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*soon FNRS C.R. at UCL and UNamur*

# Hints for Primordial Black Holes as Dark Matter in galactic and extra-galactic observations?

*based on arXiv:1707.04206, 1610.08479, 1603.05234, 1501.00460*

18th Meeting of the FNRS Contact Group  
*Astronomie & Astrophysique, Brussels Planetarium, Sep. 19 2017*

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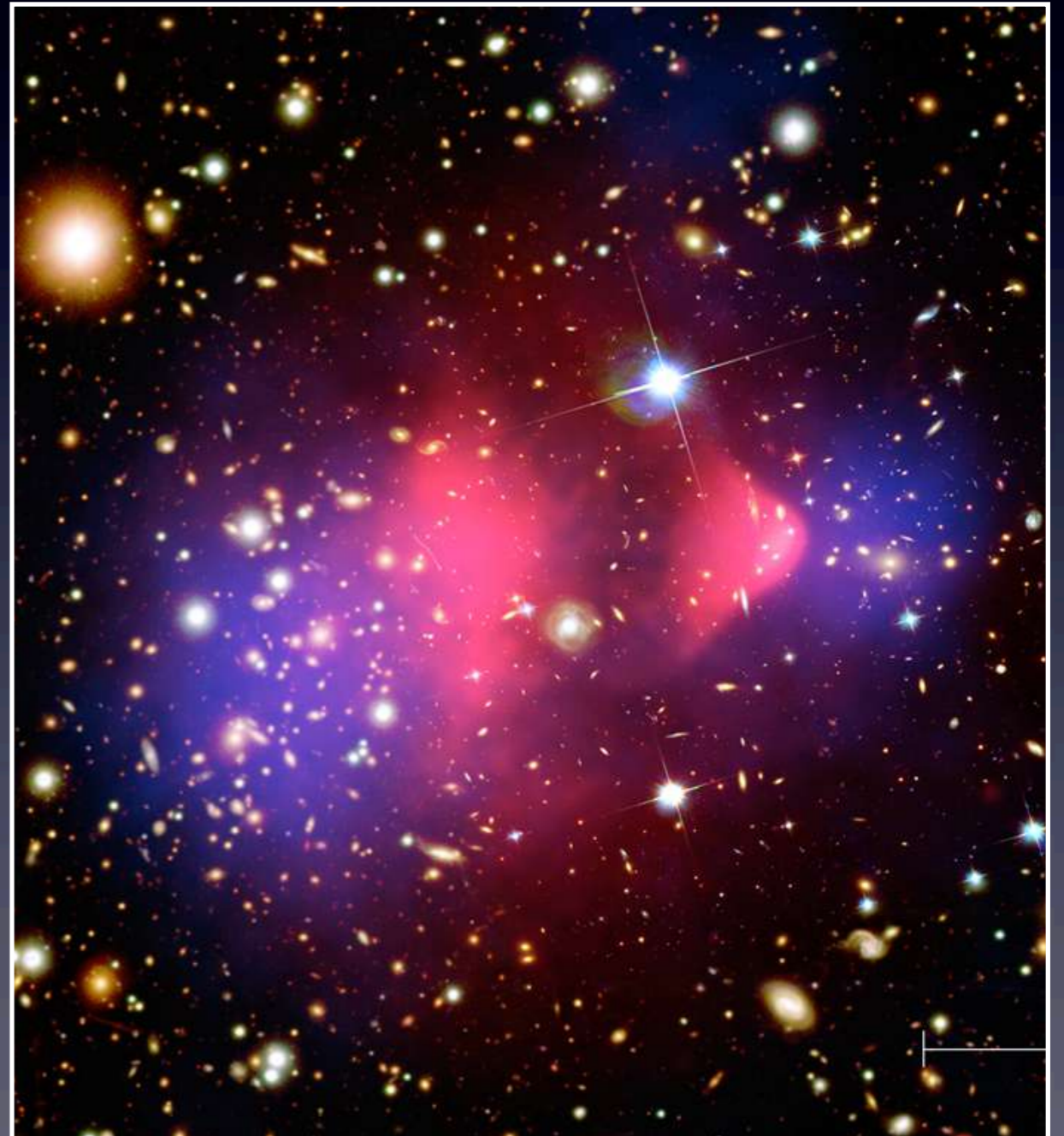
*based on arXiv:1707.04206, 1610.08479, 1603.05234, 1501.00460*

*if lazy, see review article in Scientific American, July 2017  
translated in Dutch (Eos), soon in French (Pour la Science), others...*

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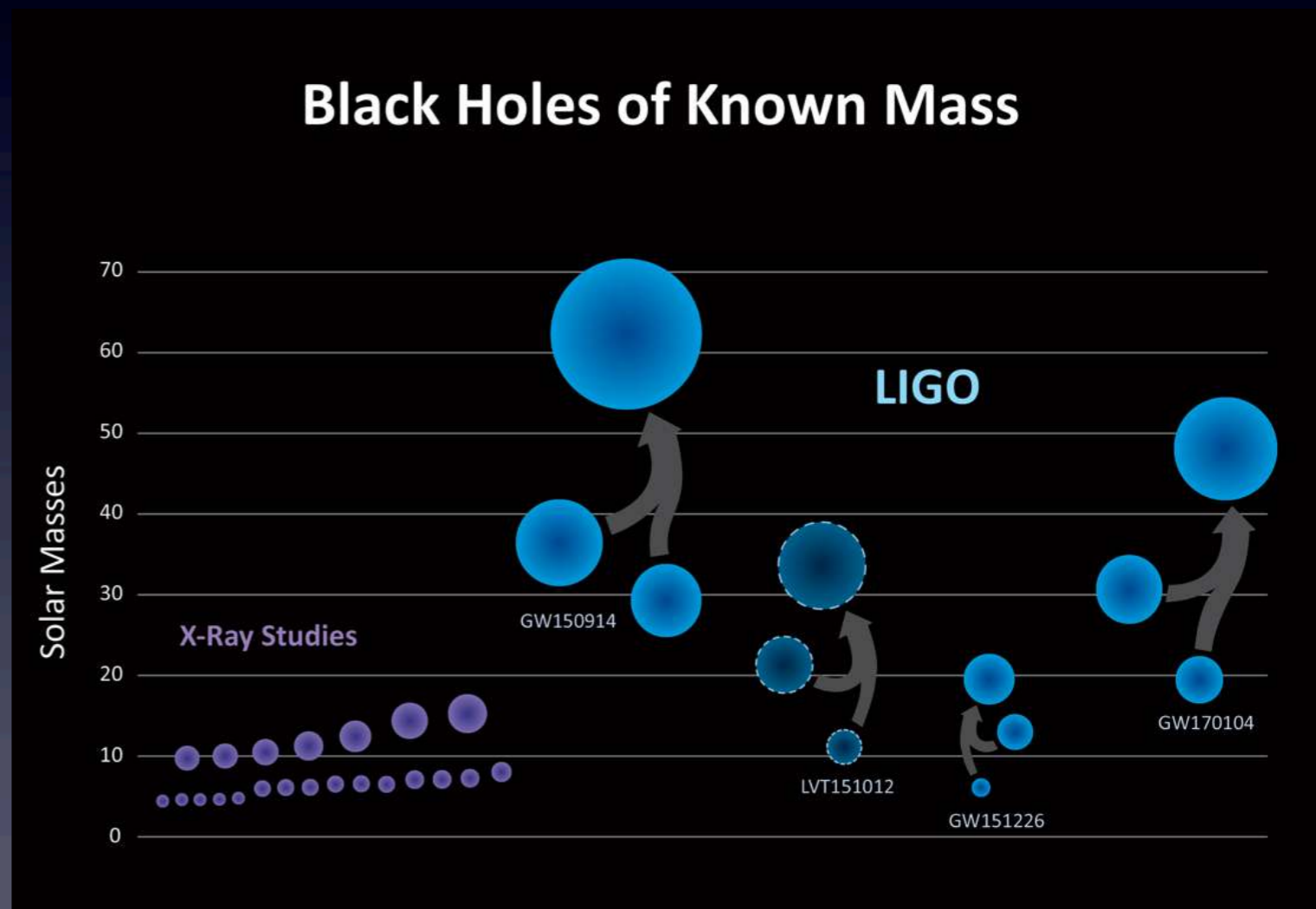
# A good Dark Matter candidate

- Do not emit light by nature
- Non-relativistic
- Nearly collisionless
- Formed in the early Universe



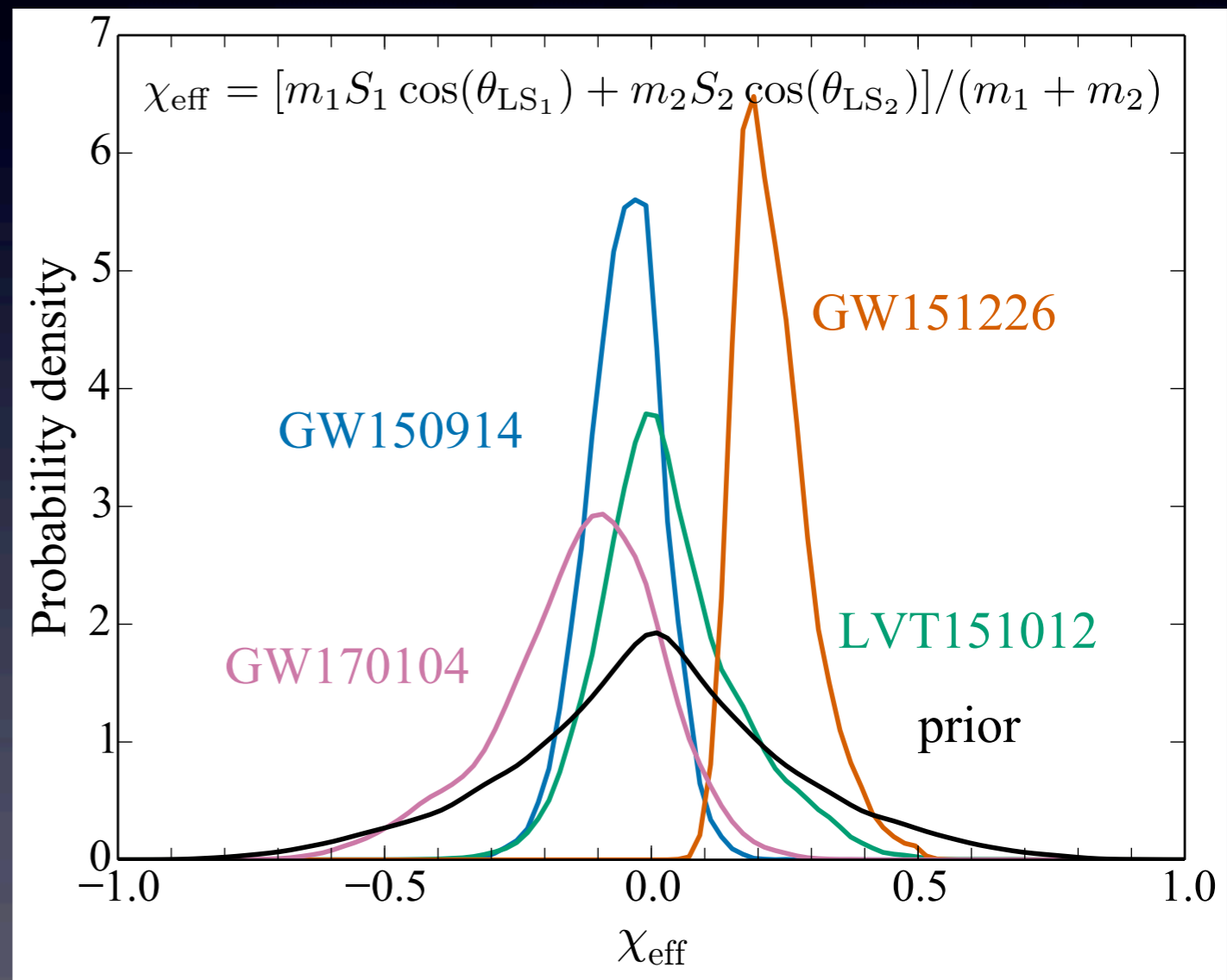
# LIGO and the strange BH mergers

- Unexpected large masses for GW150914
- 3 other events  $> 15 M_{\text{sun}}$  (several events not yet released)
- Inferred rates:  $14\text{-}158 \text{ Gpc}^{-3} \text{ yr}^{-1}$
- Non-aligned, low spins



