

PROCEEDINGS

Volume 3

# 천문관측기기 워크숍

## Astronomical Instrumentation

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2009년 12월 21일(월) ~22일(화)

정선 하이원리조트

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강원도 하이원리조트

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김광동, 박장현, 김호일, 박영식(천문연), 진호, 박수종(경희대)

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Volume 3

# PROCEEDINGS

## Astronomical Instrumentation

**In-Soo Yuk**

Editors

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Gangwondo, Korea

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Volume 3



# 인사말

갈릴레오가 망원경으로 천체를 관측한지 400 주년이 되었습니다. UN 은 이를 기념하여 올해를 세계 천문의 해로 지정하였습니다. 한국의 천문학회도 다양한 행사를 준비하여 국민에게 천문학을 널리 알리는데 노력하였습니다. 또한 올해는 한국이 거대마젤란망원경(GMT) 사업에 참여하고, 한국우주전파관측망(KVN)은 3 국에 22/43GHz 수신기를 설치하여 세계 최초로 다주파수 동시관측 VLBI 시스템 1 단계 구축을 마무리한 해이기도 합니다.

2007 년에 시작한 천문관측기기 워크숍이 어느새 3 회째가 되었습니다. 천문기기워크숍을 통하여 각처에서 개발되고 있는 다양한 기기를 논의하고 서로의 경험과 연구결과를 공유하여 더욱 발전적으로 연구가 수행되었다고 생각합니다.

이번에도 우주망원경과 지상망원경, 관측기기와 소프트웨어 등 관측 파장과 관측 대상에 관계없이 전반에 걸쳐 연구결과를 발표하고 논의하고자 합니다. 행사가 성공적으로 이루어질 수 있도록 천문관측기기워크숍에 참석하여 자리를 빛내 주시기 바랍니다.

2009 년 11 월 25 일

천문관측기기워크숍 준비위원

박병곤(의장), 육인수, 김영수, 천무영, 박귀종, 이창훈, 오세진,  
김광동, 박장현, 김호일, 박영식(천문연), 진호, 박수중(경희대)

# 천문관측기기 워크숍

2009년 12월 21일(월) ~ 22일(화)

## 12월 21일 (월요일)

1:00 **개회 및 인사말**

1:10 **1 단계 한일공동 VLBI 상관기의 개발 및 시험운영에 관한 연구**

오세진, 노덕규, 염재환, 박선엽, 정현수, 이창훈(한국천문연구원), H. KOBAYASHI,  
N. KAWAGUCHI(일본국립천문대)

1:30 **KVN 22 GHz 수신기의 위상 안정도 측정**

김수연, 제도홍, 한석태, 정문희, 이정원, 송민규(한국천문연구원)

1:50 **TRAO 다중빔 시스템 구축 현황**

강현우, 정재훈, 이창훈, 임인성, 김현구, 김봉규(한국천문연구원)

2:10 **포스터 관람 및 휴식**

2:40 **Conceptual Study of the System Architecture for IGRINS**

Moo-Young Chun(KASI), Soojong Pak(Kyung Hee Univ.), Won-Kee Park  
(Seoul National Univ.), In-Soo Yuk(KASI), Sungho Lee(KASI, Univ. of Texas at Austin),  
Tae-Soo Pyo(National Astronomical Observatory of Japan), and  
Daniel T. Jaffe(Univ. of Texas at Austin)

3:00 **Software Design for IGRINS**

Soojong Pak(Kyung Hee Univ.), Jung-Hoon Kim(Space and Earth Technology System),  
Won-Kee Park(Seoul National Univ.), Haingja Seo(Kyung Hee Univ.), Moo-Young Chun,  
In-Soo Yuk(KASI), Sungho Lee(KASI, Univ. of Texas at Austin), Tae-Soo Pyo  
(National Astronomical Observatory of Japan), and Daniel T. Jaffe(Univ. of Texas at Austin)

3:20 **Telescope interface system of CQUEAN on McDonald 2.1m telescope**

Won-Kee Park(Seoul National Univ.), Jinyoung Kim, Heeyoung Oh, Juhee Lim,  
Hyeonju Jeong, Eunbin Kim(Kyung Hee Univ), Seunghyuk Chang(Samsung Electronics),  
Soojong Pak(Kyung Hee Univ), Myungshin Im(Seoul National Univ.)

3:40 **초전도 영상소자 STJ 개발**

박장현, 박영식(한국천문연구원), 윤호섭(한국천문연구원, 연세대학교), 이진국,  
양민규(한국과학기술연구원), 정연욱, 이용호, 이상길(한국표준과학연구원), 김석환(연세대학교)

4:00 **사진 촬영 및 휴식**

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4:30	<b>Star Cluster Populations in the Interacting Galaxies</b> 황나래 (National Astronomical Observatory of Japan)
4:50	<b>Vello 천체, L1521F-IRS 의 HCN 전파 관측</b> 손정주 (한국교원대학교)
5:10	<b>Integrated Ray Tracing Simulation of Spectral Bio-signature from full 3-D Earth with Simple Atmospheric Models and Sea Ice Coverage Variation</b> Dongok Ryu, Sehyun Sung(Yonsei Univ.), Jae-Min Lee(Univ. of Oxford), Jinsuk Hong (I&A Technology), Soomin Jeong, Yukyung Jeong, Sug-Whan Kim(Yonsei Univ.)

