G. Canalizo

The Connection Between Starbursts and QSO Activity

Recent observations of low redshift quasar host galaxies indicate that mergers and significant episodes of star formation are ubiquitous in these galaxies. By constraining the timescales of such events we can gain a better understanding of the role of AGN feedback in galaxy evolution. I will discuss results from a long campaign of space- and ground-based imaging and spectroscopic observations of $z < 0.5$ hosts that imply that mergers are indeed essential for the triggering of quasars, and that these mergers invariably induce starbursts either during or shortly after the merger. There appears to be, however, a large range of values for the time delays between the merger and the onset of the nuclear activity, varying from a few Myr to more than a Gyr. We find some evidence for a bimodal distribution, although this could be a selection effect.

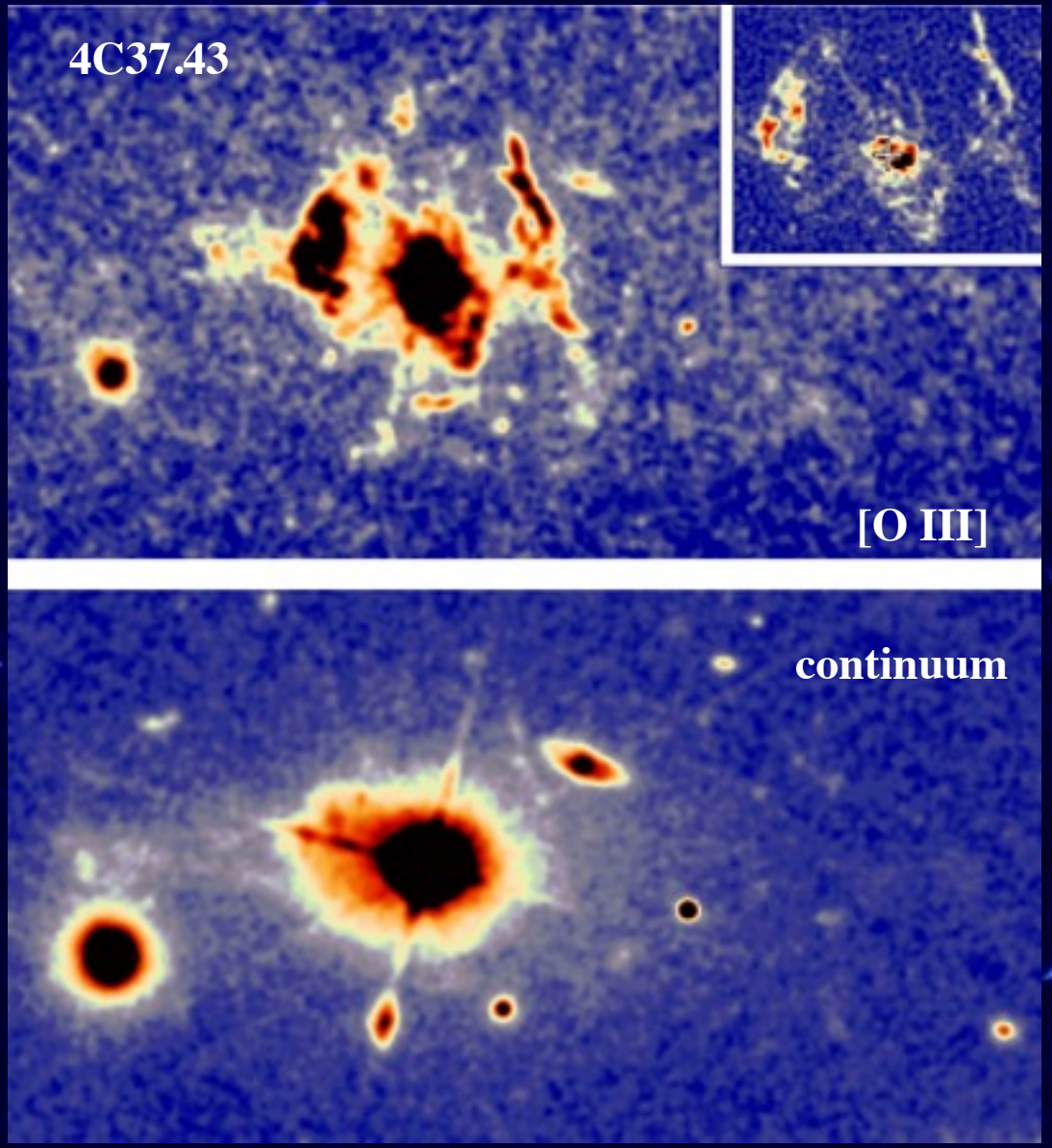
A case of observational evidence of AGN feedback

Fu & Stockton 2007, 2008, 2009:

- The most luminous cases of extended ionized gas around QSOs are due to ejection via quasar winds

- Found only in quasars with strong radio jets, associated with galaxies where there is no significant SF

- Total mass of ejected material ~ 10^9 - 10^{10} M_{sun}



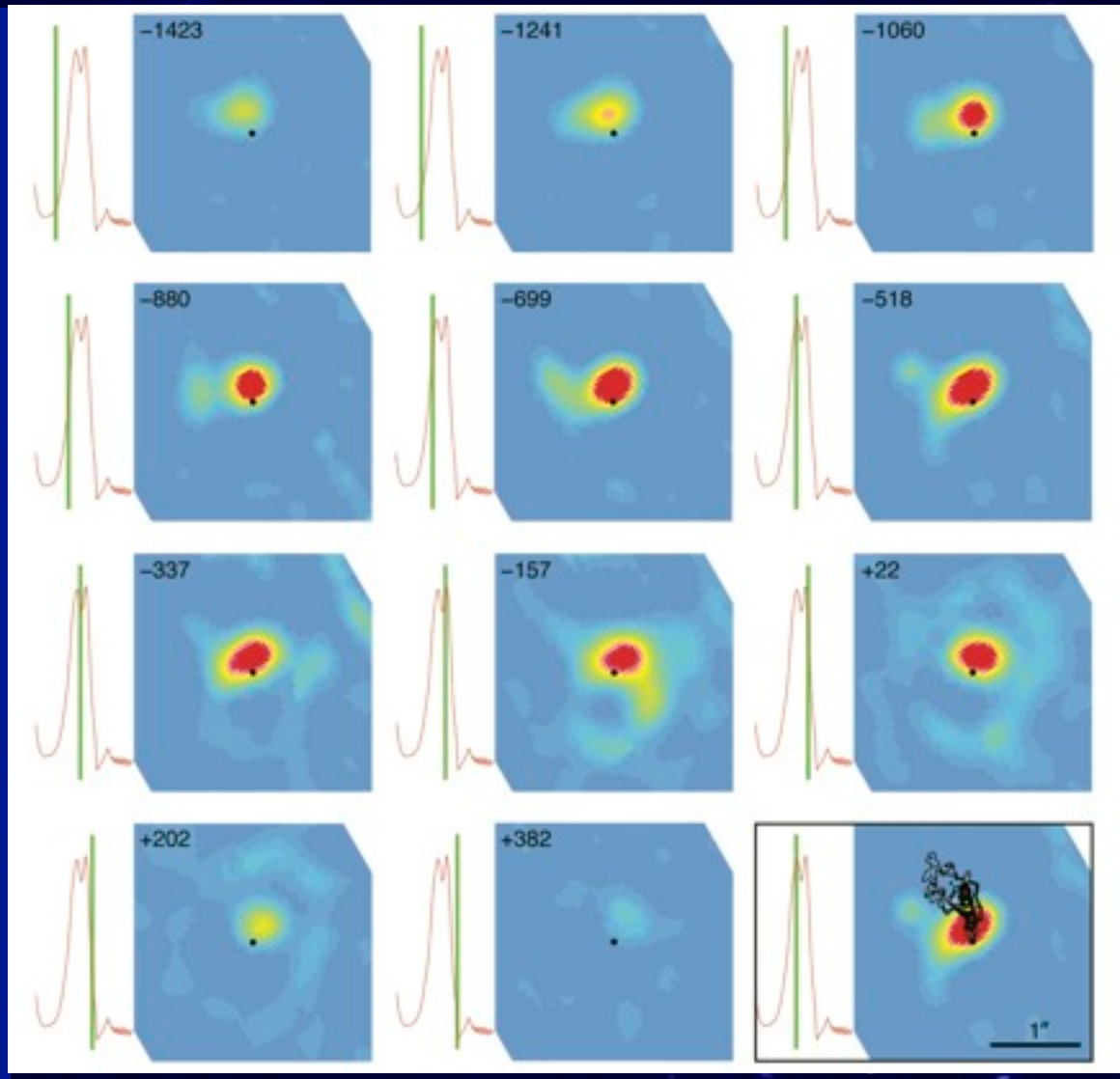
A case of observational evidence of AGN feedback

Stockton, Canalizo, Fu & Keel 2007, ApJ 659, 195

In 3C 48 we apparently see the process in action:

- The material appears to be ejected as a blast wave over a wide solid angle (approaching a hemisphere; even seen in C IV absorption in the quasar spectrum) from the base of the radio jet.

- This is consistent with what we see in the more mature EELRs around well developed radio sources.



The Connection Between Starbursts and QSO Activity: A Study Based on Low-z Host Galaxies

Gabriela Canalizo

University of California, Riverside

Collaborators: Mark Hancock (UCR), V. N. Bennert (UCSB), Alan Stockton (IfA), Bruno Jungwiert (UCR), Mark Lacy (SSC), Francois Schweizer (OCIW), Chien Peng (HIA)

Granada, June 24, 2010

The study of QSO host galaxies can shed light on some outstanding questions:

- Are QSOs really triggered by mergers?
- Is there a merger-starburst-AGN connection?
- Is there evidence that star formation is really quenched after AGN activity is triggered?
- What are the relevant time scales?

