Common chromospheres – roundchroms – as a means for the study of binary systems

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Abstract

An independent method based on the concept of common chromospheres – roundchroms – is proposed for the determination of the radii of the main components of RS CVn-type close binary systems. The essence of the method is in the coincidence of the radius of the main component of the binary system with the equipotential zero-velocity surface for some values of the Jacobi constant. As an illustration, the method is applied to a sample of 15 RS CVn-type systems, and as a result the revised radii of the main components in the systems are determined. The main parameters, particularly the volumes, electron concentrations and masses of the roundchroms, are obtained as well. Empirical dependences of the electron concentration in the roundchrom, $n_e$, and of the 2800 Mg II doublet luminosity, $L(Mg II)$, on intercomponent distance $a$ were discovered, the first in the form $n_e \sim a^{-0.85}$ and the second in the form $L(Mg II) \sim a^{1.66}$. The formation of a roundchrom in close binary systems is inevitable, and the roundchrom is as essential a physical formation for binary systems as are the corona and chromosphere for single stars.

Key words: binaries: general – stars: chromospheres – stars: fundamental parameters.

1 THE STATEMENT OF THE PROBLEM

The difficulties of the accurate determination of some parameters of the main components (as a rule cool giants) in RS CVn-type binary systems, such as their sizes and masses, are well known. It is especially difficult when the inclination of the plane of the orbit relative to the observer is very large – higher than 60° up to 90° – or when the eclipse is partial and touches only the outer layers of the extended atmosphere of the same component.

On the other hand, it is also known that in the typical chromospheric lines, and first of all in the ultraviolet doublet 2800 Mg II, the emission from these objects, RS CVn-type systems, has an obviously anomalous character. This anomaly is expressed particularly in the fact that the ratio of both luminosities, $L(Mg II)/L_{bol}$, in these objects may reach up to $10^{-3}$ or even $10^{-4}$; i.e. it is essentially, within one or two orders of magnitude, larger than we have in ordinary single cool giants in which this ratio is of the order of $10^{-5}$, and the magnesium emission has a completely chromospheric origin. Thus, according to Vilhu's (1987) review, the $L(Mg II)/L_{bol}$ ratio for the single stars is of the order of $10^{-5}$ and very rarely of $10^{-4}$. For Ursa Major group young stars, i.e. not ordinary single stars, this ratio may reach up to $8 \times 10^{-5}$ (Soderblom & Mayor 1993). For field dwarfs this ratio may extend up to $5 \times 10^{-5}$ (Ayres et al. 1981), for young solar-type dwarfs up to $7 \times 10^{-5}$ (Simon, Herbig & Boesgard 1985). For T Tauri-type stars, an observational ratio $L(Mg II)/L_{bol}$ of the order of $10^{-3} - 10^{-4}$ is possible (Simon et al. 1985). However, these objects, being permanent flare stars (Gurzadyan 1970, 1980; Rodono 1974) with very strong ultraviolet excess and intense emission lines (Herbig & Haro 1955), definitely have nothing in common with single dwarfs or with RS CVn-type systems.

We propose to approach the solution of this anomaly by means of the concept of common or contacting chromospheres, which we call roundchroms (Gurzadyan 1997a,b), enveloping both stars-components of the binary system without coming into contact with their photospheres. The method of construction of the outer configuration of this roundchrom for every definite case, i.e. for a given close binary system with known masses and radii of components
and known orbital period, is given in this paper. It is based on the identification of the outer boundary of a roundchrom with an equipotential zero-velocity surface at some value of the Jacobi constant \( C \), at which the formation of a narrow corridor near the central Lagrangian point \( L_2 \) will be ensured for the transit of gaseous matter from the main component of the system in the direction of the secondary component. The method of the determination of the main parameters of a roundchrom – particularly its volume, electron concentration and mass, including the region responsible for observed emission in the doublet of 2800 Mg II – is applied to 19 binaries, all of RS CVn-type. The parameters of the roundchroms have been estimated for these binaries (Gurzadyan 1997a,b).

With this connection comes the statement of the inverse problem, i.e. the determination of the main parameters and, first of all, the sizes of the components of close binary systems, proceeding from the assumption that the observed magnesium emission in these objects is completely of roundchrom origin. In other words, the question is about the application of the roundchrom concept as an independent means or method for the study of close binary systems. In the present article, such an attempt is realized for a sample of 15 RS CVn-type binary systems.

