THE RS CANUM VENATICORUM STARS

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ABSTRACT. The picture emerging from recent studies of RS CVn-type systems indicates the presence of very active stars showing typical solar-like activity phenomena, such as spots and flares, and possibly mutual interactions. The binary nature of RS CVns is certainly important in enforcing high stellar rotation rates, but the actual clue to the understanding of the intrinsic variability of the component stars resides in their internal structure, where the appropriate physical conditions are met for the generation and intensification of strong magnetic fields, as prescribed by the $\alpha\omega$-dynamo models. The most significant results have been derived from multi-wavelength, coordinated observations and long-term monitoring programs.

Recent highlights include: *a*) the mapping of ***compact atmospheric structures*** at various temperature regimes by light curve modelling and spectral (*Doppler*) imaging techniques; *b*) clear evidence of long-term ***activity cycles*** on RS CVn and other types of interacting binaries; *c*) the detection and measurement of ***surface magnetic fields***, as derived from the differential Zeeman splitting of spectral lines.

These results clearly demonstrate that the study of RS CVn stars can play a very fundamental role in the understanding of basic stellar physics, as well as in interpreting the characteristic variability of interacting binaries.

1. Introduction

Since the discovery of the characteristic outside-of-eclipse *photometric* or *distortion wave* on the light curve of the *RS CVn* system at Catania Observatory (Rodonò 1965, Chisari and Lacona 1965, Catalano and Rodonò 1967) and the identification of the new class of binaries named after *RS CVn* (Oliver 1974, Hall 1976), a powerful astrophysical laboratory for the study of solar-like activity on other stars, in addition to the Sun, has become available.

Afterwards, activity phenomena have been identified on other types of close binaries, *e.g.*, *BY Dra*-type (Bopp and Fekel 1977, Rodonò 1983), *UV Cet* flare stars (Rodonò 1990), *W UMa*-type (Eaton et al. 1980), *Algols* (Olson 1984), and cataclismic variables (Bianchini 1990), as well on single (Baliunas and Vaughan 1985) or presumably single stars, *e.g.*, *FK Com*-type (Bopp 1983), and *T Tau*-type (Appenzeller and Dearbon 1984, Appenzeller and Mundt 1989, Montmerle *et al.* 1991). These stars cover a sufficiently extended range of masses and ages, which has allowed us to address basic questions concerning the origin and evolution of stellar magnetic activity and its connection with the internal and atmospheric structure of stars.

Several thorough reviews have been published in recent years (Rodonò 1981, 1983; Linsky 1984; Catalano 1990: Hall 1987, 1991). Therefore, my review will be primarily concerned with the most recent findings and still unsolved questions with the intend to

