UNIVERSITY of TASMANIA

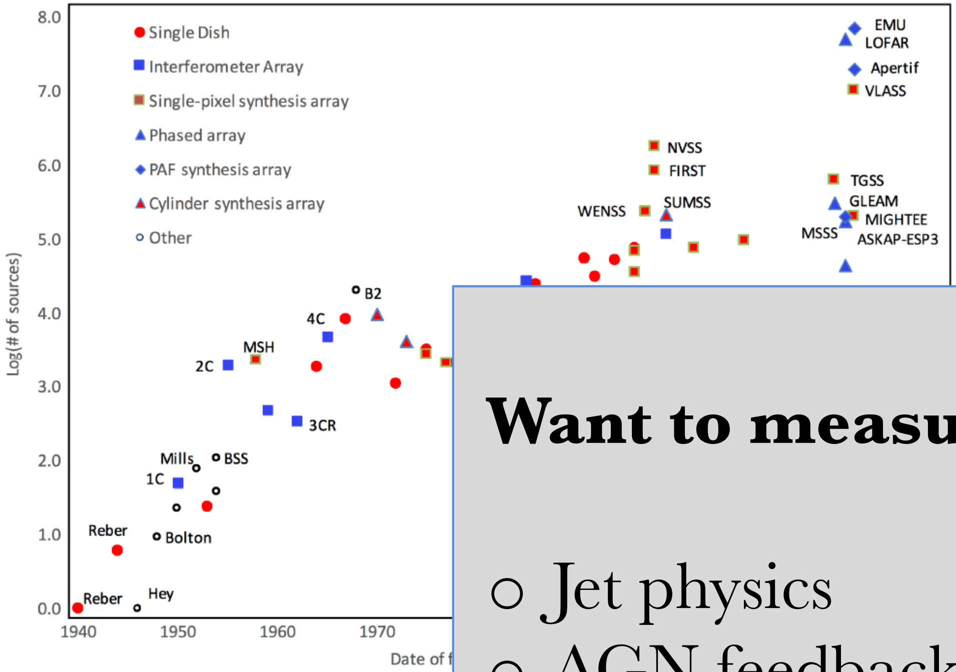
Modelling the environmental dependence of radio galaxy populations

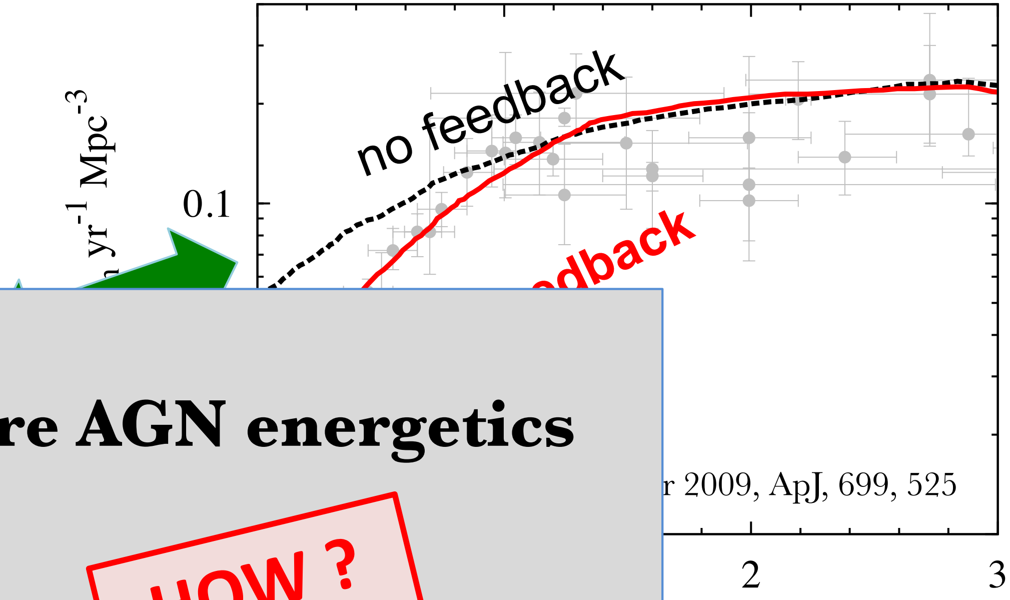
Stas Shabala

with: Ross Turner,
Payton Rodman,
Katie Vandorou

UNIVERSITY of TASMANIA

AGN feedback





-2006, Sijacki+ 2007,
ger+14 etc. etc.

Want to measure AGN energetics

- Jet physics
- AGN feedback

HOW ?

From: SEDs, (some) spatial information

Tens of million r

- can do at z
  do at $z < 0.5$

axy clusters
sive galaxies
density

➔ "radio mode" AGN feedback

Radio galaxy models

Scheuer 1974, MNRAS, 166, 513

also Begelman & Cioffi 1989, Falle 1991, Bicknell 1995, Kaiser & Alexander 1997, Willott et al. 1999, Manolakou & Kirk 2002, Shabala et al. 2008, Wang et al. 2009, Luo & Sadler 2010, Kapinska et al. 2012, Turner & Shabala 2015, Hardcastle 2018…

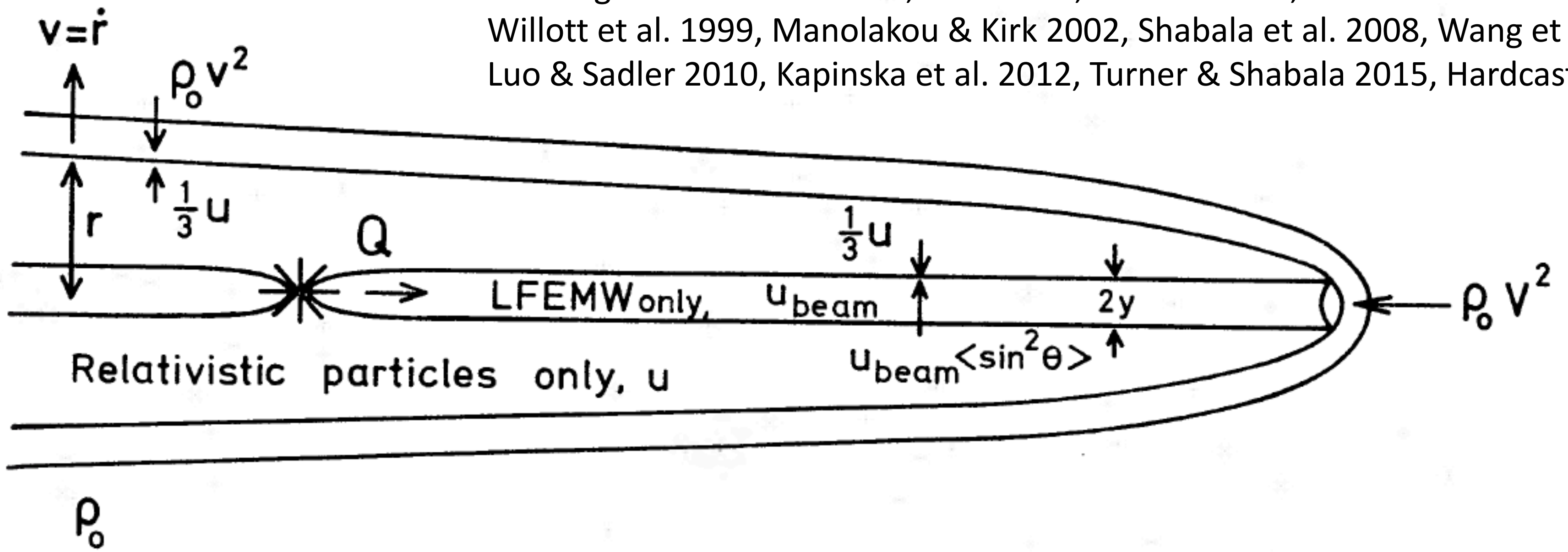
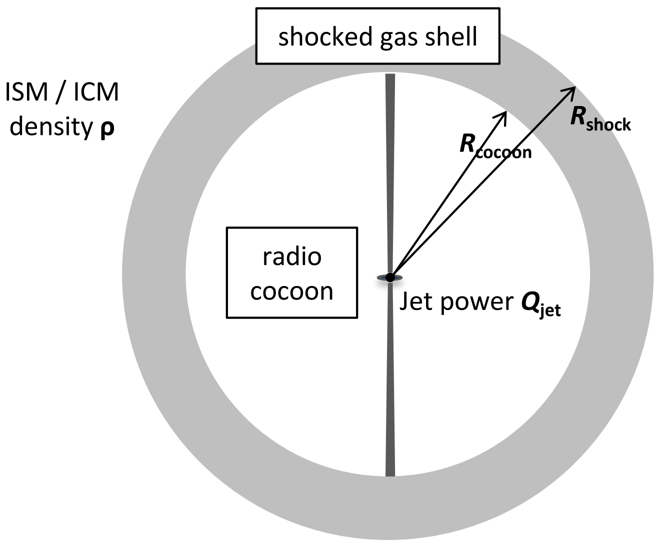


FIG. 4. *Model B.*

- Jet collimation by cocoon pressure
- Disruption / slowing down by entrainment
- Collimated jet → FR-II. Hotspots, backflow.
- Disrupted jet → FR-I. Jet flaring, (mostly) forward flow.
- Strong bow shocks vs pressure-limited expansion

UNIVERSITY of TASMANIA

Analytical models



Dynamics:

- conservation equations
- pressure continuity

Radio synchrotron emission:

- B-field, electron energy distribution, cocoon volume
- Acceleration at shocks
- Adiabatic, synchrotron, Inverse Compton losses

