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1 OVERVIEW

A recent version of this document is in my home page and a slightly older in the LN documentation archive. The API is in this URL.

1.1 Acronyms

AO Adaptive Optics
API Application Programmer Interface
BASDA Basda Applications Services Devices Architecture (of Twice-As-Nice)
CCD Charge Coupled Device
ccw counter clock wise
cw clock wise
DEC declination coordinate of the ICRF
DHCP Dynamic Host Configuration Protocol
DNS Domain Name Service
DX Right (dexter) arm of the LBT optics
EDT Engineering Design Team http://www.edt.com/
ESO European Southern Observatory http://www.eso.org
FFTS Fringe and Flexure Tracking System of Linc-Nirvana
FITS Flexible Image Transport System http://fits.gsfc.nasa.gov
GEIRS Generic Infrared Software
GUI Graphical User Interface
GWS Ground-layer Wavefront Sensor (of Linc-Nirvana)
HWS High-layer Wavefront Sensor (of Linc-Nirvana)
ICE Internet Communications Engine
https://en.wikipedia.org/wiki/Internet_Communications_Engine
https://doc.zeroc.com/
IIF Instrument Interface of the LBT
http://wiki.lbto.org/twiki/bin/view/SoftwareProducts/TCSsoftware
IP Internet Protocol
IR Infrared
LBT Large Binocular Telescope http://www.lbto.org/
<table>
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<th>Acronym</th>
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<td>LBTO</td>
<td>Large Binocular Telescope Observatory <a href="http://www.lbto.org/">http://www.lbto.org/</a></td>
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<td>LN</td>
<td>LINC-NIRVANA</td>
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<td>LUCI</td>
<td>LBT NIR spectroscopic Utility with Camera and Integral-Field Unit for Extragalactic Research <a href="http://www.mpe.mpg.de/ir/lucifer">http://www.mpe.mpg.de/ir/lucifer</a></td>
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<td>MPIfR</td>
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<td>NCP</td>
<td>North Celestial Pole</td>
</tr>
<tr>
<td>NIRVANA</td>
<td>Near-Infrared / Visible Adaptive Interferometer for Astronomy</td>
</tr>
<tr>
<td>PC</td>
<td>Pre-Commissioning Run (of Linc-Nirvana)</td>
</tr>
<tr>
<td>PCI</td>
<td>Peripheral Component Interconnect</td>
</tr>
<tr>
<td>PCS</td>
<td>Pointing Control System (of LBT)</td>
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<tr>
<td>RA</td>
<td>Right Ascension</td>
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<td>rpm</td>
<td>RPM package manager <a href="http://rpm.org">rpm.org</a></td>
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<td>TCS</td>
<td>Telescope Control System</td>
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<td>UTC</td>
<td>Universal Time Coordinated</td>
</tr>
<tr>
<td>VM</td>
<td>Virtual Machine</td>
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1.2 References

References


URL http://abell.as.arizona.edu/~hill/xlbt/lbts/002s105b.pdf


[19] C. Biddick, LBT Project, Ice Instrument Interface Control Document, 481s013. E: the first value for OffsetPointing in RADEC coordinates is not seconds of time but radians. It actually is the change $\Delta(\alpha \cos \delta)$ (9 Jul. 2016).
URL: http://abell.as.arizona.edu/~hill/xlbt/cgi/ican.cgi?481

URL: https://svn.mpia.de/trac/gulli/ln/archive/Archive/LN%20Documentation/Design%20Report%20(DES)/Optics%20(OPT)/LN-MPIA-DES-OPT-001.pdf


URL: https://svn.mpia.de/trac/gulli/ln/archive/Archive/LN%20Documentation/Interface%20Control%20Documents%20(ICD)/LN-MPIA-ICD-GEN-001.pdf

URL: http://abell.as.arizona.edu/~hill/xlbt/lbts/678s001e.doc


2 INSTALLATION

2.1 Environment

The environment variables needed for the LN installation are build around the INSROOT variable which are typically set in $HOME/.bash_login with a template like

```bash
if [[ $BASH_SUBSHELL -eq 0 ]]; then
    export INSROOT=$HOME/insroot # or similar
    export LD_LIBRARY_PATH=${LD_LIBRARY_PATH}:${INSROOT}/lib
    export PATH=${HOME}/bin:${INSROOT}/bin:$PATH
    export PYTHONPATH=${PYTHONPATH}:${INSROOT}/lib/python/site-packages
    export MANPATH=$INSROOT/man:$MANPATH
    export INFOPATH=${INFOPATH}:${INSROOT}/share/info
    export USERNAME="R._J._Mathar"
    export USEREMAIL=mathar@mpia.de
    export DOMAIN=mpia-hd.mpg.de # or mountain.lbto.org
    export QT_PLUGIN_PATH=$INSROOT/lib/plugins:$QT_PLUGIN_PATH
fi
```

(It is a bad idea to use spaces in USERNAME because the same environment variable will for example be used inside firefox for automatic directory creation, with the usual detrimental effects on Unix/Linux systems.)

2.2 SVN

The SVN sources are obtained for example with

```bash
mkdir -p $HOME/lnsw
cd $HOME/lnsw
svn checkout https://svn.mpia.de/gulli/TwiceAsNice/branch/unstable/TwiceAsNice TwiceAsNice
svn checkout https://svn.mpia.de/gulli/TwiceAsNice/branch/unstable/ln ln
svn checkout https://svn.mpia.de/gulli/ln/config config
```

This creates directories TwiceAsNice, config and ln in the current working directory. It is not recommended to work on TwiceAsNice/trunk which is usually obsolete. The sources (exported but not checked out) need roughly 490 MB of disk space. The sources (directories TwiceAsNice, ln and config) checked out need roughly 760 MB of disk space. This volume will inflate to more than 3.1 GB during compilation, which need to be available on that partition. If checked out (which means, including the .svn) this will grow to 4.8 GB. For generic information look into https://svn.mpia.de/trac/gulli/TwiceAsNice.

Some software bundles of the Linux repositories are needed:

```bash
cd TwiceAsNice
sudo ./suse-dep.install # for openSUSE, ln-x1, ln-x2, ln-x3
sudo ./centos-dep.install # for CentOS, lsys, lsys2, laos, laos2, lircs
# zypper in python3-scipy # not needed yet
```

Although this will install under openSUSE 15.0 many of the boost libraries, they are not installa
such that they will be found by `make` while compiling TaN. One usually needs to add links like

```bash
cd /usr/lib64
ln -s libboost_filesystem.so.1.66.0 libboost_filesystem.so
ln -s libboost_date_time.so.1.66.0 libboost_date_time.so
ln -s libboost_system.so.1.66.0 libboost_system.so
ln -s libboost_regex.so.1.66.0 libboost_regex.so
```

If openSUSE complains that `qwt4-devel` is not available, insert `qwt-devel` in `suse-dep.install` at its place. Note that the installation does *not* find any `cfitsio` library which may be present in the GEIRS directories.

Newer versions of TAN need the Python `astropy` package. If the compiler says it is missing run (as root)

```bash
pip install --target=$INSROOT astropy astroplan
```

Unfortunately that may install the library in `/usr/lib64/python3.4/site-packages` if `python3` is your default, where the current search options in the TAN autotools are only recognizing `python 2.7`. So you may instead need the more explicit

```bash
python --version
zypper install python-pip
pip2.7 install --target=$INSROOT astropy astroplan
```

if only `python3-pip` is installed.

## 2.3 Compiler

### 2.3.1 openSUSE

If not the default compiler (likely gcc 4.8 at the moment) is desired but the newer gcc-6, upgrade the three variables before continuing. Under openSUSE this means:

```bash
zypper install gcc6-c++ gcc6 cpp6
```

Finally add for all users in `.bashrc`

```bash
export CPP=cpp-6
export CXX=g++-6
export CC=gcc-6
```

Starting with openSUSE Leap 15.0, gcc 7 is already the default and no such step is needed.

### 2.3.2 CentOS

Under CenOS there are no such repositories. There may be ways to [http://www2.mpia-hd.mpg.de/~mathar/progs/recompileGCC.pdf](http://www2.mpia-hd.mpg.de/~mathar/progs/recompileGCC.pdf) compile it yourself. The standard way of upgrading the compiler is

```bash
yum install centos-release-scl devtoolset-7-gcc-c++
scl enable devtoolset-7 bash
```
g++ -dM -E -x c++ /dev/null | grep -F __cplusplus

2.4 Atlas

2.4.1 CentOS

For CentOS, the linear algebra package ATLAS is available as a standard package, but for openSUSE 42.3 we need to compile it if we want to compile the ln/3rdparty directory. This is actually only needed to compile sextractor, but not if one can obtain the executable sex(1) from somewhere else.

2.4.2 openSUSE

The rpm source package is obtained from https://software.opensuse.org/package/libatlas3, then moved into /usr/src, and compiled with

```
rpmbuild --recompile libatlas3-3.10.3-2.1.src.rpm
cd /usr/src/packages
CFLAGS=-shared rpmbuild -ba SPECS/libatlas3.spec
zypper install RPMS/x86_64/libatlas*devel*.rpm # answer 2 to break dependencies!
```

If the rpmbuild step stops with a message that you have throttling enabled—which seems to happen on all Intel CPU’s—try

```
cpupower frequency-set -g performance
```

and rpmbuild again. If this did not help,¹ you need to compile everything on a lower level:

```
cd /usr/src/packages/BUILD/ATLAS
mkdir tmp
cd tmp
../configure --cripple-atlas-performance --shared --prefix=/usr --libdir=/usr/lib64/atlas -b 64
make
make install
cd /usr/src/packages/SPECS
rpmbuild --rmsource libatlas3.spec
cd /usr/lib64/atlas
ln -s libsatlas.so libsatlas.so.3
ln -s libtatlas.so libtatlas.so.3
```

Finally set the CPU governor back to normal

```
cpupower frequency-set -g conservative
```

Installation of the new library may have detrimental effects on the numpy python package, which is linked to some of the linear algebra functions. So one should check that

¹I tried to load the lenovo computers with a dummy program of lnsw/ln/3rdparty/src/sexttractor/demandCPU, compiled with g++ -O0 that used the system fully on all processors which had no influence on the internal ATLAS guesser...
python
>>> import numpy
>>> import scipy.signal

still works. If this fails due to missing functions,

pip uninstall numpy
pip install --target=$INSROOT numpy
pip uninstall scipy
pip install --target=$INSROOT scipy

may bring them back.

2.4.3 gfortran

On some systems libgfortran is not properly installed because a package manager forgot symbolic links:

cd /usr/lib64
if [ -a libgfortran.so.3 ] ; then
    if [ ! -a libgfortran.so ] ; then
        ln -s libgfortran.so.3 libgfortran.so
    fi
fi

2.5 Ice

There are two installation options. To start from the rpm packages in https://zeroc.com/download.html
is apparently not advisable because the package dependencies that show up after the zypper in *
 rpm command are difficult to resolve. An alternative is to compile the source code locally after
downloading it from https://github.com/zeroc-ice/ice/releases/tag/v3.6.4:

To avoid an error message cannot find -lmcpp further down check that the mcpp library is inst-
alled:

zypper install mcpp-devel

Note that mcpp-2.7.2 is known to be buggy when slice2py is used to handle slice files that contain
C++ trailing comments that start with two slashes. So either

• use only the C-type comments /* .... */

• or use the C++-style comments only if the entire line in which they appear can be removed
  without changing the meaning of the source code;

• build your patched version of the mcpp library according to https://forums.zeroc.com/
discussion/comment/35232;

2A bug that exists for more than a decade https://bugzilla.redhat.com/show_bug.cgi?id=191497
3The basic problem is actually not within mcpp but the fact that slice2py does not call mcpp including the option
+- which enables C++ style comments.
remove the comments with your own preprocessor before offering the *.ice files to the slice programs:

cpp -finput-charset=US-ASCII -P -fpreprocessed -E -std=c99 my.ice.in > my.ice

Starting with ice 3.6.4 you also need

zypper install lmdb-devel

# git clone https://github.com/zeroc-ice/ice.git
tar xzf ice-3.6.4.tar.gz
cd ice-3.6.4
cd cpp
vi src/Makefile # if 3.6.2 add slice2py to the second block of SUBDIRS
CXXFLAGS=-O2 prefix=$HOME make install
cd ../python
vi config/Make.rules* # change the PYTHON to PYTHON3.4 version if needed
    # may need zypper install patterns-openSUSE-devel_python3
CXXFLAGS=' -O2 -Wno-int-in-bool-context' prefix=$HOME make install

Java support is trickier because the installation requires an online Internet connection:

export JAVA_HOME=${HOME}/jdk-9 # if not yet set to an existing value
# ensure the https (!) proxies are known:
export _JAVA_OPTIONS=' -Dhttps.proxyHost=web-proxy.mpia-hd.mpg.de -Dhttps.proxyPort=3128'
# put db.jar into /usr/share/java:
zypper install libdb_java-4_8-devel
cd ../java
CXXFLAGS=-O2 prefix=${HOME} make install

Finally

- set the ICEDIR environment variable in ~/.bash_login to the prefix directory used above to avoid that the ice.m4 macros of TAN look only at some other standard places.
- add $ICEDIR/lib64 or wherever the ICE library was installed to the LD_LIBRARY_PATH of Section 2.1.
- add $ICEDIR/python or wherever the ICE library was installed to the PYTHONPATH of Section 2.1.

2.6 Compilation

Being already in the directory TwiceAsNice call

rm -rf ${INSROOT}/lib/* ${INSROOT}/lib64/* ${INSROOT}/include/* \ ${INSROOT}/slice/* ${INSROOT}/bin/*
make clean
2.6.1 Patches

1. At this points one needs to edit all python.m4 files if one wants to use any Python version higher than 2.6. This can be done with a global edit like

   ```bash
   pfil=$(find . -name python.m4)
   for f in ${pfil} ; do
     sed -i 's/in python2.8/in python3.4 python2.8/' $f
     sed -i 's/="python2.6/="python3.4 python2.6/" $f
     sed -i 's/="python2.7/="python3.4 python2.7/" $f
   done
   export PYTHON=python3.4
   alias python=$PYTHON # in ~/.bashrc
   pip3.4 install pexpect
   ```

   This will still most likely fail unless the boost python wrapper has not been configured in the user-config.jam file to use that newer python version.

2.6.2 Installation

2.6.2.1 TAN  Compile TAN first:

   ```bash
   cd lnsw/TwiceAsNice
   make install -j -l 2 |& tee install.log
   ```

   Starting in 07/2017, the lead software engineer decided that the sofa and skymaker software supporting the LN software must no longer be compiled by default with the rest of the software. It now is necessary either

   - to compile it beforehand in an extra step:

     ```bash
     cd lnsw/ln/3rdparty
     autoreconf -f -i -s
     ./configure --prefix=$INSROOT
     make install
     ```

   - or to edit lnsw/ln/Makefile.am and to insert 3rdparty in front of the objects list, before laos-adsecIF.

   Starting in 07/2017, ds9 is used to create simulated images in the GWS plane; it can be installed according to the instructions in Section A.6 of [1].

   If (under openSUSE Leap 15.0) a complaint appears that -lnsl cannot be linked to, because the library is missing, this may be caused by a missing link to libnsl.so in the directory of libraries. This can be patched with

   ```bash
   cd /usr/lb64
   ln -s libnsl.so.2 libnsl.so
   ```
2.6.2.2 LN software  Then compile the bulk of the LN software:

cd ..\ln
make install -j -l 2 |& tee install.log

We avoid being stuck in potential bugs in the checks by not calling the simpler make -j.
If the configure scripts complain about missing config/compile files, go to the associated directory with the configure.ac file and call

autoreconf -i

to continue.

2.6.2.3 Drivers  The driver for the CCD’s [2] is obtained from https://edt.com/file-category/pdv/. The driver for the reflective memory card is obtained after registration from https://www.abaco.com/download/rfm2g-linux-3264-bit-pciepcipmc-driver-x86-kernels-r0900.

mv EDTpdv-5.5.3.-7.noarch.rpm /opt

cd /opt
export CFLAGS=''-shared -fPIC'
export LDFLAGS=''-shared -fPIC'
rpm -i EDTpdv*.rpm
make all
make libpdv.so

If it is not found at compile time, some TAN libraries like libBasdaVinoDeviceLittleJoeVinoDevice will not be build. If the operating system has been upgraded with either zypper up or yum up, one must recompile the EDT and reflective memory drivers, at least on Laos2 where the corresponding services are run:

cd /opt/EDTpdv ; make driver
cd /opt/RFM2G ; make install ; ./RFM2G_load ; ./RFM2G_init start

The simplest way to re-load the drivers is to reboot the computer. Afterwards the output of lsmod should list edt and rfm2g.

On lircs, and in principle also on its backup lsys2, the PLX driver and GEIRS should also be recompiled after each upgrade of the operating system. Details are in [1]. The short version is

cd $HOME/GEIRS/trunk<version>
./INSTALL.plx
make -f Makefile clean
./INSTALL

2.6.2.4 Developers  If monit is run under an account not equal to lneng, update the monit configuration to use the correct INSROOT:

cd lnsw/config
autoreconf -f -i -s
configure

To develop software when the hardware is absent, run the script in lnsw/config/makeDummydevCfg.pl
3 CONFIGURATION

3.1 IIF FITS Header Keywords

The translation of the TCS/IIF dictionary entries to FITS header keywords is configured in `config/ltcs/ltcs.iif-fits.xml`. The file is also the basis of which dictionary entries are polled regularly by the LN and available for status information with commands like `liifSnapshotGUI`. Apart from XML comments this contains a long vector of `<dic />` specifications. The attributes of a `dic` entry are:

- **dd**: The data dictionary keyword exactly as used in the ICE interface. The two-sided keywords that start with `S_` will be dynamically dispersed into one-sided keywords by the `ltcs` software depending on whether LINC is registered on the SX, the DX or both sides of the telescope.

- **type**: The type of the FITS header card. This must be one of `float`, `bool`, `long`, `string`, `double` or `int`.

- **unit**: The unit of the value of the keyword, following FITS standards [3]. Note that this is almost always different from the units used internally within the IIF specification (which is not FITS compliant). This may be the empty string, which usually indicates that these are counts or that the variable is of boolean type.

