XLUCY: Photometer control and data acquisition

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1 XLUCY

1.1 Introduction

XLUCY is a program for photometer control and data acquisition with on-line reductions. It will run on any PC running Real Time Linux and fitted with the appropriate time and photometer control cards. XLUCY runs in X-window mode; the observer is free to use the PC for other tasks even when XLUCY is integrating.

When XLUCY is running, two forms are displayed. One is used for control and interaction with the observer (the *XLUCY* form; Fig. 1) and the other displays the count rate so that the observer has a visual assessment of the quality of the data (the *monitor* form; Fig 2). Only one of these forms will be visible on the screen, but a simple mouse click will bring the other into view. In order for the displays to be more accessible to the observer, two visual display units are available in the dome. Both VDU's show the identical picture, but while one is attached to the PC in the warm room, the other can be placed in a convenient location so that it is visible from the telescope.

Observing with XLUCY is simple. There are three steps involved (i) start X-windows, (ii) tell XLUCY which photometer you are using, and (iii) tell XLUCY the name of your setup file. After the filter wheel has been initialized and the time synchronized using the one-minute pulse from the time service, you are ready to observe. Control instructions are stored in pre-recorded sequences of instructions (programs) containing the integration time, filter number, star/sky flag, etc. Before observing the star, the star name, RA and DEC should be entered. At the end of the integration sequence, XLUCY will print out the heliocentric Julian date, air mass, magnitude and colours of the star just observed. If a repetitive sequence of stars is to be observed, the sequence can be stored as a *macroprogram.* When the macroprogram (macro for short) is activated, XLUCY will automatically ready itself for the next star when the previous program has been completed. The RA and DEC is displayed in large letters on the monitor form for convenience in setting the telescope.

Normally, one should instruct XLUCY to record the data. Each night, is assigned a file name based on the last four digits of the Julian date. If the program has to be re-started during the night, data can simply be appended to the existing file. At the end of the night, data should be e-mailed to the user's home computer or stored on a diskette. Programs are available to re-reduce and plot the data.

Time is provided by the SAAO time service to XLUCY via the time card; time provided by the PC clock is not used. However, the date given by the PC is assumed to be correct. Note that the time displayed by the PC may differ by a second or two from the true time. This is not a problem as the actual time of the integration is locked to the SAAO time service and should have an absolute accuracy of less than a millisecond.

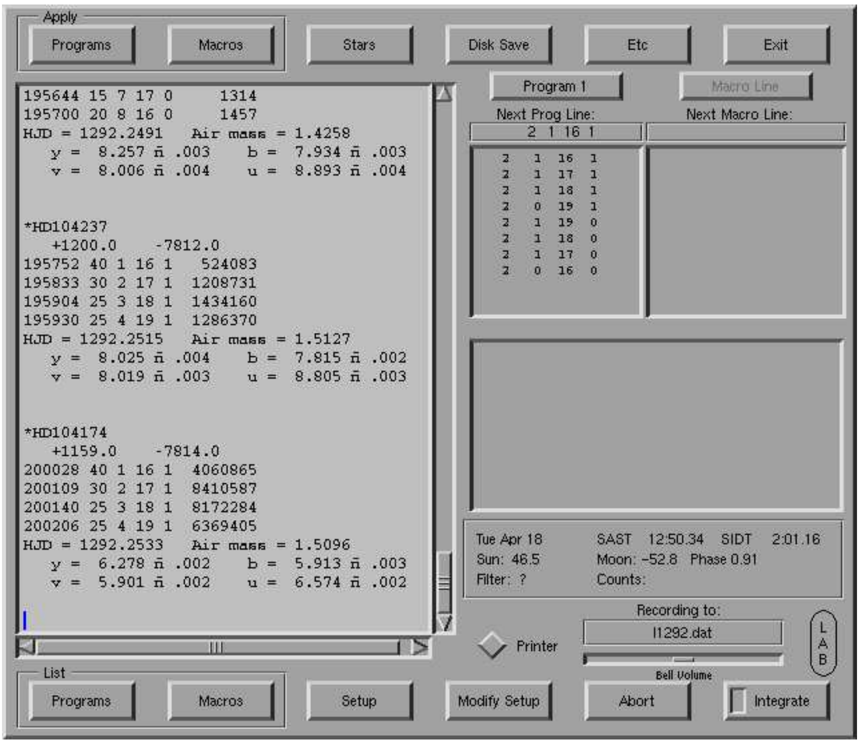

Figure 1: The XLUCY form. There are four text areas. The large area on the left is used to display data from the photometer. This is the data that is stored on disk. The top right area is divided into two parts. The one on the left displays the currently active program; the one on the right the current macroprogram. The bottom right area is used for editing programs, macros and star files and for listing other information.

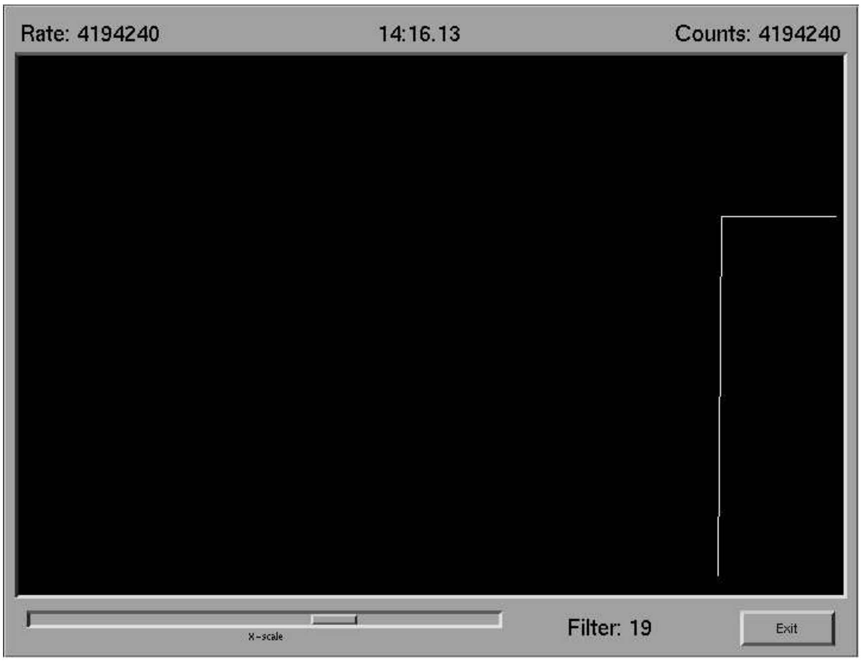

Figure 2: The XLUCY monitor form. This displays the count rate in graphical form.

