

Exploring the universe through the BORG framework and the Sibelius-Dark simulation

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Outline



• Statistics / Physical Model:

The statistical analysis and physical framework

• Data:

2M++ and its immediate result through BORG

• Simulation:

The Sibelius-Dark simulation

• Beyond:

Constraining cosmology

Simulating galaxies in large scale structures



Relating the two aspects: Data vs simulations?





How we think the data is produced





How we think the data is produced

???



The BORG model



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The BORG machine for posterior sampling





The BORG model: differentiability is required!



Rely on Hamiltonian Monte-Carlo

10

Notably: Halo bias model in BORG





- Similar phenomenology to HOD modeling
 - Power-law at low masses
 - Sharp truncation in cosmic voids
- Mathematical model with 4 parameters

$$\rho_{\rm h} = f \rho_{\rm m}^{\alpha} \exp\left[\left(\rho_{\rm m}/\rho_{\rm exp}\right)^{-\varepsilon}\right]$$



Neyrinck et al (2014, MNRAS)

Likelihood?

....





Library available in BORG:

Poisson count for galaxies in voxels Gaussian Shear lensing likelihood

But all uses linear instrument response

Data: Applying the method to 2M++



The 2M++ data + Inference setup





Initial conditions are part of a Markov Chain





Movie credit: Florent Leclercq

Jasche & Lavaux (2019)

Inference with higher degree of non-linearity



Re-Simulation: The Sibelius-Dark simulation



Expanding the initial conditions...





Large scale constraints



Small scale random realizations Sawala et al. (2022)

Sibelius-Dark run



SIBELIUS-Dark :

A resimulation of the nearby Universe (<200 Mpc)

Simulation configuration

- Code simulation SWIFT (Schaller et al 2018)
- Planck like cosmology
- Dark matter only
- L = 1 Gpc
- Simulation "Zoom" for d<200 Mpc
- N = 5078³
- 4489 cores
 3.5M CPU-h



Semi-analytic galaxy formation model: Galform



• Number counts of sub-mm selected galaxies

- Tested with observational data
 - z=0 to z=6
 - Wavelengths from far-UV to sub-mm

• K-band luminosity function and stellar mass function





The Sibelius-Dark simulation... things that work



An historical structure: the CfA great wall & Coma cluster



QUIZZ: Which one is the real one?

An historical structure: the CfA great wall & Coma cluster



Some famous galaxy clusters





2M++ galaxies

Some diagnostic on local luminosity function / Black Hole





Apparent magnitude luminosity function is alright



Galaxy redshift selection









Local void ? Or not ?









Halo mass function... maybe not 100% there?



Local group motion: something hidden in the IC



But improving with better dynamical model...



(unpublished result)

Future models... ML of course!



BORG + Field-Level Emulator (L. Doeser)



Connection with accelerated forward models WG

Forward Part – Summary statistics note: from one forward pass with same IC





Backward Part – Interfacing BORG with hades_python



Gradient test OK

for full model with LPT + Emulator



• **Time comparisons** for a 128^3 box with L=250 Mpc/h

<u>Conclusion:</u> Emulator in single precision 30% slower than BORGPM, but with 125 times more modes we can trust? (from k=0.2 to 1.0)

<u>model</u>	<u>LPT</u>	BORGPM (20 steps)	LPT+EMU (single precision)	LPT+EMU (double precision)	<u>Gadget</u>
<u>machine</u>	CPU ¹	CPU ¹	1 GPU ¹	1 GPU ¹ + CPU	16 CPU ²
forward	~0.3s	~5s	<mark>~</mark> 4s	GPU OOM	~250s
<u>backward</u>	~0.2s	~15s	<mark>∼5s</mark>	GPU OOM	

¹ Supermicro 4124GS-TNR node with 1 GPU card A100, 48 cores, ² Dell R6525 node with 2 x 32 Core AMD EPYC2 Rome 7502, 2.5 GHz

Doeser et al. (in prep)

Current BORG run with emulator

Truth:



MCMC sampling of initial conditions with self consistent test (Gaussian noise), status after 1000 samples:



Doeser et al. (in prep)

Inferred final density



Conclusion





- BORG : a model for building fair samples of IC from existing galaxy data
- Sibelius-Dark recovers the spatial galaxy distribution from nearby Universe
- Optical properties are fairly simulated with Galform
- Reproduce a Gaia-compatible M31/MW pair at right place
- Cluster masses in general good agreement with other observables
- K-band/ stellar mass function still problematic
- Halo mass function biased at small masses + Some defect for the local group velocity