Cosmology with the SKA

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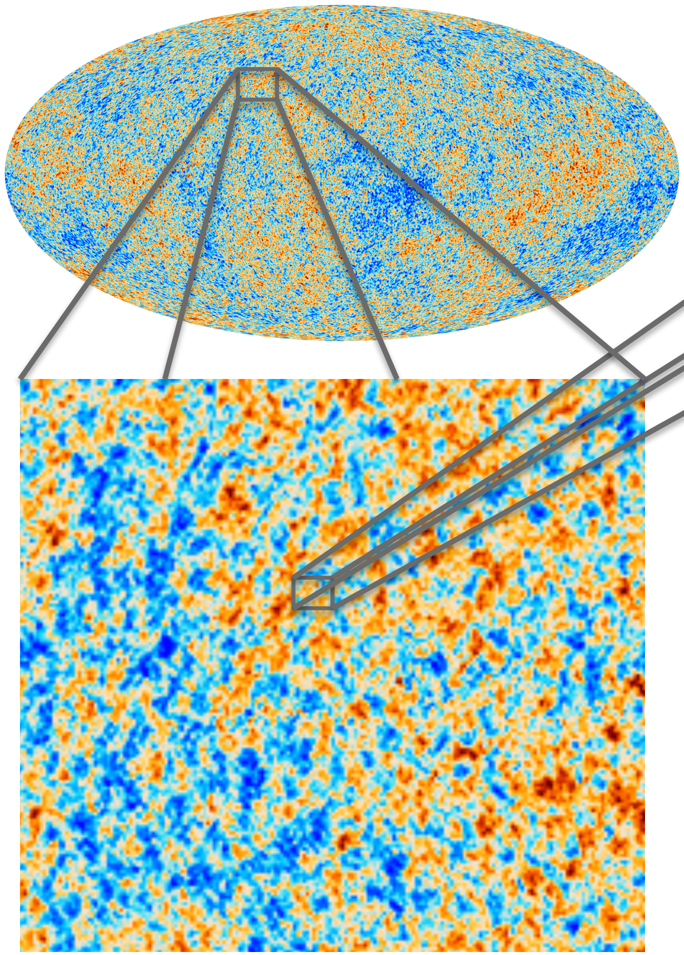
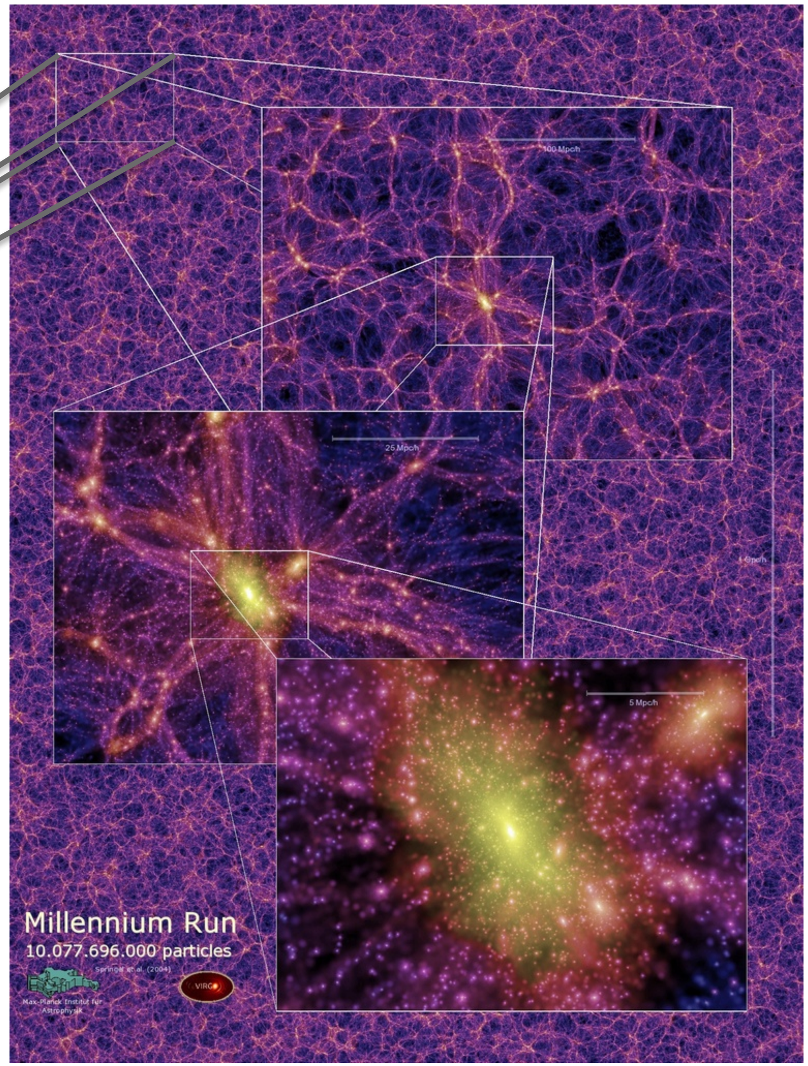
Accessing many modes

Planck

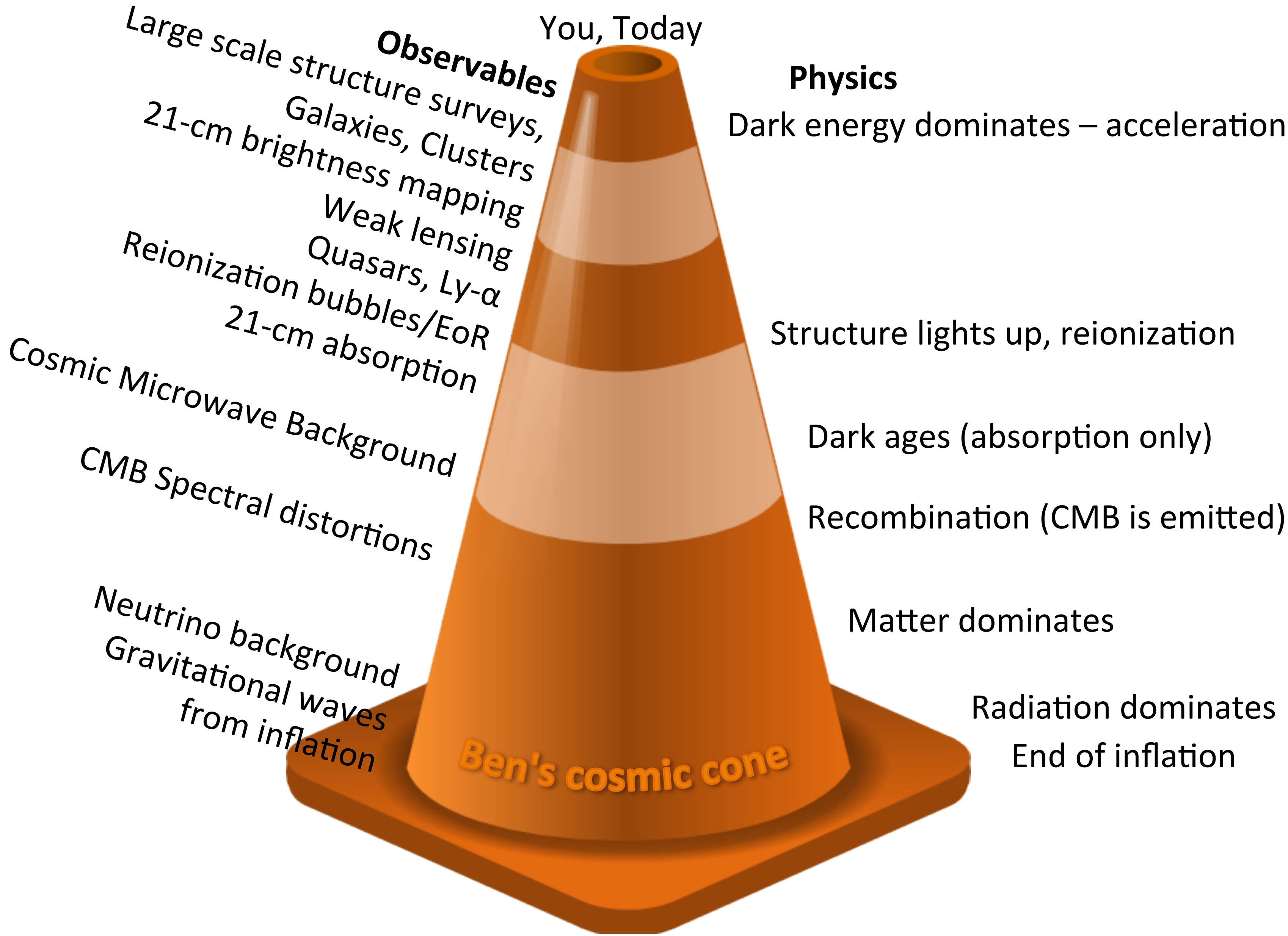


Primordial quantum perturbations as seen in the Cosmic Microwave Background

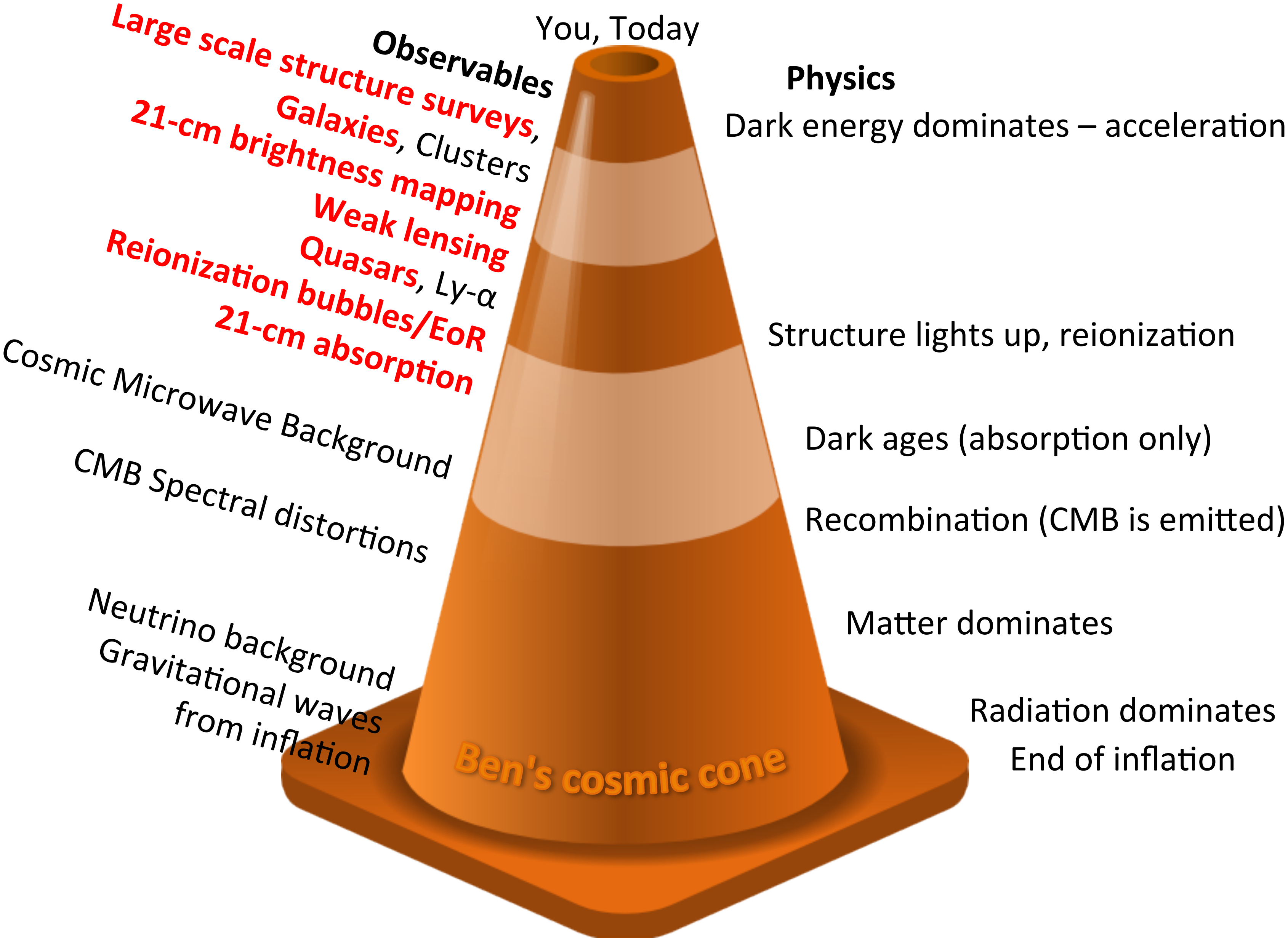
Dark matter distribution (simulated)



