Appendix D

Observing with IMPOL

The main intention of this chapter is to act as a guide in preparing and carrying out observations with IMPOL. It is assumed that the observations are made with the 1.2 m, f/13 telescope at Mt. Abu. The first section deals with the steps to be taken, by way of preparations, well in advance of the observations. The second section discusses the work to be done at the observatory before, during and after the observations.

D.1 Homework

- Use Palomar Sky Survey digitized maps to obtain an image of the sky about $0.5^\circ \times 0.5^\circ$ around the target centre. These maps may be used to study the target and the region around it. The steps necessary to obtain FITS maps from the CDROM archive of the digitized sky survey and to convert them to IRAF images, are given in Appendix E. The digitized sky maps contain information in its headers which allows to mark J2000 coordinates on the image. The steps necessary for this also, are given in Appendix E.

- *While taking printouts of these images make sure that "reversevideo" is used or the contrast is set so that the image is mostly on white background.*

- From the digitized sky maps, decide the centres of the fields which is to be observed. If a particular target needs more than one field to cover it fully, decide the centres of each of these fields.

- Generate a map of the sky around each of these centres, which is about 10×10 arcmin. On the default IRAF image the sky appears with the right ascension coordinate increasing towards left, while on the display of the data-acquisition computer of IMPOL it increases towards right (see Fig. D.2). Hence it will be useful to flip the IRAF map about the vertical axis through its centre. Mark the maps with J2000 coordinates as above. Printout the IRAF map. Again, see Appendix E for help on how to do this.

- The ranges of right ascension and declination values from which a guide star may be chosen for a given field centre are given by

$$(RA_{\text{target}} + \frac{24.7 \text{ s}}{\cos \text{DEC}}) < RA_{\text{guide}} < (RA_{\text{target}} + \frac{52.9 \text{ s}}{\cos \text{DEC}}) \tag{D.1}$$

$$(DEC_{\text{target}} - 9'15'') < DEC_{\text{guide}} < (DEC_{\text{target}} + 9'15'') \; , \tag{D.2}$$

  where (RA_{target},DEC_{target}) are the coordinates of the centre of the main field and (RA_{guide},DEC_{guide}) are the corresponding quantities of the guide star. The visual magnitudes of the guide stars may be in the range 8 to 15.

- From the digitized sky survey maps, identify atleast one suitable guide star for each of the field centres. The exact J2000 equatorial coordinates of these stars may be obtained from the HST Guide Star Catalog (refer Appendix E). It is also possible to make graphs which show the position of the guide star relative to other bright stars nearby.

- Identify a few polarized and unpolarized standard stars which fall within the right ascension and declination range available for observation. Identify guide stars for these and get their exact coordinates.

- Precess the coordinates at other epochs to current coordinates (refer Appendix E). Note these coordinates on the corresponding digitized sky maps and the guide star graphs.

- Decide the total observation time needed for each field with reference to the exposure time, filters. From the ephemeris, find out the time of moon rise and moon set during the nights of observation. With this data, plan the sequence of observations for each night. Give a unique identification number for each field and mark it on the corresponding digitized sky map (see Sec. D.2.2).

- Ensure that the dewar is properly evacuated. Make arrangements for sufficient quantity of liquid nitrogen to be available at the observatory. A conservative estimate of the requirement is 5 litres per night plus 15 litres every time the dewar is to be filled from warm condition.

- Estimate the number of tapes (or other storage medium), which will be required to archive the data. Each full frame image requires about 1.2 Mb of space and each tape can carry about 120 Mb. However, the compression option typically provides about 2:1 reduction in space requirements. Make sure that the tapes to be used are formatted (formatting each tape takes about an hour) and empty.

- Carry 3.5 in. floppies for the following :

  1. booting the computers
  2. data acquisition software
  3. instrument control software
  4. tape software

- Technical documentation of IMPOL includes
    1. set of mechanical engineering drawings
    2. Pinout details and connection diagrams of instrument control electronics
    3. Pinout details and connection diagrams of data-acquisition system
    4. A copy of this user's guide and its appendix.

D.2 At the observatory

The work at the observatory, prior to the observation involves unpacking the instrument from its storage boxes, mounting it on the telescope, cabling etc. This operation will take about five to six hours and can be done in the daytime previous to the first observation night. The next two sections here, discuss the key issues related to these operations. The observation process itself is dealt with, in the last section.

D.2.1 Mounting the instrument

- Unpack the dewar from its storage box, rest it vertically on a table and start filling liquid nitrogen. Since it is being cooled from a warm state, it will take over hour to fill fully. Leave it to settle and cool. Check occassionaly if condensation occurs on the body or on the window.

- The mounting operation is easier if the telescope is parked looking at the zenith. The first thing which is to be mounted is the adapter ring, which matches the IMPOL mounting plate with the Cassegrain port of the 1.2 m telescope. Fasten this ring by means of eight M8 bolts on to the inner race of the ball-bearing arrangement at the Cassegrain port, which allows the instrument to be rotated after mounting.

- The assembly of the main pipe upto the flange which carries the dewar, is stored as one unit fixed on the mounting plate. The XY translation stages, but without the arm carrying the guide probe, also is kept fixed on the mounting plate. This entire assembly is mounted on the telescope in one go. Marks have been made on the sides of both the ring and the plate, as an aid to ensure proper alignment.

- Once the pipe has been secured on the ring, rotate the enitre assembly so as to align the instrument axes with those of the telescope. For the acquisition and guidance system to work properly, the opening for the probe, on the wall of the pipe, should be on the west side of the instrument (see Fig. D.1). The correct orientation of the instrument has been marked on the mounting plate.

