A FORTRAN 77 PACKAGE

HEC22 / VYPAR

USER'S MANUAL

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REDUCTION OF PHOTOELECTRIC OBSERVATIONS, TRANSFORMATION TO STANDARD SYSTEMS, ARCHIVING AND RETRIEVAL

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Availability of the software

The authors make this package available to all interested colleagues upon the condition that its usage will be acknowledged in any publication based on data reduced with it, for instance, by a reference to the paper by Harmanec, Horn and Juza (1994) or Harmanec and Horn (1995, 1997).

We strongly recommend you to notify us via e-mail about your becoming a user of this software. Your e-mail address will be registered and you will be notified of any future improvement or extension of the software package.

ORGANIZATION OF THE MANUAL

This manual contains the following sections:

1. Purpose, general background and literature;
2. HEC22 program: a detailed description of its operation and practical use;
3. VYPAR program: a description how to organize data archives created by HEC22 and retrieve data sets;
4. Auxiliary programs;
5. Practical hints about the use of the software package, with suggestions for more advanced applications;
6. Limitations of the current software;
7. Contents of the package: a complete list of programs and data files contained in the package, with their description; and
8. Notes on implementation

1 PURPOSE, GENERAL BACKGROUND AND LITERATURE

This package represents a powerful tool for complete reductions, archiving and subsequent retrieval of photoelectric observations. It is especially suited for the reduction of Johnson UBV or Strömgren $uvby$ observations but it can also be adapted to reduce observations obtained in other photometric systems which use 3 or 4 filters (data obtained in photometric systems using more than 4 filters would have to be reduced in subsets of 3 or 4 filters). Reduction of observations obtained through only 1 or 2 filters are also possible but such measurements can only be transformed reliably into a standard system for stars for which the standard $U-B$ and, for one-colour observations, also the standard $B-V$ index is known in advance. This way, it is even possible to trasform to the standard system the observations of variable stars whose colour indices do not change for more than a few hundredths of a magnitude. (Note that this limitation is given by the very nature of the problem, not by imperfection of the reduction software.)

The core of the package is formed by two main programs, HEC22 (writen by P.H.) and VYPAR (written by J.H.).

Program HEC22 is designed for an automatic multi-night reduction of photoelectric observations, their stable transformation into extinction-free instrumental and standard magnitudes, and data archiving. All-sky as well as differential photometry of many different stars can be treated by the program.

Program VYPAR can be used for sorting, copying, organizing, extending and editing the data archives and for data retrieval. It also provides basic statistical information about each archive. The program allows extraction of individual or suitably averaged data for individual objects according to various criteria (data quality, origin etc.).

All-sky as well as differential data archives can be created, sorted and stored. In the already sorted archive, data is stored in an increasing order of the HD numbers of observed objects (please, note that it is necessary to assign numbers larger than 500000 to objects that do not have HD designations), and in an increasing order of Julian dates of observations for each object. This structure is suitable for the fast subsequent retrieval of data for a specific object.

A rather conservative way of programming was adopted for all programs of the package. The reward is that the package can easily be compiled and run on virtually any type of the currently used computers and under various operating systems (e.g., DOS, UNIX or VMS).

Operation of HEC22 and VYPAR is basically controlled by control records which are specified in a control data file. There must be a one-to-one correspondence between the control records and nights (or segments of nights) of measurements for HEC22. All observations from a given season can be stored and treated as a *single* data file.

For the general background of the adopted strategy of data reduction and transformation, the reader is referred to Harmanec, Horn and Juza (1994) where also many references to other relevant papers can be found. The present reduction scheme has developed from a less advanced code, HEC9 (see Harmanec, Grygar, Horn et al. 1977) with which it shares a number of structural similarities. Some general remarks on the problem can also be found in Harmanec (1994). For useful examples of the performance of HEC22, the reader is referred to, e.g., Stagg, Božić, Fullerton et al. (1988), Harmanec, Matthews, Božić et al. (1991), Harmanec, Horn and Juza (1994), Božić et al. (1995), Pavlovski et al. (1997) or Harmanec et al. (1997) for the case of UBV data, and to Štefl, Baade, Harmanec and Balona (1995) for $uvby$ data reduction.

2 PROGRAM H E C 2 2

2.1 Purpose, operation and the equations used

The Fortran77 program HEC22 is a powerful tool for complete reductions of UBV, $uvby$ or other multicolour photometry including the data archiving. It can handle several types of data. Output from most photometers can be easily tranformed into the form of input data type A or B of HEC22 (see subsection 2.2). If necessary, the user can also change the format of input data in subroutine DATA or even modify this subroutine as desired.

Program HEC22 is designed to reduce automatically all observations from a given night or a whole observing season. It employs all suitable comparison and check stars as standard stars for the calculation of the extinction and colour transformation coefficients, but the ultimate choice of stars and nights suitable for the determination of these coefficients is left to the user. We stress that in spite of the highly automated operation of the program, the initial phase of a *careful inspection* of the data from individual observing nights in the program output after the first raw data reduction *should always be performed*!

The following notation is used throughout this manual:

V, B, U, W	... standard (extinction-free) magnitudes
v_0, b_0, u_0, w_0	... extinction-free magnitudes in the instrumental system
v, b, u, w	... observed magnitudes in the instrumental system
t	... time of observation
X	... air mass

In the case of Johnson UBV photometry, the letters V, B, U refer to respective filters; in the case of Strömgren $uvby$ photometry, the following notation is used:

Strömgren filter	Notation used here
y	V
b	B
u	U
v	W

The transformation coefficients G between the observed and extinction-free magnitudes determined (or fixed) separately for each night of observations include the first-order extinction coefficients and a possibility to compensate for a linear or quadratic variation of the zero point of the system and/or extinction at zenith during the night. They read as

$$\begin{aligned} v &= v_0 + G_1 + G_5\,X + G_9\,t + G_{13}\,t^2, \\ b &= b_0 + G_2 + G_6\,X + G_{10}\,t + G_{14}\,t^2, \\ u &= u_0 + G_3 + G_7\,X + G_{11}\,t + G_{15}\,t^2, \\ w &= w_0 + G_4 + G_8\,X + G_{12}\,t + G_{16}\,t^2. \end{aligned} \qquad (1)$$

The colour transformation equations used for each magnitude (V, B, U, W) are linear in the $U - B$ index but have the form of a third-degree polynomial in $B - V$. This form of the equations is necessary to compensate for the unavoidably non-linear effect of the Balmer jump on the magnitudes of stars between mid-B to F spectral types (c.f., e.g., Cousins and Jones 1976). The colour e x t i n c t i o n coefficients in the form recommended by Young et al. (1991) are also included among the seasonal transformation coefficients. It is our experience that this form of transformation equations ensures the reproduction of the standard Johnson system within $0\overset{m}{.}01$ even in U for any standard star.

The equations are:

$$\begin{aligned}
v_0 - V &= H_1(B-V) + H_2(U-B) + H_3(B-V)^2 + H_4(B-V)^3 + H_5\,X\,B_4(B-V+0.5\,X\,B_4) + H_6,\\
b_0 - B &= H_7(B-V) + H_8(U-B) + H_9(B-V)^2 + H_{10}(B-V)^3 + H_{11}\,X\,B_4(B-V+0.5\,X\,B_4) + H_{12},\\
u_0 - U &= H_{13}(B-V) + H_{14}(U-B) + H_{15}(B-V)^2 + H_{16}(B-V)^3 + H_{17}\,X\,B_5(U-B+0.5\,X\,B_5) + H_{18},\\
w_0 - W &= H_{19}(B-V) + H_{20}(U-B) + H_{21}(B-V)^2 + H_{22}(B-V)^3 + H_{23}\,X\,B_5(U-B+0.5\,X\,B_5) + H_{24},
\end{aligned} \tag{2}$$

where $B_4 = G_6 - G_5$ and $B_5 = G_7 - G_6$.

Please, note, that in this formalism, quantities with suffix 0 are not in fact really extinction-free instrumental magnitudes but extinction-free magnitudes *uncorrected* for the colour extinction which is only taken into account in the seasonal transformation equations.

We warn that it is necessary to obtain observations of a reasonably large number of standard stars of different colours, luminosity classes and reddenings to derive reliable non-linear transformation coefficients H. Since this is not always possible, e.g., due to bad weather, the latest version of HEC22 also permits the use of bilinear transformation formulae which contain no terms of the second and third power in $(B-V)$ and converge to reasonable transformation coefficients in most situations. This compromise is, however, at the expense of a slightly worse transformation into the standard system — but still much better than would result from the use of the often applied linear transformation formulae. The possibility to derive and use *linear* transformation formulae is also included in release 13 of the program (non-zero coefficients $H_1, H_6, H_7, H_{12}, H_{14}, H_{18}, H_{20}$ and H_{24}). This can be justified in situations when the observations only include objects with a limited range of colours or for passbands covering the flat parts of the stellar energy distributions (R or even V, for instance). Note that from rel. 13 on, the user can specify the type of the transformation to be derived and used *for each passband separately*, for instance linear in V, bilinear in B and non-linear in U.