Solve equations to get time dependence of size, luminosity, radio SED

depends on jet power, density, B-field

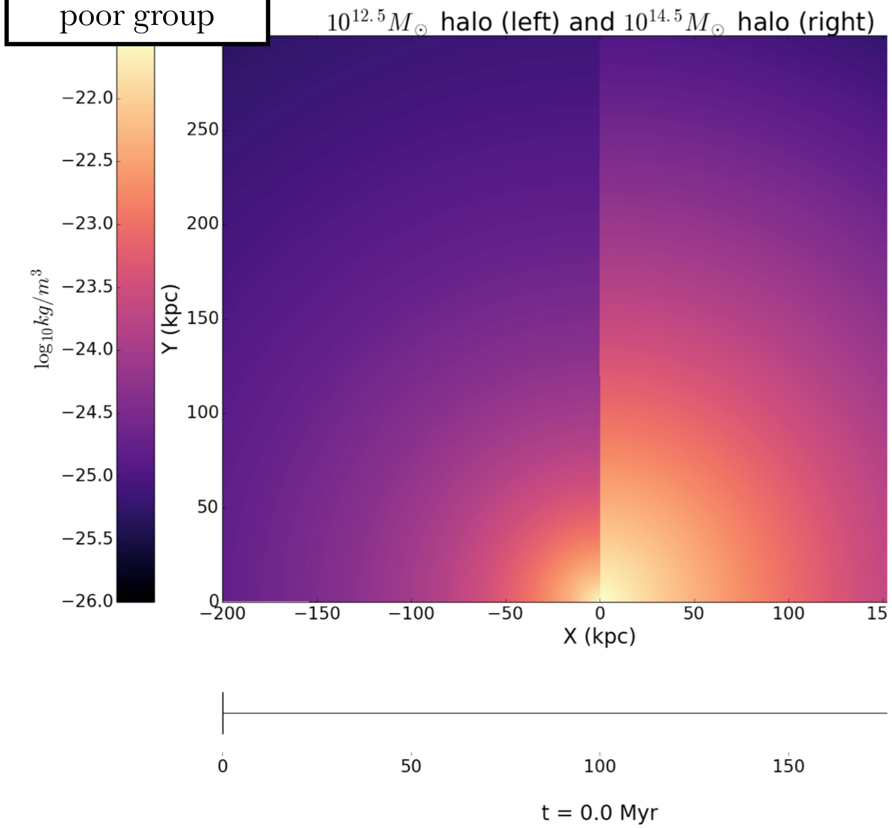
UNIVERSITY of TASMANIA

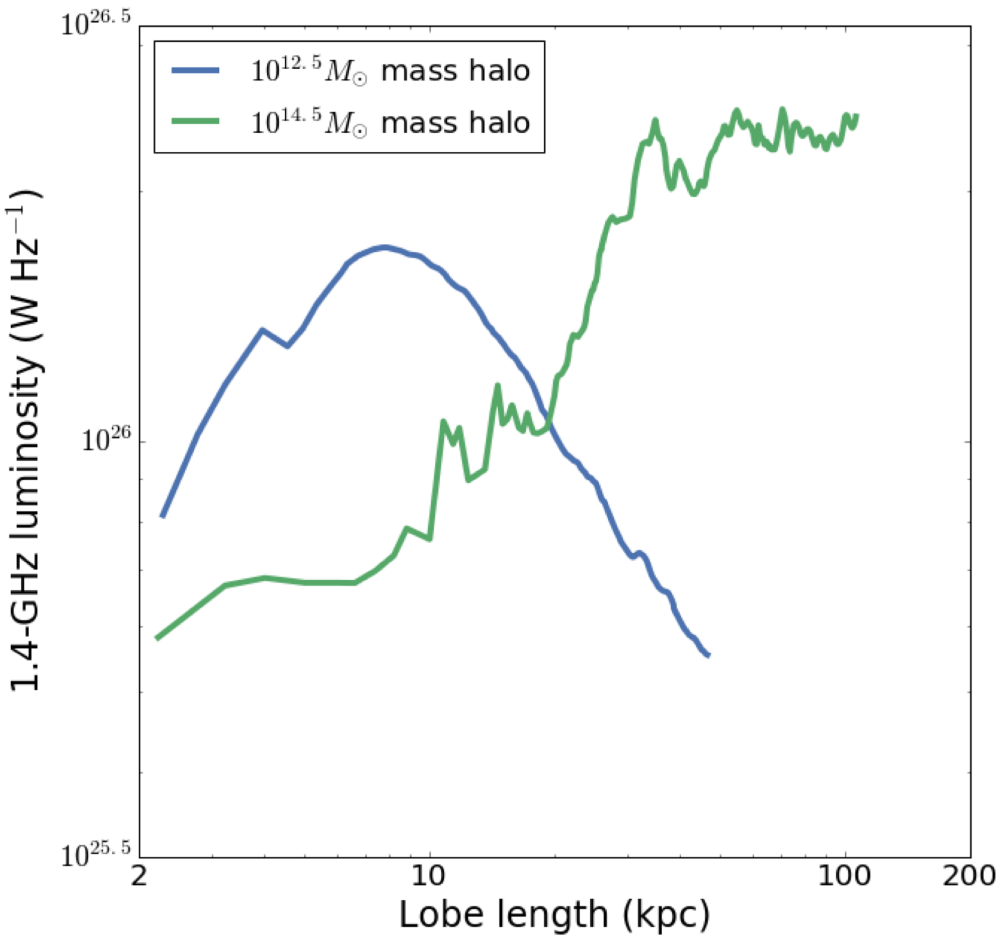
The importance of environment

Jet power = 10^{37} W
Age = 40 Myr

Simulations:
Patrick Yates

poor group





UNIVERSITY of TASMANIA

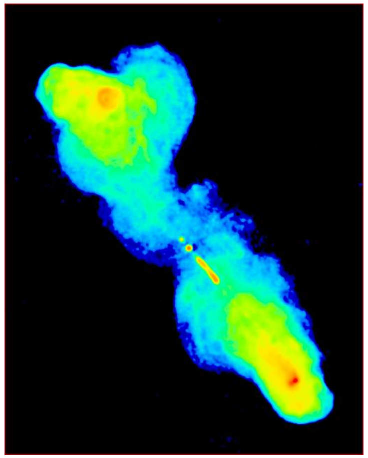
RAiSE : Radio Agn in Semi-analytic Environments

Dynamical models
AGN size and luminosity evolution

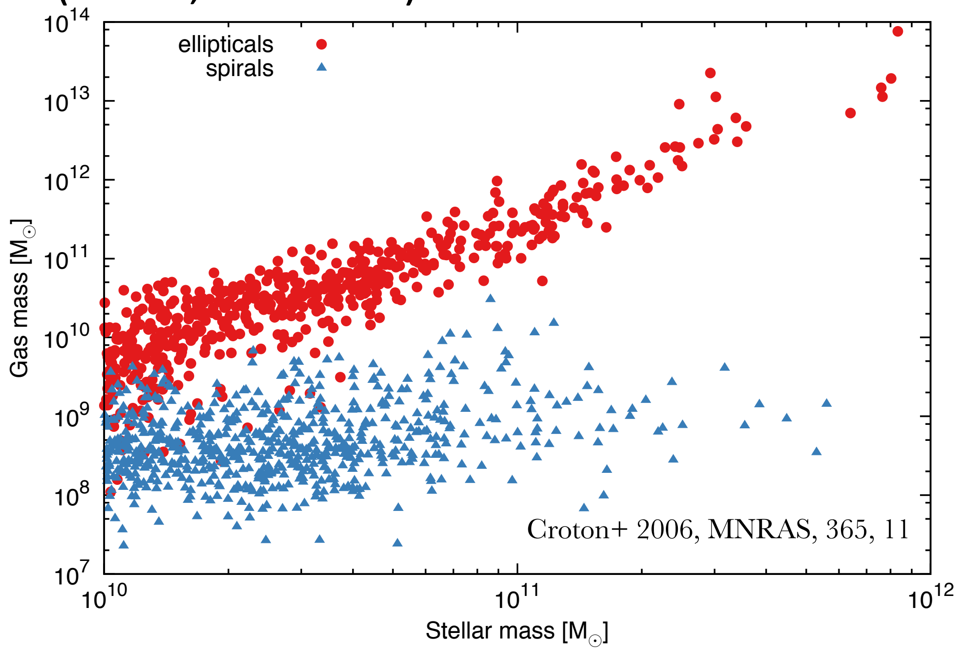
Are sensitive to environment

Gas masses from semi-analytic models

Integration of RG and galaxy formation models (Raouf, SS+ 2018)



