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Luminous MS Stars in the LMC

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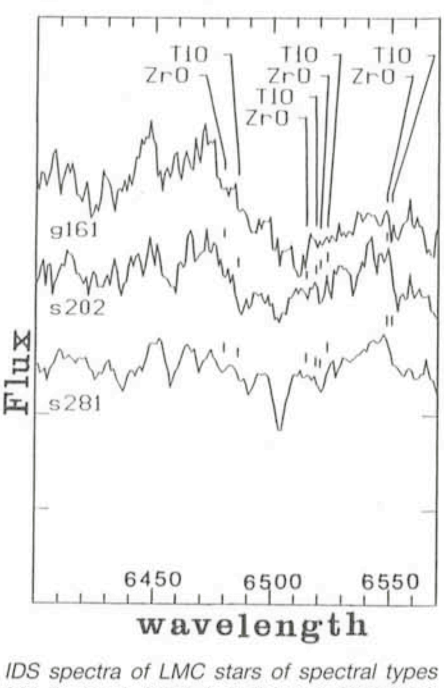
IDS spectra of a sample of stars selected from the M supergiant and M giant catalogue of Westerlund et al. (1981) have been obtained with the 3.6-m and 1.5-m telescopes. The sample covers the luminosity range from M(bol) = −9 down to M(bol) = −4. The most luminous stars are massive supergiants, while the less luminous ones are asymptotic giant branch (AGB) stars.

AGB stars are known to dredge up processed material to the surface. This produces carbon stars from oxygen-rich (M-type) stars. If the amount of material mixed to the surface is not large enough to transform the star into a carbon star, then the star becomes an MS, S or SC star. The spectral sequence M, MS, S, SC and C is an abundance sequence measuring the carbon-to-oxygen ratio. Thus MS stars have experienced some mixing and have a modified C/O ratio while M stars have not. For further details, the reader is referred to Iben and Renzini (1983) and references therein.

The MS and S classification is based on the strength of the ZrO bands, the strongest at 6473 Å. On the classification system of Keenan and Boeshaar (1980) the class MS is reserved for stars which have only slightly enhanced ZrO bands. Stars with stronger ZrO bands are called S-type. Abundance classes for S-type stars are determined from ZrO to TiO band-strength ratios.

When analysing the IDS spectra, particular attention was given to the strength of the ZrO bands. A number of S-type stars were easily found. To detect weaker enhancements in an unambiguous way, the strengths of the bands were measured by integrating the spectra in well-defined windows. Stars with luminosities around M(bol) = −6 and with types later later than around M2 were found to have slightly stronger 6473 (ZrO) features than more luminous M supergiants. Classification criteria used by Lloyd Evans (1983) indicate that this enhancement is enough to classify them as MS stars. Figure 1 shows spectra of three stars in the region of the 6473 band. The stars are from bottom to top: an M supergiant with M(bol) = −7.9, an MS star with M(bol) = −6.3 and an S star with M(bol) = −4.8. The strengths of the ZrO bands are seen to be stronger in the MS star than in the M star and, of course, much stronger in the S star. The stars are fairly close in temperature type.

In order to certify the MS classification, a number of classification standards of types M, MS and S were observed with the RETICON on the 1.5-m telescope in December 1986. The spectra cover the region from 5000 Å to 10000 Å. The dispersion is 228 Å/mm. The preliminary analysis of these spectra indicates that a few stars with 6473 features like the luminous MS stars in the LMC are found among the M-type classification standards. Thus, either the luminous MS stars are M-type or the M-type standards are actually type MS. Since MS and S-type stars frequently have a history of having once been



IDS spectra of LMC stars of spectral types M3 (bottom), M3S (middle) and S3/3 (top). The spectra are normalized to the same flux and the zero-points marked. The position of some TiO and ZrO features are indicated.

classified as type M and, when classifying in the blue spectral region, slight ZrO enhancements are easily overlooked, the latter explanation seems likely. To complicate matters further, the number of MS standards is very small and at least some of them have variable abundance class.