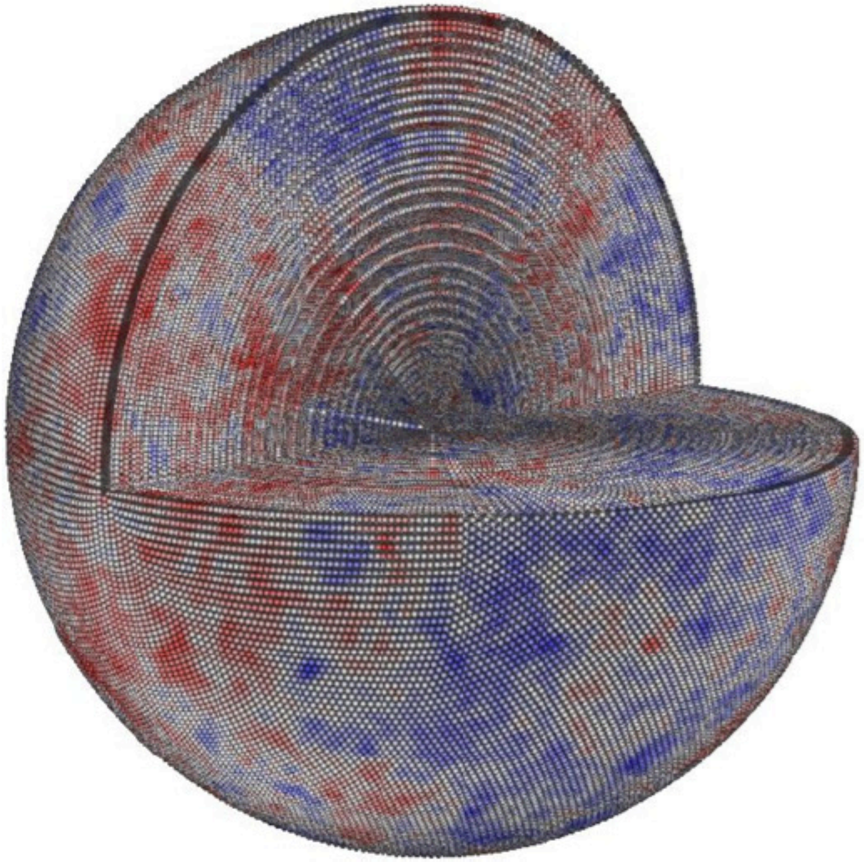
All of cosmology on one slide



Large scale structure with SKA



Primordial perturbations give rise to observations



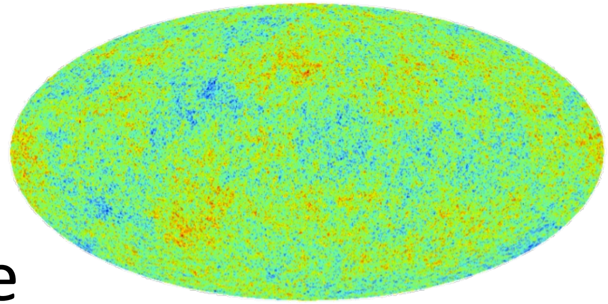
Radiative Transfer

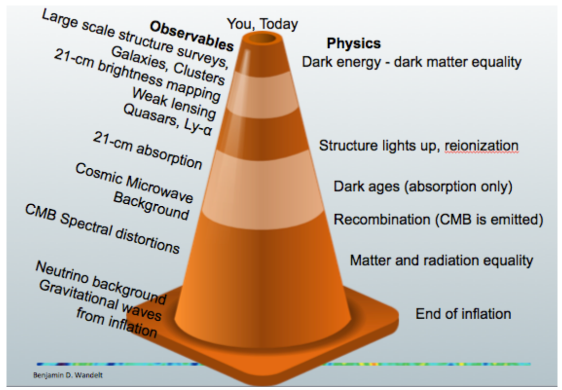
+

Gravity

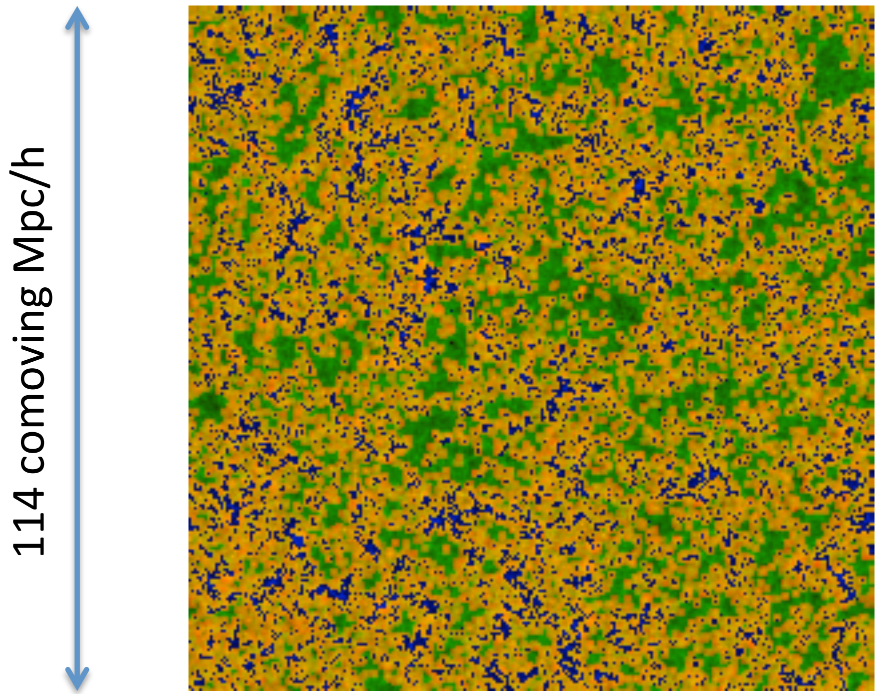
+

Astro-physics





Epoch of Reionization



z = 10.3

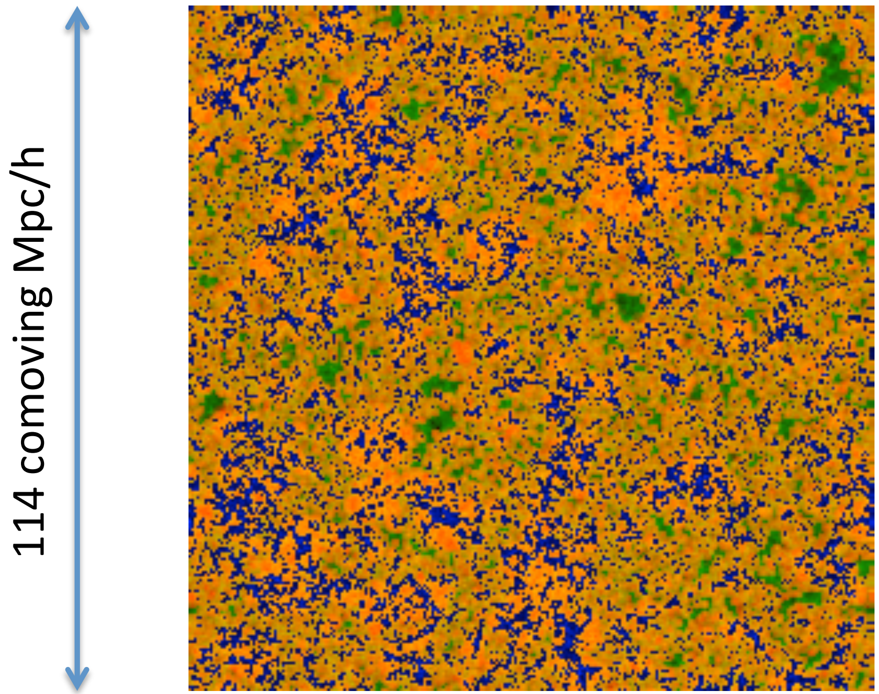
x = 20%

For details ➔ B. Semelin, A. Fialkov's talks

Once detailed physics understood a sensitive probe of the statistics of small scale perturbations (Mao et al 2013)

credit: Yi Mao

Epoch of Reionization



z = 8.2

x = 50%

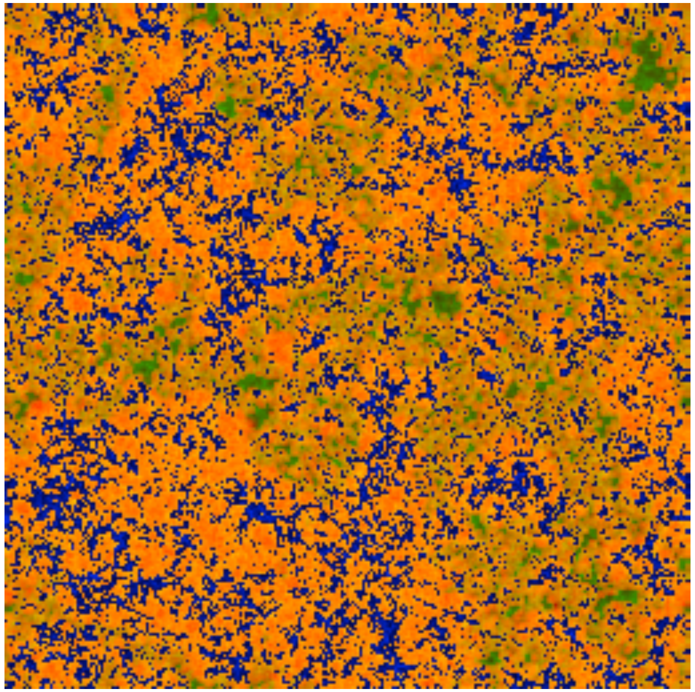
For details → B. Semelin, A. Fialkov's talks

Once detailed physics understood a sensitive probe of the statistics of small scale perturbations (Mao et al 2013)

credit: Yi Mao

Epoch of Reionization

114 comoving Mpc/h



z = 7.7

x = 70%

For details → B. Semelin, A. Fialkov's talks

Once detailed physics understood a sensitive probe of the statistics of small scale perturbations (Mao et al 2013)

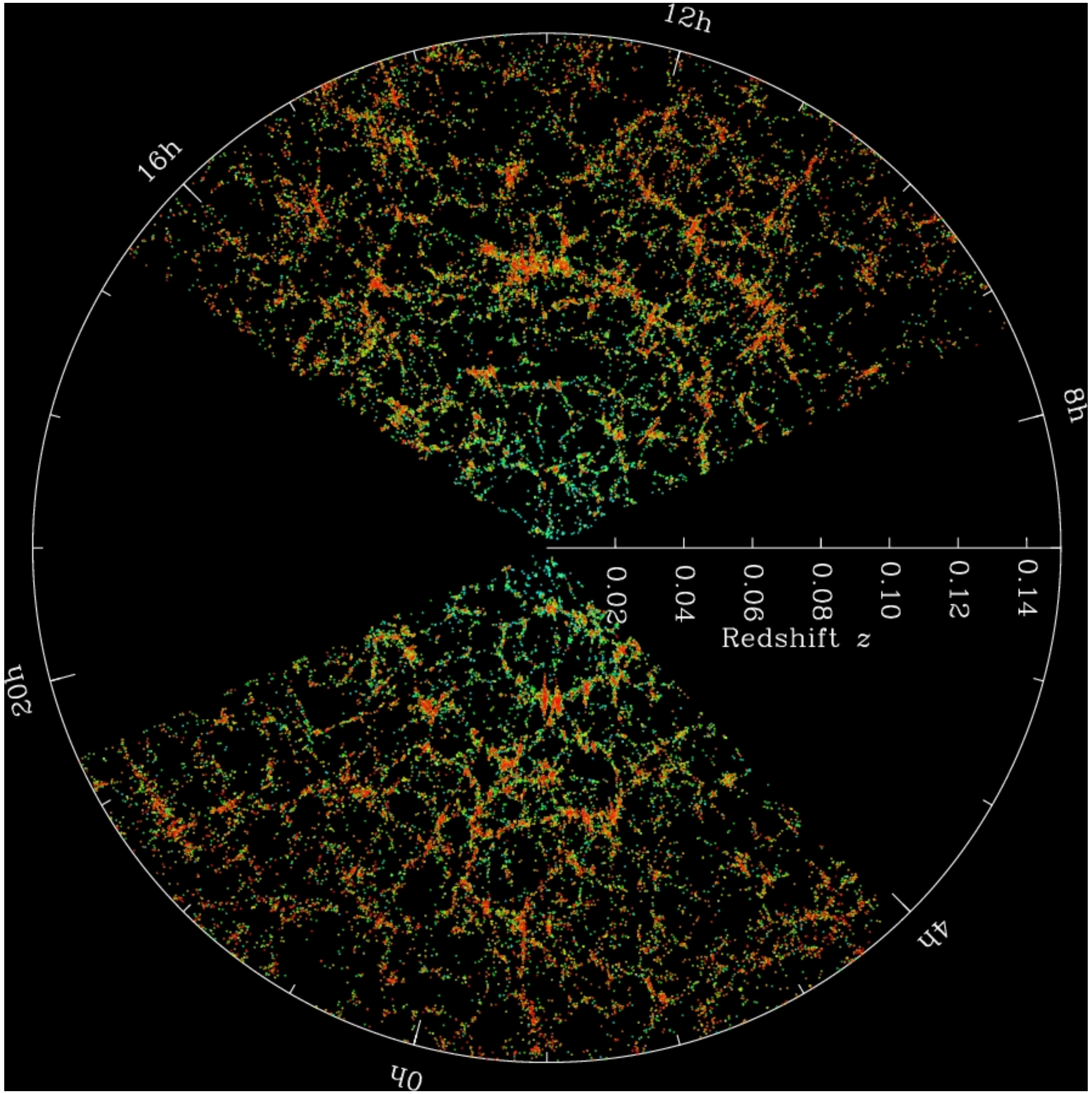
credit: Yi Mao

Unique capability of SKA: high-res spectroscopic imaging of small-scale cosmic structure over a large redshift range

Bad news for cosmologists:
Strong non-linear evolution destroys small information

Good news for cosmologists:
Non-linear evolution of large scale structure creates structure of underdense regions, ie voids, separated by filaments and walls

