Radio luminosity functions
with Radio Galaxy Zoo and machine learning

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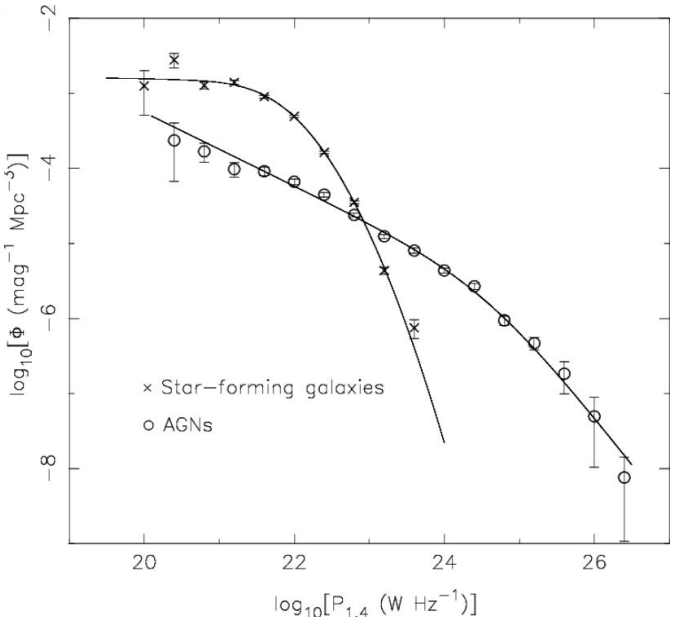
Slides: http://www.mso.anu.edu.au/~alger/ml-projects-18

Australian National University

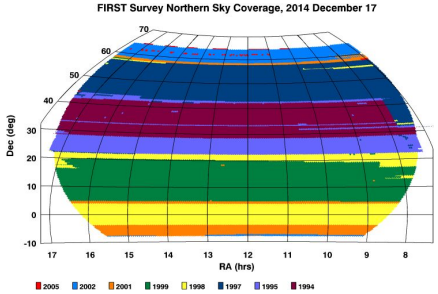
Radio luminosity functions

- Comoving density of radio sources as a function of radio luminosity
  - Units of mag^{-1} Mpc^{-3}
  - Comoving density accounts for universe size and shape over cosmic time
  - Distribution of radio source luminosities in a *physically meaningful* way
- Fractional radio luminosity functions
  - Luminosity function of a subset of sources
  - Luminosity distribution of physically-selected subsets may be different
  - Helps understand evolution and structure of radio galaxies



Radio luminosity function divided into radio due to star formation and radio due to active galactic nuclei.
Image: Mauch & Sadler (2007)

Radio Galaxy Zoo



FIRST (radio)

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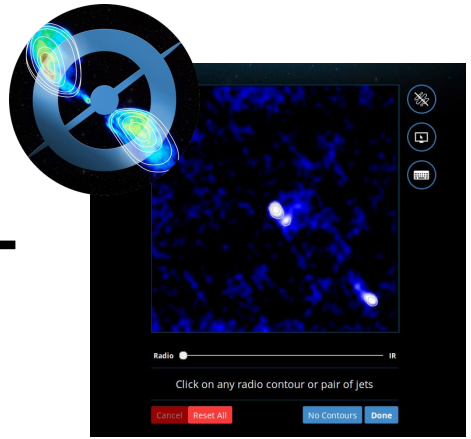
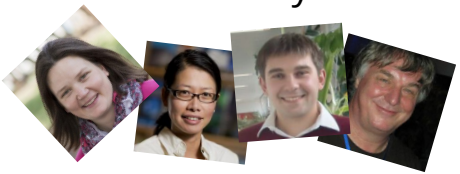


Radio Galaxy Zoo



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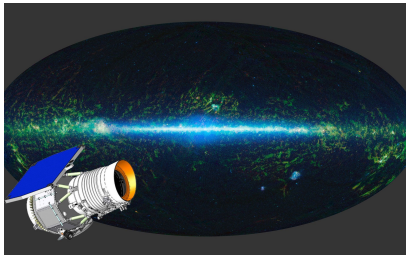
Zooniverse ID (3)	RA (4)	Declination (5)	N_{votes} (6)	N_{total} (7)	CL (8)
ARG000255v	251.679244	23.382107	41	42	0.98
ARG000255x	163.799660	23.384972	58	58	1.00
ARG000255y	138.960429	23.381641	43	43	1.00
ARG000255z	126.215156	23.381729	35	35	1.00
ARG0002560	149.273620	23.381661	40	40	1.00

