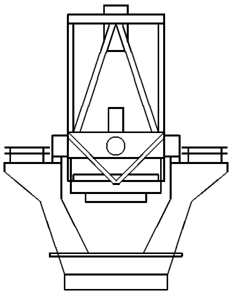
GUIDE-STAR SEARCH (GSS)

USERS' MANUAL

June 15, 1998

Robert Laing



Contents

List of Figures

List of Tables

1 Introduction

The main objective of the software described in this manual is to use the Space Telescope Guide Star Catalogue (hereafter GSC) to locate guide stars suitable for the ING Telescopes on La Palma. The GSC provides a large number of stars with (fairly) accurately-known positions. It will generally contain several stars in any of the guiding fields for all except the most perverse target positions (*e.g.* in dark clouds). The only exception is the WHT Nasmyth focus (through the derotation optics), where the field is too small to guarantee that a suitable star will be found. The software, therefore, accesses the GSC, finds suitable guide stars for a given position and telescope configuration and outputs their positions in a form suitable for the telescope, A&G and autoguider control software.

The software package is called GSS (Guide-Star Search) and runs on Vaxes under VMS. It is installed on the ING Vax Cluster and on the software development machines at RGO, and may be run from remote computers via the Internet. It provides output in the form of text files of guide star and probe positions and may be used to produce plots of the fields on a variety of graphics devices.

A more specialised application is the selection of guide stars suitable for closed-loop blind offsets. This is useful for slit spectroscopy of faint targets on either the WHT or the INT. The technique relies on the fact that the encoding of the guide probes is more precise than that of the telescope drives. A reference star whose position is known accurately with respect to the target is acquired on the spectrograph slit with the autoguider loop locked. The telescope and guide probe are then moved simultaneously by the known offset to the target, so that the same guide star remains in the autoguider field. When the guide loop is locked, the target should be accurately centred on the spectrograph slit. The fields accessible to the guide probes have peculiar shapes, so it is sensible to check in advance whether a suitable guide star will be visible both before and after the offset. If not, a different choice of reference star or slit position angle can be made.

Whilst GSS itself is an off-line application, selection and acquisition of guide stars for the WHT is integrated into the on-line control software via the TAG I-task. This uses the same catalogue, algorithms and applications code as GSS, but will generally require fewer steps to operate, and will reduce observing overheads significantly. TAG is recommended for most guide-star applications on the WHT (see the TAG Manual for more details). Even if you intend to use TAG at the telescope, it is worth running GSS to locate guide stars in advance if there is any doubt whether they will be accessible. The most obvious cases are:

1. Off-axis autoguiding with UES, where the field is small.
2. Closed-loop offsetting, as described above, where the guide star must be visible before and after the offset.

The GSS software is supported from RGO Cambridge by Marion Fisher (mpf@ast.cam.ac.uk) and Robert Laing (rl@ast.cam.ac.uk). Please report any faults or suggestions for improvements via the Defect Database or directly to the authors.

2 The Guide-Star Catalogue

The GSC contains roughly 1.9×10^7 objects with magnitudes in the range $7 - 16$, of which more than 1.5×10^7 are classified as stars. It is based on an all-sky, single epoch, single passband Schmidt survey. Astrometry, at equinox J2000, is available at the epoch of the individual plates used in the GSC (1975 – 1983) and is based on the AGK3, SAO and CPC catalogues. An analysis against CAMC measurements by Taff *et al.* (1990) showed that the GSC absolute positional errors are dominated by systematic effects and vary from 0.5 – 1.1 arcsec from plate centre to edge in the north and from 1.0 – 1.6 arcsec in the south. Relative errors at 0.5° separations vary from 0.3 – 0.8 arcsec, depending on hemisphere and magnitude. The positions are therefore not quite accurate enough to be used for blind offsetting into narrow slits.

The catalogue is subdivided into 9537 regions bounded by small circles of right ascension and great circles of declination. Data for each region are stored in separate files; these files are contained in subdirectories, each of which covers a 7.5° range of declination. The GSC is distributed on two CD ROMs in ISO 9660 format, divided at a declination of 7.5°S. All data files are in FITS table format. The catalogue is fully documented in the booklet supplied with the CD-ROM set and a series of papers (Lasker *et al.* 1990, Russell *et al.* 1990 and Jenkner *et al.* 1990).

3 Running GSS

3.1 General

The GSS may be run from any account on the La Palma Vax Cluster or on the software development Vaxes at RGO. In the latter case, outside users are not normally allowed, so a dedicated account with restricted privileges has been set up for the express purpose of running GSS. Both sets of machines are accessible over the Internet. The first step is always to set up the logical names needed by GSS, which requires a command procedure to be run from the login prompt. Thereafter, the software is started by the command `GSS`, which gives a `GSS>` prompt, and stopped by `EXIT`. If for any reason the GSS gets stuck, try `CNTRL Z` to stop an application and return to the prompt. If all else fails, `CNTRL Y` will abort the program and return you to the operating system prompt. In the rest of the manual, instructions to be typed are shown as follows:

```
$ GSS
```

or

```
GSS>DEVICE XWINDOWS
```

where `$` and `>GSS` are the VMS and GSS prompts. Neither the GSS software nor the VMS operating system are case-sensitive. Both support minimum-match abbreviation of commands.

3.2 La Palma: normal operation

In order to allow access to the GSC by multiple users, and to improve access speed, the catalogue has been copied to a magnetic disk, which should be visible to any machine in the cluster. To set up the logical names needed to run the GSS on La Palma, execute the command procedure:

```
$ @DISK$USER3:[GSS]GSS_INIT
```

(you may find it convenient to add this to your LOGIN.COM file). Then type

```
$ GSS
```

to start the software. It occasionally happens that the catalogue disk is not mounted on every node in the cluster. In order to check its availability, type:

```
$ SHOW DEVICE GSS_DISK
```

You should see something like:

```
Device                  Device           Error    Volume          Free Trans Mnt
 Name                   Status           Count     Label        Blocks Count Cnt
LPVS3$DKB300:           Mounted              0   GSTARCAT       762004    1   8
```

If the disk is not mounted, try logging into the captive account MDISK from a DECserver terminal or an X-terminal LAT session (*not* from a remote machine) and following the instructions. If you still cannot mount the disk, try running GSS from LPVS3 (to which the disk is physically attached). If all else fails, use the CD-ROM version (see below).

3.3 La Palma: operation from CD-ROM (emergencies only)

If the disk containing the GSC is, for some reason, inaccessible, then the software can access the original CD-ROM version of the catalogue. The disks are mounted on LPVS3 (LPVS3$DKB400: and DKB500:) and the drives are located next to this VaxStation. The disks should be permanently loaded in the two drives. If they are not, consult the software group (who may be using the system for VMS documentation). Do not attempt to (un)load CD's until you have had a lesson from a qualified person. It does not matter which disk goes in which drive.
Warning: the v1.1 release of the GSC should always be used, as our copies of the v1.0 disks generate an unacceptable number of hardware read errors.
In order to set up to work with the CD-ROM version, type:

```
$ @DISK$USER3:[GSS]GSS_INIT
$ DEFINE/JOB GSS_DISK CDROM
$ GSS
```

The system should respond with the `GSS>` prompt after the 15 seconds or so needed to mount the CD's. If the program is being run by someone else, there will be an error message to the effect that the disks are allocated to another user. In this case, type `SHOW DEVICE/FULL LPVS3$DKB` and note the username. Contact the offending person and ask them to exit from the GSS and/or dismount the disks. The `EXIT` command will automatically dismount the CD-ROMs, but if you have to use `CNTRL Y` to abort GSS, you will need to type:

```
$DISMOUNT GSS_DEV1
$DISMOUNT GSS_DEV2
```

If you wish to revert to the magnetic disk version, type

```
$ DEFINE/JOB GSS_DEVICE DISK
```

to reset the logical name.

3.4 RGO: the GSS account

In Cambridge, the GSS may be run from any account on the software engineering group Vaxes (GXSEG0, GXSEG1 or GXSEG2). Users without their own account should log in to the GSS account. The password to this account will change periodically: please e-mail Marion Fisher to find out the current password (mpf@ast.cam.ac.uk). To access GXSEG0 remotely, use:

```
telnet gxseg0.ast.cam.ac.uk
```

and log in with username GSS and the current password. The appropriate initialisation is done automatically, so to start the software, just type:

```
$ GSS
```

If you wish to display plots on a remote X-windows device, type:

```
$ XDISPLAY
```

before starting GSS. The GSS account has been allocated enough disk space to allow users to store output and plot files (it is a good idea to create a new subdirectory for the purpose). Files may be copied to another machine using ftp, but VMS mail is disabled. Please delete unwanted files as soon as possible: in any case they will be removed automatically after 60 days. Users who already have an account on the cluster should execute the command:

```
$ GSS_INIT
```

before starting GSS. By default, the software uses a version of the GSC on magnetic disk: the CD-ROM version of the catalogue is not normally available, and would be loaded only by special request in the event of a disk crash.

4 Simple use of the program

This section describes the most common applications of the GSS software. Fuller details of all of the available commands are given in Sections 5 – 7.

4.1 Standard configurations

In order to find guide stars, the GSS needs to be told the telescope and focal station/instrument combination (referred to as the *configuration*) and the position angle of the instrument rotator. The current configurations are:

WHT CASS WHT Cassegrain focus with the guide probe restrictions appropriate for slit-viewing, used with ISIS and FOS.

WHT AUXPORT WHT Cassegrain focus with no restrictions on guide probe movement (appropriate for LDSS and auxiliary port imaging).

WHT TAURUS WHT Cassegrain focus with Taurus (as AUXPORT, but with a different rotational offset).

WHT PRIME WHT Prime focus CCD imaging (*not* Autofib/WYFFOS, where guide stars should be found as part of the set-up of the fibre positioner).

WHT UESPROBE WHT UES Nasmyth focus with derotation optics (moving guide probe).

INT PRIME INT Prime focus (imaging CCD, photographic camera)

INT CASS INT Cassegrain focus (IDS, FOS *etc.*)

JKT CCDE JKT f/15 Cassegrain + CCD East of the pier

JKT CCDW JKT f/15 Cassegrain + CCD West of the pier

JKT WFCE JKT f/8 Cassegrain + wide-field camera East of the pier

JKT WFCW f/8 Cassegrain + wide-field camera West of the pier

NONE Nearest star search (this is independent of telescope, and is intended merely to locate the star(s) nearest to the target position, *e.g.* for use as references in blind offsetting).

In order to specify the configuration, use the command `CONFIG configuration_name` at the `GSS>` prompt. The position angle is input using the `ROTATOR` command, for example:

```
GSS>CONFIG WHT CASS
GSS>ROTATOR 180
```

4.2 Finding Guide Stars

The simplest option is to use the configuration defaults. To find stars for the INT, use commands like the following:

```
$GSS
GSS>CONFIG INT CASS
GSS>ROTATOR 90
GSS>SEARCH 12 34 56.23 30 00 02 J2000
GSS>EXIT
$TYPE OUTPUT.GS
```

This finds the brightest 10 guide stars available for the INT Cass focus at the specified position for sky position angle 90°. The position and probe coordinates for the guide star are given in OUTPUT.GS, which is the default output file name.

The next example shows how to increase the number of potential guide stars and to produce a plot of the results for the INT Prime focus.

```
$XDISPLAY
$GSS
GSS>CONFIG INT PRIME
GSS>ROTATOR 180
GSS>NUMBER 50
GSS>DEVICE XWINDOWS
GSS>SEARCH 23 23 24.56 45 56 23.1 B1950
GSS>PLOT
GSS>EXIT
$TYPE OUTPUT.GS
```

produces an X-windows plot.