2 THE ESSENCE OF THE ROUNDCHROM CONCEPT

The basic properties of the roundchrom can be formulated as follows.

(i) The roundchrom sharply increases the effective volume of the chromospheric emission around the secondary component of the system, on a scale of ten to a hundred times larger when compared with the summary volume of the chromospheres of both components, especially when the secondary is a dwarf (cool or hot).

(ii) As a rule, the roundchrom has to pass very near to the surface of the main component – more precisely, to the upper layers of its chromosphere – without increasing the effective volume of emission.

We must first formulate the principle by which we choose those objects to which the roundchrom method of determining the basic parameters of the components of the system may be applied; we must then formulate the method itself and the sequence of the solution of our inverse problem.

The first question, i.e. the principle of the choice of objects, has a simple solution: candidates are

(1) those objects with anomalously large values of the ratio \( L(Mg\, II)/L_{\text{bol}} \); more specifically when this ratio is larger than \( 10^{-5} \); and

(2) those objects with periodic variations of the flux in the emission of Mg II stipulated by the eclipse of components, partial or complete.

Further, with the known (for a given binary) masses and sizes of the components, as well as known intercomponent distances, we can construct a number of equipotential surfaces (curves) corresponding to various values of the Jacobi constant \( C \). The problem is, thus, to choose among them the surface (curve) which best satisfies the following conditions.

(a) It is necessary to have a corridor, even a narrow one, near the Lagrangian point \( L_2 \) for the transit of the gaseous matter from the main component of the system in direction of the secondary one.

(b) The equipotential surface (curve) must pass above the surface (photosphere) of the first component.

(c) The equipotential surface (curve) should be within the Roche lobe of the main component.

(d) The equipotential surface, in combination with the Roche lobe, should form an additional volume of emission around the secondary component.

Concerning condition (a): strictly speaking, the formation of a ‘narrow corridor’ between two stars is not a principal necessity; however, its formation is inevitable even if we identify, in the majority of cases, the roundchrom’s boundary with the surface of the main component of the system. The mass transfer is required to fill the volume of the roundchrom around the secondary.

The formation of this corridor at the point \( L_2 \) turns out to be inevitable for all binary systems; this is one of the important consequences of the roundchrom concept.

Condition (b) is of particular importance. The outer boundary of the roundchrom, identified with an equipotential surface, cannot pass below the surface of the star in principle. It cannot be above the Roche limit either. The only possibility that remains is that it must be slightly above the surface of the larger component. The originality of the situation is in the fact that even if the boundary of the roundchrom is identified exactly with the surface of the primary, the radius of the roundchrom around the secondary will be much larger than the size of the secondary. If this condition is realized, then our main problem – the determination or accurate definition of the radius of the main component – may be solved. The accurate definition of the radius of the main component without any change of its mass, having in mind the existence of a real dispersion in the sizes of stars at the given magnitude of its mass, could be performed. This is the essence of the roundchrom method. In the opposite case, in which the variation of the radius will exceed the limits of the known dispersion, then the method of successive approximation should be applied, i.e. by varying both the mass and the radius simultaneously until the main criterion is satisfied, i.e. the passage of the roundchrom through the upper layers of the chromosphere of the main component. This requirement may be presented in quantitative form as \( R_s \approx R_{s_{\text{true}}} \), where \( R_s \) is the radius of the main component (A) and \( R_{s_{\text{true}}} \) is the nearest distance of the roundchrom boundary from the centre of the primary star.

The sequence of computations is as follows. The equipotential surface (curve) is drawn for a number of values of the Jacobi constant \( C \) for a given ratio of mass \( \mu = \mathcal{M}_A/\mathcal{M}_B \), where \( \mathcal{M}_A \) and \( \mathcal{M}_B \) are the mass of main (A) and secondary (B) components, and for a unit intercomponent distance \( a = 1 \). Having a number of equipotential curves for different values of the Jacobi constant \( C \), we choose only one – that which gives \( R_s \approx R_{s_{\text{true}}} \) – and then the main problem, the determination of the true radius of the main component, will be solved.
At the first approximation, one can neglect the role of such phenomena as the magnetic loops, active regions, centrifugal forces etc. on the geometry and macrostructure of the roundchrom. These factors are important only for the main component of a system with a roundchrom passing close to the surface of the star, higher than the boundary of the star’s chromosphere. The essence of the roundchrom concept is simply the fact that the volume of the roundchrom around the primary does not play any role in the formation of the Mg II doublet emission of the system.

