THE STELLAR PHOTOMETERS OF HAROLD L. JOHNSON, AND THE FIRST YEARS OF THE MEXICAN NATIONAL ASTRONOMICAL OBSERVATORY AT SAN PEDRO MÁRTIR

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Abstract: The first observations made at the Mexican National Astronomical Observatory at San Pedro Mártir were stellar photometry carried out during February 1971. The first photometric instruments were those of Dr Harold L. Johnson or ones obtained for the National Autonomous University of Mexico by Professor Guillermo Haro, which were constructed according to designs of Dr Johnson. Over the next 10 to 15 years, most of the scientific output of this Observatory was produced using the 5-color and 13-color photometers. These photometers were phased out at the Observatory in the mid-1980s as more modern instruments arrived, but over the years they had been used by at least 16 principal observers to produce more than 56 publications in major international journals. Since the year 2000, eight pieces of equipment associated with these 'Johnson photometers' have been recovered and refurbished for an unofficial museum at the Institute of Astronomy in Ensenada, Baja California. The display comprises complete photometers, a partial single-channel and a two-channel photometer, an infrared photometer, cold boxes, a DC amplifier, an offset guider, and one instrument which has not yet been fully identified.

Keywords: Stellar photometry, photoelectric photometry, Harold L. Johnson, San Pedro Mártir, Mexican National Observatory

1 INTRODUCTION

1.1 Dr Harold L. Johnson and the New National Astronomical Observatory of Mexico

During the last years of the 1960s the National Autonomous University of Mexico, through its Institute of Astronomy, established a new site for the National Astronomical Observatory. The Observatory originally was founded in Mexico City in 1878,[1] and in 1951 moved to a new site in the town of Tonantzintla, near Puebla. But after a decade, this site also began to suffer from light pollution. For this reason, a satellite overview of the Mexican territory was carried out to identify the best site for a new modern astronomical observatory. Since the American astronomer Harold L. Johnson (1921–1980; de Vaucouleurs, 1995) already had access to and was familiar with this new satellite technology, his collaboration in this undertaking was very valuable to Mexican astronomers.[2] With his help, and after various exploratory visits carried out by members of the Institute of Astronomy in the Sierra de San Pedro Mártir in Baja California, authorities from the University and the Institute of Astronomy decided to erect a new National Observatory at this remote location in the Mexican Republic. The site of the San Pedro Mártir Observatory was at latitude +31° 02′ 39″ and longitude 115° 27′ 49″ west of Greenwich, and at an altitude of about 2850 m. For Mexican localities mentioned in the text see Figure 1.

Figure 1: Mexican localities mentioned in the text (map: Wayne Orchiston).

Figure 2 (top left): Three of the people who had considerable impact upon the development of the new National Observatory (left to right): engineer José de la Herran (Note 3), Dr Eugenio E. Mendoza and Dr Harold Johnson. This photograph was taken at the the Observatory during the first installation of the 0.84-m telescope, which can be seen in the background (courtesy: Oswaldo Harris, 1970).

Figure 3 (above): The 1.5-m telescope being installed at the Observatory at San Pedro Mártir (courtesy: Oswaldo Harris, 1970).

Figure 4 (left): This photograph shows the original appearance of the dome and 'green shack' for the 1.5-m telescope. The shack was an ex-military mobile radio shed used at the 1.5-m as a machine and tool shop, and also for warming up observers, eating sandwiches and quesadillas, and drinking warm beverages during the coldest nights (courtesy: M.A. Moreno-Corral, 1971).

During the summer of 1970 a 1.5-m (60-inch) disassembled reflecting telescope with an English-type equatorial mount and a metallic primary mirror arrived at the San Pedro Mártir Observatory (Figures 2–4). This instrument had originally been at the Catalina Observatory of the University of Arizona in the mountains 29 km to the northeast of Tucson. Under the supervision of Johnson, the latitude angle of the telescope mounting was modified, and the telescope was installed with the help of various Mexican students doing their undergraduate physics theses under the tutelage of Harold Johnson. Two students who stood out, not only during the erecting of the 1.5-m telescope, but also later with the 0.84-m telescope (with a primary mirror of Zerodur), were Roberto Ortega Martínez and César Sepulveda Núñez. The 1.5-m was the first telescope to opérate regularly and reliably at San Pedro Mártir Observatory and produce publishable scientific results, as is documented later in this paper. The original primary mirror of this telescope was spun aluminium (it was a 'light bucket') producing blobby images of about 10 arc-seconds, but this did not greatly concern Dr Johnson, who was mainly interested in collecting photons for photometry of fairly bright stars using appropriately large diaphragms for each photometer.

On 2 April 1980, Harold Johnson passed away in Mexico City from a heart attack (Mendoza V., 1980; De Vaucouleurs, 1995), and his remains were cremated and taken away by family members. Professor Johnson left behind a considerable legacy for Mexican astronomy, not just in personnel whom he had trained and advised but also in photometers and photometric equipment. These photometric instruments played a key role in the development, success and productivity of our National Observatory over a period of about 15 years.

1.2 The Johnson Photometric Instruments

With the passing of Professor Johnson a considerable amount of his (and the University's) photometric equipment remained in Baja California, some in Ensenada, but especially at the Observatory: complete photometers, photometer heads, offset guiders, transition modules, cold boxes, DC amplifiers, and so forth. Some continued to receive considerable use, such as the 5-color photometer (5C; *UBVRI*) and the 13-color photometers (13C; 8C + 6RC), until their eventual replacement by more modern instruments, such as the Danish 6-channel photometer (*uvby-Hβ*; Nissen, 1984) and a new infrared instrument (Roth et al., 1984), during the 1980s and 1990s. The arrival of this Danish photometer[4] towards the end of 1983 effectively marked the end of an era at the San Pedro Mártir Observatory, the era of the Johnson stellar optical photometers (although some astronomers, such as Dr Walter Fitch from the University of Arizona, preferred to bring their own specialized photometers).

