Updates from CORTES

Cosmological Radiative Transfer in Early Structures

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in collaboration with:

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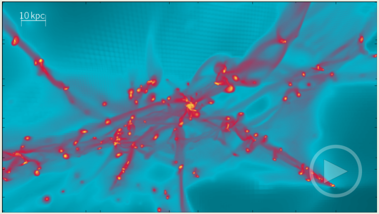

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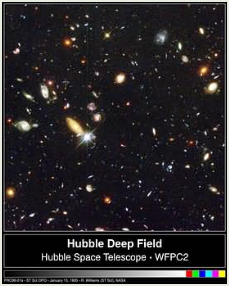
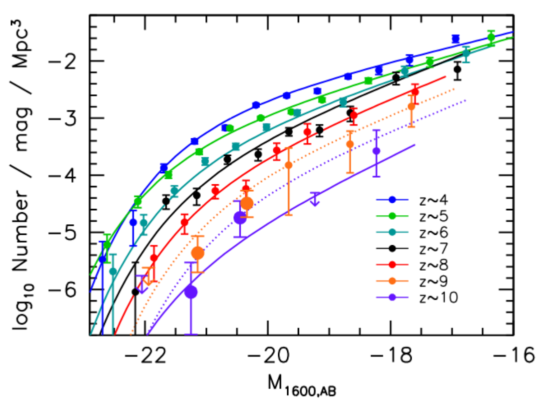
SCUOLA NORMALE SUPERIORE

Search and characterization of high-z galaxies

Optical/NIR surveys



Observed UV luminosity functions e.g. Bouwens+16



Additional probes are needed to characterize high-z galaxies

(metallicity, dust, feedback, outflow, ...)

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FIR line as a tool to characterize high-z galaxies

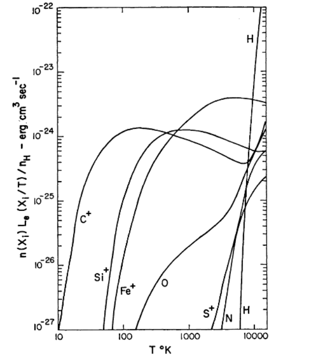
Why should we use the [C II] $\left({}^2P_{3/2} \rightarrow {}^2P_{1/2}\right)$ line at 157.74 μm?

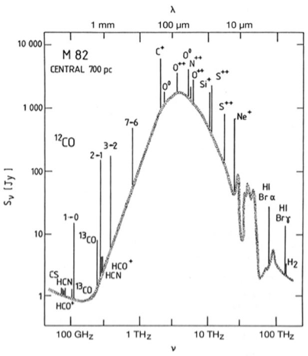
Major coolant of the ISM

Dalgarno&McCray 1972

Among the strongest FIR line

$(L_{\rm CII} \sim 0.1\% - 1\% L_{\rm FIR})$ Stacey 1993



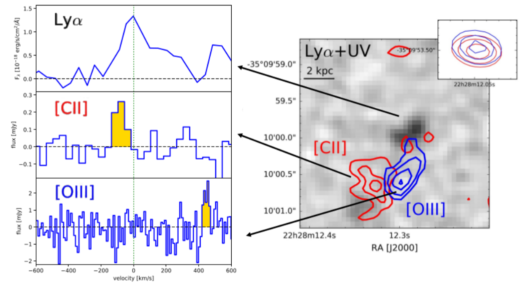


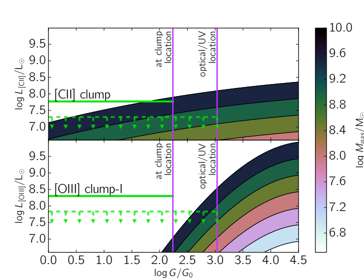
Observing the structure of high-z galaxy

The example of BDF3299: spatial offsets and velocity shifts

Maiolino+15,Carniani+17

see e.g. Capak+15, for offsets/shifts in other galaxies





Indication of in-situ star formation/merging event(s)
and/or inomhogeneous radiation field and/or photoevaporation
and/or inomhogeneous dust/metal distribution?

e.g. Carniani+17, Gallerani+18

e.g. Vallini+17, Decataldo+17

e.g. Behrens+18

To attack the problem we have to model the internal structure of high-z galaxies.

