The influence of primordial initial conditions on structure evolution in cosmological simulations

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Quantum Universe Attract.Workshop DESY Hamburg

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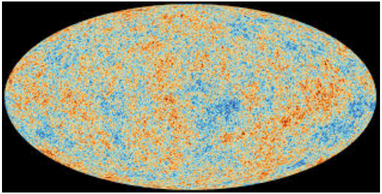
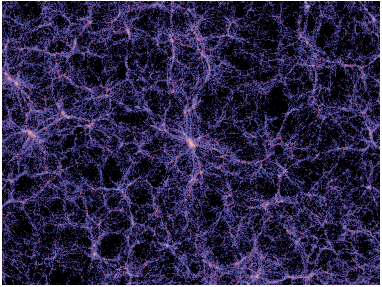
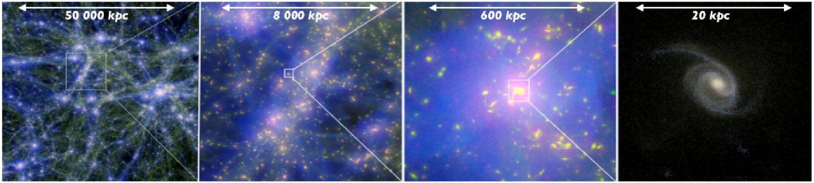
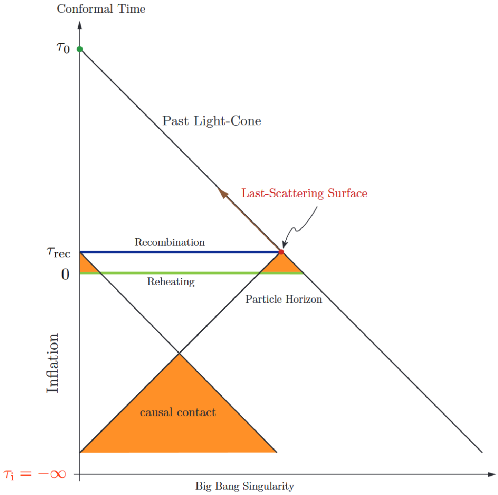
CMB & LSS - WMAP, Millenium, Mare Nostrum

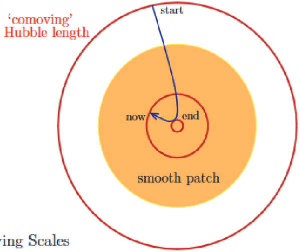


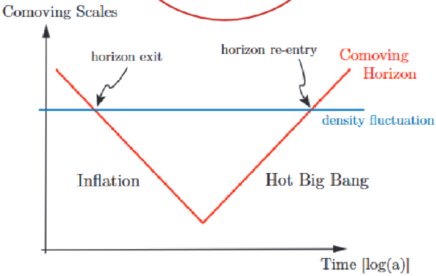




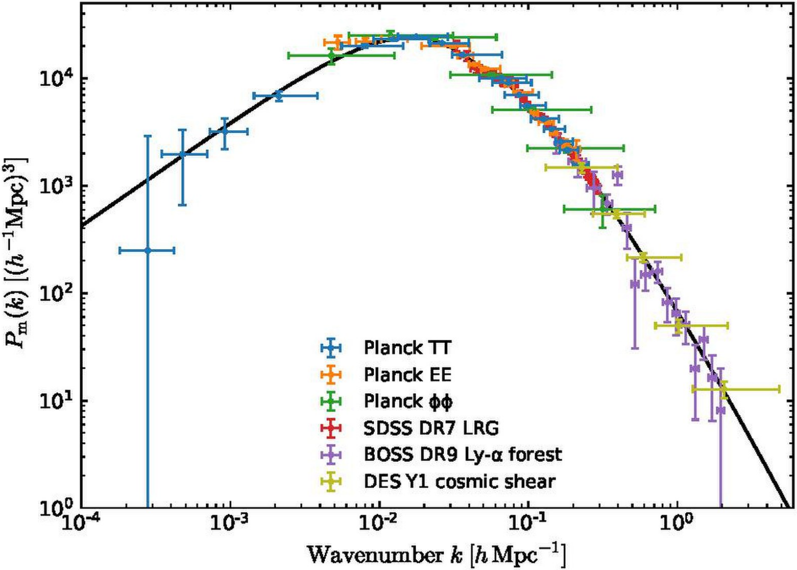
1981 Guth - Inflation



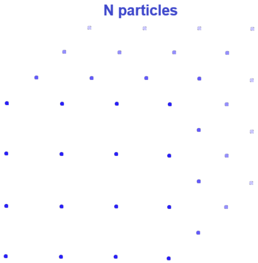


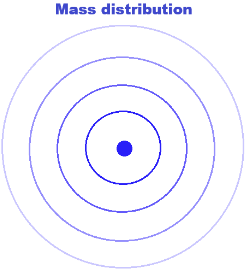


Planck 2018 - Linear Matter Power Spectrum



Gadget-4 - SPH N-body simulation tool





Kernel :

