AGN in the LSST Era

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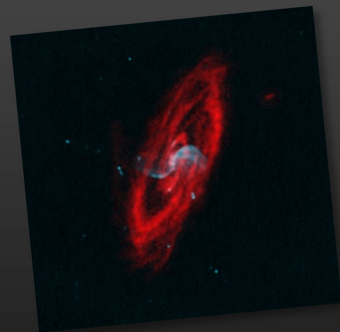
PoC: LSST-UK AGN SWG

UNIVERSITY OF BATH



The Time-Domain Niche

- Reverberation mapping in Seyferts
- Radio loud quasars
- Optically violent variables
- X-ray timing
- Optical continuum monitoring of blazars

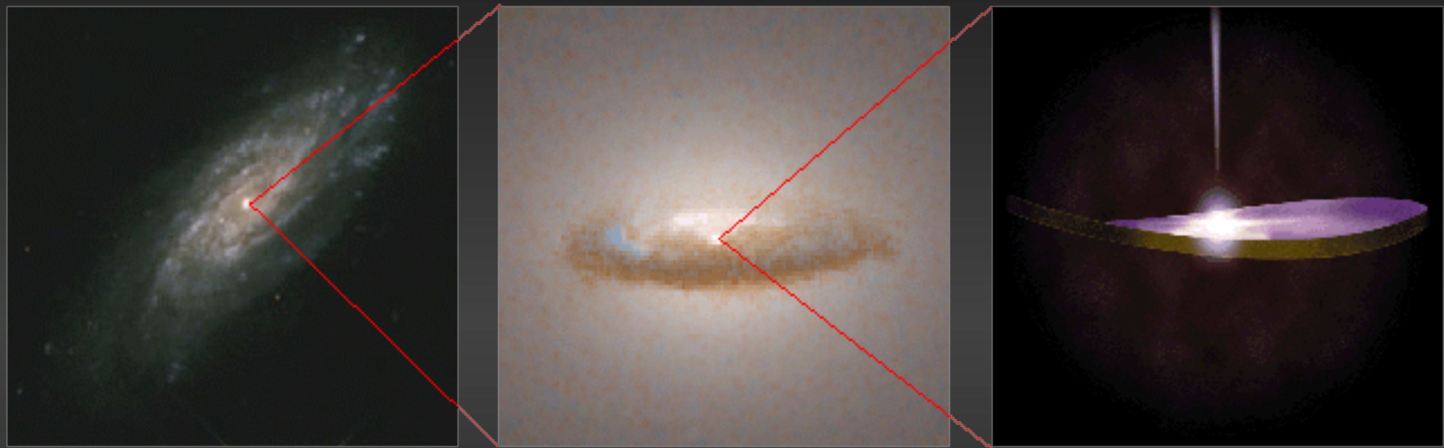

Surprising
Recoiling
Forming
Seeding
Feeding
Spinning
Black holes
Growing
Exploited
Hairy
Merging
Disruptive
Binary
Disappearing
Evaporating
Precessing


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

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

AGN in Context

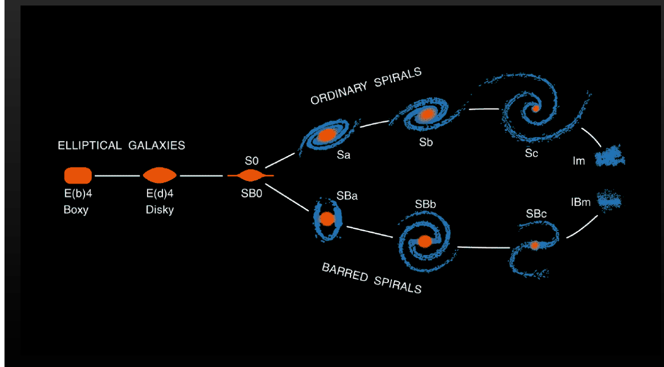


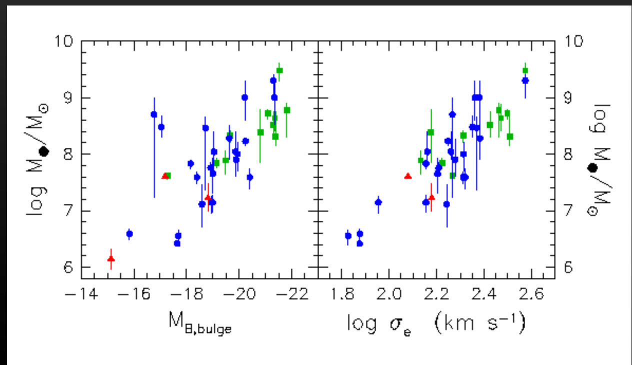
- Host galaxy

  Out to 100 kpc
- Obscuring torus

  ~hundreds pc
- Accretion disk

  10 - 100 AU





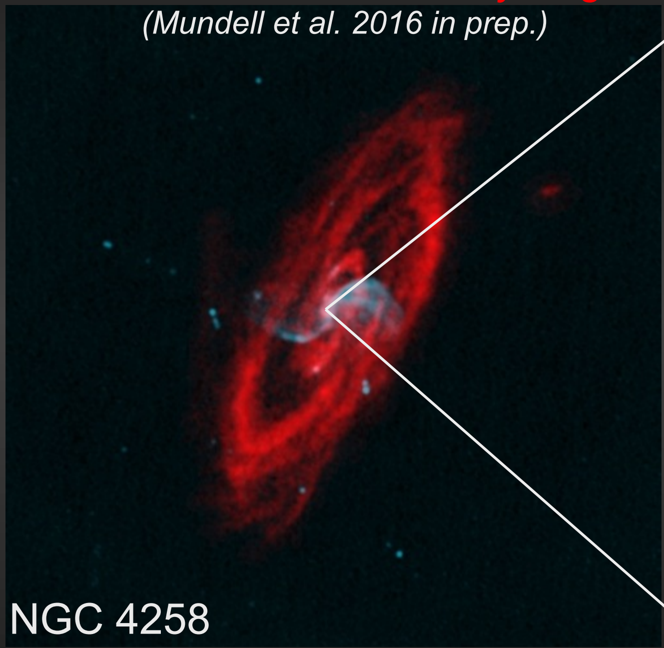
BH-bulge correlation

AGN & galaxy evolution

First Direct Black-Hole Mass

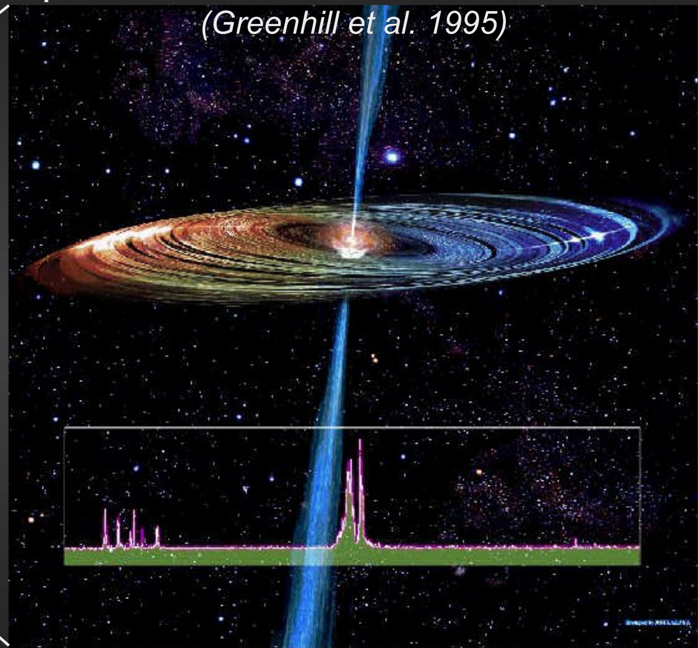
Blue= AGN *Jet*; *Red = hydrogen*

(Mundell et al. 2016 in prep.)



