The clumpy nature of star formation in NIHAO

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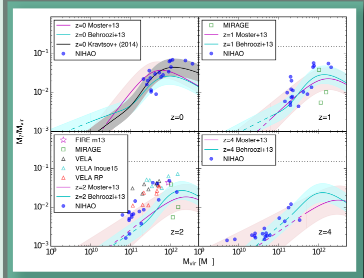
Simulated sample galaxies: NIHAO

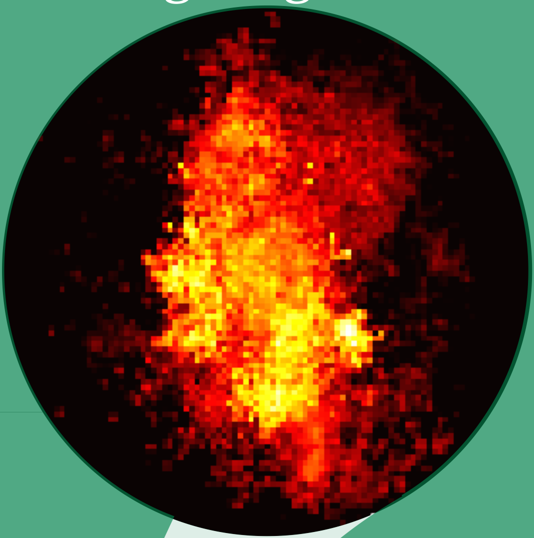


We select all the galaxies with stellar masses larger than $M_{\star}>10^{9}M_{\odot}$ at redshift z~1.5 from the NIHAO sample for our study. This leaves us with a sample of 19 galaxies which reproduces several key properties of realistic galaxies (see: [8]).

Stellar mass-halo mass relation

The NIHAO galaxies show very good agreement of the stellar mass vs halo mass relation since redshift z=4 with recent abundance matching relations. At redshift 2 and 1 some of the higher mass galaxies show a slightly to high stellar mass but still consistent with e.g. the FIRE simulation ([4]) or the VELA galaxies ([1,5]). Comparison of the different simulations shown reveals that inclusion of some sort of feedback prior to supernova (VELARP: radiation pressure, stellar winds; FIRE: radiation pressure, stellar winds, and photoionization; NIHAO: strong photoionization included as thermal energy) is needed to reproduce the stellar mass-halo mass relation.

What are the observed giant clumps in high-z galaxies?



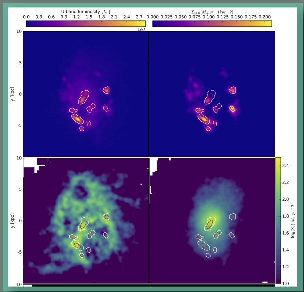
Do they spiral inwards?

Do they form the bulge?

Clumps in light but not in mass

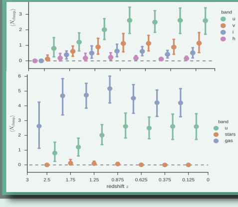
Clump selection

We select clumps in the NIHAO galaxies in an observationally motivated manner. For every galaxy and every snapshot in the redshift range z=0-3 we create UV-light images. The UV luminosity maps correspond well with the star formation rate surface density maps of young stars.



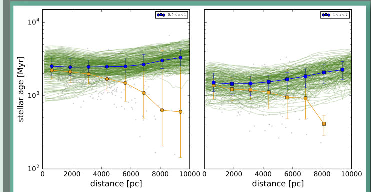
Running our clump finder on maps of increasingly longer wavelength like the v-, i- and h-band maps, the mean number of clumps per snapshot and galaxy decreases. This shows that clumps found in NIHAO are only present in young stars, preferentially emitting in the UV while for longer wavelength bands the contribution of stars from the underlying stellar disk increases. We do not find clumps in the stellar surface density maps which matches observations ([9]).

Wavelength dependence

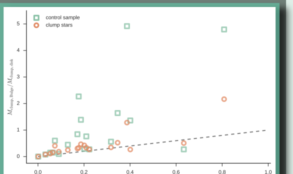


Radial age gradients

of clumps in the disk (outskirts: bluer color, center: redder color) were related to age gradients ([2,6]). Thus it is interpreted that clumps are spiralling inwards to finally merge and contribute to bulge formation. When investigating the mass weighted mean stellar ages of the clumps (yellow dots) as a function of distance from the galaxy center and comparing this to the age profiles of the underlying stellar disk (blue dots) we recover the observed trends: clumps in the outskirts are younger and clumps in the center are older.

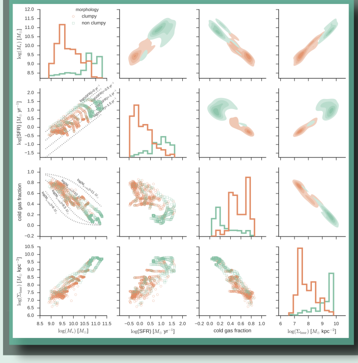


Clump mass in bulge



The mass fraction of clump stars ending up in the bulge and in the disk at redshift zero is directly proportional to the total bulge to disk ratio and compares well with the mass fraction of a control sample of stars.

Stellar clumps match observed clump properties:



Properties of clumpy and non clumpy galaxies

The property of a galaxy being clumpy (red dots) or not (green squares) correlates with basic galactic characteristics like SFR, stellar mass, cold gas fraction and compactness (defined as the mean surface density within the half-mass radius). Similar correlations are observed by [7] for galaxies from the SXDF-UDS -CANDELS field and by [6] for HST photo-z and Lyman break galaxies.

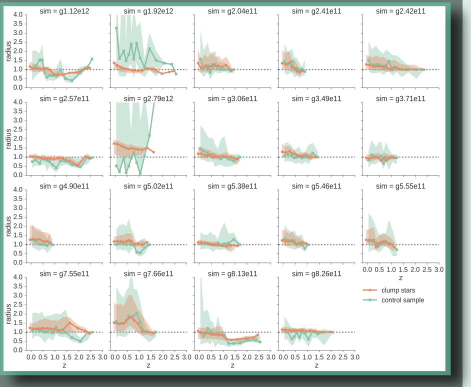
Answers:

- no clumps in stellar mass maps
- but clumps in young stars
- observed properties recovered
- clumps do not spiral inwards
- clumps do not contribute much mass to the bulge

Clumps do not spiral inwards:

Evolution of the mean radius of clump stars

For every clump we trace all clump stars through time and evaluate their mean radius. If the clump would spiral inwards the mean radius would decrease. In the plot to the right we show at every redshift the median over all clumps (red dots). For comparison we show the same for a control sample of stars of same size and initial radius but not belonging to a clump (green squares). We do not see any net inward migration of clump stars compared to average stars.



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