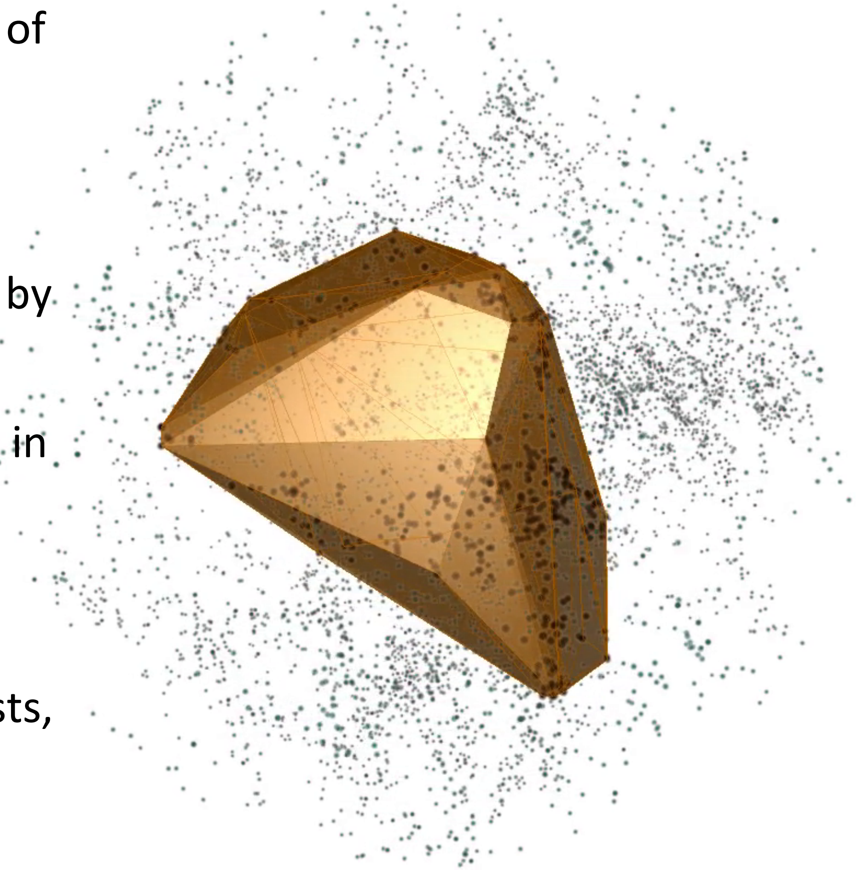
The cosmic web as seen by SDSS



M. Blanton
and SDSS

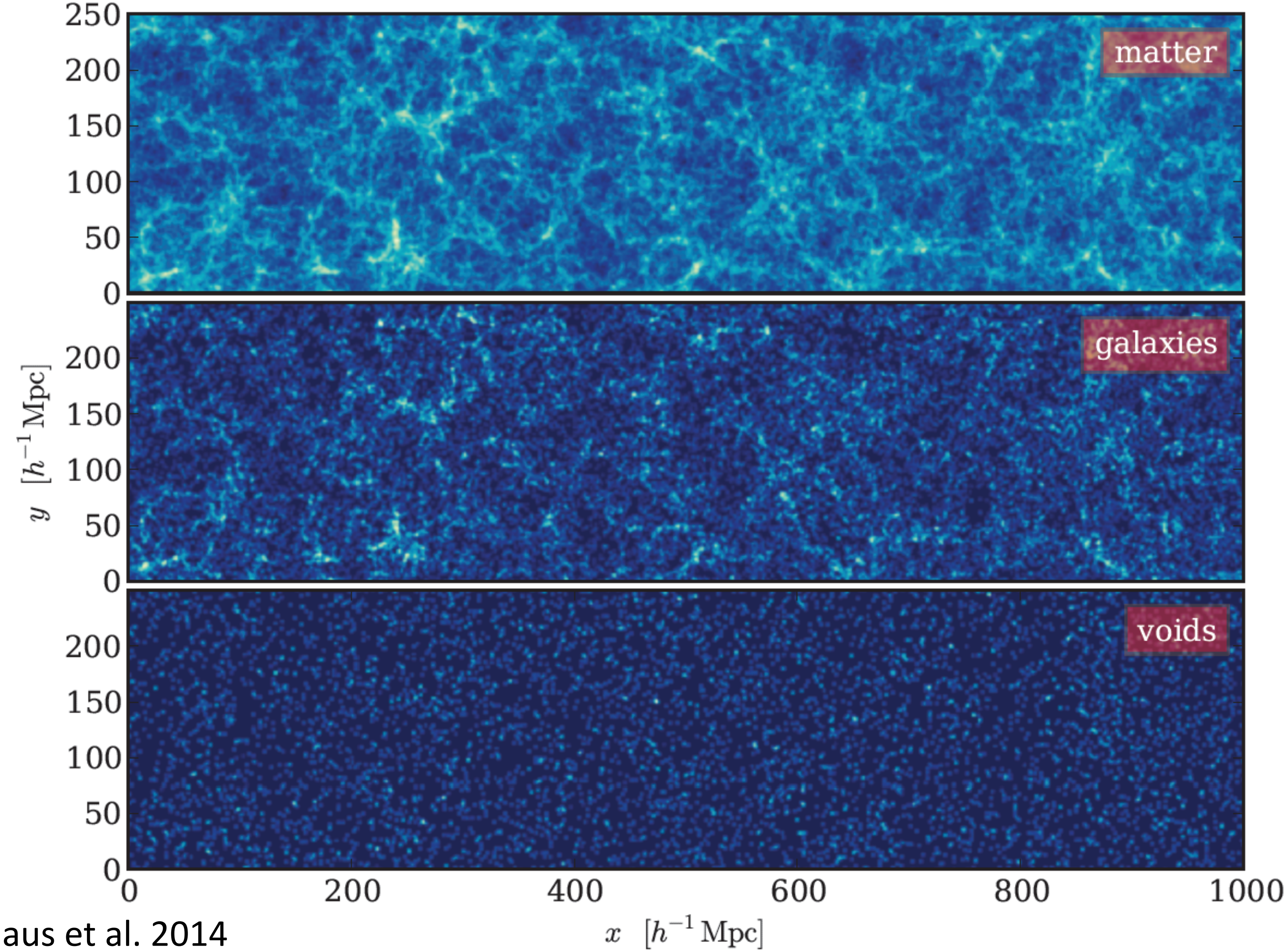
The promise of cosmic voids

- Biggest "objects" in the Universe – fill most of the volume!
- Simpler dynamics than high density regions
- Easier to link tracers to underlying dark matter
- The first regions in the universe dominated by dark energy
- If acceleration of the universe is caused by modified gravity it should act most strongly in voids.
- Neutrino signatures in profile?
- A free, additional observational probe in current and future surveys, including SKA
- Can be used to define new cosmological tests, measuring expansion history, etc.
- A new area for cosmological research



Lavaux & Wandelt 2012; Sutter et al. 2012, 2013, 2014; Pisani et al 2014, Hamaus et al 2014

Matter, galaxies, voids in simulation



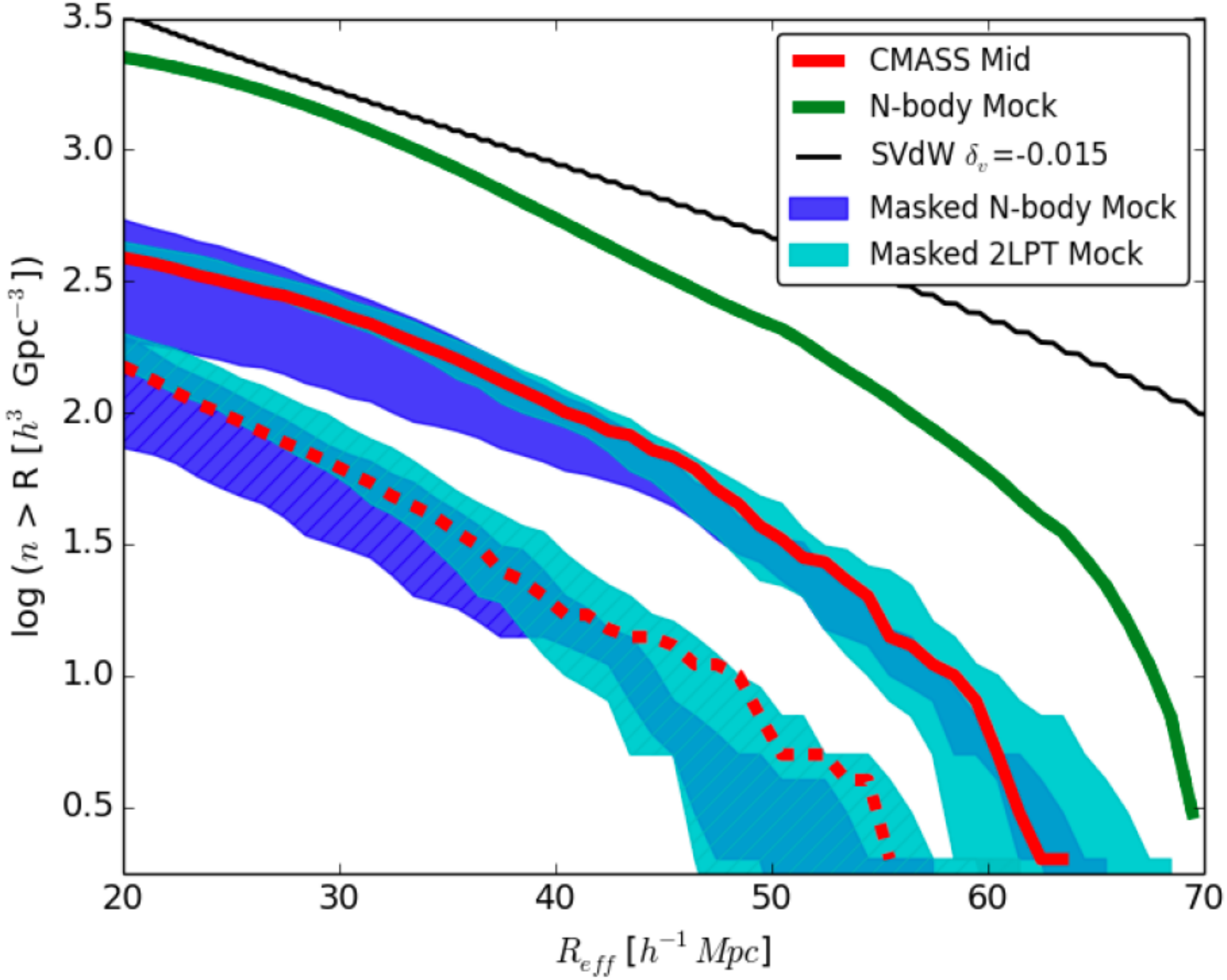
Hamaus et al. 2014

Void observables – recent progress

- Voids definition in surveys
  - E.g. voids in the SDSS DR9: Sutter et al., arXiv:1310.7155
- Their properties can be characterized
  - Effect of sparse sampling and bias on voids: Sutter et al., arXiv: 1309.5087
- Voids are related to dark matter
  - Dark matter in galaxy voids: Sutter et al., arXiv: 1311.3301
- They can be used as LSS tracers
  - Void-galaxy cross-correlations, Hamaus et al. 2014
- Voids lens background galaxies
  - Gravitational lensing of voids in SDSS: Melchior et al., arXiv: 1309.2045
- Voids can be stacked to get real space information
  - Real-space profile reconstruction: Pisani et al., arXiv: 1306.3052
- Voids can be used to define new cosmological observables
  - Alcock-Paczinsky, static ruler, galaxy bias etc.

