Rotation and variability of young very low mass objects

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Abstract. Variability studies are an important tool to investigate key properties of stars and brown dwarfs. From photometric monitoring we are able to obtain information about rotation and magnetic activity, which are expected to change in the mass range below 0.3 solar masses, since these fully convective objects cannot host a solar-type dynamo. On the other hand, spectroscopic variability information can be used to obtain a detailed view on the accretion process in very young objects. In this paper, we report about our observational efforts to analyse the variability and rotational evolution of young brown dwarfs and very low mass stars.

Key words: stars: low-mass, brown dwarfs – stars: magnetic fields – stars: rotation – stars: spots – stars: formation

1. Introduction

Variability is a key tool to study stellar properties. From simple photometric monitoring alone it is possible to measure the rotation period, if the objects exhibit asymmetrically distributed surface features, e.g. cool magnetic spots. The amplitude of the variability can be used to assess the properties of these spots, in particular if lightcurves in more than one filter are available (e.g. Bouvier & Bertout 1989). Furthermore, accretion processes can be studied in detail based on spectroscopic time series, particularly by monitoring changes in emission features like the H\textsc{ii} line, which are produced in the hot accretion flow (e.g., Johns & Basri 1995). Until the late 1990s, most variability studies have focused on stars with masses $> 0.4 M_\odot$. They provided hundreds of rotation periods (see Stassun & Terndrup 2003 for a recent review), detailed spot parameters for cool as well as for hot spots, and, for selected targets, a detailed view on the accretion process (e.g., Alencar & Batalha 2002). For lower-mass objects, however, the observational database is still sparse. This motivated us to carry out a long-term project aimed to study the variability in the very low mass (VLM) regime, focusing on VLM stars and brown dwarfs (BDs), i.e. objects with masses below $0.4 M_\odot$. Here we provide a summary of the outcomes of these studies.

2. Photometric rotation periods

About 2000 photometric rotation periods have been measured for solar-mass stars over the past 25 years (Stassun & Terndrup 2003). However, five years ago only a handful of periods were known for VLM objects (Martín & Zapatero Osorio 1997, Terndrup et al. 1999, Bailer-Jones & Mundt 1999). Motivated by this lack of information, we and other groups have determined about 500 periods for VLM objects, where most of these periods have been measured in very young clusters (Herbst et al. 2001, Lamm et al. 2004, 2005). Although the VLM rotation database is still sparsely populated in the BD regime with only about 30 periods known for substellar objects (Scholz & Eisloffel 2004a (SE04a), 2005 (SE05), Bailer-Jones & Mundt 2001, Joergens et al. 2002, Zapatero Osorio et al. 2003), we are now able to carry out meaningful comparisons between solar-mass stars and VLM objects in terms of their rotational behaviour. Our own long-term project was dedicated to study the rotational evolution on timescales of a few 100 Myrs, and provided 80 periods for VLM objects with ages ranging from 3 to 700 Myrs, increasing the number of periods in this age and mass range by a factor of 14. In the following, we will discuss mass-period relationship and rotational evolution mainly based on this sample.

In Fig. we show average period vs. mass in four open clusters. The data for Ori, IC4665, and Pleiades are taken from our own project (see Scholz & Eisloeffel 2004 (SE04b),...
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Fig. 1. Average period vs. mass for objects in four open clusters. For IC4665 and the Pleiades, the lines show a linear fit to the available period data (Scholz 2004, SE04b). For ς Ori (SE05) and the ONC (Herbst et al. 2001), the median period is plotted.

The rotation period is not the only important property that can be obtained from photometric monitoring. The amplitude of the variability can be used to assess the properties of the surface features, which are responsible for the flux modulation. For young stars and BDs, these surface features are believed to be magnetically induced cool spots. As we have shown in SE04b, the amplitudes are reduced at least by a factor of 2.4 in the VLM regime (see also the discussion in Scholz, Eislöffel & Froebrich 2005). In addition, we see evidence for a low rate of active, i.e. photometrically variable, objects in the VLM regime (SE04b). This is a clear indication for a change of the spot properties, roughly at a mass of 0.15M⊙.

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Small amplitudes can be caused by either a concentration of spots at polar latitudes, small contrast between spots and photospheric environment, low spot coverage, or a more symmetric spot distribution. To distinguish between these scenarios, Doppler imaging would be desirable. Since this is still at the edge of the observational capabilities, we carried out multi-filter monitoring to obtain first constraints on the VLM spot properties (Scholz et al. 2005). A sample of VLM stars in the Pleiades was monitored simultaneously in the I-, J-, and H-band, using two telescopes at the German Spanish Astronomical Centre on Calar Alto/Spain.

In Fig. 3 we show the results for a particular object, the star BPL129 (Pinfield et al. 2000) with an approximate mass of 0.15 M. Squares show the observed lightcurve amplitudes, the lines are model calculations for given temperature difference between spot and photosphere (ΔT) and filling factor (fraction of the hemisphere covered by spots). These models are based on theoretical spectra for VLM stars by Allard et al. (2001), and assume an effective temperature of 3200 K for BPL129. The amplitudes in all three bands are comparable and best reproduced by models with ΔT = 20 ± 30% and filling factors < 5%. These are the first constraints of spot parameters for an object with such a low mass. The value for ΔT is comparable with similar measurements for solar-mass stars, but the filling factor is quite low when compared with values for more massive stars. The major downside of photometric monitoring is that we only observe asymmetrically distributed spots. Thus, a low filling factor means that we see either low spot coverage or a symmetric spot distribution. The low amplitudes in the VLM regime are thus probably a consequence of either very few spots or a change in the spot distribution.