- As of now, there are no scales which allow exact alignment of the axes of the instrument with that of the telescope. However, alignment within a few degrees

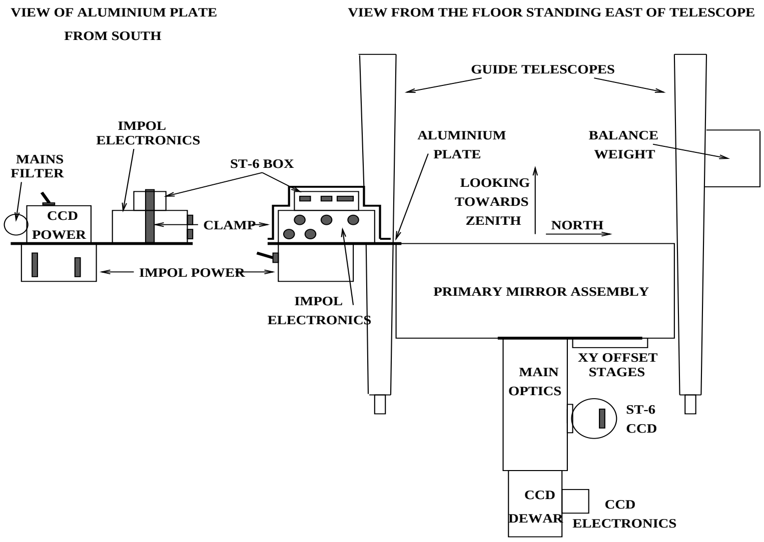


Figure D.1: Block schematic of IMPOL mounted on the 1.2 m telescope. North is towards the right and west is into the page.

can be obtained by making use of some markings on the telescope structure as well as on the instrument, for reference. After rotating the instrument to the correct orientation, tighten the locking arrangement, which prevents the ring from rotating further.

- The arm for mounting the probe can now be fixed on the XY translation stage and the probe attached to the arm. Make use of the marks on the arm and the back end of the probe to ensure that the orientation of the probe is correct - that is, the prism face is orthogonal to the optic axis of the telescope.

- Fix the optics assembly unit consisting of the elements from the fibre to the ST-6 CCD, to its clamp on the main pipe. The fibre end of the assembly should be towards the west (refer Fig. D.1). Ensure that this assembly is electrically isolated at the clamp, from the rest of the instrument. If this is not so, it has been observed to contribute additional noise to the main CCD data.

- Insert the fibre tip, at the back end of the probe, with the correct orientation and secure it with the grub screws. Again, marks have been made which show the correct orientation of the fibre.

- The four boxes namely, the IMPOL control box, ST-6 control box, power supply unit of instrument control system and the power supply unit of data-acquisition system, can, now be mounted on the aluminium platform provided for the same, on the telescope structure (refer Fig. D.1).

- Uncover the bottom flange of the pipe and mount the dewar. Make sure that the alignment mark on the dewar flange matches with that on the pipe flange. While mounting the dewar, the wire from the shutter has to be routed through a

Table D.1: The list of cable connections

No.	Cable	From	To
1.	IMPOL power	IMPOL power supply	IMPOL control box
2.	CCD power	CCD power supply	CCD box # 1
3.	ST-6 power	IMPOL power supply	ST-6 control box
4.	Image intsfr. power	IMPOL power supply	Image intsfr. box
5.	HWP motor	IMPOL control box	IMPOL main pipe
6.	X motor	IMPOL control box	X motor
7.	Y motor	IMPOL control box	Y motor
8.	ST-6 camera	ST-6 control box	ST-6 camera head
9.	IMPOL serial link	IMPOL control box	ST-6 control box
10.	ST-6 serial link	ST-6 control box	Instrument control PC
11.	CCD serial link	CCD box # 1	Data acquisition computer
12.	Data serial link	CCD box # 1	Data acquisition computer
13.	Relays	ST-6 control box	Telescope control
14.	Shutter power	Shutter	CCD box # 2
15.	Dewar	CCD box # 2	Dewar

notch provided for the purpose on the pipe flange. Ensure that the wire is sitting properly in the notch lest that it will be crushed when the flanges are tightened together.

- The last step in the mounting operation is making the cable connections. Before making each connection, ensure that the cable is properly supported so that there will be no strain on the connector itself. Note that as the telescope orientation changes during observations, the cables may move under gravity. Table D.1 list the different cables that are to be connected.

D.2.2 Other preparations

Evening before first night

- Once the instrument has been mounted on the telescope, the position of the counterweights have to be adjusted, in particular, those which correct for the off-balance about the declination axis. The correct position is at 30 cm on the scales which are available on the counterweight mounts on both north and south sides of the telescope.

- Arrange the two PCs – instrument control and data-acquisition – on a table in the control room. Make connections to the cables coming from the instrument (ST-6 serial link, CCD serial link, DATA link). Connect the tape drive unit to the instrument control PC and verify that it is working, by writing and reading data to a tape. Keep the filter sets ready in their holders.

- In order to position the probe at the correct offset during the observation of each field, it is required to give the current right ascension and declination coordinates of the center of the main field as well as that of the guide star. The equatorial coordinate pairs corresponding to all the observations may be kept in a formatted file, from which, the instrument control software will read at the time of initialization. The format allows a unique number (see Sec. D.1) to be allocated to each field and the corresponding pair of coordinates.

- The instrument control software package should have the following files. The main directory containing the files

1. impol.exe	2. impol.cfg	3. svga256.bgi
4. litt.chr	5. trip.chr	6. coordinate file

  as well as two sub-directories, (i) bas, which contains

1. init.bas	2. accept.bas	3. command.bas

  and (ii) asm, which contains, atleast

1. hmov0.asm	2. xmov0.asm	3. ymov0.asm
4. hmove.asm	5. xmoveb.asm	6. ymoveb.asm
7. lkt1.asm		

- The parameters which define each exposure like its duration, type etc. are to be kept in separate files. Before taking each exposure, the data-acquisition software will query the user for a parameter file and take an exposure accordingly. Ensure that parameters files corresponding to most frequent exposure durations are kept ready. A typical set of files could be for the following approximate durations in seconds – 0.3, 0.5, 1, 2, 5, 10, 30, 60, 120, 180, 300 etc. Parameter #11 in each file sets the exposure duration in integral multiples of 55 ms.

- The data of a night's observation has to be accumulated on the hard disk of the data-acquisition computer. Ensure that there is sufficient space for this on the disk. Delete unnecessary files. Open a fresh directory for a new observation run. It should contain the following files :

1. chcom1.exe	2. vterm.exe
3. vterm.set	4. accept.bas

- Open a subdirectory in the above directory, where the first night's data will be accumulated. Ensure that the following files are present in this subdirectory :

  1. the parameter files for exposures
  2. svga256.bgi
  3. ccd_new.exe
  4. edit1.exe
  5. display.exe

Evenings before other nights

- Reach the observatory a few hours before the beginning of observations. Archive the data of the previous night on to a magnetic tape - use space compression while archiving.
- Make a new subdirectory for each night. Ensure that there is enough space on the hard disk for the night's data. Make sure that the parameter files, executables and the bgi file from the previous night's subdirectory have been moved to this one.