The roundchrom emission is determined almost completely by its volume around the secondary; in this case the radius of the roundchrom will be 10, 20 or more times larger than the radius of the secondary, and the above-mentioned factors (magnetic fields, etc.) cannot influence the independent behaviour of the roundchrom around the secondary.

Let us stress again: the eight-shaped roundchroms enveloping both components of close binary systems are not a hypothesis but a mathematically strong result (for details of the method of computation see Gurzadyan 1996).

3 APPLICATION OF THE METHOD

Thus, the central concept of the determination of the radius of the main component of the system is clear: it is based on the assumption that the observed magnesium emission in doublet 2800 Mg II is entirely of roundchrom origin.

The principle is applied to a group of 15 close binary systems, all of RS CVn type, the list of which is given in Table 1 with all initial parameters – orbital period $P$, distances $D$, relative magnesium power $L(Mg II)/L_{bol}$, the luminosity in magnesium emission $L(Mg II)$ for the system, as well as the spectral types and classes of luminosity, masses and radii of components of the system – necessary for the construction of their roundchroms and collected from different sources (Ayres, Marsted & Linsky 1981; Basri, Laurent & Walter 1985; Strassmeier et al. 1993; Schrijver & Zwaan 1991). In cases for which the data for the masses and radii of components are absent, the Allen’s (1979) mean statistical data have been accepted for known spectral and luminosity classes.

Further, by the means mentioned above (Gurzadyan 1997a), the roundchroms of these binary systems are constructed by the identification of their outer boundaries with the zero-velocity equipotential surfaces (curves) for various values of the Jacobi constant $C$. The final curve is chosen according to an important requirement – that of having a narrow corridor near the Lagrangian point $L_1$ (in one case, UV Psc in Fig. 1, this point is shown by a cross) to allow the transit, without any difficulty, of gaseous matter from the main component of the system to the secondary one.

The final results, the roundchroms for these 15 binary systems, are presented in Figs 1–5 in which the main component of a system with a roundchrom passing close to the surface of the star, higher than the boundary of the star’s chromosphere. The essence of the roundchrom concept is simply the fact that the volume of the roundchrom around the primary does not play any role in the formation of the Mg II doublet emission of the system.

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Let us stress again: the eight-shaped roundchroms enveloping both components of close binary systems are not a hypothesis but a mathematically strong result (for details of the method of computation see Gurzadyan 1996).

Table 1. Initial parameters of a group of RS CVn-type close binary systems. Masses $M$, radii of stars $R$ and Roche lobe radii $R_L$ of components are in solar units, $M_B$ and $R_B$.

