Spectroscopic redshifts for ATLAS, the EMU pathfinder

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NRAO

Outline

- EMU – Ray's talk earlier today
- ATLAS
- Getting spectroscopic redshifts for ATLAS
- Things we wouldn't have been able to do without SPECTROSCOPIC redshifts
  - Cluster
  - Statistical redshift training…

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- EMU – Ray's talk earlier today
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- Things we wouldn't have been able to do without SPECTROSCOPIC redshifts
  - Cluster
  - Statistical redshift training…
- TAIPAN x EMU
  - Radio galaxy environments
  - Confirming RLF result
  - Robustify statistical redshifts for the low z end?

EMU:
Evolutionary Map of the Universe

- How have galaxies formed and evolved with cosmic time? (Norris et al. 2011)
- PI:
  - Ray Norris (CSIRO-ATNF)
- Project Scientists:
  - Andrew Hopkins (AAO)
  - Nick Seymour (CSIRO-ATNF)

EMU: Quick Look

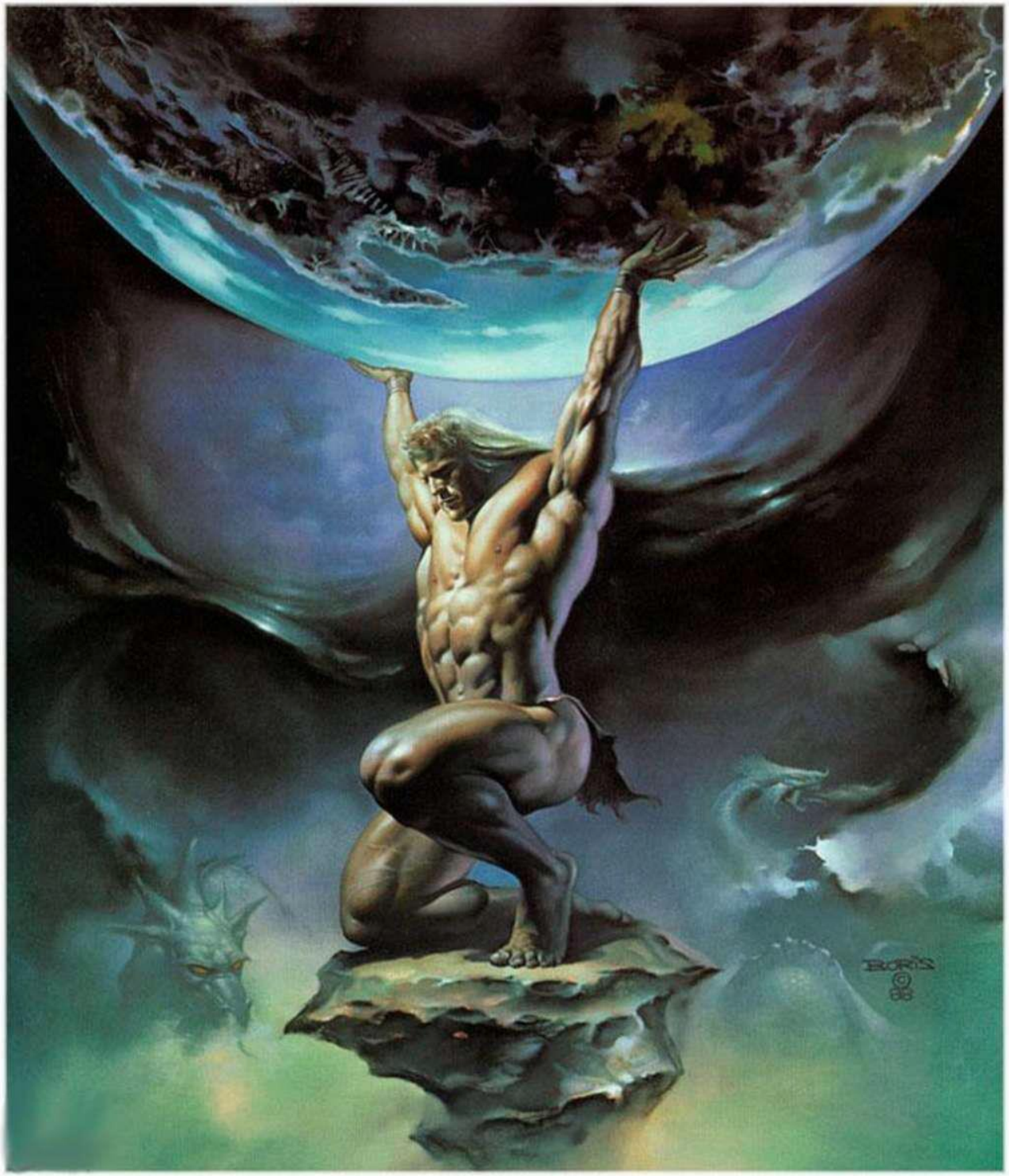
- Frequency Range: 1130 – 1430 MHz
- Sensitivity: 10 uJy/beam
- Resolution: 10 arcsec FWHM
- Area: Entire sky south of +30 dec
- Instantaneous FOV: 30 sq deg

EMU: Quick Look

- Total integration time: ~1.5 years
- Number of Sources: ~70 million

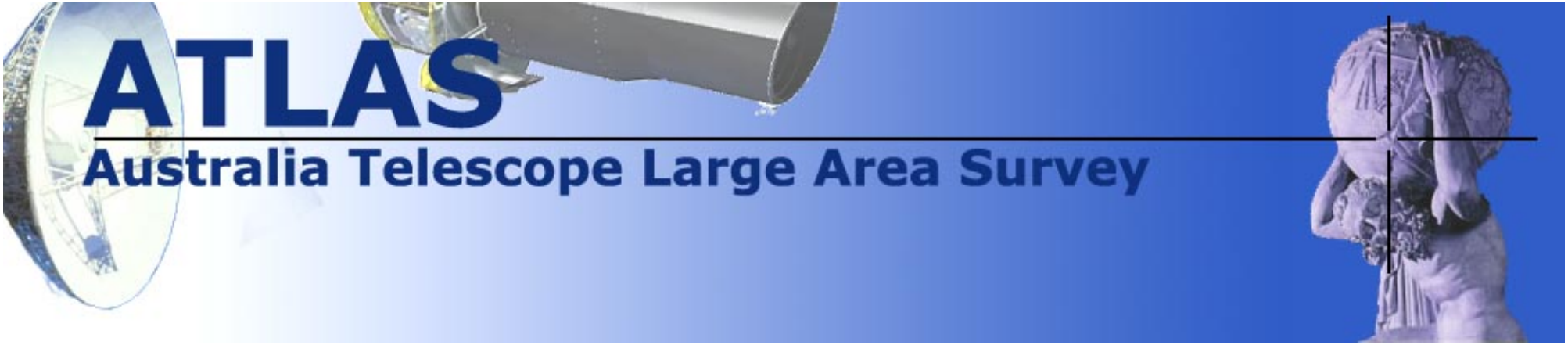
- We need redshift information to study the evolution of these 70 million radio sources!

Enter ATLAS



ATLAS:
Australia Telescope Large Area Survey

- How have galaxies formed and evolved with cosmic time? (Norris et al. 2006, Middelberg et al. 2008)
- PIs:
  - Ray Norris (CSIRO-ATNF)
  - Enno Middelberg (Bochum)



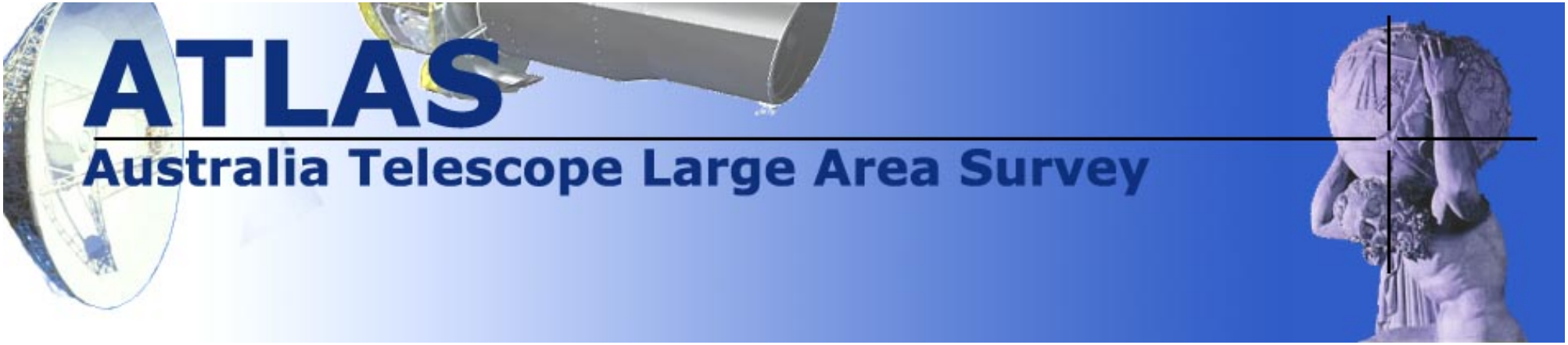
ATLAS: Quick Look

- Frequency: 1.4 GHz (pre-CABB)
- Sensitivity: 10 uJy/beam (Data Release 1: 30 uJy/beam)
- Resolution: 10 arcsec FWHM
- Area: 7 square degrees over 2 fields

ATLAS: Quick Look

- Total integration time: ~2000 hours
- Number of Sources: ~16000 (current 2000)

- We need redshift information to study the evolution of these 16000 (2000) radio sources!