Y. Kondo et al. (eds.), Evolutionary Processes in Interacting Binary Stars, 71–82.

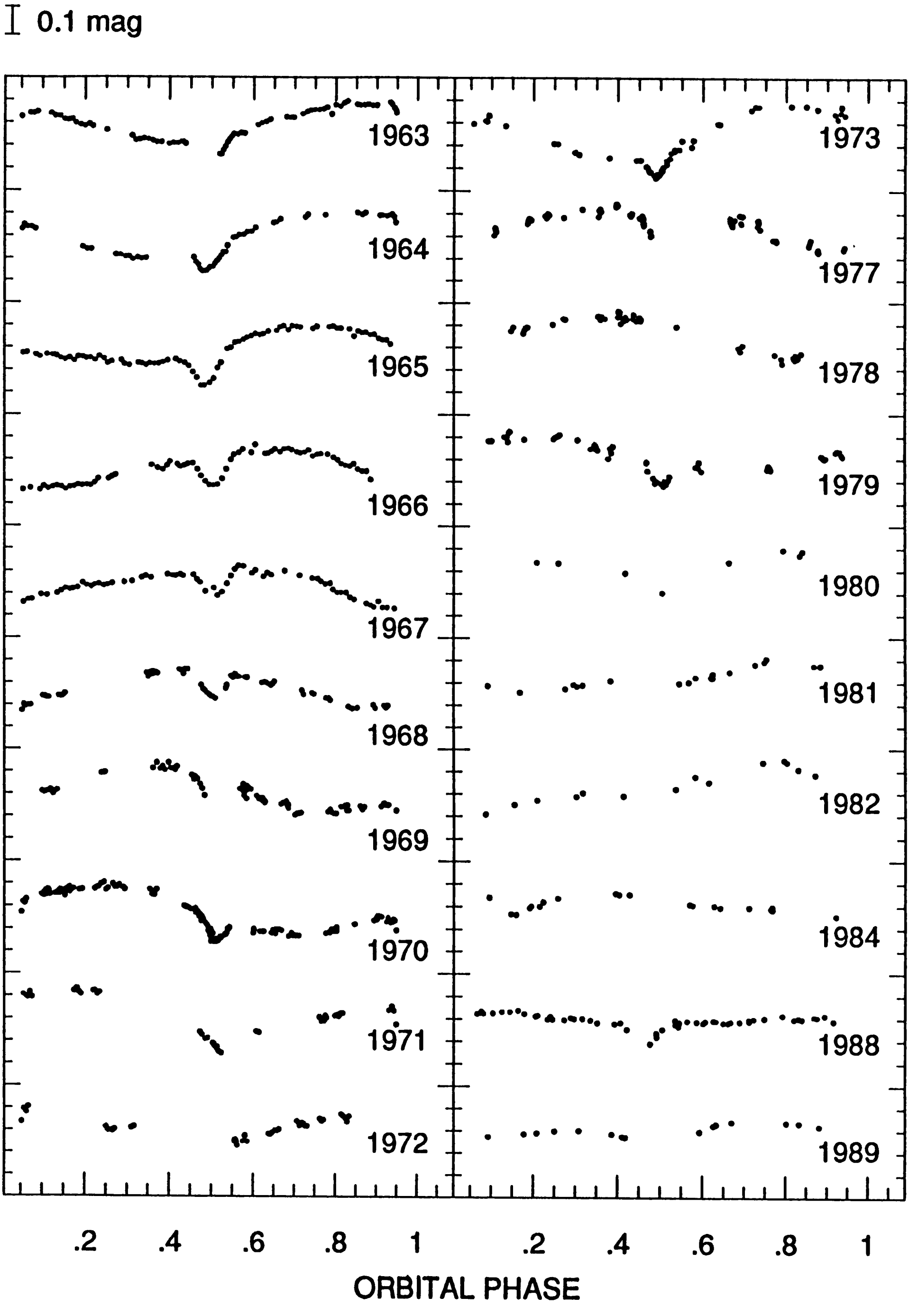

Figure 1. The migrating *photometric wave* on the *RS CVn* V-band light curve from Catania Observatory data (primary eclipses are not shown).

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offer the reader some thoughts for future developments and, hopefully, significant progress in the understanding of RS CVn systems and stellar activity.

2. The Characteristic Fingerprints of RS CVn Stars

The most typical signature of RS CVn phenomenology is illustrated in *Figure. 1*, where more than twenty years of photoelectric observations of the prototype of this class of variables are presented. The light level at maximum shows the characteristic *photometric* or *distortion wave* that migrates towards decreasing orbital phases and completes a passage across the light curve in a few years. This means that, whatever the nature and location of the dark feature or features producing the observed *photometric wave*, its rotation period is slightly shorter than the orbital period, *i.e.*, the star or the star latitude where such features are located, is not synchronized with the orbital motion. *RS CVn* is an evolved system and should have already reached synchronization. Therefore, the variable rate of the *wave* migration is more likely due to the combined effect of a differential rotation regime and of changes in the mean latitude where the dark features develop. Moreover, the *wave* mean light level, amplitude and shape, although rather stable in comparison with other RS CVn systems, show detectable variations (Rodonò 1981, Blanco *et al.* 1983), which again suggest slow changes in the surface distibution of dark features or *starspots* in a differentially rotating star. Actually, the migration rate has been increasing quite steadily from the early '60s, when a complete passage on the light curve took about 8-10 years, to the early '80s, when it took only 3-4 years. Although this behaviour is consistent with a spot forming region moving towards the equator of a differentially rotating star, other interpretations are possible (cf. Hall 1972, Catalano and Rodonò 1974, Oliver 1975, Catalano 1983). In particular, Lanza *et al.* (1991) suggest that the migration of the *distortion wave* can be due to different rotational velocities and lifetimes of old and new spot groups.

In the case of *RS CVn*, the cooler and slightly more massive K0 IV component appears to be the more active star. In other systems the *photometric wave* amplitude, shape and mean level change on much shorter time scales, as illustrated in *Figure 2*, where the systematic observations of the non-eclipsing system HD 17433 by Strassmeier and Bopp (1991) and their interpretation by an evolving spot model are presented. The picture is rather more complex when dealing with eclipsing systems with strong reflection and ellipticity effects: the migrating *photometric wave* produces changing unequal maxima at quadratures (*Fig. 3*) and the clean *wave* can be extracted only if reasonably good evaluations of the other effects can be done.

The distribution of the travelling times for a complete passage of the *photometric wave* on the light curve of RS CVn systems clusters around 9 years (Rodonò 1981). This means that the migration rate is slowest for the shortest period systems, possibly because their stronger tidal interaction, which enforces a higher degree of synchronization than on longer period systems, leads to smaller differences between orbital and rotation periods.

Most of the RS CVn systems show a *photometric wave* which migrates towards decreasing orbital phases, but in a few systems the migration direction is reversed and in others (*SS Boo, CG Cyg, AR Lac, V711 Tau*, and possibly *RS CVn* itself) changes of the

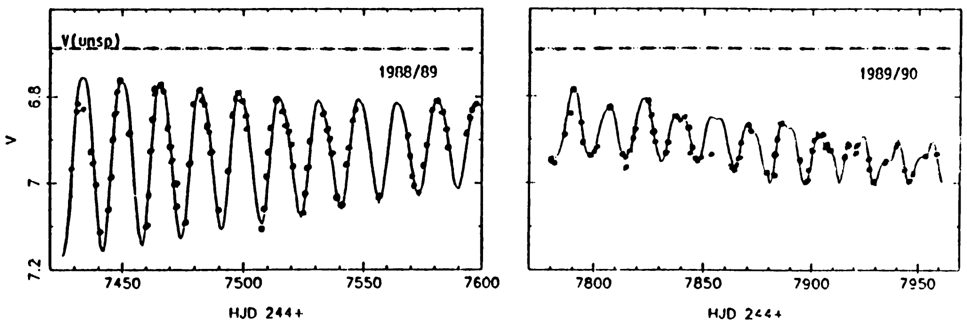

Figure 2. Light curve changes for the non-eclipsing binary *HD 17433* from Strassmeier and Bopp (1991).