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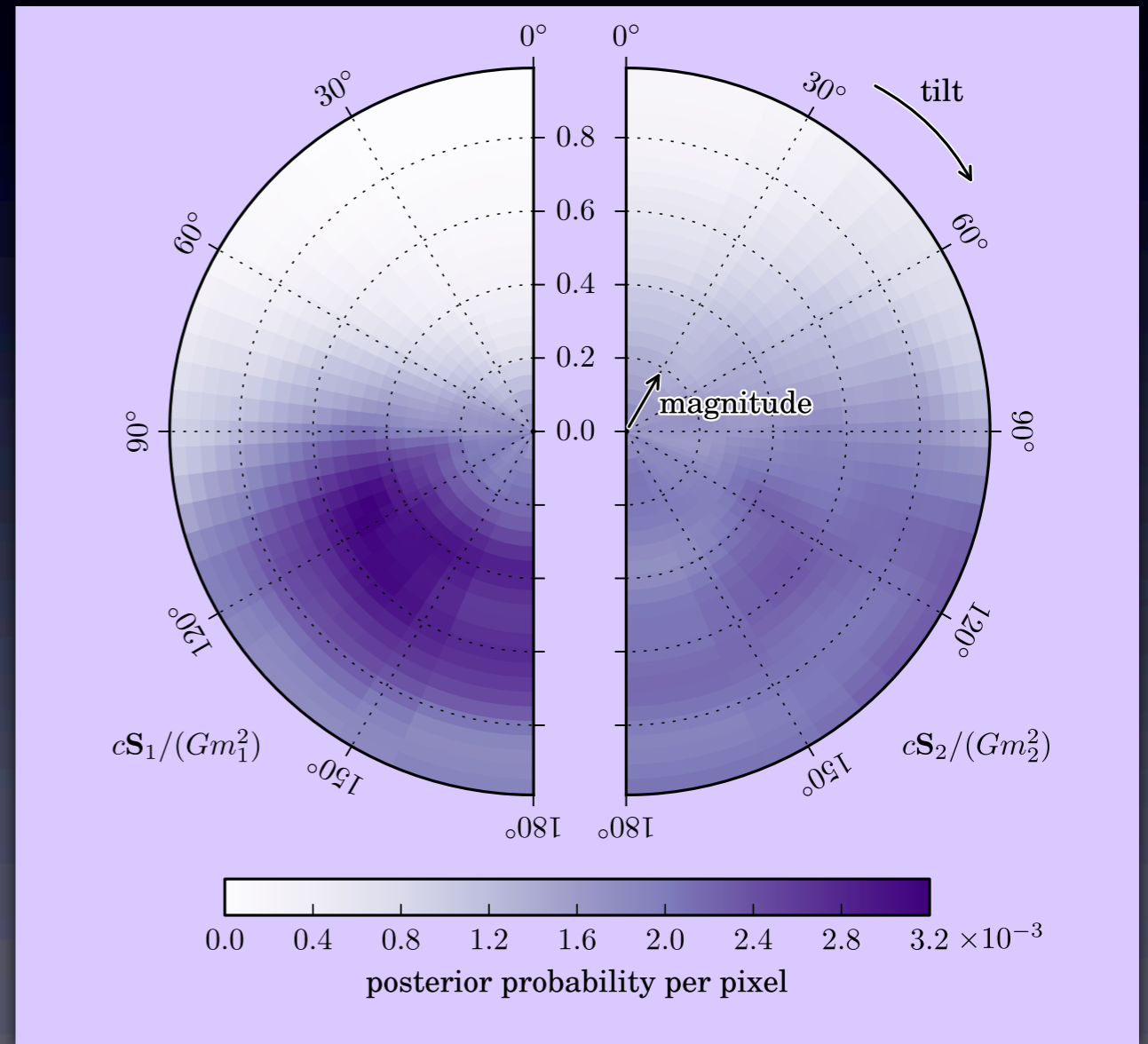
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Adv.LIGO/VIRGO June release (supl. material)

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Adv.LIGO/VIRGO June release (supl. material)

*Confirmation of « a new population of black holes »*

# LIGO and the strange BH mergers

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## The bright scenario

- From star explosion
- Low-metallicity environment
- Super-dense clusters
- BUT: why so massive?
- BUT: unrealistic rates
- Need a new model...



# LIGO and the strange BH mergers

## The bright scenario

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- BUT: why so massive?
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## The dark scenario

- Primordial
- Merging rates compatible with Dark-Matter-like abundance
- Low spins expected
- BUT: very stringent observational constraints

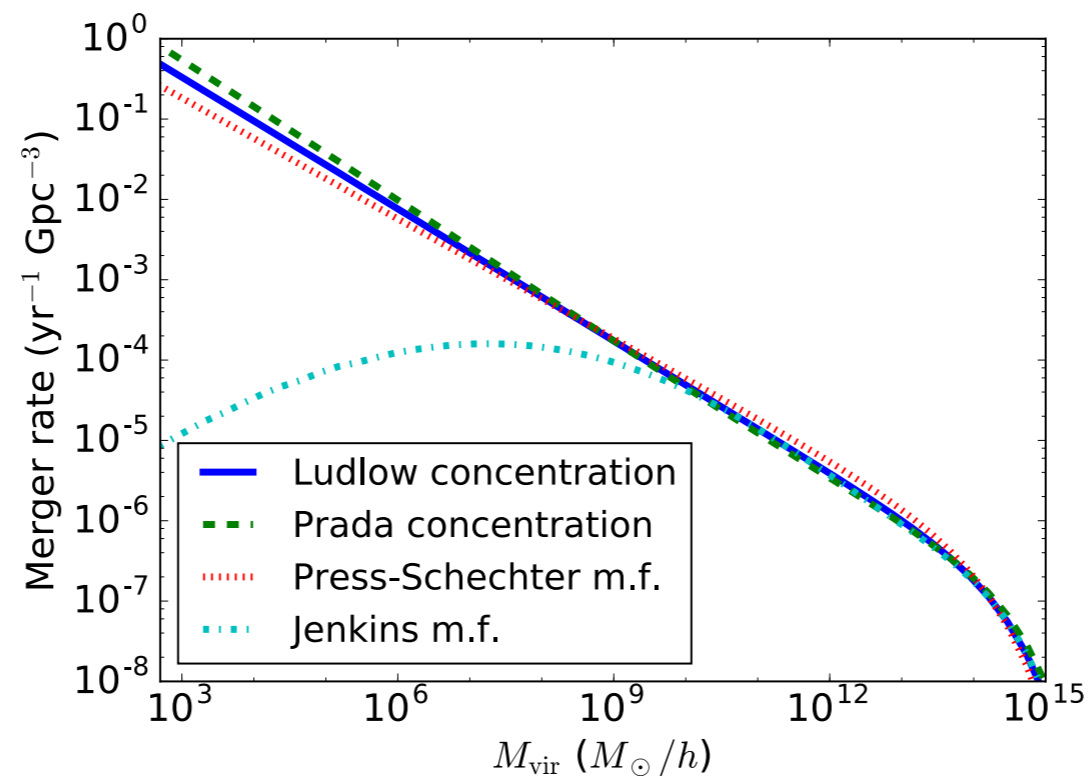
In March 2016...

- S. Bird et al., 1603.00464

## Monochromatic spectrum, extended halo mass function

$$\tau_{\text{merg}} \sim 2f_{\text{HMF}} f_{\text{DM}} (M_{\text{crit.halo}}/400M_{\odot})^{-11/21} \text{Gpc}^{-3}\text{yr}^{-1}$$

**Most mergings  
come from mini-halos.**



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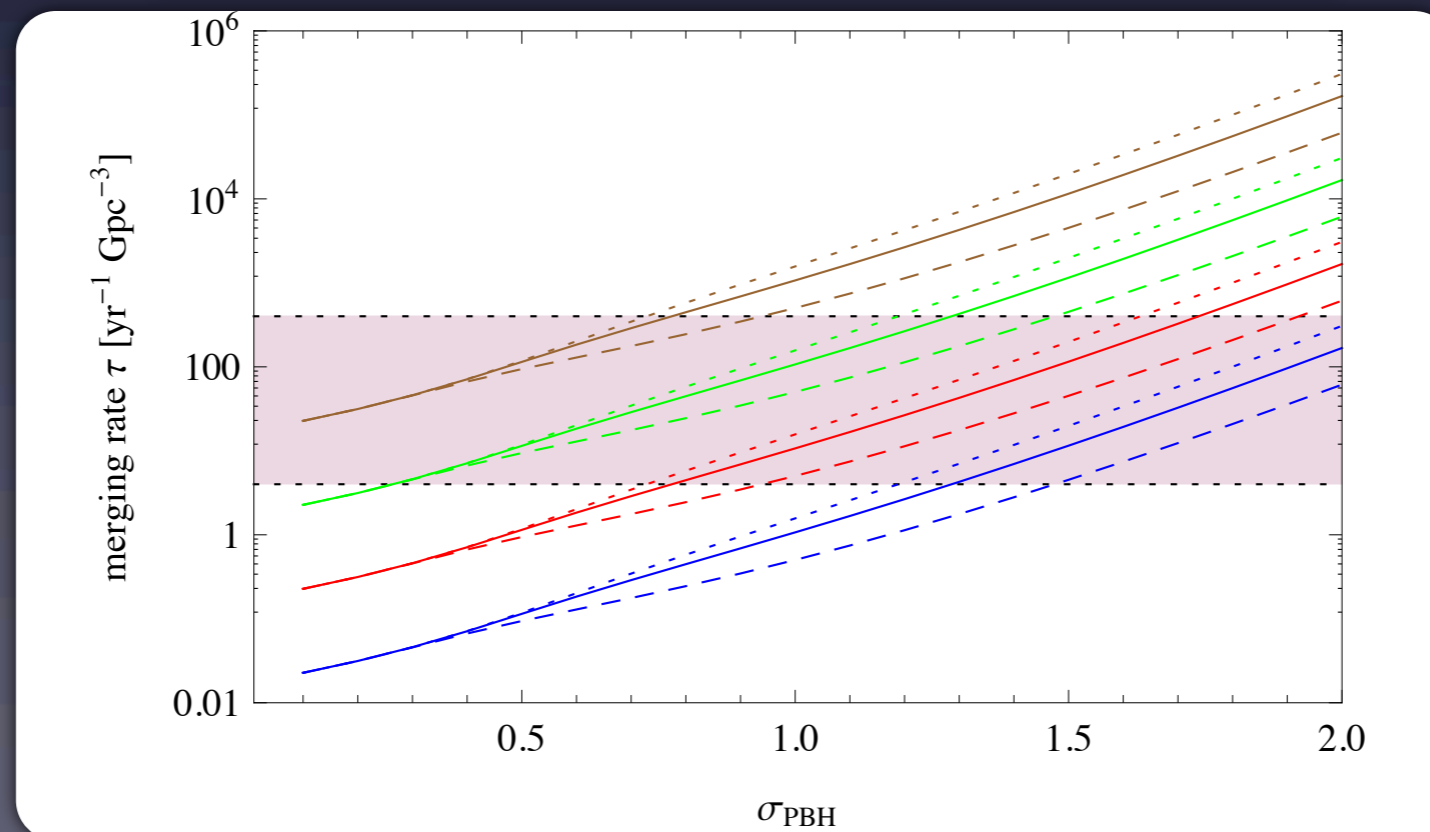
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Broad mass spectrum, natural clustering scale

$$\tau_{\text{merg}} \sim f_{\text{DM}} 10^{-8} \delta_{\text{PBH}}^{\text{loc.}} \text{Gpc}^{-3}\text{yr}^{-1}$$

Faint Dwarf Galaxies  
or Globular Clusters



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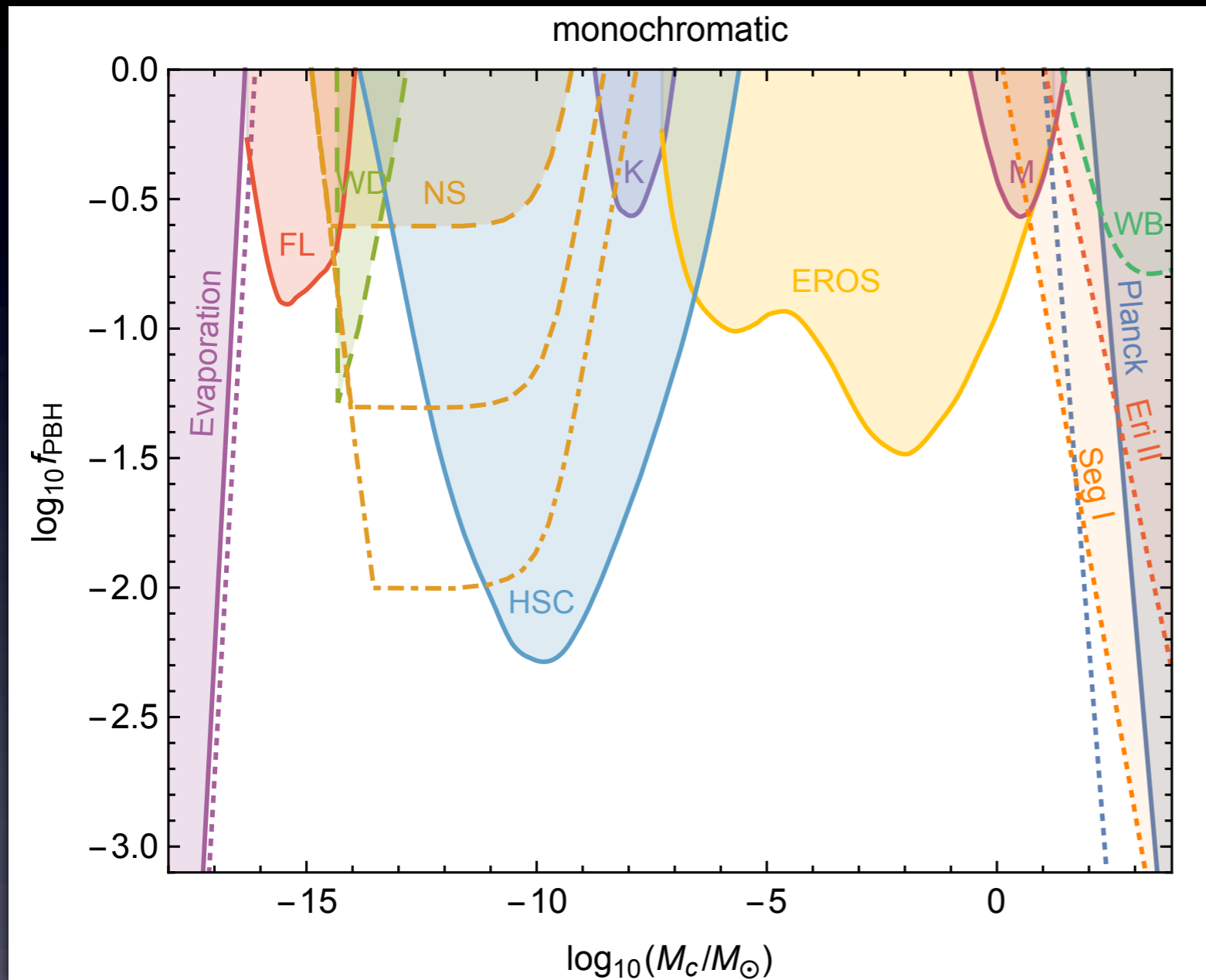
- M. Sasaki et al., 1603.08338

