Accretion and outflows of mass are among the most distinctive phenomena associated to star formation. Their observational manifestations cover a broad range of appearances and wavelengths, from the large X-ray emitting bubbles caused by stellar winds moving at several thousands of kilometres per second, to the cold dust shells around low-mass stars detected by their millimetre-wave emission. Even stars with only a few tenths of the mass of the Sun display in their earliest stages spectacular signatures of interaction with the circumstellar environment, such as the strong emission lines seen in T Tauri stars or the fast-moving jets that produce Herbig-Haro objects.

Can strong accretion and mass loss take place even at substellar masses? Young brown dwarfs are currently known to share many characteristics with the more massive T Tauri stars. The similarities include mid-infrared emission, revealed by ISOCAM (e.g. Comerón et al. 1998, Persi et al. 2000) from warm dust in circumstellar disks or envelopes that provide large reservoirs of mass for accretion. The spectra of very young brown dwarfs often display...
coexist. This is the latest-type object for which such an intense emission-line spectrum has been observed so far. The late-type spectrum and the faintness of the underlying object suggest that it is near or below the borderline separating stars from brown dwarfs, showing that such spectacular spectral signatures can be present even at masses of a few percent of a solar mass. The details of this work are described in extent in a separate paper (Fernández & Comerón 2001).

Observations

The special characteristics of the object that we present here, hereafter referred to as LS-RCrA 1 (where LS stands for La Silla) were first revealed in a slitless spectroscopy survey of the core of the R Coronae Australis star-forming region, carried out with DFOSC at the 2.2-m telescope in August, to confirm the presence of intense emission lines (Mužević & Comerón 2000). Like T Tauri stars, young brown dwarfs also have been found to possess X-ray emission (Neuhäuser & Comerón 1998; Comerón, Neuhäuser, and Kaas 1998) caused by the magnetic fields that play a fundamental role in regulating the flow of mass from the accretion disk onto the surface (Hartmann 1998). In view of these similarities, one may wonder if the spectral signposts of intense accretion sometimes displayed by classical T Tauri stars, and very often found to be correlated with strong mass loss, may also be found near the substellar limit or even below.

Here we present our observations of a very late-type faint member of the R Coronae Australis star-forming cloud that displays an unusually rich emission-line spectrum, similar to that of more massive counterparts, in which both accretion and outflow signatures

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**Figure 2:** Visible (top) and near-infrared (bottom) spectra of LS-RCrA 1, obtained respectively with FORS2 and ISAAC in March 2000. The most prominent emission lines are marked in the visible spectrum. In the infrared spectrum we mark the position of the detected lines due to H$_2$ and CO, as well as the expected positions of some atomic features that should be detectable in this region for a normal M6 star.
The lack of absorption lines is commonly interpreted as due to strong veiling of the photospheric spectrum by emission from warm circumstellar dust, that contributes most of the flux at 2 µm and beyond, and is usually correlated with the appearance of H₂ emission (Greene & Lada 1996). In that respect, the K-band spectrum of LS-RCrA 1 is "Class I-like", following the widely-used classification of young stellar objects (e.g. Shu, Adams, and Lizano 1987). However, the shape of the continuum at 2 µm is remarkably flat in that region, while the infrared JHK colours show no appreciable sign of the circumstellar excess emission that would be needed to dilute the photospheric features beyond detectability in our spectra. In other words, dust does not seem to significantly contribute to the flux of LS-RCrA 1 in the 2 micron region, which in that respect is "Class III-like". Such a co-existence of Class I-like and Class III-like features in the K-band spectrum of LS-RCrA 1 is not found among the higher-mass objects that have been studied so far, and leads us to consider other possible explanations to the lack of atomic features and the weakness of the CO bands. An interesting possibility in this respect is that the photospheric spectral features in the 2 µm region may be largely filled by emission produced in the heated infalling material near the surface of the star, without being accompanied by continuum emission (Martin 1996).

What is the mass and age of LS-RCrA 1? Its membership in the R Coronae Australis star-forming region and the vigorous accretion and mass-loss activity, found only at the earliest stages of stellar evolution, both suggest an age of only a few million years. At this age, LS-RCrA 1 should be early in its contraction track and have a relatively large radius, and therefore brightness. However, as mentioned earlier, LS-RCrA 1 is surprisingly faint as compared to objects of similar spectral type in star-forming regions. Figure 3 illustrates this: we have plotted in it the position of LS-RCrA 1 in a temperature-luminosity diagram, where those quantities are inferred from its spectral type and available photometry. Also shown for comparison are pre-main sequence evolutionary tracks and isochrones from Baraffe et al. (1998), and the positions of other very low mass stars and brown dwarfs identified in other star-forming regions. The main contribution to the error bars is due to uncertainties in translating spectral types and magnitudes into temperatures and luminosities. Since the position of the other objects plotted in Figure 3 was computed in the same way as that of LS-RCrA 1, any systematic errors in the estimate of temperature and luminosity of LS-RCrA 1 should move both LS-RCrA 1 and the other sources in the same direction and by a similar amount. Therefore, although the temperature and luminosity of LS-RCrA 1 are determined with only a rather limited accuracy, its large offset with respect to other known late-type young objects is well established.

