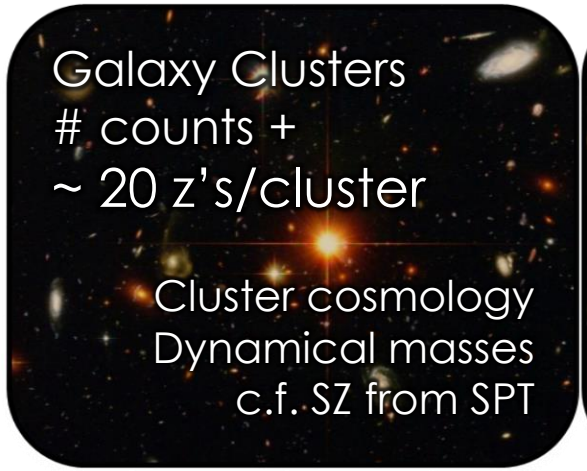
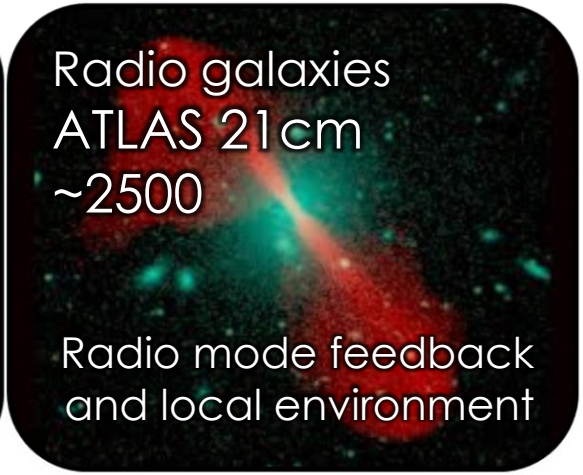
THE UNIVERSITY OF MELBOURNE

OzDES Reverberation mapping project

Anthea King – University of Melbourne

OzDES





Other transients
+ the unexpected!

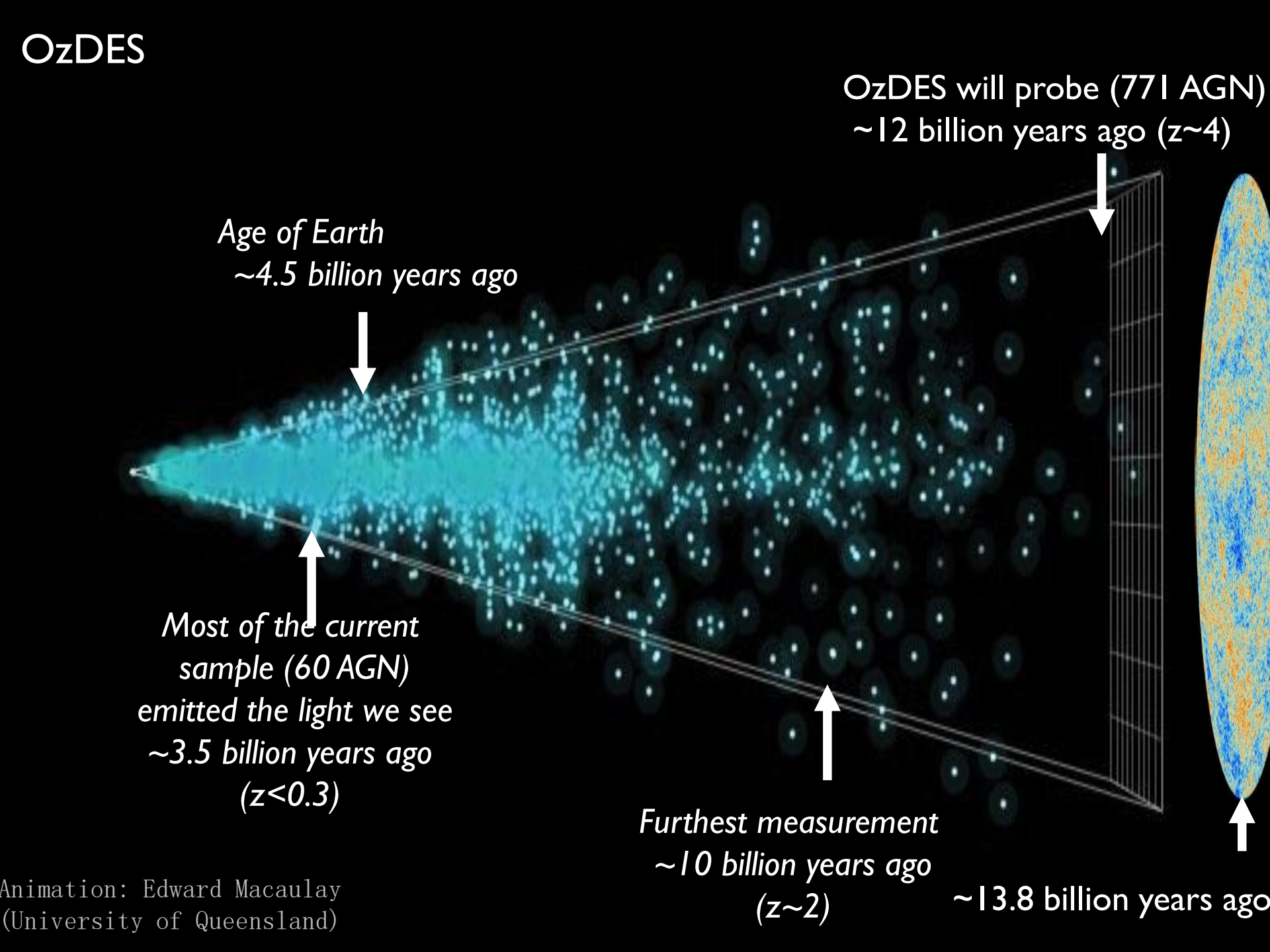
Photo-z calibration

Graphic Courtesy of Tamara Davis

Team Members

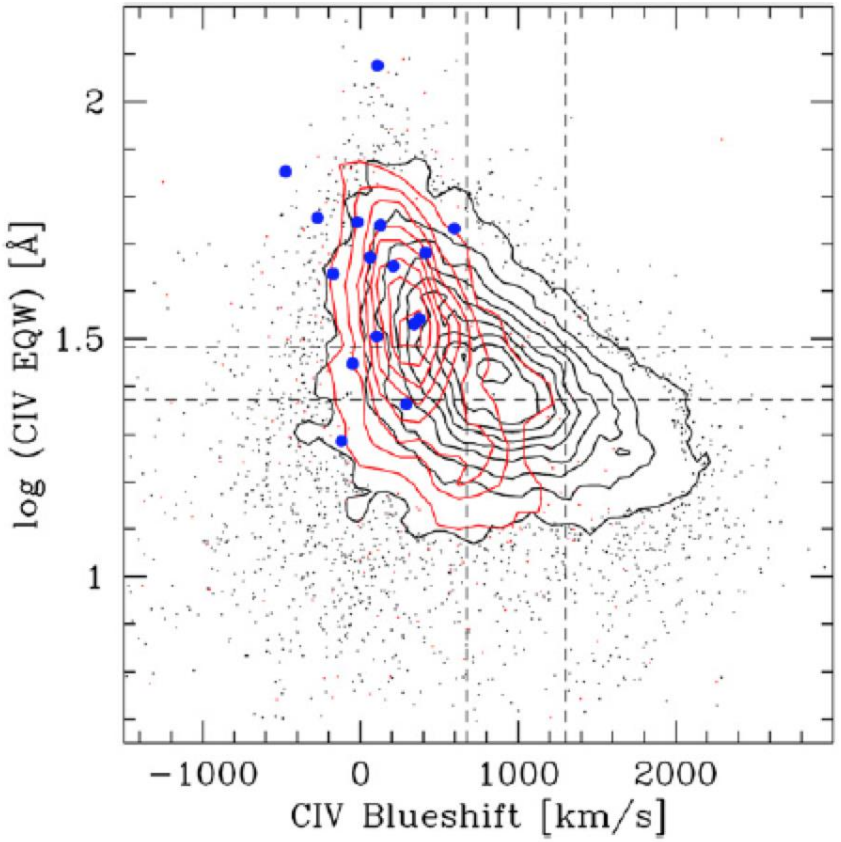
- Felipe Abdalla (UCL)
- Manda Banerji (UCL)
- Wayne Barkhouse (North Dakota)
- Chris Blake (Swinburne)
- Sarah Bridle (Manchester)
- Michael Brown (Monash)
- Aurelio Carnero (Observatorio Nacional, Brasil)
- Daniela Carollo (Notre Dame)
- Francisco Castander (IEEC/CSIC)
- Michael Childress (ANU)
- Matthew Colless (ANU)
- Chris D-Andrea (Portsmouth)
- Tamara Davis (UQ)
- Thomas Diehl (FNAL)
- Stephen Fine
- Karl Glazebrook (Swinburne)
- **Janie Hoormann (UQ)**
- Shahab Joudaki (U. Melbourne)
- Eyal Kazin (Swinburne)
- Alex Kim (LBL)
- **Anthea King (U. Melbourne)**
- Kyler Kuehn (AAO)
- David Lagattuta (Swinburne)
- Geraint Lewis (Sydney)
- Chris Lidman (AAO) - PI
- Huan Lin (FNAL)
- Ed Macaulay (UQ)
- Marisa March (Penn)
- Paul Martini (Ohio State)
- Richard McMahon (Cambridge)
- Anais Møller (ANU)
- Jeremy Mould (Swinburne)
- Dale Mudd (Ohio State)
- Ray Norris (CSIRO)
- Conor O'Neill (UQ)
- David Parkinson (UQ)
- Massao Sako (Penn)
- Brian Schmidt (ANU)
- Nicholas Seymour (CASS)
- Robert Sharp (ANU)
- Natalia Eiré Sommer
- Lee Spitler (AAO/Macquarie)
- Mark Sullivan (Southhampton)
- Rollin Thomas (LBL)
- Brad Tucker (ANU)
- Syed Uddin (Swinburne)
- Risa Wechsler (Stanford)
- Christian Wolf (ANU)
- Fang Yuan (ANU)
- Bonnie Zhang (ANU)