Some components of the old Johnson decommissioned photometers were stored randomly throughout the Observatory, or at the University's Institute of Astronomy in Ensenada, and some (such as the DC amplifiers 1 and 4) were highly cannibalized for their electronic and mechanical parts! During 1999–2000, two of the present co-authors (WJS and AC) decided to investigate which of the original Johnson photometers and accessories could be recovered and refurbished (see Schuster and Cordova, 2016).

As of December 2022, there are eight items displayed in the three glass cases at an unofficial 'Harold L. Johnson Museum' in Ensenada, which Johnson had a considerable role in the design and construction of, although their history and travel to the San Pedro Mártir Observatory varied greatly. These eight instruments are:

(1) The 5C photometer;
(2) The 8C photometer;
(3) The *JHK* (*IJK*) infrared instrument;
(4) The double photometer (although now equipped with RCA 7102 cold boxes);
(5) The offset guider/photometer mount;
(6) The *UBV* cold box (incomplete);
(7) An unidentified photometer (probably infrared and incomplete); and
(8) The No. 6 DC amplifier. (The 6RC photometer is not included since two of its main parts, the photometer head+standard lamp and the transition module, were used to construct a 'new' photometer for the Observatory at Tonantzintla, near Puebla).

This is their story.

2 THE 5-COLOR (5C, *UBVRI*) PHOTOMETER

The recovery and renovation of this 5C photometer was the spark that ignited this entire project to redeem as much as possible of the photometric equipment that had been left at the San Pedro Mártir Observatory by Harold L. Johnson. The 5C was one of the first astronomical instruments used at the Observatory.

By November 1970 the 1.5-m telescope was ready for operation, and during the second half of 1970 the 5C photometer arrived at San Pedro Mártir. The first period of observations began on 20 February 1971, when Salvador González Bedolla and Marco Arturo Moreno Corral initiated a program of *UBVRI* photometry of Am stars. After 3 months of observing Dr Eugenio Mendoza Villarreal was able to publish various papers in the *Revista Mexicana de Astronomía y Astrofísica*, as well as provide data for the undergraduate thesis in physics presented successfully to the University by González Bedolla. This 5C photometer received considerable observing time during the 1970s and 1980s, sometimes consuming 100% of the observing time on the 1.5-m or the 0.84-m telescopes! So, its importance for the history and documentation for the first years of the San Pedro Mártir Observatory is obvious. With the introduction of other instruments, the 5C was finally decommissioned during the 1980s, broken down into its different modules, and its components stored at different locations around the Observatory and in Ensenada. One of us (WJS) kept the transition module in his office for safe keeping due to its smaller size and importance and usefulness for teaching and documentation, since it contained both the filter and diaphragm wheels of the 5C photometer.

Around 1999–2000 we heard that other components of the 5C photometer were probably located at the depository for old and retired Observatory equipment, a building with a loading dock, 3 sides, and a roof, on a side road part way between the Observatory's village and the telescope zone. Indeed, the 5C's photometer head and cold box were found there! Soon after, one of the Observatory's electronic technicians (José Luis Ochoa) found the standard lamp module in one of the cabinets at the 0.84-m telescope, and one of the optical technicians (Dr Esteban Luna) found one of the original military-surplus eyepieces that Dr Johnson had used on many of his home-grown photometers, including the 5C, in a storeroom at the Institute of Astronomy in Ensenada. Except for the five (*UBVRI*) filters, which have not yet been located), the 5C photometer is now complete!

The reconditioning of this 5C photometer took several months of part-time work (by WJS) since some elements, such as the mechanical screws, had suffered oxidization, and had to be cleaned or replaced. Also, external surfaces had been contaminated by residues from black, gray or masking tapes used to affix notes or observing lists to this photometer; some residues had become nearly permanent due to aging and required considerable patience and work to remove! The photometer head was cleaned and painted flat-black to match as much as possible its original appearance. The cold box and standard-lamp module were also cleaned, as well as the transition module and the mounting plate. The internal pulley system for inserting or retracting the observing mirror, for redirecting the star light to the eyepiece or not, was tested and lightly and carefully cleaned and lubricated. The cold box was not opened for review; it contains two sections: one with an RCA 1P21 photomultiplier (PMT) for *UBV* photometry, and the other an RCA 7102 for *RI.* The control bar and transfer mirrors for switching the incoming stellar light between these two sections were tested and lightly cleaned. A description of the photometer is given in Johnson and Mitchell (1962).

The 5C photometer has 8 diaphragms, from 0.35-mm to 1-cm, drilled in a metallic, manually operated diaphragm wheel, as well as 12 positions in a filter wheel, also manually operated, adequate for the five *UBVRI* filters plus a neutral filter for the standard-lamp observations, if required.[5] As mentioned, this 5C photometer includes a cold box with two PMTs: an RCA 1P21 with a useable spectral range of ~3000 Å to ~6500 Å (i.e. from the atmospheric cutoff to the temperature-sensitive red tail of the PMT, and an RCA 7102 with a useable spectral range from about 5000 Å to ~11,800 Å (1.18μ). The cold box, thermally insulated with Santocel (silicon dioxide powder), was refrigerated with crushed dry ice at the beginning of each night and could keep the two PMTs at a temperature of –78.5°C throughout a typical observing night.

When observing a star, the electron current coming off the PMT's anode was amplified by a DC amplifier (as drawn in Johnson, 1962: Figure 5). At San Pedro Mártir Observatory all of the relatively-bright stellar photometry, V ≲ 13 magnitude (with the 5C, 8C, and 6RC photometers), was carried out with DC techniques. The gain steps of the DC amplifiers (Nos. 1 and 4) were calibrated fairly regularly (approximately every 3–6 months) using the highly stable, very accurate calibrating unit discussed and constructed for the undergraduate physics thesis of Roberto Ortega Martínez (1971), with Harold L. Johnson as advisor.

This 5C photometer is shown in Figures 5 and 6, as now displayed in the Harold L. Johnson Museum at the Institute of Astronomy in Ensenada. Figure 5 shows a frontal view of this 5C photometer, while Figure 6 shows the transition module with the filter and diaphragm wheels as well as the control bar for changing from the 1P21 PMT (*UBV*) to the RCA 7102 (*RI*). To the far right, with the label "source", can just be seen the lever for engaging, or not, the standard lamp module.