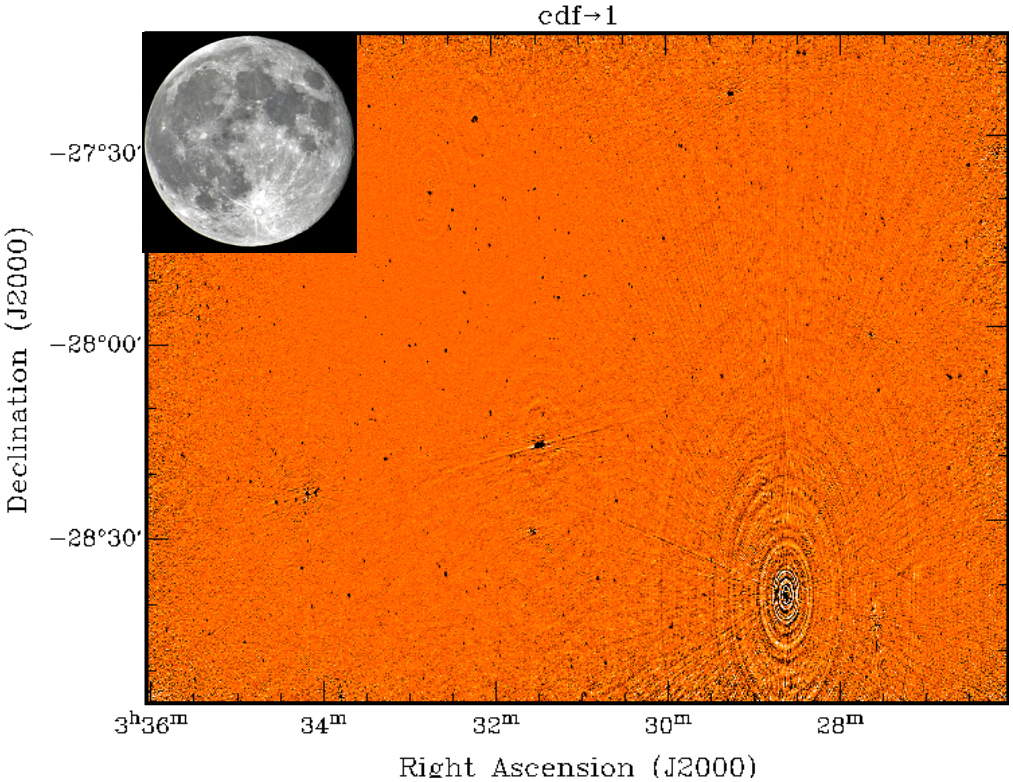


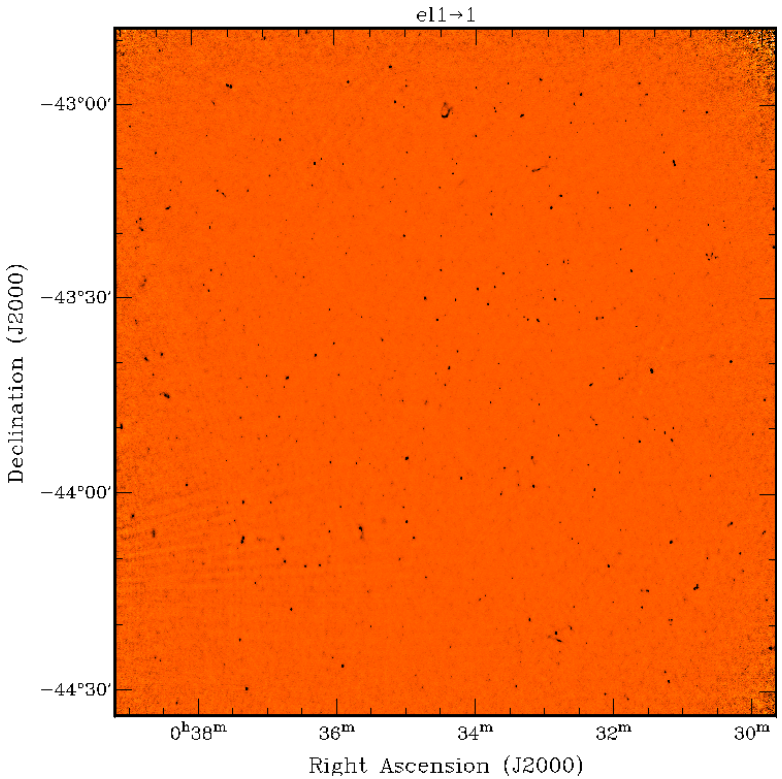
ATLAS

- **A**ustralia **T**elescope **L**arge **A**rea **S**urvey
- Uses the Australia Telescope Compact Array in Narrabri, NSW
- ATLAS aims to produce the widest deep radio survey
  - Wide = 7 square degrees
  - Deep = ~10 μJy rms at 1.4 GHz
- ATLAS comprises two fields so as to mitigate cosmic variance
  - CDFS – Chandra Deep Field South
  - ELAIS-S1 – European Large Area ISO Survey-South 1

http://www.atnf.csiro.au/research/deep/index.html

CDFS & ELAIS





- These fields were chosen as they have deep optical, infrared and X-ray data.
- ~2000 radio sources so far (~30 μJy rms), expect ~16000 when we get down to a rms of 10 μJy

ATLAS publications

- Norris et al., 2006, AJ, 132, 2409

  Deep ATLAS Radio Observations of the Chandra Deep Field-South/Spitzer Wide-Area Infrared Extragalactic Field

- Norris et al., 2007, MNRAS, 378, 1434

  Very long baseline interferometry detection of an Infrared-Faint Radio Source

- Middelberg et al., 2008, AJ, 135, 1276

  Deep Australia Telescope Large Area Survey Radio Observations of the European Large Area ISO Survey S1/Spitzer Wide-Area Infrared Extragalactic Field

- Middelberg et al., 2008, A&A, 491, 435

  The first VLBI image of an infrared-faint radio source

- Huynh et al., 2010, ApJ, 710, 698

  Evidence for Infrared-faint Radio Sources as z > 1 Radio-loud Active Galactic Nuclei

- Mao et al., 2010, MNRAS, 406, 2578

  Wide-angle tail galaxies in ATLAS

- Middelberg et al., 2011, A&A, 526, A8

  The radio properties of infrared-faint radio sources

- Norris et al., 2011, ApJ, 736, 55

  Deep Spitzer Observations of Infrared-Faint Radio Sources: High-redshift Radio-Loud AGN?

- Middelberg et al., 2011, A&A, 526, 74

  Wide-field VLBA Observations of the Chandra Deep Field South

- Mao et al., 2012, MNRAS,426, 3334

  ATLAS: Spectroscopic Catalogue and Radio Luminosity Functions

Cosmic Evolution of Radio Sources in ATLAS

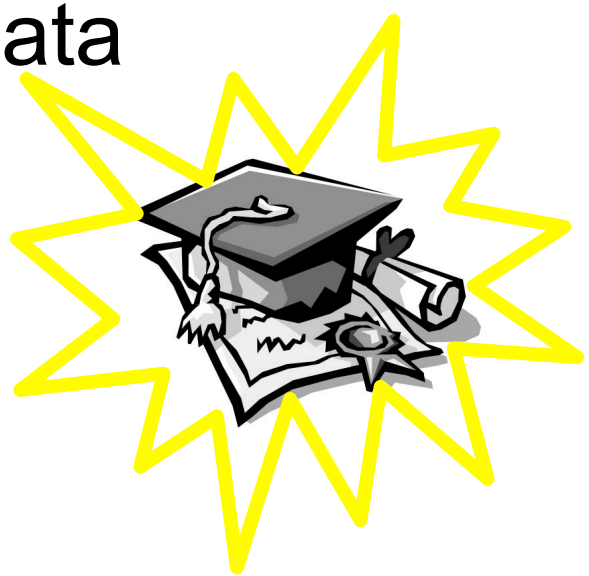
- We have a sample of radio sources at 1.4 GHz above 150 μJy (5 x rms) over 7 square degrees
- We need to know their distances so that we can determine if and how they have evolved with redshift!
- The aim of my PhD thesis was to study the evolution of radio sources by obtaining spectroscopic redshifts for the ATLAS sources

AAT

Anglo-Australian Telescope

The Dream

- Spend 8 nights observing on the AAT. Target all ATLAS sources.
- Reduce data and obtain redshifts for all ATLAS sources
- Do science with a sample that is now complete in radio and optical data
- Obtain PhD! ☺



First Impression of AAT

It didn’t get much better…

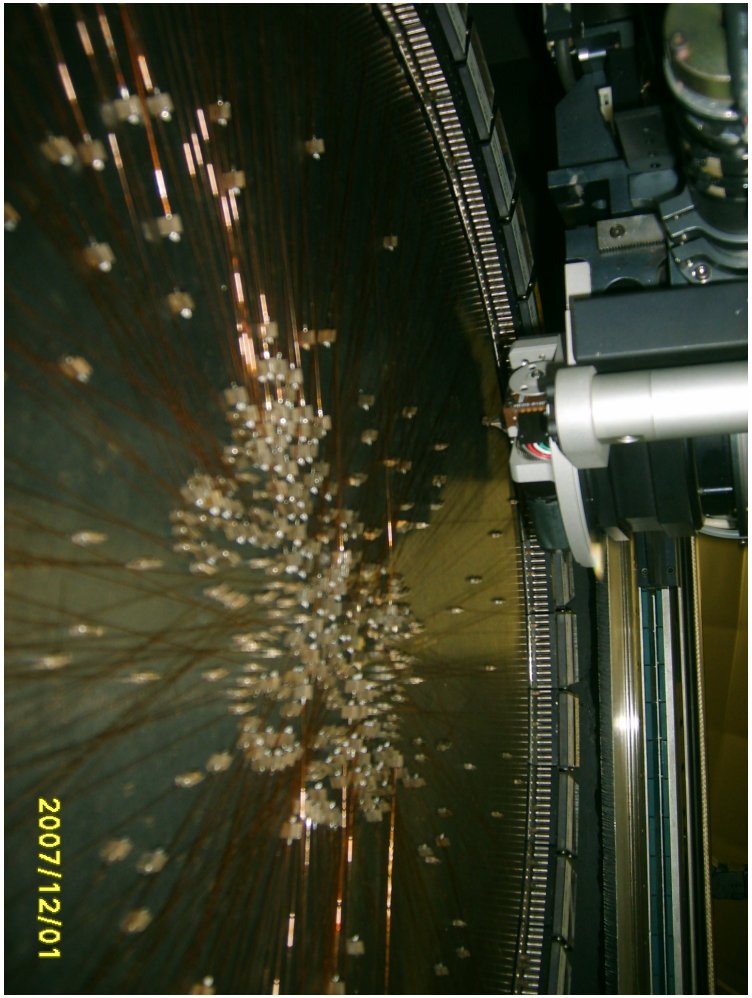
The Reality

- Spend 8 nights observing cloud/rain/fog at the AAT
- Apply for telescope time the following year (meanwhile, study WATs for a year)
- Spend 8 nights observing cloud/rain/fog at the AAT
- Apply for telescope time the following year (meanwhile, go to Caltech for 6 months and spend remaining time writing up paper)
- Spend 8 nights observing cloud/rain/fog at the AAT
- Decide that having 23% of sources with redshifts is good enough
- Spend the next year understanding the selection biases of dataset!

