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THE STELLACAM II AS AN ALL-SKY IMAGER DURING THE SCIFER 2 ROCKET CAMPAIGN

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Abstract. Due to the rise of the moon and sun during the SCIFER 2 (Sounding of the Cusp Ion Fountain Energization Region) rocket campaign over Svalbard in mid January 2008, it was necessary to come up with a solution to monitor the sky and aurora without using intensified camera systems. The reason is that intensifiers become damaged if they are illuminated directly by the moon or from scattered light from the sun. It was decided to test a simple and commercially available solution based on a fisheye lens and a video camera used by the astronomical community. The camera successfully detected satellites, stars and weak dayside aurora. Stars were used to find the camera orientation and to evaluate the lens performance. Finally, an animation is compiled to identify the target aurora and locate the source area of ion outflow sampled by the rocket.

1. Short background

The test was carried out at the new optical laboratory for auroral research at Breinosa (78.15^o N, 16.04^o E) close to Longyearbyen, Svalbard. The site named the Kjell Henriksen Observatory (KHO) was used as scientific command centre for the SCIFER 2 rocket campaign in early January, 2008. More than 15 optical instruments from several institutions around the world supported the campaign. A mosaic of ground based data of the dayside aurora was presented in real time to the primary investigator of the campaign.

The campaign started on 2 January with a launch window from 05 to 11 UT. The time slot for the whole campaign was chosen centered around the new moon at 7 January. The last day of the campaign was planned to be 15 January. Due to bad weather, low solar activity and numerous other reasons the rocket was not launched. It was then decided to try 5 more days. At this stage the intensified all-sky video camera turned off automatically, since the moon was above the horizon. And even worse, scattered light from the rising sun became more and more evident. Our scanning photometers also turned off when the sun reached and elevation of 10 degrees below the horizon. As a result, the optical support to the campaign was limited to the period 05 – 09 UT.

Under these conditions something had to be done in order for us not to be totally blinded by the moon and the sun. We decided to quickly assemble with available components an all-sky camera without the use of an intensifier. The sensitivity and resolution of the obtained images were of sufficient quality to monitor the dayside aurora in near real time. Finally, the Black Brant XII rocket was launched on 18 January from Andøya Rocket Range in northern Norway at 07:30 UT. The rocket successfully studied ion outflow in the cleft region of the magnetosphere associated with dayside aurora over Svalbard [*Kintner et al.,* 1996].

A description of the camera together with its performance and results are reported below. Satellites are identified and stars are used to find the attitude or alignment of the camera during the launch of the rocket. The rocket's on-board GPS data record has been used to calculate the view angles and to produce an animation as seen by the camera during the flight. The target aurora is clearly identified.

2. Parts and components

The sensor head is a video camera named StellaCam II purchased from the company Adirondack Video Astronomy and a circular CS-mount fisheye lens from Fujinon. See Fig. 1. The camera also known as the WATEC 120N uses a ½" CCD chip from SONY (ICX-418ALL) that claims to operate under a minimum illumination of 0.00002 lux with a F/1.4 lens as front optics. The output is a real time frame accumulated video CCIR (PAL) signal that is stored to disk every second by a PC frame grabber. Each frame is 320 by 240 pixels at 8 bit gray scale resolution.

A remote control box is used to manually set parameters such as gain, gamma correction, and number of frames to accumulate to improve the signal to noise. In our case, the gain controller was turned to half of its range (8-38dB), the gamma correction to 1.0, and the frame accumulation was set to 32. This results in a repetition / update rate of about 1 second for each stored frame.

Figure 1. Left: The StellaCam II from WATEC Inc. with its manual controller. Right: The CS-mount fisheye lens from Fujinon with a focal length of 1.4mm to 3.1mm at an aperture of F/1.4.

3. Experimental setup

The camera was mounted under a 1m diameter transparent Plexiglas dome at KHO. The idea was to position the camera in a geomagnetic reference frame with the image axis up as North and East to the left. The camera was also tilted towards the South in order to look up the local magnetic field line (~8 degrees off the vertical). But as shown below, it turned out that the tilt was off by 2 degrees and the azimuth by 12 degrees. As a consequence, it is decided to use the geographic frame as reference.

Fig. 2 shows an example image taken at 07:32:25 UT. Weak red colored dayside aurora with an average intensity of about 3 kR is seen in the zenith (not visible to the human eye). The unit Rayleigh, R, is used by both the space- and the astronomical community [*Baker and Romick,* 1976]. The effect of scattered sun and moon light is seen to the South–East and North–East, respectively. They show up as intensified regions on the horizon where the camera is over exposed.

