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ASTRONOMY AND ASTROPHYSICS

CCD photometry and astrometry for visual double and multiple stars of the HIPPARCOS catalogue*

I. Presentation of the large scale project

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Abstract. A description is given of the activities of an international working group created with the aim of obtaining both photometric and astrometric observations of visual double and multiple stars with angular separations in the range of one to fifteen arcseconds, that formed part of the HIPPARCOS Input Catalogue. The scientific aims and realisations of this European network are given. About 50 observational missions have been carried out in both hemispheres according to a pre-defined protocol. We describe the general and specifically designed methods used for the reduction of large amounts of CCD observations of double stars and give an outline of the results already presented and soon to be expected.

Key words: techniques: photometric – astrometry – stars: binaries: visual – stars: fundamental parameters

1. Introduction

1.1. A new project

Mid-1990 a large-scale project was started for combining the efforts of scientists in six European countries, from ten laboratories, with the goal to obtain accurate ground-based photometric and astrometric information on visual double and multiple stars: the European Network of Laboratories "Visual Double Stars" was founded. Both hemispheres would be covered (Oblak et al. 1992a). In 1992 a key programme was introduced at the European Southern Observatory (ESO) aiming at obtaining the photometry and the astrometry of visual double stars in the southern hemisphere: photoelectric and CCD observations would be obtained to complement the HIPPARCOS space observations on such systems (Oblak et al. 1992c). This paper is meant to be a general introduction to this vast observational effort: its aim is to extensively report on the scientific goals (Sect. 1) and the technical aspects (Sects. 2, 3, 4) as well as to introduce a series of forthcoming data papers (Sect. 5). Our programme is defined in Sect. 2. A large part consists in the description of the observational protocol (Sect. 3) and the introduction of an original reduction method specifically developed for this programme (Sect. 4), some of the more important aspects to consider in order to finally obtain data of a quality that eventually can sustain the comparison with space projects (such as HIPPARCOS). General conclusions and future prospects are formulated at the end.

1.2. The scientific goals

It is common knowledge that (visual) binary and multiple stars are prime targets for determining and calibrating basic stellar physics in general. In the first place, they serve to determine the masses and to calibrate the mass-luminosity relation. This is possible with sufficient accuracy, say better than 10%, under optimum conditions only, i.e. for a visual binary that is both sufficiently nearby and orbiting with a short period. For example, making use of the new Hipparcos absolute parallaxes, only 55 of the more than 1000 previously known orbital pairs satisfy the condition of accuracy on each component mass better than 15% (Lampens et al. 1997b). Since angular separations are generally below 1″, these are the "close" visual binaries. The photometry on the individual components for these systems almost completely relies on visual estimates of their magnitude differences. In the second place, visual binaries also serve to calibrate other stellar parameters since their common formation implies a common origin (same overall metallicity) and a same age (sharing a common isochrone), conditions that may even apply stricter

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than for open cluster members. Elimination of those generally badly known parameters allows to focus on the remaining ones that can therefore be investigated in an independent way. Such testcases may also be found among wider or "intermediate" visual binaries that have longer periods, separations larger than 1″, with high confidence that their components could not have influenced each other's evolution. For these systems however, the physical association should be clearly established (i.e. this should not concern too wide pairs). The existing photometry of the components with separations less than 10″ still relies mostly on visual estimates of Δm but also on the area-scanning technique (Franz 1966, Rakos et al. 1984) for some hundreds of visual double stars. The conventional photoelectric technique cannot be trusted in this range of separations.

In general, the vast majority of stars are members of binary or multiple systems. Recent surveys of high astrometric quality, both from space (Lindegren 1997) or from the ground, show clear evidence that improving the resolution of the instruments generates an increasing number of new detections and that the frequency of binaries is probably underestimated. The correct determination of the frequency as a function of stellar parameters such as spectral type, luminosity, population is a major constraint for the modeling of, for example, the galatic content and structure. Although more poorly known than their "single" counterparts – partly because the research is easily biased by the employed techniques and by the complication of the observational data's interpretation due to the presence of the companion stars – the binary stars deserve to be studied "in their own right".