Will focus on spectroscopic (+imaging) studies of luminous QSOs

On the triggering of Starbursts and QSO activity

Springel et al. (2005)

- Toomre & Toomre 1972: Galaxies merge and cause starbursts
  - Generally accepted, although there is still no consensus on precise relation between starbursts and mergers
  - Mergers helpful but not sufficient (cf. P. di Matteo's talk)
- Stockton 1982: Can mergers also trigger QSOs?
  - Plausible, but still debated: many studies based on *circumstantial* evidence
  - The fact that QSO host galaxies are interacting does not necessarily imply that interactions triggered the QSOs

Results from Spectroscopic Studies

QSO host galaxies tend to fall in two main groups:

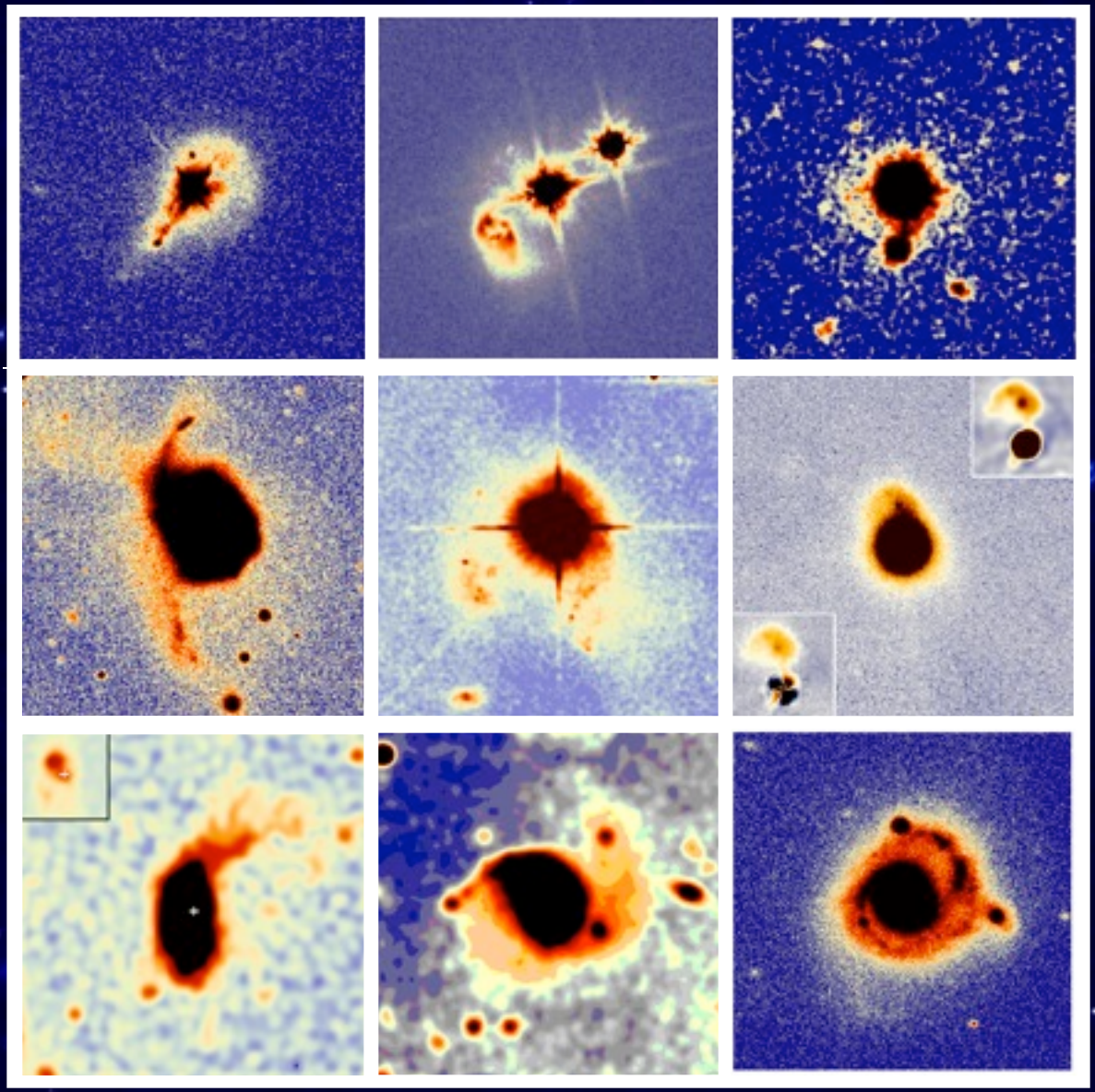
1. Galaxies with young stellar populations (1-4 x10^8 yr) and morphologies indicative of ongoing mergers

   Samples: FIR Color-selected QSOs, 'post-starburst' QSOs, 'Q+As', dust-reddened QSOs

2. Galaxies with intermediate age populations (1-2 x 10^9 yr) and morphologies indicative of older merger events

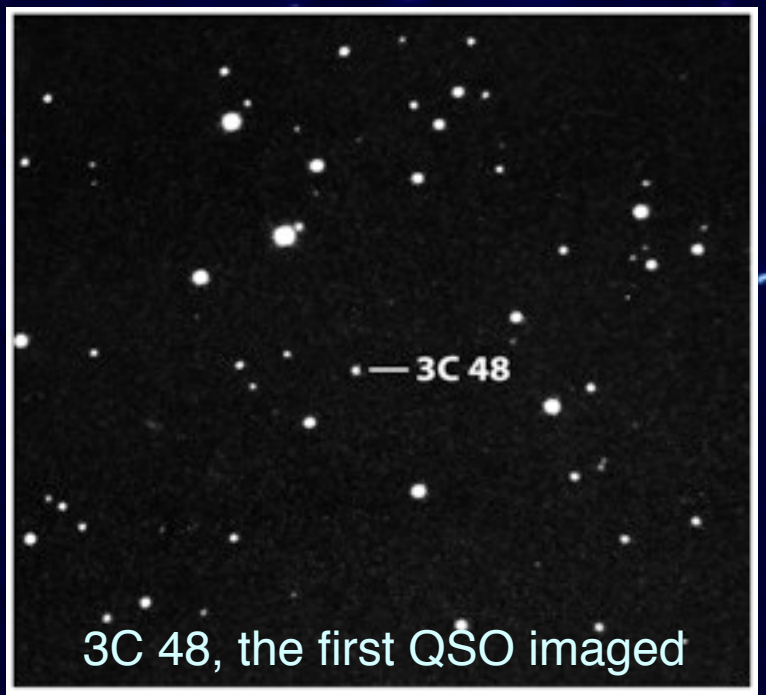
   Samples: Dunlop et al. 2003, Wold et al. 2010, Letawe et al. 2008, Canalizo et al.

Color-selected FIR QSOs



Outline of method used in Canalizo & Stockton ‘01 and subsequent work

1. Detect host galaxies.
   - Challenge: galaxies overpowered by bright nucleus
   - Tools: High resolution imaging with Adaptive Optics and the Hubble Space Telescope



3C 48, the first QSO imaged

Outline of method used in Canalizo & Stockton ‘01 and subsequent work

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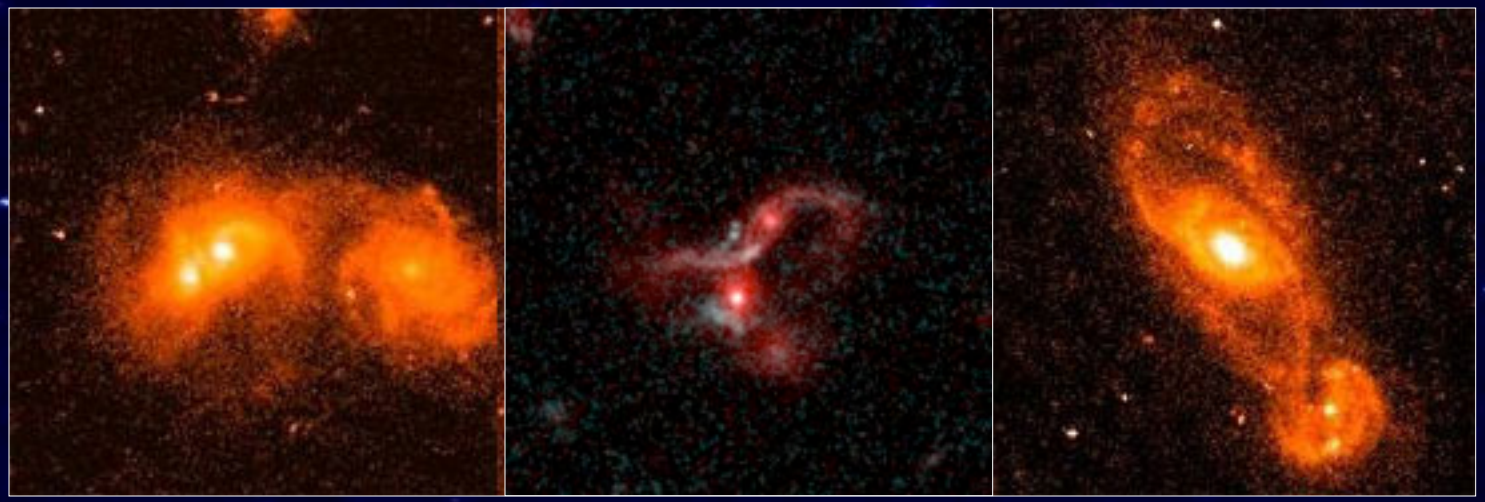
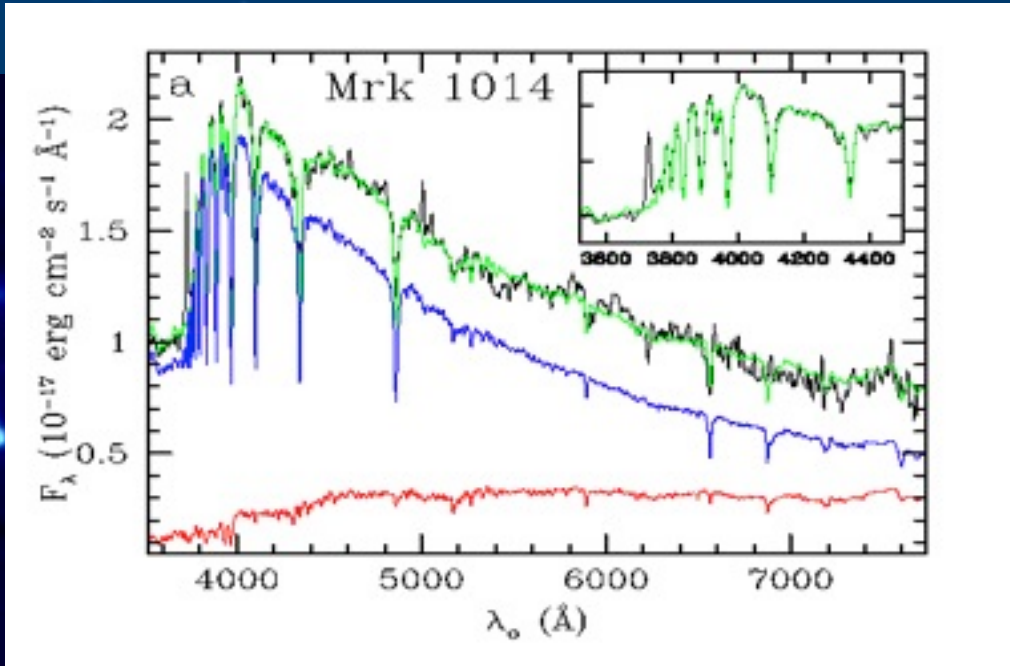
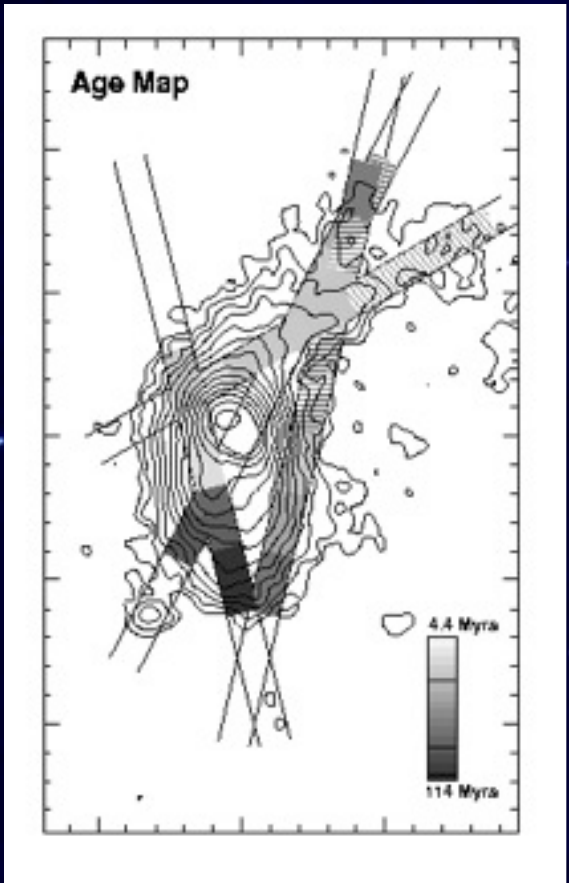
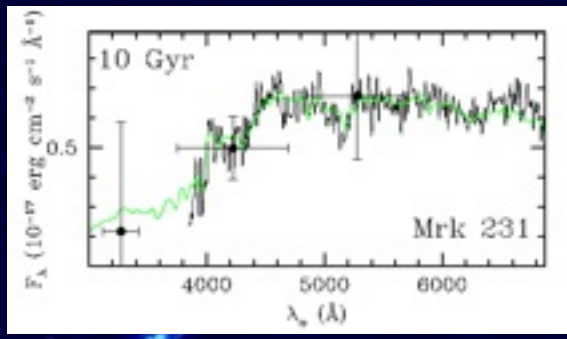


