LINC-NIRVANA
The LBT INterferometric Camera and Near-InfraRed / Visible Adaptive iNterferometer for Astronomy

A collaborative project of the MPIA Heidelberg, INAF-Arcetri, Universität zu Köln, and MPIfR Bonn
http://www.mpia.de/LINC

LINC-NIRVANA

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Twice As Nice –
Installation and User’s Manual

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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)
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/
LBTO      Large Binocular Telescope Observatory http://www.lbto.org/
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<th>Abbreviation</th>
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<td><strong>LINC</strong></td>
<td>LBT Interferometric Camera <a href="http://www.mpi-hd.mpg.de/LINC/">http://www.mpi-hd.mpg.de/LINC/</a></td>
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<td><strong>LN</strong></td>
<td>LINC-NIRVANA</td>
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<tr>
<td><strong>LUCI</strong></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>Mount Control System <a href="http://wiki.lbto.org/bin/view/Software/MCSPUBuildAndInstall">http://wiki.lbto.org/bin/view/Software/MCSPUBuildAndInstall</a></td>
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<tr>
<td><strong>MPIfR</strong></td>
<td>Max-Planck Institut für Radioastronomie, Bonn <a href="http://www.mpi-fr-bonn.mpg.de">http://www.mpi-fr-bonn.mpg.de</a></td>
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<td><strong>NCP</strong></td>
<td>North Celestial Pole</td>
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<tr>
<td><strong>NIRVANA</strong></td>
<td>Near-Infrared / Visible Adaptive Interferometer for Astronomy</td>
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<tr>
<td><strong>PC</strong></td>
<td>Pre-Commissioning Run (of Linc-Nirvana)</td>
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<tr>
<td><strong>PCI</strong></td>
<td>Peripheral Component Interconnect</td>
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<tr>
<td><strong>PCS</strong></td>
<td>Pointing Control System (of LBT)</td>
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<td><strong>RA</strong></td>
<td>Right Ascension</td>
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<td><strong>rpm</strong></td>
<td>RPM package manager <a href="http://rpm.org">rpm.org</a></td>
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<tr>
<td><strong>SE</strong></td>
<td>Star Enlarger (of Linc-Nirvana)</td>
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<tr>
<td><strong>SOFA</strong></td>
<td>Standards of Fundamental Astronomy <a href="http://www.iausofa.org">http://www.iausofa.org</a></td>
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<td><strong>SVN</strong></td>
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<td>Left (sinister) arm of the LBT optics</td>
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<td><strong>TAD</strong></td>
<td>transverse atmospheric dispersion</td>
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<td><strong>TCS</strong></td>
<td>Telescope Control System</td>
</tr>
<tr>
<td><strong>UTC</strong></td>
<td>Universal Time Coordinated</td>
</tr>
<tr>
<td><strong>VM</strong></td>
<td>Virtual Machine</td>
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1.2 References

References


[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 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}:${INSROOT}/share/info
  export USER=$USERNAME
  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 installe
such that they will be found by `make` while compiling TaN. One usually needs to add links like

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)

```
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

```
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:

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

Finally add for all users in `.bashrc`

```
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

```
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

```bash
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

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

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

```bash
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

```bash
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 installed:

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;

\(^2\)A bug that exists for more than a decade https://bugzilla.redhat.com/show_bug.cgi?id=191497
\(^3\)The 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

\[
\begin{align*}
\text{pfil} &= $(\text{find . -name python.m4}) \\
\text{for f in } \{\text{pfil}\} \text{ do} \\
& \quad \text{sed} -i 's/in python2.8/in python3.4m python2.8/' $f \\
& \quad \text{sed} -i 's/="python2.6/="python3.4 python2.6/' $f \\
& \quad \text{sed} -i 's/="python2.7/="python3.4 python2.7/' $f \\
\text{done} \\
\text{export PYTHON=python3.4} \\
\text{alias python} = $\text{PYTHON} \# \text{in ~/.bashrc} \\
\text{pip3.4 install pexpect}
\end{align*}
\]

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:

\[
\begin{align*}
\text{cd lnsw/TwiceAsNice} \\
\text{make install -j -l 2 \&\& tee install.log}
\end{align*}
\]

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:

\[
\begin{align*}
\text{cd lnsw/ln/3rdparty} \\
\text{autoreconf -f -i -s} \\
./configure --prefix=$\text{INSROOT} \\
\text{make install}
\end{align*}
\]

- 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

\[
\begin{align*}
\text{cd /usr/lb64} \\
\text{ln -s libnsl.so.2 libnsl.so}
\end{align*}
\]
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
and lnsw/config/makeLocalhostCfg.pl to let the libraries use device drivers in simulating mode and to let them all run on your local workstation.

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/geirs/* 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.\footnote{It 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.}

### 3.3 Port numbers

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

```bash
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

<table>
<thead>
<tr>
<th>port</th>
<th>config file</th>
<th>service</th>
</tr>
</thead>
<tbody>
<tr>
<td>10000</td>
<td>/alias-lbt.cfg</td>
<td>lbto.iiSimulator-svr.ALIAS</td>
</tr>
<tr>
<td>10000</td>
<td>/laos/sx/hws/wfc/laos.sx.hws.wfc.loop.float-sim.cfg</td>
<td>ADAPTER</td>
</tr>
<tr>
<td>10000</td>
<td>/ltcs/ltcs.ii-fsv.cfg</td>
<td>IIF.SVC.CFG.CONNECTION</td>
</tr>
<tr>
<td>10000</td>
<td>/ltcs/ltcs.ii-fsv.cfg</td>
<td>IIF.SVC.CFG.CONNECTION</td>
</tr>
<tr>
<td>10000</td>
<td>/laos/sx/hws/wfc/laos.sx.hws.wfc.fitsLoop-svr.cfg</td>
<td>ADAPTER</td>
</tr>
<tr>
<td>10000</td>
<td>/laos/dx/hws/moe/laos.dx.hws.moe.maps-svr.cfg</td>
<td>ADAPTER</td>
</tr>
<tr>
<td>10010</td>
<td>/alias-lbt.cfg</td>
<td>laos.sx.hws.drot.derotation-svr.ALIAS</td>
</tr>
<tr>
<td>10017</td>
<td>/laos/dx/gws/moe/laos.dx.gws.moe.magicLantern-svr.cfg</td>
<td>ADAPTER</td>
</tr>
<tr>
<td>10020</td>
<td>/alias-lbt.cfg</td>
<td>laos.sx.hws.moe.warmOptics-svr.ALIAS</td>
</tr>
<tr>
<td>10030</td>
<td>/alias-lbt.cfg</td>
<td>laos.sx.hws.moe.sensor-svr.ALIAS</td>
</tr>
<tr>
<td>10040</td>
<td>/alias-lbt.cfg</td>
<td>laos.sx.hws.moe.calibrationUnits-svr.ALIAS</td>
</tr>
<tr>
<td>10050</td>
<td>/alias-lbt.cfg</td>
<td>laos.sx.hws.se.starEnlarger-svr.ALIAS</td>
</tr>
<tr>
<td>10072</td>
<td>/alias-lbt.cfg</td>
<td>laos.sx.hws.aoc.ccdtrack-svr.ALIAS</td>
</tr>
<tr>
<td>10074</td>
<td>/alias-lbt.cfg</td>
<td>laos.sx.hws.aoc.secenter-svr.ALIAS</td>
</tr>
<tr>
<td>10080</td>
<td>/alias-lbt.cfg</td>
<td>laos.sx.hws.wfc.loop-svr.ALIAS</td>
</tr>
<tr>
<td>10100</td>
<td>/alias-lbt.cfg</td>
<td>laos.sx.gws.se.starEnlarger-svr.ALIAS</td>
</tr>
<tr>
<td>10110</td>
<td>/alias-lbt.cfg</td>
<td>laos.sx.gws.moe.sensor-svr.ALIAS</td>
</tr>
<tr>
<td>10115</td>
<td>/alias-lbt.cfg</td>
<td>laos.sx.gws.moe.anularMirror-svr.ALIAS</td>
</tr>
<tr>
<td>10120</td>
<td>/alias-lbt.cfg</td>
<td>laos.sx.gws.moe.magicLantern-svr.ALIAS</td>
</tr>
<tr>
<td>10130</td>
<td>/alias-lbt.cfg</td>
<td>laos.sx.gws.drot.derotation-svr.ALIAS</td>
</tr>
<tr>
<td>10150</td>
<td>/alias-lbt.cfg</td>
<td>laos.sx.hws.wfc.recmat-svr.ALIAS</td>
</tr>
<tr>
<td>10151</td>
<td>/alias-lbt.cfg</td>
<td>laos.sx.gws.wfc.recmat-svr.ALIAS</td>
</tr>
<tr>
<td>10152</td>
<td>/alias-lbt.cfg</td>
<td>laos.sx.gws.wfc.recmat-svr.ALIAS</td>
</tr>
<tr>
<td>10153</td>
<td>/laos/sx/gws/wfc/laos.sx.gws.wfc.recmat.working-svr.cfg</td>
<td>ADAPTER</td>
</tr>
<tr>
<td>10154</td>
<td>/alias-lbt.cfg</td>
<td>laos.sx.gws.wfc.recmat-svr.ALIAS</td>
</tr>
<tr>
<td>10156</td>
<td>/alias-lbt.cfg</td>
<td>laos.sx.gws.aoc.ccdtrack-svr.ALIAS</td>
</tr>
</tbody>
</table>
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]

