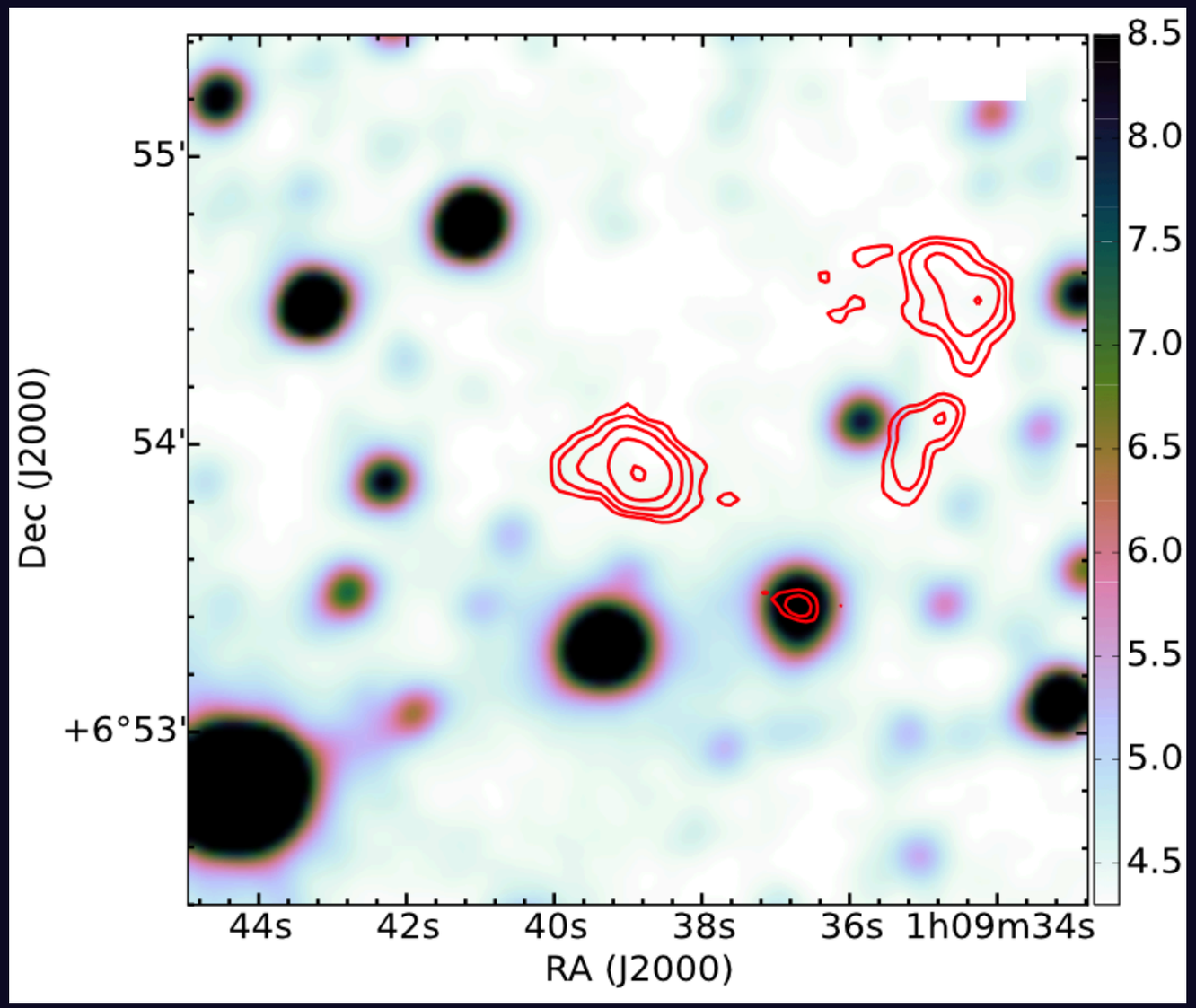
Radio Galaxy Zoo

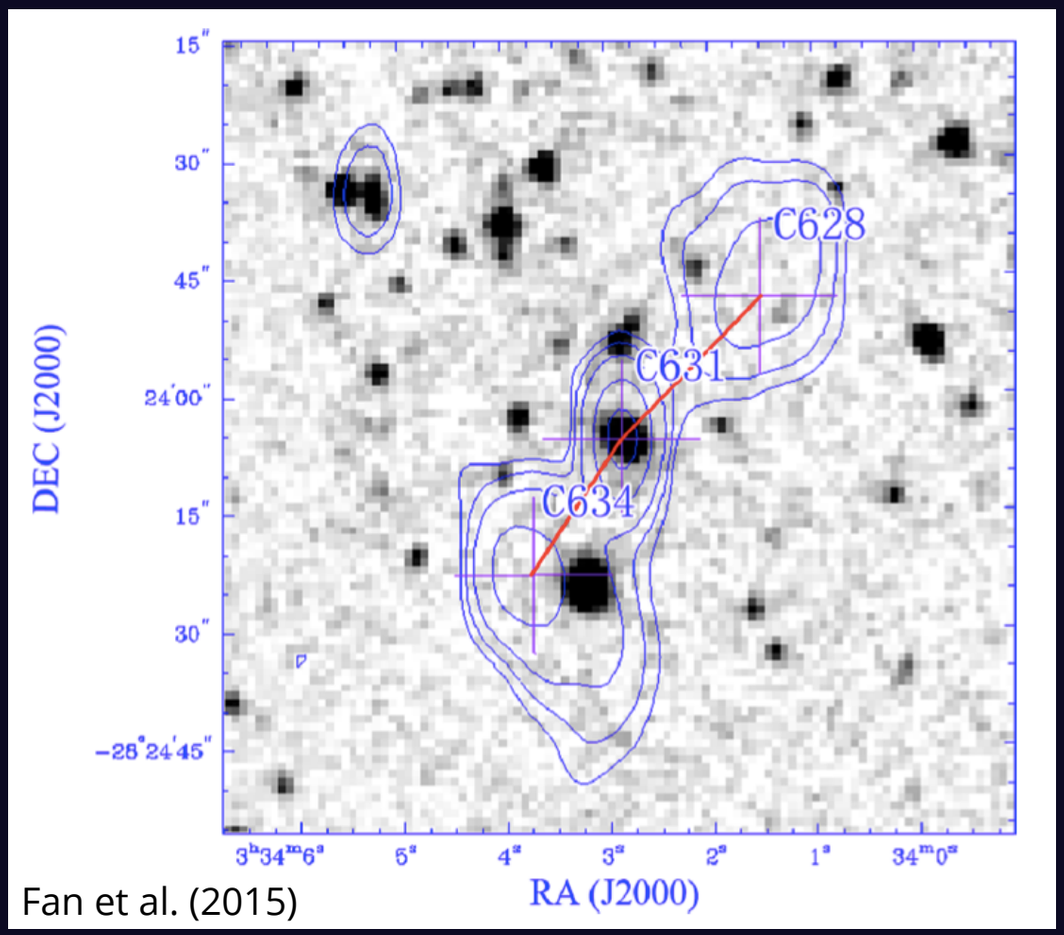
Kyle Willett
University of Minnesota
@kwwillett

Identification of the host galaxy for radio sources is critical



Banfield et al. (2015)

Automated routines



Fan et al. (2015)

