

SUN/1.24

Starlink Project  
Starlink User Note 1.24

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# STARLINK Software Collection

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## Abstract

The Starlink Software Collection is a set of software which is managed and distributed by the Starlink Project. Some of the software was written by members of the Project, but some of it comes from outside the Project. This note describes the functions of the individual items in the Collection and provides an overview of the software so that readers can identify the items they need.

The software is classified into four main divisions:

- **Packages** – are large collections of programs for people who want to analyse, convert, and display data. They are subdivided into eleven classes to help you find what you want.
- **Utilities** – are small programs devoted to a specific purpose. For example, they help you prepare for observations, write documents, and write programs.
- **Subroutine Libraries** – are for programmers writing astronomical software. They provide facilities such as astronomical calculations, data management and graphics.
- **Infrastructure** – are items which are mainly of interest to people writing programs within the Starlink Software Environment. They are included for completeness.

Each item is described in sufficient detail for you to decide whether or not to investigate it further. If you want to find out more about an item, follow the document references given opposite the item name. If you are using the hypertext version of this document, the most up-to-date document references can be found by following the link from the software item name.

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## 1 Introduction

This document contains a survey of the complete Starlink Software Collection. The level of detail should enable you to decide whether or not to investigate a specific software item further. Full details of individual items can be found in the document references.

Installation instructions are contained in SUN/212.

The strategy guiding the development of Starlink software is described in SGP/42. A major influence on this strategy is the set of Starlink Software Strategy Groups. Guidelines for members of these groups is given in SGP/44.

New users of Starlink facilities should read the Starlink User's Guide (SUG).

The World Wide Web is an important tool for informing users about the Starlink Project and its software, and Starlink has published comprehensive documentation in this medium. Eventually, this will be linked together as a single hyper-linked document by utilising the HTX utilities (SUN/188). One of the greatest advantages of the Web is its potential for updating and distributing documents more frequently and rapidly than is practicable on paper. For current information about the Starlink software and documentation you should refer to the information on the Starlink Web Site (<http://www.starlink.ac.uk/>).

This edition describes the Collection as available in the Autumn 2002 CD-ROM distribution of December 2002.

## 2 Changes since the last issue

### 2.1 New packages

Two new items have been added to the Collection since the previous edition of this document (SUN/1.23, 5 August 2003) and are indicated as such in the heading of the appropriate sections.

The new packages are:

- **AUTOASTROM** Autoastrometry of mosaics. The new document (SUN/242) *AUTOASTROM – Autoastrometry for Mosaics* describes the package. AUTOASTROM is not available under Tru64 Unix.
- **JCMTDR** Applications for reducing JCMT GSD on-the-fly data. The documents *SC/1 JCMTDR Cookbook* and *SUN/132 Applications for Reducing JCMT GSD Data 1.2-2 User's manual* describe the package.
- **STARJAVA** Starlink Java Infrastructure and Applications Set. The new document (SUN/251) *Getting Started with the Starlink Java Infrastructure and Applications Set* describes the package and </star/starjava/javadocs/index.html> describes the Starlink STARJAVA classes API. There are miscellaneous documents in </star/starjava/docs/> for individual package information and third party application documentation.

The STARJAVA package contains the following applications and classes. Note, SPLAT, TREEVIEW, JNIAST and JNIIHDS have been moved to the STARJAVA package, instead of being individual packages.

**APPLICATIONS/UTILITIES in STARJAVA****FROG V0.1a** Display and analysis of time series data (new)**SOG V0.1** Son of GAIA (new)**SPLAT V2.0** Spectral Analysis Tool (update)**TABLECOPY V0.3** Copy tables from one format to another (new)**TOPCAT V0.3b** Tool for OPerations on Catalogues and Tables (new)**TREEVIEW V2.1-3** Hierarchical data viewer (update)**CLASS LIBRARIES in STARJAVA****ARRAY V0.2** N-dimensional array manipulation and I/O (new)**ASTGUI V1.0** AST specific UI components (new)**AXIS V1.0b2** Third generation Apache SOAP (new)**COCO V1.0** Java UI for Coco (new)**DOM4J V0.1** Third party DOM access library (org.dom4j.\*) (new)**FITS V0.1** STARJAVA-specific FITS access (new)**HDS V0.1** Non-native HDS utility classes (new)**HDX V0.1** A flexible, extensible, data model for astronomical images, tables and other metadata (new)**JAIUTIL V1.0** Utility classes for JAI (new)**JETTY V4.0.4** HTTP Server and Servlet Container (new)**JNIAST V2.0-4** Java Native interface to AST (update)**JNIHDS V0.3** Java Native Interface to HDS (update)**JSKY V2.0** Java Components for Astronomy (new)**JUNIT V3.7** Third party unit testing framework (junit.\*) (new)**NDX V0.1** N-dimensional astronomical object manipulation and I/O (new)**PAL V0.1** Positional Astronomy Library (new)**RV V1.0** Java UI for RV (new)**TABLE V0.3** Generic table manipulation and I/O (new)**TAMFITS V0.93** Third party basic FITS access (nom.tam.\*) (new)**UTIL V0.1** Miscellaneous utility classes (new)**VOTABLE V1.0** VOTable I/O (new)

The STARJAVA package can be considered to be independent of the standard USSC, and in future will be distributed separately. All the STARJAVA applications and classes are distributed under the GPL licence.

The SPLAT documentation (SUN/243) *SPLAT - A Spectral Analysis Tool* has been updated and can be found in

`/star/starjava/docs/splat/sun243.htm/sun243.html`.

It also appears in the DOCS package and can be seen with the command `showme sun243`.

STARJAVA is not available under Tru64 Unix.

## **2.2 Withdrawn Packages**

No packages have been withdrawn at this release.

## **2.3 Package details**

Some packages listed in this document are not distributed on Starlink CDs for various reasons including the lack of a Linux port. These packages are mainly older packages which are not used much and which have little or no support available. These packages have amended descriptions to indicate their availability.

### 3 Packages

Starlink aims to provide *maintainable*, *portable*, and *extensible* applications packages that work in harmony by sharing a common infrastructure toolkit, standards, conventions, and above all, a standard data format. Individual packages are no longer required to perform all functions, so they are easier to change and are more adaptable to outside developments. New functions and user interfaces can be added as required. A recent example of this flexibility is the introduction of the ability to access ‘foreign data formats’ from all Starlink packages, because they use a common infrastructure library.

Applications are unified by sharing the same basic data structure – the NDF (extensible  $n$ -dimensional data format). This contains an  $n$ -dimensional data array that can store most astronomical data, such as spectra, images, and spectral-line data cubes. The NDF may also contain information like a title, axis labels and units, error, and quality arrays. There are also places in the NDF, called *extensions*, to store any ancillary data associated with the data array, even other NDFs.



### 3.1 General Purpose

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|   |                        |
|---|------------------------|
| <b>AIPS</b> — Image processing                                      | <i>Not distributed</i> |
| <b>IDL</b> — Interactive data language                              | <i>Not distributed</i> |
| <b>IRAF</b> — Image reduction and analysis facility                 |                        |
| <b>MIDAS</b> — Munich image data analysis                           | <i>Not distributed</i> |
| <b>XANADU</b> — GSFC software system                                |                        |
| <b>STARJAVA</b> — Starlink Java Infrastructure and Applications Set |                        |

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#### AIPS

SUN/207 MUD/101

**Calibrate and edit radio-interferometric data, construct images using Fourier synthesis techniques and display and analyse these images.**

The Astronomical Image Processing System (AIPS) is in widespread use by radioastronomers. It has a richer set of *general* image processing functions than any other astronomical software package.

It can:

- Deconvolve a point-spread function from an image.
- Transform one image into the coordinate system of another.
- Fourier transform an image into the complementary Fourier domain, allowing you to edit the transformed image and transform it back again (useful for removing stripes from IRAS images).
- Enhance various features in an image using gradient filters, or even the Sobel edge enhancement filter.
- Display successive planes of a data cube as a continuous movie.
- Display a spectral line data set, using hue to denote velocity and intensity to denote integral brightness.

#### IDL

MUD/29,30,31,161

**Explore and manipulate data using a comprehensive set of tools.**

The Interactive Data Language (IDL) is proprietary package, written by Dave Stern of Research Systems Inc, Denver, It is only available on some Starlink nodes. At its simplest level it can be used as a very powerful arithmetic and graphics utility for processing data arrays.

It provides:

- A programming language.
- Easy graphics and image display.
- Mathematical and transcendental functions.
- Array and string manipulation.

- Input/output.
- Type conversion.
- Other complex operations.

It can be used with minimal effort for many applications, or developed into more complex procedures as required.

## IRAF

SUN/179.MUD/104,105,154,156,157

### **Reduce and analyse data – general purpose.**

The Image Reduction and Analysis Facility (IRAF) was developed by the National Optical Astronomical Observatory (Kitt Peak), and has been adopted by the Space Telescope Science Institute in Baltimore as the principal data analysis environment for Hubble Space Telescope (HST) data. (This data can also be reduced by KAPPA and FIGARO.) It contains general image processing and graphics applications, plus programs for reducing and analysing optical astronomical data. It is as portable and device independent as possible; for example, it includes its own programming language. Although it runs on a variety of computers, in practice it usually runs best on one particular type (Suns at present).

It is a very large system which is supported by extensive documentation. Every Starlink node should have a copy of the User Handbook.

IRAF is one of several major software environments which are available to Starlink users and upon which entire data-analysis campaigns can be based. Other examples include AIPS, IDL, and MIDAS, as well as Starlink's own large collection of infrastructure tools and application packages, and the various forms of the FIGARO system. Each has its own particular strengths and special capabilities; IRAF and AIPS are the most comprehensive overall.

The excellent support provided by IRAF's home institute (with which Starlink maintains close contact) means that comparatively little national UK Starlink support is called for and provided; the same is true for the other overseas environments mentioned above.

IRAF is a sound choice for many Starlink users doing data analysis, especially where compatibility with overseas collaborators is a requirement. The choice is harder for those wishing to develop major applications of their own, who may be reluctant to adopt IRAF's non-industry-standard SPP programming language, or who feel uncomfortable with the limitations of the 'flat' IRAF data formats. Those who need formal guarantees of future support should also be very wary about committing themselves to any package which is not under UK control. However, IRAF is an important weapon in the armoury of the average Starlink data-analysis user, and likely to remain so for some years.

An important part of Starlink's present software plans is to enhance 'interoperability' with other environments, IRAF being of special importance. Starlink applications can already share data with other packages via FITS files, but in the case of IRAF this data-interchange capability will be extended by enabling Starlink applications to read and write IRAF data files. This will mean that a user can run IRAF in one window on their screen and a Starlink package (e.g. CCDPACK) in another, processing the same datasets with each. A further capability, currently being investigated, would be to run Starlink applications from the IRAF command-line just as if they were native IRAF applications.

## MIDAS

### **Reduce and analyse optical astronomy data within a basic image processing environment.**

The Munich Image Data Analysis System (MIDAS) was developed by the Image Processing Group of the European Southern Observatory (ESO). It consists of a monitor which controls the execution of individual tasks, and a large set of image processing applications. Since the results of reducing astronomical images are usually numbers (not other images), a comprehensive and flexible table system forms an essential part of the system. New applications can be added easily, even by non-professional programmers.

Its main features are:

- Support for computers with VMS and Unix operating systems.
- Device independent interfaces to peripherals by using special libraries, e.g. AGL for graphics, ID for image display, and TW for terminals.
- Support for display and hard-copy standards like X11 and PostScript.
- Easy and flexible integration of user software, written in standard Fortran and C.
- Full support for data exchange in FITS format.
- On-line help, history, and logging facilities.
- Flexible command and control language with full flow control and debugging facilities.
- Extensive interface libraries in Fortran and C for access to the MIDAS database.

It also contains extensive packages in the areas of spectral reduction (including data in long slit and échelle formats), CCD observations, crowded field photometry, object search and classification, fitting and modeling of data, astrometry, and statistical analysis.

## STARJAVA

SUN/251

Starlink is developing a set of Java data reduction and analysis tools and Java data access classes. The new Java tools and classes are needed to produce applications in the Virtual Observatory (VO) era, and to complement the AstroGrid and other VO capabilities such as the International Virtual Observatory Alliance Data Model.

You can view a section of a proposed International Virtual Observatory Alliance Data Model, including HDX, NDX and Table data structures with the WCS astrometry library at:

<http://www.starlink.ac.uk/java/java.htm>

The Starlink Java Software (STARJAVA) has had numerous changes and additions. STARJAVA can now be considered as a separate entity from the classic Starlink applications and libraries, although in this release it is provided as a standard Starlink package.

The document (SUN/251) *Getting Started with the Starlink Java Infrastructure and Applications Set* describes the package and

</star/starjava/javadocs/index.html>

describes the Starlink STARJAVA classes API. There are miscellaneous documents in

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The STARJAVA package contains the following applications and classes. Note, SPLAT, TREEVIEW, JNIAST and JNIIHDS have been moved to the STARJAVA package, instead of being individual packages.

### APPLICATIONS/UTILITIES:

FROG - Display and analysis of time series data.

SOG - Son of GAIA.

SPLAT - Spectral Analysis Tool.

TABLECOPY - Copy tables from one format to another.

TOPCAT - Tool for OPERations on Catalogues and Tables.

TREEVIEW - Hierarchical data viewer.

### CLASS LIBRARIES:

ARRAY - N-dimensional array manipulation and I/O.

ASTGUI - AST specific UI components.

AXIS - Third generation Apache SOAP.

COCO - Java UI for Coco.

DOM4J - Third party DOM access library (org.dom4j.\*).

FITS - STARJAVA-specific FITS access.

HDS - Non-native HDS utility classes.

HDX - A flexible, extensible, data model for astronomical images, tables and other metadata.

JAIUTIL - Utility classes for JAI.

JETTY - HTTP Server and Servlet Container.

JNIAST - Java Native interface to AST.

JNIHDS - Java Native Interface to HDS.

JSKY - Java Components for Astronomy.

JUNIT - Third party unit testing framework (junit.\*).

NDX - N-dimensional astronomical object manipulation and I/O.

PAL - Positional Astronomy Library.

RV - Java UI for RV.

TABLE - Generic table manipulation and I/O.

TAMFITS - Third party basic FITS access (nom.tam.\*).

UTIL - Miscellaneous utility classes.

VOTABLE - VOTable I/O.

The STARJAVA package can be considered to be independent of the standard USSC, and in future will be distributed separately. All the STARJAVA applications and classes are distributed under the GPL licence.

The SPLAT documentation (SUN/243)

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STARJAVA is not available under Tru64 Unix.

## XANADU

**Analyse spectra, timing, and images of X-ray astronomical data obtained from multiple missions.**

It was obtained from GSFC. Its home page is:

`http://heasarc.gsfc.nasa.gov/docs/xanadu/xanadu.html`.

Its principal components are:

### **XSPEC Fit X-ray spectra – command-driven, interactive.**

It is detector-independent, so it can be used for any spectrometer. It has been used to analyze data from HEAO-1 A2, Einstein Observatory, EXOSAT, Ginga, ROSAT, BBXRT, ASCA, CGRO, and IUE. It has also been used for simulations for XTE and AXAF.

**XIMAGE Display and analysis of multi-mission X-ray images.**

It is instrument-independent and analyses data from any X-ray imaging detector, provided calibration files are available. It supports detailed analysis of EXOSAT CMA, Einstein HRI and IPC, ROSAT PSPC and HRI, and ASCA GIS and SIS data. It also supports some basic analysis of optical, infrared, and radio images. It has a built in data simulation program that can simulate images of current and future X-ray missions (*e.g.* SAX, AXAF, and XMM).

