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

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Introduction

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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 – a reliable tracer of AGN activity abel2008 in the mid-infrared (mid-IR) – using the *Spitzer Space Telescope*. satyapal2009
- Given that the optical emission shows no sign of an AGN and instead is consistent with an HII star forming region [e.g.,][]secrest2012, the detection of the [Ne V] emission line suggested that 4178 in fact hosted an optically elusive AGN.
- Follow-up observations presented in secrest2012 revealed a weak (5.3σ) and predominantly soft X-ray point source coincident with the nucleus of the galaxy. secrest2012 concluded that the X-ray source properties were consistent with a heavily obscured AGN with an absorbing column density of $N_{\rm H} = 5\times10^{24}\,{\rm cm}^{-2}$, covering factor of C=0.99, and a photon index of $\Gamma = 2.3^{+0.6}_{-0.5}$.
- Estimated that the AGN is powered by a $10^4 - 10^5\,{\rm M}_\odot$ intermediate mass black hole.
- 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 based on its Wide-Field Infrared Survey Explorer (*WISE*) mid-IR colors; J0851+3926 satisfied the stringent 3-band mid-IR AGN color cut defined by jarrett2011, suggestive of a powerful, dust obscured AGN.
- Optically, presents as a 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.
- As a part of their elusive AGN campaign, bohn2020 reported the detection of a broad ($1489\pm184\,{\rm km\,s^{-1}}$ in NIRSPEC, $1363\pm31\,{\rm km\,s^{-1}}$ in NIRES) Paα emission line in both observations, authors attribute the broad Paα emission to an optically elusive AGN.
- An X-ray AGN was not detected in the imaging inferred column density of $\log(N_{\rm H}/{\rm cm}^2) \geq 24.43$ bohn2020 based on the relationship between the observed 2-10 keV and 12 μm emission derived in pfeifle2022.
- Virial mass measurements using the broad Paα emission yielded an (extinction corrected) mass of $\log({\rm M}/{\rm M}_\odot) = 6.78\pm0.50$

NuSTAR Imaging

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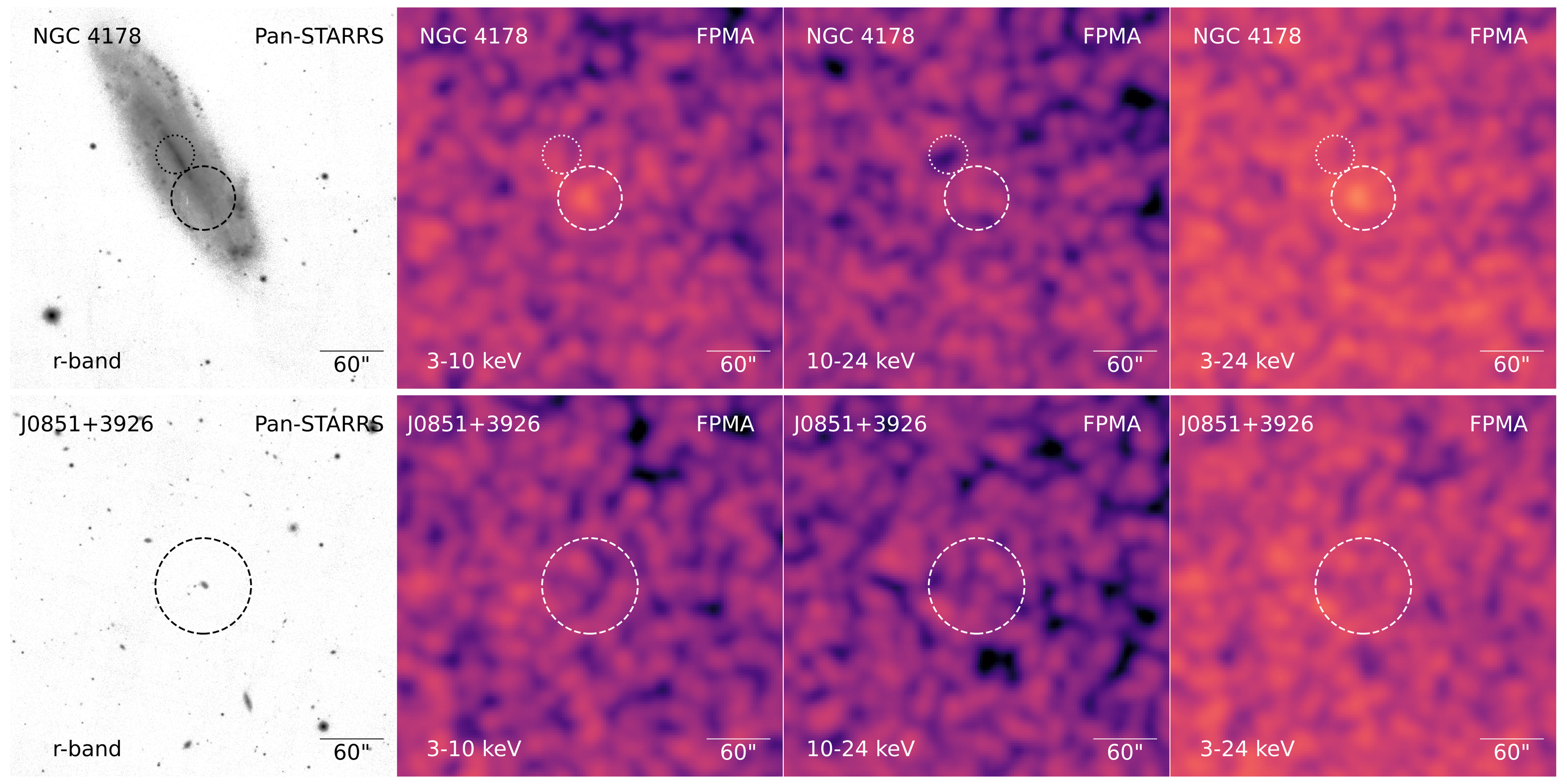