- **com**: The string in the FITS comment, excluding the unit.

- **keyw**: The FITS keyword. Note that all of these are currently restricted to 8-letters because LBTO argues it cannot handle keywords with the `HIERARCH` convention.

- **use**: This is either `true` (the default if the attribute is absent), `false` or `cmt`.
  - `true` means the corresponding dictionary entry becomes a FITS header card.
  - `false` means the corresponding dictionary entry is discarded.
  - `cmt` means the corresponding dictionary entry becomes a `COMMENT` header card.

If `use` is `cmt` or `false`, the `keyw` attribute may be missing.

3.2 ICS FITS Header Keywords

The information of the TAN property tree which are translated to FITS header cards are configured in the various files of `config/lircs/geometry/*` in the (undocumented) TAN format. Each of the `CFG.DATA.i.CONNECT` specifies a server name and a node in the property tree. The `CFG.DATA.i.NODE` specifies whether that node is to be prepended to each of the branch specifications of `CFG.DATA.i` later on. The `CFG.DATA.i` itself is a list of lists. These sublists contain four strings, in that order:

- The name of the leaf in the property tree (after prefixing with the node).
• Some name of a server on which the device handler may run; this entry is not actually needed but appended in the comment portion of the FITS header card.

• The FITS header keyword. Dots in that specification will be replaced by blanks by the interface. HIERARCH LBTO LN will always be added, so it must not be part of the configuration.

• The unit of the value, compatible with the FITS standard [3]. If the property has an attribute named UNIT, the server will use the online value of the attribute in the property tree, actually overriding that 4th entry. 4

3.3 Port numbers

The ports of various servers in use for TAN might be extracted from the configuration file

cd lnsw/config
find . -type f -exec fgrep -H 'PORT=' {} \; | fgrep -v .svn | fgrep Endpoint \ 
| grep -E -v -e '(alias-mpia|alias-localhost)' \ 
| awk -F 'PORT=' '{printf "%d %s\n",$2,$0} ' | fgrep -v ':#' | sort -n

As of 2018-11-23 we have

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4It is not sufficient to have another leaf named UNIT for this to happen, it must be an attribute of the leaf that contains the value. Unfortunately some deletionists are known to delete these attributes, so we cannot make this a standard...
There is no overlap with the standard GEIRS CAMSERVERPORT, CAMSTATUSPORT, CAMDATAPORT and CAMICEPORT which are by default in the range 28502–28511.

Of course one should be very careful not to use the same port for two different services that may run at the same time on the same computer!

## 4 Linc-Nirvana

### 4.1 Angles

#### 4.1.1 Standard Spherical Astronomy

Let

- \( A \) be the pointing azimuth. Beware of different sign conventions in different publications. We use the offset North=0, East=90 deg as in the IIF of the LBTO, xephem and astropy; this
differs from the ESO standard by 180 deg. Note that in the second edition of [4] the text said that $A$ was measured from south, but the formulae given were measuring $A$ from north; this has been corrected in the third edition.

- $a$ be the pointing altitude above the horizon. $z = \pi/2 - a$ the zenith angle. We call $A$ and $a$ the coordinates in the horizontal coordinate system.

- $\phi$ the geographic latitude of the observatory.

- $\lambda$ the geographic longitude of the observatory.

- $p$ be parallactic angle, the position angle of the zenith, in the standard sign convention. The angle by which the direction from the star along $+\delta$ must be turned ccw in the non-flipped image to get the direction $+a$ [5][6, p. 50].

- $\alpha$ the right ascension of date.

- $\delta$ the declination of date. We call $\alpha$ and $\delta$ the coordinates in the equatorial system.

- $h$ the hour angle,

- $l$ the local sidereal time, $l = h + \alpha$.

Then [7]

$$
\cos a \sin A = - \cos \delta \sin h; \tag{1}
$$
$$
\cos a \cos A = \sin \delta \cos \phi - \cos \delta \cos h \sin \phi; \tag{2}
$$
$$
\sin a = \sin \delta \sin \phi + \cos \delta \cos h \cos \phi; \tag{3}
$$
$$
\cos \delta \sin h = - \cos a \sin A; \tag{4}
$$
$$
\cos \delta \cos h = \sin a \cos \phi - \cos a \cos A \sin \phi; \tag{5}
$$
$$
\sin \delta = \sin a \sin \phi + \cos a \cos A \cos \phi. \tag{6}
$$

This system of equations can be written as a rotation around the equatorial pole by the angle $l$ equivalent to the local sidereal time, followed by a tilt of the equatorial plane by $\phi$:

$$
\begin{pmatrix}
\cos a \cos A \\
- \cos a \sin A \\
\sin a
\end{pmatrix}
= \begin{pmatrix}
- \sin \phi & 0 & \cos \phi \\
0 & -1 & 0 \\
\cos \phi & 0 & \sin \phi
\end{pmatrix}
\cdot
\begin{pmatrix}
\cos \delta \cos h \\
- \cos \delta \sin h \\
\sin \delta
\end{pmatrix}
$$

$$
\begin{pmatrix}
- \sin \phi & 0 & \cos \phi \\
0 & -1 & 0 \\
\cos \phi & 0 & \sin \phi
\end{pmatrix}
\cdot
\begin{pmatrix}
\cos l & \sin l & 0 \\
- \sin l & \cos l & 0 \\
0 & 0 & 1
\end{pmatrix}
\begin{pmatrix}
\cos \delta \cos \alpha \\
0 \\
\sin \delta
\end{pmatrix}. \tag{7}
$$

If $A$ is measured south over west as in [8, 9, 5] and in Wikipedia, the signs in front of all $\cos A$ and all $\sin A$ need to be reversed.

These equations assume that atmospheric dispersion effects are neglected and that the equatorial coordinates are precessed to the date of the observation. Note that (following experiments with the telescope simulator) the $\alpha-\delta$ coordinates obtained from the data dictionary of the TCS are not precessed that way but only propelled with respect to proper motion. The LN software is currently copying these data from the telescope, including the EQUINOX, to the FITS headers. 

\footnote{The associated description in http://wiki.lbto.org/bin/view/Instrumentation/UsefulDataDictionaryVariables seems to be incorrect, unless the telescope software on the mountain differs from the one of the simulator...}

\footnote{this may violate FITS standards that propose that the EQUINOX should be compatible with the coordinates. It
4.1.2 Parallactic Angle

The parallactic angle is the angle by which the great circle through the star and the NCP must be rotated to become the great circle through the star and the zenith. It is the dihedral angle between the two planes that contain the great circles and the global center of coordinates. It is computed by placing the star at the Cartesian coordinates

\[ s = \begin{pmatrix} \cos \delta \cos \alpha \\ \cos \delta \sin \alpha \\ \sin \delta \end{pmatrix} \]  

(8)

of the equatorial coordinate system. The NCP is at

\[ N = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}. \]  

(9)

The vector \( z \) to the zenith is given in the same coordinate system by inserting \( a = \pi/2, \cos a = 0 \) into (7) and multiplying from the left by the inverse matrix:

\[ z = \begin{pmatrix} -\sin \phi & 0 & \cos \phi \\ 0 & -1 & 0 \\ \cos \phi & 0 & \sin \phi \end{pmatrix} \cdot \begin{pmatrix} \cos l & \sin l & 0 \\ -\sin l & \cos l & 0 \\ 0 & 0 & 1 \end{pmatrix}^{-1} \cdot \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} = \begin{pmatrix} \cos \phi \cos l \\ \cos \phi \sin l \\ \sin \phi \end{pmatrix}. \]  

(10)

Technically this is easy because the matrices are rotation matrices which have inverses which are the transpose. The cross product \( s \times z \) (normalized to unit length by dividing through \( \sin z \)) is the rotation axis to move the star to the zenith

\[ \omega_z = \frac{1}{\sin z}(s \times z) = \frac{1}{\sin z} \begin{pmatrix} \cos \delta \sin \alpha \sin \phi - \sin \delta \cos \phi \sin l \\ -\cos \delta \cos \alpha \sin \phi + \sin \delta \cos \phi \cos l \\ \cos \delta \cos \phi \sin(\alpha - l) \end{pmatrix}. \]  

(11)

Finally \( \omega_z \times s \) is the third orthogonal axis and the initial direction into which the star is moved on the great circle to the zenith—not reproduced in full detail here:

\[ \omega_z \times s = \frac{1}{\sin z}(s \times z) \times s = \frac{1}{\sin z} \left[ z s^2 - s(s \cdot z) \right] = \frac{1}{\sin z}(z - \cos z s). \]  

(12)

The plane tangential to the celestial sphere at the star is spanned by the unit vectors to the north,

\[ u_\delta = \begin{pmatrix} -\sin \delta \cos \alpha \\ -\sin \delta \sin \alpha \\ \cos \delta \end{pmatrix} \]  

(13)

and to the east,

\[ u_\alpha = \begin{pmatrix} -\sin \alpha \\ \cos \alpha \\ 0 \end{pmatrix}, \]  

(14)

has some benefit; one can search for targets in the FITS files and these won’t change over time comensurate with precession...
obtained by differentiationg (8) with respect to δ and α and normalizing to unit length (see e.g. [10]). The parallactic angle \( p \) is the angle north-over-east of the initial section,

\[
\omega_z \times s = \cos p u_\delta + \sin p u_\alpha. \tag{15}
\]

By multiplying with \( u_\delta \) and \( u_\alpha \), and utilizing \( u_\delta \perp u_\alpha \) such one of the two dot products on the right hand side vanishes [11, §71]:

\[
(\omega_z \times s) \cdot u_\delta = \cos p = \frac{1}{\sin z} \left[ \cos \delta \sin \phi - \sin \delta \cos \phi \cos h \right]; \tag{16}
\]

\[
(\omega_z \times s) \cdot u_\alpha = \sin p = \frac{1}{\sin z} \sin h \cos \phi. \tag{17}
\]

This can be evaluated with the usual \texttt{atan2} functions; the \( \sin z \) factor can be dropped because it is always positive and cannot switch the quadrants of the angle. The same sign-argument applies to the factor \( \cos \phi \), so we end up with the textbook expression\[12, \text{Eq. (2.1)}\]

\[
\tan p = \frac{\sin p}{\cos p} = \frac{\sin h}{\cos \delta \tan \phi - \sin \delta \cos h}. \tag{18}
\]

The time derivative of the parallactic angle is given by implicit derivation with respect to time:

\[
\dot{p} = -\frac{\cos \phi \cos A}{\sin z} \dot{h}, \tag{19}
\]
Figure 2: The parallactic angle $p$ as a function of hour angle $h$ and declination $\delta$ with (18) for geographic latitude $\phi$ of the LBTO. The difference to Fig. 1 is: the patches of the surface where the elevation $a$, where the sine of (3) is negative and the star is not visible—have not been plotted.
where \( \dot{\theta} \approx 2\pi \times 1.002737/(24 \times 3600) \) rad/s is the time derivative of the hour angle, a full circle in a sidereal day. Note that [12, Eq. (2.2)] uses a different sign because it uses ESO’s convention of azimuths \( A \). These functions are implemented in the SkyPoint class in nice/src/libNice/Nice/Map.

### 4.1.3 LBTO Coordinate System

Consider the telescope pointing to the south on the meridian, SX and DX aligned East-West along the azimuth, and two bundles of rays approaching the telescope, the first an on-axis star in the zenith, and a second bundle of light from a star closer from the zenith. The bundle from the star closer to the zenith has an inclination to the S before hitting M1; its image in the primary focus is south from the image of the on-axis star. Moving up to M2, the second star has an inclination south compared to the on-axis star, and moving down on to M3 an inclination closer to the zenith than the on-axis star. If one wanted to create an image in a focal plane where the image in the focus after M3 shows the off-axis star up from the on-axis star, one would need to point M3 south, such that the incidence angle of the off-axis star on M3 is smaller than the incidence angle of the on-axis star. The reference cameras where North is “up” in the Gregorian foci are south of M3, both for SX and for DX. This is an effect of the primary focus below M2 due to the “fast” optics of M1 of the LBT. Each transition through a focal plane induces a 180° image rotation. For more standard M1-M2 curvatures, where the primary focus is after M3, that camera would need to be North of M3.

Note that reference systems pointing “from the instrument to M3” or “along the beam toward the detector” are not distinguished: a detector or Kodachrome film held in that (second) focal plane defines an unambiguous image with a two-dimensional coordinate system on the front. The detector surface always faces the beam.\(^7\)

We will use the standard astronomical sign convention that the image is called non-flipped if its handedness is the same is if looking with the bare eye at the sky. In non-flipped images one reaches the direction of \( +\alpha \) by turning a vector at the star position pointing to \( +\delta \) by 90° ccw. \((A, a)\) is a right-handed coordinate pair in non-flipped images. \((\delta, \alpha)\) is a right-handed coordinate pair in non-flipped images.

The images in the prime focus below M2 and the images by the camera in the Gregorian (second) foci are non-flipped.

The usual even-odd rule applies:

- In a mirror train of plane mirrors the image flips sign if the number of surfaces is odd. Actually the component of the image in the incidence plane flips its sign, the other orthogonal component keeps its sign. If the camera keeps its “up” definition orthogonal to the common set of incidence planes, each mirror triggers a left-right flip in the image.
- Each transition through an image plane rotates the image by 180°, but does not flip.

At first view it appears puzzling that that images in the LBT Gregorian instrument focal planes are not flipped, although light has passed through an odd number of mirrors (M1, M2, M3) up to there. The apparently missing flip is the one introduced when no longer looking at the sky up the light beam but looking down the beam at the images of the cameras.

\(^7\)There are other LN documents around that look through some transparent detector plane on the sky and draw ad-hoc axes on the observers side, on the back plane of the detector; their conclusions on image flips and coordinate systems differs from the ones here in signs, but not in substance.
Figure 3: Image orientation of a camera in the instrument focus after M3. The direction of the altitude $+a$ axis is $R_z = \pm 108.5^\circ$ away from the up $+z$ direction. The image is not flipped. If the time derivative of the parallactic angle is $\dot{p} > 0$, the image rotates cw on both arms, because the $(a, A)$ axes are fixed in the image plane for the LBT mount. In a video of the figure, the $+\delta$ arrow rotates cw.

In the telescope coordinate system fixed to the mount, $+z$ points towards the star, $+x$ points from DX to SX, and $+y$ points to the gallery [13]. The two cameras of zero-rotated images had to be placed in the $-y$ direction, at the (non-bent) Gregorian front. There actually are no instruments there. The positions of instruments (still using the notation of the telescope coordinate system with right-handed angles $R_z$ opposite to the direction of increasing azimuths) of the focal stations relative to that virtual camera position are

$$R_z = \begin{cases} 
90^\circ - 26.5^\circ = +63.5^\circ, & \text{LUCI DX} \\
-63.5^\circ, & \text{LUCI SX} \\
+90^\circ, & \text{LBTI, SHARK DX} \\
-90^\circ, & \text{LBTI, SHARK SX} \\
90^\circ + 18.5^\circ = +108.5^\circ, & \text{LN DX} \\
-108.5^\circ, & \text{LN SX}
\end{cases} \quad (20)$$

If the reference detector rotates with M3, the direction of N in the image rotates ccw with $+R_z$; a camera placed at the focus behind the annular mirrors experiences image rotations as in Figure 3.\(^8\)

$$\begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix}_F = s_F \begin{pmatrix} \cos R_z & -\sin R_z \\ \sin R_z & \cos R_z \end{pmatrix} \cdot \begin{pmatrix} \cos a \Delta A \\ \Delta a \end{pmatrix} . \quad (21)$$

This defines the matrix that converts topozentric horizontal coordinates to instrument focal coordinates:

$$A_{T \to F} \equiv s_F \begin{pmatrix} \cos R_z & -\sin R_z \\ \sin R_z & \cos R_z \end{pmatrix} . \quad (22)$$

\(^8\)The PCS keeps the value of $|R_z| + 180^\circ = 288.5$ in the LEFTIAA and RIGHTIAA parameters in some configuration file.
The plate scales, variables \( F_{\text{SCALE}} \) in `config/laos/*/gws/se/starEnlarger-svc.cfg`, are

\[
s_F = \begin{cases} 
601.75\mu\text{m/\text{as}}, & SX; \\
600.6\mu\text{m/\text{as}}, & DX.
\end{cases}
\]  

(23)

The transformation between \((\alpha, \delta)\) and \((A, a)\) is a passive transformation; the targets on the detector do not move but the coordinate axes are rotated instead. The \(a\)-axis is found by rotating the \(\delta\)-axis by the parallactic angle \(p\).

\[
\begin{pmatrix} 
\cos a \Delta A \\
\Delta a
\end{pmatrix} = 
\begin{pmatrix} 
\sin p & - \cos p \\
\cos p & \sin p
\end{pmatrix} 
\begin{pmatrix} 
\Delta \delta \\
\cos \delta \Delta \alpha
\end{pmatrix}.
\]  

(24)

So we define

\[
A_{E\rightarrow T} \equiv 
\begin{pmatrix} 
\sin p & - \cos p \\
\cos p & \sin p
\end{pmatrix}
\]  

(25)

as the transformation matrix to transform equatorial coordinates to topozentric horizontal coordinates. The WCS convention needs that equation in a left-handed \((\alpha, \delta)\) system, not in a right-handed \((\delta, \alpha)\) system. The associated matrix determinant on the right-hand side is negative:

\[
\begin{pmatrix} 
\cos a \Delta A \\
\Delta a
\end{pmatrix} = 
\begin{pmatrix} 
- \cos p & \sin p \\
\sin p & \cos p
\end{pmatrix} 
\begin{pmatrix} 
\cos \delta \Delta \alpha \\
\Delta \delta
\end{pmatrix}.
\]  

(26)

Multiplication with the inverse matrix from the left yields

\[
\begin{pmatrix} 
- \cos p & \sin p \\
\sin p & \cos p
\end{pmatrix} 
\begin{pmatrix} 
\cos a \Delta A \\
\Delta a
\end{pmatrix} = 
\begin{pmatrix} 
\cos \delta \Delta \alpha \\
\Delta \delta
\end{pmatrix}.
\]  

(27)

The matrix that rotates points in the \((\delta, \alpha)\) system into the non-rotated image system glued to the platform at the instrument focus after the annular mirror is a rotation with (24) into the \((A, a)\)-system and then a rotation that increases angles by \(R_z\) from the \((A, a)\)-system to the platform:

\[
\begin{pmatrix} 
\Delta x \\
\Delta y
\end{pmatrix}_F = 
A_{T\rightarrow F} \cdot A_{E\rightarrow T} \cdot 
\begin{pmatrix} 
\Delta \delta \\
\cos \delta \Delta \alpha
\end{pmatrix}.
\]  

(28)

\[
A_{T\rightarrow F} \cdot A_{E\rightarrow T} = A_{E\rightarrow F} = s_F \begin{pmatrix} 
\cos \phi_0 & - \sin \phi_0 \\
\sin \phi_0 & \cos \phi_0
\end{pmatrix},
\]  

(29)

where the direction to \(+\delta\) relative to the horizontal coordinate is given by

\[
\phi_0 = R_z - p + 90^\circ,
\]  

(30)

and \(R_Z\) is given by (20) and \(p\) the parallactic angle.

