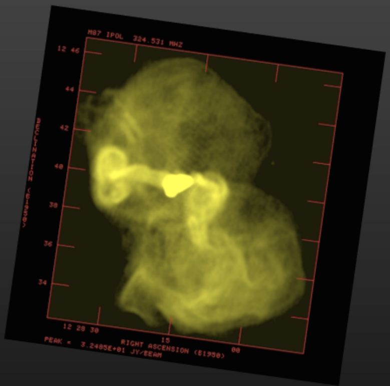
AGN in the LSST Era

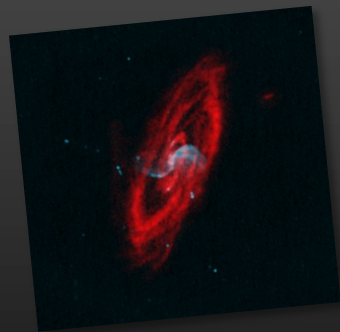


Carole Mundell

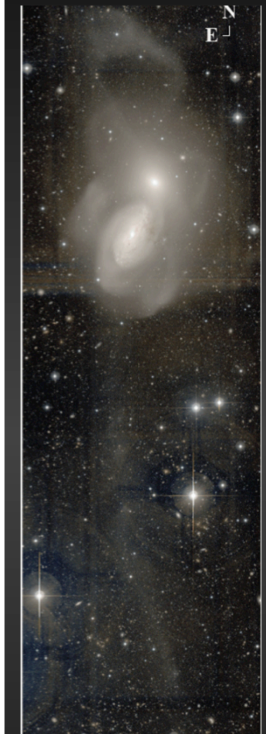
c.g.mundell@bath.ac.uk

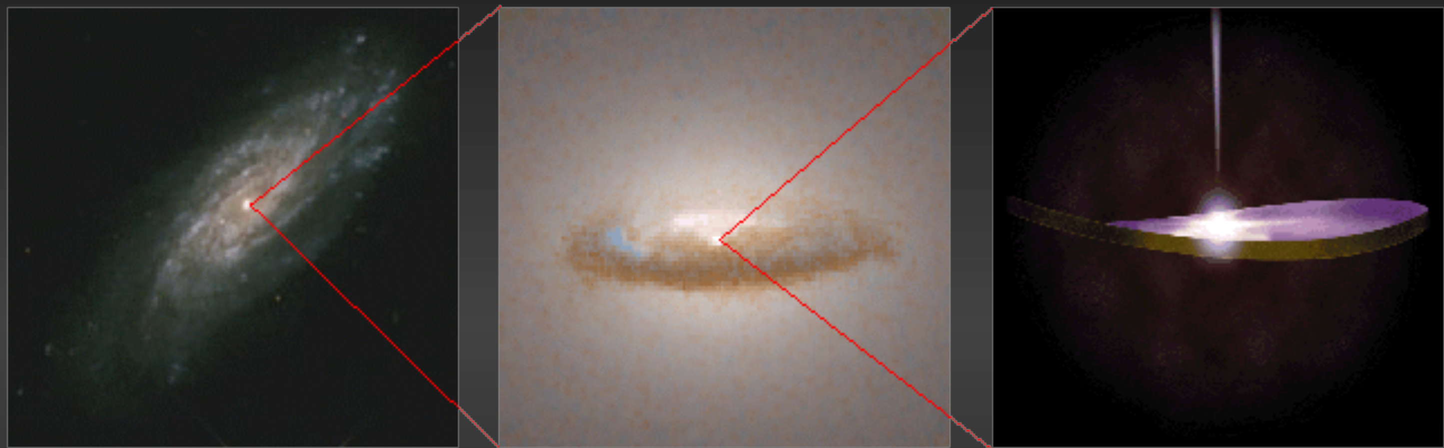
PoC: LSST-UK AGN SWG

UNIVERSITY OF BATH

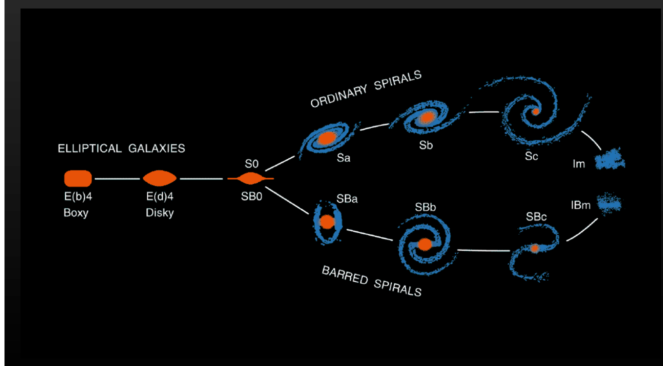


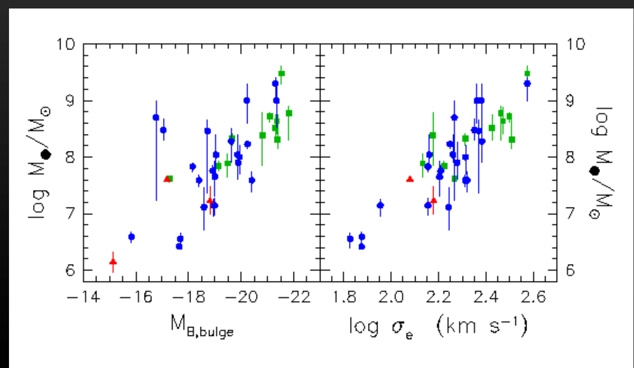
AGN as extreme use case





- Host galaxy
  Out to >100 kpc
- Obscuring torus
  ~hundreds pc
- Accretion disk
  10 - 100 AU





BH-bulge correlation
AGN & galaxy evolution

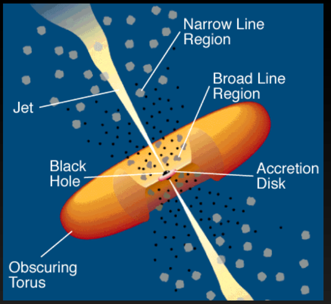
All Major AGN Science

- Radio loud AGN
  - Discovery, multi-dimensional monitoring
  - Relativistic physics (obs+theory)
- Radio quiet AGN
  - Discovery, monitoring, host environments
- Fuelling, feedback, hosts + environments
- Accretion physics
- Probing quiescent BH population

New Big Picture

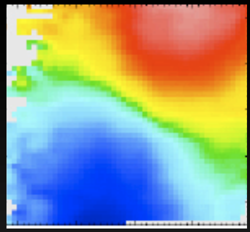
- Active galactic nuclei by power
  - Outflows, star formation and environment
- Illuminating inactive BHs
  - Flares and tidal disruptions
- The time domain challenge
  - Discovery & follow-up
  - Technology and politics
- The multi-messenger landscape

LSST-UK AGN



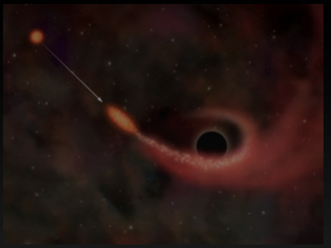
- Carole Mundell (PoC)
- Dave Alexander
- Manda Banerji
- Mark Birkinshaw
- Katherine Blundell
- Garret Cotter
- Julien Devriendt
- Chris Done
- Martin Hardcastle
- Nina Hatch
- Paul Hewett
- Keith Horne
- Matt Jarvis
- Sugata Kaviraj
- Shiho Kobayashi
- Andy Lawrence
- Daniel Mortlock
- Richard McMahon
- James Mullaney
- Paul O'Brien
- Mathew Page
- Francesco Shankar
- Adrianne Slyz
- Aprajita Verma
- Martin Ward
- Steve Warren
- Vivienne Wild
- Diana Worrall
- Andy Young

Bath, Bristol, Cambridge, Durham, Edinburgh, Hertfordshire, Imperial College, Leicester, LJMU, MSSL, Oxford, Nottingham, St Andrews…



UK Community

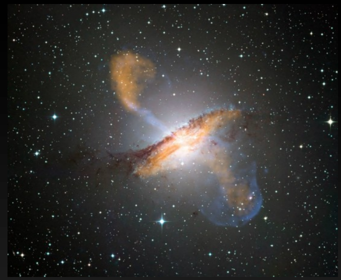
- Observational (static)
  - Strong multi-wavelength leadership
  - Imaging & spectroscopic surveys
  - Local galaxies
  - Kinematics
  - AGN and galaxy evolution



UK Community

- Observational (time domain)
  - Strong multi-wavelength leadership
  - Imaging & spectroscopic surveys
  - Rapid-response follow-up
    - High-energy nuclear flares
    - TDEs will trace quiescent black hole population cf GW BHs
  - Reverberation mapping
  - AGN for cosmology (RM to z~2.5; z’-band dropouts to z~6.5-7.5)

UK Community

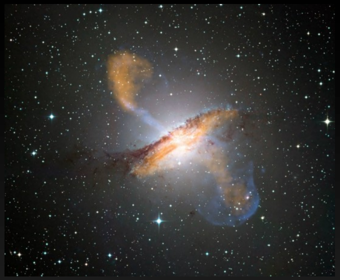


- Theoretical
  - Major simulation frameworks
  - Key for embedding new data
  - Predictions for optimisation of obs. strategy
  - BH growth, accretion & duty cycles
- Machine learning, obs-theory interface
  - AGN ID/classification cf SN (ISSC)
  - Response to alerts (10 million per night?)

