A multiwavelength investigation of the circum-nuclear environment of nearby AGNs

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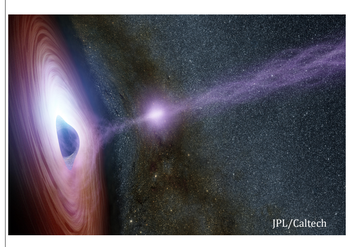
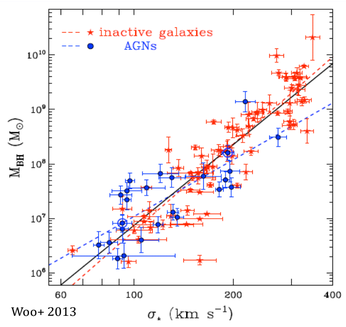
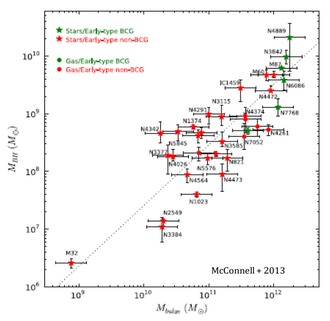
***Abstract**: The supermassive black hole scaling relationships suggest a strong connection between the accreting supermassive black holes at the centres of galaxies and their host galaxies through feedback mechanisms. We investigate the hallmarks of these processes in the nuclear regions of the host galaxies by studying about 130 nearby active galaxies (Siding Spring Southern Seyfert Spectroscopic Snap-Shot Survey (S7)) including IFU observations and multi-wavelength follow ups of a subset of the objects. We present our most recent results based on the multi-frequency data, including observations of a supermassive binary black hole precursor.*



Accreting supermassive black holes (SMBH) or Active Galactic Nuclei (AGN) generate outflows of ionised gas as well as bi-polar jets of plasma which emit strongly in radio due to the synchrotron process. Most of the AGN have low kinetic power jets that get quenched within the host galaxy but a minority of them have jets launched relativistically, typically reaching out beyond the host galaxy to a few hundred kiloparsecs and in few cases travelling to distances of even a megaparsec. Scaling relations like the M-σ relation (right) suggest that the growth of the central supermassive black holes and the growth of their host galaxies go hand in hand. It implies that the central SMBH and the host galaxy co-evolve. This suggests strong feedback processes between AGN activity and star formation around the nuclear regions of the host galaxy.



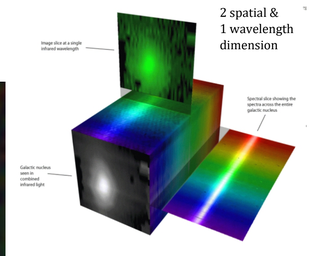


The S7: The Siding Spring Southern Seyfert Spectroscopic Snap-shot Survey

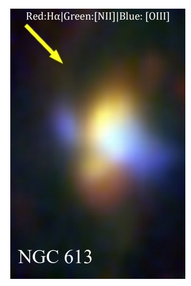
The S7 project surveyed about 130 nearby southern active galaxies. The spectroscopic survey was carried out using the Integral Field Unit called WiFeS (Dopita+ 2007) mounted on the 2.3m Australia National University telescope at Siding Spring Observatory. An IFU obtains spatially resolved spectra of the sky, in the form of a datacube (right).

The sample of AGN for the survey was selected from the Veron-Cetty & Veron Catalogue of AGN, which is the most comprehensive compilation of known AGN. They were filtered by the following criteria:

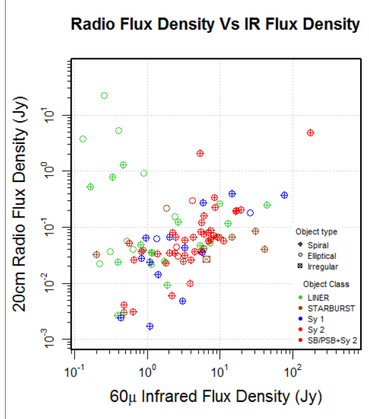
- **Declination < 10 ° North** – Accessible from Siding Spring Observatory
- **Galactic Latitude |bII| > 20 °** – To reduce the Galactic extinction effects
- **Redshift < 0.02** – To obtain several spatial beam elements across the galaxy, and to have the SII line in WiFeS spectral range
- **Radio flux density >20mJy** (soft cut-off) – To enable radio imaging follow-up using GMRT, Pune; ATCA, Australia.



Some examples of WiFes output (Thomas+17).

