SESSION I

GENERAL CHARACTERISTICS OF ACTIVE DWARFS

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GLOBAL AND PHOTOSPHERIC PHYSICAL PARAMETERS OF ACTIVE DWARF STARS

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Abstract
Physical parameters (temperature, luminosity, radius, mass and chemical abundance) of the photospheres of red dwarf flare stars and spotted stars are determined for quiescent conditions. The interrelations between these quantities are compared to the results of theoretical investigations for low mass stars. The evolutionary state of flare stars is discussed. Observational results from spectroscopic and photometric methods to determine the rotation of active dwarfs are reviewed. The possibilities of global oscillations in dwarf stars are considered and preliminary results of a photometric search for oscillation in red dwarf luminosities are presented.

1. INTRODUCTION

Flares and spots have been observed in a variety of stars. Extremes are young T Tauri stars and old subdwarfs; luminous giants and faint main sequence dwarfs; very rapid rotators (100 km/s) of the FK Com type and slow rotators (1 km/s) on the main sequence; single stars and multiples of different kinds. In this paper I will concentrate on the lower main sequence, where stars of the UV Cet and BY Dra types are located.

2. PHYSICAL PARAMETERS OF FLARE STARS

Broad band photometry and a variety of spectroscopic information on flare stars and spotted stars have been obtained to study the photospheres of these stars in their quiescence.

2.1. Effective temperature

Photometric data can be transformed into energy distributions of stars over the observed wavelength interval, and put on a flux scale calibrated in absolute units. By comparing this distribution with that of a theoretical model taking into account the effect of blanketing, one obtains an approximation to the effective temperature of the star. The

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theoretical distribution in this comparison may be the flux distribution of a model atmosphere (Mould 1976 a). Unfortunately, no set of models exists for the entire range of temperatures covered by the red dwarf stars. In default of this, black body curves have been used (Veeder 1974, Pettersen 1980). A complicating element with Planck curves is that blanketing effects cannot be dealt with directly. Veeder (1974) used the method of Greenstein et al. (1970) which compensates for blanketing in a subjective manner, while Pettersen (1980) handled the problem by fitting the Planck function to data longwards of 1 µm and simultaneously required that the integral under both distributions be equal. Figure 1 shows the empirical colour-temperature relations obtained by different authors. Also included is the one used by Johnson (1965) which was established from giants with measured diameters. The differences in certain areas of the diagram approach about 250 K. To preserve consistency in the following discussion of flare stars I shall use the results of Planck function comparisons with Pettersen's (1980) method.

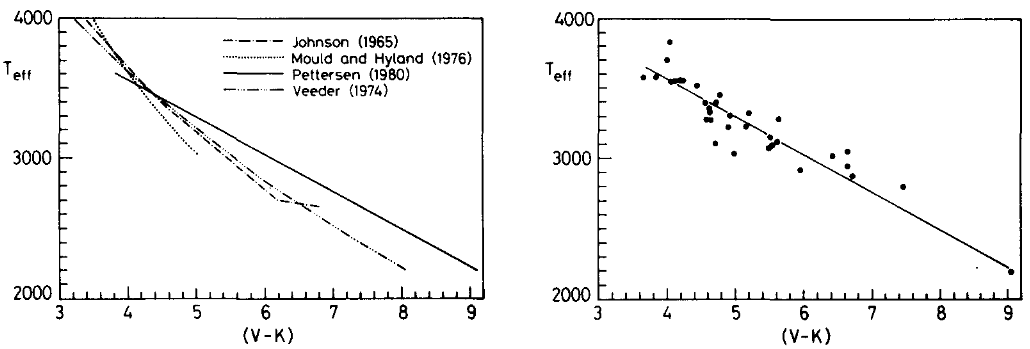

Fig. 1. Left: Empirical colour-temperature relations from different authors. Right: The linear colour-temperature relation of Pettersen (1980) based on analysis of 34 stars.

We find the empirical relations between effective temperature and various colour indices to be linear, as demonstrated in Fig. 1. Results obtained from least square analyses are given in Table 1.

Table 1: Effective temperature and colour indices.