The Time-Domain Niche

- Reverberation mapping in Seyferts
- Radio loud quasars
- Optically violent variables
- X-ray timing
- Optical continuum monitoring of blazars
- Triggered flare followup
- Host galaxy studies

Black Holes biases

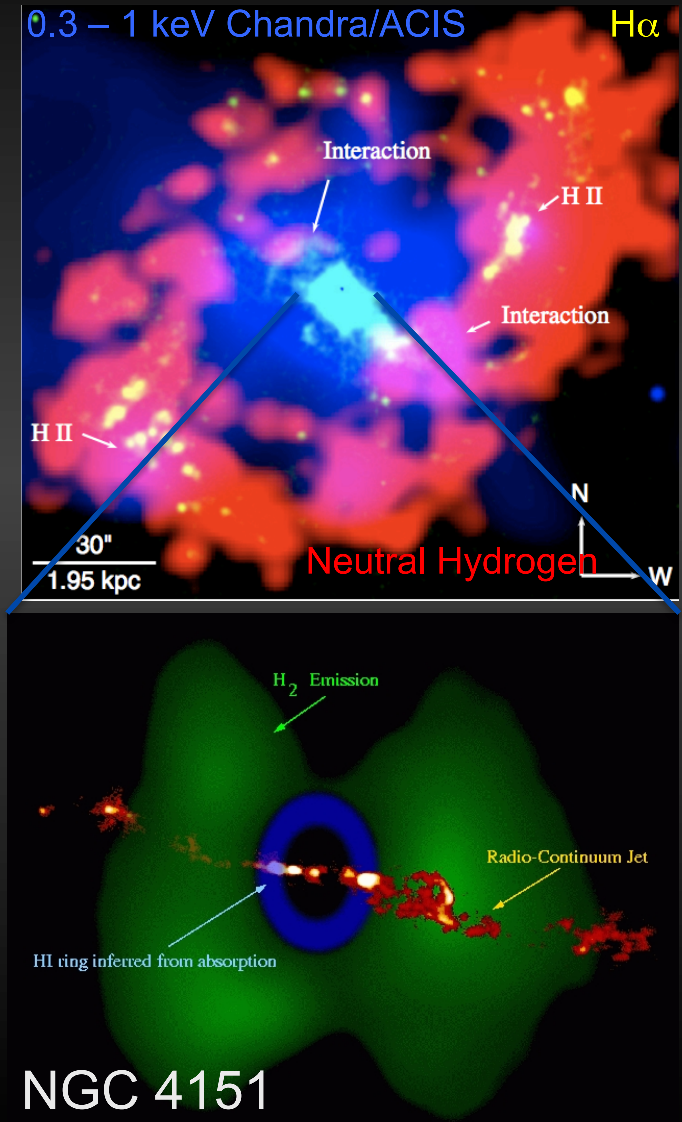


- BH mass – bulge relation biased high
  - BH masses in AGN reduced
  - BH densities reduced
  - Radiative efficiencies/BH spin increased
- Episodic activity
  - AGN lifetime reduced
  - Duty cycles/BH growth extended

Barth et al. 2016; Greene et al. 2016; Shankar et al. 2016; Wang et al. 2011

Feedback & AGN Evolution

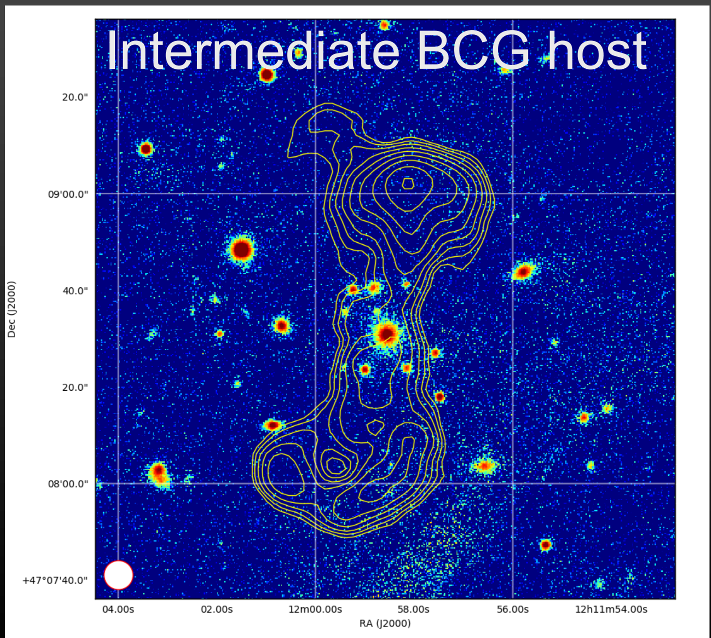
- Chandra soft X-ray emission to R = 2 kpc, L(0.5-2keV)~10^{39} erg/s (Wang et al. 2010)
- Recent AGN:host interaction
  - Mechanical energy deposited < 10^5 years or
    - *Eddington-limited outburst luminosity ~ 10,000 yr ago*
- Live systems c.f. Milky Way
- Short timescale – outbursts > 1% AGN lifetime

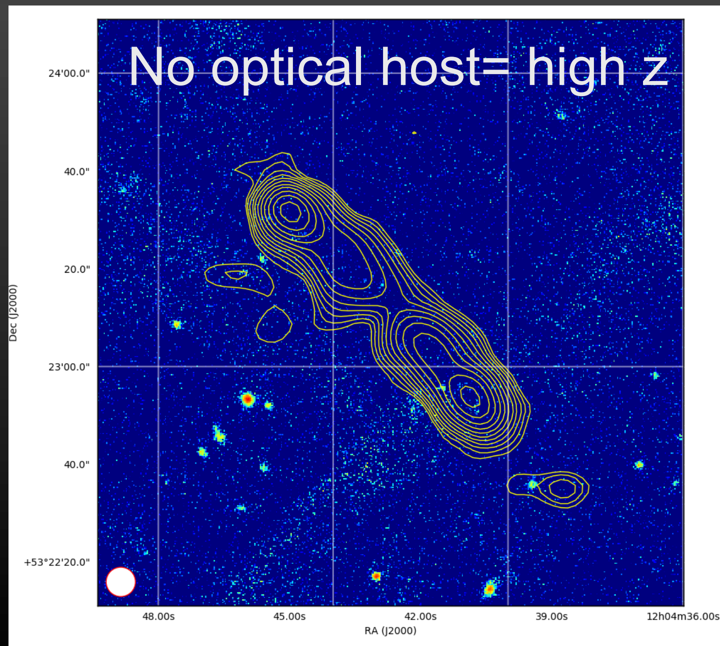


Wang+ 2010, ApJ, 719, L208; Mundell et al. 2003

LSST – SKA Synergies

- Discovery bands + cross correlation
- Even at PanSTARRS depth, no optical counterparts for 40% large, bright radio sources (Hardcastle+)
- LSST will do better; EUCLID will augment



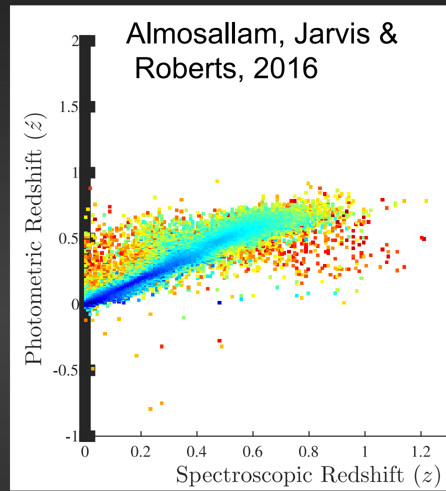


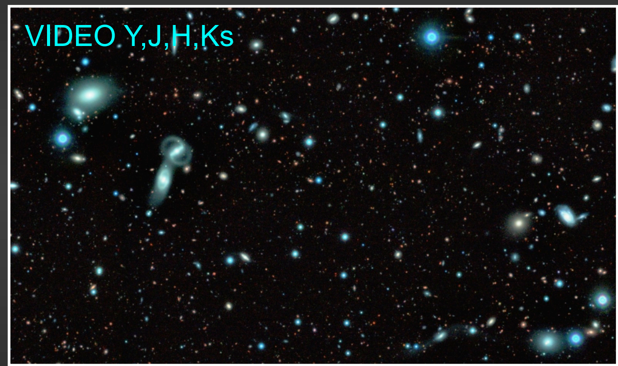
PanSTARRS I-band + LOFAR

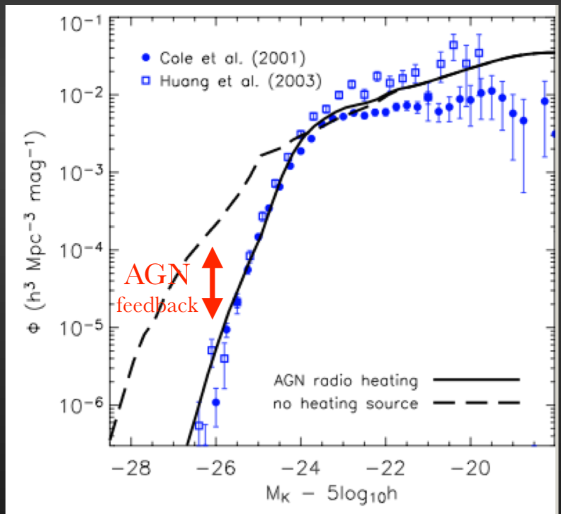
Martin Hardcastle (Hertfordshire)