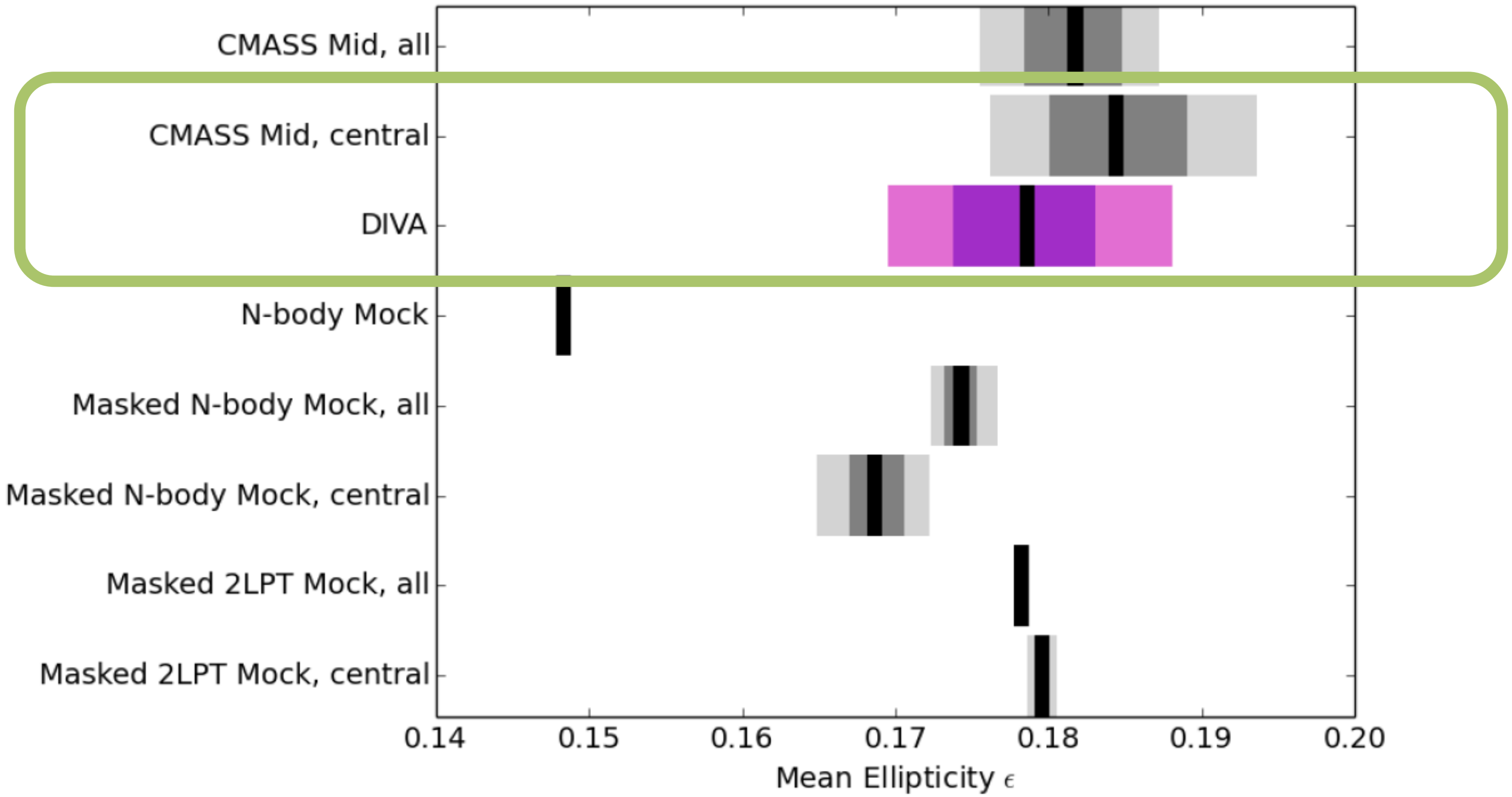
→ www.cosmicvoids.net

Void number functions in BOSS-CMASS match mock surveys



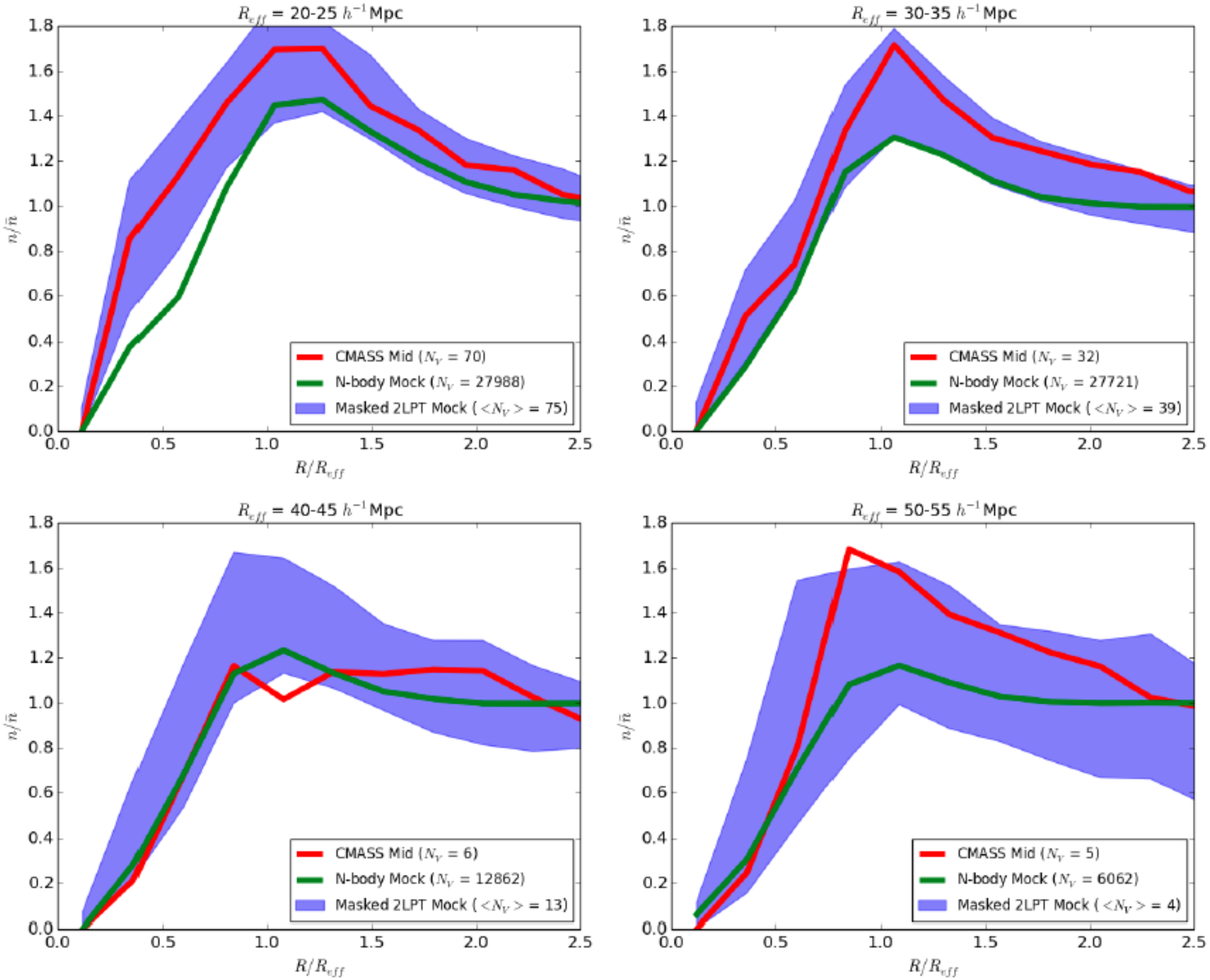
Sutter et al., arXiv:1310.7155

Void ellipticities – semi-analytic theory matches data



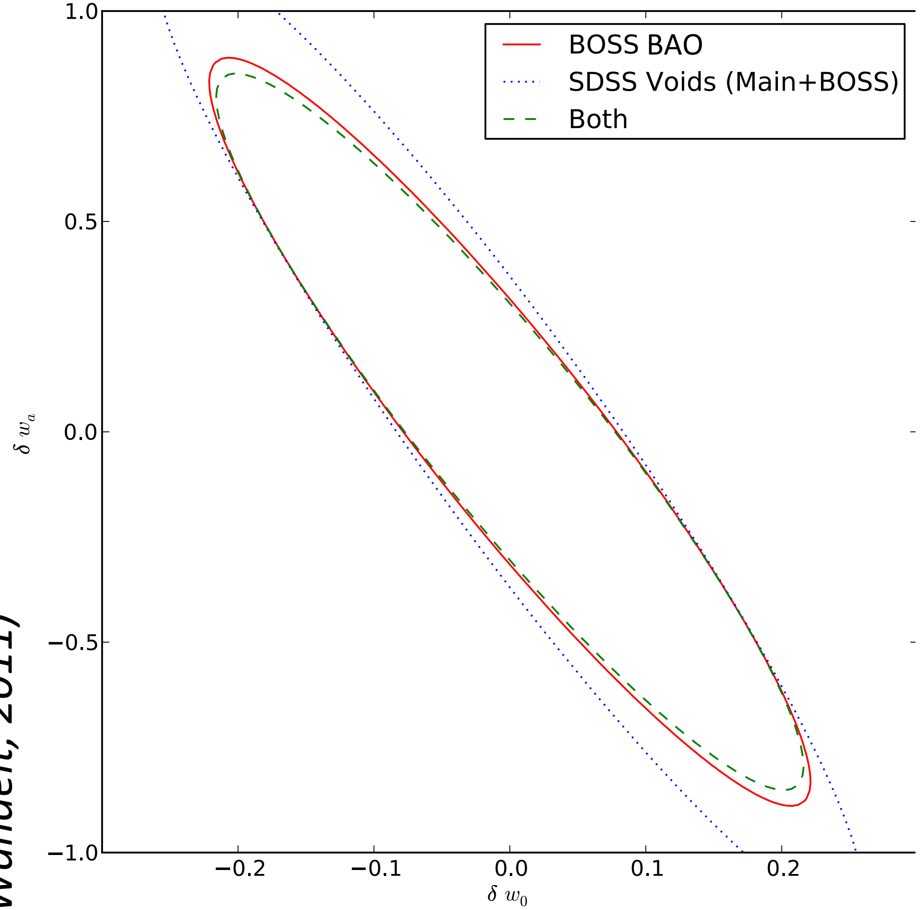
Sutter et al., arXiv:1310.7155; DIVA: Lavaux & BDW (2010)

Observed void profiles well-modeled using 2LPT mocks

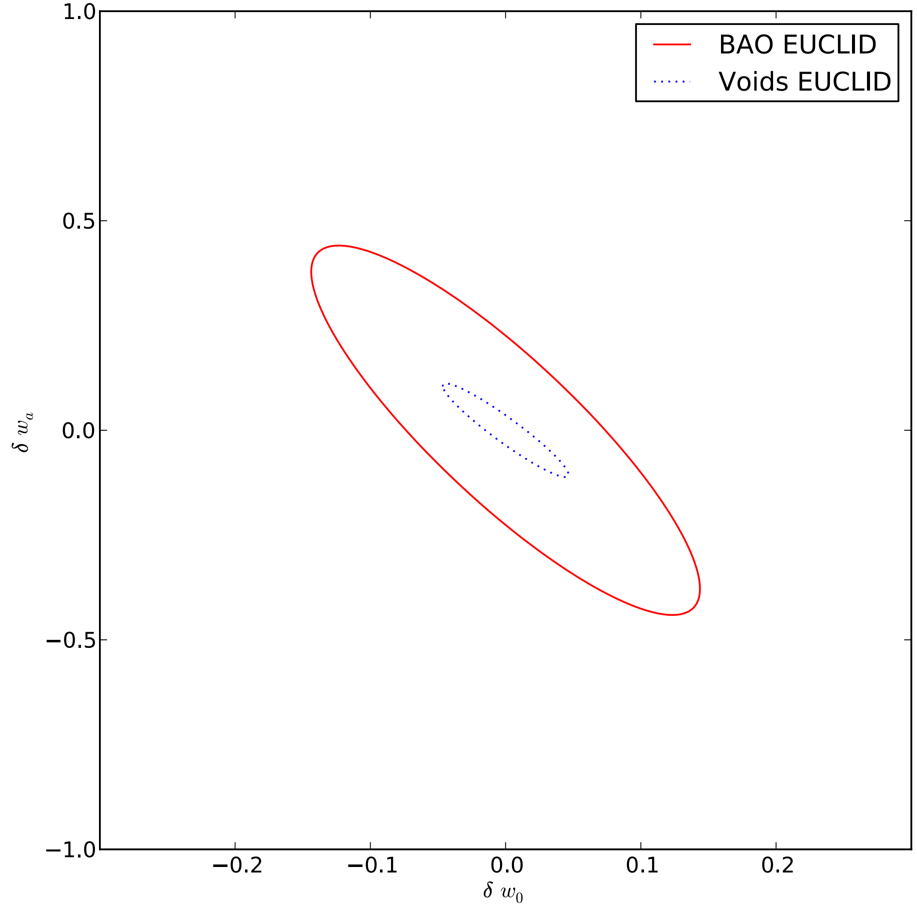


Sutter et al., arXiv:1310.7155

Dark energy constraint forecast using Alcock-Paczynski test with voids



Comparable to Baryon Acoustic Oscillation constraints for full BOSS data



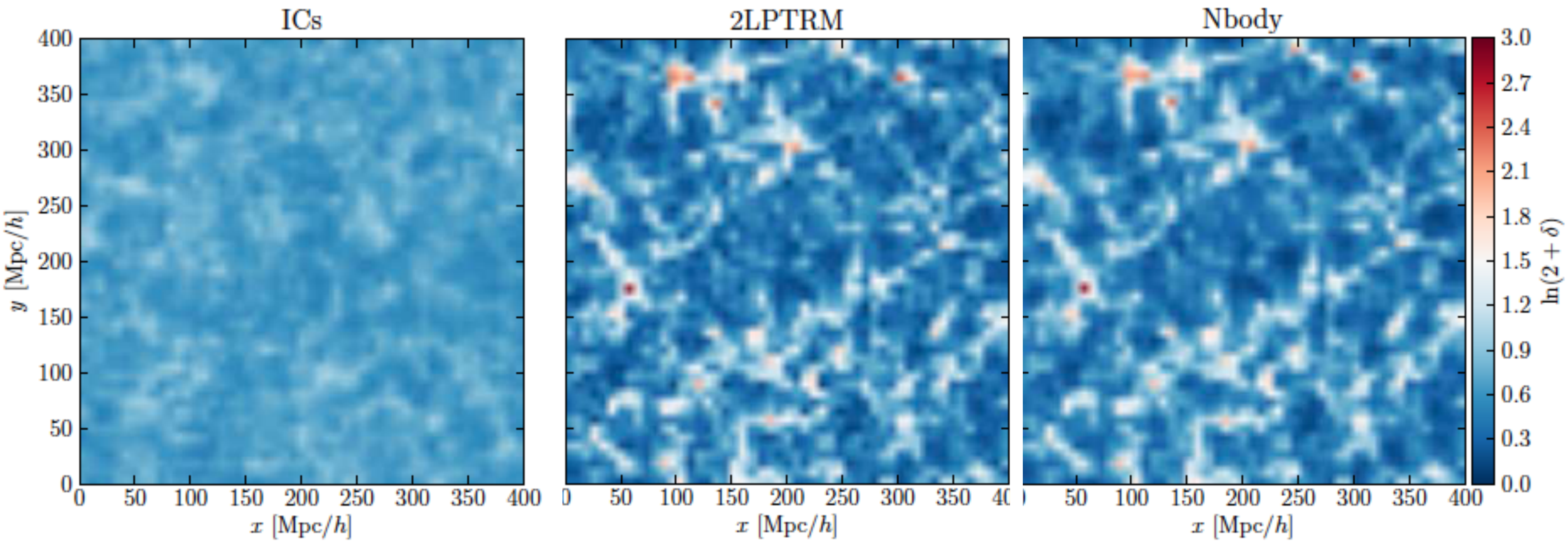
Outperforms BAO by a factor of O(10) for future data, such as EUCLID; voids alone yield double the combined FoM.

(Lavaux & Wandelt, 2011)

SKA and voids

- SKA galaxy survey + intensity mapping
- Current IM proposals target BAO (large volume, low contrast)
- Brightness temperature contrast is much larger for voids (10-20 Mpc), than for BAO
- Need 10x higher resolution than for BAO intensity mapping – easily achievable with SKA
- Potential to resolve void interiors and dynamics
- Focusing on underdense regions allows pushing analysis to smaller scales, increasing science return
- Lots of new applications to be explored

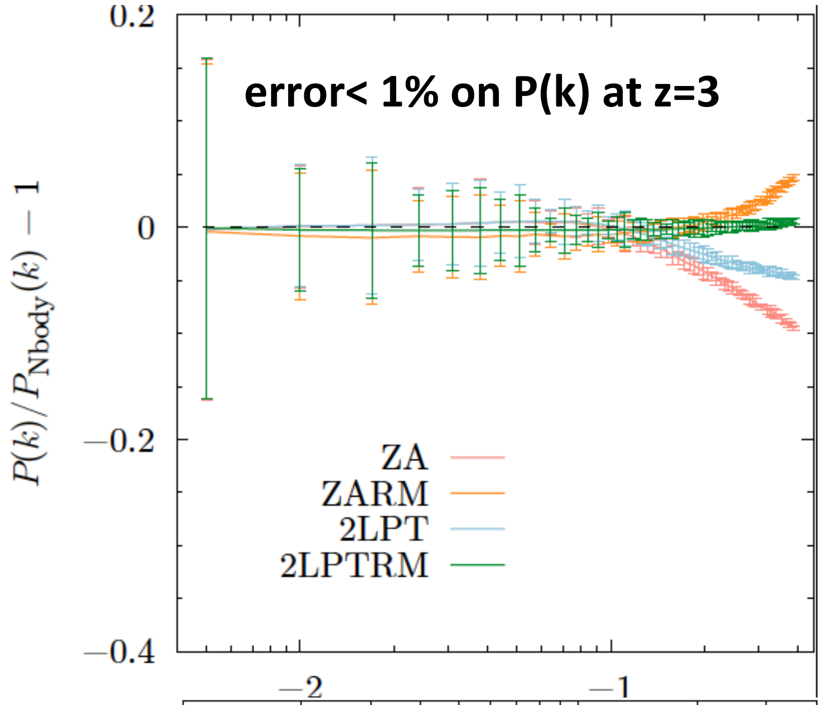
Superfast model of mildly non-linear density field: 2LPT+remapping

