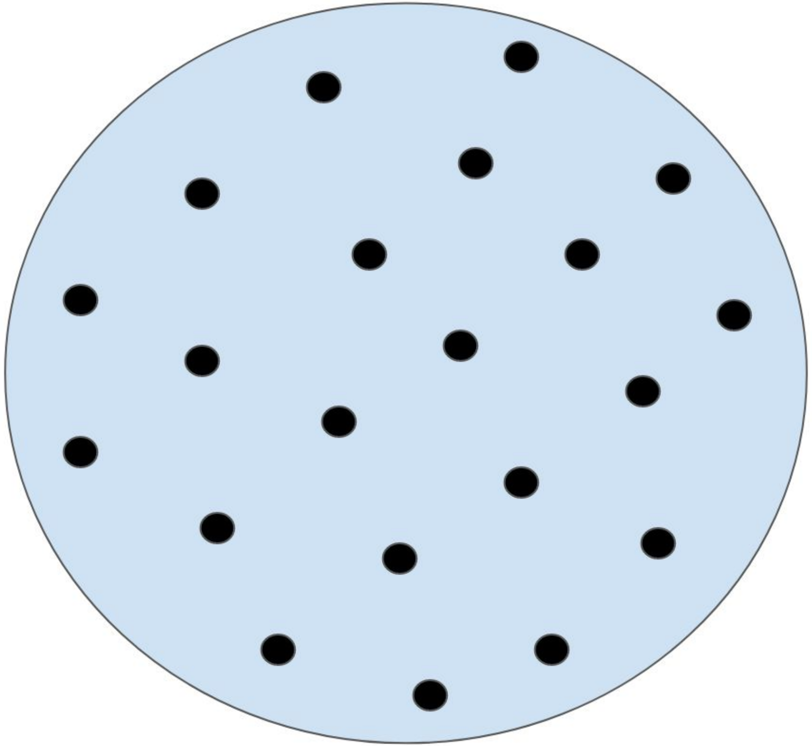
"Magnetic field seeds form black holes accretion disks."

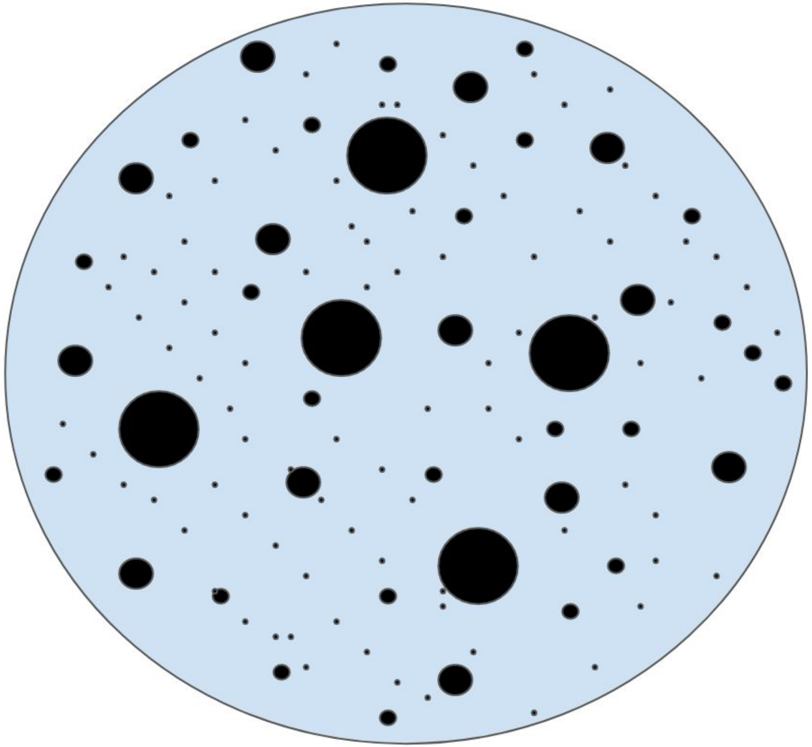
Patricio Colazo, Matthieu Schaller, Federico Stasyszyn & Nelson Padilla

Mass function of PBH

Monochromatic



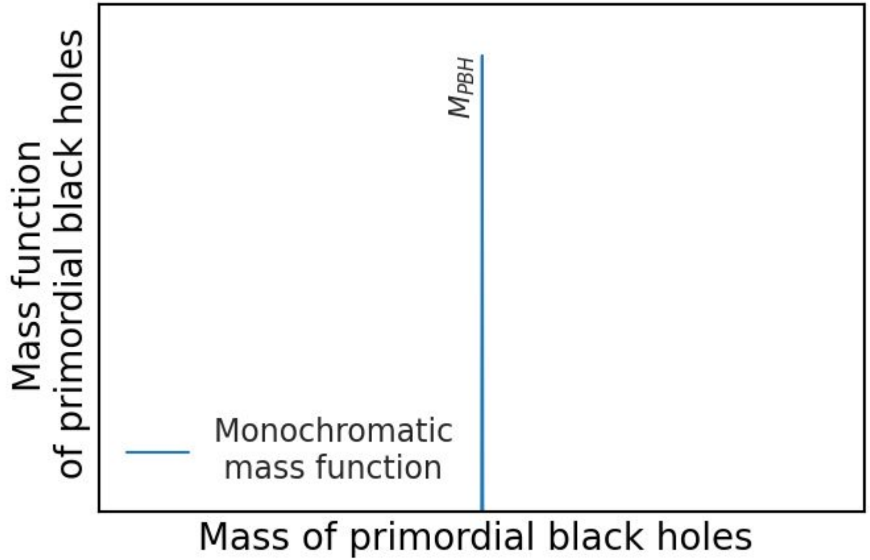
Extended



Mass function of PBH

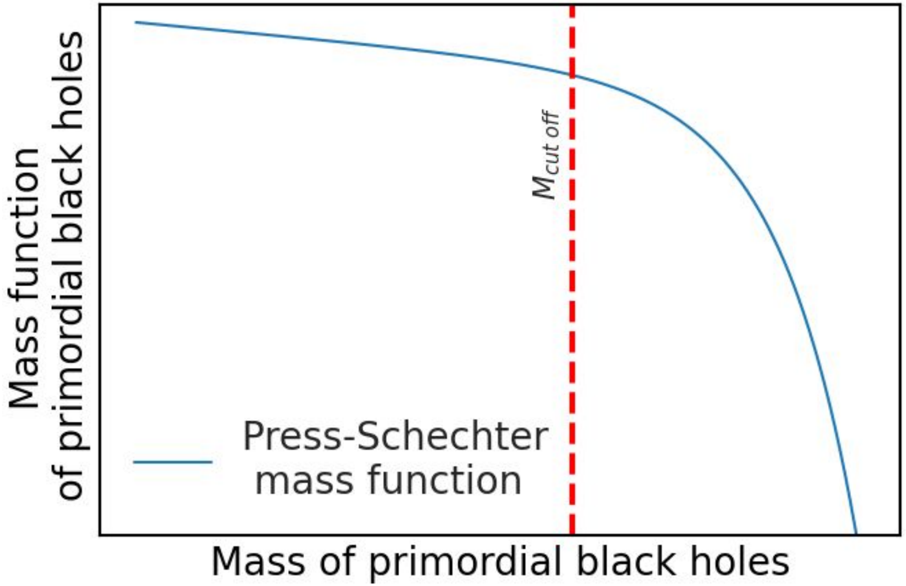
Monochromatic

with only mass of $M_{PBH} =$ ●

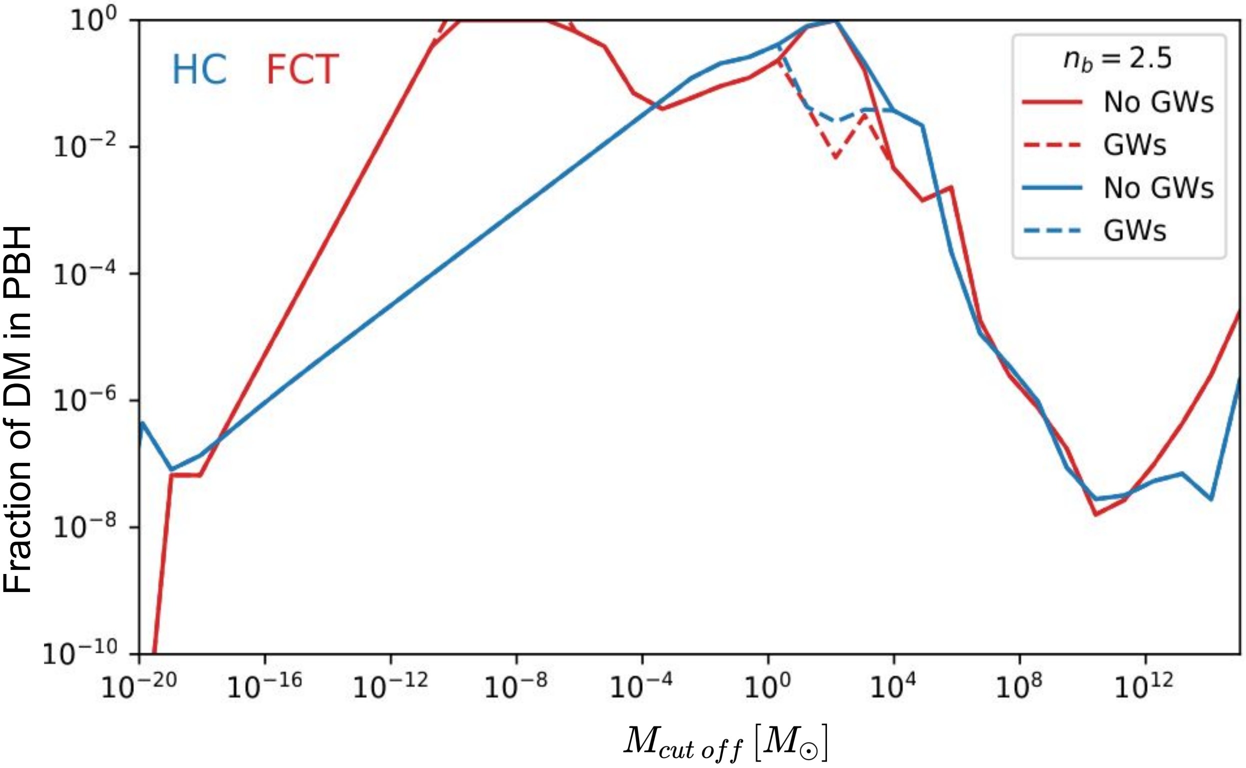


Extended

with representative mass of $M_{cut\,off} =$ ●

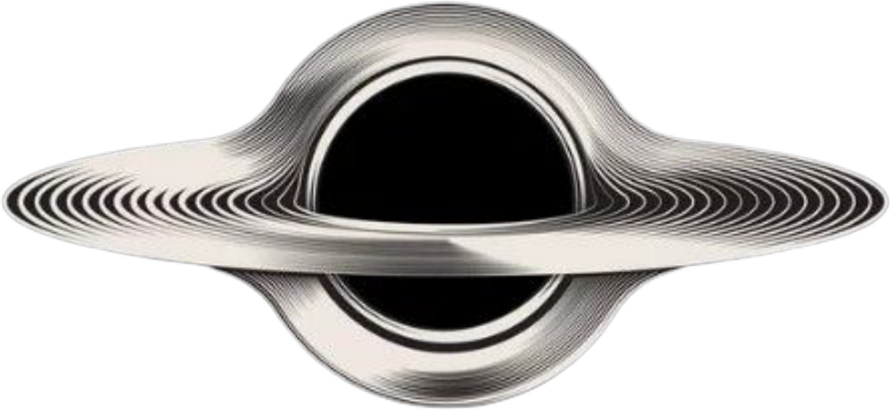


Restricted fraction



(Sureda et al. 2020)

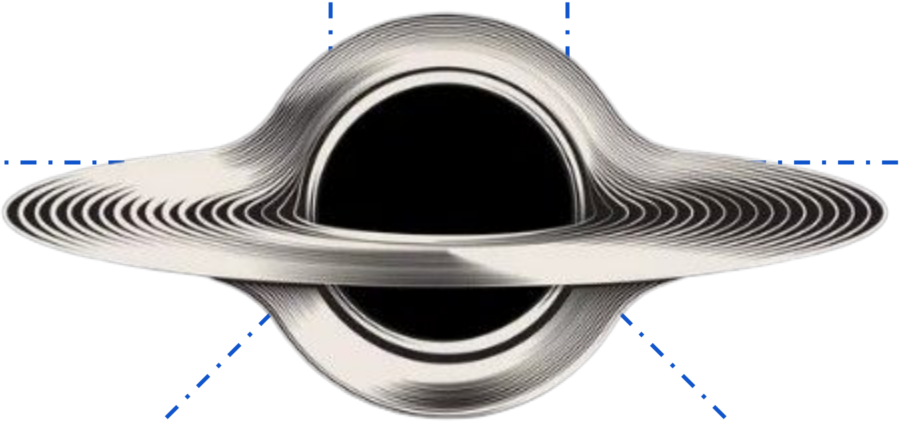
Constraint	Mass Regime
Big Bang Nucleosynthesis	$-24.3 < \log_{10}\left(\frac{M}{M_\odot}\right) < -19.8$
Extragalactic γ-ray background	$-18.6 < \log_{10}\left(\frac{M}{M_\odot}\right) < -16.2$
INTEGRAL	$-18.3 \lesssim \log_{10}\left(\frac{M}{M_\odot}\right) < -16.1$
GRB lensing*	$-16.3 \lesssim \log_{10}\left(\frac{M}{M_\odot}\right) \lesssim -14$
White dwarfs*	$-14.9 \lesssim \log_{10}\left(\frac{M}{M_\odot}\right) \lesssim -10.8$
Neutron star capture*	$-14.9 < \log_{10}\left(\frac{M}{M_\odot}\right) < -8.3$
Subaru*	$-11.4 \lesssim \log_{10}\left(\frac{M}{M_\odot}\right) \lesssim -5.2$
MACHOS	$-8 \lesssim \log_{10}\left(\frac{M}{M_\odot}\right) < 1.8$
EROS	$-7.2 \lesssim \log_{10}\left(\frac{M}{M_\odot}\right) < 0.7$
OGLE	$-6.7 \lesssim \log_{10}\left(\frac{M}{M_\odot}\right) < -0.5$
Accretion of PBHs*	$0 < \log_{10}\left(\frac{M}{M_\odot}\right) < 4$
Gravitational waves*	$1 < \log_{10}\left(\frac{M}{M_\odot}\right) < 3$
Large scale structure	$2 < \log_{10}\left(\frac{M}{M_\odot}\right) < 14$
Lensing of radio sources	$5 < \log_{10}\left(\frac{M}{M_\odot}\right) < 9$
Dynamical friction	$4 \lesssim \log_{10}\left(\frac{M}{M_\odot}\right) < 13$
Wide binaries	$2.7 \lesssim \log_{10}\left(\frac{M}{M_\odot}\right) < 8$
X-ray binaries	$0.8 \lesssim \log_{10}\left(\frac{M}{M_\odot}\right) \lesssim 7.3$
Globular cluster disruption	$4.5 < \log_{10}\left(\frac{M}{M_\odot}\right) < 11$
Galaxy disruption	$9.8 < \log_{10}\left(\frac{M}{M_\odot}\right) < 13$
Disk heating	$6.5 < \log_{10}\left(\frac{M}{M_\odot}\right) < 12.5$
CMB dipole	$16.8 \lesssim \log_{10}\left(\frac{M}{M_\odot}\right) \lesssim 22$



Dark matter candidate
(Carr & Hawking 1974; Zel'dovich & Novikov 1966; Hawking 1971; Carr et al. 2023; Liu & Bromm 2022)

The baryon asymmetry problem
(Ambrosone et al. 2022)

Gravitational wave explanation
By through PBH mergers (Bird et al. 2016; Sasaki et al. 2016; Raidal et al. 2017).



