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Multipoint Measurements of the Ion Isotropy Boundary

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Abstract.
The location of the ion isotropy boundary can be inferred from H_β (486.1nm) emission measurements made with a ground-based meridional scanning photometer (MSP). A comparison of data from MSPs operating in Gillam, Manitoba and Poker Flat, Alaska demonstrates that the instruments produce qualitatively consistent measurements. This provides the first simultaneous, two-point comparison of proton auroral brightness. Data sets of ion isotropy boundary determinations have been created for measurements from each site. An examination of simultaneous boundary identifications, separated in local time, indicates that the shape of the boundary is consistent with results from Sergeev et al. (1995) and Donovan et al. (2001).

1 Introduction

The proton aurora is the optical signature of protons precipitating into the Earth's upper atmosphere. In terms of differential ion energy flux, a double loss cone distribution is normally seen on inner magnetospheric field lines. Ions in this region of the magnetosphere are bounce trapped. On higher latitude field lines the adiabaticity conditions do not hold exactly as there is at least one pitch-angle scattering mechanism acting on particles in the vicinity of the central plasma sheet. The scattered ions completely fill the down-going loss cone and are responsible for the proton aurora. The surface between the magnetospheric domains of bounce trapping and strong pitch angle scattering is referred to as the ion isotropy boundary (Sergeev et al., 1983).

It has been shown that the latitude to which this boundary maps on the Earth correlates well to the inclination of the magnetic field at geosynchronous orbit (Sergeev et al. (1995), Sergeev et al. (1993), Donovan et al. (2001)). Therefore, knowledge of the boundary location provides a good indication of the amount of stretching in the magnetotail. This boundary has been observed with in-situ ion energy flux measurements in two ways. Data from instruments capable of pitch angle resolution can be used to determine the field line along which this boundary is located. The ion isotropy boundary (IB) is identified to be where the ratio of parallel to perpendicular ion energy flux drops sharply from ∼1.0 to less than 0.9 (Sergeev et al. (1993), Sergeev et al. (1995)). A termination of precipitating particles is directly responsible for the sudden decrease of this ratio. Therefore, the location of the cutoff of total parallel ion energy flux should correspond to this boundary. This cutoff is the b2i boundary of Newell et al. (1996). Newell et al. (1998) demonstrated that simultaneous determinations of IB and b2i boundary locations are in close agreement.

Donovan et al. (2001) developed a straightforward algorithm to infer the latitude of the b2i boundary from proton auroral (486.1nm) data obtained by the CANOPUS Gillam Meridian Scanning Photometer (MSP). Whenever viewing conditions and the latitudinal distribution permitted, they fit a Gaussian to an MSP brightness profile. From roughly ten years of data, they obtained Gaussian best fit parameters for roughly 290,000 MSP scans. By comparing the MSP brightness profiles with precipitating ion energy flux obtained by overflying DMSP spacecraft, they showed that the b2i boundary corresponded to the equatorward edge of the proton aurora. More specifically, they determined that the latitude of the b2i boundary was, on average, 1.4σ equatorward of the latitude of the peak proton auroral brightness, where σ is the standard deviation of the best fit Gaussian. In figure 1, one night of proton auroral data from the Gillam MSP is shown in keogram form. The location of the optical b2i boundary, inferred with the simple algorithm of Donovan et al. (2001), is indicated by the white symbols on the keogram. Figure 2 is a plot of the 290,000 optical b2i latitude determinations. The shape of the distribution is qualitatively consistent with the statistical local time dependence of the IB latitude as shown by Sergeev et al. (1995).

In this paper we use 'IB' to refer to this physical magnetospheric boundary as well as to boundary identifications

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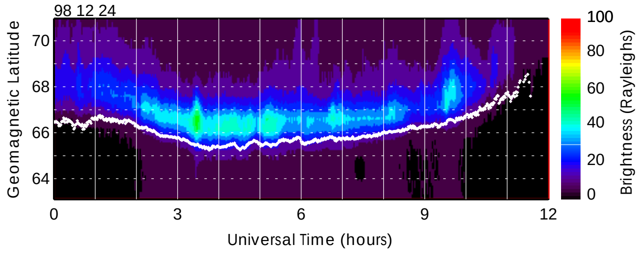

Fig. 1. Keogram of 486.1nm emissions measured at Gillam on December 24, 1998. The white symbols indicate the location of the IB estimated from the photometer data. Geomagnetic latitudes are based on a presumed emission altitude of 110km.

made from in situ measurements where pitch angle resolution is possible. We use 'b2i boundary' and 'optical b2i boundary' to refer to locations inferred from total parallel ion energy flux data and ground-based optical measurements respectively.

