CHROMOSPHERES, ACTIVITY AND MAGNETIC FIELDS

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Abstract. This brief review presents the current state of observations of stellar activity effects including the fluxes of chromospheric emission lines: CaII H+K, MgII h+k, SiII 1812 Å multiplet, CIV, as well as radio and X-ray fluxes versus B-V colours and luminosity classes, rotation periods, Rossby number and especially versus the mean magnetic flux density $\langle fB \rangle$. Results of stellar magnetic field measurements are presented.

1. Stellar Activity: What Is It?

Stellar activity means a set of phenomena that occur when the basic assumptions of a classical stellar atmosphere are not valid. The last ones are namely as follows:

1. Significant part of energy is transported from a star to space only by radiation and convection. The inevitable conversion of mechanical energy in a stellar core to heat is presumed not to alter significantly the thermal structure of the stellar atmosphere.
2. A good approximation is the atmosphere to be in hydrostatic equilibrium. That means there are no noticeable systematic flows such as winds, shocks, high-speed circulations, etc.
3. Magnetic fields are quite weak. They do not control the flow of matter and energy balance in the stellar atmosphere.

These classical assumptions lead to the situation when the mass, age, and initial chemical composition of a star determine its effective temperature, radius and gravity and hence its position on the HR diagram. The Sun is a very useful prototype of an active star. That is true, its activity is sufficiently weak as compared to other stars of late spectral types. On such stars rapid flares in X-ray, UV and microwave spectral ranges can be $10^3 - 10^5$ times more energetic than solar flares. What are the stellar pa-

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rameters that control the activity? It is well known that the surface fluxes of chromospheric emission lines (such as CaII H+K, MgII h+k, the SiII 1812 Å multiplet and CIV emission line) as well as X-ray and radio fluxes as a function of rotation period, B-V colour and luminosity class are indicators of stellar activity. These surface fluxes of active stars can be as much as 200 times larger than the basal stellar flux.

2. Stellar Parameters that Control Activity

Let us start with rotation rate (or rotation period). Stellar rotation decreases with age on the main sequence. It means that age and rotation rate are statistically interchangeable parameters and one requires additional information. Basri (1987) has proved from his investigation of RS CVn systems that rotation rather than age must be the controlling parameter. Fig. 1 shows X-ray luminosity versus stellar equatorial rotation velocity for stars of various types (see Bouvier 1990). The same correlation occurs also for the relationship between radio luminosity and rotation rate (Seaquist 1995). The next important empirical relation for stellar activity is connected with Ca II H+K and MgII h+k chromospheric line fluxes. Bouvier (1990) showed the strong correlation between both chromospheric line fluxes (Fig.2) and weaker but rather good correlation between H and CaII K fluxes. Recent ROSAT and HST observations show a good correlation between X-ray and CIV line fluxes (Ayres et al. 1993). There is correlation between the HST/FOS CIV fluxes and ROSAT/PSPC detections of cluster stars and field F-G dwarfs carried out during the ROSAT/IUE All-Sky Survey. The power law connecting the F9-G2 stars has a slope of 2.0.

3. Physical Parameters that Control Activity

The close connection between stellar rotation and chromospheric emission can be presented in terms of general stellar dynamo models. In the dynamo theory a dimensionless parameter, namely the dynamo number, characterizes the model behavior. The dynamo number NR is essentially proportional to the inverse square of the Rossby number R_0, which is the ratio of the stellar rotation period P to the convective turnover time τ_c: $NR \propto R_0^{-2}; R_0 = P/\tau_c$.

In practice, however, our knowledge of stellar convection is too limited to calculate correct convective turnover times. The reason is that the characteristic length scales, as well as the velocities, are not very well known. Recently Kim & Demarque (1996) have estimated the convective turnover timescales for Sun-like stars in the pre-main sequence and early post-main sequence phases of evolution. These estimates have been based on up-to-date physical input for the stellar models as well as on use of the micro-

