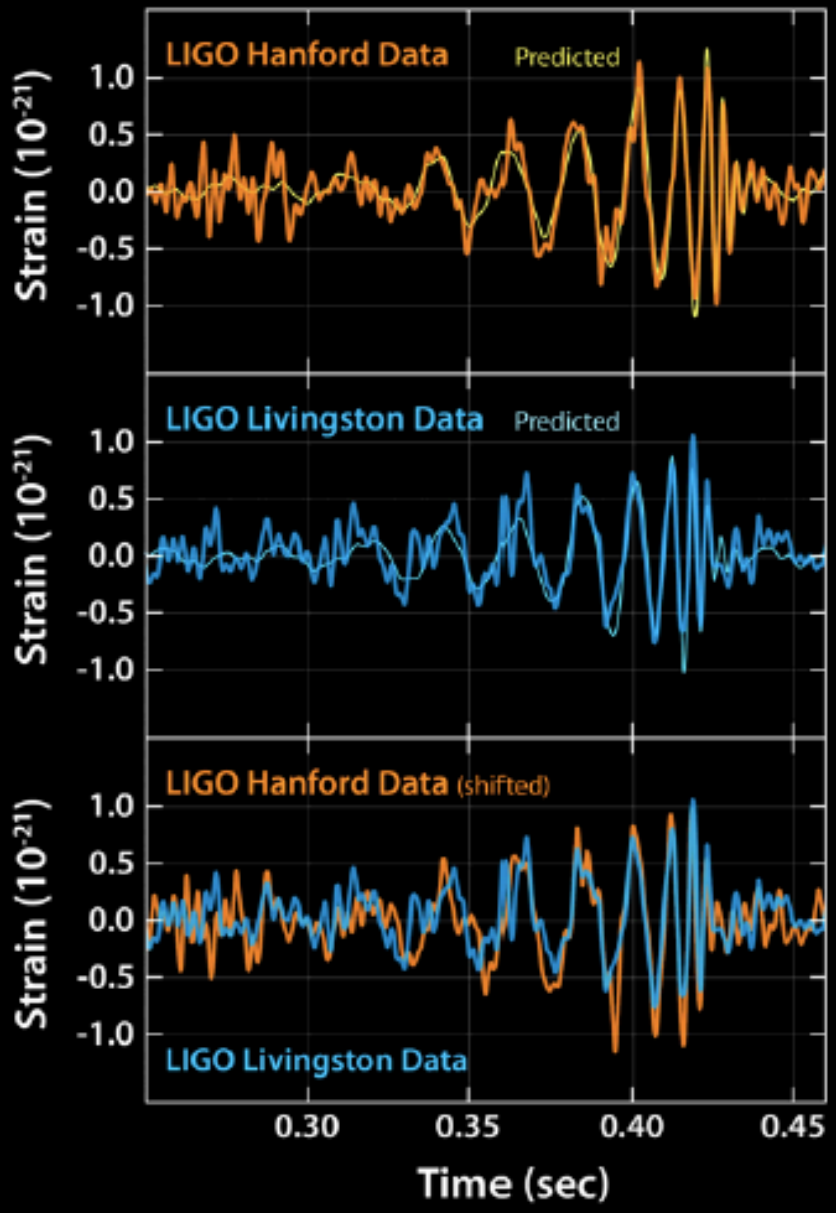
PBH, DM and MORE

Joe Silk

APS, 29 August 2016



$$z = 0.09$$

$$\mathcal{R} = 2 - 53\,\mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$$

$$30 - 35 M_\odot$$

Bird et al.2016

Close encounters of PBH form close binaries by GW emission

$$\sigma \propto v_{\rm rel}^{-18/7} M_{\rm pbh}^2$$

these are very close binaries with preferentially eccentric orbits **Cholis + 2016**

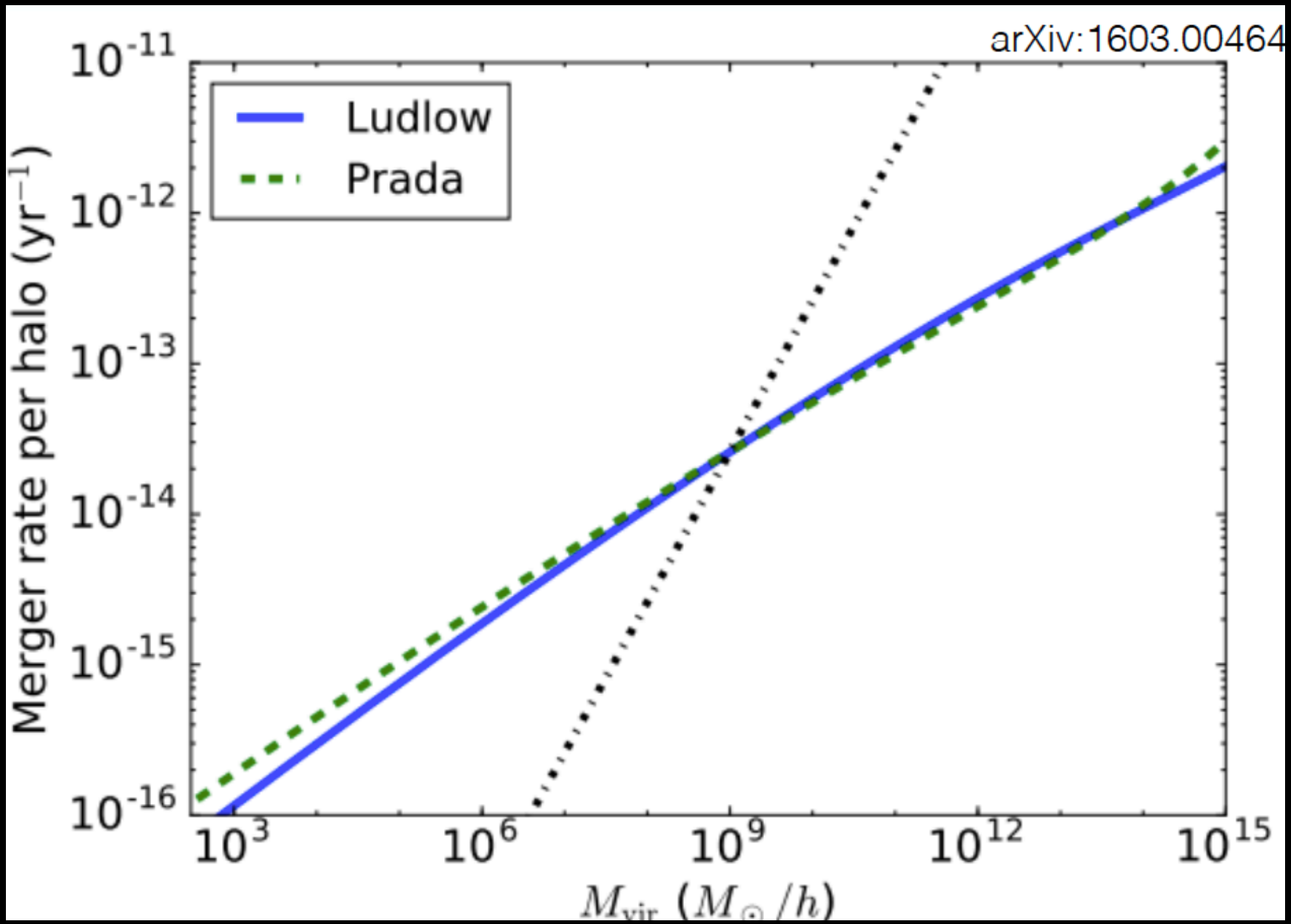
and decay on 1000yr time-scales

But there are very few mergers at typical galactic halo relative velocities

$$\Gamma_{\rm halo} \propto \int {\rm d}^3 r \frac{\rho_{\rm NFW}^2}{M_{\rm pbh}^2} \langle \sigma v \rangle$$