GENERAL PHILOSOPHY OF THE REDUCTIONS

The HEC22 program is designed for multi-night reduction. It means that all observations in a given photometric system from one season, for which one set of seasonal transformation equations can be derived and used, are stored sequentially in a single DATA file (see subsection 2.2.1 below). It is not important for the reductions and archiving whether observations from individual nights (or segments of the nights in case of a discontinuous change of atmospheric conditions, high voltage etc. during the night) are stored in the order of increasing date of observation or in some other sequence. Since, e.g., the G coefficients are kept in the computer memory and used until overwritten by a new input or calculation, the choice of a suitable order of observing nights can even be used for a more convenient arrangement of the reductions. It is necessary, however, for the proper functioning of the program to preserve the time sequence of observations *within* each segment of night which is reduced separately.

The operation of the program on each night of reduction is controlled by one record of the CONTROL file. The CONTROL file contains several integer keys which specify various inputs, type of data and similar things. There must be a one-to-one correspondence between the order of the control records in the CONTROL file and the order of individual nights (or their separate parts) in the DATA file. Moreover, it is possible to enter new values of various variables in the CONTROL file if requested by appropriate keys in the CONTROL file. Such values must appear in records immediately following the control record in question and their order (if more of them are requested by the control record) is the same as the order of the keys which cause the input. It is convenient to enter all such values which apply to the whole season (like seasonal transformation coefficients, gains or dead-time coefficient) after the first control record.

Finally, the type of each specific object (variable, comparison, check, transformation standard) is defined in TABLE OF OBJECTS where also coordinates and magnitudes of all observed stars are specified.

This way, the user is controlling the operation of the program by changing control records or — if necessary — the type of objects in TABLE OF OBJECTS and need not make any changes in the DATA file with the exception of initial omission of bad observations and splitting of some nights into two or more segments if some discontinuity was noted in the run of the O-C deviations.

The program can operate under several regimes, separately for each night. Also the level of information in the output print file can be controlled by the user. For those who have no previous experience with this type of software, it may be useful to have a look into Sect. 5 before reading the detailed description of how to control the operation of the program in the rest of Sect. 2.

2.2 Input and output files of HEC22

2.2.1 Input files

DATA FILE

The observations are stored (night by night) in one file for a whole season for which the same colour transformation coefficients will be calculated. Type A or type B data are acceptable (and can be arbitrarily combined in this data set). Their format differs somewhat from that used already for HEC9 (Harmanec et al. 1977) but is identical to that used by the previous versions of HEC22. Most of the photometers produce data which can be transformed into the form of the type A or B data using a simple conversion program (for examples see sect. 4.1 below) or data editing. (The program also recognizes data of type C and D but these special data types are specific for the photometers used at the Hvar Observatory and are not described here since they can hardly be of any wider use.)

Here are a detailed description and examples of various possible forms of the input data:

Each night of observations begins with 3 (or 4) records containing the following information:

- 1^{st} and 2^{nd} record (`input format 5A8`): Header defining the night, program etc.: any text string supplied by the user — both records will appear as one line of header in the print output
- 3^{rd} record (`input format F3.0,I3,I5,3I2,3X,4F10.5`) contains:
  - date of observation in the form day-month-year; please note that the date of the *beginning* of the night in *local time* must always be specified! If your data aquisition system is recording the time in U.T., you have to set the value of PAS to zero (see below) but be sure to have the correct U.T. date of the beginning of the night
  - number of bandpasses (filters) NC through which the observations were carried out; NC must not exceed 4
  - numerical code of the observatory; altogether, 20 different observatories with their geographic coordinates and corrections of local time to U.T. are built in release 13 of HEC22 and automatically used if their code is specified in this record; for their list see the file STATIONS.TEX of the package; if an observatory code larger than 20 is specified, the program reads the 4^{th} record with the geographic coordinates, time correction and name of the site — see below; please, do not be confused by the fact that the examples below quote different observatory codes for observatories built in the program — this is only to show the use of the 4^{th} record in the data as an example
  - number of digits of the deflections preceding the decimal point, NDIG, for DC photometers; this value can be set to zero or left blank for photon-counting photometers
  - a linear time correction of the times specified with the observations for the given night in minutes (called CTIME in the print output); this can be conveniently used in cases when some systematic error of the clock was detected after the data were recorded or to correct for the summer-time shifts, for instance; otherwise, it can again be left blank or zero
  - high voltage of the DC photometer in volts; if specified, this value is used to correct for small non-linearities of DC photometers occurring for very bright stars (c.f. Harmanec, Horn and Juza 1994); in most applications this datum should be left blank
  - integration time of photon-counting photometers in seconds. This datum is left blank or zero for DC photometers and can also be left zero for photon-counting instruments if you use some standard integration time and specify a correspondingly smaller dead-time coefficient in the input (see Sect. 5 for a detailed explanation)
  - time interval (in seconds) over which observations of a given star in each filter are to be averaged into normal points; this regime offers a solution in situations when different numbers of observations through different passbands was obtained (for Type B data only, see below). Control Key 1 has to be set to 1 (see the subsection CONTROL FILE below).
- 4^{th} record (`input format 7F10.5,A8`) may only appear in the data if an observatory code larger than 20 was specified in the 3^{rd} record. It contains:
  - geographic longitude of the site (hours, minutes, seconds) *positive* for observatories east of Greenwich; please, note that the geographic coordinates enter as real variables of up to 10 digits which allows the user to specify, e.g., only hours of latitude with its decimal fraction as in the examples below; the sign must only be specified for hours of latitude and degrees of longitude
  - geographic latitude (degrees, arcmins, arcsecs)

– an arithmetic (additive) time correction PAS (in hours) of the time recorded during the observations to Universal Time (U.T.)
– name of the observatory (max. 8 characters)

Records with the observations which follow after the three or four records described above differ for type A (condensed) and type B data

Type A data: A condensed format for multichannel photometers or observations with only one mean time associated with each complete observation in all filters

```
Input format: 1, 2 or 3-colour observations: I5,2F3.0,F9.6,6F10.0
                        4-colour observations: I5,2F3.0,F9.6,4F10.0,4F5.0
```

Each record contains:

- identification number of the observed object in the TABLE OF OBJECTS; number 0 denotes the end of the observing night or of its segment; the program then reduces this particular night and expects input data for another night (or segment) or end of file
- time of observation in hours, minutes, and seconds
- deflections in 1, 2, 3 or 4 colours (usually 1=V, 2=B, 3=U, 4=W) immediately preceded by the running number of the gain for DC photometers (thus, e.g., 1255.3 means a deflection of 55.3 in gain 12 if the number of digits NDIG was set 2 in the third record (see above), deflection 255.3 in gain 1 if NDIG=3, and so on)
  or
  counts (without any gain, of course) for photon-counting systems
- sky deflections or counts (without preceding gain) in the same order of colours, i.e. 1, 2, 3, and 4

Please, note that for 1- or 2- colour observations the sky readings must also be specified in columns 51–60 for colour 1 and columns 61–70 for colour 2; the format of data only differs for 4-colour observations

Type B data: For data for which the time of observation is recorded separately for each individual observation through a given filter

```
Input format: I1,I4,2F3.0,F9.6,F10.0
```

Each record contains:

- number of filter (colour); again $1 = V$, $2 = B$, $3 = U$, $4 = W$
- identification number of the observed object in the TABLE OF OBJECTS; number -1 denotes a sky reading through the respective filter (and for given gain in the case of DC photometers); number 0 denotes the end of the observing night or of its segment; the program then reduces this particular night and expects input data for another night (or segment) or end of file; *please, note that the order of the observations through the individual filters can be arbitrary and that the corresponding sky readings are automatically interpolated into the times of stellar observations before subtraction. However, the total number of stellar observations must be the same in all filters — otherwise an error message is generated by the program.* The only exception is regime 1 of the calculations (see above and also section CONTROL FILE below) which does data averaging and tolerates a different number of observations in different bandpasses.
- time of observation in hours, minutes, and seconds
- deflection in the specified colour immediately preceded by the running number of the gain for DC photometers (thus, e.g., 1255.3 means a deflection of 55.3 in gain 12 if the number of digits NDIG was set 2 in the third record (see above), deflection 255.3 in gain 1 if NDIG=3, and so on); note that for this type of data the gain m u s t also be specified for the sky readings (in contrast to type A data!)
  or
  counts (without any gain, of course) for photon-counting systems