To find the exact orientation or attitude of the camera, it is necessary to calibrate the image by the use of stars. 13 stars are identified in Fig. 2 by the use of the software AstroViewer. The elevation and azimuth values for each star are found by the open source program called Stellarium. The procedure is given in 3 steps. First we conduct a translation in order to move the coordinate system to the center of the image. The x–axis points to the right and the y–axis up, respectively. The image of the stars is now in the xy–plane with z equal to the negative focal length of the all-sky lens. Secondly, each star coordinate is rotated towards Geographic North and tilted to the South. Thirdly, the star azimuth values are calculated from the image coordinates and compared to the one found by Stellarium. The procedure is then repeated as a function rotation.

A tilt of 10 to the South and a rotation of 19 degrees to the North–West are found by optimizing the least squared error. The results are displayed in Fig. 3. The results are as expected. The calculated azimuth and the corresponding almanac values are one to one with a standard deviation less than 5 degree.

The radial center pixel position of a point in the image may be fitted by the function

$$R \approx 2 \times f \times \sin\left(\frac{\theta}{2}\right), \quad (1)$$

where f = 1.7mm is the focal length and θ is the angle between any object and the optical axis of the lens. Eq. (1) is known as the mapping function of a typical equal area or equisolid angle fisheye lens. The image appears like a mirror image on a ball [*Hill*, 1926].

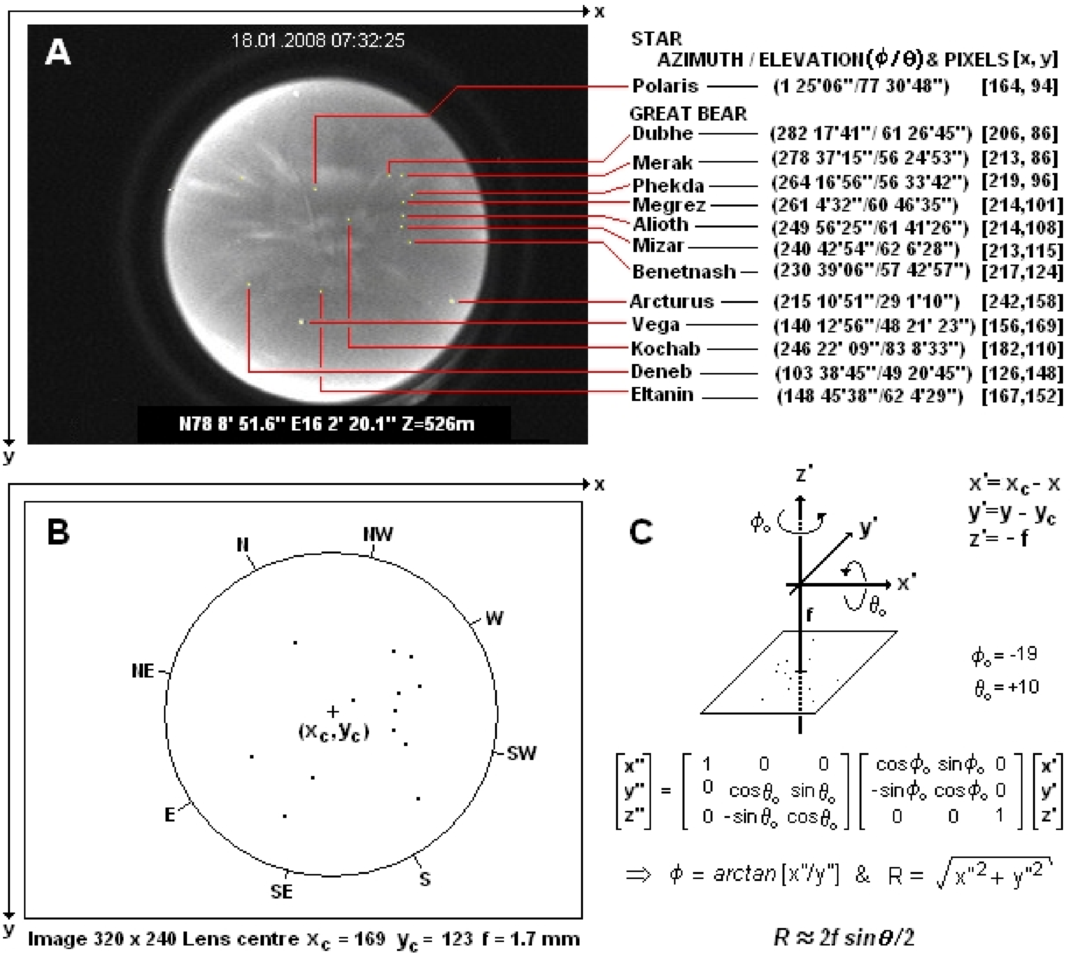

Figure 2. Panel (A): All-sky StellaCam II image at 07:32:25 UT. Stars are marked and named with view angles and image coordinates. Panel (B) shows the orientation of the image (compass rose). Panel (C): Equations used to transform star position into a geographic reference frame. φ is the calculated azimuth angle and ***R*** is the radial center distance in pixels to the stars as a function of elevation, θ.