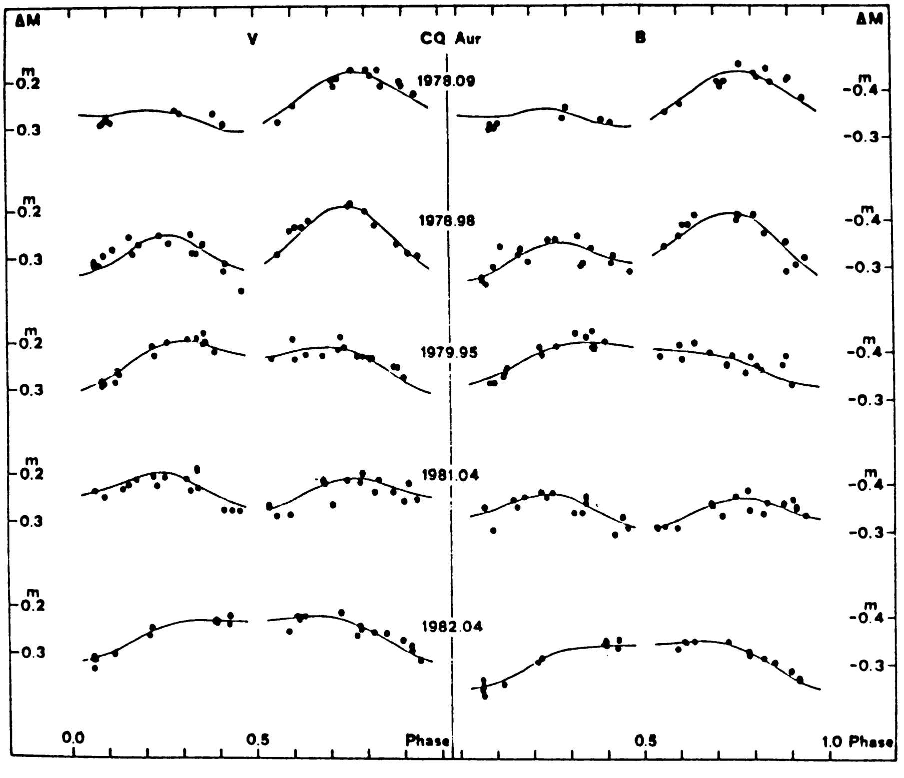

Figure 3. Light curve changes of the eclipsing binary *CQ Aur* from Blanco *et al.* (1983).

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migration direction have been found (Rodonò 1981, Catalano 1983). In *SS Boo* and *V 711 Tau* cyclically variable migration directions seem to occur. Only long-term systematic observations of many systems can confirm whether this is a common behaviour of RS CVn systems.

3. RS CVn Stars and Magnetic Activity

The claim that RS CVn stars show solar-like magnetic activity does not simply relay on the results obtained from the photometric diagnostics presented in the previous section. In addition to photospheric cool spots and activity cycles, RS CVn stars actually show the complete set of activity signatures, such as chromospheric and transition region plages, enhanced UV, X-ray and microwave flux levels and long-duration flare events involving the entire atmosphere of the active star. Such flares are up to 3-5 orders of magnitude more powerful than on the Sun and are best observed in X-ray and microwave bands, rather than in the optical and UV spectral regions, because in the latter wavebands the solar-type generally main sequence component of RS CVn systems dominates the observed combined spectrum and any wide-band flux measurements, so that for contrast reasons it is difficult to detect short-duration faint flares.

In a rather complete and recent compilation of the activity signatures detected in several types of active stars (Linsky 1988), only two question marks concerning the detection of magnetic fields and optical flares were listed, any other signature being already well established. Less than three years after Linsky's compilation, both question marks can now be replaced with "Y" (= yes), *i.e.*, both signatures have been detected with confidence. In fact, the first evidence for a faint optical flare on the short-period system *SV Cam* by Patkos (1981) has now received further support from the observations of a giant optical flare on *V 711 Tau (= HR 1099)* observed from several places during a multi-wavelength coordinated campaign (Foing *et al.* 1991). The first detection of a magnetic field on RS CVn systems is very recent: Donati *et al.* (1990) detected a field of about 1 *kGauss* with filling factor of about 14 per cent on *V 711 Tau* and Donati and Semel (1991) have got evidence for a bipolar field on σ^2 CrB.