OzDES


OzDES will probe (771 AGN)
~12 billion years ago (z~4)
Age of Earth
~4.5 billion years ago
Most of the current
sample (60 AGN)
emitted the light we see
~3.5 billion years ago
(z<0.3)
Furthest measurement
~10 billion years ago
(z~2)
~13.8 billion years ago
Animation: Edward Macaulay
(University of Queensland)

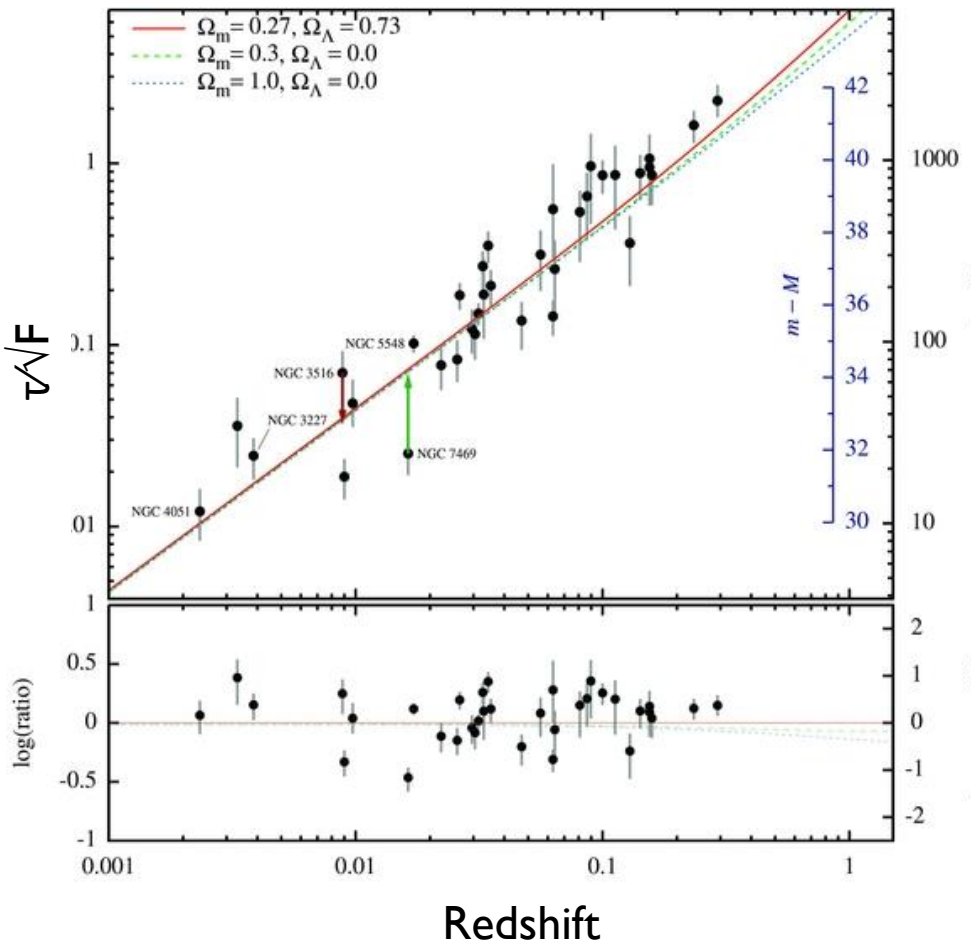
Insight gained from OzDES

* Probe broad AGN population
* Measure BH masses over large cosmic time
* Constrain R-L relationship in multiple lines
* Investigate:
  * evolution in R-L relationship with time
  * Intrinsic scatter in R-L relationship
* Due to the length of survey, get most luminous and high z objects



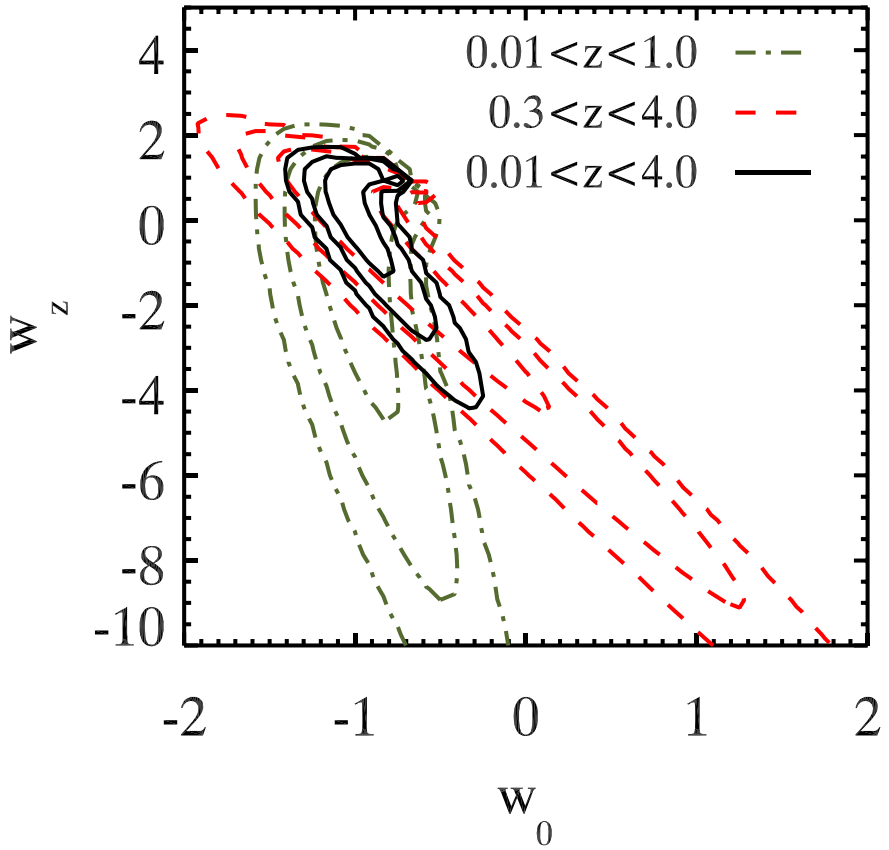
AGN as standard candles

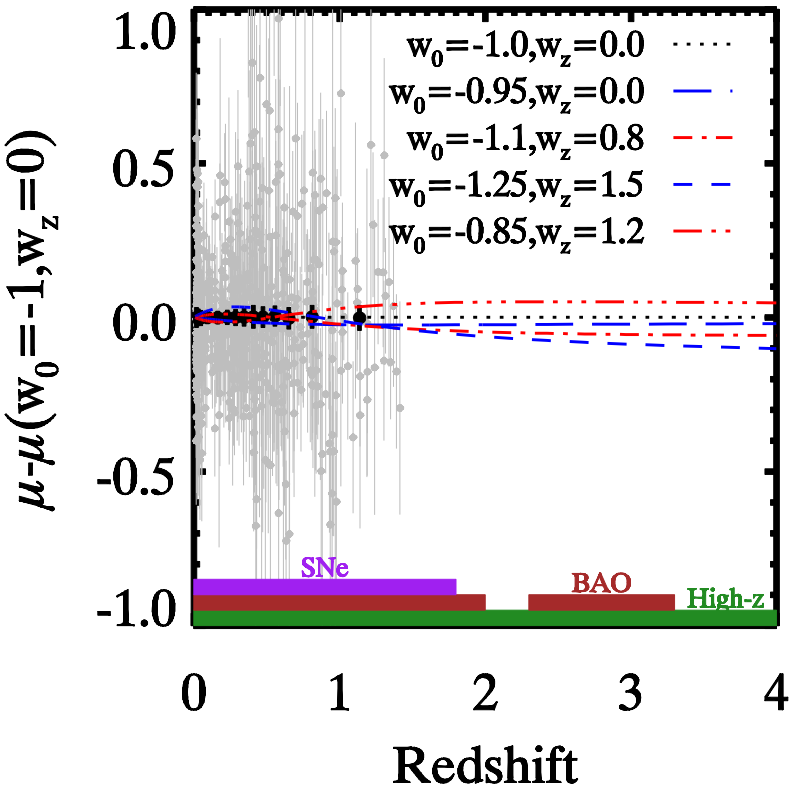
* If we reverse R-L relationship, measure τ and get luminosity
* ➔Standard candle!
* AGN span large redshift range
* Time evolution of dark energy?



