NuSTAR Observes Two Bulgeless Galaxies: NGC 4178 or J0851+3926

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Introduction

NGC 4178 and J0851+3926 are two bulgeless galaxies that have been claimed to host heavily obscured AGNs using mid-IR and/or near-IR measurements (Secrest et al. 2012, Bohn et al. 2020). Here we report on new *NuSTAR* observations of NGC 4178 and J0851+3926 which were carried out with the goal of understanding whether AGNs are present in these galaxies and to provide constraints on the obscuring columns. We detail the properties of these unique bulgeless galaxies below:

Source Properties

NGC 4178

- Bulgeless, low-mass spiral galaxy residing at a distance of 16.2 Mpc.
- High-ionization [Ne V]$\lambda 14.3\,\mu$m emission line identified by *Spitzer Space Telescope* satyapal2009.
- No sign of an AGN in the optical. The detection of the [Ne V] emission line suggested that NGC 4178 in fact hosted an optically elusive AGN [e.g.,][]secrest2012.
- Nuclear X-ray source identified by *Chandra* is consistent with a heavily obscured AGN ($N_{\rm H} = 5 \times 10^{24}\,{\rm cm}^{-2}$, C=0.99) secrest2012.
- Estimated black hole mass is $10^4 - 10^5\,{\rm M}_\odot$.
- AGN interpretation has recently been called into question by hebbar2019, who instead claimed that the X-ray emission is better fit by a hot plasma model and that the X-ray emission is likely due to a supernova remnant.

J0851+3926

- Bulgeless spiral galaxy at $z = 0.1296$ originally selected by satyapal2014 using the mid-IR AGN criteria defined by jarrett2011.
- Composite galaxy based on BPT diagram. Coupled with the lack of Balmer emission lines in the optical band, there is no definitive evidence in the optical for an AGN satyapal2014,bohn2020.
- bohn2020 detected a broad ($1489 \pm 184\,{\rm km\,s}^{-1}$ in NIRSPEC, $1363 \pm 31\,{\rm km\,s}^{-1}$ in NIRES) Paα emission line in Keck observations, authors attribute the broad Paα emission to an optically elusive AGN.
- An X-ray AGN was not detected in the *Chandra* imaging, inferring a column density of $\log(N_{\rm H}/{\rm cm}^2) \geq 24.43$ bohn2020
- Virial mass measurements using the broad Paα emission yielded an (extinction corrected) mass of $\log({\rm M}/{\rm M}_\odot) = 6.78 \pm 0.50$

My Other Work

Check out my other X-ray and/or dual AGN work, available here:

Pfeifle et al. 2019a | Pfeifle et al. 2019b | Pfeifle et al. 2022 | Dual Type I AGNs | Mid-IR Dual AGNs

NuSTAR Imaging

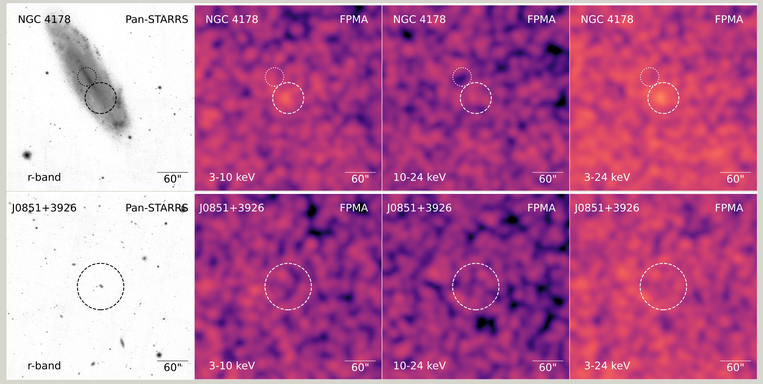

Figure 1. Pan-STARRS and *NuSTAR* FPMA imaging for NGC 4178 (top) and J0851+3926 (bottom). Left to right: Pan-STARRS r-band, *NuSTAR* FPMA 3-10 keV, 10-24 keV, and 3-24 keV bands. X-ray images are smoothed using a three-pixel Gaussian kernel and displayed with the perceptually uniform sequential color map 'magma' in matplotlib. Top: dashed 30 radius circles represent the extraction region for the ULX, while dotted 18 radius circles represent the AGN extraction region; these circles are offset by ~ 49 from one another. Bottom: dashed 45 radius circles represent the AGN extraction region.

