Studying Radio Outflows in the S7 Seyfert Sample

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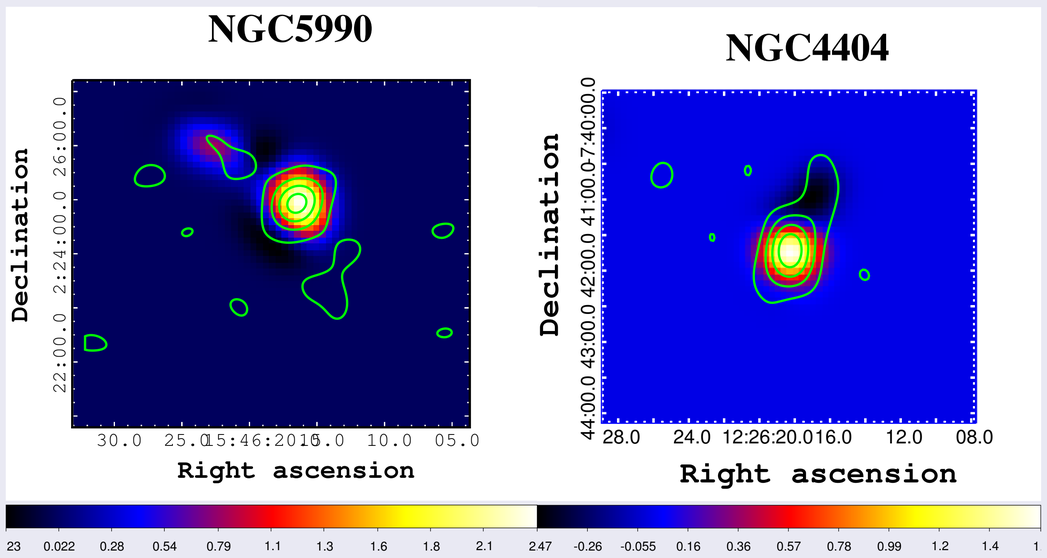
The S7-GMRT Sample

- **S7 (Siding Spring Southern Seyfert Spectroscopic Snapshot Survey) -GMRT (Giant Meterwave Radio Telescope)** sample consists of 17 Seyfert galaxies lying in the redshift range of 0.004 to 0.02. The GMRT operates from 150 MHz to 1.45 GHz frequency range. We have observed these galaxies at 610 MHz and 1.45 GHz with the GMRT. These sources are selected based on the following criteria :
  1. To be accessible to GMRT, the sources are restricted to those belonging to Southern hemisphere lying within a declination range of +/-10 deg so as to complement arcsecond-scale radio observations of S7 Seyfert sample with Australia Telescope Compact Array (ATCA) [PI: P.Shastri].
  2. We have imposed a 1.45 GHz flux density cut-off of $\geqslant$ 25 mJy (single dish radio or NVSS data; see the Veron-Cetty and Veron catalog).
  3. From the resulting 31 Seyferts, we have excluded 14 Seyferts that have existing archival Very Large Array (VLA) A- or AB- array data at 1.4 GHz (resolution $\sim$1.5 - 2 arcsec, matching that of the proposed GMRT observations at 1.45 GHz).
- The primary science goals of this study are :
  1. Look for the interplay between the radio outflows and the emission line regions in the host galaxies.
  2. Examine the relationship between the radio outflows, star formation and AGN activity.

