S. Clesse
RWTH Aachen University

Can Primordial Black Holes be the Dark Matter?

based on arXiv:1707.04206, 1610.08479, 1603.05234, 1501.00460
(work with J. Garcìa-Bellido, P. Serpico, V. Poulin, F. Calore,...)

DESY Theory Workshop,
Sep. 26-29, 2017, Hamburg

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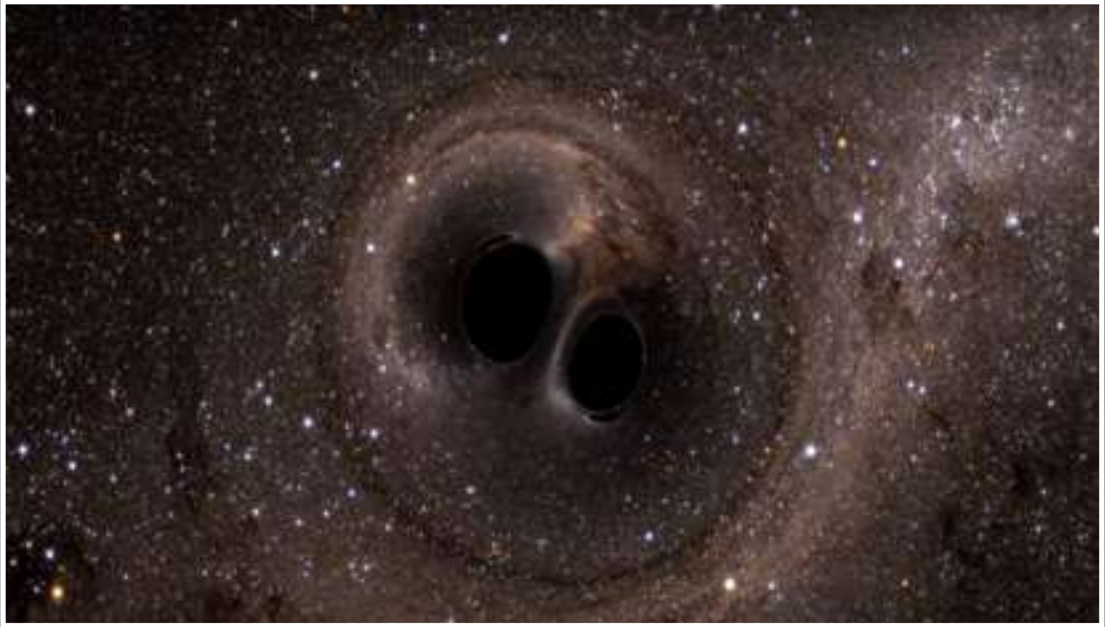