Examples of the input data files (for more examples, see the data files in the package):

i. Type A *uvby* data

```
--------------------------------------------------------------------------------
         10        20        30        40        50        60        70        80
....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|

Night  2/92 La Silla 0.5-m uvby S.Stefl
good in the evening,interrupted by cloud
16.  5 1992 421
 -4.715333                   -29.257168                         5.0  La Silla
    2 18 20 57.93600     895.4    1112.3     380.0     893.0 22.9 19.7 24.7 15.1
    1 18 22 58.89600  156770.6  237793.4  328993.6  272699.0 29.2 31.5 44.1 29.7
    7 18 25  4.17600     678.3     918.2     355.2     876.2 19.3 15.2 22.1 14.1
    2 18 27  6.86400     906.3    1112.4     388.8     905.0 22.0 16.4 23.1 14.1
   16 18 30  1.39200    1398.3    1982.5    1631.2    2067.4 40.3 37.3 28.5 24.6
   11 18 32  6.67200   42235.9   63349.6   75025.3   71451.0 34.5 31.0 30.3 25.5
    0
```

ii. Type A *UBV* data

```
UBV PHOTOMETRY BY PAVLOVSKI
                   C h a r t   P 23 / 77
11.  5 1977 3 1 0 16
  598 22 43 54.08838   771.800   656.700   972.000     5.000     5.000     5.300
  537 22 48 34.47352   783.000   665.000   987.600     5.200     5.000     5.200
  598 22 51 24.70736   771.200   656.000   973.200     5.100     5.100     5.300
  537 22 54 54.99621   786.200   668.000   993.800     5.200     5.100     5.400
  534 22 57 55.24380   689.000   576.100   759.800     4.900     4.700     4.300
  535 23  1  5.50515   681.700   571.600   760.400     4.900     4.700     4.200
  536 23  3 25.69772   677.400   566.900   896.300     4.600     4.700     4.500
  598 23  7  6.00033   769.600   655.000   971.100     4.700     4.700     4.800
  537 23  9 16.17914   778.900   662.300   986.100     4.800     4.700     4.700
  598 23 11 56.39922   767.900   653.700   969.900     4.700     4.800     4.600
  537 23 13 56.56428   776.100   661.000   984.000     4.900     4.800     4.800
  534 23 16 26.77061   679.400   567.200   755.000     4.700     4.500     4.000
  535 23 19  6.99069   672.900   564.400   754.000     4.500     4.300     4.000
  536 23 21 37.19701   671.900   562.100   889.000     4.700     4.500     4.100
  537 23 24  7.40334   775.400   660.600   983.200     4.600     4.600     4.600
  598 23 26 47.62342   767.100   653.400   970.300     4.700     4.600     4.600
  537 23 28 57.80223   779.200   662.900   986.000     4.600     4.600     4.500
  598 23 30 47.95354   770.300   655.600   972.900     4.600     4.500     4.400
  537 23 32 18.07733   780.600   664.000   989.400     4.700     4.600     4.300
    0

....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
         10        20        30        40        50        60        70        80
--------------------------------------------------------------------------------
```

iii. Type B *uvby* data:

```
--------------------------------------------------------------------------------
         10        20        30        40        50        60        70        80
....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|

Night  2/92 SAAO 0.5-m uvby P.Harmanec
35" a good clear night
13.  5 1992 422
  1.387464                  -32.378333                          -2.0  SAAO
1   2 19 16  74.0000    63355.0
2   2 19 17  45.0000    64859.9
4   2 19 18  16.0000    38113.8
3   2 19 18  47.0000    11002.2
1   6 19 21  27.0000    10383.0
2   6 19 21  58.0000     7454.1
4   6 19 22  29.0000     2655.4
3   6 19 22  60.0000      716.0
1   1 19 25  68.0000 11279269.8
2   1 19 26  39.0000 14309828.2
4   1 19 26  70.0000 12344451.8
3   1 19 27  41.0000 10861545.6
1   2 19 31  70.0000    64297.6
2   2 19 32  41.0000    66891.8
4   2 19 32  72.0000    40090.4
3   2 19 33  43.0000    11792.4
    0

....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
         10        20        30        40        50        60        70        80
--------------------------------------------------------------------------------
```

TABLE OF OBJECTS

This input file contains basic information about all observed objects:

- running number with which each star is referred to in the data file,
- relevant epoch and equatorial coordinates of given object,
- V, $B-V$, $U-B$ (and W) standard magnitudes and indices,
- type of object [variable, comparison, etc. — see below],
- HD number, and
- name of the star under which it will appear in all outputs.

Please, note that this file is similar *but not identical* in format to such a file used in the earlier versions of HEC22 for UBV.

Here is an example of the present form of the TABLE OF OBJECTS (please, note that the scale defining the position of columns and the header with the names of columns are n o t parts of the data file used by the programs):

```
--------------------------------------------------------------------------------
       10        20        30        40        50        60        70        80
....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|

 No.  Epoch  R.A.     Decl.      V      B-V   U-B     W       HD        Name
   Type
             h  m  s   o  /  //
  1 1 2000 13 25 11 -11  9 41   .961  -.102  -.047   .827    116658   Alpha Vir
  2 8 1992 13 16 58 -11 26 20  6.619   .134  1.608  7.141    115446   HD 115446
  3 9 2000 12 54 19 -11 38 55  6.004   .029  1.431  6.244    112131     HR 4901
  4 3 1992 13 18 30 -11 57  0  7.420   .000   .000   .000    115679   HD 115679
  5 3 1900 13 19 54  -8 38  0  9.088   .352  1.635 10.000    115725   HD 115725
  6 3 1900 13 14 30  -8 34  0  8.577   .560  2.197 10.043    115812   HD 115812
  7 9 1900 12 52  6  -8 22  0  6.946   .036  1.495  7.186    112504   HD 112504
  8 9 2000 13 09 57  -5 32 20  4.379   .000  1.440  4.520    114330   Theta Vir
  9 9 2000 13 26 11  -1 11 33  5.980   .088  1.563  6.369    116831     HR 5059
 10 3 2000 13 32 03 -18 43 44  6.017   .108  1.582   .000    117661      73 Vir
 11 1 2000 14 35 30 -42  9 28  2.355  -.087   .076  2.252    127972     Eta Cen

....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
       10        20        30        40        50        60        70        80
--------------------------------------------------------------------------------
```

The TABLE OF OBJECTS shown here is for $ubvy$ data; the format of the TABLE OF OBJECTS used for UBV data is identical, with the exception that there will be an empty space instead of the column containing the W magnitude.

The following "types of objects" are distinguished in the second column:

1. .... variable star
2. .... comparison star with unknown or poorly-known magnitudes
3. .... check star with unknown magnitudes
4. .... standard star with magnidutes good enough for calculation of nightly (extinction) but not seasonal coefficients
5. .... comparison star with magnitudes as type 4
6. .... check star with magnitudes as type 4
7. .... standard star with reliable standard magnitudes suitable also for the determination of seasonal transformation coefficients

8. .... comparison star with good standard magnitudes as type 7

9. .... check star with good standard magnitudes as type 7

Please, note that this — seemingly complicated — system of "types of objects" allows the user to employ as many comparison and check stars from the program as possible for the determination of the nightly and seasonal transformation coefficients. New comparisons and checks with unknown standard magnitudes must first be treated as types 2 and 3. However — as soon as their standard magnitudes are derived from several good observing nights — the whole season can be re-reduced if these preliminary standard magnitudes are entered into the TABLE OF OBJECTS and such comparisons and checks are re-defined as types 5 and 6. The program then uses also these observations for the determination of the linear extinction and zero-point shifts for each observing night. After improving the standard magnitudes of such comparisons through systematic observations over several seasons, it is then possible to include them among transformation standards and code them as types 8 and 9 in the TABLE OF OBJECTS.

To put it simply: The program uses all available observations of stars of types 4 through 9 for the determination of the nightly transformation but only stars of types 7 through 9 are used to the determination of the seasonal transformation coefficients H.

CONTROL FILE

This is the file which tells the program how to proceed with the reductions of each night of data. Each night of observations (or a separate segment of a night) must be represented by one control record with keys and there must be a one-to-one correspondence with the order of nights in the data set. In contrast to the earlier versions of HEC22, this file begins with several records which allow the user to specify all other input and output files using the names under which the corresponding files are stored (or will be stored) in the disk space of the computer.

Following is the detailed description of the format of the CONTROL file. The meaning of most keys was preserved from the previous versions of HEC9 and HEC22 but some of them had to be changed or contain more options now! Note also that in an effort to retain only one control record for each night of observation, several of the keys consist of two or more digits and represent actually several independent keys.

- 1$^{\text{st}}$ record `(input format 3I2)` contains three integer keys which specify requirements for the output files for the differential archive, all-sky archive and colour-extinction file, respectively. Zero value indicates that the respective file is not required.

- 2$^{\text{nd}}$ record specifies the filename of DATA FILE with observations in the DOS convention, i.e. up to 8 characters for the file name and up to 3 characters for the extension (for instance HVAR85.DAT).

- 3$^{\text{rd}}$ record specifies the filename of TABLE OF OBJECTS, again in the DOS convention.

- 4$^{\text{th}}$ record specifies the filename of the output file with the results of calculations.

