X-Ray Observations of Open Clusters

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Abstract. Thanks to ROSAT a large number of open clusters has been now observed in X-ray, enlarging significantly our knowledge of the evolution of stellar activity with age. Given their crowding and typical distances, observations of open clusters require to push to the extreme the performances of the instruments and of the analysis techniques.

I shall discuss some of the limits, and their impact on scientific results, inherent to today instruments and standard analysis techniques, and how and to what extent they can be solved either by more sophisticated techniques and by the next generation instruments. As examples, I show how in PSPC observations the use of a wavelet based detection algorithm allows us to improve the source detection process, and how the High Resolution Imager observations of the Pleiades allow us to solve some of the confusion problems present in the PSPC observations.

1. Introduction

Given their characteristics, open clusters have been and are among the best astrophysical laboratories to study the evolution of stars with age. X-ray observations of open clusters allow us to study the evolution of various aspects of stellar activity. A discussion of some of the main results of recent X-ray observations is the subject of the review by J.-P. Caillault (this volume), so I do not further elaborate on them. It is evident that, to understand the physics underlying the evolution of coronal structures with age, we need to observe as many clusters as possible to explore the space of the parameters that could have a role in determining the (X-ray) activity level.

In order to clarify this statement, I have reported in the scatter plot of figure 1 the distance vs. age for the known open clusters within 1kpc. The dashed line, at 500 pc, indicates the maximum cluster distance to assess cluster membership through modern astrometry. Dots indicate clusters that have been observed in X-ray with long dedicated observations, or that will be observed during the ROSAT AO6 run. The majority of the nearest clusters have been or will be likely observed with ROSAT. These observations attempt to push to the extreme the instrumental capabilities both because the observers try to reach the highest sensitivity and because these fields are very crowded and hence very difficult to be analyzed. A number of sophisticated techniques are been developed to take best possible advantage of the available observations.

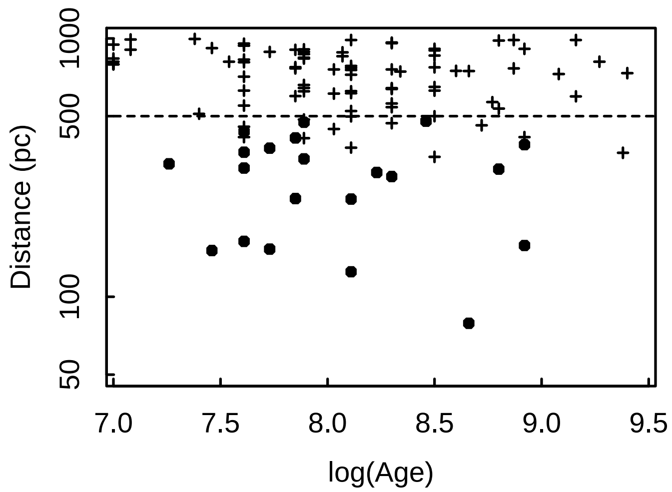

Figure 1. Distance vs. age for the open clusters within 1kpc (data from Lynga, 1987). The dashed line, at 500 pc, indicates the maximum distance to assess cluster membership through modern astrometry. Dots indicate clusters that have been observed or will be observed in X-rays with long dedicated observations.

I discuss some of the problems often encountered in my experience in present day X-ray observations of open clusters, some examples of the improvements we can obtain with new analysis techniques and if and how forthcoming instruments could help us in solving some of these problems.

2. New analysis techniques

A new detection method, particularly suited to analyze very crowded fields and detect faint sources, is based on Wavelet Transforms (WT). Some of the characteristics that make very fruitful its usage are: 1) The WT of an image depends on a characteristic spatial scale and position allowing us to study simultaneously the shape (size) and the location of imaged object; 2) The method can be applied at various scales, taking full advantage of the good spatial resolution near the image center of the PSPC (or other detector working with classical X-ray telescopes), retaining at the same time efficiency in detection of off-axis sources where the spatial resolution is worse; 3) The method allows us to determine source size and intensity.

In the following I will discuss some specific features of a WT based algorithm, developed by my collaborators and myself (Damiani et al. 1995), specially tailored for ROSAT PSPC and HRI images. Characteristics of this implementation are:

- Detection significance has been determined via extensive simulations in order to detect less than 1 spurious source per image.

- The exposure map is taken into account, for properly studying regions of the field of view particularly underexposed, such as those near ribs or edges.
- An iterative procedure to determine the background level has been adopted, in order to detect weak sources even near strong ones.

The generating wavelet function we have used is the classical mexican hat.

This detection algorithm has been applied to a crowded PSPC field on the central region of the Pleiades where more than one hundred sources are clearly present. In this case the algorithm is able to detect a number of faint sources, a sizeable fraction of which was not detected by standard detection algorithms such as those available in EXSAS (Zimmermann et al. 1993) or PROS (Worrall et al. 1992). Many of the new detections are spatially coincident with Pleiades members, making us more confident about their reality.