$$W(r,h) = \frac{1}{h^3\pi^{3/2}} e^{-\frac{r^2}{h^2}}$$

Polytropic equation of state :

$$P = K\rho^{1+\frac{1}{n}}$$

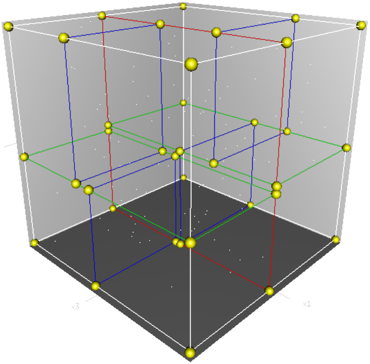
Density on particle i :

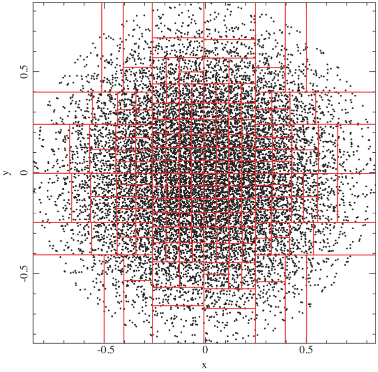
$$\rho_i = \sum_j m W(r_i - r_j, h)$$

Softening length :

$$\mathrm{F}_{soft} = \frac{G m_i m_j}{r_{ij}^2 + \epsilon^2}$$

Gadget-4 - Friend of a Friend, short and long range force

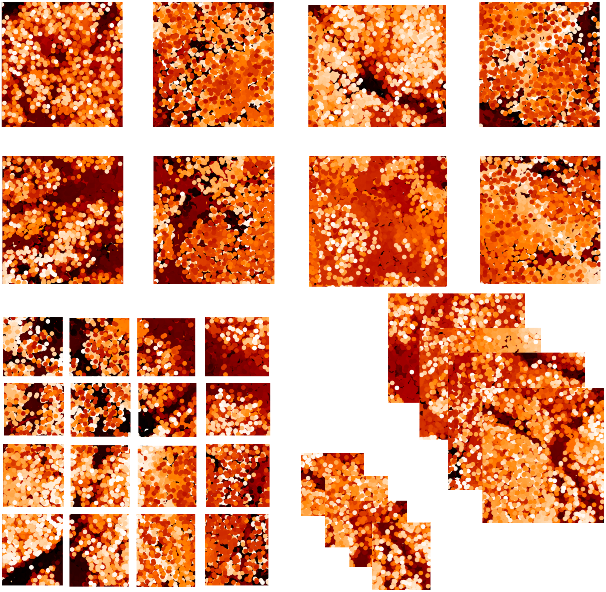




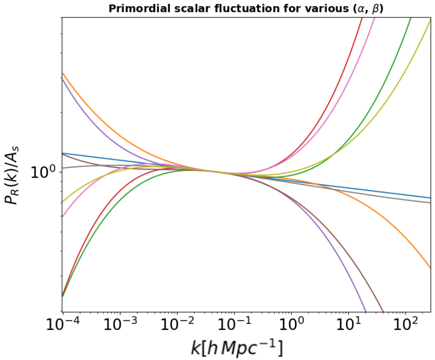
Brute-force : $N \times N$

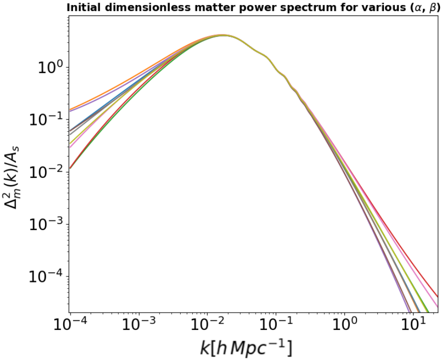
Kd-tree : $N \times \log(N)$

Gadget-4 - Folding Technique, Jenkins et al. (1998)



