CALIBRATION OF FUNDAMENTAL STELLAR QUANTITIES: SUMMARY AND CONCLUSIONS

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WHAT THE SYMPOSIUM WAS ABOUT

At a time when so much of the prestigious astronomical research is devoted to new and highly speculative phenomena, it has been rewarding to see and hear the cautions and accurate approach to the measuring and interpreting of stellar quantities. It has been shown by many speakers, perhaps clearest of all by our participant of honor Professor Popper, how insufficient attention to calibration problems can lead to erroneous results.

We have listened to many important discussions of the details of the determining of different quantities. I am proposing not to repeat all this but rather to concentrate on those aspects that deal with the calibration of the data.

It may at this time be appropriate to analyse what we have meant by our title, the four major words of which have been interpreted differently by different participants:

Calibration	relating of quantities inside a system to other quantities outside that system or the process of keeping a system autonomous
Fundamental	a primary characteristic of the star itself or a basic parameter known to the observer but not to the star
Stellar	referring to all stars or referring to all stars except the Sun
Quantities	numbers or numbers, classifications, descriptions

D. S. Hayes et al. (eds.), Calibration of Fundamental Stellar Quantities, 343–349.

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STANDARD STARS AND STANDARD SYSTEM

The symposium was given an ideal start by the chairman of the scientific organizing committee who told us what requirements a standard star should fulfill and that a reference star need not necessarily be a standard star. The obvious requirement, that a standard star is constant in the relevant characteristic, is not always easy to check but all the same quite fundamental. Batten also discussed the characteristics of a system of standards and pointed out that the standards should be suitable for the testing of the experimental set-up. He also pointed out that it is unfortunately necessary to have different standard stars for different quantities. However, Batten concluded, we may in the future not need standard stars at all; hopefully we will be able to measure the quantities directly.

Further analysis of standard star systems was made by Garrison, particularly with application to the MK system but in its philosophical approach of far-reaching consequences. In that review as well as in Keenan's review it came out quite clearly that the MK system provides an autonomous description of stellar spectra classified without regard to other observational data. Precisely this property of independence makes it useful in the study of stars by confrontation with other data. The construction of the system, given by the standards in Keenan's paper, is a model of calibration. It is also interesting to see how this method of spectrum description has evolved to contain more information without changing its basic layout.

One more point made by Garrison is worth repeating and that is that the large telescopes now available will probably contribute very little to the calibration of fundamental data, merely because of the short, incidental runs that are normally granted. The important work of establishing standard systems has to be carried out elsewhere and one can only hope that large telescope observations are satisfactorily tied in with such systems.

Carlos Jaschek described the enormous quantities of information that are available from the data centers of the world. The degree of collaboration between them is gratifying. Great credit is due to Jaschek and to the Centre des Données Stellaires, CDS, where so much of the compilation has taken place. It has always been his and his collaborators aim to make this material calibrated, standardised and unambiguous. Yet, the task is a very difficult one and it is only in certain sectors that they have succeeded so far. I think the astronomical community should wish the CDS the best of luck but also be willing to help in the endeavor to make the data handled by these data banks homogeneous and trustworthy. The danger of a very efficient procedure spreading second-rate data is obvious. Jaschek's review paper showed us the difference in concept between the observational compilation and critical compilation catalogues; the realisation of this difference is an important step and we should all appreciate that the large data bank of CDS is handled in such a responsible way.

Several papers dealt with radial velocity standards, notably the one by Scarfe who investigated the constancy of the IAU standards and the one by Walker et al. who studied the precision attainable for measurement of radial velocity variations particularly for observations with Reticon arrays.

The issuing of a microfiche containing information on standard stars was proposed by Davis Philip in a poster paper and was subsequently discussed a number of times during the meeting. The plan adopted was that a prototype should be made by Davis Philip in collaboration with the CDS and circulated among the participants for comments. The microfiche would eventually become an enclosure of the present volume.

Problems regarding calibrations for Space Telescope (ST) were discussed by Bohlin who invited comments about suitable standard sources and standard stars.

In the poster session the Griffins presented a tracing of a high-dispersion (10Å/mm) spectrum of a B7 star with line identifications. More such useful displays are planned for other spectral types.

EVER MORE ACCURATE MEASUREMENTS

Several review papers dealt with questions of positional astronomy. Corbin described how transit circles need to be accurately calibrated and how the FK5 is envisaged to go faint and to avoid some of the systematic errors of FK4. The relating of the system to faint objects, particularly counterparts of radio sources, was also discussed, as was the link with the Hipparcos and ST observations.