Results

- There are no hard X-ray emitting AGNs above an observed 10-24 keV flux of $8.02 \times 10^{-14}\,{\rm erg\,cm}^{-2}\,{\rm s}^{-1}$ in NGC 4178 and $9.40 \times 10^{-14}\,{\rm erg\,cm}^{-2}\,{\rm s}^{-1}$ in J0851+3926.
- The ULX in NGC 4178 is significantly detected by *NuSTAR* in the 3-10 keV (3.6σ) and 3-24 keV (3.1σ) energy bands, though the detection in the 3-24 keV band is dominated by the emission int he 3-10 keV band. We derived count rates of 47.0 ± 12.9 and 38.3 ± 10.2 (38.8 ± 12.5 and 29.7 ± 9.8) in FPMA (FPMB). If it is emitting in the 10-24 keV, the upper limit on the count rate is < 28.6 (< 28.8) in FPMA (FPMB).
- The non-detections with *NuSTAR* imply column densities of $\log(N_{\rm H}/{\rm cm}^2) > 24.1$ for J0851+3926 and > 24.2 for NGC 4178 if it indeed hosts an obscured AGN as suggested by Secrest et al. 2012. In the uobscured case from Secrest et al. 2012, our upper limits are consistent with the AGN being unobscured and below our detection limit.
- Comparing our *NuSTAR* observations to the results of Hebbar et al. 2019, if a supernova is responsible for the observed nuclear X-ray emission in NGC 4178 rather than an AGN, it's expected observed X-ray luminosity ($L_{2-10\,{\rm keV}} = 2.0^{+0.3}_{-0.4} \times 10^{-15}\,{\rm erg\,cm}^{-2}\,{\rm s}^{-1}$) is well below the detection limit.

NuSTAR Flux Upper Limits and Column Density Lower Limits for the AGNs

System	Γ	Observed Flux (10^{-14} erg cm^{-2} s^{-1})				$\log(N_{\rm H}/{\rm cm}^{-2})$
		2-10 keV	3-24 keV	3-10 keV	10-24 keV	
NGC 4178	2.6	< 8.03	< 6.99	< 5.23	< 7.14	< 22.0
NGC 4178	2.3	< 7.36	< 7.30	< 5.16	< 7.41	> 24.2
J0851+3926	1.8	< 4.84	< 7.47	< 3.77	< 9.40	> 24.1 (> 24.3)

Discussion

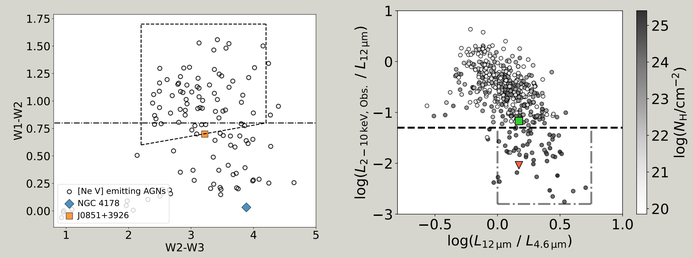

Figure 2. Left: *WISE* color-color space for [Ne V] emitting AGNs. The horizontal dash-dotted line at $y = 0.8$ denotes the mid-IR AGN criterion from stern2012; the dashed black wedge is the AGN criterion from jarrett2011. [Ne V] emitting AGNs are plotted as blue points, while NGC 4178 (J0851+3926) is plotted using a blue diamond (orange square). Right: Obscuration diagnostic from pfeifle2022 for J0851+3926. J0851+3926 is shown as an inverted red triangle. *Swift*/BAT AGNs are shown with a gray color map to illustrate how the AGN colors change with column density. The column densities are given on the auxiliary color map.

- Like many other [Ne V] emitting AGNs, NGC 4178 also does not manifest as an AGN in the mid-IR, so a lack of AGN-like properties in the mid-IR does not preclude it from being an AGN.
- However, it is still difficult to reconcile the lack of firm evidence for an AGN at most other wavelengths with the [Ne V] detection.
  - If NGC 4178 hosts an AGN with $L_{2-10\,{\rm keV}} = 10^{38}\,{\rm erg\,s}^{-2}$ (consistent with the unobscured case from Secrest et al. 2012, it would be too weak to have detected in our *NuSTAR* imaging.
  - If it hosts an AGN with $L_{2-10\,{\rm keV}} = 10^{39}\,{\rm erg\,s}^{-2}$, the upper limit suggests a CT AGN, consistent with the obscured AGN model in Secrest et al. 2012.
- It would be difficult to explain the near- and mid-IR properties of J0851+3926 without the presence of an AGN, and the inferred line-of-sight column density for this system is consistent with a CT AGN, explaining the lack of clear optical or even X-ray signatures.
- The upper limits derived for J0851+3926 imply this AGN is Compton-thick would be selected as a CT AGN when using the *Chandra* flux upper limit (red), and could possibly have been flagged as CT when using the *NuSTAR* flux upper limit (green).

Conclusions

- Neither of the AGNs in NGC 4178 or J0851+3926 are significantly detected by *NuSTAR* in any of the 3-24 keV, 3-10 keV, or 10-24 keV energy bands.
- J0851+3926 is most plausibly a heavily obscured AGN with $N_{\rm H} > 10^{24}\,{\rm cm}^{-2}$.
- NGC 4178 could be a heavily obscured AGN, but is also plausibly a LLAGN with a flux below the detection limit of NuSTAR; the [Ne V] emission line could be a light echo, tracing past activity of the IMBH, as suggested recently by Graham et al. 2019.

References

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