Constraining gravity and dark energy models with growth rate measurement

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CPPM

Big Bang ΛCDM cosmology

General relativity

$$G_{\mu\nu} = T_{\mu\nu}$$

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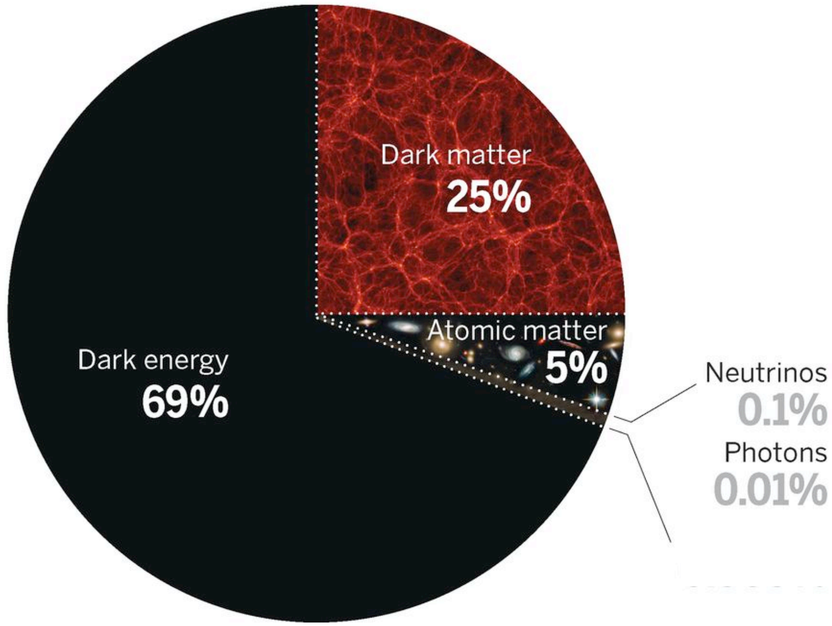
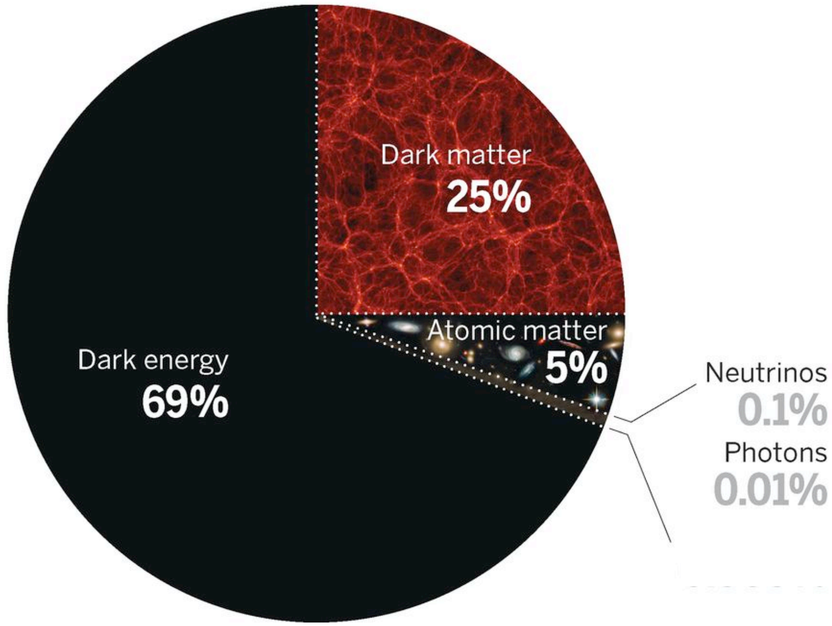


Universe content

ρ_γ ρ_ν ρ_c ρ_b ρ_Λ

Big Bang ΛCDM cosmology



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FLRW metric:

- expansion
- homogeneity
- isotropy
- Flat ?

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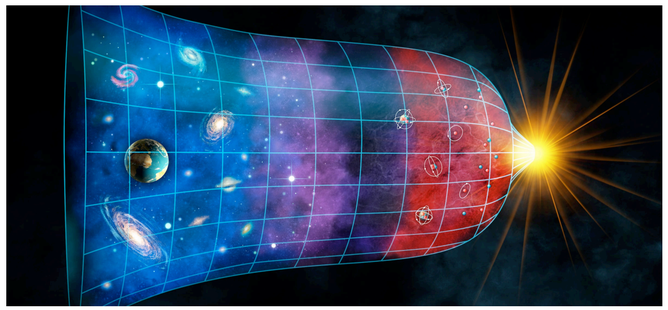

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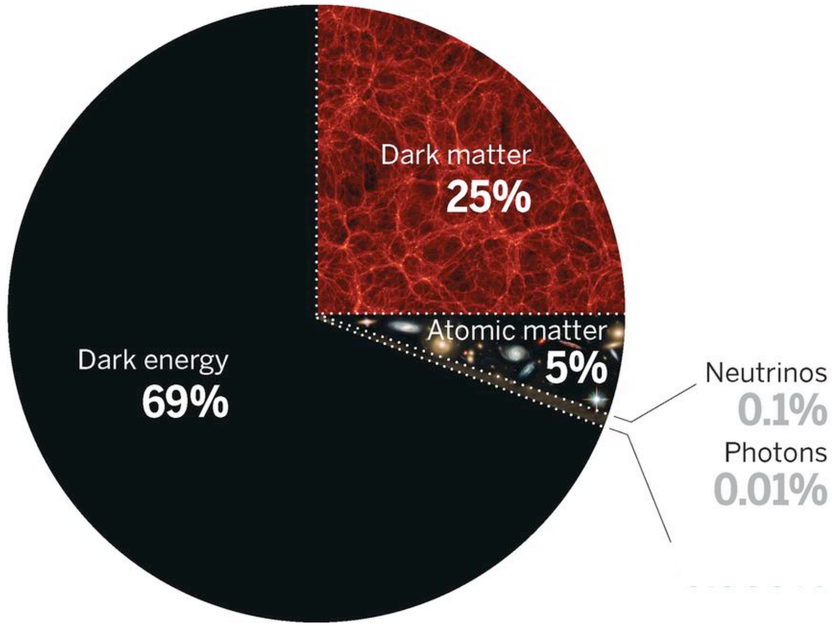

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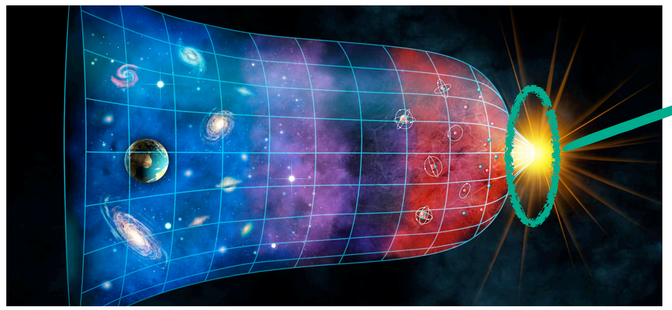
+

Initial conditions :