AAOmega on the AAT

- 8 nights in Dec 2007
- 8 nights in Dec 2008
- 8 nights in Dec 2010 for a complementary project

- AAOmega was used in multi-object mode & nod+shuffle mode
- Total observing time: 31.3 h
- Seeing: 1.2 – 3 arcsec



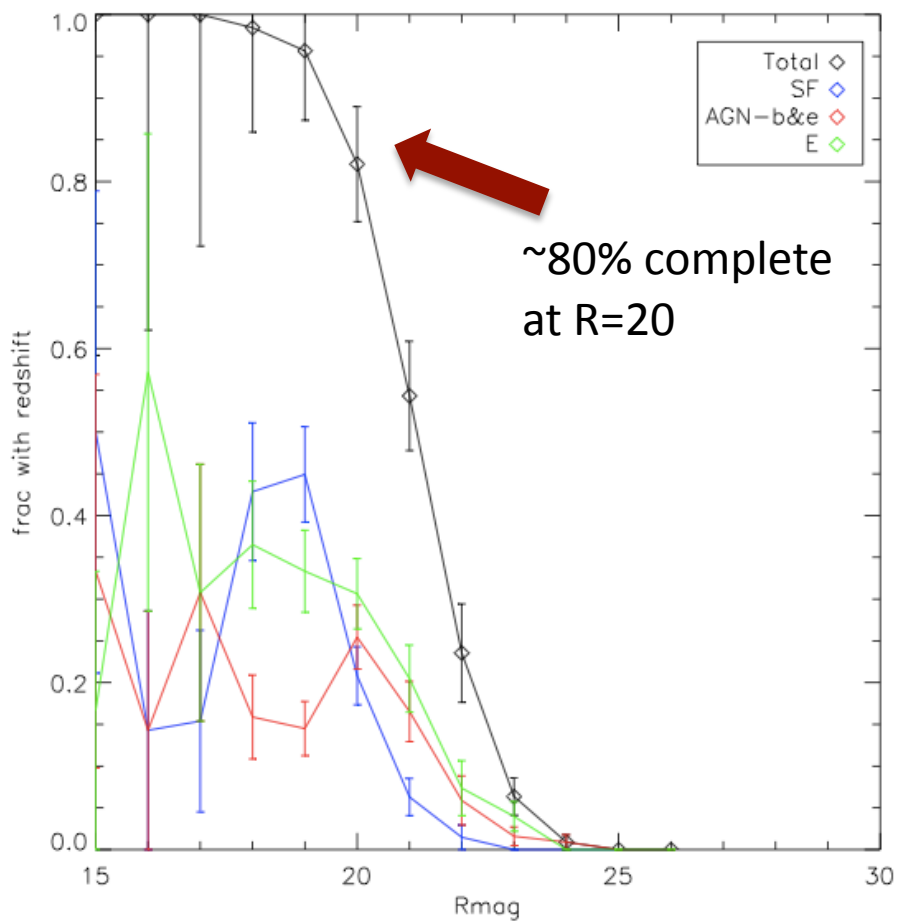
Observations

Observation	Plate	Exposure	Obs. date	Dichroic	Seeing
CDFS A bright	1	3 × 1200 [1]	20071202	5700Å	2.4
CDFS A bright	0	4 × 1200	20071204	5700Å	
CDFS B bright	1	4 × 1200	20071204	5700Å	
CDFS A med	0	4 × 1800	20071207	5700Å	1.9-2.5
CDFS B med	1	2 × 1200	20071205	5700Å	1.8-2.3
CDFS A ns	1	1 × 1500	20071206	5700Å	1.4
CDFS A ns	1	13 × 2400	20071206,07,08	5700Å	1.2-3
CDFS A ns	0	5 × 2400	20071208	5700Å	1.2 - 1.7
CDFS B ns	0	1 × 1500[2]	20071205	5700Å	2.3
CDFS A 2010	1	6 × 2400	20101206	5700Å	
CDFS B 2010	1	2100+1500	20101207	5700Å	

Observation	Plate	Exposure	Obs. date	Dichroic	Seeing
ELAIS bright	0	7 × 1200	20071205	5700Å	1.8
ELAIS bright	0	4 × 1800	20081221,22	6700Å	1.6-1.7
ELAIS bright	1	4 × 1800 [3]	20081224,25,26	6700Å	1.6-2.4
ELAIS 2010	0	1270+1770	20101208	5700Å	1.4 - 1.6

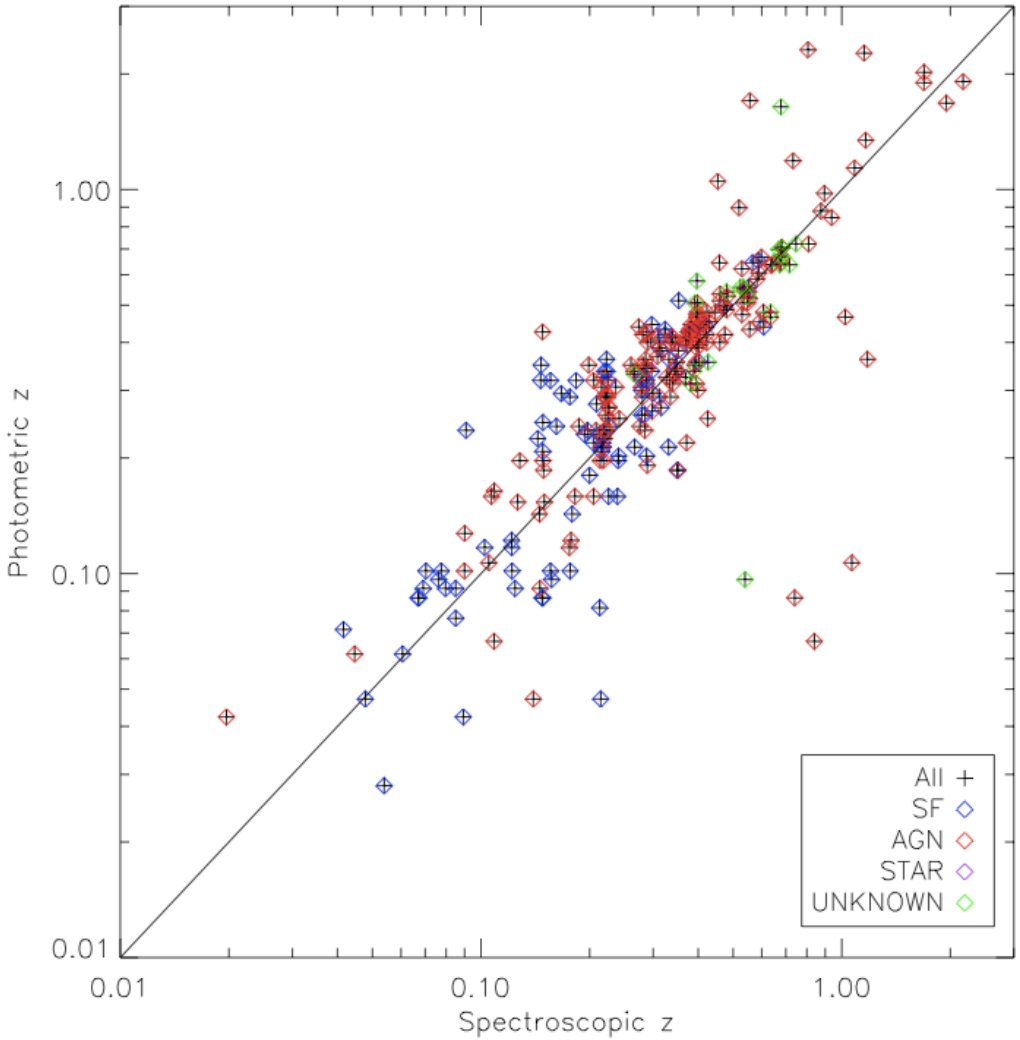
Data

- We observed a total of 1120/2018 ATLAS sources, of which 466 had quality spectra
- We also observed a total of 1080 24um excess sources, of which 697 had quality spectra. The 24um excess sources are currently being studied in the context of sources that deviate off of the FRC (Norris et al. in prep)

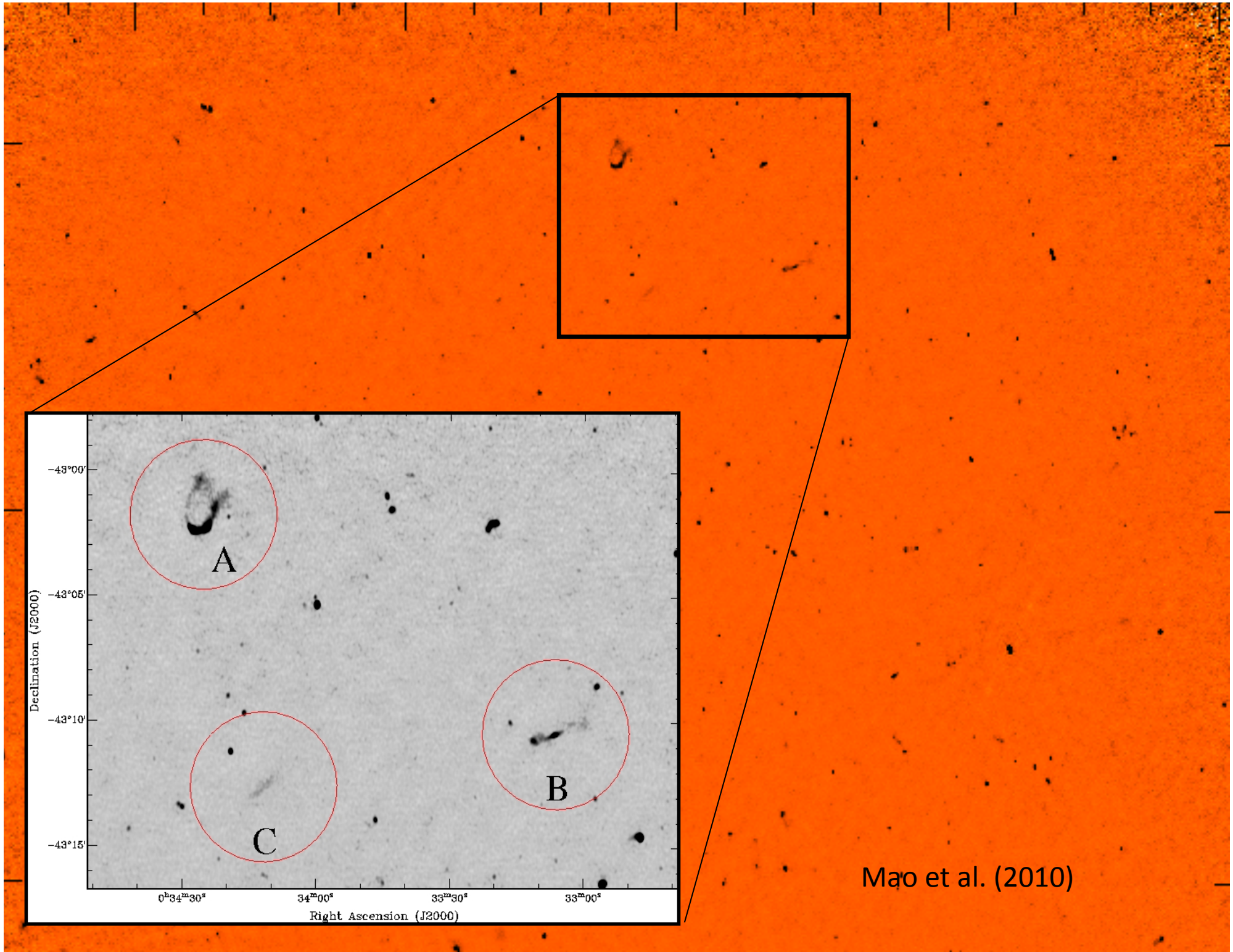


Spectroscopic redshifts are hard!

