Minimizing systematics with CLONES

(Constrained LOcal & NEsting Environment Simulations)

Jenny Sorce

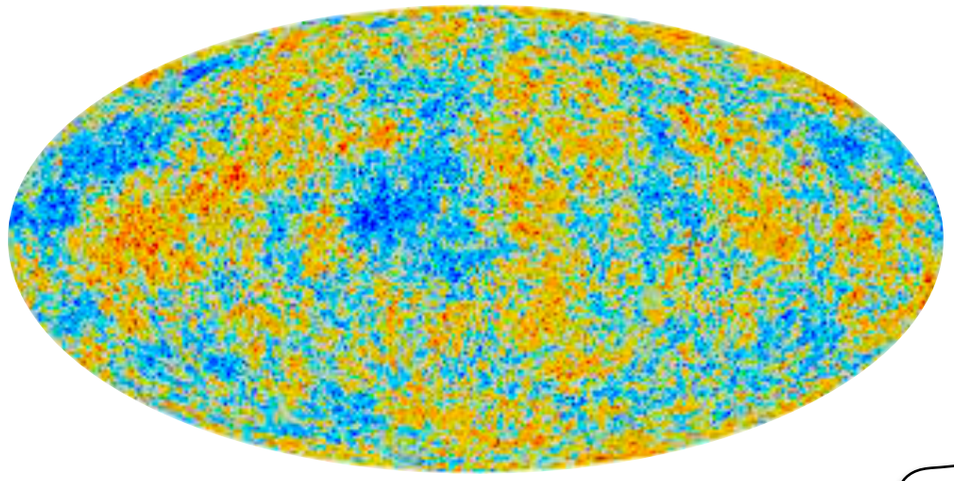
and many collaborators

Researcher at CRIStAL, Lille & Associate Researcher at IAS, Orsay &
Guest researcher at AIP, Potsdam & CAS fellow at LMU, Munich

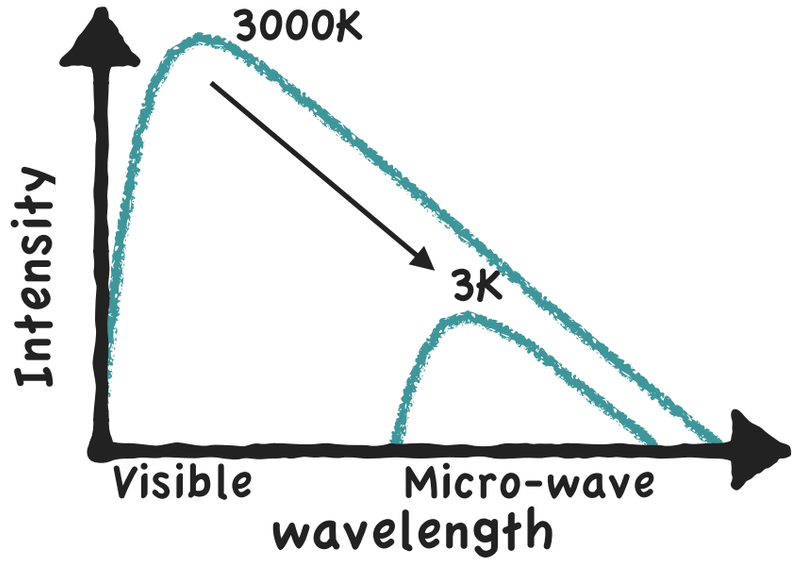
CosmoVerse@Lisbon - May 30th, 2023

Cosmology: ΛCDM?

Cosmic Microwave Background

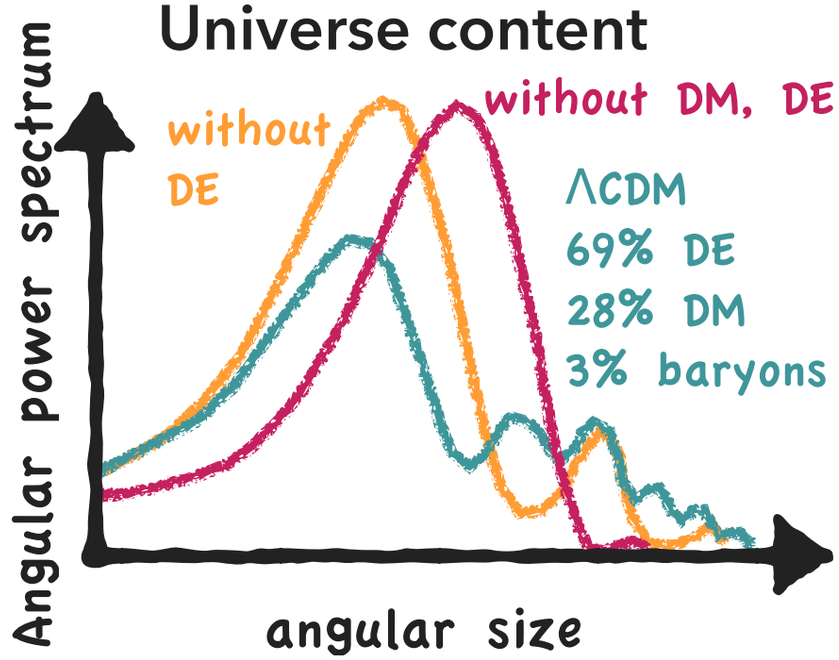


Universe expansion

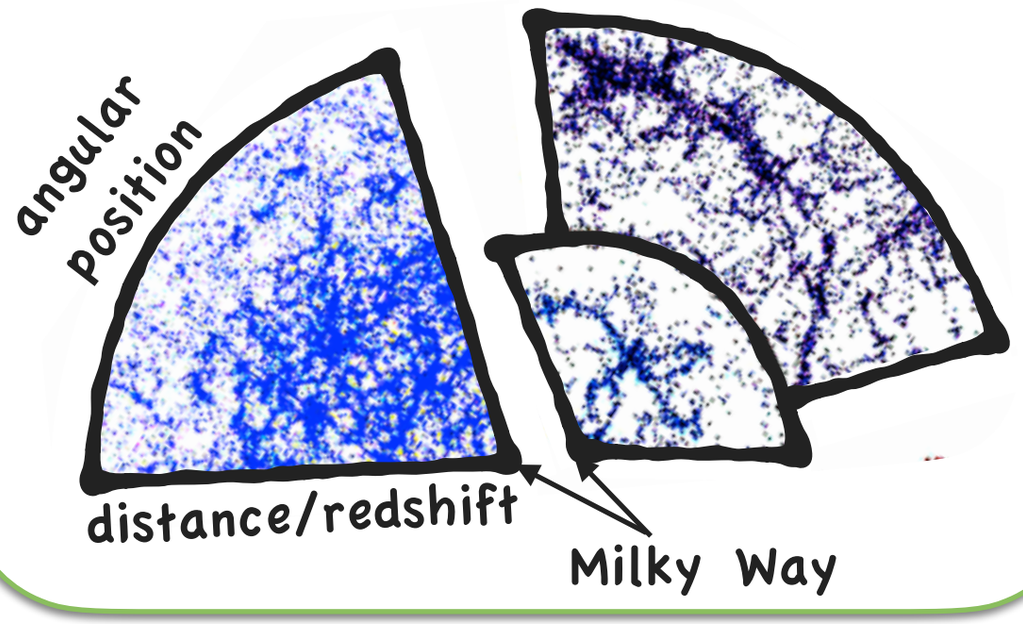


ΛCDM

Universe content

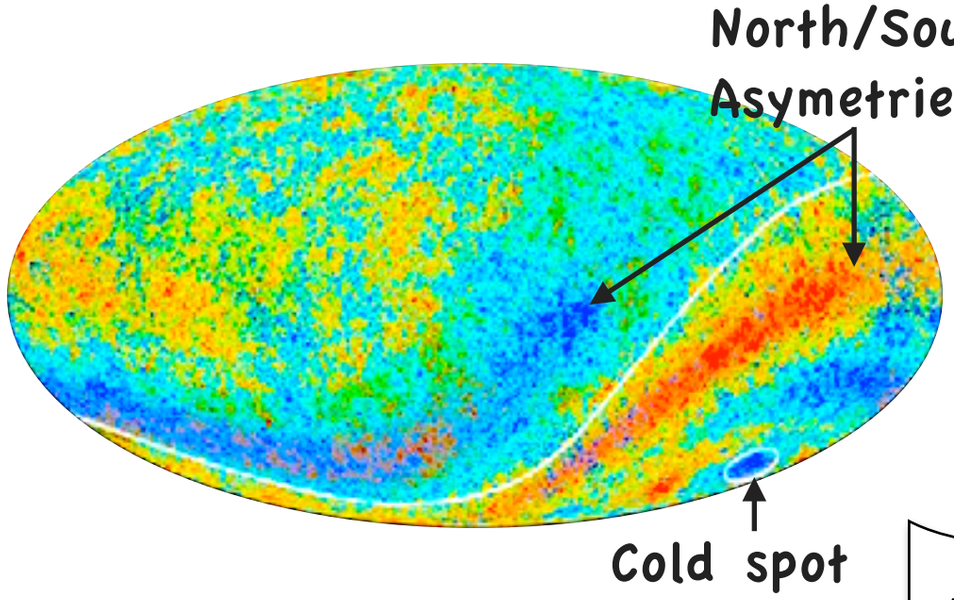


Cosmic Web and galaxies

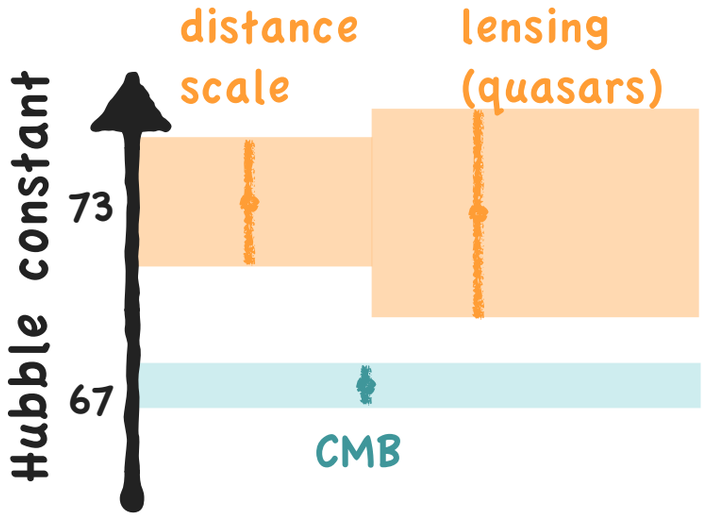


Cosmology: ΛCDM?

Anomalies in the CMB

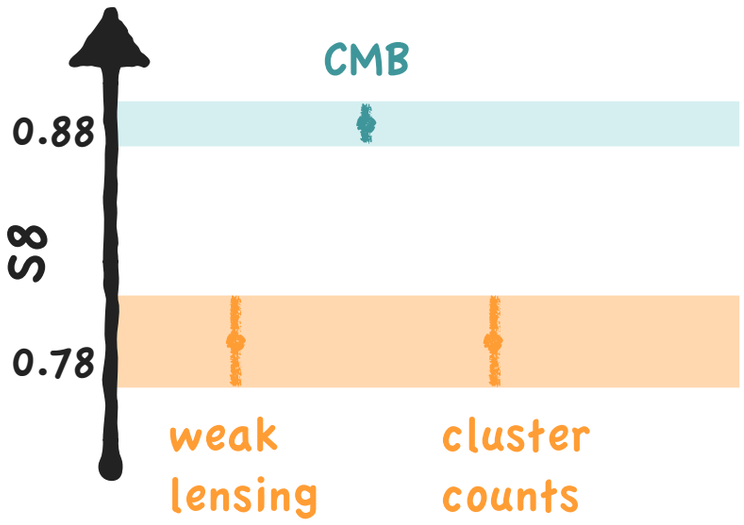


Universe expansion rate (H_0)

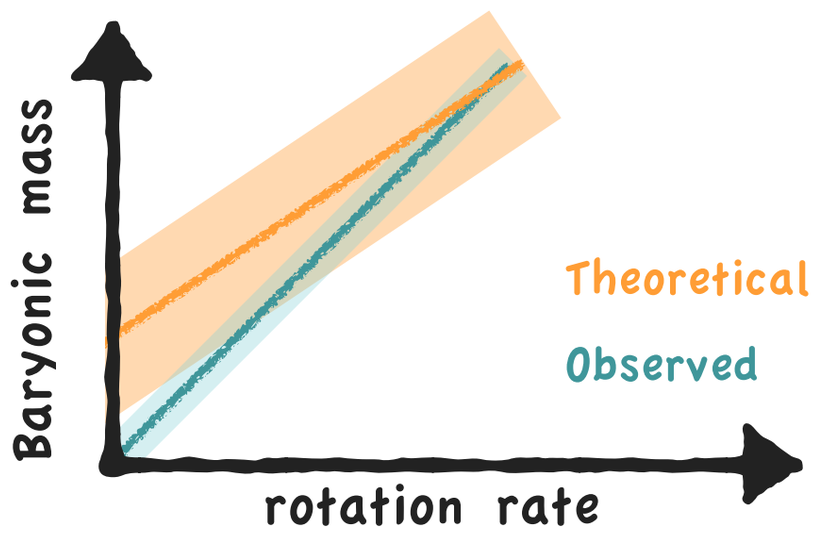


~~ΛCDM~~

S8 (σ_8, Ω_m)



Galaxy properties



Cosmology: ΛCDM?

