Disentangling tensions from systematics with CLONES

(Constrained LOcal & NEsting Environment Simulations)

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and many collaborators

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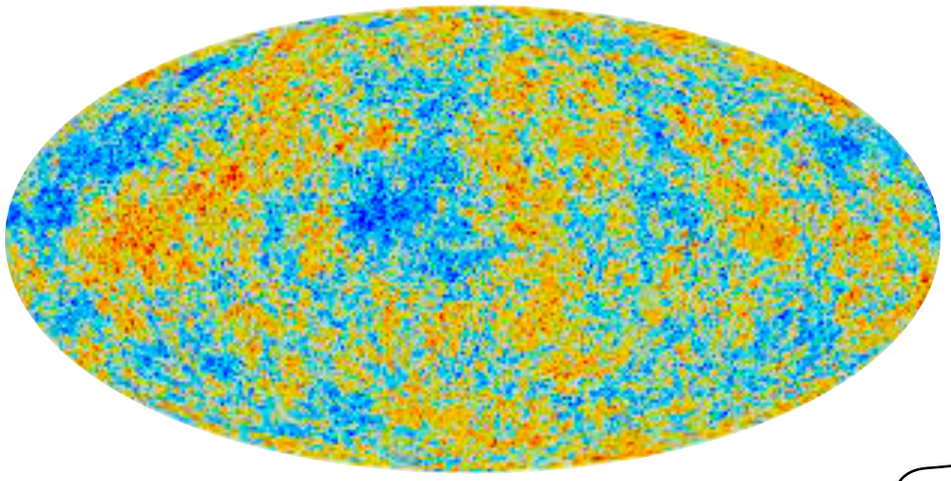
Guest researcher at AIP, Potsdam & CAS fellow at LMU, Munich

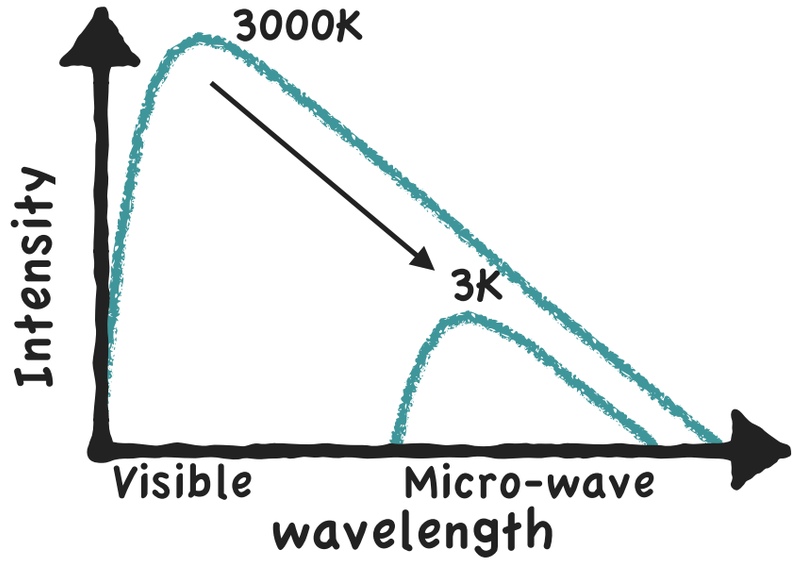
Tensions in Cosmology, Corfu - September 7th, 2023

Cosmology: ΛCDM?

Cosmic Microwave Background

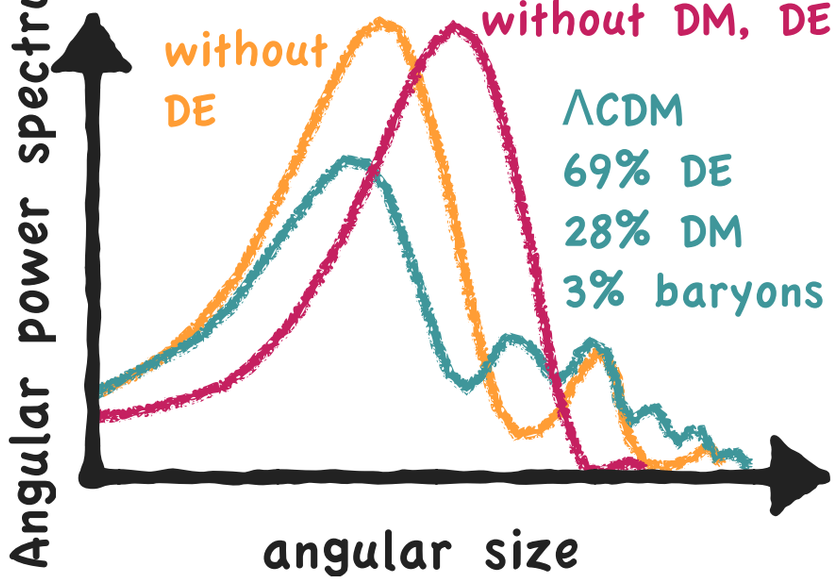


Universe expansion

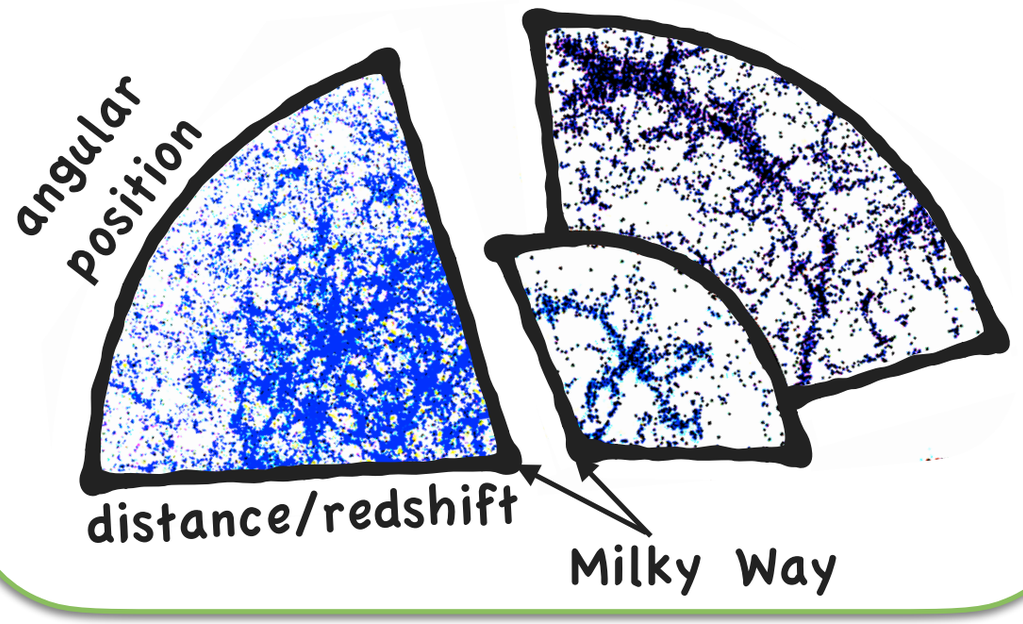


ΛCDM

Universe content

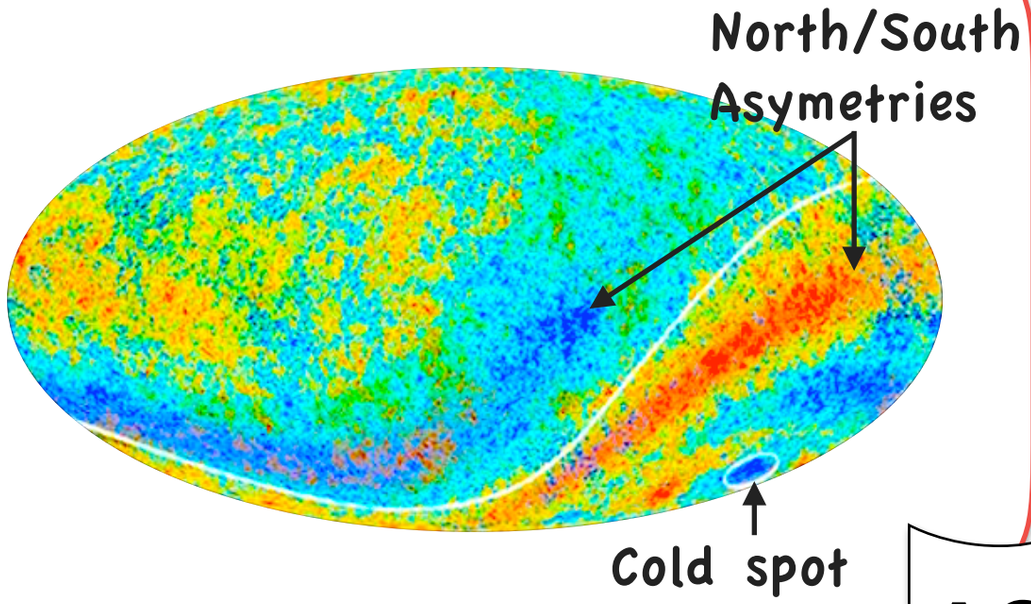


Cosmic Web and galaxies

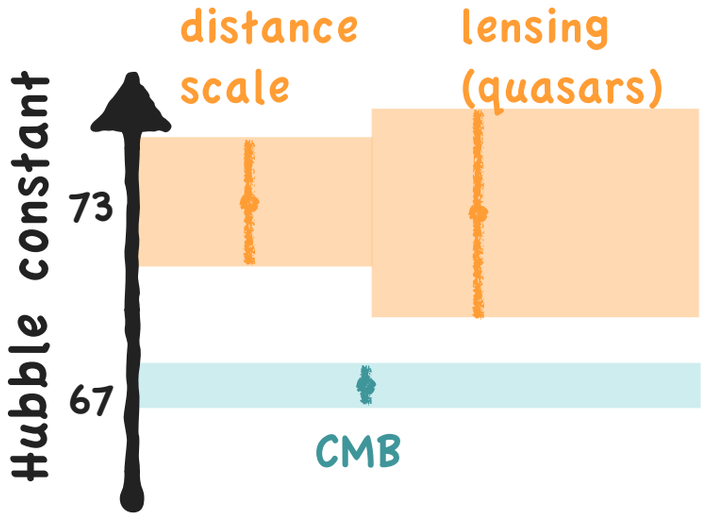


Cosmology: ΛCDM?

Anomalies in the CMB

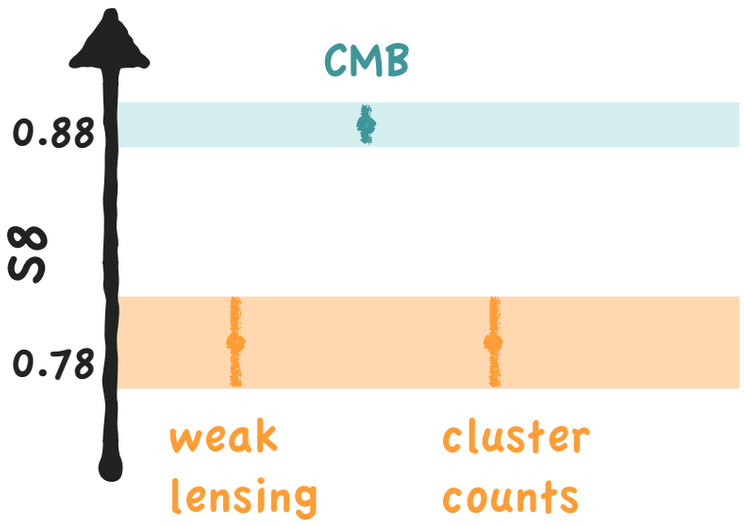


Universe expansion rate (H_0)

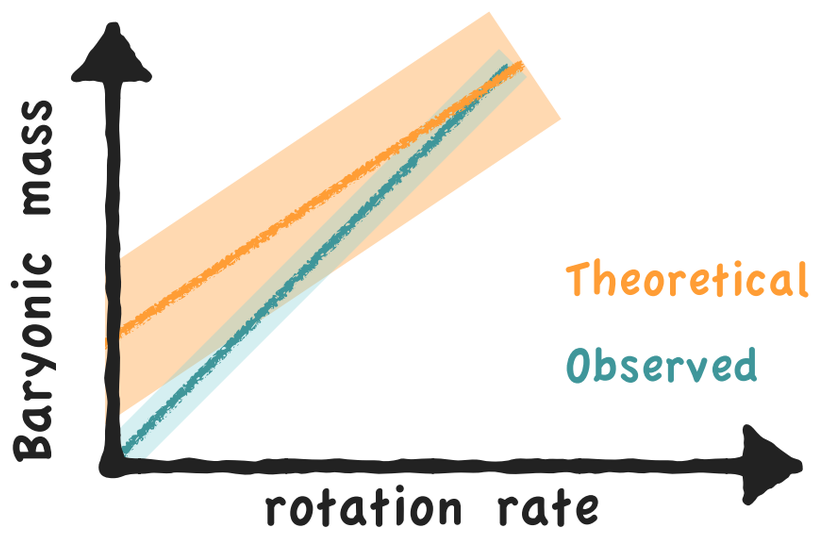


~~ΛCDM~~

S8 (σ_8, Ω_m)

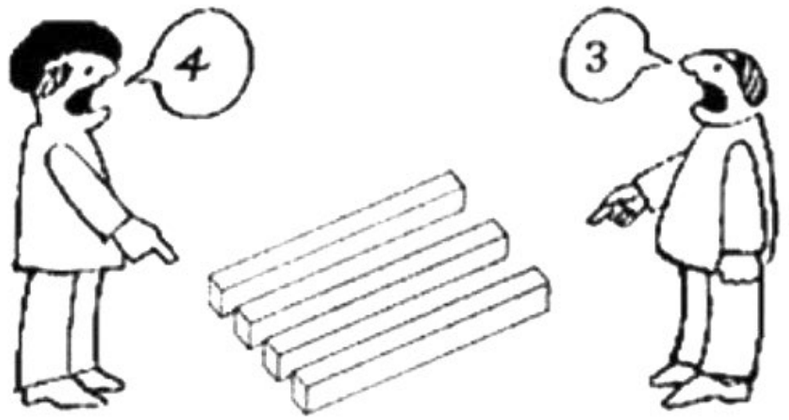


Galaxy properties



New physics or biases/ systematics?

Are we a neutral observer? Are our surveys free of cosmic variance?

