OPTICAL AND ULTRAVIOLET STELLAR FLARE SPECTROSCOPY

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ABSTRACT

As for solar flares, one of the most physically revealing types of data for M-dwarf flares are high-resolution, time-resolved spectra. Due to the intrinsically faint nature of the M-dwarf stars, spectroscopic data has tended to be of low spectral (~ 5 Å) and temporal (~ 5 min) resolution. However, with the development of image intensified spectrographs and fast, efficient digital detectors, the last several years have seen the successful acquisition of both high time and spectral resolution M-dwarf flare spectra. Recent programs have also been successfully conducted using the International Ultraviolet Explorer (IUE) satellite to obtain UV and EUV spectra of M-dwarf flares. These data reveal that dwarf M star flares are remarkably similar to solar flares in all aspects of their spectroscopic phenomenology.

1. INTRODUCTION: SOLAR AND STELLAR FLARES

The dwarf M emission line (dMe) flare stars, or UV Ceti-type stars, are a set of late-type dwarf stars which undergo intense, short-lived continuum brightenings, or flares. The basic features of stellar flares have been reviewed by Gershberg (1975), Mullan (1977), and Gurzadyan (1980), as well as in other papers presented at this meeting. As reviewed by Zirin and Ferland (1980), dMe flares are comparable in most respects to solar flares. As with solar flares, one of the most physically revealing types of data are high spectral resolution, time-resolved visible and ultraviolet spectra. In this review, I summarize the spectroscopic data base for dMe flares.

Broad-band stellar flare light curves closely resemble the spatially averaged solar extreme ultraviolet (EUV) 300-1500Å light curve shown in Svestka's(1976) monograph. The transient nature of stellar flares is well documented with a general division into "spike" and "slow" events on the basis of flare rise time in the Johnson U band

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(Moffett, 1974). This classification corresponds to a general division of solar flares into those with a "flash" phase and the rarer "spotless" flares (see Zirin and Ferland, 1980; Dodson and Hedeman, 1970). An apparent dichotomy between solar and stellar flares is the time scale for the event. The stellar continuum flare is typically an order of magnitude (minutes) shorter than solar Hα flare durations (hours). However, if the solar continuum flare, either the extremely rare "white light" flare, or the UV continuum flare time scales is used instead, then the timescales for the flash phase of solar and stellar flares are comparable. Moreover, stellar flare line emission persists for hours (Kunkel, 1970) in marked similarity to solar flares. The principle qualitative difference between solar and stellar flares is the presence for the Sun of a substantial photospheric continuum in the visible and near UV.

Energy liberated in solar flares appears to reside in atmospheric magnetic fields, although the physics of the energy release and its partial conversion to electromagnetic radiation is poorly understood (Svestka 1976, Chapter VI). Indirect evidence for substantial magnetic fields on dMe stars comes from both theoretical grounds (Mullan, 1974), and observational, including the presence of photometric variations which may be interpretted as magnetic starspots (Torres and Ferraz-Mello, 1973; Hartman and Rosner, 1979), and the strong polarization, possibly detected in radio observations of stellar flares (Spangler et al., 1974). Direct detection of magnetic fields on dMe stars is very difficult due to the tangled field topologies on their surfaces (Vogt, 1980). Although new techniques relying on high signal-to-noise, and high spectral resolution data (Robinson, 1980: Robinson et al., 1980) may reveal total magnetic flux values for dMe stars, it is unlikely that changes in this flux will be tied to specific flare events. Definitive evidence for changes in solar magnetic field configuration have yet to be detected during solar flares. There is no overriding reason to suppose that stellar flares are fundamentally different from solar flares, although it should be emphasized that both solar and stellar flares are an extremely diverse set of phenomena. Stellar flares can involve much more energy than their solar counterparts, and they are certainly more frequent and represent a much larger fraction of total stellar energy output.

The primary release of solar flare energy apparently occurs in the transition region or low corona. Since this is a nigh-temperature region at greater than 10^6K (Svestka, 1976), direct radiative flare effects appear in X-ray emission. This spectral region can be studied only with high-spectral resolution X-ray space telescopes, which have not yet yielded sufficient spectral resolution to study the flare fine structure so as to elucidate the primary energy release. However, flare effects in the solar chromosphere and photosphere may be probed through EUV, UV(1500-4000Å) and visible spectra. Observational solar flare studies have centered on the Hα line which is both readily observable and which spans a wide range of levels in the solar atmosphere. In the first portion of this review, I will summarize the principal observational features of solar visible, UV, and EUV spectra.

