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Observations of Plasma Blobs by OI 630 nm Using ASI and Photometer over Kolhapur, India

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Abstract This paper presents observations of plasma blobs by nightglow OI 630.0 nm emissions using ground-based techniques, all sky imager and photometer from Kolhapur. The nightglow observations have been made at low latitude station, Kolhapur (16.42°N, 74.2°E, and 10.6°N dip lat.) during clear moonless nights for period of October 2011–April 2012. Generally, these occur 3 h after sunset (18:00 IST). Herein we have calculated velocities of plasma blobs using scanning method, introduced by Pimenta et al. (Adv Space Res 27:1219–1224, 2001). The average zonal drift velocity (eastward) of the plasma blobs were found to be 133 ms^{-1} and vary between 100 and 200 ms^{-1}. The width (east–west expansion) and length (north–south expansion) of plasma blobs is calculated by recently developed method of Sharma et al. (Curr Sci 106(08):1085–1093, 2014b). Their mean width and length were in the range of 70–180 and 500–950 km respectively. The study shows that localized eastward polarization electric field plays an important role in the generation of plasma blobs.

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1 Introduction

Due to variation in electron density of the ionosphere, irregularities like equatorial spread-F (ESF) or equatorial plasma bubbles (EPBs) are observed in the F region. Reduction in electron densities, as compared to the background ionospheric plasma density, are known as EPBs whereas enhancement in electron density by a factor of two or more, above the background density, occurring in localized F-region are known as plasma blobs (Krall et al. 2010) over the low latitude and tropical region. The measurements of plasma blobs have been made by ''in-situ'' using satellite, ROCSAT-1 and equatorial atmosphere radar (Yokoyama et al. 2007) as well as by ground based instruments like ASI, ionosonde and photometer (Pimenta et al. 2004). The signature of plasma blobs have been studied by total electron content (TEC) measurements (Chen et al. 2008). Most of the observations show plasma blobs in association with large-scale EPBs.

The several ground based instruments are used to study the EPBs and plasma blobs over low latitude regions. The ionospheric EPBs have been widely studied while only a few publications are available on plasma blobs. The morphology and dynamics of plasma blobs is a recent and exciting topic for investigation. All sky imager (ASI) is more powerful and useful instrument which is used to study the spatial and temporal locations of ionospheric irregularities by images of nightglow OI 630 nm emission in the bottom-side of the F-region (Pimenta et al. 2007). First ground-based observations of plasma blobs have been made by OI 630.0 nm images using ASI from Cachoeira Paulista (Pimenta et al. 2004). The observations of plasma blobs have also been reported by Krall et al. (2009) using images of OI 630.0 nm of ASI from the Boston University, Arecibo. The study of plasma blobs, as enhancement in TEC measurements have been studied from Udaipur, India (Dashora and Pandey 2005).

The nightglow emission of OI 630.0 nm comes from the bottom side of F-region at an altitude of about 220–300 km. Its images are used to map the spatial and temporal locations of plasma blobs, showing enhancements in discrete plasma density near regions of depletion in plasma density structures (Pimenta et al. 2004). In this paper, the ground-based observations of plasma blobs associated with EPBs are presented, for the geomagnetic disturbed and quiet days, using OI 630.0 nm nightglow emissions by ASI and photometer from the low latitude station, Kolhapur (India). The brief review of the observations is presented in Sect. 2 and results and discussion are given in Sect. 3.

2 Observations and Method

Regular observations of nightglow emissions, OI 630.0, OI 557 nm and OH Meinel (683 and 692 nm) bands have been carried out by using ASI and photometer at the low latitude station Kolhapur (16.80°N, 74.20°E) on clear and moonless nights. For present work we have used data of nightglow OI 630.0 nm emissions. The images of OI 630.0 nm provide time evolution and spatial variations of selected atomic or molecular emissions over a wide area in the sky. The multispectral (OH, OI 630.0 and OI 577.7 nm emissions) ASI and photometer were installed at Shivaji University Campus, Kolhapur under the scientific collaborative program between Shivaji University, Kolhapur (S.U.K.) and Indian Institute of Geomagnetism (I.I.G.), Navi Mumbai, India to measure nightglow emissions. These systems can be operated for 7 nights before and after the new moon night.

In ASI three interference filters, with center wavelengths of OI 630.0, OI 557.7 nm and OH Meinel bands (720.0–910.0 nm) having exposures time of typically 120, 120 and 90 s respectively, are used to study the dynamics of ionosphere. A high resolution (1,024 × 1,024 pixels) CCD based ASI has180° field of view (FOV). Before the operation, dark counts are reduced by thermoelectrically cooling of CCD to −80 °C. The detail of experimental setup has been described in Sharma et al. (2012).