Upgren showed how the accuracy of trigonometric parallaxes has increased dramatically during the last decade. The main reason is the use of modern measuring machines, particularly the PDS machines but also Starscan at US Naval Observatory. This is so much the more important as it allows the ever more precise stellar angular diameters to be translated into linear diameters, one of fundamental stellar quantities. As was pointed out by Hanbury Brown, the trigonometric parallaxes are less accurate than the angular diameters for the 10 stars where both quantities are known. In the field of parallax measurements much hope is attached to the Hipparcos satellite which will measure stars down to 12th magnitude and will be complete to V = 8. In a poster paper Gliese and Jahreiss gave a luminosity calibration of the lower main sequence on the basis of available trigonometric parallaxes. The importance of making calibrations valid for constant volume was discussed several times during the symposium. In any case, it should always be clear whether a calibration is based on material selected according to apparent magnitude or from a volume of space.

During the last twenty years, the greatest leap towards understanding the fundamental stellar properties has been the determination of angular diameters. Three basic ways have been used:

1. The intensity interferometry, a technique which has yielded 32 diameters for early type stars.
2. Occultation observations, particularly lunar occultations, which have given information on stellar diameters for late type giants.

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3. Speckle interferometry, which has yielded diameters of a number of late type stars; this technique came into use at the time when the Narrabri interferometer already had finished its diameter program.

The future development may depend on the amplitude interferometer planned by the Sydney University group. The prototype is nearing completion and if this is successful we might look forward to the building of a 1 km instrument capable of observing stars down to V > 7. Davis outlined this and he also pointed out that both occultation methods and speckle interferometry are inherently limited in comparison with the Michelson interferometer. Resolutions down to $4 \cdot 10^{-5}$ arcsec are expected for OB stars and $2 \cdot 10^{-4}$ arcsec for other stars.

In the discussion following this paper, Evans described the achievements and the capacity of the lunar occultation method, particularly useful for late type stars. Evans also pointed out that when observing a lunar occultation of a binary from different sites, the different geometric aspects give added information for determination of the separation and position angle.

Statistical methods of obtaining parallaxes using the principle of maximum likelihood were presented by Heck in a poster. Results for absolute magnitude calibrations were given.

QUANTITIES KNOWN TO THE STARS

Masses and luminosities are fundamental quantities, the determinations of which have been the subject of several papers at this symposium. McAlister reviewed the interferometric studies of binary orbits, particularly methods of speckle interferometry. The addition of data by interferometric studies of binaries, particularly at the high-mass end of the mass-luminosity relation, have made a large impact. Although speckle observations concern very close binary pairs there is a certain overlap with orbits from visual binaries. Comparisons that can be made show no systematic differences.

On the question of a standard orbit for calibration purposes, McAlister discussed Capella's orbit but even this could not fill a requirement of 1% accuracy. An alternative would be a set of 21 standard stars with well-known separations and position angles which, if observed frequently could yield a set of standard orbits. For the future of high resolution studies McAlister pointed out the great potentials of long baseline interferometry.

The arduous task of determining masses from astrometric observations of binaries was described by Heintz. Although the new catalogue contains 850 orbits, only about 40 stars have good masses since high precision data are required for several different quantities: mass ratios, parallaxes, orbits, inclinations etcetera. A good mass calibration of the lower main sequence could, however, be made with these data.

Popper gave a lucid review of practices in evaluating eclipsing binary observations. The determination of masses, radii and luminosities from spectroscopic and photometric observations requires careful attention to correct practices. He showed with several examples how insufficient inspection of the observed spectra or non-standard photometry can lead to erroneous results, the presence of which in the literature can be of disadvantage. Computer usage is of particular value in studying photometric light-curves where different model fitting parameters can be tried out. A similar situation does not exist in the spectroscopic analysis which is more straight-forward. While the matter of determining good masses, radii and luminosites for eclipsing binaries is mainly a question of high standard of work, for the observing quantities the calibration is of highest importance.

In one poster paper Bell et al. studied the surface gravity spectroscopically for Arcturus and were able to deduce a mass - the one method available for mass determination of single stars.

In his review over the measurement of stellar rotation Slettebak described the principles and achievements of the three different methods:

1. Modulation of light by rotation when the stellar surface has an uneven brightness.
2. Distortions in radial velocity curves of eclipsing binaries.
3. Effects on spectrum line profiles.

