A SAMPLE OF EXTREME MERGER-DRIVEN STARBURST GALAXIES AS VIEWED BY THE CHANDRA AND HUBBLE SPACE TELESCOPES

Paul Sell
University of Wisconsin-Madison
Advisor: Christy Tremonti

Collaboration: Aleks Diamond-Stanic, Ryan Hickox, John Moustakas, Alison Coil, Greg Rudnick, Aday Robaina
Extreme, Fast Evolution

e.g., Baldry et al. 2004
Extreme, Fast Evolution

- Gas-rich merger
- Coalescence
- Feedback
What Drives Star-Formation Quenching in Massive Galaxies?

- Gas exhaustion?
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  - QSO and ULIRG with 100 $M_\odot$/yr ring of star formation
  - 2-3 kpc galaxy-wide 1100 km/s outflow
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Exploring the Quenching: Post-Starburst Galaxies (PSBGs)

Characteristics:

- Strong Balmer lines from A stars
- Weak nebular emission lines (e.g., [OII]) because O, B stars evolved away
Sample selection from SDSS:

- Relaxed emission line criterion to select very young PSBGs with $\tau_{\text{burst}} < 300$ Myr
- $\sim 130$ candidates at $z=0.4-0.8$ from SDSS spectroscopy
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Sample Trends:

- $M_* \sim 10^{11} M_\odot > M_*, \text{MW}$
- Very Rare ($\sim 0.02$ deg$^{-2}$)
- $v > 1000$ km/s (Mg II)
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Schwartz & Martin (2004)
Schwartz et al. (2006)
Rupke et al. (2005)
Martin (2005)
Pettini et al. (2001)
(Dwarfs, ULIRGs, LBGs)
An Extensive Multi-Wavelength Campaign

Targeted Follow-up

**MMT:**
(probing the stellar population)
- High S/N spectra of the 40 bluest galaxies

**Keck HIRES:**
(probing the detailed outflow kinematics)
- 9 galaxies

**WIYN WHIRC:**
(probing the stellar population)
- 12 galaxies

**Chandra/HST/VLA:**
(probing the AGN, jets, and morphology)
- 12 (Chandra/HST) + 17 (HST) galaxies
- Selected with the strongest [OIII] in the sample
- $\approx 100$ Myr after burst (UV/optical spectral fits)
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**Surveys**

**WISE:**
(probing the obscured AGN/star formation)
- 100 galaxies

**Spitzer:**
(probing the stellar mass)
- 100 galaxies

**GALEX and SDSS:**
(probing the broad spectrum)
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Targeted Follow-up

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HST Images
A Range of (Merger) Morphologies

- $f_{814w}$ (I-band) (rest V-band)
- ~ 6'' stamps
- ~ 6 kpc/''
2-D Image Characterization

![Image of J0905+5759 with histogram and profile plots](image)

- **J0905+5759**: 2-D Image Characterization
- **Histogram of N/bin**
  - **$R_e$ (kpc)**
  - **N/bin**
- **Profile Plots**
  - **Surface Brightness vs. Radius [kpc]**
  - **Surface Brightness vs. Radius [arcsec]**

*Wednesday, August 1, 12*
2-D Image Characterization

- Galfit (Peng et al. 2010)
  - Sersic and PSF models
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  - Size correlated with burst age?
- Highly dissipational mergers producing compact bursts
Tricky PSFs

- PSF choice is really important
- Empirical (stellar) vs. Simulated (tinytim)
Ultra-Compact, Massive Galaxies

These galaxies are remarkably compact.
Chandra X-ray Data

3″ ≈ 16.2 kpc

5″ ≈ 33 kpc
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- In many, weaker [OIII] emission and no Hβ or MgII broadlines
- Conclusion: Most are highly absorbed ($N_H \approx 10^{23} \text{ cm}^{-2}$; Heckman et al. 2005, Vignali et al. 2010) and/or intrinsically very faint
The Most Extreme Starbursts
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- A comparison with WISE IR
  1. Obscured quasar template (Polletta et al. 2007)
  2. IR SFRs (Chary & Elbaz 2001)
     - 400× brighter in infrared than an obscured quasar (Gandhi et al. 2009)
     - Implies SFR > 50 M_{⊙}/yr for 14 galaxies ⇒ sample not entirely post-burst!
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• Good agreement with SFRs from 0.1 – 3 µm SED fits (median Aᵥ = 0.4 mag)

• Lack of X-ray and [O III] emission
  ➞ IR SED does not seem to indicate buried AGN...
The Most Extreme Starbursts

\[ v_{esc} = \sqrt{2GM_*/r} \]
\[ = 2100 \left( \frac{M_*/10^{11}M_\odot}{r/200 \text{ pc}} \right)^{1/2} \text{ km s}^{-1} \]

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*HST-WISE sample (this paper, z~0.6)*

*Gas-rich mergers (z<0.3)*

*Star-forming galaxies (z~1)*

Eddington limit

Meurer+97 limit (90th percentile starburst)

Threshold for winds

Heckman (2002)
The Most Extreme Starbursts

- Small size + large SFR = high SFR surface densities (~3000 M\(_{\odot}\)/yr/kpc\(^2\))
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• All 12/25 galaxies above the Meurer et al. (1997) $\Sigma_{\text{SFR}} \approx 25 \, \text{M}_\odot/\text{yr}/\text{kpc}^2$ limit exhibit high velocity outflows with $v = -1500$ km s$^{-1}$ (median centroid)

• Heckman (2011): for $\dot{p} \approx 10^{35}$ dyne, $r_0 \approx 100$ pc, $N_H \approx 10^{21}$ cm$^{-2}$ $\Rightarrow v_{\infty} \approx 1800$ km s$^{-1}$
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- Rapid growth of the central stellar cores of ellipticals?
Summary

- Our galaxies: \( z = 0.4-0.8, M_\star \sim 10^{11} M_\odot, r_e \approx 100-1000 \) pc,

- Some galaxies: \( \sim 100 \, M_\odot/\text{yr}, \text{up to } 3000 \, M_\odot/\text{yr/kpc}^2, \)
  \( v \approx 1000-2000 \text{ km/s} \)

- Not all are post-starburst!

- Maybe our sample is simply selected to be more extreme than previous work? Need more information on burst strength/geometry.
Conclusions

• Currently, we cannot conclusively rule out AGN feedback either from a buried AGN or one that was active in the recent past.

But...

- AGN do not contribute greatly to X-ray or IR luminosity
- empirically SFR driven winds tend to have velocities equal to the escape velocity. For a compact starburst, large outflow velocities are expected.

⇒ Occam's razor: AGN feedback could be operating, but it does not seem to be required to explain the high velocity gas outflows we observe.

• So far, this work is published in:

...with more work currently being completed, so stay tuned!