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白光耀斑研究的新进展*

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摘　要

本文综述了近年来太阳和恒星白光耀斑研究的最新进展。文中着重讨论了两类白光耀斑的光谱特征，白光耀斑的大气模型，以及白光耀斑大气的加热机制等问题，并对恒星白光耀斑同太阳白光耀斑作了某些比较。

Recent Progress in the Study of White-light Flares

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Abstract

This article reviews the recent progress in the study of solar and stellar white-light flares (WLFs). The following topics are mainly discussed: (1) spectral features of two different types of WLFs; (2) semi-empirical models of the WLF atmosphere; and (3) heating mechanisms of the WLF atmosphere. A brief comparison of stellar WLFs and solar WLFs is also presented.

1　Introduction

White-light flares (WLFs) are the flares observed in optical continuum spectra. Their morphology, spectral properties, emissions at X-ray or radio wavelength are not unusual compared with those of normal flares. However, WLFs represent the extreme cases in

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flares. According to the statistics made by Neidig and Cliver[1], a "typical" solar WLF is associated with a 2B Hα flare, an ~X3 and a $\geq$ 8 GHz burst with peak flux density ~ 4000 sfu. It implies that most of WLFs are major flares. Moreover, although the solar WLFs have small spatial scales (generally only $5''$–$6''$) and short durations (generally less than 10 min), the radiative rate of a typical WLF in optical wavelength may attain 10^{28} ergs·s^{-1}, with a maximum of 2×10^{29}ergs·s^{-1} observed in the 1984 Apr 25 WLF[2]. The radiative rate observed in the strongest WLF which occurred on a dMe star is three orders of magnitude larger than that of solar WLFs[3]. The rate of a powerful WLF observed on RS CVn HR 1099 at Beijing Observatory[4] in December, 1989 and 12 hours later at other observatories[5] is as high as 10^{33}–10^{34} ergs·s^{-1}. Thus, the energy in optical continuum emissions both for solar and stellar WLFs is much larger than that in line emissions, and the former includes more than 90% of the total energy of emissions. Just due to this property, WLFs are of special importance in the flare study.

In recent years, as the observational technique progresses greatly, more and more WLFs have been observed. However, there is much controversy about their energy transport, atmospheric model and mechanism etc. It is generally believed that the initial energy release of flares occurs in the corona, while the continuum emission of WLFs comes mainly from the low chromosphere and the photosphere. Therefore, the effective transport of the energy from the corona to the low atmosphere or alternatively the possibility of its release simply in the low atmosphere makes a challenge to the traditional point of view. Thus the study of WLFs becomes recently an active frontier in solar physics as well as stellar activity research. It should be pointed out that in recent years the study of stellar WLFs is related more and more closely to that of solar WLFs, with complementing and permeating through each other. In fact, the stellar flares observed in multicolor measurements are the WLF events on stars, because the flare events can be detected only when the continuum emissions are greatly enhanced. So the number of stellar WLFs is much larger than that of solar WLFs. Naturally, because of the remoteness of the stars and the sensitivity limit of the detectors, most stellar flares observed so far are very powerful, with a total energy 10^2–10^3 times larger than that of solar WLFs. However, they have many similarities in physical essentials. Moreover, the WLFs which appeared on different stars provide a variety of"samples", which will be helpful to the study of solar WLFs. Thus, the study of the similarities and differences of the stellar and solar WLFs by means of comparison between them is a very important subject.

Based on the previous review of WLFs[6], this paper will give some complements from the current progress. The comparison between the solar and stellar WLFs (refer also to [7]) is also briefly discussed.

2 Characteristics of WLFs

According to Neidig and Cliver[1], from September 1, 1859 when the first WLF was observed by Carrington and Hodgson, to the end of 1982 there are 57 solar WLFs recorded in the world. In the recent decade, the number of WLFs has been increased by about 40. Most of them are newly observed, while some were found through the analyses of old observational data. Neidig and Wiborg[8] have given 32 additional WLFs. We have collected some other WLFs that appeared in recent literatures, and list them together in Table 1. In the table, SP stands for spectral observations, MB for multi-waveband monochromatic image and SB for single-waveband monochromatic image.

The important progress in the study of WLFs is that a concept of two types of WLFs has been proposed[9]. They have obvious different characteristics in observational properties, which are described below.

2.1 Main characteristics of Type I WLF

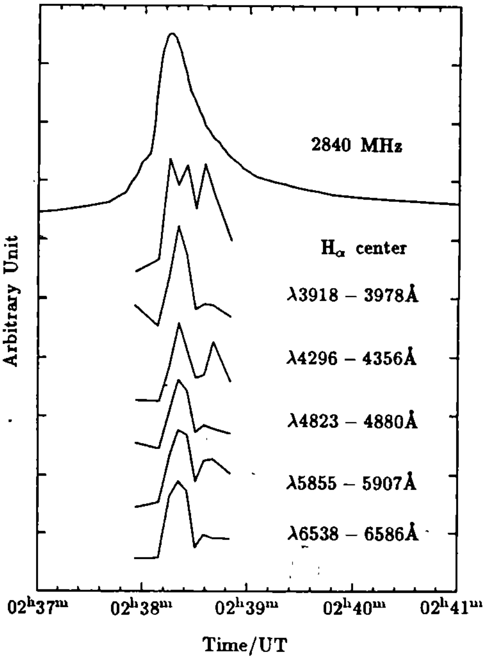

Fig. 1. Time variation of the continuum intensities in different wavelengths, the intensity at the H_α line center, and the radio flux at 2840 MHz for the 1991 Oct 24 WLF (Type I).