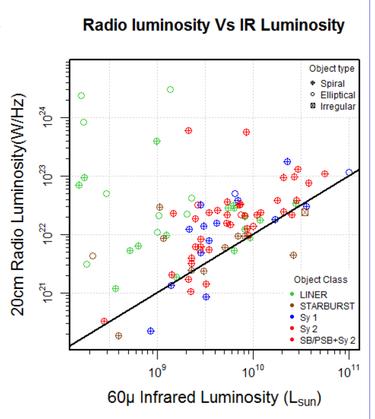


The Radio-IR correlation for the sample

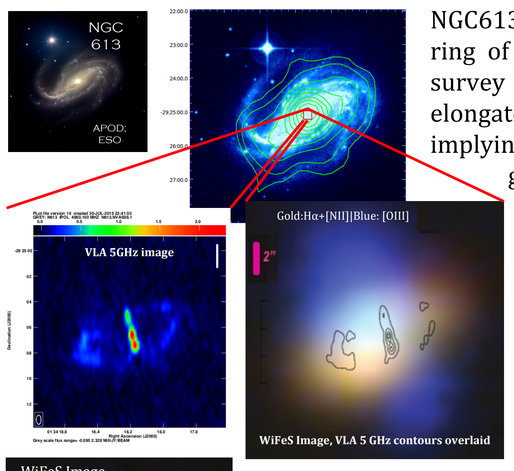


Left panel: The clustering of objects roughly around 20mJy at low IR flux densities is due to our soft radio flux density cut-off of 20mJy in sample selection.

Right panel: The black line represents mean relationship of radio-IR correlation for star-forming galaxies (Dopita, 2005). In star-forming galaxies the 1.4 GHz and the 60μ emission are due to star formation. As expected for AGN, our sample objects show a significant radio excess arising due to the radio jets.



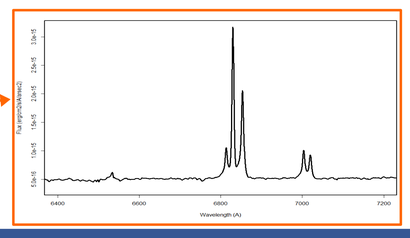
NGC 613



NGC613 is a barred spiral galaxy (VLT image, top left) with a weak inner ring of star formation. The 1.4GHz radio contours from the NVSS survey (green) overlaid on the optical image (top right) show the elongated radio emission is cospatial with the spiral structure, implying there are active star forming regions spread across the galaxy.

Our WiFeS image overlaid with the higher resolution radio image obtained from Very Large Array radio telescope is shown in 2nd row, right image.

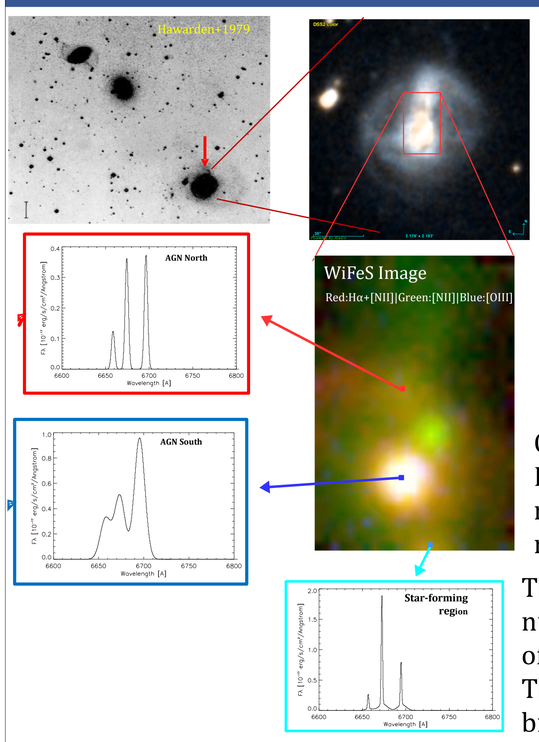
The very inner radio structure is linear, suggestive of jets from the AGN, and is aligned with the double-lobed [OIII] emission that forms an Extended Narrow-line Region. Hα+NII emission from the inner star forming region appears to aligned with the bar of the galaxy and the radio emission due to active star formation in the galaxy.



The Hα and [NII] emission lines (left) from the WiFeS data from nuclear region of NGC 613 is shown in orange box.