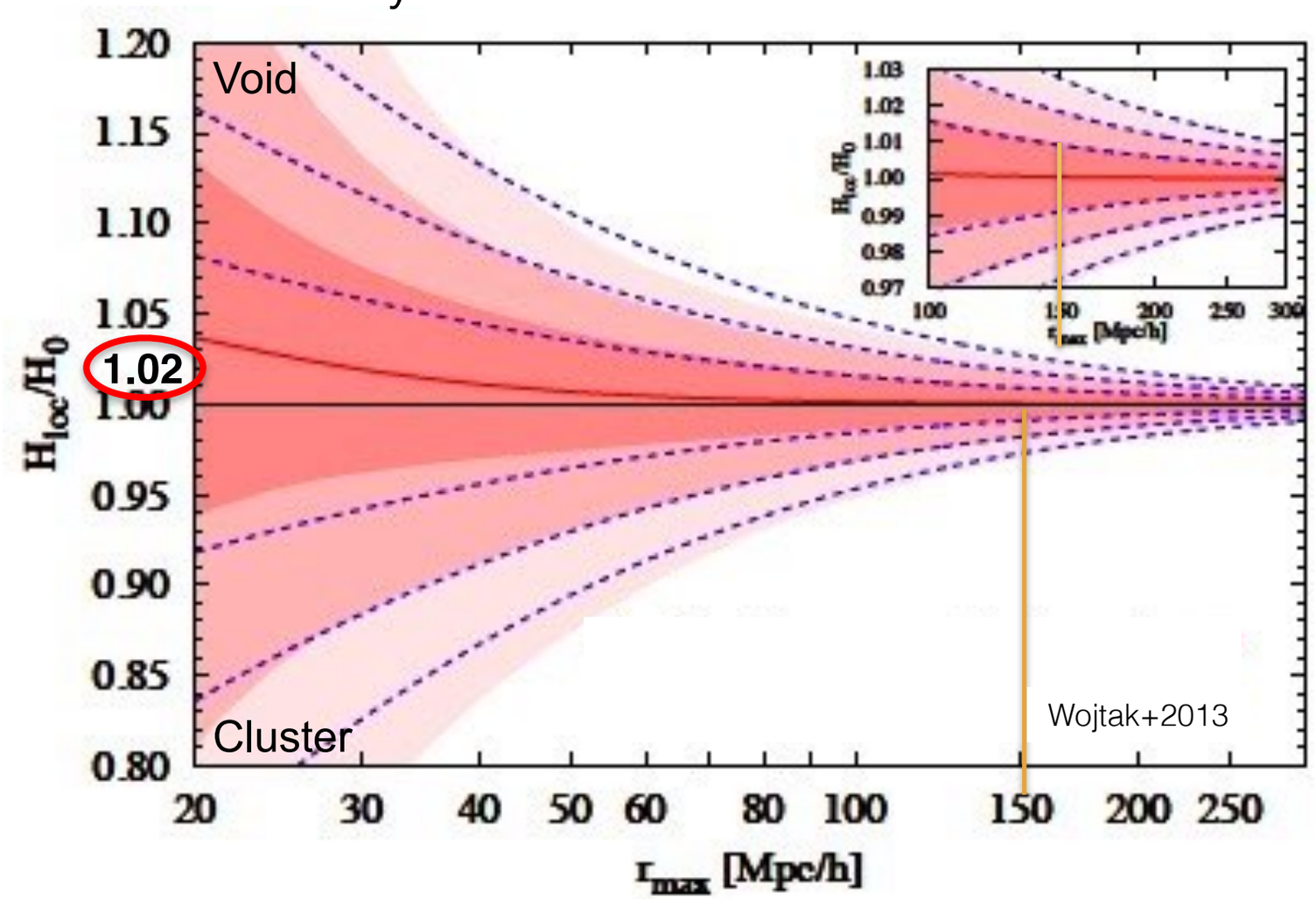


Are we comparing apple-to-apple? Do we understand enough?

What about foreground and evolution effects?

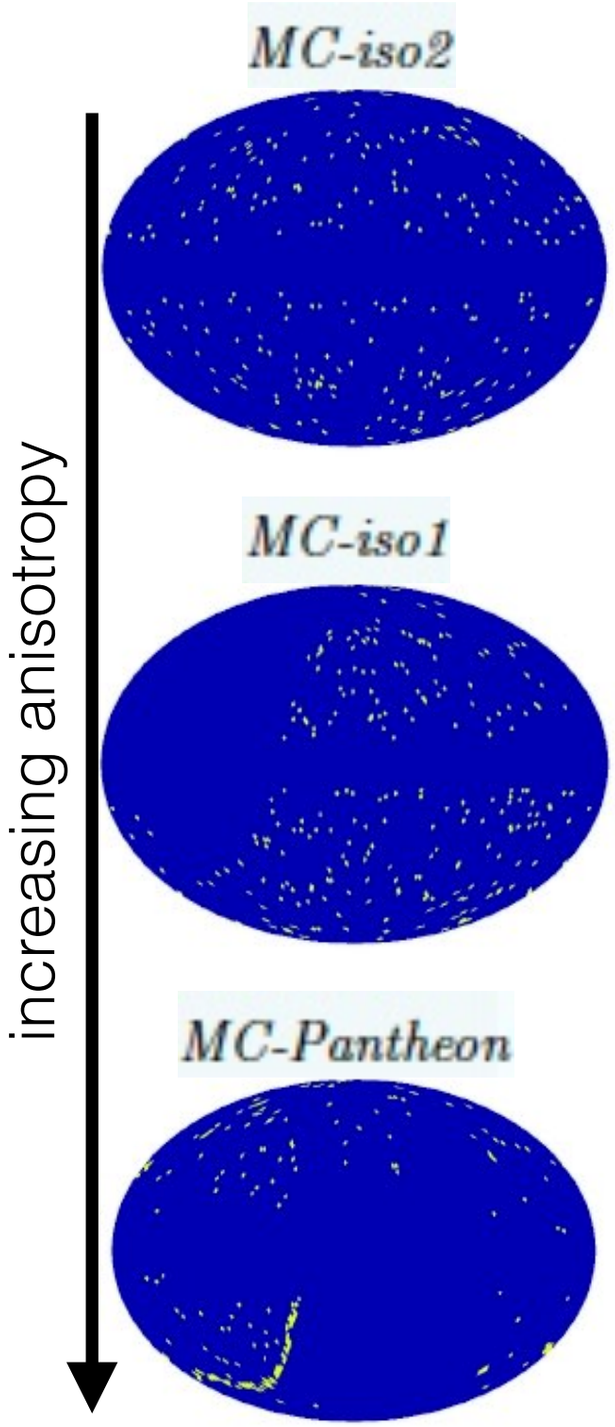
Example of H_0 ➤ Impact of the local density

As many effects on values as environments

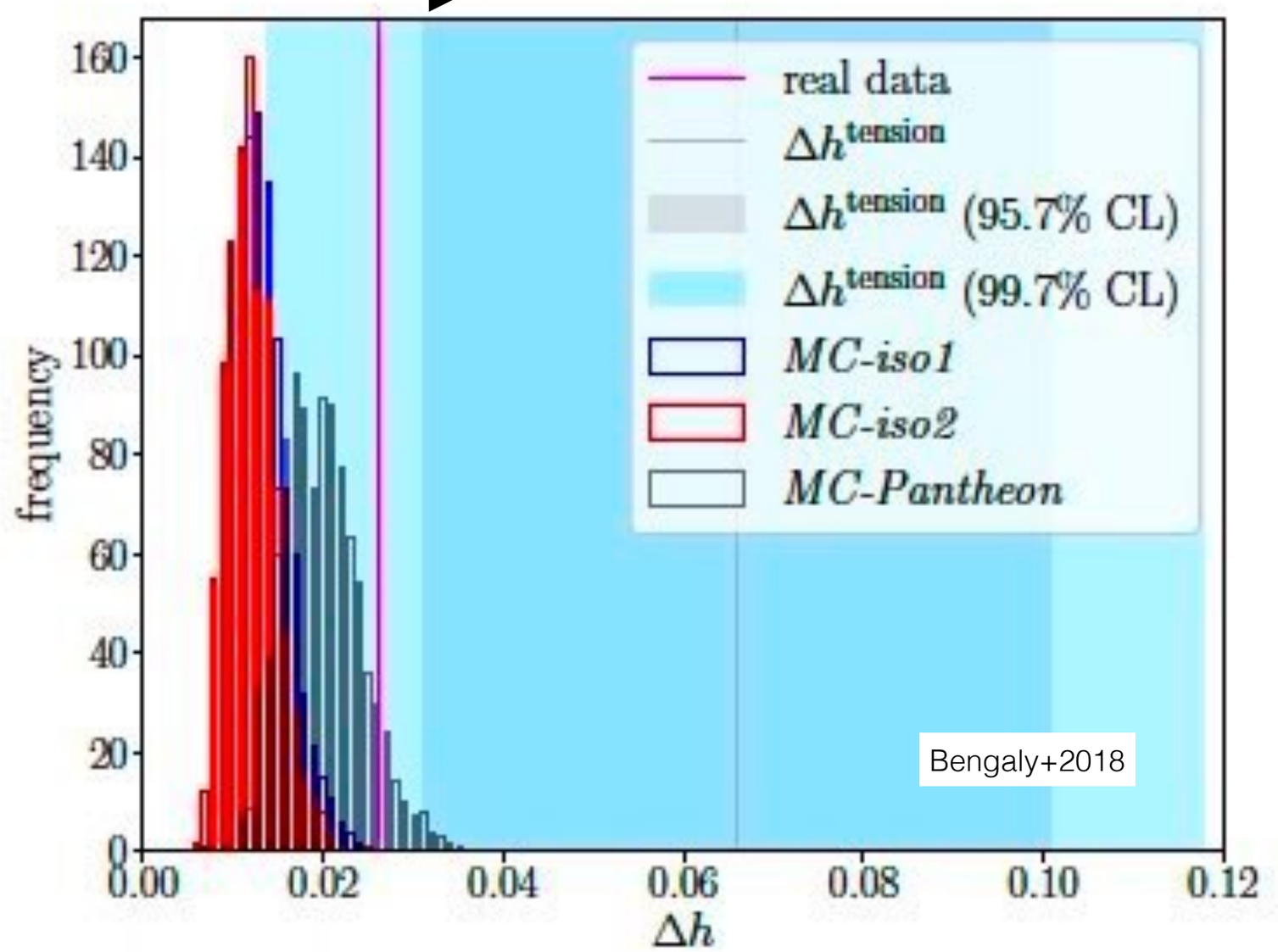


For an average environment: a 2% bias !

Example of H_0 ➤ Impact of the survey anisotropy



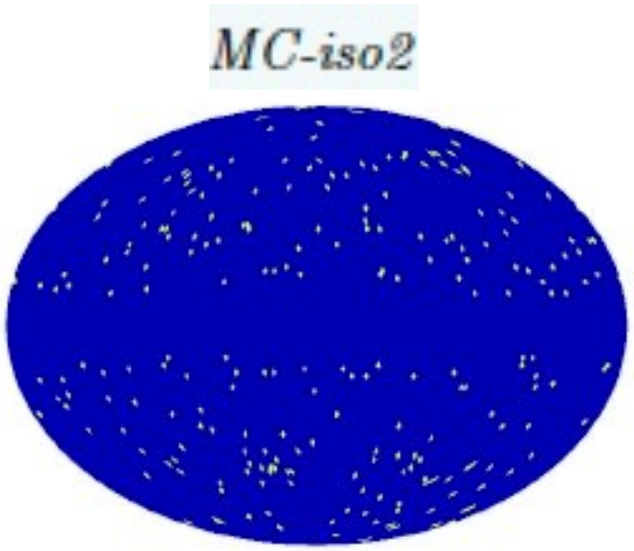
increasing anisotropy

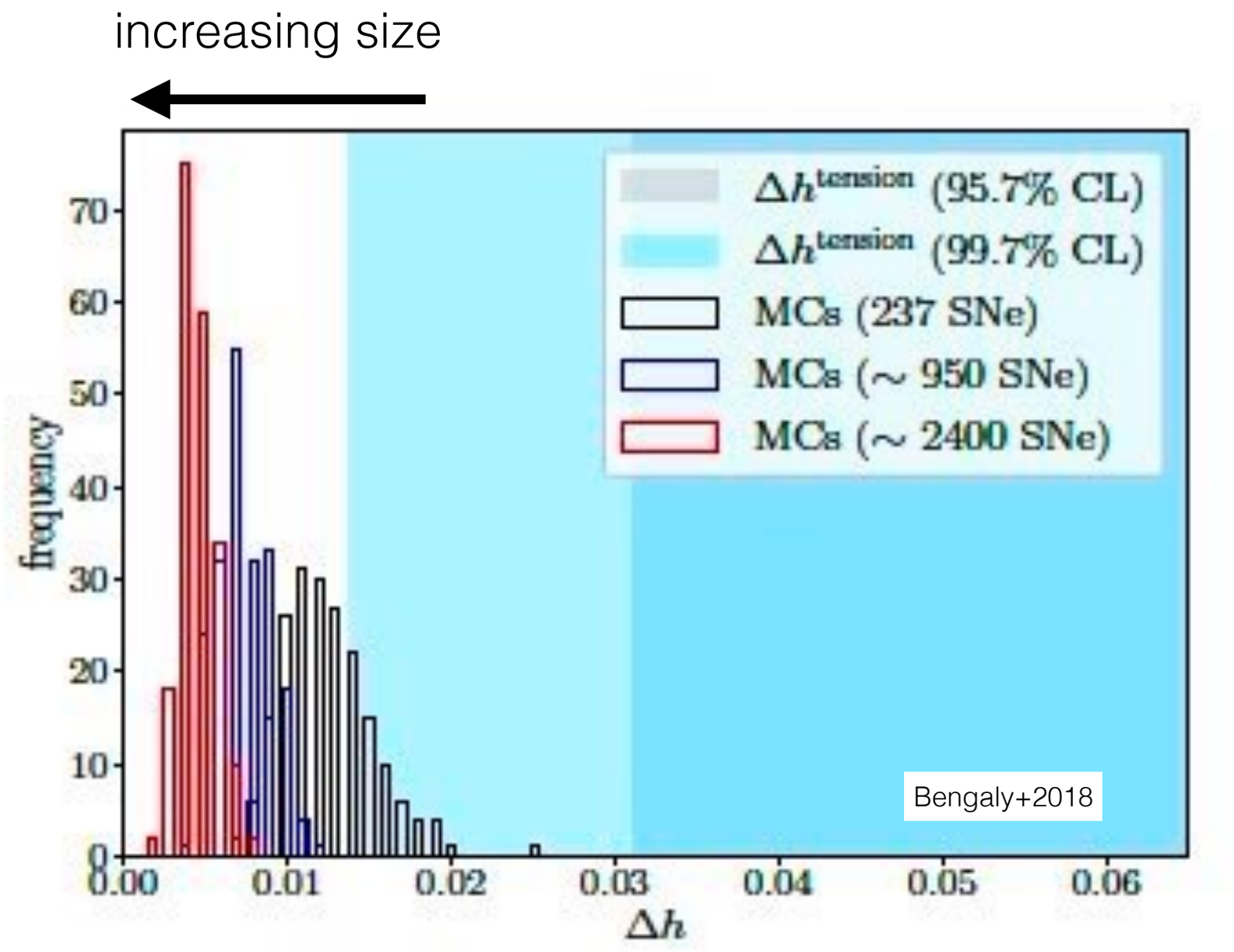


For an average survey: a 1-2% bias !