From the above evidence it is clear that RS CVn stars form one of the best and most complete astrophysical laboratory to study solar-like stellar activity, *i.e.* those activity phenomena that ultimately derive their principal energy source from magnetic fields. Open and closed field structures, contrary to the basic assumptions of classical atmospheric models, appear to be able to control in various ways and degrees the structure and energy balance of RS CVns' atmospheres, from photospheric up to coronal levels, as on the Sun. According to the fundamental requirements of the $\alpha\omega$-dynamo model, the generation, intensification and emergence at the stellar surface of magnetic field structures require the interplay of deep convection and rotation, two basic conditions which are certainly met in the tidally-coupled late-type components of RS CVn close binaries.

Several other type of stars show solar-like activity phenomena, but on RS CVn stars they appear to reach the highest levels. With respect to the so-called *basal*, *i.e.*, *minimum flux* emitted by inactive stars, the chromospheric, transition region, and coronal fluxes from RS CVns are from two to several orders of magnitude larger, even out of flaring phases.

This demonstrates that the atmospheres of RS CVn stars, even at seemingly "quiescent" state, are heavily covered by solar-like active regions. This similarity, however, can not be pushed too far because, in addition to the abnormally high level of activity, the various forms that activity manifestation can assume are quite different from solar, *e.g.*, the huge dimension of starspots, which sometimes cover up to 30 per cent of the stellar surface, and their apparent formation up to polar regions.

4. What have we learned from the study of RS CVn stars?

The major contribution to stellar physics by the study of active RS CVn stars concerns the surface and vertical structure of stellar atmospheres at the highest, *i.e. saturated* level of activity (see Vilhu 1987, Rodonò 1991). The study of these structures is important not only for the development of more realistic models of stellar atmosphere, but also because they are intimately related to the internal structure of active stars and therefore bear potentially valuable, though indirect insight into the problem of stellar formation and evolution.

Photospheric starspots. The modelling of light curve variations in terms of cool starspots has allowed us to derive the physical properties of these photospheric structures, as well as their location and distribution on the stellar surface (see Rodonò 1986). Spot covering fractions in the range 5-40 per cent of the projected stellar disk and spot temperatures cooler than the surrounding photospere by 400-1500 degrees have been obtained. While starspot dimensions are definitely non-solar, their temperature ratios with respect to the quiescent photosphere cluster around 0.80, an intermediate value between the corresponding values for sunspot *umbrae* (0.70) and *penumbrae* (0.95), with a definite tendency to favour the former value.

The above quoted *model results* on starspots should not be regarded as typical *starspot parameters*, because model limitations and observational selection favour the detection of cooler and larger spots. Actually, the spot parameters derived from modelling individual light curves are more or less affected by non-uniqueness problems. These problems are less serious when synoptic and high-precision light curves are available, so that it becomes feasible to trace the evolution of spot dimension and spatial distribution. When sufficient data covering an extended time interval are available, it has been possible to estimate differential rotation rates. The derived values are 2-3 orders of magnitudes smaller than in the Sun. Clearly, the surface differential rotation regime in close binaries is strongly affected by the tidal interaction between the two components, but this fact does not appear to hamper the operation of the $\alpha\omega$-dynamo, as in single stars. It is important to investigate whether only the surface differential rotation in close binaries is affected by proximity effects, while the rotation regime in deeper convective layers, where the dynamo operates, is relatively unaffected. In this context it might be significant that at least for one active single star the derived differential rotation is of the same order of magnitude as in the Sun (Guinan 1991).

The *Doppler Imaging Technique* offers a very powerful tool to derive starspot parameters and their surface distribution from the radial velocity characteristics of apparently

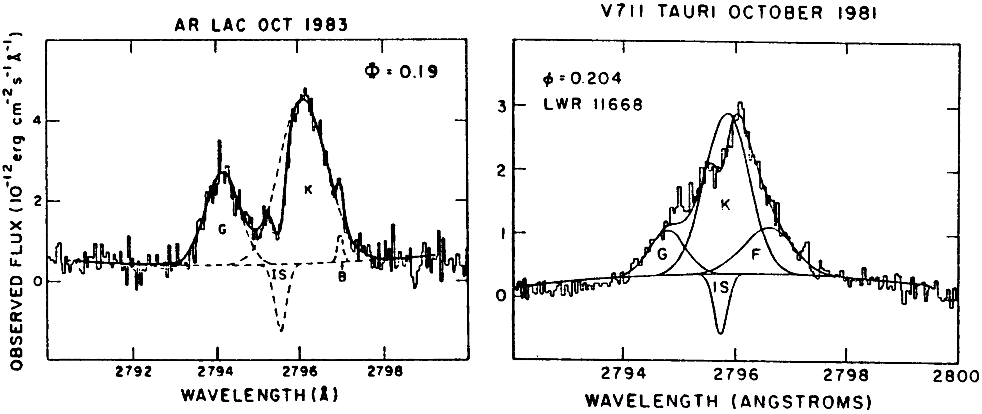

Figure 4. Spectral decomposition of Mg II k line profiles for *AR Lac* showing a plage (left) and flare component (right) from Walter *et al.* (1987) and Linsky *et al.* (1989), respectively.

