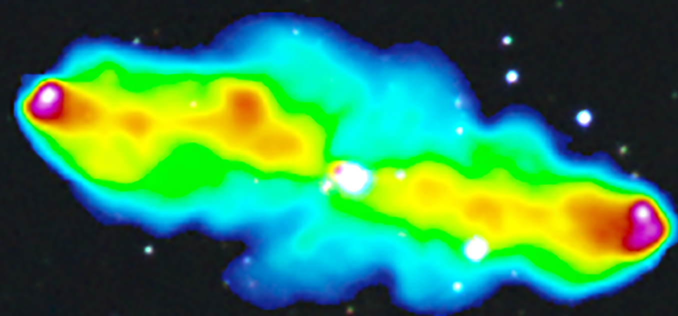
Machine learning and future surveys

Jeremy Harwood



Energetics and life-cycles of radio sources

ASTRON, March 2018

Collaborators:

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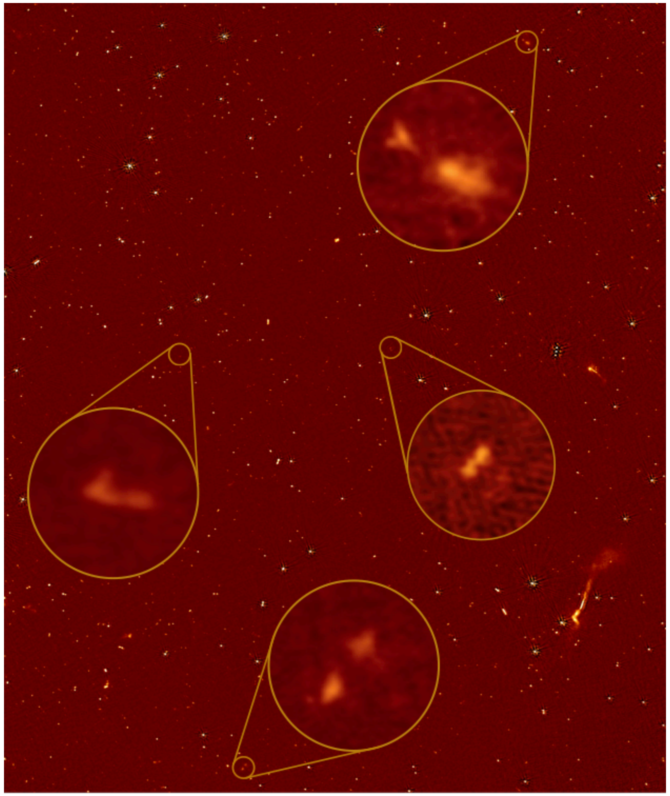
M. Jarvis (Oxford) A. Stroe (ESO) I. Heywood (CSIRO) L. Morabito (Oxford) K. Duncan (Leiden)

Automated selection to remnant galaxies (and other interesting sources)

- Originally looking to select based on spectral properties e.g. steep spectrum sources
- Many sources aren't as steep as expected at low frequencies (see Marisa's talk for more on this)
- Large surveys are often sparsely sampled i.e. lacking ancillary data for many sources
- May be too high/low to see the spectral break
- Only selecting a small subsample of remnants

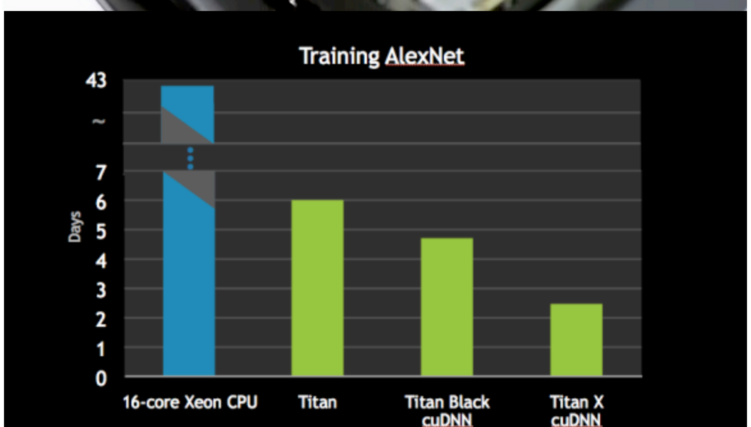


Brienza et al. 2017

How do we find remnants manually?

