Nordic Optical Telescope

TurPol

Turku **Pol**arimeter

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NOT OPERATING MANUAL No. 2

Version No. 1.0

October 27, 1999

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Chapter 1

Introduction

1.1 History & brief description

TurPol was built at Turku Observatory by V.Piirola, based on his earlier design of such a photo–polarimeter. This later version has been in use at the NOT since March 1989. Photograph 1.1 shows the polarimeter at the telescope. TurPol is

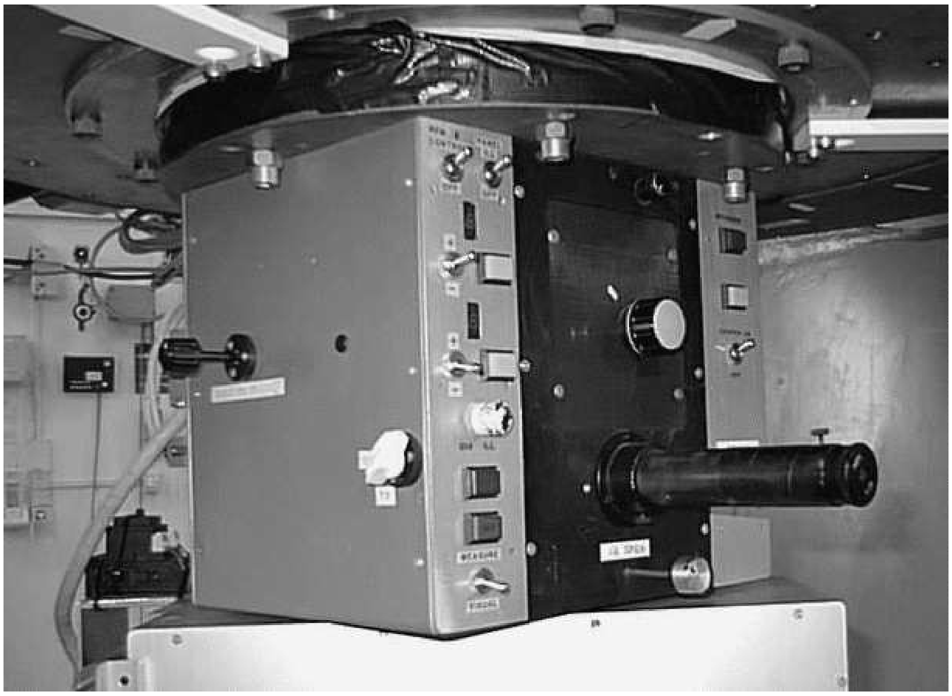

Figure 1.1: Photograph of the polarimeter on the telescope.

a 5–channel photo-electric photo–polarimeter, allowing both photometry and polarimetry to be performed in 5 channels simultaneously. The permanently mounted filters are UBVRI. The pass bands are defined by four beam-splitters, and the UB-VRI filters themselves. The use of beam-splitters gives a high throughput since they have very low absorption.

The instrument can be equipped with an achromatic half– or a quarter wave plate, respectively for linear or circular polarisation measurements. With the quarter wave plate mounted it is also possible to do simultaneous linear and circular polarimetry.

By removing the calcite polariser from the beam, the instrument can be used for 5–channel sky chopping photometry.

TurPol is remotely controlled from a PC with a CAMAC interface crate during observations. The CAMAC crate and PC are in the control room.

Chapter 2

Detailed description

2.1 Principle of operation

The principle of operation of TurPol is illustrated in Figure 2.1. The diaphragm in the focal plane of the telescope has two apertures, one passing the star's light plus the sky background, the other one passes background light equal to that going through the stellar aperture. A rotating chopper opens and closes alternate apertures, illuminating the photo-cathode of the photo-multiplier tube consecutively with the star and background light. A field lens produces an image of the telescope exit pupil on the photo-cathode, thereby avoiding image motion due to guiding errors. This is of importance because the sensitivity of a photo–cathode is generally not uniform over its surface, and any movement would give rise to spurious intensity variations.

The chopper simultaneously chops the light from two IR LEDs onto two photodiodes. This signal is used to synchronise the electronics in such a way as to accumulate the star plus sky and sky alone signals into two separate counters. Thus, sky subtracted photometry is done.

By inserting a plane parallel calcite plate into the beam before the focal plane, polarisation measurements can be made. As can be seen from Figure 2.1, the calcite plate splits the incoming beam into two relatively displaced but parallel components, the so–called ordinary and extra–ordinary rays, which are orthogonally linearly polarised. The calcite plate is constructed and placed so that the ordinary and extra–ordinary beams pass centrally through the two apertures. Each aperture now passes the light from the star and the sky, and by measuring their relative intensities, after passing through a wave-plate, the degree and angle of polarisation of the star light can be determined. In TurPol the intensities are measured at eight

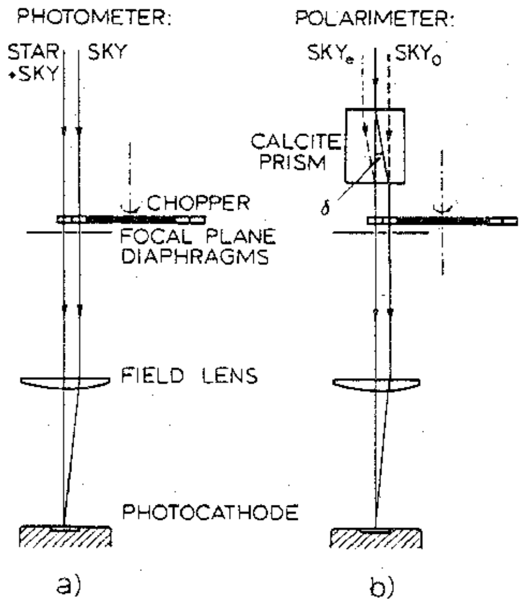

Figure 2.1: Principle of operation of TurPol.

rotational positions of the half wave plate.