Monochromatic spectrum, BH binaries from Early Universe

$$\tau_{\text{merg}} \sim f_{\text{DM}} 10^4 \text{Gpc}^{-3}\text{yr}^{-1}$$

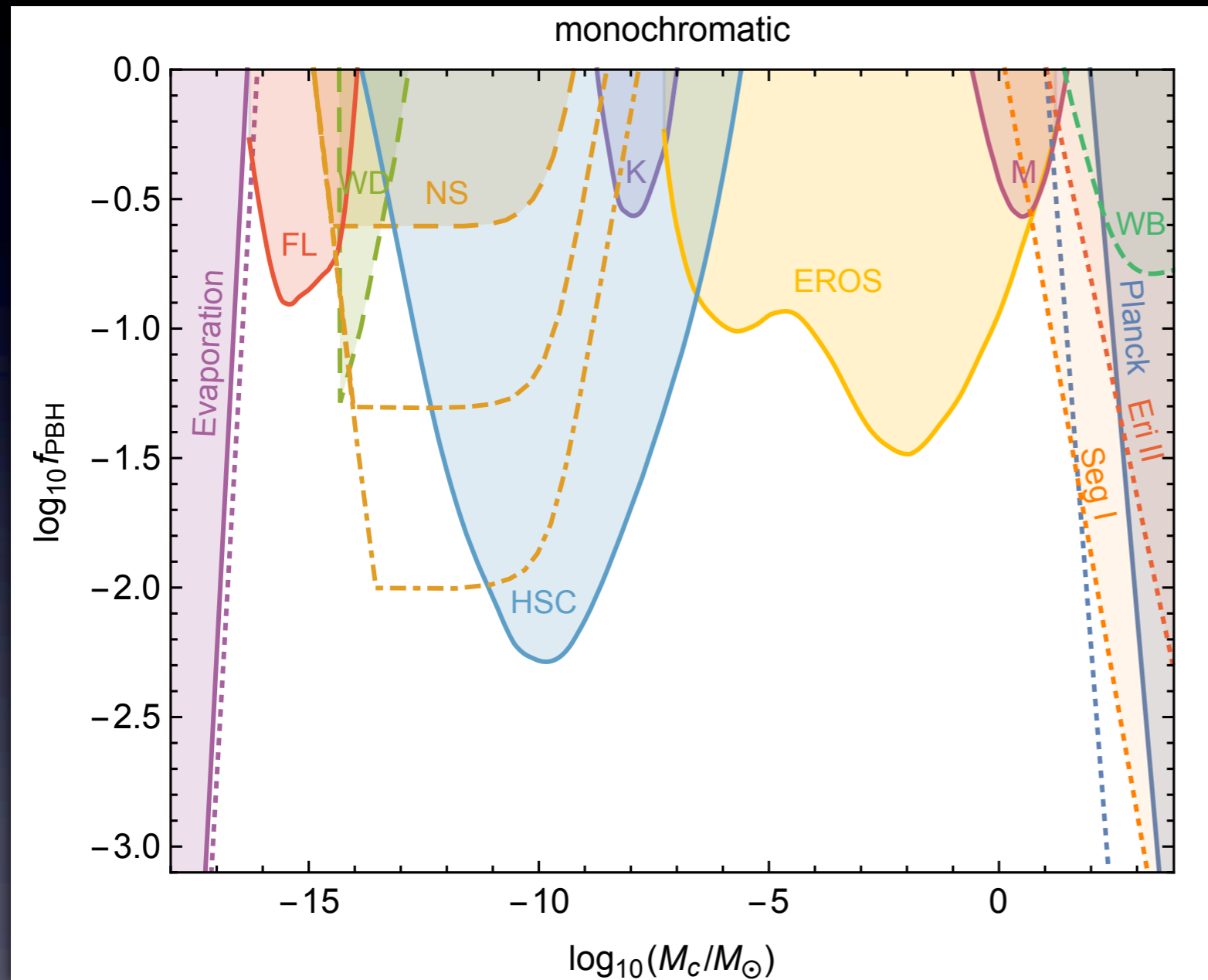
**cannot be the  
Dark Matter  
except if PBHs are  
initially clustered**

# Constraints on PBH abundances



B. Carr et al., 1705.05567

# Constraints on PBH abundances

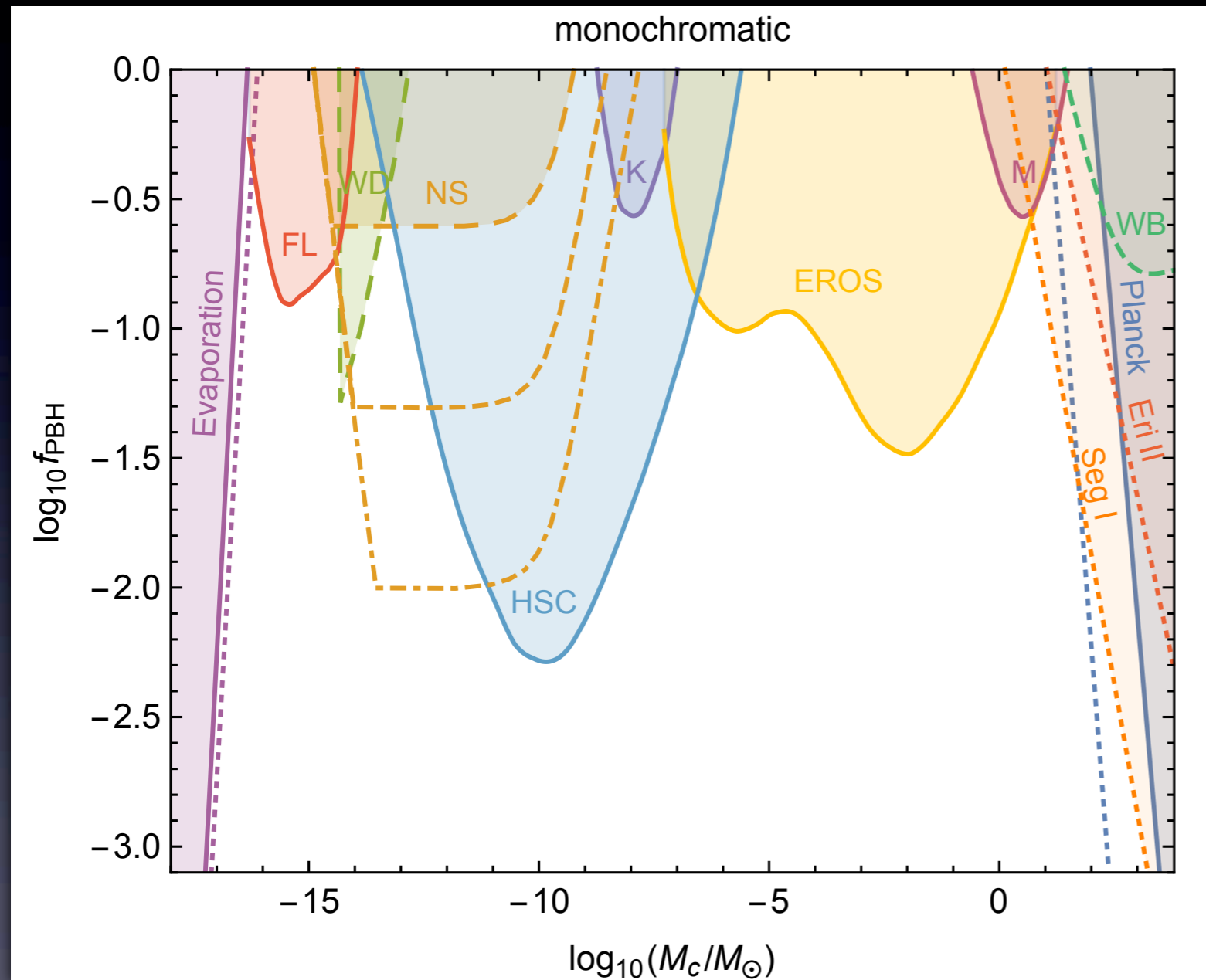


Monochromatic  
spectrum:

PBH-DM looks excluded  
in the whole mass range

B. Carr et al., 1705.05567

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Microlensing constraints  
are controversial  
and change if  
PBH are clustered!  
(SC., JGB, 1501.07565  
A. Green, 1705.10818)!

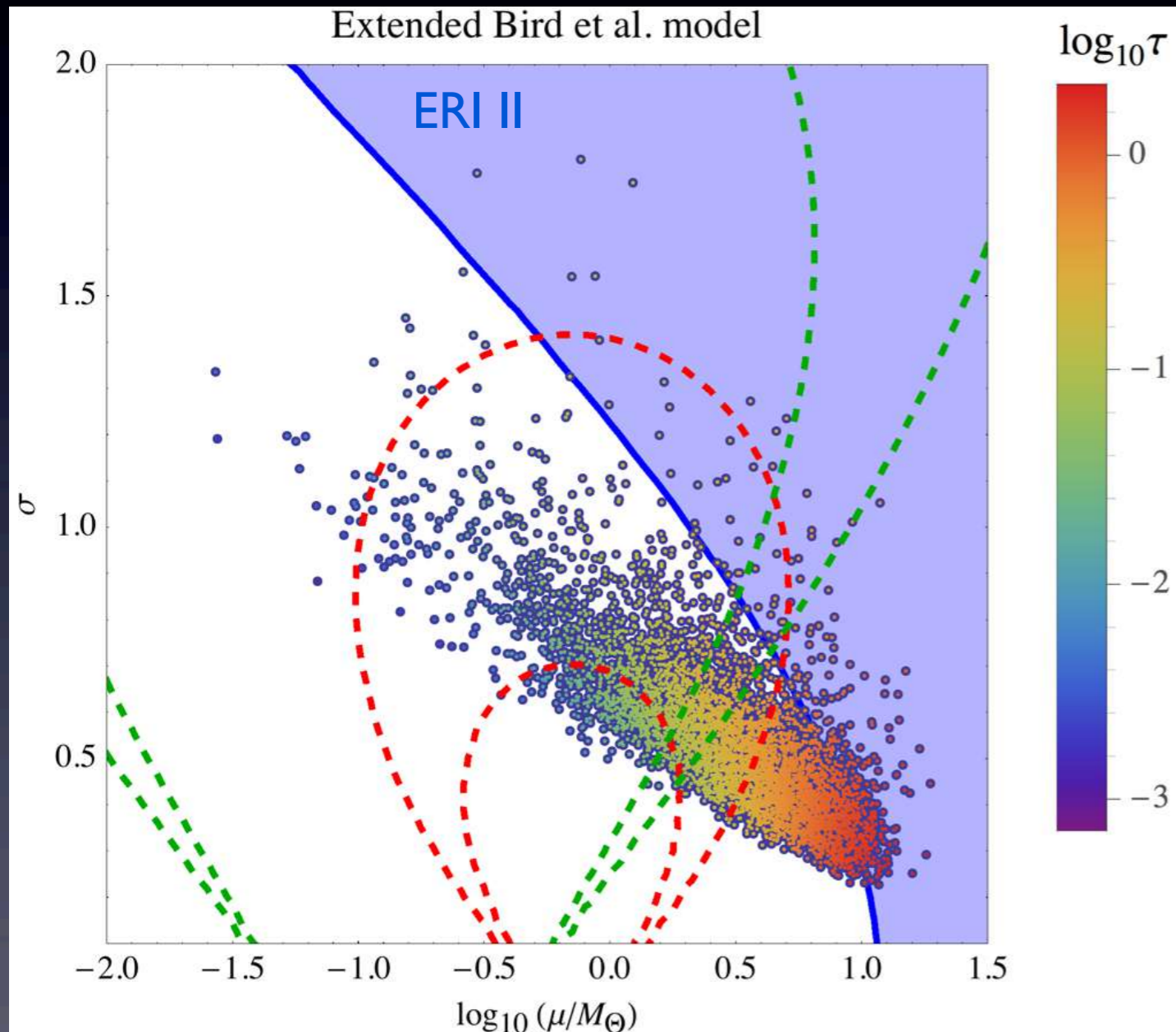
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# Four hints for PBH-DM