Input Primordial Scalar Fluctuation

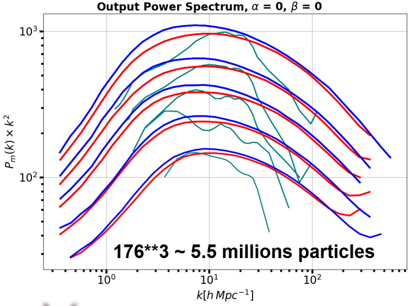


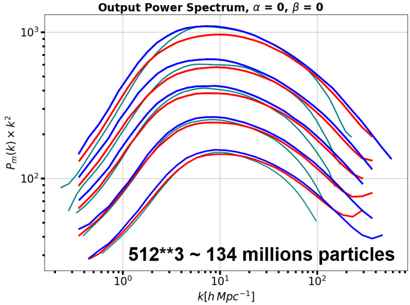


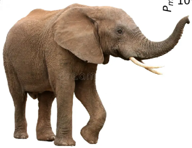
$$P_R(k) = A_s \left(\frac{k}{k_0}\right)^{n_s(k)-1} \quad ; \quad n_s(k) = n_s(k_0) + (\alpha/2) ln(k/k_0) + (\beta/6)[ln(k/k_0)]^2$$

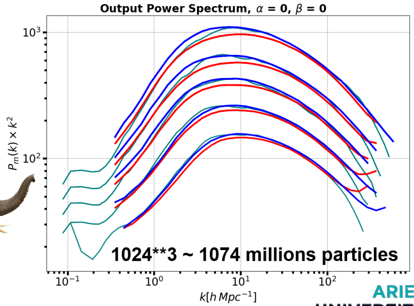
$$P_m(k) \propto P_R(k) T^2(k) D^2(z)$$

Misleading Resolution - Convergence and Behaviour

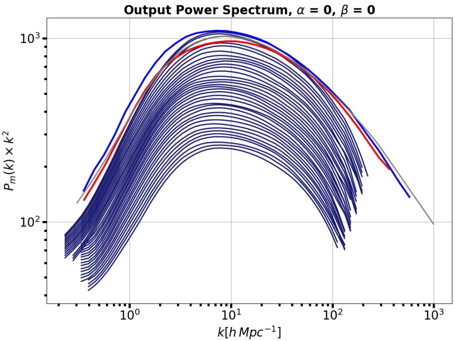


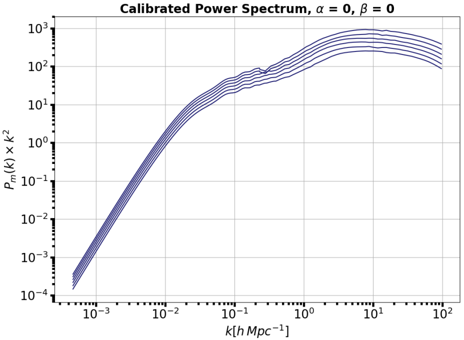






Output Matter Power Spectrum and Calibration



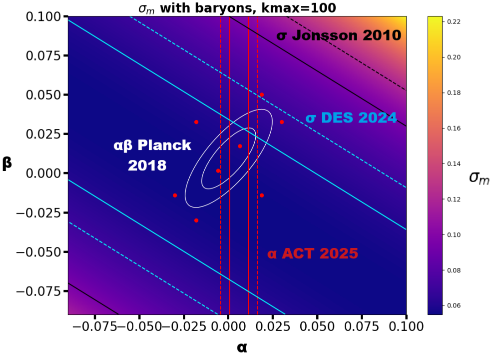


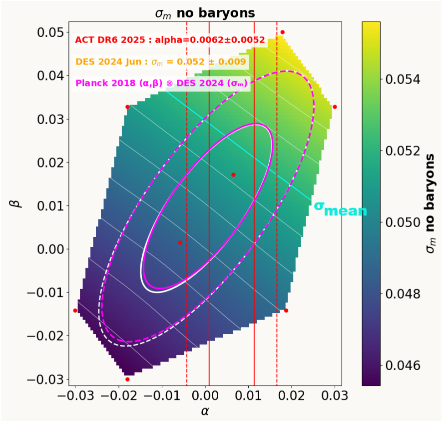
Use of CAMB in the linear regime to complete

$$k_{min} = \frac{2\pi}{\chi(z_{max}=1100)} \quad ; \qquad k_{max} = 100$$

Curve adjustment due to low resolution 512^3 vs 1024^3

2014 Ben-Dayan & Takahashi - Lensing Dispersion





Old values :

$\alpha = -0.0134 \pm 0.0090$ (Planck 2013)

$\beta = 0.020 \pm 0.016$ (Planck 2013)

$\sigma = 0.055 \pm 0.040$ (Jönsson 2010)