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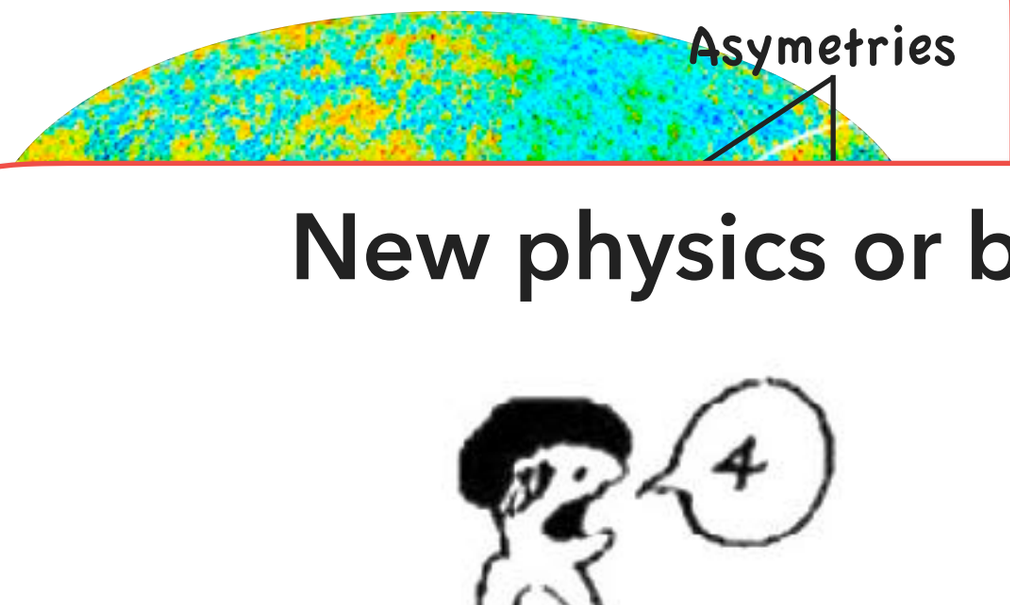

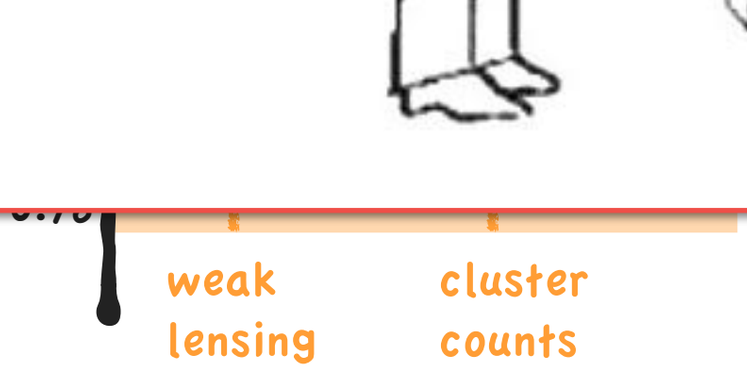

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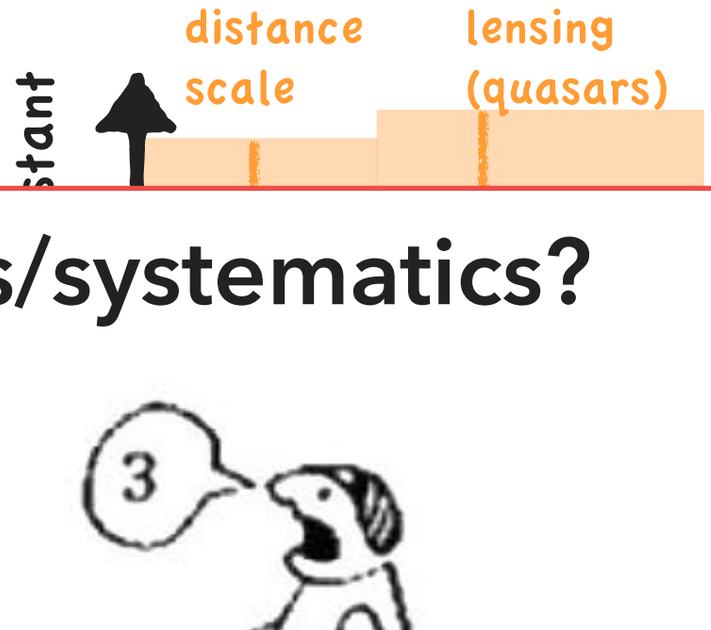
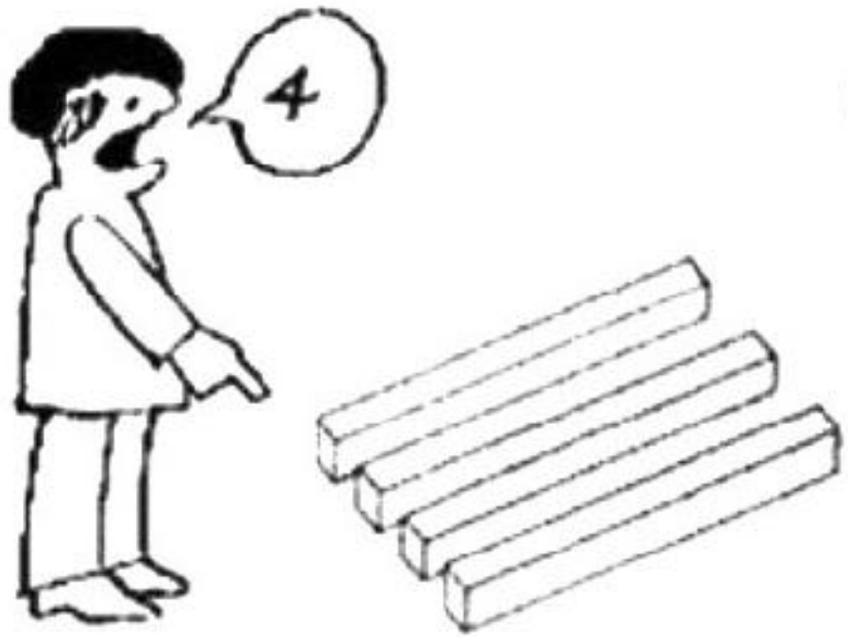
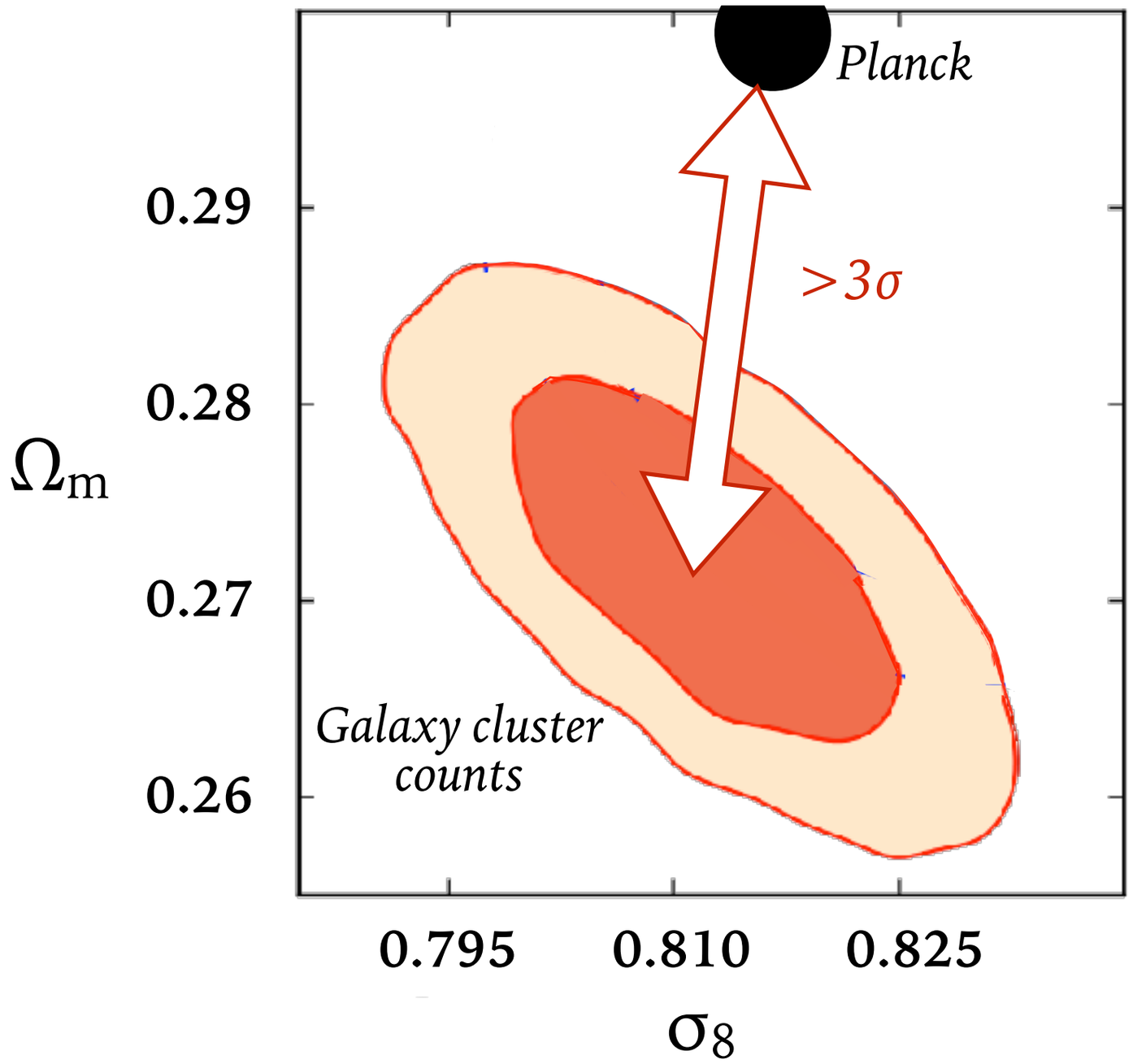


New physics or biases/systematics?