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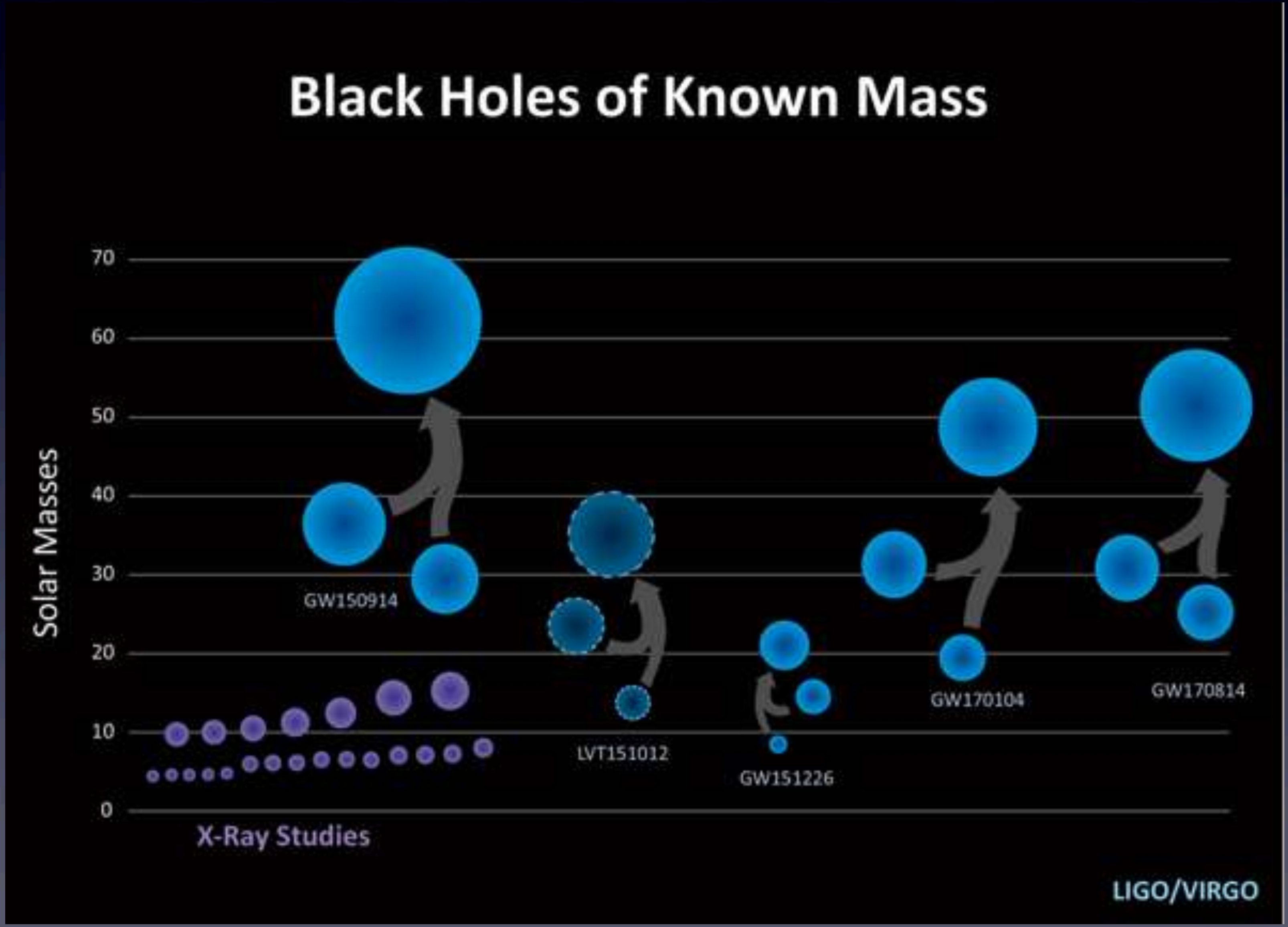
LIGO and the strange BH mergers

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



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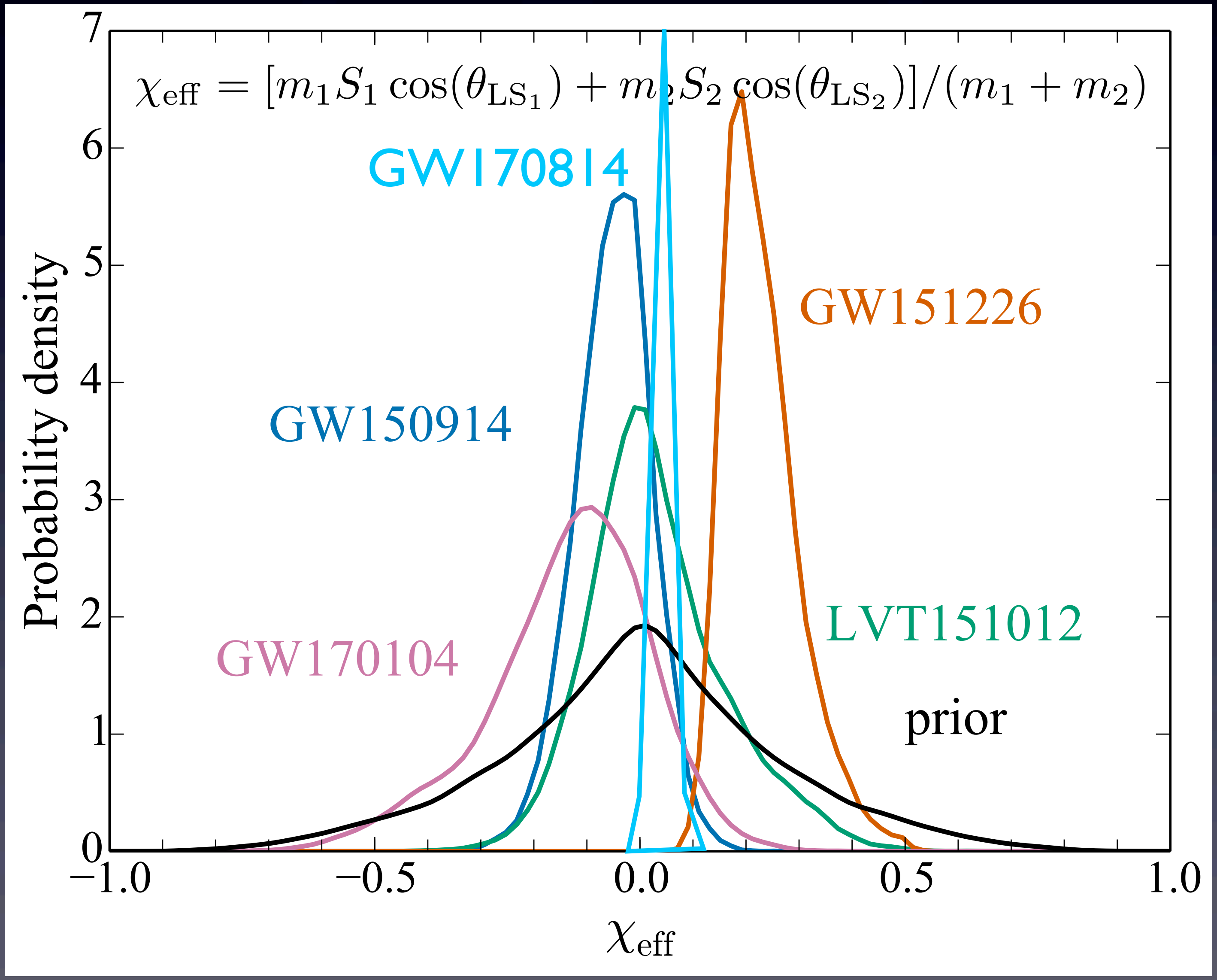