- Many well studied remnants found serendipitously
- Morphology
  - Relaxed or prototypical FRI/II?
- Compact features
  - Hotspots/inner jets?
  - Radio core?
- Spectrum
  - Steep or shallow?
  - Sharp cut off?
  - Model comparison (CI on vs off)?
- Machine learning is ideal for this!

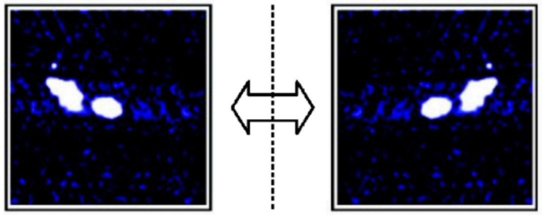
Computer science terminology



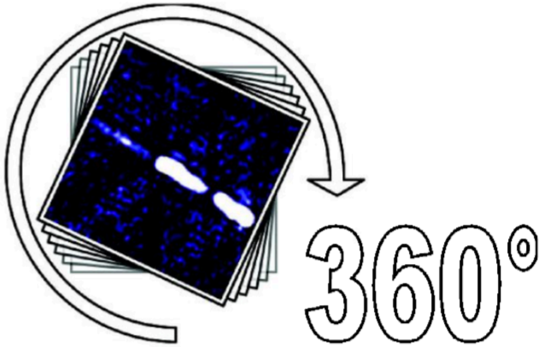
- **Supervised learning**
  - Aim to assign all input sources to a labelled group
  - Used for classification and regression
  - Training set requires labels (e.g. remnant vs. active)
  - Answer questions such as is this an FRI or FRII?
- **Unsupervised learning**
  - Aims to find structure and relationships between groups
  - Primarily for clustering (although many other uses)
  - Can be used to, for example, cluster similar morphologies
- **Feature engineering**
  - What to use and why
  - E.g. total flux, peak flux, or the ratio?
  - Key to making your method a success!

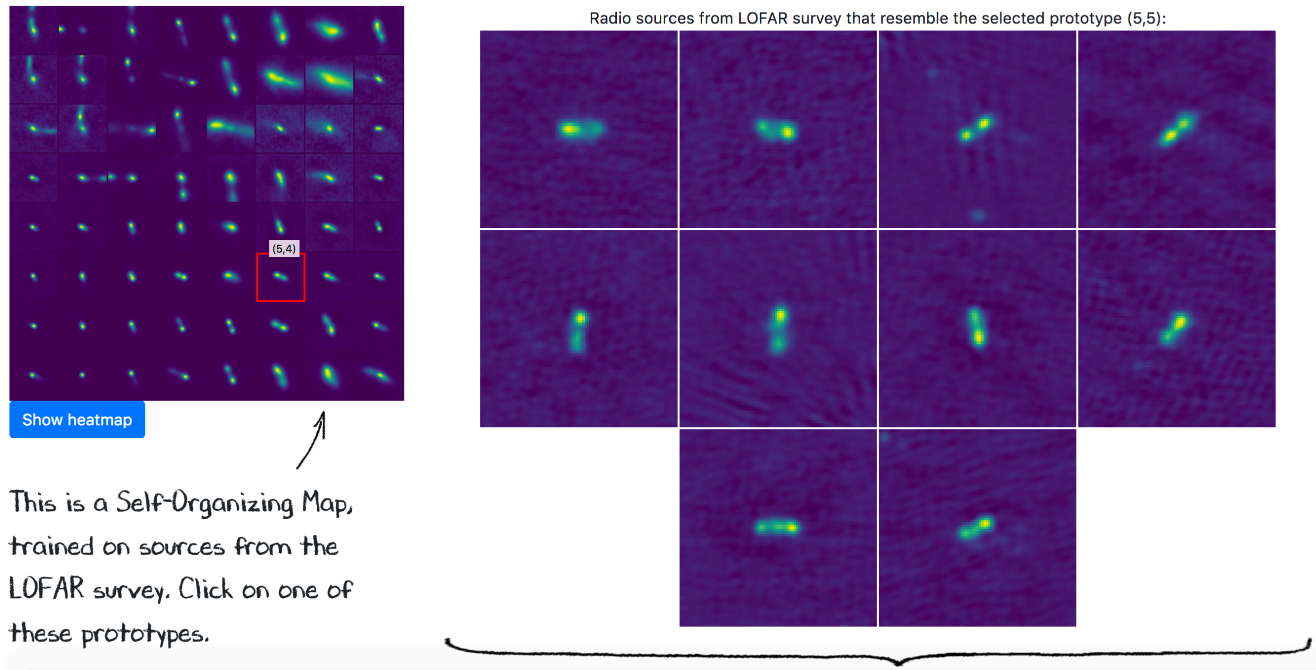
Morphological classification
(Rafael Mostert, Ken Duncan et al.)

