Determining Coordinates from LRIS Images

A User's Help File For Version 3.1 of Program COORDINATES

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(Update of Original Version of Program COORDINATES from October 1994)

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1. Introduction

Extensive use of the LRIS over more than a decade has demonstrated that the geometry of the LRIS is stable with time, which is a prerequisity for the successful design and use of slitmasks. A series of reports beginning with 'The Spatial Distortion in the LRIS" by J.Cohen from Dec. 1994, and most recently "The Spatial Distortion in the LRIS – Addendum 5" by J. Cohen and P. Shopbell from Nov. 1996 discuss this issue and model the distortion pattern of the LRIS detector focal plane.

It is very useful to be able take a direct image of a field with LRIS and then to convert positions on the LRIS image into positions on the sky, both for use in identifying sources on these images and in using such sources in future slitmask designs. The temporal stability of LRIS ensures that this is possible, and The program COORDINATES allows you to accomplish this, i.e. to take a list of positions of objects on an LRIS image (i.e. (X,Y) on the CCD) and convert them to astrometric positions on the sky.

COORDINATES was originally coded by J. Cohen and D. Clowe in 1994, Since its original creation, there have been only minor updates of the program COORDINATES. These include incorporating into the code the change in scale from the installation of a new Dewar into LRIS-R in 1996 (version 2) and the ability to compile with LINUX.

Thus a major update of the program COORDINATES is long overdue. With the recent installation of the ADC on the Keck I Telescope, we were motivated to carry out a full astrometric study of both LRIS-B and LRIS-R and to update the program COORDINATES.

The program COORDINATES relies on fits to the distortion from linearity of the LRIS focal plane. Such deviations arise primarily in the instrument optics, particularly the red and blue cameras, whose design was made more difficult by the large field on a large telescope. The derivation of the fits used here is described in detail in the report by J. Cohen and W. Huang "LRIS Astrometry As Of April 2007", of August 2007.

2. History of Astrometric Fits to LRIS Detector Focal Plane

(This section is extracted from the report "LRIS Astrometry As Of April 2007", J. Cohen and W. Huang, August 2007.)

LRIS has had a series of detector upgrades and major instrument improvements since its original installation at Keck I in late 1993. J. Cohen carried out fairly regular astrometric monitoring from the original installation through to the dewar upgrade in 1996 (LRIS-R only at that time). But there was no systematic monitoring by J. Cohen (nor to her knowledge

by the Keck staff or anyone else) between 1996 and the present. This means that there was no astrometric fit for LRIS-B between the time the new mosaic CCD detector was installed in late 2001 and the present. There is no reason to suspect that the astrometric properties of LRIS-B have changed since the installation of the upgraded mosaic two CCD detector. More seriously, no fit at all is available for LRIS-B frames taken with the original bluside 2048x2048 CCD, i.e. those taken between the date of installation of the blue side of LRIS into the instrument and the date of the detector upgrade.

Unfortunately during the installation of LRIS-B there were some unintended changes that had to be made to the LRIS-R dewar, shutter, etc. Although there may have been a small change in the astrometric properties of the LRIS focal plane after the installation of LRIS-B, there was no astrometric check to LRIS-R between that time (roughly late 2001) and the spring of 2007.

COORDINATES currently contains 4 sets of fits. The first two are for LRIS-R only, and represent the original dewar and the upgraded dewar installed in 1996. Then there are the two current fits for both red and blue LRIS cameras with and without the ADC in the beam.

The current fits for LRIS-B are used for all LRIS-B images taken after the CCD mosaic was installed in LRIS-B. Earlier LRIS-B frames cannot be processed. The current set of fits are used for all LRIS-R images taken after 2006.0, while the 1996 fits are used for LRIS-R images taken between 1996.5 and 2006.0.