Adapted from Adv.LIGO/VIRGO June release (supl. material)

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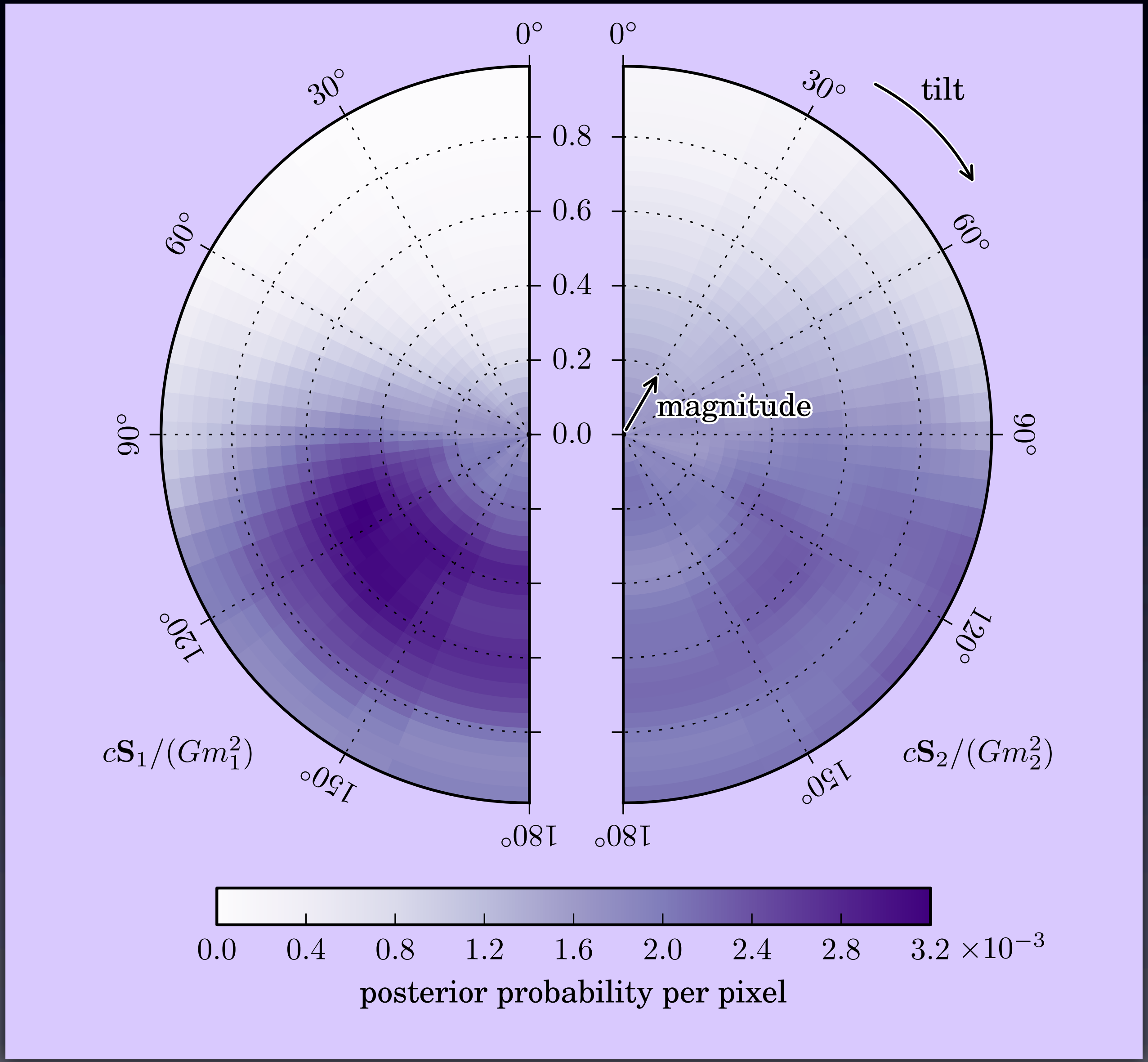

