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# An Accreting Central Black Hole in the Draco Dwarf Spheroidal Galaxy?

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## ABSTRACT

We explore whether signs of accretion could reveal a putative central black hole in Draco, one of the Milky Way's nearest dwarf spheroidal galaxies. This study may be relevant to the newly discovered population of Little Red Dots at high redshift.

*Keywords:* Dwarf spheroidal galaxies (420); Black holes (1596)

## 1. MOTIVATION

At a heliocentric distance of $75^{+4.73}_{-4.00}$ kpc (E. Vitral et al. 2024), Draco is one of the nearest dwarf spheroidal galaxies in the Milky Way's halo (A. W. McConnachie 2012). From dynamical modelling informed by Draco's stellar mass $M_\star = 2.9 \times 10^5\, M_\odot$ and Plummer radius (R. R. Muñoz et al. 2018), as well as its line-of-sight stellar velocity dispersion (M. G. Walker et al. 2007), K. Aditya & A. Mangalam (2025) infer a central black hole (BH) mass $M_{\rm BH} < 2.9 \times 10^5\, M_\odot$ and a BH-to-stellar mass ratio $M_{\rm BH}/M_\star < 1$.

The latter quantity for Draco aligns with an early prediction from theory that, if dwarf spheroidals are the preserved fossils of the first galaxies, then they may host a mass in BHs that is about 5–40% of their stellar mass (M. Ricotti & J. P. Ostriker 2004). As A. Chakraborty & T. R. Choudhury (2026) note, these early systems may have contributed to the Universe's reioinization before the onset of more conventional sources. In this context, studies of central BHs in dwarf spheroidals may offer insights into the newly discovered population of Little Red Dots at high redshift, especially as estimates for the BH and stellar masses of that population improve (e.g., R. P. Naidu et al. 2025; V. Rusakov et al. 2026).

Here, we explore whether signs of accretion could reveal a putative central BH in Draco as an outlier from the relation between luminosities $L_{\rm R}$ at 5 GHz and $L_{\rm X}$ at 1-10 keV for stellar-mass BHs with flat radio spectra, namely $L_{\rm R} \propto L_{\rm X}^{0.6}$ (E. Gallo et al. 2014). Historically, such outlier behavior for Sgr A$^*$ in A. Merloni et al. (2003, Figure 3a therein) and H. Falcke et al. (2004, Figure 3 therein) contributed to the discovery of the fundamental plane of BH activity that links $L_{\rm R}$, $L_{\rm X}$ and $M_{\rm BH}$.

The fuel accreting onto a putative central BH in Draco could originate via a Bondi-like flow from an as-yet undiscovered interstellar medium (T. J. Maccarone et al. 2005) or via a wind flowing from a red giant star near the central BH (F. Pacucci & A. Loeb 2022).

## 2. AN ARCHIVAL VLA IMAGE

Figure 1 shows an image of Draco retrieved from the NRAO VLA Archive Survey (J. H. Crossley et al. 2008). This 8.5 GHz image, obtained with the original VLA (A. R. Thompson et al. 1980) on 1991 April 17 UT, shows no discrete sources above a $3\sigma$ detection threshold in 12 regions reported for Draco's optical centroid (see figure caption). For sources with flat radio spectra, the same detection threshold would apply at 5 GHz.

XMM-Newton images in the 0.5-12 keV band also show no discrete sources in those 12 regions, with E. Sonbas et al. (2016) reporting a slightly lower depth than L. Manni et al. (2015). Even deeper XMM-Newton observations were reported by S. Saeedi et al. (2019), but only for Draco sources beyond the boundary of Figure 1.

If a central BH is present in the 12 optical-centroid regions in Figure 1, its luminosities are $L_{\rm R} < 3 \times 10^{30}$ erg s$^{-1}$ and, from E. Sonbas et al. (2016), $L_{\rm X} < 3 \times 10^{33}$ erg s$^{-1}$.