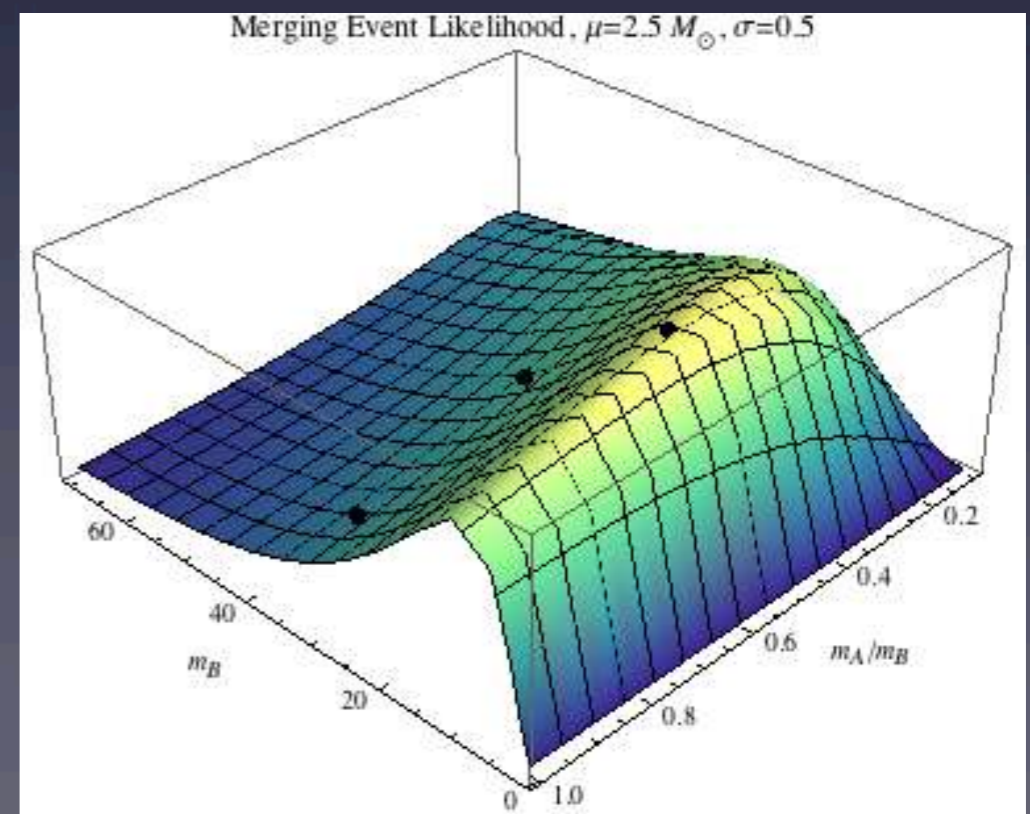


# Four hints for PBH-DM

## Hint I: BH merger rates, mass and spins

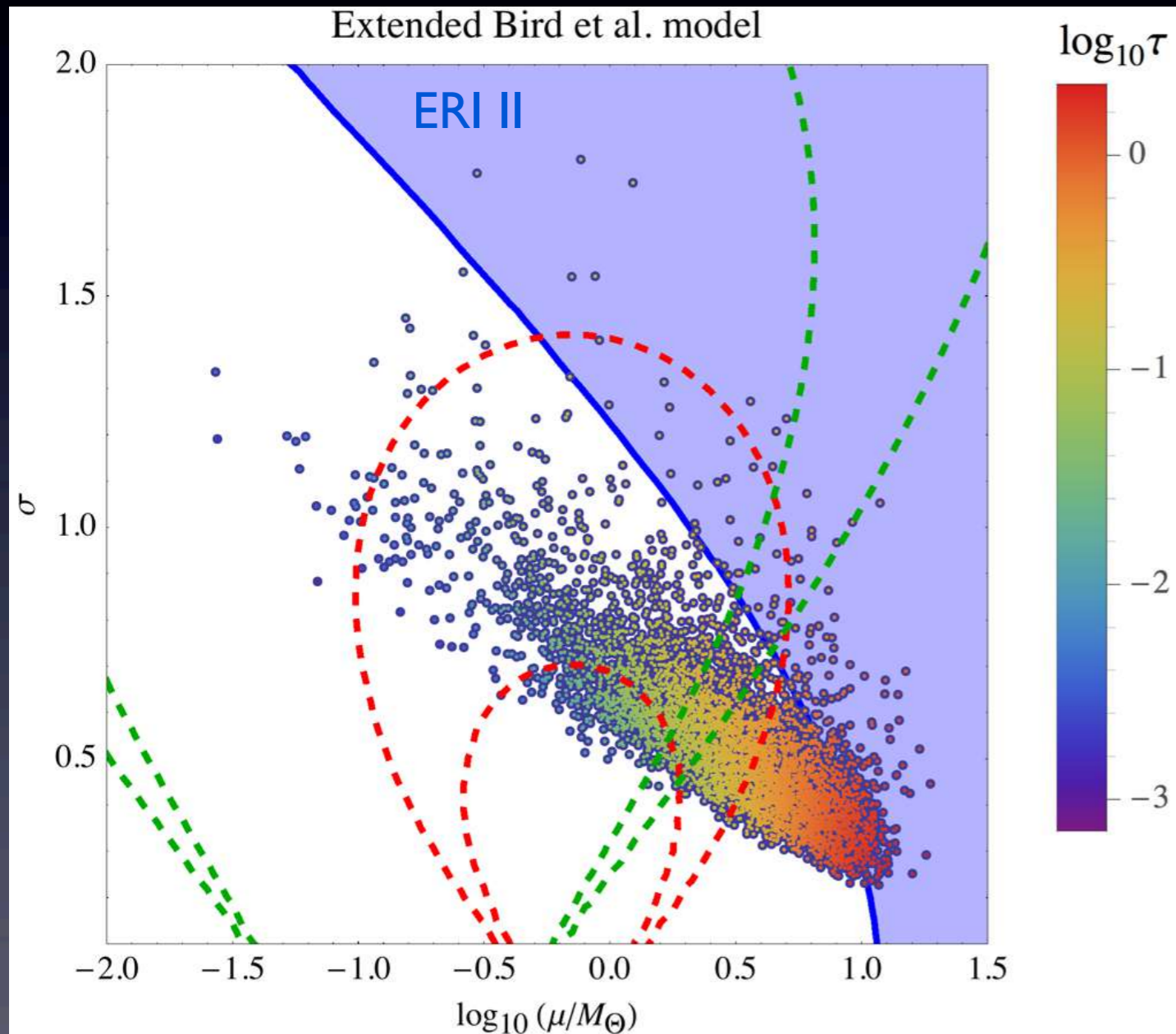


- MCMC mass spectrum reconstruction from LIGO events and rates
- Event likelihood peaks on large masses: LIGO detectability scales like inverse distance



# Four hints for PBH-DM

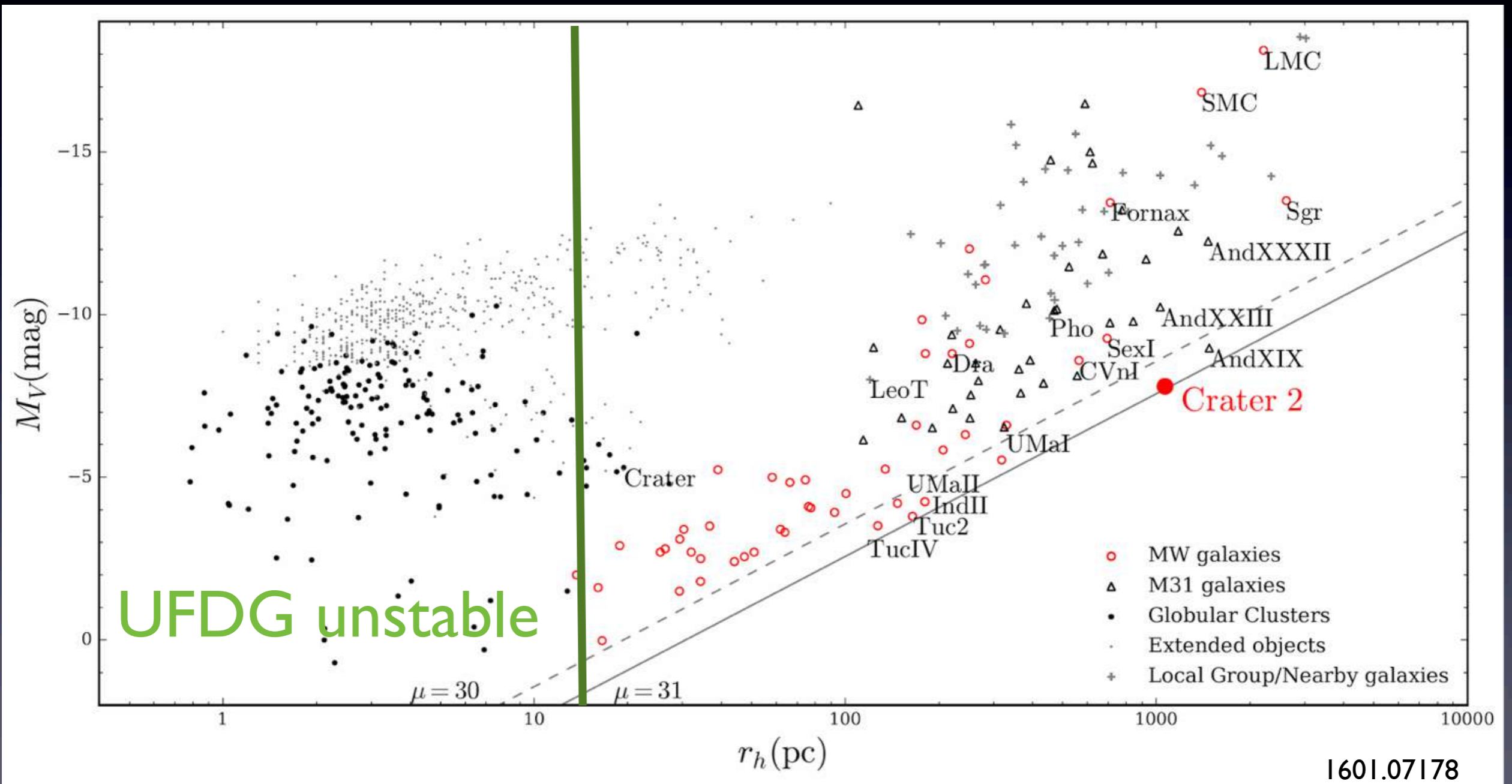
## Hint 2: Star clusters and dynamics of faint dwarf galaxies



- Dynamical heating of faint dwarfs and their star clusters
- Stable star clusters are fine-tuned or require core profile:  
Amorisco 1704.06262  
Contena et al, 1705.01820
- Solve the missing satellite/too big to fail problems due to matter accretion
- Re-analysis and N-body simulations in progress...