No mass bias for PBH binaries

The low mass halo boost



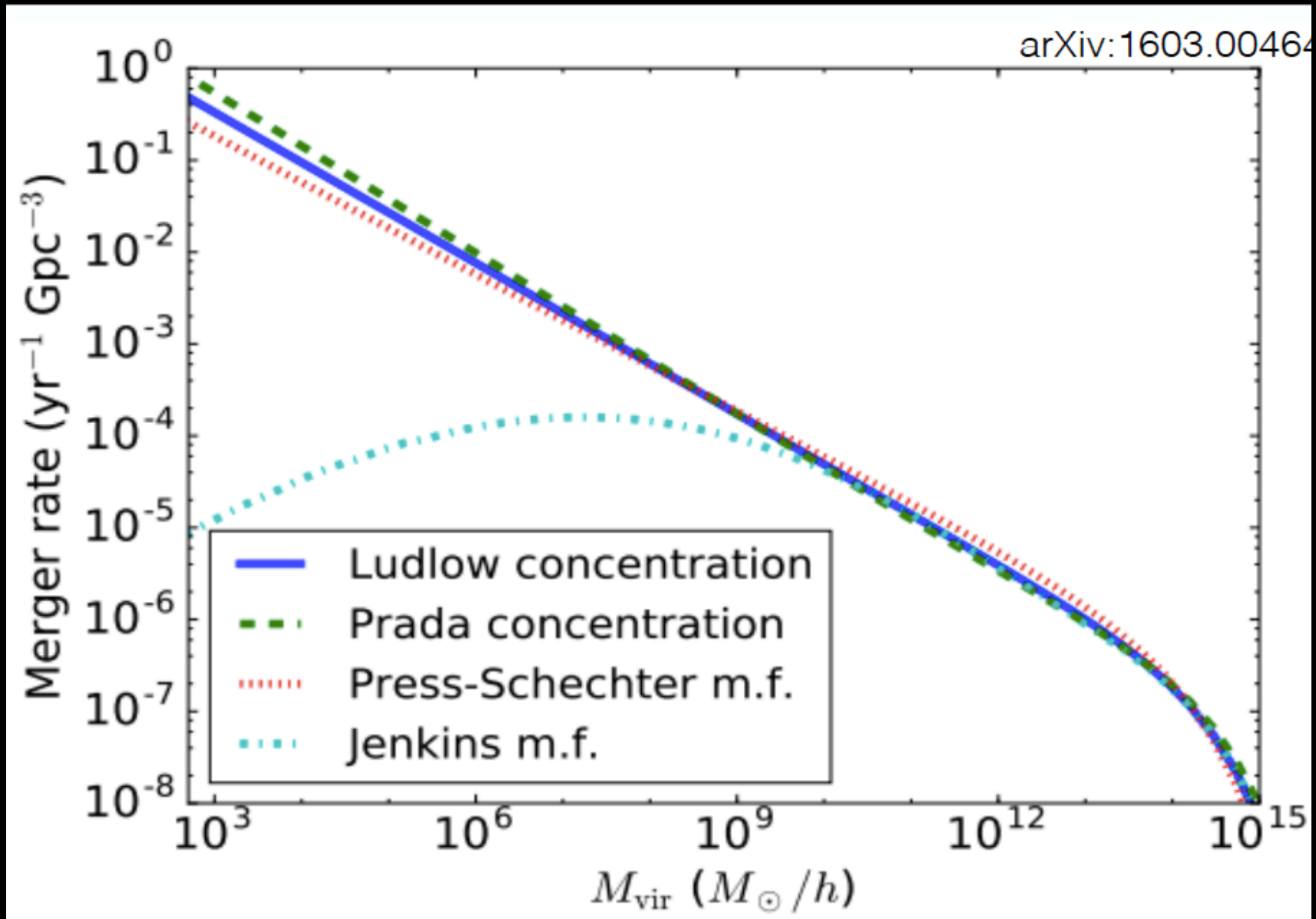
Bird et al.2016

Low mass halos dominate

Minimum mass ~ $1000M_{sun}$ to avoid ejection

Integrate over all halos to get rate

LIGO observes a few events $yr^{-1}Gpc^{-3}$
Need to go to halos below $10^4 M_{sun}$



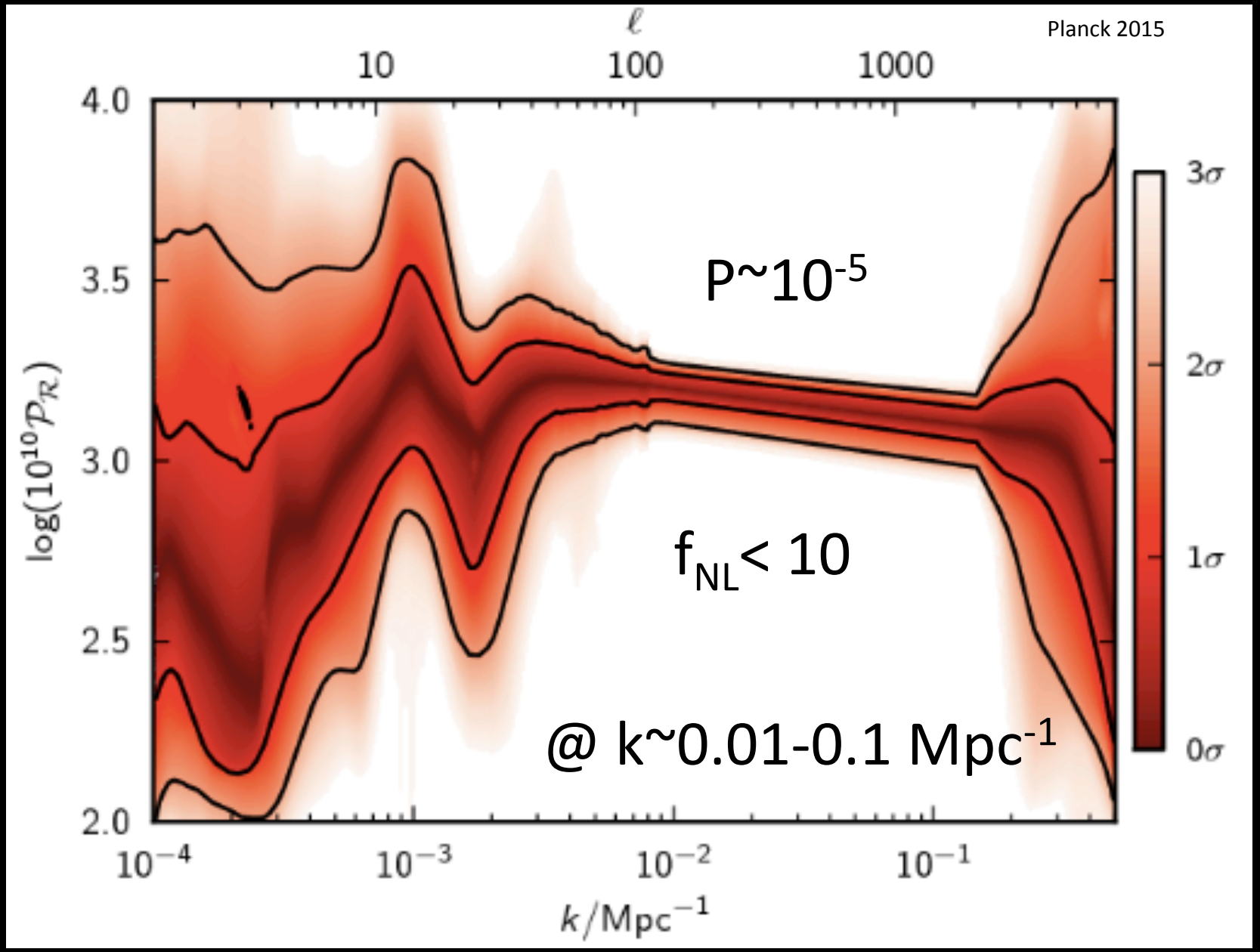
Bird et al 2016

Integrate the rate over all halos to 400 M_{sun}:
predict R = 2-30 $Gpc^{-3}yr^{-1}$

To be compared with LIGO:
R = 2-53$Gpc^{-3}yr^{-1}$

It works! But how do you make the PBH?