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5:30	휴식
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6:00	만찬
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## 12월 22일 (화요일)

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### 9:00 MIRIS 광기계부의 조립

문봉곤, 박성준, 이창희, 정웅섭, 이대회, 차상목, 박영식, 남욱원(한국천문연구원),  
양순철(한국기초과학지원연구원), Toshio Matsumoto(Seoul National Univ.),  
한원용(한국천문연구원)

### 9:20 MIRIS Data Acquisition Process

이대회, 남욱원, 차상목, 박영식, 가능현, 정웅섭, 이창희, 문봉곤, 방승철(한국천문연구원),  
이덕행(한국천문연구원, Univ. of Science and Technology), 한원용(한국천문연구원),  
Toshio Matsumoto(Seoul National Univ.)

### 9:40 Kyung Hee Cubesat Mission : TRIO (TRiplet Ionospheric Observatory) CINEMA (Cubesat for Ion, Neutral, Electron, MAgnetic fields)

이용석, 김진규, 윤세영, 남지선, 진호, 선중호, 김관혁, 이동훈(경희대학교), Robert P. Lin  
(경희대학교, Univ. of California, Berkeley), Timothy Simon Horbury(Imperial College),  
권혁진, 김경임, 지은영, 이재형, 박종선, 서정준, 박사라(경희대학교)

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### 10:00 공동 연구 협의 및 휴식

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### 10:30 KMTNet의 광시야 망원경

김승리, 박병곤, 육인수, 이충욱(한국천문연구원), 한정호(충북대학교), 이재우, 김동진  
(한국천문연구원)

### 10:50 적도의식 망원경 구동을 위한 제어회로 설계

김광동, 나자경, 임인성, 한인우, 장비호, 장정균, 윤한배(한국천문연구원)

### 11:10 The development of Korea's First Satellite Laser Ranging System

Jung Hyun Jo(KASI)

### 11:30 ARGO-M 광학계의 요구사항 및 기능 분석

나자경, 김광동, 장정균, 장비호, 조중현, 이진영, 윤한배(한국천문연구원)

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### 11:50 폐회

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### 12:00 점심식사

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## 포스터 발표

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### MIRIS 우주관측카메라 필터휠 FM 설계

차상목, 문봉곤, 정용섭, 이대회, 남옥원, 박영식, 이창희, 박성준, 표정현, 이미현, 이덕행, 가능현, 목민정, 한원용(한국천문연구원)

### 한일공동VLBI상관기의 제어 소프트웨어 개발과 운용 시험

박선엽, 강용우, 노덕규, 오세진, 변도영(한국천문연구원)

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# Conceptual Study of the System Architecture for IGRINS

Moo-Young Chun<sup>a</sup>, Soojong Pak<sup>b</sup>, Won-Kee Park<sup>c</sup>, In-Soo Yuk<sup>a</sup>,  
Sungho Lee<sup>a,e</sup>, Tae-Soo Pyo<sup>e</sup>, and Daniel T. Jaffe<sup>f</sup>

<sup>a</sup> Korea Astronomy and Space Science Institute, Korea

<sup>b</sup> School of Space Research, Kyung Hee University, Korea

<sup>c</sup> Center for the Exploration of the Origin of the Universe, Seoul National University, Korea

<sup>d</sup> McDonald Observatory, University of Texas at Austin, USA

<sup>e</sup> Subaru Telescope, National Astronomical Observatory of Japan, Japan

<sup>f</sup> Department of Astronomy, University of Texas at Austin, USA

## ABSTRACT

In this paper, the results of conceptual design study for system architecture of a high spectral resolution near-infrared spectrograph, IGRINS (Immersion GRating INfrared Spectrograph). The key concepts of the system architecture for IGRINS are Commercial Off-The Shelf (COTS), IP based, and DataBase used. COTS make IGRINS as a reliable system. The IGRINS system consist of several controllers for detector control, temperature control, motion control and house keeping equipment. As these controllers ar IP based, the standard protocol and the standard cabling can be used for the communications with main IGRINS control system. The database which contain the meta data of IGRINS control system and Images will be useful to check the heath of IGRINS system and increase the usability of the archive of IGRINS spectroscopic data.

