# X-shooter Science Verification Proposal

## Title: A search for buried or intrinsically weak AGN in X-ray powerful starbursts


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**Abstract:**

It is usually *assumed* that any galaxy with $L_x > 10^{42}$ erg/s is an AGN rather than a starburst galaxy. However, this upper limit has never been rigorously probed. Using SDSS spectra and the XMM-Newton Serendipitous Survey, we have identified star-forming galaxies with extreme X-ray luminosities ($L_x > 2.0 \times 10^{42}$ ergs/s). Here we select 4 galaxies for a pilot study, to search for the presence of AGN. Although the SDSS spectra show no evidence of nuclear activity, it is quite possible that weak optical AGN signatures may be present, such as the high ionisation lines of [Fe VII], [Fe X] and [Ne V], and low contrast broad wings on the Balmer lines of H$\alpha$ and H$\beta$, which the superior X-shooter spectra may detect. Alternatively the AGN may be present but obscured in the optical. X-shooter medium/high resolution NIR spectroscopy could reveal broad wings on Pa $\alpha$ and/or the presence of [Si VI]1.96 $\mu$m. If AGN-related signatures are definitively not detected in the high quality X-shooter data, then a starburst is the most plausible source of the strong X-ray emission. This would have implications for the interpretation of X-ray source populations in deep surveys, in that AGN cannot be assumed in all sources with $L_x > 10^{42}$ erg/s. Alternatively if an AGN is discovered, then we have potential for a new X-ray source population, whose moderate quality optical spectra show only a starburst, but which on closer scrutiny reveal nuclear activity. Either way these pilot X-shooter observations should yield an interesting and significant result.


**Scientific Case:**

Our principal aim is to use X-shooter observations for a small pilot study to determine the upper limit of the X-ray luminosity of star-forming galaxies. This is important for two reasons: firstly to fully understand the star formation processes in general, i.e., the role of binaries and diffuse components such as superwinds, and secondly to quantify the role of such galaxies in deep X-ray surveys. We propose to attack these topics simultaneously using high quality optical and near infrared spectroscopy of an X-ray selected sample of star-forming galaxies. This sample includes objects with $L_x > 2.0 \times 10^{42}$ ergs/s, that is 100–1000× more X-ray luminous than a typical star-forming galaxy found in the local universe. Their optical spectra from the Sloan Digital Sky Survey (SDSS) are indistinguishable from starbursts. In particular they display no evidence of an AGN; they have neither broad Balmer lines nor high excitation emission lines such as [Ne V], [Fe VII], [Fe X] and He II.

However, a fundamental uncertainty is whether their X-ray emission is dominated by an obscured and/or weak AGN undetectable in the optical band. We will look for conclusive evidence of an obscured AGN in the infrared, namely, broad wings on Pa $\alpha$ or the presence of the high excitation line [Si VI] (this line would not be strong unless an AGN is present because stars do not provide enough flux above its ionisation potential of 167 eV). Although one could always invoke more and more extinction to block even these signatures, past surveys of ULIRGs suggest that infrared spectroscopy remains an extremely powerful way to discover hidden AGN (Veilleux et al. 1997 ApJ 484, 92). Our proposed sensitivity will probe the likely extinction parameter space, if an AGN is present.

In addition to setting strong constraints or detections of an obscured AGN in the near IR, we will also use the high S/N optical spectra to search for weak AGN activity. This will manifest itself by the presence of weak high ionisation optical lines not produced by starbursts such as He II 4686Å, [Fe VII] 6087Å, and possibly [Fe X] 6374Å and [Fe XI] 7892Å. Also, the high S/N spectra will enable us to define the continuum accurately, and so look for weak low contrast broad wings on the H$\alpha$ line that appears to be narrow in the SDSS data.

**Highly X-ray luminous starbursts**

Our four selected targets form a pilot study, and are drawn from an X-ray selected sample of star forming galaxies. They are identified through a cross-correlation of spectroscopic targets in the 6th data release of the SDSS with X-ray sources in the second XMM-Newton serendipitous source catalogue (2XMM). The SDSS spectra were carefully examined to remove all active galaxies including narrow-line AGN, leaving 111 X-ray selected galaxies with optical spectra dominated by star-formation processes and with X-ray luminosities spanning six orders of magnitude.