\[
\begin{align*}
\cos a \sin A &= - \cos \delta \sin h; \\
\cos a \cos A &= \sin \delta \cos \phi - \cos \delta \cos h \sin \phi; \\
\sin a &= \sin \delta \sin \phi + \cos \delta \cos h \cos \phi; \\
\cos \delta \sin h &= - \cos a \sin A; \\
cos \delta \cos h &= \sin a \cos \phi - \cos a \cos A \sin \phi; \\
\sin \delta &= \sin a \sin \phi + \cos a \cos A \cos \phi.
\end{align*}
\]

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 $\phi$:

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

\[
= \begin{pmatrix}
- \sin \phi & 0 & \cos \phi \\
0 & -1 & 0 \\
\cos \phi & 0 & \sin \phi
\end{pmatrix}
\begin{pmatrix}
\cos l & \sin l & 0 \\
- \sin l & \cos l & 0 \\
0 & 0 & 1
\end{pmatrix}
\begin{pmatrix}
\cos \delta \cos \alpha \\
\cos \delta \sin \alpha \\
\sin \delta
\end{pmatrix}.
\]

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.\textsuperscript{5} The LN software is currently copying these data from the telescope, including the \texttt{EQUINOX}, to the FITS headers.\textsuperscript{6}

\textsuperscript{5}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...

\textsuperscript{6}this may violate FITS standards that propose that the \texttt{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

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

of the equatorial coordinate system. The NCP is at

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

The vector \( \mathbf{z} \) 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:

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

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

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

Finally \( \omega_z \times \mathbf{s} \) 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:

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

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

\[
\mathbf{u}_\delta = \begin{pmatrix}
-\sin \delta \cos \alpha \\
-\sin \delta \sin \alpha \\
\cos \delta
\end{pmatrix}
\]

and to the east,

\[
\mathbf{u}_\alpha = \begin{pmatrix}
-\sin \alpha \\
\cos \alpha \\
0
\end{pmatrix},
\]

has some benefit; one can search for targets in the FITS files and these won’t change over time comensurate with precession...
Figure 1: The parallactic angle $p$ as a function of hour angle $h$ and declination $\delta$ with (18) for geographic latitude $\phi$ of the LBTO. Depending on the polar distance $\pi/2 - \delta$, transit through the meridian ($h = 0$) means the parallactic angle $p$ either wraps around $-\pi \rightarrow +\pi$ or it runs through zero. See [12, Fig. 2.4].

obtained by differentiationg (8) with respect to $\delta$ and $\alpha$ and normalizing to unit length (see e.g. [10]). The parallactic angle $p$ is the angle north-over-east of the initial section,

$$\omega_z \times s = \cos p u_\delta + \sin p u_\alpha. \quad (15)$$

By multiplying with $u_\delta$ and $u_\alpha$, and utilizing $u_\delta \perp u_\alpha$ such that some dot products on the right hand side vanish [11, §71]:

$$\begin{align*}
(\omega_z \times s) \cdot u_\delta &= \cos p = \frac{1}{\sin z} [\cos \delta \sin \phi - \sin \delta \cos \phi \cos h]; \\
(\omega_z \times s) \cdot u_\alpha &= \sin p = \frac{1}{\sin z} \sin h \cos \phi. \quad (17)
\end{align*}$$

This can be evaluated with the usual 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 at the textbook expression[12, Eq. (2.1)]

$$\tan p = \frac{\sin p}{\cos p} = \frac{\sin h}{\cos \delta \tan \phi - \sin \delta \cos h}. \quad (18)$$

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

$$\dot{p} = -\frac{\cos \phi \cos A}{\sin z} \dot{h}. \quad (19)$$
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 $\dot{h} \approx 2\pi \times 1.002737/(24 \times 3600)$ 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. Note that reference systems pointing “from the instrument to M3” or “along the beam towards 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.

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

\(^7\)There are other 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.

Relative to that virtual camera position are

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

(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. The PCS keeps the value of $|R_z| + 180^\circ = 288.5$ in the $\text{LEFTIAA}$ and $\text{RIGHTIAA}$ parameters in some configuration file.

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 $p$.

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

(21)

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:

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

(22)
Multiplication with the inverse matrix from the left yields
\[
\begin{pmatrix}
-\cos p & \sin p \\
\sin p & \cos p
\end{pmatrix}
\cdot
\begin{pmatrix}
\cos a \Delta A \\
\Delta a
\end{pmatrix}
= \begin{pmatrix}
\cos \delta \Delta \alpha \\
\Delta \delta
\end{pmatrix}.
\tag{23}
\]

According to Figure 1, the direction to $+\delta$ relative to the horizontal coordinate is given by
\[
\phi_0 = R_Z - p + 90^\circ,
\tag{24}
\]
where $R_Z$ is given by (20) and $p$ the parallactic angle. 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 (21) into the $(A, a)$-system and then a rotation that increases angles by $R_z$ from the $(A, a)$-system to the platform:
\[
\begin{pmatrix}
\Delta x \\
\Delta y
\end{pmatrix}_F
= \begin{pmatrix}
\cos R_z & -\sin R_z \\
\sin R_z & \cos R_z
\end{pmatrix}
\cdot
\begin{pmatrix}
\cos a \Delta A \\
\Delta a
\end{pmatrix}
\cdot
\begin{pmatrix}
\cos \phi_0 & -\sin \phi_0 \\
\sin \phi_0 & \cos \phi_0
\end{pmatrix}
\tag{25}
\]
\[
\begin{pmatrix}
\Delta x \\
\Delta y
\end{pmatrix}_F
= \begin{pmatrix}
\cos \phi_0 & -\sin \phi_0 \\
\sin \phi_0 & \cos \phi_0
\end{pmatrix}
\cdot
\begin{pmatrix}
\Delta \delta \\
\cos \delta \Delta \alpha
\end{pmatrix}
\tag{27}
\]

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 towards the SE, 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 $\pm 0.00125$ 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 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.

To derotate flipped images requires another sign flip compared to non-flipped images.

The effective total of these sign flips 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 [14, p 7]

\[ s \approx 0.144 \text{arcsec/pix} = 4 \times 10^{-5} \text{deg/pix} = 6.981 \times 10^{-7} \text{rad/pix}. \] (28)

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 \((x_c, y_c)\) coordinate. Unless calibrated, the first approximation is \(x_c = y_c = 512.5\) pix, the center of the CCD. The values reported in the Com-3 version of [15, p 47] are

\[
(x_c, y_c) = \begin{cases} (485, 421), & \text{SX;} \\ (488, 414), & \text{DX.} \end{cases}
\] (29)
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 \textit{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 \textit{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 \textit{Ticket 1434}.

- The beam splitter optical thickness may have an effect of moving the centers sideways. See \textit{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. \(^8\)

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 both cameras,\(^9\) 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,

\(^8\)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.)