Figure 1. Pan-STARRS and FPMA imaging for 4178 (top) and J0851+3926 (bottom). Left to right: Pan-STARRS r-band, FPMA 3-10 keV, 10-24 keV, and 3-24 keV bands. X-ray images are smoothed using a three-pixel Gaussian kernel and displayed with the perceptually uniform sequential color map 'magma' in matplotlib. 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

Table 1. NuSTAR Flux Upper Limits and Column Density Lower Limits for the AGNs

System	Γ	Observed Flux (10^{-14} erg cm^{-2} s^{-1}) 2-10 keV	3-24 keV	3-10 keV	10-24 keV	$\log(N_{\rm H}/{\rm cm}^{-2})$
4178	1.8	< 6.61	< 8.19	< 5.14	< 8.02	> 24.7 (> 25.0)
4178	2.3	< 7.48	< 7.41	< 5.25	< 7.53	> 24.7 (> 25.0)
J0851+3926	1.8	< 4.84	< 7.47	< 3.77	< 9.40	> 24.1 (> 24.3)

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Discussion

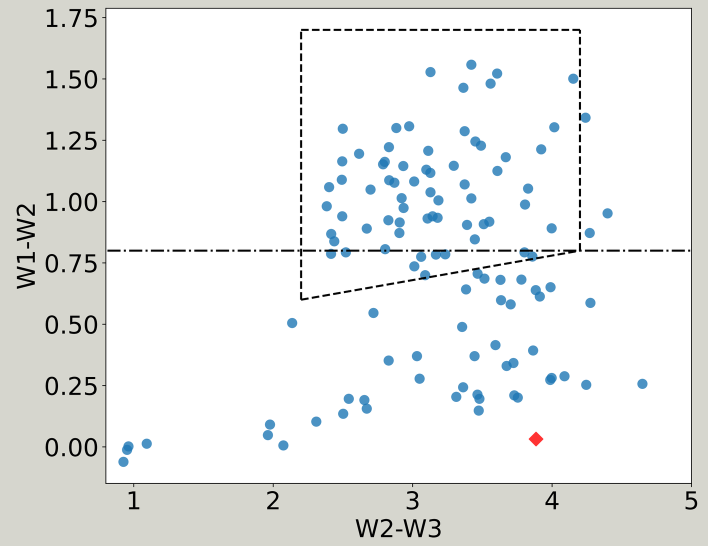

Figure 2. Caption

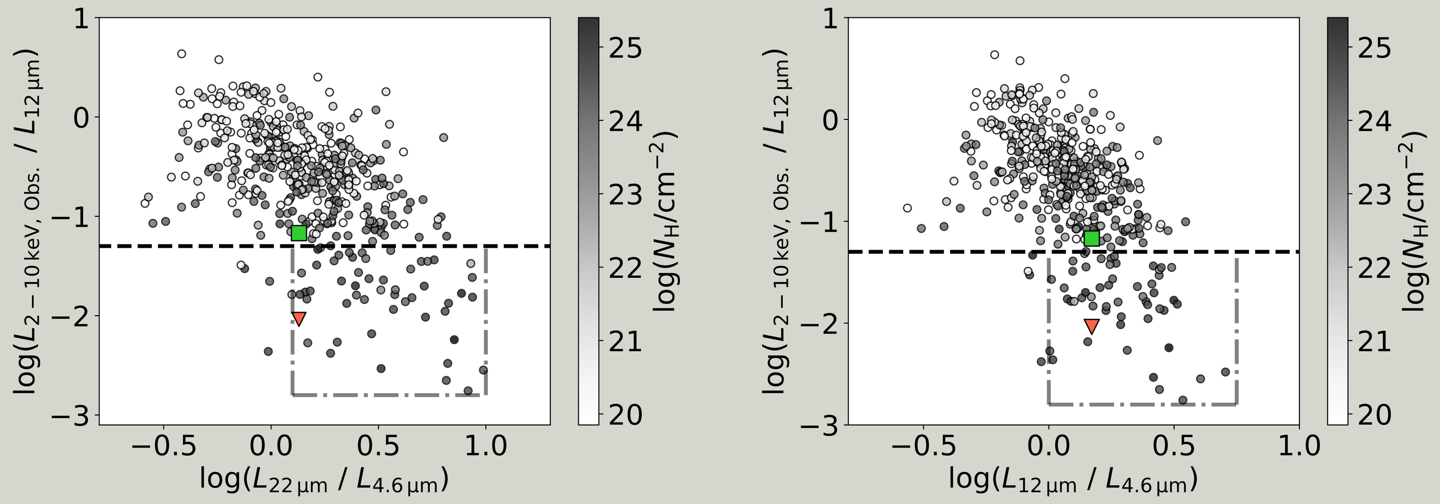

Figure 3. Caption

Conclusions

- Neither of the AGNs in 4178 or J0851+3926 are significantly detected by in any of the 3-24 keV, 3-10 keV, or 10-24 keV energy bands.
- There are no hard X-ray emitting AGNs above an observed 3-24 keV flux limit of 8.19×10^{-14} erg cm^{-2} s^{-1} in 4178 and 7.47×10^{-14} erg cm^{-2} s^{-1} in J0851+3926. For the 3-10 keV and 10-24 keV energy bands, there are no X-ray emitting