

## An Image Evaluation System for Subaru Telescope Data Archive

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### Abstract

We devised a data format of a “Quick Look Information File (QLIF)” which carries various information extracted from observational data, and have developed a QLIF creation/browsing system, named “GYOJI”, for the evaluation of data obtained with Subaru Telescope. A QLIF accommodates a two-dimensional image, typical profiles sampled from the image, one-dimensional traces of spectra, and various pixel statistics. All observational data of the telescope have a corresponding QLIF, and an observer or a user of the archive system is able to inspect the scientific information and the data quality from the QLIF without accessing the original data of complex structure and a huge size. Compared with the preview systems implemented in the astronomical archive systems in the world, GYOJI is superior in providing much information required for the data evaluation. This system has already become an indispensable part of the archive system of Subaru Telescope, and we think that this system has a great potential for the promotion of database astronomy.

Key words: astronomical data bases, archives, image processing.

### 1. Introduction

Recent development of large telescopes and observational instruments enables us to obtain data full of scientific information, and astronomical data archives become more important than ever. It is possible that astronomically important information, which the observer did not expect in the data and remains unused, can be found from the archive. Archival data can also be used for comparison/cross-identification of objects, detection of time variation, statistical analysis, etc.

When retrieving data from an archive system, a preview system is useful for the selection of the observational data visually. Most data archive systems of the world's major telescopes provide a size-reduced image of the original data. Such a simple two-dimensional image is, however, often useless for data selection and evaluation. For example, we need spectral traces for spectroscopic data. For calibration data, we cannot judge if the data is applicable to the data reduction from the size-reduced image. Only the preview system at the

Canadian Astronomy Data Center (CADC) provides spectral traces extracted from the observational data (Durand et al. 1992, Crabtree et al. 1994, Crabtree et al. 1996)<sup>#</sup>. No archive system provides information of the calibration data in a comprehensive way to date.

We introduce in this paper a data format of a “Quick-Look Information File (QLIF)” which holds various information of the observational data. A QLIF carries a size-reduced two-dimensional image, typical profiles sampled from the two-dimensional image, traces of spectra, and statistical information, all of which are essential for evaluation of the original data. If a QLIF is created from the original data in advance, the preview system can extract required sets of information quickly and easily from the QLIF and provides necessary information to the archive users.

We applied this idea to the archive system of Subaru Telescope (Kaifu 1998). The observational data produced with the telescope are large in size and are complex in structure, which cannot be easily browsed with existing viewers. Therefore the QLIF, which is compact

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and contains various information of the original data, is useful for the quick browse and evaluation of the observational data. We have developed the QLIF creation /browsing system named as "GYOJI" for the archive system of the telescope. GYOJI creates a QLIF for each of the observational data taken with the telescope in advance, and extracts required information to display it on web browsers upon request. The GYOJI system has already installed on the archive system of the telescope, and has been in operation since December 1999<sup>†</sup>.

In section 2, we show the overall structure and the data processing of GYOJI. In section 3, the format of QLIFs is explained. The implementation of GYOJI is shown in section 4. The summary and future plans appear in the final section.

## 2. System Outline

### 2.1 Data processing in STARS and GYOJI

For the data archive system of Subaru Telescope, STARS (Subaru Telescope data ARchive System; Takata et al. 2000) was developed and has been in operation since the first light. All data are stored in STARS, through which all observers retrieve their own observational data using its WWW-based interface. STARS is designed based on MOKA2<sup>‡</sup> (Mitaka-Okayama-Kiso Archive system 2, Nishihara et al. 1997, Yoshida 1997) with the functions of the on-line data registration and the user authentication to constrain the data access to qualified users.

The overall structure of GYOJI installed on STARS is illustrated in figure 1. The raw data obtained with Subaru Telescope at the summit are transferred to the Hilo base facility immediately after the observation, and are stored into a magnetic tape library. At the same time, the primary header and the ATE, if exists, are extracted and are stored separately as Header Information (HDI) files and ATE files, respectively. Then a new entry is created in the database for each of the observational data, in which the information of the observation extracted from the HDI files is registered.

GYOJI consists of two components which are independent of each other. After the observational data are transferred from the summit, "Quick-look information file Producer" (QP) creates a QLIF for each of the original observational data and stores it in a hard disk. Upon request from an archive user, "Quick-Look Information Server" (QLIS) extracts necessary information

from the corresponding QLIF and displays it on the web browser.