\(^9\)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].
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 $\phi^{(0)}_{DX}$ direction. The image shows the sum of the 10 images before the move subtracted from the sum of the 10 images after the move.

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 (26) 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:

$$\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}, \begin{pmatrix} \cos[-m(\beta + \beta_0)] & \sin[-m(\beta + \beta_0)] \\ \sin[-m(\beta + \beta_0)] & \cos[-m(\beta + \beta_0)] \end{pmatrix}. \quad (30)$$

$\beta_0$ 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,

$$\begin{pmatrix} \cos[m(\beta + \beta_0)] & \sin[m(\beta + \beta_0)] \\ \sin[m(\beta + \beta_0)] & \cos[m(\beta + \beta_0)] \end{pmatrix}. \quad (31)$$

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

$$\begin{pmatrix} \cos[2m(\beta + \beta_0)] & \sin[2m(\beta + \beta_0)] \\ \sin[2m(\beta + \beta_0)] & -\cos[2m(\beta + \beta_0)] \end{pmatrix}. \quad (32)$$

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 $0^\circ$ 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] 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.

$$m = \begin{cases} -1, & \text{HWS SX,} \\ -1, & \text{HWS DX.} \end{cases} \quad (33)$$

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

Some constant rotations depending on the pointing direction of M3 towards the instruments [13] define the transformation from $(\alpha, \delta)$ to $(A, a)$ in the first instrument focal plane coordinates: Section 4.1.3.
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, including the zero-angle of the K-mirrors with respect to their home switches and so forth.

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 \(s\) plus shifts (29).

The four reflections and the K-mirror offset are accumulated in a total angle \(\phi\)—which differs between SX and DX. These 2D rotation matrices commute, so the order does not matter.

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

\[
=\begin{bmatrix}
\cos[\phi + 2m(\beta + \beta_0)] & \sin[\phi + 2m(\beta + \beta_0)] \\
\sin[\phi + 2m(\beta + \beta_0)] & -\cos[\phi + 2m(\beta + \beta_0)] 
\end{bmatrix} \cdot
\begin{bmatrix}
\cos a \Delta A \\
\Delta a 
\end{bmatrix},
\tag{34}
\]

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 (34) becomes

\[
s \Delta x = \sin[\phi + 2m(\beta + \beta_0)] \Delta a; \tag{35}
\]

\[
s \Delta y = -\cos[\phi + 2m(\beta + \beta_0)] \Delta a. \tag{36}
\]

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

\[
\tan \phi^{(0)} = -\cot[\phi + 2m(\beta^{(0)} + \beta_0)]. \tag{37}
\]

From the reference values cited above we deduce

\[
\phi + 2m\beta_0 = \begin{cases}
-155.18^\circ, & \text{SX}, \\
-24.81^\circ, & \text{DX}.
\end{cases} \tag{38}
\]

The offset was also calibrated implicitly by considering the images of the fiber plates on the patrol camera [18]. A point on the negative horizontal axis in Figure 3 (the positive horizontal axis in [18]) appears in the patrol camera images at an angle of

\[
\gamma_0 = \begin{cases}
279.63 - 360 = -80.37^\circ, & \text{SX}; \\
266.38 - 360 = -93.62^\circ, & \text{DX};
\end{cases} \tag{39}
\]

relative to the horizontal axis, if the K-mirror angle is nominally 0° and if there is a zero offset in the CFG.TRANS.DEGREE in the kMirror-dev.cfg file.

The starting coordinate system is this time the focal plane, so plugging the inverse of the \(R_z\) matrix of (26) into (34) yields

\[
s \begin{bmatrix}
\Delta x \\
\Delta y 
\end{bmatrix}_F =
\begin{bmatrix}
\cos[\phi + 2m(\beta + \beta_0)] & \sin[\phi + 2m(\beta + \beta_0)] \\
\sin[\phi + 2m(\beta + \beta_0)] & -\cos[\phi + 2m(\beta + \beta_0)] 
\end{bmatrix} \cdot
\begin{bmatrix}
\cos R_z & \sin R_z \\
-\sin R_z & \cos R_z 
\end{bmatrix} \cdot
\begin{bmatrix}
\Delta x \\
\Delta y 
\end{bmatrix}_F. \tag{40}
\]
The negative horizontal axis implies $\Delta x = -1$, $\Delta y = 0$, so that use case is

$$ s \begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix} \bigg|_p = \begin{pmatrix} \cos[\phi + 2m(\beta + \beta_0)] & \sin[\phi + 2m(\beta + \beta_0)] \\ \sin[\phi + 2m(\beta + \beta_0)] & -\cos[\phi + 2m(\beta + \beta_0)] \end{pmatrix} \cdot \begin{pmatrix} -\cos R_z \\ \sin R_z \end{pmatrix} = \begin{pmatrix} -\cos[\phi + 2m(\beta + \beta_0) + R_z] \\ -\sin[\phi + 2m(\beta + \beta_0) + R_z] \end{pmatrix} , $$

requiring (at $\beta = 0$)

$$ \tan \gamma_0 = \tan[\phi + 2m(\beta + \beta_0) + R_z]. $$

This predicts

$$ \phi + 2m\beta_0 = \begin{cases} -151.87^\circ, & SX \\ -22.12^\circ, & DX \end{cases} $$

The quality of these estimates is probably better than (38) because it was generated without intervening changes from the parallactic angle and because it was derived with well-defined centroids of the fiber plate sources instead of matching fuzzy images of celestial sources.

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

### 4.2.2 Guiding Offsets

For the guiding offsets forwarded to the IIF one needs the constants (38), (33) and the inverse of (34) to map differential motions $(\Delta x, \Delta y)$ on the patrol camera to sky coordinates:

$$ \begin{pmatrix} \cos \alpha \Delta A \\ \Delta a \end{pmatrix} = s \begin{pmatrix} \cos(\phi + 2m\beta) & \sin(\phi + 2m\beta) \\ -\sin(\phi + 2m\beta) & \cos(\phi + 2m\beta) \end{pmatrix} \cdot \begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix} . $$

We employ the parallactic angle to rotate them to the equatorial coordinates. Inserting (23) into (44) we find the standard WCS matrix $CDi_{i,j}$ in the FITS headers for patrol camera images.

$$ \begin{pmatrix} \cos \delta \Delta \alpha \\ \Delta \delta \end{pmatrix} = s \begin{pmatrix} -\cos p & \sin p \\ \sin p & \cos p \end{pmatrix} \cdot \begin{pmatrix} \cos(\phi + 2m\beta) & \sin(\phi + 2m\beta) \\ -\sin(\phi + 2m\beta) & \cos(\phi + 2m\beta) \end{pmatrix} \cdot \begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix} $$

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 (38). 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 \texttt{createTrajectory} and \texttt{getReady} via \texttt{setPangStrtAng} and \texttt{setMotStrtAng} in \texttt{laos-drot/src/Service/LaosDrotServiceWorker.cc} in the properties \texttt{DROT.SVC.VAR.PANG\_STRT\_ANG} and \texttt{DROT.SVC.VAR.MOT\_STRT\_ANG} in \texttt{laos.sx.hws.drot.derotation-svc.cfg} and in \texttt{laos.dx.hws.drot.derotation-svc.cfg}.

See Section 8.2 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.\(^\text{10}\)

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 counter clock-wise if the nominal angle of the infrared camera derotator increased: Ticket 1471. 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.

[Full interpretation of the pupil images needs to consider that they are flipped by reflection by one mirror, flipped again because the natural look from inside the dewar at the binocular pupil is up-the-beam whereas the image on the detector is down-the-beam. Mapping from one image plane to another adds 180° of rotation, and GEIRS software in the version used in Com-5 adds another 180° rotation.]

To determine the value of \texttt{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.\(^\text{11}\). 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 \(\dot{\rho} > 0\) 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 (56), we need to feed the IR derotator motor with the negated derotator polynomials, so \texttt{CFG.DIRECTION} is \(-1\) in that case.

\(^{10}\)effectively a metal plate as long as the fringe tracker is not in use.

