CHAPTER 4

Result and Discussion

The brightness variation of Io's magnetic footprint is showed in Fig. 4.1. Comparison of Io's magnetic footprint brightness between northern and southern hemisphere shows clear different trend of variation. For one similarity, The peak brightness is about 110° for first peak and about 290° for second peak. The variation of footprint in Fig. 4.1 shows a good agreement with previous study by Bonfond et al. (2013). Near the peak emission, Io's magnetic footprint brightness in southern hemisphere appears brighter than the footprint from northern hemisphere. One explanation was suggested by Bonfond et al. (2013) to be the magnetic asymmetry between both hemispheres of Jupiter.

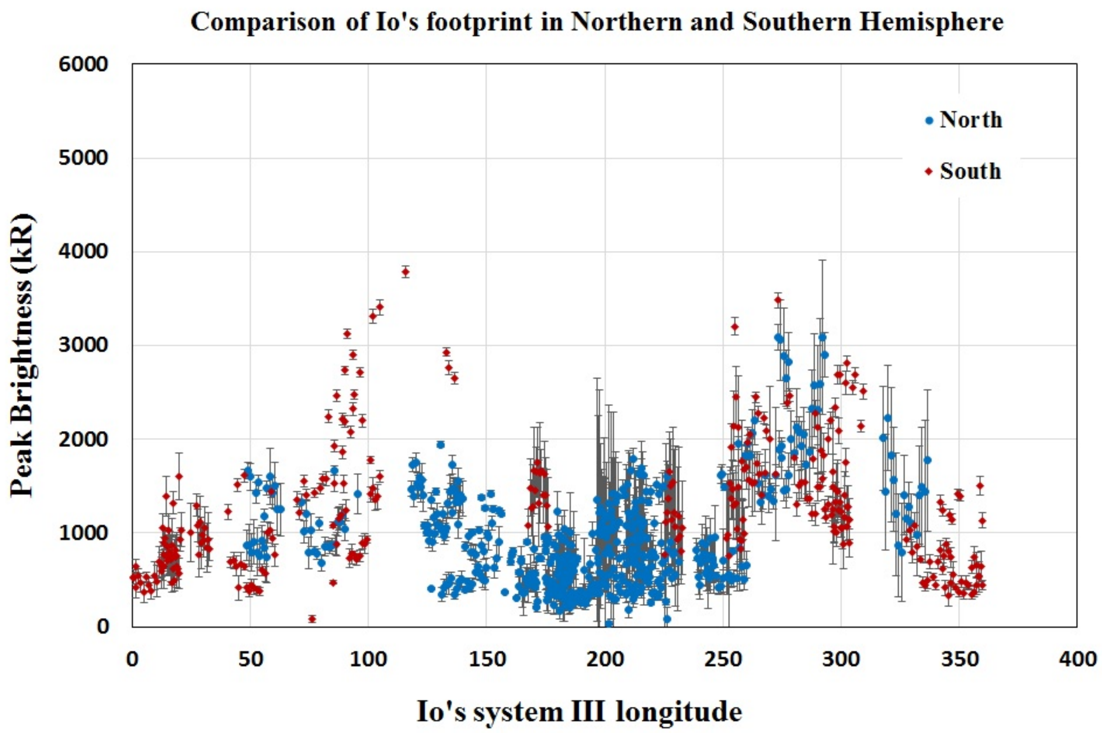


Figure 4.1: The comparison of Io's magnetic footprint from northern and southern hemispheres. Blue symbols represent the brightness in northern hemisphere and red symbols represent the brightness in southern hemisphere.

The fitted result to magnetic footprint in southern hemisphere is shown in Fig. 4.2. The magnetic footprint, which was observed before 2007, appears around the fitted trend-line near the peak emission. The maximum brightness was analysed to be $\sim$ 3,300 kR. The variation brightness between fitted data and observed data have correlation R = 99.62 %. This graph does not include the data on February 2007 because the footprint is very close to limb. When aurora emission appears near the edge, observer looks through several layers of the atmosphere, corresponding to the overestimation of footprint brightness. As a result, Io's magnetic footprint at the limb appears brighter than regular. Therefore magnetic footprint brightness near the edge cannot be analyzed and compared with other data.