## 3. IMPLICATIONS

For a stellar-mass BH that follows the $L_{\rm R} \propto L_{\rm X}^{0.6}$ relation (E. Gallo et al. 2014), Figure 2 shows that the Draco upper limit on $L_{\rm X}$ (E. Sonbas et al. 2016) corresponds to a radio luminosity $L_{\rm R} < 10^{28}$ erg s$^{-1}$. Thus

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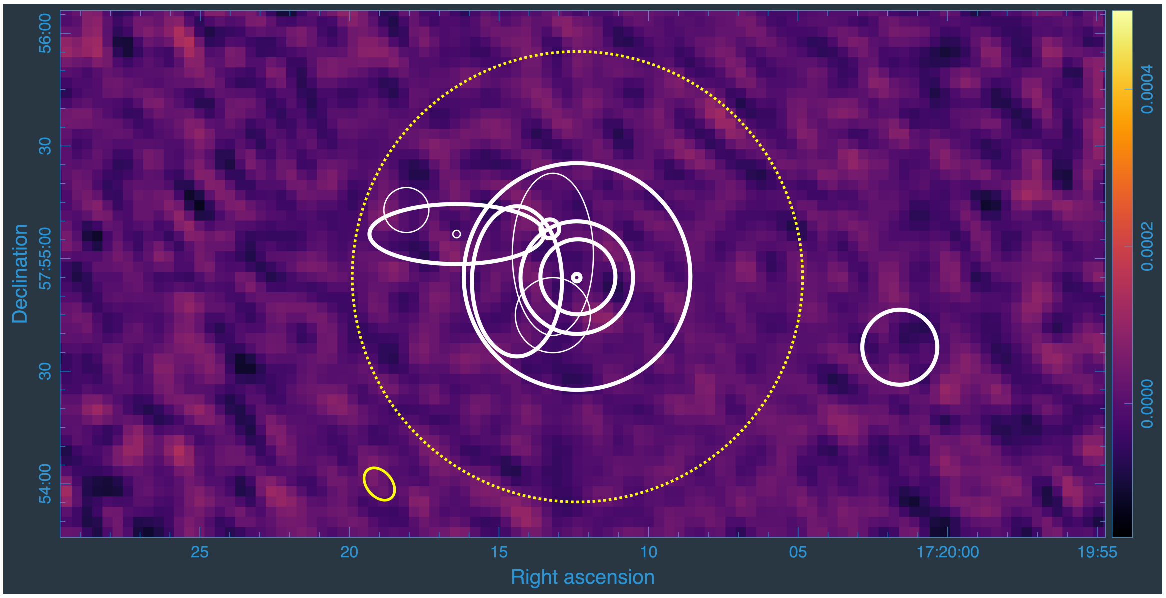


**Figure 1.** VLA image of Stokes $I$ emission at 8.5 GHz from Draco, visualized via The Cube Analysis and Rendering Tool for Astronomy (CARTA; A. Comrie et al. 2021). Yellow ellipse shows the synthesized beam dimensions at FWHM. Color bar linearly spans $-170$ to $+500\,\mu$Jy beam$^{-1}$. White ellipses convey error regions for Draco's optical centroid at a 95% CL from NED (thick lines; L. Gallouët et al. 1973; L. L. Dressel & J. J. Condon 1976; W. D. Cotton et al. 1999; E. E. Falco et al. 1999; A. W. McConnachie 2012; K. Spekkens et al. 2013; M. A. Norris et al. 2014; R. R. Muñoz et al. 2018) or from $\pm1\sigma$ estimates from the literature (thin lines; M. Odenkirchen et al. 2001; H. A. Rave et al. 2003; S. Piatek et al. 2002; N. F. Martin et al. 2008; E. Vitral et al. 2024). RMS noise is $\sigma = 30\,\mu$Jy beam$^{-1}$ in the area of $\pi\,[1']^2$ ($\pi\,[22\,\mathrm{pc}]^2$) shown as a yellow circle, enabling an equal-sensitivity search of 12 of 13 optical centroids.

an indicator of outlier behavior due to a central BH in Draco would be finding a flat-radio-spectrum source with $L_{\mathrm{R}} \gtrsim 10^{28}\,\mathrm{erg\,s^{-1}}$.