### 4.1.4 Nominal Angles

Many of the GUI’s of the instrument display angles that are derived from motor steps/counts by scaling and offset factors defined in the services BASDA configuration files. These will be called **nominal** angles, and are not necessarily related to angles in image planes or angles related to the orthogonal coordinate system of the bench. The reasons for these discrepancies are the standard ones:
the offsets have not been calibrated yet, for various reasons, including lack of interest or the unavailability of light sources and detectors that would measure inclinations along partial paths;

there are people who think that changing offset angles in the database —meant to catch these offsets from misalignments, arbitrary motor switch positions and so on—should not be done to avoid backwards incompatibilities. Some reconstruction matrices are for example tabulated for some discrete set of angles and need to be re-labelled if offset or signs change and if the matrices are applied based on angles in the database.

One example: for some reasoning that has probably been lost, looking from the annular mirror toward the GWS, increasing the nominal angle turns the device ccw for SX, whereas increasing the nominal angle turns the device cw for DX. This is actually induced by two different signs of the multipliers ±0.00125 for the conversion from angles to motor steps in `laos.dx.gws.drot.bearing-dev.cfg` and `laos.sx.gws.drot.bearing-dev.cfg`.

4.1.5 Derotator Angles

Derotation of images while integrating on a detector happens

- passively (in the sense of linear algebra) by rotating the entire GWS or infrared detector, which is equivalent to rotating the coordinate system by the negated angle of the motorized service,

- actively by rotating the beam with the K-mirrors for the HWS.

Effectively this induces a sign flip of the motor angles depending on whether GWS or HWS or science camera images are derotated.

Time derivatives of derotator angles read from the IIF have the opposite sign of the time derivatives of the parallactic angle, see Section 4.5.2.

The effective total product of these sign flips (polynomials to parallactic angle, active versus passive, ad-hoc conventions in motor software and geometry) determines which sign should be applied to convert derotator polynomials to motor steps or counts. That sign is the sign of `SVC.CFG.DIRECTION` in the five `drot-svc.cfg` configuration files.

Note:

1. The parallactic angle may increase or decrease with time. This sign of the first derivative is imprinted in the trajectories received from the IIF and does not to be considered by the derotator software.

2. The derotator services do not use the scaling factors of the configuration database mentioned above. So changing their signs would change the nominal angles but not the sense of rotation of the derotator services.

3. Sky rotation of SX and DX has the same sense, since the two coordinate systems in Figure 3 have the same orientation. Although the two optical trains of SX and DX are mirror symmetric relative to the $y$-axis, the direction to east is the global one, and this sort of symmetry-breaking implies that GWS and K-mirror bearings have the same sense of rotation for SX and DX.
4.2 Orientation of patrol camera images

4.2.1 Calibration

The pixel scale on the CCD47-20 patrol cameras is \[s_p \approx 0.144 \text{arcsec/pix} = 4 \times 10^{-5} \text{deg/pix} = 6.981 \times 10^{-7} \text{rad/pix}.\] (31)

This value is stored in the PIXSCALE properties in units of degrees in lnsw/config/laos both in dx/hws/pcam/laos.dx.hws.pcam.ccd47-svr.cfg and in sx/hws/pcam/laos.sx.hws.pcam.ccd47-svr.cfg. The usual FITS coordinate system puts the center of the K-mirror rotations at some \((x_{PC}, y_{PC})\) coordinate. Unless calibrated, the first approximation is \(x_{PC} = y_{PC} = 512.5\) pix, the center of the CCD. The values reported in the Com-3 version of [15, p 47] are

\[
(x_{PC}, y_{PC}) = \begin{cases}
(485, 421), & \text{SX}; \\
(488, 414), & \text{DX}.
\end{cases}
\] (32)

The translations and rotations \((\Delta x, \Delta y)\) used further down are measured with respect to that center of rotation.

Rotations are described by angles \(\beta\) as currently used in the instrument control software, which means they are measured in units of the K-mirror axis rotations; further down we generally need the beam rotations \(2\beta\), doubled values.

In PC1 the action of K-mirror rotations was measured on the two cameras. On SX and DX a positive rotation (defined as increasing the number of steps of the motor, not by any signed angle of opto-mechanics on the table) rotates the image clockwise.

(I added the algebra which determines the center of rotation to the wikipedia article.) As such these data are insufficient to map sky coordinates to patrol camera coordinates, because

- The cameras are on motorized stages that can be moved laterally, and these positions need to be combined to construct the expected center coordinates,
- tilted axes of the K-mirror lead to the effect that the \((x_c, y_c)\) are functions of the K-mirror angle, which means to first order that centers move on circles as a function of \(\beta\). Perhaps this can be calibrated off-sky with the auxiliary light sources, see Ticket 1434.
- The beam splitter optical thickness may have an effect of moving the centers sideways. See Ticket 1419 for plans of exchanging them.

In PC1 the motion of the target was measured on both cameras if \(A\) were changed by \(+10^\circ\) or \(a\) were changed by \(-10^\circ\), at nominal positions of the K-mirrors, \(\beta_{SX}^{(0)} = 3.66^\circ\) and \(\beta_{DX}^{(0)} = 81.46^\circ\). The targets moved by angles \(\phi_{SX}^{(0)} = 107.5^\circ\) (Figure 4) and \(\phi_{DX}^{(0)} = 82.9^\circ\) (Figure 5). The object moved almost up in the image when the telescope pointed closer to the horizon; so the altitude axis points almost up in these two patrol camera images.  

In a derotated reference snapshot one would use \(A\) as the horizontal coordinate and \(a\) as the vertical coordinate. This \((A, a)\) coordinate system is flipped with respect to the \((x, y)\) image coordinates for

\(^9\text{Some comments in the original blogs of 2016-11-24 indicate otherwise, but this turned out to be a misinterpretation of a sign in a TCS command for elevation changes (J. Hill, priv. commun. 2017-02-23.)}\)
Figure 4: On the SX side a negative change of the elevation moves the object into the $\phi_{SX}^{(0)}$ direction. The image shows the sum of the 10 images before the move subtracted from the sum of the 10 images after the move.
Figure 5: On the DX side a change of the elevation moves the object into the $\phi_{DX}^{(0)}$ direction. The image shows the sum of the 10 images before the move subtracted from the sum of the 10 images after the move.
both cameras,\(^\text{10}\) so the 2D rotation matrix that transforms between the two systems has a negative determinant; the images on the patrol cameras are flipped and rotated. A (virtual) camera at the instrument focus after the annular mirror is not flipped, and there is an odd number of 7 further reflections in the path before arriving at the patrol cameras:

1. DM2,
2. DM3,
3. piston mirror,
4. the dichroic that reflects the beams towards \(+y\) at an angle of approximately \(7^\circ\),
5. K-mirror K1,
6. K-mirror K2,

We may estimate the effect of the piston mirror and warm dichroics as follows: The beam direction before hitting the piston mirror is horizontal with an angle of 18.5\(^\circ\) relative to the \(x\) axis of the LBT coordinate system. We guess that the piston mirrors reflect the two beams strictly into the \(-z\) direction (although no such numbers appear to in the optical design documents), and then guess with a ruler from [16, Fig. 1] that the beams are reflected towards the two K-mirrors at angles of 8.5\(^\circ\) relative to the \(+y\) axis. The net effect of these two reflections is a rotation of the beam by \(-80^\circ\) (SX) or by \(+80^\circ\) (DX), without flip, always measuring angles on detectors facing the beams.

The K-mirror flips the component in its incidence plane. (It actually are three flips in the common incidence plane combined into one.) Before arrival at the first of the three mirrors of the K-mirrors, we project the star coordinates with (29) into the platform \(x-y\) coordinates and then with a passive rotation—rotation by the negative K-mirror angle \(m(\beta + \beta_0)\)—such that the second “up” component of the vector at the right of that matrix operator is in the common incidence plane of the three mirrors. Then flip the second component three times, but write down only one of the three \((1, -1)\) matrices because the product of two of them is the unit matrix:

\[
\begin{pmatrix}
1 & 0 \\
0 & -1
\end{pmatrix} \cdot \begin{pmatrix}
\cos[-m(\beta + \beta_0)] & -\sin[-m(\beta + \beta_0)] \\
\sin[-m(\beta + \beta_0)] & \cos[-m(\beta + \beta_0)]
\end{pmatrix}.
\]

(33)

\(\beta_0\) incorporates the effect that the nominal angles of the K-mirror motors are are not aligned with the horizontal coordinate system of the bench. After the last mirrors of the K-mirror we de-rotate with the inverse matrix to measure components again in the bench’s \(x-y\) system that does not depend on the K-mirror angle,

\[
\begin{pmatrix}
\cos[m(\beta + \beta_0)] & -\sin[m(\beta + \beta_0)] \\
\sin[m(\beta + \beta_0)] & \cos[m(\beta + \beta_0)]
\end{pmatrix}.
\]

(34)

The combined effect of the K-mirror is the product of these 3 matrices:

\[
\begin{pmatrix}
\cos[2m(\beta + \beta_0)] & \sin[2m(\beta + \beta_0)] \\
\sin[2m(\beta + \beta_0)] & -\cos[2m(\beta + \beta_0)]
\end{pmatrix}.
\]

(35)

\(^{10}\)The fact that the handedness of the \((A,a)\) system on both sides is the same is compatible with the equal handedness of the two axes in the PCS coordinate system, Fig. 6 and Fig. 8 in [13].
The appearance of the factor 2 in the arguments of the trigonometric functions illustrates that the beam rotates by 2\(\beta\) if the K-mirror axis rotates by \(\beta\).

At nominal angle of 0° the two K-mirrors should be at their negative limit switches, so the SX K-mirror reflections should be (almost) in the horizontal plane, and the DX K-mirror reflections (almost) in the vertical plane [17, Fig. 14]. Because according to eye witnesses the “almost up” positions are \(\approx 3^\circ\) (SX) and \(\approx 87^\circ\) (DX), we assume for the following analysis that [17, Fig. 14] is erroneous: it shows the positive and negative limit switches effectively swapped (as if their cables in the electronics had been swapped). In that case increasing the nominal motor angles means rotating the K-mirrors cw (looking down the beam observed from the warm dichroic), and rotating the patrol camera images also cw,

\[
m = \begin{cases} 
-1, & \text{HWS SX}, \\
-1, & \text{HWS DX}.
\end{cases}
\]  

This sign is equivalent to the negative slope in [18, Fig. 17].

Inside LN, the coordinate transformation between \((A,a)\) and \((x,y)\) in the Patrol Cameras is a cascade of transformations. The first is a combined rotation by the first four static mirrors in the bullet list above, a hybrid of the angles by which the elements are mounted on the bench. The second is the beam flip-rotation of \(2m(\beta + \beta_0)\) by the K-mirror.

We assume that read-out-directions of detectors are the “natural” ones and do not introduce further flips, only rotations; they are only represented by a homogeneous scale factor \(s_P\) plus shifts (32).

The four reflections are accumulated in a total angle \(\phi—\)which differs between SX and DX.

\[
s_P \begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix} = \begin{pmatrix} \cos \phi & -\sin \phi \\ \sin \phi & \cos \phi \end{pmatrix} \cdot \begin{pmatrix} \cos[2m(\beta + \beta_0)] & \sin[2m(\beta + \beta_0)] \\ \sin[2m(\beta + \beta_0)] & -\cos[2m(\beta + \beta_0)] \end{pmatrix} \cdot \begin{pmatrix} \cos a & \Delta A \\ \Delta a \end{pmatrix},
\]

\[
= \begin{pmatrix} \cos[\phi + 2m(\beta + \beta_0)] & \sin[\phi + 2m(\beta + \beta_0)] \\ \sin[\phi + 2m(\beta + \beta_0)] & -\cos[\phi + 2m(\beta + \beta_0)] \end{pmatrix} \cdot \begin{pmatrix} \cos a & \Delta A \\ \Delta a \end{pmatrix},
\]

\(37\)

We have written \(\cos a\Delta A\) to account for the shrinking of the horizontal scale as we point closer to the zenith.

The task of the calibration is to find \(\phi\) for both sides given correlated measurements of telescope motions \((\Delta A, \Delta a)\) and image motions \((\Delta x, \Delta y)\) on the patrol camera. The calibration takes for example the run with \(\Delta A = 0\), so (37) becomes

\[
s_P \Delta x = \sin[\phi + 2m(\beta + \beta_0)] \Delta a;
\]

\[
s_P \Delta y = -\cos[\phi + 2m(\beta + \beta_0)] \Delta a.
\]

\(38\)

\(39\)

The ratio \(\Delta y/\Delta x\) yields for the direction of the \(A\)-axis on the patrol cameras:

\[
\tan \phi^{(0)} = -\cot[\phi + 2m(\beta^{(0)} + \beta_0)].
\]

\(40\)

From the reference values cited above we deduce

\[
\phi + 2m\beta_0 = \begin{cases} 
-155.18^\circ, & \text{SX}, \\
-24.81^\circ, & \text{DX}.
\end{cases}
\]  

\(41\)
The values of $\phi$ and the centers of rotation $(x_{Pc}, y_{Pc})$ are stored as $\text{CFG.TRANS.WCSREFANG}$ and $\text{CFG.TRANS.BCNTR}$ in $\text{laos.sx.hws.drot.kMirror-dev.cfg}$ and $\text{laos.dx.hws.drot.kMirror-dev.cfg}$.

### 4.2.2 Guiding Offsets

For the guiding offsets forwarded to the IIF one needs the constants (41), (36) and the inverse of (37) to map differential motions $(\Delta x_P, \Delta y_P)$ on the patrol camera to sky coordinates:

$$
\begin{pmatrix}
\cos a \Delta A \\
\Delta a
\end{pmatrix} = A_{P \to T} \cdot 
\begin{pmatrix}
\Delta x_P \\
\Delta y_P
\end{pmatrix}.
$$

(49)
Inserting (27) into (49) we find the standard WCS matrix $C_{i,j}$ in the FITS headers for patrol camera images.

\[
\begin{pmatrix}
\cos \delta \Delta \alpha \\
\Delta \delta
\end{pmatrix}
= s_P
\begin{pmatrix}
-\cos p & \sin p \\
\sin p & \cos p
\end{pmatrix}
\cdot
\begin{pmatrix}
\cos(\phi + 2m\beta) & \sin(\phi + 2m\beta) \\
\sin(\phi + 2m\beta) & -\cos(\phi + 2m\beta)
\end{pmatrix}
\cdot
\begin{pmatrix}
\Delta x_P \\
\Delta y_P
\end{pmatrix}
= s_P
\begin{pmatrix}
-\cos(p + \phi + 2m\beta) & -\sin(p + \phi + 2m\beta) \\
\sin(p + \phi + 2m\beta) & -\cos(p + \phi + 2m\beta)
\end{pmatrix}
\cdot
\begin{pmatrix}
\Delta x_P \\
\Delta y_P
\end{pmatrix}
\tag{50}
\]

The fundamental principle of operation is that the de-rotation by the K-mirrors keeps $p + 2m\beta$ time-independent to freeze both images. It suffices to obtain $p$ and $\beta$ at a single point in time of the trajectory to compute the term $p + 2m\beta$; $\phi$ is the time-independent offset of (41). The software uses the simplest approach: it reads the parallactic angle $p$ and the initial point of a new trajectory $\beta$ once, at the start of the trajectory. These angles $p$ and $\beta$ are stored in the functions createTrajectory and getReady via setPangStrtAng and setMotStrtAng in laos-drot/src/Service/LaosDrotServiceWorker.cc in the properties DROT.SVC.VAR.PANG_STRT and DROT.SVC.VAR.MOT_STRT in laos.sx.hws.drot.derotation-svc.cfg and in laos.dx.hws.drot.derotation-svc.cfg. See Section 9.2 in [1] for corresponding considerations with the infrared camera.

### 4.3 Infrared Detector Images

#### 4.3.1 Orientation

Relative to the upright image of a (virtual) detector at the first focal plane above the platform (after the annular mirror), an even number of reflections pushes the beam to the infrared camera:

1. DM2
2. DM3, essentially combined with DM2 a horizontal sideways motion
3. piston mirror,
4. cold M1 upwards,
5. cold hyperbolic M2 downwards (as a function of the three tilt-focus motorized degrees of freedom),
6. wheel in front of the FFTS upwards, called the dichoric mirror.\[11\]

The image is not flipped relative to the usual astrometric maps, and in consequence GEIRS does not flip the image either. See the GEIRS manual section entitled “Coordinate Systems” for a full tracing.

#### 4.3.2 Derotation

During Com-5 it was observed that the binocular pupil image (using the pupil imager of the filter wheel on the infrared camera) turned ccw if the nominal angle of the infrared camera derotator \[11\]effectively a metal plate as long as the fringe tracker is not in use.
increased. So effectively the camera (if looking at its surface by an observer at the dichroic) is rotating clockwise (mathematically negative) if the nominal motor angle increases. The coordinate axis attached to the detector rotates but not the beam: a passive rotation by the motor angle.

