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Prospect of China's Auroral Fine-structure Imaging System (CAFIS) at Zhongshan station in Antarctica

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Abstract A new auroral imaging system is reported which is planned to be deployed at Zhongshan Station in Antarctica in the end of 2009. The system will focus on study of optical auroras in small scales and be called China's Auroral Fine-structure Imaging System (CAFIS). The project of CAFIS is carried out by support of 'the tenth five-year plan for capacity building' of China. CAFIS will be a powerful ground-based platform for aurora observational experiments. Composing and advantages of CAFIS are introduced in this brief report. Some potential study topics involved CAFIS are also considered.
Key words CAFIS, fine-structure aurora, Zhongshan station.

1 Introduction

It is well known that auroral research has a very long history (Stormer, 1955[1] and references therein). It also has long been known that aurora is extremely rich in fine structures ever since the beginning of auroral research[1]. During the long aurora research, the ground-based instruments, such as all sky cameras and scanning photometers, were the main approaches for the auroral observations. However, the present understanding of auroral physics is largely based on the most recent satellite observations, which unveiled important global auroral phenomena and dynamics, but at the expense of missing auroral fine structures. No satellite imager has so far been able to give a resolution good enough to resolve the fine-structure auroras. The fine structures of optical aurora are believed to associate with fine structures in ionospheric properties, such as its electron density and conductivity[2-3]. Although the smallest auroral features do not map far out into the magnetosphere but is caused by more local processes[4], it does not mean that the fine auroral structures are unimportant for understanding the large-scale behaviors of the magnetosphere. It is believed that the fine auroral structures are key to understand auroral particle acceleration[5-6]. Due to importance of the fine structure to understanding the auroral physics, in addition to end of the satellite auroral imaging missions, such as Polar and IMAGE, auroral research focusing on the fine structure based on the ground observations is just becoming hot[2, 7]. Under this background as well as by the support of the 'tenth five-year plan for capacity building' of China, a ground-based auroral imaging system, called China's Auroral Fine-structure Imaging System (CAFIS), is assembled for studying the fine-structure auroras. This system will be set up at Zhongshan station in Antarctica in the end of 2009 and its composing and advantages will be introduced here.

2 Composing and advantages of CAFIS

Under scheme of the 'tenth five-year plan for capacity building' of China, an auroral multiple-wavelength all sky CCD imager system is planed to be deployed at Zhongshan station. CAFIS is assembled based on this scheme but it will provide much improvement than a pure all-sky-imager system by adding several field of view (FOV) modules and filters.

3 Composing of CAFIS

CAFIS includes 4 imagers manufactured by Keo Scientific Ltd in Canada, one with a 6-position filterwheel and the other three having a single filter slot in each. Each imager consists of 4 parts, i. e., scientific imager, EMCCD (Electron Multiplying Charge Coupled Device) camera, FOV module, and filter. All the imagers are proven, custom designed f/1.2 scientific ones. The EMCCD cameras have resolution of 1024 × 1024 pixels with 13.3 × 13.3 mm (large) image area. The detailed composing and technical specifications for CAFIS are listed in Table 1.

Table1. Components of the system

Quantity	Name of the Part	Description
1	Keo Sentry 3″ Scientific Imager-6-position FilterWheel	—3-inch telecentric allsky optics —f/1.2 imaging onto CCD —High-reliability shutter —6-position filterwheel with temperature control
3	Keo Sentry 3″ Scientific Imager	—Single Filter-3-inch telecentric allsky optics —f/1.2 imaging onto CCD —High-reliability shutter —Single filter slot
4	CCD Camera: Andor EMCCD iXon 13 mm	—1024 × 1024 Pixel Sensor —13.3 × 13.3 mm Image Area
4	Keo FOV Module Drop-in Replacement Module for Wide Angle Field of View	Modules will be for 8°, 19°, 47° and 76°
2	Filter 3″ dia., 427.8 nm CWL	CWL = 'Center Wavelength'
4	Filter 3″ dia., 557.7 nm CWL	
2	Filter 3″ dia., 630.0 nm CWL	
1	Filter 3″ dia., background for 427.8 nm	
1	Filter 3″ dia., background for 557.8 nm	
1	Filter 3″ dia., background for 630.0 nm	
1	Filter 3″ dia., H-beta	
1	Filter 3″ dia., background for H-beta	
3	Filter 3″ dia., BG 3 glass	Block the slow emissions