### 2.2 Supported instruments

GYOJI currently supports three optical instruments of Subaru Telescope, Suprime-Cam (SUbaru PRIME-focus CAMera), HDS (High Dispersion Spectrograph) and FOCAS (Faint Object Camera And Spectrograph), for which we present the overview here. The detailed description of the instruments of Subaru Telescope appears in Iye (1998) and the references therein.

**Suprime-Cam** is an imaging camera mounted at the prime focus of the telescope. The field of view covers about 30' in diameter with 10 CCDs, each of which produces data with a size of about 16MB.

**HDS** is an echelle spectrograph with a spectral resolution up to 100,000, mounted at one of the Nasmyth foci. Several tens of spectra separated by a cross-disperser are obtained with two CCDs.

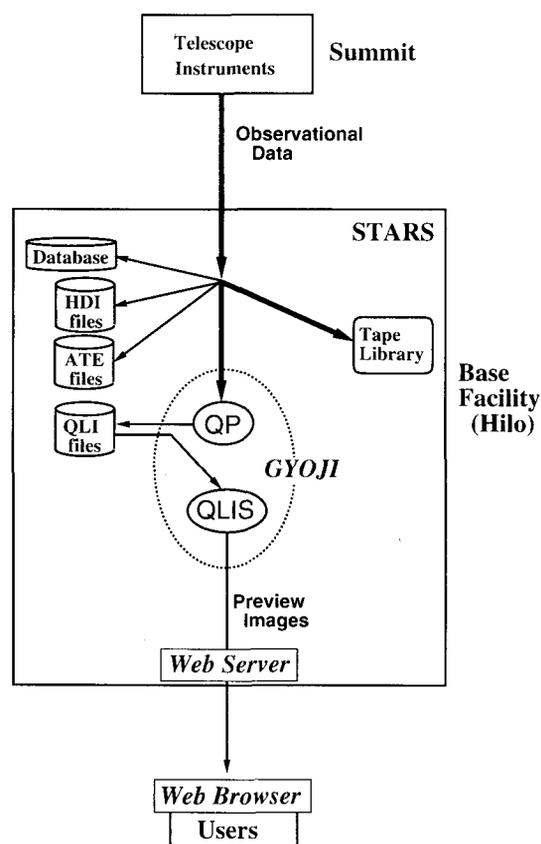


Fig. 1. The system overview of GYOJI is illustrated. The original data are transferred from the summit and stored in the tape library. HDI files and ATE files are extracted from the original data and stored separately in the hard disks. QP generates the QLIFs from the original data and stores them in the hard disks, and QLIS creates a preview image from the QLIF and delivers it to the user via the web server.

<sup>†</sup>Only data for which the proprietary period is expired are accessible with this system. The first data will be available in 2002.

<sup>‡</sup><http://moka.nao.ac.jp>

**FOCAS** is a multi-purpose camera equipped with two CCDs, which is mounted at the Cassegrain focus. In the multi-slit spectrograph mode, spectra of about 100 objects can be obtained in one exposure with a resolution up to 2000.

All observational data are generated in FITS format (Wells, Greisen & Harten 1981). The data of FOCAS and HDS have an ASCII Table Extension (ATE; Harten et al. 1988), which holds the information on the positions of the spectra in the two-dimensional image and the wavelenghts covered. We participated in the settlement of the rules of FITS header keywords and the format of the ATE, which are essential to GYOJI.

### 3. Format of the QLIF

As described in the previous section, Suprime-Cam produces data of a large size, and the data of HDS and FOCAS have multiple spectra in a single image frame. The QLIF should be designed to be compact for the quick browse, but can contain many types of the information to demonstrate the essential properties of the original data.

The format of the QLIF is based on the FITS framework, which is commonly used in astronomy and is able to store various types of information in arbitrary number of extensions. Currently GYOJI supports three optical instruments as discribed in section 2.2, and we plan to incorporate other instruments in the GYOJI system. In order to avoid entire modification of the system when a new instrument is commissioned, we classified observational data into three categories. For each of them, we designed the format of the QLIF as follows. We also summarize the structure of the QLIF in figure 2.