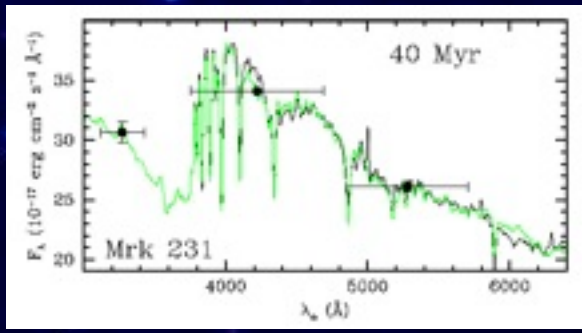
2. Detect starbursts in host galaxies and age-date them
   - Challenge: galaxies overpowered by bright nucleus
   - Tools:
   – Very high S/N Keck spectroscopy,
   – Deconvolution and subtraction of AGN contamination
   – Different stellar synthesis models (B&C'03,'07, Maraston, etc)
   – Fitting of stellar populations
     - An old ~10 Gyr population (presumably pop existing prior to merger)
     - A young population (presumably the starburst resulting from merger)

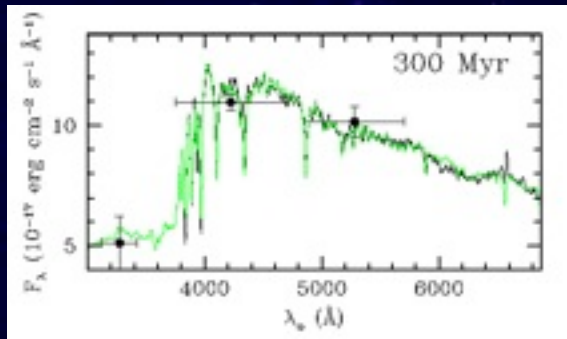


3. Map stellar populations (similar to J. Rodriguez Zaurin's work)



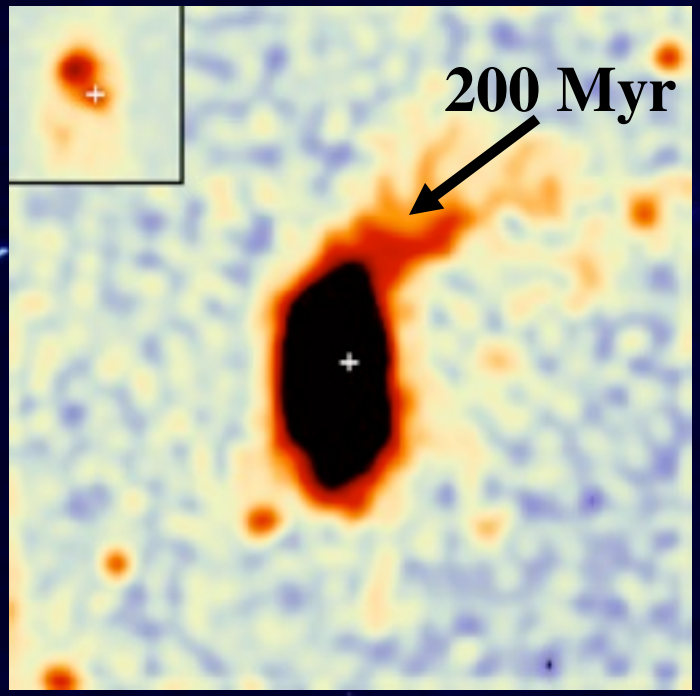


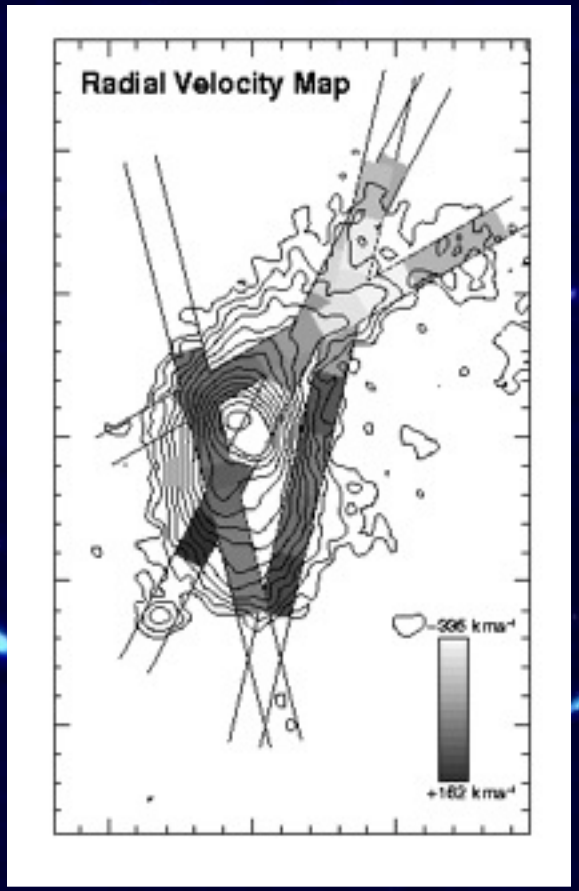




4. Age-date merger events

- Tools: simple dynamical models, guided by kinematic information obtained from spectra





Young hosts

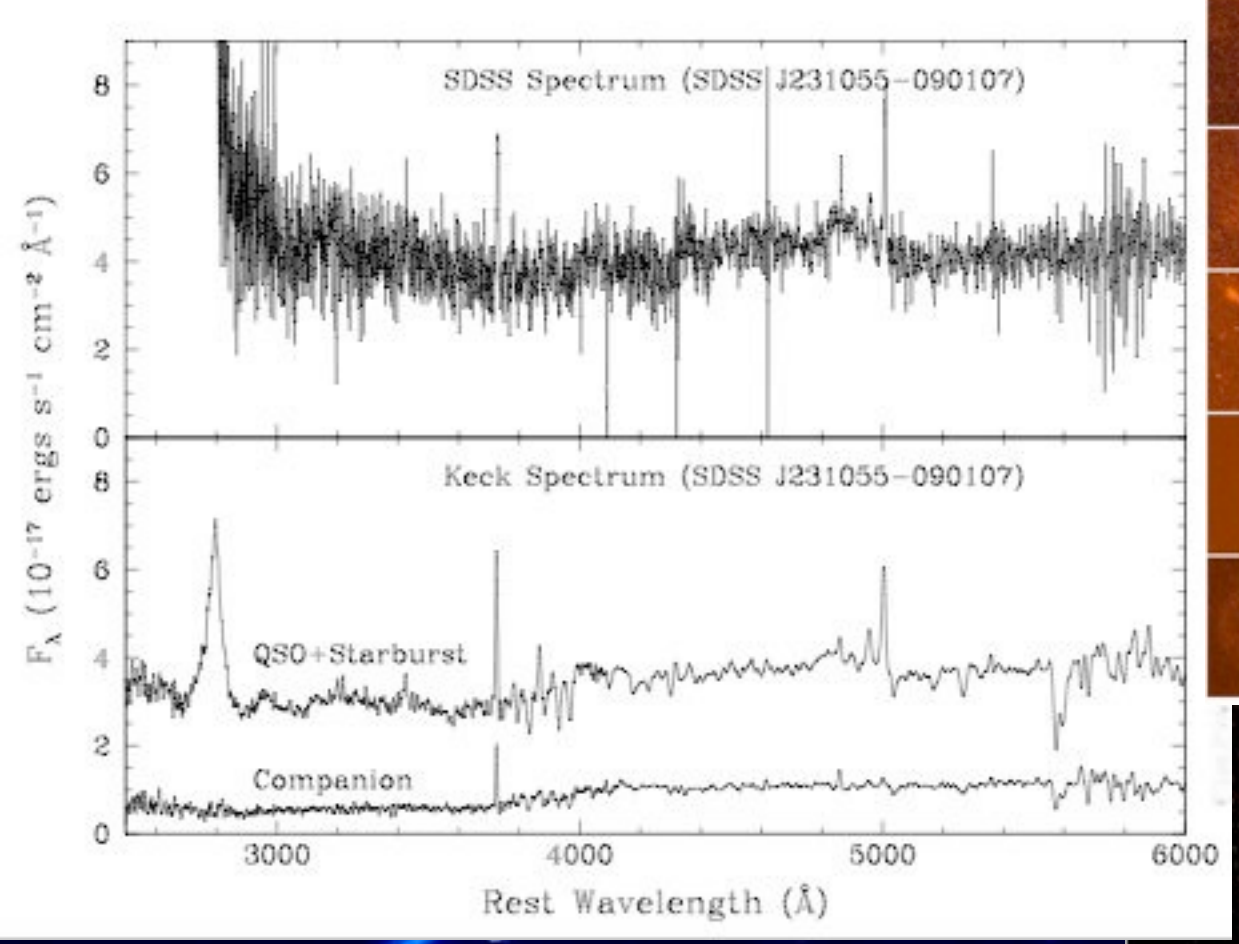
In a study of a complete sample of FIR-color selected objects we found:

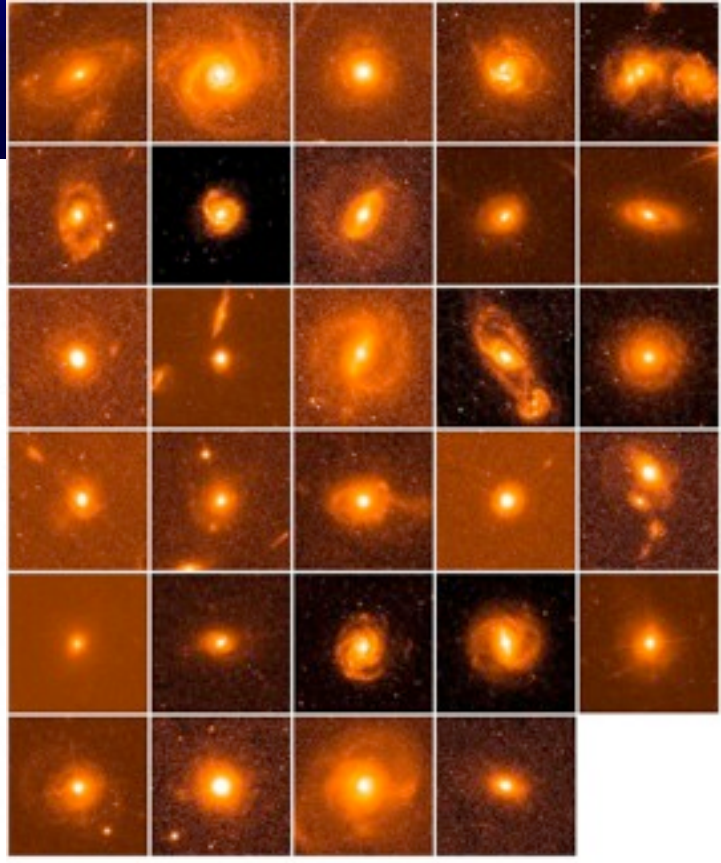
- All objects are mergers, mostly of disk galaxies
- All objects have unambiguous merger-induced starburst populations with ages < 300 Myr
- Strongest and youngest starbursts concentrated toward central regions of hosts. This traces the motion of the gas toward the nucleus (cf. L. Kewley's and D. Rupke's talks).
- Concentration of material toward nucleus triggered both central starbursts and QSO activity roughly simultaneously

- At least these QSOs are triggered by mergers that result into starbursts.
- Evidence that star formation is indeed quenched some time after the merger, and before the BH runs out of fuel.

