Chin. J. Astron. Astrophys. Vol. 4 (2004), No. 2, 176–188
( http://www.chjaa.org or http://chjaa.bao.ac.cn )

Chinese Journal of
Astronomy and
Astrophysics

# A New Catalogue of Fine Structures Superimposed on Solar Microwave Bursts *

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Received 2003 May 29; accepted 2003 July 10

**Abstract** The 2.6–3.8 GHz, 4.5–7.5 GHz, 5.2–7.6 GHz and 0.7–1.5 GHz component spectrometers of Solar Broadband Radio Spectrometer (SBRS) started routine observations, respectively, in late August 1996, August 1999, August 1999, and June 2000. They just managed to catch the coming 23rd solar active maximum. Consequently, a large amount of microwave burst data with high temporal and high spectral resolution and high sensitivity were obtained. A variety of fine structures (FS) superimposed on microwave bursts have been found. Some of them are known, such as microwave type III bursts, microwave spike emission, but these were observed with more detail; some are new. Reported for the first time here are microwave type U bursts with similar spectral morphology to those in decimetric and metric wavelengths, and with outstanding characteristics such as very short durations (tens to hundreds ms), narrow bandwidths, higher frequency drift rates and higher degrees of polarization. Type N and type M bursts were also observed. Detailed zebra pattern and fiber bursts at the high frequency were found. Drifting pulsation structure (DPS) phenomena closely associated with CME are considered to manifest the initial phase of the CME, and quasi-periodic pulsation with periods of tens ms have been recorded. Microwave "patches", unlike those reported previously, were observed with very short durations (about 300 ms), very high flux densities (up to 1000 sfu), very high polarization (about 100% RCP), extremely narrow bandwidths (about 5%), and very high spectral indexes. These cannot be interpreted with the gyrosynchrotron process. A superfine structure in the form of microwave FS (ZPS, type U), consisting of microwave millisecond spike emission (MMS), was also found.

**Key words:** Sun: flares — Sun: radio radiation — instrumentation: spectrographs

## 1 INTRODUCTION

Temporal fine structures (FS) of solar radio emission in solar flares have been found in various wavebands for more than three decades. Microwave FS superimposed on microwave bursts was reported in Allaart et al. (1990), Bruggmann et al. (1990), Isliker & Benz (1994)

* Supported by the National Natural Science Foundation of China.

and Jiricka et al. (2001). Tarnstron et al. (1972) noted that the duration of the spikes is comparable to the electron-ion collision time. Metric and kilometric type III bursts satisfy an empirical relation between the decay time and the frequency (in Hz), $\tau \doteq 10^{7.71}\nu^{-0.95}$ (s) (Alvarez & Haddock 1973). The duration of individual FS decreases with increasing frequency. Consequently, radio spectrometers with time resolutions better than 10 ms, in addition to high spectral resolution and high sensitivity are essential for observing microwave FS.

The Solar Broadband Radio Dynamic Spectrometer (SBRS) of China is the first instrument in the microwave band to acquire dynamic spectrograms of solar radio bursts over a wide frequency range (0.7–7.6 GHz), with high temporal resolution, high spectral resolution and high sensitivity (Fu et al. 2000).

The 2.6–3.8 GHz, 4.5–7.5 GHz, 5.2–7.6 GHz and 0.7–1.5 GHz component spectrometers of SBRS started routine observations respectively in late August 1996, August 1999, August 1999, and June 2000 and they just caught the 23rd solar active maximum. A description of the instruments and data calibration procedure can be found in (Fu et al. 1995; Ji et al. 2000, 2003; Yan et al. 2002; Sych & Yan 2002a). A large volume of microwave burst data with high temporal and spectral resolutions and high sensitivity have been obtained. A variety of FS superimposed on microwave bursts have been found. In this paper we will introduce our initial new results.

## 2 GLOBAL VIEW

The number of bursts observed with each component spectrometer of SBRS before the end of 2001 is shown in Table 1. The first line shows the frequency range of the spectrometer, the second line, the observed number of bursts. The third line shows the number of the bursts found with FS imposed. The ratio of the numbers in the second and third lines is shown in the fourth line. This ratio can be seen to decrease with increasing frequency.

**Table 1**

| Freq. range (GHz) | 0.5–1.5 | 1.0–2.0 | 2.6–3.8 | 4.5–7.5 | 5.2–7.6 |
|---|---|---|---|---|---|
| Num. of bursts | 108 | 526 | 921 | 233 | 550 |
| FS | 29 | 115 | 85 | 15 | 38 |
| % | 26.8 | 21.9 | 9.2 | 6.4 | 6.9 |

## 3 INITIAL RESULTS

### 3.1 Microwave Type III Bursts

1) Common features

Type III bursts are the most intensively studied form of all solar radio emission. Microwave type III bursts were first reported by Stähli & Benz (1987). They are the main phenomena of microwave FS, and are found in the whole frequency range of the five component spectrometers (Fig. 1).

The frequency drift rate (FDR) is mostly positive (from low to high frequency ) and is particularly noticeable from 40 MHz $s^{-1}$ to 22 GHz $s^{-1}$. The duration at a given frequency channel is from less than 30 ms to longer than 200 ms. The frequency range is from tens MHz to more than 1 GHz (Huang et al. 1999; Ning et al. 2000a; Ning et al. 2001; Wang et al. 2001a; Wang et al. 2001b).