**Keywords: Instrumentation: spectrographs – methods: system – techniques: spectroscopic**

## 1. INTRODUCTION

IGRINS (Immersion GRating INfrared Spectrometer) is a high resolution spectrograph for the near-infrared. It will cover all of the H and K atmospheric windows in a single exposure at a resolving power of 40,000-60,000. The instrument will have no moving parts in the cryogenic section and only a pair of flip mirrors (to access the calibration box) in the warm section. The throughput of the spectrograph should be as good or better than that of existing instruments with much smaller spectral coverage. The IGRINS team, consist of the University of Texas at Austin (UT) and the Korea Astronomy and Space Sciences Institute (KASI ), has been working since January of this year to complete a preliminary design of the instrument and to produce and characterize the high-risk components.

IGRINS will have a broad range of astronomical applications. These include characterization of young stellar objects, studies of emission from protostellar disks and envelopes, and research on binary stars, Galactic evolution, and the interstellar medium. IGRINS will initially operate at the Cassegrain focus of the McDonald Observatory's 2.7m telescope. The plan is to commission the instrument there and to carry out an initial program of scientific observations before moving IGRINS to 4 to 8m class telescopes. This model was followed successfully by a previous high- resolution spectrometer for the infrared, TEXES.

In this paper, basic concepts of the system architecture for IGRINS control will be described. More detail design of the software will be presented in another paper at this proceeding.

## 2. KEY CONCEPTS OF SYSTEM ARCHITECTURE

The basic philosophy of the system architecture for IGRINS is summarized here.

- COTS ( Commercial Off-The-Shelf ) : IGRINS is not a space instrument, but ground instrument. We have not enough time and manpower to test the self-made product in various environments. If it's not difficult to find product which satisfy the specification and has a heritage in other astronomical project, COTS will be more cost efficient and make IGRINS as a reliable system.
- IP based : IGRINS control system is entirely IP based: every device that touches hardware has an IP address. All communications links are using Ethernet. Among the many advantages of this approach are that highly standard software protocols, hardware devices and cabling can be used facilitate communications. This scheme lends itself naturally to a distributed control system which can evolve as needed.
- Database Used : Database (DB) is now being more popular in astronomical society. All data and metadata of IGRINS (except image data. It will be stored in the directory structure) will be kept in DB. Open source DB (ex. MySQL) will be used.