D.2.3 Observing

- About a couple of hours before dusk, point the telescope to the extreme south declination, so that the dewar becomes almost horizontal. Fill liquid nitrogen.
- *Ensure that the banana pins which carry power to the image intensifier (particularly, the red one) are not plugged into their sockets on the intensifier power supply unit.*
- Once the night assistants arrive, switch on the main power supply to the telescope and the instrument. Near the aluminium platform on which the power supply units etc. are mounted on the telescope, there is a power panel, which needs to be switched on, followed by the power switches of IMPOL and CCD power supplies and the ST-6 control box.
- About half an hour before the beginning of observations, open the dome shutters. Pull the window curtains to cover the windows.
- Startup the software for instrument control as well as that for data-acquisition. Complete the initialization process which takes a few minutes. Move the HWP and the XY stage motors to their respective zero positions (see Appendix E).
- Check the temperature of the CCD, by measuring the voltage at the test pins provided for the purpose on CCD box # 2. If the temperature is set correctly the voltage should be close 3.32 V. Take a short dark frame exposure (shutter closed) with the main CCD and check the pixel counts. If the CCD has been properly cooled, most of the counts should lie between 7F30H and 7F40H, with a variance of about 2 counts.

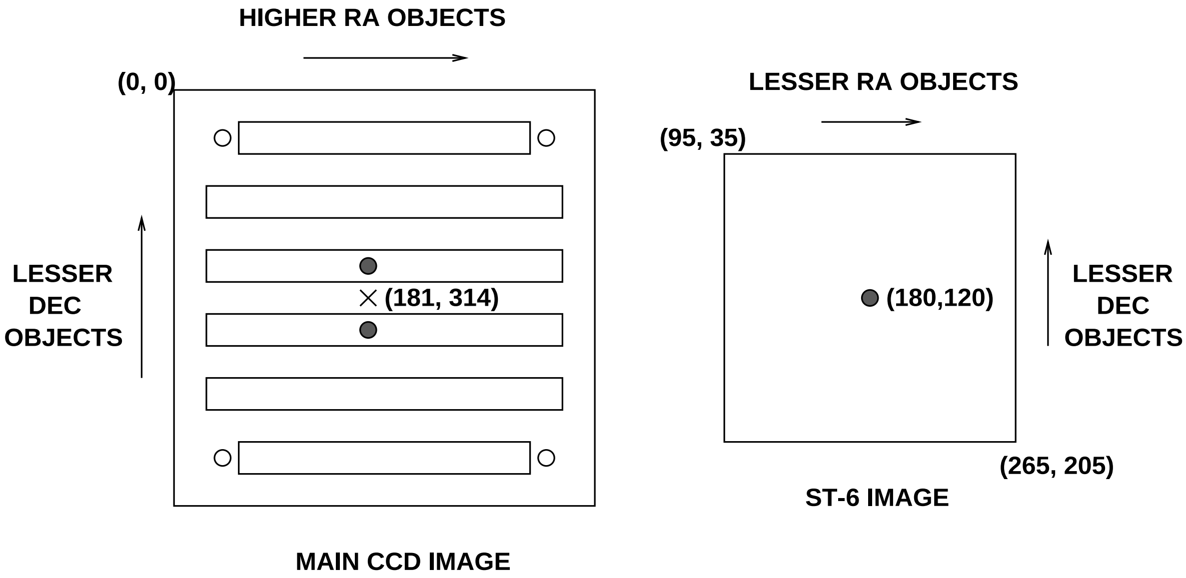


Figure D.2: The relative directions of the images on the main CCD and the ST-6 CCD.

- Insert the wideband filter in the beam path.
- On the first night of observation, the image formed by the telescope will not be in focus at the CCD of the polarimeter. Identify a bright star (V $\sim$ 10 or so) and point the telescope at it, soon after dusk. The secondary mirror position reading on the console should be set to about 78.3. Take an image with the main CCD and check the FWHM. Adjust the position of the secondary mirror, take another image and check the FWHM. Repeat the process till the FWHM of the stellar image is about 3 pixels. As one approaches close to this value of FWHM, reduce the step size to 0.01, till one crosses the position of the best focuss and then come back to the best position. The best position may be estimated as the mean between two positions giving equally defocussed images, on either side of it.
- Once the sky is sufficiently dark, turn off all the lights in the telescope floor and the nearby rooms. Plug in the intensifier power pin. *Ensure that the power pin is disconnected before turning on any light after this.*
- Point the telescope towards the first field. Take a short exposure (typically a few seconds) with the main CCD. Compare the pattern of bright stars within the field with that on the digitized sky map corresponding to the field. Fine adjust the telescope pointing followed by taking short exposures, to get the field correctly on the CCD frame. The relation between telescope motion and the motion of the main field image is as follows : (see also Fig. D.2).
  - Moving the telescope to point at lower right ascension coordinates will make the x-pixel coordinates of points on the main CCD to increase at the rate of 0.0828 /cos(DEC) seconds per pixel.

- Moving the telescope to point at lower declination coordinates will make the y-pixel coordinates of points on the main CCD to increase at the rate of 1.144 arcseconds per pixel.

- In the meantime, select the observation number that has been assigned to this field at the option provided by the instrument control software. Position the tracker probe at the correct offset (see Appendix E). The formulae used by the software for calculating the offset are

$$X_{\text{guide}} = (RA_{\text{target}} - RA_{\text{guide}}) * G_{\text{X}} + Z_{\text{X}} \tag{D.3}$$

$$Y_{\text{guide}} = (DEC_{\text{target}} - DEC_{\text{guide}}) * G_{\text{Y}} + Z_{\text{Y}} \tag{D.4}$$

  where RA and DEC stand for right ascension and declination respectively, and

$$Z_{\text{X}} = 10501;\ G_{\text{X}} = 105.8\times\cos(\text{DEC}) \text{ steps per second}$$

$$Z_{\text{Y}} = 5140;\ G_{\text{Y}} = 7 \text{ steps per arcsecond.}$$

- Once the telescope is pointed correctly, take an exposure with the ST-6 CCD. The guide star should appear in the field. If not, adjust the position of the probe, so as to get the guide star close to the centre of the tracker field. The relation between the motion of the probe and the motion of tracker field image is as follows : (see also Fig. D.2).

  - Moving the probe +X (also referred to as CW) will make lesser right ascension coordinates to come into the field of view of the probe and make the x-pixel coordinates of points in the ST-6 CCD image to decrease at the rate of about 6 steps per pixel.
  - Moving the probe +Y (also referred to as CW) will make higher declination coordinates to come into the field of view of the probe and make the y-pixel coordinates of points in the ST-6 CCD image to decrease at the rate of about 6 steps per pixel.

