Imaging attitude finder for a sounding rocket and magnesium ion imager for airglow spatial pattern

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The IAF (Imaging Attitude Finder) is an imager using a one-dimensional multi-anode photomultiplier, and determines the attitude of a spinning sounding rocket with a precision of $+/−0.6°$ by finding out stars. One of the applications of IAF, MII (Magnesium Ion Imager) is a UV version of the former optimized for measuring the MgI twilight airglow occurring at around 100 km, and images its horizontal structures by looking it from above.

Key words: Rocket attitude, star finding, magnesium ion, twilight airglow.

1. Introduction

It is usually needed to know the attitude of a sounding rocket for scientific and/or technical purpose. For example, in-situ measurement of electric field needs information about the attitude because the induced electric field $E = V_{\text{rocket}} \times B_{\text{earth}}$ depends sensitively on the difference between the rocket-velocity vector and the spin-axis vector (e.g. Nakamura et al., 1998). The NTV (N₂ Temperature of Vibration) measurement also needs attitude information because the shock wave produced by the super-sonic speed of the rocket may disturb the environment to be measured (Kurihara et al., 2006). Optical remote measurements such as of airglow also need information about the direction of the line of sight because the effect due to the slant ray path may play an important role in quantification (e.g. Iwagami et al., 2003). In daytime, a combination of a magnetometer and a sun-sensor works well to find out the absolute attitude; however, the latter may not be used in nighttime. It must be noted that at least a couple of independent information is usually needed to determine the absolute attitude.

In nighttime a sort of STS (Star Sensor) with single eye had been used for the sounding rocket experiment up to 1992 (see Table A1). It could determine the absolute attitude by itself; however, the small field of view ($2.5°$ square) did not allow providing good data set because of limited number of identified stars. It was improved later to have an N-shaped slit ($10°$ square: Iwagami et al., 1998, in Japanese), and succeeded to see four times more stars with better directional resolution. In the present paper, an improved version of STS with 8 eyes named the IAF (Imaging Attitude Finder) is described. It can also determine the absolute direction of the spin-axis of a rocket without any help from another attitude sensor. This is an important advantage of such kind of sensor; however, its disadvantage is in the complexity in the analysis procedure as will be noted in a latter section.

2. Instrumentation

In Fig. 1 the outlook (top) and the cross section (bottom) of the IAF are represented. It consists of an achromatic lens, a mask placed on the focal plane selects 8 anodes of the PMT in its 8 mm width. Although the PMT R5900U-00-L16 manufactured by Hamamatsu Photonics has 16 anodes, only 8 of them are used mostly due to limited data processing rate of the telemetry system. The pitch of the anodes is $1\text{ mm}$ corresponding to an angle of $1.15°$, and the total angular width of 8 anodes is $9.2°$. The PMT is small just having a size of $30 \text{ mm} \times 41 \text{ mm}$ in length including a connector as seen in Fig. 1. The PMT has a bi-alkali photo-cathode having sensitivity in the $300–650 \text{ nm}$ region. Both PMT and the HV supply are set in an airtight box to prevent them from discharging. Each anode has high $(×10)$ and low $(×1)$ gain output channels. The minimum bit rate needed is $25.6 \text{ kbps}$ ($8 \text{ bit} \times L$ and $H \times 200 \text{ Hz}$ sampling $× 8$ anodes). The main part of the electronics is separated, and not shown in the figure.

Since the line of sight of the IAF is usually set at $30°$ away from the spin-axis, and the spinning period is about one sec (in case of the S-310 type rocket), the instantaneous field of view ($4.6° \times 9.2°$) sweeps the star field in a doughnut shaped region with an inner and outer radiusses of $25°$ and $35°$, respectively, in a period of one second as illustrated in Fig. 2. From the pattern of signals due to stars, the direction of the spin-axis is determined if two or more stars are identified during one spin cycle. The $4 \text{ mm} (4.6°)$ length of the mask determines the duration of one star pulse (24 ms in the nominal case). The analysis procedure must take this duration into account.

3. Adjustments and Calibration

The focus is adjusted by checking an image of a point light source in a laboratory with visible inspection, and the sensitivity is adjusted by using a star or a planet such as Jupiter. Usually the full scale of the high gain channel is...
Fig. 1. Outlook (top) and cross section (bottom) of the IAF.

Fig. 2. Schematic illustration of the field of view of the IAF synthesized by the spinning motion. The instantaneous field of view (4.6° × 9.2° by 8 anodes) sweeps the star field to form a doughnut-shaped region with inner and outer radii of 25° and 35°, respectively.

set to the output of a star of the first magnitude. The main part of the data is expected to be obtained in the high-gain channel; however, the low-gain channel is sometimes useful because of unexpected disturbances such as due to aurora, moonlight, and twilight.

These procedures cannot simply be applied to the MII because its wavelength 280 nm is not visible as will be described in a latter section.

4. Examples of Results

In Fig. 3, examples of the measured directions of the spin axis of the sounding rocket S-310-33 (Iwagami et al., 2005a, b, in Japanese) are plotted. After the launch, the zenith angle of the spin axis increases gradually as far as air drug works. At around 90 km in ascent, air drug dis-appears, and the precession motion begins. Usually the radius of the precession motion is 10°–20° with a period of 150 s–250 s (see Table A1). It continues until the attitude of the rocket start to change due to drug by thick atmosphere at around 90 km in descent. In case of the S-310-33 experiment shown in the figure, the steady precession motion started at around the spin number 20 (80.84 s after the launch at 89.5 km) and ended at around the spin number 222 (291.92 s after the launch at 89.7 km). However, it must be noted that the successful determination depends mostly on fortunate capture of stars happen to come into the field of view. At some unfortunate occasions such as seen in between the spin numbers 105 and 120, no solution appears.
was obtained; this is because at least two stars (hopefully three stars) must be identified during one spin cycle to fix one spin-axis direction. The rms (root mean square) random error is estimated by fitting a precession circle to the data points to be 0.6° in the present case; however, it must be noted that this is the most fortunate example, and sometimes only a fragment of a precession circle is obtained.

