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WORKING GROUP ON INFRARED ASTRONOMY

(GROUPE DE TRAVAIL POUR ASTRONOMIE INFRAROUGE)

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1. Introduction

The evolution of ground-based infrared astronomy into a precise and accurate tool for astronomical studies continued during the past triennium. The limitation of photometric precision as practiced at the time were described and discussed in Milone (1989) and in Young, Milone, and Stagg (1994), partial solutions provided. The limitation in precision was shown to be due primarily to Atmospheric features within the passbands and the use of the edges of the atmospheric windows to define those passbands. The saturation of portions of the passbands high in the atmosphere means, especially for the longer wavelength passbands, a large difference between a linearly extrapolated zero-air mass magnitude and the actual value. The rapid curvature of the extinction curve between 1 and 0 air mass (more properly, a water-vapor mass, notwithstanding the contributions of carbon dioxide, ozone, etc.) is known as the *Forbes effect.* Since the widths of the atmospheric windows vary with altitude and the circumstances of each site, different observatories have responded to the problem in the past by redefining the Johnson system from J to Q to suit the needs of the site. The result was a proliferation of systems. As a rule, filters were selected for maximum throughput and so were not optimally placed, shaped, and narrowed to minimize the effects of the absorption bands of the terrestrial atmosphere. Given this situation and in light of the tremendous promise of high precision presented by infrared photometry (see Milone 1989), it was clear that something needed to be done to properly standardize the infrared system.

The Infrared Astronomy Working Group of Commission 25 (hereafter IRWG) was created to do just that. A subgroup of the IRWG consisting of Andrew T. Young, Milone, and Christopher R. Stagg set about examining the properties of existing passbands and in optimizing the placement and width of potential passbands within the atmospheric windows. Updated versions of Modtran were used to simulate atmospheric models, and these were used to generate a variety of models for different terrestrial sites. Stellar spectral fluxes to test the transparency variation on specific energy distributions were provided by R. L. Kurucz, and a figure of merit was introduced in the form of the angle of rotation of one vector into another in Hilbert space. The one vector represents the intial spectral flux in the passband at the top of the terrestrial atmosphere and the second the spectral flux as passed through the atmosphere. Passband placements and bandwidths were determined in order to minimize this angle of rotation, θ. Shapes of passbands were also explored, and a series of triangular passbands settled on, although trapezoidal shapes, more in line with the kinds of interference filters which can be readily produced by filter manufacturers, did not degrade performance to any major degree; indeed in some cases, depending on the window, there was a slight improvement. From a large series of such models, the selection of final

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parameters was made with a bandwidth made as large as possible to enhance throughput, but just short of a slope change (a kind of slippery slope criterion) in plots of θ vs. λ and $\Delta\lambda$, *so that small shifts arising in the filter manufacturing process would not increase* θ sufficiently to impair a passband's effectiveness.

The discussion of why an improved system was needed was recently recapitulated to some extent by Simons and Tokunaga (2002), with some important omissions, which we discuss below. This work by two members of the IRWG was spurred by the need to adopt the best filters that could be used at the Gemini sites, and thus throughput had a higher priority than for the IRWG work. The added attention given to the need to improve the transformability and linearity of the extinction determinations is vital, even if the purposes differ.

2. New Simulations

During the end of the previous, and throughout the current, triennium, a number of additional trials were carried out. Sky emission models for a tropical, 4.2 km atmosphere, a 2 km, std. atmosphere and a mid-latitude, summer 1 km atmosphere were computed for 60 passbands, incorporating a large proportion of the infrared passbands in use in the community over the past decade, including those recommended in Young et al. (1994). The results show that in all model runs including the Mauna Kea atmosphere model, the SNR of the recommended passbands demonstrates that nearly all are indeed the 'improved' passbands claimed in Young et al. (1994). For the Mauna Kea model, for which not all passbands of the IRWG set are explicitly optimized, at least one of the passbands of the MKO-NIR set defined by Tokunaga and Simons (2002) provide lower SNR values, if not lower θ values. However, we note that the advantage of a passband system that is undefined by the atmospheric windows at *all* sites where infrared photometry may be attempted is obvious. What is perhaps not sufficiently clear to all astronomers, and indeed even to some members of our own working group, is that impaired passbands are risky even for differential photometry because the water vapour content of the atmosphere may vary hour by hour, except maybe at the very best sites, during at least some times of the year, so that unless one is able to keep both target and comparison star in the same imaging frame or observe them with some rapid alternate detection process, one cannot be sure that the differential Forbes effect will be ignorable. This risk will be greatest for the lowest altitude sites where the variation of water vapour is most extreme, but since the bulk of the effect is produced high in the atmosphere, even good sites will not be immune.