- Select the size of the box which is to be used for centroid calculations during auto-guiding. Set the amount of staggering (dithering), X_speed & Y_speed parameters and the exposure time for ST-6 CCD, during auto-guiding (see Appendix E). Verify that the telescope is in *fine* guidance mode. Start auto-guiding.

- A template for observation log is given in page 137. Fill in the items at the top of the log. Watch the auto-guiding relay activation and verify that the four relays are being activated for short intervals and randomly. The relation between the relays and the direction of telescope motion is as follows :

  - +X relay moves the telescope to higher right ascension coordinates at the rate of about 5 arcseconds per second of relay activation time.

  - +Y relay moves the telescope to lower declination coordinates at the rate of about 5 arcseconds per second of relay activation time.

- Ensure that the half-wave plate is at 0° position. Insert the required filter.

- Check the counts in typical stellar images on the main CCD image. Decide the duration of individual exposures and the number of exposures to be taken at each half-wave plate position, so as to obtain sufficient signal to noise ratio. The gain of the CCD camera system is about 5 electrons per count.

- After every exposure, rotate the half-wave plate to the next position, until the exposure at 67.5° position is taken. Then rotate it in the opposite direction one step (22.5°) at a time, after every exposure till 0° is reached again. Repeat this cycling till sufficient number of exposures are accumulated at each half-wave plate position.

- Make it a practice to take a look at the image atleast after every four or five exposures. Particularly, check the counts in the overscan region of the image frame to see if the CCD is still cool. Typically, if the dewar has been filled an hour or so before observations began, it will have to be filled once more, sometime around midnight.

- While saving the images to the hard disk, the following naming convention may be used :

  [filter][object name][cycle number][HWP position].[part of object]

  where,

  filter – a letter denoting the filter. Could be any one from b,v,r,w.

  object name – acronym (atmost four letters) indicating the name of the object which is observed.

  cycle number – one or two digit number indicating which HWP rotation cycle the image belongs to.

  HWP position – one digit number indicating the HWP position at which the image was taken. Could be nay one from 0,1,2,3 corresponding to HWO positions of 0°, 22.5°, 45° and 67.5°.

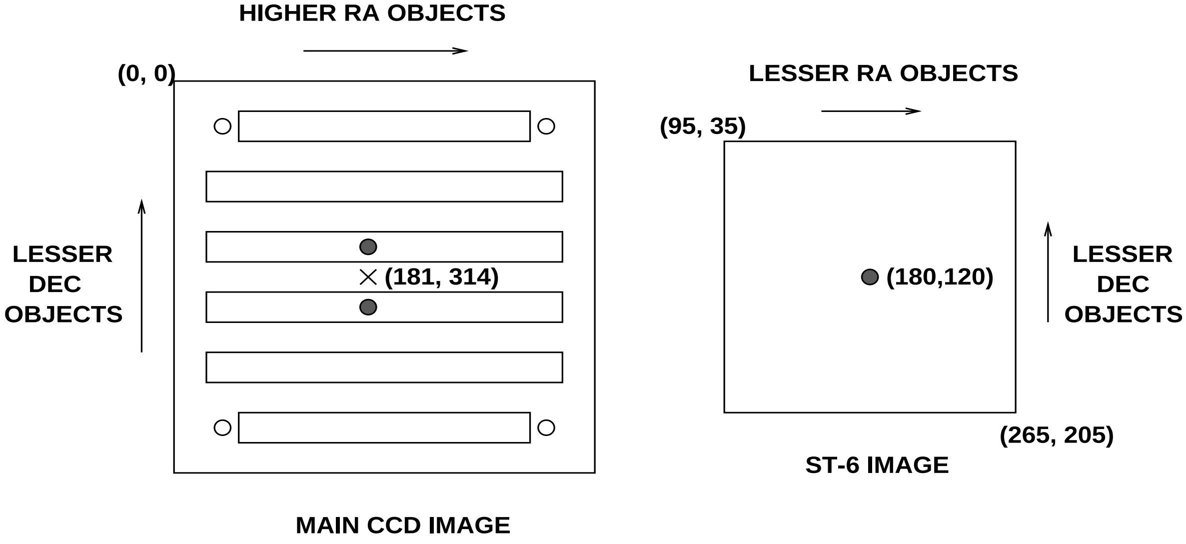
  part of object – often objects are larger than that can be covered by a single field. This number indicates which part of the object is covered by the particular field.

  Ensure that the name of the file conforms to the "8.3" format acceptable to DOS.

- Log every exposure taken. Note any remark which might be of use at a later stage. These remarks may correspond to the position of the moon, hour angle of the object during the exposure, clouds in the sky, interruption, if any, to the exposure – anything of relevance.

- Once the observation of the field is over, stop auto-guiding. Point the telescope to the next field and repeat the sequence of operations.

SUMMARY OF ACQUISITION AND GUIDANCE



Main image :

- Moving the telescope to point at lower right ascension coordinates will make the x-pixel coordinates of points on the main CCD to increase at the rate of 0.0828 /cos(DEC) seconds per pixel.
- Moving the telescope to point at lower declination coordinates will make the y-pixel coordinates of points on the main CCD to increase at the rate of 1.144 arcseconds per pixel.

Tracker Image :

- Moving the probe +X (also referred to as CW) will make lesser right ascension coordinates to come into the field of view of the probe and make the x-pixel coordinates of points in the ST-6 CCD image to decrease at the rate of about 6 steps per pixel.
- Moving the probe +Y (also referred to as CW) will make higher declination coordinates to come into the field of view of the probe and make the y-pixel coordinates of points in the ST-6 CCD image to decrease at the rate of about 6 steps per pixel.

Relays :

- +X relay moves the telescope to higher right ascension coordinates at the rate of about 5 arcseconds per second of relay activation time.
- +Y relay moves the telescope to lower declination coordinates at the rate of about 5 arcseconds per second of relay activation time.

To move an object from the main field to the tracker field, the telescope should be pointed to *lower* RA positions.

IMPOL OBSERVATION LOG

Object name	Part #	Filter	Moved probe	Yes/No
RA_{target}	$RA_{\text{telescope}}$		RA_{guide}	
DEC_{target}	$DEC_{\text{telescope}}$		DEC_{guide}	
Date & Time of start		X	Y	
ST-6 Exp. time	X_speed	Y_speed	Stagger	

Date & Time	Image name	HWP pos.	Exp. time seconds	Remarks

D.3 Data reduction

- Extract the image files from the magnetic tapes into the hard disk of a PC. This PC should either have IRAF (linux version) loaded on it or should have access to another machine where IRAF is available.