The scanning photometer having five optical filters with integration time of 15 s each is operating at Kolhapur. The FOV of the photometer is 10°. Three Stepper Motors are control the movement of five filters in the meridional and the azimuthal directions. Before starting observations, the azimuthal position and the position of particular filters were brought to a home position. The scanning photometer was kept in the north–south direction. Temperature of fillers, having a band width of 1 nm, is controlled by a temperature controller at 25 °C. The temperature coefficient of filter is 0.011 nm/0C. At 25 °C the transmission efficiency of filters is ~60 to 70 %. The scanning photometer consists of a photo—multiplier tube (EMI 9658B) as a detector which has a wide spectral response. Data from each filter are stored in the digital form in the hard disk of a PC through RS—232 port after amplification of the signal from the photomultiplier tube (EMI 9658B). It takes about 90 s to complete one sequence of observations. In the absence of a standard calibration source, we have used relative intensities in arbitrary unit. For present study we have analyzed data of OI 630.0 nm emissions. Initially the variations in intensity of nightglow emissions for each night is plotted and examined for any contamination in the data due to clouds or artificial lights. A more detailed discussion of this experimental setup is presented in Ghodpage et al. (2011, 2012, 2013).

To ascertain the effect of geomagnetic activity on characteristic of plasma blobs, we have taken data of geomagnetic index (Kp) and solar index (F10.7 cm) from the TIMED Mission Data Center (MDC) (http://www.timed.jhuapl.edu/WWW/data/timedData.php). Herein we have considered ΣKp (daily sum) index to examine the global average of geomagnetic activity.

In the present work we have concentrated on occurrence of plasma blobs in images of OI 630.0 nm. In addition to this data, we have taken photometric data to study the characteristic of plasma blobs. We found that occurrence of plasma blobs in images of OI 630.0 nm on 14 nights of observations during the period October 2011–April 2012. Based on ΣKp and F10.7 cm data, all nights were magnetically quiet. We have processed images of OI 630.0 nm to identify plasma blobs and other events. Several methods of image processing are described in literature. In present study we have used "addition method" (Sharma et al. 2014b). In this method, at first the mean/average of an hour image-data was taken and then it was subtracted from each image of an hour data. We have processed all images by using this method. The details of the same are described in Sharma et al. 2014b. Figure 1 shows few examples of processed images of OI 630.0 nm obtained on 17–18 January 2012. In Fig. 1, the dark patches (EPBs) and white patches (plasma blobs) are shown by yellow and white arrows. The processed images helped us to distinguish between EPBs and plasma blobs. The occurrences of EPBs in images of OI 630.0 nm have been reported by (Nade et al. 2012; Sharma et al. 2014a).

In present work we have used "scanning method" of Pimenta et al. (2001)to evaluate the drift velocity of EPBs from images of OI 630.0 nm. The depletion and enhancement in

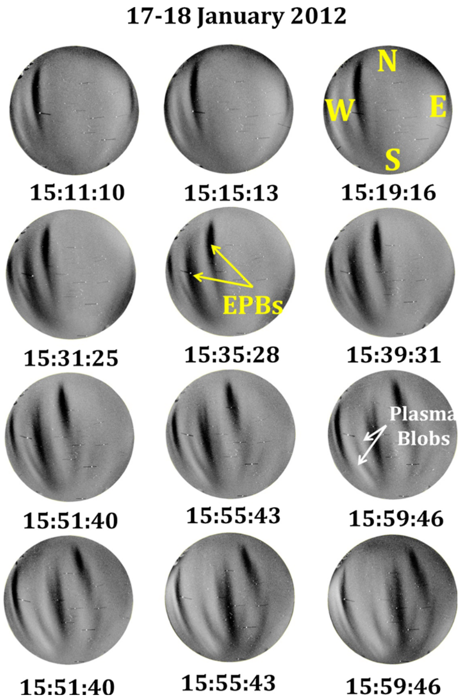


Fig. 1 A few examples of processed images of OI 630.0 nm obtained on 17–18 January 2012

