# **Current Status of CQUEAN**

Won-Kee Park<sup>a</sup>, Eunbin Kim<sup>b</sup>, Hyeonju Jeong<sup>b</sup>, Jinyoung Kim<sup>c</sup>, Juhee Lim<sup>c</sup>, Changsu Choi<sup>a</sup>, Soojong Pak<sup>b</sup>, Myungshin Im<sup>a</sup>

> <sup>a</sup> CEOU/Department of Physics & Astronomy, Seoul National University <sup>b</sup> School of Space Research, Kyung Hee University <sup>c</sup> Department of Astronomy and Space Science, Kyung Hee University

## ABSTRACT

CQUEAN (Camera for QUasars in EArly uNiverse) is an optical CCD camera system that consists of a science CCD camera, a guide CCD camera, and seven filters. In addition, a focal reducer is installed in front of the science camera to secure a larger field of view for the system. The combined sensitivity of the optics and the CCD chip is enhanced at longer optical wavelength range than conventional optical CCD camera, thus it is an adequate system to study the high redshift quasars. It is controlled with the software developed in house with python. Auto-guiding is carried out with a guider program from McDonald Observatory. Engineering run of the system was carried out from Aug. 10, 2010 to Aug. 17, 2010, with 2.1m Otto Struve telescope at McDonald Observatory, USA. In this presentation, we report the current status of CQUEAN, its performance, and the result of the engineering run.

Keywords: CCD, Optical CCD camera, high redshift quasar, test operation

## 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).

CEOU (Center for Exploration of the Origin of the Universe) has developed an optical CCD camera system, CQUEAN (Camera for QUasars in EArly uNiverse). As its name implies, CQUEAN is designed to make observation mostly of high redshift QSOs. It uses a deep depletion CCD that has enhanced quantum efficiency around 1 $\mu$ m wavelength band than conventional CCDs, because QSOs of z > 6 emit most of their fluxes beyond SDSS *z*'-band due to their extreme redshifts. It has seven filters appropriate for detection and observation of high redshift objects. In addition, CQUEAN is equipped with an auto-guiding facility to make the long exposures of faint targets, and a focal reducer to secure a large field of view.

Engineering run of CQUEAN was carried out from Aug. 10 to Aug. 17, 2010 at the McDonald observatory, USA. Every instrument was tested successfully, and some useful scientific data could be obtained. In the presentation, we describe the early results of CQUEAN engineering run, as well as the current status of CQUEAN.

### 2. CQUEAN CONFIGURATION

CQUEAN consists of five components: Science CCD camera, filterwheel, focal reducer for science CCD camera, guide CCD camera, and moving mechanism for guide CCD camera. Science CCD camera uses a deep depletion CCD which is more sensitive than conventional CCD around 1µm bands. It has 1024\*1024 pixels which size is 13µm\*13µm, thus chip size is 13.3mm\*13.3mm. In front of the camera is a filterwheel that holds seven broadband filters: g', r', i', z', Y, Is and Iz. The first three filters are similar to those in SDSS filters (Fukugita et al. 1996), while z' and Y have bit different transmissions from SDSS equivalent or in Hillenbrand (2002). Is and Iz filters are custom designed ones to study the quasars in 5 < z < 5.8. A black anodized aluminum piece is installed in the remaining filter hole to block the light when taking bias or dark exposures. 2.1m telescope at McDonald observatory has quite a large focal ratio of f/13.65 at its cassegrain focus. This large focal ratio would cause a severe oversampling on an acquired image. To solve the problem, we installed a focal reducer that reduces the focal length three fold. The resultant pixel scale of the CCD camera is 0.276 arcsec/pixel, and Field of View is 4.7\*4.7 arcminutes. As for the guiding CCD camera, we used a 1024\*1024 pixel CCD camera from Finger Lake Instrument. A flat mirror and a baffle are installed beside the science CCD camera to feed an off-axis image to the guide CCD camera. Because the expected number of adequate guide star is small, we implemented a moving mechanism for the whole guide CCD system. The moving mechanism rotates the camera system 90 degrees around the science CCD camera to view more off-axis fields.

All components of the CQUEAN are connected to control PC via USB port. While USB connection is simple, the length of connection cable is limited to 5m. Therefore, we attached the control PC to the telescope as well, and accessed the control PC from the network with another user PC. While this configuration looks complex, this allows us to use user PC as a backup in case when control PC gets in trouble. The whole configuration of CQUEAN is shown with a schematic diagram in Figure 1.