Introducing Dahlia: a prototypical LBG galaxy at z ~ 6

Dahlia characteristics (at z=6)		
dark matter	$M_{\rm dm} \sim 10^{11}\,{\rm M}_\odot$	
size	$r_{\rm vir} \simeq 15\,{\rm kpc}$	$r_{\rm eff} \simeq 0.5\,{\rm kpc}$
stars	$SFR \sim 100\,{\rm M}_\odot/{\rm yr}$	$M_\star \sim 10^{10}\,{\rm M}_\odot$
gas	$M_H \sim 10^{10}\,{\rm M}_\odot$	$M_{\rm H2} \sim 10^{8}\,{\rm M}_\odot$
metals	$Z \simeq 0.5\,{\rm Z}_\odot$	$M_{\mathcal{D}} \sim 10^{7}\,{\rm M}_\odot$

Resolution	
gas mass	$m_g \simeq 10^4\,{\rm M}_\odot$
AMR	$\sim 80 - 0.1\,{\rm ckpc/h}$
at $z = 6$	$\Delta x \simeq 30\,{\rm pc}$

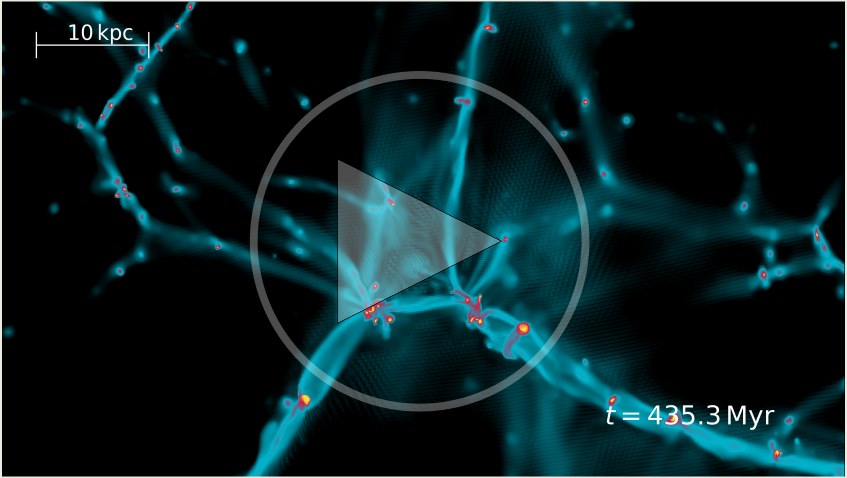
Model main features

- AMR code RAMSES Teyssier 2002
- zoom-in IC MUSIC Hahn 2011
- $\rm H_2$ based star formation (SK relation) Krumholz+09
- Stellar tracks from STARBURST99 Leitherer+10
- Thermal and kinetic energy (e.g. Agertz&Kravtsov 2015)
- GRACKLE 2.1 cooling module Bryan+14
- Kinetic energy dissipation Mac Low 1999; Teyssier+13
- SN explosions, OB/AGB winds & radiation pressure (e.g. Agertz+13, Hopkins+14)
- Subgrid modelling for blastwaves Ostriker&McKee 1988

Pallottini+17a

nomination for best image set for Wikimedia Eesti
European Science Photo Competition 2015

Formation of an high-z galaxy



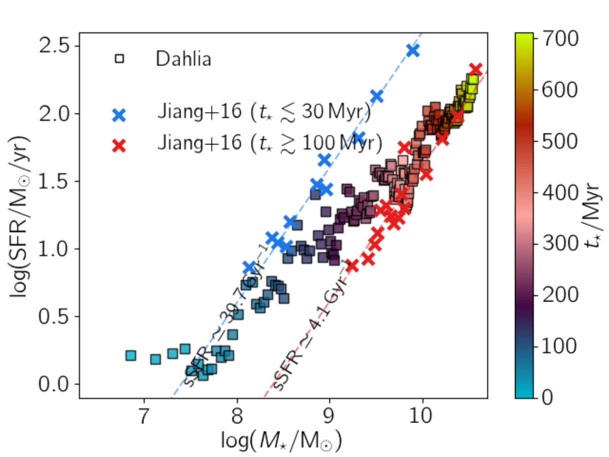
Density field evolution starting from $z \simeq 10$ to $z \simeq 9$