If taken at face value, the position of LS-RCrA 1 seems to imply that its age is of the order of several times 10⁷ years, about one order of magnitude older than the age inferred from the rest of the members of the R Coronae Australis region (Wilking et al. 1997), and also much older than other stars displaying such strong signs of accretion. The rather implausible age and the offset with respect to other young objects of similar underlying spectral characteristics leads us to look for alternative interpretations to the unexpected position of LS-RCrA 1 in the temperature-luminosity diagram.

The most obvious peculiarity that separates LS-RCrA 1 from the other very low mass objects plotted in Figure 3 is the signs of strong accretion and mass loss on an object of such a low temperature and luminosity, and this may be the reason why LS-RCrA 1 looks so old and so different from those other objects. Modellers of low-mass pre-main sequence evolution in the last decade have stressed the great importance of an appropriate, realistic treatment of the boundary condition represented by the atmosphere for correctly reproducing the evolution of temperature and luminosity as a function of time. The impact of both strong accretion and mass loss on the structure of the atmosphere of LS-RCrA 1 may thus be sufficient to invalidate a direct comparison between its observational characteristics and the predictions of theoretical models that do not take those factors into account. Indeed, calculations performed by Hartmann, Cassen, and Kenyon (1997) have found that accretion increases both temperature and luminosity with respect to the predictions of accretionless models that assume the same mass and age of the central object. The net result is to make the object appear hotter, and somewhat older, than an object of equal mass and age but without accretion. The calculations of those authors use only moderate accretion rates on central objects of larger mass than the one presented here, and can therefore not be directly extrapolated to LS-RCrA 1. However, they do suggest that LS-RCrA 1 may be actually younger than the 5 × 10⁷ years, and less massive than the 0.08 solar masses, implied by the direct comparison to pre-main sequence tracks. Since 0.08 solar masses is very close to the borderline separating low-mass stars from brown dwarfs, the possibility that accretion is actually making the spectral type appear earlier than it would be without accretion suggests that LS-RCrA 1 may have a mass well below the brown dwarf limit.

In any case, regardless of whether LS-RCrA 1 is stellar or substellar, it is...
Star Formation at $z = 2-4$: Going Below the Spectroscopic Limit with FORS1

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Introduction

The population of bright galaxies at $z = 2-4$ has been studied intensively using the Lyman-Break technique (Steidel et al. 1996; Cristiani et al. 2000). Currently, redshifts can be determined from absorption features of galaxies selected in this way down to $z = 25.5$ (e.g. Steidel et al. 2000), which is commonly referred to as the spectroscopic limit. Currently, very little is known about the galaxy population below the spectroscopic limit. This is an unfortunate situation since all the information on the chemical enrichment of young galaxies (Damped Ly-$\alpha$ Absorbers) accessible through QSO absorption lines seems to be valid mainly for galaxies significantly fainter than $R = 25.5$ (Fynbo et al. 1999; Haehnelt et al. 2000). In order to select and study galaxies fainter than the current spectroscopic limit, one has to rely on other selection criteria than the Lyman-Break. Two promising possibilities are (i) to select galaxies with Ly-$\alpha$ emission lines, and (ii) to study the host galaxies of Gamma-Ray Bursts (GRBs).

Ly-$\alpha$ Selected Galaxies

Ly-$\alpha$ selection of high-redshift galaxies has been attempted for many years, but only recently with significant success (Meller and Warren 1993; Francis et al. 1995; Cowie and Hu 1998; Pascale et al. 1998; Kuruzov et al. 2000; Fynbo et al. 2000a; Steidel et al. 2000; Kurk et al. 2000). In 1998 we detected 6 candidate Ly-$\alpha$ emitting galaxies (called S7-S12) in the field of the QSO Q1205-30 at $z = 3.036$ with deep NTT narrow-band imaging (Fynbo et al. 2000b). In March 2000 we carried out follow-up Multi-Object Spectroscopy with FORS1 on the 8.2-m Antu telescope (LTV1). We also obtained deeper broad-band B and I imaging reaching 5 (2)$\sigma$ detection limits in 1 arcsec$^2$ circular apertures of 25.9 (2.9) in the I-band and 26.7 (27.7) in the B-band (both on the AB system). The results of these observations are presented in Fynbo et al. (2001a), and summarised here.

Imaging

In Figure 1 we show image sections with Ly-$\alpha$ (top), VLT B-band (middle) and VLT I-band (bottom) for S7-S12. As seen, despite the faint detection limits, only for S7 and S9 is there a corresponding source detected in the broad bands (B(AB) = 25.6 and 25.4 respectively). For the sources S8 and

References

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