Accelerating the collapse compared to the ΛCDM model.
(Carr & Kühnel 2020; Inman & Ali-Haïmoud 2019; Liu et al. 2022).

The stochastic gravitational wave background
(Agazie et al. 2023; Yi et al. 2023).

The Core-Cusp controversy
(Boldrini et al. 2020; Liu et al. 2022; Kashlinsky 2021).

Seeds of the primordial of magnetic fields.

(Araya et al. 2021; Papanikolaou & Gourgouliatos 2023).

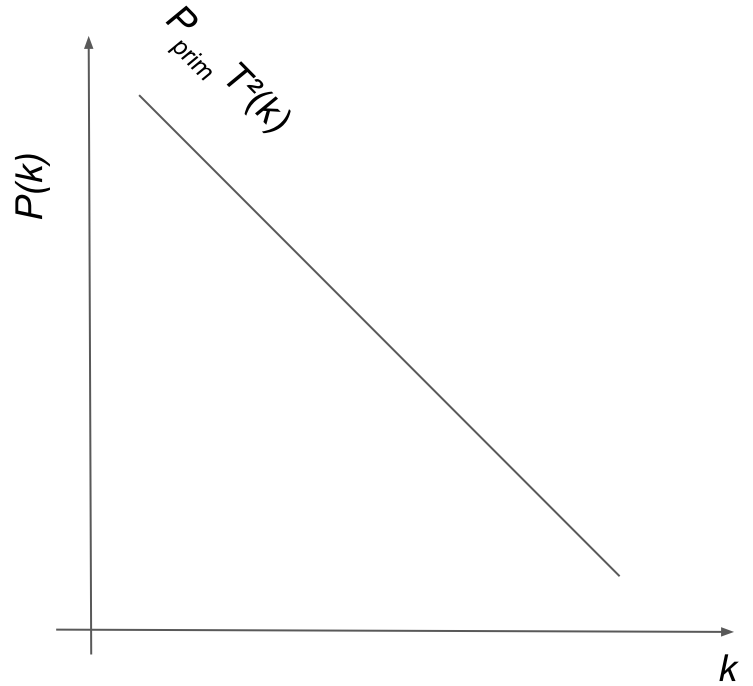
Initial Condition (IC)

Primordial Power Spectrum

The primordial power spectrum have all informations about which structures will be forming in our universe. This spectrum evolves from the end of the inflation era, and we can measure using CMB.

$$P_{prim}(k) = A_S \left(\frac{k}{k_0} \right)^{n_s}$$

$$k_0 = 0.05\, Mpc^{-1}$$

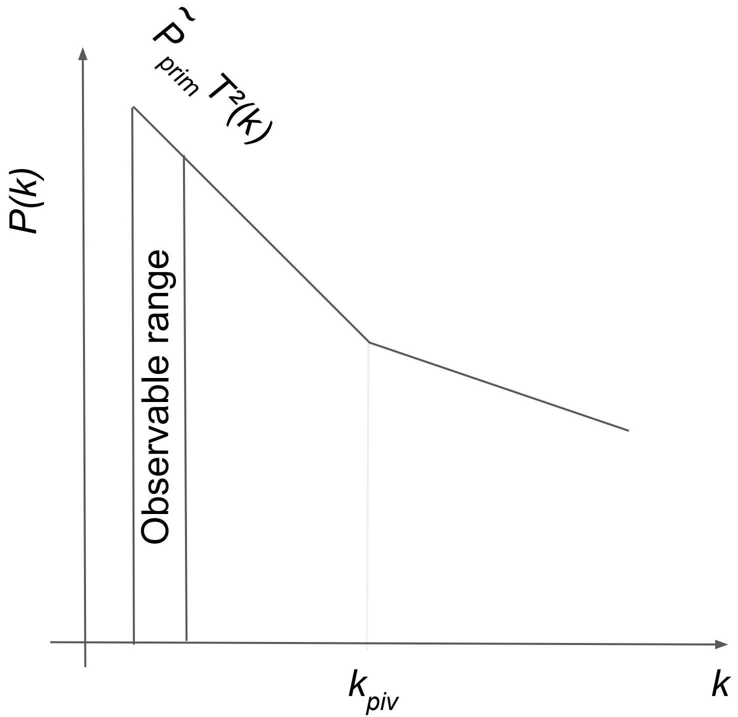


Initial Condition (IC)

Increase power on a small scale

If we want to form PBHs in the universe, so we need an alternative inflation model that has more power on small scale. This increase is set to occur after to kpiv ~ 10 Mpc-1 as it is lies beyond the observable range. The new spectral index is nb and ϵ is a normalization factor.

$$\tilde{P}_{prim}(k) = \begin{cases} A_S \left(\frac{k}{k_0}\right)^{n_s} & for\, k < k_{piv} \\ A_S\, \epsilon \left(\frac{k}{k_0}\right)^{n_b} & for\, k \geq k_{piv} \end{cases}$$



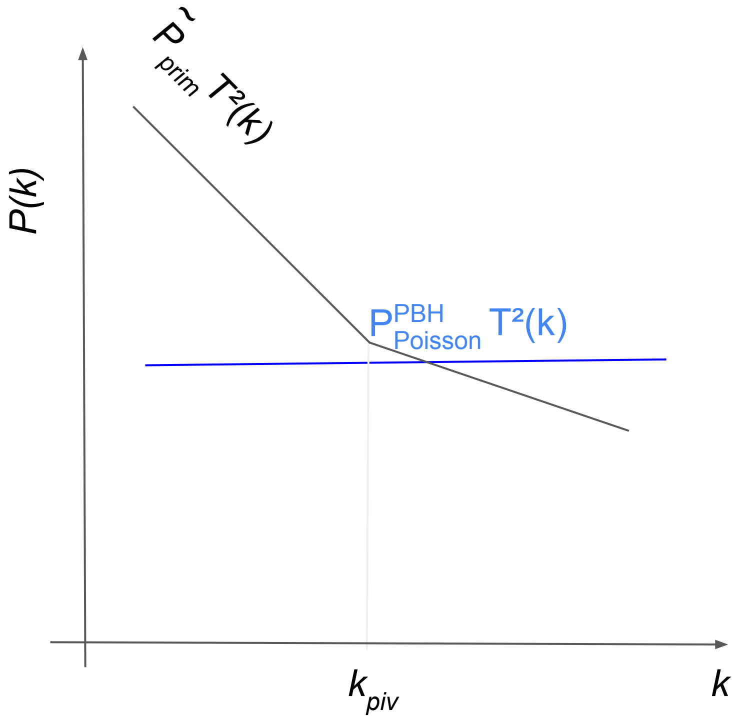
Initial Condition (IC)

Poisson effect

Then, if we have PBHs, their existence as discrete and massive particles you will have an important poisson effect on the gravitational potential which can modify the evolution of the fluctuations. The power spectrum should include this effect. We also need to account for the fraction of DM that is made up of PBHs fPBH.

$$P(k,z) = P_{Broken}(k,z) + f_{PBH}^2 P_{Poisson}^{PBH}(k,z)$$

$$P_{Broken}(k,z) = \tilde{P}_{prim}(k)T^2(k)D_1^2(z)$$



Initial Condition (IC)

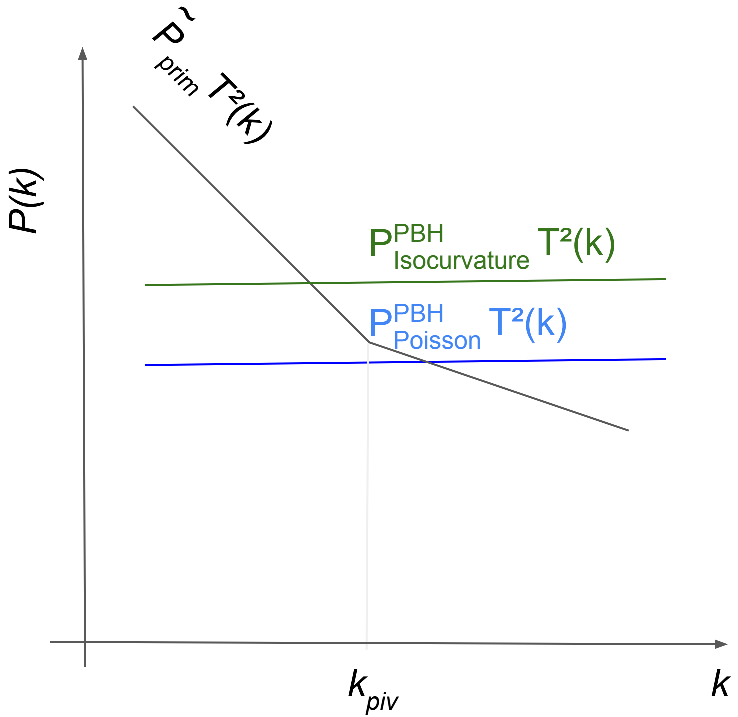
Isocurvature effect

In the vicinity of PBHs, the space curve, so that introduce a new perturbation that will be only important if the PBHs are massive. We follow (Liu & Bromm 2022) where the growth factor for these perturbations is

$$D(a) \simeq \left(1 + \frac{3\gamma}{2a_-} s\right)^{a_-} - 1, \quad s = \frac{a}{a_{\rm eq}}$$

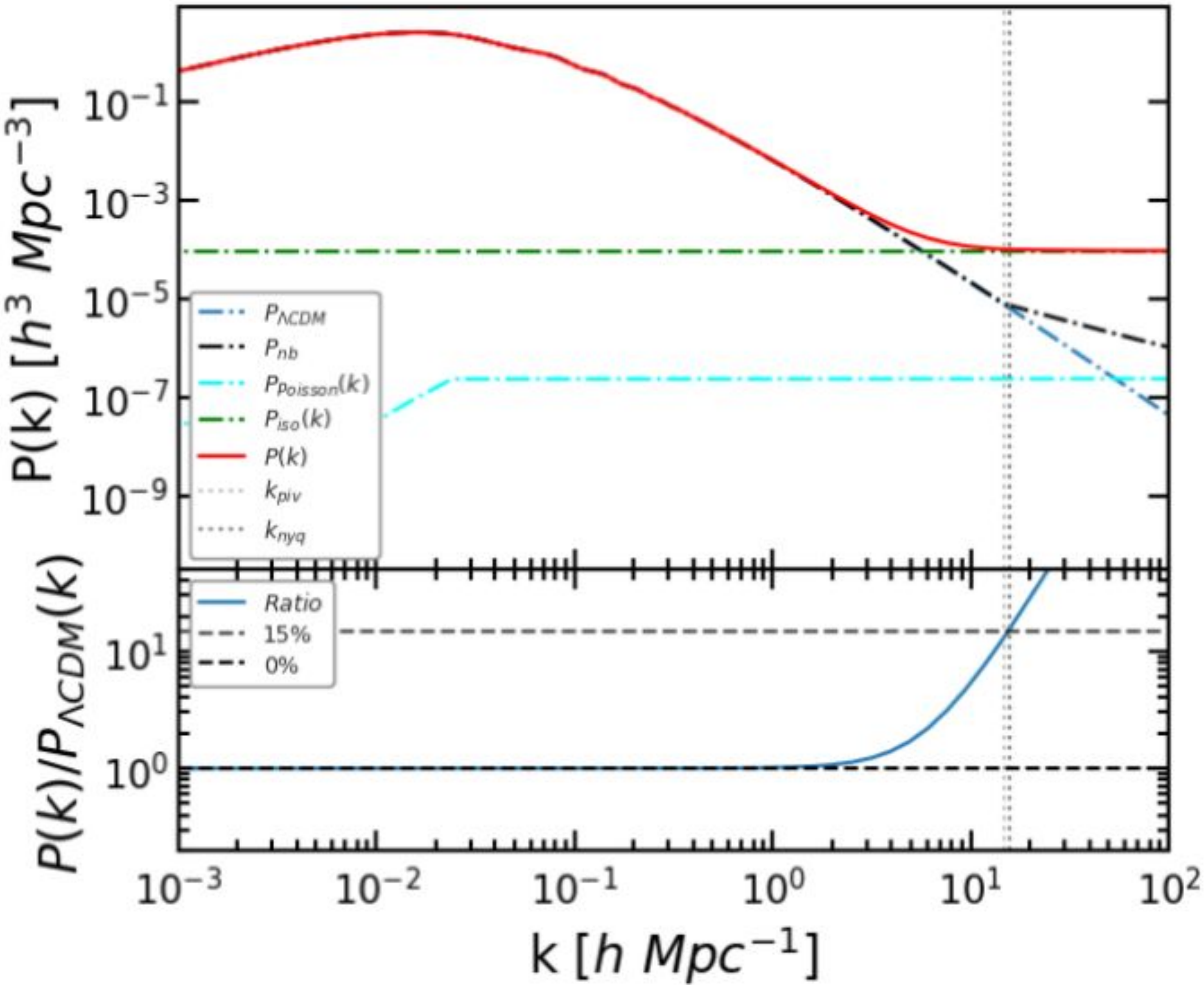
$$\gamma = \frac{\Omega_{\rm m} - \Omega_{\rm b}}{\Omega_{\rm m}}, \quad a_- = \frac{1}{4}\left(\sqrt{1 + 24\gamma} - 1\right),$$