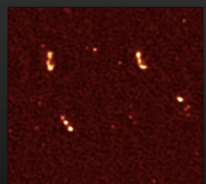
AGN evolution and Feedback

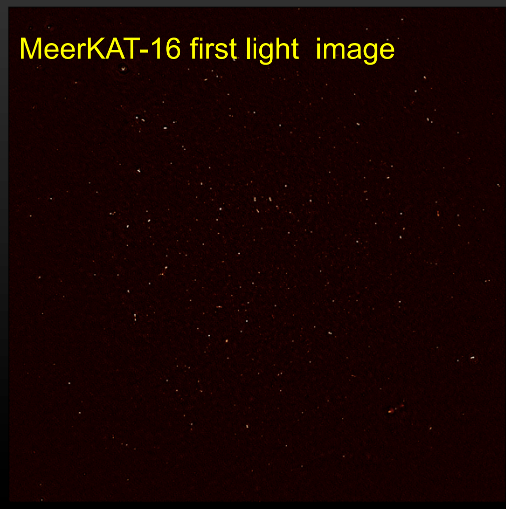
- Combine LSST + multi-wavelength data to augment AGN identification
- Combine ComCam data with radio data from MeerKAT and nearIR data from VIDEO/VEILS/SpitzerDeepDrill,
- Preparation for full LSST + Euclid + SKA1

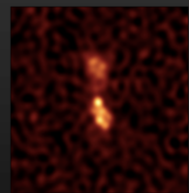


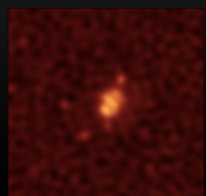


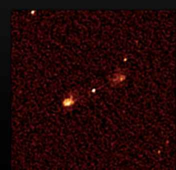






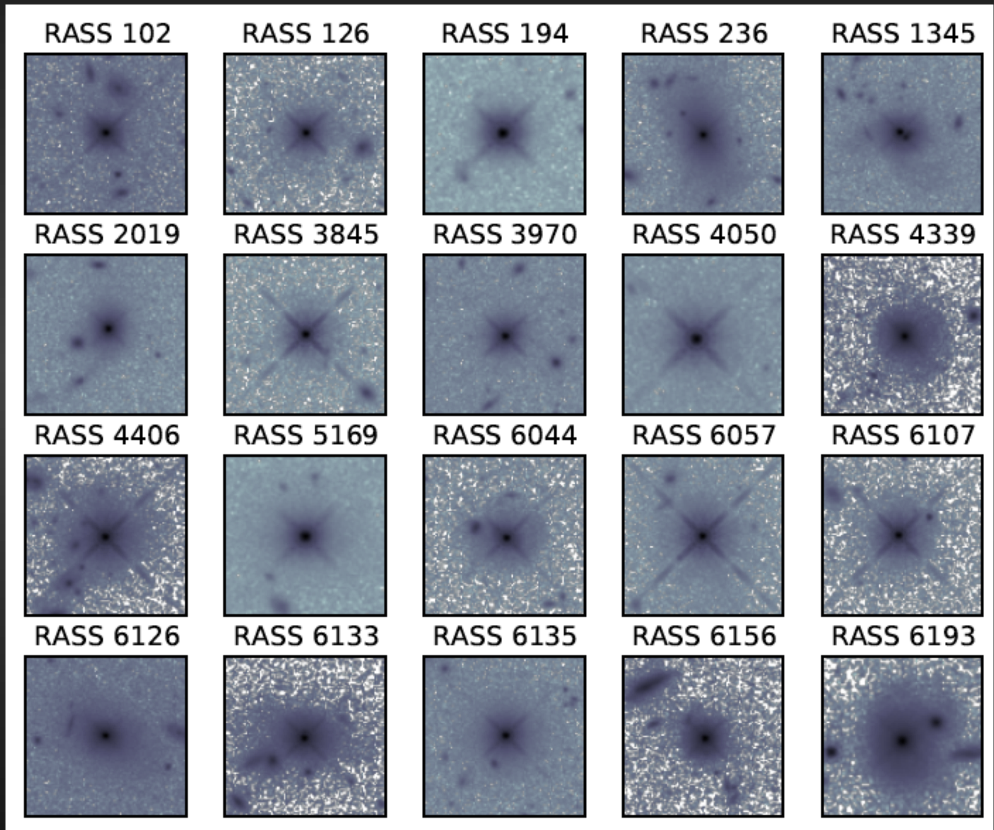


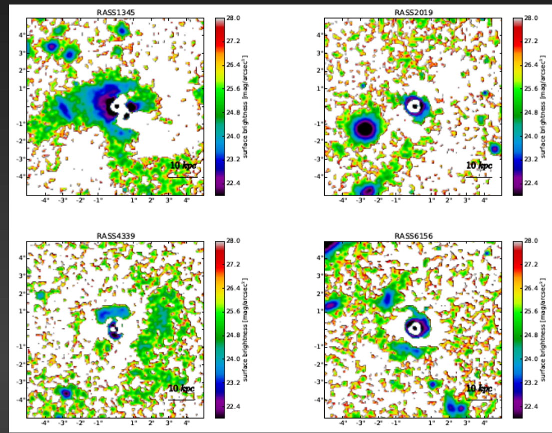


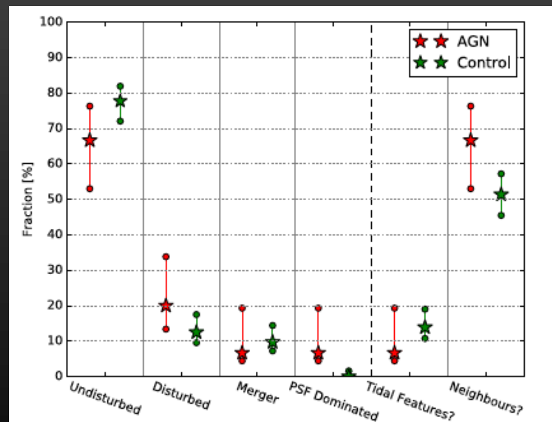


Matt Jarvis (Oxford)

