XMM - The Cool X-ray Satellite !

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ABSTRACT

We present a discussion of the capabilities of the XMM observatory pertaining to the observation of cool late-type stars in Galactic open clusters. The potential of the observatory is examined in light of recent ROSAT results for NGC 6475, a nearby and astrophysically important open cluster.

1. Introduction

Optical, UV, EUV and X-ray observations of solar-type stars (spectral types late-F→M) both in the field and young ($\lesssim$1 Gyr) open clusters have provided evidence for a correlation of increased magnetic activity manifestations (*eg.,* Hα, Ca II H & K, Mg II h & k and X-ray fluxes) with increasing rotation rate (*eg.,* Vilhu, 1984; Doyle 1987; Soderblom et al. 1993; Stauffer et al. 1994; Randich et al. 1996). Magnetic confinement and heating of plasma at various heights in the outer atmospheres of solar-type stars is believed to cause the majority of these observed chromospheric, transitional and coronal radiative losses. X-ray observations of solar-type stars help us to probe their coronal regions, where plasma temperatures can reach several million degrees, and provide clues as to the magnetic field energetics and structure.

The advantage of observing cool stars in open clusters with XMM, as opposed to its predecessors, is that its increased sensitivity, spatial resolution and energy band-width will allow, **for the first time**, the probing of the stellar dynamo for large numbers of late-type stars, of all spectral type, over the full energy range expected from their coronae, as well as simultaneously monitoring their surfaces optically. What is more, for individual late-type star systems, the Reflection Grating Spectrometer (RGS), combined with the higher sensitivity of XMM (compared to ROSAT for instance), will yield high-ish S/N, low resolution soft X-ray spectra allowing for a far more detailed spectral analysis of coronal plasma than previously possible. Furthermore, XMM's ability to observe late-type stars in the optical and X-ray energy wave-bands simultaneously (without telescope scheduling constraints etc.) will allow us to monitor the evolution of flares from the stellar surface upwards to investigate if optical and X-ray flaring phenomena are triggered by the same mechanisms (or each other ?). We also plan, **for the first time**, to monitor the evolution of circumstellar prominence systems over long time scales, allowing us to determine whether the evolution of complex structures in the corona is driven by photospheric shear, or by smaller-scale diffusive processes (as measured by star-spot evolution).

For this 1st XMM workshop contribution, we present some results from an older X-ray pointing, using the ROSAT observatory, towards the young (220 Myr) open cluster, NGC 6475. We highlight some of the failings of observing late-type stars in open clusters with the ROSAT satellite, the difficulties in progressing from X-ray detections to cluster identifications and the advantages and potential of observing open clusters with the XMM observatory.

2. X-ray Observations of NGC 6475

NGC 6475 is the closest (d = 220 pc) and most compact open cluster of those that occupy the astrophysically important position midway in age (t$\sim$ 220 Myr) between the nearby and well studied clusters of the Pleiades (t$\sim$ 100 Myr) and the Hyades (t$\sim$ 700 Myr). NGC 6475 is at an age that is diagnostically important for proposed mechanisms of angular momentum loss in low mass stars and the depletion of lithium in their convective atmospheres. The variation of chromospheric activity and X-ray luminosity with age, rotation and spectral type is of key importance in deciding between models of the internal dynamo, angular momentum loss and angular momentum transfer in stars with differing convective zone depths. Thus, high-resolution optical follow-up observations of X-ray selected NGC 6475 cluster members can be used to further constrain rotation - activity - Li - age relationships and provide useful insights into the internal physics of stars (James & Jeffries 1997; James, Cameron & Jeffries 1999).

In Figure 1, a soft $(0.1 - 0.4$ keV) and hard $(0.4 - 2.4$ keV) band image from the position sensitive proportional counter (PSPC) on-board the ROSAT X-ray satellite is presented. The central shadow-ring (due to the window support structure) is clearly visible and conveniently defines the approximate field of view (FOV) of the XMM observatory ($\simeq$ 30 arcminutes). These X-ray images clearly show that for NGC 6475 (and is also appropriate for most of the more distant clusters), the FOV of XMM is sufficiently wide to include the majority of the X-ray active cluster members. In the original analyses, X-ray selection was our primary tool for selecting members of this open cluster due to a lack of membership data. A major advantage of XMM over other X-ray satellites, both old and new generation, is that the optical monitor can be used in such a way that optical counterparts - presumably producing the X-ray emission - can be easily identified.