Absent future improvements in the location of Draco's optical centroid, the deep radio search for a central BH would involve the area of $\pi\,[1']^2$ ($\pi\,[22\,\mathrm{pc}]^2$) circled in yellow in Figure 1. To facilitate source cross-matching and frame alignments at multiple wavelengths, an angular resolution at FWHM of $0''\!.5 - 1''\!.0$ is desirable for the deep radio search. This combination of $L_{\mathrm{R}}$, search area and angular resolution argues for a conservative detection threshold $5\sigma \sim 0.3\,\mu$Jy.

A frequency near 8 GHz is desirable to favour detecting the persistent flat-spectrum emission that characterizes an accreting BH (e.g., T. J. Maccarone et al. 2005; A. Paduano et al. 2024). If $\sigma$ is the RMS noise level in a robustly weighted Stokes $I$ image, exposure calculators[3] estimate that the central BH search requires an on-target time of about 20 weeks with the Jansky VLA in its B configuration at X-band (R. A. Perley et al. 2011), but less than a day with the ngVLA's core and spiral subarrays observing in Band 2 (E. J. Murphy et al. 2018).

Background radio sources, dominantly star-forming (R. J. Wilman et al. 2008), will also be detected in the deep ngVLA image of Draco's center. Fortunately, those background sources can be distinguished from a central BH in Draco due to their finite sizes, steep spectral indices or proper motions that differ from Draco's (e.g., E. Vitral et al. 2024).

Coincidentally, the yellow circle in Figure 1 also closely conveys the sphere of influence for a BH of mass $2.9 \times 10^5\,M_\odot$, the upper limit inferred for Draco by K. Aditya & A. Mangalam (2025). Thus future studies of a central BH in Draco using individual stars would probably want to encompass those that are projected toward the yellow-circled area of $\pi\,[1']^2$ ($\pi\,[22\,\mathrm{pc}]^2$).

There are two caveats with the stellar dynamical modelling of K. Aditya & A. Mangalam (2025). First, it invokes a spherical geometry for Draco, so captures neither its 3D Plummer shape nor its modest rotation (E. Vitral et al. 2024). Second, K. Aditya & A. Mangalam (2025) do not consider the case of a non-central BH in Draco, a possible situation for some radio-selected dwarf galaxies (A. E. Reines 2022). In this regard, one ngVLA pointing covers a half-power area of $\pi\,[3'\!.7]^2$ ($\pi\,[82\,\mathrm{pc}]^2$) (E. J. Murphy et al. 2018), which could support a search for a non-central BH. Also, the 3D Plummer model for Draco has half-number radii of $10'\!.4$ (230 pc) and $7'\!.8$