It is therefore still a crucial matter to investigate the fundamental properties and the typical characteristics of double and multiple stars of all classes. The determination of the distribution functions of a minimal set of basic parameters such as true separations (linked with angular separations), mass and luminosity ratios (linked with differences of magnitudes) and differences of temperatures (linked with differences of colour indices) defines the context of this observational work.

The aim of our programme is, more specifically, to acquire and analyse the astrometric and astrophysical information of the individual components of visual binaries measured by the HIPPARCOS satellite mission. Regarding the astrometry, confrontation of recent versus past astrometric observations may lead to detect or to contradict orbital motions (e.g. Brosche et al. 1992, Bauer et al. 1994). This is especially important for the intermediate and wide pairs since a study of their relative proper motions is the only way to discriminate between physical and orbital pairs. Regarding the photometry, we believe that complementary accurate photometric multi-colour data with reliable astrophysical content are needed for a well-chosen sample of binaries and multiple systems for which good quality astrometric data already exist. Indeed, although detection of new double and multiple stars from astrometric programmes is continuing at a high rate due to their improving resolution, this high quality astrometry is generally coupled to a scarce photometry or at best a poor quality photometry of the *individual components* compared to that of the joint photometry on the system. The reason is that accurate brightnesses and colours of the components of visual systems can be obtained by conventional photoelectric aperture photometry in good conditions only if the separation is larger than the size of the used diaphragms (typically 11-13″) and if sufficient care is also taken when measuring the sky contribution. At closer separations the photometric information on the components is often either inaccurate or lacking: global photometry may exist but it has to be combined with visual estimates of the differential magnitudes (such estimates are poorly known since they can be as much as 0.5 mag off) to obtain component magnitudes. At even closer separations and at the decimag accuracy level, neither are speckle differential magnitudes easily obtainable (Carbillet et al. 1996; Ten Brummelaar et al. 1996). The (B_T, V_T) photometry of the vast majority of the stars in the HIPPARCOS catalogue was obtained in the course of the TYCHO programme (ESA 1997a), at least for systems with separations wider than 3″. Unfortunately, the Tycho photometry is not very accurate (the median precision is only 0.10 mag in $B_T - V_T$), and, moreover, the magnitude measurements of the double star components are contaminated by the companions (Halbwachs et al. 1997).

More generally, photographic magnitudes are found in very large double star catalogues such as the Washington Double Star Catalogue at USNO (Worley & Douglass 1997) and the Catalogue of Components of Double and Multiple Stars at ROB (CCDM, Dommanget & Nys 1995). The lack of accurate photometric data is reflected by the simple fact that much less than 10% of the systems listed in the CCDM (Dommanget & Nys 1995) and $\approx\ 10\%$ of the systems catalogued in the Annex of Double and Multiple Stars of the Hipparcos Input Catalogue (Turon et al. 1992) have photoelectric photometry for both components (see the 'Catalogue Photométrique des Systèmes Doubles et Multiples', CPSDM, Oblak 1988).

Nowadays, observations made with CCD detectors permit to obtain accurate individual photometric data in a separation range where previous techniques failed (Sinachopoulos & Seggewiss 1989; Argue et al. 1992; Nakos et al. 1997). We applied this observational technique to obtain the relevant data for each component of "intermediate" visual pairs (defined as having angular separations between 1″and 15″) in parallel with the conventional photoelectric technique for the "wide" visual pairs (with angular separations larger than 12″).

2. The observational programme

2.1. General description

A large programme for the systematic acquisition of accurate, homogeneous photometric colour indices of the components of several thousands of double and multiple systems was thus set up in both hemispheres with the following principal aims:

– to construct a basic sample of nearby double stars with complete astrometric and photometric information for each component of the system. By choosing those systems that belong to the HIPPARCOS programme, we made sure that the full astrometric information would be measured in space. The HIPPARCOS proper motions and parallaxes may now help to define "clean" samples (by filtering out systems that are most probably optical (Dommanget 1955, 1956, Brosche et al. 1992) as a function of parallax (i.e. distance-limited samples). The new photometric data will supplement the Hipparcos magnitudes with astrophysically significant colours that, once calibrated, will provide us hopefully with additional information such as temperature, gravity or metallicity (Oblak & Lampens 1992b).

– to improve the accuracy of the component photometric data for a large sample of visual double stars in view of applications that concern the distributions of true separations, mass ratios and colour differences. The usefulness of accurate component photometry is furthermore also evident in several other previously described applications, e.g. luminosity calibrations, age and evolution determinations, etc.