Watson et al 2011

High-z standard candles - Linear w(z)





Popular dark energy model:

Chevallier-Polarski- Linder model,

$$w(z) = w_0 - w_z z/(1+z)$$

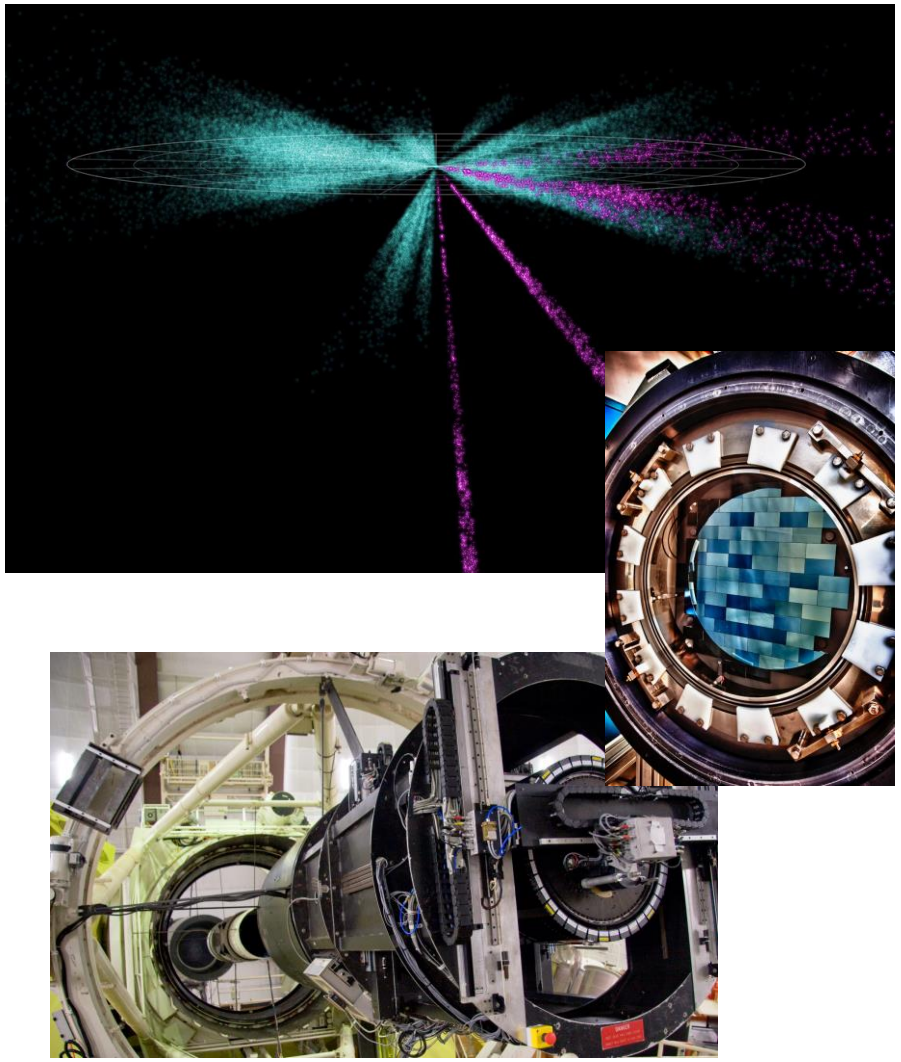
Need information over full redshift range!