To determine the value of `CFG.DIRECTION` in the configuration of the IR derotator, we map the sign of the derotator polynomials to motions of the infrared detector derotator by transponding the calculations of the SX GWS to the IR detector.\(^ {12} \) The GWS SE planes are flipped but the IR images are not; this induces one sign flip of the parallactic angle: Figure 3 is applicable, not Figure 11. If \( \dot{p} > 0 \) and the IR image rotates cw in Figure 3, we wish to freeze it by rotating the IR detector also cw. Combined with the sign deduced above, the nominal motor angle needs to increase. Considering in addition that the derotator polynomials have the opposite sign of the parallactic angle, Equation (63), we need to feed the IR derotator motor with the negated derotator polynomials, so `CFG.DIRECTION` is \(-1\) in that case:

\[
m = -1; \quad \text{IRCAM} \quad (51)
\]

### 4.3.3 WCS

GEIRS turns the IR detector image by 180° with the intend to deliver an image where North is up and East is to the left if the telescope points to the zenith. This is equivalent to zenith in the +y and the azimuth in the +x direction of the FITS coordinates. To determine the \( \delta \) axes of the world coordinate system, we have to move the \( a \) axis cw by the parallactic angle \( p \) and cw by the motor angle \( \beta_S \).

To measure any offset of the motor angle \( \beta_S \) relative to its nominal “middle” of zero degrees, 7 images of 2018-12-16 with the pupil imager were taken and angles fitted through the mid-points of the two pupils:

<table>
<thead>
<tr>
<th>File</th>
<th>ARCFILE</th>
<th>DROT</th>
<th>POS</th>
<th>fitted angle (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>c7a_0039.fits</td>
<td>ln.20181217.092111.fits</td>
<td>115</td>
<td>-13.89</td>
<td></td>
</tr>
<tr>
<td>c7a_0040.fits</td>
<td>ln.20181217.092229.fits</td>
<td>3344</td>
<td>13.59</td>
<td></td>
</tr>
<tr>
<td>c7a_0041.fits</td>
<td>ln.20181217.092348.fits</td>
<td>1729</td>
<td>-0.31</td>
<td></td>
</tr>
<tr>
<td>c7a_0042.fits</td>
<td>ln.20181217.092451.fits</td>
<td>115</td>
<td>-13.82</td>
<td></td>
</tr>
<tr>
<td>c7a_0043.fits</td>
<td>ln.20181217.092640.fits</td>
<td>115</td>
<td>-14.18</td>
<td></td>
</tr>
<tr>
<td>c7a_0044.fits</td>
<td>ln.20181217.092739.fits</td>
<td>1729</td>
<td>-0.31</td>
<td></td>
</tr>
<tr>
<td>c7a_0045.fits</td>
<td>ln.20181217.092852.fits</td>
<td>3344</td>
<td>13.59</td>
<td></td>
</tr>
</tbody>
</table>

A least squares fit through these 7 data pairs proposes the relation that the angle is \(-14.97° + 0.00853°/\text{step}\), such that the estimated offset of the order of 0.03° is negligible.

The transition from the instrument focal plane to the focal plane of the science camera rotates by the negative motor angle \( \beta_S \) (passive rotation of the image):

\[
\begin{pmatrix}
\Delta x \\
\Delta y
\end{pmatrix}_S = A_{F \rightarrow S} \cdot \begin{pmatrix}
\Delta x \\
\Delta y
\end{pmatrix}_F,
\]

(52)

where

\[
A_{F \rightarrow S} = s \begin{pmatrix}
\cos(-m\beta_S) & -\sin(-m\beta_S) \\
\sin(-m\beta_S) & \cos(-m\beta_S)
\end{pmatrix}
\]

(53)

\(^{12}\)so we have detector plane rotations, not active beam rotations...
converts plate scales $s = 1/(s_S s_F)$ and rotates the image by the motor angle. And setting $R_z = 0$ because the result should be the same for both sides by design:

$$
\begin{pmatrix}
\Delta x \\
\Delta y 
\end{pmatrix}_S = A_{F \rightarrow S} \cdot A_{E \rightarrow F} \cdot 
\begin{pmatrix}
\Delta \delta \\
\cos \delta \Delta \alpha
\end{pmatrix}
\cdot 
\begin{pmatrix}
\Delta x \\
\Delta y 
\end{pmatrix}_S .
$$

The pixel scale is $s_S \approx 0.00521$ as/px $\approx 0.1447 \times 10^{-5}$ deg.

By matrix inversion

$$
\begin{pmatrix}
\Delta \delta \\
\cos \delta \Delta \alpha
\end{pmatrix} = s_S \begin{pmatrix}
\sin(p + m\beta) & \cos(p + m\beta) \\
-\cos(p + m\beta) & \sin(p + m\beta)
\end{pmatrix} \cdot 
\begin{pmatrix}
\Delta x \\
\Delta y 
\end{pmatrix}_S .
$$

By exchanging the two equations (because WCS considers $\alpha$ the first and $\delta$ the second coordinate), equivalent to swapping the lower and upper row of the matrix, the WCS is

$$
\begin{pmatrix}
\cos \delta \Delta \alpha \\
\Delta \delta
\end{pmatrix} = s_S \begin{pmatrix}
-\cos(p + m\beta) & \sin(p + m\beta) \\
\sin(p + m\beta) & \cos(p + m\beta)
\end{pmatrix} \cdot 
\begin{pmatrix}
\Delta x \\
\Delta y 
\end{pmatrix}_S .
$$

### 4.4 User Interface

#### 4.4.1 plotSkyTrack.py

A prediction of the parallactic angle of the future is obtained by calling `plotSkyTrack.py`, which generates the GUI of Figure 6. This GUI feeds on a regular polling of the IIF information. It predicts angles by plugging the current $(\alpha, \delta)$—assuming sidereal tracking—and LBT coordinates into astroplan. It is meant to give a hint of how long the derotator stages may stay tracking before hitting one of their end switches.

#### 4.4.2 Star catalogues

##### 4.4.2.1 Linux command line

There is some auxiliary software handling local star catalogues in the format shown in [http://wiki.lbto.org/bin/view/Commissioning/LBTOStarCatalogs](http://wiki.lbto.org/bin/view/Commissioning/LBTOStarCatalogs). These ASCII files may contain comments, which means lines that start with hashes (#) or are entirely empty. All other lines define a list of target coordinates, one per line; they start with a name and contain information largely equivalent to the preset information: $\alpha$ and $\delta$, proper motions in both (milliarcseconds per year), epoch and equinox, a magnitude in R2, star color in $B - R$, and the distance (arcseconds) on the sky away from the first target. These fields are separated by white space.

The name of the cannot contain blanks (which are field separators) and should not contain underscores.

---

13 Allowing blank lines seems to be an extension to the LBTO format, which apparently does not allow those.

14 Because in a handshake between licsStarcat and the SE servers a name convention has been introduced in COM-8 where the name followed by an underscore and the magnitude is used to tag stars. This compound pseudo-name would be confusing if the star name might have underscores...
The proper motion in $\alpha$ is $\dot{\alpha}\cos\delta$, including the same scale factor of the cosine as the star definitions in the IIF. Note that recently some files have been distributed which are erroneous and do not follow that format; they contain other color indices at places where the distance should have been stated.

licsPreset sends $\alpha$ and $\delta$, the proper motions, magnitudes and color indices to the telescope, presumably to apply atmospheric refraction corrections to positions (Section 5.1), see Section position2 in [19]. licsPreset adds 0.5 $\mu$m for the wavelengths and recomputes distances to the first star where needed, so that column of star catalogs does not need to be correct.

The LN convention is that the topmost star is the target star in the field center. The guide and AO stars for patrol camera, GWS and HWS are implicitly defined by the 1 and 3 arcmin cuts in distance defined by the central hole in the annular mirror [20]. SE positions for stars farther than 1 arcmin from the target star are computed with mirror rotations, flips and plate scales for the GWS, those closer than 1 arcmin for the HWS.

The magnitudes are relevant for some GWS mockup images generated by licsStarcat. If one wants to track on an (infrared) star that is invisible or absent in the (AO) star catalog, one ought to add it at the top of the file with a faint V-magnitude of (say) 22 such that it remains basically invisible in the mockup images. Note that the Telescope Pointing System uses the wavelength in the star catalog for example for dispersion corrections of the altitude; this value and proper motions should be maintained for such infrared targets in the catalog.

The LN software has a program licsStarcat to deal with these files, Section 4.6. The output of the program consists of a star catalogue in the format outlined above.

You can prepare star catalogues at any time far away from the telescope on any computer.

### 4.4.2.2 Precession

Proper motions and precession from the J2000 coordinates to the equatorial coordinates of the epoch are implemented by calling the iauAtci13 function of the SOFA library.
4.4.2.3 Star Enlargers

A star in the field is mapped into the star enlarger’s \((x, y)\)-plane. We first project its position \(s'\) into the plane tangential to \(s\) at the target—where the target is placed in the center of the SE’s coordinate system:

\[
\hat{f}s' = s + \Delta\alpha e_\alpha + \Delta\delta e_\delta.
\]

The three factors \(\hat{f}\), \(\Delta\alpha\) and \(\Delta\delta\) are computed by the dot products with the aid of \(s \perp e_\alpha\), \(s \perp e_\delta\):

\[
\hat{f}s' \cdot s = 1; \quad \hat{f}s' \cdot e_\alpha = \Delta\alpha; \quad \hat{f}s' \cdot e_\delta = \Delta\delta.
\]

Because the angle between \(s\) and \(s'\) is < 3 arcmin set by the outer radius of the annular mirror, the inverse of its cosine is \(1/\hat{f} \geq 0.9999996\).

4.4.2.4 Star Enlargers GWS

The annular mirror flips images right-left, so the sky orientations relevant to the GWS are in Figure 11. Supposed the coordinate system of the SE’s is
Figure 8: Assignment of Star Enlargers in the focal plane of SX GWS. There is obviously more common tilt in the associated matrices than in Figure 7; tilts of that kind do not demonstrate rotations of the SE frames relative to the platform, because they are effectively recalibrated by applying the rotation offsets $\beta_0$ in (61).
Figure 9: Assignment of Star Enlargers in the focal plane of DX HWS.
Figure 10: Assignment of Star Enlargers in the focal plane of SX HWS.
Figure 11: Image orientation of a camera in the GWS focal planes. Obtained from Figure 3 by a right-left flip to account for the reflection by the annular mirror. The action of the derotating motor is not yet taken into account. Because the image is flipped, the zenith direction is found by starting at $\delta$ and rotating cw through the parallactic angle $p$. If the time derivative of the parallactic angle is $\dot{p} > 0$, the image rotates ccw.

horizontal with $+x$ pointing right in the image plane, and supposed the motor angles have no further offset and start at angle zero, this figure represents the frozen equatorial coordinate systems on the GWS SE’s.

Taking into account the flip of the $x$-values (horizontal in the bench system) in Figure 11, the coordinates for the SE in the GWS are given by switching signs in the upper row of the matrix by further multiplication with

$$
\begin{pmatrix}
-1 & 0 \\
0 & 1 \\
\end{pmatrix}
$$

(60)

If the center of the SE (bearing) is not at the center of the beam, but has coordinates $(c_x, c_y)$ in the beam system (short vector in Figure 12), one must subtract that vector to compute the position centered in the bearing system. If the GWS motor rotates ccw—viewed from the annular mirror towards the SE’s—the $(x, y)$ image axes rotate ccw by an angle $m\beta + \beta_0$, such that the final image coordinates are given by a cw (or passive) rotation with the negated angles:

$$
\begin{pmatrix}
x \\
y \\
\end{pmatrix}_G = 
\begin{pmatrix}
\cos[m\beta - \beta_0] & -\sin[m\beta - \beta_0] \\
\sin[m\beta - \beta_0] & \cos[m\beta - \beta_0] \\
\end{pmatrix}.
\begin{pmatrix}
-1 & 0 \\
0 & 1 \\
\end{pmatrix}.
\begin{pmatrix}
\Delta x \\
\Delta y \\
\end{pmatrix}_F - 
\begin{pmatrix}
c_x \\
c_y \\
\end{pmatrix}
$$

(61)

The sign factor $m = \pm1$ is introduced to let the angle $\beta$ in the motor coordinate system be positively correlated with the nominal angle; $m$ keeps track how the SE orientations are related to that internal coordinate system of the electronics, gears and switches and the sign choice of TRANS.DEGREE in the files laos.dx.gws.drot.bearing-dev.cfg and laos.sx.gws.drot.bearing-dev.cfg. $\beta$ are
Figure 12: The model of the mismatch between the center of rotation of the GWS bearing and the beam center (short arrow). The axes of the SE are rotated by an angle $m\beta + \beta_0$ relative to the beam and to the horizontal platform coordinates (dashed angle).

The angles shown to the observers; $m\beta$ increases if the motor turns ccw viewed from the annular mirror. The (signed) offset $\beta_0$ acknowledges that for a motor at 0 steps the GWS $+x$ axis may not be horizontal but have some inclination. The task of the derotation is to keep the positions fixed, constant in time $t$, as the parallactic angle changes:

$$\phi_0 + m\beta + \beta_0 = R_z - p(t) + m\beta(t) + \beta_0 + 90^\circ, \quad \frac{d}{dt}(p(t) - m\beta(t)) = 0. \quad (62)$$

(This works only if the runout $(c_x, c_y)$ is zero.) This is as expected from Figure 11: if $\dot{p} > 0$, the image rotates ccw, and the motor must rotate GWS ccw to follow, so $m\beta > 0$. Experience from recent experimentation is that the derotator polynomials $r(t)$ had signs of their time derivative that had the opposite sign of the time derivative of the motion in units of steps, $s(t)$, both for SX and for DX:

$$\text{sgn } \dot{p}(t) = -\text{sgn } \dot{r}(t). \quad (63)$$

Experience from Pathfinder (DX, see [21, p. 47]) shows that a sign flip was introduced in the LN derotator software running the motors such that the derivative of the motion in units of steps, $s(t)$, was opposite to the derotator polynomial’s angles,

$$\text{sgn } \dot{s}(t) = -\text{sgn } \dot{r}(t), \quad (DX) \quad (64)$$

such that $dp/dt$ and $ds/dt$ had the same sign. [This corresponds to $-1$ for DROT.SVC.CFG.DIRECTION in the configuration files laos.dx.gws.drot.derotation-svc.cfg and laos.sx.gws.drot.derotation-svc.cfg.] This is compatible with (62).

By the current (irrational) sign definitions of the factors TRANS.DEGREE in the configuration files
we have for \( \text{sgn } s = m \text{ sgn } \beta \)

\[
m = \begin{cases} 
+1, & \text{GWS SX;} \\
-1, & \text{GWS DX.}
\end{cases}
\]  

(65)

This leads to the puzzling experience that during derotations both motors will turn into the same directions, but the nominal angles in the user interface of the GWS bearing increase on one side and decrease on the other.

Obviously it suffices to record the sum \( p(t) - m\beta(t) \) at one point in time to recover the matrix and the positions; the derotator services do this at the start of the trajectory. An advance preview is possible that allows SE configuration even before the derotator service started if motor start positions are quasi fixed and parallactic angles are known in advance (for example by fixing the target and the start time).

### 4.4.2.5 Star Enlargers HWS

We assume by reverse engineering that the SE of the HWS experience no flip—because the patrol camera images were measured to be flipped, Section 4.2.1, and one additional dichroic relays the beam into the AO channel.

The coordinate transformation from sky positions to the SE’s two-dimensional coordinates applies scale factors of roughly 0.802 mm/arcsec.\(^\text{15}\) The 802 \( \mu \)m are compatible with the 96 mm of the 2 ar-cmin of [22, 10.4.2]. Both values ought be compatible with the numbers for \text{SE.SVC_CFG.OVERLAY.FIELD_OF_VIEW} in \text{laos.dx.gws.se.starEnlarger-svc.cfg}. A fit to 17 measured SE positions on SX during Com-2 proposes to use values that are smaller by a factor 1.012, and this matches much better with the 601.75 scale of SX [23, p. 176] and 600.6 of DX [23, p. 178].

The transformation from patrol camera to SE units is [18, Sec. 6.5]

\[
\begin{pmatrix} x \\ y \end{pmatrix}_H = A_{P\rightarrow H} \cdot \begin{pmatrix} x \\ y \end{pmatrix}_P + \begin{pmatrix} c_{Hx} \\ c_{Hy} \end{pmatrix},
\]  

(66)

where the input are horizontal and vertical pixels on the patrol camera and the output microns of the FP20 image. The matrices for the two sides have units of microns per pixel:

\[
A_{P\rightarrow H} = \begin{pmatrix} 106.131 & 41.487 \\ 41.223 & -105.846 \end{pmatrix}, \text{SX} \quad \begin{pmatrix} 112.474 & -22.77667 \\ -22.857 & -112.312 \end{pmatrix}, \text{DX}.
\]  

(67)

The two determinants are negative because the patrol camera and SE image are relatively flipped. The inverse matrices are

\[
A_{P\rightarrow H}^{-1} = \begin{pmatrix} 0.00817738 & 0.00320517 \\ 0.00318478 & 0.00819939 \end{pmatrix}, \text{SX} \quad \begin{pmatrix} 0.00853903 & -0.00173781 \\ -0.00173170 & -0.00855134 \end{pmatrix}, \text{DX}.
\]  

(68)

The offset mainly indicates the translation from FITS coordinates to SE center-coordinates.

\[
\begin{pmatrix} c_{Hx} \\ c_{Hy} \end{pmatrix} = \begin{pmatrix} -70134 \\ 24868 \end{pmatrix}, \text{SX}, \quad \begin{pmatrix} -46862 \\ 58402 \end{pmatrix}, \text{DX}.
\]  

(69)

Side note: Normalizing to unit determinant by dividing all 4 entries through the square root of the absolute value of the determinant—hence removing the scale factor of microns per pixel—the...