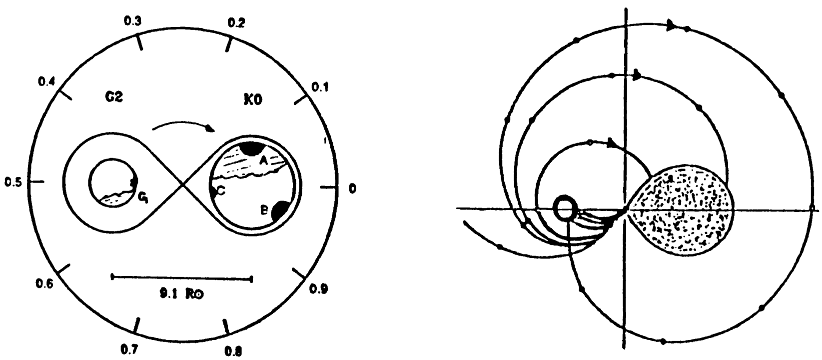

Figure 5. Plage mapping for *AR Lac* in 1989 showing active hemispheres on both stars from Pagano *et al.* (1991), and a qualitative scenario of mass flow from the inner Lagrangian point.

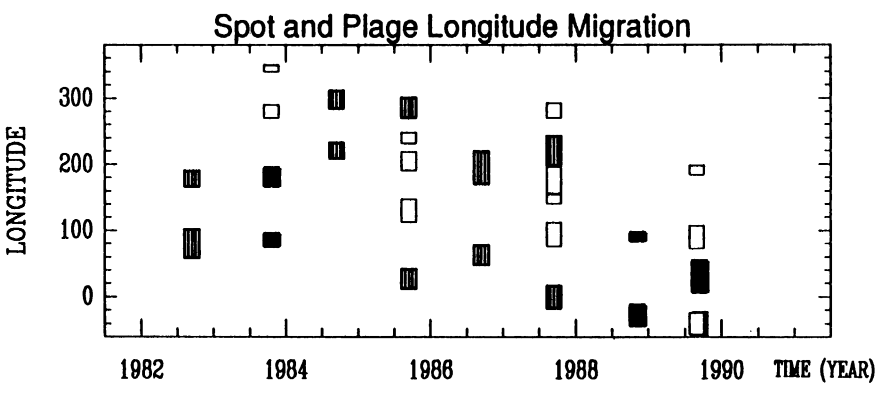

Figure 6. Longitude of plages (*open symbols*) and spots (*filled symbols*) for AR Lac adapted from Pagano *et al.* (1991) with the addition of Kang and Nha (1991) spot data (*dashed symbols*).

emission *bumps* moving across rotationally-broadened absorption line profiles, while cool spots travel across the visible hemisphere of a rotating star (Vogt and Penrod 1983, Vogt *et al.* 1987). The resulting spot parameters and resolved images of active stars' photospheres are quite valuable because *Doppler Imaging Techniques* are less affected though not completely free from uniqueness ambiguities (see Piskunov 1991, and references therein). Unfortunately, only for very few stars sufficiently extended data are available. In a recent paper, Vogt and Hatzes (1991) derive the spot distribution and differential rotation for the very active system *UX Ari.* They found a differential rotation rate one order of magnitude smaller than in the Sun and in the opposite sense, *i.e.* the angular velocity increases towards the poles. Another characteristic feature is the occurrence of huge spot formation at or close to polar regions, as already suggested by several photometric studies. This result is confirmed by the study of *EI Eri* by Hackman *et al.* (1991), who obtained such evidence from Dopplerimaging and photometric techniques.

Chromospheric and Transition Region Plages. Magnetic structures in the Sun are typically three-dimensional and from their footpoints in the photosphere, as traced by sunspots, extend up to coronal levels. In the solar chromosphere and transition region bright areas of enhanced emission are thought to be the site of magnetic energy dissipation. A similar scenario in the stellar case would require bright chromospheric and transition region plages to overlie cool photospheric spots. Monitoring of the *II Peg* UV emission-line fluxes by the IUE satellite and simultaneously the V-band optical flux has enabled us to ascertain that their variations are anti-correlated, as suggested by the above outlined spot/plage scenario. These observations have also allowed us to extract pure plage and quiescent star spectra (Rodonò *et al.* 1986, 1987; Andrews *et al.* 1988). Further and more detailed evidence on the formation of bright plages on active RS CVn stars has been obtained by a variant of the Doppler imaging technique, named *Spectral Imaging*, first applied to the emission line profiles of Mg II h and k by Walter *et al.* (1987) and Neff *et al.* (1989). This method is based on the spectral decomposition of observed line profiles into separate components due to either stars, to bright compact features, and to the interstellar medium. By studying the evolution of line profiles along a complete orbital cycle it is possible to map the plage distribution on the stellar chromospheres and to derive their physical characteristics (see also Rodonò *et al.* 1987, Byrne *et al.* 1987). In *Figure 4* typically observed line profiles and their spectral decompositions are shown. The panel on the right demonstrates the powerful capability of this method also to isolate flare events (Linsky *et al.* 1989). Spectral images of *AR Lac* chromosphere have been obtained every two years since 1983. It is interesting to note that, although systematic modifications are apparent, the region of enhanced activity has remained pretty stable on the two stars. This is suggestive of a quasi-stable dynamical interaction between the two stars, as outlined in *Figure 5.*

The question of spot/plage spatial correlation has been recently addressed by Pagano *et al.* (1991) by using the above mentioned extended series of photometric and IUE observations of *AR Lac.* They did not found a definite *one-to-one* correlation *(Fig. 6)*, but this result should not be surprising, firstly, because stellar plages appear to be much more compact than on the Sun and, secondly, because the actual configuration of magnetic loops *on* and *between* the binary system components are not known.