*****AGN can do this*****

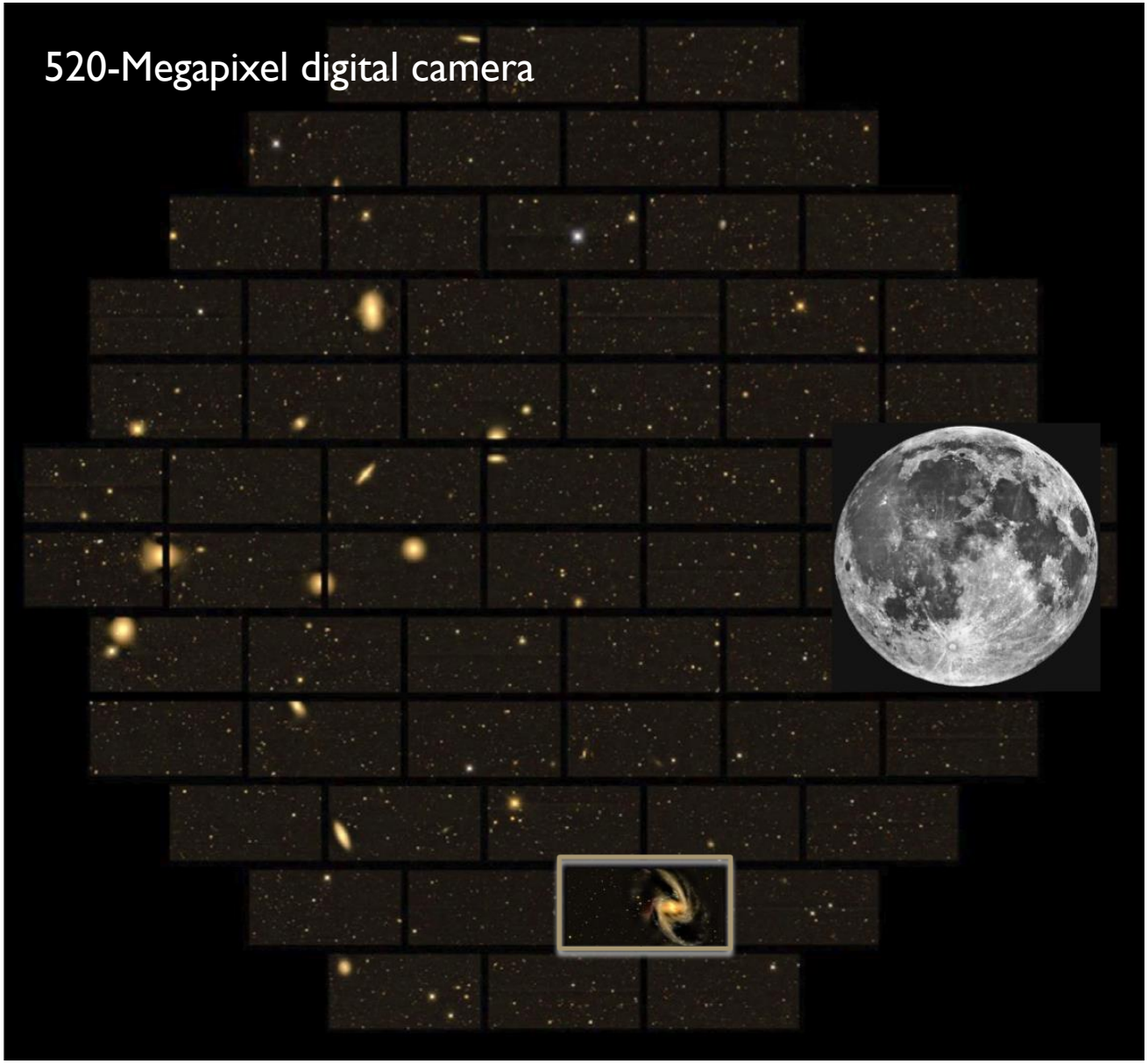
King, et al. 2014

OzDES reverberation campaign

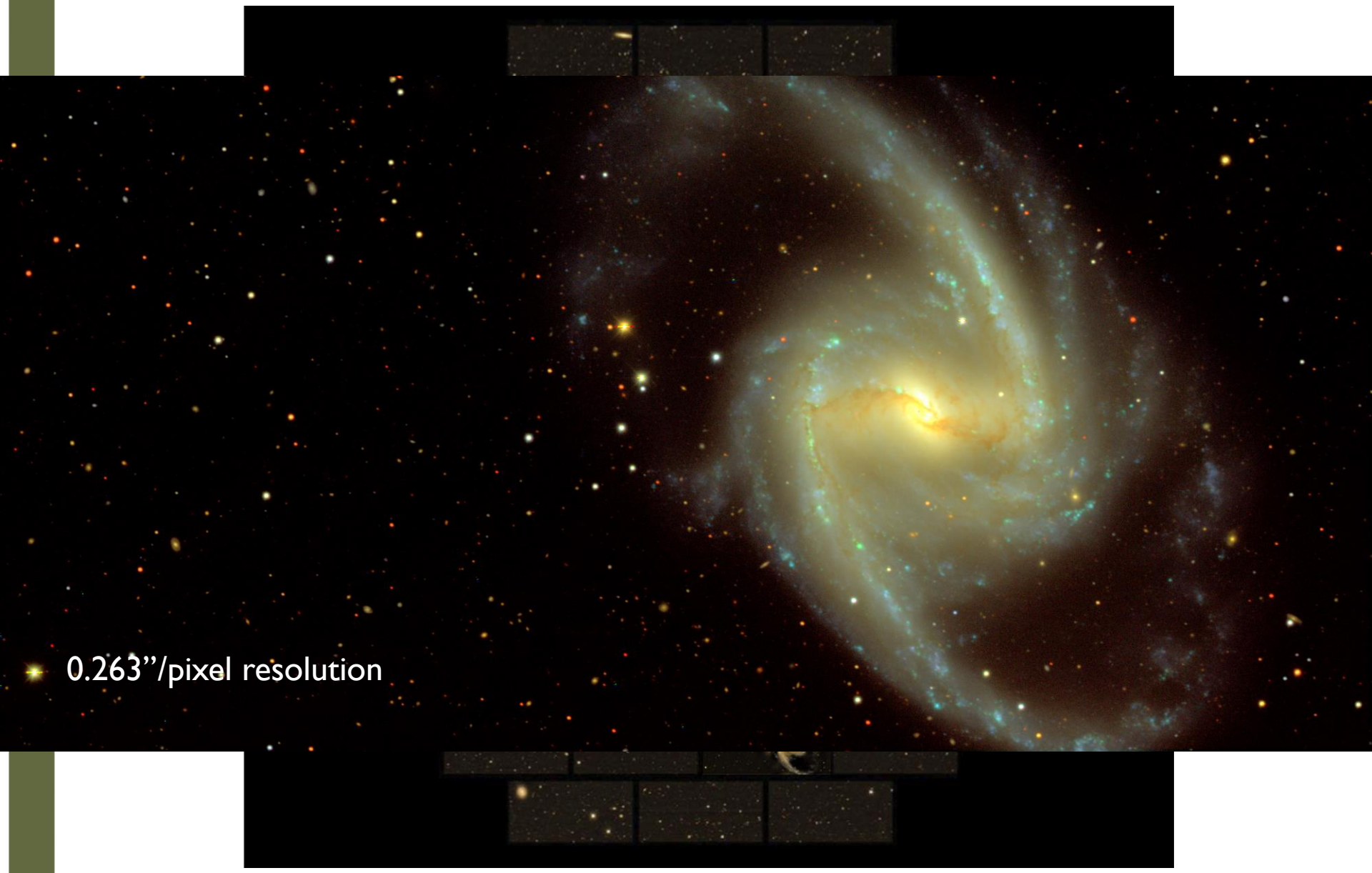
* 10 fields, 3 deg^2 each
* Currently in year 4 of observations out of six.
* Two components:
  * Imaging (DECam – 3sq deg - griz)
  * Spectra with AAOmega – (3.9m^2 AAT – 394 fibres – 365nm-960nm)
* Expect:
  * 120 continuum epochs (starting a year in advance)
  * 25 spectroscopic epochs
  * Monitoring a minimum of 771 AGN



DECam Imaging

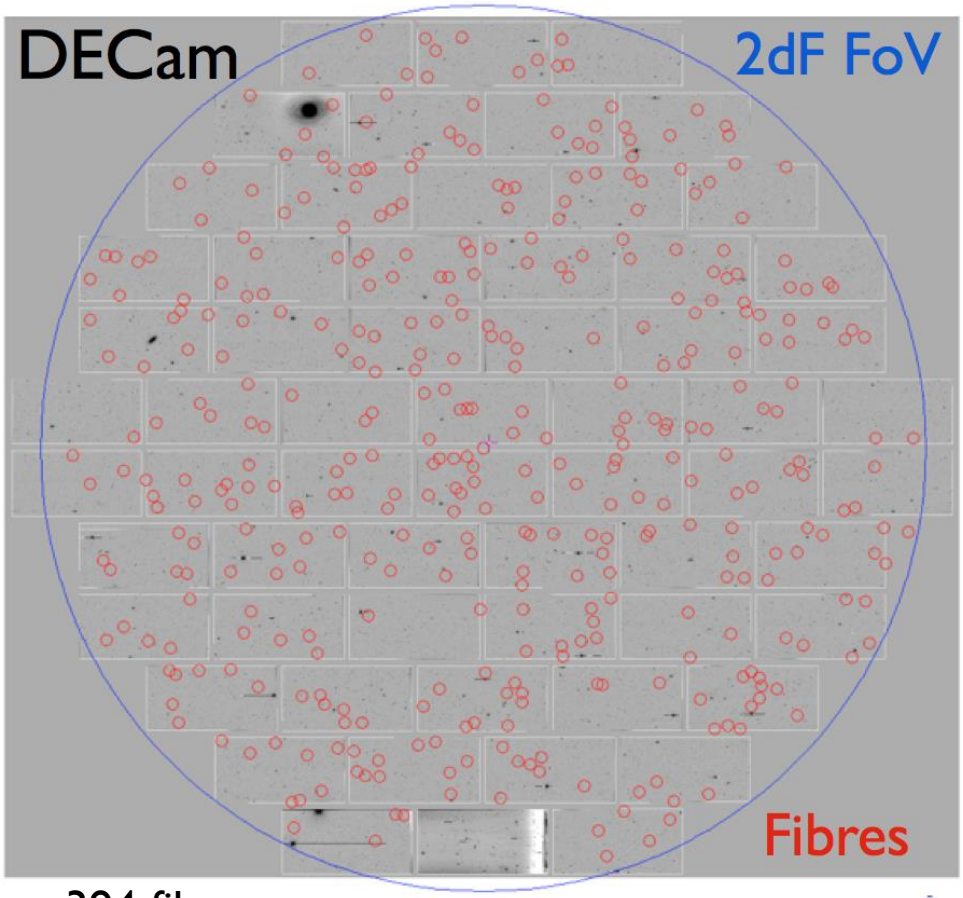


DECam Imaging

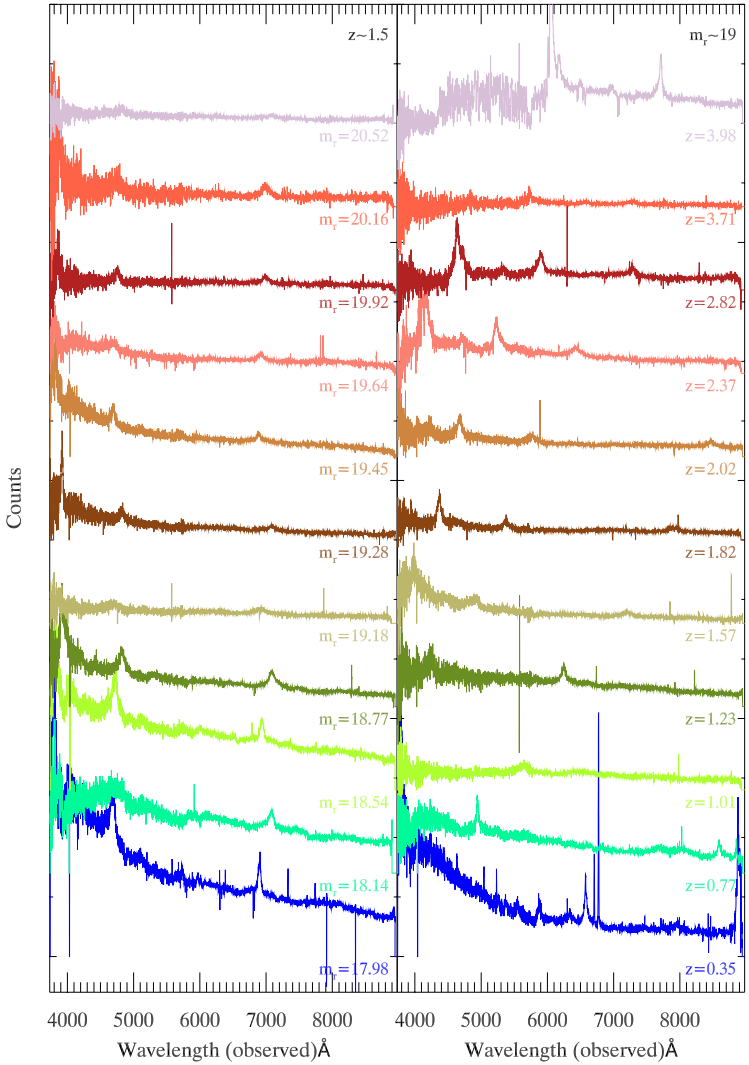


- 0.263”/pixel resolution

OzDES Spectra



394 fibres
R~1500
2” fibre diameter



Photometric Observing Plan

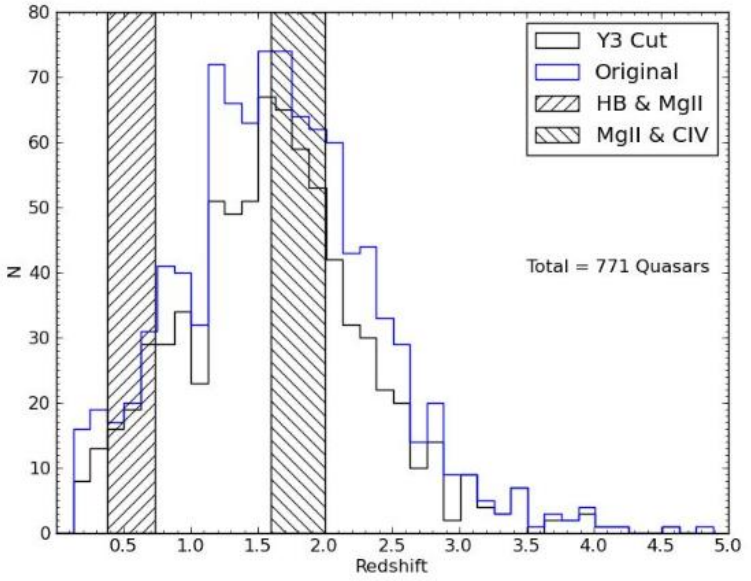
* Science Verification: 2012 November - 2013 February
* Main Survey: September 1 and February 15 between 2013 and 2017
* Images are taken in all four filters in the same night when possible
* Field not observed within last 5 nights are given highest priority
* Special preference given to the deep fields, C3 and X3
* Exposures time:
  * Shallow fields: range from 175-400 seconds
  * Deep fields: range from 600-3630 seconds