In addition, we also provide accurate astrometric and photometric data for components that, for one reason or another, were not succesfully measured or were "missed" by HIPPARCOS. This may refer to components with angular separations larger than 10″ not included in the Input Catalogue, to components with angular separations comparable to or larger than the half-width of the 'instantaneous field of view' (IFOV) (≥ 10″, i.e. a two-pointing double) for which the resulting astrometry/photometry may be perturbed and to components fainter than the companion star by more than approx. 3.5 mag or to components of those systems that were too difficult to treat and without solution.

2.2. Selection of programme stars

The selection of the programme was made starting from 11434 double systems, 1960 triple systems, 536 quadruple and 237 multiple systems of the Annex of Double and Multiple Stars, containing a majority of objects within a distance of 500 pc (Turon et al. 1992). Systems for which the component photometric information was lacking or poor have been selected by cross-examination with the CPSDM (Oblak 1988). This catalogue contains all information in three photometric systems (UBV, Geneva, Strömgren) for visual double and multiple systems, with indications on which components have been observed. We eliminated a small number of systems for which all the known components already have complete and precise photometric measurements: it is the case for ≈ 11% out of the 11853 systems listed in this catalogue. This concerns the measurements of 237 systems in the Geneva photometric system, 948 systems in the Strömgren photometric system and 1540 systems in the UBV system (Oblak and Mermilliod, 1988; Oblak et al., 1993c). The gross of the data regarding these wide visual double stars (separations larger than 10–12″) comes from works such as done by Lindroos (1981, 1983, 1985), Olsen (1982a, 1982b), Sinachopoulos (1989, 1990) and Wallenquist (1981).

We selected all systems with angular separations $> 1''$ for which either not all components had been observed or whose differential magnitudes were insufficiently precise for extraction

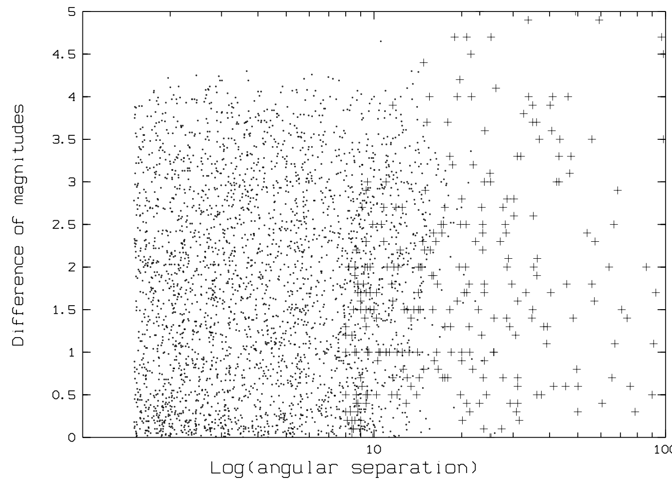

Fig. 1. Sample distribution in angular separation and differential magnitude (dots) versus double-star distribution with existing two-component photometry (crosses)

of astrophysical quantities. We found that differential colour indices are almost nonexistent in the separation range 1″ - 12″. Some 10% of visual double stars, generally the ones with separations larger than 10–12″, have colour indices for both components. Our programme consisted of northern ($\delta_A > -10°$) and southern samples ($\delta_A \leq +10°$) to be measured in various photometric campaigns and in both hemispheres. The overlapping zone in declination was observed once according to feasibility.

Since both conventional (CVT) and CCD photometry were used, the samples were also split with respect to angular separation, with a common intersection between 12″ and 15″ for calibration purposes. Systems on the CCD observational programme had to satisfy the following criteria:

$1'' < \mathrm{separation} \leq 15''$,
$0 \leq \Delta\mathrm{m} < 3$ mag,
lacking component photometry.

Our goal was thus to obtain accurate magnitudes and colours for the components of some 3000 HIPPARCOS double stars and some 600 multiple stars using both techniques (Oblak & Lampens 1992b).

