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AN INFRARED PHOTOMETRIC AND SPECTROMETRIC SYSTEM IN SAN PEDRO MARTIR

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RESUMEN

Se ha puesto en operación un nuevo fotómetro-espectrógrafo infrarrojo para el telescopio de 2.1-m del Observatorio Astronómico Nacional en San Pedro Mártir, Baja California. El sistema, equipado con detectores de InSb y un bolómetro de Ge:Ga, fue parcialmente diseñado y construido en nuestro Instituto para la obtención de fotometría en el intervalo de longitudes de onda de 1 a 20 μm y espectrometría de baja resolución ($\lambda/\Delta\lambda \simeq 100$) en el intervalo de 2.0 a 3.9 μm. Se describen los componentes del sistema y las pruebas que se realizaron en el telescopio.

ABSTRACT

A new infrared photometer-spectrometer has recently been put into operation on the 2.1-m telescope of the Observatorio Astronómico Nacional in San Pedro Mártir, Baja California. The system, which was partially designed and built in our Institute, allows wide-band photometry in the 1 to 20 μm wavelength range and low resolution ($\lambda/\Delta\lambda \simeq 100$) spectrometry in the 2.0 to 3.9 μm region using InSb photovoltaic and Ge bolometer detectors. The various components of the system are described and tests carried out on the telescope are presented.

Key words: INFRARED – INSTRUMENTS – PHOTOMETRY – SPECTROMETRY

I. INTRODUCTION

It has been recognized that the Observatorio Astronómico Nacional, located in the Sierra of San Pedro Mártir, Baja California, is a good site for infrared observations (Alvarez and Maisterrena 1977; Westphal 1974). For this reason, the new 2.1-m telescope was designed to have good characteristics for IR work. An IR system has therefore been built for this telescope and tested. Short wavelength (1-5 μm) photometry and spectrometry is performed by means of two InSb detectors, while the 5-20 μm range is covered by a Ge bolometer.

An overall description of the system is given in the remainder of this section; section II describes the oscillating secondary mirror; section III gives the characteristics of the available detectors, filters and dewars and a description of the photometer shell. Data acquisition is briefly described in section IV while the results and tests performed on the telescope are discussed in section V.

Figure 1 shows a block diagram of the system. Beam modulation ("chopping") is achieved by means of the oscillating secondary mirror. This mirror, together with the primary, provide a measured f/31 focal ratio. The reference signal for the phase sensitive amplifier (PSA) is provided by the wobbling secondary control box. Infrared and visual radiation are separated using a dichroic mirror at 45° relative to the optical axis of the telescope. Visual light goes straight into an x-y displaceable eyepiece or television camera and the IR beam is reflected to the dewar side window. Data acquisition is performed by a commercial micro-computer which stores information on floppy-disks. Beam switching ("nodding") is performed either through a micro-computer or manually.

II. OSCILLATING SECONDARY MIRROR

In the design of any infrared system, great care should be taken in subtracting background radiation efficiently. This is accomplished by alternatively exposing the detector to the object of interest and to a nearby region of the sky. Subtraction is then performed electronically in the data acquisition circuit.

The most efficient way of alternating the beam on the detector is by the use of a wobbling secondary. Wobbling the entire telescope or the primary mirror is ruled out for obvious reasons on large telescopes and focal plane chopping introduces serious background asymmetries at wavelengths longer than 4 μm.

One of the interchangeable secondary supports of our 2.1-m telescope contains an f/31 oscillating mirror. The mirror is supported by Bendix-type pivots and actuated by a linear motor. The mechanical design is very similar to the one used on the 1.3-m telescope at Kitt Peak National Observatory (Aikens 1975), though some modifications were made to the safety features and materials used. The drawings were kindly provided by R. Joyce of KPNO and the machining was done