more movies: `https://www.researchgate.net/profile/Andrea_Pallottini`

Star formation history

For Dahlia, SFR and $M_\star$ are compatible with high-z galaxy observations

Pallottini+17a,b

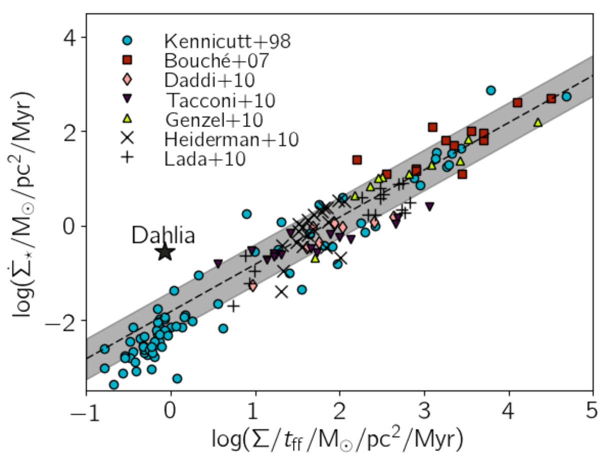


$\mathrm{sSFR} \simeq 39.7\,\mathrm{Gyr}^{-1}$ to $\mathrm{sSFR} \simeq 4.1\,\mathrm{Gyr}^{-1}$ as galaxy grows older

González+10; Stark+13; Jiang+16

Schmidt-Kennicutt relation

Schmidt-Kennicutt relation in the Krumholz+12 formulation $\dot{\Sigma}_\star - \Sigma/t_{\rm ff}$ Pallottini+17b



Dahlia is on the “high-z main sequence”
However, Dahlia is off the Schmidt-Kennicutt relation
How can we improve our models?

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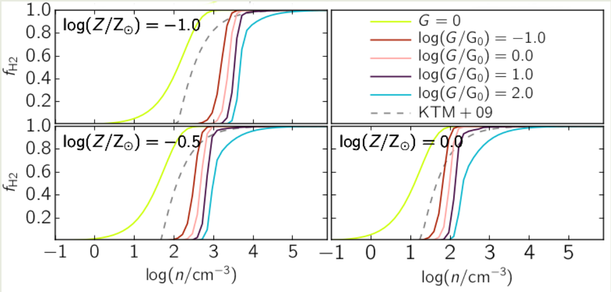
Improved model for the formation of H_2

Molecular fraction (f_{H2}) benchmark:

Pallottini+17b

equilibrium (Krumholz+09) vs non-equilibrium (Grassi+14) model



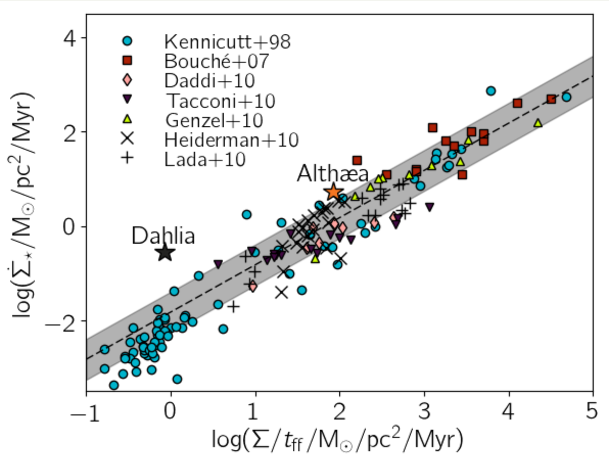
High-z environment
($Z \simeq 0.5\,Z_\odot$; **$G \simeq 100\,G_0$**):
equilibrium model $n \gtrsim 10^2\mathrm{cm}^{-3}$ (Dahlia)
non-equilibrium model $n \gtrsim 10^3\mathrm{cm}^{-3}$ (Althæa)

MW environment
($Z = Z_\odot$; **$G = G_0$**):
both models $f_{H2} \gtrsim 0.5$ at $n \gtrsim 25\,\mathrm{cm}^{-3}$