Spectrum at 22 GHz - water masers

(Greenhill et al. 1995)

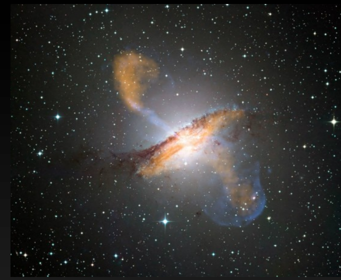


- Masers in NGC4258 -> thin warped *gas* disk around BH

  $M_\bullet = 4 \times 10^7\ M_\odot$ in $r < 0.7$ light year

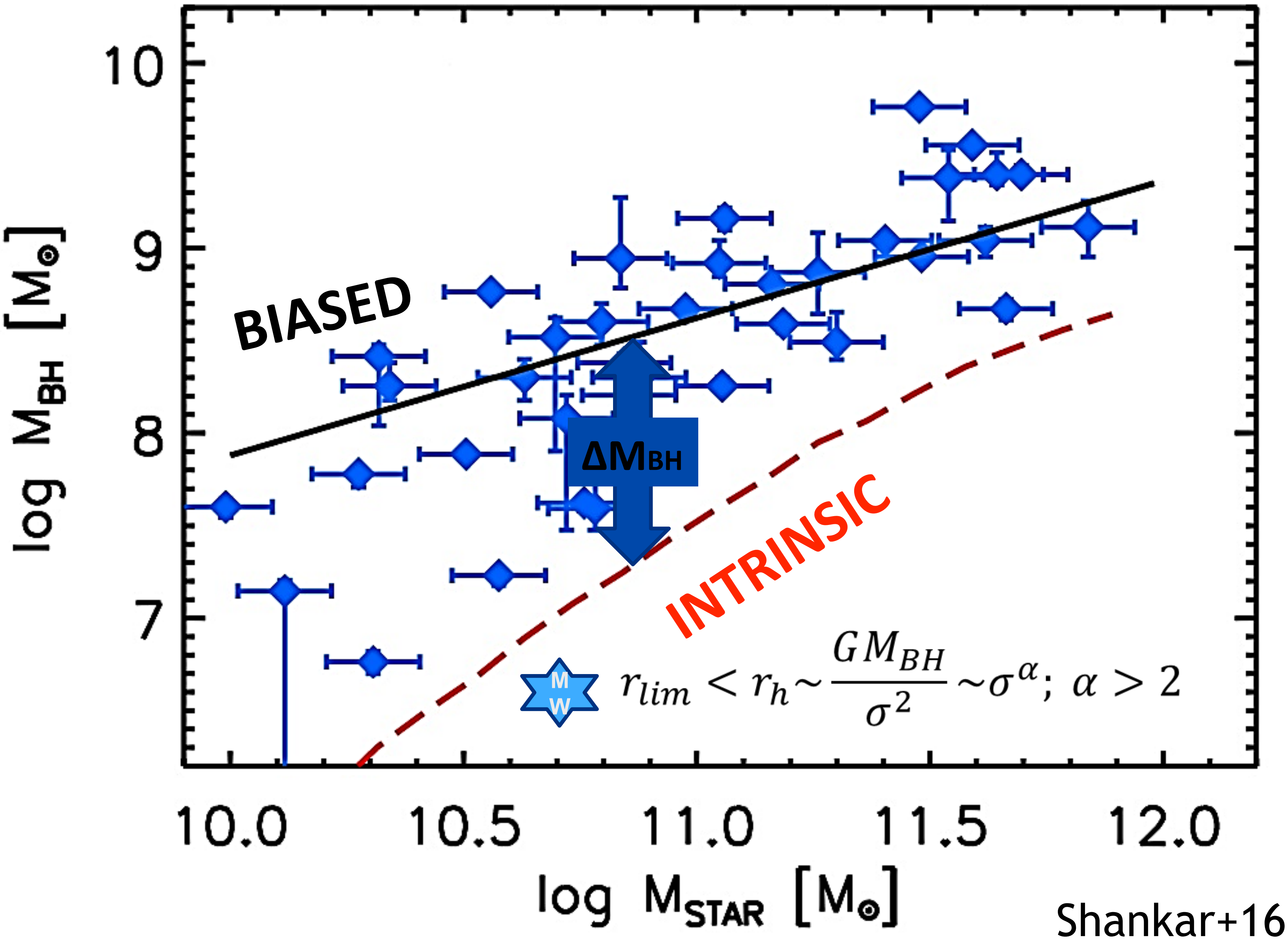
- First direct measurement of black hole influence and mass

Black Holes biases



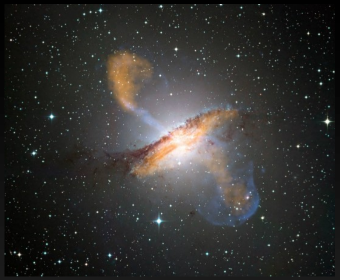
- BH mass – bulge relation biased high
  - BH masses in AGN reduced
  - BH densities reduced
  - Radiative efficiencies/BH spin increased

Shankar+16



10
9
8
7
log M_{BH} [$M_\odot$]
BIASED
ΔM_{BH}
INTRINSIC
MW
$r_{lim} < r_h \sim \frac{GM_{BH}}{\sigma^2} \sim \sigma^\alpha;\ \alpha > 2$
10.0
10.5
11.0
11.5
12.0
log M_{STAR} [$M_\odot$]
Shankar+16

Black Holes biases

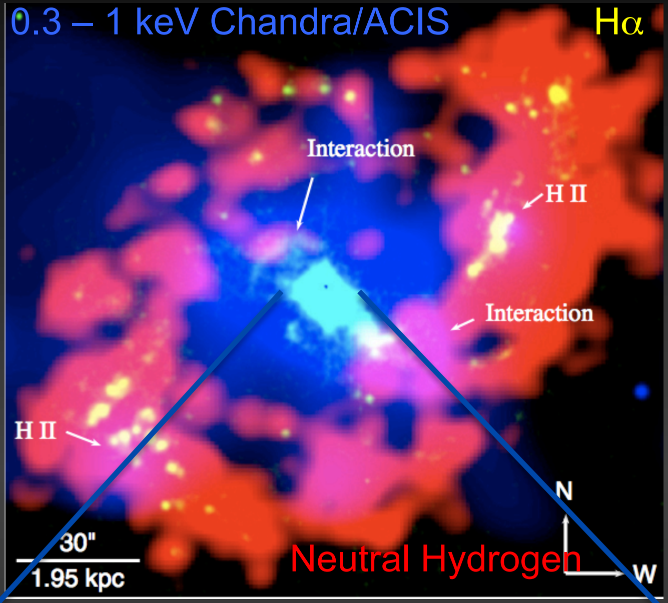


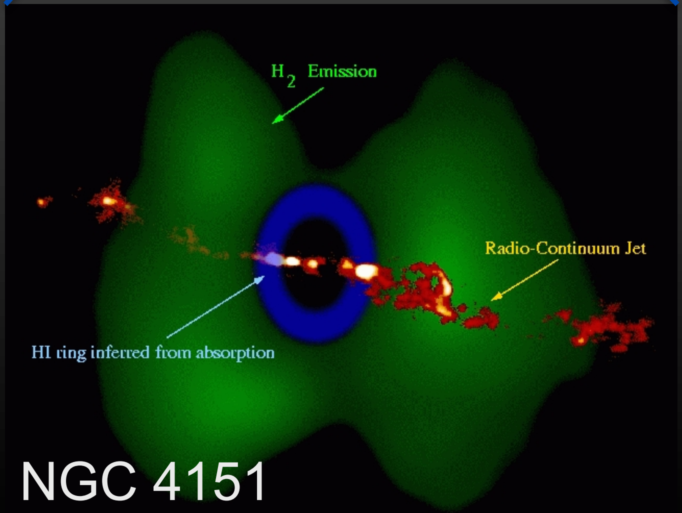
- BH mass – bulge relation biased high
  - BH masses in AGN reduced
  - BH densities reduced
  - Radiative efficiencies/BH spin increased
- Episodic activity
  - AGN lifetime reduced
  - Duty cycles/BH growth extended

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

Feedback & AGN Duty Cycles

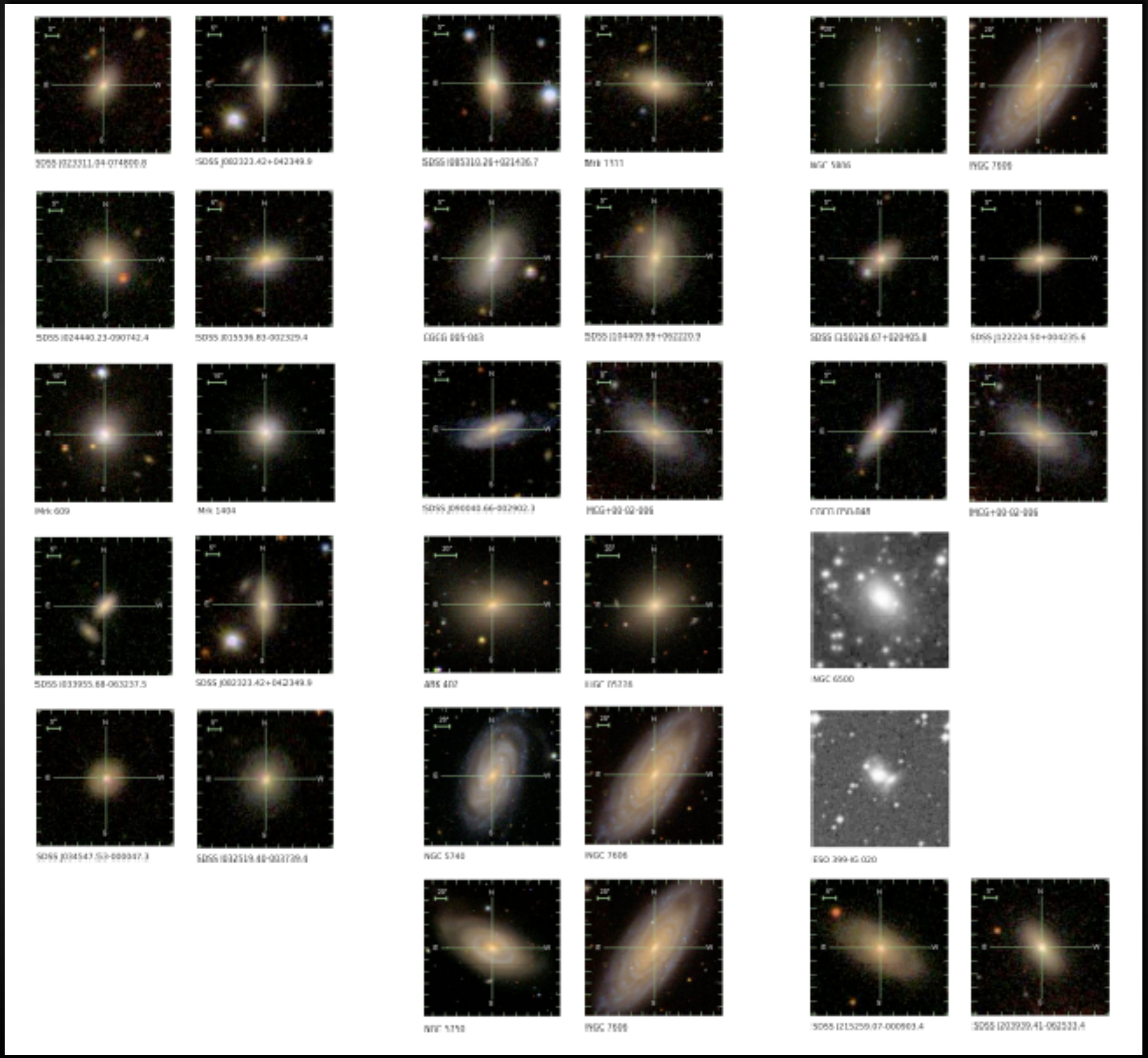
- Chandra soft X-ray emission to R = 2 kpc, L(0.5-2keV)~10^{39} erg/s (Wang et al. 2010)
- Recent AGN:host interaction
  - Mechanical energy deposited < 10^5 years or
    - *Eddington-limited outburst luminosity ~ 10,000 yr ago*
- Live systems c.f. Milky Way
- Short timescale – outbursts > 1% AGN lifetime