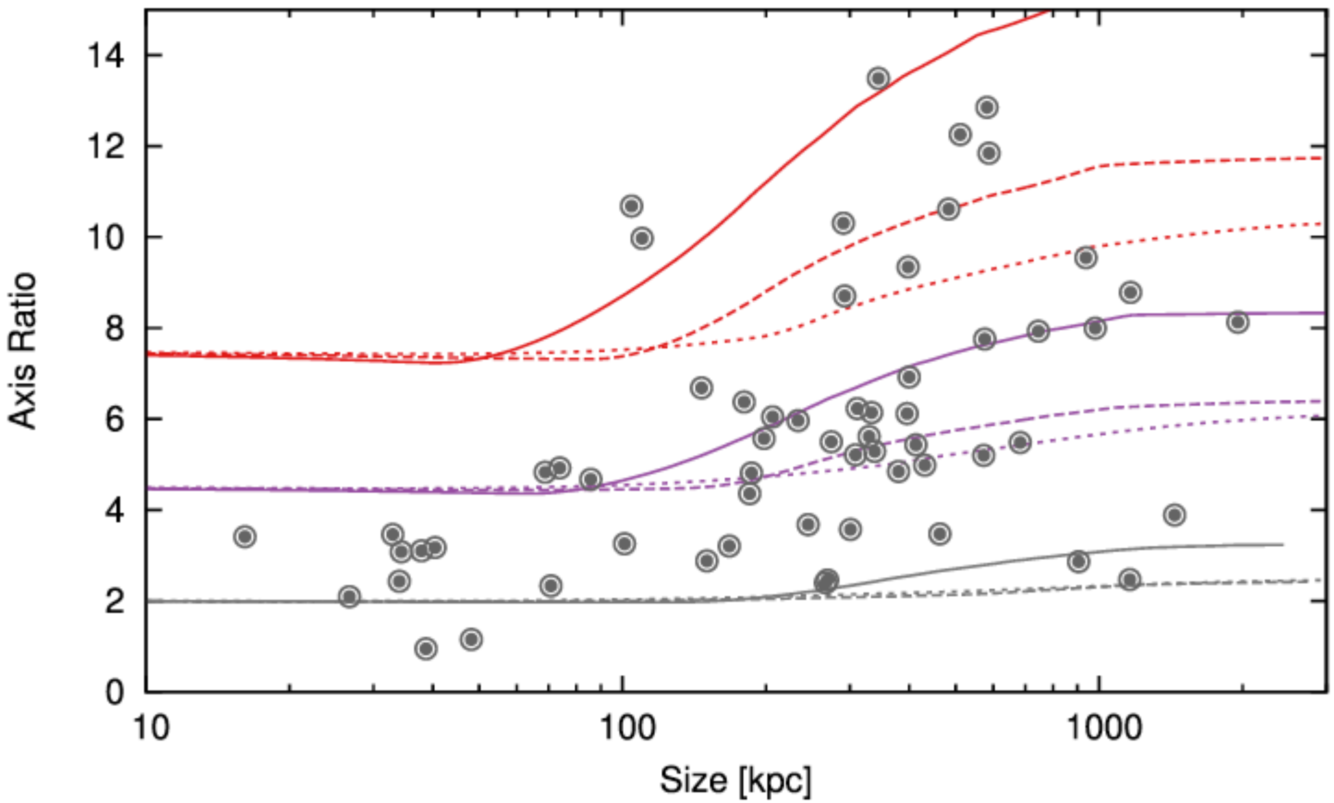
Turner & Shabala 2015, ApJ, 806, 59



RAiSE : Radio Agn in Semi-analytic Environments

Evolution of radio galaxy aspect ratio

- non-power law environments
- cocoon pinching



Turner, SS, Krause 2018, MNRAS, 474, 3361

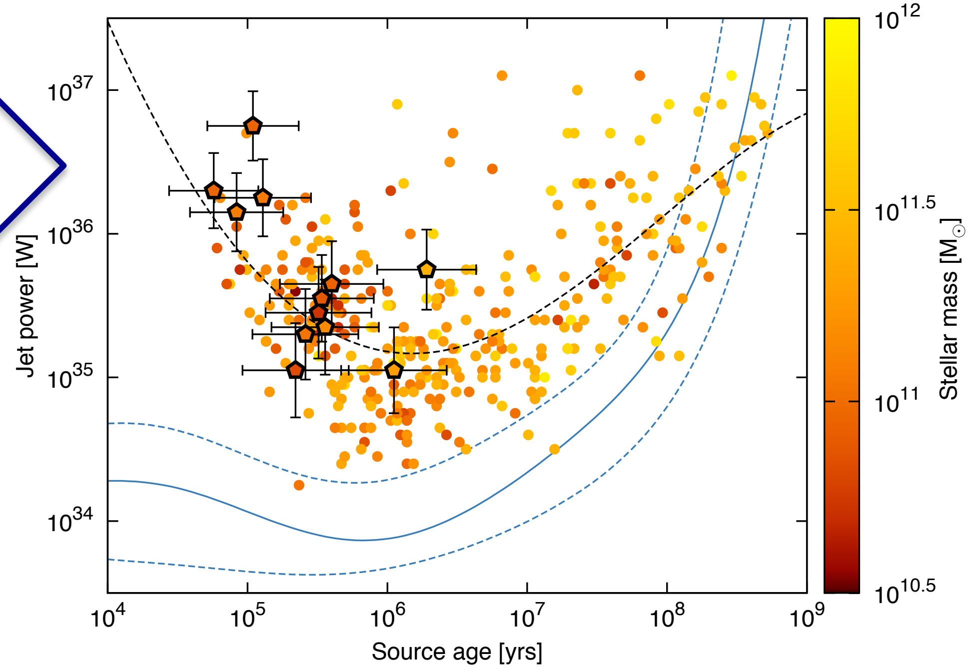
UNIVERSITY of TASMANIA

Dynamical models of radio AGN

Turner & Shabala 2015, ApJ, 806, 59

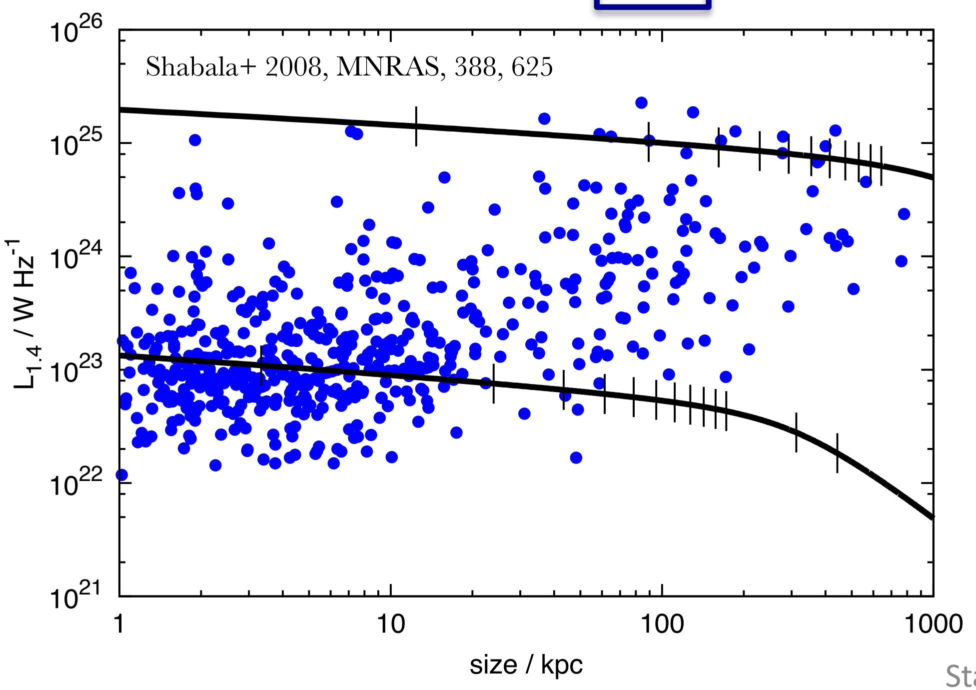
Know

1. AGN luminosities
2. AGN sizes
3. Radio SEDs



Want to know

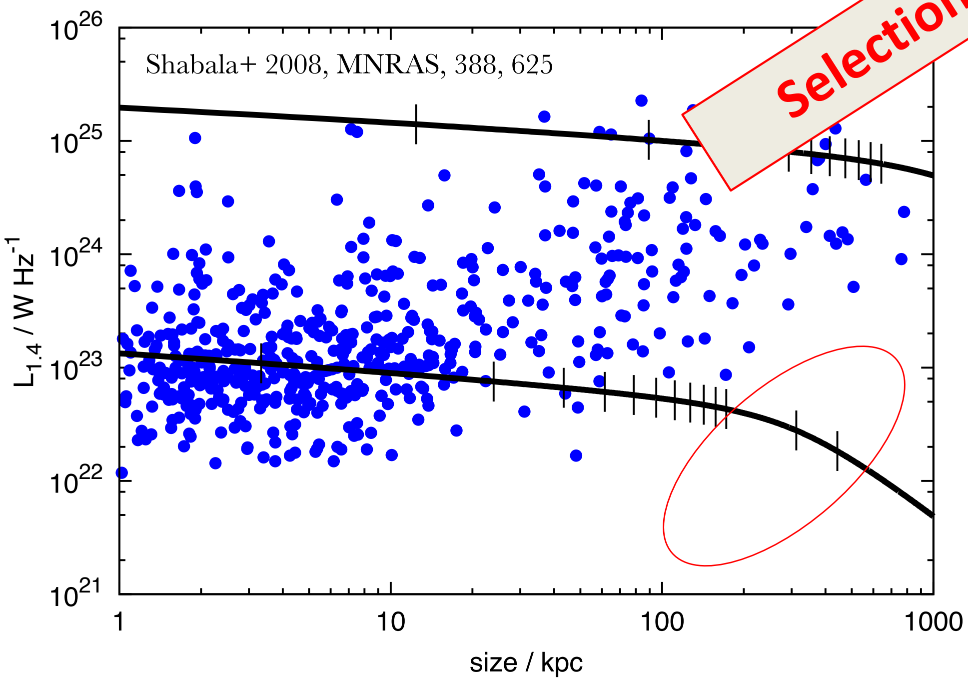
1. How powerful the AGN are
2. How long lived
3. Magnetic field strengths



Selection effects

615 AGN (Shabala+ 2008)

- 0.03 < *z* < 0.1 (volume-limited)
- Stellar masses
- Cocoon sizes
- Radio luminosities