Schmidt-Kennicutt relation

With the improved model, gas must be denser to be molecular

Pallottini+17b

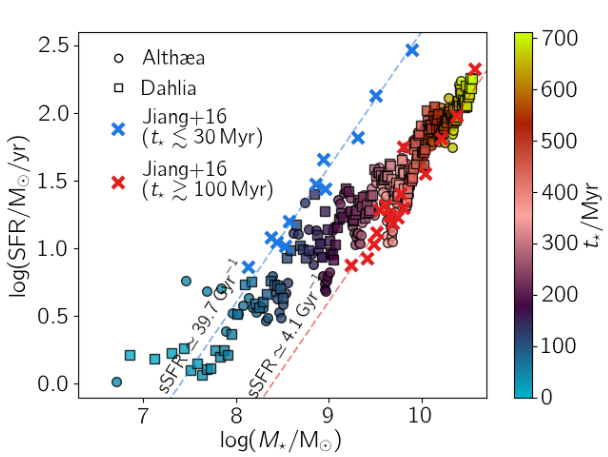


Althæa is nicely sits on the Schmidt-Kennicutt relation

Star formation history

Both galaxies are compatible with observation of main sequence at high-z

Pallottini+17b

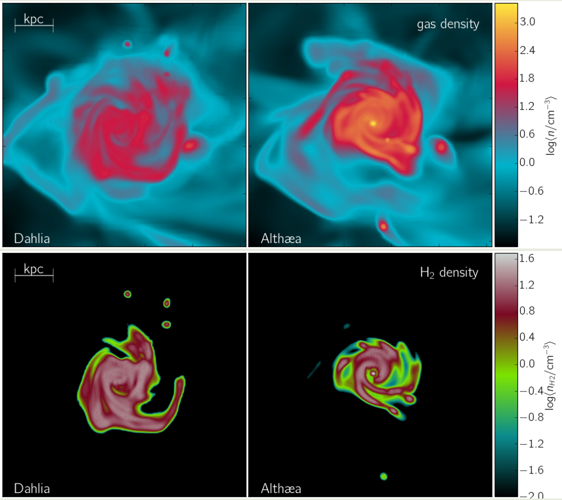


Difference within a factor ~ 2 for both $M_\star$ and SFR

Althæa has a more bursty nature than Dahlia

ISM of high-z galaxies: the impact of chemistry

Pallottini+17b



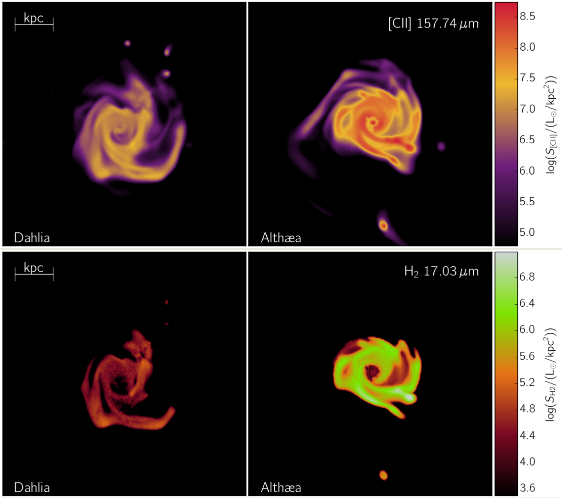
Althæa is denser then Dahlia ($\times$6.8), but has a lower molecular mass ($\times$3.5)

Althæa is more clumpy and compact

The radiation from high-z galaxies

FIR (ALMA) and Mid-IR (SPICA) synthetic observations

Pallottini+17b, see Spinoglio+17 for SPICA



Chemical modelling **does** matter: $\simeq 7\,(15)$ factor increase in luminosity of [C II] (H_2)