In situ IB or b2i boundary identifications are obtained relatively frequently. Using DMSP and NOAA spacecraft, one can find dozens of IB or b2i boundary locations on any given day. With this level of sampling, these boundaries provide an excellent means of characterizing the state of the magnetotail over the course of days (i.e., during magnetic storms), or a particular instant. They do not, however, provide a mechanism for monitoring the evolution of the state of the magnetotail on time scales of minutes (i.e., substorm growth and expansive phase activity). Furthermore, although there have been simultaneous observations of the IB at different MLTs (Sergeev et al. (1995), as well as Newell et al. (1998)), it is essentially impossible to study the MLT evolution of disturbances in the inner magnetosphere using the in situ observations. The optical b2i boundary does allow for the monitoring of this boundary on a time scale of minutes, and hence provides excellent information of relevance to, for example, substorm phenomena. Optical identification of this boundary, however, suffers from frequently bad viewing conditions, provides only limited latitude coverage, and is limited in that it offers only an inference of this boundary location. Clearly, the in situ and optical boundary identifications provide valuable, complementary information.

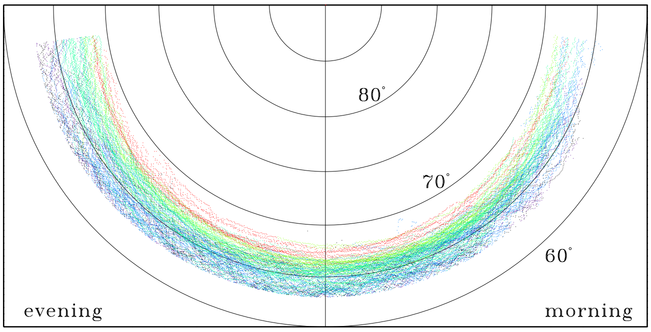

Fig. 2. Geomagnetic latitude of optical b2i determinations from Gillam MSP observations ordered according to K_p from $K_p = 0$ (in red) to $K_p \geq 5$ (in black).

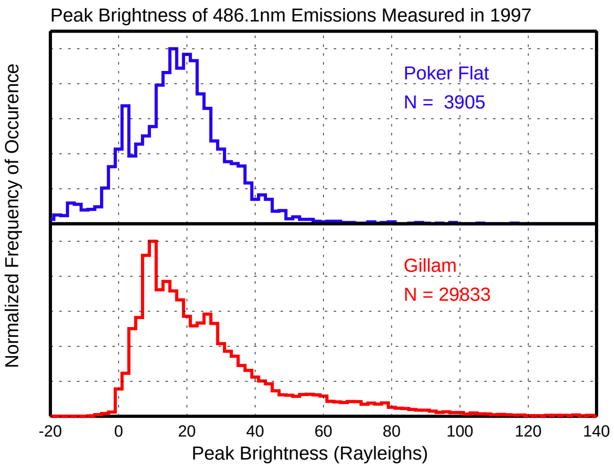

Fig. 3. Histograms of peak 486.1nm brightnesses measured by Gillam and Poker Flat MSPs in 1997.

In this paper, we extend the scope of optical b2i boundary identification by using data obtained simultaneously by two MSPs, located at similar magnetic latitudes, but separated by roughly 4.5 hours of MLT. We use the Gillam MSP mentioned above (56.4°N, 265.4°E), and the Poker Flat Research Range MSP (65.1°N, 212.6°E). Our objectives are to: 1) demonstrate that the MSP proton auroral data are mutually consistent (i.e., quantitative brightnesses are consistent with each instrument observing the same phenomena); 2) demonstrate that multipoint observations of the optical b2i boundary from the ground are feasible; 3) build up a large data set of two point optical b2i boundary observations; 4) use these two point optical b2i boundary observations to explore the shape (i.e., MLT dependence) of the b2i boundary. The two stations are well separated in local time, yet close enough that a significant number of simultaneous observations can be obtained.

2 Comparing MSP data from Gillam and Poker Flat

Stations at Gillam and Poker Flat operate meridional scanning photometers that observe 486.1nm emissions over essentially the same geomagnetic latitude range ($\sim 60^\circ$ to $70^\circ\Lambda$). Magnetic local midnight is approximately 0630 hours UT at Gillam and 1100 hours UT at Poker Flat. Since the instruments observe the same latitude range, it is reasonable to expect that the proton aurora brightness should, on average, be the same. There are possible complications. The proton auroral process is diffuse, resulting from pitch angle scattering in the vicinity of the equatorial plane. The size of the loss cone in the scattering region will be somewhat different on a flux tube over Poker Flat compared to that on a flux tube over Gillam, owing to the difference in the magnetic field at the two sites. We expect these differences to be small compared to discrepancies that would arise due to instrumental differences.