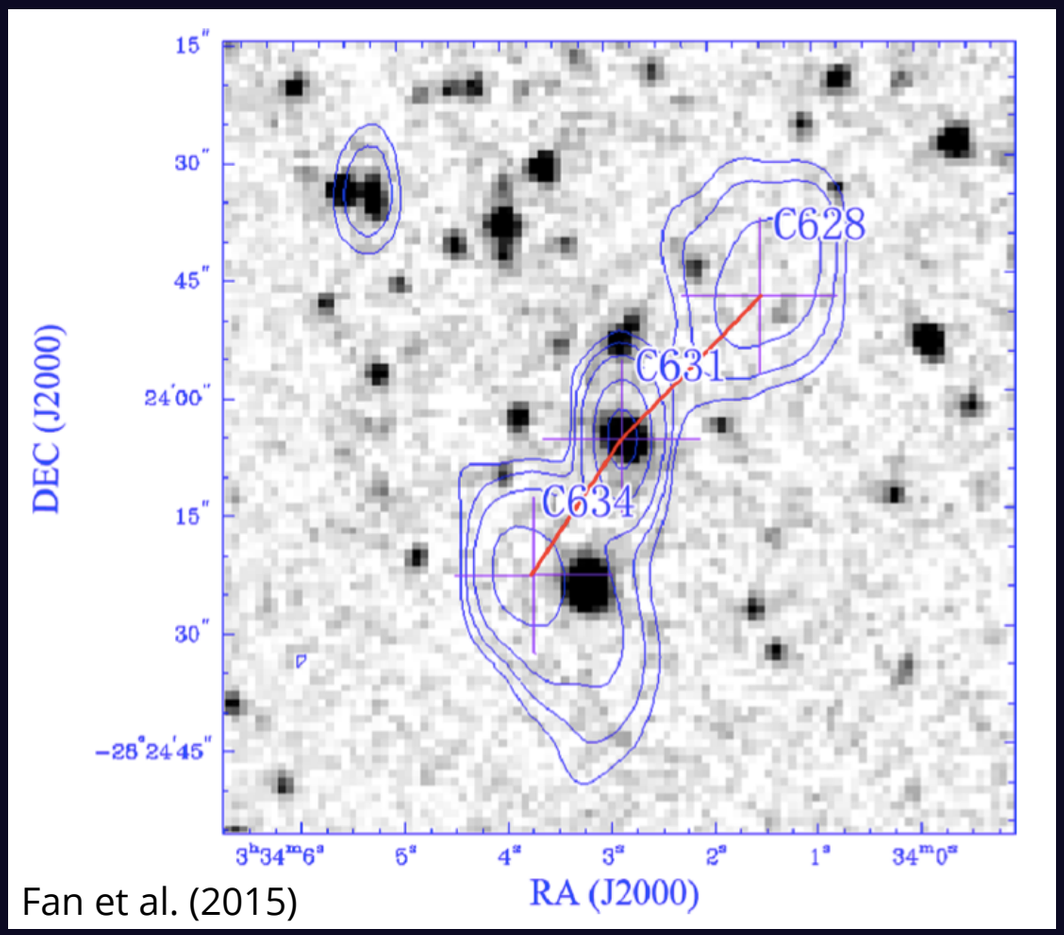
Bayesian hypothesis testing

Model $$\mathbf{m}'' = 2\mathbf{m} - \mathbf{m}'$$

Likelihood $$\mathcal{L}_{cll} = \left[\int \mathrm{d}\mathbf{m}\; p(\mathbf{m}) L_c(\mathbf{m}) L_{r_0}(\mathbf{m}) \int d\mathbf{m}' p(\mathbf{m}'|\mathbf{m}) L_{r_1}(\mathbf{m}') L_{r_2}(2\mathbf{m} - \mathbf{m}')\right]$$

Evaluate $$B_{1,2} = \frac{\mathcal{L}_1}{\mathcal{L}_2}$$

Automated routines



Fan et al. (2015)

success!

Bayesian hypothesis testing

Model $$\mathbf{m}'' = 2\mathbf{m} - \mathbf{m}'$$

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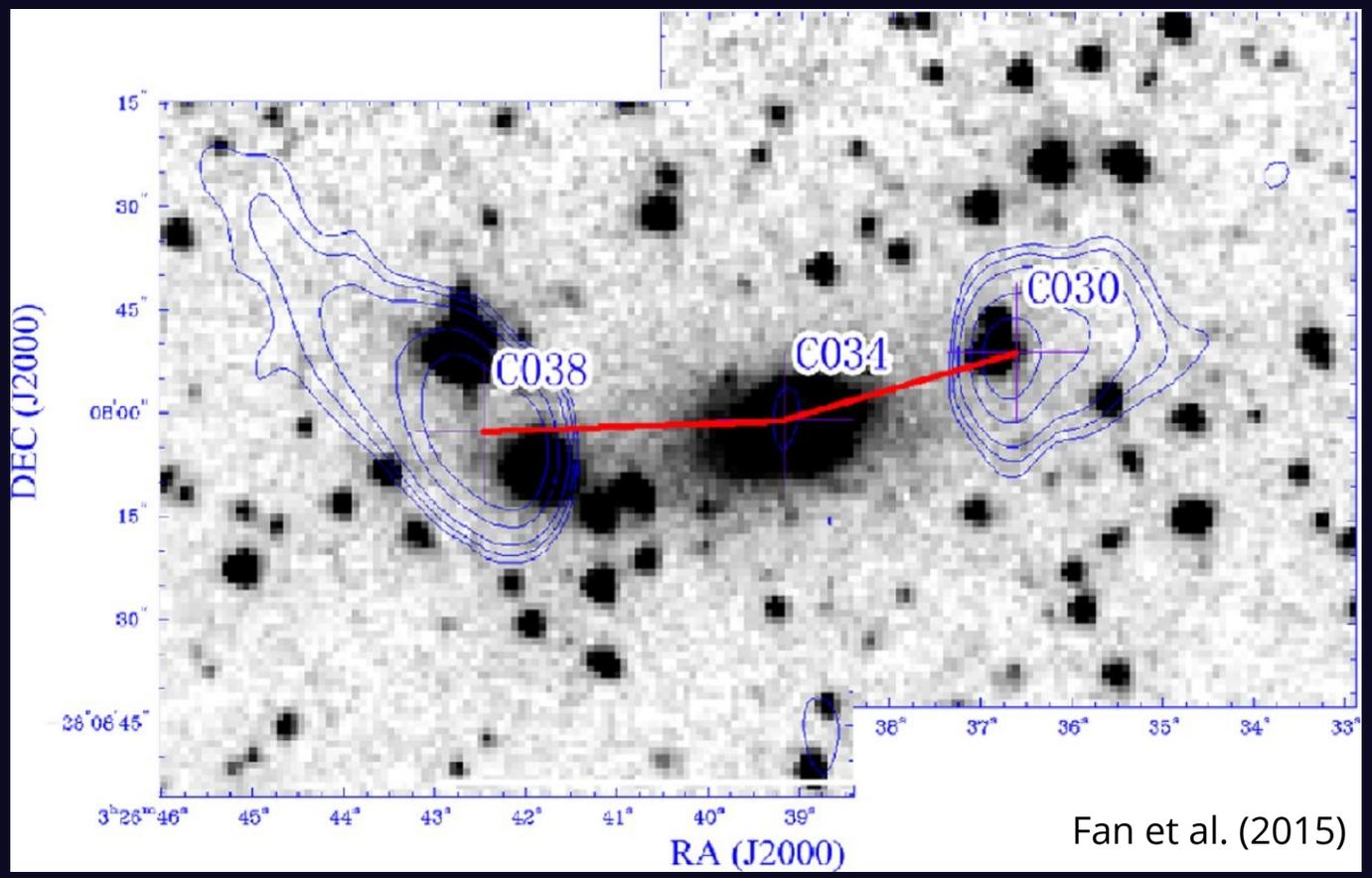
Evaluate $$B_{1,2} = \frac{\mathcal{L}_1}{\mathcal{L}_2}$$

Automated routines



Fan et al. (2015)

$$\mathrm{m}'' = 2\mathrm{m} - \mathrm{m}' + k(\mathrm{m} - \mathrm{m}')$$

$$\mathcal{L}_{cll} = \left[\int \mathrm{dm}\; p(\mathbf{m}) L_c(\mathbf{m}) L_{r_0}(\mathbf{m})\right] \times$$

$$\left[\int d\mathbf{m}' p(\mathbf{m}'|\mathbf{m}) L_{r_1}(\mathbf{m}') L_{r_2}(2\mathbf{m} - \mathbf{m}' + k(\mathbf{m} - \mathbf{m}')\right]$$

