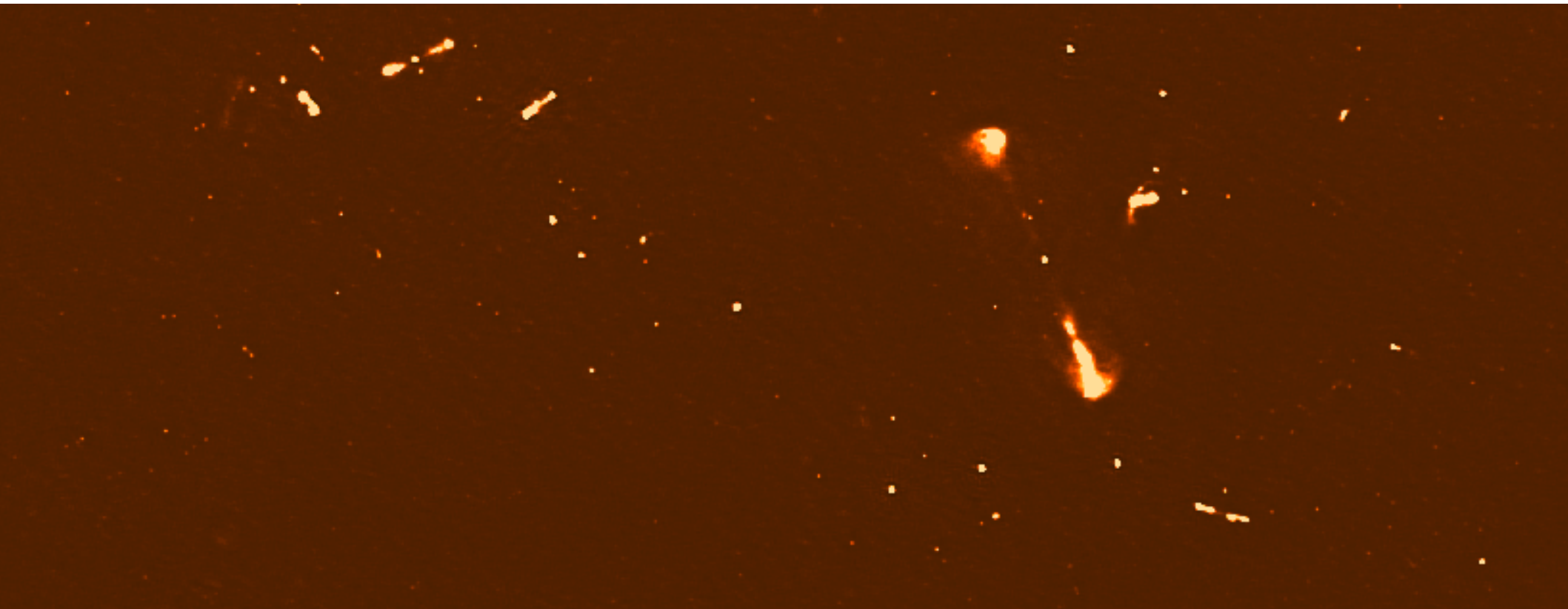


Host Galaxies of Radio Sources in LOFAR Deep Fields

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University of Edinburgh



Credits: Philip Best, LOFAR KSP,
(Radio): Cyril Tasse, Tim Shimwell, Pepe Sabater, Martin Hardcastle
(Multi-wavelength): Ken Duncan, Matteo Bonateo



Motivation and Outline

Study properties of radio galaxies and their hosts and how these properties evolve

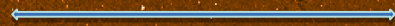
- Finding counterparts of radio sources crucial for maximising scientific output
 - Allows photo-z estimate (luminosity, physical sizes, etc.) and physical parameters
- Source classification: Separate SFGs, AGN, HERG/LERGs

Radio Data (LOFAR HBA)

Field	Data before Cycle 10	Allocated time Cycle 10-13	Analysed for Data Release 1	Depth ($\mu\text{Jy}/\text{bm}$)
Boötes	80 hrs	80 hrs	80 hrs	~37
Elais-N1	180 hrs	160 hrs	170 hrs	~20
Lockman Hole	72 hrs	80 hrs	112 hrs	~25

Deep Fields Release 1: ~ 100,000 sources over 30 sq. deg. with excellent multi-wavelength data

