A Step Towards Solving The Optical Ambiguity Of Transition Objects

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Abstract

Surveys have revealed a class of object displaying both high X-ray luminosities ($L_X > 10^{42}$ erg s^{-1}) and an ambiguity towards the presence of an active galactic nucleus (AGN), or star-formation in the optical band. If these sources are powered by star-formation activity alone, they would be the most extreme X-ray luminous star-forming galaxies known. We have investigated the mechanisms driving the X-ray luminosities of such galaxies by studying the X-ray emission from three moderate redshift (z~ 0.1) examples of this class, selected from a cross-correlation of the SDSS-DR5 and 2XMMp-DR0 catalogues. X-ray spatial and long-term variability diagnostics of these sources suggest that they are compact X-ray emitters. This result is supported by the detection of rapid short-term variability in an observation of one of the sources. The X-ray spectra of all three sources are best fitted with a simple absorbed power-law model, thus betraying no significant signs of star-formation. These results indicate that the X-ray emission is powered by AGN activity. But why are these sources optically ambiguous? We show that the most likely explanation is that the optical AGN emission lines are being diluted by star formation signatures within their host galaxies.

Introduction

- Deep & wide X-ray surveys
  - ~ 90% X-ray background = discrete sources (e.g., Lumb et al. 2002; Moretti et al. 2003; Bauer et al. 2004; Worsley et al. 2005; Hickox & Markevitch 2006)
  - Most at z ~ 0.2 – 5 with $L_X > 10^{42}$ erg s^{-1} (e.g., Hornschemeier et al 2001; Barger 2003; Brandt & Hasinger 2005; Treister et al. 2005; Silverman et al. 2010)
    - Many clearly AGNs
    - Some LINER/Transition objects
      - optically ambiguous as to how much emission is coming from AGN and how much emission is coming from star-formation
  - Powered by star-formation alone => **THE MOST POWERFUL STAR-FORMING GALAXIES KNOWN** (L_X ~ 10^{42} – 10^{43} erg s^{-1})
    - More powerful than the brightest star-forming galaxies in the local universe (e.g, Moran et al. 1999; Zezas et al. 2001; Lira et al. 2002; Ptak et al. 2003)
- Goal of this work:
  - Find evidence of what is dominating the X-ray emission of this class of object with data from closer objects with similar X-ray and optical characteristics, and thus attempt to solve this ambiguity.

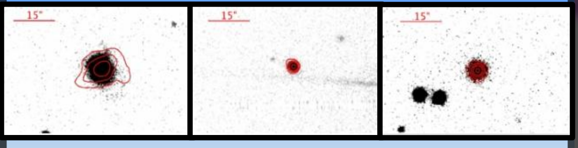

Figure 2. Close up SDSS red images of J082042.4+205715, J123719.3+114915, and J140052.5-014511, overlaid with X-ray contours. These contours were created using the Chandra observations of the three sources. It has been determined that all three sources are point-like, having analysed their point spread function against those of CHART software-generated point-like sources with similar photon count rates and energy levels.

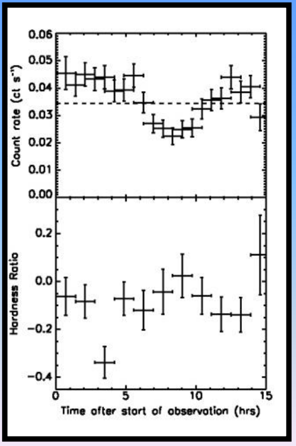

Figure 3. *Top panel:* The background-subtracted ACIS light curve of the source J140052.6-014511. The horizontal dashed line represents the constant count rate the light curve is X^2 tested against. This is the only example of a light curve in this study with such a high short-term temporal photon count variability. Most of this variability is seen as a 'dip' in the count rate of ~ ½, which lasts for ~20 ks (or ~ 6 hours). This implies that at least half the X-ray emission is coming from a region ~ 6 light hours across, consistent with the central region of an AGN. *Bottom panel:* The hardness ratio of the source, as a function of time, for this observation. Apart from the softening between ~ 10 and 15 ks into the observation, the hardness remains roughly constant throughout the observation, including the 20 ks count rate drop. This implies that the 'dip' may either be caused by an intrinsic fluctuation in the compact region output, or by a Compton-thick medium passing in front of the X-ray emission region and (at least) partially obscuring it.

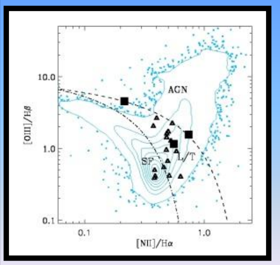

Figure 1. The emission line diagnostic diagram displaying the [NII]/Hα vs. [OIII]/Hβ flux ratios. Part of the optical source selection criteria was for the sources to display low line ratios of this nature. This can be seen in the diagram where our three galaxies' ratios are marked by the black squares. Two of the three sources have line ratios that indicate them as being on the border of the AGN and Liner/Transition regions of the diagram. The other source is situated well within the Liner/Transition region.

Source Selection and Observations

The three sources, J082042.4+205715, J123719.3+114915, and J140052.5-014511, were selected from a cross-correlation of the SDSS and 2XMMp catalogues. There were a number of criteria that the sources from both the SDSS catalogue and the 2XMMp catalogue had to fit. With the SDSS sources, there had to be low [NII]/Hα and [OIII]/Hβ flux ratios and young stellar continua in their spectra. With the 2XMMp sources, X-ray luminosity had to be ~ 10^{42} erg s^{-1}, and their on-axis photon count rate must have been ~ 0.01 ct s^{-1}.

