The XMM GT programme on stellar coronae: an overview

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ABSTRACT

The XMM Guaranteed Time programme for coronal sources is briefly presented.

1. Introduction

A significant fraction of the XMM time during the first two years of the mission will be devoted to Guaranteed Time (GT) observations proposed by the 3 Instrument PI's, the Telescope Scientist, the Survey Scientist, the 5 Mission Scientists, and the Project Scientist, on behalf of their teams. The XMM GT programme has recently been finalised and will be published at the time of the release of the first AO for Guest Observers (GO). The GT programme covers in a coherent manner the various science areas than can be addressed with XMM and will produce significant advances in all areas of X-ray astronomy. As an example, I will discuss here the proposed GT programme in the field of stellar coronae, making a comparison with the AXAF GT and approved GO programmes. The XMM GT programme on stars is the results of extensive discussions among GT holders and their teams on how to make the best scientific use of XMM capabilities for addressing fundamental problems in stellar coronal physics. The proposed observations include spectroscopic studies of nearby bright coronal sources, imaging and spectroscopic surveys of open clusters and star forming regions, monitoring and time-resolved spectroscopy of variable stellar sources, studies of stellar winds and colliding winds in binary stars.

2. Key questions in stellar coronal physics

The physics of stellar coronae has been reviewed many times, most recently by Pallavicini (1998) and Schmitt (1998), to whom I refer for details and references. In brief, our present understanding of stellar coronal emission is based on the results obtained over the past twenty years by a number of successful X-ray missions, including HEAO-1, *Einstein*, EXOSAT, GINGA, ROSAT, EUVE, ASCA and SAX. These missions have demonstrated that stars of nearly all spectral types and luminosity classes possess X-ray coronae, which are often orders of magnitude more intense than the solar corona. In early-type stars, X-rays likely originate from shock-heated winds, while late-type stars are dominated by magnetically confined coronae. For the latter stars, X-ray emission appears to depend on both rotation and age, supporting the notion that these stars are heated by dynamo-generated magnetic fields.

X-ray observations of stellar coronae provide information on a number of important physical issues, such as: a) coronal heating mechanisms; b) stellar dynamos; c) star formation and angular momentum evolution; d) coronal structures and stellar winds; e) coronal abundances; f) stellar variability and flares. The observations obtained by past and current X-ray missions, in particular the observations obtained with *Einstein*, EXOSAT, ROSAT and ASCA, have provided some clues about these problems, but have not allowed us to study these problems on a sound theoretical basis. With the new observations to be obtained with XMM and AXAF, we expect to be able to answer some of these questions and to proceed from a largely phenomenological picture to the stage where reliable models can be constructed.

3. Hot stars

The basic question with regard to early-type (O and early-B) stars is how X-rays originate in stars which lack outer convective zones (and thus dynamo-generated magnetic fields) and possess instead massive radiately-driven winds. The model currently accepted assumes that X-rays originate from shock heating in the winds. In order to test this model, XMM will observe in the GT programme a few selected objects (ζ Ori, τ Ori, ι Ori, ϵ Sco, τ Sco, ζ Pup) for determining the temperature structure and column density, as well as for velocity diagnostics and time variability. AXAF will address the same problem with essentially the same strategy and, in most cases, by observing the same objects (which are typically the brightest ones of their class).

If winds are responsible for X-ray emission, we expect enhanced emission in colliding winds in binary systems, particularly in those systems which are formed by a Wolf-Rayet and an O-type star. XMM will devote much attention in the GT programme to binary systems of various types and/or in various evolutionary stages, including observations of some binary systems (e.g. γ Vel) at various orbital phases. Again AXAF is applying the same stategy (including observations of γ Vel), albeit on a much smaller sample of stars than for the XMM GT programme.

A related question is how massive star formation occurs. XMM will address this question by observing a few O-B associations and starburst regions, both in the Galaxy and in the LMC. Proposed targets include NGC 6231, LH9 – LH10, etc. AXAF will address the same problem but using different targets (30 Doradus, NGC 3605, etc.). A unique massive object, which has always attracted much attention, is η Carinae, one of the most massive star in the Galaxy, well-known for its catastrophic explosion in the last century and for its variable behaviour. η Carinae is included in the XMM GT programme as well as in the approved first-year AXAF programme.

Contrary to O and early-B stars, which are strong X-ray emitters, late-B and A-type dwarfs are most likely not X-ray emitters at a significant level. Since these stars have neither strong winds nor outer convective zones, the absence of X-ray emission is consistent with current theoretical models. The very low upper limits established by ROSAT for nearby single A-type stars strongly support this interpretation. On the other hand, X-ray emission has been reported for several A and late-B stars, at levels comparable to that of late-type stars. Thus, either some A dwarfs are X-ray emitters (by a mechanism that we do not yet understand) or these positive detections are due to the presence of unresolved late-type companions. AXAF will address this problem by observing a number of presumably single A-type stars. On the contrary, there are no sources of this type in the approved XMM GT programme. This could be a topic for further investigation in the XMM GO programme.

