Chin. J. Astron. Astrophys. Vol. 5 (2005), No. 3, 265–272
(*http://www.chjaa.org*)

Chinese Journal of
Astronomy and
Astrophysics

# Two Sympathetic Homologous CMEs on 2002 May 22 *

Jian-Xia Cheng, Cheng Fang, Peng-Fei Chen and Ming-De Ding

Department of Astronomy, Nanjing University, Nanjing 210093; *chengjianxia@nju.org.cn*

Received 2004 October 9; accepted 2005 March 15

**Abstract** Sympathetic coronal mass ejections (CMEs) usually occur in different active regions connected by interconnecting magnetic loops, while homologous CMEs occur within the same active region with an almost the same background magnetic field, and so are similar in shapes. Two sympathetic CMEs erupted within 3 hours on 2002 May 22, originating from the same active region, AR 9948. Their multi-wavelength data were collected and analyzed. It is suggested that emerging flux triggered the occurrence of the first CME and the corresponding flare, the reconnection inflow of which in turn triggered the eruption of the second CME. Based on the fact that the two sympathetic CMEs have many similarities, in their shapes, their low-lying dimming areas, etc., we tentatively propose, for the first time, the phenomenon of sympathetic homologous CMEs.

**Key words:** sun: filament — sun: flares — sun: CMEs

## 1 INTRODUCTION

Coronal mass ejections (CMEs) are so far the largest eruptive events in the solar atmosphere. A typical CME can be described as consisting of three parts: a front loop, a cavity, and a core, the last corresponds to an erupting filament or prominence. It carries into interplanetary space some $10^{14}$ to $10^{16}$ g of magnetized material which may drive strong magnetic storms. It is widely believed that large-scale magnetic restructuring is involved in the CMEs, therefore, it is plausible that a given CME originating from a particular region, could trigger the eruption of a "sympathetic" CME initially rooted in another location. Simnett & Hudson (1997) investigated a CME event which erupted off the NE limb of the sun while another CME was already in progress off the east side of the sun $\sim 3$ hours before, so there is a possibility that the NE limb CME was triggered by the proceeding event, rather than an independent event. The first announced piece of evidence for the existence of sympathetic CMEs was presented by Moon et al. (2003), who found that the CME angular difference distribution shows a noticeable excess only within 20°, and illustrated the phenomenon with an example. It is proposed that the following CME is triggered by the preceding one with some physical connection. It has

* Supported by the National Natural Science Foundation of China.

been well established that coronal shock waves often accompany large flares, which sweep the chromosphere to form Moreton waves, and may cause oscillation or even eruption of a remote filament (Ramsey & Smith 1966). Now it is getting clearer that the coronal shock may result from a flare-associated CME, rather than from the flare itself (Cliver, Webb & Howard 1999; Chen et al. 2002), and the ensuing filament eruption may be the H$\alpha$ imprint of another CME event. Therefore, MHD shock resulting from a given CME may be one possible driving agent for a following sympathetic CME. On the other hand, a CME corresponds to an opening-up of large-scale magnetic loops, sometimes seen as the disappearance of the interconnecting loops. After the disappearance of the overlying magnetic loops, a remote flux rope system, which initially was in equilibrium under the balance of the upward magnetic pressure and the downward magnetic tension force (Low 1994) , would lose its equilibrium, and erupt as a sympathetic CME. Therefore, the opening-up of the overlying magnetic field lines covering two flux rope systems is another possible driving agent for sympathetic CMEs.

On 2002 May 21–22, two CMEs erupted off the southwest limb one after the other within $\sim 3$ hours, a strong indication of their sympathetic nature. Correspondingly, two long-duration type flares appeared, overlapping in time. The events presented a rare opportunity to study the sympathetic behaviors of both CMEs and flares in detail. The observational data are described in Sect. 2, the detailed results are presented in Sect. 3, which is then followed by a discussion in Sect. 4.

## 2 OBSERVATIONS

Two sympathetic homologous CMEs occurred in the active region AR9948 (S25W64) within 3 hours on 2002 May 22, and they were observed by the Large Angle and Spectrometric Coronagraph (LASCO) telescope (Brueckner et al. 1995) on board the Solar and Heliospheric Observatory (SOHO, Domingo, Fleck & Poland 1995).