Similar samples: Q+As and dust-reddened QSOs

Q+As

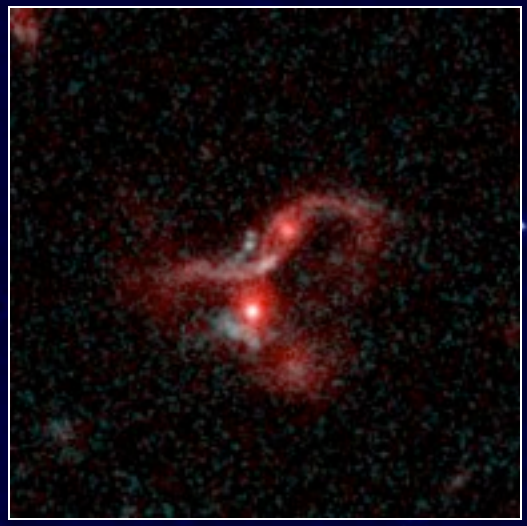




- Spectra dominated by poststarburst populations
-ACS snapshot survey shows wide variety of morphologies
- cf. M. Brotherton's talk!

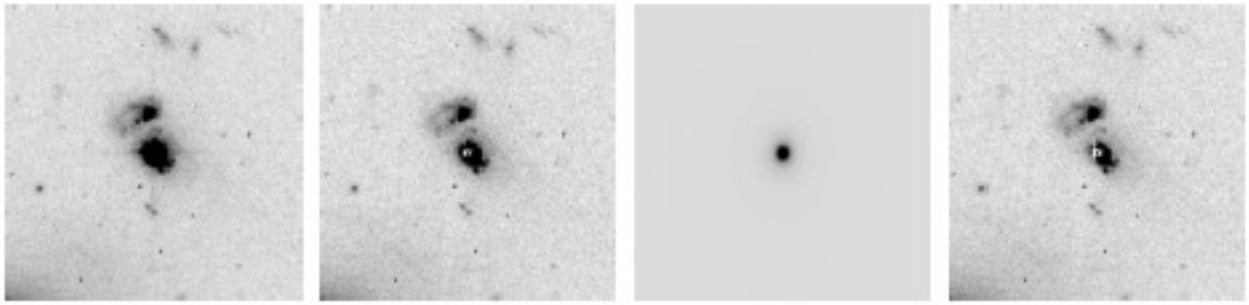
Dust-reddened QSOs

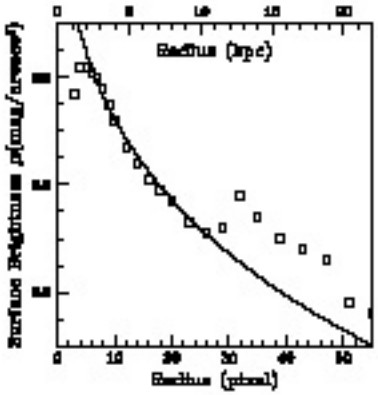
- Urrutia et al. (2008) obtained HST/ACS images of 13 red QSOs
- 11/13 show strong evidence of recent or ongoing interaction; none have deVaucouleurs profiles
- Our spectroscopy of dust-reddened QSOs show that most have post-starburst populations (Canalizo+08)



URRUTIA, LACY, & BECKER

F2M1507+3129





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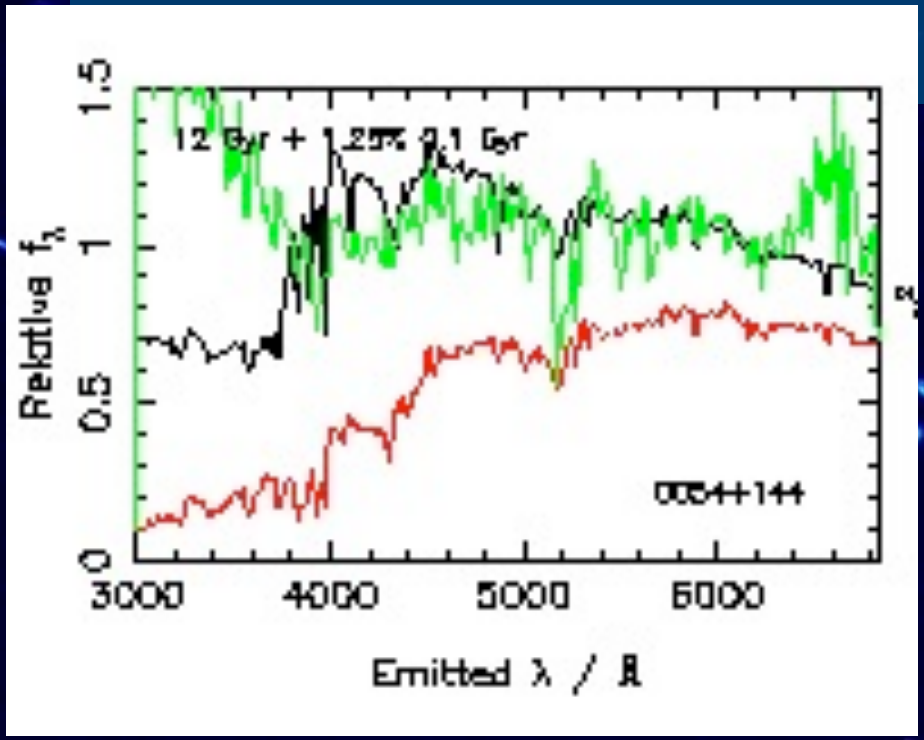
2. **Galaxies with intermediate age populations (1-2 x 10^9 yr) and morphologies indicative of older merger events**

   Samples: Dunlop et al. 2003, Wold et al. 2010, Letawe et al. 2008, Canalizo et al.

Older host galaxies: Dunlop et al.

- Dunlop et al. (2003, and series of papers leading to it): a statistically-matched sample of 13 RQQs and 10 RLQs at z~0.2, with $M_V < -23.5$
- HST/WPC2 imaging
- Off-nuclear spectroscopy with WHT and Kitt Peak 4-m



Nolan et al. 2001, MNRAS,323, 308

Fitting method:

§ Use Q0054+144 to account for QSO light

- Fix a 0.1 Gyr population
- Vary age of old population
- Determine contribution from young stars

Green line: observed data

Black line: best fit model

Dunlop et al. Results:

1. Hosts are ellipticals described by de Vaucouleurs law
2. No evidence that most have undergone recent mergers
3. Truly old stellar populations with no episodes of massive star formation in recent past

Older host galaxies: our results

We tested the idea that these hosts formed at high redshifts and have been passively evolving since (Canalizo et al. 2006, 2007, 2010 in prep; Bennert et al. 2008; Hancock et al. 2010 in prep).

- Deep Keck LRIS spectroscopy of QSO hosts dominated by spheroids (no disk) dominated by intermediate-age starbursts of ages 0.6 to 2.2 Gyr

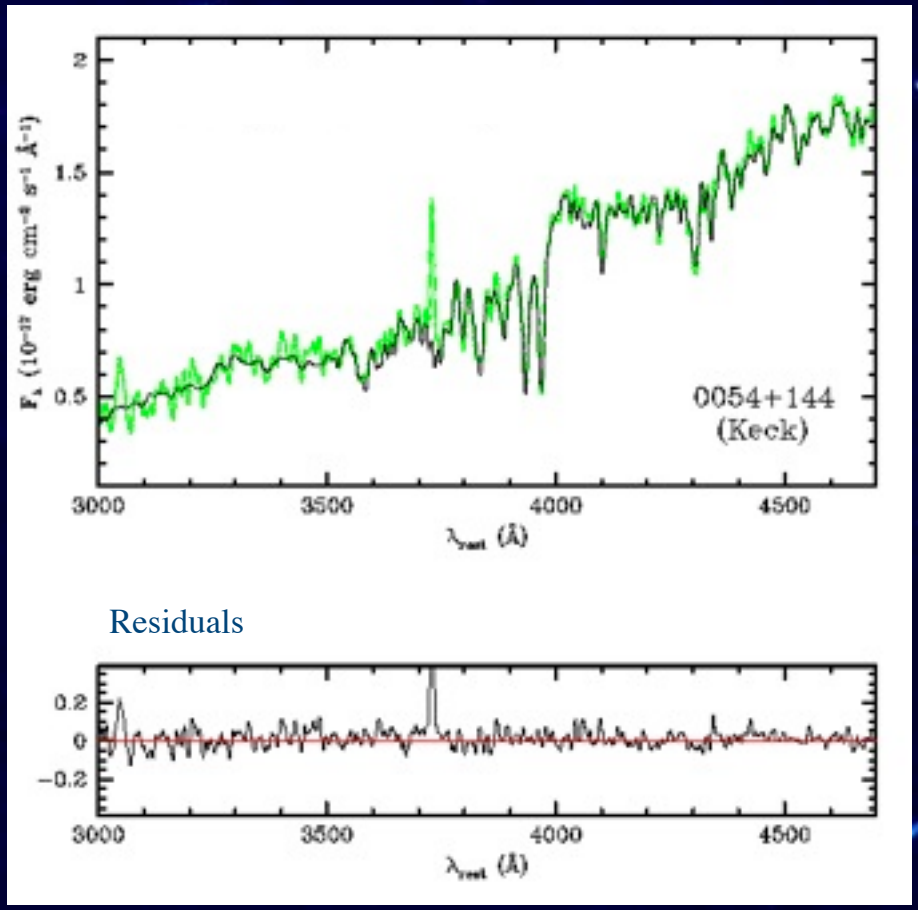
- Much deeper HST/ACS and WFPC2 imaging shows merger remnants with dynamical ages consistent with those of the starbursts

Keck spectroscopy

Fitting method:

- Subtract QSO contribution modeled by observing off-axis PSFs

- Correct for reddening
- Fit two component model and find relative contributions



