Astronomical Data Analysis Software and Systems XII
ASP Conference Series, Vol. 295, 2003
H. E. Payne, R. I. Jedrzejewski, and R. N. Hook, eds.

Representations of DEIMOS Data Structures in FITS

Steven L. Allen, De A. Clarke, Robert I. Kibrick

UCO/Lick Observatory, University of California, Santa Cruz, CA 95064

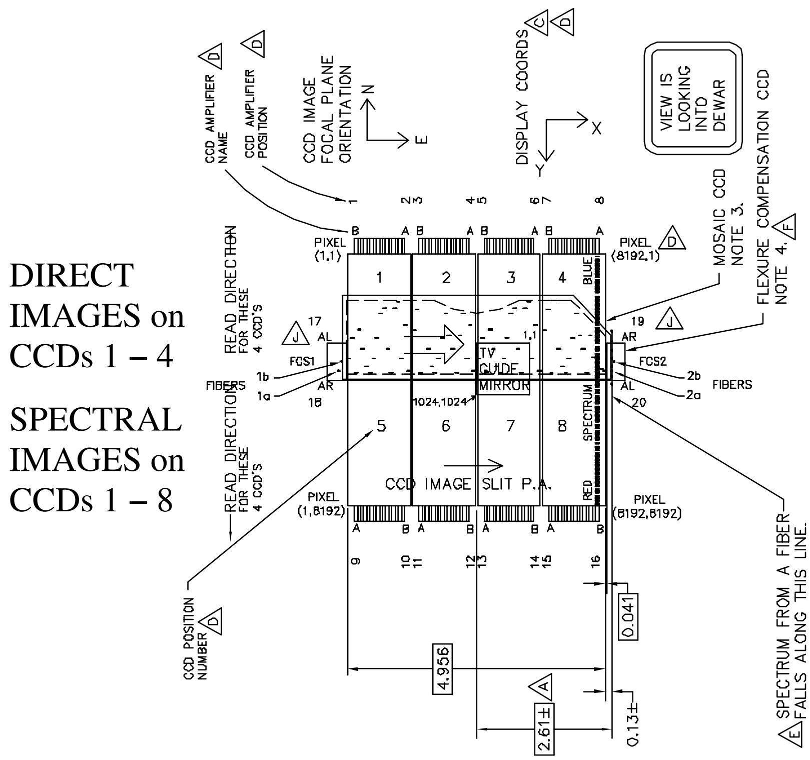
Abstract. DEIMOS (the DEep Imaging Multi-Object Spectrograph) began producing scientific data from the Keck II telescope in 2002 June. The instrument is extremely configurable, and the form of the output data is highly variable. Filters and gratings may be swapped, gratings and mirrors tilt, readout modes and active amplifiers of the 8-CCD mosaic change, and numerous field-specific astrometric slitmasks may be inserted. For archival purposes and to enable fully-automated data reduction, FITS files from DEIMOS document the instrument state, all aspects of the slitmask design, and multiple world coordinate systems for the mosaic images. The FITS files are compatible with existing local conventions for mosaic image display systems and also with incipient FITS WCS standards.

1. Introduction

The DEIMOS mosaic detector contains 10 dual-amplifier CCDs in two arrays. The science array has 8 MIT/Lincoln Labs CCDs (2048×4096 15 μm pixels) each employing both amplifiers. Four of the science CCDs can receive direct images, and all 8 can receive spectra of celestial objects through slitlets cut into masks. The flexure compensation array has 2 UCO/Lick FCS CCDs (1200×600 15 μm pixels) each employing one amplifier. The FCS CCDs receive spots of arc-lamp light from fibers. They read continuously for a closed-loop compensation of flexure caused by rotation at the Nasmyth focal plane (Faber et al. 2002).

2. HDU Structure of DEIMOS FITS files

The analog signals from the pre-amplifiers of the 16 science CCDs travel to the digitizing video inputs via coaxial cables. Following the convention set by the NOAO mosaic (Tody & Valdes 1998), all of the digitized pixel values from one science readout go into a single FITS file. Subroutines from CFITSIO (Pence 1999) build the 140 Mbyte multi-HDU file in shared memory during a readout. The memory file is written to disk at the end of the readout. The PHDU contains a null image and keywords for about 400 variables describing the state of the instrument and telescope hardware. The pixels from each video input, along with keywords that document their provenance, are placed into a separate IMAGE extension HDU. Whenever an exposure is taken through a slitmask the data acquisition system appends FITS binary tables describing that mask.



The resulting FITS file is archivally complete. It is viewable both by the IRAF ximtool using mscdisplay and by ds9 (Joye & Mandel 2000).

3. Using XML for the CCD Mosaic Problem of Numbers

In typical operation there are no changes to the identities of the CCDs, their locations in the mosaic focal plane, nor permutations of the coaxial cables. Nevertheless, it is trivial to reconfigure the hardware by permuting the cables, CCDs may be replaced and/or moved, and other mosaics may exist which have different configurations. Full documentation of the mosaic configuration by a general-purpose data acquisition system requires a schema that describes the configuration of the CCDs and their locations (world coordinates) in the focal plane. The schema describes the cabling in order to distinguish CCD amplifiers from video inputs. FITS writing software using this information should be as easy to reconfigure as the cables.

