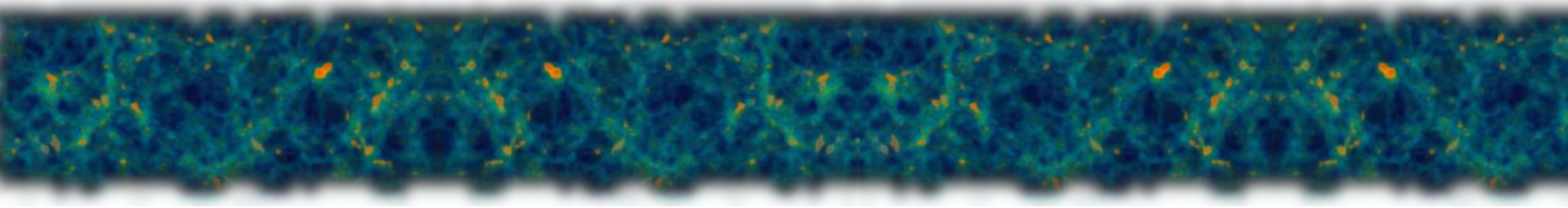


Cosmological inference from self-consistent Bayesian forward modelling of deep galaxy redshift surveys

Doogesh Kodi Ramanah

Guilhem Lavaux
Jens Jasche
Ben Wandelt

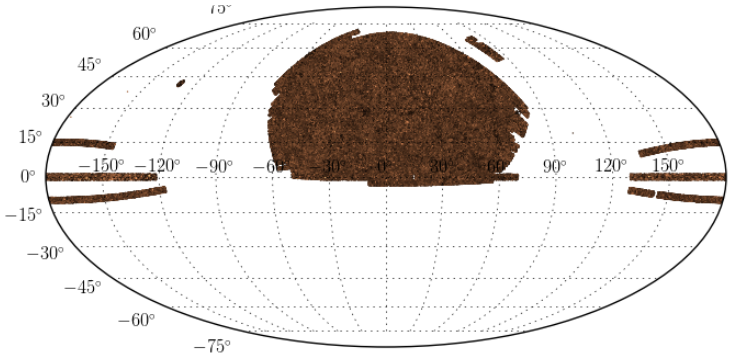
Institut d'Astrophysique de Paris

Statistical challenges for large-scale structure in the era of LSST, Oxford, 2018

Cosmological data challenges

- Incomplete noisy sky with systematic effects (masks, complex noise models, …)
- **Transformation:** physical (comoving) space ⟷ observational space

Noisy large-scale structure data



signal reconstruction

Cosmology encoded in expansion & global geometry (Alcock-Paczyński effect)

Cosmological data challenges

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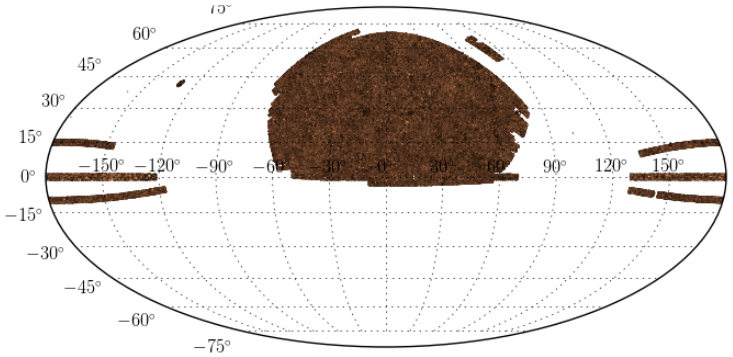
Noisy **large-scale structure data**



Credit: Assassin's Creed (Ubisoft)

AQUILA Consortium

HADES → BORG → ALTAIR

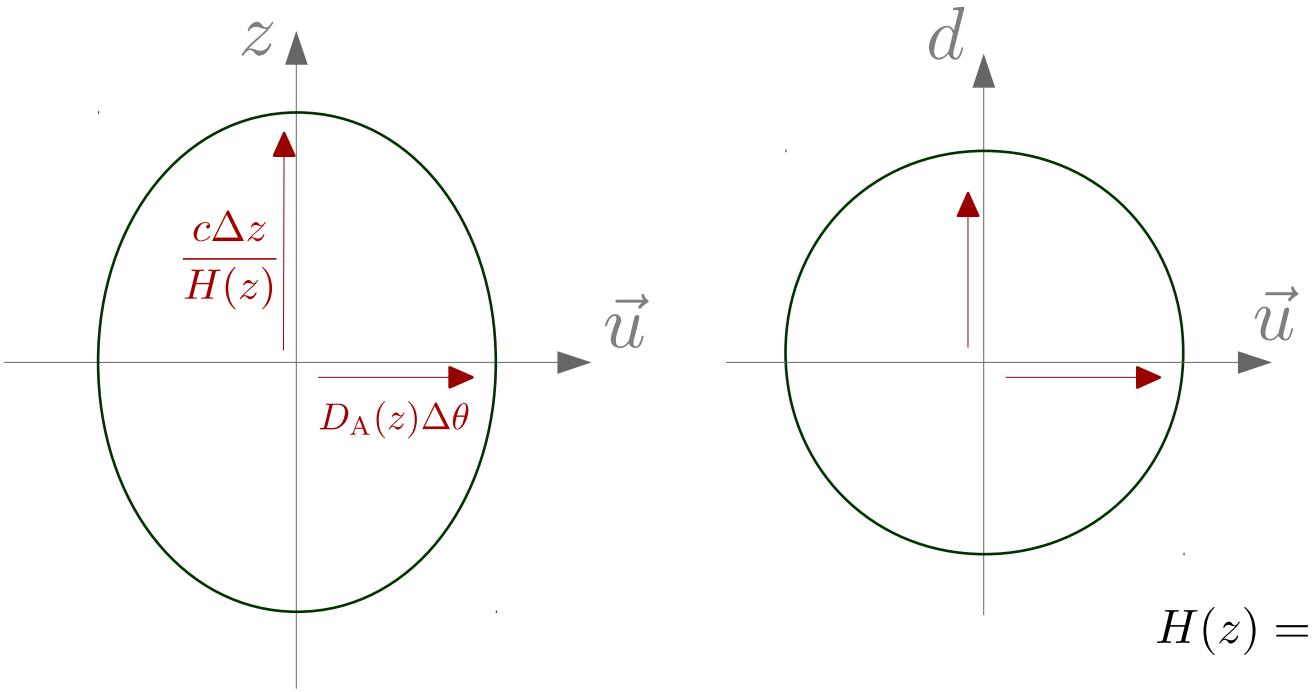
ALTAIR (**AL**cock-Paczyński cons**Tr**A**I**ned **R**econstruction) (DKR, Lavaux & Wandelt 2018, in prep.)

- Liberate cosmology → Cosmological parameter inference via the **Alcock-Paczyński (AP)** test
- Also jointly infer underlying **3D power spectrum** + more realistic (**non-linear**) **bias** model

Alcock-Paczyński Test

Coordinate Transformation

$(z, \vec{u})$ **Redshift space** $\quad \{\Omega_m, \Omega_\Lambda, \Omega_k, \omega, H_0\} \quad$ $(d, \vec{u})$ **Comoving space**



$$d = \int_{z_1}^{z_2} \frac{1}{cH(z)}$$

$$H(z) = H_0(\Omega_m(1+z)^3 + \Omega_k(1+z)^2 + \Omega_\Lambda)^{\frac{1}{2}}$$

- Test of the expansion & geometry of the Universe
- No dependence on evolution of galaxies but only on geometry of Universe