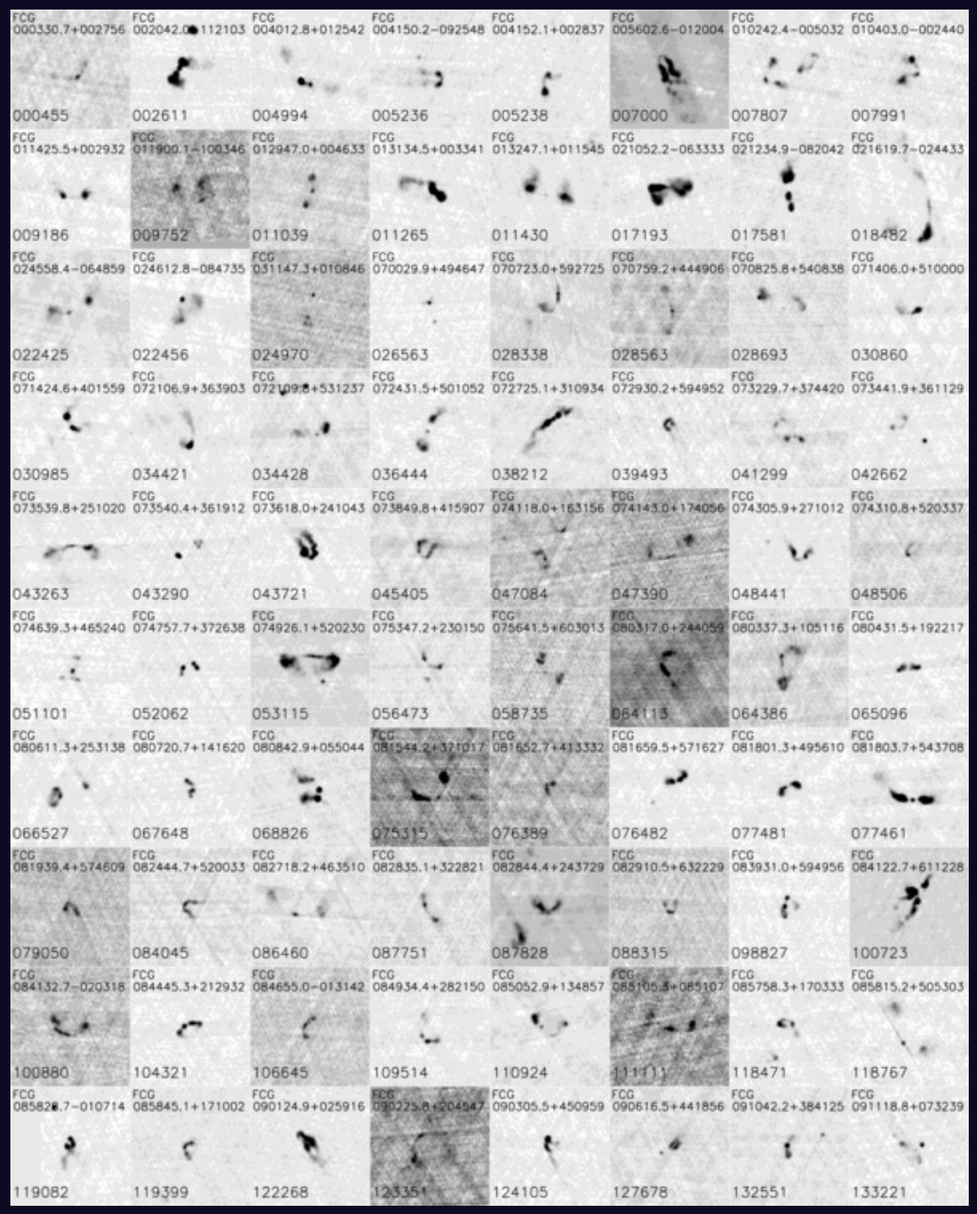
failure

Expert visual classification

Table A.1
Keys for Group Classifications, Comments, and Source Designations

Code	Classification/Comment/Designation
Group visual morphological classifications	
a	Ambiguous
b	Bent (B), little visual indication of core
bs	Bent slightly
cj	Core-jet
d	Double lobe radio galaxy—may include core-jet sources
dd	Double–double radio galaxy (DD)
irr	Irregular, distorted
lobe	Lobe, resolved lobe
mg	Multiple groupings possible
nat	Narrow-angle tail (NAT)
quad	Group of four approximately point-like sources (QUAD)
quint	Group of five approximately point-like sources (QUINT)
rc	Resolved compact source, non-point-like
ring	Ring
ring-lobe	Edge-brightened lobe or embedded ring
s	Single source (often with sidelobes) or probable chance projection of point-like source into group
sl	Sidelobe
sz	S-shaped or Z-shaped
t	Triple, no bend, little extended structure
tb	Bent triple (TB), little indication of extended structure
tbs	Slightly bent triple
td	Triple double
tri	120 deg. rotational symmetry—may include chance projections
unu	Unusual, uncommon—may be due to chance projection
w	W-shape, wiggles
wat	Wide-angle tail (WAT)
x	X-shape
Additional comments	
arc	Arc or C, possible edge-brightened lobe, bent jets, or ring fragment
asym	Asymmetric
bifurcation	A same side splitting of jet from apparent core
butterfly	Four lobe morphology
cat	Catalog
cp	Chance projection
diag	Diagonal
distorted	Smearing of prototypical morphologies with low-level emission
dl	Dogleg, generally an abrupt change in direction
pinwheel	Spiral type similar to optical star forming regions of spiral galaxies
fan	Low-level triangular shape lobe
hook	Hook, an apparent approximately 180 change in direction of jet
hymor	Hybrid FRI–FRII morphology—a few HYMOR candidates were specifically annotated
id	Identification
int	Interesting
jet	Jet or occasionally protrusion from lobe
low level	Extended low-level flux, diffuse, and/or filamentary
ppd	Perpendicular
ss	Apparent single-sided jet and/or lobe
Individual source classifications:	
A	Ambiguous
CJC	Core-jet core component
CJJ	Core-jet jet component
CORE	Core component
J	Jet
LOBE	Lobe
RC	Resolved core
RJ	Resolved jet
RING	Ring component
RL	Component of resolved lobe
S	Single source, no structure apparent, likely chance projection into group or single bright point-like source, other group members being sidelobes
SL	Sidelobe
SZJ	Jet component of S-shape or Z-shape
SZC	Core component of S-shape or Z-shape
X	Transverse component of X group

Proctor (2011)



Dozens of potential categories

~7,000 sources

Radio Galaxy Zoo

- Goal: identify multi-component radio sources and cross-match to host galaxy
- Data:
  - Radio: *FIRST* and *ATLAS*
  - Infrared: *WISE* and *SWIRE*
- Since launch in Dec 2013:
  - > 8,000 individual participants
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ZOONIVERSE

Australian National University

CSIRO

UNIVERSITY of TASMANIA

THE UNIVERSITY OF WESTERN AUSTRALIA

In Search of Erupting Black Holes

Help astronomers discover supermassive black holes observed by the KG Jansky Very Large Array (NRAO) and the Australia Telescope Compact Array (CSIRO)

Search for Black Holes

Black holes are found at the center of most, if not all, galaxies. The bigger the galaxy, the bigger the black hole and the more sensational the effect it can have on the host galaxy. These supermassive black holes drag in nearby material, growing to billions of times the mass of our sun and occasionally producing spectacular jets of material traveling nearly as fast as the speed of light. These jets often can't be detected in visible light, but are seen using radio telescopes. Astronomers need your help to find these jets and match them to the galaxy that hosts them.

Begin Hunting

NASA, ESA, S. Baum and C. O'Dea (RIT), R. Perley and W. Cotton (NRAO/AUI/NSF), and the Hubble Heritage Team (STScI/AURA)

Why do astronomers need your help?

What do astronomers hope to learn?