Coronal Structures. The solar-like atmospheric structure on magnetically active stars and particularly on RS CVn stars extends up to coronal levels. X-ray and radio observations have already provided conclusive evidence of inhomogeneous coronae in late-type stars (Vaiana *et al.* 1981, Golub 1983, Gibson 1983, Pallavicini *et al.* 1990). The most illustrative examples are given by Walter *et al.* (1983), White *et al.* (1987), Schmitt *et al.* (1991), and Rodonò *et al.* (1991) from their EINSTEIN, EXOSAT and ROSAT observations of *AR Lac* and *TY Pyx*. These observations show clear evidence of X-ray flux variation versus rotational phase and eclipses of low-lying X-ray coronal structures. While the EINSTEIN and EXOSAT observations did show eclipses only in the soft X-ray band, suggesting the presence of compact coronal features with relatively low temperature, the latest ROSAT data show eclipses also in the hard X-ray band, *i.e.* also the higher temperature component arises from low lying compact features.

As far as it concerns the *global X-ray emission* at a relatively quiescent state, the RS CVn stars obey the *rotation-activity relation* as a group, but these correlations fail within the group itself because of a saturation effect on magnetic activity. However, if the surface flux is considered, fairly good correlations with rotation period, radius, surface gravity and other stellar or system parameters are apparent (Demircan 1990). The conclusion is that at saturated levels, the dominant parameter of activity seems to be the stellar mass and, by implication, the evolutionary status of RS CVn stars.

Flares. Flare events are the most remarkable phenomena of stellar activity in late-type stars and are best observed towards shorter wavelengths, were the quiescent stellar emission is low. Again for contrast effects, optical flares are frequently observed on intrinsically faint red dwarfs, while they are rarely seen on the more luminous RS CVn stars (see § *3*). However, at X-ray, UV and radio wavelengths, the stellar background is quite faint also for RS CVn stars and many flares can be detected (see Catalano 1990, Linsky 1991, Haisch and Rodonò 1989, Haisch *et al.* 1991).

X-ray and *radio flares* are very frequently observed. They indicate very high plasma temperatures (10^6 - 10^8 K) and densities close to 10^{12} cm^{-3} with soft X-ray peak luminosities up to 10^{32} $erg\ s^{-1}$ and total X-radiation up to 10^{37} erg. The corresponding values of luminosity and total radiation for radio flares are usually smaller by several orders of magnitude, but the less dense ($n_e \leq 10^{10}$ cm^{-3}) flaring plasma can reach brightness temperatures of about 10^{10}. Although flare models basically reproduce solar compact or two-ribbon flares, the plasma parameters are orders of magnitude larger than for the Sun. The best observed *UV flare* was detected on *V 711 Tau* by Linsky *et al.* (1989). They were able to isolate the flare component from the Mg II k emession line profile of the system by multigaussian fit (*Fig. 5*). This component was significantly broadened by turbulence and redshifted by about 90 ± 20 $km\ s^{-1}$. They estimated that the total kinetic energy flux at flare peak due to downflow and turbulence was $\leq 10^{32}$ $erg\ s^{-1}$, essentially equal to the radiative luminosity. This fact asks for caution in flare energy budget evaluation usually confined only to radiative flux data. Actually, Houdebine *et al.* (1990) found evidence for flare-related high-speed flows (up to 5800 $km\ s^{-1}$) and mass loss ($10^{-13} - 10^{-10}$ $M_\odot\ y^{-1}$)

from the red-dwarf *AD Leo* which can affect significantly the evolution of the star itself.

Activity Cycles. Only for a few RS CVn systems, such as *II Peg* and *RS CVn*, sufficient photometric data are available to address basic questions related to the existence of presumably solar-like activity cycles and to derive their characteristic amplitudes and time scales. For several other systems preliminary evidence has been already collected. As shown by Maceroni *et al.* (1990), activity cycles appear to be a widespread characteristic of several types of single and binary variable stars. They found a rather surprising clustering of cycle periods about the value of 6 years for the entire sample of variable stars available to them, irrespective of the star type. Moreover, contrary to earlier evidence mainly concerning single star data (Noyes *et al.* 1984), Maceroni *et al.* (1990) found that the cycle period increases with advancing spectral type, as predicted by kinematic dynamo models (see Belvedere 1990).

Magnetic fields. The indirect evidence for magnetic fields provided by the detection of the activity signatures briefly presented in the previous paragraphs has now been confirmed by direct measurements of differential *Zeeman* splitting of magnetically sensitive and insensitive spectral lines (see § *3*). These measurements are now being done for several types of single and binary stars. The most recent results can be found in Saar's (1991) review.

