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Development of the De-spun Rocket Borne Imager 2 in support of Rocket Observations of Pulsating Aurora

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Abstract. The De-spun Rocket Borne Imager 2 (DERBI2) was designed for the February 2007 launch of the Rocket Observations of Pulsating Aurora (ROPA) sounding rocket. DERBI2 will obtain large-scale, topside images of pulsating aurora which will be ”de-spun” to minimize the effects of image blurring due to spinning of the rocket payload. This despinning is achieved via a rotating platform within the imager upon which will be mounted a back-thinned, frame-transfer CCD and supporting electronics. This CCD was chosen for superior gain and transmission characteristics, and as a result, DERBI2 is a more compact imager with a wider field of view than its predecessor.

Keywords. auroral imager, pulsating aurora, ROPA

1 Introduction

Rocket-borne instruments make ionospheric measurements that exhibit better spatial resolution than those of ground-based and most satellite-borne instruments. This makes sounding rocket measurements essential to a good understanding of the earth’s ionosphere. While auroral physics can benefit greatly from optical studies of the various emissions resulting from auroral phenomena, optical studies are more easily tackled from the ground. However, because of the motion of a spacecraft along its trajectory, the magnetic footprint of the payload may be within the field of view of a stationary, ground-based, all-sky camera for only a brief period of time and the in situ measurements may be difficult (although not impossible) to couple to ground-based images. However, with some careful considerations, an optical instrument mounted to a spacecraft can image the magnetic footprint of the payload for a significant period of time while other instruments take in situ measurements. In this way, optical instruments can easily provide context, in space and time, for the in situ measurements. This has been a motivation for several spacecraft born imagers.

Imaging from a spacecraft is complicated by the problem of image blurring created by the transverse motion of the spacecraft, as well as by rotation and coning of a spin stabilized spacecraft. Other aspects to be taken into consideration include the curvature of the magnetic field line. The mounting and field of view of the optical instrument must be such that the magnetic footprint of the payload stays within that field of view throughout the imaging period or the obtained images can not be coupled with the measurements of other onboard instruments (Ellis, 2006).

Several recent satellite projects have incorporated imagers using various means of correcting/preventing blurring due to the motion of the spacecraft. One popular method of limiting the amount of image blurring due to transverse motion is Time Delay Integration (TDI) which has been used on the Viking and Freja satellites (launched in 1986 and 1992) as well as for the IMAGE-FUV instrument (launched in 2000). The method chosen for the POLAR mission (launched in 1996) was to mount the imagers on a de-spun platform.

However, few auroral imagers have been flown on sounding rockets, although interest in the application has been on the increase. One of these first attempts at imaging from a sounding rocket was the development of the De-spun Rocket Born Imager (DERBI) for the SERSIO (launched 22 January, 2004) and CASCADES (launched 06 March, 2005) missions. DERBI is the direct predecessor of the De-Spun Rocket Borne Imager 2 (DERBI2) which has been developed for Rocket Observations of Pulsating Aurora (ROPA) and is the focus of this paper. Therefore, it is helpful to briefly discuss the design and operation of the original DERBI.

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2 Design and operation of the De-spun Rocket Borne Imager (DERBI)

The largest contributor to image blurring for an aft viewing, sounding rocket imager is the rotation of the payload, since other contributors such as payload coning (on the order of 0.1 Hz) tend to be kept to a minimum and the horizontal translation of the payload along its trajectory tends to be fairly slow, 1 km/s. Because of this, the main focus in the design of DERBI, and again DERBI2, was minimizing the blurring due to this rotation. For DERBI, this is achieved via an Integrated Optical Spinner (IOS).

DERBI consists of a photointensified camera by ITT Industries, with a c-mount lens assembly, mounted behind the IOS which works to rotate the image via a Dove prism mounted and spun on Delrin bearings. When seen through a rotating Dove prism, an image appears to rotate at twice that speed. Therefore, within the IOS, the Dove prism is rotated at half the spin rate of the rocket payload and in the opposite direction to effectively de-spin the image. This speed is controlled via a tachometer and velocity feedback loop. The result is a nearly stationary image with a small amount of residual rotation, which greatly reduces the amount of image blurring (Ellis, 2006).