**I-type QLIF**—Suprime-Cam and the imaging mode of FOCAS, etc., produce simple two-dimensional image. Archive users can evaluate their quality by visual inspection of the image. The corresponding QLIF consists of a single Header Data Unit (HDU) which stores an image with a reduced size.

**S-type QLIF**—For spectral data obtained with HDS and the spectroscopy mode of FOCAS, etc., spectra extracted from the original two-dimensional image are quite useful for the evaluation of the quality. The QLIF has an image with a reduced size in the primary HDU, and the one dimensional spectra extracted from the original image in the binary table extension (BTE; Cotton, Tody & Pance 1995).

**C-type QLIF**—For calibration data such as bias frames, dark frames, etc., archive users are not interested in the details of the original data usually.

Rather, statistical information of the image is considered to be useful for the quality evaluation. The primary HDU of the QLIF is a three-dimensional array of statistical values calculated from the original image. Typical profiles extracted from the original data are also stored in the BTE.

#### 3.1 Data stored in the primary HDU

##### (1) Common FITS keywords

The FITS header keywords adopted for the primary HDU of QLIFs are different according to the QLIF type, and we list all of them in tables 1–3. The keywords in table 1 are common for all QLIF types.

All QLIFs have the copies of the header keywords OBJECT, DATE-OBS, DATA-TYP, FRAMEID, EXP-ID, OBS-MOD, PROP-ID, INSTRUME of the original data.

For all QLIF types, global statistics of pixel values, such as the mean, the standard deviation, the minimum and the maximum are calculated and are stored in the primary header keywords PIX-MEAN, PIX-STDV, PIX-MIN and PIX-MAX, respectively. When the mean and the standard deviation are calculated, dead pixels and cosmic ray events are eliminated by iterations of the  $\sigma$ -clipping algorithm. The last two numbers of PIX-SPAR indicate the  $\sigma$ -clipping level and the number of the iterations.

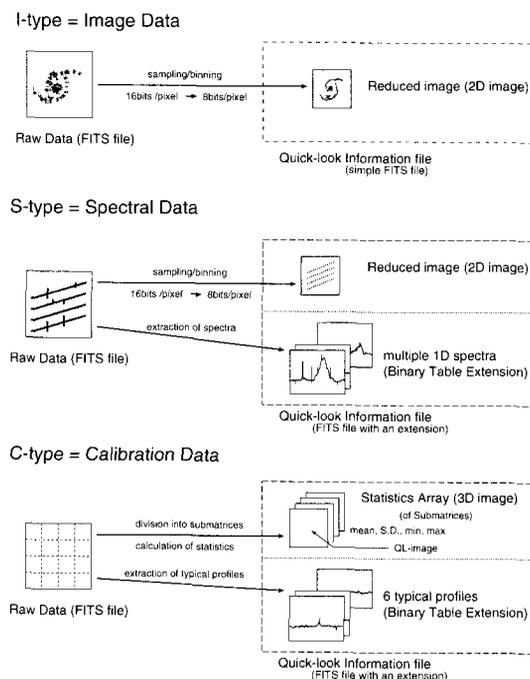


Fig. 2. Three types of QLIF formats and corresponding observational data are illustrated. QLIF files of I-, S- and C-type are created from image data, spectral data, and calibration data, respectively.

## (2) Image with a reduced size

For I- and S-type QLIFs, the original image is reduced in size and is stored in the primary HDU with the additional keywords listed in table 2. The reduction of the size is carried out in the following two steps.

1. The number of the rows and the columns of the original image is reduced by sampling or binning.
2. The pixel values of the original image are rescaled and converted from 16 bit integers to 8-bit unsigned integers.

## (3) Statistics array

The data in the primary HDU of a C-type QLIF is a three-dimensional array of statistical values which coarsely represent the original image. We refer this array as 'statistics array'. The original image is divided into submatrices of  $64 \times 64$  pixels, and the mean, the standard deviation, the minimum and the maximum values in each submatrix are calculated and are stored in the three-dimensional array by IEEE floating numbers. The first and the second axes of the array indicate the spatial position and the third axis corresponds to the different statistical plane. We correspondingly introduce the FITS keywords listed in table 3 in the primary header of the QLIF for the description of the statistics array.

## 3.2 Data stored in the binary table extension

The S- and C-type QLIFs have a BTE, where one dimensional data are stored as follows.