- Have used unsupervised learning in the form of an artificial neural network
- Uses PINK: a rotation and flip invariant ML algorithm (Polsterer, Gieseke, and Igel, 2015)
- Computationally expensive; requires GPU computing to be completed in a reasonable time
- Created a Self-Organising Map (SOM) for the Lockman Hole
- Can be mapped to other fields in order to identify similar objects (distance from prototype)



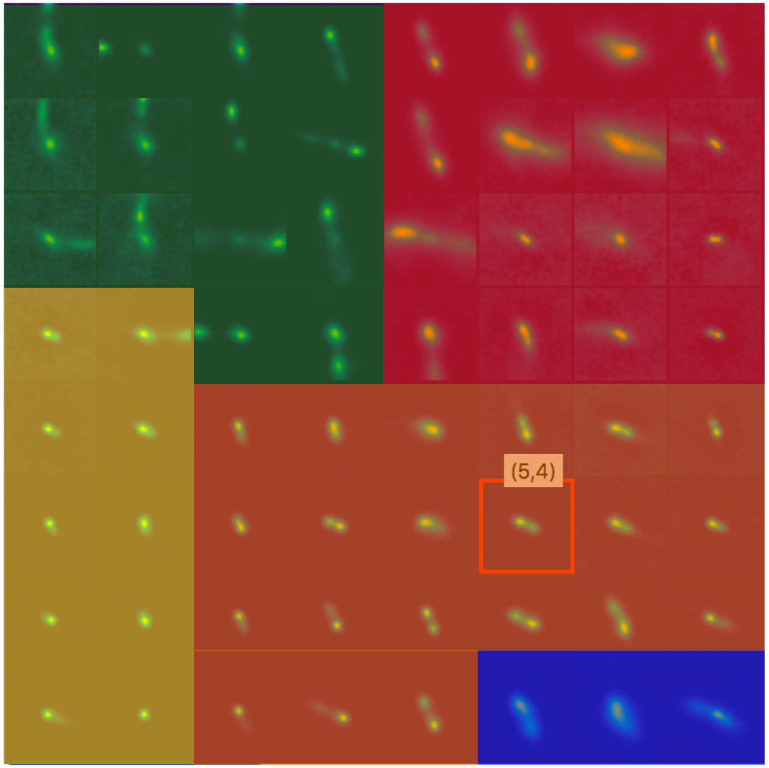
Polsterer, Gieseke, and Igel, 2015





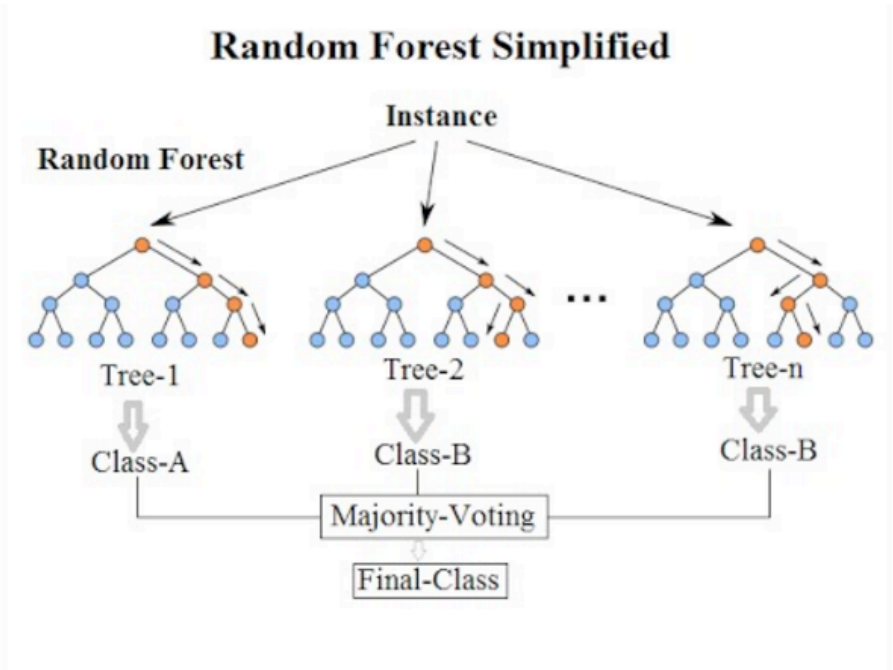
- These prototypical sources can be mapped to other fields (e.g. HETDEX)
- Preliminary tests indicated it might be possible to locate some remnant candidates based on morphology alone
- Likely to only be a specific subset e.g. 3C28 is likely a remnant, but very hard to tell from only its morphology, we need more information!