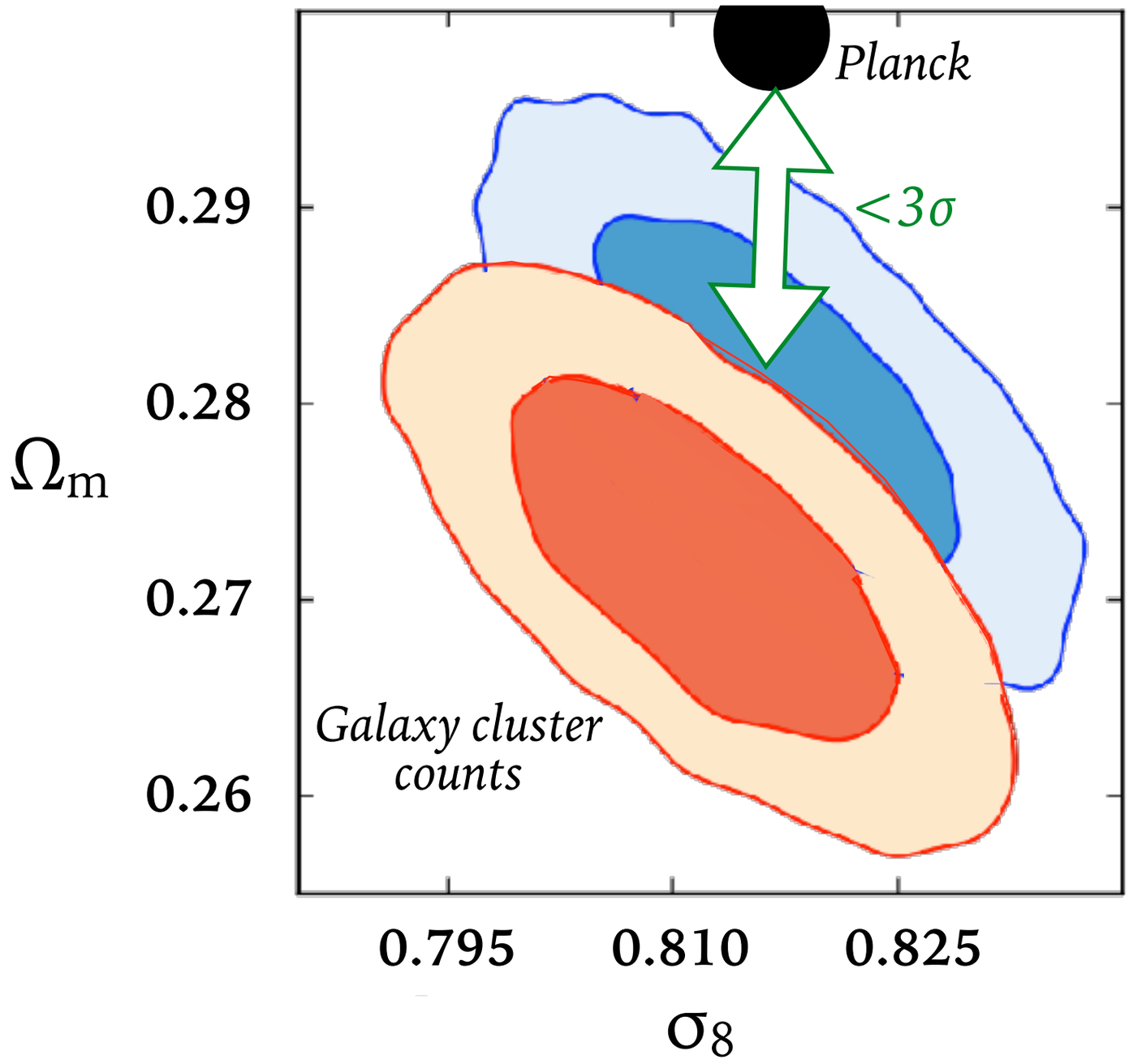
Example of S8 (σ_8, Ω_m)

Galaxy cluster mass function



Planck Collaboration, Pratt+2018

Example of S8 (σ_8, Ω_m) ➤ Changing mass calibration



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Example of S8 (σ_8, Ω_m) What and Why?

Hydrostatic equilibrium : intracluster medium

$$\frac{dP}{dr} = -\frac{G\rho M_{HE}}{r^2}$$

Spherical symmetry + no turbulent/magnetic pressure :

$$\Rightarrow M_{HE}(r) = -\frac{rP_{th}(r)}{G\mu m_p n_e(r)} \frac{d\ln P_{th}(r)}{d\ln r}$$

Gravitational potential well : DM + Baryons

$$M_{tot} = M_{DM} + M_{gas} + M_{stars}$$

↓

Hydrostatic mass bias

$$\longrightarrow \quad M_{HE} = (1-b)M_{tot}$$

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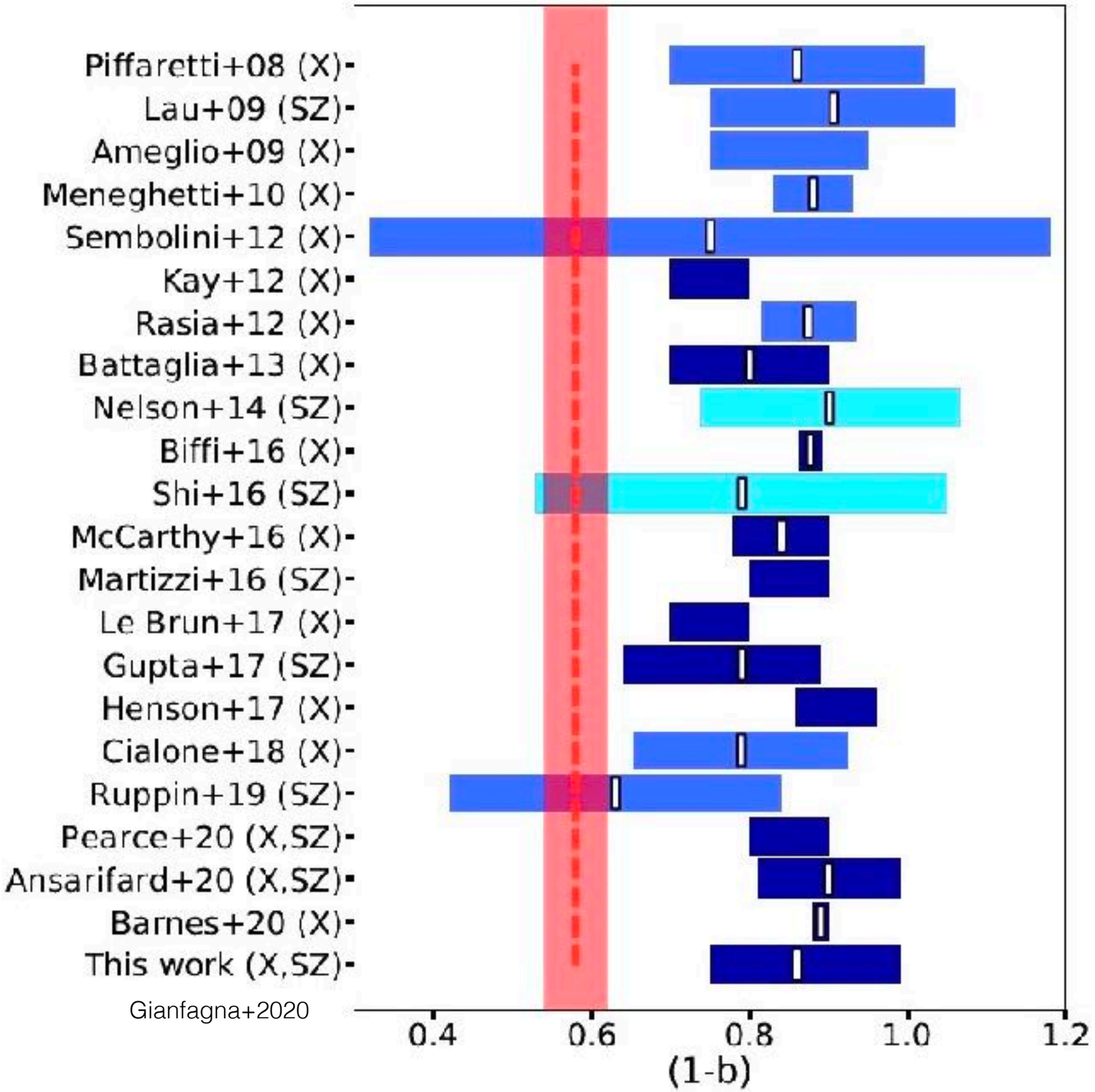
→ From cosmological simulations

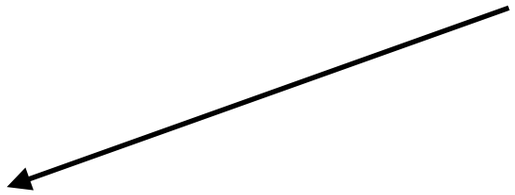
Example of S8 (σ_8, Ω_m) Huge disparity



Gianfagna+2020

Simulations & systematics

$$S8\ (\sigma_{8,}\ \Omega_m) = X +/- \sigma_{measure} +/- \sigma_{systematics}$$



- nb measurements
- instruments/tools sensitivity
  = precision

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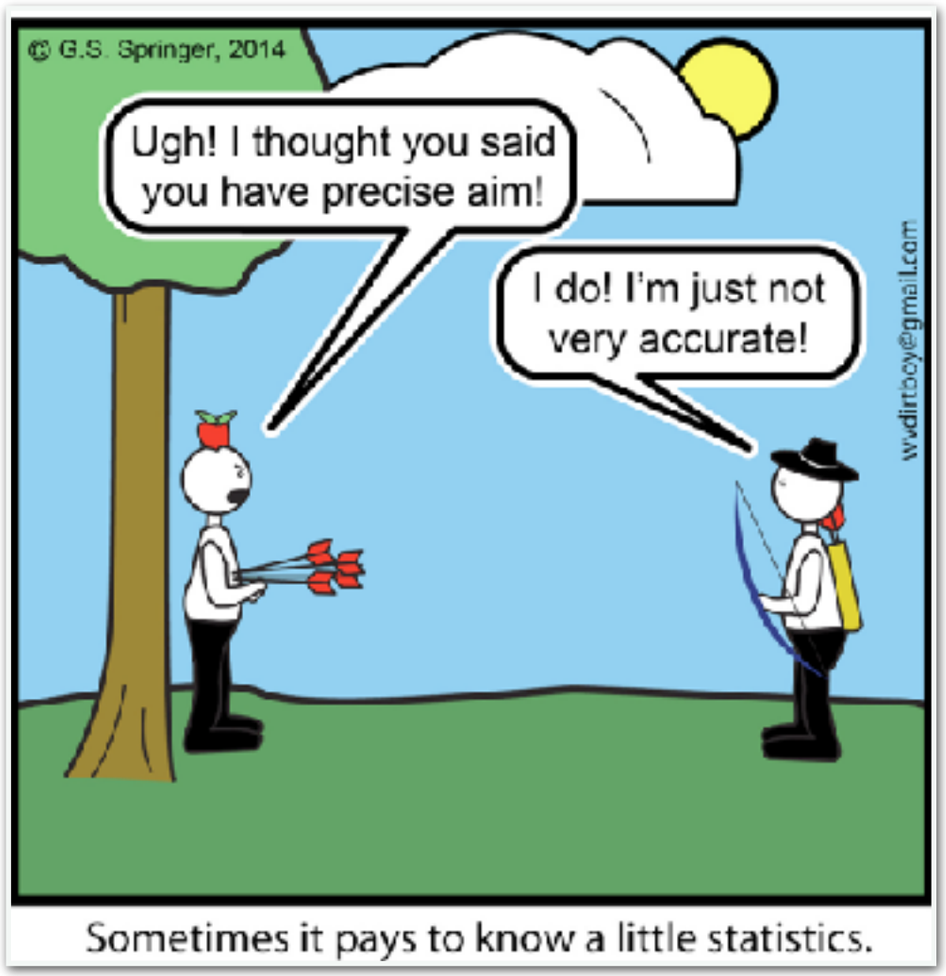
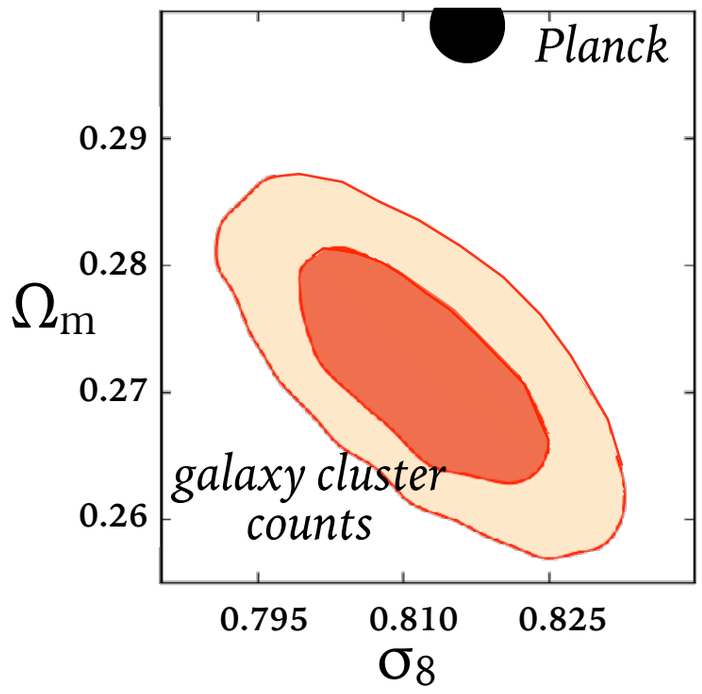
Standard cosmological simulations can give the total uncertainty but cannot reduce the systematics