4. Rocket animation

An animation is constructed to visualize the rocket trajectory as viewed from KHO. The view angles are calculated based on GPS data onboard the rocket.

Fig. 4. shows a snapshot of a single animated frame with video overlay information. Objects marked with colored squares are satellites. The red circle with a tail is the position of SCIFER 2 rocket. The green circle is the position of the rocket mapped down the geomagnetic field line to an altitude of 200 km. Each data point is translated and rotated according to the camera attitude calculated in the previous section. A video overlay projects information on date, time, position, view angles and altitude of the rocket. The compass rose indicates sky directions. Fast moving objects such as satellites are marked with colored squares. The rocket is animated as a small red circle with a tail including the previous 5 data points as it moves over the sky. A white cross is used to mark the camera zenith.

The mapped position of the rocket down the Earth's magnetic field line to an altitude of 200 km is marked with a green colored circle in the animation. The mapping is carried out using the IGRF model **-** International Geomagnetic Reference Field [cf. *Mandea and Macmillan*, 2000].

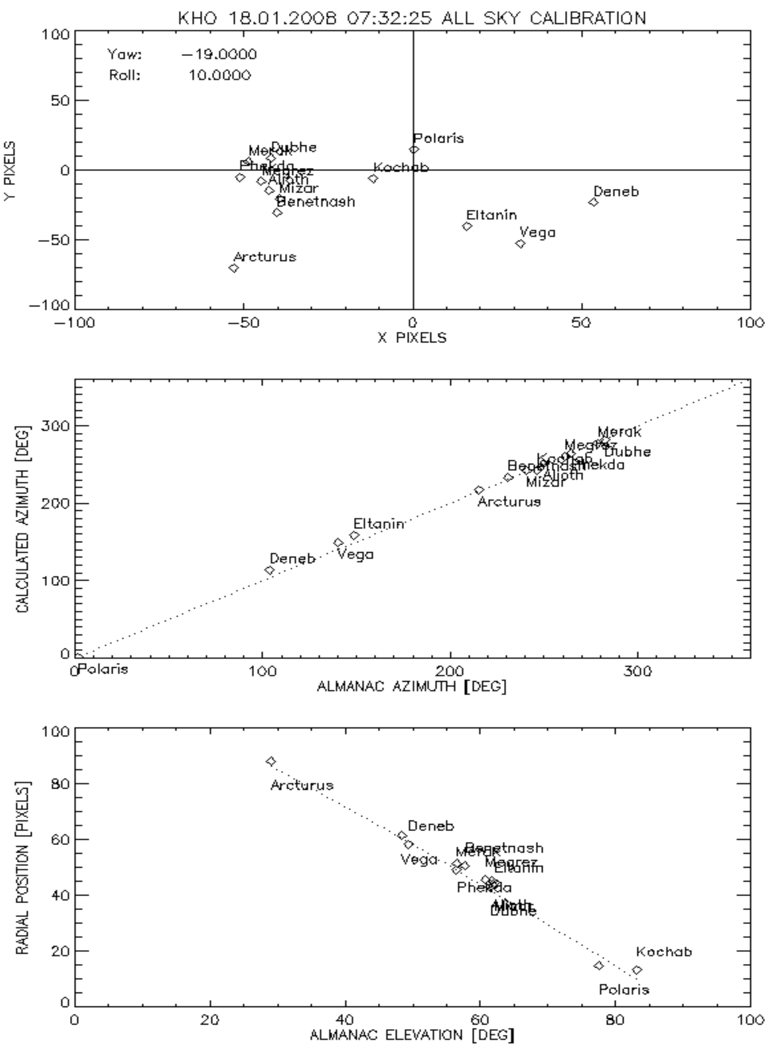

Figure 3. Upper panel show the translated and rotated star map aligned with the geographic reference frame. The calculated and tabulated (almanac) star azimuth values are seen in the middle panel. Bottom panel: Radial center pixel position as a function of star elevation.

