Development of an Astronomical Data Archive System

Ph.D. Thesis

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Extended Abstract

We have developed a data archive system for the optical telescopes of Okayama Astrophysical Observatory and Kiso Observatory. The system, called MOKA (Mitaka Okayama Kiso Archive system), is not only the first network-accessible astronomical archive system in Japan but also the prototype of the data archive system of Subaru Telescope.

Archival data contain much information besides that the observer intends to extract. It is often that an important object is found into the image, or an unimaginable phenomenon is caught in the image by chance. It is certain that comparing data obtained in various wavelength regions presents new prospects of the object. Archival data of Subaru Telescope, which mounts the wide-field imaging camera and other characteristic instruments, are expected to bring many fruitful results for us.

The archives for space mission data exist since 1970's, but it is in recent years that the construction of archives for ground-based telescopes has begun. The most crucial reason is the difficulty in reuse of the data, which is caused by the non-uniformity of the data quality. The observing procedure of ground-based observations is not definite but is freely determined by each observer, and the configuration of observational instruments is often changed. Moreover, atmospheric environment, such as weather condition, seeing, etc., also influences the quality of ground-based observational data very much. Hence, in order to retrieve valuable data quickly and to analyze them with high precision, it is essential to evaluate the data quality and to examine the environment of the observation.

There exist several archive systems which provide the shrunk preview images of the CCD frames and the atmospheric parameters at the observation, but the functions are insufficient for evaluating the data quality or for examining the observational environment. In order to inspect an imaging frame in detail, it is desired to show the image with various tonal ranges. Also, for the examination of a spectroscopic frame, the function of extracting the spectrum from the frame is essential. For the environmental information, an archival user needs the time variation of meteorological parameters rather than the parameters at a point in time. The above functions are indispensable for ground-based data archives to make its scientific productivity maximum. That is why we have developed a new data

archive system.

The functions of MOKA are provided by the user interface, which allows users to have access to MOKA from various computer platforms through the WWW (World Wide Web). Using the user interface with a WWW browser, archival users can access data objects of MOKA, which are a header information database, header information (HDI) files, quick-look image (QLI) files, and weather/sky-monitor databases, etc.

The most characteristic feature of MOKA is the highly functional user interface for evaluating the data quality and examining the observational environment. The QLI viewer shows the quick-look image of a CCD frame with the user-adjustable tonal range and with the profile along an arbitrary row or column. Those functions are helpful for inspecting details of the images and the spectra, and indispensable for evaluating the data quality and for picking up data for request. The QLI viewer is a Java applet, so that it needs no installation onto any client computers and runs on most of WWW browsers that support Java. The QLI viewer is the only previewer of the archive systems in the world which realizes the above-mentioned functions on any computer platforms.

The meteorological data viewer and the night-sky image viewer are invoked from each CCD frame in the result list of the search and are used to examine the observational environment. The meteorological data viewer displays the data of six hours around the observation time of the frame, and the night-sky image viewer shows the image at the closest time of the observation. Since the atmospheric conditions affects observational data very much, the examination of the atmospheric variation around the time of the observation is essential to evaluating the data quality. MOKA is the only data archive system in the world which integrates the environmental data with the observational data.

The Java technology is adopted not only for the above three viewers but also for the most part of the user interface of MOKA. Java realizes interoperability beyond the difference of computer platforms, and reduces redundant network traffic.

There are several multi-mode, multi-spectral instruments planned for Subaru Telescope. Though the identification and the retrieval of calibration frames are the very essential procedure for an archival user, the relation of the calibration frames with the object frames between the observational modes is very complex for multi-mode instruments, since the calibration frames are often used in common beyond the observational mode. We have studied the archive system for OOPS (Okayama Optical Polarimetry and Spectroscopy System), a multi-mode, multi-spectral instrument of Okayama Astrophysical Observatory. The table structure of the database is made use of by STARS (Subaru Telescope ARchive System) for the same type of instruments of Subaru Telescope. The most of the user interface of STARS is also made on the basis of MOKA. MOKA has greatly contributed to the rapid construction of STARS, which can start its operation from the beginning of the observation. The development of STARS, such as of preview system, is still continued on the basis of the experience of MOKA.

As for the contributions to astronomical researches, there have been several papers on galactic astronomy that utilize MOKA. The header information database is also used by the German NEO (Near Earth Objects) survey project, DANEOPS, whose research is in progress. Moreover, there are many accesses in the season when the observatories call for proposals, since many astronomers examine the feasibility of their observation plan by the use of MOKA.

The development of MOKA with the actual data of Okayama and Kiso observatories has revealed various important matters for constructing data archives. One is the header description of observational data, and we have determined the standard of the description of FITS keywords in cooperation with the FITS committee of Japan. The data headers of SNG and 1K CCD imager have been revised and unified. The new instruments of both observatories are also being developed based on the standard. The dictionary of the header keywords has also been prepared and used for the observational instruments of Subaru Telescope. We have further discussion on the quick-look images and the environmental data for the future development of the ground-based data archives, which will certainly broaden the horizon of new observational astronomy.

Contents

1 Introduction

From ancient times, astronomers have received benefits from a pile of observational records accumulated by predecessors, and have revealed many facts including phenomena in a long time scale. A Greek astronomer, Hipparchus, discovered the precession of the equinoxes, comparing his positional observation with previous ones. An English astronomer, Edmund Halley, found the proper motions of Aldebaran, Arcturus, and Sirius, comparing the positions at the time with ancient records.

The invention of photography and its application to the astronomical observation in the mid-19th century was epoch-making for observational astronomy. Photographic observations make objective records of astronomical phenomena and enable another astronomer to verify and reanalyze the object independently. The amount of the information recorded on a photographic plate is enormous, and the observer does not always extract all of them. In order to answer the request for reuse, most of observatories had prepared plate catalogs, and many astronomers have obtained fruits from the archives.

In the late 20th century, the digital technology has remarkably developed, and the digital imaging devices, such as CCD, took the place of the photographic plates. The processing speed and the storage capacity of a computer also becomes faster and larger, and data archives of these days are inconceivable without the aid of computers, which make various data processing possible and increase the availability of archives. The larger the amount of observational data becomes, the more the importance of data archives is recognized in modern astronomy. Data archives are a treasury of astronomical information, and keeping observational data in archives is a duty of the present astronomers to the future astronomers.

1.1 Astronomical studies with data archives

In recent years, the use of large-format CCDs becomes popular in imaging observation, and a high-dispersion spectrograph of a wide spectral range such as the echelle spectrograph becomes popular in spectroscopic observation. The amount of information contained in a CCD frame remarkably increases, but the observer is supposed to extract only a part of the information. There exist many objects and spectral features waiting for research in data archives.

For example, comparing images at different epochs will reveal a new appearance of objects such as the variabilities and the movements, and comparing spectra will reveal physical variations of objects. Even for a non-variable object, it is possible to obtain a very high S/N image or spectrum by summing up the data together, if it has been observed many times. A high S/N composite image brings us information on fainter objects in deeper space, and a high S/N composite spectrum shows us weaker spectral features. Comparing data obtained in various wavelength regions, such as infrared, radio, X-ray, will certainly present a new prospect of the object.

Data archives are used not only for getting scientific results but also for studying the feasibility of an observational plan or for engineering of an instrument. Parameters of previous observations are very instructive for planning a new observation. Monitoring conditions of observational data with the header values helps to analyze the behavior of an instrument and to identify the origin of errors.

1.2 Astronomical data archive systems for space and ground-based observations

Archive systems for space missions have been developed and operated since 1970's, much earlier than those for ground-based telescopes. The data archive of International Ultraviolet Explorer (IUE) is one of the oldest archives, and the ESA/IUE Observatory has established final calibration procedures and starts the data distribution at `http://iuearc.vilspa.esa.es/` (De La Peña et al. 1994). The archive system of Hubble Space Telescope (HST), which is developed at Space Telescope Science Institute (STScI), is the most productive system in the world, such that about 10% of the papers using HST observations are written with the data from the archive (Long et al. 1994, Travisano and Richon 1997; `http://archive.stsci.edu/`). The observation from space is characterized by (1) the complete and fixed design of data structure including observational status and (2) the definite procedure of the observation. Therefore data archives can be developed easily, and can achieve high scientific productivity because of the uniformity of the data quality.

On the other hand, as for ground-based telescopes, the construction of the data archives of 3–4m telescopes and the studies for 8m telescopes have started in 1990's. Table 1 shows a summary of major network-accessible data archives for ground-based telescopes. The conceptual design of the archive system for a large telescope was first done by Albrecht and Benvenuti (1994) and Albrecht et al. (1994) for the Very Large Telescope (VLT). Nishihara et al. (1994) also estimated the hardware requirements of the archive system for Subaru Telescope (Kaifu 1998), and our group continued research and development of the Subaru software system including the data archive system.

Through the operations of 3–4m telescope archives and planning of 8m telescope archives, it has been seriously recognized that data archives for ground-based observation cannot be as simple as space mission archives. For a ground-based instrument, the configuration is often changed and sometimes the data descriptions such as observation status are improved. Moreover, the observing procedure is freely determined by each observer, and hence the quality of the observational data is far from uniform. Atmospheric environment, such as weather condition, seeing, also influences the data quality. Therefore, the construction, maintenance, and the use of archives for ground-based observation are much more difficult than those for space observation.

There are a few archive systems which are trying to break these problems. For example, CFHT archive is the only system which provides preview images of ground-based observational data for quality evaluation. However, the system provides only a limited number of previews for a few instruments, and the quality of the preview images is very poor for inspecting original images. As for the observational environment, there are a few archives that store meteorological parameters in the database, such as CFHT, UKIRT, and NTT. Those systems, however, just show the parameters written in the data header of each frame, so that an archival user can hardly examine the time variation. It is the most urgent task for ground-based archive systems to solve these problems.

Table 1: Major network-accessible data archives for ground-based optical/infrared telescopes

observatory /telescope	organization	amount of raw data	URL (`http://`) reference
AAT	AAO	500GB	`site.aao.gov.au/AATdatabase/aat/` Lee and Stathakis (1994)
CFHT	CADC	≥200GB	`cadcwww.dao.nrc.ca/cfht/` Durand et al. (1994)
ING	Cambridge ASU	10–15TB	`archive.ast.cam.ac.uk/ingarch/` Zuiderwijk et al. (1994)
NTT	ESO/ST-ECF		`archive.eso.org/eso/archive.html` Albrecht et al. (1998)
UKIRT	Cambridge ASU		`archive.ast.cam.ac.uk/ukirt_arch/`
OAO	NAOJ/ADAC	8GB	`moka.nao.ac.jp` Horaguchi et al. (1999)
Kiso	NAOJ/ADAC	100GB	moka.nao.ac.jp Horaguchi et al. (1999)

1.3 Motivations and aims of the newly developed archive system

Before the development of the data archive system presented in this paper, there is no network-accessible data archive system in Japan. Our intention is to build a data archive system which provides all of the information which is held in the observational data obtained with Japanese telescopes. The present targets are the data of Okayama Astrophysical Observatory and Kiso Observatory. We also keep Subaru Telescope in view, since it mounts many attractive instruments, such as the wide-field imaging camera and the high-dispersion spectrograph (Iye 1998).

In order to realize the maximum scientific productivity for ground-based data archives, the assessment of data quality is essential for quick retrieval of valuable data from a mass of scientific exposures, since the data quality is not uniform. The examination of observational environment is also indispensable to retrieve and analyze observational data with high precision. Hence, we decided to develop an archive system with the functions of (1) inspection of quality for all kinds of observational data before retrieval, and (2) examination of the variation of observational environment.

In this paper, the author overviews the newly developed archive system, MOKA, in section 2, and describes its details and characteristics in section 3. The achievements and impacts of MOKA on astronomical research are shown in section 4, and we discuss the development of astronomical archive systems with our future plans in section 5. A summary is given in the final section.

2 System Overview

We have developed a data archive system, called MOKA (Mitaka Okayama Kiso Archive system), for observational data of Okayama Astrophysical Observatory and Kiso Observatory. MOKA is also developed as the prototype of the data archive system of the Subaru Telescope archive system. The author overviews the development, the structure and the elements with its characteristic functions in this section.