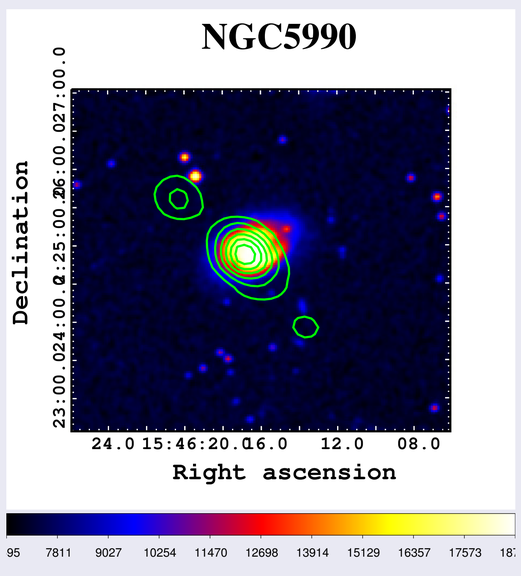
Low Radio Frequency Spectral Indices



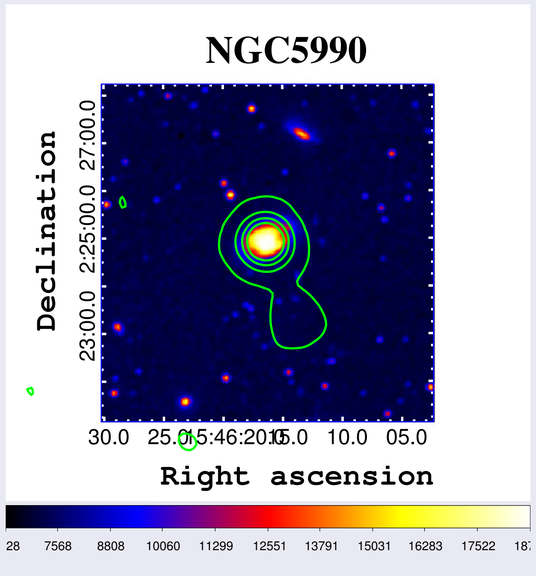
Preliminary 610 MHz - 1.45 GHz spectral index images (in colour) superimposed by the 610 MHz radio contours are presented for NGC5990 and NGC4404 above. NGC4404 is a LINER galaxy in interaction with NGC4403. We find that the emission from the galaxy as a whole has flat spectrum. In general, we find the spectral indices to be inverted.

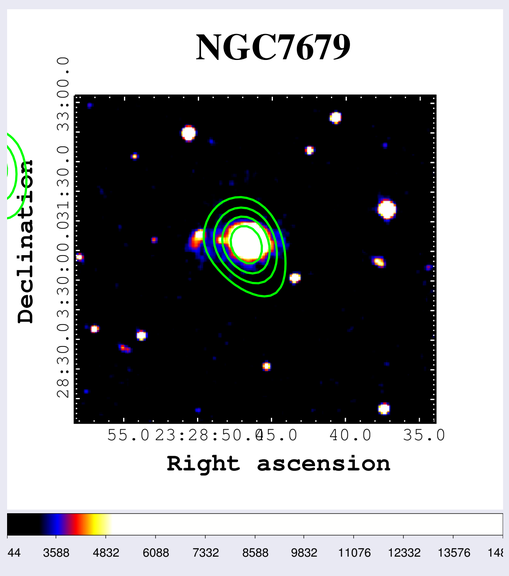
[Here, the color bar gives the α values. S $\propto \nu^{\alpha}$; S - Flux density, ν - frequency, α - spectral index]

Radio Outflows in the S7-GMRT Sample

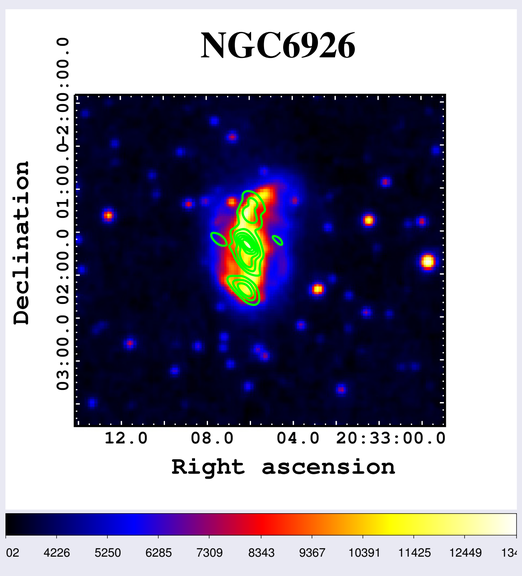


NGC5990 (left panel) is a Seyfert 2 type AGN. When observed at 1.45 GHz, a radio outflow is revealed at a position angle (PA) of $\sim$50 degrees w.r.t the major axis of the optical host galaxy which is at a PA of $\sim$120 degrees. NVSS contours overlaid on the DSS image (right panel) which also suggests that there is outflow from the galaxy.





NGC7679 is an SB0, Seyfert 1 galaxy which has significant X-ray & IR emission. It also has a radio outflow at a PA of 30 degrees.



NGC6926 is a Seyfert 2 type AGN. GMRT observations reveal radio emission along the galactic plane as shown above. This may be due to the star formation regions in the galaxy.