In two recent papers (Simons and Tokunaga 2002; Tokunaga, Simons, and Vacca 2002), a 'rationalized' MKO-IR system is presented. Presumably this system was devised because those authors recognized the advantage that an optimized new infrared set offered over existing passbands, without, however, wanting to sacrifice any throughput at the Mauna Kea site. This is understandable since the pressure to detect the faintest possible sources is very great at such a premier site.

Simons & Tokunaga and Tokunaga et al. state that the MKO-NIR passbands are useful at both mid- and high-latitude sites and that the IRWG effectively endorsed their system. However, these points need strong qualification. Considering the difference in magnitude between transmitted spectral irradiance and background emission as an effective indicator of Signal-to-Noise ratio, the IRWG passbands not only provide lower values than several of the MKO-NIR passbands in the Mauna Kea model, but nearly all seem to out-perform other filters in the other models. Indeed, at the Manchester Comm. 25 meetings, the IRWG did not endorse the MKO-NIR system but noted only that it was apparently the best of the existing systems. The IRWG, however, was not aware that there was (nor is), in fact, no list of standards values determined for these filters (Tokunaga 2002, private communication).

Obviously, if our intention were to treat only the atmospheric model for Mauna Kea (4.2 km altitude, tropical), we could have produced broader filters and would not have made use of other atmospheric models for other sites. However, our mandate was to provide transformable passbands for all sites, including those of existing observatories, where

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infrared astronomy could be done. For this reason, we also used a 1976 standard U.S. atmosphere and 2 km altitude model, appropriate for most of the major international and national observatories, and a mid-latitude, summer, 1 km altitude model, appropriate for many university observatories. Indeed, we have explored the effects even at 0 km sites, although we did not optimize the passbands for those sites, and for certain windows (e.g., M and Q), we had no choice but to model these with the 4.2 km tropical model alone.

Thus the recommended IRWG passbands enable an observer at nearly *any* site where good photometry is practiced to be able to determine and use Bouguer extinction coefficients to obtain extra-air magnitudes for at least the near infrared passbands, and perhaps also the yN and yn passbands. Our simulations tell us that such usage for the MKO-IR passbands is relatively safe to carry out only at the Mauna Kea Observatories. The good news, however, is that a convergence may indeed be achievable, with potential transformations between MKO-NIR observations at Mauna Kea sites and IRWG observations at all other sites, for the passbands with minimal Forbes effect.

3. Standard Star Observations

Thanks to the Custom Scientific Company of Tucson, Arizona, the near IR portion of the IRWG set: z, j, h, and k, has been manufactured and has been used in an IR dewar supplied by IRWG member T. A. Clark, and placed on the 1.8-m Alexander R. Cross Telescope of the University of Calgary's Rothney Astrophysical Observatory. Although the telescope has been available in its current configuration since 1997, continuing equipment problems and uncooperative skies prevented a large enough data set to be compiled until recently. Most of the observations are from 2001, although sufficient trials done much earlier suggested that the new passbands were indeed less sensitive to water vapour variation than older infrared filters.

The nightly observing procedure was to use one or two stars as Bouguer stars and observe a number of others as they crossed the meridian. Thus, if the night's extinction proved insufficiently consistent to determine linear extinction coefficients, mean values might be used to nevertheless determine extra-atmosphere magnitudes. This has indeed proven possible in a number of cases. Due to the necessary brevity of this report, the table of standard star magnitudes in the IRWG system will be provided in the ensuing publication. A brief report of the extinction coefficients and other work is given in Milone & Young (2002).

4. Future Work

We intend to publish the preliminary list of standards obtained with the IRWG system shortly, and to offer detailed responses to some of the comments regarding the system made by Tokunaga et al. (2002). Further work will involve testing the effects of aerosols of various types. Finally, we continue to invite members of the community to join the IRWG.

E. F. Milone

Chairperson of the Working Group

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