One important advantage of this method is that the possible sky polarisation is cancelled out, albeit at the cost of having to subtract twice the sky intensity. Since the sky background can be very highly polarised and variable, this is a small price to pay. Polarimetry of faint stars in the presence of moonlight is only possible due to this cancellation method, as is the high precision (0.005%) obtained on bright stars.

2.2 Construction

The diaphragm wheel holds up to 8 sets of double apertures or diaphragms, and the filter wheel can hold 8 filters for single channel photometry. Both wheels and the field viewing mirror are remotely controlled. The available diaphragms and filters are listed in Table 2.1

Below the polarimeter is mounted a box with the 4 dichroic beam-splitters, the 5 field lenses with added band pass filters, the 5 PM tubes, and the power supplies for the instrument. Part of this box is cooled using a compressor circulating glycol, keeping the PMTs at about -20^{o}C. The compressor is placed on the observing floor

Table 2.1: Filters and Diaphragms.

Number	Filter	Diaphragm
1	ND1 (10%)	10” double
2	ND2 (1%)	7.5” double
3	open	open
4	open	37.5” single
5	open	22.5” single
6	open	15.0” single
7	open	12.5” single
8	open	5.25” double

Table 2.2: Pass band defining dichroics and filters.

Band	λ_{eff} (nm)	Dichroic	Glass	Thickness
U	360	Balzers UV mirror	Schott UG 1	1mm
B	440	Fish–Schurman Blue refl.35	Schott BG 12	1mm
V	530	Fish–Schurman Blue refl.35	Schott GG 495	1mm
R	690	Fish–Schurman Red refl.32	Schott OG 590	2mm
I	830	Fish–Schurman IR refl.3117A	Schott RG 715	3mm

below the telescope.

The PMTs are provided with high voltage from two power supplies placed in the control room: the UBV channels have bialkali tubes with a dark count rate of less than $10s^{-1}$; the RI channels have GaAs tubes with less than $20s^{-1}$.

Table 2.2 lists the used dichroics and filter materials to define the pass bands. Figure 2.2 shows the obtained pass bands from the combination of beam-splitter and filter convolved with the photo-cathode sensitivity curve.

The polarimeter is controlled by a PC running under DOS and the interface to the instrument is through a CAMAC crate. The programme allows a quick set–up of the observing mode, definition of the integration time, and the number of integrations per observation. Sky measurements are automatically done in an optimised way, after off–setting the telescope. Each observation consists of a number of integrations each composed of 8 sub–integrations corresponding to 8 positions of the wave plate. The rotation and data acquisition is done automatically, only a start command has to be given. After each 8 sub–integrations the results are displayed on the screen. After one or more observations, a quick on–line data reduction can be made by one command. For special applications (e.g. rotating the entire instrument between sub–integrations) a manual mode can be selected, in which the START command has to be given for each sub–integration. The programme is mouse driven and user

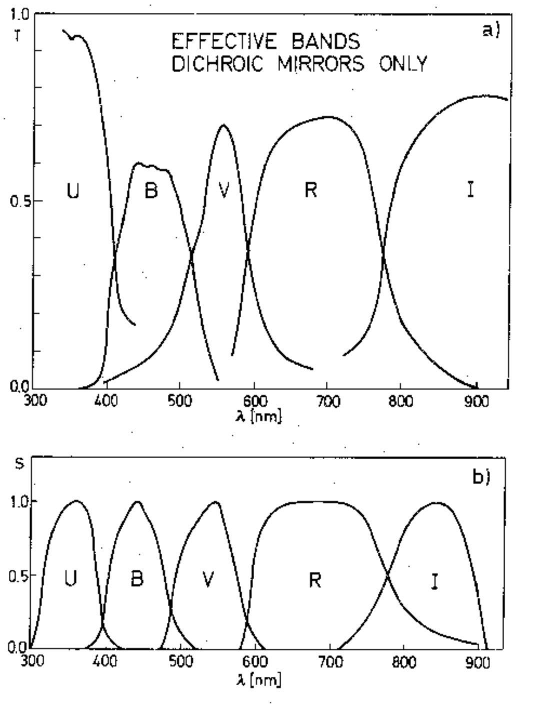

Figure 2.2: Overall pass bands of TurPol

friendly.

For linear polarisation measurements, a half wave plate is used, while for circular or combined linear and circular a quarter wave plate is inserted into the beam. In this last mode, the efficiency is 0.5 for linear and 0.7 for circular polarimetry.

By removing the calcite plate from the beam –this is done with a knob on the polarimeter– photometry can be done. The maximum time resolution in the photometric mode is about 2s, in polarimetric mode about 60s (and 5s for the simultaneously obtained photometry).

Chapter 3

Observing with TurPol

3.1 Preparation during the day

On the observing floor:

Check that the cooling system is operating, and that the indicated temperature is about -20^{o}C or lower. The cooler must be switched on at least 3 or 4 hours before starting the observations. This is usually done by NOT staff. The two red switches on top of the compressor on the observing floor under the telescope are switched to "on".

Switch POWER ON, CHOPPER ON, and REMOTE CONTROL ON, at the polarimeter (see Figure 3.1).

Check that the CALCITE PLATE knob is OUT for POLARIMETRY and push it IN for sky-chopping PHOTOMETRY.

Make sure that the SHUTTER is closed, i.e. that the knob is in the OUT position.

