OPTICAL POLARIMETRY OF SYMBIOTIC STARS

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ABSTRACT. A review of some physical mechanisms that may give rise to detectable optical polarization in symbiotic stars is presented, emphasizing the ability of polarimetry in studying the evolution of dust envelopes, the atmospheric structure of the cool component and the geometry of these systems. A brief summary of the techniques is also given. General polarimetric properties of symbiotics as well as data for a few specific systems are discussed. Proposed models for symbiotics that include the prediction of their polarimetric properties are highly encouraged. Specific suggestions for future work from the ultraviolet through the infrared and which explore the potential of the technique are advanced.

1. INTRODUCTION

For a given object, astrophysical data which have been mostly obtained up to now concern, in a given spectral domain, the intensity as a function of wavelength and time. However,one can typically not afford to throw away information encoded in the other three Stokes parameters, even in the case of symbiotic systems, where the fully application of polarimetric techniques is still in its beginning stages. Symbiotic stars show indeed great potential for such studies due to their gaseous/dusty nebulae and circumstellar environment coupled to asymmetries in the system. Polarimetry can bring information on physical processes and geometry in these systems and provide additional constraints on the models proposed for these objects.

In the next paragraphs, we first outline a few basic polarimetric techniques, followed by an assestment of the physical processes that may originate optical polarization in symbiotic stars. We then move on to the yet unclosed topic of the general polarimetric properties of symbiotic systems and discuss a few objects in some detail. A final section is devoted to suggestions for future work.

Recent, related reviews have been also presented by Aspin and Schwarz (1987) on symbiotics and by Magalhães (1987), Willson (1987)

J. Mikolajewska et al. (eds.), The Symbiotic Phenomenon, 89–100.

and Schwarz (1986) on luminous late-type giants. Please also refer to the more specific papers by Schwarz et al. (1987), Rodrigues (1987), Kudiakova (1987) and Gershberg and Shakhovskoy (1987) elsewhere in this volume, as well as Piirola (1987). The proceedings of the Vatican Conference on Circumstellar Polarization (Coyne et al. 1987) also carry several other papers of interest in this and other related fields.

Rather than attention to a complete list of observational details, we chose to emphasize here the physical mechanisms that might be present in symbiotics, which type of information, as exemplified by some data, optical polarimetry might bring us and how new observations might lead us into further insight into symbiotic systems.

2. POLARIMETRIC TECHNIQUES

Light can be more generally regarded as being partially elliptically polarized, that is, a mixture of natural (unpolarized) light and completely polarized light. The four parameters, which form the so called Stokes vector (I,Q,U,V), correspond to the need of four quantities (size, shape, orientation and sense of rotation) necessary to fully describe the polarization ellipse. For instance, for unpolarized, circulary polarized and linearly polarized light, we would have (I,0,0,0), (I,0,0,V) and (I,Q,U,0) respectively; fully linearly polarized light, say, would have $(Q^2 + U^2)^{1/2} = I$. In general, $I \geq (Q^2 + U^2 + V^2)^{1/2}$. Also, I, $Q^2 + U^2$ and V are invariant under a rotation of the coordinate system. In fact, $P = (Q^2 + U^2)^{1/2}/I$ and V/I are referred to as the degrees of linear and circular polarization, respectively. For a throuhg discussion of all these concepts, the reader is referred to Clarke and Grainger (1971). Most of this review will concern optical linear polarization.

The basic polarimetric technique is to modulate the beam with optical components which change the state of polarization in a known way. For instance, the light intensity passing through first a half-wave plate oriented at position angle ψ and a double beam analyser at position angle 0^o is (Serkowski 1974a):

$$I'(\psi) = \frac{I}{2}\left[1 \pm (Q \cos 4\psi + U \sin 4\psi)\right],$$

allowing determination of Q and U (say, through least squares) if measurements are made through ψ. The advantages of observing the two orthogonally polarized beams leaving the analyser are the economy of light and possibility of overcoming atmospheric (and other) effects. Measurements with a quarter-wave plate in the beam, in place or together with the half-wave plate, will allow also a determination of the circular polarization. Please refer to papers on instrumentation presented by Coyne et al. (1987) and Magalhães and Velloso (1987).