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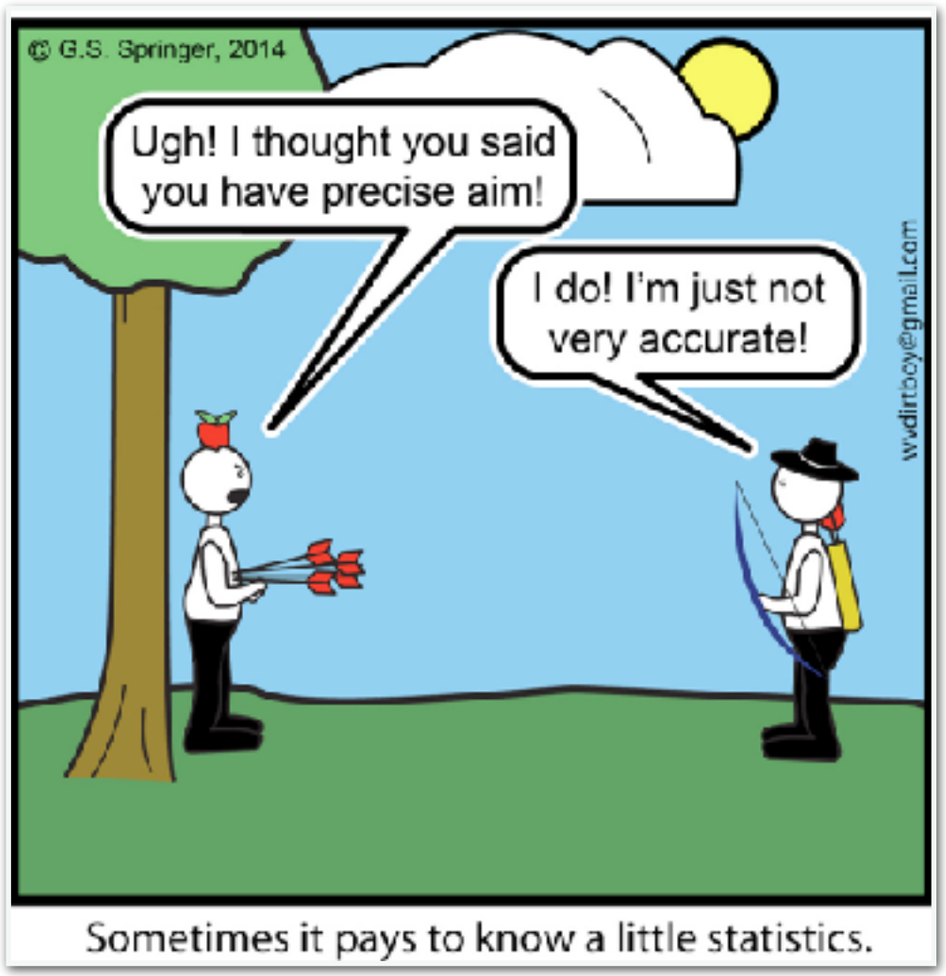

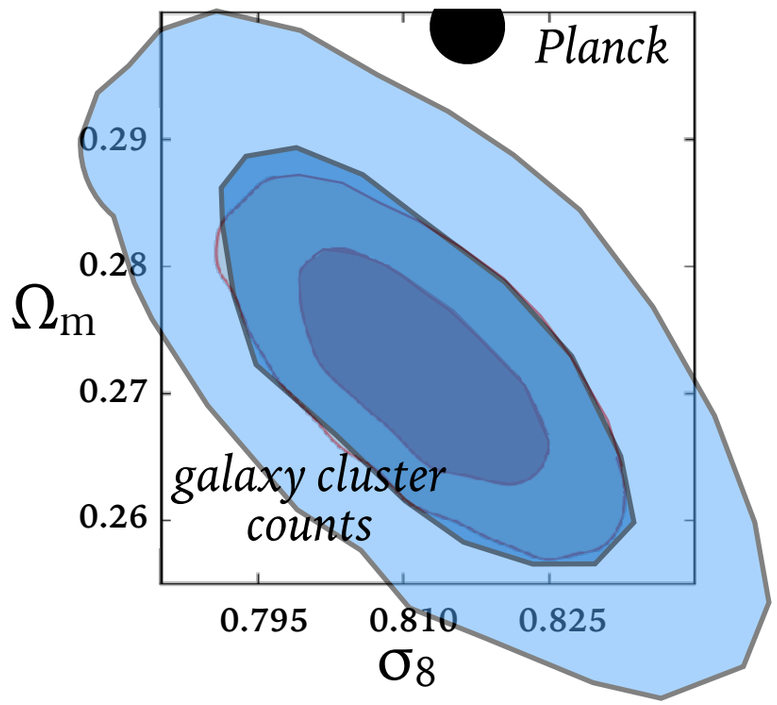

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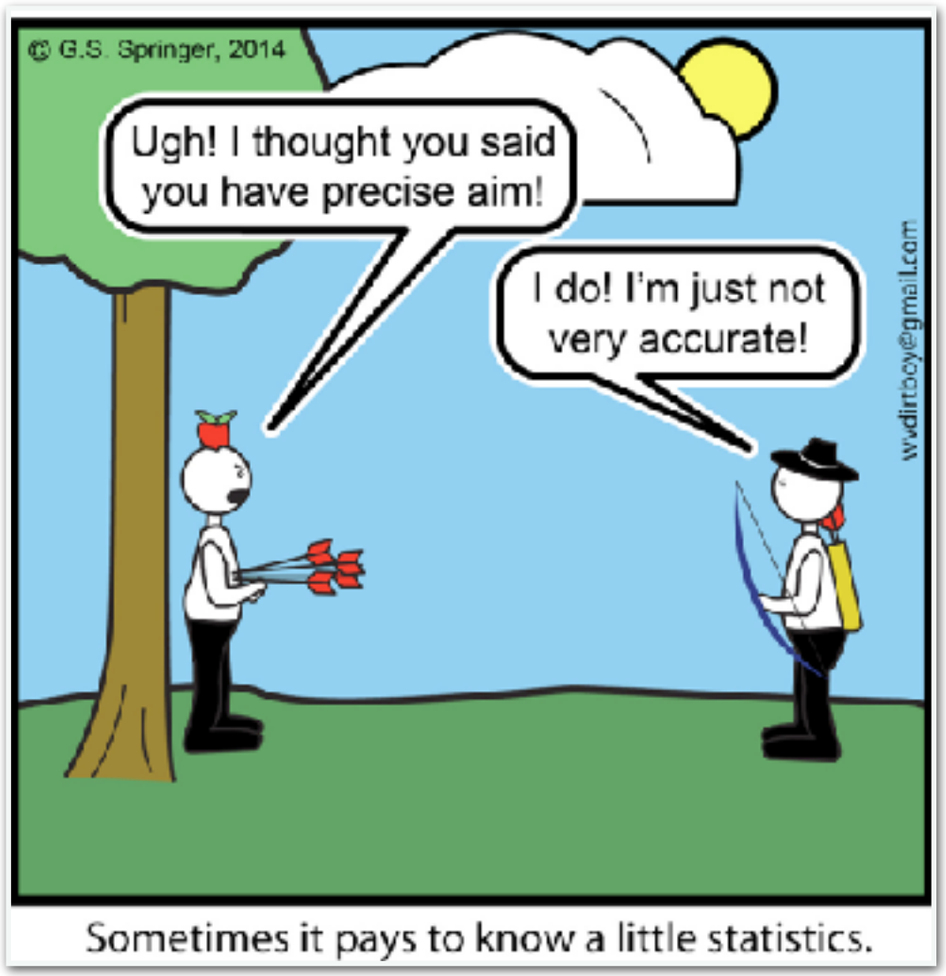

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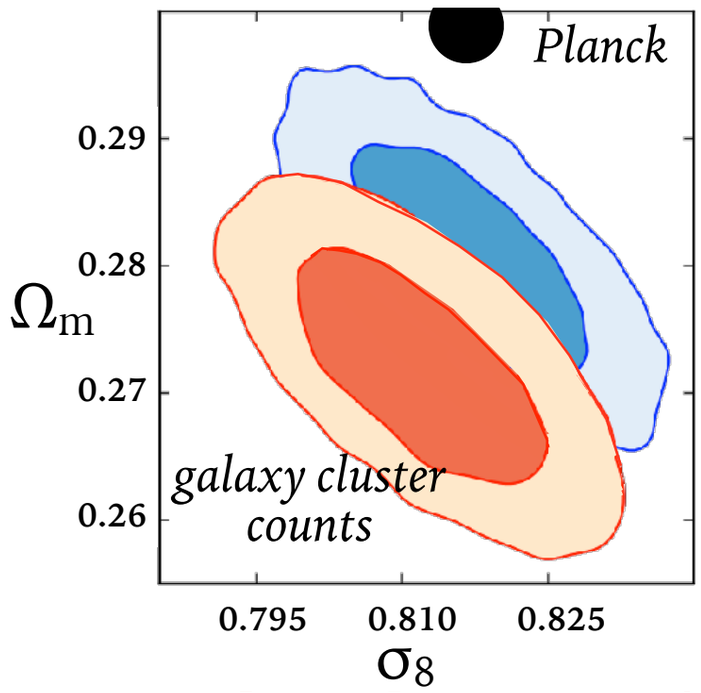
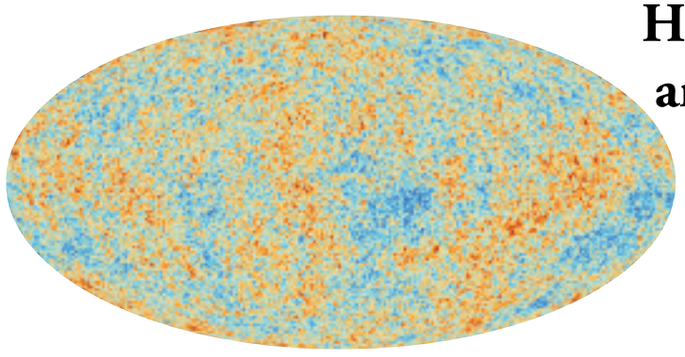


Constrained cosmological simulations can help reduce biases

Standard cosmological simulations

Initial conditions (ICs)

Part of the Universe at 13.7 light-Gyr
Photons received today have been emitted when it was ~380 000 yrs. old