On La Palma, the guide star details may be printed using `WHT_LASE OUTPUT. GS` or `INT_LASE OUTPUT.GS`. To get a hard copy of the plot, use CANON_L as the device name, and use `WHT_GLASE` or `INT_GLASE` to print the resulting CANON.DAT file, or POSTSCRIPT_L, followed by `WHT_PLASE GKS_72.PS`. A complete list of the currently-supported configurations is given in the next section.

4.3 Guide stars for closed-loop offsetting

In order to select guide stars suitable for closed-loop offsetting, the positions of the target and a nearby reference star of accurately known relative position must be entered in a catalogue. This is a simple text file, and the allowed formats are described in detail in Section 7.1. In most circumstances, only the name, RA, Dec and equinox of each object need to be specified. For example, in order to observe a target 3C789 with a reference 3C789REF, the catalogue file (BLACK.CAT) would look like:

```
3C789    20 13 14.156 45 45 45.45 J2000
3C789REF 20 13 16.020 45 44 06.34 J2000
```

To select a suitable guide star in order to observe with the INT at PA 90:

```
$GSS
GSS>CONFIG INT CASS
GSS>ROT 90
GSS>CATA BLACK.CAT
GSS>BLIND 3C789REF 3C789
GSS>EXIT
$TYPE OUTPUT.GS
```

The output gives the probe coordinates appropriate for the reference star and the offset required to acquire the target (this will be applied automatically by the INT TCS command `AUTOFFSET` described in the INT Manual, although beware the fact that the target and reference must have coordinates at the same equinox in this case).

4.4 Finding guide stars for a large number of targets

In order to determine guide star positions for a long list of targets to be observed with the same instrumental configuration, the simplest method is to make a catalogue file containing their positions (as described in the previous section) and to use the `CATSEARCH` command. For example, to list one guide star for each of the entries in a catalogue WHITE.CAT, to be observed with the JKT CCD camera:

```
$GSS
GSS>CONFIG JKT CCDE
GSS>NUMBER 1
GSS>CATSEARCH WHITE.CAT
GSS>EXIT
```

5 Configurations and Target Data

This section describes the specification of configurations and target positions in more detail. Between them, these provide all of the data needed to execute the search procedure.

5.1 Configurations

A *configuration* is the set of parameters needed to specify the search procedure for a given object and rotator position angle. The combinations of telescope and focal station currently supported were listed in Section 4.1 (see Appendix B.2 for more details). The parameters included as part of a configuration are as follows:

Geometry The descriptions of the search areas and the conversions between RA, Dec. and guide probe coordinates. These are not expected to change unless mechanical modifications are made and are not accessible to the user.

Magnitude Each configuration is associated with a magnitude range, defining the brightest and faintest possible guide stars. The defaults have been set to suit the autoguiders, but may be overridden.

Observing aperture This is specified as an (x,y) pair, in arcsec, and defines the position in the focal plane at which the target is to be observed. The origin of coordinates is at the intersection of the rotator axis with the focal plane and the x and y axes are defined in the same sense as those used by the telescope control system for aperture offsets.

WHT Cassegrain The default aperture coordinates are set to zero, as the centre of rotation is almost on the ISIS slit.

WHT Nasmyth Defaults are zero, pending further information.

INT Cassegrain The defaults are set for a position corresponding to the intersection of the IDS slit and the central column of the EEV5 detector.

INT Prime This is the only configuration for which the aperture is displaced by more than a few arcsec from the rotator axis. Some care is needed to ensure that self-consistent parameters are used by the GSS and the telescope control system. For CCD observing, the aperture used by the GSS should be the same as the nominal aperture determined for the chip centre (see INT Telescope Manual). For the plate camera, the aperture offset should be close to (0,0).

JKT Cassegrain The default is set to (0,0), which should be close to the centre of the imaging CCD.

Note that accurate blind offsetting from an off-axis guide star will require precise specification of the observing aperture (this application will only become feasible once the proposed astrometric recalibration of the catalogue is completed). Default values are held as part of the configuration.

Minimum separation This defines the minimum distance between a selected guide star and its nearest neighbour in the catalogue (whether or not the latter satisfies the selection criteria).

Number of stars This is the maximum number of stars to be selected during a search.

5.2 Target data

The parameters specified below define the target position and rotator position angle.

Target name and position in any of the coordinate systems supported by the WHT telescope control system. The following parameters are required:

Right ascension Hours, minutes, seconds, separated by spaces.

Declination Degrees, minutes, arcseconds, separated by spaces.

Equinox Mean FK4 or FK5 systems (*e.g.* B1950, J2000) or apparent coordinates of arbitrary date. (Note that this is a change from the WHT TCS, which supports apparent coordinates of current date only. This is necessary in order to allow running of the guide star search software well before the observations take place).

The remaining parameters are optional. Parallax and radial velocity, in particular, will make very small differences to the exact selection of guide stars and to the computed guide probe positions, but are retained for consistency with the TCS and to allow direct use of WHT catalogue files.

Proper motions in RA (seconds of time per year) and Dec (arcseconds per year). Defaults to zero.

Epoch (year). Defaults to equinox.

Parallax (arcsec). Defaults to zero.

Radial Velocity (kms^{-1}; defaults to zero).

It is possible to input target positions in a catalogue file in the format accepted by the WHT control system. In this case, references to a particular object are by name. The catalogue format is described in detail in Section 7.1.

Rotator position angle This is a sky position angle, in the range $0° - 360°$, as used by the relevant telescope control system. See Appendix A.2 for some subtleties affecting wide fields.

6 Commands

Data can be input either interactively or via simple command files. The normal mode of use will be to select the configuration at the beginning of a session, thereafter changing only the source position and (optionally) the rotator position angle. There follows a list of commands, subdivided into *data entry* and *actions*.

6.1 Data entry

APERTURE Enter the observing aperture coordinates (arcsec). The default values are determined by the telescope/focal station combination.

Format: `APERTURE x y`

Example: `APERTURE 10 20`

CATALOGUE Enter the name of a source catalogue to be used as a list of target positions. Standard VMS syntax, defaulting to the current directory with a .CAT extension.

Format: `CATALOGUE <filename>`

Examples: `CATALOGUE MANX` (uses MANX.CAT in the current working directory)

`CATALOGUE U3:[GUEST01.CATS]JELLICLE.CAT`

CONFIGURATION Specify the observing configuration. The current list of telescope and focal station combinations is given in Section 4.1.

Format: `CONFIGURATION <telescope> <focal_station>`

Examples: `CONFIG INT CASS`

`CONFIG NONE`

DATE Enter the epoch of observation (as a year number, to an accuracy of 3 decimal places, or in DEC standard format). The default is the current date and time.

Format: `DATE <date>`

Examples: `DATE 1994.256`

`DATE 21-DEC-1995`

`DATE 25-DEC-1999:22:00:00`

DEFAULT Reset the relevant configuration parameters to their default values. The keywords covered by this command are: `DATE`, `APERTURE`, `MAGNITUDE`, `NUMBER`, `SEPARATION` and `ALL`. The default (assumed if no parameter is given) is `ALL`.

Format: `DEFAULT <configuration>`

Examples: `DEFAULT MAGNITUDE`

`DEFAULT`

DEVICE Set the GKS device to be used for plotting. To get a list of workstation names, type `DEVICE` followed by `?` at the `_GKS Device name:`prompt (*not* `DEVICE ?`).

Format: `DEVICE <GKS_device_name>`

Example: `DEVICE XWINDOWS`

The most commonly-used device names are:

PERICOM_MG Pericom graphics terminal.

CANON_L Canon laser-printer (landscape mode). Note that a device-name of CANON_L;filename causes the plot output to be written to a file called filename rather than the usual CANON.DAT. Canon graphics can be printed on La Palma using the commands `WHT_GLASE` and `INT_Glase`.

CANON_P Canon laser-printer (portrait mode; output filename as above).

POSTSCRIPT_L Postscript (landscape mode). Again, specifying POSTSCRIPT_L;filename generates output in filename, rather than the generic GKS_72.PS. Postscript output can be printed on La Palma using the command `WHT_PLASE`.

POSTSCRIPT_P Postscript (portrait mode; output filename as above).

XWINDOWS X-window on VaxStation, Sun or X-terminal. Note that to get a window on a remote workstation, the command `XDISPLAY` should be issued at the `$` prompt before starting GSS. This is a Starlink command, and to use it you will need to execute the appropriate login procedure by typing (or including in your LOGIN.COM file) the command `@SSC:LOGIN`.

MAGNITUDE Set the bright and faint V magnitude limits. The default values are the standard values for the configuration. The allowed range is 5 – 19 (there are no stars in the GSC with magnitudes outside these limits).

Format: `MAGNITUDE` V_{min} V_{max}

Example: `MAGNITUDE 12 15`

NUMBER Set the maximum number of guide stars to be selected at a given position angle. Overrides system default (50 for NONE; 10 for all other configurations).

Format: `NUMBER <max_number>`

Examples: `NUMBER 45`

ROTATOR Input the sky position angle, as given to the relevant telescope control system, in degrees ($0° - 360°$) or specify that guide stars be found for all possible position angles using the keyword `ANY`. The latter option is meant for small fields, where there may only be a limited choice of guide stars, in order to allow a sensible choice of rotator PA. It is disabled for WHT and INT Prime and for the JKT Wide-Field Camera.

Format: `ROTATOR <angle>` or

`ROTATOR ANY`

Examples: `ROTATOR 180`

SEPARATION Set the minimum separation of guide stars (arcsec). Overrides system default (5 arcsec for telescope configurations; zero for NONE).

Format: `SEPARATION <min_separation>`

Example: `SEPARATION 2`

6.2 Actions

BLIND Determine the positions of guide stars suitable for a closed-loop blind offset between two named objects. The reference and target objects must be included in the current catalogue. This command will then select guide stars which are within the accessible field for both objects and will write the probe positions and displacements to the current output file. It does not work if the `CONFIG NONE` or `ROTATOR ANY` options are specified.

Format: `BLIND <reference> <target>`

Example: `BLIND THREE MICE`

CATSEARCH Search for guide stars around all objects in a named catalogue. The catalogue name follows standard VMS syntax and the default extension is .CAT.

Format: `CATSEARCH <catalogue_name>`

Examples: `CATSEARCH MACAVITY.CAT`

`CATSEARCH U3:[GUEST01.CAT]BASKET`

DO Filename. Search the GSC using GSS commands from the specified file rather than interactive input. Defaults to .COM extension and the current directory. Nesting of GSS commands is not supported.

Format: `DO <filename>`

Example: `DO STARS.CMD`

HELP Access to help on GSS commands and abbreviations via a VMS HELP library with the usual hierarchical structure.

Format: `HELP [<topic>]`

Examples: `HELP`

`HELP OUTPUT`

EXIT Stop the GSS program. If using the CD-ROM version of the catalogue, also dismount the disks.

Format: `EXIT`

OFFSET Determine the positions of guide stars for a closed-loop blind offset of a specified amount from a named reference object. The reference object must be included in the current catalogue. The offsets are specified in arcsec in the tangent plane parallel to RA (ξ) and Declination (η). An optional rotation, in degrees, may also be included (this is intended primarily for alignment of multislit fields on the WHT and has the same parameters as the TCS `TWEAK` command). `OFFSET` selects guide stars which are within the accessible field before and after the offset and will write the probe positions and displacements to the current output file. It does not work if the `CONFIG NONE` or `ROTATOR ANY` options are specified.

Format: `OFFSET <reference>` ξ η `[<rotation>]`

Examples: `OFFSET ALPHACEN 3.4 -23.4`

`OFFSET REF 4.5 0.0 1.3`

OUTPUT Filename. Creates and opens a new output file to be used until superseded by another OUTPUT command, and closes any previous output file. Standard VMS syntax, defaulting to OUTPUT.GS in the current directory.

