The ZFOURGE survey:
a diverse massive galaxy population
at redshifts $z=3-4$

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[Images of graphs and data]
Massive galaxy population at redshifts z > 3

• Search for progenitors of massive galaxies
• What will they look like?
• Can extrapolate backwards in time:
  – Eventually more star-formation
  – Eventually no more dust (AGB stars ~1 Gyr old)
  – Eventually low stellar masses
Massive galaxy population at redshifts $z > 3$

- What do they look like?

- Observations:
  - Red galaxies
    Marchesini et al., 2010; Ilbert et al., 2013, Muzzin et al., 2013; Stefanon et al., 2013, 2014
  - And blue galaxies
    Stark et al., 2009, Gonzalez et al., 2011, Lee et al., 2011, 2012, Oesch et al., 2013
  - And dusty submillimeter galaxies
    e.g. Sune Toft’s talk
Massive galaxy population at redshifts $z > 3$

Need a mass-limited census to assess the massive galaxy population at $z=3$-$4$. Must select at long wavelengths to access restframe optical.

Need photometric redshifts from a broad range of spectral features for photometric redshifts (e.g. the Lyman, Balmer, 4000A breaks, 1.6 $\mu$m “bump”). This ensures the identification is not limited to any particular spectral feature.
ZFOURGE filters

Old galaxy model

ZFOURGE
Fourstar Galaxy Evolution Survey

Depths
Hs, Hl & Ks ~ 25
J123 ~ 26

http://zfourge.tamu.edu/

Animation credit: Adam Tomczak
Mass-limited sample at z=3-4

Spitler et al. 2014
Flux [ergs s\(^{-1}\) cm\(^{-2}\) A\(^{-1}\)]

**Diverse population**
- 45% are quiescent
- 40% are dusty
- 15% have Lyman breaks

Spitler et al. 2014
Diverse population
45% are quiescent
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Take-away message #1:
Massive galaxies at z=3-4 show a diverse range of SEDs!
Dusty ZFOURGE $z=3-4$ galaxies: a new population?

They are faint...
They are red...
Dusty ZFOURGE $z=3$-$4$ galaxies: a newly discovered population?

- Compare to public $K_s$-band selected
  - E.g. UltraVista DR1
    $K_s < 23.4$
    Muzzin et al., 2013
    3/8 ZFOURGE galaxies with use=1

- Not in public submillimeter surveys
  - ZFOURGE dusty galaxies x5 more common and x4 lower sSFRs
Take-away message #2:

Newly discovered dusty star-forming galaxy population at z=3-4!
Massive galaxy population at $z=3$-$4$

• How do they form their stars?

• Possibilities:
  – Lyman break galaxies with SFRs $< 100 \, M_{\odot} / \text{year}$
  – Submm galaxies with SFRs $\sim 1000 \, M_{\odot} / \text{year}$
    
    see also Straatman et al., 2014

A new one:

“main-sequence” star-forming dusty galaxies at $z=3$-$4$
SFRs from UV+MIPS, confirmed with PACS

Submillimeter galaxy (SMG) sample from Toft et al., 2014

Spitler et al. 2014
Tip of the iceberg
Rare submillimeter galaxies (SMGs) with star-formation rates $\text{SFRs} > 1000 \, \text{M}_{\odot} \, \text{yr}^{-1}$

ZFOURGE results: the bulk below
Substantial population of massive dusty galaxies with SFRs $\sim 200 \, \text{M}_{\odot} \, \text{yr}^{-1}$
Typical mode of massive galaxy star-formation

• x5 more common than submillimeter galaxies
• Higher SFRs compared to Lyman breaks: massive end of star-forming main-sequence
• Is this how z=3-4 massive galaxies form stars?
• Simple calculation:
  
  \[ 200 \, \text{M}_{\odot}/\text{year} \times 0.5 \, \text{billion years} = 10^{11} \, \text{M}_{\odot} \]

!
Redshift $z > 4$ predictions

- $z=4$ quiescent galaxies, typical age 1 Gyr (Staatman et al., 2014)

So finished forming stars at $z \sim 5.5$ (12.5 Gyrs)

500 Myr of star-formation @ 200 $M_{\text{sun}}$ /year brings us back to start of SF at $z \sim 10$ (13 Gyrs)
Take-away message #3: Massive dusty galaxy could be typical star-formation mode for massive galaxies
• Mass-limited census at z=3-4
• Diverse population
  – Most are red, not like Lyman-break galaxies
  – 45% quiescent, 35% dusty, 15% blue star-forming
• Newly detected dusty galaxy population
• Represent a more typical mode of massive galaxy star formation
  – SFRs of 200 $M_{\text{sun}}$/year
Straatman et al., almost submitted