Deep XMM/ESO observations of the low-latitude area around 1E1207.4-5209

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ABSTRACT

The radio quiet neutron star 1E1207.4-5209 has been the target of several XMM-Newton observations, for a total of ~ 450 ks. It is at intermdiate galactic latitude (b ~ 10°), in a sky region with an extremely interesting mix of both galactic and extragalactic sources. Therefore, the analysis of the available EPIC data offers a unique opportunity to investigate such an interesting region. Here we report on the detection of about 150 serendipitous sources above a limiting flux of 2×10^{-15} erg cm^{-2} s^{-1} in the 0.3-8 keV energy range, whose LogN-LogS distribution is different from those measured either in the Galactic Plane or at high galactic latitudes. Moreover, we report the results of the spectral analysis performed on the brightest sources. We also performed an optical multi-band (UBVRI) follow-up of the field with the Wide Field Imager of the ESO/MPG 2.2 m telescope to search for candidate optical counterparts down to a limiting magnitude V ~ 24. We found a candidate counterpart for almost 80 % of our X-ray sources. Finally, based on both the X-ray spectra and optical multi-band photometry, we propose a classification classification for most of the brightest X-ray sources in our sample.

Scientific context

Since the launch of XMM-Newton in 1999, the radio quiet neutron star 1E1207.4-5209 has been the target of several observations, for a total of ~450 ks scheduled time. Thus, these observations make up one of the deepest X-ray surveys performed at intermediate galactic latitude (|b| ~ 10°).
This is especially interesting for two main reasons:
- both galactic and extragalactic objects contribute to the total amount of observed sources
- only few shallow surveys have been performed up to now at these intermediate latitudes

Thanks to the wide energy range, high throughput and good spectral resolution of the EPIC instrument, this dataset allows us to investigate with high sensitivity both the distant population of QSOs, AGNs, and normal galaxies, and the galactic population of stars and X-ray binaries.
The scientific exploitation of the available XMM-Newton data takes advantages from the combination of:

- a long observation time (~ 350 ks of effective exposure time)
- a low flux limit (~ 10^{-15} erg cm^{-2} s^{-1} in 0.5-2 keV)
- a wide energy range (0.3-10 keV)
- a low galactic latitude (|b| ~ 10°)

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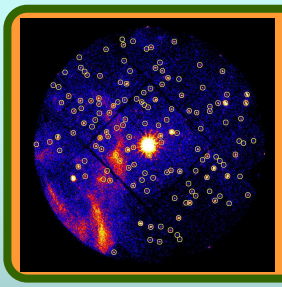
It is well suited to address important issues, such as the ratio between galactic and extragalactic X-ray contributors

To this aim, we considered as identification tools:
- the characterization of the source X-ray spectra
- the analysis of the candidate optical counterparts
- the measure of the X-ray/optical flux ratio



XMM/EPIC Observations

All the three EPIC cameras were active during these observations:
MOS1/2 † Full Frame mode
PN † Small Window mode
(→ only central target data, not analyzed)

The thin filter was used in the two longest observations, while the medium filter was used in all the other observations

The reported exposure time refers to the "net" exposure time after the rejection of time intervals affected by a high level of soft-proton flux.

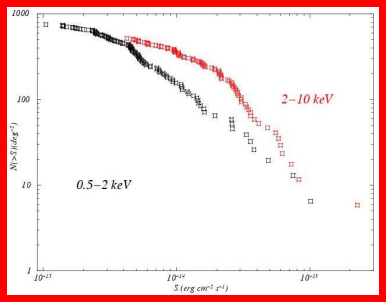
Observation ID	XMM-Newton revolution	Date (UT)	Exposure Time (ks) MOS1	MOS2
0113050501	374	2001-12-23T18:59:41	24.3	25.2
0155960301	486	2002-08-04T07:25:09	105.3	105.8
0155960501	487	2002-08-06T07:17:29	100.7	102.0
0304531501	1014	2005-06-22T12:10:05	15.1	15.1
0304531601	1020	2005-07-05T00:44:58	18.3	17.9
0304531701	1023	2005-07-10T06:43:47	7.1	9.3
0304531801	1023	2005-07-11T02:00:45	56.6	54.5
0304531901	1024	2005-07-12T11:08:22	3.5	3.2
0304532001	1026	2005-07-17T00:18:21	12.7	10.7
0304532101	1033	2005-07-31T14:03:09	2.5	2.1