**S-type** The traces of spectra are extracted from the original FITS image and are stored in the BTE. The positions of the spectra in the original image and their wavelengths are taken from the values described in the ATE of the original data.

**C-type** Six profiles along equally spaced rows and columns are sampled from the original image and are stored in the BTE.

The BTE consists of 9 columns described in Table 4. The columns  $W_0$  and  $dW$ , the wavelength of spectra at the first pixel and the pixel-to-pixel increment of the wavelength, respectively, are not used for the C-type QLIF. The last column is a variable-length array of 2-byte integers, with which the spectra/profiles are stored effectively.

## 4. Implementation

## 4.1 Quick-look information file Producer (QP)

The program QP has been developed to create QLIFs from the original FITS-formatted image files. QP is written in Fortran90 with the CFITSIO library (Pence 1999). The flow of the program is as follows.

1. QP first determines the type of the QLIF from the FITS header keywords of the original image.
2. An image with a reduced size (for I- or S-type) or a statistics array (for C-type) is created as the primary data.
3. Typical profiles (for C-type) or spectra (for S-type) are extracted and are stored in the BTE as variable

Table 1. The list of common FITS header keywords used in all types of QLIFs.

Keyword	Value (example)	Meaning
(1) SIMPLE		T standard FITS format
(2) BITPIX		8 number of bits per data pixel
(3) NAXIS		2 number of data axes
(4) NAXIS1		489 length of data axis 1
(5) NAXIS2		1023 length of data axis 2
(6) EXTEND		T there may be extensions
(7) OBJECT	'NGC3314'	object name
(8) DATA-TYP	'OBJECT'	data-type (OBJECT, BIAS, etc.)
(9) FRAMEID	'SUPA0003457'	frame-ID
(10) EXP-ID	'SUPE0003457'	exposure-ID
(11) OBS-MOD	'Imaging'	observation mode
(12) PROP-ID	's98012'	proposal ID
(13) DATE-OBS	'1999-01-30'	observation date
(14) INSTRUME	'SuprimeCam'	name of instrument used
(15) PIX-SPAR	'512 1534 1024 3069 3.00 1'	global statistics parameters
(16) PIX-MEAN		2563.63 mean in statistic area
(17) PIX-STDV		15.26 std. dev. in statistic area
(18) PIX-MIN		2401.00 minimum in statistic area
(19) PIX-MAX		3064.00 maximum in statistic area
(20) DATE	'1999-06-29T07:15:58'	QLIF creation date
(21) QP-VER	'version 1.0629'	QLIF-producer program version
(22) QLI-MODE	'I'	QLIF-type (C/I/S)
(23) END		end of the header

Table 2. The list of FITS header keywords used in I- and S-type QLIFs only.

Keyword	Value (example)	Meaning
(24) RA	'10:37:12.611'	right ascension
(25) DEC	'-27:40:58.88'	declination
(26) CRVAL1	159.30382	reference point value in axis 1
(27) CRPIX1	-300.75	reference pixel in axis 1
(28) CTYPE1	'RA---TAN'	pixel coordinate system in axis 1
(29) CDELT1	-3.3331999E-05	pixel size in axis 1
(30) CRVAL2	-27.68421	reference point value in axis 2
(31) CRPIX2	49.00	reference pixel in axis 2
(32) CTYPE2	'DEC--TAN'	pixel coordinate system in axis 2
(33) CDELT2	3.3331999E-05	pixel size in axis 2
(34) RED.PAR	'2 2 4 4Sampling'	parameters for image reduction
(35) BSCALE	1.20015	scaling factor of pixel value
(36) BZERO	2521.91772	offset of pixel value

Table 3. The list of FITS header keywords used in C-type QLIFs only.