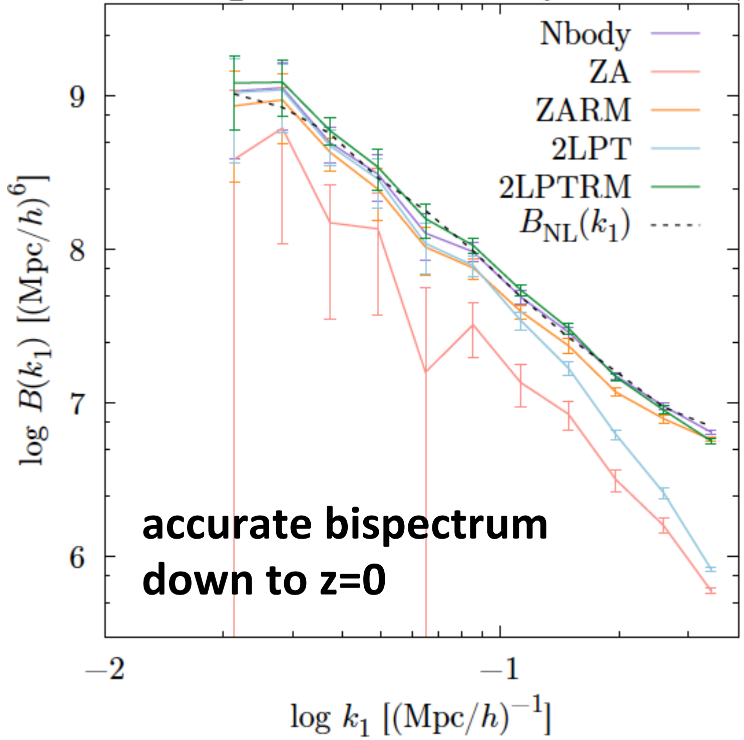


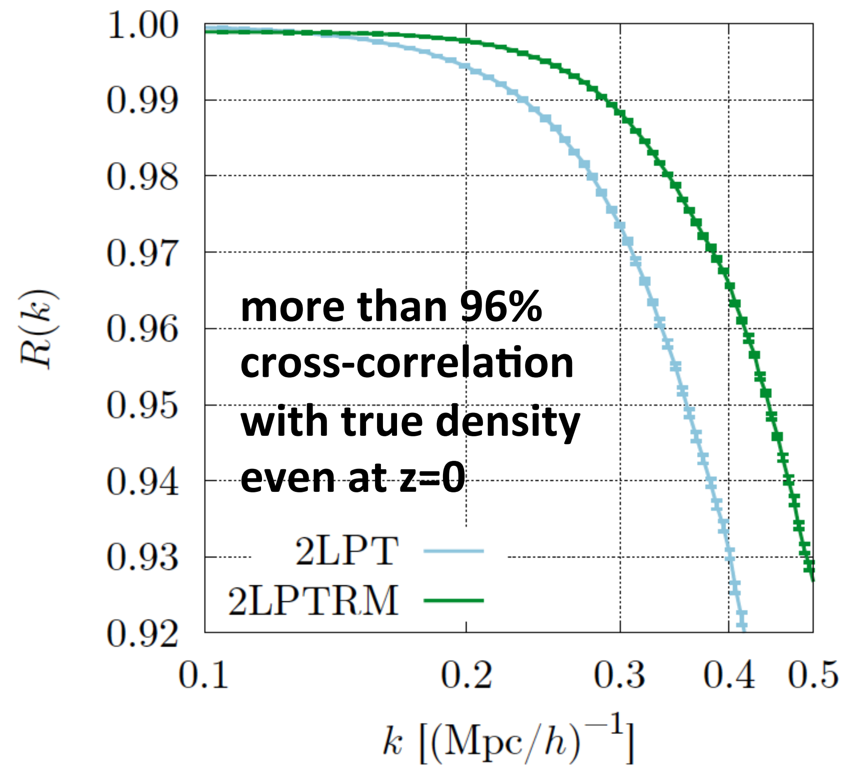
Leclercq, et al., 2013

2LPTRM: Quantitative agreement of 2&3-point functions down to k ~ 0.4 h/Mpc

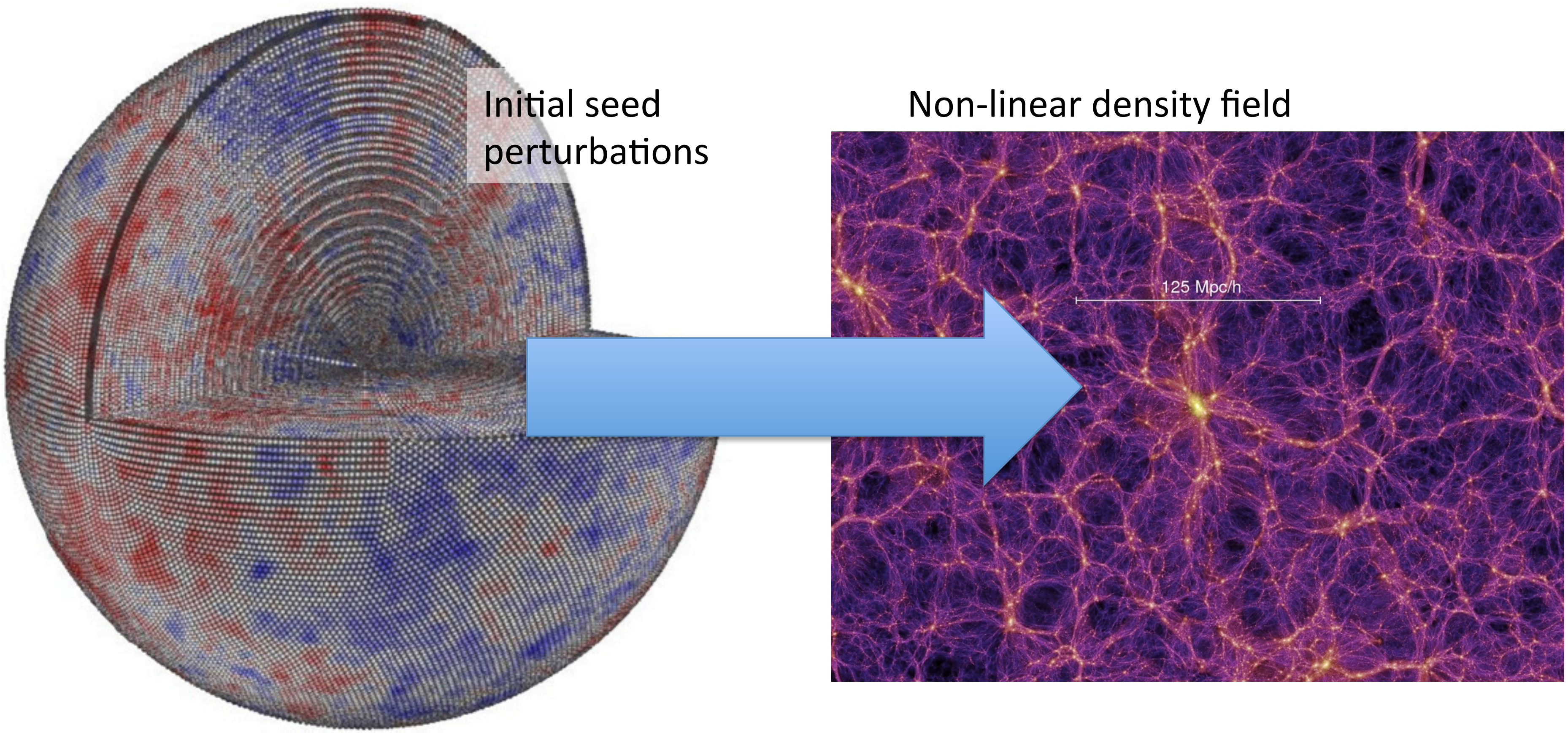
Leclercq, Jasche, Gil-Marin, BDW 2013





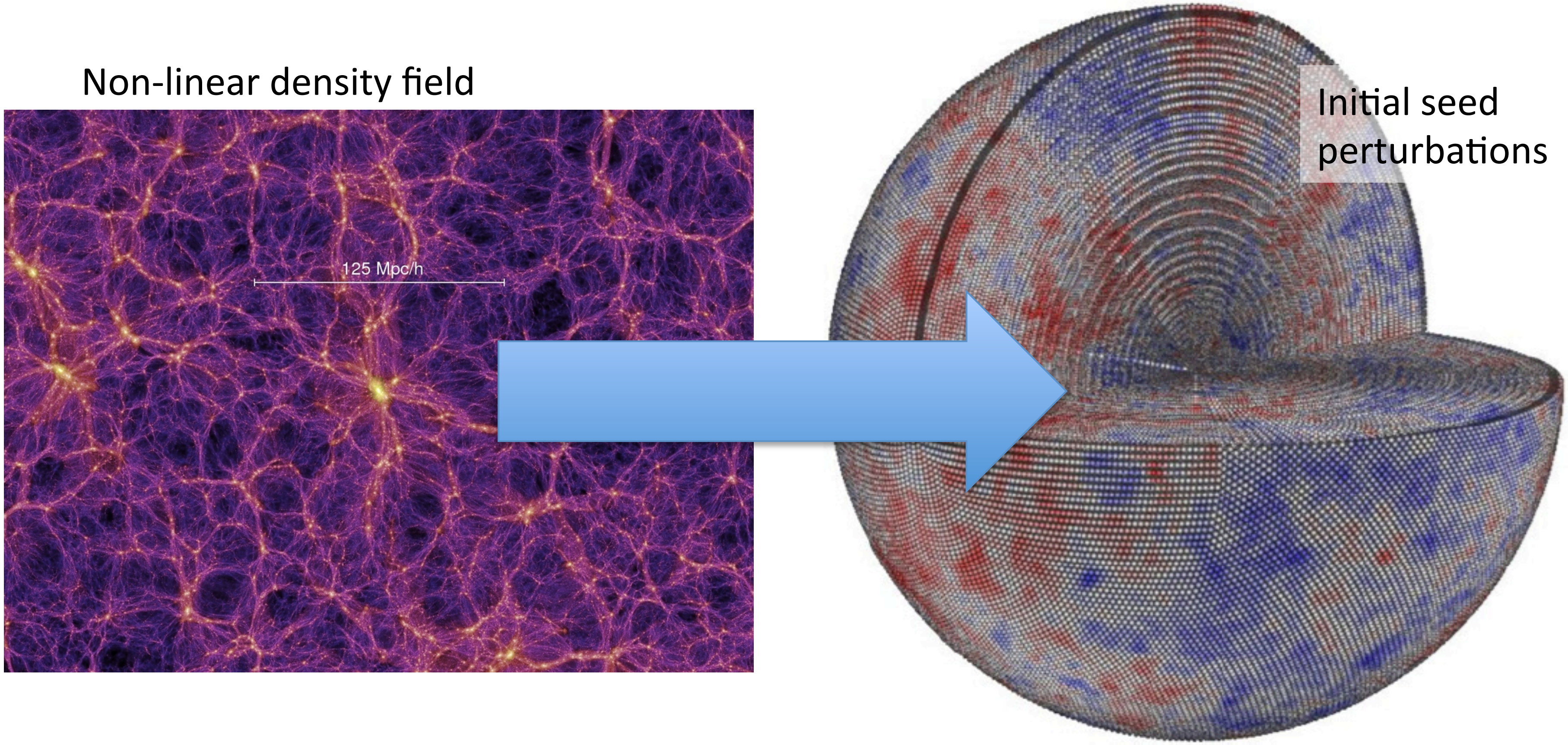


Observables arise from the initial perturbation field

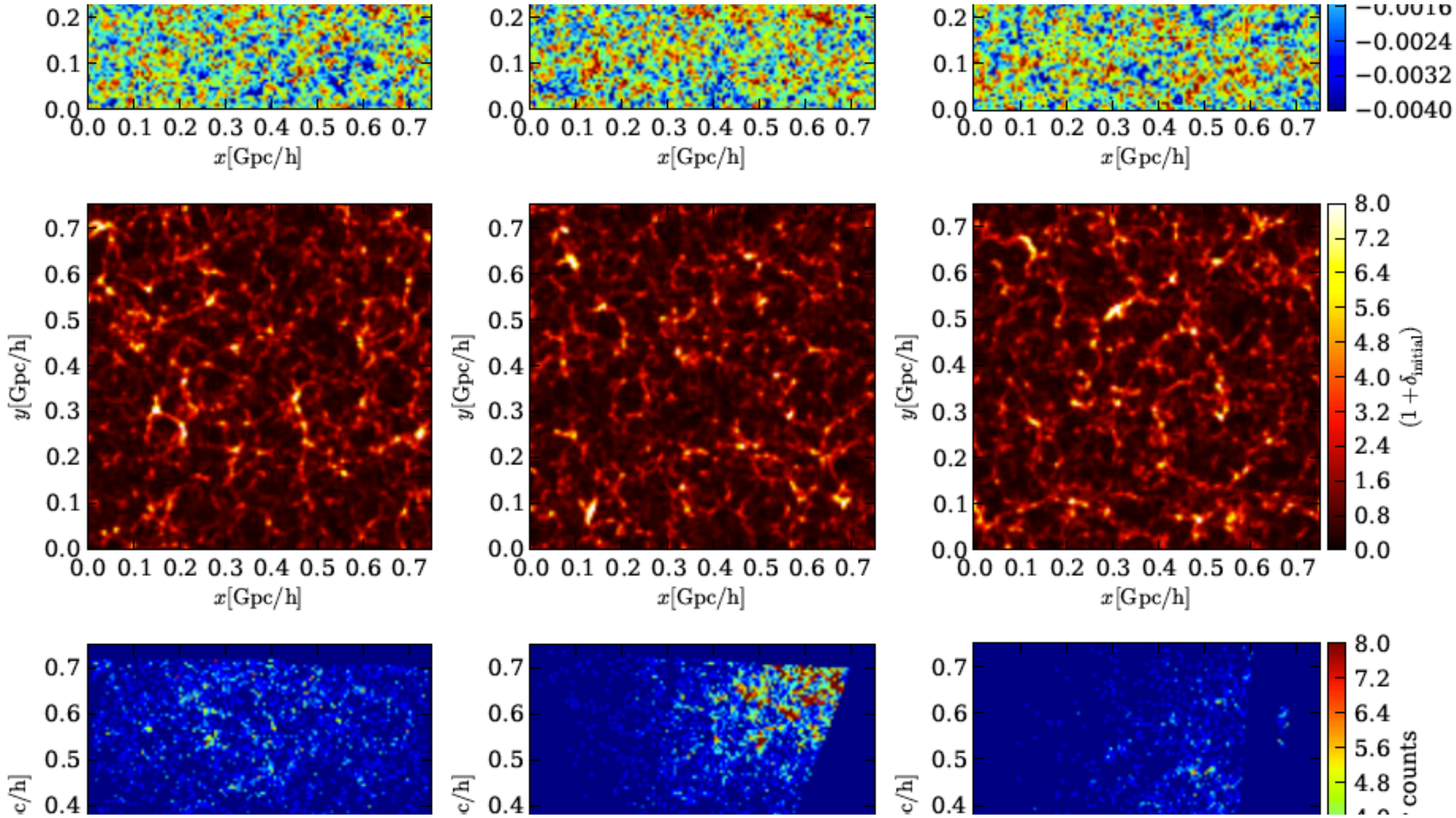


What if we could fit N-body simulations to data and infer initial conditions and dyamical histories for our Universe?