High spectral resolution observations of line profiles in flare stars could provide data with which to test flare models for both solar and stellar flares. Most data on stellar flares are obtained by broadband visible photometry. However, there is some data on UV and EUV radiation (Haisch et al., 1981, 1982; Butler et al., 1981), X-rays (Kahn et al., 1979; Haisch et al., 1981; Kahler et al., 1982), and radio radiation (Spangler et al., 1974) from flares. However, the intrinsic faintness of the dMe stars has made it extremely difficult to obtain spectroscopic observations with sufficient temporal or spectral resolution to apply fully the diagnostic methods of solar flare research. The development of new digital high speed detectors promises spectral data both in the visible and UV which will be adequate for detailed analyses. These data, although important in isolation, become even more valuable when coordinated with other types of visible, X-ray, UV, and radio observations. In the second part of this review, I summarize the available spectral observations, which in and of themselves suggest approaches for new coordinated programs.

2. SOLAR FLARE SPECTROSCOPY

An outstanding review of solar flare spectroscopy in the visible wavelength regions has been presented by Svestka (1972), and the brief summary in this paper will closely follow that review. In general, solar flare visible radiation is emitted in spectral lines, with only extremely rare instances of continuum emission. Depending on the size of the flare, the Balmer lines of hydrogen go into emission. The larger the flare, the higher up the Balmer series the emission extends, up to H_{16} in very large flares. Also in large flares, lines of neutral and singly-ionized metals are excited, suggesting that the flare is progressively heating deeper layers of the atmosphere. Neutral helium lines, which are not normally present in the solar spectrum, go into absorption in small flares, and into emission for larger flares. In the largest flares, He II lines such as λ 4686 also appear in emission.

The Balmer spectrum of hydrogen has been the most extensively studied in solar flares. In a following paper, M. Giampapa will discuss how electron density, flare optical thickness, electron temperature, non-LTE conditions, and hydrogen density can be deduced from Balmer line data. Although the central hydrogen emission core has a width comparable to the solar photospheric absorption lines (1 to 2 Å), broad emission wings can extend over 10 Å. This fact, taken with the non-broadening of metallic emission lines, indicates that Stark broadening is the mechanism responsible for the hydrogen line widths (Svestka, 1972). Among the best available solar flare spectra are those published for Hα during the great flares of August 1972 (Zirin and Tanaka, 1973). Figure 1 reproduces a portion of the 7 Aug 1972 flare showing the key features from the maximum Hα emission period. Most of the flare emission is confined to the narrow (~ 2 Å) central peak.

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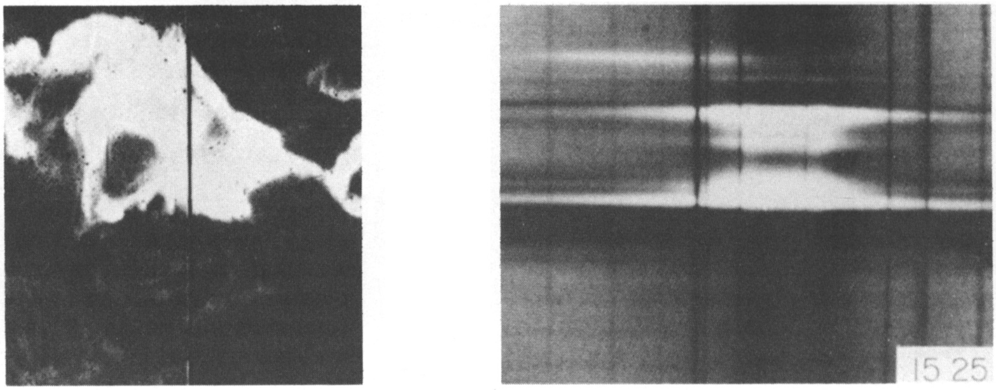

Figure 1. Hα filtergram and spectrum taken by Zirin and Tanaka (1973) for the 7 Aug 1972 flare maximum. The spectrum covers ~ 10 Å; red is to the left.