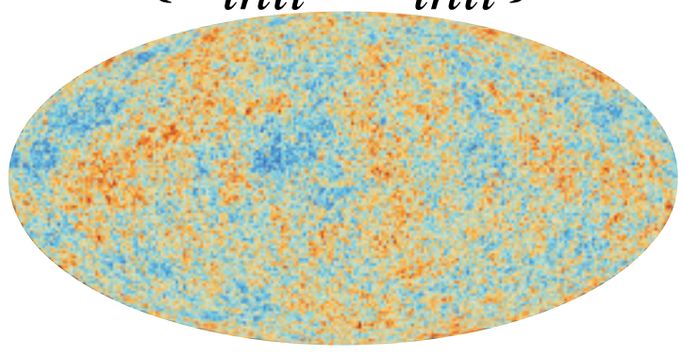


Homogeneous and Isotropic Universe → $P(k)$ → **Gaussian initial density field**

$$\delta(\mathbf{k}) = \sqrt{P(\mathbf{k})}.\omega(\mathbf{k})$$

initial conditions of a random patch of the Universe

$$\{\delta_{init}\ , v_{init}\}$$



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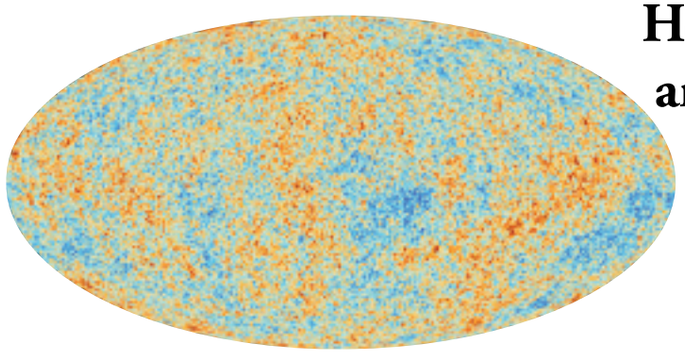

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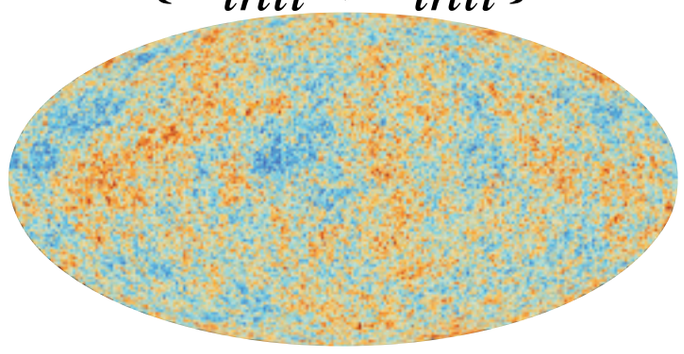

Why only δ ? → **Linear perturbation theory (Euler+ Continuity+Poisson)** → $\nabla . v = -\dot{a} f \delta$

NB: only divergent (no tidal) but periodic boundaries

Standard cosmological simulations

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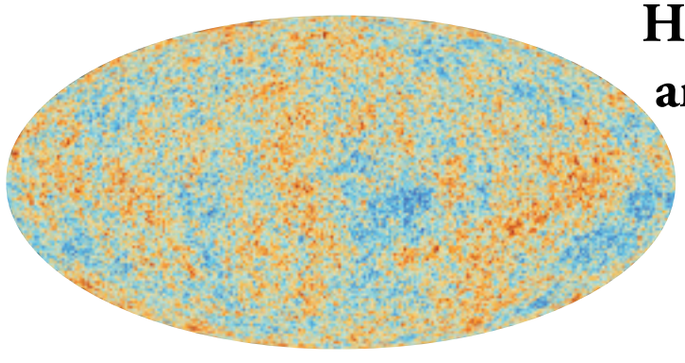

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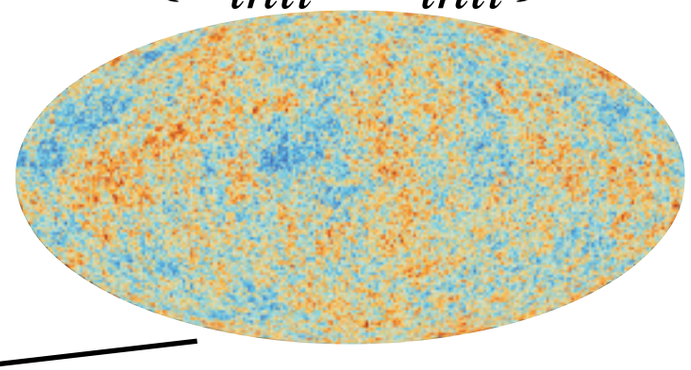
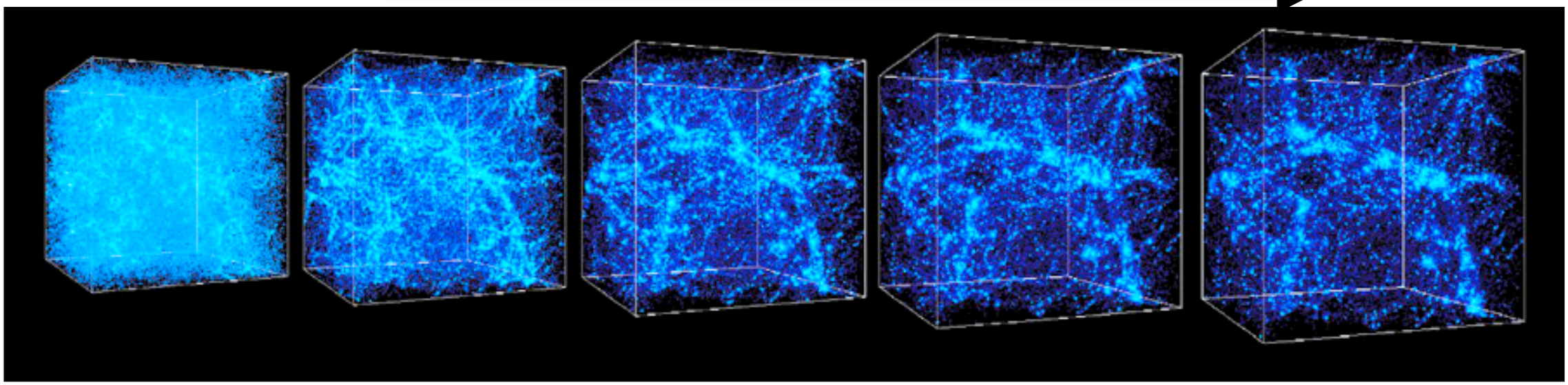


Linear perturbation theory + "kick"

Evolution



Constrained cosmological simulations

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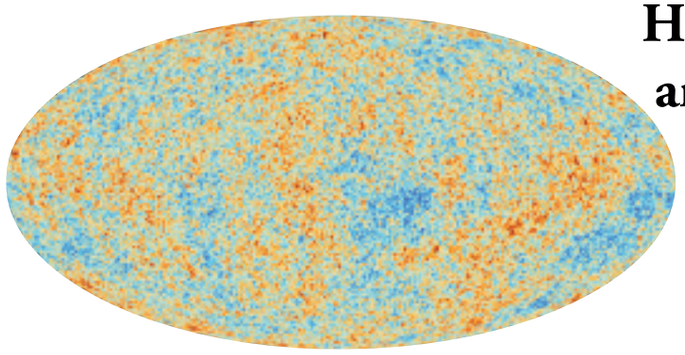

Homogeneous and Isotropic Universe → $P(k)$ → **Gaussian initial density field**

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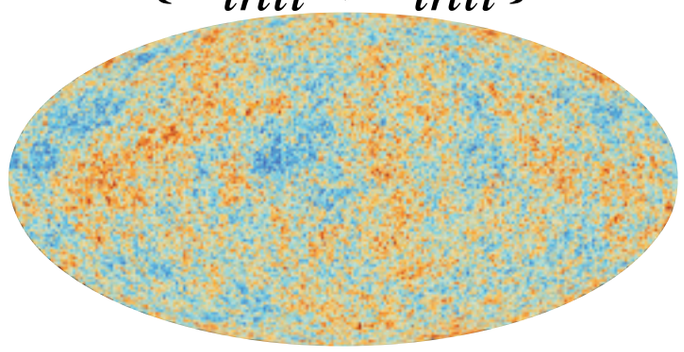
initial conditions of the local Universe

$\{\delta_{init}, v_{init}\}$



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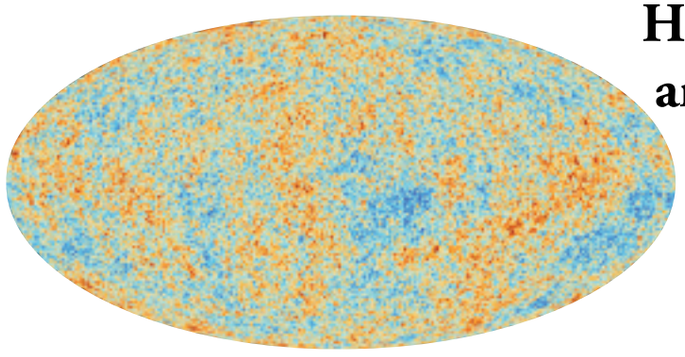

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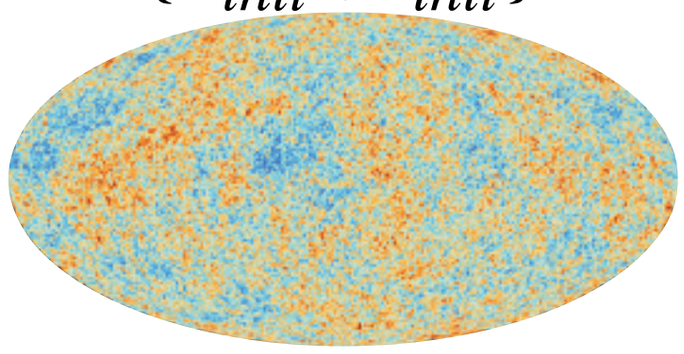
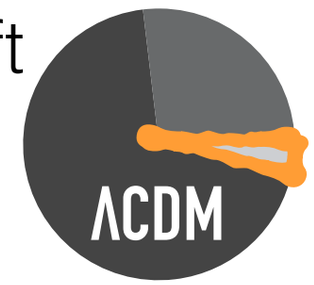


Type of constraints

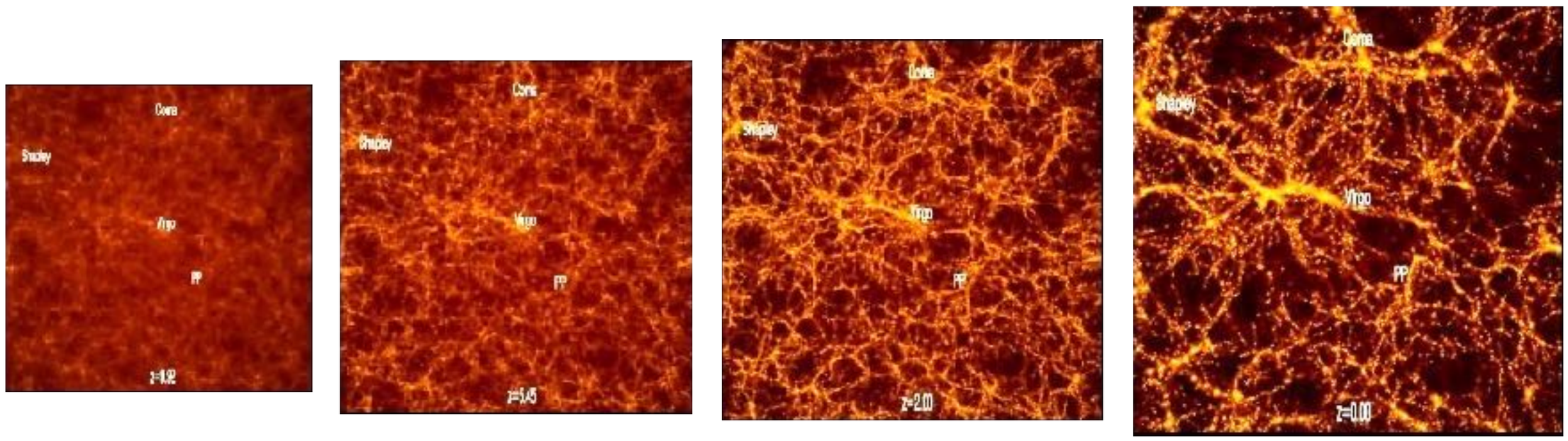
Redshift



Peculiar velocity

NB: both with pros and cons!