1.2 Starting Linux

You should normally leave the PC running Linux. When the PC is switched on, it will automatically boot into Linux mode. You require a username and password to use the system. These are

```
Username: ccd
Password: ?????
```

but you should ask the responsible astronomer for the correct username and password in case this has changed. Next you must start X-windows if it is not already running:

```
startx
```

The screen will blank out and a blue background will appear. On the top left hand of the screen you will see the `pager` form consisting of a small square subdivided into nine smaller areas. Next to it will be a display of the date and time according to the PC. It may not be too accurate, but this is not a problem because `XLUCY` obtains the correct time from the SAAO time system.

The pager form is a visual representation of the nine virtual screens that may be used. In other words, you can click on any of the nine squares to display a different virtual screen. The two display units can only display identical pictures and should not be confused with virtual screens. You can think of a virtual screen as if there are nine screens arranged in a square, only one of which is actually visible. For example, you may have `XLUCY` in one screen, the monitor on another screen, `Netscape` on a third screen and an `xterm` window on a fourth screen. You can display any one of them on both display units by clicking on the appropriate square in the pager.

Start an `xterm` terminal window by clicking the left button of the mouse and choosing `Connections` and `Xterm`. At this stage you can examine the contents of your account. The convention that we have adopted at SAAO is that users of the `ccd` account should create a subdirectory in which to store their data files. In other words, you are free to delete any loose files in the main directory, but be a little more circumspect in deleting subdirectories unless you are running short of space. The `df` command will tell you how much disk space is available.

Create your subdirectory, choosing an identifiable name (your username at SAAO or elsewhere would be a good choice) and go to that subdirectory:

```
mkdir lab
cd lab
```

(omit the `mkdir` command if you have already created the directory). This is where your data files will be stored. Whenever `XLUCY` is started, it will store data at the place from where it is invoked. Every time you login, please make sure you are in the proper subdirectory before starting `XLUCY`.

1.3 Starting XLUCY

You can start `XLUCY` by clicking anywhere on the screen background and selecting `XLUCY` from the menu. Alternatively, type

```
xlucy
```

from an `xterm` window. This will start up the monitor (Fig. 2) and the photometer select (Fig. 3) forms. The photometer select form will appear in the centre of the screen, but the monitor form will be visible in the next virtual

Figure 3: The photometer select form.

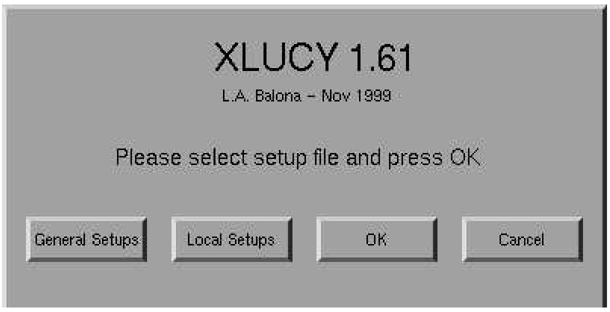

Figure 4: The setup form.

screen to the right. For this reason, you should not select the rightmost virtual screens when starting `XLUCY`, since the monitor form will not be visible. By clicking on the pager you can now bring either the monitor or photometer select forms into view.

The photometer select form has a button labeled *Photometer* and displaying *Manual* as the selected photometer. You need to click on this button to display a drop menu listing all available photometers. At the moment they are

```
Manual
Modular
STAP
UCT
```

The manual photometer assumes that control is entirely by hand, and photometer control is disabled. Select the photometer you want. This will bring up the setup form (Fig. 4).

This form allows you to select a particular pre-recorded setup file. A setup file contains the information required for your particular filter wheel arrangement and for on-line reductions. The setup file normally resides in your directory. If you are using `XLUCY` for the first time, no such file will be present. There are two standard setup files always available. These are called `UBVRI2.sup` and `uvby2.sup` for the 0.5-m and `UBVRI4.sup` and `uvby4.sup` for the 1.0-m and reside in a special directory. As their names suggest, they contain setup data for the $UBVRI$ and the Strömgren *uvby* systems. The setup file must have the suffix `.sup`.

If you have not yet created your own setup file, please select one of these four files by clicking on the *General Setups* button. This will bring up a file browser (Fig. 5). Select the file you want by clicking on the name and clicking the *Ready* button, or simply double-clicking on the name. Once you have modified the

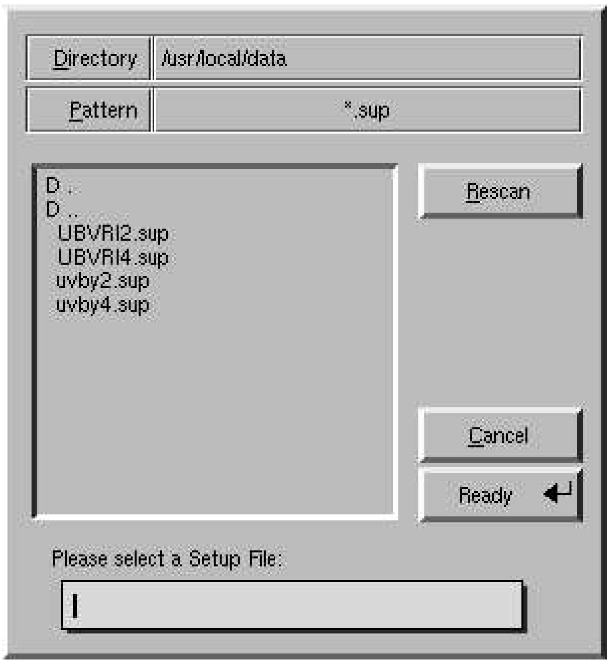

Figure 5: The file browser.

general setup file for your own purposes (see below), you will be able to assign a file name to it and store it in your directory. The next time you start `XLUCY`, click on *Local Setups* to read your customized setup file.

