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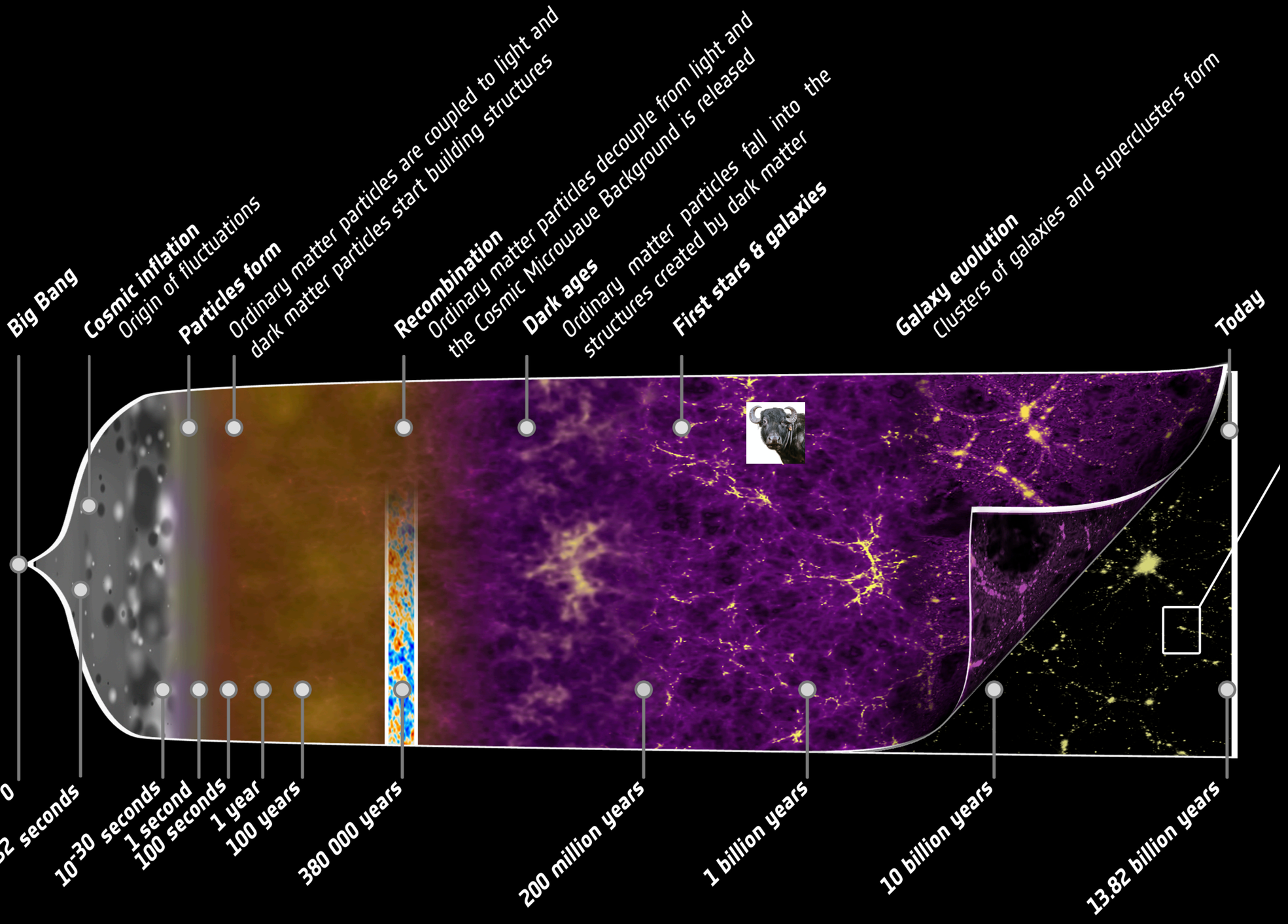
Galaxy population constraints on cosmology and star formation

Sahlén & Zackrisson 2021, arXiv:2105.05098

Martin Sahlén

Uppsala University

BUFFALO Collaboration Meeting, 12 July 2021


Big Bang
Cosmic inflation
Origin of fluctuations
Particles form
Ordinary matter particles are coupled to light and dark matter particles start building structures
Recombination
Ordinary matter particles decouple from light and the Cosmic Microwaue Background is released
Dark ages
Ordinary matter particles fall into the structures created by dark matter
First stars & galaxies
Galaxy euolution
Clusters of galaxies and superclusters form
Today
0
10-32 seconds
10-30 seconds
1 second
100 seconds
1 year
100 years
380 000 years
200 million years
1 billion years
10 billion years
13.82 billion years

