Zooniverse Case Study: Radio Galaxy Zoo

O. Ivy Wong

Evolutionary Paths in Galaxy Morphology: a Galaxy Zoo meeting
Powerhouse Museum, Sydney, 26 September 2013

CSIRO Astronomy & Space science
www.csiro.au

Julie Banfield (CASS), Amit Kapadia (Adler), Melanie Gendre (Jodrell), Enno Middelberg (Bochum), Arfon Smith (Adler/GitHub)**, Ray Norris (CASS),** Laura Whyte (Adler)**, Chris Lintott (Oxford),** Larry Rudnick (Minnesota)**, Karen Masters (Portsmouth), Kevin Schawinski (ETH), Kyle Willett (Minnesota),** Heinz Andernach (Guanajuato)**, Rob Hollow (CASS), Nick Seymour (CASS),** Minnie Mao (NRAO), Steven Bamford (Nottingham), Tania Burchell (NRAO), Loretta Dunne (Canterbury), Lucy Fortson (Minnesota), Samuel George (Birmingham), Ian Heywood (CASS), Matt Jarvis (Oxford/Western Cape), Hans-Rainer Kloeckner (MPIfR), Vicky Lo (CASS) **& Stas Shabala (Tasmania)**

As galaxies evolve, when & how do they get their SMBH & AGN?

Some of the things we learnt from Tuesday …

- AGNs may play a role in the quick transition of low-mass ETs (cf Schawinski)

- Radio morphology is an excellent tool for:
  - ➡ probing the triggering mechanisms of AGN (Shabala)
  - ➡ disentangling the evolution from interaction → SF → onset of AGN (Shabala & Banfield)

Credit: Feain, T. Cornwell & R.D. Ekers (CSIRO); R. Morganti (ASTRON), N. Junkes (MPIfR). Photo of the ATCA and Moon: S. Amy

How do Supermas … **es** form **&** evolve**?**

In the context of galaxy evolution, how do supermassive black holes form and evolve

- accretion model for mass build-up of SMBHs takes several 10^9 years
- what about AGNs spotted at $z > 5$?

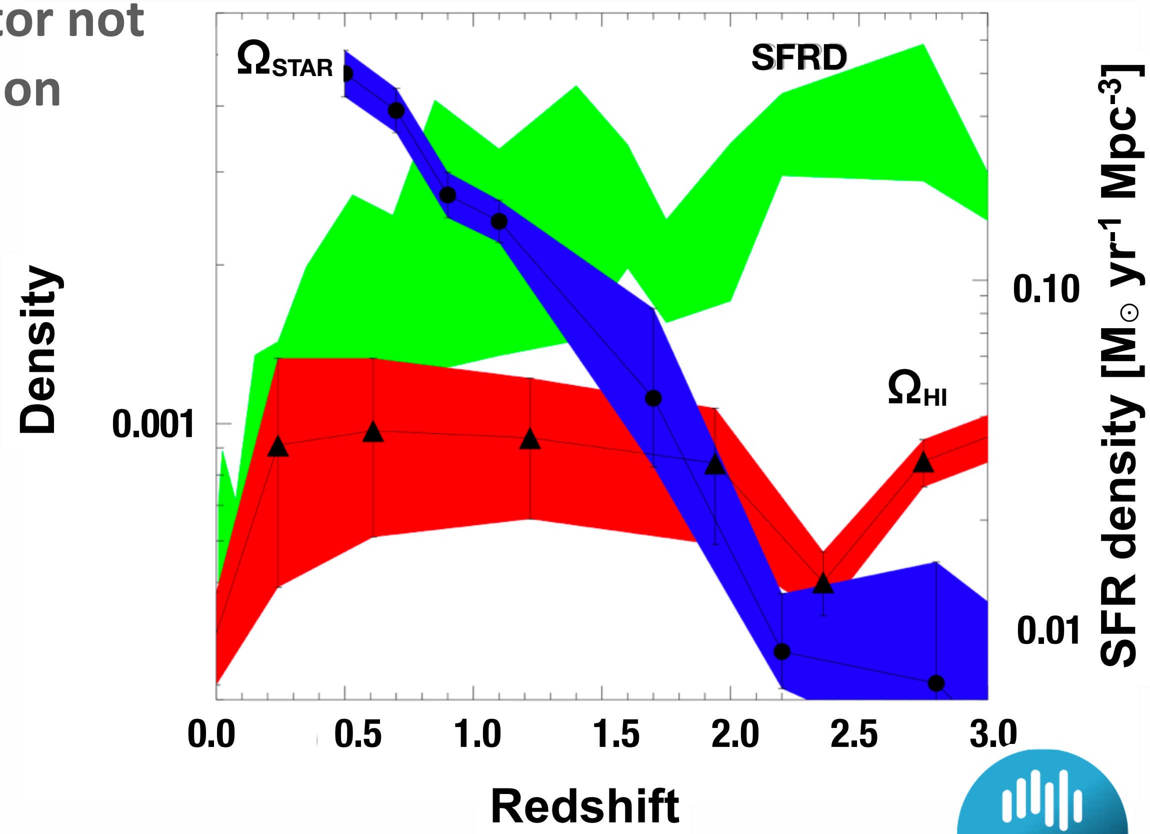
How do SMBHs affect **host galaxies (& their neighbours)?**

- fewer than a dozen systems studied in any detail

Need very large samples of radio observations

- Very large radio surveys
  - ➡ large statistical sample to sample every stage of evolution, however rare or brief
  - ➡ a good star formation indicator not biased by dust or mol. emission