2.1 Development of the Mitaka Okayama Kiso Archive system (MOKA)

After the study of system requirements of Subaru Telescope, we started the development of MOKA in 1994, and the development has been advanced in three stages. In the first version (MOKA1; Horaguchi et al. 1994), we prepared a database of FITS header information, preview images, a previewer for the images, and a user interface using the data with high precision. Hence, we decided to develop an archive system with the functions of (1) inspection of quality for all kinds of observational data before retrieval, and (2) examination of the variation of observational environment.

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Motif library. We then added a function of data requests to the observatories and two external tools, a name resolver and a coordinate converter (Takata et al. 1995). However, at that time, the system was X-Window based, so that the user had to login to the UNIX server of MOKA, which is placed at the Astronomical Data Analysis Center (ADAC) of National Astronomical Observatory (NAOJ) at Mitaka, and to transfer the window to his/her terminal.

We replaced the interface with a WWW-based one using CGI (Common Gateway Interface) in the next version (MOKA2; Yoshida 1997; Nishihara et al. 1997). MOKA then became accessible from any client computers with a WWW browser through the Internet, and was officially announced to astronomical communities in 1996. However, the function for inspecting data quality is limited, as the quick-look image viewer runs only on a few computer platforms. Moreover, MOKA2 provides no information on observational environment such as the weather condition.

In order to realize the advanced preview function on any computer platforms and to provide practical information on observational environment, we started the development of MOKA3 in 1997. Most part of MOKA3 has been developed with Java (Horaguchi et al. 1999), so that the image previewer becomes platform-independent.

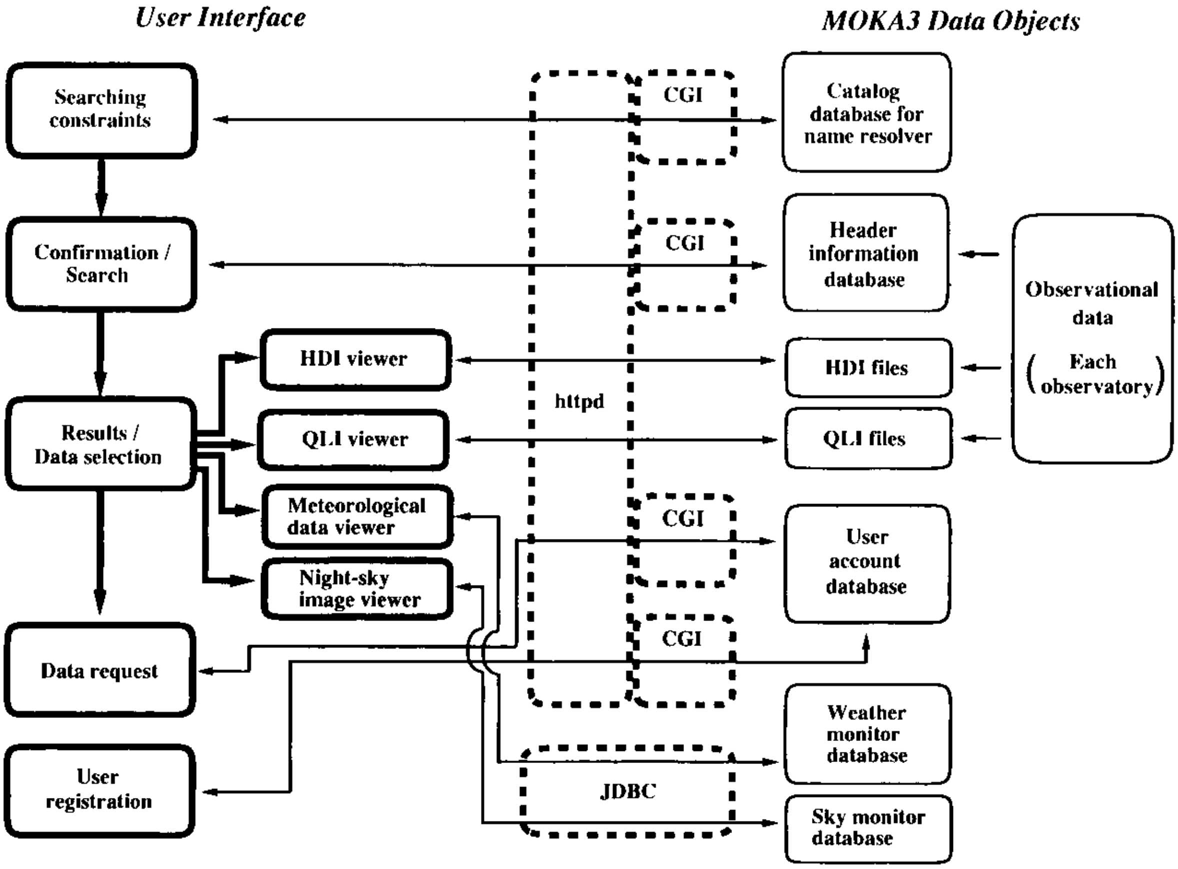


Figure 1: Schematic structure of MOKA3. The user interface is shown on the left-hand side (thick boxes), and the data objects are on the right-hand side (thin boxes).

2.2 Structure and the elements of MOKA

The structure of MOKA3 is illustrated in figure 1. The system consists of two parts, a set of user interface (left-hand side of the figure) and the data objects (right-hand side of the figure). The user makes access to the MOKA3 data objects by the user interface which is loaded to the WWW browser on his/her local computer.

The data objects of MOKA3 are:

(1) **observational data,**
raw observational FITS files stored and managed at each observatory
(2) **header information (HDI) files,**
containing the header part of the raw FITS files, and used to browse the whole of the header contents
(3) **a header information database,**
containing header keyword values extracted from the header information of all observational data, and used for the frame search
(4) **quick-look image (QLI) files,**
made from the data part of the raw FITS files, and used to evaluate image quality of the frame
(5) **weather/sky-monitor databases,**
containing meteorological data and night-sky images of Okayama Astrophysical Observatory, and used to examine the observational environment
(6) **a catalog database,**
containing data of astronomical catalogs, and used to resolve an object name to its celestial coordinates
(7) **a user account database,**
containing accounts of registered users who are authenticated to retrieve raw observational data, and used for user collation and data shipping

The user interface of MOKA3 consists of several pages and panels that are shown in the WWW browser, and of several viewers that appear as a new independent window (figures 2–4).

The details of the user interface and the data objects are described in section 3.

2.3 Solution to the difficulties in the archives for ground-based observations

The QLI viewer of MOKA3 has accomplished the first aim of the development, i.e., inspection of quality for all kinds of observational data before retrieval. The QLI viewer shows not only the preview image of an observational frame, but also the profile along an arbitrary row and column. A spectrum taken in a spectroscopic frame is easily checked

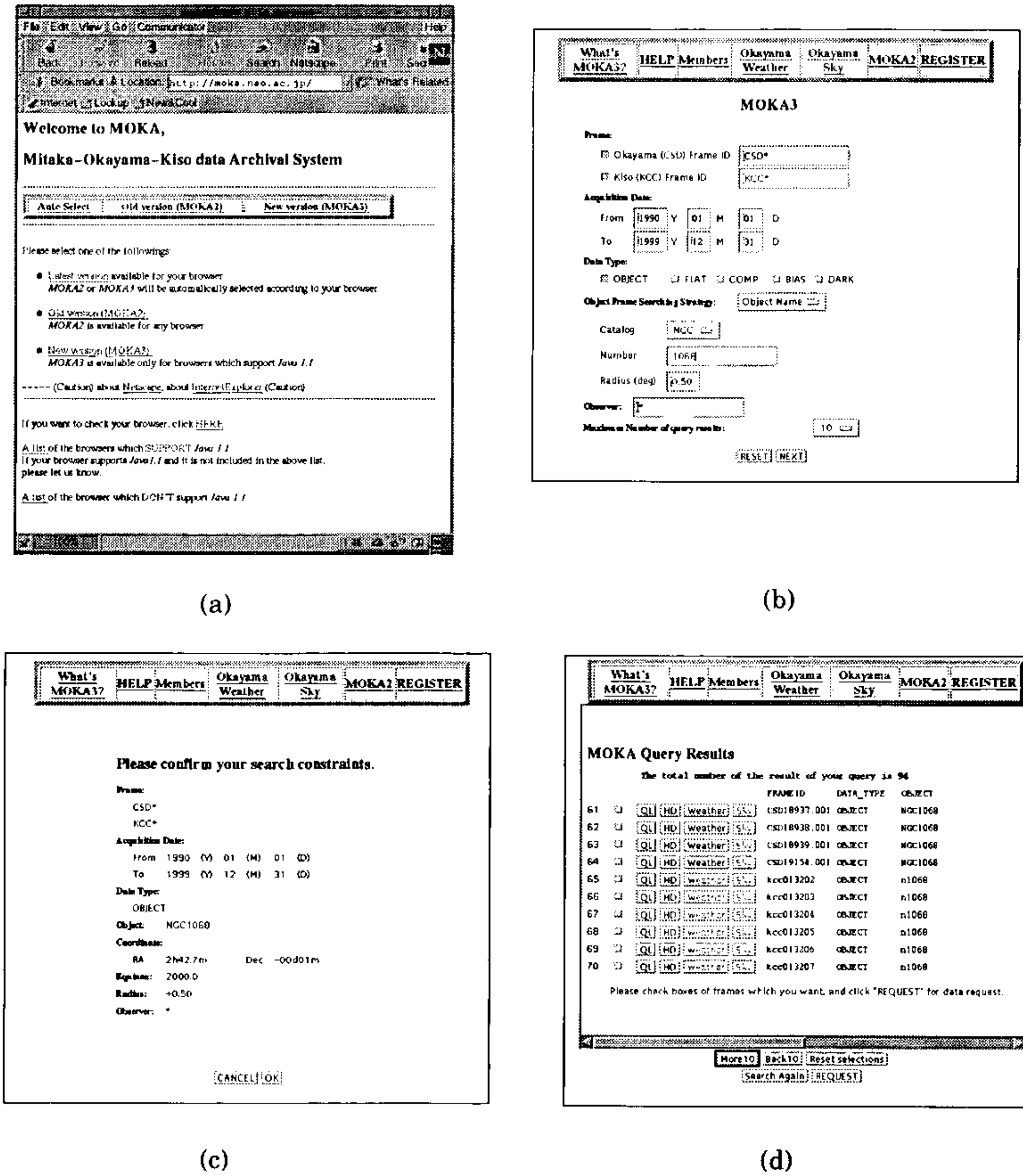


Figure 2: The top page and the panels provided in the main interface applet of MOKA3. (a) Entrance page of MOKA (http://moka.nao.ac.jp). (b) Search panel. Instruments, observation dates, image types, an object name/position, etc. can be specified as search constraints. (c) Confirmation panel. (d) Result panel. "Weather" and "Sky" buttons for the environmental data viewers (figures 3c,d) are inactivated for frames which have no data.