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Confirmation of « a new population of black holes »

In March 2016...

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  Monochromatic spectrum, extended halo mass function

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

Most mergings come from mini-halos

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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...

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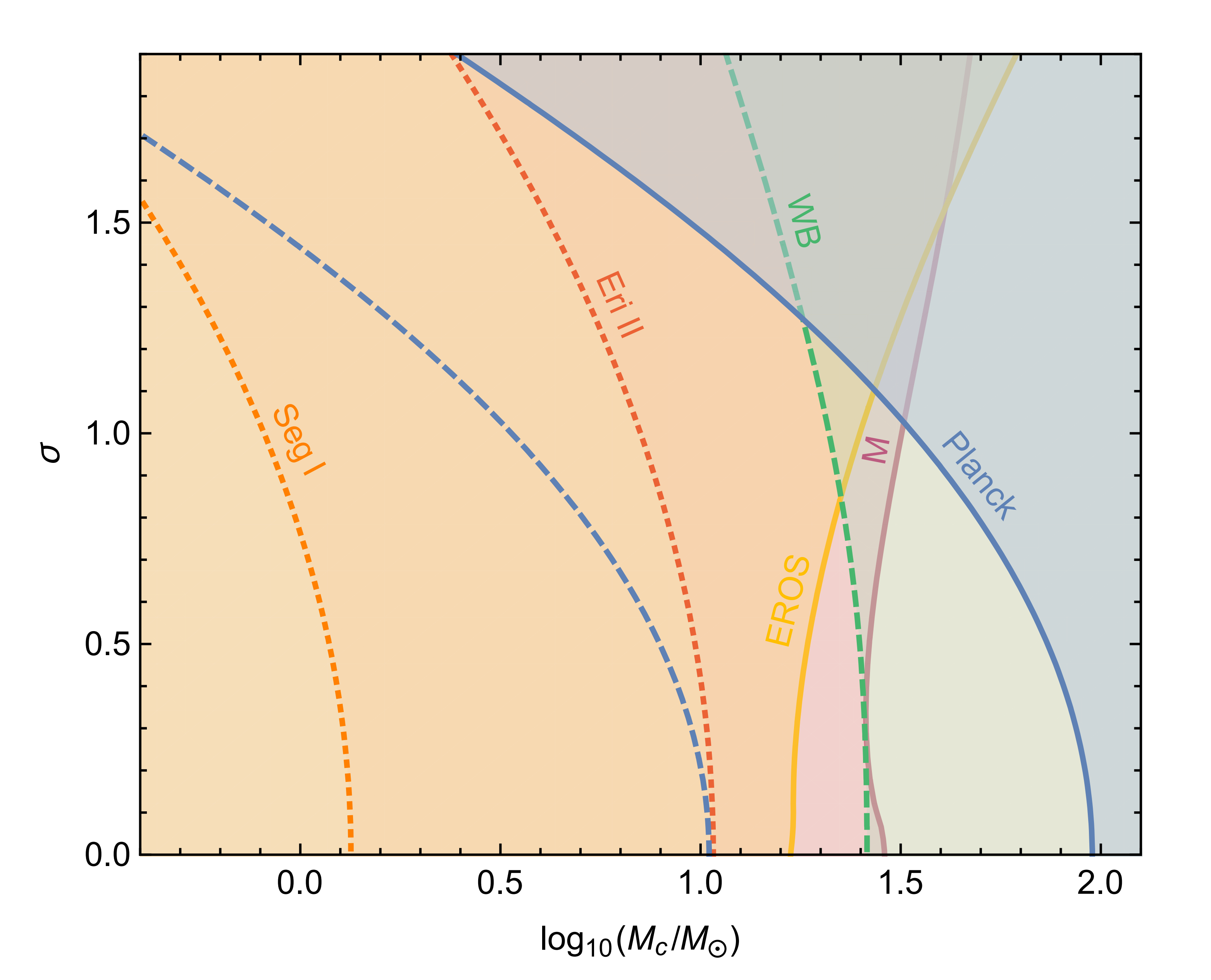
The dark scenario