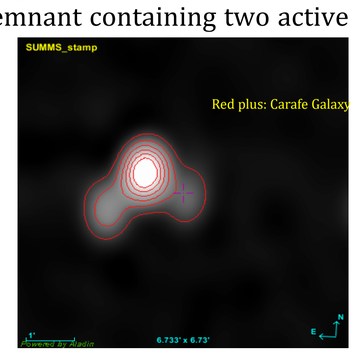
The emission lines are stronger and much broader than SF regions, as expected.

ESO202-G023: The Carafe Galaxy



ESO202-G023 is one of a nearby galaxy trio. It was shown by Rifatto+2001 to be a merger remnant containing two active nuclei.

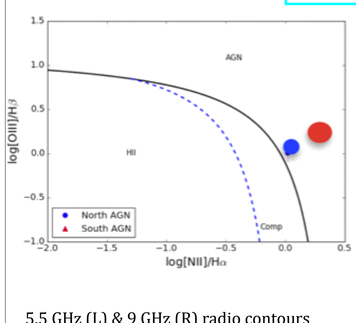
The low frequency radio detections from SUMMS, TGSS ADR1 (right) etc, are a blend from a nearby radio AGN and Carafe galaxy which is seen in our ATCA images at 1.4, 5.5 and 9 GHz as well.



Our WiFeS image (left) is also consistent with result from Rifatto et al. We see a luminous nucleus (AGN South) and a much fainter 2nd nucleus (AGN North), ~3.4 kpc to the north.

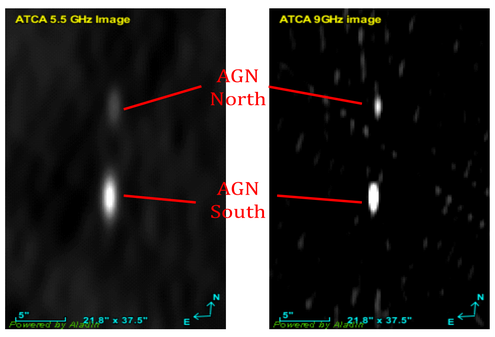
The Hα and [NII] emission lines from the WiFeS data from nuclear regions of 2 AGNs and SF region at the southern edge of the image are shown here in red, blue and cyan boxes.

The emission lines are narrow for the SF region and much broader for the AGNs as expected.

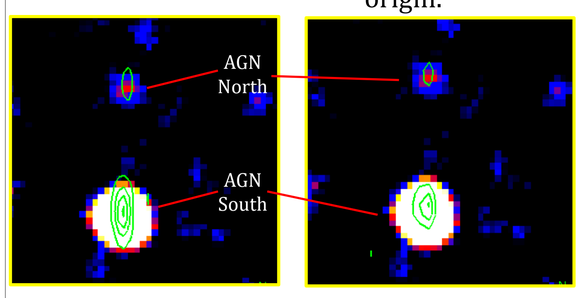


Our BPT diagram (left) classification based on the WiFeS data classifies them as AGNs of LINER type.

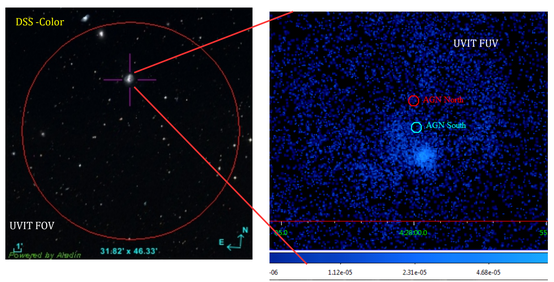
1.4, 5.5 and 9GHz ATCA radio observations (right) show 2 distinct radio sources with steep spectra, whose positions coincide with the 2 AGNs seen in the WiFeS images images, suggesting that the radio emission is synchrotron in origin.



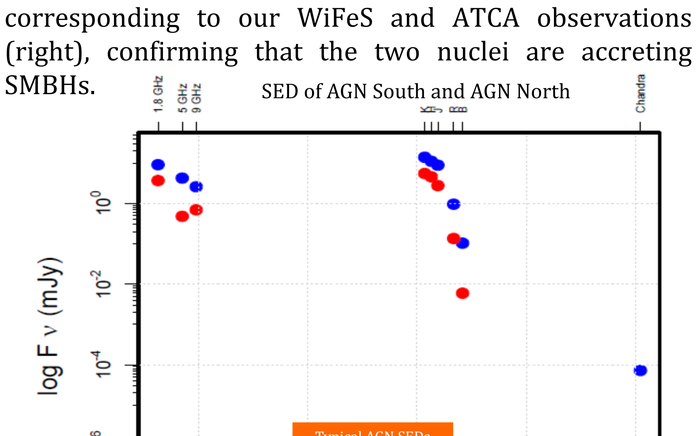
5.5 GHz (L) & 9 GHz (R) radio contours (ATCA) overlaid on Chandra image



Our Chandra data in the spectral range of 0.8-9 keV (images on left) shows xray emission from the two nuclei corresponding to our WiFeS and ATCA observations (right), confirming that the two nuclei are accreting SMBHs.

