Perseus in Sicily: From Black Hole to Cluster Outskirts
Proceedings IAU Symposium No. 342, 2018
K. Asada, E. de Gouveia Dal Pino, M. Giroletti,
H. Nagai & R. Nemmen, eds.

doi:10.1017/S1743921318005161

Probing the B-fields of AGN jets on kiloparsec scales - NGC 6251

Sebastian Knuettel and Denise Gabuzda

Department of Physics, University College Cork,
Cork, Ireland
email: s.knuettel@mars.ucc.ie

Abstract. By constructing images of the Faraday rotation measure (RM) of large scale astrophysical jets, the line-of-sight magnetic field component and electron density in the region of Farady rotation can be investigated. A significant gradient in the RM transverse to the jet direction may indicate a corresponding gradient in the line-of-sight magnetic field, implying a toroidal or helical magnetic field, which would, in turn, imply the presence of an associated electrical current in the jet. The detection of such large scale gradients can reliably demonstrate that helical or toroidal fields can persist to large distances from the central AGN. We present a kiloparsec-scale Faraday rotation map of NGC 6251 that shows statistically significant transverse RM gradients across its kiloparsec scale jet structure that imply an outward current.

Keywords. galaxies: active, magnetic fields, polarization, galaxies: individual (NGC 6251).

1. Introduction

The radio emission from astrophysical jets is primarily synchrotron and can be highly linearly polarised, making the behaviour of the polarised radiation a useful tool in examining the B field environment of these jets. Faraday rotation plays an important role in the detection such magnetic fields. This phenomenon occurs in regions with free electrons and magnetic field, where the polarization angle of an electromagnetic wave changes according to the equations: $\chi_{\rm obs} = \chi_0 + {\rm RM}\lambda^2$, ${\rm RM} \propto \int_0^d n_e \vec{B} \cdot {\rm d}\vec{l}$; where $\chi_{\rm obs}$ is the observed polarization angle, χ_0 is the intrinsic (zero wavelength) polarization angle, $\vec{B}$ is the magnetic field, ${\rm d}\vec{l}$ is a path element along the line of sight, n_e is the electron density, and λ is the observing wavelength. Gradients in the Faraday rotation measure (RM) as evidence for toroidal magnetic fields on parsec and kiloparsec scales have been discussed by Gabuzda *et al.* (2018) and Christodoulou *et al.* (2016). The presence of a transverse RM gradient across the kiloparsec-scale jet of NGC 6251 was suggested by Perley *et al.* (1984). To accurately determine the statistical significance of these gradients the original data used in Perley *et al.* (1984) were downloaded from the VLA archive and analysed again using modern standard methods in AIPS.

2. Overview

An approximately 25″ section of the jet shows monotonic transverse RM gradients with significances of over 3σ, see Figure 1. The plot to the right shows the significances of the gradients for a series of transverse RM slices along this section of the jet with the dashed lines representing the 2σ and 3σ thresholds. This significance was calculated using the end point RM values and their associated errors from the χ versus λ^2 fits:

$$\text{significance}(\sigma) = \frac{|{\rm RM}_1 - {\rm RM}_2|}{\sqrt{\Delta{\rm RM}_1^2 + \Delta{\rm RM}_2^2}} \tag{2.1}$$

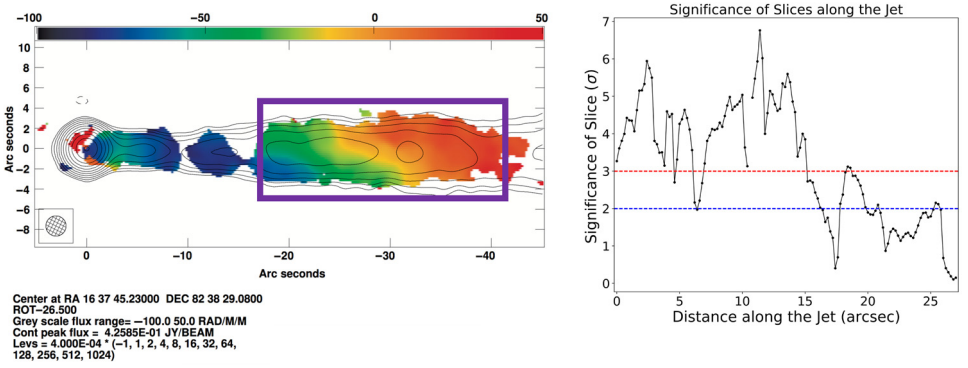

Figure 1. RM map of the inner part of the kiloparsec scale jet of NGC 6251 is given in the left panel. The colour scale represents the RM in $\mathrm{rad\,m^{-2}}$, the contours of total intensity at 1.37 GHz are in black and start at 0.4 mJy and increase in factors of 2. A 2″ circular beam was used to produce the RM map and contour map. Note that the image has been rotated by 26.5° in the clockwise direction. The right panel shows a plot of the significances of the gradients shown by a series of transverse slices in the region bordered by the purple box in the left panel.

Here the subscripts indicate the endpoint values of the RM gradient. The Galactic component of the RM has been estimated to be $\simeq -49\,\mathrm{rad\,m^{-2}}$ in Perley *et al.* (1984) and has been subtracted from the map; this reveals gradients where the RM changes from positive to negative, a clear indicator that the line-of-sight magnetic field is changing direction across the jet, rather than just the electron density.

3. Implications

NGC 6251 shows statistically significant transverse RM gradients across its kiloparsec scale jet that imply an outward current, as is indicated by the right-hand rule for the relationship between current and associated B field. While it has been suggested the jet of NGC 6251 is collimated due to the more dense intergalactic medium around it, X-ray observations suggest the pressure of the intergalactic medium is not sufficent and magnetic confinement seems more likely (Mack *et al.* (1997)). This result adds to previous detections of significant transverse Faraday rotation gradients across large-scale jets, which have all corresponded to outward currents (11 in Christodoulou *et al.* (2016) and Knuettel *et al.* (2017)). This is a highly statistically significant result, and may provide key information about the system of currents and magnetic fields generated in AGN jets. Combining this with results for AGN jets on parsec scales, which imply a predominance of inward currents, this suggests that the jets have a current/magnetic field configuration similar to that of a co-axial cable as dexcribed by Gabuzda *et al.* (2018).

References

Christodoulou, D. M., Gabuzda, D. C., Knuettel, S.,Contopoulos, I., Kazanas, D., & Coughlan, C. P. 2016, *A&A*, 591, A61

Gabuzda, D. C., Nagle, M. & Roche, N. 2017, *A&A*, 612, A67

Knuettel, S., Gabuzda, D., & O'Sullivan, S., 2017, in: E. Angelakis, M. Boettcher & J. L. Gómez (eds), *Polarized Emission from Astrophysical Jets*, Galaxies 2017, 5, p. 61

Mack1, K.-H., Kerp, J., & Klein, U., 1997, *A&A*, 324, 87087

Perley, R. A., Bridle, A. H., & Willis, A. G. 1984, *ApJS*, 54, 291

https://doi.org/10.1017/S1743921318005161 Published online by Cambridge University Press