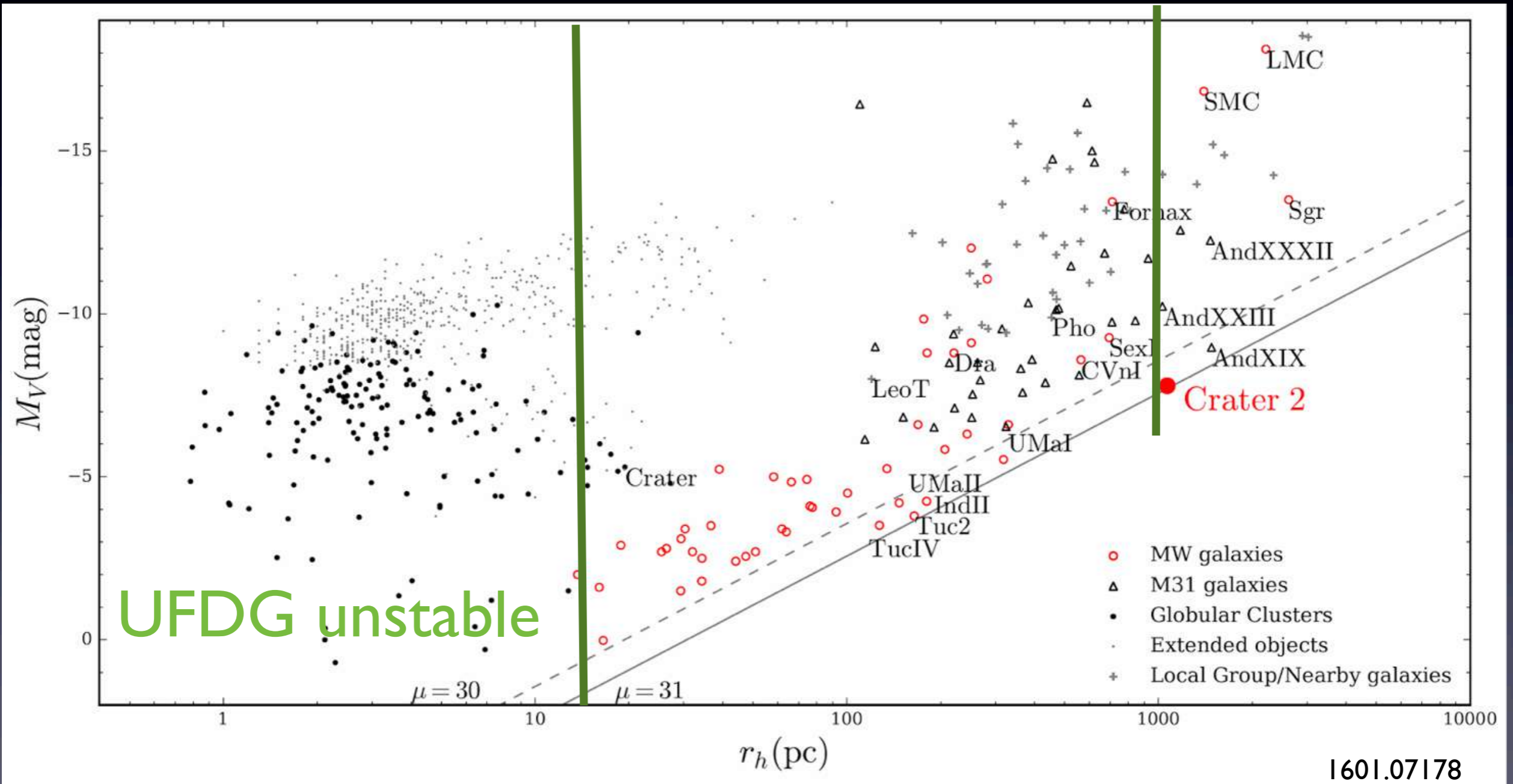
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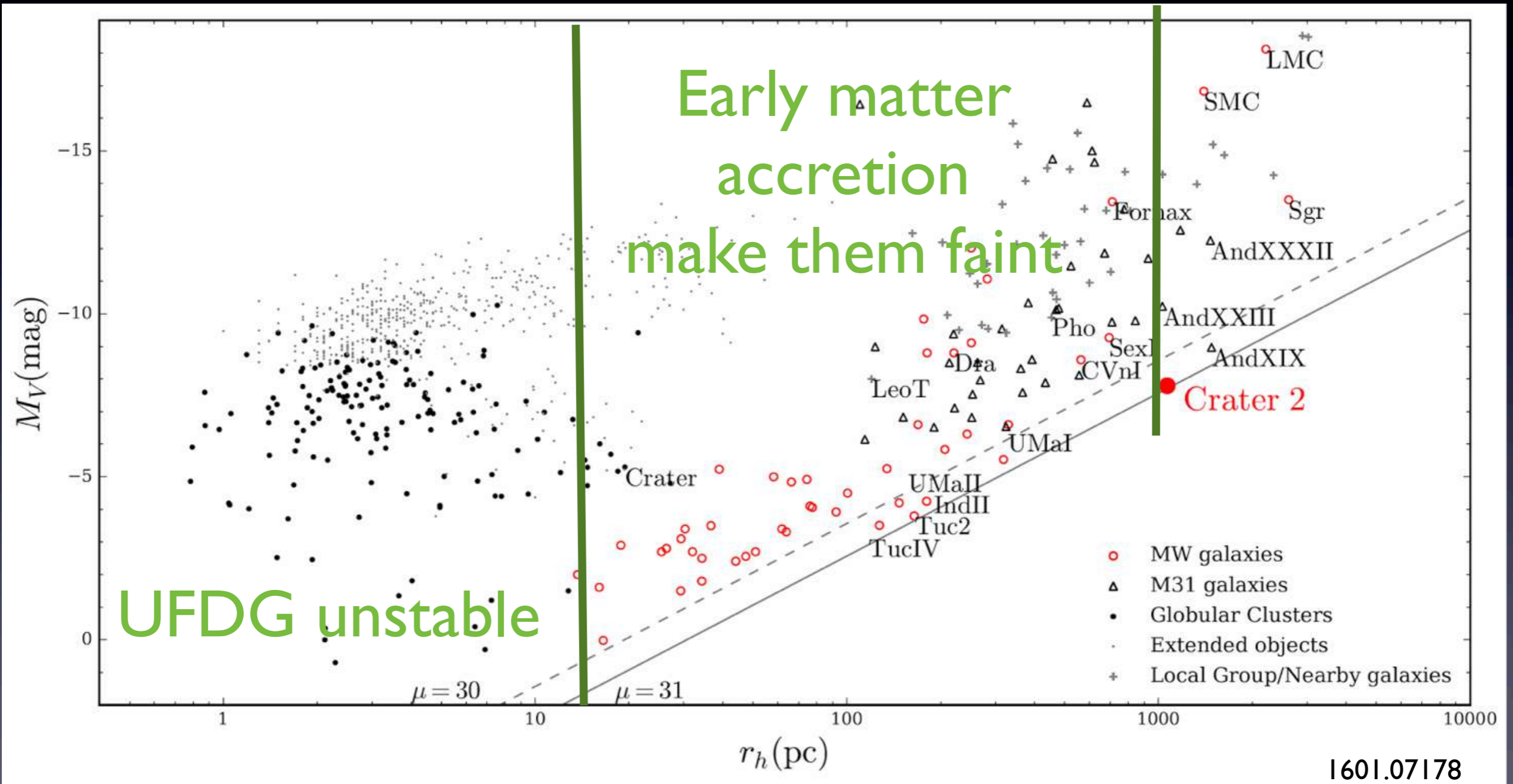
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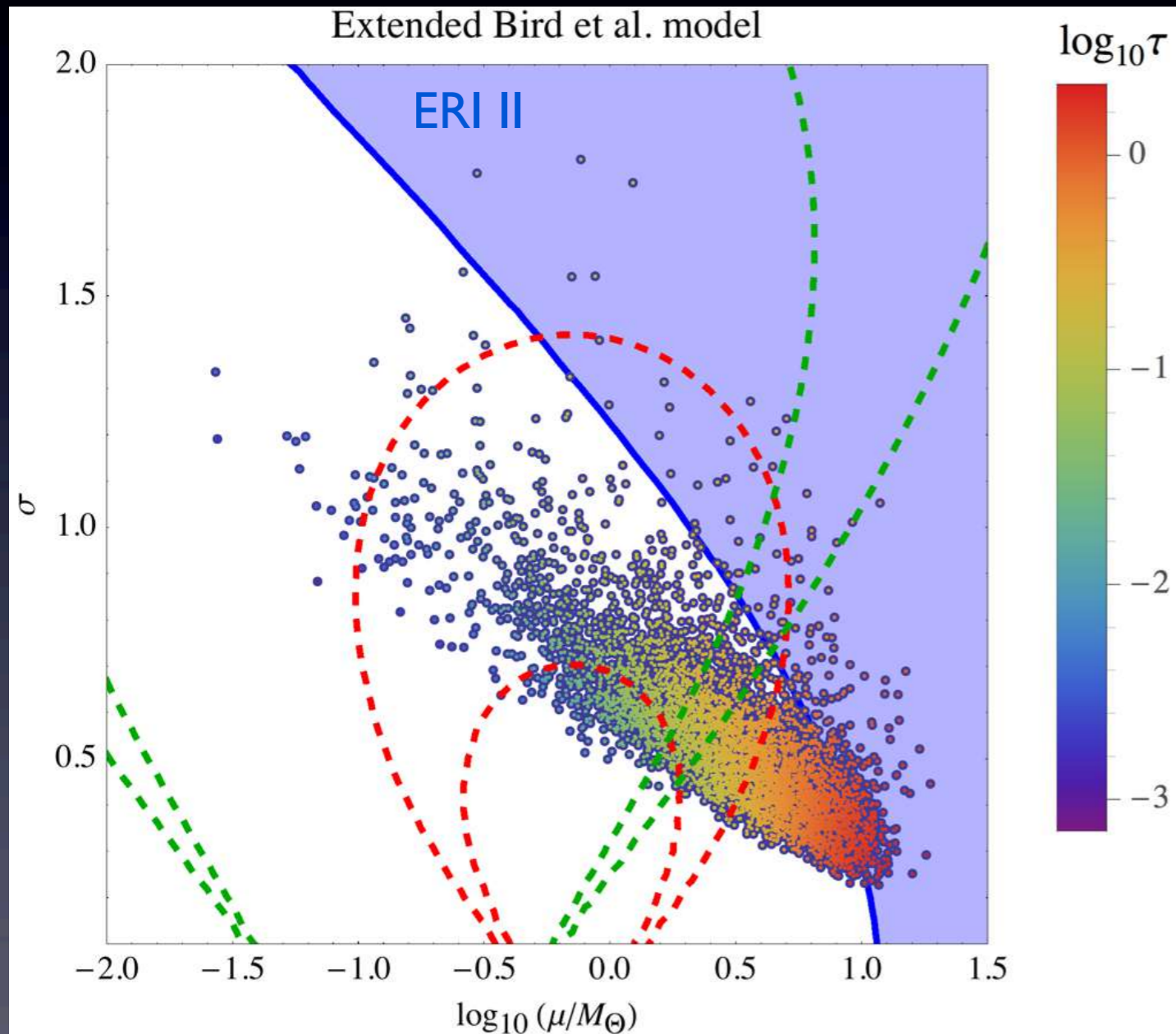
# Four hints for PBH-DM

## Hint 3: Microlensing of M31 and quasars

- 56 microlensing events in M31: between 15% and 30% of halo compact objects in range  $[0.5-1]$   $M_{\text{sun}}$  (1504.07246)
- 24 micro-lensing of quasars by galaxies: between 15% and 25% of halo compact objects in range  $[0.05-0.45]$   $M_{\text{sun}}$  (1702.00947)
- Also in Magellanic cloud surveys, but still controversial

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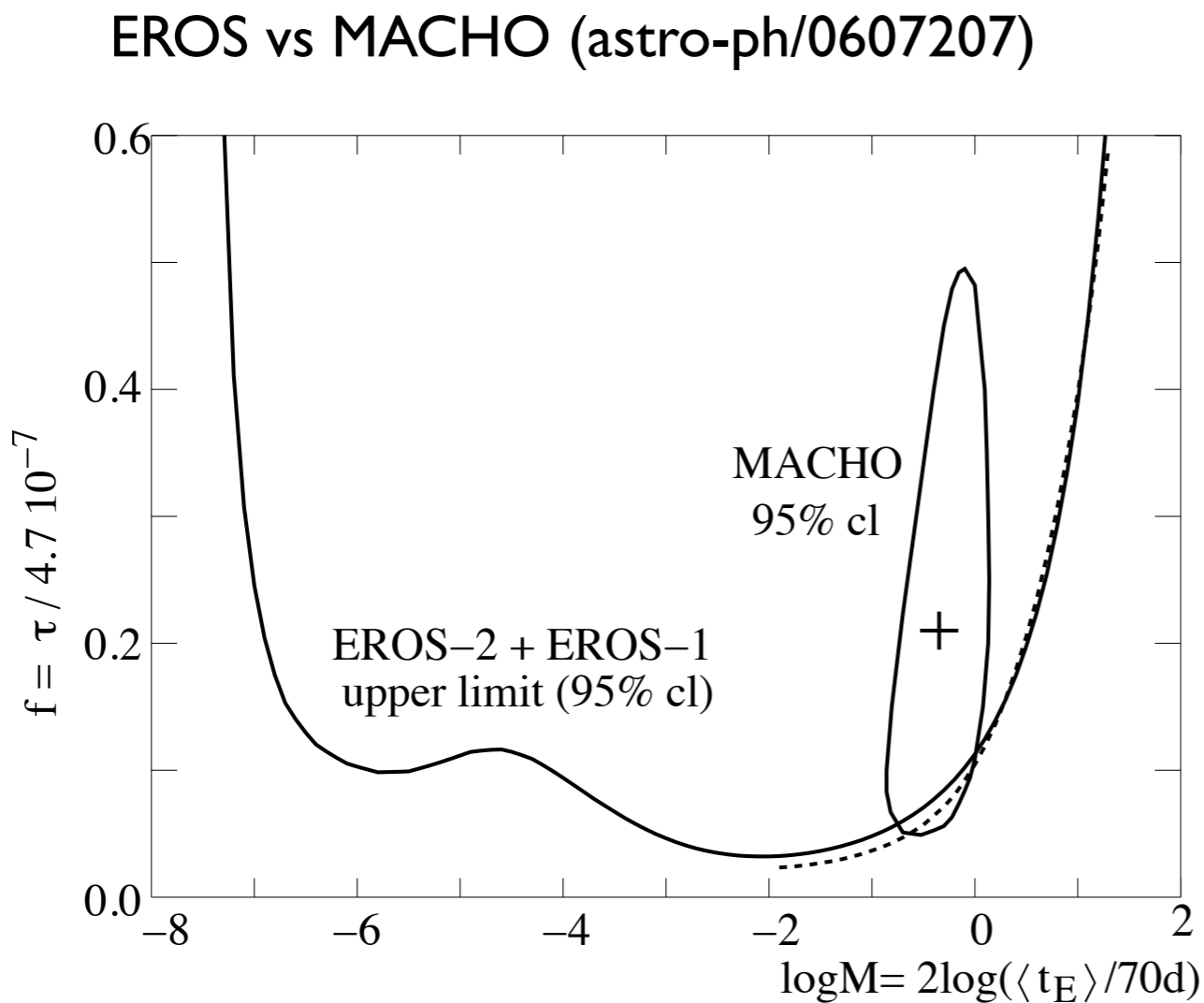
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# Four hints for PBH-DM

## Hint 4: Spatial correlations in CIB and X-ray background

LIGO gravitational wave detection, primordial black holes and the near-IR cosmic infrared background anisotropies

A. Kashlinsky<sup>1</sup>,

### ABSTRACT

LIGO's discovery of a gravitational wave from two merging black holes (BHs) of similar masses rekindled suggestions that primordial BHs (PBHs) make up the dark matter (DM). If so, PBHs would add a Poissonian isocurvature density fluctuation component to the inflation-produced adiabatic density fluctuations. For LIGO's BH parameters, this extra component would dominate the small-scale power responsible for collapse of early DM halos at  $z \gtrsim 10$ , where first luminous sources formed. We quantify the resultant increase in high- $z$  abundances of collapsed halos that are suitable for producing the first generation of stars and luminous sources. The significantly increased abundance of the early halos would naturally explain the observed source-subtracted near-IR cosmic infrared background (CIB) fluctuations, which cannot be accounted for by known galaxy populations. For LIGO's BH parameters this increase is such that the observed CIB fluctuation levels at 2 to 5  $\mu\text{m}$  can be produced if only a tiny fraction of baryons in the collapsed DM halos forms luminous sources. Gas accretion onto these PBHs in collapsed halos, where first stars should also form, would straightforwardly account for the observed high coherence between the CIB and unresolved cosmic X-ray background in soft X-rays. We discuss modifications possibly required in the processes of first star formation if LIGO-type BHs indeed make up the bulk or all of DM. The arguments are valid only if the PBHs make up all, or at least most, of DM, but at the same time the mechanism appears inevitable if DM is made of PBHs.