- The image files are saved by the data acquisition system of the instrument in ASCII form. Use the program *rfits.exe* to convert the ASCII files into FITS files. If IRAF is loaded on a different computer, transfer the FITS files to that computer. Since a large number of files are created during data analysis, it is convenient to use the following convention in saving these FITS files, to enable easy handling :

  – Open a directory which corresponds to a particular observation run. Open subdirectories in it which correspond to each night of observation. Make further subdirectories for each night, corresponding to each field which was observed during that night. Store all the FITS images of a field in its subdirectory.

  – The naming conventions of the FITS files may be the same as that was described in page 133, except that the '8.3' convention stipulated by DOS need not be followed here. It is recommended that the FITS files have an extension '.FITS' or '.FTS'.

- The custom made IRAF package for data reduction consists of the following files, each of which corresponds to one IRAF task. Ensure that all these tasks are loaded when IRAF is started.

1. getcenters.cl	2. makepairs.cl	3. mkratios.cl
4. dopol.cl	5. vwpol.cl	6. drwvec.cl

- *The following steps refers to the reduction of data from one field.*

- The first step in reducing the data, is to convert the corresponding FITS files into IRAF image files. To avoid confusion, we will hitherto refer to the IRAF image files as *frames*.

- Create a file which contains a list of flie names of all the frames, but without the *.imh* extension. The order in which the file names are to be listed is as follows. First, the four frames corresponding to the four HWP positions from the first cycle, in the order 0°, 22.5°, 45°and 67.5°. This is to be followed by the frames from the next cycle and so on. It is emphasized that the file names *must* be listed in quadruplets, in this fashion, and not in any other order.

- The beginning point of analysis is defining a set of coordinates at which aperture photometry is to be carried out. In the case of stellar fields, these coordinates are the centres of the stellar images and may be determined by running the IRAF task DAOFIND on one of the frames, preferably the first one in the list which was created above. Once the stellar coordinates have been identified in one frame, create a file containing a list of these coordinates in a two-column, x y format.

- The next task is to determine the coordinates of these stars in all the other frames, given that there might be slight shifts in stellar image positions between different frames. For this, display the first frame, identify a few (three or more) isolated, prominent stars in the first frame, determine their approximate coordinates using the cursor and list these coordinates in another file.

- Run the task GETCENTERS which will do the following three things :

  - It will use the short list of prominent stars to determine the shift of each frame from the first frame.
  - It will use the full list of stellar coordinates created from DAOFIND, for the first frame, as reference, and create a new list of stellar coordinates for each frame, by adding the corresponding shift.
  - It will create a coordinate file for each frame, listing the coordinates of all the stars, in a two-column x y format.

- Run the task MKRATIOS which will do the following things :

  - Do aperture photometry for each frame at each of the stellar coordinate positions. These positions are picked from the corresponding files which were created by the GETCENTERS task above.
  - Identify stellar image pairs (ordinary and extraordinary) in all the frames. For this, it automatically calls the task MAKEPAIRS. Create a coordinate file for each frame, in which coordinates and fluxes of the stellar image pairs are listed one below the other. That is, the four columns of the first row in the file will contain the x & y coordinates of the ordinary image of the first star, its flux and the sky counts; and the second row, these quantities of the extraordinary image of the same star. This is followed by two rows corresponding to the second star and so on.
  - Calculate the value of F from the first quadruplet of frames and determine the values of total flux, total sky, R(0°), R(22.5°), R(45°) and R(67.5°) for the first star. Write these values in a file. Repeat for the second quadruplet and so on till the last quadruplet. Then, determine and write these values for the second star and so on till the last star.

- Run the task DOPOL, which will do the fitting to determine p and θ and the errors on them. The results of fitting are written into a specified fileas a table. The columns of this table contain identification numbers of the ordinary and the extraordinary images, p, σ_p, θ, σ_θ, χ^2 value from fitting, magnitude of star, F, error estimated from dispersion in $R(\alpha)$ values and error estimated from photon statistics.

- Inspect the polarimetry table. The results of any star for which the following conditions occur, may be considered suspectful and its data needs closer inspection.
  - The value of F is less than about 0.9 or larger than about 1.1.
  - The error calculated from the dispersion in $R(\alpha)$ is not consistent with that calculated from photon statistics.
  - If the value of χ^2 is quite different from the total degrees of freedom. The total degrees of freedom is four less than the total number of frames.
- As an aid for inspecting the goodness of fit, the task VWPOL produces the result of the fitting, one star at a time, on a graphical interface.
- If polarimetry is to be repeated with another photometric aperture, the steps starting with running MKRATIOS are to be repeated.
- Create a final polarimetric data table, in which all the stars with bad measurements have been eliminated.
- Display a Digitized Sky Survey (DSS) image of the region under study. Compare it with a frame and visually identify the stars which have polarimetric measurements.
- Run the task DRWVEC to overlay polarization vectors on the (DSS) image. This task can read the polarization data (p and θ) from the polarimetry table created by DOPOL, or a table made with the same format.
- The first time DRWVEC is run, the positions on the DSS image where the polarization vectors are to be marked have to be indicated using the cursor. Whenever a vector is marked, this task will append the coordinates of the position on the DSS image, to a specified file. If the vector overlaying is to be repeated, it is sufficient to give this file to DRWVEC. In case this file is modified, ensure that the order in which the coordinates are listed is the same as the one which the stars are listed in the polarimetry table.

Appendix E

Observing with IMPOL - README

Notation

Below given are examples of notation used here to indicate whether a particular command refers to DOS (instrument control and data-acquisition), UNIX or IRAF.

C:\impol>	$\Longrightarrow$	DOS
pluto(anr):	$\Longrightarrow$	UNIX
cl>	$\Longrightarrow$	IRAF

E.1 Homework

Mounting a CD in the drive

Assume that CDROM drive is connected to a machine called *flora*. Mounting the drive involves, inserting a CD into the drive and typing the following from any machine that has network access to flora.

```
pluto(anr):rsh flora cdmount
```

Precess coordinates using IRAF

If the coordinates of the required field are in epochs other than J2000, precess them to J2000. IRAF has a task which allows to do this. For example to precess from 1950 coordinates to J2000 coordinates, do the following.

```
cl>astutil
as>precess STDIN 1950 2000
5:10:32.1 -20:33:17
```

The precessed coordinates will be printed on the screen. Now another pair of coordinates may be entered and so on. To exit from the task, press `^D`.