Colour index	Number of data	Correlation coefficient	Linear fit	Typical scatter
B-V	35	-0.88	$T_{eff}=-1510(B-V)+5738$	±156 K
V-R	29	-0.90	$T_{eff}=-\ 645(V-R)+4469$	±112 K
R-I	29	-0.95	$T_{eff}=-\ 648(R-I)+4311$	± 79 K
V-K	35	-0.93	$T_{eff}=-\ 264(V-K)+4624$	±120 K

Several molecules manifest themselves in the photospheric spectra of red dwarfs, with feature strengths in accordance with the temperature of the

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star. Spectroscopic and photometric observations have revealed temperature sensitivity in TiO, VO, CaH (Jones et al. 1981, Mould 1976 b, Wing 1978), CO, H_2O (Persson et al. 1977), FeH (Cohen 1978), and CaOH (Boeshaar 1976). The response of some of these molecules to a change in temperature is very nearly linear (e.g. H_2O, CaH, FeH, and TiO). CO and CaOH show strong non-linear effects (Fig. 3). The temperature dependences are valid for all population types among dM stars and flare stars, so the effects of metallicity on the temperature relations must be small.

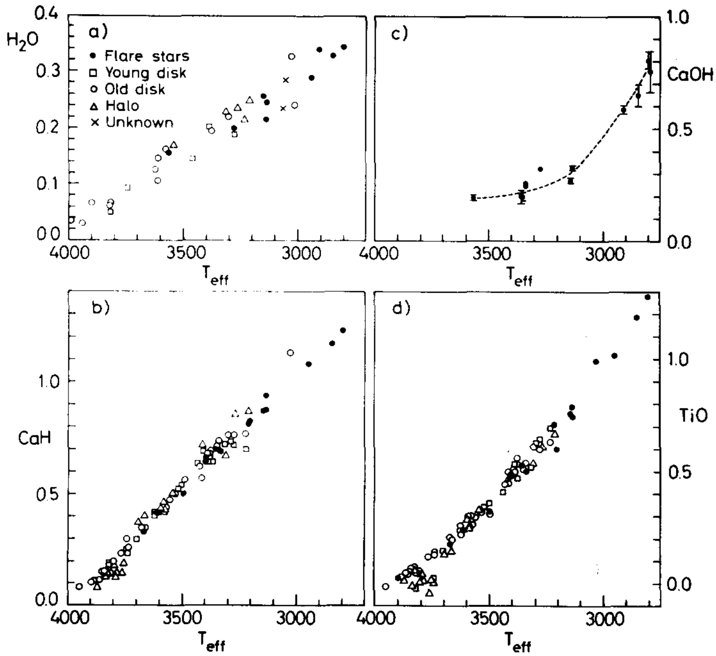

Fig. 2. Empirical relationships between effective temperature and the strengths of molecular features in red dwarf stars. The photometric data used as ordinates are from a)Persson et al. (1977), b) and d) Jones et al. (1981) and Mould (1976), c) Pettersen (unpublished).

2.2. Bolometric luminosity and bolometric correction

More than 90% of the flux emitted by red dwarfs is contained within the spectral region from 0.36 μm to 3.6 μm. By integrating the flux distribution over all wavelengths assuming the fitted Planck function to continue on either side of the observed optical and infrared regions, we obtain the bolometric flux emitted by the star. By normalizing to the sun this can be put on the bolometric magnitude scale.

The bolometric correction, defined as $BC=M_{bol}-M_V$, can now be obtained.

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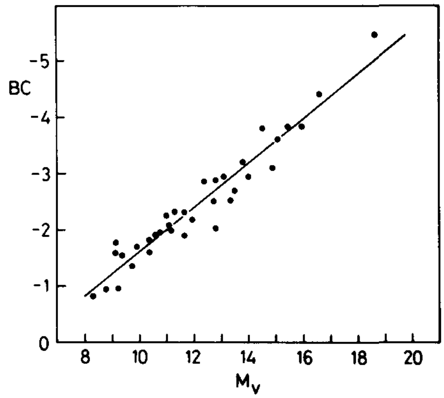

Fig. 3. Bolometric correction versus absolute visual magnitude.

Figure 3 demonstrates that BC is a linear function of M_V. A least square analysis yields

$$BC = -0.397\ M_V + 2.386$$

valid for $8<M_V<19$. The standard deviation for a typical value in BC, given a value of M_V, is $\sigma=\pm0.27$.

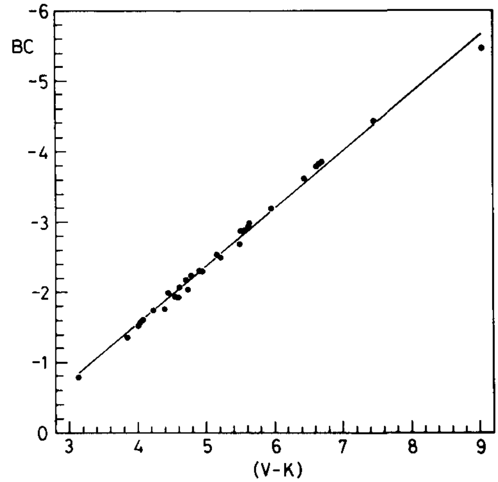

Fig. 4. Bolometric correction versus the (V-K) colour index.