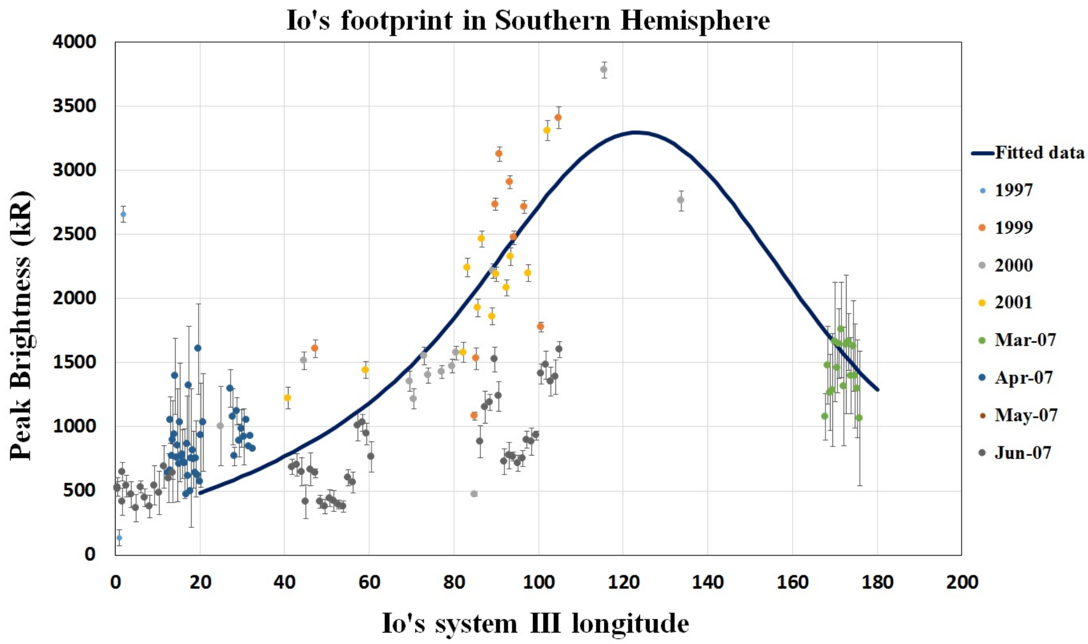


Figure 4.2: Variation trends of Io's magnetic footprint in southern hemisphere.

The magnetic footprint brightness from aurora in northern hemisphere is highly (as seen in Fig. 4.3) variable. Fitting a trend line to the brightness variation becomes very challenging. The maximum brightness was found to be $\sim$ 1,600 kR (Fig. 4.3). The correlation between fitted data and observed data have correlation R = 97.38 %. The maximum brightness is fainter than footprint in southern hemisphere. In addition, the magnetic field in northern polar region is stronger than magnetic field in southern region (Vogt et al., 2015). In the north, mostly charged particles were trapped at the loss cone region and reflected along magnetic field line to the opposite region (Equation 2.6). When charged particles gyrate to weaker region of magnetic field, the greater number of particles can travel into auroral region, resulting in brighter Io's magnetic footprints in southern region than those in northern region.