<table>
<thead>
<tr>
<th>Name</th>
<th>$P$ (days)</th>
<th>$D$ (au)</th>
<th>$L(Mg II)$ $\times 10^{38}$ erg s$^{-1}$</th>
<th>$L(Mg II)/L_{bol}$</th>
<th>Spectral type</th>
<th>$M_A$ ($M_\odot$)</th>
<th>$R_A$ (R$_\odot$)</th>
<th>$R_L$ (R$_\odot$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV Psc</td>
<td>0.566</td>
<td>125</td>
<td>2.4</td>
<td>0.9</td>
<td>k2 V</td>
<td>1.2</td>
<td>1.0</td>
<td>1.9</td>
</tr>
<tr>
<td>TZ CrB</td>
<td>1.14</td>
<td>21</td>
<td>4.2</td>
<td>1.1</td>
<td>f6 V</td>
<td>1.1</td>
<td>1.0</td>
<td>2.2</td>
</tr>
<tr>
<td>V S24 Arx</td>
<td>1.68</td>
<td>39</td>
<td>2.1</td>
<td>0.9</td>
<td>G3 IV</td>
<td>3.0</td>
<td>2.3</td>
<td>4.1</td>
</tr>
<tr>
<td>CF Tuc</td>
<td>2.60</td>
<td>90</td>
<td>4.9</td>
<td>2.2</td>
<td>K4 IV</td>
<td>2.2</td>
<td>3.3</td>
<td>5.3</td>
</tr>
<tr>
<td>WW Dra</td>
<td>4.50</td>
<td>180</td>
<td>4.8</td>
<td>0.9</td>
<td>G5 IV</td>
<td>2.5</td>
<td>3.9</td>
<td>7.4</td>
</tr>
<tr>
<td>BS CVn</td>
<td>4.60</td>
<td>180</td>
<td>7.2</td>
<td>1.4</td>
<td>F5 IV</td>
<td>1.3</td>
<td>1.9</td>
<td>6.1</td>
</tr>
<tr>
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<td>14.17</td>
<td>75</td>
<td>19.3</td>
<td>3.2</td>
<td>G3 III</td>
<td>3.1</td>
<td>12</td>
<td>18.6</td>
</tr>
<tr>
<td>HK Lac</td>
<td>24.4</td>
<td>150</td>
<td>40.0</td>
<td>3.0</td>
<td>K0 IV</td>
<td>6.0</td>
<td>15</td>
<td>29.1</td>
</tr>
<tr>
<td>V792 Her</td>
<td>27.5</td>
<td>80</td>
<td>16.8</td>
<td>1.5</td>
<td>F3 IV</td>
<td>1.4</td>
<td>2.6</td>
<td>20.6</td>
</tr>
<tr>
<td>HR 7275</td>
<td>28.5</td>
<td>250</td>
<td>33.9</td>
<td>2.5</td>
<td>K1 IV-III</td>
<td>16.9</td>
<td>27</td>
<td>53.1</td>
</tr>
<tr>
<td>RZ Eri</td>
<td>39.2</td>
<td>143</td>
<td>12.0</td>
<td>2.0</td>
<td>K0 IV</td>
<td>2.0</td>
<td>13</td>
<td>28</td>
</tr>
<tr>
<td>Λ And</td>
<td>53.7</td>
<td>30</td>
<td>18.2</td>
<td>1.0</td>
<td>G8 IV-III</td>
<td>2.8</td>
<td>18</td>
<td>43</td>
</tr>
<tr>
<td>HR 4665</td>
<td>64.4</td>
<td>130</td>
<td>85.1</td>
<td>2.8</td>
<td>K0 III</td>
<td>2.8</td>
<td>20</td>
<td>44</td>
</tr>
<tr>
<td>12 Canum</td>
<td>80.2</td>
<td>134</td>
<td>25.7</td>
<td>3.5</td>
<td>K0 III</td>
<td>3.5</td>
<td>20</td>
<td>44</td>
</tr>
<tr>
<td>HR 7428</td>
<td>109</td>
<td>30</td>
<td>62</td>
<td>3.2</td>
<td>A0 V</td>
<td>3.2</td>
<td>63</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. Roundchroms (shaded) for close binary systems UV Psc, CF Tuc and IL Hya. Broken circles are the outer limits of Roche lobe. Solid half-circles are the initial radii of the main component of the system.
ponents (A) are on the left, the eight-form solid curves are the outer boundaries, and the solid circles are the inner boundaries of the roundchroms. The shaded areas are the roundchroms themselves. The Roche lobes are shown by broken circles, the radii of which for components A and B are: $R_A^\text{L}(q)$ and $R_B^\text{L}(1/q)$ respectively, where $q$ is the mass ratio and $R_i(q)$ is determined according to the relationship (Eggleton 1983):

$$R_i(q) = \frac{0.49q^{2/3}}{0.6q^{2/3} + \ln(1 + q^{1/2})},$$

where $a$ is the intercomponent distance (in units of solar radius $R_\odot$).

$$a = 4.21P^{0.5}(M_A + M_B)^{0.5}.$$  \(1\)

Table 1 is quite different; here the radii of the stars are smaller than the roundchrom boundaries, i.e. $R_\star < r_\star$ (these are shown by solid half-circles in all figures). So, assuming $R_\star \approx r_\star$, i.e. assuming a completely roundchrom origin for the observed magnesium emission in these binary systems, we obtain the most probable radius of the main component of the system. The correction of the radius of a star yields a revision of its spectral type or luminosity class as well.