1605.04023  
1709.02824

# ...and future prospects

- Detecting a BH below the Chandrasekar mass (LIGO)
- Numerous merging events seen in GW detectors (LIGO, VIRGO, ET...)
- GW Stochastic Background (PTAs, LISA, LIGO)
- Detecting faint dwarf galaxies (DES, Euclid)
- Microlensing surveys (Euclid)
- 21 cm signal (SKA)
- CMB (Planck, S4, LiteBird)
- Star position and velocities (GAIA), LMXB, PS in GC



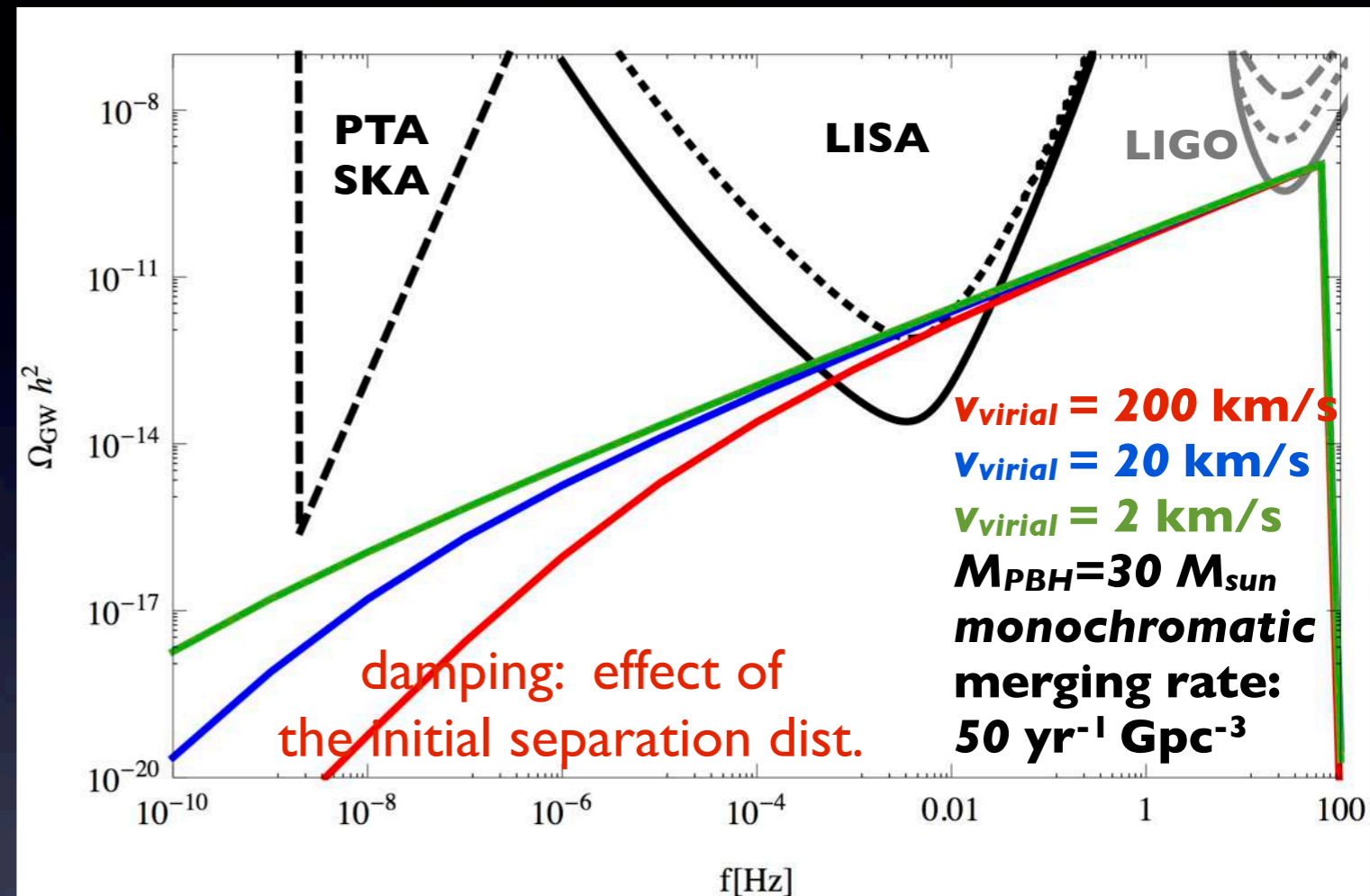
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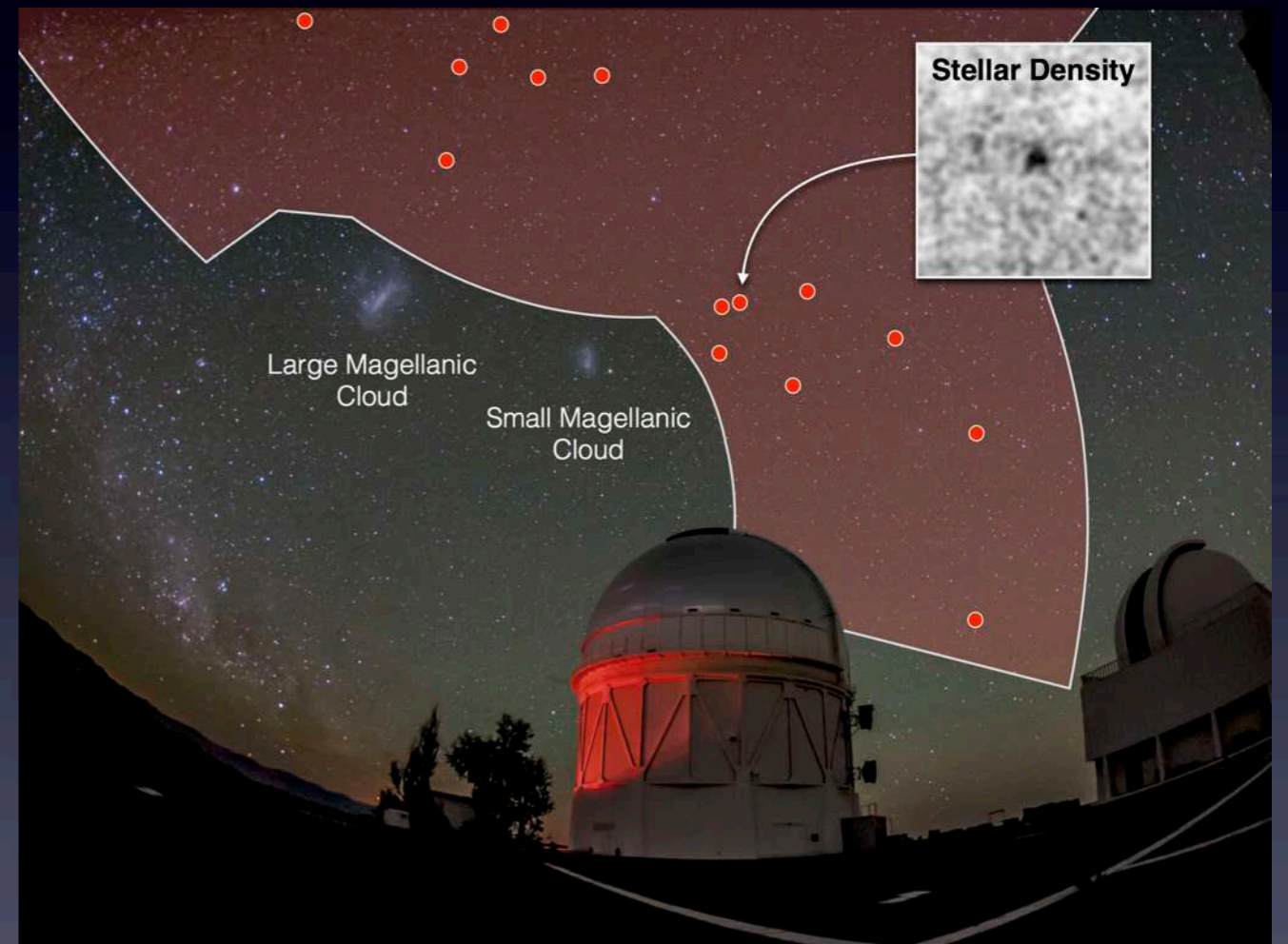
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Clustering allows to distinguish stellar and primordial origins  
SC, JGB, 1610.08479