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The relations between BC and colour indices also show no deviation from linearity (Figure 4). Table 2 gives the results of the least square analyses. A comparison with the (BC, colour)-relations of Johnson (1965) reveals good correspondance for BC≯-2. For BC<-2 Johnson's (1965) values of BC for a given value of a colour index are consistently smaller than our values.

Table 2: Bolometric correction and colour indices.

Colour index	Number of data	Correlation coefficient	Linear fit	Typical scatter
B-V	33	-0.933	BC=-4.816(B-V)+5.430	±0.36
V-R	26	-0.988	BC=-2.267(V-R)+1.689	±0.13
R-I	26	-0.988	BC=-2.124(R-I)+0.874	±0.13
V-K	30	-0.997	BC=-0.816(V-K)+1.709	±0.07

2.3. Radius

As the effective temperature T_{eff} and the bolometric luminosity L is now determined, the radius R of a spherical star can be found from

$$L = 4\pi R^2 \sigma T_{eff}^4$$

where σ is the Stefan-Boltzmann constant. In Fig. 5 we show the empirical radius-luminosity relation for flare stars. Also drawn are theoretical relationships by Ezer and Cameron (1967), Copeland, Jensen and Jørgensen (1970), Hoxie (1970), and Grossman, Hays and Graboske (1974). The relation of the last work fits the observations.

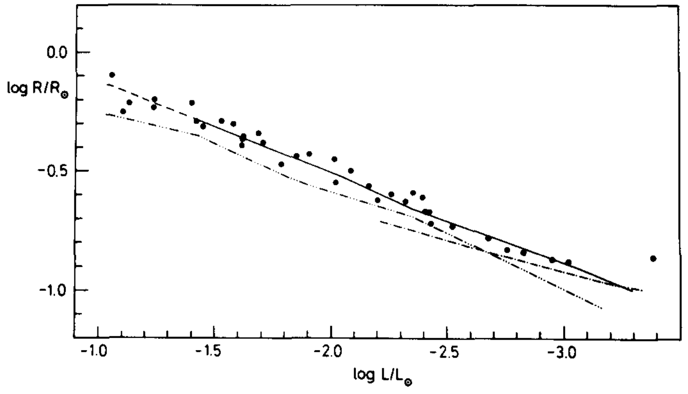

Fig. 5. The radius-luminosity relations of Ezer and Cameron (1967)-•••-, Hoxie (1970)-•-•-, and Grossman, Hays and Graboske (1974)——, compared to empirical results for flare stars. The relation of Copeland, Jensen and Jørgensen (1970) is almost indistinguishable from that of Ezer and Cameron.

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2.4. Masses and the mass-luminosity relation

For flare stars and a few non-flaring red dwarfs we have compiled astrometrically determined masses. All masses are accurate to 0.05 $M_\odot$ or better, according to the literature sources. The bolometric luminosities of the individual components were determined from multicolour photometry or by using the relationship between bolometric and visual magnitude. Twenty-one stars are plotted and identified in the mass-luminosity diagram in Fig. 6. The scatter of the observed data points is so large that the theoretical mass-luminosity relations of the workers listed in the previous paragraph will all fit the observations. We have drawn the theoretical mass-luminosity relations from Grossman, Hays and Graboske (1974) for models at ages 10^8 and 10^9 years, for the mass interval from 0.085 $M_\odot$ to 0.5 $M_\odot$.

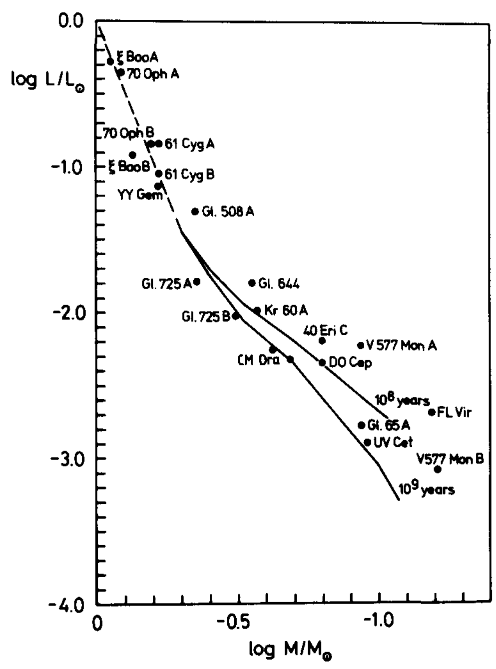

Fig. 6. The mass-luminosity relations of Grossman, Hays and Graboske (1974) for ages 10^8 and 10^9 years compared to data for red dwarfs.