From their position in the colour-magnitude diagram, the MS stars are estimated to have masses around 5 $M_\odot$. Most of the carbon stars in the field investigated by Wood et al. (1983) were found to have pulsational masses around 1 $M_\odot$. The luminous J-type (^{13}C-rich) carbon stars (Richer et al. 1979) probably represent higher masses. The J-type carbon stars are known not to have enhanced s-process element abundances while the N-type, non-J, carbon stars have this enhancement. Unfortunately, s-process element abundances are not available for the MS stars but would be very useful in determining the relation between the two groups of carbon stars and the MS stars. This relation is at present not clear, but the MS stars are more massive than the bulk of ordinary N-type carbon stars and may be more closely related to the luminous J-type carbon stars.

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HD 187474: the First Results of Surface Magnetic Field Measurements

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1. Introduction

The upper main-sequence chemically peculiar stars (CP, see Preston 1974) were the first non degenerate stars definitely showing magnetic field with large scale structure. The magnetic field usually observed in CP stars is dipolar. More complicated structures are perhaps present, but their contributions are certainly smaller (Landstreet, 1980). As the star rotates, the visible hemisphere changes and magnetic field variations are observed. The magnetic field seems to play an important role in the physical phenomena occurring in the magnetic CP stars (diffusion, blanketing, structure of the atmosphere, . . .), and a better knowledge of it is therefore important for our understanding of the CP phenomenon.

The magnetic field is detected through the splitting of a line into several components: π components are symmetrically displaced around the central wavelength λ_o, while σ components are displaced to shorter or longer wavelengths. In the most simple case, the line is split into a triplet pattern with three components: one undisplaced π component and two symmetrically displaced σ components. These components are also polarized and their polarizations depend on the magnetic field orientation.

The mean displacement of the σ components from the central wavelength λ_o is given by:

$$\Delta\lambda = 4.67 \times 10^{-13} zB\lambda_o^2 \qquad (1)$$

for wavelength expressed in Å; z is the mean Landé factor of the σ component and B is the magnetic field in gauss. The mean Landé factor of the σ components z is also called effective Landé factor (geff). It appears immediately that this displacement is very small, of the order of 100 milliangström per kilogauss at 5000 Å for z = 1. Generally it is smaller than broadening due to other mechanisms (thermal, collisional broadening), the most important and unavoidable one is the rotational broadening.

The splitting measured in circularly polarized light gives access to the average longitudinal magnetic field, also called "effective" magnetic field (Heff). It is the average on the visible hemisphere of the magnetic field projection on the line of sight. One advantage of this method is that by recording separately the right and left circularly polarized light, small relative displacements of the same line, between the two spectra, can easily be detected. Several different methods of circular polarization measurement across spectral lines have been used to deduce stellar effective magnetic fields (Landstreet, 1980).

The splitting measured in unpolarized light gives access to the surface magnetic field (Hs), which is the average magnitude of the field over the visible hemisphere. The Hs value is then deduced from the displacement observed on classical spectra. It is difficult to measure and very often the Zeeman pattern of the lines are not resolved in stellar spectra.

It is a pity, because Hs values are more representative of the magnetic energy and less sensitive to the field geometry than Heff values. And Hs is certainly more suitable to study the influence of the magnetic field on other stellar characteristics (rotation, abundances, ...), or the correlation with parameters of interest in CP stars (photometric index of peculiarity for example). Moreover, the knowledge of Hs variation, in addition to that of Heff, is necessary to get a better idea of the field geometry.

2. Method and Data for Surface Magnetic Field Measurements

As said above, the displacement of the magnetic component is very small and Resolved Zeeman Pattern (RZP) can be observed only in the most favourable cases, at least in slowly rotating stars (Vsini < 10–20 km/s). Although CP stars rotate more slowly than main-sequence stars of the same spectral type, the sample where Hs can be measured directly from resolved splitting is limited.

Few CP stars (34) have been measured for Hs, among them only 12 show RZP (Didelon, 1983). Extensive Hs measurements along the whole period of variation are available for only 4 stars (Landstreet, 1980).

In order to go further and to measure Hs in a greater sample, the differential broadening due to magnetic field, must be studied. The first attempt to compare the widths of lines with different Landé factors was done by Preston (1971). More accurate analyses must compare similar lines which are formed under the same atmospheric conditions and have approximately the same strengths. So