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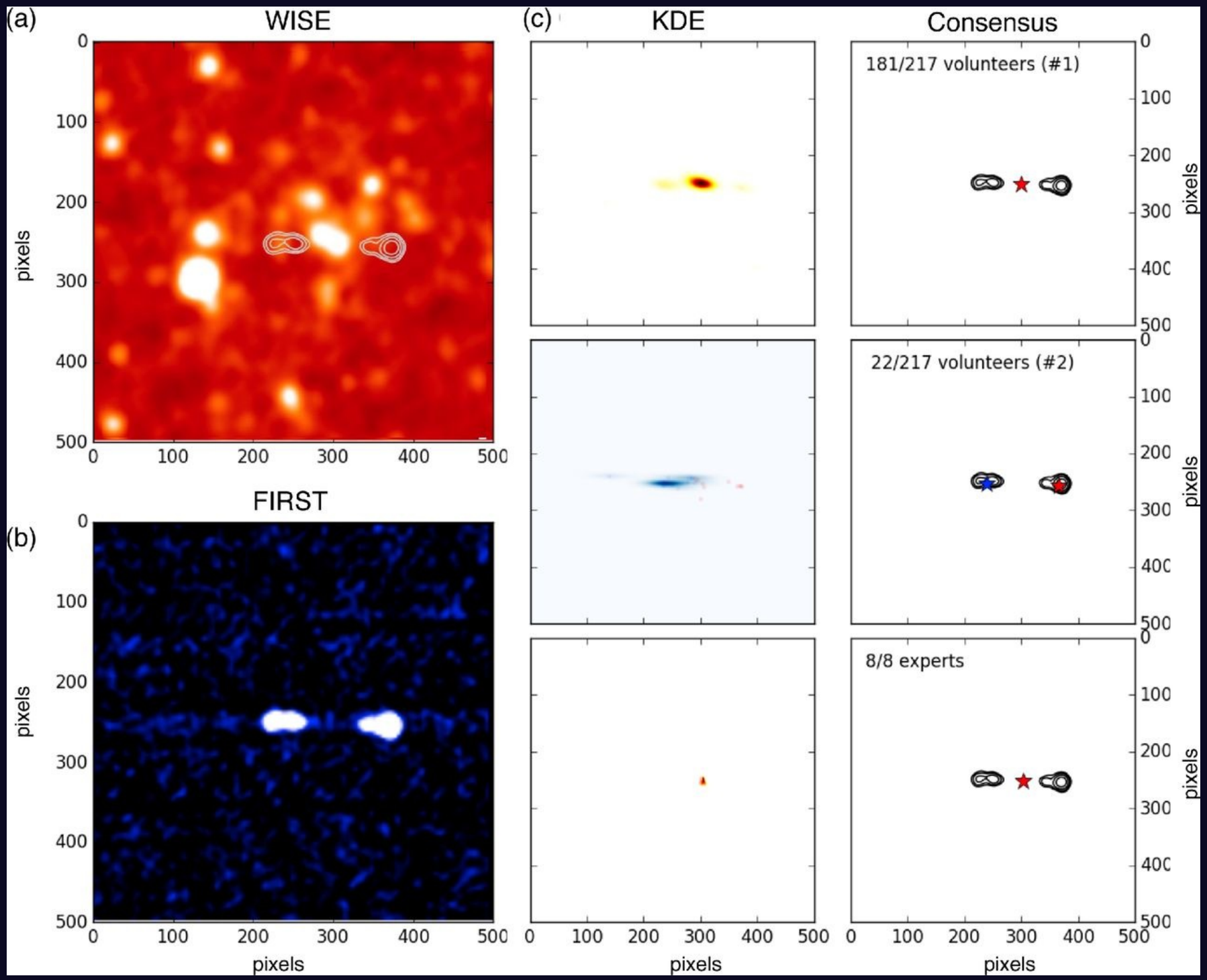
Data products



Banfield et al. (2015)

RGZ catalog

rgz_subject.json — UNREGISTERED

rgz_subject.json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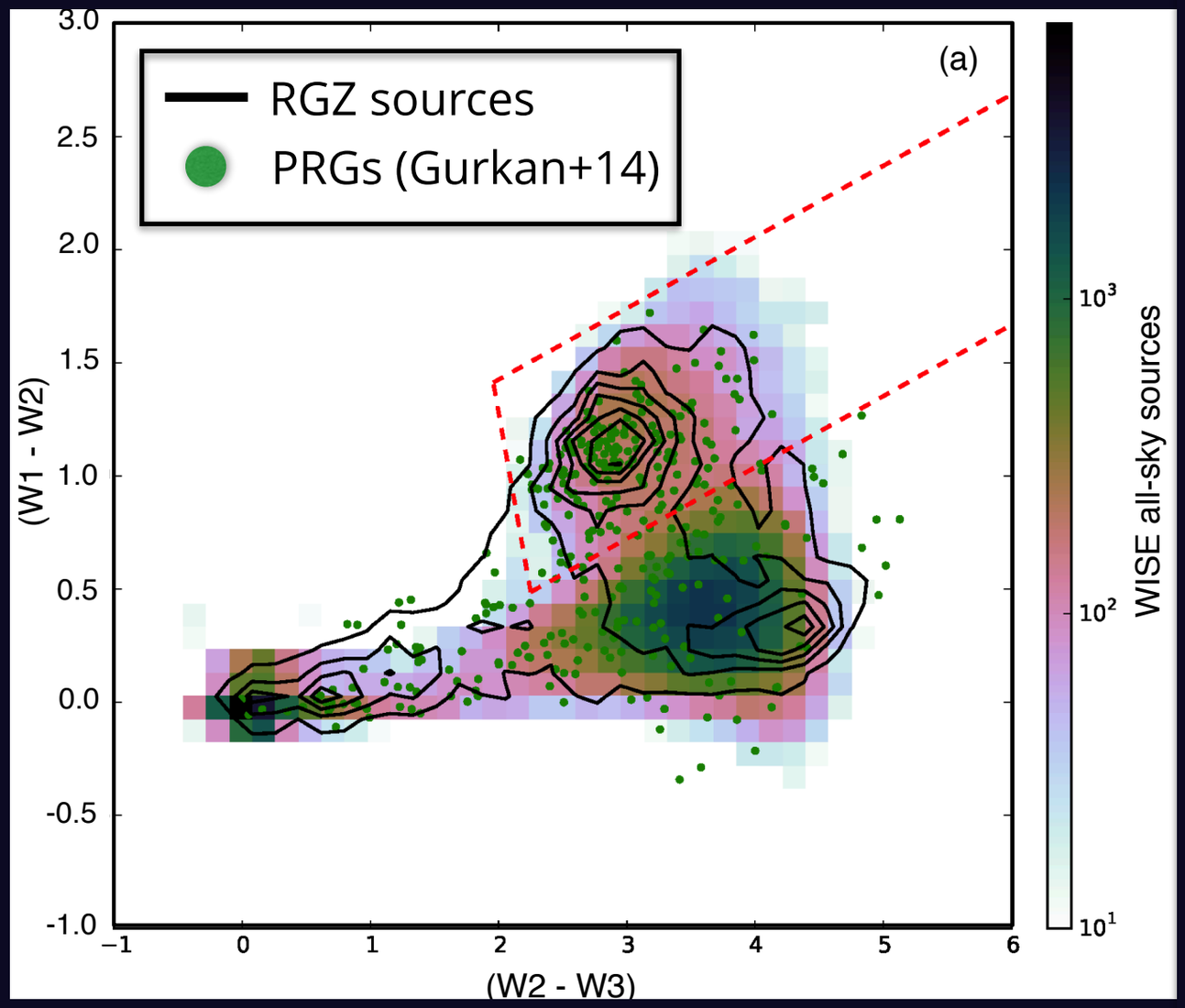
Line 26, Column 10 — Tab Size: 4 — JSON