Goals

- Tractable MCMC parameter inference (UV LF, CF)
- Physically grounded semi-analytic models
- Cosmological sensitivity
- Inclusion of systematics
- “Proof of concept”
- Public tool

Modeling

Luminosity function

$$\Phi(M_a, M_b, z) = \epsilon_{\rm syst} \int_M \int_{M_{\rm min}(z)} W[M; M_a, M_b] p[M|\langle M\rangle(M_{\rm h}, z)] n_h[M_{\rm h}, z] dM_{\rm h} dM,$$

Magnitude - halo mass relation

$$\langle M_{\rm UV}\rangle(M_{\rm h}, z) = M_0 - 2.5 \left[\log_{10} f_\star(M_{\rm h}, z) + \log_{10} \frac{\Omega_{\rm b}}{\Omega_{\rm m}} + \log_{10} \frac{\dot{M}_{\rm h}(M_{\rm h}, z)}{M_\odot {\rm yr}^{-1}} - \log_{10} \frac{\kappa}{M_\odot\,{\rm yr}^{-1}/({\rm ergs\,s^{-1}\,Hz^{-1}})}\right]$$

$$p(M_{\rm UV}|\langle M_{\rm UV}\rangle) = \frac{1}{\sqrt{2\pi}\sigma_M} \exp\left[-\frac{(M_{\rm UV} - \langle M_{\rm UV}\rangle)^2}{2\sigma_M^2}\right]$$

Star forming efficiency

$$f_\star(M_{\rm h}, z) = \frac{N(1+z)^{\gamma_N}}{\left(\frac{M_{\rm h}}{M_{\rm p}}\right)^{\alpha(1+z)^{\gamma_\alpha}} + \left(\frac{M_{\rm h}}{M_{\rm p}}\right)^{-\beta(1+z)^{\gamma_\beta}}}$$

Dust extinction

$$\langle A_{\rm UV}\rangle = 4.43 + 0.79\ln(10)\sigma^2_{\beta_{\rm UV}} + 1.99\langle\beta_{\rm UV}\rangle$$

Halo mass accretion rate

$$\dot{M}_{\rm vir} = \frac{\sigma_8^{\rm sim}}{\sigma_8} \frac{H(z)}{H_{\rm sim}(z)} \dot{M}_{\rm vir}^{\rm sim},$$

$$\frac{\dot{M}_{\rm vir}^{\rm sim}}{h^{-1}\,M_\odot\,{\rm yr}^{-1}} = \eta(z) M_{\rm vir,12}^{\xi(z)} \frac{H_{\rm sim}(z)}{H_0^{\rm sim}}.$$

Halo mass function

$$n(M_{\rm h}, z)\,{\rm d}M_{\rm h} = -F(\sigma)\,\frac{\rho_{\rm m}(z)}{M_{\rm h}\sigma(M_{\rm h}, z)}\,\frac{{\rm d}\sigma(M_{\rm h}, z)}{{\rm d}M_{\rm h}}\,{\rm d}M_{\rm h}$$

Bolshoi / MultiDark N-body sim.

Cosmology correction

$$M_{\rm UV}^{\rm fid} = M_{\rm UV} + 5\log\left(\frac{d_{\rm L}(z)}{d_{\rm L}^{\rm fid}(z)}\right)$$

$$\Phi_{\rm fid} = \Phi\frac{dV_{\rm fid}/dz}{dV/dz}$$

arXiv:2105.05098

Data and Priors

- B15: Bouwens 2015 UV luminosity function, z = 4 - 10
- H18: Harikane et al. 2018 correlation function (subset of 2 data points, in fixed cosmology) -> SFR constraint, z = 4 - 7