Elais-N1: 20 μ Jy/bm rms



1 degree

Elais-N1: 20 μ Jy/bm rms



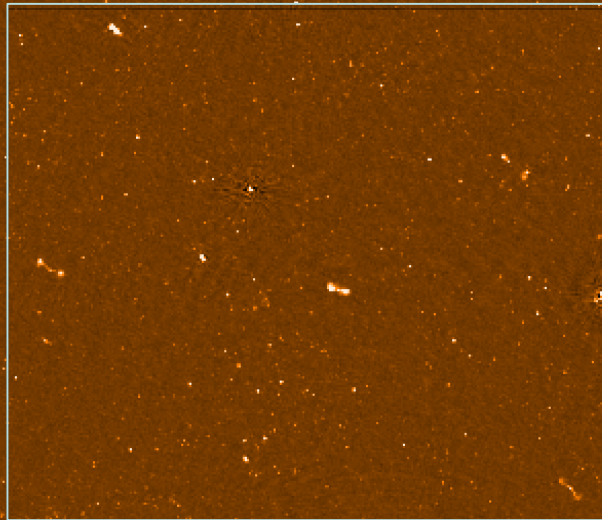
1 degree

Elais-N1: $20\mu\text{Jy}/\text{bm rms}$



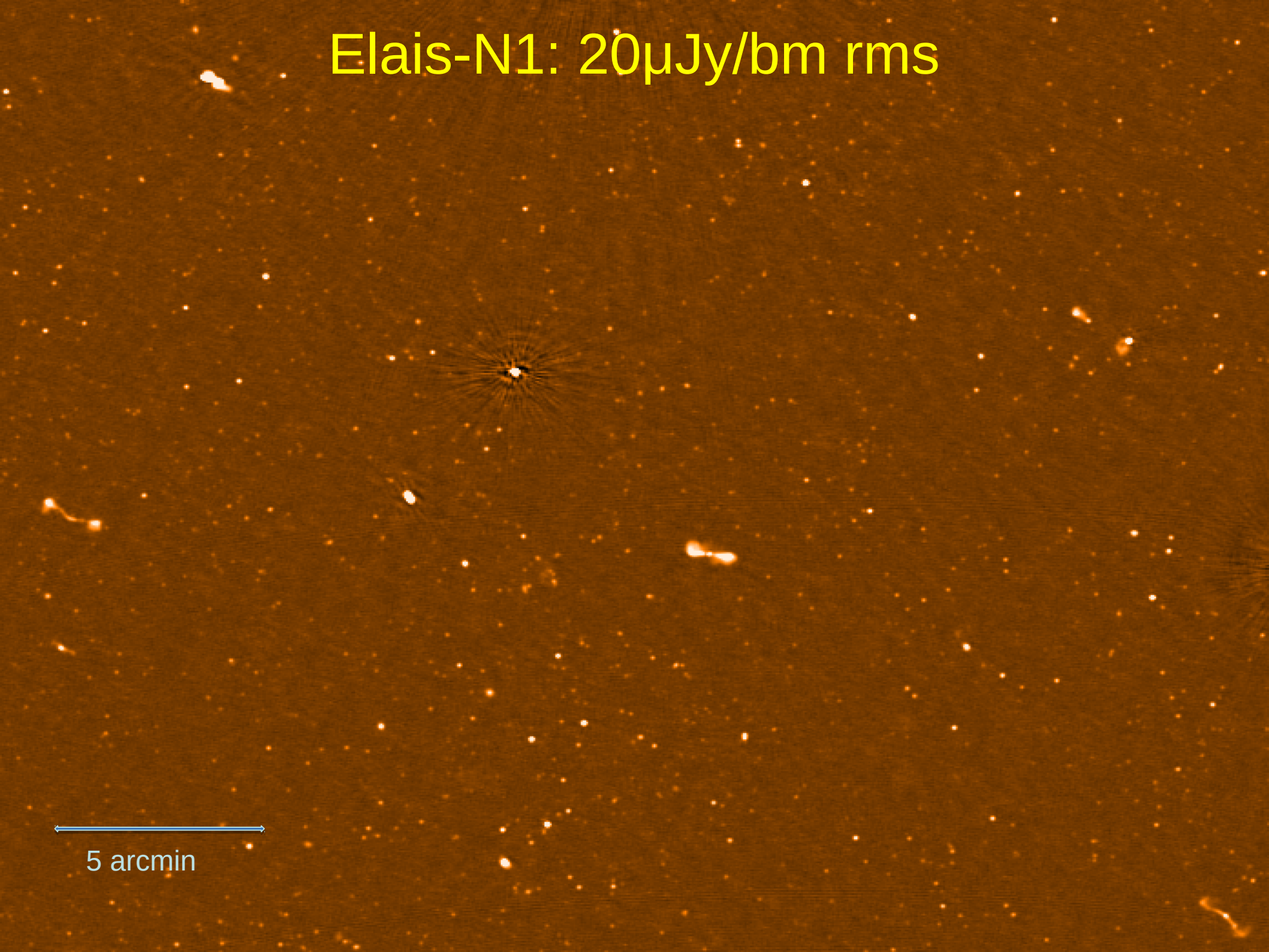
15 arcmin

Elais-N1: $20\mu\text{Jy}/\text{bm rms}$



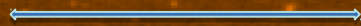
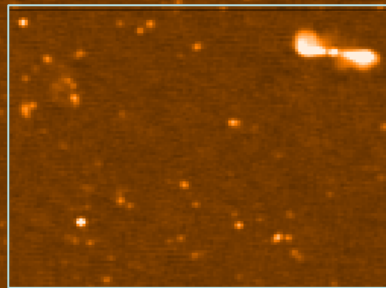
15 arcmin

