

Background and Motivation

Radio surveys are used to study a variety of areas, from the evolution of active galactic nuclei (AGN), cosmological parameters to galaxy clusters. Knowing the redshift of a radio galaxy plays a crucial part in developing our understanding of these areas as well as leading to intrinsic properties such as physical size and luminosity (Norris, R., 2017, Duncan, K., et al., 2019)

Cross-identification is the matching of optical/infrared sources from other surveys with radio sources. It is essential but also difficult. For simple, isolated objects this can be done in an automated fashion with a likelihood ratio, but with larger, more complex structures it is often achieved through human classification (Duncan, K., et al. 2019, Williams, W., et al., 2019).

Project Aim

The aim of this project is to use the innovative method of ridgelines to trace the path created by the fluid flow in jets to improve the likelihood ratio method for determining host galaxies for sources classified by LOFAR Galaxy Zoo.

References

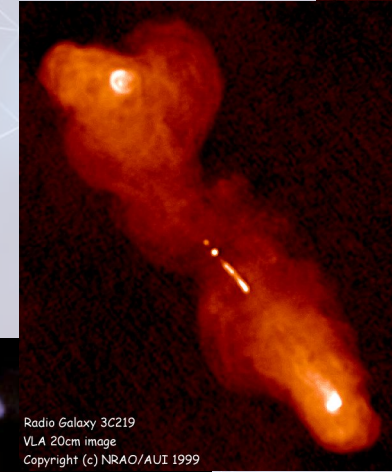
Duncan K. J., et al., 2019, A&A, 622
Norris R. P., 2017, Nat. Astron., 1, 671
Williams W. L., et al., 2019, A&A, 622

Using Ridgelines to Improve the Statistical Cross-Identification of Optical Counterparts for LOFAR

Credit: HST



Two different types of radio jets.



Check out the 2x2 view of the poster

Many properties of the universe can be studied through radio continuum surveys which are observing millions of sources...

LOFAR and the Data

Using the LOFAR Two-Metre Sky Survey (LoTSS) DR1, a 120 – 168 MHz continuum survey with a resolution of 6" which covers 424 deg² of the northern hemisphere (Shimwell, T. et al., 2019). LoTSS DR1 contains ~320,000 sources where 73% have optical counterparts (Williams, W. et al., 2019), ~23,000 of these are classified as AGN (Hardcastle, M. 2019). The sample of 991 radio sources come from the AGN set, and have flux > 30 mJy and size > 60".

Host Identification

For the cross identification of optical hosts with radio sources, two methods were implemented on the LoTSS DR1 data. For sources < 30" a likelihood ratio was applied for a statistical determination. Williams, W. et al. (2019) use a combination of colour, magnitude and distance from the LOFAR catalogue position to calculate the LR. If the source was large or contained multiple components it was sent to LOFAR Galaxy Zoo (LGZ) for a team of citizen scientists to determine. In DR1 ~12,000 large and complex sources went to LGZ for classification.

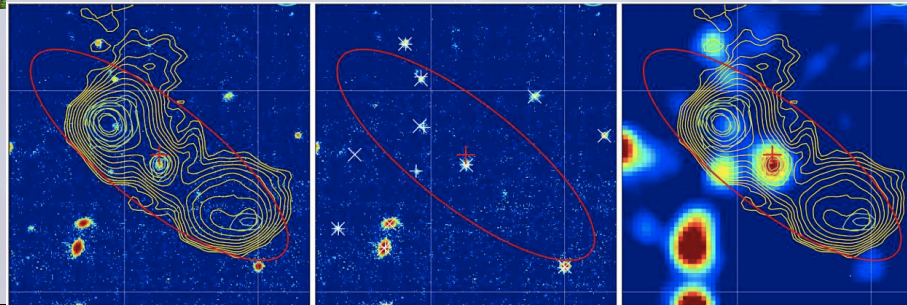
References

Hardcastle M. J., et al., 2019, A&A, 622, 12
Shimwell T. W., et al., 2019, A&A, 622
Williams W. L., et al., 2019, A&A, 622

LOFAR Data, LOFAR Galaxy Zoo and Optical Host Determination



The images a citizen scientist uses in LOFAR Galaxy Zoo to determine a host galaxy.



Images showing a LOFAR station and their locations across Europe



Credits: iLOFAR, lofar.ie

LGZ Image: The yellow contours are LoTSS, green are FIRST; in the left and central images the colour is Pan-STARRS and on the right it is WISE (band 1). The Pan-STARRS and WISE catalogued sources are the x's and +'s respectively.

Credit: Williams et al. (2019)

...where the optical hosts can be hard to identify. In LoTSS DR1 **~12,000 radio sources went to citizen science** for host determination.

Ridgelines trace the path of highest flux along a radio source, and have been successful on a sample of large, complex sources...

VLA 20cm image (c) NRAO/AUI 2000

What is a Ridgeline?

This work is following a similar approach to Pushkarev et al. (2017)'s total intensity ridgelines. A ridgeline is defined as the pathway of connected points, of highest intensity, along the direction of the radio source.

How to Draw a Ridgeline?

