$NuSTAR$ Observations of Heavily Obscured Quasars Selected by WISE

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Introduction

A key goal of the Nuclear Spectroscopic Telescope Array ($NuSTAR$) program is to find and characterize heavily obscured quasars, luminous accreting supermassive black holes hidden by gas and dust. Based on mid-infrared (IR) photometry from Wide-field Infrared Survey Explorer (WISE) and Sloan Digital Sky Surveys (SDSS), we have selected a large population of obscured quasars; here we report the $NuSTAR$ observations of four WISE-selected heavily obscured quasars for which we have optical spectroscopy from the Southern African Large Telescope (SALT) and W.M.Keck Observatory.

Optical Spectroscopy

We follow the successful strategies of Stern et al. (2014) and Lansbury et al. (2014), applied to our SALT WISE-selected obscured quasar sample (Hainline et al. 2014). In order to maximize the likelihood of **identifying Compton-thick sources**, we have targeted four objects for which fits to the spectral energy distributions (SEDs) indicate significant nuclear dust extinction of $A_\nu > 20$.

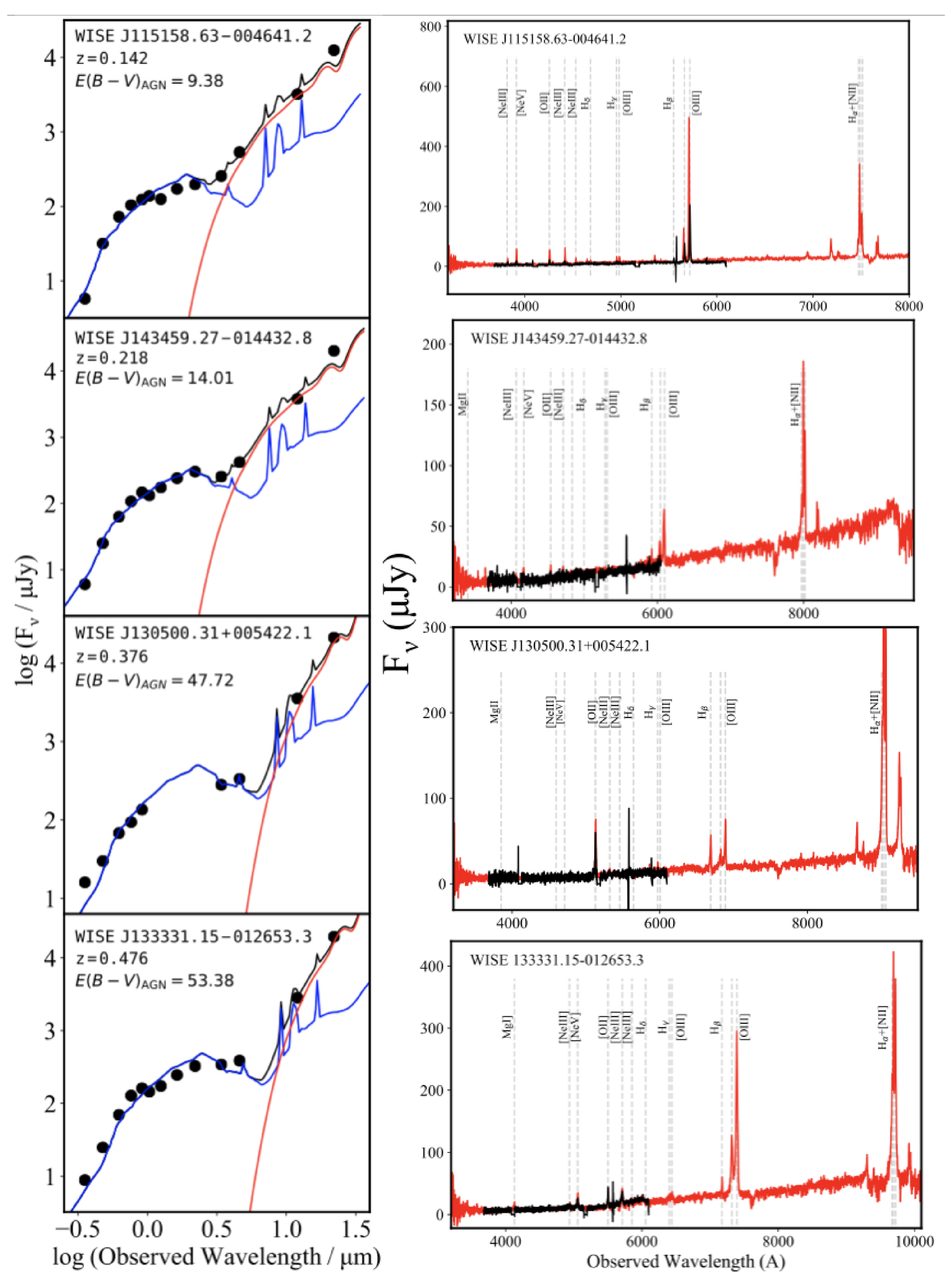

Figure 1: We chose our targets as AGNs based on their SED fitting from WISE *(left)*; and their optical spectra from SALT *(right; black lines)* and Keck *(right; red lines)* show all the targets have strong [OIII] emissions and large extinction in Balmer line. With optical diagnostics, all the targets were confirmed to be AGNs.