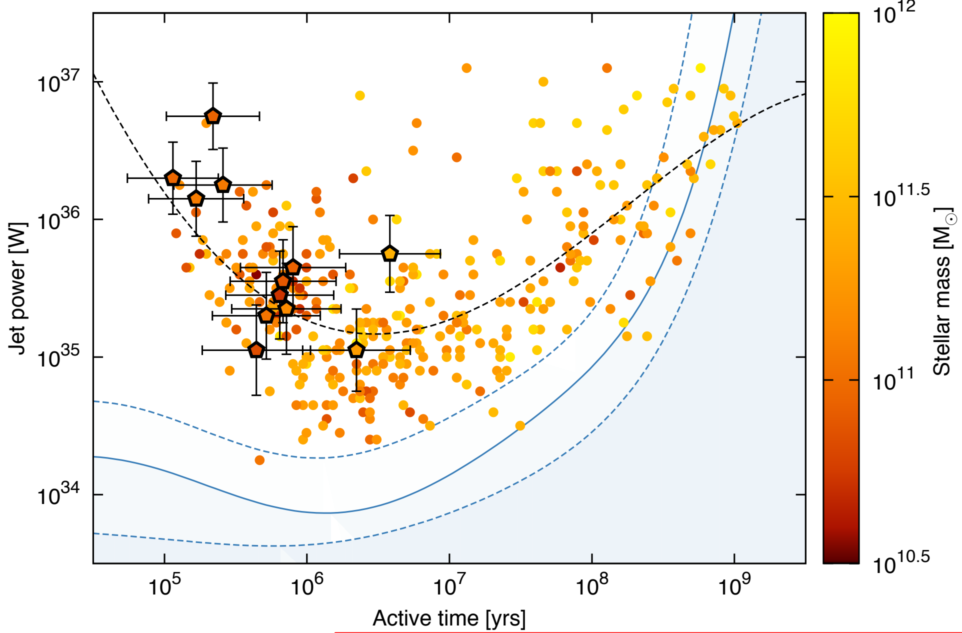
Selection effects

Turner & Shabala 2015, ApJ, 806, 59

Size + Luminosity + Stellar mass

use **semi-analytic models** for gas density

Jet power + age



Low power, old sources have low surface brightness

Marginalization

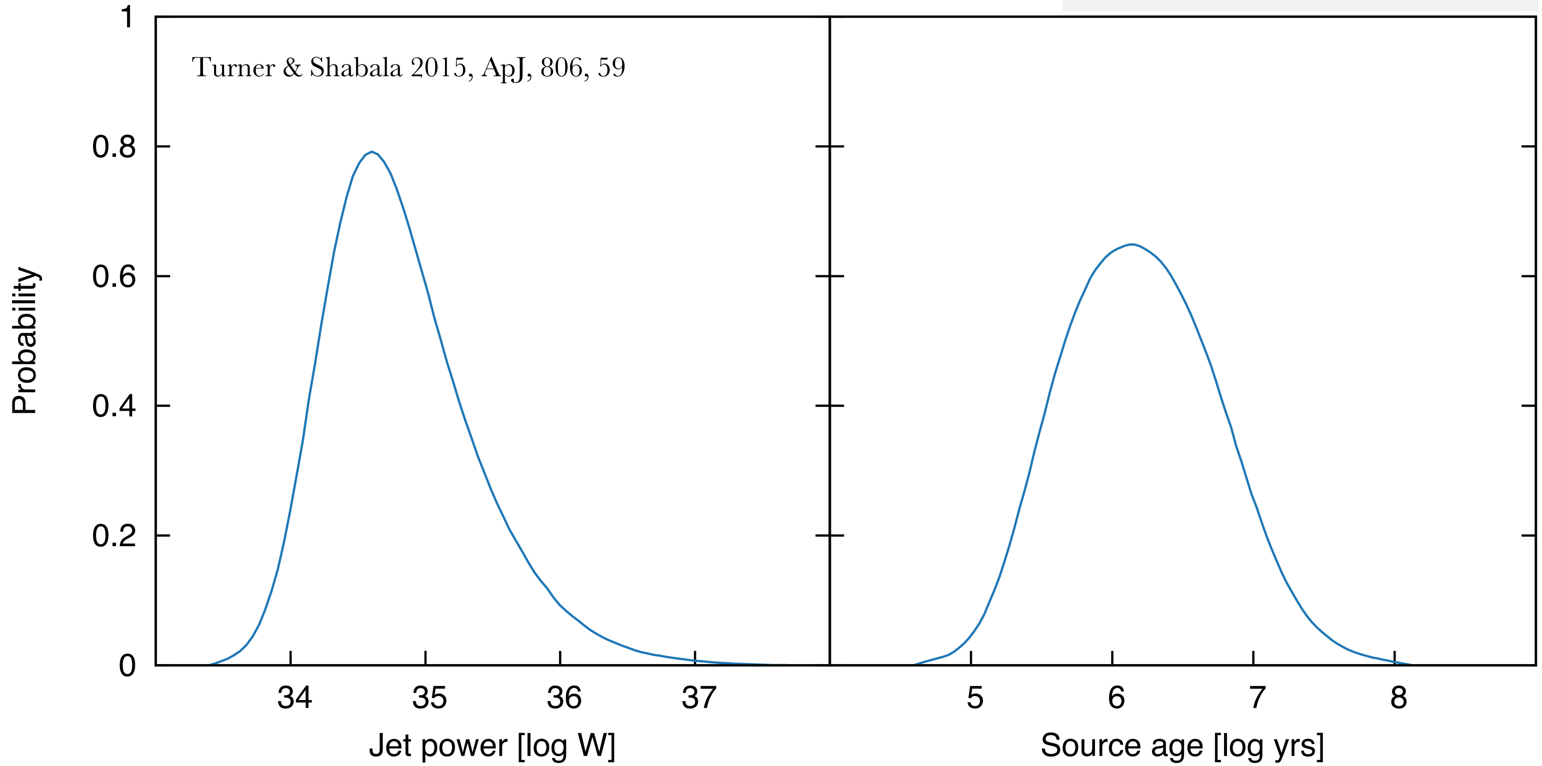
615 AGN (Shabala+ 2008)

- 0.03 < *z* < 0.1 (volume-limited)
- Stellar masses
- Cocoon sizes
- Radio luminosities

Size + Luminosity + Stellar mass

Marginalization over pressure profiles

Jet power + age



UNIVERSITY of TASMANIA

Selection effects

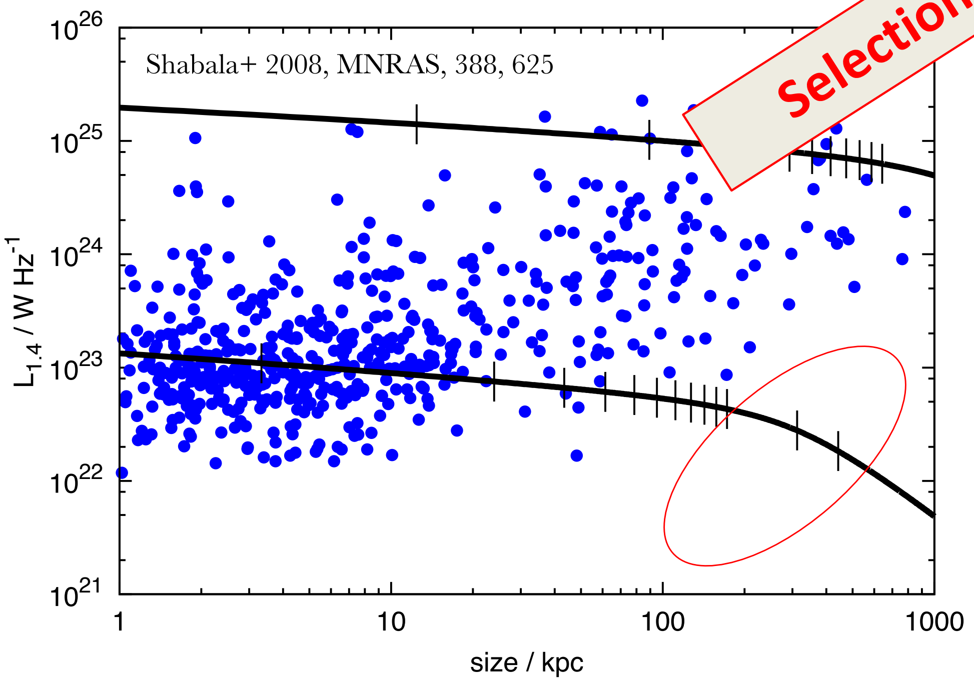
615 AGN (Shabala+ 2008)

- 0.03 < *z* < 0.1 (volume-limited)
- Stellar masses
- Cocoon sizes
- Radio luminosities

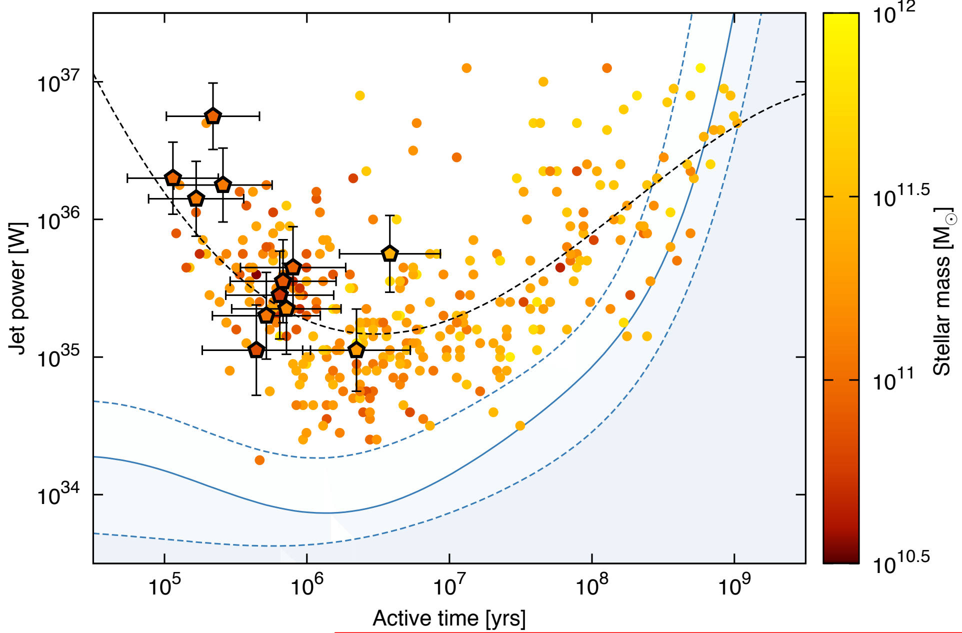
Size + Luminosity + Stellar mass

use semi-analytic models for gas density

Jet power + age



Selection effects



Turner & Shabala 2015, ApJ, 806, 59

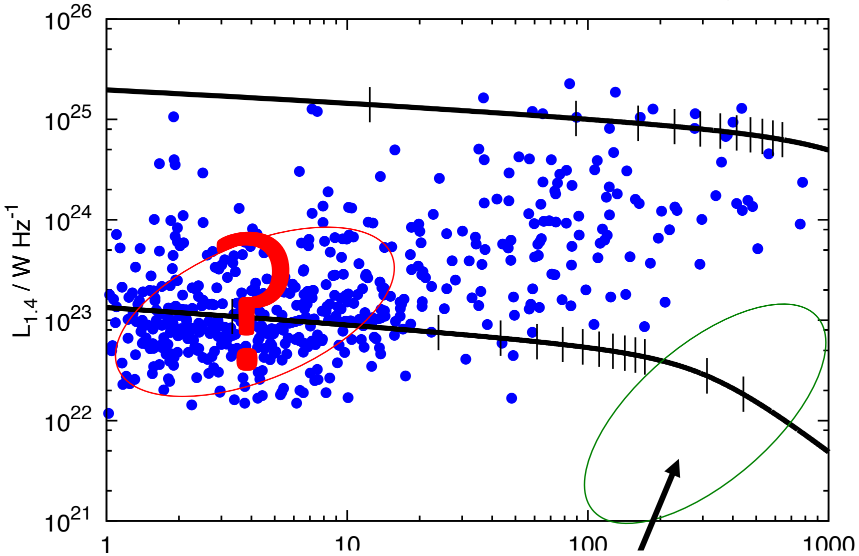
Low power, old sources have low surface brightness