An important thing to bear in mind is that polarimetry requires typically relatively high precision, by normal photometric or spectrophotometric standards, usually much better than 0.1% and according to one's objects and aims: whether determining wavelength dependence, differences between continuum and spectral features or time variability. Much of this need is of course due to the low values of polarization often found. Nevertheless, many polarimeters have now been built which are basically photon noise limited. Even with such equipment however, information does not come for free and polarimetry typically means long integration times, even for relatively bright objects!

Now, a word about interstellar polarization, which is typically superimposed on the measurements. A good way to separate the effects is via a QxU plot, as discussed, for example, by Serkowski (1970). For instance, the superposition of an intrinsic polarization with an interstellar one give in general an observed wavelength dependent position angle, with the two planes of symmetry more apparent in such a plot. Frequently, in fact, the intrinsic position angle is itself wavelength dependent (section 5). One can estimate the interstellar component at distinct wavelengths by observations of nearby stars and assuming a typical wavelength dependence for the interstellar grains. Of course, if one is interested only in differences in polarization between close spectral features, interstellar polarization will not hide them.

3. SOME PROCESSESS THAT MAY CRIATE POLARIZATION IN SYMBIOTICS

Basically, scattering processes are in principle bound to be related to most polarimetric observations in symbiotic systems. Among them, we can cite:

- molecular scattering: cool star's atmosphere (TiO, H_2)
- dust scattering: cool star's envelope, system's envelope
- resonance scattering: cool star, emission lines.
- electron scattering: disk/jet around hot component.

Below, we discuss evidences for each process and lay the background for the remaining sections.

In complex systems like the symbiotics, one may perhaps gain insight into details of some physical processes by studying the individual components, although the interaction among them is of obvious importance. In the case of symbiotics, we can start by looking at the cool companion, which shows at least the first three effects mentioned above. Incidentally, single Luminous Late Type Variables (LLYV's) have been among the first objects to be detected with large and variable polarization. Please refer to Magalhães (1987) for a review of this still evolving field.

Observationally, the optical polarization in LLTV's typically decrease with wavelength, which is normally taken as indicative of Mie (grains) or Rayleigh (small grains, molecules) scattering. Sometimes , temporal correlations between P and brightness exist, as illustrated by V CVn (Coyne and Magalhães 1977), where maximum polarization occurs close to minimum light. Basically, the models that were put forward involve scattering in an non-spherically symmetric circumstellar dust cloud (Kruszewski et al. 1968, Shawl 1975) or photospheric scattering, coupled with an asymmetry across the stellar disk (Harrington 1969).

One of the observational points that would lead more or less naturally to dust scattering models was the rather strong correlation between the average optical polarization and the infrared excess (Dyck et al. 1971a). While it is true that newer observations of highly reddened objects show sometimes large, variable polarization in the near infrared (McCall and Hough 1980) and that multiple dust scattering in such kind of objects is also evidenced by circular polarization measurements (Angel and Martin 1973), Forrest et al. (1975) have not observed significant changes in the [L]-[0] colour while the objects were simultaneously polarimetrically variable. I think is important to stress here that, in the optical, where scattering dominates, one tend to 'see' the effect of smaller grains (say, around a tenth of a micron, if dielectrics) while, since thermal emission is proportional to the mass in the form of dust, in the IR we tend to see the larger grains, presumably further out from the star.

Actually, long term polarimetry may turn out to be very important as a more or less direct probe into the evolution of dust envelopes around LLTV's and, I believe, around symbiotics as well. Data of over a decade for L_2 Puppis (Fig. 1; Magalhães et al. 1986b) show that symmetry of the envelope approached that observed in the IR many years earlier, at which time the wavelength dependence of the polarization indicated increasingly larger grains. For comparison, the variable's period is only 141 days.

Photospheric scattering predicts changes in polarization across the object's spectral features. Higher spectral resolution observations showed that molecular scattering in the photosphere of these late-type stars is indeed one of the ingredients in producing their observed polarization (Landstreet and Angel 1977; McLean and Clarke 1977; Coyne and Magalhães 1977). Interestingly enough, some stars may show enhanced polarization across an observed absorption feature like a TiO band (Coyne and Magalhães 1979; Magalhães et al. 1986a) without position angle rotation. In the framework of Harrington's model, this fact has been interpreted (Magalhães 1981) as a subtle combination of the ratio of absorption to scattering as a function of optical depth coupled with a stronger gradient of the source function at the band depth. As we shall see in section 5, symbiotics may indeed show changes in polariation across TiO bands and other features.