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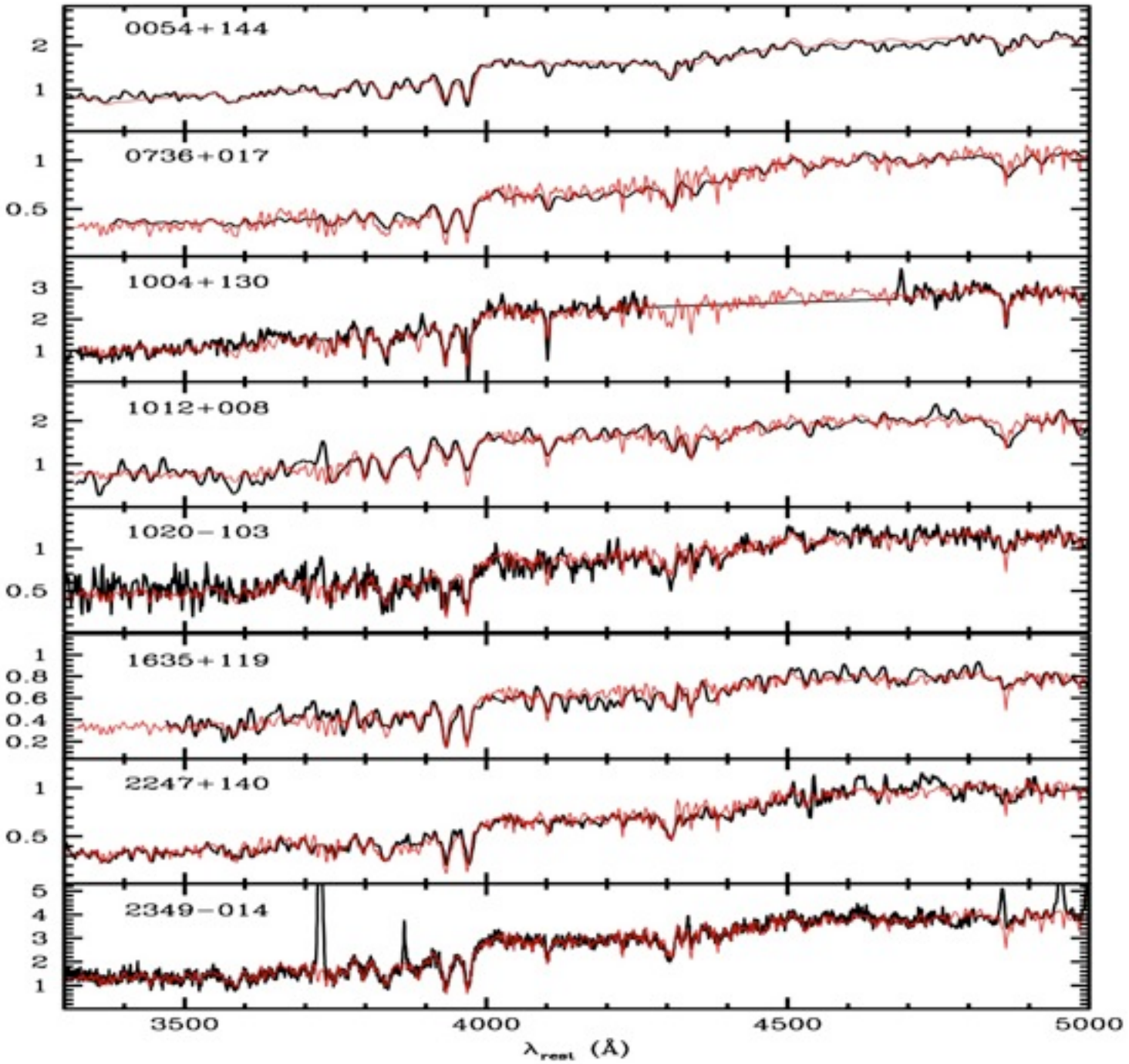

0054+144
0736+017
1004+130
1012+008
1020−103
1635+119
2247+140
2349−014
3500
4000
4500
5000
λrest (Å)

	Charlot & Bruzual (2007)		Maraston (2005)
Object	Starburst Age (Gyr)	Contribution by Mass	Starburst Age (Gyr)
0054+144	1.9	15%	2.0
0137+012	1.7	16%	2.0
0244+194	1.3	29%	1.5
0736+017	2.2	10%	2.0
0923+201	1.7	30%	1.0
1004+130	1.9	26%	0.9
1012+008	0.2	0.8%	0.6
1020-103	1.5	30%	(0.1)
1217+023	0.6	3.0%	0.6
1635+119	1.6	20%	1.0
2135-147	2.4	25%	3.0
2141+175	0.7	9.1%	0.6
2247+140	---	0%	1.0
2349-014	1.0	7.2%	0.8

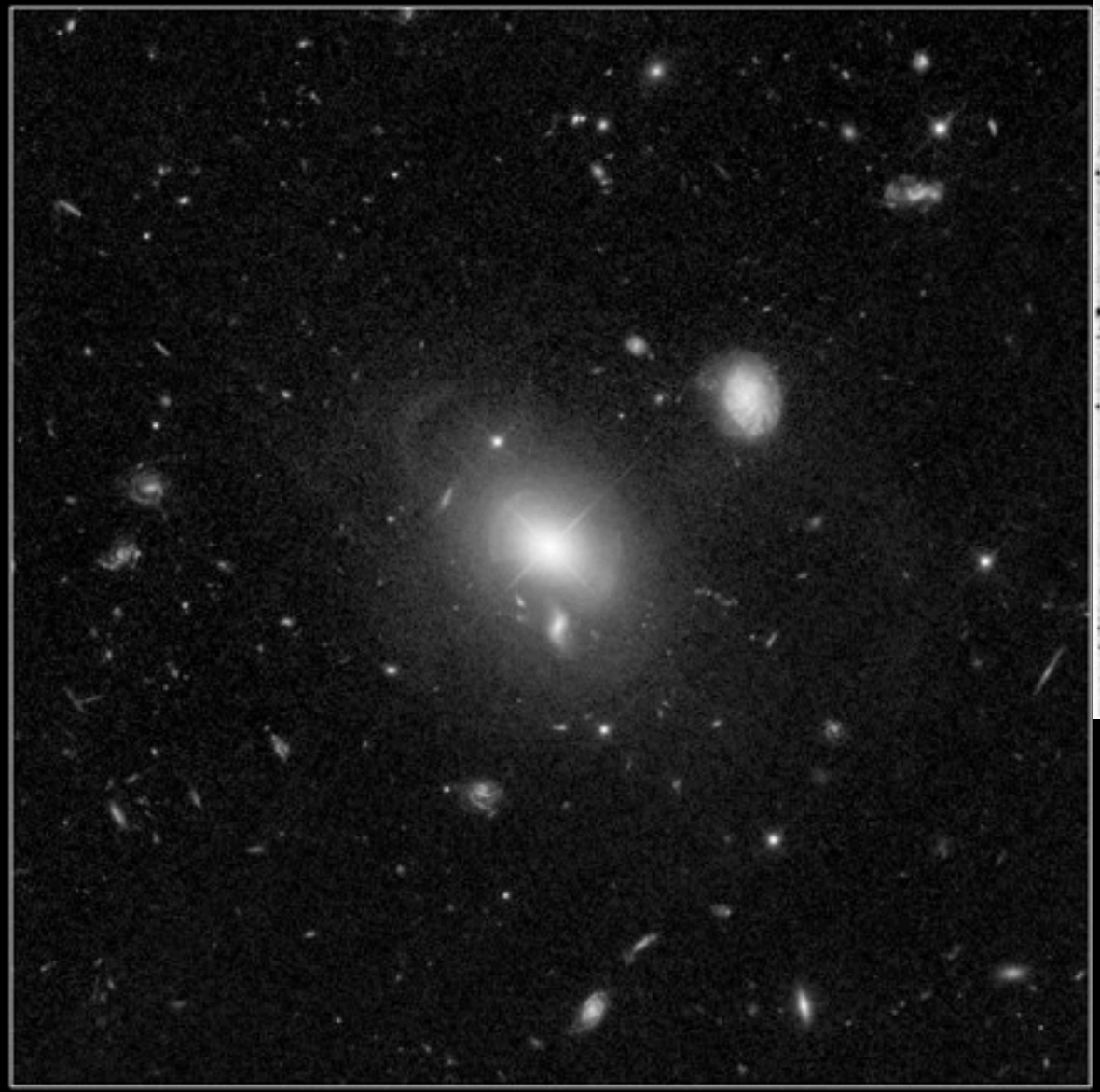
Canalizo & Stockton, in prep

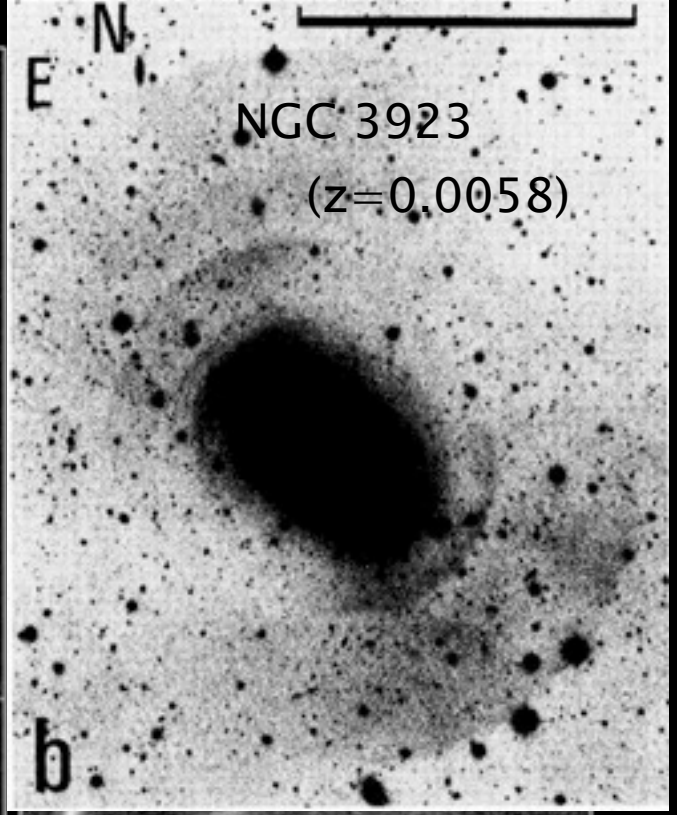
QSO MC2 1635+119

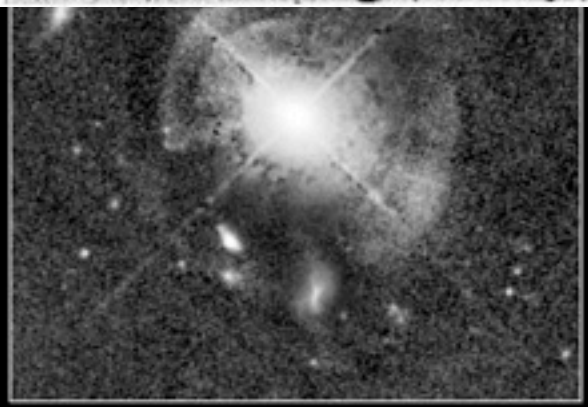
Hubble Space Telescope • ACS/WFC

NASA, ESA, and G. Canalizo (University of California, Riverside)

STScI-PRC07-39







QSO MC2 1635+119

Hubble Space Telescope • ACS/WFC

NASA, ESA, and G. Canalizo (University of California, Riverside)