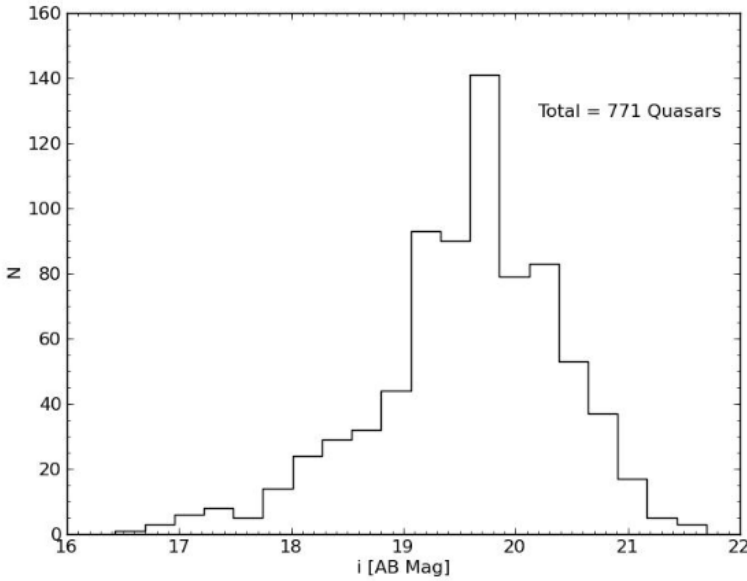
Spectroscopic Observing Plan

* 100 nights – Spectroscopic time
* Original plan (5 years): 12 nights 2013, 16 nights 2014, 20 nights 2016, 24 nights 2017 and 28 nights 2018
* Revised plan (6 years): 12 nights 2013, 16 nights 2014, 20 nights 2016, 20 nights 2017, 20 nights 2018, 12 nights 2019
* 4 nights ~ 1 observation of all 10 fields with weather

Sample

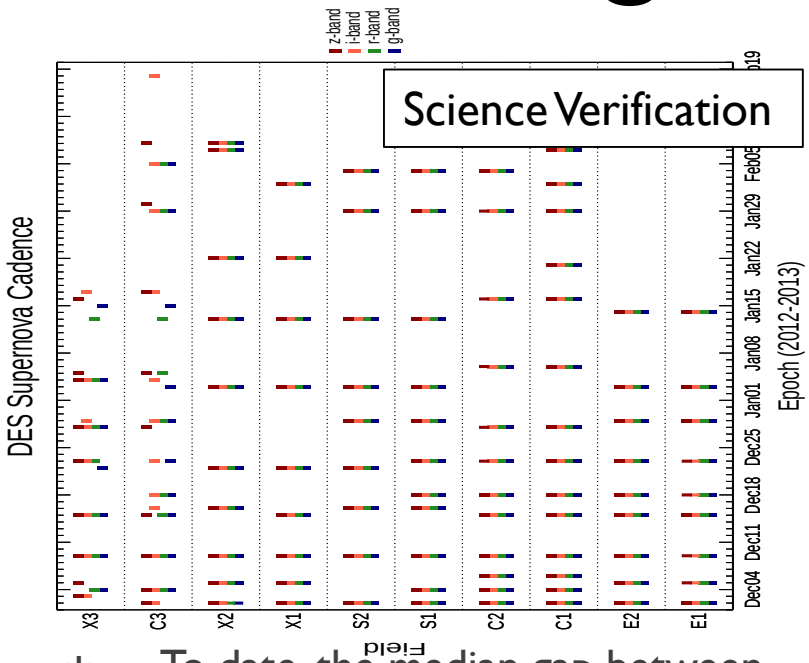
* 3331 quasar candidates were observed in Year 1 (2013)
* After visual inspection sample was reduced to 989 objects for Year 2 (2014)
* Final 771 quasars were then chosen wrt:
  * S/N in emission line measurement
  * Number of lines present
  * High redshift/long lag
  * Number of continuum epochs (position with respect to chip gaps)