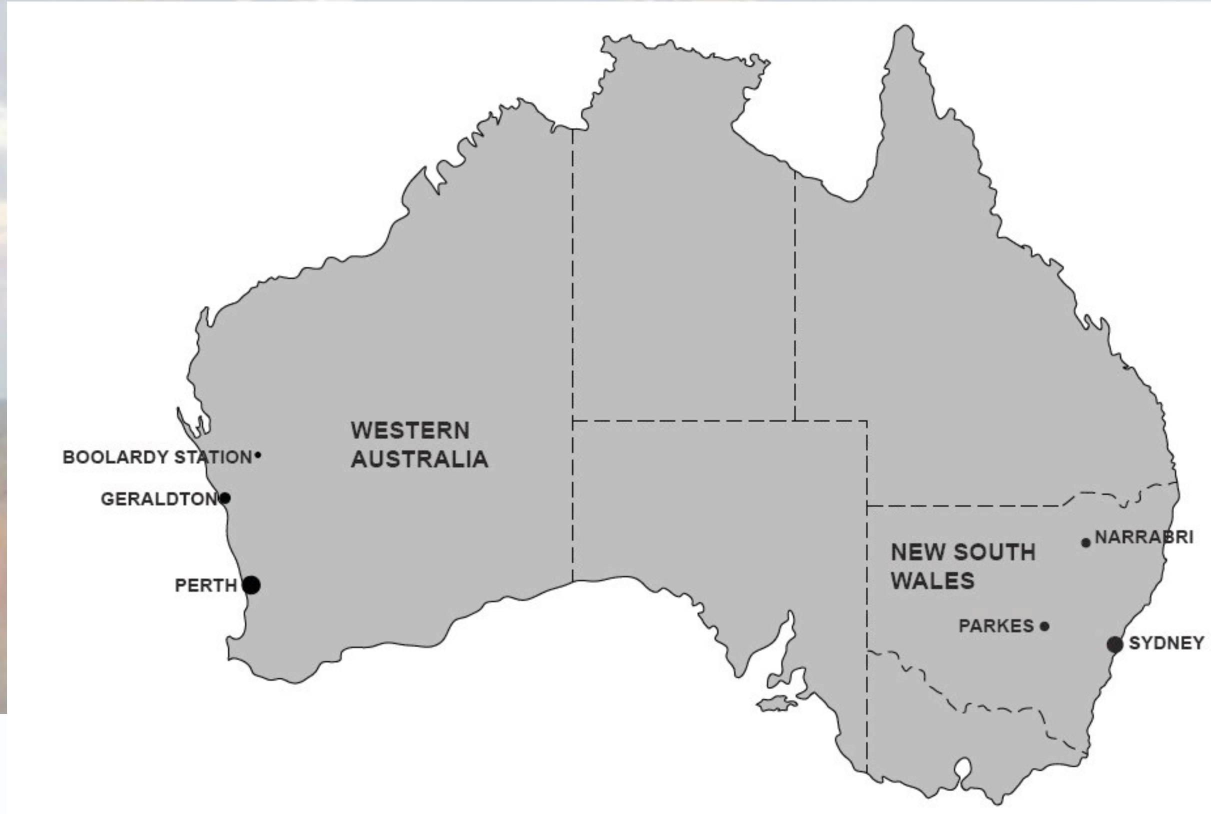
Putman+2009



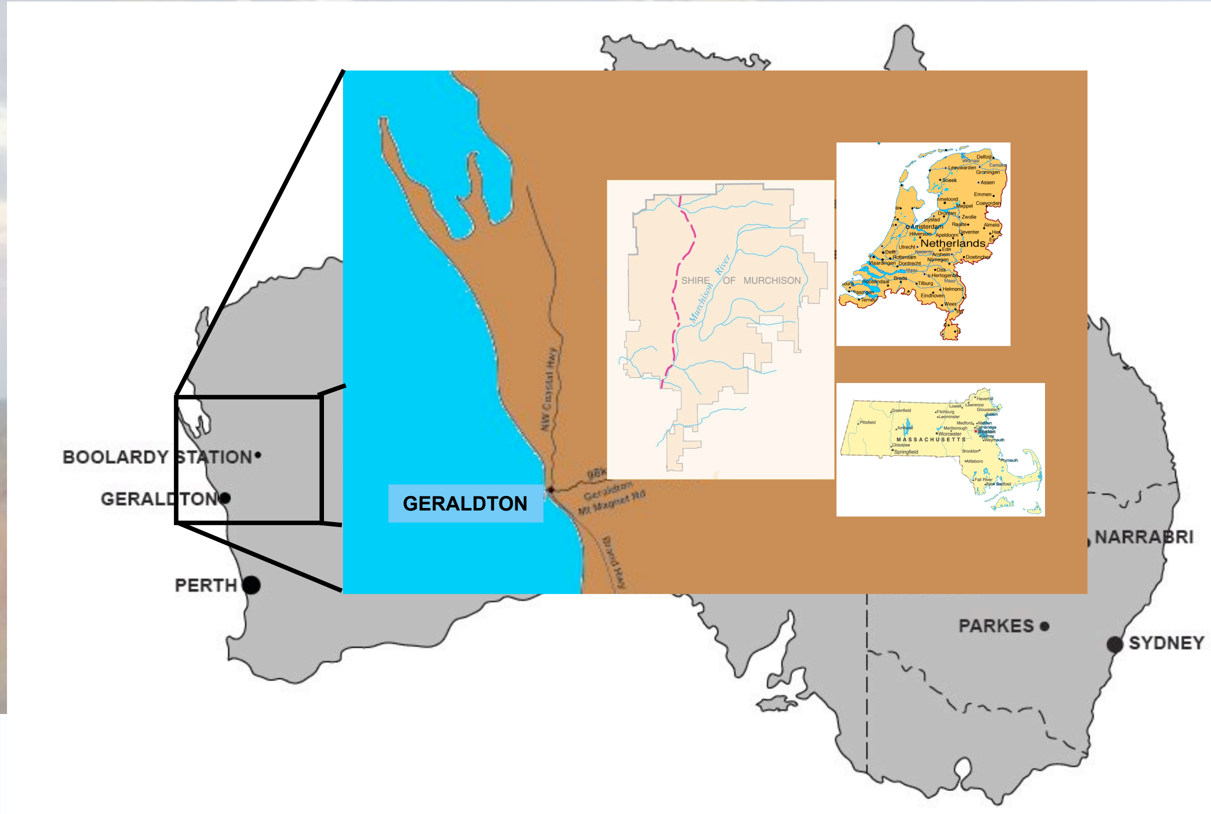
Australian **SKA** Pathfinder (**ASKAP**)