Radio Galaxy Zoo cross-identification catalogue



WISE (infrared)

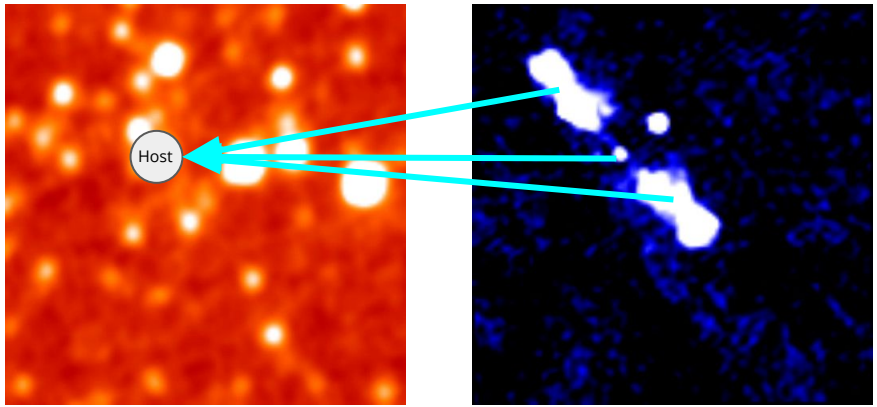
Cross-identification as binary classification

- Cross-identification
  - Match radio emission to infrared host galaxies
  - Output of Radio Galaxy Zoo
- Can be cast as binary classification
  - Binary classification is well-understood
  - Lots of off-the-shelf classification models
  - Easy to train
- Problems:
  - Converting cross-identification catalogues to binary labels loses information
  - Unclear how uncertainties in this formulation are related to dataset or physical uncertainties

$$f : \mathbb{R}^d \rightarrow \mathbb{R}$$

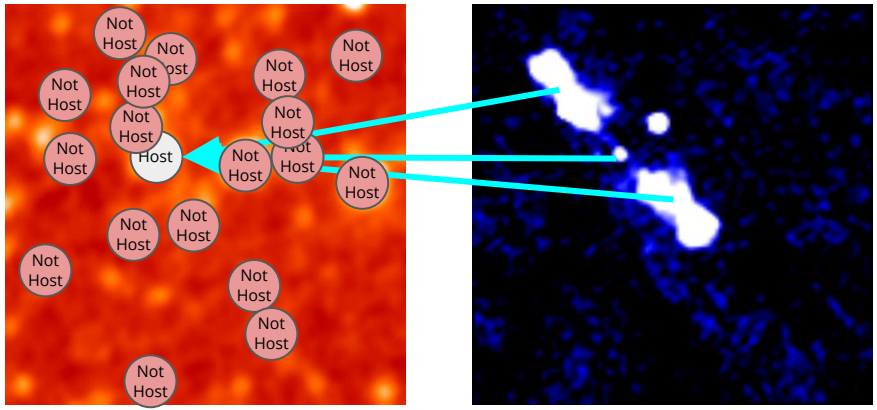
$$\text{xid} : \text{Radio} \rightarrow \text{IR}$$
$$\text{xid}(r) = \text{argmax } f(i; r)$$
$$i \in \text{IR objects}$$