The final results, namely the revised radii $R_\star$ of the main components and the revised spectral and luminosity classes for our sample of binary systems, are presented in Table 2. In the third column, the ratios $R_\star^\prime/R_\star$ are given (taking the magnitudes of $R_\star$ from Table 1); this ratio is within the range of 1.5–2.5 $R_\odot$

Some examples of the revised spectral classes are as follows.

**12 Cam** The initial spectral class was K0 III, revised to K0 II with the changing of the radius of the main component from 24 up to 54 $R_\odot$. For a star K0 of luminosity class II, the possible limit of the radius is 80 $R_\odot$ (Allen 1979).

**RZ Eri** The initial spectral class was K0 IV, revised to K0 III with an increasing of the radius from 13 up to 25 $R_\odot$, which is close to the limiting size for a K0-type and III luminosity-class giant.
HR 7275 The initial spectral type is estimated as K1 IV–III, revised to K1 III with an increase of the radius from 16 up to 23 Rₜ. The limiting size for a K1 III giant is 26 Rₜ.

HR 7428 The initial class was K2 III–II, revised to K2 II with an increase of the radius from 30 up to 73 Rₜ. Limiting radius is 90 Rₜ.

λ And Initial class G8 IV–III, revised to G8 II with a changing of the radius from 18 up to 41 Rₜ. The limiting radius is 70 Rₜ.

Of course, the masses of the stars also should be revised; however, having in view the weak dependence of both inter-component distance a and Roche radii on mass, this factor may be ignored.

Returning to Table 2, we would like to note that the changes in spectral types, and especially in the classes of luminosity, are very small. As for the changes in the radii of the primary component, Rₐ, they are in some cases as much as a factor of 2–2.5 – this, however, is not large compared with the scatter between the results discovered by various authors for a single object, as may be seen from the data collected in Table 3 for a few RS CVn-type binary systems. The scatter in the distances, D, reaches up to 3.4 times, and between the radii Rₐ up to 3.3 times (!) that for a single binary system.

In such conditions – if, for example, in the case of RS CVn we discovered a radius that was a factor of 1.34 larger than its previously known value – the mass should be changed accordingly, which would have an influence on the intercomponent distance a, etc. Such changes might have other, less essential consequences that would nevertheless influence the optical light curve near eclipse of the system.
4 PARAMETERS OF ROUNDCHROMS

The determination of the other parameters of the roundchrom may be carried out with the following sequence. First of all, we determine the physical, i.e. emitting, volume of roundchrom $V$ with the reduction of the spherical volumes of both stars with radii $R_a$ and $R_b$ according to the relationship

$$V = V_\star a^3 \frac{4\pi}{3} (R_a^3 + R_b^3),$$  

(3)

where $a$ is the intercomponent distance and is given by the relationship in equation (2); $V_\star$ is the unitless ($a = 1$) volume of a figure formed as a result of the rotation of the equipotential curve around the axis $OX$ (Gurzadyan 1996):

$$V_\star = \int y^2 \, dx,$$  

(4)

where $x$ and $y$ are mutually connected with one another by an equipotential equation written for the plane $XOY$:

$$x^2 + y^2 + \frac{2(1 - \mu)}{\sqrt{(x-x_c)^2 + y^2}} \frac{2\mu}{\sqrt{(x-x_c)^2 + y^2}} = C.$$  

In equation (4), the integration is carried out from the limiting point from the left of the equipotential surface on the axis $OX$ up to the limiting point from the right.

We have, for the complete power of magnesium emission of the roundchrom, i.e. for $L(Mg \, II)$,

$$L(Mg \, II) = \varepsilon(Mg \, II) \, V,$$  

(5)

where $\varepsilon(Mg \, II)$ is the volume emission coefficient in the $k$ and $h$ lines of Mg II in erg cm$^{-3}$ s$^{-1}$ (Gurzadyan 1997c):

$$\varepsilon(Mg \, II) = 1.16 \times 10^{-20} n_e^2 T_e^{-1/2} \exp\left( -\frac{51400}{T_e} \right),$$  

(6)

where $n_e$ is the electron concentration and $T_e$ is the electron temperature in the roundchrom. When derived, equation (6) assumes that the magnesium in the roundchrom is completely in a singly ionized state [i.e. $n(Mg^+) = n(Mg) = 1$], hydrogen is ionized completely [i.e. $n(H)/n_e = 1$], and the relative abundance of magnesium is $n(Mg)/n(H) = 2.5 \times 10^{-5}$. In subsequent calculations, the electron temperature in a roundchrom is assumed to be $T_e = 10^4$ K.