These methods are all old, suggested before this century, and have yielded a lot of data. The third method is now also used in Fourier analysis of line profile and in CORAVEL observations, where the width of the minimum gives information on rotation. It appears that the Fourier methods make the most use of the line profile information but that their application requires a good understanding of the light distribution over the stellar disk.

PHOTOMETRY, SPECTROSCOPY AND THE UNDERSTANDING OF SUCH DATA

The review by Rufener gave a good insight into the problems of photometric calibration. Particularly the problems of changing detector technology were discussed. Rufener made a distinction between the stars that are used for comparison purposes in the reduction of the observations and the standard stars. A standard system should contain stars in all areas of the HR diagram and be used to understand the final result of each stellar observation.

While Rufener's concern was to give an internally consistent photometric system, the paper by Hauck tried to relate photometric data from a number of systems to determinations of effective temperature. The calibrations of B-V and B2-V1 from the UBV and Geneva systems in terms of effective temperature were given for unreddened stars. A catalogue of 104 stars were proposed as a standard for T_{eff} calibrations.

Several important contributions concerned the calibration of the uvby system. Three different papers by Ardeberg and Lindgren, by Antonello and by Nelles et al., all showed endeavors to push the uvby

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system towards later spectral types. Manfroid has investigated the effect on the uvby system of rectangular spectral response curves, such as will be achieved by a dispersing photometer with slits but without filters. He suggests the use of two different uvby systems.

Regarding the absolute calibration of photometry we heard a most impressive account of the state of affairs by Hayes. He first concluded that despite a number of other indications, Vega is constant and good for use as a primary standard. The calibration of Vega against black-body sources on the Earth has been carried out by several groups and the results agree in the visual region to within about $0\overset{m}{.}01$, in the infrared somewhat less well. The absolute flux calibration is made with an accuracy of about 1½ percent. Comparisons between Vega and the Sun are very difficult but similar results have been achieved by several groups. The fact that the B-V value for the Sun thus determined does not agree with the B-V for stars with the spectral class (G2V) for the Sun could be indicative of a peculiarity in the Sun's color, but the low precision in the B-V determinations make such a conclusion premature. It would be of value to study the Sun's color also in other photometric systems. One of the high precision data series on solar radiation referred to by Hayes, was the measurement by Neckel and Labs which was presented as a poster at this symposium.

Giusa Cayrel gave an inspired talk about high-dispersion spectroscopy, particularly for the Hyades stars where the dispersion between [Fe/H] values is now much lower. It is quite clear that Reticon observations have a tremendous potential, but at the same time this is obviously a detector that as yet needs to be perfected. The long discussion about what S/N really means when such a detector is discussed would have been better among detector specialists. We congratulate Cayrel on her results and wish her better and better oscillator strengths to work with.

The usefulness of M67 as a standard of reference was pointed out by Janes. This open cluster is very well studied and its composition and age are very close to those of the Sun. Physically it is more similar than the Hyades to the Sun and its distance can be determined directly.

Straižys discussed the different photometric systems in terms of metallicity indices. For several of the systems reddening effects can not easily be removed while other systems are so designed as to establish a valid metallicity scale even in the presence of reddening effects. However, Straižys pointed out the lack of model atmosphere data, general enough to provide calibration of metallicity indices.

Gustafsson showed us, on the other hand, that the state of the art in model atmosphere calculation is high - that a lot of the discrepancies that were present earlier now have been removed through better programs which take more lines into account, through a better understanding of the geometry of the atmosphere and through other, more reasonable parameters. Some effects are less clearly understood. Recent studies of microturbulence and convection need to be introduced. As a whole the situation is improving fast with better observations, also in UV and IR, with better computational programs and with new physical data for input to the models.

Several poster papers gave results from model atmosphere work in terms of expected photometric data. Bessell and Scholz had calculated colors from models for M giants and supergiants with different abundances. Buser and Kurucz attempted to calibrate the UBV system in terms of physical parameters.

Code told us about the problems with calibration of UV observations and also about the usefulness of UV data; the UV colors discriminate better than the optical between stellar temperature classes and they measure the interstellar extinction better. Also, the addition of UV colors should help in the study of several astrophysical quantities, temperature, surface gravity, metallicity. Analysis of composite spectra is another area of future space research.

HOPES FOR THE FUTURE

It seems quite clear that vast improvements in the quantity and quality of available data can be expected for the next ten-year period for:

trigonometric parallaxes
angular diameters
radial velocities
high dispersion spectroscopy
model atmospheres

Let me end by a quotation from D.M. Popper: "The heart of the matter is care and judgment."

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