5. Which relevant astrophysical questions can we expect to answer from the study of RS CVn stars?

The characteristic parameters of activity features on RS CVn stars already contain crucial information on the physics of stars. It is particularly significant that in the last dozen years we have been able to derive reliable data on the range covered by stellar activity parameters and the characteristic time scales of activity phenomena. More work is clearly necessary, but as a consequence of those studies the ubiquitous presence and astrophysical relevance of magnetic fields is now widely recognized and, more importantly, specific observational and theorethical studies have been devised and are being actively pursued.

Some specific questions that stellar activity studies will be able to answer concern the role of magnetic fields in *a*) stellar plasma magnetodynamics, *b*) structure and energy balance of stellar atmospheres, *c*) stellar structure and evolution, *d*) stellar rotation evolution and angular momentum loss, *e*) binary system interaction and evolution.

Moreover, the insights concerning the effects of magnetic fields in astrophysical plasmas, as gained from the above studies, and their extension to *galactic dynamos* and to the physics of special objects, such as *SS 433*, *AGN*s and *accretion disks*, will prove to be very rewarding.

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data and preparing Figure 1.

References

Andrews A.D., *et al.*: 1988, *Astron. Astrophys.* **204**, 177.

Appenzeller I., Dearbon D.P.S.: 1984, *Astrophys. J.* **278**, 689.

Appenzeller I., Mundt R.: 1989, *Astron. Astrophys. Rev.* **1**, 291.

Baliunas S.L., Vaughan A.H.: 1985, *Ann. Rev. Astr. Astrophys.* **23**, 379.

Belvedere G.: 1990, *Mem. Soc. Astr. Ital.* **61**, 273.

Bianchini A.: 1990, *Astron. J.* **99**, 1941.

Blanco C., Catalano S., Marilli E., Rodonò M.: 1983, in Byrne and Rodonò (1983), p. 387.

Bopp B.W.: 1983, in Byrne and Rodonò (1983), p. 363.

Bopp B.W., Fekel F.C.: 1977, *Astron. J.* **82**, 490.

Byrne P.B., Doyle J.G., Brown A., Linsky J.L., Rodonò M. : 1987, *Astron. Astrophys.* **180**, 172.

Byrne P.B., Rodonò M. (*eds.*): 1983, *Activity in Red-Dwarf Stars*, Proc. IAU Coll. 71, Reidel Publ. Co..

Catalano S.: 1983, in Byrne and Rodonò (1983), p. 343.

Catalano S.: 1990, in NATO-ASI on *Active Close Binaries*, ed. C.Ibanoğlu, Kluwer Acad. Publ., p. 411.

Catalano S., Rodonò M.: 1967, *Mem. Soc. Astr. Ital.* **38**, 395.

Catalano S., Rodonò M.: 1974, *Publ. Astr. Soc. Pacific* **86**, 390.

Chisari D., Lacona G.: 1965, *Mem. Soc. Astr. Ital.* **36**, 433.

Demircan O.: 1990, in *Active Close Binaries*, ed. C.Ibanoğlu, Kluwer Ac.Publ., p. 431.

Donati J.-F., Semel M.: 1991, in Tuominen *et al.* (1991), p. 326.

Donati J.-F., Semel M., Rees D., Taylor K., Robinson R.: 1990, *Astron. Astrophys.* **232**, L1.

Eaton J.A., Wu C.C., Rucinski S.M.: 1980, *Astrophys. J.* **239**, 919.

Foing B.H., *et al.*: 1991, work in progress.

Guinan E.: 1991, *These Proceedings.*

Gibson D.M.: 1983, in Byrne and Rodonò (1983), p. 273.

Golub L.: 1983, in Byrne and Rodonò (1983), p. 83.

Haisch B.M., Rodonò M. *(eds.)*: 1989, *Solar and Stellar Flares*, *Sol. Phys.* **121**.

Haisch B., Strong K.T., Rodonò M.: 1991, *Ann. Rev. Astron. Astrophys.* **29**, in press.

Hackman T., Piskunov N.E., Poutanen M., Strassmeier K.G., Tuominen I.: 1991, in Tuominen *et al.* (1991), p. 321.

Hall D.S.: 1972, *Publ. Astron. Soc. Pacific* **84**, 323.

Hall D.S.: 1976, in *Multiple Periodic Variable Stars*, ed. W.S.Fitch, IAU Coll. 29, p. 287.

Hall D.S.: 1987, *Publ. Astr. Inst. Czech. Acad. Sci.*, **70**, 77.

Hall D.S.: 1991, in Tuominen *et al.* (1991), p. 353.

Houdebine E.R., Foing B.H., Rodonò M.: 1990, *Astron. Astrophys.* **238**, 249.

Kang Y.W., Nha Il-S.: 1991, in *Surface Inhomogeneities in Late-type Stars*, eds. P.B.Byrne, D.J.Mullan, Springer-Verlag, in press.

