mostly anonymous.

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