Median stacking of serendipitous high-frequency radio observations of Sloan Digital Sky Survey active galactic nuclei

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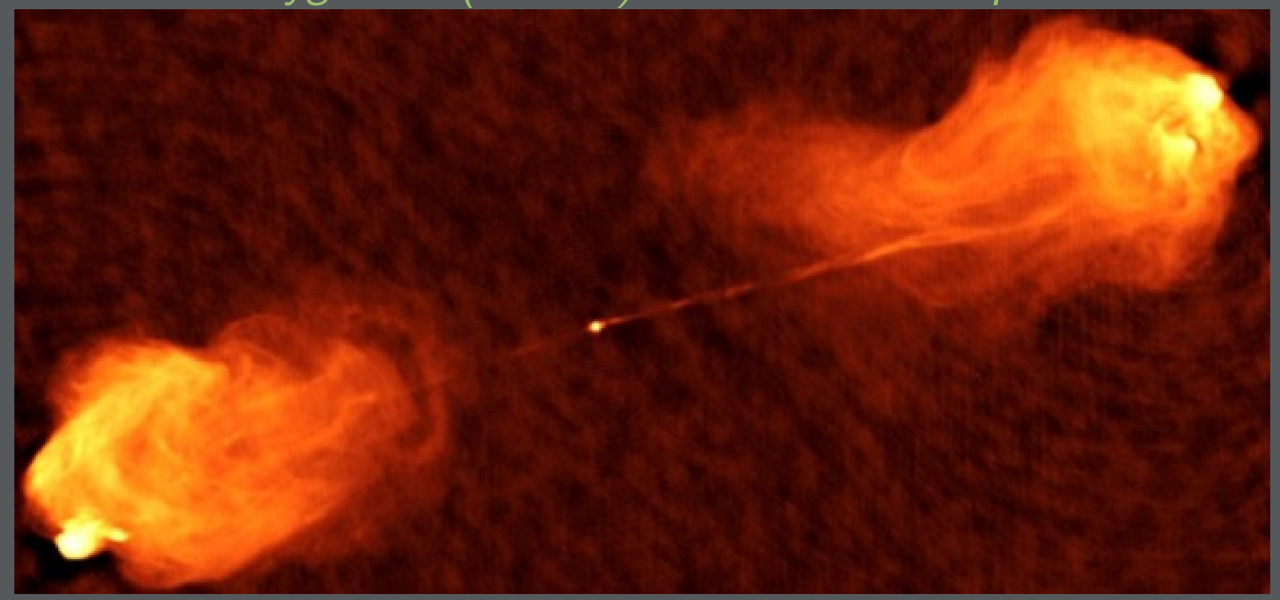
Cygnus A (3C 405) 4.8 GHz VLA map.



(Credit: courtesy of C. Carilli, NRAO / AUI)

Abstract

One of the major points of interest in the study of galaxies, is why some sources are radio-loud and others are not. To gain insight into this problem we build an un-biased radio sample using serendipitous VLA observations of Active Galactic Nuclei (AGN) selected using Sloan Digital Sky Survey optical spectra, and study the dependence of core radio-loudness on various physical parameters, like black hole mass, ([O III]) luminosity and redshift. To avoid "pollution" of our radio data by steep-spectrum radiative processes due to star-formation we constrain ourselves to high frequency 8 GHz X-band. As most of the AGN are distinctly below the normal detection limit we employ a median stacking method as this is shown to be a better indicator of the true average radio flux density than the mean, since the latter is more sensitive to outliers. Here we present some of our preliminary results.

	AGN	QSO
$M_{\rm BH}$ ($M_\odot$)	$7.0 \le \log M_{\rm BH} \le 9.5$	
S/N [O III], [N II], H_α	≥ 3	
redshift	$0.04 \le z$	$0.04 \le z \le 0.8$
H_α/H_β	$> 3\sigma, \ge 2.86 - 2\sigma, \le 10$	
Final Number	48796	3603

Tab. 1: *Number of optical sources available for matching to radio. We infer $M_{\rm BH}$ from velocity dispersions (Tremaine+ '02) and only use high quality SDSS spectra (S/N ≥ 3 in specified lines and credible values for the balmer decrement H_α/H_β). The latter gives us $z \le 0.8$ on the QSOs. To avoid aperture effects (Kewley+ '05) we exclude sources $z \le 0.04$.*

Mass-scaling of Black Hole Physics

Evidence that the physics governing Black Holes (BH)s scales with mass, across the entire observed ∼9 decade mass range, has been increasing for the last decade or so. Solar-mass Black Holes (in X-ray binaries, XRBs) are seen in two main states called the "soft" and "hard" state. The hard state usually exhibits flat-spectrum, steady radio emission. We also observe a canonical transition luminosity above which we no longer see XRBs in the soft state (Maccarone 2003). The object of this work is to explore if in supermassive BH systems (viz. Active Galactic Nuclei, AGN) we observe similar behaviour. However, although XRBs show state transitions on humanly observable timescales (weeks/months), AGN evolution is typically on timescales of millions of years. We therefore explore the question above by studying many supermassive sources simultaneously, starting from Sloan Digital Sky Survey (SDSS) optical data.

