Optical photometry and spectroscopy of the flare star Gliese 229(= HD42581)

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Summary. We present optical flare photometry and a search for spotted variations on the star Gl229. These results rule out the presence of a large-scale asymmetric spot distribution and indicate a low level of flare activity. This is in agreement with other indicators of stellar activity including coronal X-ray emission and radiative losses from the lower chromosphere as gauged from the strength of Ca\(\text{II}\) and K and the Balmer lines.

1 Introduction

Gliese 229(=HD 42581 = BD –21° 1377) is given by Gliese (1969) as of eighth magnitude, spectral type dM1Ve and at a distance of 5.75±0.30 pc. Joy & Abt (1974) classify it as dM2.5 on the basis of the relative strengths of its blue spectral region TiO bands while Boeshaar (1976) assigns it to dM1. The ‘e’ suffix in Gliese’s catalogue indicates emission in at least Ca\(\text{II}\) and K, while its absence in the classifications of Boeshaar and Joy & Abt records the absence of Balmer emission. Woolley et al. (1970) give galactic orbital eccentricity \(e=0.07\) and inclination 0.005 which would suggest that it belongs to the solar comoving group.

Kunkel (1973) discovered the flare star nature of Gl229, recording two small flares in 6.68 hr of observation. These flares were of exceptionally tiny amplitude, the peak \(U\)-band light being only \(\sim 0.01\) mag brighter than the quiescent star. Thus, while Gl 229 was shown to flare in the manner of the UV Ceti flare stars, it appeared that the time-integrated energy emitted in flare light was very much lower than for ‘normally active’ flare stars. Thus it may resemble other low-activity flare stars such as Gl 825 (Byrne 1981).

The X-ray luminosity of Gl 229 quoted by Tsikoudi (1982) is \(L_X=28.8\). This would indicate that at the coronal level Gl 229 emits almost as powerfully as such highly active stars as Gl 867AB (\(L_X=29.0\)) and Gl 719 (=BY Dra, \(L_X=29.5\)). A conflicting value for \(L_X=26.8\) has been published by Agrawal, Rao & Sreekantan (1983). There is a general consensus that the coronae of late-type dwarfs are heated by interaction between the gas of the star’s outer
atmosphere and large-scale closed magnetic loops similar to those seen on the Sun. Flares are a manifestation of the energy released when such loops restructure themselves. Thus the lower value of \( L_X \) would be more consistent with the observed low mean energy-loss rate in flaring.

A further inconsistency with the view of Gl229 as a low-activity star is the conclusion by Bopp & Espenak (1977) that it may be a BY Dra-type spotted variable with an amplitude of \( \Delta V \sim 0.02 \) mag. All of the known M-star spotted variables are also active flare stars. Furthermore, Vogt, Soderblom & Penrod (1983) measured a rotational velocity of \( v \sin i = 3 \text{ km s}^{-1} \), although they remark that this value is on the border-line of detectability by their methods and so is highly uncertain. It is probably better to treat it as an upper limit. Nevertheless, available data suggest that there is a lower limit of \( \sim 5 \text{ km s}^{-1} \) for the onset of the BY Draconis syndrome (Bopp & Fekel 1977; Vogt et al. 1983). Thus unless the rotational axis of Gl229 is close to the line of sight \( (i < 35^\circ) \) we would not expect it to generate large spot groups.

In view of the various uncertainties surrounding the nature of Gl229 and its associated chromospheric activity we decided to redetermine some of its fundamental observed activity parameters. These include a redetermination of its flaring energetics, a search for BY Draconis variability and a measurement of its chromospheric radiative loss rates in Ca H and K and several of the hydrogen Balmer lines.

2 Observations

Our observations of Gl229 were made during three fortnight intervals, viz. 1984 February 14–27, March 20–April 2 and April 17–30. Photoelectric photometry was carried out at the 75- and 50-cm telescopes of the South African Astronomical Observatory at Sutherland, using a locally developed version of the ‘People’s Photometer’ and a data acquisition system under the control of a Data General NOVA minicomputer. Monitoring for flares was carried out using an EMI 6256 photomultiplier tube and a glass filter which together approximate to the Johnson U-band. 5-s integrations were used throughout. Dates and times of monitoring will be found in Table 1. The total effective monitoring time was 20.3 hr. In this time one small flare was recorded; its light curve is given in Fig. 1.

Table 1. Flare monitoring times.

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<td>1 - 2</td>
<td>19:05 - 20:17</td>
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Figure 1. Light curve of the flare plotted in terms of raw U-band count rate versus time.