- 5$^{\text{th}}$ to 7$^{\text{th}}$ records specify the filenames of the output files for the differential archive, all-sky archive and computed linear extinction coefficients. Each of them must appear in this data set *when and only when* the corresponding key in the first record is non-zero!!!

- 8$^{\text{th}}$ to n^{th} records contain control keys for each night of observation, sequentially in the order as the individual nights appear in the data file. For the two- to five-digit keys, the digits are denoted a, b, c, d, i.e. numerically
  key = 10a + b, or
  key = 100a + 10b + c, or
  key = 10000a+1000b+100c+10d+e, respectively

- Key 1 *a two-digit key*
  - digit a: > 0 ... indicates that another part of the same observing night will follow immediately in the data file. This option gives the user the possibility to break one night into parts if necessary (e.g. because of the change of voltage or other reasons for a discontinuous jump in the zero point of the system) by just using one zero record in the data file at the point of split, the usual records with the header, date of observation etc. being omitted; the previously entered values for the same night are used instead.
  - digit b:
    - 0 ... differential photometry
    - 1 ... differential photometry with unequal number of observations in different passbands; normal points over specified intervals of time will be created; this regime is meaningful for type B data only
    - 2 ... pure all-sky photometry
    - 5 ... calculation of the colour transformation coefficients from all previously reduced nights for which Key 9 > 99
    - -1 ... endfiles and stop
- Key 2 a non-zero value specifies the input of three (four in case of Strömgren photometry i.e. when the NC parameter in the data file is set equal to 4) records with the colour transformation coefficients (`input format 6F10.5`) following immediately after the corresponding key record. If the first record also contains a non-zero dead-time coefficient, the data are automatically handled as coming from a photon-counting instrument (no gains are expected) and the dead-time correction is applied automatically during the processing. Please, read the detailed comments on the use of the dead-time coefficient in Sect. 5
- Key 3 a non-zero value specifies input of one record with the extinction coefficients $G_4, G_5, G_6, (G_7)$ (`input format 4F10.5`).
- Key 4 a positive value specifies the input and *the number* of gains (calibration coefficients) in magnitudes. The maximum allowed number of gains is 30; they enter with format `8F10.5`, i.e. eight per one record; the number of records with the gains is controlled by the *value* of key 4 and equals to MOD(key4,8)
- Key 5 specifies the type of data:
  - 0... data A,
  - 1... data B,
  - -1... data B with sky readings already subtracted from the stellar deflections; see the description of the data files above for more details
  - 2... data C,
  - 3... data D,
- Key 6 *a two-digit key*
  - digit a:
    - 0 ... no trend
    - 1 ... linear trend
    - 2 ... quadratic trend of the zero points during the night is calculated for the stars used to derive the nightly transformation coefficients;
  - digit b:
    - 0 ... calculation of the first-order extinction coefficients is required
    - 1 ... fixed extinction, read from the CONTROL file (see key 3) or calculated in a preceding night, is used
- Key 7
  - -1 ... suppresses prints into PRINT file. (Note that positive values of this key no longer produce printed output of the original data as it was the case with releases 7 and earlier since the data file can now be viewed directly with the help of any suitable data editor.)
  - $<$ -1 ... cancels the suppression of the prints. This option allows the user to obtain the output for just one or a few nights of the whole season which still need some inspection while retaining all observations as a single data file; suitable during the initial phase of data inspection and removal of bad observations. Note that this key must be set equal to zero when the data archives are being created during final reductions

– Key 8
  * $\neq 0$ asks for input of TABLE OF OBJECTS (usually with the first night of data);
  * < 0 causes the table not to be reproduced in the print file;
  * ± 1 input of another TABLE OF OBJECTS is requested; the user must specify the filename of the new TABLE OF OBJECTS in a record immediately following the control record;
  * ± 2 addition and/or expansion of a previously entered TABLE OF OBJECTS will be read *directly from the CONTROL file*; records of such additional TABLE OF OBJECTS must be followed by one blank or zero record; all items of the previously entered TABLE, not overridden by the newly entered additions, will remain in computer memory. This gives the user a possibility to define, for instance, different magnitudes of the comparison, which turned out to be variable in some predictable way, for each observing night.
– Key 9 *a three-digit key*
  * digit a: a positive value indicates that the night is suitable for calculation of colour-transformation coefficients
  * digit b: a positive value indicates that the night is suitable for the determination of all-sky standard magnitudes
  * digit c: a subjectively assigned quality of the night:
    · 1... poor night,
    · 2... standard night,
    · 3... excellent night
– Key 10 a non-zero value specifies input of records re-defining types of some objects specified by TABLE OF OBJECTS. Records re-defining the type of objects enter with format `2I5` and contain the identification number of the object from the TABLE OF OBJECTS and new type; the last record with re-definition must be followed by one zero or blank record
– Key 11 specifies what should appear in the output file with results of reduction. It has no effect on data archiving.
  * 0 ... no printout at all
  * 1 ... only headers and extinction coefficients appear in the print file
  * 2 ... print file contains condensed information on the least-squares solution for the G coefficients and the fit for the extinction stars, but no differential photometry. This type of output can readily be displayed on the screen of a terminal or a personal computer
  * 3 (or more) .... a complete print (some lines are *longer* than 80 characters!)
– Key 12 *a five-digit key*
  * digits a through d: these apply — in that order — to transformation formulae (2) for W, U, B, and V, respectively
    · 0 ... complete non-linear transformation coefficients for all terms in $(B-V)$ and $(U-B)$ are calculated and used if Key1 = 5 is included at the end of the control records
    · 1 ... bilinear transformation is calculated and used
    · 2 ... linear transformation is calculated and used
    · digit e: > 0 ... suppresses the calculation of seasonal colour-extinction coefficients; only the remaining transformation coefficients are calculated if required by Key1 = 5
  * Observers (`format 3I3`) Observers are coded by 3-digit numbers and these codes are also archived. VYPAR then uses the file OBSERVER with the list of observers and abbreviations of their names and provides the abbreviations of the observers instead of the original numerical codes along with the retrieved data
  * Identification (`format A10`) Last 10 columns of each key record can be used to identify the night to which it belongs. This is useful since the user can immediately check in the output whether the one-to-one correspondence of the key records and nights of observations in the data set has been preserved.

An example of input file with control records for *ubvy* data

Please, note the *obligatory* position of the dead-time coefficient 4.0D-08 in the first record with the seasonal transformation coefficients H. In this example, calculation of seasonal coefficients is requested at the end of the file; only nights for which Key 9 > 99 will be used for the determination of the H coefficients; note also that the extinction coefficients are specified for two nights of data for which a fixed extinction is requested

```
--------------------------------------------------------------------------------
        10        20        30        40        50        60        70        80
....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|

 0 0 0              non-zero values require output archives and extinction
SAAO.DAT            data file
uvby.TAB            table of objects
PRINT               output print file
    2    1    1    0   -1   11   -1   -1  113    0    3    0          SAAOGA1/92
  -.07717   -.00319    .10127   -.07095   -.05941    4.0D-08
  -.10582   -.00128    .01175    .01224   -.26277
  -.12547    .00786   -.02076    .06745   -.05261
  -.10732    .01197    .15224   -.07830   -.03418
  0.22      0.27       0.6       0.36
   12                  -1    0            113                           SAAOG1B/92
    2                  -1    1              1                           SAAOG2/92
    2                  -1   10            112                           SAAOG3/92
    2                  -1    0            112                           SAAOG4A/92
   12                  -1   20            112                           SAAOG4B/92
    2                  -1    0              1                           SAAOG5A/92
   12                  -1   10            111                           SAAOG5B/92
    2                  -1   10            112                           SAAOG6A/92
   12                  -1   11            112                           SAAOG6B/92
    0         1        -1   11              1                         7 SAAO01/92
0.27        0.34       0.85       0.50
    0                  -1    0              2                         7 SAAO02A/92
   10                  -1    0              2                         7 SAAO02B/92
    5
   -1

....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
        10        20        30        40        50        60        70        80
--------------------------------------------------------------------------------
```

2.3 Output files

Several output files can be requested in the input CONTROL file (see below), but only one file name must always be specified, namely the output file PRINT (or whatever name you prefer) which contains all information about the reductions and results and essentially corresponds to the prints generated by earlier versions of HEC22. However, since complete information is not always needed, the user can ask for four different forms of this output using Key 11 in each control record (see above).

Note that the output file of results (tentatively denoted PRINT) mainly serves the purpose of initial checking of the data quality, identification of poor or erroneous observations etc. It is much more convenient to archive the final, clean data and use VYPAR to extract the observations in their final, digital form. In the most recent version of the program, HEC22 rel. 13.1, the rms errors printed after the mean UBV values for each star are the rms errors *per 1 observation*, similarly as in VYPAR (see below). Previous versions of HEC22 contained the rms errors of *the mean values* on the output which were less informative as an indicator of the data quality.