INFLATION

Universe content

ρ_γ ρ_ν ρ_c ρ_b ρ_Λ



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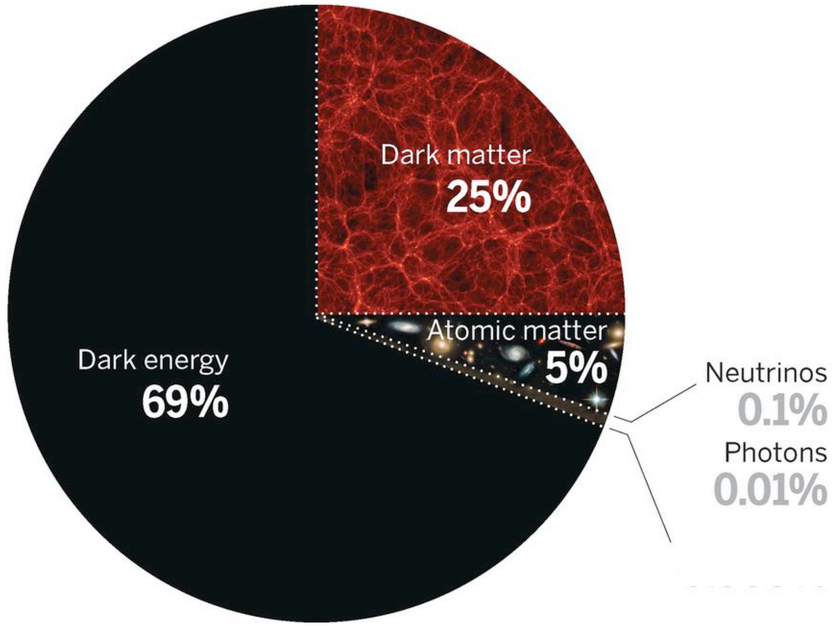

General relativity

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FLRW metric:

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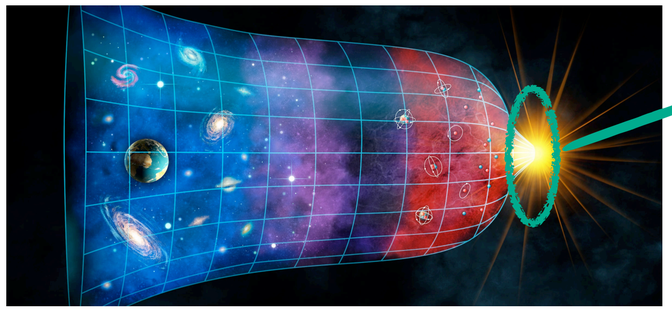
+

Initial conditions :

INFLATION

Universe content

$\rho_\gamma \; \rho_\nu \qquad \rho_c \; \rho_b \qquad \rho_\Lambda$



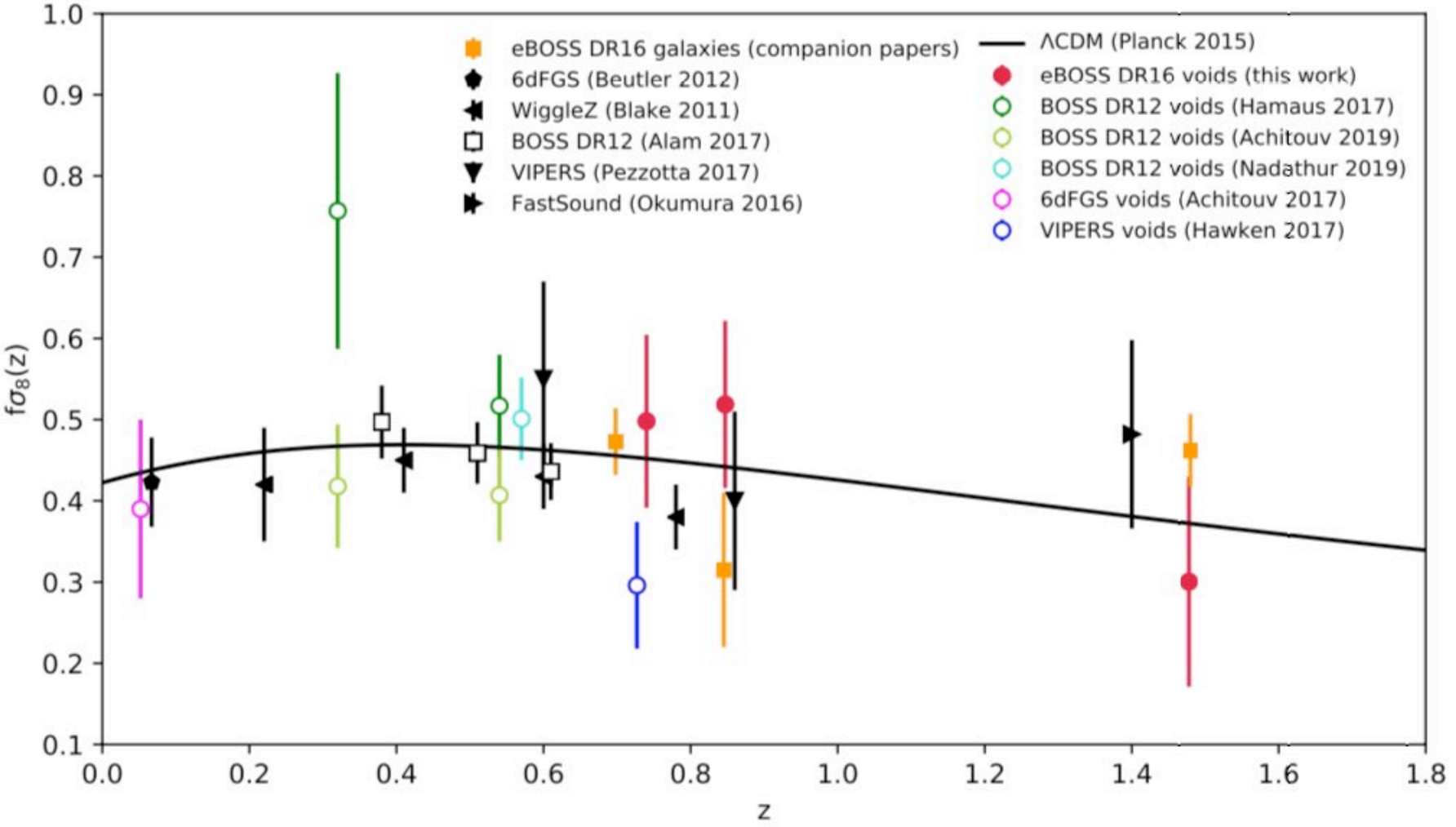
$$\left[\Omega_k, H_0, \quad \sigma_8, \; n_s, \quad \Omega_m, \Omega_b, \Omega_r, w_0, w_a\right] = \Theta$$

Perturbative cosmology

$$\rho_i = \bar{\rho}\left(1 + \delta_i\right) \qquad \delta_i(\vec{r}, a(t), \Theta)$$