Table 2. UBV(RI)$_c$ photometry of Gliese 229. Gliese 229's magnitude and colours are nightly means and they were differenced with those of HD 43396 whose mean magnitude and colours were found to be $V=5.904 (B-V)=+1.322 (U-B)=+1.365 (V-R)_c=+0.693 (V-I)_c=+1.313$.

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Means 8.158 +1.478 +1.222 +1.002 +2.038
±0.007 ±0.006 ±0.009 ±0.019 ±0.016
Table 3. Details of the spectra of Gl 229.

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<th>DATE (Mid-exposure)</th>
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<th>EXP (Secs)</th>
<th>WAVELENGTH</th>
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<td>(10⁻¹ ergs cm⁻² s⁻¹)</td>
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* ergs cm⁻² s⁻¹ Å⁻¹ at line peak sampled over a 0.6Å pixel.

Gl 229 and two nearby comparison stars, HD 42042 and HD 43396, were also measured on a large number of nights through filters approximating to the Johnson UBV and Cape (RI)ₐ systems. Red measurements were made using a separate channel on the photometer equipped with an EMI 9659 photomultiplier tube. Transformations to the UBV(RI)ₐ system were achieved by reference to Cousins’ E-Region standard stars (Menzies, Banfield & Laing 1980). Measures for individual nights are given in Table 2 as nightly means.

Two spectra of Gl 229, one in the region of Ca H+K and one around Hα, were obtained on the 1.88-m telescope at Sutherland using the image tube spectrograph with the Reticon Photon Counting System. Details of the spectra are given in Table 3. A reciprocal dispersion of 45 Å mm⁻¹ was used. The spectra were corrected for instrumental response by dividing by spectra of the white dwarfs LTT 3864 (Stone & Baldwin 1983) in the blue and Wolf 485A (Oke 1974) in the red.

They were then placed on an absolute flux scale referring to Willstrop’s (1964) flux calibration for the star HD 17987 (= Gl 887), an M2 dwarf. The precise spectral type of Gl 229 is somewhat uncertain (see Introduction above). So in seeking a star of similar spectral type among Willstrop’s absolute flux standards we have compared their (V-R)’s measured by Cousins (1980b). The most satisfactory agreement was with HD 17987. Thus the flux distribution of Gl 229 was assumed to be identical with it, while the flux scale was scaled according to their relative V magnitudes. The resultant spectra are shown in Fig. 2.

3 Results

3.1 Flares

The U-band energy of the flare shown in Fig. 1 was derived by first calculating the equivalent duration, \( P_U \), according to the equation

\[
P_U = \Sigma (I_t - I_0) / I_0 \Delta t
\]

where \( I_0 \) is the intensity of the quiescent star, \( I_t \) is the summed intensity of the flare plus star and \( \Delta t \) is the integration time (Gershberg 1972). The sum was carried out over the duration of the flare. The Gl 229 flare has a value \( P_U = 4.68 \text{ s} \). \( P_U \) can be converted to energy by multiplying by the quiescent luminosity of the star in the U-band, \( q_U \). We derived this by interpolating the data in Moffett’s (1974) tables 2 and 16 to give log \( q_U = 30.82 \) where \( q_U \) is in erg s⁻¹. The resultant U-band flare energy is log \( E_U = 31.49 \).

For the intercomparison of different stars’ flare energetics a useful quantity is the time-averaged flare energy release, \( L'_U \), which is given by the sum of the energies released in all observed flares in the U-band divided by the total monitoring time. Its value for Gl 229 is log \( L'_U = 26.62 \) where \( L'_U \) is in ergs⁻¹.
Figure 2. The spectrum of Gl229 in (a) the blue and (b) red spectral regions. The vertical scale is in erg cm$^{-2}$ s$^{-1}$ Å$^{-1}$ at the Earth.
3.2 BY Dra variability

The results given in Table 2 suggest that there is no variability in Gl229 with $\sigma_V \sim 0.007$. The differences $\Delta V$ (Gl229−HD 43396) and $\Delta V$ (HD 43396−HD 42042) show no difference in scatter after one widely discrepant point for HD 42042 has been removed. The difference in scatter between the star-star differences and the magnitudes on the standard system can be satisfactorily accounted for in terms of zero-point drift. We therefore feel confident in stating that at the time of our observations Gl229 did not vary in $V$ by more than 0.01 mag.