2.5. Abundances: spectroscopic results

A curve of growth analysis was done by Hartmann and Anderson (1977) from high dispersion spectra in the red at a resolution of about 0.1 Å. They observed the bright flare stars BY Dra and EQ Vir, and for comparison the non-flaring slow rotators 61 Cyg A and B. Using the solar curve of growth for iron and various model atmospheres, their analysis yielded

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abundances for seven metals. There are no abundance differences between the dMe flare stars and the dM stars in this study, and the abundances found are solar.

Abundance analysis was also done by Mould (1978 b) on five early M dwarfs from Fourier transform spectra between 15000 Å and 25000 Å, with moderate resolution. Two of the stars are absorption line stars (Gliese 15 A and 229), and a third one is 61 Cyg B. A study of the atomic lines leads Mould (1978 b) to conclude that 61 Cyg B and Gliese 229 have solar composition, whereas Gliese 15 A and 411, which he classifies as subdwarfs, are underabundant in metals with respect to the sun.

Rotational lines of the CO and OH molecules are clearly visible in the spectra of M dwarfs. For temperatures below 3500 K one can also identify rotational lines of H_2O. Mould (1978 b) measured several lines of CO and OH, and also calculated synthetic spectra for these molecules. He predicted a rather clear-cut abundance sensitivity for OH, and a low one for CO. Yet the measured values of OH in the stars he observed are very similar, and he suggests that oxygen is not underabundant to the extent of the other metals, even in the old disk subdwarfs Gliese 15 A and 411.

The dispersion in the Hertzsprung-Russell diagram for early M type disk population stars is basically a metallicity dispersion. Mould (1978 b) found that metal-rich stars are overluminous with respect to the metal-poor ones.

The light element Li is of particular interest, as its presence in the spectrum of a nearby star is usually taken as an indication of extreme youth. M dwarf flare stars generally do not show the 6707 Å Li-line, with the only exception of the rapid rotator V1005 Ori=Gliese 182 (Bopp 1974, de la Reza et al. 1981). An abundance near the interstellar value of $n(\mathrm{Li})/n(\mathrm{H})=10^{-9}$ was determined by de la Reza et al. (1981). For several other dwarfs an upper limit was set two orders of magnitude lower.

Li has been reported in several rotating dwarfs with spectral types earlier than M0 (see Table 3), both among spotted stars and plage stars. The masses of these stars are between 0.8 $M_{\odot}$ and 1.2 $M_{\odot}$. For such stars convective overshoot may produce the required dependence on mass and age, by extending the mixing region deep enough to allow Li burning (Straus et al. 1976).

2.6. Chromospheric effects on photometric metallicity determinations

The metal-to-hydrogen ratio can be measured by intermediate band photometry. The Strømgren uvbyβ system uses a line blanketing index dominated by iron lines as a measure of metallicity. The interpretation of such a parameter may not be unique for active stars, however, as the presence of stellar chromospheric activity may affect the photometric index through filling-in of the cores of strong non-magnetic lines as a result of heating in the lower chromosphere. Giampapa et al. (1979) therefore compared measurements of the quiet solar photosphere and an active solar region in the uvbyβ-system. The effect of the active region was to decrease the apparent metal abundance relative to the quiet sun by about 35%. In red dwarfs an apparent low metallicity measurement may thus be the result of active regions present on the star.

2.7. Molecular features and metallicity

Superposed on the relationships between temperature and strengths of molecular features is the sensitivity towards other quantities, at least for some of the molecules observed in red dwarfs. MgH is a luminosity discriminator for K stars as CaH is for M stars. Mould (1976) found TiO to be an indicator of metal abundance for the hotter (T_{eff}>3600 K) M dwarfs. Halo population dwarfs and old disk subdwarfs can be distinguished from old disk main sequence stars by their weaker TiO for a given temperature (Mould 1978 a).