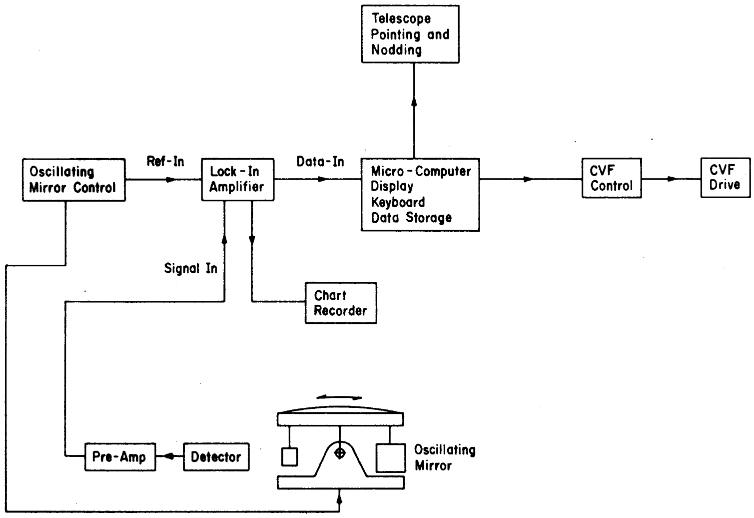

Fig. 1. Block diagram of the IR system.

by Astro-Mechanics Inc. The mirror was polished and aluminized at the Instituto de Astronomía, Universidad Nacional Autónoma de México (IAUNAM) where the electronic system was also designed and built (Iriarte 1982).

Figure 2 shows a block diagram of the electronic system used to control the oscillation of the secondary mirror. This consists of a servo system with feedback provided by the error signal and its first derivative (i.e., {reference square wave – position signal}= error). Velocity feedback is provided by the time derivative of the position signal. The second derivative of the position is used in order to gain stability at extreme positions. An accelerometer is used to eliminate unwanted resonances and a notch-filter eliminates the natural frequency of the mechanical system. A low-pass filter is included to eliminate a high frequency component in the position transducer.

A safety circuit inhibits the operation of the mirror when an adjustable maximum throw is exceeded. A DC integrator grants stability to the base-line of the oscillation.

All feedback gains are controlled independently at the sum-point and the final signal is used to drive a "master-slave" power amplifier system. Full circuit diagrams are available on request.

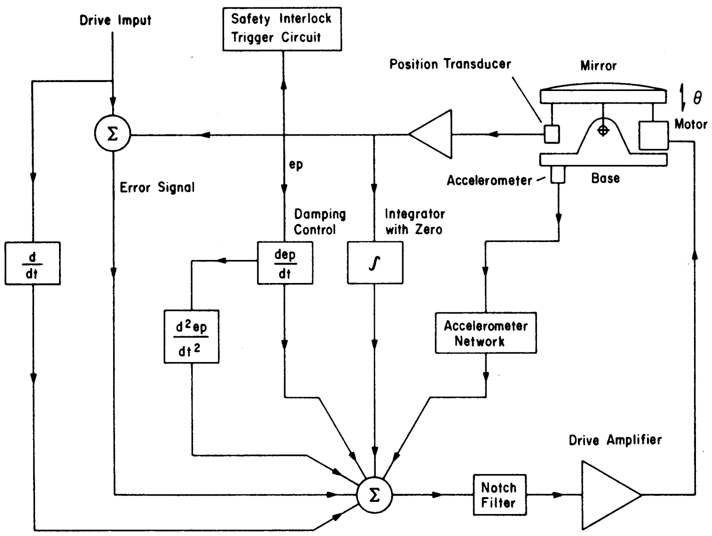

Fig. 2. Block diagram of the wobbling secondary control electronics.

Normally, the chopping is done in declination, but any axis can be chosen by rotating the mechanism. The amplitude, frequency and offset for off-center chopping can be adjusted from the control box. The frequency range, using the internal oscillator, is 6-20 Hz but other frequencies may be selected with an external wave generator. The maximum throw is 4 arcmin with a reasonable wave-form at 6 Hz. Normally a 30 arcsec throw is used and at 10 Hz the rise time is 6 msec.