3.3 Spectra

The spectra shown in Fig. 2 are consistent with a spectral classification in the range early M. The Ca $H$ and $K$ lines are strongly centrally reversed. The width of these lines is the instrumental width, i.e. FWHM=1.28 Å ($\pm 48$ km s$^{-1}$). This gives no useful information on stellar rotation since an upper limit of $v \sin i=3$ km s$^{-1}$ has already been established by Vogt et al. (1983). The radial velocity of the emission features is +17 km s$^{-1}$ which is in reasonable agreement with the value of +6.4±7.2 km s$^{-1}$ given by Pettersen (1976).

The flux in Ca $H$ and $K$ was estimated by summing together the central four pixels which seem to constitute the line in each case. Following Linsky et al. (1979) and Giampapa et al. (1981) we reckon the flux from the zero flux level. The resulting fluxes are given in Table 3. It is difficult to gauge realistic errors on these values but they are probably correct to about 10–20 per cent taking into account both the uncertainties in the calibration procedure and in Willstrop’s original calibration.

We have examined the spectra carefully in the region of the lines of H$\alpha$, H$\gamma$, H$\delta$ and H$\epsilon$ for evidence of emission and found none. Absorption features were found at each wavelength except H$\epsilon$ which is probably masked by the adjacent Ca $H$ line. Our resolution is insufficient to rule out small emission reversals in the cores of the lines. We can however conclude that there is no emission above the local continuum level. Table 3 gives an upper limit on the peak flux density in the H$\epsilon$ line.

4 Discussion

4.1 Absence of spot variations

Our failure to observe spot variations is consistent with the proposal of Bopp & Fekel (1977) and Vogt et al. (1983) that large-scale spottedness does not set in late-type stars until a rotational velocity of $>5$ km s$^{-1}$ is achieved. Vogt et al. have placed an upper limit to $v \sin i=3$ km s$^{-1}$. The radius of Gl229 from its spectral type is $R \sim 0.6 R_\odot$. An equatorial rotational velocity of $\leq (3/\sin i)$ km s$^{-1}$ would correspond to a period of $P \geq 10.1 \sin i$ day. It is interesting that an examination of the X-ray behaviour of a sample of late-type stars suggests a fundamental change in the X-ray heating at a point corresponding to $P \sim 10$ day (Walter 1982; Byrne et al. 1984). Since the heating of the X-ray corona depends on closed loop structures, as does the generation of spots, these observations suggest a real change in behaviour of surface magnetic fields at a rate of rotation corresponding to $v_{eq} \sim 3–5$ km s$^{-1}$ in the late-type dwarfs.

In Section 1 we discussed the ambiguity in the quiescent X-ray flux from Gl229. There are several possible reasons for the discrepancy. The observation quoted by Tsikoudi (1982) was recorded with the HEAO-A satellite. This instrument has a very wide field of view and so confusion of sources is a distinct possibility. Agrawal et al. (1983) however used the IPC detector on the Einstein satellite which, being an imaging detector, has very good spatial resolution. For this reason we favour their value of X-ray flux. We might further add that, even if the higher X-ray
flux is a valid measure of Gl229, there is still the possibility that it was observed during a flare when soft X-ray flux can be enhanced for periods up to an hour. In Fig. 3 we plot values of X-ray flux against rotational period for a number of M dwarfs (taken from Byrne et al. 1984). We have indicated the position of Gl229 on this diagram by a horizontal line. It will be seen that its position is consistent with it being beyond the break in the log $L_X$ versus log $P$ diagram.

4.2 SURFACE FLUXES OF CHROMOSPHERIC EMISSION LINES

Gliese (1969) gives Gl229's distance as $d=5.75 \pm 0.30$ pc. In order to derive fluxes at the stellar surface we also need the stellar radius. Pettersen (1980) derived stellar radii for a large sample of M-dwarfs. His method employs published far-infrared and $UBVRI$ photometry to first determine the stars' bolometric luminosity $L_{bol}$, and effective temperature, $T_e$. The surface area $4\pi R_e^2$ is then equated to $L_{bol}/\sigma T_e^4$, hence yielding a radius in each case. We have combined Pettersen's radii with the Johnson $V$ and $R$ photometry of Veeder (1974) to derive a relationship by least squares between log $(R/R_o)$ and $(V-R)$ of the form

$$\log (R/R_o) = -0.518(V-R) + 0.448.$$  

The data and this linear fit are plotted in Fig. 4a. The correlation coefficient for the fit is $r=-0.93$. The $(V-R)$ photometry for Gl229 given in Table 2 is on the Kron–Cousins system and so had to be transformed to the Johnson system before application of the above equation. This was done by

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using the transformations given in Cousins (1980a). The resultant value for Johnson \((V-R)\) was

\[ +1.339 \]

giving a radius of \(R/R_\odot = 0.59 \pm 0.08\).