ASKAP

ASKAP

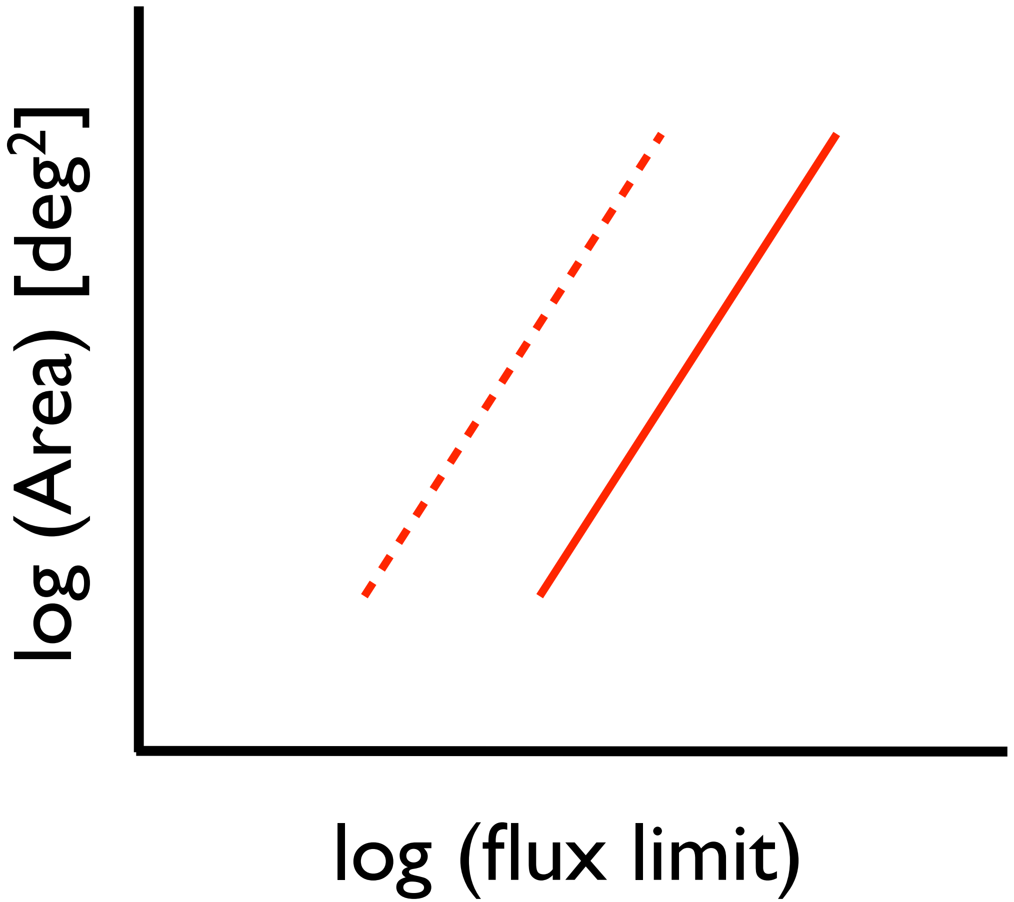

WESTERN AUSTRALIA
BOOLARDY STATION
GERALDTON
PERTH
NEW SOUTH WALES
NARRABRI
PARKES
SYDNEY

ASKAP

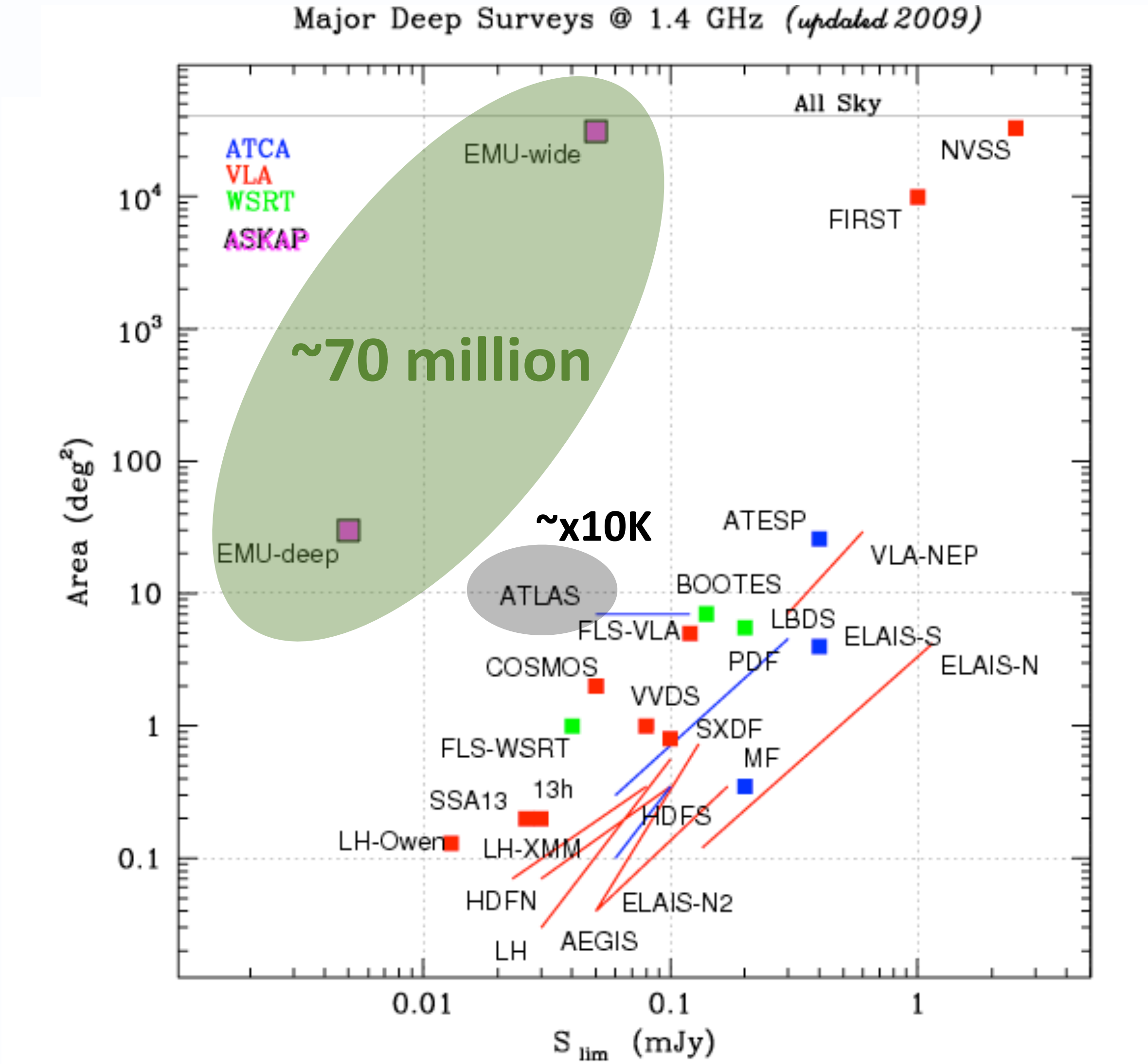


Population density ≃ 1 nanoperson m^{-2}

Larger surveys = Larger Datasets



Larger surveys = Larger Datasets



Prandoni & Andernach (2009)

- 75% of entire sky @1.1 - 1.4 GHz
- 40x deeper than NVSS (rms~10 μJy)
- 5x better angular resolution (10”)
- expect ~70 million sources

+

- Wodan using Apertif (WSRT)
- expect ~30 million sources

} 4 π sky

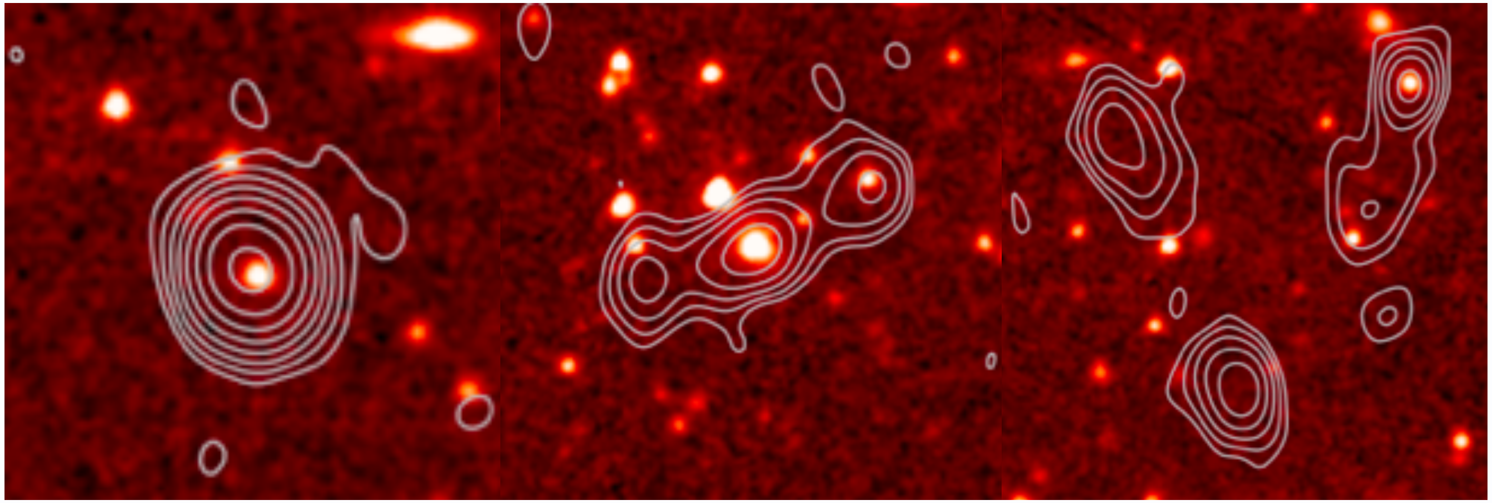
Complementary optical/IR surveys

Survey Name	Area (sq. deg)	Wavelength Bands	Mag. Limit[a]	EMU Detected (%)	Survey Matched (%)
WISE[1]	40000	3.4, 4.6, 12, 22 μm	80 μJy	23	100
Pan-Starrs[2]	30000	g, r, i, z, y	$r < 24.0$	54	50
Wallaby[3,b]	30000	20 – 26 cm	1.6 mJy[c]	1	100
LSST[4]	20000	u, g, r, i, z, y	$r < 27.5$	96	67
Skymapper[5]	20000	u, v, g, r, i, z	$r < 22.6$	31	66
VHS[6]	20000	Y, J, H, K	K< 20.5	49	66
SDSS[7]	12000	u, g, r, i, z	$r < 22.2$	28	22
DES[8]	5000	g, r, i, z, y	$r < 25$	71	17
VST-ATLAS[9]	4500	u, g, r, i, z	$r < 22.3$	30	15
Viking[10]	1500	Y, J, H, K	K< 21.5	68	5
Pan-Starrs Deep[2]	1200	0.5 – 0.8, g, r, i, z, y	$g < 27.0$	57	4

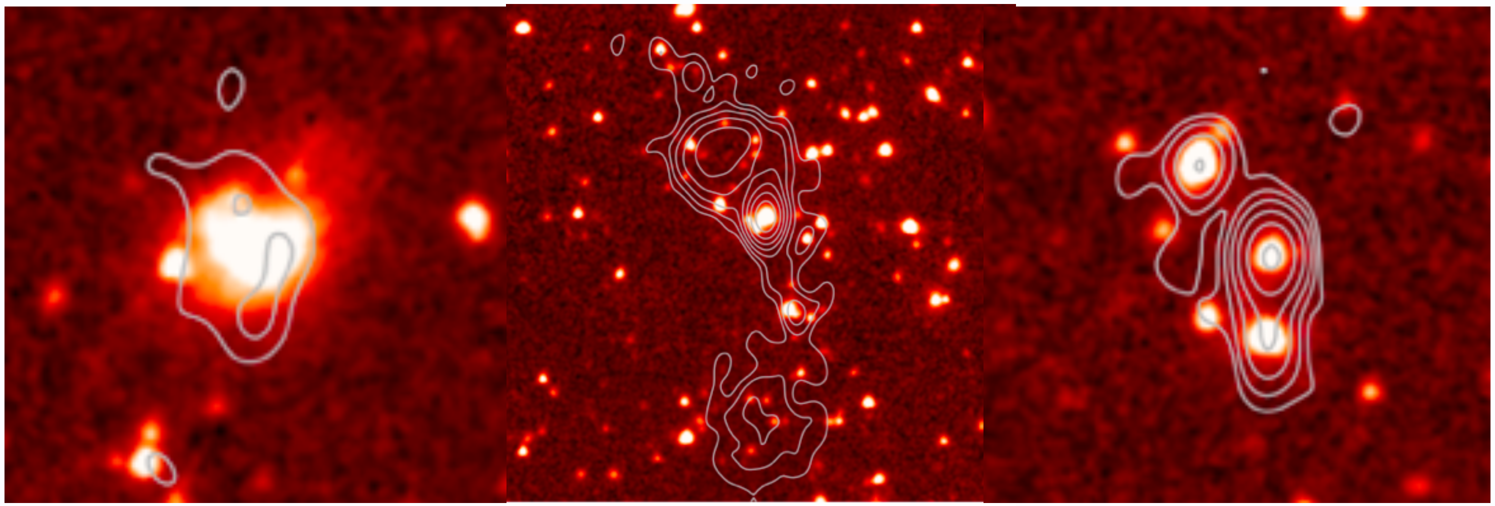
Radio morphologies...