(a) There is a good time correlation between the maximum of continuum emission and the peaks of hard X-ray (HXR) and microwave radiations. For example,multi-waveband spectral data with temporal resolution of 5 s have been obtained for the 1991 Oct 24 WLF by the solar tower telescope at Nanjing University. It is probably the highest temporal resolution achieved so far for WLF's spectral observations. Figure 1 shows the time variations of the radio emission, the continuum emission and the intensity at Hα line center of this WLF[10]. It indicates that the difference between the time of the maximum of continunm emission and the peaks of HXR and microwave emission is within the time resolution (5 s). Using wide passband filter data in 5 000Å continunm with a time resolusion of 0.5 s for the 1989 Mar 7 WLF, Neidig *et al.*[11] concluded that, relative to HXR, there is a delay of 2.5 s in the continuum emission. Neidig and Kane[12] analysed the time series of emissions for eight WLFs and pointed out that the delay of WLF's maximum relative to

Table 1. Newly added solar white-light flares

Date			Obs. type	Maximum time			Imp.	Loc.	Ref.
year	month	day		I_c	HXR	H_α			
1959	8	18	SP			1105	3B/—	N12 W33	[55]
1963	9	26	SP	0716		0721	—/—	N15 W75	[56]
1972	6	25	SP			0454	1B/M2	N09 E20	[55]
1974	11	10	SP		0329	0331	1N/—	N12 E02	[57]
1979	9	19	SP	2302	2304	2308	3B/X5	N06 E33	[20]
1980	2	11	SB			2037	1B/—	N11 E61	[8]
1982	6	3	—	1145	1144	1148	2B/X8	S09 E72	[8]
1982	6	15	SP	1519	1512	1512	2B/X1	S22 E66	[21]
1982	12	30	SP		0143	0149	1N/M7	S13 W22	[58]
1983	5	9	MB			2311	2B/X2	S30 E40	[59]
1984	4	25	MB	0002	0001	0001	3B/X13	S12 E43	[8]
1984	5	19	MB		2152	2152	1B/X4	S10 E67	[8]
1984	5	20	MB		2253	2305	2B/X10	S06 E53	[8]
1984	5	21	MB			2023	2B/X3	S08 E41	[8]
1984	5	22	MB		1457	1500	2B/M6	S09 E26	[8]
1988	6	24	SB		1647	1648	1B/X6	S17 W52	[8]
1989	1	10	MB	2026	2025	2046	1B/X1	S31 E30	[8]
1989	1	18	SP			0718	1F/X1	S30 W65	[60]
1989	1	18	MB			1819	3B/X1	N26 W23	[8]
1989	3	7	MB		1455	1455	2B/X2	N32 E65	[8]
1989	3	8	MB		1855	1855	—/M5	N30 E49	[8]
1989	3	9	MB			1532	4B/X4	N30 E38	[8]
1989	3	10	MB		1913	1920	3B/X5	N31 E22	[8]
1989	3	11	MB		1537	1540	2B/X1	N28 E13	[8]
1989	3	11	MB			1938	2B/X1	N27 E10	[8]
1989	3	16	MB		1525	1527	2B/X4	N36 W47	[8]
1989	3	17	MB		1736	1744	2B/X7	N33 W60	[8]
1989	8	16	—			0107	2N/X20	S18 W84	[8]
1991	6	4	SB			0339	3B/X12	N30 E70	[8]
1991	6	6	MB				4B/—		[61]
1991	6	9	SB			0140	3B/X10	N34 E04	[62]
1991	6	11	SB			0206	3B/X12	N31 W17	[62]
1991	6	15	MB			0815	3B/X12	N33 W69	[8]
1991	3	27	MB			0444	—/—	S24 W43	[63]
1991	10	24	SP,SB			0240	2N/X2	S14 E59	[64]
1991	10	27	SP,SB			0548	3B/X6	S13 E15	[64]
1991	11	15	SB			2239	3B/X2	S13 W19	[64]
1991	12	3	SB			1639	2B/X2	N17 E72	[64]

HXRs is 8.4±8.3 s. Analysing two of four WLFs observed by YOHKOH(that is, the 1991 Nov 15 and Dec 3 flares), Hudson *et al.*[13] indicated that, within the time resolution(~ 10 s) of observations, continuum emissions of WLFs and HXRs attained their maxima simultaneously. Previous work (e.g., [14–16]) also showed the same results qualitatively.