This step completes the startup sequence. As soon as you have chosen the setup file, the `XLUCY` form (Fig. 1) will appear and remain there until you exit from `XLUCY`. Depending on the choice of photometer, a *Filter Wheel Initialization* form will appear on top of the data form. After a while, it will disappear on successful filter wheel initialization. Next, you need to wait until the minute pulse arrives. Notice that the SAST is continuously displayed on the box below the bottom right text area. Before the minute pulse arrives, the time is in red; afterwards it is in black. In this box there is some information on the altitude of the Sun and Moon and lunar phase.

The final step before observing is to select or create a program and to activate it. If you are already familiar with the contents of the setup file, go to Section 5.

1.4 The setup file

We saw how to read a setup file from disk. Now we describe what the setup file contains and how it is used. The setup file is an ordinary text file which you could edit with a text editor, but it is probably more convenient to do this job from within `XLUCY`. To understand the setup file, it will be helpful to view each entry of the file by clicking on the `Modify Setup` button in the `XLUCY` form. The following entries are defined

```
Comment
Dead Time
Filter Wheel
Colour Eqn
Extinction
Zero Points
```

`Nonlinear ZP`

These items refer to the blocks between the hash signs in the setup file and are described below. In addition, the setup file includes data blocks defining programs, macroprograms and the filenames of the program and standard stars. We discuss these later. Selecting an item causes the appropriate block to be displayed in the bottom right text area of the `XLUCY` form. You may edit the contents by clicking to the desired line and typing in the correct values. When you have finished, click on the left text area. You will be asked if you wish to apply the changes just made.

When you exit from `XLUCY`, you will be asked if you wish to save your current setup file. You may also choose to save the current setup file by clicking on `Disk Save` and selecting `Save Setup`.

During the night you may decide to observe with a different set of filters. There is no need to restart `XLUCY` - just click on the `Setup` button to invoke the `Setup` form and read a new setup file. Click on `OK` if you have invoked `Setup` but want to cancel.

1.5 Comment

This box displays information on the setup file. For example, it will contain the author and date of the file, the telescope, tube, filter set etc. If the data are to be modified, the information in this box should also be modified.

1.6 Dead time

The dead-time correction is a factor applied in the reduction procedure to correct for overlapping pulses which can occur if the star is bright. This box lists the dead-time correction (in nanoseconds) for each range of filter numbers. There are 100 possible filter numbers, 0 to 99. A filter number is a particular channel and filter combination as described below.

1.7 Filter wheel

Most photometers allow a maximum of ten filter positions in a filter wheel. For the purposes of reduction, a filter is different if it is used with a different tube or with a neutral density filter as this changes the transmission properties. In `XLUCY` we use the convention that the same filter is selected whenever the remainder is the same when divided by the number of filters in the wheel. For example, if there are ten filters in the wheel then filter 1 is selected if the filter number is 1, 11, 21, 31,...,81, or 91. If there are 6 filters in the wheel, then filter 1 is selected if the filter number is 1, 7, 13, 19...etc.

The reason for employing this system is that it affords a compact definition of a particular filter, tube and neutral density filter combination. For example, 11 and 21 might refer to the same filter, but 11 might be used in combination with a blue tube while 21 might be used in conjunction with a red tube. Hence they must be treated as different filters in the reductions. There are four channels (counters) available for each photometry card, so a large number of combinations is possible.

The *Filter wheel* box contains three data items for each filter position in the wheel: the filter number, the filter name (must be no more than four characters) and an optional brief comment. These items must be separated by one or more spaces. Here is an example:

```
  10   -    Beta Source
```

```
11  Unat  Johnson
12  Bnat  Johnson
13  Vnat  Johnson
14  Rnat  Cousins
15  Inat  Cousins
16  unat  Stromgren u
17  vnat  Stromgren v
18  bnat  Stromgren b
19  ynat  Stromgren y
```

In the example, filter 13 is the Johnson V filter. A suitable name would be `Vnat`, implying that the natural V system results from using this filter.

It is very important to make sure that the filter positions displayed are indeed the correct ones. Verify this by comparing the filter positions with those in the Photometer Log Book. If you have difficulty with this, consult the resident astronomer responsible for filter wheel changes. If necessary, change the entries to correspond to the entries in the Photometer Log Book.

1.8 Colour equations

Here is an example of the colour equations

```
  V = 1.0*Vnat
B-V = 1.0*Bnat - 1.0*Vnat
U-B = 0.9*Unat - 1.0*Bnat + 0.1*Vnat
V-I = 1.1*Vnat + 0.1*Bnat - 0.9*Inat
```

The entries are self-evident. They are a list of equations describing the transformation from the natural to the standard system. Note that the standard system names must be different from the filter names, otherwise confusion will arise. Use `V` or `VJ` to describe the transformed Johnson V, and `Vnat` to describe the natural system. Upper and lower case letters are treated as different symbols.

Please note that there must always be a number multiplying the filter on the right hand side of the equation. For example, `V = Vnat` will not work. You must use `V = 1.0*Vnat`.

1.9 Extinction coefficients

Here is an example of the extinction coefficients:

```
Vnat = 0.13
Bnat = 0.27
Unat = 0.60 + 0.10*Bnat - 0.10*Vnat
Inat = 0.07
```

Note that the left hand side of the equations refer to the extinction coefficient for a given filter, so the filter name must appear here as well as on the right hand side (if a colour term is required).

1.10 Zero points

These are the zero points to be applied to the colour equations to give the standard system. Example:

```
  V  = 19.23
B-V  = 0.020
U-B  = -0.06
V-I  = -0.12
```

The names appearing on the left must clearly be the same as those appearing on the left of the colour equation (not necessarily in the same order). You may not know the zero points in advance. In this case, type in any number (zero for example).