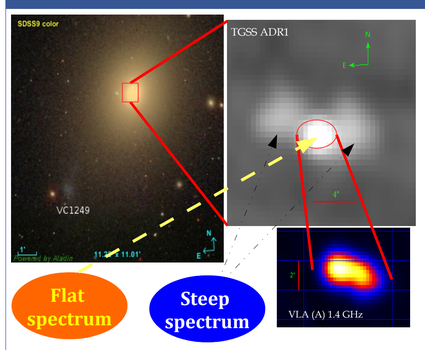


The two AGNs are not detected in our UVIT images (left). However, the bright star-forming region corresponding to bright Hα emission with narrow line widths is detected. The Balmer decrement is consistent with heavy extinction in the region of the AGN.



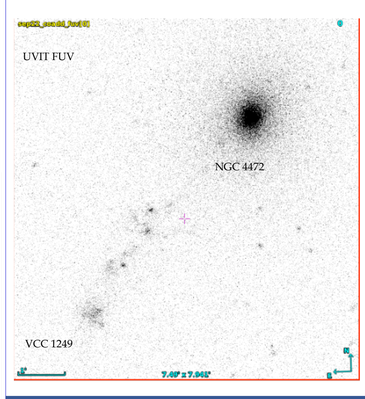
The SED of both AGNs plotted together (right) clearly shows both have steep radio spectrum.

NGC 4472

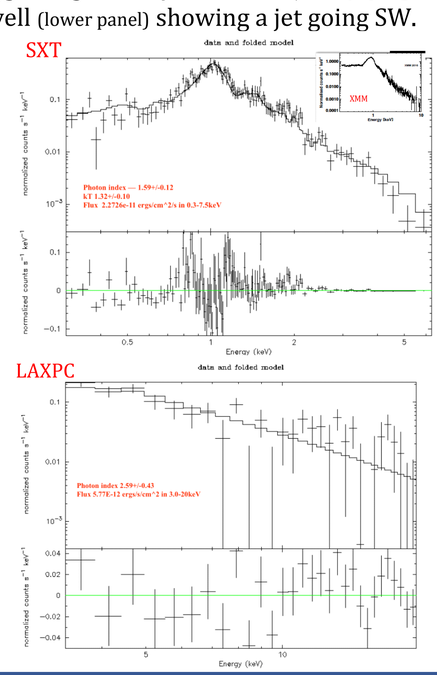


NGC 4472 is part of a much larger Virgo cluster of galaxies. The 150MHz image shows a triple structure suggesting twin synchrotron jets (top right panel), seen on the smaller scale as well (lower panel) showing a jet going SW.

It was also observed with SXT & LAXPC instruments (in X-ray frequencies) onboard the ASTROSAT satellite.The results have shown that the X-ray data from our observations are broadly consistent with RXTE data and XMM data.



It was also observed with UVIT (in UV frequencies) onboard the AstroSat satellite. We observe tidal debris due to hydrogen stipping of nearby dwarf galaxy VCC1249 due its interaction with NGC 4472 in our UVIT images with higher angular resolution (FUV image on right), as observed by Battaia+ (2012) GALEX Ultraviolet Virgo Cluster Survey (GUViCS) NUV images.



Summary

- The radio-IR scatterplot for the active galaxies clearly shows excess radio emission over that predicted by star formation in several cases, which is clearly due to the AGN.
- For many of our objects, we observe nuclear star formation regions showing ring-like structure, interpreted as the Inner Lindblad Resonance, and perpendicular to the extended emission line regions and radio jets including NGC 613.
- NGC 4472 shows triple radio structure with a flat spectrum core and steep spectrum lobes suggesting twin jets. Our UVIT image shows tidal debris due to interaction with dwarf galaxy VCC 1249.
- The presence of two accreting SMBH at a separation of ~3.4 Kpc in the nuclear region of the merged Carafe galaxy is evident based on multiple lines of evidence. Thus, we find that the Carafe galaxy hosts a precursor to binary supermassive black hole system in its central region.

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