Stellar Locus Regression
User Manual

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Contents

Chapter 1

Introduction

Stellar Locus Regression (SLR) is a method of directly adjusting the instrumental broadband optical colors of stars to bring them into accord with a universal stellar color-color locus, producing accurately calibrated colors for both stars and galaxies. This is achieved without first establishing individual zero-points for each passband, and can be performed in real-time at the telescope. In High et al. (2009) the authors demonstrated how SLR naturally makes one wholesale correction for differences in instrumental response, for atmospheric transparency, for atmospheric extinction, and for Galactic extinction. We are offering open-source access to our IDL routines, validated and verified for the implementation of this technique.

Figure 1.1 schematically outlines the technique and Figure 1.2 shows the effect of using SLR on uncalibrated data. The core IDL tools we have developed are available at http://stellar-locus-regression.googlecode.com.
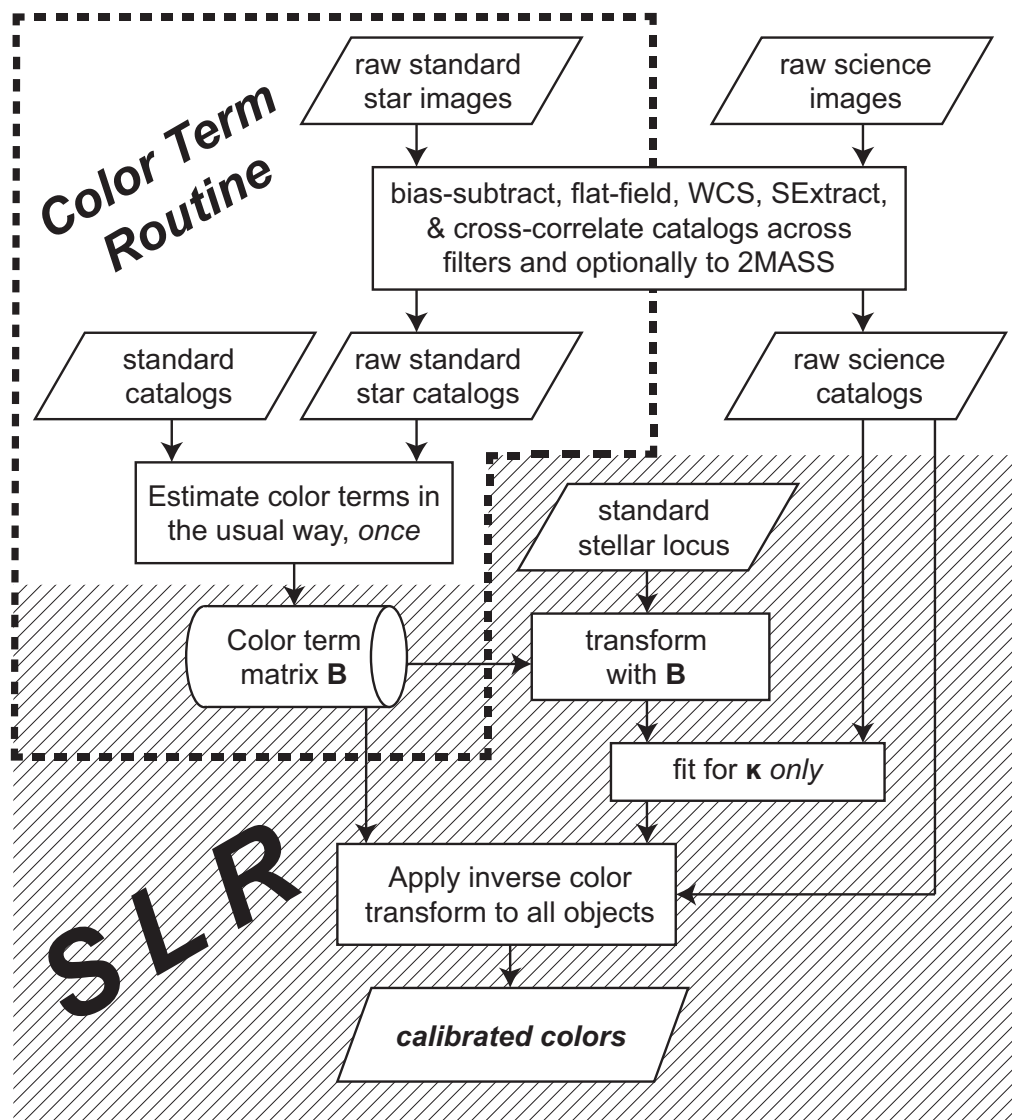
Figure 1.1: SLR flow chart for calibrating colors. The hashed region denotes parts of the algorithm that are unique to SLR, while the non-shaded region shows steps that are more traditional. The dotted region denotes the color term estimation routine, which need only be performed once per detector.
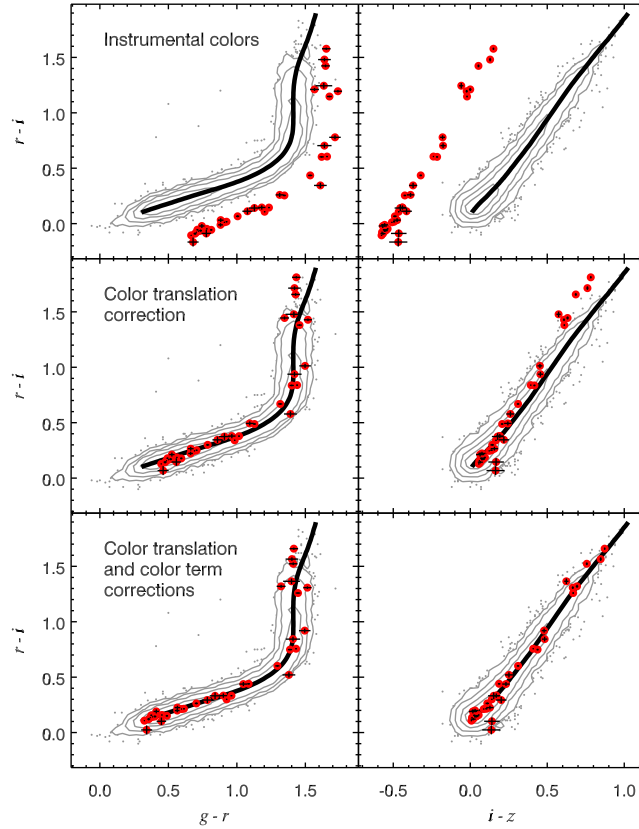
Figure 1.2: An illustration of Stellar Locus Regression (SLR). Colors are plotted on the SDSS photometric system. All panels show the standard stellar locus (black line and gray density contours), reproduced from Covey et al. (2007). Red points are stellar colors obtained from a Source Extractor analysis of flat-fielded Magellan 6.5 m IMACS images. *Top panels:* The instrumental IMACS colors are plotted, with a clear mismatch between them and the standard locus. *Middle panels:* SLR is performed with only a common translation vector applied to the instrumental colors. Note the color-dependent discrepancies in the upper right portions of the central panels. By way of example, the vectors show the expected direction and magnitude of extinction by Galactic dust ($A_r = 0.2$) and the atmosphere (1.3 airmasses). *Bottom panels:* Color terms are measured from a single observation of a field containing standard stars. Fixing these color terms, a new best-fit translation is determined, which brings the observed colors onto the SDSS-calibrated color system, as defined by the stellar locus. This SLR analysis, when the corrections are then applied to all objects in the photometric catalog, allows us to rapidly obtain highly accurate colors on the SDSS system, directly from flat-fielded data, with a single correction step that accounts for atmospheric extinction, Galactic extinction and instrumental response differences.