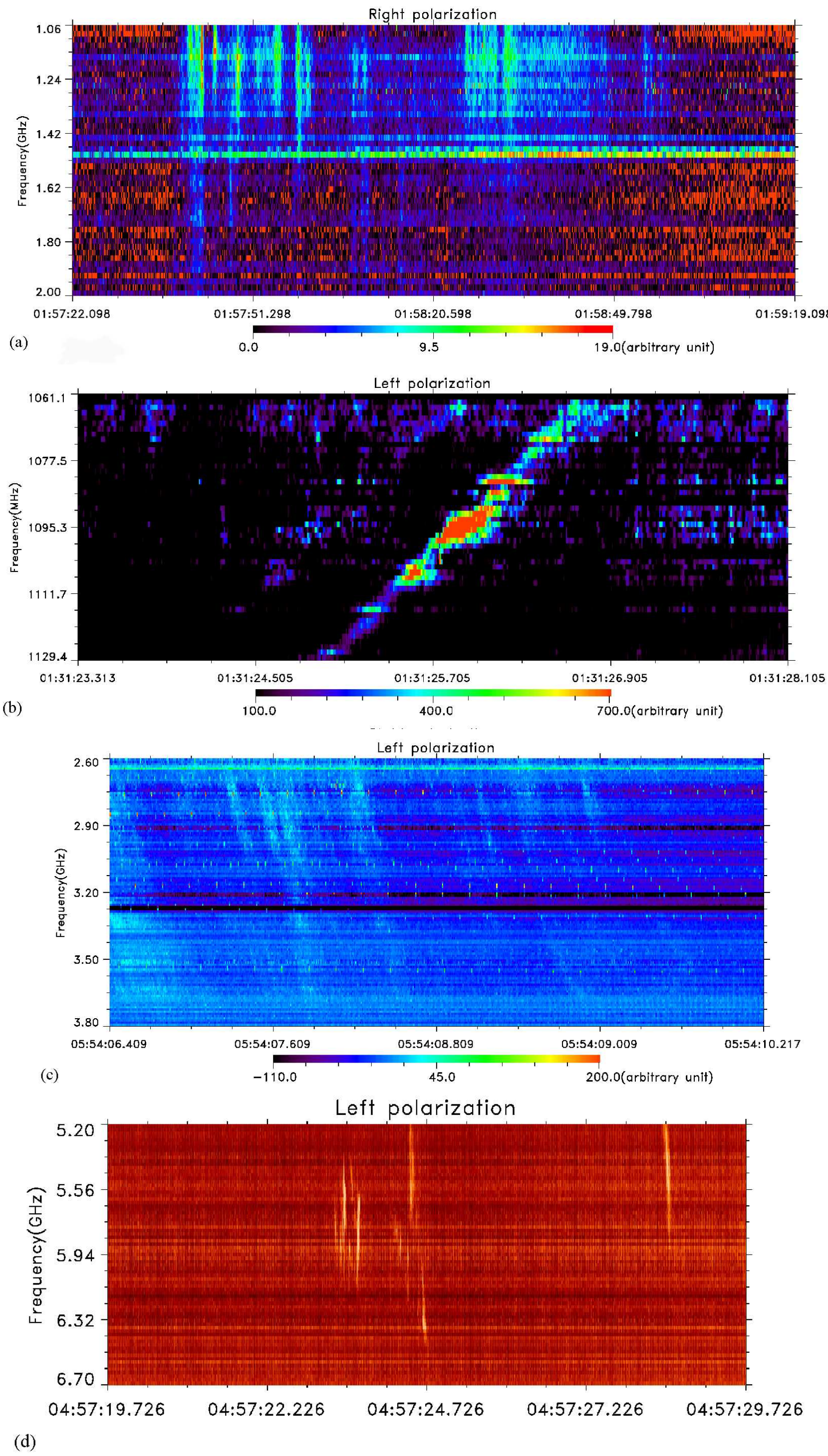


Fig. 1 Microwave type III burst in different frequency bands: (a) in 1.0–2.0 GHz with a fast frequency drift rate; (b) in 1.0–2.0 GHz with a slow frequency drift rate; (c) in 2.6–3.8 GHz; (d) in 5.2–7.6 GHz.

Solar microwave type III bursts have attracted wide attention as a signature of energetic electron beams in the low corona.

2) Type III burst pair in 1–2 GHz

A microwave type III burst pair characterized by two branches with FDR of –0.31 GHz $s^{-1}$ and +0.325 GHz $s^{-1}$, respectively, and a separatrix frequency between 1660 MHz and 1760 MHz, superimposed on the microwave burst of 1994 January 5 (Fu et al. 1997). A "frequency gate" without type III emission appears between the start frequencies of the two branches. It can be deduced that the height of the electron acceleration of this event is at $3 \times 10^4$ km above the photosphere and the height range of the electron acceleration region, as well as the height range of the forming region of type III bursts is about 650 km. In Huang et al. (1998) a very good power-law distribution with an index of 4.5 could be fitted to the energy spectrum of the electron beams. The electron beams may be accelerated by an electric field with a strength of $10^{-4}$ $Vm^{-1}$. Ning et al. (2000b) estimated $\beta \approx 0.01$ in the reconnection region and deduced the beam velocity as $1.07 \times 10^3$ km $s^{-1}$ after leaving the reconnection region, if the ambient magnetic field is 100 G. The most crucial problem in the understanding of the solar flare process is the localization of the energy release and acceleration region (Aschwanden & Treumann 1997). To find the separatrix frequency of type III burst pair, particularly in microwave, is significant for resolving this problem.

3) Microwave type U bursts (Fig. 2)

Type U bursts are interpreted as the signature of electron beams following magnetic fields lines. The total duration of type U bursts decreases with increasing frequency: metric bands, 5–40 s; decimeter bands, 1 s; centimeter bands, < 1 s. Some results are shown in Table 2.

**Table 2**

| | Fu et al. (1994) | Wang et al. (2001a) | Wang et al. (2001c) |
|---|---|---|---|
| $f_T$ (GHz) | $3.2 \sim 3.4$ | $2.63 \sim 2.70$ | 1.16 |
| $\Delta f_u$ (MHz) | $60 \sim 200$ | $340 \sim 360$ | $\sim 700$ |
| FDR (GHz $s^{-1}$) | $-7 \sim -28$ | $-1.7 \sim -3.0$ | $-0.1$ |
| $t_r$ (ms) | $8 \sim 24$ | | |
| $t_t$ (ms) | $6 \sim 48$ | $224 \sim 264$ | $\sim 10^4$ |
| PD | > 80% | 80% | |

$f_T$ —top frequency; $\Delta f_u$ — frequency range of individual type U burst; r.b. — rising branch; FDR — frequency drift rate in r.b.; $t_r$ — duration of r.b.; $t_t$ — total duration; PD — polarization degree.