Keyword	Value (example)	Meaning
(37) NAXIS3	4	length of data axis 3 (fixed)
(38) CTYPE3	'STATISTICS'	data type in axis 3 (fixed)
(39) PLANE1	'mean'	values in 1st plane (fixed)
(40) PLANE2	'standard deviation'	values in 2nd plane (fixed)
(41) PLANE3	'minimum'	values in 3rd plane (fixed)
(42) PLANE4	'maximum'	values in 4th plane (fixed)
(43) OS-POS	'R'	position(s) of oversecan pixels

Table 4. The structure of the binary table extension.  $W_0$  and  $dW$  are assigned but not used for C-type data. One-dimensional spectra for the S-type QLIF, or profiles for the C-type QLIF are stored in the variable-length array with 2-byte integers.

parameter	content	unit	format
$X_0$	X-coordinate of the starting point in original data	pixel	floating
$Y_0$	Y-coordinate of the starting point in original data	pixel	floating
$dX$	sampling interval in X-direction	pixel	floating
$dY$	sampling interval in Y-direction	pixel	floating
$W_0$	wavelength in starting point	nm	floating
$dW$	wavelength resolution	nm	floating
Order or ID	order of spectrum or identifier of profile		integer
$np$	number of data points in a spectrum or profile		integer
profile/spectrum	spectrum or profile itself		integer array

length arrays.

4. The process log is generated and a status code is returned to `stdout`.

The status code is marked in the STARS database and is used to check if the QLIF is correctly created.

## 4.2 Quick-Look Information Server (QLIS)

QLIS is a set of server programs which extracts information from the corresponding QLIF and transfers it to a remote web browser. The programs are mostly written as a Java Servlet which we chose because it makes easier to extend the function of the QLIS. In fact, we have implemented the function to create a mosaicked image from a set of QLIFs of a single exposure, which utilizes the Java JDBC function (see below).

QLIS has two image modes, FITS mode and GIF mode. In FITS mode, QLIS simply reduces the size of the QLIF by sampling the pixels and transfers it to the user's web browser. The FITS image is displayed on the web browser with a viewer "NAOimage" (named after one of the authors of this paper, NAOki Yasuda: Baba et al. 1999, Baba et al. 2000), coded as a Java Applet. GIF mode is provided for web browsers which do not support Java Applet, or for client machines which cannot run NAOimage smoothly. QLIS converts the QLIF into a preview image in GIF format to show it on the web browser directly. Graphical web browsers usually support GIF format, and the size of a GIF image is usually much smaller than that of a FITS image by virtue of the built-in compression method, which ensures fast data transfer.

We show the preview images of object frames taken by Suprime-Cam (I-type), HDS, and FOCAS (S-type) displayed in FITS mode with NAOimage in figures 3–5. The image in the primary HDU is displayed in the main panel, with a panner and a magnifier in the sub-panels. The coordinates and the pixel value at the cursor position are also shown. The user can change the

graylevel or the colormap, and magnify the image in the main panel. A profile along an arbitrary line or one of the spectra stored in the BTE can be plotted in another window. For Suprime-Cam, we implemented the "exposure view" mode, with which a mosaicked image composed of the frames taken by a single exposure is displayed (figure 6). The exposure ID is written in the FITS header of the QLIF, so that the collection of the QLIFs of the same exposure are searched from the STARS database with the Java JDBC application, and the mosaicked image is created by aligning them according to the World Coordinate System written in the FITS header. In figure 7, a preview image of a calibration data of Suprime-Cam (C-type) is shown in FITS mode. Any plane of the statistics array can be displayed by pressing the key assigned to each statistical plane. In GIF mode, a preview image composed of a reduced image and/or spectra/profiles stored in the BTE can also be displayed (figures 8, 9). As shown in figures 3–9, a menu of the user's selection is displayed in the left frame of the browser, with which the user is able to specify the format and the size of the image, and the IDs of the spectra/profiles to be shown.

## 4.3 QP and QLIS implemented on STARS

QP is triggered once a day by UNIX `cron` on a Sun 167MHz UltraSparc workstation, and produces QLIFs for the data obtained during the night before. It takes about 10 seconds to create a QLIF with the sampling method for the size reduction, which is fast enough to process all observational data of a night. For the primary image of the I- and S-type QLIFs, the rows and columns are reduced to the quarter of the original image. This is because the disk space available was assumed to be 140GB in 3 years, and assuming that observational data of about 300~400 frames are produced in one night on average, the size of a QLIF is figured out to be smaller than 300kB. After `gzip` compression, a QLIF becomes small enough to satisfy this storage limit, keeping enough resolution for the quality evaluation of the original data.

QLIS is invoked in GIF mode as a default by clicking the "QL-IMG" button on the query result page of STARS (figure10). Then a grayscale GIF image is created with the default size and the gray level, and is displayed on the web browser.