Obtaining digitized sky maps from Palomar Sky Survey CDROM archive

Mount any of one of the sky survey CDs. Go to a directory where there is enough space to keep an image. Type

```
pluto(anr):/user1/vam/getimage/getimage
```

Enter a filename, centre coordinates of the required field and the field size in the format indicated. You will be prompted to mount a particular disk which contains the required field. Mount this disk and press carriage return. The FITS file will be stored in the current directory. To convert it to an IRAF image, go to the directory (from within IRAF) and type

```
cl>rfits fitsfile * iraffile
```

An IRAF image will be created which contains the field.

Marking the sky map with equatorial coordiantes

The $[-*, *]$ argument of the first command below flips the x coordinate of the IRAF image, while displaying it.

```
cl>disp iraffile[-*,*] 1
cl>stsdas
st>analysis
an>gasp
ga>makewcs iraffile
ga>bye
an>bye
st>graphics
gr>sdisplay
sd>disc iraffile
gr>bye
an>bye
st>bye
```

Obtaining HST Guide Star Catalogue graphs of a region

Mount the correct CD in the drive. From within IRAF type

```
cl>stsdas
st>analysis
an>gasp
ga>regions
```

The user will be prompted to enter the center coordinates, field size etc. A table showing the details of guide stars present within the region will be printed on the screen and the output will be displayed on the graphics display of IRAF. To obtain the table in a text file edit the appropriate parameter of the "regions" task. To obtain a printout of the graph, type

```
ga>regions >G metafile
ga>stdplot metafile
ga>bye
an>bye
st>bye
```

E.2 At the observatory

E.2.3 Observing

Initializing the instrument control software

Once the instrument has been powered on, the software may be started by going to the impol directory in the instrument control PC and typing

```
C:\impol>impol
```

The software will first establish communication with the instrument at the telescope. On success, the user is asked whether it should go ahead with initializing the instrument. Answer "y" if you are running the software for the first time after switching on the power supply or after resetting the IMPOL control box. Once initialized, you can skip this step by typing "n", even if the PC has been powered off, in between, for some reason and you are starting the software afresh. The initialization takes a few minutes to complete and the user is informed of the progress. Once it is complete, the user is asked whether it should move the half-wave plate and the probe to "zero" position. Answer "y", everytime the software is started up.

The user is now given the option of choosing between the auto or manual mode of operation, but only the manaul mode has been implemented now. Another option, to exit the software, has been provided during its debugging stage and has not been disabled since. Then the software will display the name of the default parameter file and ask the user to name a new file, if necessary. This is the file from which the equatorial

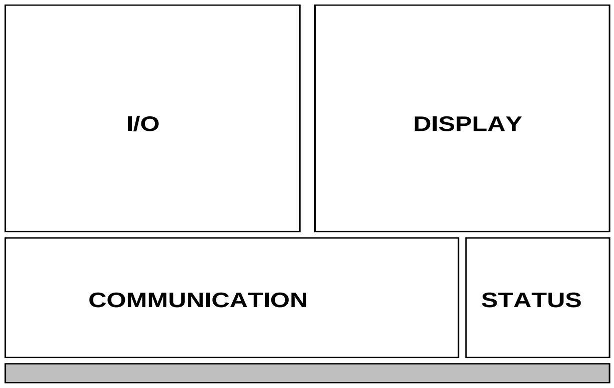


Figure E.1: The windows displayed by the instrument control software.

coordinates of the observation fields are read. The menu bar which allows the user to switch the software to the half-wave plate (HWP) control or tracker (TRACKER) control modes, is displayed at the bottom of the screen.

Using the instrument control software

The software displays four windows on the screen and a menu bar at the bottom (see Fig. E.1). At any menu level, except at the main menu, pressing <ESC> takes you back to the previous menu. At any stage, if <Alt - x> is pressed, the software exits immediately. The hot keys which allow to slect a menu option are highlighted in green on the menu bar. For many of the operations, the values of one or more parameters will have to be set. Once the appropriate menu option is selected, these parameters along with their current values are displayed in one of the windows. To change a particular parameter, press the corresponding highlighted letter, enter the new value and press <RETURN>. The new value will now be displayed. Some of the parameters, just toggle within a finite number of options. In those cases, just pressing the corresponding highlighted key successively, allows the user to toggle through the options. The structure of the software is described below. An item is marked with a star, if it has a sub-menu and the options of the sub-menu will be discussed subsequently.

Main menu

Restart – Restart the software.

HWP$\star$ – Switch the software to half-wave plate control mode.

Tracker$\star$ – Switch the software to acquisition and guidance control.

CCD – Switch the software to main CCD control mode (not implemented).

Exit – Exit the software mode

HWP

Rotate – Rotate the half-wave plate by a specified number of steps in a specified direction at a specified speed. After this option has been selected, the user is prompted to press 'g" to start motion or <ESC> to cancel rotation. A message on the screen indicates that the motion is in progress and once it is over, the display of the current HWP position is updated.

Move to position – Move the HWP to one of the four positions ($0°$, $22.5°$, $45°$, $67.5°$). With this option, the HWP is first moved to $0°$ position by making use of the opto-electronic marker and then moved to the required position.

<ESC> – Return to the previous menu.

Tracker

$\uparrow, \downarrow, \leftarrow, \rightarrow$ – Move the probe by a specified number of steps, in a specified direction at a specified speed. The convention is $\uparrow$ – +X (CW), $\downarrow$ – −X (CCW), $\rightarrow$ – +Y (CW), $\leftarrow$ – −Y (CCW). Once the arrow key is pressed, the probe is moved and the display of the current probe position updated.

Zero – Move the probe to zero position.

Point$\star$ – Menu which allows to position the probe using the equatorial coordinates of the field center and the guide star. This menu also allows moving the telescope by activating the relays which are used by the auto-guider to correct the telescope pointing.

Grab$\star$ – Menu which allows to acquire an image with the ST-6 CCD, display and examine. The auto-guiding may be started from within this menu.

<ESC> – Return to the previous menu.

Point

$\uparrow, \downarrow, \leftarrow, \rightarrow$ – Move the telescope by activating the relays. The convention is $\uparrow$ – +X (higher RA), $\downarrow$ – −X (lower RA), $\rightarrow$ – +Y (higher DEC), $\leftarrow$ – −Y (lower DEC). The relay is activated for 1s, every time an arrow key is pressed.