Format: `OUTPUT <filename>`

Examples: `OUTPUT WHT.GS`

`OUTPUT DISK$USER1:[GUEST01.CATS]TARGETS.GUIDE`

PLOT Plot the positions of the selected guide stars on the selected device. The plot is centred on the rotator axis and shows the positions of the selected guide stars in the focal plane coordinate system (x left-right; y up-down; PA 0° vertical). The target position is marked by an open star, and the rotator axis (if the target is not on it) is marked by an open circle and dot. The outline of the field is drawn, together with an "L" indicating North and East. An open circle indicates that the object is classified as stellar on all available plates. An x represents an object with a non-stellar classification on all plates and a circle with a superposed x represents an ambiguous classification. Larger symbols correspond to brighter objects.

Format: `PLOT`

SEARCH Search the catalogue for guide stars around a target position specified explicitly. The RA, Dec and Equinox are required; other positional information can be entered using optional qualifiers, as follows:

/RAPROPER proper motion in RA (seconds of time per year)

/DECPROPER proper motion in Dec (arcseconds per year).

/EPOCH (year). Defaults to equinox.

/PARALLAX (arcsec). Defaults to zero.

/RADVEL radial velocity (kms^{-1}; defaults to zero).

Examples:

```
SEARCH 20 12 13.33 -30 45 55.2 B1950
SEARCH 19 57 57 30.233 04 06.77 J2000 /RAP=0.001 /DECP=-0.12 /EP=1945.5
```

This command is for use when a catalogue has not been specified (*e.g.* for small numbers of objects).

SHOW displays the parameters of the currently-selected configuration (`SHOW CURRENT`) or lists all the available configurations (`SHOW CONFIG`). The former is the default.

Format: `SHOW <keyword>`

Examples: `SHOW`

`SHOW CONFIG`

SOURCE causes the GSC to be searched around the position of a named object in the current catalogue, using the current configuration and rotator PA. The name should follow the requirements of the WHT TCS (up to 20 characters; embedded spaces require double quotes).

Format: `SOURCE <sourcename>`

Example: `SOURCE M87`

7 Input and output files

7.1 Catalogues

A *catalogue file* is a list of target names and positions in the format used by the WHT TCS. A catalogue is simply a text file of positional information in free format with spaces as separators. All data for an entry should be on one line of the file. Anything following an asterisk or exclamation mark is treated as a comment and is ignored. Do not use tab, control or other peculiar characters. The parameters must be in the order: Name, Right Ascension, Declination, Equinox, proper motion in right ascension, proper motion in declination, Epoch, Parallax, Radial velocity. The first four parameters are mandatory and the remainder are optional with sensible defaults. The formats and units of the necessary parameters are as follows:

- **Name**—up to 20 characters. Embedded spaces are allowed, but if they are used, then the name must be enclosed in double quotes (*e.g.* `"NGC 7027"`).
- **Right ascension**—hours, minutes, seconds, separated by spaces.
- **Declination**—degrees, minutes, seconds, separated by spaces.
- **Equinox**—for *mean* positions, a leading letter indicates the coordinate system:
  `B` implies mean pre-IAU76 or FK4
  `J` implies mean post-IAU76 or FK5

  The letter is followed immediately by a number indicating the epoch of the mean equator and equinox of that system (*e.g.* `B1950.0` or `J1987.5`).
  For *apparent* positions this field should contain the word `APPARENT` (abbreviable to `A`). In order to

maintain strict compatibility with the WHT TCS, no epoch is specified, and the `DATE` command should be used to set the epoch of observation.

The formats, units and defaults of the optional parameters are as follows:

- **Proper motions**—in right ascension (seconds of time per year) and declination (arcseconds per year). Default to zero if not specified.
- **Epoch of position**—(year). This should not be confused with the equinox. The epoch of observation is used in conjunction with the proper motions to correct for the space motion of the object. If the epoch is not specified, then it is assumed to be the same as the equinox.
- **Parallax**—(arcseconds). Generally negligible. Defaults to zero if not specified.
- **Radial velocity**—(km s^{-1}, positive for a receding object). Generally unimportant. Defaults to zero if not specified.

Examples of catalogue files are:

- The simplest possible catalogue contains only name, right ascension, declination and equinox:

```
3C567    12 34 56.78  -01 23 45.6  B1950
NGC123   00 12 46.6    05 34 56    J1987.5
COMET    12 12 12.12  +12 12 12.1  A
```

- A more complicated entry might include proper motions:

```
SP1  00 31 22.2  -12 24 21  B1950.0  0.011 -0.17
```

- The ultimate in complexity has parallaxes and radial velocities too:

```
S01-07  00 50  7.596  -10 38 39.54  J2000  -0.01531 -0.2287 2000  .059   8
S01-22  01 06  7.724  -23 59 33.07  J2000  -0.00225 -0.0409 2000  .000   0
```

7.2 Command Files

A GSS *command file* is a list of commands identical in format to an interactive terminal session. It is executed from within the GSS program using the `DO` command. An example might look like:

```
CONFIG WHT CASS
CATALOGUE TABBY.CAT
ROTATOR 90
SOURCE SIAMESE
ROTATOR 0
SOURCE ALLEY
```

7.3 Output Files

There is a single output file for each session unless a deliberate change is made using the `OUTPUT` command. This contains the following information:

The name or position of the target and the assumed configuration details.

The J2000 positions of all of the guide stars meeting the selection criteria, up to the specified number.

The calculated guide probe coordinates for each of the guide stars (x y or r θ).

The magnitudes of the guide stars (to be used in evaluating integration times).

An asterisk after the probe position indicates that the object is classified as stellar on all GSC plates and a ? represents an ambiguous classification. No symbol is given for objects classified as non-stellar on all plates. These should only be used as guide stars in case of dire need.

For example:

```
  GSS - LIST OF GUIDE STAR DATA FOR GIVEN TARGETS
=====================================================

Key: * = star, blank = non-star, ? = ambiguous object
=====================================================

Target:                      Equinox  PA   Tel  Focus
20  0  0.00  +40  0  0.00    J2000.0  0.0  WHT  CASS
  Date       Apx     Apy  Vmax  Vmin
1993.060     0.0     0.0   8.0  16.0

   RA2000       Dec2000     Mag        r     theta
19 59 26.30  +39 51 51.59   9.72    27231.   128486.  *
20  0 32.97  +39 51 36.04   9.88    28812.    52998.
20  0  7.59  +39 49 37.99  11.38    28238.    82003.  *
------------------------------------------------------
```

In addition, the `BLIND` command generates some additional information:

The position of the reference star.

The probe offsets required to move between the reference and the target.

For instance:

```
  GSS - LIST OF GUIDE STAR DATA FOR GIVEN TARGETS
=====================================================

Key: * = star, blank = non-star, ? = ambiguous object
=====================================================

Reference: REFERENCE            Equinox  PA
20  0  0.00  +40  0  0.00       J2000.0  0.0
Target:    TARGET               Equinox  PA
20  0  0.00  +40  0 10.00       J2000.0  0.0
Tel  Focus       Date       Apx     Apy  Vmax  Vmin
```

```
 INT  CASS       1995.975    23.6     1.5   6.0  14.0

    RA2000       Dec2000     Mag        x          y      del x     del y
 19 59 26.30  +39 51 51.59   9.72   570092.   586001.        0.      1853.  *
 20  0 32.97  +39 51 36.04   9.88   427869.   588885.        0.      1853.
------------------------------------------------------
```

Here, the guide probe coordinates are for the *reference* object, and del x and del y are the amounts by which the probe should be moved in order to acquire the target.

References

Jenkner, H. *et al.* , 1990. *Astron. J.*, **99**, 2081.
Lasker, B. *et al.* , 1990. *Astron. J.*, **99**, 2019.
Russell, J.L. *et al.* 1990. *Astron. J.*, **99**, 2059.
Taff, L.G. *et al.* 1990. *Astrophys.J.*, **353**, L48.

A Search Procedures: General

A.1 Definitions

Define the following variables:

F The focal length (mm).

ψ The sky position angle in radians.

ψ_0 The offset between the coordinate system of the guide probe and that of the instrument rotator, in radians.

ϵ The handedness of the guide-probe coordinate system (±1).

x y Guide probe coordinates, in encoder units.

$\mathbf{x}_{min}$ $\mathbf{x}_{max}$ $\mathbf{y}_{min}$ $\mathbf{y}_{max}$ xy limits on the area within which guide stars may be selected, in encoder units.

r θ Polar coordinates of the guide probe (encoder units; r is positive by definition).

$\theta_{min}\theta_{max}$ $\mathbf{r}_{min}$ $\mathbf{r}_{max}$ Limits on the area within which guide stars may be selected, in polar coordinates; encoder units).

$\mathbf{e}_r$ $\mathbf{e}_\theta$ The linear and angular encoder scales in mm/encoder unit and rad/encoder unit, respectively.

$\mathbf{x}_0$ $\mathbf{y}_0$ The position of the centre of rotation in encoder units in the guide probe coordinate system (used for xy systems only).

$\mathbf{r}_0$ The radial offset for guide probe coordinates, in encoder units (used for rθ systems only).

All of the existing A&G boxes on the La Palma telescopes use xy stages for their guide probes, with the exception of the WHT Cassegrain system, which has an rθ arrangement. A general description of the search areas may be given as follows (note that not all configurations use every constraint):

1. $x_{min} < x < x_{max}$ and $y_{min} < y < y_{max}$ (within a rectangle).
2. $[(x-x_0)^2 + (y-y_0)^2]^{1/2} \leq r_{max}$ or $r \leq r_{max}$ (within a circle: this may be either a result of vignetting or a restriction on the mechanical travel of the probe).
3. $(x-x_0)^2/l^2 + (y-y_0)^2/m^2 > 1$ (inner ellipse excluded). A minimum radial travel for an rθ system is a special case. A similar condition, $[(x-x_0)^2 + (y-y_0)^2]^{1/2} > r_{min}$ or $r > r_{min}$ is used for the `ROTATOR ANY` option, where the available area is always a circular annulus.
4. $x < x_-$ or $x > x_+$ or $y < y_-$ or $y > y_+$ (*i.e.* the area $x_- < x < x_+$ and $y_- < y < y_+$ is *excluded*).
5. The probe azimuth is in the range $\theta_{min} < \theta < \theta_{max}$.

A.2 Conversion between equatorial coordinate systems

The required conversions are between mean (FK4 and FK5) or apparent coordinates of arbitrary date and mean FK5 coordinates referred to equinox J2000 and the epoch of observation. The algorithms used are those in the COCO package (SUN 56), which is based on SLALIB (*q.v.*) subroutines. Users should be aware of a subtle difference in the way that sky position angle is specified for the WHT and the other two (equatorial) telescopes. The WHT is an altazimuth telescope, and corrects continuously for field rotation. The instrument rotators are controlled in such a way that the position angle on the sky is defined in the coordinate system used for the target (B1950, J2000, *etc.*). The GSC positions are in the J2000 system, and the GSS software therefore corrects the input position angle for the effects of precession before computing guide probe positions. By contrast, the instrument rotators on the INT and JKT are not designed for continuous movement, and are left in a fixed position, independent of coordinate system. This effectively corresponds to adopting a sky position angle defined in geocentric apparent coordinates, and the GSS operates on this assumption. Effects such as differential refraction and pointing model corrections are not included in the GSS software, since they require knowledge of the time of observation and the details of the telescope models. For most practical purposes, the definition of position angle is of little importance, and the assumptions made by the GSS will be the most appropriate. Applications in which precise positioning is required over a wide field may require a careful check to ensure that the position angles used by the TCS, GSS and any other astrometric software are self-consistent.

