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The star formation rate function of z ~ 1 - 7 galaxies

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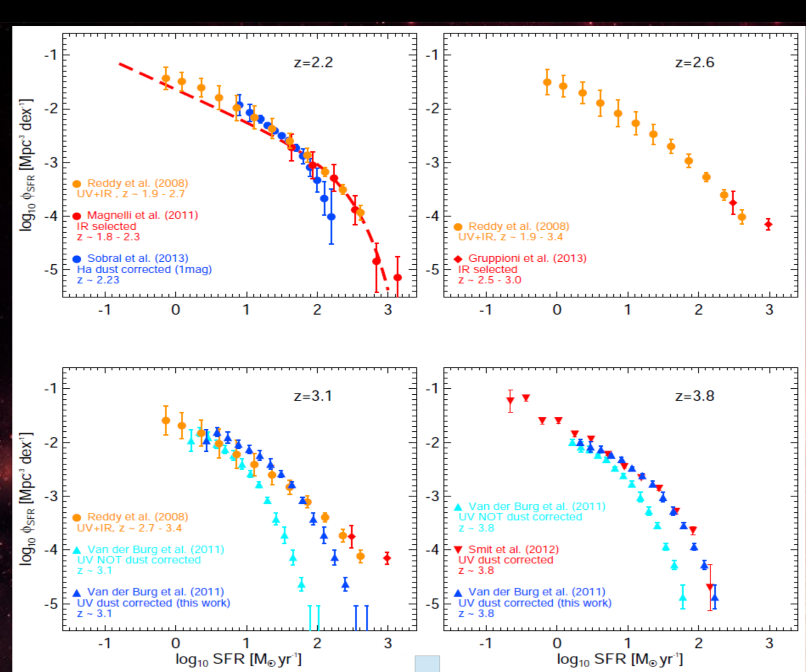
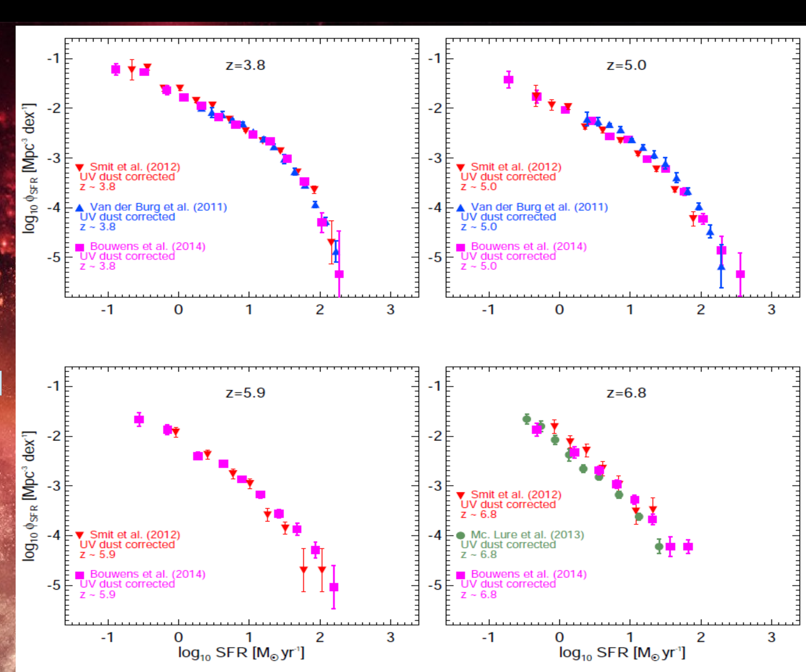
Abstract