Clustering and morphological classification



- Clustering is the key to unlocking the power of the self-organised map
- Group the map in to N categories based on their morphology
- Maybe able to classify FRI / IIs but this may be secondary for our purposes
- Compact, extended, relaxed etc. is what we want to know
- Importantly, clustering will provide binary and/or analog parameters for morphology that can feed in to the bigger picture

Random forest algorithm



- Need to use all the information we have about sources to unlock the power of ML
- Singular decision trees are fairly common in astronomy
- Simplest (and fastest) solution, but not convinced it is the correct one long term
- Algorithms such as random forest are far more commonly used in the (non-astro) ML world due to reduced over fitting
- This is more complex and requires greater thought wrt to the parameter space

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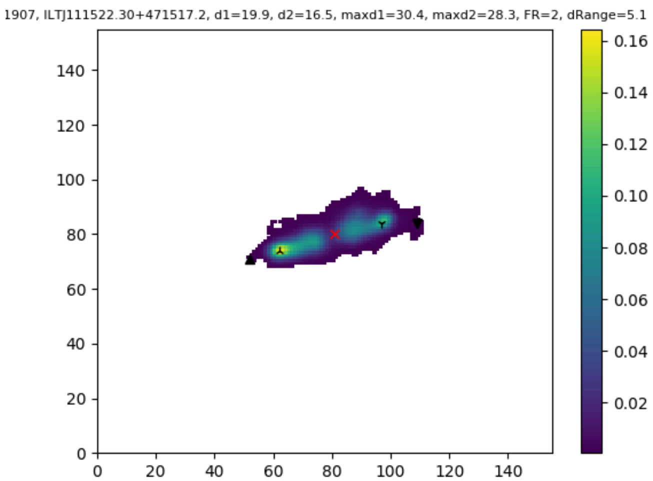
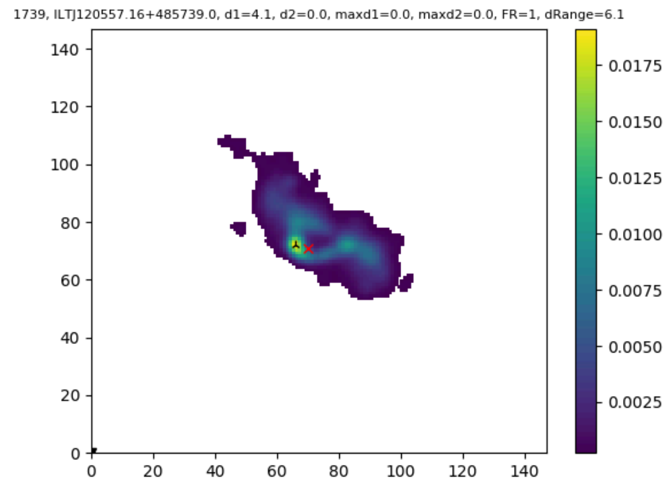
LOFAR

Feature engineering for remnant sources





- **What features (observable properties) can/should we use to find remnants?**
- **Known impact: spectral index, CI on/off model fitting, morphology**
- **Unknown impact: peak/total flux ratio, redshift, FRI/II classification, environment**
- **Code such as FRMAL by Beatrix Mingo (pictured above) may be more efficient for FRI/II**