Reconstructed power spectrum, from CMB



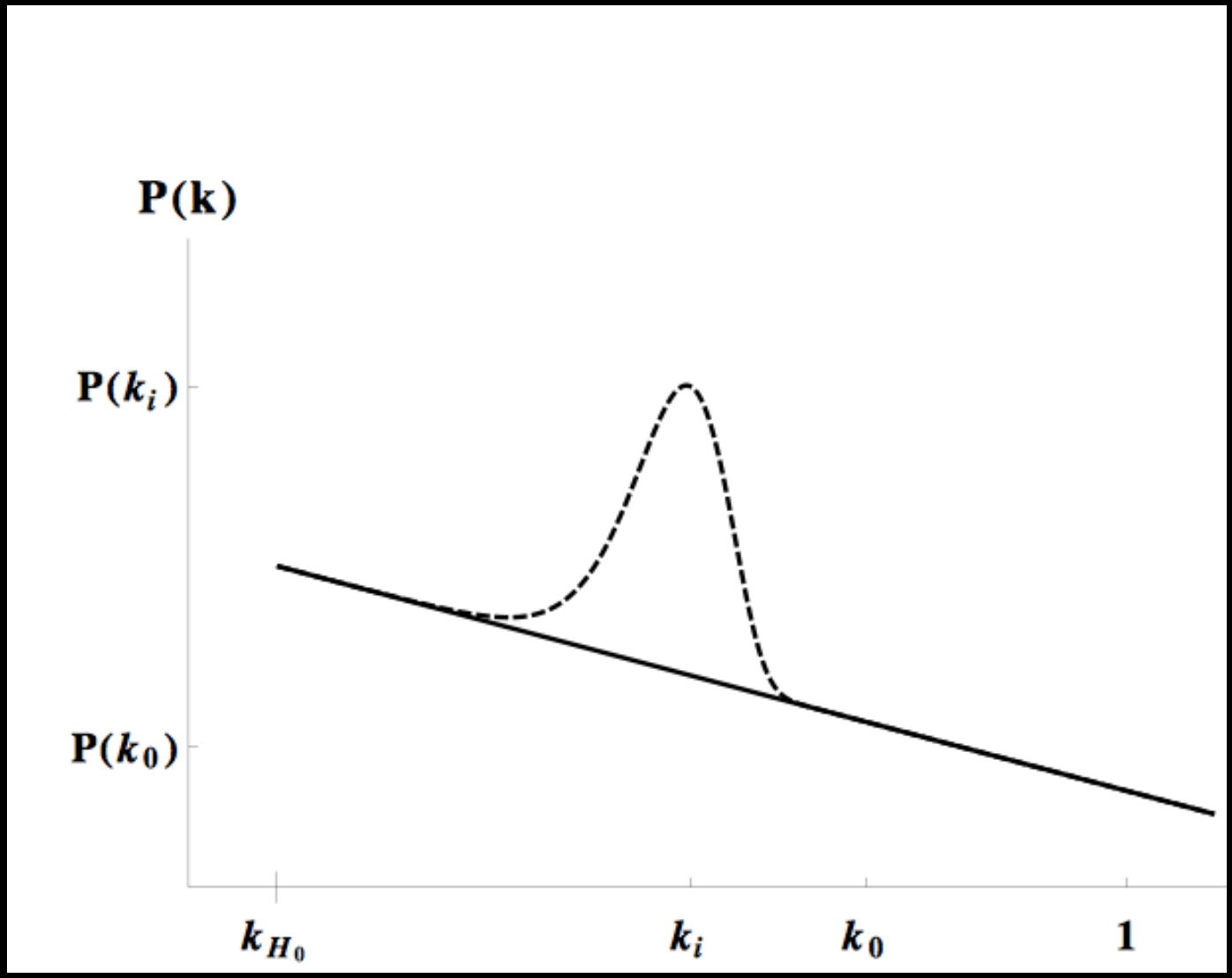
Need P~ 0.01-0.1 to make a PBH (eg at $k \sim 10^3$ Mpc^{-1} or ~ M_{sun})

Due to modest primordial nongaussianity
in the initial density fluctuations

The predicted value to form the (LIGO-motivated) PBH is $f_{NL} \sim 1/P$
(Byrnes, Musco, Sasaki….) where P is fluctuation amplitude

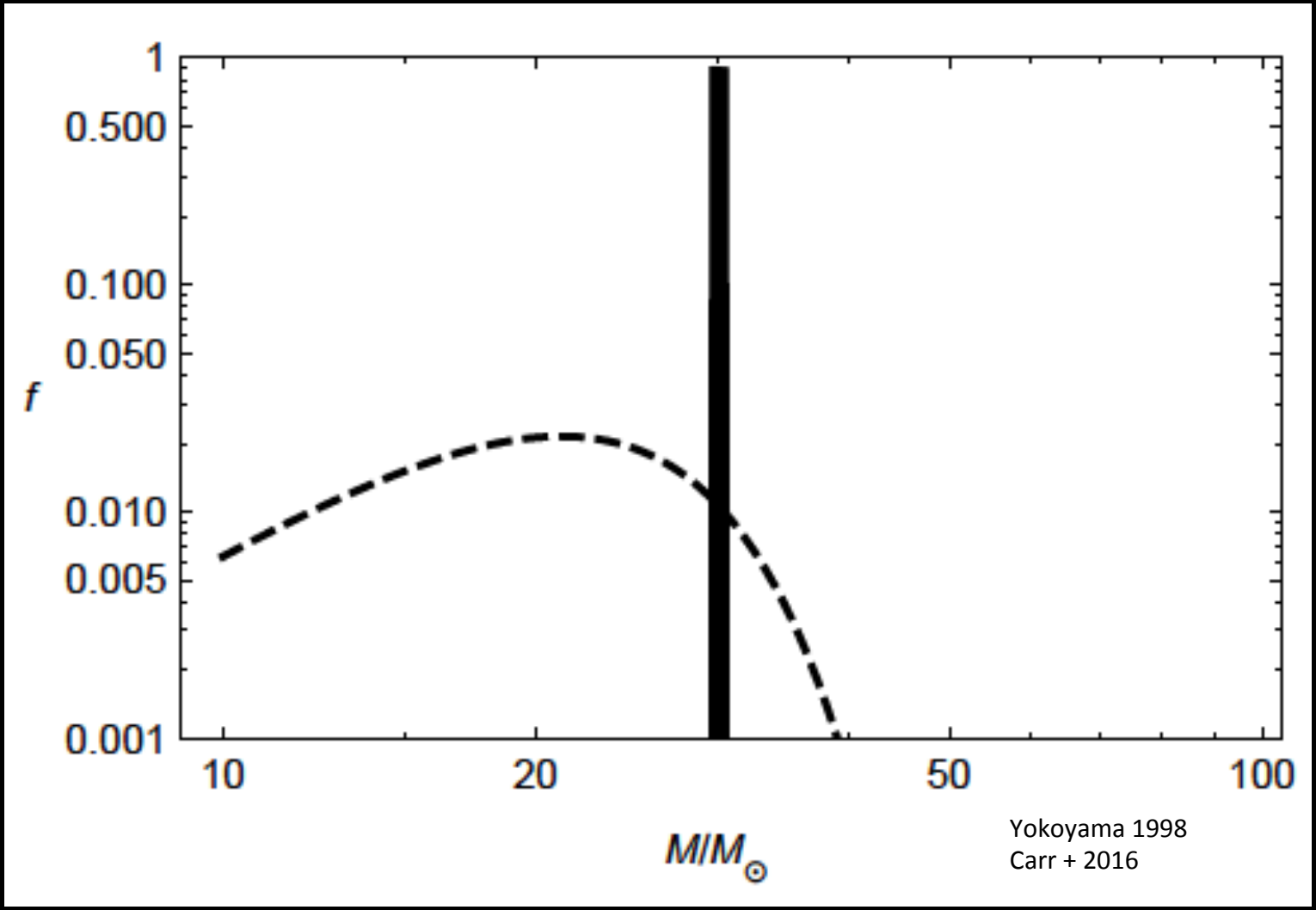
Use of PBH to set f_{NL} limits of 10- 100 is feasible
& constrains PS over a totally unprobed regime