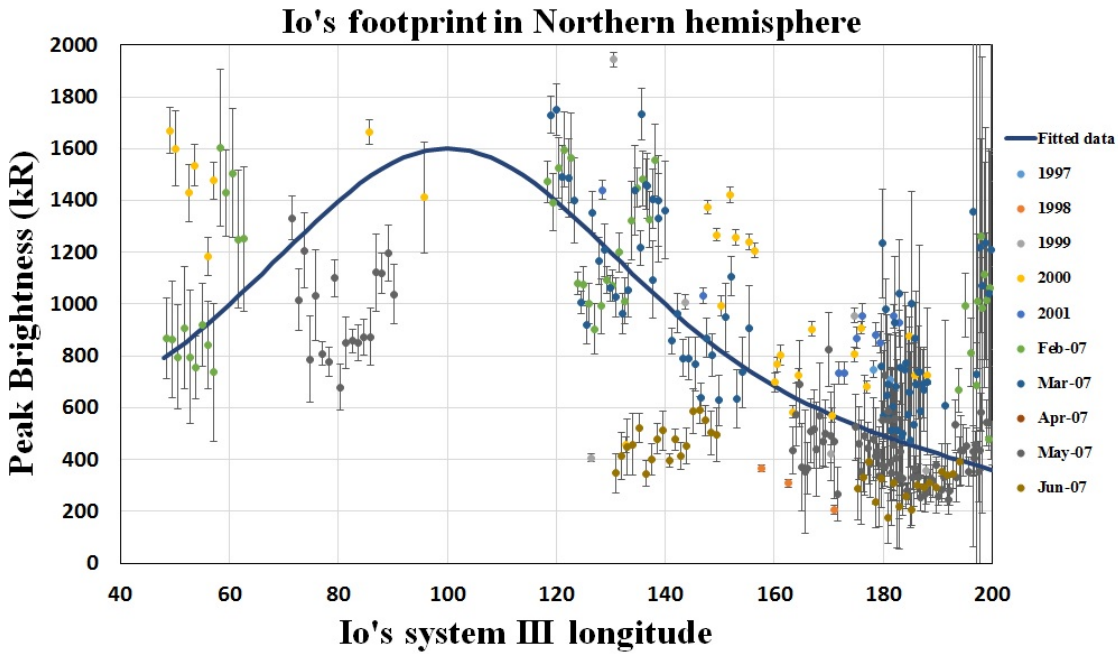
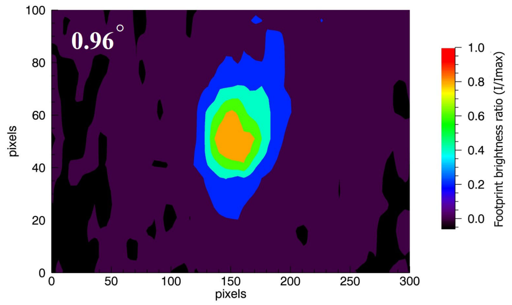


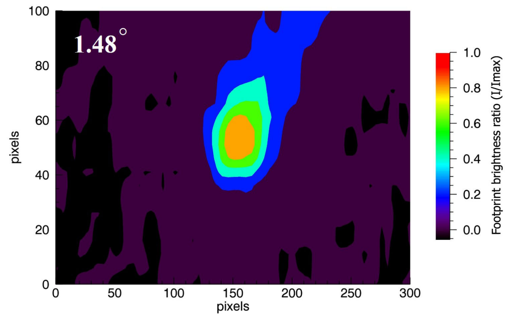
Figure 4.3: Variation trends of Io's magnetic footprint in northern hemisphere.

4.1 Feature of Magnetic Footprint Emission

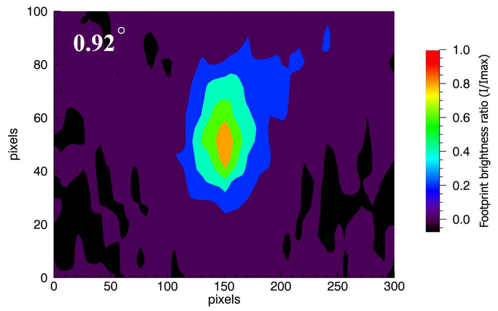
In previous study, Io has strong volcanic eruption at the end of February and the beginning of March, while other eruptions started at the end of May to the beginning of June. The spot at the similar longitude were compared in several longitudes. Fig. 4.4, Fig. 4.5 and Fig. 4.6 show Io's footprint brightness ratio in each spots. Structure of Io's footprint varies at different observing times for similar Io's system III longitudes. The comparison of brightness and extended angle of magnetic footprint was presented in Table 4.1.