\(^{11}\)so we have detector plane rotations, not active beam rotations...
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 (to be confirmed). This is equivalent to zenith in the +y and the azimuth in the +x direction of the FITS coordinates. To determine the δ axes of the world coordinate system, we have to move the a axis cw by the parallactic angle \( p \) and ccw by the motor angle \( \beta \) (assuming zero offset here which remains to be calibrated...). The angle of \( \delta \) towards +x is \( \pi/2 - p + \beta \) (which fixes the left column of the following matrix) and of the angle of \( \alpha \) is \( \pi - p + \beta \) (which fixes the right column):

\[
\begin{pmatrix}
\Delta x \\
\Delta y
\end{pmatrix} =
\begin{pmatrix}
\cos(\pi/2 - p + \beta) & \cos(\pi - p + \beta) \\
\sin(\pi/2 - p + \beta) & \sin(\pi - p + \beta)
\end{pmatrix} \cdot
\begin{pmatrix}
\Delta \delta \\
\cos \delta \Delta \alpha
\end{pmatrix}.
\]

By matrix inversion

\[
\begin{pmatrix}
\Delta \delta \\
\cos \delta \Delta \alpha
\end{pmatrix} =
\begin{pmatrix}
\sin(p - \beta) & \cos(p - \beta) \\
-\cos(p - \beta) & \sin(p - \beta)
\end{pmatrix} \cdot
\begin{pmatrix}
\Delta x \\
\Delta y
\end{pmatrix}.
\]

By exchanging the two equations (because WCS considers \( \alpha \) the first and \( \delta \) the second coordinate) and assuming a pixel scale \( s \approx 0.00521 \) as/px \( \approx 0.1447 \times 10^{-5} \) deg, the WCS is

\[
\begin{pmatrix}
\cos \delta \Delta \alpha \\
\Delta \delta
\end{pmatrix} = s
\begin{pmatrix}
-\cos(p - \beta) & \sin(p - \beta) \\
\sin(p - \beta) & \cos(p - \beta)
\end{pmatrix} \cdot
\begin{pmatrix}
\Delta x \\
\Delta y
\end{pmatrix}.
\]

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. These ASCII files may contain comments, which means lines that start with hashes (#) or are entirely empty.\(^\text{12}\) 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.

\(^\text{12}\)Allowing blank lines seems to be an extension to the LBTO format, which apparently does not allow those.
The python program plotSkyTrack.py shows an extrapolated plot of the telescope altitude, azimuth and parallactic angle over the next 20 minutes.

The name of the cannot contain blanks (which are field separators) and should not contain underscores.\footnote{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 \texttt{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 \(s \perp e_\alpha, s \perp e_\delta\):

\[
\hat{f}s' \cdot s = 1; \quad \hat{f}s' \cdot e_\alpha = \Delta\alpha; \quad \hat{f}s' \cdot e_\delta = \Delta\delta.
\]
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 (54).
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.
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 \( 1/f \geq 0.9999996 \).

The coordinate transformation from sky positions to the SE’s two-dimensional coordinates applies scale factors

\[
 f = \begin{cases} 
 0.613 \text{ mm/arcsec} & \text{(GWS)}; \\
 0.802 \text{ mm/arcsec} & \text{(HWS)}; 
\end{cases} \tag{51}
\]

The 613 \( \mu \)m are taken from [20] for the GWS and have been scaled with the ratio of the \( F \)-ratios 20/15.28 to a HWS figure. The 802 \( \mu \)m are compatible with the 96 mm of the 2 arcmin of [21, 10.4.2]. Both values ought be compatible with the numbers for SE.SVC.CONFIG.OVERLAY.FIELD_OF_VIEW in 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 [22, p. 176] and 600.6 of DX [22, p. 178]. The same scaling factor appears if one takes positions via the `getKFPcoordinates()` function of the IIF measured already in millimiters; so these have to be scaled with the unitless

\[
 f = \begin{cases} 
 1 & \text{(GWS)}; \\
 1.309 & \text{(HWS)}.
\end{cases} \tag{52}
\]

In an unrotated coordinate system—first coordinate along \( \delta \), second along \( \alpha \)—the star has coordinates \( (f \Delta \delta, f \Delta \alpha) \) in the SE plane.

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 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

\[
\begin{pmatrix} 
 -1 & 0 \\
 0 & 1
\end{pmatrix}.
\tag{53}
\]

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:

\[
\begin{pmatrix} 
 x \\
 y
\end{pmatrix} = \begin{pmatrix} 
 \cos[-m \beta - \beta_0] & -\sin[-m \beta - \beta_0] \\
 \sin[-m \beta - \beta_0] & \cos[-m \beta - \beta_0]
\end{pmatrix} \cdot \begin{pmatrix} 
 -1 & 0 \\
 0 & 1
\end{pmatrix} \cdot \begin{pmatrix} 
 \cos \phi_0 & -\sin \phi_0 \\
 \sin \phi_0 & \cos \phi_0
\end{pmatrix} \cdot \begin{pmatrix} 
 f \Delta \delta \\
 f \cos \delta \Delta \alpha
\end{pmatrix} - \begin{pmatrix} 
 c_x \\
 c_y
\end{pmatrix} \tag{54}
\]

The sign factor \( m = \pm 1 \) 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
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.

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 $m\beta + \beta_0$ relativ to the beam and to the horizontal platform coordinates (dashed angle).
coordinate system of the electronics, gears and switches and the sign choice of TRANS.DEGREE in the files \texttt{laos.dx.gws.drot.bearing-dev.cfg} and \texttt{laos.sx.gws.drot.bearing-dev.cfg}. \( \beta \) are 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:

\[
\phi_0 + m\beta + \beta_0 = R_x - p(t) + m\beta(t) + \beta_0 + 90^\circ, \quad \frac{d}{dt} (p(t) - m\beta(t)) = 0. \tag{55}
\]

(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, \( s(t) \) was opposite to the derotator polynomial’s angles,

\[
\text{sgn} \dot{s}(t) = - \text{sgn} \dot{r}(t). \tag{56}
\]

Experience from Pathfinder (DX, see \cite[p. 47]{23}) shows that a sign flip was introduced in the LN derotator software running the motors such that the sign of the motion in units of steps, \( s(t) \) was opposite to the derotator polynomials in the configuration files \texttt{laos.dx.gws.drot.derotation-svc.cfg} and \texttt{laos.sx.gws.drot.derotation-svc.cfg}.

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

\[
m = \begin{cases} 
+1, & \text{GWS SX;} \\
-1, & \text{GWS DX.}
\end{cases} \tag{58}
\]

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.

Then flip the vertical component to account for the dichroic that reflects the beam upwards to the SE:

\[
\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \tag{59}
\]
The product of (26) by the previous 2 matrices is

\[
\begin{pmatrix}
  x \\
  y
\end{pmatrix}
= \begin{pmatrix}
  \cos[\phi_0 - 2m(\beta + \beta_0)] & -\sin[\phi_0 - 2m(\beta + \beta_0)] \\
  \sin[\phi_0 - 2m(\beta + \beta_0)] & \cos[\phi_0 - 2m(\beta + \beta_0)]
\end{pmatrix}
\begin{pmatrix}
  f\Delta \delta \\
  f\cos \delta \Delta \alpha
\end{pmatrix}
\]

\[
= \begin{pmatrix}
  \cos[-2m(\beta + \beta_0)] & -\sin[-2m(\beta + \beta_0)] \\
  \sin[-2m(\beta + \beta_0)] & \cos[-2m(\beta + \beta_0)]
\end{pmatrix}
\begin{pmatrix}
  \cos \phi_0 & -\sin \phi_0 \\
  \sin \phi_0 & \cos \phi_0
\end{pmatrix}
\begin{pmatrix}
  f \cos \Delta \alpha \\
  f \cos \delta \Delta \alpha
\end{pmatrix}.
\] (60)

It describes how a star off-target by $\Delta \delta$ and $\Delta \alpha$ in the star catalogue is converted to HWS SE positions by the combined action $\phi_0$ of the telescope mirrors, the action $\beta$ of the K-mirror rotation, and offsets $\beta_0$ (that incorporate differences between nominal K-mirror angles and geometric K-mirror angles, the aforementioned beam rotations induced by the warm dichroic, and the rotation of the SE image plane relative to the $\approx 8.5^\circ$ main axis of the K-mirrors.)