5. Application of IAF (MII)

The MII (Magnesium Ion Imager) is a UV version of the IAF just added an UV interference filter for measuring the Mg\(^+\) 279.6 and 280.3 nm doublet twilight airglow. This airglow is related closely to the Es (sporadic E layer) event, and is expected to show its formation process. If such process is connected to modulation by atmospheric waves or instabilities, some horizontal wavy patterns should be seen in the airglow structure. The aim of the MII is to look for such structure on board a sounding rocket flying above them (Kurihara et al., 2010).

Some modifications from IAF are there in its instrumentation. In case of the S-310-38 rocket experiment (Kurihara et al., 2010), an interference filter with a center wavelength of 278.4 nm and a FWHM (full width of a half maximum) of 16.3 nm was added in front of the lens. A fused silica single lens was used in place of an achromatic lens because the latter does not work in the UV region. The PMT used is R5900U-06-L16 having a sensitive wavelength region of 160–650 nm with a silica window and a mask of 1 mm × 8 mm. Because of the smaller mask and the shorter wavelength than for the IAF, the instantaneous field of view (1.25° × 10.0°) is much shorter but a little wider than that for the IAF (4.6° × 9.2°). The line of sight of the MII was set downward 30° away from the spin-axis of the rocket to see the horizontal pattern appearing in the Mg\(^+\) airglow distribution occurring at around 100 km from the rocket flying above it as illustrated in Fig. 4.

The focus adjustment needs the following two steps: (1) adjustment by using a lamp with inspection of its visible image and (2) correction of the focus position by using calculated difference in the focal lengths between visible and UV. The sensitivity is adjusted by using a UV lamp with a known irradiance. In case of the S-310-38 experiment, the full scale of the high gain channel was set to 11.2 kR although the expected radiance of the Mg\(^+\) airglow was 1 kR (Kurihara et al., 2010) because a serious superposition of the Rayleigh scattered sunlight was anticipated.

In Fig. 5, the horizontal structure of the Mg\(^+\) twilight airglow seen from the MII flying above the airglow layer (Kurihara et al., 2010) is shown. The 30 km (0.3° in latitude) scale structures seen in the horizontal distribution seems to be due to modulation by the atmospheric gravity waves coming from the lower atmosphere, and seem to support the wind shear scenario to cause the Es event.

6. Remaining Problems and Future Improvements

The largest disadvantage of the IAF is its complexity in the data analysis. The identification of stars has not been automated, and still needs human handling. It will be improved if suitable software is introduced for identifying stars. Or it may already be possible to use a couple of GPS (global positioning system) sensors placed at the top and the bottom of a rocket to find out the spin-axis direction.

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Appendix A

The attitudes of the S-310 type sounding rocket measured by the IAF and its ancestor STS (star sensor) so far are summarized in Table A1. The measured parameters of the circular precession motion (direction of the center, radius, period and duration) as well as the launching parameters are listed. They should be important information for future scientific planning as well as for technical purpose such as in designing the new rocket of the next generation.

References


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Fig. 5. Horizontal distribution of the Mg\(^+\) airglow found by the MII. The wavy structures with a scale of 30 km (0.3° in latitude) suggest a modulation due to atmospheric gravity waves (figure after Kurihara et al., 2010).
<table>
<thead>
<tr>
<th>Rocket ID</th>
<th>Launch date</th>
<th>Launch direction</th>
<th>Precession circle</th>
<th>Notes</th>
</tr>
</thead>
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<tr>
<td>S-310-38</td>
<td>06Feb2008</td>
<td>18° 135°</td>
<td>30° 85° 25°</td>
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<td>18° 135°</td>
<td>32° 125° 18°</td>
<td>wave2004 campaign</td>
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<tr>
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<td>20° 107°</td>
<td>43° 65° 27°</td>
<td>seek2 campaign</td>
</tr>
<tr>
<td>S-310-31</td>
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<td>18° 107°</td>
<td>38° 92° 7°</td>
<td>seek2 campaign</td>
</tr>
<tr>
<td>S-310-30</td>
<td>06Feb2002</td>
<td>12° 135°</td>
<td>28° 160° 12°</td>
<td>2nd NTV&lt;sup&gt;4&lt;/sup&gt; experiment</td>
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<tr>
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</tr>
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<td>S-310-25</td>
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<td>26° 120° 28°</td>
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<td>S-310-24</td>
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<td>7° 154° 12°</td>
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<td>S-310-20</td>
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<td>28° 138° 8°</td>
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<tr>
<td>S-310-19</td>
<td>01Feb1989</td>
<td>12° 144°</td>
<td>7° 89° 9°</td>
<td>1st O experiment</td>
</tr>
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</table>

<sup>a</sup>cza (center zenith angle)  
<sup>b</sup>laa (launch azimuth angle)  
<sup>c</sup>laa (launch azimuth angle)  
<sup>d</sup>cycles (number of precession circles completed)  
<sup>e</sup>NTV (nitrogen temperature of vibration)  
<sup>f</sup>TMA (trimethyl aluminum: glowing matter)  
<sup>g</sup>STS (star sensor)