Therefore, at a constant value of $T_e$, we have for $L(Mg \, II)$ from equations (5) and (6)

$$L(Mg \, II) \sim n_e^2 V,$$  

(7)

Combining equations (4), (5) and (6), we obtain the following relationship for the determination of electron concentration in a roundchrom (Gurzadyan 1997a):

$$n_e = 1.16 \times 10^{13} [L(Mg \, II)/V]^{1/2} \, cm^{-3},$$  

(8)

where $L(Mg \, II)$ is the luminosity of the binary system under examination in magnesium doublet emission:

$$L(Mg \, II) = 4\pi D^2 F(Mg \, II),$$  

(9)

where $D$ is the distance of the star (binary system) and $F(Mg \, II)$ is the observed flux in the magnesium doublet, 2800 Mg II, corrected for interstellar extinction.

The obtained values of $V$ and $n_e$ for our collection of binary systems are presented in Table 4, together with the values of intercomponent distance $a$, mass ratio $\mu$, Jacobi constant $C$, and unitless volume of roundchrom $V_\star$ (which, on average, is of the order of 0.5 for all binaries). In the last column of this table, the values of the masses of roundchroms, $M_r = \mathcal{M}/\mathcal{M}_0$, are given, where $m_1$ is the mass of a hydrogen atom. As we see, the roundchrom volumes vary within extremely wide limits (five orders), and the roundchrom mass, $\mathcal{M}/\mathcal{M}_0$, varies in the range $10^{-12}$ to $10^{-3}$.

As for the electron concentration $n_e$, it is of the order of $10^6$ cm$^{-3}$ independent of the size and the volume of the roundchrom, and in the first approximation it may be assumed as a constant magnitude for all close binaries. So the roundchrom seems to be a formation too homogeneous for all RS CVn-type close binary systems.
Roundchroms have been already constructed, including the determination of all physical and geometrical parameters, for more than 40 RS CVn-type close binary systems (Gurzadyan 1997a,b): for all of them the known radii of components have been used practically without any changes.

The main aim of the present study is to show that the application of the roundchrom concept can also act as a tool for the revision of some parameters, particularly the radii of the primary. Thus, the 15 objects with revised radii examination in the present articles are a special selection.

5 ABOUT THE OPACITY OF THE ROUNDCHROM IN MAGNESIUM EMISSION

At the linear diameter of the roundchrom ~ 10 R⊙ around wavelengths analogous with, e.g., the emission line 303.78 Å, the roundchrom is an opaque medium for resonance lines of ionized magnesium. However, this circumstance, as may easily be shown, does not prevent the escape of all Mg II photons generated in the interior of the roundchrom.

The magnesium ion Mg II possesses three interesting properties.

(a) The Mg II ion does not have metastable levels, does not produce forbidden lines and, hence, does not take part in the cooling process of the medium.

(b) The photons k (2795) and h (2803) Mg II cannot be utilized at the Bowen fluorescence process, i.e. for the realization of the transitions by other ions (atoms) with the same wavelengths analogous with, e.g., the emission line 303.78 Å, which may be used (at least in principle) for the realization of the transitions \( ^3P_2 \rightarrow ^3P_0 \) [O III] with 303.80-Å effective wavelength.

(c) Resonance photons k and h Mg II cannot be split into 2γ photons in the same way that \( L_γ \) photons of hydrogen allow the escape of two photons of arbitrary wavelengths (in the region of \( \lambda > 1216 \) Å) after a definite number of acts of pure scattering (Gurzadyan 1997c).

The last property (c) is of special importance. This means that in any medium that is optically thick in Mg II lines, k and h Mg II photons may test an infinite number of acts of pure scattering without any losses (in the absence, of course, of dust particles).

Further, in contrast to the Sun’s chromosphere, the roundchrom (which has a spherical form) is completely open and is homogeneous from all sides, and although the optical depth in Mg II lines is very large, the photons h and k Mg II, after testing an infinite number of acts of pure scattering into the roundchrom, should sooner or later leave the medium (e.g. the roundchrom). All Mg II photons generated in the roundchrom, independent of its optical depth, should escape without any losses. Having in view very high electron concentrations in the roundchrom as compared to the nebulae, the relaxation time does not play any role here.