## 3. BLOCK DIAGRAM

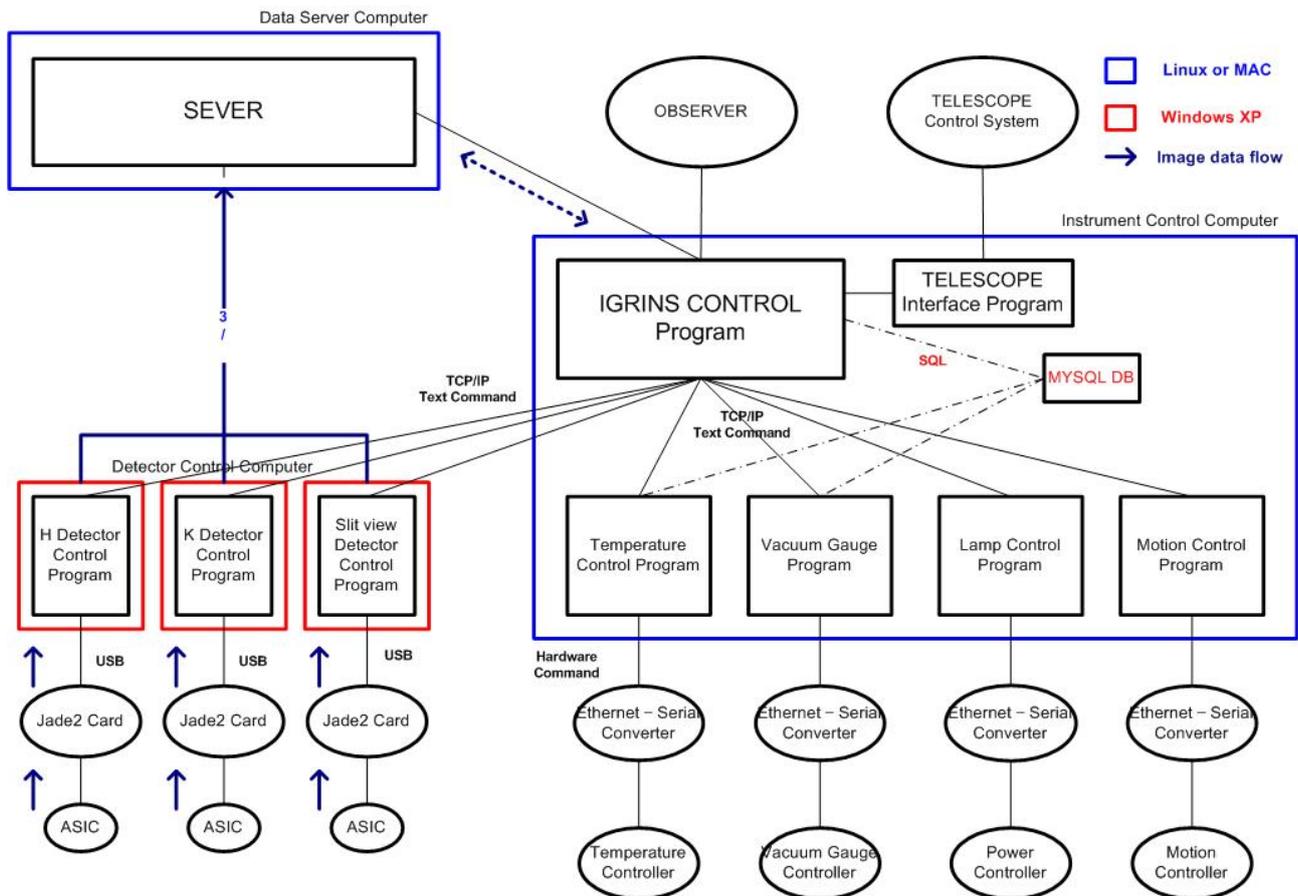


Figure 1. overview of system architecture for IGRINS

Here is the block diagram of system architecture of IGRINS control.

For the control of IGRINS, we need 5 computers.

1. Data Server computer (DSC) : Linux or Mac
2. Instrument Control Computer (ICC) : Linux or Mac
3. Detector Control Computer for H band (DCCH) : XP
4. Detector Control Computer for K band (DCCK) : XP
5. Detector Control Computer for Slit view and autoguiding (DCCS) : XP

The operating system of Detector Control Computers (DCC ) should be MS windows XP because the ASIC manufacture - Teledyne supply the hardware control Application Programming Interface (API) under the MS .net COM DLL environment.

The operating system of DSC and ICC is not determined yet. Linux machine is cheap and more popular in Korea. So it's easy to find an engineer who is familiar with Linux. But there are too many variances of Linux OS and its hardware.

#### **4. TCP/IP TEXT COMMAND**

Communication between IGRINS control program and hardware control programs are done by simple ASCII text using TCP/IP protocol. It's a server-client model. So each hardware control program become a server which are waiting a command from a client - IGRINS control program.

When the server program get a command from the client program, they should send a answer immediately, even just saying OK. The command set for each server will be defined at Software design document.

#### **5. IMAGE DATA FLOW**

The image data generated at ASIC will be transfered to Detector Control Computer (DCC) through JADE2 card, using USB. At the end of each exposure, the raw data will be saved at the hard disk drive (HDD) of DCC in simple FITS format and send to DSC through Ethernet.

The protocol for image data between DCC and DSC is not determined yet. TCP/IP and UDP are candidates for the protocol between DCC and DSC. TCP/IP is more reliable, but more overhead than UDP. NSF can be a protocol between ICC and DSC and we think about the hardware equipment to share storage like Fiber Channel based Storage Area Network (SAN).

#### **6. DATABASE AND SQL**

The house keeping programs - temperature control program and vacuum monitoring program - will open the database and upload their house keeping data by given periods. The IGRINS control program open the database and check the most recent house keeping data. And the IGRINS control program save all information of each exposure in Database.

## **7. INTERFACE WITH TELESCOPE**

Simple TCP/IP communication is enough for that. We got the command sets of 2.7m telescope control system (TCS). We are waiting for any documents about communication between 2.7m TCS and PI instrument.

It will be better to implement this part as a separate program like other hardware control program, because the target telescope can be changed.

## **8. USER INTERFACE**

Basic user interface is Graphic User Interface (GUI). Only key information will be displayed in GUI. An Observer can set up the object name, exposure time and readout mode. The detail GUIs will be described in Software design document.

Text command and script file should be another way for user interface. It depend on the observational scenario that an observer need a console window to permit a text command or run a script file. If an observer need some complicate and repeatable actions like dithering pattern, the script will be better user interface than GUI. If not, GUI is enough and convenient.

# Software Design for IGRINS

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## ABSTRACT

We present the results of preliminary design study for software of a high spectral resolution near-infrared spectrograph, IGRINS (Immersion GRating INfrared Spectrograph). The cross-dispersed echellogram of IGRINS can show the entire range of spectra in the H and K-bands. Since the raw echellogram patterns are too complex to be analyzed during observations, we will implement distortion corrected quick look viewer and data reduction pipeline. In addition, the observation planning modules will be developed for preparing efficient observations.

**Keywords: Instrumentation: spectrographs – methods: data analysis – techniques: image processing – techniques: spectroscopic**

## 1. INTRODUCTION

IGRINS (Immersion GRating INfrared Spectrograph) is a cross-dispersed near-IR spectrograph designed using silicon immersion gratings (see the other papers in this workshop). This instrument can cover the complete H-band and K-band in one exposure with a spectral resolving power of greater than 40,000. IGRINS is designed to be compatible with telescopes of diameters ranging from 2.7m (the Harlan J. Smith telescope at McDonald Observatory) to 8–10m. Commissioning and initial operation will be on the 2.7m telescope from 2013.