Chapter 2

Quick Start

1. Download the SLR code.

2. Install and set up the Goddard astronomy IDL libraries, idlutils, and the Markwardt IDL libraries.

3. Download the stellar locus data of Covey et al. (2007) and put them in a directory <data-dir>/covey.

4. Set environment variables (here in tcsh):

```
% setenv SLR_INSTALL <install-dir>/slr-v2.1
% setenv SLR_DATA <data-dir>
% setenv PATH {$PATH}:$SLR_INSTALL/bin
```

5. Verify your installation (see §3.5):

```
% cd $SLR_INSTALL/example_data
% slr.csh low_reddening.ctab low_reddening.slr.ctab
% slr.csh high_reddening.ctab high_reddening.slr.ctab
% idl
IDL> slr_demo
IDL> slr_docs
```

Chapter 3

Installation

3.1 Download

First, go get the latest version 2 download at http://stellar-locus-regression.googlecode.com. Untar it with

```
tar xzvf slr-v2.1.tar.gz
```

Put the package in some directory <install-dir>. This can be /usr/local/idllibraries or $HOME or whatever you prefer. The package root directory will then be <install-dir>/slr-v2.1.

Version 2.1 and higher require only IDL, and do not require Analyst. Version 2.0 and prior require IDL with the Analyst add-on, which costs extra.

3.2 IDL Libraries

You'll need these idl libraries:

1. idlutils from http://www.astro.princeton.edu/~schlegel/code.html. Any installation procedure will do, but you probably want the latest idlutils tar file, e.g. idlutils-v5_3_0.tar.

2. *The latest* Goddard astro libraries from http://idlastro.gsfc.nasa.gov. Note that idlutils comes with an old version of the Goddard libraries that is *incompatible with this implementation of SLR*. Get the latest one.

3. Markwardt libraries from http://www.physics.wisc.edu/~craigm/idl. You want cmtotal.tar.gz.

Put them in your typical IDL directory. For example, use a directory you can remember <pro-dir>, like /usr/local/idllibraries.

Don't forget to add them to your IDL_PATH with shell startup file entries similar to:

```
% export IDL_PATH=$IDL_PATH:+<pro-dir>/idlutils:+<pro-dir>/markwardt
```

in bash or

```
% setenv IDL_PATH {$IDL_PATH}:+<pro-dir>/idlutils:+<pro-dir>/markwardt
```

in tcsh.

Of course all of this assumes you have properly initialized the IDL_PATH, for example in tcsh:

```
% setenv IDL_BIN /usr/local/itt/idl/bin
% source $IDL_BIN/idl_setup
% setenv IDL_PATH <IDL_DEFAULT>
```

3.3   Standard Stellar Locus

SLR gets the standard stellar locus data from the directory $SLR_DATA/covey.

Go get Kevin Covey's stellar locus data, which he makes available on his own website. You'll need the stellar data
http://www.cfa.harvard.edu/~kcovey/research/superclean.fits
and the median locus line data:
http://www.cfa.harvard.edu/~kcovey/research/medianlocus.tbl
Put them in some directory <data-dir>/covey. We suggest putting them in the <install-dir>/example_data/covey subdirectory of your installation. Set SLR_DATA. If you used our suggestion, then you would issue

```
% setenv SLR_DATA <install-dir>/example_data
```

The directory $SLR_DATA/covey must exist and contain medianlocus.tbl and superclean.fits.

3.4   Environment Variables

Now set some environment variables in your cshrc or bashrc file. Remember to insert the appropriate directories. Example is for tcsh:

```
% setenv SLR_INSTALL <install-dir>/slr-v1.0
% setenv SLR_DATA <data-dir>
% setenv IDL_PATH {$IDL_PATH}:+$SLR_INSTALL/pro
% setenv PATH {$PATH}:SLR_INSTALL/bin
```

We've used the example directories mentioned in this install file. This should let the demo (see below) work properly. If you made different choices, you must make sure these environment variables reflect them.

3.5 Verifying Your Installation

If everything is set up properly, you can run the demo by invoking idl and running:

```
% cd $SLR_INSTALL/example_Data
% idl
IDL> slr_demo
```

The first time you run it, it will take some time (it's reformatting the data to an optimal, IDL-friendly format). It will be faster the second time.

The demo will run SLR on the example Sloan Digital Sky Survey data that comes with your installation. You should see plots of the stellar locus (you must hit enter to continue), a visualization of the numerical regression, and results for best-fit parameters printed to screen.

3.5.1 Running slr.csh Using Example Data

Go to the directory $SLR_INSTALL/example_data, then issue at the commandline (you have to be in same directory as your input file):

```
% cd $SLR_INSTALL/example_data
% slr.csh low_reddening.ctab low_reddening.slr.ctab
```

This will run SLR on the example colortable we provided (first argument), and output SLR calibrations to another colortable (second argument). The output colortable is equal to the input colortable but with the additional appended columns GR, RI, etc, which are the calibrated colors g - r, r - i. Estimated color errors, with bootstrap errors added in quadrature, are also output.

Browse the log file that SLR generates, in this case lowext_stars3_fwhigh.slr. This contains the color calibrations with bootstrap errors.

If that works then you should also be able to run

```
% cd $SLR_INSTALL/example_data
% slr.csh high_reddening.ctab high_reddening.slr.ctab
```

3.5.2 Running slr.csh with Your Own Data

To run SLR on your own data, issue the command (again, in the same directory as your input file):

```
% slr.csh input.ctab output.slr.ctab <config-file>
```

The configuration file can optionally be specified. If none is given, then the default file is used, $SLR_INSTALL/config/default.config.