III. DETECTORS, DEWARS AND PHOTOMETER SHELL

Two cryogenic containers (hereafter called Dw 1 and Dw 2 respectively) containing InSb detectors are available for broad-band *JHKLM* photometry (Dw 1) and for 2.0-3.9 μm spectrometry using a continuously variable filter (CVF) and *JHKL* photometry (Dw 2). Both detectors were acquired from Santa Barbara Research Industries. The detector in Dw 1 has a 0.5 mm diameter and nominal impedance of 2.08×10^9 Ω at 77 K while that in Dw 2 has a 0.25 mm diameter and nominal impedance of 6.0×10^9 Ω at 77 K. Both dewars were manufactured by Infrared Laboratories Inc. (model HD-2) who also provided the pre-amplifiers (model LN-7). These have two feedback resistors which can be switched externally with values of (at 77 K) 2.0×10^8 and 1.25×10^{10} Ω in Dw 1 and 6.5×10^9 and 2.5×10^{10} Ω in Dw 2. The high-valued resistors are used for low background noise conditions (typically with *J*, *H* and *K* filters) and the low-valued resistors are used for high background noise conditions (*L* and *M* filters) in order to avoid saturation.

TABLE 1

CHARACTERISTICS OF FILTERS AND AVAILABLE APERTURES

Dewar 1

Detector: InSb (NEP = 2.8×10^{-15} W Hz$^{-1/2}$)

Filter	λ_0 (μm)	$\Delta\lambda$ (μm)	Aperture (mm)	Aperture (arcsec)
J	1.25	0.32	1.5	4.6
H	1.65	0.28	2.5	7.7
K	2.23	0.35	3.8	11.8
L'	3.8	0.7	4.5	14.0
M	4.7	0.6	...	...

Dewar 2

Detector: InSb (NEP = 1.0×10^{-15} W Hz$^{-1/2}$)

Filter	λ min (μm)	λ max (μm)	$\lambda/\Delta\lambda$	Aperture[a] (mm)	Aperture[a] (arcsec)
CVF	2.0	3.9	100	2.0	6.2
J,H,K,L					

Dewar 3

Detector: Ge Bolometer (NEP = 6.2×10^{-15} W Hz$^{-1/2}$)

Filter	λ_0 (μm)	$\Delta\lambda$ (μm)	Aperture (mm)	Aperture (arcsec)
M	4.84	0.9	1.5	4.6
N	10.39	5.34	2.0	6.2
Q	19.6	8.6	3.0	9.3
N_1	8.0	0.6	4.0	12.4
N_2	8.60	0.91	...	...
N_3	10.92	0.58	...	...
N_4	11.31	1.95	...	...
Q_1	18.00	3.63	...	...

a. Fixed aperture.

For the 5-20 μm interval we have used a Ge bolometer operated at 1.2 K (dewar 3). The detector, preamplifier and dewar were provided by Infrared Laboratories Inc. The NEP for this detector is 6.2×10^{-15} W Hz$^{-1/2}$. The installed filters allow broad-band photometry in the standard *M, N* and *Q* bands, while narrow-band filters in the 8-13 μm interval allow a closer examination of the spectral distribution of objects emitting in the 10 μm atmospheric window. Filter characteristics and available apertures are shown in Table 1.

The photometer shell consists of an aluminum box designed to provide a rigid support for the detectors. Included in the photometer shell are also the beam splitter (at 45° with respect to the telescope optical axis) and an eyepiece (see below).

Dealing with detectors as small as 0.25×0.25 mm^2, particular care has to be placed on the need for alignment of the various dewars. Each dewar is mounted on a base that has two degrees of freedom for rotation about two axes. The base itself can be lowered or raised relative to the photometer wall. These bases can be mounted and dismounted from the photometer shell without losing alignment and the beam splitter can also be adjusted with respect to the optical axis. Combining the collimation of the secondary mirror, the position of the beam splitter and the alignment of the detectors, a combination of maximum signal and minimum background and offset can be easily obtained.

Beam splitting is provided by a dichroic element which reflects approximately 60% at 1.0 μm and 90% or more at 2.0 μm and longer wavelengths. Visible light is transmitted to an x-y displaceable eyepiece where a $5' \times 5'$ field is available for offsetting. A television camera will replace the eyepiece in the future.