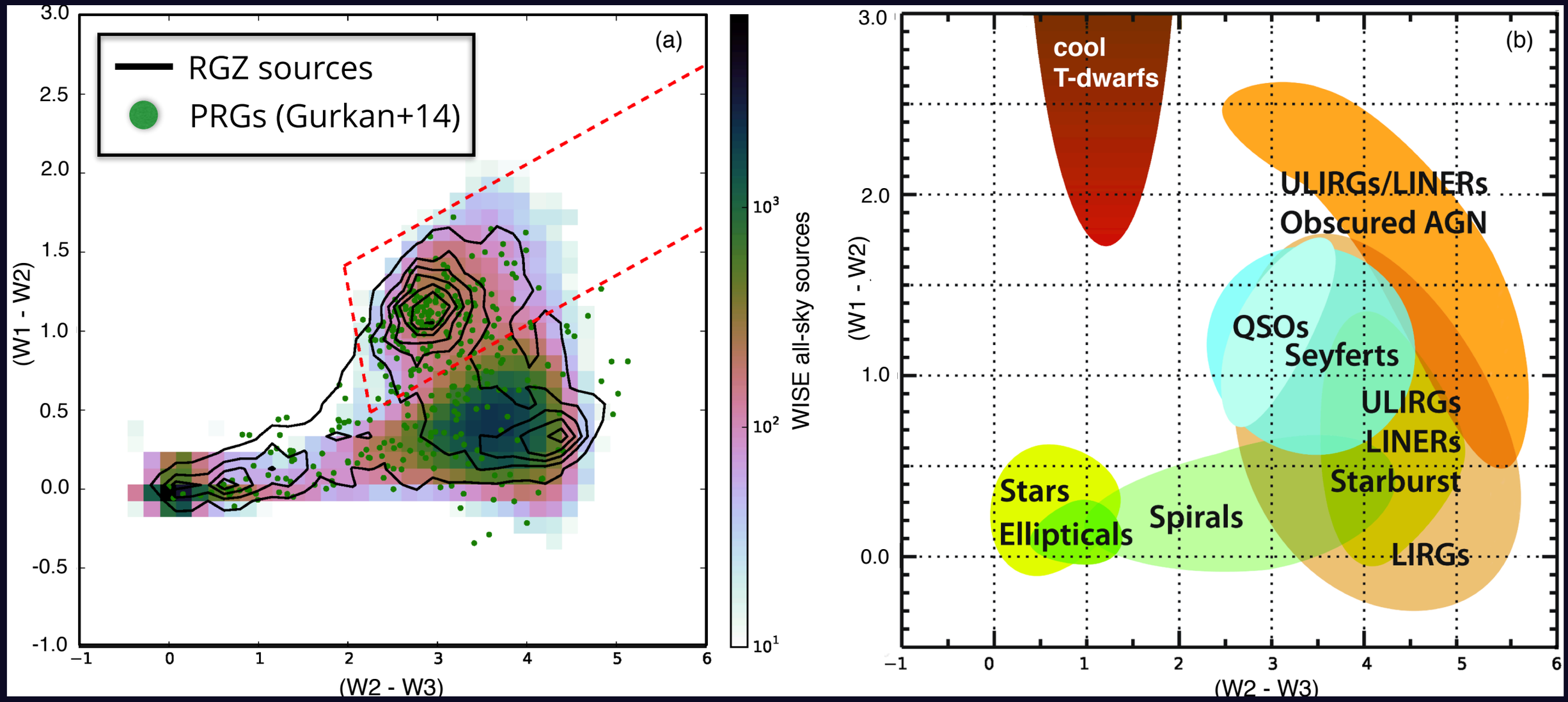
Willett et al. (in prep)

Science - WISE colors of radio hosts



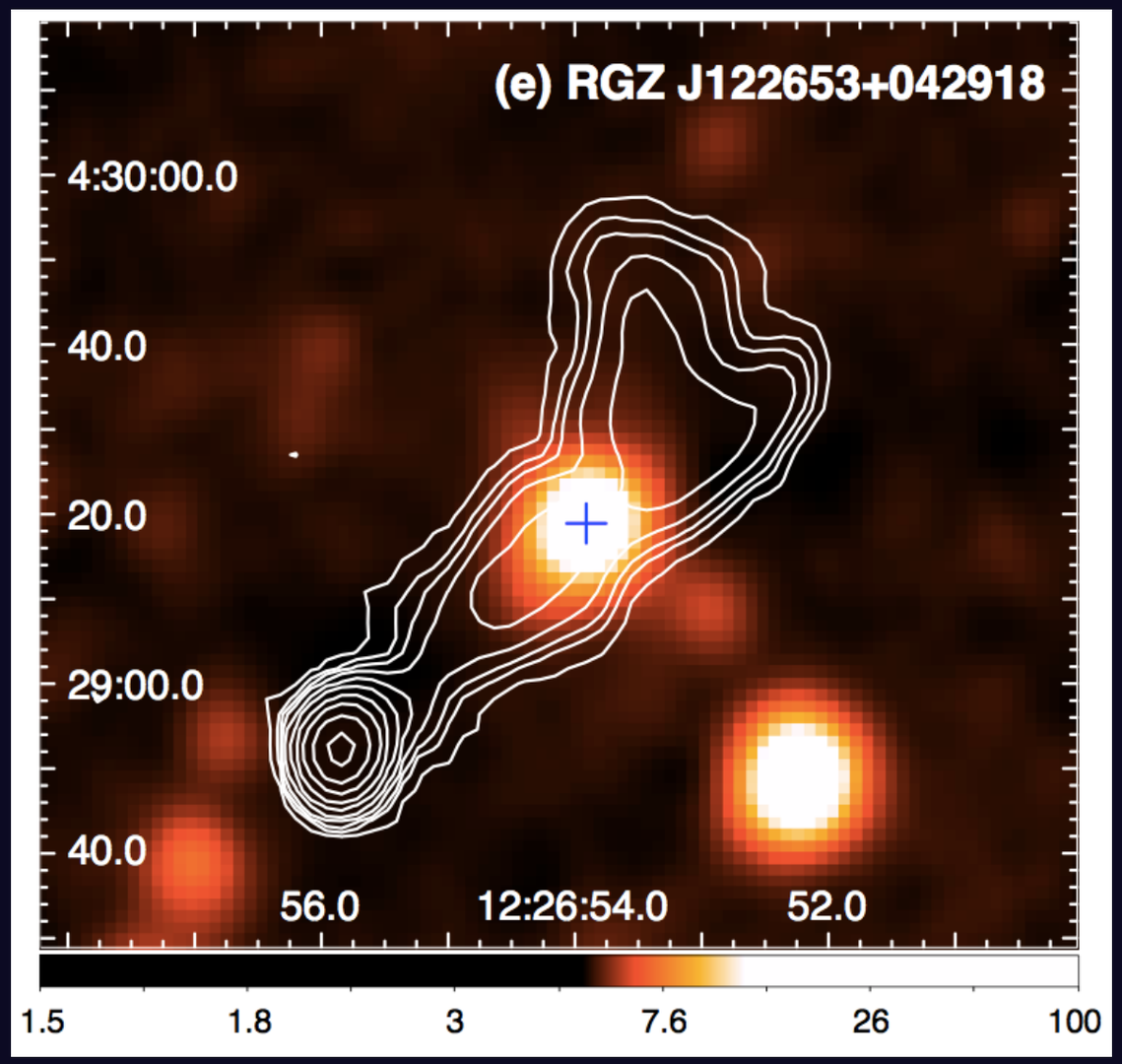
Banfield et al. (2015)