1.11 Non-linear corrections

It is not very likely that a straight linear transformation will reproduce the standard system over a wide range of colours. The non-linear corrections are applied over different colour ranges. These corrections are interpolated linearly in terms of the given colour. For example

```
V-I = -0.200  0.000  0.350  0.450  1.800  3.700
 V  =  0.016  0.000  0.005 -0.003  0.000 -0.042
B-V = -0.400 -0.100  0.100  0.400  1.050  2.000
B-V = -0.003 -0.003  0.000  0.005  0.002 -0.036
B-V = -0.400  0.200  0.500  0.800  1.100  2.000
U-B =  0.006  0.006 -0.006  0.010  0.000  0.000
V-R = -0.200  0.100  2.000  2.000  2.000  2.000
V-R =  0.014  0.000  0.000  0.000  0.000  0.000
V-I = -0.400  0.100  1.800  3.700  3.700  3.700
V-I =  0.005  0.000  0.000 -0.054 -0.054 -0.054
```

The lines displayed in this box must be treated in pairs. The top line of a pair is the colour used in the interpolation; the bottom line is the correction at the given colour. If you do not want non-linear corrections to be applied, delete the table (deleting the top line is sufficient) by using the space bar.

1.12 Standard stars

For the purpose of setting the zero-points and calibrating the colour equations one often needs to observe standard stars. The general setup files `UBVRI2.sup`, `uvby2.sup` etc. contain the names of the standard star files for the particular photometric system. These files are called `UBVRI.std` and `uvby.std` and contain the name, position, magnitudes and colours of the stars in the particular system. These data can be viewed by clicking on the `Stars` button and selecting the `Standard Stars` menu.

1.13 Program stars

A program star is any star which is not a standard. Program stars may be entered by means of an asterisk in front of the name while you are observing. Click on the left display panel to enter the names. For example,

```
*HD123456
1223.5 -3212.3
```

will cause an entry for program star HD123456 with position $12^h23^m.5$, $-32^o12'.3$ in the current epoch. The star name is case insensitive and can be of any length. Spaces are ignored. The position may be entered on the same line separated by a space (or comma) as shown above, or on separate lines. In both cases enter the RA first and then the DEC.

If the program star already exists in the table, the RA and DEC will be displayed as soon as you have entered the name. About 3500 program stars can be stored in memory. Clearly, it is a good idea to enter all your program stars before you start observing. You will also want to display or edit your list of program stars. Do this by clicking on the `Stars` button and choosing `Program Stars`. These will be listed on the bottom right panel. The list can be edited and saved.

1.14 Programs

`XLUCY` can read a set of programs for controlling the photometer. Each line of instructions consists of four numbers:

1. the integration time
2. a pause flag indicating whether to proceed immediately to the next filter at the end of the integration (1) or to pause indefinitely (0)
3. the filter number
4. a flag indicating star (1) or sky (0).

A maximum of 32 lines of this kind constitute a program. Up to ten different programs can be stored. They are called 0, 1, 2, 3,...9. Here is an example of a program:

```
60   1  11  1
40   1  12  1
30   1  13  1
20   1  14  1
20   0  15  1
20   1  15  0
20   1  14  0
20   1  13  0
30   1  12  0
40   0  11  0
```

The first line states that filter 11 must be selected and that the integration time is 60 seconds. The star is being observed and at the completion of the integration the filter wheel is automatically positioned at the next filter (filter 12) and the second line of the program executed. The fifth line states that the integration time on the star is to be 20 seconds on filter 15 but that after the end of the integration, the next program line will not be executed until the observer requests it by flicking the *integrate* switch on the photometer or by clicking on the `Integrate` button. The sixth line states that the object observed is the sky and that the integration time is 20 seconds. After this integration, the next line is automatically executed.

1.15 Listing/entering a program

If you want to look at a particular program or change its contents, click on the `Programs` button on the *bottom* bar (labeled by `List`) and select the program number. The program, if it exists, will be displayed on the bottom right text area. You may edit it if it exists or type in the program from scratch if the area is blank. When you have finished, click on the left text area to save the contents. Please remember to type in the final enter on the last line, otherwise the program will discard this line.

1.16 Activating a program

To put a program into operation, click on the `Programs` button on the *top* bar (labeled by `Apply`). The program will be displayed on the right panel of the top right text area. The other panel is used for displaying the current macroprogram (see below). Above the program display area the is an extract from a line in the program. This is the line which will be executed at the start of the next integration. Above this display, there is a button which is labeled by the current program number. This button is used to change the line which is to be executed.

1.17 Changing a program while it is executing

It is easy to modify the program that is currently executing by clicking the mouse in the program display window and making the required changes. The changes will only come into effect when you click the mouse button on the left window. The changes will be copied to a new program - program 11 and will remain active until a new program is loaded.

1.18 Changing the program line

It is often useful to modify the flow of the program so that it will start on a different line at the end of the current integration. The button which displays the current program number (just below the *Disk Save* button), contains a drop-down menu which lists the program lines. Select from this list the line you want to be executed at the next integration.

1.19 Cancel program

To cancel a program, click on the `Programs` button on the *top* bar and select `Cancel Program`. If you are integrating, on-line reductions will be forced at the end of the current integration and the program canceled. If the integration has stopped and the program is paused, reductions will be forced. You need to select a new program for the next integration.

1.20 End program

Sometimes it is useful to force on-line reductions at the next pause in the program. Suppose, for example, that the first part of the program are star measurements and, after a pause, the second part sky measurements. You may decide that it is not necessary to do the sky measurements. In that case, select this menu item which will force reductions at the pause and end the program at that point. The current program remains active.

1.21 Program 0

Program 0 is reserved for a special application - it may be appended to a currently active program. For example, suppose you wish to observe the sky only occasionally and not after every star. You can set up program 0 for sky only and another program for star only. Whenever you want to observe the sky, click on the `Programs` button on the *top* bar and select `Append Prog 0`. Program 0 will now be appended to the current program. It will be removed after the last integration.

If you change your mind and wish to remove program 0, select `Remove Prog 0` from the `Programs` apply drop menu.

