A&A manuscript no.
(will be inserted by hand later)

Your thesaurus codes are:
08(19.31.3; 19.36.1; 19.53.1; 19.08.1)

ASTRONOMY
AND
ASTROPHYSICS
14.3.1996

Research Note

An optical flare on YZ CMi

A. G. Gunn[1], J. G. Doyle[1], M. Mathioudakis[1,2], and S. Avgoloupis[3]

[1] Armagh Observatory, College Hill, Armagh BT61 9DG, N. Ireland
[2] Center for EUV Astrophysics, University of California, Berkeley, CA-94720, USA
[3] University of Thessaloniki, Department of Physics, Section of Astrophysics, GR-54006, Thessaloniki, Greece

July 1993

Abstract.

We present and discuss observations of an energetic optical flare on the dM4.5e star YZ CMi (Gl 285). The flux-time variations and energy release of the flare are fully consistent with previous observations of this star. The observations have also revealed a symmetric excess emission in the bases of the chromospheric Balmer lines. If due to a bulk plasma motion event, the maximum extension in the Balmer wings represents a Doppler velocity of ~ 250 kms^{-1}.

Key words: stars: flares – stars: UV ceti-type

1. Introduction

Late-type stars often display strong emission in the cores of spectral lines such as Ca II H & K and the Balmer series. It is now well established that chromospheric activity is a direct result of the magnetic dynamo. Time resolved spectroscopy has revealed some general features of the emission process during dMe flares (Rodonó et al. 1989; Moffet & Bopp 1976). The U-band flux can increase by up to 8 magnitudes within several minutes (Gurzadyan 1984) whereas the Balmer lines are somewhat slower to respond. The dynamic aspect of dMe flares has also been discussed recently in some detail. Red and blue asymmetries or wavelength shifts have been observed in the Balmer and Ca II lines (Bopp & Moffet 1973; Doyle et al. 1988; Houdebine et al. 1990), the Mg II resonance lines (Linsky et al. 1989; Neff et al. 1989) and the C IV lines (Bookbinder et al. 1992). We recently observed a strong blue asymmetry in both Balmer and Ca II lines during a flare on AT Mic (Gunn et al. 1993). Such observations are usually interpreted as mass flow events associated with the penetration of the chromosphere by a particle beam injected from the apex of a magnetic loop and the subsequent heating of the chromospheric plasma (van den Oord 1988; Emslie 1978; Brown 1971). A flare observed on YZ CMi by Doyle et al. (1988), however, displayed all the general features of dMe flaring but showed a symmetric excess Balmer emission which is difficult to account for in this context. Similarly, the derived velocities of the apparent upflowing flare plasmas are highly non-thermal and thus at variance with thermal models.

In May 1992 the SAAO 1.9m telescope equipped with the Unit Spectrograph and the Reticon Photon Counting System (RPCS) was used for a spectroscopic survey of chromospheric emission from late-type dwarfs. During this campaign several of the dMe stars were observed during flare activity and here we present and discuss the spectroscopic observations of a flare on YZ CMi (Gl 285).

YZ CMi has been classed as dM4.5e (Gliese 1969) and is a member of both the UV Ceti and BY Dra groups of variables. Amongst the limited number of multi-wavelength studies of dMe stars, YZ CMi has presented some interesting results. Kahler et al. (1982) discussed optical, radio and X-ray observations of two flare events on YZ CMi and found a basic similarity with the solar case; an impulsive and gradual phase in the U-band emission and evidence for the acceleration of energetic electrons. Doyle et al. (1988) observed a 1.2 magnitude flare on YZ CMi which was not correlated with their simultaneous X-ray data. During that event the Balmer lines displayed a symmetric excess emission in the wings, which implied Doppler velocities of ~ 300 km s^{-1}.

In this paper we present spectroscopic observations of a particular flare on YZ CMi, consider the flux variations and energy release during the flare and compare these with the range of dMe luminosities.