\(^{15}\) 613 \( \mu \)m have been taken from [20] for the GWS and have been scaled with the ratio of the \( F \)-fratios 20/15.28 to a HWS figure.
$A_{P \rightarrow H}$ matrices are
\[
\begin{pmatrix}
0.932859 & 0.364655 \\
0.36233 & -0.93033
\end{pmatrix}, \quad \text{SX} \quad \begin{pmatrix}
0.9807149 & -0.198601 \\
-0.1993 & -0.9793
\end{pmatrix} ; \quad \text{DX}.
\] (70)

These matrices are modelled as
\[
\begin{pmatrix}
\cos \gamma_1 & -\sin \gamma_1 \\
\sin \gamma_1 & \cos \gamma_1
\end{pmatrix} \cdot \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \] (71)

The diagonal matrix switches the vertical component between the SE and the patrol camera, representing the dichroic that reflects the beam upwards. The arguments of the two eigenvalues of the two matrices are the rotation angles (in radians), the relative angle of rotation from patrol camera to SE coordinate systems:
\[
\gamma_1 = \begin{cases} 
+0.372\text{rad} = 21.31^\circ ; & \text{SX} \\
-0.200\text{rad} = -11.48^\circ & \text{DX}
\end{cases}
\] (72)

One would expect angles near ±8.5° here because apparently the box with the AO cameras (and SE’s) is aligned with the x-y grid of the platform. Actually the numbers are different, because the cylindrical tubes of the patrol cameras and their front optics can be inserted rotated by any angle into the associated structures (not only by multiples of 90°).

Note that all these transformations do not take into account the axis runout of the K-mirrors, which is of the order of 40 pixels (6 arcseconds) in diameter on SX [18, Fig. 17].

4.4.2.6 HWS to GWS Offloading  The transformation of HWS to GWS coordinates works as follows: patrol camera coordinates are derived via the inverse of (66). Instrument focal plane coordinates are from there computed with the inverse of (43), and finally GWS coordinates with (61).

The parallactic angle is not needed here, but the two nominal angles and offsets of the K-mirror and GWS barrel.

4.4.2.7 Non-common Path  The transformation of HWS star enlarger to infrared/science camera coordinates works as follows: patrol camera coordinates $(x, y)_P$ are derived via the inverse of (66). Instrument focal plane coordinates $(x, y)_F$ are from there computed with the inverse of (43) utilizing the constants (41), the nominal K-mirror angles $\beta$, and the signs (36). Finally science camera coordinates $(x, y)_S$ are computed with (52) using the nominal angle $\beta_S$ of the motor that rotates the science camera.

The relation between star enlarger coordinates to CCD coordinates on the wavefront sensors is not part of this manuscript because unknown to the author. Apparently there is only one further reflection (off the pyramid) which flips along some axis depending on the way the pyramid relays the beam to the CCD, and there is the standard free parameter how the CCD surface is mounted in the mechans. The reference plate scale is 27 pixels for 2 arcmin on the sky [22, Table 13].

4.5 Notes on the IIF

The general description of the software interface is Biddick’s 481s013 [19].
4.5.1 Wait For End-of-slewing

The end of the slewing transition after a PresetTelescope is indicated by IIFAllOnSource of the data dictionary changing to 1. The two individual IIFAzOnSource and IIFElOnSource will independently reach that state earlier.

4.5.2 Offset of the Rotator Polynomials

While slewing, the ParAngle of the data dictionary is apparently changed with the temporary pointing on sky. The angles of the GetRotatorPolynomial are those associated with the (intended, look-ahead) target position. So to correlate the rotator polynomial angles with the parallactic angle, one either needs to wait until the telescope is “on source,” or take the parallactic angle from R_\text{TargetParAngle} and L_\text{TargetParAngle} of the data dictionary (with a due conversion factor of 180/\pi). This is demonstrated with the following table which shows data during a test run on 2017-02-02, all angles in degrees (in POSITION mode of the preset):

<table>
<thead>
<tr>
<th>MJD UTC</th>
<th>ParAngle</th>
<th>R_TargetParAngle</th>
<th>OnSource</th>
<th>(\sum) angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>57786.74725407407</td>
<td>17:55:59.410</td>
<td>-67.775</td>
<td>177.150</td>
<td>0</td>
</tr>
<tr>
<td>57786.75008483796</td>
<td>18:00:04.057</td>
<td>-13.883</td>
<td>139.645</td>
<td>0</td>
</tr>
<tr>
<td>57786.75115641204</td>
<td>18:01:36.742</td>
<td>-146.999</td>
<td>138.788</td>
<td>0</td>
</tr>
<tr>
<td>57786.75254762731</td>
<td>18:03:36.935</td>
<td>137.697</td>
<td>137.697</td>
<td>1</td>
</tr>
<tr>
<td>57786.75476923612</td>
<td>18:06:48.874</td>
<td>135.998</td>
<td>135.998</td>
<td>1</td>
</tr>
<tr>
<td>57786.74827083341</td>
<td>18:12:04.905</td>
<td>133.313</td>
<td>133.313</td>
<td>1</td>
</tr>
<tr>
<td>57786.76413278935</td>
<td>18:20:17.815</td>
<td>129.393</td>
<td>129.393</td>
<td>1</td>
</tr>
<tr>
<td>57786.76666434028</td>
<td>18:23:56.649</td>
<td>127.750</td>
<td>127.750</td>
<td>1</td>
</tr>
<tr>
<td>57786.7683262037</td>
<td>18:26:20.042</td>
<td>126.705</td>
<td>126.705</td>
<td>1</td>
</tr>
<tr>
<td>57786.77862875001</td>
<td>18:41:10.308</td>
<td>120.715</td>
<td>120.714</td>
<td>1</td>
</tr>
<tr>
<td>57786.78041345167</td>
<td>18:43:44.444</td>
<td>119.758</td>
<td>119.757</td>
<td>1</td>
</tr>
<tr>
<td>57786.78364978009</td>
<td>18:48:24.068</td>
<td>118.076</td>
<td>118.076</td>
<td>1</td>
</tr>
<tr>
<td>57786.7851730324</td>
<td>18:50:35.736</td>
<td>99.271</td>
<td>73.039</td>
<td>0</td>
</tr>
<tr>
<td>57786.78871634259</td>
<td>18:55:41.792</td>
<td>72.241</td>
<td>72.240</td>
<td>1</td>
</tr>
</tbody>
</table>

The last column in that table shows the sum of the first (leading) coefficient of the polynomial of GetRotatorPolynomial of the right side and the value of R_\text{TargetParAngle} read from the data dictionary. The top value was obtained with an incomplete preset send only to the SX and most likely refers to an older state left from a previous LUCI run.

We take the sum of the parallactic angle and the rotator angle to get numbers that are (almost) constant in time; this sign combination is the effect of assigning a role of “annihilating” the effect of the parallactic angle to the rotator angles as discussed above.

There is a magic offset angle between the parallactic angle of the target and the rotator polynomial of \(\approx 248.8^\circ\). (The jitter in the sum of the two angles is most likely a result of a time jitter of the order of 3 seconds between reading the data dictionary values and then obtaining first the rotator polynomials of SX and then the rotator polynomials of DX.) By which reasoning would the telescope software think that at zero parallactic angle there is an angle of 248.8\(^{\circ}\) in the LN path? In a software test run in April 2014 this sum was 248.4\(^{\circ}\) and 248.85\(^{\circ}\). No such angle is mentioned in the coordinate description [13] or the wiki. The most likely explanation is that the angle is 270\(^{\circ}\) - \(\tau_k\), where \(\tau_k\) was still configured in the PCS with the obsolete Pathfinder value of 21\(^{\circ}\) as of
June 2017. This value within the PCS was corrected to 18.5° in Oct. 2017.

So it is possible that the PCS sets the derotator polynomial angle at the first preset equal to the parallactic angle of the target (as if already on the sidereal track)—adjusted for the beam rotation that is basically a fixed angle proportional to how far M3 bends the beam away from the center-line between the two telescopes.

The derotator angles of the interface are a result of two parameters maintained inside the PCS (J. Hill, priv. commun., 2017-01-26)

- **LEFTZEROPOINT/RIGHTZEROPOINT** to negotiate a direction of “North up” on some (representative) detector of an instrument,
- **LEFTSCALE/RIGHTSCALE** a sign of the rotator trajectory. If set to +1 this is the same as the LUCI direction.

We note that some technical documentation on the rotator polynomials [24] measures time in TAI MJD whereas the software interface [19] uses UTC MJD. The contemporary difference of 37 seconds in early 2017 between both time scales at the times relevant to the table and polynomial speeds less than of 0.009° per seconds during the hour of the measurement could account for 0.3° at most. We will assume that both documents are correct while the PCS well takes care of the time scales.

### 4.5.3 Direct Access via Python

Creation of a ICE proxy in Python that allows to send any of the telescope commands via the IIF is shown as an example in `lnsw/ln/ltcs/test/iif/lbto/LbtoIifExample.py`. The main steps are

- to initialize ICE,

  ```python
  import Ice
  import lbto
  ic = Ice.initialize(sys.argv)
  ```

- to get a proxy to an IIF server,

  ```python
  ip = ic.stringToProxy("Factory -t:default -h iif.mountain.lbto.org -p 10000")
  ```

- then to connect to the server by deciding whether this should act on the left, right or both arms of the bentGregorianBack stations

  ```python
  iif_sdx = iif_factory.create('LN_IIF','bentGregorianBack both','LINC')
  ```

- define at least a pair of stars which are (formally) a guide star and a target star for the preset

- start a sequence of commands

---

16 J. Hill, priv. commun, citing LEFTTAA and RIGHTTAA = 291, 2017-06-30
17 J. Hill, priv. commun, setting LEFTTAA and RIGHTTAA = 288.5, 2017-10-10
18 That would introduce the parallactic angle by queer assumptions with a wrong additive offset that does not match the sign choice of the velocities of the polynomials.
• logout from the interface
  
ic.destroy()

A snapshot of the most important contents of the data dictionary and a coarse overview of the Rotator Polynomials over the next minute is obtained with `lbtoSnapshot.py`, see `lnsw/ln/ltcs/src/iif`.

### 4.6 Commands

The following overview of commands on the Linux shells is reproduced in a small font, because it is usually read by calling

```
info linc
```

from the Linux command line on a computer where the software is installed. If that command does not show a menu of the command lists, make sure that the standard search path for the `info` command includes `$INSROOT/share/info`:

```
echo $INFOPATH
```

This variable is usually set in `$HOME/.bashrc`, see Section 2.1. If someone destroyed that `$INFOPATH` shell variable, one may also call this with a full path:

```
info ~/lnsw/ln/lics/doc/linc.info
```

or with an explicit directory search path:

```
info -d $INSROOT/share/info linc
```
# Linc-Nirvana Linux Command Interface

Max-Planck Institute of Astronomy, Heidelberg
3 February 2020

Richard J. Mathar
mathar@mpia.de

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Overview

Command interfaces to Linc-Nirvana, based on the TwiceAsNice Software of MPIA. This documentation is maintained in HTML at URL https://svn.mpia.du/gnu/TwiceAsNice/branch/instable/in/lircs/doc/.

1 AutoGuider.py

AutoGuider.py -sx -st lircsStarcat

Starts the auto-guider and Patrol Camera monitor on either the SX or the DX side. Guiding both sides is achieved by calling the AutoGuider.py twice with two different arguments of the side option. This file with the starcatalog can be specified with either the long option --targFile or with the short option -t.

1.1 Buttons and Use

To start the functionality, the usual first action is to press the Monitor button which starts reading patrol camera frames of the associated side and showing them in the main window on the right. (In cosmetics and monitoring stage was started automatically, but that automation was removed later on the request of the PI arguing that this was not expected and that the user should edit the configuration file. This is certainly an exception; the other down Linc-Nirvana services start without expecting the user to modify configuration parameters.) For now, this requires that the group of IF servers at the bottom of monit files (http://linc.linc.in:2812) is running (although this should not be necessary, because reading the cameras is some internal facility that has no interface to telescope software). Depending on the computer environment in which the command is run, the program may decide to run a new instance of the development mode. In that case it prints the message

```
Trainless mode
```

to standard output when it is started. Here Trainless means without accessing sources of TwiceAsNice (TwA).

The Monitor button is labelled as

- Monitor
  - if pressing it starts reading patrol camera images
- Stop Monitor
  - if pressing it stops reading patrol camera images

Pressing the AutoGuide button enters a mode of guiding (sending offsets/corrections to the telescope) by analyzing the patrol camera images. The button can only be pressed if the Monitor is active (because otherwise there would be no new images to analyze).

3 acquisitionFindReferenceStars.py

acquisitionFindReferenceStars.py

3 acquisitionSpiralSearch.py

acquisitionSpiralSearch.py

Print the time right now in the local timezone of Phoenix/Azizona. This is mainly a shortcut for people working in Germany or on computers with a UTC default time zone.

6 cleanupConfig.py

7 indiserver

The indiserver is specified and started on the lircs.linc computer to respond to property queries from the FACSUM (facility summary) clients with the aim to monitor LINC specific parameters that may be useful for LBTI handling. In particular the temperature and pressure parameters of LINC-INFRAVA are of interest in emergency power supply cases.

7.1 Compilation

The compilation within LINC-NIRVANA consists of two parts:

- compilation of the standard indiserver binary into $SINSHOOT. This happens by compiling the lincs library and then compiling the indiserver. The standard steps are

```
cd ~/lnsw/ln/3rdparty
autoreconf -iv
./configure --prefix=$SINSHOOT
make install
```

This is to be done because the 3rdparty subdirectory of the source code is usually not included into the auto-tools of the standard make.

This compilation will skip a lot of the default indiserver installation because the LINC-NIRVANA case does setup configure or initialize devices through the indiserver but only passive queries of some parts of the property tree.

The lincs indiserver libraries and headers end up in $SINSHOOT/lib, $SINSHOOT/include and so on.

- compilation of a device "LINC"

```
cd ~/lnsw/ln/lircs
make install
```

This will create $SINSHOOT/bin/indi_linc_lircs. Note that the source code tree is figure out whether the indiserver has been compiled: if this was not the case, no valid indi_linc_lircs file will be created and the indiserver will die after some failed attempts to connect to that “device”

The standard use case on the jenkins test installation is that the indiserver is compiled and started on lircs.linc with indiserver $SINSHOOT/bin/indi_linc_lircs &

The indiserver is started on lircs.linc with indiserver $SINSHOOT/bin/indi_linc_lircs & and can be tested then with

indiserver -t getprop

3.2 Implementation

The LINC-NIRVANA INDI device responds to "get property" queries of some client (which supposedly is the FACS3) by looking at the properties and values found in the $LINC-INFRAVA/indi_getprop

```
giru/mh charger/Nirvana.nirvana 2
```

located in the GEIRS directories (For that reason it is futile to call the indiserver on another computer, because GEIRS is only compiled and living on lincs.linc). This is enforced by the indiserver which assembles some of the LINC-NIRVANA property values. So the set of properties that are reported by the INDI server is not configured in some extra files, but is just a reassembled set of the very same set of values that are assembled for the header keywords of the infrared detector FITS files.

The LINC-NIRVANA INDI device does not report any values that are assembled from the ifawe, which reflects the telescope status. (That would be futile, because FACS3 is already aware of these). As implemented, the LINC-NIRVANA INDI device contains no de-

8 initStages.py

9 laos.dx.gws.drot.deotation-svr_GUsh.sh

Control [start, stop,...] the derotator motor for the GWS on the DX side. Note that the GUI will not show the buttons and fields unless the associated service has been started for example with monit or with rchbardash start laos.dx.gws.drot.deotation-svr GUsh.sh
opposite of a good human-machine interface, where the red colors should be reserved for erroneous states and the green colors for the good working states.

control (start, stop,...) the derotation (K-mirror) motor for the HWS on the DX side. Note that the GUI will not show the buttons and fields unless the associated service has been started for example with monit or with

```
rcbasdard.sh start laos.dx.hws.drot.derotation-svr
--CONFIG=laos/dx/hws/drot/laos.dx.hws.drot.derotation-svr.cfg
```

control (start, stop,...) the derotation motor for the HWS on the SX side. Note that the GUI will not show the buttons and fields unless the associated service has been started with monit or with

```
rcbasdard.sh start laos.sx.hws.drot.derotation-svr
--CONFIG=laos/sx/hws/drot/laos.sx.hws.drot.derotation-svr.cfg
```

The Python script lbtoEquat2Horiz.py converts horizontal coordinates (altitude and azimuth) to equatorial coordinates (right ascension and declination) and vice versa. The transformation is correct at time 'now' when the script is executed and for the LBTO geographic coordinates.

This is meant to give a quick idea of how close the target may be to the horizon. The azimuth convention is N=0, E=+90 as elsewhere in the software. The functionality does not depend on or connect to the IIF.

The transformation from equatorial to horizontal is done with

```
lbtoEquat2Horiz.py
```

where right ascension and declination are either provided in degrees or in the hex-decimal hour and degrees format.
The reverse transformation from horizontal to equatorial is done by adding the option `-r`, which is echoed on output, not only those with errors. This gives an feedback on which files have actually been checked. The option `-p` is used to print these catalog files for the most common error that is frequently found in catalog files of the LN commissioning; it triggers that every subsetting `nan` is substituted in place by the string `0 0` in every catalog file.

61 licsCatChk.sh
licsCatChk.sh [-v] [-p] [catfile catfile2 ...]

The Linc-Nirvana star catalog files in the directories listed on the command line are individually checked for syntax errors with `licsCatChk` See Chapter 60 LincCatChk, page 10. The script actually assesses every file with the suffix cat = a catalog file to be tested. This is a convenient wrapper for the `licsCatChk` which only checks files but not entire directories, and which does not modify files. The option `-v` can be used for more verbose output: such file with the suffix cat is echoed on output, not only those with errors. This gives an feedback on which files have actually been checked. The option `-p` is used to print these catalog files for the most common error that is frequently found in catalog files of the LN commissioning; it triggers that every subsetting `nan` is substituted in place by the string `0 0` in every catalog file.

If there are no directories or files names on the command line, the current working directory is checked. For example:

cd /data/2019-10-Com9
licsCatChk.sh -v targets targets2

deletes files from the command line one by one, even if the catalog file passes all these tests. If the option is not used, only erroneous files are reported.

62 licsFmodehead
licsFmodehead fitsfile.fits [tplhdrfile1.tpl] [tplhdrfile2.tpl] ...

