ALMA observations of Hα emitters at z~2

from MAHALO to SWIMS-18

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> *Tadaki et al. 2013, ApJ, 778, 114 Tadaki et al. 2014, ApJ, 780, 77 Tadaki et al. 2015, ApJL, 811, L3 Tadaki et al. in prep*

1. Review of recent z~2 galaxy studies

2. ALMA observations of Hα emitters at z~2

Hubble sequence is already in place at z~2.5

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Quenching mechanisms

Dekel+06, Foerster Schreiber+14, Martig+09

Quenching mechanisms

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well as measurement uncertainties. A positive trend of fortfolder mass, with the trend becoming stronger with the trend becoming stronger when correlating for trend becoming stronger with the bulget with the bulget with th bulge formation can be key for quenching of star formation, whatever the cause

than at z ∼ 1.

 $s_{\rm c}$ and within the effective radius, 160 kpc, $21, 14, 1$ and red circles show SFGs and red circles show SFGs and red circles show $S_{\rm c}$ Σ_{1kpc}: stellar mass within a central 1 kpc region t at dashed red lines show the 2 σ show the σ show the σ

Quiescent galaxies has a dense stellar core paths along that relation. We define this track as a structural "main sequence" (Σ-MS) . At log(M/M!)! 10 we find an increasing number of compact considering to the compact α of α α of α Σ10). We capture this trend by this second-order polynomial to log M τους που πρ blue line). These galaxies may deviate upwards from the Z-MS due to dissipation that cause a rapid core growth **(proto-bulge?)**

the strong decline of ∠ 1 decline of ∠

^e . The lower scat-

and 0.3 dex, for SFGs and quiescent galaxies, as expected

Wet (gas rich) compaction

Figure 6. Compaction and quenching in V07. Shown are images of face-on projected density of the cold component made of gas and stars younger than orming cisks can be smaller than stellar cisks star-forming disks can be smaller than stellar disks

ring develops. The dense stellar core remains intact from the BN to the RN phase, while in this case an extended stellar envelope develops around the RN core.

Zolotov+15

peaked and smooth stellar mass distributions

ilar mass at z = 0, which are quenched systems

Observational studies with Hα emission FIG. 5.— The average radial distribution of Hα emission in galaxies in bins of stellar mass indicated at the top of each panel. The filled circles show the **TANICS MILLI II** toriously irregular appearance, with bright clumps

radial profiles measured directly from the stacked Hα images. The open circles show the profiles corrected for the effect of the PSF. The lines show the best fit exponentials for 0.5*rs* < *r* < 3*rs* to the PSF-corrected profiles. There appears to be some excess flux over a pure exponential at small and large radii. The short

in stellar mass M ~ 4 × 109 to 5 × 10¹¹ M[⊙] and

as stellar mass, this serves as evidence that on average, galaxies are growing larger in size due to star formation. of the Ha can be accounted for by this single exponential disk single exponential disk single exponential disk ara larnar than etal star-forming disks are larger than stellar disks

size-mass relation of the ionized gas disks (*rH*^α − *M*∗) with:

Nelson et al. 2015. Tacchella et al. 2015a \ldots morphologies. And \ldots formation in the early star formation \ldots *Nelson et al. 2015, Tacchella et al. 2015a*

an example, the Ha maps of the Ha maps of the galaxies shown in Fig. 3 are shown in Fig. 3 are shown in Fig. 3

Observational studies with dust emission

The Astrophysical Journal, 799:81 (14pp), 2015 January 20 Simpson et al. *ALMA 870um maps on K-band image for z=2-4 SMGs*

star-forming disks are smaller than stellar disks except for the final four panels, which are classed as potentially lensed SMGs (images are separated by a blank panel). Each panel is 5!!× 5!! and we contour the ALMA maps over the green contours on each interest on the green contours on the green contours on the green co represents where the ALMA 870 µm surface brightness is 50% of the peak value; for an ideal point source this contour should be identical to the size of the ALMA beam FWHM (bottom right of each panel). We note that the red contour appears more extended than the o. We note

1. Identification of a compact starburst in extended stellar disks for normal SFGs at z~2 ↑ this talk

2. Looking at a correlation between angular momentum and compact starburst

3. Statistical studies with a larger sample from MAHALO-ALMA to SWIMS-18-ALMA

1. Review of recent z~2 galaxy studies

2. ALMA observations of Hα emitters at z~2

MApping HAlpha and Lines of Oxgen with Subaru (PI: Kodama)