Radio and Infrared Properties of the Kiloparsec Outflows

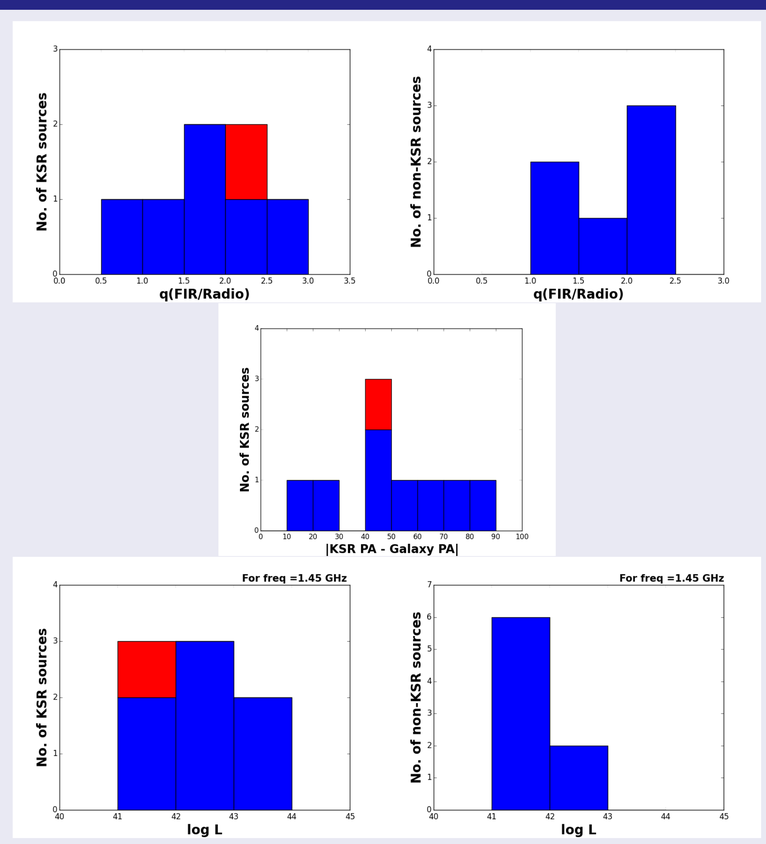
1. (Top left panel) Comparison of the distribution of q (far infrared-FIR-radio continuum ratio) for KSR (Kiloparsec Radio Structures). Overall, the sources with KSR have lower q values when compared to that of the non-KSR sources in the present sample i.e., there is excess radio continuum relative to that of FIR continuum.

$$q = \log[(FIR/3.75 \times 10^{12} Hz)/S(1.4GHz)] \quad (1)$$

where S is flux density and

$$FIR = 1.26 \times 10^{-14}[2.58S(60\mu m) + S(100\mu m)] \quad (2)$$

2. (Top right panel) Comparison of the distribution of q for non-KSR sources. Most of them fall within the FIR-radio correlation for normal spiral galaxies (Helou et al.,1985).
3. (Middle panel) Histogram of the $\triangle$PA in degrees between the KSR axis and the host galaxy major axis for the 9 KSR S7-Seyferts at both frequencies.
4. (Bottom left panel) Comparison of the distribution of the luminosity of the radio source (L) at 1.45 GHz for non-KSR sources. On average, the luminosity for the non-KSR sources is $log(L)$ = **41.87**
5. (Bottom right panel) Comparison of the distribution of the luminosity of the radio source at 1.45 GHz for KSR sources. On average, the luminosity value for the KSR sources is $log(L)$ = **42.20**. Thus, KSR sources are more luminous on average when compared to that of non-KSR sources.



Results from the S7-GMRT Sample

1. Out of 17 Seyfert galaxies observed at 610 MHz and 1.45 GHz with the GMRT, 9 sources exhibit outflows, while one does not show a radio detection. The percentage of extended or marginally extended sources was found to be **55%**. This detection rate is significantly greater than previously observed in the literature (Gallimore et al.2006; Singh et al. 2014). This attests to the usefulness of observing at low radio frequencies in order to detect diffuse radio outflows.
2. In the present sample, the majority of $\triangle$PA values fall in the range of 40 - 50 degrees, which implies that the KSR axis prefers to align at an oblique angle with the galaxy major axis (similar results were found by Colbert et al. 1996a and Gallimore et al. 2006).
3. The radio outflow axis usually aligns with the minor axis of the host galaxy, if the KSR originates from a starburst. Therefore, our results suggest that most of the KSR sources may not be starburst-driven but are rather AGN-driven in the present sample.
4. In the 1^{st} and 2^{nd} histograms, we have compared the distribution of q for the KSR and non-KSR Seyferts and we observe that they are distributed differently. The KSR sources tend more towards the lower q values when compared to that of the non-KSR sources. This suggests that there is excess radio continuum relative to the far-infrared continuum.
5. The radio sources of KSR Seyferts are more luminous than the non-KSR Seyferts.
6. Overall, this study suggest that the radio outflows in S7-GMRT sample are related to AGN activity.

Future work

- To find the brightness temperature of the radio emission in order to verify if the radio outflow is AGN-driven.
- To study the connection between the radio outflows from AGN and Extended Narrow Emission Line Regions (ENLR).

References

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Colbert et al. 1996a, ApJ, 467, 551
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