Figure 5 (left): The 5C photometer as now displayed in its glass case at the Harold L. Johnson Museum at the Institute of Astronomy, in Ensenada. A photograph of Dr Johnson can be seen in the upper left corner (photograph: W.J. Schuster, 2022).

Figure 6 (above): A close-up of the transition module of the 5C photometer. The diaphragm and filter wheels can be seen as well as the control bar for changing from the 1P21 PMT (*UBV*) to the RCA 7102 (*RI*) (photograph: W.J. Schuster, 2022).

3 THE 13-COLOR PHOTOMETERS (8C AND 6RC)

3.1 Their Arrival in Baja California, Mexico

The 13C photometers arrived in Ensenada during the second half of August 1973, slightly more than one month after the arrival of the principal observer at the San Pedro Mártir Observatory (WJS, who arrived on 2 July 1973). The 13C photometers came to Ensenada from Tucson, with Professor Johnson, and were unpacked in the foyer of the Centro de Investigaciones Cientificas y Educación Superior de Ensenada by WJS with the help of technicians and students (e.g. August Johnson, who was Harold's son). The photometers became operational at the Observatory during the final months of 1973, and continued to be in use until at least 1984. Their first use was to provide 13C observations of sub-dwarf stars for the doctoral dissertation of William J. Schuster (1976a). The studies of Johnson et al. (1968) and of Johnson and Mitchell (1968) had suggested the usefulness of these multi-band photometric systems for understanding the evolutionary status and line blanketing of these subdwarf stars. A description of the 8C and 6RC photometry bands and photometers is given in Johnson and Mitchell (1975).

3.2 The 8C Photometer

The 8C photometer is part of the 13-color (13C) photometric system of Johnson and Mitchell (1975), Mitchell and Johnson (1969), and Johnson et al. (1967), which is a "... medium-narrow-band photometric system ..." that is "... homogeneous to an unusual degree over the entire sky ..." and is "... free from significant systematic errors either in right ascension or declination." It should therefore be useful for the comparison, standardization, and calibration of other photometric systems. Johnson and Mitchell (1975: Table 3) also provided an absolute calibration for the 13 bands since this work originally was financed by NASA to be combined with satellite ultraviolet (1000 to 3000 Å) measurements and the Johnson infrared broad bands (*JHKLMNOPQ*). These observations would provide Spectral Energy Distributions for stars and other astronomical objects over the range 1000 Å to 20 µm, as well as for studies of interstellar reddening and extinction, stellar classifications, bolometric magnitudes, effective temperatures, and so forth.

The 8C photometry is especially useful for stellar classifications, and for color–magnitude and color–color diagrams, since for example, the colors 45-63, 58-99, or 72-80 measure well the slope of the Paschen continuum, colors like 35-45 and 33-52 the Balmer jump, and the 37 band is located where the Balmer lines converge. The 37-45 color is especially outstanding for measuring stellar metallicity differences (via differences in line blanketing) for FGK-type stars with a range of about 0.45 magnitude between extreme Population I and Population II stars for the δ(37-45) excess measured with respect to the Hyades cluster (Schuster, 1979b), compared to a range of ~0.30 magnitude for the δ(*U*-*B*) excess of the Johnson-Morgan *UBV* system, and ~0.20 magnitude for the δ_1 excess of the Strömgren–Crawford system.

Figure 7: The 8C photometer as seen in its display case in Ensenada. The mounting plate, photometer head, transition module, and cold box can be discerned as well as part of the standard-lamp module at the back. The eyepiece at the front of the photometer head is a simulation plastic replacement, since the original has been lost. The cork stopper at the front of the cold box can be removed to fill the cold box with crushed dry ice for refrigerating the PMT (1P21) (photograph: W.J. Schuster, 2022).

The 8C photometer shown in the Figure 7 photograph is as it is now displayed in the Harold L. Johnson Museum in Ensenada. The cold boxes of the 6RC photometer are shown as part of the double photometer, discussed below and displayed in Figure 9. A backup cold box was provided for the 6RC photometer since the RCA 7102 PMT was somewhat delicate and temperamental in its operation.

3.3 The 6RC Photometer

Prior to 1999 the Observatory Manager had suggested to the technician David Hiriart (now with a PhD) that he undertake a technical project to construct a 'new' photoelectric photometer for the Observatory at Tonantzintla. For this project, components of the 13-color 6RC photometer, such as the photometer head and transition module, were expropriated. For this reason the complete 6RC photometer could not be included in the Harold L. Johnson Museum in Ensenada (only its cold box and backup cold box), but parts of it are included in the 'PHOTOMETER' of the 1-m telescope at Tonantzintla, with an RCA 7102 PMT, 2 narrow-band filters, and 6RC filters (58, 72, 80, 86, 99, and 110) from one of the new 13C filter sets purchased by the University in 1980. The 6RC photometry extended the 13C system to approximately 1.1 µm (the 110 filter), and measures the Paschen jump with colors such as 80-86 or 72-99, and the Brackett continuum with 99-110. This Tonantzintla '6RC' photometer has pulse-counting electronics, rather than DC, and nowa-days is mainly mounted on the 1-m telescope for public viewing, and for student and family groups, for example.