HD	HJD-2400000	Observers	Code	△ V	△ B	△ U	X	△ X	$HD_{comp.}$
3	45254.2550	1	11012	2.557	2.701	3.001	1.273	.063	222439
3	45254.2668	1	11012	2.554	2.698	2.988	1.226	.055	222439
3	45254.2731	1	11012	2.553	2.691	2.995	1.204	.052	222439
3	45254.2793	1	11012	2.548	2.697	2.995	1.183	.048	222439
3	46287.5775	3007	10112	.633	.814	1.571	1.001	-.004	223229
3	46287.5858	3007	10112	.625	.811	1.553	1.002	-.006	223229
3	46287.5941	3007	10112	.628	.835	1.563	1.005	-.008	223229
3	46289.5540	3007	10012	.630	.820	1.565	1.003	.001	223229
3	46289.5616	3007	10012	.631	.835	1.576	1.001	-.001	223229
3	46289.5686	3007	10012	.639	.824	1.547	1.001	-.003	223229
3	46290.5554	3007	11112	.619	.813	1.568	1.002	.000	223229
3	46290.5624	3007	11112	.637	.817	1.565	1.001	-.002	223229
3	46290.5693	3007	11112	.629	.819	1.575	1.001	-.004	223229
28	41691.1894	4008	11112	-3.850	-3.058	-1.485	1.564	-.062	35619
144	45307.3222	17	10113	-.366	-.391	-.263	1.098	.038	2626
144	45307.3340	17	10113	-.371	-.394	-.248	1.110	.040	2626
144	45307.3423	17	10113	-.366	-.396	-.253	1.120	.042	2626
144	45309.3048	17	11113	-.368	-.392	-.262	1.089	.036	2626
144	45309.3145	17	11113	-.366	-.393	-.248	1.096	.038	2626
144	45309.3200	17	11113	-.372	-.399	-.253	1.102	.039	2626
144	46692.5822	35013	10112	-.361	-.404	-.255	1.170	.047	2626
144	46692.5933	35013	10112	-.330	-.380	-.230	1.191	.048	2626
144	46692.6016	35013	10112	-.366	-.423	-.271	1.209	.049	2626
144	46692.6092	35013	10112	-.374	-.412	-.261	1.226	.049	2626
358	46989.4817	3035	11112	-.160	-.921	-1.851	1.579	.575	194093
358	47000.4222	3035	11113	-.470	-.479	-.903	1.918	.144	218045
358	47000.5111	3035	11001	-.450	-.535	-.988	1.227	.004	218045
358	47005.4490	3035	11112	-.133	-.901	-1.847	1.500	.498	194093
358	47006.4352	3035	11112	.020	-.225	-.797	1.592	.215	159561
358	47038.4520	5010	11001	-.414	-.500	-.914	1.103	-.043	218045

DIFFERENTIAL ARCHIVE

This *unformatted* output file contains all individual differential observations, along with all relevant pieces of information. It can be made "readable" as an ASCII file with the help of program VYPAR (see sect. 3) but it is normally expected that it will remain in the condensed form and will be processed and further used directly with the help of VYPAR.

An example of an UBV archive file, transformed to ASCII format by VYPAR, is shown below:

The following quantities are given in the individual columns:

1. **Column HD:** HD number of the star observed; numbers > 500000 were assigned to faint stars without HD numbers.
2. **Column HJD-2400000:** Heliocentric Julian Date of the mid-time of the three-colour observation minus 2400000.
3. **Column Observers:** Up to three observers who observed on the given night are identified by a integer which can have up to 9 digits. Within it, each observer is identified by a three-digit code (from 001 to 999); for identification of the names of individual observers, see file OBSERVER. Thus, for instance, the last four observations of HD 144 included in the sample archive above have the observer code 35013 which means that they were secured by observers Nos. 13 and 35, i.e. by Dr. Petr Hadrava and Mr. Jaroslav Honsa. (Note that the observer code in ASCII format is treated as one integer and does not contain insignificant leading zeros.)
4. **Column Code:** This code gives information about observing station and data quality. It has the form of a five-digit number $abcde$ where individual digits contain information about the observing station and data quality as described below:
   - digit a: digital code for the observing station; see the file STATIONS
   - digit b: provides information about the extinction:
     * 0... fixed extinction was used
     * 1... extinction was derived from all available observations of stars of types 4 to 9 (see TABLE OF OBJECTS)
   - digit c: Values 1 or 0 denote that the data from this particular night were or were not used for the determination of the seasonal transformation coefficients, respectively
   - digit d: Values 1 or 0 denote that the data from this particular night are or are not suitable for the determination of all-sky magnitudes, respectively
   - digit e: denotes the quality of of given night estimated from the scatter of the data:
     * 0... a non-photometric night; the data are stored only because they may document that the observed objects did not exhibit some variations larger than $0\overset{m}{.}1$ on that particular night; such nights are very rarely found in the archives
     * 1... a night of poor quality
     * 2... a normal photometric night
     * 3... an excellent, stable night
5. **Column △ V:** The magnitude difference in the sense variable minus comparison in the V band
6. **Column △ B:** The magnitude difference in the sense variable minus comparison in the B band
7. **Column △ U:** The magnitude difference in the sense variable minus comparison in the U band
8. **Column X:** The value of the air mass at the time of the observation
9. **Column △ X:** The difference in the air mass between the variable and comparison star $(X_{\mathrm{var.}} - X_{\mathrm{comp.}})$
10. **Column $\mathbf{HD}_{\mathrm{comp.}}$:** The HD number of the comparison star used.

ALL-SKY ARCHIVE

This output file is similar in format to the previous one and contains HJDs, information about the observing station and observing conditions, V, B, U, and W all-sky magnitudes of all measured stars point by point, and air masses. Again, use VYPAR to view it on the screen.

EXTINCTION FILE

If the user wishes to investigate the behaviour of the linear extinction coefficients during the observing season, it is possible to define this output file, which will contain the Julian Dates and the linear extinction coefficients for all nights for which these coefficients were calculated (not fixed).

3 Program V Y P A R

3.1 General information

This program is designed for sorting, organizing, appending and copying the data archives and for subsequent data retrieval. It operates on the *unsorted* archives created by HEC22. Since we felt the most frequent operation to be carried out by users of the archives will be the extraction of all observations of a given star from the archives, the archives produced by HEC22 are first sorted according to HD numbers of individual observed stars and in increasing order of Julian Dates for each object.

Operation of the program is controlled by a CONTROL file requested from the user after the start of the program (similarly as for HEC22).

The CONTROL file contains one information control record followed by task control record(s) (for one or more tasks) controlling the run of the program VYPAR.

The first (information) record is of the format `(I5,5X,A12)`. The first key of the record specifies whether a 3- or 4-colour archive will be treated while the other (string) parameter is the filename of the TABLE OF OBJECTS also used by the HEC22 program (containing coordinates, standard magnitudes etc.; see Section 2.2.1 of this manual for details).

Every task control record has the same first part `(format 3I5)`: keys 1, 2 and 3 are read for any task. The other part of the task control record differs somewhat from one mode of operation to another.

3.2 Description of individual parameters of the task control record:

Key 1 (columns 1-5) specifies the required task:

- 0 ... Termination of the program
- 1 ... Sorting archive
- 2 ... Copying (extracting a part of) archive
- 3 ... Overview of the content of the archive. The program derives the mean magnitudes for all stars and other statistical information for this task
- 4 ... Retrieval of individual observations for a given star
- 5 ... Retrieval of averaged observations for a given star with a rigidly repeated averaging interval
- 6 ... Retrieval of observations averaged over a specified time bin, with optimally chosen beginnings of the averaged intervals
- 7 ... Transformation of archive from the condensed binary form to an ASCII file which can be simply viewed and/or edited by any text editor. Created ASCII archive file can also be transported to another computer operating under a different operating system
- 8 ... Transformation of ASCII archive file to the binary condensed file. The newly created binary archive is automatically sorted (to be prepared for further use by the program)

Key 2 (columns 6-10) defines the input archive:

```
> 0 ... the task control record must be followed by a record
        (format A12) containing the filename of the input archive

  0 ... the input archive defined in the preceding task will be used;
        if no input archive has been defined previously, an error occurs
        and the program is terminated
```

Key 3 (columns 11-15) defines the output file:

```
> 0 ... the task control record (and conditionally input
        filename record --- see preceding Key 2 description) is (are)
        followed by a record (format A12) containing the filename of
        the output file for the task

  0 ... output file of the current task will be appended to the
        output of the preceding task. If no output file has been defined
        so far, a default file with filename VYPAR.OUT will be created.
        This option is valid only for task modes 3 through 6 which have
        ``printable" output. If --- for all other modes of operation ---
        a file with a name identical to the output filename already
        exists, it will be overwritten with the newly created one.
```

The above described parameters of the control record are obligatory and have the same meaning for all modes of operation (tasks) of the program.