intensity of OI 630.0 nm emissions is the signature of EPB and plasma blob. Difference between EPBs and plasma blobs in intensity of OI 630.0 nm is shown in three panels of Fig. 2. In this figure, Fig. 2a shows the normal nightglow intensity obtained by the east–west scan of OI 630.0 nm image recorded on 20–21 January 2012 at 04:37:30 IST. This data (east–west scanned) has been smoothed by 50 point average and fitted with polynomial of order three with periodic boundary condition. Figure 2b shows the east–west scan of OI 630.0 nm image taken on 20–21 January 2012 at 22:12:11 IST. The depletions in intensity of OI 630.0 nm as compared to normal value is the signature of EPBs. This image shows occurrence of EPBs. We found the signature of plasma blobs on 24–25 February 2012 at 21:50:42 IST. Intensity variation (scanned (east–west) this image from zenith) is presented in Fig. 2c. This Figure shows the enhancement of nightglow intensity. This enhancement is the signature of plasma blob. In Fig. 2b, c, the red arrows indicate depletion and enhancement in the intensity, respectively. Figure 2d–f shows corresponding scanned images for Fig. 2a–c respectively. The red and blue line shows the portion of plasma blob and EPBs respectively. Yellow line indicates the line scanning area of image.

In this paper we have presented observations of plasma blobs using ASI and photometer from low latitude station Kolhapur. The plasma blobs occurred between two EPBs separated in longitude. The detail of its occurrence is discussed in results and discussion section.

3 Results and Discussion

The plasma blobs occurred associated with EPBs. The positions of EPBs in images of OI 630.0 nm depend on apex height of F-layer at the magnetic equator (Sahai et al. 1994).

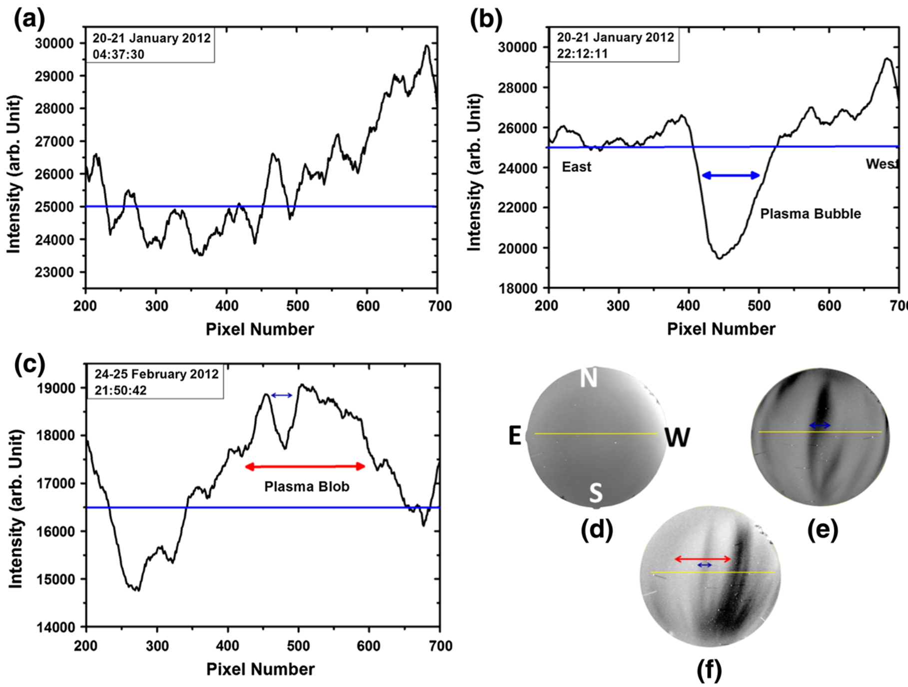


Fig. 2 The normal, depleted and enhanced intensities of nightglow OI 630.0 nm emission obtained by east–west scan of all sky image of same emission, indicated by (**a**), (**b**) and (**c**) respectively. **d**, **e** and **f** show, corresponding scanned images. These images were recorded by ASI from Kolhapur on 20–21 January 2012 at 04:37:30 IST, 22:12:11 IST and 24–25 February 2012 at 21:50:42 IST. The *red* and *blue lines* show the portion of plasma blob and EPBs respectively. *Yellow line* indicates the line scanning area of image. (Color figure online)

Figure 3 illustrates the positions of EPBs in image of OI 630.0 nm as function of apex height, shown by circles (white coloured), at an altitude 250 km over Kolhapur. The red line indicats zenith (10.6°N) at Kolhapur, center of image. From Fig. 2, it is clear that when the position of EPBs are at circles 1, 2 and 3 then corresponding apex height of F-layer around 300–400, 400–600 and 600–800 km. Mostly the positions of EPBs in images occurred at circles 2 and 3, this suggest that the higher apex height of F-layer caused EPBs over Kolhapur. During magnetically disturbed days, the height of F-layer at the magnetic equator has higher than that of off-equator. Several investigators (e.g. Sahai et al. 1998; Sharma et al. 2014a) have reported that the probability of generation of EPBs increase with magnetic activity. The signature of EPBs in the equatorial (northern) region and off-equatorial (southern) region of the images depends on height of F-layer (Rajesh et al. 2010).