Let's have a look at radio data

take home message is that there are a zoo of radio morphologies.. ID-ing host galaxies can get tricky



Easy



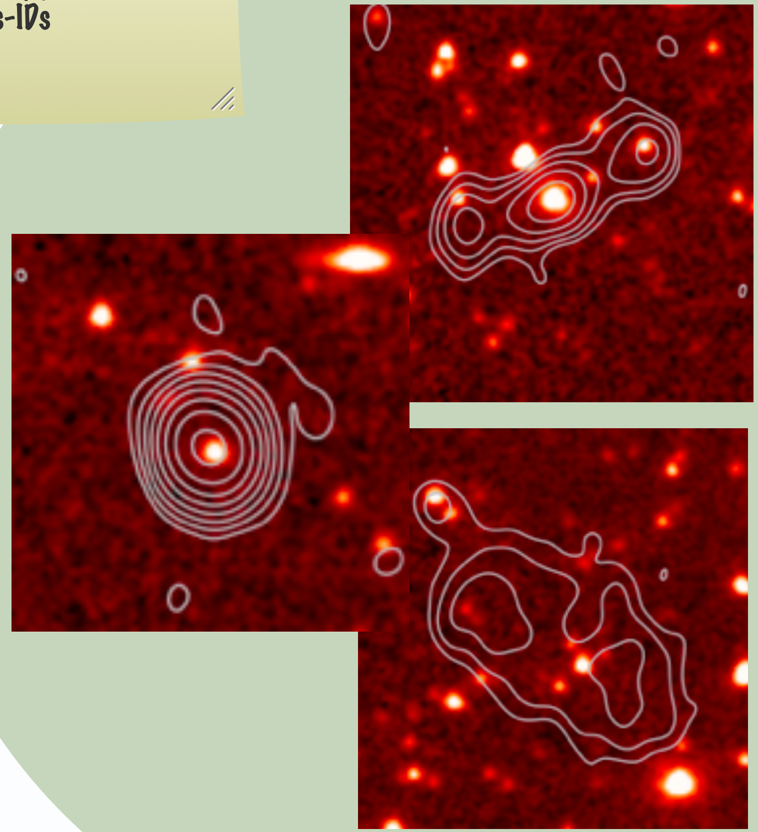
Less easy

Multi-core automated … ng...

in fact, given how far our computing power has progressed, our automated algorithms are able to do a satisfactory job on these easy cross-IDs

Dark ages

Now



Current expectations

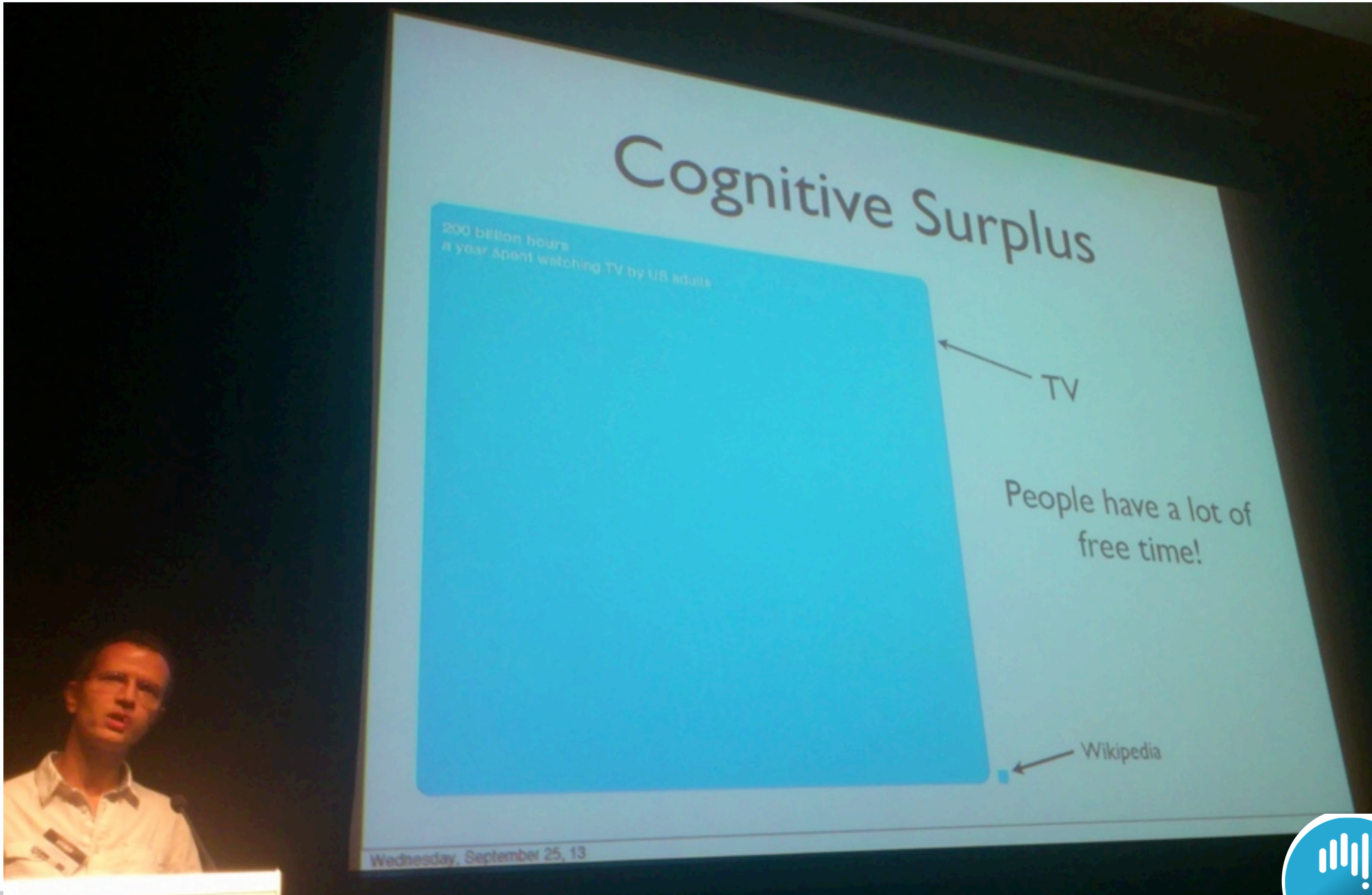
eyeballing 10^2-10^3 different of kettle of fish to what is coming soon.

- Auto computers : ~70% of cross-IDs
- No IR IDs : ~20%

- Complicated morphologies : ~10%

➡ **10% of EMU ~ 7 million sources (+3 million from Wodan)**

Zooniverse: an excellent tool for large datasets


Cognitive Surplus
200 billion hours
a year spent watching TV by US adults
TV
People have a lot of free time!
Wikipedia
Wednesday, September 25, 13

Zoo volunteers can :

- match the radio emission to the host galaxy/galaxies responsible

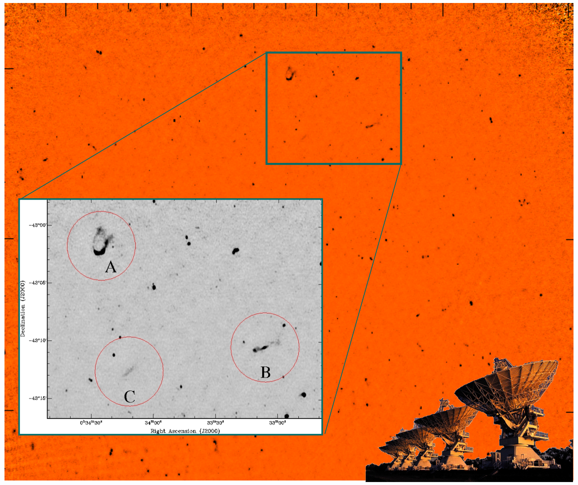
- classify the radio morphologies:
  - compact/extended/multiple/WATs
  - existence of central components
  - if radio lobes exist, are they attached or separate ?
  - measure angles between elongated radio emission etc....

The journey of a thousand miles begins with a single step.

