XMM-NEWTON OBSERVATIONS OF PLEIADES-AGE K DWARFS

A. Brown¹, F. Day¹, T. R. Ayres¹ and C. Ambruster²

¹Center for Astrophysics and Space Astronomy, University of Colorado, Boulder, CO 80309-0389, USA
²Department of Astronomy, Villanova University, Villanova, PA 19085, USA

Abstract

We present XMM-Newton observations of young, active K dwarfs that are designed to study how coronal structure changes as a function of stellar rotation rate. RGS and EPIC spectra are being obtained for a sample of essentially identical, nearby (within 50 pc) Pleiades-age K dwarfs. Our XMM targets (HD220140 – \( P_{\text{rot}} = 2.76 \) d; HD174429 \( P_{\text{rot}} = 0.95 \) d; HD17925 \( P_{\text{rot}} = 6.6 \) d; HD82443 \( P_{\text{rot}} = 5.4 \) d) plus previously observed stars cover the rotational period range 0.5 to 6.6 days, and thus sample both the saturated and linearly-dependent portions of the rotation activity relation. Currently, only two of our observations have been processed into the XMM archive and our analysis is at a preliminary stage. We present the spectra obtained so far and our initial results.

Key words: Stars: activity – Stars: X-ray Grating spectroscopy – Satellite observatories: XMM-Newton

1. Introduction

Stellar activity shows a strong correlation with stellar rotation (cf. Wilson & Skumanich 1964; Wilson 1966; Kraft 1967; Walter 1982; Simon, Herbig, & Boesgaard 1985; Ayres et al. 1996) and many rapidly rotating stars appear in X-rays to have “saturated” coronae completely filled with “active-region”-like structures (Vilhu & Walter 1987). Such stars show high levels of coronal activity, rotational modulation (particularly from starspots in the optical), and flaring. Detailed investigation of this correlation requires study of homogeneous samples of stars with common properties that differ in only one of the dominant variables (e.g. rotation rate, mass, age) that are likely to control the physical processes generating stellar dynamo activity. However, many studies of the parameters controlling coronal activity have used large heterogeneous samples with many relevant variables in addition to rotation, such as age, mass, and evolutionary state (e.g. Pallavicini et al. 1981, Majer et al. 1986, Dempsey et al. 1993, Hempelmann et al. 1995).

Many rapidly rotating stars are members of binary systems (e.g. the RS CVn binaries), where synchronous rotation has been enforced tidally on the individual stars in the system. Single rapidly-rotating stars are rarer and are generally relatively young stars. A significant number of the nearby single active dwarfs have been found to be members of the Local Association, a widespread stellar aggregate that includes the Pleiades and \( \alpha \) Per clusters (Eggen 1992, Montes et al. 2001). All-sky surveys by ROSAT and EUVE have led to the identification of many new active dwarfs, of which a significant fraction have proved to be Local Association members (Jeffries & Jewell 1993; Jeffries 1995).
Very rapidly rotating stars appear in X-rays to have "saturated" coronae, which may well be completely filled with "active-region"-like structures, and whose coronal activity level does not change with rotation rate. As the rotation rate declines, a break-point is reached beyond which the activity becomes linearly-dependent in \( \log \left( \frac{L_x}{L_{bol}} \right) \) vs. \( \log \) (Rotation Period) plots.

2. The young K dwarf sample

For a number of years we have been studying a group of stars that offers special advantages for understanding the influence of rotation rate on stellar activity. This group of young Pleiades-age, single, K dwarfs provides a unique chance to study and model coronal and transition region properties of active dwarf stars. The properties of the sample are listed in Table 1. We have studied the thermal and nonthermal coronal properties of these stars using ROSAT X-ray data, EUVE coronal spectroscopy, VLA radio continuum observations (Brown et al. 1996), and HST UV chromospheric and TR emission line spectra (Ambruster et al. 1998). Our ROSAT data show that the group of stars directly samples the saturated and linearly-dependent portions of the rotation-activity correlation at least for the thermal X-ray corona. This split occurs at around a rotational period of 2 days (Ambruster, Brown, & Fekel 1994). The UV and X-ray activity levels of young K dwarfs decline significantly as their rotation period increases beyond this 2 day divide (see Fig. 1).

Our sample is highly uniform, spanning the narrow spectral type interval K0-K3, and the dominant variable affecting the stars’ coronal activity is rotation rate, which ranges from 0.4 to 6.6 days based on optical photometric spot modulation. Because the stars are the same age and spectral type, this sample has the major virtue of minimizing the effect of two other significant variables controlling stellar activity: age and mass.

It is important that these are single stars, since when studying close binaries it is hard to separate out the tidally induced contribution to atmospheric activity. Of the stars in our sample only HD17925 shows weak radial velocity variability that might indicate a wide binary.

3. Observations

We are currently using XMM-Newton to study the coronal properties of our sample of young active Local Association K dwarfs and thereby determine how the detailed properties of coronal structure (e.g. temperature and emission measure distributions, electron densities, elemental abundances) change for different rotation rates. Observing time was awarded to observe 4 stars (Cycle 3, program 20306): completed observations are HD220140 (V368 Cep) for 30 ksec on 2003 Dec 27-28; HD17925 (EP Eri) for 50 ksec on 2004 Jan 20-21; HD174429 (PZ Tel) for 50 ksec on 2004 Apr 7. Currently only the data for HD220140 and HD17925 have been processed into the XMM archive. HD82443 is a Priority C target.