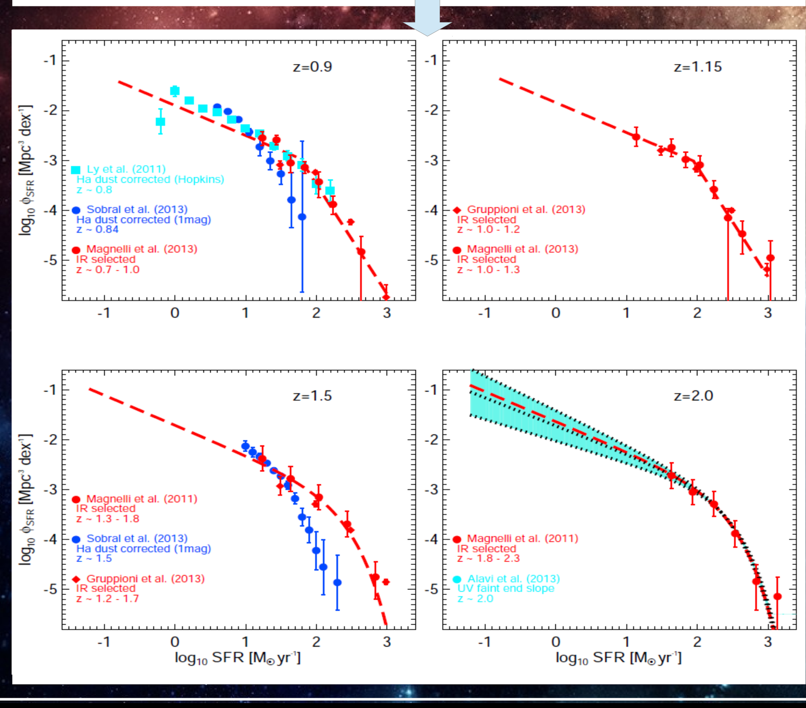
We study the evolution of the Star Formation Rate Function (SFRF) of z ~ 1-7 galaxies using cosmological hydrodynamic simulations. The SFRF is the histogram of the SFRs of the observed galaxies and a simple integration of it gives the cosmic Star Formation Rate Density (SFRD). We investigate the effect of different feedback recipes and Initial Mass Functions (IMFs) and determine how these affect the shape of the simulated SFRF. In our configurations both galactic winds and AGN feedback act simultaneously in a complex interplay. We show that our fiducial model, with momentum driven winds and "efficient" AGN feedback, is able to reproduce the observed SFRFs and SFRD at these high redshifts.

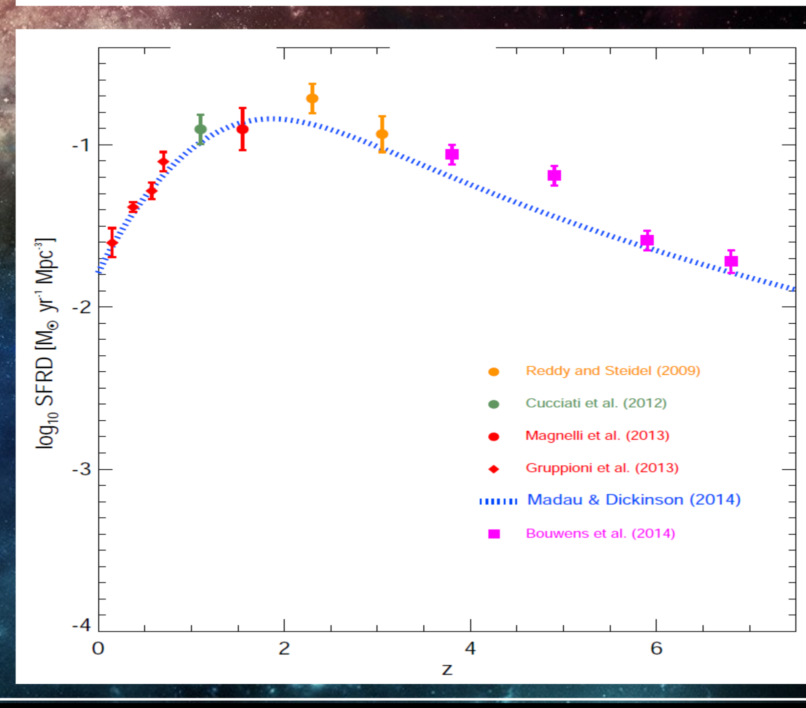
Observations

To obtain properties of galaxies like SFR we have to rely on the UV, Hα and IR light that we observe. However, the UV and Ha luminosities from these objects are subject to dust attenuation effects from internal and intergalactic dust. The observed and corrected luminosities of a galaxy (L_{OBS} and L_{COR}) are related with each other: $L_{OBS} = L_{COR}\, e^{-\tau}$, where τ is the optical depth. The corrected UV and Ha luminosities can be used to obtain the intrinsic SFR of the observed galaxies by using a conversion relation (e.g. Kennicutt 1998). IR light is not subject to dust attenuation effects and it can provide useful constraints for the SFRs of high mass objects. We follow the procedure of Smit et al. (2012) and convert various luminosity functions in the literature to SFRFs by transforming the luminosity bins to SFR bins (Katsianis et al. in preparation). An integration of the SFRFs gives the evolution of the cosmic SFRD.