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

\[
\begin{pmatrix}
  106.131 & 41.487 \\
  41.223 & -105.846
\end{pmatrix}, \text{SX} \begin{pmatrix}
  112.474 & -22.77667 \\
  -22.857 & -112.312
\end{pmatrix}, \text{DX}
\] (61)

where the input are horizontal and vertical pixels on the patrol camera and the output microns of the FP20 image. We will not use the offset which mainly indicates the translation from FITS coordinates to SE center-coordinates. The two determinants are negative because the patrol camera and SE image are relatively flipped. 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 matrices are

\[
\begin{pmatrix}
  0.932859 & 0.364655 \\
  0.36233 & -0.93033
\end{pmatrix}, \text{SX} \begin{pmatrix}
  0.9807149 & -0.198601 \\
  -0.1993 & -0.9793
\end{pmatrix}; \text{DX}.
\] (62)

These matrices are modelled as

\[
\begin{pmatrix}
  \cos \gamma_1 & -\sin \gamma_1 \\
  \sin \gamma_1 & \cos \gamma_1
\end{pmatrix}\begin{pmatrix}
  1 & 0 \\
  0 & -1
\end{pmatrix}.
\] (63)

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:

\[
\gamma_1 = \begin{cases}
+0.372\text{rad} = 21.31^\circ; & \text{SX} \\
-0.200\text{rad} = -11.48^\circ. & \text{DX}
\end{cases}
\] (64)

One would expect angles near $\pm 8.5^\circ$ 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].
4.5 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 IIFE1OnSource 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 – TargetParAngle and L.TargetParAngle of the data dictionary (with a due conversion factor of 180/π). 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</th>
<th>UTC</th>
<th>ParAngle</th>
<th>R_TargetParAngle</th>
<th>OnSource</th>
<th>∑ 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>
<td>354.4310</td>
</tr>
<tr>
<td>57786.75008483796</td>
<td>18:00:04.057</td>
<td>-13.883</td>
<td>139.645</td>
<td>0</td>
<td>248.7466</td>
</tr>
<tr>
<td>57786.75115641204</td>
<td>18:01:36.742</td>
<td>-146.999</td>
<td>138.788</td>
<td>0</td>
<td>248.7476</td>
</tr>
<tr>
<td>57786.75254762731</td>
<td>18:03:36.935</td>
<td>137.697</td>
<td>137.697</td>
<td>1</td>
<td>248.7502</td>
</tr>
<tr>
<td>57786.75476923612</td>
<td>18:06:48.874</td>
<td>135.998</td>
<td>135.998</td>
<td>1</td>
<td>248.7540</td>
</tr>
<tr>
<td>57786.75842708334</td>
<td>18:12:04.905</td>
<td>133.313</td>
<td>133.313</td>
<td>1</td>
<td>248.7594</td>
</tr>
<tr>
<td>57786.76413278935</td>
<td>18:20:17.815</td>
<td>129.393</td>
<td>129.393</td>
<td>1</td>
<td>248.7690</td>
</tr>
<tr>
<td>57786.7666434028</td>
<td>18:23:56.649</td>
<td>127.750</td>
<td>127.750</td>
<td>1</td>
<td>248.7714</td>
</tr>
<tr>
<td>57786.7683262037</td>
<td>18:26:20.042</td>
<td>126.705</td>
<td>126.705</td>
<td>1</td>
<td>248.7749</td>
</tr>
<tr>
<td>57786.77862875001</td>
<td>18:41:10.308</td>
<td>120.715</td>
<td>120.714</td>
<td>1</td>
<td>248.7857</td>
</tr>
<tr>
<td>57786.78041354167</td>
<td>18:43:44.444</td>
<td>119.758</td>
<td>119.757</td>
<td>1</td>
<td>248.7880</td>
</tr>
<tr>
<td>57786.78364978009</td>
<td>18:48:24.068</td>
<td>118.076</td>
<td>118.076</td>
<td>1</td>
<td>248.7910</td>
</tr>
<tr>
<td>57786.7851730324</td>
<td>18:50:35.736</td>
<td>99.271</td>
<td>73.039</td>
<td>0</td>
<td>248.8745</td>
</tr>
<tr>
<td>57786.78871634259</td>
<td>18:55:41.792</td>
<td>72.241</td>
<td>72.241</td>
<td>1</td>
<td>248.8725</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.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 ≈ 248.8°. (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° 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.\textsuperscript{14} This value within the PCS was corrected to $18.5^\circ$ in Oct. 2017.\textsuperscript{15}

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.\textsuperscript{16}

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 $0.009^\circ$ per seconds during the hour of the measurement could account for $0.3^\circ$ 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 \texttt{lensw/ln/ltcs/test/iif/ltboto/LtboIifExample.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_sd = iif_factory.create(‘LN_IIF’,’bentGregorianBack both’,’LINC’)
  ```

\textsuperscript{14} J. Hill, priv. commun, citing LEFTIAA and RIGHTIAA = 291, 2017-06-30
\textsuperscript{15} J. Hill, priv. commun, setting LEFTIAA and RIGHTIAA = 288.5, 2017-10-10
\textsuperscript{16} 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.
• 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
• 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 menue 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/ltcs/doc/linc.info
```

or with an explicit directory search path:

```
info -d $INSROOT/share/info linc
```

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- **laos.dx.hws.GUI.sh** ............................................................................................. 5
- **laos.dx.hws.aoc.status.GUI.sh** ............................................................................ 5
- **laos.dx.hws.moe.annularMirror-svc.GUI.sh** .......................................................... 5
- **laos.dx.hws.moe.sensor-svc.GUI.sh** .................................................................... 5
- **laos.dx.hws.moe.sensor.svc.GUI.sh** .................................................................... 5
- **laos.dx.hws.moe.warmOptics-svc GUI.sh** ............................................................... 5
- **laos.dx.hws.pcam.ccd47-svc GUI.sh** .................................................................... 5
- **laos.dx.hws.se.starEnlarger-svc GUI.sh** ............................................................... 5
- **laos.dx.hws.wfc.loop-svc GUI.sh** ........................................................................ 5
- **laos.dx.hws.wfc.loopWFC GUI.sh** ....................................................................... 6
- **laos.dx.hws.wfc.loopWFC Slopes.sh** .................................................................... 6
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**Linc-Nirvana Linux Command Interface**
Max-Planck Institute of Astronomy, Heidelberg 13 January 2020

Richard J. Mathar mathar@mpia.de

---
Overview

Command interfaces to Linc-Nirvana, based on the TwiAxNice Software of MPA. This documentation is maintained in $HeadURL: https://svn.mpia.de/gulli/TwiceAsNice/branch/unstable/in/linc/doc/linc.texi $.

1 AutoGuider.py

AutoGuider.py -m sx -t starcat.cat

AutoGuider.py -m dx -t starcat.cat

Starts the auto-guidor 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.

The side can be specified with either the long option --side or with the short option -m.

The file with the star catalog can be specified with either the long option --starCat 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 Com.1 this 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 first. 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/Ifs (http://lins.lmc/ifs:2512) is running (although this should not be necessary, because reading the camera 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 in a single developer mode, in that case it prints the message:

TaN-less node

To standard output when it is started. Here TA-N less means without accessing services of TwiceAxNice (TxN).

The Monitor button is labelled as

* Monitor

if pressing it starts reading patrol camera images

* Stop Mon

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

4 acquisitionSpiralSearch.py

5 acquisitionSpiralSearch.py

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

6 cleanupConfig.py

7 indiserver

syntax: indiserver $INSHROOT/bin/indi_linc_lircs

The indiserver is compiled and started on the lircs.linc computer to respond to property queries from the FACSINU (facility summary) clients with the aim to monitor LINC specific parameters that may be useful for LITO handling. In particular the temperature and pressure parameters of LINC-NIRVANA 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 $INSHROOT. This happens by compiling the indiserver standard make.