The instruments differ in terms of construction, operation, and calibration. The Poker Flat MSP employs a tilting-filter system to isolate emission and background wavelengths while the Gillam MSP uses a rotating filter wheel. Observations at the Gillam station are produced once per minute and are binned into 17 geomagnetic latitude bins (based on a presumed emission altitude of 110 km) whereas the Poker Flat MSP produces a scan consisting of 181 one-degree elevation angle measurements approximately every 16 seconds. As such, it is reasonable to expect that the quantitative brightnesses measurements made by each instruments would not be consistent when observing the same phenomenon. In other words, if the two instruments measure the brightness of a 20 R proton aurora, how do the measured intensities compare? In order to develop a capacity to carry out multipoint, ground-based optical observations of the IB, we must ensure that observations from the different instruments are comparable.

A data set was created from Poker Flat measurements between January 1995 and April 1999 which included days with good viewing conditions and periods of good observations from Gillam. The Poker Flat measurements were smoothed to one-minute bin intervals and re-binned from 181 elevation angle bins to 17 latitude bins identical to those of the Gillam data. A statistical comparison of the brightnesses measured at Poker Flat and Gillam indicates that the instruments measure quantitatively similar intensities. This is illustrated by the peak brightness histograms in figure 3. As the measurements made by each instrument are consistent, it is reasonable to perform a comparison of simultaneous Poker Flat and Gillam observations.

The proton auroral brightness correlates well with integrated energy flux of $<$30 keV ions (Donovan, work in progress). Hardy et al. (1989) has demonstrated that the maximum energy flux of 30 eV to 30 keV ions occurs premidnight. This agrees with the statistical results of Creutzberg et al. (1988) that demonstrated ground-based 486.1nm observations are brighter just prior to midnight. Therefore, the brightness of the proton aurora is expected to have a systematic local time dependence. Donovan et al. (2001) found that the most equatorward extent of the proton auroral oval is shifted duskward from midnight by approximately 45 minutes to 2322 hours MLT. Therefore, the pairs of measurements were classified as being made either before or after 0800 hours UT, approximately the time at which the midpoint between the stations passes the statistical location of the equatorward most point of the proton auroral oval. The Gillam station should be closer to the brightest section of the oval than Poker Flat before 0800 hours UT while after this time the reverse is true. Simultaneous measurements of peak brightnesses are shown in figure 4. The groupings are clearly divided. Measurements made before 0800 hours UT are more intense at Gillam (shown in red) and after 0800 hours UT emissions are brighter at Poker Flat (shown in blue). With these simultaneous measurements, we confirm the statistical picture that proton auroral emissions are more intense just before midnight. Only pairs where both measurements were greater than 7 Rayleighs were used in this comparison.

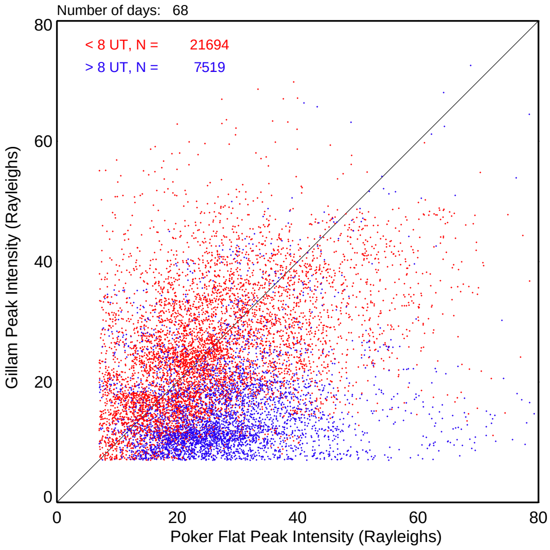

Fig. 4. Comparison of peak 486.1nm brightnesses measured simultaneously at Gillam Poker Flat. Measurements made before 0800 hours UT are plotted in red while those made after are plotted in blue.

3 A two-point study of the IB

IB latitudes were inferred from the Poker Flat data set via the algorithm developed by Donovan et al. (2001). A data base of over 10,000 pairs of simultaneous optical b2i determinations was produced from observations made at the two stations. The top plot in figure 5 shows the first multipoint, ground-based determinations of the ion isotropy boundary. In this example, the optical b2i measurements at Gillam do not differ from those measured Poker Flat 4.5 hours later. The shape of the boundary remains constant over the period of observation. The diurnal geomagnetic latitude variation of the proton auroral oval with MLT is apparent in the keograms of 486.1nm emissions as well as in the plot of optical b2i determinations.