[3] https://obs.vla.nrao.edu/ect/ and https://ngect.nrao.edu/

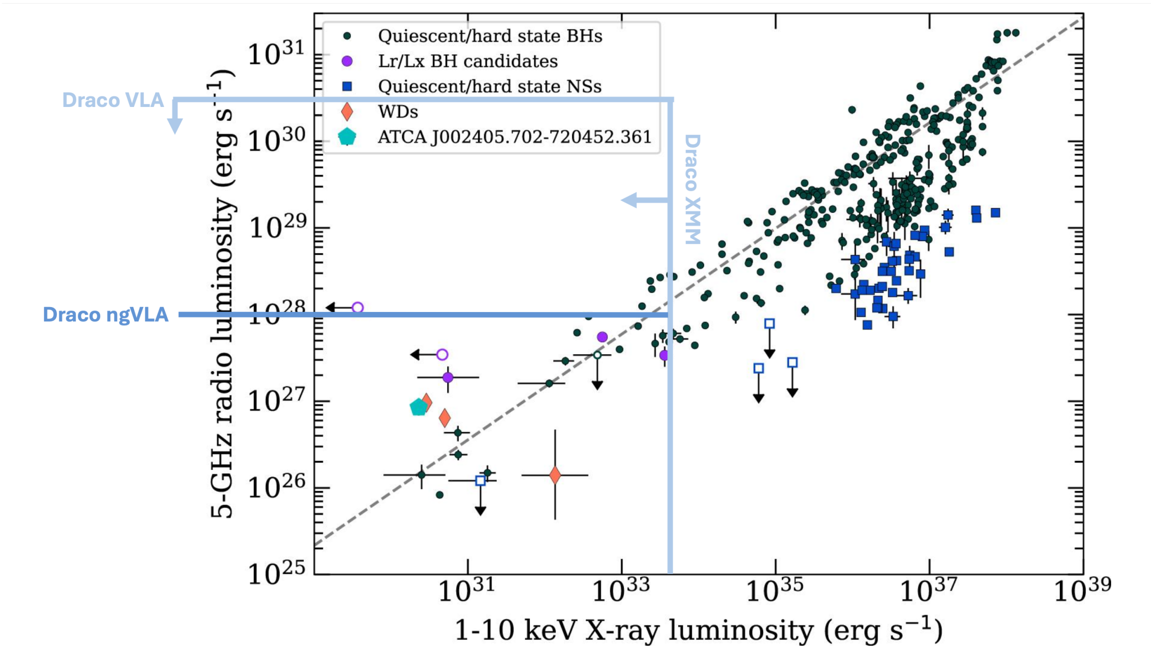


**Figure 2.** Relation between luminosities $L_{\rm R}$ at 5 GHz and $L_{\rm X}$ at 1-10 keV for stellar-mass BHs, adapted from A. Paduano et al. (2024).

(170 pc) (E. Vitral et al. 2024). That optical Plummer area could be observed with a modest ngVLA mosaic.

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*Facilities:* XMM-Newton, VLA, Jansky VLA, ngVLA

*Software:* CARTA (A. Comrie et al. 2021), matplotlib (J. D. Hunter 2007)

## REFERENCES


Aditya, K., & Mangalam, A. 2025, arXiv e-prints, arXiv:2512.14146, doi: 10.48550/arXiv.2512.14146

Chakraborty, A., & Choudhury, T. R. 2026, in Encyclopedia of Astrophysics, Volume 4, Vol. 4, 433–452, doi: 10.1016/B978-0-443-21439-4.00088-2

Comrie, A., Wang, K.-S., Hsu, S.-C., et al. 2021, CARTA: The Cube Analysis and Rendering Tool for Astronomy, 2.0.0 Zenodo, doi: 10.5281/zenodo.4905459

Cotton, W. D., Condon, J. J., & Arbizzani, E. 1999, ApJS, 125, 409, doi: 10.1086/313286

Crossley, J. H., Sjouwerman, L. O., Fomalont, E. B., & Radziwill, N. M. 2008, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 7016, Observatory Operations: Strategies, Processes, and Systems II, ed. R. J. Brissenden & D. R. Silva, 70160O, doi: 10.1117/12.787890

Dressel, L. L., & Condon, J. J. 1976, ApJS, 31, 187, doi: 10.1086/190380

Falcke, H., Körding, E., & Markoff, S. 2004, A&A, 414, 895, doi: 10.1051/0004-6361:20031683

Falco, E. E., Kurtz, M. J., Geller, M. J., et al. 1999, PASP, 111, 438, doi: 10.1086/316343

Gallo, E., Miller-Jones, J. C. A., Russell, D. M., et al. 2014, MNRAS, 445, 290, doi: 10.1093/mnras/stu1599

Gallouët, L., Heidmann, N., & Dampierre, F. 1973, A&AS, 12, 89

Hunter, J. D. 2007, Computing in Science & Engineering, 9, 90, doi: 10.1109/MCSE.2007.55