3.   Logic Flow of The Program COORDINATES

The following steps occur within the program:

1) read in the necessary data from the input file

2) subtract off the appropriate non-image pixels from (X,Y) for each object. This removes the pre-image pixels in X and pixels in Y. This has to be done because (1,1) on an image, once it is written to disk, includes these extra pixels, which are not really on the CCD, whereas internally within COORDINATES, pixel (1,1) is at the beginnig of the physical detector.

3) For LRIS-B only, transform (X,Y) on the CCD to take into account the geometry of the mosaic CCD detector. The details of this, which includes shifts and rotations of one of the two CCDs with respect to the other, are described in the document "LRIS Astrometry As Of April 2007" of August 2007 by J. Cohen and W. Huang.

4) apply the appropriate 3rd order (10 coefficient/axis) transformation to go from (X,Y) on the CCD to (X,Y) in arc-seconds on the sky. The origin of the coordinates here is the center of the field, i.e. the center of the CCD or CCD mosaic. The selection of which such fit is used was described in §2.

5) rotate the result of step 3 using the known position angle at which the LRIS observations were obtained to derive for each object its position in arc-sec North and East with respect to the center of the field.

6) apply a correction for atmospheric refraction

7) set the zero point of the coordinates (various ways to do this are discussed in more detail below).

8) derive the RA and Dec for each object of interest by combining the offsets and the centerfield position

9) write an output file suitable for use with AUTOSLIT. The center of the field as used in the first line of the AUTOSLIT input file is taken as the average of the RA and DEC for the set of objects. Depending on the location of the objects of interest within the LRIS image, this may be quite different from the center of the field of the image itself (i.e. the telescope pointing used for the observation).

COORDINATES uses a set of character parsing routines written by Drew Phillips of Lick Observatory as well as several routines from the SLALIB library written by Pat Wallace.

I suggest that before your LRIS run, you get COORDINATES running at your home institution, and try it out.

4. Modifications for COORDINATES Version 3.0

The motivation for updating program COORDINATES at the present time is the commissioning of the atmospheric dispersion compensator (ADC), which corrects the image of a star to be a point even when it is not at the zenith by compensating for atmospheric dispersion. Also LRIS-B was not installed at the time of the last major upgrade of COORDINATES; it is now included with this update.

Another major addition to the code made in version 3.0 is to incorporate a check of position angle as determined by the reference stars versus that commanded to the instrument rotator by the telescope drive and control system, i.e. that specified by the observer prior to the acquisition of a LRIS direct image.

There are a number of minor changes. For example, the format of the FITS header keyword for the date the observation was acquired ("DATE") was changed in 2000 to accomodate the new century. As many of these minor issues that were known to us as possible were fixed.

COORDINATES version 3.0 was released in August 2007. A problem was reported in Jan. 2008 in the part of the code that tunes up the position angle described in §VII. This problem is described in that section and is fixed in COORDINATES version 3.1, released in Feb. 2008.

5. The Input Data File

The necessary data for COORDINATES consists of the list of (X,Y) pixels on the CCD for the objects of interest whose astrometric positions you wish to determine. These values must be obtained using your favorite image analysis software on the LRIS image before you try to use COORDINATES. In addition the magnitudes of the objects, their priorities for multi-slit observation, and their names are desirable, although not mandatory.

We also need a set of parameters that describe the observation, such as the rotator position angle, the center field pointing RA and DEC, the epoch of that position, the elevation, etc. All of these parameters are contained in the header of the LRIS image file. Instead of requiring you to find them all and put them in a file, you are only asked to supply the name of the FITS image[1]. The program reads the FITS header of the LRIS-B or LRIS-R direct image to find the appropriate information.

At the present time (August 3, 2007) it is impossible to tell from the keywords in the headers of LRIS images whether or not the ADC is in use. Until the LRIS software is modified appropriately by Keck personnel so that the ADC position is contained in the FITS header the user will have to indicate whether or not the ADC is used in the COORDINATES input file. Thus the last section of the input file should contain the ADC status, with 1 representing the ADC in use, and 0 representing otherwise. The default, if this is not done, is to assume that that the ADC was used for all frames taken after the installation of the ADC. This section of the input file is optional, and if omitted, the ADC status will revert to the default value.