(b) There is a strong Balmer jump in the spectra of Type I WLFs. Generally, a value, $c = (I_{\rm f} - I_{\rm b})/I_{\rm ph}$, is used to denote the increase of continuum emission, where $I_{\rm f}$ is the intensity of WLF's continuum, $I_{\rm b}$ the intensity of the background at the same wavelength, and $I_{\rm ph}$ the intensity of the undisturbed photosphere. For Type I WLF, if one uses wide passband filter to do observations, c may attain several tens to hundreds percents in the Balmer continuum. For the 1981 Apr 24 WLF, a value of 360% of c has been recorded[17]. However, in spectral observations, the value of c is generally somewhat low, only 10%–30%. The difference may be related to the fact that the slit of the spectrograph was not on the brightest kernel of the WLF. Moreover, the influence of emission lines on the observations with wide passband filters is also not negligible. Besides, it should be mentioned that because of the mixture of Balmer lines, the Balmer jump may appear at the wavelength longer than the Balmer limit ($\lambda = 3646$ Å), sometimes even at $\lambda = 3700$ Å, as indicated by Neidig and Wiborg[18].

(c) Balmer lines are strong and very broad. This is a marked characteristics in the spectra of Type I WLF. Generally, the full width in $\rm H_\alpha$(width measured at the 5 percent enhancement level) may attain 20–30 Å. Neidig[64] even suggested that a $\rm H_\alpha$ full width ≥ 20 Å could be taken as a spectral criterion for WLFs. As an example, Figure 2 shows our observational results (solid lines) for the $\rm H_\alpha$ and Ca II K lines of the 1991 Oct 24

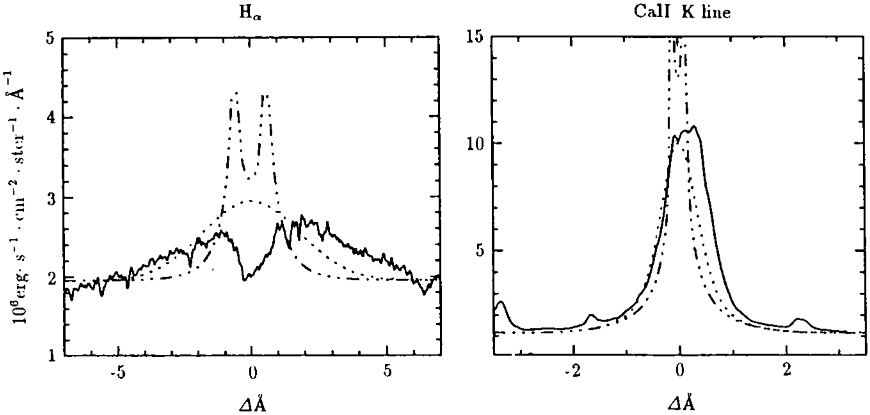

Fig. 2. Observed (solid lines) and computed (line with three dots per dash) $\rm H_\alpha$ line and Ca II K line for the 1991 Oct 24 WLF, corresponding to the peak time of the continuum emission. The computations are made for the semi-empirical model shown in Fig. 4. The theoretical profiles convolved with a macroturbulent velocity of 100 $\rm km\cdot s^{-1}$ and 30 $\rm km\cdot s^{-1}$ for the $\rm H_\alpha$ and Ca II K line, respectively, are shown by dashed lines.

WLF. It can be seen that, in addition to the broadness of the H_α line, there is a very strong reversal at the line center. This is also an outstanding characteristics. Besides, in the spectra of Type I WLFs, Balmer lines of H15–H16 may be even distinguished and the full width of H14–H15 may attain as wide as 4–5 Å. By comparison, the widths of metallic lines are relatively narrow, without great difference relative to normal flares (see e.g., Fig.2).

Besides the three marked characteristics described above, the increase of blue emission at $\lambda < 4000$ Å, i.e., the so-called "blue" excess, is probably one of important properties of Type I WLFs. It may be attributed to[2]: (1) the mergence of Balmer lines near the Balmer limit[19], (2) the higher temperature of the flare relative to the quiet Sun, (3) the influence of numerous photospheric and chromospheric emission lines at blue wavelength. Because of the fewness of spectral data, it remains to be checked whether there is also a " blue excess " for the Type II WLFs.

2.2 Main characteristics of Type II WLFs

(a) There is no obvious corresponding relation between the time of continuum maximum and that of the peaks of HXRs and microwaves. The former could be earlier by

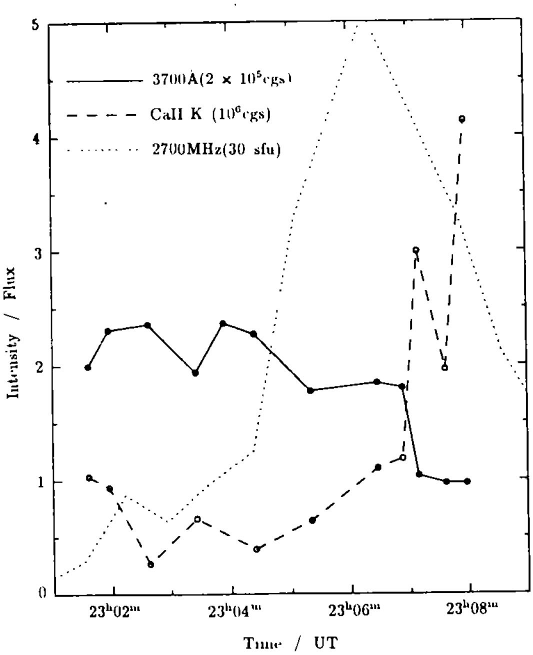

Fig. 3. Time variations of the continuum intensity at 3 700Å, Ca II K line intensity and the radio burst flux at 2 700 MHz for the 1979 Sept 19 WLF.