2. Observational data

The optical spectra cover the wavelength range 3750 Å to 4250 Å incorporating the higher Balmer lines and Ca II lines. The time exposure ranged from 120 to 360 seconds. After flat-fielding, each exposure was wavelength calibrated by reference to arc spectra and have a resolution of ~ 1 Å. An atmospheric extinction correction was also applied by reference to standard tables (Spencer Jones 1980) and a flux calibration achieved with regular observations of standard stars. The flux calibration is estimated to lie within about 20%. The data-reduction was achieved with the FIGARO software (Shortridge & Meyerdierks 1992) and analysis carried out using the STARLINK DIPSO package (Howarth & Murray 1987).

Send offprint requests to: A. G. Gunn

3. Results and discussion

The sequence of nine spectra begins at 17:02 UT on 18 May 1992 and cover approximately 39 minutes. The first integration displays the lowest (quiescent) flux level which increases within 10 minutes to the flare maximum at 17:12 UT. Since this flare is similar in many respects to the one observed on YZ CMi by Doyle et al. (1988) in March 1985, we will use the acronym D88 to refer to this event.

3.1. Line identification and fluxes

As expected for chromospheric flaring on dMe stars, the hydrogen Balmer lines are visible in emission, our observations being reliable down to Hθ (3771 Å). There is no evidence of He I emission at 4026.2 or 4120.8 Å, which was observed during the D88 flare event on this star. An unidentified feature/line is present in both flare and quiescent spectra at 3905 Å which is visible throughout the observations. This feature/line was visible in similar observations of AT Mic (Gunn et al. 1993) taken during the same program and we believe it may be an instrumental effect.

The most significant aspect of these data is the broad excess emission visible in the Balmer lines during the flare. This excess emission was also seen in the D88 event. In contrast to the flare observed on AT Mic (Gunn et al. 1993), the YZ CMi event shows no evidence of excess emission in the wings of the Ca II H & K lines and involves the Balmer lines only. Furthermore the Balmer excess is much more symmetric around the line centre. Fig. 1 shows a sequence of spectra throughout the flare for the Hδ line which clearly displays the evolution of the excess emission and the variation of continuum flux during the flare. The preflare spectra show no significant excess emission.

The line fluxes and widths were measured for each spectrum by fitting a series of gaussian components to the lines. In Table 1 are shown values of the integrated line fluxes for four members of the Balmer series and measurements of the continuum flux in the Hδ region. The continuum level increases by a factor of $\sim$2.5 from quiescent level to flare maximum. Also shown in Table 1 is the total flux at Earth (in erg) and the flare maximum luminosities (in erg s^{-1}) for each line. These measurements were made without subtracting the photospheric contribution (quiescent spectrum). A comparison of the total flare energy associated with each line with those given for the D88 flare shows an agreement to within $\sim$ 10% if the difference in integration times is taken into account. The flare peak luminosities of these lines show a similar agreement although the present flare appears to be marginally more energetic in line emission.

An important indicator of flare activity is the time-averaged flare luminosity observed in a particular band. Using our spectroscopic measurements we estimate the total radiative energy release during the flare in the observed wavelength range (3600-4200 Å) by first subtracting the quiescent spectrum from the flare spectra. By taking integration time into account and assuming a distance of 6.1 pc (Gliese 1969) the total energy release due to the flare in the 3600-4200 Å band is $E_{3600-4200} \sim 1.5\ 10^{30}$ erg. Photometric observations (D88 and Kahler et al. (1982)) revealed U-band energies of $1\ 10^{31}$ erg and $1.2\ 10^{31}$ erg (respectively) for other flares on YZ CMi. Since these flares are very similar we believe our energy estimate to lie within a factor of 2-3 of the true U-band energy release (the U-band spectral region covers a slightly larger range). The time-averaged flare luminosity is then $\sim 1\ 10^{27}$ erg s^{-1} which is less than the time averaged X-ray enhancement of $1.2\ 10^{28}$ erg s^{-1} (D88). A comparison of the ratio of quiescent state energy to the time averaged flare energy reveals a remarkable similarity in these two flares. These values are far less than the stellar bolometric luminosity of $\sim 4\ 10^{31}$ erg s^{-1} (Pettersen 1980; Doyle et al. 1985).