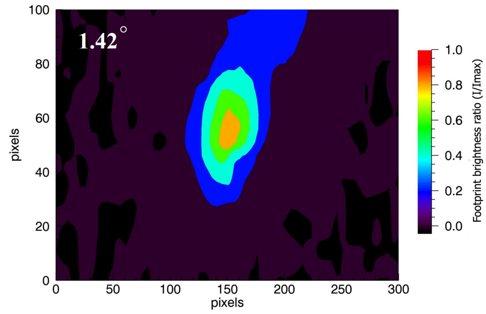
(a) 21 February 2007 at 15:21:22



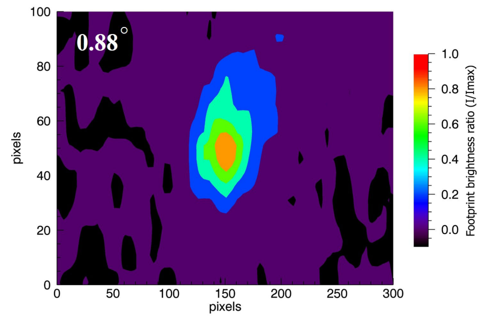
(b) 4 March 2007 at 10:23:41



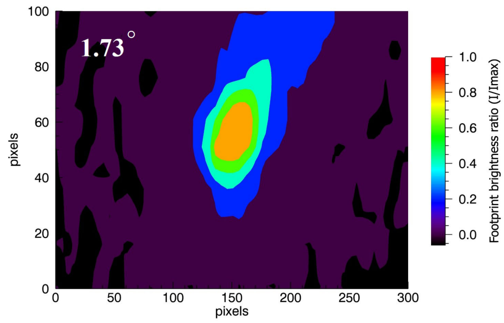
(c) 21 February 2007 at 15:23:42



(d) 4 March 2007 at 10:26:01



(e) 21 February 2007 at 15:30:42



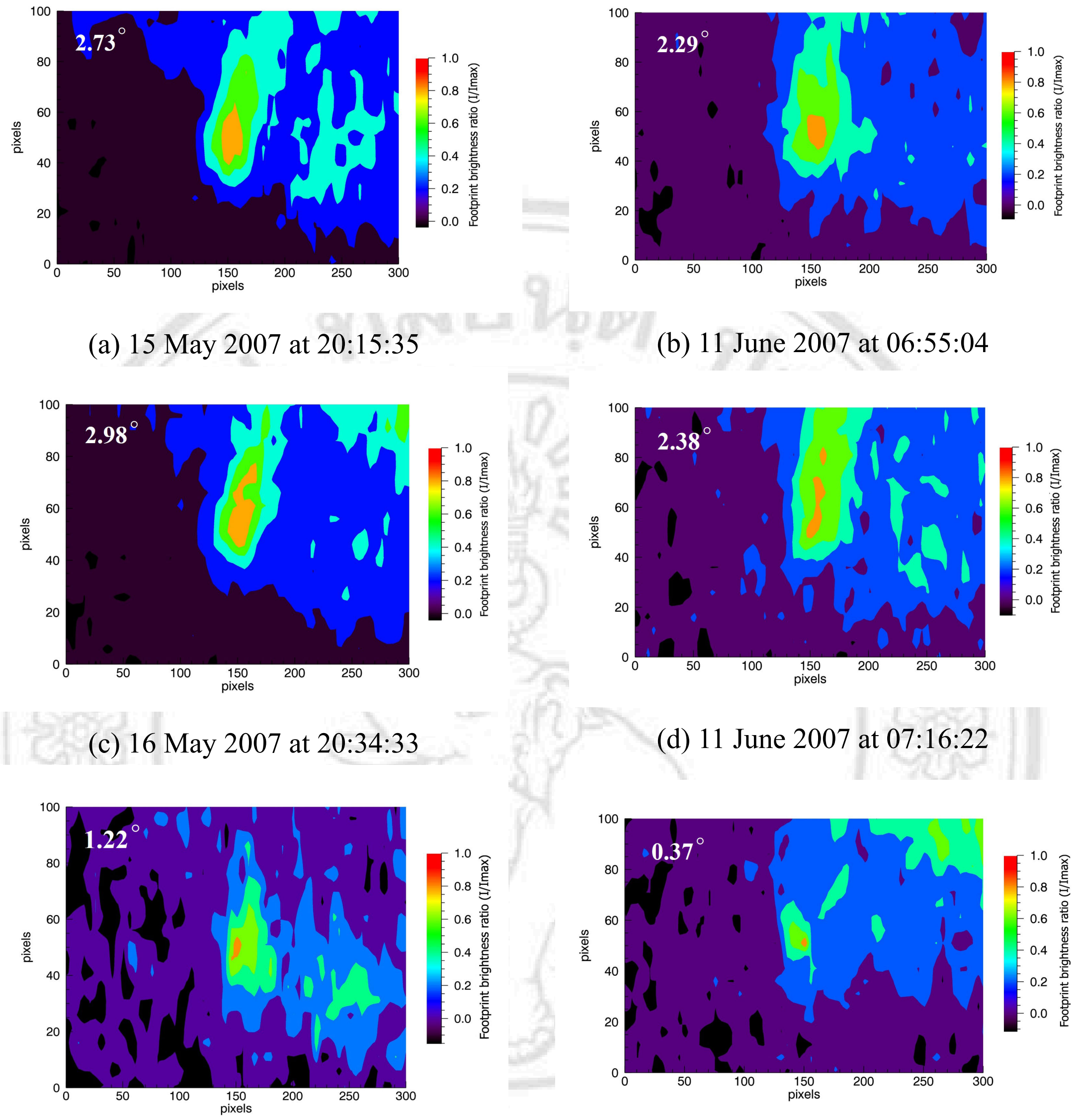
(f) 4 March 2007 at 10:30:41

Figure 4.4: Comparison extended angles of footprint at similar longitudes, which are a) 118.31°, b)118.94°, c) 119.39°, d) 120.02°, e) 122.64°, and f) 122.19°, in Northern hemisphere between February (left) and March (right).

Table 4.1: Comparison of magnetic footprint's brightness in northern hemisphere between February 2007 and March 2007 when Io located at similar locations.

UDATE	TIME	Io's system III longitude	Brightness (kR)	Lfactor	Extended angle (degree)
21/2/2007	15:21:22	118.31	1471.45	1.86	0.96
4/3/2007	10:23:41	118.94	1729.27	2.12	1.48
21/2/2007	15:23:42	119.39	1391.89	1.84	0.92
4/3/2007	10:26:01	120.02	1752.36	2.14	1.42
21/2/2007	15:30:42	122.64	1565.06	1.82	0.88
4/3/2007	10:30:41	122.19	1487.09	2.17	1.73

At first, the extended angles of magnetic footprint observed in February 2007 and March 2007 appears to be corresponding with Io's magnetic footprint brightness and Limb brightening correction factor (Lfactor). The correlation between brightness and Lfactor is R= 46.84 %, while correlation between brightness and extended angle is R= 54.41 %. Larger values of Lfactors were found for magnetic footprint observed in February then those for March. This result shows a good correlation with the increment of extended angles of magnetic footprints from February to March. However the brightness variation is not completely consistent with the variation of extended angles. Therefore one factor which could control extended angle of Io's magnetic footprint probably be the limb brightening factor. In table. 4.1, Io's brightness is brighter in early March than those found in late February. However at longitude $\sim 122^{\circ}$ (Fig. 4.4e and Fig. 4.4f) Io's footprint in February is slightly brighter than that in March. This result suggests that volcanic activity on Io is not only factor controlling the brightness of Io's magnetic footprint. Therefore various factors should be further analyzed in detail.



(a) 15 May 2007 at 20:15:35

(b) 11 June 2007 at 06:55:04

(c) 16 May 2007 at 20:34:33

(d) 11 June 2007 at 07:16:22

(e) 22 May 2007 at 20:22:03

(f) 11 June 2007 at 06:40:46

Figure 4.5: Comparison extended angles of footprint at similar longitudes, which are a) 184.36°, b) 184.11°, c) 193.15° d)193.99 e) 176.54°, and f) 177.48°, in Northern hemisphere between May (left) and June (right).