The possibility of detecting all Mg II photons born in the roundchrom should be considered one of the interesting properties of roundchroms as a physical formation.

One more argument: very large turbulent velocities in the emission medium – up to 150–200 km s\(^{-1}\) and more recorded for the emission medium practically in all RS CVn-type systems – is a factor well known to favour a strong increase in the transparency of the emission medium.

Thus, the number of Mg II photons born in the interior of a roundchrom accounts for the complete luminosity of the system in Mg II lines. A roundchrom is an ideal medium for pure scattering processes for Mg II photons.

Practically all observed Mg II emission would originate from an extended region around the secondary, therefore the examination of Mg II light curves for eclipsing systems may give observational evidence for this prediction. This can be the subject of a separate study.

6 THE DEPENDENCE OF ELECTRON CONCENTRATION ON INTERCOMPONENT DISTANCE

In Fig. 6, a relationship is drawn between \( n_e \) and \( a \), according to the data of three groups of RS CVn-type systems summarized in Table 5. The first group consists of seven objects with \( P \approx 0.6–25 \) d (Gurzadyan 1997a), the second group of 12 objects with \( P \approx 0.7–60 \) d (Gurzadyan 1997b), and the third group is the 15 objects from Table 3 of the present article with \( P \approx 1–110 \) d, making 34 binaries in total, all of RS CVn type. The scatter of the points in Fig. 6 seems to be real and is caused, apparently, by various relative sizes of the radius of the secondary components compared with the radius of their Roche lobes.

Although the mean value of electron concentration seems to be the same and of the order of \( 10^{10} \) cm\(^{-3}\), at least in the limits of one order of magnitude for all roundchroms


Figure 6. Empirical relationship between the electron concentration \( n_e \) in the roundchrom and the intercomponent distance \( a \) (in units of solar radius R⊙) according to the data for 34 close RS CVn-type binaries.
with extremely wide limits of roundchrom volumes, the existence of a real variation in the limits of an order, i.e. in $n_e \sim (1-10) \times 10^{10} \text{ cm}^{-3}$, as follows from Fig. 6, also seems to be real. Then we can derive from Fig. 6 for the dependence of $n_e$ on the intercomponent distance $a$ approximately

$$n_e \sim a^{-0.85}. \quad (10)$$

However, with the appearance of additional data the numerical value of the index in this relationship may be changed slightly.

7 ON THE OBSERVATIONAL LAW OF MAGNESIUM EMISSION

In Fig. 7, a graphic picture of the relationship between the observed magnesium luminosity $L(\text{Mg} \, \text{II})$ and the roundchrom intercomponent distance $a$ is presented, using more or less carefully collected data for 53 RS CVn-type binary systems. The list of these systems is presented in Table 6 with the adopted intercomponent distances $a$, distances from the Sun $D$, and luminosity in magnesium emission $L(\text{Mg} \, \text{II})$. The distances $D$ are chosen from among the existing estimations, taking that which seems most probable for each given case (Drake, Simon & Linsky 1989; Strassmeier et al. 1993; Basri et al. 1985; Stewart et al. 1987). The observed 2800 Mg II fluxes $F(\text{Mg} \, \text{II})$ are from Basri et al. (1985), Budding, Kadoure & Gimenez (1982), Oranje (1986) and Schrijver & Swann (1991).

Some of these systems, i.e. UV Leo, A Tri, HD 102077, $\theta$ Dra and I Gem, have not been included in the Strassmeier et al. (1993) catalogue. The data for these objects were collected from the above-mentioned sources and their roundchroms have been constructed separately (Gurzadyan 1997a). In the upper right corner of Fig. 7 the position of 22 Vul -- a binary system with a gigantic roundchrom for which $a = 318$ $R_\odot$ -- is shown as well, according to early results obtained for this extremely interesting and extraordinary system (Gurzadyan 1997b).