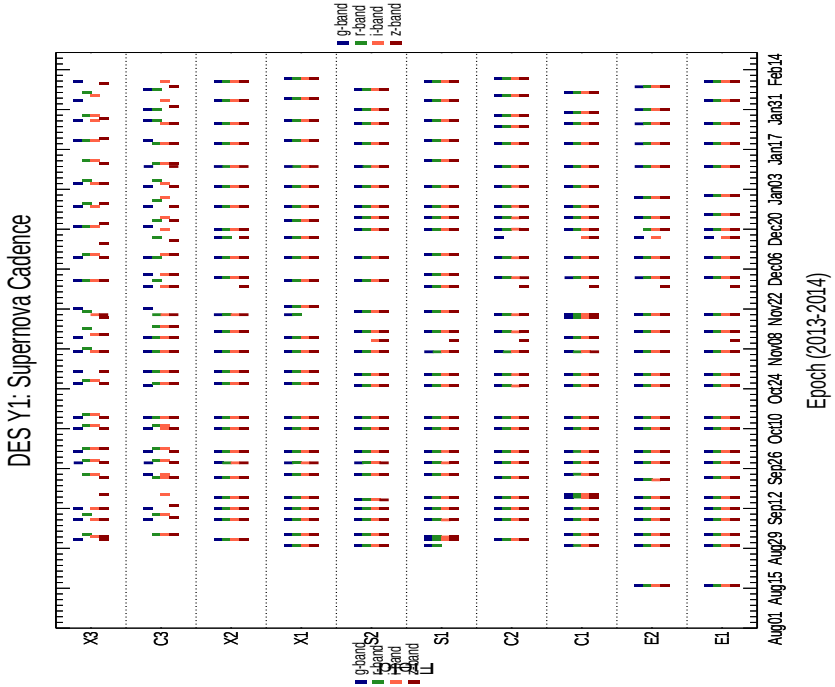


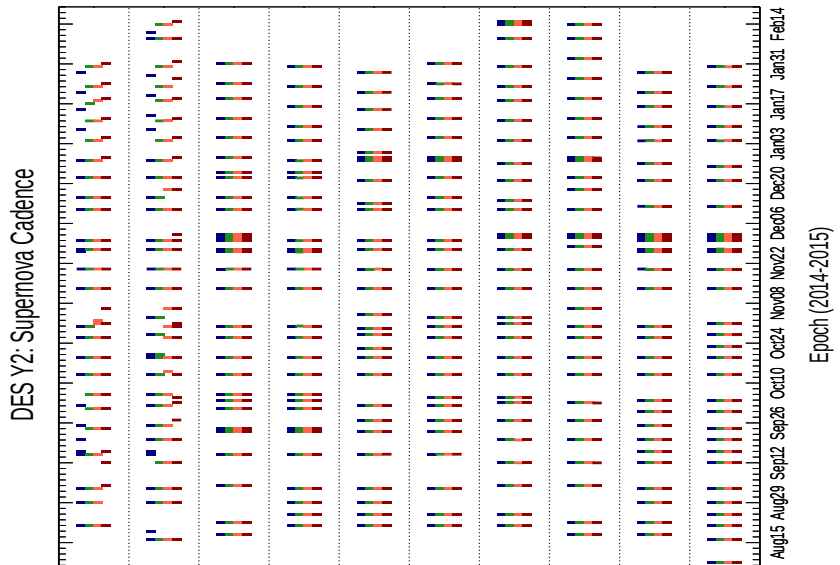


Field	C1	C2	C3	E1	E2	S1	S2	X1	X2	X3
Number	57	78	79	79	87	80	87	76	71	77

Progress - DES



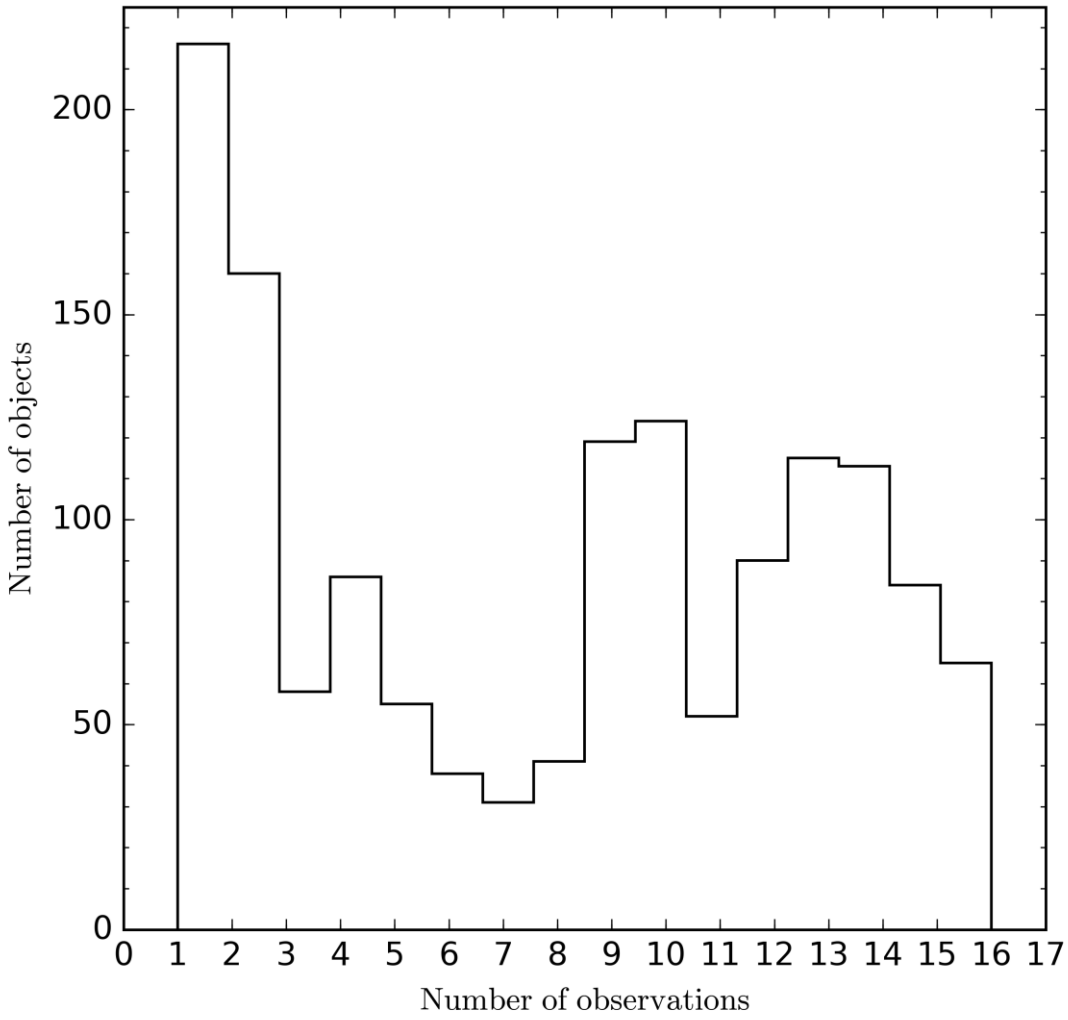




* To date, the median gap between consecutive observations is 6.5d and the maximum gap ranges between 12 and 21d

* First year release:
  * Absolute photometric calibration: the absolute zeropoints of the r and i filters to be within 2%, the g and z to be within 3%, and the Y to be 5% of absolute.
  * Relative photometric calibration: g-r: 2%, r-i: 1.5%, i-z: 2%, z-Y: 2%.

Progress - OzDES



Challenges of OzDES

- Low number of spectroscopic measurement,
- Monitor intrinsically more luminous objects:
  - Longer lags
  - Lower variability
- Generally fainter in flux
  - Lower signal to noise
- Fiber spectroscopy vs slit spectroscopy
  - Possible loss of flux due to misalignment or seeing affects

Flux Calibration

* Relative flux calibration is done using F-type stars
* 10-15 observed in each field
* Sensitivity map is then created over whole FoV
* Absolute flux calibration is performed by scaling to DES photometry measurements
* Photometry taken from nearest epoch (generally within 3 days of spectra)
* Currently getting close to expected 10%
* In some sources, emission line flux measurements will be limited by S/N

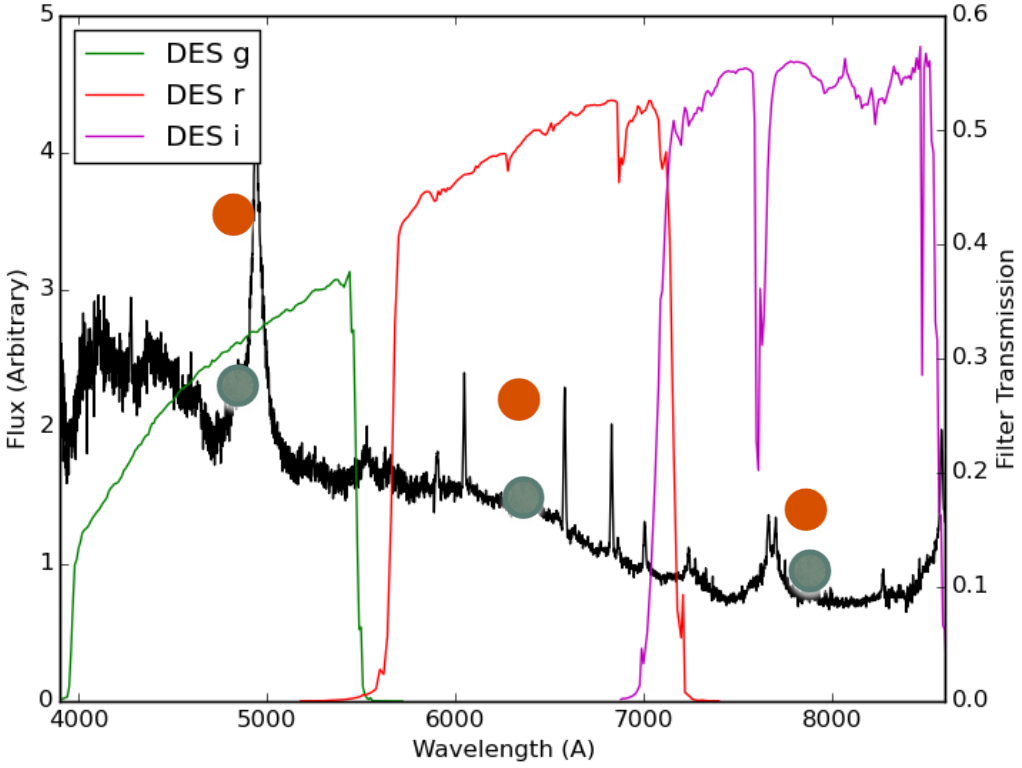


Figure courtesy of Dale Mudd

Spectral **P**roperties of **A**GN Modelled through **M**CMC (**SPAMM**)

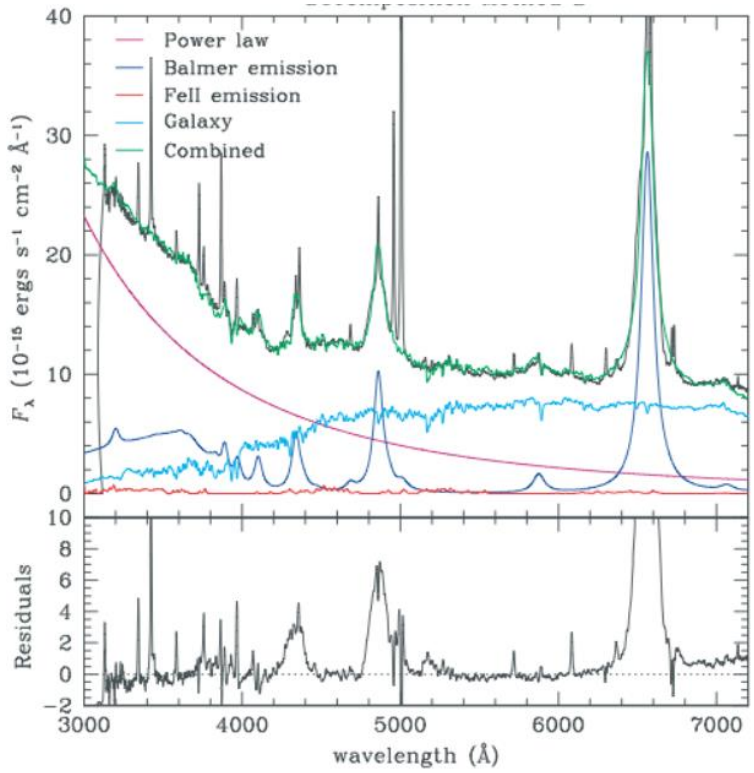
Use MCMC spectral decomposition software to automate line fitting procedure.

Project led by Gisella de Rosa (STScI)
Project Members: Myself, Marianne Vestergaard, Bradley Peterson, Michael Fausnaugh, Dale Mudd, Jo Taylor, Kelly Denney, Justin Ely, Gerard Kriss, Kevin Croxall, Anna Pancoast, Roberto Assef, Paul Martini

Goal is to release as public code.