Initial Sample Selection

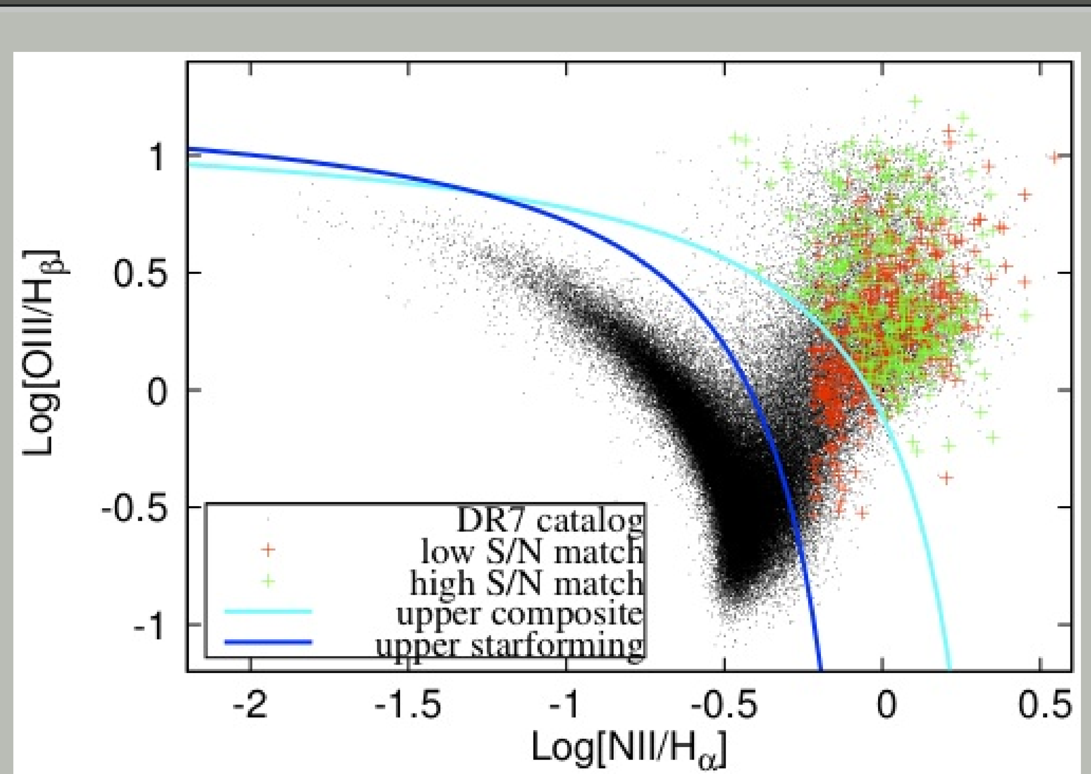


Fig. 1: *BPT (Baldwin+ '81) diagram for matched galactic AGN.*

We select AGN using SDSS optical line ratios of galaxies that adhere to the selection criteria in Tab. 1 and applying to the precepts in Brinchmann+ '04. Most studies of AGN are riddled with biases due to sample selection. To avoid these effects we only use sources that have been observed serendipitously in radio and only use high frequency 8 GHz X-band, to avoid pollution by steep-spectrum radio emission from star formation, as we want to focus on the core to find evidence for AGN "states".

Imaging Results

As source fluxes are expected to be sub-detection limit, we median-stack the radio maps listed in Tab. 2 according to prescribed mass bins and do a statistical study physical parameters of interest. We use only the lowest RMS radio map per source of interest to avoid skewing the distribution towards any particular source and stack the images in luminosity space to account for different redshifts. Unfortunately not enough serendipitous quasi-stellar AGN observations are available for stacking (see Fig. 3).

