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Age, mass and temperature dependence of X-ray activity on brown dwarfs

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Abstract. We present *Chandra* observations of three brown dwarfs in different evolutionary stages. Combining our data with X-ray data on brown dwarfs from the literature yields a sample that covers the age range from ~ 1 Myr to ~ 1 Gyr. Since brown dwarfs cool and dim as they age, this allows us to study the influence of various stellar parameters ($T_{\rm eff}$, $L_{\rm bol}$, mass, age) onto their X-ray activity.

Key words. X-rays: stars – stars: brown dwarfs, coronae, activity – stars: individual: HR 7329 B, Gl 569 B, HD 130948 B

1. Introduction

Late-type stars have long been known to display signatures of magnetic activity evidencing solar-like dynamo action (Rosner et al. 1985). But objects at the bottom of the main-sequence and in the substellar regime are fully convective and cannot drive a solar-like $\alpha\Omega$-dynamo. The efficiency of alternative field-generating mechanisms for very low mass stars and brown dwarfs is both difficult to predict and observationally poorly constrained.

Systematic investigations of chromospheric Hα activity in the solar neighborhood suggest a decline of Hα emission beyond spectral type ~ M7 (Gizis et al. 2000; Mohanty & Basri 2003). X-ray emission is a complementary activity indicator probing the hottest part of the atmosphere, the corona. Beyond spectral type M6 the X-ray regime is widely unexplored to date. In particular the effects of mass, age, effective temperature, and luminosity on coronal emission near and beyond the substellar boundary have remained obscure so far. The generally low activity level of evolved brown dwarfs may be due to (i) poor coupling between matter and field in their cool, widely neutral atmospheres, (ii) the $L_{\rm x} - L_{\rm bol}$ relation which for optically faint objects implies small X-ray luminosities, (iii) a mass-dependence of X-ray emission as known for higher-mass stars.

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The purpose of this article is a first systematic study of X-ray emission from BDs in different evolutionary phases (~ 1 Myr - Gyr), to understand which parameters determine their X-ray activity.

2. Sample

One pre-requisite for constraining the influence of stellar parameters on BD X-ray emission is to know the age and effective temperature or bolometric luminosity. The mass can then be deduced from evolutionary models.

Fig. 1 shows the BD cooling curves from Burrows et al. (1997). The data points represent BDs detected in X-rays with *Chandra* or *XMM-Newton*, compiled from the literature. Non-detections are not shown for clarity. The three targets for which we present here new *Chandra* observations are marked with filled circles.

The diagram is poorly populated because the age of brown dwarfs is difficult to access by observations. We have chosen our targets among companions to main-sequence stars for which the age is known. Because of their spatial vicinity to the bright main-sequence stars these BDs can be resolved in X-rays only with the *Chandra* X-ray Observatory.

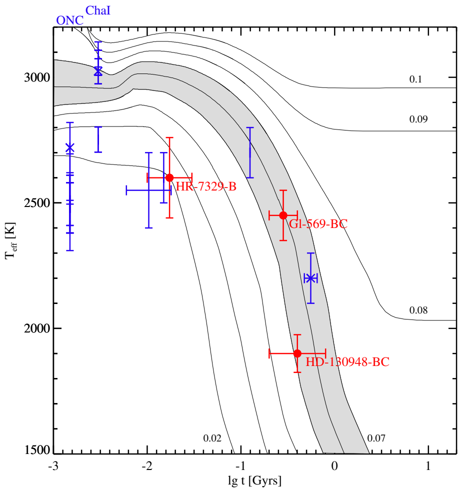

Fig. 1. BDs with known age that have been detected with *XMM-Newton* or *Chandra* on the model tracks from Burrows et al. (1997) in steps of 0.01 $M_\odot$. The 0.08 $M_\odot$ track marks the separation from stars to BDs. *Filled circles* – BDs observed in the *Chandra* program described in this paper; the remaining objects are compiled from the literature. BDs detected in X-rays only during a flare are marked by a cross symbol. The grey-shade indicates the distinct mass range studied in Fig. 4.