However, the bright flare kernels show emission extending over at least 10 Å. The strongly redshifted emission feature is also typical of solar flares. Taken as an integrated flare spectrum, the emission asymmetry does not change the center of the emission, but makes one of the wings stronger. At the outset of a solar flare a short-lived blue wing enhancement often occurs. The blue asymmetry disappears within a minute or two and a strong red asymmetry appears, which reaches its maximum roughly concurrent with Hα flare maximum, and then decreases within about five minutes. These phenomena have been interpreted as motions within the flaring region (see Banin, 1965; Severny, 1968); the blue asymmetry is due to a surge during the flash phase, and the red asymmetry is due to condensing material in later flare phases.

The prominent lines of He I, λλ5876, 6678, and 10830 appear in absorption in small flares and in emission during larger ones. The He I lines probe slightly hotter regions ($T_e \sim 2 \cdot 10^4$ K) than the Balmer lines (Te ~ 10^4K). The He II lines, most conspicuously λ4686, but also such lines as λ5411, probe the region ($T_e \sim 10^4 - 10^5$ °K) between the low-temperature chromospheric flare and the high-temperature coronal X-ray flare ($T_e \sim 10^{6}$° K).

The Ca II H and K lines (λλ3968, 3933) are strengthened during solar flares. These lines are potentially extremely important diagnostics for conditions throughout the solar and stellar chromosphere (see Linsky, 1980). Excellent chromospheric models based on these lines have been developed for all classes of late-type stars, including the dMe stars (Giampapa et al., 1982). The most notable solar flare effect on the H and K line profiles is the disappearance of the central reversal in the emission core.

Metallic lines, both neutral and singly ionized, are probes of the low solar photosphere where $T_e < 10^4$ °K. A thorough study of flare

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metallic emission lines has been made by Letfus (1964). Metallic lines are typically very narrow, and only occasionally show broadening attributable to material motions (Jeffries and Orrall, 1961). For some events, strong metallic lines in solar flare spectra show a self-absorption (Svestka, 1963). There have been several studies on the sequence with which various lines appear during solar flares, but the results are somewhat contradictory as to whether metallic emission lines appear before or after Balmer emission (Svestka, 1972).

Solar flare EUV emission is a probe of the transition region between the chromosphere and corona. Good data in this spectral region derive primarily from the OSO 4, OSO 6, Skylab, and Solar Maximum Mission Satellites. EUV bursts, both line and continuum, appear simultaneously with the hard X-ray burst, impulsive microwave burst, white light flare, and flare flash phase, but are on the average a few minutes earlier than the Hα and soft X-ray maximum. The EUV burst, lasting a few minutes at most, is much shorter than the Hα or soft X-ray flare, but longer than the hard X-ray burst. Emission lines, representing temperatures of 10^4 °K to 10^6 °K, occur in spectral lines ranging from neutral hydrogen and oxygen to highly ionized species such as Fe XVI. Lines arising in the chromosphere ($T_e \sim 10^4$ °K) and transition region ($T_e \sim 10^5$ °K) dominate during the flare impulsive phase, while coronal emission lines ($T_e \sim 10^6$ °K) dominate during later flare phases.

3. STELLAR FLARES

Stellar flare spectroscopy is a difficult observational task. Until recently, most stellar flare observations were accidental. Because of the intrinsic faintness of the dMe stars, flare spectroscopic data are usually of low spectral and temporal resolution. However, high-efficiency digital detector spectrometers coupled to large telescopes are making available a growing body of good stellar flare spectra. These data, often taken as part of coordinated flare patrols along with X-ray, UV, EUV, optical photometric, and radio data provide powerful dignostics upon which to base stellar flare modeling.

The main body of dMe stellar flare spectroscopy is summarized in Table I. The first spectrum of a stellar flare on a dMe star was reported by Joy and Humason (1949), who noted greatly enhanced Balmer lines in one 144-minute exposure of UV Cet. They also noted the λλ4471, 4026 lines of He I, as well as the λ4686 line of He II. There were a number of other "accidental" dMe flare spectra taken during the 1950-1965 period. Gurzadyan (1980) notes some of these data; in the interest of brevity, they are not all included in Table I nor in this discussion. Herbig (1956) noted both enhanced Hβ and Ca II emission in BD+4°4048B, and Joy (1958) reported that the Balmer lines in UV Cet doubled in width. However, the utility of flare spectra is greatly enhanced by simultaneous photometry.