Growth rate of structures : $$f = \frac{\partial \delta_m}{\partial \ln(a)}$$

$$\Theta = \left[f\left(H_0,\, \Omega_m,\, w_0,\, \ldots\right),\, \sigma_8,\, n_s\right]$$


eBOSS DR16 galaxies (companion papers)
6dFGS (Beutler 2012)
WiggleZ (Blake 2011)
BOSS DR12 (Alam 2017)
VIPERS (Pezzotta 2017)
FastSound (Okumura 2016)
ΛCDM (Planck 2015)
eBOSS DR16 voids (this work)
BOSS DR12 voids (Hamaus 2017)
BOSS DR12 voids (Achitouv 2019)
BOSS DR12 voids (Nadathur 2019)
6dFGS voids (Achitouv 2017)
VIPERS voids (Hawken 2017)
fσ8(z)
z
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8

Galaxies as dark matter tracers

Continuity $$\frac{\partial \delta}{\partial \tau} + \theta + \vec{\nabla} \cdot (\delta \vec{u}) = 0$$

Euler $$\frac{\partial \theta}{\partial \tau} + H\theta + \vec{\nabla} \cdot [(\vec{u} \cdot \vec{\nabla})\vec{u}] = -\frac{3}{2} H^2 \delta$$

Poisson $$\Delta \Phi = \frac{3}{2} (aH)^2 \Omega_m \delta$$

$$\theta = \vec{\nabla} \,.\, \vec{u}$$

Galaxies as dark matter tracers

$$\delta_g = O(\delta)$$

$$u_g = u$$

Continuity $$\frac{\partial \delta}{\partial \tau} + \theta + \vec{\nabla} \cdot (\delta \vec{u}) = 0$$

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Perturbation theory

$$\delta(\vec{k}) = \sum_{n=1}^{\infty} \delta^{(n)}(\vec{k})$$

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Observables

Random fields

$$\delta_g(\vec{r}, t)$$
$$u_g(\vec{r}, t)$$

Can’t predict !

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Two point correlation function

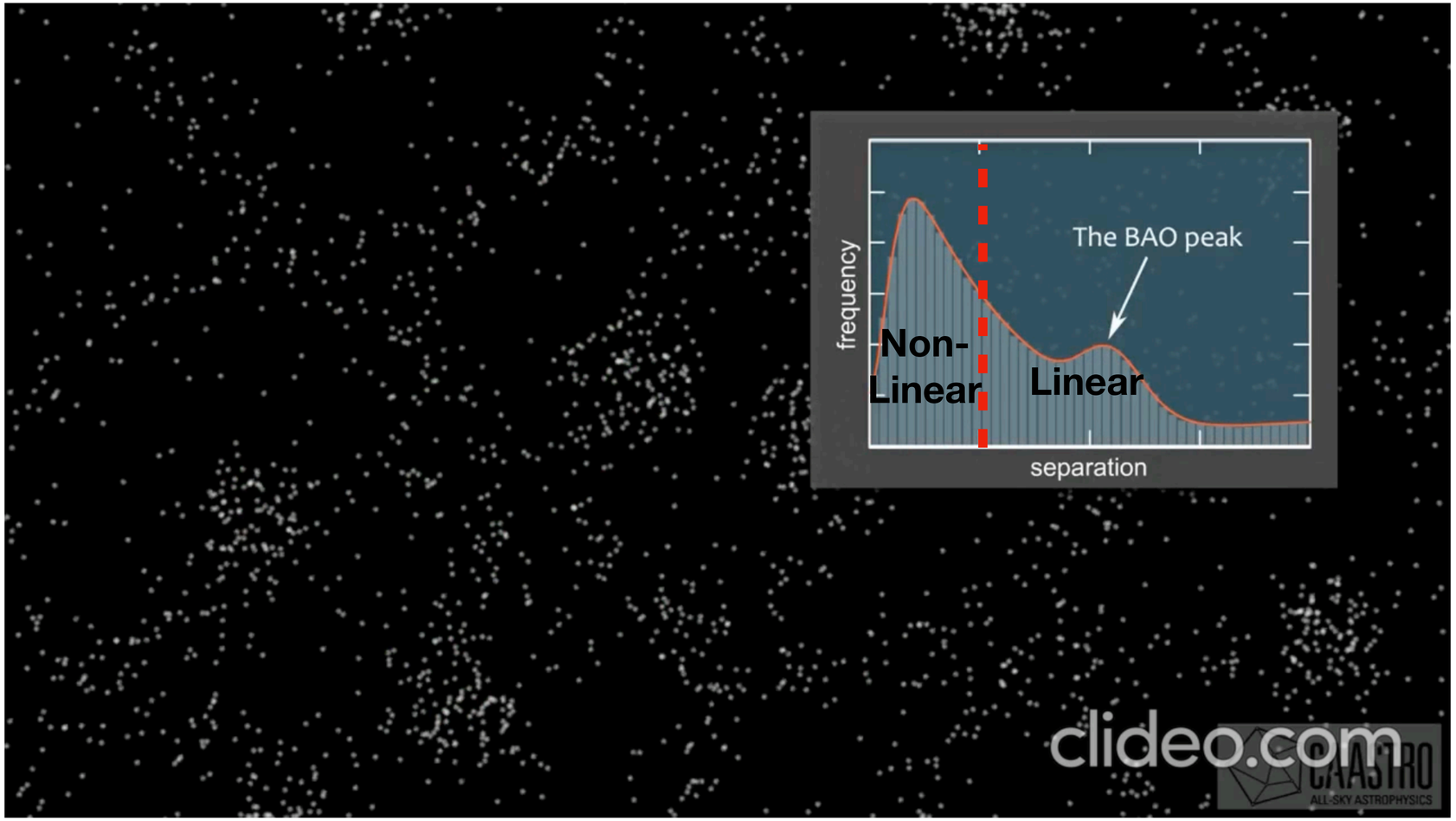
$$\langle \delta_g(\vec{r}_1, t)\delta_g(\vec{r}_2, t)\rangle = \xi_{gg}(\vec{r}_1 - \vec{r}_2, t)$$

$$\langle u_g(\vec{r}_1, t)u_g(\vec{r}_2, t)\rangle = \xi_{uu}(\vec{r}_1 - \vec{r}_2, t)$$

Observable !

The observable

2 point correlation function



Correlation function

$$\xi(\vec{r}) \equiv \langle \delta(\vec{x})\delta(\vec{x}+\vec{r}) \rangle$$

$\langle \cdot \rangle =$ Average over different realizations of the Universe

$=$ Average over a large volume

Likelihood inference

Likelihood

$$\mathscr{L} = \frac{1}{(2\pi)^n \det(C)^{1/2}} \exp\left(-\frac{1}{2}[\vec{d} - \vec{m}(\vec{p})]^T C^{-1}[\vec{d} - \vec{m}(\vec{p})]\right)$$