3. Results

In Fig. 2 we show the *Chandra* ACIS images of stellar systems with BD secondary observed within our program. A brief summary of the results is as follows:

- HR 7329: The BD emits X-rays at a level of $\log L_x = 27.2$ erg/s. The primary star (labeled ‘A’ in Fig. 2) has spectral type A0 and is not detected with *Chandra* in agreement with the theoretical expectation that intermediate-mass, fully radiative stars are no X-ray emitters.
- Gl 569: The secondary is a BD binary (Zapatero Osorio et al. 2004). It was unexpectedly bright during the *Chandra* observation (~ 250 counts) due to a large flare (see Stelzer 2004). The primary is detected as well, not surprisingly, because it is a known flare star.
- HD 130948: The secondary is a BD binary (Potter et al. 2002), and is undetected with *Chandra*. This image demonstrates the superior point-spread-function of *Chandra* that allows us to put a sensitive upper limit for the BD ($\log L_x < 25.6$ erg/s) at a separation of only 2.6″ from the bright primary.

Fig. 3 represents the fractional X-ray luminosity (L_x/L_{bol}) versus age. The detection of quiescent emission from the *evolved* BD Gl 569 Bab shows that persistent X-ray activity does take place beyond the youngest ages in substellar objects.

In Fig. 4 we present the first analysis of the relation between L_x and T_{eff} for BDs. To avoid mixing different parameters that may influence the X-ray activity we restricted the sample to objects in the mass range 0.05 – 0.07 $M_\odot$. There is a clear decline of L_x with surface tempera-

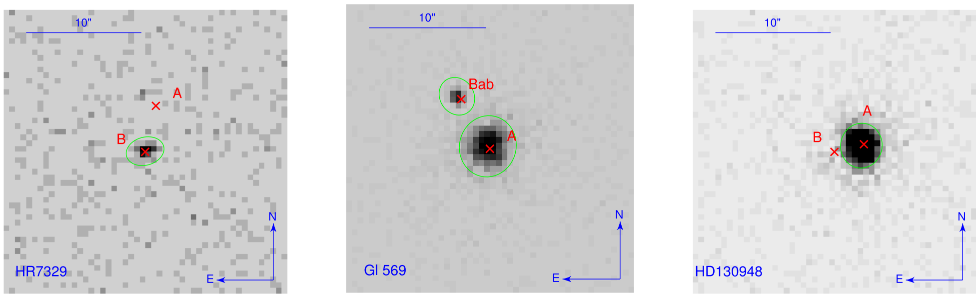

Fig. 2. X-ray images of stellar systems with BD secondary observed with *Chandra* ACIS.

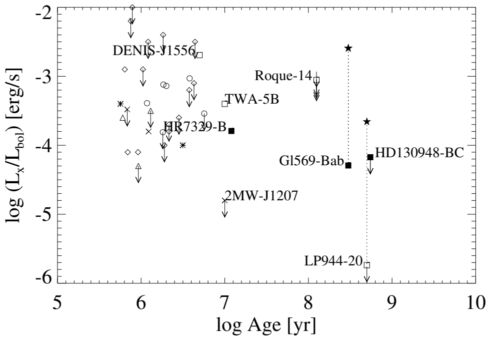

Fig. 3. Ratio of L_x/L_{bol} versus age for BDs: *triangles, diamonds, open circles* – bona-fide BDs in star forming regions (spectral types ≥ M7) with a random one order of magnitude spread in age centered on 0.5 Myr for ρ Oph, 1.5 Myr for IC 348, and 2 Myr for Cha I; *x-points* – BDs with accretion signatures in the Hα profile; *squares* – evolved BDs; *star symbols* – flares. See Stelzer (2004) for references.

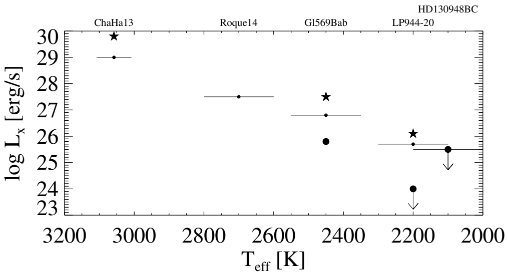

Fig. 4. Relation between L_x and T_{eff} for BDs in the mass range 0.05 – 0.07 $M_\odot$.

ture, that may indicate the loss of coupling between magnetic field and the increasingly neutral matter. A similar conjecture was made for the observed decay of chromospheric Hα activity in L dwarfs (Mohanty & Basri 2003), and underlined by calculations that yield high electrical resistivity in these cool atmospheres (Mohanty et al. 2002). The only sensitive X-ray measurement below $T_{eff} \sim 2200$ K, i.e. in the regime of the L dwarfs, is the upper limit of HD 130948 BC.

4. Summary

The approach of observing BD companions to main-sequence stars allows us to define a well-defined sample for an investigation of the influence of various stellar parameters on BD X-ray emission. We are working on a more detailed analysis decoupling the effects of effective temperature, bolometric luminosity, mass and age.

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