Figure 4 shows the sequence of OI 630.0 nm all-sky images obtained on 15–16 February 2012 at 21:12:20–21:29:34 IST. Figure 3 is showing that the plasma blobs occurred in association with EPBs. Pimenta et al. 2007 have also reported that plasma blobs occurred in association with EPBs. Herein, we have considered, the day with $\Sigma Kp \geq 26$ index to be magnetically "disturbed" days. Based on data of Kp index and solar flux (F10.7 cm), all nights of observations having signature of plasma blobs were magnetically quiet. Table 1 illustrates magnetic and solar conditions of nights having signature of

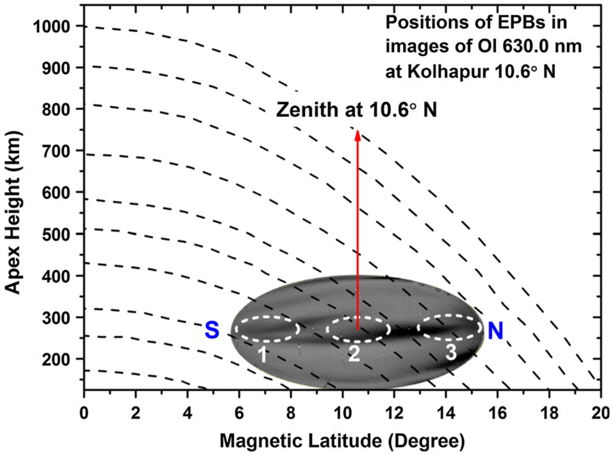


Fig. 3 Schematic of the positions of EPBs in image of OI 630.0 nm as function of apex height over Kolhapur

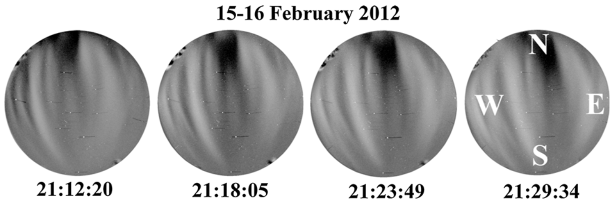


Fig. 4 Few examples of sequence of processed images of OI 630.0 nm obtained on 15–16 February 2012

plasma blobs. We found that the motion of plasma blobs and EPBs were eastward throughout the observations, except during major geomagnetic storm on 6–7 April 2000 (ΣKp = 38; Dst (max.) = 288 nT) when it was westward motion (Pimenta et al. 2007).

The signature of plasma blobs associated with EPBs in images of OI 630.0 nm has suggested that the apex height was responsible for generation of plasma blobs. Generally, the plasma blobs occurred 3 h after sunset over low latitude regions. Le et al. 2003 have suggested that the signature of plasma blobs occur towards the off-equatorial region ($\sim\pm10°$ to $\pm20°$) of the equatorial anomaly. The similar results have also been found by Pimenta et al. (2004, 2007). As electron density of F-layer increases the intensity of OI 630.0 nm emissions also increases because the rate of emissions depends on the concentration of ions. The plasma blobs in F-layer occurred after 21:00 LT (local time) near the equatorial anomaly region (Le et al. 2003).We found that signature of plasma blobs in images around 22:00 IST over Kolhapur. Typically, plasma blobs were observed during midnight period between $\sim$21:30 and 23:30 IST on all nights of observations; except on 22–23 April 2012 when these were observed post-midnight at 03:00–03:30 IST.

Herein we have calculated velocities of plasma blobs using scanning method. For this purpose, all images having signature of plasma blobs, were scanned from east to west. Figure 5 shows signature of plasma blobs (enhancement) and EPBs (depletions) variations in intensity of OI 630.0 nm obtained from images, recorded at 21:37:58 IST and 21:49:29 IST on 21–22 November 2011. The peak values of enhancement in intensity are 420 pixels

Table 1 The magnetic and solar condition of night of observations having signature of plasma blobs