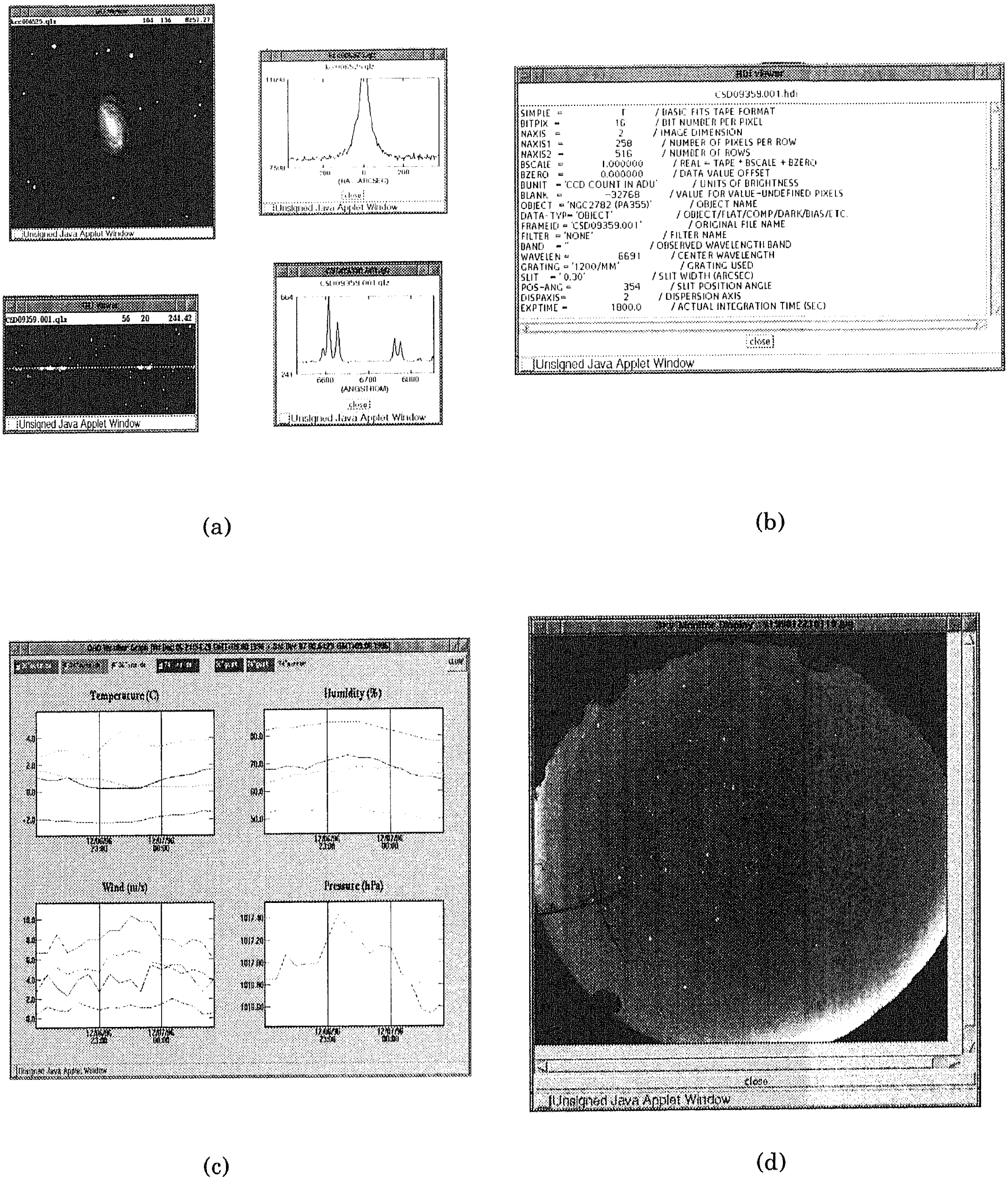
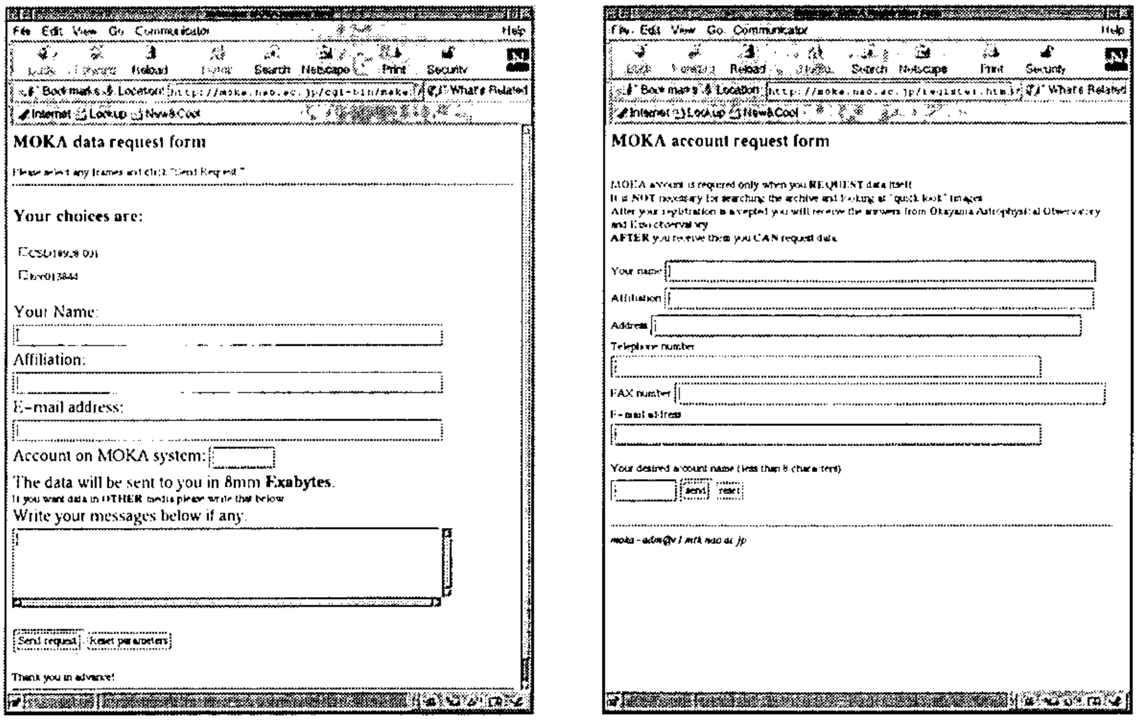


Figure 3: Viewer applets of MOKA3. (a) QLI viewer. Users can magnify the image, adjust its brightness and contrast, and draw the profile along a row and a column. (b) HDI viewer. (c) meteorological data viewer. (d) night-sky image viewer.



(a) (b)

Figure 4: Pages for the data request. (a) Request page. (b) Registration page. Users who want to make a request must obtain an account prior to their first request.

by the viewer. The QLI viewer can also adjust brightness/contrast of a QLI image interactively, and hence the user is able to examine the image in detail.

The second aim, examination of the variation of observational environment, is achieved by the meteorological data viewer and the night-sky image viewer. The viewers are invoked from the result panel and show the time variation of meteorological data and the night-sky image at the observation time of a frame.

The details of the features are described in section 3, and we have further discussion in section 5.

2.4 Other characteristic features of MOKA

Most parts of MOKA3 has been developed with Java. Though the image previewer of MOKA2 is a platform-dependent program and needs individual installation onto each client computer, the QLI previewer of MOKA3 needs no installation and runs on any WWW browsers supporting Java 1.1, since it is coded as a Java applet.

Another characteristics of MOKA is the shared management of the data objects. The HDI files, QLI files, and the header information database are made from raw observational data at each observatory. The data objects are transferred to the public server at ADAC and further transferred to each other observatories for local use.

The details of the features are described in the following section.

3 System Description

3.1 Flow of data search/request and user interface

The typical sequence of the user process is as follows: (1) make connection to the MOKA server, (2) specify search constraints for desired frames, (3) browse the resultant list of frames, (4) preview/check each frame and environmental data, and then (5) make a request of the selected frames to the observatories. In accordance with the above sequence, the user interface of MOKA3 consists of an entrance page, search panel, confirmation panel, result panel (figures 2a–d), QLI viewer, HDI viewer, meteorological data viewer, night-sky image viewer (figures 3a–d), request page, and registration page (figures 4a,b). The relationship between the user interface and the data objects is as follows.

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A user who makes access to the URL, `http://moka.nao.ac.jp`, will see the entrance page (figure 2a) and can choose the MOKA2 CGI interface or the MOKA3 Java interface at this page. We keep the old MOKA2 interface because there exist a few WWW browsers that do not support Java 1.1, with which the MOKA3 interface has been developed.

When the user selects the MOKA3 interface, the search panel shown in figure 2b appears. The user can specify search constraints, such as instrument, observation date, object name, celestial region, etc., at this panel, and confirm input constraints at the next confirmation panel (figure 2c). For object frames, the user can specify a celestial position by the equatorial coordinates or an object name. In the case that an object name is specified at the search panel, the name resolver is invoked. The input value in the field of catalog sequence number is checked and complemented according to the rule of the specified catalog, such that NGC 893 to NGC 0893, and then a query is submitted to the catalog database. The returned position of the object is shown in the confirmation panel. The header information database is then searched by the query command generated from the confirmed constraints, and the list of frames which satisfy the constraints is shown in the result panel (figure 2d). Each row of the list corresponds to one observational frame, and is accompanied with a check-box and four buttons: "QL", "HD", "Weather", and "Sky".

The user can preview the QLI file of the frame by pressing the "QL" button (figure 3a) and browse the HDI file by pressing the "HD" button (figure 3b). The QLI viewer can show not only the preview image of the data but also the profile along an arbitrary row and column. Details of the QLI viewer are described in section 3.3.2.

For the frames of Okayama Astrophysical Observatory, the meteorological data viewer and the night-sky image viewer are invoked by clicking the "Weather" and "Sky" button (figures 3c, d), respectively. The viewers search the weather/sky-monitor databases according to the observation time of the frame, so that the user can examine the time variation of the atmospheric condition around the time of the observation. For more details concerning the environmental data viewers, see section 3.3.3.

The user who wants to request raw observational data can select frames of his/her preference by the check-boxes in the result panel. By pressing the "REQUEST" button at the bottom of the result panel, the request page (figure 4a) appears next. The user can confirm specified frame-IDs and submit a request for the data in the request page. If the user has not yet had his/her account, he/she must get an account through the registration page (figure 4b), since only registered users are allowed to make the data request. After collating his/her account-ID with the user account database, an e-mail is sent to each observatory with the specified frame-IDs, and the requested data will be sent from the observatories by a magnetic tape. Data transfer through the network from the staging disk by ftp is also available if the amount of data is not so large.

3.2 Data objects of MOKA

The author presents in this section the details of the data objects, such as files and databases, of MOKA which are introduced in section 2.2.

3.2.1 raw observational data files

MOKA deals with observational data files obtained with the Spectro-Nebular-Graph (SNG; Kosugi et al. 1995) of Okayama Astrophysical Observatory and the single-chip 1K CCD imager (Yoshida et al. 1995) of Kiso Observatory.

SNG is the tridimensional spectroscopic instrument attached to the Cassegrain focus on the 188-cm telescope at Okayama Astrophysical Observatory. The detector is a PHOTOMETRICS 516×516 CCD (PM516A) having a pixel size of 20 μm. Spatial resolution of the spectrograph is $0''.74$ pixel^{-1}, and the spectral resolution is from 700 to 7000 depending on the installed grating. The spectral coverage spans 2400 Å at maximum with this CCD. Since SNG is the slit-scanning type of spectrograph, the observer gets two-dimensional spectroscopic data by each exposure. The typical size of a FITS file is about 250kB.

At Kiso Observatory, data are obtained with a single-chip CCD camera placed at the prime focus of the 105-cm Schmidt telescope. The camera is equipped with a virtual-phase, front-illuminated CCD chip TC-215, manufactured by Texas Instruments of Japan. The chip has 1024×1024 pixels with a pixel size of 12 μm but the effective imaging area is limited to 1000×1018 pixels. An exposure covers an area of 12 arcmin square, and the size of a FITS file is about 2Mbytes.

The raw observational data are kept and managed at each observatory, and the proprietary period, during which the observer can use the data exclusively, is set to two years for Okayama Astrophysical Observatory and one year for Kiso Observatory. An archival user can request the data after expiration of the the proprietary period. The number and the statistics of frames registered in MOKA are presented in Appendix A.

3.2.2 header information (HDI) files

An observational data file is written in FITS format (Wells et al. 1981), which consists of a header part and a data part. An HDI file is created from the header part of the original FITS file, and is a simple text file. It contains all of the header information of the original frame, and is used to browse the whole of the header. In the process of extraction from FITS headers, the object coordinates (right ascension and declination) are transformed to those at equinox J2000, and two keywords, RA2000 and DEC2000, are added to each HDI file. Several header keywords are also modified or added in order to satisfy the standards of keyword description. An HDI file contains about 60 keywords and additional descriptions such as comments and history. The size of each file is about 5–6kB.