From the SED fits shown in Figure 1, we obtained **intrinsic (unobscured) infrared luminosities** at rest frame 6 μ m, assuming that the mid-IR provides a reliable tracer of the intrinsic AGN luminosity.

Observation and X-ray Analysis

We obtain $NuSTAR$ images in each Focal Plane Module (A and B) of all four targets. Only one source (SDSS J143459.27-014432.8) has a significant detection. We subtracted the backgrounds and calculate the net counts of all 8 images in 3–24 band. We compute **observed X-ray luminosities, or upper limits** for each of the four targets.

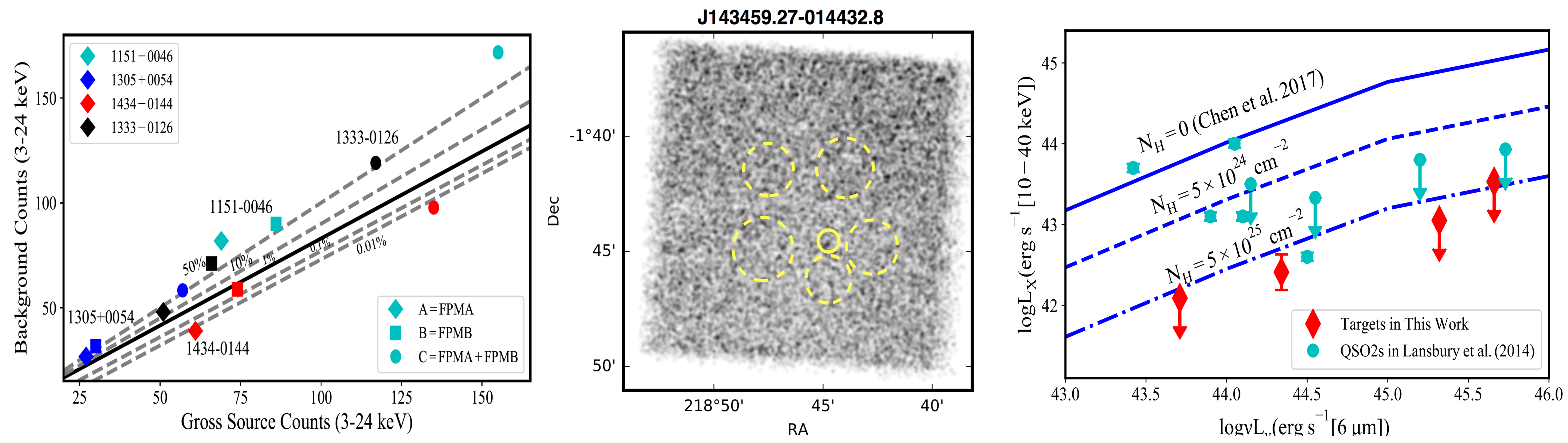

Figure 2: $NuSTAR$ photometry at 8–24 keV for our targets. Gross source counts and background counts (scaled to the source aperture) are shown. The dashed lines indicate tracks of constant Poisson no-source probability. The solid black line shows our adopted detection threshold of PB = 1% *(left)*; Module A X-ray images of the only detected target with source (solid) and background (dashed) regions in energy band 3–24 keV *(middle)*; Hard X-ray (10–40 keV) luminosity vs. infrared (6μm) AGN luminosity: Red dots are our targets after $L_{[\mathrm{OIII}]}$ corrections; Cyan dots are targets from Lansbury et al. (2015) *(right)*.

To study the level of X-ray obscuration in these objects, we first consider the intrinsic relationship between mid-IR and X-ray luminosities defined for unobscured (type 1) AGNs in Chen et al. (2017), and use the $MyTorus$ model (Murphy & Yaqoob 2009) to determine the level of suppression of X-ray luminosities with column densities of 5×10^{24} cm^{-2} and 5×10^{25} cm^{-2}, separately. **Our objects are luminous quasars with corresponding gas column densities N_H around 5×10^{25} cm^{-2}.** This indicates that mid-IR color selection is efficient at selecting heavily obscured quasars, some with very high $N_\mathrm{H} > 5 \times 10^{24}$ cm^{-2} as shown by the $NuSTAR$ data.