UNIVERSITY of TASMANIA

Selection effects

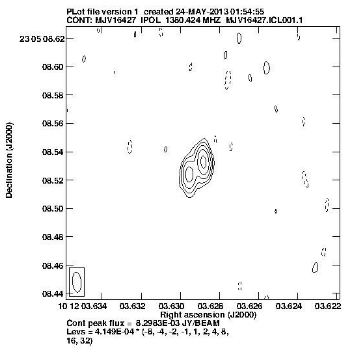
- Quantifying selection effects
  - Big and faint: old sources
  - Small and faint: young, frustrated or **undetectable** ?
- Shabala+12: radio AGN in isolated galaxies appear compact in FIRST / NVSS
  - VLBI follow-up shows pc-scale jets
  - Consistent with **"invisible" large-scale lobes in poor environments**

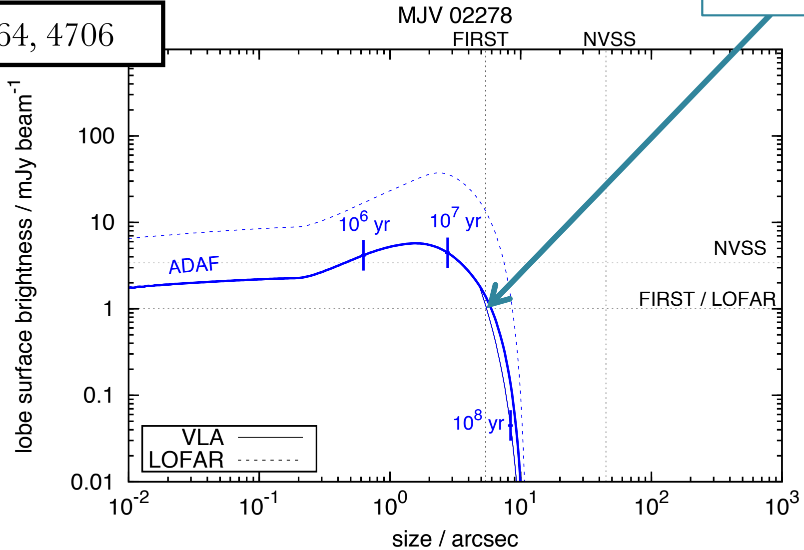
Shabala+ 2008

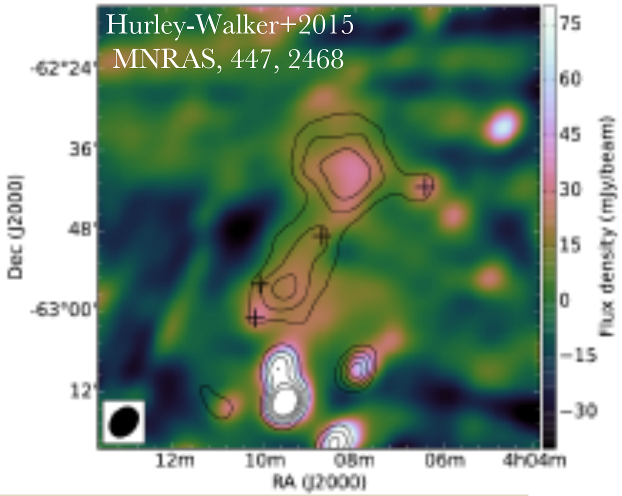


undetectable after this point

Shabala+17, MNRAS, 464, 4706

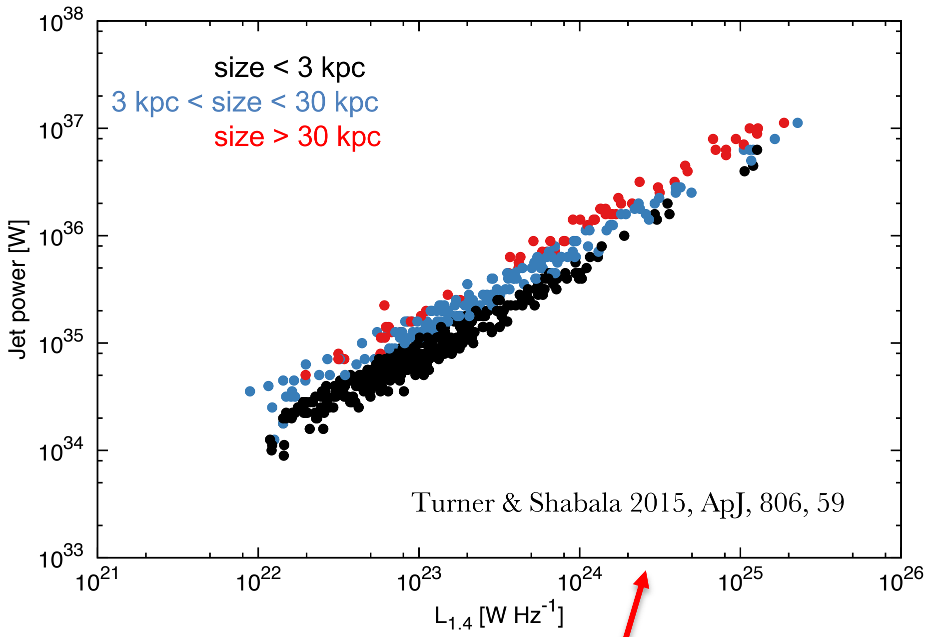


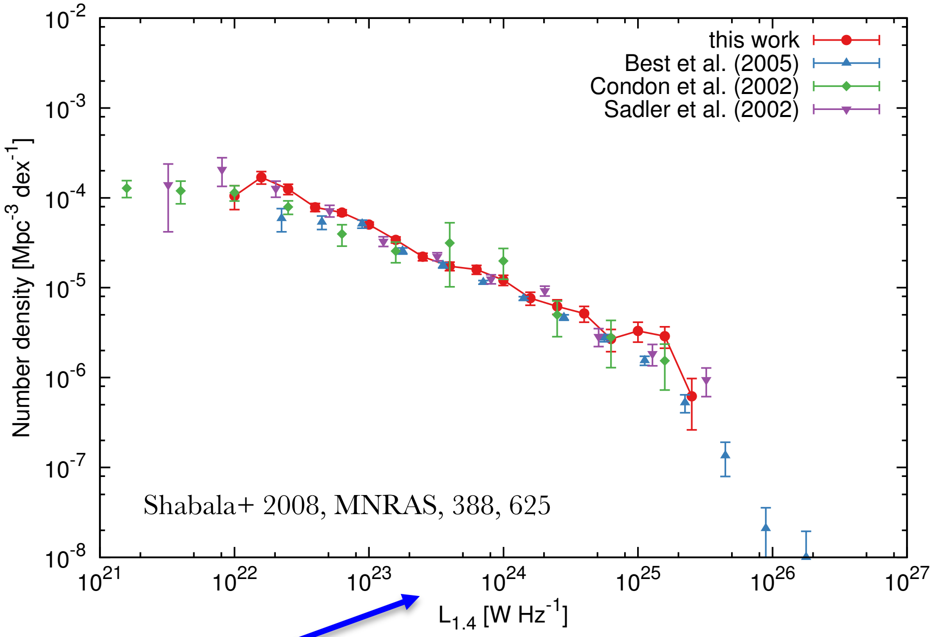




Expect many more with LOFAR / MWA / SKA-low

Where is the feedback energy?