—LaoZi (4th century BC)

Phase 1: Match the radio emission to its host galaxy

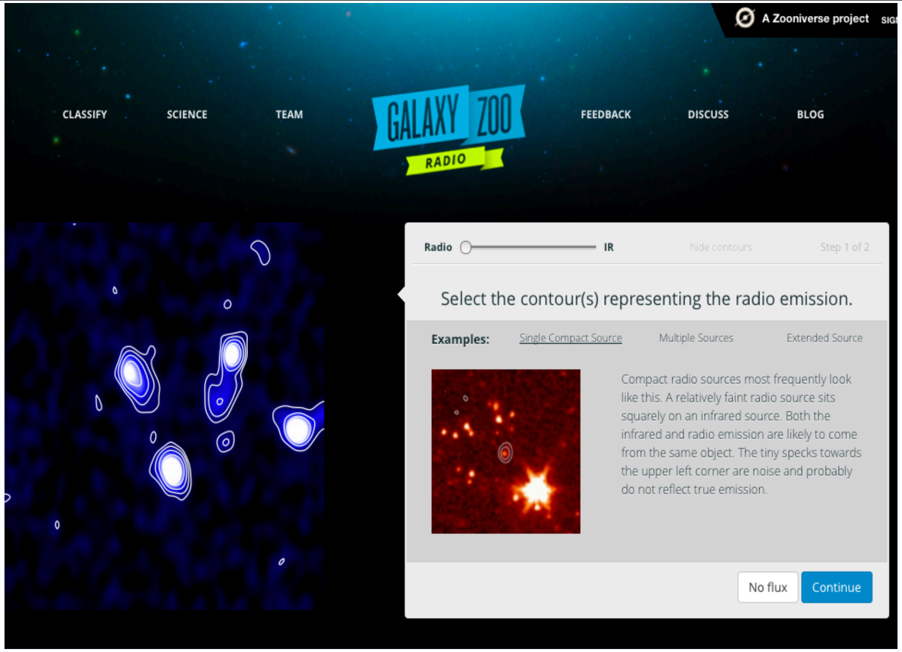
ATLAS



+

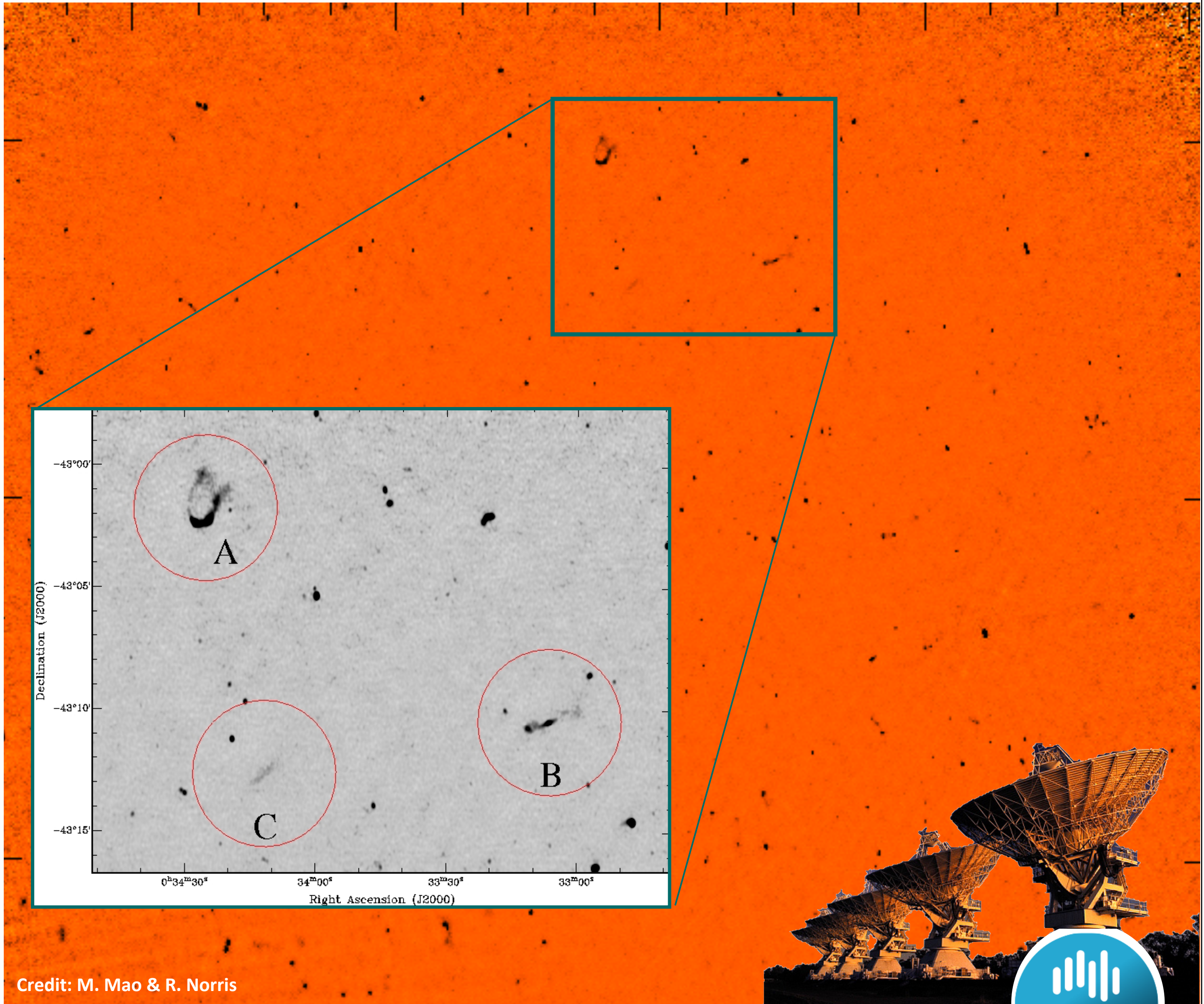
SWIRE

Zooniverse environment



Australia Telescope Large Area Survey (ATLAS)

- 7 square degrees
  ➡ centred on CDFS & ELAIS-S1 fields
- ~10,000 galaxies
- RMS ~ 10μJy
- Resolution: 10”



Premise of current beta:

- match the radio emission to the host galaxy/galaxies responsible
  ➡ use pre-IDed ATLAS+SWIRE sample of the ELAIS-S1 field from Middelberg+08

- classify the radio morphologies:
  ➡ no "complex" measurements at this stage

earlier alpha test of a more complex workflow appeared to have confused people

So we are keeping this beta simple to evaluate the effectiveness of the volunteers by comparing with published cross-IDs.

deal with the radio contours vs IR images

Interface:

Slides between images to examine whether they have compact/extended/multiple radio sources

↓

Select the radio emission by clicking on the contours

↓

Draw a circle around host galaxy

What we get :

- Number of radio components corresponding to each IR galaxy
- coordinates of 4 'corners' + centre of each radio blob
  ➡ these 5 coordinates enough to provide simple radio morphology

- coordinates of one or more host galaxies corresponding to radio emission

CLASSIFY | SCIENCE | TEAM | GALAXY ZOO RADIO | FEEDBACK | DISCUSS | BLOG

In Search of Erupting Black Holes

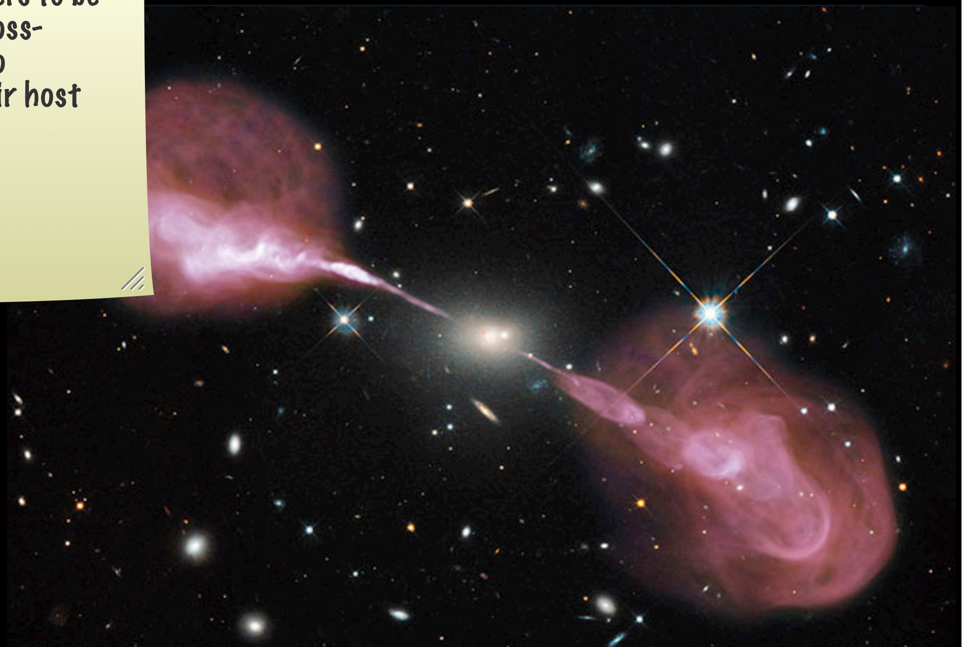
Help astronomers discover supermassive black holes observed by the Australia Telescope Large Area Survey.