Using these values for distance and stellar radius we derive fluxes for the \(H\) and \(K\) lines as given in Table 3. Giampapa et al. (1981) have determined Ca \(H+K\) fluxes for a sample of seven dM and dMe stars. As a measure of the relative amounts of chromospheric non-radiative heating they compare the ratio \(R_{HK} = F_{HK}/\sigma T_e^4\) between the sample stars, where \(F_{HK}\) is the surface flux in the \(H\) and \(K\) lines and \(\sigma T_e^4\) is the bolometric luminosity defined in terms of the effective temperature \(T_e\). We again also derived \(T_e\) for Gl229 from Pettersen’s work. Fig. 4b plots his values of \(T_e\) against Veeder’s \((V-R)\). A least-squares fit gives a linear relation of the form

\[ \log T_e = -0.091 (V-R) + 3.681 \]

with a correlation coefficient \(r = -0.93\). Using \((V-R)\) from above we derive \(T_e(Gl\ 229) = 3620\) K and the corresponding value for \(R_{HK}\) will be found in the final column of Table 3.

Fig. 5 is adapted from Giampapa et al. and includes, in addition to their stars, Gl229 from this work, Gl461 from Doyle & Byrne (1985) Gl820A from Linsky et al. (1979) and the rest from Linsky et al. (1982). We note that while Gl229’s chromospheric radiative loss rate is not as low as the quiescent stars, Gl 380, Gl 393, Gl 411 and Gl 526, it is a factor of two to three times lower than the active flare stars Gl517, Gl285, Gl803 and the chromospherically active K dwarf Gl 144. \(R_{HK}\) for Gl229 is about five times its value for the mean quiet Sun (=7.7\times10^{-6}, Linsky et al. 1979).

Fig. 5 may be somewhat misleading however as it implies a relatively small difference in chromospheric radiative losses between the active dMe and less active dM stars. The ‘e’ suffix records the presence of the Balmer lines in emission. Linsky et al. (1982) have shown that the radiative losses in the Balmer series can be a factor of 5-17 times greater than in either Ca \(H\) and \(K\) or Mg \(h\) and \(k\). So the hydrogen emission lines dominate the radiative cooling of the lower chromospheres of the more active stars. We have shown that these lines are in absorption in
Gl 229 and so contribute negligibly to the overall energy balance. Thus were we to include the energy in the Balmer emission lines in Fig. 5 the most active stars (Gl 65AB, 285, 517, 616.2 and 803) would stand higher in the diagram by at least an order of magnitude.

The presence of a strong Hα absorption line is entirely consistent with the presence of a chromosphere on Gl 229 as indicated by the Ca H and K emission. Cram & Mullan (1979) calculated the response of the Balmer lines to the presence of a chromosphere of varying electron density and temperature gradient overlying a normal late-type stellar photosphere. Their published calculations were based on a photospheric model of effective temperature $T_{\text{eff}}=3500\, \text{K}$ which is not too different from the value of 3620 K derived for Gl 229 above. Their models indicate that in the absence of any chromosphere extremely weak Balmer absorption is generated, reflecting the low photospheric temperature which cannot excite significant numbers of hydrogen atoms to the $n=2$ level necessary for absorbing Hα photons. As a chromosphere of increasing density and temperature gradient is added, the Balmer lines are first driven more deeply into absorption as collisional excitation to the $n=2$ level becomes increasingly significant. If the density and temperature gradient are further increased the core of the line becomes entirely collisionally controlled within the chromosphere and it is eventually driven into emission.

From our spectrum of Gl 229 we have estimated the equivalent width of Hα by fitting a Gaussian profile to the line. Our main source of error in this procedure is likely to be the fixing of
the continuum in such a heavily blanketed region of the spectrum. We have adopted a linear interpolation between the highest points within ±50 Å of the line as a working compromise. Cram & Mullan say that in their models the Hα absorption did not develop significant wings. So at our spectral resolution a Gaussian seems an adequate approximation to the line profile. The resulting equivalent width is ~−1.1 Å. Cram & Mullan's models predict an equivalent width of only −0.08 Å for a 'naked' photosphere with $T_{\text{eff}}=3500$ K. The maximum absorption equivalent width reached in their models with chromospheres is ~−0.7 Å. This may change however with increasing $T_{\text{eff}}$ (the equivalent width of Hα in the Sun is ~−4 Å) and also with other model parameters such as the position of the temperature minimum. So, without a more detailed modelling of Gl229's atmosphere, we conclude that the observed strong Hα absorption supports the presence of a chromosphere of intermediate density and temperature gradient.