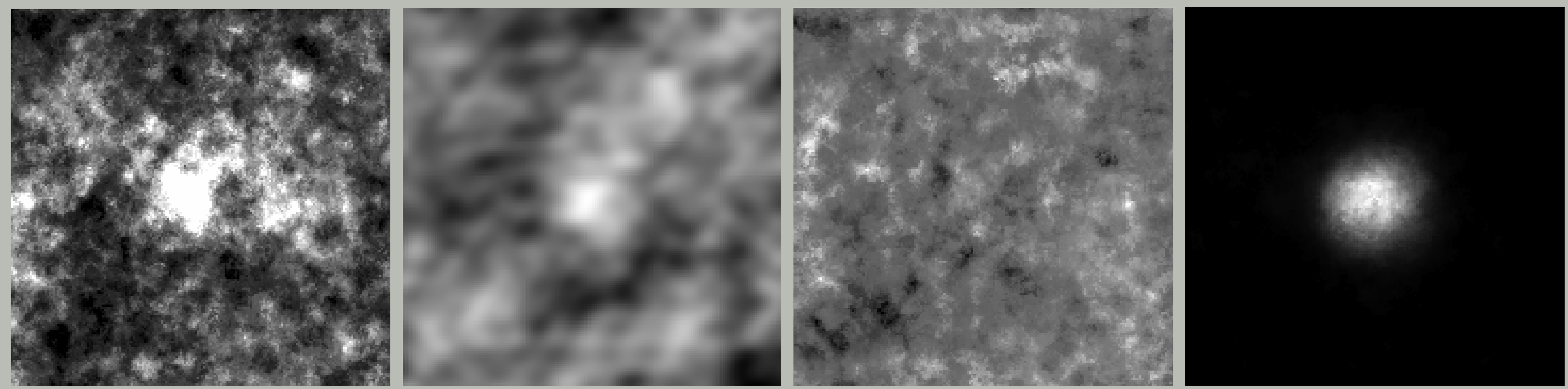


Fig. 2: *Stacked images of VLA A configuration galactic AGN. From left to right: 1) A median-stack 377 serendipitous observations covering the entire mass range $7.0 \le \log M_{\rm BH} \le 9.0$. 2) A mean-stack with much higher background indicating median-stacking is more suited for our purposes. 3) A median-stack of 122 images in the $7.0 \le \log M_{\rm BH} \le 7.5$ range for comparison with the left image – clearly not showing a source. 4) A median-stack of 291 non-serendipitous sources to indicate targeted sources have a much higher luminosity compared to the background.*

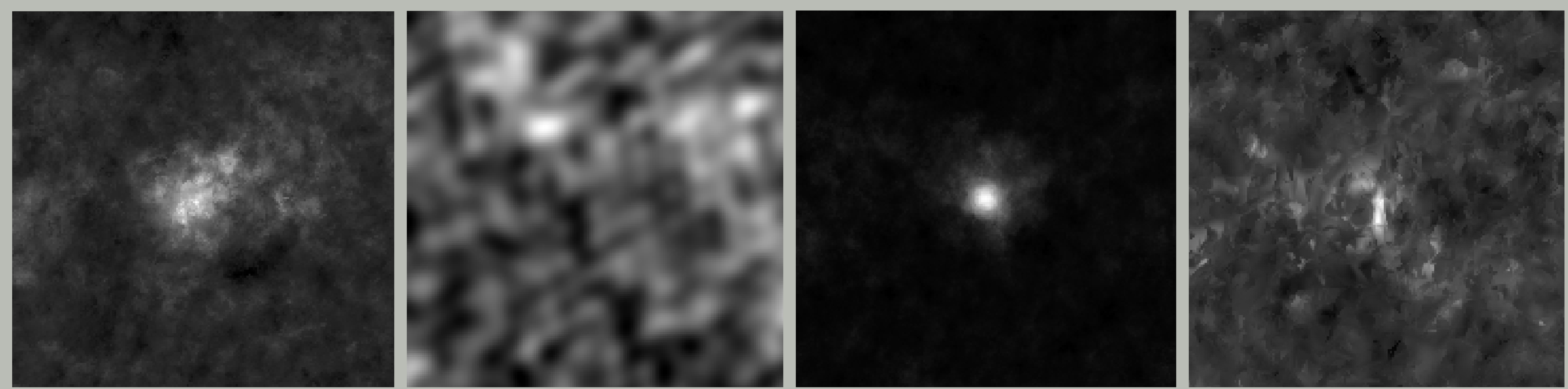


Fig. 3: *Median-stacked images of VLA A configuration galactic AGN. From left to right: 1) Stack of 102 images covering the higher mass range $8.0 \le \log M_{\rm BH} \le 9.0$, at lower accretion rate (cf. caption Fig. 3). 2) Same as left left image, but high accretion rate. Only 2 images were available, confirming dearth of high mass, high accretion rate sources. 3) Stack of all 377 serendipitous images in entire $7.0 \le \log M_{\rm BH} \le 9.0$ range, however stacked according to brightest or least bright pixel to accommodate positional inaccuracies. 4) Stack of all (25) available serendipitous QSO images, ostensibly showing a source.*

References

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Cross-Matching Results

	serendipitous optical	serendipitous radio	non-serendipitous optical	non-serendipitous radio	Total optical	Total radio
galactic AGN	614	1716	397	843	977	2558
QSO	51	105	157	961	202	1065
Total	665	1821	554	1804	1179	3623