Alcock-Paczyński Test

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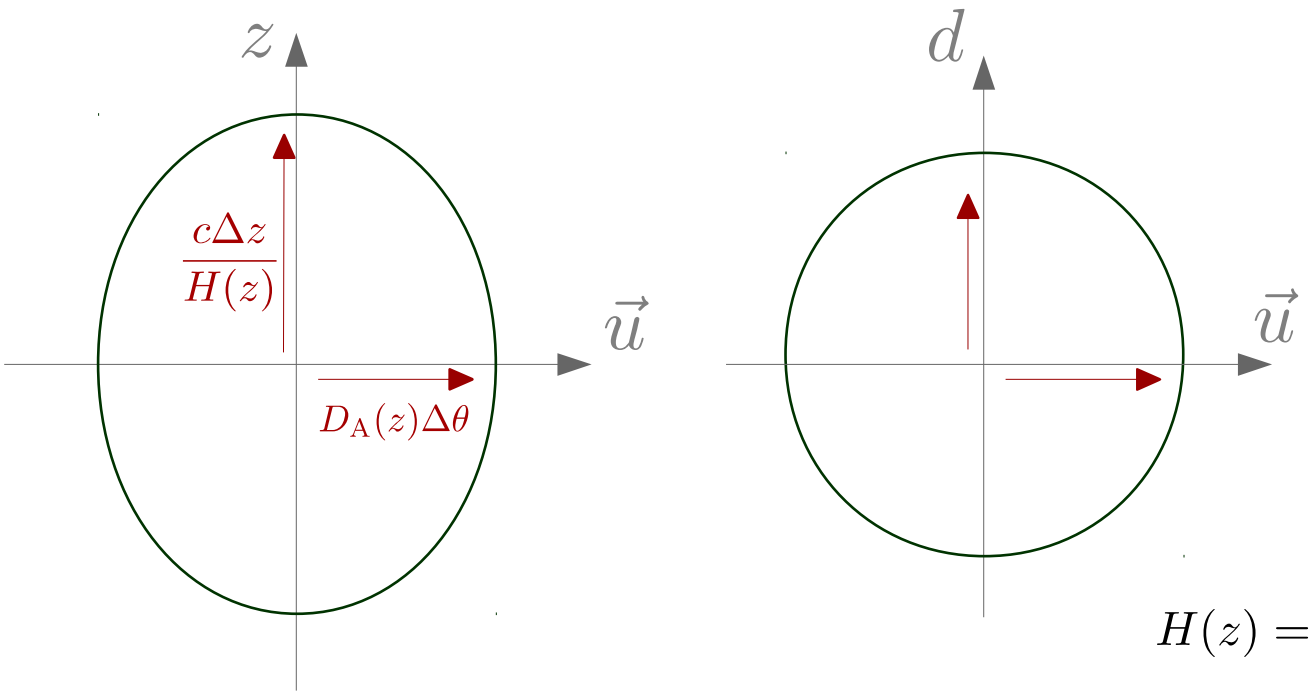

- Distortions due to assumption of incorrect cosmological parameters
- Structure: **Spherical → Ellipsoidal**
- Statistical distribution: **Isotropic → Anisotropic**

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$$H(z) = H_0(\Omega_m(1+z)^3 + \Omega_k(1+z)^2 + \Omega_\Lambda)^{\frac{1}{2}}$$

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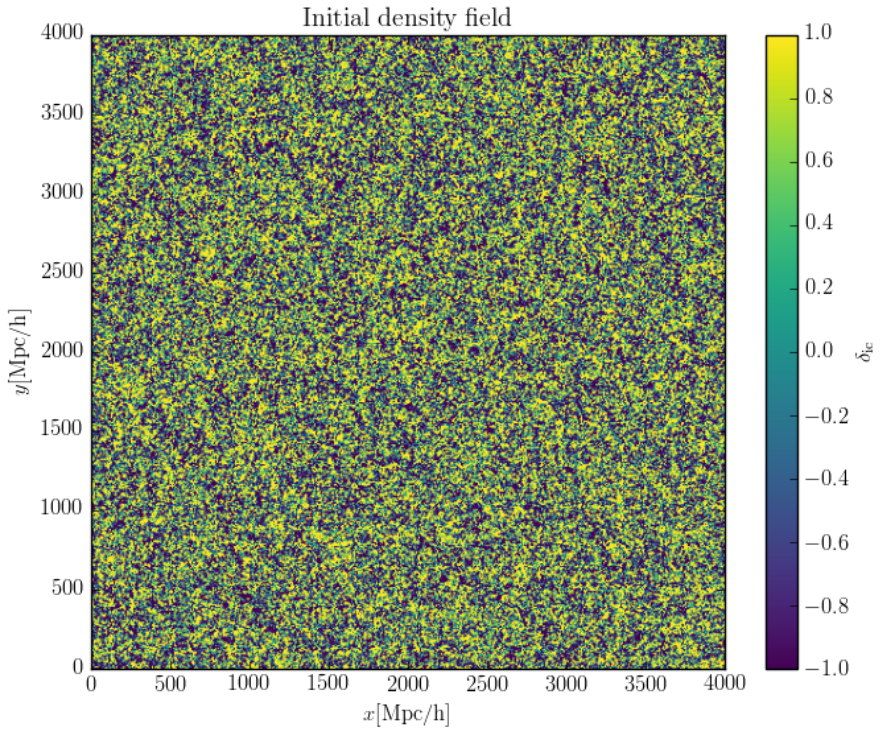
Visualising cosmic expansion

[Standard ΛCDM]

- $\{\Omega_{\rm m} = 0.3089,\ \Omega_\Lambda = 0.6911,\ \Omega_{\rm k} = 0,\ \omega = -1,\ h = 0.6774\}$

Initial conditions



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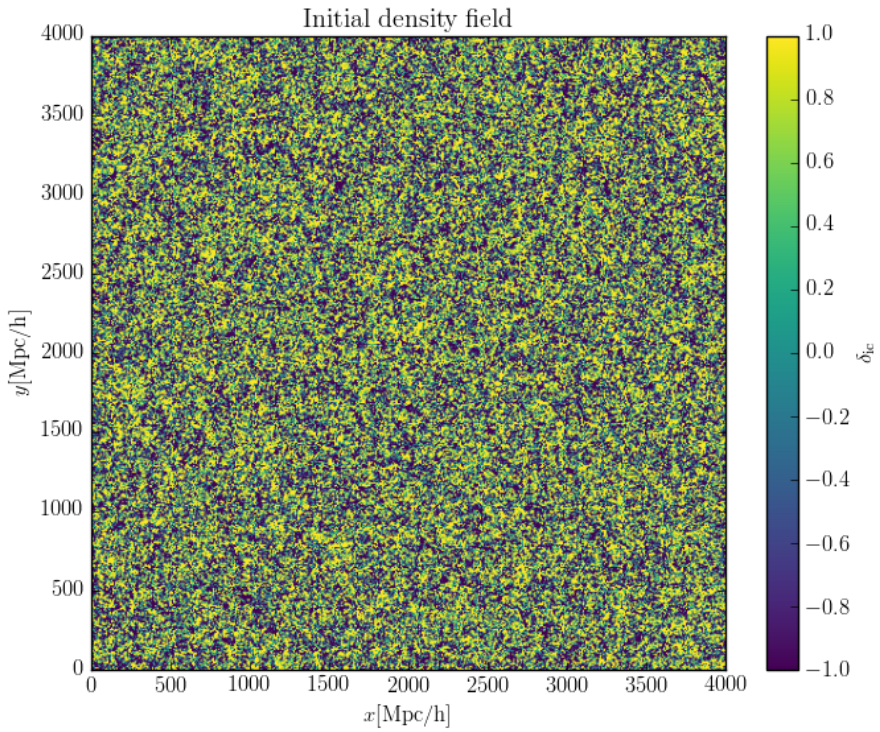
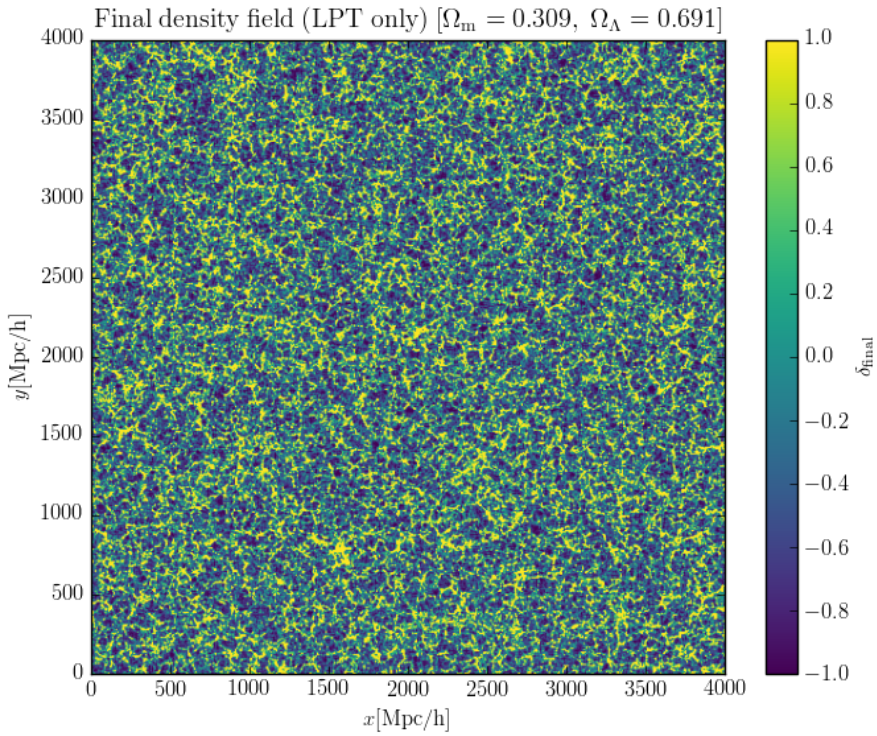