Prior to their use at the Observatory at San Pedro Martir the 13C photometers were used mostly with the 21-inch photometric telescope at the Catalina observing station of the University of Arizona's Lunar and Planetary Laboratory for Johnson and Mitchell's (1975) northern observations of bright stars, and with the 16-inch telescope at Cerro Tololo Inter-American Observatory in Chile for their southern 13C observations.[6]

4 THE PHOTOELECTRIC PHOTOMETERS OBTAINED BY DR GUILLERMO HARO

Three of the photometric instruments included in the Harold L. Johnson Museum in Ensenada were obtained for the Institute of Astronomy by Professor Guillermo Haro with help from Professor Johnson. This process took place during the years 1950–1961, and also included the acquisition of the 1-m Tonantzintla telescope and the training of personnel such as Braulio Iriarte in astronomical photoelectric techniques. This period has been excellently documented by Cristina E. Siqueiros V. in her Master's Thesis (Siqueiros, 2021). Her documentation was in-depth since Cristina was granted permission to use the 'Archivo Guillermo Haro' (Guillermo Haro Archives), managed by the Poniatowska Family, which contains a large collection of letters to and from Professor Haro mainly with astronomers such as H.L. Johnson, W.A. Hiltner, B. Iriarte, E.E. Mendoza, W.W. Morgan, G. Münch, H. Shapley, and H. Zwicky, plus letters between H.L. Johnson and W.L. Richards, between B. Iriarte and E.E. Mendoza, and so forth.

In 1950 Guillermo Haro became Director of both the National Astronomical Observatory of Tacubaya (in Mexico City) and the National Astrophysical Observatory at Tonantzintla, and he developed a keen interest to use the new technique of photoelectric photometry in Mexico (Siqueiros 2021). For the next 11 years H.L. Johnson and B. Iriarte played key roles in this ambitious and complicated undertaking. By 1961 the single-channel and two-channel photometers had reached the Observatory at Tonantzintla (Johnson, 1962), having passed from the workshops of W.L. Richards of Austin, Texas, through the McDonald Observatory for testing by Johnson and Iriarte (Siqueiros, 2021), and then on to Tonantzintla. These two early photometric systems have provided three items for the Harold L. Johnson Museum:

(1) the photometer head offset guider (discussed in Section 4.1 below);
(2) the double photometer (the two-channel device mentioned above, and documented below in Section 4.2); and
(3) the *UBV* cold box for the 1P21 photomultiplier tube (discussed in Section 4.3).

This equipment was the property of the University and obtained by Professor Haro with funds from the Rockefeller Foundation and the Universidad Nacional Autónoma de México (Siqueiros, 2021), and was later moved to the Observatory at San Pedro Mártir.

The designs for these two photometers were by Dr H.L. Johnson, who provided them to Dr Aden Meinel, the Director of Kitt Peak National Astronomical Observatory in Arizona. Meinel arranged for two sets of photometers to be constructed, one for the Mexicans and the other for Australian astronomers, as requested by Dr Bart Bok, the Director of Mount Stromlo Observatory (*ibid.*).

All of these photometers can rightly be called Johnson photometers since the designs were his. In fact, eight copies of the blueprints were obtained: one for the Mexican Observatory, six copies so that Johnson and Iriarte could obtain construction-cost quotations from several workshops, and an eighth copy so that Johnson and Iriarte could keep an eye on the construction of these two photometers (*ibid.*). Since at the time both Iriarte and Johnson were at the Department of Astronomy, University of Texas, Austin, it was quite convenient that the final contract was given to the W.L. Richards Company in Austin, Texas. The two photographs listed as Figures 8 and 10 in Johnson's 1962 paper published in *Astronomical Techniques* were provided by this company. The finished photometers were sent to McDonald Observatory, where they were tested by Johnson and Iriarte.

Braulio Iriarte and the photometers arrived at Tonantzintla during the first months of 1961, and the final tests were made there by Iriarte alone, at the suggestion of Johnson to Haro. The funding for the equipment and the American visit came from the University in Mexico City and from the Rockefeller Foundation as part of its contribution to obtain the 1-m telescope and its auxiliary instruments. Professor Haro invited Professor Johnson to participate in these final on-site tests of this photometric equipment at Tonantzintla, but Johnson refused, insisting that Iriarte was entirely capable having been trained at Lowell, Yerkes, and McDonald Observatories by him and by Dr W.A. Hiltner (Iriarte et al. 1965; Siqueiros, 2021).

4.1 The Photometer Head -- The Offset Guider

The photometer head (offset guider) was the last instrument to be recovered for the H.L. Johnson collection, and was found by one of the authors (MAMC) in 2016 in its own special wooden storage box in one corner of the old upstairs dark room at the Institute of Astronomy in Ensenada. We had searched extensively for this important component over several years and were almost convinced that it had been appropriated or else cannibalized for its component parts. Instead, it was found nearly complete, and only a couple of the smaller pieces that hold the horizontal micrometer had to be reconstructed by another author (AC). The horizontal micrometer is the original, recovered by the mechanical technician Eduardo López, but the vertical micrometer is a substitute component.

This instrument was part of the equipment obtained by Dr Haro during his campaign over the years 1950–1961 to provide a telescope, photometers, and trained observers to bring photoelectric photometry to Mexico. This also was part of the scientific package that Braulio Iriarte installed and tested on the 1-m telescope at Tonantzintla in the first months of 1961. A technical drawing of this 'Offset Device' is given in Johnson (1962: Figure 6), and the finished product, as constructed by the W.L. Richards Co., is presented in Johnson (1962: Figures 8 and 10) and is shown here in Figure 8. This device served as the photometer-head and offset-guider for both the single-channel and the two-channel photometers.

As offset device/guider this apparatus allowed the observer to obtain photoelectric photometry of a very faint star, which may not have been visible to the observer, while using the micrometers plus the movable eyepiece to guide the telescope manually using a much brighter guide star during the exposure. The telescope scale in the focal plane plus a previous photograph of the region allowed the positioning, via the micrometers, of the faint star in the photometer's diaphragm while the brighter guide star was centered in the movable eyepiece for guiding.