Note that if the ADC is in the beam, even if it is not in use (i.e. the prisms are not

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[1]There is no suport for Figaro files in Version 3 of COORDINATES. Only FITS files are supported. Earlier versions did provide such support.

rotating), perhaps to due mechanical problems, the astrometric fit must be that for when the ADC is in use.

If you have a number of stars with known high precision coordinates in the image, you can use them to determine the zero points in RA and DEC of the coordinates of the objects. These are called reference stars, and for them you need their (X,Y) positions in the LRIS image, their true coordinates, and the epoch of those coordinates. In many LRIS images, there may be no stars with accurately known coordinates. HST Guide Star Catalog stars can be used to set the zero point if no other source of known positions of stars is available. The USNO–B1.0 catalog of Monet et al or the 2MASS database can also be used for this purpose if the images of such bright stars are not overly saturated.

If you intend to use the position tuning option described in §7, at least 10 reference stars are required.

A typical input file is given below. The first line contains the name of the LRIS image. That is followed by the reference object data, one reference object per line, if there are any reference objects. Then comes the data for the objects. Note that (X,Y) CCD are floating point numbers. If you wish to omit an entry, the magnitude for example, type "" instead of a number. If an entry is omitted, the default values will be used. They are 2000.0 for epoch, 20.0 for magnitude, and 999 for priority (an integer).

The lines in the input file are parsed, and hence the entries do not have a fixed location or format, but must be in the correct order on the line. Additional information such as the star identification can be added to the end of each line. Object names are up to 10 characters long.

I am very greatful to Drew Phillips of Lick Observatory, who wrote the original version of this section of the code. Any errors in it are undoubtedly due to the extensive hacking I've done since 1995 on the code he gave me.

The default value for the maximum number of objects is set at 1000 and the maximum number of reference stars is set to 22. If you have exceed either of these limits, edit the source code, changing the parameter "max_obj", the maximum number of objects, or the parameter "max_ref" to a suitable value, and then recompile the program.

Here is an example of an input file for LRIS-B, with the ADC not in use.

lblue0062.fits
\REFERENCE

2390.988 2259.641	6 4 21.21 24 5 52.00 1950.0	3132 13.17 (1) NGC2158
2575.821 2253.299	6 4 23.04 24 5 52.80 1950.0	4108 13.38 (53) NGC2158
2700.064 2091.007	6 4 24.28 24 6 14.80 1950.0	1116 13.34 (58) NGC2158
1607.247 3307.301	6 4 12.38 24 3 30.10 1950.0	Q 13.38 (649) NGC2158
1875.744 2879.139	6 4 15.07 24 4 28.00 1950.0	3340 13.81 (765) NGC2158
1210.092 3272.965	6 4 08.47 24 3 35.50 1950.0	P 13.73 (4) NGC2158
1947.916 1143.739	6 4 15.92 24 8 23.30 1950.0	2357 14.69 (202) NGC2158
3382.999 1328.677	6 4 31.02 24 7 57.70 1950.0	O 15.23 (2) NGC2158
3068.192 2232.992	6 4 27.91 24 5 55.40 1950.0	1137 14.93 (351) NGC2158
3014.368 2722.975	6 4 27.37 24 4 48.80 1950.0	4271 14.18 (562) NGC2158

\OBJECTS

1476.045 1196.458	14.43 100	2416
3813.798 3244.629	13.76 100	4512
2143.985 2266.591	14.91 100	14
2455.289 2299.182	15.14 100	3127
2660.984 2169.618	15.17 100	4104
2344.389 2178.775	14.62 100	87
2939.866 1397.328	14.70 100	1336
3689.133 1260.726	15.61 100	K