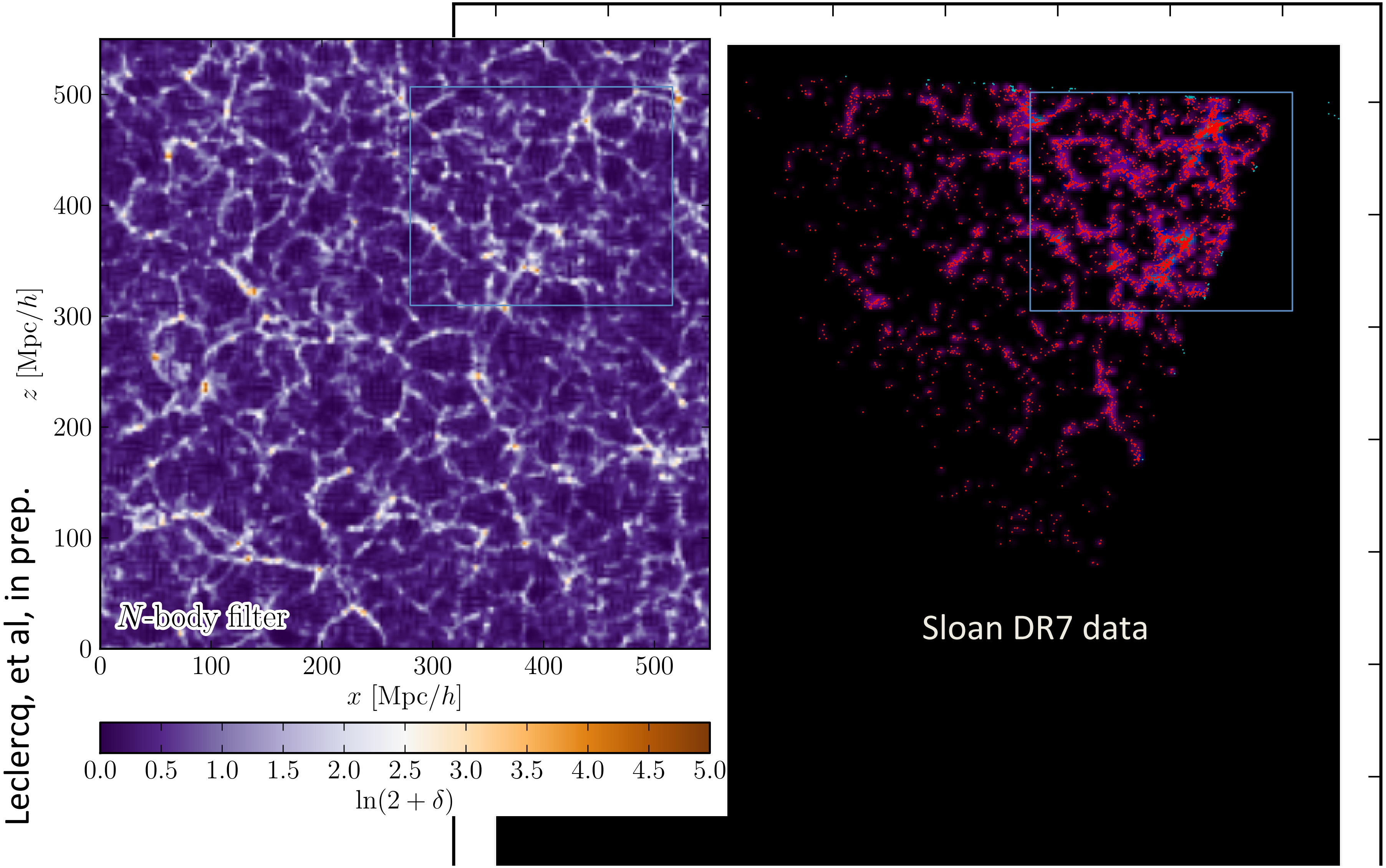
Non-linear density field



Fully Bayesian, non-linear reconstruction of initial conditions from Large Scale Structure probes

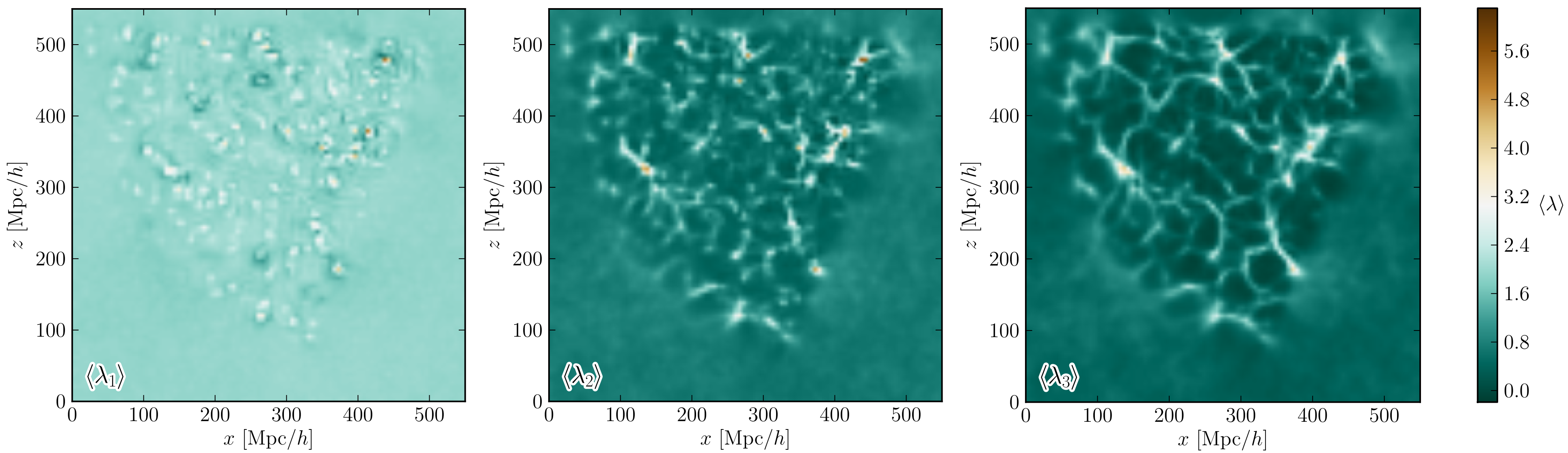


Fully non-linear constrained dynamical history of our universe



Leclercq, et al, in prep.

Cosmic morphology



Reconstructed eigenvalues of the local shear tensor constrained by Sloan with gravity prior

(Leclercq, et al, in prep.)

Take home messages

- There is more to life than BAO
  - SKA *uniquely* suited to cosmic web and voids since BAO intensity mapping experiments aim for large volume and low resolution
  - Tests of initial perturbations on small scales and during EoR
- New science potential from higher resolution large scale structure probes such as SKA using powerful priors that *know* about gravity

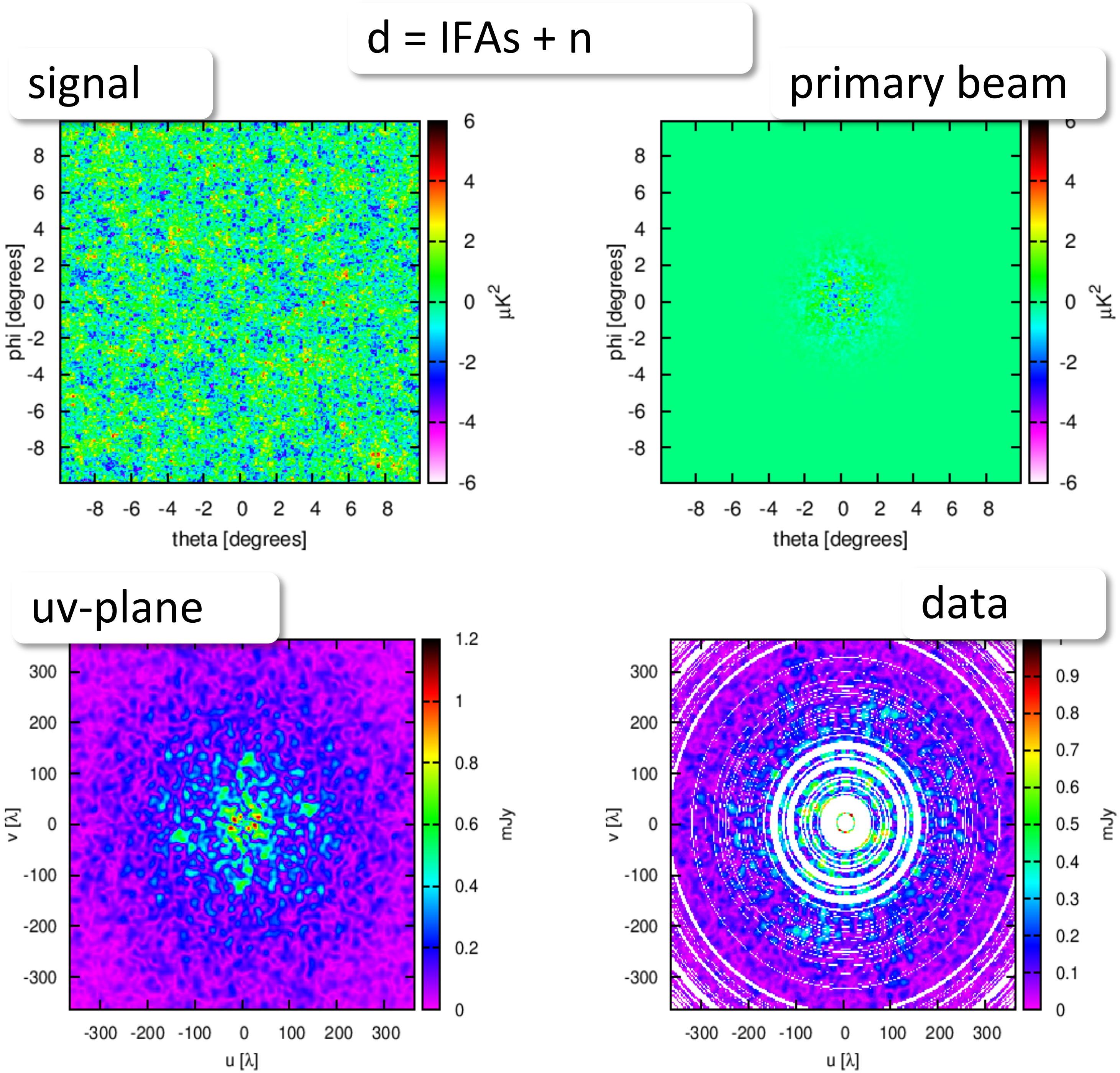
If there's time:

Power spectrum inference from radio interferometers using Gibbs sampling

and

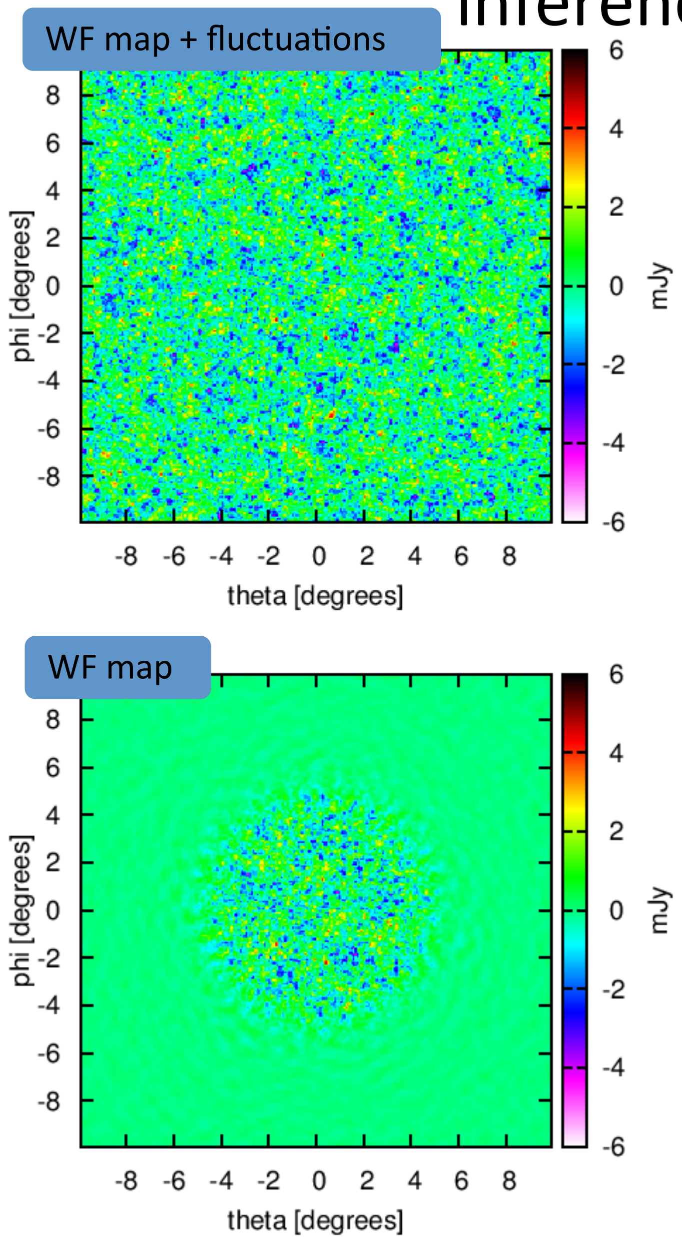
Probabilistic image reconstruction for radio interferometers