Elais-N1: $20\mu\text{Jy}/\text{bm rms}$



5 arcmin

Elais-N1: $20\mu\text{Jy}/\text{bm rms}$



5 arcmin

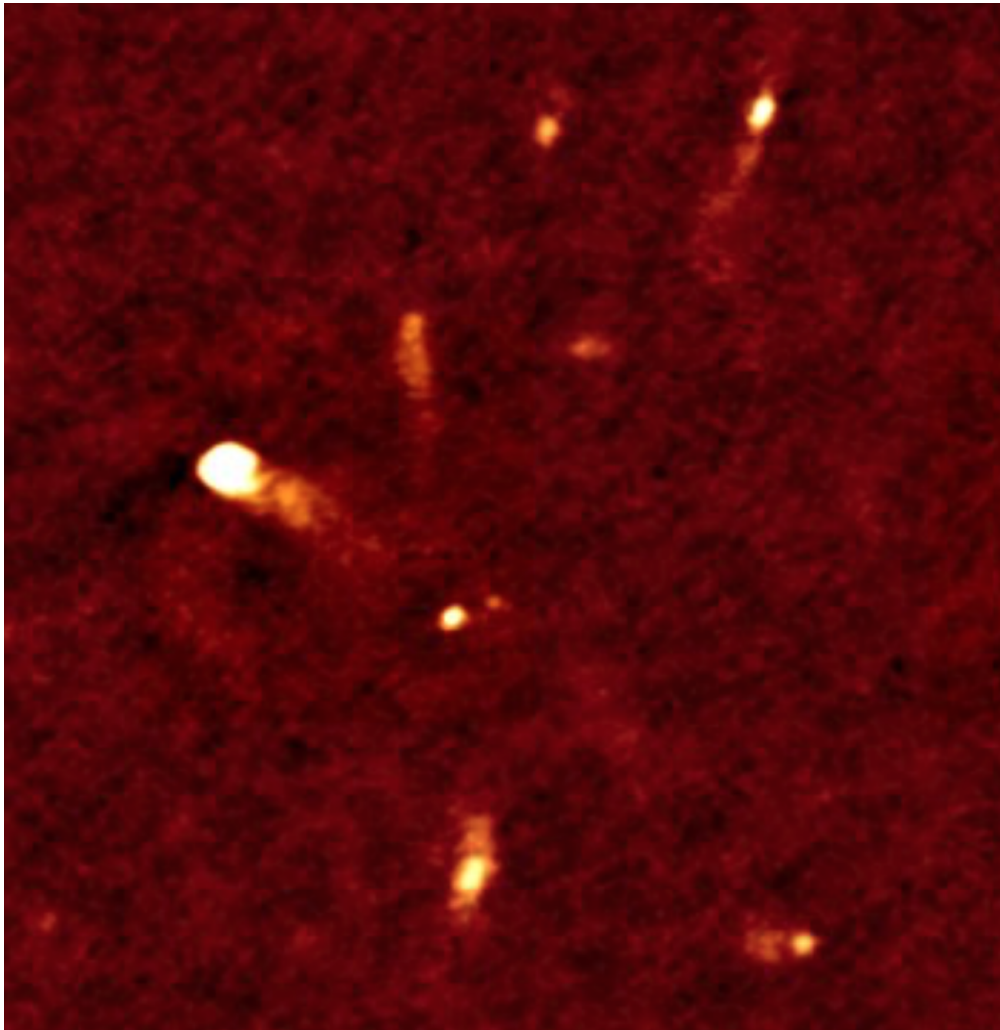
Elais-N1: 20 μ Jy/bm rms



1 arcmin

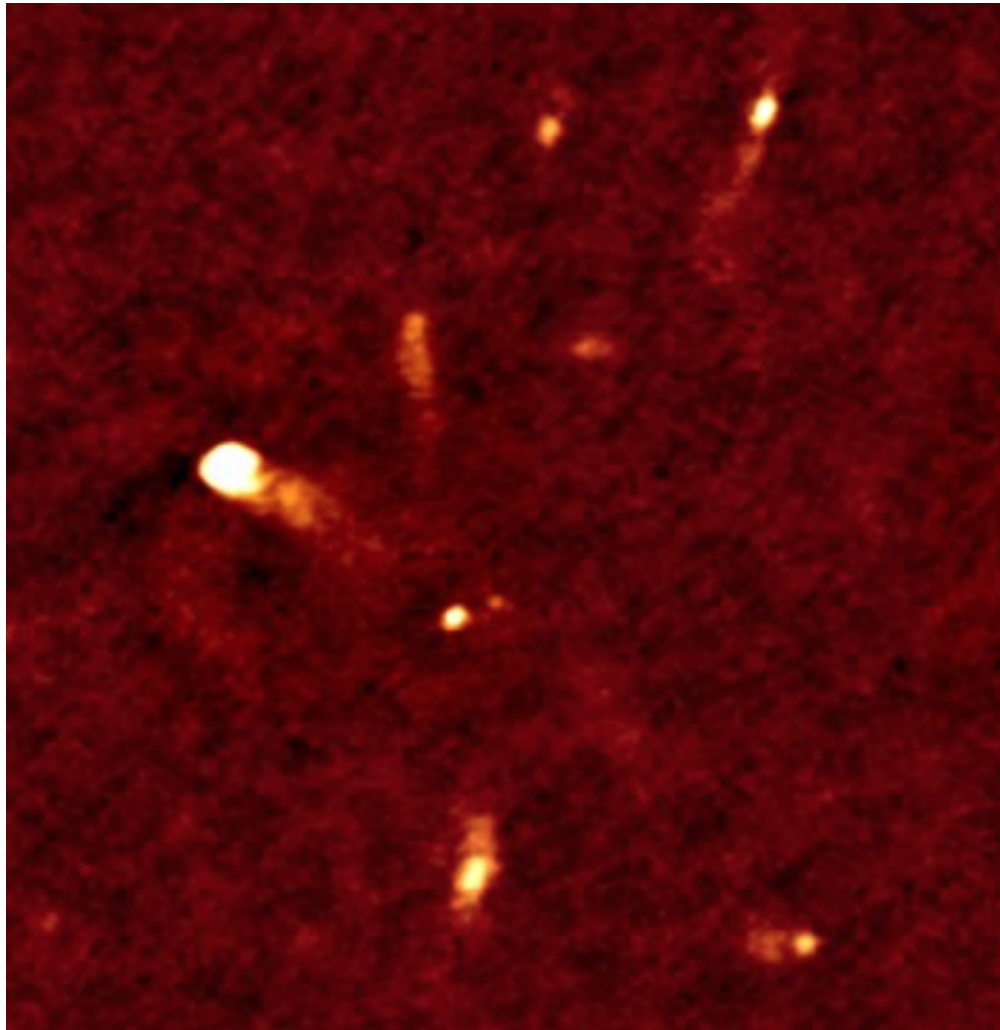
Fireworks region

8 hrs

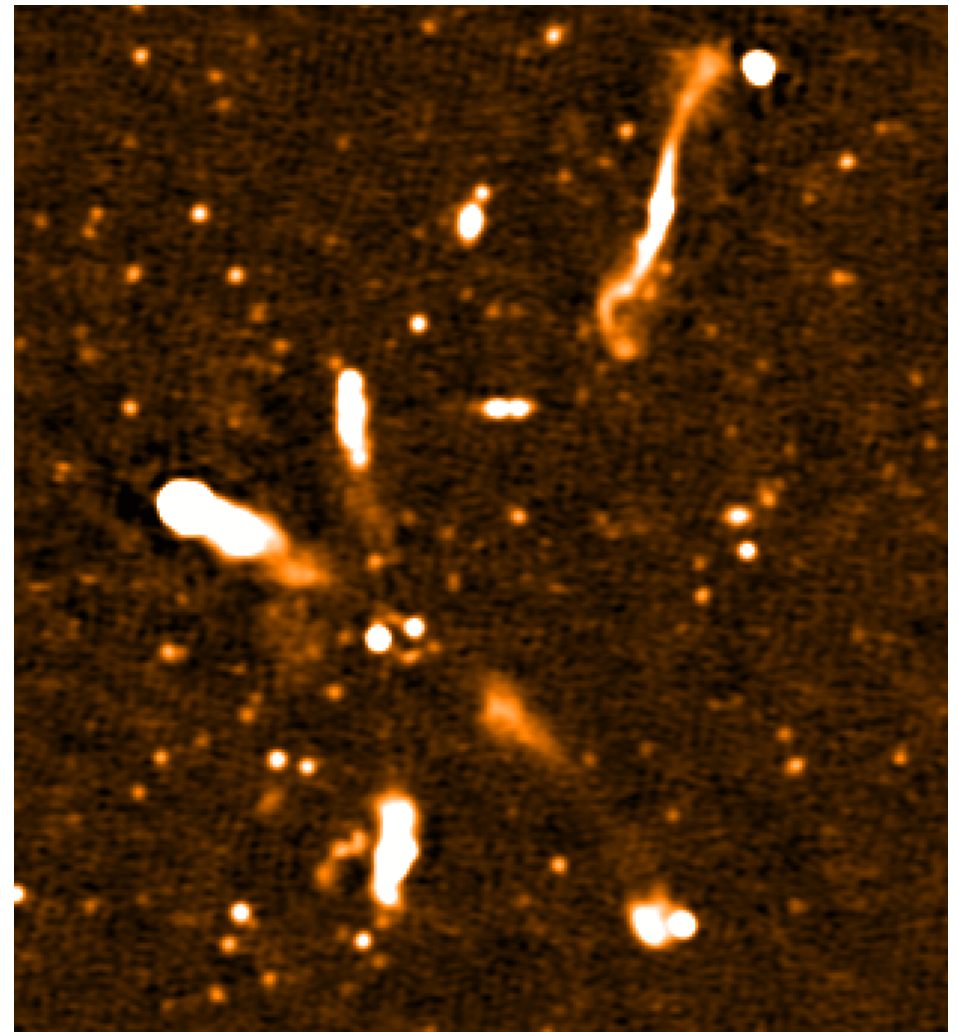


Fireworks region

8 hrs



170 hrs



Optical Data

- Multi-wavelength information crucial in maximising scientific output
- ELAIS-N1 has deep photometry
 - Optical ugrizy bands: PanSTARRS, HSC, CFHT/MegaCAM
 - IR: UKIDSS J and K, Spitzer 3.6, 4.5, 5.8, 8 and 24 μm
 - FIR: Herschel bands
 - GALEX NUV and FUV
- Forced, matched aperture catalogues
 - Images re-gridded onto common pixel scale
 - Create deep detection images
 - Perform forced photometry (using SExtractor)