Which asymmetries over stellar disk may give the necessary polarization? Harrington (1969) suggested non-radial pulsations or temperature variations across the stellar surface. Coyne and Magalhães (1979) suggested that even a very slow rotation may induce systematic pole-to-equator temperature differences, due to von Zeippel's theorem. Data for L_2 Puppis, across the CaI 4226 line led Codina and Magalhães (1980) suggest that these star might show spots as seen at that wavelength, causing the polarization to vary across that line. Clarke and Schwarz (1984), Doherty (1986) and Lefevre (1987) also considered a spot model to explain the observations of LLTV's. A fully, consistent treatment of the radiative transport of light leaving a spherical, eventually spotty, photosphere showing limb polarization, with further scattering by a dust envelope, is certainly needed.

Coyne and Magalhães (1977) first proposed, based on their

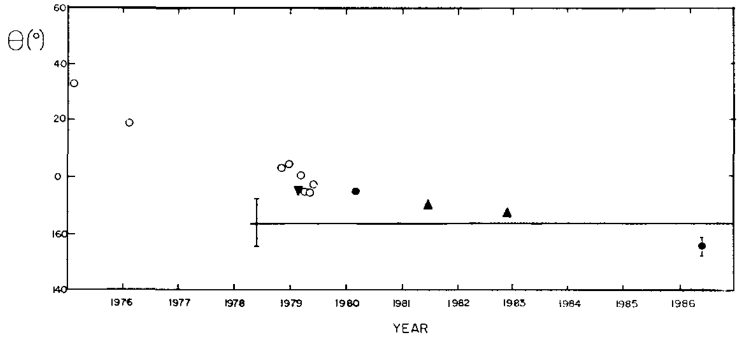
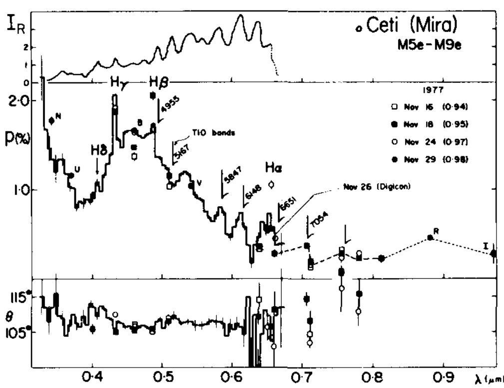


Fig. 1. Visual polarization position angle for the red variable L_2 Pup. The scattering cloud evolves towards the geometry given by infrared measurements (solid line) (Magalhães et al. 1986).



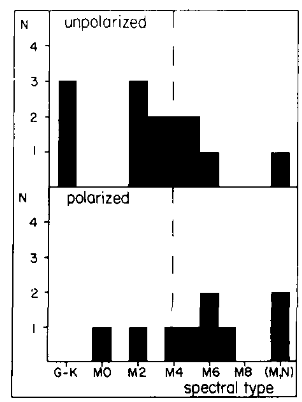


Fig. 2. (left). Spectropolarimetry of Mira near maximum light (McLean and Coyne 1978), showing polarization changes across spectral features and an increase into the UV.

Fig. 3. (right). Distribution of polarized and unpolarized symbiotics according to the spectral type of the cool companion (Schulte-Ladbeck and Magalhães 1987).

narrow-band observations, that fluorescence scattering (of which resonance scattering is a particular case) would produce higher polarization than in the continuum across certain spectral features, like hydrogen emission lines. In LLTV's these lines result which from a schock front moving outwards during portions of a late-type variable's cycle (e.g., Wallerstein 1975). While more quantitative and observational work are definitely needed, recent models of Willson, Bowen and collaborators (see Willson 1987 for a review) also predict this effect. Higher resolution data by McLean and Coyne (1978) of Mira (o Ceti) may indeed be taken as indicative that this process in indeed operative. Fig. 2, from these authors, is instructive in showing several of the features mentioned above and which are typical of the polarization in late-type variables, including an eventual 'dip' in the UV which might be due to additional molecular opacity (Coyne and Magalhães 1979).