* compilation of the std.indi_linc_lircs

7.2 Invocation

The indiserver is started on lircs.linc and can be tested with

# indiserver $INSHROOT/bin/indi_linc_lircs

7.3 Implementation

The LINC-NIRVANA INDI device responds to *get property* queries of some client (which supposedly is the FACSIM) by looking at the properties and values found in the $INSHROOT/indi_linc_lircs_2 file, 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 lircs.linc.)

The auto guider in its current state locates the brightest pixel in the image by computing the information for relative offsets and its arrows in the patrol camera image from pointing information continuously updated by TCS queries, and those will settle to the correct values at the end of slewing. (Currently the AutoGuider does not try to draw stars of the star catalog into any of its maps. If ever it does, it ought to line-up the mid-point of the online pointing with the coordinates of the target in its star catalog to detect whether its star catalog has become invalid.)

2 acquisitionCenteringSE.py

This will create $INSHROOT/bin/indi_linc_lircs. Note that the source code tries to figure out whether the indiserver has been compiled: if this was not the case, a 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 indispens directory is not compiled, so neither the indiserver nor the LINC-NIRVANA device are compiled. For that reason, unit test scenarios for the server should not be called by default from the autotools tools.

7.2 Invocation

The indiserver is started on lircs.linc with

indiserver $INSHROOT/bin/indi_linc_lircs

and can be tested with

indiserver $INSHROOT/bin/indi_linc_lircs

8 initStages.py

9 laos.dax.gws.drot.deotation-svr_GUil.sh

This will start the indiserver on lircs.linc.

$INSHROOT/bin/indi_linc_lircs

and can be tested with

indiserver $INSHROOT/bin/indi_linc_lircs

3rdparty

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

This compilation will skip a lot of the default indiserver installation because the LINC-NIRVANA case does not support to configure or initiate devices through the indiserver but only passive queries of some parts of the property tree. The indiserver libraries and headers end up in $INSHROOT/laos_dax.gws.drot.deotation-

--SVR_GUIL.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

rbchandler.sh.laos.dax.gws.drot.deotation-svr --SVR_GUIL.sh

rbchandler.sh.laos.dax.gws.drot.deotation-svr --SVR_GUIL.sh

The buttons in the derotator GUI are misleading. They show green arrows, when the derotator is stopped, and red rockets when the derotators are running. This is about the
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.

The syntax for the GUI scripts is:

```bash
laos.dx.hws.drot.derotation-svr_GUI.sh
daos.dx.hws.drot.derotation-svr
```

Control (start, stop, etc.) 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 with the following command:

```bash
rcbasdard.sh start laos.dx.hws.drot.derotation-svr --CONFIG=laos/dx/hws/drot/laos.dx.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` in the form of:

```bash
ra/degrees dec/degrees
```

where right ascension and declination are either provided in degrees or in the hex-decimal hour and degrees format.
Chapter 59: lics.sx.hws.drot.py

53.2 alt/az to ra/dec
The reverse transformation from horizontal to equatorial is done by adding the option 
\[\text{lbtoEquat2Horiz.py} \ -r \ \text{alt/degrees az/degrees}\]
where altitude and azimuth angle either provided in degrees or in the hex-decimal degrees format.

54 lics.drot.py
lics.drot.py
Starts derotation on all 5 derotation motors (sx/dx, gw/lh, and infrared detector) at their current positions.

55 lics.dx.gws.drot.py
lics dx gws drot.py
Starts derotation on the DX GWS bearing at its current position.

56 lics.dx.hws.drot.py
lics dx hws drot.py
Starts derotation on the SX HWS K-mirror at its current position.

57 lics.irc.drot.py
lics irc drot.py
Starts derotation of the motor of the infrared/science detector.

58 lics.sx.gws.drot.py
lics sx gws drot.py
Starts derotation on the SX GWS bearing at its current position.

59 lics.sx.hws.drot.py
lics sx hws drot.py
Starts derotation on the SX HWS K-mirror at its current position.

60 licsCatChk
licsCatChk [-v] catfile.cat [catfile2.cat...]
All Linc-Nirvana star catalog files on the command line are checked for common errors, 
including integer and floating point formats in the RA/DEC coordinates, proper motions and 
magnitudes. Errors are printed if the hex value of the RA coordinate is not an integer in 
the range 0 to 24, if the coordinate value of the DEC coordinate is missing a sign or not 
an integer in the range -90 to +90, if the minutes of the two coordinates are not unsigned 
numbers in the range 0 to 60, if the seconds in the two coordinates are not positive floating 
point numbers in the range 0 to 60, if the two equinox fields do not refer to J2000, if the 
proper motions are not floating point numbers.

61 licsCatChk.sh
licsCatChk.sh [-v] [catfile catfile2...]
The Linc-Nirvana star catalog files in the directories listed on the command line are indi-
vidually checked for syntax errors with licsCatChk See Chapter 60 (LincCatChk), page 10.
The script actually assumes every file with the suffix cat is 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.

62 licsFmodhead
licsFmodhead fitfile.fits tplhdrfile1.tpl [tplhdrfile2.tpl...]
The file fitfile.fits is changed by adding the template header lines in tplhdrfile1.tpl 
and further optional files into the primary header.

63 licsGwsMockup
licsGwsMockup [-s (sx|dx)] lbtocatfile
The program generates a fake image of a virtual camera in the Linc-Nirvana system.
Stars are simulated with one arcsecond of seeing, with an integration time inversely propor-
tional to the flux of the brightest star, and assuming a background of 22 mag per arcsecond
in 45 degrees diagonal in the alpha/delta system, the two values need to be the same.
The images are flipped and rotated such that the x axis of the
sky coordinates is echoed in every catalog file.

64 licsLogMergeAllHosts.sh
This shell script gathers the log-file lines on the level of INFO on the LS hosts (linc, linc2, 
lics...), sorts them according to date and time, eliminates the coloring, and copies the 
merged file into $HOME/log/log.of/ for debugging purpose.

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] [raoffsetarcsec decoffsetarcsec]
licsOffset [-t] is a server to raoffsetarcsec decoffsetarcsec
If the switch -t is used, the server 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 or the PCA GUI of the LN operator, for example.) This means to move along the 45 degrees diagonal in the alpha/delta system, the two values need to be the same.

65.2 Offset Star Enlargers
licsOffset [-v] [-s all] raoffsetarcsec decoffsetarcsec
licsOffset [-v] [-s all] is a server to raoffsetarcsec decoffsetarcsec
If the switch -s is used, the server defines one subset of 1, 2 or 4 of the 4 85 sub-systems that Linc-Nirvana has. The 4 SE sets are configured by choosing the same offsets for all four sets in 4 SE sub-systems. If the switch -v is used, the motion of the two star enlargers of one side or one individual star enlarger set assuming offsets in right ascension and declination. The string after the -v defines a subset of 1, 2 or 4 of the set of 4 85 sub-systems that Linc-Nirvana has.
The 4 SE sets are configured by choosing the same offsets for all four sets in 4 SE sub-systems. If the switch -v is used, the motion of the two star enlargers of one side or one individual star enlarger set assuming offsets in right ascension and declination. The string after the -v defines a subset of 1, 2 or 4 of the set of 4 85 sub-systems that Linc-Nirvana has.
68.1 Support HWS SE positioning

The program retrieves a patrol camera image, analyses which stars are in it, 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-colinear SE arms to reach those positions, and eventually to move those SE arms.

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

The program's 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). Get the final output by star brightness (priority) according to the sex pseudo-magnitude. Return these as a SexPoint with units of pixels.
3. Map this list to SE coordinates (with one of Klymak'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 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 dx GUI with a superimposed coordinate system of the SE plane (in units of microns). This GUI can be prevented with the `-r` option.

If you wish to click on a star in that dx GUI and to freeze the associated pair of (x,y) coordinates to copy to the numbers into the SE GUI, select Edit->CurrentStar in the dx GUI menu and click on the star's position in the image. Then the dx GUI does not change the coordinates when the mouse cursor leaves that GUI.

The program is usually called indirectly from within `licsStarcat` Sec Chapter 71 [licsStarcat], page 24.

The program is not available (which means: it does nothing) if the executable and associated files are not mounted, use

```
lnsw/data/config/ltcs/*-dev.cfg
```

on the same arms (left, right or both) of the telescope as configured in the files may at the same time be either both or one side.

The option `-r` reveals that the contents is not yet mounted, use

```
lctcxfind
```

mount -a as super user to mount it, or use

```
lctcxf2
```

on that image. Eliminate stars that are outside the 1 arcmin radius (because the patrol camera has a slightly larger FOV). Get the final output by star brightness (priority) according to the sex pseudo-magnitude. Return these as a SexPoint with units of pixels.

The program returns to the Linux shell if

- the telescope does not contact the telescope's GUI server directly but forwards the command to the Linc-Nirvana proxy implied by the `-f` option, so this server needs to be running to have any effect.
- the telescope does not work for the OffsetPointing command that may be started from within the AutoGuider: the IF/Proxy server will terminate if the IF's authentication differs from the LINC configuration. The configurations may agree to either both arms or the same arm of the telescope.

Note that this is not available with the lincoes GUI server, or the option `-f` is not used, the command line argument.