The syntax of XML and the many tools that manipulate it provided a convenient means of designing a general mosaic detector schema. The result is a set of entities describing CCD and amplifier types with their designed characteristics, and as-designed layout of different types of mosaics. Other entities describe names and peculiarities of individual CCDs, as-built names and locations of CCDs in mosaics, and wiring configurations. The XML data translate into C data structures used by the data acquisition system when writing FITS headers. Neglecting WCS information (see next section), there are 86 FITS keywords describing the mosaic in a 16-amplifier science readout.

4. World Coordinate Systems in IMAGE HDUs

Complete documentation of the provenance of each of the pixels in a multi-HDU FITS file, and correct viewing of the mosaic image, require a considerable amount of bookkeeping. DEIMOS images include three of the keywords defined for the NOAO mosaic, but the principal coordinate information is communicated via the standard FITS WCS keywords (Greisen & Calabretta 2002, Calabretta & Greisen 2002).

The real-time data acquisition system currently calculates the keyword values for 5 alternate, linear WCSs. The algorithm employs concatenation of numerous linear transformations which are components of each complete WCS. The components of the WCS start with the amplifier readout parameters, but many of the subsequent components are obtained from the XML schema describing the mosaic layout. A 16-amplifier DEIMOS FITS file contains approximately 1100 FITS keywords which document these WCSs in each of the image HDUs. Future addition of non-linear types of WCS will further increase this number.

Image The image WCS is a redundant reiteration of the default FITS array coordinates. It is the same for all images, and is equivalent to IRAF "logical".

Amplifier Each CCD pixel reads through an amplifier producing an array of digital values (`cpix`) in memory with a known WCS (`cpix2amp`). Transfer of pixel values to a FITS image array implicitly uses `cpix2fits` which inverts to `fits2cpix`. The amplifier WCS is the concatenation of `fits2cpix` and `cpix2amp`.

CCD The relation between amplifier pixels and CCD pixels (`amp2ccd`) is defined by the type of CCD in use. The CCD WCS is the concatenation of `fits2amp` and `amp2ccd`.

Pane & Detector Pane coordinates conform to longstanding pixel conventions at Lick; the observer uses them to define CCD readout windows. Detector coordinates conform to mosaic conventions at NOAO. The transformations `ccd2pane` and `ccd2ndet` are defined by the design of the mosaic in use and concatenated with the CCD WCS (`fits2ccd`).

slitmask, boresight, & other non-celestial The relation between CCD pixels and any other coordinate system is defined by applying astrometric techniques to direct images. These are concatenated with `fits2ccd`.

celestial The relation between FITS pixels in a direct image and celestial coordinates is defined by `fits2boresight` plus additional WCS keywords giving Euler angles of celestial orientation information from the telescope pointing.

spectral Defining a WCS for multi-slit spectra is beyond the current scope of FITS conventions. It will require the use of a locally-defined binary table.

5. Slitmask Schema for Design, Manufacturing, Observation and Archiving

The characteristics of DEIMOS slitmasks are described with seven normalized tables in a database. The observer creates mask designs using software that produces a FITS file containing binary tables. The tables in the FITS file are isomorphic with their counterparts in the relational database of all slitmasks. FITS serves as an expedient and self-documenting means of transporting subsets of the database.

The observer submits the FITS tables via WWW to request manufacture of the slitmask. Upon completion each slitmask receives a unique barcode which is added to the records in the database. When masks are loaded, DEIMOS scans barcodes, queries relevant data, writes records into FITS binary tables, and appends those to appropriate FITS image files. The tables are listed below.

ObjectCat Names of celestial objects and their astrometric properties

MaskDesign Name of a mask design plus its celestial pointing characteristics

DesiSlits Celestial coordinates of slitlets

SlitObjMap One slitlet may contain more than one object

MaskBlu "Blueprint" is "Design" corrected for distortion and refraction on its date of use

BluSlits Blueprint coordinates of slitlets on the metal of the mask

Mask Manufacturing data and barcode number for each particular mask

Further details of DEIMOS operation and data structures are available via http://deimos.ucolick.org/.

References

Calabretta, M. R., & Greisen, E. W. 2002, A&A, 395, 1077

Faber, S. M., et al. 2002, in SPIE Proc., Vol. 4841-186, in press

Greisen, E. W., & Calabretta, M. R. 2002, A&A, 395, 1061

Joye, W., & Mandel, E. 2000, in ASP Conf. Ser., Vol. 216, Astronomical Data Analysis Software and Systems IX, ed. N. Manset, C. Veillet, & D. Crabtree (San Francisco: ASP), 91

Pence, W. 1999, in ASP Conf. Ser., Vol. 172, Astronomical Data Analysis Software and Systems VIII, ed. D. M. Mehringer, R. L. Plante, & D. A. Roberts (San Francisco: ASP), 487

Tody, D., & Valdes, F. G. 1998, in SPIE Proc., Vol. 3355, 497