$$P_{iso}(k) \simeq \left[\bar{f} D(a)\right]^2 / \bar{n}_{PBH},$$



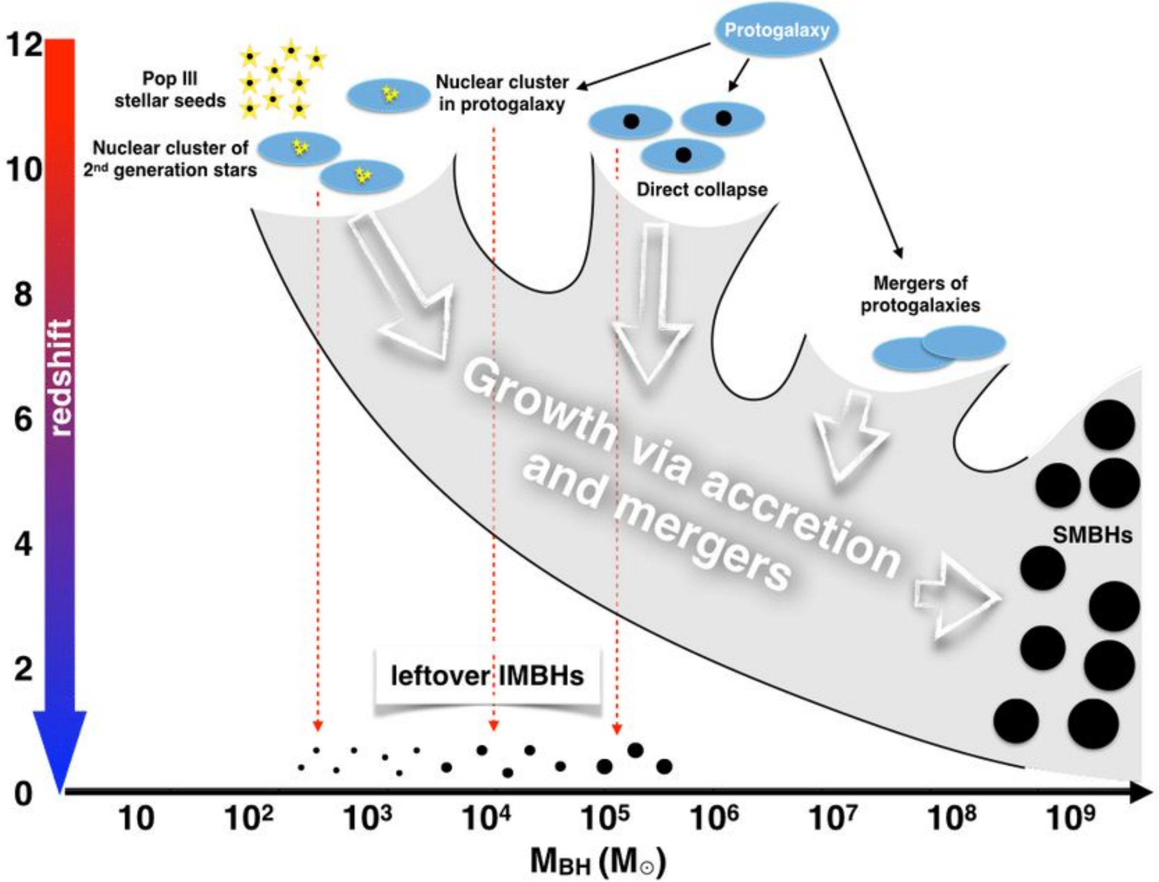
The full initial power spectrum

$$P(k,z) = \tilde{P}_{\mathrm{primordial}}(k)\, T^2(k)\, D_1^2(z) + f_{PBH}^2 P_{Poisson}^{PBH}(k,z) + P_{iso}(k,z),$$



10^{-1}
10^{-3}
10^{-5}
10^{-7}
10^{-9}
P(k) [h^3 Mpc^{-3}]
$P_{\Lambda CDM}$
P_{nb}
$P_{Poisson}(k)$
$P_{iso}(k)$
$P(k)$
k_{piv}
k_{nyq}
$P(k)/P_{\Lambda CDM}(k)$
Ratio
15%
0%
10^1
10^0
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
10^2
k [h Mpc^{-1}]

SEEDS OF SMBH



Mezcua (2017).

SEEDS OF SMBH

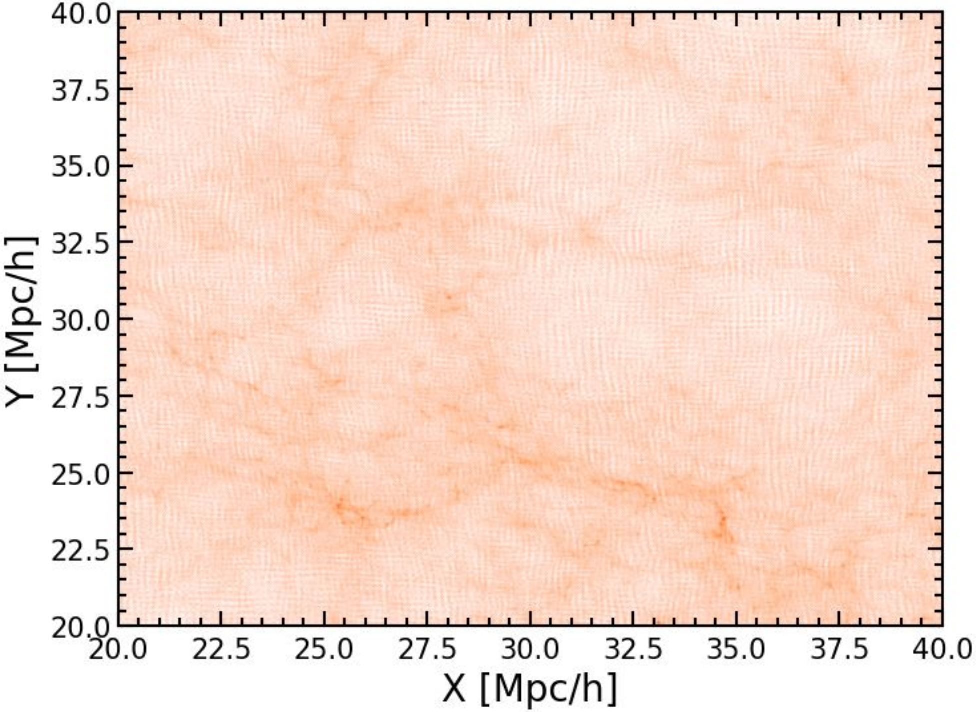
$$n(> M_{\mathrm{pbh}}) = \int_{M_{\mathrm{min}}}^{\infty} \frac{dn}{dM}\, dM$$

+ The same number density of present-day galaxies with > 10^{10} solar masses.

$7 \times 10^{-4} h^3 \mathrm{Mpc}^{-3}$ (Ross et al. 2015)

We obtain $M_{min} = 7.57 \times 10^4\ M_\odot$

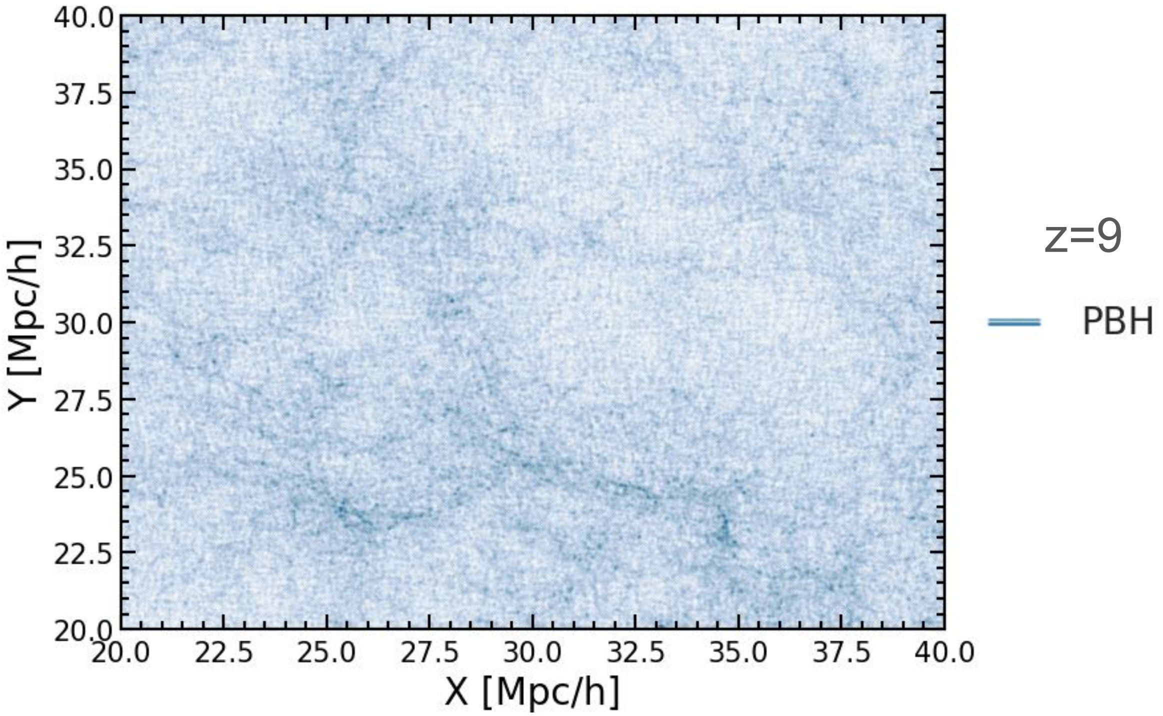
Comparison between PBHs and CDM



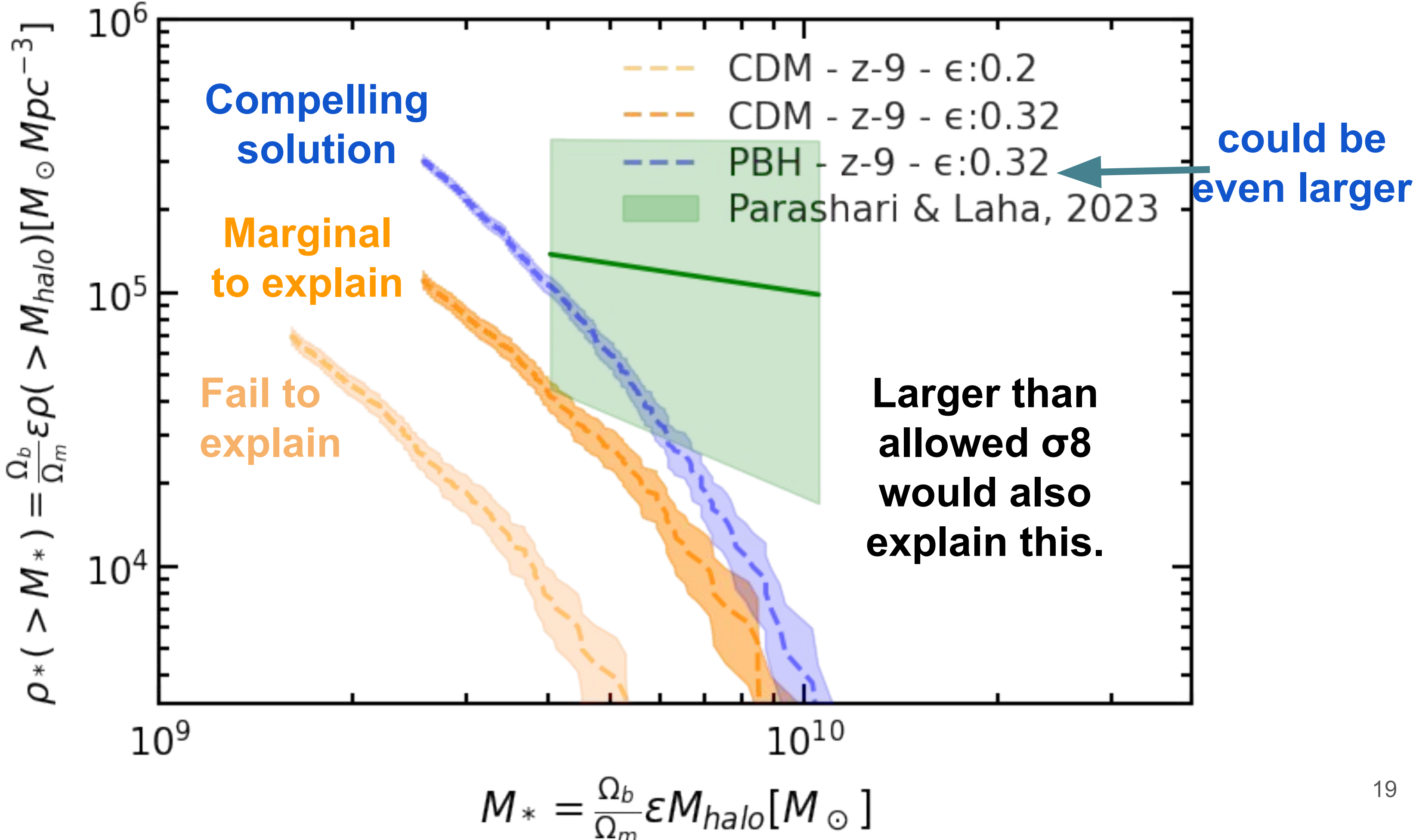
z=9

CDM

Comparison between PBHs and CDM



Cumulative stellar mass function at z = 9



How PBHs could generate PMF?