Lanza A.F., Rodonò M., Zappalà R.A.: 1991, in NATO-ARW on *Angular Momentum Evolution of Young Stars*, eds. S.Catalano and J.R.Stauffer, Kluwer Ac. Publ., p. 289.

Linsky J.L.: 1984, in Proc. Third Cambridge Workshop on *Cool Stars, Stellar Systems and the Sun*, eds. S.L.Baliunas and L.Hartmann, Springer-Verlag, p. 244.

Linsky J.L.: 1988, in *Multiwavelength Astrophysics*, ed. L. Córdova, Cambridge Univ. Press, p. 49.

Linsky J.L.: 1991, *Mem. Soc. Astr. Ital.*, in press.

Linsky J.L., *et al.*: 1989, *Astron. Astrophys.* **211**, 173.

Maceroni C., Bianchini A., Rodonò M., Van't Veer F., Vio R.: 1990, *Astron. Astrophys.* **237**, 395

Montmerle T.,, Feigelson E.D., Bouvier J., Andrè Ph.: 1991, in *Protostars and Planets III*, eds. E.H.Levy and J.I.Lunine, Univ. Arizona Press, in press.

Neff J.E., Walter F.M., Rodonò M.: 1989 *Astron. Astrophys.* **215**, 79.

Noyes R.W., Hartmann L.W., Baliunas S.L., Duncan D.K., Vaughan A.M.: 1984, *Astrophys. J.* **279**, 778.

Oliver J.P.: 1974, Ph.D. Thesis, Univ. of California, Los Angeles (CA, USA).

Oliver J.P.: 1975, *Publ. Astr. Soc. Pacific* **87**, 695.

Olson E.C.: 1984, in *Advances in Photoelectric Photometry* **2**, 15.

Pagano I., Rodonò M., Neff J.E.: 1991, in *Surface Inhomogeneities in Late-type Stars*, eds. P.B.Byrne, D.J.Mullan, Springer-Verlag, in press.

Pallavicini R., Tagliaferri G., Stella L.: 1990, *Astron. Astrophys.* **228**, 403.

Patkos L.: 1981, *Astrophys. Letters* **22**, 1.

Piskunov N.E.: 1991, in Tuominen *et al.* (1991), p. 309.

Rodonò M.: 1965, *Ph.D. Thesis*, University of Catania, Italy.

Rodonò M.: 1981, in NATO-ASI on *Photometric and Spectroscopic Binary Systems*, eds. E.B. Carling and Z.Kopal, Reidel Publ.Co., p. 285.

Rodonò M.: 1983, *Adv. Space Res.* **2**, No. 9, 225.

Rodonò M.: 1986, in Proc. Fourth Cambridge Workshop on *Cool Stars, Stellar Systems and the Sun*, eds. M.Zeilik and D.M.Gibson, Springer-Verlag, p. 475.

Rodonò M.: 1990, in *Flare Stars in Star Clusters, Associations and the Solar Vicinity*, IAU Symp. 137, eds. L.V.Mirzoyan, B.R.Pettersen, M.K.Tsvetkov, p. 371.

Rodonò M.: 1991, in NATO-ARW on *Angular Momentum Evolution of Young Stars*, eds. S. Catalano and J.R.Stauffer, Kluwer Ac. Publ., p. 207.

Rodonò M., *et al.*: 1986, *Astron. Astrophys.* **165**, 135.

Rodonò M., *et al.*: 1987, *Astron. Astrophys.* **176**, 267.

Rodonò M., *et al.*: 1991, *work in progress.*

Saar S.H.: 1991, *Mem. Soc. Astr. Ital.*, in press.

Schmitt J.H.M.R., et al.: 1991, *Highlights of Astronomy*, in press.

Strassmeir K., Bopp B.W.: 1991, *Astron. Astrophys.*, submitted.

Tuominen I., Moss D., Rüdiger G. *(eds.)*: 1991, *The Sun and Cool Stars: activity, magnetism, dynamos*, Proc. IAU Coll. 130, Springer-Verlag, Berlin.

Vaiana G.S., *et al.*: 1981, *Astrophys. J.* **245**, 163.

Vilhu O.: 1987, in Proc. Fifth Cambridge Workshop on *Cool Stars, Stellar Systems and the Sun*, eds. J.L.Linsky and M.E.Stencel, Springer-Verlag, p. 110.

Vogt S.S., Hatzes A.P.: 1991, in Tuominen *et al.* (1991), p. 297.

Vogt S.S., Penrod G.D.: 1983, in Byrne and Rodonò (1983), p. 379.

Vogt S.S., Penrod G.D., Hatzes A.P.: 1987, *Astrophys. J.* **321**, 496.

Walter F.M., Gibson D.M., Basri G.S.: 1983, *Astrophys. J.* **267**, 665.

Walter F.M., Neff J.E., Gibson D.M., Linsky J.L., Rodonò M., Gary D.E., Butler C.J.: 1987, *Astron Astrophys.* **186**, 241.

White N.E., Shafer R., Parmar A.N., Culhane J.L.: 1987, in Proc. Fifth Cambridge Workshop on *Cool Stars, Stellar Systems and the Sun*, eds. J.L.Linsky and M.E.Stencel, Springer-Verlag, p. 521.