Data vector

$$\vec{d} = \begin{bmatrix} \xi_0 \\ \xi_1 \\ \cdots \\ \xi_n \end{bmatrix}$$

Model

$$\vec{m}$$

Parameters

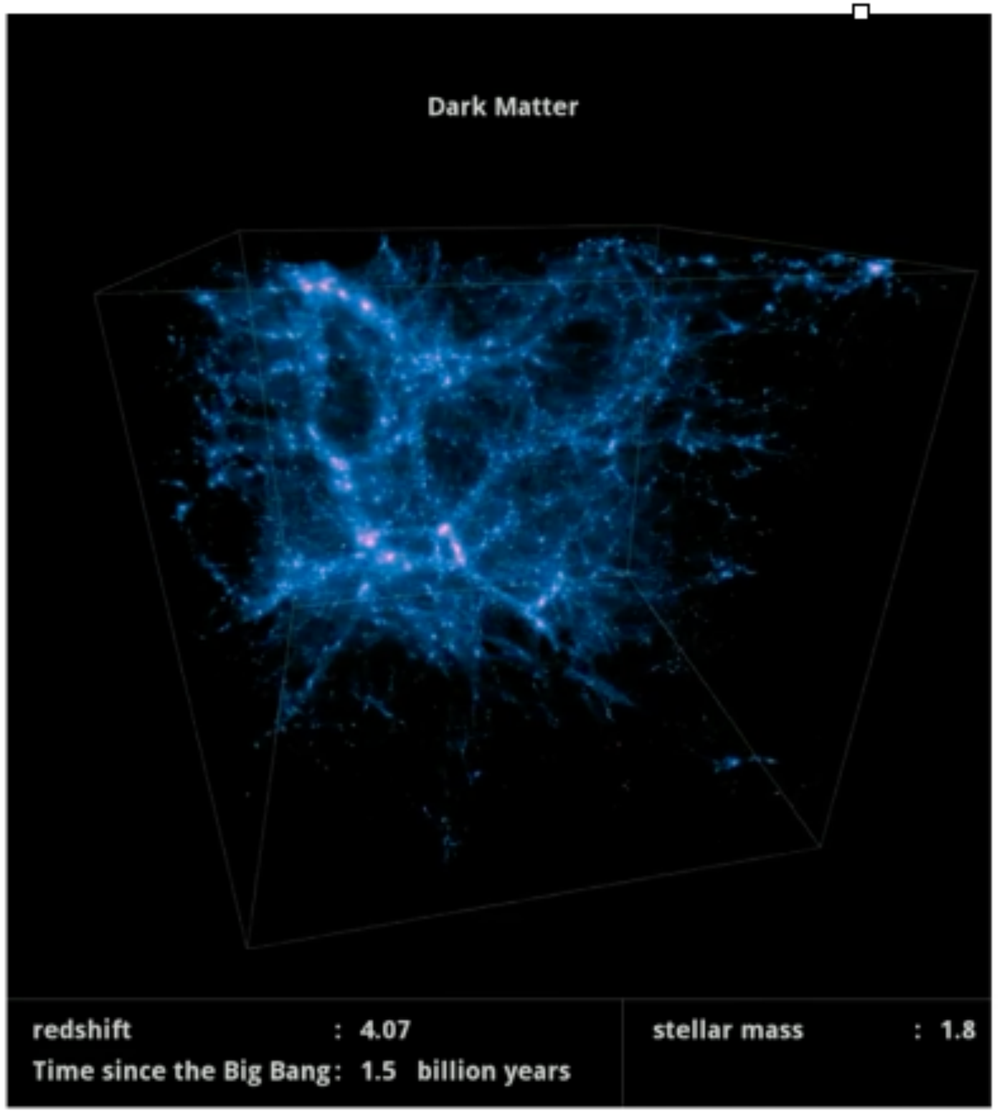
$$\vec{p}$$

Covariance matrix

$$C_{ij} = \langle \xi_i \xi_j \rangle$$

Noise + Cosmic variance

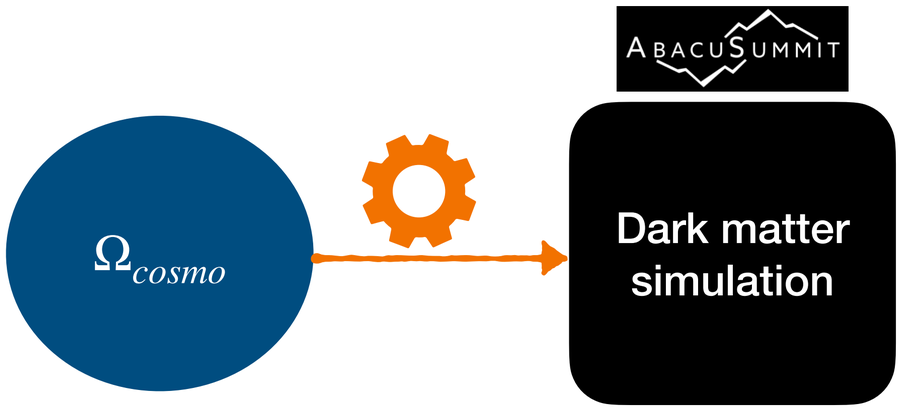
N-body simulations

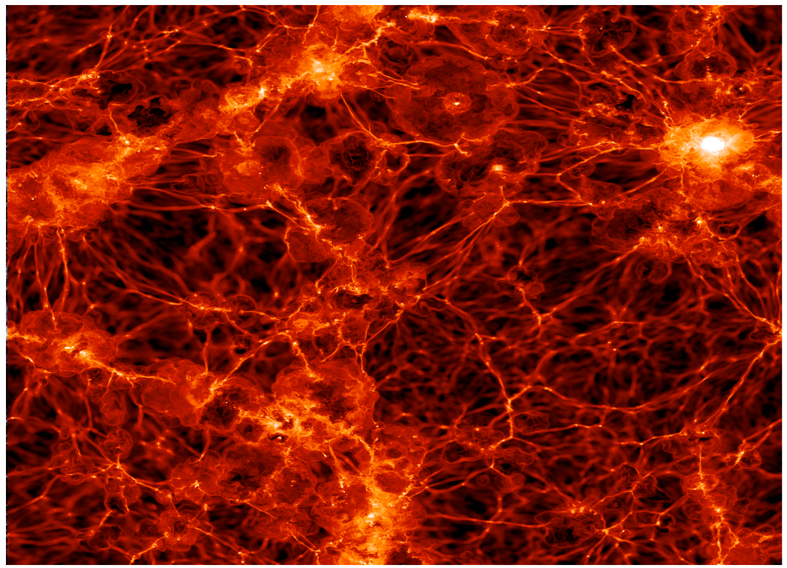


Dark matter only

- Chose cosmological parameters + gravity model
- Draw some random field IC
- Solve Iteratively the dynamical equations