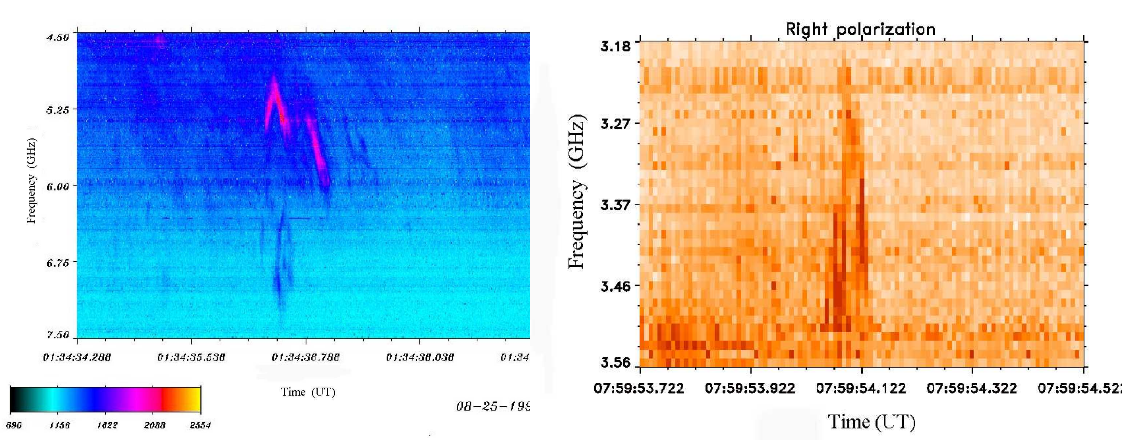


Fig. 2 Microwave type U burst (right panel) and a cluster of microwave type U bursts.

4) Microwave type M and N bursts

Type U, M, and N are sub-classes of type III bursts. They are much rarer than normal type III bursts. Wang et al. (2001b) and Ning et al. (2000c) reported microwave type M and N bursts from SBRS data (Fig. 3).

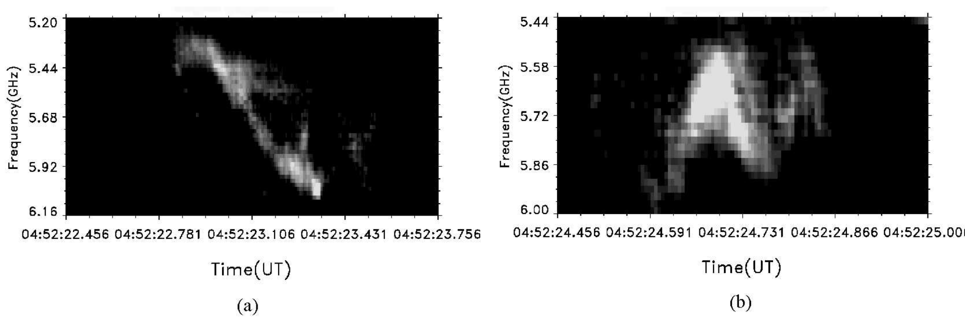


Fig. 3 Microwave type N (a) and M bursts (b).

## 3.2 Microwave Millisecond Spike (MMS) Emission

1) Common features (Fig. 4)

Solar radio spike emission is characterized by very short duration, very narrow frequency bandwidth, high polarization, and irregular sequences in frequency and in time. It has been observed for about 40 years, but mostly in meter and decimeter frequency bands. As mentioned above, radio spectrometer with high temporal, high spectral resolution and high sensitivity is needed for MMS observing. Benz et al. (1992) reported 46 spike impulses in 6–8 GHz during about 2000 hours of observation. Using SBRS data, Chernov et al. (2001a) reported five events of MMS with the following parameter values: half-power duration: 10–20 ms, peak flux: 10–160 sfu, PD: 0–100%, and wave mode: X in 2.6–3.8 GHz. Wang et al. (1999) reported 11 events of MMS with duration: 20–70 ms (mean 43 ms), peak flux: 60–280 sfu (mean: 192 sfu), PD:

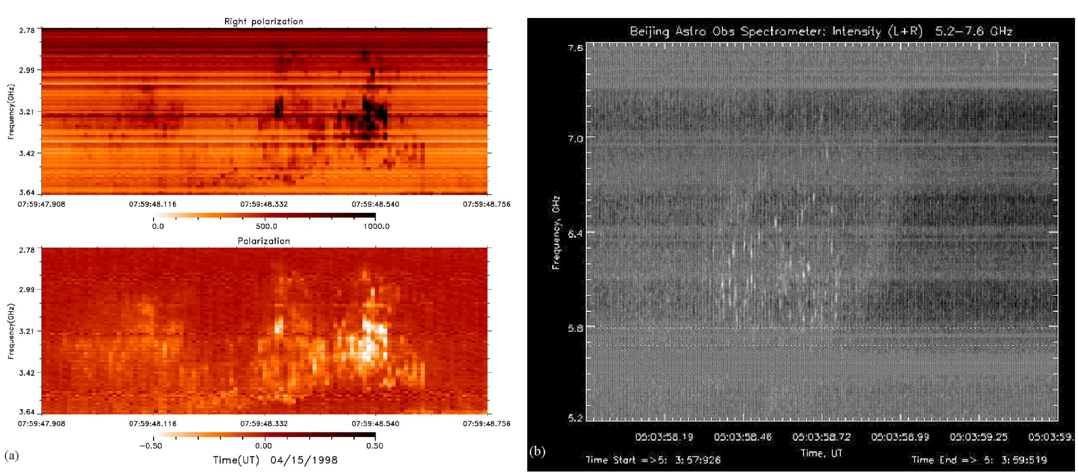


Fig. 4 MMS in 2.6–3.8 GHz (left panel), on 1998 April 15 (Upper: right polarization; Lower: polarization degree) and intensity in 5.2–7.6 GHz (right panel).

0–100% (mean: 40%), and total bandwidth: 30–300 MHz (mean: 117 MHz, 3.7% of center frequency) in 2.6–3.8 GHz frequency range. Wang et al. (2002) reported that 5076 MMS were detected in the burst of 2001 June 24 in 660–1270 MHz, that the absolute bandwidths of most of them (92% at less than 2.8 MHz, and 70% at less than 1.4 MHz) were in the range (0.22%–0.11%). These results are one order of magnitude smaller than that of Benz (1986) and considerably smaller than the results of Sillaghy & Benz (1993) and Messmer & Benz (2000). The strongly polarized MMS (70%–100%) were 73% of the total, and the very weakly polarized ones (0–30%), only 4%. 85% of all the MMS had half power durations of less than 16 ms. Wang (2003) reported an MMS cluster event at the highest frequency, the parameters of the cluster are: number of spikes: 99, duration of each spike: $< 10$ ms, central frequency: 5.87 GHz, and average bandwidth of each spikes: 24.5 MHz, 0.4% of the central frequency. Wang et al. (2002) presented an analysis of the MMS in 2.6–3.8 GHz in the 1998 April 15 event.