The whole animation is available for download here:

Animation	**Movie**	**Size [KB]**
http://kho.unis.no/Gallery/Scifer2/Tracker/All-Sky-180108-0730-0800.avi	AVI	187 905
http://kho.unis.no/Gallery/Scifer2/Tracker/All-Sky-180108-0730-0800.wmv	WMV	5 233
http://kho.unis.no/Gallery/Scifer2/Tracker/All-Sky-180108-0730-0800.mov	MOV	49 979

Table 1 gives an overview of the objects observed in the animation from 07:30-08:00 UT on 18 January, 2008.

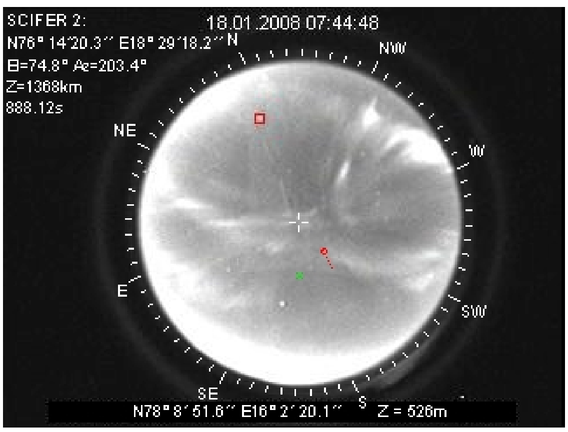

Figure 4. Snapshot of a single animated frame with video overlay information.

#	Symbol	Time period [UT]	Quadrant	Object ID
1		07:30:08 – 07:30:28	NW	
2		07:31:18 – 07:31:20	NW	
3		07:34:16 – 07:35:21	NW	
4		07:35:21 – 07:35:40	NE	
5		07:41:09 – 07:41:11	NE	
6		07:44:00 – 07:44:09	NW	
7		07:44:35 – 07:44:50	NE	
8		07:45:31 – 07:45:31	SE	
9		07:46:55 – 07:47:04	SW	
10		07:49:03 – 07:50:47	SE - SW	
11		07:51:43 – 07:52:35	NW	
12		07:53:31 – 07:54:14	NW - NE	
13		07:31:18 – 07:52:24	S - NE	SCIFER 2
14		07:31:18 – 07:52:24	S - NE	Position of SCIFER 2 mapped down the earth's magnetic field line to 200 km of altitude.

Table 1. The table shows over flying objects as seen from KHO in the time period 07:30 – 08:00 UT on 18 January, 2008.

Note that the camera is not operating with single sequential exposed frames in real time (25 new frames per second). The video output of the camera shows the run time mean in real time of the frames. This technique is developed for imaging of objects not moving fast like stars and planets, increasing the signal to noise. It actually works surprisingly well on aurora too, as long as the accumulation time is kept as short as possible compared to the movement of the aurora over the sky. In other words, the accumulated change of the aurora is observed in real time. This effect is not seen in the above animation, since each animated frame is the result of the total accumulated frames per second.

The SCIFER 2 rocket payload flew over weak dayside aurora, located north of the camera zenith moving slowly northward during the flight. These arcs, named by *Sandholt et al.* [1989] Poleward Moving Auroral Forms (PMAFs), are produced by precipitating low energy electrons exciting atomic oxygen OI at wavelengths 6300 Å (red) and 5577 Å (green). The intensities of the arcs are just a few kR with a red to green ratio close to 5 [*Deehr et al.*, 1980]. The peak altitude of the red emission is in the range 200 – 220 km [*Sigernes et al.*, 1996]. The rocket as seen from KHO reached the horizon close to geographical South at 07:33:00 UT. The auroral activity was at this time stable, but fading slowly to almost disappear 4 minutes later. From this point in time the activity increased, and by the time the rocket past its highest altitude (1468 km), the activity was again high with arcs all over the sky.

The magnetic field line mapping from the rocket down to the red emission peak altitude of 200 km may identify the low energetic electron precipitation region of the sky that is associated with ion outflow. There is no doubt that the rocket crossed several of these mapped regions with active arcs seen to the South - East of the animated trajectory. Communication with the rocket was lost at 07:52:26 UT with the payload falling down towards the horizon about 30 degrees off North towards East.

5. Concluding remarks

The described StellaCam II camera with the Fujinon fisheye lens has proven itself to be a reliable and cost efficient alternative when intensified camera systems cannot be used on aurora. The cameras real time running mean video output works well for dayside auroral morphology studies. It helped us to be able to identify the target and locate the source areas of ion outflow. As a consequence, the SCIFER 2 rocket was launched successfully.

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