No photometric investigations of molecular features has yet been published where flare stars are distinguished as a group relative to non-flaring M dwarfs. The observations of Jones et al.(1981) and Mould (1976) permit such a comparison. We have transformed the data to a common system (i.e. that of Mould) for 84 dwarfs, 14 of which are flare stars. In the (CaH, TiO)-diagram (Figure 7) a certain scatter is observed in the slightly non-linear correlation. This dispersion is what one would expect from the main sequence dwarf models of Mould (1976), when the metal abundance is varied between the solar value and one tenth of this. Unfortunately,

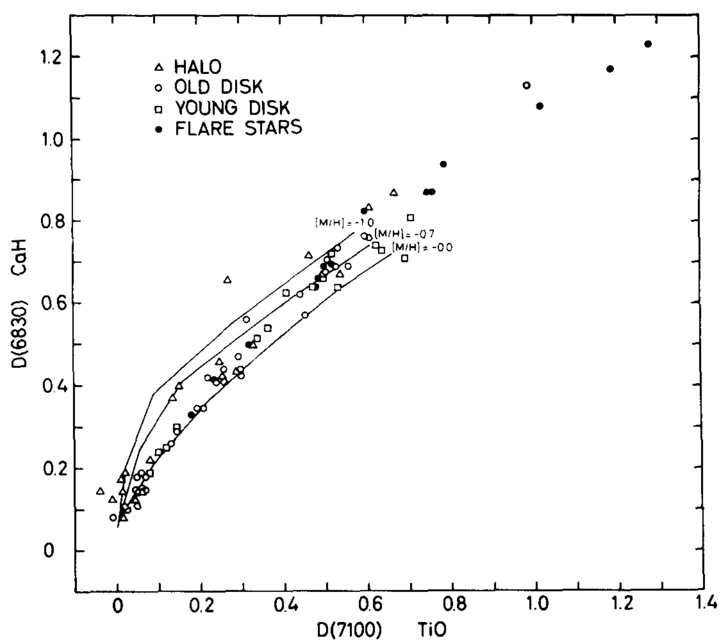

Fig. 7. Photometrically determined quantities for molecular band heads reveal an abundance sensitivity. The lines are theoretical relations from Mould (1976).

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no theoretical comparison can be made for T_{eff}<3000 K. The halo population stars tend to lie above the disk stars, and the flare stars have no particular characteristic in this diagram. From an abundance viewpoint, they appear to be normal dwarfs.

3. STRUCTURE AND EVOLUTION OF RED DWARFS

The Hertzsprung-Russell diagram in Fig. 8 contains those red dwarf flare stars and spotted stars that are single or are single components in binary systems. Also drawn are the theoretical hydrogen main sequences by Ezer and Cameron (1967), Copeland, Jensen and Jørgensen (1970), Hoxie (1970). None of these series of low mass star models fits the observed sequence of stars. The theoretical main sequence that does fit the observations is that of Grossman, Hays and Graboske (1974) with chemical composition X=0.68 and Z=0.03, and with the convective mixing length parameter ℓ/H_p=1. We have also included the evolutionary tracks for masses between 0.085 $M_\odot$ and 0.5 $M_\odot$.

The stars approach the main sequence during their contraction phase almost vertically in the HR-diagram, as fully convective bodies. Models heavier than 0.3 $M_\odot$ develop a radiative core before they reach the main sequence, at ages between 10^7 and 10^8 years. Masses smaller than 0.3 $M_\odot$ remain fully convective also on the hydrogen main sequence. The scatter of the sequence of observed stars is so large that both the 10^8 and 10^9 years isochrones are contained within the sequence.

Very recently the question was brought up whether the very low mass stars are actually fully convective. Using Kruger 60 as an observational case for which mass, temperature and luminosity is available, Cox, Shaviv and Hodson (1981) calculated models for the latest molecular opacities available using ℓ/H_p as the only free parameter. Their method was to integrate from the surface inwards, and the results are values of ℓ/H_p in the surface layer in the range 0.07-0.17, rather than the more conventional values 1-2. Such small values lead to higher temperatures and for some solutions a radiative core develops. The appearance of the radiative core is a very sharp threshold, and depends strongly on the value of ℓ/H_p. A recalculation of two of the models from Grossman et al. indicates that these models may need revision, using new molecular opacities.