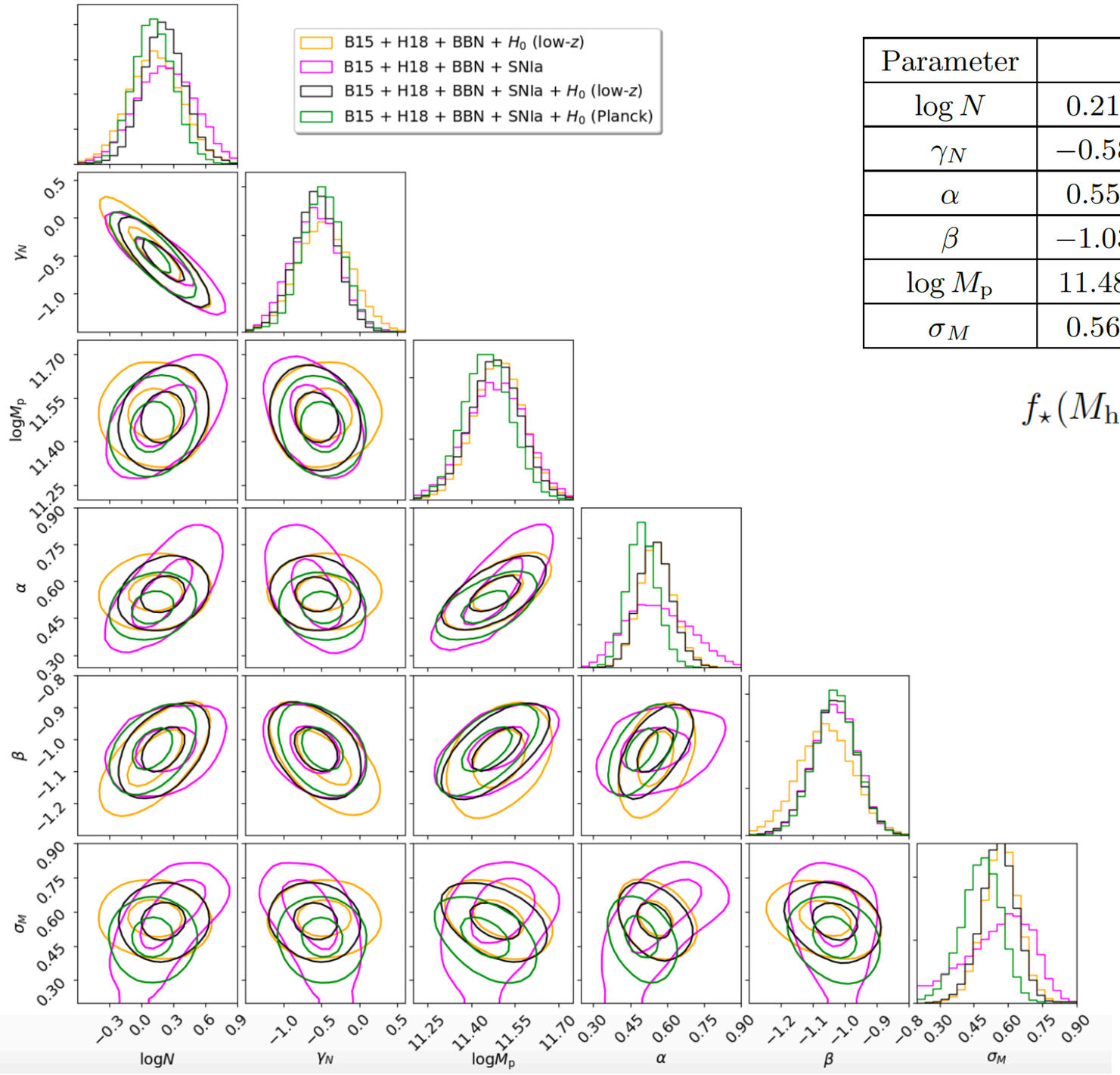
$\mathbf{n_s\ Planck}$	$n_{\rm s} = 0.9649$
BBN	$\Omega_{\rm b}h^2 = 0.0222 \pm 0.0005$
SNIa	$\Omega_{\rm m} = 0.298 \pm 0.022$
$\mathbf{H_0\ low{-}z}$	$h = 0.7348 \pm 0.0166$
$\mathbf{H_0\ Planck}$	$h = 0.674 \pm 0.005$
Syst.	$\epsilon_{\rm syst} = 1.00 \pm 0.15$

I: B15+H18+BBN+SNIa+H_0 (low-z)

II: B15+H18+BBN+SNIa+H_0 (*Planck*)

III: B15+H18+BBN+H_0 (low-z)

IV: B15+H18+BBN+SNIa.