Mechanics of generate Primordial magnetic fields

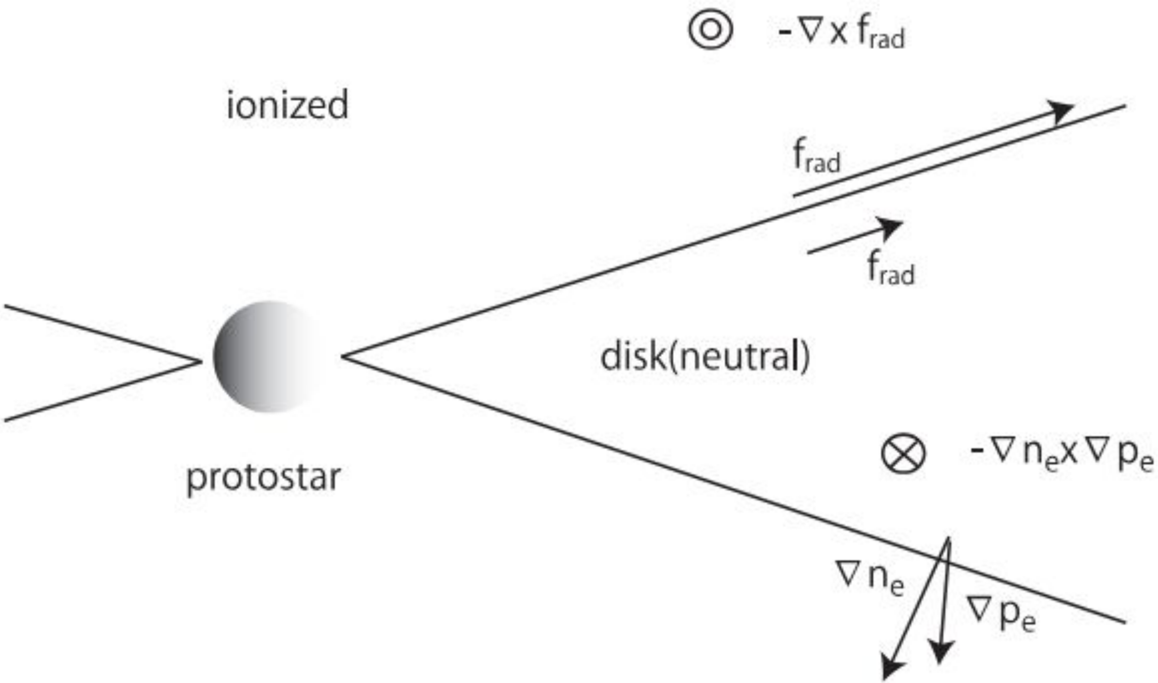
Magnetic field generation from PBH distributions

- Aims
  - They shows two different ways where PBHs could give a primordial magnetic fields
- How to magnetize them
  - Biermann battery
  - Magnetic monopoles

Araya+(2021)

Biermann battery

Biermann Battery



Yuki Shiromoto+(2014)

Correlation with Density Fluctuations

The overall distribution of PBHs can trace the density fluctuations $\delta(x)$ in a particular process. The accumulation of PBHs in matter overdensities can lead to the coherent generation of magnetic fields.

Simple Assumption

The simplest assumption is that matter inhomogeneities become sources of fluctuation for other fields, up to a correlation parameter. Intuitively, wherever there is a matter overdensity, the accumulation of PBHs is expected, each surrounded by an accretion disk with a certain angular momentum J with random orientation.

Primordial Torques and Magnetic Fields

Overdensities generate their own primordial torques on their respective size scales. Therefore, wherever there is an accumulation of PBHs (and thus dark matter), there should also exist a net magnetic field coherently summed.

Araya+(2021)

Magnetic field for an accretion disk

The contribution to the magnetic field generated by each PBH, taking as a reference value the one produced at a distance of $4\,r_{\rm isco}$ from its centre (Safarzadeh 2018), at redshift z, is

$$B_{\rm Bier}(M, |\vec{x}' - \vec{x}|, z) = \frac{\mathcal{C} B_{\rm B}(M)}{a(z)^3} \left(\frac{4\, r_{\rm isco}(M)}{|\vec{x}' - \vec{x}|} \right)^3 , \quad (17)$$

where $\mathcal{C}$ is a parameter that accounts for the correlation degree of the constituents, $a(z)$ is the cosmological scale factor at redshift z, the interval $|\vec{x}' - \vec{x}|$ is measured in comoving coordinates, and

$$B_{\rm B}(M) \approx 10^{-2} \left[\frac{\rm Gauss}{s} \right] \left(\frac{M}{5.0\,{\rm M}_\odot} \right)^{-9/4} \left(\frac{GM}{(4\, r_{\rm isco})^3} \right)^{-1/2} . \quad (18)$$

Araya+(2021)

Magnetic monopoles

Possible but difficult to produce monopoles and anti-monopoles in the early Universe

Bai & Orlofsky (2020) Araya+(2021)

Kind of BHs

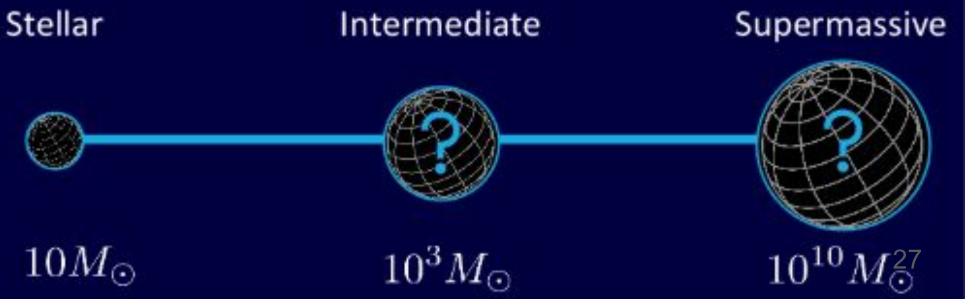
J. Sureda

PRIMORDIAL BLACK HOLES

- Zel'dovich & Novikov (1966)
  - Collapse of an overdense region in the very early Universe
- Broad mass range
  - $10^{-38} M_\odot \lesssim M_{\rm PBH} \lesssim 10^{15}\ M_\odot$
- Noreña et al., 2020: dimensionless spin parameter could be as high as a~1

ASTROPHYSICAL BLACK HOLES

- Collapse of a dying star
- Limited mass range
- a=0 to ~1



Imbalance of charge

Aims → Estimation of the electrical charge that black holes could have when they are immersed in the ionized plasma within galaxies.

Summary → $dQ_{BH}/dt = dQ_{accretion}/dt - dQ_{Hawking}/dt$

→ Origin of BH
→ Spin and mass
→ Density of plasma

Hawking athermal (Schwinger) since it emits due to the chemical potential

Padilla+(2023)

Imbalance of charge

- ★ If the black hole charge is greater than the Gibbons limit for pair-producing charge, then the discharge rate is positive.

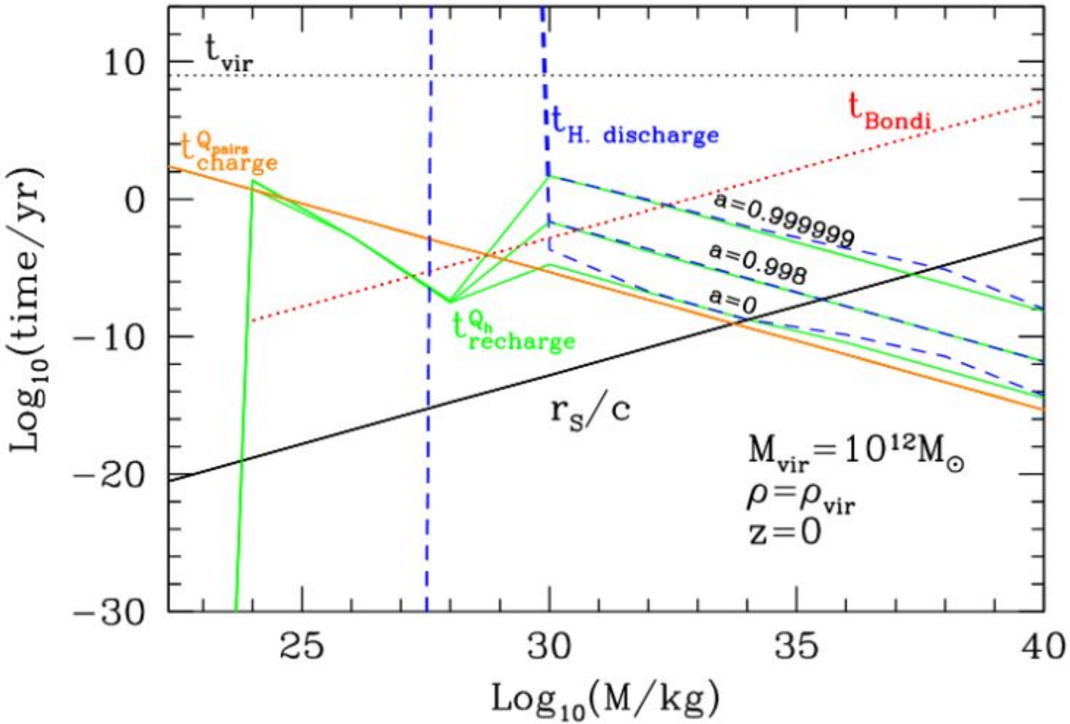
- ★ For $Q \leq Q_{pairs}$, the rate is zero, that is, a charge below pairs is stable if no charges accumulate on the black hole.

- ★ That this charge corresponds to an excess of one charge every ~10^{39} baryons, which corresponds to the maximum charge that could be maintained due to the gravitational attraction of any massive object.

$$U_G/U_C = \frac{G m_e m_p}{k_C e^2} \sim 10^{-39},$$

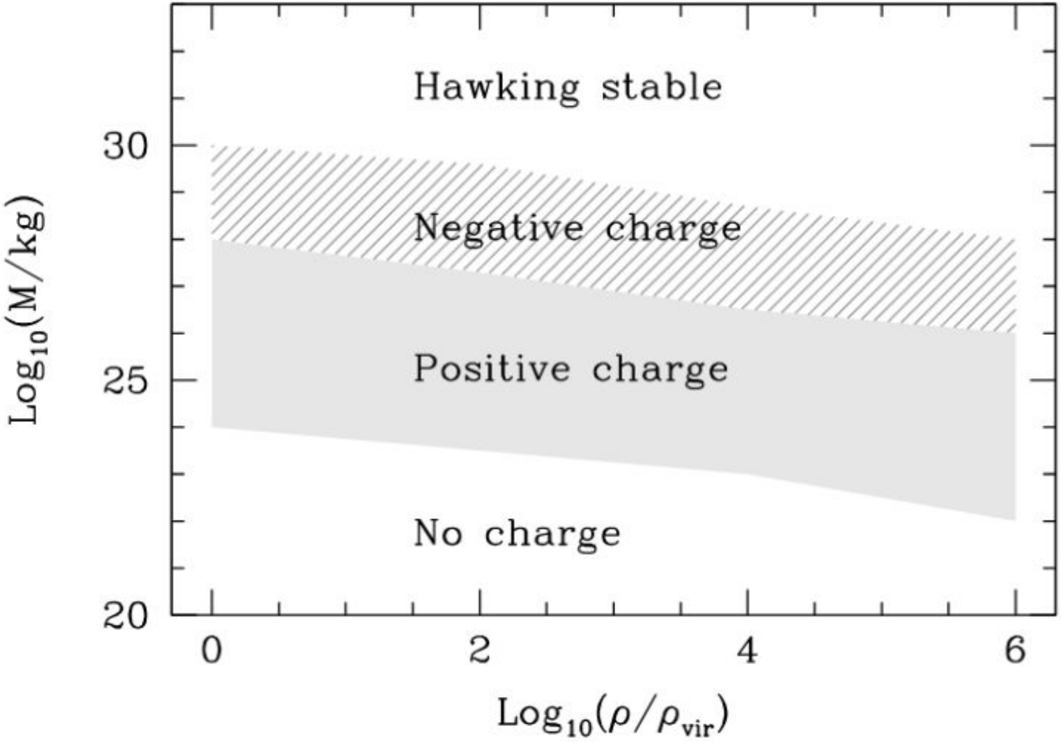
Padilla+(2023)

Imbalance of charge



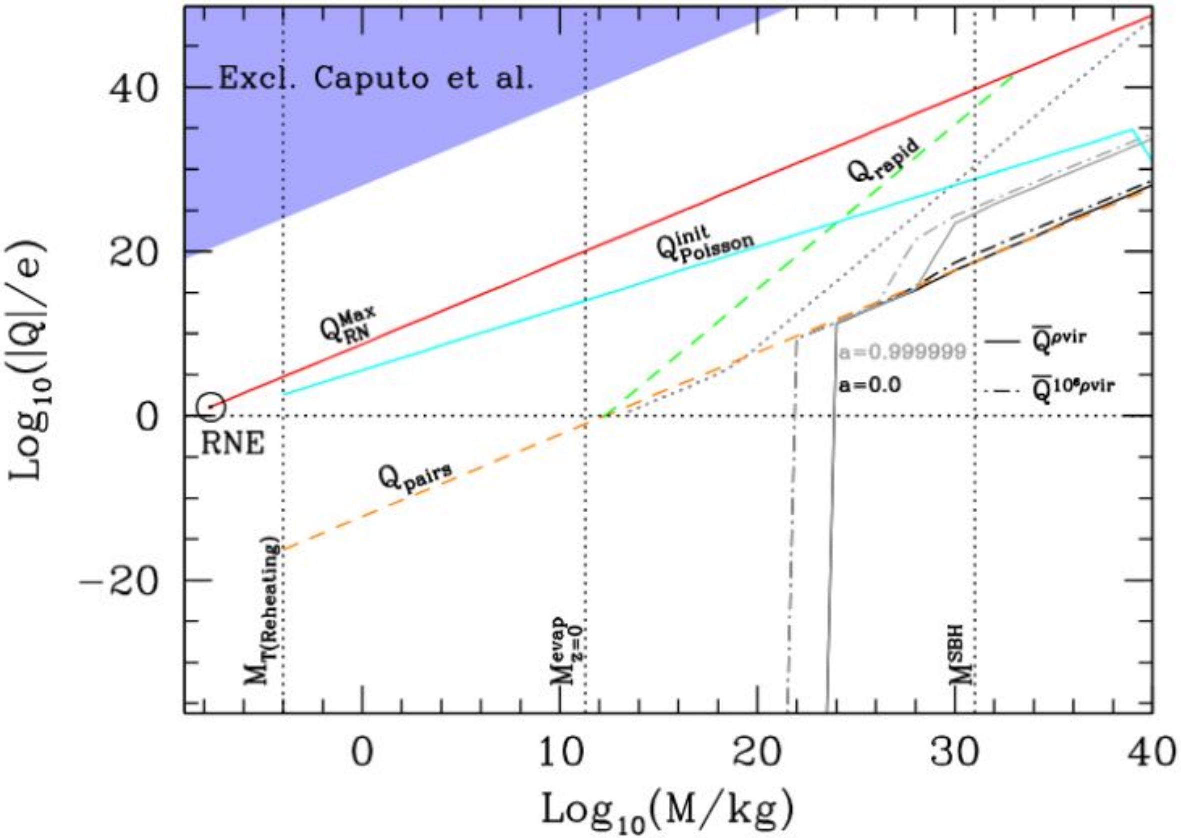
Padilla+(2023)

Imbalance of charge



Padilla+(2023)

Imbalance of charge



Padilla+(2023)

Imbalance of charge

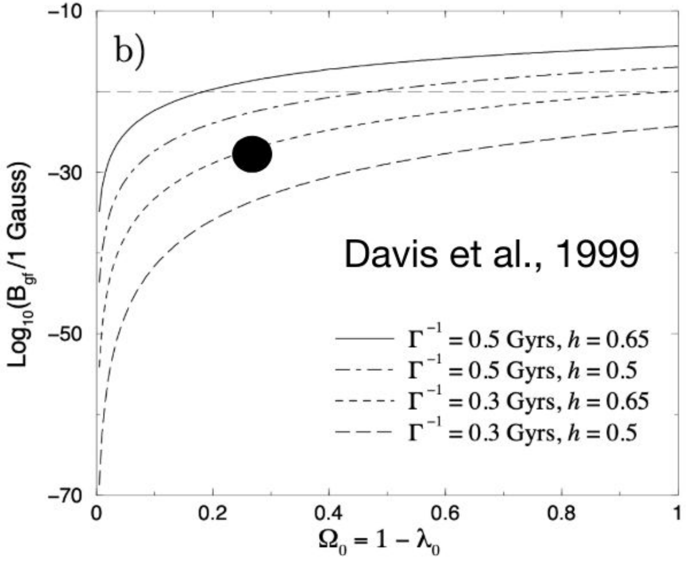
★ Black holes surrounded by high-density or high-spin plasma can exceed the particle pair discharge limit Qpairs established by Gibbons in 1975 if $M > 10^{22}$ kg

★ Taking into account the uncertainties in the required seed fields of $B_{seed} \sim 10^{(-30 \pm 5)}$ G, this charge lies in the range $|Q_{galaxy}|/M_{vir} = 10^4$

Padilla+(2023)

Imbalance of charge

For fixed dynamo amplification rate (Gamma), the seed value depends strongly on cosmological parameters. The commonly accepted required seed is 1e$^{(-30+-5)}$G on sub-Mpc scales due to uncertainties in Gamma (Liu et al. 2021, Martín Álvarez et al., 2023).