The Source Detection

We extracted the data of the two MOS cameras to maximize the Signal-to-noise ratio
The source detection was performed on three energy ranges:
- two standard coarse, soft/hard ranges 0.5-2 and 2-10 keV
- the total range 0.3 and 8 keV

The source detection was based on the minimum detection likelihood criterium, in each energy range we selected only sources with a detection likelihood L>8.5
The data set was divided in two time windows:
- group 1 between 2002 December 23 and 2005 August 5th (three observations)
- group 2 between 2005 July 22 and 2005 July 31 (seven observations)

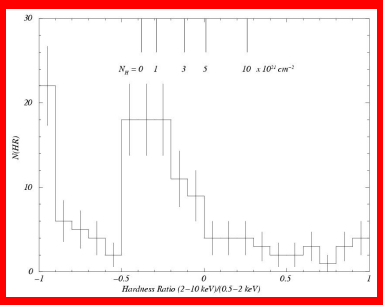
The source detection was performed, with a completely automatic routine, both on these two groups of observations separately, in order to investigate the possible long time source variability, and on the total data set of two pointings, to maximize the exposure time to ~ 340 ks.



Range (keV)	0.5-2	2-10	0.3-8	Total
Group	N(%)	N(%)	N(%)	N
1	101 (76.5)	68 (51.5)	123 (93)	132
2	84 (78.5)	42 (39)	97 (90.6)	107
3	114 (72)	87 (60)	135 (94)	144

The increase in the observing time implies an increase in the fraction of the sources detected in the hard and in the total energy band

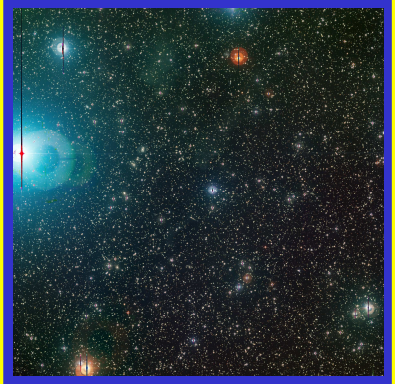
Then we calculated the Log(N)-Log(S) distribution of the detected sources by assuming a template AGN spectrum to estimate the source flux, i.e. an absorbed power-law with photon index Γ = 1.7 and an hydrogen column density $N_H = 1.3\times10^{21}$ cm^{-2}



For all the detected sources we calculated the hardness ratio between the count rates in the soft (0.5-2 keV) and hard (2-10 keV) energy bands. The histogram of the HR distribution shows that most of the sources have -0.5 < HR < 0, while for a large fraction HR ~ -1. On the other hand, only few sources have very hard spectra (HR ~ +1). We compared the measured HRs with the estimated values in the case of a power-law spectrum with photon index Γ = 1.7 ("standard" model for an AGN) and 5 different values of the hydrogen column density. The results are shown as vertical segments on the top of the graphic. In the direction of 1E1207.4-5209 the galactic N_H is 1.3×10^{21} cm^{-2}, therefore sources with HR ≤ -0.3 are probably galactic (stars). Sources with HR ≥ -0.3 could be, e.g. highly absorbed galactic accreting X-ray binary systems or extragalactic sources with intrinsic absorption. This is a reasonable result, since at the intermediate galactic latitude (|b| ~ 10°) of 1E1207.4-5209 we expect to find both galactic and extragalactic X-ray sources.

Optical observations with WFI

The Wide Field Imager (WFI) of the ESO/MPG 2.2 m telescope at La Silla (Chile) has a field-of-View of 33.7' × 32.7', which matches very well with the EPIC FOV => we used WFI to perform a complete optical coverage of the same sky region, with the aim of looking for candidate counterparts of the detected X-ray sources.