The idea is for users to be able to help us cross-identify the radio sources with their host galaxies

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

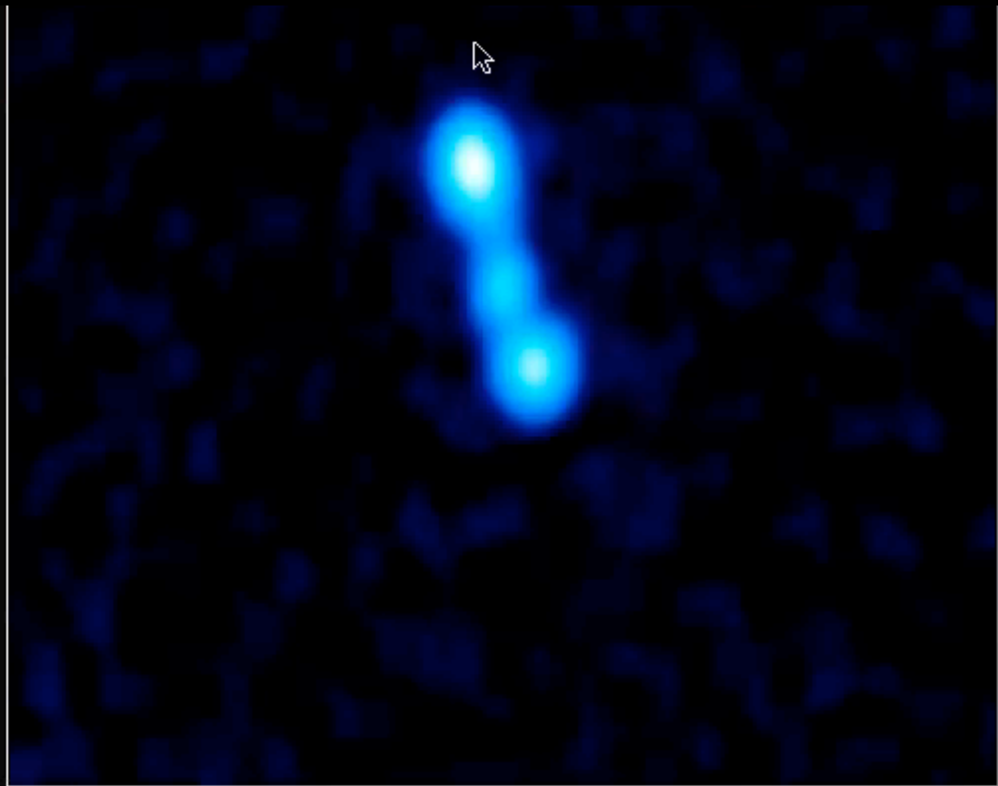


Credit: NASA, ESA, S. Baum and C. O'Dea (RIT), R. Perley and W. Cotton (NRAO/AUI/NSF), and the Hubble Heritage Team (STScI/AURA)