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

Constraints on PBH abundances



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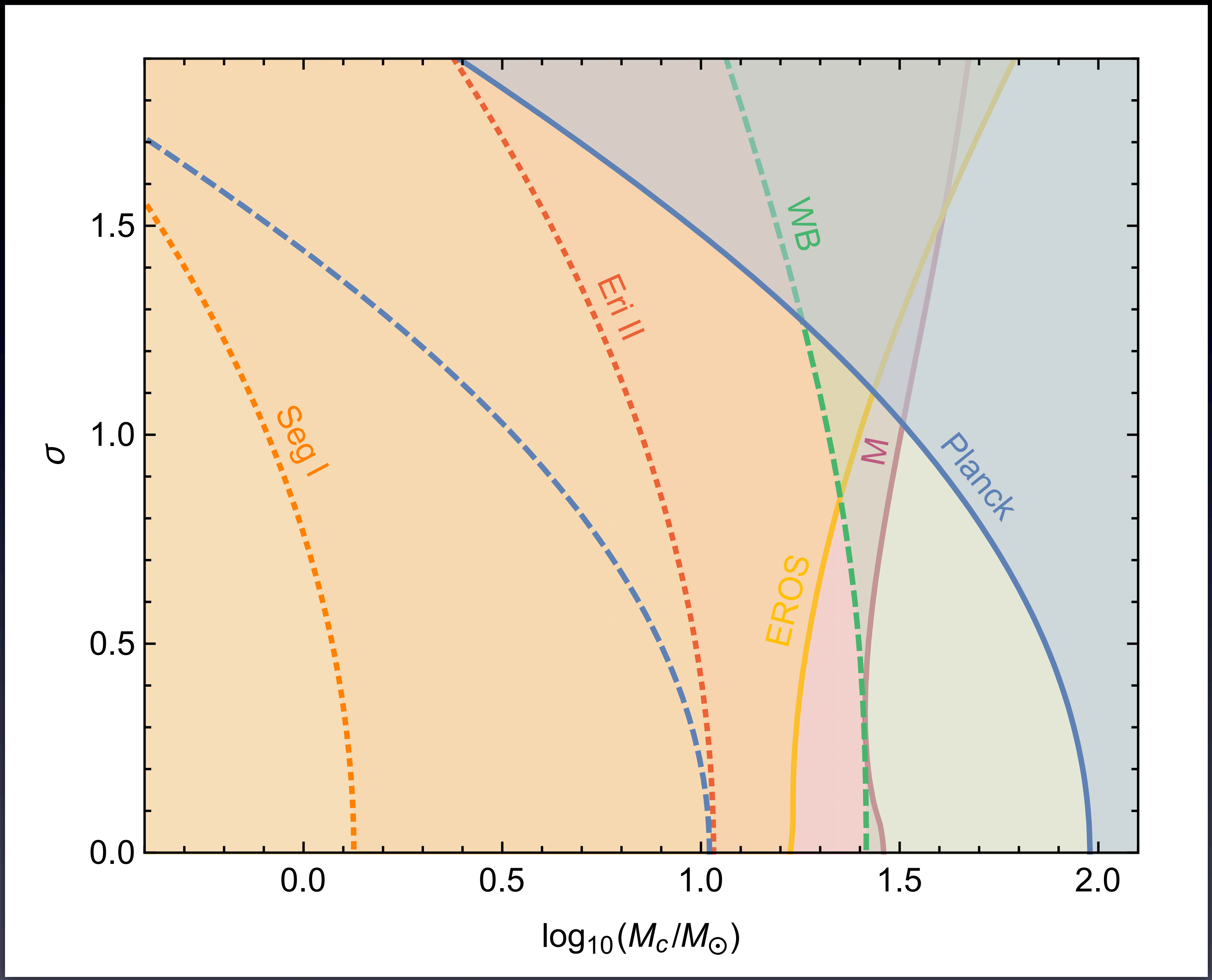