In the control room:

Check that the desired wave plate is in the polarimeter. The quick way to do this is to check which plate is in the box in the control room; the other one is therefore in the polarimeter. For linear polarimetry use the $\lambda/2$ plate, for circular (or simultaneous linear and circular) polarimetry the $\lambda/4$ plate. Only NOT staff

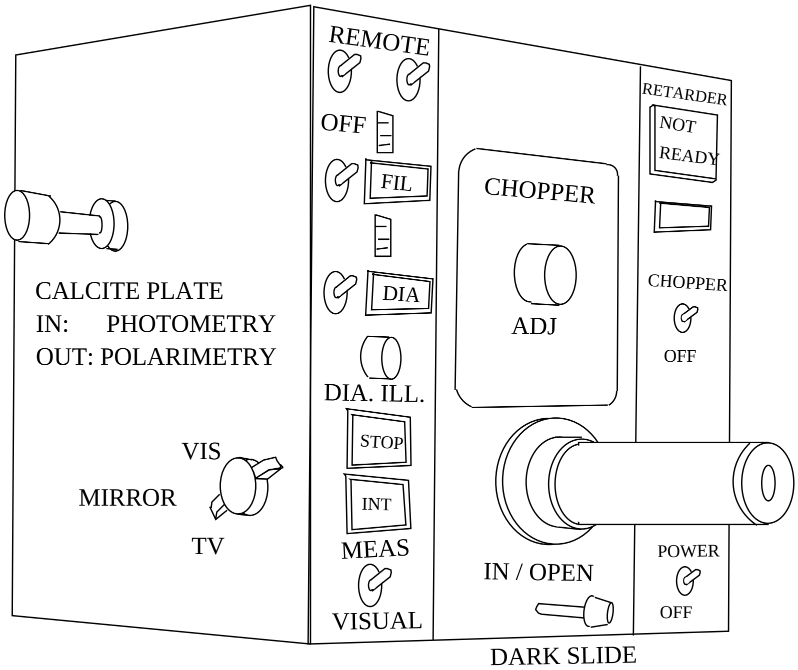

Figure 3.1: The polarimeter with it's controls.

should change the wave plate.

Check that the high voltage power supplies have been set to zero voltage, and if not, set them to zero. Also make sure that they are switched off. Switch on the CAMAC crate in the control room with the power switch at bottom left of the unit. Switch on the high voltage power supplies. Turn the voltage selection knobs to the correct settings. The UBV supply should have the voltage -1150 V and the RI supply -1800 V. These positions are marked on the front panels of the power supplies. **Do not to put too high a voltage on the tubes, as this will cause permanent damage!**

On the PC called TAMAR type **d:** and **cd observer**. Make a sub–directory for yourself by typing **md name**, if not already done. Go to your sub–directory by typing **cd name**. Then start the polarimeter control programme by typing **pp**. If the mouse does not work, exit from the PP programme, type **pp mouse**, and **pp** again. You should now have a running control programme.

Click the left mouse button on the FILE pull down menu to open the data file for the coming night. Give a filename including the date **p***yymmdd***.dat** is preferred.
On startup of the PP programme, some default parameters are set: linear polarimetry, integration time 10s, number of cycles 4. These values are normally used for

stellar observations and one complete cycle takes about 15 minutes. For details about the various observing modes see the section on Observing below.

You are now ready to set–up the polarimeter on an object.

3.2 Setting up at the beginning of a run

3.2.1 Setting up the Telescope Control System (TCS)

After starting up the telescope and building (see startup sheets or TCS manual) and once it is dark enough, switch the guide TV on by typing **tv-on** at the TCS keyboard.

To observe with TurPol you need 3 TCS configurations: **periscope (pe)** to centre the object in the diaphragm, **centre (ce)** to be able to acquire fainter objects, and **guide (gu)** to allow auto guiding on a guide star. Here the procedure to do these set–ups is described. Unless the TCS is rebooted for some reason, these set–ups have to be done only once, at the beginning of a TurPol run.

Point the telescope to a bright star (magnitude 5 or so) and set–up the periscope configuration by giving the TCS the commands **pe-in, gp-po 35000 158500, tu-fo-po 22700, tv-fi o, tv-fo-po 350**. You should now see two illuminated diaphragms on the TCS guide probe screen. From the PP programme, put in diaphragm no.3 (open), and find the star by moving the telescope in small steps. Set the step size with **tm-os 5 5** and move using the arrow keys on the TCS keyboard. Once found, centre the star, put in diaphragm no.1 and re-centre with steps of, say, $0\farcs5$. Note that two images of the star should be visible, one in each diaphragm image. Minor adjustments of the all the above parameters may now be made if needed. Telescope focus is used to make the (slightly astigmatic) e-image in the RH diaphragm, as round as possible. Once happy with the set–up, give the command: **cc-ad-tv pe** to adopt the periscope set–up, and mark the diaphragm positions on the screen with a felt tip pen. Give the TCS command: **pr-po-ad** to give this permanent off–set to the telescope pointing to bring objects into or very near the diaphragms with every new pointing. To reset these off–sets to zero, if needed, you can give the command: **pr-po-re**.

With the bright star well centred in the diaphragms, type: **tv-fi g, tv-fo-po 600, pe-ou, gp-ce** to set–up the centre configuration. You should see the bright star near the centre of the screen. Mark its position with a felt tip pen. This configuration is only used when an object is not found in the periscope configuration, or to centre on objects that are too faint for the periscope, which has high magnification and a long optical path. Type **cc-ad-tv ce** to adopt the centre configuration.

The initial guide configuration is made by typing: **tv-fi o, tv-fo-po 660, pe-ou, gp-pa** and then **cc-ad-tv gu**.

You are now ready to start observing.

Note that after these initial pe, ce, and gu set–ups have been done, they are used for the duration of the observing run, unless the TCS is rebooted. Then the parameters have to be defined again, so it is useful to write down the optimal initial parameters just in case a reboot has to be done.