IV. DATA ACQUISITON

The AC signal from the detector is phase-locked and amplified using an ITHACO, DYNATRAC-3 PSA, synchronized by the reference signal from the secondary control box. The DC output from the PSA is digitized and fed into an Apple II micro-computer which controls the integration. The data, with all relevant parameters of the observation (filter, aperture, gain and time) are stored on floppy-disks. Reduction and error determinations are done on-line but final reduction is performed separately, night by night, at the end of the run. Spectrometry is performed in a similar manner but with the micro-computer also providing the pulses for moving the CVF stepping motor. Two modes are available for CVF observations: the "point by point photometry" which consists in performing photometry in the standard way at each resolution step of the filter and the "rapid scanning" spectrometry which consists of quick integrations (typically a fraction of a second) in each resolution step until the whole wavelength range is completed in each beam and adding successive scans until the required signal to noise ratio is obtained.

The Apple micro-computer performs the beam switching of the telescope, allowing also differential pointing with 10 arcsec accuracy over a 5×5 degree field. The computer also allows the mapping of small areas of the sky. At 2 μm a 1.5×1.5 arcmin map is performed in approximately 20 min detecting objects brighter than $m_K \simeq 11$ in a 9 arcsec diameter aperture. Spatial resolution ranges from 6 to 12 arcsec.

V. TESTS AND RESULTS

The system was successfully tested during three observing runs in 1982 and it is currently providing astronomical data (Tapia *et al.* 1984).

The tests included: noise measurements of the detectors, effective f/ratio of the optical system, beam profiles, emissivity of the various components and of the whole system, stability and detection limits. All tests were satisfactory; the quality of the system is revealed in the final figures for detection limits. These were ob-

TABLE 2

PHOTOMETRY AND SPECTROSCOPY DETECTION LIMITS[a]

Filter	Diaphragm (arcsec)	Sky Noise [b]	Measurements of Faint Stars
J	11.8	17.0	16.4
H	11.8	16.8	16.2
K	11.8	16.4	15.8
L	7.7	. . .	12.1
M	7.7	. . .	9.7
N	7.7	. . .	6.3
Q	7.7	. . .	2.5
CVF (2.0-2.5 μm)	6.2	. . .	7.1
CVF (2.9-3.9 μm)	6.2	. . .	3.4

a. In magnitudes for 3σ, 1 hour.
b. Derived by measuring an object-free field and taking the 3σ value as a limit.

tained from the signal to noise ratios of faint objects and extrapolated to 3σ for one hour integration time and from combined detector noise and sky brightness measurements. Significant improvements of the InSb detectors are found when liquid nitrogen is pumped and the detectors are exposed to a bright light through the *J* filter for about 60 s ("*J* flashing"). This is now a standard procedure. Table 2 shows the values obtained for the various wavelengths and detectors.

The effective focal ratio of the system has been measured and turns out to be f/31.

Beam profiles are measured periodically and after each realignment. In Dw 1 the beam profile shows a "square" profile with 90% of the aperture being flat. The profiles are equal in right ascension and declination, indicating a circular beam.

Since the InSb detectors are d.c. coupled, we have been able to obtain an indication of the background conditions of the entire system by measuring the d.c., level at the pre-amplifier of the detector in Dw 1. The results are as follows: the voltage obtained from placing a black surface at room temperature in front of the detector is defined as 100% emissivity; the signal obtained by pointing the detector to the sky (20° from zenith) is only 6% of the black body value. The photometer shell contributes with 13% (a relatively high value due mainly to the beam splitter, and which will be improved shortly). The telescope contributes only 7%. All measurements were made through the L' filter with 11.8 arcsec aperture.

Background asymmetries are very small, if any, and can be minimized with adequate alignment. At 5 μm, and with a beam separation of 1 arcmin, no offset can be detected at 3 mV sensitivity in the lock-in amplifier.

Several people collaborated during the various stages of this project. The optical work was done by R. Noble and J. Sasián, the mechanical work was done by A. Córdova and the secondary support was designed by J. de la Herrán. We are indebted to L. Carrasco and J. Hackwell for their very helpful advice and especially to B. Jones for invaluable help during the final stages of this project. The use of some facilities of CASS-UCSD is gratefully acknowledged. This is Contribution No. 115 of Instituto de Astronomía, UNAM.

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