STScI-PRC07-39

QSO MC2 1635+119

Hubble Space Telescope • ACS/WFC

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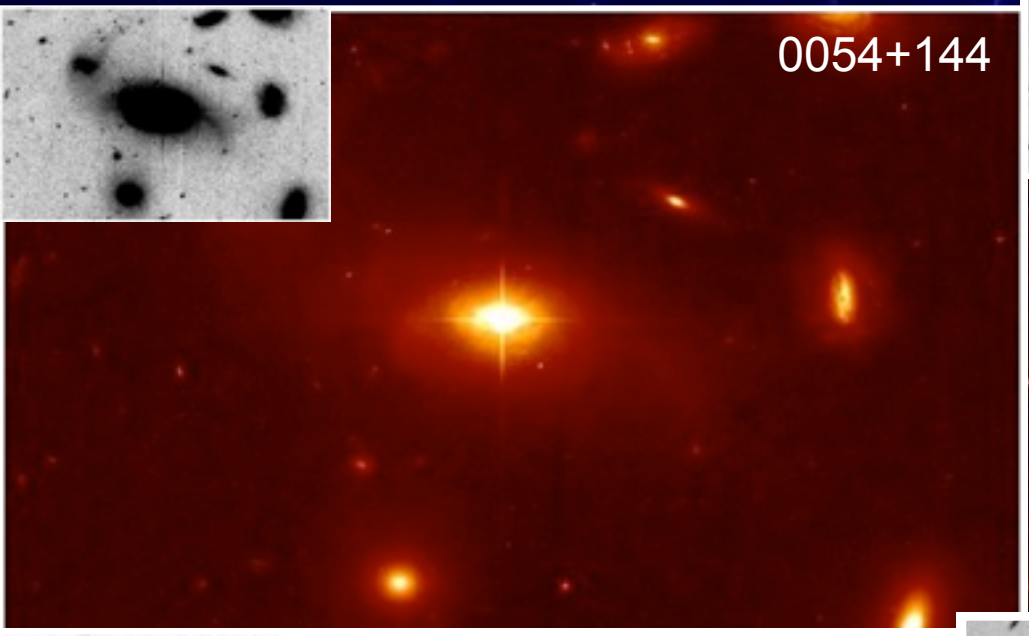
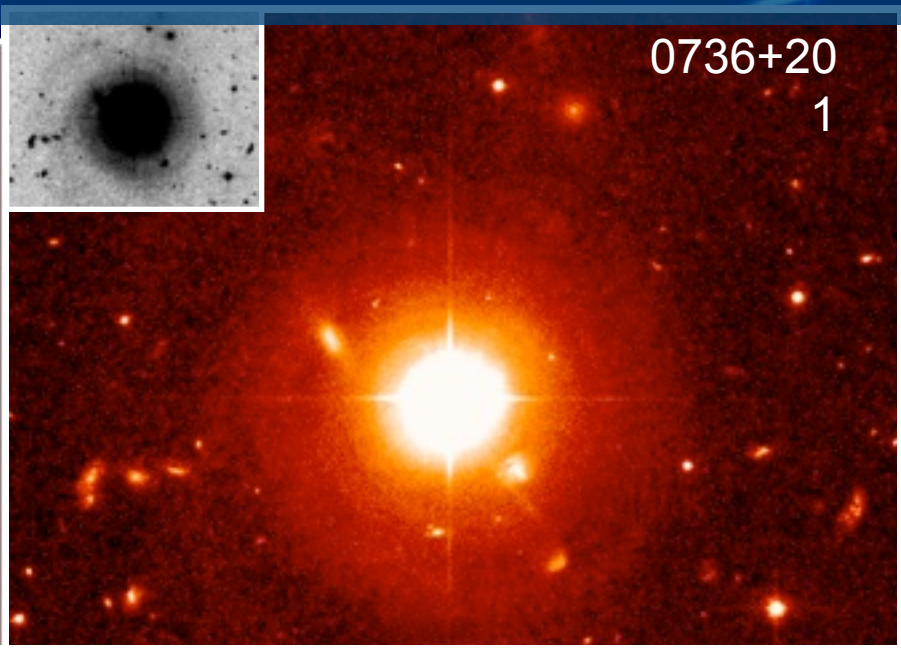
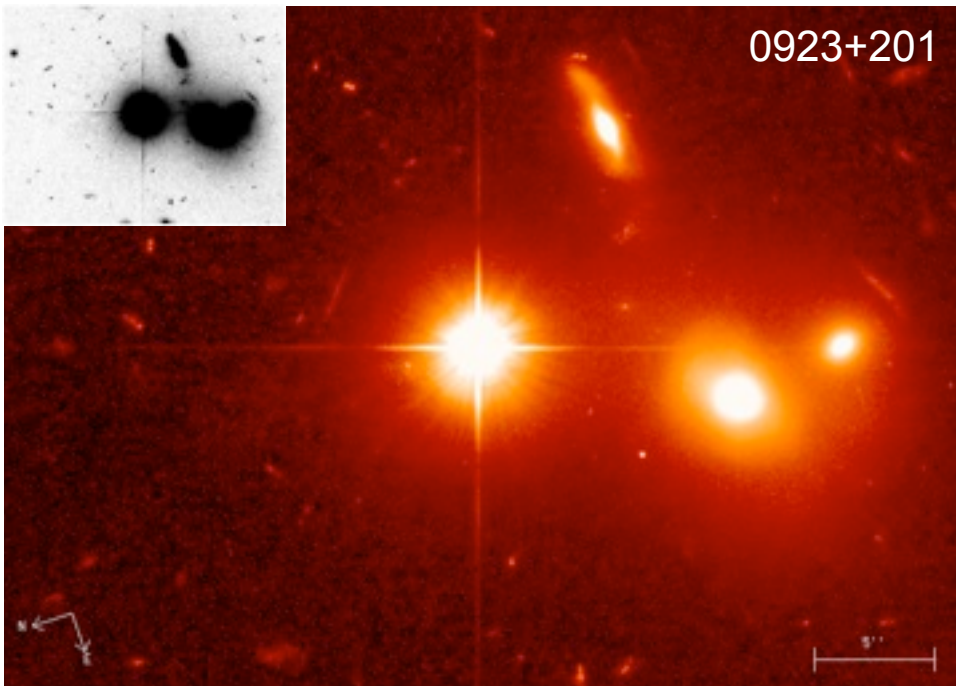
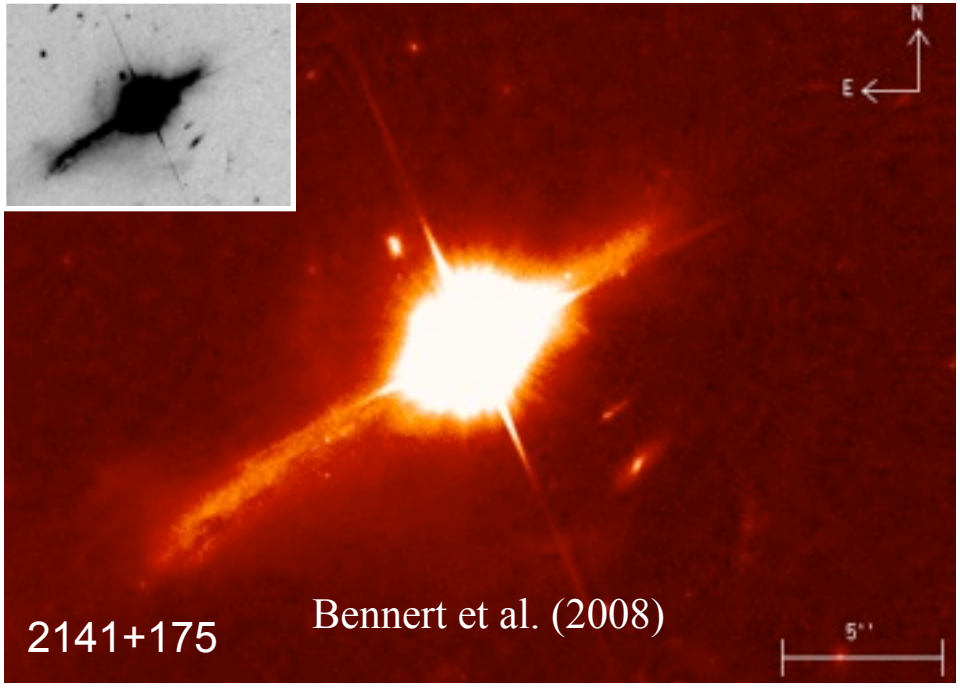
STScI-PRC07-39