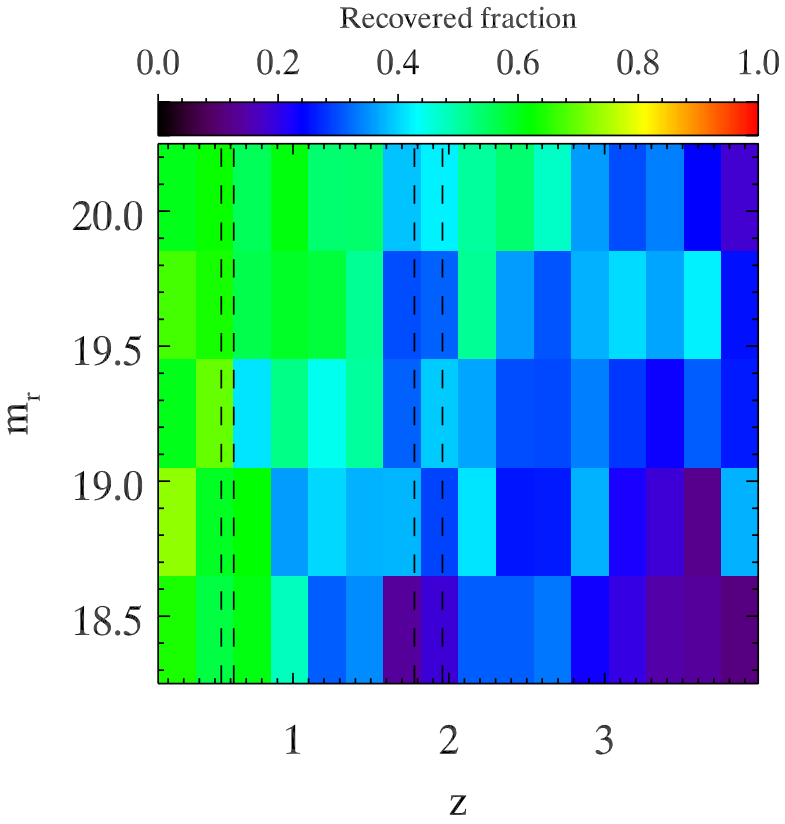
Main components:

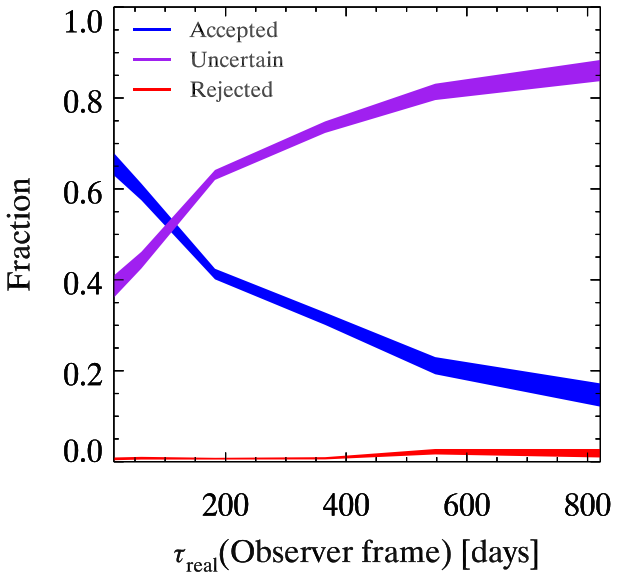
* Nuclear Continuum,
* Balmer Continuum,
* High Order Balmer lines,
* Fe II/III emission,
* Host galaxy and reddening,
* Nuclear reddening,
* Broad and narrow emission lines.

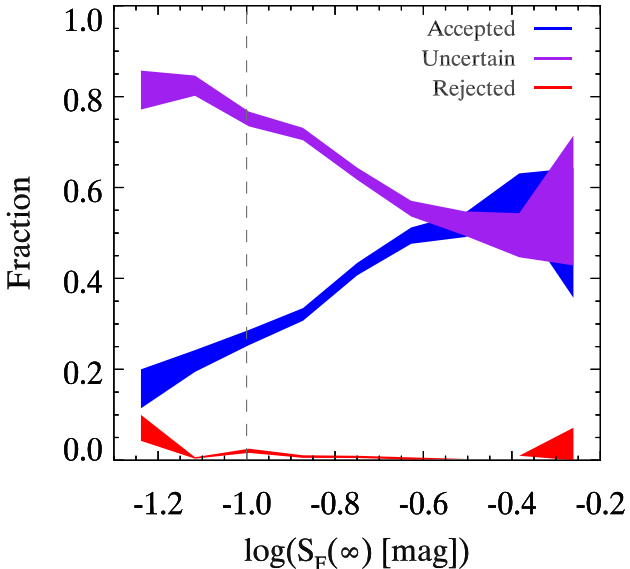


Fraction of recovered lags

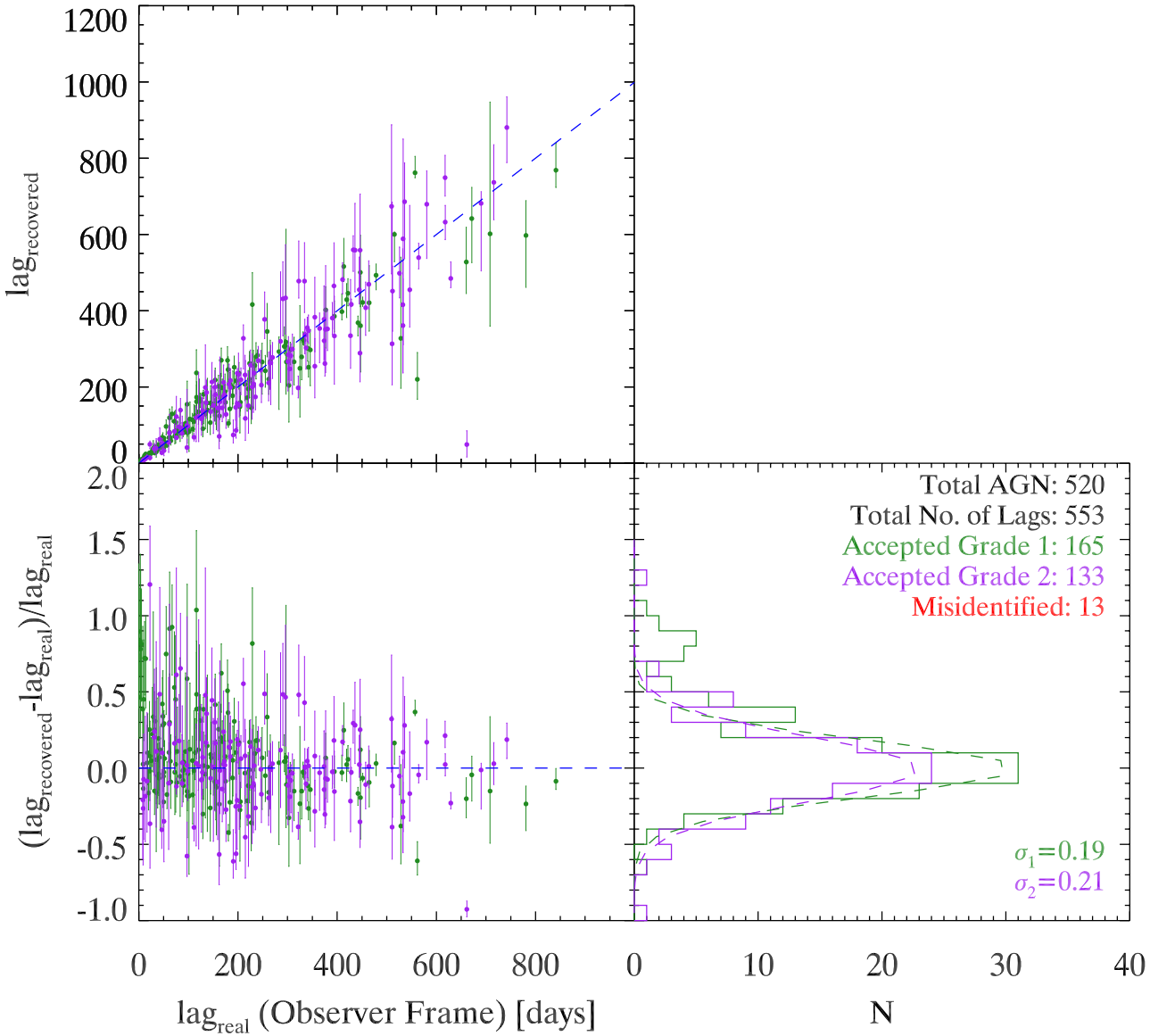
* Low redshift-faint objects most easily recovered
* Short lags and large variations