The file fitsfile.fits is changed by adding the template header lines in tplhdrfile1.tpl and further optional files into the primary header. For the valid syntax of template header files consult the cfitsio programmer’s manual.

63 licsGwsMockup
licsGwsMockup [-s] [sx|dx] lbtocatfile
The program generates a fake image of a virtual camera in the focal plane of the SX or the DX side (exactly one of which must be selected by the `-s` switch) by rendering the catalog file (last command line parameter) with the simulator of the sky model. This is done by using the `fitsfile` parameter, which can only be used, if the catalog file passes all these tests which are respectively found in catalog files of the LN commissioning; it triggers that every subsetting `nan` is substituted in place by the string `0 0` in every catalog file.

64 licsLogMergeAllHosts.sh
This shell script gathers the log-file lines on the level of INFO on the LN hosts (host, host2, lincs...), sorts them according to date and time, eliminates the coloring, and copies the merged file into file in `$INSROOT/var/log/lincs` which is subsequently found in catalog files of the LN commissioning; it triggers that every subsetting `nan` is substituted in place by the string `0 0` in every catalog file.

65 licsOffset
The command moves the telescope and/or a subset of star enlarger arms at the same time defined by a stroke and direction in the equatorial system (in sky coordinates).

65.1 Offset Telescope
licsOffset [-t] [target] [raoffsetarcsec] [decoffsetarcsec]
licsOffset [-t] [server] [-a] [index] [raoffsetarcsec] [decoffsetarcsec]

If the switch `-t` is used, this sends two differential pointing offsets to the telescope, an offset in right ascension and an offset in declination. The offset in RA is not the bare offset in the right ascension, but it includes the cosine of the declination (as usual for proper motion catalogs). The declination offset is calculated with the GSC catalog of the declination coordinates of the RA in the declination, not the cosine of the declination itself, which is used for proper motion catalogs. The offset in RA is the sum of the offsets in the RA and the Declination, not the sum of the offsets in the RA and the Declination.

licsOffset [-t] [server] [-a] [index] [raoffsetarcsec] [decoffsetarcsec]

When the switch `-a` is used, the server defines to `licsFmodehead`, which is the standard setup of the telescope on the mountain. Otherwise one may use `-d` to use a different local host directly by changing the template header lines in file tplhdrfile1.tpl.

65.2 Offset Star Enlargers
licsOffset [-v] [-s] [-a] [index] [raoffsetarcsec] [decoffsetarcsec]
licsOffset [-v] [-s] [-a] [index] [raoffsetarcsec] [decoffsetarcsec]
licsOffset [-v] [-s] [-a] [index] [raoffsetarcsec] [decoffsetarcsec]

When the switch `-a` is used, the server defines to `licsFmodehead`, which is the standard setup of the telescope on the mountain. Otherwise one may use `-d` to use a different local host directly by changing the template header lines in file tplhdrfile1.tpl.
Chapter 67: licsPreset

65.3 United operation

The command line options -t, -s are commonly combined. See for example

```
licsOffset -t -s all -0 5.5
licsOffset -t -s dx -0 0.0 -3.3
licsOffset -t -s all -0.2 2.2
licsOffset -t -s ax 0.0 0.1 5.5
```

The command uses the same library as licsStarCat Chapter 71 (licsStarCat), page 24, and licsPreset Chapter 67 [licsPreset], page 15, to compute the image transformations. The offsets for the star enlargers are forwarded to licsOffset.pt see Chapter 60 [licsSE Offset.pl], page 23.

66.2 Support Locating Stars in PCam/Autoguider

```
licsPreset [-b] [-s] [-O] cat
```

If the program is called with three trailing parameters (as shown) it displays the Patrol Camera image of that side with def, assumes that

1. the current R-mirror angle (in degrees) is as given in the -s,
2. that the current parallactic angle (in degrees) is as given in the option -p, and that the final three arguments are
3. the current right ascension in degrees
4. the current declination in degrees
5. the star catalog file in the LBIT format for the current pointing.

It shows the Patrol Camera image (frozen, at the time of the call) as is, which means showing the sky flipped and rotated in the opposite direction (in RA and Dec) to compensate for the associated shift of the image plane, with the projection to stay locked on target stars even if the telescope moves. In a perfect world with instantaneous effects without delays and precise SE positioning, that action would allow keeping the AO loop closed while dithering or taking flat fields on the infrared detector.) So the expected invocation is that the -t and the -s are used at the same time with a single pair of offsets.

The option -v lets the program print the computed offsets in units of microns in the associated SE focal plane to stdout.

The steps are

1. get a single picture of the patrol camera on one side. Which side is configured by the command line option.
2. Run sex on that image. Eliminate stars that are outside the 1 arcmin radius (because the patrol camera has a slightly larger FOV). Output by star brightness (priority) according to the sex pseudo-magnitude. Return these as a SexPoint with limits of pixels.
3. Map this list to SE coordinates (with one of Colyer’s matrices of 2017-03, depending on side) which again is a SexPoint
4. construct an association with SE arms (1-8) with the associated Starcat library function, and call licsPreset.py to display in the SE GUI the proposed position of the SE arms.

The program shows the current Patrol Camera image flipped and rotated in a gui with a superimposed coordinate system of the SE plane (in units of microns). This GUI can be prevented with the -b option.

If you wish to click on a star that is Sex image and to freeze the associated pair of (x,y) coordinates to copy the numbers into the SE GUI, select Edit->Crosshair in the SexMenu and click on the star’s position in the image. Then the SexGUI can only change the coordinates when the mouse cursor leaves that GUI.

The program is usually called indirectly from within licsStarCat, page 24.

The program is not available (which means: it does nothing) if the executable sex in theestrator was not found at compile time.

In Nov. 2017 it was found that

1. the collision detection in the motor library is not safe enough to avoid collisions;
2. the localization of the stars in saturated images is not faithful with the current implementation;

so the line in the licsPreset.py that would actually try to move the SE’s has been commented.

67.1 Preset Telescope and start tracking

```
licsPreset [-t] [-b] starcat.cat
licsPreset [-t] [-b] [-s] server starcat.cat
```

This sends a preset to the telescope given the file name with the star catalog as the final command line argument.

The starcat file must be available on the local file system of the computer where the command is started. Usually that would be a file in the /data directory which is cross-mounted from lincse. If

```
cd /data/tis
```

reveals that the contents is not yet mounted, use lincsFtdisk mount - mount as super user to mount it, or use licsPreset on linc where this is usually the case.

The telescope operator should have authorized LINC

on the same arms (left, right or both) of the telescope as configured in the lincs/config/lincs.conf of the Linc-Nvius proxy server through the following configuration: MOON and COMMANDSIDE properties. Since Jan 2018 this is no longer strictly required. The Telescope Operator may authorize LINC on both sides or only one, and the configuration in the LINC files may at the same time be either both or one side.

66.1 Support HWS SE positioning

The program retrieves a patrol camera image, analyzes which stars it is, converts the pixel positions to the focal plane coordinates of the HWS SE on the associated side, and tries to figure out a set of non-colliding SE arms to reach those positions, and eventually to move those SE arms.

The option -s selects either the SX or the DX side of the telescope.

The steps are

1. get a single picture of the patrol camera on one side. Which side is configured by the command line option.
2. Run sex on that image. Eliminate stars that are outside the 1 arcmin radius (because the patrol camera has a slightly larger FOV). Output by star brightness (priority) according to the sex pseudo-magnitude. Return these as a SexPoint with limits of pixels.
3. Map this list to SE coordinates (with one of Colyer’s matrices of 2017-03, depending on side) which again is a SexPoint
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67.1 Preset Telescope and start tracking

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licsPreset [-t] [-b] starcat.cat
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This sends a preset to the telescope given the file name with the star catalog as the final command line argument.

The starcat file must be available on the local file system of the computer where the command is started. Usually that would be a file in the /data directory which is cross-mounted from lincse. If

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The telescope operator should have authorized LINC

on the same arms (left, right or both) of the telescope as configured in the lincs/config/lincs.conf of the Linc-Nvius proxy server through the following configuration: MOON and COMMANDSIDE properties. Since Jan 2018 this is no longer strictly required. The Telescope Operator may authorize LINC on both sides or only one, and the configuration in the LINC files may at the same time be either both or one side.

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The program retrieves a patrol camera image, analyzes which stars it is, converts the pixel positions to the focal plane coordinates of the HWS SE on the associated side, and tries to figure out a set of non-colliding SE arms to reach those positions, and eventually to move those SE arms.

The option -s selects either the SX or the DX side of the telescope.

The steps are

1. get a single picture of the patrol camera on one side. Which side is configured by the command line option.
2. Run sex on that image. Eliminate stars that are outside the 1 arcmin radius (because the patrol camera has a slightly larger FOV). Output by star brightness (priority) according to the sex pseudo-magnitude. Return these as a SexPoint with limits of pixels.
3. Map this list to SE coordinates (with one of Colyer’s matrices of 2017-03, depending on side) which again is a SexPoint
4. construct an association with SE arms (1-8) with the associated Starcat library function, and call licsPreset.py to display in the SE GUI the proposed position of the SE arms.

The programs shows the current Patrol Camera image flipped and rotated in a gui with a superimposed coordinate system of the SE plane (in units of microns). This GUI can be prevented with the -b option.

If you wish to click on a star that is Sex image and to freeze the associated pair of (x,y) coordinates to copy the numbers into the SE GUI, select Edit->Crosshair in the SexMenu and click on the star’s position in the image. Then the SexGUI can only change the coordinates when the mouse cursor leaves that GUI.

The program is usually called indirectly from within licsStarCat, page 24.

The program is not available (which means: it does nothing) if the executable sex in theestrator was not found at compile time.

In Nov. 2017 it was found that

1. the collision detection in the motor library is not safe enough to avoid collisions;
2. the localization of the stars in saturated images is not faithful with the current implementation;

so the line in the licsPreset.py that would actually try to move the SE’s has been commented.
During that stage the licsPreset-client shows a status of *Start External Profile...* and a field labeled *Pa* shows the parallactic angle at the time when derotation started. The background color is green then. Note that those parallactic angles of the various derotators differ, because the motion start independently and asynchronously at different times.

To start the derotators the associated motors must have been powered on (use licsStarcat start) and the associated servers must have been started, http://laos2.linc:2812.

The computer on which licsPreset is run and the server where the derotator services are run must have sufficiently close clocks on the operating system (usually achieved by running NTP servers on both), because derotator services are executed on absolute time scales on the licsPreset-client and forwarded as such to the server, which restarts the services if the trajectories start in the past or in a too close future.

If the -d is used and also -v, a call of Chapter 71 [licsStarcat], page 24, is issued once or more for one of the derotators. The obvious benefits are:

- that the operator does not need to call licsStarcat separately,
- that the timing is optimised,
- and that the star catalog file name needs to be known only at one place.

If the -d all is used but one side of the telescope is not authorized for Linc-Nirvana, harmless errors of the form *Error while asking for rotator polynomials* are printed for that non-authorized side, once for HWS and once for GWS. (The TCS server does not produce rotator polynomials for non-authorized sides.)

Note that prestarting and restarting the derotators with licsPreset still allows the operator to stop, reposition and restart derotators via the derotator GUIs at any time, see Chapter 39 [linc.xs.linc.dor.dor.rotation-erverserv.GUI], page 7, See Chapter 33 [linc.xs.gw.dor.dor.rotation-erverserv.GUI], page 6, See Chapter 17 [linc.xs.linc.dor.dor.rotation-erverserv.GUI], page 5, See Chapter 9 [linc.xs.gw.dor.dor.rotation-erverserv.GUI], page 4.

### 67.3 Prestart Star Enlargers to Park Positions

- licsPreset -d all
- licsPreset -d xx
- licsPreset -d dx
- licsPreset -d linc.xs.linc.dor.dor.star.enlarger-erverserv
- licsPreset -d linc.xs.linc.dor.dor.star.enlarger-erverserv
- licsPreset -d linc.xs.linc.dor.dor.star.enlarger-erverserv
- licsPreset -d linc.xs.linc.dor.dor.star.enlarger-erverserv
- licsPreset -d linc.xs.linc.dor.dor.star.enlarger-erverserv

Moves all 4 or the two star enlargers of one side or one individual star enlarger motor to the park position. The option -v followed either by all or by a single name of a star enlarger server moves all services in parallel or the one addressed by the configuration file name to a position preferred for starting the derotation. Neither the -d all is mandatory; you cannot write the file name licsPreset right after the -d. The options -v xx and -v dx start the RHS and GWS derotators on their side and also rotation of the infrared detector, as if the infrared detector were a common element of both sides. The cases -d all, -d xx and -d dx spawn subprocesses which execute individually; even if one of the derotators runs into problems (because motors or services other interfaces fail), the others will continue their mission. The obvious reason for that robust behavior is that integration into an automated system can use a fixed syntax -d all because the subsystems figure out by themselves whether they are currently active/cooperating or not.

Note that this command uses the parameters of the configuration files for the five derotator motors, in particular the travel ranges, backlash, and the transformation matrix that are mandatory, you cannot write the file name licsPreset right after the -d. The options -v xx and -v dx start the RHS and GWS derotators on their side and also rotation of the infrared detector, as if the infrared detector were a common element of both sides. The cases -d all, -d xx and -d dx spawn subprocesses which execute individually; even if one of the derotators runs into problems (because motors or services other interfaces fail), the others will continue their mission. The obvious reason for that robust behavior is that integration into an automated system can use a fixed syntax -d all because the subsystems figure out by themselves whether they are currently active/cooperating or not.

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68.1 Command line options
The command [and Python script] rewrites the derotator motor of the infrared camera to the position it had at the start of the previous derotation, and optionally starts a derotation there based on the parallactic angle polynomials it gets from the telescope interface.

The option `-g` (meaning `go`) triggers that another derotation starts after that first motion to the previous start position.

The option `-D` followed by a number which is a duration in seconds indicates how many seconds of the upcoming trajectory should be requested from the IIF interface. If the option is not set, half an hour (1800) is inserted. This duration only has some meaning if the `-g` option is also used.

The option `-t` followed by a time in seconds can be used to schedule the start of the derotation by some delay into the future. If the option is not used, the program tries to use a small delay sufficient to retrieve the trajectory polynomials from the IIF and to upload them to the motor controller. This delay has no meaning unless the `-g` option is also used.

68.2 Rationale
Each derotator service stores its motor start angle in its private property tree when derotating. This delay has no meaning unless the start angle usually stems from the previous call of licsPreset, so it is quasi optimized for the trajectory of the parallactic angle associated with the current target, and can generally be reused for trajectories in the near future without a risk of hitting some motor limits.

The aim of the rewinding procedure is to keep the motor angles used by the infrared camera near a small interval such that all predicted infrared background in the optics (that unfortunately will be rotating while derotating the objects images) is quasi constant for all exposures. That should simplify subtracting such instrument background from the images.

The command is currently called from within SeeSEOffset.py, one can call licsRewind.py based on further information it can gather from any services, or it does not.

69 licsSEOffset.py

To disable that automated rewind/derotate mechanism of GEIRS, either put all lines in QueueEFiles into comments, or add a line exit 0 near the top of licsRewind.py.

The aim of the rewinding procedure is to keep the motor angles used by the infrared camera near a small interval such that all predicted infrared background in the optics (that unfortunately will be rotating while derotating the objects images) is quasi constant for all exposures. That should simplify subtracting such instrument background from the images.

The command is currently called from within SeeSEOffset.py, one can call licsRewind.py based on further information it can gather from any services, or it does not.

The command selects a subset of the 8 or 12 star enlargers of one of the four fields (GWS, HWS, SX, DX) and moves the active star enlargers by the same relative amount in their global x/y coordinate system. The last two parameters of the command are the x- and y-coordinates of the SE enlargers that are to be moved. The first step of debugging this command mechanism is to test that licsRewind.py and QueueEFiles work as expected. These are part of the Linc-Nirvana service package, not of GEIRS.

Because log files are created on the computer that runs the SE service, one usually needs to run the script on lircs.

The syntax:

- Without command line argument, the script scans the log files of the 4 services.
- With two command line arguments, the first option is expected to be either sx or dx, and the second either gws or hws. This constructs the log file name using the environment variable $INSROOT and scans that file.
- With one command line argument, the file with that name is scanned.

The standard output contains a time stamp (first field the date, second the time of the day, currently the local time zone because this is the standard of the Linux machines) and then blank-separated x and y coordinates of the SE heads in the order SEDx, SEDy, SEbx, SEby... in units of microns.

The script tries to eliminate log lines that are generated while observers run the SE positions through the associated GUI or with search scripts. This is implemented by configuring a time span of currently 90 seconds (as a variable in the script), and printing log lines only if there is no other SE motion activity within that time span into the future.

If a plot over these positions as a function of time is desired, and suppose the output of licsSEhist.pl has been redirected to SE.txt, one can call gnuplot and enter

```bash
time 0.1 360000 set xrange [-150000:150000]
set yrange [-150000:150000]
set xlabel "x"
set ylabel "y"
plot 'SE.txt' using 1:3:4:5 with lines title 'SE1', \n'sE.txt' using 1:5:6:7 with lines title 'SED2', ...
```

The script extracts SE plane positions for the 12 or 8 SE heads from the current file in the $INSROOT log directory.
71.1 Submit to Star Enlargers

71.1.1 Syntax

liscStarcat [-f limiting | yy/mm/dd] [rr-mm-ss-] [x] [y] [z] [x] [y] [z] / [x] [y] [z] [x] [y] [z]

The program attempts to contact the up to four derotator servers to retrieve the motor angles, the TCS proxy server for the parallactic angle, to assign the catalog stars to Star Enlarger arrays, and to submit the coordinates to the SE positions appear in the operator's GUI. The usual application of this call is that only a single input file (in the liscStarcat catalog format) is specified, where the interest is in the comments in the output that contain the distances to the target and the SE coordinates and assignments, for example:

liscStarcat -W/Linux/nlncy/catguide/text/catalog

71.1.2 Option K

By default the program maps the sky (ra/dec) positions of the star catalog by standard transformations of spherical astronomy (neglecting refraction, including precession...) to the focal plane that is located after the the annual mirror. If the -K option is used, the program tries to query instead the kernel focal plane coordinates from the TCS. This may have advantages in principle but fails on the mountain. Do not use -K for now because it seems that there are flips of coordinates that are not understood yet; in particular the coordinates computed by the 2018A TCS on the museum are not compatible with the telescope simulator sim-2018h and the CAS document 025681z. The advantages of this FPC mediation triggered with -K are:

- Scale changes in the focal plane that stem from focusing mechanisms of MI, M2, or any flexure modules that are incorporated in the FCS algorithms are taken into account.