1.22 Recording data

Normally, you will definitely want data that you acquire to be saved to a disk file. To record data, press the `Disk Save` button and select `Record Data`. This instructs the computer to open a file of your choice on the hard disk. `XLUCY` chooses an appropriate file name for you based on the last four digits of the Julian date. The file name will be displayed and you have a chance of accepting or changing the name. If the file already exists, you will be prompted as to whether you want to append to the end of the existing file or to overwrite the file. Anything which gets displayed on the left panel will be recorded on this file, including any comments that you may wish to enter.

The filename that you have chosen for recording will be permanently displayed below the right hand bottom panel. Be sure to check that recording is enabled before you start serious observing.

1.23 Printing

Since it is very easy to scroll backwards and forwards on the left panel and to insert comments at any point, there is probably no need for a printer. However, if you need to print, put the printer online and press the `Printer` check box with the mouse.

1.24 Starting an integration

Before you can start an integration, you need to load the program to be executed. Do this by by clicking on the `Programs` button on the top bar and selecting one of the ten possible programs. Note that there are two `Programs` buttons. The button on the top bar *applies* the program; the button on the bottom bar simply *lists* the program on the bottom right panel. The selected program will be displayed in the top right panel. If the program does not exist, this panel will be blank and the integration will not start.

Next, you must enter the name of the star prefixed by an asterisk, for example

```
*HD123456
```

If the star is listed in the `program stars` file, the RA and DEC will be printed as soon as you have typed in the name. Otherwise, you need to enter the RA and DEC as mention in Section 4.9:

```
*HD123456
1223.5  -3212.3
```

There are two ways of starting an integration. You can either click on the `Integrate` button or press the remote start switch on the photometer. If this switch is already up, put it down and then up again.

If everything is ready to go, you should hear a bleep followed by the SAST of the start of integration. Otherwise you might get an error message such as **Viewing prism not retracted**. The integration will start as soon as the fault is corrected.

At the end of the integration, the filter wheel will move immediately to the next filter. If the pause flag in the program is set to 1, the integration will start at once, otherwise it will only start if the `Integrate` button or the remote start switch is pressed. Even if the pause flag is set to 1, you can force an indefinite pause by putting down the remote start switch or clicking on the `Integrate` button during the integration.

1.25 The data line

At the end of each integration, you will get a typical data line like the following displayed on the left text area:

```
215235 10 2 13 1     1260234
```

The first number is the SAST of the start of the integration ($21^h52^m35^s$). The next number is the integration time in seconds. The third number is just a running index. Next comes the filter number (13). The fifth number is the star/sky flag (1 for star, 0 for sky) and finally the number of counts.

As each line of data is displayed, it will be recorded. Anything typed on the left text area will also be recorded. Feel free to enter comments at any time. You can scroll text up and down and enter comments at any point. This will all be recorded.

Whenever some action is required of the observer, a buzzer will sound (if installed on your particular photometer). This occurs, for example, whenever it is necessary to move from a star to a sky position.

1.26 Aborting an integration

To abort an integration, click on the `Abort` button or press the remote abort switch on the photometer. Notice that the integration time on the data line is set to zero to flag the abortion. Notice also that the program is not advanced to the next line. Starting the integration will simply repeat the current program line.

1.27 Filter wheel initialization

The filter wheel in the photometer is controlled by `XLUCY` unless the manual option is selected during initialization. In order for `XLUCY` to know the position of the filter wheel, it looks for filter centre markers and a fiducial marker indicating filter position 0. This is done automatically during initialization.

Normally you will not need to initialize the filter wheel more than once per night unless the computer loses track of the filter position. The only time this should occur is when you are observing a star which is too bright for the photomultiplier. In this case the filter wheel is immediately moved to a position between filters to cut off the light and you will get an **over-illumination** message on the screen. To restart the integration, you need to do some corrective action, such as abandoning the star or inserting a neutral density filter, and initializing the filter wheel.

To initialize the filter wheel, click on the `Etc` button and select `Init filter`. When the filter wheel is being initialized, a box will appear briefly giving details of the number of filter positions and the number of steps for a compete revolution of the wheel. This box disappears of its own accord after a few seconds. You may have to reload and re-start the program.

1.28 The monitor form

The purpose of the monitor form is to display the count rate in an analog fashion so that the state of the data can be assessed at a glance. Every second during an integration the screen is refreshed with the data points moving from right to left. Scaling is made automatically from the count rate during the first second. Scaling for a sky reading is maintained at the value appropriate to the star through the same filter.

Several numbers are displayed across the top bar. These are (from left to right) the number of counts per second, the SAST, and the accumulated number of counts. On the bottom bar the filter number is displayed. There is also a slide which you can move to adjust the magnification in the time axis.

Before the start of a program, the RA and DEC of the star is displayed in large letters on the monitor. This could be of help in setting on the star. The monitor reverts to normal at the start of an integration.

1.29 On-line reductions

Now that we have seen all the information necessary for on line reductions, let us see how it works in practice. To start observing, enter the name of the star preceded by an asterisk (example: `*HD123456`). If the star is a standard or a program star, the RA and DEC will be displayed. If not, enter the RA and DEC as described in Section 4.9.

When you have acquired the star in the beam, start the integration by putting up the remote start switch or by clicking on `Integrate`. This causes the SAST of the start of the integration to be displayed. The integration always starts precisely on the second.

We have mentioned that there is a flag in the program which allows the next integration to start by an action of the observer rather than an immediate start when the filter has been positioned. The same effect can be achieved, irrespective of the value of this flag, by leaving the remote start switch in the down position. Clicking on `Integrate` can also be used for the same purpose.

At the end of the program, the on-line reductions will be displayed. The Julian day and air mass are calculated at the half-way point between the start of the first star integration and the end of the last star integration. If no sky has been observed, the last sky values obtained with the same filter numbers will be used. If these do not exist, an error message will be displayed.

The following steps are followed in calculating the reduced magnitudes and colours:

1. The heliocentric Julian day and air mass is calculated assuming a time midway between the start of the first star integration and the end of the last star integration.

2. The dead-time corrections are applied to the star and sky count rates and sky values subtracted from the corresponding star values. The latest sky readings for a given filter are always used.