It can:

- Read images and event files.
- Rebin images, smooth, and display.
- Detect and remove sources, statistical analysis.
- Correct for vignetting, exposure, background, and point spread function.
- Mosaic images.
- Contour plots and overlays.
- Convert sky grids and pixel-coordinates.
- Change equinox.
- Slice x/y image.
- Generate point spread functions.
- Select circular, annular, and box regions.
- Interface to saomage.
- Extract spectra and lightcurves from event data.
- Simulate images.

Its display and graphic capabilities are based on the PGPLOT graphics package, which supports most terminals and workstations. The saomage package can also be spawned to display images and select regions.

While XIMAGE is a multimission package, it must first ‘know’ about the calibration information associated with a mission in order to be able to make a detailed image analysis. Some functions are mission-independent (*e.g.* display), but others are not (*e.g.* source detect). It will read images from an unknown mission, but beware of trying to make a detailed analysis – adding new missions usually requires either adding new files and/or adding new calls and relinking XIMAGE.

**XRONOS Analyse timing – general purpose.**

Although designed mostly for X-ray astronomy, it is basically detector and wavelength-independent. It has been used to analyse data from the Einstein Observatory, EXOSAT, and Ginga, as well as optical photometry and helioseismology data. It includes programs for:

- Light curve(s).
- Hardness ratio and colour-colour plotting.
- Epoch folding.
- Power spectrum.
- Autocorrelation and cross-correlation.
- Time skewness and statistical analysis.

It consists of a collection of programs, each dedicated to one task, which can be run from the control environment provided by the XRONOS program. This is characterised by three different user interfaces: ‘question/answer’, ‘partial question/answer’, and ‘command driven.’ Command files are supported by the last two. Its applications can be run in command-driven fashion within the EXOSAT Database System.

XANADU also contains native versions of:

- **PGPLOT** — High-level graphics.
- **QDP** — Data plotter.
- **FITSIO** — FITS I/O on disk.

Of these, PGPLOT and FITSIO are also distributed independently by Starlink.

## 3.2 Pipeline systems

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**ORAC-DR** — UKIRT and JCMT instrument data reduction pipeline

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**ORAC-DR**

**SUN/230, SUN/231, SUN/232, SUN/246**

### **General purpose data reduction pipeline**

ORAC-DR is the data reduction component of the ORAC system used for telescope and instrument control at the United Kingdom Infrared Telescope (UKIRT) and the James Clerk Maxwell Telescope (JCMT) on Hawaii. It provides a general purpose automatic data reduction pipeline for the CGS4, UFTI and IRCAM instruments on UKIRT and the SCUBA instrument on JCMT.

ORAC-DR recipes to drive the reduction of a set of observations made to a known observation pattern at the telescopes. The headers data of each dataset is read to discover which data processing recipe to apply to it. The data reduction is performed by tasks from other Starlink packages such as KAPPA, CCDPACK, SURF, POLPACK and PHOTOM. It can also use GAIA for image display.

### 3.3 Image Processing & Photometry

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**ATOOLS** — Coordinate frame manipulation  
**CCDPACK** — CCD data reduction  
**DAOPHOT** — Stellar photometry  
**ESP** — Extended surface photometry  
**EXTRACTOR** — Automatic detection of objects on an astronomical image  
**GAIA** — Graphical image analysis  
**KAPPA** — Image processing & visualisation  
**KAPRH** — Retired KAPPA tasks  
**PHOTOM** — Aperture photometry  
**PISA** — Position, intensity, and shape analysis  
**SAOIMAGE** — Astronomical image display  
**STARMAN** — Stellar photometry  
**SX** — Data visualisation

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#### ATOOLS

##### **Manipulation of coordinate frame descriptions.**

ATOOLS is a new package of applications which manipulate descriptions of coordinate frames, mappings, *etc.*, in the form of AST Objects. Each application within the ATOOLS package corresponds closely to one of the functions within the AST library. ATOOLS thus provides a high-level interface to the AST library.

#### CCDPACK

SUN/139

##### **Reduce CCD-like data, and mosaic frames together.**

You can debias, remove dark current, pre-flash, flatfield, register, resample, and normalize your data.

Perhaps the most important and useful feature of the package is its ability to handle large numbers of data files automatically, so that repetitive reduction procedures can be handled in a straightforward and efficient way. This uses a scheduling system that only requires knowledge of the frame types (bias, flatfield, *etc.*) and important CCD geometric features. Using this information, it can decide how to reduce your data and may then run the necessary programs. The frame types and detector characteristics can be obtained from FITS headers, for certain telescopes/CCDs, so your job could be reduced to identifying the telescope/detector used and the frames you want reducing.

The automated reduction system can be controlled from an X-based GUI that has been specifically designed to help novice and/or occasional users of CCD data (although it is expected to appeal to the more experienced as well). Ease-of-use is achieved by limiting the options to those of immediate concern by providing a selection of known detectors and by having a context-sensitive help system. It also aims to be complete by allowing you to define the necessary geometric characteristics of your data interactively (if they cannot be obtained elsewhere). An equivalent command-line interface is also available.



Its core is a suite of programs to process large amounts of data. Consequently, *all* the routines process *lists* of data, and also record progress using a log system.

As well as performing the usual instrumental corrections, you can also remove defects and generate and propagate data errors. Debiassing can be performed using only the bias strips as well as using bias frames (combined to reduce noise levels). Calibration data can be combined using many different techniques (mean, median, trimmed mean, etc.), so you can pick a method that makes the most efficient use of your data.

Data registration is based primarily on the *linear* transformation (allowing offsets, scalings, rotation, and shear), although more general transformations can be used.

General linear transforms can easily be determined using an interactive procedure to display and select image features. Alternatively, if your datasets are just shifted with respect to each other, you may be able to register them by using a series of commands which locate all the objects in all the frames, determine the object-object correspondence, and then derive the transforms. A graphical application is also provided that allows you to select the objects to be used by identifying image pairs that overlap and have some objects in common.

Data resampling uses registering transforms which it stores inside your data, removing the need to remember them. They may also be applied to 'rubber-sheet' the data into novel configurations.

Normalisation and combination (often called mosaicing) is provided in a single *comprehensive* application, which is designed to deal with very large datasets. This uses robust methods to determine scale and/or zero-point corrections.

The CCDPACK package may be run from the IRAF CL.

## DAOPHOT

SUN/42 MUD/9,10

### Stellar photometry of crowded fields.

It does the following tasks:

- Find objects.
- Aperture photometry.
- Obtain the point spread function.
- Profile-fitting photometry.

Profile-fitting in crowded regions is performed iteratively, which improves the accuracy of the photometry. It does not directly use an image display (which aids portability), although three additional routines allow results to be displayed on an image device. It uses image data in NDF format, which means it is interoperable with other Starlink packages.

## ESP

SUN/180

### Photometry of galaxies and other extended objects.

It can:

- Detect/identify flatfielding faults.
- Remove cosmic ray events.
- Median-filter images on a defined scale.
- Determine whole-image statistics including median and modal count, kurtosis, and skewness.

- Determine the local background value on a number of different parts of an image.
- Perform galaxy profiling using intensity analysis.
- Perform galaxy profiling using contour analysis.
- Perform 2-d Gaussian profiling (GAUFIT).
- Generate galaxy pie-slice cross-sections.
- Display graphs showing the profiling/cross-section results.
- Detect faint diffuse objects in an image.

It processes images in NDF format, so you can use it in conjunction with packages like KAPPA, CCDPACK, FIGARO, PHOTOM, JCMTDR, and PISA. You can define areas to exclude or include in the analysis, using keyword descriptions in text files.

### Extractor

SUN/226

#### Locate and parameterize objects in a 2-d image.

EXTRACTOR is a program for automatically detecting objects on an astronomical image and building a catalogue of their properties. It is particularly suited for the reduction of large scale galaxy-survey data, but also performs well on other astronomical images.

EXTRACTOR is a development of Emmanuel Bertin's SExtractor (Source-Extractor) program repackaged for use in the Starlink Software Environment. This means that it uses the Starlink parameter system, accepts images in NDF format and uses the AST library for astrometry.

### GAIA

SUN/214

#### A traditional image display tool (like SAOIMAGE), but which can integrate other programs.

It is derived from the RTD (Real Time Display) tool, developed as part of the VLT project at ESO. RTD is free software under the terms of the GNU copyright.

The current version is a preliminary release which is intended to assess the impact of GAIA/RTD's enhancements for performing highly interactive graphical image analysis. It provides the following functions:

- Display images in FITS and NDF formats (it will display many other formats using the 'on-the-fly' data conversion ability of NDF).
- Pan, zoom, and manipulate data range and colour table.
- Continuously display of cursor position and image data value.
- Continuously display of the RA and DEC coordinates for suitable images (*i.e.* FITS images with WCS headers – Guide Star Catalog images for instance).
- Display many images (clones), each in its own window.
- Annotate in colour, using text and line graphics.
- Print the displayed image and annotations to a PostScript file.
- Profile in real time (*i.e.* move a line around on the image and see the image data values displayed as a profile change).
- Real time pixel value table (the data values in a region about the cursor).

- Aperture photometry – A highly interactive environment for controlling the positions, sizes, and orientations of circular and elliptical apertures. The sky estimates can be made from annuli of these apertures, or from related sky apertures. The measurements can be in either instrumental magnitudes or mean counts.
- Patch images – Select arbitrarily shaped regions on an image and replace them with a surface fit to other regions, together with an artificial noise component. An ideal way to remove cosmetic defects from an image.
- Interactive ARD regions – Calculate statistics, mask out and extract arbitrarily shaped parts of your images, define ARD regions for other programs to use.
- Blink images – Animate displayed images (as quickly as your hardware/CPU combination allows), or cycle through them by hand.

The GAIA package may be run from the IRAF CL.

## KAPPA

SUN/95

**General-purpose functions, particularly suitable for image processing, data visualisation, and manipulating NDF components.**

KAPPA is the backbone of Starlink's application packages. Its facilities integrate with the more specialised Starlink packages described in this survey. Thus, the functionality of KAPPA should not be regarded in isolation.

It can process data in formats other than NDF, such as FITS and IRAF, by using an 'on-the-fly' conversion scheme. Many commands can process data arrays of arbitrary dimension, and others work on both spectra and images. It operates from both the Unix C-shell, and the ICL command language.

KAPPA should not be perceived as a rival to FIGARO. Now that FIGARO is integrated with other Starlink packages, they should be seen as complementary, with FIGARO concentrating on spectroscopy and KAPPA on image processing.

In a wider context, KAPPA offers facilities which are not in IRAF, for instance: handling data errors, quality masking, a graphics database, availability from the shell, as well as more  $n$ -dimensional applications, widespread use of data axes, and a different style. It also integrates with instrument packages developed at UK observatories.

With the automatic data format conversion, and the likelihood that KAPPA and other Starlink packages will be available from within the IRAF command language, you should be able to pick the best or relevant tools from both systems to get the job done.

Currently, about 180 commands are available from both the Unix C-shell and from the ICL command language. They provide the following facilities:

- Generate NDFs and text tables using FITS readers, and import and export ancillary data through the NDF FITS extension.
- Generate test data and create NDFs from text files.
- Set and examine NDF components.
- Define or calculate a sky co-ordinate system for use in conjunction with IRAS tools.
- Arithmetic, including a powerful application that handles expressions.
- Edit pixels and regions, including polygons and circles, re-flag bad pixels by value or median filtering, and paste arrays over others.

- Mask regions, and pixels whose variances are too large.
- Change configuration: flip, rotate, shift, subset, change dimensionality.
- Mosaic images; normalise NDF pairs.
- Compress and expand images.
- Generalised resampling of NDFs using arbitrary transformations.
- Filter: box, Gaussian, and median smoothing; very efficient Fourier transform, convolution.
- Deconvolution: maximum-entropy, Lucy-Richardson, Wiener filter.
- Two-dimensional-surface fit.
- Statistics, including ordered statistics, histogramming; pixel-by-pixel statistics over a sequence of images.
- Inspect image values.
- Centroids of features, particularly stars; fit stellar Point Spread Functions (PSFs).
- Enhance detail using histogram equalisation and Laplacian convolution, enhance edges via a shadow effect, threshold.
- Calculate polarimetry images.

There are also many applications for data visualisation:

- A graphics database, AGI, to pass information about pictures between tasks; tools to create, label, select pictures, and obtain world and data co-ordinate information from them.
- Image and greyscale plots with a selection of scaling modes and many options such as axes.
- Create, select, save, and manipulate colour tables and palettes (for axes, annotation, coloured markers and borders).
- Snapshot an image display to hardcopy.
- Blink and control visibility of image-display planes.
- Line graphics: contouring, including overlay; columnar and hidden-line plots of images; histogram; line plots of 1-d arrays and multiple-line plot of images; pie sections and slices through an image; vector plot of image; all of which offer some control of the appearance of plots.

KAPPA handles bad pixels, and processes quality, variance, and other information stored within NDFs. In order to achieve generality, it does not process non-standard extensions; however, it does not lose non-standard ancillary data since it copies extensions to any NDFs that it creates.

Although oriented towards image processing, many commands will work on NDFs of arbitrary dimension, and others operate on both spectra and images. Many applications handle all non-complex data types directly, for efficient memory and disk usage. Those that do not will usually undergo automatic data conversion to produce the desired result.

Its graphics are device independent. X-windows and overlays are supported.

The KAPPA package may also be run from the IRAF CL.

**KAPRPH****SUN/239****Retired KAPPA commands**

KAPRPH is a package containing commands retired from the KAPPA package (see SUN/95). These commands have been removed from KAPPA but are retained in KAPRPH to satisfy any occasional need there may be for them. KAPRPH is documented in SUN/239.

KAPRPH contains the following retired KAPPA commands:

CONTOVER, GREYPLOT, INSPECT, MOSAIC, QUILT, SNAPSHOT, TURBOCONT

as well as a help command: KRHELP.

**PHOTOM****SUN/45****Aperture photometry.**

It has two basic operating modes:

- Use an interactive display to specify the positions for the measurements.
- Obtain those positions from a file.

The aperture is circular or elliptical, and the size and shape can be varied interactively on the display, or by entering values from the keyboard or parameter system. The background sky level can be sampled interactively by manually positioning the aperture, or automatically from an annulus surrounding the object.

It is used by the Graphical Astronomy and Image Analysis tool (GAIA) which integrates the tasks of aperture photometry with an image display tool. This allows the detailed inspection of objects and their environments, and provides a highly interactive environment for placing, rotating, and resizing apertures.

**PISA****SUN/109****Locate and parameterize objects in a 2-d image.**

The Position, Intensity, and Shape Analysis package (PISA) is applicable in most areas of astronomy where direct imaging is required. It is particularly intended for faint object detection and can do this automatically, based on software used with the APM automatic plate measuring machine.

Its core is a routine which performs image analysis on a 2-d data frame. It searches for objects having a minimum number of connected pixels above a given threshold, and extracts the image parameters (position, intensity, shape) for each object. The parameters can be determined using thresholding techniques, or an analytical stellar profile can be used to fit the objects. In crowded regions it can deblend overlapping sources.

**SAOIMAGE****SUN/166. MUD/140****Display astronomical images.**

You can manipulate images in a number of ways, see the changes applied, and when you are happy with the result, print it on a Postscript printer. It uses X-window hardware.

It can:

- Scale between limits.
- Magnify, zoom, pan.

- Do histogram equalisation.
- Scale – Log and square root.
- Use false colour with built-in or user-specified colour tables. Clicking on a colour bar pops up a graphical representation of the colour table's RGB values. These can be adjusted interactively, or a previously saved colour table can be loaded.
- Stretch the contrast.
- Change gamma ( $\gamma$ ) to give non-linear contrast, so that the display assigns more shades of grey to the darker or lighter end of the scale. This may suit the eye better than a linear scale.
- Type text on an image.