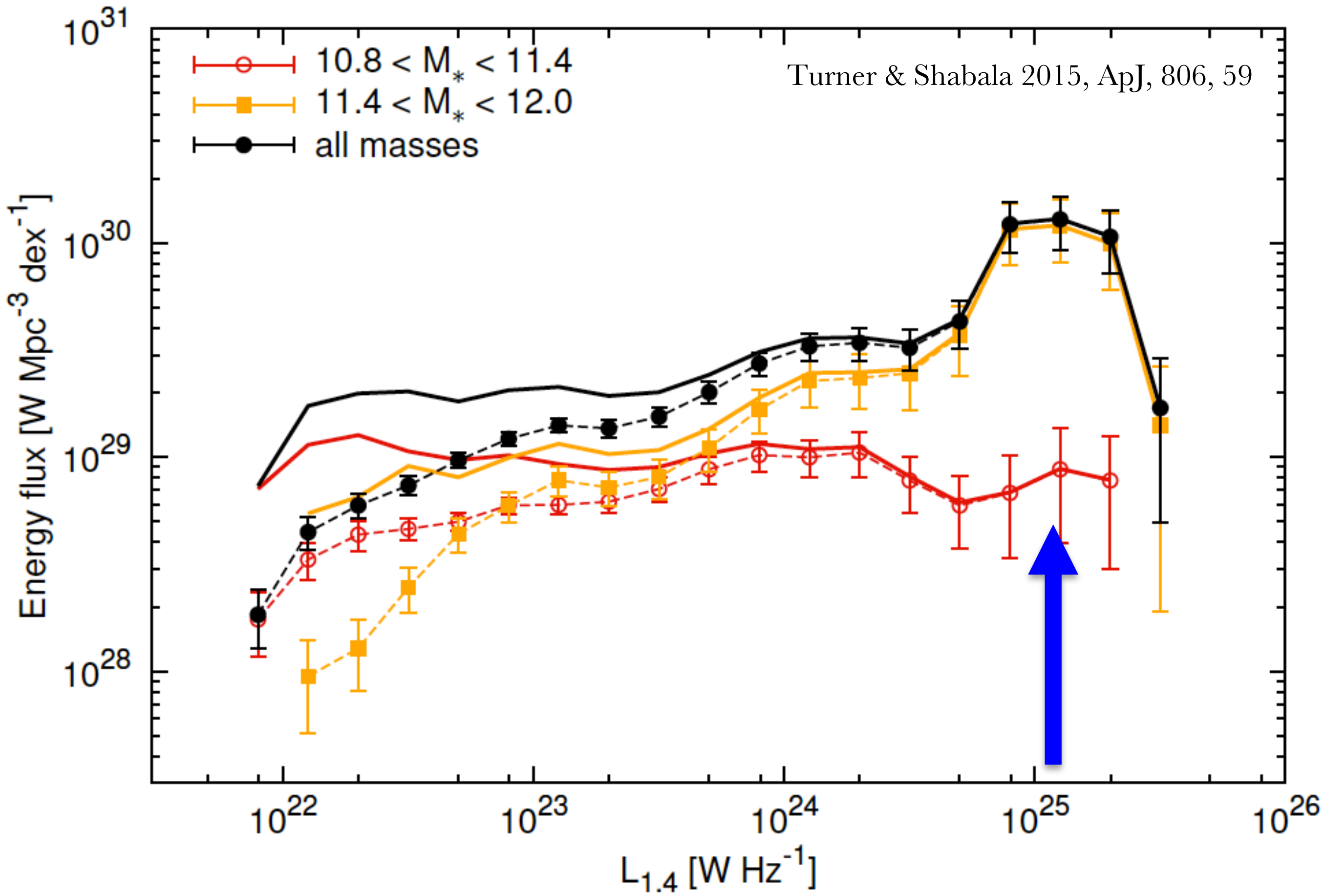
Bright sources have **higher** jet powers…

… but are more **rare**

➔ which sources dominate feedback energetics?

Convolve Q_{jet} – L_{radio} relation with RLF

Where is the feedback energy?



Powerful sources can do **more feedback**, despite being rare

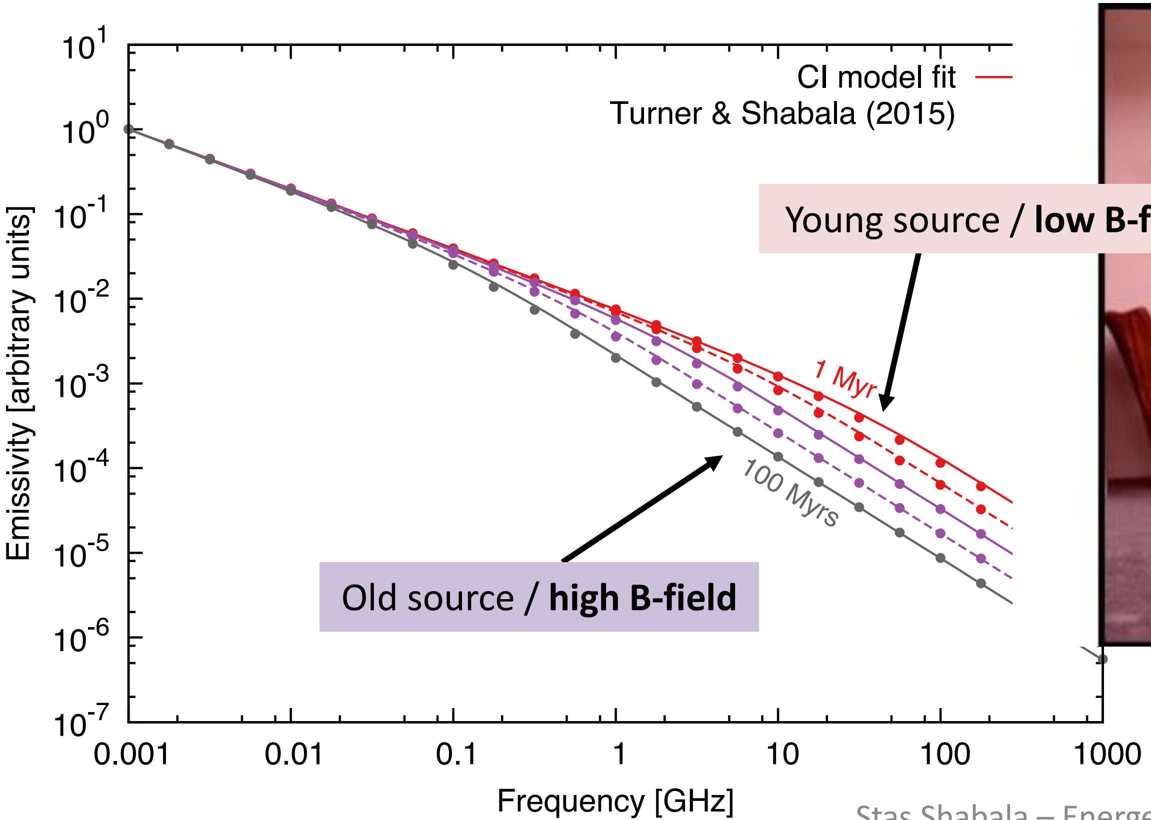
Using radio SEDs

✧ Use full radio SED

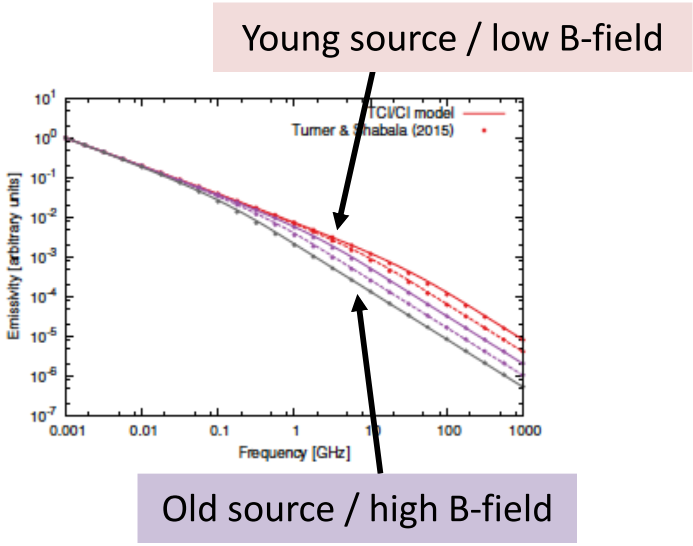
- So far only used size + monochromatic luminosity

➔ Equipartition assumption

Turner, SS, Krause 2018, MNRAS, 474, 3361



Using radio SEDs



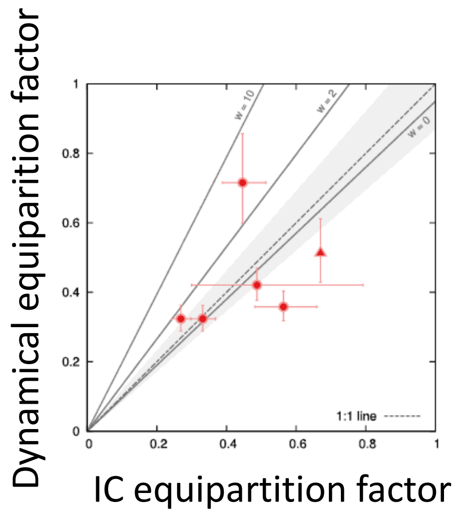
Turner, SS, Krause 2018, MNRAS, 474, 3361

- ✧ Use full radio SED
  - So far only used size + monochromatic luminosity
  - ➔ Equipartition assumption
  - Questionable from observations (e.g. Croston+ 05)
  - Dynamical vs spectral age discrepancy

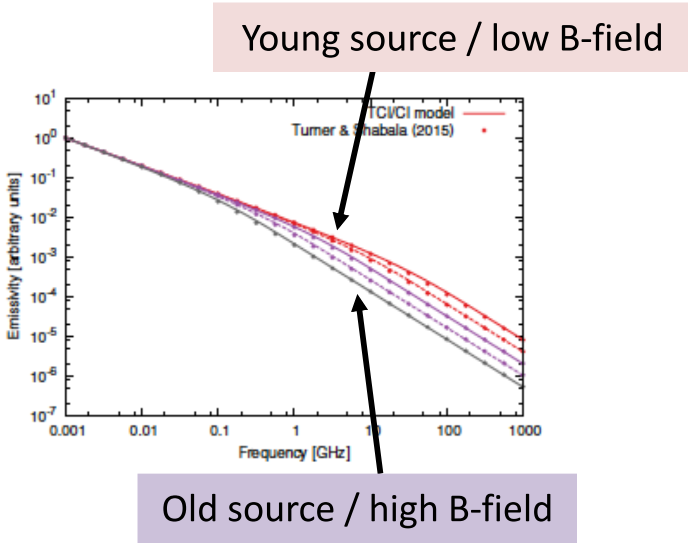
- ✧ Radio SED
  + Dynamical model
  + semi-analytic environment

Bayesian inversion →

Jet power
AGN age
B-field



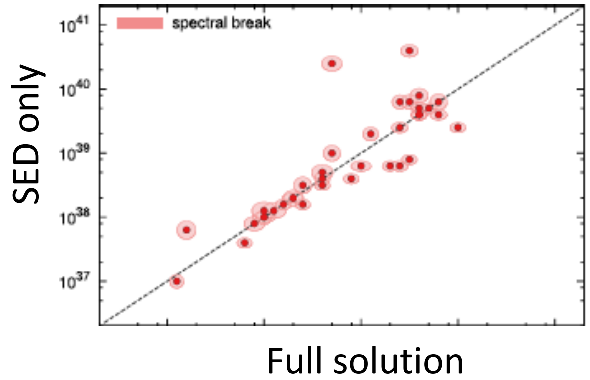
Using radio SEDs



- ✧ Use full radio SED
  - So far only used size + monochromatic luminosity
  - ➔ Equipartition assumption
  - Questionable from observations (e.g. Croston+ 05)
  - Dynamical vs spectral age discrepancy