Example of H_0

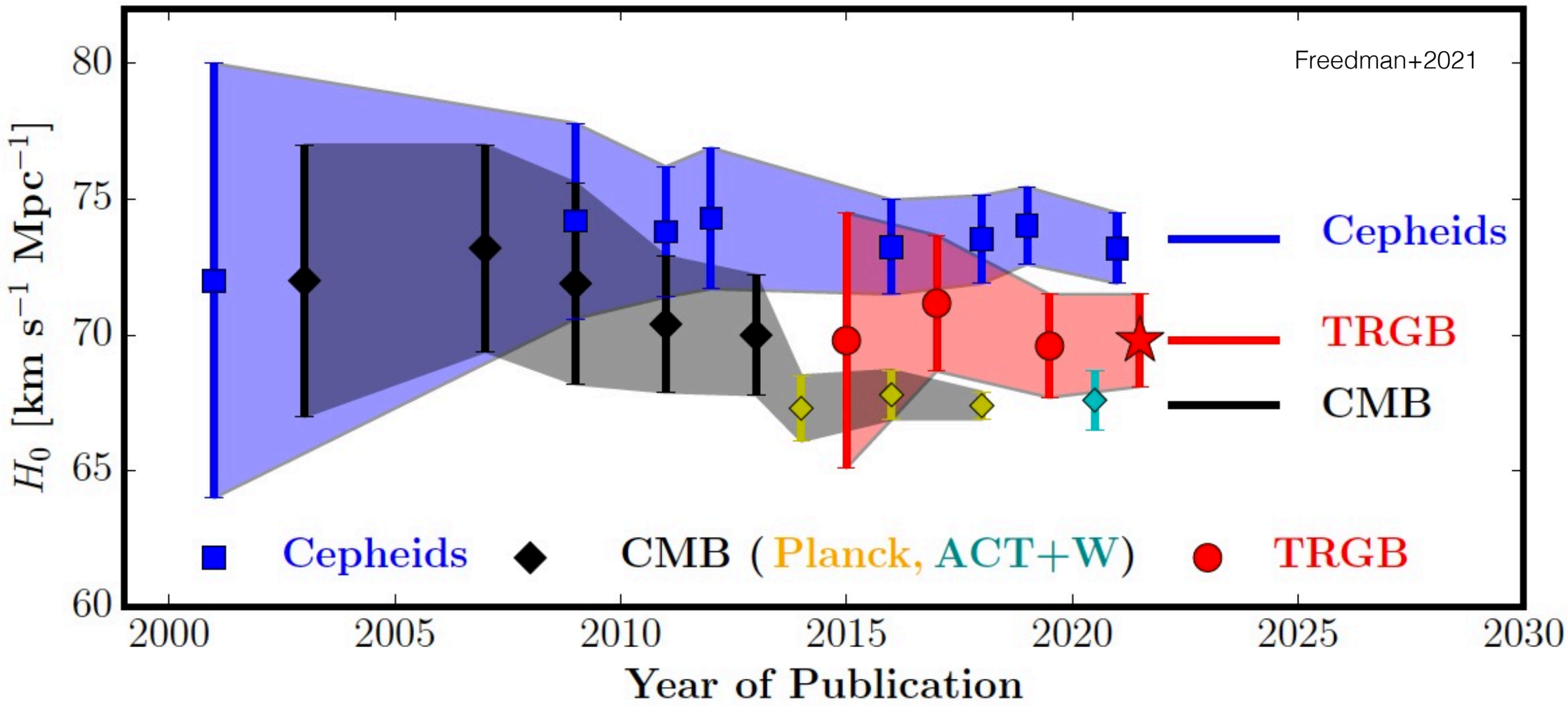
Impact of the survey size





For a survey size divided by 10: a 1-2% bias !

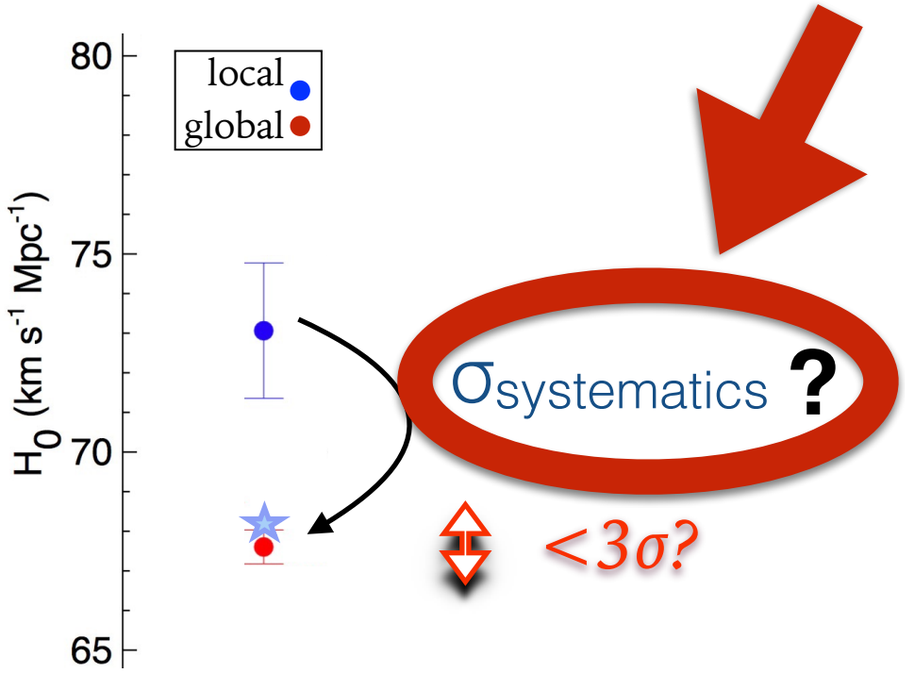
Example of H_0 ➤ Impact of the calibrator nature



For different calibrators: a 5% difference !

Example of H_0 → Multiple biases

local density	For an average environment: a 2% bias !
survey anisotropy	For an average survey: a 1-2% bias !
survey size	For a survey size divided by 10: a 1-2% bias !
calibrator nature	For different calibrators: a 5% difference !



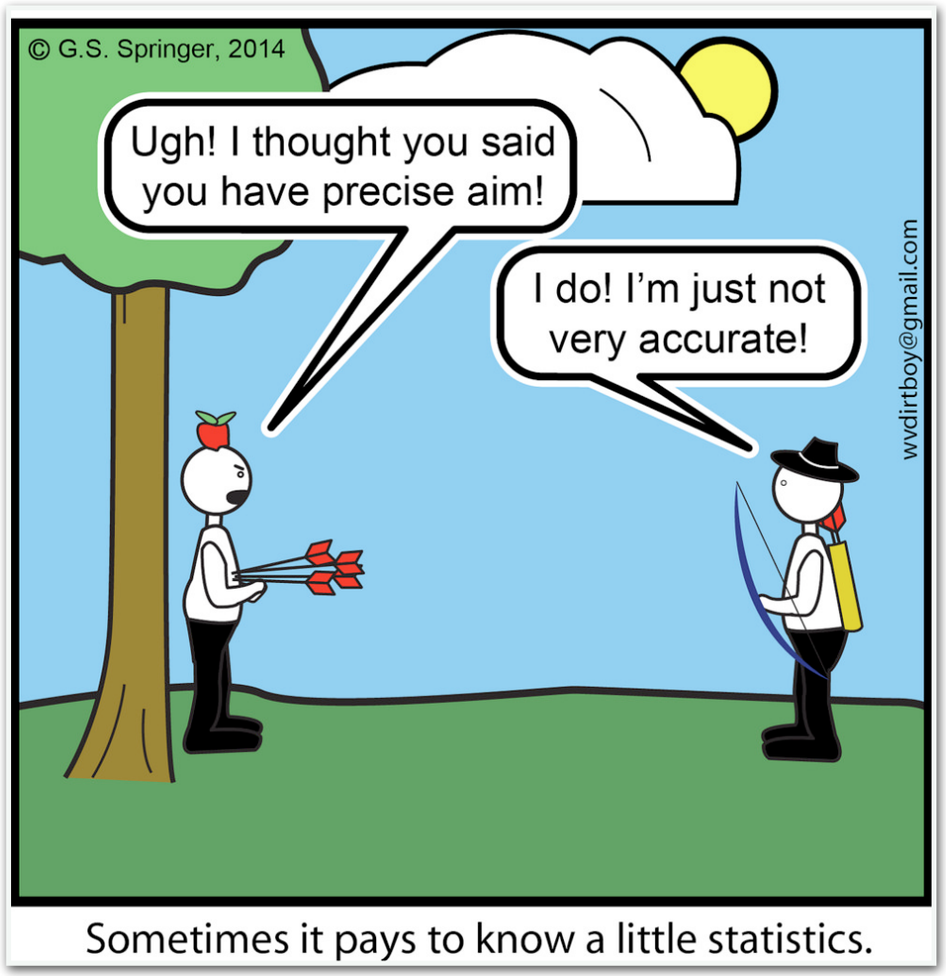
→ ΛCDM is not (yet) ruled out

Simulations & systematics

$$H_0 = X \pm \sigma_{measure} \pm \sigma_{systematics}$$

- nb measurements
- instruments/tools sensitivity
  = precision

Standard cosmological simulations can give the total uncertainty but cannot disentangle tensions and systematics



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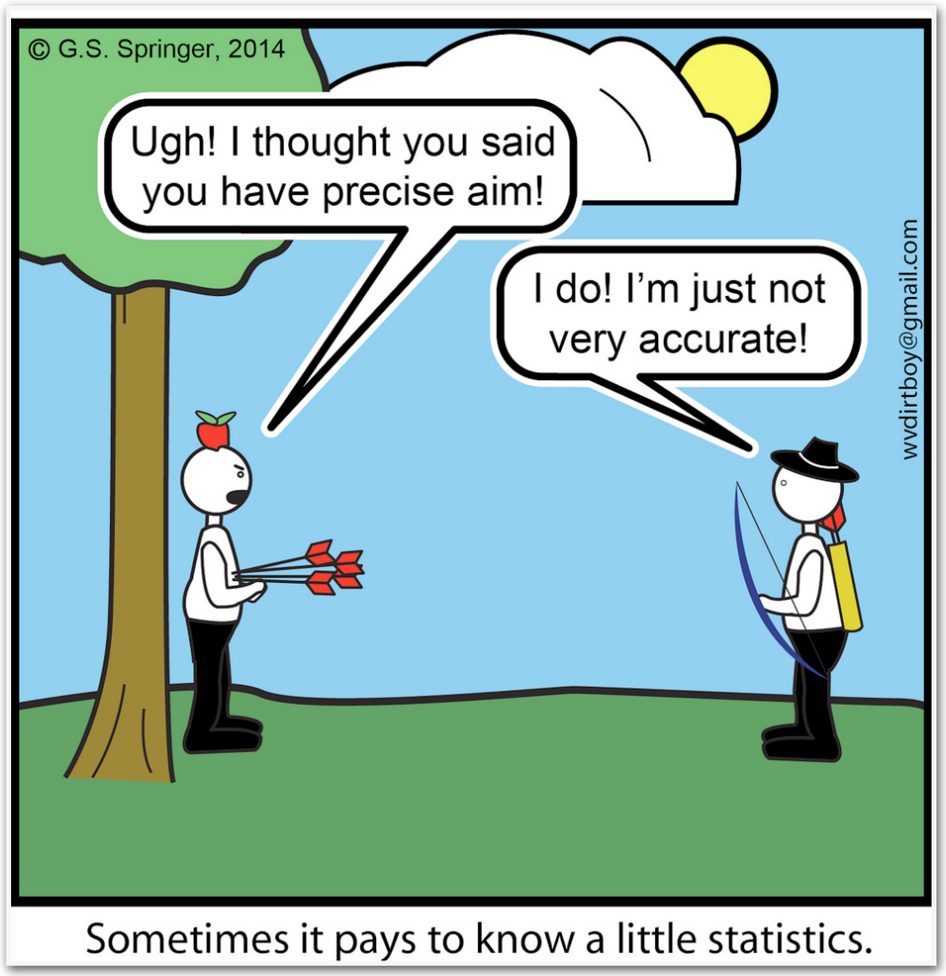


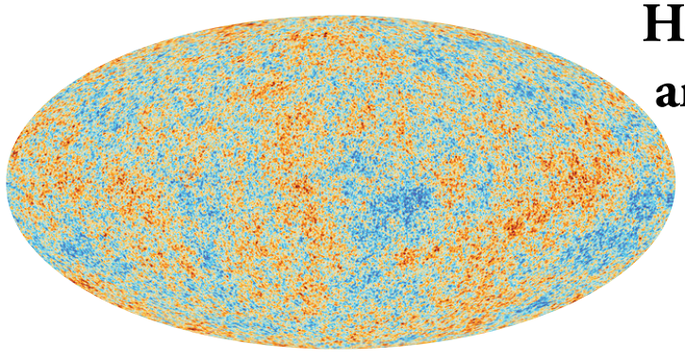
Standard cosmological simulations can give the total uncertainty but cannot disentangle tensions and systematics

Constrained cosmological simulations can help disentangling real tensions from systematics (by reproducing our particular case)

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

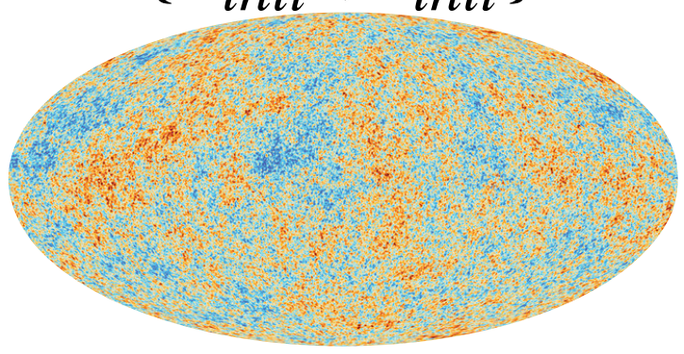


Homogeneous and Isotropic Universe → $P(k)$ → **Gaussian initial density field**

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

initial conditions of a random patch of the Universe

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



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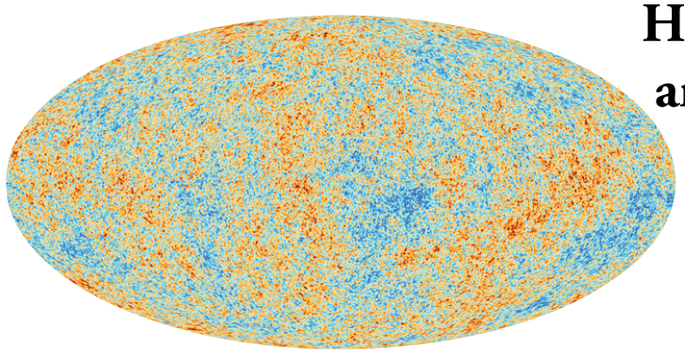

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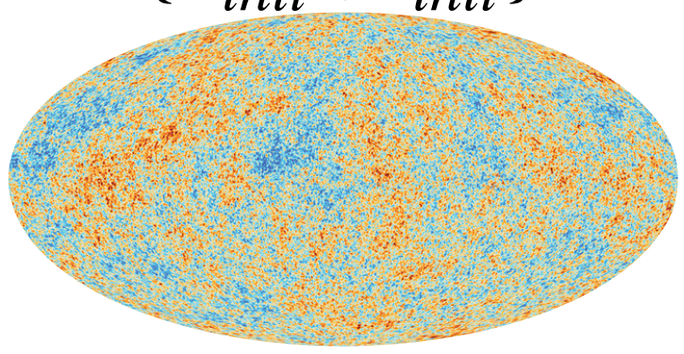

Why only δ ? ⟶ **Linear perturbation theory (Euler+ Continuity+Poisson)** ⟶ $\nabla . v = -\dot{a} f \delta$