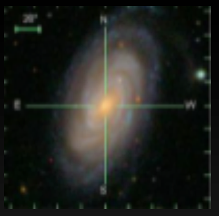


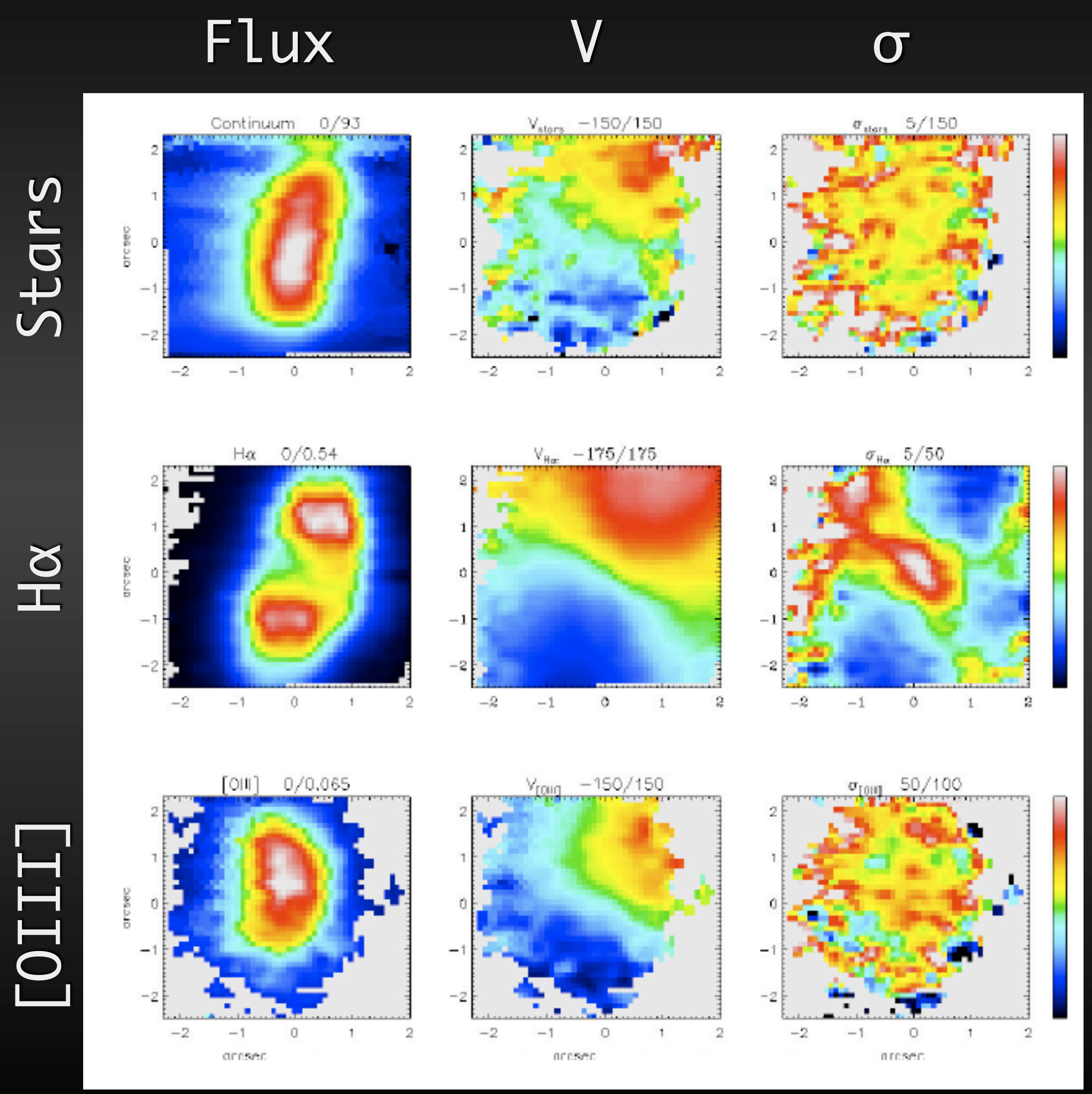
Wang+ 2010, ApJ, 719, L208; Mundell et al. 2003

Fueling black holes



NGC 5740





- Seyfert 2
- SABb
- z = 0.0052

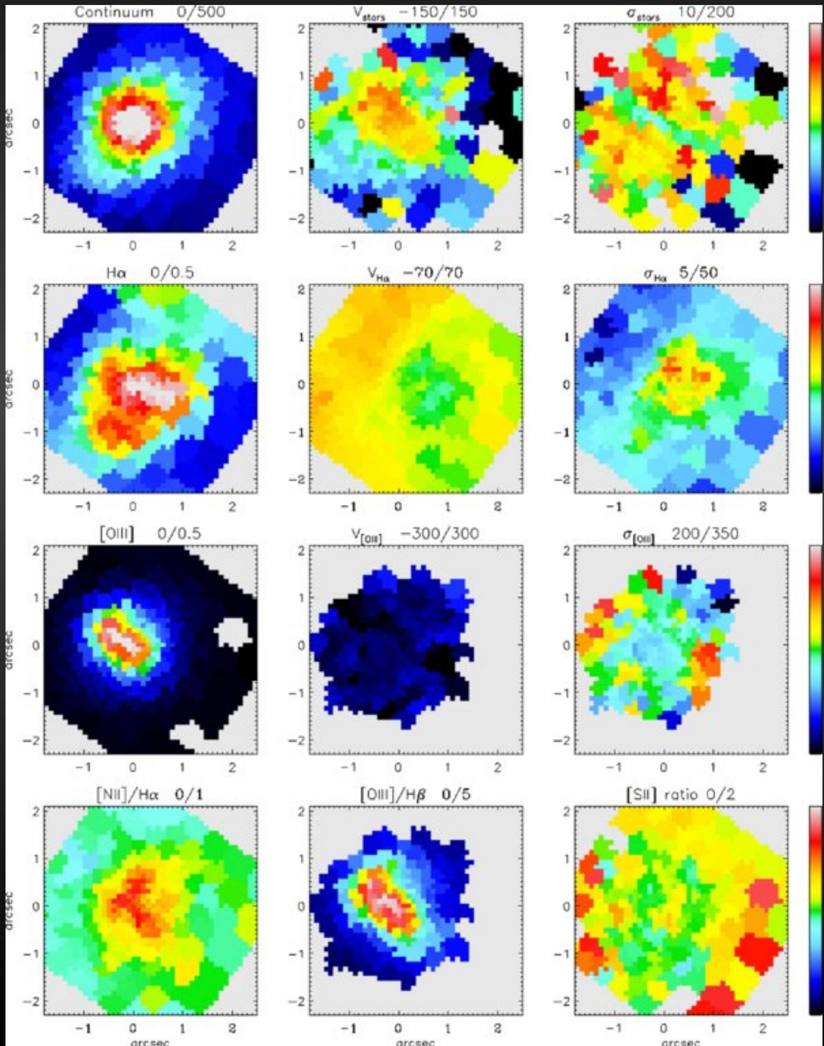
~300 pc

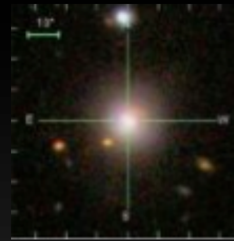
- Features:
  - Bar
  - Global rotation
  - Gas-streaming or outflow?