It is relevant to recall here the Hipparcos observational strategy in the case of adjacent stars (Turon et al. 1992). With respect to angular separations, systems with separations $< 10''$ represent one entry only, with the 35″ wide IFOV pointing at either the primary, the photocentre or the geometric centre, depending on separation and $\Delta\mathrm{Hp}$. Systems with (maximum) separations $\geq 10''$ have two or more entries in the Input Catalogue (e.g. a two-pointing double). In such cases an alterning observing strategy has often been used, again depending on $\Delta\mathrm{Hp}$. Some well-separated components had to be included for the purpose of correction only. With respect to magnitudes, the bulk of the stars are brighter than Hp = 10 mag, with an upper limit Hp = 12.4 mag (corresponding to V magnitude equal to 12.1 or 12.5 mag depending on the star's colours (Grenon et al. 1992). On the other hand, the Survey is essentially complete within the following magnitude limits:

$V \leq 7.9 + 1.1 sin|b|$

for spectral types earlier than or equal to G5,

$V \leq 7.3 + 1.1 sin|b|$

for spectral types later than G5.

Some results of this first astrometric space mission with respect to double stars deserve to be mentioned: from the systematic monitoring of a sample of 118.000 stars over 3 years, 3000 newly resolved doubles and several thousands of suspected doubles have been detected. In the (ρ, Δm) plane, the distribution of these new discoveries shows a high concentration in the practically unexplored regime ($\rho < 1''$, ΔHp < 4 mag)(Fig. 1 in Lindegren et al., 1997). It is also the first time that such a vast material of differential magnitudes (in the Hp passband) with a precision of 0.1 mag has been obtained for double stars of close and intermediate separation.

In terms of physical parameters, what kinds of double stars are actually considered by our programme? Limitations on the V magnitude of the primary components are obviously set by the abovecited mission constraints. Such limitations imply that, with respect to main sequence primaries,

– there are no faint M dwarfs (with absolute magnitudes ≥ 16 mag) in the sample,
– solar-type analogues (absolute magnitudes ≈ 5 mag) are included up to some 200 pc,
– dwarfs with spectral types earlier than F5 (absolute magnitudes ≤ 4 mag) are included up to 500 pc.

Limitations on the V magnitudes of the secondary component, on the other hand, are governed by the observational restriction Δm < 3 mag. This limits the range of the observable mass ratios. Depending on the spectral type, observable values range from unity up to a factor of 2 to 3.

By performing all-sky photometry with the CCD technique, we are entering a regime in angular separation where individual components are now photometrically measured with the same accuracy as with the conventional (photoelectric) technique currently used for joint systems and for individual components of wide pairs. The working area in the (ρ, Δm) plane is illustrated by Fig. 1. At the distance of 25 pc, conventionally adopted for the nearby stars, angular separations between $1''$ and $15''$ represent true separations ranging from 25 to 375 A.U. Taking an upper distance-limit of 500 pc, these values represent separations beyond 500 A.U. Therefore – though a wide range is covered- our sample specifically addresses that part of the distribution in true separation that is longward of the peak value near to 50 A.U. (cf. Fig. 1 in Dommanget and Lampens 1993). It will furthermore be adequate to investigate the natural "drop-off" for separations larger than some 2000–3000 A.U.

2.3. *Summary of campaigns*

Observations by this group have been performed in various observatories situated in both hemispheres. In the North we observed at Calar Alto (CAL, Spain), Jungfraujoch (JFJ, Switzerland), Observatoire de Haute-Provence (OHP, France), La Palma (LPL, Canary Islands). In the South the La Silla observatory was our unique facility (ESO, Chile). A three year lasting ESO Key Programme was dedicated to this project for the years 1992–1995 (7-009-49 K: Periods 49 to 54). Tables 1 and 2 summarize all the campaigns and the used instrumentation for South and North respectively. N.N. is the number of nights. Abbreviation codes for observers can be found in Table 3.