Luminous Quasar Systems



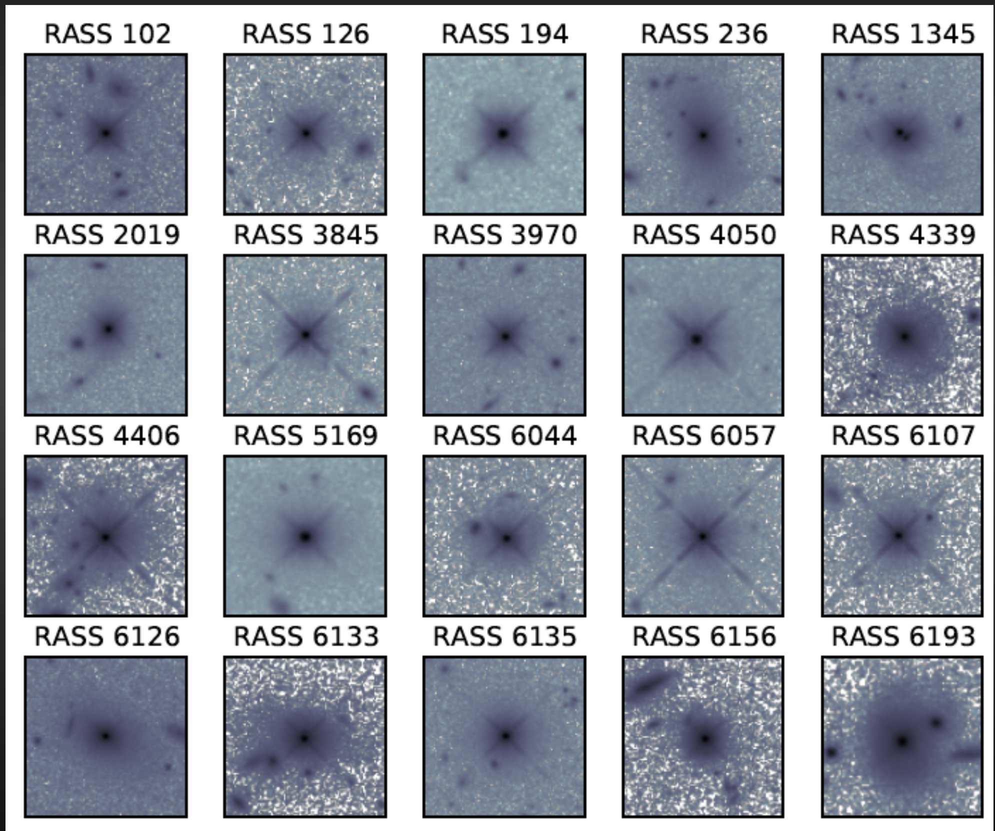


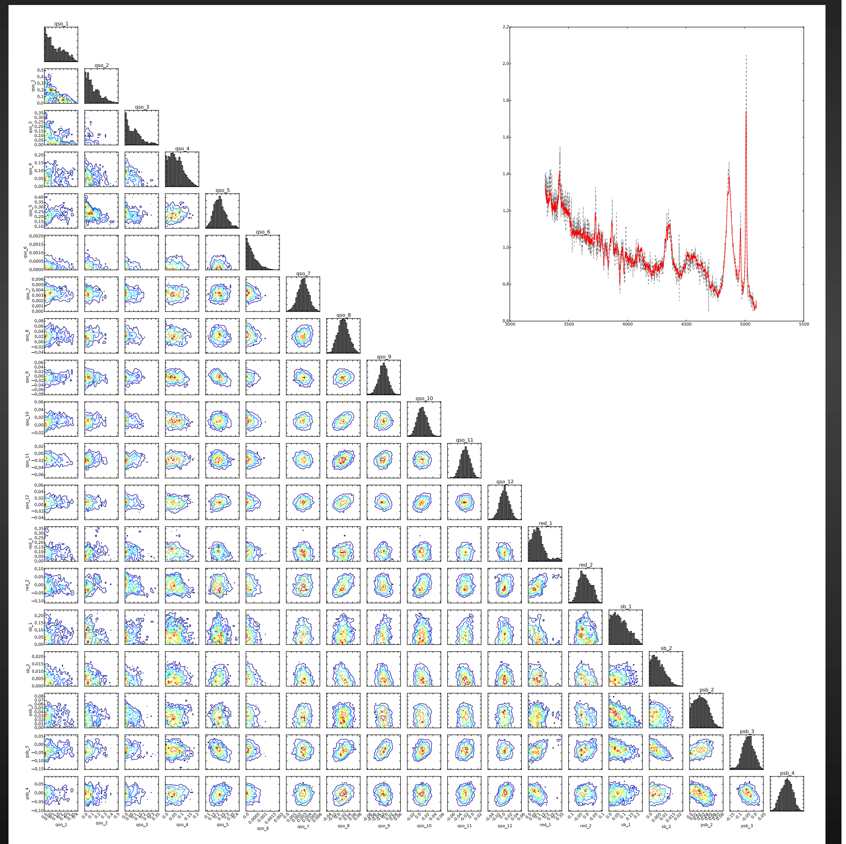


Villforth+17, MNRAS, 466, 812

Host galaxies of z~0.6 quasars: Major mergers not prevalent at highest quasar luminosities

Luminous Quasar Systems

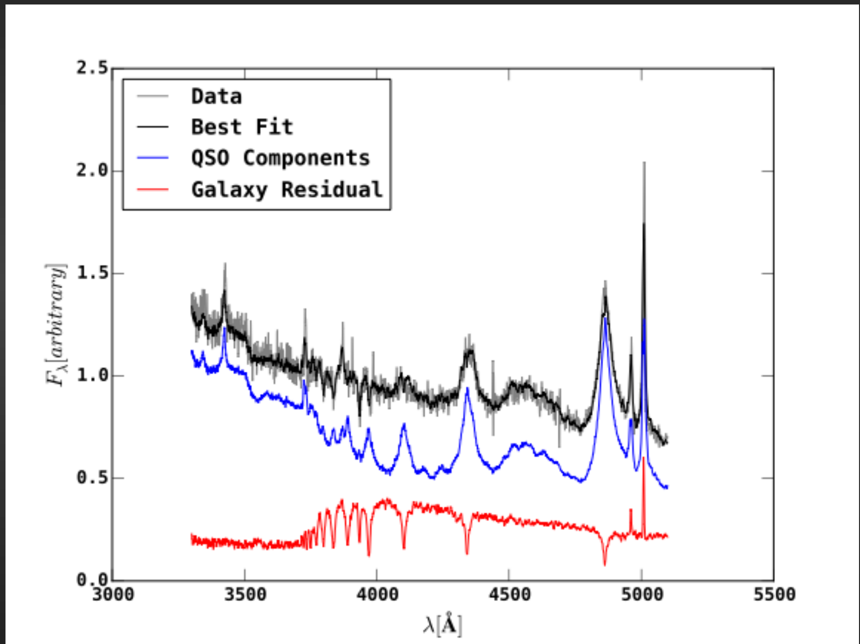


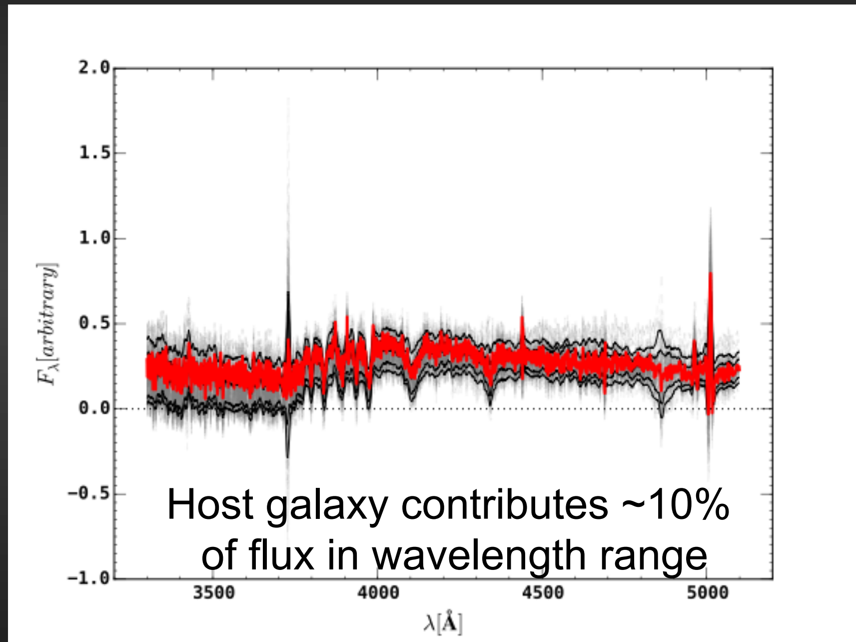


Bayesian MCMC spectral decomposition of luminous quasars (L_{bol} = 10^{45} erg/s)

Villforth, Wild, Hewett in prep

Luminous Quasar Systems





Timescales & lifetimes: SF vs accretion vs feedback vs duty cycles

>4000 SDSS quasars analysed so far

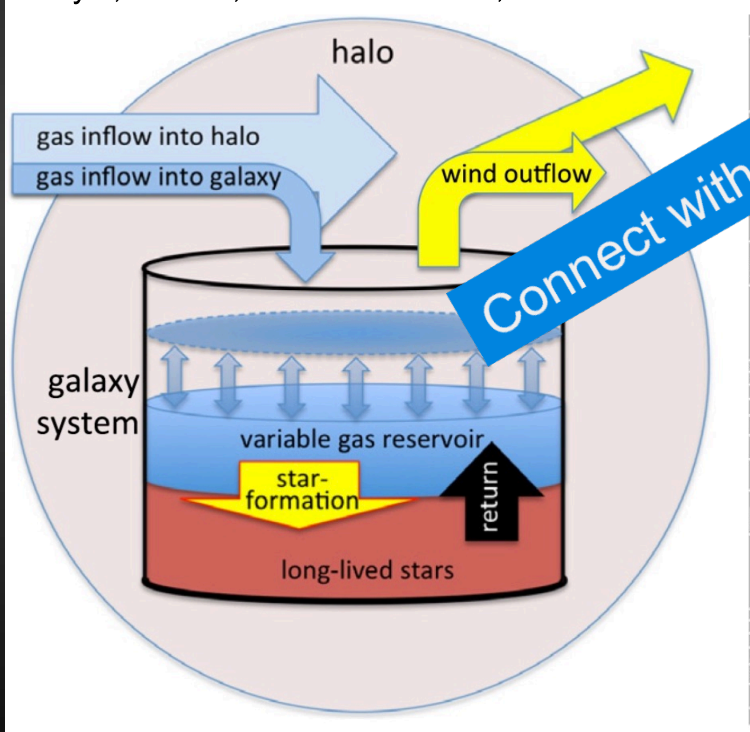
8m+ Spectroscopy for LSST?

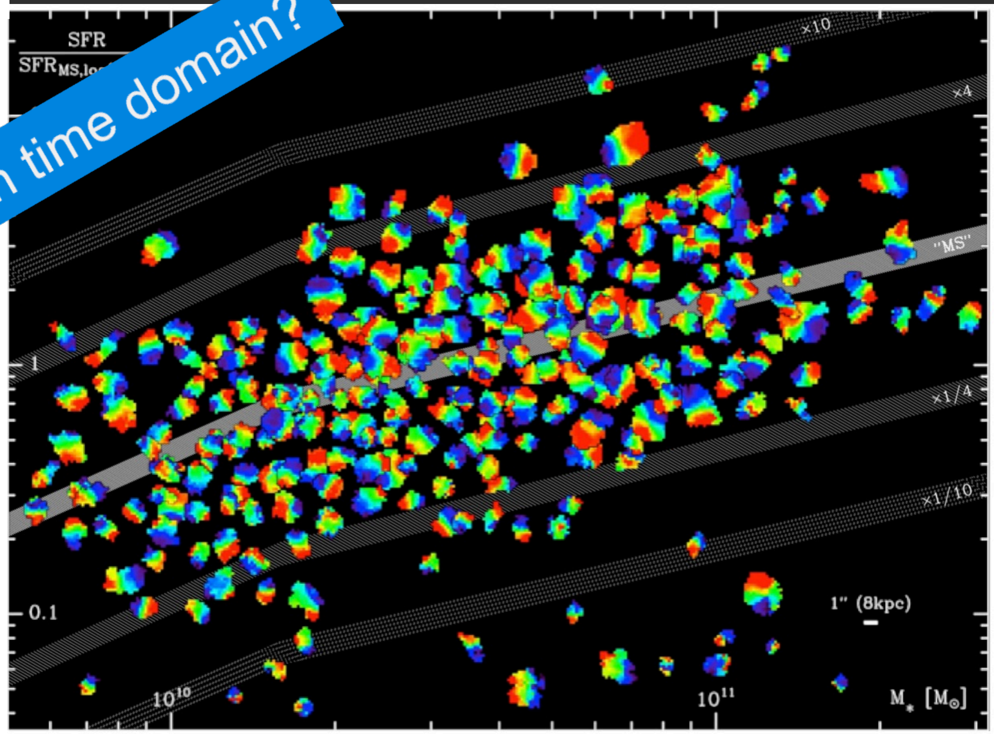
C. Villforth (Bath)

Galactic outflows vs z

S. Wuyts (Bath)

Wuyts, Genzel, Forster Schreiber, Wisnioski et al.