Learning from Radio Galaxy Zoo



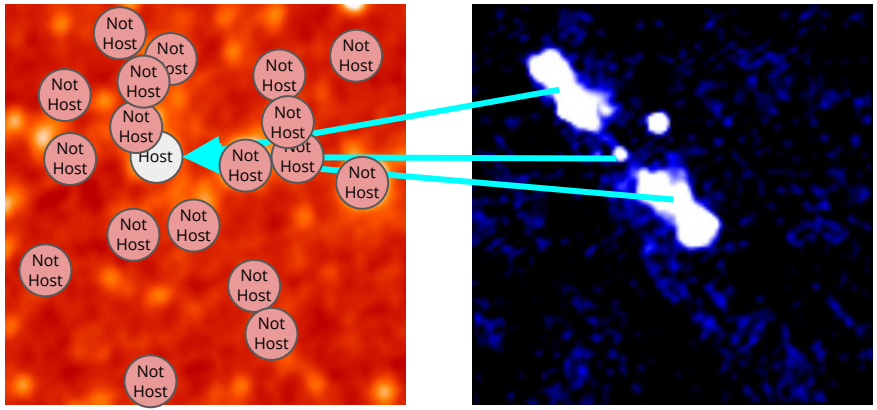
- Assign hosts positive labels

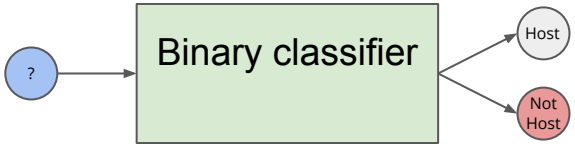
Learning from Radio Galaxy Zoo



- Assign hosts positive labels
- Assign everything else negative labels

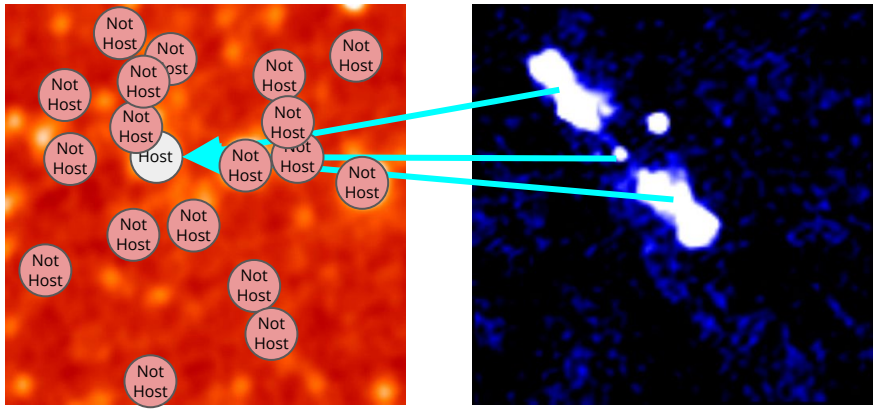
Learning from Radio Galaxy Zoo





- Assign hosts positive labels
- Assign everything else negative labels
- Train classifier to identify *host* and *not host* classes

Learning from Radio Galaxy Zoo



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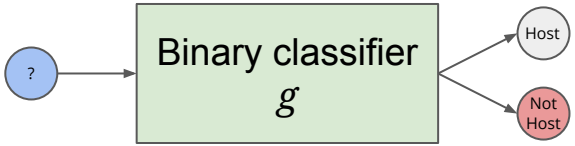
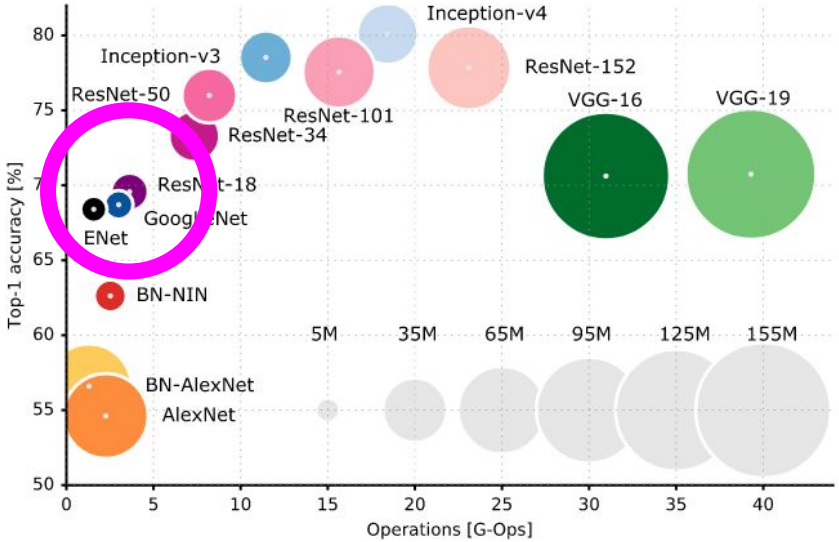


$$\text{xid} : \text{Radio} \rightarrow \text{IR}$$

$$\text{xid}(r) = \underset{i \in \text{IR objects}}{\text{argmax}}\ g(i)\ \mathcal{N}(r, i)$$