Yoneda et al. (2013) showed eruptions of Io's volcanoes near the end of May through the beginning of June. As seen in table 4.2, Io's footprint brightness was found to be lower from the middle of May to June. This low brightness probably be a result of relaxation of interactions due to the volcanoes and also due to the positions of Io near the edge of torus. The extended angle relates well with limb brightening factor. The correlation (R) both between brightness and Lfactor and between brightness and extended angle are equally

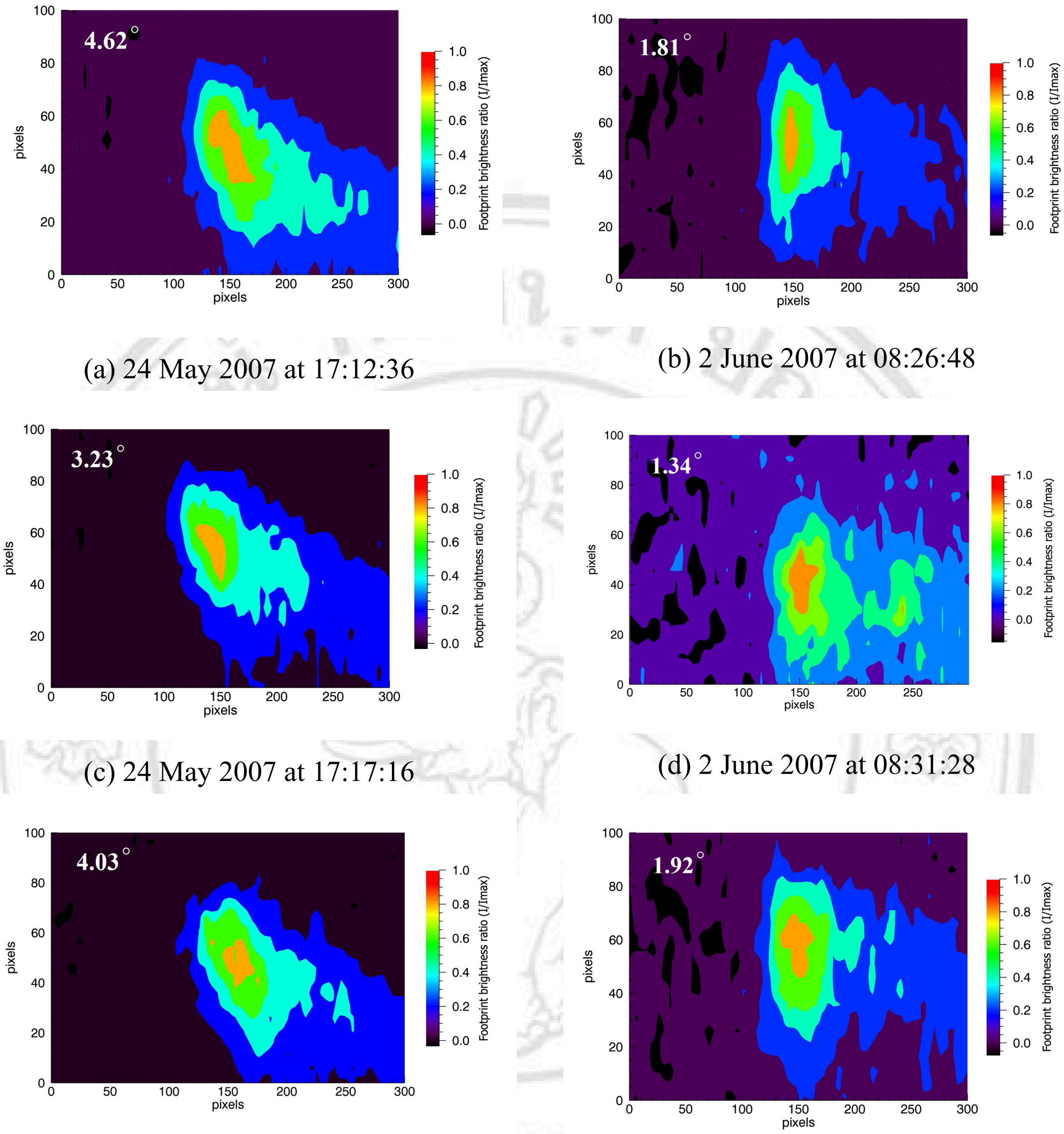
62.28 %. However there are some spots stay unchanged at longitude $\sim 177^{\circ}$. These two spots have similar Lfactor but extended angles are very different. Thus not only limb brightening factors could control expanded angle but also other factors, which are required insight analysis, could influence the extended angle as well.