The SOHO/LASCO consists of three nested coronagraphs, labelled C1, C2, C3, and only C2 and C3 were at work at the time. Their fields of view range from 2–6.0$R_\odot$, 3.7–32$R_\odot$, respectively, with corresponding spatial resolutions of 11.4 and 56 arcsec. The *EUV Imaging Telescope* (EIT, Delaboudiniere et al. 1995) on board SOHO images the solar transition region and inner corona extending from the solar disk to 1.5$R_\odot$. It works in four different wavelengths: 171, 195, 284 and 304 Å with a temporal resolution of about 12 minutes. In this paper, the Fe XII 195 Å images are analyzed for associated activities near the source region of the two CMEs. It is found that two solar filaments erupted in the source region. Note that the filaments appear as dark features in the Fe XII 195 Å images. The longitudinal magnetic field in the photosphere was observed by the *Michelson Doppler Imager* (MDI, Scherrer et al. 1995) on board SOHO.

As indicated by the *Geostationary Operational Environmental Satellite* (GOES), two solar flares classified as C9.7 and C5.0 occurred during the events, with one-to-one correspondence to the two CMEs. Both flares possessed two-ribbon structures in the H$\alpha$ images observed by the Huairou Solar Observing Station (HSOS) of the National Astronomical Observatories of China (NAOC).

## 3 ANALYSIS AND RESULTS

### 3.1 First Event

As shown in Fig. 1, the first CME was seen at beginning at 00:06:06 UT in the white light with the LASCO C2 coronagraph. In the SW direction we can see a bright front loop with a cavity and an embedded core. After 00:42:05 UT the CME appeared in the C3 field of view with an angular width extending up to 180°. From 00:06:06 UT to 00:26:06 UT, the bright front loop shifted from 3.23$R_\odot$ to 4.85$R_\odot$. Thereafter, it disappeared from the C2 field of view, and

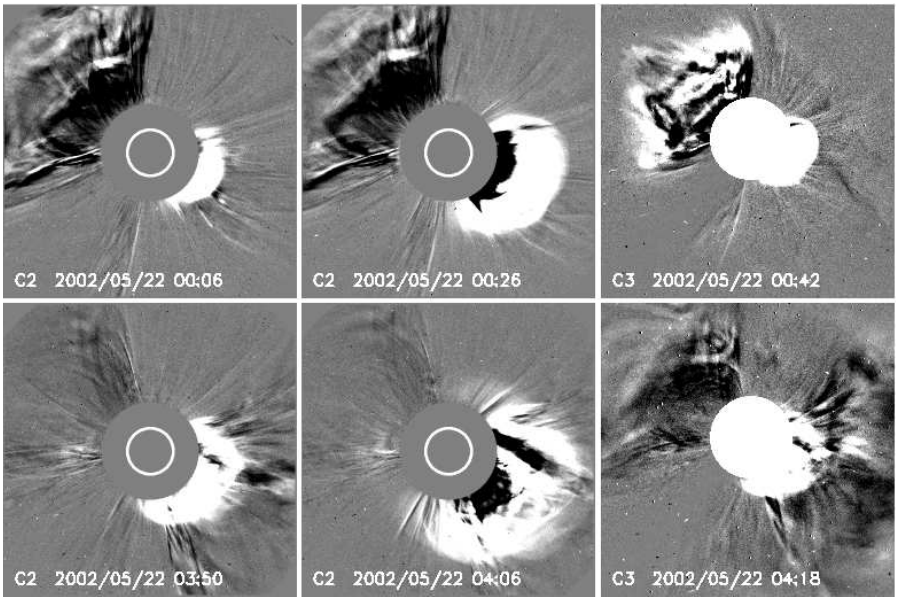


**Fig. 1** Evolution of the first CME (*upper panels*) and the second CME (*lower panels*).

was visible in C3, where its front loop propagated with a nearly constant speed before it went out of the C3 field of view at $26.27R_{\odot}$. A C9.7 flare, associated with the first CME started to appear at 23:48 UT on 2002 May 21. As seen from the EIT movie, a filament began to rise, expanded and finally erupted at 23:24:11 UT on May 21 before the flare occurred. According to the GOES soft X-ray observation, the flare underwent its pre-flare phase from 23:30 UT, and the soft X-ray flux reached its peak at about 00:25 UT. As for the onset of the first CME, Fig. 3 displays the evolution of a magnetogram near the active region before the two eruptions. It is highlighted by the emergence of a pair of magnetic elements with opposite polarities between the negative sunspot and an extended positive magnetic region that was the channel of the first erupting filament. According to the criteria given by Feynman & Martin (1995) and Chen & Shibata (2000), the new emerging flux is reconnection-favored. The magnetic reconnection between the emerging flux and pre-existing magnetic field causes line-tied field lines to detach from the solar surface, removes the constraint over the flux rope and finally triggers the eruption of the filament to form the first CME. A similar case was analyzed by Zhang, Wang & Nitta (2001).