In going from one object to the next the following procedure is the most efficient:

a) Finish an observation with a sky measurement.
b) Type **ag-of** to stop the auto-guider.
c) Preset to the next object and wait until the telescope tracks.
d) Type **cc-ad-tv gu** to store the x and y coordinates of the guide probe.
e) Type **cc-ce-tv** and centre the object.
f) Type **cc-pe-tv** to fine–tune the centring in the diaphragms.
g) Type **cc-gu-tv** and wait until the guide star appears on the screen.
h) Type **ag-re-on** and wait until "auto-guide" appears on the TCS screen.
i) Type **ag-of** then **tm-os 60 60** do one offset (with an arrow key), and take a sky measurement.
j) Do one offset to get back, and type **ag-on** to start auto-guiding.
k) Take your polarimetric measurements.

Repeat the above for each object. On the following pages the observing procedure is described in more detail.

3.3 Polarimetric observations

3.3.1 Linear polarimetry

On startup of the PP programme, some default parameters are set: linear polarimetry, integration time 10s, number of cycles 4. These values are normally used for stellar observations and one complete cycle takes about 15 minutes. You can normally use the default set–up for linear polarimetry. Give a star number for identification of your object. For objects brighter than about 9th magnitude, filter no.1 (ND1) may have to be used, and for those brighter than 6th, filter no.2 (ND2). The list of available diaphragms and filters is given in Table 2.1. PP will warn and close down when too much light reaches the PMTs, but be careful with very bright stars.

Go to the dome and open the SHUTTER of the polarimeter head (see Fig. 1) by pushing it IN. **Take great care with flashlights and keep the dome lights off when the shutter is opened.** The SHUTTER must be closed (position=OUT) during the day for the safety of the photomultipliers.

Point the telescope to your first object. You will see that the guide probe moves to a position; this is given by the automatic guide star selection programme running on the lisa PC. When a beep is given and the TCS states that it is tracking, you should see the guide star. If not because the star is too faint, give the command: **tv-fi o**. When doing this for the first time during a run, fine tuning of the tv focus may be done, using the command **tv-fo-po nnn**. **When the guide star is visible and in focus, type cc-ad-tv gu to adopt this guide configuration. Note that the guide TV has an automatic over–exposure detection system to protect the camera. When a star that is too bright is detected, the system puts in the gray filter, if still too bright the camera is closed.**

Type **cc-pe-tv** to go to the periscope configuration, wait for it to arrive, and you should see your object in the diaphragms. Fine tune the centring by typing **tm-os .5 .5** and using the arrow keys to move the telescope. When well centred, type **cc-gu-tv**, move the arrow on the auto guider screen onto the guide star, click on the middle mouse button (star), and type **ag-re-on** to start auto-guiding with automatic centring of the guide probe box on the star. Once the text **auto-guide** has appeared on the TCS screen, type **ag-of** to switch the auto-guider off, and do an off–set of, say, 60″ by typing **tm-os 60 60** and giving one off–set step with an arrow key. Start a SKY integration in the PP programme. Once this integration is finished, do the opposite off–set step to bring the star back into the auto-guider box, and type **ag-on** to start auto-guiding without centring the box. This will bring the star back into the centre of the diaphragm. Now you can start integrating by clicking INT on the PP screen. If you did not see your object after going to the periscope mode, it may be that it falls just outside the diaphragm. Either "hunting around" with small off–set steps or going to the centre configuration with **cc-ce-tv** and putting the object on the mark on the screen will get you your object.

Once one or more complete observing cycles have been done, with sky samples in between, stop the auto-guider with **ag-of**, and finish with another sky sample. A complete sky measurement is only one sub–integration, and thus takes little time.

To go to another object, follow the instructions above. **It is recommended, especially when the sky is bright and rapidly varying, to take a SKY measurement before and after each object observation cycle.** Sky background can be highly polarised too (this is cancelled by the polarisation optics), but the varying intensity reduces the S/N of the data. So frequent measurements are needed to allow good interpolation of the sky brightness to be done.

3.3.2 Notes

Note that due to the long optical path and high magnification in the periscope optics, only stars of about magnitude 12 or brighter can be seen there. This also depends strongly on the seeing, and the moon phase. For fainter, and therefore invisible objects, either a blind off–set can be done from a nearby brighter object, to which the off–set is accurately known, or the CE mark has to be relied upon. Once centred using the centre position, fine centring can be done by stepping in small steps and "peaking–up" the signal in the count-rate box on the PP screen. The signal goes down sharply when the object hits the edge of the diaphragm, count steps to the other side, and put in the centre by taking half the number of steps in the opposite direction. Do this in both RA and Dec. When StanCam is running, it can be used for centring by calibrating the centre of the diaphragms onto the CCD pixels and using a CCD image to determine an accurate off–set. StanCam is the CCD standby camera of the NOT which is always mounted and available when requested in the NIRF. This method has not been used to date.

Average polarisation degree and angle values from the accumulated observations of the object can be viewed at any time by clicking on the REDUCE menu, Averages option. The associated errors are also displayed. Another useful item here is the "View Listing" option, which shows the list of data obtained up to that point, including instrumental magnitudes.

The error message 'Retarder found in wrong position' may appear, if the stepper motor has lost one or more steps. The effect in the measured position angle is usually entirely negligible (a small fraction of a degree) and the message can be neglected. Remove it from the screen with a mouse click. The retarder is automatically put in the correct position at the start of each measurement cycle (set of 8 sub–integrations).

The error message 'TMP Channel 2 timeout' is seen immediately after starting the PP-POLAR program if the Polarimeter head power is not ON, or the chopper does not rotate. Cure this by switching ON the power, or the chopper OFF and ON again.