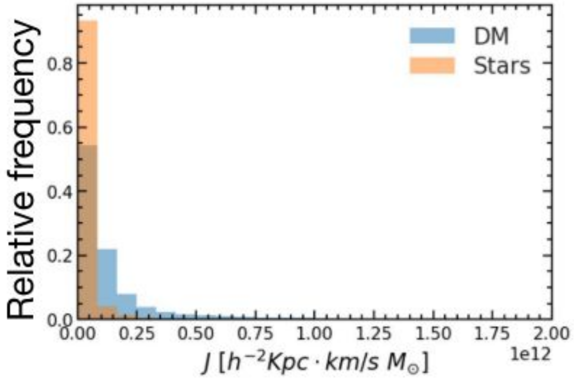


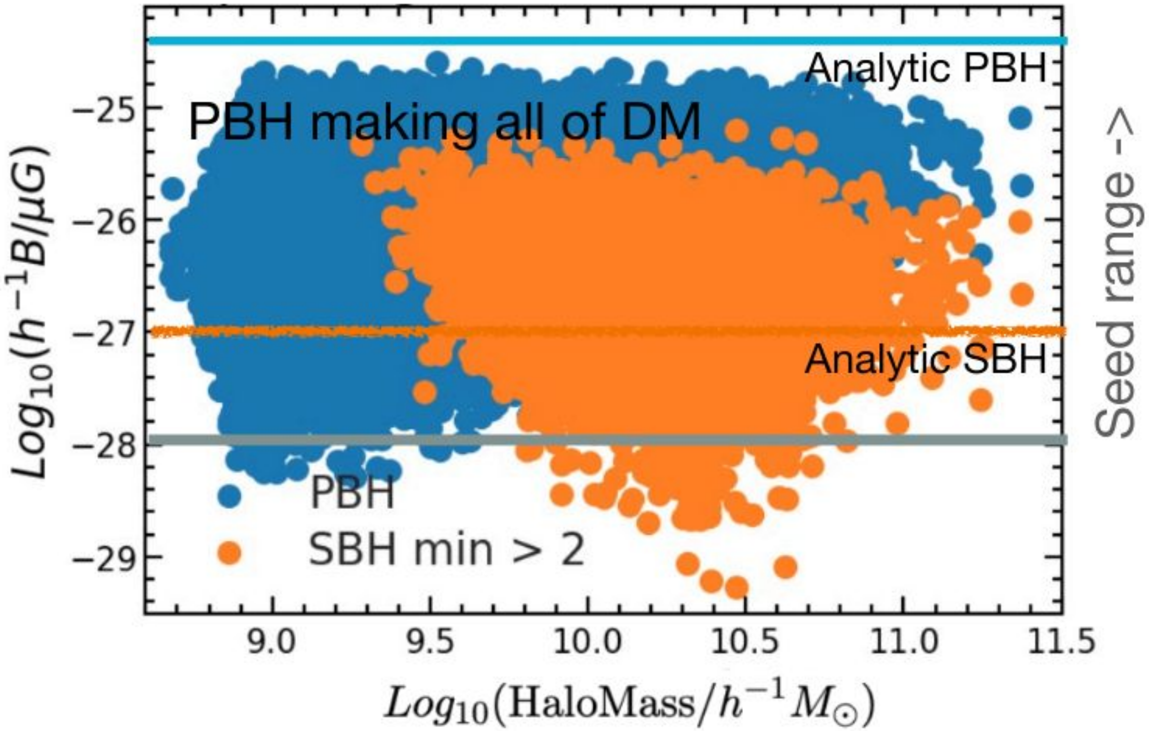
Flat universes

Padilla+(2023)

Check in simulation

Magnetic field strength at r_{vir} for DM (made of PBH, blue), and at $r_{1/2}$ for stars, assuming 0.07 in SBHs, adopting Q_{pairs}/M.





Colazo+(In prep)

Our Idea

1

Charge seeds

SBHs or PBHs produce a Coulomb potential in all Universe

2

Obtaining Electric field

Using the definition of Coulomb potential to obtaining a E

3

Solve Maxwell equations

Calculate iterative the Faraday's law and Ampere-Maxwell law. We need define current, time integration, etc

4

Check the other equation

That process only works in high-redshift.

Charge seeds in simulation

PBHs

$$p_Q = \frac{2\,G\,m_e\,(f_{pbh}\cdot m_{DM})}{k_c\cdot|e|} = AM_{BH}$$

$$A := \frac{2\,G\,m_e}{k_c\cdot|e|}$$

SBHs

Salpeter(1955)

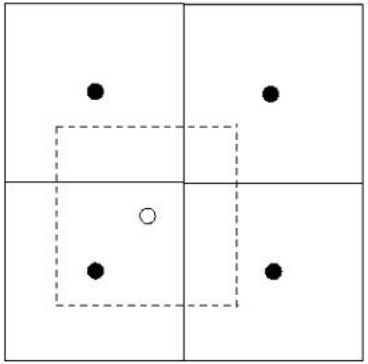
$$p_Q = \frac{2\,G\,m_e\,(0.07\cdot m_*)}{k_c\cdot|e|} = AM_{BH}$$

$$A := \frac{2\,G\,m_e}{k_c\cdot|e|}$$

Obtaining Electric field

$$\Phi(\mathbf{x}) = \frac{1}{4\pi\epsilon_0}\int_V \rho(\mathbf{x}')G(\mathbf{x}, \mathbf{x}')\, d^3x' - \frac{1}{4\pi}\oint_S \Phi(\mathbf{x}')\frac{\partial G}{\partial n'}\, da'$$

Convolution + Periodicity boundary



"Cloud-In-Cell" interpolation

Romain Teyssier

Solve maxwell equations

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t},$$

$$\nabla \times \vec{B} = \mu_0 \vec{J} + \mu_0 \epsilon_0 \frac{\partial \vec{E}}{\partial t},$$

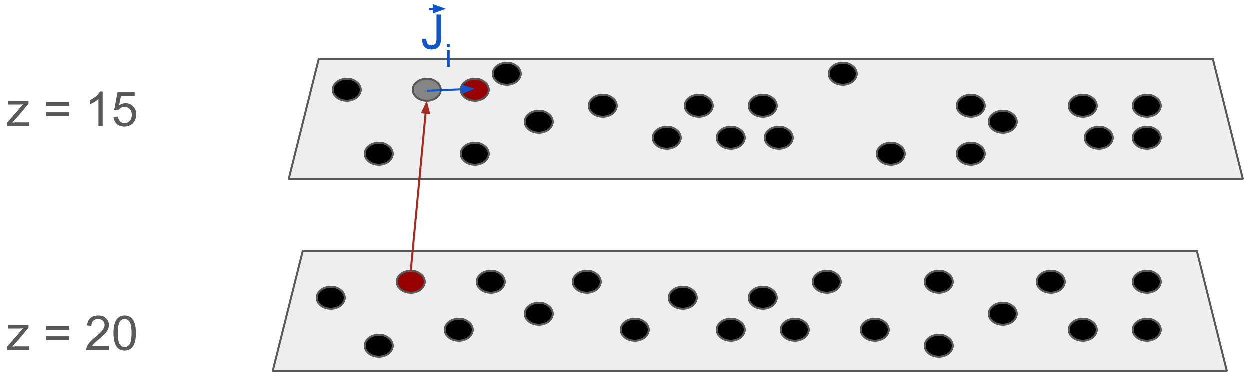
Iterative

We need:

- ★ Current
- ★ Integration time

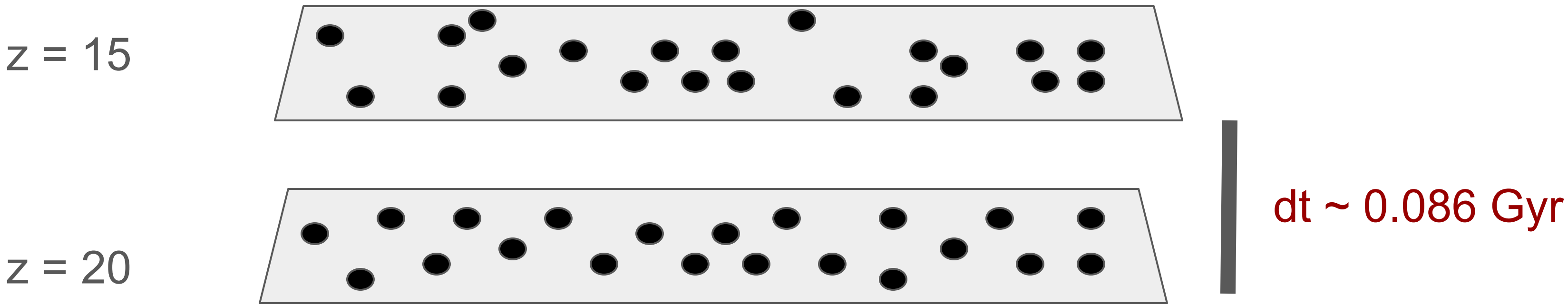
Solve maxwell equations

Current



Solve maxwell equations

Integration time



What do we expect?

When we compare different seeds we want to see if it is possible to distinguish the signals produced from each other in the power spectrum slopes

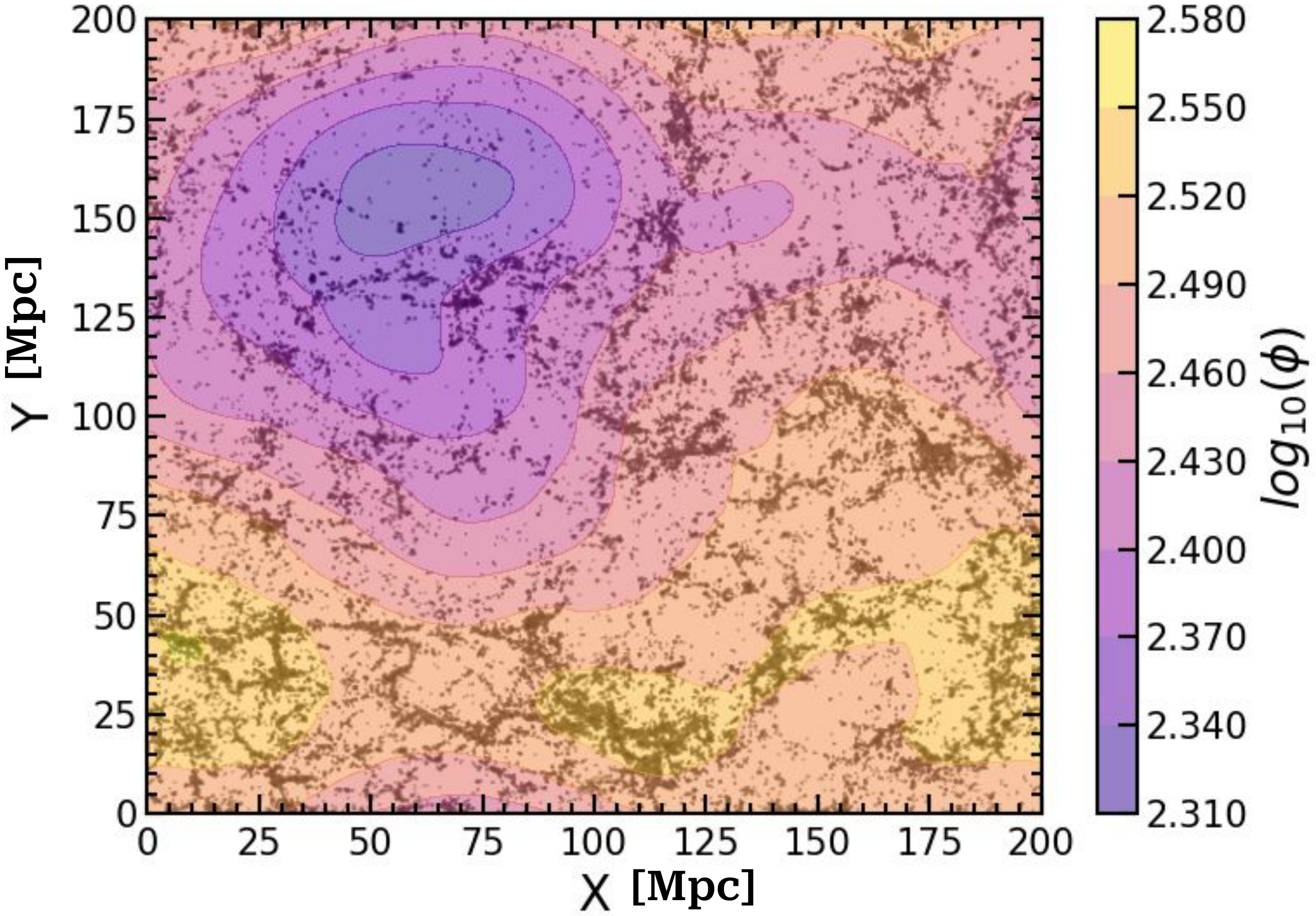
Example of Coulomb potential on large scale

(In arbitrary units)

Full-hydro Large-scale structure simulations with All-sky Mapping for the Interpretation of Next Generation Observations.