2) MMS pair

Liu et al. (2002) reported a pair of MMS emission. Its FDR was measured to be ($-21$ GHz s$^{-1}$, 56 GHz s$^{-1}$). The separatrix frequency was 2900 MHz. The polarization degree has a wave-like variation with frequency with an average value of about 25% in LCP. The MMS pair differs greatly from type III burst pairs. For the latter in a certain frequency range there is no emission around the separatrix frequency, and this is not so in the former. This feature may help to better understand the mechanism of MMS (Fig. 5).

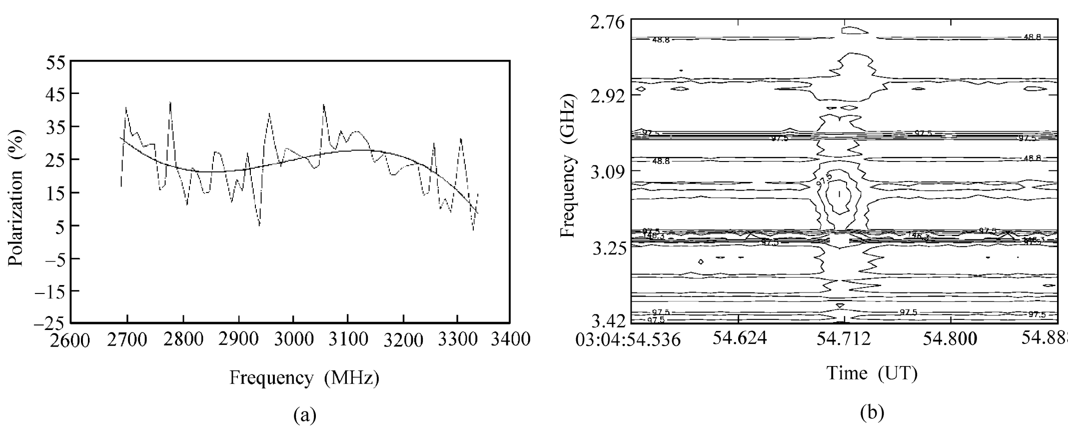


Fig. 5 MMS pair polarization degree plot in the event on 1997 Nov. 2 (a) and contour map (b).

3) A new model of MMS

Chernov et al. (2001a) considered a new model based on the interaction of Langmuir wave with ion-sound waves: $l + s \rightarrow t$, it can operate in shock fronts issuing from magnetic reconnection regions. Two MMS events on 1997 November 4 and 28 were discussed using this new model. MMS are probably a unique manifestation of flare fast shocks in radio emission.

### 3.3 Zebra Pattern Structures (ZPS) and Fiber Bursts (FB)

ZPS and FB are well-known FS in metric and decimetric continuum emission of type IV bursts. In microwave we can only find some indications of a probable zebra-pattern in Isliker & Benz (1994). Jiricka et al. (2001) reported them in frequencies lower than 2 GHz. However, now with the new microwave spectrometer SBRS we have observed detailed ZPS and FB at higher frequencies.

Figure 6 shows a ZPS in 2.6–3.8 GHz and 5.2–7.6 GHz. Ning et al. (2000d) reported ZPS (EEL) in the 1998 April 15 event in 2.6–3.8 GHz. Using the data of SBRS, Chernov et al. (2001b) presented 19 cases of ZPS and FB in four microwave bursts in a frequency range around 3 GHz and one such case in the range 5.2–7.6 GHz. These are compared with the results in metric band in Table 3. The FB and ZPS have about the same spectral parameters. Table 3 reveals that the microwave ZPS and FB have different characteristics from those in the metric band. For the 2002 April 22 event more than 30 Zebra and FB stripes were observed (Yan et al. 2002b).