An example: resonant particle production coupling with inflaton



Erfani 2016

a broad spectrum of PBH is inevitable



Yokoyama 1998
Carr + 2016

If dark matter consists of PBH…

- Expect dark matter spans a broad range of PBH masses

The same mechanism that forms ~30 Msun PBH plausibly forms a wide range of subdominant PBH in terms of DM

- Rare IMBH ~10^5 M_{sun}

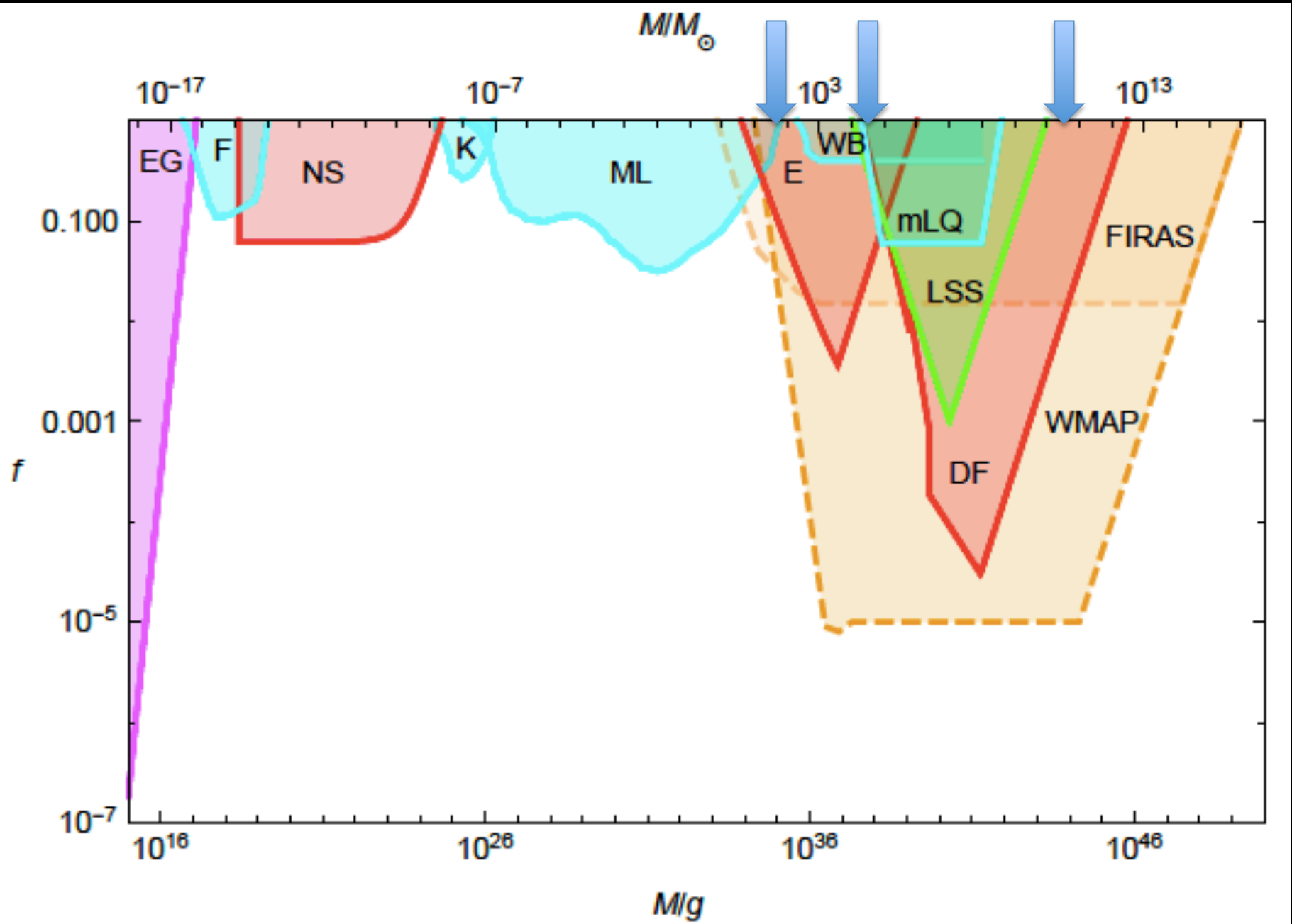
Constraints from number density

- Rarer UMBH ~ $10^{10}M_{sun}$

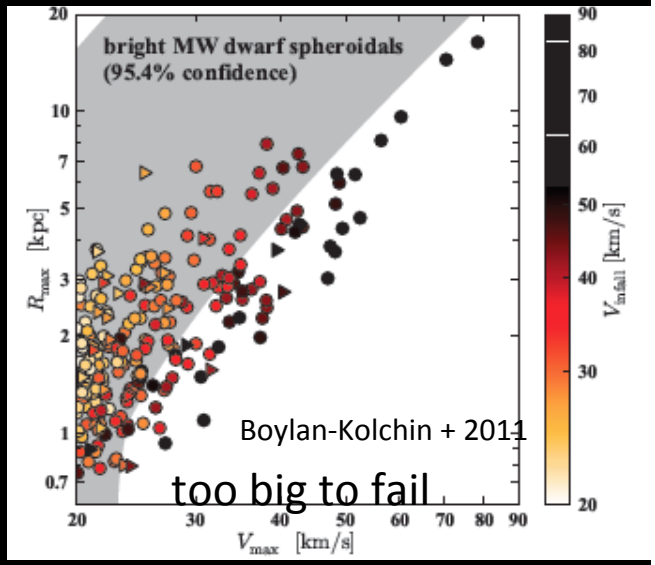
Constraints from CMB μ distortion

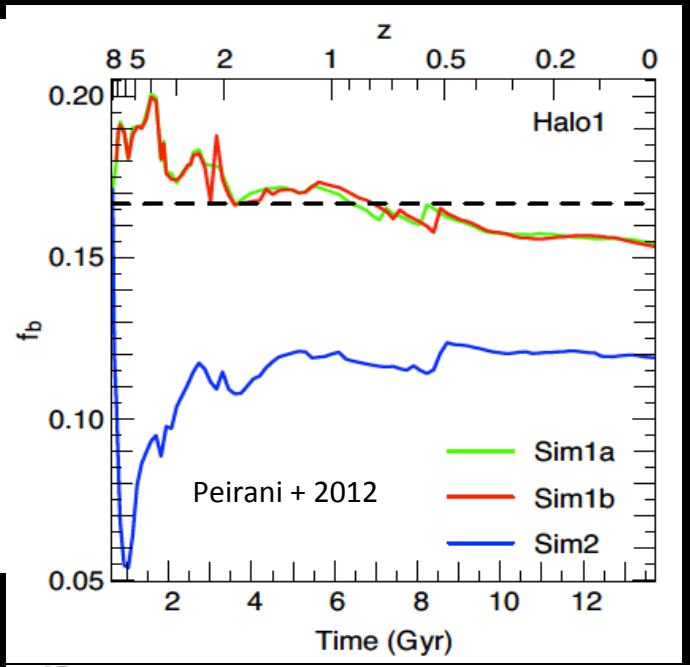
Primordial black holes

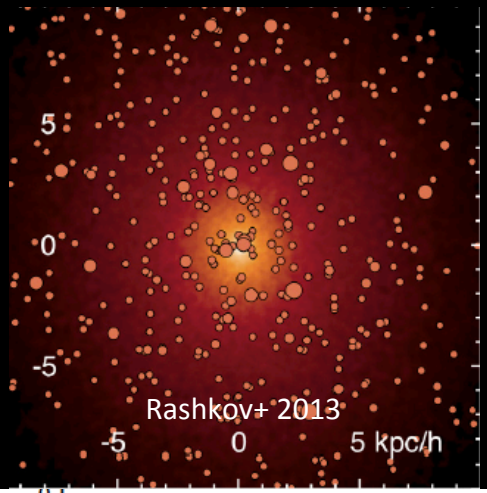
Carr + 2016



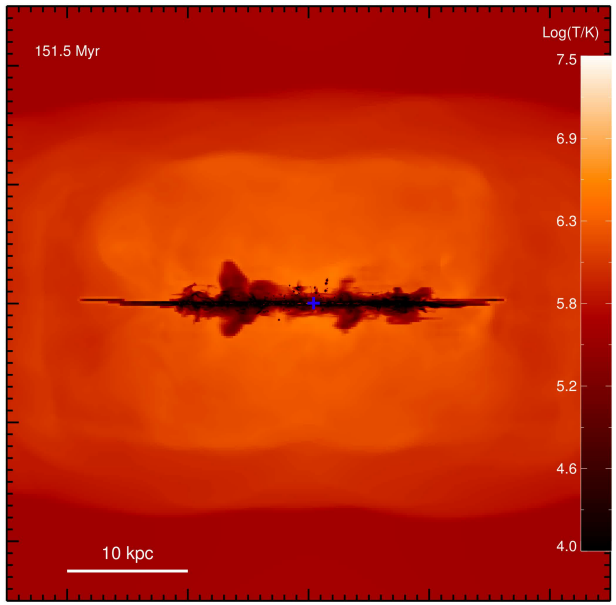
IMBH are useful…could they be PBH of 10^4-10^5 M_{sun} ?