This has the same output as the previous section. The requirements for the input file are as follows:

1. The first line is a description of the columns followed by a # for example:

```
# ID RA Dec type tmixed g g_err r r_err i i_err z z_err ...
```

where the ellipsis ... means there are more acceptable columns you can
specify. See §5 for a full description of the "colortable".

Chapter 4

Conventions

Define mathematical conventions.
   Assumptions.
   Glossary of terms.

Chapter 5

The Colortable

SLR reads data from and outputs results to what we call *colortables*. These are simple ascii files with a single header that starts with `#` and one row of data per object. The header values are columns names, and each row corresponds to one object. Here's a simple (truncated) example:

```
# ID         RA         Dec type tmixed        g  g_err        r  r_err ...
    0 254.00649  34.33696    1       0  20.672  0.025  19.795  0.018 ...
    1 254.05269  34.36260    1       0  16.426  0.004  15.849  0.004 ...
    2 254.02026  34.34031    1       0  23.670  0.283  21.607  0.072 ...
    3 254.00436  34.36294    1       0  20.381  0.021  19.012  0.011 ...
    4 254.02655  34.34580    1       0  18.203  0.006  17.059  0.005 ...
...
```

The ellipses ... here mean there can be additional columns and rows.

The data must be fixed width. The header strings however need not be fixed width. Empty or erroneous data must generically be represented by the character "-" (dash).

While there is a minimal subset of columns that must be present for SLR to work properly, it is acceptable for there to be extra columns that the code doesn't formally recognize or use. This way you can carry extra information in the colortable, such as `ID` in the example above.

Table 5.1 lists the columns that are recognized and used by the SLR code.

Table 5.1: Colortable columns.

Column name	Type	Unit	Required?	Description
ID	*string*	J2000 deg	Yes	Object identifier.
RA	*float*	J2000 deg	Yes	Right ascension.
Dec	*float*	J2000 deg	Yes	Declination.
type	*integer*		Yes	$1 = $ star, $3 = $ galaxy.
Continued on next page...				

Table 5.1 continued: Colortable columns.

Column name	Type	Unit	Required?	Description
tmixed	*boolean*		Yes	Is the `type` ambiguous between the bands?
U	*float*	mag	No	U-band magnitude.
U_err	*float*	mag	If U present	Uncertainty in Johnson U-band magnitude.
B	*float*	mag	No	B-band magnitude.
B_err	*float*	mag	If B present	Uncertainty in Johnson B-band magnitude.
V	*float*	mag	No	V-band magnitude.
V_err	*float*	mag	If V present	Uncertainty in Johnson V-band magnitude.
R	*float*	mag	No	R-band magnitude.
R_err	*float*	mag	If R present	Uncertainty in Johnson R-band magnitude.
I	*float*	mag	No	I-band magnitude.
I_err	*float*	mag	If I present	Uncertainty in Johnson I-band magnitude.
u	*float*	mag	No	u-band magnitude.
u_err	*float*	mag	If u present	Uncertainty in SDSS u-band magnitude.
g	*float*	mag	No	g-band magnitude.
g_err	*float*	mag	If g present	Uncertainty in SDSS g-band magnitude.
r	*float*	mag	No	r-band magnitude.
r_err	*float*	mag	If r present	Uncertainty in SDSS r-band magnitude.
i	*float*	mag	No	i-band magnitude.
i_err	*float*	mag	If i present	Uncertainty in SDSS i-band magnitude.
z	*float*	mag	No	z-band magnitude.
z_err	*float*	mag	If z present	Uncertainty in SDSS z-band magnitude.
J	*float*	mag	No	J-band magnitude.
J_err	*float*	mag	If J present	Uncertainty in SDSS J-band magnitude.
H	*float*	mag	No	H-band magnitude.
H_err	*float*	mag	If H present	Uncertainty in SDSS H-band magnitude.
K	*float*	mag	No	K-band magnitude.
K_err	*float*	mag	If K present	Uncertainty in SDSS K-band magnitude.

Chapter 6

Configuration Parameters

SLR reads ascii configuration files that the user can edit. Comments can be used with the character `#`. There must be at least one space between the paramter name and its value. Arrays (vectors) are comma-separated lists; there must be no spaces in such lists. Each parameter in the config file must have a corresponding value next to it. There can be no empty fields. All parameters must be present in the file.