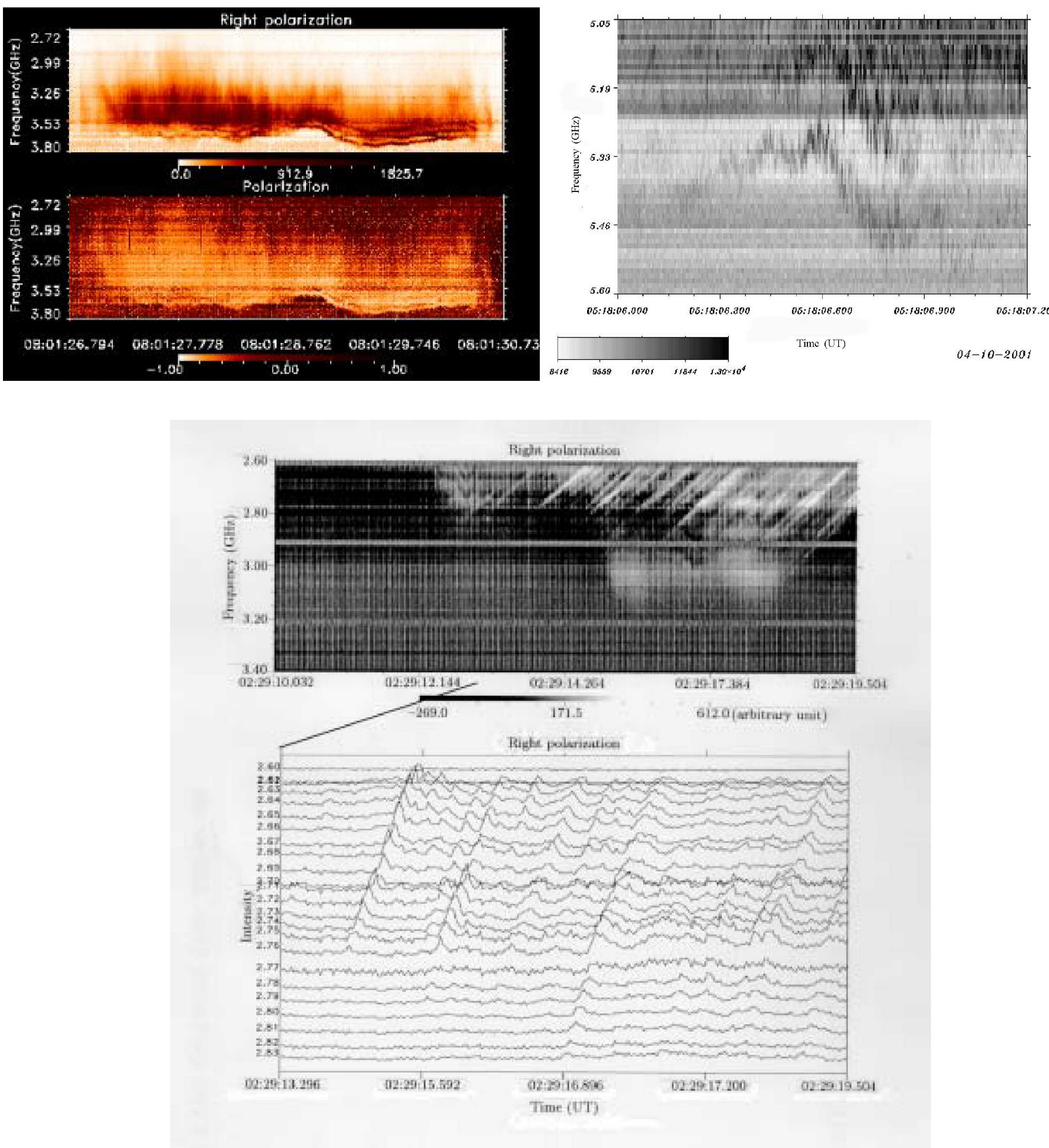


Fig. 6 ZPS 1998 April 15 (upper left), 2001 April 10 (upper right), and FB 2000 October 29 (buttom panel), in 2.6–3.8 GHz.

**Table 3**

| | Microwave Chernov et al. (2001b) | Metric band Kuijpers (1980) |
|---|---|---|
| $\Delta t$ | ZPS 1–2 s (up to 8 s) | |
| | FB packets 1–2 s (up to 42 s) | 5–10 s |
| $f$ | $< 4$ GHz | 160–320 MHz |
| $\Delta f_{\rm ea}$ | 20–70 MHz (average 30–35 MHz) | |
| $f_{\rm s}$ (MHz) | 60–70 MHz (for ZPS and FB) | ZPS: 160–200 MHz: $2 \sim 3$ MHz |
| | | 800–900 MHz: 20 MHz |
| $\Delta f_{\rm e}$ (MHz) | 20–30 (for ZPS and FB) | FB: $\leq 1$ |
| $n$ | $2 \sim> 6$ | ZPS: 5–20 (up to 70) |
| | | FB: 10–30 (up to 300) |
| $\Delta f$ (MHz) | 200$\sim>$ 500 | ZPS: $\geq 40$ |
| | | FB: 30 (up to 120) |
| FDR | FB –244 MHz s$^{-1}$ * | FB: $10^{-2}f + 6 \times 10^{-5} f^2$ |

$\Delta t \sim$ duration, $f$ — frequency basically observed, $\Delta f_{\rm ea}$ — frequency separation between the emission and the neighboring low frequency absorption, $f_{\rm s}$ — frequency separation between emission stripes, $\Delta f_{\rm e}$ — emission frequency bandwidth, $n$ – number in one group, $\Delta f$ — frequency extent, $*$ for the event on 2000 October 29.

### 3.4 Drifting Pulsation Structure (DPS)

Recently, in Kliem et al. (2000) and Karlicky et al. (2001) slowly negatively drifting pulsation structure (DPS) was presented and interpreted as a signature of dynamic magnetic reconnection. The slow negative drift of the whole DPS is caused by the upward motion of the plasmoid of the whole reconnection region to one of lower plasma density. Figure 7 (Liu et al. 2003; Wang et al. 2001c) shows two kinds of DPS, with FDRs usually at –3 MHz s$^{-1}$ and $\sim -60$ MHz s$^{-1}$. DPS are closely associated with CME. It is possible that DPS in decimetric frequency band manifests the initial phase of the CME.

### 3.5 Microwave Millisecond Quasi-period Pulsation (MMP)

Using the SBRS data, Fleishman et al. (2002a, b) reported two events that display quasi-periodic narrow band millisecond pulsation both in intensity and polarization in a microwave burst with $\tau \sim 50$ ms ($f \sim 3$ GHz). Large time delays between the L- and R-polarization components were found, causing the observed oscillations in the degree of polarization. The theoretically predicted dependence of the group delay on frequency ($\sim f^{-3}$) agrees excellently with the observed delay frequency dependence. Physical parameters of the emission source and the "delay site" were determined within the proposed model.

### 3.6 Microwave "Patches"

The definition of "Patches" is not quite clear. According to previous observations, the patches have durations between one and some tens of seconds; their circular polarization is usually weak, and their flux density is not very high (Isliker & Benz 1994). Wang et al. (2001c) presented a microwave patch event between 3.0–3.8 GHz on 1998 June 12 (Fig. 8). This "patch" is characterized by a very short duration of $\sim 300$ ms, a very high flux density of 1000 sfu, a very high polarization of 100% RCP, an extremely narrow bandwidth of $\frac{\Delta f}{f} \sim 5\%$, and very high spectral indexes. These observational characteristics seem to suggest that the more likely emission mechanism is plasma or maser emission rather than gyrosynchrotron emission.