Final (LPT) density field



Comoving space

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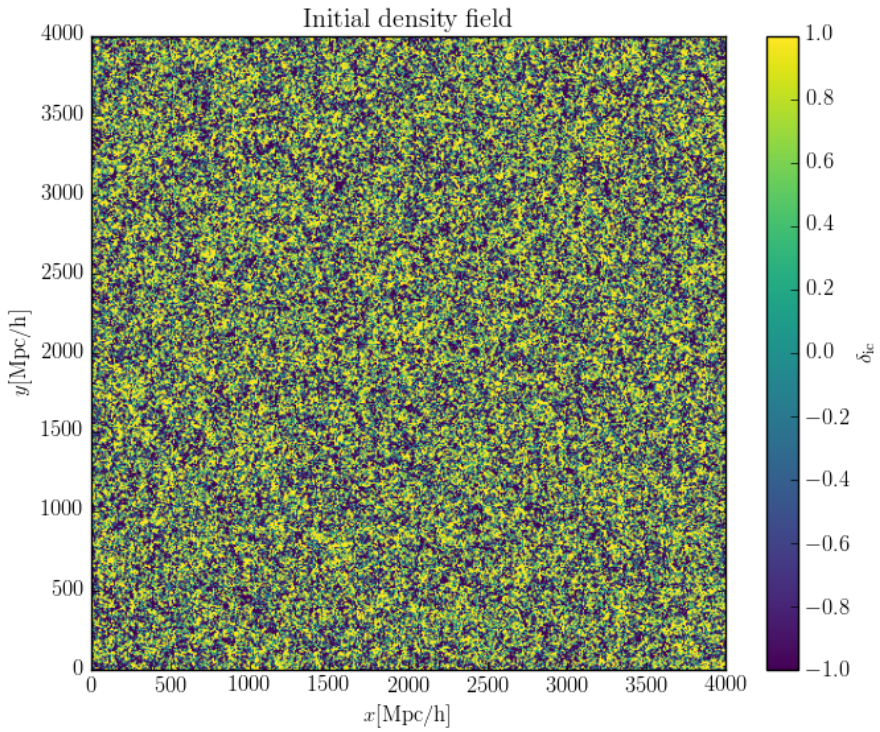
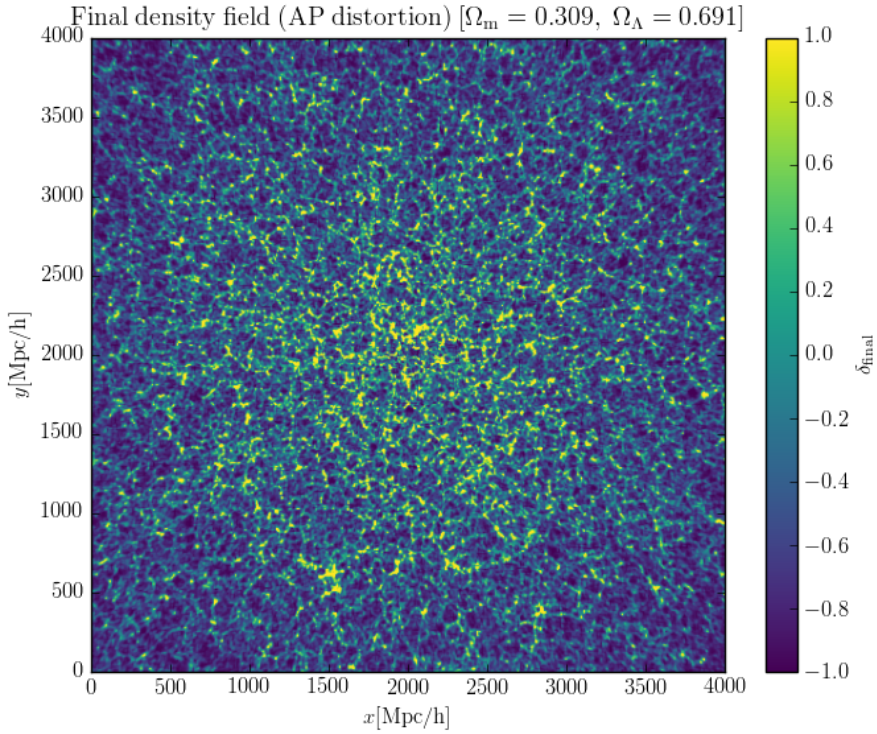


Final (LPT+AP) density field



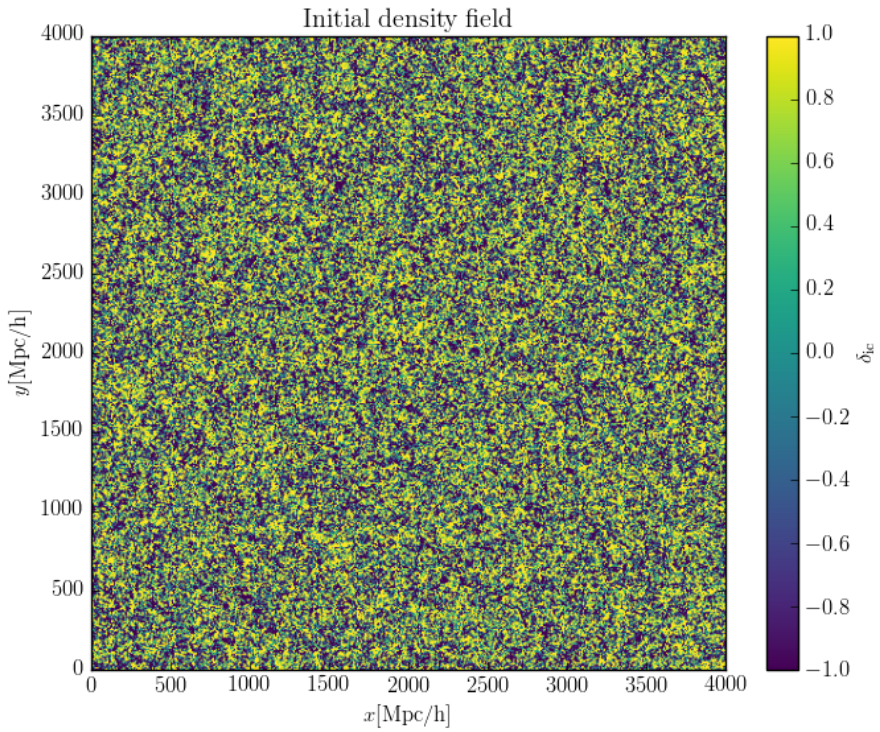
Redshift space

Visualising cosmic expansion

[Einstein-de Sitter Universe]

- $\{\Omega_{\rm m} = 1.0,\ \Omega_\Lambda = 0,\ \Omega_{\rm k} = 0,\ \omega = -1,\ h = 0.6774\}$

