6. STELLAR PHOTOMETRY WITH MODERN ARRAY DETECTORS

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INTRODUCTION AND BASIC REFERENCES FOR STELLAR PHOTOMETRY WITH CCD

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1 Project and aims of the meeting

An object of this meeting is to define and emphasize the best practices that allow stellar photometry done with array detectors to be as accurate as possible. We dream of applying simple and clearly justified principles; in reality, we find the equipment has physical and technical properties that interfere with each other. Photometry is a method, a metrology; so we first have to define the desired accuracy. Some will be happy with 0.1 magnitude; others need 0.01, or even 0.001 magnitude. The necessary precautions must be matched to these ambitions.

2 Conditions for stellar photometry

The first requirement is precision of measurements. Although there are some difficulties, there are already means of extracting the signal with high precision. This topic has been studied most thoroughly, but some difficulties remain, particularly when fields are crowded.

The second requirement is for known, stable passbands, which must match the standard ones. This point has frequently been underestimated. If we all want to measure the same thing, accurately as well as precisely, it is of first priority to fix and check the right passband. Later transformations by mathematical recipes cannot recover the physical information that has not been included in the measurements. When using CCD's, it is vital to take the greatest possible care about this point.

The reduction to outside the atmosphere, and the relation to a standard system is also a problem. It is necessary to observe enough standard stars, of the right distribution of colors and magnitudes. To have adequate sets of such stars remains a challenge.

The above, unavoidable requirements cannot easily and perfectly be fulfilled with an array detector.

However, if the following conditions are met:

a) The matching of the passbands is tested and good enough.

b) The knowledge and control of the stability of all the functions of the camera (filters and detector) are ascertained.

D. McNally (ed.), Highlights of Astronomy, Vol. 8, 617–621.

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c) The chromatic properties of the instrument (the colour equation) are methodically and periodically evaluated relatively to a standard having an extended range in colours and magnitudes.

d) The star's signals are precisely deconvolved and summed-up.

e) Some stars within each field are well known in the given system.

It should then be possible to reach or even improve the threshold of accuracy required.

3 Basic references for stellar photometry with CCD

In the following I have attempted to set up, with the help of several experts in the field, a number of references, of course non-exhaustive, which are listed as follows:

3.1 General overview

(1975)	**Sequin, C.H., Thompsett, M.F.** *Charge Transfer Devices, Academic Press, N.Y.*	
(1975)	**Barbe, D.F.** *Proc. IEEE* **63**, *38*	
(1984)	**Djorgovski, G.** *in Proc. of the workshop on improvements to photometry, NASA Conf. Pub. 2350*	CCD's: Their cause and cure.
(1985)	**King, I.R.** *in "Data analysis in astronomy" Proc. of the Erice workshop (40.012.096)*	Cluster photometry: present state of the art and future developments.
(1985)	**Fort, B.** *in "New aspects of galaxy photometry", 8th IAU European Regional Astr. Meeting Toulouse, p. 3*	
(1986)	**Tyson, J.A.** *JOSA. A.* **3**, *2131*	Low light-level CCD imaging in astronomy.
(1986)	**Walker, A.R.** *in IAU symp. 118, p. 33, Ed. J.B. Hearnshaw, P.L. Cottrell, Reidel, Dordrecht*	CCD photometry with small telescopes.
(1986)	*An ESO-OHP workshop held in Saint-Michel, ed. Baluteau & D'Odorico*	The optimization of the use of CCD detectors in astronomy.
(1988)	**Janesick, J.R.** *as guest editor, Optical Engineering* **26**, *685-1076*	15 papers on characterization, modelling, manufacture, theory and application of CCD.
(1988/89)	**McLean, I.S.** *under preparation*	An introductory text to CCD's.

3.2 Hardware description and development report

(1980)	*Proceedings of the SPIE* **264** *(29.012.068)*	
(1980)	**Leach, R.W. et al.** *PASP* **92**, *233*	Description, performance and calibration of a CCD camera.
(1981)	*Proceedings of the SPIE* **290** *(32.012.098)*	
(1984)	*Proceedings of the SPIE* **445** *(38.012.098)*	
(1984)	*Proceedings of the SPIE* **501** *(40.012.047)*	
(1985)	**Gudehus, D., Hegyi, D.** *Astron. J.* **90**, *130*	The design and construction of a CCD image system.
(1986)	**Mackay, C.D.** *Ann. Rev. of A. & A.* **24**, *255*	"CCD in Astronomy".
(1986)	*Proceedings of the SPIE* **627** *(42.012.092)*	
(1987)	**Gunn, J.E. et al.** *PASP* **99**, *618*	Description of the Palomar Observatory CCD camera.