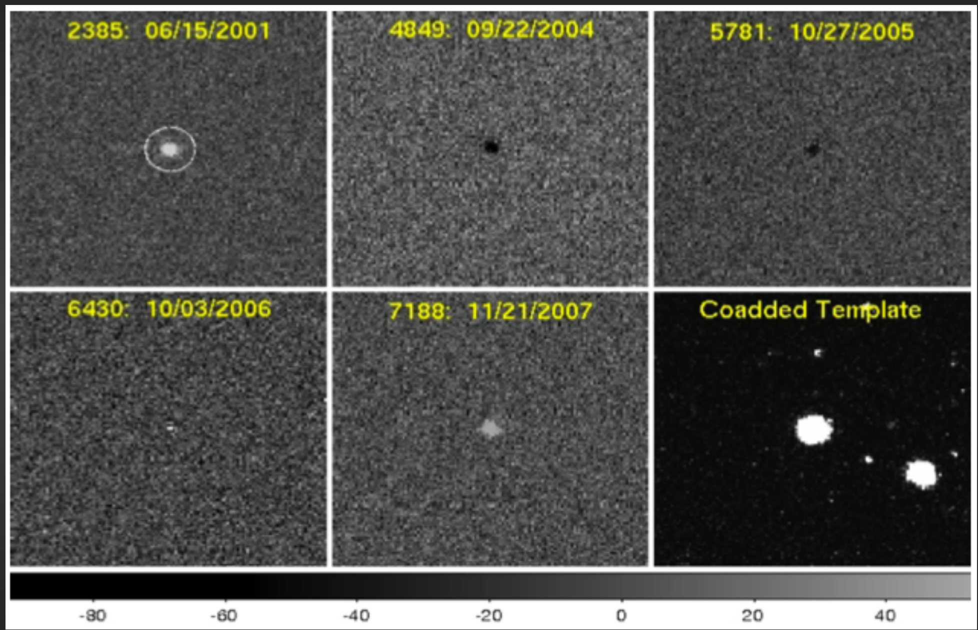
Connect with time domain?

Gas regulator model

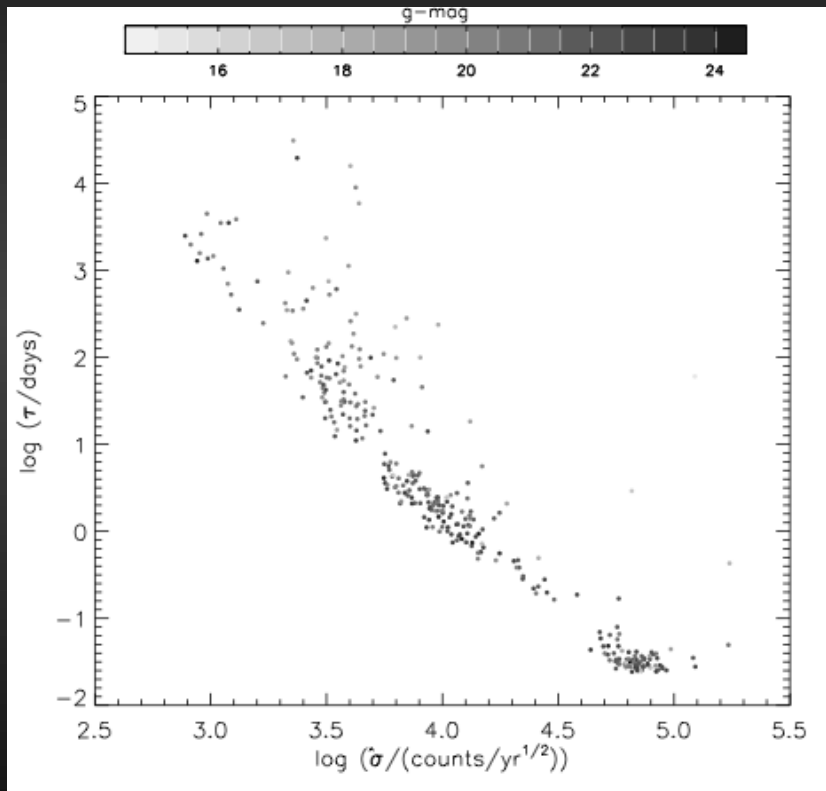
> 600 deep galaxy cubes 0.6 < z < 2.6

Outflows ubiquitous but what dependence on SFR, Mstar, Mdyn … ?

Variability Selected AGN in Difference Images



Difference images of variable
Quasar, co-added template

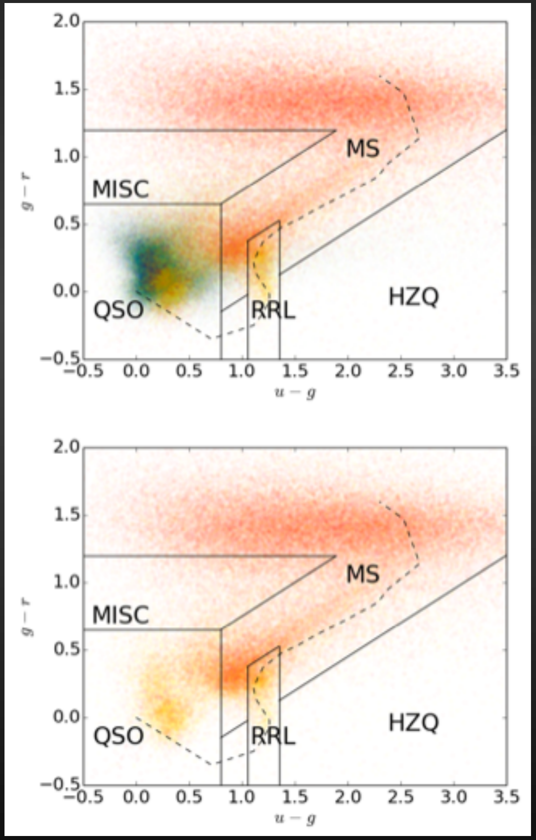


SF for X-ray selected point sources
Colour coded by g-band mag
Faint sources = shorter timescales?

Choi et al. 2014

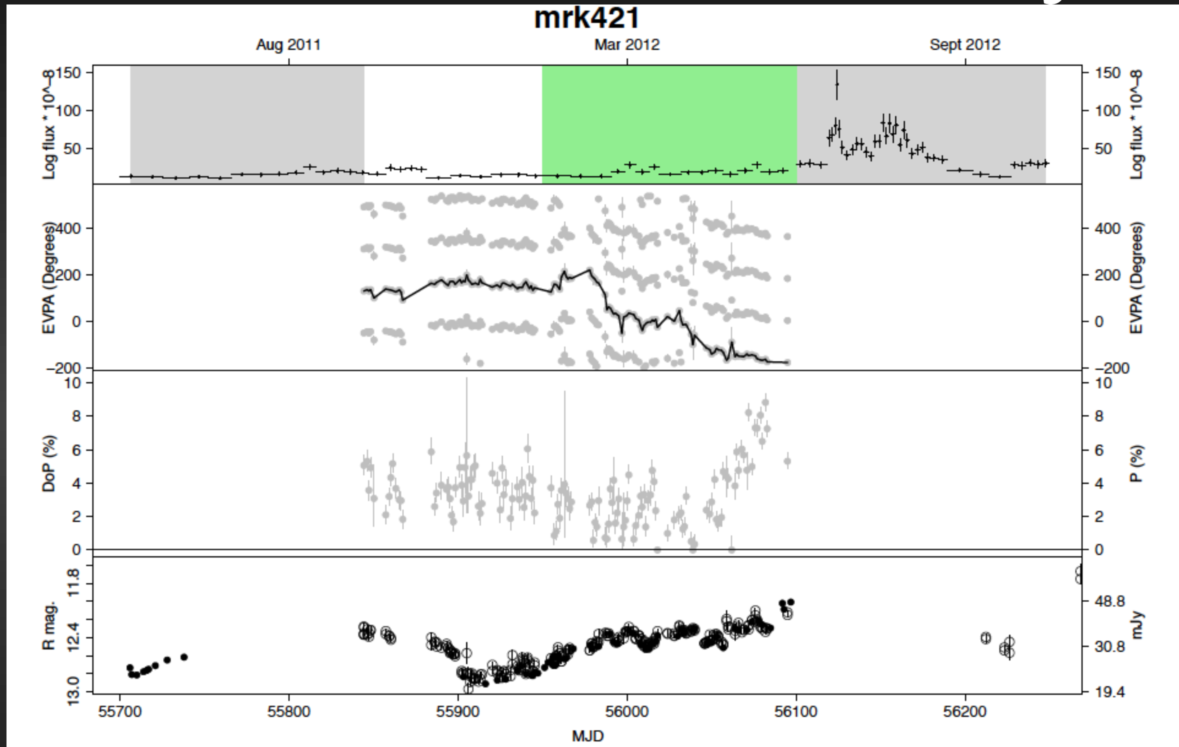
SDSS IV eBOSS - TDSS

- Spectroscopic ID of 220,000 luminosity-variable objects across 7500 deg^2
- Variability complements colour selection
- Additional redder quasars
- Mitigates redshift biases
- More higher blazars BALQSO than from color-selected samples.