CAUTION ! Do not switch on the fluorescent lights in the control or electronics room during an integration, as bursts of error counts may result.

If you STOP an integration in the Polarimetric mode, it is recommended to make a SKY integration before restarting. The retarder position is initialised when you click INT after the STOP command.

PAUSE is a toggle switch and will not interrupt the measurement sequence, except for halting the integration, and the flip mirror is turned so that the centring of the star in the diaphragm can be checked with **pe-t**, if deemed necessary.

3.3.3 Circular polarimetry

In order to measure circular polarisation, the half-wave retarder plate is replaced by the quarter-wave retarder. By requesting the quarter-wave retarder in your NIRF (see the NOT web pages), NOT Staff will prepare Turpol by installing this retarder.

With the quarter-wave retarder plate installed, there are two observing modes available:

Circular polarimetry. Select from the MODE menu. The $\lambda/4$ plate is rotated in 90 deg steps, and therefore the 'Wheel' light is illuminated during every second sub–integration. The REDUCE menu functions for circular polarisation reduction are available as for linear polarimetry.

Simultaneous circular and linear polarimetry. After the installation of the $\lambda/4$ plate, the observations are carried out in the Linear polarisation mode, where the retarder is being rotated in 22.5 deg steps. The efficiency in this mode is about 0.7 for circular, and 0.5 for linear polarisation measurements. The off-line reduction program **cirli** (see Chapter 4 on Data Reduction) takes these factors into account and lists the corrected circular and linear polarisation data in the respective output files.

However, the on–line reduction for linear polarisation under the REDUCE menu assumes the use of the $\lambda/2$ plate, and therefore the linear polarisation values listed on the screen have to be multiplied by a factor of 2 to get the true values.

3.4 Photometric Observations

The procedure for photometric observations with TurPol is the same as for linear or circular polarimetry. After pointing the telescope, centring the object in the diaphragms, and starting auto-guiding, a sky sample should be taken and then an integration can be started with the INT command in PP.

Note that for photometry, the calcite plate has to be removed from the beam by pushing the knob on the polarimeter IN. Note that in this mode only one of the diaphragm images on the TCS screen will contain the star; the other has only sky signal.

Standard stars have to be observed regularly during the night, well spread out over air masses equal to those of the science objects, and over spectral types, to get a good solution for the night. This is needed both for the extinction, and for the transformation to the standard system. For equations see Appendix 6.2.

3.5 Closing down in the morning

In the control room:

Turn both high voltage supplies to zero. **Do not switch them off!**

Close the data file and exit from the PP program.

Transfer your data onto a floppy disk or ftp them to your home institute.

In the dome:

Close the SHUTTER of the polarimeter head by pulling the knob out.

Do not switch the polarimeter off!

Chapter 4

Data reduction

4.1 Basic reduction for linear polarimetry

In addition to the quick–look on–line data reduction, there are several programmes available to reduce TurPol data.

The main reduction programme is **polred** which computes the polarisation parameters and raw magnitudes. A file with the instrumental position angle and it variation from filter to filter is needed. Default values, valid for observations made with field 0 set at the TCS, are in the file cor.dat in the form:

```
17.4
.74 3.2 .0 -3.7 -3.6
```

where the first line is the zero point correction, and the second line contains the wavelength dependent components, both given in degrees. The corrections are for UBVRI from left to right. The file is read in free format and a space has to be used as a separator between values.

To reduce the data, type **polred** and you will be prompted for an output filename, an input filename, and the angle off–sets filename. When one file (usually one complete night of data) is reduced **polred** asks you for another input filename, allowing several nights of reduced data to be stored in one output file. To exit **polred**, type **end**.

The sky background used by **polred** is the interpolated value between each sky measurement, if the star number and diaphragm have not been changed. In the case where either the diaphragm or ND filter have been changed, the first sky background value taken with the same setup is used.

The Stokes parameters p_x and p_y are calculated from the eight sub–integrations, and the associated errors are computed from photon statistics (E_1), and from a least squares fit to the eight sub–integrations (E_2). If $E_2 \geq 2E_1$ the sub–integration with the largest residual is discarded, and the remaining 7 sub–integration are used instead. This is done to eliminate bad data points which can be due to transient electrical interference, or other disturbances such as the star being close to the edge of the diaphragm. If frequent rejections take place, the star was too close to the edge.

The second line of the data file has to start with the code number 9, and then have the date, while the third line starts with code 8 and has the command for setting the polarimetric mode. The very last line of a night's file should start with a 9 again to indicate the end of the data.

4.2 Basic reduction for simultaneous linear and circular polarimetry

This reduction is identical to the one for linear polarimetry described above, but is executed using the programme **cirl** instead of **polred**.

4.3 Further reductions: averages, nightly means, and normal points

The programme **kokpol** can compute average values for a number of stars, the nightly mean values for stars, normal points, and can do phase corrections for stars that vary periodically.

The programme needs a file, say, **star.sta** with the numbers of the stars for which averages have to be computed. In addition, the epoch of zero phase (last 4 digits of the Julian day number), period (in days), coordinates (α and δ in decimal form) for the calculation of the heliocentric correction to the normal points. If data is not relevant, put zeroes in the file.

kokpol prompts for filenames, and (in a self explanatory way) asks what kind of averaging procedure has to be applied. The output file from **polred** is the input file for **kokpol**. The output files **plotfin.sa** for plotting the nightly means and **plotfil.sa** for the normal points are shown. if asked for. The user specified output file contains the results in tabular form for printing.

Note that if there is more than one input file, the programme **pickup** has to be run first to collect into one file all the stars that have been specified in the **star.sta** file. The **copy** command under DOS can also be used to do this.