MKN 609

Flux V σ

Stars Hα [OIII] [OIII]/HB

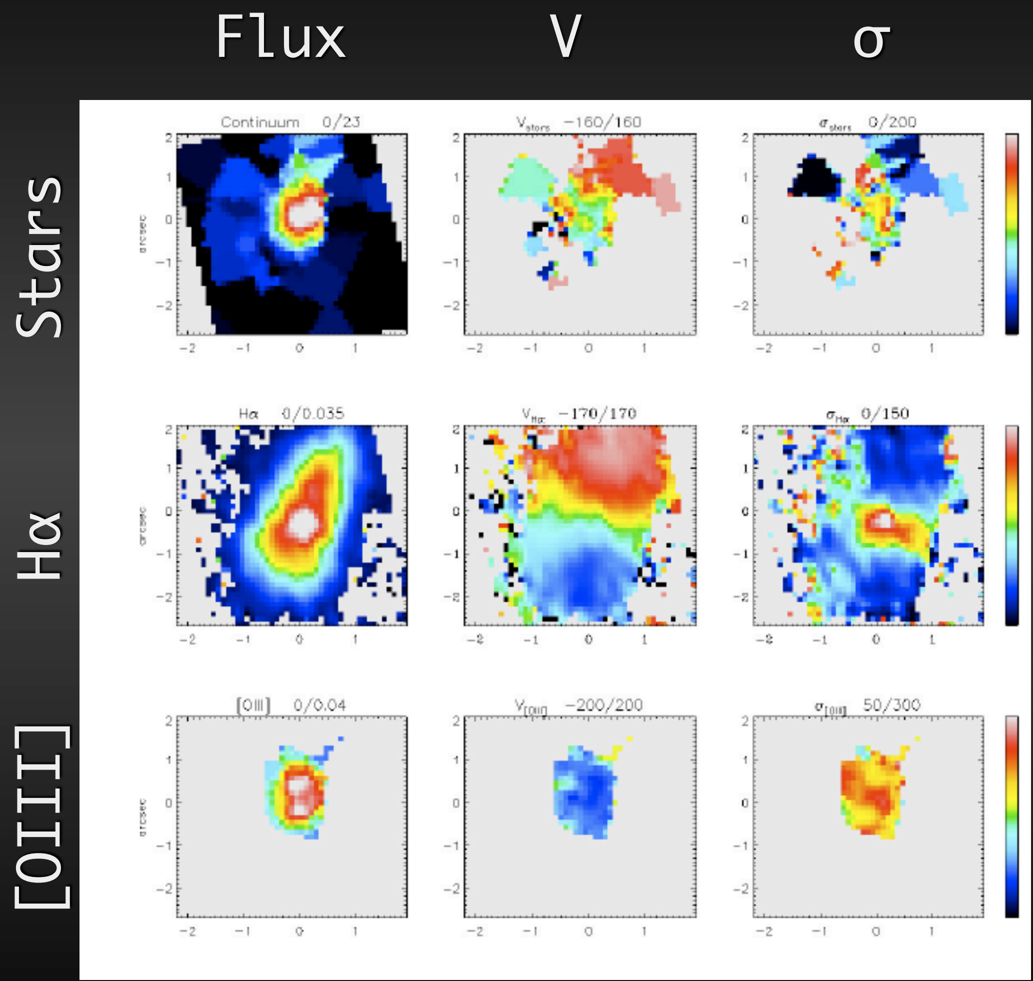


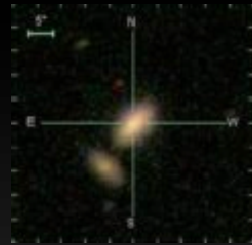


- Sy 1.5 / SB
- S0a
- z = 0.031

- Hydrogen disk damaged by outflow
- Oxygen flow speed: 300 km/s
- Extent: ~2 kpc

SDSS J033955.68-063237.5





- NLAGN
- S0a
- z = 0.031

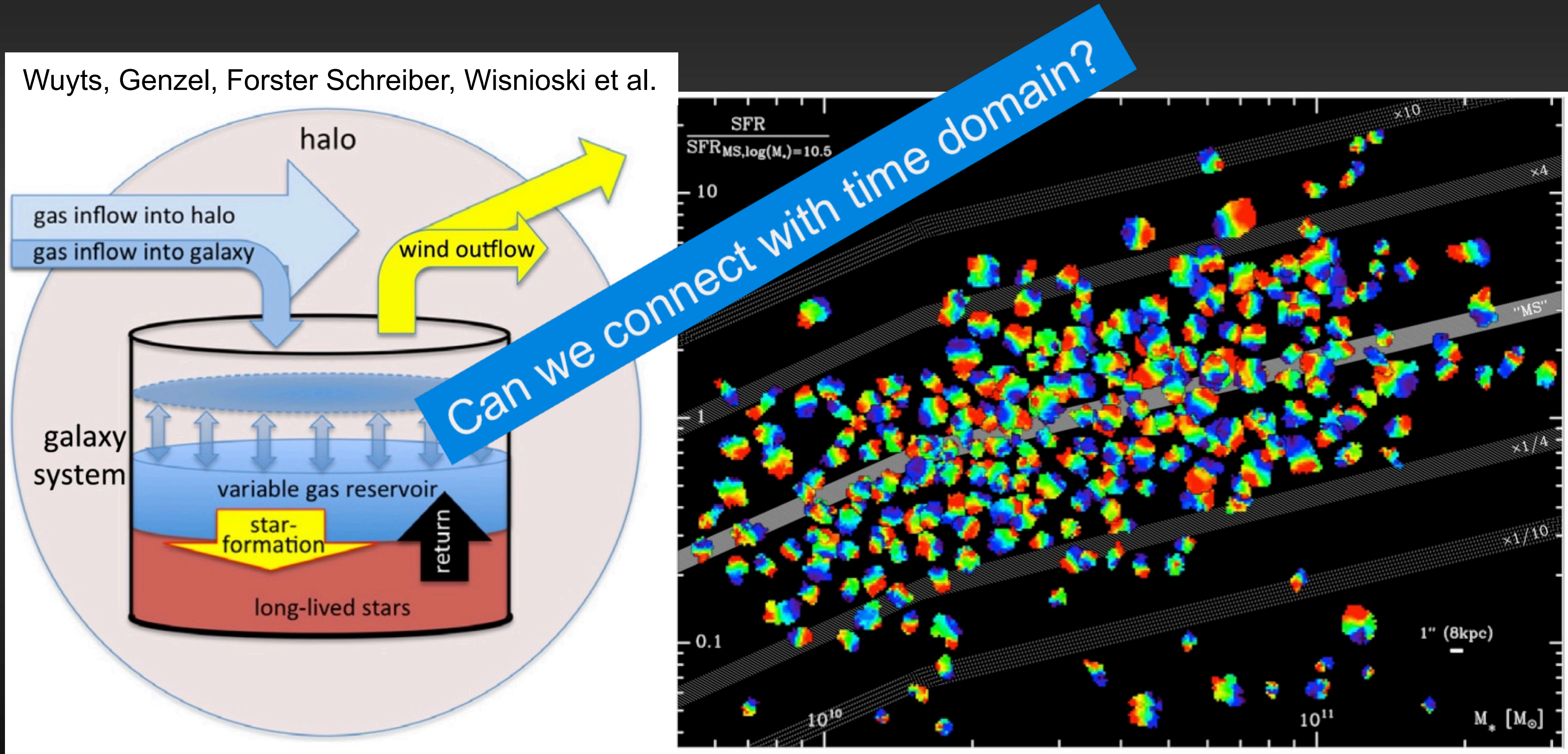
- Rotating SF disk
- Oxygen flow speed 200km/s
- Extent: ~2kpc

Results

- Gas necessary, but not sufficient (also Mulchaey & Regan 98; Martini+ 03; Simoes Lopes+ 07)
- Ionised gas: AGN 100% , Inactives - 35%
- Quiescent, star-forming rotating disks (Hα)
- Extensive, high-speed outflows ([OIII])
  - Not typical in local galaxies
  - Evolution in AGN feedback already at $z=0.05$
  - No host stellar evolution to $z<1$, but *rapid gas evolution*
  - Extend IFU study to $z=0.1$ and beyond