4. Cool stars

Late-type (F to M) stars constitute the largest fraction of coronal sources to be observed with AXAF and XMM. There are several important issues that we would like to address: which is the heating mechanism of stellar coronae ? How coronal properties depend on mass, rotation and age ? How can we infer (and model) the spatial structuring of coronae from spatially unresolved observations? These basic questions can be addressed in a number of ways: a) by observing a well selected sample of nearby stars with widely different masses, rotations and ages; b) by building large statistical samples of stars, using mainly serendipitous observations; c) by observing stars in open clusters of different ages (and thus using homogeneous samples of stars, all with the same age and metallicity, but different masses).

With regard to the first approach, XMM has included in the GT programme a number of bright stars of different spectral types and ages, including well-known stars like Procyon (F5IV), α Cen (G2V + K1V), π^1 UMa (G1V), κ Cet (G5V), β Hyi (G2IV), and several M dwarfs. AXAF has included in the first-year programme several of the same sources, but not as many as those appearing in the XMM programme. These bright stars are ideal targets for obtaining high-quality spectra to be used for the application of plasma diagnostic techniques. Large samples of stars of different masses, rotations and ages will be obtained serendipitously, while observing other targets. This will allow the construction of large unbiased samples that can be used to investigate the dependence of spectral properties on basic stellar parameters.

Among late-tpe stars, a special place is taken by active binaries (RS CVn's, Algols and W UMa systems) which are the brightest among coronal sources. Therefore, they are ideal sources for medium to high resolution spectroscopy (as it will be possible with the transmission gratings on AXAF and the reflection gratings on XMM) and for application of plasma diagnostics techniques for temperature, density, elemental abundances, and, in some cases, flow velocities (particularly with AXAF). Moreover, a few nearby RS CVn binaries are eclipsing systems which are ideally suited for mapping the distribution of active regions over their surface. Active binaries are also characterized by high temporal variability, with strong, long-enduring events. Thus, they offer also the possibility of time-resolved spectroscopy during flares. For all these reasons, active binaries have often been used as stellar prototypes for modelling purposes, although it is unclear whether they are really representative of "normal" stars in general. XMM has several of these systems in its GT and calibration programmes, including well-know systems like Capella, Algol, HR 1099, UX Ari, AR Lac and others. The *same* objects are also included in the GT and GO programmes of AXAF, which is a clear indication that the number of coronal sources suited for high-resolution spectroscopy and application of diagnostics techniques is unfortunately limited.

M dwarfs are another class of late-type stars which is particularly interesting. They are characterized by frequent flares, which raises the question whether their quescient emission originates from low-level microflaring activity. Moreover, late M dwarfs are fully convective and an important problem is to understand whether dynamo action in fully convective stars is different from the one operating in other late-type stars (where it may originate from field amplification at the boundary of the convection zone and of the radiative interior). Finally, it would be interesting to test whether dynamo action and coronal activity occurs also in brown dwarfs (BD), just below the substellar limit. Many M dwarfs, particularly well-known flare stars (YY Gem, EV Lac, EQ Peg, AD Leo, etc.) are included in the XMM GT programme, with the specific aim of detecting and studying stellar flares. The probability of detecting flares in observations lasting a few tens of kiloseconds is, however, a matter of hit or miss. The same data however will provide high-quality spectra for the quiescent emission. AXAF is using basically the same stategy on a smaller sample of objects (YY Gem, AD Leo, AU Mic, Proxima Cen). In addition, the superior detection capability of AXAF (due to its higher spatial resolution) will allow searching for X-ray emission from very-low mass stars and BDs (e.g. VB 8, VB10, LP 944-20), an area which is apparently neglected in the XMM GT programme.

5. Open clusters and star forming regions

Galactic open clusters are ideal samples to study the dependence of coronal activity on rotation and age and hence to study dynamo action in stars. ROSAT has carried out extensive imaging observations of stellar clusters covering the age range from $\sim$ 30 Myr to $\sim$ 700 Myr. A few older clusters have been observed as well. To improve significantly with respect to ROSAT, both imaging (AXAF) and spectroscopic (XMM) observations with higher sensitivity and spectral resolution are needed. AXAF is capable of extending to fainter limits the census of low-mass stars in clusters; on the other hand, the higher throughput of XMM will allow medium resolution (CDD) spectroscopic observations of many cluster members and, in a few cases, high-resolution observations with the RGS. XMM has indeed a quite vigorous GT programme on stellar clusters, with pointings at the Pleiades, the Hyades, α Persei, IC 2602, IC 2391 and Praesepe. These observations will allow investigating the variation of spectral properties (particularly temperature) as a function of age. On the contrary, it is somewhat surprising that the approved first-year GT and GO programmes for AXAF contain only two open clusters, the Pleiades and IC 2516, in spite of the fact that AXAF could detect many new faint members of nearby open clusters. It is also surprising that, except for an observation of NGC 188, there are virtually no clusters older than the Hyades in both the XMM and AXAF programmes, a situation that could be corrected for in subsequent GO programmes.