Parameter	I.	II.	III.	IV.
$\log N$	0.21 ± 0.20	0.11 ± 0.20	0.13 ± 0.26	0.21 ± 0.28
γ_N	-0.58 ± 0.29	-0.50 ± 0.28	-0.48 ± 0.36	-0.57 ± 0.33
α	0.55 ± 0.07	0.50 ± 0.06	0.55 ± 0.07	$0.55^{+0.14}_{-0.12}$
β	-1.03 ± 0.07	-1.02 ± 0.07	-1.06 ± 0.09	-1.03 ± 0.07
$\log M_{\rm p}$	11.48 ± 0.09	11.45 ± 0.08	11.49 ± 0.09	11.48 ± 0.11
σ_M	0.56 ± 0.08	0.48 ± 0.09	0.57 ± 0.08	$0.56^{+0.14}_{-0.20}$

$$f_\star(M_{\rm h}, z) = \frac{N(1+z)^{\gamma_N}}{\left(\frac{M_{\rm h}}{M_{\rm p}}\right)^{\alpha(1+z)^{\gamma_\alpha}} + \left(\frac{M_{\rm h}}{M_{\rm p}}\right)^{-\beta(1+z)^{\gamma_\beta}}}$$

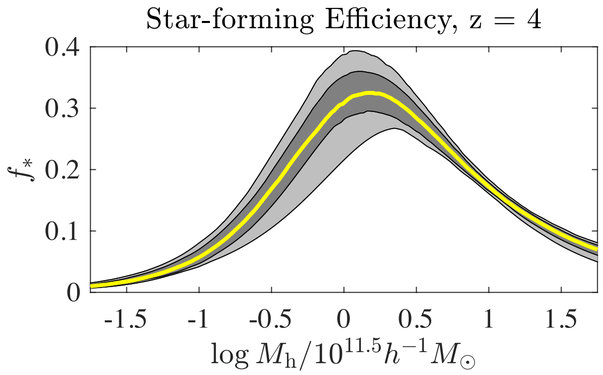
I: B15+H18+BBN+SNIa+H_0 (low-z)

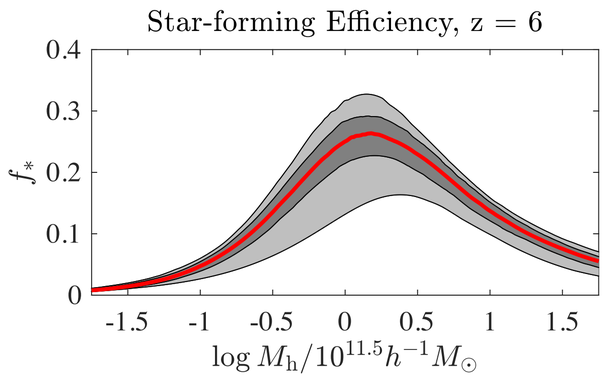
II: B15+H18+BBN+SNIa+H_0 (*Planck*)

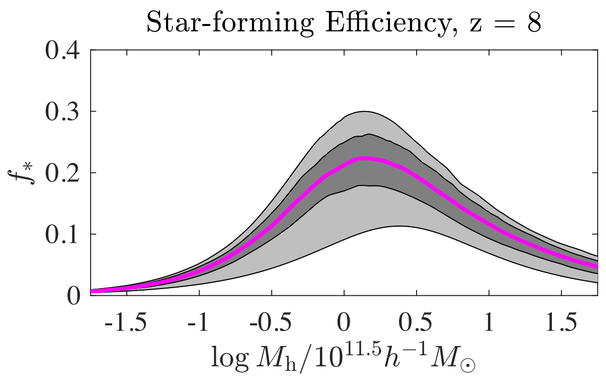
III: B15+H18+BBN+H_0 (low-z)

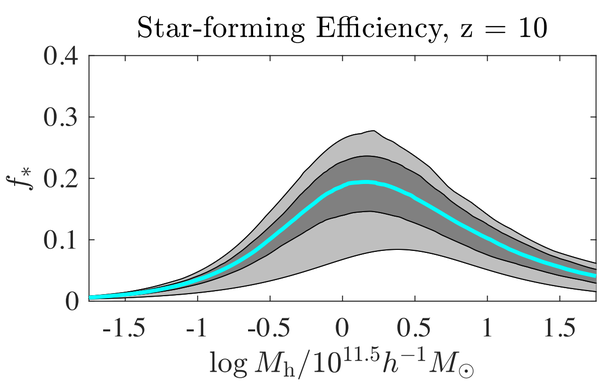
IV: B15+H18+BBN+SNIa.

