3 mm Observations of Radio Galaxies with the Green Bank Telescope

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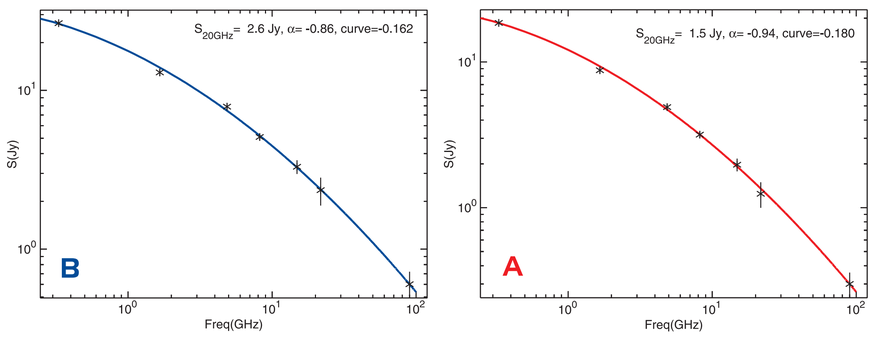
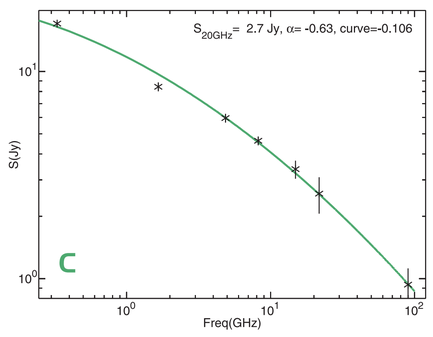
One of the outstanding problems in the radio jets from AGNs is the question of particle acceleration. X-ray observations of extended jets clearly show that the relativistic particle acceleration occurs over an extended region. The balance between particle acceleration and energy losses are shown in the SED with a break in the radio/mm region frequently indicating the maximum energy of the surviving particles. The recently commissioned MUSTANG 3 mm bolometer camera on the GBT allows sensitive measurements of the extended regions of radio galaxies with enough resolution (8") to detect variations in the spectral break. Recent results on M87 and Hydra A will be presented.

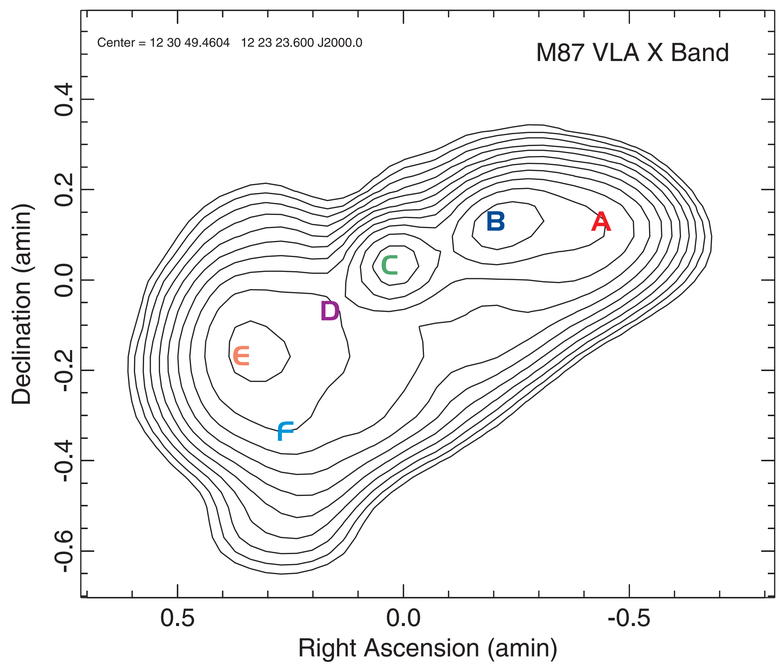
M87

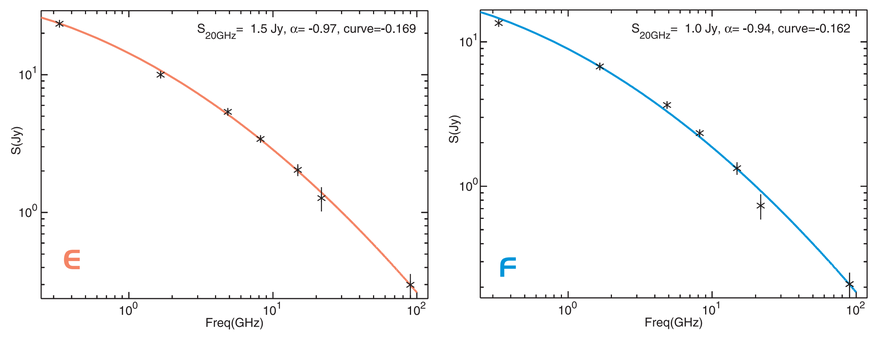
The point spectra in M87 are in shown in Figure 5 corresponding to positions (A-F) marked in Figure 6. The reference frequency used was 20 GHz. Fitted parameters are shown in Figure 5. The spectral index and spectral curvature images are shown in Figures 7 and 8. Note the extended blue regions around the edges in Figure 8. These are faint regions in the MUSTANG images and this color indicates physically implausibly positive curvature. This is likely the result of residual scattered emission from the brighter regions which has not been properly removed in the deconvolution. This extra emission makes the MUSTANG image appear significantly brighter in these regions than the source really is, resulting in the positive curvature.