Other features:

- Blink between images.
- Regions – A description of a region of an image can be saved. This can be used to flag regions as bad, or to examine only the counts within a certain region. This is mainly useful in conjunction with the IRAF and PROS (X-ray) packages.
- Tracking – The pixel coordinates and values under the mouse pointer and the region around it can be displayed and constantly updated.
- IRAF image display.
- Hard copy.

## STARMAN

SUN/141

### Stellar photometry.

*STARMAN is not distributed on Starlink CDs and has not been ported to Linux. It is optionally available at UK Starlink sites.*

Starman's many image and table handling programs have other uses, but its main applications are:

- Crowded-field photometry.
- Aperture photometry.
- Star finding.
- CCD data reduction.

The package is a coherent whole, for use in the entire process of stellar photometry from raw images to the final standard-system magnitudes and their plotting as colour-magnitude and colour-colour diagrams. Its functions are:

- Stellar Photometry
  - Convert raw CCD images to calibrated ones.
  - 'Dust-ring' flat-field dealer.
  - Find star positions
  - Determine stellar profiles
  - Crowded-field, and also simple, stellar photometry measurers.

- Average photometry estimates from different images.
- Plot colour-magnitude and colour-colour diagrams.
- Add ‘fake’ stars to an image.
- Automatic aperture photometry for all bright well isolated stars.
- Image Handling
  - Image display.
  - Interactive image work. *Display*: zoom, pan, pixel value, ‘slice’, solid-body plots, colour, crowded-field stellar photometry output, *etc.*; *Measurement*: interactive aperture photometry, interactive position file making; *Manipulation*: maths, rotation, weeding, *etc.*; ‘GUI’-like interaction.
  - Extensive general programs: Maths, joining, cutting, reading, *etc.*.
- Table Handling
  - Spreadsheet, Calculator.
  - Input, Output, Listing.
  - Graphical plot, Star chart.
  - Joining.
  - Extensive general programs: sort, weed, statistics, matching, position transforming, *etc.*.

SX

SC/2, SG/8, SUN/203

**Enhancements to DX.**

DX (Data Explorer) is a scientific data visualisation and analysis package marketed by IBM. It can visualise and display many sorts of astronomical data. It employs a data-flow driven client-server execution model, and provides a comprehensive range of data manipulation, visualisation, and display functions. Visualisations can be generated using a visual programming editor or a text-based scripting language.

Starlink recommends DX for displaying 3-d scalar and vector data. However, it is not available at all Starlink sites – ask you Site Manager.

The SX enhancements have a number of purposes. They:

- Fill a few minor omissions in the functionality of basic DX.
- Provide easy-to-use functions to accomplish common tasks in a single step.
- Allow standard Starlink NDF data structures, and data in other common astronomical formats, to be imported into DX.



### 3.4 Spectroscopy

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**DATACUBE** — IFU datacube analysis

**DIPSO** — Spectrum analysis and plotting

**ECHOMOP** — Échelle data reduction

**FIGARO** — General data reduction

**NDPROGS** —  $n$ -dimensional data analysis

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**DATACUBE**

**SUN/237, SC/16**

#### **IFS datacube manipulation and visualisation.**

DATACUBE is a new package which provides a set of tools for manipulating and visualising IFS (Integral Field Spectrograph) datacubes. Also known as an IFU (Integral Field Unit), the IFS is relatively new in astronomical instrumentation and is therefore rapidly developing. The DATACUBE package has been implemented mainly as a series of scripts which drive existing Starlink packages to manipulate IFU data. This approach allows changes to be made to tasks quickly as data analysis requirements evolve. There are also a small number of IFU-specific tasks implemented in Fortran.

IFU data analysis is discussed in detail in the cookbook *The IFU Data Product Cookbook*(SC/16).

**DIPSO****SUN/50****Analyse and visualise spectroscopic data.**

A powerful and versatile package, specifically tailored to the requirements of modern astronomical research.

It can access a large number of spectra simultaneously. This lets you perform the same operations repeatedly on successive spectra, either manually or using scripts, ensuring uniformity in the data (especially important for time-series spectroscopy). It can plot spectroscopic data rapidly and conveniently, and combines analysis and high-quality graphical output in a simple command-line driven environment.

It began as a simple plotting package incorporating some basic astronomical applications. Indeed, if you just want to read in some data, plot them, and measure some equivalent widths or fluxes, you can do this easily. To make more complicated things possible, a number of extra functions and parameters are provided. A macro facility allows convenient execution of regularly used sequences of commands, and a simple Fortran interface permits 'personal' software to be integrated with the program. User programs can be added to the system and defined as new commands.

The following operations are available:

- Arithmetic.
- Fit emission lines.
- Measure equivalent widths.
- Measure fluxes.
- Fourier analysis.
- Interstellar line analysis.
- Model atmospheres.
- Model nebular continua.
- Fit polynomials.
- Simple statistics.

**ECHOMOP****SUN/152****Reduce échelle spectra data frames.**

Options range from full-scale automated reduction to step-by-step order-by-order manually assisted processing. It was written originally to reduce data from the University College London Échelle Spectrograph (UCLES), but the algorithms are sufficiently flexible to reduce spectra from many sources.

It can:

- Locate spectral orders
- Remove cosmic rays.
- Detect bad image rows/columns and saturated pixels.
- Trace spectral orders.
- Determine object channels.
- Generate flat-field balance model.

- Model scattered light.
- Extract optimal spectrum.
- Correct échelle blaze.
- Extract quick-look spectra.
- Locate lines in arc spectra automatically.
- Calibrate wavelengths of arc spectra.
- Fit distortion for spectral orders.
- Extract distorted orders.
- Scrunch extracted spectral orders.
- Produce distortion-free image.
- Plot data used for a reduction.
- Output products.

**FIGARO**

SUN/86.MUD/12,13,14

**Reduce and analyse astronomical data.**

FIGARO is a general-purpose data reduction package. It contains particularly extensive facilities for reducing spectroscopic data, but also has powerful facilities for manipulating direct images and data cubes. Starlink recommends it as the most complete spectroscopic data reduction system in the Collection.

It can be used interoperably with other packages, most notably KAPPA, because it supports the NDF data format, and therefore all foreign formats for which conversion utilities exist. These include its old DST format, FITS, and IRAF. The use of NDF also means that you can automatically record data processing history, and can operate on sub-sets of spectra and images. Another feature is the propagation of error/data-quality arrays through the data reduction calculations.

It can:

- Analyse absorption lines interactively.
- Do aperture photometry.
- Calibrate B stars.
- Calibrate flat fields.
- Calibrate using flux calibration standards.
- Calibrate wavelengths of spectra.
- Correct S-distortion.
- Extract spectra from images and images from data cubes, and insert spectra into images and images into data cubes.
- Extract spectra from images taken using optical fibres.
- Fit Gaussians to lines in a spectrum interactively.
- Generate and apply a spectrum of extinction coefficients.
- Input, output, and display data.

- Look at the contents of data arrays, other than graphically.
- Manipulate complex data structures (mainly connected with Fourier transforms).
- Manipulate data arrays ‘by hand’.
- Manipulate images and spectra (arithmetic and more complicated).
- Process data taken using FIGS (the AAO’s Fabry-Perot infra-red grating spectrometer).
- Process échelle data – in particular the UCL échelle in use at the AAO.

The programs from the old SPEC DRE and TWODSPEC packages have been merged with FIGARO and provide additional facilities:

- **Hyper-cubes:** In general, the data being processed are a hyper-cube where each row or hyper-column is a spectrum. A single spectrum can be an appropriate section of the hyper-cube cut out ‘on the fly’ as the data are accessed.
- **Coherent storage of fit results:** The results of line or continuum fits are stored with the data. When a hyper-cube is a coherent set of spectra, fit results are also stored coherently. For example, in a 3-d data set, the 2-d map of line integrals is immediately available to display routines.
- **Bad values and variance:** Bad values (or quality information) are recognised and ignored or propagated, as appropriate. If variance information is preset, it is propagated or used in the processing.
- **Analysis of line profiles:** Analysis of calibrated long-slit spectra, fitting of Gaussians, either manually or automatically in batch, handling of data with two spatial dimensions, such as Taurus data.

The topics addressed by the applications are mainly:

- **ASCII I/O:** The data and errors of hyper-cubes can be written to or read from printable/editable tables. Bad values are converted between the two formats. Single spectra can be read, even if the axis data are not linear or monotonic.
- **Graphics:** Displays allow full control of the plot, including font, colour, line styles, error bars, *etc.* Overlay on previous plots according to their ‘world coordinates’ is possible, including overlays on grey/colour/line plots made using KAPPA, PONGO, *etc.*
- **Cube processing:** You can extract averaged hyper-planes from hyper-cubes, assemble hyper-cubes from hyper-planes, or fill in a hyper-cube from several given hyper-cubes.
- **Arc line axis (wavelength) calibration:** While full user interaction via graphics is granted, automatic arc line identification is also possible.
- **Re-sampling:** You can either re-sample all spectra in a hyper-cube, or re-sample and average into one spectrum any number of input spectra. Information about the covariance between pixels can be carried through to a line fit routine.
- **Spectral fits:** You can fit polynomials, blended Gaussian or triangle profiles. Fit results are stored along with the data and can be turned into fake data sets for later subtraction, division, *etc.*

The FIGARO programs may be run from the IRAF CL but the former SPEC DRE and TWODSPEC programs are not yet available under the IRAF CL.

**NDPROGS****SUN/19****Manipulate and display images of up to six dimensions.**

*The NDPROGS package is no longer supported and will be withdrawn if operating system or compiler changes cause it to fail. It is not distributed on Starlink CDs but may be installed at UK Starlink sites as a legacy package.*

Primarily, it is designed to manipulate Taurus spectral line data cubes, which are 3-d images in which two of the dimensions are spatial and the third is spectral. However, it contains no instrument-specific features, and can therefore be used to analyse similar data.

The term 'image' here simply means a regular data array, which might be anything from a 1-d spectrum or profile to a 4-d array consisting of several long-slit spectra with polarization vectors. The upper limit of six dimensions is imposed by the software which interfaces with HDS and has no other significance.

The package can read FIGARO images, and images written by NDPROGS can be read by any FIGARO program which can handle the number of dimensions involved. It duplicates the functions of standard FIGARO programs as far as 1-d, 2-d, and 3-d images are concerned, but with new features. It will also accept NDF format files. Most NDPROGS routines now handle data quality and error arrays, thus widening the scope and accessibility of the package.

### 3.5 Time Series & Polarimetry

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**PERIOD** — Time series analysis

**POLMAP** — Linear spectropolarimetry

**POLPACK** — Dual beam imaging polarimetry

**TSP** — Time series & polarimetry

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#### PERIOD

SUN/167. SSN/25

#### Search for periodicities in data.

It is menu-driven. You can:

#### Read and write data

- Read raw data from both Ascii tables and FITS format OGIP files.
- Store calculated fits in a log file.
- Output power spectra to Ascii files.
- Output modelled/modified data.
- Invoke the QDP plotting/fitting package (allows labelling).

#### Examine data

- Generate a power spectrum showing periodicities.
- Fold the data on a given period.
- Fit sine curves to the input data.
- Set data points to unity to investigate spectral leakage.

#### Manipulate data

- Remove background trends in the data via polynomial fits.
- Create test data.
- Add noise to data.
- Add or subtract known periods to/from data.

Many sophisticated techniques are used to search data for periodicities; data points do not have to be equally spaced. You don't need in-depth knowledge of the methods employed in order to use them. They can be treated as black-boxes. These include:

- Chi-squared analysis of a folded sine fit versus frequency.
- Cleaned and discrete Fourier power spectra.
- Phase dispersion minimization (PDM Stellingwerf).
- Lomb-Scargle normalized periodograms.
- String-length (Dworetsky) versus frequency estimates.
- Periods from the periodogram.
- Significance estimates.

Significance estimates for periods derived by most methods are notoriously unreliable. In PERIOD, the Fisher randomisation method, one of the best, is employed.

**POLMAP****SUN/204****Analyse linear spectropolarimetry data.**

A linear polarization spectrum is a set of Stokes vectors  $(I_\lambda, Q_\lambda, U_\lambda)$ . Hence, linear spectropolarimetric data is 4-d (6-d if the variance arrays of the Stokes parameters are included) and cannot be manipulated using standard spectral analysis packages such as DIPSO.

Its user interface is similar to DIPSO's, but doesn't provide its wealth of spectral analysis routines. It is designed specifically for the spectropolarimetrist. The manual includes a simple step-by-step guide to the program, and some example data analysis recipes.

It is complimentary to TSP (like FIGARO is to DIPSO). TSP runs under the Starlink software environment and can handle time-series and polarimetric data. It is biased towards data reduction and can handle several different instruments. POLMAP, on the other hand, does no data reduction, but was designed with data analysis in mind. POLMAP can also display data that TSP cannot handle, and can read and write TSP polarization spectrum format files.

**POLPACK****SUN/223****Imaging Polarimetry data reduction**

POLPACK is a package of applications for mapping the linear or circular polarization of extended astronomical objects. Data from both single and dual beam polarimeters can be processed.

POLPACK processes data in NDF format. Other astronomical data formats may also be processed using transparent on-the-fly data conversion facilities provided by the NDF subroutine library, and the CONVERT package.

The facilities provided by POLPACK include:

- alignment of images on the sky.
- extraction of O and E images from a single frame.
- sky subtraction.
- calculation of Stokes parameters.
- binning of Stokes parameters.
- creation of catalogues of polarization vectors.
- graphical display of vector maps.

POLPACK does not provide facilities for performing instrumental corrections such as flat-fielding, de-biasing, *etc.* Such corrections should be applied to the data before using POLPACK, so that POLPACK can assume that pixel values are proportional to the combined intensity of sky and object. Corrections can be made, however, to take account of any differences in the exposure times between raw frames, and any difference in the sensitivity of the two channels of a dual-beam polarimeter. These corrections rely on redundancy in the supplied data, and require a specific set of analyser positions to be used.

**TSP****SUN/66****Reduce time-series and polarimetric data.**

Time-series and polarimetry facilities are missing from most existing data reduction packages, which are usually oriented towards either spectroscopy or image processing, or both. TSP, however, can process the following data:

- Spectropolarimetry obtained with the AAO spectropolarimeters using wave-plate or Pockels cell modulators in conjunction with either IPCS or CCD detectors.
- Infrared spectropolarimetry obtained with the IRPOL polarimeter module in conjunction with the CGS2 grating spectrometer and the UKT6 and UKT9 CVF systems at UKIRT.
- Infrared imaging polarimetry obtained with the IRIS instrument at the AAT and with similar instruments.
- Time series imaging and polarimetry obtained with the AAO Faint Object Polarimeter.
- Time series polarimetry obtained with the Hatfield Polarimeter at either UKIRT or AAT.
- Time series polarimetry obtained with the University of Turku UBVRT polarimeter.
- Five-channel time series photometry obtained with the Hatfield polarimeter at the AAT in its high speed photometry mode.
- Time series infrared photometry data obtained with the AAO Infrared Photometer Spectrometer (IRPS).
- Time series optical photometry data obtained using the HSP3 high speed photometry package at the AAT.



### 3.6 Database Management

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**CATPAC** — Catalogue and table manipulation

**CURSA** — Catalogue and table manipulation

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#### **CATPAC**

**SUN/120**

##### **Manipulate catalogues and tables.**

*CATPAC is no longer supported and is not distributed on Starlink CDs. CATPAC may remain as a legacy package at UK Starlink sites.*

It can input, process, and report tabular data, including astronomical catalogues. In particular, it can:

- Create and delete catalogues.
- Report catalogues.
- Manipulate information about catalogues.
- Manipulate data in catalogues.