Table 1. Time allocation for CCD and conventional photometry: South (Key Programme included)

Type	Date	Observer	Per	N.N.
CCD	DUT 0.9m			
	Oct 91	J. CUYPERS	48	10
	Feb 92	W. SEGGEWISS	48	7
	May 92	J. CUYPERS	49	5
	Aug 92	P. LAMPENS	49	5
	Nov 92	E. OBLAK	50	5
	Mar 93	J. CUYPERS	50	5
	Jun 93	SINACHOPOULOS	51	4
	Aug 93	M. BURGER	51	6
	Dec 93	P. LAMPENS	52	5
	Feb 94	SINACHOPOULOS	52	5
	May 94	J.L. HALBWACHS	53	5
	Aug 94	P. LAMPENS	53	5
	Nov 94	E. OBLAK	54	5
	Jan 95	E. OBLAK	54	6
CVT	ESO 0.5/1m			
	May 92	J. CUYPERS	49	2
	Aug 92	P. LAMPENS	49	3
	Nov 92	E. OBLAK	50	5
	Mar 93	J. CUYPERS	50	4
	Jun 93	SINACHOPOULOS	51	3
	Aug 93	M. BURGER	51	4
	Dec 93	P. LAMPENS	52	4
	Feb 94	SINACHOPOULOS	52	3
	Aug 94	P. LAMPENS	53	5
	Nov 94	E. OBLAK	54	4

The status of the overall project is presented in Table 4. For these statistics, usage was also made of the first large-scale results for CCD astrometry and photometry of double stars of the Hipparcos Input Catalogue during 1986 and 1987 (Argue et al. 1992; referred to as "the" La Palma observations (LPA)). The CCD part of our programme has been completed to 56% of our initial objective, with a global contribution of 26% coming from LPA data, another 34% coming from observations by this group and 4% of data in common.

In the North, the main contribution of 35% comes from LPA observations while the ESO/OHP/CLA/LPL observations represent 25% and common stars from both sites contribute another 5%. The part of not observed northern systems represents another 35%.

In the South, the ESO observations represent a majority (35%) while 14% comes from LPA observations and common

Table 2. Time allocation for CCD and conventional photometry: North

Type	Date/Filters	Observer	Site	N.N.
CCD	V(R)I			
	Dec 91	OBL/FRO	OHP	7
	Mar 92	OBL/LAM	OHP	4
	Aug 92	E. OBLAK	OHP	6
	May 93	OBL/ZOL	OHP	6
	May 93	OBL/EMA	LPL	7
	Jun 93	SEG/LAM	CAL	5
	Apr 94	OBL/CMA	OHP	11
	Oct 94	OBL/CMA	OHP	11
	May 95	OBL/CMA	OHP	6
	Dec 95	CHARETON	OHP	5
	Jan 96	OBL/MOR	OHP	13
	Nov 96	OBL/FAL	OHP	10
	Feb 97	OBL/CHA	OHP	11
	Oct 97	E. OBLAK	OHP	11
	Jun 98	E. OBLAK	OHP	9
CVT	$UBVB_1B_2V_1G$			
	Feb 90	J. CUYPERS	JFJ	10
	Apr 91	P. LAMPENS	JFJ	15
	Jan 92	P. LAMPENS	JFJ	10
	Feb 93	LAM/HAL	JFJ	10
	Feb 94	P. LAMPENS	JFJ	10
	Jan 95	LAM/RUY	JFJ	10
	Mar 95	LAM/RUY	JFJ	10
	Feb 97	P. LAMPENS	JFJ	14

Table 3. Abbreviation codes for observers

Code	Observer
CMA	C. MARTIN
CHA	M. CHARETON
EMA	E. MARTIN
FAL	J.L. FALIN
FRO	M. FROESCHLE
HAL	J.L. HALBWACHS
LAM	P. LAMPENS
MOR	G. MORLEY
OBL	E. OBLAK
RUY	G. RUYMAEKERS
SAL	M. SALAMAN
SEG	W. SEGGEWISS
ZOL	E. ZOLA

stars contribute another 4%. The part of not observed southern systems represents 47%.

Also to be found in Table 4 is the number of observations of multiple systems: coverage was achieved for 41% in the South and only 16% in the North. At the request of the Hipparcos Double Star Working Group in 1993 an additional set of 81 triple systems with maximum separations between $1''$ and $15''$, but minimum separations (almost) always *below 1''* and no restriction in Δm (called ‘Multiple WG’ in Table 4) was observed with a partial coverage of only 31%. Another one hundred double stars of the Catalogue of Nearby Stars (Jahreiß and Gliese, 1991) that were not in the Annex of Double and Multiple Stars, have been introduced in the programme lateron, with results to be presented on a independent basis. The overall percentage of absolute photometry for all our southern runs (ESO only) spanning the period Oct. 91–Jan. 95 is about 40% of the truly observed time.