### 3.2 Second Event

At 03:50 UT the second CME was first seen in C2 at a height of $4R_{\odot}$ (see the lower panels of Fig. 1). The CME reached $5.95R_{\odot}$ at 04:06:05 UT. Thereafter, it went out of the C2 field of view, and underwent a steady evolution in C3. It traveled with a nearly constant speed until it went out of the field of view at 06:42:05 UT.

At 02:50 UT, a dark filament began to be active. Between 03:12 UT and 03:24 UT, the filament erupted rapidly. At about 03:25 UT, the flare underwent its rise phase, and the soft X-ray flux peaked at about 03:45 UT.

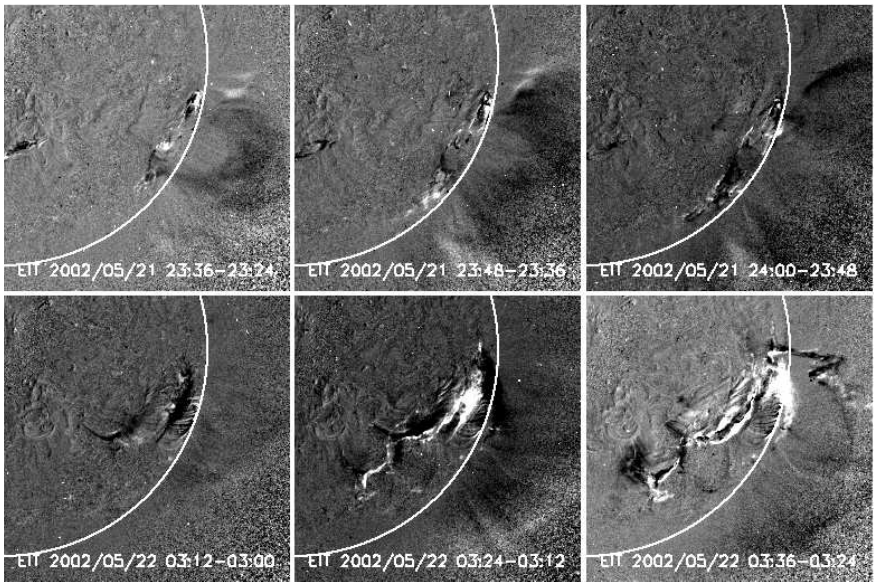


**Fig. 2** EIT 195Å running difference images showing the EUV dimming associated with the two CMEs. Dimming occurred during the first event in upper panels, and that in the second event in the lower panels. Extended EUV dimmings in both two events are very similar with each other.

### 3.3 Summary of the Two Events

As shown above, each of the two events involved three solar phenomena: a CME, a filament eruption, and a flare. As can be seen from the EIT images, the second eruption was more drastic than the previous one (Fig. 2). Their temporal relationship is synthesized in Fig. 4, with the filament eruptions (asterisks) and the height-time evolutions of the two CMEs (solid lines) superimposed on the GOES soft X-ray (dashed line) light curve. The time of occurrence of the filament eruptions were determined by examining both the EIT 195 Å and the H$\alpha$ images, and the crosses connected by solid lines in the figure correspond to the front loop heights measured from the LASCO images. The first CME propagated with a speed increasing from $\sim 937$ km s$^{-1}$ to $\sim 1243$ km s$^{-1}$, and the second CME propagated with a speed increasing from $\sim 1400$ km s$^{-1}$ to $\sim 1740$ km s$^{-1}$.

It can be seen that the two CMEs had many similarities: (1) each of them was associated with a filament eruption and a two-ribbon flare; (2) both of them originated from the same active region; (3) the morphologies are similar during the LASCO field of view as seen in Figs. 1 and 4; (4) as illustrated in Fig. 2, the low-lying EUV dimmings on the disk are also similar for the two CMEs.