A.3 Choice of an initial search area

The object here is to choose an area of sky, bounded by curves of constant Right ascension and Declination, which *just* includes the guide field. The outer boundaries of the guide fields are either circular or rectangular in the tangent plane. In the former case (except for targets near the Poles), the ranges of RA and Dec are given by:

$$\Delta\alpha = \arctan(R/f \cos\delta_0)$$

$$\Delta\delta = R/f$$

where R is the radius of the guide field and f is the focal length. This formula fails for the case where $\delta_0 + R/f > \pi/2$ or $\delta_0 - R/f > -\pi/2$ (*i.e.* the guide field includes one of the Poles), in which case all stars with $\delta > \delta_0 - R/f$ (in the North) or $\delta < \delta_0 + R/f$ (in the South) are selected.

For rectangular guide fields, the RA and Dec of each corner are derived from its tangent-plane position using the formulae:

$$\tan(\alpha - \alpha_0) = \xi \sec\delta_0/(f - \eta\tan\delta_0)$$

$$\tan\delta = \frac{\eta + f\tan\delta_0}{[(f + \eta\tan\delta_0)^2 + \xi^2\sec^2\delta_0]^{1/2}}$$

and the widest range in each coordinate is used in the initial search. A similar caveat applies to guide fields around the Poles, for which the selection is made on Declination alone, as for circular guide fields.

A.4 Equatorial to tangent plane conversion

The first step in the conversion process is to derive the *standard coordinates* ξ and η for the guide stars. These are given by:

$$\xi = \frac{\cos\delta\sin(\alpha-\alpha_0)}{\sin\delta\sin\delta_0+\cos\delta\cos\delta_0\cos(\alpha-\alpha_0)}$$

$$\eta = \frac{\sin\delta\cos\delta_0-\cos\delta\sin\delta_0\cos(\alpha-\alpha_0)}{\sin\delta\sin\delta_0+\cos\delta\cos\delta_0\cos(\alpha-\alpha_0)}$$

A.5 Apertures

The objective here is to direct the light from an object of interest to a particular point (an *aperture*) in the focal plane. Apertures are specified in angular units. They cause the tangent-plane coordinates ξ, η to be modified to $\xi'\eta'$, as follows:

$$\xi' = \xi + (-x_A\sin\psi - y_A\cos\psi)$$

$$\eta' = \eta + (+x_A\cos\psi - y_A\sin\psi)$$

where x_A, y_A is the aperture position as given to the TCS.

A.6 Radial distortion

The standard coordinates are then corrected for the effects of radial field distortion:

$$\xi' = \xi D(\rho)$$

$$\eta' = \eta D(\rho)$$

$$\rho = (\xi^2+\eta^2)^{1/2}$$

These effects should be negligible for the JKT f/15, INT f/15 and WHT f/11 foci, but corrections are required for WHT and INT Prime and JKT f/8. In particular, WHT Prime requires precise location of guide stars, since the autoguider field is small. The formula:

$$D(\rho) = 1 + a\rho + b\rho^2 + c\rho^3 + d\rho^4$$

is appropriate, with coefficients as given in Table 1.

A.7 Conversion to guide-probe coordinates

The $\xi'\eta'$ coordinate system are then rotated, translated and scaled to the guide probe system, using the relations:

$$x = (f/e_r)[\xi'\cos(\psi+\psi_0) - \eta'\sin(\psi+\psi_0)] + x_0$$

$$y = \epsilon(f/e_r)[\xi'\sin(\psi+\psi_0) + \eta'\cos(\psi+\psi_0)] + y_0$$

$$r = [(x-x_0)^2+(y-y_0)^2]^{1/2}$$

for xy systems and

$$x = (f/e_r)[\xi'\cos(\psi+\psi_0) - \eta'\sin(\psi+\psi_0)]$$

$$y = (f/e_r)[\xi'\sin(\psi+\psi_0) + \eta'\cos(\psi+\psi_0)]$$

Table 1: Radial distortion coefficients for corrected foci.

Configuration	a	b	c	d
WHT Prime	1.2797	27.458	24320.0	0.0
INT Prime				
JKT f/8	0.0	13.32	0.0	0.0

Table 2: Limiting magnitudes, plate scales and encoder scales (xy systems).

Configuration	Magnitude range	Focal length/mm	e_r	ϵ	ψ_0 rad
WHT PRIME	6.5 – 14.5	11624.5	+0.001	−1	3.0931
WHT UESPROBE	6.5 – 16.5	46257	+0.0009806	−1	-1.5906
INT PRIME	6 – 14	8357	+0.0393	+1	4.71239
INT CASS	6 – 14	38216	+0.001	+1	3.14159
JKT WFCE	5 – 13	8060	+1.0	−1	6.250
JKT WFCW	5 – 13	8060	+1.0	−1	3.108
JKT CCDE	5 – 12	15000	+0.005	+1	0.000
JKT CCDW	5 – 12	15000	+0.005	+1	3.141

$$r = (x^2 + y^2)^{1/2} - r_0$$
$$\sin e_\theta \theta = x/(x^2 + y^2)^{1/2}$$
$$\cos e_\theta \theta = y/(x^2 + y^2)^{1/2}$$

for $r\theta$ systems.

B Detailed description of the search areas

B.1 Tables

The current best estimates for these parameters are given in Tables 2 – 5 and the associated notes.

Table 3: Limiting magnitudes, plate scales and encoder scales (rθ systems).

Configuration	Magnitude range	Focal length/mm	e_r	e_θ	ϵ	ψ_0
WHT CASS	8 – 16	45738	0.001	$\pm 1.7453 \times 10^{-5}$	+1	1.57996
WHT AUXPORT	8 – 16	45738	0.001	$\pm 1.7453 \times 10^{-5}$	+1	1.57996
WHT TAURUS	8 – 16	45738	0.001	$\pm 1.7453 \times 10^{-5}$	+1	−0.01876

Table 4: Guide probe offsets and limits (xy systems).

Configuration	x_{min}	x_{max}	y_{min}	y_{max}	x_0	y_0
WHT PRIME	0	110000	0	20000	56401	97417
WHT UESPROBE	0	73600	0	71000	35939	34844
INT PRIME	550	1850	900	1850	512	281
INT CASS	405000	595000	405000	595000	497919	499938
JKT WFCE/W	139.1	240.0	90.8	180.0	142.9	96.9
JKT CCDE/W	1	29200	1	29200	14146	13000

Table 5: Guide probe offsets and limits (rθ systems).

Configuration	r_{min}	r_{max}	θ_{min}	θ_{max}	x_0	y_0	r_0
WHT CASS	0	40000	30000	180000	0	0	112040
WHT AUXPORT	0	40000	0	180000	0	0	112040
WHT TAURUS	0	40000	0	180000	0	0	112040

B.2 Notes

B.2.1 WHT CASS

The travel of the autoguider probe defines a semi-annulus (see above). Note, however, that the probe can obstruct the slit-viewing optics (not the slit itself) for $\theta < 30000$, giving an additional azimuth restriction. The excluded inner region (a circle) is treated as a special case of the ellipse mentioned earlier, with $l = m$.

B.2.2 WHT AUXPORT

This configuration is identical to the previous one, except for the absence of a lower limit to θ (the slit viewing optics are not used).

B.2.3 WHT TAURUS

This is identical to WHT AUXPORT except for a different position-angle offset (the PA reference is defined by the Taurus detector, rather than the ISIS slit unit).

B.2.4 WHT UESPROBE

The limits on the search area are set by the autoguider probe x and y travel and vignetting by the derotation optics. They should also be affected by the shape of the central aperture in the autoguider mirror, for which there are several alternatives. Since this is not in focus, partial vignetting of the guide star occurs, and the effects are complicated. For the moment, no correction is implemented.

B.2.5 INT PRIME

The search area is a rectangle in the unvignetted field and the guide probe cannot obscure the CCD Camera. The only conditions on x and y are therefore:

$$x_{min} < x < x_{max}$$

$$y_{min} < x < y_{max}$$

Vignetting sets the value of r_{max}. Note that the aperture offset to the centre of the detector depends on the chip and is large.

B.2.6 INT CASS

The outer boundary of the guide probe field is set by the onset of vignetting (no vignetting at 10 arcmin radius; 50% at 11 arcmin, so $r_{max} = 3.1998 \times 10^{-3}$ rad) for the latter figure and the xy limits. The inner boundary of the field is set by the need to avoid obstructing the spectrograph slit with the guide probe, giving a rectangular excluded area. The full 4 arcmin length of the slit has been used in calculating the size of the inner boundary.

B.2.7 JKT f/8 (WFCE and WFCW)

The guide field is a rectangle defined by the range of travel of the guide probe, with a smaller rectangle chopped out of one corner so as to avoid vignetting of the central region of the field. The additional condition excludes the region with: $x < x_+$ and $y < y_+$, with $x_+ = 156.9$ mm and $y_+ = 111.4$ mm. Note that the "encoder scale" quoted for the JKT f/8 (WFC) configurations is not a bit size. The WFC guide probe is positioned manually and its location is read in mm.

B.2.8 JKT f/15 (CCDE and CCDW

The outer edge of the field is a circle of radius 16 arcmin (defined by the filter wheel). The guide probe is on an xy stage and can cover all of this area except for a small part outside its -y range and a cut-out at large x and y. The inner edge of the field is elliptical with a semi-major axis of 14 arcmin along x and a semi-minor axis of 10 arcmin along y. The ellipse is produced because the autoguider is fed by a flat mirror with a circular hole inclined at 45° to the optical axis. The additional conditions are:

$$x^2/l^2 + y^2/m^2 > 1$$

$$x^2 + y^2 < r_{max}^2$$

and the area with $x > x_+$ and $y > y_+$ is also excluded.

B.2.9 NONE: simple search

This application selects all stars within a given angular radius of the target position. Applications are production of finding charts, and selection of reference stars for the MARTINI image-sharpening instrument and for blind offsetting. The plots are labelled in arcsec from the target position.

C The CONFIG.DAT file

Configuration parameters will change from time to time, usually as a result of mechanical modifications, and additional configurations are likely to be added. The definitive list of configurations is held in the file GSS_DIR:CONFIG.DAT, which may be read or printed. Each configuration is defined by a block starting with `CONFIG`. The variables defining the configuration are then listed, in fixed order, with variable names as comments. The translation between variable names and the symbols used earlier is given in Table 6. Note that the variables RVEL, THVEL, XVEL and YVEL are used only by the TAG I-task.

D Example Plots

Table 6: CONFIG.DAT variable names.