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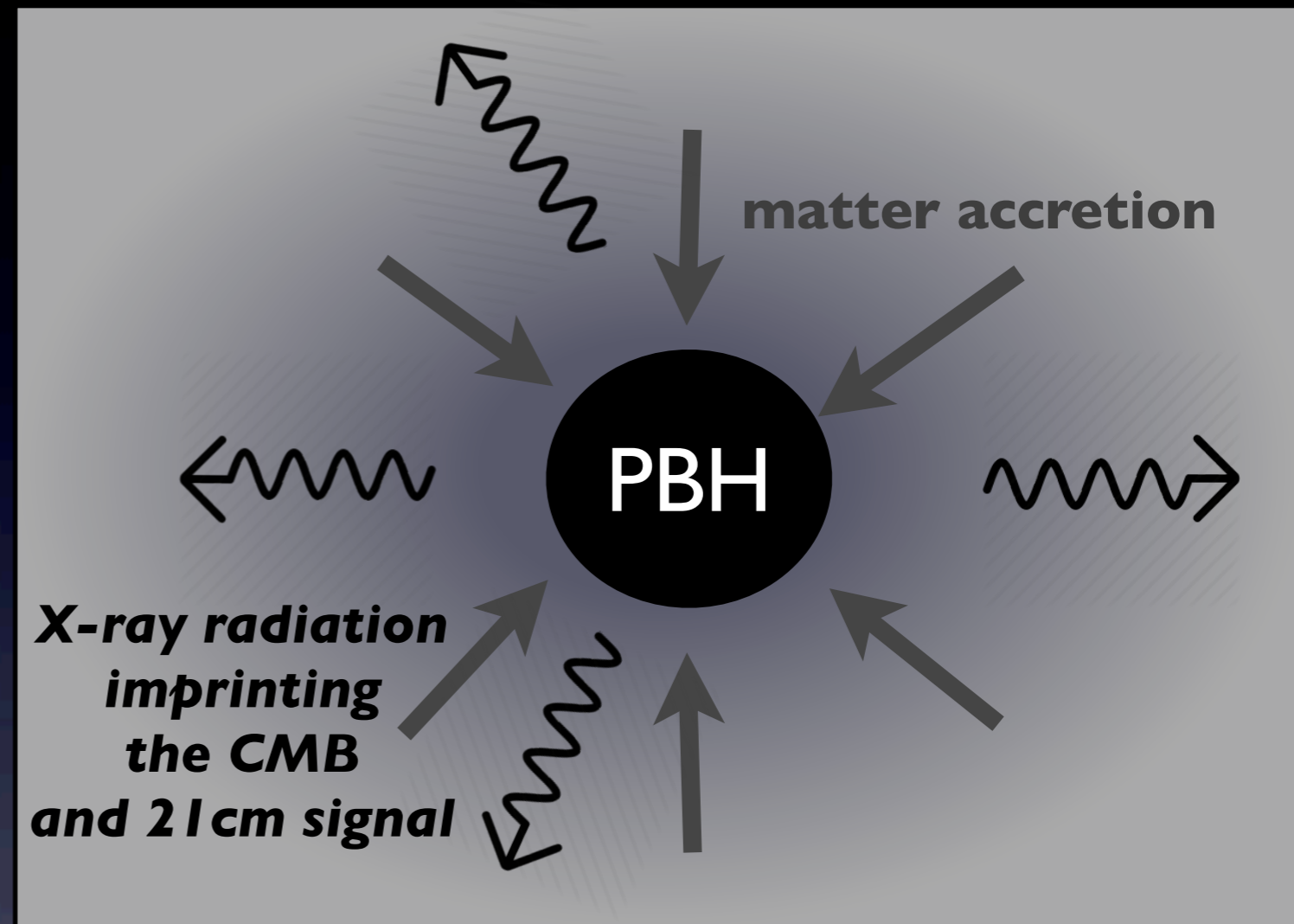
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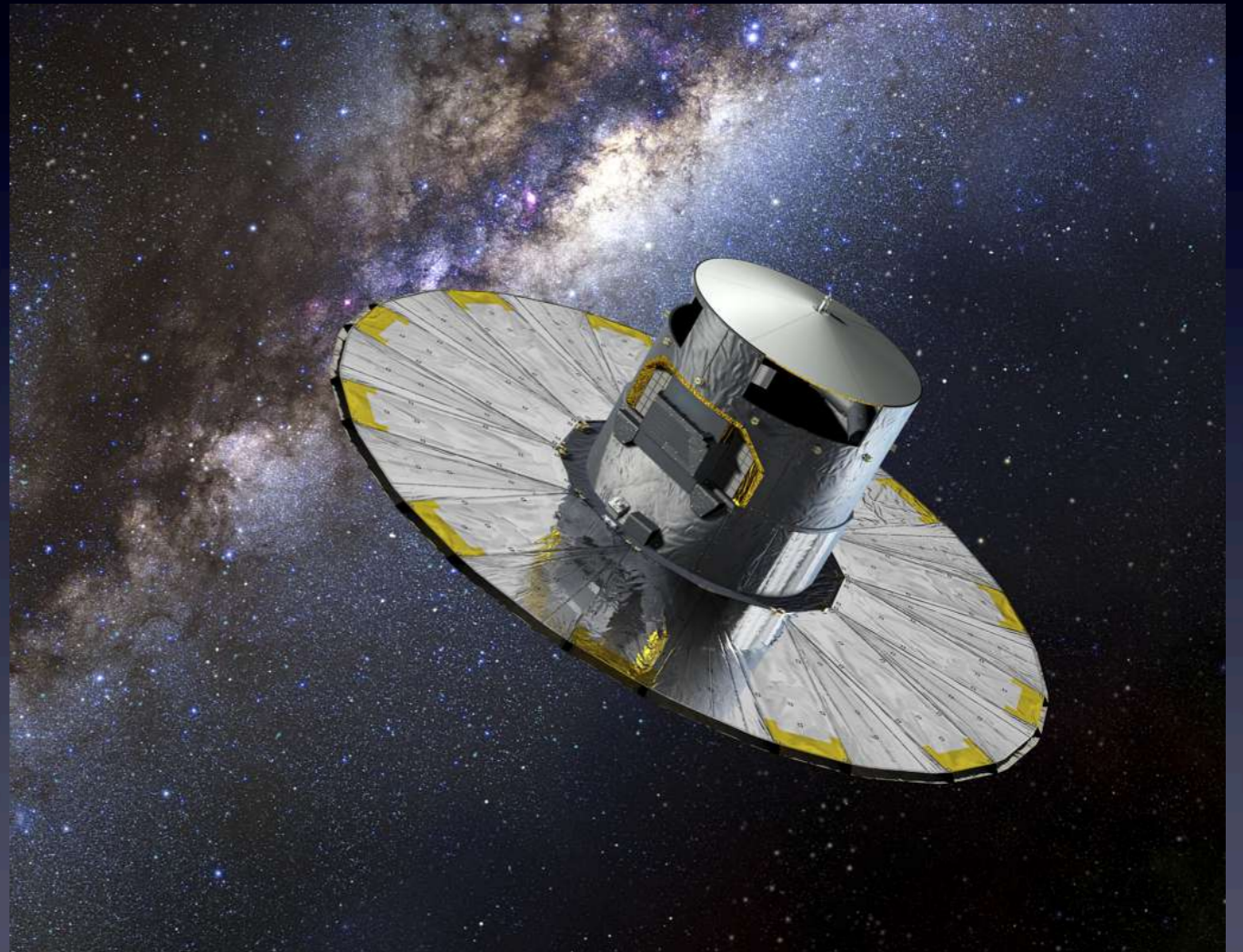
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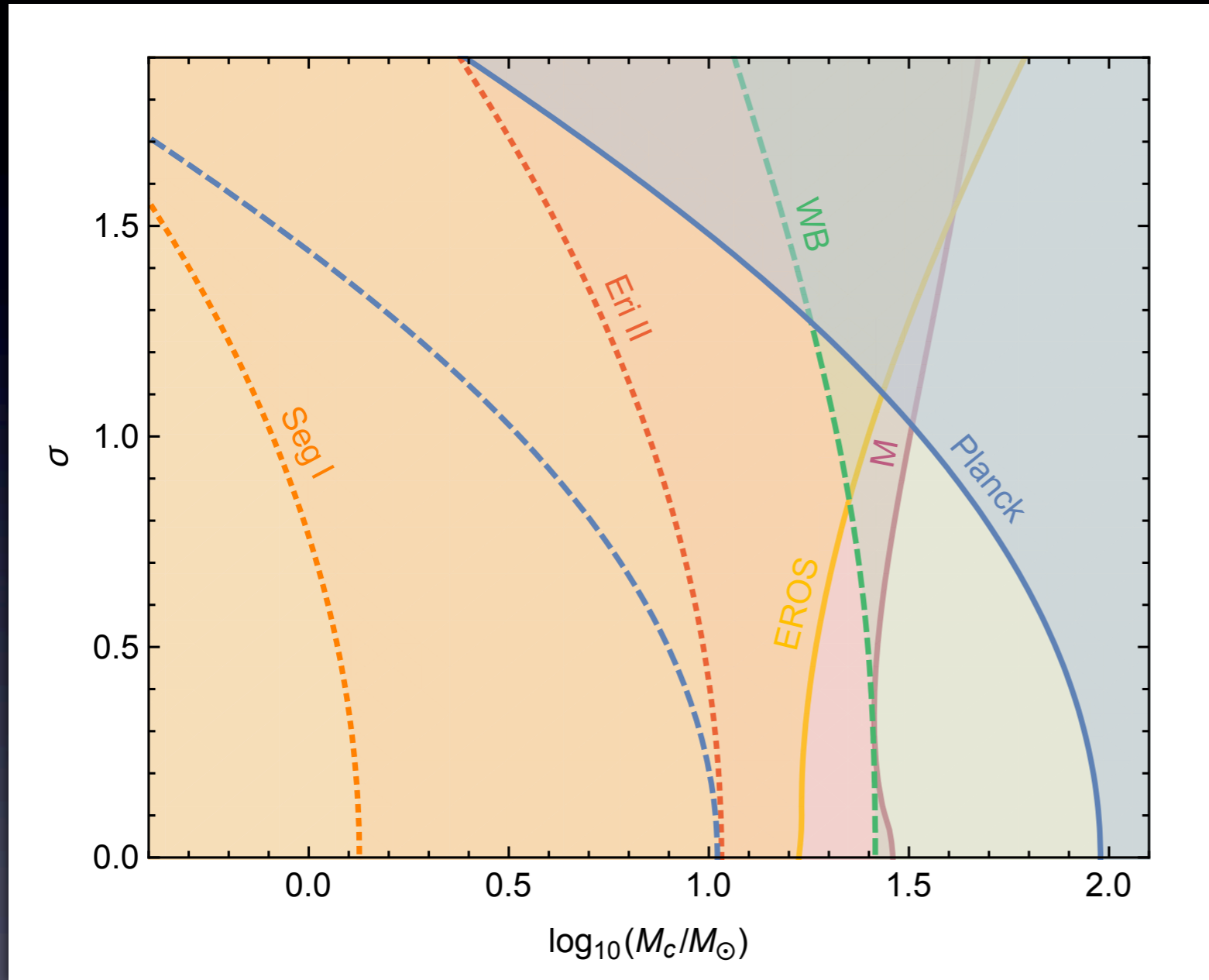
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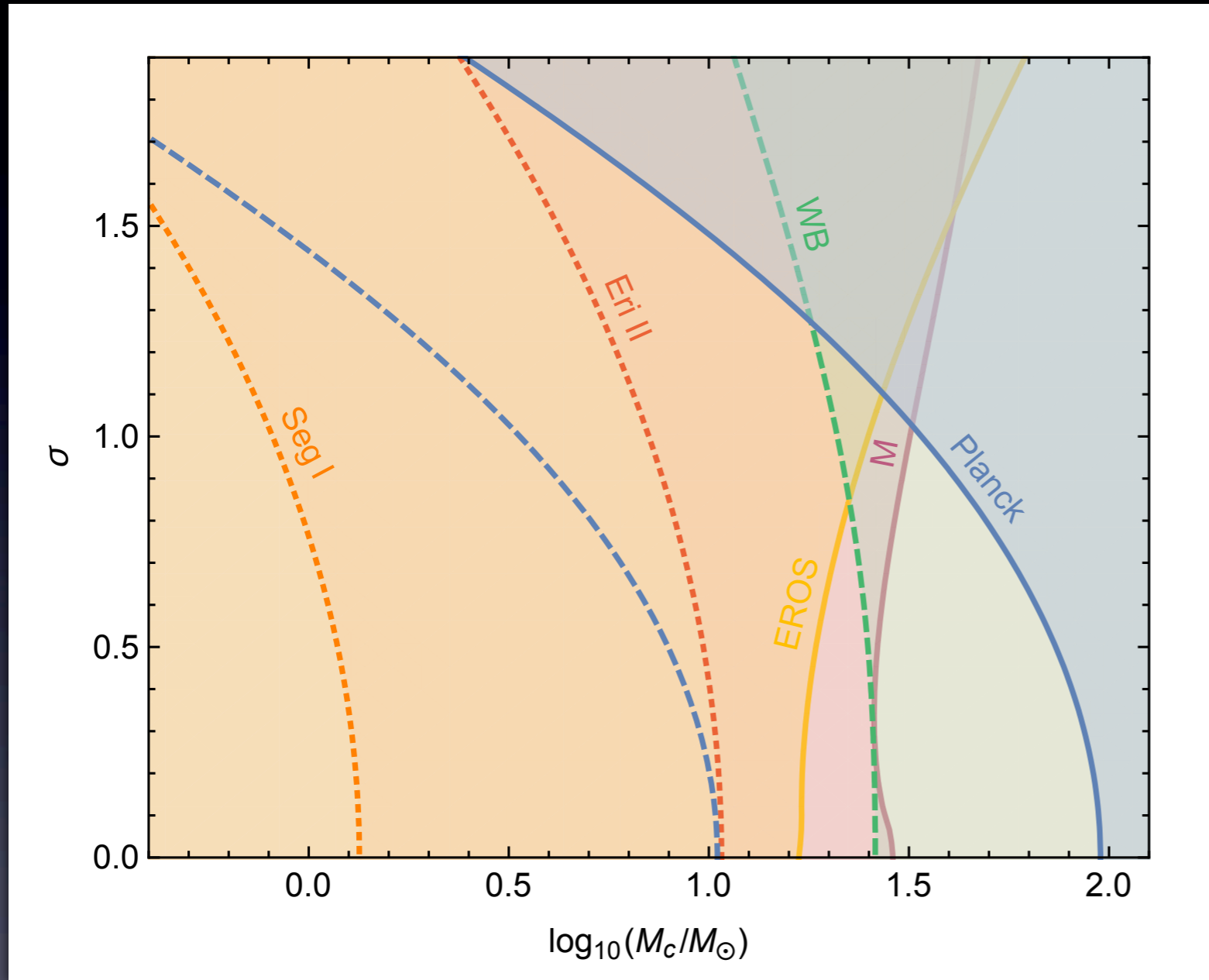
Thank you  
for your attention