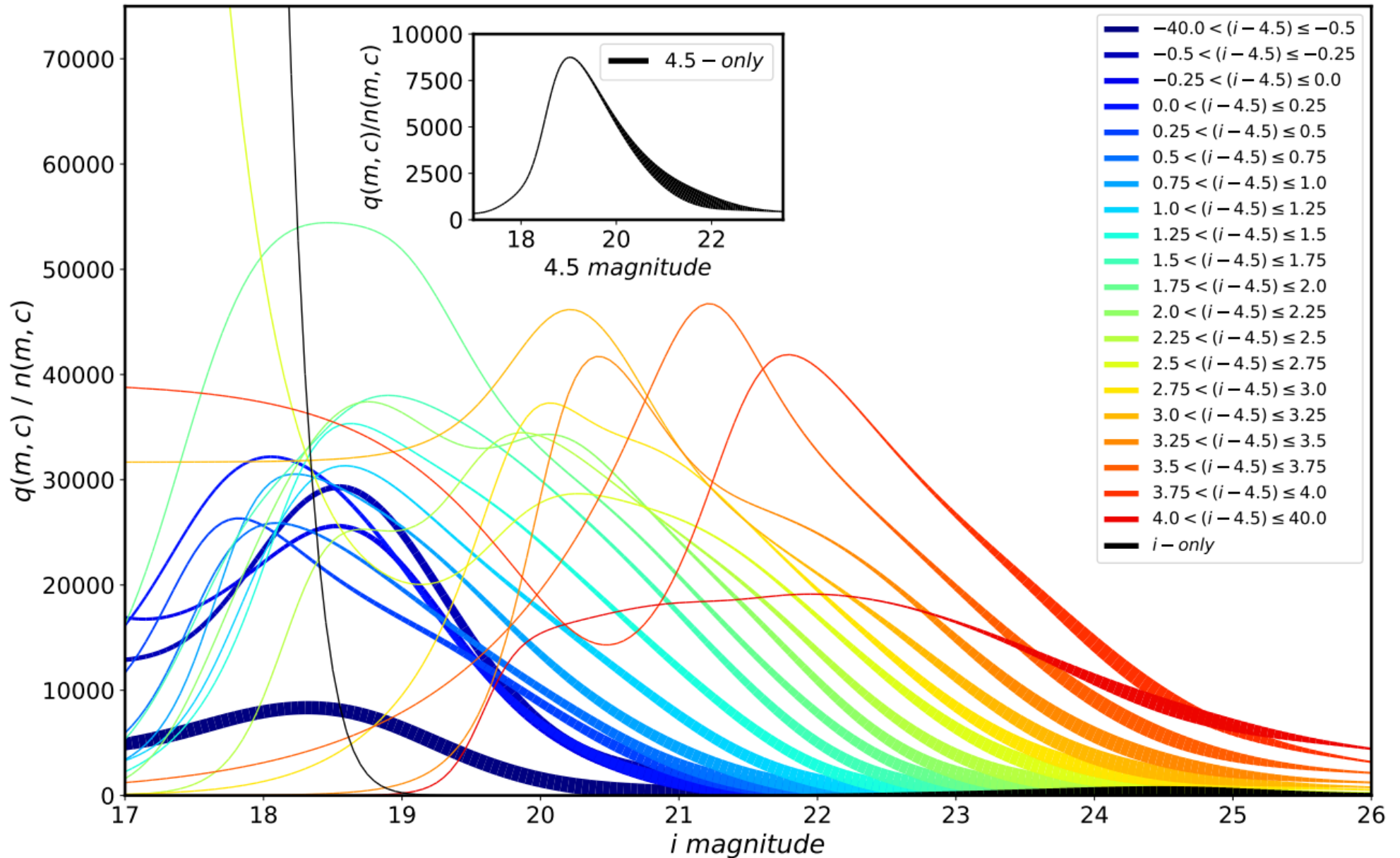
Likelihood Ratio Cross-Match

- Likelihood Ratio (LR) technique - statistical tool to find counterparts to radio galaxies

$$LR = \frac{f(r)q(m, c)}{n(m, c)}$$

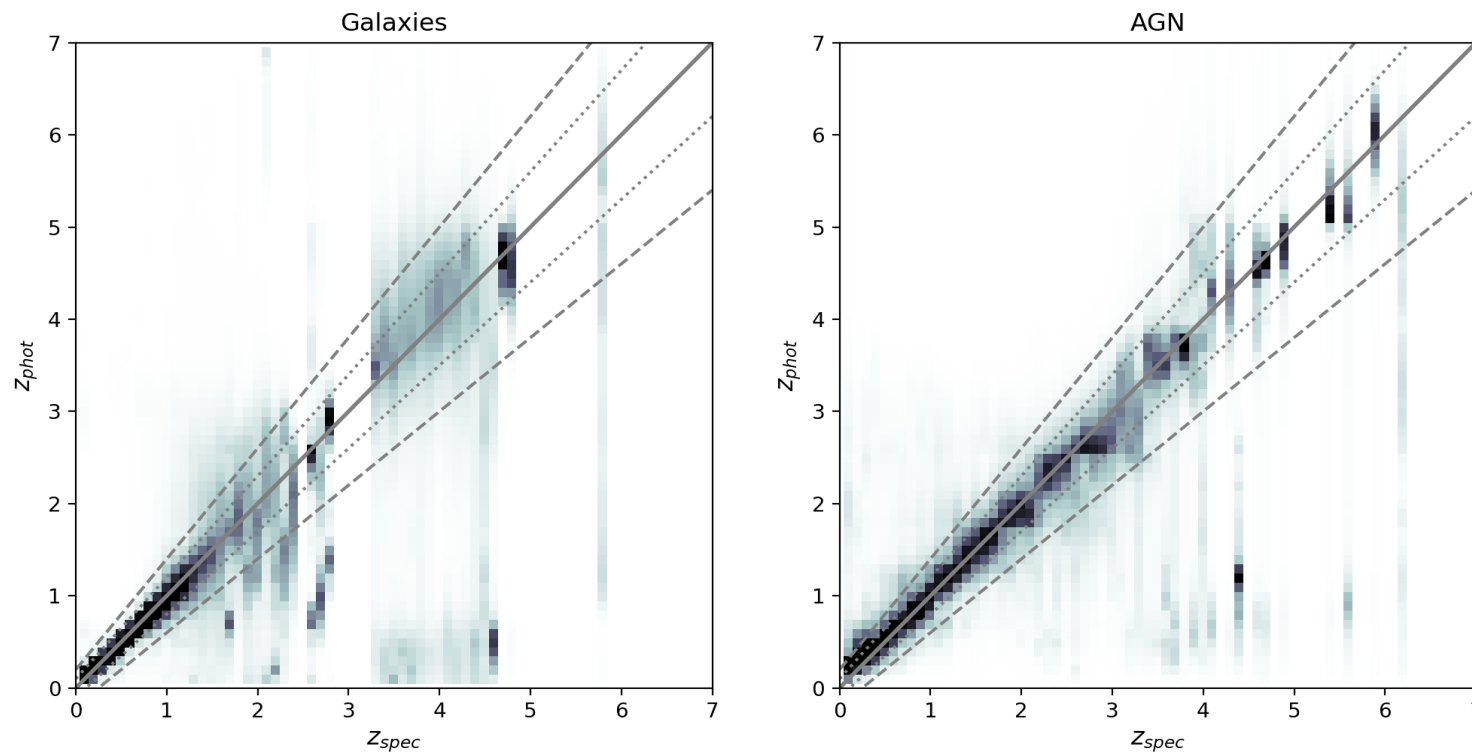
1. Magnitude info. only to estimate $q(m)$ (Fleuren+2012)
 2. Split by (i-4.5) colours bins to estimate $q(m,c)$
 3. Rederive LR's and iterate until $q(m,c)$ converges (Nisbet 2018, Williams+2019)
- In ELAIS-N1: Cross-ID fraction > 95%
 - Visual classification used when LR is not suitable