CATPAC was designed as a replacement for SCA but is being superseded by CURSA (see below).

#### **CURSA**

**SUN/190**

##### **Manipulate catalogues and tables.**

It can:

- Browse or examine catalogues.
- Select subsets from a catalogue.
- Sort catalogues.
- Copy catalogues.
- Pair two catalogues.

Subsets can be extracted from a catalogue in a format suitable for plotting by other Starlink packages such as PONGO. It can access catalogues held in the following formats:

- FITS,
- Small Text List (STL),
- CHI/HDS format used by CATPAC.

Catalogues in the STL format are simple Ascii text files.

### 3.7 Specific Wavelengths

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ASTERIX — X-ray data processing

SPECX — Millimetre-wave spectral reduction

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ASTERIX

SUN/98. MUD/4

#### Analyse astronomical data in the X-ray waveband.

*ASTERIX has been withdrawn from the Starlink Software distribution and is no longer included on Starlink CDs (from Spring 2000) due to the end of funding for the ROSAT satellite program. It may remain as a legacy package at UK Starlink sites.*

Continued ‘best efforts’ support may be provided by the Space Research group at the University of Birmingham for the recent development version. This may be found on the Asterix Home Page (see <http://www.sr.bham.ac.uk/asterix/>). No support will be provided for the Starlink version.

Many of its programs are general purpose and are capable of analysing any data in the correct format. It is instrument-independent, and currently has interfaces to the EXOSAT and ROSAT instruments.

Its data are stored in HDS files, and are therefore compatible with many other Starlink packages. There are basically two different types:

**Binned data** – (*e.g.* time series, spectra, images) are stored in NDF format. Data errors (stored in the form of variances) and quality are catered for.

**Event data** – store information about a set of photon ‘events’. Each event will have a set of properties, *e.g.* X-position, Y-position, time, raw pulse height.

The input data are first processed by an instrument interface. Event data are then processed and binned, and the binned data are processed. Finally, graphical output is generated.

The commands may be classified as follows:

- Interface to particular instruments (EXOSAT, ROSAT, *etc.*)
- Event dataset and binned dataset processing.
- Data conversion and display.
- Mathematical manipulations.
- Time series analysis.
- Image processing.
- Spectral analysis.
- Statistical analysis.
- Data quality analysis.
- HDS editor.
- Source searching.
- Graphical and textual display.

**SPECX**

SUN/17. MUD/69,70

**Reduce and display mm and sub-mm data.**

Although it can process spectra from many different instruments, it is particularly applicable to JCMT data. It can:

- Process up to eight spectra simultaneously.
- Save current status of system after each command is executed.
- List and display spectra on a graphics terminal, and print hardcopy on many printers.
- Do single and multiple scan arithmetic, scan averaging, etc.
- Store and retrieve intermediate spectra in storage registers.
- Fit and remove polynomial, harmonic, and Gaussian baselines.
- Filter and edit spectra.
- Determine important line parameters (peak intensity, width, etc).
- Calculate Fourier transforms and power spectra.
- Calibrate data.
- Assemble a number of reduced individual spectra into a map file, and contour any plane or planes of the resulting cube.
- Execute macro-command sequences and indirect command files.

It uses its own data format, so it is not possible to access directly reduced spectra from other packages. However, it can import data from GSD-format data files, as produced by the JCMT; write out maps and spectra in the file formats of FIGARO and KAPPA; and write spectra and maps to Ascii files for input into other packages.

### 3.8 Specific Instruments

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**CGS4DR** — CGS4 (UKIRT) data reduction

**FLUXES** — JCMT flux density calibration

**IRAS90** — IRAS data reduction

**IRCAMDR** — IRCAM (UKIRT) data reduction

**IRCAMPACK** — IRCAM (UKIRT) data reduction

**IUEDR** — IUE data reduction

**JCMTDR** — JCMT (UKT14) data reduction

**REPACK** — ROSAT (WFC) data reduction

**SURF** — SCUBA data reduction

**WFCPACK** — ROSAT (WFC) data reduction

**XRT** — XRT data tools

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#### CGS4DR

SUN/27

##### Reduce CGS4 data.

*Cgs4dr is not available on Linux.*

The fourth generation *cooled grating spectrometer*, CGS4, operates on UKIRT in the 1–5  $\mu\text{m}$  region at resolutions in the range  $\lambda/\Delta\lambda \sim 300\text{--}20000$ . To reduce background noise, it is maintained on the telescope in vacuum at cryogenic temperatures. It achieved first light at UKIRT on 4 February 1991. On 22 April 1995 a new InSb  $256 \times 256$  array was commissioned. The new array is much more sensitive than previous detectors, and on a good night you can acquire and reduce  $\sim 100$  Mb of high quality data.

CGS4DR was designed and tested within the FIGARO and ADAM environments. The output data is readable by standard FIGARO applications, although not all may handle the quality and error arrays correctly.

It can reduce spectrographic data automatically. No system, however, will do everything you want, so some post-processing may be needed. The aim is to produce publishable quality spectra at the telescope via an automated reduction paradigm.

It can:

- Allow a wide variety of data reduction configurations.
- Interlace oversampled data frames.
- Reduce known BIAS, DARK, FLAT, ARC, OBJECT and SKY frames.
- Wavelength calibrate via suitable ARC lines.
- Flux calibrate via a suitable STANDARD.
- Remove the SKY, residual sky OH-lines ( $\lambda < 2.3 \mu\text{m}$ ) and thermal emission ( $\lambda \geq 2.3 \mu\text{m}$ ) from data.

- Add data into groups for improved signal-to-noise.
- Extract and de-ripple a spectrum.
- Maintain an index of reduced observations.
- Maintain, if required, an archive of observations.
- Plot data in a variety of ways.

**FLUXES****SUN/213**

**Calculate accurate topocentric positions of the planets, and also integrated flux densities of five of them at a number of wavelengths, for the JCMT telescope on Mauna Kea, Hawaii.**

It provides calibration information at the effective frequencies and beam-sizes employed by the UKT14 and SCUBA receivers on this telescope.

The filter centre and widths are shown for each wavelength used. The filter frequencies are the effective frequencies for 1mm of water vapour.

The calculated planet positions should normally be accurate to better than 1'' of arc. The value for the Moon is less accurate than this, and for critical applications requiring sub arc-second accuracy you should use a different method.

The version distributed by Starlink has been modified to employ the highly accurate JPL ephemeris in all planetary position calculations. It also adopts the Starlink parameter interface, and a more robust file reading system.

A script, FLUXNOW, runs the program for the current time and date. This gives you current positions and flux levels for all the planets.

**IRAS90****SUN/82, 161, 163, 165****Process IRAS data.**

*IRAS90 is not distributed on Starlink CDs and is no longer supported though it may remain as a legacy package on UK Starlink sites. There is no Linux port.*

The Infrared Astronomical Satellite (IRAS) flew in 1983. It carried three instruments: a main detector array, a low resolution spectrometer (LRS), and a chopped photometric channel (CPC). Most of the observations were part of a whole sky survey, but some pointed observations of specific objects were made. Raw data was calibrated and cleaned up to produce a data set called the Calibrated Reconstructed Detector Data (CRDD). This was the source of the final data products, which include catalogues and images.

Several items of Starlink software can be used to process and examine IRAS data. Use KAPPA to process and display images, DIPSO to analyse LRS spectra, CURSA to access and report on the catalogues. However, the most closely related software is IRAS90. This can process CRDD data to produce an image of a region of the sky, or search for and examine an object at a given position.

**IRCAMDR****SUN/41**

**Reduce, analyse, and display data from IRCAM3. It can also handle any 2-d image in the standard Starlink NDF data format.**

*IRCAMDR is not distributed on Starlink CDs and there is little or no support. There is no Linux port. IRCAMDR may remain as a legacy package at UK Starlink sites. Reduction of IRCAM data is now best performed using the ORAC-DR data reduction facility.*

IRCAM3 is a camera on the United Kingdom Infra-red Telescope (UKIRT). In addition to handling IRCAM3 images of  $256 \times 256$  pixel size, it can handle IRCAM1 and IRCAM2 images of  $62 \times 58$  pixels. Almost all the applications (with the exception of **med3d**) will work on NDF images of any physical (pixel) dimensions, for example,  $1024 \times 1024$  CCD images can be processed (**med3d** median-filters stacks of images up to  $256 \times 256$  in size at present).

It can:

- Display images, line graphics, colour tables.
- Reduce data, including automatic single-star photometry and bad/hot pixel removal.
- Register and mosaic images, and determine positions.
- Extract and smooth images, do arithmetic, change dimensions.
- Statistical analysis.
- Photometry.
- Polarimetry.

## IRCAMPACK

SUN/177

### Process IRCAM data.

IRCAM is an infrared camera on the United Kingdom Infra-red Telescope (UKIRT).

CCDPACK and KAPPA will probably do most of the processing you require. IRCAMPACK provides extra facilities. It can:

- Interpret and process the specific header information stored within IRCAM data files.
- Normalise frames to unit total exposure time.
- Provide a simple imaging polarimetry reduction procedure.

## IUEDR

SG/3, 7. SUN/37. MUD/45, 46,47

### Process data from the IUE échelle spectrograph, starting with the raw image and finishing with the fully calibrated spectrum.

The International Ultraviolet Explorer (IUE) is an ultraviolet telescope in geosynchronous orbit.

It can:

- Examine the contents of IUE tapes to find what images are present.
- Read RAW, GPHOT, and PHOT images from IUE tapes onto disk. Provide them with default calibrations. (Can also read extracted spectra from IUESIPS.)
- Display images for assessment of validity and quality. Various interactive operations can be performed, including bad-pixel marking, image modification, and feature identification.
- Extract spectra from IUE images. This uses techniques that are enhancements of those in the TRAK program. Spectra exposed in either resolution mode (HIRES or LORES) can be extracted from RAW, GPHOT, or PHOT images (the latter being the newer-style Photometric images that retain geometric distortion). You can correct photometric LORES images obtained with the SWP and LWR cameras for defects in the original ITF calibration.

- Produce line-by-line spectra, corresponding to the IUESIPS product.
- Produce fully calibrated spectra. This includes various forms of wavelength correction, absolute calibration, and (for HIRES) ripple correction. There is also a semi-empirical correction for the HIRES background (order-overlap) problem.
- Display graphs to aid spectrum extraction and calibration. Various types of graphics terminals can be used.
- Combine spectra from groups of échelle orders (HIRES) or from different apertures (LORES) by mapping and averaging them onto an evenly-spaced wavelength grid.
- Write spectra to Starlink NDF files, which can then be processed by DIPSO and other Starlink software. Output includes individual extracted order and aperture spectra or combined spectra. Files can also be created in the same format as that written by TRAK.

**JCMTDR**

SC/1. SUN/132

**Reduce continuum mapping data obtained with the UKT14 instrument on the JCMT.**

*JCMTDR is now distributed on Starlink CDs. There is now a Linux port.*

The James Clerk Maxwell Telescope (JCMT) at Mauna Kea Observatory observes in the millimetre-wave part of the spectrum.

The program can:

- Transform JCMT map data into a tangent plane image centred on a given position. Optionally, rebin each input dataset individually before coadding them into the result.
- Append an IRAS astrometry structure to a rebinned map, so that IRAS90 can be used on it to overlay coordinate grids, object positions, etc.
- Correct JCMT data for the effect of atmospheric extinction.
- Convert JCMT data from GSD format to FIGARO format.
- Convert a JCMT map file into a format suitable for further processing (deconvolution and resampling) by DBMEM.
- Convert an image into a ‘time spectrum’ with map pixels sorted in order of increasing LST of observation, and vice versa.
- Deconvolve the chopped-beam from a dual beam map of a source.

Data files can be read in either ‘old FIGARO’ or NDF formats; NDF is recommended as this allows other Starlink packages to process the data. IRCAMPACK can also access the main data arrays, although other parts of the data structure will be inaccessible.

**REPACK**

SUN/208

**Handle ROSAT Wide Field Camera survey data.**

*REPACK is not distributed on Starlink CDs though it may remain as a legacy package at UK Starlink sites. There is no linux Port. With the demise of the ROSAT satellite there is no support for REPACK.*

During the period from July 1990 to January 1991, the ROSAT Wide Field Camera (WFC) performed the first ‘all sky survey’ at extreme-ultraviolet (EUV) wavelengths. The whole sky, or  $\approx 96\%$  of it, was imaged in two passbands, S1 and S2, covering the ranges 60–140Å and 110–200Å respectively. An initial bright source catalogue (BSC) of 383 sources was produced by Pounds et.al. A new list, the 2RE Catalogue of

479 sources, has recently been published. The survey data (images and ‘raw’ photon event files) are now in the public domain. REPACK fully exploits this data.

The data is available through the Leicester Data Archive Service (LEDAS). Images were sorted from the event files and screened for ‘high background’ and ‘moon in WFC field-of-view’ and named after the ecliptic latitude and longitude of the region of sky that they covered. They are  $\approx 2.7^\circ \times 2.7^\circ$  in extent with a resolution of  $1 \times 1$  arcmin<sup>2</sup> per pixel. The photon event files are overlaid on a similar ecliptic grid system. Some 13,000 image pairs and 13,000 event files were produced by this scheme, covering almost the whole sky.

Images can be retrieved in various formats: HDS, FITS, and GIF. REPACK only operates on HDS format images. Event files, available just in FITS format, can be sorted to ASTERIX (HDS) datasets such as images and light-curves.

## SURF

SC/10, 11.SUN/216

### SCUBA data re-reduction facility

SURF is a set of programs for reducing demodulated Submillimetre Common-User Bolometer Array (aka SCUBA) data obtained from the James Clerk Maxwell Telescope.

The facilities provided by SURF include:

- nod compensation,
- flatfielding,
- extinction correction,
- single beam restoration,
- sky noise removal,
- despiking,
- array overlay.

## WFCPACK

SUN/62

### Produce ASTERIX (HDS) datasets from Wide Field Camera data collected during the pointed phase of the ROSAT mission.

*WFCPACK is not distributed on Starlink CDs though it may remain as a legacy package at UK Starlink sites. There is no linux Port. With the demise of the ROSAT satellite there is no support for WFCPACK.*

A sort program generates datasets such as time series and images from pre-processed event data supplied as part of the ROSAT WFC Observation Datasets (RWODs). An exposure program corrects them allowing for instrument characteristics. In addition, a simple database manager allows an index of RWODs to be maintained and searched. The programs make use of the ADAM/ICL environment, and a number of ICL procedures are provided to perform some of the more commonly required operations, such as extracting background subtracted lightcurves.

## XRT

### ROSAT XRT data access.

The XRT is a package provides access to ROSAT XRT data stored in FITS files for analysis by other Starlink Packages. The tools are based on the ASTERIX ROSAT XRT toolset from version 2.3-b1, but do not include the ASTERIX analysis tools.

At present the documentation and Help facilities are copies of the ASTERIX files, so that some of the tools used in examples may be no longer available.



### 3.9 Format Conversion

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**CONVERT** — Data format conversion

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**CONVERT**

**SUN/55**

**Convert the standard Starlink *n*-d data format NDF to and from other formats.**

A major advantage of this package is that it deals sensibly (as far as possible) with header information, which can be lost during translation by less robust software.

Currently, the Unix version can handle these formats:

- Text (Ascii).
- FIGARO (version 2) DST file.
- GASP image.
- GIF image.
- IRAF image.
- IRCAMPACK data file.
- FITS (including some IUE final archive products and ISO datasets).
- PBMPLUS PGM (output only).
- TIFF image (output only).
- Sequential unformatted.