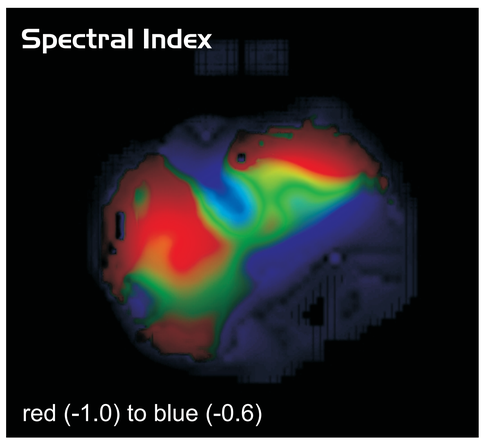
M87 is a two–sided FRI jet source in which both jets bend into the line of sight limiting the distance from the nucleus to which they can be observed. The jets on either side of the nucleus (position C) show fairly small variation in spectral index and curvature. The approaching jet (positions A, B) have somewhat flatter spectra that in the receding jet (positions D, E, F). There is some curvature in each of the spectra indicating relative energy losses at higher energies but very little evidence for systematic variations along the jets. This implies that particle acceleration continues along the observable region of the jets.

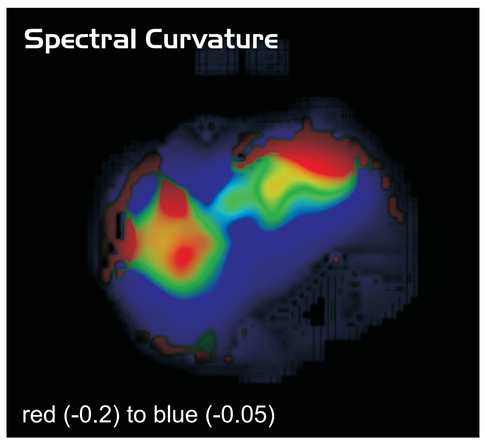






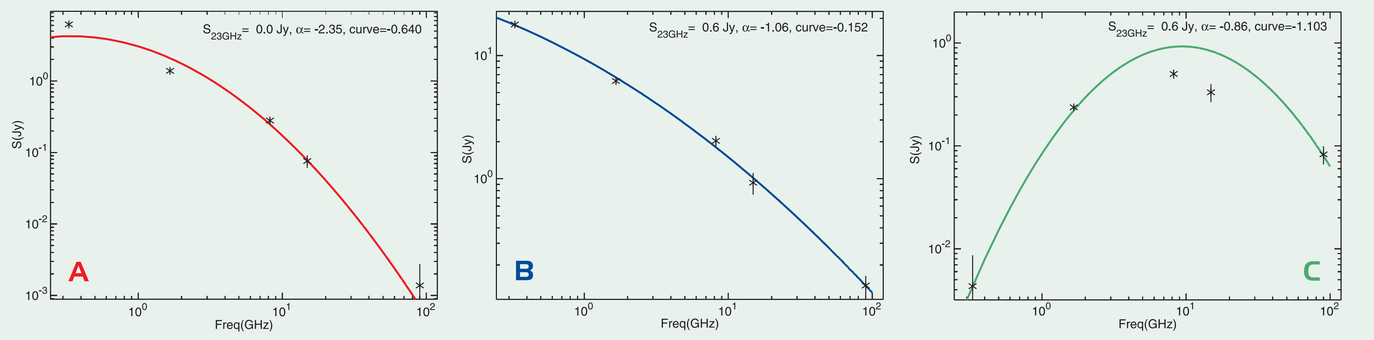


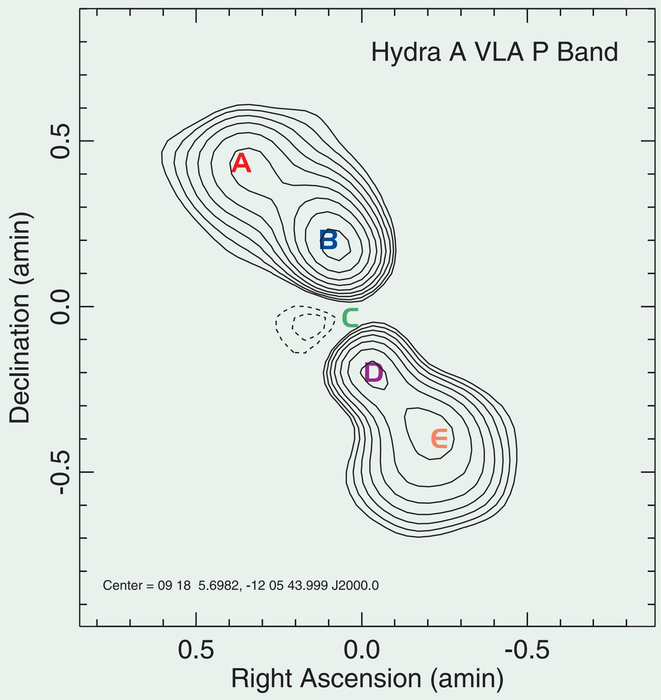


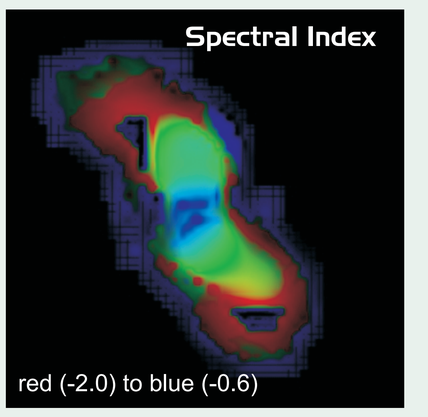


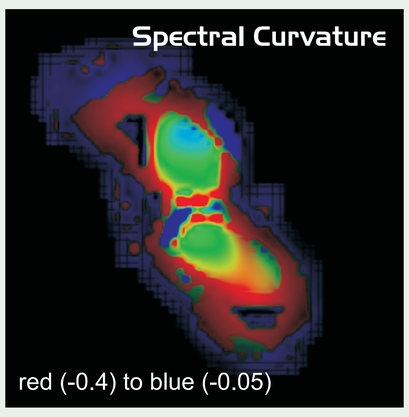
Regions shown are the same as the contour plot. The intensity is a function of the flux density, saturated and with a square root stretch.

Hydra A

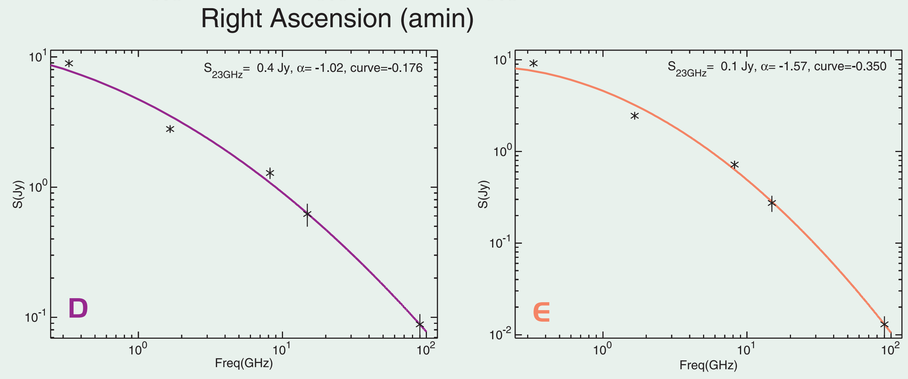








Regions shown are the same as the contour plot. The intensity is a function of the flux density, saturated and with a square root stretch.



The point spectra for Hydra A are in Figure 9 corresponding to positions marked in Figure 10. The reference frequency used was 23 GHz. Fitted parameters are shown in Figure Figure 9. The spectral index and spectral curvature images are shown in Figures 11 and 12.