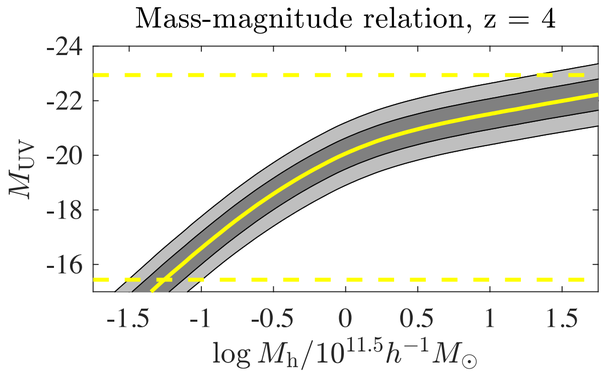
Star-Forming Efficiency and Magnitudes

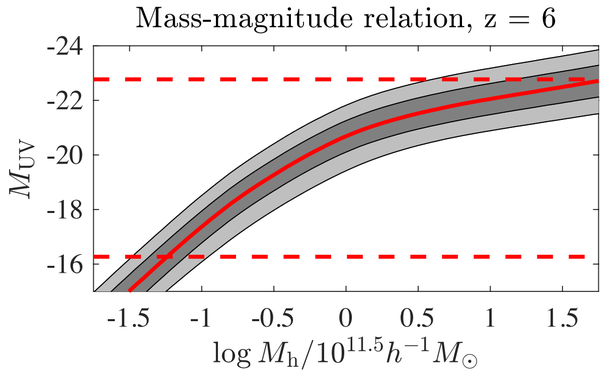


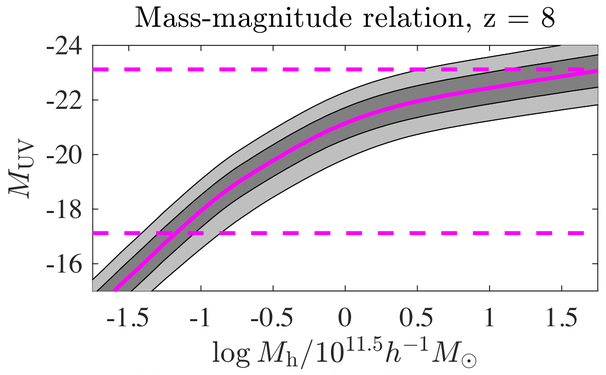


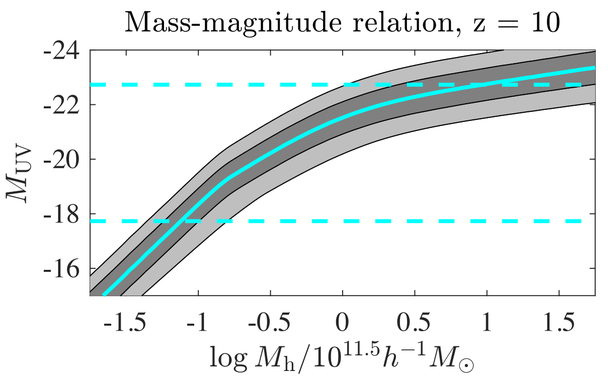












Cosmology

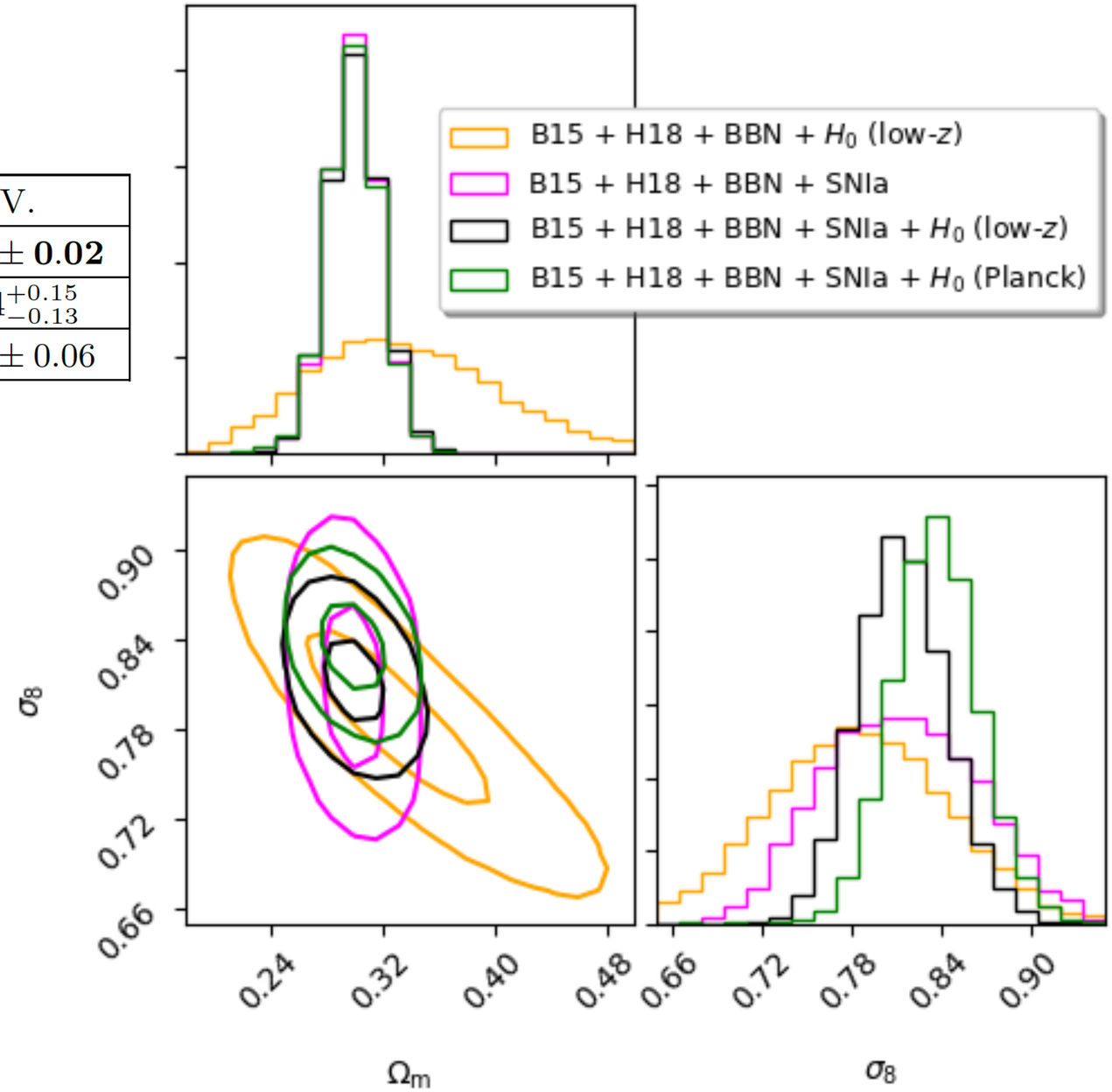
Parameter	I.	II.	III.	IV.
$\Omega_{\rm m}$	$\mathbf{0.30 \pm 0.02}$	$\mathbf{0.30 \pm 0.02}$	0.33 ± 0.07	$\mathbf{0.30 \pm 0.02}$
h	$\mathbf{0.73 \pm 0.02}$	$\mathbf{0.674 \pm 0.005}$	$\mathbf{0.73 \pm 0.02}$	$0.74^{+0.15}_{-0.13}$
σ_8	0.81 ± 0.03	0.84 ± 0.03	0.78 ± 0.06	0.82 ± 0.06

I: B15+H18+BBN+SNIa+H_0 (low-z)

II: B15+H18+BBN+SNIa+H_0 (*Planck*)

III: B15+H18+BBN+H_0 (low-z)

IV: B15+H18+BBN+SNIa.



http://galaxymc.cloud

GALAXYMC

galaxymc.cloud v1.0p1 / M. Sahlén, Astronomy and Space Physics, Uppsala University 2021.
Paper I version. Computes galaxy UV luminosity functions based on the Sahlén & Zackrisson 2021 model.