As follows from Fig. 7, the existence of a dependence -- even if too strong -- between the magnesium luminosity $L(\text{Mg} \, \text{II})$ and the intercomponent distance $a$, in the form of a relatively narrow belt, seems to be obvious: the larger the intercomponent distance $a$, the larger the magnesium luminosity $L(\text{Mg} \, \text{II})$ should be for any close binary system with a known intercomponent distance $a$. The central position of this relationship may be presented in the form

$$L(\text{Mg} \, \text{II}) \sim a^{1.66}.$$
\[ L \left( \text{Mg II} \right) = 2.92 \times 10^{25} a^{1.56} \, \text{erg s}^{-1}, \]  
where \( a \) is expressed in the units of solar radii.

Thus the observed magnesium emission in RS CVn-type systems strongly depends on the intercomponent distance \( a \), according to the law

\[ L \left( \text{Mg II} \right) \sim a^{1.56}. \]  

It should be noted that \( L \left( \text{Mg II} \right) \) does not depend, say, on the radius of the main (cool) component \( R_o \) of the system; in this case the source of magnesium emission may easily be identified as the chromosphere of this component.

The discovered dependence of \( L \left( \text{Mg II} \right) \) on the intercomponent distance \( a \) should be interpreted as a direct confirmation of the non-chromospheric origin of this emission, e.g. that this emission is generated in a medium, the volume of which depends on the intercomponent distance only; such a volume may be the roundchrom.

From equation (3) we can write, at first approach, \( V \sim a^3 \) if we neglect the second term with the radii of the components. Then we can derive from (7), for observed luminosity \( L \left( \text{Mg II} \right) \) in combination with equation (12),

\[ L \left( \text{Mg II} \right) \sim a^{1.30}, \]  

which differs from the law in equation (12), thus confirming the importance of the second term in equation (3) in calculations of the emitting volume of the roundchrom.

8 ABOUT STARSPOTS

We now briefly address the role of starspots. The existence of a correlation between stellar spots and chromospheric activity seems to have some observational confirmation. The main conclusion of these investigations (see, for example, Engvold et al. 1988) results in a ‘spotted’ interpretation of the entire set of observations, in that the starspots are analogous to sunspots but have considerably larger sizes, being the centres of magnetic active regions on the stars and the sources of all types of enhanced emission, exceeding the corresponding solar values by the order of 10–100 times.

Realizing that there is nothing to rule out the formation of a large group of starspots, note that the ‘spotted’ interpretation, particularly for observed ultraviolet emission, is quite descriptive without having any quantitative calculations or even estimations. In all cases the problem concerning the mechanism by which enhanced chromospheric emission is generated remains, as before, open.

Incidentally, the relations of particular authors to the ‘spotted’ concept, particularly Engvold et al. (1988), is no more than a ‘working hypothesis’.

It is impossible to find a quantitative demonstration that the active regions may be a source of enhanced or strongly enhanced Mg II doublet emission. If the regions are the regions with increased ionization and enhanced emission in the high excitation lines (C IV, N V, Si IV etc.), then we should also expect to find magnesium in the state of Mg II and higher (for details of the formation of these lines in various conditions see Gurzadyan 1997c). The active regions cannot be a source of strongly enhanced emission in the low excitation lines in general or of Mg II emission in particular. Enhanced Mg II emission needs a large emission volume, at least of an order as large as the effective volume of the proper chromosphere; such a medium may be the second half of the roundchrom – around the secondary of the system.

It seems that these two concepts, the starspots and the roundchrom, may be connected or even joined if we follow the suggestions that (1) the region of starspots is at the same time the region of the outflow of gaseous matter in the direction of the Lagrangian point \( L_2 \), and (2) that the orbital rotation of the system is synchronized with the axial rotation of the main component. The roundchrom is symmetrical relative to the \( OX \) axis but not to the \( OY \) axis, therefore a periodic screening by the main component of the most effective part of the roundchrom connected with the space around the secondary component should become inevitable. This is another correlation between the stellar spots and the chromospheric emission.

As to the synchronization of rotations, according to Middlekoop & Zwaan (1981), giants in binary systems with periods less than 120–200 d will be synchronized; Middlekoop (1981) argued that this limiting period is closer to 10 d for dwarfs in such binaries.

9 CONCLUSIONS

(a) The formation of roundchorms in close binary systems is inevitable.

(b) The roundchrom is an independent physical formation for binary systems in the same way as are the corona and the chromosphere for single stars.

(c) The roundchrom concept may be used as a means for the study of binary systems, particularly for the determination of the radii of their main components.

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