The problematic optical identification we encountered when researching ROSAT pointings in open clusters can be easily understood in terms of the crowded optical fields of the open clusters themselves (due to their low Galactic latitude). The crowding issue is evident in the low Galactic latitude (b$\simeq -4^{\circ}.5$) cluster NGC 6475, as can be seen in Figure 2, in which a pair of V band

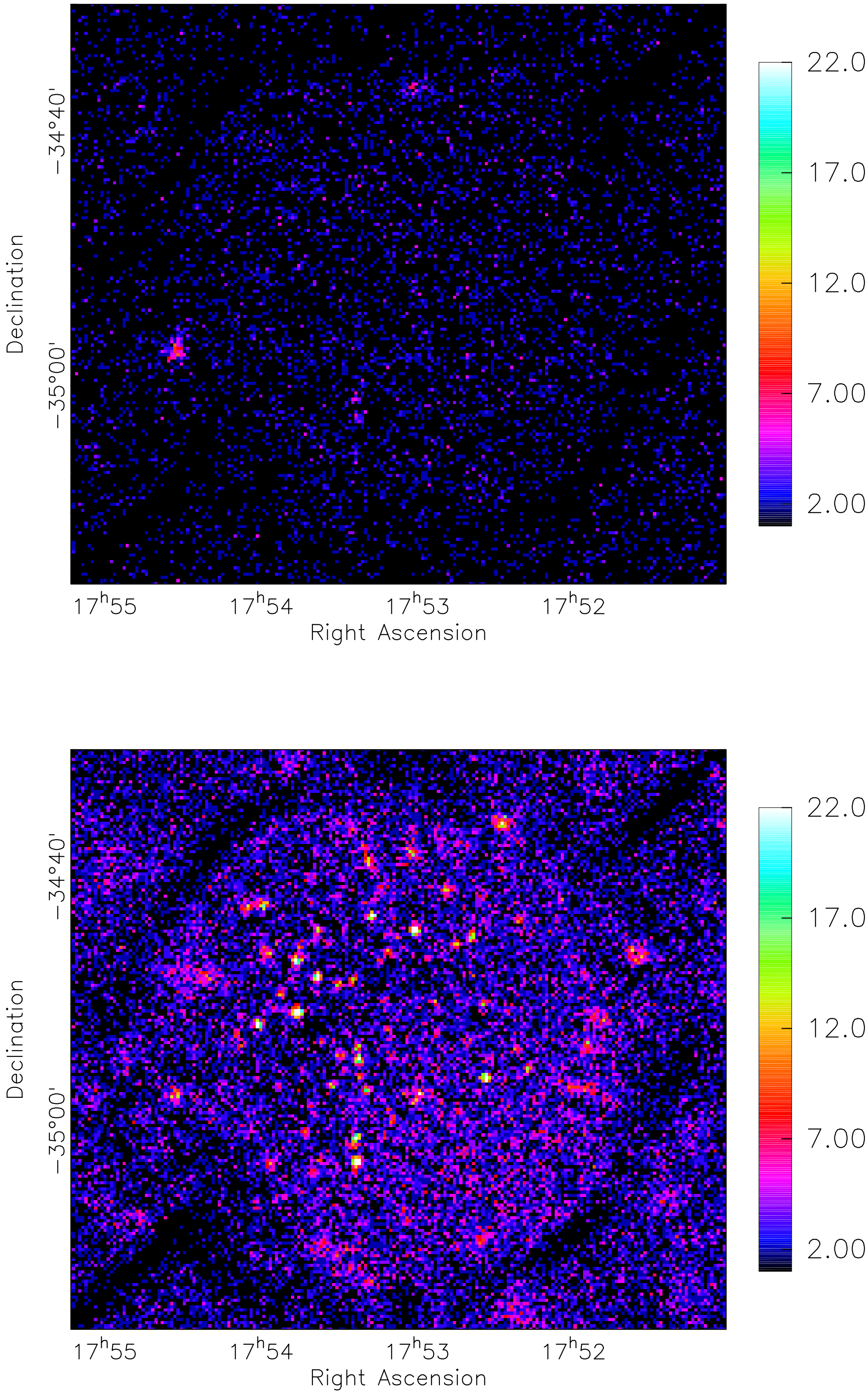

Fig. 1.— The upper plot is a soft band ROSAT PSPC X-ray image, and the lower plot is the corresponding hard band ROSAT PSPC X-ray image, taken in the vicinity of NGC 6475. Both plots depict sources detected in the central ring (∼ 30 arcminutes) of the ROSAT PSPC. Thus, the nominal field of view of XMM (30 arcminutes) will encompass the majority of X-ray sources in NGC 6475. The units of the colour bars are X-ray photon flux (counts).