Obscuration

The uncorrected [OIII] luminosities in our work are quite low compared to the QSO2s in Reyes et al. (2008). However, after applying the corrections by Balmer lines to both our targets and those in Reyes et al. (2008), we found that our targets have [OIII] luminosities consistent with the larger sample. Our targets have an [OIII] extinction as a factor of 40 to 50. Based on [OIII] extinction, $E(B-V)$ of our host galaxies is in the range 1-2.

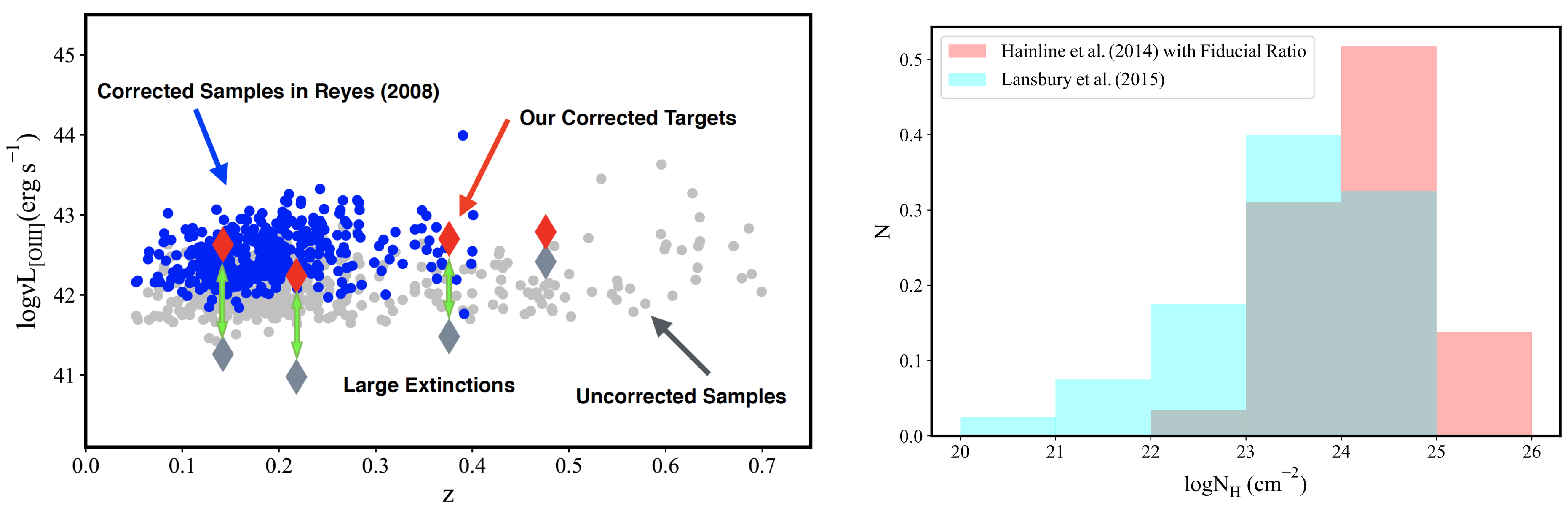

Figure 3: [OIII] luminosity vs Redshift: Diamond dots are our targets; Blue dots are QSO2s in Reyes et al. (2008); Grey dots are uncorrected original data *(left)*; The $NuSTAR$ N_H distribution of QSO2s at $z < 0.5$: Red columns are WISE-selected QSO2s in Hainline et al. (2014), adopting observed ratio); Cyan is SDSS-selected QSO2s in Lansbury et al. (2015) *(right)*.

Yet three out of four targets might have a larger column density. **This indicates that there may be a larger fraction of heavily-obscured quasars than is currently known.**

Conclusion

We report $NuSTAR$ observations of four targets belonging to a large population of heavily obscured quasars selected by WISE based on mid-IR photometry. Three out of four objects are too faint to be detected, while the other one has only a marginal detection.

1. From the upper limit and net counts of our X-ray observations in different bands, it is very likely that our targets have corresponding gas column densities N_H to be around 5×10^{25} cm^{-2}.
2. While the host galaxies also show large extinctions, yet it is not adequate to explain such high N_H of AGNs. This indicates different scales of obscuration.
3. WISE and optical selection can identify heavily obscured quasars that may be missed in X-ray.

References

Harrison et al. 2013, ApJ, 770, 103
Hainline et al. 2014, ApJ, 795, 124
Lansbury et al. 2015, ApJ, 809, 115
Lansbury et al. 2014, ApJ, 785, 17
Murphy & Yaqoob 2009, MNRAS, 397, 1549
Reyes et al. 2008, ApJ, 136, 2373
Stern et al. 2012, ApJ, 753, 30
Trouille et al. 2011, ApJ, 742, 46
Chen et al. 2017, ApJ, 837, 145