3.2.3 header information database

We store the values of principal header keywords in a relational database. All processes concerning frame search utilize this database. Relational database management system (RDBMS) is the most popular and the *de facto* standard of database management system. The query interface, Structured Query Language (SQL), is internationally standardized by ISO. RDBMS manages data with a set of "tables", and figure 5 shows the scheme of the header information database of MOKA, which consists of two tables. The tables, 'CSD' and 'kcc', store keyword values of the instruments, Okayama SNG and Kiso 1K CCD, respectively, but trivial keywords such as NAXIS, TEL-LONG, TEL-LATI, which never vary, are omitted from the tables, because the number of columns of a table affects

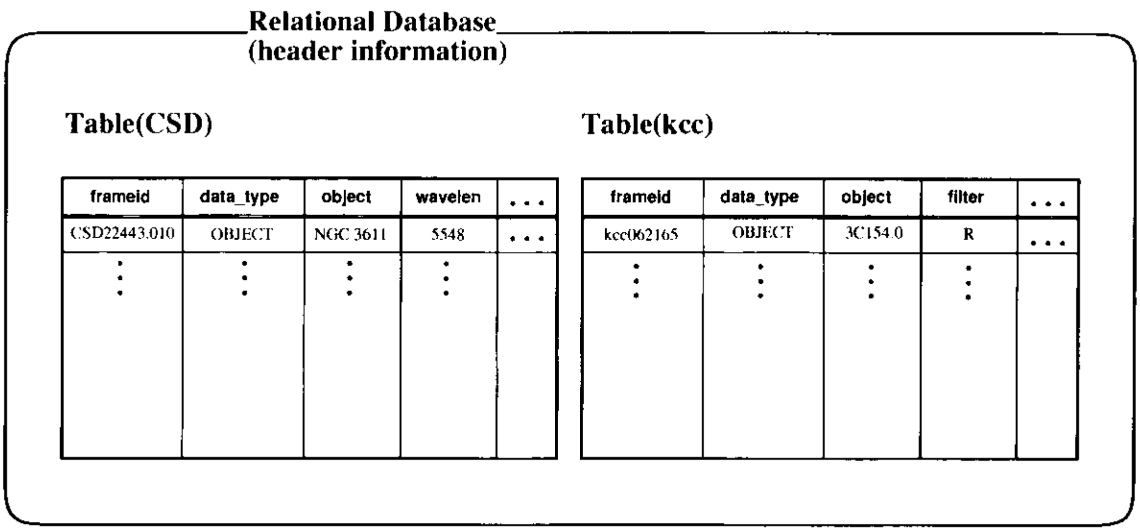

Figure 5: The scheme of the header information database of MOKA. A relational database consists of a set of database tables. The header information database of MOKA consists of the two tables, CSD and kcc, which store the keyword values of the Okayama SNG data and the Kiso 1K CCD data, respectively.

the performance of database. Stored keywords and their attributes of the two tables are shown in Appendix B.

There are some redundant columns which are not in header keywords but are added in the tables. For example, rasec and decsec are such columns, which are calculated from ra, dec, and equinox. Since the attribute of ra and dec are a character string and the expression is different between observatories, it is not easy to compare such value with those of the other observatory. Hence, we added rasec and decsec, both of which have numerical values of the position at equinox J2000 in arcsec unit, to the header information database for quick comparison. Jd_start, which is the modified Julian day at the time when an exposure starts, is also such a kind of column for comparing the observation date/time.

The header information is registered shortly after data acquisition, while QLI files are not available for one year after the observation to protect the observers' proprietary right.

3.2.4 quick-look image (QLI) files

A QLI file is made from the data part of the original FITS file and is used to evaluate the image quality of the exposure. We adopt the FITS format also for QLI files, since it is the standard data format in astronomy and can be handled with various astronomical applications.

The header part of a QLI file contains the pixel size, the file name of original data, parameters for image reduction, coordinate parameters, etc. as keywords and their values. The data part contains image data which is reduced from the original image by binning, sampling, and rescaling of pixel values, as follows.

First, pixels are binned by $N_{\rm col}$ in the column direction and by $N_{\rm row}$ in the row direction. The image is further reduced by sampling the binned pixels with the intervals, $\Delta_{\rm col}$ and $\Delta_{\rm row}$, in the column and row directions, respectively. After binning and sampling, the data are transformed from 16 bit/pixel to 8 bit/pixel by scaling with the statistical parameters, μ (the average count of the original image) and σ (the standard deviation of the original image), and clipping with parameters, $V_{\rm low}$ and $V_{\rm high}$. The pixel values are mapped so that $\mu - V_{\rm low} \times \sigma$ and $\mu + V_{\rm high} \times \sigma$ correspond to 0 and 255, respectively. The values below $\mu - V_{\rm low} \times \sigma$ and above $\mu + V_{\rm high} \times \sigma$ are clipped and are assigned to 0 and 255, respectively.

Adopted parameters and reduction rates of the image size are summarized in table 2. Since the information in dispersion direction is more essential than in slit direction for spectral observation, the binning factor along the row direction is set smaller than the factor along the column direction for the SNG data, while the factors are the same in both direction for the Kiso 1K CCD imaging observation. Data sampling reduces the calculation steps, but is used only for the Kiso 1K CCD data of large size, because the method drops the information of omitted pixels. For the calibration frames such as flat, larger factor is adopted to save the storage space. Rescaling to 8-bit, which means mapping to 256 levels, is efficient for data size reduction, and provides sufficient levels for quick inspection on the screen with eyes, if appropriate clipping parameters are selected.

Figure 6 shows histograms of pixel values of a typical imaging frame obtained with 1K CCD imager. The upper panel is a histogram in linear scale, and the lower is in log scale. The peak indicates the sky level of the image, and the width of the peak indicates the noise level, which is nearly equal to σ. The gently declining shoulder of the right side of the peak is formed by pixels in the light of objects, which shift the mean level (μ; dashed line) rightward from the peak. Hence, we have adopted $\mu - 0.5\sigma$ for the lower clipping level (left-side dash-dotted line), taking the peak width σ into consideration. As for the higher clipping level, we examined several levels between the maximum pixel value and the noise level, and have set the level to $\mu + 3.0\sigma$ (right-side dash-dotted line) so that diffuse objects are clearly visible. Figure 7 is an example of a QLI image, which is created from the original image shown in figure 8.

By the use of processes described above, the size of a QLI file is reduced to about 10kB, which can be transferred within several seconds through the network of effective speed at several kB/sec. The QLI files are further compressed by `gzip` program and are

Table 2: Parameters for the QLI files and the reduction rates of the image size

parameter		1K CCD (image)		SNG (spectrum)
		object	calibrations	
binning factor				
in column direction[1]	$N_{\rm col}$	2	2	4
in row direction[2]	$N_{\rm row}$	2	2	3
sampling pitch				
in column direction	$\Delta_{\rm col}$	5	10	1
in row direction	$\Delta_{\rm row}$	5	10	1
clipping parameter				
low	$V_{\rm low}$	0.5	0.5	1.5
high	$V_{\rm high}$	3.0	3.0	9.5
reduction rate of QLI file		1/200	1/800	1/24
typical size of original FITS file		2 MB	2 MB	250 kB[3]
typical size of QLI file[4]		14 kB	6 kB	14 kB

Note: [1] slit direction for SNG data
[2] dispersion direction for SNG data
[3] assume 2×1 binning
[4] include header

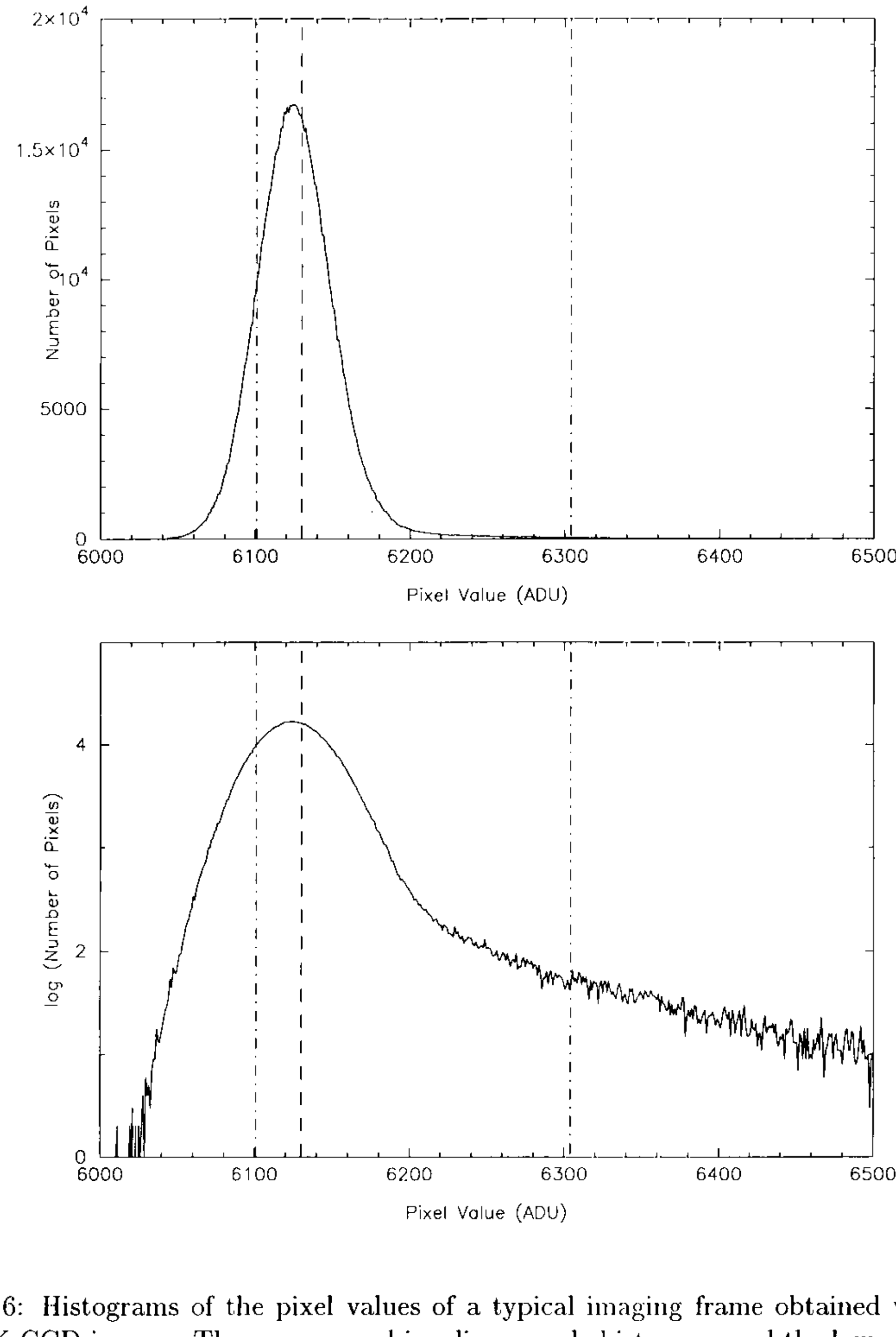

Figure 6: Histograms of the pixel values of a typical imaging frame obtained with the Kiso 1K CCD imager. The upper panel is a linear-scale histogram and the lower panel is a log-scale histogram. The dashed line indicates the mean level of the pixel values. The dash-dotted lines on both sides of the mean level indicate lower and higher clipping levels, respectively.

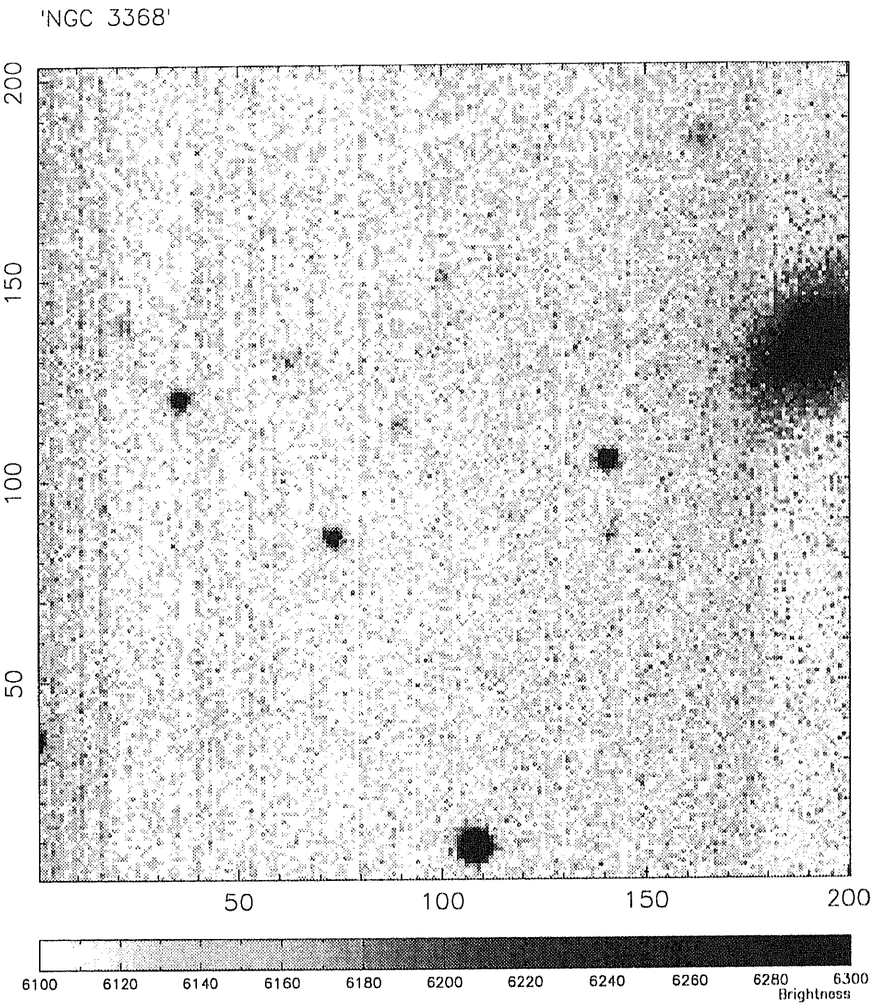

Figure 7: An example of a QLI image.