Observation No – Select the equatorial coordinates corresponding to the particular observation number.

Program – Change the equatorial coordinates of the field center.

Track – Change the equatorial coordinates of the guide star.

Go – Position the probe at the offset corresponding to the above coordinates.

Misc – Allows to set the values of four parameters, namely the Z_X, Z_Y, $G_X = 15 \times G_Y$ (see page 132).

<ESC> – Return to the previous menu.

Grab

Show⋆ – Display the image that was last acquired with the ST-6 CCD.

Hunt⋆ – Allows to set the various parameters related to auto-guiding and to start auto-guiding.

Misc – Allows to set parameters related to the exposures taken with the ST-6 CCD. The default values are adequate most of the time, it is preferable not to change these parameters.

<ENTER> – Take an exposure of the guide field with the ST-6 CCD. The exposure duration, type of frame (whether shutter is to be opened or not – light or dark frames, while taking an exposure), and the pixel coordinates of the part of the CCD frame to be downloaded to the instrument control computer, may be specified before taking an exposure. It can also be specified whether an earlier acquired dark frame is to be subtracted from the acquired image and whether it is to be displayed automatically, after downloading to the computer. The "Wait time" is the number of seconds after pressing <ENTER>, which the computer waits before beginning to take an exposure.

<ESC> – Return to the previous menu.

Show

Display – Display the image that was last acquired with the ST-6 CCD. A cursor which is activated by the arrow-keys, is provided to check the pixel values of the image. There is also a provision for setting the contrast in the display using the "Background" & "Range" or "Auto-contrast" parameters. Background is the pixel level which corresponds to the minimum grey level on the screen, while Background+Range, corresponds to the maximum grey level. Once these values are changed, toggle "Auto-contrast" to "no" and then press "d", to obtain a display with the new contrast settings. Toggling "Auto-contrast" to "yes", makes the background and range settings ineffective.

Save – Save the image which has been last acquired with the ST-6 CCD. The image is saved as an ASCII file.

<ESC> – Return to the previous menu.

Hunt

Go⋆ – Start auto-guiding. The X speed and Y speed parameters allow to set the gain of the feedback loop (telescope movement in arcseconds for each second of relay activation time). If the X flip option is set to "yes", the relay activation scheme is flipped with respect to the default , that is the +X relay is activated in place of −X relay and vice-versa. Similarly, for the Y flip option. "Seeing" allows for the change of image scale on the ST-6 CCD if the probe designed for good seeing conditions is used. "Nod throw" decides the amount of stagger to be introduced in the telescope pointing while auto-guiding. "Hunt box size" allows to set the size of the box used for centroid calculations. "Calibrate" option is disabled now. If "Log track error" is set to "yes", then a log file is created which contains inforamtion regarding the centroid shifts and relay activation times during each loop of auto-guiding.

<ESC> – Return to the previous menu.

Go

Rotate – Rotate the half-wave plate by a specified number of steps in a specified direction at a specified speed. A message on the screen indicates that the motion is in progress and once it is over, the display of the current HWP position is updated.

Zero – Move the HWP to one of the four positions (0°, 22.5°, 45°, 67.5°). With this option, the HWP is first moved to 0° position by making use of the opto-electronic marker and then moved to the required position.

<ESC> – Stop auto-guiding. Return to the **Grab** menu.

Initializing the data-acquisition system

Once the instrument has been powered on, the initialization is carried out by going to the impol directory (which should contain the files chcom2.exe, vterm.exe, vterm.set and accept.bas) in the data-acquisition PC and typing

```
C:\impol>chcom2
C:\impol>vterm
```

Press the space bar on the keyboard. The message "" should now be displayed on the screen. If it doesn't, reset the CCD controller. Press space bar again and the message will appear. Then press <Alt - t>. Now a barrage of text will flow across the screen, which will end with the prompt ">". Now press <Shift - a>. The screen will display ">B". Once this happens, the data-acquisition system has been initialized. Press <Cntrl - Break>.

Editing the parameters for exposure control

The parameters which control the exposure are read from a file by the data-acquisition software. A utility (edit1.exe) is provided to create/modify parameter files. To start this utility, type

```
C:\impol>edit1
```

The user is asked for the name of the parameter file which is to be modified (otherwise the utility creates a file with a default name) and then the file is read. The parameters are displayed along with a serial number and their current values (their default values, if it is a new file). To edit a particular parameter, type the corresponding serial number and press <RETURN>. After modifying the parameter, press <RETURN> to confirm the new value. Then user may modify another parameter or press 0 to exit the utility. The important parameters in this list are the ?? and the 11^{th}, which decide the status of the shutter (open/closed) during the exposure and the exposure duration respectively. The exposure duration is set as an integral multiple of 55 ms.

Acquiring, displaying and storing data

The data-acquisition software allows to acquire take an exposure, acquire the data, display and examine it and finally save it in the hard disk, if required. To start this software, go to the correct directory (which should contain the files ccd_new.exe and svga256.bgi) and type

```
C:\impol>ccd_new
```

The user is requested to give the name of the parameter file to be used for the exposure. Once the exposure is taken and the data is acquired, it is displayed on the screen. The user can, then, use the arrow keys to move a cursor around on the image and see the pixel values (displayed in hexadecimal notation). If the <Cntrl> key is kept pressed while using the arrow keys, the cursor moves faster. Press "q" or "Q" to quit the display. Then the user is provided three options

1. Display
2. Save
3. Continue
4. Quit

To select an option press the corresponding hot-key indicated in capital letter. Choosing option 1, allows the user to set new contrast levels (lower and upper pixel values which correspond to the minimum and maximum grey levels on the display) and go back to the display mode. Option 2 allows the user to specify a filename and save the data in the hard disk. Option 3 allows to continue with taking another exposure. Selecting option 4 allows to quit the software.

E.3 Data reduction

Passing/Editing the parameters needed for a task within IRAF

The IRAF editor 'eparam' allows to modify the value of any IRAF task, with the following command :

```
cl>epar taskname
```

To modify the value of a parameter, take the cursor to the corresponding row using the arrow keys, type in the new value and press $< CR >$. To confirm the new values and exit from the editor press $\hat{D}$. Some parameters (called psets) of certain tasks will have a subset of parameters. To access a parameter in a subset, take the cursor to the corresponding pset and press ':e'. The contents of the subset will then be loaded in the editor, which can then be modified as above.