Another problem typically present in these crowded exposures is the capability to separate sources close each to other. In general, standard algorithms are able to separate close sources of similar intensity but tend to miss weak sources near a strong one, biasing the results against the weakest sources. In the same Pleiades image discussed before, the WT method is able to recognize weak sources near strong sources in pairs not separated by standard algorithms.

Of course it is not always possible to de-blend close sources. Fig. 2 (panel a) shows, as example, a region that has been observed at large offaxis in a PSPC image. In this case the source crowding and the size of the point response function at these large offaxis produce a region of great confusion making difficult the detection and flux determination of individual sources. In such case the wavelet algorithm is not able to separate individual sources and we really need instrumentation with higher spatial resolution. We have performed a series of HRI pointings on a number of Pleiades regions with similar confusion problems, in which it is particularly evident the improvement obtained with higher spatial resolution.

Fig. 2 shows a comparison between a PSPC (panel a) and an HRI observations (panel b) of the same region, on the same scale. Although the livetime of the HRI observation makes it less sensitive than the PSPC observation, its better spatial resolution produces a dramatic improvement in our detection capabilities. Now, we are able to resolve the emission from individual stars and hence to obtain good X-ray photometry also in these crowded regions.

3. The future

The sensitivity achieved with the past and present X-ray missions allows us to reach the median of the X-ray luminosity distribution of dG stars for many clusters, allowing the tracing of the evolution of the X-ray emission level for these stars. At the moment, however, the functional form of the X-ray luminosity decay with age is unknown, so as it is not completely clear the origin of the observed spread in X-ray emission of coeval dG stars. Furthermore, in order to evaluate in an unbiased way the X-ray properties of dG stars in clusters, we still need to detect the X-ray faintest dG stars, what requires deeper X-ray exposures.

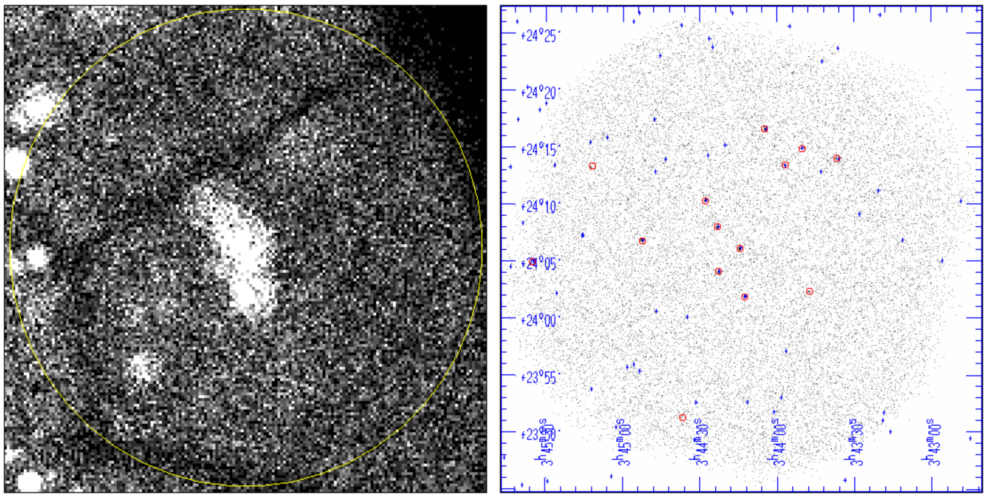

Figure 2. ([a] - left) Region on the Pleiades observed at large offaxis with the PSPC. ([b] - right) The same region observed with the HRI

Analogous considerations for dM stars show that the situation is more difficult for low mass stars, that are intrinsically X-ray fainter. For these stars we have been able to reach the median values only in few clusters. Detailed studies of dM stars in most clusters have to wait for the forthcoming launch of AXAF or XMM, that will be able to detect sources at fluxes as low as $10^{-15} ergs\ sec^{-1} cm^{-2}$.

Reaching these low fluxes in very crowded fields poses other problems, for example the contamination due to field stars. Let us consider a Pleiades-like cluster at a distance of 500 pc and at low galactic latitude. Fig. 3 shows the expected logN-logS relation of dM field stars at this latitude (dashed line), the expected logN-logS for cluster member dM stars (long-dashed line), and the sum of the two (solid line). In the present and following discussions the prediction on X-ray counts of field stars have been obtained with XCOUNT (Favata et al. 1992), a tool for predicting X-ray stellar counts of disk population stars in our Galaxy, based on the Bahcall & Soneira (1980) Galaxy model, modified to take into account different spatial distribution of stars with different age, on X-ray luminosity functions of nearby stars (Schmitt et al. 1985, Maggio et al. 1987, Barbera et al. 1993) and of the nearest clusters (Micela et al. 1988, 1990), and on galactic hydrogen distribution from the radio observations of Lockman (1984). The fraction of field dM stars, detected at the same fluxes of the dM cluster members, is of order 20% of the total number of dM detected stars, posing a non trivial problem in assessing the properties of emission of low mass cluster members in the absence of a-priori knowledge on cluster membership. Furthermore, the expected apparent magnitude distribution of detected cluster members and that of detected field stars have a large overlap making useless a criterion based on apparent magnitude or on the ratio f_X/f_V to discriminate dM cluster members from dM field stars.