Likelihood Ratio Results



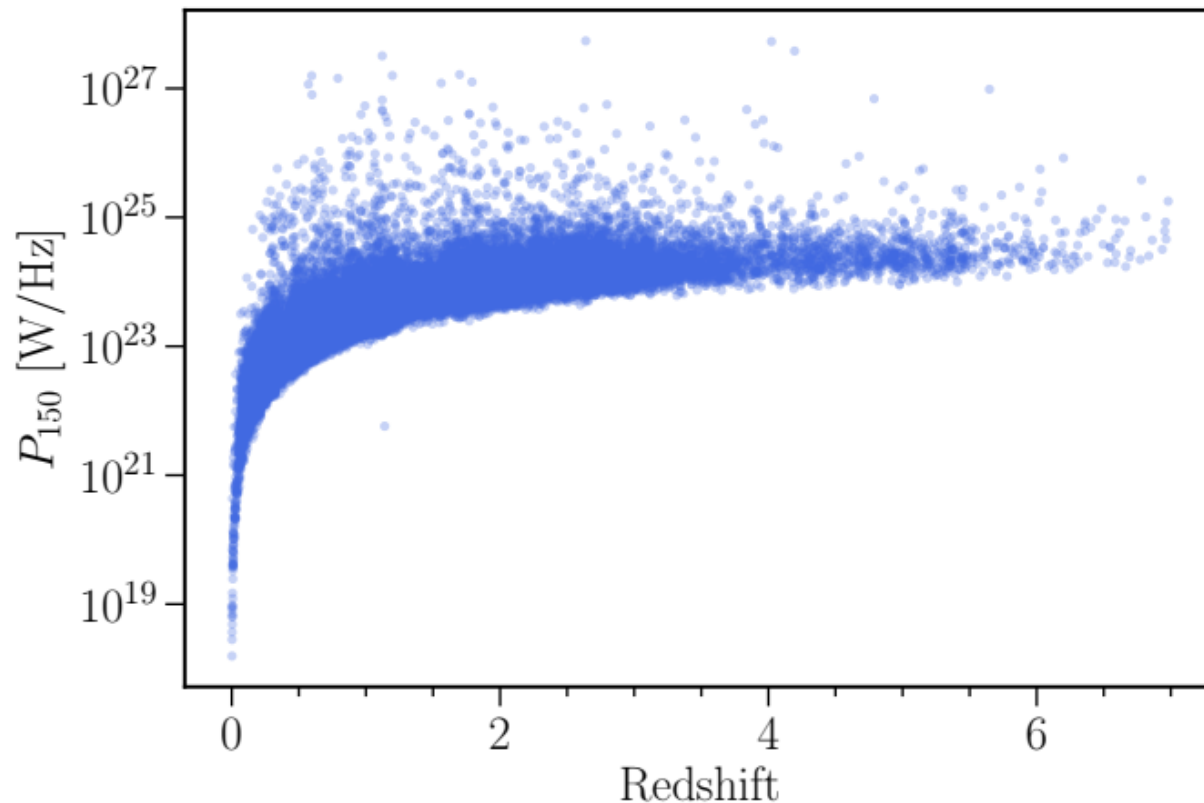
Photometric Redshifts

- Credit: Ken Duncan
- An optimised hybrid technique combining templates and machine learning (Duncan+2019)
- Robust till $z \sim 1.5$ for galaxies and $z > 3$ for AGN



Photometric Redshifts

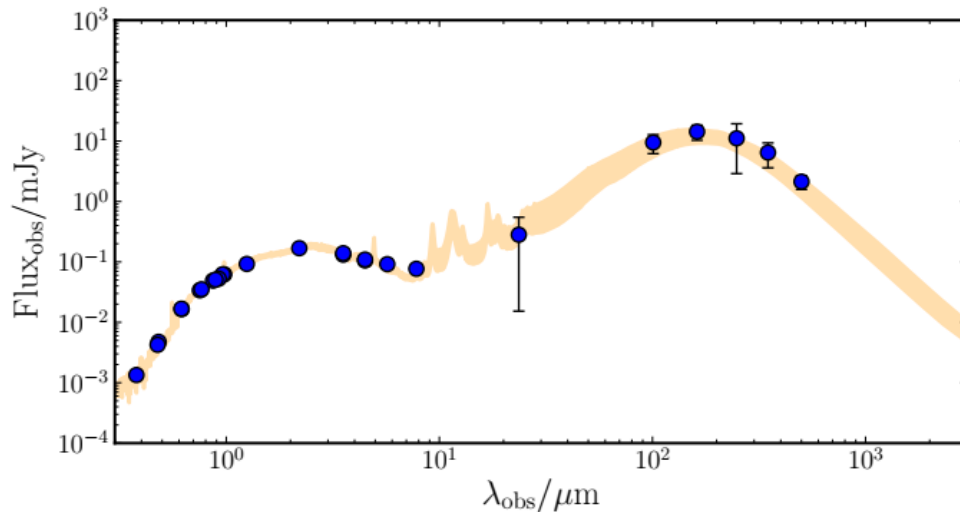
- Credit: Ken Duncan
- An optimised hybrid technique combining templates and machine learning (Duncan+2019)