The averaging procedure weights the observations with the inverse square of the errors, taking the larger of E_1 and E_2, making sure that the weights never exceed the theoretical maximum given by simple photon shot noise.

4.4 Additional corrections to the instrumental constants

If the average values obtained for standard stars deviates much from those in the catalogues, the results obtained from **polred**, can be corrected with the programme **addcor**, and then **kokpol** can be run again. The (usually small) corrections for bf addcor are read from a file **cor.add** which should contain:

```
1.4
0. 0. 0. 0. 0.
0. 0. 0. 0. 0.
0. 0. 0. 0. 0.
```

where the first line is the added correction to the zero point of the instrumental position angle, the second line the wavelength dependent position angle corrections relative to the V band (=0), and the last two lines contain respectively the five instrumental polarisation values for p_x and p_y, in the order UBVRI. These corrections may also be input by hand prompted by the programme **addcor** as it runs. The constants used by **polred** can also be updated by the values used by **addcor**. This has the advantage that they do not have to be filled in every time the programmes are run. For observing runs of up to about two weeks this is OK.

The zero point of the position angle and its wavelength dependent components are best determined from observations of standard stars with high polarisation. The corrections given in the constants file are *added* to the observed values.

The instrumental polarisation values are determined from observations of unpolarised standard stars. These data are to be reduced using a special version of **kokpol** called **kokinst** which takes the rotation from equatorial angle to telescope optics angle into account. This can be necessary because in alt–az telescopes the angle between the polarimeter and the telescope changes during the observations, which when the telescope produces its own polarisation, will have an effect on the measured instrumental polarisation. At the NOT this telescope polarisation has been found to be negligibly small and zeroes can be used in the **cor.add** file.

4.5 Photometry reduction

There are two programmes for the basic photometric reduction: **fotmon** for when the data was obtained in the sky chopping mode, and **fotmo** for data obtained in the non–chopping or single channel mode. For the latter, the sky background measurements must be indicated by a measurement code 3, as first digit on the line containing the star number. If more than one sky measurement has been taken the programme makes a linear interpolation with time, assuming that the star number has not changed.

The raw photometric data contained in the output file from **polred** as part of the polarisation measures, can be extracted and written in a more compact form by the programme **fotli**, which also puts the data into the same format as the output files from **fotmon** and **fotmo**. The magnitudes are the average of the 8 sub–integrations done in polarisation mode; higher time resolution can be obtained by running the programme **fastfot**, which computes the magnitudes from each individual sub–integration.

For further reduction, a file (e.g. **staf.sta**) containing the following information must be made:

```
1234 6789.1234 0.123456 12.45 16.72 0.0038 0 0 0 0 0
67321 0. 0. 11.68 24.54 0. 9.432 .249 .362 .453 .395
```

```
etc.
```

where the columns give the star number, epoch of minimum light (Julian day number), period (days), α, δ (both in decimal form), heliocentric correction (days), V, U–B, B–V, V–R, and V–I (in magnitudes). The magnitudes and colours are given only for standard or comparison stars and should be entered as zeroes for programme stars.

There are two programmes for differential photometry reduction: **fotlim**, giving UBVRI magnitudes, and **fotlin** which gives V, U–B, B–V, V–R, and V–I. Both programmes compute the extinction and transformation to a standard system with coefficients in the programme. This gives satisfactory results for differential photometry where by the object and comparison star are not too far apart both on the sky, and in spectral type. The zero point correction can be interpolated between each comparison star observation with the programme **fotout** which uses the output files from **fotlim** and **fotlin** as input, and lists the final results for the science star observations in its output file.

4.6 Plotting the data

There are some self explanatory plotting programmes available:

- **plota4l** plotting normal points of the degree polarisation as a function of phase, with a file produced by **kokpol** as input.
- **plota4c** same for circular polarisation.
- **plotpa4** same for position angle of linear polarisation.
- **plotal** plots nightly means or normal points of degree of polarisation as function of phase. The range is given for each of UBVRI.
- **plotpa** same for position angle.
- **plotaxy** plots nightly means or normal points of Stokes parameters as a function of phase. Scaled automatically, either for each of UBVRI, or from the keyboard.
- **jdplotp** plots polarisation as a function of Julian date.

- **jdplotxy** the same for p_x and p_y.
- **jdplota** the same for position angle.
- **jdplot** plots both p and its angle as a function of JD.
- **hsplot3** plots UBVRI magnitudes as a function of phase from a file made by "fotlim".
- **plota4m** plots normal points of UBVRI magnitudes with error bars, made by "fotnorm".
- **plota4mb** the same but plotted over two phases.

Chapter 5

Appendices

5.1 Mounting Turpol on the telescope

TurPol must be mounted on the adaptor in such an orientation that the ocular tube is pointing 180^o AWAY from the StanCam dewar. Otherwise the periscope optics for viewing the diaphragms on TV do not work properly.

The correct mounting bolts are:
Make sure that the tubes leading to the cooling unit are free to move with the telescope movement and do not snag on anything.

5.2 Changing the wave plate (Staff only!)

Normally TurPol is equipped with the $\lambda/2$ retarder, which provides measurements of linear polarization only. In order to measure circular & linear polarisation simultaneously, or to do circular polarimetry, the $\lambda/2$ plate must be replaced by the $\lambda/4$ plate.

To do this, you have to remove the 4 small bolts (3mm Allen key) from the upper part of the back cover of the polarimeter, disconnect the motor cable and slide out the module in which the wave plate is mounted. Note that to be able to slide the module out, you have to also remove two of the big instrument mounting bolts on that side. Take the module into the control room or electronics room to be able to work on a table.