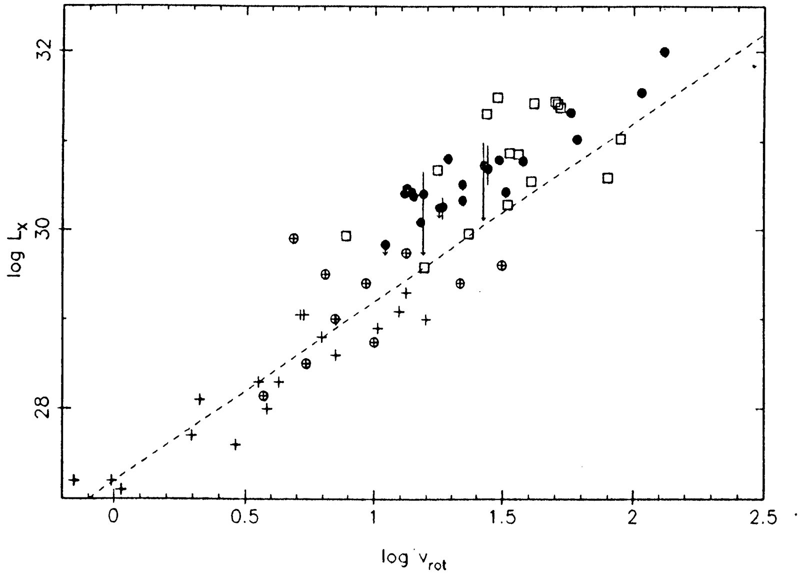

Fig.1. X-ray luminosity vs. stellar equatorial velocity for TTS (•), late-type dwarfs (+), dK$_e$ - dM$_e$ stars (⊕) and RS Cvn systems (□) from Bouvier, 1990.

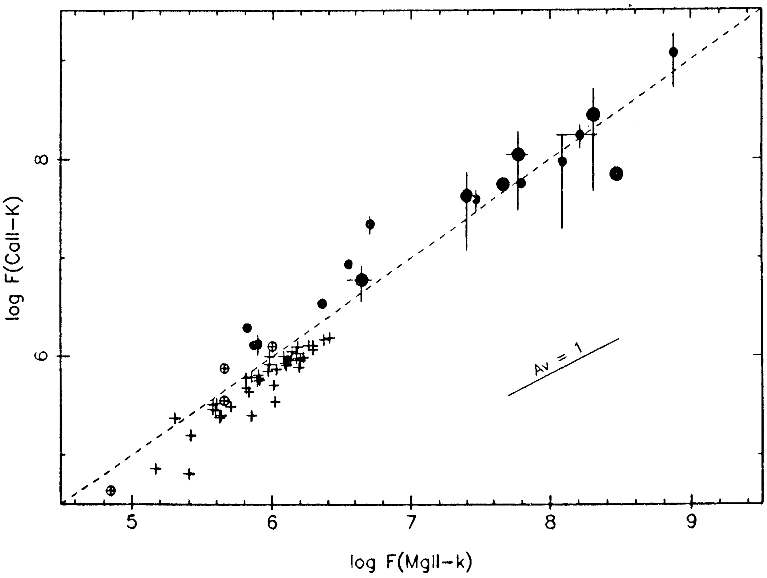

Fig.2. CaII K line flux vs. MgII k line flux from Bouvier, 1990.

scopic diffusion coefficients of Michaud and Proffitt (1993). Kim & Demarque (1993) have calculated the non-local convective turnover time τ_c as a function of age and mass. Near the main sequence τ_c remains nearly constant with time for a given mass. There is a simple relation between R_0 and age:

$$R_0 = 0.94 t_9^{1/2} \tag{1}$$

where t_9 is stellar age in Gyrs.

Vilhu & Walter (1987) showed a correlation of the fractional X-ray flux versus the Rossby number and the fractional Mg II 2800 emission line strength versus the inverse Rossby number. The angular-momentum-loss mechanism is determined by the Rossby number and produces so called magnetic braking process in cool dwarfs (Vilhu & Moss 1986). The general form of this mechanism was suggested by Vilhu:

$$\dot{J}/J \sim R_0^{-2} \tag{2}$$

Magnetic braking is one of the most important global aspects related to coronal physics. In contact binaries it may be a factor that controls the evolution. The next step is the correlation between magnetic field flux and CaII, MgII and X-ray fluxes (Marcy 1984). To study the relationship between magnetic field and stellar activity Saar (1988) has compared photospheric magnetic flux densities, i.e. the product $\langle fB \rangle$, where f is the fill factor, with observed outer atmosphere emissions. Fig.3 shows CaII K core excess flux density $I_{Ca\mathrm{II}}$ versus $\langle fB \rangle$. The CaII H+K excess flux density appears to saturate for values of $\langle fB \rangle$ above 10^3 G. The power law of Fig.3 fits (Schrijver et al. 1989):

$$I_{Ca\mathrm{II}} = 0.055 \langle fB \rangle^{0.62} \tag{3}$$

Using these observational data it is possible to fit the mean magnetic flux density to the following expression (Skumanich et al. 1975):

$$\langle fB \rangle = 2800 R_C - 200G \tag{4}$$

where R_C is a dimensionless intensity of CaII H+K flux.

Finally, the observations allow us to determine the relationships between the mean magnetic flux density and Rossby number and, what is is very important, between the filling factor and Rossby number. In the current observational data magnetic flux density exhibits strong correlations with the Rossby number:

$$\langle fB \rangle \sim R_0^{-(1.2\pm0.1)} \tag{5}$$

and with the stellar rotation (see Haisch et al. 1994, Linsky & Saar 1987, Saar 1989)

$$\langle fB \rangle \sim \Omega^{1.3\pm0.1} \tag{6}$$

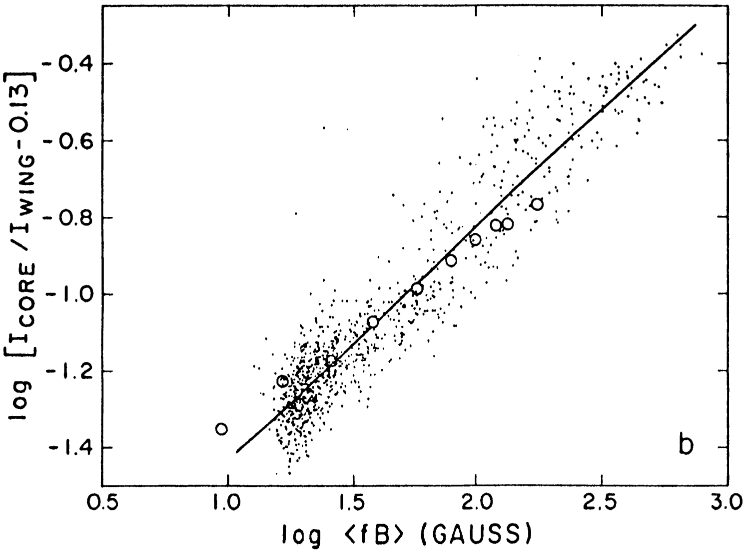

Fig.3. The CaII K core wing intensity ratio vs. the value of the mean magnetic flux density <fB>.

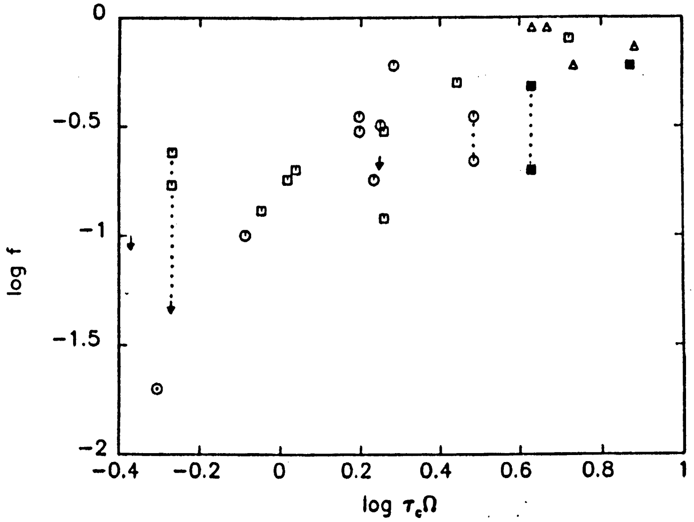

Fig.4. Magnetic filling factor vs. $\tau_c\Omega$.