- Pilot deep ACS study of five QSOs from the Dunlop et al. sample



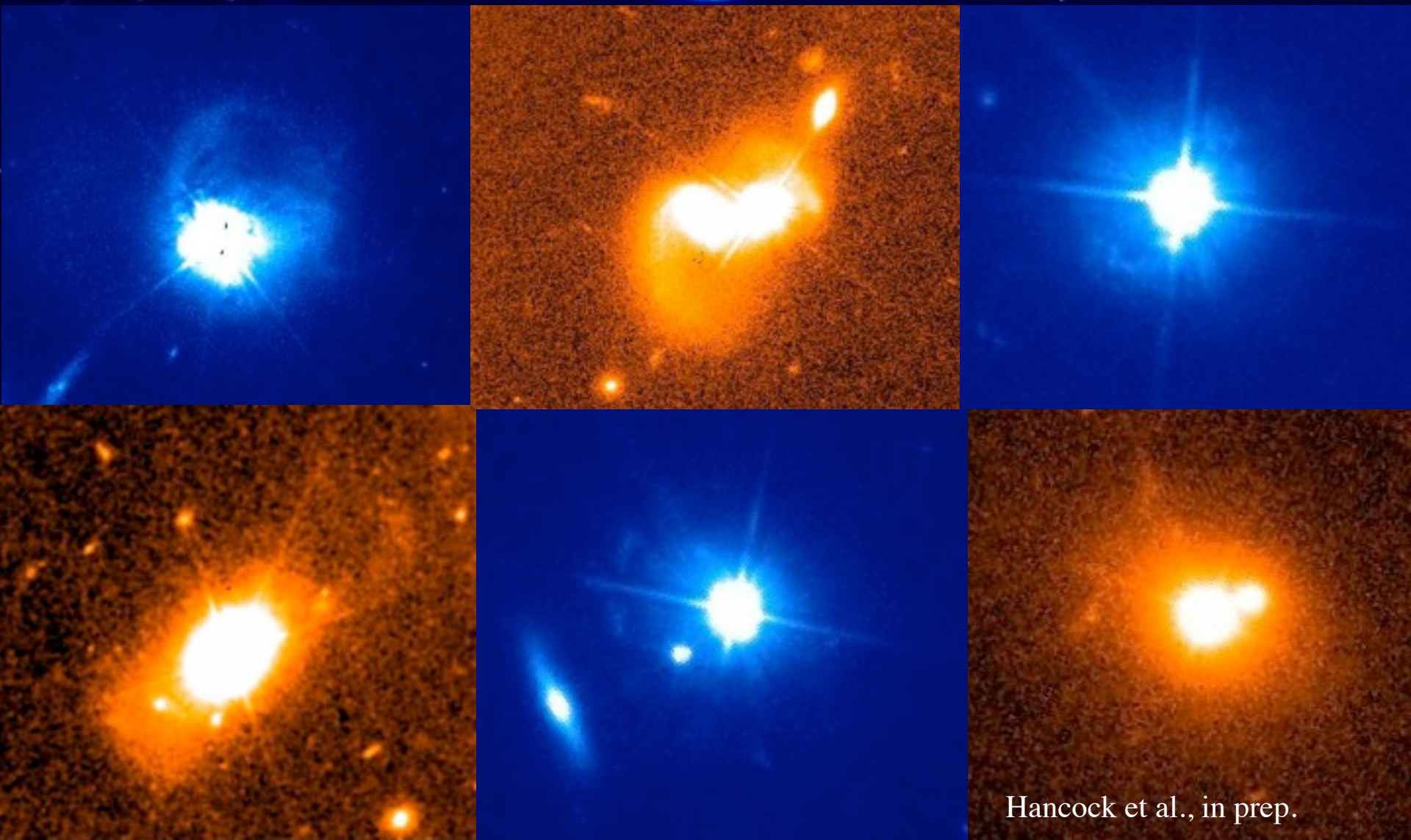






Better statistics

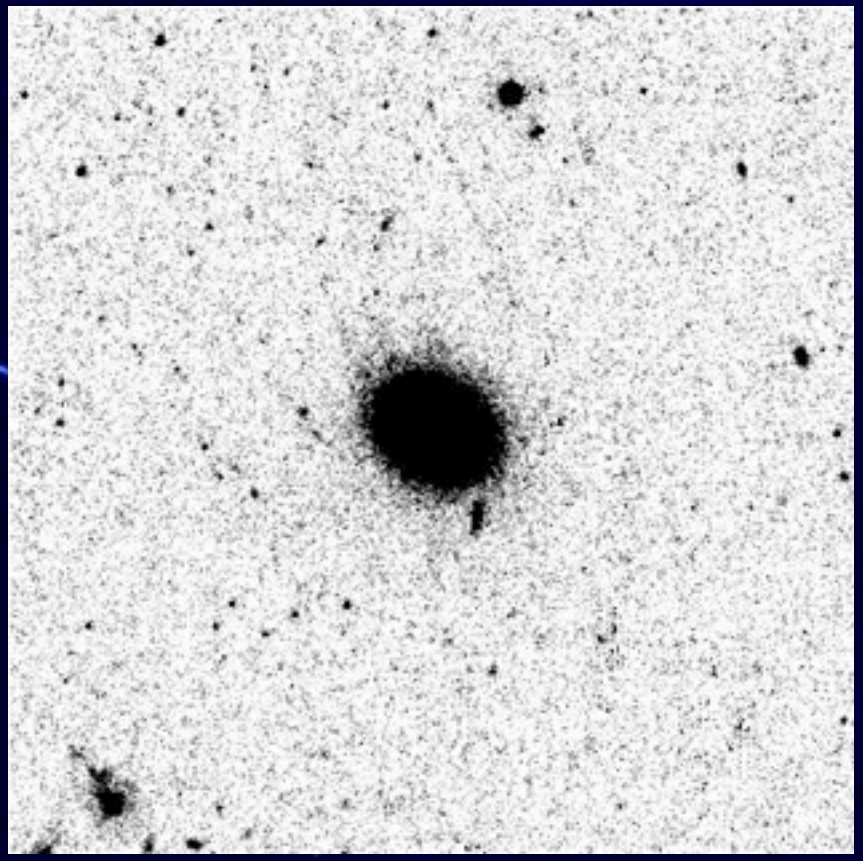
- Deep WFPC2 observations of 14 additional QSOs

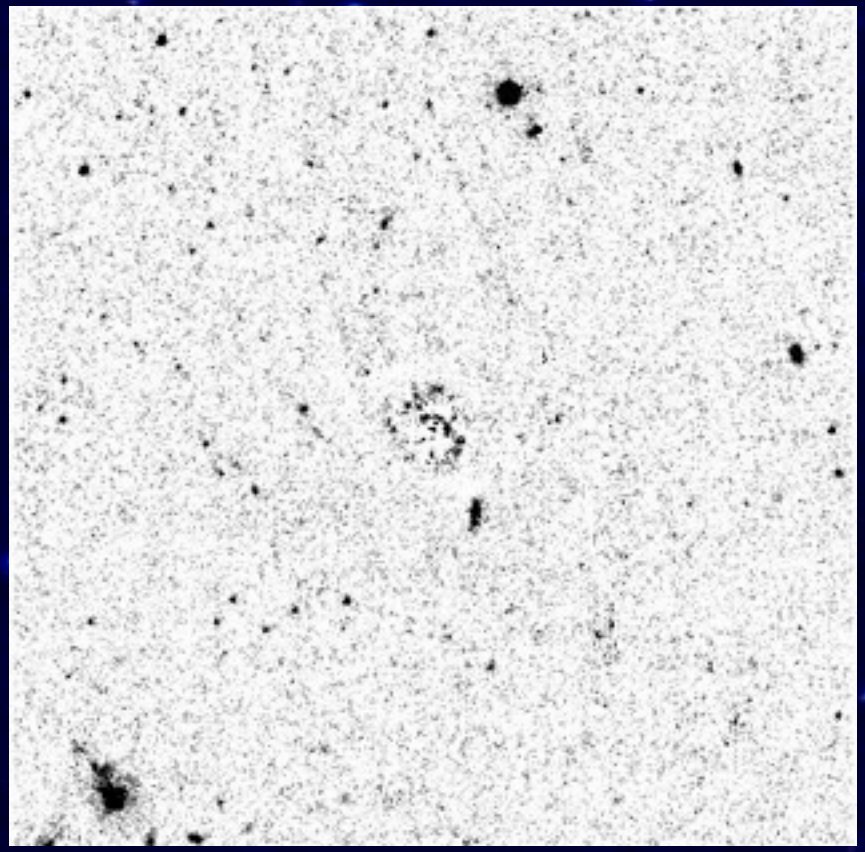


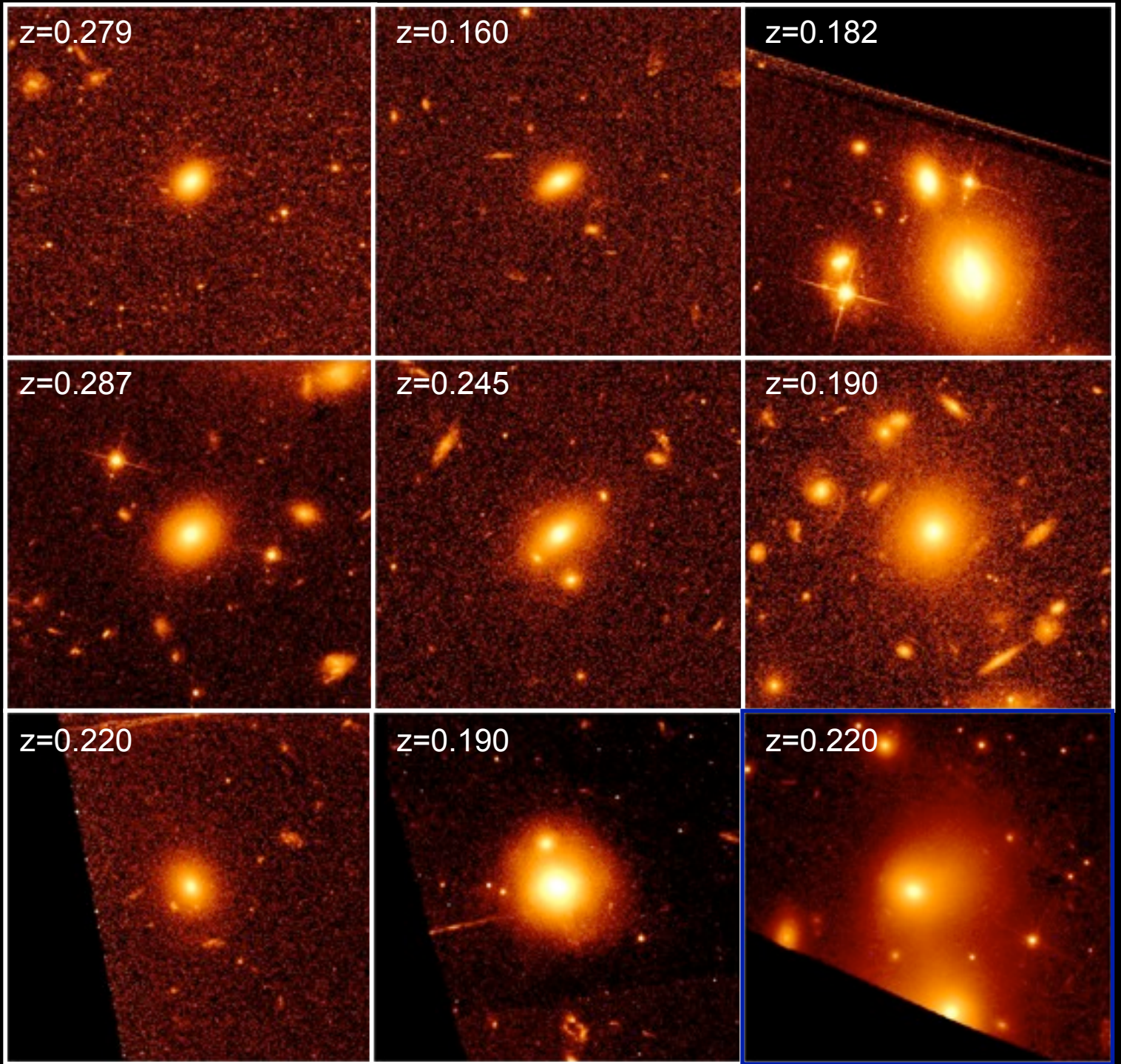
Hancock et al., in prep.