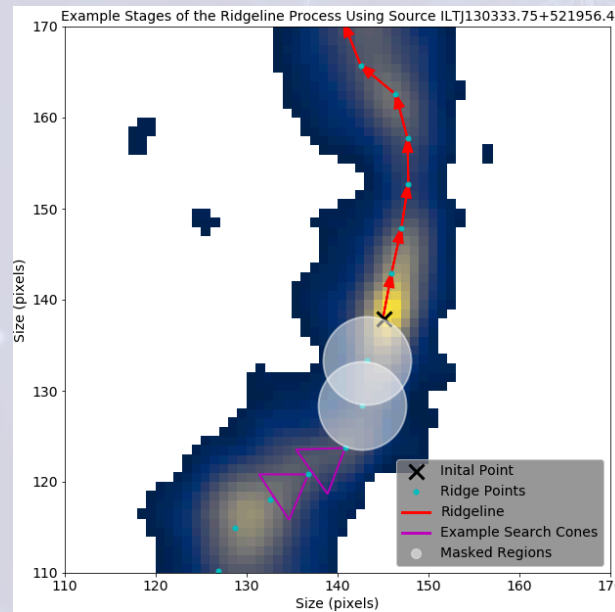
- Initial point at the highest flux (black cross).
- Search directions, cones and ridge points are determined.
- Search cones placed on the ridge points (magenta triangles).
- Highest flux on the edge of the search cone used as next point (cyan dots).
- Previous points masked around, radius one beam width (white circles).
- Repeat and connected to form the ridgeline (red).

Pathways Produced

For the sample of large and bright sources the ridgeline code has a success rate of 96% (950).

Images A – D show examples of successfully drawn ridgelines, including crossing gaps in emission (C) and different morphologies (a wide angled tail, D).

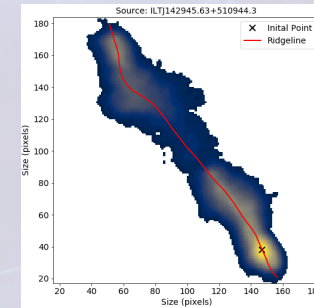
References
Pushkarev A. B., Kovalev Y. Y., Lister M. L., Savolainen T., 2017, MNRAS, 468, 4992



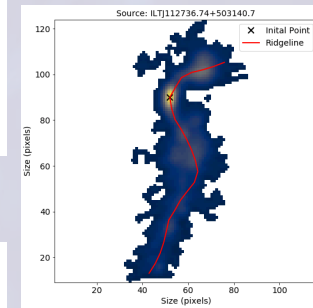
The different stages in forming a ridgeline, described to the left.

Ridgeline Construction and Examples.

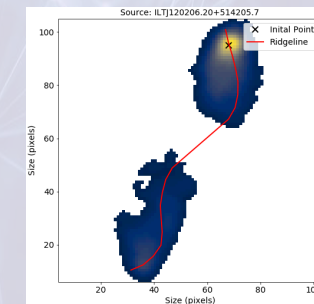
A



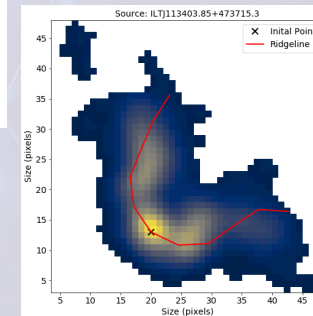
B



C



D



...the likelihood ratio method can be improved using ridgelines reducing the quantity of hosts to be identified through LOFAR Galaxy Zoo.

Likelihood Ratio and Ridgelines

Using the shortest distance to the ridgeline (the smaller of the perpendicular distance or distance to the closest point), and distance to the LOFAR catalogue, the Best, P. et al. (2003) LR was calculated, for each of the 30 closest possible counterparts. The Williams, W. et al. (2019) method was used applying the magnitude to the LR (i-band and W1-band). The maximum LR was then compared against the known hosts.

Surface Brightness

The average brightness along the ridgeline can be determined and is the surface brightness (SB) profile, classifying distances along a ridgeline. To calculate a host's location along a ridgeline in relation to its brightest points. The position of the dips and peaks were studied and the distance to either were calculated.

Results and Next Steps

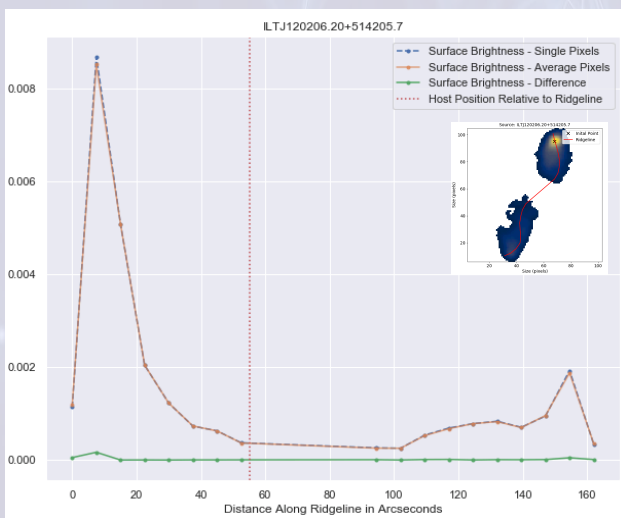
The table shows the percentage of hosts found with 64% found by multiplying the LR from using the distance to LOFAR and the ridgeline and 69% with the W1-band magnitude inclusion.

The next steps are to include colour into the LR and a parameter for the host distance along the ridgeline based on the SB Profiles

References

Best P. N., et al., 2003, Mon. Not. R. Astron. Soc, 346, 627
Williams W. L., et al., 2019, A&A, 622

A surface brightness profile showing the morphology of brightness along a ridgeline. The red dotted line shows the host's location. The smaller image shows the original ridgeline overlaid on the source.



The table shows the percentage of successfully found hosts. Combining the W1-band magnitude with the multiplied distance LR 69% of the optical counterparts can be determined.

Parameter	LOFAR	Ridge	Multiply	i - band	W1 - band
Successes	58 %	41 %	64 %	49 %	69 %

Results Using Ridgelines to Improve the Likelihood Ratio and Possible Next Steps