Finally, the literature on electron (Thomson) scattering polarization is far more extensive and will not be reviewed in detail here. The mechanism can perhaps be more easily understood, however, as it results basically from scattering off ionized, non-spherically symmetric (disks, jets, streams) distributed material surrounding the star. Be stars are a classical example (Coyne and Kruszewski 1969), with the wavelength independent mechanism modified by emission and abosrption effects in the plasma. Rudy and Kemp (1978) and Brown, McLean and Emslie (1978) showed how one can derive parameters like the inclination of a binary system from the modulation on the polarization curve as a function of the phase. This effect has been also explored in the context of binaries containing Wolf-Rayet stars (Drissen et al 1987; Meliani et al. 1987).

4. GENERAL POLARIMETRIC PROPERTIES OF SYMBIOTICS

As we have seen, scattering mechanisms and asymmetries present may induce polarization in symbiotics and provide insights into many physical processes. Many basic questions still need answers, however: how common is polarization among symbiotic systems? Which is its wavelength dependence, origin and time variability? Are there correlations with other observed properties (spectra, IR type and so on)? Can we discriminate against competing models for symbiotics? As we shall see below and in the next section, the answers to most of the questions are still being actively pursued.

In the search for the general properties of symbiotics, Schulte-Ladbeck (1985) has presented the results of a survey of northern symbiotics. She found intrinsic polarization to be present in several objects among 18 northern symbiotics and relations possibly existent between the presence of intrinsic polarization and the spectral type of the late-type star and between the presence of intrinsic polarization and IR type. All this would suggest that dust scattering is responsible for the observed polarizations. One should note that a possible lack of variation of the polarization across a particular TiO band would not by itself be indicative of dust (as opposed to photospheric) scattering because, from single variables' studies, this effect is likely to both depend on the particular band and time (Coyne and Magalhães 1979). R Aqr (section 5) seems indeed to confirm this.

A 'southern extension' of such work has recently begun (Schulte-Ladbeck and Magalhães 1987), with 9 out 23 symbiotic stars then showing detectable intrinsic polarization. Polarized symbiotic stars are observed at a slightly higher frequency when the associated cool companion is of spectral type later than M4. This is illustrated in Fig. 3, confirming, to the extent that the available data allow, the earlier finding of Schulte-Ladbeck (1985). Concerning a possible correlation with IR type, of the total sample then available there were 16 S-type objects (with 4 polarized) and 6 D-type (with 5 polarized), the probability of observing such number of intrinsically polarized D-type stars being only about 3%.

The distribution of symbiotic stars in colour-colour diagrams has been also investigated by Schulte-Lacbeck and Magalhães (1987) employing IRAS colours. The IR types were formerly defined by their H-K indices (Allen 1982) but it is illustrative to notice the striking separation that the IRAS data allow, a fact independently noticed by Whitelock (1986). Remarkably, R Aqr stands among the S-type objects in such diagrams. Intrinsically polarized objects are found among in both S- and D-types among the IRAS diagrams.

The survey referred to is being presently undertaken at telescopes at ESO, Hawaii and Brazil (Schwarz et al 1987). In order to cover a great number of objects, a search for a difference between the polarization at the broad R filter and an Hα filter is undertaken. Together, whenever possible, with time variability between distinct epochs, they should give a good indication of how frequent is the presence of intrinsic polarization among symbiotics, allowing statistical studies on a wider and more signficant basis.

5. OBSERVATIONS OF SPECIFIC OBJECTS

With the physical processes discussed above as a background, we now resume some of the observational results on specific symbiotics.

5.1. CH Cyg, CI Cyg and AG Peg

Piirola (1982, 1983) has detected variable linear polarization in these S-type symbiotics (Fig. 4). In 1978, the polarization has increased sharply into the ultraviolet, with very small values in the red and infrared. In early 1978 and May 1980, Piirola notices the appearance of a red component, which leads to a rotation of the position angle with wavelength, with the polarization of this red component increasing into the infrared. In 1981, this component had again disappeared, with the polarization then peaking around the B filter. All these facts may be taken as indicative of changes in the dust size distribution and its geometric distribution, the red/infrared observations suggesting grains with size around 1 μm and a change in size from 0.05 μm to about 0.1 μm to explain the optical/UV data.