Initial conditions



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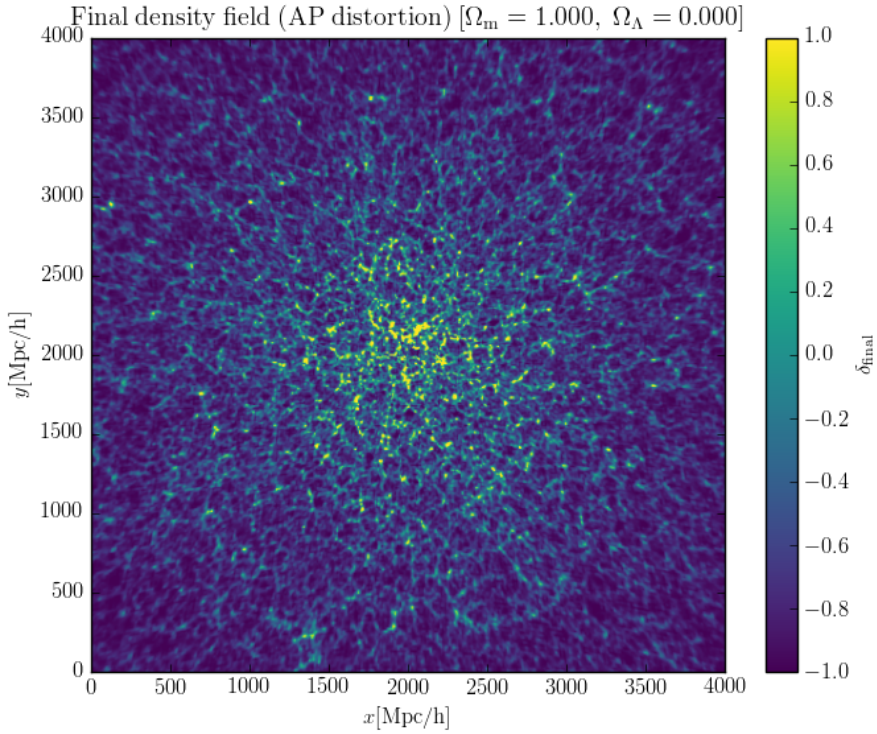
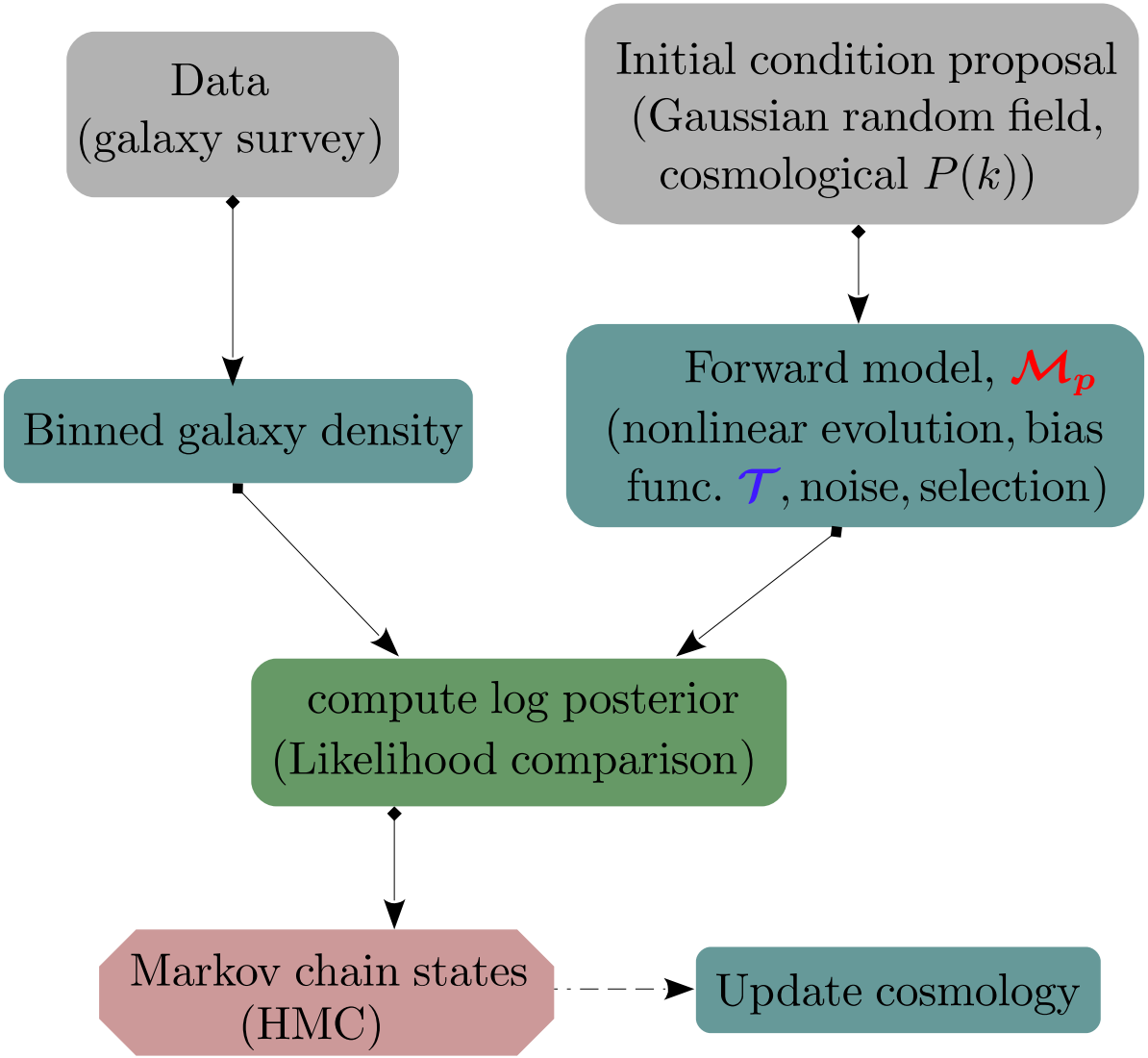