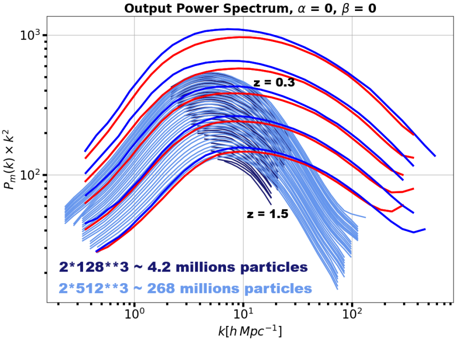
New values :

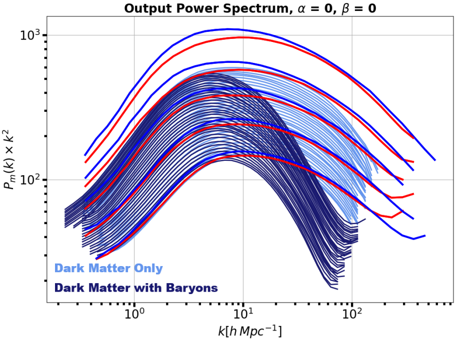
$\alpha = 0.0011 \pm 0.0099$ (Planck 2018)

$\beta = 0.009 \pm 0.012$ (Planck 2018)

$\sigma = 0.052 \pm 0.009$ (DES 2024)

Power Spectrum - Forecast with baryons

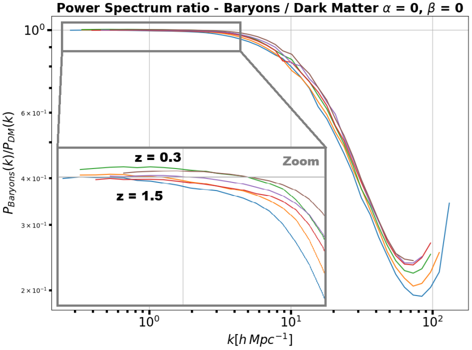


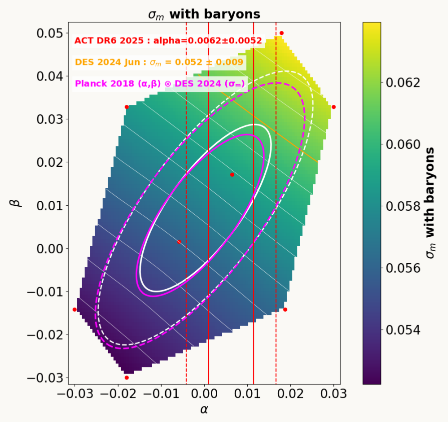


Completion : 80% of simulation 1 → 0/8 simulations ready ;
7 times longer than DM only

Baryons → Gaz cooling ✓ Interstellar medium ✓ Stellar feedback (supernova, galactic winds) ✓ Artificial viscosity ✓ Metal lines × Dust × Magnetic fields × Cosmic rays × AGN (× but soon !)

Lensing dispersion - Forecast with baryons





With baryons : $\sigma_m \rightarrow +\ 15\%$, will increase again with z $\in [0.3, 0]$

Weak lensing helps to constrain (α, β)

Impact of a lack of resolution is unknown (268 millions particles)

Conclusion

- Inflation → Nonlinear → Simulations → Matter power spectrum (small scales), constrained by weak lensing :

$$\sigma_\mu^2 \simeq \left(\frac{5}{\ln 10}\right)^2 \frac{\pi}{\Delta\eta^2}\left(\frac{k_{eq}}{H_0}\right)^3 \int d\eta_1 dp P_\Psi(p,\eta_1) p^2 (\eta_1 - \eta_s^{(0)})^2 (\eta_0 - \eta_1)^2$$

- Which in return constrains the primordial scalar fluctuations through the running parameter α and its derivative β :

$$P_R(k) = A_s \left(\frac{k}{k_0}\right)^{n_s(k)-1} \quad ; \quad n_s(k) = n_s(k_0) + (\alpha/2) ln(k/k_0) + (\beta/6)[ln(k/k_0)]^2$$

- Useless for DM only, but promising with baryons and others measures (Planck, ACT). Uncertainty improvements on σ_m will help a lot in the futur. Weak lensing is going to be a new probe.

- For now, Planck leads the constrain on (α, β), and alternatively, we can use it to efficiently constrain σ_m (baryons is a forecast) :

$$\sigma_m(DM) = 0.0499 \pm 0.0028 \quad ; \quad \sigma_m(baryons) = 0.0574 \pm 0.0032$$