Westoby+2007, ApJ, 382, 1541; Westoby+2012 ApJS, 199, 1

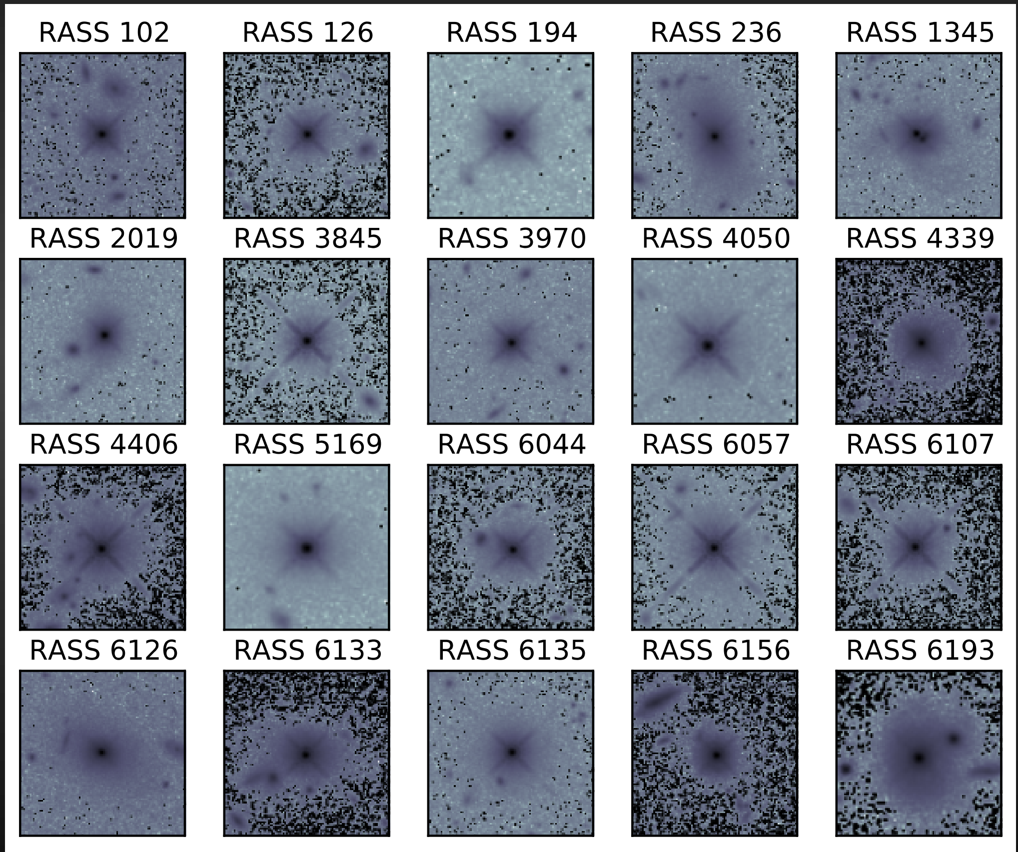
Galactic outflows through cosmic time

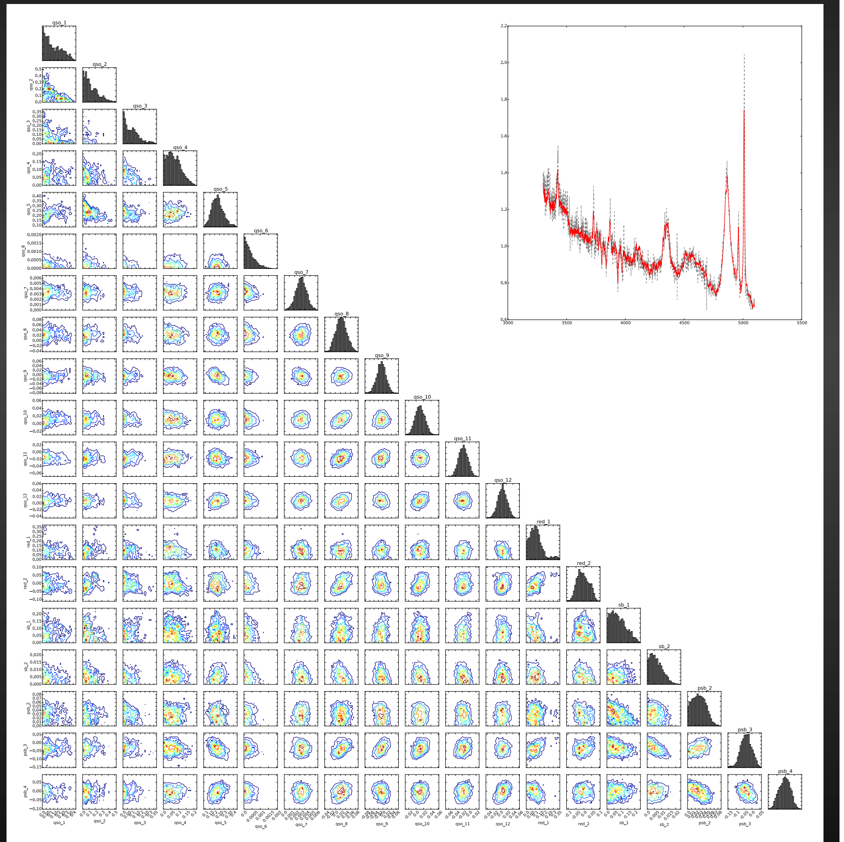


Gas regulator model > 600 deep galaxy cubes 0.6 < z < 2.6

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

Luminous Quasar Systems

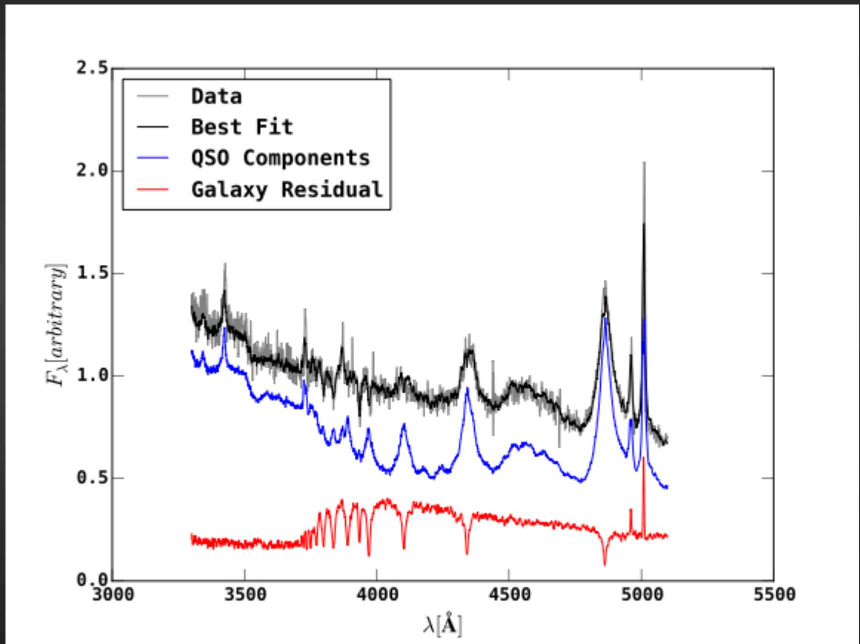


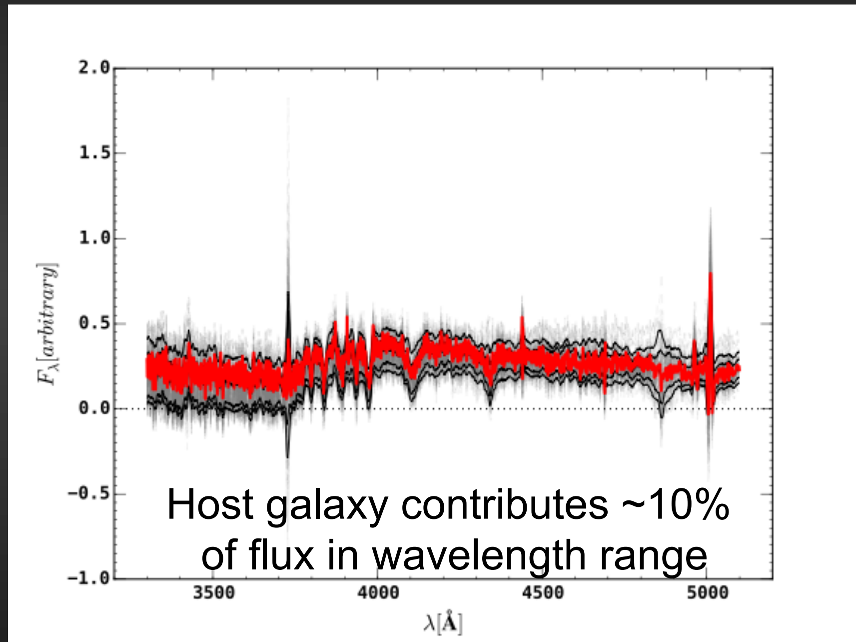


Bayesian MCMC spectral decomposition of luminous quasars ($L_{bol} = 10^{45}$ erg/s)