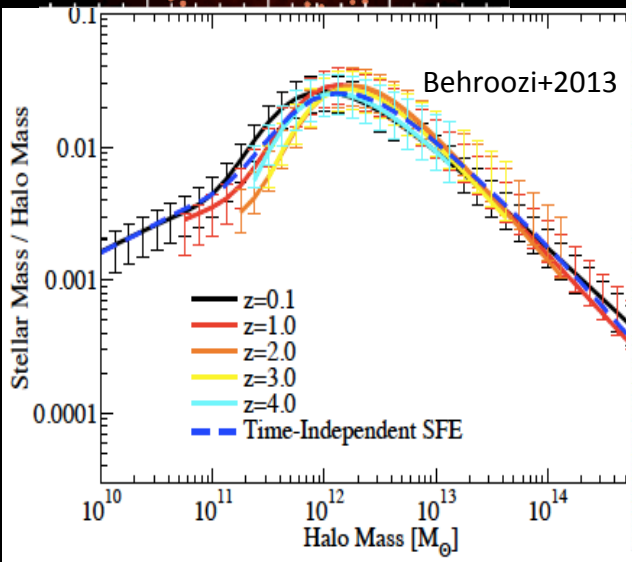


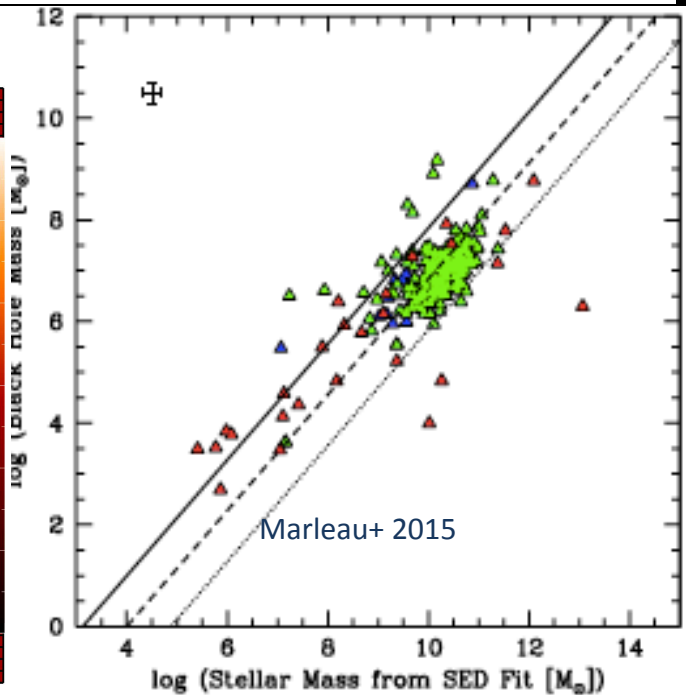




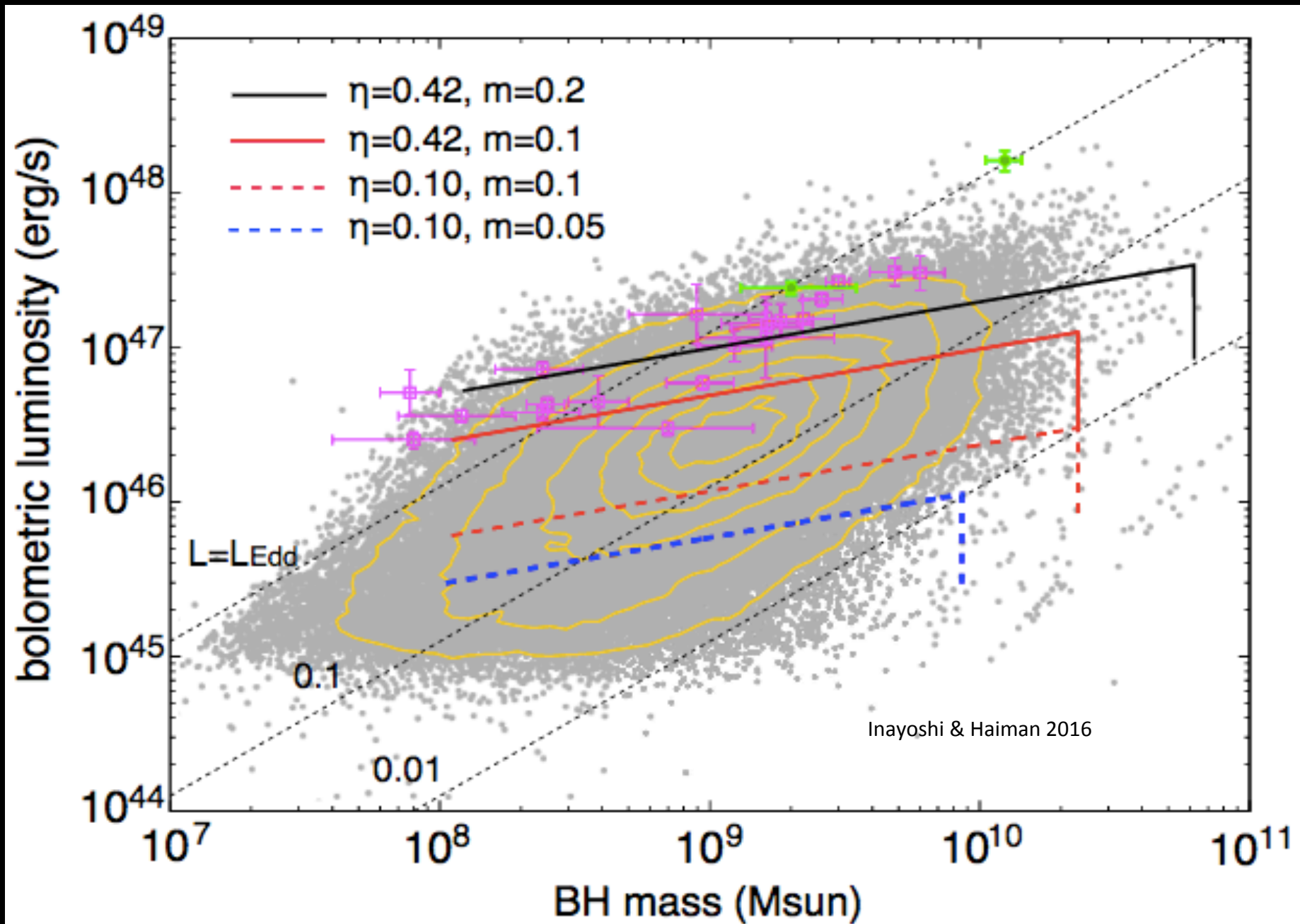
Gabor 2015

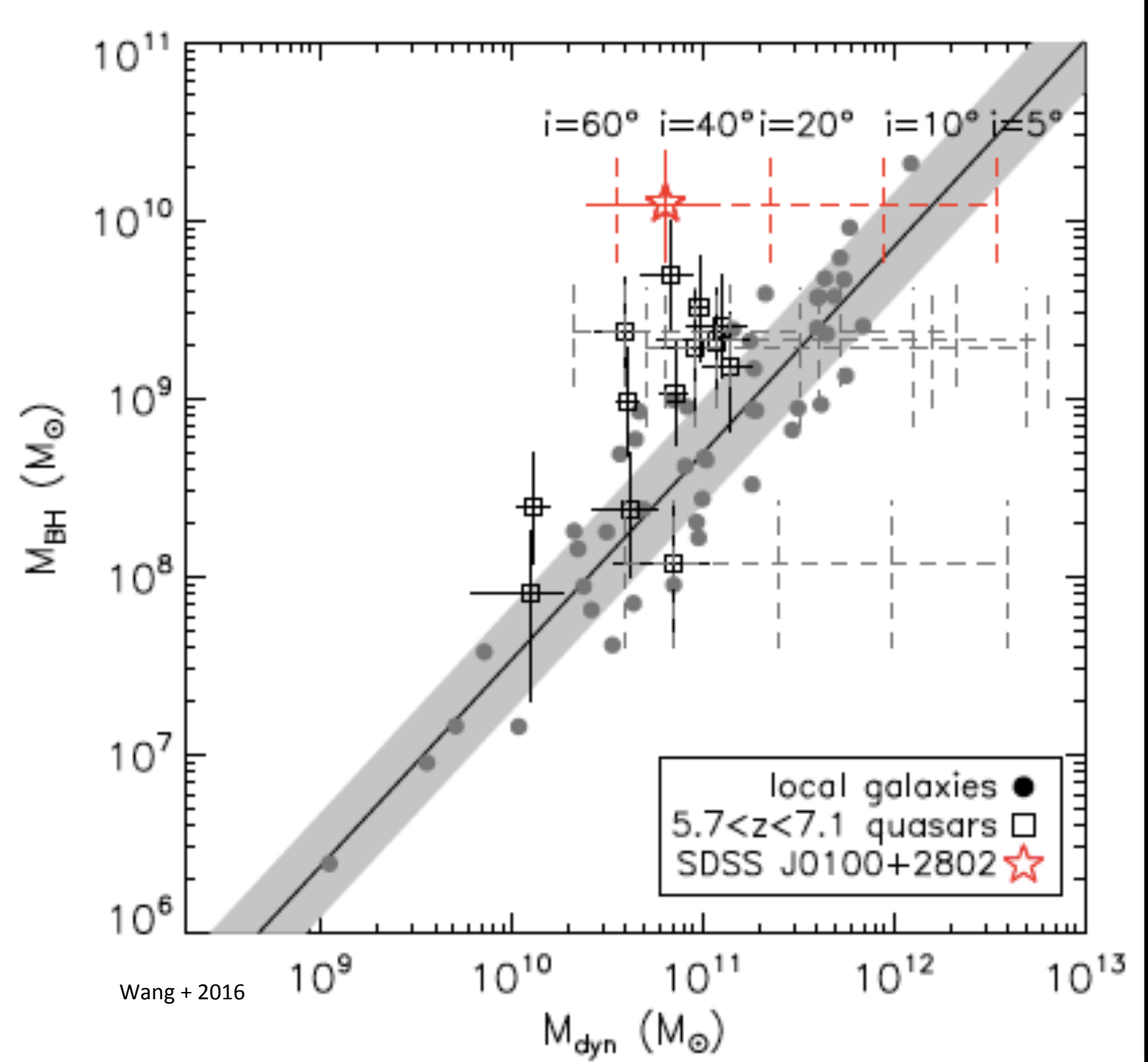






Maximum mass of a non-primordial SMBH

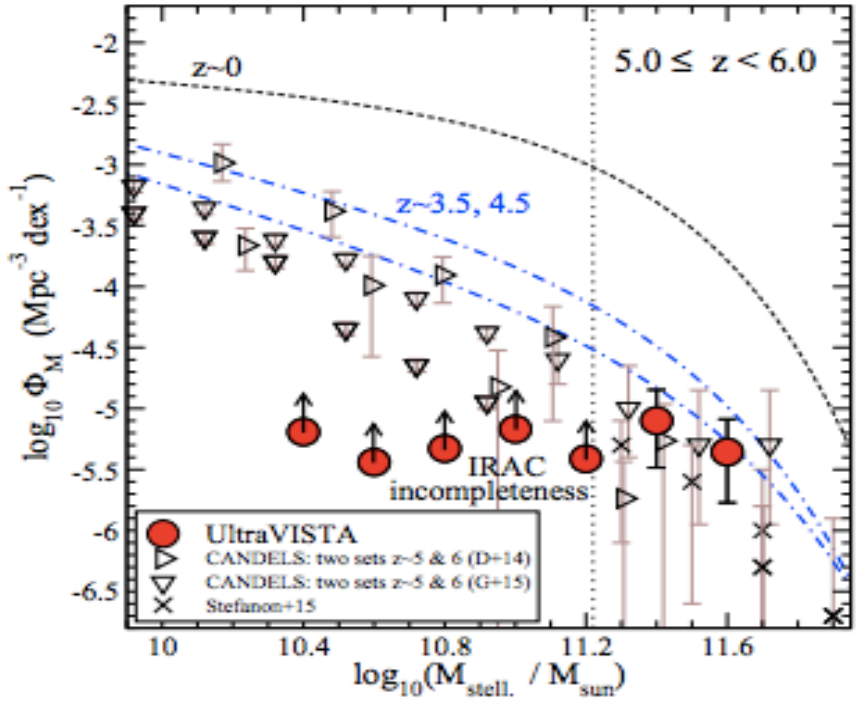


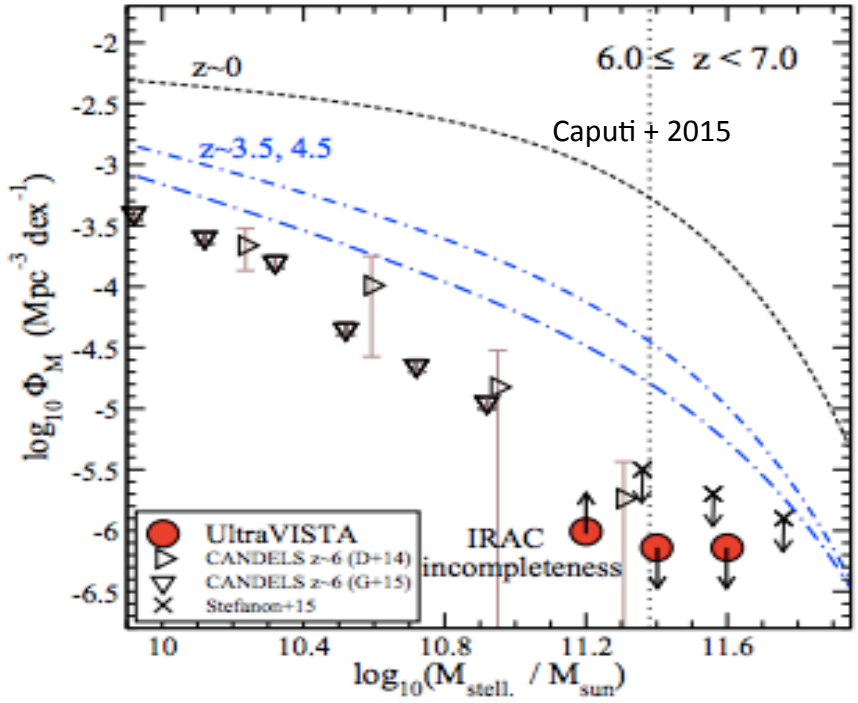