Science - WISE colors of radio hosts



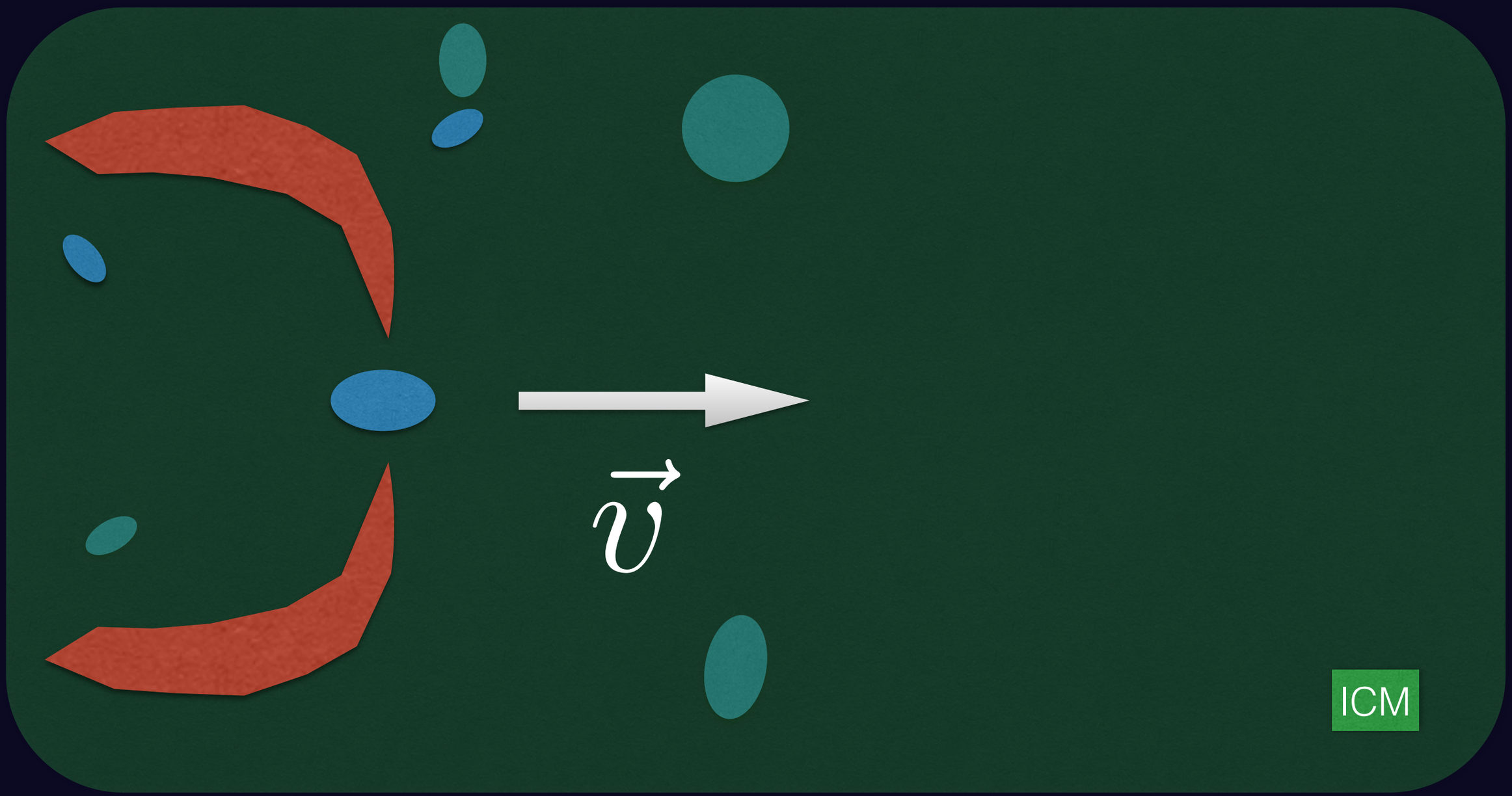
Banfield et al. (2015)

Science - identification of hybrid radio galaxies

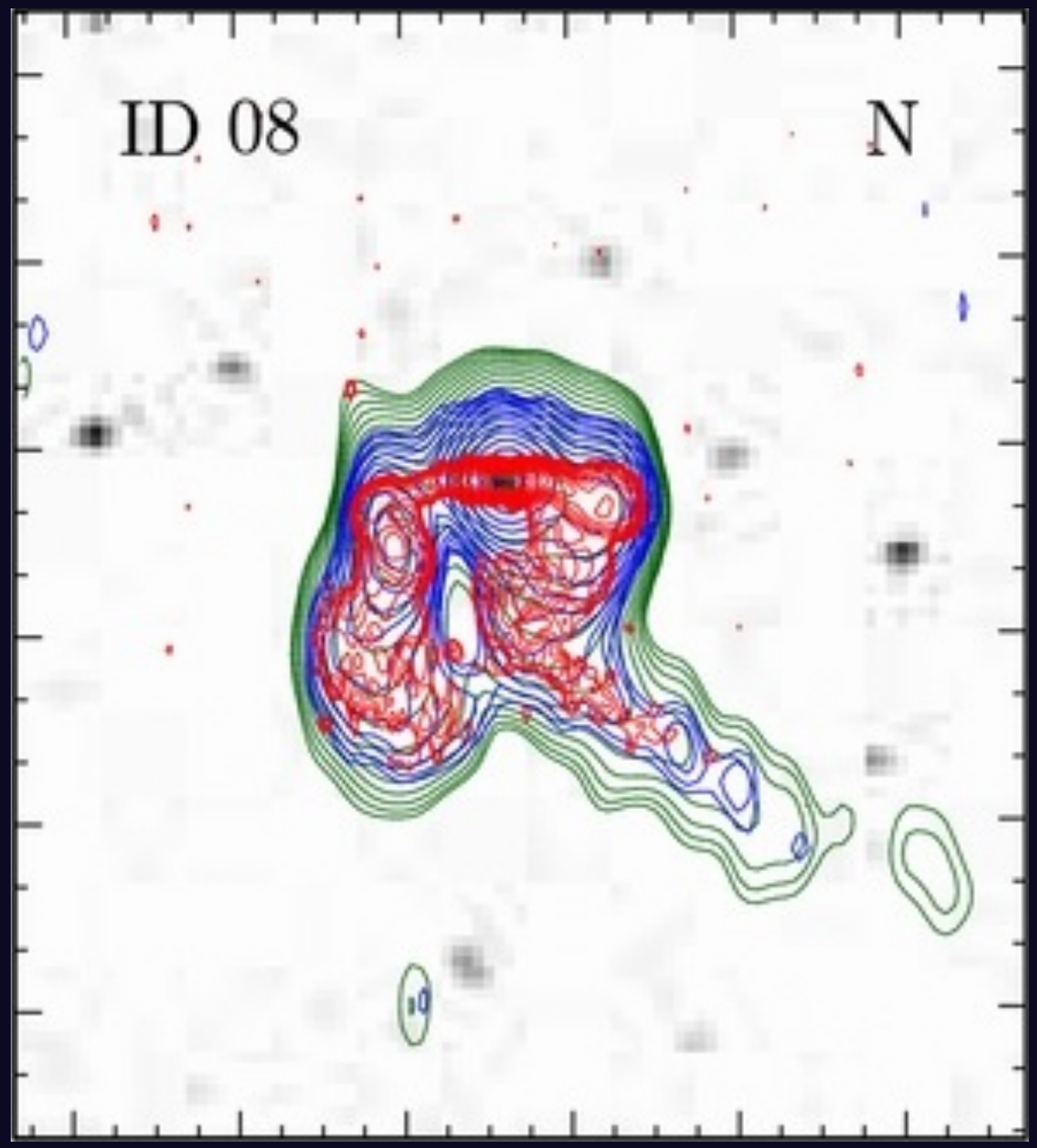


Kapińska et al. (submitted)