Villforth, Wild, Hewett et al. in prep

Luminous Quasar Systems



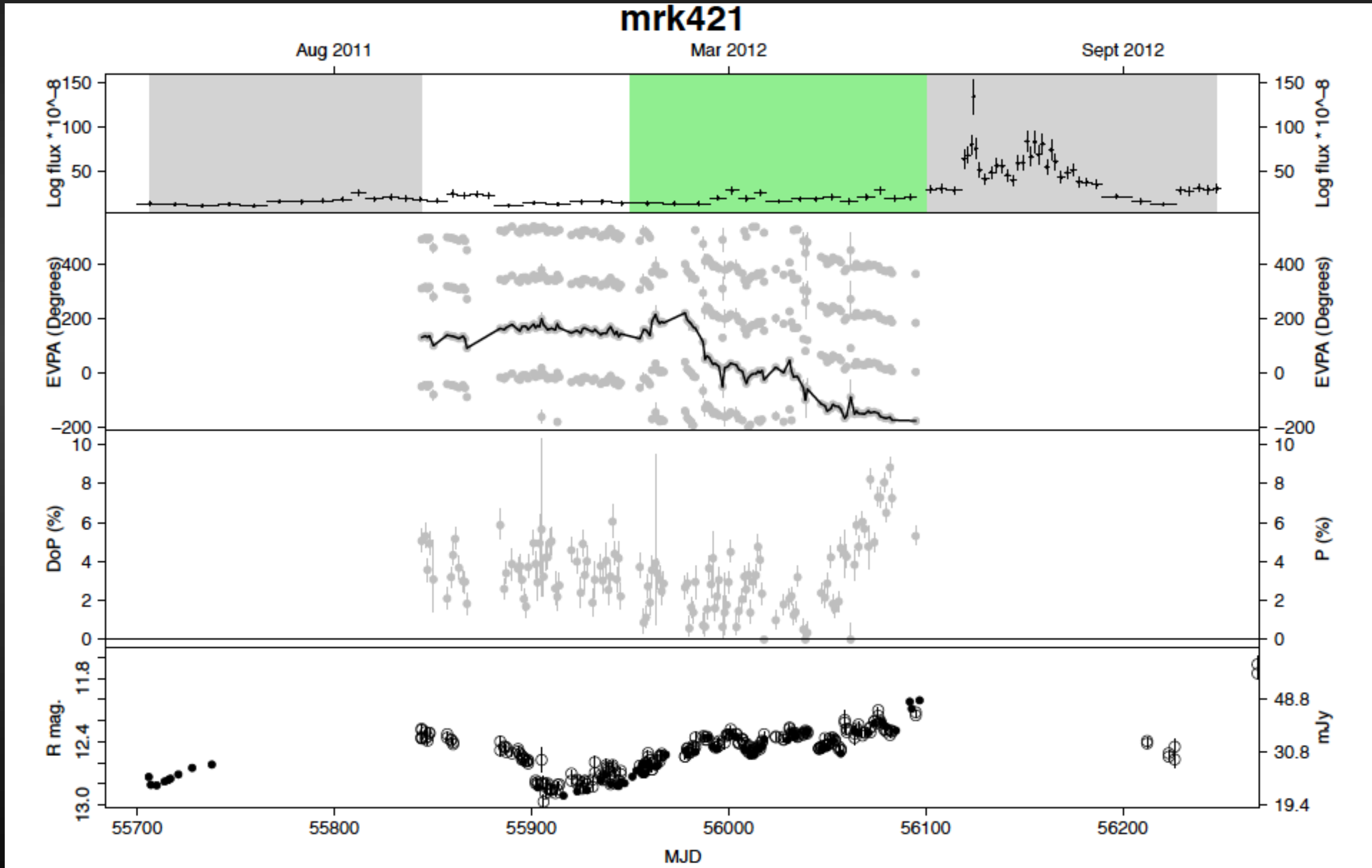


Timescales & lifetimes: SF vs accretion vs feedback vs duty cycles

>4000 SDSS quasars analysed so far

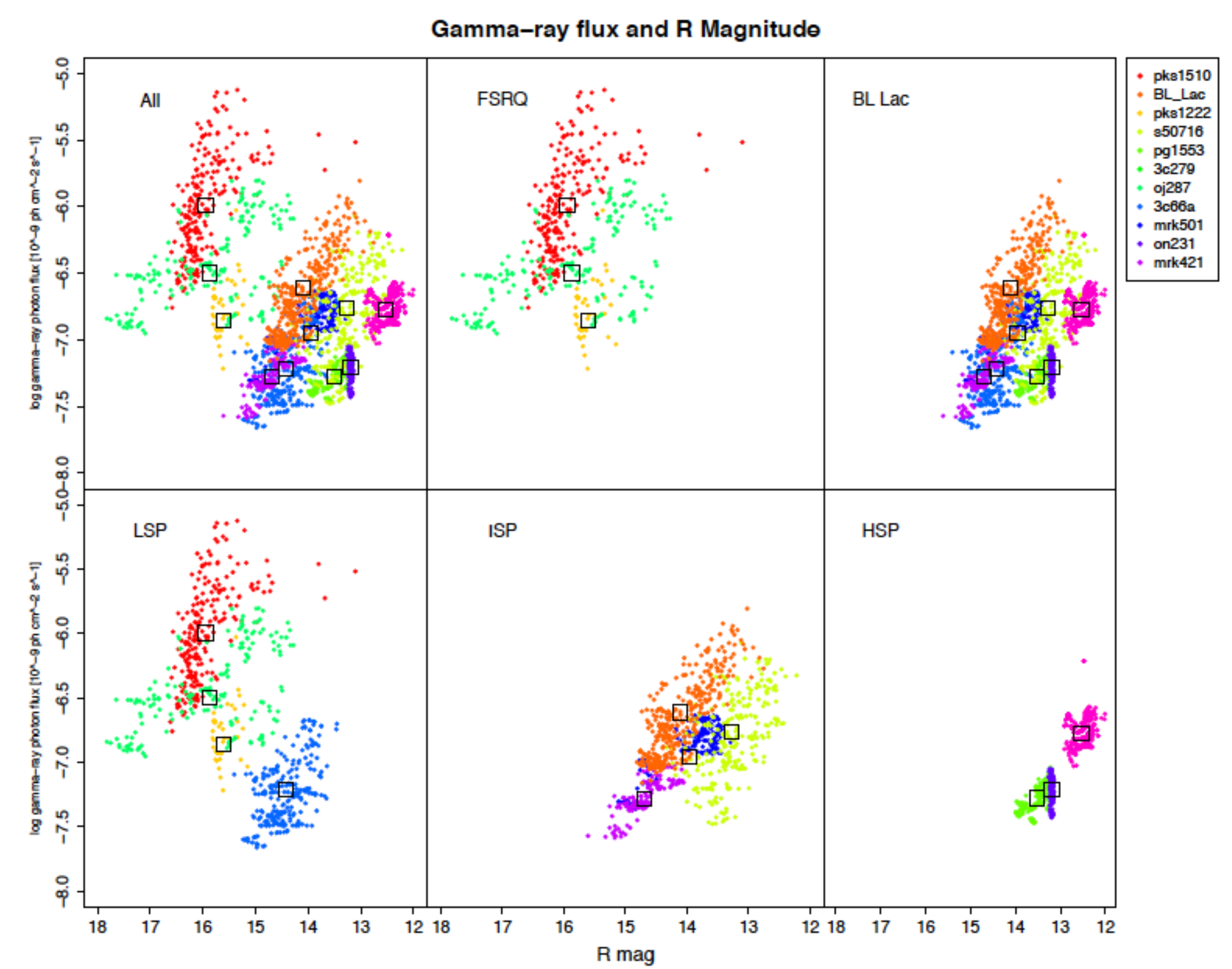
Villforth et al. in prep

Real-time variability



Precursor predictions for γ-ray flares?

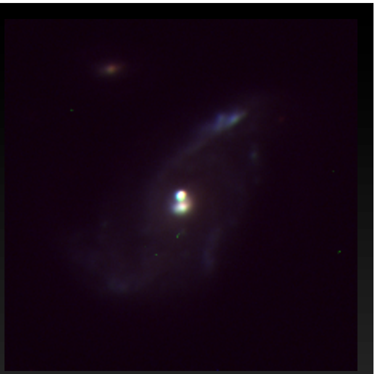
Jermak et al. 2016



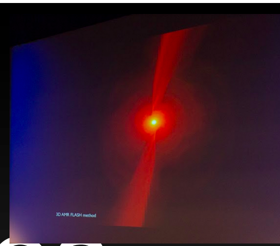
Correlations from long-term monitoring

Jermak et al. 2016

AGN as Transients



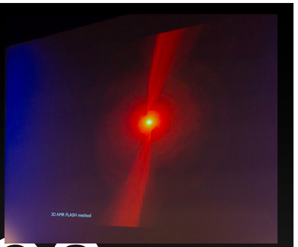
- Gamma-ray flare triggers optical follow-up
- CTA + LSST
- Also GW + LSST
- LSST transients self-triggers – more challenging
  - Filtering, classification, optimisation
- Other communities developing strategies