Wang + 2016

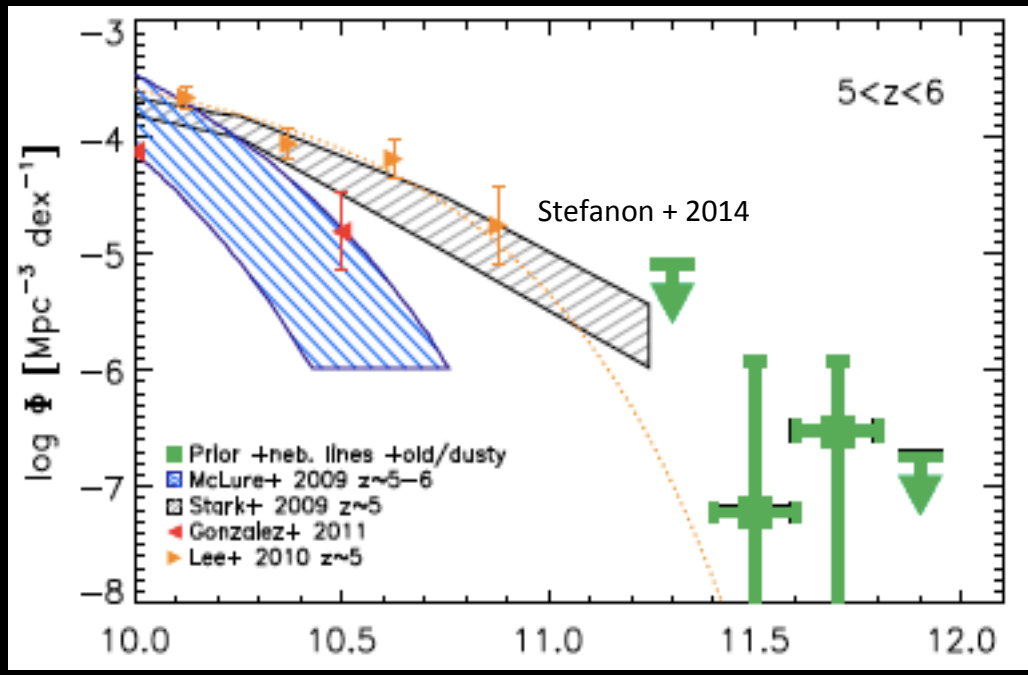
a monster at z=6.3!

The most massive galaxies at high z





Semi-analytical gf models fail to explain them



- PBH are subdominant
- Redshifting of radiation density enhances Ω_{pbh} by $(1+z)/1+z_{eq})$ at $z>z_{eq}$
- PBH mass is horizon scale ~f c^3t/G ~10^5 f t M_{sun} where f~ 0.3