The CQUEAN control program is a GUI program written in python. The backend routines for instrument control part uses the Software Developer Kit (SDK) supplied by each vendor. At present, GUI consists of two windows: Data Taking window and Quick Look window. Through Data Taking window, the user can control the science CCD camera, filterwheel, and moving mechanism of the guide CCD camera system, to obtain the image data. This window also displays the current status of 2.1m telescope. The control of guiding CCD camera as well as auto-guiding is done with a separate program, agdr, supplied from McDonald Observatory.



Figure 1. Schematic representation of CQUEAN configuration

# 3. INSTALLATION AND TEST OPERATION

The engineering run of CQUEAN was carried out from Aug. 10 to Aug. 17, 2010 at the 2.1m Otto Struve telescope in McDonald Observatory, USA. It took about three hours to assemble all parts of CQUEAN and to attach it to the cassegrain focus of the 2.1m telescope. Figure 2 shows the CQUEAN attached at the cassegrain focus of the 2.1m telescope.

Test operation showed that all components worked as expected. However, agdr, the auto-guiding software, had to be modified so that it can update in real time the position angle of guide CCD image frame as the camera rotates around the optical axis. Although the best operating temperatures for CCD cameras are yet to be decided, we cooled down the science CCD camera and the guide CCD camera to -70°C and -30°C, respectively, in accord with the ones used in the vendor test. It took about 10 minutes to cool down the science CCD camera before starting the observation. Series of bias images, and dark images of various exposure times were obtained at every night at various temperatures to examine the behavior of the camera according to temperature. Also dome and twilight flat images were obtained for all filters available. The analysis of the acquired data is in progress.

The control software showed a couple of problems that need to be fixed. The most severe problem found was that Quick Look window in the program crashed often when it had to repeatedly display images in short time interval, due to memory management problem. And it turned out that program needs a redundancy such that it should remain operational even when it cannot communicate with external devices such as TCS of the telescope, which was not the case in this run. Also, the current version of software lacks a couple of essential functionalities for observation such as quick data quality checking. All of these problems will be fixed in next version of program.



Figure 2. CQUEAN attached to the telescope. Science CCD camera is the silver box in the center, and guide CCD camera is the small black box in the upper right part of the system. The big black box in the left is the control PC. The motor below the science CCD camera moves the arm to rotate guide CCD camera.

Figure 3 shows examples of CQUEAN images obtained during the test run. Although bias level is uniform and constant over all region of the chip, dark level shows non-uniformity between lower and upper part of the chip for exposures longer than 100 seconds. We are now investigating on the origin of this non-uniformity. Also vignetting is seen in the raw object images at all four corners of the chip due to the limited width of focal reducer optics. However, they could be removed to some extent with flattening in the final product.



Figure 3. Examples of images obtained with CQUEAN. (a) bias image, (b) dark image of 300 sec. exposure, (c) i-band raw object image, and (d) flattened image of same field.

# 4. SCIENTIFIC OBSERVATION

During the engineering run, we obtained several scientific data with CQUEAN. Previously known high redshift QSOs were observed so that we can check the data quality of CQUEAN. On every possible night, we made observation of AB photometry standard star for calibration purpose, and we made observation of several high redshift QSO candidates. We could successfully observe the afterglows of two Gamma Ray Burst (GRB) events, GRB100814A and GRB100816A, that occurred during the engineering run. Initial results of these observations were reported to GCN circular (Im et al. 2010a, 2010b). More detailed analysis of these data is on going. In addition, we obtained some spectacular images of selected astronomical targets as the First Light images, which are displayed in Figure 4.



Figure 4. Selected astronomical objects observed with CQUEAN. (left) Interacting galaxy group, Arp 319, (right) Galactic globular cluster, Messier 15.

### 5. SUMMARY AND CONCLUSION

CQUEAN is an optical CCD camera system which consists of several elements: It is equipped with deep depletion CCD chip and seven filters. We built a focal reducer to secure a larger field of view. And a guide CCD camera is attached for long exposures. With these components, we built an optical camera system that aims to make observation of high redshift objects in early universe.

Test run of CQUEAN was carried out from Aug. 10 to Aug. 17, 2000 at the McDonald observatory. We confirmed that all hardware worked successfully, although the software showed some problems that need to be fixed in the next version. The calibration data as well as scientific data were acquired during the run, which includes observation of GRB afterglows, high-z QSOs and high-z QSO candidates. We are now analyzing the data. The regular scientific observation with CQUEAN will begin from next run on.

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