The disadvantages of this approach are:

- The pointing control system (PCS) of the IIF must have be configured correctly (including the MI angle).
- The response of the IF to the source is slow, and apparently proportional to the number of stars in the catalog. It takes typically 20 seconds or longer before FPCs are available. The associated problems are inpatient observers who may misinterpret this as a hangup of the software, plus a finessness of time scales that comes into play because the FPCs are a coordinate system that rotates at the speed of the parallactic angle.

71.1.3 Option f

The -f option specifies a cut-to-exclude targets fainter than limiting. The default value is 30, which means effectively all stars that one could imagine in a Linc-Nirvana context are kept. If the star catalog has been extracted in automated ways from some servers and is highly populated (with typically more stars than the number of star enlarger arms), this option is a kind of manual filter that may help to put priority to the brighter stars and to maximize flux in the AO detectors.

71.1.8 Option H

The -H option specifies a nominal angle (in degrees) for the K-mirror rotation with the same offset as used in the GUI. If not specified the program tries to contact the server of the K-mirror of the associated side(s), and if this fails the default is 45-deg, which is near the middle of the range for both SX and DX. There is no interface to specify two different angles for SX and DX because this is a debugging option. (The derotator services should be responding in normal operation.)

71.1.9 Option b

The -b option enters a batch mode, which in fact means that pop-up GUIs are suppressed. On request of Thomas Bertram during Com-3, this option is permanently activated by a cpp setting in the source code, so use only as necessary during debugging.

71.1.10 Algorithm HWS

For the HWS SE predictions two algorithms are foreseen:

- The current version reads the star catalog, runs its stars through proper-motion, precession updates, filters them through the distance of 1 arcmin to the first star, derives a total angle from K-mirror and parallactic angle, and projects these coordinates into the SE plane(s). The advantage of this approach is:

  - The operator has full control over which stars are considered candidates for the HWS AO stars.
  - The Patrol Camera is not needed.
- The second version reads a Patrol Camera image at the associated side, runs this with the extractor to detect stars (a Gaussian filter with 0.8 arcsec: FWHM, signal-to-noise limit set to 2), and maps these positions with the coordinate transformation matrix of 2017-03 (prior backwards through the dichro) to the SE plane(s). The advantages of this approach are:

  - Whatever the axis runouts of the K-mirrors or telescope flexures are, there are implicitly taken care of because the Patrol Camera image is taken after the beam has passed through the K-mirror. So actually the transformation matrices through the telescope, through the two mirrors of the HWS AO system, the reflections by the piston mirror, the warm dichro, the 3 K-mirrors reflections and the dichro that separates the patrol camera and the AO beam need not to be calibrated.
  - Parallactic angle and K-mirror angle are not needed. The algorithm is robust against jitters in time or against these servers running or against the derotator running.
  - It does not matter whether the operator used a wrong file argument for the star catalog in the call, because the file is actually not needed. In the same realm, errors of proper motions and the like in the star catalog are irrelevant.

The disadvantages are:

- The program attempts to contact the up to four derotator servers to retrieve the motor angles, the TCS proxy server for the parallactic angle, to assign the catalog stars to Star Enlarger arrays, and to submit the coordinates to the SE positions appear in the operator’s GUI. The usual application of this call is that only a single input file (in the liscStarcat catalog format) is specified, where the interest is in the comments in the output that contain the distances to the target and the SE coordinates and assignments, for example:

liscStarcat -W/Linux/nlncy/catguide/text/catalog

71.1.11 Algorithm GWS

The GWS SE predictions use the following procedure: The star coordinates of the catalog are projected along the RA and DEC directions of the target star, and forwarded to the focal plane that is located after the annual mirror. If the -H option is used, the program tries to contact the server of the K-mirror of the associated side(s), and if this fails the default is 45-deg, which is near the middle of the range for both SX and DX. The program attempts to contact the up to four derotator servers to retrieve the motor angles, the TCS proxy server for the parallactic angle, to assign the catalog stars to Star Enlarger arrays, and to submit the coordinates to the SE positions appear in the operator’s GUI. The usual application of this call is that only a single input file (in the liscStarcat catalog format) is specified, where the interest is in the comments in the output that contain the distances to the target and the SE coordinates and assignments, for example:

liscStarcat -W/Linux/nlncy/catguide/text/catalog

71.1.12 Trouble Shooting

Potential problems are:

- The command is issued before the derotators started their (slow) derotation, such that the motor angles are not correctly retrieved and not correlated with the parallactic angles as they should. Run the liscStarcat command again if that happened.
- The catalog file at the end of the command line is not the same as the one used for the telescope preset, so the stars in the catalog are not where the telescope is looking at. Run the liscStarcat command again if that happened.

71.2 retrieve

liscXephem -W/Linux/nlncy/catguide/text/catalog

This is a combined action of getting a part of the NOMAD star catalog (online, not working if the server on the main net or the internet or any intermediate proxy are down) and converting it to our catalog format. The -r option defines the search radius on the sky in degrees. The two equatorial coordinates either in degrees or in the hh:mm:ss and .mil format are the mandatory final parameters. The current defaults for the two parameters are:

- A limiting magnitude of 14 (specify after the -r option)
- A cone radius of 0.07-deg equivalent to four arcminutes.

72 licsXephem

lcsXephem [ -W/Linux/nlncy/catguide/text/catalog]

This translates LITO catalog files to the xephem format (http://www.clearsky institute.com/xephem/help/xephem.html) format, copies this to the xephem/linc.edl file in the home/
The GUI for the sideways detector position stage. According to a system
for the derotator stage
for the secondary mirror in the cold. This comprises the 3 degrees
Chapter 73: liifSnapshot.py

directory, and calls xephem to show where the stars are currently on the sky. This gives a
the XEphem database; the option -a triggers that all stars are copied.

The command line arguments should be ASCII files in the LKTO format (as used elsewhere). It is
convenient to let the Linux shells expand all catalogs in a directory with the usual wild card
expansion mechanism, which means, to use an argument of the format somedir/*.-cat.

xephem must have been installed as detailed in LN-MPIA-MAN-ICS-010 (https://svn.
mpia.de/trac/gal/us/Archive/Archives/LN2Document/Manuals/L220v0460/In

Use in default. Once the xephem window pops up, click on Data and select Files. In the
new window click again on Files and select inn., which has just been created by the
program. The remove the SeemsIx, edb and LHR05.edb with the Delete button in the
subwindow such that only inn. edb remains. Then in the main window click on Data
and select Index to get an overview which stars have been loaded. (Actually on the first star of
each of the LKTO catalog files has been exported to avoid that the view gets too crowded.
The catalog appears twice: (i) with the base file name, and (ii) with the type name which was
the first fold of that star in the LKTO catalog.)

Then in the main window on Viewer and select Sky view, click at the left on the
the display that is close to the natural almanac system. Optionally click on the Gear symbol
in the menu to remove the constellations contour lines. The click repeated times on the
top light bulb to let the stars of our additional catalog appear in the order of magnitudes.
[It seems one must repeat that brightness adjustment each time the zoom scale is changed with
the left slider and also after some other modifications.]

In the GUI with the index one can click on one or more of the stars and then on Sky Point
to get it marked in the image window.

liixXephem /data/2017-06-Con2/targetlists/bestof_starrings10mag/*.-cat

73 liiisSnapshot.py

liiisSnapshot.py [-g]

Print an overview of the IIF variables in the current state.
The set of variables that is shown can be changed by commenting the items of the very long
list in the source code of liiisSnapshot.py in or out.
If the option -g is added, a rough snapshot of the current detorator polynomials is also
printed.

78 lsfits

lsfits
lsfits Holde.fits
lsfits Holde.fits[extensionspec]

Print headers of FITS files listed by the command line arguments. The command line
argument can be a FITS file name and headers of all extensions are printed. It can be a
header index in brackets, starting with index 0 for the primary header. It can be a header
name in brackets.

Note that the Linux shell tries to expand these brackets, one must usually quote
these bracket expressions.

lsfits hugo.fits
lsfits hugo.fits[1]
lsfits hugo.fits["GUT"]

On computers where GEHASH is installed, one may as well use fits2a.
On computers where the heatools are installed, one would prefer to use the more versatile fits2a.

79 lsys.cab.int-svr_GUI.sh

This GUI offers buttons to switch power on or off in subunits of the 6 LS control racks
where they are assessible by switchable power lines. The button in the upper right corner switches
all of these individual power lines at the same time.

There is a button for the ROE-NIR which acts on the read-out electronics rack of the
NIR detector. There is no risk to interrupt the operations of the Hubble Space Telescope
here because that power is hooked up on the UPS and not switchable here. However, we
know that the power of the ROE basically feeds the pre-amplifiers of the detector outputs,
and if these are switched off the detorator unit will usually be cooled by the operational
temperature of the pre-amps, and one may need up to 5 hours to return to normal operation of the
science detector. In short: do not switch off that ROE-NIR power during those
stretches of days/night when Linc-Nirvana operations are scheduled to use the science
detector, but do switch off that ROE-NIR power while the instrument is cooling down or
warning up.

The associated hardware switches are in the LN Power off Page (http://wiki.lbt.org/
bin/view/Instrumentation/LnPowerOffPage).

81 lsys.cryo.int-svr_GUI.sh

A display of the most important TCS pointing information.

87 plotSkyTrack.py

Plots the parallactic angle and the altitude and azimuths for the next 20 minutes assuming
sidereal tracking.

The IF is regularly polled for the current information to update the plot.
It gives a hint of how long the detorator stages may stay tracking before hitting their
limit switches.

88 setTargets.py
The command `start_nirvana_new` starts the detector control software, GEIRS. The command can only be executed on the machines where the software is installed, usually `lircs` and as a backup `lsys2`.

The detector can only be read out from computers where the associated interface boards are installed and connected to the detector, `lircs` or `lsys2`.

5 IR OPTICS

5.1 Atmospheric Dispersion

An estimate of the transverse chromatic atmospheric dispersion (TAD) is obtained from the first approximation $R = (n - 1) \tan z$ [25], where $R$ is the difference in the apparent and true zenith angles in radian (at 1 rad $\approx 206265''$), $z$ the zenith angle, and $n$ the real part of the refractive index of air. Estimated values of the refractive index at the observatory are shown in Figure 13. They illustrate the (tiny) influence of water content in the atmosphere which was missing in the earlier report [26].

1. The first result is that since $n - 1$ is of the order of $1.9 \times 10^{-4}$, $R$ is of the order of $39'' \tan z$. This may lead to an (apparent) distortion of $\Delta R \approx 1.9 \times 10^{-4} (1 + \tan^2 z) \Delta z$ over the field of view. LN covers $\Delta z \approx 2048 \times 0.005'' \approx 10''$, so at an average $\tan z \approx 1$ the relative linear distortion across the field relative to astronomical catalogues is $\Delta R \approx 2 \times 1.9 \times 10^{-4} \times 10'' \approx 0.004''$.

2. The second result is that, even if no filters are used, the full chromatic dispersion over all relevant infrared bands is $\Delta n \approx 4 \times 10^{-7}$, the associated $\Delta R$ is $\approx 0.08'' \tan z$. At a pixel scale of 0.005'' of the science detector, these are 16 pixels.

The dispersion between the red and the infrared bands is of the order of $\Delta n \approx 2 \times 10^{-6}$, the associated $\Delta R$ is $\approx 0.4'' \tan z$. Given the pixel scale (31) on the guiding camera, this is a natural offset by 3 pixels between patrol and science channels.

Figure 13: Real part of the refractive index at 690.0 hPa (the typical LN atmospheric pressure), 7 °C and three different relative humidities between 40 and 80% [27].
6 TROUBLE SHOOTING

6.1 FAQ

1. Q: What is the relevance of source files occurring at different places with the same name, like

```
/doc/include/Nice/Qt/SetIconSearchPath.cc
./doc/include/Nice/Util/FileByPath.h
./doc/include/Nice/Util/FileByPath.cc
./src/libNice/Nice/Util/FileByPath.h
./src/libNice/Nice/Util/FileByPath.lo
./src/libNice/Nice/Util/.libs/FileByPath.o
./src/libNice/Nice/Util/.deps/FileByPath.Plo
./src/libNice/Nice/Util/FileByPath.cc
```

A: The files in the doc subdirectories are only (old) versions used to create documentation for doxygen and therefore irrelevant to real applications. To remove these insert

```
NODYXYGEN = true
```

in the Makefile.am of the associated directory so doxygen is not called during make.

2. Q: Why are there old 149.*.*.* IP-Adresses at many places in the .cfg files of TwiceAsNice?

A: These are remnants of old test configurations. These are not actually relevant because the LN configuration files are kept in the separate ln/config subversion folders.

3. Q: In my python program the import Ice emits an error

```
ImportError: dynamic module does not define init function (initIcePy)
```

A: You may need to enforce an explicit Python interpreter if Ice was compiled for another Python version. Either edit the

```
#!/usr/bin/env python
```

at the header of the python file (discouraged because often these scripts are distributed across various computer platforms) or call an explicit version with

```
python3.4 .....py
```

4. Q: How can we reverse-lookup the IP addresses in the log-files to computer names on the subnets?

A: The IP table is in trac.

5. Q: How is the simulating (dummy) IIF server switched in that is a substitute of the LBTO IIF server?

A1: Replace the alias file to point to the simulating servers and start the simulator:
cd ~/lnsw/config
rm alias.cfg
ln -s alias-localhost.cfg alias.cfg
LbtoIIFSimulator --LOGGER.LEVEL=INFO --CONFIG=ltcs/ltcs.iifDummyLocalhost-svr.cfg &

Replace the ltcs.iif-svr.IIF end point of the derotation services by ltcs.iifDummyLocalhost-svr.IIF in the five config files of the motors:

./laos/sx/hws/drot/laos.sx.hws.drot.derotation-svc.cfg
./laos/sx/gws/drot/laos.sx.gws.drot.derotation-svc.cfg
./laos/dx/hws/drot/laos.dx.hws.drot.derotation-svc.cfg
./laos/dx/gws/drot/laos.dx.gws.drot.derotation-svc.cfg
./lircs/drot/lircs.moe.drot-svc.cfg

A2: The better solution is proposed in Section 7.1.1. The LBTO telescope simulator responds which much more realistic timing to the various queries than our hand-sewn lbtoIIFSimulator.

6. Q: Which GUIs are there?
   A: See the output of

   info linc

   or call

   find ~/lnsw/config/scripts -name "*GUI.sh" | sort

7. Q: I want to open firefox but this is already used by someone else under the same user name on the same machine.
   A: Use opera instead.

8. Q: ICE complains about ports already in use but does not show which ones.
   A: To get this information one needs to recompile ICE and insert a line that shows which connection it is trying to establish. One needs to insert a debugging output near the bind call in the function doBind in the file cpp/src/Ice/Network.cpp that roughly looks like

   std::cerr << __FILE__ << " " << __LINE__ << " bind " << IceInternal::addrToString(addr) << " fd " << fd << std::endl ;
   if(::~bind(fd, &addr.sa, size) == SOCKET_ERROR)
   ...

7 EXTERNAL SOFTWARE

7.1 LBTO SW

7.1.1 Telescope Simulator

7.1.1.1 Oracle's VirtualBox A virtual machine for the TCS simulator software is set up with

```
zypper install virtualbox
zypper install libvirt-daemon-vbox libvirt-daemon-driver-vbox
```

Then remove the `usb` lines in `/etc/udev/rules.d/60-vboxdrv.rules`. Then reboot the host computer such that the `/dev/vboxdrv` exists.


```
cd 'VirtualBox VMs'
mkdir TCS
cd TCS
```

With the call

VirtualBox

and clicking on File→load Appliance this is installed as a virtual machine. Additional instructions are in [http://wiki.lbto.org/bin/view/Software/UsingTCSSimulatorAppliance](http://wiki.lbto.org/bin/view/Software/UsingTCSSimulatorAppliance).

For openSuse use `yast2→User and Group management` to add the required users (lneng, nirva, ...depending on the environment) to the `vboxusers` group. Note that this group is not initially shown but in the list that displayed after selecting `Filters→System users`. You probably need to log out and in to be allowed to start the virtual machine.

7.1.1.2 At LBTO On the mountain, the virtual machine starts the TCS simulation on the IP address 192.168.156.48.

The configuration of the VM in the VirtualBox Manger is::

- In File→Preferences→Network leave the NAT Networks and Host-only Networks empty
- In Settings→Network select the Bridged Adapter on em1, where em1 is the OpenSUSE interface board on the host.
- In `/etc/hosts` we have

```
127.0.0.1 localhost localhost.localdomain localhost4 localhost4.localdomain4
::1 localhost localhost.localdomain localhost6 localhost6.localdomain6
127.0.0.1 tcs-sim.linc.lbto.org tcs-sim.linc tcs-sim
192.168.156.48 tcs-sim.linc.lbto.org tcs-sim.linc tcs-sim
192.168.156.40 lsys.linc.lbto.org lsys.linc lsys
192.168.156.231 ln-x1.linc.lbto.org ln-x1.linc ln-x1
```

The class-A network for a host on mountain.lbto.org may be commented and is not useful in simulation.