ATLAS: Spec z vs. Phot z



- ATLAS: Australia Telescope Large Area Survey (Norris et al. 2006, Middelberg et al. 2008)
- Photo-z from Rowan-Robinson et al. (2008)
- 5 optical bands and 2 IR bands
- Broad agreement but basically a scatter plot at z>1

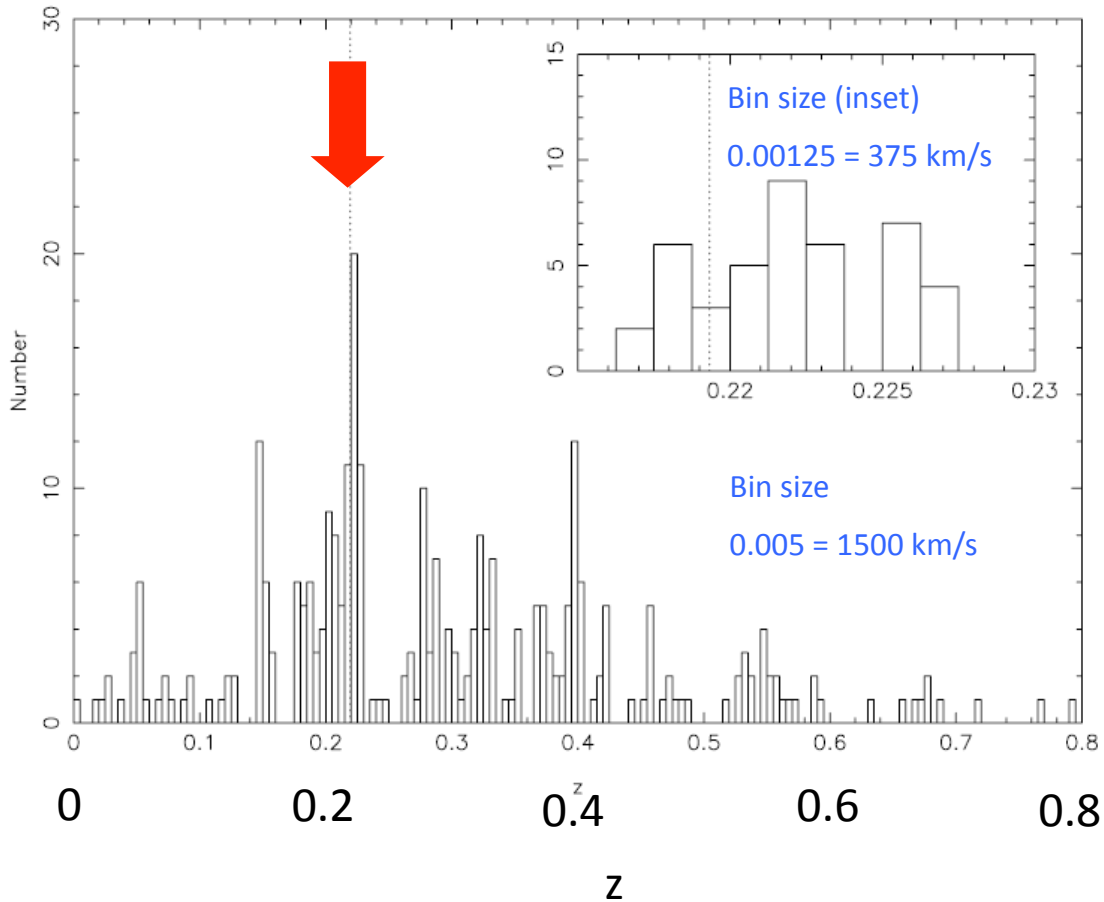


Mao et al. (2010)

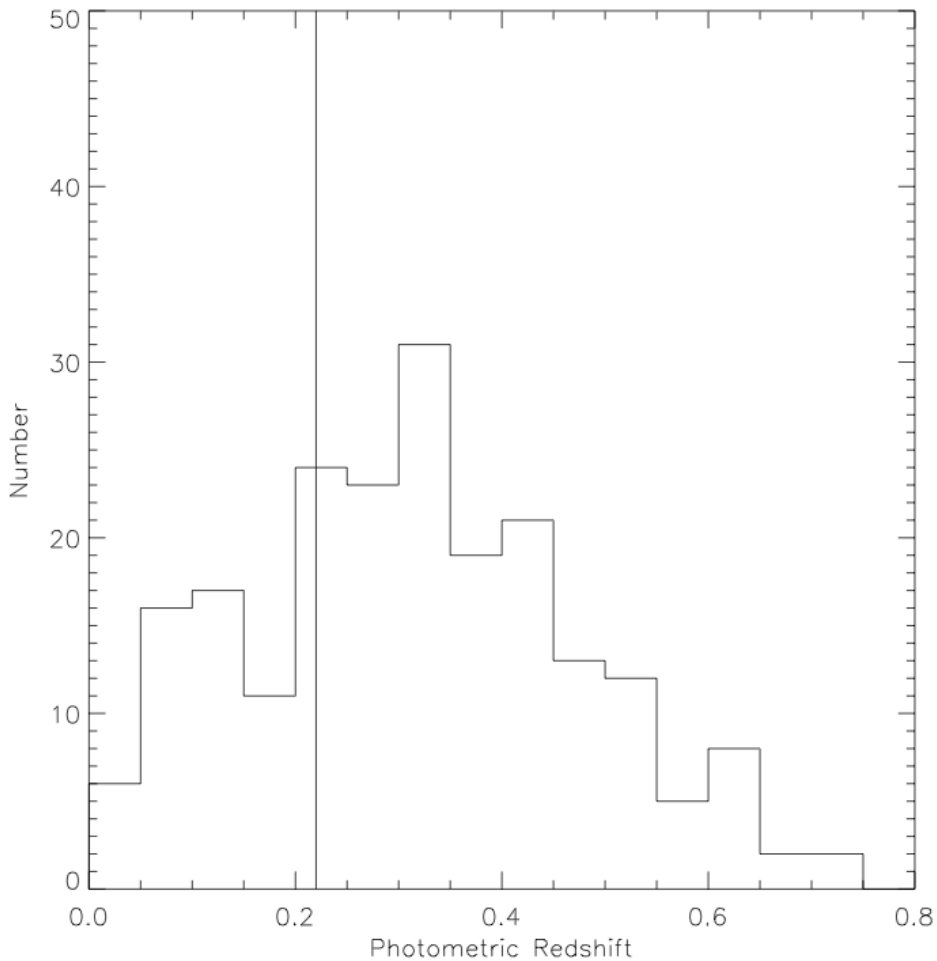
Redshift Distribution

There are a total of 309 sources with spectroscopic redshifts within a degree of S1189

- Peak at z~0.22!
- 42 galaxies in 3 'peak' bins
- Significant to 7σ
- Velocity dispersion 870 km/s
- Similar to rich, local Universe clusters undergoing mergers (e.g. A3667, A3376)
- Inset shows 3 'peak' bins
- The distribution in the inset is **not** Gaussian and shows substructure, consistent with merging systems

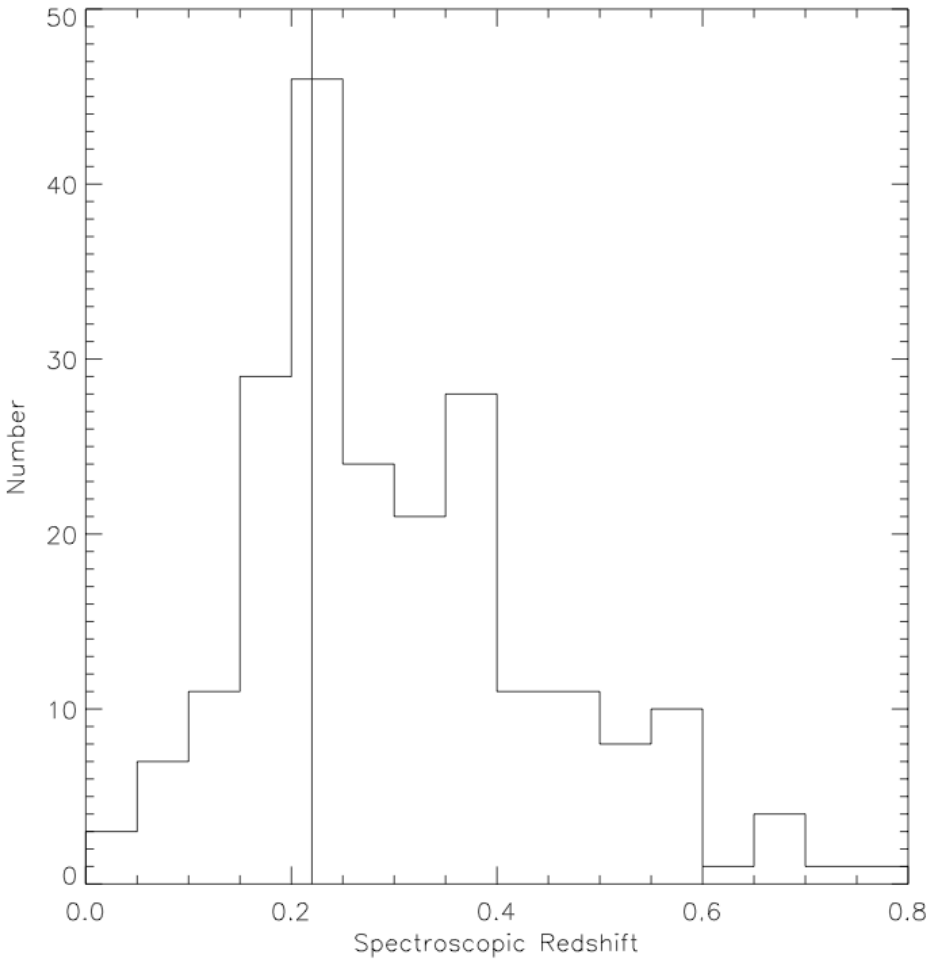


Spectroscopic vs. Photometric



- Binsize z=0.05
- Photometric redshifts from Rowan-Robinson (2008)
- Spectroscopic redshifts from our AAOmega observations