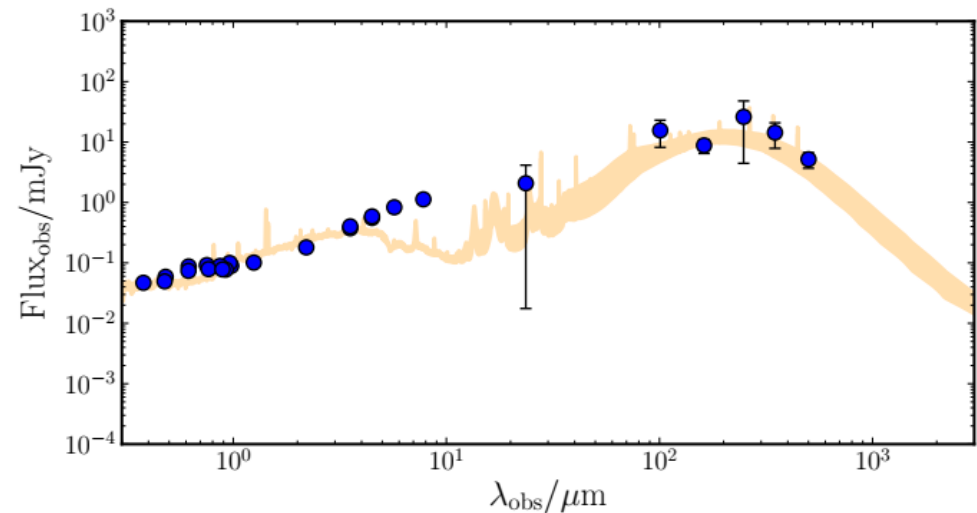
Physical Parameters/Classification

- Extraction of physical parameters ongoing using
 - MagPHYS, CIGALE, AGNFitter and Bagpipes
- Bagpipes: Good fits when no AGN component

