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1. Introduction

During the reporting period we worked towards a conclusion for two of our three principle tasks. Dr. Michael Flasar completed work on the transport of water through the martian boundary layer, and has moved to Goddard Space Flight Center. Alex Woronow completed his work on martian cratering and his Ph.D., and has now moved to the Lunar and Planetary Laboratory of the University of Arizona.

The principle investigator also completed an investigation of the photometric properties of Io in collaboration with Dr. Yuk Yung.

The third major branch of our work, planetary observing, will greatly increase in scope in future years. We also intend to investigate further the problem of water transport on Mars by collaborating with the Viking project.

2-1. Echelle spectrograph and Kron Camera

(Dr. David Latham)

Good progress was made over the past six months on the project to develop instrumentation for Planetary Spectroscopy using the 61-inch telescope at Agassiz Station. The echelle spectrograph was assembled over the summer and put into operation on the telescope in October. A few dozen good spectra were taken, including some plates of Io covering 4000 to 7000 Å at about 2 Å/mm.

The Kron Camera was also assembled over the summer, and an S-11 cathode with about 13% quantum efficiency was applied successfully in August. Use of the Kron Camera at the telescope is waiting for completion of the 30KV voltage divider and delivery of some special high voltage cables.

The source of the distortion (about 12%) in the Mt. Hopkins Kron Camera was traced to the corrector lens, which was originally designed at the Naval Observatory to map the focal plane of their 40-inch Ritchey-Chretien telescope onto the curved cathode. This required a two-element lens with a wild aspheric in order to correct for the astigmatism of the 40-inch. A new single-element lens has been designed specifically to match the camera to the spectrograph. The lens has been fabricated and will be tested shortly. This represents a major breakthrough if it works out, because it will very much simplify the tracing and reduction of echelle spectra taken with the Kron Camera.

2-2. Properties of the martian surface

(Alexander Woronow)

Work has been completed on two important aspects of the analysis of martian crater statistics. First, craters in the diameter range 10-250 km were demonstrated to have a log-normal size-frequency distribution, not a log-log distribution as previously assumed. This implies that dates derived from straight isochrons on a log-log model using craters of less than 40 km diameter could be systematically underestimated by an order of magnitude. Second, using the log-normal model, regions on Mars were sought that had statitstically anomalous crater size-frequency distributions. Twelve such regions were located. Most important among these are 1) the northern volcanic plains; 2) the area south of -30° latitude; and 3) a region centered on +35° latitude, 10° west longitude.

The first of these, the northern volcanic plains, has an over-abundance of small craters. This is most likely caused by a decrease in the mean radius of the impacting bodies with time. This is the first evidence for such an effect.

The second region, that area south of -30° latitude, has a deficiency of small craters. This result is consistent with the observations of Soderblom, *et al.*, that an eolian blanket covered many craters up to 10 km diameter. This study, however, demonstrates that some regions have had craters beyond 20 km diameter affected.

The third region, that centered on +35° latitude, 10° west longitude, displays a deficiency of large craters. This observation, coupled with associated morphologies of channels and knobby terrain, makes this region the most likely site found for large quantities of subsurface ice.

These and additional results were incorporated in the Ph.D. thesis of Alexander Woronow, which was defended this September. A condensation of the thesis is in preparation for submittal to JGR. Alex Woronow has accepted a post-doctoral position with Robert Strom at the Lunar and Planetary Laboratory of the University of Arizona, where he is currently examining the implications of crater saturation and equilibrium through computer generated stochasitc model, and examining the time evolution of impacting bodies as recorded on Mercury.

No further work on this part of the project will take place at Harvard.

2-3. Martian water

(Dr. Michael Flasar, Ralph Kahn)

A paper on the diurnal behavior of Martian water, described in the previous report, has been accepted for publication by Planetary and Space Science.

As of October, Dr. Flasar has taken a position at the Goddard Space Flight Center with R. Hanel's group as a National Reserach Council Resident Research Associate. He is studying the problem of thermal convection within the interior of Jupiter. Special emphasis is being given to the question of how the planet's rapid rotation affects the convection flow; in particular, does rotation induce a meridional variation in Jupiter's flux of internal heat? The effects of possible first-order phase transitions in inhibiting thermal convection will also be investigated. Dr. Flasar's work was begun in August and September under this grant and any relevant publications will acknowledge this support.

Further work along two main lines is proposed in this area. Ralph Kahn, as part of his thesis research, will investigate climatological time scale transport of water, based upon the understanding of the boundary layer reached by Flasar.

As an immediate problem, Kahn and Goody have joined the Viking imaging team as guest investigators. This results from the prediction of our previous work that ice mists should exist between about 2400k and 1000k, even in tropical regions. Enquiries were made through Dr. Soffen and Professor Mutch as to whether the Viking camera was suitably programmed to record these mists--if they exist.

We have now entered into a collaboration with Dr. James Pollack of Ames Research Center. We will jointly design observing sequences and the programs needed to invert the data. Ralph Kahn will spend most of the summer at JPL working with the Viking team.

Ralph Kahn's salary is being paid from fellowship funds. The Viking project has, however, no money for his expenses, and these will be charged to NGL 22-007-228. A visit by Goody and Kahn to Ames Research Center has already been made with support from the grant.