Constrained cosmological simulations → e.g. CLONES



Evolution

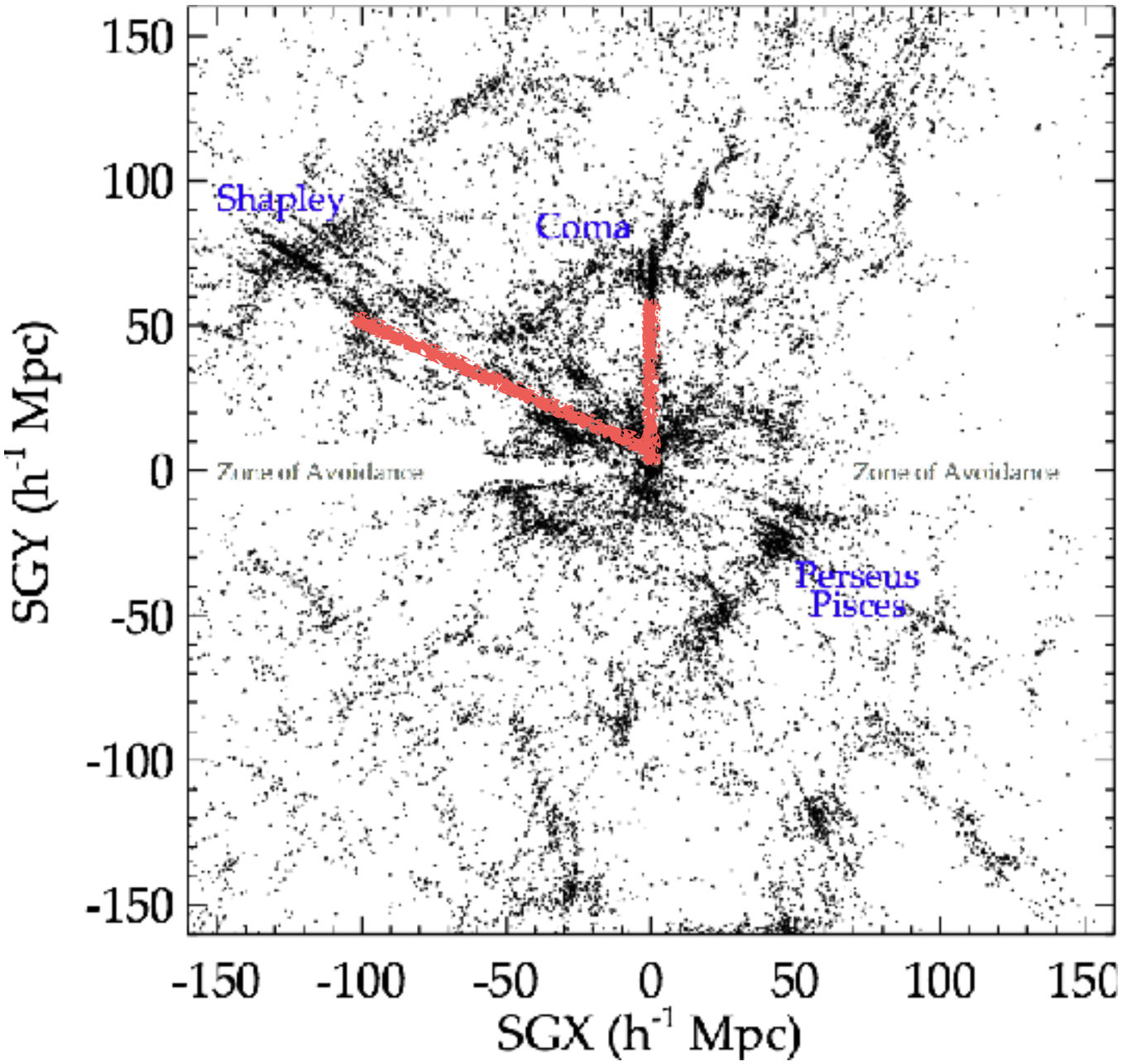
Sorce+2016

Sorce2018

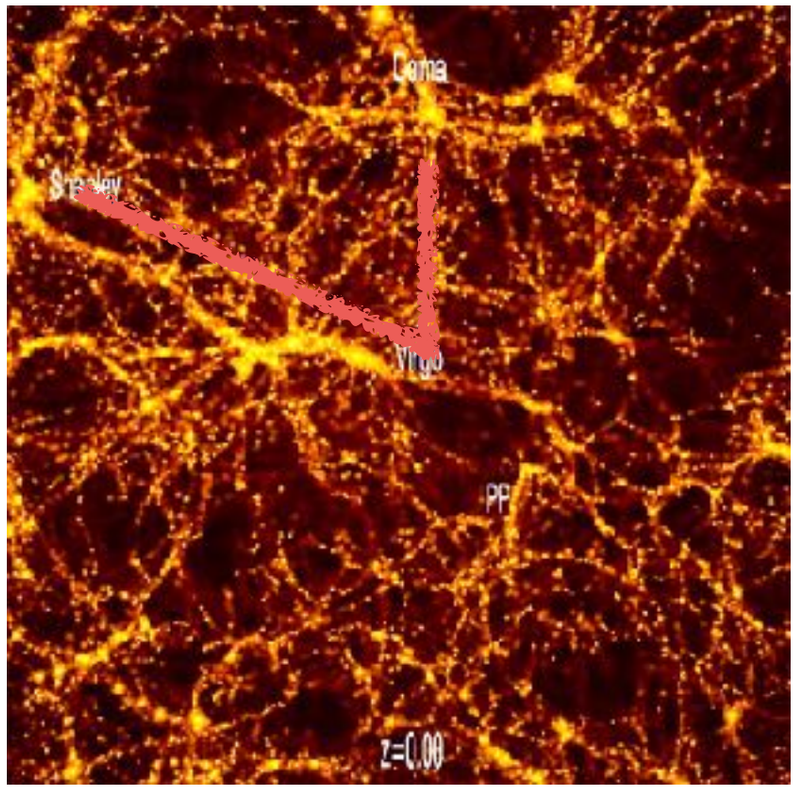
CLONES = Constrained LOcal & Nesting Environment Simulations

CLONES: an independent M_{tot} estimate?

Sorce2018



Note the fingers of gods

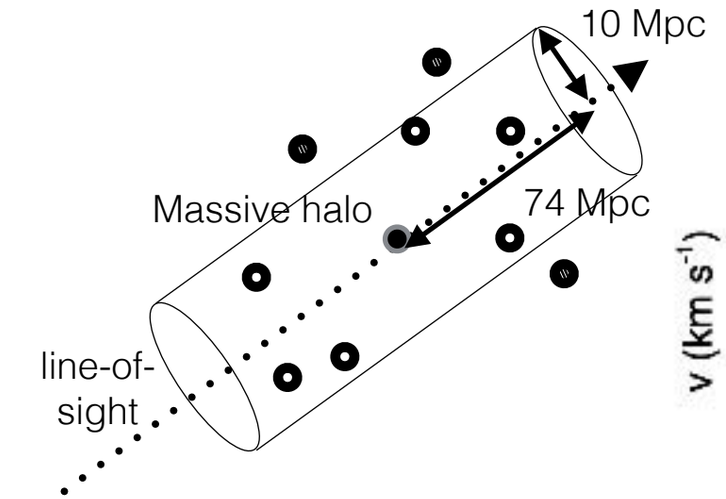


500 Mpc/h, 1024^3 particles,
DM only, Planck cosmology

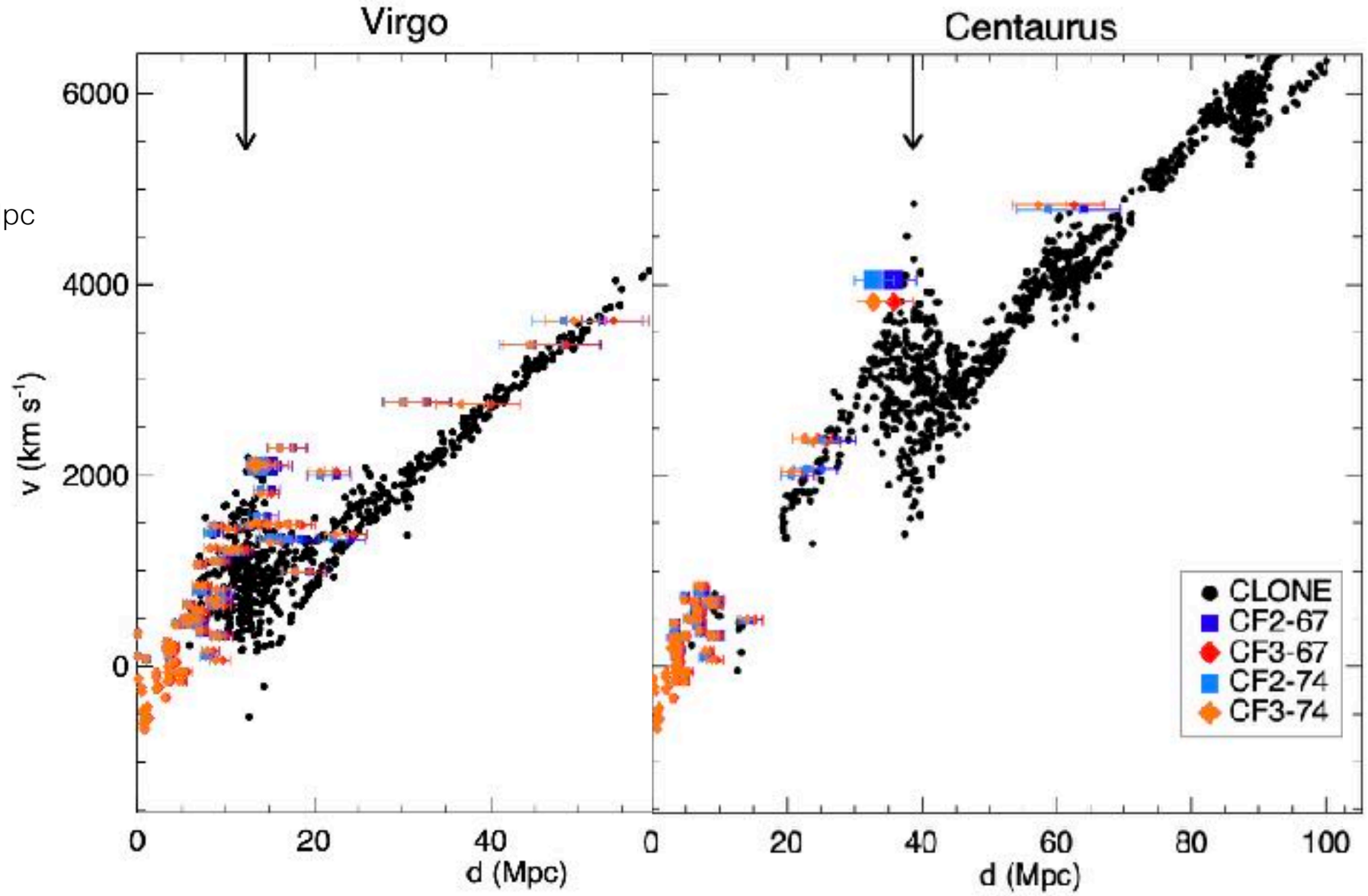
CLONES: an independent M_{tot} estimate?