Turner, SS, Krause 2018, MNRAS, 474, 3361

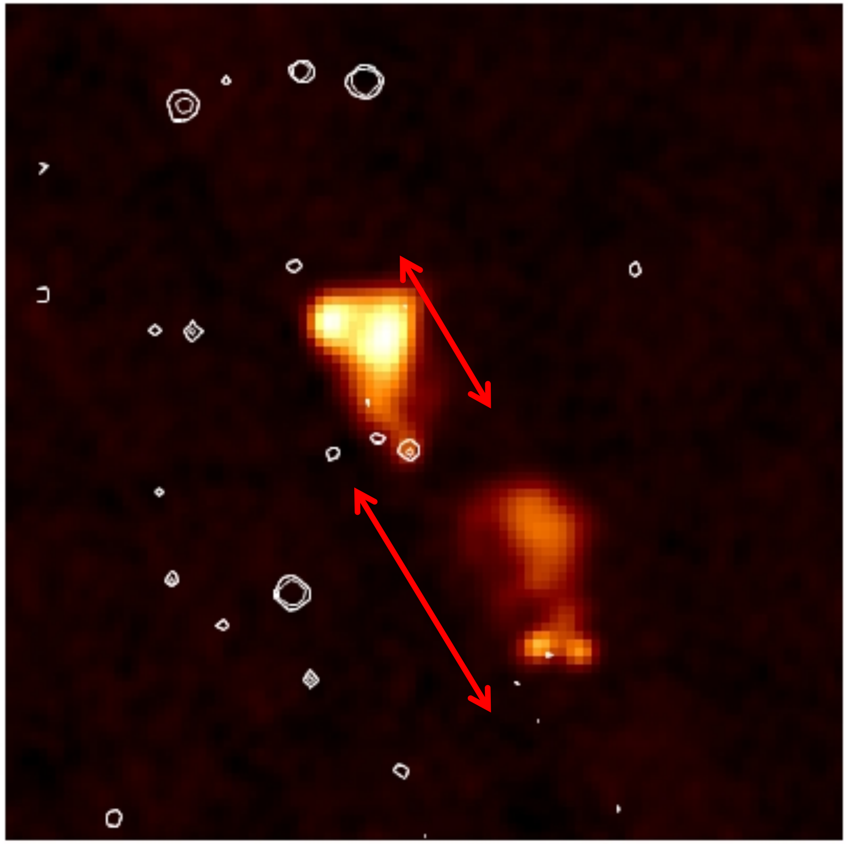
- ✧ Radio SED + Dynamical model + semi-analytic environment —Bayesian inversion→ Jet power, AGN age, B-field



- ✧ Extracting data from limited observations
  - radio SEDs alone (e.g. unresolved sources) can still determine jet power

UNIVERSITY of TASMANIA

Quantifying environment



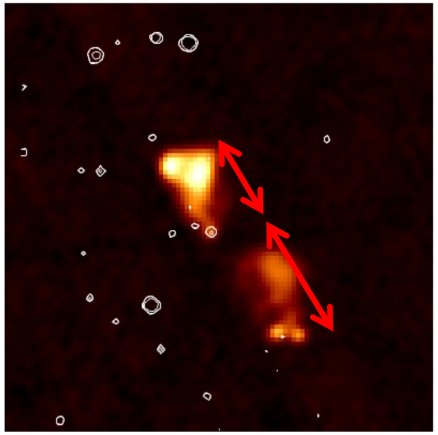
GALAXY ZOO RADIO

Radio Galaxy Zoo project:
Environments of asymmetric radio sources
(*Payton Rodman, UTAS undergrad*)

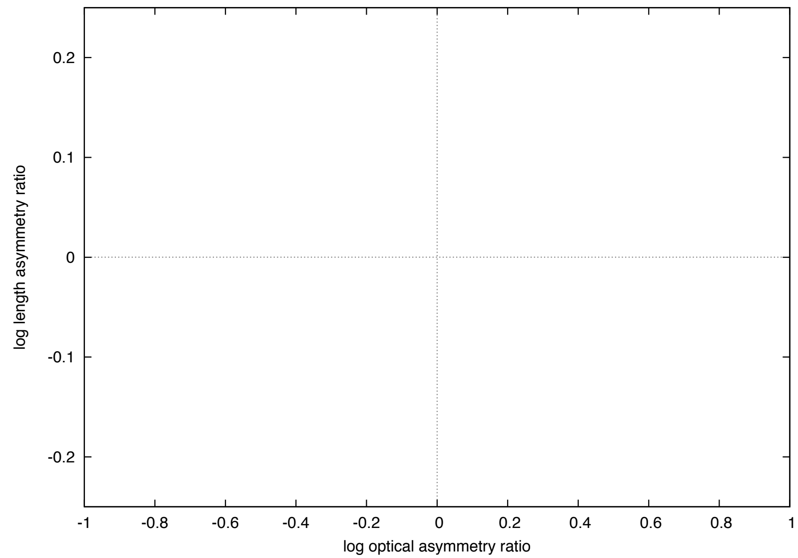
- Radio asymmetry (length, luminosity) vs galaxy clustering

UNIVERSITY of TASMANIA

We should all care about the environment…



Galaxy luminosity function to 1 Mpc



Length of lobe

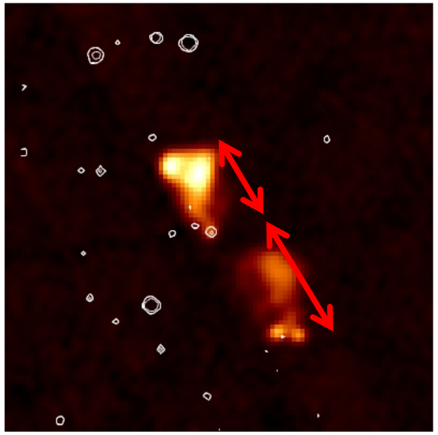
Rodman+ in prep.

Start with 2679 2/3 component sources

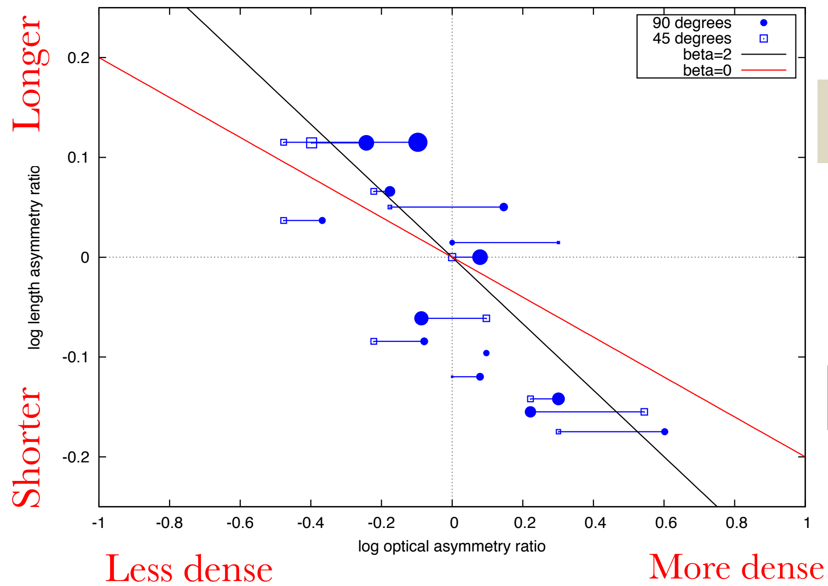
- z<0.3
- Straight
- At least one lobe > 100 kpc
- >10 SDSS galaxies

→ **16 FR-IIs**

We should all care about the environment…



Galaxy luminosity function to 1 Mpc



length $\propto \rho^{1/(5-\beta)}$

for density profile $\rho \propto r^{-\beta}$

Rodman+ in prep.

Length of lobe

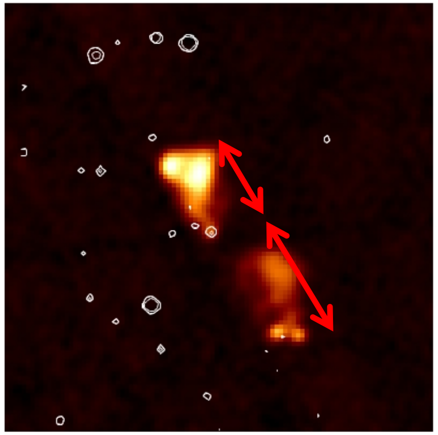
- Shorter lobes typically associated with greater galaxy clustering
- Consistent with models

Scatter due to:

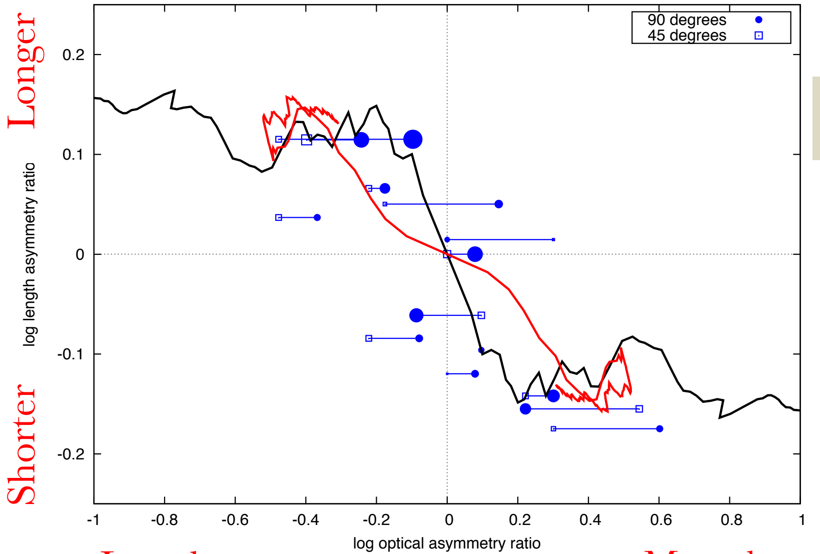
- Clustering – gas density mapping
- Different environments