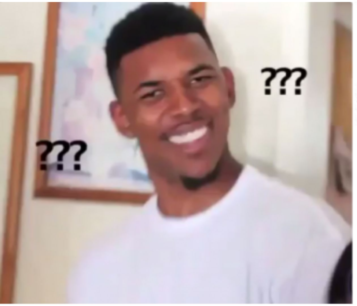
The FLAMINGO project

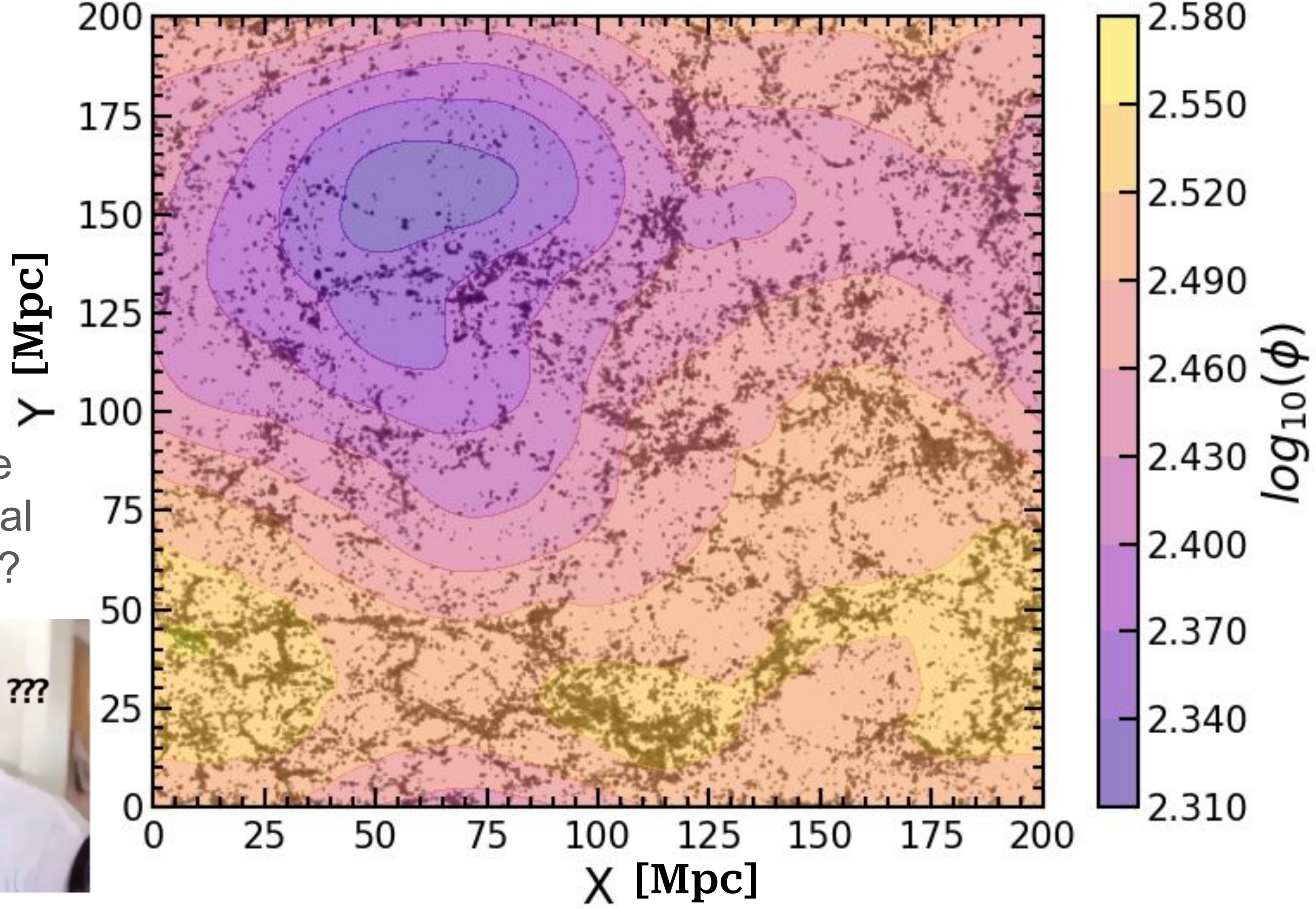
Kugel+(2023) Schaye+(2023)



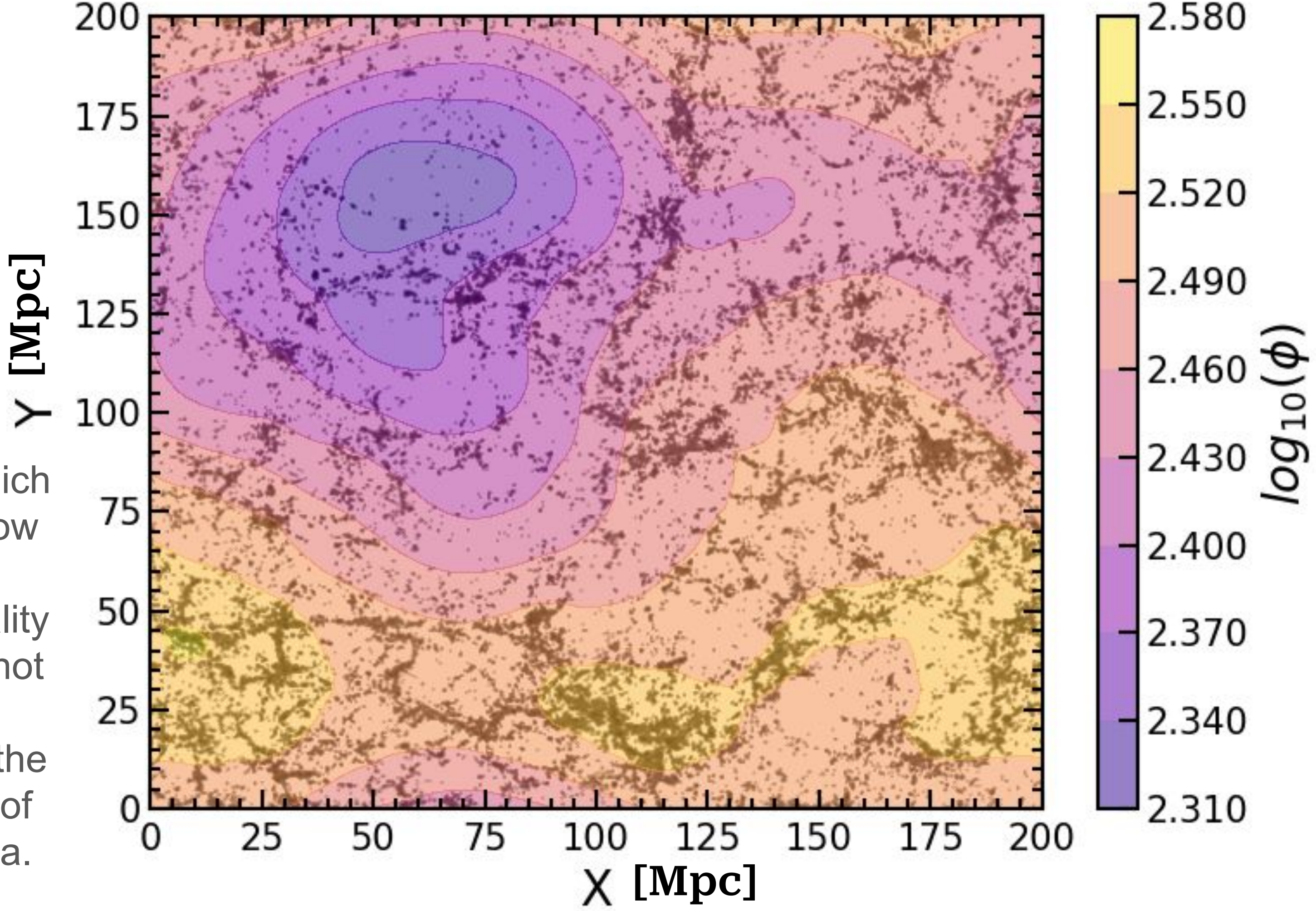
200
175
150
125
100
75
50
25
0
Y [Mpc]
0
25
50
75
100
125
150
175
200
X [Mpc]
2.580
2.550
2.520
2.490
2.460
2.430
2.400
2.370
2.340
2.310
$log_{10}(\phi)$

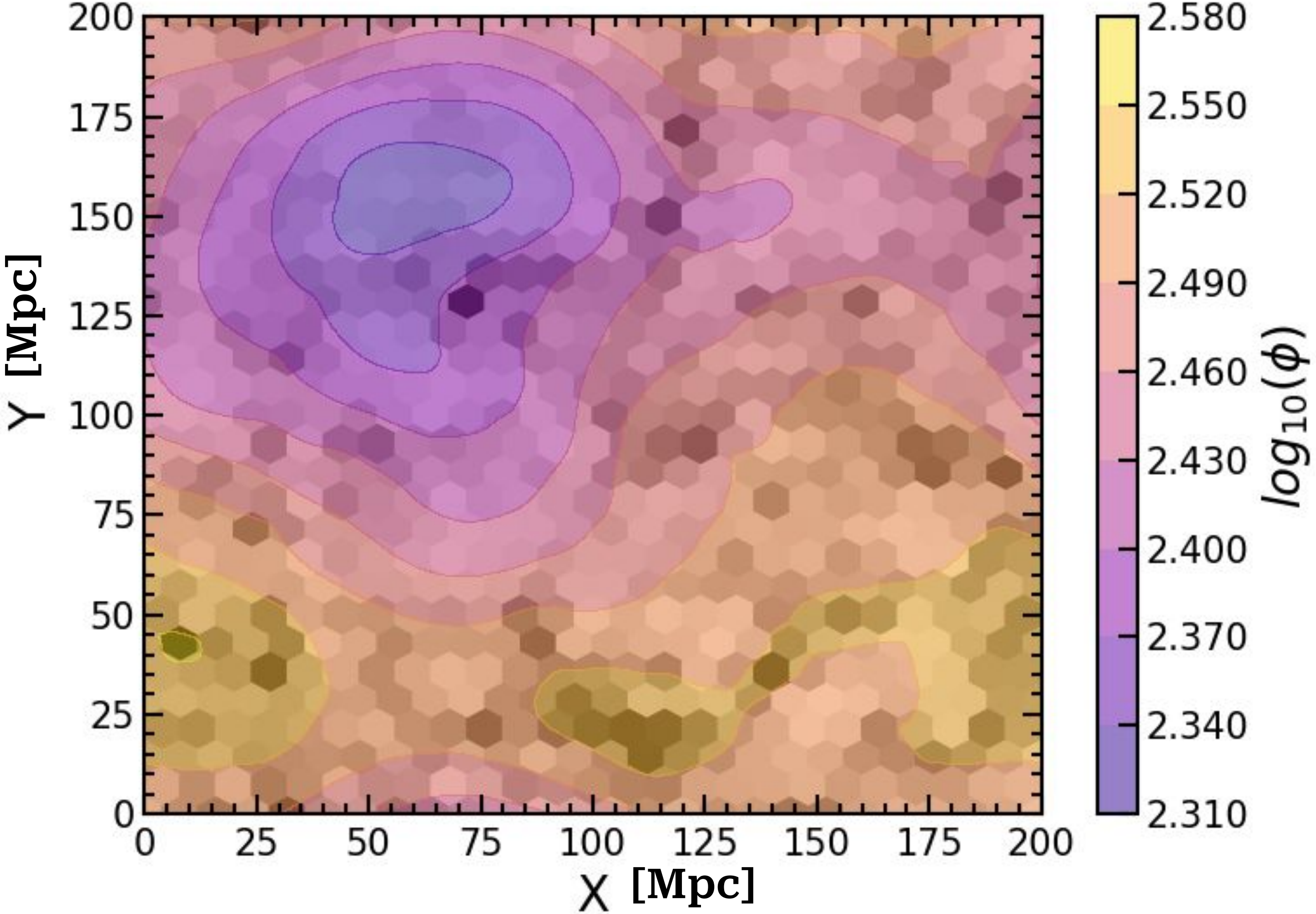
Are the universe not neutral charged?



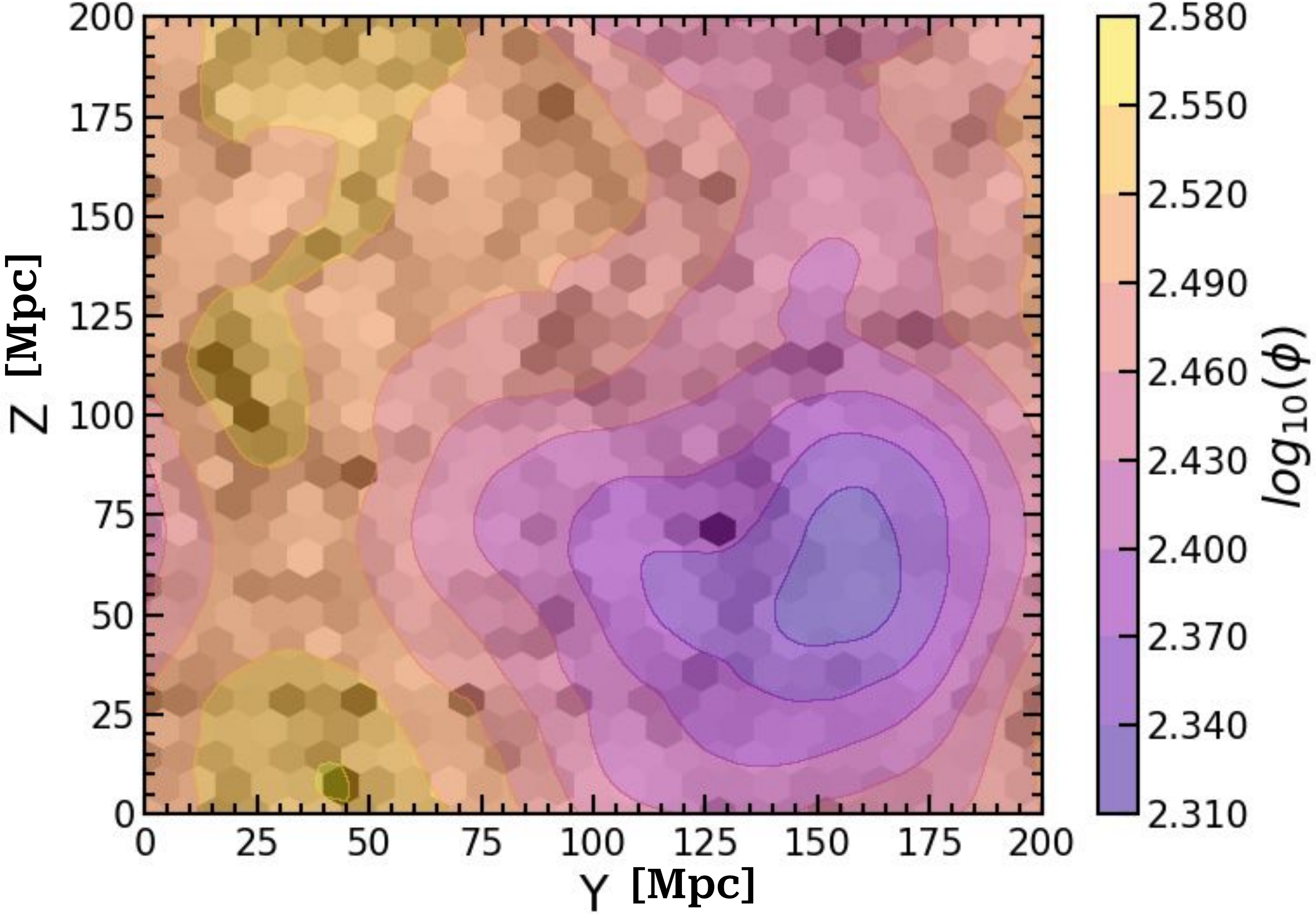


Below 10^-30, which is a very low level of non-neutrality that does not prevent assuming the neutrality of the plasma.