4.2 The Two-channel Photometer

The idea for this two-channel photometer was developed by Johnson while at the Lowell Observatory during the period 1956–1958, as documented in the Sky & Telescope article (Johnson 1958) and in *The Lowell Observer* by Lockwood (2008). This instrument was designed for observing very faint stars by using one channel for the star and simultaneously the other channel for an adjacent sky region, im-

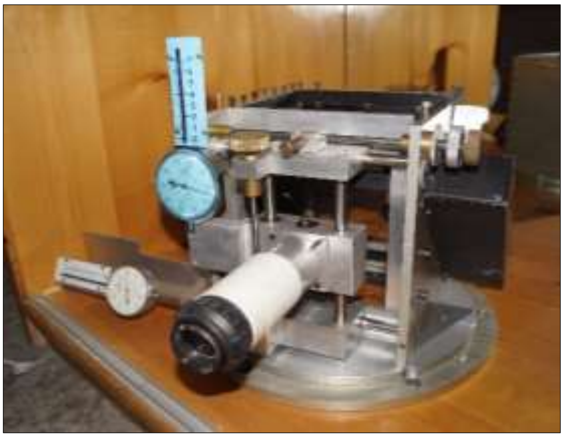

Figure 8: The photometer head/offset device as displayed in the Harold L. Johnson Museum in Ensenada. The horizontal micrometer is one of the original instruments, but since the original vertical micrometer has not been located, another micrometer (loaned by Dr Esteban Luna), has been substituted, accompanied by a photographic reproduction (photograph: W.J. Schuster, 2022).

proving the observing efficiency by approximately a factor of 8, depending on the sky conditions, i.e. its brightness and constancy. The original version of this instrument is shown in the first figure of Johnson (1958) and Lockwood (2008: Figure 1). Our version, obtained through the efforts of Dr Haro with the assistance of Harold Johnson and Braulio Iriarte, as mentioned above, was constructed in Austin, Texas, by the W.L. Richards Co. and was delivered to the Observatory at Tonantzintla in 1961 by Iriarte. This photometer is pictured in Johnson (1962: Figure 10); this figure includes the photometer head (a.k.a. 'The Offset Device') described above. Our Figure 9 shows this instrument as displayed at the Harold L. Johnson Museum in Ensenada, the only difference being the two cold boxes (from the 6RC photometer), which have RCA 7102 PMTs instead of the original

Figure 9: The double photometer as shown in its display case in the Harold L. Johnson Museum in Ensenada. These cold boxes hold RCA 7102 photomultiplier tubes for RI or 6RC photometry rather than the original 1P21s for UBV. The triangular 'heart' of this double photometer in the bottom centre of the photograph contains the double-diaphragm disk and the aluminized prism for separating the 'star' and 'sky' channels; an eyepiece could be introduced for guiding. The two corks show where crushed dry ice can be inserted for cooling the PMTs. The middle photograph in this display case is after Johnson (1962: Figure 10), and the right-hand photograph shows this photometer being used with the 74-in telescope of the University of Toronto. The rolls and strips of paper at the bottom of this display case indicate how the photometric data from the first years at the San Pedro Mártir Observatory were frequently taken and reduced: printers and chart recorders, followed by punched paper tape for input into a Nova computer (photograph: W.J. Schuster, 2022).

1P21s. The triangular 'heart' of this double photometer was also stored in the offfice of the first author (WJS) for a number of years to protect it.

4.3 The *UBV* Cold Box (The 1P21 Refrigeration Box)

Johnson (1962: Figure 8) shows a complete and assembled copy of this cold box (refrigeration box) as the upper part of the 'complete single-channel photoelectric photometer', the only difference from our version being a spacer for use with an f/32 telescope. The Figure 8 photograph (by W.L. Richards Co.) shows this cold box mounted above the photometer head (offset device), as described above in Section 4.1. Johnson (1962: Figures 3 and 4) show technical drawings for this refrigeration box and for the 1P21 mounting within this box, respectively.

As can be appreciated in the photograph of our Figure 10, the *UBV* cold box in our collection is very incomplete, having been cannibalized. Thus, it is missing its 1P21 photomultiplier, its socket, one of the aluminum sides, and the silicon dioxide powder (Santocel) used as thermal insulation around the outer bronze tube, which holds the refrigerant (crushed dry ice) plus the inner tube which holds the 1P21. The filters are also missing from the bayonet, which has positions for as many as 5 filters. Nor has the second *UBV* cold box—needed to complete the double photometer—been located. Our one *UBV* cold box on display (Figure 10), has been left open, with one side completely open, missing its aluminum panel, and another with the aluminum sides folded outward by ~90 degrees so that visitors to the museum can appreciate the assemblage and workings of a cold box. At the very top of Figure 10 the diaphragm wheel can be seen with 8 positions: 0.35, 0.87, 1.54, 2.00, 3.00, 4.00, 7.00, and 9.00m m.

In later versions of the Johnson photometers this style of cold box has been replaced by two modules: one is strictly a refrigeration box and the other a filter box, as shown in the technical drawing in Johnson (1962: Figure 7), which contains both a diaphragm wheel as well as the filter wheel, instead of a bayonet. So, for example, the photometers 5C, 8C, and 6RC at San Pedro Mártir National Observatory were composed of three modules: (a) a mounting unit (photometer head) with eyepiece, transfer optics, and a standard lamp (or standard source) module attached behind; (b) the filter box (transition module) with the diaphragm and filter wheels plus field lens; and (c) the refrigeration box with refrigerant, and one or two PMTs.

Figure 10: The *UBV* cold box/1P21 refrigeration box for the single-channel photoelectric photometer. This has been highly cannibalized, but one can still identify the filter bayonet (the horizontal structure), the diaphragm wheel at the very top, and the hole in the bronze cylinder where the PMT (1P21) should be inserted. The bronze cylinder would be filled with crushed dry ice as refrigerant and should be surrounded by silicon dioxide powder (Santocel) as thermal insulation (photograph: W.J. Schuster, 2022).

5 THE *JHK* (*IJK*) PHOTOMETER

This infrared photometer, presented in our Figure 11, was found nearly intact, in its own storage/transport box, located on the second level of the commodities warehouse at the Observatory, (i.e. on San Pedro Mártir). It even had the three filters, *JHK*, as identified on the outside of this instrument, installed in the bayonet, and was missing only its eyepiece; AC has now adapted another astronomical eyepiece with illuminated crosshairs. In addition, two very long Allen-style wrenches, used to align the PbS cell (detector), were missing from the back of the detector module.