The object of the SERSIO mission was to better understand the processes behind ionospheric outflows of atomic oxygen and therefore DERBI-SERSIO was equipped with a bandpass filter centered at the 630 nm auroral emission. The mission called for a 32-degree field of view which was not directly compatible with the Dove prism which will tolerate up to a 12-degree angle of incidence. This problem was addressed by additional optics, designed to "squeeze" the larger field of view into this 12-degree acceptance angle.

One objective of the CASCADES mission (see Fig. 1) was to gain information about the spatial and temporal structures of electron precipitation using DERBI. DERBI-CASCADES was developed with a 16-degree field of view and a small amount of distortion was tolerated rather than incorporate the complicated "squeezing" optics utilized for the SERSIO mission. DERBI-CASCADES was equipped with a RG645 Schott filter to transmit wavelengths above 630 nm.

It is the successful design of DERBI that has inspired the development of a new edition, called DERBI2, to accommodate very large fields of view.

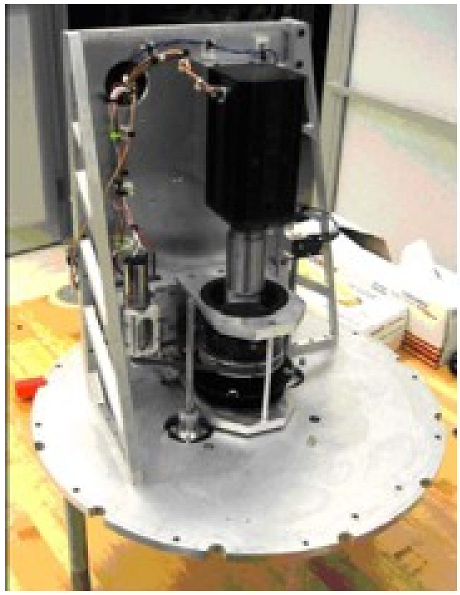

Fig. 1. DERBI-CASCADES flight instrument

3 Objectives of ROPA

DERBI2 was developed for the ROPA sounding rocket project which is scheduled for launch in February 2007 from Poker Flat Research Range in Alaska. The focus of the ROPA project is the pulsating aurora, a phenomenon which is characterized by quasi-periodic intensity modulations within a diffuse background aurora. Many physical properties of the pulsating aurora have been well documented. Observations have shown that the patches pulsate with a period of 2-20 s, averaging 8 s. The pulsating patches vary greatly in shape and size with the shape changing on a timescale of minutes (Johnstone, 1978). The patches also drift at nearly the same speed, at a rate of around 1 km/s, toward the east (Royrvik and Davis, 1977).

It is fairly well accepted that the pulsating aurora is caused by energetic electrons, and there is evidence suggesting that the process that releases these energetic electrons occurs at the equatorial region of the magnetosphere. The first set of evidence comes from the velocity dispersion which has been observed from sounding rockets (for example Bryant, 1975) between higher energy electrons and lower energy electrons arriving at the ionosphere. This velocity dispersion has been used to calculate the distance to the electron source which has been shown to be somewhere near the equatorial region. The second set of evidence comes from simultaneous, conjugate observations of the pulsating aurora in the northern and southern hemispheres (Belon, 1969; Davis, 1969; Gokhberg, 1970), which may suggest a source region near the equatorial plane.