3. The corrected star count rates are converted to magnitudes and the extinction corrections are applied.

4. The colour equations are applied.

5. The zero-points are added.

6. The non-linear corrections are applied.

1.30 Setting the zero-points

To set the zero-point for on-line reductions, a standard star must be observed. At the end of the program, when the reductions have been calculated, click on the `Stars` button and select `Apply zero-point`. This causes the zero points to be reset so that a re-reduction will give the standard magnitude and colours for the star.

1.31 Terminating `XLUCY`

`XLUCY` can be terminated gracefully at any stage by clicking on the `Exit` button. Before exiting, `XLUCY` will prompt you for the name of the setup file and the program star file that will be created in your local directory. Remember that setup files should end in `.sup` and program star files in `.str` (Examples: `mysetup.sup`, `mystars.str`). Any files of the same name will be overwritten. Be sure to save these data. If you fail to do this, any modifications and additions you have made since you started running `XLUCY` will be lost. In most cases, `XLUCY` will warn you to save your setup data if it has detected that you have made additions or alterations.

At this stage you have all the necessary information to operate the photometer using on-line reductions. The remaining chapters describe some specialized commands. These can be ignored if you are satisfied with the fundamentals.

1.32 The Macroprogram

A *macroprogram* (or macro for short) is a list of star names followed by the program number under which the star is to run. To enter a new macro, click the bottom `Macros` button and select the macro number you want to use. If a macro of that number already exists, it will be displayed in the left of the top right panels, otherwise you will need to enter a the macro. Here is an example of a macro:

```
HR2497     4
HR2680     3  2
HR2532     3
```

Here the star HR2497 will be executed with program 4. When the program block has finished, `XLUCY` assumes that the next star to be observed will be HR2680 and will type in that information on the left panel, just as if you had done it by hand. HR2680 will be execute under program 3, but in addition, it is being observed with neutral density filter number 2. This facility is only useful in the Modular photometer. For convenience, the ND filter number will be displayed together with the RA and DEC on the monitor form. After HR2680 has been observed, HR2532 will be taken as the next star. After HR2532, the next star will be HR2497 and the sequence repeats itself.

1.33 Listing/entering a macro

If you want to look at a particular macro or change its contents, click on the `Macros` button on the *bottom* bar (labeled by `List`) and select the macro number. The macro, if it exists, will be displayed on the bottom right text area. You may edit it if it exists or type in the macro from scratch if the area is blank. When you have finished, click on the left text area to save the contents. Please remember to type in the final enter on the last line, otherwise this line will be discarded.

1.34 Activating a macro

To put a macro into operation, click on the `Macros` button on the *top* bar (labeled by `Apply`). The macro will be displayed on the left panel of the top right text area. The other panel is used for displaying the current program (see above). Above the macro display area the is an extract from a line in the macro. This is the line which will be executed at the end of the current macro line. Above this display, there is a button which is labeled by the current macro number. This button is used to change the line which is to be executed.

1.35 Changing a macro while it is executing

It is easy to modify a macro that is currently executing by clicking the mouse in the macro display window and making the required changes. The changes will only come into effect when you click the mouse button on the left window. The changes will be copied to a new macro - macro 10 and will remain active until a new macro is loaded.

1.36 Changing the macro line

It is sometimes useful to modify the flow of the macro so that it will start on a different line. The button which displays the current macro number (just below the *Exit* button), contains a drop-down menu which lists the macro lines. Select from this list the line you want to be executed.

1.37 Canceling a macro

Click on `Macros` in the top bar and select `Macro Cancel` to disable the macro (this can be done while observing the last star).

1.38 Using neutral density filters

A frequent problem occurs when it is necessary to employ a neutral density filter in the course of a sequence of observations. The on-line reductions will, of course, reflect a different zero point which can't be helped. What is annoying is that the sky count rate for the particular filter will be incorrect. Unless a sky is measured the next time the ND filter is removed, subsequent sky readings will be in error. This may lead to wasted time during repeated use of ND filters.

To overcome this problem, simply use a different filter number for the measurement with a ND filter. For example, in a wheel with ten filter positions, filter numbers 12 and 22 both select filter position 2. However, the readings for these two filters are stored separately and separate reductions will be performed. This means that the correct sky readings will be used provided you are consistent in assigning the same filter number to the same filter + ND filter combination.

1.39 The counters

The photometry interface board has four counters which can be connected to four different photometers if required. In most photometers, only one or two counters are used. The counters are labeled as counter 0, 1, 2, 3 or 4. On startup, `XLUCY` reads a special file called xlucy.config which stores the default counters in use for each photometer. Normally, these do not need to be changed.

1.40 Counter list

To display which counter is in use, click on `Etc` and select `Counter list`. The output will appear in the bottom right text form and may look like this:

```
999 999       0    Counter 0:
 10  19 1000000    Counter 1:
 20  29 1000000    Counter 2:
999 999       0    Counter 3:
```

Each line consists of three numbers. The first two numbers lists the range of filter numbers corresponding to that counter. For example, filter numbers 10 to 19 inclusive will read counter 1 and filter numbers in the range 20 - 29 (inclusive) will read counter 2 in the above example. Counters 0 and 3 are effectively disabled because the filter number will never be set to 999.

The third number is the maximum count rate (counts/second) for over-illumination. If the count rate exceeds this value at any time, the filter wheel will be interposed in the light beam to cut off the light to the photomultiplier.

1.41 Counter apply

If you need to change the counter to be selected or the over-illumination count rate, you should first of all select `Counter list` and edit the list in the bottom right text area. Click on the left text area to save the changes, then select `Counter apply`. Please do not change the over-illumination to an unreasonably large amount as you might destroy the photomultiplier tube next time you set on a bright star.

1.42 Restore counters

To restore the counter list to its original state, click on `Restore counters`.

1.43 Disable Errors

If for some reason you need to disable the hardware errors, select this option from the `Etc` button.