Tab. 2: *The optical AGN listed in Tab. 1 are matched to all available (∼10^5) archival VLA X-band observations. Sources in the centre 10% of the FOV by area are considered non-serendipitous. In total ∼1200 SDSS AGN are matched to ∼3600 VLA A, B and C config observations. ∼70% of these have been reduced successfully.*

Radio-Loudness

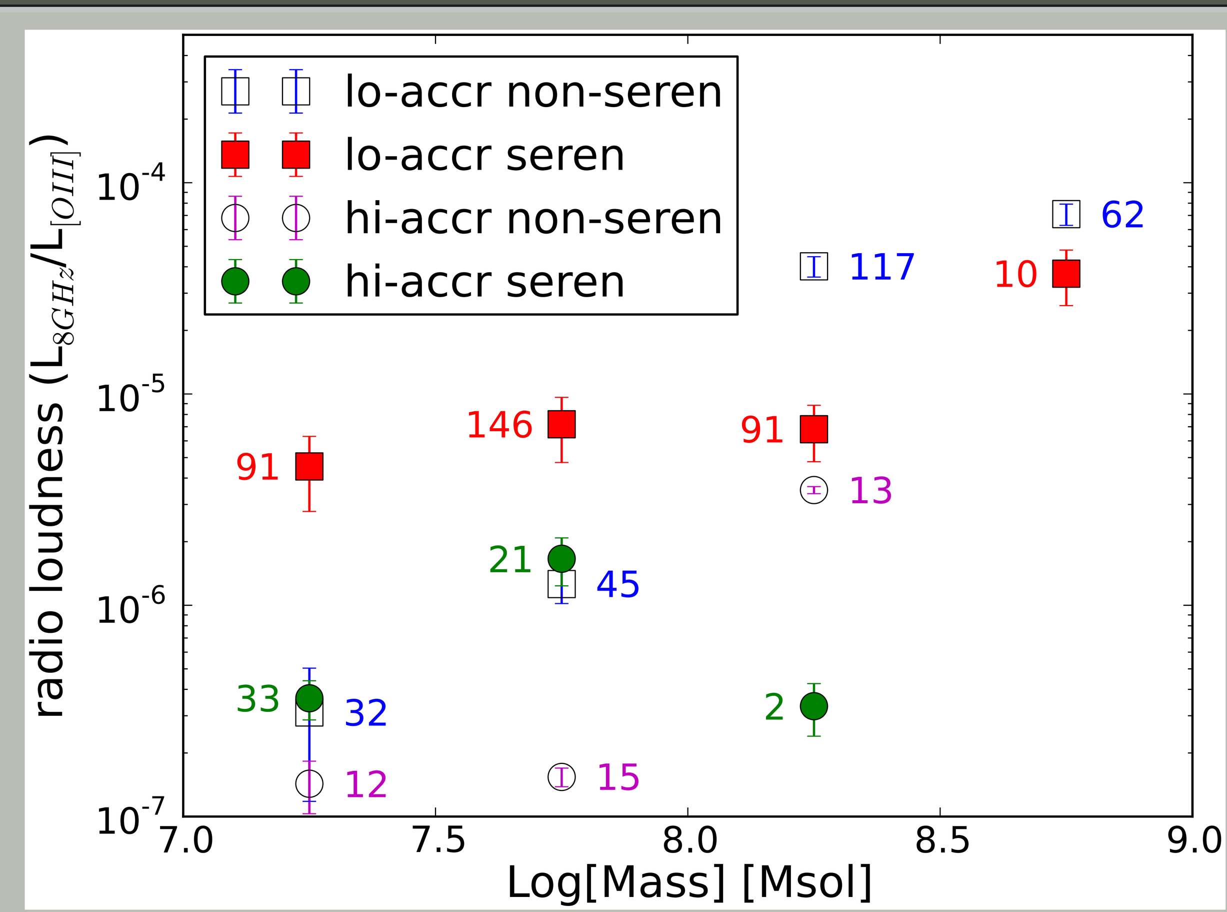

Fig. 4: *Median Radio Loudness (median 8GHz luminosity / median [O III] luminosity) for the sources in Figure 2. Sources are split into low-accretion and high-accretion rate sources, corresponding to $L_{\rm [OIII]}/L_{\rm Edd}$ from Kewley+ '06. They observed a split in the $L_{\rm [OIII]}/\sigma^4$ distribution which they attributed to LINERS/Seyferts. Numbers indicate the stacked image totals.*

Fig. 4 shows no strong evidence for radio-loudness increasing with mass in the serendipitous sample. The origin of the large differences between the serendipitous and non-serendipitous samples at low mass demands further study.