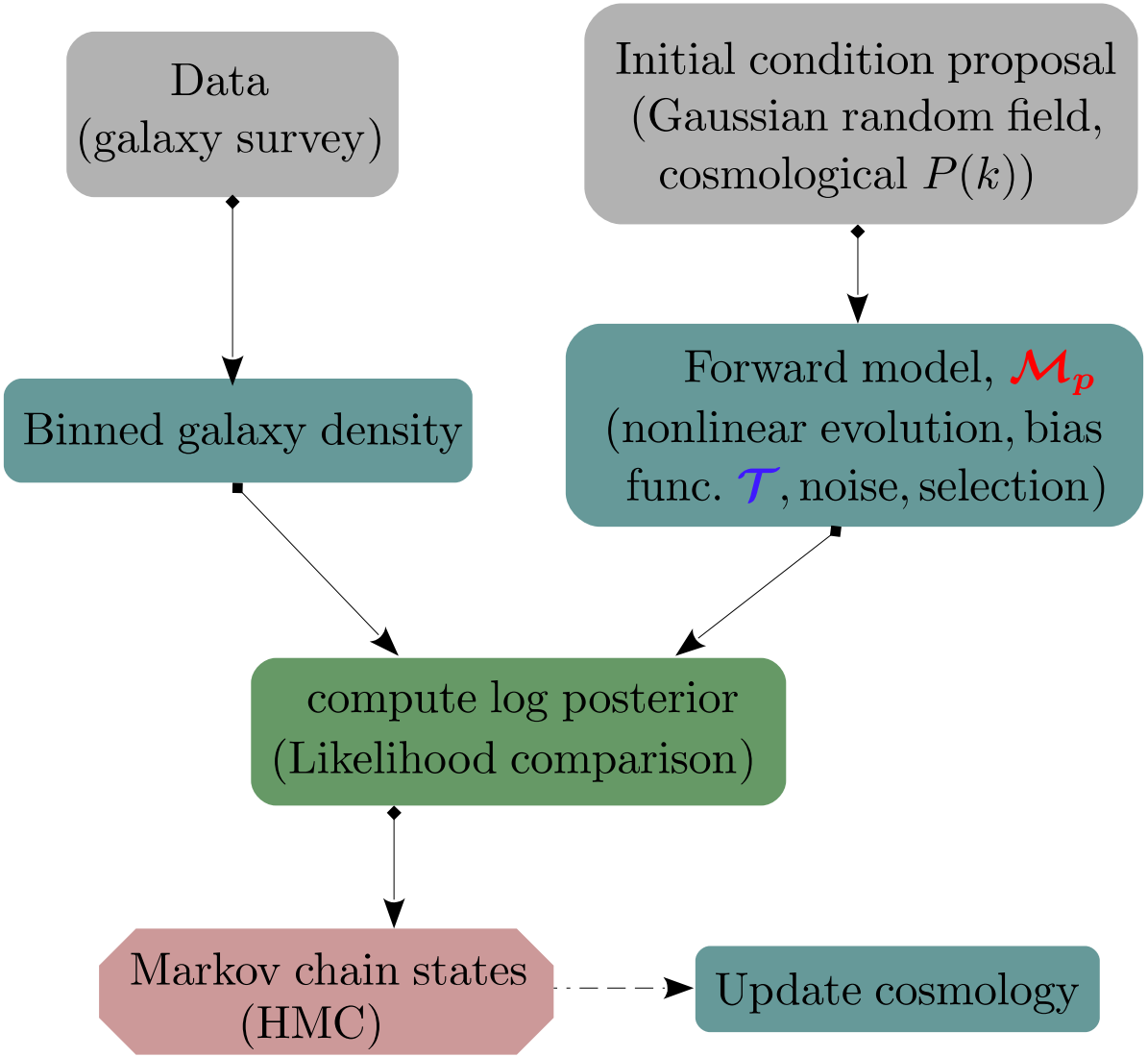
Redshift space

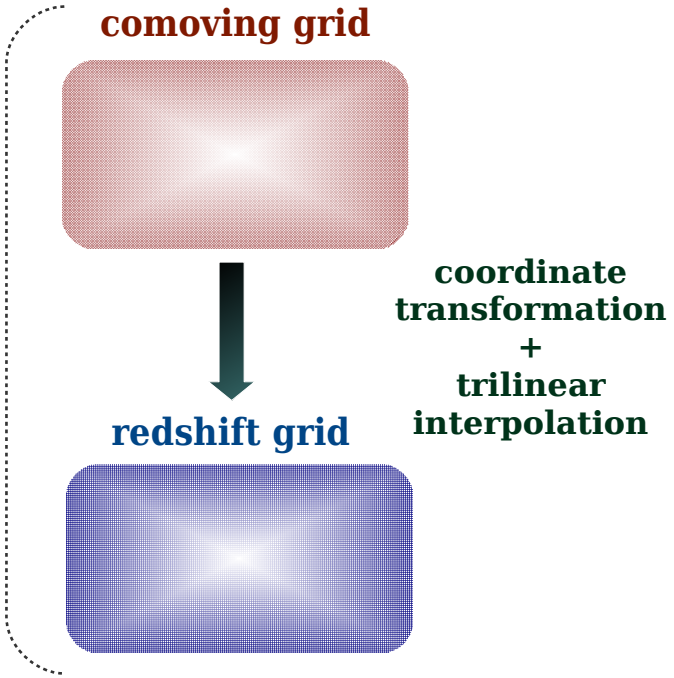
ALTAIR reconstruction scheme



Data model: $N_p^g = R(z_p)\bar{N}_p^g \mathcal{T}\left(1 + \mathcal{M}_p\{[\hat{\delta}_k]_{\tilde{p}}\}_p\right)$

ALTAIR reconstruction scheme





$$\delta_p^{(z)} = \mathcal{M}_p[\delta^{(x)}]_p$$

- Redshift space representation allows comparison with data via likelihood

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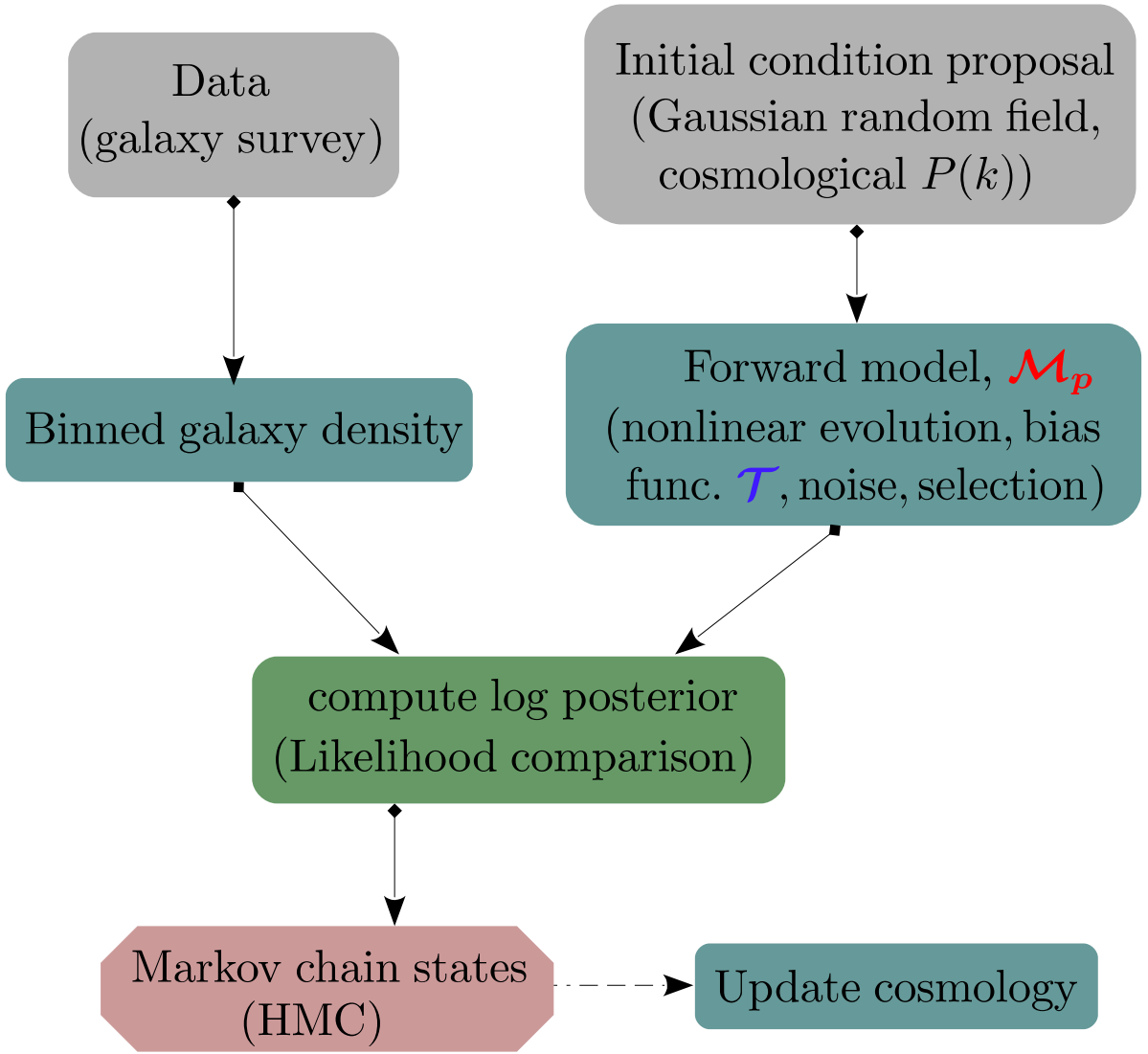
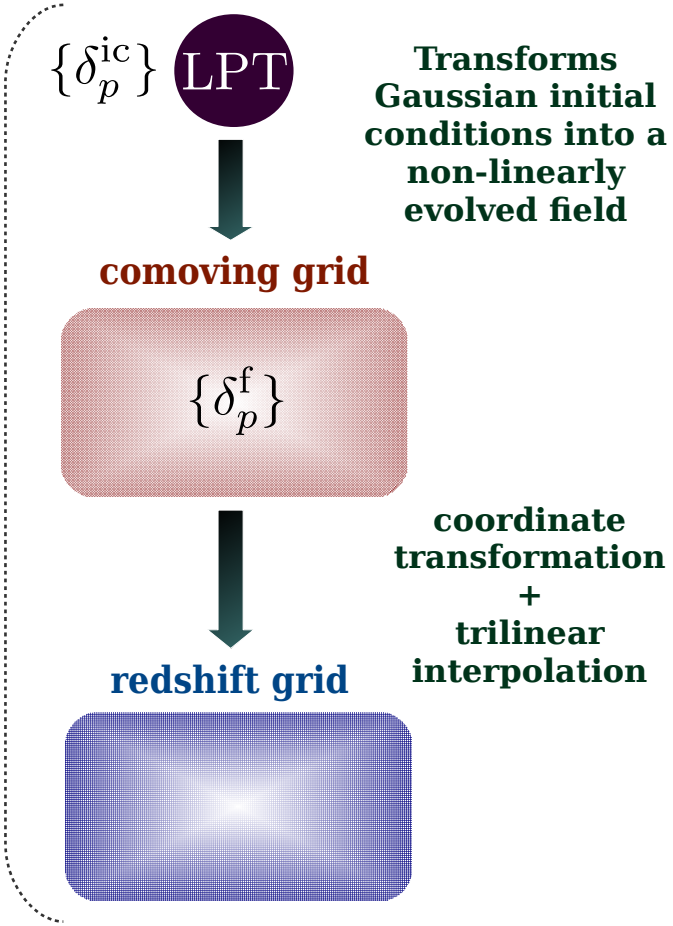
ALTAIR reconstruction scheme