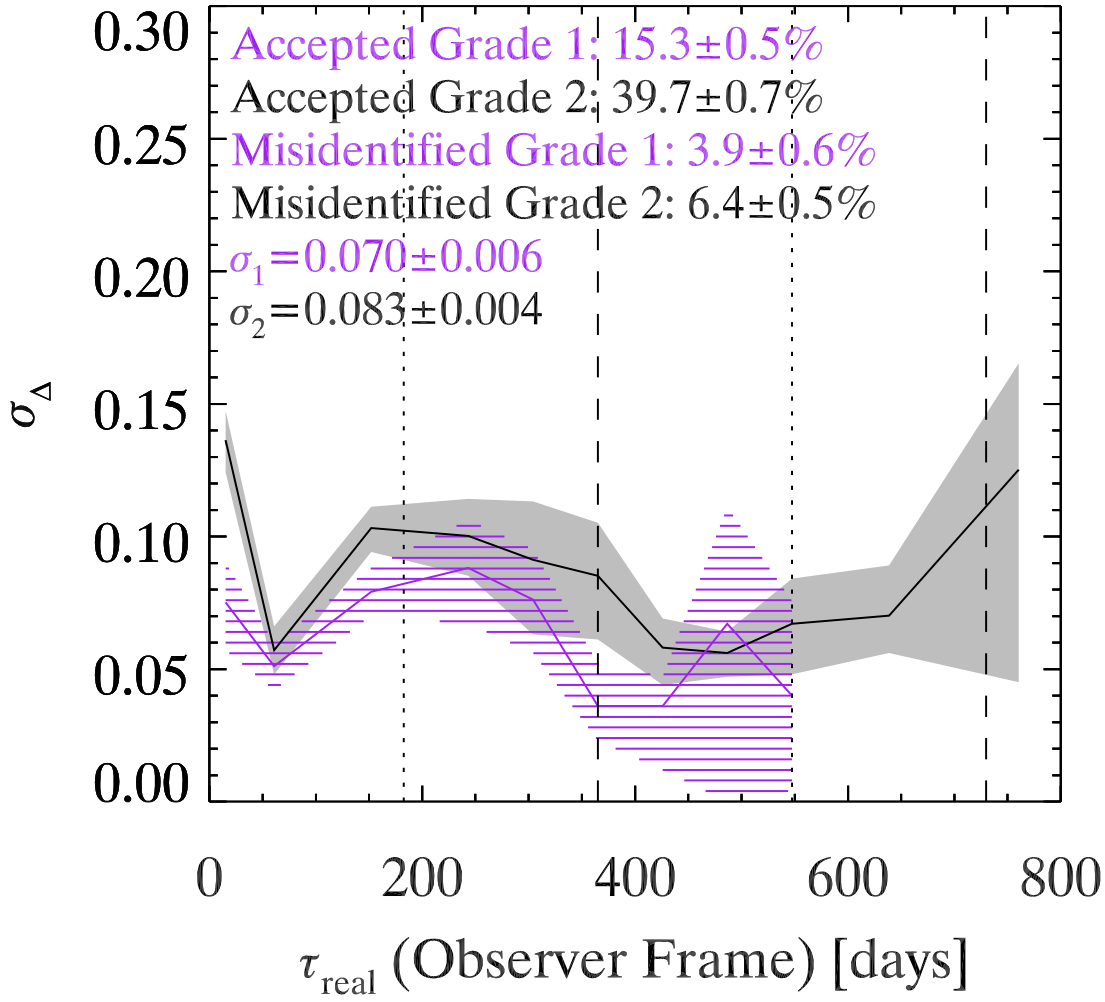




Accuracy

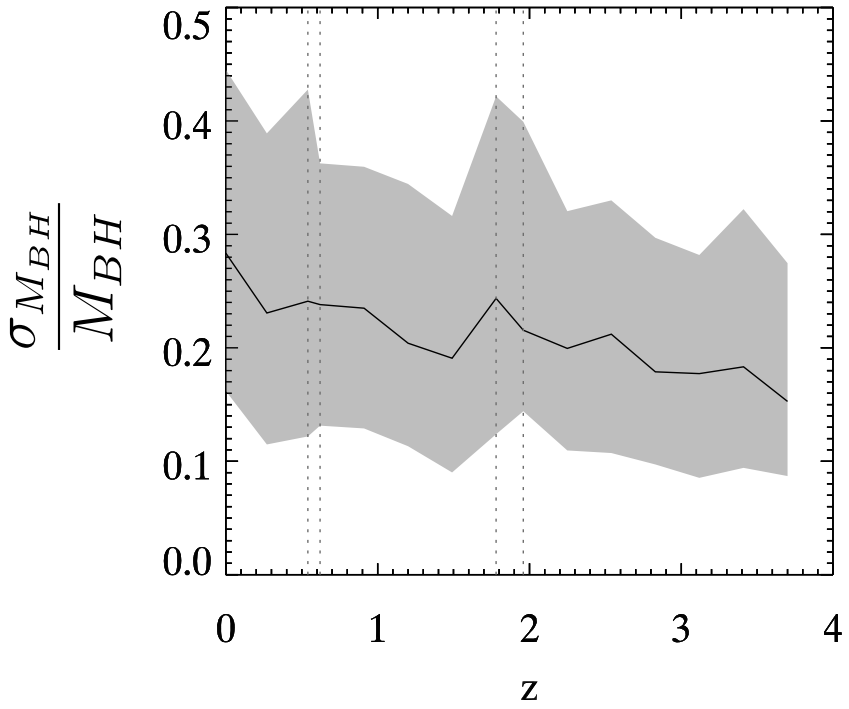

1200
1000
800
600
400
200
0
lag_recovered
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
(lag_recovered-lag_real)/lag_real
0
200
400
600
800
lag_real (Observer Frame) [days]
Total AGN: 520
Total No. of Lags: 553
Accepted Grade 1: 165
Accepted Grade 2: 133
Misidentified: 13
σ1=0.19
σ2=0.21
0
10
20
30
40
N

Accuracy – Seasonal gap effects



Recovered black hole masses (Direct)

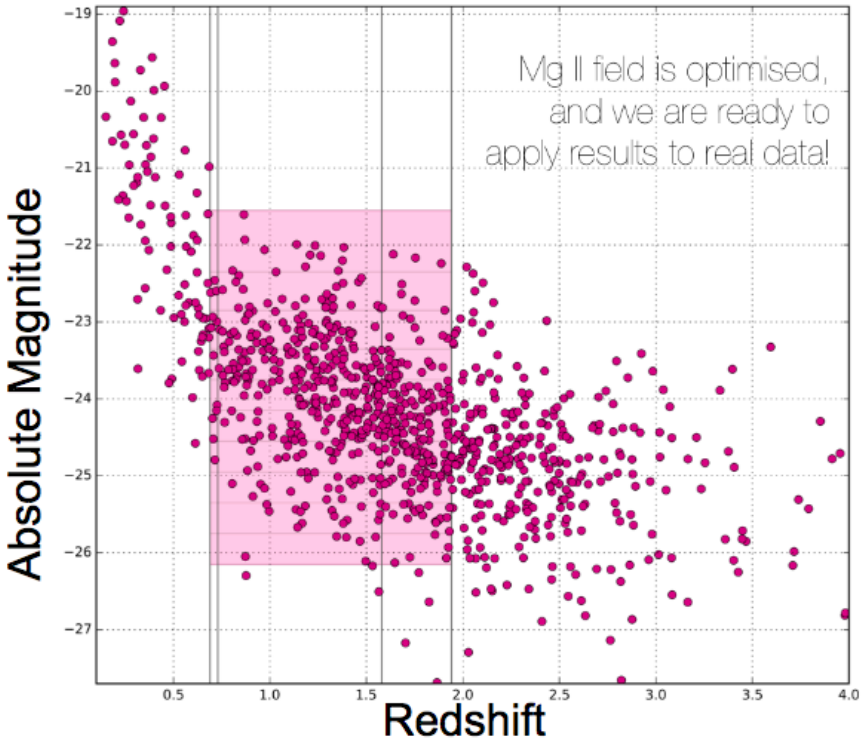
* Currently error dominated by lag uncertainty
* => $\frac{\sigma_{M_{BH}}}{M_{BH}} \approx \frac{\sigma_{R_{BLR}}}{R_{BLR}}$

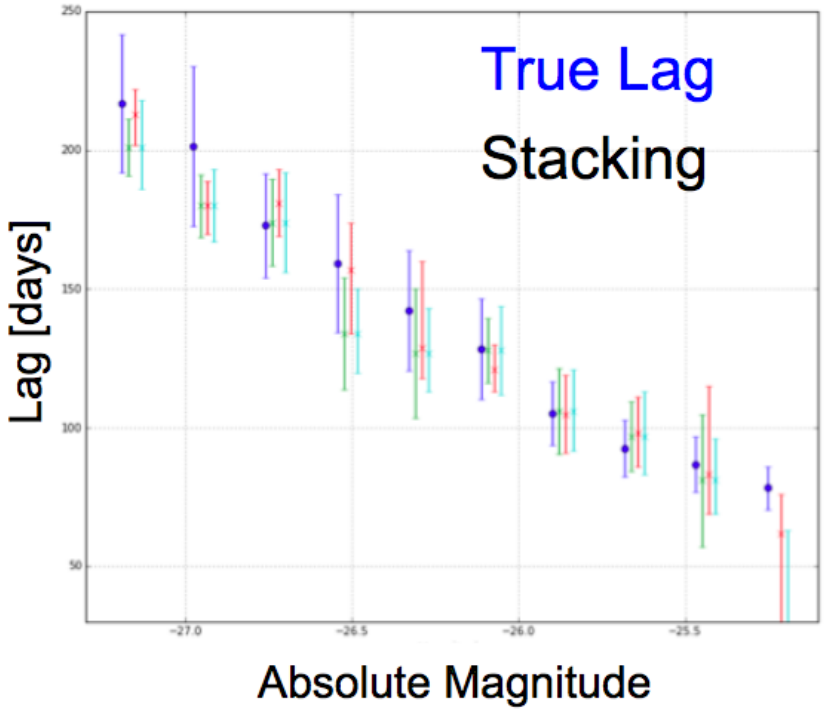


Stacking

* For early science and objects with low variation or small number of epochs
* Following Fine and Brewer: stack signal from individual objects
* Stack individual lag likelihood distributions for AGN with similar luminosities

Work by Natalie Eire Sommer





Ongoing/Future projects

* Continuum reverberation mapping (Dale Mudd)
* Emission line properties and variability (focussing on CIV) (Harry Hobson)
* Stacked spectra (Natalia Eire Sommer)
* Early Science results (Janie Hoorman)

Wrap up

* In year 4 out of 6
* Observing 771 Quasars
* Aim to measure black hole masses for a broad population, measure R-L relationship for Hβ, Mg II and C IV, and investigate evidence of evolution of R-L relation or sources of intrinsic scatter
* Expect to recover lags for ~40% of sample
* Will use automated spectral decomposition software (SPAMM) to analyse spectra