Renovation of this photometer was fairly simple and straightforward: the exterior was cleaned, and the chopper cover was painted flat black. To display the photometer body plus the detector and preamplifier boxes connected and upright, as if mounted on a telescope, two wooden support boxes with differing heights have been provided (by the University's Works Department) and installed within the glass display case.

This *JHK* photometer has a very similar layout to the *JKLM* photometer discussed in Johnson and Mitchell (1962: Figure 3). It has a PbS detector and a mechanical chopper which rapidly alternates the observation "... between the star and an immediately adjacent sky region …" in order to cancel the infrared background from the sky, telescope, and other contributors. This alternating signal is synchronized to an AC amplifier using a synchronizer light source and photocell within this photometer.

This IR photometer was used very little at San Pedro Mártir; one of us (WJS) observed a few nights on the 1.5-m telescope with Richard Mitchell, and then other IR instruments took its place, such as that of Roth et al. (1984). In his correspondence with personnel at Tonantzintla (Eduardo de la Rosa, pers. comm., 29 June 1965; Siqueiros 2021), Dr Johnson also refers to this instrument as the *IJK* photometer.[7] Other useful and interesting papers concerning this broad-band infrared photometry are Johnson (1966) and Johnson et al. (1966).

Figure 11: One of the infrared photometers developed by Dr Johnson and his team, left at the Observatory at San Pedro Mártir, and referred to as the '*JHK* infrared photometer' (and the *IJK*' photometer in some of Dr Johnson's letters). It uses the PbS detector 'A' of Dr Johnson. In this photograph the chopper unit is painted black, the standard source module is above this, the detector module is behind the photometer at about the same level, and the electronics (amplifier) module beneath this. Only the very end of the filter bayonet can be seen protruding from between the photometer body and the detector module; the three filters remain installed (photograph: W.J. Schuster, 2022).

Figure 12: The DC amplifier No. 6, which appears very similar to amplifiers 1 and 4, which were used much more at the Observatory at San Pedro Mártir, but have been highly cannibalized. The 0.5 and 2.5 magnitude gain steps, adjusted by the two knobs on the right, were calibrated every 3–6 months using the apparatus of Ortega (1971) (photograph: W.J. Schuster, 2022).

6 The DC (AC) Amplifier No. 6

For most of the stellar photometry carried out with the Johnson photometers on the 1.5-m and 0.84-m telescopes at San Pedro Mártir over the years 1971 to ~1985, the techniques were DC, making use of the DC amplifiers Nos. 1 and 4, built according to the design of Professor Johnson (e.g. see Johnson, 1962: Figure 5). The gain steps of these two amps (2.5 and 0.5 magnitudes) as seen in Johnson and Mitchell (1962: Figure 12) and in our Figure 12 were calibrated approximately every 3–6 months using the calibrator (with a highly constant source and very accurate potentiometer) as designed, constructed, and documented for the undergraduate physics thesis of Roberto Ortega (1971). However, by the year 2000 these two amps (1 and 4) had been highly cannibalized by the Observatory personnel, missing many of their internal electronics components as well as their backs, bottoms, and/or sides! The DC amplifier No. 6 was little used at the San Pedro Mártir Observatory, and so luckily escaped this decimation. The external appearance of No. 6 is very similar to the other two DC amps, and since it was also constructed by H.L. Johnson and his team it has also been included in the Museum as representative of a Johnson DC amplifier.

Figure 13: A Johnson photometer found and refurbished by the mechanical technicians of the Institute of Astronomy, Ensenada, for possible use in a site museum, which eventually never included this instrument. The black box is wooden, and has been provided only so that this 'unknown' photo-meter can be displayed upright with its mounting plate at the top (photograph: W.J. Schuster, 2022).

7 The 'Unknown' Photometer

The 'unknown' Johnson photometer was found in one of the storage rooms at the Institute of Astronomy in Ensenada. It was obviously a Johnson-style photometer, quite similar in design, appearence, and construction to other Johnson photometric instruments, so it was cleaned and renovated by personnel from the mechanics shop at Ensenada for possible use in a proposed site museum near the entrance to the National Park where the San Pedro Mártir National Observatory is located. However, by the time this museum was finished its message and format had evolved, and so this 'unknown' photometer was not displayed there.

Numerous astronomers, technicians, assistants, and students (including August Johnson, Harold`s son) were questioned about this apparatus, but none could provide a precise identification. It appears to be an infrared photometer that was never finished, or was finished but then cannibalized. It has numerous open screw holes along the sides and considerable empty space below suggesting that a chopping unit is missing and perhaps also an additional electronics package. To display this 'unknown' photometer a plastic replica of an eyepiece was provided by the mechanical technicians at the Institute of Astronomy in Ensenada, as well as a black wooden box and cardboard tubes by the Works Department of the University so that it can be presented upright with its mounting plate at the top, positioned as if mounted on a telescope.

This 'unknown' photometer is shown here in Figure 13. The mounting plate used to connect this instrument to a telescope, is at the top, and an electronics box is at the bottom, with two protective, or support, posts in front. The black wooden box, mentioned above, has been placed on this electronics unit to support the main weight of this photometer so that it can be displayed upright.

8 DISCUSSION: RESEARCH BASED ON THE JOHNSON PHOTOMETERS AT THE INSTITUTE OF ASTRONOMY IN ENSENADA

The 2.1-m telescope at the National Observatory at San Pedro Mártir was inaugurated on 17 September 1979 (Poveda and Allen, 1987). Up to that date nearly all of the astronomical observations made at the Observatory were carried out with the 1.5-m and 0.84-m telescopes and the Johnson photometers, with the 5C, 8C, and 6RC being almost exclusively the 'main work-horses'.