4.3 OPTICAL FLARE ENERGETICS

The time-averaged flare energy release, $L_{U}$, given in Section 3.1 is, of necessity, approximate since we are dealing with a single event. Nevertheless, we may compare it with the mean relationship between $L_{U}$ and $q_{U}$, the quiescent U-band luminosity, derived in Byrne et al. (1984) for the most active dMe stars. Gl229 falls 2½ orders of magnitude below its predicted position on this line as shown in Fig. 6. In this respect it is very similar to the other low-activity flare star Gl825 (Byrne 1981).

Doyle & Butler (1985) have suggested that a strong correlation should exist between time-averaged flare energy release and the quiescent X-ray flux. Their suggested relationship used with the X-ray flux of Agrawal et al. (1983) predicts a value of $L_{U}$ 3–4 times larger than that recorded here. It is difficult to decide whether this discrepancy is due to a real difference between the coronal/chromospheric heating rates in dM and dMe stars, or simply to poor statistics in the determination of the time-averaged flare energy release in Gl229. The derived estimate of flare activity is consistent however with the absence of variations due to spots and the low level of chromospheric radiative losses.

![Figure 6. Log $L_{U}$ plotted against log $q_{U}$ (adapted from Byrne et al. 1984).](image-url)
5 Conclusions

In the case of the solar surface Ca H and K emission is quite a widespread phenomenon, being associated with the ‘network’ at the boundaries of convection cells. In these areas it appears to be linked to weak concentrations of magnetic flux. Over sunspots and active regions in general Ca H and K emission is greatly enhanced but not to such a great extent as the Balmer emission lines for instance and other higher temperature species. This is presumably a result of the more organized nature of the magnetic flux in such regions which permits a coherent magnetic structure to extend far beyond the surface of the star into the coronal regions. It is widely held that the energy deposition which goes to heat the outer, hotter regions is carried on via these large-scale magnetic loops. Thus X-ray emission from the solar corona for instance arises almost exclusively near spots and active regions.

Flares occur on the Sun associated with the more diffuse ‘plage’ regions (spotless flares). Very large flares, however, including ‘white-light’ flares are found exclusively in the region of large spots, i.e. with large-scale organized magnetic flux.

It is therefore tempting to draw on these facts and suggest some general properties of stellar activity which relate to the solar case. Observations suggest that, in the case of the M and later K dwarfs, the BY Draconis syndrome (i.e. the presence of a large concentration of magnetic flux in the shape of a large spot or spot group) occurs only for those stars rotating with periods \( \lesssim 10 \) day. Similarly observations, such as those presented here, suggest that at about this same rotation period the presence of strong Balmer emission in addition to strong Ca emission also disappears. Furthermore, again at about the same rotation period, the time-averaged energy of optical flaring drops sharply, as does the mean optical flare energy.

Although the observational data is as yet sparse we suggest that these facts are linked through a fundamental change in the organization of surface magnetic field at about this 10-day rotation period in the late-type dwarfs. Stars with shorter rotation periods manage to concentrate magnetic flux into large spots. Associated with these are large white-light flares and greatly enhanced Balmer emission and localized, enhanced X-ray emission. Stars with longer periods than this have a much smaller degree of flux concentration and a much more uniform distribution of that flux over the surface. These stars will be plage-like, i.e. Ca emission stars and exhibit relatively weak flares analogous to the spotless flares on the Sun. X-ray flux from such stars should decrease sharply as there are no quasi-stable large magnetic loops reaching into the coronal layers to provide the necessary heating.

This scenario, if true, suggests the following optical observational tests. First, if the large ‘white-light’ flares are associated with spots or spot groups a phase-effect should be seen amongst the largest flares in BY Dra stars. One must be careful here to examine only the most energetic flares, i.e. those in which the optical continuum dominates and which are characterized by longer time-scales for both rise and decay (see for instance Byrne 1983). The total flare population will also include those analogous to the solar ‘spotless’ flares and whose radiation may be dominated by line emission from the upper chromosphere.

Secondly, a modulation of the hotter atmospheric emissions with rotation is to be expected. The hotter the temperature of formation of the species the greater the anticipated effect. Thus we would probably expect maximum contrast between the spot and general surface in X-rays. Nevertheless, the Balmer lines would be more suitable than H and K for detecting this effect among the fastest rotators. Such a modulation has been recorded for the RS CVn stars (Byrne et al. 1983).

Observations are under way in an effort to measure these effects.

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References