- Maximum PBH mass at thermalization horizon ~ $10^{11}M_{sun}$

Consider 3 cases:

- M_{PBH} ~ 30 M_{sun} : LIGO
-
- 3.10^4 M_{sun} : nucleosynthesis

- 3.10^{10} M_{sun} : galaxy formation

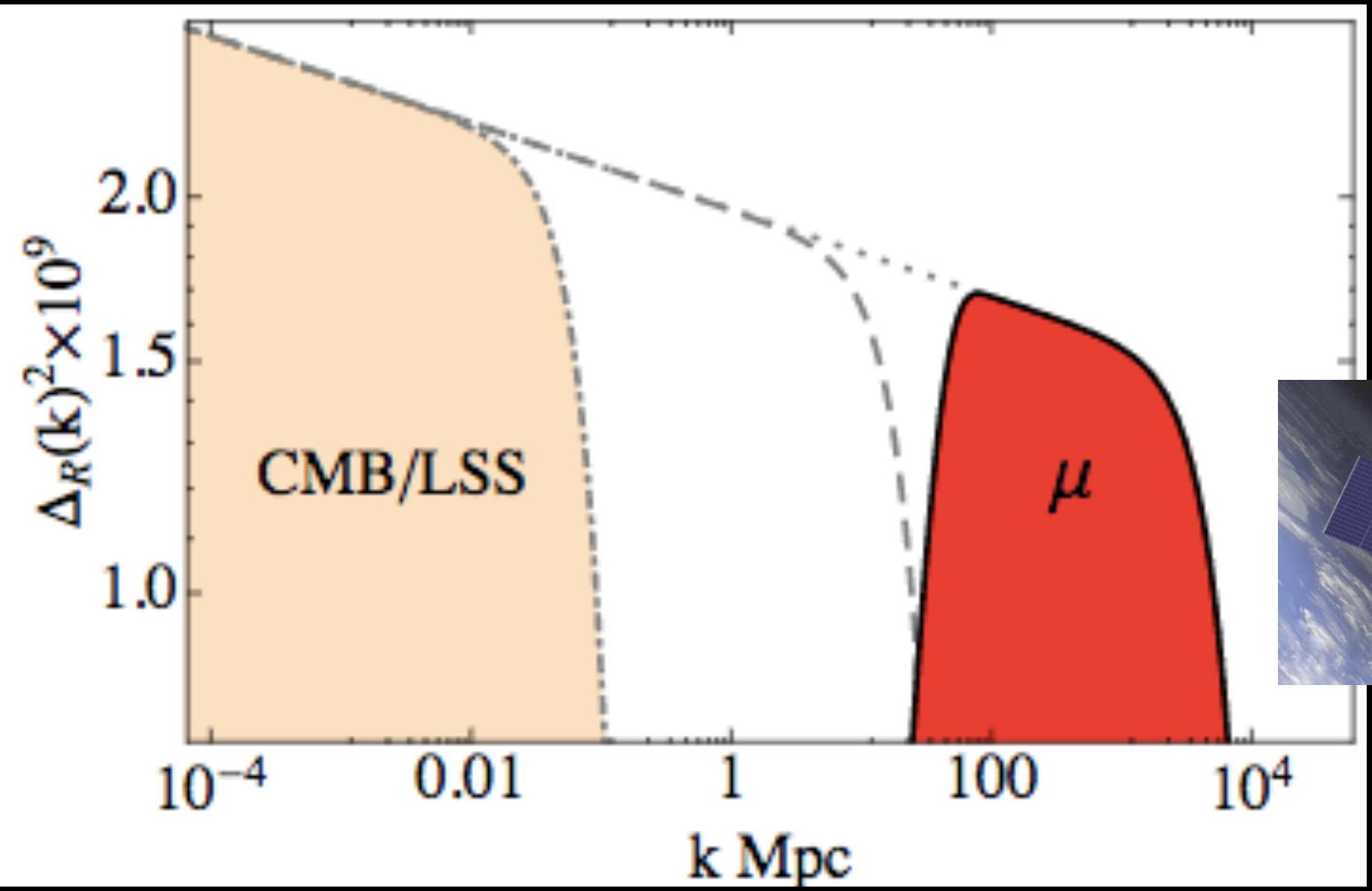
PBH over a wide mass range may contribute to DM