Piirola (1983) has also obtained data for CI Cyg and AG Peg. For both objects, a strong rotation of position angle with wavelength is observed, confirming the presence of intrinsic polarization. Moreover, he notes a discontinuity in the $\theta(\lambda)$ curve around the wavelength at which the hot spectrum emerges, evidencing the need for a model where the hot or the cool component dominates, according to wavelength, with the steep increase into the blue for CH Cyg indicating that light from

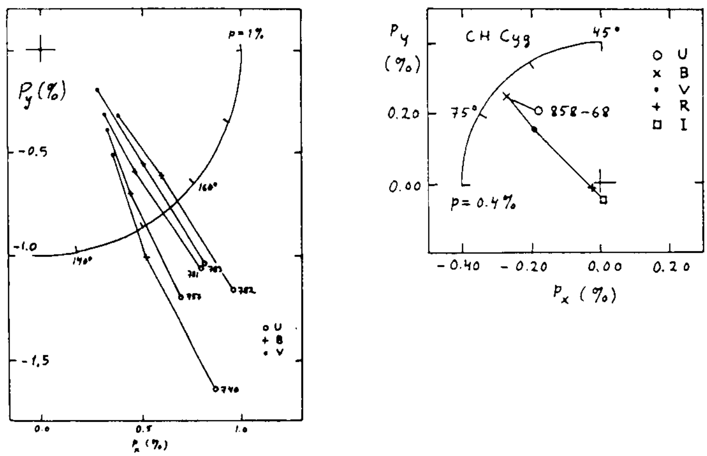
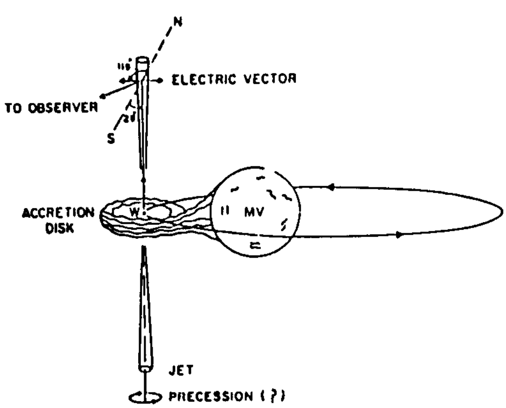


Fig. 4. QxU plots of polarization data for CH Cyg in September 1978 (Piirola 1982, left) and September 1981 (Piirola 1983, right), showing changes in geometry and mean particle sizes as the observed polarization maximum shifts from the U to the B band.



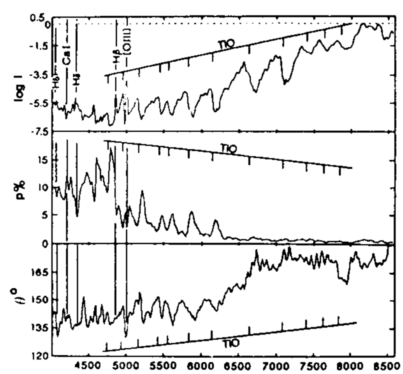


Fig. 5. (left). A model for R Aqr (Deshpande et al. 1987), where the UV polarization arises from light from the subdwarf W scattered off the jets and the RI polarization comes from a scattering shell around the mira variable MV.

Fig. 6 (right). Spectropolarimetry of R Aqr (Aspin et al. 1986), showing changes across spectral features and overall rotation in position angle with wavelength.

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the hot source is being scattered in the cool giant's envelope. Piirola (1987) presents extensive polarimetry of CH Cyg (and other northern symbiotics) from 1978 through 1986, allowing dust formation and evolution in the circumstellar envelope to be monitored.

Whenever possible, (quasi) simultaneous near IR polarimetry would be highly valuable, as the grain size distribution evolves and its effect is likewise felt also in that wavelength range.

5.2. HM Sge

Data presented for HM Sge by Efimov (1979), gathered in 1977, show varaibility on a time scale of months. The intrinsic polarization increased into the red, indicative of relatively large (0.2 μm, if silicate) grains. Schulte-Ladbeck (1985) has observed similar wavelength dependence, albeit at a distinct polarization level. She notes that the strong line emission of the object might dilute the polarization in the UBV region. As also noted by her, HM Sge is a prime target for high resolution spectropolarimetric studies, which would be valuable in deriving the relative geometry between the line emission and scattering regions.