4 Advantages of CAFIS

The EMCCD technique developed in the most recent years shows tremendous advantages in comparison with both image-intensified CCD and bare CCD techniques[8]. It provides an on-chip gain that practically eliminates the readout noise, thus enabling very high frame rates with good signal-to-noise ratio. The CAFIS imagers can provide the highest temporal resolution (frame rates) of 30 frames per second in practical, which is one of the advantages of CAFIS.

Table 1 lists 4 FOV modules that are for 8°, 19°, 47° and 76°, respectively, as well as a variety of filters in different wavelengths. All of the modules and filters can be easily replaced and assembled to the imagers, which provide CAFIS significant flexibility for auroral observational experiments. As a summary, CAFIS owns the following advantages.

1) CAFIS can realize truly simultaneous exposures at 4 channels of 427.8 nm, 557.7 nm, 630.0 nm, and H-beta lines by using the 4 imagers. It should be mentioned that the imager with filterwheel can be easily used as a single-filter imager.

2) CAFIS can provide background observations for emission in the 4 channels (i. e., 427.8 nm, 557.7 nm, 630.0 nm, and H-beta lines). The main function of the background observation is to subtract continuum emissions (from broadband sources, such as scattered moonlight, etc.) that spill into the filter's passband. The background channel was chosen as close as possible to the signal channel for the best results but without significant auroral emissions within its passband. Thus, it is guaranteed that all the remaining signals (after subtraction) will be actually originated from the given auroral line or band emission. The background observations are vital when quantitative works on the data should be conducted, for example, to find electron characteristic energy or fluxes. It also should be noticed that if the background observations will be carried out by putting the background filters to the imager with filterwheel, truly simultaneous observations at any 3 of the 4 channels are enabled by using the three single-filter imagers. The filter wheel speed can be optimized and fined tuned, so that filter-change speed between adjacent filters is 0.5 seconds or less. Thus, the penalty is only that "truly simultaneous" background observations for each channel can not be achieved. In fact, this is not normally a problem with slow emissions like 630.0 nm. In the case of chaotic, fast emissions like 557.7 nm, it could be hard to make quantitative works even with simultaneous observations.

3) CAFIS can make parallel observation in multiple scales by using the 4 FOV modules. This character should be the most advantageous for this system, with which a great number of observations can be designed as they are necessary. For example, the routine auroral observation with full of view at 427.8 nm, 557.7 nm, 630.0 nm, and the 3 background channels can be carried out by using the imager with filterwheel. At the same time, if the pulsating aurora is interested, the all-sky modules can be removed from any two of the single-filter imagers and be replaced by 76° and 47° modules, respectively. Furthermore, if 47°, 19°, and 8° FOV modules are mounted to the three single-filter imagers, respectively, they will enable the studies on flickering aurora, black aurora, auroral filaments, and narrow arcs. Realization of these functions relies on that the EMCCD cameras are very flexi-

ble. It can realize either long-time exposures or fast 30-frame-per-second exposures, which all are under control of software. Of course, in order to get sufficient flux at the faster frame rates, appropriate filters should be used, which are also prepared (i. e., BG 3 glass filter) in CAFIS. In one word, by combination of the modules and filters, CAFIS will be able to provide a great number of observational patterns that are full of meaning in science. Whereas, these possible observation patterns will not be exhausted here.

5 Potential study topics involved CAFIS

CAFIS can make parallel observation in multiple scales and owns obvious advantages in study on the fine-scale auroral structures. Here the fine-scale structures refer to the auroral forms with spatial scales from ~30 m to several or tens kilometers and with temporal scales shorter than about 1 s, which include narrow arcs, auroral filaments, black auroras, curls, rays, and others. Measuring these structures put high demands on the instrumentation for the high temporal and spatial resolutions. Fortunately, CAFIS will be a powerful platform for measuring such fine-scale auroras. It is the most important that there are still many unanswered questions regarding formation mechanisms of those auroral fine-scale structures. In fact, it is believed that as so far there is no small-scale structure for which the mechanism is completely understood[2]. For the potential study topics involved CAFIS, some of the topics suggested by Borovsky (1993)[5] for the ground-based observations are still highly relevant and should be considered. Beside those, a few other topics are also listed below.