Is it possible to explain the change in the spot properties as well as the fast rotation of VLM objects in the context of the fundamental properties of these objects? Maybe the most significant difference between solar-mass stars and VLM objects is that the latter will never develop a radiative core. Today it is widely believed that the large-scale magnetic field of the Sun is produced in the interface layer between convective and radiative zone by means of an !-type dynamo. The fully-convective VLM objects cannot have such a dynamo, because they have no radiative core. Since they are still magnetically active (see e.g. Mohanty & Basri 2003), they must have an alternative type of dynamo. One suggestion is that VLM objects host a turbulent dynamo, which works throughout the convection zone, and which should generate only small-scale magnetic fields (Durley et al. 1993). If we assume that this model is adequate, we expect fast rotating objects, because small-scale fields would cause inefficient angular momentum loss by stellar winds. We also expect a change in the spot properties, probably to a more symmetric spot distribution. Thus, our main results are consistent with a scenario where VLM objects have only small-scale fields because they are fully-convective.

4. Monitoring accreting brown dwarfs

In our photometric monitoring campaigns in very young clusters in Orion, we found not only low-amplitude, strictly periodic lightcurves. In addition, we identified 11 objects showing high-amplitude variations with amplitudes up to 1 mag and partly irregular variations (SE04a, SE05). These highly variable VLM objects show lightcurves very similar to those of classical T Tauri stars, which are strongly variable because they accrete material from a circumstellar disk. The usual interpretation for their variability is the existence of hot spots formed by the accretion flow, which co-rotate with the objects and therefore cause high-amplitude variations. Instabilities in the accretion process can account for irregular variability. Therefore, we explain the high-amplitude variations of VLM objects as a consequence of ongoing accretion. This interpretation is confirmed by near-infrared photometry and low-resolution spectroscopy: Highly variable objects tend to show infrared colour excess and strong Hβ emission, indicative for the existence of an accretion disk. Thus, we have identified a sample of accreting VLM objects by means of a variability study.

Accreting objects show a very complex type of variability. To disentangle the contributing effects, and to study hot spots, accretion rate variability, and disk geometry on VLM objects, we carried out the first comprehensive spectroscopic monitoring campaigns for accreting young BDs. Here we show first results from high-resolution monitoring based on spectra taken with the MIKE spectrograph at the Magellan/Clay 6.5-m telescope on Las Campanas in spring 2005. In a first paper we report about dramatic changes in the H profile and intensity for the BD 2M1207 (Scholz, Jayawardhana, & Brandeker 2005, Jayawardhana et al., this volume). To demonstrate that strong accretion rate variations are not unique in the substellar regime, we show in Fig. a part of the H time series for the BD 2MASS J11013205-7718249, a likely member of the Cha I star forming region. On timescales of 1-2 days, the equivalent width in H increases by a factor of six, and the 10% width by a factor of two. This corresponds to a change in the accretion rate by about an order of magnitude (Natta et al. 2004). At the same time, alternative accretion indicators appear in the spectra, e.g. HeI and H.
emission, which are faint or not detected before this burst. In addition, the H\ profile develops a significant red absorption feature, indicating infalling material. Thus, we probably witnessed a strong accretion burst on this object.

In total, we monitored six brown dwarfs with high-resolution spectroscopy, and all six targets are variable. Therefore, variability information is essential to assess the accretion properties of stars and BDs. As shown by Mohanty et al. (this volume), the accretion rate is correlated with object mass, but the individual objects scatter by one order of magnitude around this correlation. This accretion-mass relationship might be explained by Bondi-Hoyle accretion (see Padoan, this volume), but in this case we should expect much less scatter. Here we demonstrate that accretion rate variability might account for the largest part of the noise. By taking into account information about variability, we might be able to constrain correlations between accretion rate and fundamental properties more precisely.

5. Conclusions

We report on a variety of variability studies of VLM stars and brown dwarfs, aimed at a deeper understanding of rotation, activity, and accretion for objects with masses < 0.1\,M\,. In a long-term project, we measured 80 rotation periods for VLM objects with ages between 3 and 700\,Myr. At all evolutionary stages, we see a clear tendency of decreasing average periods with decreasing mass in the VLM regime. The rotational evolution can be understood by taking into account contraction and weak angular momentum loss by stellar winds. From an analysis of the variability amplitudes and multi-filter monitoring, we see evidence for a change in the properties of magnetic spots at 0.1\,M\,. Either VLM objects have a symmetric spot distribution or very low spot coverage in comparison with more massive stars. Accretion shows up in monitoring studies as high-amplitude photometric variation and as strong variability in accretion-related emission lines, in particular H\,. We demonstrate that VLM objects in some cases show accretion rate variations up to one order of magnitude. Variability studies are thus an important component in the investigation of substellar properties.

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