\ADC

0   (0 = no ADC, 1 = Yes ADC)

\END

6. Setting the Zero Point of the Coordinates

Normally there are one or more reference stars with known astrometric positions within a particular LRIS image. These can be used to determine the zero point of the coordinates. The solution for the reference stars is printed out, with the individual values of calculated position versus true coordinates in RA and DEC for each reference star. If there are 2 or more reference stars, the mean and sigma for RA and DEC zero point offsets are also printed out. If you like that solution, you can specify that it be used. You can choose instead to retreat to the centerfield telescope pointing. If it looks like there is one discrepant reference star (check the list of differences in RA and Dec typed on the screen and look for big outliers), and you have at least 4 reference stars, you can eliminate one of the reference stars and redo the fit. (You can not eliminate more than one reference star.)

A potential problem is that the rotator position angle given in the image header may not be exactly correct because of small initializing errors in the Keck instrument rotator. Errors of less than $\sim 0.1°$ in rotation over the LRIS imaging field can be ignored. Larger errors will lead to a noticable rotation between the reference star astrometric coordinates and the (X,Y) of the reference stars, and in such cases the position angle needs to be adjusted. See §7 for a detailed description of the procedure.

If there are no stars with known accurate coordinates in the LRIS image, then there is only one way to determine the zero point, namely to adopt the RA, Dec, and epoch of the center of the field from the telescope drive and control system given in the image header. In this case one hopes that the telescope pointing is correct relative to the celestial known astrometric frame. If the only purpose of the coordinates of the set of objects is to design multi-slits, this should be accurate enough, given that small errors in the RA and Dec of the field center can be removed through the slit mask alignment procedure. Using stars from 2MASS or the USNO-B1.0 Survey with coordinates from the relevant database may not be feasible in many cases as such bright stars will be saturated on long exposure Keck/LRIS images; the database of the Digital Sky Survey extends to fainter magnitudes.

7. Tuning Up The Position Angle

Position angle discrepancies Δ(PA) between the PA as determined from the positions of stars on the LRIS image and that of the instrument rotator on the Keck I Telescope will occur if the Dewar rotation on either the red or blue side of LRIS is not correctly aligned so that the central column in the red side detector (central row on the LRIS-B CCD mosaic) is parallel to the Dec axis when the commanded position angle is 0.0°. In the past, this

alignment for LRIS-R was generally correct such that $-0.15 < \Delta(PA) < 0.15°$. Mechanical or electronic problems with the LRIS instrument rotator can also give rise to position angle discrepancies.

A $\Delta(PA)$ of 0.15° will cause an error in the output position inferred from the program COORDINATES of an object which is located in the extreme corner of the LRIS imaging field of ∼0.6 arcsec. To avoid such errors, the current version of the program COORDINATES has an option to determine the position angle directly from the reference stars with known astrometric coordinates detected on a LRIS image.

A minimum of 10 reference stars with high quality coordinates on the sky is required in order to use this new feature. Two independent values of position angle from the reference stars are calculated; they appear in the screen output together with their mean. If the mean value disagrees with that from the Keck I Telescope drive and control system as given by the FITS keyword ROTPOSN (where ROTPOSN = PA $-90°$) read from the header of the LRIS direct image by more than the parameter "pa_tol", currently set to 0.15°, then you are given a chance to redo the calculations using the PA found from the reference stars. This is the recommended way to use program COORDINATES provided that sufficient reference stars are available.

For LRIS-B you **must** use the position angle tuning mode, i.e. you must input at least 10 reference stars. This is because the current rotational alignment of the LRIS-B Dewar as of early spring 2007 is incorrect by ∼ 0.4°. At present the rotational alignment of the LRIS-R Dewar appears to be correct to within ∼ 0.1°. However, this is no guarantee of future accuracy as the rotational alignment may change any time one of the two Dewars is removed and then reinstalled in the instrument. It is therefore highly recommended that you use the position angle tuning mode for LRIS-R as well.