Simulation based inference





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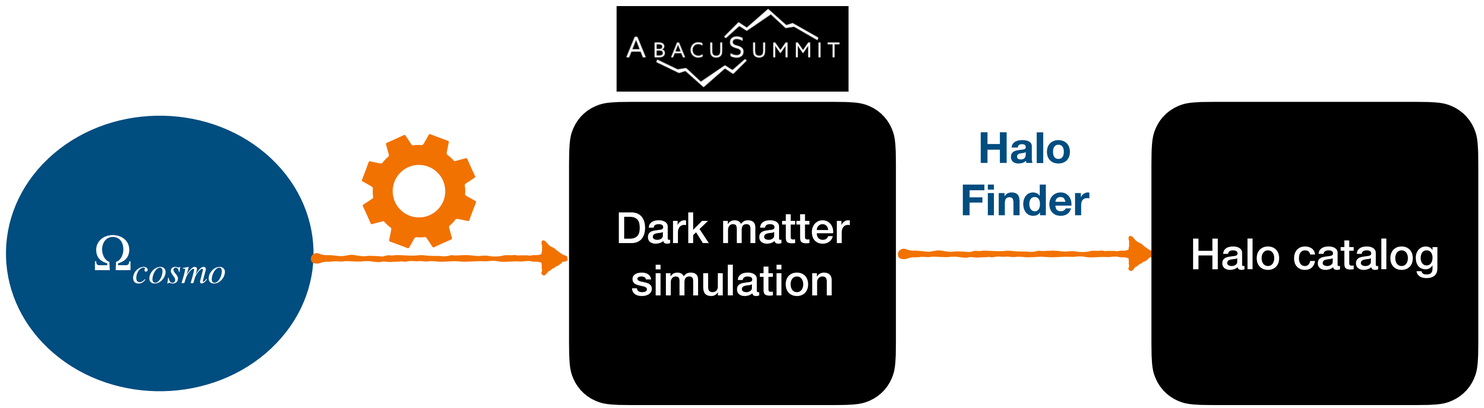

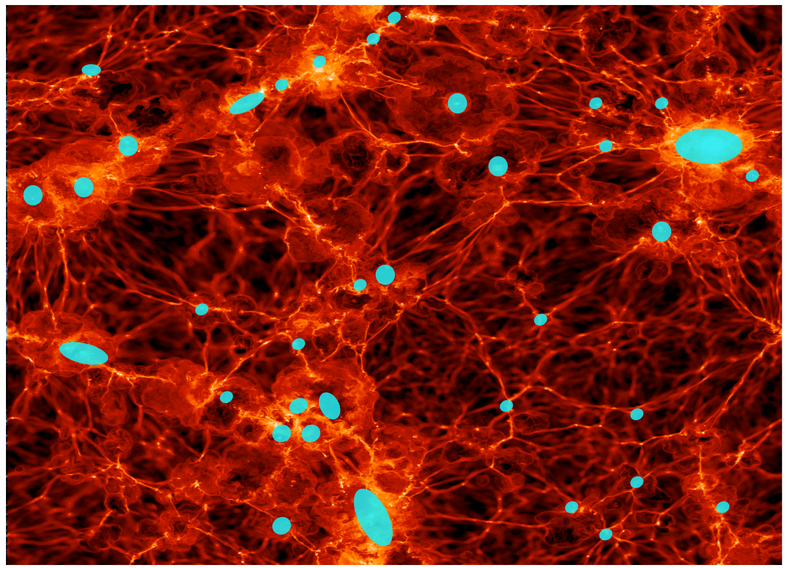

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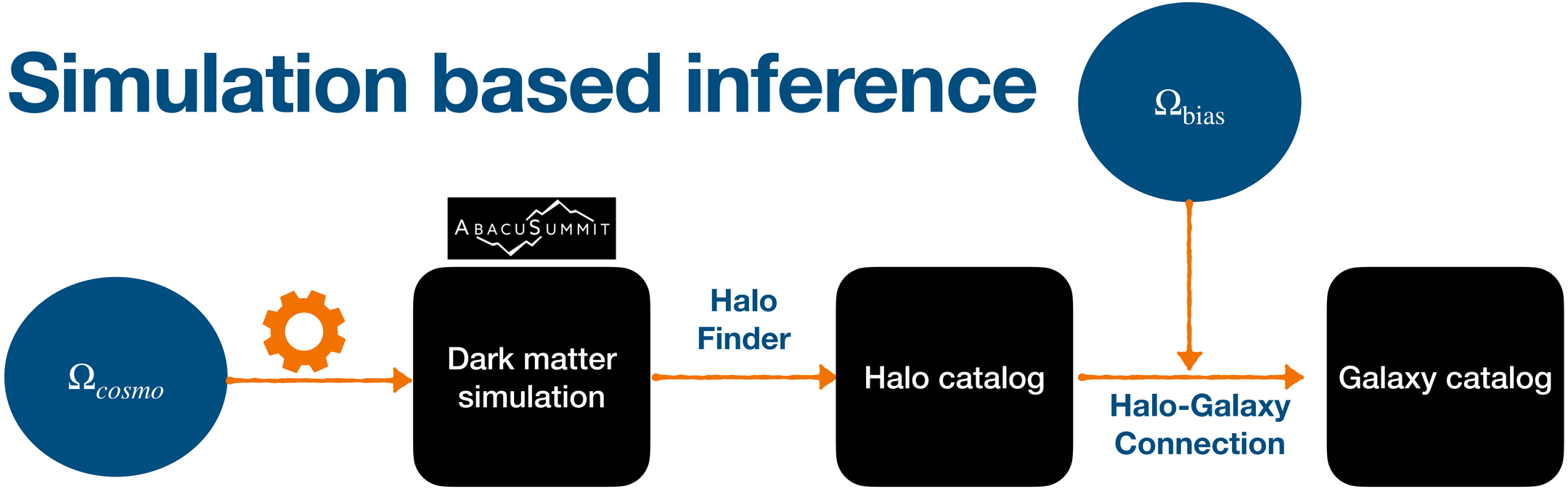