(Morganson+16)

Real-time variability

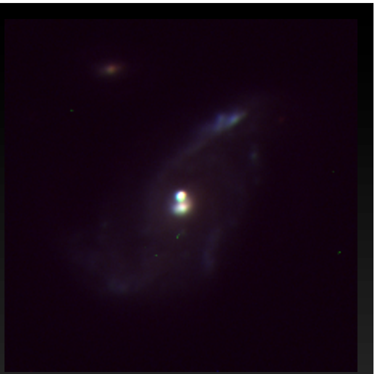


Jermak+2016, MNRAS, 462, 4267

Monitoring known blazars, changing-look quasars, newly discovered AGN.

Precursor predictions for γ-ray flares?
External triggers? Autonomous follow-up

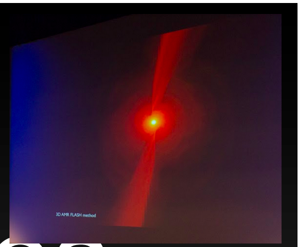
AGN as Transients



- Gamma-ray flare triggers optical follow-up
- CTA + LSST
- Also GW + LSST
- LSST transients self-triggers – more challenging
  - Filtering, classification, optimisation
  - Changing look quasars vs flares
- Other communities developing strategies

Tracing quiescent black holes

- TDEs
  - small number discovered so far; some puzzles
  - Optical (non-relativistic?) – abundances patterns, origin of UV/optical from large r, low X-ray columns, post-starburst hosts, *spectra could reveal type & mass of disrupted star (Cenko et al)*
  - 3D AMR flash simulations for feeding rate
  - Stellar tidal radius of M-S star inside R_{Sch}
  - *Peak timescale + peak mag – estimate type of disrupted star (Ramirez-Ruiz et al.)*



Tracing quiescent black holes

• LSST will find thousands

• Classification & follow-up vital but challenging

• Loss cone depleted for high BH mass, but full for low mass > search dwarf galaxies?

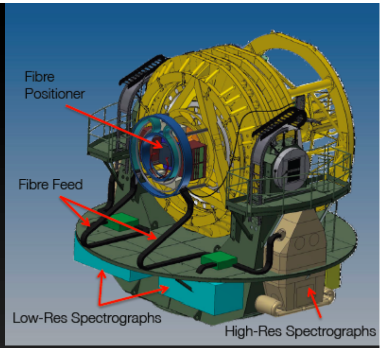
• High-energy (relativistic) TDEs rare

•Multiwavelength co-ordination

• TDE unification scheme?!

disrupted star

ESO – VISTA 4MOST



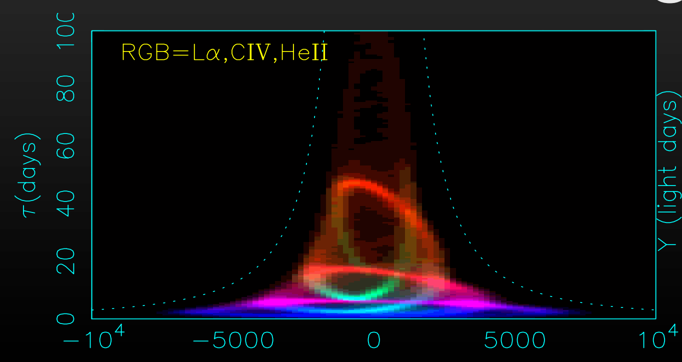
- ESO MOS on the 4-m VISTA telescope (Paranal) to be commissioned by 2022.
- Galactic & extragalactic surveys
  - UK consortium buy-in to lead TiDES 250,000 fibre hours + TiDES core mission: follow-up and supplement LSST
  - 'Live' transients, monitoring etc
    - ESO operations mode change needed
    - Community developing follow-up strategy now

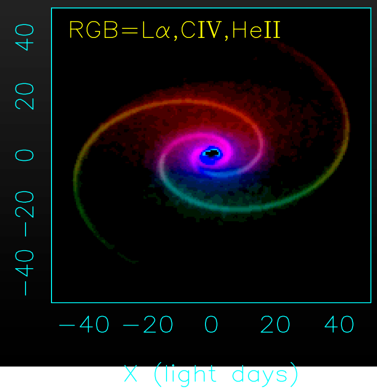
Instrument Specification

Specification	Concept Design value
Field-of-View (hexagon)	>4.0 degree^2 (⌀>2.5°)
Multiplex fiber positioner	~2400
Medium Resolution Spectrographs # Fibres Passband Velocity accuracy	R~5000-8000 1600 fibres 390-930 nm < 2 km/s
High Resolution Spectrograph # Fibres Passband Velocity accuracy	R~20,000 800 fibres 395-456.5 & 587-673 nm < 1 km/s
# of fibers in ⌀=2' circle	>3
Area (5 year survey)	>2h x 16,000 deg^2
Number of 20 min science spectra (5 year)	~100 million

Reverberation Mapping

- Reverberation mapping campaign within TiDES: monitor about 1,000 AGN for broad-line reverberation mapping; 0 < z < 4 (mostly at z < 2.5)
- Kinematic black hole masses into early universe, e.g. galaxy evolution cf TDE

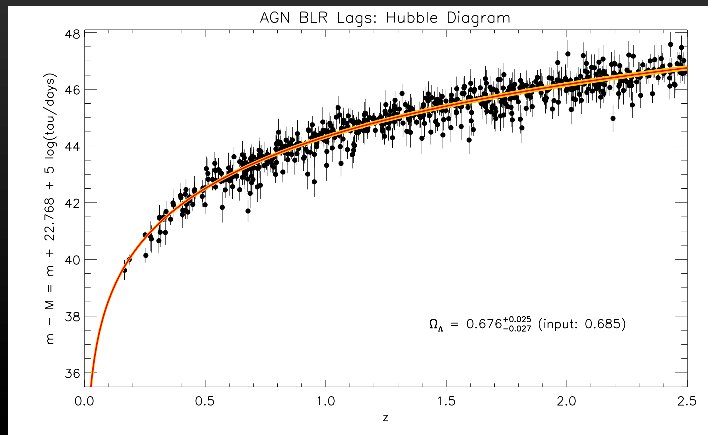




Keith Horne et al.

Reverberation Mapping

- Broad-line lag-luminosity relation now used as standardisable candle (e.g. Watson et al. 2011; King et al. 2014, 2015; Shen et al. 2015)
- ~12,000 TiDES fibre hours reserved
- LSST complements with high-quality multi -band continuum light curves with systematics *independent* of TiDES

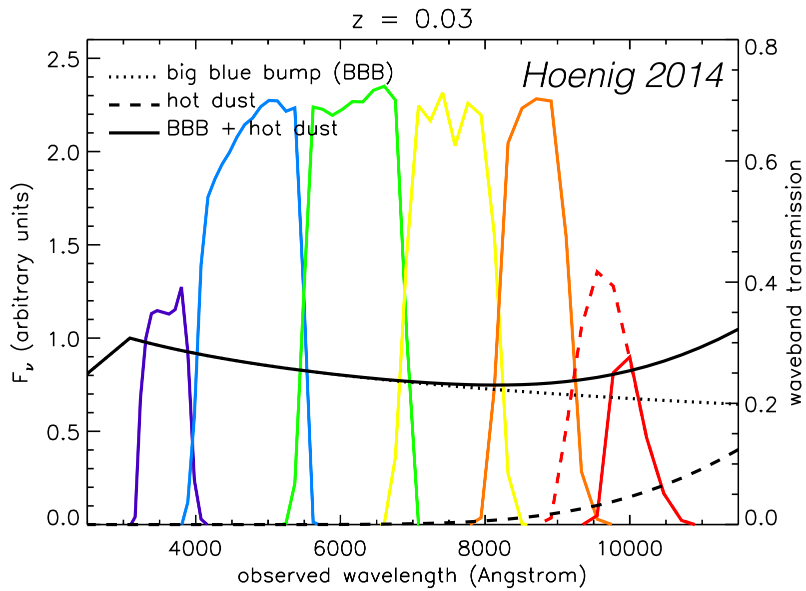


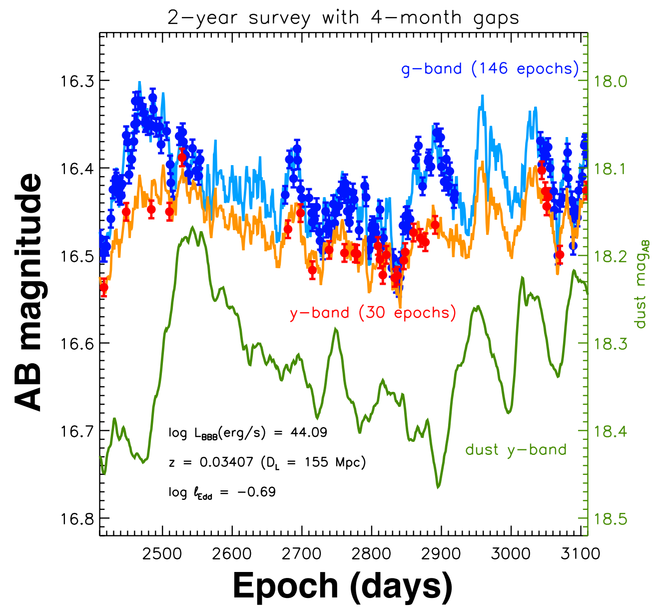
Dust reverberation mapping

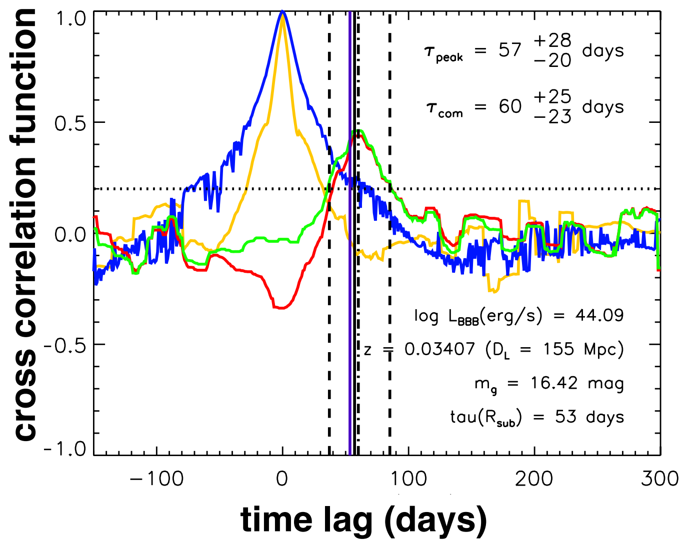
- Wien tail of hot dust emission reaches into (red) optical bands
  - decompose ugrizy into disk+dust light curves
  - techniques similar to photometric emission line reverberation mapping (e.g. Chellouche & Daniel 2012; Chellouche & Zucker 2013)
  - Dust lag-luminosity relation a standardisable candle (e.g. Hoenig et al. 2017, MNRAS 464, 1639)
    - requires local set of AGN