3.3 Software packages and descriptions

(1985)	**Stetson, P.** *Dominion Astrophysical Observatory, Victoria, B.C., Canada*	DAOPHOT User's Manual.
(1986)	**Tody, D.** *SPIE* **627**, *733*	The IRAF Data reduction and analysis system.
(1987)	**Stetson, P.** *PASP* **99**, *191*	DAOPHOT: A computer program for crowded-field stellar photometry.
(1988)	*MIDAS User's guide, vol. A & B*	Image processing group ESO, Garching.

3.4 Specific problems

3.4.1 PSF fitting

(1983)	**Buonanno, R., et al.** *Astron. Astrophys.* **126**, *278*	Automated photographic photometry of stars in globular clusters.
(1983)	**King, I.R.** *PASP* **95**, *163*	Accuracy of measurement of star images on a pixel array.
(1984)	**Walker, A.R.** *MNRAS* **209**, *83*	CCD observations of photoelectric standard stars.
(1985)	**Gudehus, D., Hegyi, D.** *Astron. J.* **90**, *130*	The design and construction of a CCD image system.
(1986)	**Smith, G.H. et al.** *Astron. J.* **91**, *842*	CCD photometry of the globular cluster Pal 5.
(1987)	**Bendinelli et al.** *Astron. J.* **94**, *1095*	The Newton-Gauss regularized methods.

(1987)	**Mighell, K.J.** *The Messenger* **47**, *24*	Crowded field photometry using EFOSC and Romafot.

3.4.2 Flat fielding (see paper hereafter by P. Stetson)

3.4.3 Cosmic ray removal

(1980)	**Goad, L.E.** *SPIE* **264**, *136*	Statistical filtering of cosmic ray events from astronomical CCD images.

3.4.4 Fringes removal

(1987)	**Bica, E., Alloin, D.** *Astron. Astrophys.* **186**, *49*	Near IR spectral properties of star clusters and galactic nuclei.
(1987)	**Yee, H., Green, R.** *Astron. J.* **94**, *618*	The environment of the quasar PG 1613 +65: a close interacting pair.

3.4.5 Artifacts

(1980)	**Lorre, J., Gillespie, A.** *SPIE* **264**, *123*	Artifacts in digital images.

3.4.6 Sensitization to UV

(1985)	**Cullum, M. et al.** *Astron. Astrophys.* **153**, *L1*	Spectroscopy to the atmospheric transmission limit with a coated GEC CCD.
(1986)	**Robinson, L., Osborne, J.** *SPIE* **627**, *492*	CCD's at Lick Observatory.
(1988)	**Oke, J.G. et al.** *PASP* **100**, *116*	CCD testing at Palomar Observatory.

3.4.7 Pass-band matching

(1986)	**Walker, A.R.** *in IAU symp. 118, p. 33, Ed. J.B. Hearnshaw, P.L. Cottrell, Reidel, Dordrecht.*	CCD photometry with small telescopes.
(1987)	**Massey, P. et al.** *NOAO Newsletter* **12**, *28*	Out with the Mould, in with the Blue.

3.4.8 Linearity

3.4.9 Rapid sampling

(1985)	**Dunham, F.W. et al.** *PASP* **97**, *1196*	A high-speed dual-CCD imaging photometer.
(1986)	**Howell, S.B., Jacoby, G.H.** *PASP* **98**, *802*	Time-resolved photometry using a CCD.
(1986)	**Stover, R.J.** *SPIE* **627**, *195*	High-speed CCD imaging stellar photometer.

3.4.10 Standard stars and correlation to standard

(1984)	**Schild, R.** *PASP* **95**, *1021*	CCD photometry of M67 stars useful as BVR1 standards.
(1985)	**Christian, C. et al.** *PASP* **97**, *363*	Video camera / CCD standard stars (BVR1).
(1985)	**Olszewski, E.W., Aaronson, M.** *Astron. J.* **90**, *2221*	The Ursa minor dwarf galaxy: still an old system.

3.5 Sample or reference applications

(1980)	**Leach, R.W. et al.** *PASP* **92**, *233*	Description, performance and calibration of a CCD camera.
(1984)	**Walker, A.R.** *MNRAS* **209**, *83*	CCD observations of photoelectric standard stars.
(1986)	**Murray, C.A., Dierker, S.B.** *JOSA A* **3**, *2151*	Use of an unintensified CCD detector for low-light-level Raman spectroscopy.
(1987)	**Hesser, J.E. et al.** *PASP* **99**, *739*	47 Tuc color-magnitude diagram.
	Stetson, P., Harris, W. *Astron. J., in press*	M92 Color-magnitude diagram.