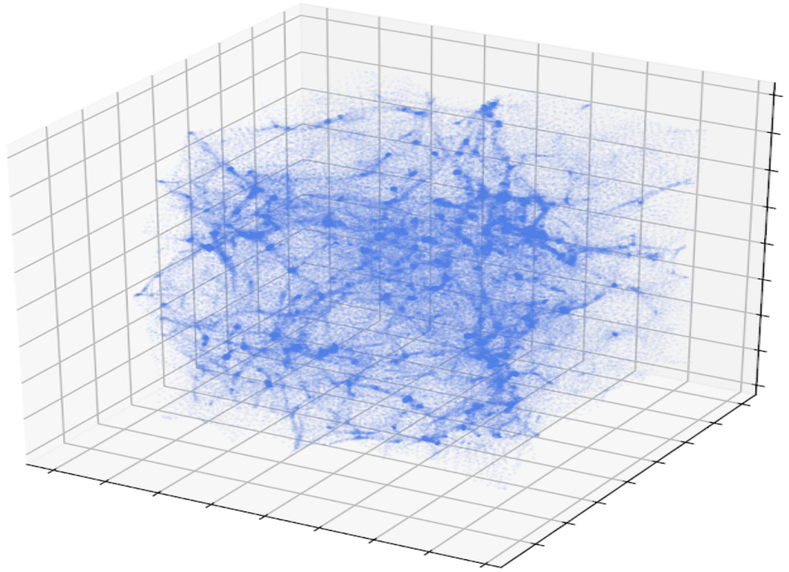

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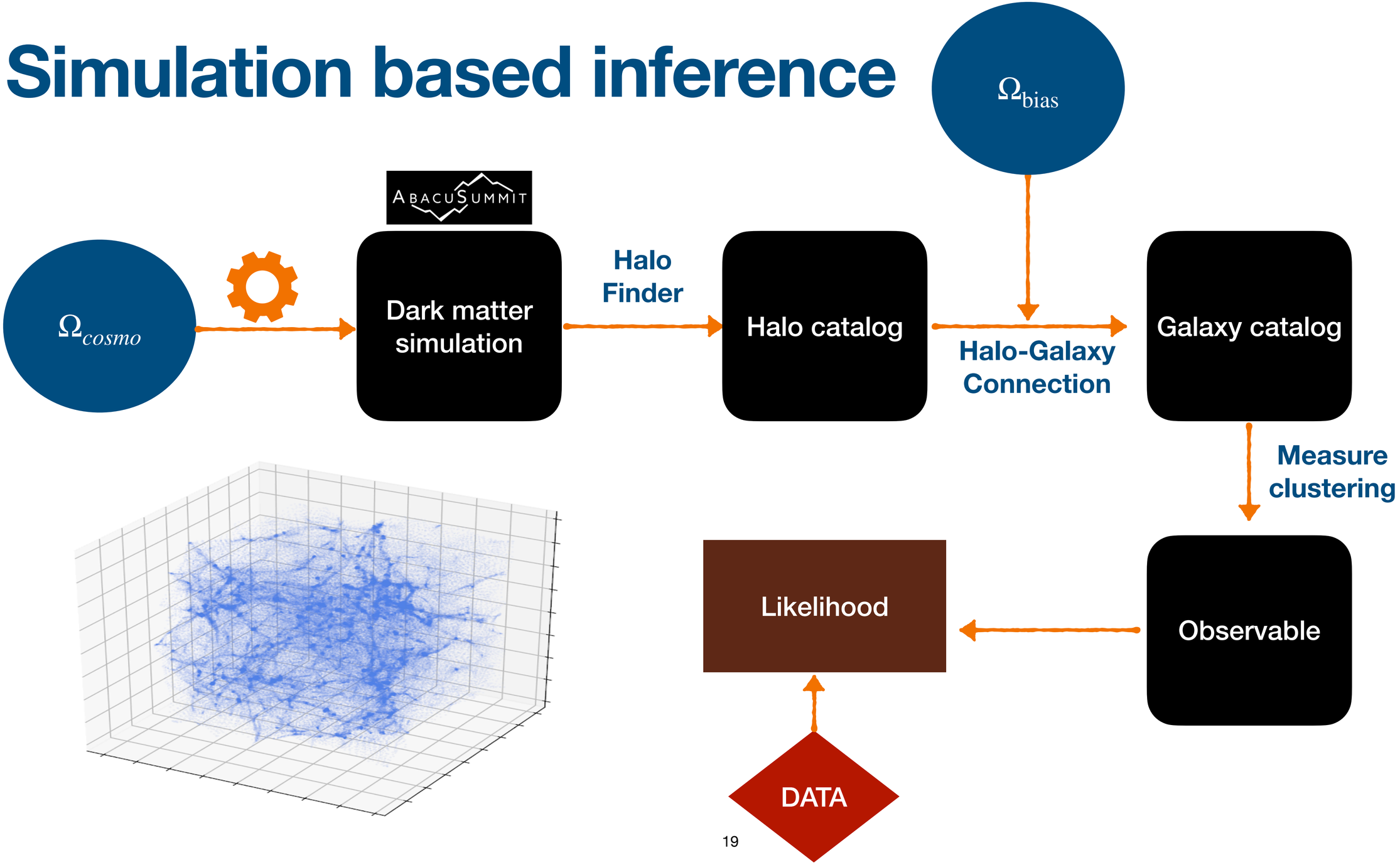

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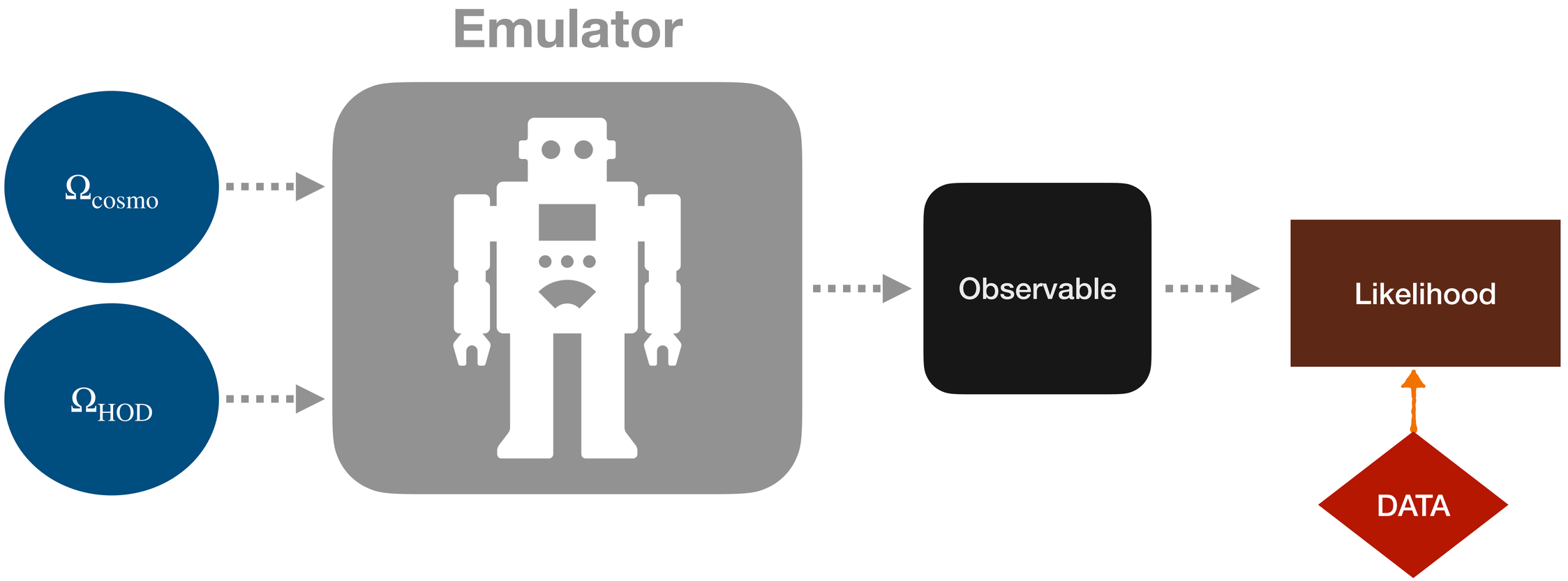