## 4 DISCUSSION

### 4.1 Phenomenological Model for Sympathetic CMEs

Sympathetic events can be defined as the occurrence of an eruption induced by another event occurring elsewhere with some physical connection. Many studies dedicated to sympathetic

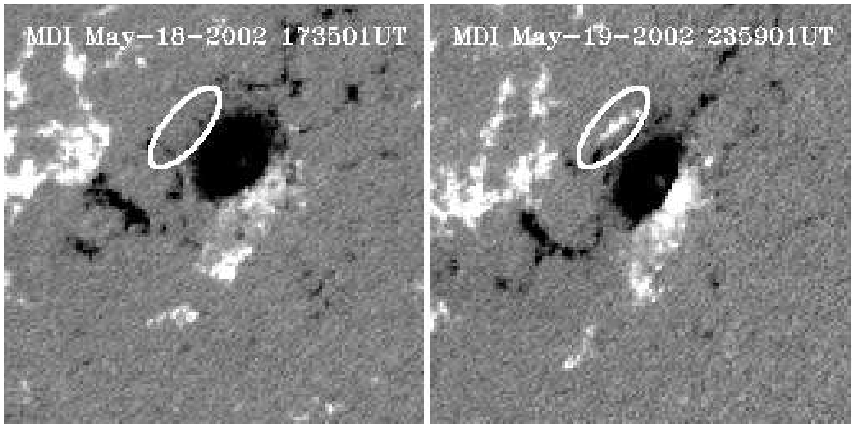


**Fig. 3** Magnetic field evolution of the active region AR9948 seen in the SOHO/MDI magnetogram. The ellipses indicate the places where new flux emerged.

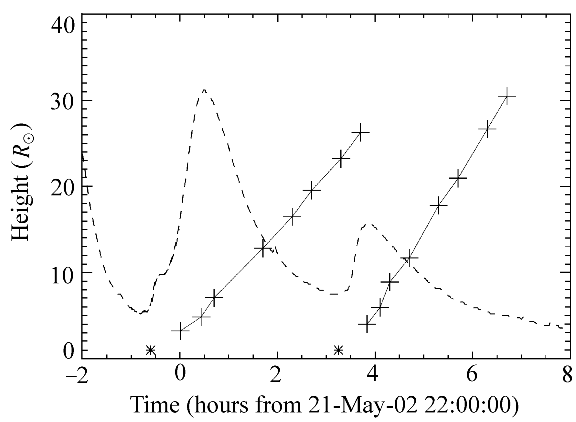


**Fig. 4** Height-time profiles (solid lines) of two CMEs and the GOES soft X-ray light curve (dashed line). Crosses designate the height of the CMEs at different times, while the asterisks indicate the onset of the filament eruptions, respectively.

flares suggest that fast-mode waves, or shock waves, heat conduction or energetic particles, may be the agent of driving sympathetic flares. The existence of sympathetic flares is consistent with the avalanche model of solar flares (Lu & Hamilton 1991). In contrast, there is much less work done on sympathetic CMEs, though the research on the waiting time distribution of CMEs also suggests that CMEs can also be described by the avalanche model (Yeh, Ding & Chen 2002). This is probably because CMEs occur much less often as solar flares, and sympathetic events account for only a small fraction of all events. Moon et al. (2003) presented the first piece of evidence for the existence of sympathetic CMEs, the events analyzed in this paper may be the second example to confirm the existence of sympathetic CMEs, though there were already

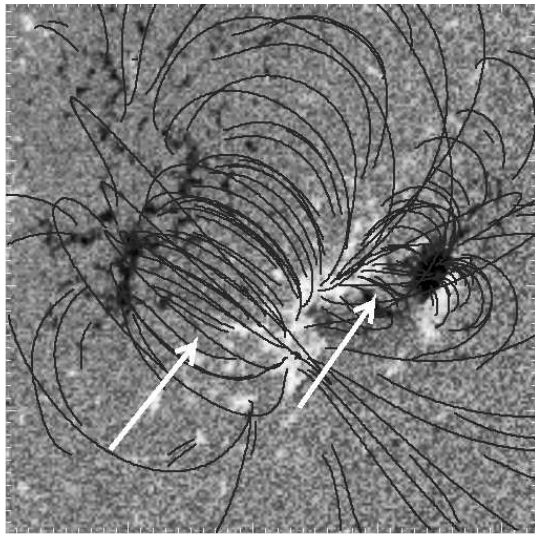

**Fig. 5** Potential field distribution in the corona extrapolated from the MDI magnetogram. Arrows indicate the locations of the neutral lines, which are co-spatial with the two filaments, respectively.

observations of sympathetic filament eruptions more than about 40 years ago . In the current point of view, these eruptive filaments would develop to be the core of large-scale CMEs.

