Constraining the origin(s) of radio emission from radio-quiet QSOs

High-resolution VLA observations of a volume-complete (0.2 < z < 0.3) sample

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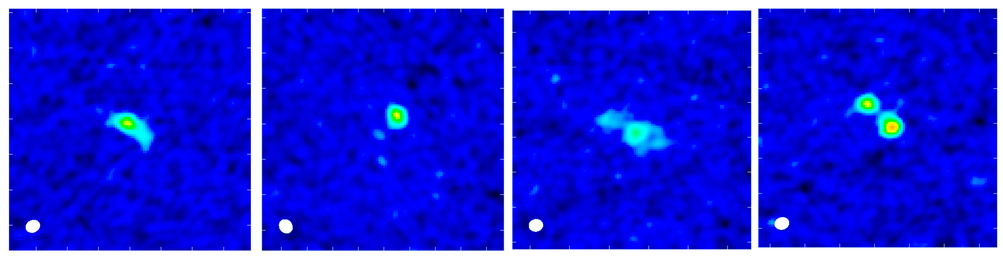
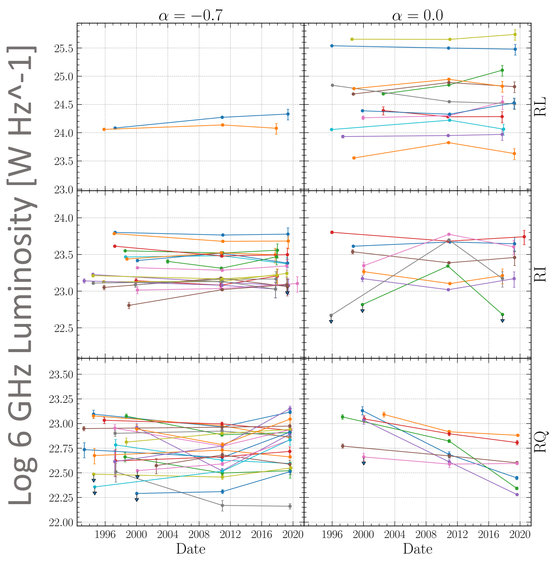
The Very Large Array (VLA)



Background

The origin of radio emission from radio-quiet QSOs (RQQs) remains an elusive problem. While powerful AGN-driven jets fuel the emission in radio-*loud* objects, much controversy has been raised as to what produces the radio emission in RQQs—whether it be star formation processes, winds driven by the AGN, or even scaled-down AGN jets. Part of the reason the origin(s) remain ambiguous is that radio emission in RQQs is confined to the host galaxy, making resolving any morphological features difficult.

Kimball et al. (2011) presented an unbiased volume-complete sample of 178 QSOs, revealing for the first time that **radio-quiet QSOs are not radio-silent**. The entire subsample of 128 RQQs (L_6GHz < 10^23 W Hz^-1) was shown to be unresolved on a ~3.5''-scale. We take this investigation a step further, presenting high-resolution (0.33'' or ~1.3kpc at z=0.25) VLA observations of this volume-complete subsample, finding that **all RQQs are capable of exhibiting extended >1.3kpc radio morphologies.**



Decades-long light curves of subset of our RQQs in parallel with radio-intermediate and -loud QSOs, constructed with the help of FIRST (Becker et al. 1995) and VLASS Epoch 1 (Lacy et al. 2020) data. This plot shows: (i) the radio emission from RQQs is variable, and (ii) radio-quiet sources are dominated by steep-spectrum (alpha~-0.7) emission, while radio-louds have flat spectrum (alpha~0.0).

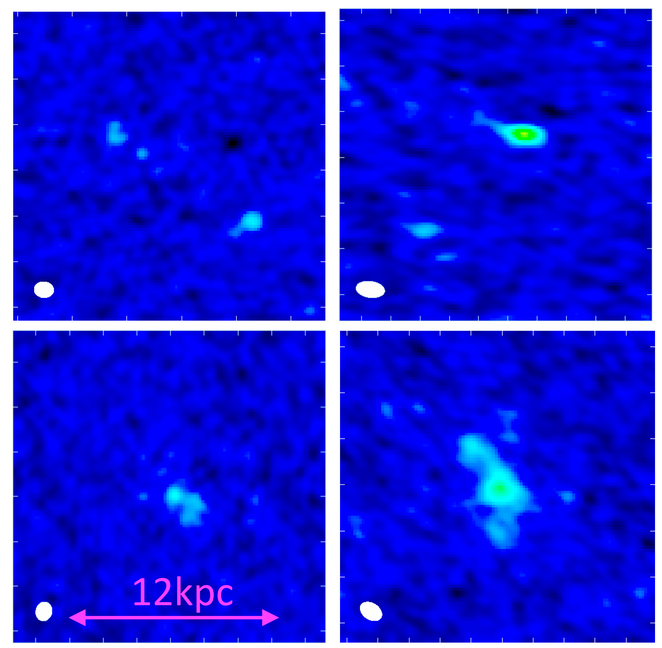
Sub-galactic morphologies throughout the entire radio-quiet population: what do they look like?

Context:

Kellermann et al. (2016) showed that all of our RQQs are unresolved on a 3.5''-scale (~14kpc at z=0.25)– effectively translating to: "none of the radio emission in RQQs escapes the QSO host galaxy". Smaller, carefully-selected samples of RQQs have shown complex extended morphologies at intermediate scales. While these results show the myriad natures of RQQs among their extremities, it is not clear how they may generalize to an *entire population* of RQQs.

Results:

Roughly 50% of RQQs in our volume-complete sample exhibit complex extended morphologies (~3arcsec-wide exemplary images on the right and above) with variable radio emission (Figure on the left). Morphologies range from multi (>2)-component, to uncollimated, to a clear edge-brightened double.



What next?:

Our results essentially *are* the answer to the question "what do RQQs look like?"; the science question then naturally shifts to "what are we looking at?". While many RQQs exhibit extended morphologies, one could argue that the morphologies we see are illustrations of several different physical mechanisms (e.g., AGN-SF feedback, shocks from uncollimated wind outflows, or simply jets smaller than those seen in radio-loud objects). Future work discerning the many potential origins includes:

- *VLBA Observations:* What is the *jet-contribution*? Are the extended morphologies due to jets?
- *Optical Spectroscopy:* Are optical properties correlated with certain radio morphologies? Do sources that are predicted to have strong winds appear to resemble them?

Increasing Resolution/Brightness Temperature

Radio Luminosity Function → High-res VLA Observations → VLBA Observations

(Kimball et al.: RQQs are *not* radio-*silent*!)

(Reveal sub-galactic appearances)

(Jet contribution to RQQs?)

For Further Information
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Kimball, Condon, Kellermann, Ivezić, Perley 2011, ApJL, 739, 29
Kellermann, Condon, Kimball, Perley, Ivezić 2016, ApJ, 831, 168
Becker, White, Helfand 1995, ApJ, 450, 559
Lacy et al. 2020, PASP, 132, 1009