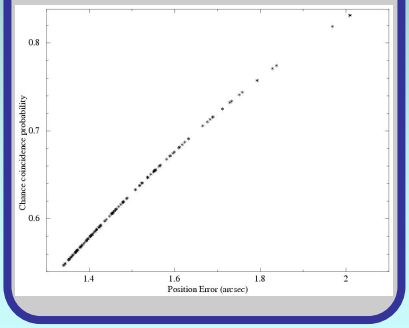
The observations were performed in five filters (U, B, V, R and I), in order to maximize the optical spectral coverage and to optimize the object classification in the color space. In this way we found 64910 sources. For each filter we obtained the following results:

Filter	U	B	V	R	I
Number of sources	18275	33536	47574	53294	45085
Limiting magnitude	23.3	24.7	24.4	24.0	22.7

In addition, to extend our passband coverage to the near-infrared, we used the Two Micron All Sky Survey (2MASS) catalogue, which provides photometry in the J, H and K passbands down to limiting magnitudes of 15.8, 15.1 and 14.3, respectively. Finally, we cross-correlated the catalogues of the WFI and 2MASS sources (with a fixed cross-correlation radius of 1 arcsec) to produce a source optical-to-IR catalogue

X-ray/optical cross-correlations

Based on 6 X-ray sources with a clear optical counterpart in the WFI catalogue, the position of all the detected sources were corrected with the IRAF task wregister. Each source position is affected by a systematic astrometric error of 1.34" plus a statistic error ranging between ~0.1" and ~1.5" (depending of the count statistic). Therefore, the total uncertainty on the source position (i.e. the quadratic sum of both errors) is between 1.34" and 2.01".
In order to be conservative, we searched for candidate WFI/2MASS counterparts by selecting candidates within a cross-correlation radius equal to three times the source position error. In this way, we found at least one candidate optical-IR counterpart for 112 of the 144 X-ray sources (i.e. 78 % of the total sample). A total of 195 candidate counterparts were found because multiple matches were obained for several X-ray sources. This proves that the WFI observations were deep enough to pinpoint at least one candidate counterpart for most of our X-ray sources.
Due to the fore/background contamination, the cross-correlation between the X-ray and optical catalogues is affected by spurious matches. The probability of chance coincidence between an X-ray and an optical source is given by $P = 1\text{-}e^{-\mu\pi r^2}$, where r is the X-ray error-circle radius and μ is the surface density of the optical sources. In our case, μ = 0.016 arcsec^{-2} (64910 sources/33.7x32.7 arcmin^2) and r = 4.02-6.03", therefore the probability of chance coincidence is between 55 and 83 % (see figure below). This means that, at our limiting magnitude, contamination effects cannot be ignored and it is possible that several of the candidate counterparts are indeed spurious matches.



Analysis of the brightest sources

We performed an individual analysis on the 39 brightest sources, with at least 500 counts:
- we accumulated individual spectra and generated ad hoc response matrices and ancillary files, in order to perform a spectral fit with thermal and not-thermal spectral models.
- we looked for the best-fit spectral model among a power-law, a bremsstrahlung, a black-body and a mekal emission model
- based on the candidate optical counterparts, we compared the measured X-ray/optical flux ratios with the typical range of values for the known classes of X-ray sources
- finally, we also compared the classification suggested by the X-ray spectral fits and the X-ray/optical ratio with the photometric classification based on the WFI data

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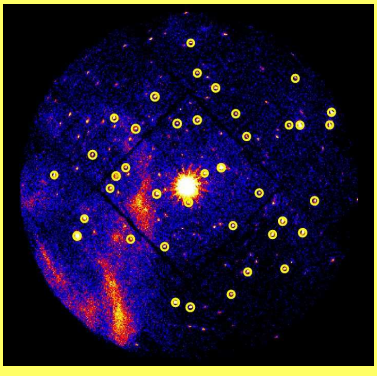
We obtained
- a firm identification for 15 AGNs
- a very likely identification for 14 sources: 8 AGNs and 6 stars
- a tentative identification with an extragalactic object for 2 sources
- no possible identification for the remaining 8 sources



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