SF galaxy



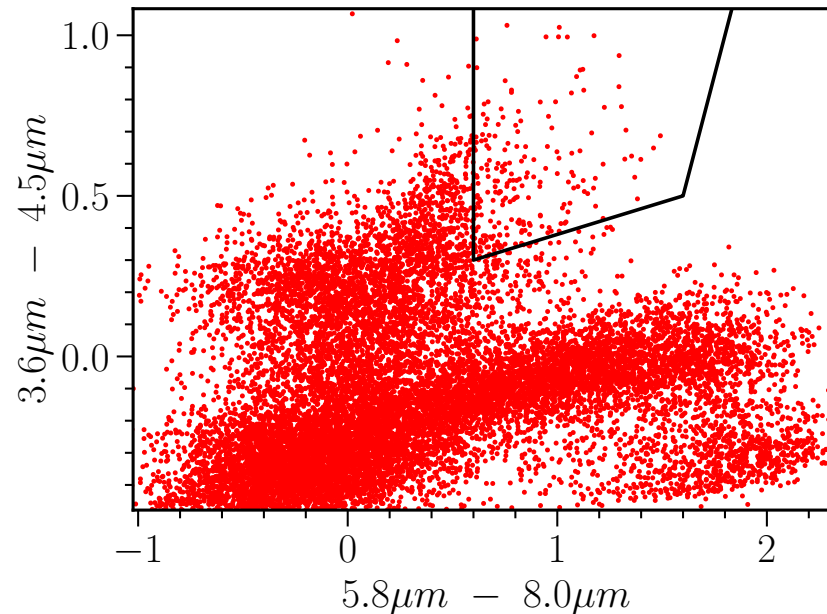
AGN



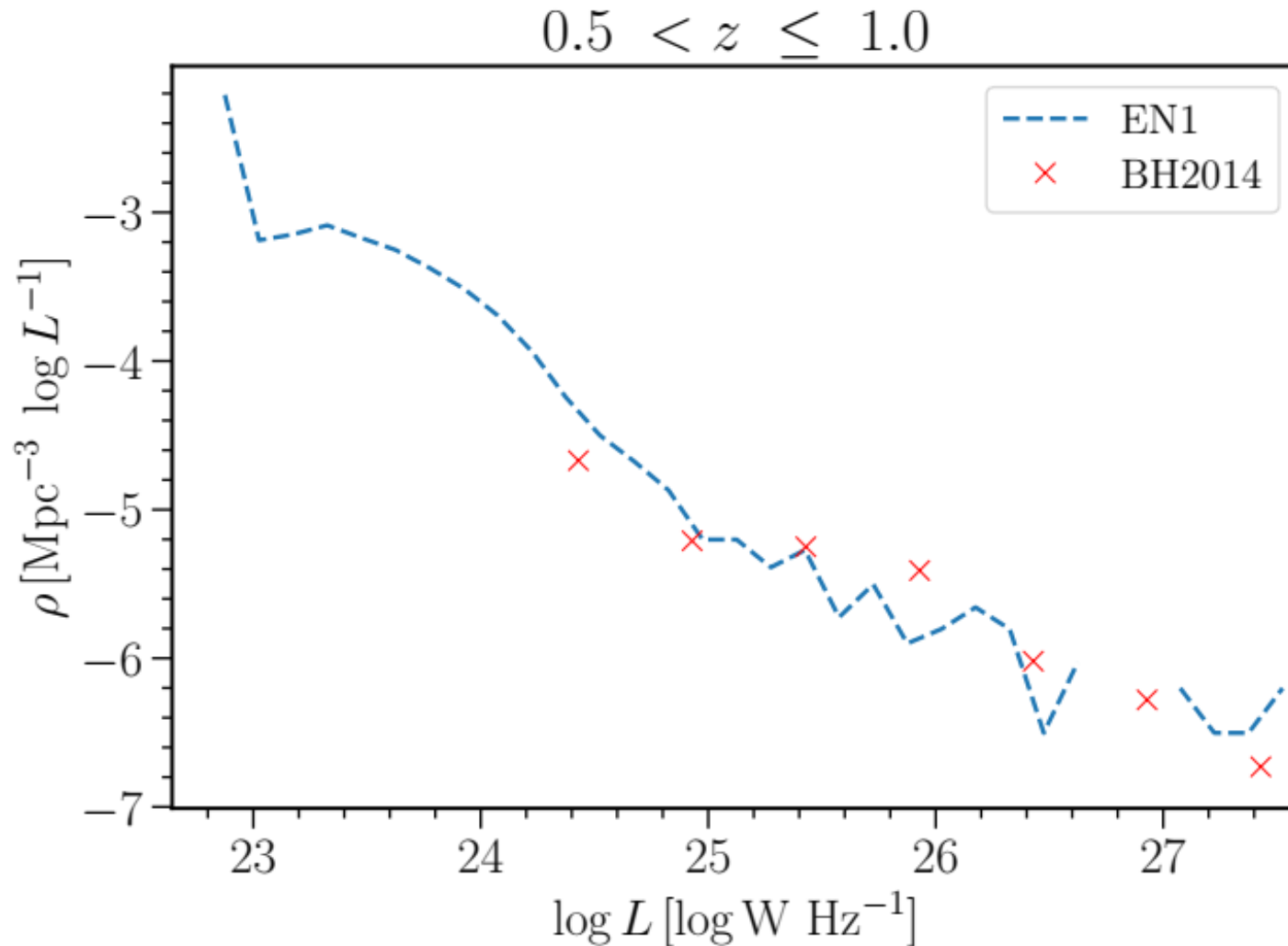
Credit: Rachel Cochrane

Physical Parameters/Classification

- Source Classification (SFG vs. AGN)
 - MIR colour-colour diagnostic (Stern+2005 and Donley+2012)
 - FIR-radio correlation using $24\mu\text{m}$ flux (Bonzini+2013) and $250\mu\text{m}$ flux (Hardcastle+2016)

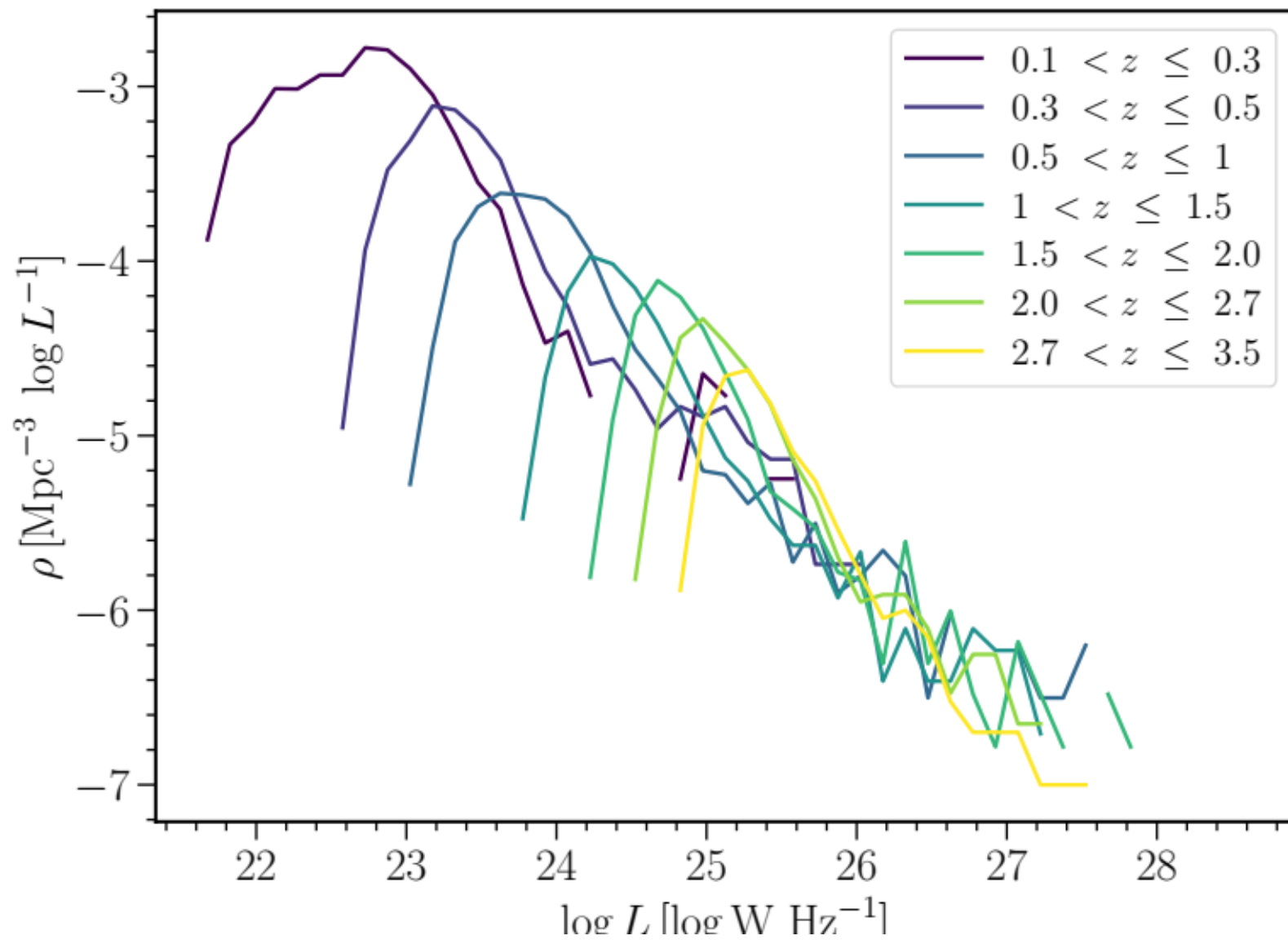


Radio Luminosity Function



Conclusions

- Deep LOFAR imaging at $20 \mu\text{Jy}/\text{bm}$ level - more data being processed!
- Statistical LR cross-match rate of $> 95\%$
- **In progress:** Extracting physical properties
 - Finalising source classification methods
- LOFAR Deep fields DR1: Multi-wavelength properties of $\sim 100,000$ radio sources in premier Northern extragalactic fields
 - Data products released within consortium
 - Public data release late 2019/early 2020 (planned)



Physical Parameters/Classification

- Extraction of physical parameters ongoing using
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