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TRIENNIAL REPORT 2009-2011

1. Introductory Background

The formal commissioning of the IRWG occurred at the 1991 Buenos Aires General Assembly, following a Joint Commission meeting at the IAU GA in Baltimore in 1988 that identified the problems with ground-based infrared photometry. The meeting justification, papers, and conclusions, can be found in Milone (1989). In summary, the challenges involved how to explain the failure to achieve the milli-magnitude precision expected of infrared photometry and an apparent 3% limit on system transformability. The proposed solution was to redefine the broadband Johnson system, the passbands of which had proven so unsatisfactory that over time effectively different systems proliferated, although bearing the same "$JHKLMNQ$" designations; the new system needed to be better positioned and centered in the spectral windows of the Earth's atmosphere, and the variable water vapour content of the atmosphere needed to be measured in real time to better correct for atmospheric extinction.

The IRWG then established criteria for judging the performance of existing infrared passbands and experimented with passband shapes, widths, and placements within the atmospheric spectral windows. The method and coding were initiated and largely carried out by A. T. Young, and, aided by C. R. Stagg, Milone ran the simulations. The full details of the criteria and results of the numerical simulations were presented by Young *et al.* (1994). Subsequent work, described in WG-IR and/or Commission 25 reports, included the use of a newer MODTRAN version (3.7) to check and extend previous work. This part of the program proved so successful in minimizing the effects of water vapour on the source flux transmitted through the passband that the second stage, real-time monitoring of IR extinction, was not pursued, although this procedure remains desirable for unoptimized passbands designed for specific astrophysical purposes. Considerable work has now been done in measuring the emission of precipitable water-vapor (as we note below), so this goal may be nearing achievement.

During subsequent triennia, the WG concentrated on gathering and presenting evidence of the usefulness of the near-IR IRWG infrared passband set, viz., the iz, iJ, iH, iK passbands. A series of field trials of this suite was conducted over the years 1999–2003 with an InSb detector in a double-well Dewar mounted on the 1.8-m telescope at the Rothney Astrophysical Observatory of the University of Calgary in the foothills of the Canadian Rockies. The results of those trials and the details of further work were presented in Milone & Young (2005). This paper showed that not only were the near-IR suite of the IRWG passbands more useful to secure precise transformations than all previous near-IR passbands, but that they were also superior in at least one measure of the signal-to-noise ratio. This evidence was further discussed and refined in Milone & Young (2007). As a consequence, the original purpose of the IRWG has been achieved, but resistance to the widespread adoption of the new passband system is, nevertheless, still strong, and passbands that somewhat compromise the IRWG recommendations have been advanced in order to provide more throughput, at the cost of precision and standardization. Thus, nonoptimized passbands are still in use at infrared observatories around the world. The situation is described in Milone & Young (2011a), and below.

It would be incorrect to conclude, however, that the work of the IRWG has had no impact on the IR community. As noted in previous IRWG reports, there is now a general acceptance of the principles enunciated in Young, Milone, & Stagg (1994).

2. Membership in the IRWG

The WG-IR has had the policy of being open to input from its members at all times following the initial consultations with all segments of the infrared community. We maintain this open policy for membership, and consider all members interested in improving the precision and accuracy of infrared photometry to be members. The above list, therefore, is a subset of the full membership.

3. Developments in the 2009-2011 Triennium

The IRWG met during the Rio de Janeiro GA in Session 2 on Aug. 7, 2009, and was chaired by E. F. Milone. Recent highlights of the work of the IRWG were described in Milone (2009). In Milone & Young (2005), and further in Milone & Young (2007), correlations were shown among: our figure of (de)merit, θ, a measure of the distortion of the spectral irradiance of starlight as it descends the Earth's atmosphere; a measure of the Forbes effect (the rapid change in slope of the extinction curve with decreasing airmass); the extinction coefficient between 1 and higher airmasses; and a measure of the signal to noise ratio. Milone & Young (2008) argued for the suitability of the IRWG passbands to provide millimagnitude precision for variable star infrared photometry at *any* photometric site, irrespective of its elevation. Directed to both professional and amateur astronomers, this paper compares extinction coefficients obtained using a sample of old IR filters with those using the IRWG passbands determined from the same night at the RAO. The coefficients for the old passbands are seen to be greater by factors ~ 2 or more, as predicted by the simulations and numerical experiments. The very small Forbes effect seen with the IRWG passbands permits the use of the Bouguer extinction coefficients to obtain more accurate outside-atmosphere magnitudes than is possible with others, for which the Forbes effect can be debilitatingly large. A similar theme was emphasized in a

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column in the General Assembly's daily newspaper, *Estrela D'alva*, Day 10, p.4. Thanks to bulk prices (for lots of 9 or greater) by Custom Scientific, Inc. of Phoenix, Arizona, it may be possible to achieve substantial cost savings in the manufacture of the IRWG filters. Hopefully, photometer manufacturers will be induced to offer installation of the IRWG iz and iH filters in their IR instruments.