NB: only divergent (no tidal) but periodic boundaries

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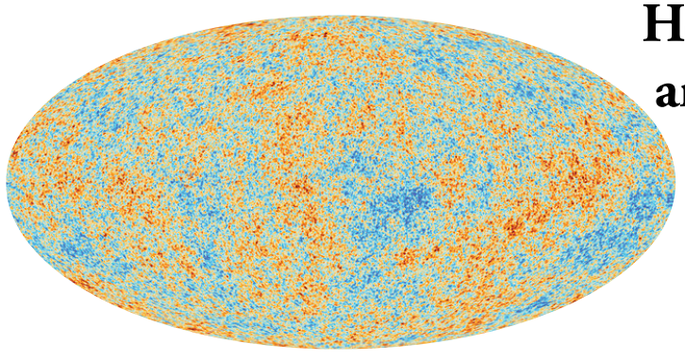

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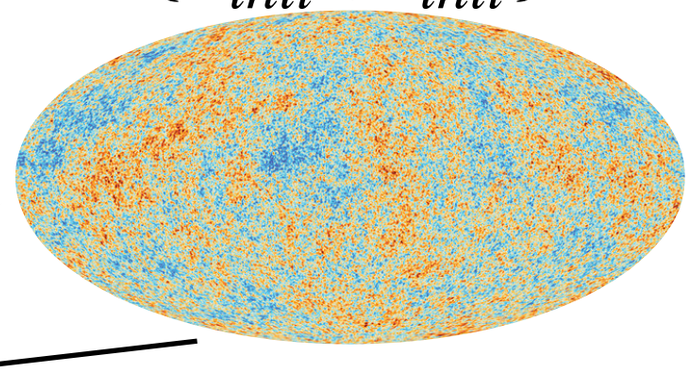
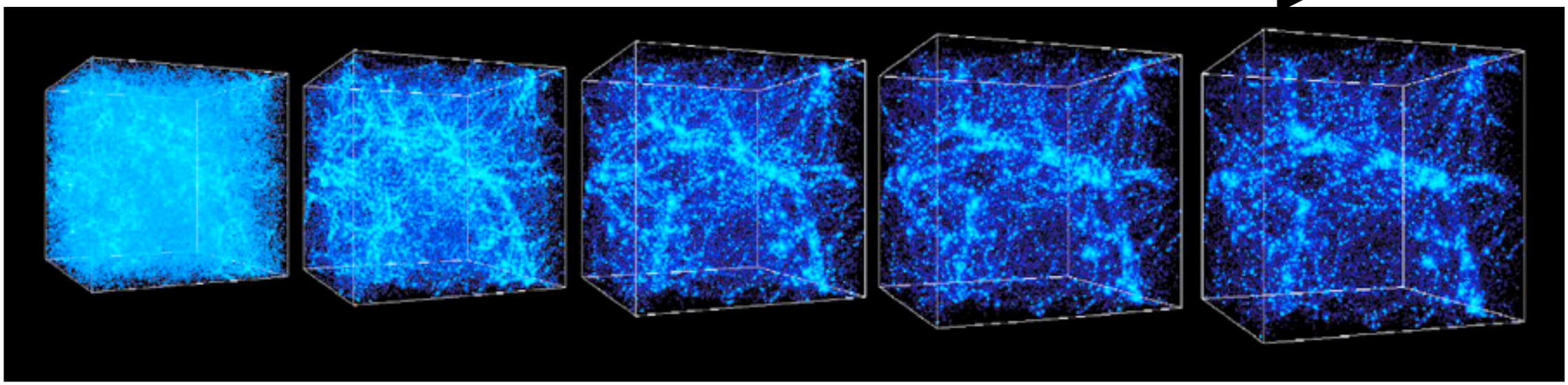


Linear perturbation theory + "kick"

Evolution



Constrained cosmological simulations

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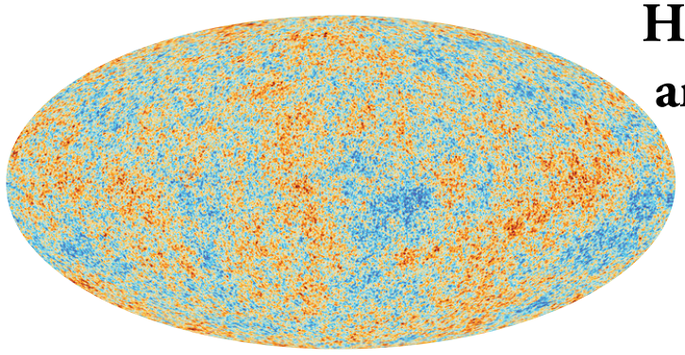

Homogeneous and Isotropic Universe → $P(k)$ → **Gaussian initial density field**

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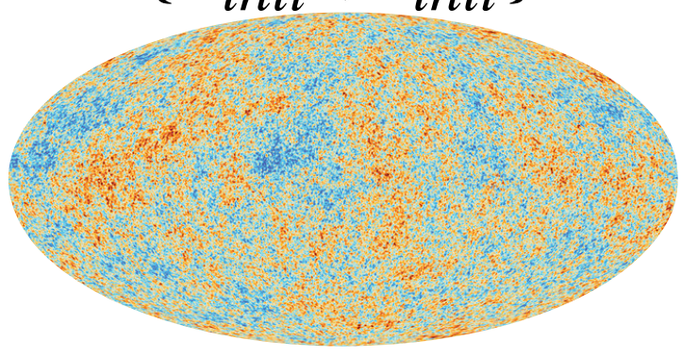
?

initial conditions of the local Universe

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



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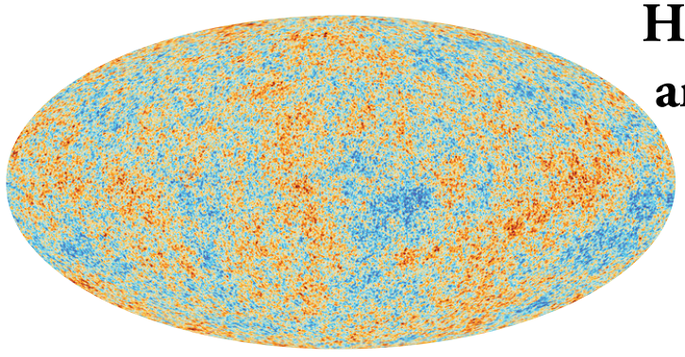

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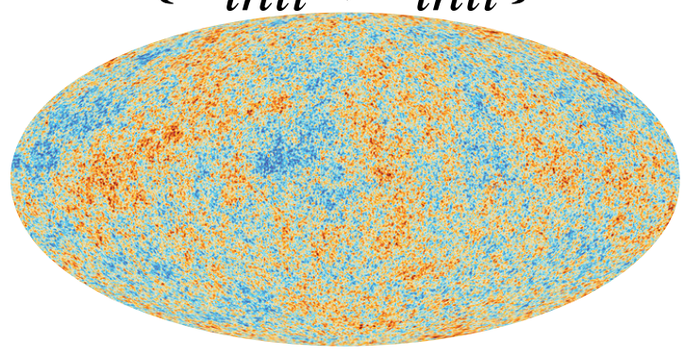
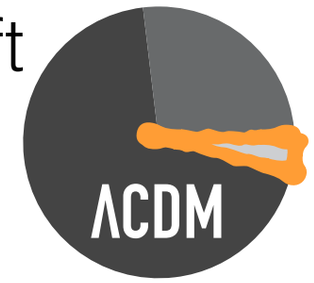


Type of constraints

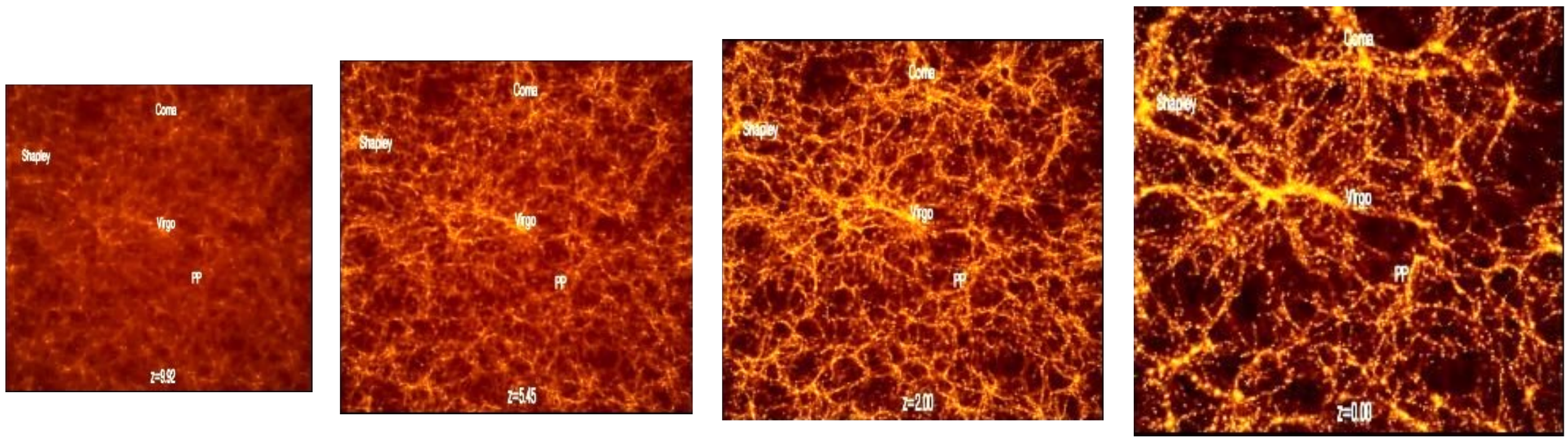
Redshift



Peculiar velocity

NB: both with pros and cons!

Constrained cosmological simulations e.g. CLONES



Evolution

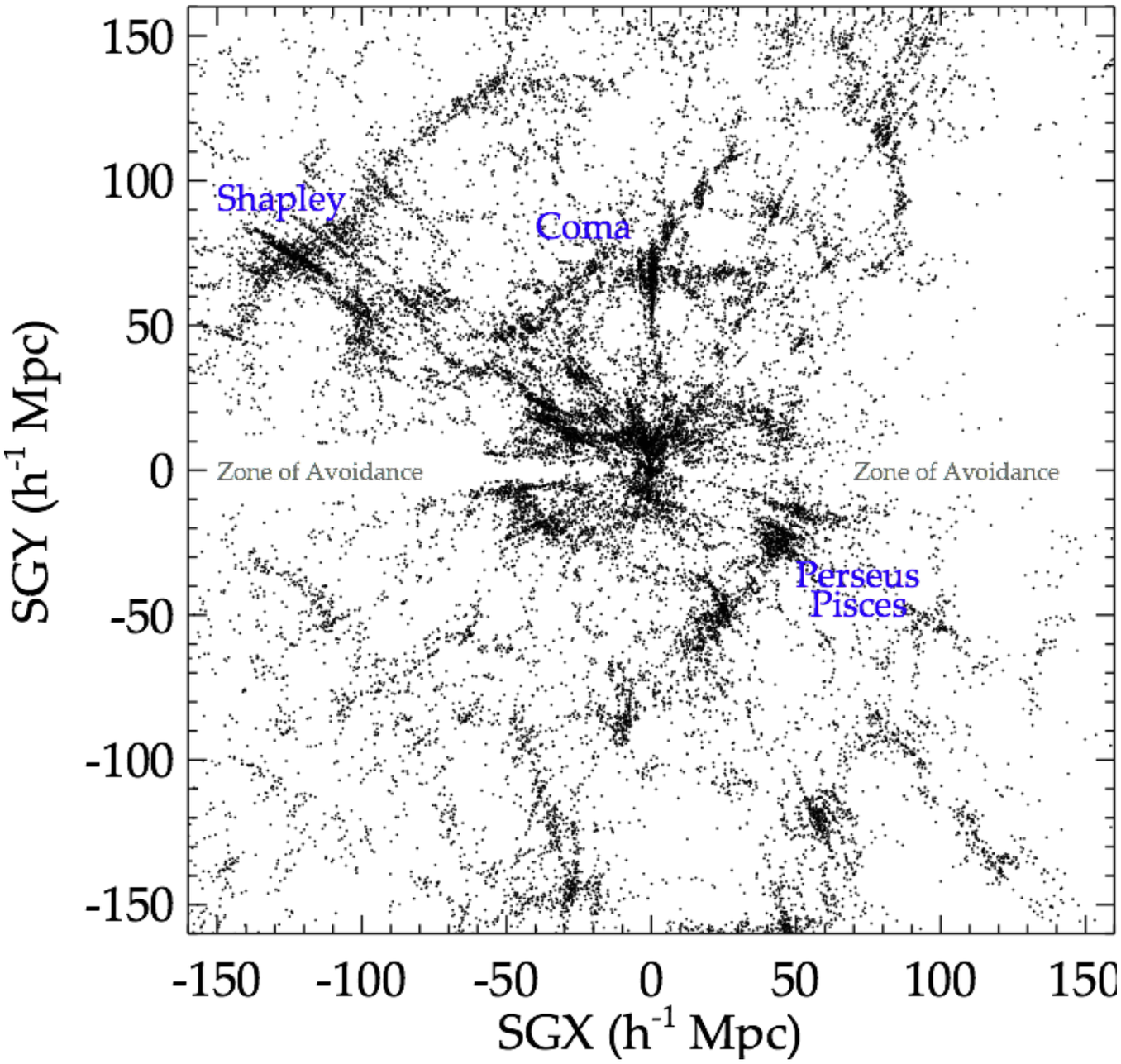
Sorce+2016

Sorce2018

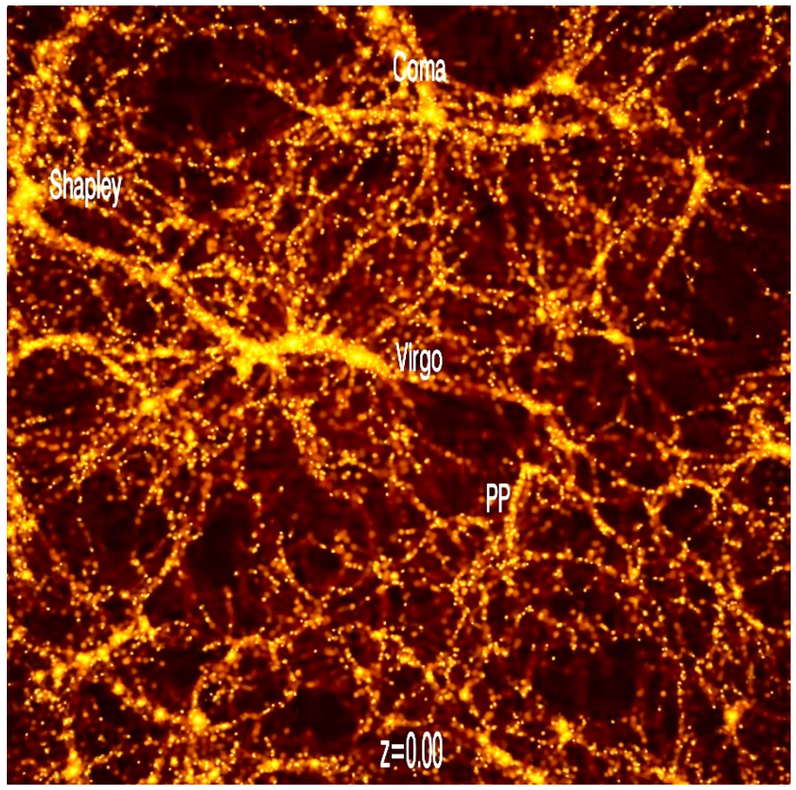
CLONES = Constrained LOcal & Nesting Environment Simulations