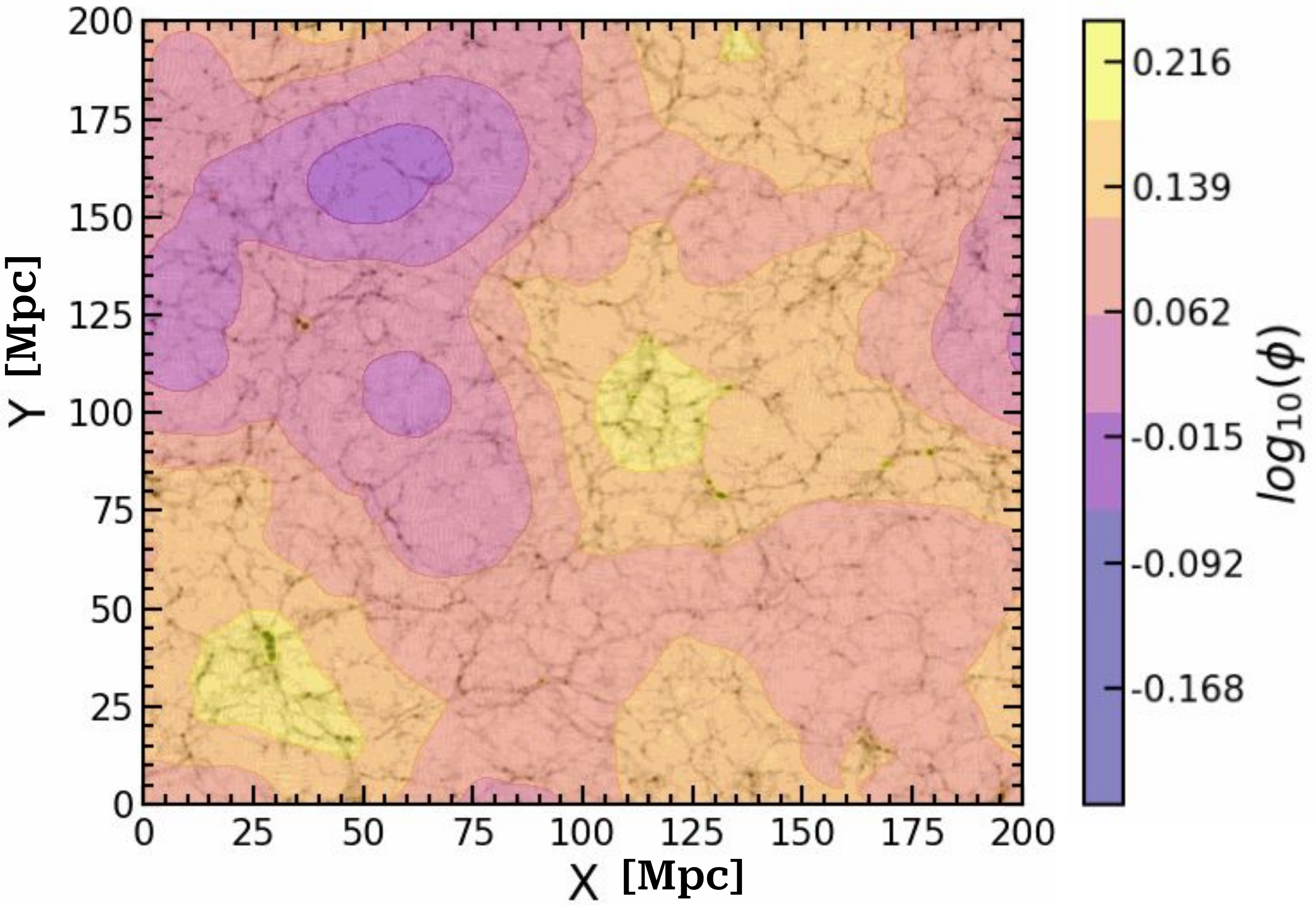




Y [Mpc]
X [Mpc]
$log_{10}(\phi)$
2.580
2.550
2.520
2.490
2.460
2.430
2.400
2.370
2.340
2.310
0
25
50
75
100
125
150
175
200



Z [Mpc]
Y [Mpc]
$log_{10}(\phi)$
2.580
2.550
2.520
2.490
2.460
2.430
2.400
2.370
2.340
2.310
200
175
150
125
100
75
50
25
0



200
175
150
125
100
75
50
25
0
Y [Mpc]
0
25
50
75
100
125
150
175
200
X [Mpc]
0.216
0.139
0.062
-0.015
-0.092
-0.168
$log_{10}(\phi)$

Summary

01	The BHs as seed with three mechanisms	Biermann battery Accretion from plasma Unbalanced charge when their formed
02	Obtaining a Primordial magnetic field	With Fourier transform and maxwell equation we can calculate at high-redshift snapshots the primordial magnetic field
03	Compare difference seeds	The assumption of SBHs or SBHs or other mechanisms could have difference in the power spectrum slope.

Thanks!