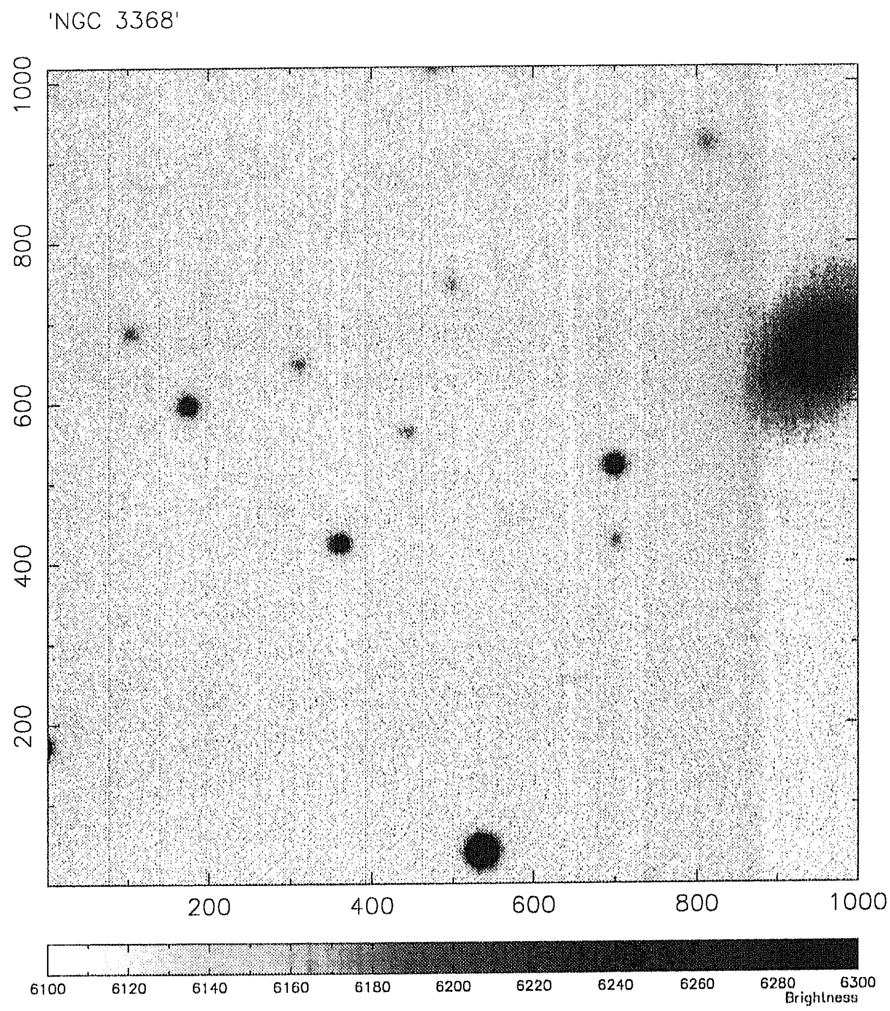

Figure 8: The original raw image of QLI shown in figure 7.

passed to the QLI viewer, which is described in section 3.3.2.

3.2.5 weather/sky-monitor databases

The weather/sky-monitor databases store and manage meteorological data and night-sky images of Okayama Astrophysical Observatory, respectively. These environmental data are used to check weather conditions at the time of observations and to evaluate the quality of observational data. The weather-monitor system (Yoshida et al. 1998) has been in operation since 1996 April at Okayama Astrophysical Observatory. Four monitoring stations record the atmospheric temperature, humidity, atmospheric pressure, wind speed, etc. every minute. The data are averaged for each station and sent to the database server every ten minutes. The sky-monitor system consists of an optical CCD camera and a fish-eye lens that scopes the whole sky. Since the coverage of one CCD frame is smaller than the field of view of the lens, the position of the CCD is shifted and 2×2 frames are mosaicked to obtain a whole-sky image. The process takes about five minutes. The date and time of creation and the name of the combined image file are stored in the database.

3.2.6 catalog database

The catalog database is another relational database which is used by a name resolver. The name resolver of MOKA3 returns the equatorial coordinates at equinox J2000 of a specified object when its name is given. The database stores object names and coordinates into tables extracted from eleven catalogs: A (Abell), AGK3, ESO, HD, IRAS, M (Messier), MRK, NGC, IC, SAO, and UGC (table 3).

Table 3: Catalogs stored in the catalog database for the MOKA3 name resolver

Catalog Name	Standard Format*	Example	Number of objects
AGK3 Catalog	`AGK3_$######`	`AGK3 +890038`	183145
SAO Catalog	`SAO_######`	`SAO 134261`	258997
Henry Draper Catalogue	`HD_######`	`HD 271809`	272150
IRAS Point Source Catalog	`IRAS_#####$####a`	`IRAS 04082+1141A`	245889
Messier Catalog	`M_###`	`M 051`	107
New General Catalogue (NGC2000)	`NGC_####a`	`NGC 4486B`	8241
Index Catalog (a part from NGC2000)	`IC_####`	`IC 1613`	5386
Uppsala General Catalog of Galaxies	`UGC_#####`	`UGC 04046`	12940
ESO/Uppsala Survey Catalog	`ESO_###-???###`	`ESO 409-???012`	18422
Markarian Catalog	`MRK_####`	`MRK 0123`	1469
Abell Catalog	`A_####`	`A 1234`	2712

*) '_', '#', '$', and 'a' indicate a single space (indispensable), a digit, a sign symbol (plus or minus), and an alphabet, respectively. Preceding '0's in # must not be omitted.

3.3 New tools and interfaces implemented on MOKA

3.3.1 highly functional previewer for data quality evaluation

The QLI viewer is a Java applet which is invoked from the result panel (figure 2d). After decompressing the specified QLI file, the applet opens a new window, and displays the image in the default style. The user can magnify the preview image, adjust its brightness and contrast continuously, display the position and the pixel value of the original image at the point of the cursor, and plot the profile along an arbitrary row or column. The profile for imaging data is plotted with angular scale and the profile for spectral data is plotted with the wavelength scale (figure 3a). Since the QLI viewer is a Java applet and all of the image manipulations are locally processed without additional transfers of any data, the performance of the manipulation is very quick and smooth. There is no preview system in the world other than MOKA3 that is able to change the display level dynamically and to extract its profile interactively.

Another merit of the Java applet is its interoperability. Since the QLI viewer of MOKA2 was a system-dependent plug-in program called from a WWW browser, the available computer platforms were limited and the individual installation of the browser is required. In contrast with MOKA2, the QLI viewer of MOKA3 is loaded onto a client computer on demand and runs on any WWW browsers that support Java 1.1 without installation.

3.3.2 environmental data viewer integrated with observational data archive

The meteorological data viewer and the night-sky image viewer are Java applets, which are invoked by a "Weather" button and a "Sky" button in the result panel, respectively. Each button is linked to each viewer applet on the http server at Okayama Astrophysical Observatory, and an applet downloaded onto a client computer makes an access to the environmental database server with the Java database connectivity (JDBC) interface. The meteorological data viewer (figure 3c) displays the data in six hours around the observation time of a frame, and the night-sky image viewer (figure 3d) shows an image at the closest time of observation. At present, the environmental data are available only for Okayama Astrophysical Observatory. The data for Kiso Observatory will be available soon.

3.3.3 user interfaces developed with Java applet

The main interface of MOKA3 (figure 2) is a Java applet, and can perform the following functions at the search panel (figure 2b) locally on the client computer: (1) check on the validity of the input values before the query is submitted to the header information database on the MOKA server, (2) conversion of the input coordinates from equinox B1950 to J2000, (3) layout of the input fields according to the searching strategy. MOKA provides three ways (strategies) to specify the constraint on the celestial region for the object: (1) by the object name and the search radius, (2) by the central position (a pair of right ascension and declination) and the search radius, and (3) by the rectangle area (two pairs of right ascension and declination). According to the user-selected searching strategy, the applet hides redundant fields for the positional constraint and dynamically reconstruct the search panel. It is important to mask confusing fields, since data archives should be easy to use for inexperienced users.

3.3.4 prototype system of a multi-mode, multi-spectral instrument

There are several multi-mode instruments planned for Subaru Telescope. Faint Object Camera and Spectrograph (FOCAS; Sasaki et al. 1997) is one of such instruments that implements both imaging observation and spectroscopic observation. A multi-mode instrument can switch its mode quickly, in general, and the calibration frames are usually used among observational modes in common.

The identification and the retrieval of the calibration frames are the very essential procedure for an archival user. However, the relation between the object frames and the calibration frames becomes complex for multi-mode instruments. It is favorable that the archival user is able to retrieve the calibration frames without awareness of the interrelation between observational modes. Therefore we have decided to make a prototype of a multi-mode instrument, taking the instruments of Subaru Telescope into consideration.

The multi-spectral instruments of Subaru Telescope are also the ones that cannot be treated within the framework of MOKA. One is High Dispersion Spectrograph (HDS; Noguchi et al. 1998), which is a echelle spectrograph and can take several tens of spectra in a single exposure. Another is FOCAS in multi-slit mode, which takes multi-object spectra through the slit mask in one exposure. Since the number of spectra depends on the grating configuration of HDS and the number of objects depends on the slit mask of FOCAS, the amount of information on the observation is not definite, and therefore the table structure cannot be a simple flat table for such instruments. Hence we have also examined the multi-spectral instruments.

In order to make the prototype of the archive system for multi-mode, multi-spectral instruments, we chose Okayama Optical Polarimetry and Spectroscopy system (OOPS; Sasaki et al. 1995a,b; Yutani et al. 1995) of Okayama Astrophysical Observatory as a target instrument, because OOPS has been made as the prototype of FOCAS and has the same five observational modes: imaging, imaging polarimetry, spectroscopy, spectro-polarimetry, and multi-slit spectroscopy (Takata et al. 1995). We present here the most reasonable solution that solves both problems of multi-mode, multi-spectral instruments simultaneously; i.e., the use of "view".