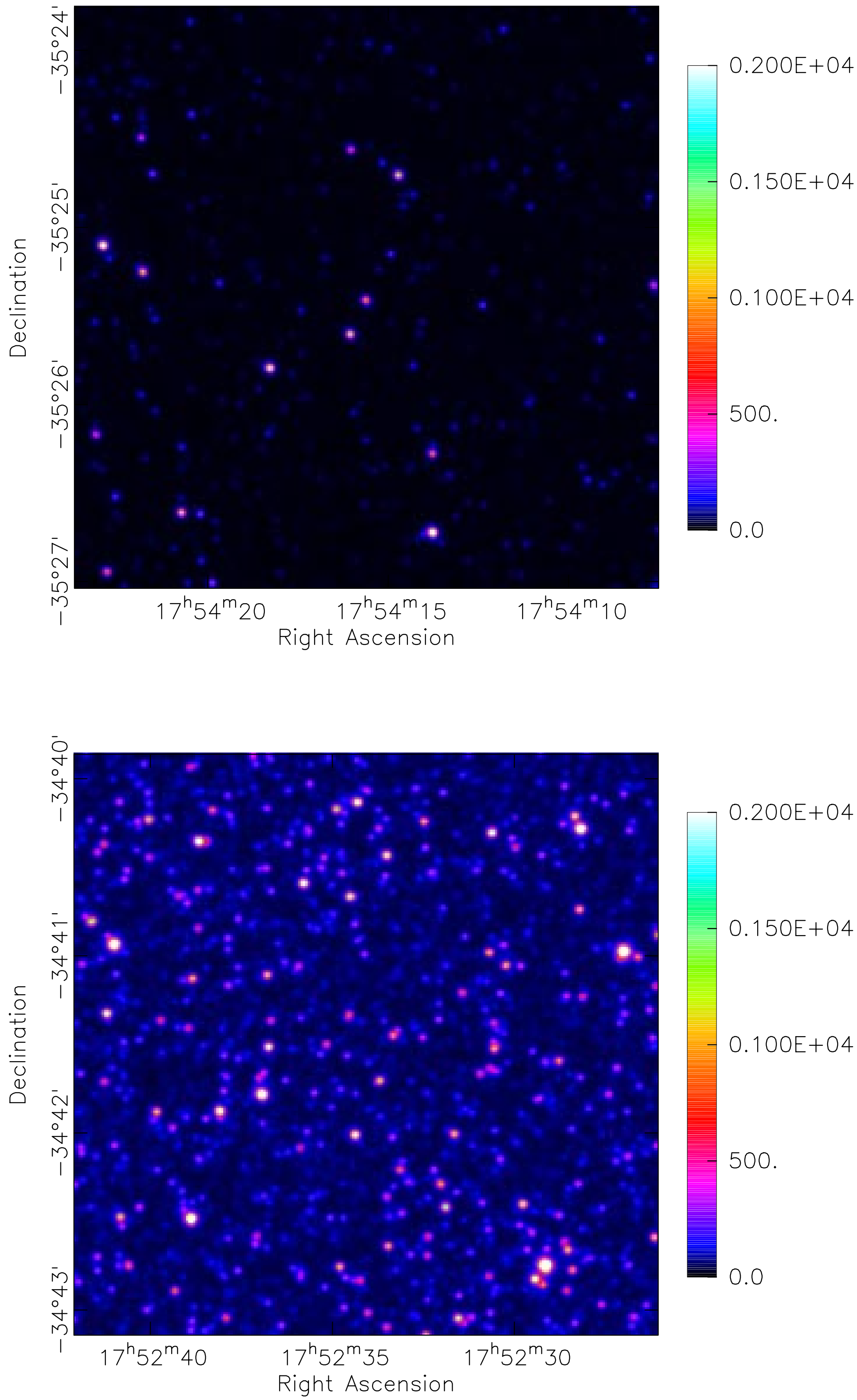

Fig. 2.— Comparison CCD images, taken in the V filter, of two ROSAT PSPC X-ray sub-fields in NGC 6475. The upper plot is a short (25 sec) exposure whereas the lower plot is a deeper exposure (200 sec) of a different field. The colour intensity scale represents CCD photon counts (ADUs). The low Galactic latitude of NGC 6475 (b$\simeq -4^{\circ}.5$) makes optical identification of the X-ray source problematic. The Optical Monitor on-board XMM will enable a more definitive optical identification in such low Galactic latitude open clusters, as well as permitting the study of optical flares (in several filters) and the tracking of surface feature (such as star-spots) rotational evolution on some of the more rapidly rotating stars.

CCD images are shown for two selected X-ray fields in NGC 6475. It is evident that even with the on-axis spatial resolution of XMM ($\sim$ 15 arcseconds), any off-axis source may still have several optical counterparts, and the number of optical counterparts maybe numerous depending on the X-ray field. A fuller analysis of the BVI$_c$ photometry we obtained at the South African Astronomical Observatory (James, Cameron & Jeffries, 1999) allowed us to select stars which are photometric members of the cluster and are in ROSAT X-ray error circles, although such is the spatial resolution of ROSAT+PSPC, high or intermediate resolution spectroscopy is still required to definitively assess which star is X-ray active.

The benefits of using the Optical Monitor are multi-fold. The broad-band filters available for use with the OM will allow simultaneous multi-colour photometry of 17 square arcminute sections of selected open clusters to be performed. Furthermore, continuous monitoring of an open cluster by the OM, during an X-ray observation, should reveal the star-spot motions expected to occur on rapid rotators as they spin on their axes. A correlation analysis could be performed to show expected relations between star-spot activity (and hence magnetic fields and rotation rates) and X-ray emission.

The spectroscopic capabilities of XMM will also be of considerable import when observations are made of late-type stars, although probably not so for those in open clusters. At the secondary focus of XMM lies the Reflection Grating Spectrometer (RGS) which will provide low resolution ($\simeq 100 - 600$) X-ray spectra in the lower energy range of $0.35 - 2.5$ keV. The RGS will yield X-ray spectra which can be used for spectral modelling of the emitting plasma, thus constraining temperatures, emission measures and magnetic structure (loop) models far better than was previously possible.