HD220140, HD82443, and HD17925 probe the rotation-dependent part of the activity relation (rotation periods 2.8 → 6.6 days, while HD174429 has a "saturated" activity level.

3.1. RGS observations

XMM-Newton carries two reflection grating spectrographs (RGS): the integrated RGS1 spectrum for HD220140 is shown in Fig. 2, while the RGS2 spectrum for HD17925 is shown in Fig. 3. Both spectrographs suffer from gaps in their spectra coverage due to dead CCD detectors; fortunately these gaps cover different wavelength regions. The first order RGS spectral resolution is varies from 600 at 35Å to 1900 at 10 Å. The RGS spectra are dominated by the strong Fe XVII, Ne X, Ne IX, O VIII, and O VII emission lines that are typical seen from the hot (10^7 K) corona of active stars.

There are clear differences between the spectra from HD220140 and HD17925. The corona of the more rapidly rotating HD220140 is hotter than that of HD17925. This can be seen from the relative strengths of the O VII –
Table 1. Properties of young early-K dwarf sample

<table>
<thead>
<tr>
<th>Star</th>
<th>Spectral Type</th>
<th>V Rot. Period (Days)</th>
<th>Distance (pc)</th>
<th>ROSAT PSPC (c s(^{-1}))</th>
<th>Radio S(_{3}) cm (mJy)</th>
<th>XMM Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD197890</td>
<td>BO Mic</td>
<td>9.3</td>
<td>0.42</td>
<td>44.4±3.3</td>
<td>~1.2</td>
<td>calibration</td>
</tr>
<tr>
<td>HD36705</td>
<td>AB Dor</td>
<td>6.8</td>
<td>0.51</td>
<td>14.9±0.1</td>
<td>~1.3</td>
<td>50 ksec AO2</td>
</tr>
<tr>
<td>HD174449</td>
<td>K0 V</td>
<td>8.4</td>
<td>0.95</td>
<td>49.7±2.0</td>
<td>1.5</td>
<td>50 ksec AO2</td>
</tr>
<tr>
<td>HD82558</td>
<td>LQ Hya</td>
<td>7.8</td>
<td>1.66</td>
<td>18.3±0.4</td>
<td>2.73</td>
<td>69 ksec AO2</td>
</tr>
<tr>
<td>HD1405</td>
<td>K2 V</td>
<td>8.7</td>
<td>1.75</td>
<td>~30</td>
<td>0.70</td>
<td>60 ksec AO2</td>
</tr>
<tr>
<td>HD220140</td>
<td>V368 Cep</td>
<td>7.5</td>
<td>2.76</td>
<td>19.7±0.3</td>
<td>2.75</td>
<td>30 ksec AO2</td>
</tr>
<tr>
<td>HD139084</td>
<td>V343 Nor</td>
<td>8.1</td>
<td>4.2</td>
<td>39.8±1.8</td>
<td>1.42</td>
<td>~3</td>
</tr>
<tr>
<td>HD82443</td>
<td>K0 V</td>
<td>7.0</td>
<td>5.36</td>
<td>17.8±0.3</td>
<td>0.71</td>
<td>≤0.06</td>
</tr>
<tr>
<td>HD17925</td>
<td>K2 V</td>
<td>6.0</td>
<td>6.6</td>
<td>10.4±0.1</td>
<td>1.2</td>
<td>≤0.07</td>
</tr>
</tbody>
</table>

Figure 3. XMM-Newton RGS2 spectrum of HD17925 produced by the SAS pipeline processing.

O VIII lines and the Ne IX – Ne X lines. This is expected based on earlier ROSAT and EUVE measurements of these stars.

3.2. EPIC OBSERVATIONS

Strong X-ray emission is detected by EPIC from both stars. The observed EPIC count rates are 4.7 ct s\(^{-1}\) for HD220140 and 1.7 ct s\(^{-1}\) for HD17925. The M dwarf proper motion companion to HD220140 is clearly present in the EPIC images - this star lies roughly 10 arcseconds southwest of HD220140.

We have made a preliminary examination of the EPIC event lists and do not find any obvious flares. Longer time scale smoother variations do appear to be present.

4. CONCLUSIONS

We had hoped to have all three datasets for the Priority A targets available in time for this meeting, but this was not possible. The EPIC, RGS, and OM data for HD220140 and HD17925 are all of excellent quality and we have begun a preliminary analysis using the pipeline products for these stars. Good signal-to-noise spectra are available from both the RGS and EPIC. The coronal temperature distribution of HD220140 is distinctly hotter than that of the slower rotating HD17925, based on the emission line strengths in the RGS spectra. Large flare outbursts do not appear to be present for either star; a small flare lasting 10 minutes appears to be present in the OM data for HD220140. This low level of flaring is not unexpected because the largest outbursts tend to occur on the most rapidly rotation stars, such as HD36705 (AB Dor). Of our targets, PZ Tel would be most likely to show major flaring.

Acknowledgements

This work was supported by NASA grant NNG04GE69G and NSF grant AST-0206367.

References