Using the potential-field extrapolation method based on a Green's function solution developed by Sakurai (1982), we construct the 3D coronal magnetic field from the MDI magnetogram. Figure 5 displays the magnetic field around the active region. It is found that the two erupting filaments are initially located along the two magnetic neutral lines indicated by the two arrows. After the eruption of the first CME, strong perturbation would propagate outward, and would disturb the pre-eruption structures of the second CME which are so close to the first flaring site. Since there is no other significant disturbance within the interval of the two CMEs, we postulate that the first CME induced the occurrence of the second one that appeared 3 hours later, hence the two are sympathetic events. We conjecture the following scenario for the two sympathetic CMEs: new magnetic flux emerges inside the first filament channel as indicated by Fig. 6a, which, according to Feynman & Martin (1995) and Chen & Shibata (2000), is reconnection-favored. The local reconnection between the emerging flux and the pre-existing coronal field removes the constraint of the line-tied field lines over the flux rope, which rises after the loss of equilibrium. Then a current sheet is formed below the rising flux rope. As the reconnection is induced in the current sheet, the flux rope and overlying field lines are ejected to form the first CME. At the same time, the first flare appears as a result of the magnetic reconnection. The reconnection inflow, which is convergent toward the reconnection point, would therefore pull the second flux rope up only when the reconnection point has risen to a height higher than the second filament, as depicted in Fig. 6b. This is consistent with the fact that the second CME was initiated in the late phase of the first flare as indicated by Fig. 4. In this way, the second flux rope (or filament) loses its equilibrium, causing a current sheet to form below. The fast reconnection in this current sheet led to the ejection of the second CME above the current sheet and of the second flare below, both of which are sympathetic events.

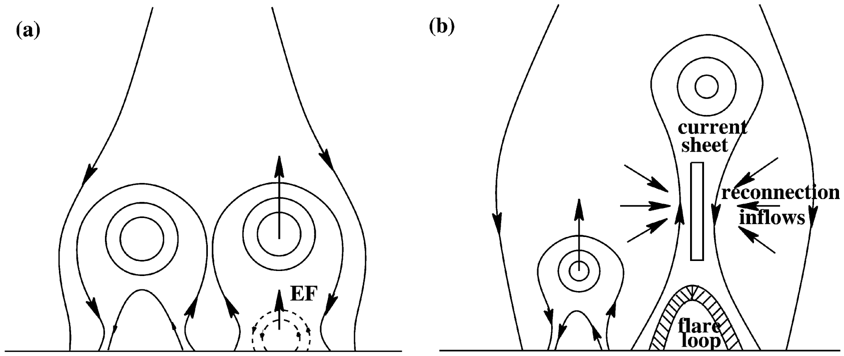


**Fig. 6** Sketch of the model for the homologous sympathetic CMEs. (a) Emerging flux (EF) triggers the onset of the first CME, and the reconnection below the flux rope leads to a fast eruption of the CME above and the appearance of the first solar flare below; (b) The reconnection inflow associated with the first event pulls up the neighboring flux rope, which finally erupted to form the second CME.

In a word, we propose that the reconnection inflow is the driving agent of the sympathetic CME on 2002 May 22. This analysis also implies that the physical connection of at least some sympathetic flares can only be understood when taken together with the CMEs.