For the astronomical instruments, roles of software are mainly to interface among hardware components, science data, and users. In this work, we have designed the software modules between users and hardware components and between users and science data. Goals of this work are to define the scope of the whole software development, to analyze the required software works for instrument operations and science observations, and to propose the software development plan which should be accompanied with the whole hardware development plan.

## 2. SOFTWARE MODULES AND USERS

We classify the users of the IGRINS software as instrument developer, instrument operator, and data operator. (see Figure 1). The instrument developer can test the hardware components using the stand-alone software modules (or low-level software) which are usually provided by hardware vendors. The test can be done by the IGRINS electronics team, but the software team will develop the interfacing software modules (or high-level software) between the electronics parts and the instrument control software. During the system integration phase, all the hardware components need to be connected to and operated by the integrated instrument control software. The instrument developer should monitor all the hardware parameters during the integration test.

During science observation nights, there will be an instrument operator and a data operator. The instrument operator maintains, tests, and calibrates the hardware components and runs observing modes. There will be options to show all the hardware parameters for instrument experts, but the normal observation mode only shows important hardware parameters. The data operator runs data reduction pipeline modules and processes spectroscopic data to decide further observation processes.

We will use an instrument control computer (ICC) and a data server computer (DSC) for the high-level software modules.

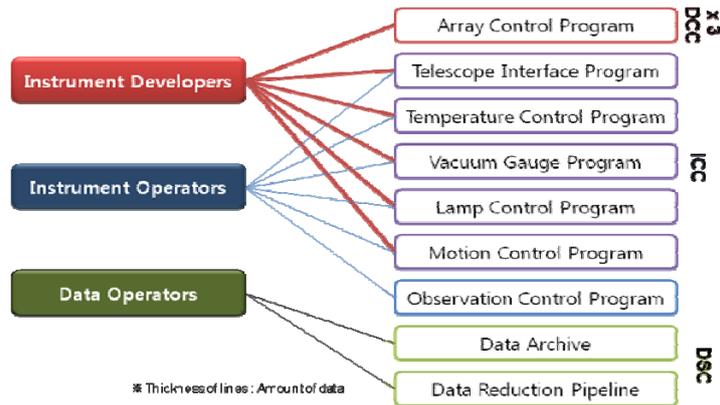


Figure 1. Interface diagram between the users and the software modules.

The roles of ICC are:

- to monitor and/or control IGRINS hardware components, i.e., temperature, vacuum, lamp, and motion;
- to interface with Telescope Control System;
- to show quick look views of the IR arrays; and
- to run observations.

During the science observations, DSC archives the raw data from the ICC and runs data reduction pipeline as real-time process. The data operator checks the parameter sets for the pipeline.

### 3. QUICK LOOK MODULE

It is essential to see if the slit of IGRINS is placed on the observation target as planned, and the telescope is tracking the object accurately. During the observation, the instrument operator should pay attention to the three images from Slit-viewing array, H-band spectroscopy array (in the form of 2-d image), and K-band spectroscopy array. Thus, we need three quick-look windows for monitoring the data as well as the observation itself.

The quick-look windows work in event-loop structure in such a way that they wait for the output data from IGRINS, and automatically display the data upon receiving them from each detector control computer. In addition, quick-look windows are equipped with several utility functions such as simple data analysis as a first check on the acquired data. The detailed functions will differ between windows for spectroscopic data and the one for imaging data.

## 4. OBSERVATION MODES AND DATA REDUCTION PIPELINE MODULE

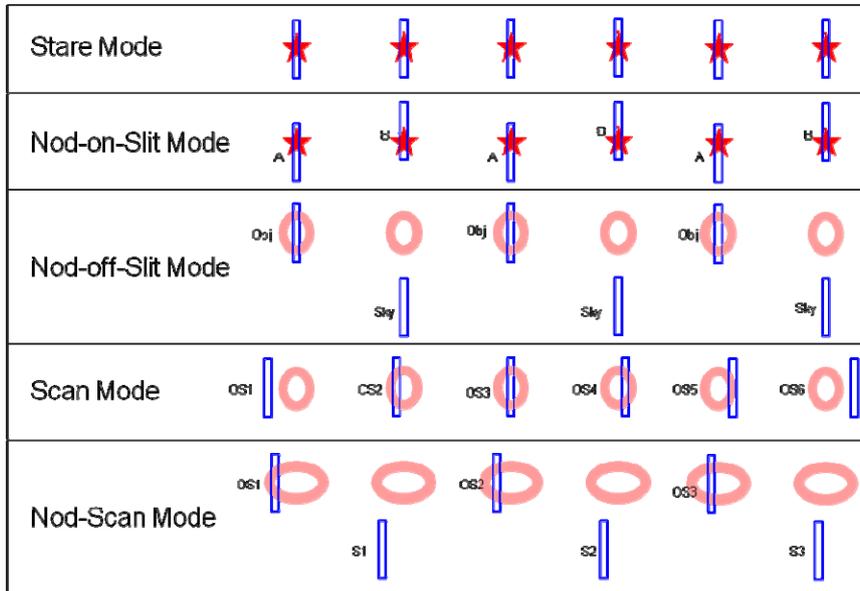


Figure 2. Observation modes of IGRINS.