Table I. Spectra of Stellar Flares

Wavelength Range	Resol'n	Time Resol'n	Star	Reference and Remarks
Blue		144min	UV Cet	Joy & Humason (1949). No photometry. One plate had enhanced & broadened H lines. He I and He II emission.
3500-5000Å	430Å/mm	4.5 hr	BD+4°4048B	Herbig (1956). Very bright Hβ. Ca II lines brighten less than H. No photometry.
Blue	80Å/mm	100min	UV Cet	Joy (1958). Visual photometry. H lines double in width.
Hα,Hβ, 4226Å ±1000Å	6-7Å	1-2min	AD Leo UV Cet	Gershberg & Chugainov (1966,1967). Simultaneous photometry. H lines broaden, Hβ goes from 5.2Å to 10Å.
3500-5000Å	15Å	5min	Wolf 359	Greenstein and Arp (1969). No photometry. Greatly broadened H lines.
3500-7000Å	6Å	30min	AD Leo	Gershberg & Shakhovskaya (1971). Red asymmetry in H line wings. Simultaneous photometry.
3500-4900Å	15Å	7min	EV Lac YZ CMi AD Leo	Kunkel (1970). Simultaneous UBV photometry. Ca II lines rise slower than H lines.
3800-6000Å	8Å	3min	UV Cet	Bopp & Moffett (1973). High-speed photometry. Relative timings of H, He, and Ca II lines. He flashes.
all H lines	3Å	20min	AD Leo	Kulapova & Shakovskaya (1973). With photometry. Hα width increases to 15Å.
3700-5700Å	8Å	3min	UV Cet YZ CMi EV Lac YY Gem	Moffett & Bopp (1976). With high speed photometry. Hβ lags U band by 1-17 min. Complex line response.
Hβ±30Å	10Å	107sec	UV Cet	Moffett et al. (1977). High speed phototometry. Hβ increases much more than continuum.

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Table I. Spectra of Stellar Flares (Continued)

Wavelength Range	Wavelength Resol'n	Time Resol'n	Star	Reference and Remarks
5300-7300Å	0.24Å	2min	AD Leo	Schneeberger et al (1979). Has photometry. No width change in Hα.
5090-5350Å	0.5Å	5min	YZ CMi	Mochnacki & Schommer(1979). No photometry. Numerous Mg I, Fe I, Fe II emission lines.
3200-7000Å	20-160Å	10-30sec	YZ CMi AD Leo	Mochnacki & Zirin (1980). Spectrophotometry. Inverse Balmer decrement during flash phase.
1200-3200Å	6Å	5-10min	Prox Cen	Haisch et al. (1981). Simultaneous X-ray, radio. No photometry. 1200-2000Å increase less than a factor of 2. Possible Mg II emission during X-ray flare.
1200-2000Å	6Å	100min	Gl 867A	Butler et al. (1981). No other obs. High temperature lines enhanced more than low temperature ones.
4200-5900Å	4Å	33sec	YZ CMi	Kahler et al. (1982). Simultaneous X-ray, radio, optical data.
1200-3200Å	6Å	60min	Prox Cen	Haisch et al. (1982). Simultaneous X-ray. Numerous transition region lines well observed during flare.
5000-7000Å	0.24Å	3min	YZ CMi	Scheeberger et al. (1982). Simultaneous photometry. Balmer lines not broadened in 6 flares. Hβ response lags behind Hα.
3500-7000Å	0.25A-3.8Å	3min	UV Cet	Giampapa et al. (1983). Very large flare (5 mag in U). Broad red-shifted wings with narrow core in H & He lines.