Subsequent papers supporting the IRWG passbands were read at three venues, in the interval 2009–2011. A paper on IR as well as optical precision was presented at the AAS meeting in Long Beach, California, in Jan., 2009, in the first of two sessions entitled Photometry: Past and Present. The sections were organized by Milone for the Historical Astronomy Division of the AAS. The paper was expanded into three articles in the volume, *Astronomical Photometry: Past, Present, and Future* (Milone & Sterken (2011)). The article on the development of IR photometry is cited as Milone & Young (2011a). At the *Telescopes from AFAR* conference, held in Waikaloa, HI in Feb., 2011, Milone & Young (2011b) summarized the development of the IRWG passband recommendations. This presentation and the paper based on it are, at present writing, posted on the conference website †.

For anyone interested in observing with the new IRWG passbands, a list of standard stars is available in Milone & Young (2005). Although this list is not extensive, zero points were adopted to approximately match those of the Mauna Kea near-IR set (for the JHK passbands); a link to the latter set is available at the Commission 25 website‡.

Because the IRWG standard star magnitudes listed in Milone & Young (2005) have had zero points added to them to provide "familiar" values, this list can also be used to standardize observations made with the IRWG filters, at sites such as Mauna Kea. Moreover, they may be useful at lower altitude observatory sites, but ONLY if the IRWG passband are used. This is because the Forbes effect is significant for any passband system than the IRWG, but will be negligible for much of the photometry carried out with the IRWG near-IR set, and in the iN passband.

4. Other New Developments in IR Astronomy

The following sample of work reported in the 2009–2011 interval may be of interest to IR photometrists.

• van Dokkum *et al.* (2009) used three overlapping "J" passbands and two "H" passbands to locate the Balmer jump & 400nm break in galaxies over the z red shift range 1.5 to 3.5 and compare their passbands to the atmospheric transmission curve. The breaking of the conventional passbands into shorter segments, at least in part to improve transmission through the atmosphere, is a welcome step, even if it is not the main purpose of the work.

• Hodgkin *et al.* (2009) described the calibration of the photometric system for the wide-field camera of the UKIRT telescope ("$ZYJHK$"). Among other uses, the WFCAM hosts the UKIRT Infrared Deep Sky Survey (UKIDSS). The "$ZYJHK$" passbands extend from 0.84 to 2.37 μm. The 2MASS point source catalog provided the primary foundation for the calibration. Neither the 2MASS JHK_2 nor the Near-IR Mauna Kea JHK passbands were optimized to block water-vapor absorptions.

• Kanneganti *et al.* (2009) discuss a new infrared camera for the University of Virginia's Fan Mountain Observatory. The camera employs an IGC Polycold closed-cycle refrigeration system. "FanCam" employs a HAWAII-I 18.5 μm pixel detector array, and

† http://tfa.cfht.hawaii.edu/papers/milone_tfa_paper.pdf
‡ iauc_25.saao.ac.za

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is used on a 31-in telescope. The camera appears to work well, although the background is very high, a condition to which the "JHK" passbands probably contribute strongly. The paper contains the statement that despite the wet, low-elevation characteristics of the site, "the J, H, and K_s bands are virtually unaffected by water-vapor, ... permitting high precision photometric observations." This phrase alone indicates that the work of the IRWG is far from complete. Of course, if the IRWG passband designations iz,iJ,iH,iK were inserted instead, the statement would be more nearly correct.

• Meixner *et al.* (2010) describe the WHIRC high-resolution infrared camera installed on the 3.5-m WIYN telescope at Kitt Peak. The detector is a Raytheon VIRGO 2048 x 2048 HgCdTe array. A tip-tilt module provides diffraction–limited imaging from 0.4 to 2.4 μm. It is currently equipped with 1.061 μm, He (1.083 μm), Pa β, [Fe II], Br γ (the latter three repeated with a red-shift equivalent to 4500 km^{-1}), H_2, and CO. They report internal precision among a 5 star sample of $\pm$0.02 mag.

• Monson & Pierce (2009) discuss the performance of the `BIRCAM` array camera of the Wyoming Red Buttes Observatory, where it is mounted on a 24-in telescope. They equip this instrument with "JHK" filters.

• Pickels & Depagne (2010) synthesize "ZY" passband magnitudes, among many others, for 2.7 million stars in the Tycho2 Catalog, by integrating spectral atlases. The "Z" passband does not resemble the "iz" or "yz" (as it was referred to in Young, Milone, & Stagg (1994)) passband of the IRWG set, but "Y" resembles it, as does the "Y" passband proposed by Hillenbrand *et al.* (2002).