Depending on the science targets, IGRINS will have several observation modes as follows.

- Stare Mode: We use this mode for pointing and focusing point sources. Image data will be saved.
- Nod-on-Slit Mode: This is the most typical mode for point source observations. The data reduction pipeline will use (A-B) subtraction results.
- Nod-off-Slit Mode: This is for extended source observation. The frequency of the sky observation can be set in the observing parameters.
- Scan Mode: This is for mapping a small (slit length size) extended source. The first and the last slits are placed off from the source, in order to be used as sky observations.
- Nod-Scan Mode: This is for mapping a large extended source. The frequency of the sky observation can be set in the observing parameters.

The observer can create custom observation mode using observation sequence script, but the data reduction pipeline modules only support the pre-defined observation modes.

The data reduction pipeline will reduce the raw data in real time. The analysis of the cross-dispersed echellogram patterns is very complex (Rayner et al. 2003; Cushing et al. 2004). The reduction process starts with preprocessing of the raw data and finding of the order extraction solutions, distortion solutions, and wavelength solutions as follows (Pyo 2002):

- Preprocessing (for all raw data)
  1. bad pixel correction
  2. cosmic-ray event correction
- Flat (with Tungsten-Halogen Lamp)
  1. Preprocessing
  2.  $(Flat_{on} - Flat_{off}) \Rightarrow Flat$
  3. order aperture extraction  $\Rightarrow$  **Order Extraction Solution**
- Wavelength Calibration (with Th-Ar Lamp)
  1. Preprocessing
  2.  $(ThAr_{on} - ThAr_{off}) \Rightarrow ThAr$
  3. order aperture extraction using Order Extraction Solution
  4. spatial distortion correction  $\Rightarrow$  **distortion solution**
  5. wavelength calibration  $\Rightarrow$  **wavelength solution**

- 6. convert 2D data to 1D spectra
- Standard Star (OB type stars in Nod-on-Slit Mode)
  1. Preprocessing
  2. (A - B)
  3. order aperture extraction along the stellar continuum ⇒ *updated Order Extraction Solution*
  4. spatial distortion correction using distortion solution
  5. wavelength calibration using wavelength solution
  6. extract 1D spectra ⇒ Standard Star Spectra

## 5. OBSERVATION PLANNING MODULE

We will also develop observation planning software modules with which observers can estimate their observation feasibility and required observing time. This software package runs on DSC, but is independent from the data reduction pipeline. Observers can install this program module on their home computers before their observation run.

The modules consist of:

- Telluric Spectrum Simulator, which calculates the model atmospheric transmission at the given PWV values and the Doppler shifts by the Earth orbiting motion;
- Exposure Time Estimator, which calculates the estimated sensitivity on the wavelength, the PWV and the seeing values;
- Parallax Angle Calculator, which calculates the exact position of target (HA, Dec) on the weather conditions (P, PWV, T).

## 6. MAINTENANCE AND FUTURE WORK

The software codes should be in modular form to make minor modifications (e.g., changing GUI window formats and adding parameters in the control windows) possible by non-professional programmers. Upgrading hardware components may need software engineers.

In the future, we may move IGRINS to other big telescopes. For 4m class telescopes, changes will be required mostly on the telescope interface and guiding routines. We also expect some hardware upgrades, but the data reduction pipeline will not be changed. For 8m class telescope (e.g., GEMINI), there are many requirements for the instrument and software. It might be necessary to upgrade many hardware components and software interface concept. In this case, we may need major software upgrading works.

## 7. ACKNOWLEDGEMENT

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# Telescope interface system of CQUEAN on McDonald 2.1m telescope

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## ABSTRACT

CQUEAN (Camera for QUasars in EARly uNiverse) is an optical CCD camera which has enhanced quantum efficiency at around  $1\mu\text{m}$  band, thus efficient for observation of objects in early universe. CQUEAN is going to be attached to the cassegrain focus of the Otto Struve 2.1m telescope at McDonald Observatory, USA. We are designing a hardware adapter to attach a filter wheel and the camera to the telescope. Since the telescope has a large focal ratio of  $f/13.65$ , we plan to install a focal reducer between the filter wheel and the telescope to reduce the focal length for larger field of view and proper sampling of sources on the detector. Software for instrument control and observation will be developed using python.