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Gershberg and Chugainov (1966,1967) were the first to study the response of chromospheric emission lines to a flare with coordinated spectroscopic and photometric observations. Since the FWHM of Hα in flare stars is roughly 1-2Å (Worden and Peterson, 1976), low spectral resolution observations cannot reveal detailed information on the response of emission lines to the flare. Moreover, typical flare light curves show that flare phenomena are extremely rapid. Thus, spectral data with high time resolution are essential. Recently, data with spectral resolutions near 0.2Å have become available (Schneeberger et al., 1979, 1982; Mochnacki and Schommer, 1980; Giampapa et al., 1983). The development of efficient digital detectors has also helped in getting higher time resolution data. Using a multichannel scanner, Mochnacki and Zirin (1980) have achieved time resolutions of 10 seconds for a large flare on YZ CMi. In the following summary, I review the principal observational aspects of the spectroscopic data listed in Table I.

3.1. Balmer Lines: Balmer Decrement

The ratio of Balmer series line intensities (Balmer decrement) during the flare can be an important indication of physical parameters such as electron density (Zirin and Ferland, 1980). Kunkel (1970) reported an increment, rather than a decrement, where Hβ, Hγ, and Hδ may actually exceed Hα in intensity by up to a factor of two during flare maximum. Higher Balmer lines do show a decrement during flare maximum, with the decrement becoming steeper for the higher series lines. The lower Balmer series reassert the decrement as the flare progresses. Zirin and Ferland (1980) point out that, although poorly studied, there is some evidence of the same behavior in the low Balmer lines during solar flares.

As discussed by Svestka (1972), the highest member of the Balmer series which appears in emission during the flare can provide information on the optical depth within the flaring region. Although there is a paucity of high S/N spectra in the near UV, data such as that reproduced in Figure 2 (Giampapa et al, 1982) show that Balmer emission is present until at least H_{13}.

3.2. Balmer Lines: Balmer Continuum

In solar flares Balmer continuum observations are applicable for temperature determinations (Svestka, 1976). Solar flare Balmer continuum emission is often absent during flares, but this may be an observational selection effect due to the high background. Kodaira et al.(1976) saw no evidence for Balmer continuum emission in dMe flares. However, Mochnacki and Zirin (1980) did report Balmer continuum emission for a large flare on UV Ceti. Zirin (1982, private communication) has confirmed that Balmer continuum emission is an occasional feature of stellar flares.

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3.3. Balmer Lines: Widths

Due to low spectral resolution, much of the data in Table I are useless for studying line profiles. Equivalent width results, usually quoted from spectra with resolutions worse than a few Ångstroms, provide little information of value. Since there are no good models of dMe atmospheres, nor good scanner observations of dMe continuum flux, it is very difficult to place equivalent width data on any sort of flux scale. Moreover, the continuum is changing rapidly due to the flare continuum, and probably slowly due to rotation of active regions in and out of the field of view (BY Dra syndrome). Equivalent widths are only meaningful if they can be used to compare emission flux in one line to another. Clearly, due to the problems outlined above, this is not generally possible.

Although there have been numerous reports of Balmer line broadening during flares, the spectroscopic data upon which this is based has marginal resolution to study the broadening. High-resolution Balmer data from Schneeberger et al. (1979, 1982) with resolutions of 0.2Å tend not to show broadening at all. It is apparent from the data in Figure 2 that the Balmer lines (and He I lines) are broadened and asymmetric to the red, while Ca II is unbroadened. A high-resolution Hα profile during a large UV Cet flare from Giampapa et al. (1983) shows that the dMe flare broadening is very similar to the solar flare results in Figure 1. In the Figure 1 spectrum, most of the flare emission is confined to a core no broader than the photospheric absorption width. However, the flare kernels do have an extremely broad profile, with some redshifted, broadened emission as well. The broadening of high series ($n > 10$) Balmer lines discussed by Svestka (1972) has not been reported for dMe flares. Nonetheless, one must conclude that dMe flares exibit Balmer line behavior virtually identical to that of a solar flare.

3.4. Helium Lines

Joy and Humason (1949) noted He I λλ4471, 4026 and He II λ4686 in an UV Cet flare. Gershberg and Chugainov (1966, 1967) noted other He I lines in dMe flares, such as λλ4921, 5876. In remarkable similarity to solar flares (see Svestka, 1972), He I lines only appear in the larger dMe flares, and He II lines are present only in the strongest flares (see Gurzadyan, 1980).