Starting in February 1971, through 1979, and ending approximately in 1984–1985, these Johnson photometers produced a large proportion of the scientific output of the Observatory. We have identified 16 principal observers and 56 publications based on *UBVRI* and 13-color data from these instruments in use at the Observatory that were published in international journals (*Astronomical Journal*, *Astronomy & Astrophysics*, *Astronomy* & *Astrophysics Supplement Series*, *Astrophysical Journal*, *Astrophysics and Space Science*, *Publications of the Astronomical Society of the Pacific*, *Revista Mexicana Astronomia & Astrofisica*, etc.) over the time interval 1971–2001. These publications cover a wide range of astronomical topics: variable stars of many different types; open clusters; pre-main sequence stars; subdwarf and solar-type stars; O, B, and Be stars; trapezia, double, and multiple stars; stars of HII regions; stars associated with radio and IR sources; Seyfert galaxies; and atmospheric extinction.

The following list documents these publications, with emphasis on retired or deceased astronomers: Mendoza and González (1974): metallic-line stars; Mendoza (1971): FU Ori; Mendoza et al. (1978): Am stars; González et al. (1980): Am stars; González et al. (1987a): HD 1826, binary star; González et al. (1987b): δ Cep, β Cep star; Peniche et al. (1980): HD 185332, δ Scuti star; Peniche et al. (1985): YZ Bootis, δ Scuti star; Daltabuit et al. (1976): NGC 1068, Seyfert galaxy; Binette et al. (1989): NGC 3227, Seyfert galaxy; Quisbert et al. (1989): NGC 3227, Seyfert galaxy; Mitchell et al. (1985): solar colors; Moreno et al. (1986): NGC 7538 IRS 5, 6, and 7, nebulae; Moreno (1980): HR 4715, HR5329, and HR 7331, δ Scuti stars; Alvarez et al. (1982): variable Be stars; Alvarez et al. (1981): Be stars; Alvarez et al. (1987): B variable stars; Chavarría-K and de Lara (1981): pre-main sequence stars; Schuster and Alvarez (1983): Be stars; Warman et al. (1979): 4 Canum Venaticorum, δ Scuti star; Warman et al. (1974): HR 1170 and HR 7563, δ Scuti stars; Peña and Warman (1979): HR 1170 and HR 7331, δ Scuti stars; Chavarría-K et al. (1987): selected Sharpless HII regions; Chavarría-K (1985): LkH-α 198, Herbig Ae Be star; Hobart et al. (1985): HD 94033, δ Scuti star; Hobart et al. (1989): EW Aqr, δ Scuti star; Jarzebowski et al. (1981): KP Persei, β Cep star; and Schuster (1979a): sub-dwarf stars.

The following additional 28 studies (listed in alphabetical order) complete the total research output at San Pedro Mártir National Observatory involving the Johnson stellar photometers: Bertaut et al. (1982): S CrA and Co-35 10525, variable stars; Bravo Alfaro et al. (1997): A0–K0 supergiants; Carrasco et al. (1979): Nova V1500 Cygni 1975; Craine et al. (1976): IRC+10420; Dunham et al. (1990): Pallas Occultation of 1 Vul; Garrido et al. (1985): 28 And, δ Scuti star; Jarzebowski et al. (1979): 12 and 16 Lac, β Cephei stars; Jarzebowski (1982): Ap stars; Peña et al. (1983a): DQ Cephei, δ Scuti star; Peña et al. (1983b): HR 5005, δ Scuti star; Rolland et al. (1986): CY Aquarii, SX Phe-type star; Roth et al. (1979): Trapezium-like objects; Schuster and López (1976): Comet West; Schuster (1976b): solar-type stars; Schuster (1979b): subdwarf stars, metallicity calibration; Schuster (1979c): subdwarf stars; Schuster (1981): subdwarf stars; Schuster (1982a): O-type stars; Schuster (1982b): 13C SPM, 1973–1979; Schuster (1984): B-type stars; Schuster and Guichard (1984): Be and shell stars; Schuster et al. (1984): Occultation of 1 Vul by Pallas; Schuster et al. (1985): 13C SPM, 1980–1983; Schuster et al. (2001): atmospheric extinction at San Pedro Mártir; Schuster et al. (2002): atmospheric extinction at San Pedro Mártir; Sterken et al. (1986): BW Vul, β Cep star; Warman et al. (1977): Trapezium-type syst-ems; Yamasaki et al. (1983): BD+43 1894, δ Scuti star.

References for all of the studies mentioned in the two previous paragraphs are listed below in Section 12.

9 CONCLUDING REMARKS

The great variety of observers and astronomical themes in this compendium of international publications, making use of *UBVRI* and 13C data from the Johnson photometers at the San Pedro Mártir National Observatory, emphasizes their great importance to this Observatory over the years 1971–1985. The photometric observers at San Pedro Mártir 'kept the ball rolling', so to speak, over those critical, challenging, but very interesting first years!

10 NOTES

1. For the history of 'modern' astronomy in Mexico, see Anguiano (1880), Beltrán y Puga (1893), Gallo (1928), Moreno Corral and Schuster (2020), and Zubieta (1985).
2. Harold Lester Johnson has been described as "… one of the most productive and influential observational astrophysicists …" of the twentieth century (de Vaucouleurs, 1995: 243). He was born in Denver, Colorado, on 17 April 1921, and after graduating in mathematics from the University of Denver he worked on war-time radar when Albert Whitford and Gerald Kron introduced him to photoelectric photometry, a field he would devoted his life to. He began by completing a PhD at the University of California, Berkeley. Between 1948 and 1969 he worked at Lowell, Washburn, Yerkes, and McDonald Observatories and the Lunar and Planetary Laboratory at the University of Arizona, all the while expanding the boundaries of photoelectric photometry.

   It was while he was at the University of Arizona that Johnson began collaborating with Mexican astronomers (Mendoza V., 1980). In 1969 he joined the Institute of Astronomy at the National University of Mexico on a part-time basis, transferring to a full-time Chair in 1979 when he moved to Mexico City. However, he also maintained his links with the University of Arizona and with Stewart Observatory.