Converting FITS files to IRAF image files

To convert a FITS file called fitsfile to an IRAF image called iraffile :

```
cl>rfits fitsfile * iraffile
```

If the names of all the FITS files are listed in a file called 'ftslist', and the corresponding IRAF image names in another file called 'imlist', the conversion to IRAF images can be done with the following command. This will take the first file in ftslist and create an IRAF image file with the first name in imlist and so on.

```
cl>rfits \@ftslist * \@imlist
```

Finding centres of stellar images in a frame, using DAOFIND

Edit the following parameters, before running the DAOFIND task. *Image* is the name of the frame; *output* may be set to *default*. *datap* is a pset, which defines the data dependent parameters of which the relevant ones are scale = 1; *fwhmpsf* to be set to the FWHM of the stellar images; *sigma* to be set equal to the approximate standard deviation of sky pixel counts in the frame; *datamin* to be set a few sigmas below the typical median sky counts and *datamax* to be set to the maximum useful data value. *findp* is another pset in which the only relevant parameter is *threshold*, which defines the threshold (in number of sigmas over mean), above which DAOFIND will look for stellar images. To run DAOFIND, type

```
cl>digiphotx
di>daophotx
da>daof
```

If the parameter *output* is left to *default*, the result of running DAOFIND will be written in a file with name *framename.coo.1*. A more detailed description of DAOFIND and its parameters are given in the help files for DAOFIND, datapars and findpars and can be obtained by typing, say

```
cl>help daofind
```

Finding shifts between frames and creating stellar coordinate files

The GETCENTERS task may be used for this purpose. The relevent parameters are : *images* which should be the name of a file (with the prefix '@') containing a list of the frames to be used by the task, for example '@imlist' (see also Sec. D.3). The first frame in the list is used as the reference frame for finding the shifts. *centers*, which defines the names of the output files in which the stellar coordinates are to be written, may be set to *default*, whereby the coordinates will be written in files with the naming convention *framename.ctr.1*. *findstars* may be set to *no*. *coords* should be the name of a file which contains the exact coordinates of the stars, measured in the reference frame. *shiftcoords* should be the name of a file which contains the approximate coordinates of a few isolated, prominent stars. *shifts* is the name of a file in which the determined shifts between the frames will be logged. *bigbox* is the size of the box used for an initial crude centre determination of the stellar images. *boxsize* is the size of the box used for accurate centre determination. GETCENTERS make use of the IRAF task IMCENTROID for finding the shifts between the frames.

Doing photometry and determining the ratios $R(\alpha)'s$

The task MKRATIOS may be used for this purpose. The parameter *images* is the same as above – the name of a file (with the prefix '@') containing a list of the frames to be used by the task, for example '@imlist'. *ctrlist* is the input list of stellar coordinate files. Setting this to *default*, will use the output files which were created by the GETCENTERS task above.

polfile is the name of the file in which the calculated fluxes, ratios etc. will be finally written to. *dophot* is to be set to *yes* to make this task do photometry on all the frames, using the DIGIPHOTX.DAOPHOTX.PHOT task. This parameter may be set to *no*, if photometry has already been done on the frames. *darkcount* sets the zero level of the CCD counts. The output of the photometry task is usually contained in files with the naming convention *framename.mag.1*. *photlist* may be set to *default* to let MKRATIOS use these files.

dosort is to be set to *yes* to make this task identify stellar image pairs (ordinary and extraordinary) from the photometry output files and write the the results in a new set of photometry files. The names of these new files are created by prefixing a letter, indicated by the *prefix* parameter, to the names of the photometry output files. Two stellar images are considered to form a pair only if their x-coordinate difference is less than *xdiffmax* and their y-coordinate difference lies between *ydiffmin* and *ydiffmax*.

fitskypars is a pset, in which there are three relevant parameters. *salgorithm* refers to the sky fitting algorithm to be used for determining the sky value. *median* has been found to be the optimum choice. *annulus* refers to the inner radius of the annulus around the star from where the sky is to be calculated. *dannulus* refers refers to the width of the above annulus. If a constant value of sky is to be used for all the stars, this value may be set in *skyvalue*.

photpars is another pset, in which the main parameter of relevance is the radius of the photometry aperture to be used. Typically, this is set equal to the FWHM of the point-spread function. *zeromag* is another parameter which can be used to add a zero-offset to the magnitude values reported.

More details of the PHOT task and the associated parameters are available with its help documentation in IRAF.

Determining FWHM of PSF and the standard deviation of sky counts

A task useful for this purpose is DAOEDIT. Display any one of the frames and give this frame as *image* parameter of DAOEDIT. After starting the task, take the cursor to a star on the display and press 'r'. A radial profile of the star will be plotted in the graphics window. The median sky value within the annulus chosen in *photpar* pset, also will be reported. Press 'q' to quit this task. More details are in the IRAF help documentation.

Determining polarization values using DOPOL

The parameter *ratfile* is the input file containing the ratios $R(\alpha)$, the star and sky fluxes etc, for each star. This file, if edited, should retain the same format as is produced by MKRATIOS task. *polfile* is the name of the file in which the polarimetry table is to be written to. If *eliminate* is set to *yes*, a second round of fitting is done, after eliminating those ratios which are more than *threshold* sigma levels away from the results of the first fitting. The *polfile* will then contain the results of this second fitting round and *nratfile* file will be a copy of *ratfile*, but with the eliminated ratios marked as zeroes.

Overlaying a vector plot on a Digitized Sky Survey image using DRWVEC

Display the digitized sky survey image. Display any one of the frames from IMPOL. *vecfile* should be set to the name of a file containing polarimetry output data in the format produced by DOPOL. If *readcur* is set to *yes* the positions on the display where each vector is to be marked should be indicated by the cursor. The corresponding coordinates are then appended to *posfile*. However, if *readcur* is *no*, the coordinates are assumed to be available in *posfile* and the vectors are marked at the corresponding positions on the display. *scale* is a simple multiplying factor which allows to adjust the length of the vectors marked. *dvpar, pltpar, axispar, wcspars* and *wlpars* are psets which define various parameters related to the graphics and image displays. More details about these are available as help documentation in IRAF.

vecfile is the file which contains polarimetry table, *ratfile* is the file which contains the corresponding ratios etc. produced either by MKRATIOS or DOPOL. If *drwerr* is to set to *yes*, error bars are marked on the graphics output window, one which is equal to twice the error calculated from the dispersion in the ratios and the other one equal to twice the error calculated from photon noise calculations. *dvpar, pltpar* and *axispar* are psets, as has been previously mentioned.