2-4. Photometric properties of the surface of Io and their influence on line formation in the atmosphere

(Dr. Yuk Yung)

The following is the abstract of a paper written by Yuk L. Yung and Richard M. Goody, and submitted for publication in Icarus.

Abstract

We give a quantitative theory of line formation in an atmosphere above a

surface with backscattering properties. Sufficiently high spatial and spectral resolution spectra of resonance lines in Io region A can yield data on the surface scattering properties as well as the number density of scattering molecules.

We discuss macroscopically homogeneous models of scattering from the surface of Io and conclude that multiple reflection from crystal facets is the most likely cause for the observed phase variations of the geometric albedo.

This work is important for the interpretation of spectra as discussed in section 3, below.

2-5. Imaging of Io in the NaD lines

(Frank Murcray)

Our picture of the sodium system is now similar to the hydrogen torus proposed by McDonough and Brice for Titan. Its form will depend upon the escape process from Io and the forces encountered subsequent to escape. We cannot predict the form or behaviour of the forces with any confidence, and the one-dimensional data which have been obtained by Wehinger and Wyckoff (1974 [illegible] eckler *et al.* (1974, 1975) and by us are tantalizingly inadequate for visualizing the spatial distribution of sodium. Two-dimensional images from which we can study the time dependence and morphology of the sodium system within 2 to 3 arc-minutes from Io are essential. Unfortunately they are very difficult to obtain.

We have taken images through a 7Å filter centered on the D_2 line, using the Mt. Hopkins Kron camera. We believe that we can just detect the sodium emission near to Io but light scattered in the telescope from Jupiter is very strong even when we take precautions to eliminate it.

The Na line can be picked out with a spectrograph because the high resolution discriminates against the continuum radiation (the Io lines are less than 100mÅ wide) but, more importantly, the line and adjacent continuum are recorded side by side and simultaneously on a very small area of the detector. We could probably get a good sodium image with a 7Å filter if a continuum image could be interwoven with it and differences formed at a later stage. This is a general problem in the imaging of diffuse astronomical objects.

We have designed and are building a two-dimensional imaging system which has many of the advantages of a high-resolution spectrometer.

Consider a conventional spectrometer whose entrance slit is replaced by a grid of clear and opaque strips perpendicular to the dispersion, and spaced by a distance, Δ . If this grid were illuminated with strictly monochromatic light and a camera placed at the exit aperture the grid would be imaged exactly and a one-dimensional scan along the dispersion would produce a record such as is shown in Figure 1(c). This is the case $\varepsilon \to \infty$ where ε is the ratio of Δ to the width of the line (see Figure 2.).

Now consider a wide line (ε small) with the same central intensity. A scan of the image will look like Figure 1 (b). The average signal must increase proportionally to the line width of the illuminating line but, for $1 >> \varepsilon$ the ripple on the record will rapidly decrease because of overlap. Provided that we have a linear detector with large dynamic range (as is the case for the Kron camera) we can concentrate attention on the ripple.

For example, it would be possible to convolute the record with a sampling function such as that shown in Figure 1 (c), which has a zero average, and therefore no response to a continuum. Figure 2 shows the result of scanning such a function over the record in a computer simulation.

The important feature of Figure 2 is the rapid fall off near $\epsilon = 1$. If we pick Δ so that $\epsilon \approx 4$ for the Na lines there is a dramatic discrimination against wider lines. The secondary peak near $\epsilon = 5 \times 10^{-2}$ should not be realized if an appropriate blocking filter is used (about 10Å wide will suffice if we optimize for 0.1Å lines). The slow fall off of response as ϵ increases is not important since we do not anticipate lines narrower than the NaD lines. The problem is to discriminate Io emission against solar lines which are at least 10 times wider.

Recovery of the image may follow a process similar to that described if performed on the computer. An alternative, optical procedure is illustrated in Figure 3.

We are currently building the equipment needed for this imaging device. Dr. David Latham of SAO is constructing an improved version of the Mt. Hopkins echelle spectrograph for the Agassiz telescope. In collaboration with R. Brown he is also constructing a Kron camera for use on the spectrograph and for other purposes. It is hoped that both instruments will be ready by the end of the summer.

While they are being constructed we have designed and constructed entrance grid to replace the entrance slit system. We have also built an offset guider. This work is of interest to members of the SAO because of its application to the general problem of nebula imaging. Dr. Lawrence Mertz has constructed an alternative system based upon a wedge interferometer. We expect to work both projects on a collaborative basis.

Since we are not dealing with very faint or small objects the sky conditions in Massachusetts should not be as disadvantageous for this work as it is for more conventional astronomy. We hope that much of our observation can therefore take place at the Agassiz station although we will probably need to take advantage of the better skies of Mt Hopkins at a later stage.

In recent months our work has advanced rapidly. Dr. Mertz's interferometer has been tested by Mertz and Murcray on the Agassiz 61" telescope. Murcray has taken the instrument to Mt. Hopkins and has used it with an image tube. Fringes have been obtained of the Orion nebula and also in the general area of Io. Plates are now being processed. The laser analysis device has been constructed in the laboratory.

We are still some way from having solved all of the problems associated with the interferometric image. However, we are solving them one by one and performance seems to correspond to prediction at each stage.

Simultaneously with our work on the interferometer, the imaging system designed for the echelle spectrograph is nearing completion. The offset guide is complete and the entrance grid has been purchased. A three-stage image tube belonging to SAO would be ideal as a detector. Work has to be done on the image tube, however, before it is ready for use. We are also still waiting for final tests on the Kron tube.