The following formats can only be handled by the VMS version:

- Starlink Interim BDF file.
- DIPSO file.

### 3.10 Mathematics & Statistics

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**ASURV** — Astronomical survival statistics

**MAPLE** — Mathematical manipulation

*Not distributed*

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**ASURV**

**SUN/13. MUD/5,6**

**Analyse statistically astronomical data with upper limits.**

Observational astronomers frequently encounter the situation where they observe a particular property of a previously defined sample of objects, but fail to detect them all. The data then contains ‘upper limits’ as well as detections, preventing the use of simple and familiar statistical techniques in the analysis. However, a variety of other statistical methods exist to deal with these problems which are collectively called ‘survival analysis’ or the ‘analysis of lifetime data’ from their origin in actuarial and related fields. The upper limits are called ‘censored’ data points. ASURV is a menu-driven stand-alone computer package to help astronomers use some of these methods.

No statistical procedure can magically recover information that was never measured at the telescope. However, frequently there is important information implicit in the failure to detect some objects which can be partially recovered under reasonable assumptions. ASURV provides several two-sample tests, correlation tests, and linear regressions – each based on different models of where upper limits truly lie – so that you can judge the importance of the different assumptions.

**MAPLE**

**SUN/107. SGP/47. MUD/52,137-139,144,145**

**Interactive symbolic algebra computation.**

It can perform hundreds of algebraic functions for use at all mathematical levels, and can provide solutions to many types of problem:

- Arithmetic with integers, fractions, and polynomials.
- Power series.
- Differentiation and integration of functions.
- Systems of equations.
- Differential equations.
- Linear optimization.
- Tensor manipulation.
- Symbolic and numeric approximation.
- Automatic generation of Fortran code and  $\text{\LaTeX}$  source for mathematical expressions.

In addition, it can generate plots to illustrate graphically any function, including user-defined functions. You can also extend or redefine the numerous functions by writing MAPLE programs in the built-in Pascal-like language to create specialized functions.

More general information about computer algebra software is available in SGP/47.

It is marketed by WATCOM, Waterloo, Ontario, CANADA.

### 3.11 Graphics

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**MONGO** — Interactive data plotting

*Not distributed*

**PONGO** — Interactive data plotting

**SM** — Interactive data plotting

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**MONGO**

**SUN/64. MUD/54**

**Plot data interactively.**

You can build up a complicated diagram, including graphics, text, axes, and so on, and then create publishable quality output. In general, it has been superseded by PONGO.

**PONGO**

**SUN/137**

**Plot data interactively.**

It is like MONGO, but uses Starlink-PGPLOT as the plotting package. It is more powerful than MONGO and is Starlink-compliant, which means you can use it in conjunction with ICL and AGI. Features include:

- Read data from a text file using a command with the following features:
  - the ability to read character strings as well as numeric values.
  - support for comment lines and column headings.
  - error trapping during file input.
  - user specification of column delimiters, allowing  $\LaTeX$  and  $\TeX$  format tables to be read.
  - selective reading of data.
- Use Fortran-like statements to perform mathematical manipulations on data.
- Specialised extra data columns.
- Interactive cursor functions.
- Error ellipses.
- Vector plots.
- Simple statistical analyses.
- Resample data.
- Draw user-specified functions defined by Fortran-like statements.
- Plot astronomical positional data in one of several geometries.
- Read positions as Right Ascension and Declination.

The PONGO package may be run from the IRAF CL.

**SM****MUD/159,160****Draw graphs and plots interactively.**

It has some image handling capability, but works mostly with vectors. It can:

- Generate a nice-looking plot with a minimal number of simple commands.
- View the plot on screen then, with a simple set of commands, generate hardcopy.
- Build and save your own plot routines, which can then be invoked with a single user-defined command.
- Keep a history of your plot commands, which you can edit and define as a plot routine for reuse.
- Specify plot data from within the program, or read it from a simple file.

## 4 Utilities

### 4.1 Astronomical Utilities

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**ASTROM** — Basic astrometry

**AUTOASTROM** — Autoastrometry for Mosaics

**CHART** — Finding chart and stellar data system

**COCO** — Celestial coordinate converter

**ECHWIND** — Échelle observation planning

**FINDCOORDS** — Find coordinates of named objects

**HDSTOOLS** — HDS file manipulation

*NEW*

**HDSTRACE** — HDS object lister

**NAOS** — NAOMI guide star tool

**OBSERVE** — Star observability checker

**RV** — Radial components of observer's velocity

**SKYCAL** — Interactive almanac and calculator

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**ASTROM**

**SUN/5**

#### **Basic astrometry – simple plate reduction.**

It is designed to allow the non-specialist to get good results with a minimum of trouble and esoteric knowledge. You supply a text file containing information about the exposure and the positions of reference and unknown stars; it performs the various coordinate transformation and fitting operations required, displays a synopsis report on your terminal, and prepares a detailed report for printing.

**AUTOASTROM**

**SUN/251**

We describe the autoastrom package, which provides an interface to the ASTROM application. This creates a semi-automatic route to doing astrometry on CCD images.

THIS IS BETA SOFTWARE. Some features work only partially or unreliably. It does not have all the functionality of a production release. The interface may well change.

Starlink's ASTROM application provides powerful astrometry facilities, for analysing astronomical images; it is, however, rather cumbersome to use. As described in SUN/5, ASTROM can:

- obtain the plate centre and plate scale of a CCD image, by comparing plate positions of objects with those in a reference catalogue, and fitting with both four- and six-component distortion models;
- with enough data, obtain cubic distortion and plate tilt, using seven- to nine-component models;

- if enough information is available, it will do the reductions in observed place, correcting for atmospheric refraction.

Autoastrom provides a shell around ASTROM so that, as well as the core astrometric facilities of ASTROM, autoastrom will:

- work on a CCD image provided as an NDF, as long as it has at least rough astrometry (plate centre and scale);
- automatically download appropriate reference catalogue information from catalogue servers supported by the SkyCat library;
- insert the astrometric results into the original NDF, as a WCS component;
- alternatively or additionally make the astrometry available as a set of FITS-WCS header cards.

## CHART

SUN/32

**Plot star fields (positions, magnitudes, and other data) from the CSI79, SAO, AGK3, PERTH70, and Dixon non-stellar objects catalogues.**

*CHART is not distributed on Starlink CDs but it may remain as a legacy package at UK Starlink sites. There is no Linux port and little support available. CHART will be superseded by facilities in CURSA in the near future.*

You can specify a series of search areas, place magnitude or total number limits on the search, and choose which source catalogues to include or exclude. After the search is made, you may list the results at a terminal or on a printer. Positional information may be precessed to a specified equinox. In the case of astrometric data, proper motions may be applied up to a specified epoch.

You can plot the results in the form of an overlay or finding chart. Extra objects, *i.e.* with positions supplied by you, may be added to the plot at this stage. The plot may be made on any GKS device, and a number of different plot options are available, such as scale and area, an RA and Dec coordinate grid, and various forms of error box.

You may also use the results as input to an astrometry program, *i.e.* it can be used to select astrometric stars as positional references. In this case, you will be asked to supply  $x,y$  positions for the reference stars from a measuring machine, and can then convert unknown  $x,y$  positions to RA, Dec or vice versa. ASTROM performs the actual astrometry, from within CHART if necessary.

## COCO

SUN/56

**Convert star coordinates from one system to another.**

Both the improved IAU system, post-1976, and the old pre-1976 system are supported. It can transform between the following coordinate systems:

- mean  $[\alpha, \delta]$ , old system, with E-terms (loosely FK4).
- mean  $[\alpha, \delta]$ , old system, no E-terms (some radio positions).
- mean  $[\alpha, \delta]$ , new system (loosely FK5).
- geocentric apparent  $[\alpha, \delta]$ , new system.
- ecliptic coordinates  $[\lambda, \beta]$ , new system (mean of date).
- galactic coordinates  $[l^I, b^I]$ , IAU 1958 system.

The input/output arrangements are flexible to allow a variety of operating styles: interactive, input from a file, report to a file, batch, etc. Also, in addition to the report which is produced, the results are available in raw form, to a fixed resolution, and free from extraneous formatting; this file is intended to be read easily by other programs.

It offers control over report resolution, and has simple online help. All input is free-format, and defaults are provided where this is meaningful.

In order to comply with the IAU 1976 recommendations, all position data published from 1984 on should be given in the new system, using equinox J2000.0. However, for years to come, positions will frequently be given in the old system, using equinox B1950.0. Discriminating astronomers and astrophysicists are best advised to give both B1950 and J2000 positions for sources mentioned in their publications; the conversion can be done using COCO.

## ECHWIND

SUN/53

**Plan observations with either the Utrecht échelle spectrograph (UES) or the UCL coudé échelle spectrograph (UCLES).**

It can be run at your home institution, when preparing an observing proposal, or before or during an observing run.

It lets you view interactively that part of the spectrum which will fall on the detector for a given central wavelength. This is achieved by drawing a complete échellogram in an X-window, along with a box representing the exact size and shape of the detector. The positions of individual spectral lines can also be marked on the display. You can then move the detector window around by moving a crosshair cursor to the desired centre of the detector, and then clicking the left-hand mouse button to set the detector position, or else by explicitly specifying the desired central wavelength. At each position the screen displays the minimum, central, and maximum wavelengths and order numbers falling on the detector, as well as an estimate of the length of the detector (in Angstroms). The position of the box can be marked on the screen, so as to ease preparation of observations where multiple overlapping wavelength ranges are required. You can also save the current detector position in a text file.

## FINDCOORDS

SUN/240

**Finding the Coordinates of a Named Object.**

FINDCOORDS is a new utility for using the name of an astronomical object to look up its equatorial coordinates. You simply enter the name of the object and its coordinates are displayed. Type:

```
findcoords object-name
```

For example:

```
findcoords ngc3379
```

If the name is recognised then the equatorial coordinates of the object will be displayed. The Right Ascension is shown in sexagesimal hours and the Declination in sexagesimal degrees; both are for equinox J2000.

FINDCOORDS works by submitting a remote query via the Internet to the version of the SIMBAD name-resolver provided by ESO (the basic SIMBAD is maintained by the Centre de Données astronomiques de Strasbourg, CDS). Consequently, findcoords will only work on computers with a suitable Internet connection. Also, the name given must be recognised by SIMBAD, though the latter's dictionary of names is very extensive.

**HDSTOOLS****SUN/245****HDS file editing and manipulating tools.**

HDSTOOLS is a suite of tools for editing and manipulating HDS files. They are updated versions of the tools once available in the ASTERIX package. The following tools are available:

- HCOPY - Copy HDS data objects.
- HCREATE - Create an HDS data object of specified type and dimensions.
- HDELETE - Delete an HDS object.
- HDIR - Produce a simple summary of an HDS object.
- HDISPLAY - Display the contents of a primitive HDS object.
- HFILL - Fill an HDS data object with a specified value.
- HGET - Return information about an object.
- HHELP - Obtain HELP on the HDSTOOLS package.
- HMODIFY - Modify the value of an HDS object.
- HREAD - Read a file into an HDS object.
- HRENAME - Rename an HDS data object.
- HRESET - Change state of a primitive HDS object to undefined.
- HRESHAPE - Reshape an HDS object.
- HRETYPE - Change the type of an HDS structure object.
- HTAB - Display one or more vector objects in table form.
- HWRITE - Write an HDS object into formatted or unformatted file.

**HDSTRACE****SUN/102****List the contents of an HDS data structure.**

The Hierarchical Data System (HDS) is one of the most popular features of the Starlink environment as it enables associated data items to be stored together in a single file, but in a structured fashion.

**NAOS****SUN/235****Finding Guide Stars for use with NAOMI on the WHT.**

The NAOS package may be used to find guide stars suitable for use with the NAOMI adaptive optics system available on the William Hershell Telescope (WHT) on La Palma.

NAOMI usually requires a relatively bright guide star located close to the target object being observed. You prepare a list of potential target objects and NAOS remotely searches a version of the USNO PMM astrometric catalogue to find suitable guide stars for these targets. You would usually use NAOS at your home institution prior to travelling to La Palma to observe with NAOMI.



**OBSERVE****SUN/146**

**Show the observability of a star through the year from a given geographical location.**

It generates a plot that shows, for a complete year the:

- Star rising & setting times.
- Times the star is  $30^\circ$  above the horizon.
- Times of astronomical twilight.
- Phase, rising, and setting times of the Moon.
- Distance of the Moon from the star.

**RV****SUN/78**

**List the components, in a given direction, of the observer's velocity on a given date.**

This allows an observed radial velocity to be referred to an appropriate standard of rest. It also computes light time components to the Sun, allowing the times of phenomena observed from a terrestrial observatory to be referred to a heliocentric frame of reference.

The accuracies, of better than  $0.01 \text{ km s}^{-1}$  and 0.1 s, are adequate for most classes of work, the notable exception being some pulsar observations.

The input/output arrangements are flexible to allow a variety of operating styles: interactive, input from a file, batch, etc. All input is free-format. The normal operating style is interactive: prompts appear on a terminal, data are entered specifying the report required, and a listing is sent to disk for later printing.

**SKYCAL****SUN/187. MUD/158**

**Almanac and calculator – interactive.**

This consists of two programs:

- **SKYCALC** – an 'Interactive Almanac.' It helps you plan and execute observing runs, and allows easy calculation of airmasses, twilight, lunar interference, coordinate transformations and such – nearly everything except the weather.
- **SKYCALENDAR** – a 'Nighttime Astronomical Calendar' to calculate and print astronomical calendars.

Both programs have several preset Observatory locations to choose from. You can also specify your own.

## 4.2 General Utilities

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**DOCFIND** — Starlink document search

**EMAIL** — E-mail address search

**FORUM** — Computer conferencing

**JRE** — Java Runtime Environment

**NEWS** — Starlink news system

**PERL** — Practical extraction and report language

**PERLMODS** — Additional CPAN Modules for Perl

**PINE** — E-mail interface

**STARADMIN** — User database maintainer

**STARPERL** — Additional Modules for Perl

**XDISPLAY** — X window display setup

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**DOCFIND** **SUN/38**

**Search Starlink document and keyword indexes for a specified keyword.**

You can display or print any document that is found. Unfortunately, it will not print L<sup>A</sup>T<sub>E</sub>X documents in a satisfactory form. Thus, its main use is to find documents, not print them. Stocks of Starlink Notes and Papers are kept at every Starlink site, so you can get a paper copy.

It has been superseded by the more powerful `showme` and `findme` commands provided by the HTX utility.

**EMAIL** **SUN/182**

**Look up information needed to send e-mail.**

The program searches the Starlink user database and the on-line World E-mail Guide for usernames and sitemames.

**FORUM** **SUN/205. SSN/33**

**Starlink's conferencing software.**

It is based on the World Wide Web and provides similar capabilities under Unix to those provided by the DEC product VAXnotes under VMS. Its main features are that it:

- Retains an archive of entries or notes, organized in a hierarchy.
- Restricts access.

Users can both read existing notes and submit new ones. One difference to VAXnotes is that while VAXnotes could maintain an index of all Conferences, even when they were located on separate systems at several Starlink sites, FORUM maintains an index only for each instance of FORUM.

**JRE****Java Runtime Environment.**

JRE is a copy of the standard Java Runtime Environment which has been wrapped to allow installation in the Starlink software. The JRE is included to provide a standard stable base on which to base Starlink Java tools.

**NEWS****SUN/195****Starlink's News service.**

Just type news and follow the instructions.

**PERL****SUN/193****A language for manipulating text, files, and processes easily.**

It provides a more concise and readable way to do many jobs that were formerly accomplished (with difficulty) by programming in the C language or one of the shells. There are several O'Reilly books on Perl that will help you understand and use it. *Learning Perl* and *Programming perl* are two of these books. Chapter 39 of *Unix Power Tools* gives an introduction to Perl.