However, the theory behind the creation of the pulsating aurora is somewhat sparse, consisting mainly of two mechanism, the Relaxation Oscillator (Davidson and Chiu, 1991) and the Flowing Cyclotron Maser (Tagirov, 1986; Trakhtengerts, 1986; Demekhov and Trakhtengerts, 1994), that may produce the source of energetic electrons that induces the pulsations. The Relaxation Oscillator Mechanism is dependent upon the growth of VLF waves due to temperature anisotropy in the electron population. The VLF waves then change the pitch angle of the electrons via Cyclotron Resonance Interaction (CRI) causing pitch angle diffusion, which results in pulsating aurora. This pitch angle diffusion causes a more isotropic particle population at the source, which causes the VLF waves to die away until a new anisotropy builds up and the cycle begins again. The Flowing Cyclotron Maser theory consists of a similar mechanism; however, a flux tube of cold plasma acts as a resonator for the VLF waves.

The first of two main objectives of ROPA is the study of the spatial and temporal structures of pulsating aurora and through image mapping the study of such structures in the energetic electron source region near the equatorial plane. This objective will be addressed primarily by the two DERBI2 instruments.

The second main objective is the study of current closure in regions of pulsating aurora. This objective will be addressed mainly by the particle and field measuring instruments but will be complemented nicely with information about the corresponding environment of pulsating patches from the images obtained by the DERBI2 instruments.

In addition to these two main objectives are several secondary objectives including a measurement of the drift speed of pulsating patches which will be calculated from the DERBI2 data and compared with the $\mathbf{E} \times \mathbf{B}$ speed of magnetospheric plasma. This will act as a measurement of the amount of coupling between the magnetospheric plasma and the pulsating aurora.

4 DERBI2-ROPA: Optical design considerations

The primary and secondary objectives of the ROPA project make the success of the DERBI2 instruments critical to the success of the project as a whole. In order to gain understanding of the structure of the pulsating patches, the DERBI2-ROPA instruments will have a very large, 116-degree field of view providing large-scale images of the pulsating auroral patches much larger than those which can be obtained by ground based all-sky cameras. This large field of view is obtained via a Cosmicar Pentax C30405TH, 4.8 mm, f/1.8, CCTV lens. With a 512x512 CCD array and an apogee of approximately 700 km (600 km above the pulsating aurora), DERBI2-ROPA is expected to image an area spanning around 1920 km with a spatial resolution of nearly 3.75 km/pixel at apogee, which is sufficient for imaging most pulsating patches which tend to span up to 50 km (Johnstone, 1978).

In order to obtain information as to the structure of these patches the first DERBI2-ROPA instrument will image emissions, including visible and near infrared, from the pulsating aurora with minimal filtering. The second DERBI2-ROPA instrument will image perhaps the most prominent of the visible emissions, the Nitrogen emission at 428 nm.

Due to the extremely large field of view of the DERBI2-ROPA instruments it is unacceptable to use narrow band, interference filters for this application due to dependence of the transmission curve on angle of incidence. Not only is blue-shifting a problem when using these filters with an uncollimated light source, but at very large angles of incidence the transmission curve can dramatically change shape to the point where widening the passband of the filter toward the blue is not sufficient to pass the desired light, even for the 428 nm auroral emission which is very narrow and much more intense than other emissions near this wavelength.

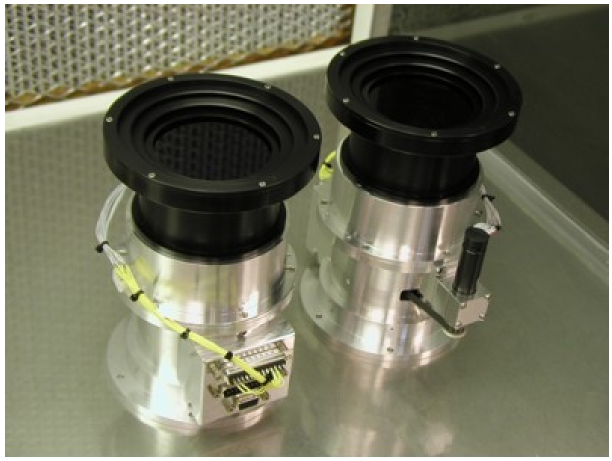

Fig. 2. DERBI2-ROPA flight instruments

The resolution of this problem was to use a custom made, colored glass filter from Barr Associates. The advantage of this type of filter is that the transmission curve does not shift in wavelength or change shape and shows minimal attenuation of the signal with increasing angle of incidence, at the expense of narrowness of the transmission curve (approximately 40 nm FWHM rather than a 1-2 nm passband) and percent transmission (the maximum transmission is about 50% at center wavelength rather than the 80-90% transmission of a narrow band, interference filter).

