Final Report
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Title: Observing Compton-thick AGN with the European missions XMM and Herschel

Project overview/ Introduction

The last years were very prolific for X-ray Astronomy because of the launch of two major missions, the European XMM and the US Chandra. The number density of sources found in deep X-ray observations reaches about 20,000 per sq. degree. This is to be compared with about a few hundred which comes from optical AGN surveys. Thus X-ray wavelengths have proved to be the most efficient way of detecting Active Galactic Nuclei i.e. supermassive black holes. However, even X-ray survey have difficulties in identifying the most obscured AGN, namely sources with obscuring column densities around 10^{24} cm^{-2} (or equivalent optical obscurations of AV~400 mag !). The identification of this 'hidden' part of the Universe is the scope of the current project. For this purpose we employ not only deep X-ray observations but also IR observations. The advantage of the IR observations is that the obscured radiation is re-emitted at these wavelengths making these sources copious IR emitters. Our analysis takes place mainly in the Chandra Deep Field South. This is the region of the sky with the deepest X-ray observations ever obtained (3Ms of XMM and 4 Ms of Chandra) but also with a variety of multi-wavelength observations (e.g. Spitzer, Herschel). In summary, we believe the major goal of the project which was development of IR methods for finding heavily obscured AGN, training in IR data analysis and comparison with X-ray spectral analysis techniques has been completely fulfilled.

Overview achievements relative to objectives.

In the first year of the project we finished with all the necessary steps for the data reduction in both X-ray (XMM and Chandra) as well as mid-IR wavelengths (Spitzer and Herschel). Moreover, we proceeded with the data analysis of heavily obscured sources according to XMM spectroscopy (Comastri et al. 2011). We performed X-ray and mid-IR analysis in various potentially interesting classes of sources, e.g. mid-IR excess AGN which are believed to host heavily obscured nuclei, (Georgantopoulos et al. 2011a). We developed tools for fitting the Spectral Energy Distribution of sources as well as for X-ray background synthesis models. In more detail, the specific tasks pursued during the full two year duration of the project were the following.

Work packages/Deliverables

XMM source detection. After cleaning of periods of high particle background, we derived the list of XMM sources detected in various energy bands (0.5-2 keV, 2-8 keV and 0.5-8 keV). The source detection was performed in the combined PN, MOS1, MOS2 images to optimize the sensitivity. About 400 sources have been detected.

X-ray Spectral analysis for the selection of candidate Compton-thick sources. The spectral reduction has been performed with the XMM specific SAS tools. Because of the large number of observations (~90) and the large number of sources (~400), it is obvious that this task cannot be performed manually (it would require 400x90=36,000 spectral extractions and thus few years for completion). Instead, scripts have been developed in order to automate the spectral extraction procedure. A quick look analysis of the spectra has been presented in Comastri et al. (2011). A more detailed analysis of all the X-ray

sources with flat (candidate highly obscured sources) is presented in Georgantopoulos et al. (2012). Herschel analysis SEDs is also presented in the same paper.

Chandra spectral analysis of X-ray sources. To enhance the X-ray photon statistics we extracted X-ray spectra for all Chandra sources using the 4Ms Chandra event files. The joint XMM/Chandra fitting of the candidate heavily obscured sources are given in Georgantopoulos et al. (2012). Other papers where Chandra spectral fits of interesting classes of sources are presented are Georagantopoulos et al. (2011a, 2011b, 2011c).

IR photometric analysis (Spitzer and Herschel) of CDFS sources. The Spitzer catalogs used are available online. The Herschel observations in the CDFS are led by D. Elbaz. OABO is part of this collaboration. The Herschel catalogs have been obtained from our collaborators at Saclay in France. We developed a spectral energy distribution tool which fits the IR data in order to decompose the AGN from the star-forming galaxy contribution. More details s well as description of the AGN and galaxy templates used are given in Georgantopoulos et al. (2011c).