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



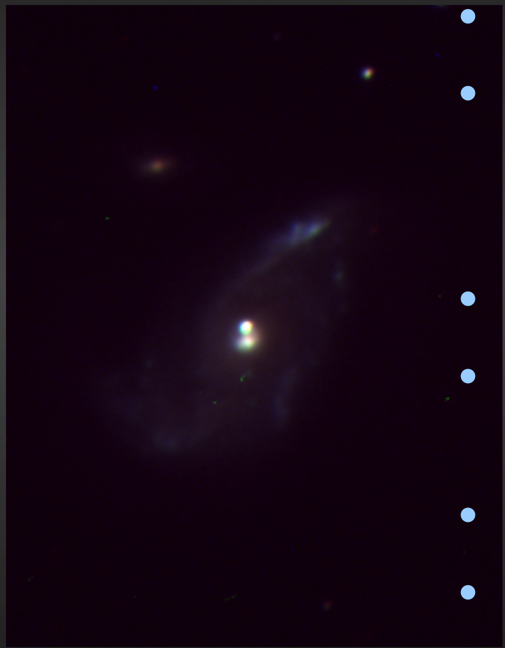
- T

s,

- 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

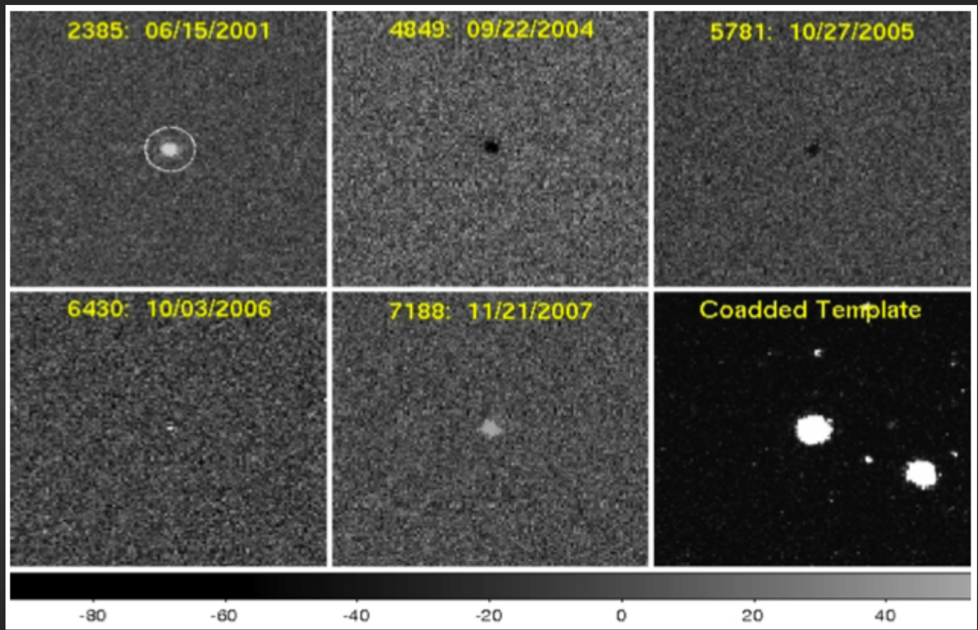
Tracing Quiescent Black Holes



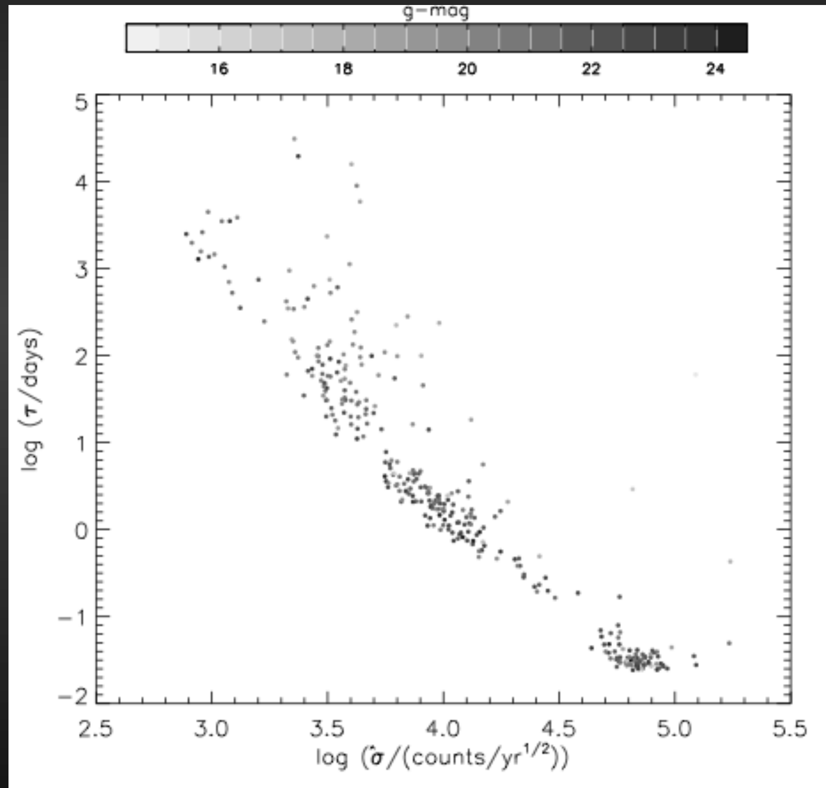
- NGC4708
- 3-mag nuclear flare (ATLAS 0.5m detection – Tonry+2016 Atel #9151)
- Liverpool Telescope follow-up
- Multi-colour imaging, spectroscopy, polarimetry
- Small bulge, good contrast
- Pre-peak SN 1a (Mundell +2016 Atel #9165)

*IR TDE flare – reprocessed dust at 0.1pc
Van Velzen+17 AAS Meeting #229, id.207.03
*Superluminal components
Perlman+17 AAS Meeting #229, id.250.58 ***+many other TDE abstracts***

Variability Selected AGN in Difference Images



Difference images of variable
Quasar, co-added template

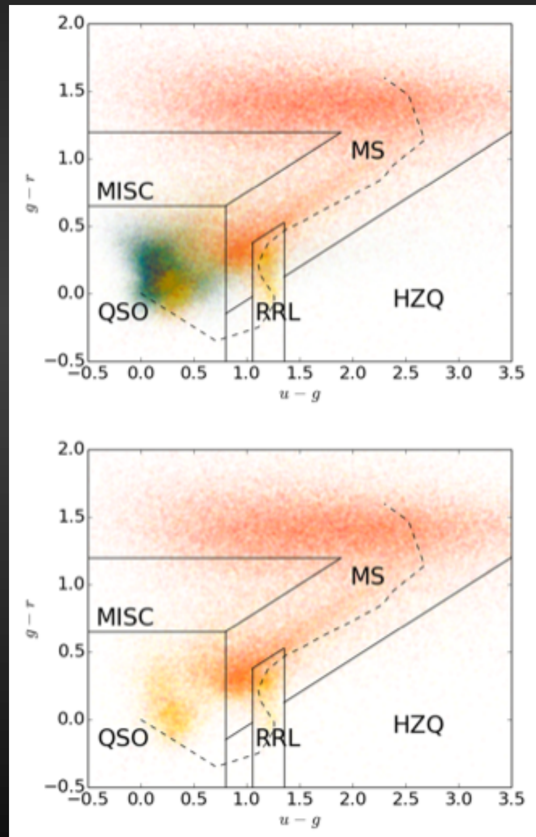


SF for X-ray selected point sources
Colour coded by g-band mag
Faint sources = shorter timescales

Choi et al. 2014

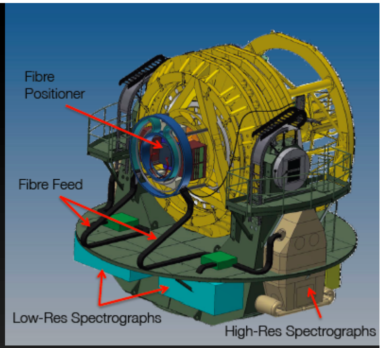
SDSS IV eBOSS - TDSS

- 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)