Objects with masses smaller than 0.085 $M_\odot$ never ignite the hydrogen in their cores. Evolutionary tracks for such low masses have been calculated as far as the deuterium burning main sequence. Such objects contract almost vertically in the HR-diagram. Stevenson (1978) developed formulae for the contraction phase and the subsequent degenerate cooling phase. The contraction phase lasts 10^6-10^8 years for black dwarfs with masses 0.01 $M_\odot$ and 0.08 $M_\odot$. The lifetime for black dwarfs in the deuterium burning phase is a few times 10^7 years (Grossman et al. 1974). At the end of their contraction phase the core becomes degenerate. The black dwarf then cools and gets fainter. The thermal energy is much less than the total internal energy in this phase, and the radius remains almost

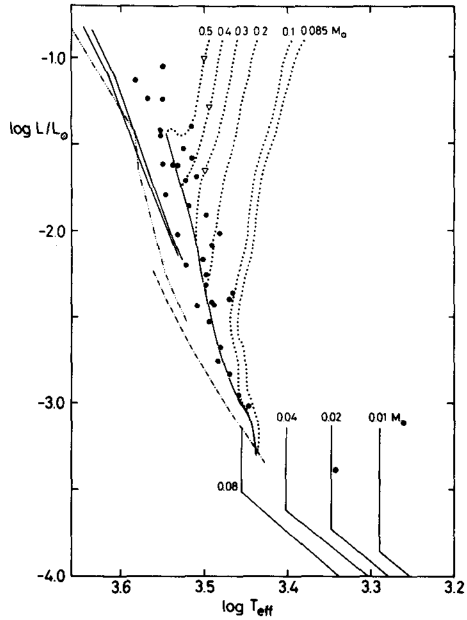

Fig. 8. The Hertzsprung-Russell diagram for nearby flare stars. Theoretical main sequences from Ezer and Cameron (1967)-••-••-, Hoxie (1970)-•-•-, and Copeland, Jensen and Jørgensen(1970) — are too warm for a given luminosity. The theoretical main sequence of Grossman, Hays and Graboske (1974) for $0.085 \leq M/M_\odot \leq 0.5$ fits the observations well. The ∇ marks on the pre-main sequence evolutionary tracks indicate where a radiative core develops. Schematic tracks for very low mass black dwarfs are also indicated.

constant. The energy is now conserved in making the electron gas degenerate. In Fig. 8 we have indicated schematically the "evolutionary tracks" for $0.01 \leq M/M_\odot \leq 0.08$. The position of Gliese 752 B=VB 10 near the track for a mass of 0.02 $M_\odot$ is remarkable among the flare stars. The star is still contracting towards the degenerate state. Its age is approaching 10^8 years, and it is well below the deuterium burning phase, where it stayed for about $4 \cdot 10^7$ years.

A particularly interesting point about low mass stars, say $M/M_\odot < 0.3$, is whether they all are frequent flarers. It has been the impression of observers for some time that all stars fainter than a certain absolute magnitude are emission line stars and therefore are likely to flare. The most frequent flarers, like UV Cet and G51-15, are among these low luminosity stars.

Basically, the question of whether all low mass stars are flare stars, has to do with the perseverance of the observers. There are, however, several examples of negative searches for flares in low mass stars.

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Gliese 905 showed no flares in the U-filter in 3.2 hours of monitoring, and 29.4 hours of B-filter monitoring by Andersen (private communication) and Shakhovskaya (1974) was also negative. Kunkel (1973) detected no flares on Gliese 752 B in 5.5 hours, and the only report of activity on this star is still the spectroscopic observation by Herbig (1956). Non-emission line stars are also being discovered among the faintest red dwarfs. Liebert et al. (1979) found several stars with no Hα emission in a sample of large proper motion stars with $M_V>15$.

4. ROTATION

Observational studies of the rotation of active dwarfs and flare stars have been made by both spectroscopic and photometric methods. The rotational broadening of spectral lines is the basis for the spectroscopic analyses, and the uneven flux distribution across the stellar disk producing a rotational modulation is the interpretative basis for photometric studies.

4.1. Rotational broadening of absorption lines

The first attempt to analyze absorption line profiles in flare stars for the purpose of determining their rotation was made by Anderson, Schiffer and Bopp (1977). They observed the bright flare stars EQ Vir (single) and BY Dra (binary), but the spectra were noisy and the expected rotational broadening was only slightly larger than the instrumental width, so their results are quite uncertain. For EQ Vir they determined (v sin i) near 10 km/s, with an uncertainty of at least 2.5 km/s. For BY Dra they put an upper limit to (v sin i) of 10 km/s.