It is difficult to predict where this project will be in six months or which of the two instruments and alternative detectors will be more suitable. We are advancing on several fronts at the same time and the chances of success look good.

3. Future work on planetary observing

With the agreement of Dr. Robert Fellows, the work of Dr. Robert Brown is being transferred to NGL 22-007-228. The three main objectives of this work are described below.

3-1. Search for fluorescent emissions

The sodium emission from Io and the Lyman-alpha emission subsequently discovered by Carlson and Judge (1974) during the Pioneer 10 flyby both draw attention to the possibility that other bodies in the outer solar system may have tenuous atmospheres. If Jupiter satellites are icy, as proposed by Lewis, the ice is probably evaporating at the present time and the satellites should be surrounded by escaping atoms which could fluoresce. The same may also be true of some of the asteroids.

We propose to search for fluorescent emissions from icy objects, satellites or asteroids. The species Li, Ca, K, Mg, O have already been sought on Io, with negative results. We also have some spectra of the other three Gallilean satellites which we are in process of comparing.

The equipment available to us is ideal for exploratory spectroscopy. A larger telescope than 60" would be valuable for very faint objects but there are many for which we can obtain good spectra with a reasonable exposure time. Cassegrain echelle spectrographs are fast and more effective than spectrographs on many larger instruments. The combination of cross-dispersion and a Kron camera allows us to store up to 1000 Å of spectrum with photometric accuracy and a dynamic range of 10^4.

The problem with this system is the immense amount of high quality data stored on a single Kron plate. It is too good to be used only for visualinspection and we have therefore developed techniques for computer processing.

We have modified the Mann microdensitometer of the SAO so that spectral scans can be put automatically onto tape. Programs have been written which can translate and scale the data so that two spectra from the same region can be registered to an accuracy higher than the spectral resolution. Two spectra from different objects can then be differenced. A section of two spectra and the difference spectrum are shown in Figure 4.

With these automatic data handling techniques we will be able to analyze a large number of spectra with minimum effort on our part, and we propose, over the next two years to exhaust the spectral range of the present Kron tube cathode for Jupiter satellites and the larger asteroids, looking both at the discs and the nearby sky.

3-2. Rotation rates of Uranus and Neptune

The characterization of dynamical regimes in a planetary circulation depends upon the rotation rate (Stone, 1973). In the case of Uranus and Neptune surface markings cannot be seen sufficiently well to determine the rotation rate and there is considerable doubt as to the significance of the published data.

The problem is reviewed by Newburn and Gulkis (1973). Data from time variability of the light curve of Uranus are contradictory. The Doppler shift work of Moore and Menzel was performed in 1928 and 1930 with prism spectrographs. It is very hard to believe that their measurements are of any significance although they claim 5 to 7% accuracy.

We could make very much more accurate measurements with modern spectrographs. With well resolved discs 1% accuracy should present no difficulty. Uranus can just be resolved under normal conditions, but the disc of Neptune cannot be explored.

The least possible distortion by the spectrograph along the slit is required to take advantage of disc resolution and the best instrument known to us is the stigmatic echelle spectrograph of the KPNO 150". We shall seek time on this instrument in Spring, 1976. Preliminary measurements will be made at Mt. Hopkins in May of this year.

An alternative approach, which we shall probably have to use for Neptune, is to combine all the light from the planet and to fit the resultant line shape numerically. To do this we must know the direction of the rotation axis. It is commonly assumed that the rotation axis is perpendicular to the plane of the satellites. Unfortunately, the only data capable of confirming this, the direction of faint bands on Uranus, fails to do so. Unless observations can be made from the proposed LST many accurate spectrometric observations over several decades will be needed to solve this problem. It is time to start the process.

3-3. Thermal anomalies on Venus

The dense atmosphere, the ubiquitous clouds and the slow rotation rate of the planet put the Venus atmosphere in an interestingly different parametric range from Earth (Gierasch, Goody and Stone, 1970). This has led to a series of studies of possible Hadley circulations in the lower atmosphere (Goody and Robinson, 1966; Stone, 1974; de Rivas, 1975). The proposed Pioneer-Venus missions of 1978 have been designed to explore this deep circulation. There is little further than can be done to investigate this phenomenon from Earth before this mission is completed.

At those levels where solar radiation is absorbed (60 km above the surface) a diffuse circulation, having a boundary-layer character, can be observed. This is the remarkable 4-day circulation (Young and Schubert, 1973), about which there are many theories: eventually, of course, a complete theory must embrace both the boundary layer and the interior, but such work is still in its infancy.

Any doubts as to the reality of the 4-day circulation were put to rest by the Mariner 10 fly-by (Murray *et al.* 1974). Although much interesting detail was revealed in the blue images they do not give us any obvious hints as to the physical causes of this circulation.

The 4-day circulation was first detected from Earth, although the observations were difficult to interpret. This emphasizes, however, the need to pursue all available observational data, particularly when the phenomena appear to be time-dependent and therefore related to dynamical effects. One class of data which shows this promise, but has not been fully exploited, is represented by the thermal maps of Murray, Wildey and Westphal (1963) and Westphal, Wildey and Murray (1965).

Attempts to analyze these maps in some detail have been made by Goody (1965) and Ingersoll and Orton (1974). Limb darkening, solar related effects and equator-to-pole gradients are fairly well described observationally although theoretical explanations are lacking.

