

## X-ray Emission from Old and Intermediate Age Brown Dwarfs

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**Abstract.** We report on two recent *XMM-Newton* observations of Brown Dwarfs in the Pleiades cluster and in the field aiming to constrain the age dependence of X-ray emission from substellar objects.

### 1. Introduction

The standard picture of solar-type magnetic activity is expected to break down for very-low mass stars: being fully convective throughout the interior they lack the interface between radiative core and convective envelope in which the solar-type  $\alpha\Omega$ -dynamo is thought to reside. In spite of these theoretical predictions X-ray and H $\alpha$  activity has been observed on stars with masses below the fully convective boundary, corresponding to spectral type  $\sim$ M3 (Fleming et al. 1995, Gizis et al. 2000). Recent H $\alpha$  observations of ultracool field dwarfs indicate, however, a decline of activity setting in near the substellar limit at spectral type M9 (Mohanty & Basri 2002, see also Basri this volume).

While there is a substantial data base on chromospheric activity, only few X-ray observations of very low-mass (VLM) field dwarfs have been performed so far. Virtually all of the X-ray emitting field dwarfs with spectral type later than  $\sim$ M7 have been detected only during a temporary outburst, with quiescent emission below the detection threshold (see Sect. 3). Whether this is due to a lack of sensitivity of the respective observations, or whether these objects indeed are X-ray quiet can now be tested with a new generation of X-ray instruments onboard *XMM-Newton* and *Chandra*.

X-ray observations with *ROSAT* have shown that young Brown Dwarfs (BDs) are more readily detected than older ones, as they show higher levels of activity (Neuhäuser et al. 1999). Due to the absence of an internal energy source the evolution of BDs goes along with a decrease of effective temperature. The accompanying drop of the ionization fraction may prevent coupling of the gas to the magnetic field, thus shutting off activity. Probing the relation between activity and the evolution of atmospheric conditions requires high-sensitivity X-ray observations of VLM stars and BDs at different ages.

### 2. Observations

In order to examine the dependence of X-ray emission on age and/or effective temperature, we observed two BDs in different evolutionary stages: (a) the

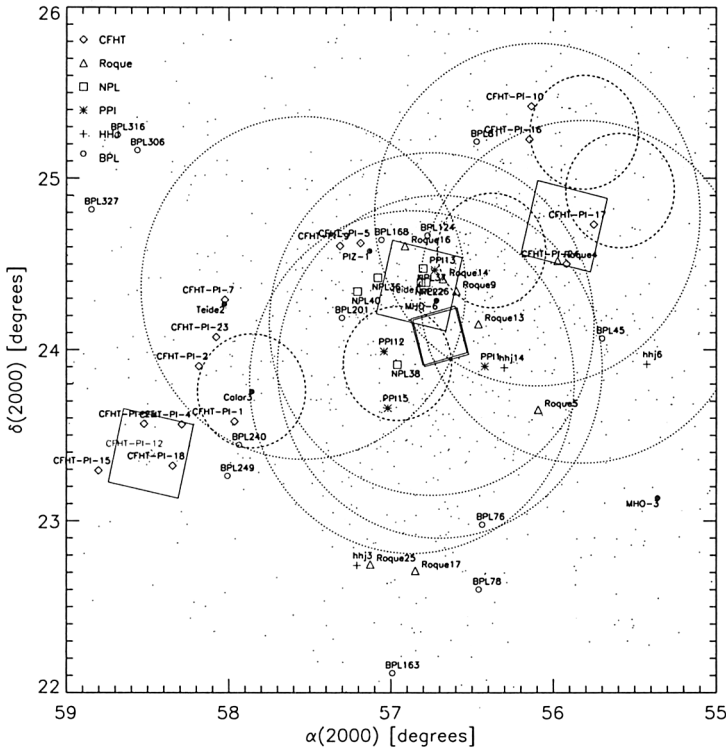


Figure 1. Sky map of the Pleiades region with position of X-ray pointings by *ROSAT* (small circles = HRI, large circles = PSPC), *Chandra* (small squares), and *XMM-Newton* (large squares); dots are Pleiades members.

~ 100 Myr old BD CFHT-P112 in the Pleiades cluster, and (b) Denis J1228-1547 which is a BD binary in the field at an age of ~ 500 Myr.

The Pleiades cluster has been extensively monitored with past and present day X-ray instrumentation (see sky map in Fig. 1 presenting all X-ray observations centered on the Pleiades since the *ROSAT* mission). None of the earlier observations was deep enough to reach into the substellar regime. In particular the limiting sensitivity of pointed *ROSAT* observations in the Pleiades region is  $\lg L_x \sim 28.5\text{--}29.0$  erg/s (Stelzer & Neuhäuser 2001). Two long exposures with *Chandra* included no BDs in the field (Krishnamurthi et al. 2000, Daniel et al. 2002). Here, we discuss one of the three *XMM-Newton* pointings performed up to now. As seen from Fig. 1 CFHT-P112 is located in a region of the cluster which is widely unexplored in X-rays so far. CFHT-P112 is the optically brightest of the BD candidates in the Pleiades, and its position above the main-sequence in the color-magnitude diagram indicates it could be a binary (Bouvier et al. 1998). Unresolved binaries should have a higher probability of detection,

and therefore also Denis J1228-1547, a BD binary with  $\sim 0.3''$  separation, is a favorable target for X-ray studies.