- In `/etc/hostname` we have a single line

19see the permissions on VBoxHeadless on openSUSE 13.1 for example
tcs-sim

- In /etc/resolv.conf we have

  search linc.lbto.org
  nameserver 192.168.156.40

- In /etc/sysconfig/network we have

  NETWORKING=yes
  HOSTNAME=tcs-sim
  DNS1=192.168.156.40
  SEARCH=linc.lbto.org

- In /etc/sysconfig/network-scripts/ifcfg-enp0s3 we have

  NAME="enp0s3"
  DEVICE="enp0s3"
  ONBOOT=yes
  DHCP_HOSTNAME=tcs-sim
  NETMASK=255.255.255.0
  UUID=...
  IPV6INIT=yes
  BOOTPROTO=None
  IPADDR=192.168.156.48
  TYPE=Ethernet
  DEFROUTE=yes
  IPV4_FAILURE_FATAL=no
  IPV4_AUTOCONF=yes
  IPV6_DEFROUTE=yes
  IPV6_FAILURE_FATAL=no
  DNS1=192.168.156.40
  DOMAIN="linc.lbto.org"
  PEERDNS=yes
  PEERROUTES=yes
  IPV6_PEERDNS=yes
  IPV6_PEERROUTES=yes

All of this configuration has already been done on ln-x1. So for the operator who wants to test the software without actually having access to the telescope (interface), the action is to type

VirtualBox &

on the ln-x1 Linux command line, to click on the green Start arrow in the menue, or all in one

VirtualBox --startvm TCS &

VBoxHeadless --startvm TCS & # openSUSE 13.1
Figure 14: The TCS 2018A simulator as seen with the vncviewer just after start-up.

and to watch the virtual machine booting until the root@tcs-sim-prompt appears in its local window. If questions pop up concerning security holes for USB putthrough, disable that feature (we don’t work with USB on the virtual machine.) After starting the virtual machine one should be able to ping 192.168.156.48 from lsys and from ln-x1, and be able to ping 192.168.156.40 on the console of tcs-sim.

Install the vncviewer with yum/zypper and run

vncviewer 192.168.156.48:0 &

to open the LBT TCS Control GUI. Press the 8 individual Start buttons or just the button to start all subsystems, from LSS to OSS. Acknowledge the Continue question. Watch the buttons to turn green in about a minute. In the subsystems area open the IIF control GUI, the PCI control GUI and optionally the MCS GUI by pressing the associated GUI buttons. Click on the

20 Once the virtual machine has booted, the VirtualBox Manager window and that console window of the virtual machine can be minimized to save space.

21 Ignore messages related to misconfigured swing arms, side monitors and other subsystems...

22 If they don’t pop up, make sure that the vncviewer window is big enough because new windows may hide in
Control button in the IIF GUI to authorize LINC on one or both sides of the telescope, which means pull-down to select LINC or NONE and click on Authorize; if one of the two arms is authorized for None, its correlated region in the PCS area will disappear. The GUI then looks similar to Figure 14.

Edit the endpoint in the TaN configuration file `config/lucs.*.iif-svc.cfg` on lsys to replace the HOST `iif.mountain.lbto.org` by `192.168.156.48` and restart the associated LN IIF server so it communicates with that host for the tests.

### 7.1.1.3 Networking Example MPIA

This here illustrates the setup for the virtual machine (named `tcs-sim`) on an openSuse host (named `irws2`) where the virtual machine needs only to be accessed from that single host (which runs TAN). So the assumption is that the VM does not need to reach the `mpia-hd.mpg.de` network. We set up a subnet 192.168.56.x (named `irws2.mpia-hd.mpg.de`) on the host in which the only computers are `irws2.mpia-hd.mpg.de` (192.168.56.1) and `tcs-sim.mpia-hd.mpg.de` (192.168.56.100).

- On the host `irws2` set up a local DNS server:
  - `zypper install -t pattern dhcp_dns_server`
  - `zypper install bind bind-utils`
  - `zypper install dnsmasq dnsmasq-utils yast2-dns-server`
  - with `yast2`→DNS Server enable Reload after saving... and Start During System Boot. In the Forwarders forwarder list use the standard DNS servers (for example 149.217.41.6, 149.217.40.8 and 149.217.41.10). In the DNS Zones add two new zones (type Master), (i) `irws2.mpia-hd.mpg.de` and (ii) `1.56.168.192.in-addr.arpa`.
  - with `yast2`→Hostnames add
    * `192.168.56.1 irws2.mpia-hd.mpg.de irws2`
    * `192.168.56.100 tcs-sim.mpia-hd.mpg.de tcs-sim`
    to the existing list.
  - with `yast2`→Network Settings→Overview add a device with the Name Ethernet Network card, the IP Address 192.168.56.1 and the Device vboxnet0. Under Routing add in the table for the destination 192.168.56.100 the Netmask /8 and the Device vboxnet0.

- Start the VM on the host with VirtualBox.
  - In the File→Preferences→Network menu leave the NAT Networks blank, goto Host-only Networks, click on + to add vboxnet0, then on the screwdriver symbol to edit the Adapter 192.168.56.1 and the IPv4 network mask 255.255.255.0. Do not enable the DHCP Server.
  - In the Settings→Network select Adapter 1, enable it, attach to Host-only Adapter and Name vboxnet0, with advanced settings to Allow All and Cable connected.
  - In the VirtualBox menu Start the TCS VM. Add in `/etc/hosts` the two lines
    `192.168.56.100 tcs-sim.irws2.mpia-hd.mpg.de localhost tcs-sim`
    `192.168.56.1 irws2.irws2.mpia-hd.mpg.de irws2`
Put a sharp (#) in front of the line that contains `mountain.lbto.org` because this should not be accessed remotely. Check that the `/etc/hostname` is `tcs-sim`. In `/etc/resolv.conf` add

```bash
nameserver 192.168.56.1
```

In `/etc/sysconfig/network` add

```bash
NETWORKING=yes
GATEWAY=192.168.56.1
HOSTNAME=tcs-sim.irws2.mpia-hd.mpg.de
```

In `/etc/sysconfig/network-scripts/ifcfg-enp0s3` change `BOOTPROTO=dhcp` to `BOOTPROTO=none`. Set `IPADDR=192.168.56.100`, `PREFIX=24`, `GATEWAY=192.168.56.1`, `DNS1=192.168.56.1`, and `DOMAIN=irws2.mpia-hd.mpg.de`. The same settings can probably also be edited by calling `/bin/nmtui`.

– In the CentOS7 command line on the VM the simulator ought to be already alive:

```bash
ps -elf | fgrep mcs
```

The standard tests are:

1. on the host one gets a valid response from `nslookup tcs-sim irws2` and from `ping tcs-sim` (at least after the VM has been started).
2. on the host one gets the main TCS GUI from `vncviewer tcs-sim:0`.
3. on the terminal of the VM one gets a valid output from `ping irws2`.

The major test is that the `licsPreset` command for the telescope lets the reddish error number in the PCS menu run down to zero and turn green once tracking. (This will not happen for example if the target coordinates are below the horizon, if authorization was faulty or if the `licsPreset` did not comply with the policies of the binocular control of the TCS.) If one clicks on the `Source details` within the PCS GUI, the target coordinates, proper motions, magnitude and so on of the `Target` should align with the characteristics of the first entry in the star catalog that was used for the `Preset`.

7.1.1.4 Shutdown

Because the VM will probably keep a full processor of its host machine busy, it is explicitly recommended to shut it down when no longer needed! Once the tests with the virtual machine for the telescope are finished,

1. Click on `Stop all subsystems` in the TCS Control GUI of your `vncviewer` which will turn all backgrounds red there after a while. This action is actually superfluous. You might even before click on `End of Observing` before in the IIF Control GUI. Close the `vncviewer` GUI.
2. type `shutdown now` after the `root@tcs-sim-prompt` in the VM shell as if this were a real computer. (This usually requires to acknowledge that the virtual machine grabs the mouse
pointer...). This is not really required but lets the associated desktop of the virtual machine disappear and avoids that the VirtualBox Manager asks later on whether it should save the status of the machine somewhere on disk. The desktop window should disappear and the status in the Virtual Box Manager GUI turn to **Powered Off**.

3. Click the **File → exit** menu in the Oracle VirtualBox Manager GUI to close it.

4. Don’t forget to restore the standard Twice-As-Nice configuration files with the host `iif.mountain.lbto.org` and to re-start the service(s) that use(s) that configuration!

### 7.1.2 Telescope ICE Interface

The general description of the software interface is Biddick’s 481s013 [19]. We comment on various not-so-obvious undocumented features of the software.

#### 7.1.2.1 OffsetGuiding

The value for the offset sent from the instrument to the interface representing the AZ coordinate must be the product of the change in the azimuth by the cosine of the elevation (ALT), not the bare AZ value. This is aligned with the standard interfaces of proper motions and other features in differential coordinate systems of star catalogues. Both the AZ and the ALT component must be in radians. The ALT component must be provided with the opposite sign (!) of what is intended. This means whereas a positive value of the AZ increases the mid-point along the azimuth, a positive value of the ALT **decreases** the mid-point along the altitude/elevation. That add-hoc sign flip appears for example within the function `SetGuideOffset` in the file `AG_Utils.py` in the LN Autoguider.

The server side does not accumulate values obtained by subsequent **OffsetGuiding** commands, but regards them as corrections relative to a fixed zero-offset defined at preset-time. So if you send a $\Delta a = 5 \times 10^{-7}$ and then $\Delta a = -2 \times 10^{-7}$, the telescope selects a section on the sky which is at $\Delta a = -2 \times 10^{-7}$ rad (actually $+2 \times 10^{-7}$ including the internal sign flip) away from where it was at the start of tracking. The LN autoguider lets the observer define initially a reference point ("hot spot") on the patrol camera, measures in a loop basically the actual position of some star, and computes a vector pointing from the reference to the measured position. In that sense the computed vectors are already accumulated offsets and should be sent as such, without adding them up and without another additional flip of the signs of the offset, to the **OffsetGuiding**. The python programs of the LN autoguider do all rotations in a tangential plane around the current beam center. Because the telescope interface requires bare numbers in flat two-dimensional projections, including the cosines of the latitudes of the spherical coordinate systems, all these computations are a sequence of pure rotations, flips and radial scalings, and scalings with the cosines of the latitudes disappear.

#### 7.1.2.2 OffsetPointing2

The value for the offset send from the instrument to the interface representing the RA coordinate must be the product of the change in the right ascension by the cosine of the declination (DEC), not the bare RA value. This is aligned with the standard interfaces of proper motions and other features in differential RA coordinate systems of star catalogues. Opposite to the **OffsetGuiding**, the signs of both coordinate requests are as expected: a positive value of the parameter increases $\alpha$ or increases $\delta$.

Because currently the telescope’s server does not allow to send (relative) pointing offsets in the
AZALT system\textsuperscript{23}, one must actually take the AZALT coordinates, rotate them to the RADEC system on the client side with (7), which differentially, linearized to first order, is effectively a rotation by the parallactic angle (27), and send these RADEC delta parameters to the telescope. It obviously helps that the cosine factors in those azimuthal components are integrated into both “tangential” projections: that local transformation is actually a pure rotation (including a flip depending on which of the coordinates are regarded as the “upper” and “lower” components). This client-side rotation is for example implemented within the \texttt{SetOffset} function in the file \texttt{AG\_Utils.py} in the LN Autoguider.

7.1.2.3 Kernel Focal Plane Coordinates

The kernel focal plane coordinates \((k_x, k_y)\) of a star are (by some heuristics) related to the position coordinates \((f \Delta \delta, \cos \delta \Delta \alpha)\) by aligning \(\delta\) with \(+k_y\) and \(\alpha\) with \(+k_x\), and introducing the angle

\[
\tau_k = |R_z| - 90^\circ = 18.5^\circ
\]  

(73)

— the same for SX and DX.\textsuperscript{[13, Fig. 6 and 8]} The definition of \(\tau_k\) is illustrated in Fig. 15. To obtain the coordinates in a right-handed \(\alpha - \delta\) system from a right-handed \(k_x, k_y\) system one must employ a rotation of the coordinate system by \(\pi/2 - \tau_k\):

\[
\begin{pmatrix}
\frac{f \cos \delta \Delta \alpha}{f \Delta \delta}
\end{pmatrix} =
\begin{pmatrix}
\cos(\tau_k - \pi/2) & -\sin(\tau_k - \pi/2) \\
\sin(\tau_k - \pi/2) & \cos(\tau_k - \pi/2)
\end{pmatrix}
\begin{pmatrix}
k_x \\
k_y
\end{pmatrix}.
\]  

(74)

\[
\begin{pmatrix}
\frac{f \Delta \delta}{f \cos \delta \Delta \alpha}
\end{pmatrix} =
\begin{pmatrix}
\sin(\tau_k - \pi/2) & \cos(\tau_k - \pi/2) \\
\cos(\tau_k - \pi/2) & -\sin(\tau_k - \pi/2)
\end{pmatrix}
\begin{pmatrix}
k_x \\
k_y
\end{pmatrix}
\]

\[
= \begin{pmatrix}
-\cos \tau_k & \sin \tau_k \\
\sin \tau_k & \cos \tau_k
\end{pmatrix}
\begin{pmatrix}
k_x \\
k_y
\end{pmatrix}.
\]  

(75)

This can be inserted into the r.h.s. of (61) to obtain the transformation from kernel-focal-plane coordinates to SE planes.

\textsuperscript{23}Michele De La Pena, priv. commun. to Tom Herbst
The drawback here seems to be that the TCS Build 2018A uses a coordinate system that differs from the one in the simulator 2016B and the one described above. There is at least one additional sign flip. During LN commissioning in January and April 2018 this lead to massive problems of employing these coordinates for SE acquisition purposes. Because the team does not have surplus telescope time to debug these numbers, the LN instrument control software does not the use the focal plane coordinates since the second day of COM-4.

7.2 Python

If

which pip

returns nothing, installation of pip on Centos 7.2 is done with

```
curl "https://bootstrap.pypa.io/get-pip.py" -o "get-pip.py"
python get-pip.py
```

Errors from python of the type

Import Error: No module named astroplan

can be met by installing the module with

```
 pip install --target=$INSROOT astroplan
```

These python modules are evolving quickly; upgrades are done with

```
 pip install --target=$INSROOT --upgrade astroplan
```

and it’s useful to run

```
 pip list --outdated
```

once in a while.

To install a recent (!) matplotlib get the required png library

```
yum install libpng-devel
pip download six
pip install --target=$INSROOT six-1.10.0-py2.py3-none-any.whl
git clone git://github.com/matplotlib/matplotlib.git
cd matplotlib
python setup.py install
```

7.3 Xephem

7.3.1 Installation

xephem is obtained from http://www.clearskyinstitute.com/xephem/ and compiled with

```
 gunzip xephem-3.7.7.tgz
tar xf xephem-3.7.7.tar
cd xephem-3.7.7/GUI/xephem
```
yum install motif-devel # for CentOS
zypper install motif-devel # for openSUSE
make
alias xephem='(cd ${HOME}/xephem-3.7.7/GUI/xephem; ./xephem &)'
rm ../../../xephem-3.7.7.tar
mkdir -p ${HOME}/.xephem

and called with

xephem &

For use with licsXephem one should add

export XEPHEM_HOME=${HOME}/xephem-3.7.7/GUI/xephem

to $HOME/.bashrc.

Additional star catalogues can be compiled following these instructions.

There is not much use of loading FITS images into XEphem, because ds9 seems to cover an equivalent set of tools. The FITS images created by most GEIRS patterns are of the BITPIX = 32 type, but XEphem only accepts BITPIX= 8 or 16 or -32. So as an intermediate step one needs to convert the pixels with the heatools (see the Appendix of [1]) akin to

chimgtyp GEIRSfile.fits tmp.fits FLOAT

The new file tmp.fits has BITPIX = -32 and is accepted by XEphem. (View → sky view → Images → Load and Save).

### 7.3.2 LBTO parameters

Click on the Local button click on the Chicago, Illinois button, and in the new window on create and set LBT, Arizona for the Site name, Latitude to 32:42:05, Longitude to 109:53:21 (West is positive here in XEphem!), Elevation to 3221, Zone name to MST with Offset to 7, DST name to MST with Offset to 7 24. Click on Set main and Save and Close. Under Local set the Atmospheric pressure to 681 hPa and click Update. Under Preferences set the time zone to UTC. To get an overview, click on View and select the overview.

Alternatively insert into $HOME/.xephem/XEphem the lines

<table>
<thead>
<tr>
<th>XEphem.Elevation:</th>
<th>3221.0 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>XEphem.Lat:</td>
<td>32:42:05</td>
</tr>
<tr>
<td>XEphem.Pressure:</td>
<td>681 hPa</td>
</tr>
<tr>
<td>XEphem.Sitename:</td>
<td>LBT, Arizona</td>
</tr>
<tr>
<td>XEphem.TZName:</td>
<td>MST</td>
</tr>
<tr>
<td>XEphem.TZone:</td>
<td>7:00:00</td>
</tr>
<tr>
<td>XEphem*TZone.Local.set:</td>
<td>False</td>
</tr>
</tbody>
</table>

24 there is no DST in Arizona
7.3.3 Where is the LBT?

The HORIZONS web interface https://ssd.jpl.nasa.gov/horizons.cgi sets up the following geographic/geodetic parameters for an observer at the LBT [G83]:

- altitude is 3182.3 m;
- latitude is 32 deg 42 min 05.3 sec N;
- longitude is 250 deg 06 min 37.4 sec E;

These are actually the same coordinates one would obtain from converting the geocentric distances and angles of the MPC Obscode G83 to WGS84 geodetic coordinates.

According to http://abell.as.arizona.edu/~lbtsci/scihome.html and the LBTO brochure of http://www.lbto.org/overview.html the coordinates are

- altitude is 3221 m;
- latitude is 32 deg 42 min 04.71 sec N;
- longitude is 109 deg 53 min 20.63 sec W (equivalent to 250 deg 06 min 39.4 sec E);

According to [28] the altitude is 3192 meters.

The overall differences are small: The difference of 0.6" in latitude between the sources is $2.9 \times 10^{-6}$ radians or 18 meters at a radius of 6370 km. The difference of 2" in longitude is $9.7 \times 10^{-6}$ radians or $\cos(32^\circ) \times 6370$ km or 52 meters.

7.4 doxygen

doxygen is obtaine from http://www.doxygen.org and compiled with

tar xzf doxygen-1.8.14.src.tar.gz
cd doxygen-1.8.14
mkdir build
cd build
cmake -G "Unix Makefiles" ..
make
mv bin/doxygen ~/work/bin/Linux # or wherever the PATH variable points to
cd ../
rm -rf doxygen-1.8.14*
doxygen -version