Lagrangian Perturbation Theory



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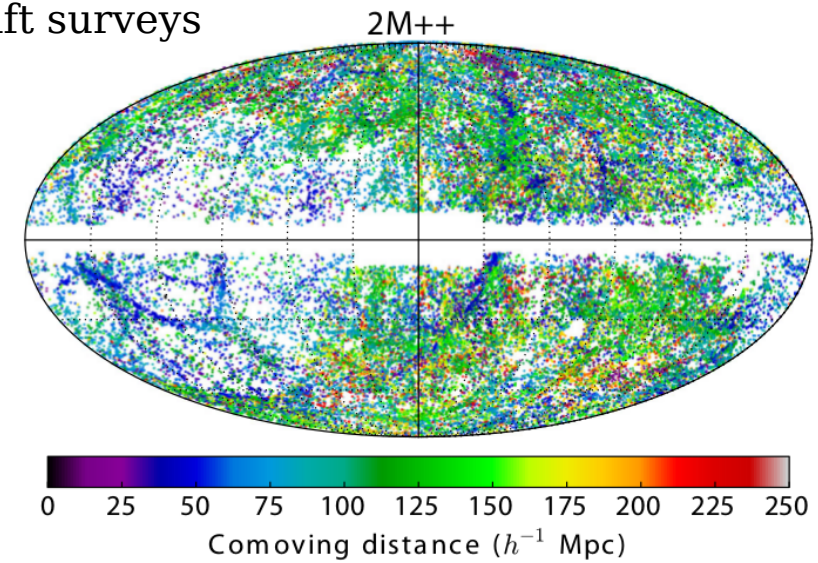
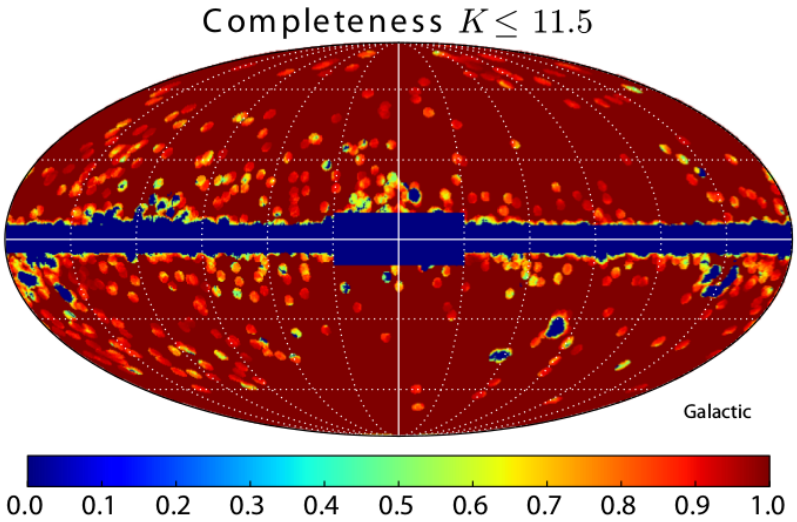
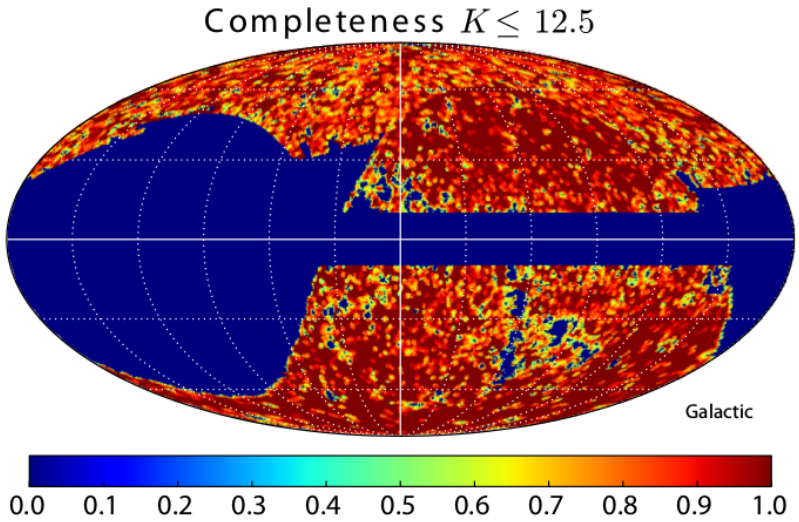
Validation on mock catalogues (A) - 2M++

2M++ galaxy compilation : (Lavaux & Hudson 2011)

- Superset of {**2MASS, SDSS-DR7, 6dFGRS-DR3**} redshift surveys
- Greater depth & higher sampling than **IRAS** survey
- Sub-divided into 2 *K*-bands
- Anisotropic selection and strong galaxy clustering







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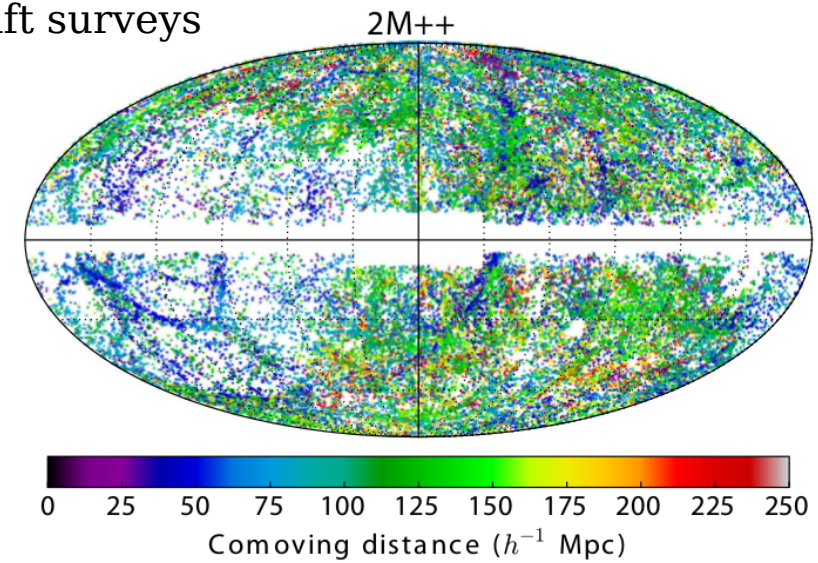
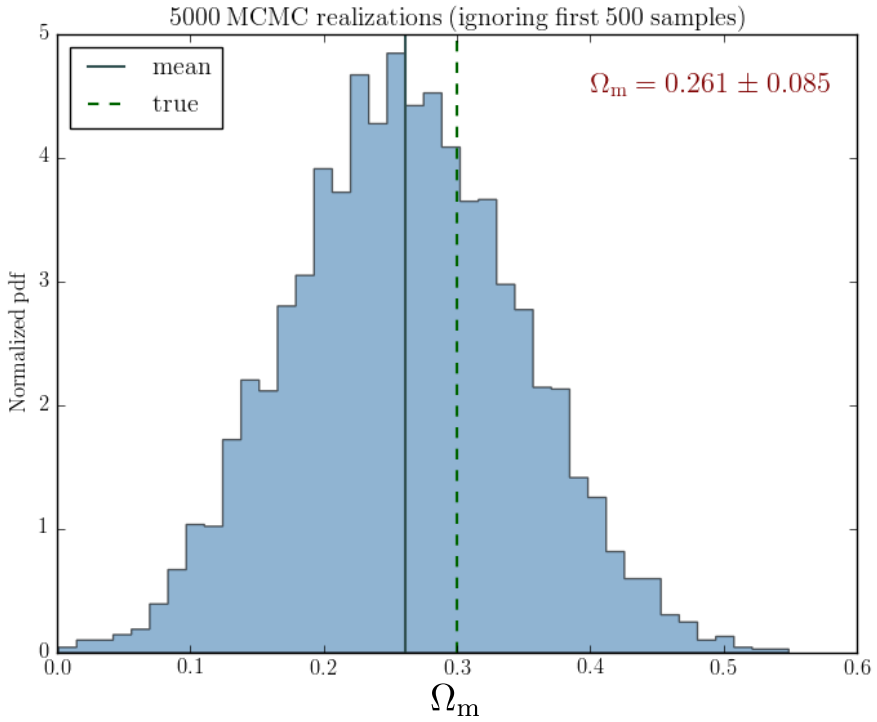