**PERLMODS****SUN/193****Additional CPAN modules for the Perl package**

PERLMODS is a package of additional modules from CPAN (Comprehensive Perl Archive Network) which are added to the standard PERL installation to provide extra facilities needed by the STARPERL modules and by the SURF package.

**PINE****SUN/169, 170. MUD/141****Read e-mail.**

Just type pine to start it. A lot of on-line help is available.

**STARADMIN****SSN/27****Build and maintain a database of Starlink users.**

Used by Starlink Site Managers to manage their user lists.

**STARPERL****SUN/222, SUN/228****Additional modules for the Perl package**

STARPERL is a package of additional Starlink modules which are added to the standard PERL installation to provide facilities such as NDF access (NDFPERL).

**XDISPLAY****SUN/129****Get output from an X-client to display on the screen of your X-terminal.**

In other words, it provides an easy way to use remote X windows.

### 4.3 Document Preparation

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**A2PS** — Ascii to PostScript converter  
**EMACS** — Text editor  
**GHOSTSCRIPT** — PostScript previewer  
**HTX** — Hypertext utilities  
**ISPELL** — Spelling checker  
**JED** — Text editor  
**LATEX2HTML** —  $\text{\LaTeX}$  to HTML converter  
**NUTPU** — Text editor  
**PSMERGE** — PostScript file manipulator  
**STAR2HTML** — Starlink document to HTML converter  
**TEX** — Document preparation system

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**A2PS** **SUN/184**

**Convert Ascii format files to PostScript format for printing on PostScript printers.**

This gives a nicer looking output.

**EMACS** **SUN/34, 170. MUD/102**

**A powerful text editor with many advanced customizable features.**

It is fairly easy to make it emulate EDT and EVE. This makes it convenient for users familiar with these VAX/VMS editors.

**GHOSTSCRIPT** **SUN/197**

**PostScript interpreter.**

This provides:

- An interpreter for the PostScript language.
- A set of C procedures that implement the graphics capabilities that appear as primitive operations in the PostScript language.

**HTX** **SUN/188**

**Hypertext cross-reference utilities.**

These are used to maintain large sets of documents which use HTML, the Hypertext Markup Language. They can also form the basis for hypertext help systems for other software. There are three components:

- **hlink** – a hypertext linker. This establishes hypertext links between documents which use HTML, and maintains the integrity of these links when the documents are changed.
- **findme** – searches for documents by keyword and displays a list of those found.
- **showme** – displays a specified part of a document using a web browser.

**ISPELL**

**SUN/189**

**Check spelling.**

A screen-oriented spell-checker that shows spelling errors in the context of the original file, and suggests possible corrections when it can figure them out.

**JED**

SUN/168,170

**Edit text.**

A text editor which provides a reasonably good emulation of EDT, together with a few extra facilities such as cut-and-paste of rectangular regions, unlimited undo, horizontal scroll, and display of two or more windows.

**LATEX2HTML**

SUN/201. MUD/152

**Convert  $\LaTeX$  to HTML.**

*LATEX2HTML is now included in the STAR2HTML package.*

Processes  $\LaTeX$  source files into a set of Hypertext Markup Language (HTML) files, suitable for browsing with hypertext viewers and web browsers.

**NUTPU**

SUN/192

**Process text.**

A fully programmable text processing utility. It can build new text processors and batch-oriented text manipulation routines. Its main value for Starlink users is its close emulation of EDT.

**PSMERGE**

SUN/164

**Merge PostScript files.**

Merges one or more EPSFs into a single PostScript file. An EPSF (Encapsulated PostScript File) is a PostScript file structured so that it can be incorporated or included into another PostScript file (so that, for example, a diagram created with a graphics application can be inserted into a text document created with a word processor).

Input files can be individually rotated, scaled, and shifted. Output files can be either EPSF or 'normal' PostScript suitable for a printer. This allows:

- Pictures created by different applications to be overlaid.
- Multiple pictures to be pasted onto a single page.
- Pictures to be scaled before insertion into a  $\TeX$  document.

**STAR2HTML**

SUN/199.

**Convert Starlink documents to Hypertext.**

Processes Starlink document  $\LaTeX$  source files into a set of Hypertext Markup Language (HTML) files, suitable for browsing with hypertext viewers and web browsers.

This is a major component of Starlink's system for producing hypertext documents, which also includes TEX, HTX, GHOSTSCRIPT, the dvips processor, and PERL.

The processing to hypertext is performed by  $\LaTeX2HTML$  which is bundled with STAR2HTML.  $\LaTeX2HTML$  is not used directly because Starlink documents use a series of additional macros to allow inter-document cross referencing within the Starlink document collection.

**TEX**

SUN/9,12,93.MUD/48-51,72-3,79,80,126,132-3,152.SSN/24

**Produce high quality text and diagrams by type-setting.**

$\LaTeX$  is a document preparation system based on  $\TeX$ , but easier to use. The current versions are  $\TeX$  v3.1415 and  $\LaTeX$ 2e (Dec 1994). The final output is usually produced by a laser printer.

Starlink recommends that you create your documents using  $\LaTeX$ 2e with formats based on skeleton files such as `/star/docs/sun.tex`.

SUN/12 is a cookbook showing how to generate common kinds of format using  $\LaTeX$ ; this is a quick way to learn how to use it. SGP/28 and SGP/50 give advice on how to produce documents in a suitable style for Starlink.

## 4.4 Programming Support

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**FTNCHEK** — Fortran source code checker

**GCC** — C compiler

**GENERIC** — Generic Fortran subroutine compiler

**MESSGEN** — Error message generator

**SPAG** — Fortran code improver

**SPT** — Software porting tools

**STARX** — X library linker

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### **FTNCHEK**

SUN/172. MUD/153

**Detect errors in Fortran 77 source code, especially mistakes that tend to be missed by compilers and linkers.**

Probably its most valuable feature is the careful checks it performs on subprogram interfaces. It examines the actual arguments in each CALL statement (or FUNCTION call) and compares them with the corresponding formal arguments of the SUBROUTINE (or FUNCTION) subprogram. It warns of mismatches in the number of arguments, and incompatibilities in the data type and dimensions of each one. It also checks that arguments used before being set in a subprogram have defined values on entry, and correspondingly that arguments are set on exit when their values are used later in the calling program.

### **GCC**

**The GNU C compiler.**

### **GENERIC**

SUN/7

**Support generic subroutines.**

Preprocesses a *generic* Fortran subroutine – one written to cover several different data types – into one routine per data type, and concatenates these routines into a file. The file is then compiled by the Fortran compiler to produce an object module.

### **MESSGEN**

SUN/185

**Associate error messages with status values returned by Starlink infrastructure routines.**

This works in conjunction with the Starlink Error Message Service (EMS). It enables more informative error messages to be sent to the user.

### **SPAG**

SUN/63. MUD/127

**Improve the structure of the source code of a poorly organised Fortran program.**

*SPAG is commercial software and is not distributed on Starlink CDs. Access is available to registered Starlink users on the central service machine at RAL – contact Hiten Patel ([hiten@star.rl.ac.uk](mailto:hiten@star.rl.ac.uk)) for access.*

'SPAG' stands for 'Spaghetti Unscrambler.' It re-orders blocks of statements in such a way that the structure of the code is improved, while remaining logically equivalent to the original program. The result improves the readability and maintainability of badly-written Fortran code. It is marketed by Polyhedron Software.



**SPT****SUN/111****Software porting tools.**

A set of tools to convert code between operating systems (principally between VMS and Unix, and between different flavours of Unix). They:

- Convert file name specifications in Fortran INCLUDE statements and 'escape' backslash characters. The output file on VMS is in Stream\_If format so it can be read on Unix systems using NFS.
- Manage the creation and removal of soft links on Unix systems. Generally, these will point to Fortran INCLUDE files, thereby providing a machine-independent way of writing INCLUDE statements.

**STARX****SSN/21****Link X libraries.**

A Starlink environment package that provides a system-independent method of linking with X libraries. This relieves other libraries and applications from having to worry about the various complications involved. It allows the X library linking strategy to be changed easily, without changing any of the other Starlink environment components.

## 5 Subroutine Libraries

### 5.1 Astronomical & Mathematical

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**JPL** — Solar system ephemeris

**MEMSYS** — Maximum entropy image reconstruction

**NAG** — Mathematics, statistics, and graphics

**PDA** — Public domain algorithms

**SLALIB** — Positional astronomy

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**JPL**

**SUN/87**

**Provide extremely accurate position and velocity data for any of the nine planets, the Moon, and the solar system and Earth-Moon barycentres (also nutation components) for any given epoch in the range of the ephemeris (1960 to 2025).**

For many years, the Jet Propulsion Laboratory has distributed definitive solar system ephemeris tapes containing files of ephemeris data, plus Fortran programs to read them. The ephemerides come from direct numerical integration of the equations of motion of the large bodies in the solar system, subject to fitting to a variety of observations. For distribution they are expressed in terms of Chebyshev polynomials.

The version distributed by Starlink is the DE200/LE200, the one most consistent with the latest IAU resolutions. Users of the old (VMS-only) version should note that this new version differs in some important respects. Existing applications will need to be changed before they can be linked against the new library, and existing executable programs are not compatible with the new format of ephemeris file.

**MEMSYS**

**SUN/117. MUD/53**

**Quantified maximum entropy image reconstruction.**

*The MEMSYS libraries are commercial software and are licenced for UK Starlink sites only. MEMSYS is not distributed on Starlink CDs. Access restrictions apply at Starlink sites (see below).*

Two versions are available: MEMSYS3 and MEMSYS5.

The algorithms used in both are similar, but the programming interfaces are quite different. New applications should be written using MEMSYS5, which provides more functionality than MEMSYS3. MEMSYS3 is retained primarily for the benefit of people who want to maintain old applications.

They find and use maximum entropy reconstructions of images, power spectra, and other such additive distributions from arbitrary sets of data. They were written by J. Skilling and S. Gull of Maximum Entropy Data Consultants Ltd, and embody their 'Classic' Maximum Entropy algorithm, described in more detail in the MEMSYS3 user's manual.

The algorithms of both MEMSYS3 and MEMSYS5 differ greatly from their previous MEM algorithms, in that they are based on a fully Bayesian analysis of the image reconstruction problem. They provide the following extra functions:

- Calculate automatically the most probable noise level in the input data.

- Estimate errors in the output reconstruction.
- Handle negative data values.
- Handle limited non-linearities in the data.
- Calculate Poisson or Gaussian statistics for input data noise.

MEMSYS deals with ‘data sets’ and ‘images’. A *data set* holds information corresponding to the available experimental data, and an *image* holds information corresponding to the ‘true’ image from which the data was generated. It handles problems where the relationship between data and image can be described as follows:

$$F_k = \sum_{j=1}^{M_k} (R_{kj} * f_j) + n_k \quad (1)$$

where  $F_k$  is the  $k$ th data value,  $M_k$  is the number of data values,  $f_j$  is the  $j$ th image value,  $R_{kj}$  is the response of sample  $F_k$  to pixel  $f_j$ , and  $n_k$  is the noise on sample  $k$ .

This is a linear relationship between data and image. It can also cope with non-linear data, so long as the data  $D_k$  can be expressed as follows:

$$D_k = \Phi(F_k) \quad (2)$$

where  $\Phi$  is some known function with known derivative, and  $F_k$  is linearly dependent on the data.

The image and data set are described as 1-d arrays purely for ease of access within the package. In fact, they could be of any dimensionality. The calling program needs to set up the correspondence between  $n$ -d coordinates and the 1-d coordinate used above. For instance, for a 2-d image with coordinates ( $pix, lin$ ) the relationship may be

$$j = pix + NPIX * (lin - 1) \quad (3)$$

where  $NPIX$  is the number of pixels per line of the image.

A common use is to deconvolve a 2-d image, given a Point Spread Function (PSF). In this case, the data is linear and the matrix  $R_{kj}$  embodies the PSF.

Before using it you must sign a form (available from your Site Manager) accepting certain conditions.

## NAG

SUN/28,29. MUD/55,56,57,58,128

### Mathematical subroutine library.

*The NAG libraries are commercial software and are licensed to UK Starlink sites only. The software is not distributed on Starlink CDs.*

The Numerical Algorithms Group (NAG) library is commercial software. The current versions are Mark 18 for the Numerical library and Mark 4 for the Graphics library. Double precision versions of the Numerical Library are provided and, where available, single precision versions are also provided. The Graphics Library is in double precision form.

The routines cover a very wide area of numerical and statistical mathematics. They are extensively documented in a reference manual, guide, and introductory book. These are available at every Starlink site, and copies of the NAG newsletters are kept at RAL.

The standard library organises its routines into the following chapters:

- A02 – Complex arithmetic.

- C02 – Zeros of polynomials.
- C05 – Roots of one or more transcendental equations.
- C06 – Summation of series.
- D01 – Quadrature.
- D02 – Ordinary differential equations.
- D03 – Partial differential equations.
- D04 – Numerical differentiation.
- D05 – Integral equations.
- E01 – Interpolation.
- E02 – Curve and surface fitting.
- E04 – Minimizing or maximizing a function.
- F01 – Matrix operations, including inversion.
- F02 – Eigenvalues and eigenvectors.
- F03 – Determinants.
- F04 – Simultaneous linear equations.
- F05 – Orthogonalisation.
- F06 – Linear algebra support routines.
- F07 – Linear equations (LAPACK).
- F08 – Least-squares and eigenvalue problems (LAPACK)
- G01 – Simple calculations and statistical data.
- G02 – Correlation and regression analysis.
- G03 – Multivariate methods.
- G04 – Analysis of variance.
- G05 – Random number generators.
- G07 – Univariate estimation.
- G08 – Nonparametric statistics.
- G10 – Smoothing in statistics
- G11 – Contingency table analysis.
- G12 – Survival analysis.
- G13 – Time series analysis.
- H – Operations research.
- M01 – Sorting.
- P01 – Error trapping.
- S – Approximations of special functions.
- X01 – Mathematical constants.
- X02 – Machine constants.
- X03 – Innerproducts.
- X04 – Input/output utilities.
- X05 – Date and time utilities.

**PDA**

**SUN/194**

**Mathematical subroutine library.**

This is intended to replace the NAG library in Starlink application code. It is coded in Fortran and has a Fortran 77 binding. The interface is mostly double precision, although the Fourier transform part provides for both double and single precision and the routines from DIERCKX exist only for single precision.

**SLALIB**

SUN/67

**Positional astronomy library.**

*SLALIB* makes accurate and reliable positional-astronomy applications easier to write.

Most of the routines are concerned with astronomical position and time, but some have wider trigonometrical, numerical, or general applications. *ASTROM*, *COCO*, and *RV* all make extensive use of *SLALIB*, as do several telescope control systems around the world. Current versions are written in Fortran 77 and run on VAX/VMS, several Unix platforms, and PC. A generic ANSI C version is also available from its author.

Its main functions are:

- String decoding, sexagesimal conversions.
- Angles, vectors, rotation matrices.
- Calendars, timescales.
- Precession, nutation.
- Proper motion.
- FK4/5, elliptic aberration.
- Geocentric coordinates.
- Apparent and observed place.
- Azimuth, elevation.
- Refraction, air mass.
- Ecliptic, galactic and supergalactic coordinates.
- Ephemerides.
- Astrometry.
- Numerical methods.