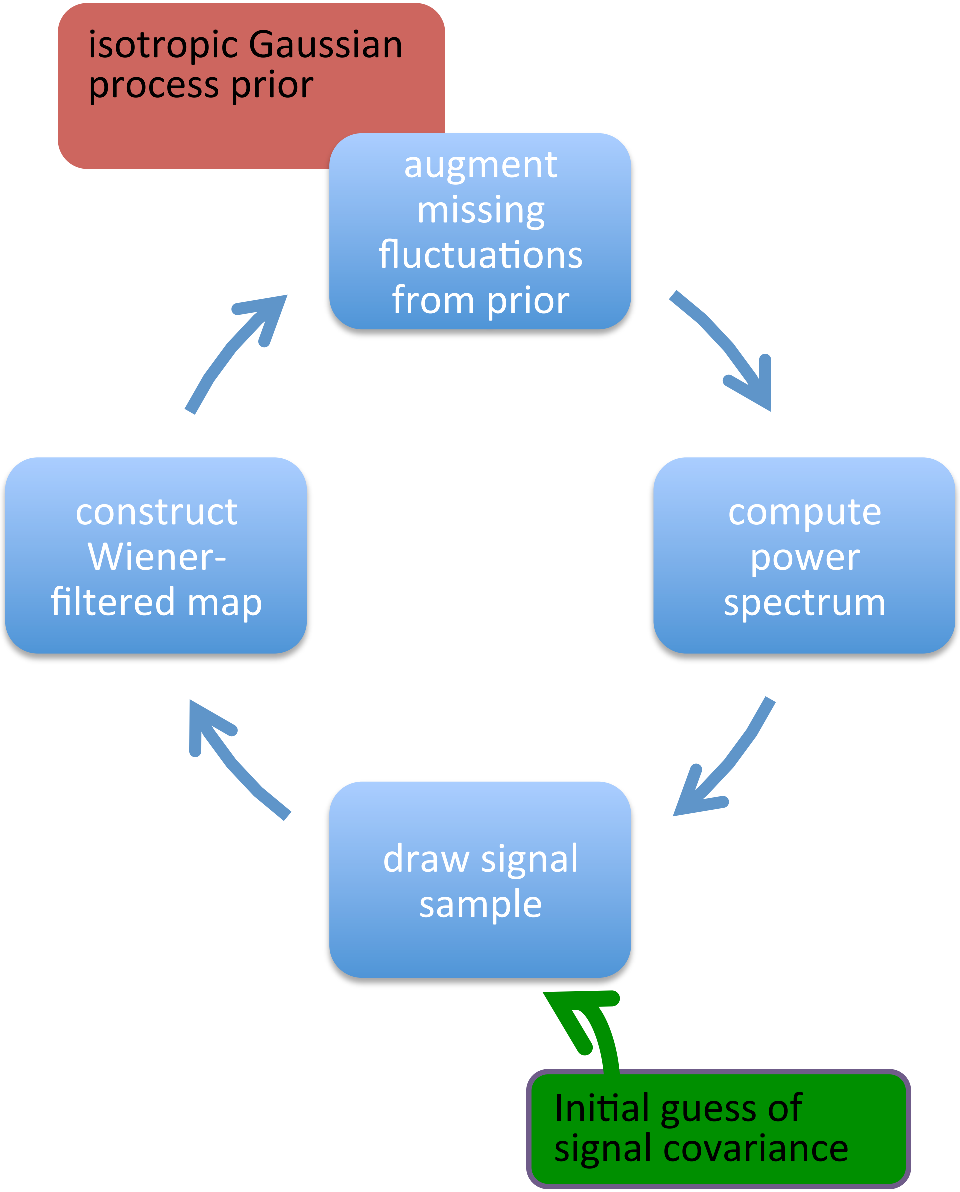
- Sutter, Wandelt, Malu (2011)
- Sutter et al., this months' issue of MNRAS, arXiv:1309.1469§



d = IFAs + n
signal
primary beam
uv-plane
data
phi [degrees]
theta [degrees]
μK^2
v [λ]
u [λ]
mJy

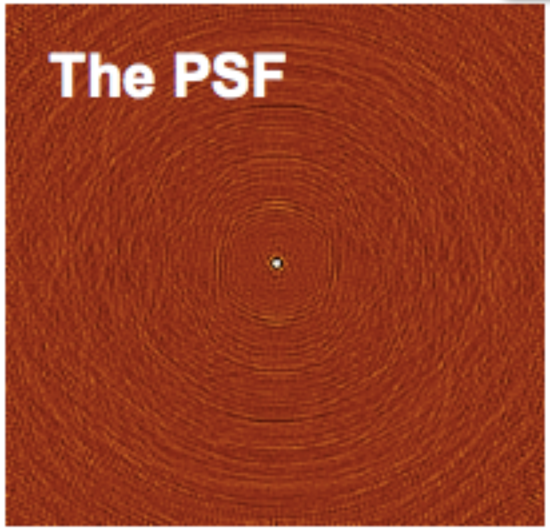
Gibbs sampling is a both power spectrum inference and non-linear Wiener filter

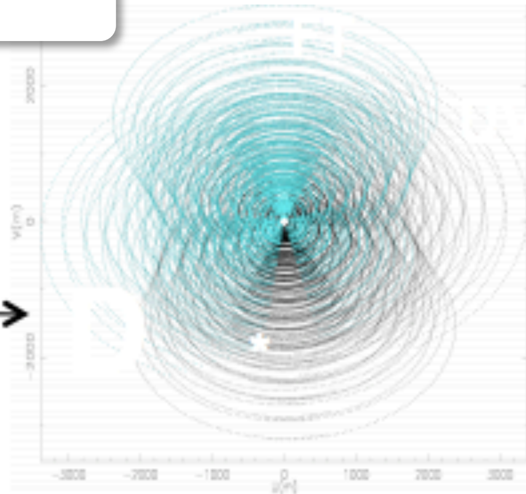


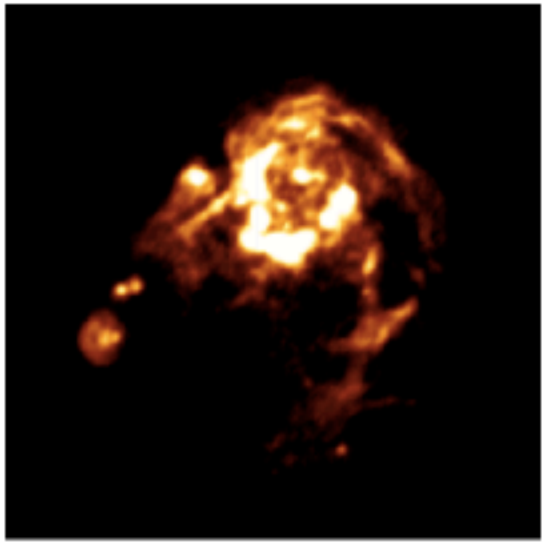


(Sutter, Wandelt, Malu. 2011; Karakci et al. 2013)

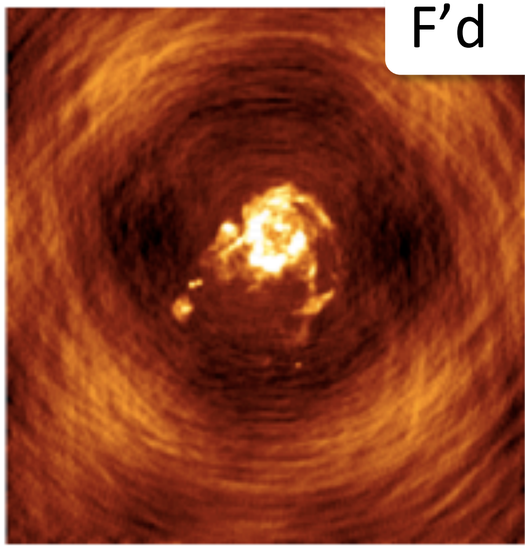
$$d = IFAs + n$$







True image



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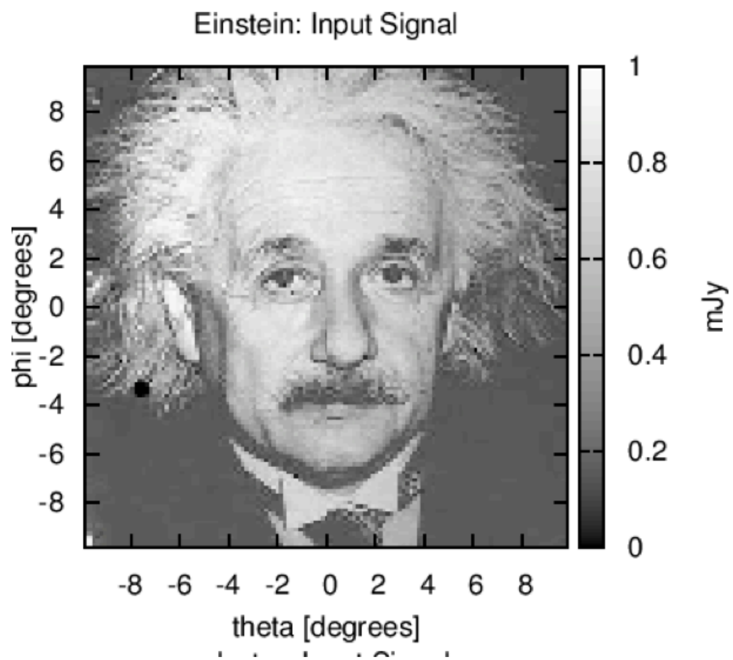
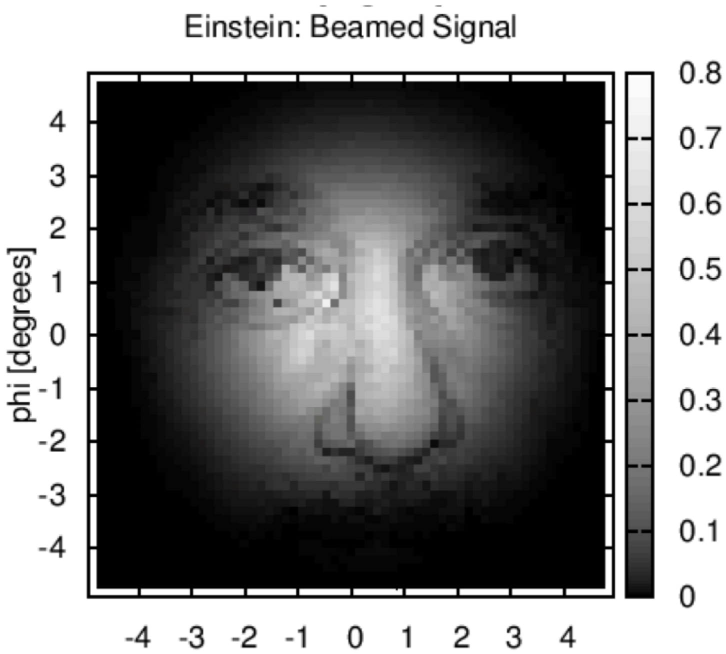
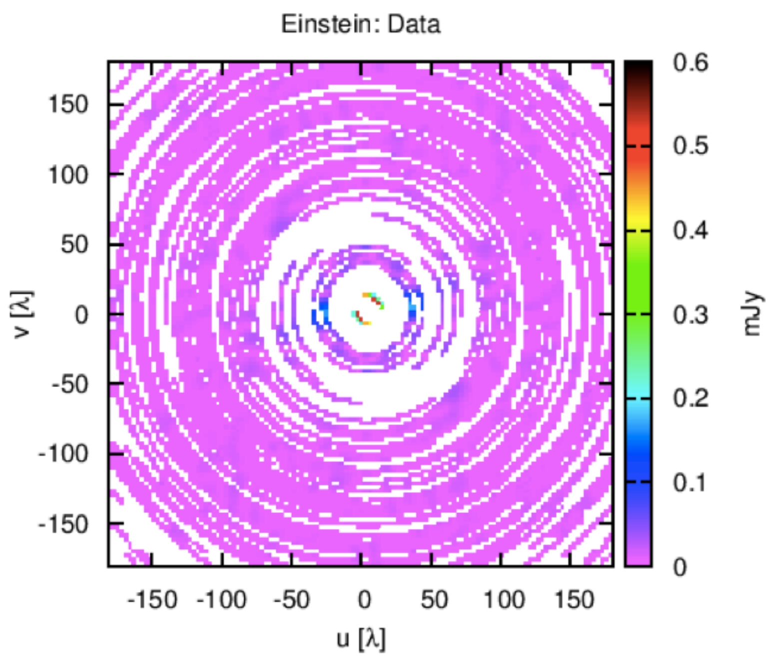
Dirty Image