CLONES and the local LSS

Sorce2018

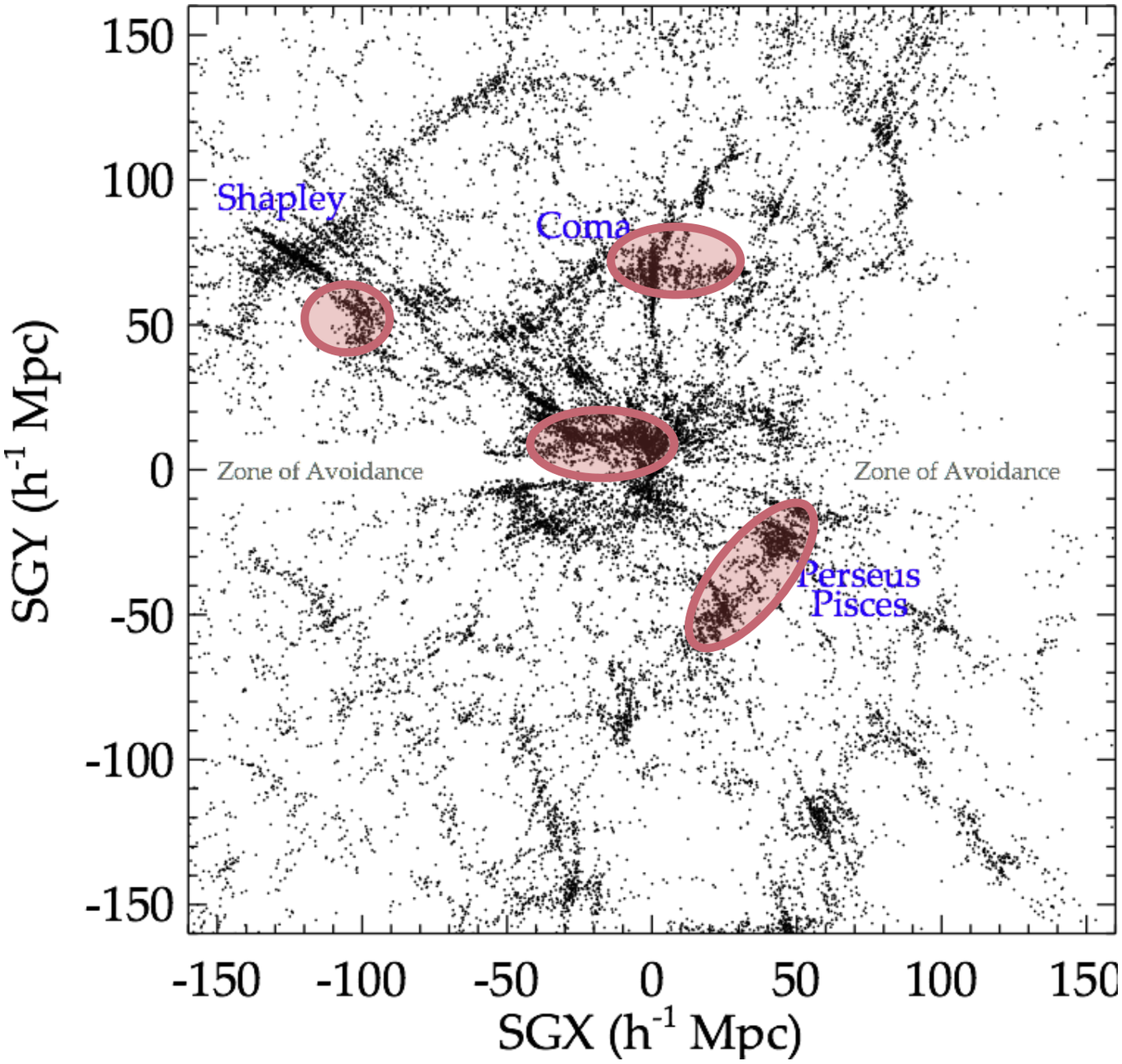


Note the fingers of gods



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

CLONES and the local LSS



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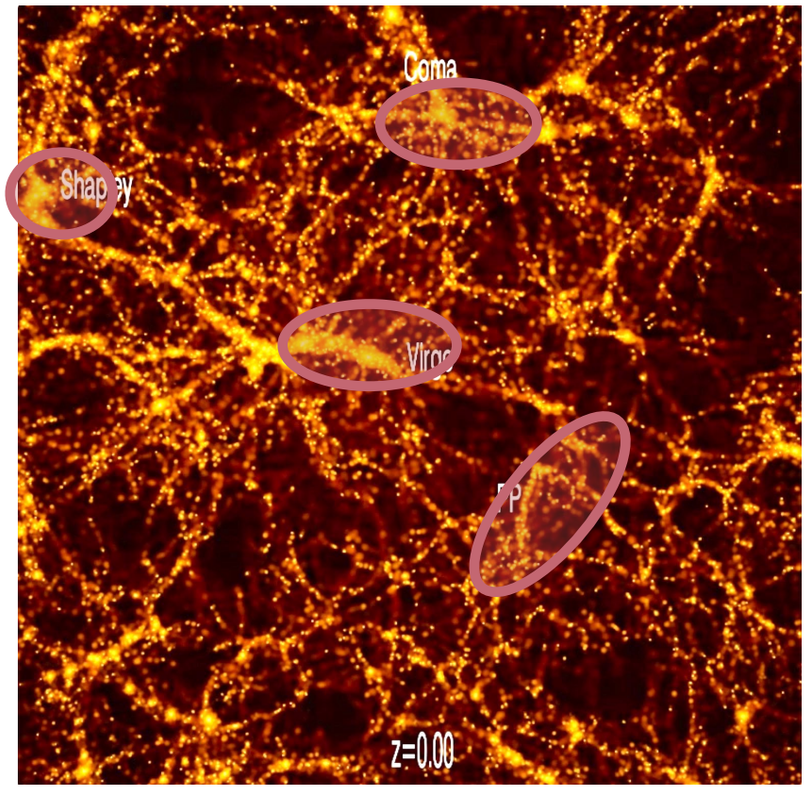

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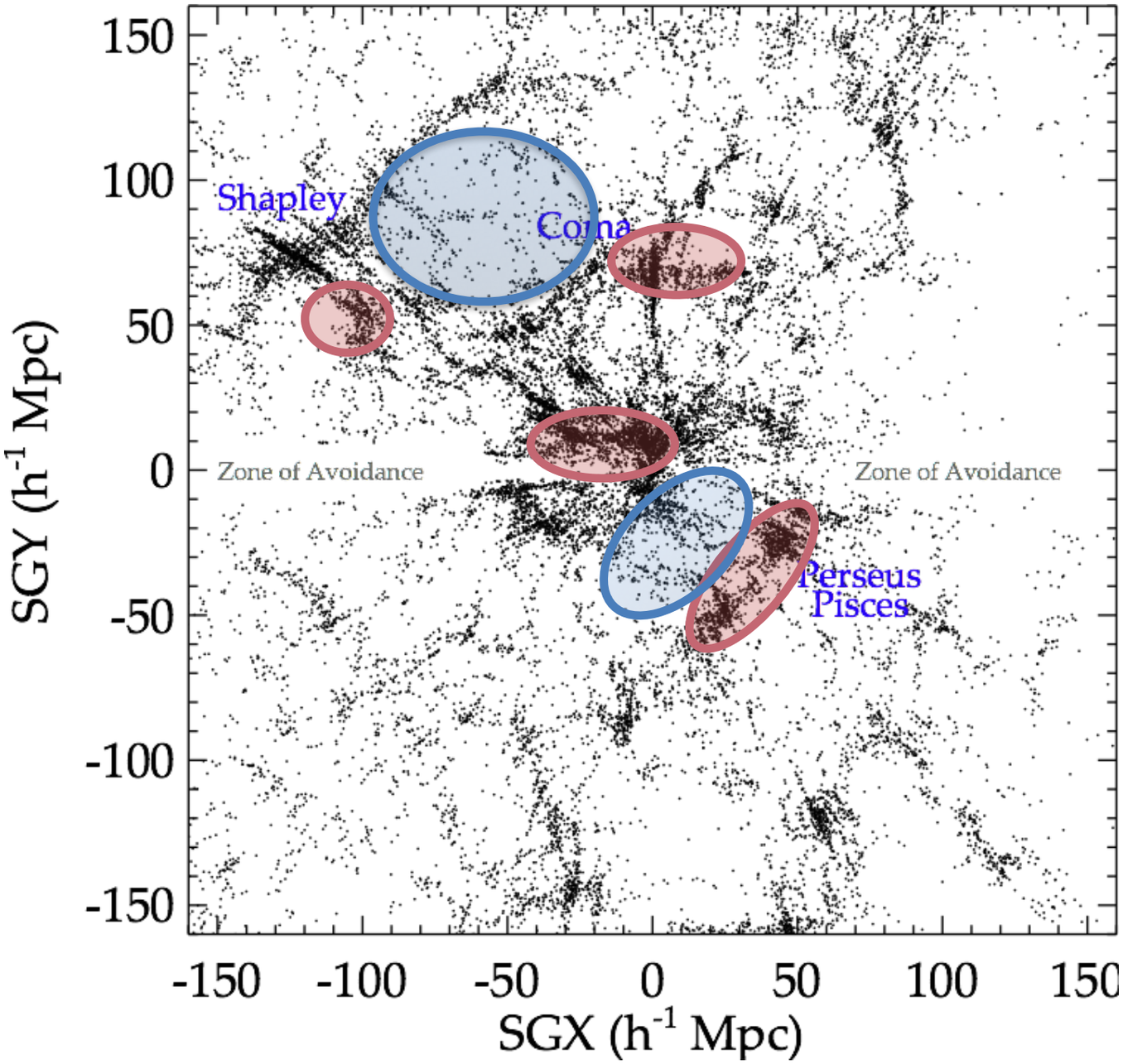

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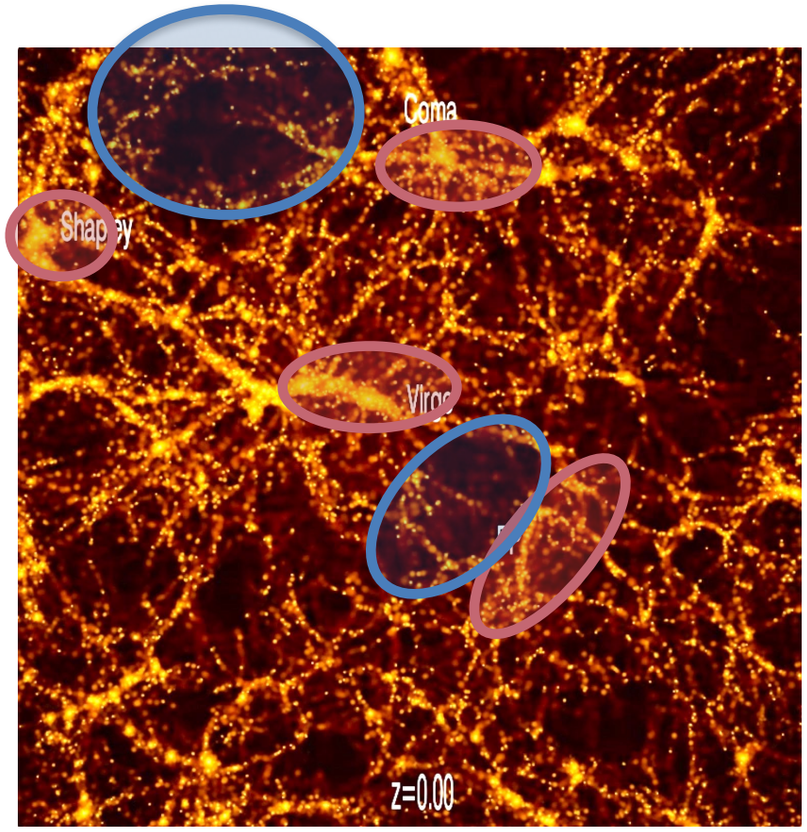

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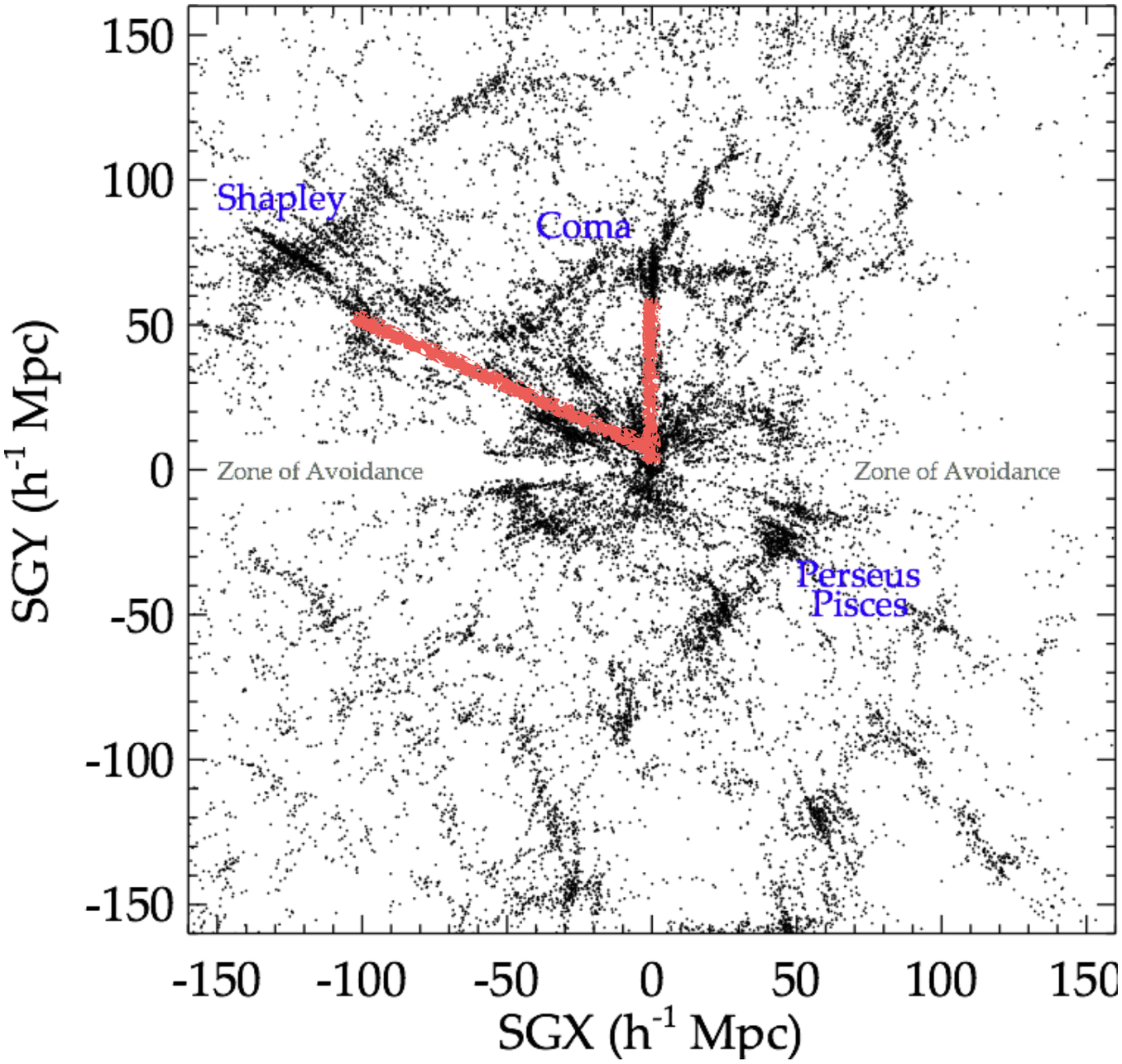