3.5. Metal Lines

Mochnacki and Schommer (1979) identified numerous Fe I, Fe II and Mg I lines, including the strong Mg I B lines, in a large YZ CMi flare. The fact that these lines are apparent only at high spectral resolution suggests that most absorption lines may have emission phases during large flares. At the limit of their resolution (0.5 Å), Mochnacki and Schommer saw neither line broadening nor displacement from the photospheric absorption rest wavelength. Moreover, none of the lines showed any asymmetries. Mochnacki and Schommer also pointed out that high- resolution line profiles may reveal magnetic field information through Zeeman pattern analysis similar to that proposed by Robinson (1980) for absorption lines. Using a simple form of that analysis, Mochnacki and Schommer set an upper limit of 7.5 kilogauss for magnetic fields within the flaring region.

The Ca II H and K lines (λλ3968, 3933) appear strongly in emission in non-flare dMe spectra and are essential diagnostics for determining low chromosphere models (Giampapa et al., 1982). Enhanced Ca II emission during flares was studied by Gershberg and Shakhovskaya (1971) and Bopp and Moffett (1973). Gurzadyan (1980) notes that Ca II enhancement is generally less than Balmer line enhancement, a fact which is readily apparent in Figure 2. Bopp and Moffett also note a red asymmetry in the Ca II wings during some flares.

3.6. UV and EUV Line Emission

Lines in the UV and EUV region probe the transition region between the chromosphere and corona. Since only the closest dMe stars emit enough flux in the UV or EUV to be detected with the International Ultraviolet Explorer (IUE) Satellite, the best space UV and EUV spectrograph yet available, there are only very limited flare spectra available for this important region. Haisch et al. (1981) were the first to obtain IUE spectra during a time which coordinated ground- and space-based observations indicated a flare was occurring on Proxima Centauri. The IUE data were sufficient to set only an upper limit of a factor of two in the excitation of EUV emission lines, although there was marginal evidence for an enhancement of the Mg II H and K lines (λλ2803, 2793). The enhancement of the Mg II lines during flares should be very similar to the Ca II H and K lines since they share similar excitation, and the Mg II lines are formed at only slightly higher levels in the chromosphere (Gurzadyan, 1980). Two other UV and EUV flare detections have been made with the IUE. Butler et al. (1981) detected a flare on Gliese 867A, but had no coordinated observations to determine other flare parameters. A strong UV continuum was present during the flare along with enhanced lines of N V, O I, C I, CII, CIV, Si II, Si IV, and He II. The lower ionization lines (with the exception of N V) were enhanced by smaller amounts than the higher ionized lines. He II λ1640 was enhanced the least. Recently, Haisch et al. (1982; see also the paper by Haisch in this volume) observed a large flare on Proxima Centauri simultaneously with the IUE and the Einstein X-Ray satellite. One spectrum (1200 - 2000 Å) covering the flare X-ray maximum showed considerable enhancement of many lines (He II, C I-IV, N V, Al III, and Si II-IV), with lesser enhancement the lower the excitation temperature of the line. During the decay phase of the flare only weak C I, C IV, and N V lines were present. By comparison to a well-studied solar flare, the ratio of soft X-ray flux to transition region flux is about 10 times larger for the dMe star, indicating that the radiative energy loss from the transition region compared to the corona is more important than for the un.

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3.7. Asymmetries and Mass Motions

Line asymmetries, probably indicative of mass motions, have been seen for a number of stellar flares (see Gershberg and Shakovskaya, 1971; also note the red asymmetries in the Balmer and He I lines in Figure 2). Bopp and Moffett (1973) measured shifts which suggest downflow velocities of 1100 km/sec for the Balmer lines, and 600 km/sec for the Ca II K line. As mentioned previously, the redshifted emission may well arise from a small portion of the flare, in similarity to the solar data in Figure 1.

In solar flares, most of the emission is not shifted from the line rest position. Similarly, most stellar flare spectra do not show shifts in the central part of the emission lines. One exception is the spectrogram by Greenstein and Arp (1969) which suggests displacements of the emission lines by tens of km/sec. Careful examination of this spectrum also suggests that the plate shifted during the exposure, based on apparently doubled comparison lines. No reliable evidence exists for overall shifts of emission lines during stellar flares.