1) Measuring optical emission line ratios. Because CAFIS can realize 'truly simultaneous' observations in multiple lines, it enable the observers to measure the optical emission line ratios. The importance of this work can refer to the statement of Borovsky (1993)[5]. 'Measuring the relative intensities of the various spectral lines (such as N_2^+ and O_2^+ lines) can determine whether the airglow is produced by very energetic electrons in the gas (which can ionoize molecules) or by less energetic electrons (which may not be capable of ionizing molecules). With such line-intensity measurements, it may be possible to determine whether fine-scale arc are produced by low-energy discharge processes owed to ionospheric electric fields and/or plasma waves or whether the fin-scale arcs are produced by the precipitation of energetic electrons.'

2) Correlation fine-scale arcs with larger arc structures. This topic also refers to Borovsky (1993)[5]. 'Since an auroral arc requires both a generator mechanism and an accelerator mechanism, there may be two spatial scales associated with arc, one for each mechanism'. 'By correlating occurrence of fine-scale sturcutres with the occurrence of larger structures, information about the matching of accelerator mechanisms to generator mechanisms may be gleaned'.

3) Measuring auroral-arc temporal fluctuations. Many of the auroral-arc electron-acceleration mechanisms and generator mechanisms have temporal fluctuations associated with them, and these fluctuations may lead to predictable fluctuations in the airglow intensities of auroral arcs. Examining arc fluctuations may be of help in deciding the merit of auroral arc theories, and it may provide clues for new mechanisms.

4) Study on the rayed structures in 'dayside corona'. Yang et al. (2000)[9] noticed that the noon region of the oval does not feature a 'gap' of discrete aurora; instead, it is occupied by auroras termed 'dayside corona'. The dayside corona always consists of fine-scale rayed structures and shows occurrence peak in an area where the origin of precipitation may come from a number of different magnetospheric regions. As pointed out by Yang et al. (2000)[9], further subdividing of the dayside corona and associating them specifically with the possible source regions should be considered.

5) Making statistics on each fine-scale auroral form. This work has not been extensively done because most previous studies on the fine-scale auroras were based on observational campaigns[10]. Thanks to the routine auroral observation at Zhongshan station, a designed observational plan for examining the fine-scale structures can be carried out through a whole winter with CAFIS. With these detailed observations, it is great expects to acquire new knowledge for the fine-scale auroras.

6) Study on proton aurora. The H emission lines observed from the ground can be used for indirect measurements of proton precipitations. In fact, the existence of proton precipitation in the auroral regions was first inferred from ground-based observations of Doppler-shifted hydrogen Balmer series emissions[11]. Two H emission lines of the Balmer series can be observed from the ground, i.e., H-alfa at 656.3 nm and H-beta at 486.1 nm. However, even though the H-alfa line is brighter, the close spectral proximity to the bright N2(1P) emission makes it difficult to obtain clean line profile. As a result, the H-beta line is commonly selected for observations. CAFIS can also be used for H-beta line observation, which along with other auroral emissions will enable the observers to probe magnetospheric processes pertaining to aurora occurrence.

6 Summary

By the support of the 'tenth five-year plan for capacity building' of China, a new auroral observation system, CAFIS, will be deployed at Zhongshan station in Antarctica in the end of 2009. CAFIS is a powerful platform for auroral observation characterized as significant flexibility and advantages. Besides guaranteeing the routine auroral observations at 427.8 nm, 557.7 nm, and 630.0 nm emission lines, CAFIS will, at least, be enabling the observers to involve the studies on those fine-scale auroras, such as narrow arcs, auroral filaments, black auroras, curls, rays, and others. CAFIS also provide observers capability for indirect measurement of the proton precipitation. Hopefully, CAFIS will open a new era for auroral research at upper atmospheric division (UAP) at PRIC.

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