5.3. R Aqr

This is polarimetrically the best observed (and least understood?) symbiotic so far. Schulte-Ladbeck (1985), who presents 1983 data and lists references up to that date, finds a very strong increase of the polarization into the UV, indicative of Rayleigh scattering. Also, a relatively strong wavelength rotation of the position angle indicates that the circumstellar material scatters the light from the two stars.

Deshpande et al (1987) present further, more recent (1984) observations and clearly deserve merit for advancing a concrete model. Employing earlier data from Serkowski (1974b) and Schulte-Ladbeck's, the authors confirm the very large increase in polarization into the UV, small variation in $\theta(U)$ around 120 degrees and large variations in both polarization and position angle in the VRI filters. They propose a model in which a white sub-dwarf dominates the ultraviolet light which is scattered off a precessing jet (Fig. 5), while in the VRI region the Mira companion dominates. They note that the relative constancy in the UV position angle does not support the model of Spergel et al (1983), where discrete clumps that form in the mira's wind are eventually excited by the UV flux from the hot companion.

The situation may by bound to be more complicated, however. Aspin et al (1986) present spectropolarimetric data of November 1983, which show a great number of details (Fig. 6): increases in polarization across TiO bands and decreases across the [OIII] and Balmer lines, position angle changes across these features, an overall rotation in $\theta(\lambda)$ and an increase in polarization across the CaI 4226 line. Their preliminary interpretation call for two or more mechanisms giving rise to the observed polarization, with the possible existence of both spots on the cool stellar companion and resonance scattering at the

CaI line. Time dependent spectropolarimetry of R Aqr should clearly be of immense value.

Schwarz and Aspin (1987) analyse long (17 years) trends in the R Aqr data. They find large variations in the polarization in the blue , as opposed to small ones in the red, with some dilution due to the [OIII] line. They note that the variations in the position angle in UVR are quite strong; I believe this latter point poses the need for some modification to Deshpande et al's picture, which is based on a relatively small variation in $\theta(U)$. Schwarz and Aspin note that, contrary to o Ceti itself, maximum polarization occurs at minimum light. As we saw in section 3, however, this behaviour is similar to other late-type variables.

As a final remark, I would like to mention that, in view of the electronic densities (10^6 cm^{-3}) observed in R Aqr's jet (Schwarz and Aspin 1987; Michalitsianos and Kafatos 1987), an optical depth for Thomson scattering of the order of, say, 0.1 would require a rather large ($\sim$ 0.05 pc) physical path, if the jet is to be responsible for part of the observed polarization in R Aqr.

6. CONCLUDING REMARKS

Symbiotics do offer several sites for scattering of optical radiation as well as the needed asymmetries. Judicious polarimetry can hence prove useful in several respects, probing the evolution of dust envelopes, the atmospheric structure of the cool component and the geometry of particular systems. In this regard, theoreticians and observers alike should try to make an effort in predicting the polarization properties of their models, given the high accuracy of polarimetric measurements nowadays possible; models with such predictions should clearly be at an advantage as compared to others and could be more readily refined.

We have here not discussed magnetic processes such as the ones that can take place near the surface of a magnetic white dwarf. An accretion disk would tend to observationally swamp such effects but these merit a closer look, for instance through circular polarimetry.

Polarimetry may also help discern between competing models for symbiotics, as we have seen. Also, polarimetric data as a function of phase for eclipsing systems like AR Pav and SY Mus, when screening of the hot component by the cool component occurs, should furnish a more direct (and perhaps the only one) evidence for disks, information on geometry and on the density and type of scatterers.

In other instances, spectropolarimetry might prove highly valuable in unravelling the relative positions of the emission line regions of some systems as well as probing into the cool companion's atmosphere through observations across features like TiO bands and resonance lines.

Finally, models of resonance line profiles from accretion flows (Tylenda 1987) have been constructed. My suggestion here is that resonance scattering in emission lines are bound to produce detectable polarization across these features. Observations with the forthcoming

Space Telescope's Faint Object Spectrograph, in its polarimetric mode, should yield a good deal of information and constraints on the geometry and physics of the emission line regions in symbiotic systems.

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