Features of these maps which have been little investigated are the thermal anomalies, such as that seen near the S-pole by Murray *et al.* (1963). In view of the paucity of data on Venus and the probable relevance of any large scale temporal variations to the planetary circulation, either as cause or effect, we believe that these phenomena should be further investigated. It has not been clear, for example, whether thermal anomalies definitely exist. If they do, we may be able to understand their relationship to the circulation if we know their size, their intensity, their lifetimes and their preferred motions, if any. As pointed out by Ingersoll and Orton we cannot distinguish, from measurements at a single wavelength, whether the effect is due to changes in cloud density or changes in cloud temperature. Measurements at more than one wavelength would be required for this purpose, and as a consequence we have concentrated attention on "black" detectors which can, in principle, be used at any wavelength.

Apart from the decision with respect to the detector our other two major decisions have been to use the Mt. Hopkins 60" telescope because of its availability and to attempt image stabilization for accurate and reproducible mapping. The large diffraction image (approximately 2" diameter) of the Mt. Hopkins telescope is unsatisfactory, but we judged ready availability to be more important than high resolution when studying time-varying pheromena.

The decision to stabilize the image led to the use of the coudé focus. We had hoped that the large signal from Venus would allow us to compensate for other difficulties associated with this focus. For technical reasons it led us into a slow scanning mode with an undesirable amount of the 1/f detector noise which gives image "streakiness", despite careful image processing. This has set the limit of accuracy to our measurements.

Our equipment consists of a Low-type bolometer with an image stabilizer and computer-controlled raster scanning and chopping equipment. A schematic diagram is shown in Figure 5. We obtained our first series of thermal maps in the period November 1973 to January 1974. Since that time we have been developing the many software programs needed to remove instrumental distortion, reduce the noise, remove limb darkening (to a first approximation) and to map onto an oriented mercator projection.

Figure 6 shows one example of a thermal map. Note that most of the limb darkening has been removed and the remaining energy contours are close. Well-known, solar-related effects can be found in this image, but there is also a general warming in the S mid-latitudes which is reproducible and has not previously been reported. The anomaly in the north-west segment also repeats in neighboring records but only for a few days. We have therefore confirmed the existence of time-dependent anomalies and have shown that the 60" telescope can resolve at least the larger ones.

During the next grant period we have both short-term and long-term objectives. Our existing equipment, being based on computer instructions, can be used in many modes. This summer a scanning secondary will be added to the Mt. Hopkins telescope which can be controlled with our equipment to perform raster scans. The detector can then be used at Cassegrain. Image stabilization will not be possible but hopefully scanning can be rapid enough to make this unnecessary. These procedures should give great improvements in signal-to-noise ratio and the rate of acquisition of data.

On the longer term we would like to use the Mt. Hopkins Multi-Mirror Telescope, provided that the images can be phased in the infrared. If so, resolution as good as 1 arc-sec could be available for thermal imaging. Approximately one year from now we plan to become involved in the development of the infrared imaging system for this telescope. We do not intend to contribute hardware, however, since budgets are already set up for this purpose.

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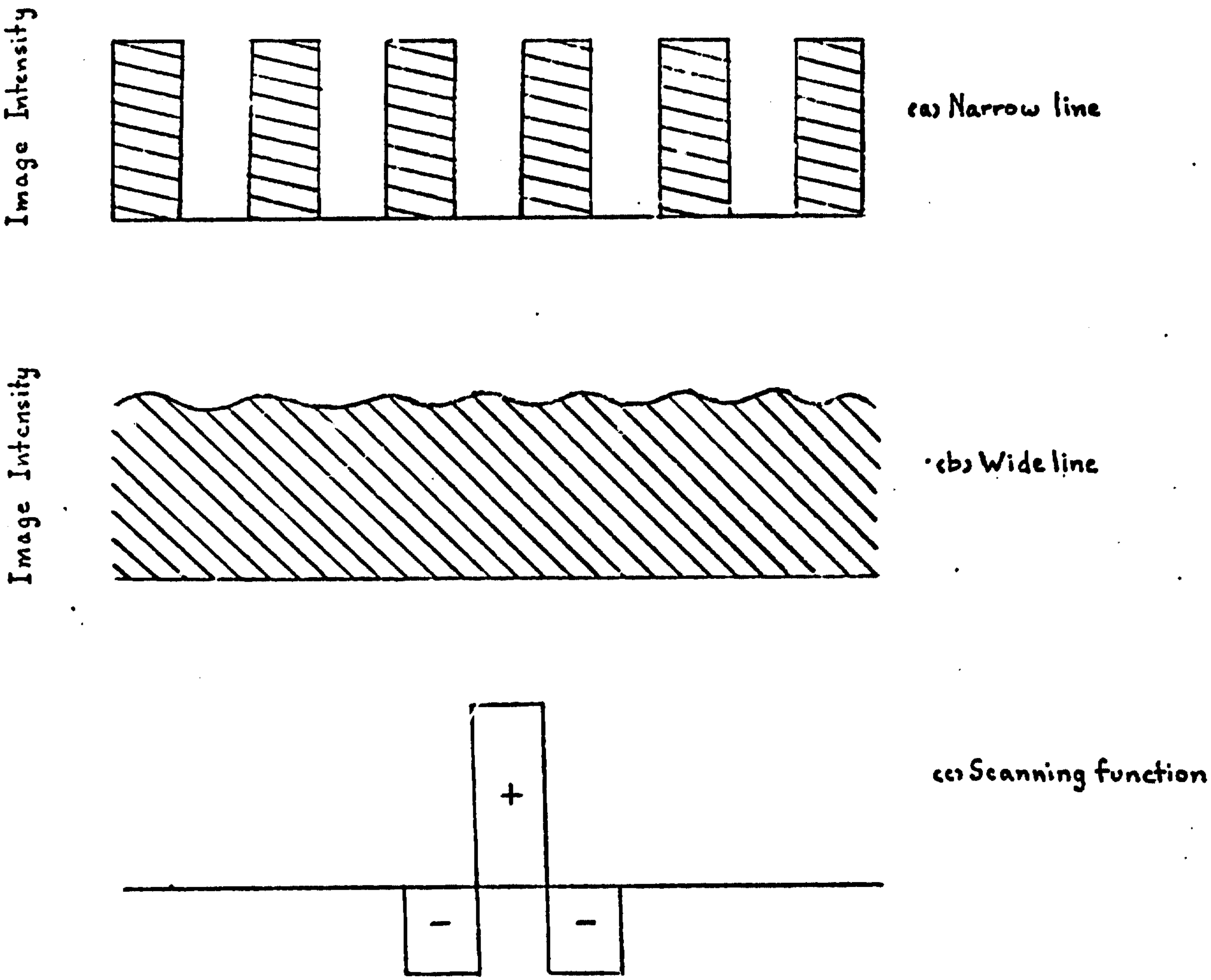