	$z_{formation}$	$\Omega_{PBH\ formation}$	$\Omega_{PBH\ today}$
PBH 30 M_{sun}	3.10^{11} (10^{-3} s)	$\Omega < 10^{-8}$	< 1
PBH 3.10^{4} M_{sun}	10^{10} (1 s)		
rarity to avoid nucleosynthesis problems			
~10^{-7} horizons form PBH at t~1 s		$\Omega < 10^{-7}$	< 0.1
PBH 3.10^{10} M_{sun}	10^{7} (10^{6} s)		
avoid μ distortion ~ $\Delta\rho_{rad}/\rho_{rad} < 10\text{-}4$ (FIRAS)			
~0.0001 horizons form PBH at z~10^{6}		$\Omega < 10^{-4}$	< 0.01

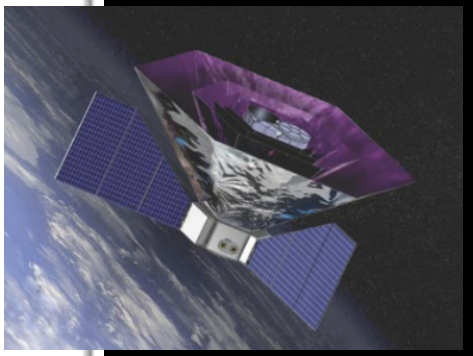
Future limits on substructure from fluctuation damping

~$10^{15}M_{sun}$ ~$10^{6}M_{sun}$

Pajer & Zaldariagga 2012

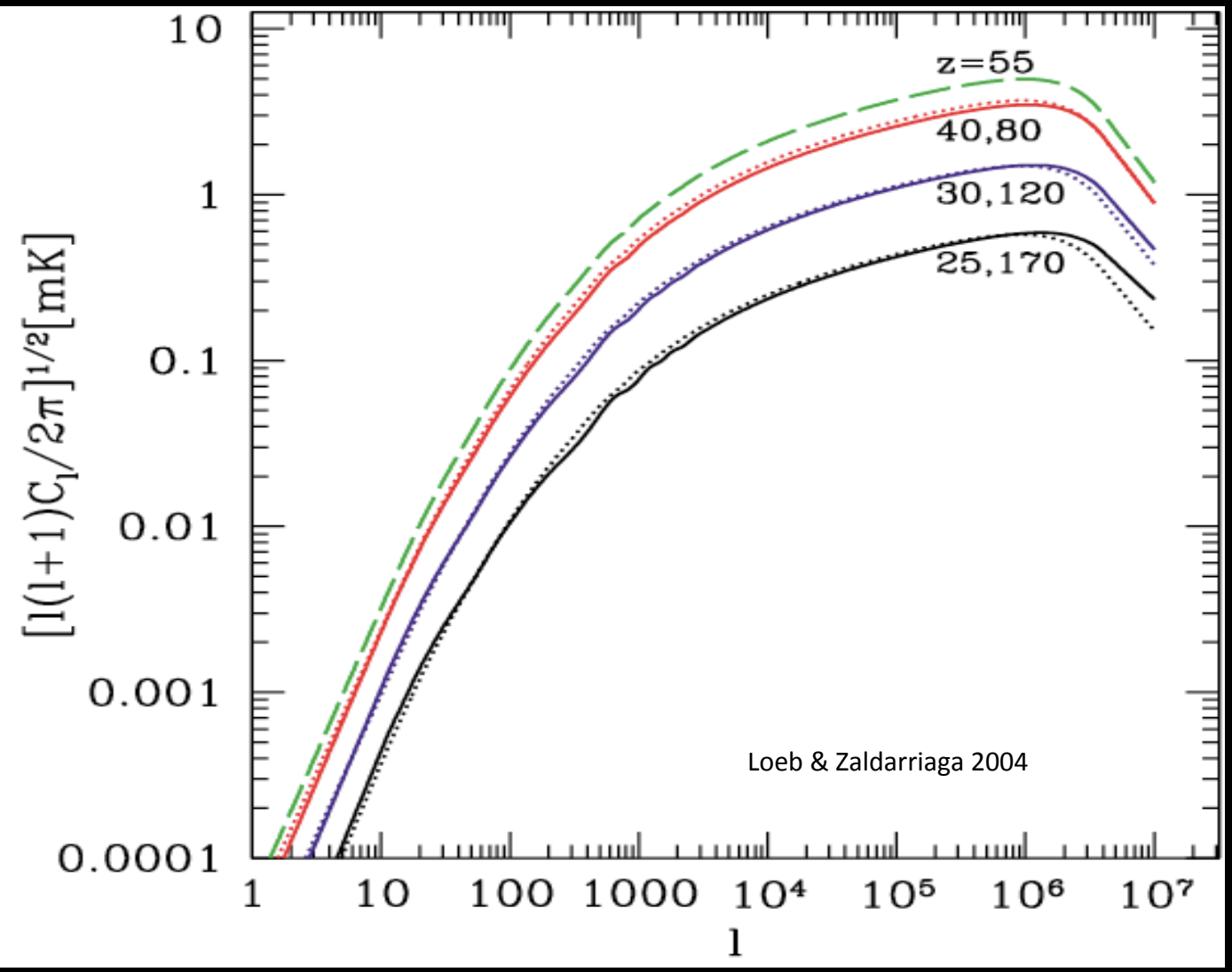


We'll need PIXIE

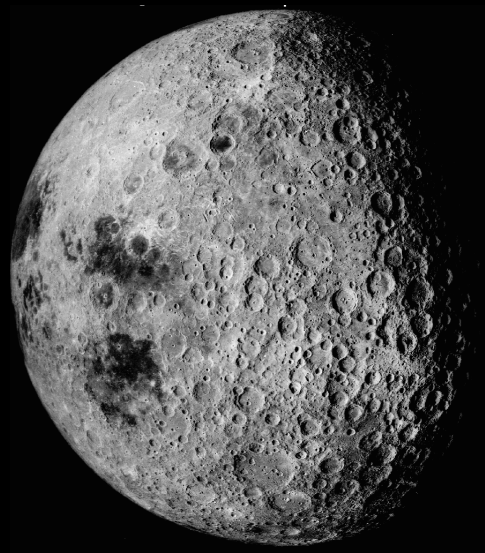


2017+5, optimistically

Future limits on substructure from 21cm in dark ages



We'll need a telescope array here!



2050??

Summary

PBH are a unique opportunity
to probe DM and cosmology

They can solve several astrophysical problems:

Dark Matter

Seeds of SMBH

Seeds of rare massive galaxies at high z