The Connection Between Mergers, Starbursts and QSO Activity

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

- Are QSOs really triggered by mergers?  
  (according to Yoshi Taniguchi this question was answered in 1988)
- 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 at $z < 0.6$
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, LoBAL QSOs, ‘post-starburst’ QSOs, dust-reddened QSOs

2. Galaxies with intermediate age populations (1-2 x 10^9 yr) and morphologies indicative of older merger events
   Samples: Dunlop+03, Wold+10, Letawe+08, Canalizo+
Color-selected FIR QSOs

Canalizo & Stockton ‘01
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 HST

3C 48, the first QSO imaged
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 population (presumably pop existing prior to merger)
       • A young population (presumably the starburst resulting from merger)
3. Map stellar populations

[Diagram of stellar populations with age maps and spectra]
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 merger-induced post-starburst populations with ages < 300 Myr (and most are < 150 Myr)

• Strongest and youngest starbursts concentrated toward central regions of hosts. This traces the motion of the gas toward the nucleus

• AGN activity likely to have been triggered shortly after central starbursts
• 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: “post-starburst” quasars, dust-reddened QSOs, (a fraction of) LoBALs
Post-starburst QSOs
- Spectra dominated by post-starburst populations
- ACS snapshot survey shows wide variety of morphologies
  (But note that many of these have Seyfert luminosities)

Hiner+12, submitted

Cales+11
Dust-reddened QSOs

- **Urrutia+08**: HST/ACS images of 11/13 red QSOs show strong evidence of recent or ongoing interaction (cf. Michael Gregg’s talk)

- **Canalizo+12, Hiner+ in prep**: imaging + spectroscopy of dust-reddened QSOs from Cutri et al. sample show that many have post-starburst populations and disturbed morphologies
Low Ionization BAL QSOs

- Canalizo & Stockton '02: four LoBALs at z < 0.4 are mergers and ULIRGS
- Lazarova+12: volume-limited sample of 22 LoBALs at 0.5 < z < 0.6: A few ULIRGs, most have (low) SFRs comparable to non-BAL QSOs (already “quenched”) many show post-starburst populations and disturbed morphologies.
Results from Spectroscopic Studies

QSO host galaxies tend to fall in two main groups:

1. Galaxies with young stellar populations (1-4 x 10^8 yr) and morphologies indicative of ongoing mergers
   Samples: FIR Color-selected QSOs, LoBAL QSOs, ‘post-starburst’ QSOs or ‘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+03, Wold+10, Letawe+08, Canalizo+
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 (shallow) imaging
- Off-nuclear spectroscopy with WHT and Kitt Peak 4-m

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+06, 07, 12, in prep; Bennert+08).

- Deep Keck LRIS spectroscopy of QSO spheroidal hosts (with no disk) are 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
<table>
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<th>Object</th>
<th>Starburst Age (Gyr)</th>
<th>Contribution by Mass</th>
<th>Starburst Age (Gyr)</th>
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<td>0054+144</td>
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<td>(0.1)</td>
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Canalizo & Stockton+12
NGC 3923 (z=0.0058)

QSO MC2 1635+119
*Hubble Space Telescope • ACS/WFC*

NASA, ESA, and G. Canalizo (University of California, Riverside)
• Pilot deep ACS study of five QSOs from the Dunlop et al. sample
• Deep WFPC2 observations of 14 additional QSOs
• Recall that these were all classified as ellipticals with no signs of mergers in shallow surveys
Control Sample

- A control sample of inactive elliptical galaxies selected from shallow images, matched in redshift and effective radii.
- Deep (3+ orbits) HST/ACS imaging and deep Keck spectroscopy
- Work in progress: most well fit by deVaucouleurs profiles and old stellar populations
Other Samples

- Letawe+10 and Wold+10: samples of 20 and 10 QSOs, respectively, at z < 0.3, observed with VLT, Keck, and WIYN
- Observing techniques and fitting methods completely different from ours
- Yet, they find dominant stellar populations distinguishable from inactive ellipticals, with ages in the order of a Gyr (i.e., consistent with our results)
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
QSO activity may occur $> 1$ Gyr after onset of star formation (although in most cases in our particular samples it occurs $< 0.5$ Gyr after)

→ The two distinct populations that we observe may correspond to main epochs of accretion during a merger
QSO episodes

Numerical simulations designed to trace the evolution of stellar velocity dispersions during the course of a merger

QSO episodes
Morphologies of the two populations consistent with simulations

QSO episodes

Ages of the two populations *roughly* consistent with simulations.

Hosts with young populations predicted by numerical simulations

Hopkins12
QSO episodes

Hosts with older populations also predicted, but…

Simulation by Paul Torrey, courtesy of Sara Ellison
QSO episodes

Hosts with older populations also predicted, but...

In Lisa Kewley’s words, here’s the big elephant in the room.

Where are the young populations in the more advanced merger hosts?

Simulation by Paul Torrey, courtesy of Sara Ellison
Where are the young populations?

Current stellar population studies of spheroidal host galaxies are unable to retrieve spectra from the central ~8-10 kpc. Young populations could be concentrated in this region.

PSF subtracted WFPC2 images; Canalizo+ in prep.
Summary

• Are quasars really triggered by mergers?
  Yes, in most (if not all) cases

• Is there a merger-starburst-AGN connection?
  Very likely, at least for QSOs. It appears that every time a merger triggers a QSO, it also triggers a starburst

• Is there evidence that star formation is really quenched after AGN activity is triggered?
  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. This is qualitatively consistent with numerical simulations, but the more evolved mergers are either hiding or missing a younger component predicted by simulations.
The End