Figure 1. Exit aperture images for entrance grids illuminated with narrow and wide lines.

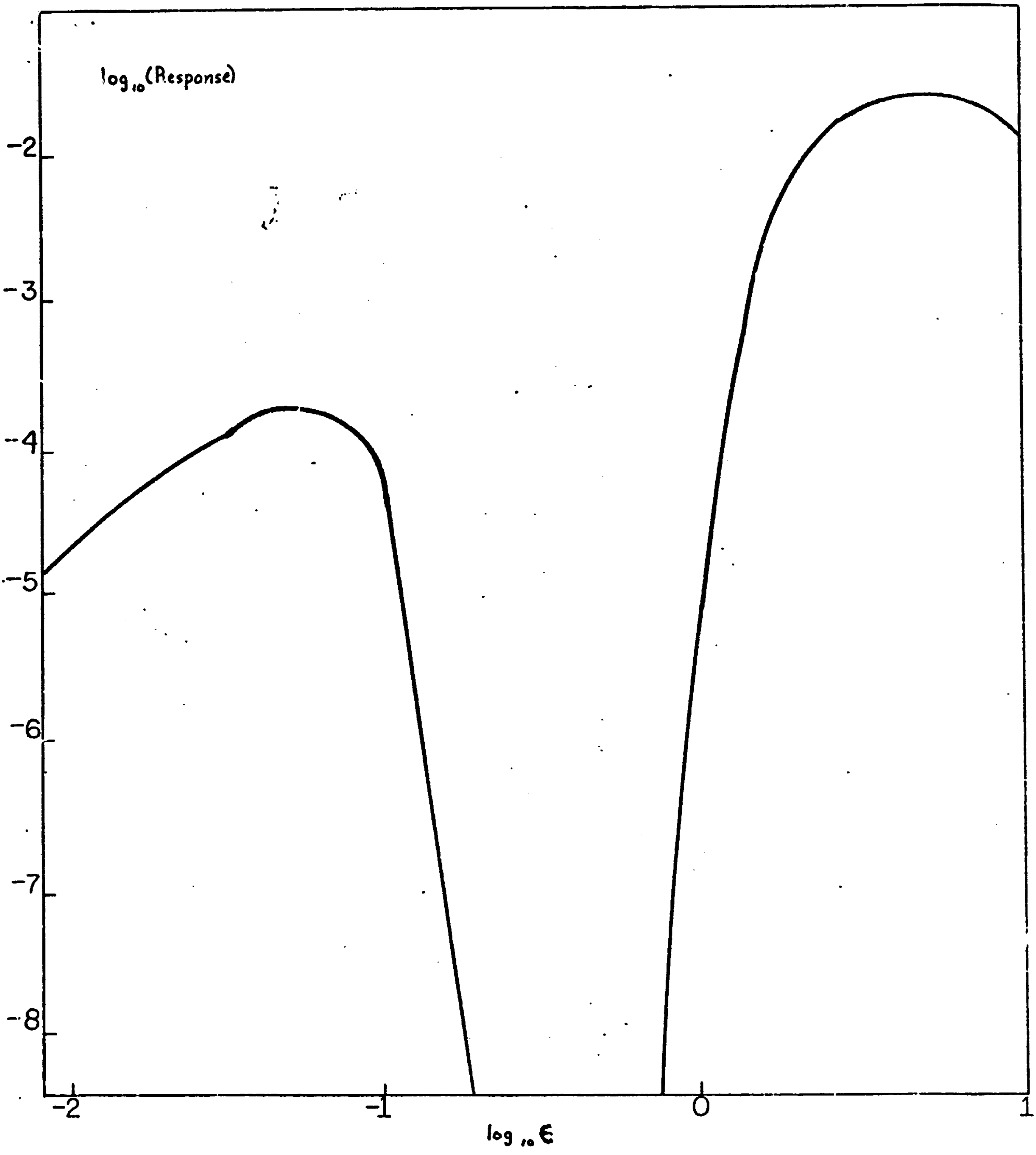

Figure 2. Response as a function of line width for lines of equal central intensity (19 line grid).