The quiescent energy observed from YZ CMi in the May 1992 observations was only 60-70% of that for D88. However, the time averaged flare energies are similar, which implies that the flux enhancement during the May 1992 flare was much greater than observed for D88. It is possible that the D88 spectra begin shortly after the flux enhancement has begun. These new data show a remarkable consistency in the flare emission from YZ CMi.

Fig. 1. A sequence of spectra showing the Hδ line from YZ CMi throughout the flare (a quiescent profile is also shown). Notice the large symmetric excess in the base of the line.

Table 1. Integrated line fluxes at Earth for the flare plus preflare (in units of 10^{-13} erg cm^{-2} s^{-1}) for four spectral lines plus a continuum region close to Hδ for YZ CMi. The total flux (in erg) and the flare maximum luminosities (in erg s^{-1}) are also given for each line (assuming a distance of 6.1 pc).

Time (UT)	Hδ	Hζ	Hη	Hθ	Hδ continuum (erg cm^{-2} s^{-1} Å^{-1})
Preflare	1.26	0.55	0.38	0.03	$8.54\ 10^{-15}$
17:12	4.45	3.01	2.69	1.28	$2.25\ 10^{-14}$
17:15	4.51	4.02	2.32	0.91	$1.34\ 10^{-14}$
17:17	2.82	1.78	1.54	0.55	$9.09\ 10^{-15}$
17:20	3.46	1.74	1.32	0.52	$8.96\ 10^{-15}$
17:23	2.53	1.57	1.77	0.11	$1.01\ 10^{-14}$
17:29	2.16	1.41	1.32	0.08	$9.23\ 10^{-15}$
17:35	2.02	1.07	1.24	0.03	$1.07\ 10^{-14}$
Total flare energy (erg):	$1.00\ 10^{30}$	$8.03\ 10^{29}$	$7.85\ 10^{29}$	$2.06\ 10^{29}$	
Flare peak luminosity (erg s^{-1})	$1.57\ 10^{26}$	$1.41\ 10^{26}$	$9.40\ 10^{25}$	$4.48\ 10^{25}$	

3.2. Excess Balmer emission

The excess emission observed during this flare consists of a broad and symmetric base to the Balmer lines. A similar observation was made by Doyle et al. (1988). We have attempted to address the problem of the excess emission by investigating the Hδ profile shape. Using the Marquardt algorithm for the least-squares estimation of non-linear parameters (Marquardt 1963) and a series of user supplied analytical functions, we determined that for the localized plasma the Hδ emission is best modelled by the summation of two gaussian components.

The excess emission, which appears to be a feature of chromospheric flares on YZ CMi, can be interpreted either as a turbulent or random mass motion effect. Rotational broadening is not sufficient to explain the profile shape during the integration times in question. Similarly, the width of the line precludes pressure broadening since the electron densities necessary far exceed those normally associated with chromospheric plasmas (10^{12} - 10^{14} (Rodonó 1986)). To check this assertion we used numerical Stark profiles (Vidal et al. 1973) to fit our data. Even the higher electron densities could not accomodate the line wings nor the central component and accounted for less than 1 % of the excess emission.

If the broad excess emission is due to a turbulent or random mass motion effect, the maximum extension in the Balmer wings implies a Doppler velocity of ~ 250 km s^{-1}, which is consistent with other observations of excess emission in dMe flares (Houdebine et al. 1993). This velocity is also in remarkable agreement with that found for the D88 flare. Assuming that the profile is formed by a random thermal motion and taking a particle mass equal to the mean ion mass for solar abundances ($2.16\ 10^{-27}$ kg), this corresponds to a kinetic temperature of $\sim 5\ 10^{6}$ K.

4. Conclusions

We have presented spectroscopic observations of a flare on the dM4.5e star YZ CMi. The data show features associated with dMe flares, namely, an impulsive and decay phase in the line intensities and a slow decay time in the Ca II lines. An estimate of the energy release in the wavelength range 3600-4200 Å due to the flare yields $1.4\ 10^{31}$ erg which compares well with U-band energies of previously observed flares on YZ CMi.