several minutes relative to the later[20]. Sometimes the continuum maximum could also occur after the impulsive phase or in the gradual phase of flares [21,22]. As an example, Figure 3 gives the time variations of the continuum emission, the radio burst at 2 700 MHz and the intensity of Ca II K line for the 1979 Sept 19 WLF.

(b) There is no obvious Balmer jump in the spectra.

(c) Balmer lines are relatively weak and narrow. Generally, the highest Balmer lines do not appear. For the 1979 Sept 19 WLF, as an example, at the time of the first peak of continuum emission, there were no Balmer lines higher than H11 appeared[23].

Many known WLFs belong to the Type I, while only about six can be classified as Type II, that is, the flares of 1972 Aug 7[24], 1970 June 24[21], 1982 June 15[26], 1979 Sept 19[20], 1980 July 1[25] and 1984 May 20[6]. Of course, due to low time resolution and/or the lack of spectral data, some WLFs observed previously might belong to the Type II. In addition, there are probably intermediate WLFs with a mixture of both types.

3 Atmospheric models of WLFs

The method often used previously to study the structure of WLFs is to assume that the emission comes from an unified thin atmospheric layer. Taken the assumption of LTE or given the population densities or the deviation coefficients at some atomic levels, and chosen different temperatures, the emergent continuum emission can be computed and compared with observations. One can thus determine the temperature, electron density and the position of this thin layer, and then discuss the emission sources (e.g., [8], [22]). The advantages of this method are convenient and easy to use, but the shortcomings are oversimplification and inaccuracy in the computation of the line emissions compared to the observations.

Recently developed method of non-LTE modelling provides a more precise way to study the WLF's atmosphere. By solving simultaneously the equations of hydrostatic and statistical equilibrium, as well as the equations of transfer and conservation of particles, through adjusting the distributions of temperature and microturbulence velocity, one can obtain the atmospheric model, which well reproduces the observed continuum emission and the line profiles. It should be indicated that, strictly speaking, the assumption of hydrostatic equilibrium is not suitable to flares. However, because the continuum emission comes mainly from the low chromosphere and the photosphere, where the density of mass is high and the velocity is not large, it is still an approximately reliable assumption for the WLFs. To use the non-LTE method, it is necessary to have good spectral data. Unfortunately, such useful data have been obtained so far only for more than ten WLFs. At present, only two atmospheric models of WLFs have been published, i.e., the models for the flares of 1982 June 15[26] and 1979 Sept 19[20]. They all belong to Type II WLFs. We have recently obtained semi-empirical models for other two WLFs (the flares of 1991

Oct 24[10] and 1974 Sept 10[27]), which are classified as Type I WLFs. Fig. 4 and 5 give the temperature distributions for one Type I WLF and two Type II WLFs respectively. For comparison, the atmospheric models, F1 and F2[28], which represents a typical weak and a typical strong "normal flare", respectively, are also plotted in the figures. It can be seen that, comparing to the pre-flare atmosphere (FQ in Fig. 4), the outstanding characteristics for Type I WLFs is a great enhancement of chromospheric temperature and a moderate increase of photospheric temperature. On the contrary, for Type II WLFs there is no obvious increase in chromospheric temperature, while the temperature of the photosphere increases greatly. Detailed calculations[10,23] indicated that the continuum emission of Type I WLFs comes mainly from the bound-free transitions of hydrogen atoms in the low chromosphere and the upper photosphere, and the negative hydrogen ions (H^-) have also some contribution. While for Type II WLFs, it comes mainly from H^- in the photosphere. This may help to clear up the long-existing controversy on the sources of WLF's emissions.

By the way, it should be mentioned that there is so far no dynamic model specially for WLF. It probably has no essential difference from that for "normal" flares, because the typical red asymmetry of line profiles appears also in the WLF's spectra (see e.g., Fig. 2).