Spectroscopic vs. Photometric



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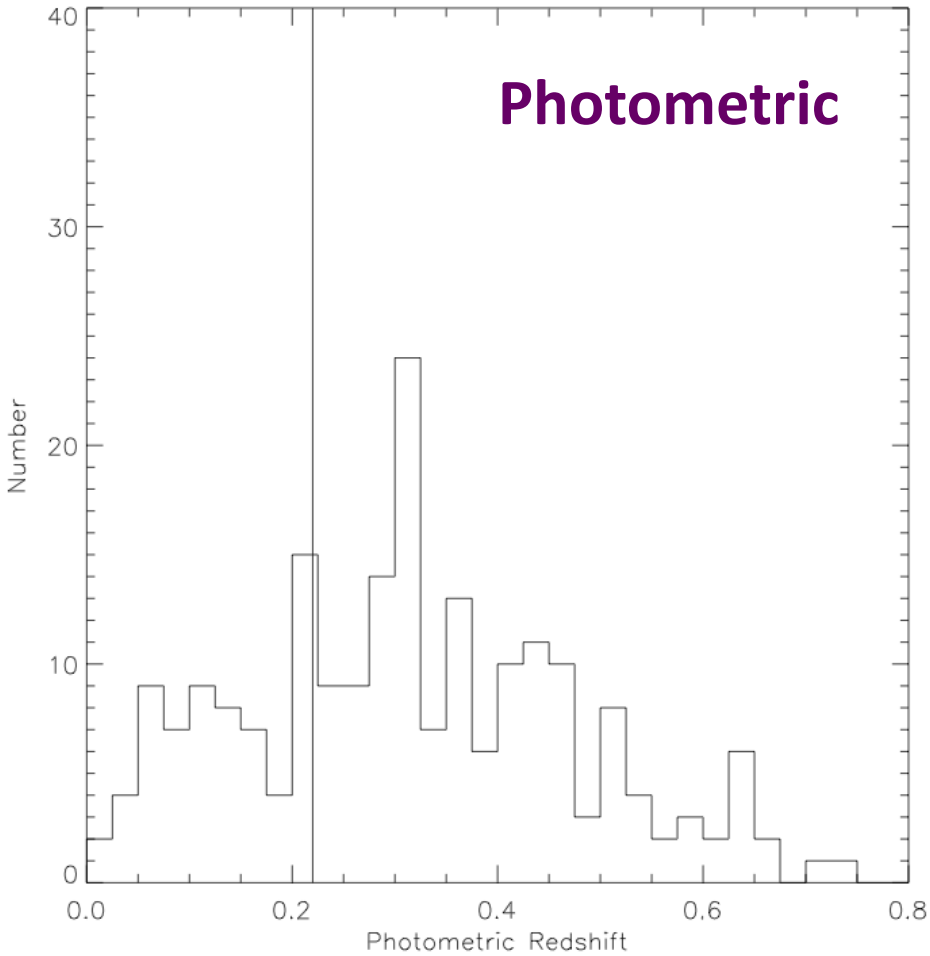
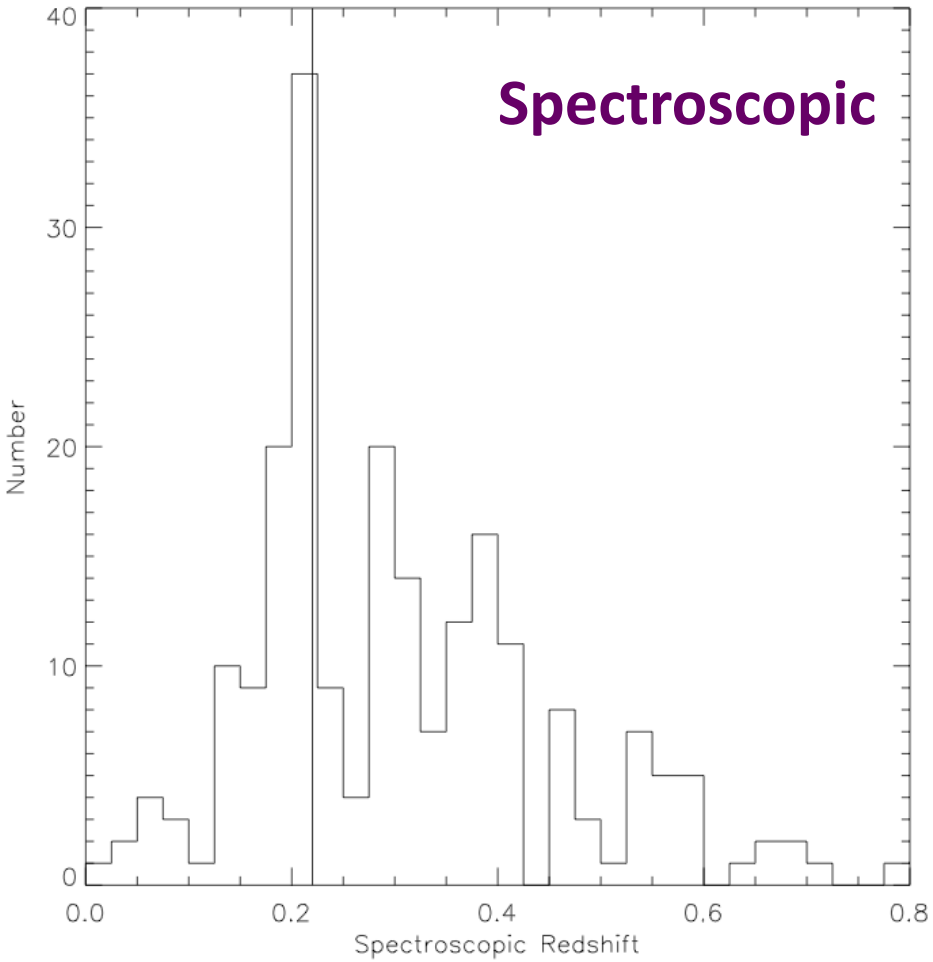
Spectroscopic vs. Photometric

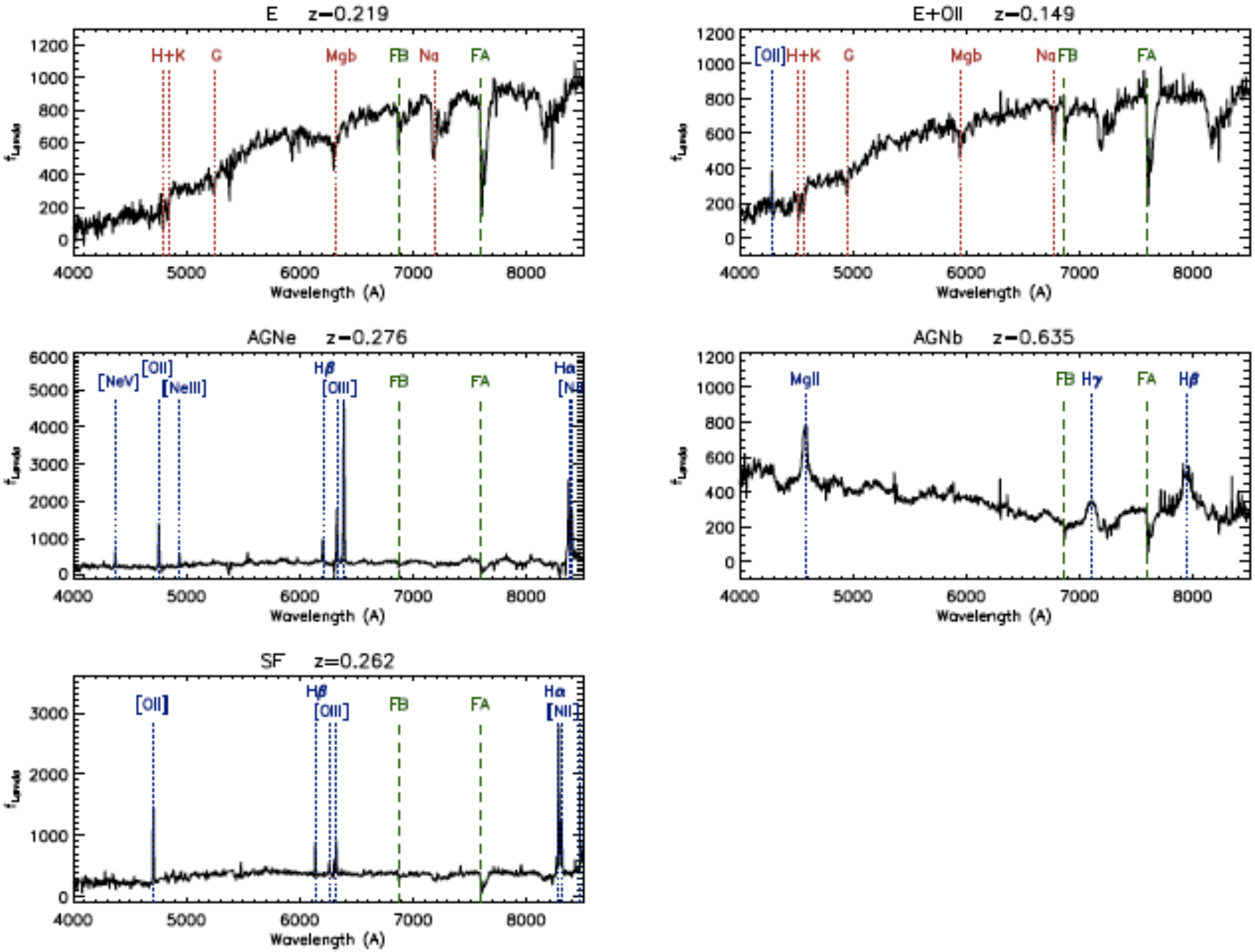


- Binsize z=0.025
- Photometric redshifts from Rowan-Robinson (2008)
- Spectroscopic redshifts from our AAOmega observations

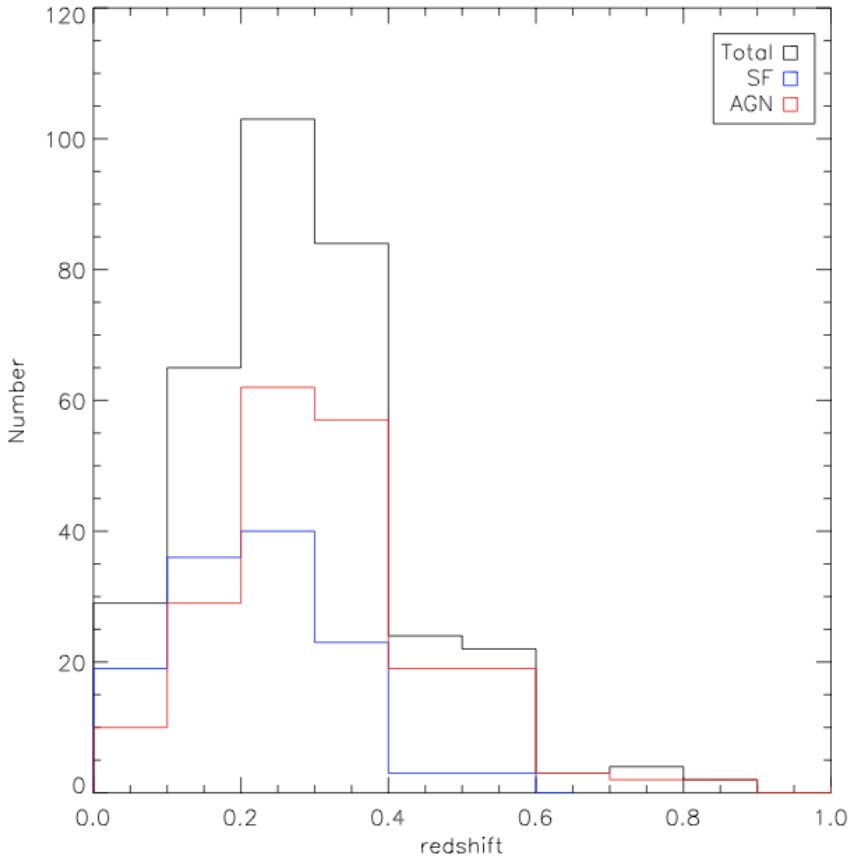
Spectroscopic vs. Photometric



- Binsize z=0.025
- Photometric redshifts from Rowan-Robinson (2008)
- Spectroscopic redshifts from our AAOmega observations


E z=0.219
H+K
G
Mgb
FB
Na
FA
E+OII z=0.149
[OII]
H+K
G
Mgb
Na
FB
FA
AGNe z=0.276
[NeV]
[OII]
[NeIII]
Hβ
[OIII]
FB
FA
Hα
AGNb z=0.635
MgII
FB
Hγ
FA
Hβ
SF z=0.262
[OII]
Hβ
[OIII]
FB
FA
Hα
[NII]
Wavelength (A)