It is difficult to commonly inform archival users of the complicated relation between the object frames and the calibration frames. It is desired to describe the relationship between the observational modes in the database definition itself, and the use of "view" is a solution. The view is a virtual table and is defined by an SQL statement. By describing the relation for calibration into the definition statement, the user can retrieve necessary frames for calibration in any observational modes (figure 9). The use of the view enables us

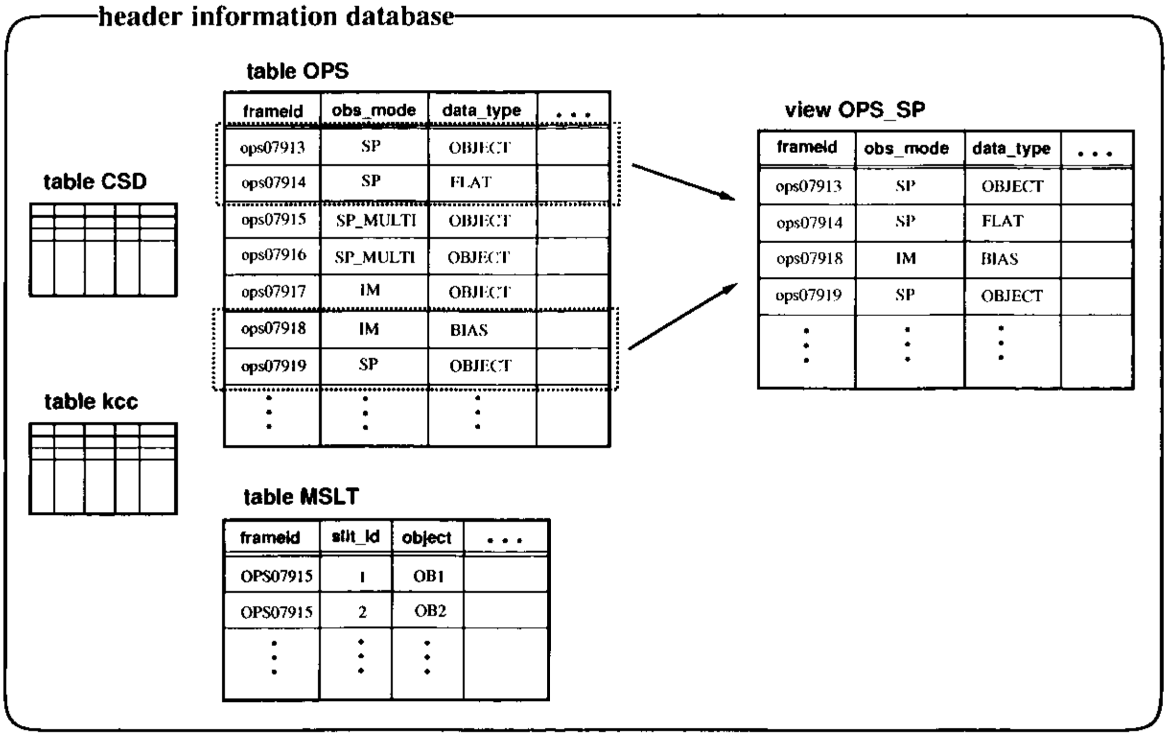

Figure 9: An example of the definition of a view in the header information database. Shown is the view for the OOPS spectroscopic mode, which is created with the calibration frames of other modes.

to treat each mode of the multi-mode instrument independently, like a simple single-mode instrument. It also helps the development of the system and its maintenance.

For the multi-spectral observation, which brings indefinite number of spectra, it is a unique solution to define two tables; one for common information on an image, and the other for each spectrum of an image. By the use of the SQL "join" function, which combines each corresponding row of tables, we can treat each spectrum of the observational frame as if it were a single spectral exposure. Figure 10 is an example of joined view of multi-slit observation. An archival user can search every object in a multi-slit frame, as well as a single-object frame of other instrument.

The actual definition of the tables and the views for OOPS are shown in Appendix C.

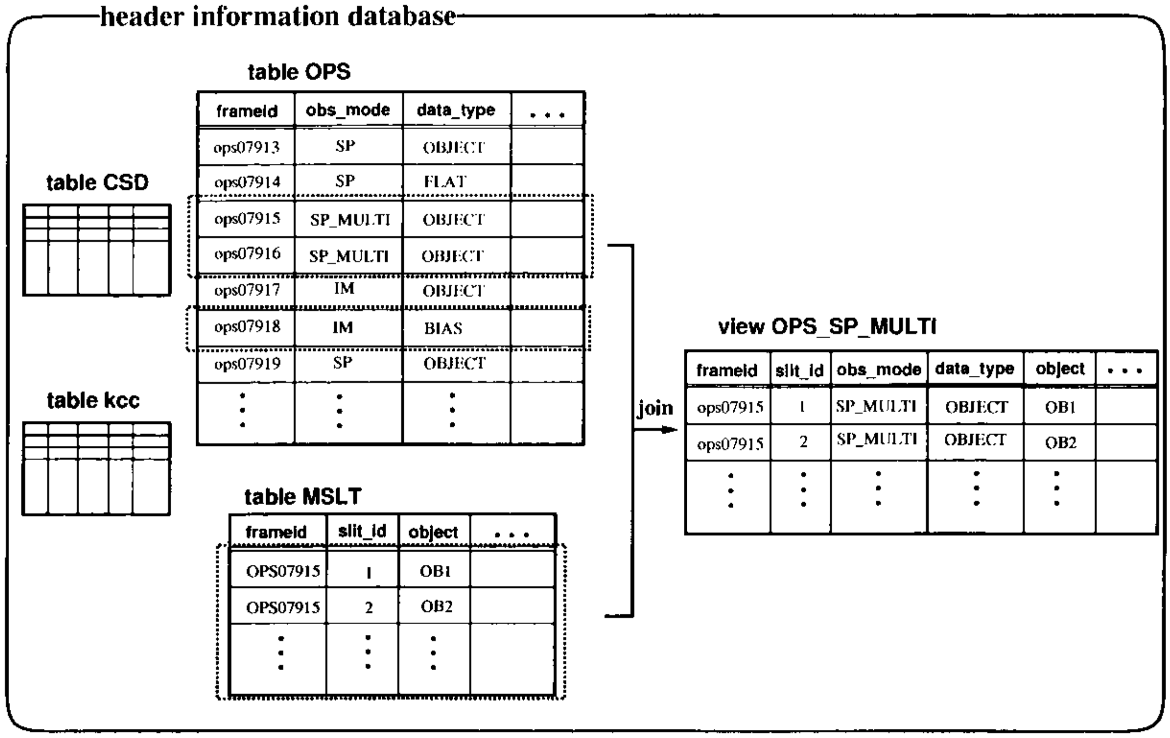

Figure 10: Definition of the view for the object frames of the OOPS multi-slit spectroscopy mode. Each information of the slit is joined with the common information of the frame by frameid, and constitutes a row of the view.

Unfortunately, OOPS is not implemented to MOKA, because the header keywords have many defects, but the framework is succeeded by Subaru Telescope data archive system (STARS; Takata et al. 1998).

3.4 Shared management and operations of distributed servers

One of the characteristics of MOKA is its shared management. MOKA is operated in collaboration with Okayama Astrophysical Observatory, Kiso Observatory, and ADAC. The three facilities are responsible for their raw observational data and the public server, respectively. Each observatory also makes HDI files and QLI files for new observational data and maintains the header information database of each instrument. The database and

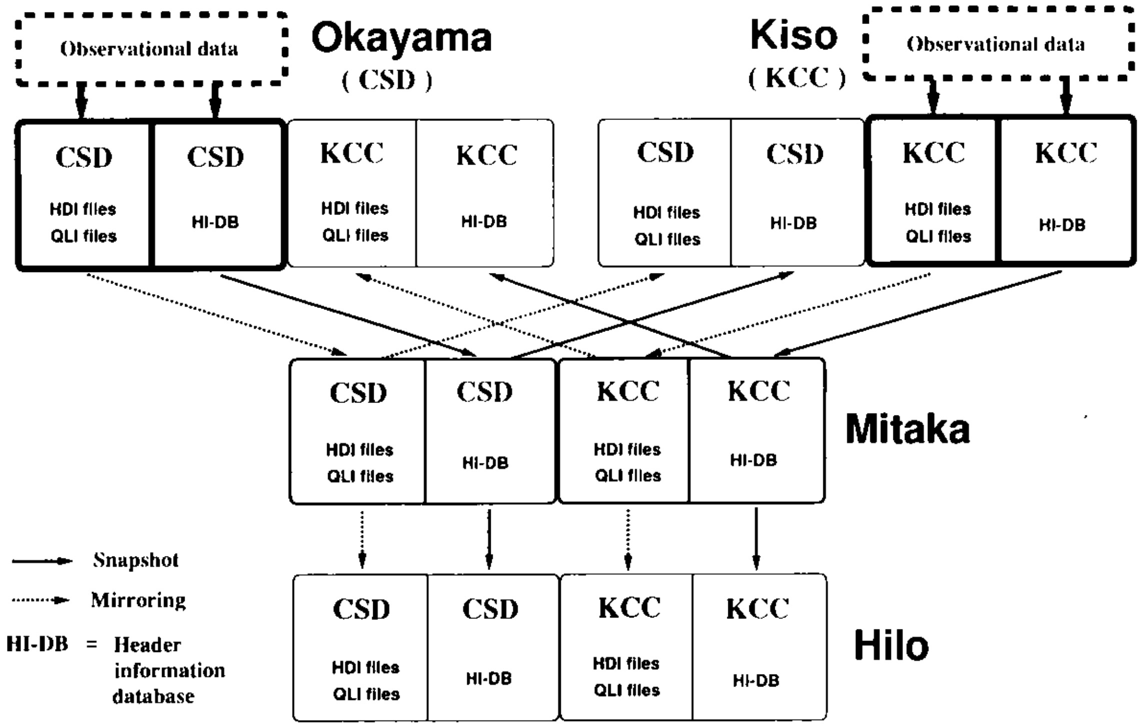

Figure 11: Schematic flow of the data distribution between the operating servers. The SNG data (CSD frames) of Okayama Astrophysical Observatory are managed at Okayama. The 1K CCD imager data (KCC frames) of Kiso Observatory are managed at Kiso. The HDI files, QLI files, and the tables of the header information database are distributed to the other servers from each observatory.

the files are gathered to the ADAC at Mitaka, and are exchanged to the other observatories and also to the Hilo base facility of Subaru Telescope.

The local servers at Okayama and Kiso observatories are operated for engineering use, i.e., checking instrument conditions and analyzing its behavior. The server at Hilo is operated for development of Subaru Telescope data archive system, STARS.

The schematic flow of the data is shown in figure 11. The header information database and the QLI/HDI files of Okayama CSD data and Kiso KCC data are made at each observatory where they originated. The database is copied to the other three servers immediately using the "snapshot" function of the MOKA3 database management system, ORACLE. We use the differential "snapshot", which makes the update of the database easy and quick. The newly produced QLI/HDI files are independently transferred to the other servers by ftp (mirroring).

4 Achievements and Contributions of MOKA

4.1 Astronomical studies

MOKA is a data archive system which provides the observational data to any users who study astronomy. From former days, observational data have been managed at the observatory where the observation had been done, but it was difficult for an external user to know what objects had been observed, and when and how the observation had been done. Now MOKA users can easily get all of such information with the excellent quick-look image and the environmental information through the Internet. The number of access to MOKA is about 700 per a year. In a sense that a data archive gives astronomers potential of getting data on their interesting objects, it is not too much to say that the development of an archive system is equivalent to make an observational instrument.

Although the archival data of MOKA are not obtained by a large telescope, there have been several papers on galactic astronomy that utilize MOKA (Tomita et al. 1998, Tomita et al. 1999, Takeuchi et al. 1999). They use the data of Okayama and/or Kiso observatories and introduce MOKA to see the quick-look images of their observation. The header information database of Kiso 1K CCD imager is also used by the DANEOPS project, which is the German NEO (Near Earth Objects) survey project organized by

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The establishment of the proprietary period for the data of Okayama Astrophysical Observatory is one of the most important achievements of MOKA. Until the service of MOKA opened, the proprietary period for the data of Okayama observatory was not defined, and the observer could exclusively keep and use his/her observational data forever. The discussion about the proprietary period had continued for two years since 1994, and the agreement was "Observational data are released after two years of the observation with the consent of the observer." It takes further three years to remove the clause on the observer's consent from the agreement. The establishment of the proprietary period not only prompts the use of archival data but also prompts the research and publication by the observers themselves.

The number of the access to MOKA increases in the season of the call for proposals, since many astronomers refer to the information on previous observations and examine the feasibility of their observation plan. This is another virtue of MOKA.

4.2 Basic design of Subaru Telescope data archive system (STARS)

The development of MOKA aimed not only to build the practical data archive system for Okayama and Kiso observatories but also to make the prototype system for the Japanese next-generation large telescope, i.e., Subaru Telescope. Actually, the Subaru Telescope data archive system, STARS, adopts the basic structure of MOKA, and inherits the framework of the header information database, HDI files, and QLI files. The production rate of observational data is so huge at Subaru Telescope that the raw data are stored in the tape library system, which spends much time for data retrieve. Therefore the HDI and the QLI files are all the more important.

The data structure of the raw observational file is also designed in order to get the quick-look image easily. For example, the information on echelle orders of HDS, such as the spectral positions, are described in the ASCII table extension (ATE) of the FITS file. The ATE information is utilized not only at the making process of the QLI file but also at the time of the observation in order to browse the raw data (Baba et al. 1999).