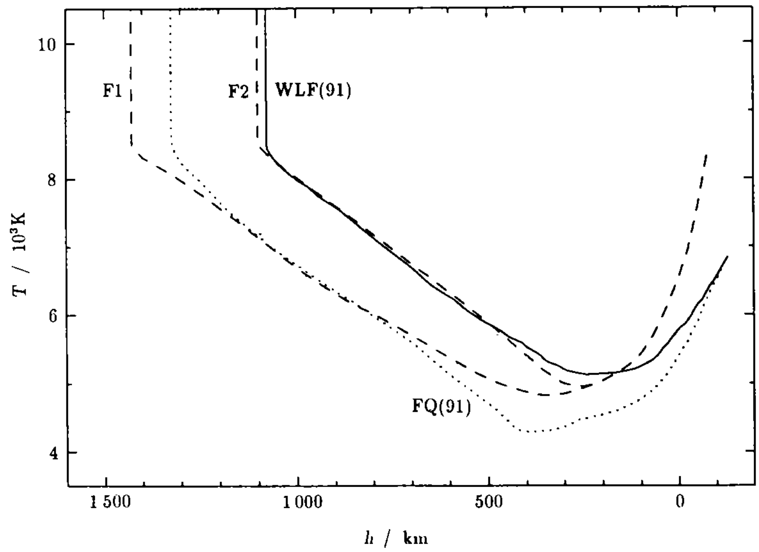

Fig.4 Temperature distributions of the semi-empirical models for the 1991 Oct 24 WLF(Type I). FQ(91)(dotted line and WLF(91)(solid line) correspond to the time of pre-flare and the peak of continuum emission respectively. The flare semi-empirical models F1 and F2 of Machado *et al.*[28] are also shown by dashed lines.

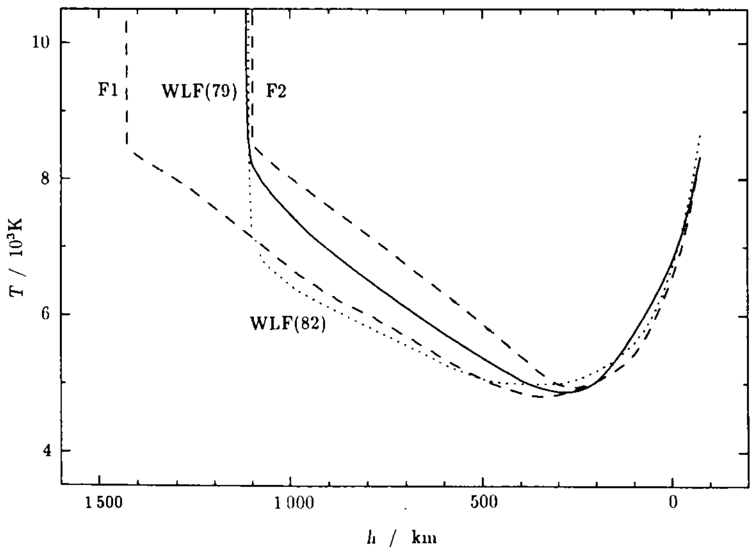

Fig. 5. Temperature distributions of the semi-empirical models for the Type II WLFs of the 1982 June 15 (dotted line) and the 1979 Sept 19(solid line) events.

4 WLF's production mechanisms

It is generally believed that the continuum emission of WLFs comes mainly from the low chromosphere and the middle and upper photosphere. The results of semi-empirical modelling provide convincing arguments. Recently, by analysing the distribution of 86 WLFs on the solar disk, Neidig *et al.*[8] concluded that an emission source located in the middle photosphere up to 150 km can well explain the observed distribution, while a photosphere source located lower than 150 km plus a chromospheric emission source can also reproduce the observational results.

Now that the continuum emission of WLFs mainly comes from the low chromosphere and the middle and upper regions of the photosphere, while it is also believed that the flare energy release takes place in the corona, how the energy of WLFs is transported to the low atmosphere becomes a prominent problem. Several mechanisms have been proposed, but each has its own difficulties. Neidig[2] has summarized some of them. The main possible mechanisms are as follows.

4.1 Electron beam bombardment

Mainly based on the fact that there is a good corresponding relation between the time of the maximum of continuum emission and that of the peak of HXR and microwave, more and more people considered that the energy of WLFs comes probably from the energy deposit of electron beam bombardment on the chromosphere[11,12,14,16]. Neidig and Kane[12] pointed out that the peak power in nonthermal electrons above 50 keV is typically an order of magnitude larger than the peak WLF power, and the electron beam can penetrate through and heat the chromosphere. Our recent computation indicated that[29], taking into account the effects of nonthermal ionization and excitation, the atmosphere heated by electron beam can produce very wide Balmer emission lines, and the strong reversal at the H_α line center will appear. These are just the observational characteristics of spectra for Type I WLFs. Thus, the electron beam bombardment is probably the heating mechanism for these WLFs. Obviously, electron beam cannot heat the photosphere directly, because it would need the beam energy higher than 900 keV, while the total energy carried by them would be two orders of magnitude smaller than the WLF energy. So there should be a mechanism, which can transport the energy deposited in the chromosphere to the photosphere. Chromospheric condensation and emission may give some contributions. Using semi-empirical modelling, Aboudarham and Hénoux[30] and Hénoux[31] indicated that the effects of nonthermal ionization and excitation by electron beam can increase the opacity in the photosphere and in the temperature minimum region, so that the enhancement of chromospheric emission can heat these regions and produce WLFs. However, some difficulties remain. Particularly, why are most of the flares, which have strong X-ray emissions and microwave bursts, not WLFs, though their high-energy electron beams bombard the chromosphere in the same way? It seems that the special environment and conditions for the production of WLFs have to be studied in detail.