It gives programmers a basic set of positional-astronomy tools which are accurate and easy to use. It is:

- Readily available, including source code and documentation.
- Supported and maintained.
- Portable – coded in standard languages and available for multiple computers and operating systems.
- Thoroughly commented, both for maintainability and to assist those wishing to cannibalize the code.
- Stable.
- Trustworthy – some care has gone into testing it, both by comparison with published data and by checks for internal consistency.
- Rigorous – corners are not cut, even where the practical consequences would, in most cases, be negligible.
- Comprehensive, without including too many esoteric features required only by specialists.
- Practical – almost all the routines have been written to satisfy real needs encountered during the development of real-life applications.
- Environment-independent – the package is completely free of pauses, stops, I/O, etc.
- Self-contained – it calls no other libraries.

## 5.2 Data Access & Management

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**ARD** — Region description language  
**AST** — World Coordinate System data handling  
**ARY** — ARRAY data structure access  
**CAT** — Catalogue access  
**CFITSIO** — Disk FITS I/O (C and Fortran)  
**FIO** — Fortran I/O  
**FITSIO** — Disk FITS I/O  
**GRP** — Manipulation of groups of objects  
**GSD** — Read Global Section Datafiles  
**HDS** — Hierarchical data system  
**IMG** — Simple image data access  
**MAG** — Magnetic tape handling  
**NBS** — Noticeboard system  
**NDF** — NDF data structure access  
**NDG** — Access to groups of NDFs  
**PAR** — Parameter system  
**PRIMDAT** — Primitive numerical data processing  
**REF** — HDS object referencing  
**TRANSFORM** — Coordinate transformation

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**ARD****SUN/183****Describe regions of a data array.**

The Ascii Region Definition system provides a textual language for describing regions within a data array, together with software for converting a textual description into a pixel mask.

The textual language is based on a set of keywords identifying simple shapes (boxes, circles, lines, etc.). These can be combined using Boolean operators (AND, OR, NOT, etc) to create more complex shapes. Data arrays can be multi-dimensional.

**ARY****SUN/11****Access Starlink ARRAY data structures built using HDS.**

Details of these structures and the design philosophy behind them can be found in SGP/38, although familiarity with that document is not necessarily required in order to use the routines.

ARY is an essential component of the NDF system, which contains routines for accessing Starlink NDF structures.

The main reason for using it is to access ARRAY structures stored in NDF extensions. At present, it only supports the 'primitive' and 'simple' forms of the ARRAY data structure.

It can:

- Access existing arrays.
- Create and delete arrays.
- Create and control identifiers.
- Create placeholders.
- Copy arrays.
- Enquire and set array attributes.
- Use message system routines.

**AST****SUN/210,SUN/211****A library for handling World Coordinate Systems in astronomy**

The AST library may be used for attaching world coordinate systems to astronomical data, for retrieving and interpreting that information and for generating graphical output based on it.

The programmer's manual should be of interest to anyone writing astronomical applications which need to manipulate coordinate system data, especially celestial coordinate systems. AST is portable and environment-independent.

**CAT****SUN/181****Create, read, and write astronomical catalogues and similar tabular datasets.**

It supports the following formats:

- FITS tables (Ascii and binary).
- STL (Small Text List; simple lists in text files).
- CHI/HDS.
- SCAR/ADC (on VAX/VMS only).

**CFITSIO**

SUN/227. MUD/166,167

**Access FITS format files on disk.**

This new library provides both a C implementation of a FITS i/o library and a Fortran wrapper for it. Thus one can use it from C or Fortran as required.

The CFITSIO library is written and actively maintained by William Pence of HEASARC (High Energy Astrophysics Science Archive Research Center) at the Goddard Space Flight Center, USA. It is fully compliant with the FITS Year 2000 directive. This is the recommended library for access to FITS files.

**FIO**

SUN/143

**Access sequential and direct-access data files in a machine-independent way.**

It consists of stand alone FIO and RIO routines, which can be used independently of the Starlink software environment, plus routines to interface to the Starlink parameter system.

**FITSIO**

SUN/136. MUD/16,162

**Access FITS format files on disk.**

This is a Fortran-only library for access to FITS files. It is no longer being developed and is not compliant with the FITS Year 2000 directive.

Users requiring a library for FITS access are recommended to use the CFITSIO library.

**GRP**

SUN/150

**Handle groups of objects which can be described by character strings.**

These objects can be things like file names, astronomical objects, numerical values, etc. It can store and retrieve such strings within groups, and pass groups of strings between applications by means of a text file. It can also create groups in which each element is a modified version of an element in another group.

**GSD**

SUN/229

**Global Section Datafile (GSD) access library.**

This library provides read-only access to Global Section Data files (GSD files) created at the James Clerk Maxwell Telescope. A description of GSD itself is presented in addition to descriptions of the library routines.

Its main use is in SPECX to read the GSD files created by the heterodyne instruments used on the JCMT.

**HDS**

SUN/31,39,92,102.SGP/38

**Store and retrieve data flexibly.**

The Hierarchical Data System is the basic Starlink data system and is of great importance to the Project. Its most significant features are the following:

- It manipulates entities called *data objects*. These can be scalars or arrays of up to seven dimensions.
- A data object has a tree-like shape whose components comprise other objects. The only restriction is that the leaves must be primitive data types. The degenerate form of an HDS tree is a single scalar or array of a primitive data type. The non-degenerate form is called a structure, which comprises two or more components.



- The primitive data types include the usual Fortran numeric, logical, and character types, together with signed and unsigned bytes and words.
- You can tree-walk. Any branch or sub-branch of a tree can be treated as a data object in its own right.
- Data objects are dynamic in the sense that programs can add, modify, or delete components to or from a tree.
- Subsets of primitive arrays can be defined and manipulated as separate data objects, and arrays can be mapped as vectors.

More powerful data systems have been built on top of HDS in order to make specific types of data object easier to handle. These include ARY for handling arrays, and NDF for handling objects in the standard Starlink data format.

**IMG****SUN/160****Easy access to astronomical image data and associated headers.**

It is of most interest to astronomers who write their own software and require uncomplicated access to their image data. In this context, an 'image' may be an ordinary (2-d) image, but could also be a spectrum (1-d) or 'data cube' (3-d).

Because of Starlink's automatic format conversion facilities, this library also gives programmers straightforward access to a wide range of astronomical data formats, including FITS and IRAF files as well as Starlink NDF data.

**MAG****SUN/171****Handle magnetic tapes.**

Astronomical data on magnetic tapes can be in many formats. The MAG library allows you to write programs to read this data on any type of computer and tape drive. It doesn't interpret the data format – it deals in tape blocks, and knows nothing about FITS, VMS BACKUP, tar, etc.

MAG lets you write portable software. This is very useful since different computers can differ greatly in their facilities for handling magnetic tapes. For example, on VMS it is quite common to treat magnetic tapes as normal Fortran sequential files that can be opened, read, written, and closed using the Fortran statements OPEN, READ, WRITE, and CLOSE. On Suns, this is not the case, and special routines are provided for processing magnetic tapes. These differences are hidden from the programmer by the MAG package.

It can:

- Allocate a tape drive and mount a tape.
- Open and close tape devices.
- Read and write data contained in tape blocks.
- Move tapes relatively (skip files/blocks and rewind).
- Position tapes absolutely.

Not all operations are available on all types of tape deck. Also, the status values returned by different machines can differ.

**NBS****SUN/77****Share data between processes.**

NBS stands for *Noticeboard System*.

A given process may own many noticeboards and may access ones owned by others. Normally, the only process that writes to a noticeboard is its owner, but other processes subvert this rule if necessary.

Noticeboards are identified by name, and each can contain a hierarchy of items. Each item has a name, type, structure/primitive attribute, and, if primitive, a maximum number of dimensions, maximum number of bytes, current shape, and value. The type and shape are not used by the routines, but their values can be put and got, and they can be used when implementing higher-level routines on top of the noticeboard routines.

Noticeboards are self-defining – a process can find and access data from a noticeboard without knowing anything about what it contains.

**NDF**

SUN/33.SSN/20

**Access data stored in NDF format.**

The *Extensible n-Dimensional Data Format* is the standard Starlink format for  $n$ -d arrays of numbers, such as spectra, images, etc, and it forms the basis of most Starlink spectral and image-processing applications. A 'stand-alone' version is available for programs which do not use the Starlink software environment.

The main reason for using NDF is to simplify data exchange between applications. In principle, it should enable you to process the same data with any Starlink package. In practice, previous attempts to define a standard data format for this purpose have met with two serious obstacles. Firstly, different software authors have interpreted the meaning of data items differently, so that although several packages might be capable of reading the same data files, they actually perform incompatible operations on the data. Secondly, many authors have found a pre-defined data format to be too restrictive and have ignored it.

The NDF data structure has, therefore, had to satisfy two apparently contradictory requirements:

- Its interpretation should be closely defined, so different (and usually geographically separated) programmers can process it in consistent and mutually compatible ways.
- It should be adaptable, so it can hold data associated with many software systems whose detailed requirements vary considerably.

This problem has been solved by introducing the concept of *extensibility*, and by dividing the data structure into two parts – a set of *standard components* and a set of *extensions* – each of which individually satisfies one of the two requirements. The structure consists of a central 'core' of information, whose interpretation is well-defined and for which general-purpose software can be written with wide applicability, together with an arbitrary number of extensions, which may be used by specialist software but whose interpretation is not otherwise defined. Those who wish to know more of the background to this philosophy can find a detailed discussion in SGP/38.

**NDG**

SUN/2

**Routines for Accessing Groups of NDFs.**

The NDG package provides a means of giving the user the ability to specify a list (or "Group") of NDFs as a reply to a single prompt for an parameter. NDG can process NDFs which are stored as components within an HDS container file, and can also process foreign data formats using the CONVERT utilities that the NDF library uses (as described in SSN/20).

**PAR**

SUN/114

**Parameter system.**

A convenient way for programs to exchange information with the outside world through I/O channels called *parameters*. These enable a user to control a program's behaviour.

It supports numeric, character, and logical parameters, and is currently implemented only on top of the ADAM parameter system. Parameter values may be obtained, with or without a variety of constraints. Results may be put into parameters to be passed to other applications. Other facilities include setting a prompt string, and suggested defaults.

**PRIMDAT****SUN/39****Process primitive data.**

Does arithmetic, mathematical operations, type conversion, and inter-comparison of any of the primitive numerical data types supported by HDS. Provides:

- Processing facilities which are not normally available.
- A uniform interface.
- Improved portability and efficiency.
- Facilities for processing bad data.
- Numerical error handling.
- A set of constants.

A distinction is drawn between three classes of primitive data, which differ in their interpretation and in the algorithms best suited to processing them:

- **Values** – scalar data which may take one of the defined *bad values* (sometimes called ‘magic’ values), whose presence signifies that the affected datum is undefined.
- **Vectorised arrays** – 1-d arrays of *values* (or arrays treated as 1-d) whose elements are processed in the way described above.
- **Numbers** – always interpreted literally as scalar numerical quantities (*i.e.* *bad values* are not recognised on input and are not explicitly generated on output).

**REF****SUN/31****Handle references to HDS objects.**

Stores references to HDS data objects in special HDS reference objects, and lets you obtain locators to reference objects. Helps make your software portable.

You can:

- Create a reference object and put a reference in it.
- Obtain a locator to an object (possibly via a reference).
- Obtain a locator to a referenced object.
- Create an empty reference object.
- Put a reference into a reference object.
- Annul a locator which may have been obtained via a reference.

Its two main uses are:

- To maintain a catalogue of HDS objects.
- To avoid duplicating a large dataset.

**TRANSFORM****SUN/61****Relate different coordinate systems.**

Provides a standard, flexible method for manipulating coordinate transformations and for transferring information about them between programs. It can handle coordinate systems with any number of dimensions, and can efficiently process large (i.e. image-sized) arrays of coordinate data using a variety of numerical precisions.

No specific support for astronomical coordinate transformations or map projections is included at present, but routines for handling these should appear in future. The current system provides tools for creating a wide variety of coordinate transformations, so it should be possible to construct some of the simpler astronomical transformations explicitly, if required.

It can:

- Define linear and non-linear graphics coordinate systems.
- Attach coordinate systems to datasets (e.g. relating image pixels to sky positions).
- Describe distortion in images and spectra.
- Store and apply instrument calibration functions.

It uses HDS to store information in standard data structures for interchange between applications. These may be used as building blocks when constructing larger HDS datasets, and also when designing 'extensions' to the standard Starlink NDF data structure.

### 5.3 Graphics

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**AGI** — Applications graphics interface

**GKS** — Graphical kernel system

**GNS** — Graphical workstation name service

**GRAPHPAR** — ADAM graphics

**GWM** — X graphics window manager

**IDI** — Image display interface

**NCAR** — High-level graphics

**Native-PGPLOT** — High-level graphics

**Starlink-PGPLOT** — High-level graphics

**SGS** — Simple graphics system

**SNX** — Starlink extensions to NCAR

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**AGI**

**SUN/48**

#### **Graphics database.**

Used in Starlink programs to store, between applications, information about the various plots on a graphics device. It records their position and extent. These can be recalled later either to overlay plots, or to recreate the picture.

Obvious uses are to align pictures, or to obtain cursor coordinates from an existing picture. But it has other uses, *e.g.* to slice up the screen into areas for subsequent plotting using more complicated patterns than just a regular grid; the areas can be different sizes or overlap.

**GKS**

**SUN/83,113. MUD/27. SSN/39**

#### **Low-level graphics library.**

The Graphical Kernel System is an international standard. The current version is 7.4 and this what you should use.

It has two major advantages over other graphics packages:

- It is an international standard, and thus portable.
- No other package provides the ability to write such device independent graphics programs. Only with GKS can you write a program that will run, and produce good pictures, on all devices supported by the implementation, including devices not supported at the time the program was written. Nonetheless, programs can still fully exploit all the facilities offered by the hardware.

In addition, the Starlink implementation has several advantages of its own:

- It is likely to be well supported.

- It is used on several thousand computers, of many different types, throughout the UK academic community. This means that the software has received a large amount of testing under a wide variety of conditions, and should be highly reliable.
- It contains features which are not all found in any other single package:
  - Area fill with several fill styles on *all* devices.
  - Cell array supported on dot matrix printers.
  - Multiple fonts.
  - Selective clearing of display surface.

The advantages of GKS also apply to graphics software which use it, such as SGS.

## GNS

SUN/57

### Support names for GKS graphics devices.

Almost any graphics program requires you to identify a graphics device to use. When it uses GKS, they are identified by two integers: a 'workstation type' and a 'connection identifier.' ('Workstation' is GKS terminology for a graphics device of any description.) You can't remember the workstation types of all Starlink's graphics devices, so the *Graphics Name Service* has been provided to translate 'friendly' and easy-to-remember names into their GKS equivalents.

Most high level graphics packages, such as SGS and Starlink-PGPLOT, call GNS to do the required name translation when a workstation is opened, so unless you are writing programs that open GKS workstations directly, or need to make specialised device inquiries, you will not need to call GNS routines yourself.

It can:

- Translate workstation names to their GKS equivalents.
- Generate a list of the names and types of available graphics devices.
- Answer a variety of enquiries about the properties of a particular graphics device; for example, its category (pen plotter, image display, etc) or its VMS device name.

It is used internally in IDI and AGI, but this isn't normally apparent to the programmer.

## GRAPHPAR

SUN/113

### Access the graphics libraries GKS, SGS, and Starlink-PGPLOT from Starlink programs.

These are the components of GKS, SGS and Starlink-Pgplot that provide the interface to the respective libraries from ADAM programs.