Variable name	Symbol	Unit	Notes
FOCLEN	F	mm	
XY FLAG			F for $r\theta$; T for xy systems
PA_OFFSET	ψ_0	rad	
FLIP	ϵ		
PA_COORD_SYS			T for moving rotator
SCALER	e_r	mm/bit	
SCALETH	e_θ	rad/bit	
RADA	a		
RADB	b		
RADV	c		
RADD	d		
X0	x_0	bits	
Y0	y_0	bits	
R0	r_0	bits	
XMIN	x_{min}	bits	
XMAX	x_{max}	bits	
YMIN	y_{min}	bits	
YMAX	y_{max}	bits	
RMIN	r_{min}	bits	
RMAX	r_{max}	bits	
THMIN	θ_{min}	bits	
THMAX	θ_{max}	bits	
LAXIS	l	bits	
MAXIS	m	bits	
XMINUS	x_-	bits	
XPLUS	x_+	bits	
YMINUS	y_-	bits	
YPLUS	y_+	bits	
X_AP	x_A	rad	
Y_AP	y_A	rad	
V_MIN	V_{min}	mag	
V_MAX	V_{max}	mag	
MIN_SEP		rad	Minimum separation
NUM_STARS			Number of stars

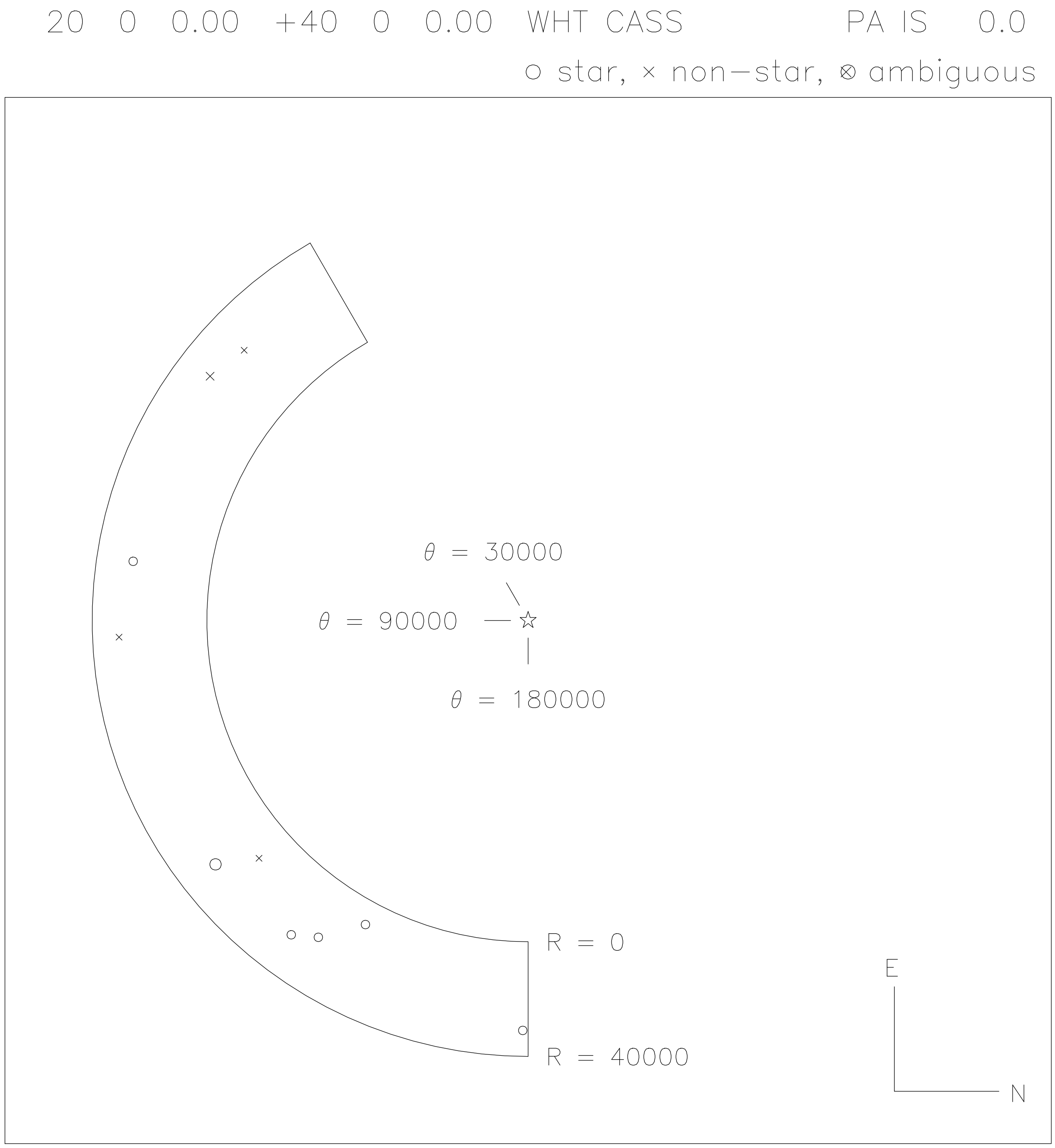


Figure 1: WHT CASS configuration.

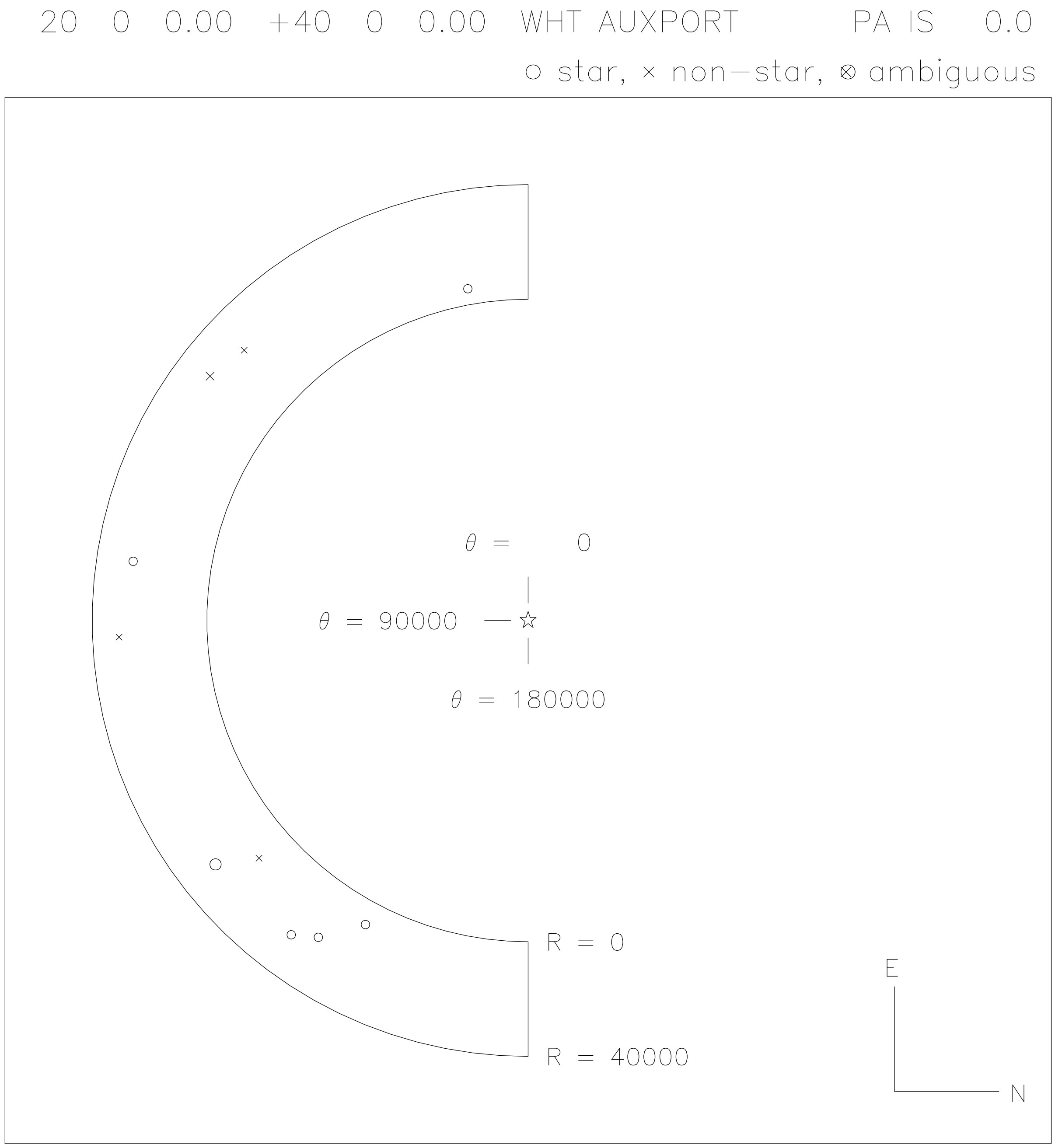


Figure 2: WHT AUXPORT configuration.

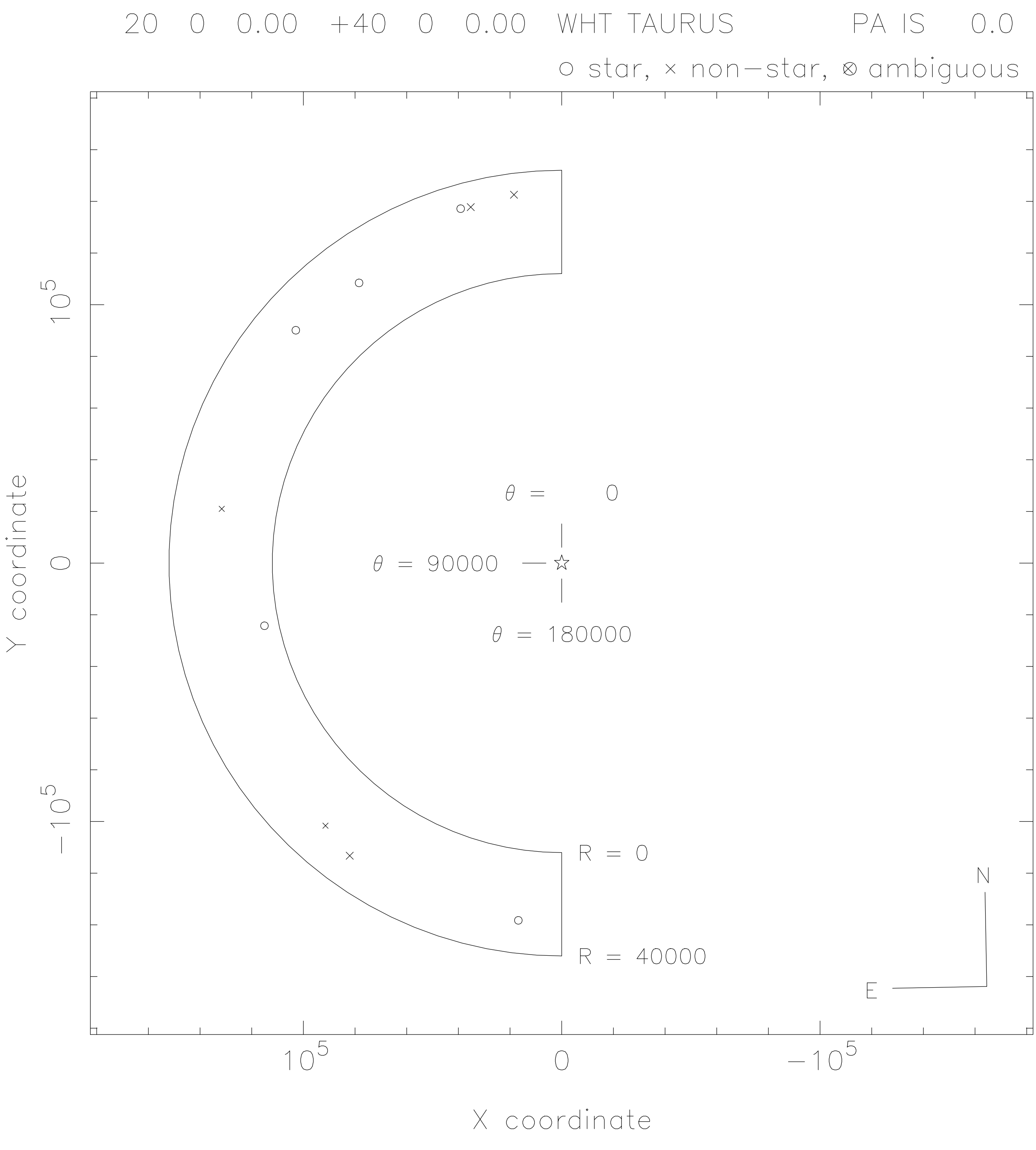


Figure 3: WHT TAURUS configuration.