4.2 Proton beam bombardment

High energy proton beam can also heat the chromosphere. With the same velocity of electron beam, it can penetrate to deeper layers than the electron beam. So the proton beam was proposed many years ago to explain the energy source of WLFs. However, recent study[33] has shown that there is statistically no obvious corresponding relation between the WLF and the γ-ray burst produced by proton beam. Moreover, the H_α line in the atmosphere bombarded by a proton beam is relatively narrow and without strong central reversal, which are not consistent with observations[34]. Besides, only protons with energy greater than 20 MeV can penetrate into the low chromosphere. Whether there are enough protons with such high energy during WLFs still remains to be studied. Simnett[35]proposed that the low-energy protons are the main carrier of energy during the impulsive phase of flares. They heat rapidly the upper chromosphere and then through condense waves etc. heat indirectly the lower atmosphere to produce the WLFs. This idea needs to be further studied quantitatively. Machado *et al.*[36] also suggested that the low-energy protons can effectively heat the upper chromosphere and do not produce obvious γ-ray emission because of their low energy. By the backwarming of Balmer continuum emission, the photosphere can be heated and produce H^- continuum emission.

4.3 Irradiation by 1-1030 Å emission

It is well known that the soft X-rays (1–10 Å) and EUV emission (10–100 Å) of flares may heat the chromosphere[37,38]. However, the maximum of the continuum emission of Type I WLFs is generally earlier by several minutes than the peak of SXRs and corresponds roughly to EUV maximum. Moreover, at the time of the maximum of continuum emission, the typical radiative rate in SXR (1– 8 Å) is one order of magnitude smaller than WLF's rate. So it seems that the soft X-rays cannot explain WLFs. Strong EUV radiation, which could be produced through heating the transition region and the upper chromosphere by high-energy particle, might greatly heat the chromosphere. But as pointed out by Poland *et al.*[39], a fundamental problem is that the EUV photons are difficult to reach the low chromosphere and the upper photosphere, which is ordinarily opaque to most EUV radiations. Machado *et al.*[36] proposed the backwarming by the Balmer continuum to solve this problem. That is, the chromosphere greatly heated by EUV radiation could produce strong Balmer continuum emission, which in turn penetrates into the deep layer and produces WLFs. This mechanism is difficult to explain Type II WLFs, because they have no strong Balmer emissions.

4.4 Alfvén wave

Emslie and Sturrock[40] suggested that the dissipation of Alfvén waves in the region with high resistivity might explain the heating in the temperature minimum region of flares. The result of their calculations can explain the heating with an energy deposit rate $\sim 10\ \mathrm{ergs{\cdot}s^{-1}{\cdot}cm^{-3}}$, but whether it could provide the rate as high as $\sim 10^3\ \mathrm{ergs{\cdot}s^{-1}{\cdot}cm^{-3}}$ for WLFs remains to be further studied. If this mechanism works, the WLF's emission should attain the maximum several seconds later than hard X-rays. Some observations seem to support this expected result.

4.5 Local Joule dissipation

It seems that the scenario of energy released in the corona and then transported to the lower atmosphere is hardly acceptable for the Type II WLFs. Therefore, Mauas and Machado[41] and Mauas *et al.*[26] suggested that the energy is released probably in the photosphere. By analysing the 1979 Sept 19 WLF, we have also proposed that[20,23] this WLF, at least for the first peak two minutes prior to the peak of HXR, can only be explained by a heating source located in the photosphere. A possible source is the Joule dissipation of local currents, but it needs to be studied in more detail.

4.6 Chromospheric condensation

Recently, by use of non-LTE atmospheric modelling, Gan *et al.*[42] demonstrated that when the temperature in the chromospheric condensation is higher than that of the surrounding chromosphere (i.e., attaining 9 000–10 000K), and the transition region goes down to the column density higher than 10^{-4} g·cm^{-2}, the condensation can produce detectable continuum emissions and a Balmer jump. This new mechanism is able to explain some of Type I WLFs, but needs to be quantitatively studied by dynamical models of WLFs.

From the above description it can be concluded that there is so far no definite and satisfactory mechanism to explain the WLF's emission. The main difficulty is how to find an effective mechanism, by which the energy can be transported rapidly from the transition region and the upper chromosphere into the lower chromosphere and the photosphere, or instead, the energy can be released directly in the photosphere, and the upper atmosphere can be heated as well. Such a mechanism should be operated only in the special environment and conditions of WLFs. For the future, it is necessary to accumulate and analyse more observational data, especially high-quality spectral and multi-bands photometric data, coupled with X-rays, γ-rays and microwave measurements, and to do more quantitative studies.

5 Comparison between solar and stellar WLFs

Recent observations show that the stellar WLFs are ones of the common active phenomena on later-type stars. Many WLFs have been observed on dKe/dMe stars. Their total energy in optical bands is 10^{28}–10^{35} ergs, and the duration is from several seconds (mictoflares) to hours. The WLFs on the active binary RS CVn are even two orders of magnitude stronger than those on dMe dwarf. Though physical parameters of stellar WLFs are diverse, they have some common characteristics. Especially, the WLFs on dMe dwarf are similar to solar WLFs in many aspects.