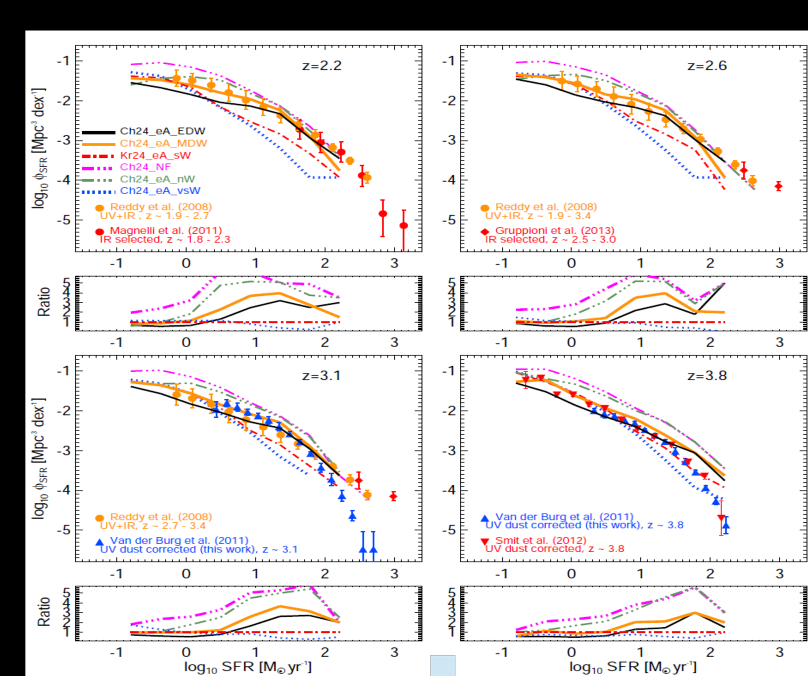


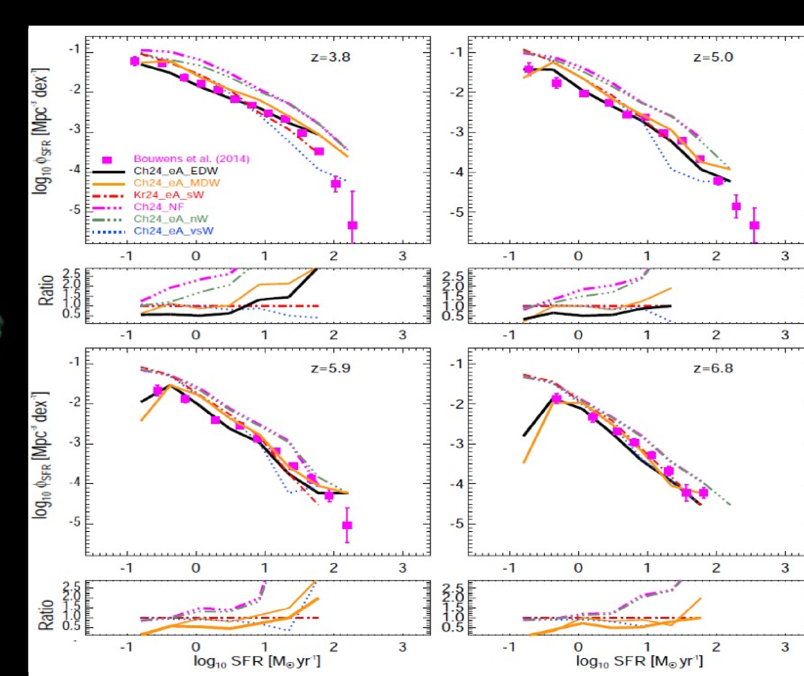


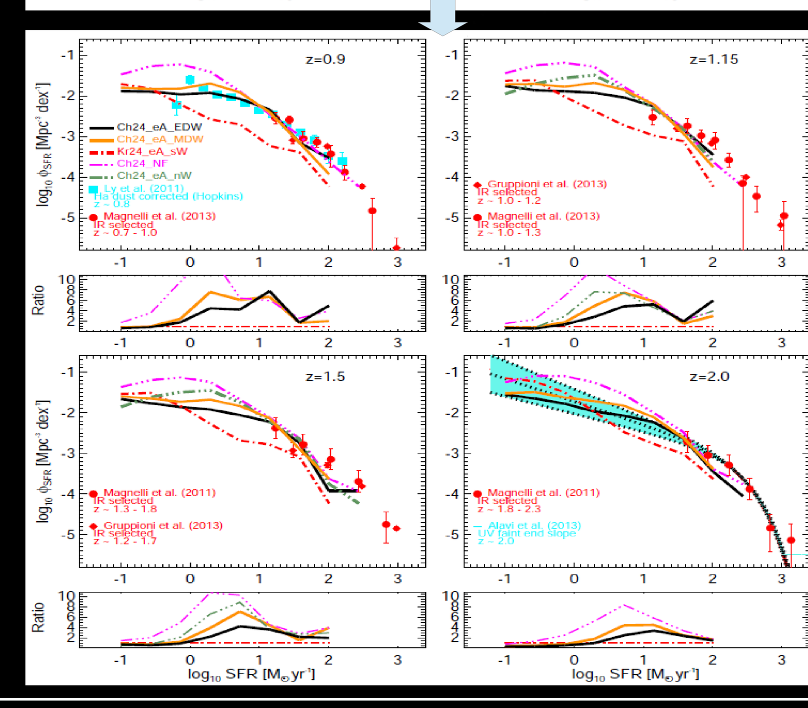
Simulations vs Observations

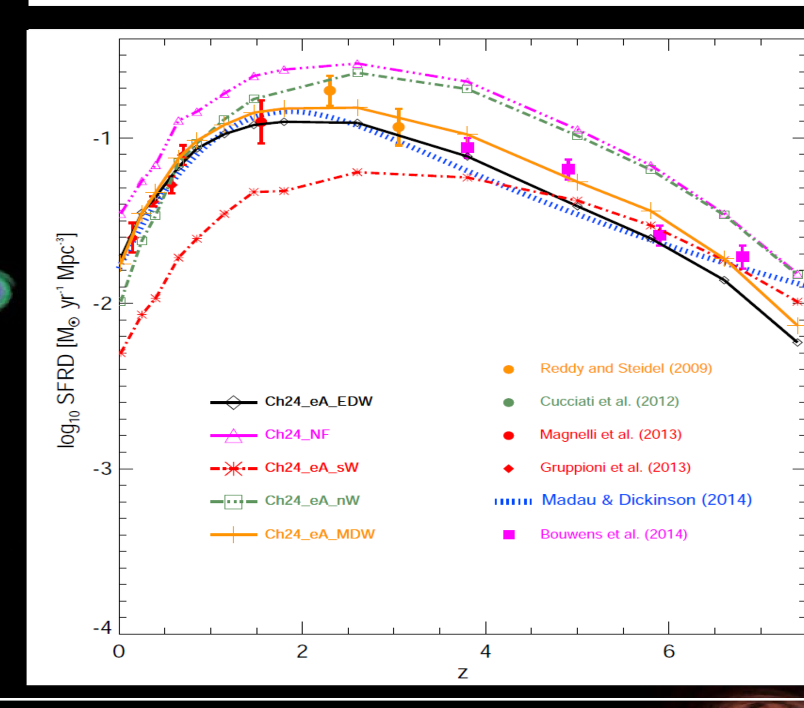
Simulations without feedback overpredict the number of objects at all SFRs for all redshifts. We stress that feedback is crucial at early times. Energy driven winds and momentum driven winds are efficient for objects with low star formation rates since their wind mass loading factor is higher for low mass halos (Puchwein & Springel 2013).