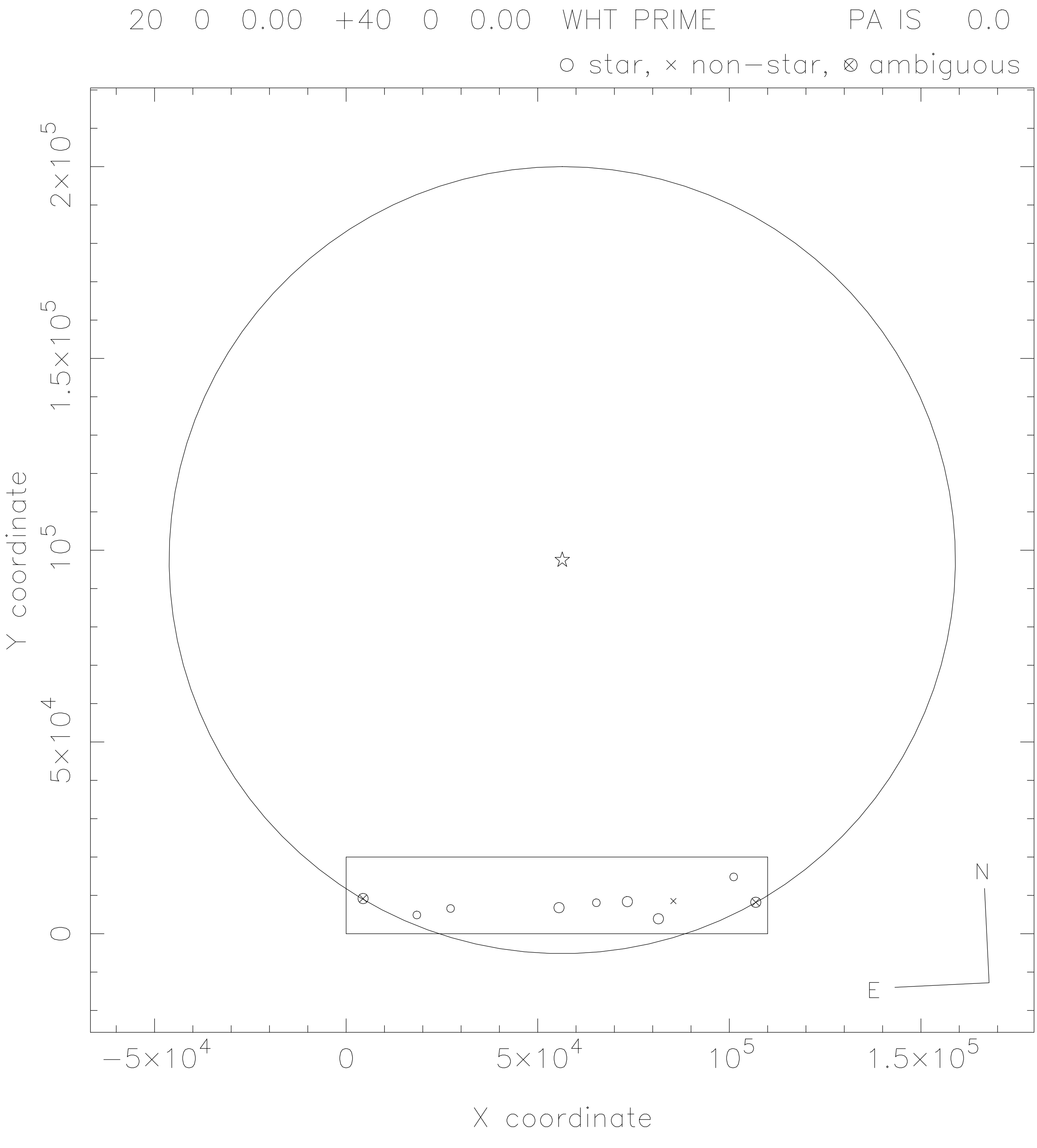


Figure 4: WHT PRIME configuration.

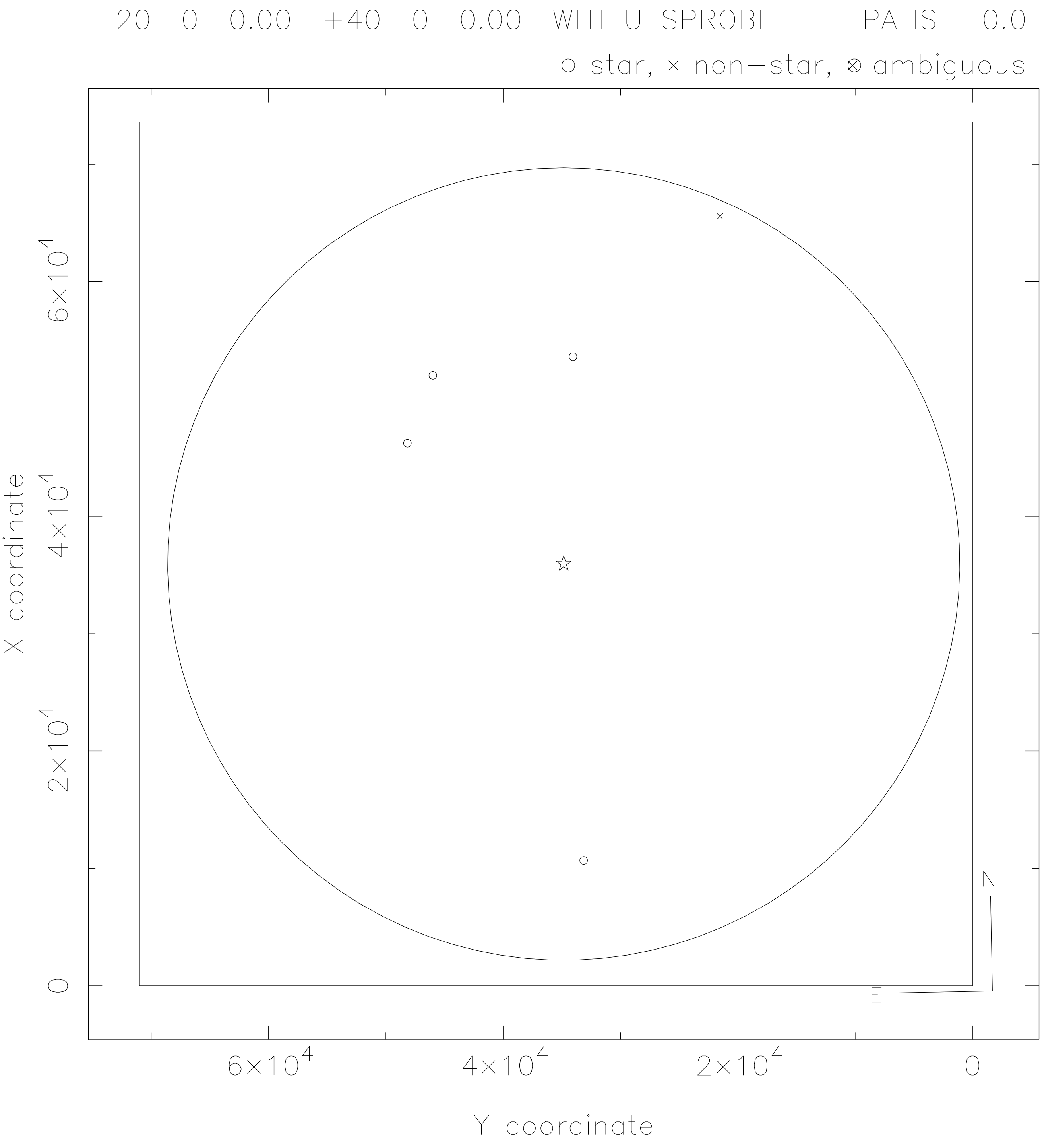


Figure 5: WHT UESPROBE configuration.

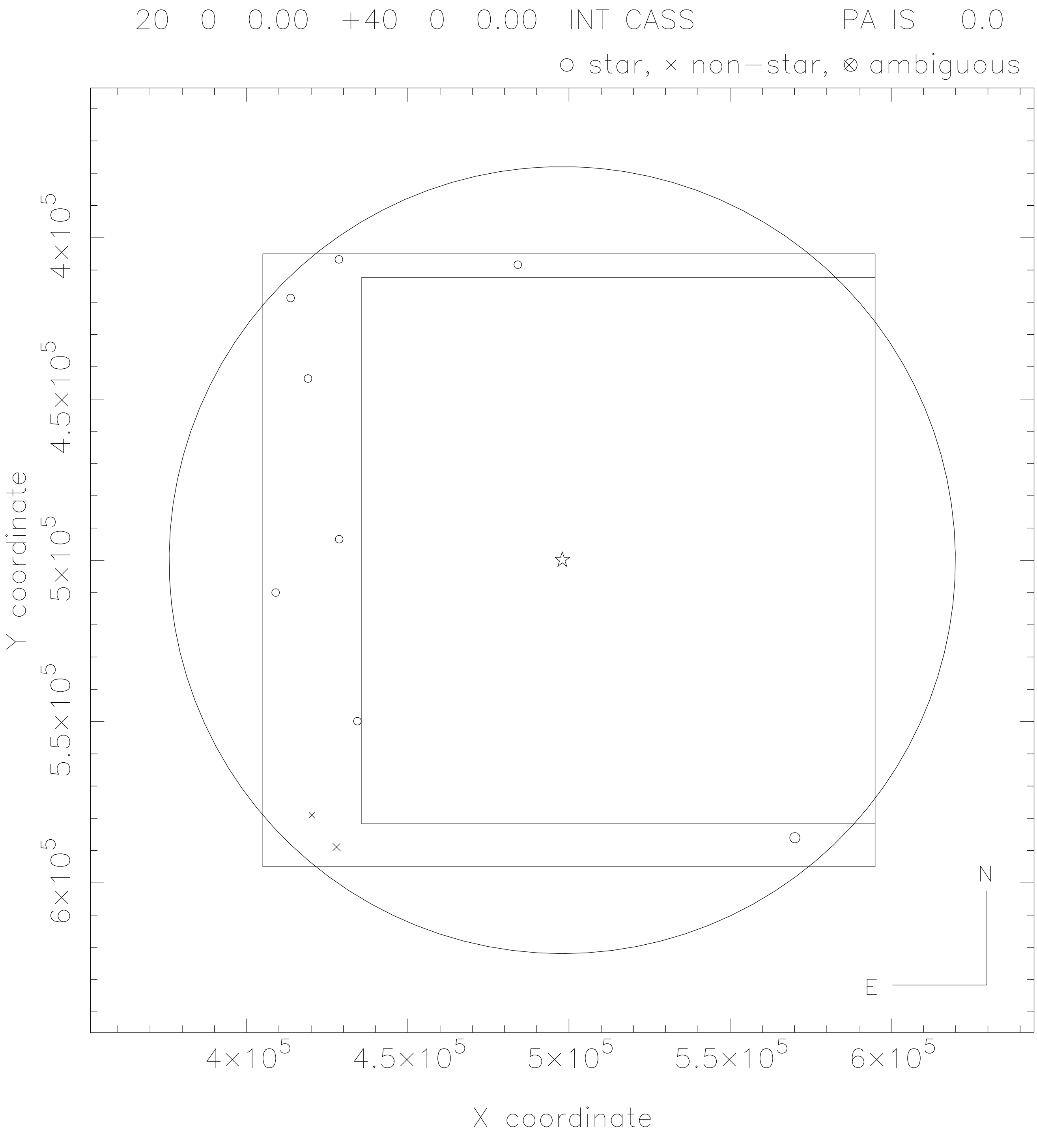


Figure 6: INT CASS configuration.