The sources were observed using the *XMM-Newton* EPIC-MOS and PN and *Chandra*'s ACIS-S and I instruments. All three sources had initial data from serendipitous *XMM-Newton* observations. J082042.4+205715 had a serendipitous *Chandra* observation. Follow up observations were taken on the sources with both *XMM-Newton* and *Chandra*. A total of nine observational data seta were analysed in this work, three with J082042.5+205715 data, two with J123719.3+114915 data, and four with J140052.6-014511 data.

Spectral Results

- J082042.4+205715:
  - Hard power-law slope (Γ ~ 1.4 – Γ ~ 2.1)
  - Low absorption
  - Physically acceptable best fitting power-law + MEKAL (Mewe et al. 1985; Mewe et al. 1986; Kaastral 1992) model in one data set
    - 6% upper limit to luminosity from MEKAL of ~2 X 10^{41} erg s^{-1}
- J123719.3+114915:
  - Power-law photon index varies from 0.2 – 1.8 (likely due to poor data quality)
  - High absorption levels
- J140052.5-014511
  - Soft power-law slope (Γ ~ 2 – Γ ~ 2.7)
  - Low absorption levels
  - Physically acceptable best fitting power-law + MEKAL model in one data set
    - 9% upper limit to luminosity from MEKAL of ~ 10^{42} erg s^{-1}

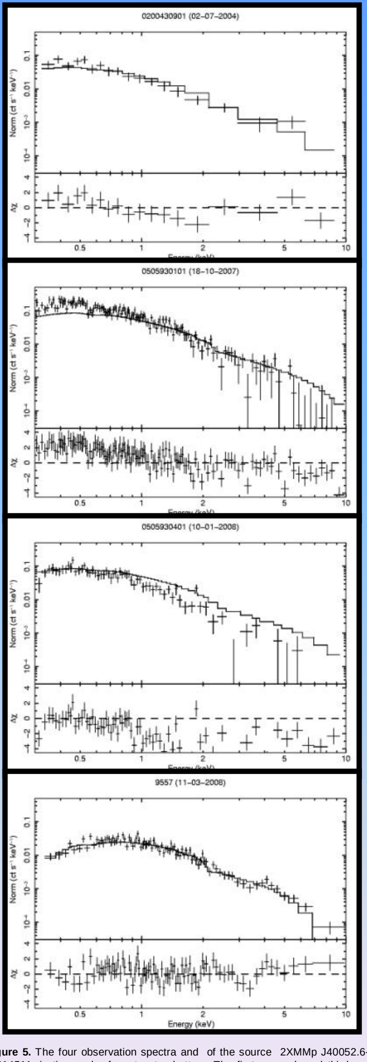

Figure 5. The four observation spectra and of the source 2XMMp J40052.6-014511, in time order from top to bottom. The first, second, and third are those of the three *XMM-Newton* observations. The bottom spectrum is that of the *Chandra* ACIS-S 9557 observation. The four spectra are plotted against the absorbed power-law model best fitting to the *Chandra* data. ΔX is plotted under each of the spectra. Clearly, there is a variation of power-law photon index and photon index normalization between the spectra.

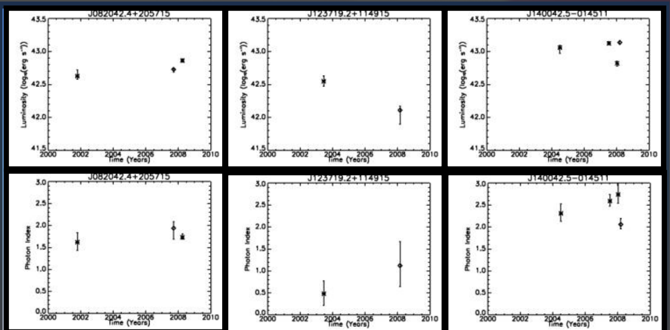

Figure 4. Plots of photon index vs. time (lower three) and luminosity vs. time (upper three) of the three sources. The diamonds represent the data from the *Chandra* observations, and the asterisks represent the data from the *XMM-Newton* observations. Significant long term variability can be seen in the luminosity of the three sources. The photon index of the source J140052.6-014511 is also seen to vary with time.

Discussion and Conclusion

The point-like nature of the sources tells us that there is no extended star forming region within the galaxies' nuclei (c.f., Fig. 2). The long-term variability in source luminosity and photon index implies that the three sources are compact (c.f., Fig. 4, Fig. 5). Both of these findings imply the presence of AGN activity. These results are backed up in the case of J140052.5-014511 with short term variability during its *Chandra* observation (c.f., Fig. 3).

All three X-ray spectra are consistent with AGN activity. Note however the 99% upper limits to luminosity that the MEKAL in the spectral fits of J082042.4+205715 and J140052.5-014511 infer star forming luminosities of ~2 X10^{41} erg s^{-1} and ~ 10^{42} erg s^{-1}.These luminosities are within the luminosity range of large star forming galaxies.

All of our analysis results indicate the presence of AGN activity within the three galaxies. But why is it unclear what is powering the optical emission? It is most likely due to the AGN optical emission being diluted by stellar emission within the host galaxies. Evidence of this can be seen in the [NII]/Hα and [OIII]/Hβ line ratios (c.f., Fig. 1).

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