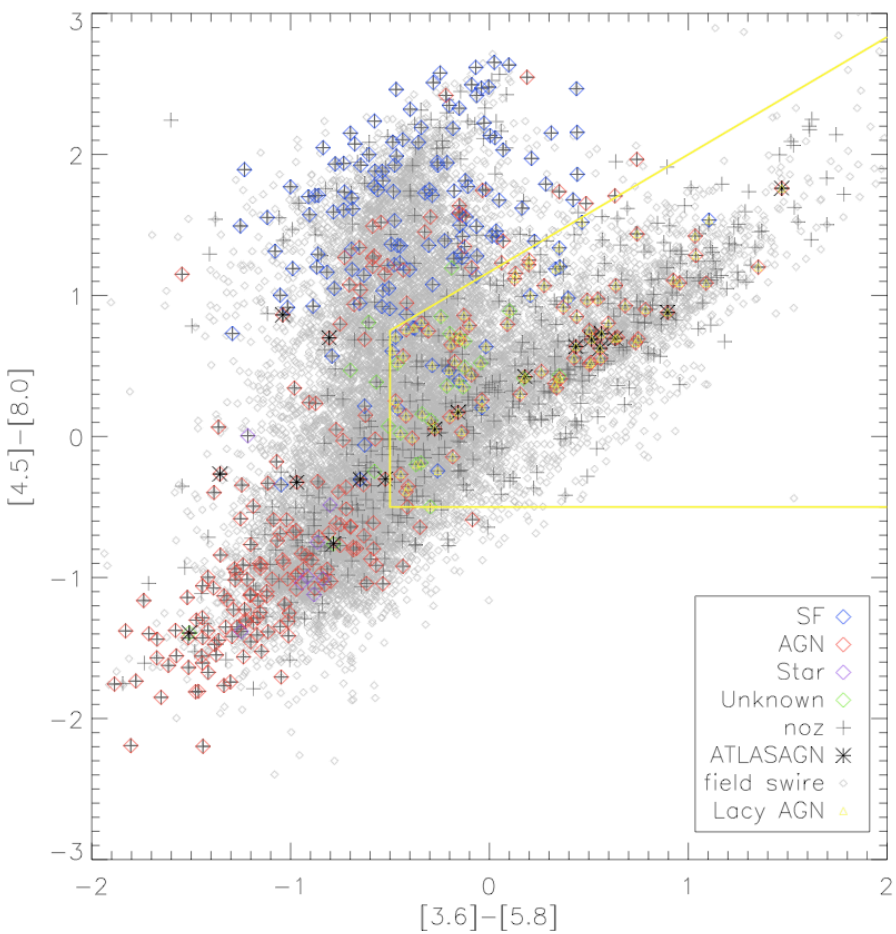
Redshift distribution



- 466 with spectroscopic redshifts
- 142 SF
- 282 AGN
- 10 stars
- 32 unclassified
  - Ie. Has enough spectral features to redshift, but unable to classify

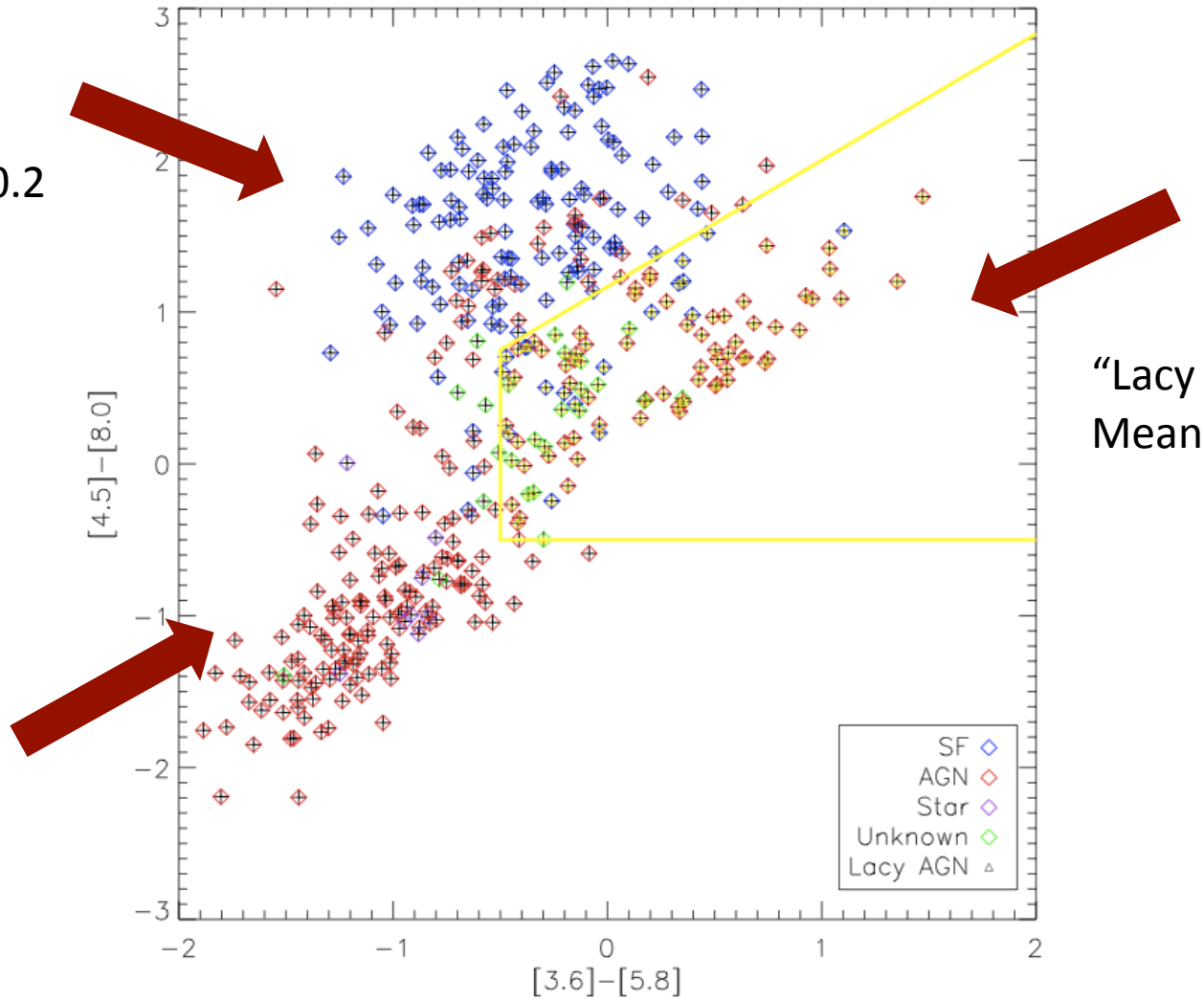
A quick look at statistical redshifts

- We compared our spectral classifications with mid-infrared colour-colour diagrams similar to using the SWIRE data from Spitzer (e.g. Lacy et al. 2004, Richards et al. 2006).