2 REDUCING PHOTOMETRIC DATA FROM XLUCY

2.1 The output from XLUCY

We will take an example of output from XLUCY and work through it to see how the on-line reductions are obtained. We shall assume the following constants:

```
Dead-time correction: 40.0 nanoseconds.

  Pos  Var     Name
  16  unat  Stromgren u
  17  vnat  stromgren v
  18  bnat  Stromgren b
  19  ynat  Stromgren y


Colour equations:

     y = 1.0*ynat
     b = 1.0*bnat
     v = 1.0*vnat
     u = 1.0*unat

Extinction coefficients:

  ynat = 0.130
  bnat = 0.190
  vnat = 0.310
  unat = 0.600

Zero points:

   y = 20.000
   b = 20.000
   v = 20.000
   u = 20.000
```

As an example, we take the following output:

```
*HD104481
   +1201.1    -7318.0
192026 40  1  16  1   501660
192107 30  2  17  1  1251649
192138 20  3  18  1  1052863
192159 20  4  19  1   850406
192243 15  5  19  0     2024
192259 15  6  18  0     2160
192315 15  7  17  0     1853
192331 20  8  16  0     1761
HJD = 1293.2255   Air mass = 1.4714
   y =  8.239 + .002    b =  7.918 + .002
```

```
v =  7.994 + .003    u =  8.878 + .003
```

2.2 The dead-time correction

The first step is to correct the observed counts (star and sky) for dead time. The electronics might count two pulses as one if they follow each other very closely. The resulting count rate will be an underestimate of the true count rate. Clearly, the discrepancy will be worse for the brightest stars. To correct for this effect, we use the following formula

$$N = \frac{n}{(1 - n\tau)}$$

where N is the true number of counts/sec and n is the observed number of counts/sec. The quantity τ is the *dead-time constant* measured in seconds. In our case $\tau = 40 \times 10^{-9}$. Applying this formula to the example, we obtain:

```
Counts corrected for dead-time:

*HD104481
   +1201.1    -7318.0
192026 40 1 16 1   501912
192107 30 2 17 1  1253741
192138 20 3 18 1  1055085
192159 20 4 19 1   851855
192243 15 5 19 0     2024
192259 15 6 18 0     2160
192315 15 7 17 0     1853
192331 20 8 16 0     1761
```

2.3 Sky subtraction

Next we find the count rate (counts/sec) for each filter:

```
Count rates:

 SAST   t              N      Rate
192026 40 1 16 1   501912  12547.800
192107 30 2 17 1  1253741  41791.367
192138 20 3 18 1  1055085  52754.250
192159 20 4 19 1   851855  42592.750
192243 15 5 19 0     2024    134.933
192259 15 6 18 0     2160    144.000
192315 15 7 17 0     1853    123.533
192331 20 8 16 0     1761     88.050
```

Then we subtract the sky rate from the star plus sky rate and convert to a magnitude, $m = -2.5 \log_{10}(Star - Sky)$:

```
Remove sky and convert to magnitude:
```

SAST	t				N	Rate	Star-Sky	Mag
192026	40	1	16	1	501912	12547.800	12459.750	-10.238773
192107	30	2	17	1	1253741	41791.367	41667.834	-11.549502
192138	20	3	18	1	1055085	52754.250	52610.250	-11.802676
192159	20	4	19	1	851855	42592.750	42457.817	-11.569894

2.4 Extinction correction

The next step is to apply the correction for atmospheric extinction. We do not measure the extinction coefficient on every night. Instead, we adopt the mean extinction coefficients which are measured at Sutherland from time to time. The magnitude corrected for extinction, m_0, is calculated using:

$$m_0 = m - E_\lambda \times \text{Air\_mass}$$

The air mass is calculated from the position of the star and the time. In our example `air mass = 1.4714`. We obtain the following:

Extinction correction:

SAST	t				m	E	m0
192026	40	1	16	1	-10.238773	0.600	-11.121613
192107	30	2	17	1	-11.549502	0.310	-12.005636
192138	20	3	18	1	-11.802676	0.190	-12.082242
192159	20	4	19	1	-11.569894	0.130	-11.761176

2.5 Colour equations

Next, we apply the *colour equations* which is a transformation between the natural system and the calibrated system. We have chosen a trivial transformation in our example:

```
y = 1.0*ynat = -11.761176
b = 1.0*bnat = -12.082242
v = 1.0*vnat = -12.005636
u = 1.0*unat = -11.121613
```

2.6 Zero points

The final step is to apply the zero points to the values from the colour equations:

Filter	m	ZP	m+ZP
y	-11.761176	20.00	8.2388
b	-12.082242	20.00	7.9178
v	-12.005636	20.00	7.9944
u	-11.121613	20.00	8.8784

The zero point is a number chosen so that the observed magnitude of a standard star matches the tabulated magnitude. In the example above, the zero point is a single number. In general, the zero point varies with the colour of the star because the transformation is not entirely linear. In such a case there is an additional step: the addition of a non-linear zero point correction. A colour index is calculated after the zero point is applied. The colour index is used in a look up table (the non-linear corrections) to determine a small correction by linear interpolation. This correction is added to $m + ZP$. In the present example, non-linear corrections are not used. The last column is precisely the result of the on-line reductions.

2.7 The heliocentric Julian date of the observations

In a multi-filter set of observations such as in this example, we would like to attach a time which is representative of the observations of the star as a whole. Of course, we could give individual times for the mid-exposure of each filter, but in `XLUCY` the assumption is that you are observing objects which do not vary in brightness by a significant amount during the time taken to observe the object through all the filters. If this is not the case, you should be using `XMILLY`. Given this assumption, `XLUCY` adopts the time which lies midway between the start of the first star observation and the end of the last star observation.

In the example the time is midway between SAST 19:20:26 and 19:22:09 which is SAST 19:21:17.5 = UT 17:21:17.5. The fractional geocentric JD is given by $(UT - 12:00:00)/24 = 0.2231$. To this value must be added the *heliocentric time correction* for the star. This is the time measured at the Sun and allows for the motion of the earth around the Sun. Since light from the Sun takes 8 minutes to reach the Earth, the maximum value of this correction is 0.0056 days, which occurs for a star in opposition on the Ecliptic. In this example the heliocentric correction is 0.0024 days.