X-ray background synthesis models. The extragalactic X-ray light, the X-ray background carries the signatures of all the X-ray sources in the Universe, detected or undetected. Thus X-ray background synthesis models have the potential to constrain the properties of very faint (and hence probably highly obscured sources) which have not been detected individually in deep X-ray exposures. We made modifications to X-ray background synthesis models with the aim of using recent developments on AGN X-ray spectra (in particular the strength of the reflection component as well as the high energy cut-off of the X-ray spectrum). The goal was to explore the full parameter space without constraining a priori any parameters.

Exploring new methods for finding Compton thick AGN: Molecular lines. The HIFI spectrograph on board Herschel can provide valuable diagnostics on the physics of molecular gas. In particular CO and HCN observations can identify sources with large reservoirs of molecular gas. We exploited analogous ground based observations of molecular lines in a sample of local Ultra-luminous IRAS galaxies which have X-ray observations available. We found that the sources with high amounts of molecular gas have high probability of harboring Compton-thick nuclei according to X-ray observations.

Exploring new methods for finding Compton-thick AGN: Silicate absorption features. In Georgantopoulos et al. (2011c) we exploit the possibility of recognizing Compton-thick sources through their large optical depth, τ, silicate absorption features at 9.7 μm. It is found that this method is highly promising, albeit it cannot produce statistically complete samples. This means that although high-τ sources are by default heavily obscured, the opposite is not true, i.e. there are Compton-thick sources which present no absorption at 9.7 μm.

Selecting Compton-thick sources on the basis of Lx/L6μm luminosity ratios. In this paper (Georgantopoulos et al. 2011d) we explored the use of the Lx/L6 luminosity ratio as a Compton-thick indicator. Using both XMM and Chandra data (7 Ms total exposure time resulting in the most sensitive view of the Universe ever achieved), we found that low Lx/L6 ratios imply large amounts of obscuration. However, the most interesting finding of this work is that there are bona-fide Compton thick sources which do not show low Lx/L6 ratios rendering this technique incomplete.

Searching for highly obscured sources in various mid-IR/sub-mm classes of sources.

Because of the excellent quality of X-ray data in the CDFS, it is easy to check for the presence of heavily obscured or Compton-thick sources using X-ray spectroscopy. We checked mid-IR excess (24μm) relative to their optical emission. These sources have been often claimed to comprise exclusively Compton-thick AGN. In Georgantopoulos et al. (2011a) we conclude that the fraction of highly obscured sources can not be more than 50%. Another class of sources we examined are the sub-mm galaxies detected in the LABOCA survey (Georgantopoulos et al. 2011b). We find a small fraction of heavily obscured sources among this class of galaxies in contrast to previous beliefs.

Researcher training activities

a. IR (Herschel and Spitzer) training and development of SED tools. This was a critical part of the project aiming to transfer expertise to the researcher. It is interesting that all the papers of the researcher in the last two years have to do with IR data analysis. The development of spectral energy distribution tools played an important role in this training.

b. Workshops & Conferences. The researcher has participated in a large number of workshops an conferences. This contributed significantly in his training but also had an important role in his visibility at international level. In particular, the workshops and conferences attended in the duration of the project were:

i) Herschel symposium Nordwijk, Netherlands, May 2010
ii) COSMOS AGN consortium meeting Munich, February 2010
iii) The extreme X-ray Universe, Leicester, July 2010
iv) Black Holes and Revelations, Ferrara, April 2010
v) NHXM meeting, Valencia, November 2010
vi) X-ray Astronomy up to 511 keV, Ferrara, September 2011
vii) 3rd Galileo-xu Guanqi High Energy Astrophysics conference, Beijing China, October 2011
viii)EROSITA conference, Garmisch Panterkirchen October 2011
ix)The X-ray Universe 2011, Berlin, June 2011
x)International X-ray Observatory Conference, Rome, March 2011
xi)XMM/CDFS meeting Barcelona, May 2011
xii)XMM/XXL meeting Bonifacio, May 2011

c. Seminars. In the environment of Bologna, the researcher had the opportunity to attend up to 4 seminars per week (two jointly organised by the Department of Astronomy and OABO/INAF) one by the Institute of Space Physics and one by the Institute of Radio Astronomy. The researcher also gave a series of colloquia on his work (two in Bologna and one in Monteporzio observatory in Rome).

