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PHOTOMETRY AS A FUNDAMENTAL TOOL, BUT BE CAREFUL!

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RESUMEN

La fotometría es la más fundamental de todas las herramientas observacionales usadas en astronomía. Mide el brillo de estrellas (u otros objetos) y también otros rasgos característicos sobresalientes en la distribución de la energía emitida. Se pueden usar y en efecto se usan estas mediciones de magnitud, color, diferencias de color y otros parámetros para estimar las temperaturas superficiales, las luminosidades no enrojecidas, las distancias y otros detalles importantes. Todo esto nos da información importante sobre la estrella u otro objeto, útil en estudios de estructura y evolución estelares, estructura galáctica y de las propiedades del material interestelar, en realidad de todos los aspectos observacionales de la astronomía.

Sin embargo como en todas las técnicas, debe ponerse mucho cuidado si se desea obtener datos precisos. Es muy fácil cometer errores accidentales o sistemáticos que nos conduzcan a interpretaciones incorrectas de los datos. Se dan varios ejemplos, relacionados con la fotometría de cúmulos abiertos y con las propiedades del enrojecimiento interestelar. Una buena comprensión de las estrellas, el gas y el polvo en la Galaxia exige lo mejor de los fotometristas.

ABSTRACT

Photometry is the most fundamental of all the observation tools used in astronomy. It measures the brightness of stars (or others objects) as well as other strong features in the energy distribution output. One can and does use these measures of magnitude, color index, color differences, and other parameters to estimate surface temperatures, true luminosities, metallicity, strengths of strong lines, interstellar reddening and absorption, distances, and other important details. All these give us important information about the star or other object, useful for studies of stellar structure and evolution, galactic structure as well as for the properties of the interstellar matter, in fact, for almost all of any observational work in astronomy.

However, as with all techniques, great care must be paid if one is to obtain precise and accurate data. It is only too easy to make accidental or systematic errors that can lead to serious misinterpretations of the data. Several examples are given, relative to photometry of open clusters and of the interstellar reddening properties. A good understanding of stars, gas, and dust in the galaxy demands the very best from photometrists.

Key words: **TECHNIQUES: PHOTOMETRIC**

1. INTRODUCTION

Photometry is undoubtedly the most fundamental of all astronomical observations. It is hard to imagine ıny research of any nature that does not use photometric results in some way or another. The measurement of

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brightness and of broad band spectral features in a star or other object's flux output is at the heart of much c what we all do. We all do photometry or use the results of someone else's observations.

Photometry and spectroscopy are very complementary, as are photometry and theory. In fact "complementarity" is one of the most operative words relative to approaches and to progress in ou understanding the universe about us.

However, while basically very simple, photometry is very often much understood. To do good analysis, i goes without question that we need accurate and precise photometry.

What we measure in photometry is really an integral of the effect of many things: the flux output of the sta or other object, including any shells or disks about it (and whatever else nature may have put there to confus us), interstellar matter, the Earth's atmosphere, the telescope, the filters, the detectors, and other things a well. All of these are changing with time (etc). We are trying to estimate something of interest to use, perhap the stellar apparent brightness or some strong special feature in its spectrum. We are trying (we hope) to avoi the adverse impact of other things that may well confuse our understanding. The selection of our observin site, our telescope, our detector, and our filters all can impact the success of our estimate of the parameter o interest. Photometric systems have usually been designed (one hopes) to be efficient estimators of what we ar trying to understand and to avoid the adverse impact of those things that are most likely to mess us up. W try to chose the photometric "system" that will do the best job for us. Simple in principle, but often difficul in practice.

Having a good understanding of what is going on is critical. There are adverse effects of rotation, shape emission, double or multiple stars, line shape, spots, flares, shells, disks, the interstellar matter and its uniformity variable stellar or emission background, the faintness of our object, atmospheric seeing and variability, clouds filter leaks and cut-off characteristics, temperature effects and anything involved, detector changes, and s on. With all of this, it seems impossible to think of doing precise not to speak of accurate photometry. In addition, there are issues such as separation of the observed parameters, sensitivity to the feature we are tryin to measure, the ease of doing it, standard stars and calibrations, reduction methods, information resolution and so on. How can one manage? But it has been done. But not as often as one would like, or even as on thinks.