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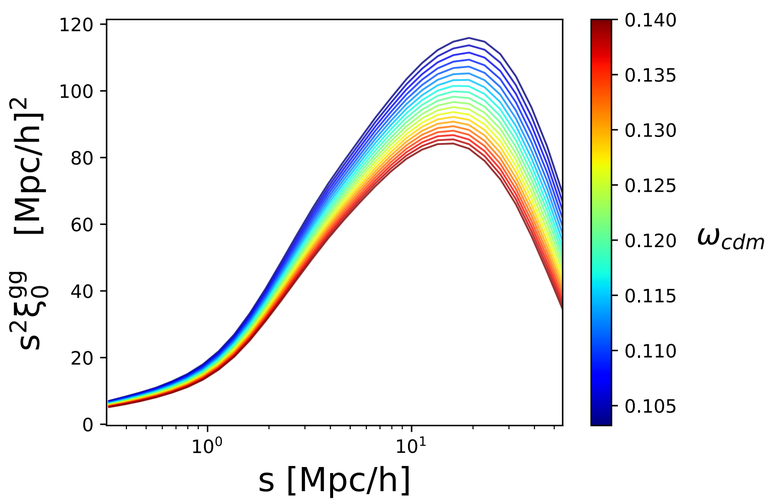
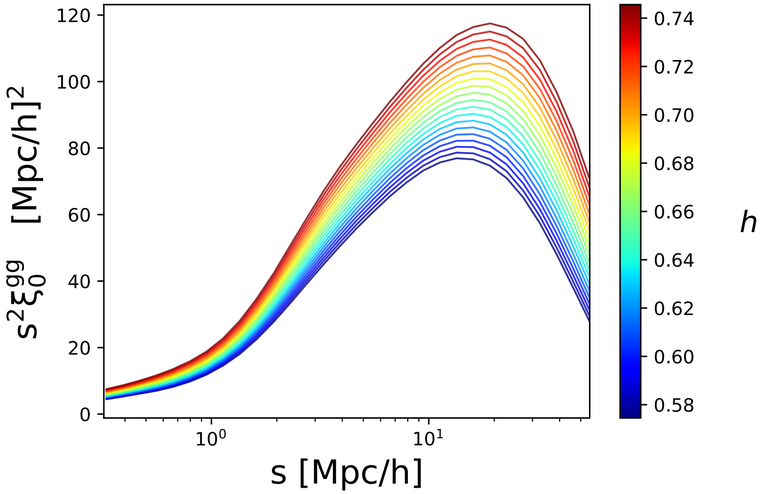
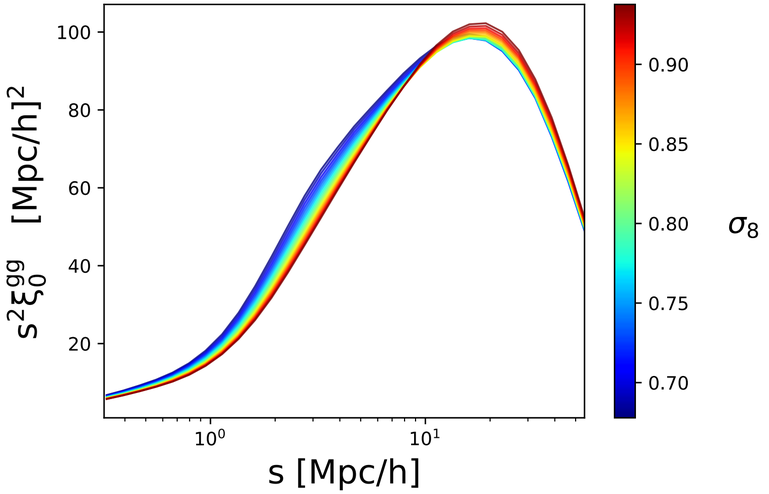
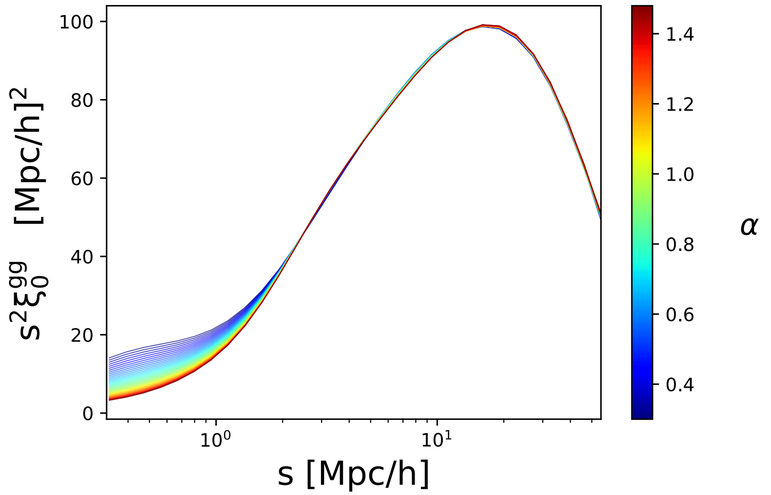
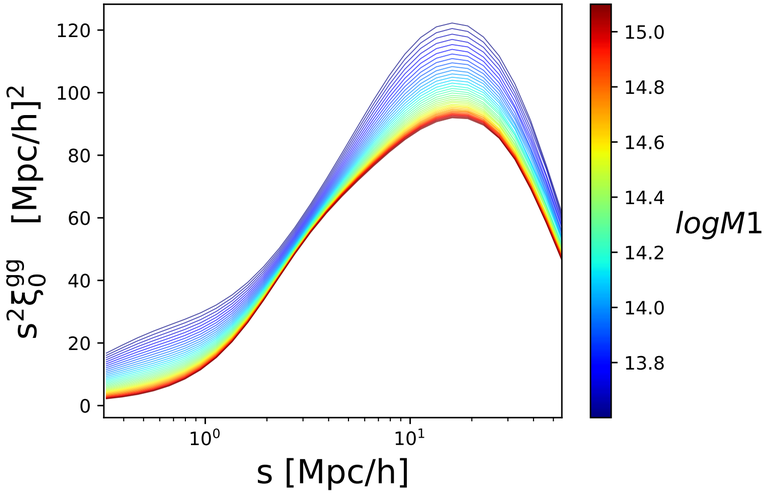
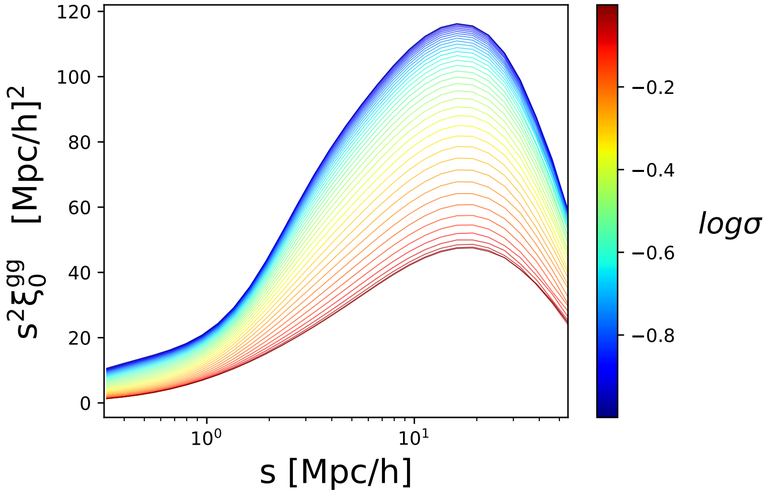