### 4.2 Are these Sympathetic CMEs also Homologous?

Recently, Zhang & Wang (2002) proposed the concept "homologous CMEs" to describe consecutive CME events that originate from the same source region and resemble each other in appearance. According to their definition, homologous CMEs should satisfy the following conditions: (1) each member of homologous CMEs must be associated with a member of homologous flares; (2) extended EUV dimming must be similar among homologous CMEs and flares; (3) the coronagraph appearance of the homologous CMEs and flares must resemble each other, where the definition of homologous flares states that members of a series must have the same main footpoints as defined by H$\alpha$ or EUV kernels, and share the same general shape in the main phase as defined by H$\alpha$ ribbons or EUV images (Woodgate et al. 1984). According to our data analysis in Sect. 3, the sympathetic CMEs occurring consecutively within $\sim 3$ hours on 2002 May 22 resemble each other in the LASCO coronagraph appearance, although the second event has a little larger angular span near the south limb of the sun as revealed in Fig. 1. Also, the running difference images of SOHO/EIT indicate that the low-lying EIT dimming regions of the two CMEs are also similar, though the EIT dimming of the second CME is somewhat extended to the south limb, compared to that of the first event. Therefore, the two sympathetic CMEs satisfy the last two conditions for homologous CMEs proposed by Zhang & Wang (2002), but violate the first condition since the associated flares in our events occurred in different locations, though within the same active region, and are sympathetic flares rather than homologous flares. Here, we tentatively and slightly extend the definition of homologous CMEs given by Zhang & Wang (2002), by leaving out their first condition. The reason is as follows. Flares are small-scale phenomena with a size typically smaller than $2.3'$, while CMEs are large-scale eruptions with an average angular width of $72°$, corresponding to some global magnetic restructuring. The CME shape is determined by the large-scale background magnetic field, while the associated flares could be at any position within the angular span of the CME. So, it is plausible that two

CMEs with associated flares at different locations can resemble each other in appearance and hence are classified to be homologous CMEs when the CMEs propagate to a certain distance, say $2R_{\odot}$, if there are interconnecting magnetic loops covering over both flares. Note that in the early phase when the CMEs are still developing in the low corona, they are confined around the associated flares, therefore are different in appearance.

In the two sympathetic events analyzed in this paper, the two erupting filaments were adjacent to each other, therefore, their flux ropes are probably nested in the same global magnetic structure, as is indicated by a magnetic extrapolation in Fig. 5, the ejection of which will result in similar CMEs and different flares. In this sense, we tentatively propose that the sympathetic CMEs occurring on 2002 May 22 are also homologous based on the relaxed definition of homologous CMEs.

**Acknowledgements** The authors thank the referee for constructive comments which helped rearrange the manuscript and Dr. T. Sakurai for providing the magnetic extrapolation code. We are grateful to Prof. J. Wang, Drs. S. D. Bao and Y. Liu for their help. SOHO is a project of international cooperation between ESA and NASA. This work is supported by FANEDD (200226), NSFC (10403003, 10221001, 10333040) and NKBRSF (G20000784).

## References

Brueckner G. E., Howard R. A., Koomen M. J. et al., 1995, Solar Phys., 162, 357
Chen P. F., Shibata K., 2000, ApJ, 545, 524
Chen P. F., Fang C., Ding M. D. et al., 1999, ApJ, 520, 853
Chen P. F., Wu S. T., Shibata K. et al., 2002, ApJ, 572, L99
Cliver E. W., Webb D. F., Howard R. A., 1999, Solar Phys., 187, 89
Delaboudiniere J.-P., Artzner G. E., Brunaud J. et al., 1995, Solar Phys., 162, 291
Domingo V., Fleck B., Poland A. I., 1995, Solar Phys., 162, 1
Feynman J., Martin S. F., 1995, J. Geophys. Res., 100, 3395
Gary G. A., Moore R. L., Hagyard M. J. et al., 1987, ApJ, 314, 782
Low B. C., 1994, Phys. Plasma, 1, 1684
Lu E. T., Hamilton R. J., 1991, ApJ, 380, L89
Moon Y.-J., Choe G. S., Wang H. M. et al., 2003, ApJ, 588, 1176
Qiu J., Wang H. M., Cheng C. Z. et al., 2004, ApJ, 604, 900
Ramsey H. E., Smith S. F., 1966, AJ, 71, 197
Sakurai T., 1982, Solar Phys., 76, 301
Scherrer P. H., Bogart R. S., Bosh R. I. et al., 1995, Solar Phys., 162, 129
Simnett G. M., Hudson H., 1997, in Proc. 31st ESLAB Symp., Correlated Phenomena at the sun, in the Heliosphere and in Geospace, ed. A. Wilson (ESA-SP-415; Noordwijk), 437
Woodgate B. E., Martres M.-J., Smith J. B. Jr. et al., 1984, AdSpR, 4, 11
Yeh C. T., Ding M. D., Chen P. F., 2002, in Proc. 8th IAU Asian-Pacific Regional Meeting, Volume II, 2002, Ed. S. Ikeuchi, J. Hearnshaw, and T. Hanawa, p.471
Zhang J., Wang J. X., Nitta N., 2001, Chin. J. Astron. Astrophys., 1(1), 85
Zhang J., Wang J. X., 2002, ApJ, 566, 117