These filters are mounted within a black anodized, bladed baffle assembly (see Fig. 2), which acts to block or attenuate any light from outside of the field of view that may reflect off of other spacecraft components.

5 DERBI2: Mechanical design considerations

The main consideration for the mechanical design of the DERBI2 instruments was the de-spinning of the images to prevent blurring due to the rotation of the payload. The de-spinning mechanism of DERBI2 relies on a slip ring from Moog Components Group to make the electrical connection between the rotating section, consisting of the CCD and supporting electronics, and the stationary section, consisting of the motor/power circuitry and telemetry connection. Within

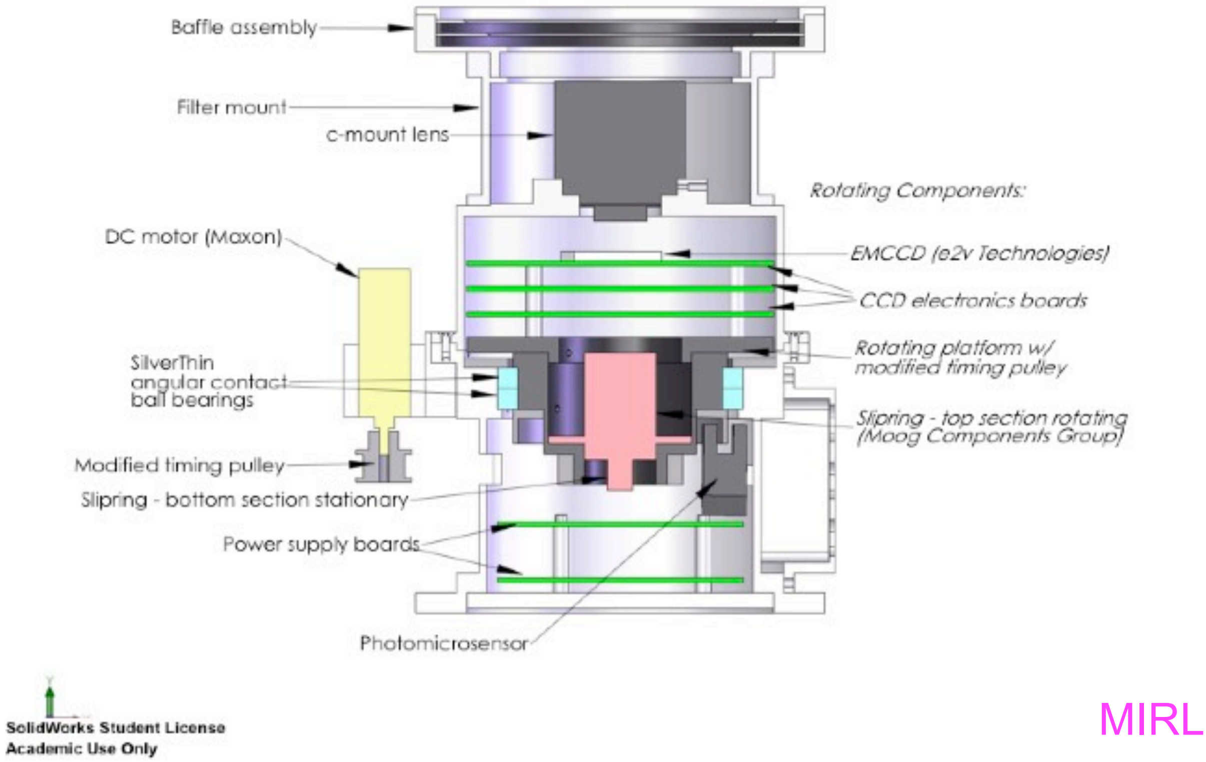

Fig. 3. DERBI2-ROPA configuration diagram

the slip ring, connection is made between the rotating and stationary portions via metal brushes.