## GWM

SUN/130

### Create graphics windows on an X display that do not disappear when a program terminates.

X was designed to support GUIs and it has two properties that make an X window fundamentally different from a traditional graphics device. Firstly, windows 'belong' to application programs and are deleted when the application exits, unlike the picture on an image display which remains there until replaced by something else. Secondly, application programs are expected respond to 'events' occurring in their windows; things like key presses, mouse movements, etc. One event type that all applications must handle is the 'window expose' event which occurs whenever part of a window that was invisible – because another application's window was obscuring it for example – becomes visible. The application is

responsible for restoring the contents of the newly exposed part of the window, but only an application designed as an X application can do this; an application that is using X via a graphics package, such as GKS or IDI, but is otherwise a conventional application that knows nothing of X, cannot.

The X graphics window manager<sup>1</sup> makes a window on an X display behave like a traditional graphics device by making the lifetime of the window independent of any applications program and by handling window expose events. Applications still send plotting commands directly to the window; they don't have to go via a 'server' process, so there is no adverse impact on performance. All communication between the window manager and the application is via the X server, and the graphics window manager does not have to run on the same machine as the application.

---

<sup>1</sup>Not to be confused with the Window Manager which allows you to move windows around the screen, iconize them, etc.



**IDI****SUN/65. MUD/28****An international standard for displaying astronomical data on an image display.**

It is intended for programs that need to manipulate images to a greater extent than can be done with GKS and its offspring. Thus, it does not supersede GKS, but offers features not available in GKS. It is not as good as GKS for producing line plots or character annotation – it does have routines to draw lines and plot text, but these are primitive and offer you little control over how the result will appear in terms of character size, style of line width, etc.

Its major strength is its ability to perform many types of interaction using the mouse. Like GKS, it can display an image, move the cursor, and rotate the look-up table. However, it can also scroll and zoom, blink the memories, and read back a representation of the whole display, which can then be used to obtain hardcopy. It allows these functions to be programmed in a device independent way, so a program can use any device for which IDI has been implemented.

It is not possible, at present, to mix GKS and IDI calls on the same display because the two packages use completely different display models. However, it is possible to run the packages one after the other. For example, IDI could follow GKS, and the display could be opened without resetting it. However, this is an undesirable approach since the results could be unpredictable. A better solution is to use AGI to mediate between them.

**NCAR****SUN/88. MUD/59****High-level graphics utilities.**

This extensive suite was obtained from the National Center for Atmospheric Research in Boulder, Colorado. (An associated software item called SNX contains some Starlink extensions to it.)

The routines are thoroughly documented and just a few simple calls will produce graphs of excellent appearance. They also very flexible, with dozens of plot details independently controllable to give you exactly the result required. The plots provided are:

- Annotated curves or families of curves.
- Contours for 1-d and 2-d data, with labels.
- Dashed lines with labels.
- Continental, national, and US state boundaries in nine map projections.
- Graph paper, axes, etc.
- Halftone (greyscale) pictures from 2-d arrays.
- Histograms.
- Iso-value surfaces (with hidden lines removed) from 3-d arrays.
- Software characters.
- 3-d displays of a surface (with hidden lines removed) from 2-d arrays.
- Vector flows of fields for which planar vector components are given on regular rectangular lattices.
- Lines in three space.
- 2-d velocity fields.

**Native-PGPLOT**

SUN/15, 113. MUD/61

**A high-level graphics package for plotting  $x,y$  plots, functions, histograms, bar charts, contour maps, and grey-scale images.**

Complete diagrams can be produced with a minimal number of subroutine calls, but control over colour, line-style, character font, *etc.* is available if required. It was written with astronomical applications in mind and has become a *de facto* standard for graphics in astronomy.

Native-PGPLOT is the original version from Tim Pearson at Caltech based on the low-level graphics package known as GRPCKG. It has the same user interface as Starlink-PGPLOT, and non-ADAM applications can be moved from one version to the other simply by re-linking using the appropriate libraries.

**Starlink-PGPLOT**

SUN/15,113.MUD/61

**A high-level graphics package for plotting  $x,y$  plots, functions, histograms, bar charts, contour maps, and grey-scale images.**

Complete diagrams can be produced with a minimal number of subroutine calls, but control over colour, line-style, character font, *etc.* is available if required. It was written with astronomical applications in mind and has become a *de facto* standard for graphics in astronomy.

Starlink-PGPLOT is the version based on the Starlink GKS library and has the same user interface as Native-PGPLOT. Non-ADAM applications can be moved from one version to the other simply by re-linking with the appropriate libraries.

This is the version supported by Starlink for its applications.

**SGS**

SUN/85,113

**A friendly interface to a subset of GKS.**

SGS stands for 'Simple Graphics System.'

Many of its features are low-level (e.g. draw a line), but there are some routines of a slightly higher level (drawing arcs, formatted numbers, etc). It does not include routines for high-level operations like drawing annotated axes or complete graphs. Many plotting programs can be written entirely with SGS or higher-level calls. There will, however, be occasions when GKS routines are used as well; usually because a specialised feature of GKS is needed.

It can:

- Control workstations and zones.
- Plot lines, text, and markers.
- Control character attributes.
- Accept graphical input.
- Do GKS inquires.

**SNX**

SUN/90

**Starlink extensions to NCAR.**

They provide more convenient access to certain features of NCAR without sacrificing flexibility. (Beginners may be daunted by the mass of features offered by NCAR, and unless they take the extreme step of reading the manual they may give up before realising what the package can do for them.)

The AUTOGRAPH part of NCAR, used in conjunction with SNX and SGS, offers an alternative to Starlink-PGPLOT for graphing one variable against another. SNX enhances the power of AUTOGRAPH and makes it easier for the beginner.

It can:

- Open AUTOGRAPH/SGS/GKS with a single call.
- Plot a finished graph, with annotation, by means of a single call.
- Include special characters in graph labels (Greek, subscripts, mathematical symbols, etc.).
- Plot character strings anywhere on the graph.
- Manage the graphics device display surface via the SGS system of zones while using AUTOGRAPH to do the plotting.
- Align the AUTOGRAPH and SGS coordinate systems.
- Save and restore the state of AUTOGRAPH so that multiple active plots can be managed.
- Perform cursor input.

## 5.4 Other

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**CHR** — Character handling  
**CNF** — Mixed C and Fortran programming  
**EMS** — Error message service  
**HLP** — Interactive help system  
**KAPLIBS** — General purpose KAPPA routines  
**MERS** — Message and error reporting  
**ONE** — Odds and Ends library  
**PCS** — Parameters and communications  
**PSX** — POSIX interface

---

**CHR** SUN/40

**Augment the limited character handling facilities of Fortran 77.**

Converts Fortran data types into text strings and the reverse, does wild card matching, string sorting, paragraph reformatting and justification. It can be used for building text strings for interactive applications, or as a basis for more complex text processing applications.

It can:

- Change case.
- Compare and edit strings.
- Encode and decode Fortran data types.
- Make enquires about character strings.
- Enhance portability.
- Search for strings.

**CNF** SUN/209

**Mix program segments written in Fortran and C in a portable manner.**

It provides:

- C macros to hide the different ways that computers pass information between subprograms.
- C functions to handle Fortran character strings and logical values.

**EMS** SSN/4

**Construct and store error messages for future delivery to a user via ERR.**

ERR is the Starlink Error Reporting System, which is part of MERS. It can be regarded as a simplified version of ERR without the binding to any software environment (e.g. for message output or access to the parameter and data systems). It conforms to the error reporting conventions of MERS.

**HLP****SUN/124****Retrieve named items from a hierarchical library of text.**

Functionally, it is very similar to the VAX/VMS Help system. Major differences:

- Implemented in a portable way and not tied to the VAX.
- Allows independent creation of multiple libraries which are bound together at run-time and appear to the user as a single tree.

It is free-standing and does not call any other Starlink packages.

**KAPLIBS****SUN/238****General purpose KAPPA libraries**

KAPLIBS is a new package containing several Fortran subroutine libraries that were previously distributed as part of the KAPPA package. These libraries contain general purpose subroutines which may be of use to anyone developing their own KAPPA-like applications. SUN/238 contains brief documentation, but users of KAPLIBS will probably find it useful to examine the source code of relevant KAPPA commands.

**MERS****SUN/104****Report messages and errors.**

There is a general need for programs to inform the user about:

- What they do – for example, what is going on.
- What results have been obtained – final, or intermediate if this would be helpful.
- What errors have occurred – why the program crashed, or to ask for more sensible parameter values.

MERS comprises two libraries to help you do this:

- **MSG** – Message Reporting System, used for reporting non-error information.
- **ERR** – Error Reporting System, used specifically for reporting error messages.

**ONE****SUN/234****Odds and Ends library**

The ONE library is a small set of Fortran and C routines of a general nature and usefulness but which are not appropriate to be included in any of the more focussed Starlink libraries.

The routines are written in C but are callable direct from Fortran.

**PCS****SSN/29****Parameter and communication system.**

Application programs often need to obtain parameter values from a variety of sources and to communicate with other programs. The Parameter and Communication Subsystems (PCS) are a set of closely-related subroutine libraries which provide these facilities for many Starlink applications and associated user-interfaces.

These libraries will not generally be called directly by application programs, but form a basic part of ADAM, the Starlink Software Environment.

**PSX****SUN/121****Use the POSIX and X/OPEN libraries.**

Lets you use operating system facilities in a machine independent way.

## 6 Infrastructure

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**ADAM** — Starlink software environment

**EXPECT** — Interactive program control

**ICL** — Command language

**INIT** — Starlink initialisation files

**SAE** — Starlink applications environment base files

**STARTCL** — Starlink additions to TCL

**TCL** — Embeddable tool command language

**TK** — X window toolkit for TCL

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**ADAM**

**SG/4, 6. SUN/101, 113, 115, 134, 144. SGP/45. SSN/64**

### **Starlink's main software environment.**

It has many aspects which, taken together, provide users with a coordinated environment for analysing data and writing programs. ADAM software also controls many telescopes and instruments at observatories.

In the minds of users doing data analysis, ADAM is usually identified with its application programs, such as KAPPA and CCDPACK. However, it is really just the kernel of the system, in other words, the subroutine libraries. Many of the libraries associated with ADAM are also available as stand-alone libraries, thereby making it easier to take code to non-Starlink computers. Some of the libraries used in ADAM programs are Starlink libraries that predate ADAM, while others are commercial packages. In fact, it is impossible to have a perfect definition of what is or is not an ADAM program. The best one seems to be 'an ADAM program is one that uses the ADAM parameter system to interact with the user.' The fact that different groups of users have different ideas of what constitutes an ADAM program is not a failing of ADAM; it demonstrates the different ways in which it can be used.

As mentioned above, ADAM applications are really distinct from the ADAM kernel. However, without application programs, ADAM would only be half a system. Most of the packages described in this note are ADAM programs. There are also software tools to aid in writing ADAM programs, and data analysis tools to browse data files.

One of ADAM's most important features is that it provides a standard method of data storage called NDF (extensible  $n$ -d data format). NDF files have standard components that all programs recognise, while also allowing for any extensions that may become necessary for particular applications. Use of NDF means that data files can be exchanged between different packages without the need to convert file formats. This is very useful, as having to change file formats is very annoying and takes up extra disk space. NDF is layered on HDS, the hierarchical data system. By using HDS (version 4.0 or later), it becomes possible to read and write data files on different computer systems completely transparently, so no explicit data conversion needs be done, even when moving from one computer to another.

ADAM programs can generally be run either from the command language of the host, or from the ICL command language. ICL is a simple programming language in itself, somewhat along the lines of BASIC. It can be quite useful for doing simple operations, but is not fast enough for any major processing. Use of ICL makes it easier to build sequences of operations into ICL procedures. It is generally quicker to

run ADAM programs from ICL if they are to be run several times, since the programs only have to be activated once. On the other hand, the ability to run ADAM programs from the shell is very useful for debugging.

One of the most distinctive features of ADAM is the parameter system. This provides a method whereby a program can interact with a user, or with other programs. For a single program, a series of write and read statements could sometimes be used instead, but for anything more complex this becomes unacceptable. It is particularly difficult to maintain a standard style, and *ad hoc* fixes to problems abound. Use of the parameter system provides a consistent user interface, a means of storing the value of a parameter between invocations of a program, and the facility to pass the values of parameters from one program to another.

From the perspective of a programmer, ADAM provides many subroutine libraries that perform common functions. They provide such diverse functions as character handling, access to hierarchical, relational, and simple data, graphics, the parameter system, error and message reporting, numerical calculations, etc. Some of these libraries are provided purely for use in ADAM programs, whereas others, such as the NAG library and graphics libraries, have a much wider use.

Although any subroutine library can be used in an ADAM program, those that have been written specifically with this in mind are much easier to use. ADAM libraries conform to the Starlink standard on the use of inherited status, which greatly reduces the amount of code needed to test for error conditions. They also report any error conditions via the error message service. This lets the programmer get at the error messages as well the error code, to see if the error can be handled internally or whether to send the error report on to the user.

By using the facilities provided in a consistent manner, simple programs can be easily linked together to perform complex operations. In particular, programs from packages written to do completely different things can process each other's data, thereby avoiding unnecessary duplication of software, with the attendant waste of effort, both in writing the program and in maintaining it.

Finally, it should not be forgotten that ADAM originated as a telescope and instrument control system. The way that ADAM programs are written when used in these circumstances is rather different from when they are used for data analysis. Use of ADAM for instrument control is not the province of this document. However, it is interesting to note that programs written for data acquisition tasks are rather like windows programs, which have become common.

## EXPECT

SUN/200

### **Emulate a user sitting at a terminal.**

When combined with TK, it can put a GUI in front of an existing application without modifying it.

## ICL

SG/4,5

### **A programmable user interface to an astronomical data reduction or data acquisition system.**

It is one of the main user interfaces for the ADAM software environment. In some ways it is similar to a high level programming language such as Fortran or Pascal, but it has some important differences:

- It is a *command* language. One of its main uses is to let you type commands with few restrictions on the format.
- It is an *interactive* language. It provides a complete environment for entering, editing, and debugging programs, rather than relying on external editors, linkers, etc.
- It is a *programming language* suitable for relatively simple and straightforward programs.



**INIT****A grouping of the Starlink login resource files and other associated bits and pieces.**

The `.cshrc` and `.login` files are now handled like standard packages and are edited by the install procedure to contain the correct root path for the USSC set. This allows easy installation on systems where the directory `/star` does not exist.

**SAE****SUN/191****Starlink application environment.**

INIT gathers together the global `include` and `error` files needed by the infrastructure and applications. It is purely an administrative grouping.

**STARTCL****SUN/186****Extend TCL and TK.**

A public domain utility called TCL/TK is in wide use as a command language and user interface builder. STARTCL comprises three extensions to TCL and the TK Toolkit that enable TCL/TK applications to cooperate with Starlink applications. These are:

- A TK widget that displays Starlink graphics by emulating the `gwm` graphics window server and a `gwm` canvas item.
- An interface to the ADAM message system.
- An interface to the ADAM notice board system.

**TCL****SUN/186, 200. MUD/164****Control and extend applications using a scripting language.**

TCL stands for *Tool Command Language*.

**TK****SUN/186, 200.****MUD/164 Build GUIs.**

An X window toolkit for use with TCL and EXPECT. It can build Motif-like user interfaces using TCL scripts instead of C code.

## 7 Acknowledgements

The majority of the text for this document was plundered from existing Starlink documents by Mike Lawden who compiled and edited editions up to 1997.

The current form of this document was developed by Martin Bly who was editor from 1997 to 2002.

Most of the raw material came from the introductory sections of appropriate Starlink User Notes, but material was also grabbed from other sources, such as Starlink Bulletin articles and Starlink Panel papers, where these provide extra insight into the significance and functions of a software item.

As this note covers *all* Starlink's software, I acknowledge and thank *all* the authors of Starlink documents for providing the source material. Thanks particularly to Mike Lawden for his work on pervious editions.

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