Our fiducial model with Chabrier IMF, efficient AGN feedback and momentum driven winds is in agreement with the observed SFRFs and SFRD.





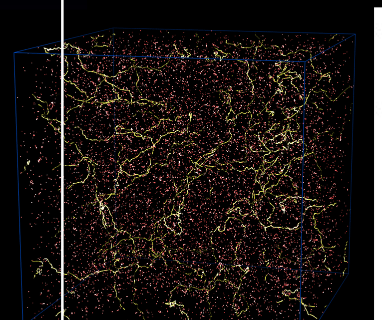




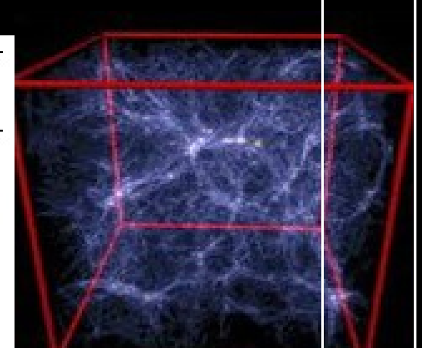
Simulations

We rely on the hydrodynamic code P-GADGET3(XXL), a modified and improved version of GADGET-3. For the first time it combines different physical processes, which have been developed and tested separately. The main features of our code are: self-consistent star formation/stellar evolution and chemical enrichment, several galactic winds feedback prescriptions, AGN feedback and low-temperature cooling by molecules/metals.