CONICET

UNC Universidad Nacional de Córdoba

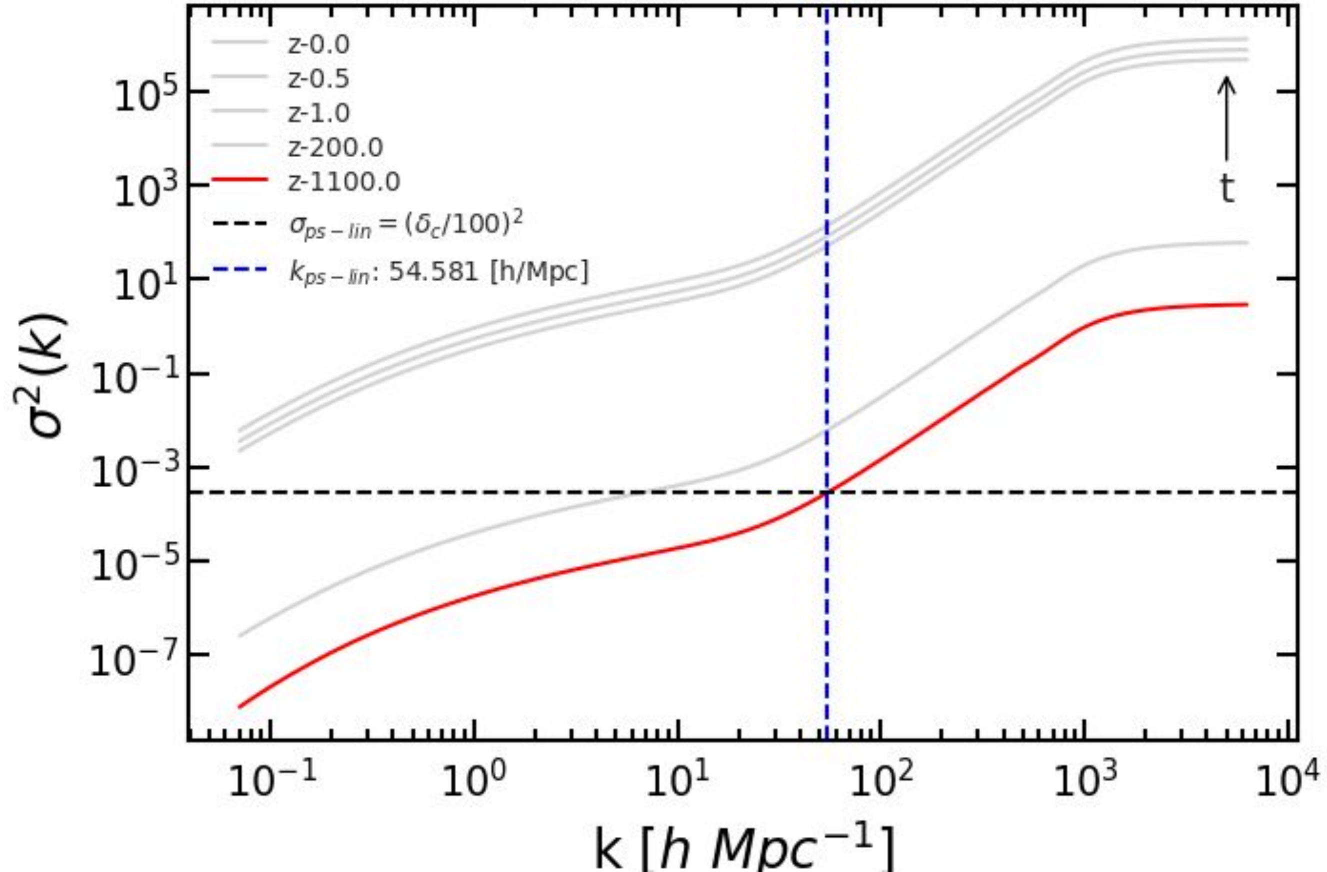
I A T E

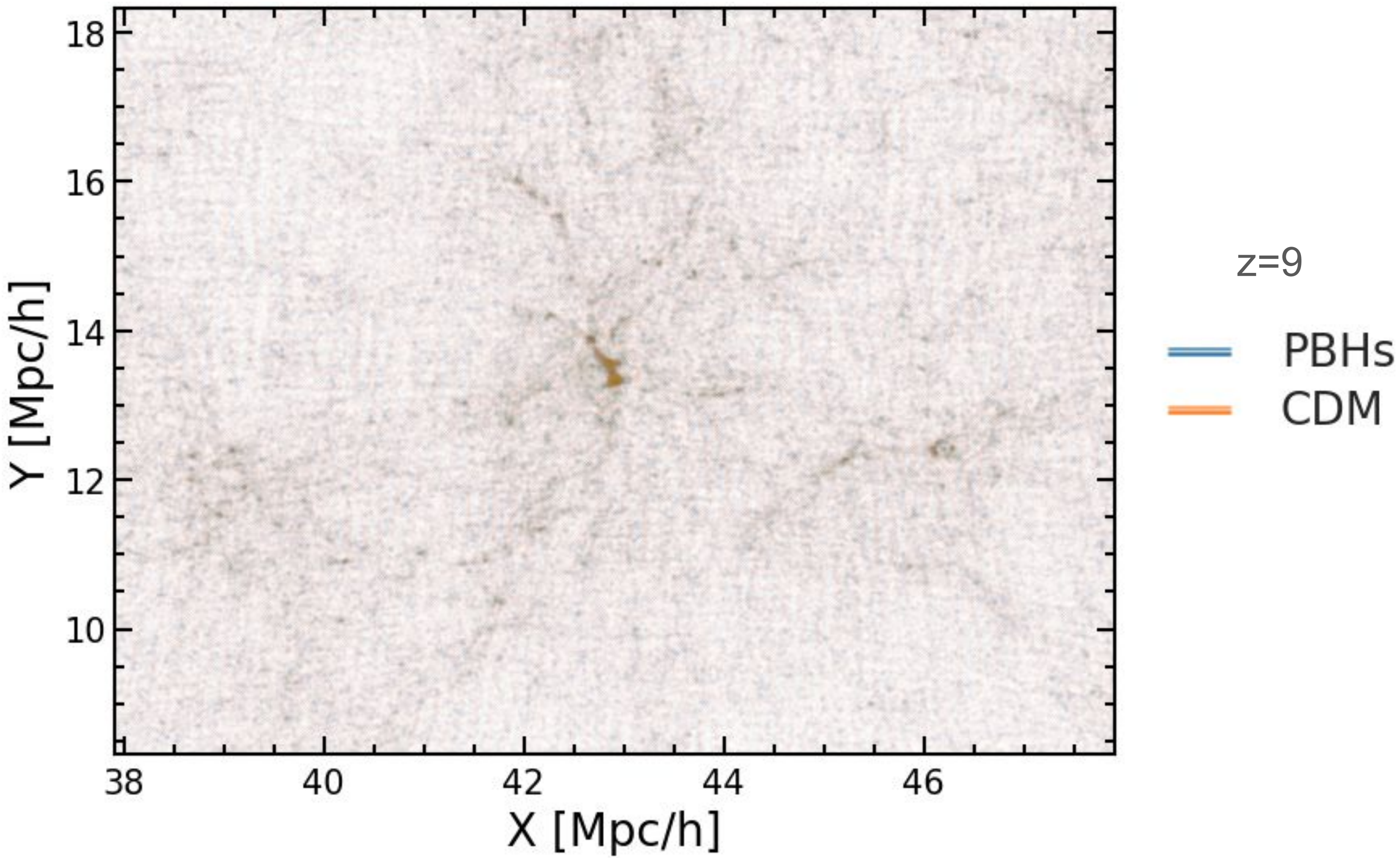
Universiteit Leiden

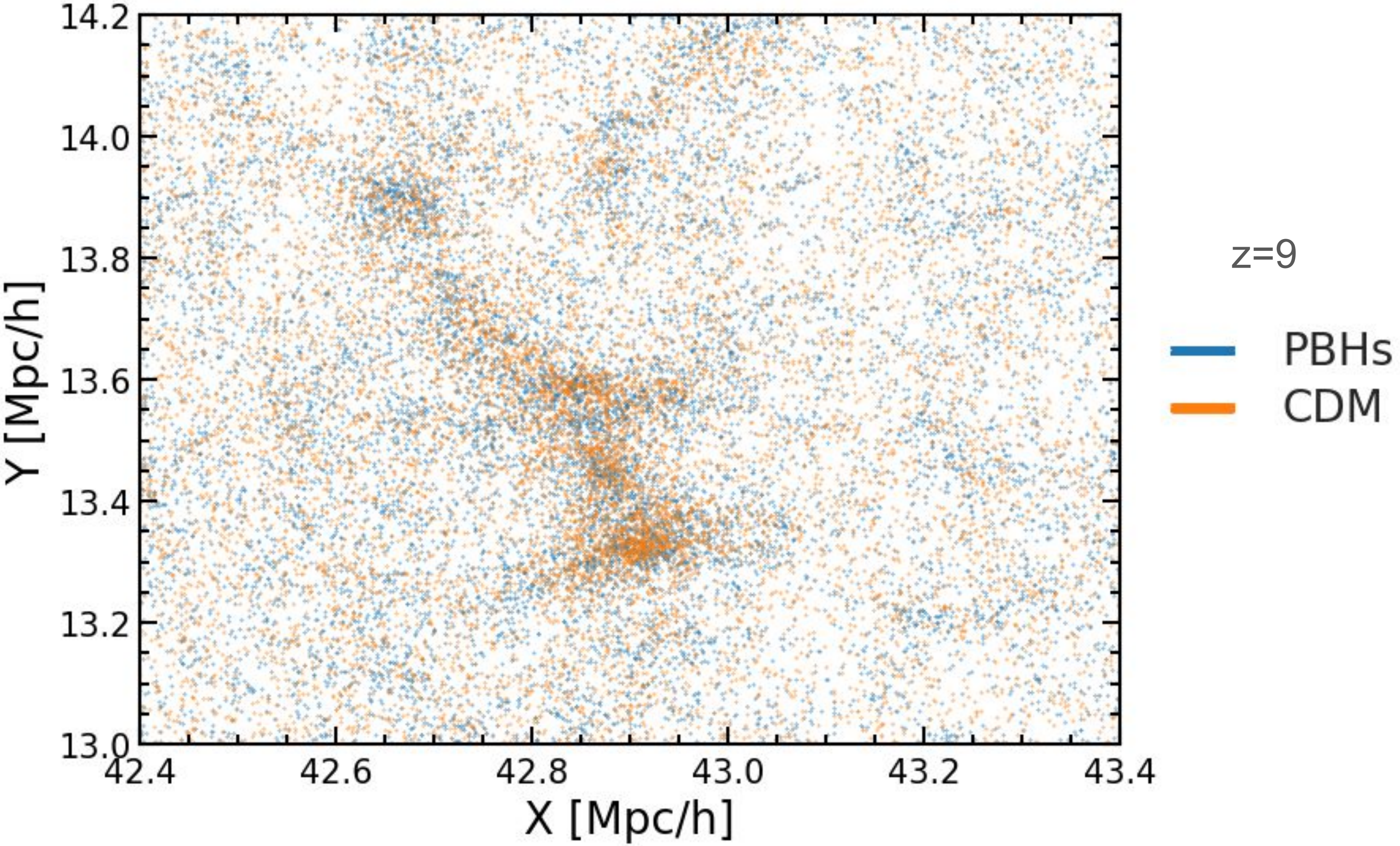
Thanks!

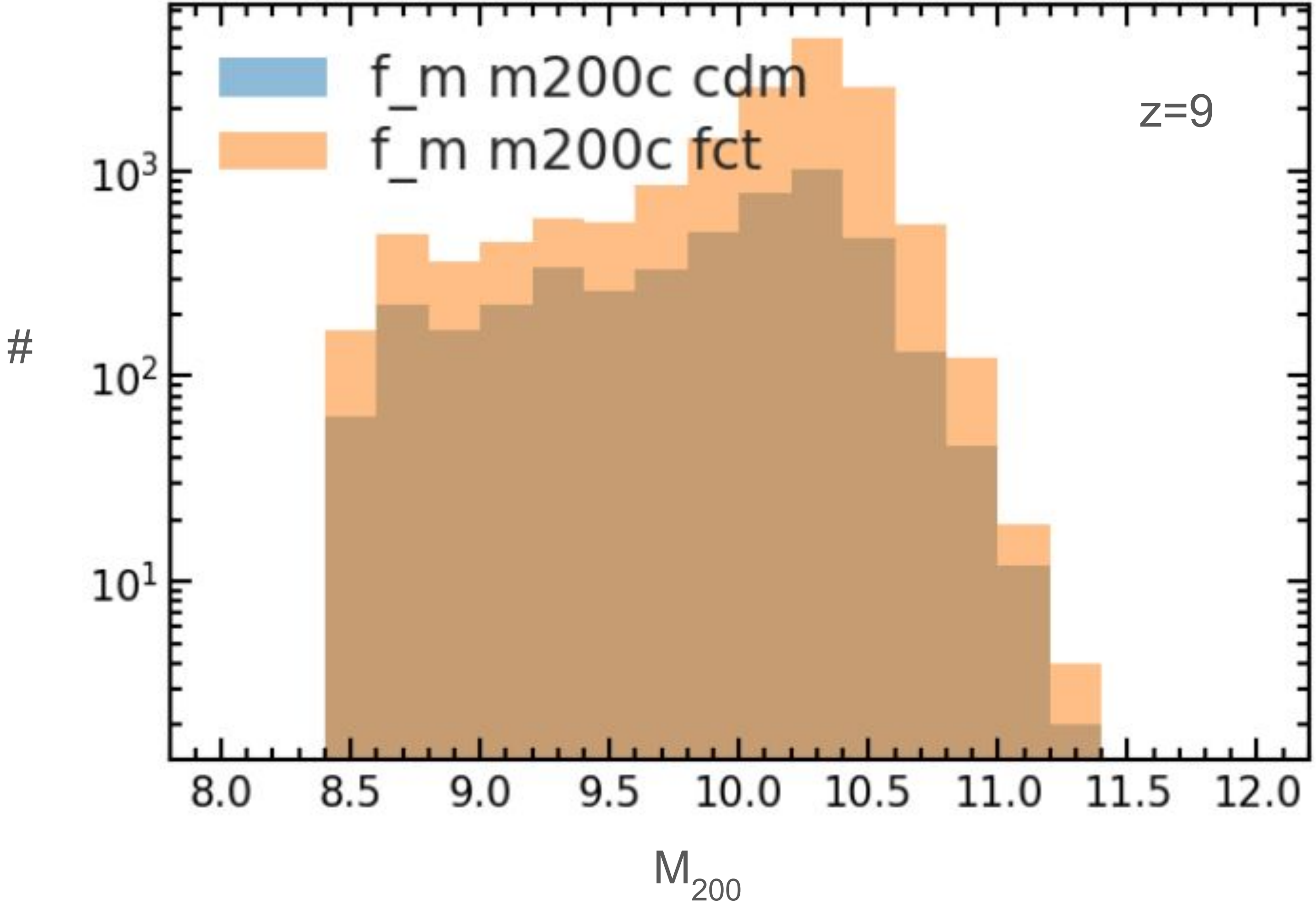
Thanks!

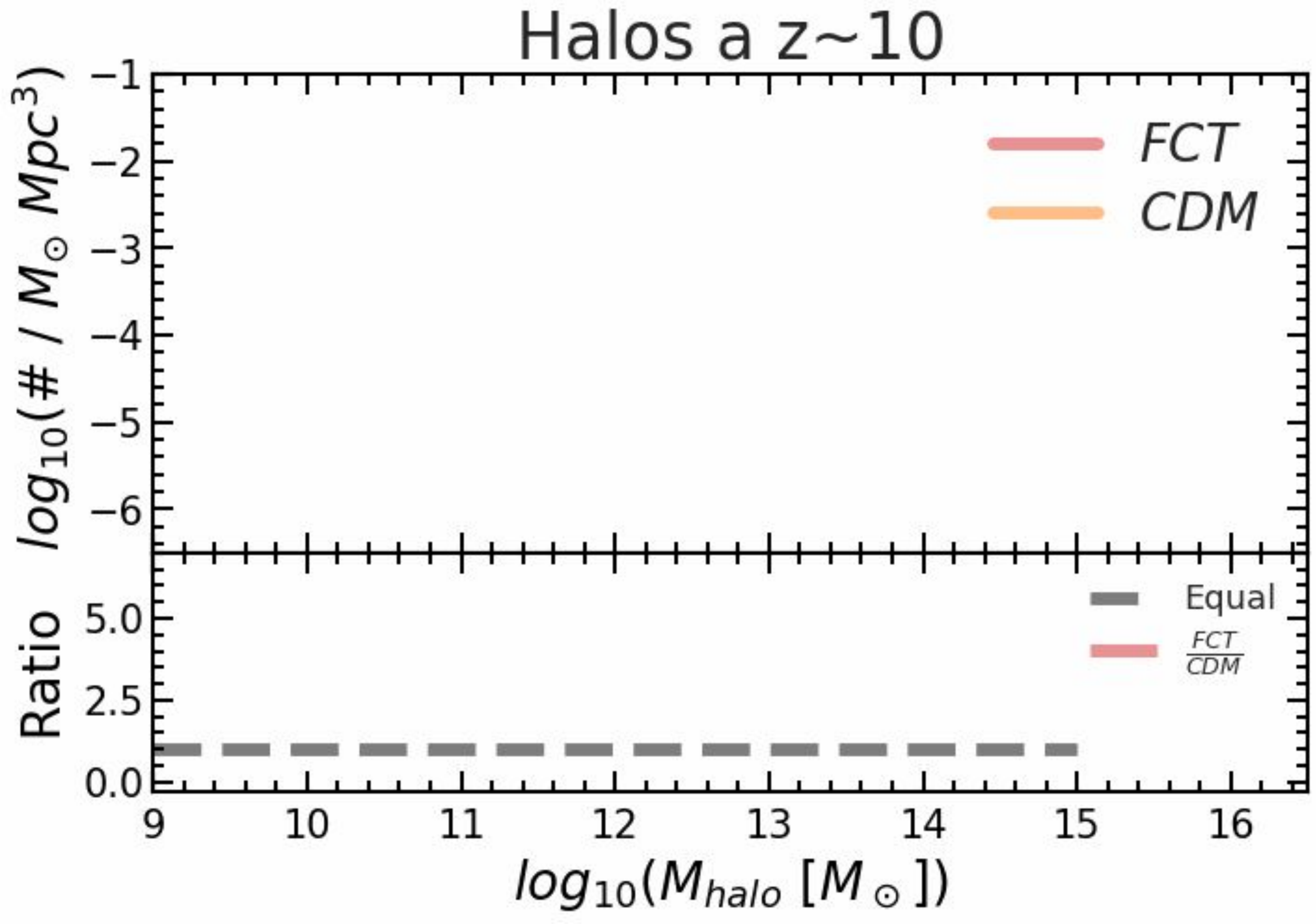
Initial Condition (IC): σ^2 vs k



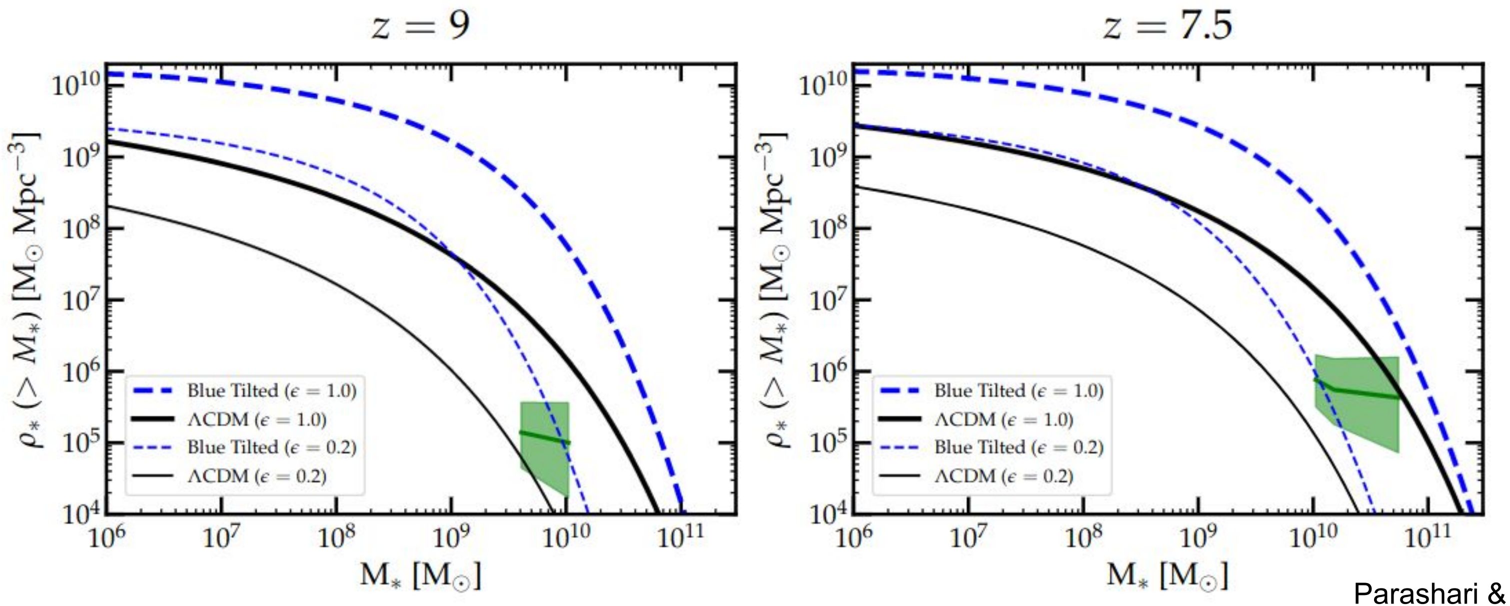

18
16
14
12
10
Y [Mpc/h]
38
40
42
44
46
X [Mpc/h]
z=9
PBHs
CDM


14.2
14.0
13.8
13.6
13.4
13.2
13.0
Y [Mpc/h]
42.4
42.6
42.8
43.0
43.2
43.4
X [Mpc/h]
z=9
PBHs
CDM


f_m m200c cdm
f_m m200c fct
z=9
#
M200
10^3
10^2
10^1
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0


Halos a z~10
$log_{10}(\# \ / \ M_\odot \ Mpc^3)$
−1
−2
−3
−4
−5
−6
FCT
CDM
Ratio
5.0
2.5
0.0
Equal
$\frac{FCT}{CDM}$
9
10
11
12
13
14
15
16
$log_{10}(M_{halo} \ [M_\odot])$

The discovery of JWST



Parashari & Laha (2023)

Figure 1. The CCSMD of galaxies with stellar mass content more than M_* for $z = 9$ (**left-hand panel**) and 7.5 (**right-hand panel**). The black and blue curves are for the standard ΛCDM cosmology and the cosmology with a blue tilted primordial power spectrum (k_p = 1 h Mpc^{-1} and m_s = 2.0), respectively. The thick and thin curves are for ϵ = 1.0 and 0.2, respectively. The green bands represent the CCSMD that we have computed using observations by Labbé et al. (2023) and corresponding spectroscopic updates.