The targets proposed here all have extreme X-ray luminosities of $L_x > 2.0 \times 10^{42}$ erg/s in the full XMM band (0.3–12 keV), and $z < 0.27$ to ensure that Pa-$\alpha$ and [Si VI] lie within the K-band. We have roughly 20 such objects in total, and the 4 selected are representative of the group. Finally, we determined that X-shooter can achieve the required sensitivity in 60–90 minutes. If we can show that these high $L_x$ sources are not substantially contaminated by obscured AGN, then this implies star formation rates over 150 solar masses per year, assuming that the relationship of Grimm et al. (2003, MNRAS 339, 793) can be extrapolated to these higher luminosities. Alternatively, if broad Pa $\alpha$ is detected, then we can use it to set lower limits on the extinction of the material obscuring their broad line region, and to estimate $A_v$ if broad Pa $\beta$ is also detected.

In summary, this pilot study of extremely high $L_x$ star-forming galaxies should show whether they are really pure starbursts, or whether they harbour weak or obscured AGN. This will be important to our understanding of star formation, the search for hidden AGN, and for the interpretation of source populations in deep X-ray surveys.

## Targets and observing mode

| Target | RA | DEC | V mag | Mode (slit/IFU) | Remarks |
|---|---|---|---|---|---|
| SDSS J1400–0145 | 14 00 52.6 | -01 45 11 | 18.0 | slit | First priority; 6 × 900 sec exposures |
| SDSS J1237+1149 | 12 37 19.3 | +11 49 16 | 18.4 | slit | Second priority; 4 × 900 sec exposures |
| SDSS J0148+1354 | 01 48 57.0 | +13 54 52 | 19.3 | slit | Third priority; 6 × 900 sec exposures |
| SDSS J2318+0016 | 23 18 55.5 | +00 16 19 | 19.2 | slit | Fourth priority; 6 × 900 sec exposures |

## Time Justification:

We have used the exposure time calculator to estimate the S/N of a point source in each X-shooter arm. The SDSS spectra show these four targets to be starburst galaxies with some intrinsic extinction. We therefore use the "Starburst Galaxy 5" template (which represents $0.51 \leq E(B-V) \leq 0.60$; Kinney et al. 1996, ApJ 467, 38) to model their UVB and VIS spectra. This is normalized by converting the SDSS PSF magnitudes to V band. For the NIR spectra, we assume a power-law of $f_\lambda \propto \lambda^\alpha$, with $\alpha$ in the range of -0.7 to 0.0 based upon the spectral slope from 5000 to 9000Å measured from the SDSS data. This was normalized using the 2MASS $K_s$ magnitudes after including an aperture correction of 0.5 mag to account for the lower spatial resolution of the 2MASS data. Apart from these specifications, we adopt the default simulator parameters for sky conditions (3 days from new Moon, airmass = 1.2, and 0.80" seeing) and instrument setup (slits of 1.0, 0.9 and 0.9 arcsec for the UVB, VIS and NIR arms and the "high 1×1 slow" detector mode). Exposure times of 3600–5400 seconds are chosen such that the lowest S/N achieved per pixel across the 4000–9000Å band matches the average S/N per pixel of the (lower resolution) SDSS spectra in the $r$ band, where the SDSS sensitivity peaks (these S/N ratios are 30, 20, 13 and 14 respectively for 1400–0145, 1237+1149, 0148+1354 and 2318+0016). We would therefore obtain higher resolution spectra and significantly increase our sensitivity to broad features.

The chosen exposure times will provide sufficient sensitivity in the K band to test for the presence of obscured AGN by the detection of any broad Paschen lines and [Si VI]. If we use the observed X-ray flux to predict the intrinsic broad Pa $\alpha$ line strength (assuming all of the X-rays are from an obscured AGN), then we would be able to detect such lines with 5-$\sigma$ confidence through 12–18 magnitudes of $A_v$ extinction (27 magnitudes in the case of 1400–0145). Alternatively, if these objects are composites of starbursts with weak AGN, then detections of weak coronal lines in the optical could be used in combination with the X-ray/coronal line correlations of Gelbord et al. (MNRAS in press; arXiv:0904.3156) to quantify the relative contribution of the AGN.

We note that we do not require the exact observing conditions listed above (the default conditions from the exposure time calculator). We are not particularly sensitive to the phase of the Moon because if the background level is high at short wavelengths, we can still achieve our science goals using optical features longward of 6000Å (including the coronal lines of [Fe VII], [Fe X], [Fe XI] and any broad wings on H $\alpha$) along with the NIR spectra. We have no preferred position angles for the slits. Seeing as poor as 1.5" could be tolerated, although we do strongly prefer photometric conditions because fluxes or flux limits for any broad line components would allow us to establish quantitative rather than qualitative results. As such, we require that standard star observations be included with the calibration data.