**Keywords:** Optical CCD camera, focal reducer, high redshift quasar

## 1. INTRODUCTION

The most distant quasars are an important tool to understand the nature of early universe. They are used to probe the transition from neutral to ionized state of intergalactic medium, and they can give us clues to the very early growth of supermassive blackholes in massive galaxies (Willot et al. 2009). Because they are very luminous, they can be observed with medium size telescope. Due to their extreme redshifts, however, most of their emissions can be observed from around  $1\mu\text{m}$  wavelength and longer. Recent availability of large format Near-Infrared arrays and/or deep-depletion optical CCDs makes a survey of high redshift quasars more feasible.

CEOU (Center for Exploration of the Origin of the Universe) is developing an optical CCD camera system, CQUEAN (Camera for QUasars in EARly uNiverse). CQUEAN will use a deep depletion CCD which has enhanced quantum efficiency around  $1\mu\text{m}$  wavelength band. Thus it will be an efficient tool to observe high redshift quasars of  $z > 7$ . It is going to be attached to the Otto Struve 2.1m telescope at the McDonald Observatory in USA. The seeing condition at McDonald Observatory is around  $1.2''$ , and the site has dark night sky, adequate conditions for observation of high redshift quasars. However, the telescope has a large focal ratio which causes a small field of view for the instruments at its cassegrain focus.

As a first step toward larger astronomical instrument project, we have bought a commercially available CCD camera and appropriate filters to build CQUEAN. And we are making a telescope interface with focal reducer for CQUEAN to secure a larger field of view at the 2.1m telescope. In this presentation, we describe our project to manufacture the telescope interface and its current status.

## 2. HARDWARE INTERFACE

In order to install the science CCD camera to the telescope, we need to develop a hardware interface system. The hardware interface should hold a filter wheel in front of the science CCD camera. In addition, a separate CCD camera is going to be attached behind the telescope to guide it automatically. This CCD camera will see point sources from an off-axis image of the telescope. Therefore, the telescope adapter has to hold the guiding CCD camera module as well as a facility to feed the off-axis image to the guiding CCD camera. The schematic diagram of the telescope interface structure is shown in Figure 1.

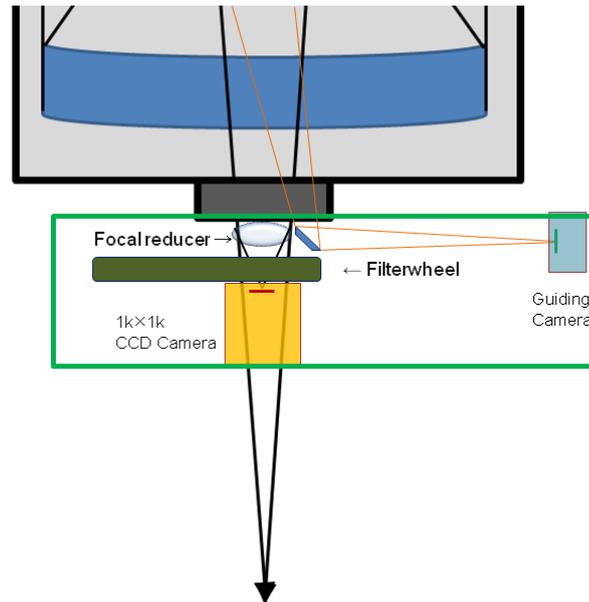


Figure 1. Schematic diagram of the telescope interface. The whole components will be included in one structure which is indicated with green box in the figure.

We plan to install seven filters for CQUEAN. Broadband filters include  $g'$ ,  $r'$ ,  $i'$ ,  $z'$ , and Y. The first three filters have very similar characteristics to those of SDSS filters (Fugugita et al. 1996), while  $z'$  filter will have narrower bandwidth than the corresponding SDSS filter to avoid the atmospheric absorption band at around 9500Å. Our Y filter will also have narrower bandwidth than the original Y filter specification (Hillenbrand 2002), to minimize the effect of air glow. In addition, we plan to install two additional filters to enable effective selection of quasar candidates at  $5 < z < 5.8$ .

The McDonald 2.1m telescope has rather a large focal ratio of  $f/13.65$  at its cassegrain focus. The resolution and pixel size of our science CCD camera are  $1024 \times 1024$ , and  $13 \mu\text{m} \times 13 \mu\text{m}$ , respectively. Thus, the camera would have a pixel scale of  $0.094''/\text{arcsec}$ , and field of view of  $1.6' \times 1.6'$ , which is not adequate for our scientific objectives. To solve this situation, we plan to install a focal reducer in front of the optics of the CCD camera system. As can be seen in Figure 2, it consists of four lenses to reduce the focal length of the telescope to three fold, while trying to minimize the degradation of image qualities. The resultant pixel scale and field of view for CQUEAN will be  $0.283''/\text{arcsec}$ , and  $4.82' \times 4.82'$ , respectively.