Sr. no.	Night of observations	Occurrence time of plasma blobs (IST)	ΣKp index	F10.7 cm
1	22–23 October 2011	23:00–00:00	02	164
2	19–20 November 2011	23:30–00:00	06	141
3	21–22 November 2011	21:00–22:00	01	140
4	25–26 December 2011	21:45–22:30	03	144
5	17–18 January 2012	22:00–22:30	04	139
6	21–22 January 2012	21:00–21:30	06	142
7	23–24 January 2012	21:30–23:00	07	144
8	15–16 February 2012	21:15–22:15	18	105
9	20–21 February 2012	22:15–23:20	14	111
10	24–25 February 2012	21:30–23:00	6	109
11	27–28 February 2012	21:45–22:30	12	106
12	28–29 February 2012	21:30–22:00	11	103
13	18–19 March 2012	21:45–22:30	11	102
14	19–20 March 2012	21:15–21:45	08	102
15	25–26 March 2012	21:00–22:45	04	101
16	22–23 April 2012	02:45–03:15	07	148

and 320 pixels respectively. Thus, the difference in pixel values is 100 pixels. We have converted this pixel value into actual value by using relation between earth centered angle (ψ) and mean radius of the earth (R_h), described by Sharma et al. (2014b),

$$Arc = Radius \times Angle = R_h \times \psi \tag{1}$$

$$\psi = \cos^{-1}\left(\frac{R_h^2 + R^2 - r^2}{2R_h R}\right). \tag{2}$$

where R_h the sum of is mean radius of the earth and height of airglow emission layer and r is the distance between location of imager and signature of plasma event in the ionosphere, recorded in image of OI 630.0 nm. We have assumed that the nightglow OI 630.0 nm emissions are generated at an altitude of about 250 km. Most of variations in the electron density occur at about 250 ± 20 km altitude (Takahashi) Takahashi et al. 1993. Similarly, Taori et al. 2013, Pimenta et al. 2003 and Sekar et al. 2007 have also reported that the nightglow OI 630.0 nm emission are generated at thermospheric altitude about 250 km. From Kolhapur, ASI having 140° FOV covers ±6° latitude and longitude from the zenith, this corresponds to a horizontal distance of about ~1,220 km diameter at an altitude 250 km (Nade et al. 2013). Thus we have taken corresponding value of pixel conversion for 140° FOV, 1 pixel is equal to 1.533 km (please refer Table 1 of Sharma et al. 2014b). Thus actual distance covered by plasma blob from one place to another was 153.3 km in 691 s, and corresponding zonal drift velocity was 221 ms^{-1}. Similarly, calculated zonal drift velocity of EPBs was about 237 ms^{-1}. The enhancement in intensity of OI 630.0 nm obtained by photometer is observed for specific date and time. Figure 6 illustrates the signature of plasma blob and EPBs in intensity of OI 630.0 nm emission obtained by photometer on 19–20 March 2012. We have smoothed this intensity data using FFT analysis which is indicated by red line in Fig. 6. This red line shows the normal

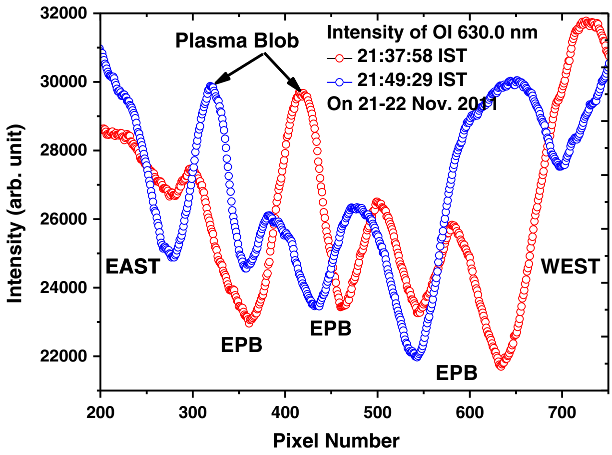
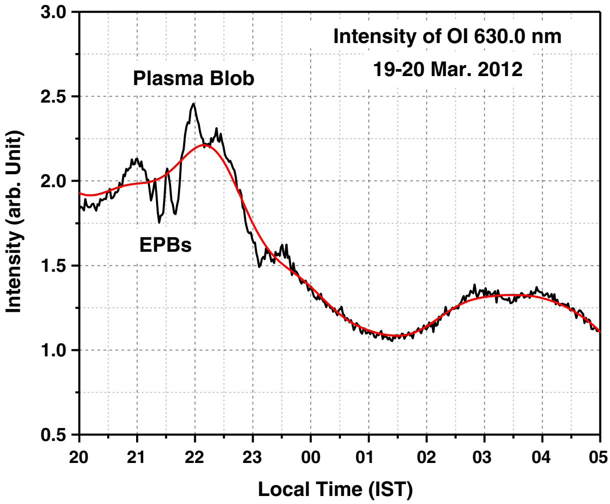