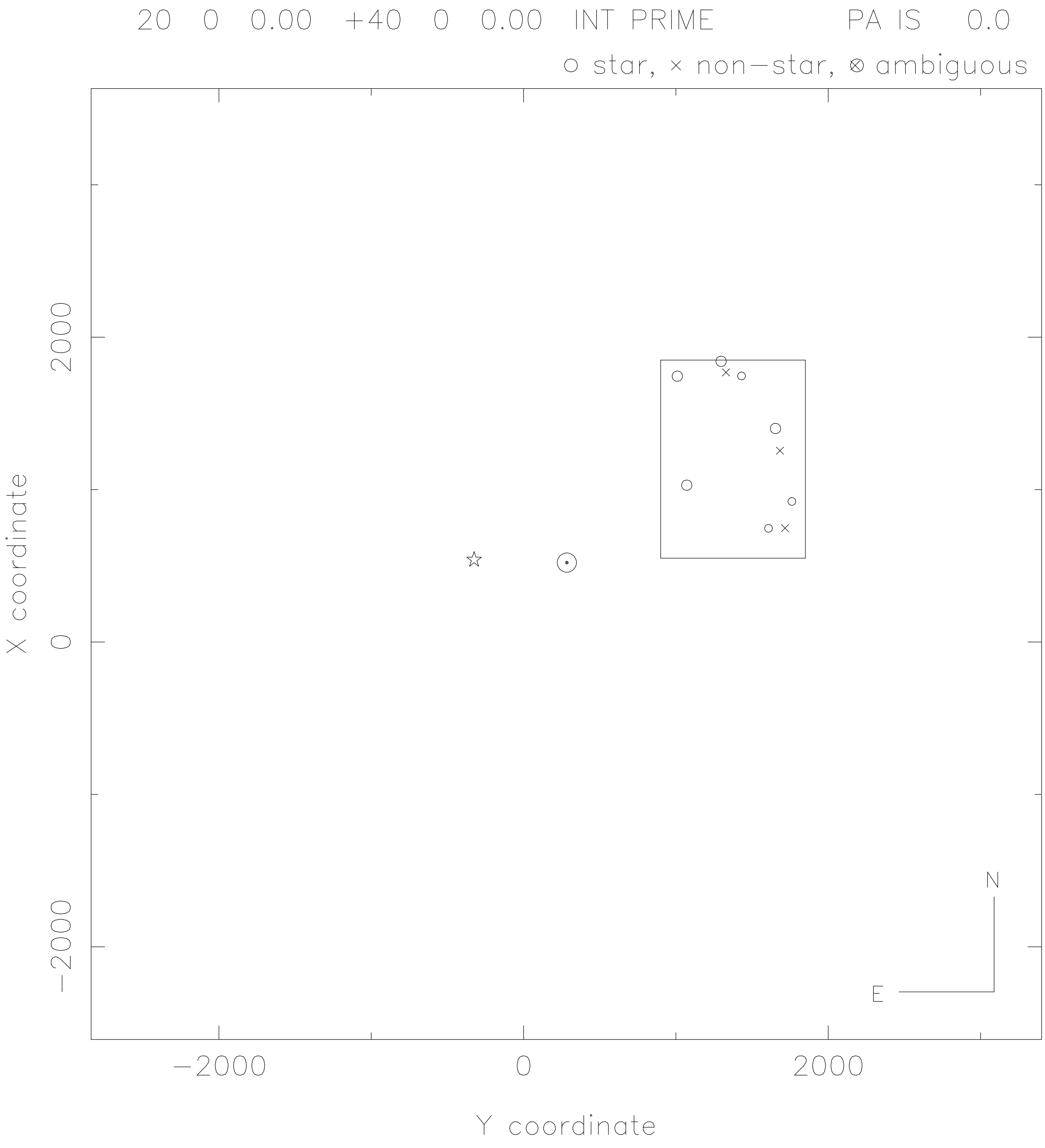


Figure 7: INT PRIME configuration.

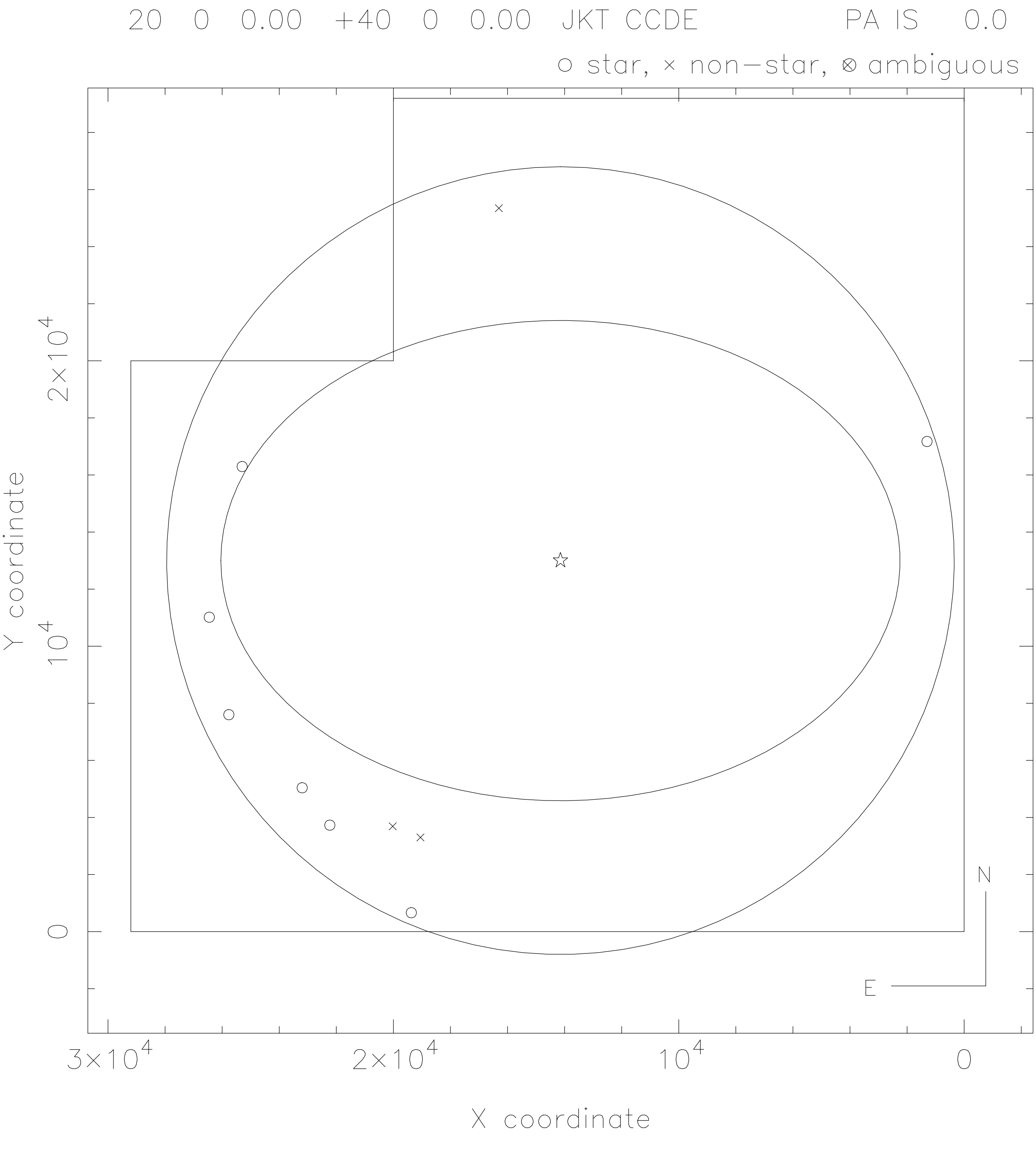


Figure 8: JKT CCDE configuration.

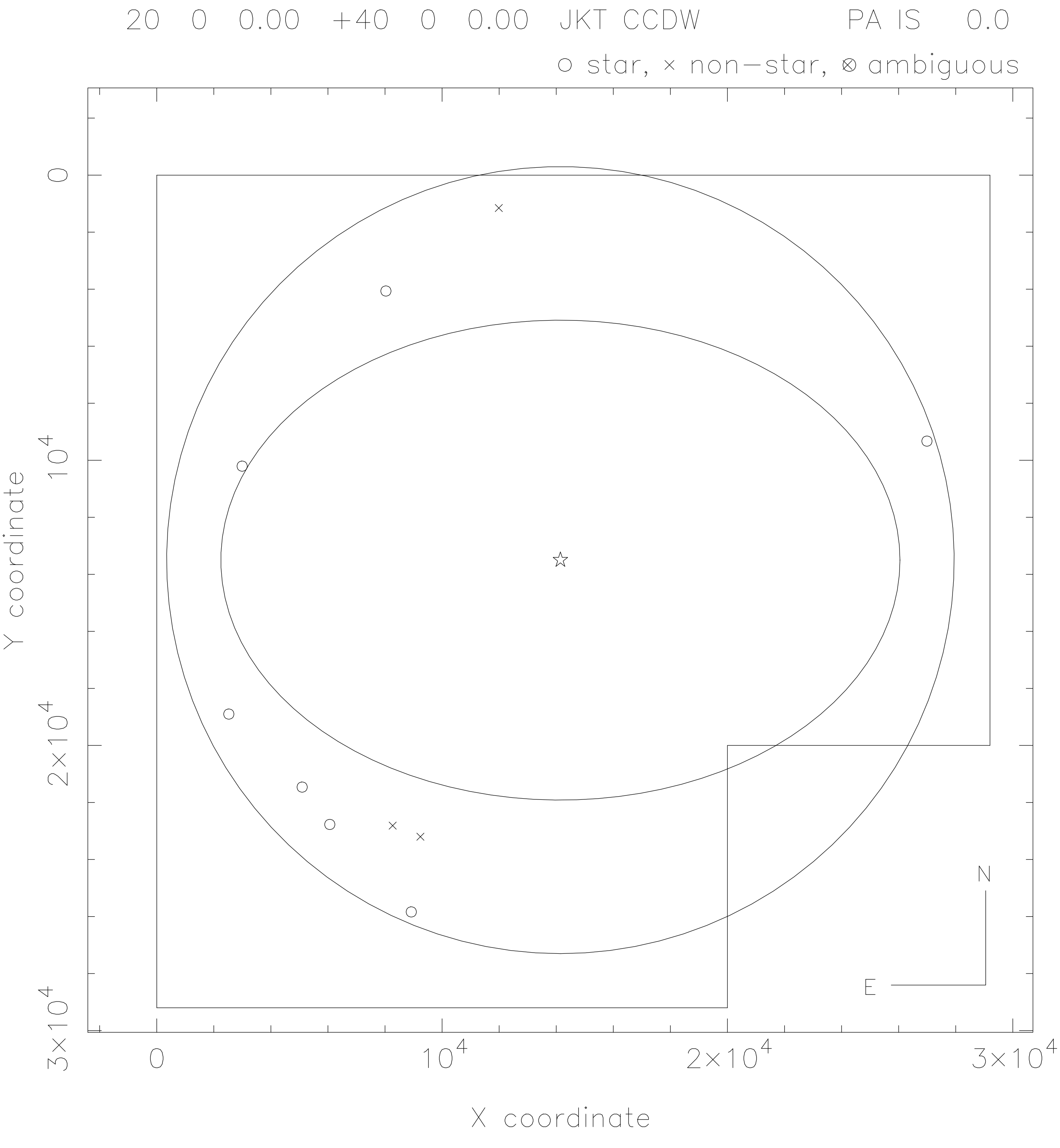


Figure 9: JKT CCDW configuration.