In the following table we present the runs that were used to investigate the evolution of the SFRF and GSMF at z ~ 4 -7 (Tescari et al. 2014, Katsianis et al. 2014).

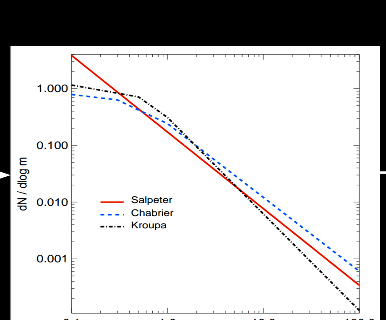


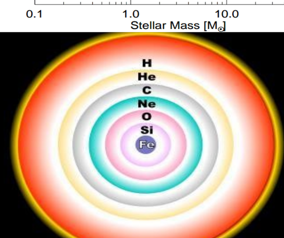
Run	IMF	Box Size [Mpc/h]	N_{TOT}	M_{DM} [$M_\odot/h$]	M_{GAS} [$M_\odot/h$]	Comoving Softening [kpc/h]	Feedback
Kr24_eA_sW	Kroupa	24	2×288^3	3.64×10^7	7.32×10^6	4.0	Early AGN + Strong Winds
Ch24_eA_nW	Chabrier	24	2×288^3	3.64×10^7	7.32×10^6	4.0	Early AGN + no Winds
Ch24_eA_vsW	Chabrier	24	2×288^3	3.64×10^7	7.32×10^6	4.0	Early AGN + Very Strong Winds
Ch24_NF	Chabrier	24	2×288^3	3.64×10^7	7.32×10^6	4.0	No Feedback
Ch24_eA_MDW[b]	Chabrier	24	2×288^3	3.64×10^7	7.32×10^6	4.0	Early AGN + Momentum-Driven Winds
Ch24_eA_EDW[c]	Chabrier	24	2×288^3	3.64×10^7	7.32×10^6	4.0	Early AGN + Energy-Driven Winds



IMF

IMF determines the number density of stars per logarithmic mass interval. It sets also the amount of energy released by Supernovae (SN).





Galactic winds feedback

SN driven galactic winds inject kinetic and thermal energy into the Intergalactic Medium. Furthermore, SNe pollute the Interstellar Medium with elements heavier than H and He that were created inside stars. 3 wind models are considered.

$$\dot{M}_w = \eta \dot{M}_\star$$

Constant wind model

$$\eta = 2 \qquad v_w = 450\ \mathrm{km/s}$$

Energy driven wind model

$$\eta = 2 \times \left(\frac{450\ \mathrm{km/s}}{v_w}\right)^2 \qquad v_w = 2\sqrt{\frac{GM_{halo}}{R_{200}}} = 2 \times v_{circ}$$

Momentum driven wind model

$$\eta = 2 \times \frac{450\ \mathrm{km/s}}{v_w} \qquad v_w = 2\sqrt{\frac{GM_{halo}}{R_{200}}} = 2 \times v_{circ}$$

AGN feedback

Matter is accreted onto super massive black holes at the centers of the galaxies. This process releases energy back to the IGM.

Conclusions and discussion

Our results can be summarised as follows:

a) We combine observations from various groups to get constraints on the SFRF of galaxies. The observed SFRFs derived from different indicators (UV, Hα, IR) are consistent once the effects of dust attenuation are taken into account.

b) We reproduce the observed galaxy star formation rate function of galaxies. Galactic winds start to be active at z ~7 and shape the whole distribution. We favor a model with momentum driven winds and efficient AGN feedback.

c) Our simulations reproduce the observed cosmic star formation rate density. This reflects the good consistency of the simulated and observed star formation rate functions.

References

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[6] Katsianis A., Tescari E., Wyithe S., in preparation