## 5. Summary and Future Plan

We devised a data format of Quick Look Information File, which is designed to be compact but is able to carry various information of observational data. The

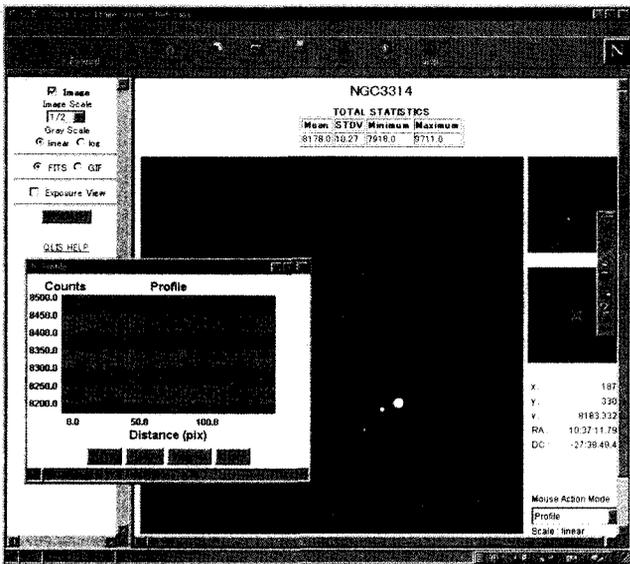


Fig. 3. The preview image of data taken by Suprime-Cam (I-type) displayed in FITS mode. In the right frame, the main panel, the panner and the magnifier are displayed. The coordinates and pixel values at the cursor position are also shown. The menu of the user's option is displayed in the left frame. A profile taken along the line drawn in the main panel is plotted in the other window.

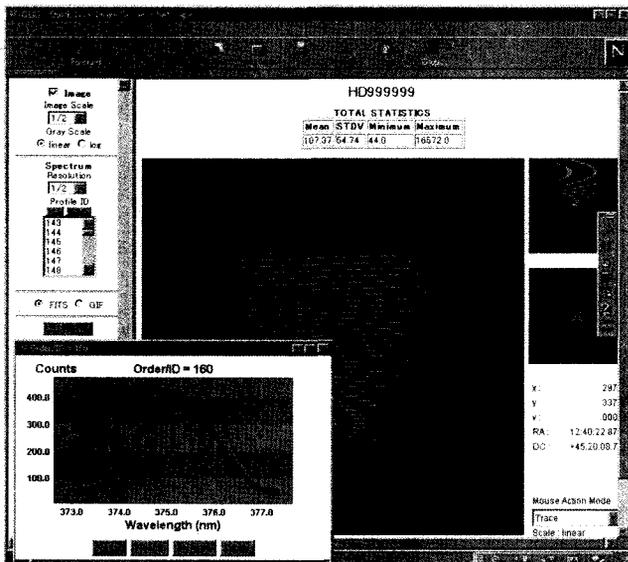


Fig. 4. The preview image of data taken by HDS (S-type) displayed in FITS mode. In the main panel, several tens of spectra are shown, one of which is extracted and displayed in the other window.

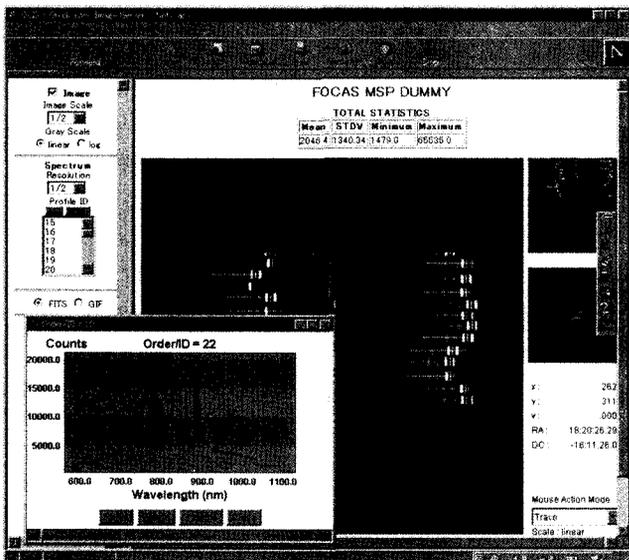


Fig. 5. The preview image of data taken by FOCAS (S-type) displayed in FITS mode. The spectra of multi-slit observation is shown in the main panel, and one of the spectra is extracted and displayed in the other window.