It is useful to order the reference stars in the input by increasing $X(CCD)$ or $Y(CCD)$. This will make it easy to see the need for a small position angle check by looking at the section of the screen output called "Results of reference star offsets in arc-sec". A systematic variation of the "Delta RA" or "Delta DEC" values across the detector is a symptom of the need for tuning the position angle. The variation of these across the field with the correct PA should be less than 0.2 arcsec.

In Jan. 2008 Marc Rafelski reported a case of an LRIS-B image he had obtained for which the position angle tuning section of the code COORDINATES version 3.0 failed. This was traced to an issue of determining the correct quadrant for the position angle. All the 14 images used in the testing of the code in late 2007 did function correctly, but by chance did not cover the full set of possible quadrants for the position angle. The code has been fixed

in version 3.1 by adding a few lines to the subroutine solve_matrix in which this correction is calculated.

8. The Output Files

The output of program COORDINATES seen on the keyboard is somewhat more verbose than in previous versions. In particular, a list is given of the values for parameters read from the FITS keywords in the image header. After that, the keyboard output is fairly similiar to that of previous versions, until the position angle check is carried out, if sufficient reference stars are supplied for this to occur. A few new lines of output follow giving two independent values for the solved PA and their mean, as well as the solution for the RA and Dec offset of the centerfield from that read from the FITS header keywords. The latter are denoted "delta X,Y of centerfield" and are in arcsec.

There are two output files. The first, "coordinates.list", is a listing of the final coordinates for all the objects in a format suitable for use as a input file into the LRIS slit-mask assignment program Autoslit. The second is "arcsec.list". This file, after giving some information about the input list and results of intermediate calculations, gives offsets in arc-sec in RA and Dec with respect to the center of the field before any atmospheric refraction corrections are applied. The beginning of the "coordinates.list" output file corresponding to the input file listed above is given below. This is the list after tuning the position angle. The centerfield position is the average of the RA and Dec for all the objects. The equinox is the date of the LRIS image. The last two entries on each object line are set to 0.0; they are for the object's proper motion, if known.

```
        CENTER 9999 0.00      6 4 22.9898 +24 6 8.1840 1950.0 2007.2     0.0 0.0
2416      100 14.43      6 4 11.2738 +24 8 16.5620      1950.0 2007.2     0.0 0.0
4512      100 13.76      6 4 35.2223 +24 3 38.3217      1950.0 2007.2     0.0 0.0
14        100 14.91      6 4 17.7734 +24 5 50.9583      1950.0 2007.2     0.0 0.0
```

Here is the beginning of the corresponding "arcsec.list" output file:

LRIS-Blue used here

Reference stars: delta(RA), delta(Dec) (arc-sec)
with respect to the center of the field.
No atmospheric refraction correction applied.

```
1      25.65 -28.19
```

```
2      50.71 -27.26
3      67.49 -5.17
4      -94.37 -170.88
5      -57.91 -112.83
6      -148.11 -165.93
7      -47.77 122.54
8      159.08 98.31
9      117.37 -24.25
10      110.29 -90.84
```

Objects now:

```
1      -111.38 115.40 2416
2      218.25 -160.64 4512
3      -21.44 -29.59 (14)
```

9.   Caveats

Here are some caveats about COORDINATES:

The maximum number of reference stars with known coordinates is 22.

The maximum number of objects with unknown coordinates is 1000.

At least 10 reference stars are required for position angle tuning to be enabled.

In this version, the epoch of all the reference stars must be the same. No precession is done internally.

It is assumed that a 4 amplifier readout is used for LRIS-Blue.

It is assumed that the direct image from LRIS was read out without binning of pixels.

See the list of available distortion fits and which ones are used for direct images taken at different times discussed in §2 for details.

Fits have been carried out using specific filters. As far as we know, there are no measurable differences for the distortion pattern between any of the current LRIS filters.