The same method was applied by Vogt and Fekel (1979). They compared an absorption line profile of BY Dra to that of 61 Cyg A. The analysis assumed equal macroturbulence in the two stars and the interpretation is that any excess broadening in BY Dra is due to rotation. Using a rotational velocity of 2 km/s for the comparison star, they found (v sin i)=8.5±2 km/s

4.2. Rotation from a cross-correlation technique

A method has been developed by Benz and Mayor (1981) which utilize a cross-correlation analysis between the spectrum of the star and a reference mask in the spectrograph. This observing technique has long been known as a very efficient way of obtaining accurate radial velocities (Griffin 1967). The position of the correlation dip yields the radial velocity of the star, and the width of the dip reflects the width of the absorption lines in the spectrum. A correlation exists between the width and (v sin i). Lucke and Mayor (1980) applied this method to BY Dra. They obtained for the two components of this binary (v sin i)=8.1±0.3 km/s (primary) and (v sin i)=7.4±1.1 km/s (secondary).

4.3. Rotational flux modulation by photospheric spots

A photospheric spot group on a rotating star will modulate the flux received through a broad band filter during photometry in conformity with its rotation period. Analysis of photometric data yields the equatorial rotational period , independent of the inclination of the rotation axis of the star. Twenty-two stars have had their rotational period measured this way, and with radii estimated as described earlier, these quantities can be transformed into equatorial rotational velocities. Spotted stars in Table 3 cover the spectral types from G8V to dM4.5e. More than one half are members of binary systems, and most of them are known to flare.

4.4. Rotational modulation by chromospheric plage areas

Narrow band photometry (bandwidth=1 Å) of the Ca II H and K lines relative to nearby continuum windows, has revealed rotational modulation of the Ca flux in several FGK main sequence stars. The situation is analogous to spotted stars with plage areas causing the modulation. Nineteen stars have had their rotational period determined (Vaughan et al. 1981), as given in Table 3. None of the plage stars are known to show classical flare activity.

4.5. Rotational velocities of active dwarfs

Among the subset of spotted stars and that of plage stars, none have been measured with both techniques. A comparison between the results of the two methods is therefore not possible at this time. As judged from only two stars, the results of spectroscopic methods and spot photometry are in reasonable agreement.

Examination of Table 3 reveals that for a given spectral type

- members of binary systems tend to be faster rotators than apparently single stars
- spotted stars tend to be faster rotators than plage stars

5. GLOBAL OSCILLATIONS IN RED DWARF STARS

The central density of low mass stars is low, $\rho_c/\bar{\rho}<6$ for $M/M_\odot<0.3$. The amplitude of radial adiabatic oscillations increases little from the center of the star to the surface. The destabilizing effects of nuclear reactions can therefore result in vibrational instability.

Because of differences in the constitutive physics of the various star models, results of pulsation calculations are difficult to evaluate. Low mass stars show strong non-ideal gas interactions and these were only recently taken into account (Opoien and Grossman 1974). Large uncertainties are also introduced by the treatment of convection. In stability analyses a linear theory of the time dependence of convection has been used with mixing length type models.

5.1 Results for radial oscillations

The most modern calculations of radial pulsations in red dwarfs are those of Gabriel and Grossman (1977), who studied equilibrium models on the

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unstable for $M/M_\odot \geq 0.1$. The 0.085 $M_\odot$ model is stable, but opacities and the equation of state are not well known for this small mass. Also, the stability analysis is inconclusive for stars with radiative cores, i.e. for $M/M_\odot \geq 0.3$. For some values of the relative perturbation of the pressure scale height stability will occur, while for others there is instability. The period of the fundamental mode is between 14 and 44 minutes for the mass range $0.1 \leq M/M_\odot \leq 0.5$, and the e-folding times are between $3 \cdot 10^7$ years and $2 \cdot 10^8$ years. This is shorter than the corresponding lifetimes of the stars. It could take more than 10 times the e-folding time for the pulsation to manifest itself and the models are therefore marginal candidates for the growth of observable oscillations. The models are also unstable on the deuterium main sequence, and the oscillation period decreases as the star contracts towards the hydrogen main sequence.

5.2. Theoretical results for non-radial oscillations

Stability analysis has shown that slightly evolved models for 1 $M_\odot$ star are unstable against some low-order gravity modes. Since stars on the lower main sequence, except the fully convective ones, have essentially the same structure as the solar models, one may expect that they are also unstable, at least during part of the main sequence phase. Noels et al. (1976) made stability calculations for models of 0.5 $M_\odot$ and 0.6 $M_\odot$. Both are found to be unstable for a certain fraction of the main sequence phase. The instability is driven by nuclear reactions, as in the sun. The periods of the adiabatic oscillations are between 36 and 47 minutes for the 0.5 $M_\odot$ star, and between 58 and 67 minutes for the 0.6 $M_\odot$ star.