Table 4.2: Comparison of magnetic footprint's brightness in northern hemisphere between May 2007 and June 2007 when Io located at similar locations.

UDATE	TIME	Io's system III longitude	Brightness (kR)	Lfactor	Extended angle (degree)
15/5/2007	20:15:35	184.36	280.78	2.48	2.73
11/6/2007	6:55:04	184.11	257.36	2.03	2.29
15/5/2007	20:34:33	193.15	533.54	2.95	2.98
11/6/2007	7:16:22	193.99	392.21	2.30	2.38
22/5/2007	20:22:03	176.54	493.16	1.97	1.22
11/6/2007	6:40:46	177.48	391.35	1.91	0.37

The different features of Io's magnetic footprint spots were noticed from data in northern hemisphere. In figure 4.5, Io is near the edge of plasma torus. As a result the footprint multiple spots clearly appear. While, in figure 4.4, Io move toward near the center of the plasma torus. This position is very dense region of plasma. Therefore charged particles were refracted along magnetic field with the influence of strong Alfvén disturbance. As a result, Io's magnetic footprint spots have high brightness with well confined extended angle (small angle). On the other hand, in figure 4.5, with less dense plasma environment and longer distance for Alfvén wave to travel through the torus, Io's magnetic footprint spots have low brightness with more diffused extended angle (big angle).

In southern hemisphere, the data of Io's footprint brightness is less than those in northern hemisphere. Thus it is difficult to find spots which are at the similar longitude. As mentioned earlier, in southern region, emission data on February was not analyzed because the footprints are very close to the limb. Therefore the footprint brightness in south region will be compared only during May and June (Fig. 4.6).



(a) 24 May 2007 at 17:12:36

(b) 2 June 2007 at 08:26:48

(c) 24 May 2007 at 17:17:16

(d) 2 June 2007 at 08:31:28

(e) 24 May 2007 at 17:19:36

(f) 2 June 2007 at 08:33:48

Figure 4.6: Comparison extended angles of footprint at similar longitudes, which are a) 343.23°, b) 343.07°, c) 345.40°, d) 345.24, e) 346.48°, and f) 349.32° in southern hemisphere between May (left) and June (right).

Table. 4.3 shows brightness of footprint during late May and the beginning June. It must be noted that the footprint's longitude was not near the longitude of peak brightness. Thus, Io's magnetic footprint is not very bright. As seen in Fig. 4.6 at Io's systen III longitude $\sim$ 300°-350° Io's footprint brightness is very low. However the extended angles still correspond well with limb brightening factors. The correlation between brightness and Lfactor is R= 94.28 %, while correlation between brightness and extended angle is

R= 77.14 %. Therefore, this is another confirmation that we need to investigate other factors that could influence the relation between Io's system III longitude and Io's magnetic footprint brightness.

Table 4.3: Comparison of magnetic footprint's brightness between May 2007 and June 2007 at the similar spots in southern hemisphere.

UDATE	TIME	Io's system III longitude	Brightness (kR)	Lfactor	Extended angle (degree)
24/5/2007	17:12:36	343.23	751.24	2.58	4.62
2/6/2007	8:26:48	343.07	619.83	2.21	1.81
24/5/2007	17:17:16	345.40	810.00	2.63	3.23
2/6/2007	8:31:28	345.24	328.87	2.16	1.34
24/5/2007	17:19:36	346.48	739.83	2.60	4.03
2/6/2007	8:33:48	349.32	464.24	2.18	1.92