Other parameters read from the task control record:

Mode = 1 (sorting the archive):

Key 4 (columns 16–20):

```
> 0 ... the task control record (and possible input and/or output
        filename records) are followed by a record (format A12)
        containing the filename of the {\it sorted} archive which is
        to be merged with the sorted archive defined in the first
        filename record (requested by Key2 > 0).
```

Mode 2-6 (copy, overview, lists of individual or averaged measurements):

The following 5 parameters allow one to select a subset from the input archive to be processed in some of the above-mentioned modes.

```
Obs (columns 16-17, format I2): A numerical code of the observing
    station; if > 0, only data obtained at that specific station
    will be extracted

Q   (column 18, format I1): Only data from the nights with quality
      greater or equal to Q are considered

CS  (column 19, format I1): Only data from the nights which meet the
    following demands are used:
      CS = 0 ... all nights
      CS = 1 ... nights which were used for all-sky photometry
      CS = 2 ... nights which were used for the definition of
                 the colour system
      CS = 3 ... nights which were used for both, all sky photometry
                 and the colour system definition

Tmin (columns 41-50, format F10.0) and
Tmax (column 51-60, format F10.0): Only measurements obtained between
                 Tmin and Tmax are considered; if Tmin(Tmax)=0,
                 no lower (upper) time limit is applied.
```

Mode 4-6 (retrieval of individual or averaged data from archive):

```
STAR (column 21-32, format either A12 or A2,I10): name of the star
      of which data are to be retrieved. The name must be identical
      to that used in the TABLE OF OBJECTS (it is case sensitive!).
      If the first 2 characters of this parameter (columns 21,22)
      are 'HD' then the star is identified by its HD number read by
      format I10 from columns 23 through 32. If the first three
      characters of the parameter (column 21,22,23) are 'ALL',
      data for all stars from the input archive are retrieved.

AVE (columns 33-40, format F8.0): meaningful only for modes 5 or 6.
      Averaging time interval (in days) used for computation
      of normal points from the retrieved data.

COL (column 20, format I1): List of observations in bandpass
      number COL only is required (note that the same convention
      as for HEC22 applies, i.e. $1=V$, $2=B$, $3=U$ for the Johnson,
      and $1=y$, $2=b$, $3=u$, $4=v$ for the Stromgen photometry is
      used unless the user defines his (her) system in another way)

P (columns 61-70,format F10.0) and
T0 (columns 71-80, format F10.0): linear phase for period P and
      epoch T0 will be calculated and appear in the output lists
      of the retrieved data; if P = 0 is specified, the phase will
      be set 0 everywhere
```

4 AUXILIARY PROGRAMS

4.1 Programs HEC922, SAAO22, SILLA22 and ESO5022

SILLA22:

This program converts the data obtained with the Danish 0.5-m at La Silla to type A data format for use with HEC22. Its operation is self-explanatory. The program asks the user to specify the names of the Danish-telescope output file and HEC22 input file, date of the beginning of observing night in the order day-month-year (in free format) and also some comments on the quality of the night (40 characters at maximum).

!!!!!! I m p o r t a n t !!!!!

Before running the program, you have to construct a file named TAB.CON in which you specify the running numbers to be used in TABLE OF OBJECTS for each observed star, denoted by alphabetic characters (names) in the La Silla Danish telescope output data file.

An example is included in the package:

SILLA.INI is the output data file from the Danish telescope;

SILLA.H22 is the HEC22 input file;

TAB.CON is the obligatory auxiliary file just described.

SAAO22:

This program converts the output data from the LUCY program running on the control computer of the 0.5-m photometric telescope at Sutherland, South Africa, to type B data format for use with HEC22. Please, note that the dead-time correction is applied already by the control program at SAAO so that you have to specify a value which is “almost zero” (1.D-55, for instance) for the value of the dead-time coefficient in the corresponding control record before reducing the data with HEC22. This is necessary to inform the program that the data are in counts and that no gains will be applied. Note also that the control program at SAAO subtracts the sky readings immediately so that you have to set Key 5 = -1 in the control records of HEC22. Otherwise, just run the program and follow its instructions.

!!!!!! I m p o r t a n t !!!!!

Before running the program, you have to construct two files:

1. File named TABSAAO.CON in which you specify the running numbers to be used in TABLE OF OBJECTS for each observed star, denoted by alphabetic characters (names) in the LUCY SAAO output data file and also the info about the usage of filters; and

2. File SAAO.CAL with the transparencies of the grey filters used to attenuate the light of bright stars.

An example is included in the package:

SAAO.INI is the output data file from the LUCY program;

SAAO.H22 is the HEC22 input file;

TABSAAO.CON and SAAO.CAL are the obligatory auxiliary files just described.

ESO5022:

This program converts the data obtained with the ESO 0.5-m La Silla telescope to type B data format for use with HEC22. Its operation and structure is similar to that of SILLA22 program. The program uses the same TAB.CON. Unlike SILLA22, the ESO5022 program can be used in two different modes, denoted 0 and 1. These modes differ in the way in which the stellar deflections are corrected for sky readings. Because the dead-time correction i s i n c l u d e d in one of the modes (mode 0) of the program, 2 extra parameters specifying the photomultiplier and mode used are required at the input.

Mode 0: Each stellar measurement is corrected individually for the corresponding sky reading after the dead-time correction is applied to them. The following dead-time constants, which are the same for all filters, are applied to the photomultiplier tubes used at the ESO 0.5-m telescope:

```
----------------------------------------------------------------------
Photomultiplier  Dead-time per 1 sec.     Source
----------------------------------------------------------------------
 EMI 9789 QB       58.dex(-9)            Poretti (1992)
 Hamamatsu         77.dex(-9)            Lehmann (1995) (private com.)
----------------------------------------------------------------------
```

Unfortunately, to the best of our knowledge, no reliable determination of the dead-time constant is available for the Quantacon RCA 310134 A02 photomultiplier tube.

It is assumed that the observations begin with a block of 4 star integrations and each block of star observations is followed by a block of 4 sky readings. The order of measurements in the u, v, b, y filters in the blocks is arbitrary and can even vary during the night.

When running the HEC22 program, a non-zero but a negligibly small value of the dead-time coefficient (e.g. 1.D-55) must be specified in the control file (8th record). The data type (Key 5) is -1.

Mode 1: No correction for the dead-time and no sky subtraction is applied during the run of the ESO5022 program. The input can contain sky readings and sky deflections in an arbitrary order. (We point out here that HEC22 requires the same number of stellar measurements in all filters unless you would use the averaging mode 1. However, this is not formally tested in the ESO5022 program but only in HEC22.)

During the run of HEC22, a proper dead-time coefficient must be specified and is applied. Relevant sky readings are interpolated to the times of stellar readings and subtracted. The data type (Key 5) is 1.

Note: Program ESO5022 was developed by S. Štefl who should be consulted for details if necessary (Internet: `sstefl@sunstel.asu.cas.cz` and the same postal address as P. Harmanec).

4.2 Program DODIFAPT

This program uses the data from the first operational automatic photoelectric telescope (APT), the Phoenix-10, for one group of stars, in exactly that form in which a user gets it from the APT customer service and transforms it into the form of a differential archive which can be further handled with program VYPAR. Its action is again self-explanatory, you just have to specify the HD numbers of the stars from that particular group.

4.3 Program HEC922

This program converts the data in the form used by our previous code HEC9 to the input data format for HEC22. This is probably out of fashion by now but since colleagues at several observatories were using the HEC9 program, we mention this possibility here. Interested potential users should contact us directly for instructions how to use this program.

5 PRACTICAL HINTS ABOUT THE USE OF THE SOFTWARE PACKAGE

5.1 A practical example of the use of HEC22

The action of the program is best illustrated by an example.

a) Run HEC22 with the control file HEC22.K1, data are in HEC22.DAT, TABLE OF OBJECTS observed at Hvar (with improved Johnson magnitudes from Harmanec, Horn and Juza 1994) is UBV.TAB. The program will reduce all nights of data and calculate the colour transformation coefficients. You will see the iterations on the screen but they are also saved in the print file, which should be identical to the RES1 file provided with this package. Note that the iteration starts with a nearly instrumental system. You can verify the stability of convergence by setting all H coefficients to exact zeros, the result should be the same with an accuracy better than $0\overset{\mathrm{m}}{.}001$.

b) Copy the resulting seasonal transformation coefficients into proper records of the key file HEC22.K2.

c) Run HEC22 with key records HEC22.K2. Note that now you specify the output files for both archives. This will automatically cause output of data into both archives after the colour system has converged, but note that you must set Key7=0 to allow the data output. In this example, the archives will be created under filenames DIF and ABS and all calculated linear extinction coeffcients will be stored in file EXT. You can view the content of the files DIF and ABS using VYPAR in mode 7. A complete print of the results can be found in file RES2.

d) Now, you have to use VYPAR. Run VYPAR with the CONTROL file EXAMPLE1.VYP contained in the package. By this run the archives ABS and DIF created by program HEC22 are transformed to ASCII format — files ABS.ASC and DIF.ASC are saved. You can compare these new files with the files of identical names contained also in the software package. The files should also be identical.