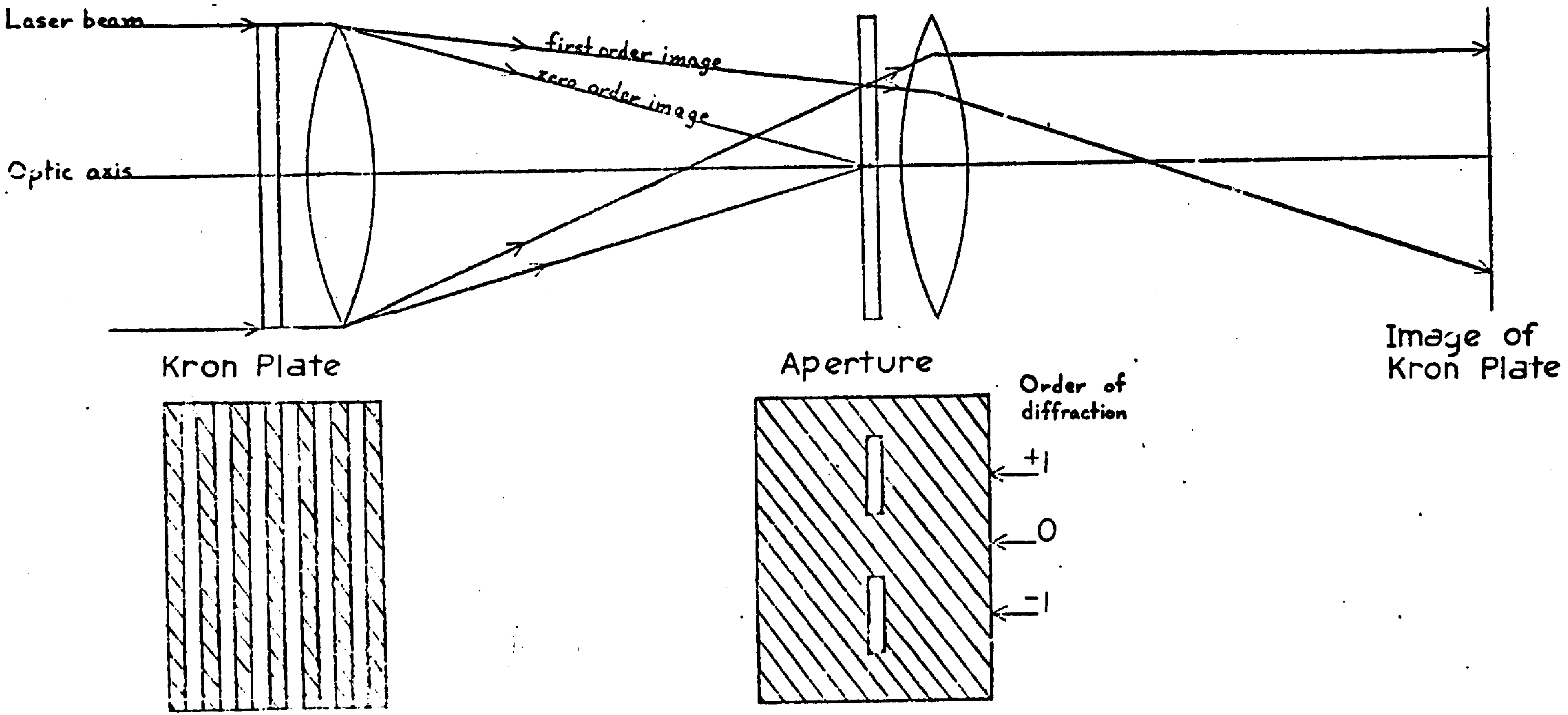

Figure 3. Optical processing of Kron Plate

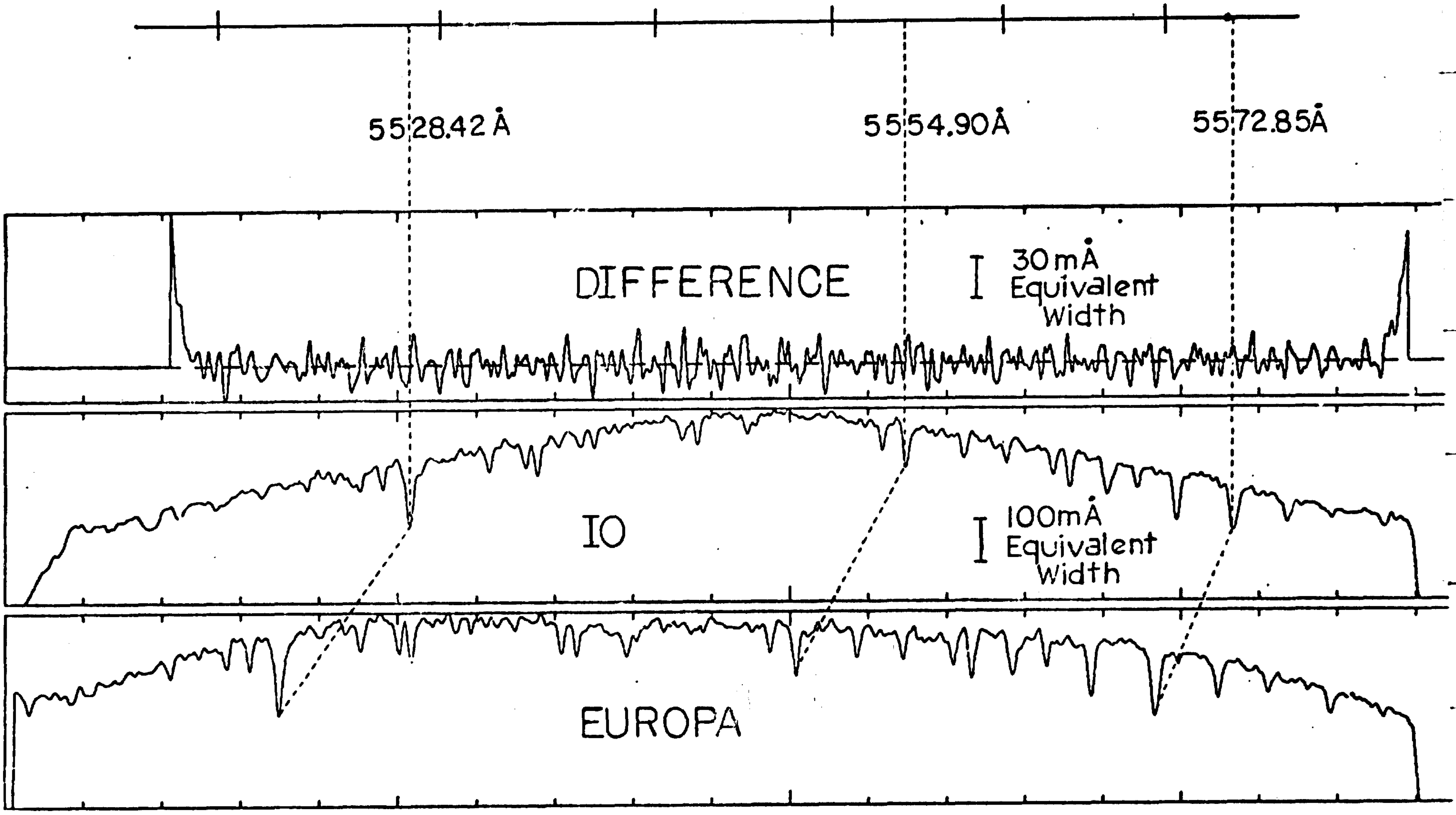

Figure 4. Io and Europa spectra in the same wavelength range and the difference spectrum after processing.