Fig. 5 The signature of plasma blobs (enhancement in intensity) and EPBs in intensity of OI 630.0 nm obtained by east–west scans of OI 630.0 nm images obtained at 21:37:58 IST and 21:49:29 IST on 21–22 November 2011

Fig. 6 The signature of plasma blob and EPBs in intensity of OI 630.0 nm emissions obtained, on 19–20 March 2012, by measurements of photometer. *Red line* indicates the smoothed intensity. (Color figure online)



variation in intensity of OI 630.0 nm emissions. We found that, on 19–20 March 2012, EPBs occurred at 21:22 IST and 21:37 IST while plasma blob occurred at 22:00 IST.

The F-region nightglow OI 630.0 nm emissions were measured by photometer from Kolhapur during clear moonless night. Simultaneous measurements of ASI and photometer are showing occurrence of plasma blobs in intensity of OI 630.0 nm. In the present work we have discussed three cases. Figure 7a, b show the signature of plasma blobs and EPBs in the intensity of OI 630.0 nm emissions obtained by ASI and photometer on 21–22 January 2012. The data of image shows that the plasma blobs occurred during 22:00–22:30 IST and we have found that in photometer measurements, the peak value of intensity occurred at 22:12 IST. Therefore the enhancement in intensity is the signature of plasma blobs. Based

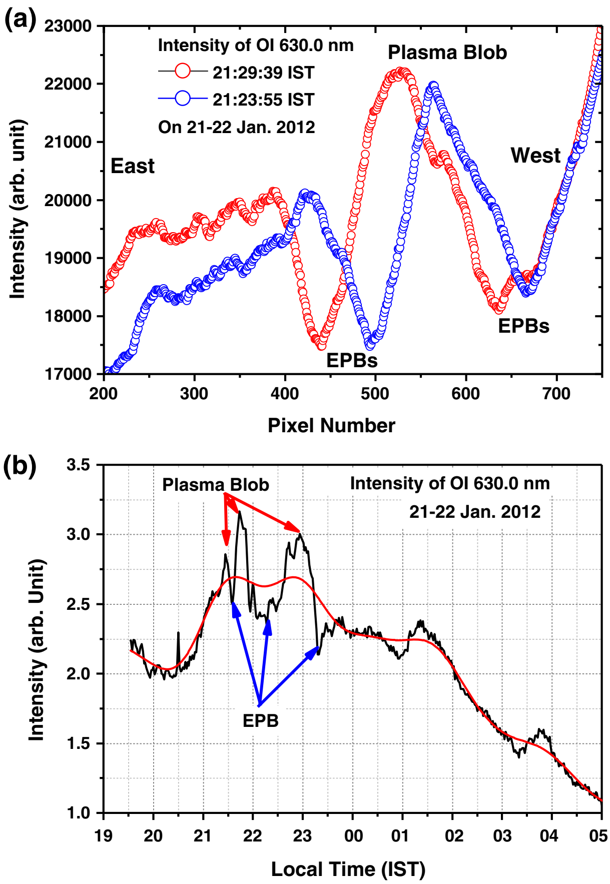


Fig. 7 The signature of plasma blobs and EPBs in intensity of OI 630.0 nm emissions obtained by ASI (**a**) and photometer (**b**) on 21–22 January 2012

on data of magnetic index (ΣKp index = 04) and solar flux (F10.7 cm = 139), 21–22 January 2012 were magnetically quiet.

Figure 8a, b show the signature of plasma blobs and EPBs in the intensity of OI 630.0 nm emissions obtained by ASI and photometer on 15–16 February 2012. On 15–16 February 2012, the plasma blobs were occurred during 21:15–22:15 IST and peak enhancement occurred at 22:00 IST and 22:30 IST in intensity of OI 630.0 nm obtained by photometer. Therefore the enhancement in the intensity is signature of plasma blobs. The magnetic index (ΣKp index) and solar flux (F10.7 cm) were 18 and 105 respectively on 15–16 February 2012. This night was also magnetically quiet.

Figure 9a illustrates signature of plasma blobs and EPBs in intensity of OI 630.0 nm obtained from east–west scan of images, recorded at 21:30:20 IST and 21:41:27 IST on 28–29 February 2012. Occurrence period of plasma blobs on 28–29 February 2012 was 21:30–22:00 IST. We found that this night was magnetically quiet because ΣKp index and F10.7 cm were 11 and 103 respectively. In addition with image data, the signature of plasma blob was also found in intensity obtained by photometer on same time, it is presented in Fig. 9b. The plasma blobs occurred at 21:15 IST and 21:52 IST in intensity of OI 630.0 nm emissions obtained by photometer on 28–29 February 2012. Table 1 shows the occurrence of period of plasma blobs.