The last, and very important, characteristic of XMM discussed here is the extensive energy range of X-rays that can be detected. ROSAT has a rather meager energy range of $0.1 - 2.4$ keV. It is evident from ROSAT observations of some open clusters that the stellar coronae surrounding some of the more rapidly rotating stars have temperatures which produce X-ray emissions outside the ROSAT energy pass-bands. For instance, Gagné, Caillault & Stauffer (1995) provide analyses of X-ray observations of G & K-dwarf Pleiads which show that single and two temperature plasma models both yielded moderately hotter coronal temperatures for the more rapidly rotating stars in their sample. The energy range of XMM is $\sim 0.1 - 15$ keV which should be sufficiently wide to detect the vast majority of the X-ray emission expected from the coronae of even the most rapidly rotating solar-type stars.

3. Summary

We can summarise the potential of XMM for studying the X-ray emission from the late-type stars in open clusters by focussing on the major areas in which XMM is superior to its predecessors.

- Sensitivity - XMM has an effective area approximately 10 times that of ROSAT at 1 keV, which will result in far lower exposures times, depending on relative detector efficiencies, to reach the same limiting flux sensitivity for the open clusters already surveyed by the ROSAT satellite.

• Optical Monitoring - The on-board co-aligned Optical Monitor will permit simultaneous observations in the blue-green UV/Optical for source identification, variability studies and low resolution (±20 Å) spectroscopy of the X-ray field being observed. The OM will be particularly useful in the source identification of X-ray fields in optically crowded open cluster images, especially for lower Galactic latitude clusters.

• X-ray Spectroscopy - We believe the plasma models used to fit previous X-ray datasets of open clusters will be better constrained by RGS on-board XMM. The RGS will provide low resolution (R up to 600) X-ray spectra of the targets being studied from which elemental abundances and plasma diagnostics can be derived.

• Extensive Energy Range - The vastly increased energy range of XMM over that of ROSAT will permit the detection of higher temperature X-ray emitting coronal plasmas expected in the most rapidly rotating late-type stars in young ($\lesssim$300 Myr) open clusters.

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