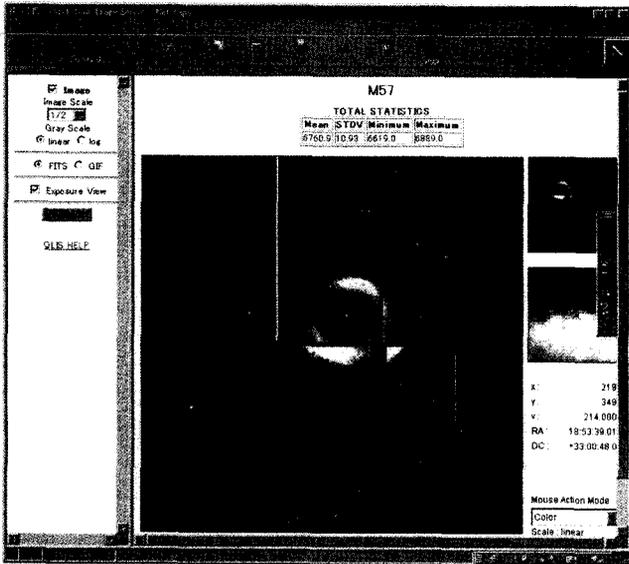


Fig. 6. The preview image of data taken by Suprime-Cam in "exposure view" mode. The mosaicked image is created from the frames taken in a single exposure.

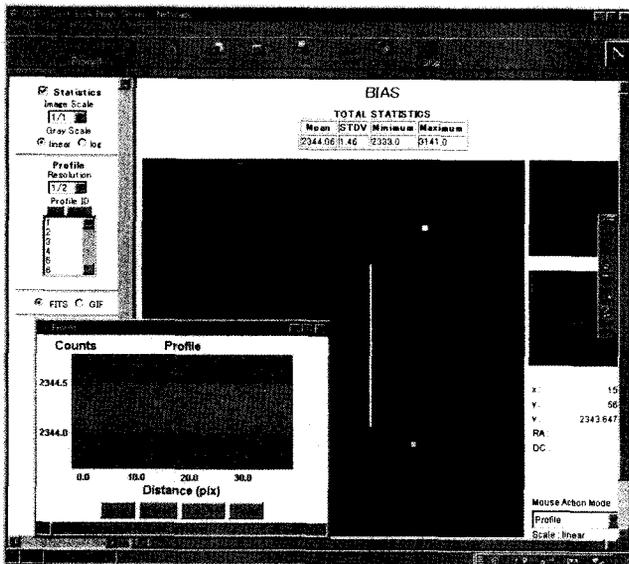


Fig. 7. The preview image for Suprime-Cam calibration data (C-type) displayed in FITS mode. The statistical plane can be selected by pressing the assigned keys. The profile along the line drawn in the main panel is also shown in the other window.

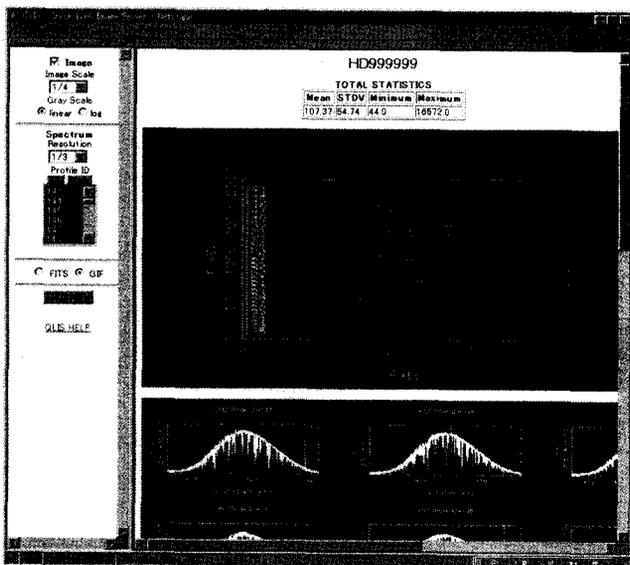


Fig. 8. The preview image for HDS (S-type) displayed in GIF mode. The spectra are plotted by selecting their ID number in the "Profile ID" shown in the left frame of the browser. The ID numbers are also shown in the reduced image in the right frame for the identification.