At variance with the case of open clusters, both AXAF and XMM appear to have a strong observing programme on star forming regions (SFRs), which shows that this is a very promising field in coronal research. XMM has in its GT programme observations of ρ Oph, Sco-Cen, R CrA, IC 348, and NGC 2023 and 2024 in Orion. AXAF has a particularly strong programme on Orion and the Trapezium region (as appropriate for the high spatial resolution of AXAF), plus pointings at ρ Oph, IC 348 and R CrA. Both XMM and AXAF have also in their programmes spectroscopic observations of selected targets (TW Hya, SU Aur, HD 283572, etc.) in Taurus-Auriga. Moreover, both satellites will observe for an extended period of time the young star AB Dor, which is a nearby isolated star that was believed for a long time to be a PMS object. From the Hipparcos parallax, AB Dor is now known to be a ZAMS star with an age similar to that of the Pleiades.

The observations of SFRs will allow addressing several important questions in coronal physics. They will provide the inital mass function (IMF) for different star forming regions as well as allowing us to understand how coronal activity varies with age during PMS evolution. Medium-resolution (CCD), and in a few cases high-resolution (grating) spectra will be obtained for both Classical T-Tauri (CTT) and Weak-lined T-Tauri (WTT) stars, thus determining whether and how stellar winds and/or the interaction between the star and the surrounding disk affect coronal emission. Moreover, the good response up to energies of $\sim$ 10 keV will allow investigating X-ray emission from protostars, i.e. from deeply embedded sources with ages of the order of 0.1 Myr or less. The high variability of PMS objects will allow studying flares in objects of different ages, for comparison with flares on the Sun and other late-type stars.

6. Other stellar sources

There are a few other types of sources that will be observed by XMM and AXAF early in the mission. An interesting question is the origin (and nature) of the coronal/wind Dividing Line (DL) separating giants with X-ray coronae and low mass loss rates from redder giants with no high-temperature coronae but with strong low-velocity cool winds. This transition may be due to a change in the nature of the dynamo, which in turn is related to a change in the properties of rotation and convection in giants in different evolutionary stages. ROSAT has confirmed the existence of such a DL between yellow and red giants, but has also shown that the DL apparently disappears among supergiants. In the XMM GT programme a few observations are planned for single X-ray emitting giants (β Cet, ϵ UMa, ι Vir, etc., for comparison with active RS CVn and F Com stars); there are no plans however for investigating possible low-level X-ray emission to the right of the DL. The same is true for AXAF which seems to devote very little attention to "normal" giants, except for the bright supergiant Canopus (F0I).

AXAF devotes instead considerable attention, contrary to XMM, to the late stages of evolution of stars, particularly to planetary nebulae, which are observed for both stellar emission and for wind emission. Several planetary nebulae (e.g. NGC 1360, NGC 7027, NGC 6543, etc.) are included in the AXAF first-year programme, whereas none is in the XMM GT programme.

Finally, several white-dwarfs (WDs) are included as calibration targets in the AXAF programme, and one (HZ 43) is also in the XMM programme.

7. Conclusions

Both XMM and AXAF will have a vigorous stellar programme in the early phases of the mission. Comparison of the two programmes is not straightforward, since the approved XMM GT programme is for 2 years while the approved AXAF GT programme refers only to the first year. Moreover, while the XMM GO programme has still to come out, the approved AXAF GO programme for the first year is already available. Taking these differences into account, we can nevertheless make some preliminary considerations. The 2-years GT programme for XMM, plus the calibration and PV programmes (which are not yet completely finalised), contain 90 coronal targets, for a total observing time of $\sim$ 3.8 Ms. On the other hand, the 1-year GP and GO programme approved for AXAF, plus the calibration and PV programmes, include 65 coronal targets for a total observing time of 4.0 Ms. The two programmes are therefore roughly comparable in terms of observing time, with XMM having somewhat shorter average exposure time for target with respect to AXAF. The two programmes are also rougly comparable in terms of scientific objectives, except for a few notable exceptions. The AXAF programme is certainly weaker than XMM in the study of open clusters, whereas is devotes some attention to targets (e.g. A-type stars, very-low mass stars and BDs, planetary nebulae) which are apparently neglected by XMM. Both missions will spend considerable time in doing spectroscopy of bright sources (hot stars, RS CVn binaries, flare stars), often by observing the same targets. Typically, XMM observes more targets for each class of stars than AXAF, consistently with the typically shorter exposure times. Both XMM and AXAF appear to have a strong observing programme for young objects and star forming regions. In any case, albeit the main science topics in coronal physics appear to be adequately addressed by both missions, ample room remains for additional targets and/or pointings to be proposed in the GO programme. Guest observers therefore should have ample opportunities for additional pointings in the above mentioned science areas, as well as for proposing new science that has not yet been considered in the approved GT propgramme.

REFERENCES

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