3.8. Timing and Flare Decay

The relative sequence of line, continuum, radio, and X-ray emission during the flare is extremely important in determining at what levels in the stellar atmosphere the flare occurs, and which physical mechanisms are operating. Although, like the solar data (Svestka, 1972), the stellar results are somewhat contradictory, certain features do stand out.

The most basic fact of line and continuum radiation during the flare is that, although the line emission rises with the continuum flash phase of the flare, the line emission decays considerably slower (Kunkel, 1970). Observations of a large flare on YZ Cmi (Schneeberger et al., 1982) show $H\alpha$ and $H\beta$ emission not fully decayed to a quiescent level 2.5 hours after the continuum flare. In that work and others (Mochnacki and Schommer, 1980; Mochnacki and Zirin, 1981), the $H\alpha$ emisson appears to rise simultaneously with the continuum flash flare. However, Gershberg and Chugainov (1966, 1967) show the $H\alpha$ response delayed by 3 to 5 minutes, and the $H\beta$ response delayed by 5 to 10 minutes. Schneeberger et al. (1982) also found that, while $H\alpha$ seemed to respond instantly to the flare flash, $H\beta$ emission could be delayed by up to 20 minutes. Bopp and Moffett (1973) reported a general trend of the higher series Balmer lines to decay more rapidly than the lower ones. This effect is consistent with the observation that the Balmer "increment" discussed in Section 3.1. reverts to a decrement after the continuum flash phase. The red asymmetries in the Balmer lines seem to occur only near flare maximum and decay rapidly, more or less in step with the continuum light (Bopp and Moffett, 1973). Mochnacki and Zirin (1980) show that the Balmer continuum enhancement occurs simultaneously with and decays more slowly than the overall continuum flare, but still faster than the Balmer line emission.

Gurzadyan (1980) suggests that flare emission lines follow a general rule in that the higher the ionization potential of the ground state, the later the emission appears, and the shorter it lasts. Helium lines appear later than the H lines and decay more rapidly (for example, see Bopp and Moffett, 1973; Gershberg and Chugainov, 1966, 1967). But Mochnacki and Zirin (1980) indicate that the He I λ5876 line developed in time similarly to the Balmer lines in a YZ CMi flare. He I and He II lines are also observed to appear later and decay faster during solar flares (Svestka, 1972). However, this effect is explained by the fact that the initial response of He I λλ5876, 6678, and 10830 to a flare is to go first into absorption, later go into emission, and then return to absortion in later flare stages before completely disappearing. The time response of other lines to flares has been, as for the Sun, little studied. The available data suggest that Ca II H and K lines appear later, and decay later than the Balmer lines, as well as showing a lower amplitude response to the flare (Gershberg and Shakovskaya, 1971). Mochnacki and Schommer suggest that the same behavior exists for the Mg I, Fe I, and Fe II emission lines.

Clearly, much more coordinated, multi-spectral, time-resolved coverage is needed before a coherent picture emerges of the time development of dMe flares. One area which needs attention is to define what differences, if any, are present for emission line development between slow and fast flares.

4. SUMMARY

Through a growing body of high spectral resolution and high time resolution stellar flare spectroscopy, one fact becomes apparent: the better the quality of the data, the more qualitatively similar are solar and stellar flare phenomena. The small differences seem to be associated with the much greater relative importance of the outer atmospheric (and flare) regions to the energy balance of the dMe star. Future opportunities and requirements for flare observations, both for the Sun and for the dMe stars, center on coordinated multi-spectral observations. It is hoped that a major product of this colloquium will be programs for continued and expanded observations of this type.