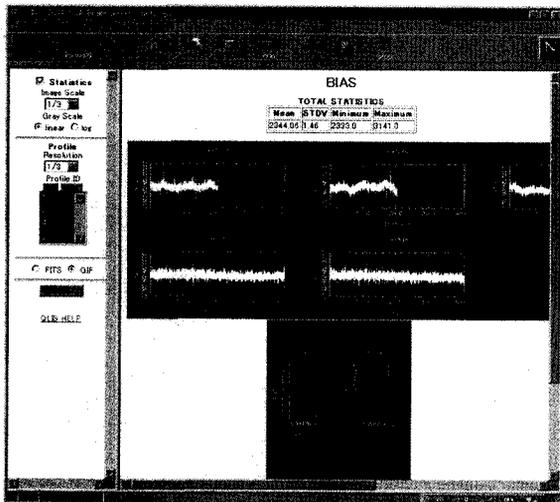


Fig. 9. The preview image for Suprime-Cam calibration data (C-type) displayed in GIF mode. The profiles are displayed by selecting their ID numbers in the "Profile ID" shown in the left frame of the browser.

QLIF creation/browsing system, GYOJI, is developed for the archive system of Subaru Telescope. The GYOJI system creates a QLIF for each of the observational data, and upon the request from an archive user, GYOJI extracts requested information from the QLIF and displays it on the user's web browser. Compared with other preview system implemented in the archive systems of the world's major telescopes, GYOJI provides much more information and makes the data evaluation far easier. We still continue improvement and enhancement of the GYOJI system, and conceive the following functions to be added.

As mentioned previously, GYOJI currently does not support infrared instruments. This is because the creation of a QLIF needs complicated processes for these instruments. For optical CCDs, we can create a QLIF of enough quality on frame by frame basis. On the other hand, we are not usually able to create a QLIF of sufficient signal-to-noise ratio from one frame for infrared data. We need to stack many frames together, subtract bias and dark frames, and do flat-fielding and sky subtraction to create a QLIF of enough quality. Namely, the creation of a QLIF needs a subset of the full data reduction for the infrared instruments. However, GYOJI currently has no means to get the information about the relations between the frames needed for the reduction, which will be supplied by SOSS (Subaru Observation Software System; Kosugi et al. 2000) as the "Observational Data Set" (Kosugi et al. 1998). We plan to support the infrared instruments after the settlement of the specification of the Observational Data Set and the implementation of the reduction engine, DASH (Dis-

tributed Analysis System Hierarchy; Yagi et al. 1999).

When one selects data from the archive system, it would be convenient to view many frames at one time. Thumbnail images are useful for this purpose, and we plan to implement the function to exhibit thumbnail images of selected frames.

The statistical values stored in the header of the QLIFs are useful for monitoring the instruments. The statistical values of bias/dark frames vary when the condition of the instrument changes. Therefore, we will be able to find an accident of the instrument by on-time monitoring the statistical values. To enable the on-time monitoring, a QLIF should be created just after the frame is taken and transferred to the Hilo facility on-line. Currently the CPU which drives the QP does not have enough power and may cause trouble of the data flow, so the QP is triggered once a day by UNIX cron. We expect that the situation will be changed after the system replacement.

QLIFs are not used only for the evaluation of the archival data. ISAS (the Institute of Space and Astronomical Science) and NAOJ (National Astronomical Observatory of Japan) have developed an astronomical image server named MAISON (Multiband Astronomical Imaging Service ON-line, Watanabe et al. 2000),<sup>§</sup> which overlay several images retrieved from different astronomical image servers. For example, one can view

Fig. 10. The query result page of STARS. The information which corresponds to each observational frame is shown in each row. QLIS is invoked by clicking the "QL-IMG" button.

<sup>§</sup><http://maison.isas.ac.jp>

an optical image on which a contour plot of a radio or an X-ray image is superposed. MAISON needs to retrieve the images from the image servers quickly, but does not require an image of a high resolution. QLIFS created by GYOJI are very compact and easy to access compared to the original data, so that GYOJI is suitable for one of the image server of the MAISON system.

Comprehensive use of archival data, including those of Subaru Telescope, will lead us to a new aspect of the universe. We believe that GYOJI will contribute to investigations which exploit archival data and promote astronomical researches with archives and databases.

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