Unscrew and remove the $\lambda/2$ plate from its holder and put the $\lambda/4$ plate instead (or vice–versa, of course). The orientation of the $\lambda/4$ wave plate optical axis must be such that in the starting position, defined by just actuating the micro-switch, the optical axis marked with the golden lines in the cylindrical wave plate mounting must be at 45^o to the sides of the rectangular black aluminium plate supporting the unit. This is most easily done by rotating the large gear clockwise from this starting position by an amount corresponding to two full rotations of the small gear (which has a fiducial mark to be able to do this). In this position, the wave plate mark should be placed parallel to the sides of the unit, or "vertical" when you hold the module with the small gear downwards.

The orientation of the $\lambda/2$ plate should also be parallel to the sides as above, but with the big gear in the starting position defined by the micro-switch. The surface of the wave plate mount with the optical axis mark should look upwards, i.e. be visible from the side of the big gear.

Changing the wave plate should be done by NOT staff only.

5.3 CAMAC crate and tests

CAMAC CRATE CONFIGURATION

Crate controller K-16
Dataway display
Timer TMP-Module
Polarimeter Interface Module
Counter #2
Counter #1

1 U, 3 V, 2 B, 4 R

N1, N2, NP, NTPM, NDD, NCC

Terminal, To IBM/PC

NCC = MAX. position
NDD - ANY position
NP - ANY position
NTPM = NP + 2

N2 = NP - 2
N1 = N2 - 1

FOR OBSERVATION MODE:

1. Install the jumpers inside the NP module in position "1".
2. Run PP.EXE from personal directory.

FOR SELF TESTING MODE:

1. Disconnect the 38-pin ELCO from polarimeter.
2. Reinstall both jumpers inside the NP module in position "2".
3. Disconnect and short "OUT 5" from NP module.
4. Run PP_ DEMO.EXE.

Note! (For all computer men):

PC-CAMAC adapter card use I/O ports 0x340 hex - 0x34F hex and IRQ 9. Don't conflict!

5.4 Using the periscope in TurPol

Figure 5.1 shows the periscope system in TurPol. MIRROR 1 is operated by the switches MEAS/VIS on the photometer head or TV/MEAS on the remote control box. When looking through the eyepiece MIRROR 2 must be turned off (= position VIS) from the VIS/TV knob on the left side of the photometer head. When using the TV-camera for centring the object from the control room turn MIRROR 2 to position TV. DO NOT USE FORCE (the system has been damaged and the mirror does not take a firm position by itself any more), just lightly turn it against the end-stop. When using periscope system the chopper must be pushed completely in, otherwise it blocks the light to the TV. DIAPHRAGM 4 is so large that it cannot be used when chopper is pushed in. It must be pulled out and the periscopic system cannot be used. Other diaphragms can be used with chopper in position and thus also with the periscopic system. When using DIAPHRAGMS 5, 6 and 7 chopper must be moved A LITTLE BIT OUT of its innermost position. See following pages on how to adjust the chopper.

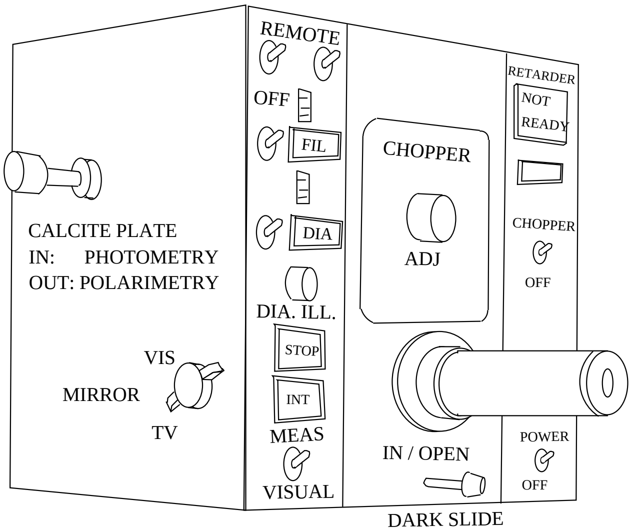

Figure 5.1: The periscope system in TurPol.

5.5 Adjusting the chopper

Figure 5.2 shows the chopper and its system of adjustment. The position of the chopper is adjusted with a screw connected to the adjustment knob. When it is rotated the chopper moves *in* (counter- clockwise) or *out* (clockwise). The screw is kept in its position by a springloaded steel ball in the groove on the shaft. The chopper can be moved rapidly out (visual wide field viewing, diaphragm 3, empty) by pulling the knob out. When pushed in the chopper position remains unchanged if the knob has not been rotated. The chopper has concentric slits on two radia (see drawing). When using double diaphragms the chopper must be adjusted so that the common border of the slits is in between the diaphragms. This can be done most easily by switching the chopper on and off with the dome illuminated. The more experienced can also do it in the dark by using the field illumination (adjustment knob on TurPol). Double diaphragms can be used for single channel photometry by switching chopper off. Be sure that the chopper stops so that the diaphragm (usually lower) is completely open. It may be nacessary to do chopper on-off a few times.