As another example of the use of program VYPAR you can run it with the following CONTROL file

```
--------------------------------------------------------------------------------
         10        20        30        40        50        60        70        80
....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|

EXAMPLE2.VYP:

    3     ubv.tab                # of colours   Input objects table file

    1    1    2

abs                                      input archive file name (col#10>0)

abs.sor                                  output file name (col#15>0)

    1    1    2

dif                                      input archive file name (col#10>0)

dif.sor                                  output file name (col#15>0)

    3    1    2

abs.sor                                  input archive file name (col#10>0)

out3                                     output file name (col#15>0)

    3    1    0

dif.sor                                  input archive file name (col#10>0)

    4    1    2   3         5 AND

abs.sor                                  input archive file name (col#10>0)

out4                                     output file name (col#15>0)

    5    1    2          KX AND 0.055

dif.sor                                  input archive file name (col#10>0)

out5                                     output file name (col#15>0)

    6    0    2  2  HD    218393 0.055

out6                                     output file name (col#15>0)

    0

....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|....|
         10        20        30        40        50        60        70        80
--------------------------------------------------------------------------------
```

During this run the following activities take place:

– sorting of archive ABS and saving the result to ABS.SOR

– sorting of archive DIF and saving the result to DIF.SOR

– making overview of the archive ABS.SOR; the result is saved in the file OUT3

– making overview of the archive DIF.SOR; the results are appended to the file OUT3

– producing list of individual data for the star 5 AND (selecting only data for nights used for absolute photometry and for colour-system definition from the archive ABS.SOR); the results are saved in the file OUT4

– producing "floating" means by 0.055 day for star KX AND from the archive DIF.SOR; results saved in the file OUT5

– producing "fixed" means by 0.055 day for the star HD 218393 using only data from nights with the quality equal to, or better than 2 from the archive DIF.SOR defined in the preceding task; results are stored in the file OUT6

5.2 Checking and preparing the data and control records

Although the programs can run and reduce the data from each season quite automatically, an initial phase of careful preparation of control records and various checks of data with respect to their quality cannot be avoided. We recommend to proceed as follows:

a) For the first run of the data, use the seasonal transformation coefficients from the previous season or zeros (i.e. data in an instrumental system). Also fix the extinction coefficients at their standard mean values for the given site. Ask for a complete output of the results, setting Key11=3 in the first control record.

b) Carefully investigate the output of the program, identify and correct or omit possible erroneous observations. Special attention must be paid to the run of O-C deviations for standard stars. You will have to decide on their basis, and taking into account the actual range of air masses, whether or not it is possible to allow for the calculation of the extinction coefficients in the given night. Our advice is not to calculate extinction if the range of air masses is smaller than 0.15. In some cases, it is also obvious from the run of the deviations that a linear or even quadratic change of the zero point must be allowed for or you will note an abrupt change in the run of the deviations. In this latter case it is recommendable to split the night into two parts to be reduced independently. If you fail to recognize such cases, you may end up with totally wrong extinction coefficients. If you are forced to split the night into two or more parts for the reductions, it may happen that extinction coefficients cannot be calculated in all parts. If so, try to use fixed extinction, which was calculated in that part of the night which permitted it, also for the reduction of the remaining parts of this night. Be very cautious to allow for a simultaneous calculation of the extinction coefficients and zero-point drifts in situations when the air mass of your standard-star observations varies more or less monotonically with time. The correlation between the two is very high then and it is recommendable to fix the mean extinction (or nearest calculated extinction) and allow for the drift of the zero points only. You will often have to make several attempts before you find the correct solution, i.e. the correct set of control keys for each night. You may profit from a proper use of Key7 to display on output only those nights for which you still look for the correct solution and suppress the output for those which are already O.K.

c) When you have finished the detailed inspection of your observations, night by night, and removed bad observations, misidentifications etc., and set properly the calculation of nightly transformation coefficients, you can decide which nights are good enough to be used for the determination of the seasonal transformation and, more generally, define the quality of each night (by properly setting Key 9 in the control records). Then, you can run HEC22 again, allowing for the calculation of seasonal transformation. Note that you should not try to calculate all coefficients, including colour extinction, in cases of limited data. Our experience is that the colour extinction coefficients will only be derived reliably if the season you reduce contains observations of standard stars at air masses over 1.5. If not, it is always better to fix the colour extinction coefficients at some small negative values and allow only the determination of the other coefficients.

You should also be aware of the fact that the standard $B-V$ and $U-B$ (or $b-y$ and $u-b$) colour indices are not mutually independent but are functions of each other for stars of a given luminosity class. Since many standards are main-sequence objects, there is usually a strong correlation between the H coefficients for $B-V$ and $U-B$ in each equation. Unless you have also included reddened stars and stars of other luminostity classes among your transformation standards, it is better not to attempt the cubic transformation. You should limit yourself to a bilinear or even linear transformation in such cases.

In practice, it is easy to make tests since the run of the program is fast, even for large data sets. If the convergence will end with a value of any of the H coefficients larger than about 0.3, you should n o t accept such a result as satisfactory! It may indicate several facts: either that only (bi)linear transformation is possible or that the nightly transformation is grossly in error for some of the nights involved in the calculation of the seasonal transformation. You must check all individual nights again and perhaps exclude some of them from the process.

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

 The current reduction scheme, if properly applied, will give you
 really rewarding results but your critical judgement remains very
 important. Do not use HEC22 blindly and do not trust the results
 without a careful inspection.

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
```

One remark should be added on a feature which appears a bit confusing. Since the seasonal transformation coefficients are calculated by an iterative scheme, it was necessary to allow also for convergency of zero coefficients $H6, H12, H18$ and $H24$. Note also, however, that the nightly transformation has its zero coefficients $G1$ to $G4$ and, in the optimal case, the H zero coefficients should all be zero after convergence is achieved. In practice, you will usually end up with small non-zero values. This also happens in cases when you allow calculation of colour extinction terms and these are poorly defined. If any of them comes out greater than zero, the program sets it zero for the next iteration. This may cause larger non-zero values of the zero coefficients $H6$ to $H24$. If this happens, it is also recommended to fix the colour extinction terms at some reasonable values and give up on their calculation for the given season.

5.3 Some examples of a more advanced use of the software

a) The dead-time coefficient for photon-counting photometers: its specification and determination

HEC22 normally uses a dead-time coefficient which must be known in advance and specified in the CONTROL file. However, since the operation of the program is quite fast even on smaller computers, it is easily possible to derive the correct value of the dead-time coefficient by trial and error. Select several suitable nights from the observing season in question. These nights should contain observations of a representative selection of brighter standard stars. You can use these nights for calculation of seasonal transformation coefficients while varying the input value of the dead-time coefficient and investigate the rms errors of the fit as a function of dead-time. The correct value of dead-time coefficient should correspond to the smallest rms. As a final check, you should investigate the colours of the brightest standard stars from the sample. Since the number of counts in different filters usually differs quite significantly (quite often the blue filters give the highest number of counts and the blue magnitudes are therefore most affected by the dead time), measured colours of stars represent an ultimate test of the correct choice of the value of the dead-time coefficient.

An important fact to realize is that the dead-time coefficient is usually specified for a one-second integration while your observations consist typically of something like ten-second or twenty-second integrations. You have two ways of handling the problem. You may specify the true one-second dead-time value in the input control record and then you must also specify the actual integration time used for each night at the third record of data (which begins with the date of observation, cf. Sect. 2.2.1 above). This is necessary in situations when you combine data with different integration times during one season. If you use a standard integration time TINT over the whole season, you can simply specify the dead-time coefficient DTK in the control record which is correspondingly smaller than the true one-second dead-time DTC, i.e. use DTK = DTC/TINT. Then, you need not and *must not* specify the integration time TINT in the data file. Note also that the structure of existing types of input data of HEC22 does not provide you with the possibility to use different integration times with different filters in the photometer. If this is your case, you will have to re-calculate your measurements into one-second integrations using an auxiliary program. Please, note that this is exactly what is carried out by the program SILLA22 (cf. Sect. 4) which transforms the data from the Danish 0.5-m photometer into the form of HEC22 input data. You can, therefore, follow this example.

b) What to do if the same object served different purposes in different observing runs?

A thing which often happens in differential photometry is that one decides for some reasons to change the comparison or check star. It is, of course, possible to include the same star into TABLE OF OBJECTS under two or more different numbers, each time with a different type of object. However, in cases when you later plan to improve the standard all-sky magnitudes of the given star on the basis of your observations, this is not an ideal solution. A better approach is to specify the finally accepted type of object in the TABLE OF OBJECTS and use Key10 to re-define type of object locally for your earlier observations whenever necessary.

c) How to deal with one- or two-colour observations

By the nature of the transformation equations, it is only possible to calculate the coefficients of seasonal transformation equations using observations in three (or four) bandpasses. HEC22 rel.13 can, however, reduce observations through one or two filters (and in some cases even derive the seasonal transformation for them) *under the condition* that realistic $B-V$ and $U-B$ indices can be specified for all program stars in TABLE OF OBJECTS. Note also that in one-colour observations the program expects you to calculate the V magnitude. If observations in, say, only B colour are to be reduced to the standard system, it is necessary to replace the V magnitudes by B magnitudes for all standard stars in TABLE OF OBJECTS, preserving the $B-V$ and $U-B$ indices.

d) How to edit already existing data archives

VYPAR has no direct option to edit the archives since good data editors of ASCII files are now available under all commonly used operating systems. We therefore advise to use mode 7 of VYPAR, i.e. to create an ASCII file archive, edit it by a standard editor and use VYPAR once more (in mode 8) to transform and sort the edited archive back into the condensed form. If your archive after expansion to ASCII form gets larger than that which your editor can handle, you will have to use VYPAR in mode 2 to split the archive into two or more segments sequentially in time, then to expand to ASCII and edit individual segments, transfer them back to the condensed form and sort. Here is a practical example of control records of VYPAR for such an operation (these examples are also included in the software packet and you can apply them to the sample data archives abs):