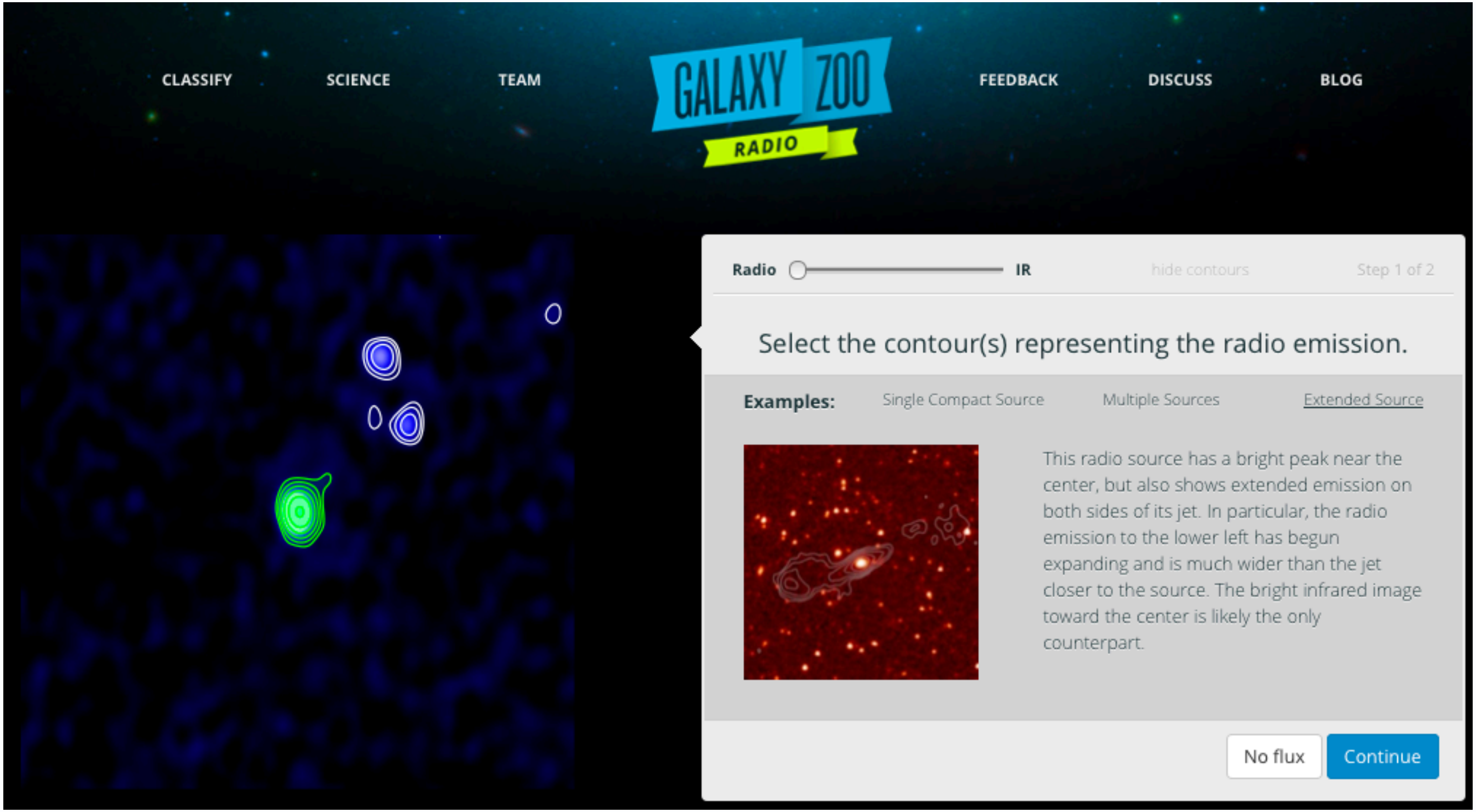
CLASSIFY SCIENCE TEAM GALAXY ZOO RADIO FEEDBACK DISCUSS BLOG

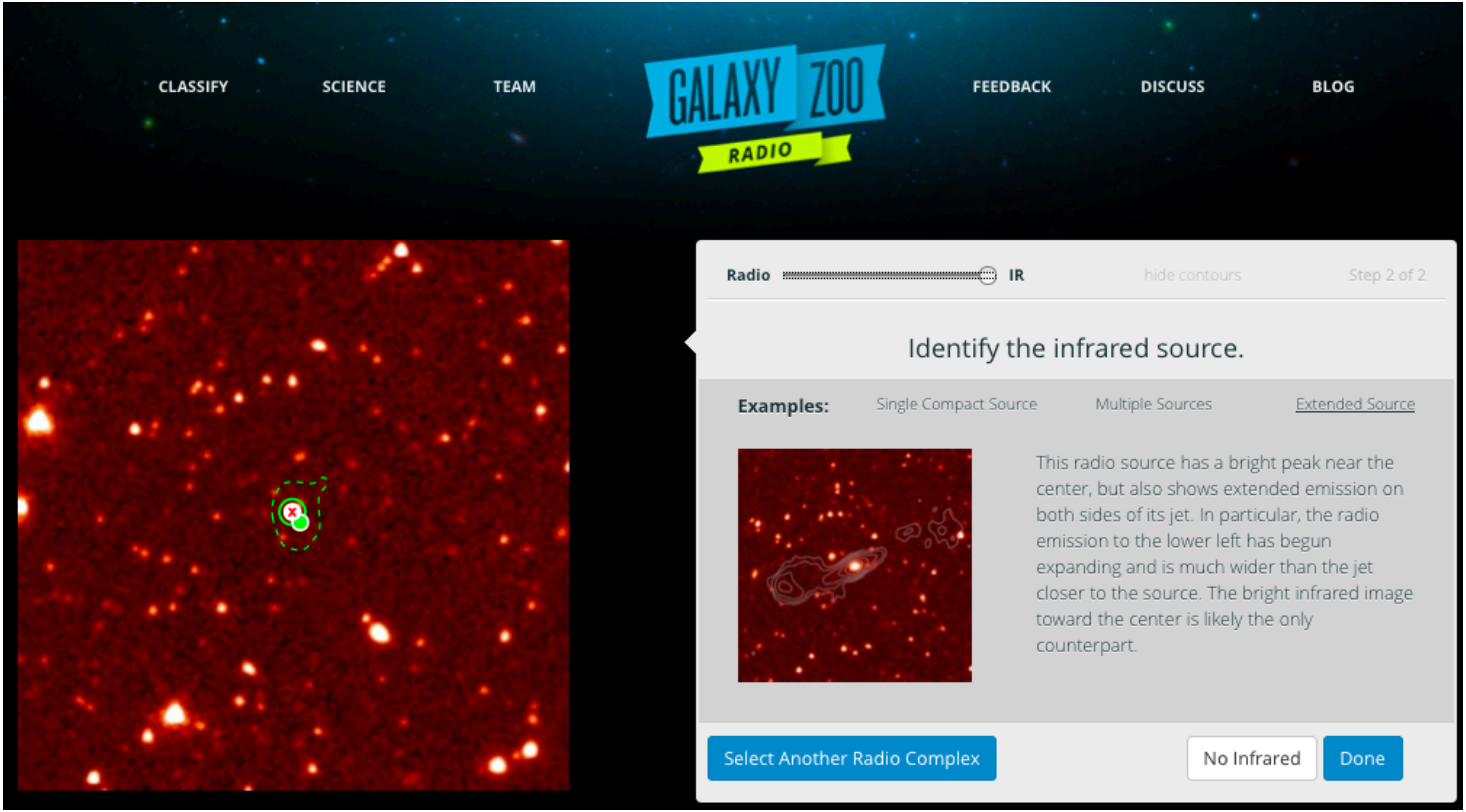
In Search of Erupting Black Holes

Help astronomers discover supermassive black holes observed by the Australia Telescope Large Area Survey.