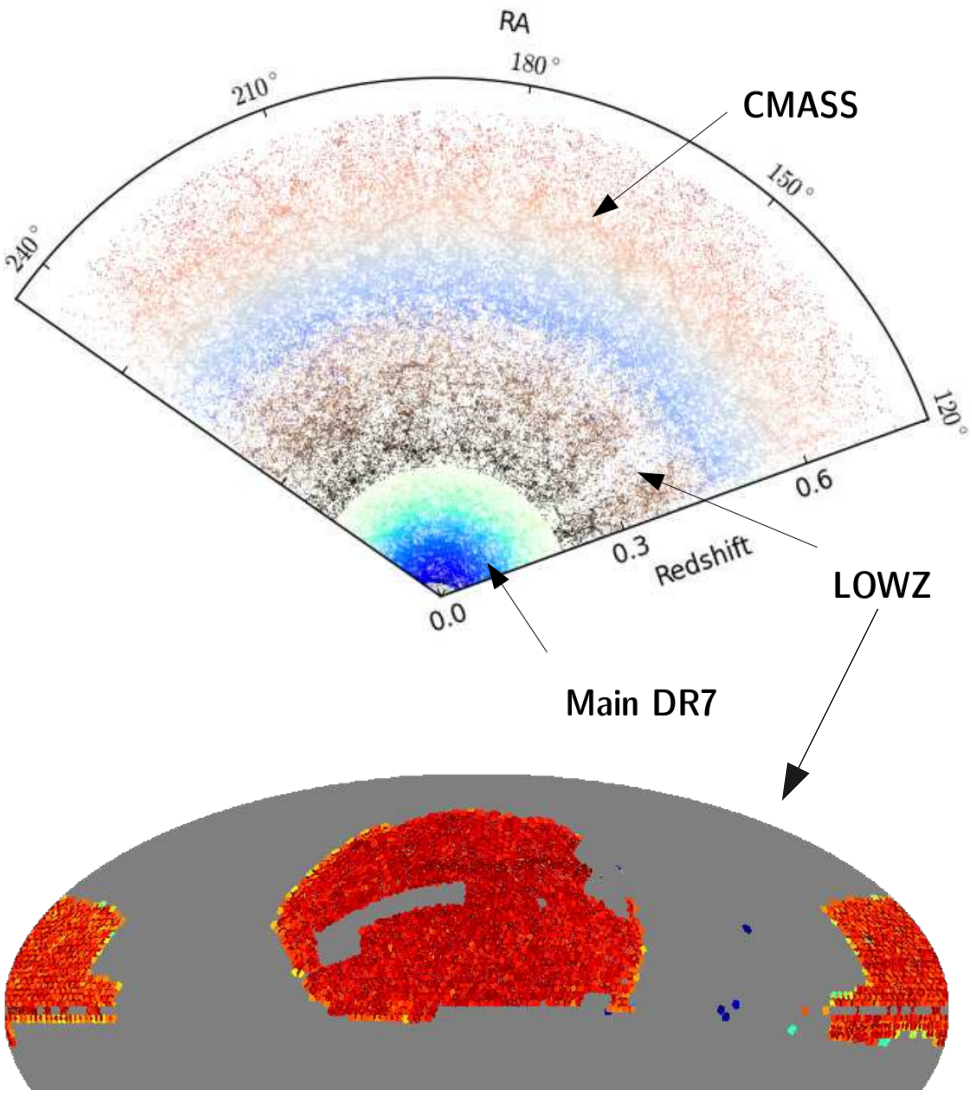
Simulation box Grid with 32^3 voxels, 1200 Mpc side length

- Tested on low-resolution mock data
- Forward model: **LPT** + **AP**
- ~ Linear expansion regime
- Broad posterior for $\boldsymbol{\Omega_m}$

Validation on mock catalogues (B) - SDSSIII

Simulation box Grid with 128^3 voxels
4000 Mpc side length

- Forward model: **LPT** + **AP**
- Highly structured survey geometry & selection effects

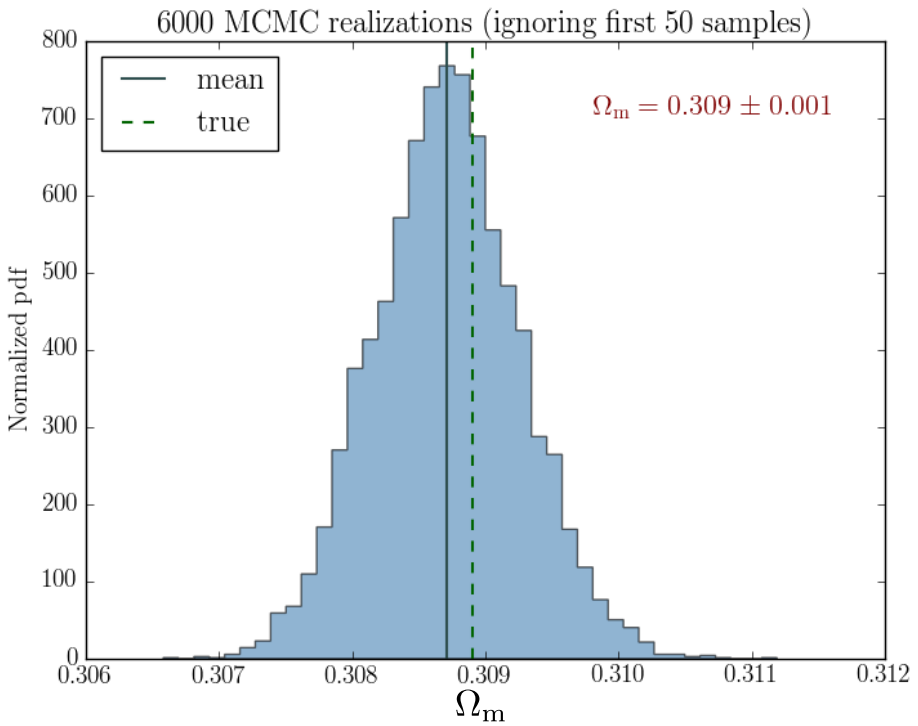


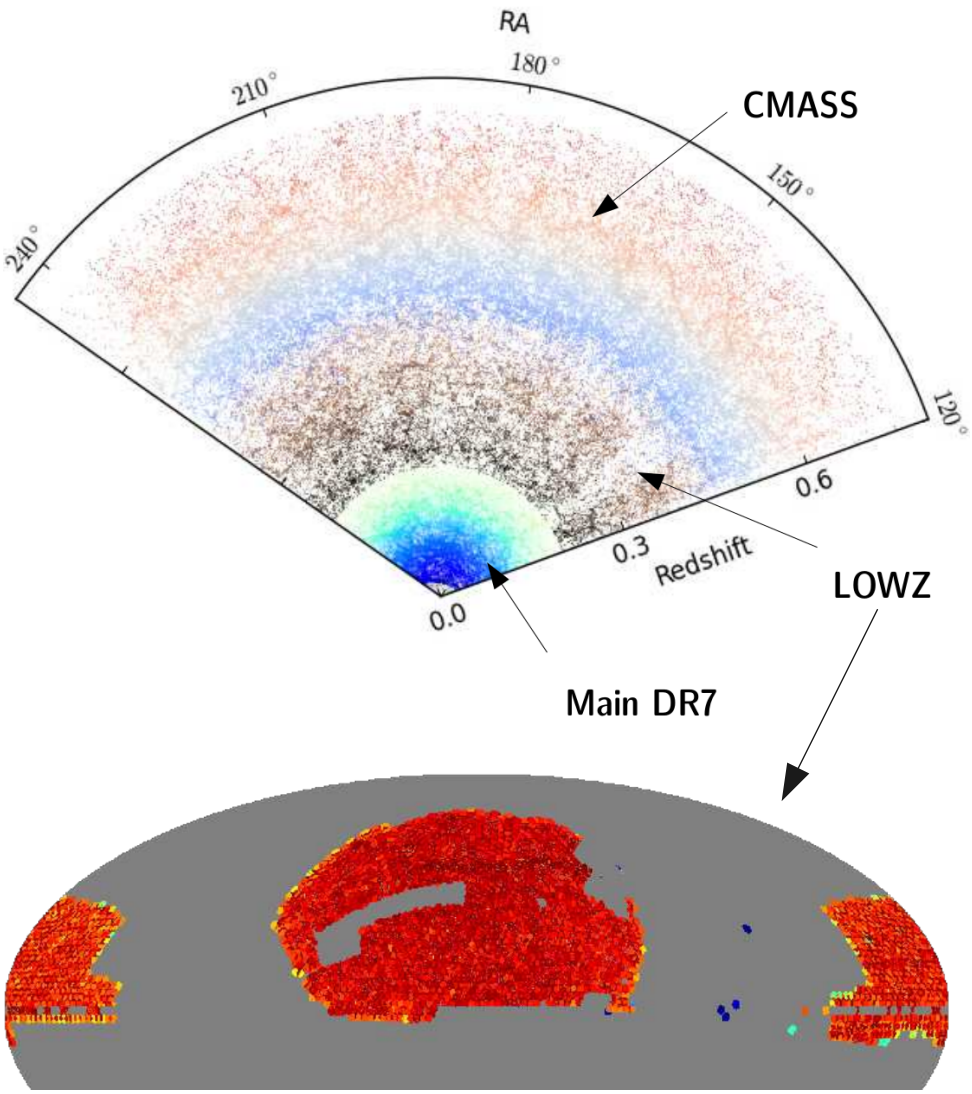
Sky completeness

Validation on mock catalogues (B) - SDSSIII

Simulation box Grid with 128^3 voxels
4000 Mpc side length

- Forward model: **LPT** + **AP**
- Probing higher redshift range; AP distortion due to cosmic expansion is much more informative
- Tight constraints on $\boldsymbol{\Omega_m}$