Jet bending angles



Intercluster medium

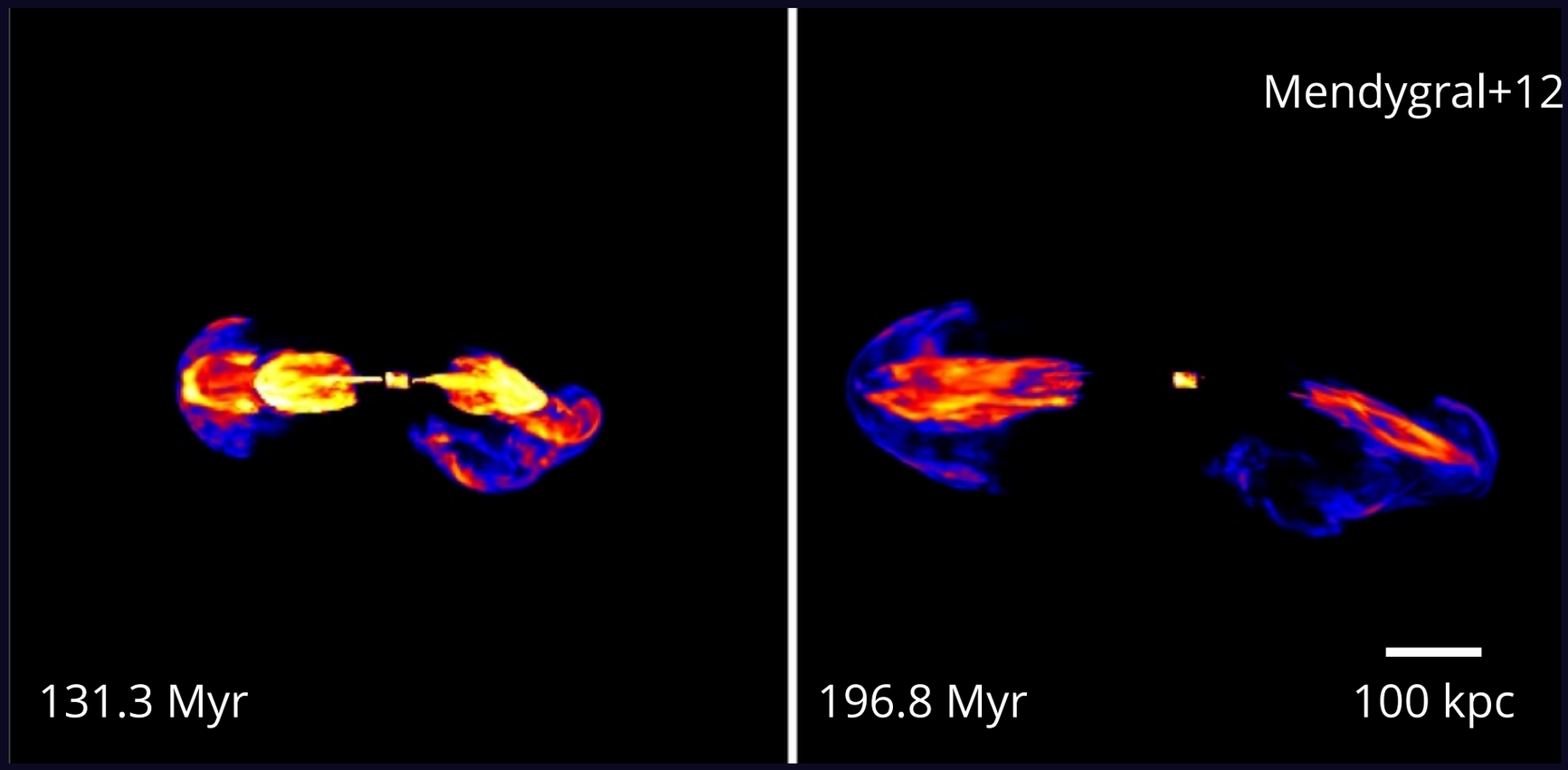


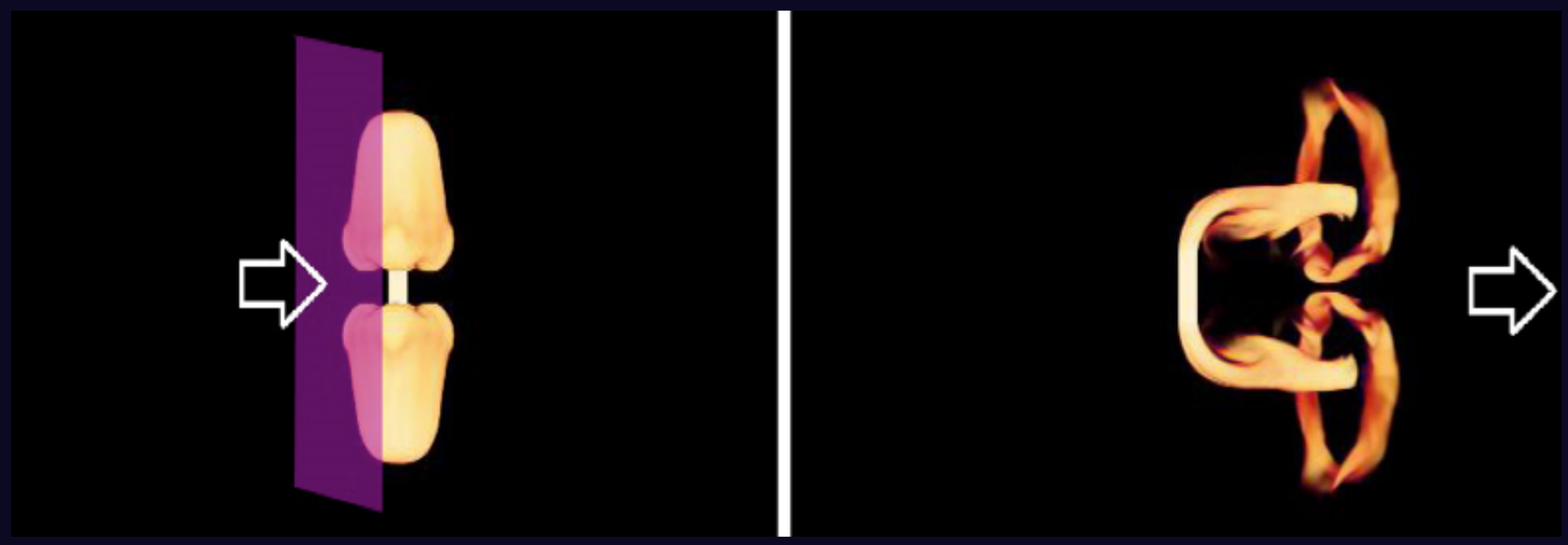
Dehghan+14

Indicators of ICM pressure, dynamical state, merger history, etc.

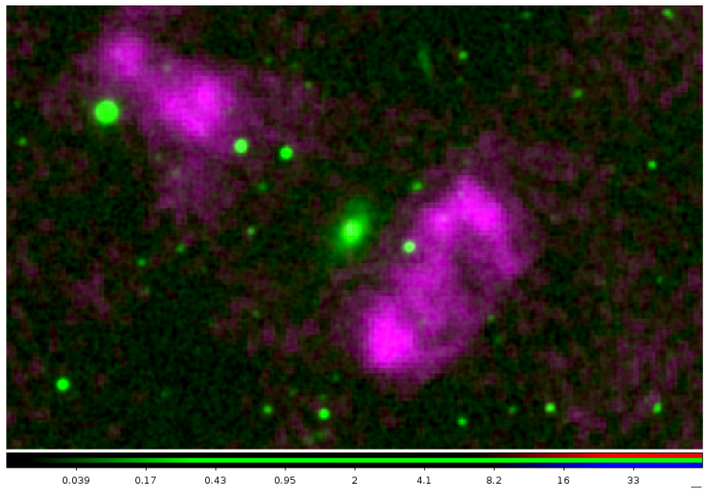
$$\frac{\rho_{\rm ICM} v_{\rm gal}^2}{h} = \frac{w\Gamma^2\beta^2}{R}$$

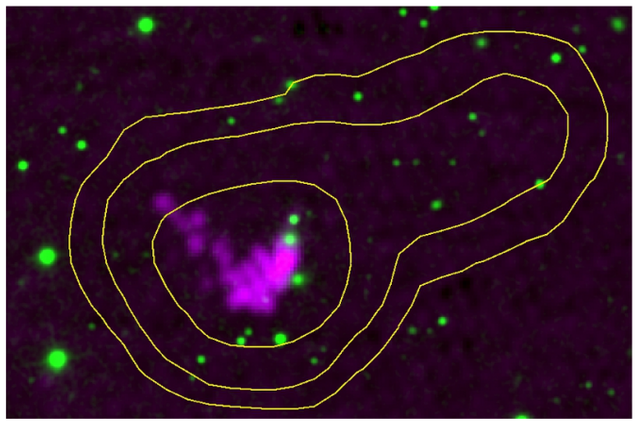
Comparing the observations to simulations