The heliocentric correction, t, is calculated as follows:

$$t = -0.0057755r\{\cos\lambda_\odot \cos\alpha \cos\delta + \sin\lambda_\odot(\sin\epsilon \sin\delta + \cos\epsilon \cos\delta \sin\alpha)\}$$

where r is the distance of the Sun in astronomical units, $\lambda_\odot$ is the longitude of the Sun, α is the RA of the star, δ is the declination of the star and ϵ is the inclination of the rotation axis of the earth.

2.8 The air mass

The amount of air is along the optical path of the star is proportional to $\sec z$ where z is the zenith distance of the star. A small correction term is added for refraction to give:

$$\text{Air\_mass} = \sec z\{1.0 - 0.0012(\sec^2 z - 1)\}$$

3 PLOTSTAR

3.1 Introduction

When observing the same stars repeatedly, it is very helpful to be able to see a graphical display of the magnitude versus time. This can be done by running a separate program, `plotstar`. This program will read the current `XLUCY` output file (or any other `XLUCY` output file) and plot from the online reductions.

You can run `plotstar` from the menu bar or type `plotstar` in an xterm window. This will bring up a form containing buttons on the left hand side and a large plotting area on the right (Fig. 6).

3.2 Input File

The first thing you need to do is select which file you want to plot (which could be the current file to which `XLUCY` is writing). Clicking on this button will bring up a file browser. Double click on the file or single click and press `Ready`.

3.3 Star List

Now you need to select which stars you want to plot. Click on this button to bring up a list of all stars observed and select the star you want to plot. Repeat for all the stars that you require. Note, however, that there is room to show only four plots, so selecting more than four simply overwrites one of the others. By default, the HJD is plotted on the X-axis and the magnitude, or whatever happens to be the first variable, on the Y-axis.

3.4 X-scale; Y-scale

Change the X-scale by clicking on `X Scale` and entering the starting and stopping HJD for the plot. Click on `Y Scale` to enter the magnitude per tick.

3.5 Y variable

If you want to show another variable, click on this button and type in the variable you require. You need to click on the `Star List` button to re-plot with the new variable.

3.6 Crop

Often, one or two observations will be wrong and cause problems in plotting the star on a reasonable scale. Click on this button and type in the number of outlying measurements you wish to remove. This will get rid of wrong magnitudes.

3.7 Update

If you are repeating observations of the same star, you can get `plotstar` to update automatically. Click on this button and select an update time in minutes. Typing zero will stop the update.

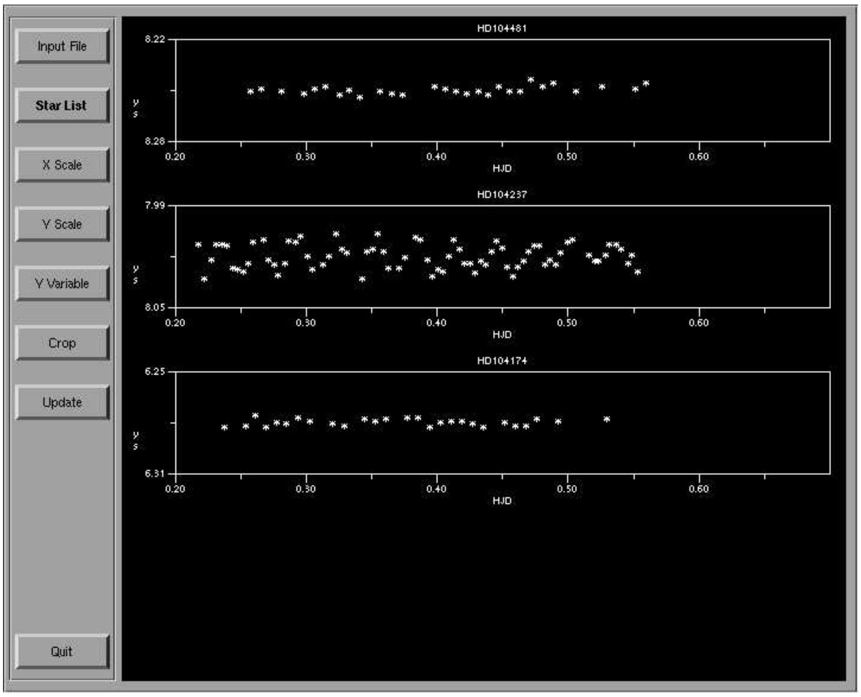

Figure 6: The `plotstar` form. There are four graphics area; any four stars can be plotted versus HJD, air mass, etc.

4 SAVE

4.1 How to save your data files

At some stage you will want to save your data files to diskette or e-mail them to your home institute (or both). If you are unfamiliar with Linux, it may be easier to type
save
from an xterm window. This brings up a form with labeled buttons (Fig. 7).

4.2 Format a diskette

Insert a diskette in the drive and click on this button. Formatting takes a while, so please be patient. Remember that any data on the diskette will be lost!

4.3 Copy to diskette

Insert a formatted diskette in the drive an click on this button. A menu will be displayed of the files in the current directory. Select the file you wish to copy to diskette and click on `Ready` (or simply double-click on the file). The file will be copied to diskette.

4.4 Copy from diskette

This is the inverse of the previous operation and works in exactly the same way.

4.5 Lists file on diskette

The file listing will be displayed in the xterm window.

Figure 7: The `save` form.

4.6 E-mail files

Clicking on this button will bring up a form in which you enter the e-mail address(es). Clicking on `OK` will then bring up a list of files in the current directory. Click on the file you want to e-mail and click on `Ready` (or double-click on the file name). The file will be e-mailed to the specified destination(s) with the file name as the subject content. Please note that the data file is uu-encoded before mailing. The recipient must use uudecode to restore the original file.

5 Known bugs

Please report any bugs (or suggestions) to Luis Balona (`lab@saao.ac.za`). This is very important, otherwise they will not be cured.

The most important bug (one which I cannot repeat or find a likely cause) is the following. After an *Overillumination* message the program crashes (forms disappear) on attempting to re-initialize the filter wheel. However this bug is not repeatable. Most of the time everything works fine after re-initialization.