A quick look at statistical redshifts

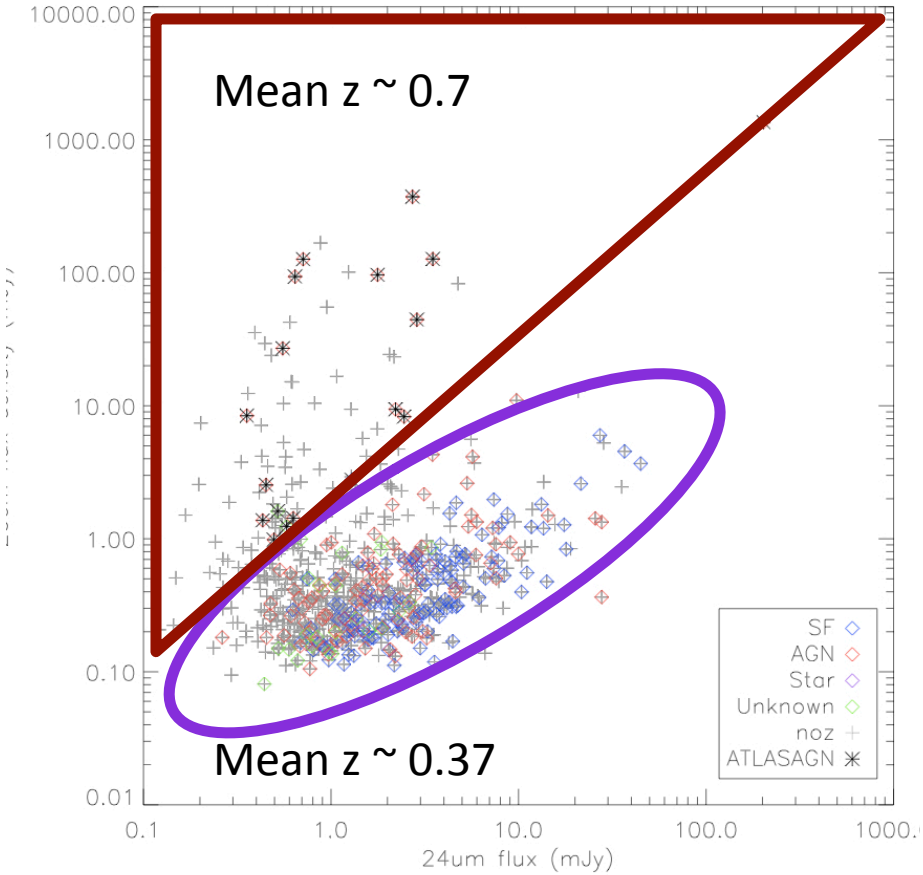
Mean z ~ 0.2

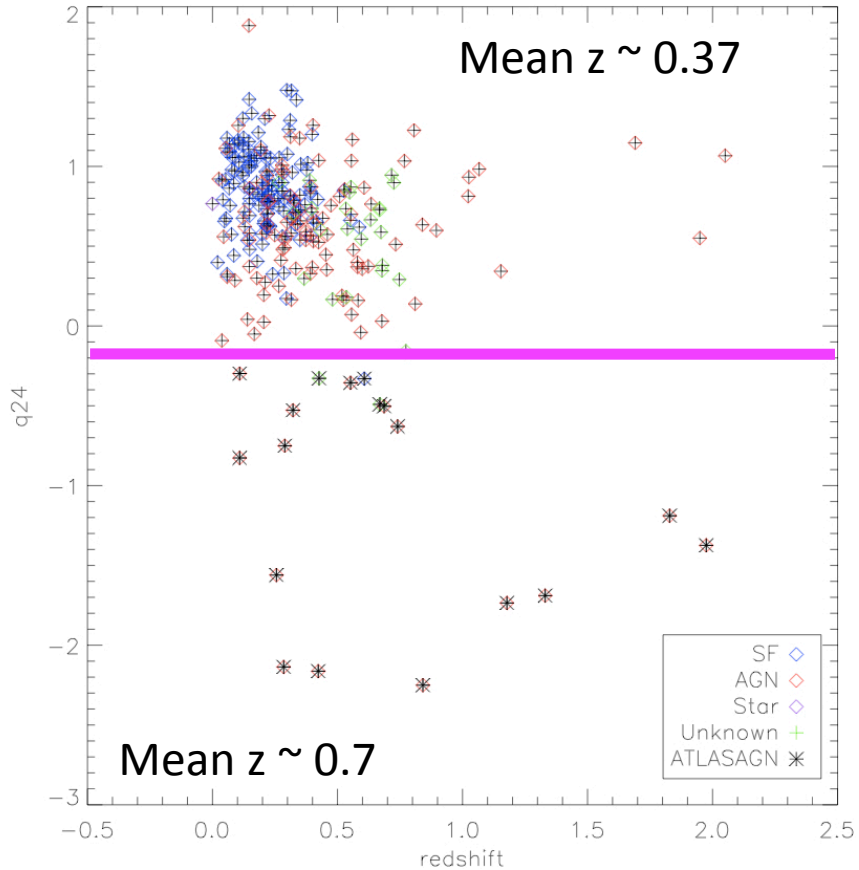


"Lacy Wedge"
Mean z ~ 0.6

Mean z ~ 0.4

Far-infrared Radio Correlation



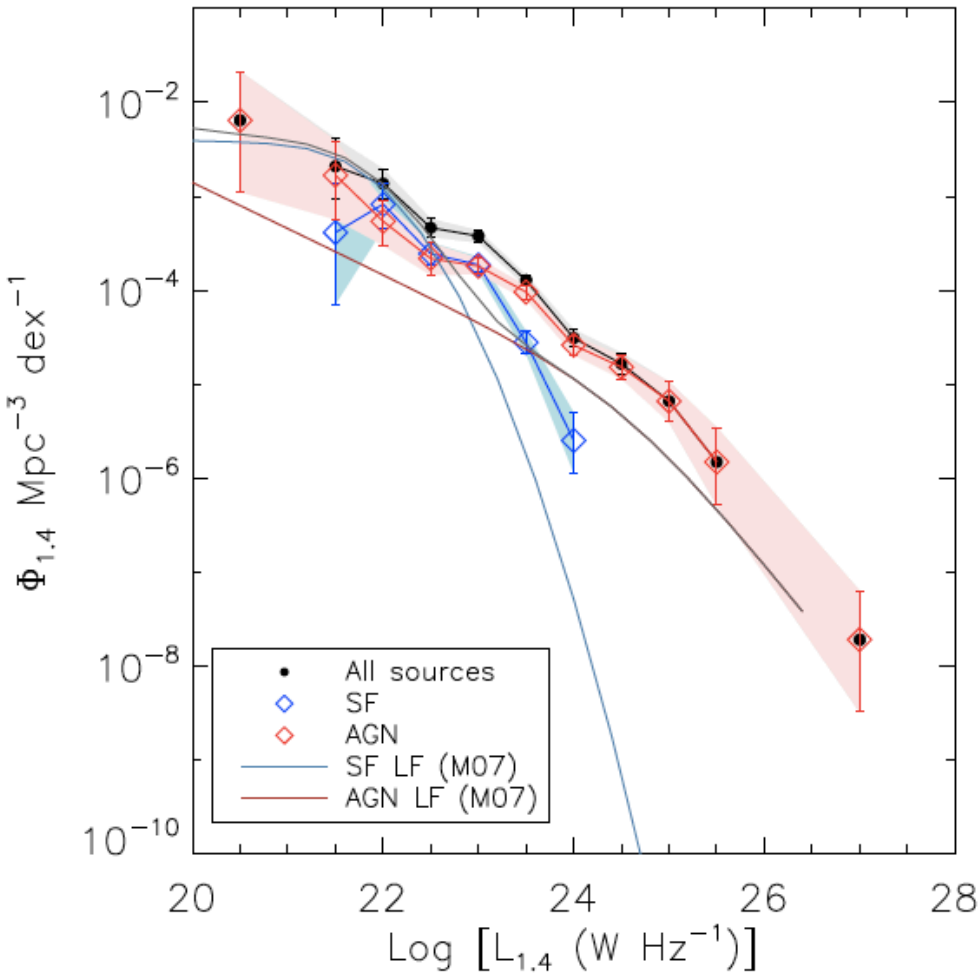



ROAR!

What can TAIPAN do for EMU?

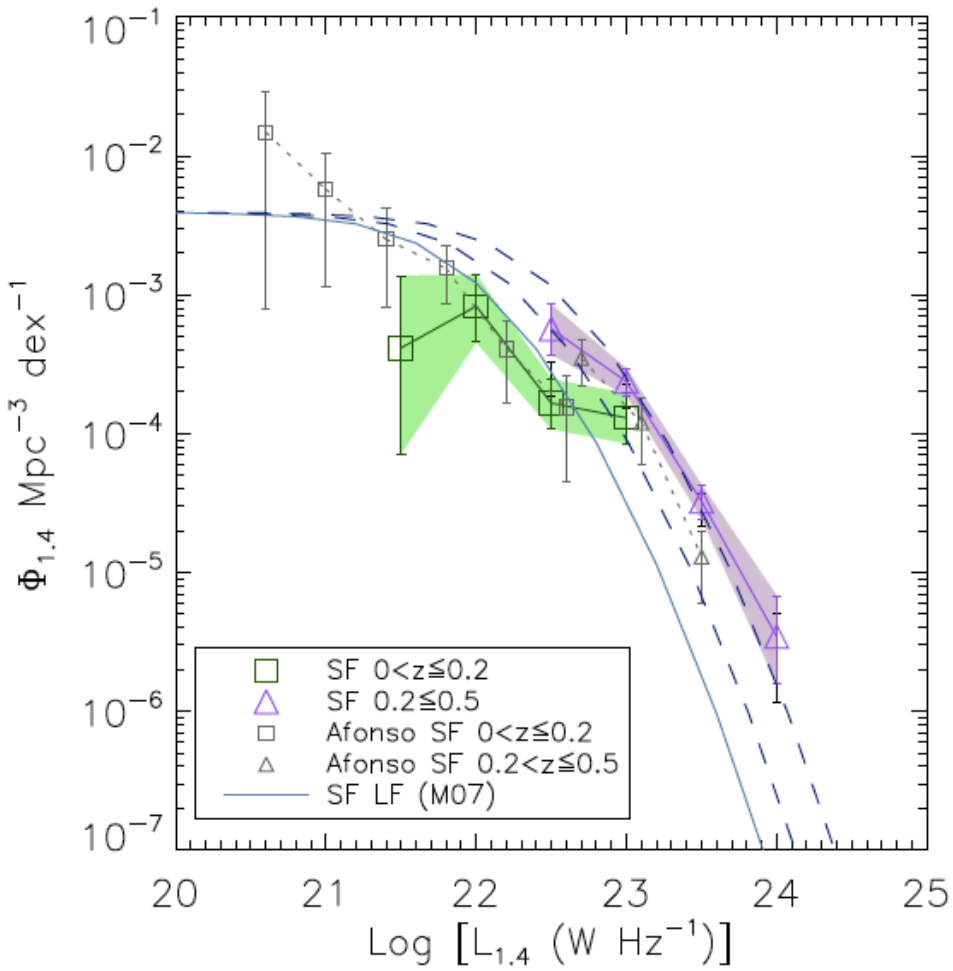
- Mainly already covered in Ray's talk this morning
- Two specific things I care about
  - The environments of radio galaxies
    - WATs
    - Giant radio galaxies
  - The local radio luminosity function

Radio Luminosity Functions



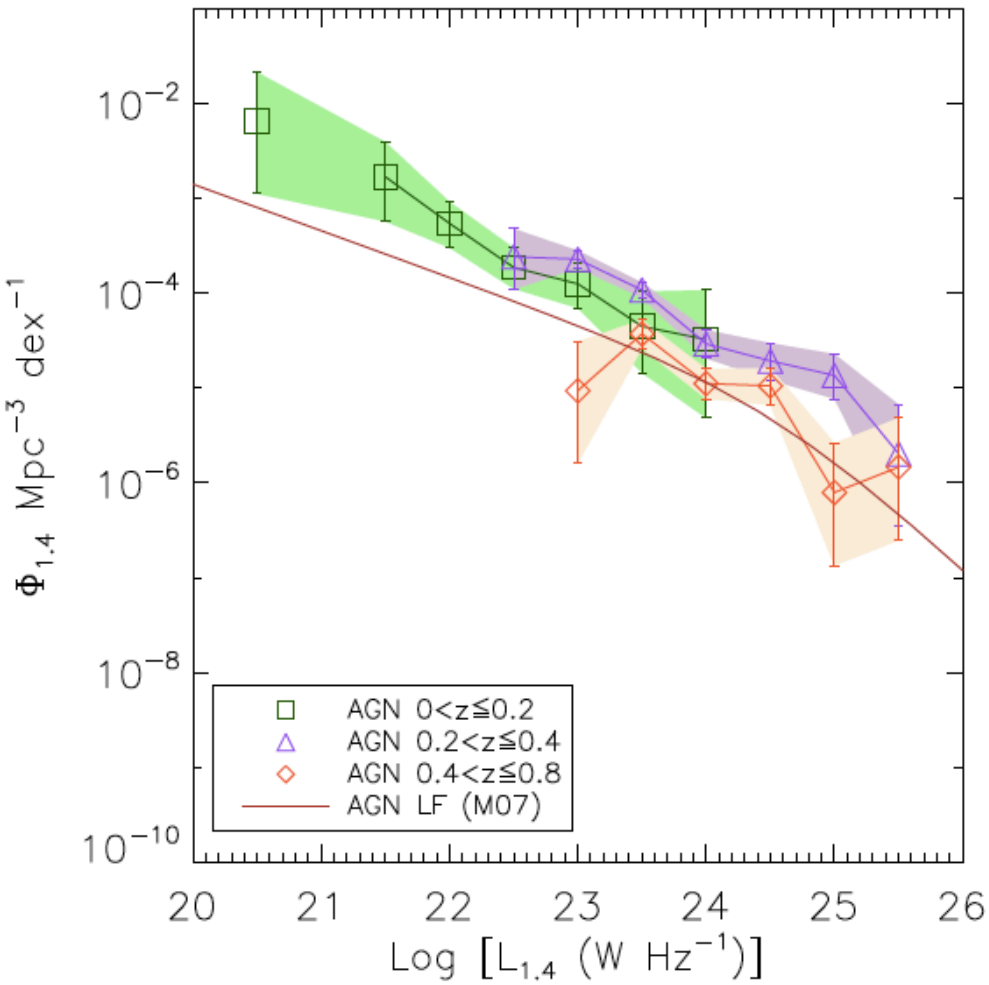
- Radio Luminosity Function → RLF
- Used the spectroscopic classifications to construct RLF for both star-forming (SF) galaxies and AGN