• Querel, Naylor, & Ferber (2011) present an algorithm with which to calculate precipitable water vapor from infrared water-vapor emission measured with their IRMA instrument, and others, by matching the observations with their Blue Sky Transmission and Radiance Atmospheric Model (BTRAM), which makes use of the HITRAN 2008 molecular parameters data base. This is the sort of achievement which can lead to the complete solving of the infrared extinction problem. The real-time modeling of water-vapor content is what is needed to obtain the remaining corrections to observations made through passbands already optimized to block water-vapor.

5. Discussion

Clearly, a sharp break from the nomenclature of the Johnson passbands has not occurred, as the above papers illustrate. Many Infrared astronomers continue to use "$JHKL$" designations (now more commonly designated with a subscript "s" on "K" or by primes, to indicate a slight change in profile to lessen the effect of the water-vapor bands' absorption and thermal emission) even though there has been, at least until recently, no single passband system in use with those designations.

The Mauna Kea near-IR suite of passbands described by Tokunaga & Vacca (2007), is one of the best of the incrementally improved systems, but it is, nevertheless, *not* optimized for extinction and standardization, nor for a measure of the signal-to-noise ratio, and falls short of the IRWG specifications. This will result in a significant Forbes effect at sites other than the highest elevation sites (Mauna Kea, Mt. Evans).

That observers are applying the Johnson designations to the Mauna Kea near-IR set is not surprising because that is what Tokunaga, Simons, & Vacca (2002) called them, thus resulting in confusion in nomenclature with earlier passbands.

The IRWG suggests that the designations be assigned, instead, only to the atmospheric windows most prominently associated with the original Johnson passbands — see Milone & Young (2005).

The Mauna Kea near-infrared suite, an incremental improvement over older passbands sets, although falling short of the IRWG prescription, typifies the movement of infrared astronomy toward the goals of the IRWG.

In addition to promotion of the IRWG passbands, the following tasks still need to be carried out by future Infrared Astronomy Working Groups:

• Acquisition and testing of several sets of near IRWG passbands for distribution to several observing sites†.

• Establishment of standard star observations across the entire sky, and their dissemination, including placement on the IRWG‡ or Commission 25 website.

• Encouragement of instrument suppliers to make use of the iz and iH passbands in low-cost photometers.

• Fabrication of the iL, iN, and possibly the in filters. The simulations consistently showed the iN passband to result in quite modest Forbes effects even at low-elevation sites.

6. Closing remarks

The IRWG has now been in existence for two decades. Even with incremental improvements in IR passbands in use at the major IR observing sites around the world, other passbands suffer from the penchant of many IR observers to use the spectrally widest passbands they can fit into the atmospheric windows. Such passbands are, de facto, less desirable for use at lower sites, such as KPNO, CTIO, and all other observatory sites below 4 km elevation.

We do not agree with the assertion of Tokunaga & Vacca (2007) that the large Forbes effect from nonoptimized passbands is important only in photometry of very cool objects or that it is removably generally by application of simple color terms. However, the issue can be resolved by simultaneous observation of the same objects through the IRWG and the Mauna Kea passbands at 2-km or lower elevation sites.

More work clearly needs to be done to promote the IRWG passbands, for all applications, and especially time–variable observations, because of the continuous variation in water-vapor content, and thus, in the Forbes effect.

We recognize that astronomers are a conservative lot, and even though there is no standard $JHKLMNQ$ system to which they need to be loyal, infrared astronomers have been particularly reluctant to adopt and try new broadband filters, except to isolate particular spectral features. In most cases they may not want to sacrifice white-light filters (which is what conventional infrared filters have been, effectively) for narrower ones that provide less overall throughput, but are *not* defined by the edges of the atmospheric windows.

Such an attitude is understandable in observers operating in what can be called a "discovery" mode, where high precision and accuracy are not critical, but photometrists have basically different aims. One legitimate concern is that data taken in other IR passbands may not transform to the IRWG system, with the possible exception of data in the newer Mauna Kea set used at one of the few sites in the world where it is truly suitable, and when conditions there are dry. Consequently, it seems that only demonstrations of the superiority of the IRWG passbands set when used on specific targets will convince many to use them. Therefore, we urge photometrists with a strong interest in precise

† IRWG filters are now available at bulk prices from Custom Scientific, Inc., of Phoenix, AZ. Current prices may be obtained from that company.

‡ http://people.ucalgary.ca/∼milone/IRWG/

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photometry to give these passbands a try at observatories where photometry is done, either with a chopping secondary and LIA system, as at the Rothney Astrophysical Observatory, or with array cameras.

The widespread adoption of the Mauna Kea set as the "JHK" passbands of the day indicates that evolution, if not revolution, is possible in this field. The fact that generations of broadband filters, although widely different in profile, bear the same names, is, of course, bizarre. Commission 25 has added the issue of passband designation recommendations to its agenda.

Eugene F. Milone
Chair of the Working Group

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