2. A FEW EXAMPLES

Let me give a few quick examples from published data on research I have been doing in the last months particularly on stars in a few young open clusters. Such data are most useful in studies of color magnitud diagrams, in comparisons to stellar evolution, in studies of interstellar reddening and absorption, and i calibrations of the photometric parameters themselves. Clearly, precise and accurate data are needed. Wha do we find?

In one such cluster, two relatively bright stars ($V = 9.44$ and 8.95) have six published values, plus my ow new data. The V magnitude and the $B - V$ values agree rather well, though the scatter in $B - V$ is highe than would be expected for such bright stars. Probably the precision of some of the data is not too good. Fiv of the $U - B$ values agree rather well with each other (even rather low scatter), but the other two are off b 0.10 magnitude! This is unacceptable photometric accuracy, and it would seriously compromise any conclusion about the characteristic of the clusters or of the interstellar reddening. Clearly, one of the authors has goofed and the other has reduced his data to the same (erroneous) $(U - B)$ zero point.

Two fainter stars in the same cluster have data by two of the observers. These stars are fainter, and th data are more likely to be adversely impacted by variable background (and other things). Here are the values

Table 1. *UBV* Values for Two Stars in NGC 6611 from Two Observers

V	$(B-V)$	$(U-B)$	V	$(B-V)$	$(U-B)$
13.13	1.23	0.08	13.42	0.93	−0.07
13.02	1.32	−0.08	13.52	0.93	−0.29

Clearly, there are problems. And this is photoelectric photometry, with the published typical value c observational "errors", plus or minus a few hundreds at the most. The real problem comes when one tries t se such data for drawing scientific conclusions. Remember too that the faintest (and reddest, in this case) ars in the data set are often the ones that the critical conclusions about interstellar reddening laws hang on.

In another young cluster, we find the following for six different observers (except for me, not the same ones ; in the other cluster), from over ten stars in each comparison (*UBV* data, and standard error for one star), lative to our data:

Table 2. Differences in *UBV* Values for Stars in NGC 1502 from Six Observers

ΔV		$\Delta(B-V)$		$\Delta(U-B)$	
0.005 ±	0.016	0.010 ±	0.008	0.004 ±	0.005
−0.011	0.034	0.004	0.008	−0.011	0.017
−0.014	0.014	−0.010	0.006	0.003	0.008
0.009	0.017	−0.007	0.015	−0.093	0.020
−0.013	0.025	−0.012	0.008	−0.079	0.024
0.006	0.017	−0.026	0.010	−0.080	0.019

Clearly, there are differences in precision and accuracy. I have grouped the data into two sets, to highlight ie $(U-B)$ differences.

There are four different *uvby* data sets available too for this same cluster. Here the differences of the other iree to ours is (for $b-y$, m_1, and c_1):

Table 3. Differences in *uvby* Values for Stars in NGC 1502 from Three Observers

$\Delta(b-y)$		Δm_1		Δc_1	
0.010 ±	0.005	0.001 ±	0.009	−0.005 ±	0.009
−0.043	0.012	0.052	0.011	−0.058	0.024
0.066	0.021	−0.020	0.020	0.051	0.029

Again, clearly there are differences in precision and accuracy. Why the problems? There can be many asons (note the lists of potential pitfalls given above), most having to do with lack of understanding of the ısics of photometry. Let me mention at least two of the key reasons that probably have caused most of ie problems here: There is variable interstellar reddening, especially in the first cluster as well as probable ıriable background (emission) problems. The choice of suitable standard stars for transformations was poor ıo reddened OB stars!) for a few of the observers. In one case at least, the reduction techniques were quite ɔn-standard and probably led to some of the problems, especially when coupled with the lack of good standard ars. There may well have been other problems as well, of course.

It would be easy to go on with more examples and with more discussion of the whys and wherefores, but I ıink I have made my point. Remember that these observers were all "photometrists", not even non-observers: ;trophysicists or theoreticians!

3. REAL LIFE IN TODAY'S OBSERVING

Let me elaborate a bit more on the real life difficulties of doing photometry that most of us face. Let ie call it "Photometry at a National Observatory". There is a good deal of excellent equipment, including ate-of-the-art photometers. However, they are continually being upgraded or improved or worked on, both ardware and software. At each observing run, one is faced with a new setup, hence a new system really. Indeed, ıch run one may well have a different detector and a different filter set as well. Then there is the problem of ıstrumentation changes, with all the associated potential for problems (such as wiring mixups). Usually too, iere is the fact that one may not get the number of nights needed (if one in fact gets any) and that some of what one gets is cloudy or marginal seeing. Furthermore, there are either no small telescopes anymore or the are disappearing. Hence, adequate time for standards and for understanding systems is impossible. And a some of these places, stars and the optical and photometry are certainly not where the action is.