RLF for SF galaxies



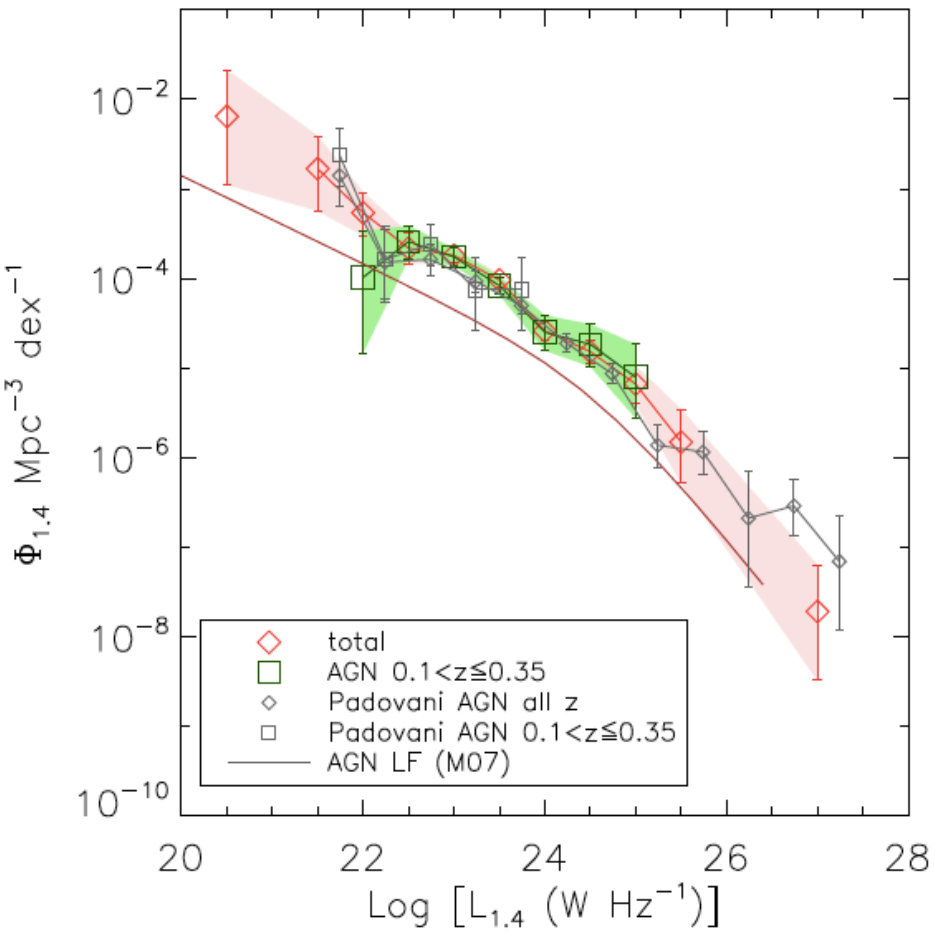
- Separated SF RLF into two redshift bins
  - 0 < z < 0.2
  - 0.2 < z < 0.5
- Results consistent with pure luminosity evolution
- Agrees well with previous work by Afonso et al. (2005)

RLF for AGN



- Separated AGN RLF into three redshift bins
  - 0 < z < 0.2
  - 0.2 < z < 0.4
  - 0.4 < z < 0.8
- Results inconsistent with previous work by Mauch and Sadler (2007)

RLF for AGN



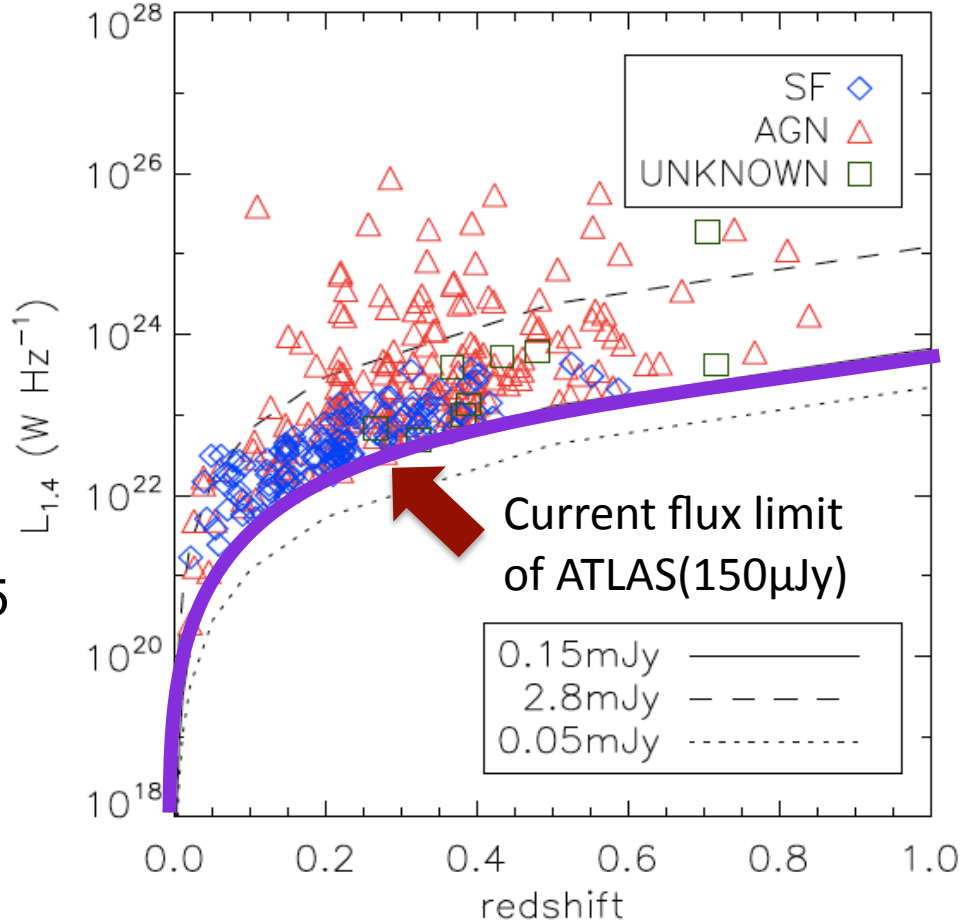
- Results consistent with previous work by Padovani et al. (2011) and Smolcic et al. (2009)
- Attribute the inconsistency to the Mauch & Sadler work to deeper radio data and different selections…

Summary

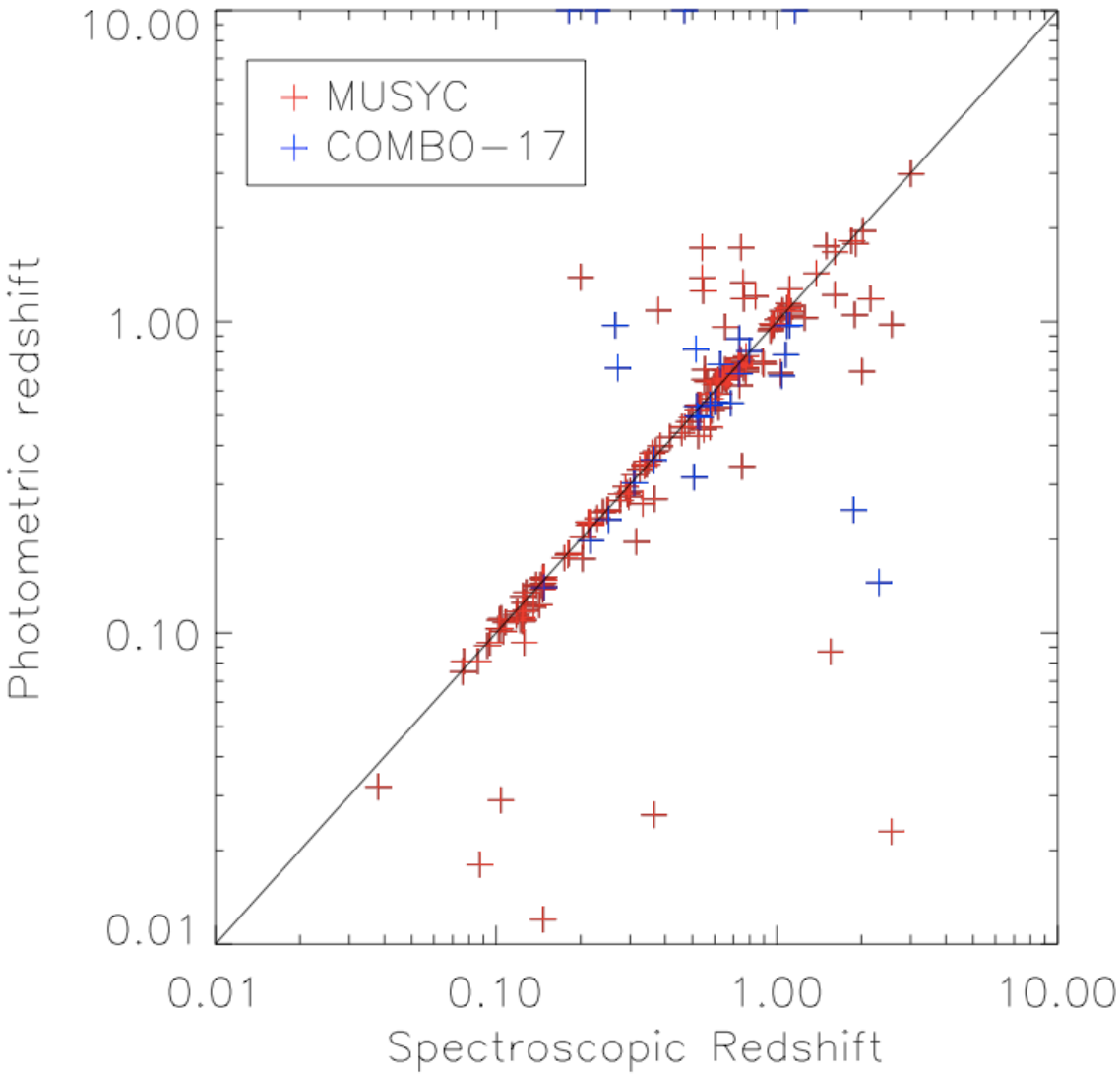
- ATLAS is an ideal testbed for EMU
- Spectroscopic redshifts are necessary for studying galaxy cluster kinematics and the environments of galaxies
- Spectroscopic redshifts may be used to train statistical redshifts
- TAIPAN will enable us to
  - Study the environments of radio galaxies
  - Probe the local RLF with a much higher degree of accuracy than previous studies!

Radio Luminosity Functions

- Sensitivity of ~0.15mJy
- Cf Mauch & Sadler (2007): ~2.8mJy
- We can probe the luminosity function for low-luminosity (~$10^{23.5}$ W/Hz) out to z ~ 0.6!



ECDFS: Spec z vs. Phot z



- Phot-z from MUSYC survey (Cardomone et al. 2010) and COMBO-17 (Wolf et al. 2004)
- COMBO-17 uses 17 bands to derive phot-zs
- MUSYC uses 32 bands to derive photo-zs
- These are among the best photometric surveys conducted to date!
- Good agreement but still basically a scatter plot at z>1
- (The mean z of EMU sources will be z ~ 1 for SF sources and z~1.9 for AGNs)

ATLAS Spectroscopy

- We have obtained 466 new spectroscopic redshifts in the CDFS and ELAIS-S1 fields
- These data enable us to study the cosmic evolution of radio sources in ATLAS
- These data also have important legacy value for the next generation of deep surveys…