Moreover, also the conventional photometric part of our programme at ESO suffered heavily from poor climatological conditions: this part has been carried out to as little as 24% of our initial goal.

Some programme stars have been deliberately observed twice while some just happened to be in common between our observations and “the” La Palma (LPA) ones. For the CCD programme, this amounts to 297 cases out of 1698 for the doubles and to 16 cases out of 162 for the multiples. These data are very useful in the assessment of the computed errors for both the astrometry and the photometry.

3. The observational method

3.1. The common protocol

Two different techniques were employed, each of which required a specific protocol to be taken into account by all observers. Multi-colour observations have been obtained with the V (occasionally R) and I passbands of the Cousins system or sufficiently close to it. At ESO, CCD observations at the Dutch telescope were gathered through a Bessel V and a Gunn *i* filter.

The conventional photometric protocol is a classical one: programme objects and standard stars of the Cousins system taken from a list compiled by M. Grenon (1991) on the basis of lists prepared by Menzies et al. (1989, 1991) and Taylor & Joner (1989) were alternatively observed in all filters under photometric sky conditions only. At ESO, the same V(R)I filters were used. At Jungfraujoch (Switzerland), the Geneva photometric system with filters $UBVB_1B_2V_1G$ was employed. The standard star measurements were regularly spaced both in time and in colour. Special care was taken when measuring the sky contribution for each component (specifically if the angular separation was of the same order as the diaphragm size): we tried systematically to measure it diametrically opposed with respect to the other component and at about the same distance in angular separation. Observations are being reduced in a standard way and results on this part of the programme will be reported later on (after the presentation of all our CCD results).

A strict protocol was set up concerning the use of the CCD technique:

– we systematically avoided binning;
– sky flat-fields in each filter were taken at the beginning and at the end of each observing night; bias frames were taken more regularly during the night;
– focus sequences were made for each filter at the start of the night and, because of the focus problems (continuous shifts not always related to temperature effects), we frequently

Table 4. Status of CCD Observations

Type/Hem.	Content	Selected	Observed	%
CCD		Nr	Nr	
All	Multiple	618	161	26
	Double[a]	3014	1013	30+4
	La Palma[a]	3014	786	22+4
	common	3014	109	4
	all Doubles	3014	1690	56
Overlap[b]	Multiple	81	23	28
	Double[a]	375	289	77
North	Multiple	405	65	16
	Double[a]	1481	441	25+5
	La Palma[a]	1481	589	35+5
	common	1481	71	5
	all Doubles	1481	959	65
South	Multiple	295	120	41
	Multiple WG	81	25	31
	Double[a]	1908	746	35+4
	La Palma[a]	1908	355	14+4
	common	1908	81	4
	all Doubles	1908	1020	53

[a] with the double stars common to our and the LPA campaigns
[b] the zones overlap between $\delta_A > -10^\circ$ and $\delta_A \leq +10^\circ$

had to monitor and adjust the focus during the night in all our runs (compared to the short exposure times used for the acquisition of a single frame, the time needed for adjustment was not negligible, especially for the 0.9m Dutch telescope);

- for the double star programme we used whenever possible a 200x200 pixels window on the CCD chip for quick readout and fast file transfer on tape; the full chip was used specifically for the flat-fields, the multiple star programme and for the calibration (see Sect. 3.2 below);
- the 16-bits dynamic range was used whenever possible (requiring e.g. a one bit change option at the Dutch telescope);
- neutral density filters (with magnitude reductions of 2.5 or 5 mag) were employed on both programme and standard stars throughout the night if the former objects would have required exposure times below one second without them;
- for each object and each filter, a sequence of multiple exposures was defined with exposure times up to 30 s (sometimes 60 s) adapted so as to have maximum efficiency without overexposing the primary component. Mean exposure times are of the order of 10 s. The number of exposures in the sequence was evaluated as $10^{-0.4\Delta m}$, a function of the catalogued magnitude difference $\Delta m_{AB} = m_{V,B} - m_{V,A}$, with a maximum of 17 for $\Delta \mathrm{m} = 3$ mag.
- as for the conventional programme, standard stars from the list (Grenon 1991) were taken at regular intervals for the extinction calculation and to transform the data to the standard V(R)I system. Two possibilities were considered:
  a) under photometric conditions: insertion of few standards (about two per hour) permits to obtain standard magnitudes and colours and their differences;
  b) under non-photometric conditions: no standard stars observations; instrumental differences of magnitudes and colours only were acquired, implying some loss of accuracy.