Maccarone, T. J., Fender, R. P., & Tzioumis, A. K. 2005, MNRAS, 356, L17, doi: 10.1111/j.1745-3933.2005.08584.x

Manni, L., Nucita, A. A., De Paolis, F., Testa, V., & Ingrosso, G. 2015, MNRAS, 451, 2735, doi: 10.1093/mnras/stv1009

Martin, N. F., de Jong, J. T. A., & Rix, H.-W. 2008, ApJ, 684, 1075, doi: 10.1086/590336

McConnachie, A. W. 2012, AJ, 144, 4, doi: 10.1088/0004-6256/144/1/4

Merloni, A., Heinz, S., & di Matteo, T. 2003, MNRAS, 345, 1057, doi: 10.1046/j.1365-2966.2003.07017.x

Muñoz, R. R., Côté, P., Santana, F. A., et al. 2018, ApJ, 860, 66, doi: 10.3847/1538-4357/aac16b

Murphy, E. J., Bolatto, A., Chatterjee, S., et al. 2018, in Astronomical Society of the Pacific Conference Series, Vol. 517, Science with a Next Generation Very Large Array, ed. E. Murphy, 3, doi: 10.48550/arXiv.1810.07524

Naidu, R. P., Matthee, J., Katz, H., et al. 2025, arXiv e-prints, arXiv:2503.16596, doi: 10.48550/arXiv.2503.16596

Norris, M. A., Kannappan, S. J., Forbes, D. A., et al. 2014, MNRAS, 443, 1151, doi: 10.1093/mnras/stu1186

Odenkirchen, M., Grebel, E. K., Harbeck, D., et al. 2001, AJ, 122, 2538, doi: 10.1086/323715

Pacucci, F., & Loeb, A. 2022, ApJL, 940, L33, doi: 10.3847/2041-8213/ac9b21

Paduano, A., Bahramian, A., Miller-Jones, J. C. A., et al. 2024, ApJ, 961, 54, doi: 10.3847/1538-4357/ad0e68

Perley, R. A., Chandler, C. J., Butler, B. J., & Wrobel, J. M. 2011, ApJL, 739, L1, doi: 10.1088/2041-8205/739/1/L1

Piatek, S., Pryor, C., Armandroff, T. E., & Olszewski, E. W. 2002, AJ, 123, 2511, doi: 10.1086/339698

Rave, H. A., Zhao, C., Newberg, H. J., et al. 2003, ApJS, 145, 245, doi: 10.1086/367724

Reines, A. E. 2022, Nature Astronomy, 6, 26, doi: 10.1038/s41550-021-01556-0

Ricotti, M., & Ostriker, J. P. 2004, MNRAS, 352, 547, doi: 10.1111/j.1365-2966.2004.07942.x

Rusakov, V., Watson, D., Nikopoulos, G. P., et al. 2026, Nature, 649, 574, doi: 10.1038/s41586-025-09900-4

Saeedi, S., Sasaki, M., Stelzer, B., & Ducci, L. 2019, A&A, 627, A128, doi: 10.1051/0004-6361/201834983

Sonbas, E., Rangelov, B., Kargaltsev, O., et al. 2016, ApJ, 821, 54, doi: 10.3847/0004-637X/821/1/54

Spekkens, K., Mason, B. S., Aguirre, J. E., & Nhan, B. 2013, ApJ, 773, 61, doi: 10.1088/0004-637X/773/1/61

Thompson, A. R., Clark, B. G., Wade, C. M., & Napier, P. J. 1980, ApJS, 44, 151, doi: 10.1086/190688

Vitral, E., van der Marel, R. P., Sohn, S. T., et al. 2024, ApJ, 970, 1, doi: 10.3847/1538-4357/ad571c

Walker, M. G., Mateo, M., Olszewski, E. W., et al. 2007, ApJL, 667, L53, doi: 10.1086/521998

Wilman, R. J., Miller, L., Jarvis, M. J., et al. 2008, MNRAS, 388, 1335, doi: 10.1111/j.1365-2966.2008.13486.x