THE PHYSICAL CONNECTION BETWEEN MASSIVE GALAXIES AND LYMAN ALPHA BLOBS

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with Jim Geach, Lluis Mas, Mark Dijkstra, Matt Turk, Robert Thompson, Romeel Dave
CAVEAT:

I KNOW ABSOLUTELY NOTHING ABOUT LYMAN-ALPHA BLOBS.
PART I: DUSTY GALAXIES

Barger et al. 1998
Hughes et al. 1998
PART I: DUSTY GALAXIES

<table>
<thead>
<tr>
<th></th>
<th>submillimeter galaxies (SMGs)</th>
<th>the milky way</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{bol}$</td>
<td>$10^{13-14} , L_\odot$</td>
<td>$2 \times 10^{10} , L_\odot$</td>
</tr>
<tr>
<td>$M_*$</td>
<td>$10^{11-12} , M_\odot$</td>
<td>$3 \times 10^{10} , M_\odot$</td>
</tr>
<tr>
<td>SFR</td>
<td>$&gt;1000 , M_\odot/yr$</td>
<td>$2-3 , M_\odot/yr$</td>
</tr>
<tr>
<td>$M_{halo} ,(z=0)$</td>
<td>few $\times 10^{14} , M_\odot$</td>
<td>$10^{12} , M_\odot$</td>
</tr>
</tbody>
</table>
PART I: DUSTY GALAXIES
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Semi Analytic Models
Baugh et al. 2004
Lacey et al. 2014
Cowley et al. 2015,2016

Idealized
Chakrabarti et al. 2006
Narayanan et al. 2008,2010
Hayward et al. 2010,2011,2014

Cosmological Simulations
Dave et al. 2010
Shimizu et al. 2012

Zooms

Key Predictions
- Flat Stellar IMF*
- \(<\text{duty cycle}\>) = 0.1 \text{ Gyr}
- 3-6 physically unassociated galaxies
- \(<M^*>\sim10

- \sim50\% \text{ of SMGs are mergers}
- \sim50\% \text{ of SMGs are blends}
- Half of blends are unassociated
- Duty cycle (SB) \sim 0.1 \text{ Gyr}
- \(<M^*>\sim10

- \sim2\% \text{ of SMGs are mergers}
- SFR
- Duty cycle \sim 1 \text{ Gyr}
- \(<M^*>\sim5\times10

Numbers compiled in Casey, Narayanan & Cooray 2014
PART I: DUSTY GALAXIES

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Dave et al. 2010
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Key Predictions

- Flat Stellar IMF*
- \(<\text{duty cycle}> = 0.1 \text{ Gyr}\)
- ~50% of SMGs are mergers
- ~50% of SMGs are blends
- Half of blends are unassociated
- Duty cycle (SB) \(\sim 0.1 \text{ Gyr}\)
- \(<M^*>\sim 10^{10} \text{ M}_\odot\)
- ~2% of SMGs are mergers
- SFR
- Duty cycle \(\sim 1 \text{ Gyr}\)
- \(<M^*>\sim 5\times 10^9\)

Numbers compiled in
Casey, Narayanan & Cooray 2014
PART I: DUSTY GALAXIES

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Key Predictions
- Flat Stellar IMF*
- \(<\text{duty cycle}> = 0.1 \ \text{Gyr}\)
- 3-6 physically unassociated galaxies
- \(<M^*> \approx 10^{10} \ \text{M}_\odot\)

Cosmological Simulations
- \(~2\% \text{ of SMGs are mergers}\)
- SFR
- Duty cycle \(~1 \ \text{Gyr}\)
- \(<M^*> \approx 5 \times 10^{10} \ \text{M}_\odot\)

Zooms
- Dave et al. 2010
- Shimizu et al. 2012

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### Semi Analytic Models
- Baugh et al. 2004
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- Chakrabarti et al. 2006
- Narayanan et al. 2008, 2010
- Hayward et al. 2010, 2011, 2014