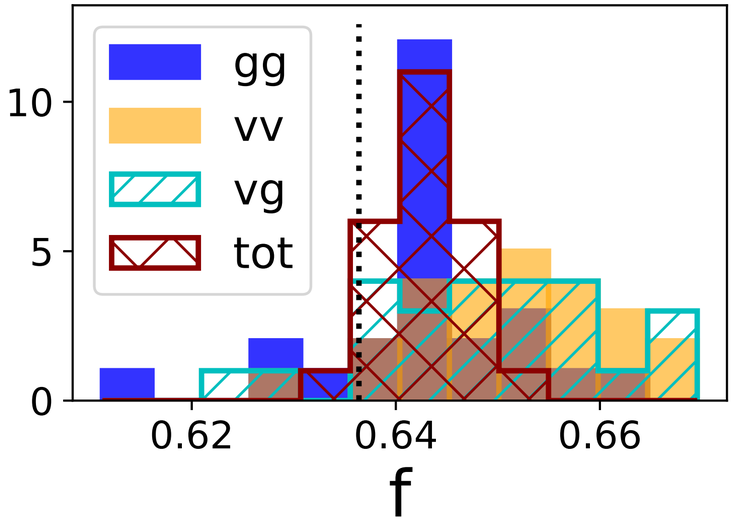


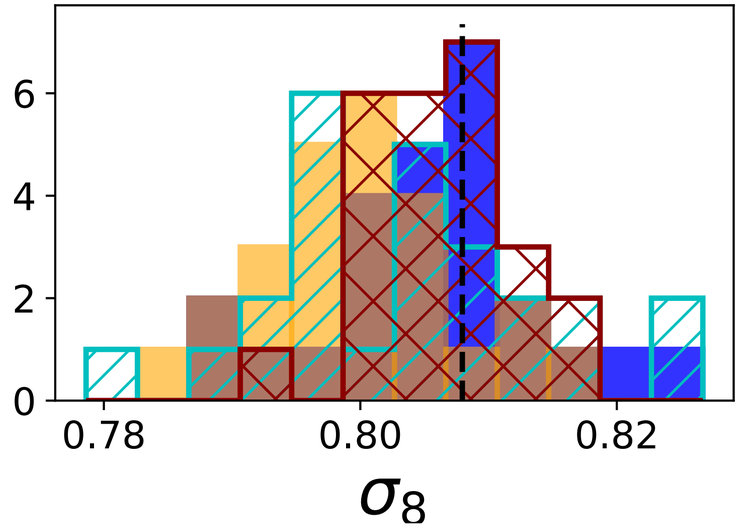


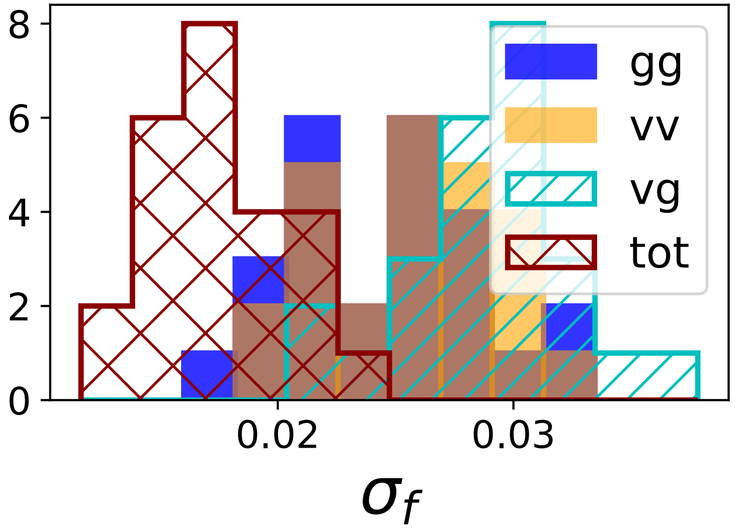


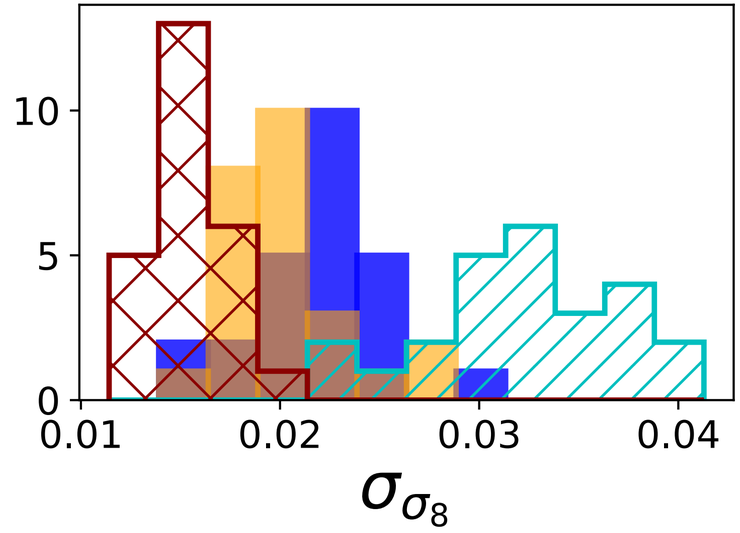


Recovery test on 25 ideal mocks

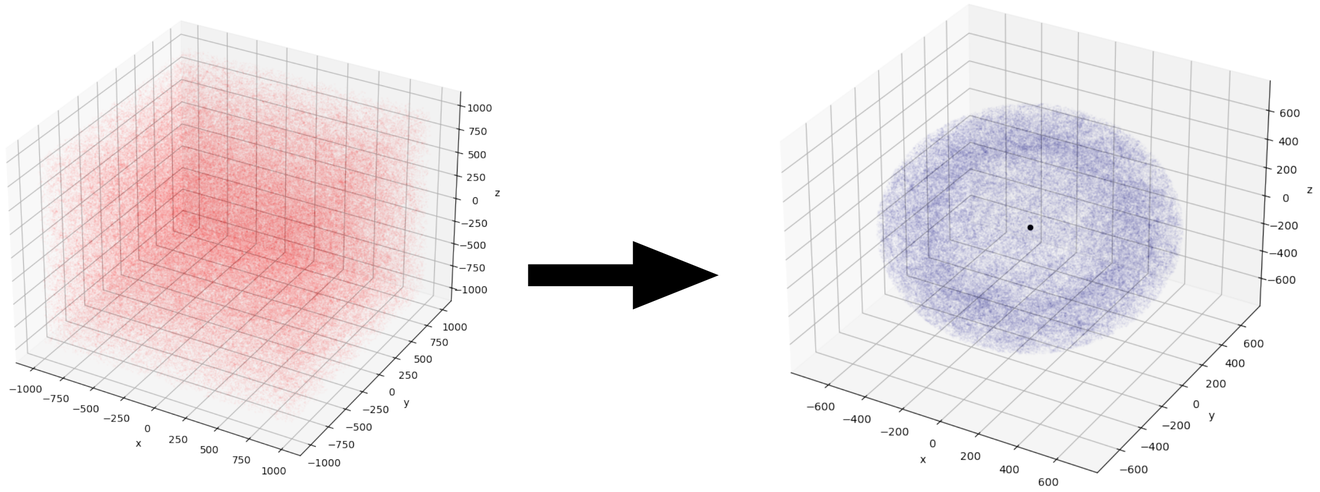








Modeling observational effects



Survey footprint

Galaxy density + velocity errors + (RA,DEC,z)->(x,y,z) + …

Conclusion

- Build new emulator to match DESI BGS data
- Go to lower redshift
- Extend the galaxy-halo parameters
- Include additional systematic effects ?

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Thank You

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