Sergeev et al. (1995) demonstrated that the latitude of the IB at the midnight meridian correlates well to the inclination of the magnetic field at geosynchronous orbit. As measurements are made at every local time, an offset cosine curve was used to map a boundary measurement made at any MLT to the midnight meridian. Donovan et al. (2001) developed a similar mapping for optical b2i determinations. The peak of the cosine curve was found to be shifted to 2322 hours MLT. Therefore, we expect the proton auroral oval, and hence the IB, to be roughly symmetric about this point. As the stations are equidistant from the most equatorward extent of the proton auroral oval at 0800 hours UT, we expect their respective boundary identifications to be at the same latitude. The top panel of figure 5 indicates that there is a local time dependence on the difference between simultaneous optical b2i latitudes determined from each station. This difference is more clearly illustrated in figure 6. A linear least-squares fit to the difference between optical b2i determinations made when both stations were on the night side of the Earth (be-

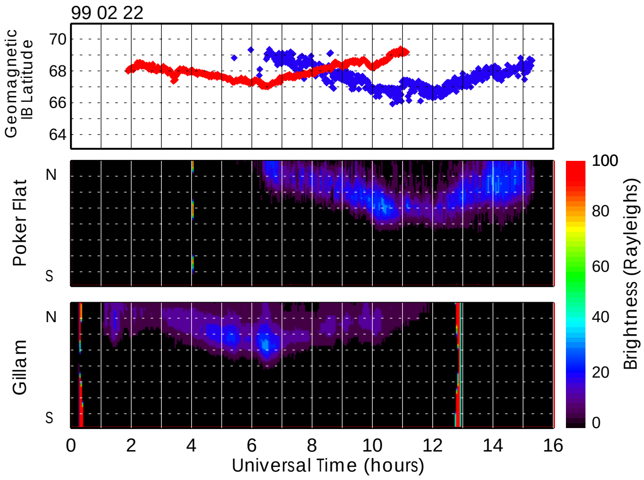

Fig. 5. The middle and lower panels are keograms of 486.1nm emissions obtained by the Poker Flat and Gillam MSPs on February 22, 1999. In the top panel, optical b2i latitudes inferred from the Poker Flat and Gillam measurements are shown in blue and red respectively.

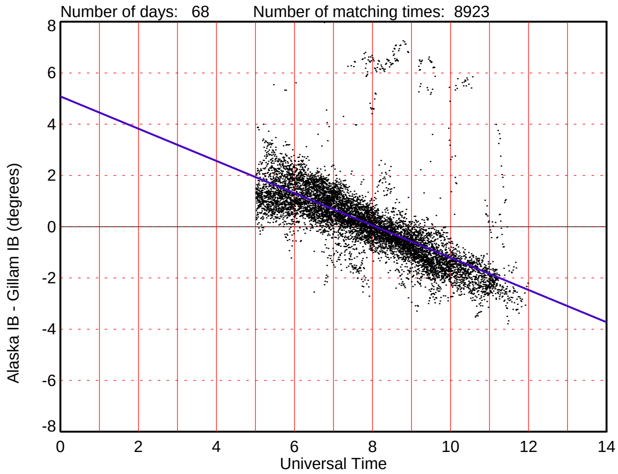

Fig. 6. Difference between the optical b2i latitudes inferred from Poker Flat and Gillam measurements.

tween 0500 and 1230 hours UT) yields:

$$IB_A - IB_G = (-0.629 \pm 0.007)t_{UT} + (5.08 \pm 0.06) \qquad (1)$$

The difference is minimized at approximately 0800 hours UT. This confirms that the stations are equidistant from the most equatorward extent of the proton auroral oval at this time. As the difference between the two stations is linear within approximately 2 hours of 0800 hours UT (2322 hours MLT), the shape of the IB is on average symmetric from 2122 to 0122 hours MLT. This result is consistent with the work of Sergeev et al. (1995) and Donovan et al. (2001) who used an offset cosine curve to model the shape of the IB.

4 Discussion

The ion isotropy boundary is an important magnetospheric boundary that differentiates between regions of bounce trapping and strong pitch angle scattering. Ground-based optical determinations of this boundary are possible using a simple algorithm provided observing conditions are good. A comparison of MSP data from Poker Flat and Gillam indicated that brightness measurements are quantitatively consistent. Merging the two data sets, we obtained over 10,000 simultaneous pairs of optical b2i measurements. With this, we demonstrated that the most equatorward extent of the proton auroral oval is offset duskward from the midnight meridian by approximately 45 minutes and that the IB is symmetric within 2 hours MLT of this point. This is consistent with the MLT variation of the IB determined by Sergeev et al. (1993).

Multipoint measurements of the boundary will enhance our understanding of the topology of the inner magnetosphere. Complemented with simultaneous IB identifications at other local times and at high latitudes (i.e., Polar), quantitative knowledge of the shape of the IB surface will provide an excellent mechanism with which we can test empirical and physical models of the magnetosphere. With near-continuous multipoint determinations of the IB, it is possible to distinguish between “local” and “global” events. Furthermore, we can use these multipoint observations to study the evolution of inner magnetospheric disturbances.

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