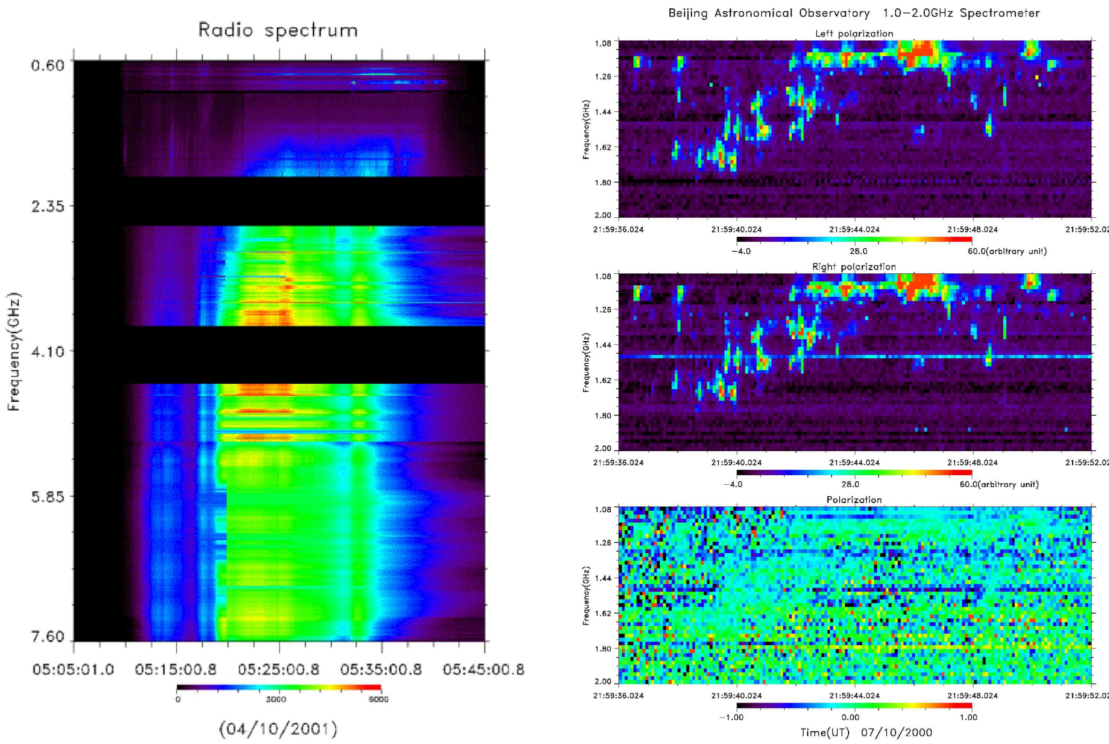


Fig. 7 Two kinds of drift pulsation structures.

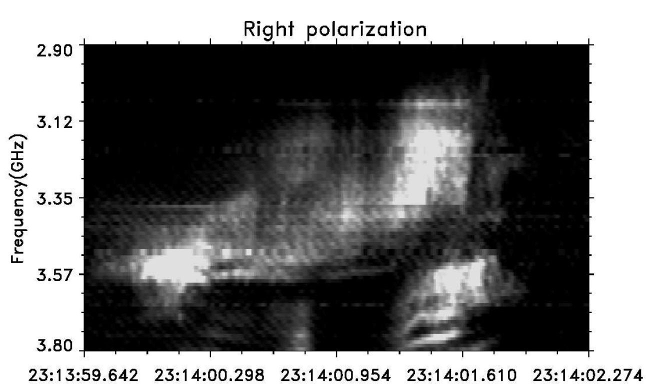


Fig. 8 Microwave patch in 2.6–3.8 GHz in the burst on 1998 June 12.

### 3.7 Structures that have not been classified

1) Quasi-periodic drifting structures

An example is shown in Fig. 9 (Xu et al. 2001); it possibly reflects fluctuations (inhomogeneities) of electron density in the magnetic loop.

2) Necklace-like structures

This is shown in Fig. 10 (Xu et al. 2000). Electron beams may be reflected at places as a magnetic mirror, a steep density gradient, a shock wave front, and so on.

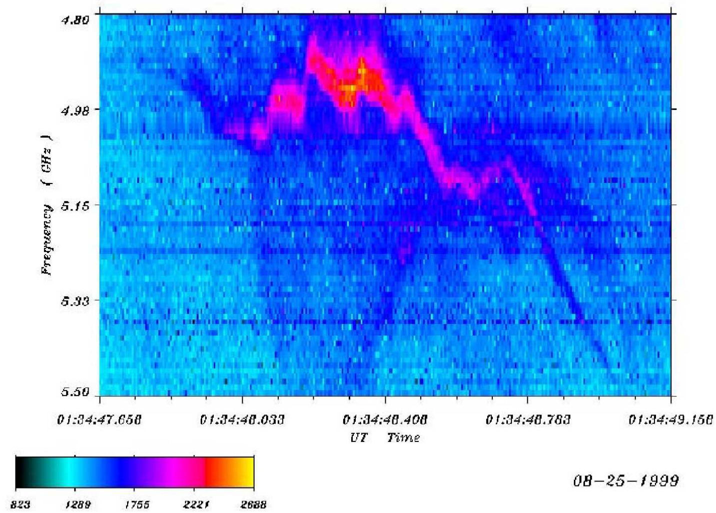


Fig. 9 Quasi – periodic drifting structure in 4.5–7.5 GHz.

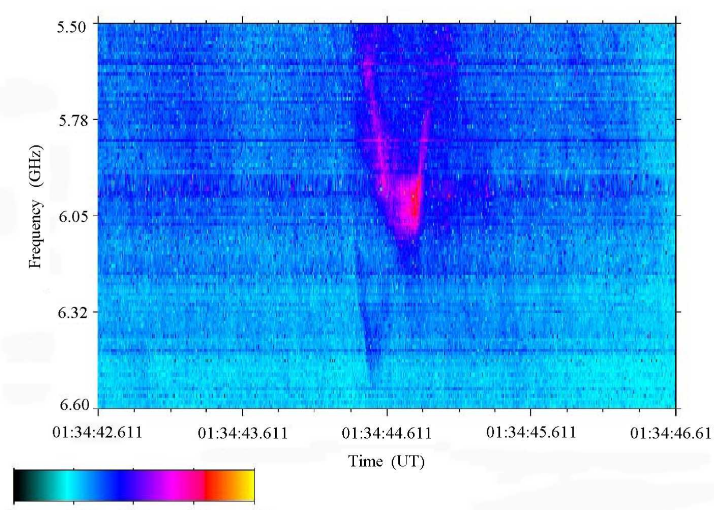


Fig. 10 Necklace-like structures in 4.5–7.5 GHz.