10.   How to Compile COORDINATES

The program COORDINATES is written in Fortran and was originally coded as a FIGARO command, but in its present version is is self contained. It does not use any subroutines or libraries that are not appended to the main routine[2]. COORDINATES has as input an ascii file and a LRIS image stored as a FITS file. The two output files are ascii files. There is no graphical input or output.

The compilation of Version 3 is simple,

f77 –o coordinates coordinates.f

COORDINATES must be run in the directory in which the input file and the FITS direct image are located, otherwise the full file name may be longer than the length of the character string allocated within the program (set to 50 characters).

The COORDINATES tar archive also contains an example input file, and a small Fits image that can be used to try to run it, in case you don't already have any LRIS direct images in hand.

To compile COORDINATES under LINUX, two small code changes must be made, both in the main program.

(1) The variable REC_LEN must be set to 20 instead of the current value of 80.

(2) The line of code which follows,

    if (vstring(1:1).eq. '\\') then

must be replaced by:

    if (vstring(1:1).eq. '\') then

A typical compile command line under LINUX is:

    ifort -O2 -i-static -o coordinates coordinates.f

This compilation is done using the Intel® Fortran compiler (ifort) under Linux. The more commonly used free Fortran compiler (g77) may not compile the code.

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[2]For historical reasons dummy versions of various FIGARO routines in the form of subroutines are appended to the program. These were formerly collected into a file called fake_dta_fig.f and can be ignored. The code for these subroutines can be deleted if desired. If you do this you must edit out the section handling Figaro files in the main program.

10.1.   Porting to Other Fortran Compilers

Other Fortran compilers may not support some of the functions used by COORDI-NATES. In particular, note that the code uses SIND and COSD, which are the sine and cosine of an angle expressed in degrees. The code also uses ATAND, the arc tangent of an angle expressed in degrees. Some compilers may only support those functions for angles expressed in radians.

The code also uses the function ENCODE to express numbers as character strings. Some compilers may not support this feature, which can be rewritten as suitable WRITE statements.

11.   Converting Offsets to Coordinates

If you have a list of offsets in arc-sec East and North of some known position, and you need to prepare a file for Autoslit, a program called "offset_list" can be used. This program uses many of the same routines as does the program COORDINATES and is basically a modification of it.

The first line of the input file contains the field center RA and the second contains the field center Dec. Subsequent lines are offsets of objects in seconds of arc in RA and Dec from the field center, followed by an integer object identification code. The output is a file with coordinates for each object.

Again the maximum number of objects is 1000, but it can raised by changing the value of the parameter "max_ob" in the source code and re-compiling the program.

The compilation is straightforward,

f77 -o offset_list offset_list.f

This code is independent of the modifications made for COORDINATES version 3.0.

12.   The TAR Archive for COORDINATES Version 3.1

The tar archive for COORDINATES Version 3.1 is available on the LRIS page at the Keck web site. It is also available from J. Cohen's home page, www.astro.caltech.edu/ jlc. The archive contains the source file for coordinates, this help file, the Aug. 2007 LRIS astrometry report, and the code for calculating coordinates from offsets. It contains a sample

input file, which has the results of testing with selected screen output edited in after the line "END" in the input file. A short version of the FITS file, containing the full header structure, is also included so that the user can run a test case using this image.

In J.Cohen's workstation, these are files:

/home/gringo/jlc/lris/coordinates/april2007/coordintes_ver3.1_14feb2008.f
/home/gringo/jlc/lris/coordinates/offset_list.f
This file = /home/gringo/jlc/lris/coordinates/help_docs/coordinates_version3.1.pdf
/home/gringo/jlc/lris/coordinates/april2007/report_spring2007.pdf
/home/gringo/jlc/lris/coordinates/april2007/lblue0062_small.input
/home/gringo/jlc/lris/coordinates/april2007/lblue0062_small.fits