(a) Optical radiation shows strong "UV excess", i.e., the intensities in the multicolour photometry are

$$I(U) > I(B) > I(V) > I(R). \tag{1}$$

(b) The maximum of continuum emission appears generally earlier than the intensity peak of emission lines[43] and the peak of SXR[44]. Though there is so far no joint observational data of HXR and optical radiation for stellar WLFs, some observations imply that the peak of high-energy SXRs is earlier than that of low-energy SXRs[45], and coincides with that of microwave burst[43]. Of course, for some stellar WLFs, there is no obvious time corresponding relation between the optical emission and the microwave burst, just as in the case of solar Type II WLFs.

(c) Generally, there are strong Balmer emission lines and their widths are wide, corresponding to a turbulent velocity of 50–200 km·s^{-1}. The lines have remarkable red asymmetry, resulting in a Doppler velocity of 25–100 km·s^{-1} (see reviews [7] and [46]). The electron density in the high temperature region of flares deduced from the variation of SXR flux is about 10^{11}–10^{12} cm^{-3}. The temperature is 10^7–10^8 K. As judged from the obvious increase of the emission measurement, $\int n_e^2 dV$, during WLFs, the transition region should descend greatly at this time.

All these facts imply that there are similar observational characteristics between stellar and solar WLFs. So they have probably some similar physical process and are produced by more or less similar mechanisms, but only the eruptive scale and area of the former are much larger than that of the later.

In recent years, some new progress in the observations of stellar flares has been achieved. Analysing the spectra of two dMe starts, Falchi *et al.*[47] found that the spectral property of one flare event on V1054 Oph star is similar to that of the solar Type I WLFs, while two flares on V1216 Sgr star are similar to the solar Type II WLFs. One major flare on the RS CVn II Peg star was observed simultaneously by the GINGA X-ray satellite and a ground telescope in Johnson U-band. The measurement made by Doyle[48] indicated that the energy of continuum emission in U-band is greater than 6.6×10^{34}ergs, while the energy of X-rays in 1-10 keV is more than 4.6×10^{34}ergs, resulting in a total energy greater than 3×10^{35} ergs. Barstow *et al.*[49] reported the first stellar flare detected in EUV. Hawley and Pettersen[50] made spectral observations of a major flare on dwarf M star AD Leo and obtained for the first time the temporal variations of the energy in optical and UV radiations.

There is also some progress in the theoretical study of stellar flares. Katsova *et al.*[51,52] used a simple hydrodynamic model to explain the spectra of stellar flares. Kopp and Poletto[53] proposed a "dot" model, including the heat conduction, chromospheric evaporation, radiative losses and gravitation etc., and obtained the time variations of the mean temperature, density and velocity in flare loops. Hawley and Fisher[54] calculated a detailed dynamic model similar to that for solar flares. The model is a magnetically confined loop and includes the photosphere , the chromosphere and the transition region. It is supposed that the site of energy release is in the corona and the heating of low atmosphere is due to X-rays radiation. Assuming energy and hydrostatic equilibrium, they solved the non-LTE radiative transfer equation, obtained the line profiles and continuum spectra within 1 000–9 000 Å and compared the results with observations. The study on the flare dynamic models needs to be done further. Besides, the research on semi-empirical models is also an interesting subject.

6 Conclusion

In summary, the study of solar WLFs has recently achieved much important progress both in observations and in radiative mechanisms. We are now getting deeper and deeper understanding on the physical property, the height, the radiative mechanism and the energy transport of solar WLFs, while the study of stellar WLFs becomes more and more active. It is expected that these two fields of study will permeate through and help each other in future, and form one of important active frontiers in the solar-stellar research.

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References

[1] Neidig D F , Cliver E W. AFGL-TR-38-0257, 1983

[2] Neidig D F. Solar Phys., 1989, 121: 261

[3] Gurzadyan G A. Flare stars. New York: Pergaman, 1980

[4] Zhang Rongxian *et al.* Inf. Bull. Variable Stars, 1990, No. 3456

[5] Henry G W , Hall D S. Ap. J., 1991, 373: L9

[6] Wang Jingxiu, Shen Longxiang, Fang Cheng. Progress in Astronomy, 1986, 4: 175

[7] Zhai Disheng. Progress in Astronomy, 1992, 10: 114

[8] Neidig D F, Wiborg P H, Gillam L B. Solar Phys., 1993, 144: 169

[9] Machado M E *et al.* In: Neidig D F ed. The Lower atmosphere of solar flares, Proc. of the National Solar Observatory/Solar Maximum Mission Symposium, Sunspot, 1985, Sunsport: NSO, 1986: 483

[10] Fang Cheng *et al.* Solar Phys., 1994, submitted

[11] Neidig D F *et al.* Ap. J., 1993, 406: 306

[12] Neidig D F, Kane S R. Solar Phys., 1993, 143: 201

[13] Hudson H S *et al.* Publ. Astron. Soc. Japan, 1992, 44: L77

[14] Kane S R *et al.* Ap. J., 1985, 290: L45

[15] Kurokawa H, Takakura T, Ohki K. Publ. Astron. Soc. Japan, 1988, 40: 357

[16] Canfield R C *et al.* In: Kundu M R, Woodgate B eds. Energetic phenomena on the sun. NASA CP-2439, [s.l.]:[s.n.], 1986. chap. 3