Depending on instrumental properties other problems can arise. Let us consider now the expected logN-logS of stars of all spectral types of the Pleiades-

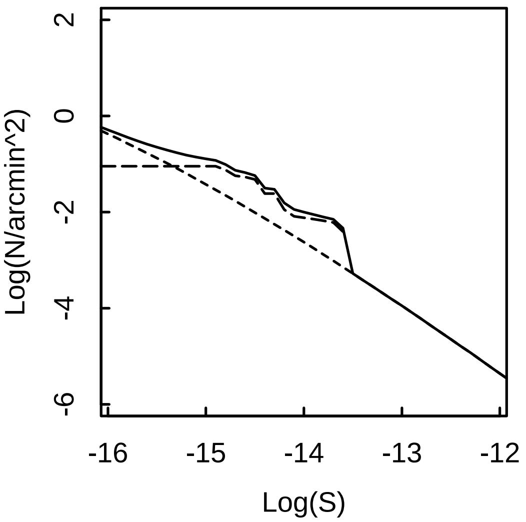

Figure 3. Expected logN-logS for dM0-dM5 X-ray detected stars at latitude $b = 5^\circ$ in presence of a Pleiades-like cluster at 500 pc (Solid line). The dashed line represents the logN-logS of dM field stars, while the long-dashed line is the expected logN-logS for the dM cluster members.

like cluster I have considered above, together with the logN-logS of field stars of all spectral types, as it is plotted in fig. 4. Let us consider now the case of the future XMM-EPIC detector whose throughput could allow us to detect sources as weak as $10^{-15} erg/sec/cm^2$ and that will have a spatial resolution of 20". These two instrumental properties are reported in figure as two (solid) lines: The vertical one represents the nominal sensitivity, while the horizontal one represents the instrumental confusion limit, reached when there is one source for 40 spatial bins. Since the horizontal line intersects the expected logN-logS at fluxes larger than the nominal sensitivity, in general we cannot obtain X-ray photometry for sources with flux below the confusion limit and hence, de facto, the limited spatial resolution limits the sensitivity of the instrument, at least in a region as crowded as that considered here. In such a case we should be careful in drawing spectral information for the strongest sources too, because the presence of nearby weaker sources could in principle distort the spectral shape of the more intense source. On the other hand, EPIC will allow us to obtain good spectroscopy for the sources of the nearest clusters, such as the *real Pleiades*, that are very far from the confusion limit and for which we will be able to collect more than 5000 photons for more than half of the members.

A similar analysis for the AXAF-HRC results in the confusion limit shown as the dashed line in fig. 4. This shows that with this instrument it will be possible to obtain reliable X-ray photometry of individual sources even in crowded cluster fields, allowing us to obtain unbiased X-ray luminosity functions for virtually all open clusters within 500 pc.

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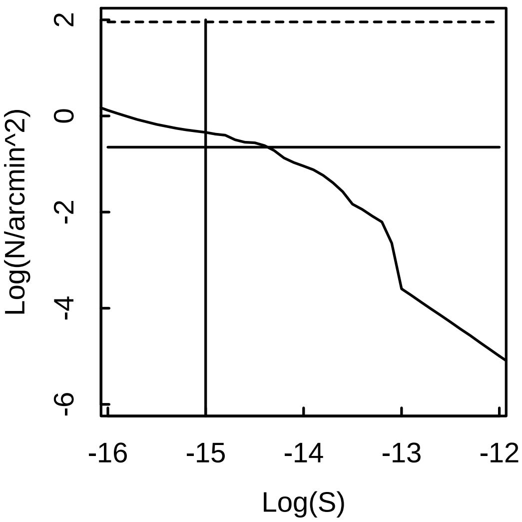

Figure 4. LogN-logS for a Pleiades-like cluster at 500 pc plus field stars at latitude $b = 5°$. The vertical line indicates the typical sensitivity of observations with AXAF or XMM. The horizontal solid line is the confusion limit of the XMM-EPIC detector indicating that in such a field the limited spatial resolution will limit the sensitivity of the observations. The horizontal dashed line indicates the confusion limit of the AXAF-HRC detector.

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