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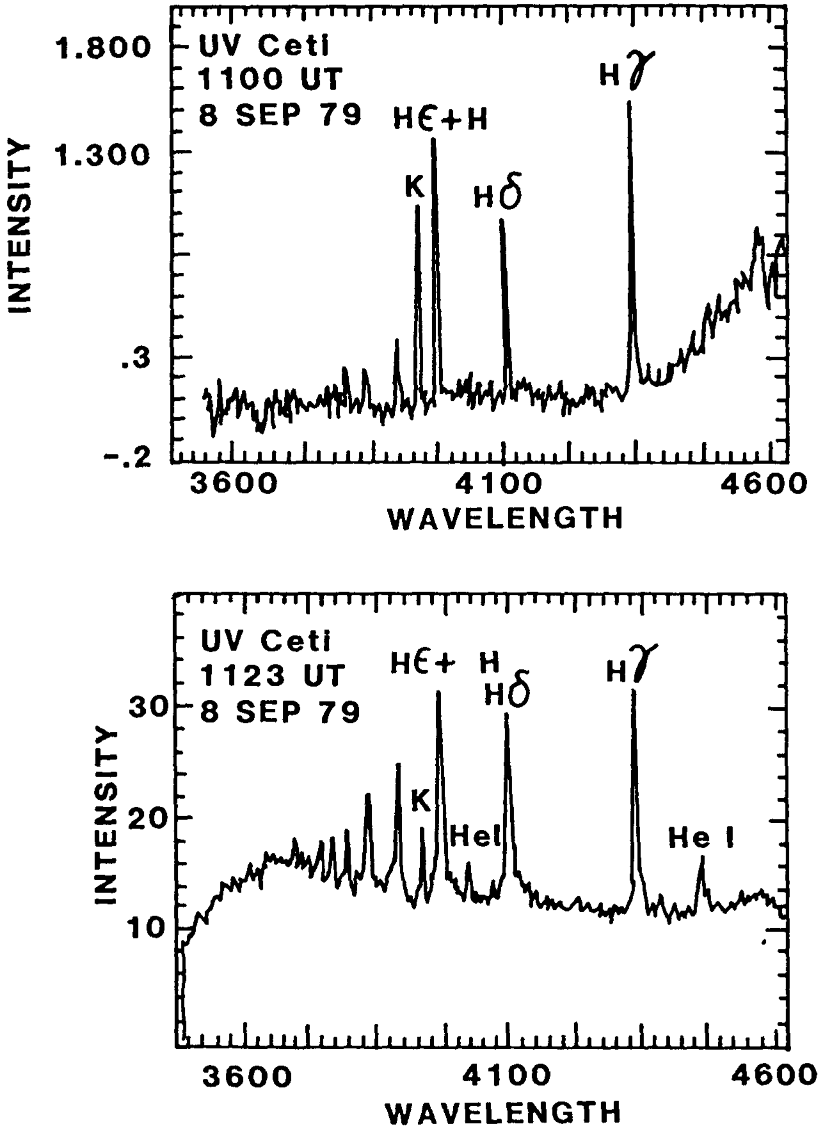

Figure 2. Blue spectra for the dMe star UV Cet from Giampapa et al (1983). The top spectrum shows UV Cet in a non-flare state. The botton spectrum was taken during flare maximum of a 5 magnitde (U-band) flare. Spectral resolution is 3.8Å, and time resolution 3 minutes. Note the broadened and redshifted hydrogen and helium lines.

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DISCUSSION

Goldberg: Among your suggestions for future programmes was one for observations in the 500-50A region. How many stars do you expect to penetrate the opacity below 912 A?

Worden: The data which I have seen suggests that we should be able to make observations out to 10-20 pc. This would include most of the flare stars.

Stencel: The science working groups on the Far Ultraviolet Explorer has addressed this question in some detail. In fact some of their results will be published in the proceedings of the recent ESA IUE meeting. The answer is that hundreds of flare stars will be observable below 700 A. I also have a question. In the Sun the broadening of Hα is occasionally very severe. Could you comment on the difficulty of mapping wavelength into velocity to determine physical motions especially in lines like Hα which are Stark broadened.

Worden: Stark broadening is the predominant broadening mechanism. It is difficult to disentangle Stark broadening from that due to mass motion. So one should be careful in interpreting wavelength shifts. There are no observations that are reliable, in my opinion, in stellar flares that show that the central peaks of the hydrogen lines shift nor are there in the Sun. We see extended wings. An important point to remember when you are looking at stellar flares is that you are looking at different areas in different parts of the lines. In the core you are seeing the whole flare apart from those regions which may be undergoing mass motions. In the wings one may be seeing a surge. So it may be very risky to interpret a shift simply as material motion. We have the same problem with a solar surge.

Vaiana: Going back to the question of how far one might see, it would be important to be able to reach at least some of the T-Tauri stars, say in the Pleiades or Hyades. This would be especially so if they could be reached in their quiescent states as well as of course in their flaring state. Then we would have a much better description of these very active young stars.