- ‣ MOIRCS narrow-band survey in SXDF-CANDELS field
- ‣ high-resolution NIR/optical images are available
- ‣ NB209/NB2315 can trace Hα emission at z=2.19/2.53

Tadaki et al. 2013

Sample selection

- \rightarrow ~100 Ha emission-line galaxies were identified
- \blacktriangleright MOIRCS spectroscopy confirms the redshift with success rate of 90%

 \mathcal{A} 0040 NB209-16 *Tadaki et al. 2013*

Star-forming galaxies at z>2 have a clumpy structure

band, *H*¹⁶⁰ band images by WFC3, and the estimated spatial distribution of stellar mass (see the text for the estimation technique). The size of each image is 3!! on \blacktriangleright ~40% show clumpy structure

(A color version of this figure is available in the online journal.) ▶ stellar mass distribution is smooth

a difference between clumpy and non-clumpy galaxies on the

 α icoliapse or an external small galaxy. We find that α of α of 10 $\frac{1}{2}$ 100 $\frac{1}{2}$ and $\frac{1}{2}$ in the main term of main the main term of main term of main term of $\frac{1}{2}$ *Tadaki et al. 2014, see also Wuyts et al. 2012*

an additional component) is a clump formed by gravitational

▶ ~40% show clumpy structure

▶ stellar mass distribution is smooth

Tadaki et al. 2014

A nuclear clump is redder than off-center clumps

nuclear red clump is dusty star-forming?

Tadaki et al. 2014, see also Foerster Shreiber et al. 2011, Guo et al. 2012 gray symbols.

A center clump has high Hα/UV ratio

right, three-color V606/I814/H160, *V*606-band images, and *H*160-band images ▶ ALMA enables us to identify such a dusty star-forming component

sizes are matched to ∼0.

star-forming regions are located within the galaxies, we fit the

Tadaki et al. 2014, Tadaki et al. 2015, ApJL, 811, 3L $taumotan. 2011, 1412010$ of all $2010, 14002, 011, 02$

sample

- 11 Hα emitters at z=2.5
- 1 Hα emitter at z=2.2

observation

- dust continuum (265GHz, 1.131mm)
- 0.53″x0.41″ resolution (natural weight)
- rms~0.055 mJy/beam
- $SFR_{5\sigma}$ ~30 M_{sol}/yr (Dale&Helou 02, T_d=30K)

Tadaki et al. 2015, ApJL, 811, 3L

Tadaki et al. 2015, ApJL, 811, 3L

ALMA observation 1 $\frac{1}{2}$

50

Uncertainties for size measurements at 870um

For objects with S/N>8, uncertainties for flux/size measurement are 15-20%.

A compact starburst in extended stellar disks?

GALFIT run on HAWKI/K image (HUGS: Fontana et al. 2014)

- 1. $7'' \times 7''$ cutout images are used for fitting
- 2. sources within 1.5″ radius are fitted simultaneously
- 3. other neighboring sources are masked **Central Random Central Persons** Central Random Central Seeing Magnitude Contral Central Seeing Magnitude Contral Seeing Magnitude Contral Seeing Magnitude Contral seeing Magnitude C
- 4. input parameters are taken from GALFIT outputs in WFC3/H-band (van der Wel et al. 2014) *K*-band
- center position: almost fixed $(\pm 1.0$ pixel $\sim 0.01''$)
- re,n, mag: free (0.05"<re<3.5", 0.2<n<8.0) $\overline{\text{fixed}}$
- q,pa: fixed
- sky: fixed (median sky value is calculated in 7″× 7″ image where all objects are masked) G oods-waardigen sky value is calculated in $7''\times7''$ image where all objects are masked) ixed (median sky value is calculated in $7^\circ \times 7^\circ$ image where all objects are masked)

in case where the H-band counterpart does not exist, the SExtractor outputs are used as initial guess.

H-band

Simulations with GALFIT

compare input with output (GALFIT results with mimic images)

Uncertainties for size measurements

we can measure sizes with <15% accuracy for K<24 galaxies

Mass-size relation for normal star-forming galaxies

Wet compaction?

From MAHALO to SWIMS-18

For massive normal SFGs with logM^{*}>10.9, we can detect dust emission with ALMA 6-8 minutes integration

MAHALO: \sim 20 massive Hα emitters in \sim 90 arcmin² \times 2 NB filters

SWIMS-18: \sim 720 Ha emitters in 1 deg² \times 2 NB filters

NB data is not necessarily deep (5σ~23 mag)

deep K-band images are needed to measure rest-frame optical sizes

seeing < 0.4″ -> K-band observations? seeing =0.4-0.6″ -> SWIMS-18?

or WFIRST?