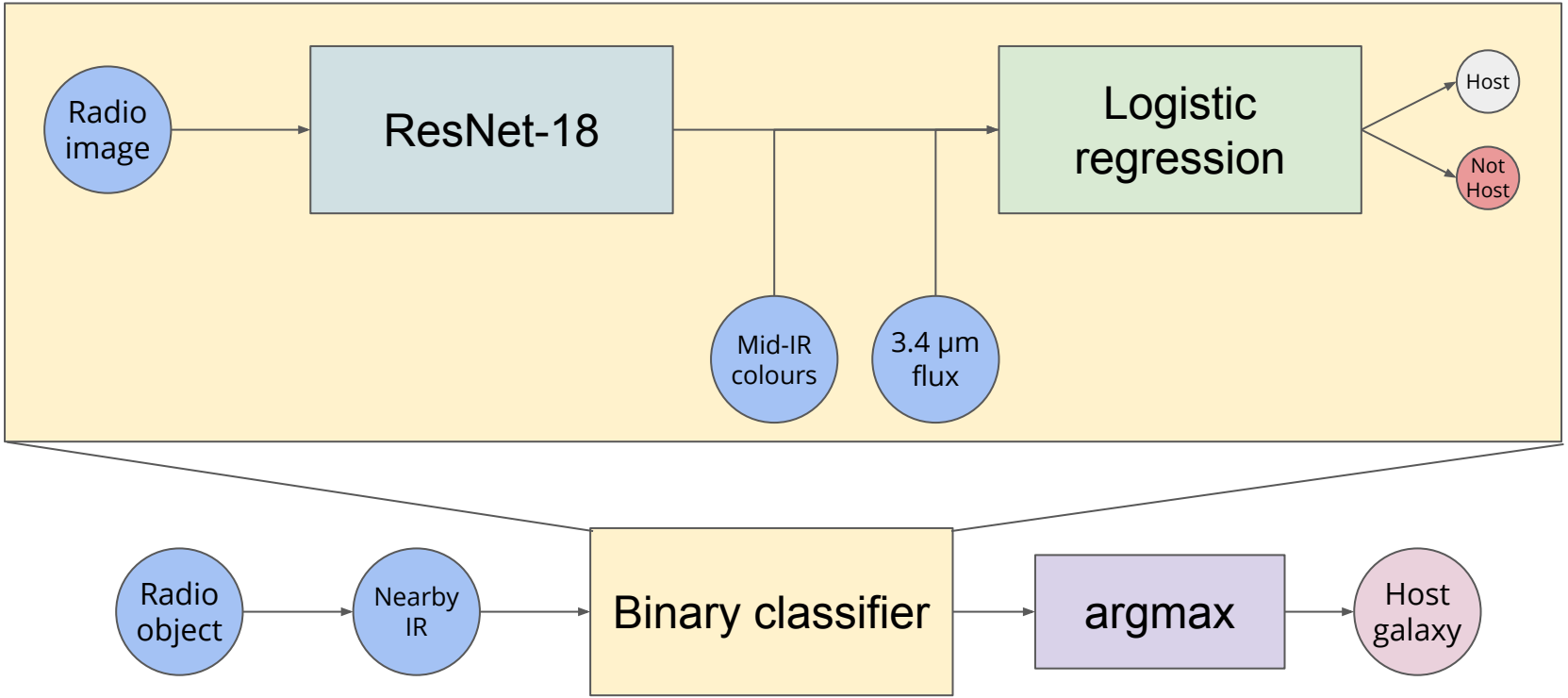
Binary classification model

- ResNet-18 (multiclass)
  - Good accuracy
  - Low complexity
  - Very fast to train and use
- Remove last layer and replace with a binary classifier
- Add non-image features
  - Mid-infrared colours
  - 3.4 μm flux
  - Room for improvement — e.g. add redshifts