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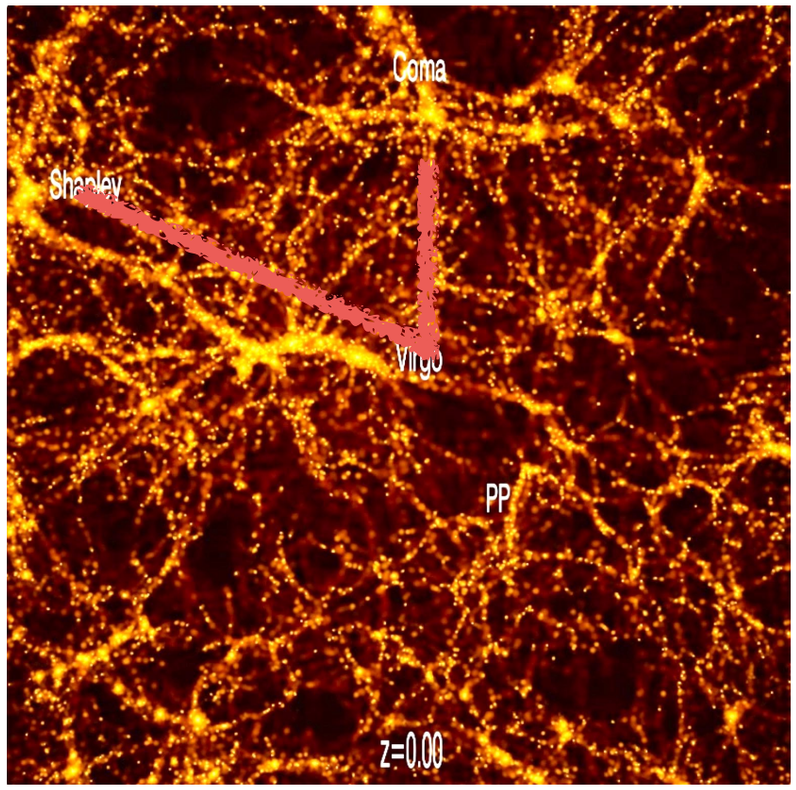
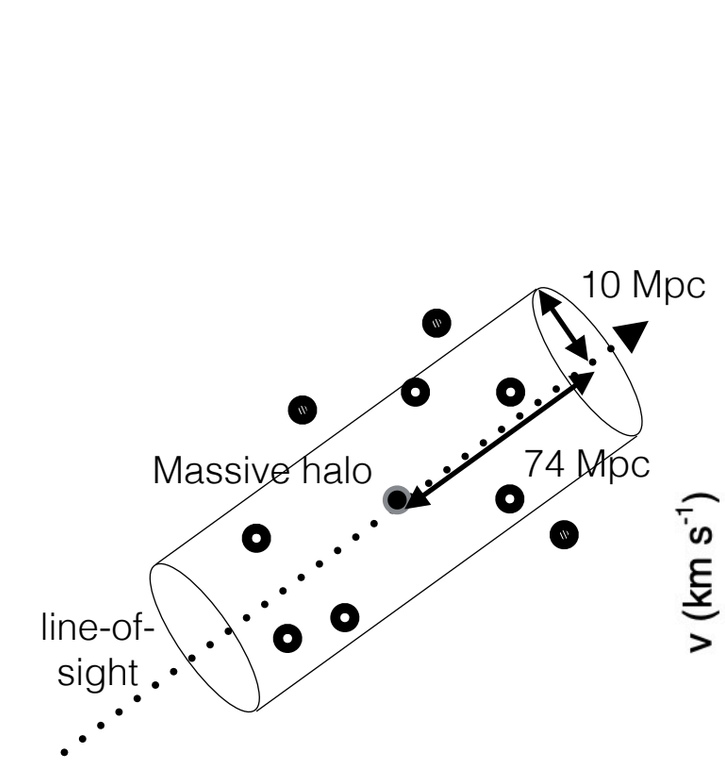


500 Mpc/h, 1024^3 particles,
DM only, Planck cosmology

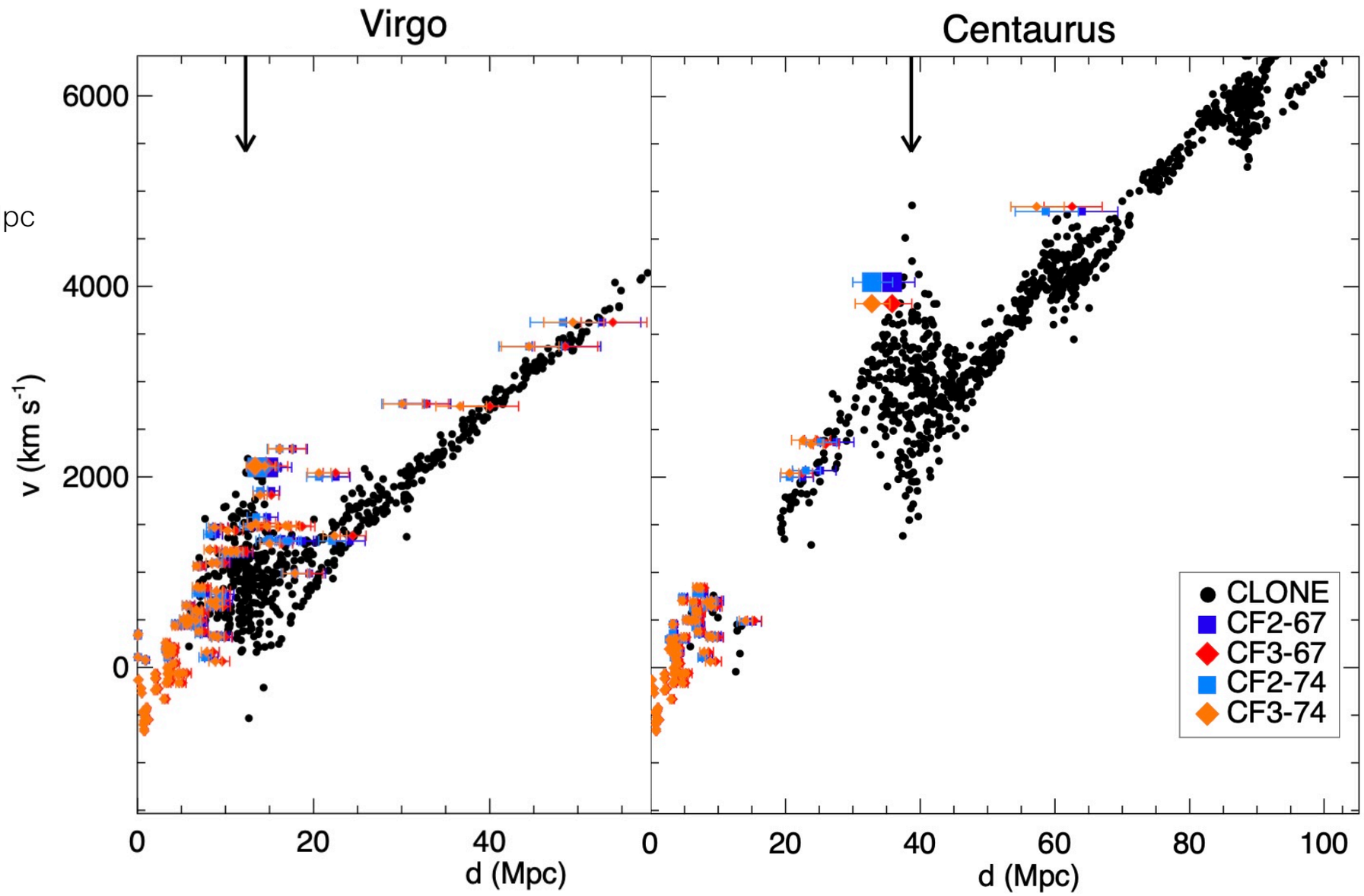
CLONES and the local clusters

Sorce+submitted

Velocity wave signatures in the Hubble diagram



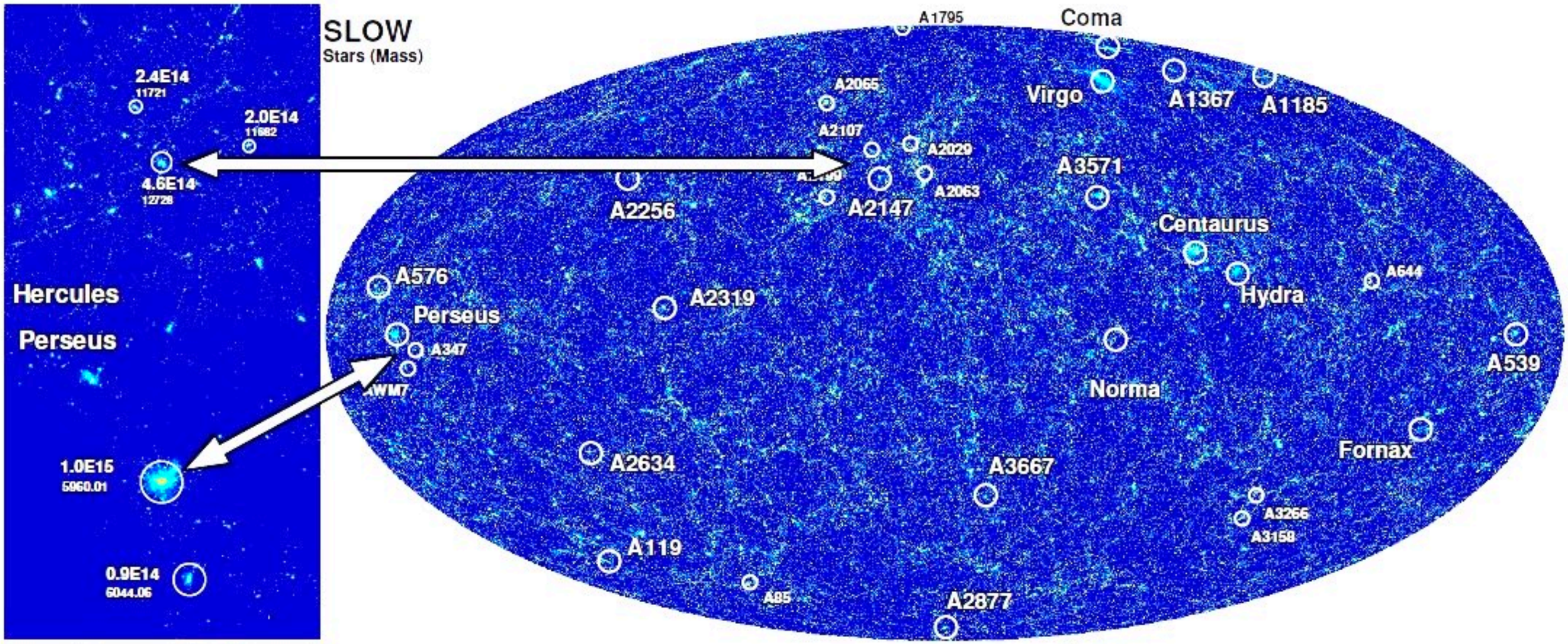
Synthetic observer
= center of the box



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

CLONES and the local clusters

Dolag,
Sorce+2023



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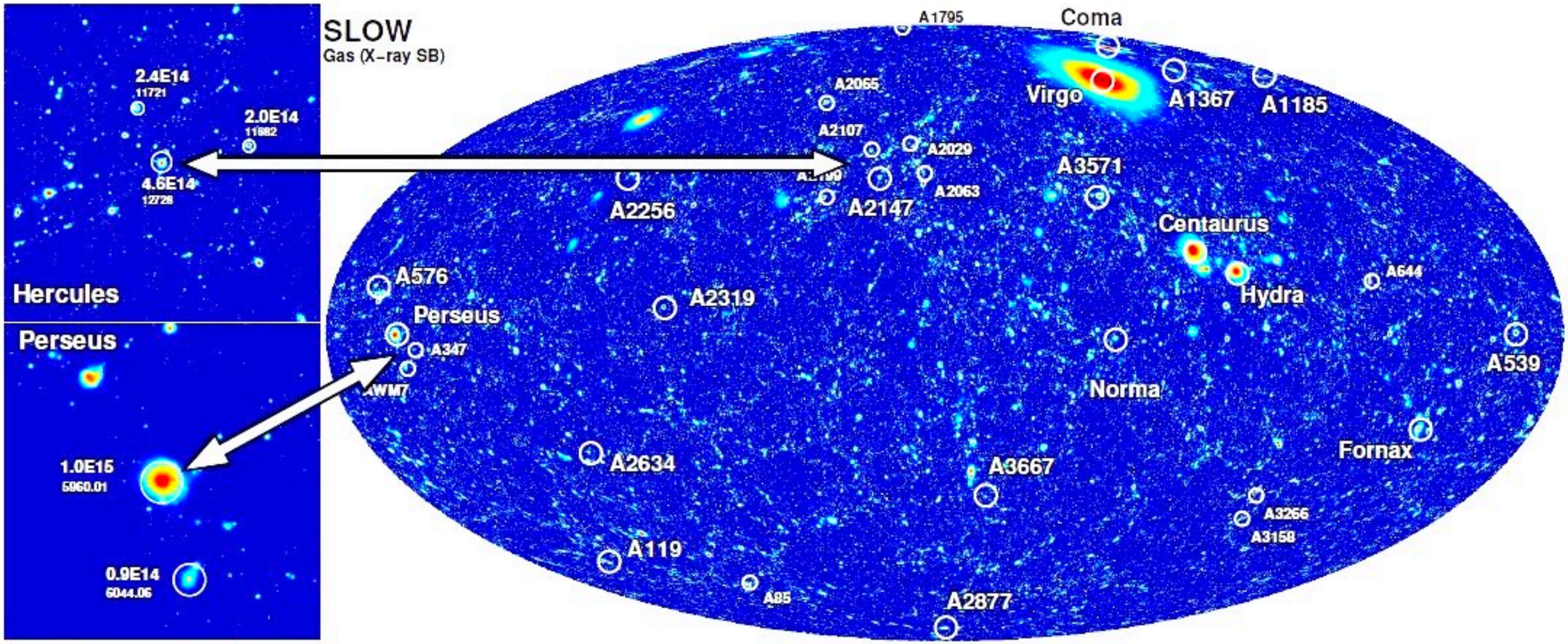