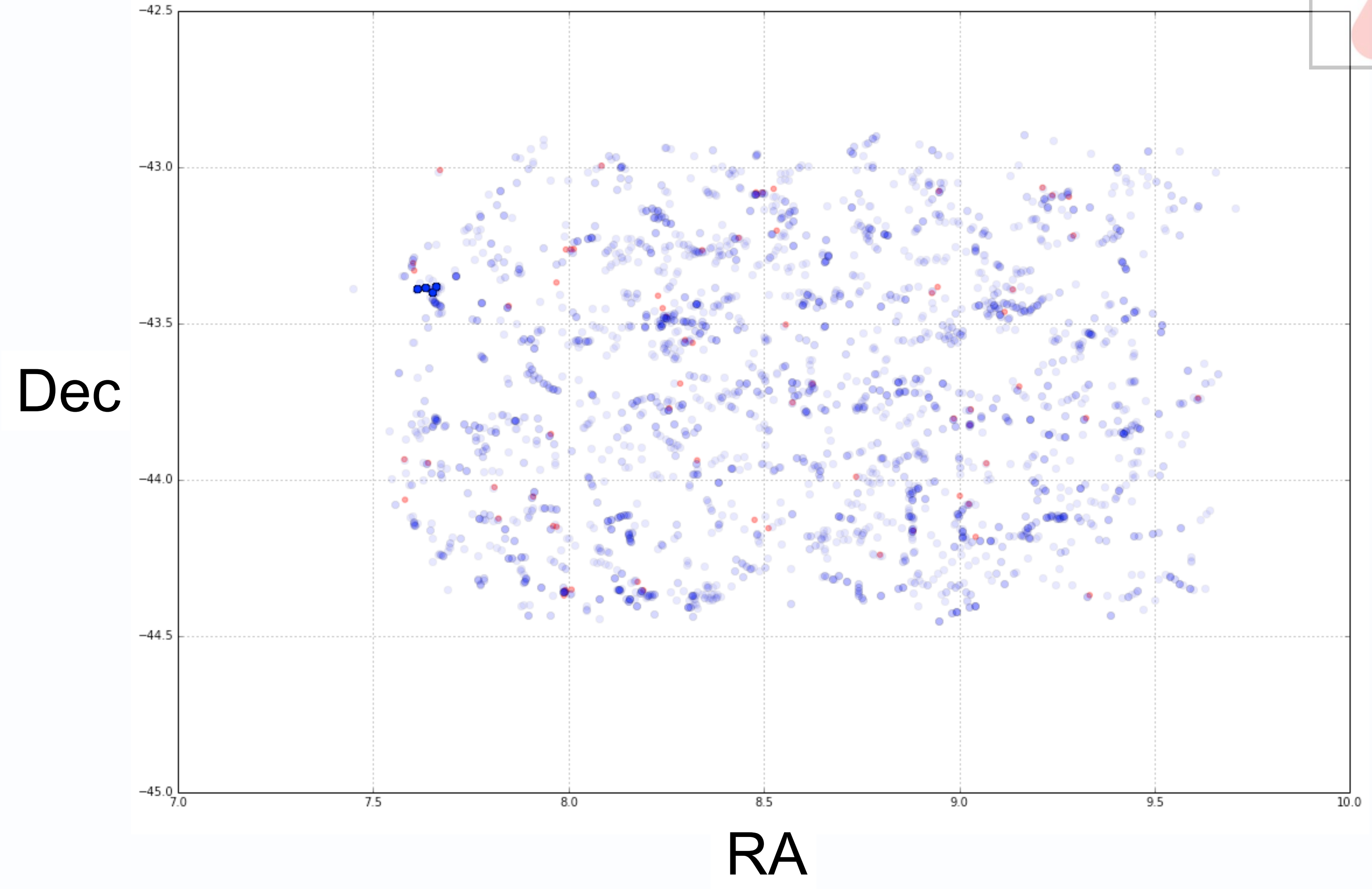


RADIO INFRARED

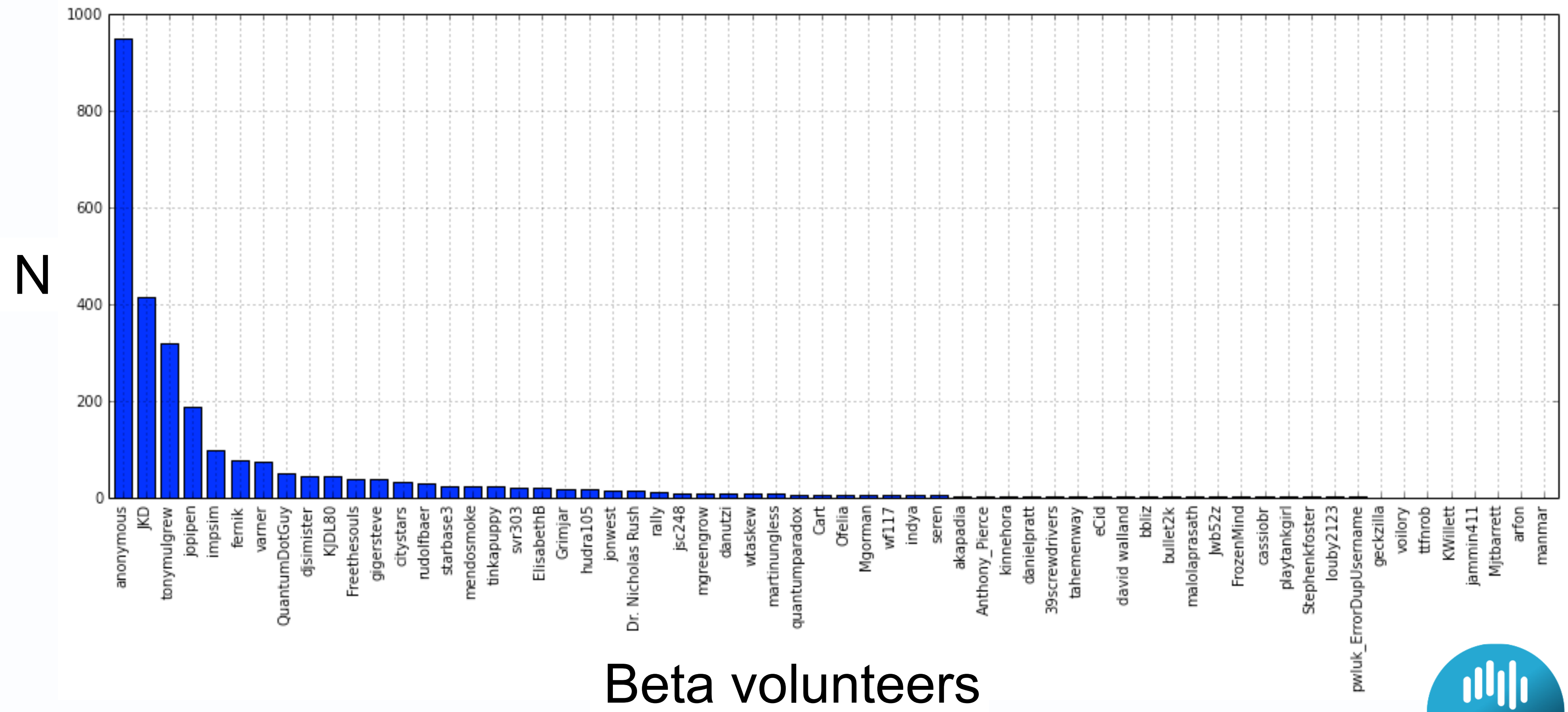

CLASSIFY
SCIENCE
TEAM
GALAXY ZOO
RADIO
FEEDBACK
DISCUSS
BLOG
Radio
IR
hide contours
Step 1 of 2
Select the contour(s) representing the radio emission.
Examples:
Single Compact Source
Multiple Sources
Extended Source
This radio source has a bright peak near the center, but also shows extended emission on both sides of its jet. In particular, the radio emission to the lower left has begun expanding and is much wider than the jet closer to the source. The bright infrared image toward the center is likely the only counterpart.
No flux
Continue


CLASSIFY
SCIENCE
TEAM
GALAXY ZOO
RADIO
FEEDBACK
DISCUSS
BLOG
Radio
IR
hide contours
Step 2 of 2
Identify the infrared source.
Examples:
Single Compact Source
Multiple Sources
Extended Source
This radio source has a bright peak near the center, but also shows extended emission on both sides of its jet. In particular, the radio emission to the lower left has begun expanding and is much wider than the jet closer to the source. The bright infrared image toward the center is likely the only counterpart.
Select Another Radio Complex
No Infrared
Done

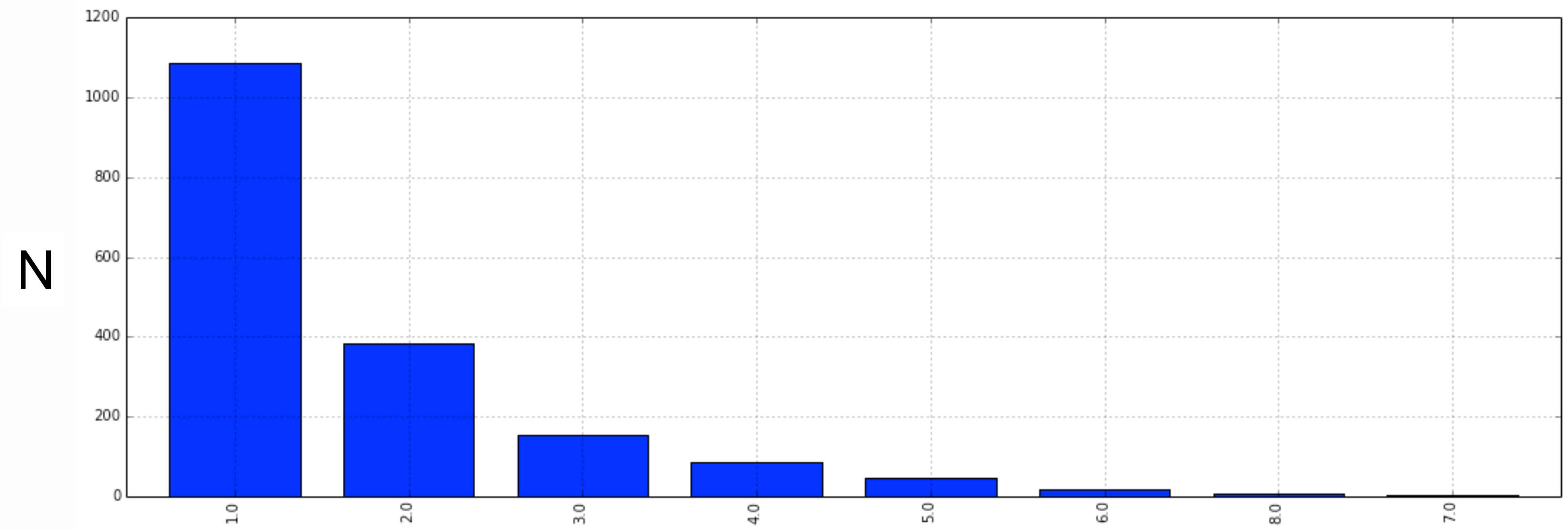
Beta testing w ELAIS-S1...



Beta testing (ii)

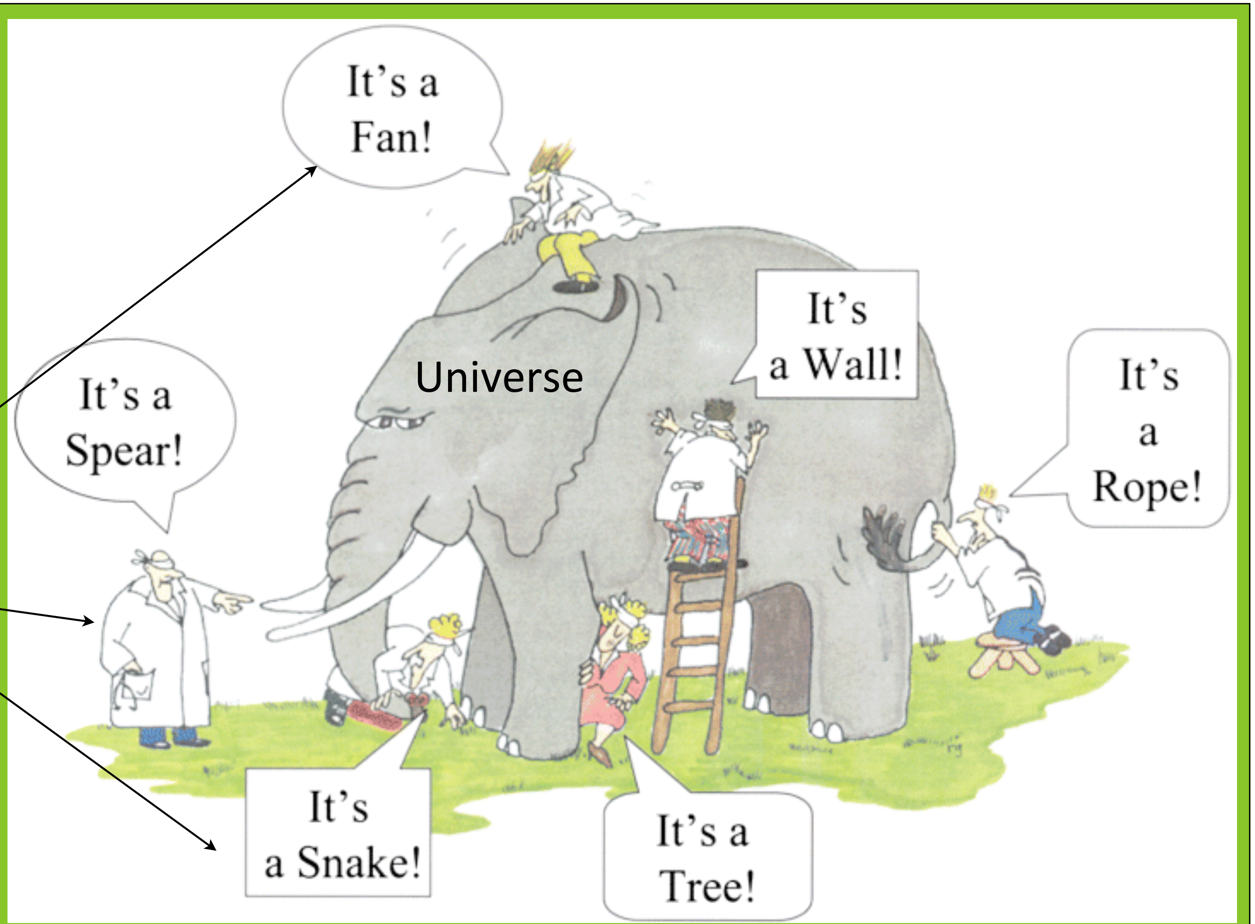


Beta testing (iii)



N-radio components/image

various methods



Thank you

CSIRO Astronomy & Space Science
O. Ivy Wong
Australian Research Council Super Science Fellow

t +61 2 9372 4148
e ivy.wong@csiro.au
w www.atnf.csiro.au/people/Ivy.Wong