Status: *v1.0p1 in normal operation.*

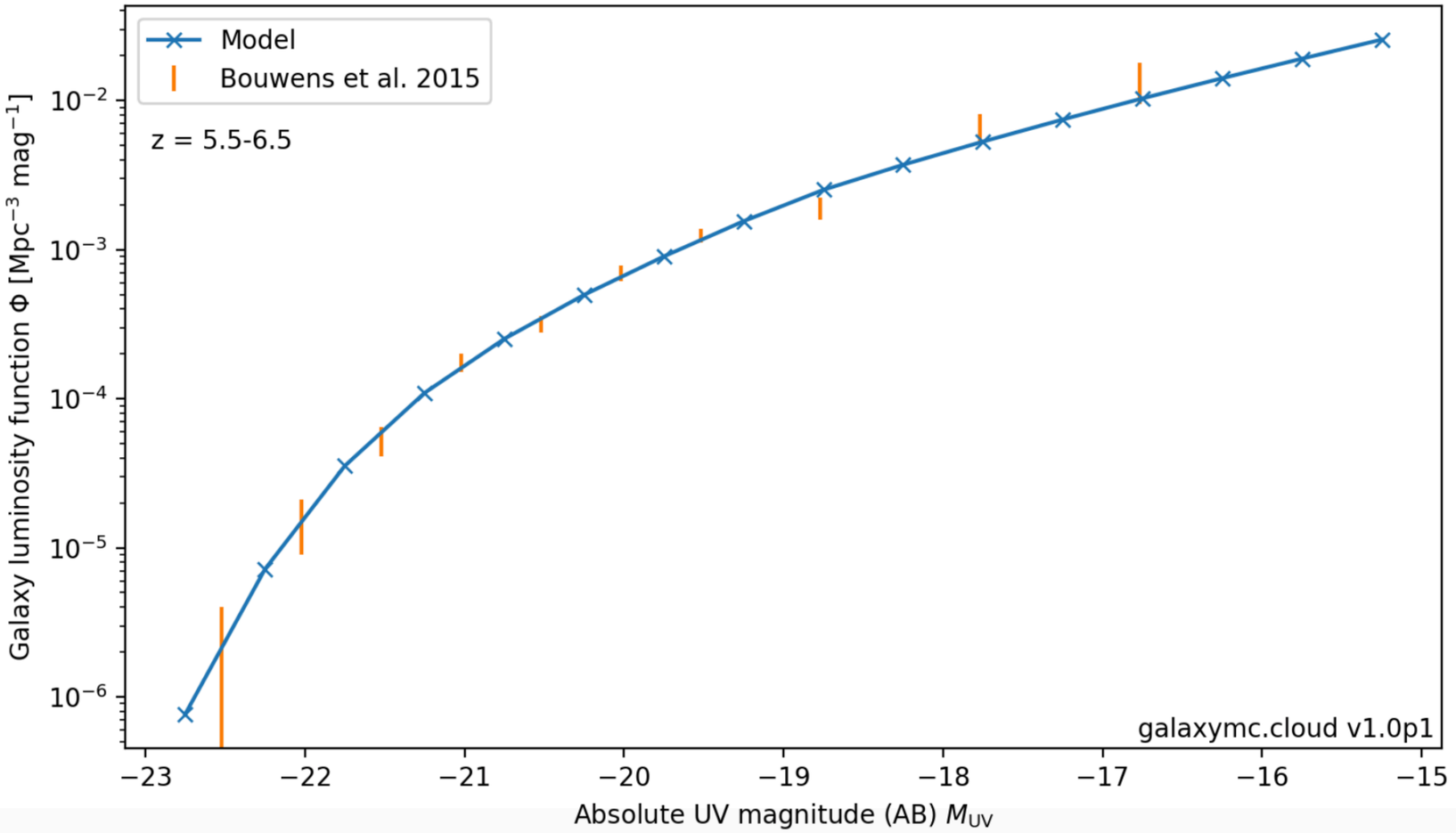
Compute

Cosmology

Ω_m	0.298
Ω_b	0.0412
H_0 [km/s/Mpc]	73.48
σ_8	0.813
n_s	0.9649

Star formation

log N	0.21
γ_N	-0.58
log M_p	11.48
α	0.55
γ_α	0.0
β	-1.03



Download plot data

Ongoing Work

- Investigation of impact of additional systematics
- Full range of LF, CF, stellar mass data incl. BUFFALO
- Flexible lensing distributions
- Additional semi-analytic models;
- Inclusion of non-standard dark matter models

- **Input and suggestions (models, projects, online functions, …) welcome: martin.sahlen@physics.uu.se**