Hydra is also a two–sided FRI radio galaxy with a weak, strongly self–absorbed core (position C). In this galaxy, both the spectral index and curvature increase dramatically along the visible portion of the jets. This suggests that particle acceleration slows or stops fairly early in the jet. The spectral index at the reference frequency of 23 GHz, given in the figures, is very steep outside of the region of the core becoming abnormally steep in the north (Position A). This indicates very little reacceleration of electrons in the outer regions of the jets.

Conclusions

Observations at 90 GHz using the MUSTANG camera on the GBT can be used to measure the high radio frequency spectra of the synchrotron emission in extended AGNs. MUSTANG observations of M87 and Hydra A have been compared with lower frequency images obtained from data in the VLAarchive to derive spectra along the observable portions of the jets in these FRI radio galaxies. In M87, some spectral steepening is observed in the spectrum but there are no systematic variations along the jet. This indicates that there is continued reacceleration of the relativistic electrons to balance the electron energy losses due to synchrotron emission, incerse Compton scattering and other mechanisms. The situation in Hydra A is very different. In the jets in this galaxy, the spectra become increasingly curved along the jet. This indicated that the electron energy losses exceed any energy resupplied by reacceleration of the electrons. In the northern jet, the high frequency spectrum becomes exceedingly steep (α =-2.35 at 23 GHz) indication a complete depletion of the higher energy electrons.