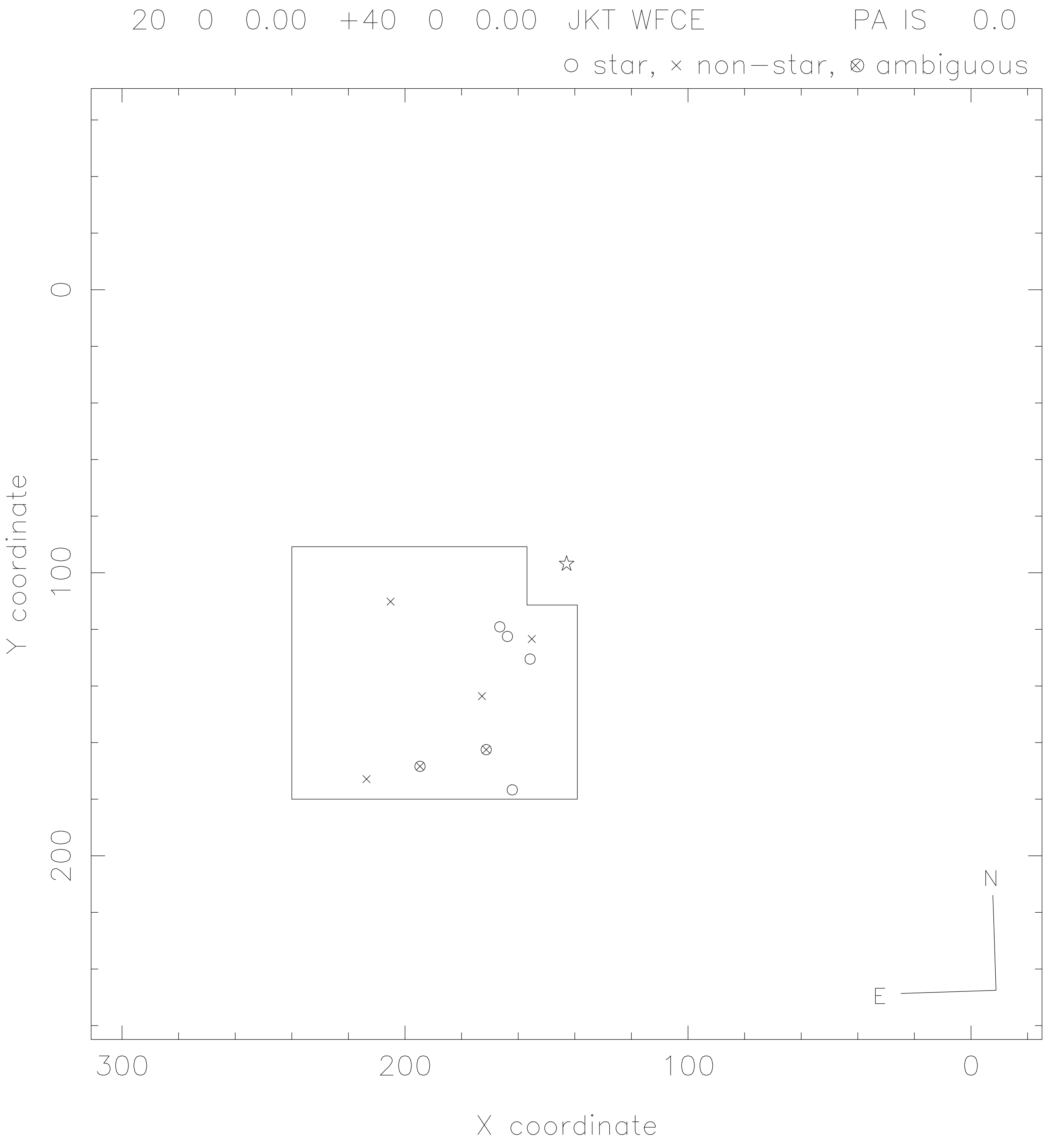


Figure 10: JKT WFCE configuration.

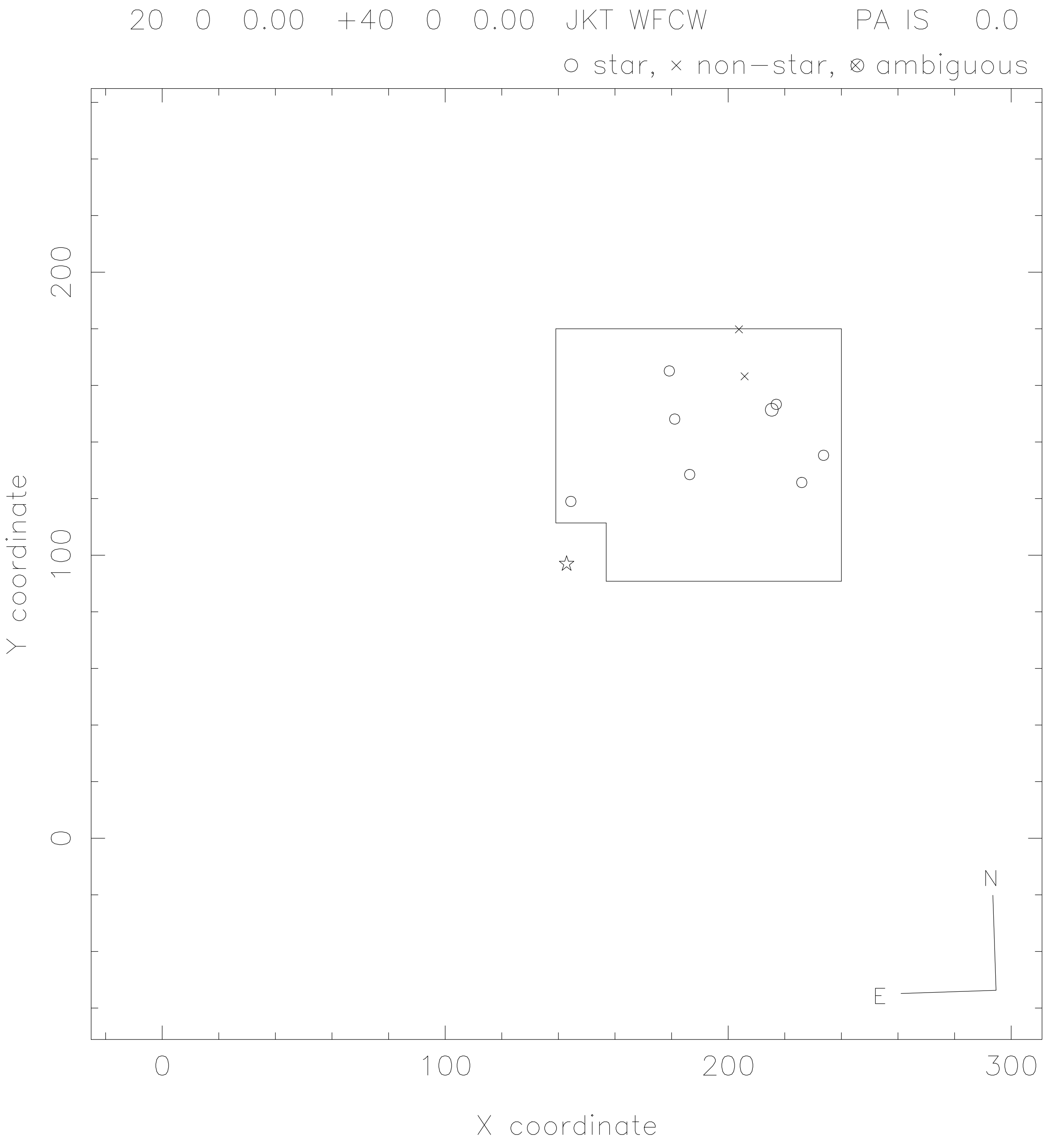


Figure 11: JKT WFCW configuration.

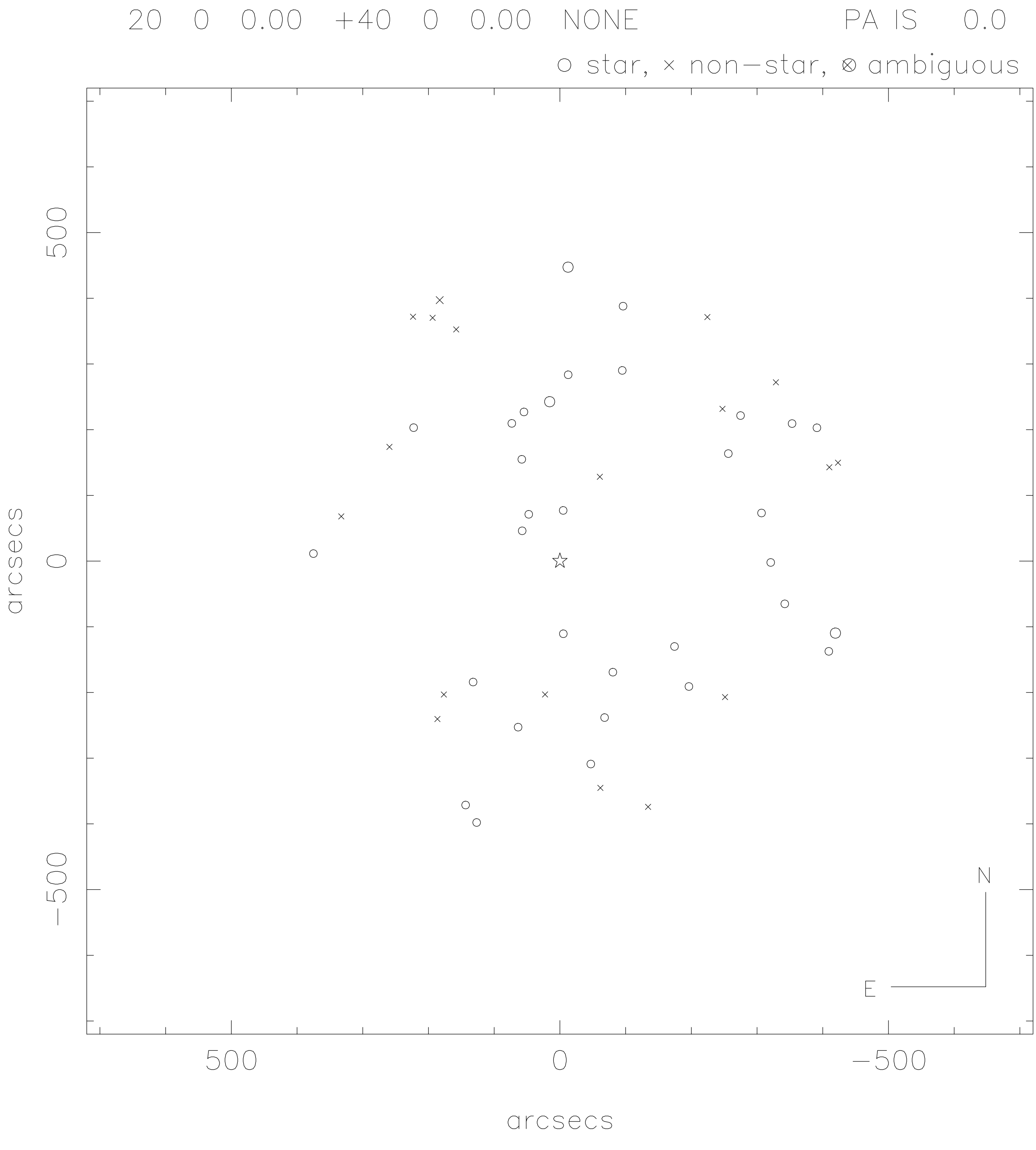


Figure 12: Configuration NONE.