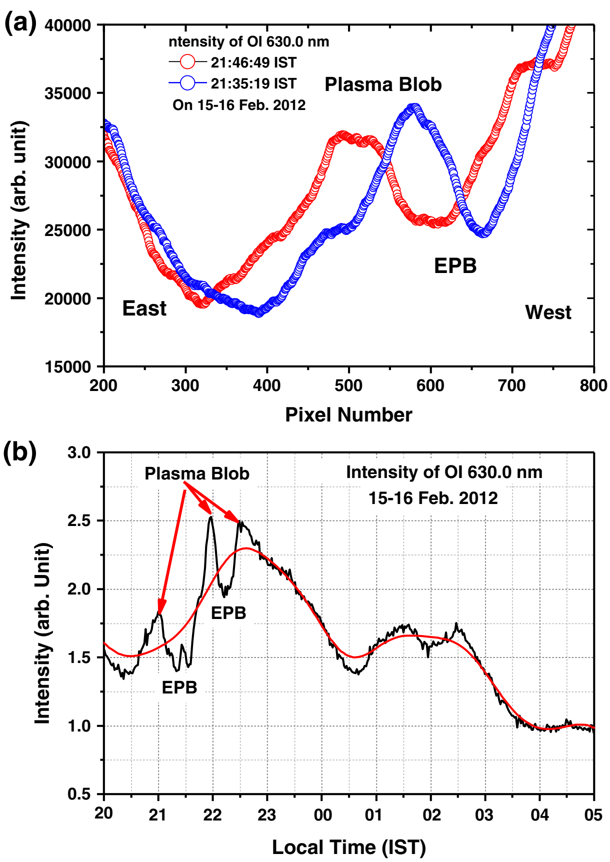


Fig. 8 The signature of plasma blobs and EPBs in intensity of OI 630.0 nm emissions obtained by ASI (**a**) and photometer (**b**) on 15–16 February 2012

Herein, we have calculated velocity of plasma blobs and EPBs from successive images of OI 630.0 nm having signature of plasma blobs. For more accuracy we have taken their average values. These calculated mean velocities of plasma blobs and EPBs are 140 and 160 m/s, respectively. The average eastward velocity of the plasma blobs is 140 m/s and it varies from 100 to 200 m/s. The eastward zonal velocities of plasma blob were comparatively less than that of the EPBs in several cases. These results are in good agreement with previous studies made by other researchers. Pimenta et al. 2004 have reported that the mean eastward velocities of the plasma blobs and EPBs were 80 m/s and 140 m/s respectively.

Additionally, we have calculated width (east–west expansion) and length (north–south expansion) of plasma blobs using method described by Sharma et al. (2014b). These are in the range of 100–200 and 500–900 km respectively. The calculated width of plasma blobs is in agreement with the results presented by Pimenta et al. (2004, 2007) They have reported east–west expansion of plasma blobs to be 110–180 and 150–180 km respectively. While we found that the range of north–south expansion of plasma blobs are comparatively higher than the ranges, 200–460 km and 190–240 km (Pimenta et al. 2007, 2004) respectively. The summary of results of the present work is given in Table 2. Table 2 shows the average width, length and velocity of plasma blobs. The effects of geomagnetic and solar indices on occurrence, length, width and velocity of plasma blobs,