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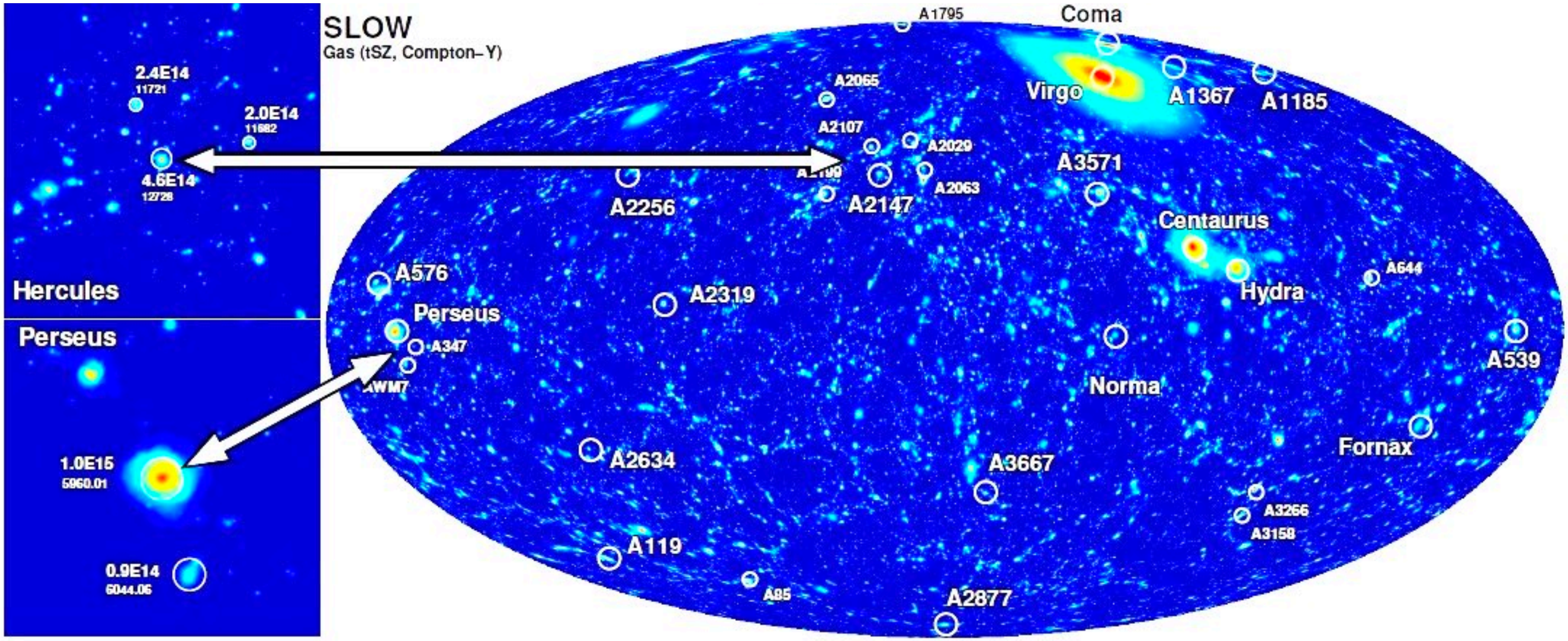
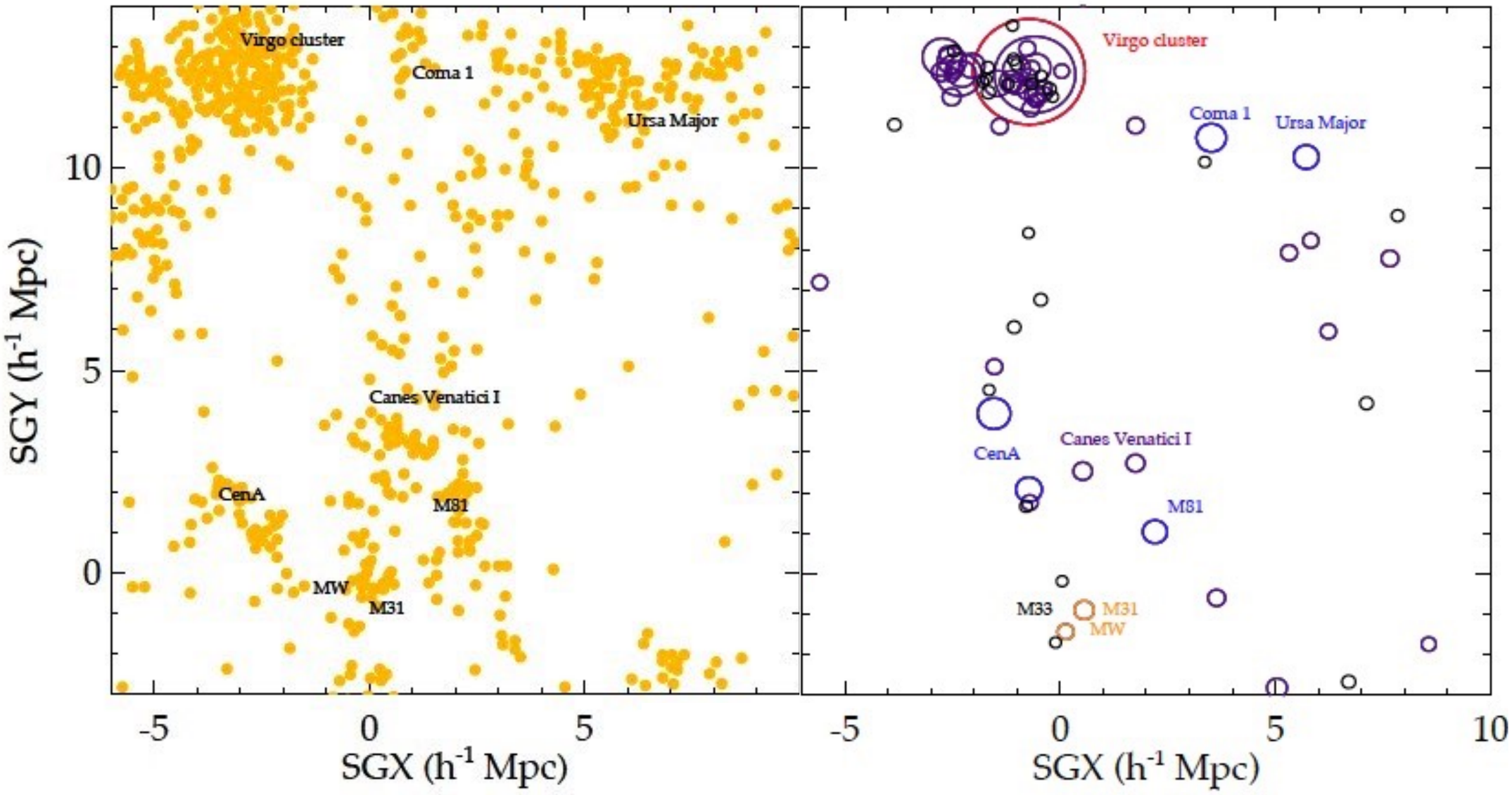


CLONES and the very local LSS

Ocvirk, Aubert, Sorce+2020

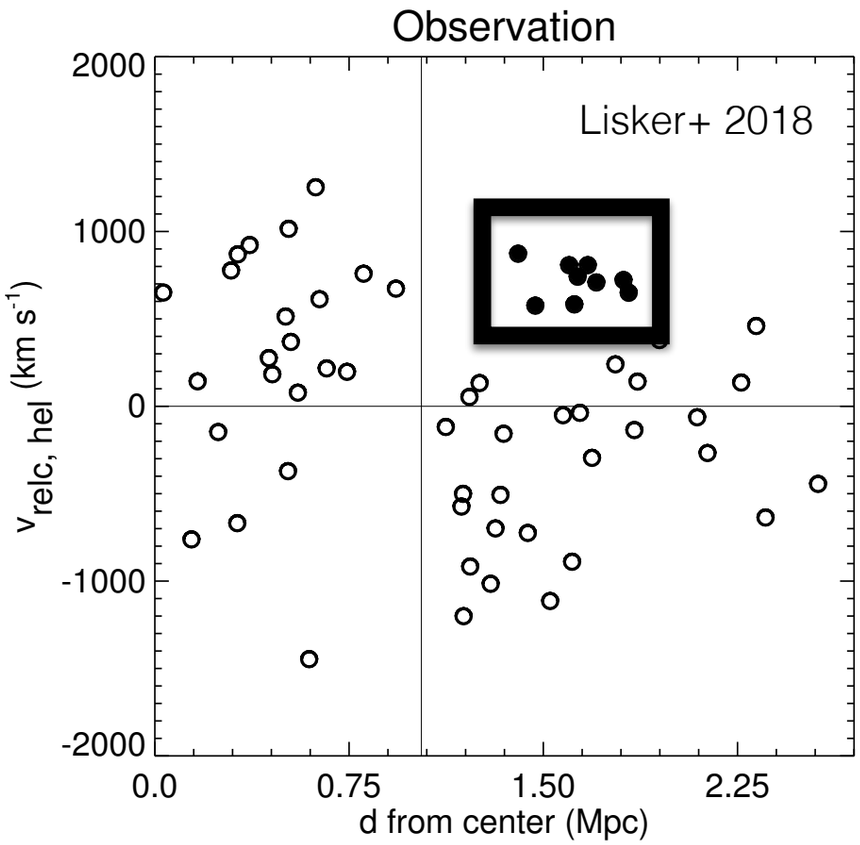


64 Mpc/h, 2048^3 particles, DM only, Planck cosmology

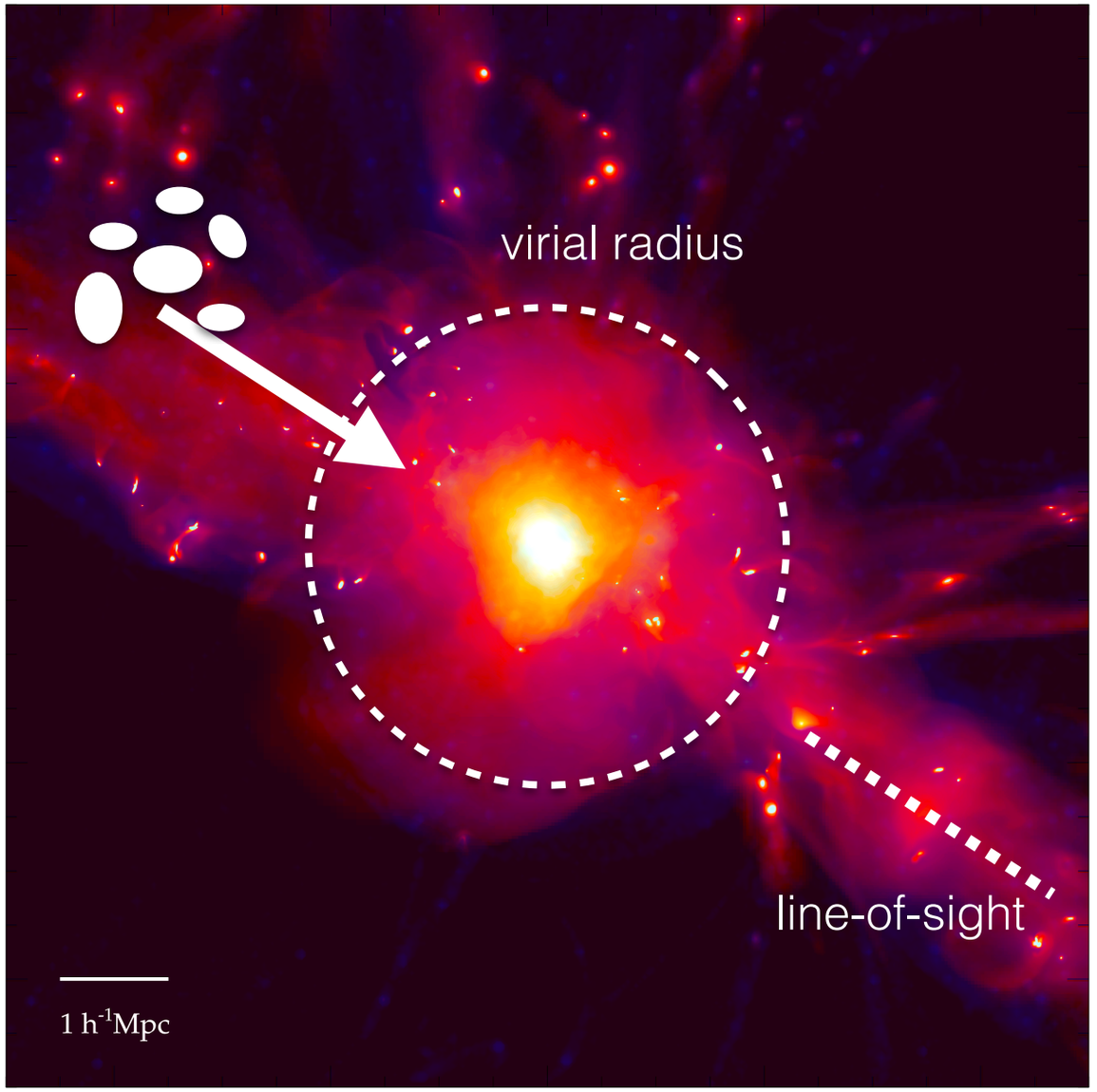
Sorce+2021

Simulated & Observed Virgo clusters

Lisker+2018: from observation, remnant of a group of ~10% $m_{cluster}$ that infall 2-3 Gyr ago



Group of galaxies that fell within the line-of-sight?