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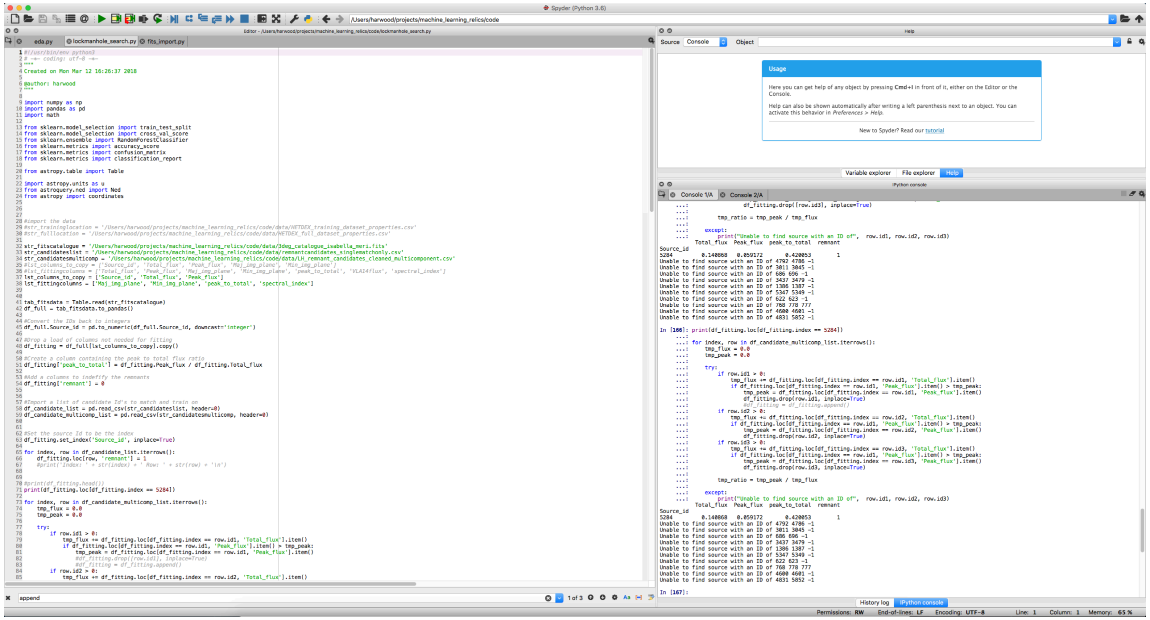


- **Development of the code and feature engineering is underway**
- **Looking at the Lockman hole using the known candidates. This will expand to include a wider variety of remnants as we begin to better understand the parameter space**
- **Main problem: a small training set! Cross verification is currently not possible**
- **One possible solution to this is to combined fields with known candidates e.g. H-ATLAS**

RadioLife

VLA GHz survey of extragalactic sources in the XMM-LSS field (AGES - XL)

- 30 of the brightest extended sources in the XMM-LSS field
- 97 hours split between L- and C-band at ~1 arcsec resolution
- Large amount of ancillary data available (e.g. LOFAR, XMM, VIDEO, DES)
- One of the MeerKAT MIGHTEE fields, and lower resolution (but wider field) survey by Ian Heywood (Oxford)
- Help develop methods for radio galaxies the MIGHTEE surveys

AGES-XL: Science goals and progress

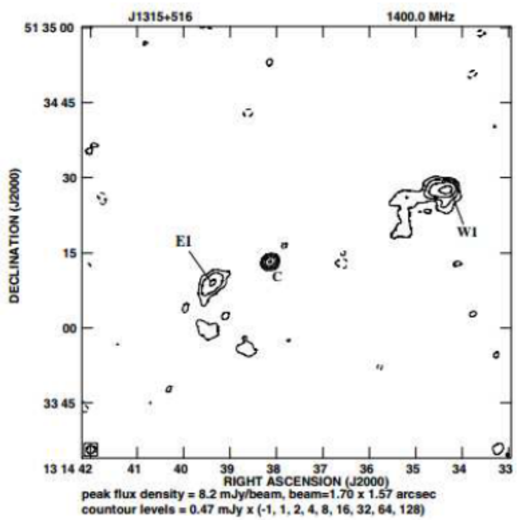
- **Primary science drivers:**
  - What are a robust set of parameters for models of spectral ageing for the radio galaxy population?
  - If the hotspot/lobe discontinuity common in the population?
  - Are recently revised energetics robust?