```
lctcxf2 [flags] -f sexPointing2
```

The program returns to the Linux shell if

- the telescope does not contact the telescope's GUI server directly but forwards the command to the Linc-Nirvana proxy implied by the `-f` option, so this server needs to be running to have any effect.
- the telescope does not work for the OffsetPointing command that may be started from within the AutoGuider: the IF/Proxy server will terminate if the IF's authentication differs from the LINC configuration. The configurations may agree to either both arms or the same arm of the telescope.

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lctcxf2 [flags] -f sexPointing2
```

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Note that this is not available with the lincoes GUI server, or the option `-f` is not used, the command line argument.
Chapter 67: licsPreset

During that stage the laos.xx.xxx.drot GUI’s show a status of Start External Profile...,
and re-assign star enlargers, the proxy server creates rotator polynomials even if the TO has not authorized the instrument. If the proxy server realizes that the instrument is not authorized at all or not authorized at the side it is active, the proxy server does not ask the telescope interfaces for the polynomials but creates them itself, based on the current pointing coordinates of the geographic position on the mount and the implementation of the SOFA library. So for tests of the functionality of the rotators on the mountain during bad weather conditions of when another instrument is operative, the rotator trajectories may run into one of its neighbours. This may happen if the backslash removal operations are not fast enough.

The obvious reason for that lenient behavior is that integration into an automated system can be a fixed syntax - all because the subsystem figures out by itself whether they are currently active/cooperating or not. The park position is defined by setting the motor along the y to the zero (home) position at the beginning of the trajectory. This preset of the star enlargers prepares for motions to be triggered by either the one on which the telescope is currently tracking or the one that is preset with 'bentGregorianBack both' for the FOCAL.

The two derotators for SX and the two derotators for DX request the sided derotator of the infrared detector is fed with the polynomial angle would lead to a start angle outside the limits of the motor, the value is reduced (in absolute value) to keep the start angle in the limits. Numerous angles will generally shorten the maximum derotation time. The most important side effect of this option is that this implicitly also rotates matching star pairs of the correlation angle by the same offset. Note that the effect on the beams that run through the K-mirrors is twice that of the offsetAngles.

The computer on which licsPreset is run and the server where the rotator services run must have sufficiently close clocks on the operating system (usually achieved by running NTP servers on both), because derived polynomials are computed on absolute time scales on the licsPreset-client and forwarded as such to the server, which reduces to start motors if the trajectories start in the past or in a too-close future. If the -t option is used and also -r, a call of Chapter 71 [licsStarcat], page 24, is issued once the licsPreset server.

Note that this command produces the parameters in the configuration files for the five derota-

tors in the following trajectory, and the resulting task is to control the instrument.

- The cases -d all, -d sx and -d dx span subprocedures 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 lenient behavior is that integration into an automated system can be a fixed syntax - all because the subsystem figures out by itself whether they are currently active/cooperating or not. The park position is defined by setting the motor along the y to the zero (home) position at the beginning of the trajectory. This preset of the star enlargers prepares for motions to be triggered by either the one on which the telescope is currently tracking or the one that is preset with 'bentGregorianBack both' for the FOCAL.

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Note that this command produces the parameters in the configuration files for the five derota-

tors in the following trajectory, and the resulting task is to control the instrument.
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 /GEIRS/scripts/QueueFiles on lics.lins.hbo.org, such that QueueFiles does nothing and returns immediately. Alternatively you can also tell the licsRewind.py to do nothing by adding a "quit" early in $INSROOT/bin/licsRewind.py on lica.lins.hbo.org. In GEIRS versions >= 7795-15 there is a check box "g" in the controls GUI right off the road button that tells GEIRS to use or to ignore the entire QueueFiles call. This means for Line-Nirvana, the GEIRS operator can decide prior to each read whether the rewind mechanism is executed or not. If the check mark at the box "q" is set, GEIRS calls QueueFiles and the detector motor rewrites to its previous location at the next read, otherwise GEIRS does not call QueueFiles and the detector derotation is not affected. (Not affected means it continues on its trajectory whatever that currently may be.) A first step of debugging this rewind mechanism is to test that licsRewind.py and QueueFiles work as expected. These are part of the Line-Nirvana source package, not of GEIRS.

69 licsSEOffset.py

licsSEOffset.py --CONF="", --LOGFILE="", --delta=delta

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 north/south coordinate system. The last two parameters allow the user to define the offset in x and y coordinates of the selected SE or categories.

The command creates an SE offsets file which contains the new x,y coordinates of the selected SE or categories.

70 licsSEhist.pl

licsSEhist.pl
licsSEhist.pl in duc
licsSEhist.pl in dux
licsSEhist.pl in dx
licsSEhist.pl in dx duc
licsSEhist.pl in dx dux
licsSEhist.pl in dx dux duc

The script extracts SE plane positions for the 12 or 8 SE heads from the current file in the $INSROOT log directory.
71.1 Syntax
Merges one or more of the LBITO star catalog ASCII files, optionally applies a cut on the brightest magnitudes that should persist, sorts the resulting stars by distance from the first, and writes the merged catalog to standard output (likely to be redirected into another file).
The program attempts to contact the up to four derotator servers to retrieve the motor angles, the TCS sync proxy for the parallactic angle, to assign the catalog stars to Star Enlarger arms, 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 LBITO star 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:

```
licsStarcat -m ~/lnsw/lnsw/guider/test.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 has many 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 mounter are not compatible with the telescope simulator sim2018 and the CAX document 02x1156.

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 models 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 angles)
- The response of the IF to the queries 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 inopportune observers who may misinterpret this as a hangup of the software, plus a fuzziness of time scales that comes into play because the FPC are in 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 limitmag. The default value is 30, which means effectively all stars that one could imperceptibly in a Linc-Normals context are kept. If the star catalog has been automated in truncated 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.

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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 0 deg, which is near the middle of the range for both SX and DX. 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 windows 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 or non-use of the switch has no effect.

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 are:
- 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 ratio between 2.2, and maps these positions with the coordinate transformation matrix of 2017-01 (quasi backwards) through the dx/sy) to the SE plane(s). The advantages of this approach are:
  - Whatever the axis runouts of the K-mirrors or telescope flexures are, these 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 dichroic, the 3 K-mirror reflections and the dichroic that separates the patrol camera and the AO beam need not 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 is the call, because the file is actually not used. In the same realm, errors of proper motions and the like in the star catalog are irrelevant.

The disadvantages are:

- The current version only works with the patrol camera being on.

Chapter 71: licsLincStarcat

71.2 retrieve
This is a combined action of getting a part of the NOMAD star catalog (online, not working properly), and then usually closed), because time consuming operations are only attempted on one side. Examples:

```
licsStarcat -r ~/licsLinc/guider/test.catalog
```

Chapter 71: licsXephem

71.2.1 Option r
The -r option retrieves a time stamp of an observation at which the conversions for proper motions and parallactic angle should take place. The four supported formats of the argument are:

- It contains an ISO (http://en.wikipedia.org/wiki/ISO_8601) specification of the time: the 4-digit year, the 2-digit month, the 2-digit day of the month, a T and the hour, minute and second, separated by slashes, the T and colons is indicated. The seconds should be followed either by a Z to indicate Ztd/UTC time, or a sign and hours and minutes for the time zone offset. Use for example -t 2017-10-11T03:00:02 to assume observation in the early morning in UTC of October 11. Use for example -t 2017-10-11T03:00:02Z to assume observation in the early morning of October 11 in the Arizona time zone, which is 7 hours west of UTC all year long. If the local computer is running in some other timezone, use -t "-07:00:00Z" to obtain the current time in UTC.

- It contains an hour, minute and second as HH:MM:SS: this is a time interval into the future relative to ‘now’, where ‘now’ is the time when the program is executed. Use for example -t 20:30:00 to assume observation in half an hour.

- It contains minutes and seconds as MM:SS: this is a time interval into the future relative to ‘now’, when the program is executed. Use for example -t 20:30:00 to assume observation in twenty seconds.

- If ‘t’ is absent, the time, when the program is started is taken by default. This means in particular that the program ought to be started after the derotator started: then the options -t, -r, -a are superfluous because the angles needed to predict SE positions can be retrieved online from the derotator services.

71.2.1.5 Option a
The -a option specifies one of the two sides of the telescope, SX or DX. If the option is not used, the command tries to engage both sides. Using the option to add a constraint on the side is beneficial if the entire setup uses only one side of the optics (the other then usually closed), because time consuming operations are only attempted on one side. Example:

```
licsStarcat -a sx -r ~/licsLinc/tcs/guider/test.catalog
```

71.2.1.6 Option g
The -g option specifies the AO subsystem, either box or gun. If not specified, the program tries to engage both sides.

71.2.1.7 Option G
The -G option specifies a nominal angle (in degrees) for the GWS bearing with the same offset as used in the GUI. If not specified, the program tries to contact the server of the GWS of the associated side(s), and if this fails the default is 0 deg, which is near the middle of the range for both SX and DX.

Chapter 72: licsXephem
By default, only the first star in each catalog file is copied to the XEphem database; the option -a triggers that all stars are copied.

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

zeno must be installed as detailed in LN-MPIA-MAN-ICS-010 (https://svn.mpia.de/trac/gals/linc/archive/Archives/LRTODocumentation/Manuals/linc2009.pdf). In the LRTO documentation, the \Instrument\levelController\levelSoftware\lo\zeno-\level\linc2009-\level\linc2009.100.pdf.

Use in detail. Once the zeno window pops up, click on Data and select Files. In the new window click again on Files and zoom to on the left side of the window to get a display at the USM symbol in the menu to remove the constellations contour lines. The click repeated times on the top left button to let the stars of our additional catalog appear in the order of magnitudes. If we must repeat that brightness adjustment each time the zoom scale is changed with the left slider and also after some other modifications...

Then in the main window on Viewer and select Sky view, click at the left of the display to get a display that is close to the natural sky system. Optionally click on the CTA symbol in the menu to remove the constellations contour lines. The click repeated times on the top left button to let the stars of our additional catalog appear in the order of magnitudes. If we 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.

lsfits /data/2017-06-Com2/targetlists/bestof_starringsum60mge/+/-cat

73 liifSnapshot.py

liifSnapshot.py

Print an overview of the IIF variables in the current state.

The set of variables that is shown can be changed by commenting the item of the very long list in the source code of liifSnapshot.py in or out.

If the option -g is added, a rough snapshot of the current derotator polynomials is also printed.

80 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 accessible 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 BOE-NIR which acts on the read-out electronic rack of the NIR detector. There is no reason to interfere with the operation of this button here because that power is hooked up on the UPS and not switchable here. However, we know that the power of the BOE basically feeds the pre-amplifiers of the detector outputs, and if these are switched off the detector unit will usually be cooled below the operating 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 BOE-NIR power during these stretches of days/months when Linc-Nirvana operations are scheduled to use the science detector, but do switch off that BOE-NIR power while the instrument is cooling down or warming up.


81 lsys.cryo.int-svr_GUI.sh

82 lsys.fits.int-svr_GUI.sh

83 lsysChkNTP.sh

Runs a date command on the ln-x PC’s and the Linc-Nirvana servers laos, laos2, lsys, lsys2 and lsysWeb and lircs.moe.dwr, lircs.moe.dpos, lircs.moe.smc... gives a hint of how longer the derotator stages may stay tracking before hitting their limit switches.

84 lsysCryostatControl.py

Opens a window and shows the updated contents of the most important variables of the IIF (TCS) dictionary with pauses between updates. The display is terminated by either typing CTRL+c in the window or closing the window with the X-button of the window manager.

The list of variables is the same as the one placed into FITS header keywords. It is configured in the file config/linc/linc.iif-fits.xml.

The meaning of the parameters is shown in http://wiki.ltn.org.nz/Software/svn/releases/0.18/0.18/SOURCES/linc.iif-fits.xml, or an equivalent place where year and semester refer to the current TCS release.

Note that this does not contact the IIF server directly but shows the values obtained by the ltsa-iif-svr, so this server needs to be running to get periodic updates of the values. (This is the same server that is used to request the derotator polynomials from the TCS. So this will be already running if any of the 5-derotator services for the GRS, HRS or infrared detector is running.) The updates will become obvious if one looks at clock type parameters like UTC or LST.

75 lircs.moe-svr_GUI.sh

lircs.moe-svr_GUI.sh

lircs.moe-svr_GUI.sh start

The usage without the command line option is the same as the usage with the command line option start.

This opens/closes 5 windows related to the movable optical elements in the cryostat:

• lircs.moe GUI for the derotator stage

76 lnDeployAtLbt.sh

77 lnDeployAtMpia.sh

85 lsysWebCameraControl.py

Idly starts the camera control process for each of the Linc-Nirvana remote controllers

86 ltsa-iif-svr_GUI.sh

A display of the most important TCS pointing information.

87 plotSkyTrack.py

Plots the parallel angle and the altitude and azimuth 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 derotator 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`.


Index

(Index is nonexistent)
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 \( \approx 206264'' \)), \( z \) 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 (28) 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].](image-url)
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.

Obtain the VM software from `http://people.lbto.org/~shooper/TCS.ova`.

```
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`.

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.\(^\text{17}\)

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

\(^{17}\)see the permissions on VBoxHeadless on openSUSE 13.1 for example
tcs-sim

- In `/etc/resolv.conf` we have

```bash
search linc.lbto.org
nameserver 192.168.156.40
```

- In `/etc/sysconfig/network` we have

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

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

```bash
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 menu, 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.\textsuperscript{18} 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.\textsuperscript{19} In the subsystemes area open the IIF control GUI, the PCI control GUI and optionally the MCS GUI by pressing the associated GUI buttons.\textsuperscript{20} Click on the

\textsuperscript{18} Once the virtual machine has booted, the VirtualBox Manager window and that console window of the virtual machine can be minimized to save space.

\textsuperscript{19} Ignore messages related to misconfigured swing arms, side monitors and other subsystems...

\textsuperscript{20} 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/ltcs.*.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.irws2.mpia-hd.mpg.de (192.168.56.1) and tcs-sim.irws2.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.irws2.mpia-hd.mpg.de irws2
    * 192.168.56.100 tcs-sim.irws2.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 screw driver 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

```
nameserver 192.168.56.1
```

In `/etc/sysconfig/network` add

```
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 edited by calling `/bin/nmtui`.

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

```
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 $\Delta \alpha = 5 \times 10^{-7}$ 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 send 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 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\(^1\), 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 (23), 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 \((f \cos \delta \Delta \alpha, f \Delta \delta)\) by aligning \(\delta\) with \(+k_y\) and \(\alpha\) with \(+k_x\), and introducing the angle

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

---the same for SX and DX--- [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 \(\pi/2 - \tau_k\):

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

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

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

\(66\)  
\(67\)

This can be inserted into the r.h.s. of (54) to obtain the transformation from kernel-focal-plane coordinates to SE planes.

\(^{21}\)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 22. 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>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>XEphem.Elevation</td>
<td>3221.0 m</td>
</tr>
<tr>
<td>XEphem.Lat</td>
<td>32:42:05</td>
</tr>
<tr>
<td>XEphem.Long</td>
<td>109:53:21</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>

22 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 obtained 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