Control Sample

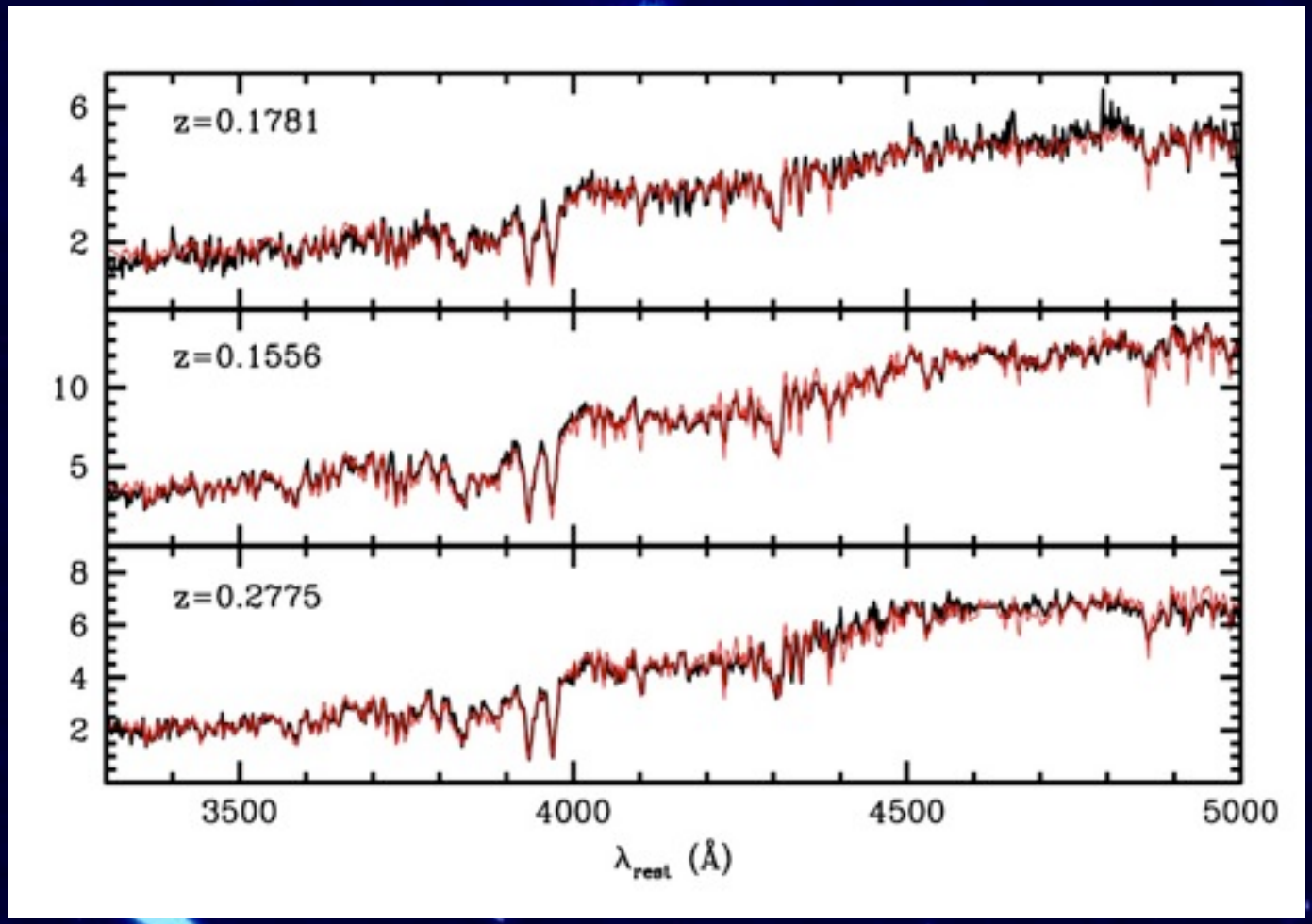
- Would we find similar structure in inactive ellipticals if we looked "hard enough"? (cf. C. Ramos Almeida's talk)
- A control sample of inactive elliptical galaxies at z~0.2: Deep






z=0.279
z=0.160
z=0.182
z=0.287
z=0.245
z=0.190
z=0.220
z=0.190
z=0.220

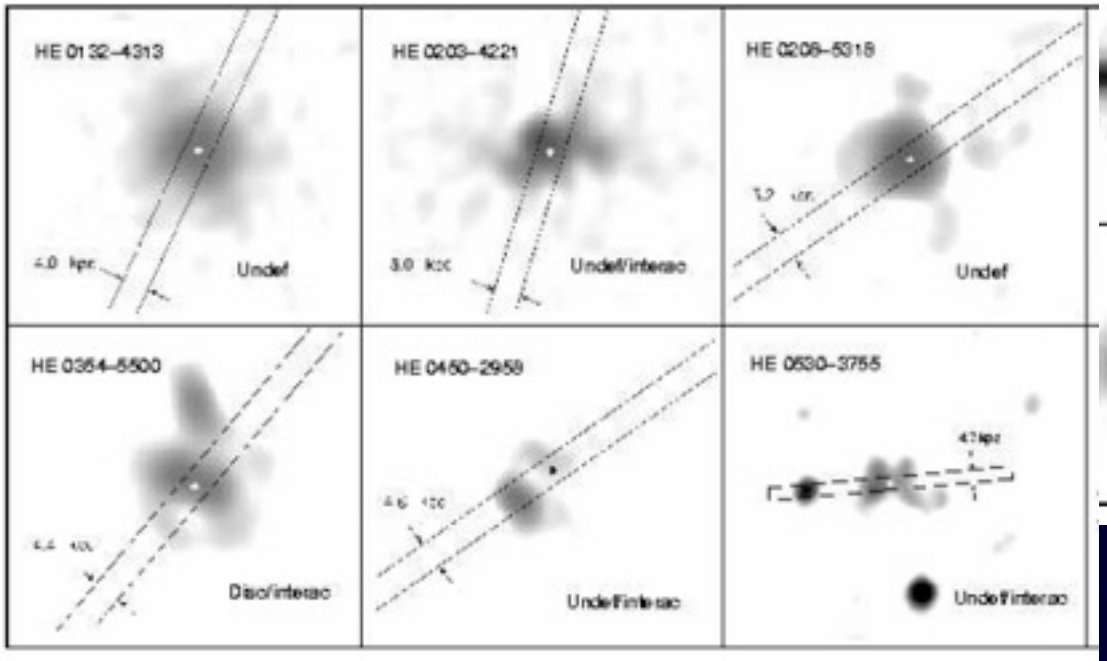
Control Sample of Inactive Elliptical Galaxies: Deep Keck Spectra

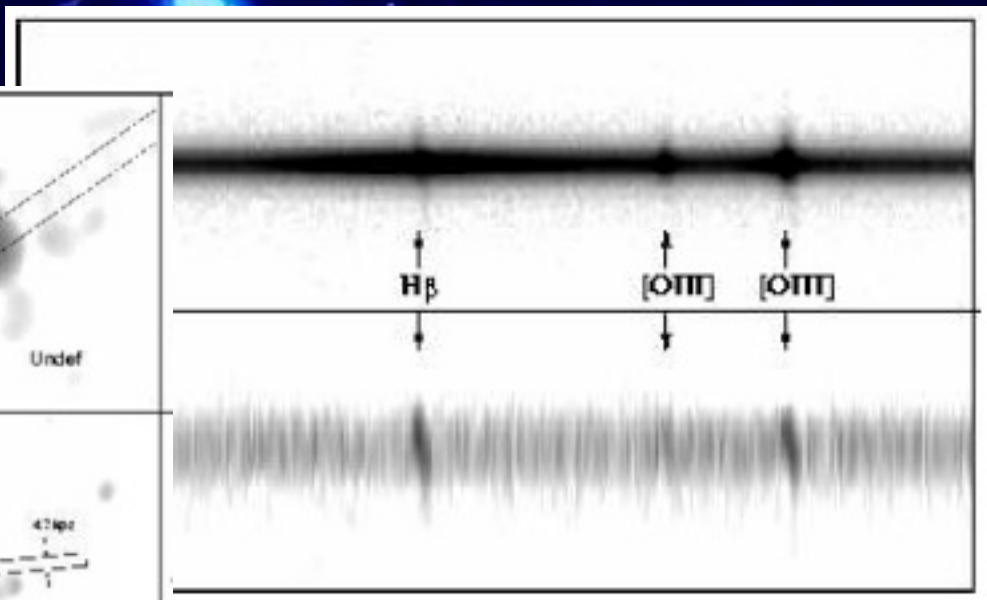


Canalizo et al., in prep

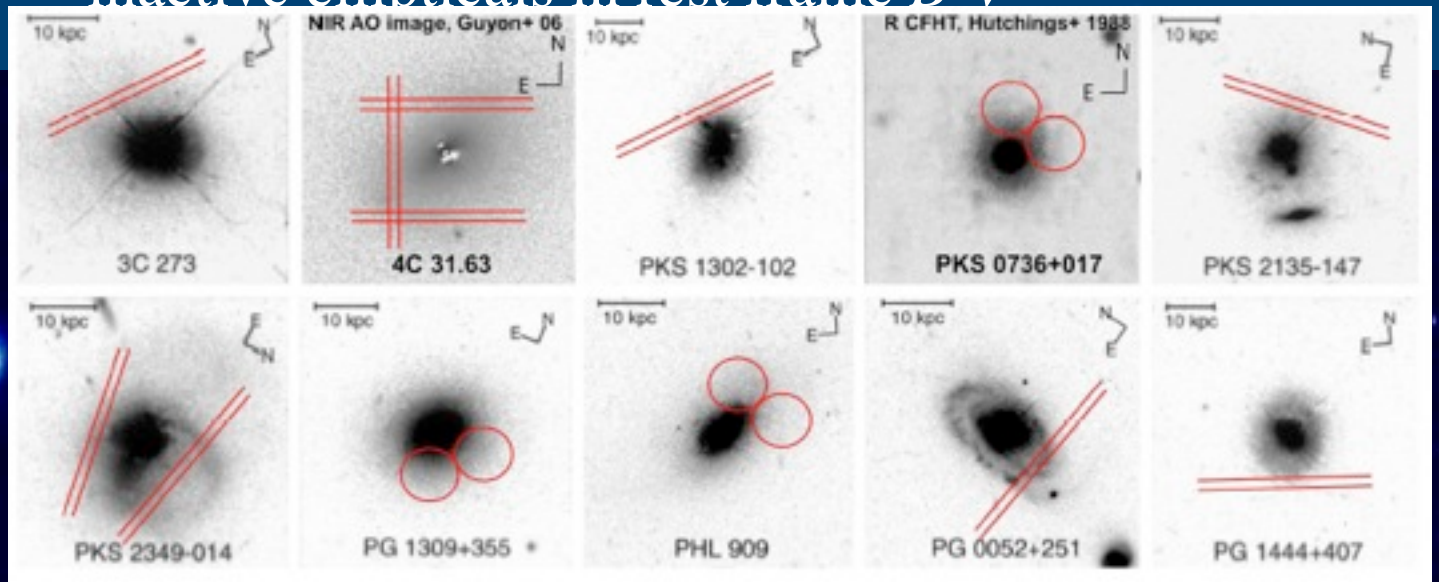
- Well fit by purely old pops.

- Letawe et al. 2007:
  - On-axis VLT/FORS1 spectra of 20 QSO hosts at *z~0.3 (including ellipticals, disks, and disturbed hosts)*
  - MCS deconvolution method (Courbin et al. 2000)
  - Measure Lick indices
  - Find that hosts harbour large amounts of gas





- Wold et al. 2010:
  - Off-nuclear Keck and WIYN spectra of ten QSO hosts at $z < 0.3$
  - Fitting method based on Cid Fernandes et al. 2005 (combining instantaneous models of 15 different ages) and accounting for scattered QSO light and reddening
  - They find an average light-weighted age of 2 Gyr for the sample
  - Elliptical QSO hosts are distinguishable (bluer) from inactive ellipticals in rest frame *B-V*



In summary…

- QSO host galaxies that appear to be spheroidal in shape are the products of relatively recent mergers (~1 Gyr)
- These mergers resulted in massive star formation at that epoch

The bottom line

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QSO activity may occur > 1 Gyr after merger and onset of star formation (although in most cases in our particular samples it occurs < 0.5 Gyr after)

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Possible interpretation:

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Possible interpretation:

- Activity is likely episodic and can be triggered again ("rejuvenated") over long timescales by, e.g., infalling material from tails

Summary

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  Stellar populations in QSO hosts tend to be post-starburst with little or no current star formation. Whether AGN quenched SF is not clear.

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  Stellar populations in QSO hosts tend to be post-starburst with little or no current star formation. Whether AGN quenched SF is not clear.

- What are the relevant time scales?

  QSOs are found in galaxies with starbursts of ages either ~100 Myr or ~1-2 Gyr (could be a selection effect). Either QSOs are triggered twice (or more times) during each merger, or a fraction of QSOs have a long delay.


The End