Table 6.1 describes all configuration paramaters.

Table 6.1: Configuration parameters.

Parameter	Type	Description
Colors to calibrate		
`colors2calibrate`	*string array*	Colors to be calibrate by SLR. Comma separated list, eg, `gr,ri,iz,zJ`
`kappa_fix`	*boolean array*	Fix κ? There must be one entry for each `colors2calibrate`. Can be mixed, eg, `1,0,0,0`.
`kappa_guess`	*float array*	*Initial* values of κ for the fitting routine whenever `kappa_fix` is 0, or *fixed* values of κ whenever `kappa_fix` is 1. In magnitudes. There must be one entry for each `colors2calibrate`.
`kappa_guess_err`	*float array*	Values of errors for κ, used when not bootstrapping or when only transforming the colors. In magnitudes.

Continued on next page...

Table 6.1 continued: Configuration parameters.

Parameter	Type	Description
kappa_guess_range	*float array*	Range of acceptable values of κ, used by the fitting routine. In magnitudes. There must be one entry for each colors2calibrate.
Color terms		
colorterms	*float array*	Color terms to use.
colortermbands	*string array*	Comma separated list of the bands that use the color terms. If none, then color terms are not used.
colormult	*string array*	Comma separated list of the colors that multiply the colorterms.
Program behavior		
transform_only	*boolean*	If yes, then don't do regression and just calibrate the data using the input κ and colorterms. If no, fit for κ and then perform the color transformation.
force	*boolean*	Force a re-read of ascii data? If not, then read from IDL .sav files if they exist.
verbose	*integer*	Verbosity level, 0, 1, or 2.
plot	*boolean*	
postscript	*boolean*	Write figures to postscript files instead of to screen? plot must also be set.
interactive	*boolean*	Prompt user for response periodically?
animate_regression	*boolean*	Plot each iteration of the fit?
weighted_residual	*boolean*	Use the error-weighted residual?
nbootstrap	*integer*	Number of bootstraps to perform.
debug	*boolean*	Debug mode?
Limits and conditions on the data		

Continued on next page. . .

Table 6.1 continued: Configuration parameters.

Parameter	Type	Description
type	*integer*	The type identifying stars, which are used in the fit.
tmixed	*boolean*	Whether to allow for point/extended source ambiguity in objects used in the fit.
deredden	*boolean*	Deredden the objects before fitting, using Schlegel et al. (1998)?
have_sfd	*boolean*	Are the maps of Schlegel et al. (1998) available? Must exist in $DUST_DIR/maps.
cutdiskstars	*boolean*	Cut out disk stars with Galactic $|Z| <$ zeelow before fitting, using Jurić et al. (2008)?
zeelow	*float*	Lower limit of allowable Galactic scale height Z for stars. Assumes they are main-sequence, and already calibrated. Only used if cutdiskstars is set. In parsecs.
beelow	*float*	Lower limit of allowable Galactic latitudes $|b|$, in deg.
snlow	*float*	Lower limit of allowable signal-to-noise in all bands used in the calibration.
color_min	*float array*	Hard lower limits on the colors. Each list entry is ordered to correspond to colors2calibrate. In magnitudes.
color_max	*float array*	Hard upper limits on the colors. Each list entry is ordered to correspond to colors2calibrate. In magnitudes.
mag_min	*float array*	Hard lower limits on the magnitudes. Each list entry is ordered to correspond to the ordered set of all magnitudes appearing in colors2calibrate. In magnitudes.

Continued on next page...

Table 6.1 continued: Configuration parameters.

Parameter	Type	Description
mag_max	*float array*	Hard upper limits on the magnitudes. Each list entry is ordered to correspond to the ordered set of all magnitudes appearing in colors2calibrate. In magnitudes.
max_locus_dist	*float*	Maximum distance to standard locus line allowable, in magnitudes.
max_weighted_locus_dist	*float*	Maximum error-weighted distance to standard locus line allowable. In magnitudes.
magerr_floor	*float*	Error to add to all magnitude errors in quadrature, in magnitudes.

Chapter 7

Outputs

7.1 Output Colortable

7.2 The SLR Log File

Chapter 8

Frequently Asked Questions

Is there documentation of each IDL function? Yes, you can generate
the html documentation for all IDL function with:

```
IDL> slr_docs
```

This will make the SLR IDL help page $SLR_INSTALL/docs/www/idl_help.html,
which you can open in a web browser.

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