### 3. Results

The data were analysed using the standard *XMM-Newton* SAS, version 5.3.0. Strong background flaring restricted the useful exposure time to  $\sim 8.5$  ksec for CFHT-P112 and  $\sim 6$  ksec for Denis J1228-1547. Source detection was performed in three energy bands in the range from 0.3 to 5.0 keV using a combination of local, map, and maximum likelihood detection mechanism. Neither CFHT-P112 nor Denis J1228-1547 are detected at a *ML* detection threshold of 10. Upper limits to the source flux derived under the assumption of a one-temperature, 1 keV Raymond-Smith spectrum plus photo-absorption are listed in Table 1. To facilitate comparison with earlier X-ray observations of VLM objects, the luminosities were converted to the 0.1 – 2.4 keV band covered by *ROSAT*.

Table 1. X-ray properties of two BDs observed with *XMM-Newton*.\*

| Instr.           | Cts | Expo<br>[s] | $F_x$<br>[erg/s/cm <sup>2</sup> ] | $\lg L_x$<br>[erg/s] | $\lg (\frac{L_x}{L_{bol}})$ | $\lg L_x$<br>(RASS) |
|------------------|-----|-------------|-----------------------------------|----------------------|-----------------------------|---------------------|
| CFHT-P112        |     |             |                                   |                      |                             |                     |
| pn               | 14  | 8593        | $< 4.1 \cdot 10^{-15}$            | $< 27.28$            | $< -3.48$                   | $< 29.3$            |
| MOS 1+2          | 29  | 34481       | $< 3.5 \cdot 10^{-15}$            | $< 27.76$            | $< -3.00$                   |                     |
| Denis J1228-1547 |     |             |                                   |                      |                             |                     |
| pn               | 20  | 5889        | $< 4.0 \cdot 10^{-15}$            | $< 26.15$            | $< -3.14$                   | $< 27.3$            |
| MOS 1+2          | 15  | 15596       | $< 5.8 \cdot 10^{-15}$            | $< 26.30$            | $< -2.99$                   |                     |

\*Counts are measured in the broad band of EPIC (0.3 – 5 keV), but X-ray flux and luminosity and their  $3\sigma$  confidence upper limits apply to the *ROSAT* band of 0.1 – 2.4 keV; last column are data from RASS.

In Fig. 2 the newly derived upper limit for Denis J1228-1547 is compared to X-ray observations of other field dwarfs: M-stars from the Catalog of Nearby Stars (CNS; Gliese & Jahreiss 1991) detected in the *ROSAT* All-Sky Survey (=RASS; data from Hünsch et al. 1999), and field dwarfs later than M6 observed with *ROSAT* in pointed observations and/or with *Chandra* (see Neuhäuser et al. 1999, Fleming et al. 2000, Rutledge et al. 2000, Schmitt & Liefke 2002). The *XMM-Newton* observation of Denis J1228-1547 presented here is the first attempt to extend the study of X-ray activity into spectral class L. The upper limit derived from the RASS is improved by  $\sim 1$  order of magnitude for this object despite the considerable loss of observing time (due to high background). Note, that at the time of target selection only three BDs in the field had been discovered. In the near future, longer *XMM-Newton* observations of the nearby early L-type dwarfs identified since then are likely to provide faint detections or meaningful upper limits populating the lower right of Fig. 2.

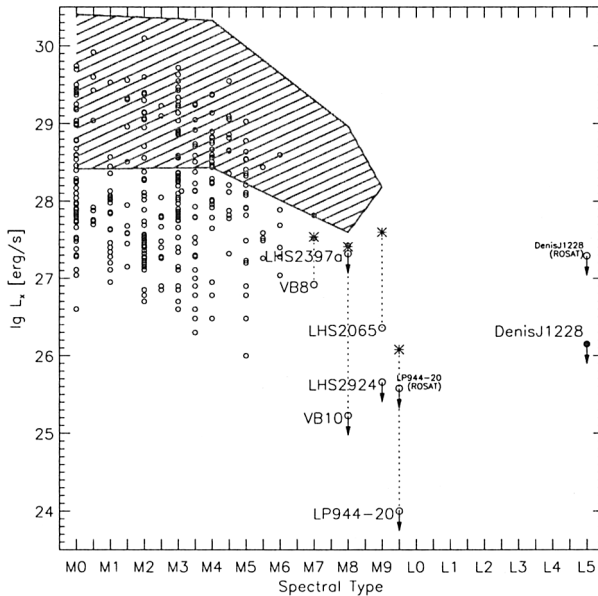


Figure 2.  $\lg L_x$  over spectral type for field M and L dwarfs. Asterisks denote flares, arrows denote upper limits for non-detections. For Denis J1228-1547 and LP 944-20 both the *ROSAT* and the *XMM-Newton* or *Chandra* measurements are given. The typical region occupied by younger objects of the same spectral type found in star forming regions (data from Mokler & Stelzer 2002) is shown as hatched area.

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