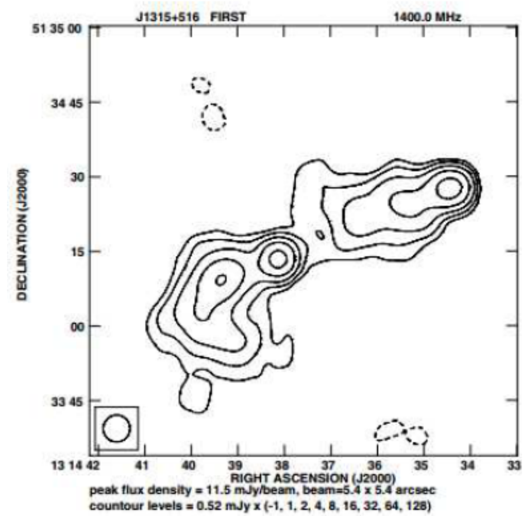
- **In conjunction with other surveys (e.g. MeerKAT, LOFAR) this will help to solve:**
  - What is the characteristic age and lifespan of nearby radio galaxies?
  - How does this age vary as a function of redshift?

- **73/97 hours observed, final observations will be taken summer 2018**

- **Plenty of opportunity to get involved either with the planned science or your own projects!**

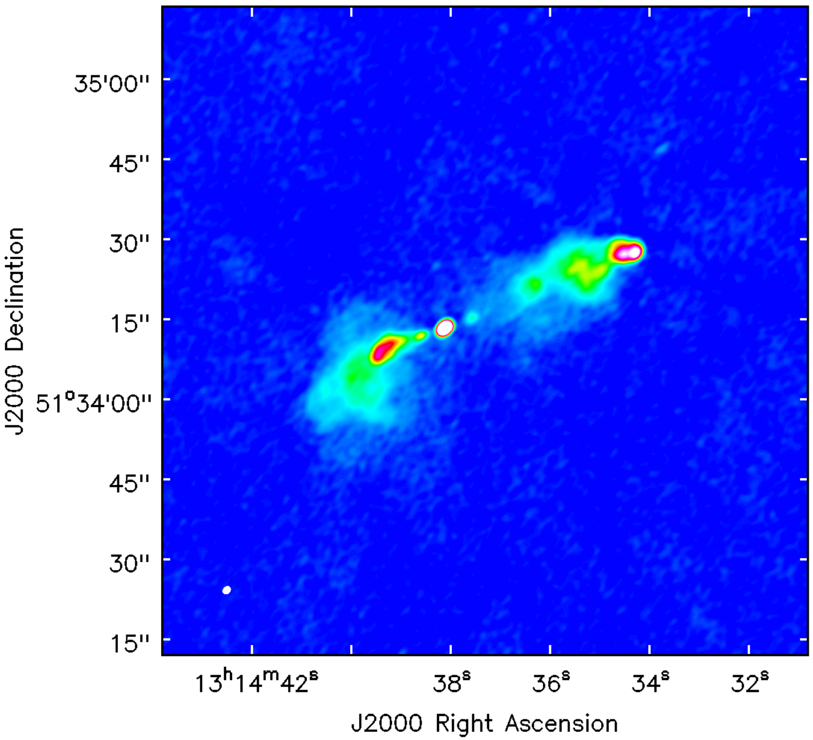
Hybrid Morphology Objects (HYMORS)





- **Discovered by Gopal-Krishna & Wiita (2000) and observed as FR I on one side and FR II on the other**
- **Very few studies have been performed to date. Recently, only a Galaxy Zoo search by Kapinska et al. and a new object found by de Gasperin (2017)**
- **No detailed spectral studies of the original samples or any broadband observations that capture both compact and diffuse emission**

Hybrid Morphology Objects (HYMORS)



JVLA observation of J1315+516 (z = 0.63) at 6 GHz
Full bandwidth between 4 & 8 GHz (C-band)
1.65”x1.25”resolution, combined B&C config.

- **5 examples discovered by Gawronski et al. (2006) in the FIRST survey**
- **25 hrs JVLA time awarded to observe the sample at L- (1-2 GHz) and C-band (4-8 GHz)**
- **Observed in multiple configurations give ~1” resolution but also capture the diffuse emission**
- **First image now complete (left) thanks to Tessa Vernstrom (Dunlap Institute)**
- **Spectral analysis of the first source soon!**

Conclusions

- Machine learning provides a potentially powerful tool for identifying remnant radio galaxies and other sources in large radio surveys
- We cannot rely purely on one parameter (e.g. morphology), if we wish to achieve a robust candidate list and include more than a subset of remnants
- Machine learning can be computationally expensive and often requires specialist setups e.g. GPU rigs − plan for this!
- First results should be ready later this year, hopefully expanding the search to the full LoTSS survey (and beyond) as it progresses
- AGES-XL is now almost complete. Let me know if you would like to get involved!
- First images showing combined compact and extended emission of HYMOR produced − spectral analysis to follow shortly