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

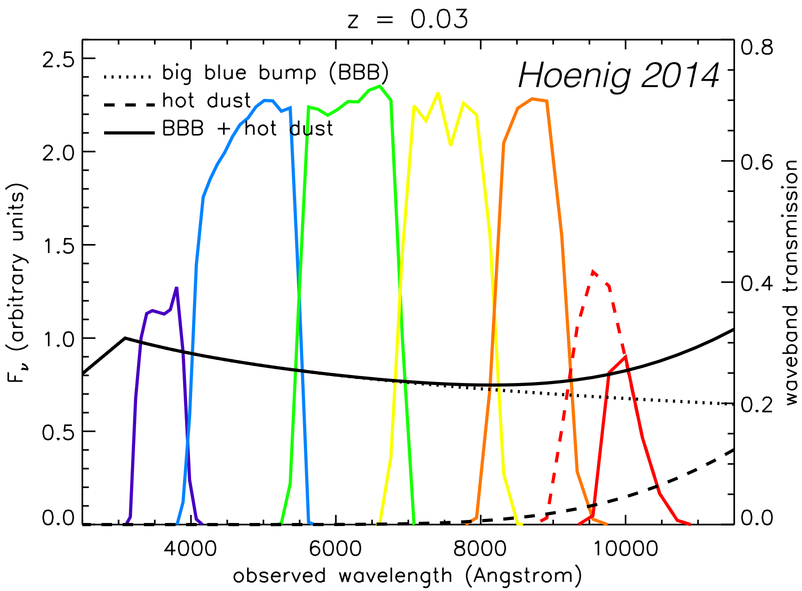
Instrument Specification

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

Dust reverberation mapping

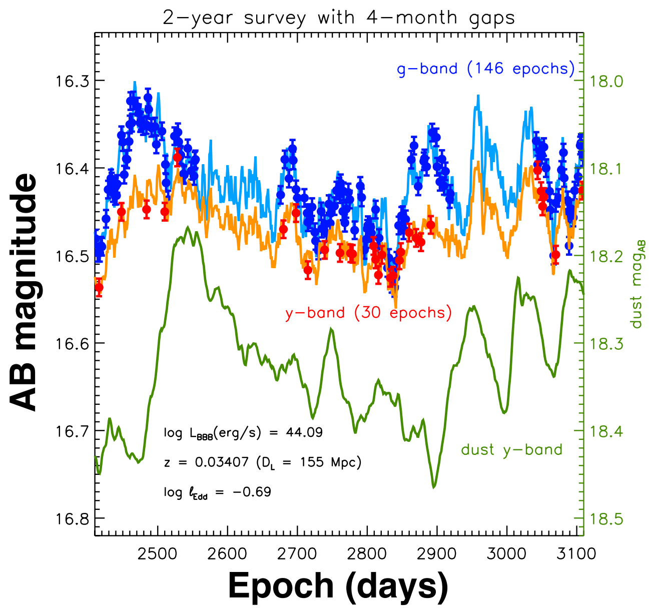
- Wien tail of hot dust emission reaches into (red) optical bands
  - decompose ugrizy into disk and dust light curves
  - use techniques similar to photometric emission line reverberation mapping (e.g. Chellouche & Daniel 2012; Chellouche & Zucker 2013)

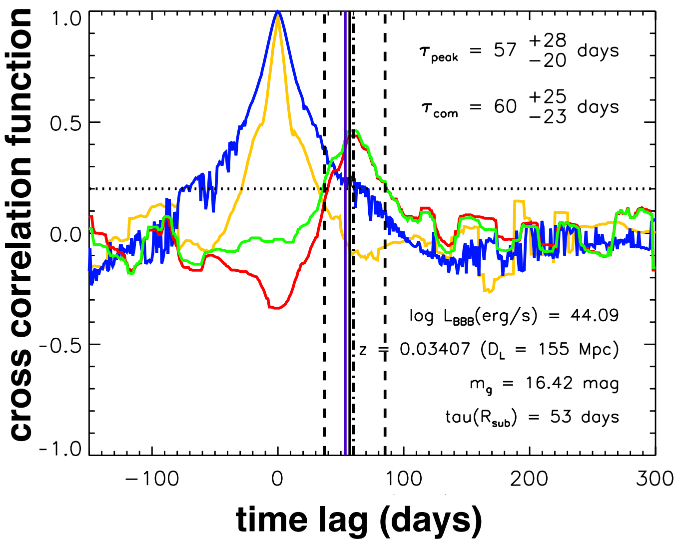
AGN hot dust lags with LSST



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



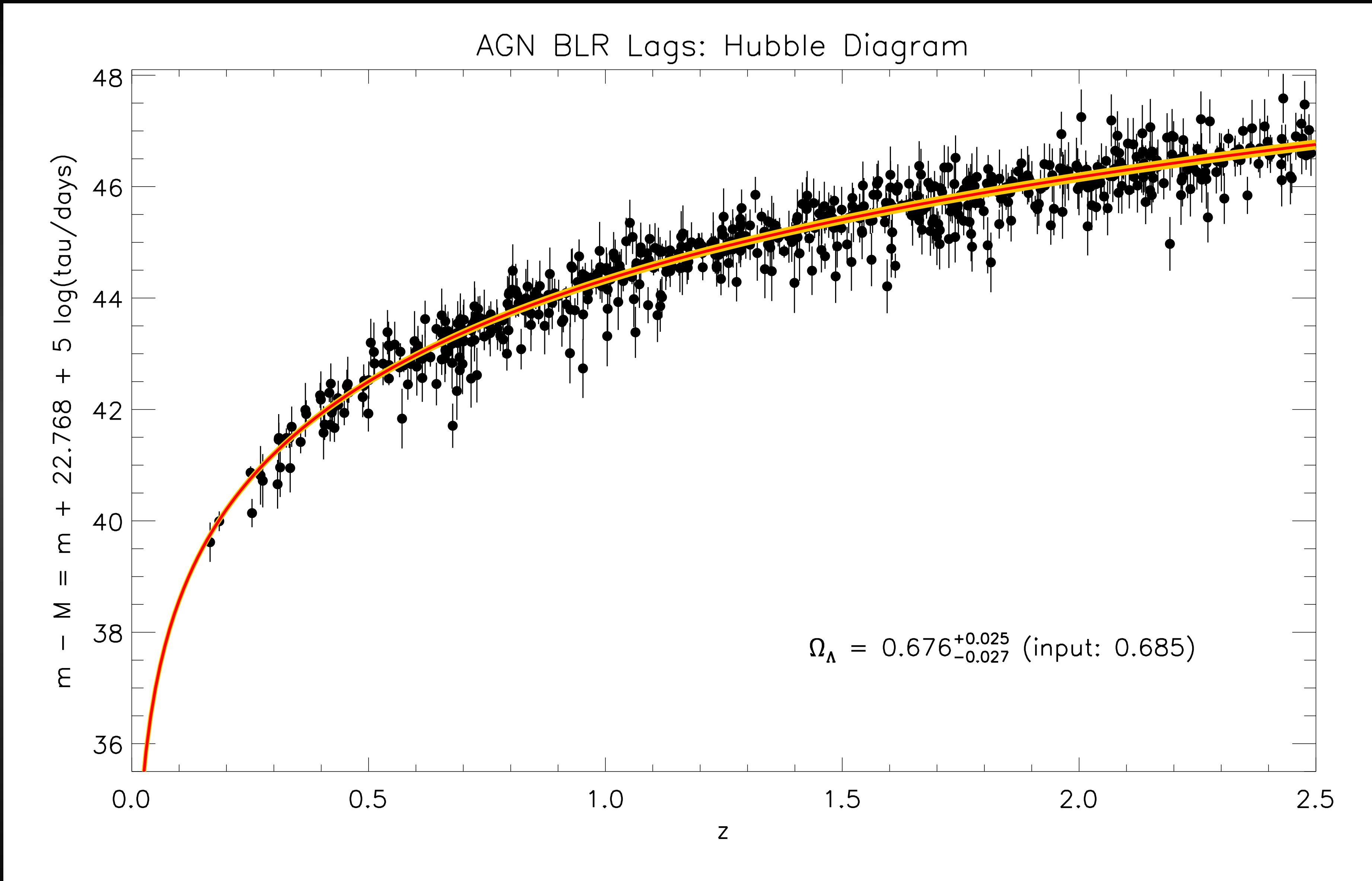


Dust reverberation mapping

- Dust lag-luminosity relation now used as a standardisable candle (e.g. Hoenig et al. 2017, MNRAS 464, 1639) —> requires local set of AGN
- Immediate action: Need to adjust AGN simulator to include dust as a *variable* source, not just constant (Hoenig- work in progress)

Reverberation Mapping

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



AGN BLR Lags: Hubble Diagram
m − M = m + 22.768 + 5 log(tau/days)
z
48
46
44
42
40
38
36
0.0
0.5
1.0
1.5
2.0
2.5
$\Omega_\Lambda = 0.676^{+0.025}_{-0.027}$ (input: 0.685)

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

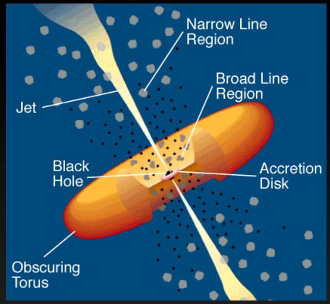
Challenges

- Precursor surveys
- AGN identification and classification
- Alerts – into and out of LSST
- Dynamic range – AGN accute problem
- PSF, faint features, variability, LCs
- Addition of spectroscopic information
- Feasible in real time?

Summary

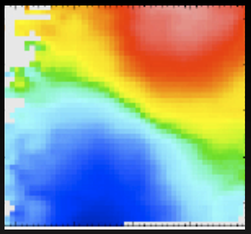
- AGN with LSST perhaps most diverse technical/scientific case
- Host galaxy to nucleus + dynamic range
- Variability + spectroscopy helps
- Fast transients – AGN flares, TDEs probe new physics
- Autonomous follow-up after filtering
- Community co-ordination key

LSST-UK AGN



- Carole Mundell
- 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
- 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

UK Community

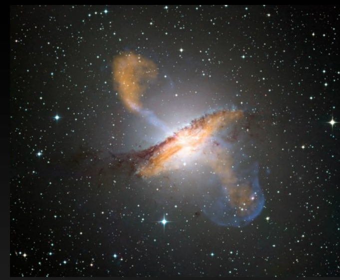


- Observational (static)
  - Strong multi-wavelength leadership
  - Imaging & spectroscopic surveys
  - Local galaxies
  - Kinematics
  - AGN and galaxy evolution

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?)

Thank you!