Works published since last meeting

- L. Vallini, A. Ferrara, **A. Pallottini**, S. Gallerani; *Molecular cloud photoevaporation and far-infrared line emission*, 2017, MNRAS, Vol. 467, 1300-1312.
- S. Gallerani, L. Zappacosta, M. Orofino, E. Piconcelli, C. Vignali, A. Ferrara, R. Maiolino, F. Fiore, R. Gilli, **A. Pallottini**, R. Neri, C. Feruglio; *X-ray spectroscopy of the* $z = 6.4$ *quasar SDSS J1148+5251*, 2017, MNRAS, Vol 467, 3590-3597.
- F. Pacucci, **A. Pallottini**, A. Ferrara, S. Gallerani; *The nature of the Lyman*α *emitter CR7: a persisting puzzle*, 2017, MNRAS, Vol 468, L77-L81.
- M. Ginolfi, R. Maiolino, T. Nagao, S. Carniani, F. Belfiore, G. Cresci, B. Hatsukade, F. Mannucci, A. Marconi, **A. Pallottini**, R. Schneider, P. Santini; *Molecular gas on large circumgalactic scales at* $z = 3.47$, 2017, MNRAS, Vol. 468, 3468-3483.
- S. Carniani, R. Maiolino, **A. Pallottini**, L. Vallini, L. Pentericci, A. Ferrara, M. Castellano, E. Vanzella, A. Grazian, S. Gallerani, P. Santini, J. Wagg, A. Fontana; *Extended ionised and clumpy gas in a normal galaxy at* $z = 7.1$ *revealed by ALMA*, 2017, A&A, Vol. 605 A42.
- A. Das, A. Mesinger, **A. Pallottini**, A. Ferrara, J. Wise; *High-mass X-ray binaries and the cosmic 21-cm signal: impact of host galaxy absorption*, 2017, MNRAS, Vol. 469, 1166-1174.
- **A. Pallottini**, A. Ferrara, S. Bovino, L. Vallini, S. Gallerani, R. Maiolino, S. Salvadori; *The impact of chemistry on the structure of high-z galaxies*, 2017, MNRAS, Vol. 471, 4128-4143.
- D. Decataldo, A. Ferrara, **A. Pallottini**, S. Gallerani, L. Vallini; *Molecular clumps photoevaporation in ionized regions*, 2017, MNRAS, Vol 471, 4476-4487.
- L. Spinoglio & 68 authors; *Galaxy evolution studies with the SPace IR telescope for Cosmology and Astrophysics (SPICA): the power of IR spectroscopy*, 2017, PASA, Vol. 34, e057.
- J. Matthee, D. Sobral, F. Boone, H. Röttgering, D. Schaerer, M. Girard, **A. Pallottini**, L. Vallini, A. Ferrara, B. Darvish, B. Mobasher; *ALMA reveals metals yet no dust within multiple components in CR7*, 2017, ApJ, Vol. 851, 145.
- S. Gallerani, **A. Pallottini**, C. Feruglio, A. Ferrara, R. Maiolino, L. Vallini, D. A. Riechers; *Evidence for outflows in* $z \sim 6$ *galaxies with ALMA*, 2018, MNRAS Vol. 473, 1909.
- L. Vallini, **A. Pallottini**, A. Ferrara, S. Gallerani, Sobacchi E., C. Behrens; *CO line emission from galaxies in the Epoch of Reionization*, 2018, MNRAS, Vol. 473, 271-285.
- P. Barai, S. Gallerani, **A. Pallottini**, A. Ferrara, A. Marconi, C. Cicone, R. Maiolino, S. Carniani; *Quasar outflows at* $z \geq 6$*: the impact on the host galaxies*, 2018, MNRAS, Vol. 473, 4003-4020.
- C. Behrens, **A. Pallottini**, A. Ferrara, S. Gallerani, L. Vallini; *Dusty galaxies in the Epoch of Reionization: simulations*, 2018, accepted by MNRAS

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Conclusions

1) Our typical LBG form a H_2 disk of mass of $\sim 10^8 \mathrm{M}_\odot$, effective radius $\simeq 0.5\mathrm{kpc}$, and scale height $\simeq 200\mathrm{pc}$

2) The total [C II] luminosity is $\sim 10^8 \mathrm{L}_\odot$, and 95% of the emission arises from the H_2 disk.

3) An improved chemical treatment allows us to better reproduce current observational constraints and in turn improve our predictions.

4) New models are incoming and new simulations are currently under production, stay tuned for more next year.