The observed Balmer lines during this event display a highly symmetric excess emission, which was also observed during similar observations by Doyle et al. (1988). We have modelled this emission in some detail and conclude that the profile is best described as the summation of two gaussian components. We have ruled out the possibility of pressure or rotational broadening. However, due to the optically thick nature of the lines, it has not been possible to derive meaningful physical parameters associated with the profile. If, however, the broadening is assumed to be a turbulent or mass motion effect, then the maximum extension in the wings implies a velocity of ~ 250 km s^{-1}.

The symmetric nature of the emission is difficult to account for with the present particle injection models of chromospheric heating. One possibility which has already been advanced in the case of YZ CMi (Doyle et al. 1988) is that a succession of plasma flows has been observed during the integration time of the flare spectra and the net effect produces a uniform velocity field.

Acknowledgements.
Research at Armagh Observatory is grant aided by the Dept. of Education for N. Ireland. We also acknowledge the computer support by the STARLINK project funded by the UK SERC. JGD wishes to thank the British Council for a travel grant to visit colleagues in Greece. AGG would like to thank Armagh Observatory for a research scholarship.

References

Bookbinder J. A., Walter F. M., Brown A., 1992, in Giampapa M. S., Bookbinder J. A., eds, Cool Stars, Stellar Systems, and the Sun. ASP Conference Series Vol. 26, p. 27
Bopp B. W., Moffet T. W., 1973, ApJ, 185, 239
Brown J. C., 1971, Solar Phys., 18, 489
Doyle J. G., Byrne P. B., Butler C. J., 1985, A & A, 156, 283
Doyle J. G., Butler C. J., Byrne P. B., van den Oord G. H. J., 1988, A & A, 193, 229
Emslie A. G., 1978, ApJ, 224, 241
Gliese W., 1969, Catalogue of Nearby Stars. Veroff. Astron. Rechen-Inst., Heidelberg, Nr. 22
Gunn A. G., Doyle J. G., Mathioudakis M., Houdebine E. R., Avgoloupis S. 1993. A & A (submitted)
Gurzadyan G. A., 1984, Astr. Spa. Sci., 106, 1
Houdebine E. R., Foing B. H., Rodonò M., 1990, A & A, 238, 249
Houdebine E. R., Foing B. H., Doyle J. G., Rodonò M., 1993, A & A, 274, 245
Howarth I. D., Murray M. J. Dipso- Starlink User Note 50. Rutherford Appleton Laboratory, 1987
Kahler S. et al., 1982, ApJ, 252, 239
Linsky J. L., Neff J. E., Brown A., Gross B. D., Simon T., Andrews A. D., Rodonó M., Feldman P. A., 1989, A & A, 211, 173
Marquardt D. W., 1963, J. Soc. Ind. Appl. Math., 11, 431
Moffet T. J., Bopp B. W., 1976, ApJ, 231, 61
Neff J. E., Linsky J. L., Walter F. M., Rodonò M., 1989, A & A, 215, 79
Pettersen B. R., 1980, A & A, 82, 53
Rodonò M. et al., 1989, IAU Colloquim, 104, 53
Rodonò M., 1986, in Johnson H. R., Querci F. R., eds, The M-type stars. NASA SP-492, p. 409
Shortridge K., Meyerdierks H., Figaro- Starlink System Note 40.8., Rutherford appleton Laboratory, 1992.
Spencer Jones J. H., 1980, MNASSA, 39, 89
van den Oord G. H. J., 1988, A & A, 207, 101
Vidal C. R., Cooper J., Smith E. W., 1973, ApS, 25, 37

Email addresses

A. G. Gunn	Internet	agg@star.arm.ac.uk
J. G. Doyle	Internet	jgd@star.arm.ac.uk
M. Mathioudakis	Internet	mihalis@cea.berkeley.edu

This article was processed by the author using Springer-Verlag LaTeX A&A style file 1990.