### Cosmological Simulations
- Dave et al. 2010
- Shimizu et al. 2012

#### Key Predictions
- Flat Stellar IMF*
- <duty cycle> = 0.1 Gyr
- 3-6 physically unassociated galaxies
- <M*>~10¹⁰ M☉

- ~50% of SMGs are mergers
- ~50% of SMGs are blends
- Half of blends are unassociated
- Duty cycle (SB) ~ 0.1 Gyr
- <M*>~10¹¹ M☉

- ~2% of SMGs are mergers
- SFRₘₐₓ ~ 600 M☉/yr
- Duty cycle ~1 Gyr
- <M*>~5x10¹¹ M☉

*Numbers compiled in Casey, Narayanan & Cooray 2014*
powderday: dust radiative transfer for the masses

Narayanan, Turk, Robitaille, Thompson et al. in prep.

https://bitbucket.org/desika/powderday
https://powderday.readthedocs.org

Narayanan, Turk, Robitaille, Thompson et al. in prep.
PART I: DUSTY GALAXIES
(In Cosmological zoom simulations)

Narayanan, Turk, Feldmann et al. 2015, Nature
PART I: DUSTY GALAXIES
(In Cosmological zoom simulations)

- The central contributes ~70% of the total observed submm flux
- Typically 3-4 associated counterparts

Narayanan, Turk, Feldmann et al. 2015, Nature
PART 2: LAB1: OBSERVATIONS

Lya  ALMA sub-mm  STIS UV

Geach, DN, Matsuda, Hayes, Mas, Dijkstra et al. 2016
PART 2: LAB1: THEORY

STIS UV

ALMA sub-mm

Geach, DN, Matsuda, Hayes, Mas, Dijkstra et al. 2016
PART 2: LAB1: THEORY

- Modeled using TLAC (Gronke et al. 2014) by L. Mas
- Contour: $10^{-18}$ erg s$^{-1}$ cm$^{-2}$ arcsec$^{-2}$ (Matsuda et al. 2004)
- Only galaxies serve as sources
Part 3: Massive Galaxies—>Labs

Central starburst galaxies, detected with ALMA.

Surrounding satellites — Low mass companions. Most of these are too faint to detect directly.

Central galaxies are emitting Ly-α photons from star formation.

The photons scatter off clouds of cold gas in the circumgalactic medium. Most of the cold gas is around satellites.

Scattered Ly-α escapes to our line of sight, giving rise to extended blob.

Image by ESO Press Office

Geach, DN, Matsuda, Hayes, Mas, Dijkstra et al. 2016
PART 3: MASSIVE GALAXIES—>LABS

Animation by Lluis Mas

Geach, DN, Matsuda, Hayes, Mas, Dijkstra et al. 2016
PART 3: MASSIVE GALAXIES—>LABS

HiPerGator2.0
PART 3: MASSIVE GALAXIES —> LABS
PART 3: MORE MASSIVE GALAXIES MAKE BRIGHTER LABS
PART 3: MASSIVE GALAXIES—>LABS: SCATTERING OR COOLING?

Cooling important at the ~50% level
Central Source/Scattering

Geach et al. 2014, 2016
Cen & Zheng 2013
Hayes et al. 2011
You et al. 2016

Gravitational cooling

Haiman et al. 2000
Fardal et al. 2001
Nilsson et al. 2006
Smith & Jarvis 2007
Goerdt et al. 2010
Rodsahl & Blaizot 2015

Photoionization/Fluorescence

Ohyama et al. 2003
Geach et al. 2011
Prescott et al. 2012, 2015
Cantalupo et al. 2014
PART 3: MASSIVE GALAXIES $\rightarrow$ LABS

PREDICTIONS

Swarms of UV Satellites

High $L_{bol}$ galaxies as Centrals

High Multiplicity Fraction

Dey, Bridge, Colbert

Geach+
TAKE HOME POINTS

- Some LAB luminosities and morphologies can be explained from central sources and scattering alone.
- (Subtle point) — requires extended star formation in centrals which also solves issues in SMG formation.
- Direct predictions:
  - UV-bright Satellites
  - ULIRG/High SFR centrals

OPEN QUESTIONS

- What is the continuum between LAHs and LABs?
- Are AGN necessary to power the most luminous LABs?
- What fraction of LABs are powered by scattered light from centrals/satellites?