## 4 BASIC UNITY OF MICROWAVE FS

Is there any basic unity of the microwave FS? Figure 11 shows that a microwave type U burst, a ZPS and an unclassified FS with numerous fast MMS with durations at the time resolution limits of the spectrometer, 8 ms and 5 ms (Ning et al. 2000a; Chernov et al. 2001b; Chernov et al. 2003). Completely different emission mechanisms have so far been proposed for these FS and the MMS. There are two possibilities: 1) There are two kinds of FS, one is made up of MMS, the other is not. 2) All FS consist of MMS, but most of the MMS were not be found, because the limited temporal resolution and sensitivity of existing observing instruments.

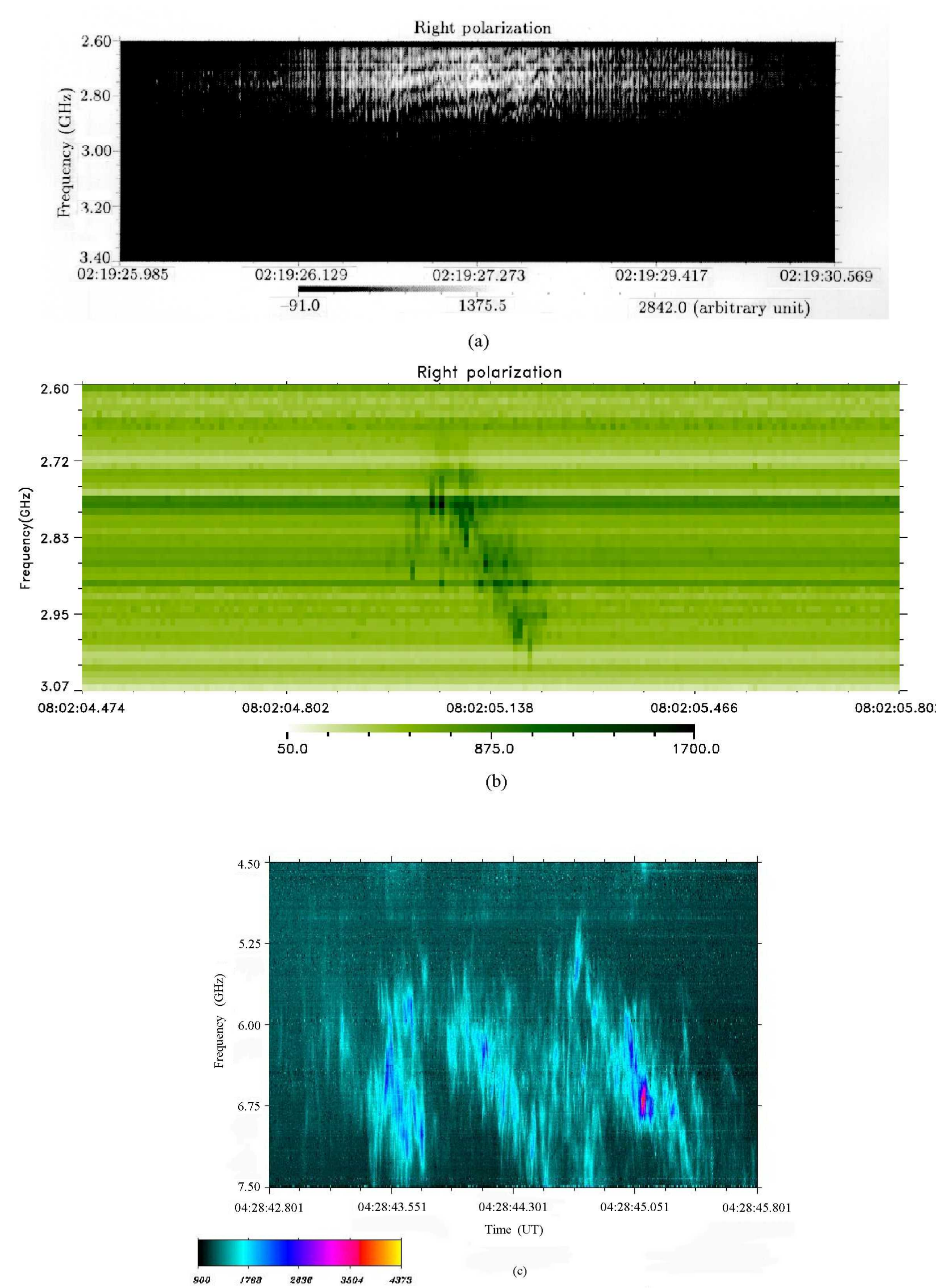


Fig. 11 Elementary unity of microwave FS in ZPS (a), type U burst (b) and an unclassified structure (c).

## 5 CONCLUDING REMARKS

The SBRS has been working properly in the 23rd solar maximum with wide frequency coverage in microwave, high temporal and spectral resolutions, and high sensitivity for first time. The results obtained should be helpful for a better understanding of particle acceleration, energy release and conversion in the low corona.

The observations show that FS occur less often in microwave than in lower frequency bands, but they are much more complex, and sometimes difficult to identify them with the classifications in the lower frequency bands. It is possible that more intense propagation effects take place here, and the physical circumstance, magnetic field configuration and dynamic process during flares are more intricate in the low corona.

Emission of the quite sun increases with frequency, while the intensity of microwave FS decreases with frequency, this circumstance places an ultimate limit on the observation of the latter. For gathering new information from weak intensity data, data processing techniques such as the wavelet method are significant.

Co-operative analysis of observational results from other space and ground facilities is very important and will be further strengthened. Making a comprehensive analysis of the important types of FS, such as microwave type III bursts, MMS, microwave type U bursts and so on is an urgent task.

Obviously, the emission mechanism of most microwave FS is not incoherent, and significant theoretical interpretation is to understand the energy release and particle acceleration processes in flares. The phenomena that some FS consist of numerous fast spikes with durations at the time resolution limit of the spectrometers charge us to revise the known theories.

**Acknowledgements** SBRS was supported by Chinese Academy of Sciences. This research was supported by the National Natural Science Foundation of China under grants Nos. 10225313, 19833050 and 49990451, and by the Chinese Academy of Sciences. It was also supported by the Ministry of science and technology of China under grant No. G2000078403.

