Radio Galaxy Zoo





Identification of the host galaxy for radio sources is critical



Automated routines



Bayesian hypothesis testing

Model $\mathbf{m}'' = 2\mathbf{m} - \mathbf{m}'$ Likelihood $\mathcal{L}_{cll} = \left[\int d\mathbf{m} \ p(\mathbf{m}) L_c(\mathbf{m}) L_{r_0}(\mathbf{m}) \right]$ $\int d\mathbf{m}' p(\mathbf{m}' | \mathbf{m}) L_{r_1}(\mathbf{m}') L_{r_2}(2\mathbf{m} - \mathbf{m}') \right]$ Evaluate $B_{1,2} = \frac{\mathcal{L}_1}{\mathcal{L}_2}$

Automated routines





 \mathcal{L}_2

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

Likelihood $\mathcal{L}_{cll} = \left[\int \mathrm{d}\mathbf{m} \ p(\mathbf{m}) L_c(\mathbf{m}) L_{r_0}(\mathbf{m}) \right]$
 $\int \mathrm{d}\mathbf{m}' p(\mathbf{m}' | \mathbf{m}) L_{r_1}(\mathbf{m}') L_{r_2}(2\mathbf{m} - \mathbf{m}') \right]$
Evaluate $B_{1,2} = \frac{\mathcal{L}_1}{2}$

Automated routines



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

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

Code	Classification/Comment/Desi	gnation			
Group visual morphological classif	ications	gnaton			
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 five approximately point-like sources (QUAD)				
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 proj	ection of point-like source into group			
sl	Sidelobe	× 2 ×			
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 projecti	ons			
unu	Unusual, uncommon—may be due to chance projection				
<i>w</i>	W-shape, wiggles				
wat	Wide-angle tall (WAL)				
x	x-snape				
Additional comments					
arc	Arc or C, possible edge-brightened lobe, bent jets, or ring fr	agment			
asym	Asymmetric				
butterfly	Four lobe morphology				
cat	Catalog				
CD	Chance projection				
dĩag	Diagonal				
distorted	Smearing of prototypical morphologies with low-level emiss	sion			
dl	Dogleg, generally an abrupt change in direction				
pinwheel	Spiral type similar to optical star forming regions of spiral g	alaxies			
fan	Low-level triangular shape lobe				
hook	Hook, an apparent approximately 180 change in direction of	i 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 nux, diffuse, and/or filamentary				
ppu	Apparent single sided jet and /or lobe				
aa Turuu u	Apparent single-such jet and/or tobe				
Individual source classifications:	. 11				
A	Ambiguous				
	Core-jet core component				
CORE	Core component				
I	Iet				
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	n into group			
	or single bright point-like source, other group members bein	g sidelobes			
SL	Sidelobe				
SZJ	Jet component of S-shape or Z-shape				
SZC	Core component of S-shape or Z-shape	Proctor(2011)			
X	Transverse component of X group				

Expert visual classification

FCG 000330.7+002756	FCG 002042.00112103	FCG 004012.8+012542	FCG 004150.2-092548	FCG 004152.1+002837	FCG 005602.6-012004	FCG 010242.4-005032	FCG 010403.0-002440
2.1	5	*	i.		R	10	
000455	002611	004994	005236	005238	007000	007807	007991
FCG 011425.5+002932	FCG 011900.1-100346	FCG 012947.0+004633	FCG 013134.5+003341	FCG 013247.1+011545	FCG 021052.2-063333	FCG 021234.9-082042	FCG 021619.7-024433
	15	:	-	14	-	+	1
009186	009752	011039	011265	011430	017193	017581	018482
FCG 024558.4-064859	FCG 024612.8-084735	FCG 031147.3+010845	FCG 070029.9+494647	FCG 070723.0+592725	FCG 070759.2+444906	FCG 070825.8+540838	FCG 071406.0+510000
	37	2	.		140	*.s.	
022425	022456	024970	026563	028338	028563	028693	030860
FCG 071424.6+401559	FCG 072106.9+363903	FCG 072109:8+531237	FCG 072431.5+501052	FCG 072725.1+310934	FCG 072930.2+594952	FCG 073229.7+374420	FCG 073441.9+361129
5	. C		1	1	¢	Ġ.,	э.
030985	034421	034428	036444	038212	039493	041299	042662
FCG 073539.8+251020	FCG 073540.4+361912	FCG 073618.0+241043	FCG 073849.8+415907	FCG 074118.0+163156	FCG 074143.0+174056	FCG 074305.9+271012	FCG 074310.8+520337
10	• *	ø	a de la compañía de l		1.		e - e
043263	043290	043721	045405	047084	047390	048441	048506
FCG 074639.3+465240	FCG 074757.7+372638	FCG 074926.1+520230	FCG 075347.2+230150	FCG 075641.5+603013	FCG 080317,0+244059	FCG 080337.3+105116	FCG 080431.5+192217
1	r	24	÷.	1,	5	17	
051101	052062	053115	056473	058735	064113	064386	065096
FCG 080611.3+253138	FCG 080720.7+141620	FCG 080842.9+055044	081544.2+371017	FCG 081652.7+413332	FCG 081659.5+571627	FCG 081801.3+495610	FCG 081803.7+543708
0 *	;	2		· · · ·	~	r	~
066527	067648	068826	075315	076389	076482	077481	077461
FCG 081939.4+574609	FCG 082444.7+520033	FCG 082718.2+463510	FCG 082835.1+322821	FCG 082844.4+243729	FCG 082910.5+632229	FCG 083931.0+594956	FCG 084122.7+611228
•	۲	N. 4.	1	v	v	i	Ť
079050	084045	086460	087751	087828	088315	098827	100723
FCG 084132.7-020318	FCG 084445.3+212932	FCG 084655.0-013142	FCG 084934.4+282150	FCG 085052.9+134857	FCG 085105.5+085107	FCG 085758.3+170333	FCG 085815.2+505303
20	c	e	6	1. 10 1	a starting	9	1. C
100880	104321	106645	109514	110924	11111	118471	118767
FCG 085828.7-010714	FCG 085845.1+171002	FCG 090124.9+025916	HCG 090225.8+204547	FCG 090305.5+450959	FCG 090616.5+441856	FCG 091042.2+384125	FCG 091118.8+073239
1	٢	1	A.	4		f (5
119082	119399	122268	123351	124105	127678	132551	133221