Ando (1976) made an extensive investigation of non-radial p-mode oscillation with high order spherical harmonics ($\ell > 10$). Of interest to us are his coolest main sequence models of 0.8 $M_\odot$ and 1.0 $M_\odot$. He neglected the influence of the core as p-modes with $\ell > 10$ are trapped in the envelope of the star. The excitation of p-modes is mainly due to the κ-mechanism of the hydrogen ionization zone. Unstable modes are found for $10 \leq \ell \leq 10^3$, but the uncertainties are considerable because the coupling between convection and pulsation was ignored in the stability analysis. Observationally, high ℓ-modes do not give rise to light variability or radial velocity variations, but they show up as a non-thermal velocity field in the stellar atmosphere.

5.3. Observations

We have analyzed time series observations of flare stars by a Fourier technique to search for luminosity oscillations. To obtain optimal signal-to-noise ratios and in order to avoid large effects due to flares, we concentrate on photometric data in the R-filter, taken with a time resolution of 9 seconds. The low mass flare binaries UV Cet and FL Vir were observed with the McDonald Observatory 2.1 m telescope. The longest series lasted in excess of 4 hours and the rms deviation in the measurements are generally less than 0.005 mag. We have detected no convincing peaks in the power spectra produced from the time series observations, not even at the frequencies expected from the theoretical results. If red dwarf stars oscillate, their amplitudes are below our present detection limit.

6. SUMMARY

Based on photometric information the low mass flare stars and spotted stars are shown to be main sequence stars with solar composition. In this respect they are not different from non-flaring disk population M dwarfs. They rotate faster than non-flaring dwarfs, however. Single flare stars have equatorial rotation velocities of 4-20 km/s, those in binaries 7-39 km/s. No red dwarfs have been detected to oscillate yet, although there are theoretical expectations for this.

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DISCUSSION

Haisch: In terms of dynamo theory it seems critically important whether these stars have an interface between the radiative core and the convective zone. Could you comment on the models which suggest that above a certain mass stars should have this interface while below it they are fully convective? Furthermore, what does this mass mean in terms of spectral type?

Pettersen: (Part of reply lost) There is a star observed (van Biesebrock 10) which has a mass of 0.16 solar masses. According to the models of Grossman et al (1974) it is fully convective. New models with revised molecular opacities indicate that there are solutions in which even a star as small as that will develop a radiative core. I have talked within the framework of Grossman et al 1974 models and it may be that better ones are available. Actually, stars with masses about 0.2 - 0.3 $M_{\odot}$ may not be fully convective. In terms of spectral type this occurs at about M4 to M5.

Vaiana: When one observes spotted stars for instance, apart from the long time-scale variations are fluctuations on a shorter time-scale observed?

Pettersen: The technique generally used in observing spotted stars is to measure the star once per night. This makes it difficult to detect variation on a time-scale shorter than one day. I do not know of any published report of such observations.

van Leeuwen: I have been observing stars like this in the Pleiades with periods as short as 5 to 10 hours. The light curves are stable over a period of one year, with amplitudes of about two-tenths of a magnitude.

Baliunas: I would just like to say that in my talk tomorrow I will show some work we have been doing spectroscopically and spectrophotometrically on short time-scale variations in some spotted - and dM-type stars.

Weiss: I was a bit surprised that you discussed G-mode oscillations and rejected P-mode oscillations. In the Sun the G-mode oscillations have only been identified with a period of 2 hrs 40 mins and there is no adequate theoretical interpretation of those. Whereas the P-mode oscillations have been observed in abundance with a 5 mins' period, have been studied in great detail and are regarded as being driven by the convective zone. Therefore I would expect these as being most likely in the late-type stars.

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Pettersen: My problem was that the only available observations are photometric and so variations in luminosity are those which are sought.

Linsky: I was interested by your comment that the plage stars do not show flares. The plage stars are believed to be those which have few plages and so exhibit rotational modulation in brightness. Others do not show rotational modulation because they have many plages uniformly distributed on the surface. For instance 61 CygA and B, although they are very old stars, show nice rotational modulation and they are obviously not flare stars.

Soderblom: Earlier you showed a relationship between radius and luminosity. If that relationship is extrapolated to one solar radius it does not correspond with one solar luminosity. Does the relationship turn over before this point or might there be some other problem?

Pettersen: The relationship shown is based on the modelling of Grossman, Hays and Graboske and their model calculations were only done for stars of mass up to 0.5 $M_{\odot}$. These cannot necessarily be extrapolated to reach 1 $M_{\odot}$.

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