[17] Neidig D F. Solar Phys., 1983, 85: 285

[18] Neidig D F, Wiborg Jr P H. Solar Phys., 1984, 92: 217

[19] Donati-Falchi A, Falciani R, Smaldone L A. In: Neidig D F ed. The Lower atmosphere of solar flares, Proc. of the National Solar Observatory/ Solar Maximum Mission Symposium, Sunspot, 1985, Sunspot: NSO, 1986: 136

[20] Fang Cheng *et al.* Science in China (Ser. A), 1993, 36: 217

[21] Mauas P J. Ap. J. Suppl., 1990, 74: 609

[22] Boyer R *et al.* Solar Phys., 1985, 98: 255

[23] Ding Mingde *et al.* Ap. J., 1994, in press

[24] Machado M E, Rust D M. Solar Phys., 1974, 38: 499

[25] Ryan J M *et al.* Ap. J., 1983, 272: L61

[26] Mauas P J, Machado M E, Avrett E H. Ap. J., 1990, 360: 715
[27] Hu Ju *et al.* Acta Astron. Sinica, 1994, in press
[28] Machado M E *et al.* Ap. J., 1980, 242: 336
[29] Fang Cheng, Hénoux J C, Gan Weiqun. Astron. Astrophys., 1993, 274: 917
[30] Aboudarham J, Hénoux J C. Astron. Astrophys., 1986, 156: 73
[31] Hénoux J C. In: Švestka Z *et al* eds. Eruptive Solar Flares. [s.l.]:[s.n.], 1992
[32] Švestka Z. Solar Flares. Dordrecht: Reidel, 1976: 89
[33] Xu Aoao *et al.*, Acta Astron. Sinica, 1991, 32: 36
[34] Hénoux J C, Fang Cheng, Gan Weiqun. Astron. Astrophys., 1993, 274: 923
[35] Simnett G M. Solar Phys., 1986, 106: 165
[36] Machado M E, Emslie A G, Avrett E H. Solar Phys., 1989, 124: 303
[37] Hénoux J C, Nakagawa Y. Astron. Astrophys., 1977, 57: 105
[38] Fang Cheng, Hénoux J C. Astron. Astrophys., 1983, 118: 139
[39] Poland A I, Milkey R W, Thompson W T. Solar Phys., 1988, 115: 277
[40] Emslie A G, Sturrock P A. Solar Phys., 1982, 80: 99
[41] Mauas P J, Machado M E. In: Neidig D F ed. The Lower atmosphere of solar flares, Proc. of the National Solar Observatory/Solar Maximun Mission Symposium, Sunspot, 1985, Sunspot: NSO, 1986: 192
[42] Gan Weiqun *et al.* Ap. J., 1992, 397: 694
[43] Rodono M *et al.* In: Haisch B M , Rodono M eds. Solar and stellar flares. Dordrecht: Kluwer, 1989. 53
[44] de Jager C *et al.* Astron. Astrophys., 1986, 156: 95
[45] Doyle J G *et al.* Astron. Astrophys., 1988, 191: 79
[46] Byrne P B. Solar Phys., 1989, 121: 61
[47] Falchi A *et al.* Astrophys. Lett. Commun., 1990, 28: 15
[48] Doyle J G. M.N.R.A.S., 1991, 248: 503
[49] Barstow M A. Nature, 1991, 353 (6345): 635
[50] Hawley S L, Pettersen B R. Ap. J., 1991, 378: 725
[51] Katsova M M, Livshits M A. Sov. Astron., 1991, 35: 65
[52] Katsova M M *et al.* M.N.R.A.S., 1991, 250: 402
[53] Kopp R A, Poletto G. In: Armagh Obser. bicentenary colloq. on surface inhomogeneities on late-type-stars. [s.l.]:[s.n.], 1992: 295
[54] Hawley S L, Fisher G H. Ap. J. Suppl., 1992, 78: 565
[55] Baranovskii E A, Koval A N. Bull. Crim. Astrophys. Obs., 1982, 65: 31
[56] Sotirovski P *et al.* Astron. Astrophys., 1992, 262: 597
[57] Yin Suying, Fang Cheng, Ding Mingde. 1994, to be published
[58] Huang Youran, Yin Suying, Fang Cheng. Acta Astron. Sinica, 1991, 32: 421
[59] Zirin H, Wang Jingxiu. 1994, in preparation
[60] Xuan Jiayu *et al.* Chin. Sci. Bull., 1992, 37: 391
[61] Zhu Cuilian, Gao Feng, Qiao Qiyuan. CSGD, 1991, April-May issue: 78
[62] Sakurai T *et al.* Publ. Astron. Soc. Japan, 1992, 44: L7
[63] Korobova Z B. Solar Phys., 1992, 139: 205
[64] Neidig D F. Solar Phys., 1978, 57: 385