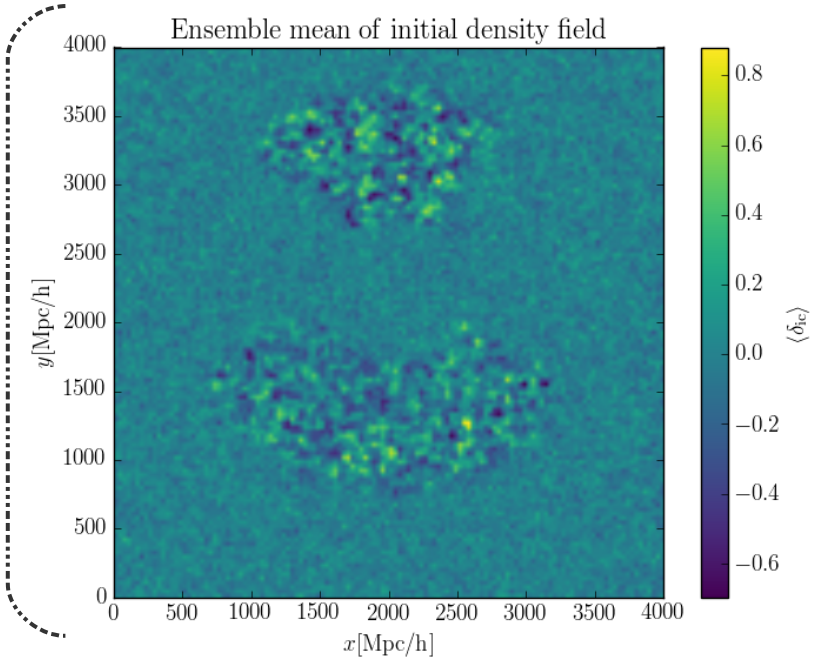
Sky completeness

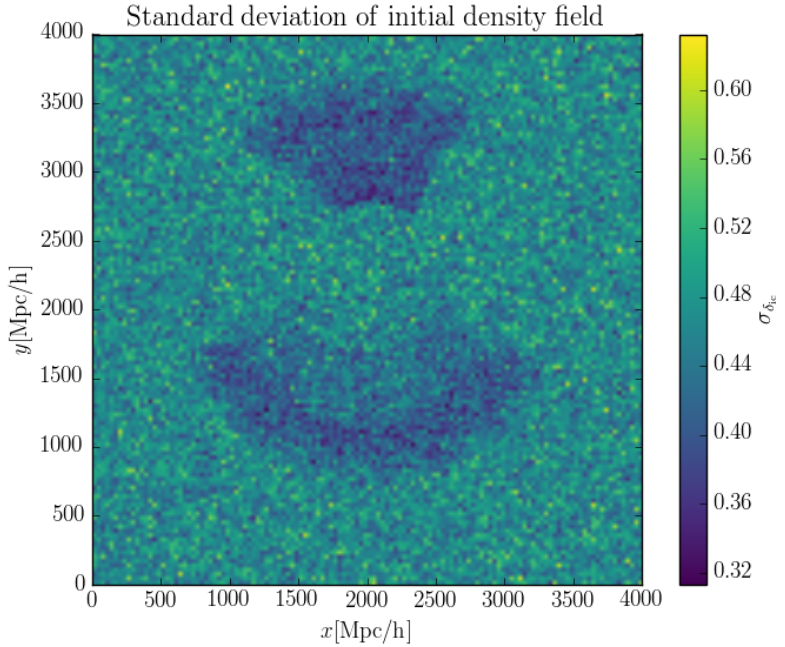
Ensemble mean & error maps

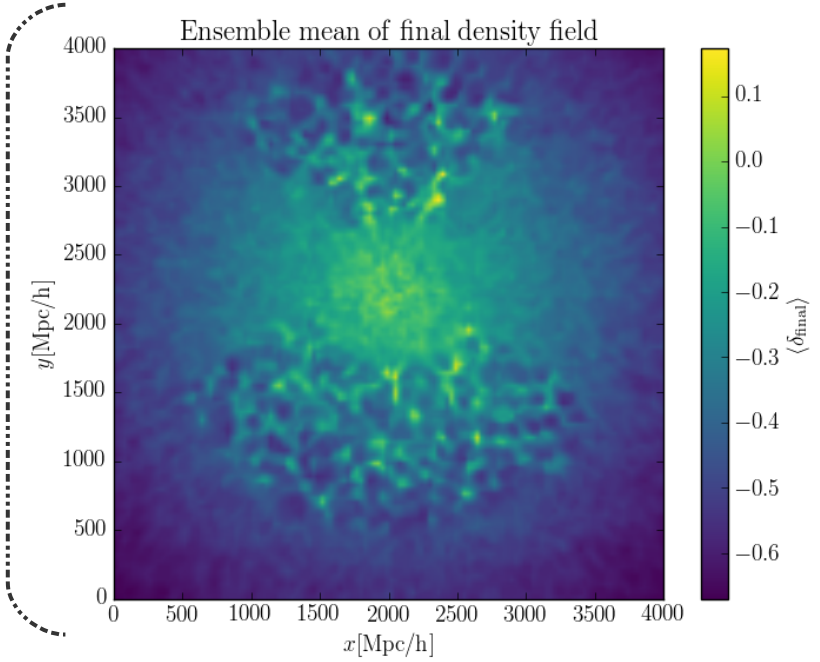
Initial density field

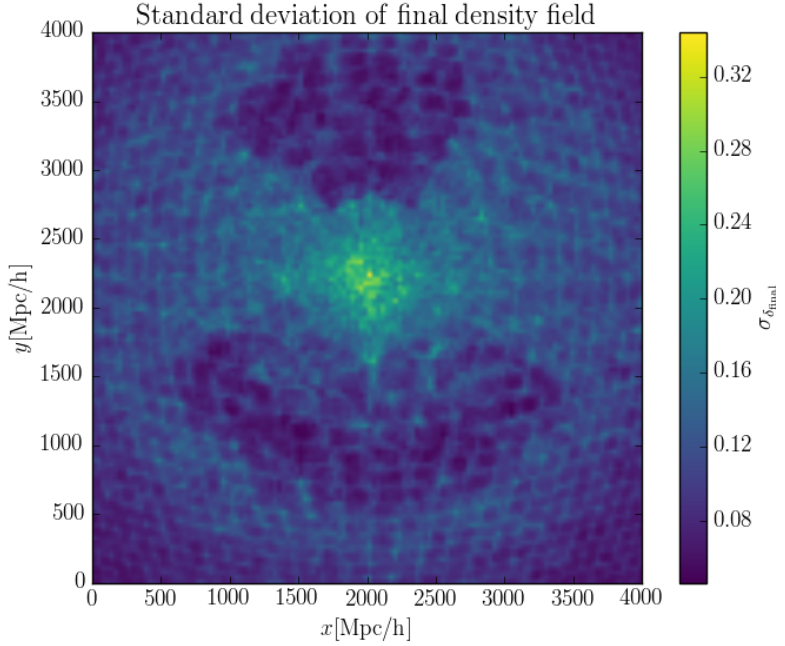
Slice through 3D density field

Final density field









Current & future work

Current project: (DKR, Lavaux & Wandelt 2018c, in prep.)

- ✓ Implemented forward model for **AP distortion** and cosmological parameter sampler
- ✓ Tested on low-resolution mock (2M++, SDSS-III) data
- ✓ Chain forward models: **LPT** + **AP**
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- Assess impact of redshift space distortions (**RSDs**) on cosmological constraints

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Future work:

- Encode power spectrum inference in the block sampling scheme

Follow-up project

- Account for **RSDs** in the data model
- Showcase application of **ALTAIR** on real data sets (e.g. **SDSS-III**):

  → Joint inference of 3D density field, underlying power spectrum & cosmological parameters

Relevant for current & next-generation galaxy redshift surveys (Euclid, LSST, …)