## Compact Starbursts: Extreme Star Formation and Feedback at High Density <u>Aleks Diamond-Stanic</u> Grainger Fellow, University of Wisconsin





What is the efficiency of star formation at high density?

How does feedback from compact starbursts impact the surrounding gas?

## What do I mean by starbursts?

discussion led by D. Elbaz:

- (I) high SFR
- (2) high SFR / <SFR>
- (3) Mass / SFR << Hubble time
- (4) higher sSFR than main sequence
- (5) high SFE = SFR / Mgas
  - $\rightarrow$  all of the above!



note: these blue nuggets are actually blue

compact starbursts in our sample are relevant for questions:

 How do you form blue nuggets? (A. Dekel: wet compaction)
How do you quench star formation? (P. Lang: form a bulge)
What are consequences of dense, turbulent collapse? (talks by F. Renaud, P. Hopkins, many others)

## Why are galaxies so bad at converting gas into stars ?



simulations, semi-analytic, semi-empirical models suggest stellar feedback explains inefficient star formation for halo masses up to  $\approx 10^{12} M_{\odot}$ 

# What causes the exponential cutoff in star formation efficiency for $M_{halo} > 10^{12} M_{\odot}$ ?



simulations and semi-analytic models have implementations for:

(1) halo quenching / "radio mode"(e.g., Vogelsberger+ 2014)

(2) superwinds / "quasar mode"(e.g., Schaye+ 2014)

note: cosmological simulations that reproduce stellar mass function at  $M_{halo}>10^{12} M_{\odot}$  (e.g., Illustris, EAGLE) require strong AGN Feedback

C. Hayward: "a cosmological simulation is a SAM with a resolution problem"

# What do observations tells us about how galaxies become quiescent ?



suggests that central stellar density is best predictor of quiescence (better than stellar or halo mass)



Implies that quiescent galaxies formed stars at high surface densities before quenching (see also talk by P. Lang)

#### What is the efficiency of star formation at high density?



#### How does feedback from compact starbursts impact the surrounding gas?



Can superwind feedback from compact starbursts explain how massive galaxies are quenched (blue nugget to red nugget)?











Coil



Tremonti Moustakas

Geach

Hickox

Sell

Rudnick

#### Can Compact Starbursts Mimic Quasar-Mode Feedback ?



sample of galaxies at z~0.6 ("mistakes" in SDSS quasar target selection) follow-up spectroscopy →1000 km s<sup>-1</sup> outflows HST imaging → compact sizes Tremonti, Moustaks, ADS

outflow velocity  $\propto r^{-1/2}$  for stellar feedback

see also Tremonti, Moustaks, ADS 2007 Geach, Hickox, ADS+2013 Sell, Tremonti, Hickox, ADS+2014 Geach, Hickox, ADS+2014 ADS, Coil+2015

How do SFR surface densities compare to main sequence, gas-rich mergers ?



data from from Wuyts+2011, Veilleux et al. 2006, Overzier et al. 2009, Arp 220

#### Eddington-Limited Star Formation in Compact Massive Galaxies



most extreme physical conditions -> most extreme velocities

#### What about molecular gas, star formation efficiency ?



point from yesterday: expect compact galaxies to be offset in SFR / Mgas even if they fall on the Kennicutt-Schmidt relation

galaxies with high  $\sum$ SFR have high SFE = SFR / Mgas

our biggest uncertainty: L\_IR (no far-IR Herschel data)

> similar plot shown by M. Dessauges-Zavadsky

SFR / Mgas implies nearly 100% SF efficiency, gas suppy exhausted in t  $\approx$  10 Myr

# Can cold molecular gas be ejected into galaxy halos by stellar radiation feedback ?



| What is the molecular gas content of these galaxies ?   | CO indicates high SF efficiency<br>(Geach, Hickox, ADS+ 2013, 2014)   |
|---|---|
| What are the properties of the outflowing ionized gas ? | Keck / HIRES spectroscopy probes<br>velocity structure, acceleration<br>mechanism (ADS+ 2015)                   |
| What about ongoing AGN activity ?                       | X-ray, UV, optical, IR show sub-<br>dominant AGN contribution<br>(Sell, Tremonti, Hickox, ADS+ 2014)            |
| Are these blue nuggets the progenitors of red nuggets?  | complementary to work at z>2 by<br>Barro+2013 (talk by A. Dekel), Patel+2013,<br>Stefanon+2013, Williams+2014   |
| Is the stellar mass as compact as the light ?           | How does the outflow velocity<br>compare to the escape velocity ?<br>(PI: Diamond-Stanic, Cycle 22 HST program) |
| Do these galaxies have analogs in the local universe ?  | Lyman Break Analogs<br>(highlighted in talk by J. Chisholm)   |

Could these compact starbursts (blue nuggets) be the progenitors of compact quiescent galaxies (red nuggets) ?



note: energetic outflows of ionized and molecular, short gas depletion times suggest that these compact starbursts are in the act of quenching

## These galaxies are remarkably compact ! Is the stellar mass as compact as the light ?



How much mass is in the extended component? Cycle 22 HST program (PI: Diamond-Stanic) will measure spatially resolved U-V and V-J colors

#### How can we characterize the low-ionization outflows?

Outflows at low spectral resolution with Keck / LRIS (R ~ 1000)



## The benefit of working at high spectral resolution

Outflows at low spectral resolution with Keck / LRIS (R ~ 1000)

Outflows at high spectral resolution with Keck / HIRES (R ~ 40,000)



#### What can we learn from absorption-line profiles?



the covering factor of this outflow is velocity and ion dependent

Mg II profiles for 6 of the 15 galaxies observed with Keck/HIRES

Can simulations reproduce this velocity structure ?

→ first high-resolution spectroscopy of superwinds outside the local universe

What is the efficiency of star formation at high density? nearly 100% signature of highly turbulent gas that is self-gravitating?

How does feedback from compact starbursts impact the surrounding gas?

can eject  $\approx 10^9 M_{\odot}$  of cold gas out of the galaxy at high velocity

Yes !



Can superwind feedback from compact starbursts explain how massive galaxies are quenched (blue nugget to red nugget) ?

#### Extra Slides

#### What does feedback look like ?

Messier 82 as seen by the Hubble Space Telescope

## What does feedback look like ?

ionized gas seen by WIYN 3.5 meter telescope

## What does feedback look like ?

dust seen by the Spitzer Space Telescope

### Hubble Space Telescope (stars shown in yellow)

Spitzer Space Telescope (dust shown in red)

Chandra X-ray Observatory (hot gas shown in blue) What is the efficiency of star formation at high density? nearly 100% signature of highly turbulent gas that is self-gravitating?

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#### Can Compact Starbursts Mimic Quasar-Mode Feedback ? Yes!



Can this type of superwind feedback explain how massive galaxies are quenched?

Can this contribute to the exponential cutoff in the stellar mass function ?



Maybe



## Can star formation feedback launch >1000 km s<sup>-1</sup> outflows?