The magnetic filling factor appears to be the dominant magnetic parameter controlling rotation ~ activity and rotation ~ age relations (Fig.4, see also Haish et al. 1994, Giampapa 1987):

$$f \sim (\tau_c/\Omega)^{0.9\pm0.2} \tag{7}$$

4. Stellar Radio Emission

It was discovered that only a small fraction of ordinary stars are comparatively luminous in the radio wavelength range though the fraction of the total energy emitted in the radio due to thermal processes must have large effective emitting surfaces owing to the presence of strong mass outflows. Stars also be detectable if non-thermal processes provide high effective brightness at radio wavelengths. The detection of radio emission from close binaries can be provided by the influence of a stellar companion. Table 1 represents basic radio emission mechanisms responsible for radio emission of stars (Seaquist 1995).

5. Conclusions

In the last section of my paper I present the current status of observed magnetism in stars of various types. Table 2 shows type of a star (first column), directly measured or indirectly estimated stellar magnetic field magnitude (second column) and radiation mechanism or method of a measurement (third column).

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TABLE 1. Radio Emission Mechanisms

Mechanisms	Source size	T_B	Circul. polar.	Time Var.	Stars where observed
Thermal bremsstrahlung	large $R \gg R_s$	low $\sim 10^4$	low (~ 0)	low (years)	Sun, OB stars, K, M giants
Gyroresonance emission	large $R > R_s$	10^7	low	low	Sun, AM Her quiescent comp αM_e
Gyrosynchrotron or synchrotron	moderate $R \leq R_s$	$10^8 - 10^{10}$	mod. $< 30\%$	mod. (min,hr)	Sun, αM_e, RS Cvn, OB, B_P, A_P(CP)
Cyclotron maser	small $R \ll R_s$	high 10^{20}	$\sim 100\%$	high	Sun, αM_E flare AM Her-outburst
Plasma radiation+plasma-maser instability	small $R \ll R_s$	10^{17}	$(10 \div 90)\%$	high	Sun, αM_E fl, AM Her-outburst

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TABLE 2.

Type of Star	Magnetic Field Magnitude	Radiation Mechanism or Measurement Method
Neutron Stars (Radio pulsars)	$(10^{12} \div 10^{13})$G for Her X-1 $5 \times 10^{12} G (\sim 10^{12} G)$	Cyclotron Lines in X-ray (Radio-emission Pattern) $L \sim B_s^2 R_s^6 \Omega^4$
White Dwarfs	$(10^6 \div 10^8)G$	circular Polarimetry Zeeman Splitting in a Strong Magnetic Field
Magnetic Ap Stars	$(10^3 \div 10^4)G$	Zeeman Splitting
RS Canum Venaticorum Expanded Halo	$\sim 10^3 G$ $\sim 200G$	High Resolution Spectrum Circular Polarimetry (Kemp et al, 1985) Thermal Gyrosynchrotron
Flare Stars	$\geq 10^3 G$ for AD Leonis (dM3.5e)$3.5 \times 10^3 G$	High Resolution Infrared Spectroscopy (Johns-Krull, Valenti, 96)
WR Stars Nonthermal Radio-emission W-R ~1/6 of thermal ones or 1/3 OB stars	$\sim 1500G$ $\sim 100G$ $\sim 10G$	Magnetic Stellar Wind (Maheswaran and Casinelly, 1988): $B_r(R) \leq M^{1/2} U^{3/2} / \Omega R^2$) Gyroresonance Radiation from surface of hot stars (Underhill, 1994) Shock Acceleration (White, 1985)
T Tau	$(10^3 \div 10^4)G$	Circular Polarimetry (Nadeu and Bastien, 1986) Linear Polarization with Faraday Rotation (Gnedin and Red'kina, 1984)
Be Stars	$(10 \div 100)G$	Magnetic Stellar Wind (Maheswaran & Cassinelly, 1988) Linear Polarization with Faraday Rotation Gnedin and Silan'tev, 1984)
Early-Type Stars ($\xi Per, \lambda Cep$)	$(70 \div 200)G$	Magnetic Stellar Wind
Cool Dwarfs, G Dwarfs	$(20 \div 300)G$	Equipation CaIIH+K Fluxes