All of this can and does lead to what I call "Second Class, First Class Astronomy". That means tha the scientific program is first rate, but the observational restrictions limit what can be done, often severel compromising the effort. I don't think that it is getting any better with the new technology. Things are mo complicated, change more often, and many observers are getting further and further removed from the sk buried in the computer room, and out of touch with both the sky and the instrumentation and the details (the software. Hence, real understanding of what is going on is difficult or impossible. Photometry like tha mentioned above may well become more common rather than less common. We must do better rather tha worse!

4. WHAT TO DO

I won't go into detail here about "What To Do?" Other papers have discussed this topic at length, an Commission 25 (Photometry) meetings and symposia have dwelt on the issues for decades. I talked at son length about it in a paper at the recent meeting in Cape Town honoring Alan Cousins on his 90th year. (It interesting to note that even today Cousins is probably doing the most accurate photometry of any of us, and h is doing it from the middle of a large city and with an electron tube amplifier and a Brown strip chart recorder Sufficient to say here: If you want to get good data, yourself or from the literature, you must understan photometry. It appears simple, but it can be a trap, leading to interesting but erroneous conclusions abou stars, gas, and dust in the Galaxy.

We must insist, in astronomy, that a balanced program of support will include support for photometry, fo small telescopes, for adequate coordination of their use, and for sufficient time on such telescopes to insure "Fir Class, First Class Photometry". As I said in South Africa, we could even have a new generation of photometr with the new panoramic detectors and with an implementation of a global network of small telescopes doir excellent photometry everywhere. If we don't do these things, then I fear that we will face losing touch wit observations and the systems. We will see more "second class" observations and science, more systematic error more marginal data. Let us hope that we do better in our support of these fundamental things, like standard photometry, and effective small telescopes.

I think that we can, but we must actually do it. Let me repeat my last paragraph from the paper at th Cousins' meeting, where I summarized some of the positive results of such efforts:

"We would then see:

1. New technology, detectors and instrumentation, new telescopes, including new generation sma ones, an essential component in a balanced funding approach to astronomy. We need it all, ar we will be getting some of it without question.
2. Better understanding of photometry and photometric systems.
3. More and better data. And adequate archiving of the data.
4. More and better standard stars. More tie-ins.
5. A wider range of standard stars, in character and faintness.
6. Better astronomy, better science. Precise and accurate photometry is fundamental to it all.

Thanks for inviting me to Eugenio Mendoza's "party". It has been great. We shared a lot in the ear days, the days at Yerkes, when so many nice things relative to photometric systems and the new detectors ar telescopes of the day were being developed. They were grand times in many ways. Today's times are far mo hectic, it seems, but grand in many ways as well. With care, today's photometrists have great opportuniti and I wish us all well. My best wishes to Eugenio too, in all his current and future endeavors and adventure:

DISCUSSION

Herbig: You mentioned that some photometric systems survive and others do not. What are the reasons?

Crawford: a) Some systems are better designed to answer scientific questions, etc., b) some have been used by the initial observers, and have lots of exposure to other observers, c) others have a good (adequate) set of standard stars.

Feinstein: Some systems survive because there are easy to use. If you take care of a few things, specially standard stars, the system will work.

Crawford: I agree. One must take care, and one must choose and use standard stars with care.

Turner: I have a comment and a question. My comment concerns the plot of m_1 vs. $(b - y)$, which exhibits greater scatter with increasing redness of the star. It is similar to Johnson's plot of $(V - I)$ vs. $(B - V)$, which implies variations in reddening law around the Galaxy. My question concerns the large differences in published photometry that you demonstrated. Do these originate in differences in the properties of the new detectors or in the standardization of the photometry?

Crawford: a) Yes, much scatter can reflect such effects, but one must be careful, because the fainter and redder stars also have the potential for more observational scatter. We need more and better data, as usual. b) I think definitely not the detector, but in transformation (inadequate) to the system. Often it reflects a rather poor choice of standard stars, as well.

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