```
File EXAMPLE3.VYP:  During the processing, archive ABS is split into
                    two parts ABS1 and ABS2 at JD 44816.0 and both
                    partial archives are transformed in ASCII code

    3     ubv.tab               # of colours   Input objects table file

    2    1    2                                    44816.0

abs                             input archive file name (if col#10>0)

abs1                            output file name (only if col#15>0)

    2    0    2                          44816.0

abs2                            output file name (only if col#15>0)

    7    1    2

abs1

abs1.asc

    7    1    2

abs2

abs2.asc

    0
```

Now, you can easily edit any errors in the ASCII form archives using some standard editor. Then, use VYPAR again according to the following example:

```
File EXAMPLE4.VYP: Both partial ASCII archives are transformed back to
                   binary form (and sorted automatically); then both
                   archives are combined into one sorted archive again

    3     ubv.tab              # of colours   Input objects table file

    8    1    2

abs1.asc                       input archive file name (if col#10>0)

abs1.sor                       output file name (only if col#15>0)

    8    1    2

abs2.asc                       input archive file name (if col#10>0)

abs2.sor                       output file name (only if col#15>0)

    1    1    2    2

abs1.sor

abs3.sor

abs2.sor

    0
```

e) How to share the data archives with another party

The disadvantage of storing the data archives in the condensed (unformatted) form is that they cannot be directly shared by users working on different types of computers. We therefore recommend to expand the archives into ASCII data files via mode 7 of VYPAR and send them to your partner (e.g. via ftp). He or she will then have to use VYPAR on his (her) computer to re-create condensed archives.

f) Investigating your natural system?

It is obvious that even a user who dislikes the form of transformation equations we offer may profit from the use of HEC22 and VYPAR. It is simply possible to reduce your data with all transformation coefficients set effectively to zero, create all-sky archives and investigate the functional relation between your natural and a standard system using, for instance, the seasonal mean all-sky values for all observed standard stars.

6 LIMITATIONS OF THE CURRENT SOFTWARE

The present HEC22 rel. 13 can handle photometric observations secured through a maximum of four different bandpasses. Multicolour observations could be reduced only step by step. It would be necessary to split the data into groups of 3-4 magnitudes (with one overlapping magnitude), select suitable colour indices, prepare input TABLE OF OBJECTS with proper magnitudes and indices of all standard stars and reduce the subsets separately.

The nightly transformation equations do not provide the possibility to model a monotonic change of the linear extinction coefficient during the night. For instance, for a linear change of the extinction coefficient, one would have to include a term depending on $X \times t$, the product of air mass and time. Poretti and Zorbi (1993) argued that a variable extinction occurs even at good sites. We investigated various long observing runs at our disposal and found that in almost all cases, the residuals varied with time t but not with $X \times t$. We, therefore, believe that the most typical situation is that what actually varies is the zero point of the linear extinction, i.e. the overall transparency (due to a slight haze, for example), not the dependence of the transparency on the air mass. Such a change can, of course, be wavelength-dependent, i.e. the trends in different passbands can be different. If the linear extinction coefficients really vary during the night, the only possibility with the existing versions of HEC22 is to split the night suitably into several segments and reduce them separately.

There are the following limitations on the data tables (which can, however, be changed by proper changes of the dimensions of relevant data fields):

- maximum of 999 different objects in TABLE OF OBJECTS

- maximum of 900 observations during each observing night

VYPAR has no option which would allow direct editing of the already existing archives since this can now more easily be carried out with the help of existing data editors — see Sect. 5.3 for advice how to proceed.

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

Any questions concerning the programs as well as reports of their
possible malfunctions should be addressed to the first author.
Any suggestions how to improve this manual will also be appreciated.

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
```

7 LIST OF CONTENTS OF THE REDUCTION PACKAGE

7.1 Fortran 77 programs:

- HEC22.FOR ... complete reductions of photoelectric observations
- VYPAR.FOR ... sorting, copying and organizing data archives, data retrieval
- HEC922.FOR ... converts input data of the earlier HEC9 code (Harmanec et al. 1977) into data of HEC22
- SAAO22.FOR ... converts output data of the $uvby$ photometer of the SAAO 0.5-m telescope into input data of HEC22
- SILLA22.FOR ... converts output data of the $uvby$ photometer of the LaSilla Danish 0.50-m telescope into input data of HEC22
- ESO5022.FOR ... converts output data from the ESO 0.50-m telescope into input data of HEC22
- DODIFAPT.FOR ... transforms reduced data from Phoenix-10 automatic telescope into differential archive treatable with VYPAR

Executable DOS versions of all programs, suitable for personal computers, are also included.

7.2 Standard input files:

- UBV.TAB ... TABLE OF OBJECTS for UBV photometry
- UVBY.TAB ... TABLE OF OBJECTS for $uvby$ photometry
- OBSERVER ... list of names of observers and their abbreviations used by VYPAR
- TAB.CON ... conversion table from names used at the Danish La Silla 0.5-m telescope to running numbers of TABLE OF OBJECTS
- TABSAAO.CON ... a similar conversion table for SAAO 0.5-m data
- SAAO.CAL ... table with transparencies of grey filters at SAAO

7.3 Examples of data files:

- HEC22.DAT ... input type A data (UBV)
- HEC22.K1 ... control records for HEC22.DAT — calculation of seasonal transformation
- HEC22.K2 ... control records for HEC22.DAT — final reduction and creation of all-sky and differential archives and file with calculated extinction coefficients
- RES1 ... "print" output of HEC22 — protocol from iterative calculation of seasonal transformation coefficients i.e. result of the run of HEC22 with CONTROL file HEC22.K1
- RES2 ... file with results of the run of HEC22 with CONTROL file HEC22.K2 i.e. a complete protocol about final reductions
- DIF.ASC, ABS.ASC ... unsorted differential and all-sky archives in "readable" ASCII form created by running subsequently HEC22 with HEC22.K2 CONTROL file and VYPAR with EXAMPLE1.VYP CONTROL file
- EXT ... file with linear extinction, night by night, from the run of HEC22 with control records HEC22.K2
- EXAMPLE1.VYP through EXAMPLE4.VYP ... various demonstration control files to be run with program VYPAR
- OUT3 through OUT6 ... output files from VYPAR run with the EXAMPLE3.VYP CONTROL file
- SAAO.INI ... output data from SAAO 0.5-m telescope produced by LUCY program
- SAAO.H22 ... HEC22 input data created by the conversion program SAAO22 from SAAO.INI data
- SILLA.INI ... output data from the Danish 0.5-m telescope at La Silla
- SILLA.H22 ... HEC22 input data created by the conversion program SILLA22 from SILLA.INI data

7.4 Auxiliary file:

- STATIONS ... a list of observatories (with their geographic coordinates and some other pieces of information) arranged according to numerical codes used by HEC22 and VYPAR

8 NOTES ON IMPLEMENTATION

We did our best to test both main programs, HEC22 and VYPAR, on several different types of computers and have reasonable confidence that they can be used under different operating systems. Note, however, that the FORTRAN version of HEC22 is provided in Microsoft Fortran for DOS machines and contains a command $ LARGE followed by specification of several larger data fields in the main program and several subroutines. Please, delete this command before compiling the program with any other FORTRAN compiler.

Since the programs can be used under different operating systems, we have only included their compiled (executable) versions suitable for personal computers running under the DOS operating system.

Finally, it is necessary to mention that we made every effort during the development of this software to preserve the data format in spite of various modifications. This remains true for VYPAR and for the INPUT DATA file of HEC22. We warn, however, that some gradual changes of the exact structure of the CONTROL FILE of HEC22 were inevitable. In particular, the CONTROL FILE used with releases 11 and 12 of HEC22 will only be properly treated by rel. 13 if non-linear transformation was requested by Key#12. If bilinear trasformation was used, you will have to modify Key#12 according to instructions in the subsection CONTROL FILE of Sect. 2 above.

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