BAPTISTE FAURE - CEA SACLAY

HIERARCHICAL FRAGMENTATION IN HIGH REDSHIFT GALAXIES REVEALED BY HYDRODYNAMICAL SIMULATIONS AND STRONG GRAVITATIONAL LENSING

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GIANT CLUMPS

- Disk like kinematics (Genzel et al, 2008)

- Giant clumps properties:
  - Mass ~ $10^8$ and $10^9$ M$_\odot$ (Elmegreen & Elmegreen, 2005)
  - SFR ~ 20%-50% of the whole galaxy
GIANT CLUMPS

(a) Clumpy galaxies at high redshift
UDF1801 (z=1.6)
UDF4006 (z=2.3)
UDF6462 (z=1.6)
UDF6911 (z=2.1)

(b) Modern spiral galaxies
M33
M33 (z=1.2)
M81
M81 (z=2)

©Bournaud, 2009
CLUMP EVOLUTION

Strong feedback effect:
Clumps are short-lived
~20 Myr

(Oklopčić et al 2016, Hopkins et al 2015)

Weaker feedback effect:
Clumps are long-lived
~ 500 Myr
=> Bulge growth

(Bournaud et al 2014, Ceverino et al 2012, Agertz et al 2009)

New debate:
Do they exist at all?
STRONG GRAVITATIONAL LENSING

Cava et al, 2018

Dessauges-Zavadsky et al, 2015
SUB-PARSEC SIMULATIONS

- Simulations made with RAMSES AMR Hydro code
- Stellar formation and feedback

|                | Simulation 1        | Simulation 2        | Simulation 3        |
|----------------|---------------------|---------------------|---------------------|
| **Gas mass**   | $20 \times 10^9$ MSun | $35 \times 10^9$ MSun | $64 \times 10^9$ MSun |
| **Gas fraction**| ~50%                | ~50%                | ~50%                |
| **Typical size**| 5 kpc               | 13 kpc              | 12 kpc              |
| **Feedback**   | SN+HII+Radiative    | SN+HII+Radiative    | SN                  |
| **Max res.**   | 1.5 pc/px           | 0.4 pc/px           | 0.2 pc/px           |

+1 from Behrendt et al, 2016 with different IC and FB
SIMULATIONS: FULL RESOLUTION

Full resolution

Full resolution
Mock observation at HST resolution vs Full resolution simulation.
Mock observation at HST resolution vs full resolution simulation.

[Graph showing mock observation and full resolution simulation with arrows indicating differences.]
MASS DISTRIBUTION

**Gas mass distribution of clumps**

- **Density function**

  - **Gas mass** \([\log(M/M_\odot)]\)

- **Stellar mass distribution of clumps**

  - **Density function**

  - **Stellar mass** \([\log(M/M_\odot)]\)

**Total mass distribution of clumps**

- **Density function**

  - **Total mass** \([\log(M/M_\odot)]\)
VIRIAL PARAMETER

\[ \alpha = \frac{5 \sigma_v R_{1/2}}{GM} \]
TAKE HOME MESSAGE

- Giant clumps not detected in strongly lensed clumpy galaxies
- Presence of sub-clumps separated by lensing
- Giant clumps have a physical existence (i.e., they are gravitationally bound)
- Future work on physical properties of giant clumps and sub-clumps