## References

Allaart M. A. F., Van N. J., Slottje C., Sondaar L. H., 1990, Solar Phys., 130, 183

Alvarez H., Haddock F. T., 1973, Solar Phys., 30, 175

Aschwanden M. A., Treumann R. A., 1966, In: Proc. of CESRA Workshop, Lecture Notes in Physics, 108

Benz A. O., 1986, Solar Phys., 104, 99

Benz A. O., Su H., Magun A., Stehling W., 1992, A&AS, 93, 539

Bruggmann G., Benz A. O., Magun A., Stehling W., 1990, A&A, 240, 506

Chernov G. P., Fu Q. J., Lao D. B., Hanaoka Y., 2001a, Solar Phys., 201, 153

Chernov G. P., Yasnov L. V., Yan Y. H., Fu Q. J., 2001b, Chin. J. Astron. Astrophys., 1, 525

Chernov G. P., Yan Y. H., Fu Q. J., 2003, A&A, in press

Csillaghy A., Benz A. O., 1993, A&A, 274, 487

Fleishman G. D., Fu Q. J., Huang G. L., Melnikov V. F., Wang M., 2002a, A&A, 385, 671

Fleishman G. D., Fu Q. J., Wang M., Huang G. L., Melnikov V. F., 2002b, Physical Review Letters, 88(25), 251101

Fu Q. J., Qin Z. H., Ji H. R., Pei L. B., 1995, Solar Phys., 160, 97

Fu Q. J., Ji H. R., Lao D. B., Liu Y. Y., Chen Z. J., Cheng C. L. et al., 1997, Acta Astrophysical Sinica, 17, 441
Fu Q. J., Ji H. R., Liu Y. Y. et al., 2000, In: C. Fang, J. C. Henoux, M. D. Ding eds., Proc. of the First France-Chinese Meeting on Solar Physics, Beijing: International Academic Publishers, 282
Fu Q. J. Ning Z. J., Liu Y. Y., 1999, Publ. Purple Moun. Obs., 18, 159
Huang G. L., Fu Q. J., Qin Z. H., 1999, Ap&SS, 266, 389
Huang G. L., Qin Z. H., Yang G., Fu Q. J., Liu Y. Y., 1998, Ap&SS, 259, 317
Isliker H., Benz A. O., 1994, A&A, 104, 145
Jiricka K., Kalicky M., Meszarosova H., Snizek V., 2001, A&A, 375, 243
Ji H. R., Fu Q. J., Liu Y. Y., Cheng C. L., Ceng Z. J. et al., 2000, Acta Astrophysical Sinica, 20(2), 209
Ji H. R., Fu Q. J., Liu Y. Y., Cheng C. L., Ceng Z. J., Yan Y. H., Zeng L. P., Ning Z. J., Tan C. M. et al., 2003, Solar Physics, 213, 359
Karlicky M., Yan Y. H., Fu Q. J., Wang S. J., Jiricka M. H., Liu Y. Y., 2001, A&A, 369, 1104
Kliem B., Karlicky M., Benz A. O., 2000, A&A, 360, 715
Kuijpers J., 1980, In: Radio Physics of the Sun, Proc. IAU Symp. No. 86, 341
Liu Y. Y., Fu Q. J., Qin Z. H., Huang G. L., Wang M., 2002, Science in China (Ser.A), 45, Supp. 114
Liu Y. Y., Fu Q. J., Wu H. A., Qin Z. H., Wang M., Xu F. Y., Tan C. M., 2003, Proc. of the Second France-Chinese Meeting on Solar Phys., Beijing: International Academic Publishers, in press
Messmer P., Benz A. O., 2000, A&A, 354, 287
Ning Z. J., Fu Q. J., Lu Q. K., 2000a, PASJ, 52, 919
Ning Z. J., Fu Q. J., Lu Q. K., 2000b, Solar Phys., 194, 137
Ning Z. J., Yan Y. H., Fu Q. J., Lu Q. K., 2000c, A&A, 364, 793
Ning Z. J., Fu Q. J., Lu Q. K., 2000d, A&A, 364, 853
Ning Z. J., Fu Q. J., Yan Y. H., Liu Y. Y., Lu Q. K., 2001, Ap&SS, 277, 615
Stähli M., Benz A. O., 1987, A&A, 175, 271
Sych R. A., Yan Y. H., 2002, Chin. J. Astron. Astrophys., 2(2), 183
Tarnstron G. L., Philip K. W., 1972, A&A, 17, 267
Wang M., Fu Q. J., Xie R. X., Huang G. L., 1999, Solar Phys., 189, 331
Wang M., Fu Q. J., Xie R. X., Huang G. L., Duan C. C., 2001a, Solar Phys., 199, 157
Wang M., Fu Q. J., Xie R. X., Duan C. C., 2001b, A&A, 380, 318
Wang M., Fu Q. J., Xie R. X., Duan C. C., 2001c, Solar Phys., 203, 145
Wang M., 2003, Proc. The Second France-Chinese Meeting on Solar Physics, Beijing: International Academic Publishers, in press
Wang S. J., Yan Y. H., Fu Q. J., 2001a, A&A, 373, 1083
Wang S. J., Yan Y. H., Zhao R. Z., Fu Q. J., Tan C. M., Xu L., Wang S. J., Lin H. A., 2001b, Solar Phys., 204, 155
Wang S. J., Yan Y. H., Fu Q. J., 2001c, A&A, 370, L13
Wang S. J., Yan Y. H., Fu Q. J., 2002, Solar Phys., 209, 185
Xu F. Y., Yao O. J., Meng X., Wu H. A., 2001, Chin. J. Astron. Astrophys., 1(5), 469
Xu F. Y., et al., 2000, Chin. Phys. Letter, 17, 850
Yan Y. H., Deng Y. Y., Karlicky M., Fu Q. J., Wang S. J., Liu Y. Y., 2001, ApJ, 551, L115
Yan Y. H., Tan C. M., Xu L., Ji H. R., Fu Q. J., Song G. X., 2002a, Sciencs in China (Ser.A), 45S, 89
Yan Y. H., Fu Q. J., Liu Y. Y., Chen Z. J., 2002b, Proce. 10th European Solar Physics Meeting, Solar Variablity: From Core to Outer Frontiers, 2002, p.375