Sorce+submitted

Velocity wave signatures in the Hubble diagram



Synthetic observer
= center of the box



500 Mpc/h, 2048^3 particles, DM only, Planck cosmology

CLONES: hydrostatic mass bias & projection effects

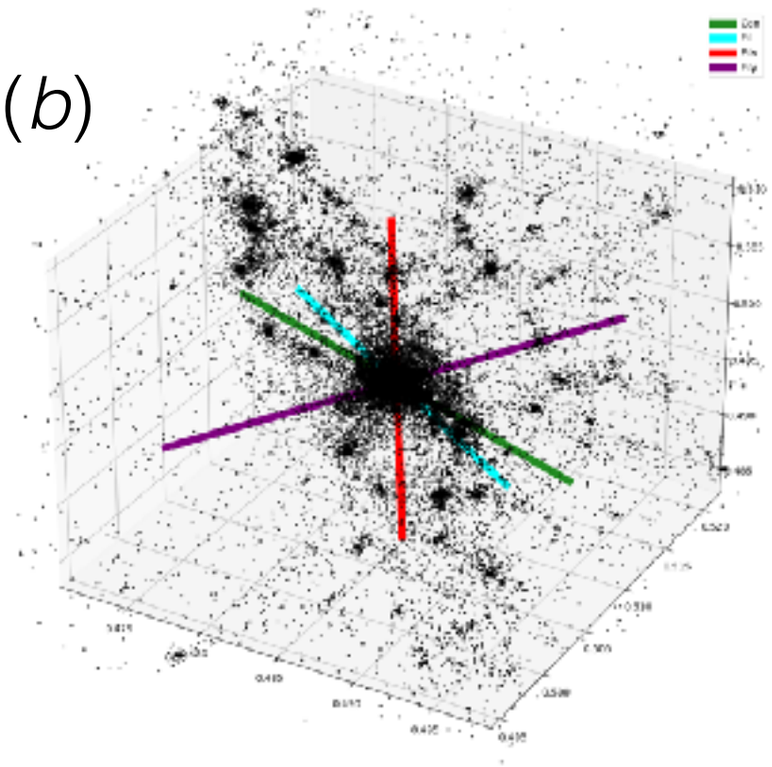
Théo Lebeau

Project: using a CLONE of the local Volume that contains replicas of local clusters to study the impact of

- the dynamical state of the cluster (substructures, morphology)
- the local Environment (connectivity)
- the formation history (accretion from filaments, merging)

on the hydrostatic mass bias (*b*)

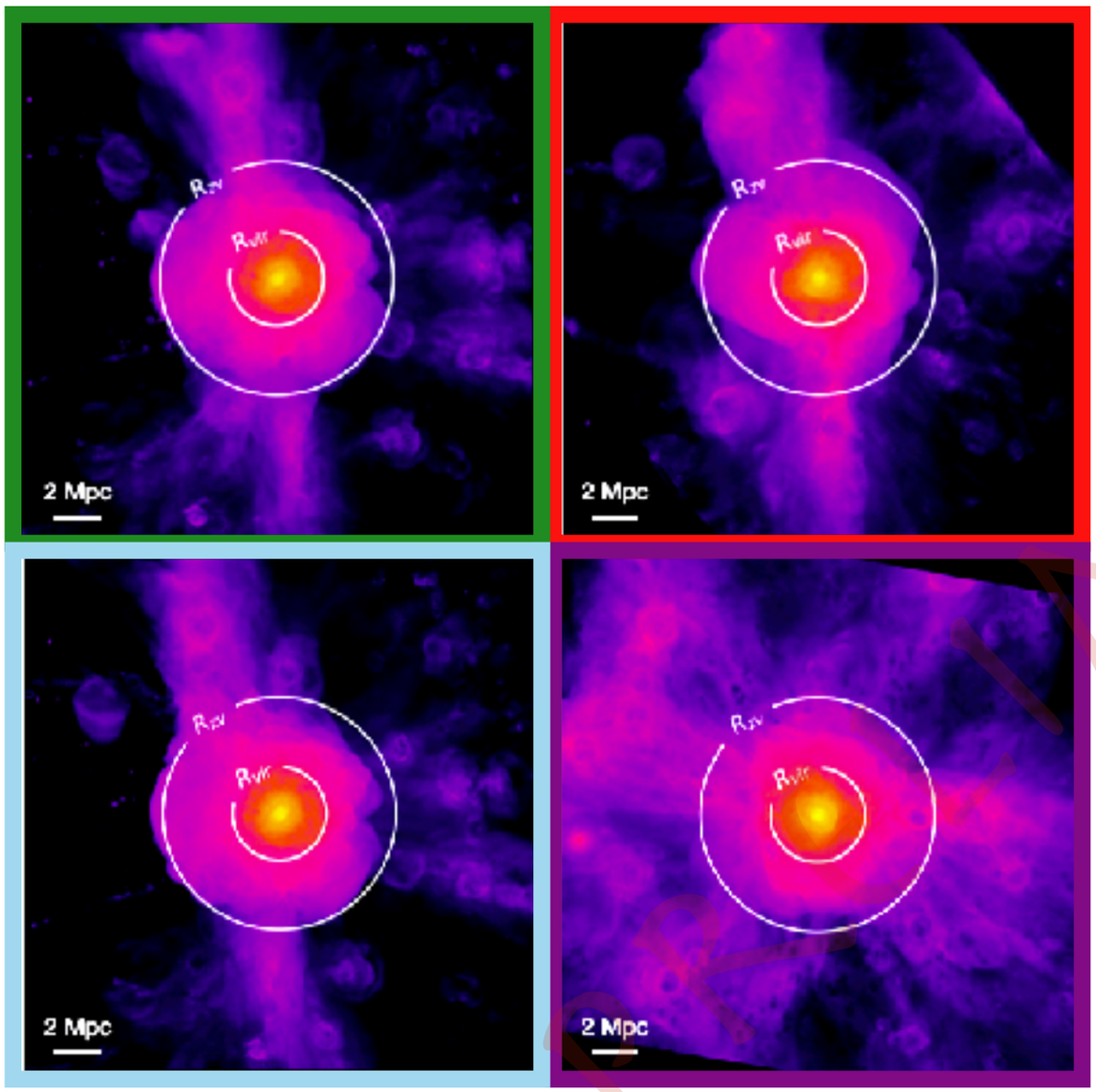
-> Example of the projection effects on the hydrostatic mass bias in the case of the Virgo cluster

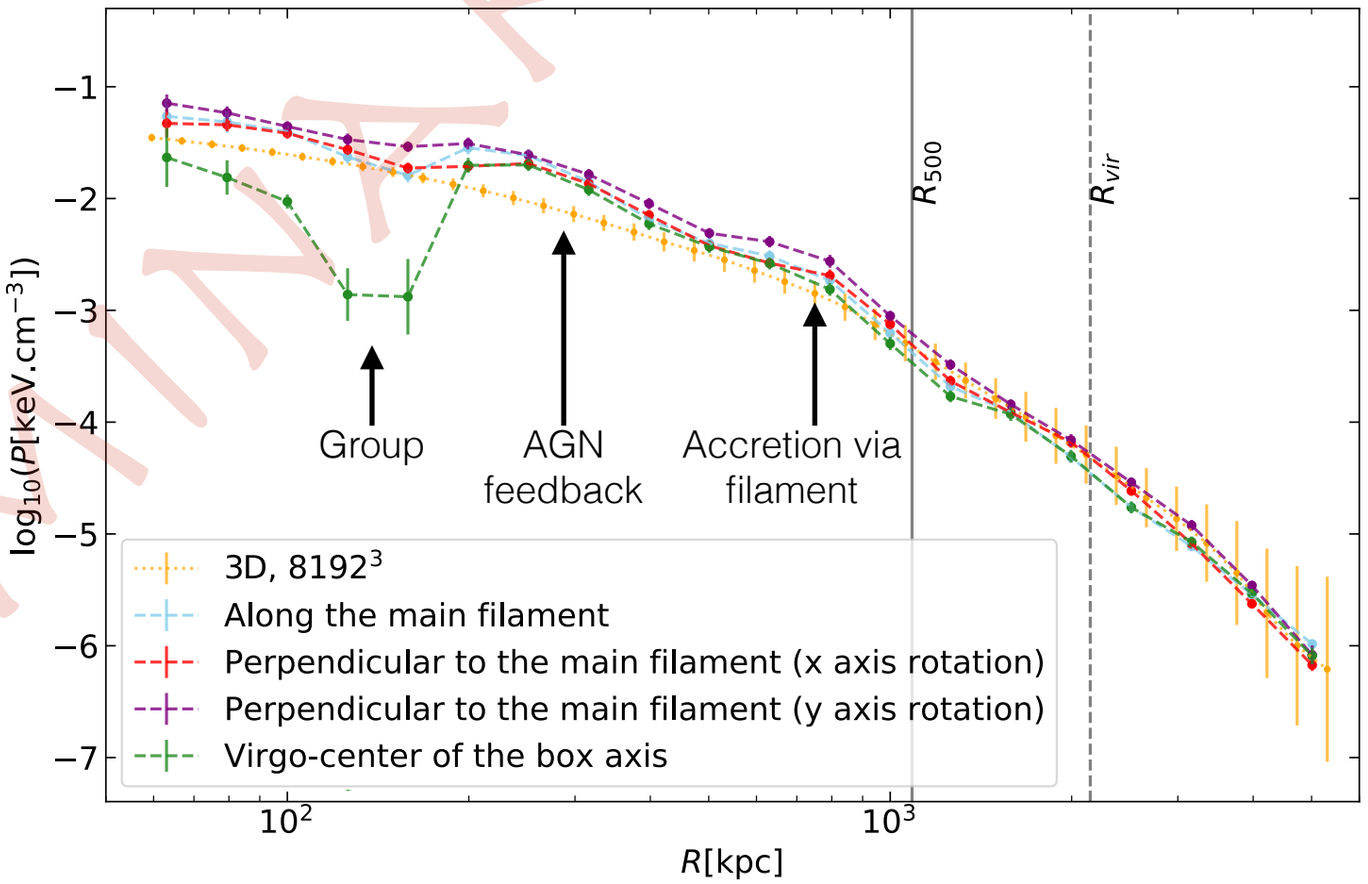


CLONES: hydrostatic mass bias & projection effects

Théo Lebeau

Example of the Virgo galaxy cluster





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Lebeau+in prep.

CLONES: hydrostatic mass bias & projection effects

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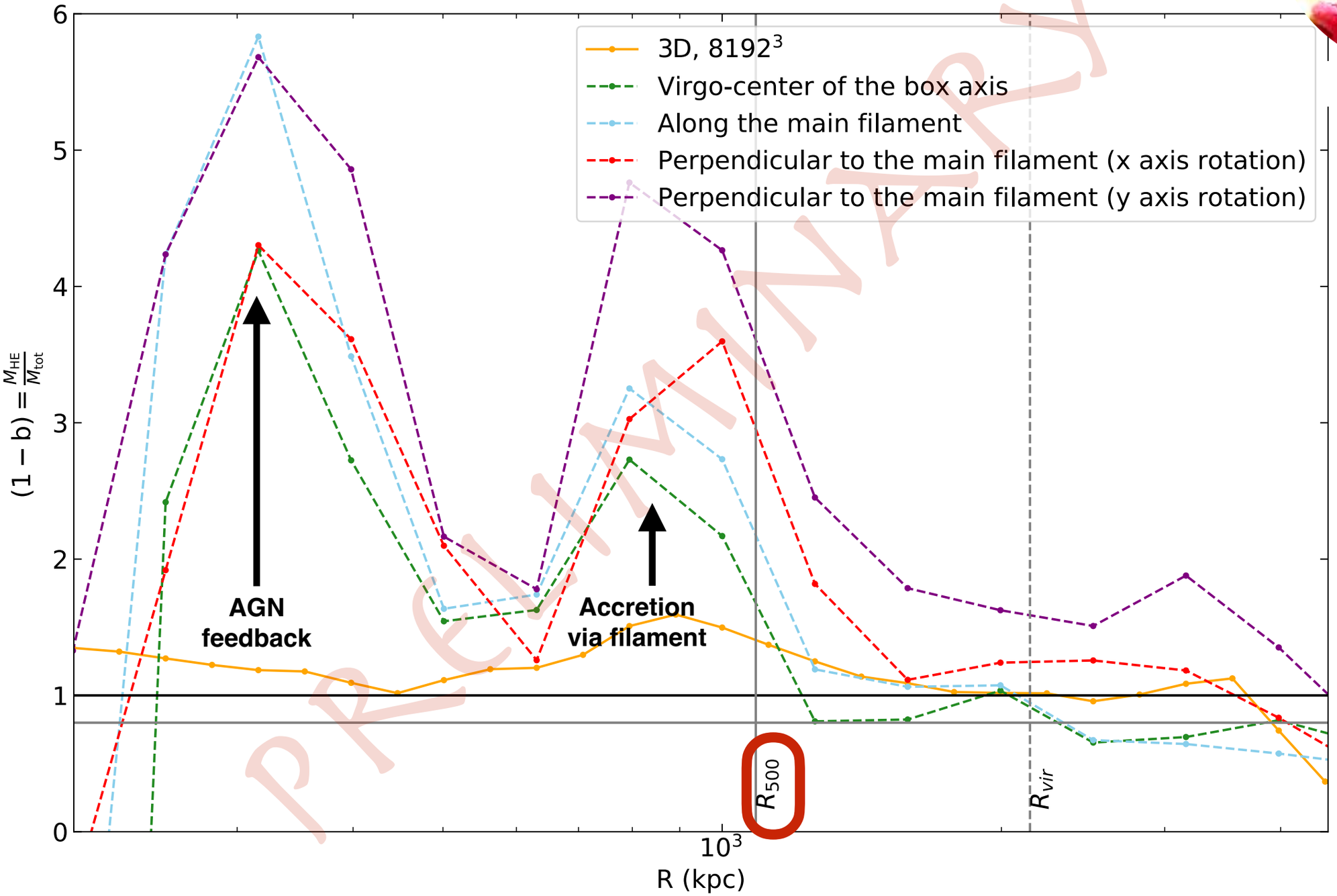