The CCD and supporting electronics are mounted on a rotating platform that is held in place with a pair of SilverThin back-to-back angular-contact ball bearings from Mechatronics, providing a stiffer mounting than ordinary ball bearings. This spinning assembly has been successfully vibration tested and continues to function properly.

The platform is de-spun using a DC motor from Maxon Motors (Re-16), which is mounted outside of the imager housing and attached to the rotating platform with a timing belt and pair of timing pulleys (see Fig. 3). Because the spin rate of the rocket will in the end be set to 1 Hz to within a small amount of error, the spin rate of the platform is fixed to 1 Hz and any small amount of residual rotation in the images will be removed during post-processing. The position of the rotating platform within its rotation is measured by an Omron photomicrosensor which is mounted in the stationary, bottom section of the imager.

6 DERBI2: CCD characteristics

The CCD that has been chosen for DERBI2-ROPA is a back-thinned, frame-transfer CCD (CCD097) by e2v Technologies, with a 512x512 pixel array, chosen for its superior gain and transmission characteristics. This CCD has a quantum efficiency of approximately 70% at a 428 nm wavelength. Due to space and power limitations, the DERBI2-

ROPA CCDs are not equipped with thermal electric coolers and therefore using the electron multiplying register of the CCD to amplify the signal is unacceptable due to significant amounts of noise introduced as the CCD heats to warmer temperatures. This reduction in space and power usage comes at the expense of signal to noise ratio as CCD operation at warmer temperatures introduces additional dark current noise, both with and without making use of the electron multiplying register. The result of this compromise is that the dynamic range of the imagers is approximately 1 kR to several tens of kR.

Since the pulsation period tends to range from around 2-20 s, averaging around 8 s (Johnstone, 1978), the average pulsation can be resolved well by DERBI2-ROPA which obtains 10-bit digital images at a rate of 2 frames/s (300 ms integration time).

7 Contrasting DERBI and DERBI2

The design of DERBI2 is much different from that of its predecessor. The main difference regards the method of despinning the images acquired from a sounding rocket, the spinning of the CCD in the case of DERBI2 and the spinning of a Dove prism in the case of DERBI. Each method has advantages and disadvantages.

One advantage of building a camera (with the CCD mounted on a rotating platform such as for DERBI2) is the ability to custom design the camera electronics which allows custom setting of certain parameters such as frame rate and integration time, gain, sensitivity, and, in the case of DERBI2, the use of onboard data compression. However, the advantage to purchasing a high quality, intensified, low light camera from a company such as ITT Technologies (and equipping it with rotating optics such as those used for DERBI) is the significant decrease in complexity of the supporting electronics as compared with the custom electronics design of DERBI2. Also, a stationary CCD may be easily equipped with an image intensifier (as is the case for DERBI) which intensifies without requiring the use of a thermal electric cooler.

In terms of the optical design, the use of a Dove prism either severely limits the field of view of the instrument or requires an additional optical assembly to collimate the light entering the prism due to distortions associated with the prism. However, this limitation allows for the application of narrow band interference filters to any DERBI imager. In contrast, DERBI2 may be equipped with a wide-angle lens without ill effects; however, the alignment of the optical axis of the lens assembly with the center of the CCD sensor is important.

Although there are advantages to using the DERBI design for certain applications, DERBI2 is a more compact imager with all electronics contained within the main body of the 20 cm imager. The DERBI2 design also allows for the complete in-house design of the CCD electronics and allows more flexibility in terms of field of view which creates a more versatile imager.

For future applications, DERBI2 can greatly benefit from the incorporation of a thermal electric cooler to allow usage of the electron multiplying register by reducing noise levels, which will increase the signal to noise ratio of the camera system.

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