3.2. *The astrometric calibration*

A by-product of our CCD observations is the relative geometric configuration of the objects. But different campaigns mean different CCD's, so varying scales and also varying orientations. In order to determine the orientation of the CCD stars were trailed over the full length of the chip and a number of "wide" double stars of fixed configuration (separation larger than 10″) from the lists by Brosche & Sinachopoulos (1988, 1989) called "astrometric standards" were observed to determine the scale at first. Later we realized that much higher accuracy could be obtained by the inclusion of open star cluster observations (Sinachopoulos et al. 1993). Finally, homogeneization of the astrometric data was achieved through direct comparison with the Hipparcos results. The transformation from the local coordinates to Hipparcos coordinates was done by minimizing the squares of all positional differences. Stars with large discrepancies (at the 3σ-level) were not included in the final calculation of the transformation. This allowed the determination of the orientation and of the scale at 0.07°, resp. at the 0.01% level (Oblak et al. 1997).

In the near future, we plan to provide a revised list of wide double stars of steady configuration because they serve well for a first order approximation of the scale and orientation values and because they are more widely dispersed on the sky than the until now available open clusters.

3.3. *Remarks on the Charge Coupled Devices*

A summary is given in Table 5. Mentioned are the observatory and telescope, the date, the general features of the CCD's used in the various campaigns such as identification number, pixel width, saturation level. Scale values and zero-points for the orientation will be given later. Worth mentioning is the fact that the stellar images obtained at the Dutch telescope always showed ellipticity. This is also taken into account in our reductions.

4. The reduction method

4.1. *Pre-reduction*

The raw CCD images in the various filters are treated in a standard way, i.e. bias subtracted and flat-fielded. Since our programme stars are bright, the results are not very sensitive to the choice of the used flat-fields. Median (sky) flats normalized to unit intensity over a couple of nights within one mission serve their purpose well as long as care is taken that identical observing conditions prevailed (no insertion/removal of neutral density filters; no CCD dismounting; no filter cleaning operation, etc.)

4.2. *Reduction of differential measurements*

Various packages exist for the accurate astrometric and photometric reduction of CCD images in crowded fields: they take

Table 5. Summary of CCD characteristics

Site/Date	CCD Nr.	Pxl.w.	Satur.
ESO	DUT 0.9m	(μ)	(KADU)
Oct 91–Nov 92	7	22	16.8
Mar 93	5	30	50
Aug 93–Dec 93	29	27	32
May 94	5	30	50
Aug 94	29	27	64
Nov 94–Jan 95	33	27	64
OHP	0.8/1.2m	(μ)	(KADU)
	RCA1	30	22
91–98	RCA2	30	19
	TK512	27	32
CLA	1.2m	(μ)	(KADU)
93	TEK4	27	18
LPA	1.0m	(μ)	(KADU)
93	EEV7	22	64

advantage of some well-exposed, isolated stars in the field of interest. The larger the number of isolated stars, the better the accuracies (e.g. DAOPHOT developed and distributed by P. Stetson (1987)). However they cannot be applied here: the limited chip size coupled to the brightness of the objects makes that the majority of our frames show two overlapping profiles, usually without any other star in the field. A direct profile fitting method, that allows the separation of the individual profiles of the closest pairs, i.e. the pairs with separations somewhat larger than the width of the seeing disk, is thus desirable.

A one dimensional profile fitting method has been used by Sinachopoulos (1992): it implies fitting a Franz profile to a row and a column projection for each frame via a least squares method supported by an expert system. It was applied to double stars having separations generally larger than $5''$. The reduction of closer pairs observed at La Palma was done by applying another method based on centroids and isophotes (Irwin 1985). Our approach is different: a specific two-dimensional profile fitting method was developed within the MIDAS software package (Cuypers 1997). This reduction method fits with a least squares technique a bidimensional Moffat profile (Moffat 1982) with elliptical isophotes to all the components simultaneously. Since the angular separation of the components is generally less than the size of the isoplanatic area, the shape of the point spread function can indeed be considered identical for all components. This method favourably compared to DAOPHOT and was succesfully applied to systems with up to 10 “components” (Lampens & Seggewiss 1995). The data obtained consists, after sky subtraction, of relative positions and differential magnitudes in each of the filters.