As mentioned in section 3.3.4, we have studied how header information of OOPS can be described in the database of MOKA. The tables of STARS for multi-mode multi-spectral instruments inherit the table structure for OOPS. The style of the graphical user interface of MOKA is also inherited by STARS.

5 Discussion

5.1 Newly developed features to solve the problems of ground-based archives

The author pointed out several problems of the presently operated data archive systems for ground-based observation. One is about the quality evaluation of the observational data, and the other is about the examination of the observational environment which have much influence on the calibration process of the retrieval data.

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In order to inspect the quality of the observational data, we have introduced the QLI files and developed the QLI viewer. Created QLI files have enough latitude between the sky level and the bright object level in the image, and can be transferred within a tolerable waiting time. The QLI viewer provides many advanced functions for data quality evaluation, which other ground-based archives have never been equipped with. By adjusting the brightness/contrast of the QLI, the archival user can inspect the details of the image in various levels. For the spectroscopic frames, the user can confirm the quality of the spectrum by tracing the profile. We declare that the first aim of evaluating data quality has been accomplished, though further development for Subaru Telescope is planned as described in section 5.2.

As for the observational environment, we have developed the viewers for the meteorological data and the night-sky images for Okayama Astrophysical Observatory, and have made links between the environmental data and the observational data. The user can instantly refer to the environmental condition around the time of observation that he/she wants to retrieve. We have made the best system under the restrictions of the hardware for environment monitoring, though it is desired more environmental information such as seeing, transparency, etc.

5.2 Problems left and plans for the future

5.2.1 quick-look image files

QLI files for calibration frames

The purpose of quick-look files is quality evaluation of the raw observational frames, and we have made the QLI files of MOKA by the methods of binning, sampling, etc. The methods are the most suitable way to make quick-look files for the object frames, and are also applied to the calibration frames. However, considering that the statistical information is essential for calibration frames, another method of quality evaluation is supposed. We are developing the new quick-look image browsing system, OZEKI (Hamabe et al. 1999), for Subaru Telescope. The OZEKI system will prepare three types of quick-look file format, which are for the imaging frames, the spectroscopic frames, and for the calibration frames.

calibrated QLI files

Fortunately, we can create the quick-look images for the instruments dealt with MOKA from the raw data alone. However, it is certain that there exist the observational data whose quick-look images cannot be created without calibration such as the data of infrared observation. The observational data obtained with mosaic CCDs also need reduction processes such that combining the frames and adjust the levels. Automatic processing of observational data is not so easy, but it must be challenged in the near future.

file size of the QLI files

Quick-look image files must have sufficient image quality to evaluate its original image quality, but, on the other hand, the file size must be small for the quick network transfer. One of the factors that determine the optimum size of the quick-look images is the effective speed of the network, since the faster the network speed is, the larger file we can transfer. In recent years, as the throughput of the network has been much improved, we have mitigated the reduction factors of the QLI files of MOKA, and the size of a present gzip-compressed QLI file is about 10–30kB. The user can browse the QLI image within one second through the network of several tens kB/sec, which is the typical transfer rate of the recent academic networks.

Another factor which determines the size of the quick-look images is the size of the storage area, because the image preview system works effective when the files are placed on the fast storage device. In fact, we have designed the format of the STARS quick-look images, and have determined the file size by the storage space and the data production rate of Subaru Telescope. The size of the storage area, in which the archive system stores the QLI files for several years, is several hundred GB, and the production rate of the raw data is about 3TB/year. Hence, we have determined the reduction factors as 1/50 for the STARS QLI files. We are going to examine and to design the QLI format for the new instruments of Subaru Telescope.

5.2.2 environmental data

time variation of the night-sky images

The environmental data are mainly used for the assessment of the image quality, the data selection, and for the planning of the calibration procedure. As for the parameters of weather condition such as temperatures, atmospheric pressure, the examination of the time variation is essential, and hence the function of the graphical viewer becomes important. We are developing the interface to show the night-sky images of Okayama

Astrophysical Observatory by the animation.

on-line observation log system

There are many environmental information that is not described in the data headers, such as the memorandum in the observation logbook. Observers often write memorandums with drawings into the logbook during their observation. In spite of the importance for evaluating observational data and for the subsequent data reduction, such information is not stored in a machine-readable form, and archival users can hardly refer to the information. We are going to develop the on-line log system and to integrate with the archive system for Subaru Telescope (Takata et al. 1995).

5.3 Header information database and the rolls of header files

contents of the header information database

The header information database is the fundamental database not only for the scientific research but also for the engineering use. The use of the data archive from the viewpoint of engineering will certainly improve the instrument conditions and the calibration procedures. The author plans to examine the behaviors of the calibration frames statistically, and to establish the standard calibration procedures of the observations.

benefits of the RDBMS and the usefulness of the views

At first, we adopted SYBASE as the RDBMS for MOKA, but have changed it to ORACLE in order to realize as similar database environments to Subaru Telescope as possible. Since SYBASE and ORACLE are both RDBMS and have the common SQL interface, the replacement of RDBMS was smoothly done without any difficulties. There are other kinds of database management systems such as object-oriented database, but the use of RDBMS that has the standardized query interface has brought a lot of benefits to us.

Another characteristics of RDBMS is the "View", which has many possibilities. As described in section 3.3.4, we utilized the views to represent the complicated relation of calibration frames between the observational modes of the multi-mode instrument. The view is also able to be used for masking proprietary frames from general users, for example. We declare that the concept of the view is indispensable for the future practical data archive system.

flexibility of the database structure and the rolls of header files

The initial design of the database tables should be done carefully, but also the alteration of the table structure have to be prepared, since the contents of the data headers may be modified according to the improvement of an observational instrument. The values of the header keywords also need to be corrected sometimes, because of a bug in the observation program. The header files can be used for:

(1) browsing the whole of the data header contents.

Comments and history descriptions in the data headers are not stored in the header information database, because the amount of the description is indefinite and the described positions in the data header are essential.

(2) backup and reconstruction of the header information database.

It is not realistic to recall all of the raw data to read the data headers for database reconstruction, because the file size of the raw data is very large.

(3) replacement of incorrect data headers of the raw observational data.

Even if incorrect keyword values are found, the raw observational data must not be changed, because they are THE originals. The author proposes on-the-fly replacement of the data header, which replaces the incorrect data headers of raw data files with the corrected header files when the raw data are retrieved from the data library.

5.4 Header description of observational data

In the constructing process of MOKA, there come out many problems of the header keywords of the observational data. It is no exaggeration to say that supplementing the contents of incomplete headers was so hard that the efforts was as large as the development of the system.

Some header keywords were against the rules of FITS header description. For example, the keyword name that designates the origin of the celestial coordinates of the object must be EQUINOX but was EPOCH for both instruments. In the header of 1K CCD imager, the attribute of EPOCH was not real but characters, and furthermore the string was "PRESENT".

Since we sincerely recognized that it was very important for the construction of data archives to establish strict rules for the header description, we have made the standard

Table 4: Modified header keywords and the unified names

keyword in original FITS header		unified name
Okayama SNG	Kiso 1K CCD	
DATA-TYP	OBS-TYPE	DATA-TYP
OTIME	ITIME	EXPTIME
EPOCH	EPOCH	EQUINOX
JST-STRT	JST	JST-STRT
JD	—	JD-STRT
ZD	ZNT-DST	ZD-STRT
FILTER	FIL-TYPE	FILTER
TELESCOP	OBS-TEL	TELESCOP
DETECTOR	CCD-CHIP	DETECTOR
IMG-SIZE	SEEING	IMG-SIZE

of description for FITS keywords in cooperation with the FITS committee of Japan. The standard prescribes (1) ranks of importance of keywords, such as basic, essential, and optional, (2) unique names for the standard keywords, such as EXPTIME for exposure time, and (3) description of the values, such as the units of numerical keywords and the semantics of character keywords. We unified the header description of both observatories with this standard, and then the construction of MOKA became possible. Table 4 shows the inappropriate keywords of both instruments that were to be modified through the process of database construction.

The header keywords of the Kiso 2K CCD data, which are going to be built into MOKA, also follow this standard. As to Subaru Telescope, the dictionaries of the header keywords (`http://www.subaru.nao.ac.jp:8001/fits/fits.html`) are made for all of the instruments based on this standard, and the data headers are being made complete.

5.5 Toward future astronomical studies

There are a few services which provide the interface like a search engine to the existing space mission archives, such as the Astrophysics Multispectral Archive Search Engine (AMASE; Cheung et al. 1999) and Multimission Archive at Space Telescope (MAST; Christian et al. 1999). We plan to make an interface that combines the information of other data archives with MOKA more directly; for example, the overlay of the quick-look images of different archives. The first target is Multiband Astronomical Imaging Service ON-line (MAISON; `http://maison.isas.ac.jp`), which is operated by the Institute of Space and Astronautical Science and ADAC, which serves survey images of optical (DSS), infrared (IRAS), and radio (Green Bank). Comparing the archival data of an object with the different wavelengths, such as optical, infrared, radio, and X-ray, will certainly bring a new prospect of the object.

Looking toward a mass of the objects stored in the data archives, data mining comes within the scope as a new research method. The keyword parameters and the physical parameters derived from the analysis of each object are regarded as a point in a multi-dimensional space. Statistical analysis of the set of the points, such as searching the correlation between the parameters and the clustering in the subspace, will give a new acquaintance with astronomy.

6 Summary

We have developed an astronomical data archive system for the optical telescopes of Okayama Astrophysical Observatory and Kiso Observatory. The system, called MOKA

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6 Summary

We have developed an astronomical data archive system for the optical telescopes of Okayama Astrophysical Observatory and Kiso Observatory. The system, called MOKA

(Mitaka Okayama Kiso Archive system), is the first practical data archive system in Japan and deals with the imaging data of Kiso 1K CCD imager and the spectroscopic data of Okayama SNG.

There are several data archives for ground-based observation in the world, which hold the valuable observations and open to the astronomical communities. However, they have no practical functions for evaluating the data quality and for examining the influence of the observational environment, though the data quality of ground-based observational data is various and is strongly affected by the atmospheric condition, etc. Hence, we have developed the following unique functions with our archive system, from the viewpoint of the astronomers whose aim is extracting the scientific products to the maximum from the archives, not of the software engineers who aim at the development of the system with advanced technologies.

The newly developed functions that we present in this paper are the QLI viewer and the environmental viewers. The QLI viewer of MOKA enables the archival users to examine the observational frames in detail with the quick-look images. The viewer also provides the profile of the frame, which is useful to inspect the frames of spectroscopic observation. The environmental data viewers of MOKA, which are directly invoked from the observational frames in the result panel, show the night-sky images and the time variations of atmospheric conditions around the time of the observations. The viewers provide unrivaled useful functions for the examination of the observational environment. Those functions are realized with Java applets, so that the users can utilize the advanced functions from any computer platforms in the same manner.

We have developed MOKA not only to build the practical data archive system of Okayama and Kiso observatories but also to make the prototype of STARS (Subaru Telescope data archive system). STARS inherits the framework of MOKA, such as the header information database, HDI files, and QLI files. The author presents the method how to describe relations of calibration frames to other observational frames of multi-mode instrument, and that is also taking Subaru telescope into consideration.

Through the construction of MOKA, we have established the standard of the FITS keyword descriptions and unified the description of both observatories. The importance of the complete descriptions of data header information now comes to be recognized by the instrument engineers and the observatories through our efforts.

Through the development of the unrivaled archive system, we have revealed the essentials for constructing data archives and have realized the indispensable functions for the ground-based data archives. The development of the system gives a new vision for astronomical data archive systems, and broaden the horizon of new observational astronomy, i.e., database astronomy.

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Appendix A Statistics of the data registered in MOKA

At present (1999 October), the header information database of MOKA registers 32910 frames for Okayama SNG and 50014 frames for Kiso 1K CCD imager. Table A-1 shows the statistics of frames of each data type. The ratios of object frames to total frames are 26% in number and 71% in exposure time for Okayama SNG data, and 46% in number and 62% in exposure time for Kiso 1K CCD data. Since SNG is a spectroscopic instrument, the observation needs many calibration frames of short exposure. On the other hand, imaging observation with 1K CCD needs fewer frames for calibration but the calibration frames for flat-fielding need long exposure.