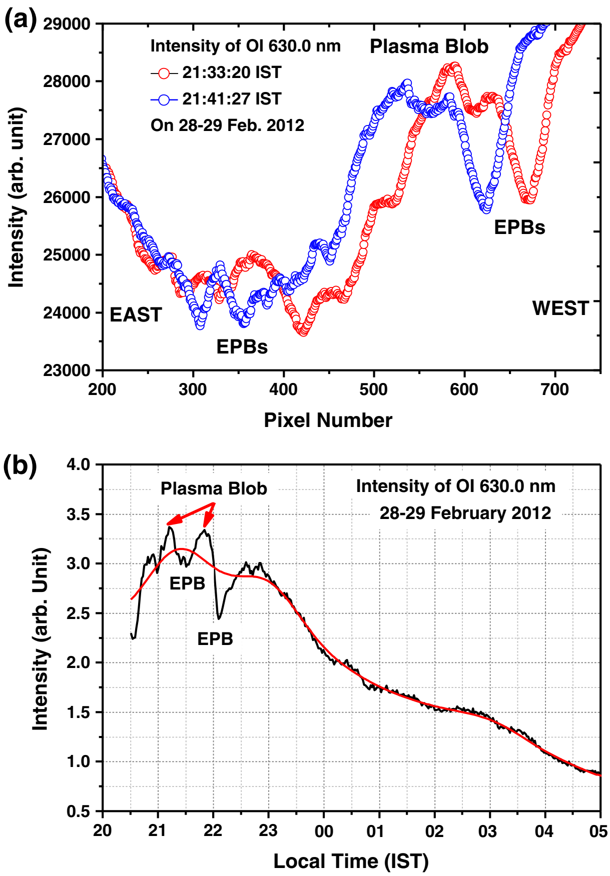


Fig. 9 The signature of plasma blobs and EPBs in intensity of OI 630.0 nm emissions obtained by ASI (**a**) and photometer (**b**) on 28–29 February 2012

have not been seen. It is confirmed from Table 1 and 2. Park et al. 2003 found no correlation in the occurrence of blobs and the magnetic activity or daily variation of solar activity. The plasma blobs rarely depend on the level of solar activity in contrast with the EPBs (Park et al. 2008). However, no clear explanation is offered for these findings.

The comparative results of ASI and photometer data are presented in Table 3. We found enhancement in mean intensities, obtained by photometer and ASI, nearly same, 30 and 32 % than that of normal values, respectively, during occurrence of plasma blobs. The plasma blobs were developed just after the reversal of electric field (Pimenta et al. 2007), when the drift velocity changes from upward (eastward electric field) to downward (westward electric field). We have also observed the eastward motions of plasma blobs associated with EPBs (in all nights). The EPBs originated from the bottom-side of F-region, as expected, whereas the blobs were produced by local vertical perturbations in the topside of ionosphere (Kil et al. 2011). Electric field causes the polarization within the EPBs mapping to the anomaly latitudes ($\sim\pm10°$ to $\pm20°$) along the magnetic field lines, and latter was responsible for formation of plasma blobs (Le et al. 2003). Therefore, the depletions in plasma density cannot extend to higher latitudes and remain limited to anomaly crests. The formation mechanism of the plasma blobs seems to be related to the existence of EPBs Pimenta et al. 2004. However, more coordinated measurements are necessary to verify the proposed theories.

Table 2 The average width, length and velocity of plasma blobs calculated by images of OI 630.0 nm

Sr. No.	Night of observations	Width (km)	Length (km)	Velocity (ms^{-1})
1	22–23 October 2011	72	948	148
2	19–20 November 2011	125	790	210
3	21–22 November 2011	92	733	98
4	25–26 December 2011	155	660	98
5	17–18 January 2012	107	530	127
6	21–22 January 2012	104	744	110
7	23–24 January 2012	105	721	138
8	15–16 February 2012	122	844	128
9	20– 21 February 2012	102	852	115
10	24– 25 February 2012	100	842	123
11	27–28 February 2012	108	751	167
12	28–29 February 2012	182	810	130
13	18–19 March 2012	115	571	170
14	19–20 March 2012	105	570	151
15	25–26 March 2012	95	790	98
16	22–23 April 2012	158	586	114

Table 3 The percentage of enhanced intensity of nightglow OI 630.0 nm emission with normal intensity measured by photometer and ASI from Kolhapur

Sr. no.	Night of observations	Photometer (%)	ASI (%)
1	22–23 October 2011	38	32
2	19–20 November 2011	24	27
3	21–22 November 2011	27	30
4	25–26 December 2011	26	34
5	17–18 January 2012	37	34
6	21–22 January 2012	29	23
7	23–24 January 2012	33	30
8	15–16 February 2012	36	34
9	20–21 February 2012	30	27
10	24–25 February 2012	32	30
11	27–28 February 2012	37	32
12	28–29 February 2012	38	34
13	18–19 March 2012	39	37
14	19–20 March 2012	28	25
15	25–26 March 2012	29	30
16	22–23 April 2012	36	34

4 Conclusions

The plasma blobs associated with EPBs occurred over low latitude station, Kolhapur. The observations of OI 630.0 nm emissions were made by ASI and photometer during October 2011–April 2012. Generally, plasma blobs occurred 1 h after sunset. The average zonal drift velocity (eastward) of the plasma blobs were found to be 133 ms^{-1} and vary between

100 and 200 ms^{-1}. Their mean width (east–west expansion) and length (north–south expansion) were in the range of 70–180 and 500–950 km respectively. The observations show that localized eastward polarization electric field plays an important role in generation of plasma blobs.

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