4.3. *Reduction of magnitudes in a standard photometric system*

We already reported that during nights of good photometric quality standard stars in the Cousins system have been observed (see Sect. 3). These stars were used in a least squares model to derive extinction values for each night and transformation coefficients from the instrumental to the standard system. The differences between both pairs of standard passbands (V,*i*)*(Bessell/Gunn)* vs. (V,I)*(Cousins)* are not negligible but they are safely treated by the transformation equations.

If possible, several nights of the same observing campaign were reduced simultaneously in order to obtain more accurate values for the zeropoints and transformation coefficients. Nights with neutral density filters were always treated separately. Colour corrections were linear. A breakpoint in colour was introduced when necessary in order to have the possibility of using different colour corrections for blue and red stars.

In general, transformation errors were shown to be of the order of 0.02–0.03 mag (Lampens et al. 1997a).

Instrumental global magnitudes (for the system) have also been computed for all observed programme stars. Individual component magnitudes were then derived from these and the differential magnitudes obtained earlier. All component magnitudes have been subsequently transformed into the Cousins standard system, after correction for the extinction. Errors on the CCD global magnitudes are comparable to those from photoelectric photometry (a few millimag in good conditions): they come from the photon statistics. On the other hand, errors on the differential magnitudes are introduced through the fitting procedure and are somewhat larger: they are much reduced by taking a series of exposures (and depend on angular separation as well as on the difference itself, Lampens et al. 1997a). These two error sources contribute differently to the errors on the component magnitudes that will be listed in the forthcoming papers of the series.

5. Prospects and conclusions

5.1. *First results and prospects*

First but preliminary results have already been presented on various occasions (Oblak et al. 1993b; Oblak et al. 1996; Lampens et al. 1997a; Oblak et al. 1997). The data papers should soon follow. A detailed comparison with the recently published Hipparcos data will be done after completion of the reduction for all missions. In addition, we will publish a list of astrometric calibration double stars: these are the wide double stars of our lists with steady configuration that can be used anywhere on the sky for estimating the scale and the orientation of CCD cameras.

5.2. *General conclusions*

1. We obtained high-quality astrometry and all-sky multicolour photometry for the components of intermediate visual double stars using small telescopes of the 1m class equipped with a CCD. The final accuracy level of our data matches that of the Hipparcos mission for systems with angular separations in the range $2''$ to $12''$. This has been possible thanks to the introduction and application of a strict protocol combined with the common usage of a dedicated reduction procedure.

2. We used this specific reduction tool for images containing up to 10 "components" and for separations ranging from very large (over 30″) to very close, i.e. down to the limit imposed by the seeing disk. The method proved to be superior to a reduction by means of the cluster reduction package DAOPHOT (also available in the MIDAS software).
3. We were able to provide a priori ground-based values for the geometric configuration of hundreds of "intermediate" visual double and multiple systems for the HIPPARCOS double star reduction: for several systems with angular separations above 1″, this new information, given along with the individual colour indices of the components, allowed to remove the ambiguities generated by the grid step ($\sim 1.2''$) and thus to improve the reliability of the Hipparcos Catalogue solution. These results were also valuable for providing a good starting point during the double star re-reduction by the Hipparcos Reduction Consortia (Falin & Mignard 1998).
4. Such observations allow to deduce a very sparsely known quantity among close visual binaries: the colour difference between individual components. This information has been very useful for comparing with the data from the Hipparcos mission. Component colour indices are important astrophysical parameters that are missing in too many researches on double and multiple stars: however they are easily and accurately obtained for those systems with separations in the intermediate range with simple means in excellent photometric conditions. The determination of the distribution functions of true separations, mass and luminosity ratios, differences of temperatures for a significant sample of double stars are obvious future applications, profitable in the domains of e.g. stellar formation and modeling of double stars. Of course, we will include the $\approx 11\%$ of (wide) systems already having good and complete photometry in such studies.

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