d. Weekly meetings. The x-ray and IR group at INAF/OABO organises weekly meetings (with the participation of 8-10 researchers) where recent papers in the field are discussed together with the progress achieved by the members of the groups in their work fields. These meeting play a pivotal role in the training aspects.

e. Regarding the work in X-ray background population synthesis models, the researcher had the opportunity to work within the environment of the world leading group in this field. A paper on X-ray background models including predictions for the Nustar mission to be launched in February 2012 is just before submission.

f. Participation in the science working group of ESA's M3 candidate mission NHXM. The researcher had the opportunity to be invited as a member of the candidate NHXM mission. This mission aspires to observe the hard X-ray sky (>10 keV) with imaging optics (~30 arcsec FWHM) obtaining the most sensitive observations of the hard X-ray sky. The work (simulations etc) as well as exchange of ideas in the framework of this group resulted in acquiring key training.

g. Observing time Proposals. The candidate made as Principal Investigator or Co-Investigator a number of proposals (XMM and Chandra). The XMM proposal on high-τ 9.7μm AGN (PI I. Georgantopoulos) was successful and resulted in observations of a dozen of such systems with XMM. The goal is to check whether these systems are heavily obscured. In 2011 the researcher submitted a 450ksec XMM proposal for observing the 16 sq. degrees Herschel-ATLAS survey. The results on this proposal are still pending. Moreover, the candidate participated in a number of optical and sub-mm proposals.

h. International collaborations. Important synergies have been forged with institutes which are key players in the analysis of Herschel data and in particular with Saclay in France. These collaborations revolved around two axes. First, the Spitzer spectral analysis of sources in the CDFS. Second, the photometric analysis of Herschel sources in the CDFS. Expertise for the development of SED fitting tools has also been acquired through these collaborations. In particular there have been close collaborations with Dr. Elbaz, Dr. Dasyra and Dr. Mullaney at Saclay.

REFEREED PAPERS RELEVANT TO THE PROJECT.

The following papers relevant to the project have been submitted in 2010 and 2011 or about to be submitted in international refereed journals.

1. Georgantopoulos, I. et al., 2010, A&A, 520, L4 **Molecular Lines as tracers of Compton-thick AGN**

2. Rovilos et al. 2010, A&A, 522, 11, **Optically faint X-ray sources in the Chandra deep field North: Spitzer constraints**

3. Georgantopoulos, et al. 2011a, A&A, 522, 11, **X-ray detected infrared excess AGN in the Chandra deep fields: a moderate fraction of Compton thick sources**

4. Comastri et al. 2011, A&A, 526, L9, **The XMM Deep survey in the CDF-S. I. First results on heavily obscured AGN**

5. Georgantopoulos et al. 2011b, A&A**,** 526, 46, **X-ray observations of sub-mm LABOCA galaxies in the eCDFS**

6. Georgantopoulos I. et al. 2011c, A&A, 531, 116, **X-ray observations of highly obscured $\tau_{9.7\ \mu m} > 1$ sources: an efficient method for selecting Compton-thick AGN?**

7. Georgantopoulos et al. 2011d, A&A, 534, 23**. On the L_x - $L_{6\ \mu m}$ ratio as a diagnostic for Compton-thick AGN,**

8. Rovilos et al. 2011, A&A submitted **XMM-Newton and Herschel search for an AGN star-formation connection in the CDFS**

9. Georgantopoulos et al. 2012, A&A, in preparation **XMM and Herschel observations of highly obscured AGN in the Chandra Deep Field South**