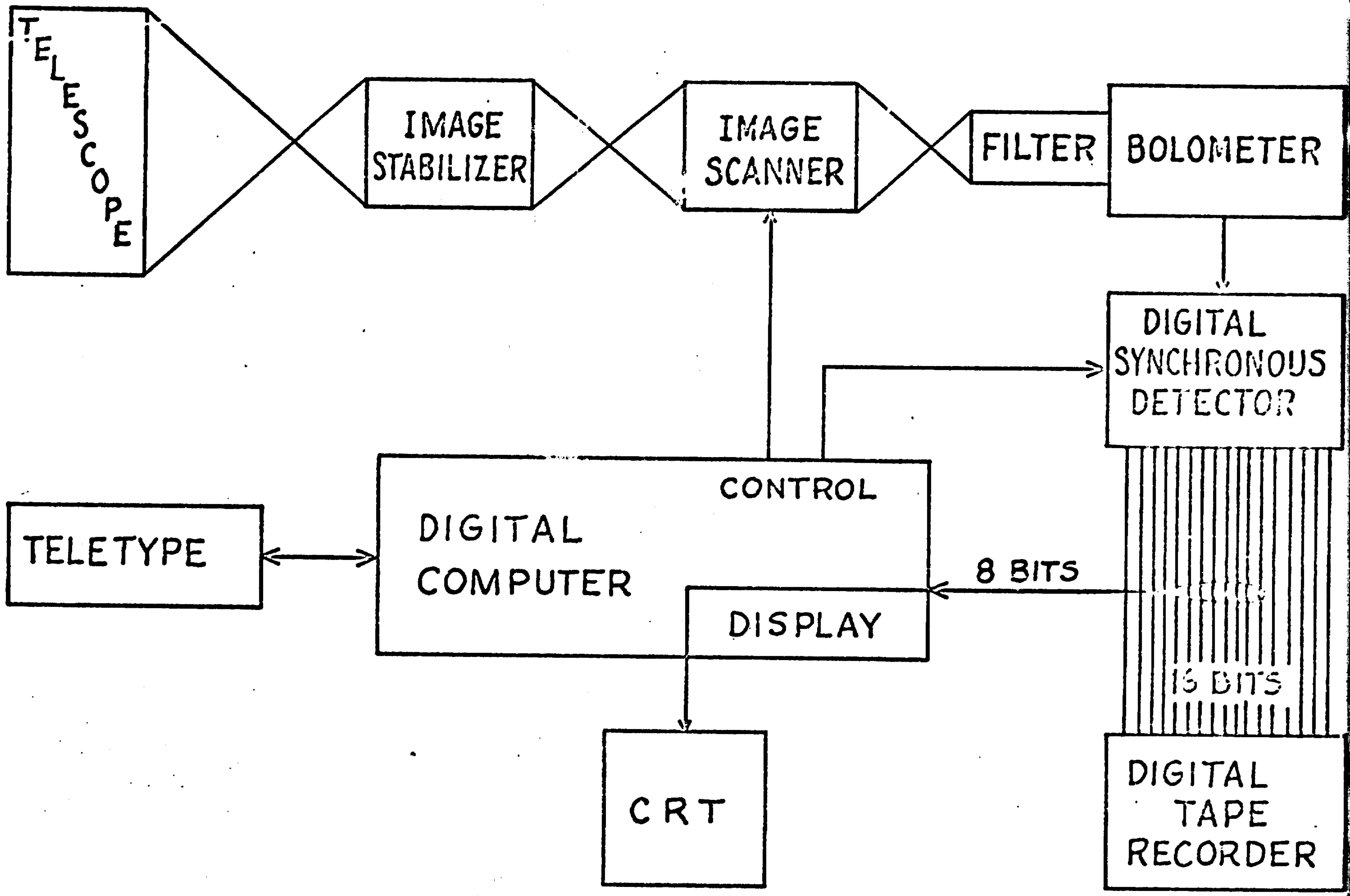

Figure 5. Thermal mapping equipment.

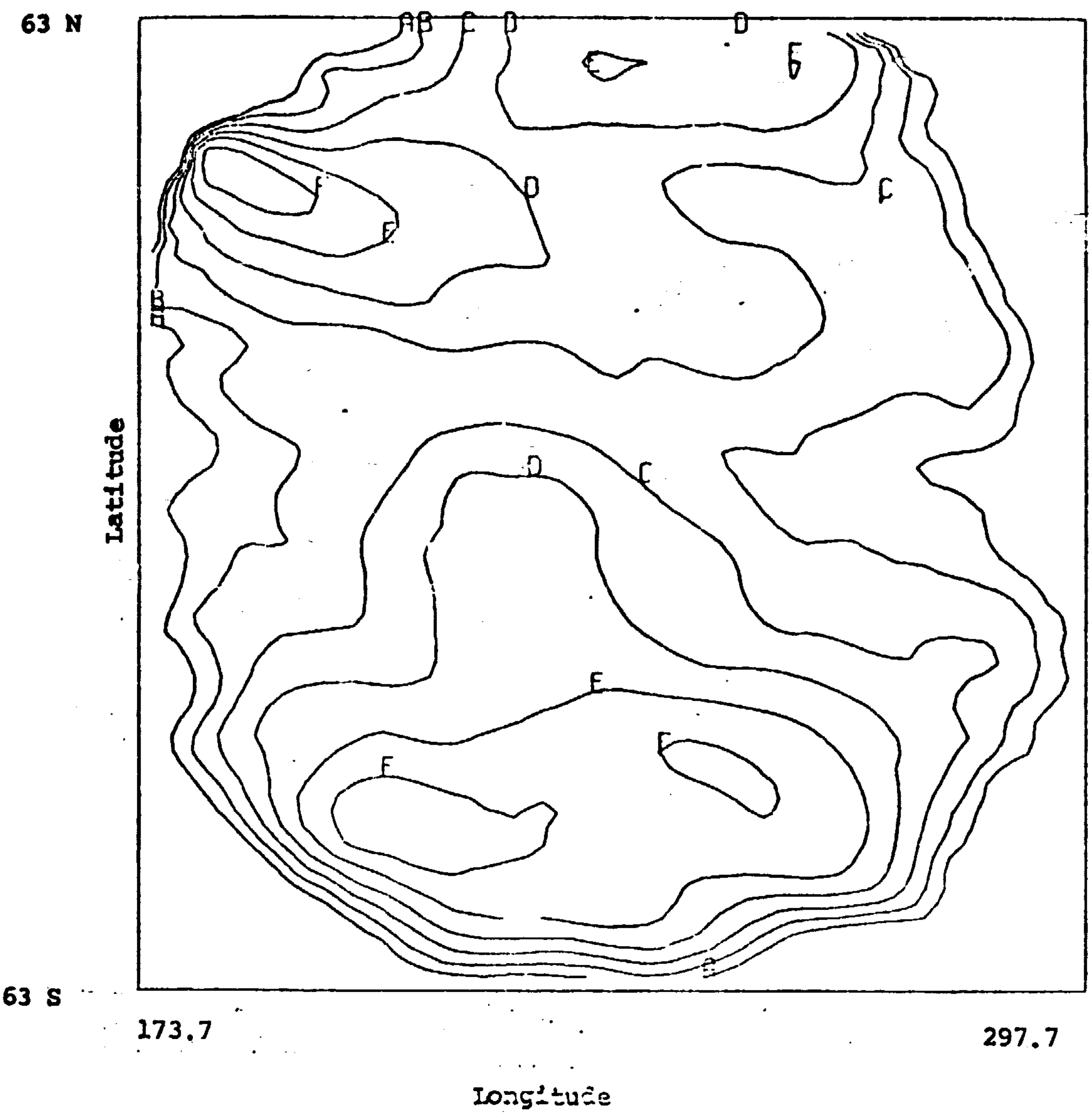

Figure 6. Thermal emission intensities for Venus 12/24-25/73. This is a mercator projection with limb darkening partially removed. Contours are separated by 5% of the central intensity.