Sebastian Hoenig (Southampton)

AGN hot dust lags with LSST







Relative Contributions of Hot Dust to Wavebands at Different Redshifts

Redshift	$z = 0$	$z = 0.05$	$z = 0.1$	$z = 0.2$	$z = 0.3$
i band	0.019	0.012	0.007	0.003	...
z band	0.073	0.052	0.031	0.014	0.004
y band ($y3$)	0.206	0.158	0.109	0.053	0.020
y band ($y4$)	0.168	0.126	0.085	0.041	0.015

Sebastian Hoenig

Lensed AGN

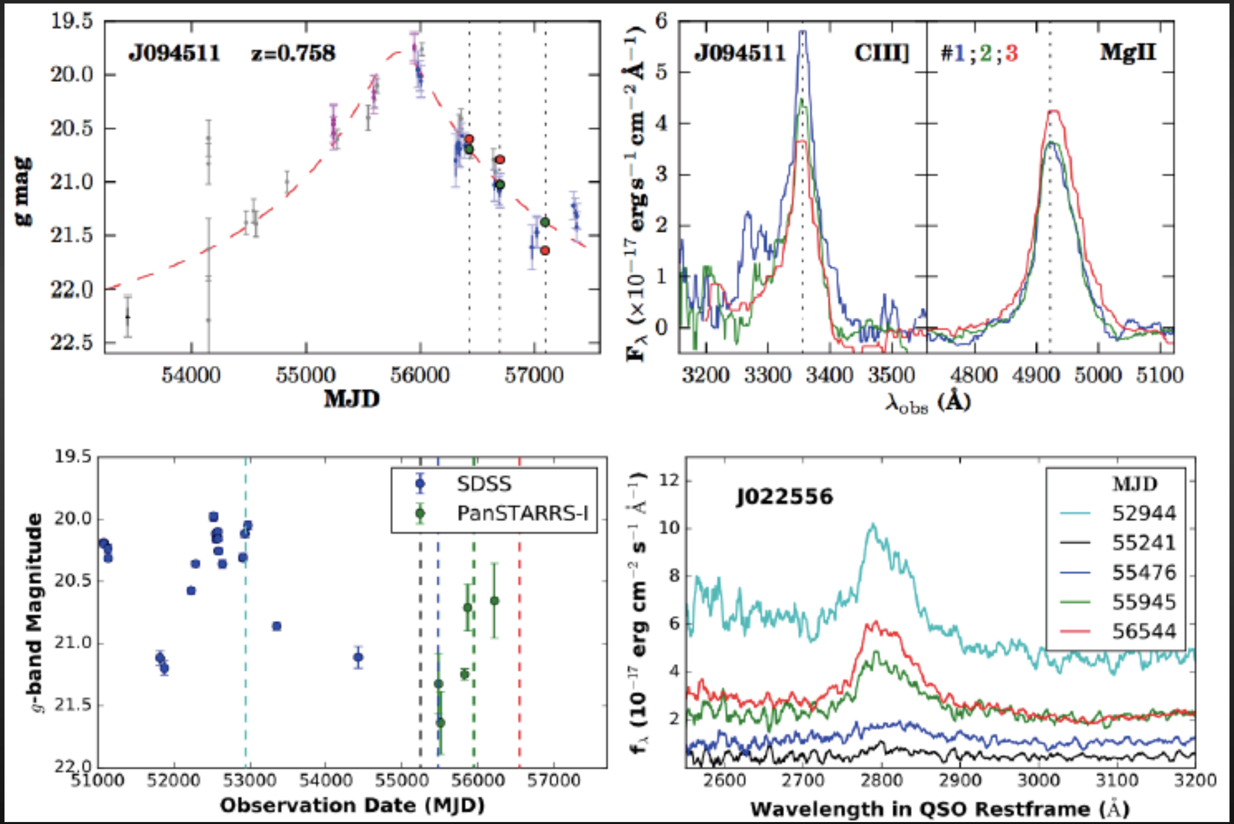


Figure 1: *Two contrasting hypervariables.* **Microlens candidate J094511** *(top row, from Bruce et al 2017) shows a smooth light curve over many years well fitted by a simple microlensing model. Spectral epochs are indicated by vertical dotted lines. Mg II is essentially unchanging and so is much bigger than the lens; CIII] does change, but by less than the continuum, giving a partially resolved transverse size.* **CLQ J022556** *(bottom row, from Homan et al in preparation) shows a more erratic light curve. The MgII line collapses and then recovers, in clear response to the ionising continuum.*

Microlensing events
Light curve and spec

Strong lensing
time delays

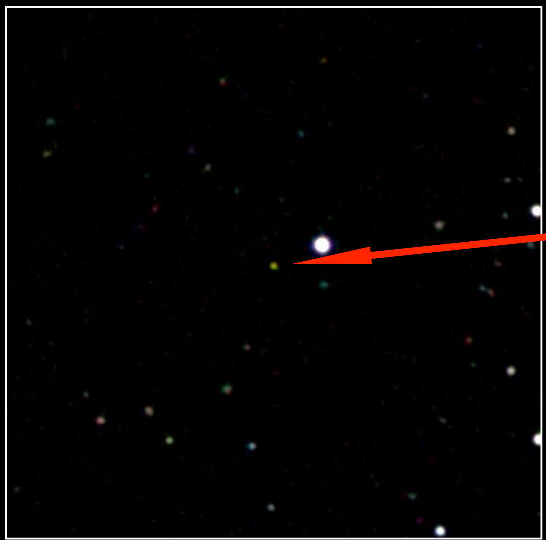
All lensed

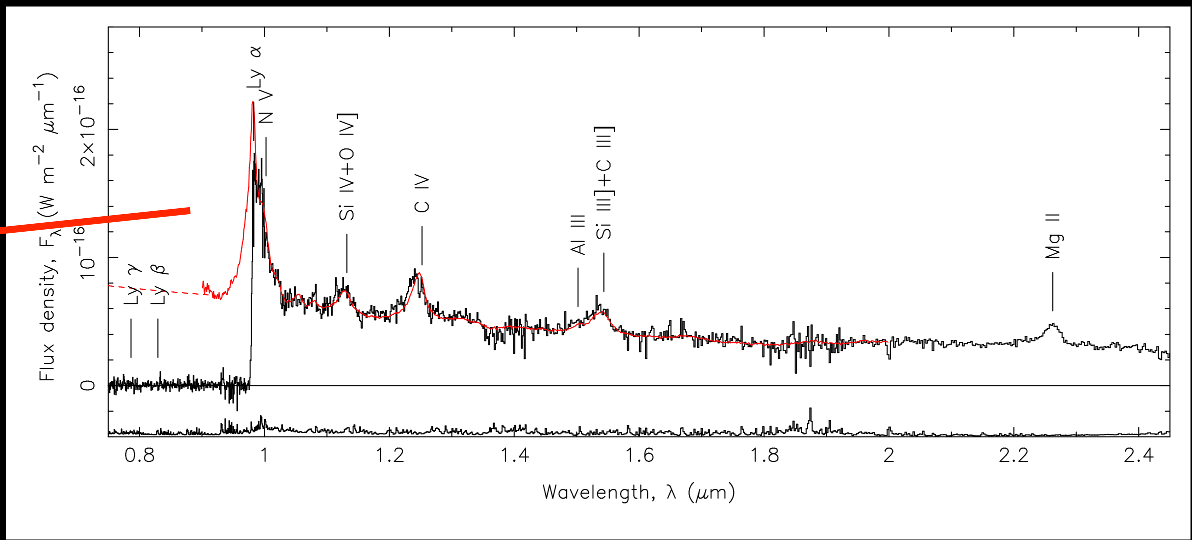
Andy Lawrence

Aprajita Verma

Discovering *z* > 6.5 quasars with LSST

Daniel Mortlock
(Imperial College London)





(Mortlock et al. 2011)

Discovering $z > 6.5$ quasars with LSST

- Quasars at $z > 6.5$ will be strongly detected in LSST *y* images and will be absent in LSST *ugriz* images.

- Separate from $z \sim 2$ galaxies and brown dwarfs with EUCLID NIR photometry and WISE FIR photometry.

- Major problem will be spurious false positives from data processing artefacts, rare events, spurious drop-outs, etc.

- Machine learning will have to be used in place of visual inspection.