5.6 Photometric Transformation equations

The applicable transformation equations from the instrumental to the standard UBVRI system are given by:

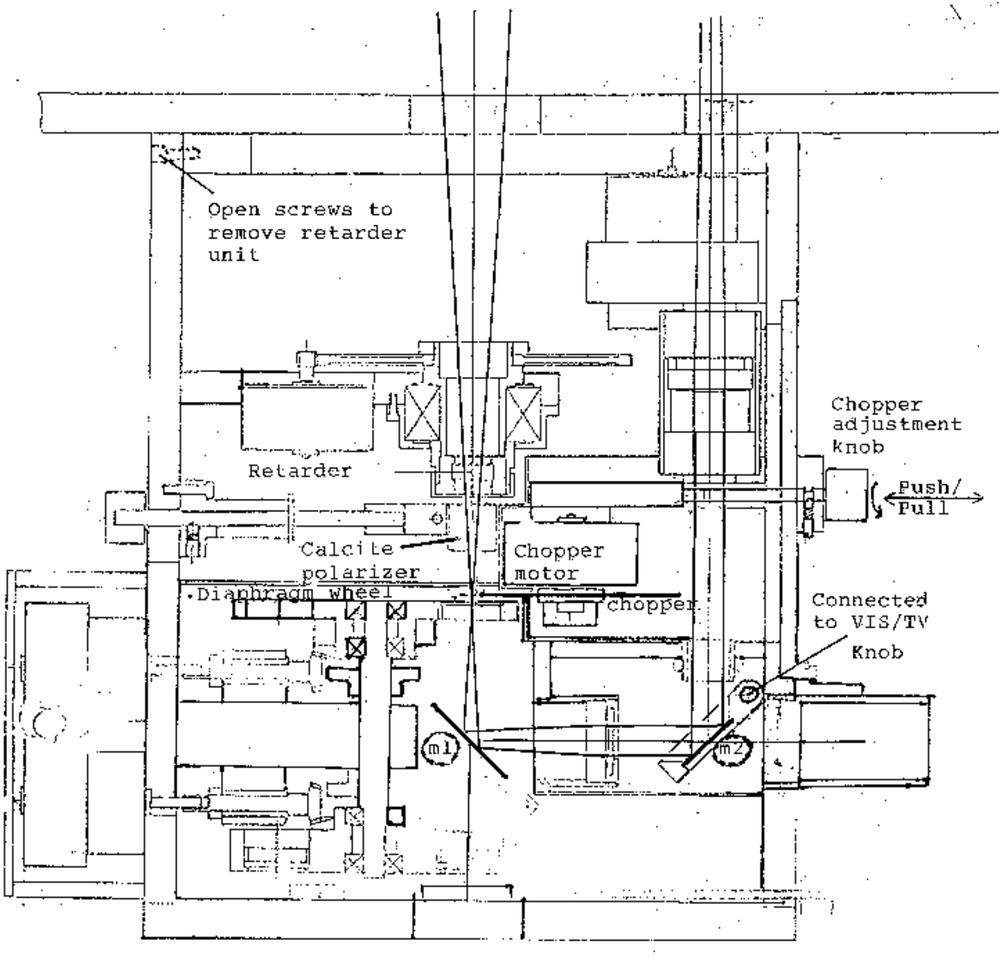

Figure 5.2: The chopper and its system of adjustment. **m1** and **m2** are Mirror 1 and Mirror 2 respectively in the instrument.

$$\begin{aligned}
\text{U-B} &= 0.992(\text{U-B})_o + \text{C}_1 \\
\text{B-V} &= 1.170(\text{B-V})_o + \text{C}_2 \\
\text{V-R} &= 0.995(\text{V-R})_o + \text{C}_3 \\
\text{V-I} &= 1.150(\text{V-I})_o + \text{C}_4 \\
\text{V} &= \text{V}_o - 0.05(\text{B-V}_o) + \text{C}_5
\end{aligned}$$

where the C_i are the zero-points which are determined each night from standard star observations.

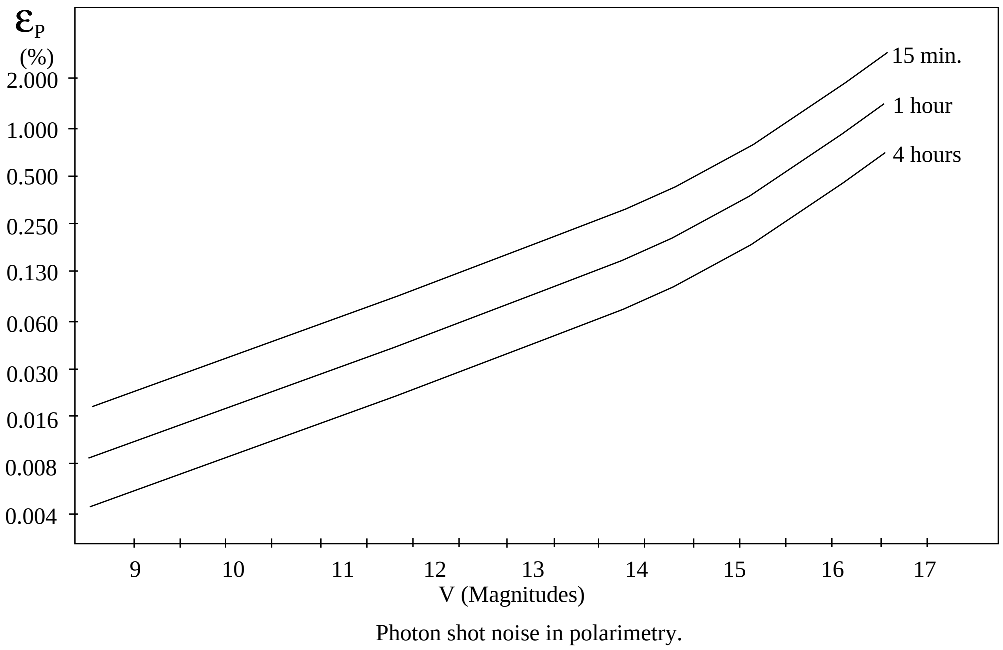

Figure 5.3: Errors due to photon shot and scintillation noise for TurPol at the NOT.

5.7 Estimated errors based on photon shot noise

Figure 5.3 shows the estimated errors in the degree of polarisation due to pure photon shot noise and scintillation (at 3%), for different integration times as a function of magnitude of the observed object.