UNIVERSITY of TASMANIA

We should all care about the environment…



Galaxy luminosity function to 1 Mpc



length $\propto \rho^{1/(5-\beta)}$

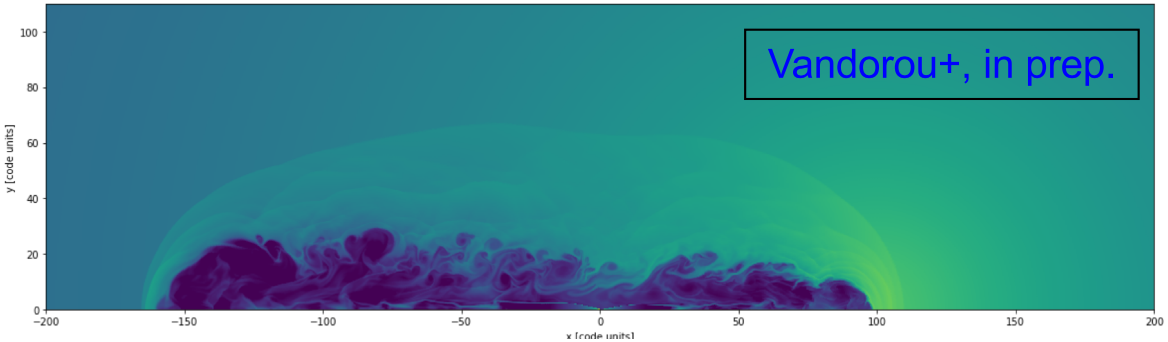
for density profile $\rho \propto r^{-\beta}$

Length of lobe

Less dense

More dense

Consistent with numerical simulations !



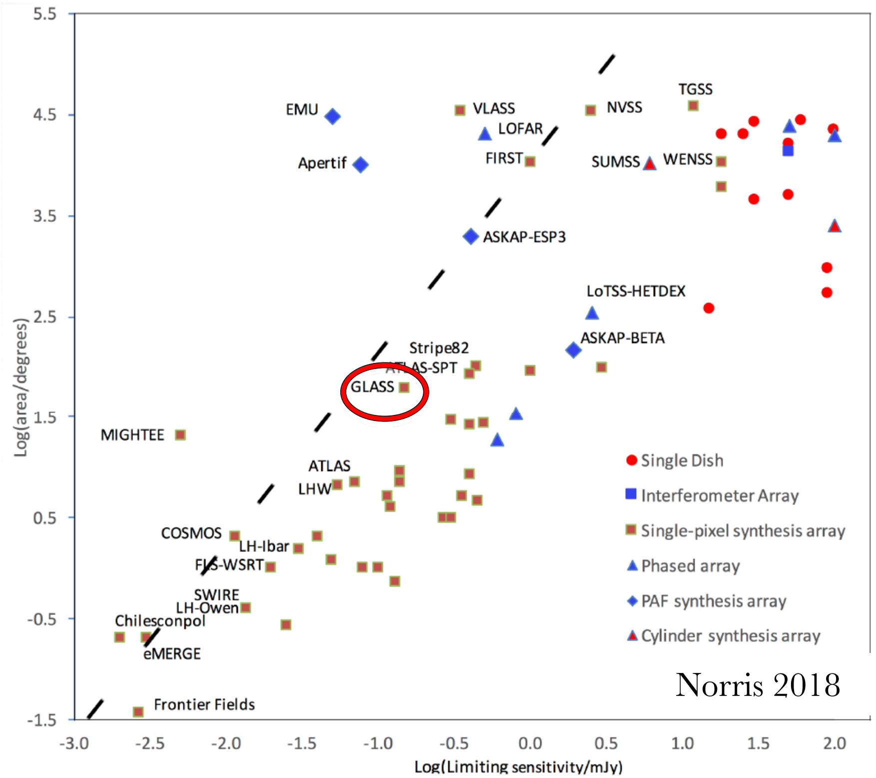
(*Katie Vandorou, UTAS Honours*)

2D hydro sims of jets in asymmetric environments

- One jet towards, one away from cluster centre
- Consistent with data
- Jet – gas asymmetry scaling **depends on position in cluster**

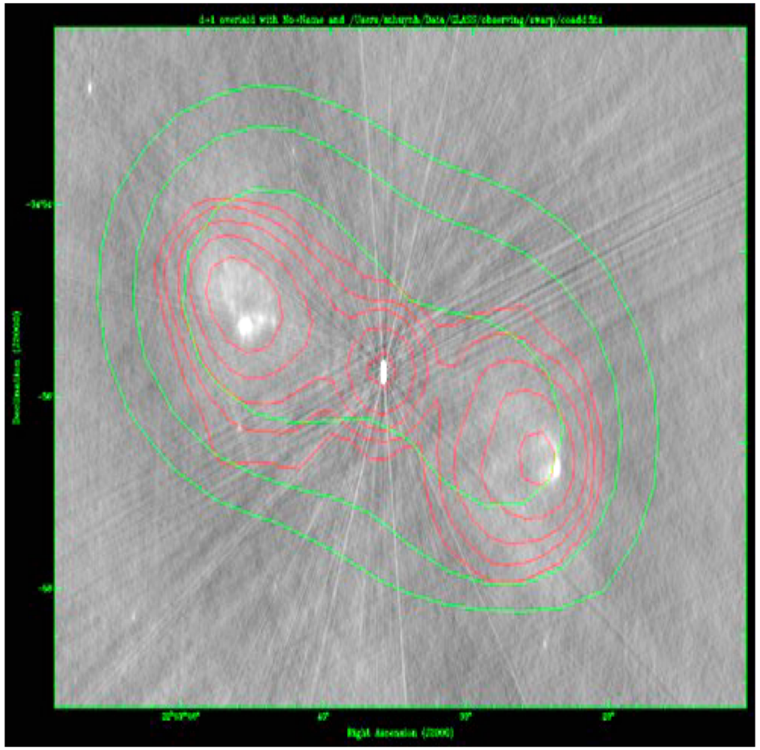
UNIVERSITY of TASMANIA

GAMA Legacy ATCA Sky Survey (GLASS – PI: Minh Huynh)



5.5 – 9.5 GHz @ ATCA

30 μJy rms



GLASS 5.5 GHz

GLEAM MWA 139 – 170 MHz

NVSS 1.4 GHz

UNIVERSITY of TASMANIA

GAMA Legacy ATCA Sky Survey (GLASS – PI: Minh Huynh)

60 sq deg GAMA G23 field

5.5 – 9.5 GHz @ ATCA

30 μJy rms

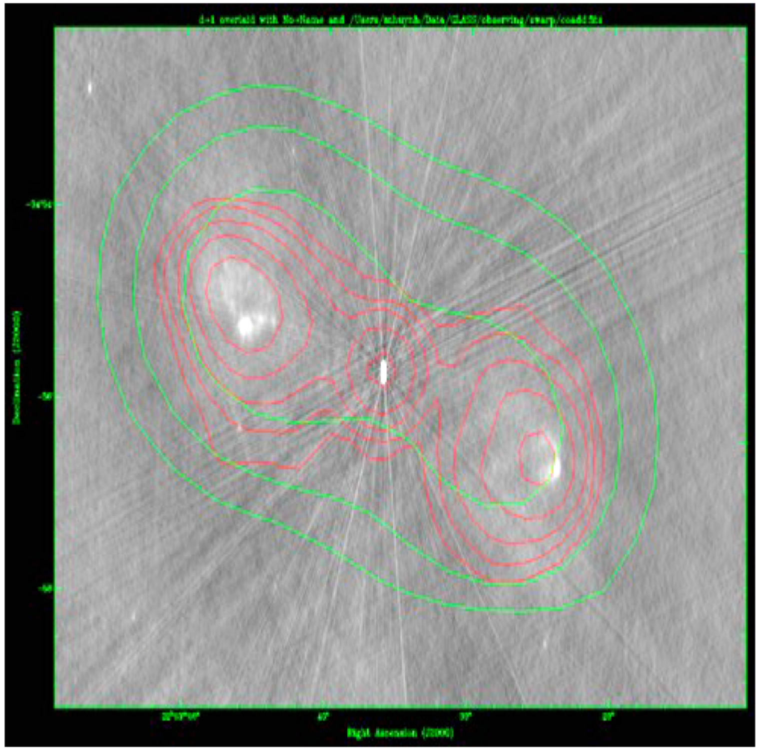
MWA, GMRT, ASKAP EMU

@ 140 MHz – 1.4 GHz

Environments: Galaxy clustering from

GAMA group catalogues

Future: ASKAP EMU + Taipan



GLASS 5.5 GHz

GLEAM MWA 139 – 170 MHz

NVSS 1.4 GHz

UNIVERSITY of TASMANIA

Summary

- Dynamical radio source models can extract jet energetics and lifetimes from continuum survey data

- Environment dependence
  - Size-luminosity tracks
  - Low-surface brightness lobes

Shabala et al. 2017, MNRAS, 464, 4706

- RAiSE: semi-analytic galaxy formation models used to quantify jet environments
  - Departure from self-similar evolution
  - In good agreement with observations
  - Jet powers and lifetimes of low-z radio AGN

Turner & Shabala 2015, ApJ, 806, 59

Turner+ 2018, MNRAS, 473, 4179

- Parameters estimation is possible from limited data
  - Jet power from radio continuum SEDs alone
  - Jet age from source size

Turner, SS, Krause 2018, MNRAS, 474, 3361

- Galaxy clustering is a useful measure of environment
  - Radio Galaxy Zoo and GLASS ATCA Legacy Survey