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CLONES: hydrostatic mass bias & projection effects

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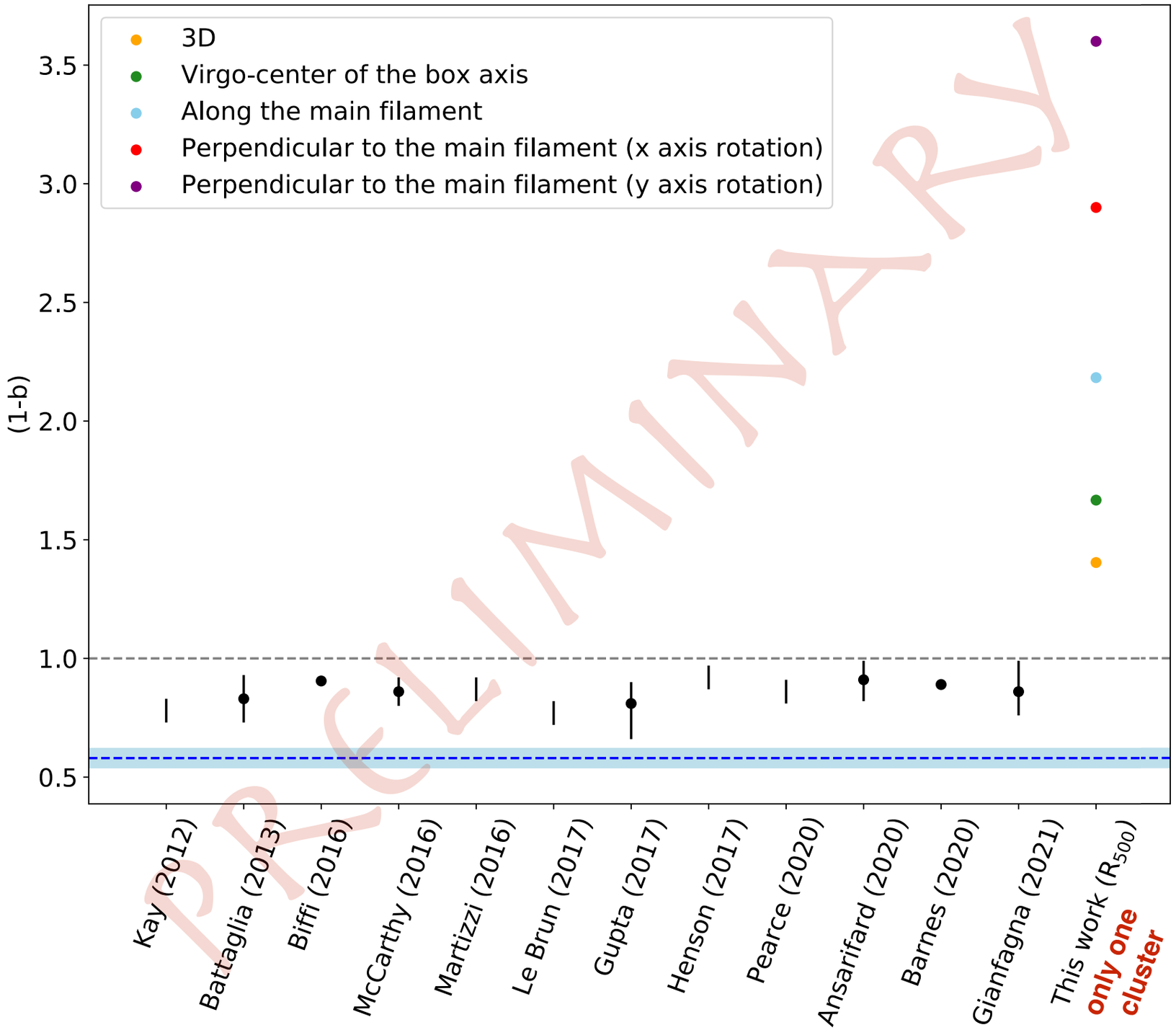
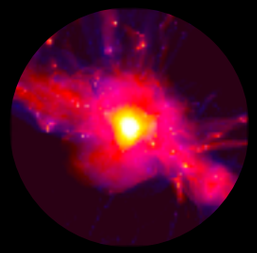


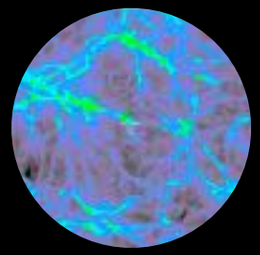
Lebeau+in prep.

CLONES are widely used

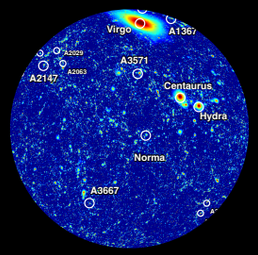
and more…



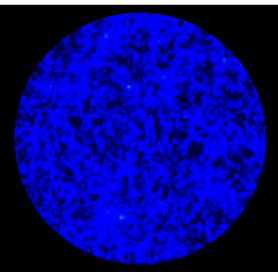
Virgo Cluster
(Sorce+2016, 2019, 2021, in prep., Olchanski & Sorce 2018, Lebeau+ in prep.)



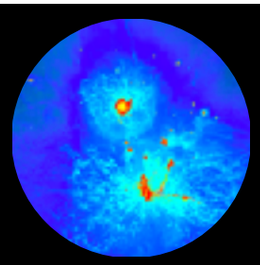
Cosmic Rays in the local Universe
(Hackstein+2018, Boess+in prep.)



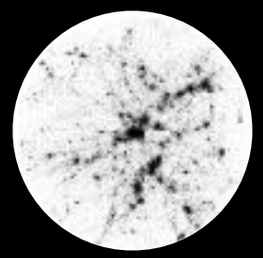
SLOW: local web
(Dolag, Sorce+2023)



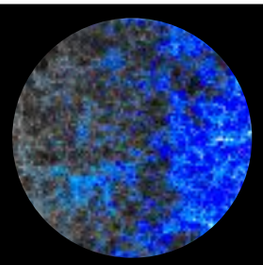
LOCALIZATION: local cluster signatures
(Sorce, Aghanim, Lebeau, Jung, Dolag)



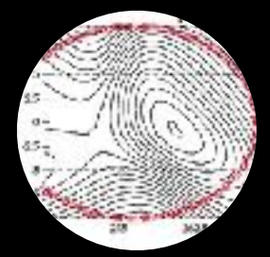
HESTIA: Local Group
Carlesi,Sorce+2016,Carlesi+2016, 2017, Libeskind+2020, Damle+2022, Newton+2022; Luis+2022, Dupuy+2022, Arora+2022, Khoperskov+2022a,b,c



Coma connectivity
(Malavasi, Sorce, Dolag, Aghanim submitted)



CoDa: Reionization of the local Universe
(Ocvirk+2020, Lewis+2020, Gronke+2021, Sorce+2022, Lewis+2022, Park+2022)



Zone of Avoidance
(Sorce+2017)

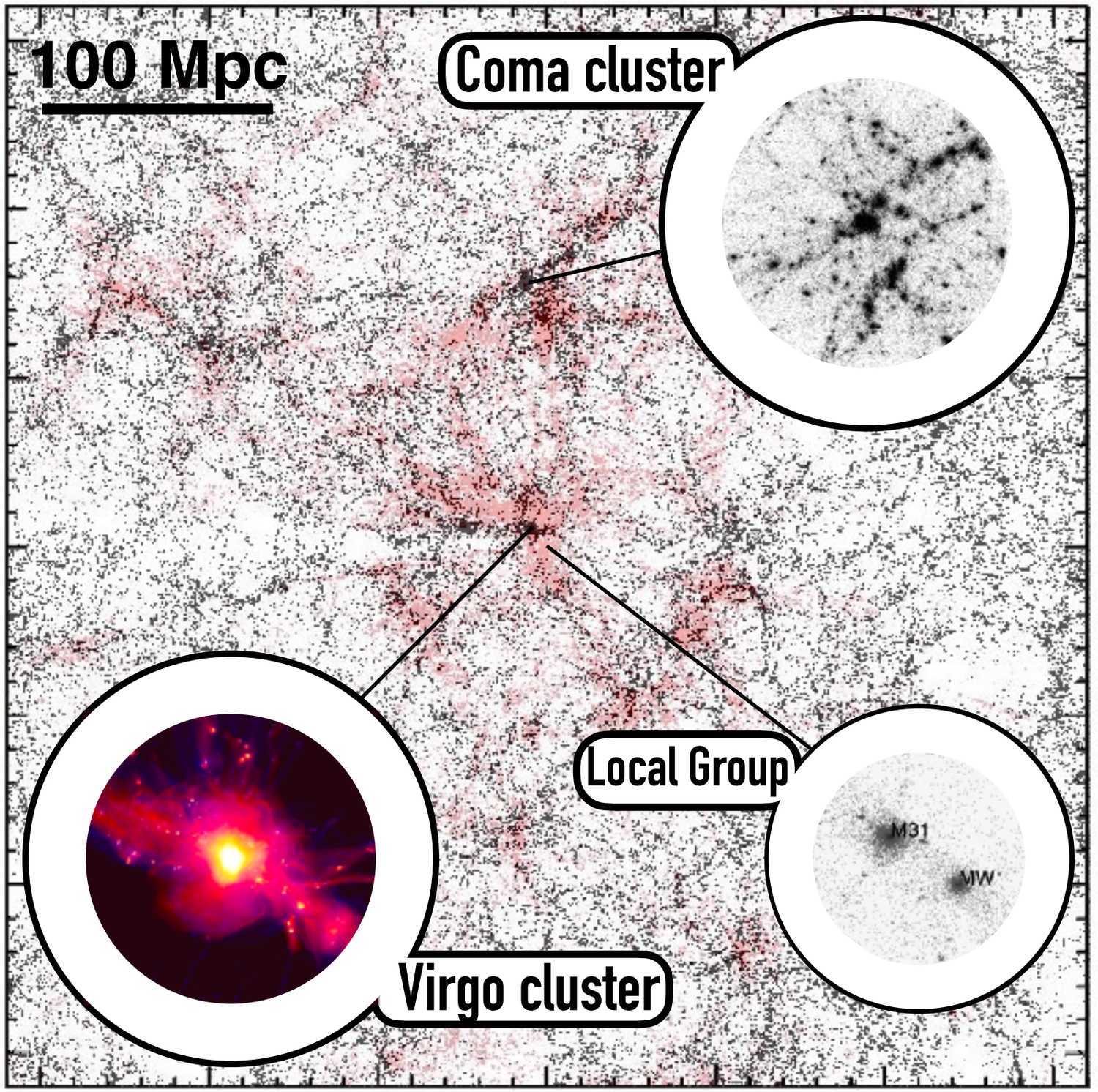
Conclusion

- **Standard** cosmological simulations give only the full uncertainty

- **Constrained** cosmological simulations can permit **reducing biases/systematics**

- **CLONES are constrained** cosmological simulations valid down to the cluster scales with induced smaller scales

- CLONES are **widely used** and **maybe you are the next users!**



Thank you, Merci, Grazie,

Gracias, Danke,

Mahalo, 谢谢, ありがとう,

תודה, Obrigada, Dank u,

Tak, Cảm ơn, Dziękuję, 감사합니다

Kiitos, Aitäh, diolch, dankewol,

ಧನ್ಯವಾದಗಳು, …*

* Missing your ‘thanks’ spelling? It means I did not get the chance to learn how to say it so far