Daniel Mortlock

Discovering $z > 6.5$ quasars with LSST

Examples of spurious drop-outs from SDSS:

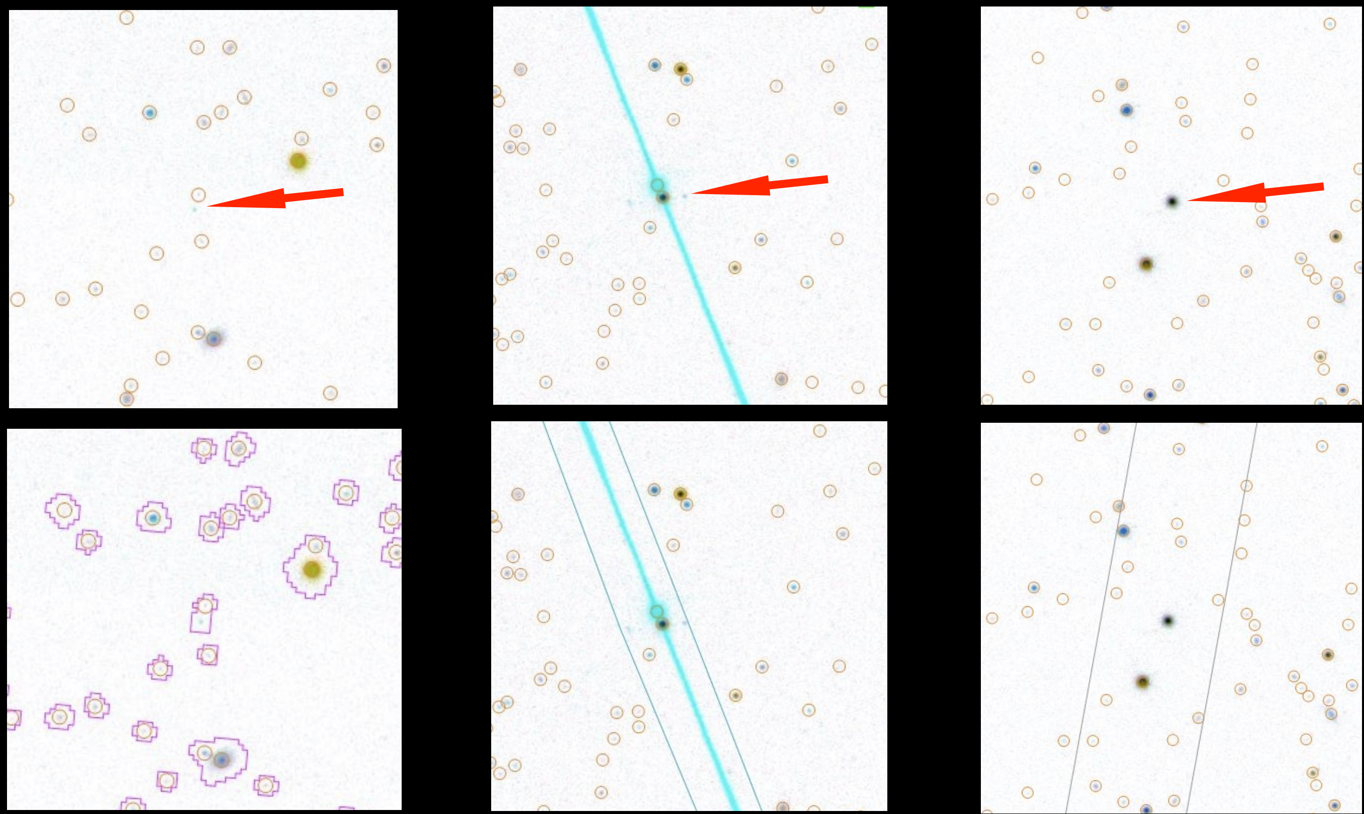
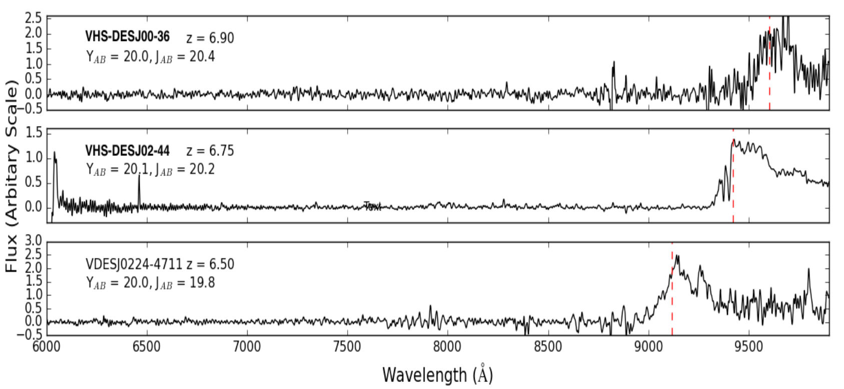
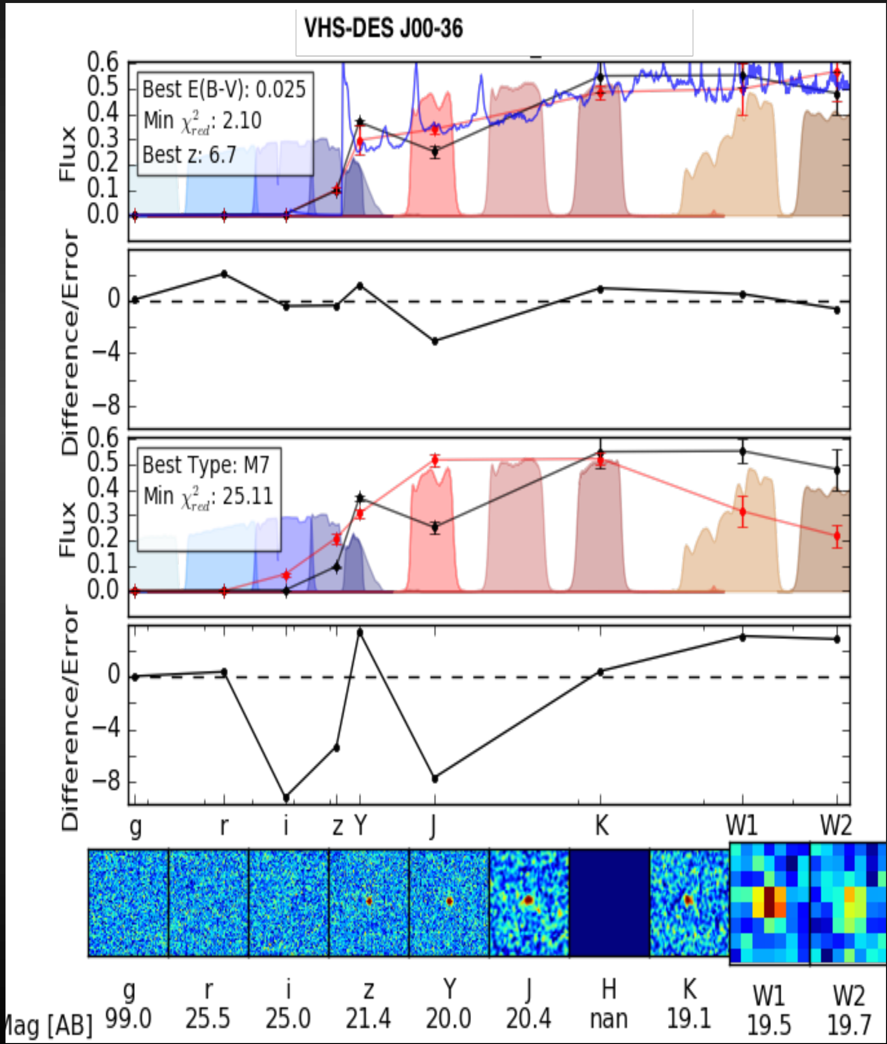


Image as seen

Image with meta-data added

Supermassive Black Hole formation and evolution z > 7 quasars





- LSST z and y band drops
  - Pixel level listdriven forced aperture and model photometry on LSST data using VISTA Hemisphere based J band images and catalogue
  - Pixel level model based photometry on NEOWISE-R image using VISTA Hemisphere based J band and K band images and catalogue
  - LSST + VISTA + WISE SED based probabilistic photometric classification; e.g. Reed, McMahon et al. 2015, 2017 for DES + VISTA + WISE
  - Supervised Machine Learning based classification; e.g. Ostrovski, McMahon et al, 2017

Richard McMahon, Sophie Reed, Manda Banerji+

Summary

- AGN with LSST perhaps most diverse technical/scientific case
- Host galaxy to nucleus + dynamic range
- Variability + spectroscopy helps
- Fast transients – AGN flares, TDEs probe new physics
- Autonomous follow-up after filtering
- Autonomous co-ordination
  - multi-scale, multi-use brokers

Notes

- Multi-scale brokers
- Multi-scale compute resource
  - Distance from LSST site related to speed of response needed
  - Fast transient ID/followup vs static survey science
- Cadence design (including colour cycles)
- Amendments to simulators
- Level 3 development – UK lead/funding

Consider joining
USA AGN Science Collaboration
New Science Roadmap in prep

UK members so far:
Mundell (Leads Extreme Variability WG)
Hoenig, Lawrence, Jarvis +


Multi-messenger Landscape
Next decade and beyond
IceCube (ν)
CTA (TeV)
Swift satellite(γ, X, optical
Discovery & response)
SKA (radio)
aLIGO/Virgo (GW)
Optical – rapid response
LSST (optical – survey)
GAIA satellite