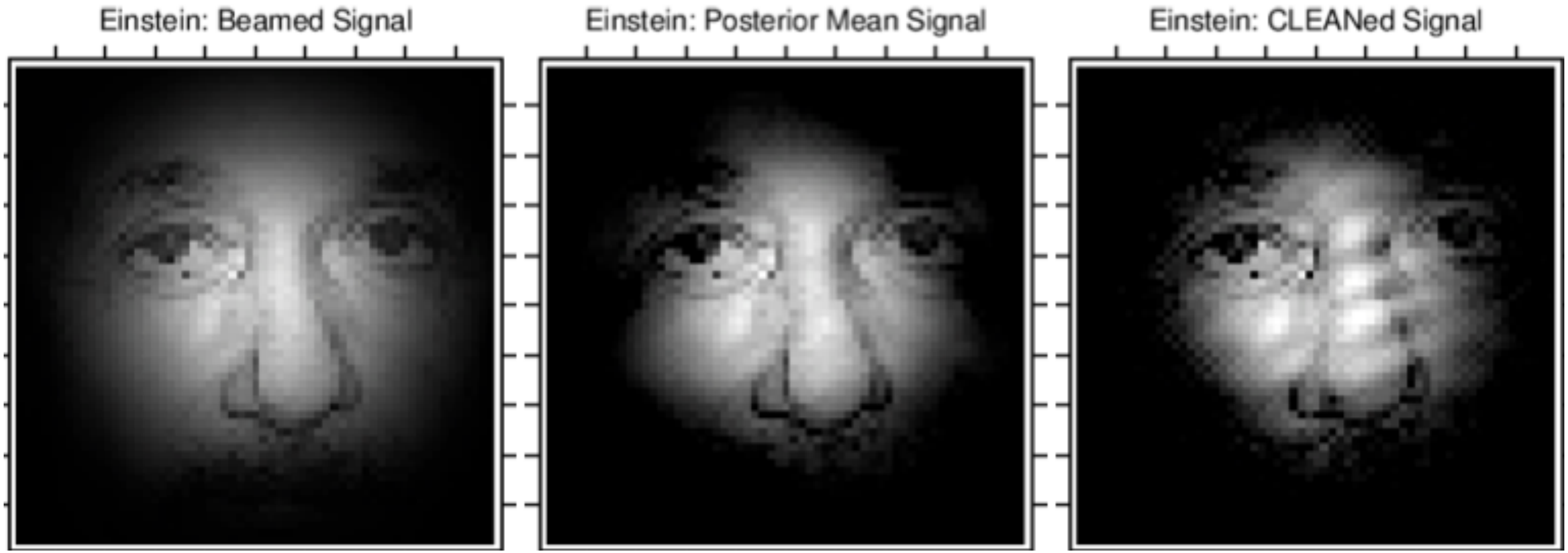






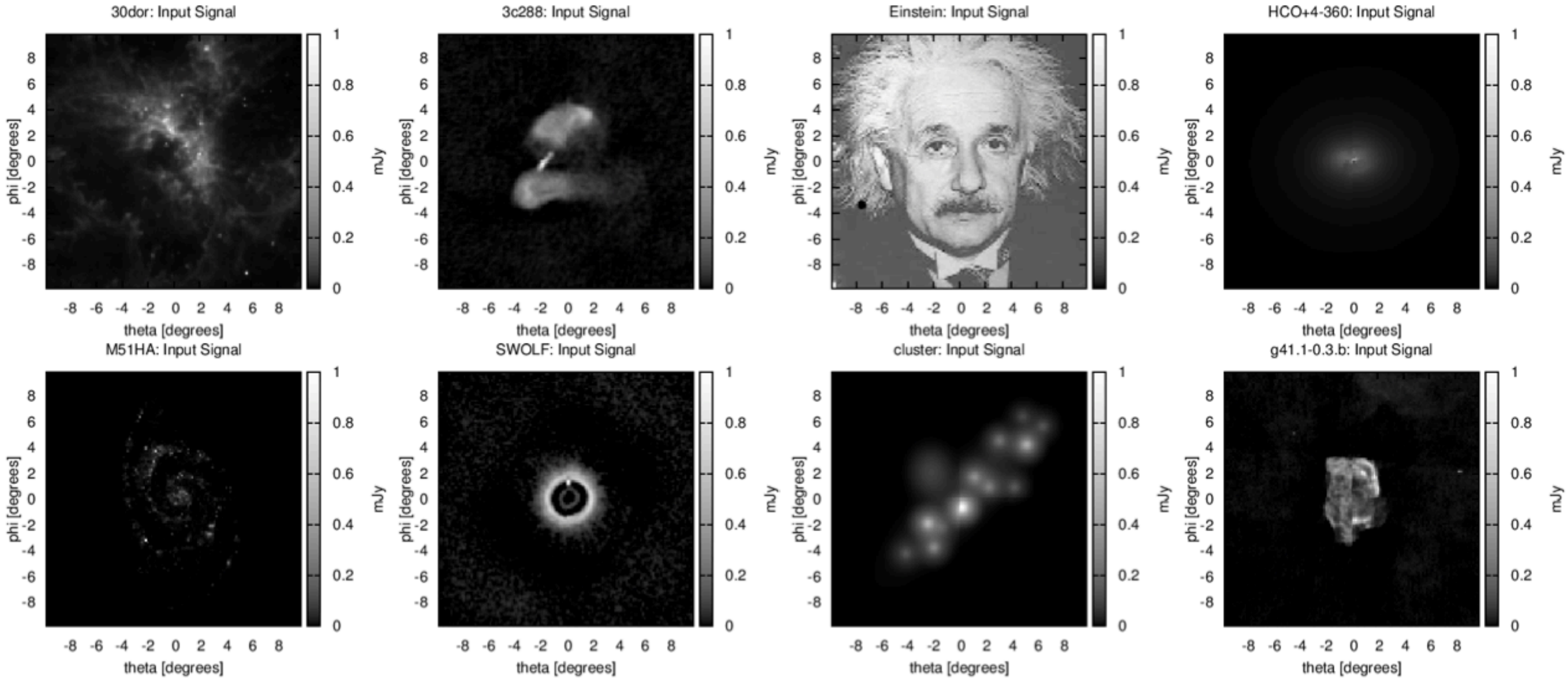
(Sutter et al. 2013)

example: Einstein results

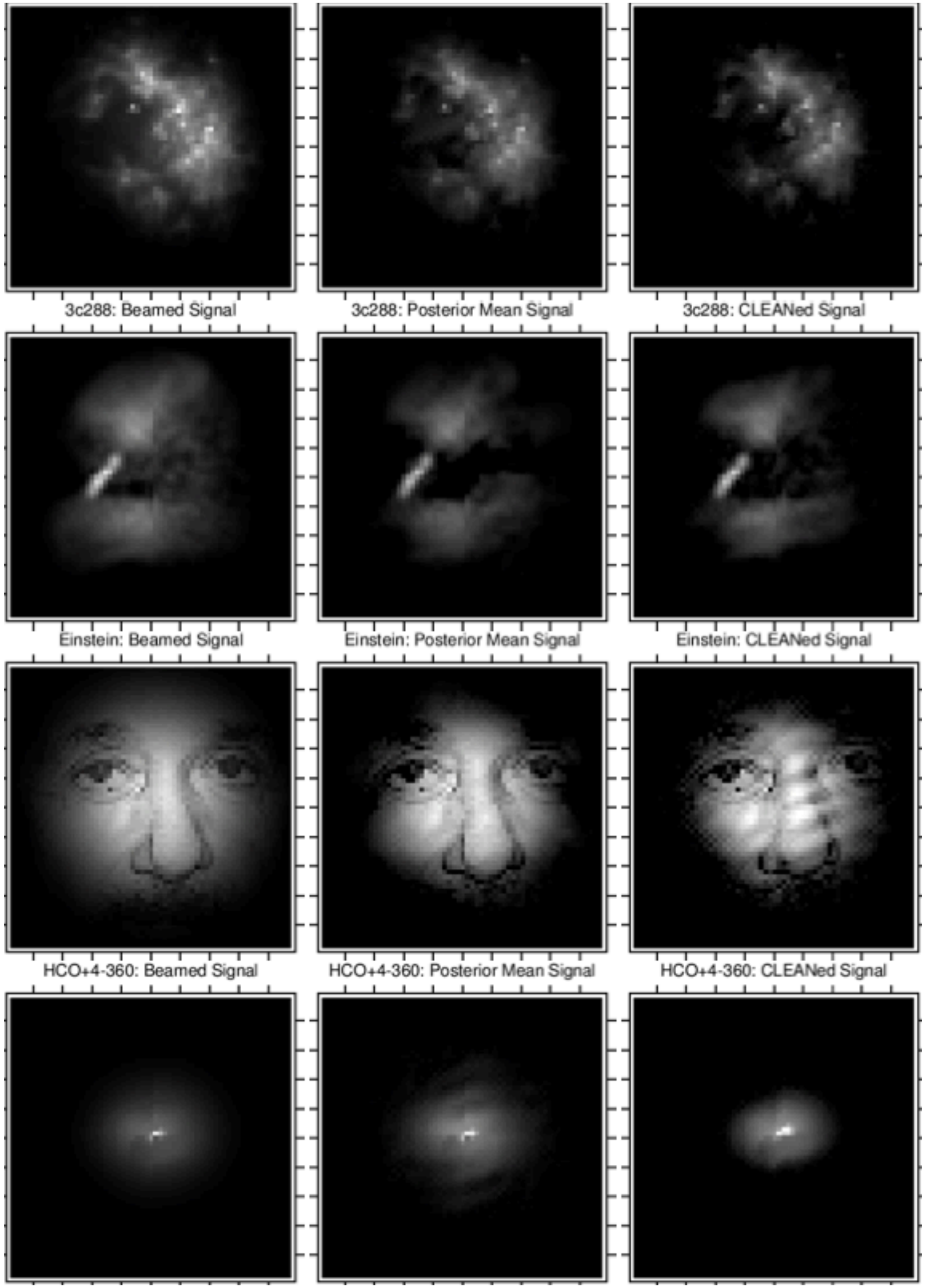


(Sutter et al. 2013)

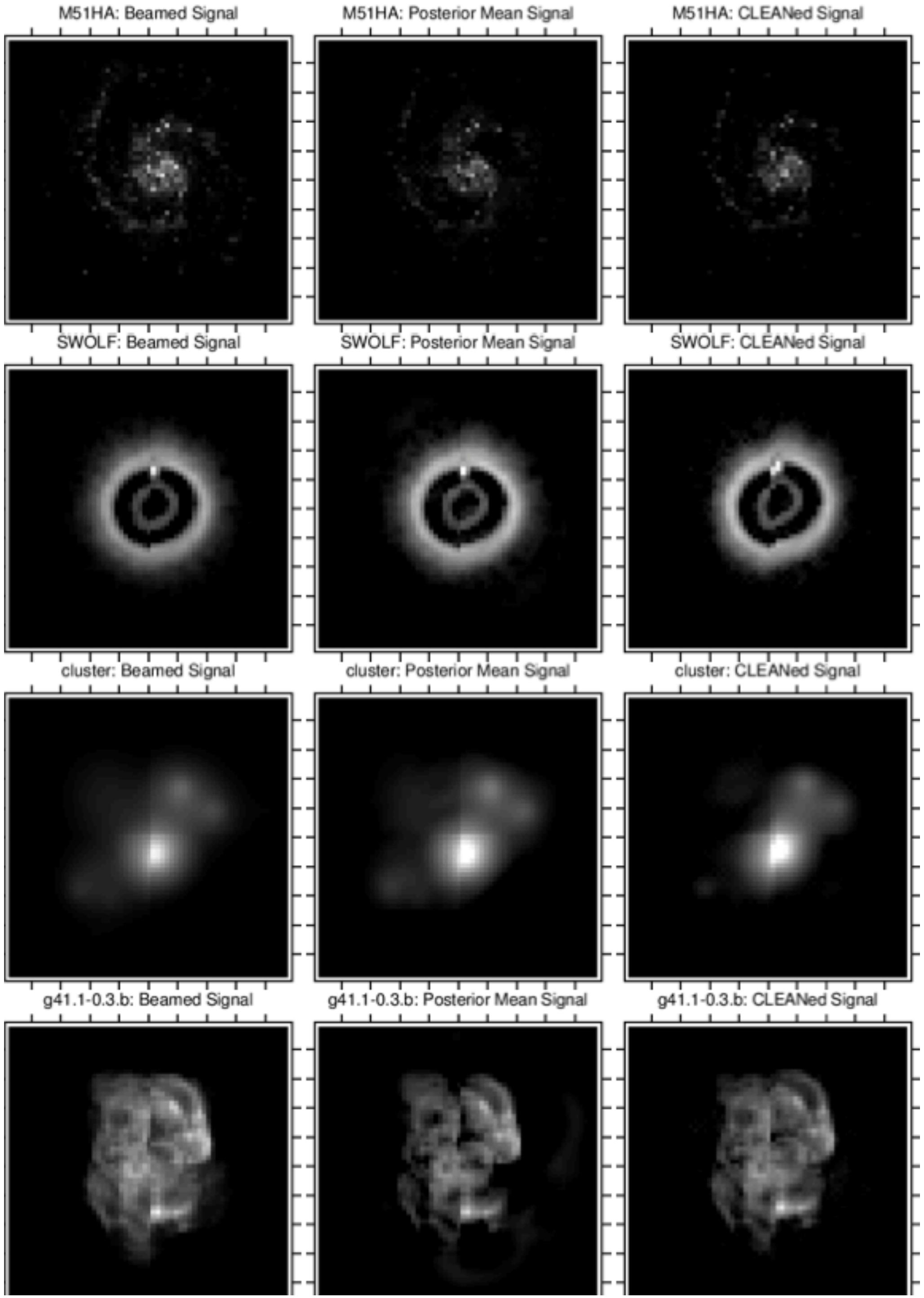
test images



(Sutter et al. 2013)

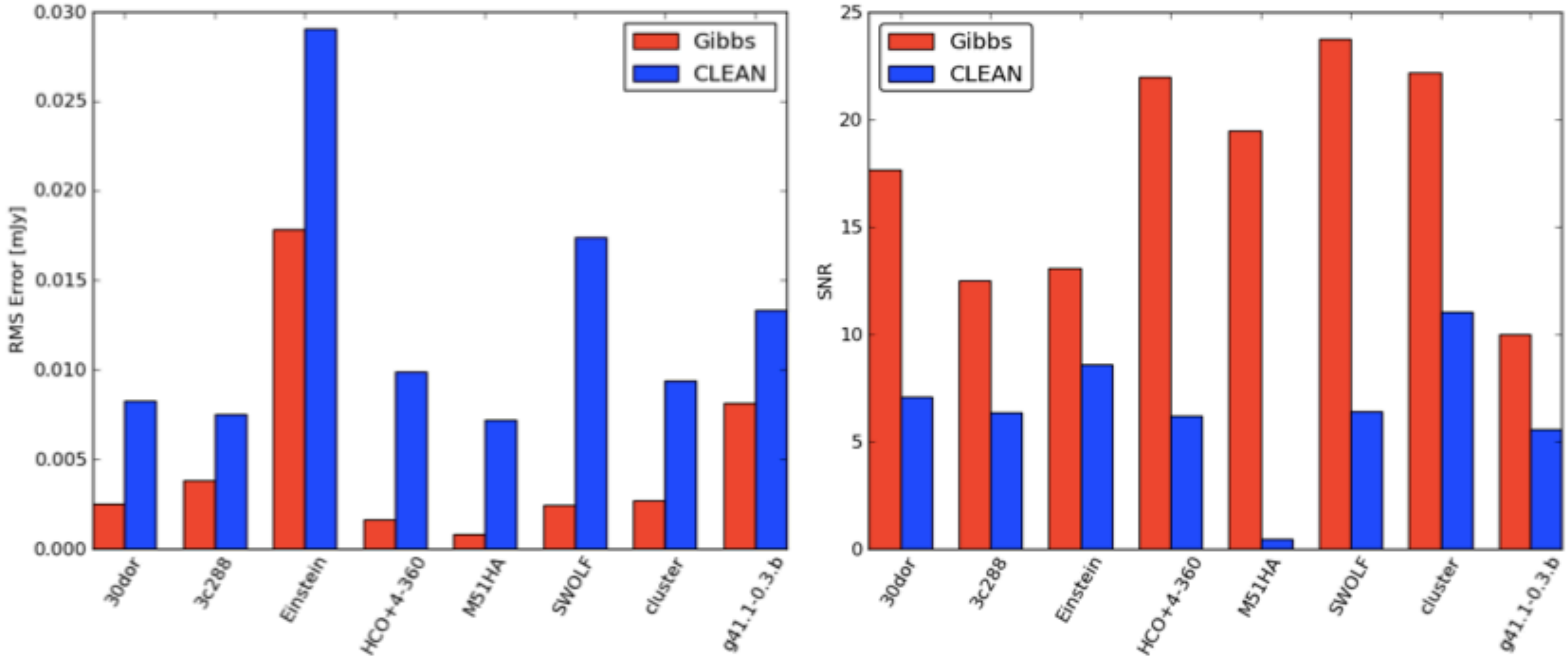


(Sutter et al. 2013)



(Sutter et al. 2013)

Gibbs performs better than CLEAN



(Sutter et al. 2013)

➔ **J.-L. Starck's talk**
Similary underlying ideas:
Bayesian prior favors "sparse" solutions