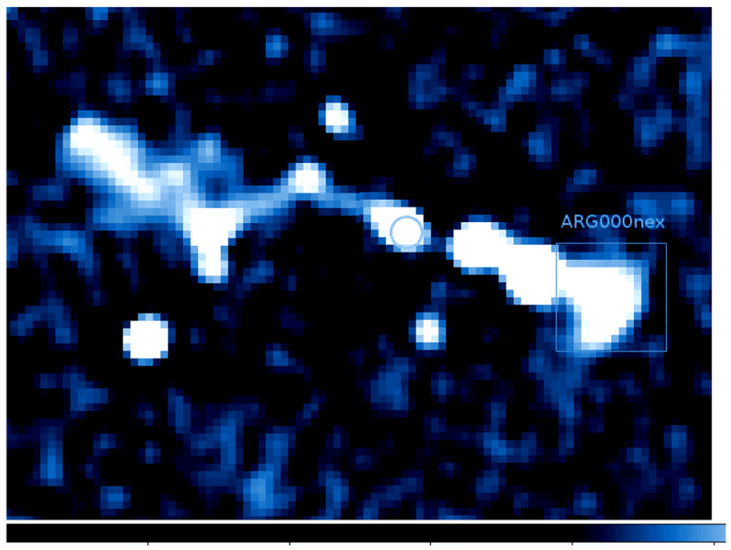


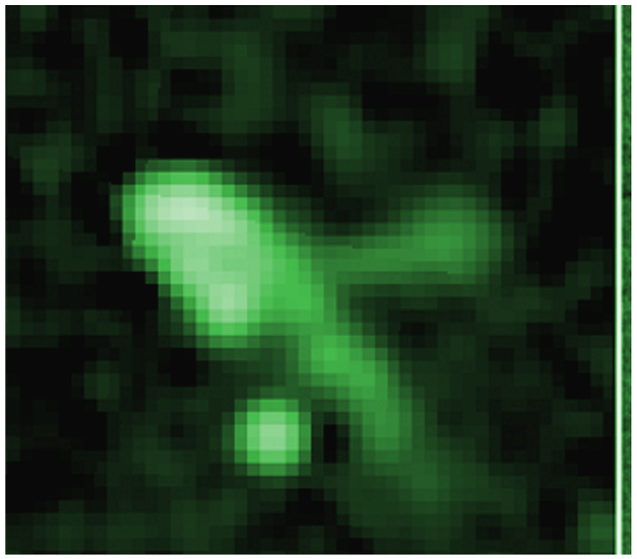


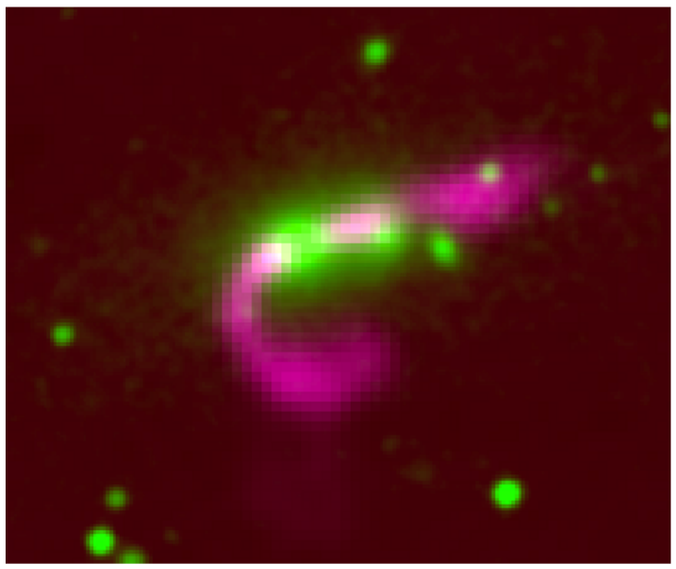
Mendygral & Jones (in prep)

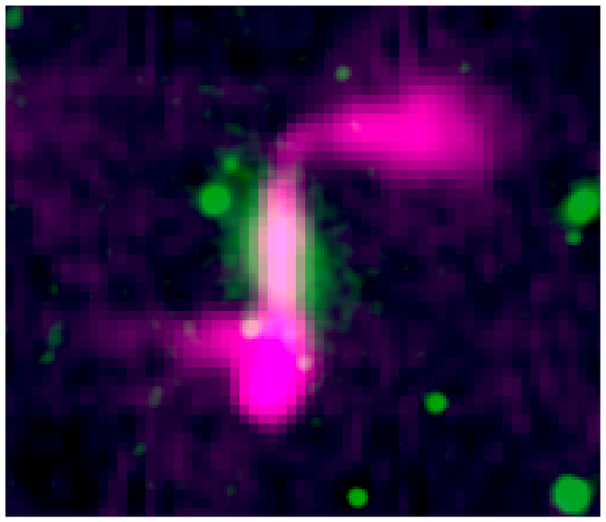








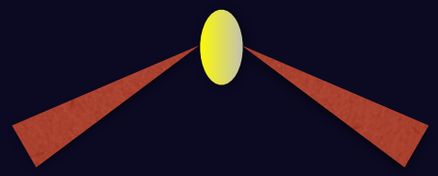


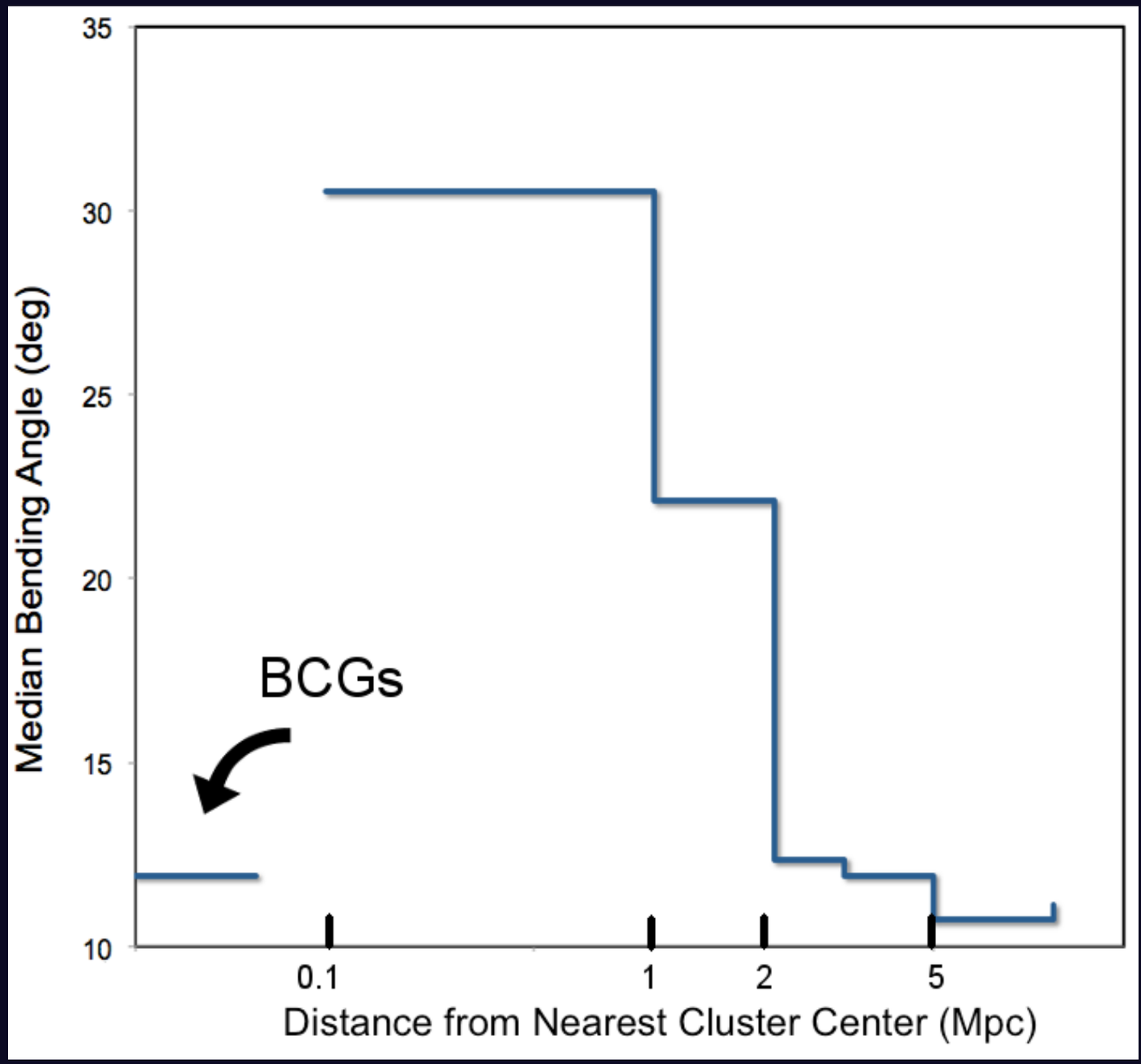


Sharply-bent radio galaxies from RGZ

Rudnick et al. (in prep)

Bending angles of radio jets near galaxy clusters





Rudnick, Willett, Garon et al. (in prep)

Citizen science is a good thing for radio astronomy

1. The data sets are already too large for science teams to individually inspect, and they're about to get much larger.
2. There is useful science to be extracted from tasks that non-professionals can perform.
3. More inspection of the data enables serendipitous discoveries.
4. Citizen science has massive additional benefits in engagement, outreach, and education.

What is the future of citizen science in radio astronomy?

new surveys

rare and unusual

training sets
for machine learning

detailed analysis
of radio sources

time domain/
multi-frequency

?

Grazie.

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