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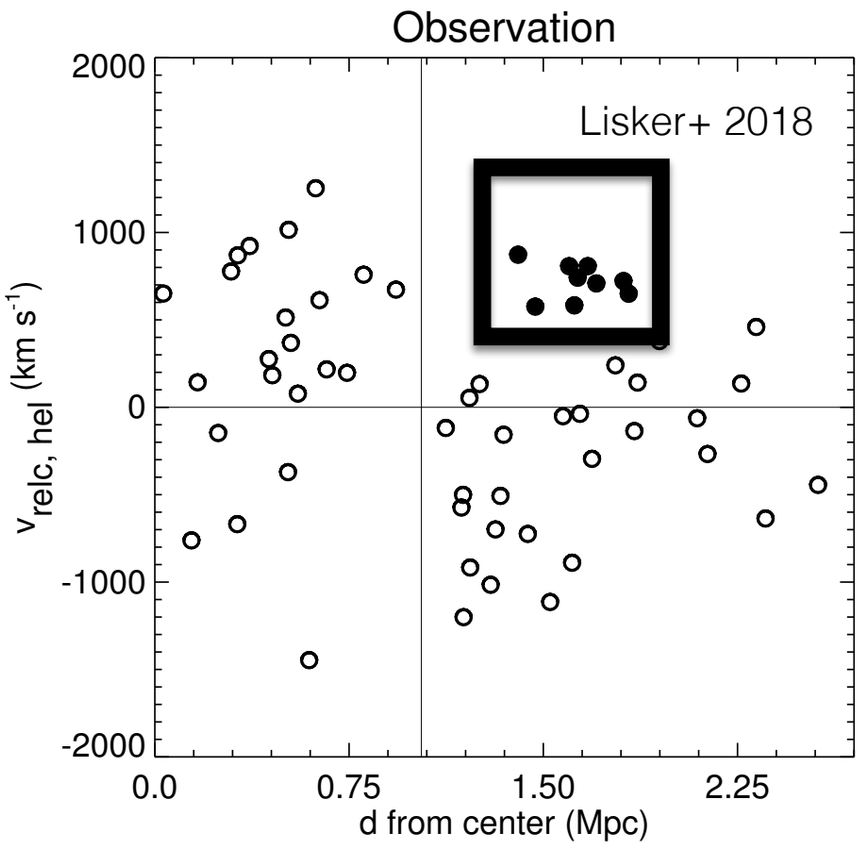

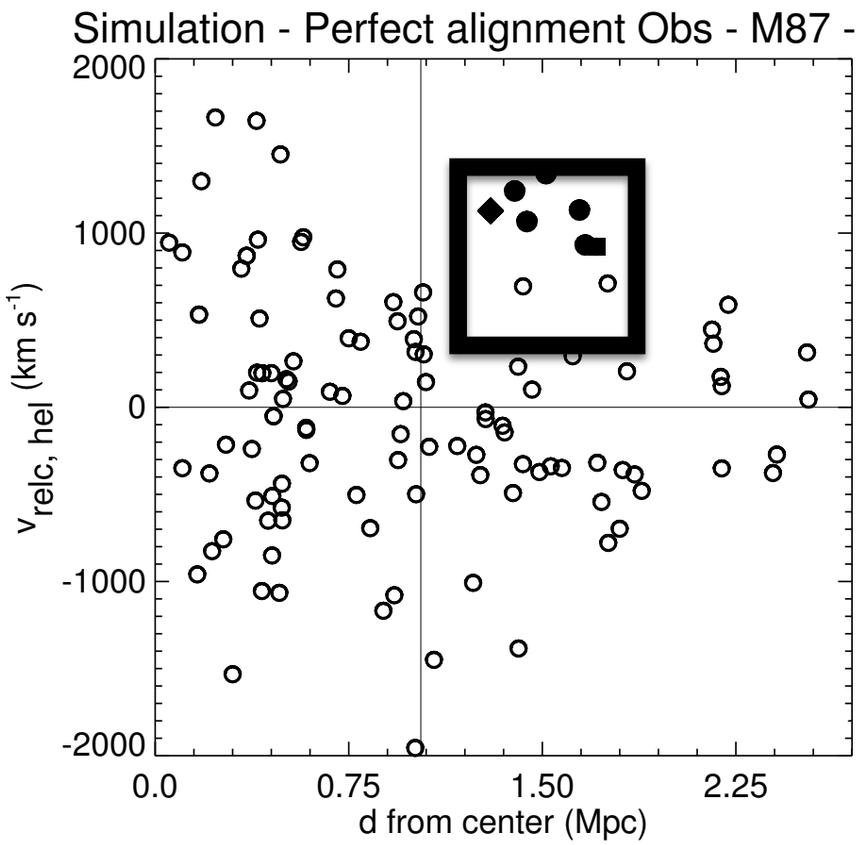

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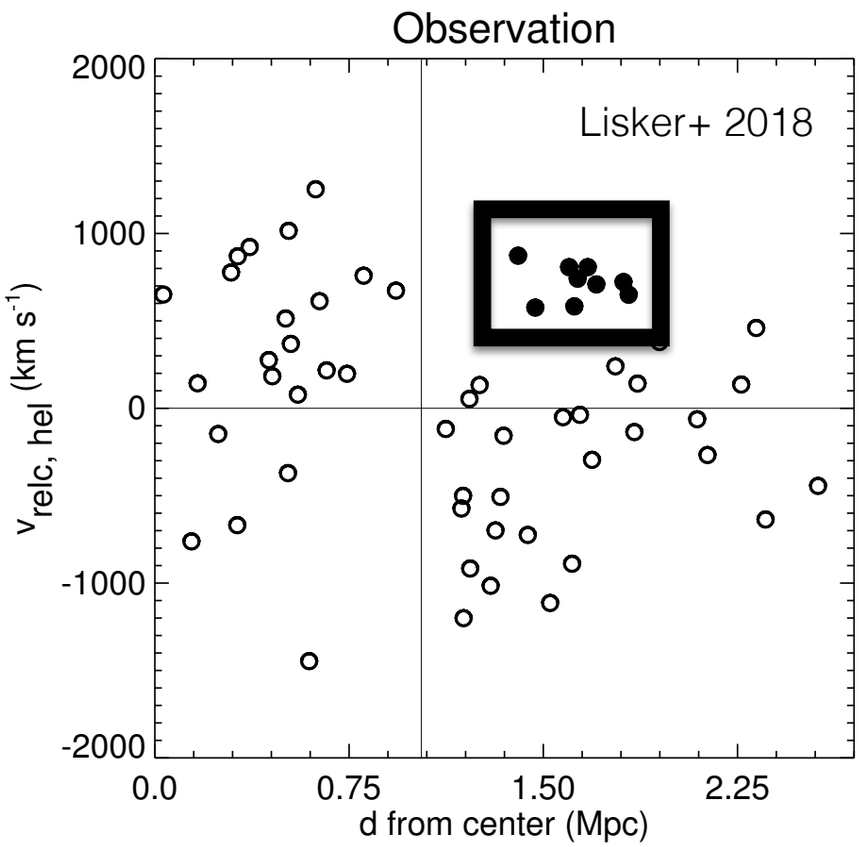
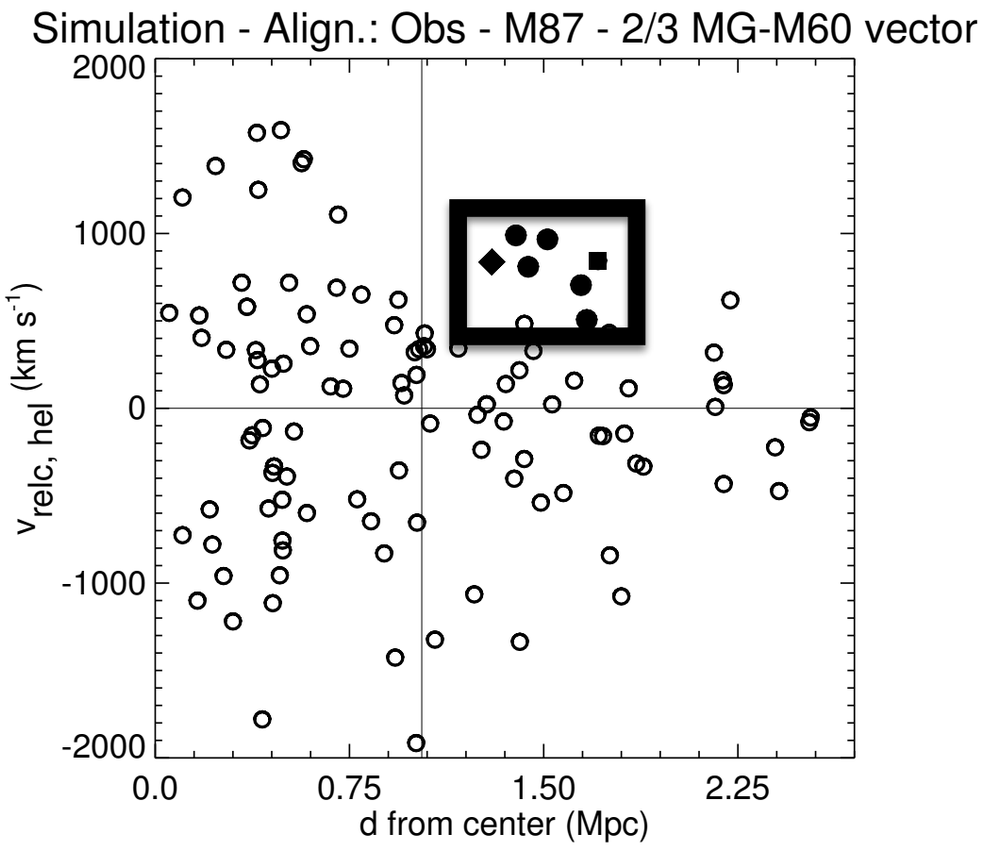
Simulated & Observed Virgo clusters

Lisker+2018: from observation, remnant of a group of ~10% $m_{cluster}$ that infall 2-3 Gyr ago





Group of galaxies that fell quasi within the line-of-sight

Sorce+2021

Agreement with observational predictions

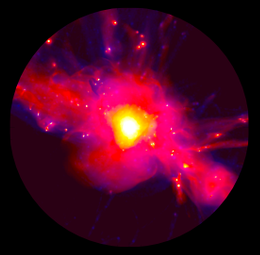
Why using CLONES?

Because they can reproduce what we observe (quasi) free of cosmic variance, they can reduce biases and help solve the question :

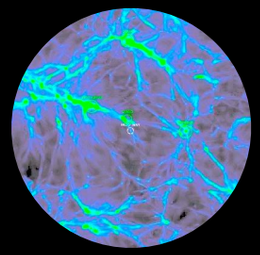
tensions or systematics ?

CLONES are widely used

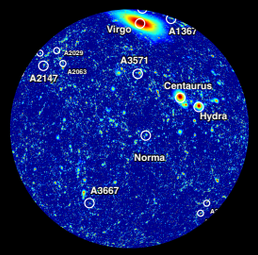
and more…



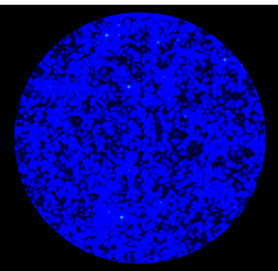
Virgo Cluster
(Sorce+2016, 2019, 2021, in prep., Olchanski & Sorce 2018, Lebeau+submitted.)



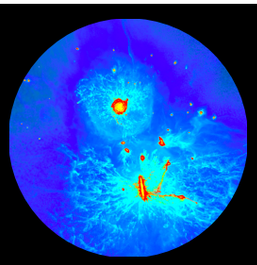
Cosmic Rays in the local Universe
(Hackstein+2018, Boess+in prep.)



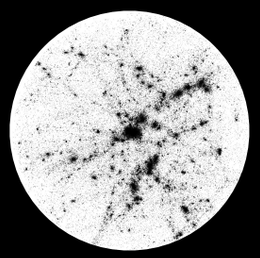
SLOW: local web
(Dolag, Sorce+2023)



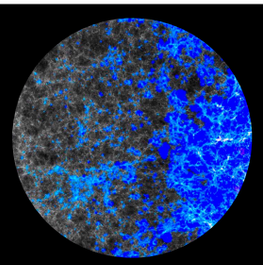
LOCALIZATION: local cluster signatures
(Sorce, Aghanim, Lebeau, Jung, Dolag)



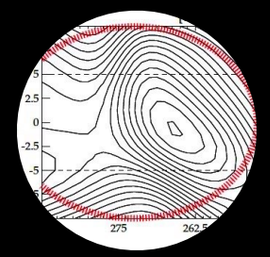
HESTIA: Local Group
Carlesi,Sorce+2016,Carlesi+2016, 2017, Libeskind+2020, Damle+2022, Newton+2022; Luis+2022, Dupuy+2022, Arora+2022, Khoperskov+2022a,b,c



Coma connectivity
(Malavasi, Sorce, Dolag, Aghanim 2023)



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



Zone of Avoidance
(Sorce+2017)

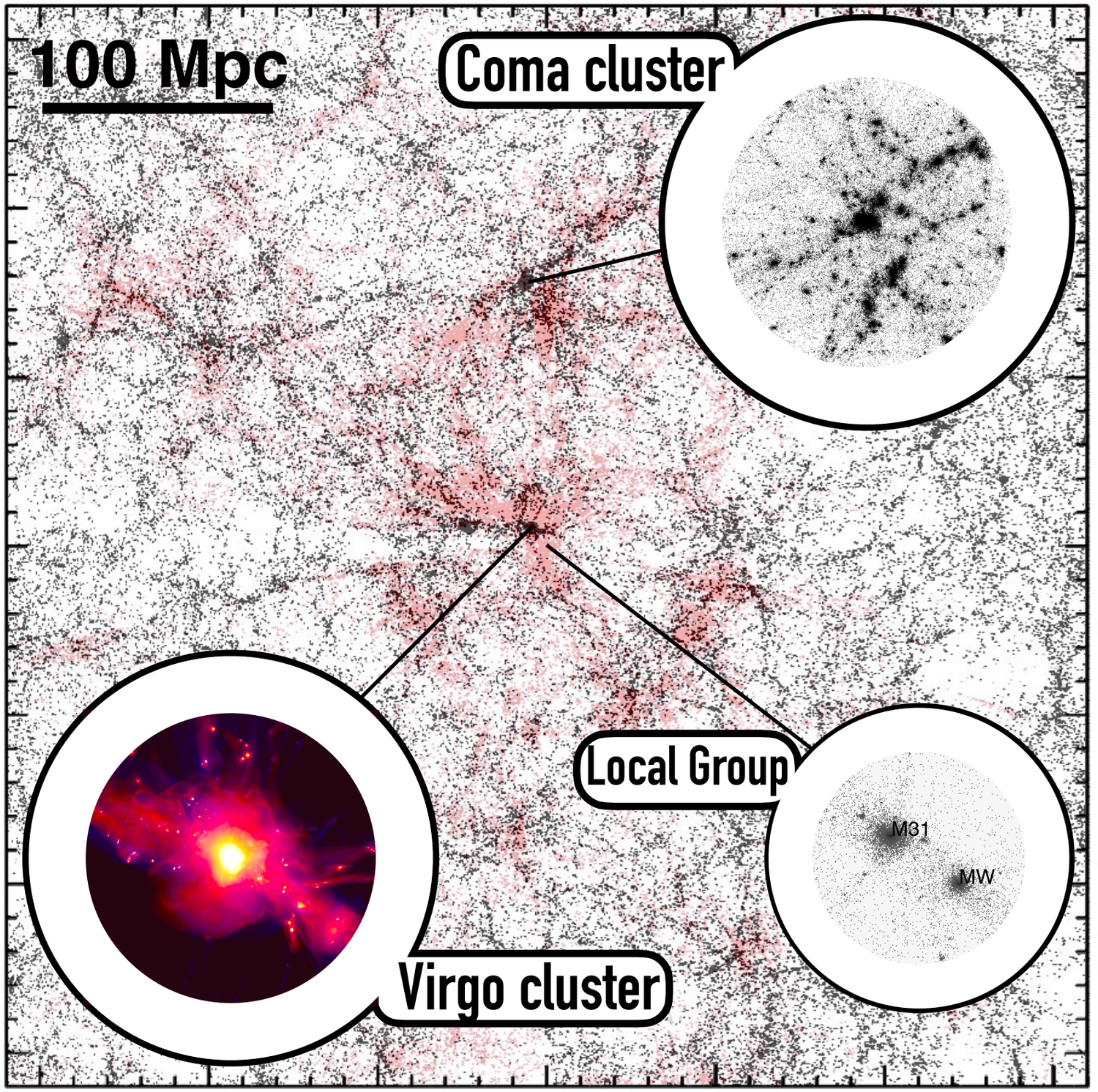
Conclusion

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

- **Constrained** cosmological simulations can permit **disentangling tensions from systematics (by reducing biases)**

- **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, ευχαριστώ

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