Trade-offs between network complexity and accuracy on ImageNet.
Image: Canziani et al. (2016)

Binary classification model



Luminosity function

- RGZ-Ex contains 214 214 cross-identified radio sources with 26 268 redshifts
  - >4x more sources than RGZ
  - >2x more sources with redshifts than RGZ
- Large sample allows us to build a radio luminosity function of extended sources
  - Luminosities up to 10^{26} W/Hz
  - Close match to Mauch and Sadler (2007) radio AGN luminosity function

Radio Galaxy Zoo: radio luminosity functions of extended sources

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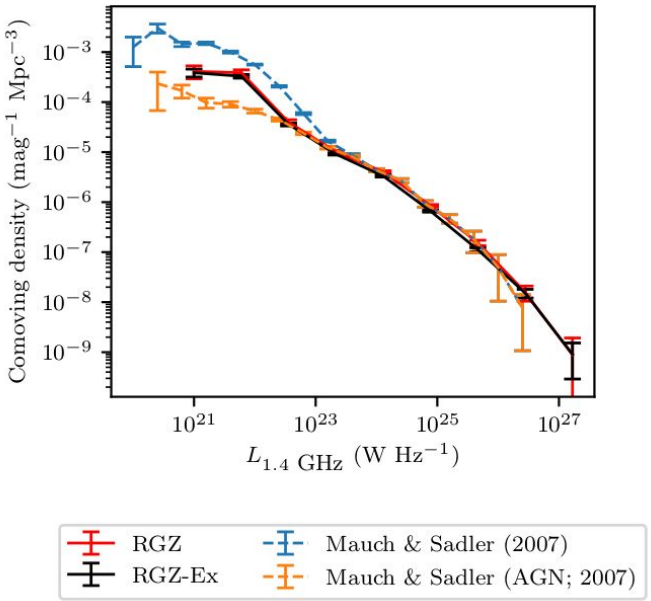
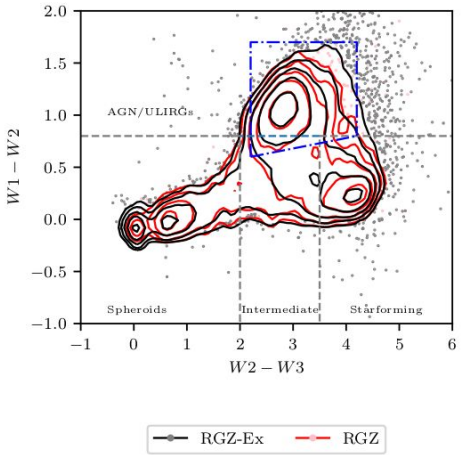
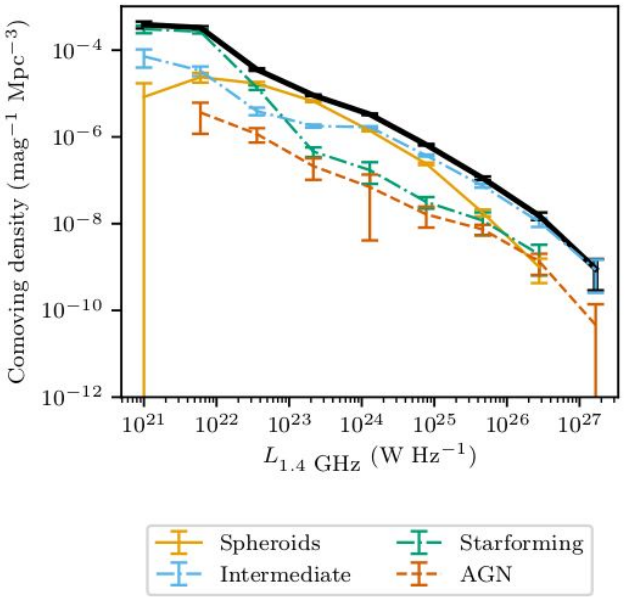


Fractional luminosity function (Mid-IR)

- Divide radio luminosity function based on mid-infrared host colours
  - “Extended” starforming sources below 10^{23} W/Hz (manually verified)
  - Radio-loud sources dominated by “intermediate” galaxies





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