AGNs above an observed flux of 5.14×10^{-14} erg cm^{-2} s^{-1} and 8.02×10^{-14} erg cm^{-2} s^{-1} for 4178, respectively, or 3.77×10^{-14} erg cm^{-2} s^{-1} and 9.40×10^{-14} erg cm^{-2} s^{-1} for J0851+3926, respectively. These flux limits are derived assuming a power law photon index of $\Gamma = 1.8$.
- The non-detections with *NuSTAR* imply column densities of $\log(N_{\rm H}/{\rm cm}^2) > 23.7$ and > 24.1 for 4178 and J0851+3926, assuming $\Gamma = 1.8$ and a covering factor of C=0.5.
- Comparing our observations to the results of hebbar2019, if a supernova is indeed responsible for the observed nuclear X-ray emission in 4178 rather than an AGN, it's expected observed X-ray luminosity ($L_{2-10\,{\rm keV}} = 2.0^{+0.3}_{-0.4}\times10^{-15}$ or $L_{3-10\,{\rm keV}} = 6.4^{+1.0}_{-1.0}\times10^{-16}$ erg cm^{-2} s^{-1}) is well below the detection limit of our observations.
- J0851+3926 is most plausibly a heavily obscured AGN. 4178 could be a heavily obscured AGN, but is also plausibly a LLAGN with a flux below the detection limit of NuSTAR; the previously detected [Ne V] emission line is likely a light echo, tracing past activity of the intermediate mass black hole.

References

[1] Claude E. Shannon. A mathematical theory of communication. *Bell System Technical Journal*, 27(3):379–423,