Table A-1: Statistics of the frames of each data type

	Okayama SNG				Kiso 1K CCD			
data type	number		exptime (sec)		number		exptime (sec)	
OBJECT	8432	(25.6%)	6458671	(70.8%)	23142	(46.2%)	21394822	(62.0%)
BIAS	8931	(27.1%)	8204	(0.1%)	14596	(29.2%)	40	(0.0%)
DARK	1434	(4.4%)	2210603	(24.2%)	35	(0.1%)	185592	(0.5%)
FLAT	5953	(18.1%)	392039	(4.3%)	12241	(24.5%)	12938743	(37.5%)
COMP	8089	(24.6%)	45451	(0.5%)	–		–	
others	71	(0.2%)	9438	(0.1%)	0	(0%)	0	(0%)
total	32910		9124486		50014		34519197	

Appendix B Definition of the database tables for Okayama SNG and Kiso 1K CCD

The header keyword values of raw observational FITS files are stored in the database tables, CSD and kcc. CSD is a table for Okayama SNG data, and kcc is a table for Kiso 1K CCD data. A database table is defined by a set of columns, and each column is defined with its attribute.

Table B-1: Columns of the CSD table and the corresponding keywords of the data header of SNG

column name	header keyword	column attribute	note
frameid	FRAMEID	VARCHAR2(28)	
bitpix	BITPIX	NUMBER(10)	
naxis1	NAXIS1	NUMBER(10)	
naxis2	NAXIS2	NUMBER(10)	
data_type	DATA_TYP	VARCHAR2(22)	OBJECT/BIAS/....
object	OBJECT	VARCHAR2(32)	
ra	RA	VARCHAR2(30)	Original R.A.
dec	DEC	VARCHAR2(30)	Original Dec.
equinox	EPOCH	NUMBER(16,7)	
ra2000	–	VARCHAR2(30)	R.A.(J2000)
dec2000	–	VARCHAR2(30)	Dec.(J2000)
rasec	–	NUMBER(10)	R.A.(J2000) in arcsec
decsec	–	NUMBER(10)	Dec.(J2000) in arcsec
zd	ZD	NUMBER(10)	zenith distance
date_obs	DATE-OBS	VARCHAR2(30)	
ut	UT	VARCHAR2(30)	
jst_start	JST-STRT	VARCHAR2(30)	
jd_start	JD	NUMBER(12,6)	modified Julian day
exptime	EXPTIME	NUMBER(12,6)	exposure time in sec
telescope	TELESCOP	VARCHAR2(34)	
instrument	INSTRUME	VARCHAR2(34)	
grating	GRATING	VARCHAR2(22)	
wavelen	WAVELEN	NUMBER(12,6)	central wavelength in Å
waverng	WAVERNG	NUMBER(12,6)	range of wavelength in Å
slit	SLIT	VARCHAR2(22)	slit width in arcsec
pos_ang	POS-ANG	NUMBER(10)	slit position angle
detector	DETECTOR	VARCHAR2(28)	CCD chip used
obs_mode	–	VARCHAR2(20)	
ctype1	CTYPE1	VARCHAR2(20)	type of physical coord. on axis1
cdelt1	CDELT1	NUMBER(10,6)	pixel size on axis1
ctype2	CTYPE2	VARCHAR2(20)	type of physical coord. on axis2
cdelt2	CDELT2	NUMBER(10,6)	pixel size on axis2
bin_fct1	BIN-FCT1	NUMBER(10)	binning factor on axis1
bin_fct2	BIN-FCT2	NUMBER(10)	binning factor on axis2
ccd_temp	CCD-TEMP	VARCHAR2(20)	
filter	FILTER	VARCHAR2(20)	
observer	OBSERVER	VARCHAR2(42)	
weather	–	VARCHAR2(22)	
seeing	IMG-SIZE	VARCHAR2(22)	

Table B-2: Columns of the kcc table and the corresponding keywords of the data header of the 1K CCD imager

column name	header keyword	column attribute	note
frameid	FRAMEID	VARCHAR2(28)	
bitpix	BITPIX	NUMBER(10)	
naxis1	NAXIS1	NUMBER(10)	
naxis2	NAXIS2	NUMBER(10)	
data_type	OBS-TYPE	VARCHAR2(22)	OBJECT/BIAS/....
object	OBJECT	VARCHAR2(32)	
ra	RA	VARCHAR2(30)	Original R.A.
dec	DEC	VARCHAR2(30)	Original Dec.
equinox	EPOCH	NUMBER(16,7)	
ra2000	–	VARCHAR2(30)	R.A.(J2000)
dec2000	–	VARCHAR2(30)	Dec.(J2000)
rasec	–	NUMBER(10)	R.A.(J2000) in arcsec
decsec	–	NUMBER(10)	Dec.(J2000) in arcsec
zd_start	ZNT-DST	NUMBER(10)	zenith distance
date_obs	–	VARCHAR2(30)	
ut_start	–	VARCHAR2(30)	
jst_start	JST	VARCHAR2(30)	
jd_start	–	NUMBER(12,6)	modified Julian day
exptime	ITIME	NUMBER(12,6)	exposure time in sec
telescope	OBS-TEL	VARCHAR2(34)	
objprism	PRISM	VARCHAR2(22)	object prism
prism_dir	PRSM-DIR	VARCHAR2(22)	direction of object prism
instrument	–	VARCHAR2(34)	
detector	CCD-CHIP	VARCHAR2(28)	CCD chip used
obs_mode	–	VARCHAR2(20)	
ctype1	CTYPE1	VARCHAR2(20)	type of physical coord. on axis1
cdelt1	CDELT1	NUMBER(10,6)	pixel size on axis1
ctype2	CTYPE2	VARCHAR2(20)	type of physical coord. on axis2
cdelt2	CDELT2	NUMBER(10,6)	pixel size on axis2
bin_fct1	–	NUMBER(10)	binning factor on axis1
bin_fct2	–	NUMBER(10)	binning factor on axis1
ccd_temp	CCD-TEMP	VARCHAR2(20)	
filter	FIL-TYPE	VARCHAR2(20)	
observer	OBSERVER	VARCHAR2(100)	
weather	WEATHER	VARCHAR2(100)	
seeing	SEEING	VARCHAR2(100)	

Appendix C Definition of the database tables and the views for the multi-mode, multi-spectral instrument, OOPS

Table C-1 shows the definition of the main database table, OPS, for the OOPS header information, and table C-2 is of the additional table, MSLT, for the multi-slit observation. The views for the imaging, imaging polarimetry, spectroscopy, and spectro-polarimetry mode, are respectively defined from the OPS table with the selected columns (table C-3) by the constraints (table C-4). For the multi-slit spectroscopy mode, the OPS table and the MSLT table are joined by frameid, and also the view, ops_sp_multi, is defined.

Table C-1: Columns and the attributes of the OPS table

column name	attribute*	note
frameid	char(15)	
bitpix	smallint	
naxis1	smallint	
naxis2	smallint	
data_type	char(10)	OBJECT/BIAS/...
object	char(20)	
ra	char(12)	R.A. of frame position
dec	char(12)	Dec. of frame position
equinox	real	
ra2000	char(12)	R.A.(J2000)
dec2000	char(12)	Dec.(J2000)
rasec	int	R.A.(J2000) in arcsec
decsec	int	Dec.(J2000) in arcsec
zd	tinyint	zenith distance
date_obs	char(8)	
ut_start	char(12)	
jst_start	char(8)	
jd_start	float	in Modified J.D.
exptime	real	in sec
telescope	char(20)	
instrument	char(20)	
grating	char(10) null	
wavelen	real null	central wavelength in Å
waverng	real null	range of wavelength in Å
slit	char(15) null	
detector	char(15)	CCD chip used
obs_mode	char(8)	observational mode
ctype1	char(8)	type of physical coord.
cdelt1	real	pixel size on axis1
ctype2	char(8)	type of physical coord.
cdelt2	real	pixel size on axis2
bin_fct1	tinyint	binning factor on axis1
bin_fct2	tinyint	binning factor on axis2
ccd_temp	real	
filter	char(8) null	
observer	char(25)	
weather	char(20) null	
seeing	real null	
transpar	char(20) null	
pol_angle	real null	
group_id	char(15) null	ID for POL mode datasets

*) The types of attributes of the table are different from CSD and kcc, because the database management system (DBMS) was SYBASE when this table definition was examined, while the present version of MOKA adopts ORACLE as its DBMS.

Table C-2: Columns and the attributes of the MSLT table for the OOPS multi-slit mode

column name	attribute*	note
frameid	char(15)	
slit_id	smallint	
slit_x	smallint	physical position of slit
slit_y	smallint	physical position of slit
slit_length	real	
slit_width	real	
object	char(20) null	
ra	char(12)	R.A. of slit position
dec	char(12)	Dec. of slit position
equinox	real	
ra2000	char(12)	R.A.(J2000) of slit position
dec2000	char(12)	Dec.(J2000) of slit position
rasec	int	R.A.(J2000) in arcsec
decsec	int	Dec.(J2000) in arcsec

*) The types of attributes of the table are different from CSD and kcc, because the database management system (DBMS) was SYBASE when this table definition was examined, while the present version of MOKA adopts ORACLE as its DBMS.

Table C-3: Columns of the views for OOPS observational modes

column name	ops_im	ops_im_pol	ops_sp	ops_sp_pol	ops_sp_multi
frameid	ops	ops	ops	ops	ops
slit_id	–	–	–	–	mslt
bitpix	ops	ops	ops	ops	ops
naxis1	ops	ops	ops	ops	ops
naxis2	ops	ops	ops	ops	ops
data_type	ops	ops	ops	ops	ops
object	ops	ops	ops	ops	mslt
ra	ops	ops	ops	ops	mslt
dec	ops	ops	ops	ops	mslt
equinox	ops	ops	ops	ops	mslt
ra2000	ops	ops	ops	ops	mslt
dec2000	ops	ops	ops	ops	mslt
rasec	ops.rasec	ops.rasec	ops.rasec	ops.rasec	mslt.rasec
decsec	ops.decsec	ops.decsec	ops.decsec	ops.decsec	mslt.decsec
zd	ops	ops	ops	ops	ops
date_obs	ops	ops	ops	ops	ops
ut_start	ops	ops	ops	ops	ops
jst_start	ops	ops	ops	ops	ops
jd_start	ops	ops	ops	ops	ops
exptime	ops	ops	ops	ops	ops
telescope	ops	ops	ops	ops	ops
instrument	ops	ops	ops	ops	ops
grating	–	–	ops	ops	ops
wavelen	–	–	ops	ops	ops
waverng	–	–	ops	ops	ops
slit	–	–	ops	ops	ops
slit_x	–	–	–	–	mslt
slit_y	–	–	–	–	mslt
slit_length	–	–	–	–	mslt
slit_width	–	–	–	–	mslt
detector	ops	ops	ops	ops	ops
obs_mode	ops	ops	ops	ops	ops
ctype1	ops	ops	ops	ops	ops
cdelt1	ops	ops	ops	ops	ops
ctype2	ops	ops	ops	ops	ops
cdelt2	ops	ops	ops	ops	ops
bin_fct1	ops	ops	ops	ops	ops
bin_fct2	ops	ops	ops	ops	ops
ccd_temp	ops	ops	ops	ops	ops
filter	ops	ops	ops	ops	ops
observer	ops	ops	ops	ops	ops
weather	ops	ops	ops	ops	ops
seeing	ops	ops	ops	ops	ops
transpar	ops	ops	ops	ops	ops
pol_angle	–	ops	–	ops	–
group_id	–	ops	–	ops	–

Table C-4: Definition constraints of the views for OOPS observational modes

view	definition constraint
ops_im	obs_mode="IM" or data_type="BIAS" or data_type="DARK"
ops_im_pol	obs_mode="IM_POL" or obs_mode="IM" and data_type="FLAT" or data_type="BIAS" or data_type="DARK"
ops_sp	obs_mode="SP" or obs_mode="IM" and data_type="FLAT" or data_type="BIAS" or data_type="DARK"
ops_sp_pol	obs_mode="SP_POL" or obs_mode="IM" and data_type="FLAT" or data_type="BIAS" or data_type="DARK"
ops_sp_multi	obs_mode="SP_MULTI" and ops.frameid=mslt.frameid and data_type!="BIAS" and data_type!="DARK" (for slit-mask images) obs_mode="IM" and data_type="FLAT" or data_type="BIAS" or data_type="DARK" (for non-mask images)