# Constraints on PBH abundances



B. Carr et al., 1705.05567

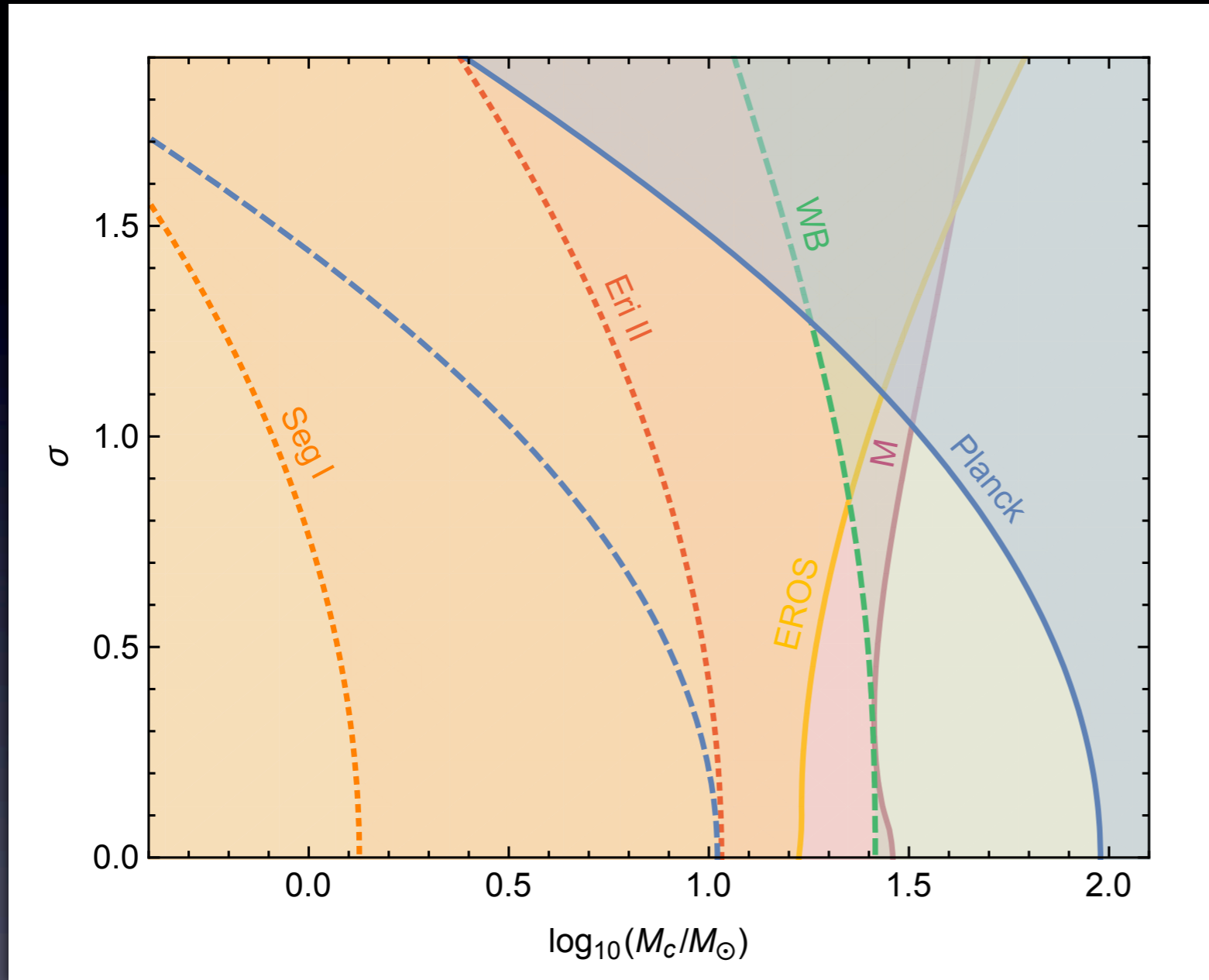
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PBH-DM looks excluded  
in the whole parameter  
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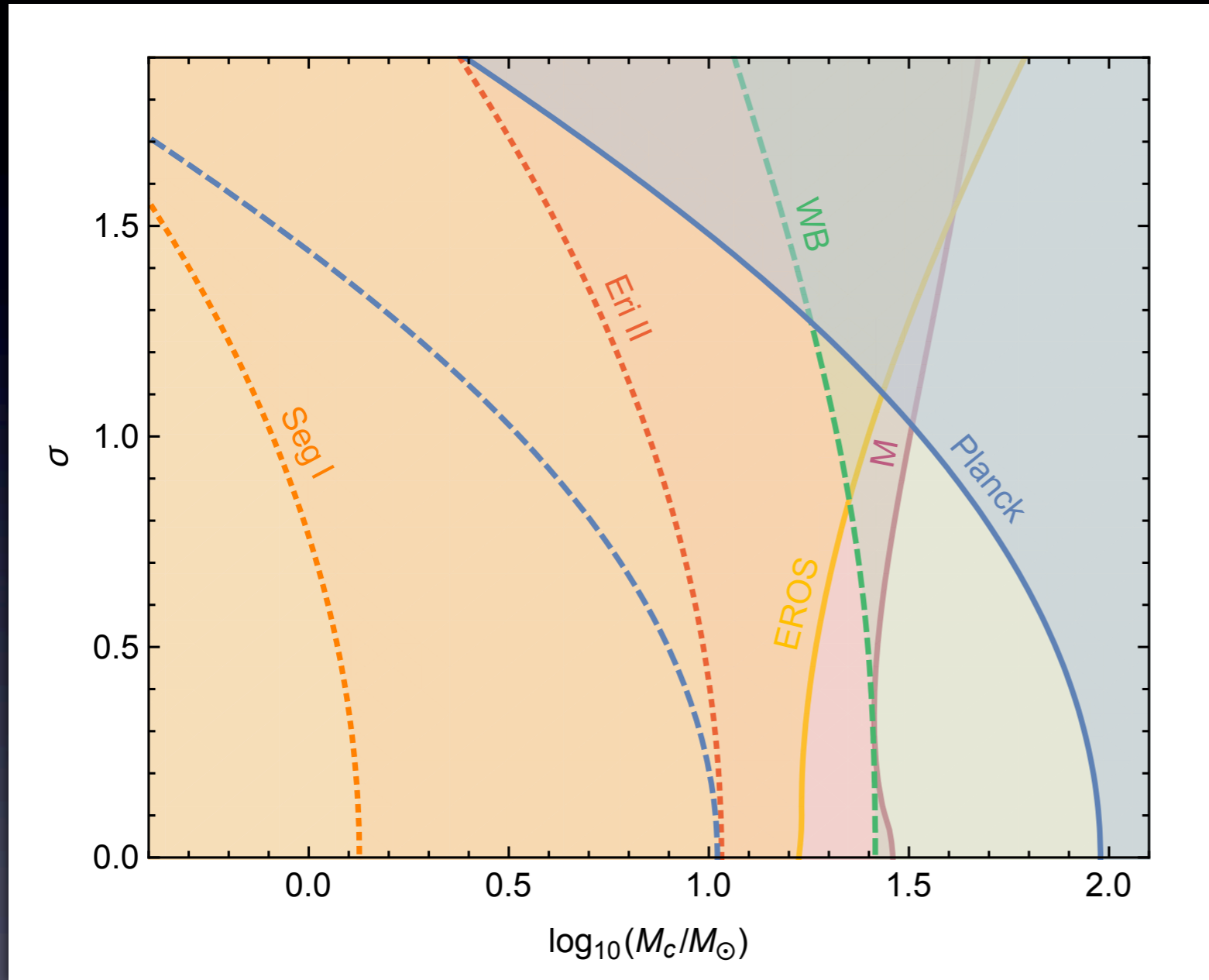


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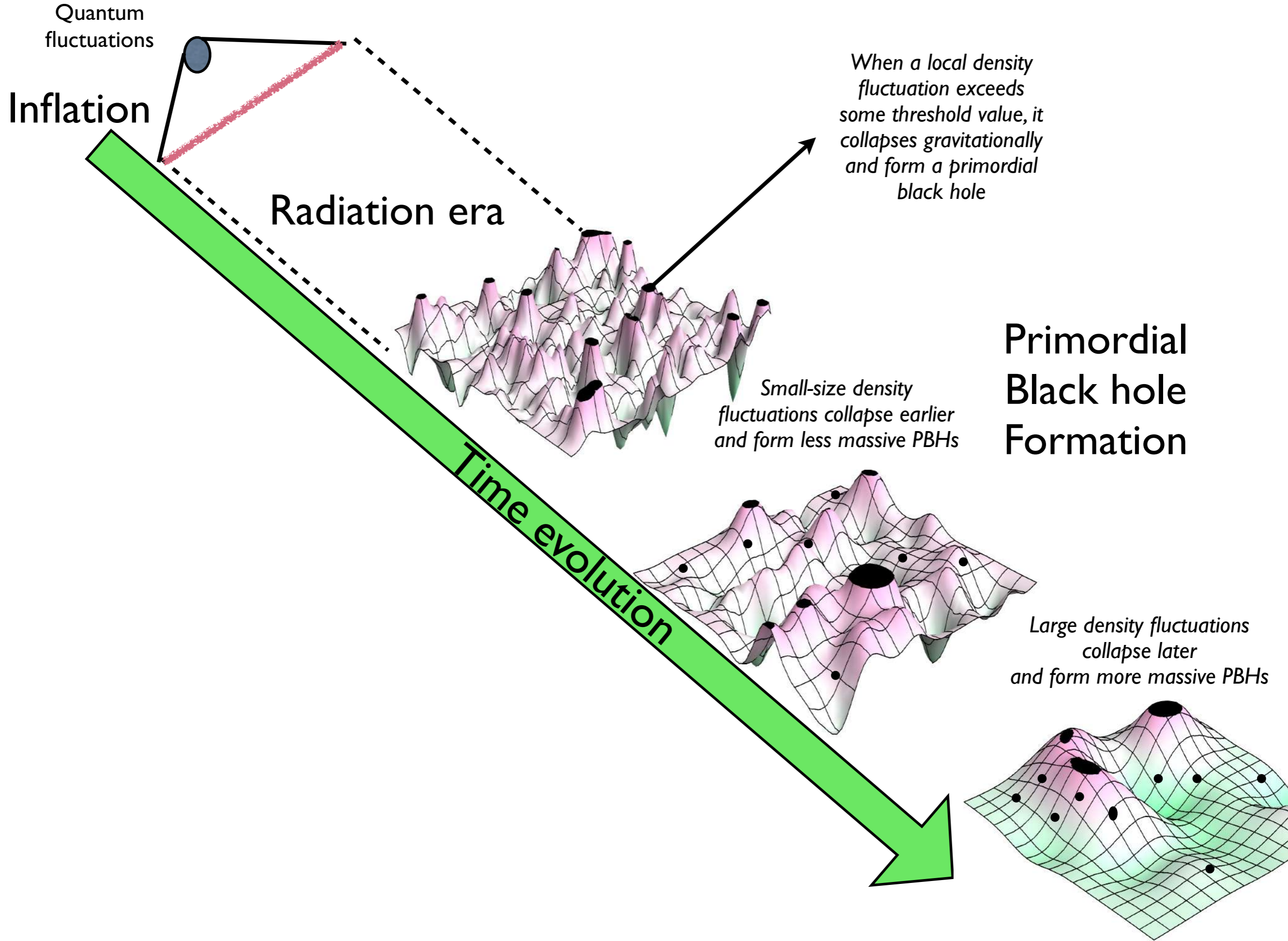


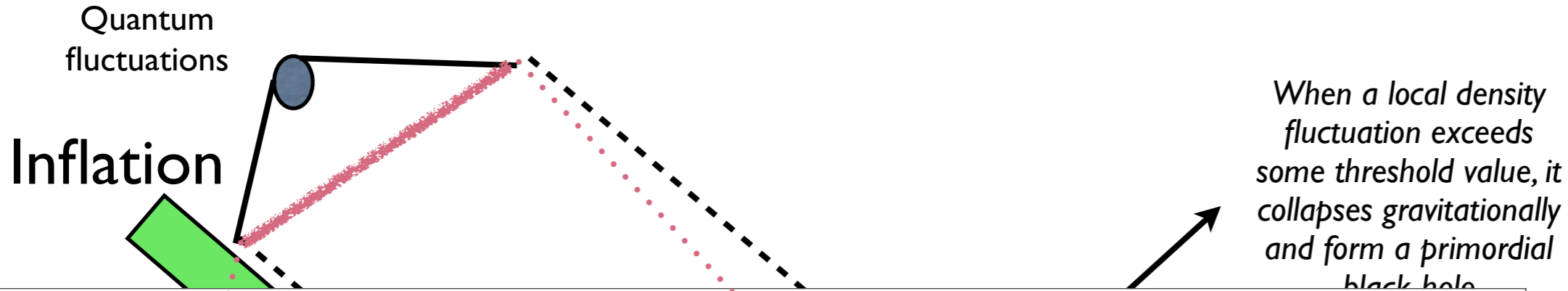
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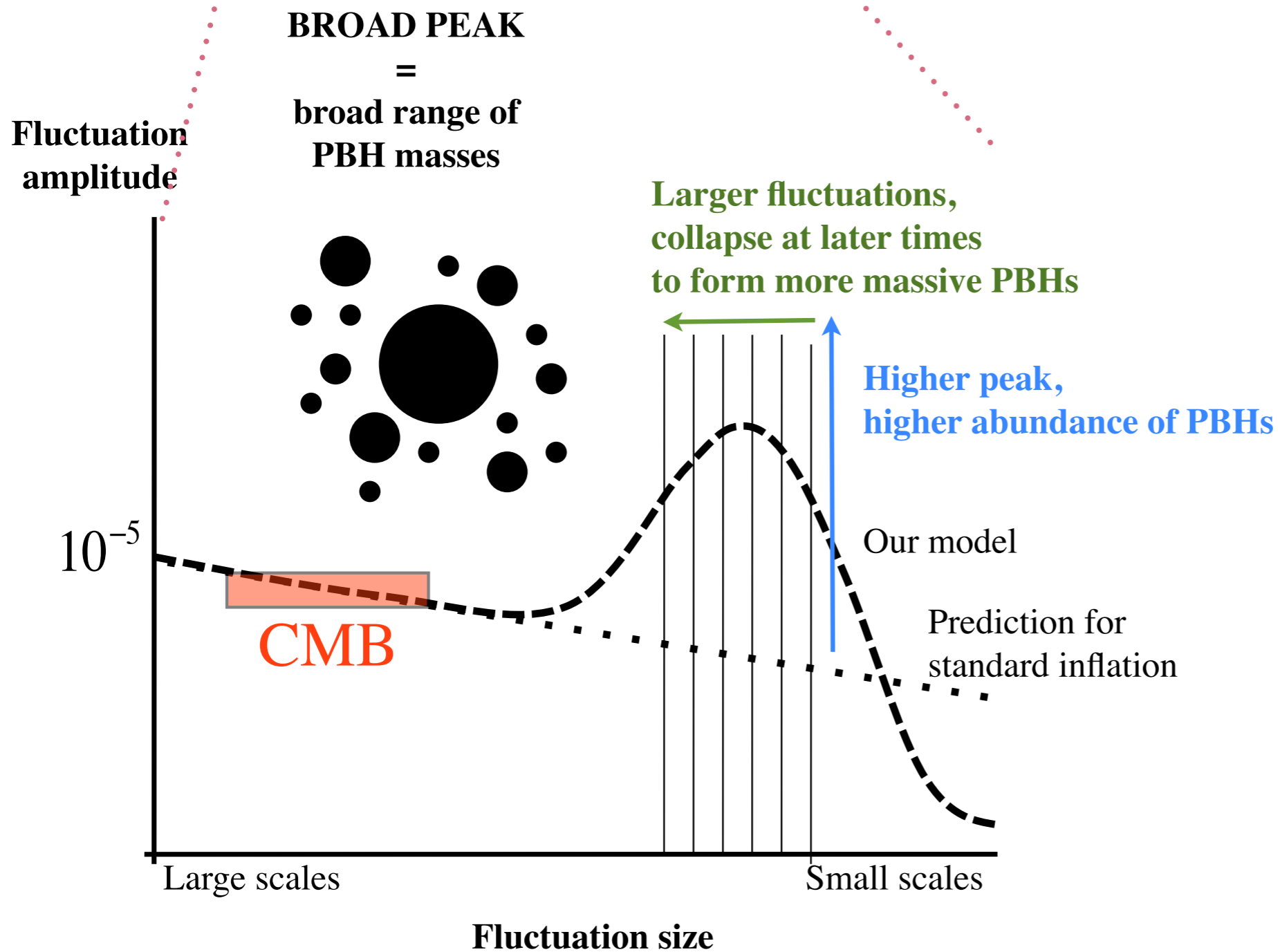
Segue I constraints  
cannot be simply  
extrapolated to  
the broad case

B. Carr et al., 1705.05567





## Spectrum of density fluctuations after inflation



## Primordial Black hole formation

Large density fluctuations collapse later and form more massive PBHs