   Harold Johnson "… was always willing, even eager, to share his profound knowledge of photometry and electronics with students, associates and colleagues." (de Vaucouleurs, 1995: 256–257). He died from a heart attack on 2 April 1980, while in Mexico City.
3. On 5 September 2022 Engineer José de la Herran passed away in Mexico City at the age of 96. José was in charge of installing the first three telescopes at the National Observatory at San Pedro Mártir, and his unique design for the mounting was used for the 2.1-m telescope. In 1983 he won the Mexican National Prize for Science in Technology and Design. He was not only an engineer but also an astronomer, musician, historian, and museologist, and had a considerable museum in his house with scientific, technological, and astronomical pieces.
4. During the last months of 1983 the *uvby*-Hβ 6-channel photometer arrived in Ensenada from Brorfelde, Denmark, after being nearly 'lost' during customs proceedings in Mexico City. The astronomer Dr Poul Erik Nissen and technician Jens Klougart from Denmark unpacked, assembled, and tested this new instrument both in Ensenada and at San Pedro Pártir Observatory. Since the renewed H.L. Johnson 1.5-m telescope was not yet ready, Professor Nissen received nights with this 6-channel photometer on both the 0.84-m and 2.1-m telescopes.

   The first Mexican observers to use this new photometer (José Guichard, Estela de Lara, and WJS) were awarded an observing run during March 1984 to carry out *uvby*-Hβ photometry of high-velocity and metal-poor stars with the now refurbished and modernized 1.5-m telescope; on some nights they were able to observe as many as 125 stars, both program and standard stars, with this simultaneous 6-channel (4+2) photometer.
5. This standard lamp was observed after each star and was maintained constant by a small internal PMT and feed-back electronics.
6. The northern observers were mostly E. Rhoads and A.S. Latham, and southern observers Fred Forbes, Richard Mitchell, and W. Stonaker (Johnson and Mitchell, 1975).
7. The *H* band was not one of Johnson's original infrared broad-bands, but was included later for observations by Mendoza (1967); see also the papers by Wing (1994) and Wing and Jorgensen (2003) to appreciate the history and late appearance of this *H* band.

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Dr William J. Schuster was born in Elkhart, Indiana, USA, in 1948 and received his undergraduate BS Degree in Astronomy from Case Western Reserve University (Tau Beta Pi, 1970), and his PhD Degree in Astronomy from the University of Arizona (Phi Beta Kappa, 1976). The photometric observations for his Doctoral dissertation, supervised by H. L. Johnson, were made at the Mexican National Observatory, San Pedro Mártir (OAN/SPM), where he continues to work to this day.

His main observational projects have concerned stellar photometry, spectroscopy, kinematics, and dynamics of Galactic halo and thick-disk stars, as well as photometry of subdwarf and solar-type stars, standard stars,

atmospheric extinction, and asteroids. William has gained expertise within three photometric systems: 13-colors of Johnson–Mitchell, *uvby*-beta of Stromgren–Crawford, and *UBVRI* of Johnson–Kron–Cousins. For example, his groups have determined solar colors for these three photometric systems using data from the OAN/SPM. He has published over 80 research papers in international journals, which have garnered more than 3000 citations. William has supervised 5 Bachelor theses, 4 Masters, and 3 PhDs, participated in numerous Observatory summer schools and outreach events, and taken data at observatories in Mexico, Chile, the Canary Islands, and the USA.

Apart from astronomy, William loves photography, jazz and classical rock music, watching movies, reading novels, hiking, and basketball, and specially his two children: Pilar Citlali and Daniel William.

Antolin Cordova Vidal was born In Ensenada, Mexico, in September, 1953. His basic education was provided by the public school system and adult education. He is a Mexican citizen and is married. His training as a precision machinist was obtained on the job; for example, he became a trained lathesman for working aluminum at 'Fundacion Mechanica' over a period of two years. Later he worked six years at 'Taller Valdez', 1976–1981, where he advanced to become foreman of this workshop. He then worked from 1981 to 1989 for the Institute of Astronomy at the Universidad Nacional Autónoma de México, having tenure after 1984! From 1989 to 1992 he was employed as a contract machinist in the San Diego, CA, area and especially for the company 'Sierra Telesis' where he assisted with the fabrication of yachts from 1992 to 1994. In June 1994 he returned to the Institute of Astronomy as an outside contractor, and then was employed full-time from October 1994 until his retirement.

At the University, Antolin worked in the group of precision machinists carrying out maintenance at the National Observatory on San Pedro Mártir, and the construction of new astronomical instruments at the machine shop in Ensenada. These instruments included the IR photometer of Tapia and Roth, mountings for gratings and CCDs, filter wheels for various instruments and telescopes, and new guide systems such as that for the telescope at the University of Guanajuato, and so forth. During any spare time, and according to his own interest and motivation, Antolin has enjoyed salvaging and refurbishing old scientific instruments, such as the photometric equipment of H.L. Johnson!

Marco Arturo Moreno Corral was a pioneer in the development of the National Astronomical Observatory, in Sierra San Pedro Mártir, Baja California, Mexico. In 1971 he began observations there in photoelectric photometry, collaborating since then on diverse tasks that allowed the start-up of this research center. His main areas of research have been Galactic Kinematics, Planetary Nebulae, HII Regions, Low Mass Stars of the T Tauri type, as well as the study of the History of Exact Sciences in Mexico. During 1989–1990 he was coordinator of the Astrophysics Area at the National Institute of Astrophysics, Optics and Electronics located in Tonantzintla, Puebla, Mexico.

In addition to various research papers, he has published books and book chapters, where he has reported his research on the historical development of astronomy, physics, and mathematics in Mexico. In 2001 he was a member of the Organizing Committee of the Symposium, "Astronomical Heritage of the Third World Cultural Areas," held in Mexico City for the XXIst International Congress on the History of Science.

He is currently retired, but continues to work on research on the historical development of astronomy in Mexico between the sixteenth and nineteenth centuries.

Cristina Siqueiros studied for a BA in Physics at the Universidad Nacional Autónoma de México. Then she completed her Master degree in Philosophy of Science in the area of history of science. She is currently pursuing a doctorate degree in the same area.

Her main research interest has been the Mexican history of astronomy during the mid-twentieth century, placing a major focus on transnational history and history of instruments and material culture.