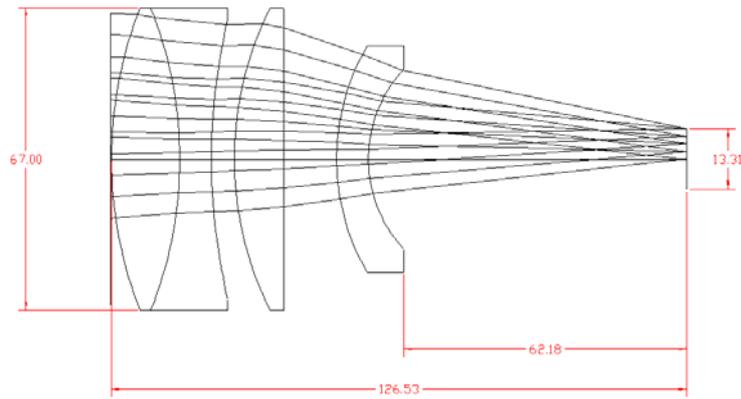


Figure 2. The optical configuration of focal reducer. It consists of four spherical lenses.

At present, we are carrying out the tolerance analysis on the current optical configuration of the focal reducer, and the mechanical design of the telescope hardware interface including the focal reducer lens barrel. The test of the focal reducer and related configuration will be carried out upon the completion.

### 3. SOFTWARE INTERFACE

The software for CQUEAN interacts with an observer to set up the CQUEAN system for observation. For example, it sets the filter according to observer's input, and it also sets up the readout mode and exposure time of the CCD camera before an exposure is started. The observation of a target is made either in a long exposure or in a series of short exposures according to predefined dithering pattern to suppress large noise. It displays each obtained image on a computer console upon acquisition so that an observer can visually inspect them. Then the software saves the acquired data in a FITS format to the computer hard disk, with various observation information gathered from the filter wheel and the telescope. It also interfaces with the telescope control system to point the telescope to a target before starting observation. Figure 3 displays the system structure of CQUEAN where connections among various software and hardware components are shown.

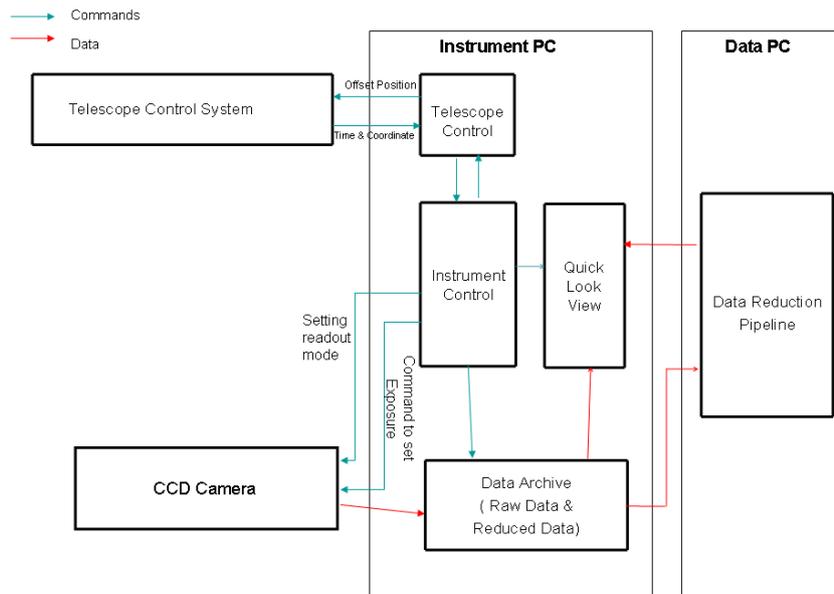


Figure 3. System structure of the CQUEAN. We assume two computers, each for instrument control and data processing in this diagram.

A suite of software is going to be developed to implement the requirements described above. We will use Python as our language since it is relatively easy to develop and to maintain the software, with a CCD camera developer kit supplied by the CCD camera maker. To save time for coding, freely available utility programs (ex. ds9 as quick-look window) will be integrated as much as possible into the CQUEAN software development.

We are going to use the auto-guiding software originally developed for 2.7m telescope by McDonald Observatory. They are now adapting the software to 2.1m telescope. It will control the guide CCD camera to obtain the images of guiding star. It will calculate the amount of offset from the image, and then it will interact with telescope control system to track the target object. It will be a separate program from the CQUEAN control software.

#### **4. CONCLUSION AND SUMMARY**

We described the telescope adapter system for CQUEAN, an optical CCD camera with enhanced QE at  $1\mu\text{m}$  wavelength range. It will be an efficient tool for survey of quasars in early universe. In order to make efficient observation with McDonald 2.1m telescope, we are designing a focal reducer which will offer a wider field of view. A program for observer interface will be developed by us with python. The CQUEAN project will be a step toward larger astronomical instrumentation projects by universities.

#### **5. ACKNOWLEDGEMENT**

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