~7,000 sources

Dozens of potential categories

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
 - 1.3 million classifications
 - 76,000 completed images (45% of total)

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2

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.



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

Begin Hunting

Why do astronomers need your help?

What do astronomers hope to learn?



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Data products



Banfield et al. (2015)

000

Line 26, Column 10

rgz_subject.json

Tab Size: 4

JSON

RGZ catalog

Willett et al. (in prep)

rgz_	subject.json ×
1 2	{
3	"consensus" : {
4	"IR_dec" : 23.382187439864733,
5	"level" : 0.95,
6	"n_users" : 19,
7	"n_total" : 20,
8	"IR_ra" : 251.6793575106417,
9	"label" : "a"
10	},
11	"FIRST_id" : "FIRSTJ164643.0+232255",
12	"Zooniverse_id" : "ARG000255v",
13	"radio" : {
14	"totalFluxErr" : 0.19719586712238948,
15	"TOTALLUMINOSITY" : 2.064642/8100285020+24,
70	
23	J, "totalFlux" + 10.37368653018283.
25	"maxPhysicalExtent": 65.80235971854495.
26	"totalLuminositvErr" : 3,924728417038814e+22.
27	"outermostLevel" : 0.930111283664487.
28	"numberComponents" : 1,
29	"peakLuminosityErr" : 5.244638954533885e+21,
30	"components" : [
31	{ 🚥
48	}
49],
50	"totalCrossSection" : 1666.717816315769,
51	"peakFluxErr" : 0.02635140617356362,
52	"maxAngularExtent": 0.2/641135/8150844,
53	"numberPeaks" : 1, "totalSolidAnglo" : 105 97400705077024
55	1
56	"catalog id": 1.
57	"AllWISE" : {
58	"w3snr" : 1.1,
59	"numberMatches" : 1,
60	"w3mpro" : 12.196,
61	"designation" : "WISEAJ164643.03+232254.9",
62	"w1sigmpro" : 0.039,
63	"w4mpro" : 9.163,
64	"WZSNF" : 14.4,
65	18": 201.0/931//,
67	"w1mpro" + 15-446
68	"w2sigmpro" : 0.076.
69	"dec" : 23.3819347.
70	"w4snr" : -0.5.
71	"w1snr" : 27.8
72	},
73	"SDSS" : {
74	"z_err" : 0.04391507,
75	"i_err" : 0.0148469999999999999,
76	"redshift" : 0.254488,
77	"redshift_type" : 0,
78	"g_err" : 0.03306/25, Uradahift arr‼ : 0.0350720000000000
/9	"reashift_err": 0.0258/200000000003,
00 91	u_err : 0.330030/, "numberMatches" : 1
82	"a" : 20,73353.
02	g · Lot / 0000 /

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



<u>Indicators of ICM</u> <u>pressure, dynamical state,</u> <u>merger history, etc.</u>

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

Dehghan+14



Comparing the observations to simulations



Mendygral & Jones (in prep)





0.039 0.17 0.43 0.95 2 4.1 8.2 16 33



Sharply-bent radio galaxies from RGZ



-0.0012



Rudnick et al. (in prep)

-0.0021

-0.0018

Bending angles of radio jets near galaxy clusters



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 <u>much larger</u>.
- 2. There is <u>useful science</u> to be extracted from tasks that non-professionals can perform.
- 3. More inspection of the data enables serendipitous discoveries.
- Citizen science has massive additional benefits in engagement, outreach, and education.

What is the future of citizen science in radio astronomy?

rare and unusual

<u>new surveys</u>

<u>training sets</u> for machine learning

<u>detailed analysis</u> <u>of radio sources</u> <u>time domain/</u> <u>multi-frequency</u>

Grazie.