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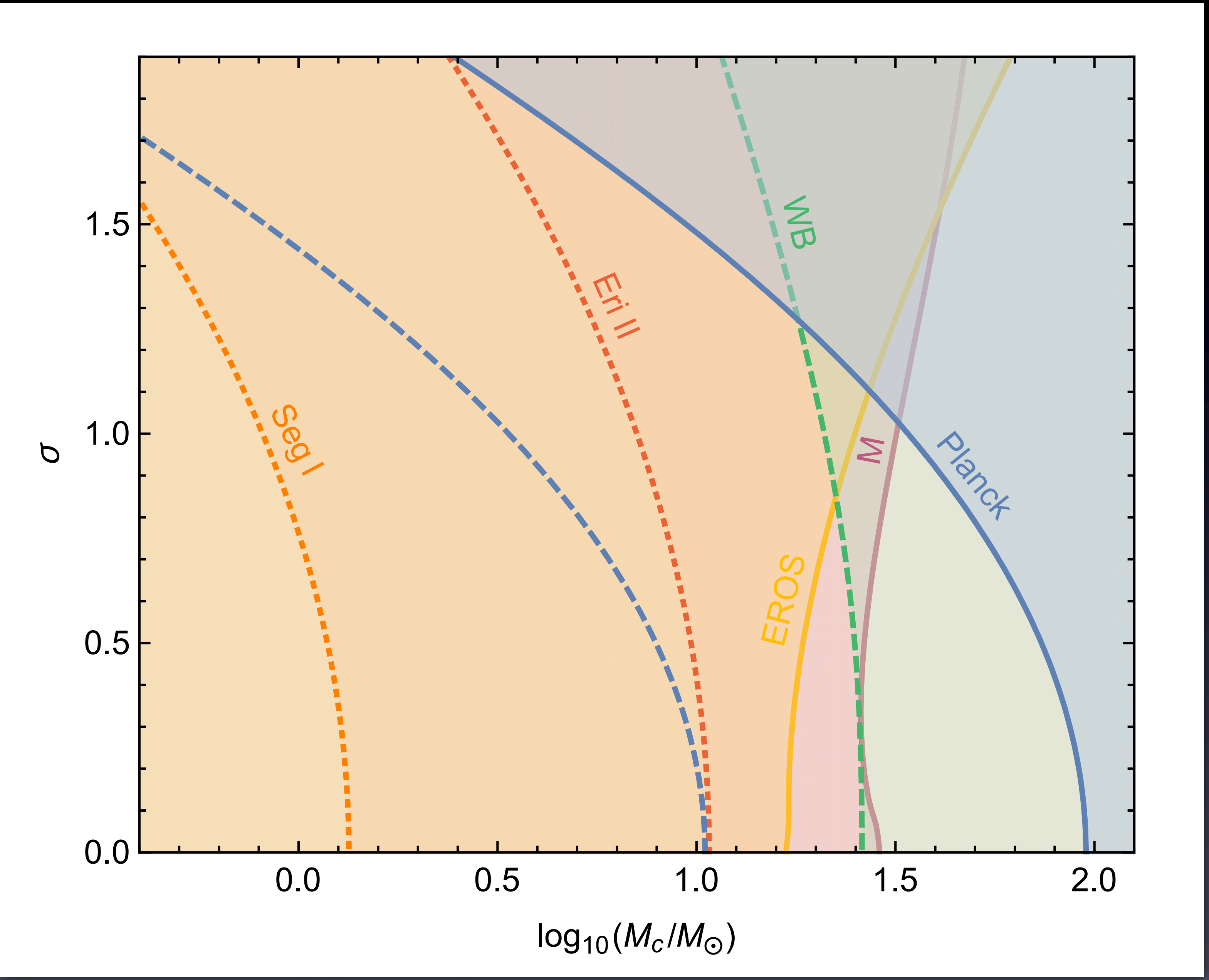

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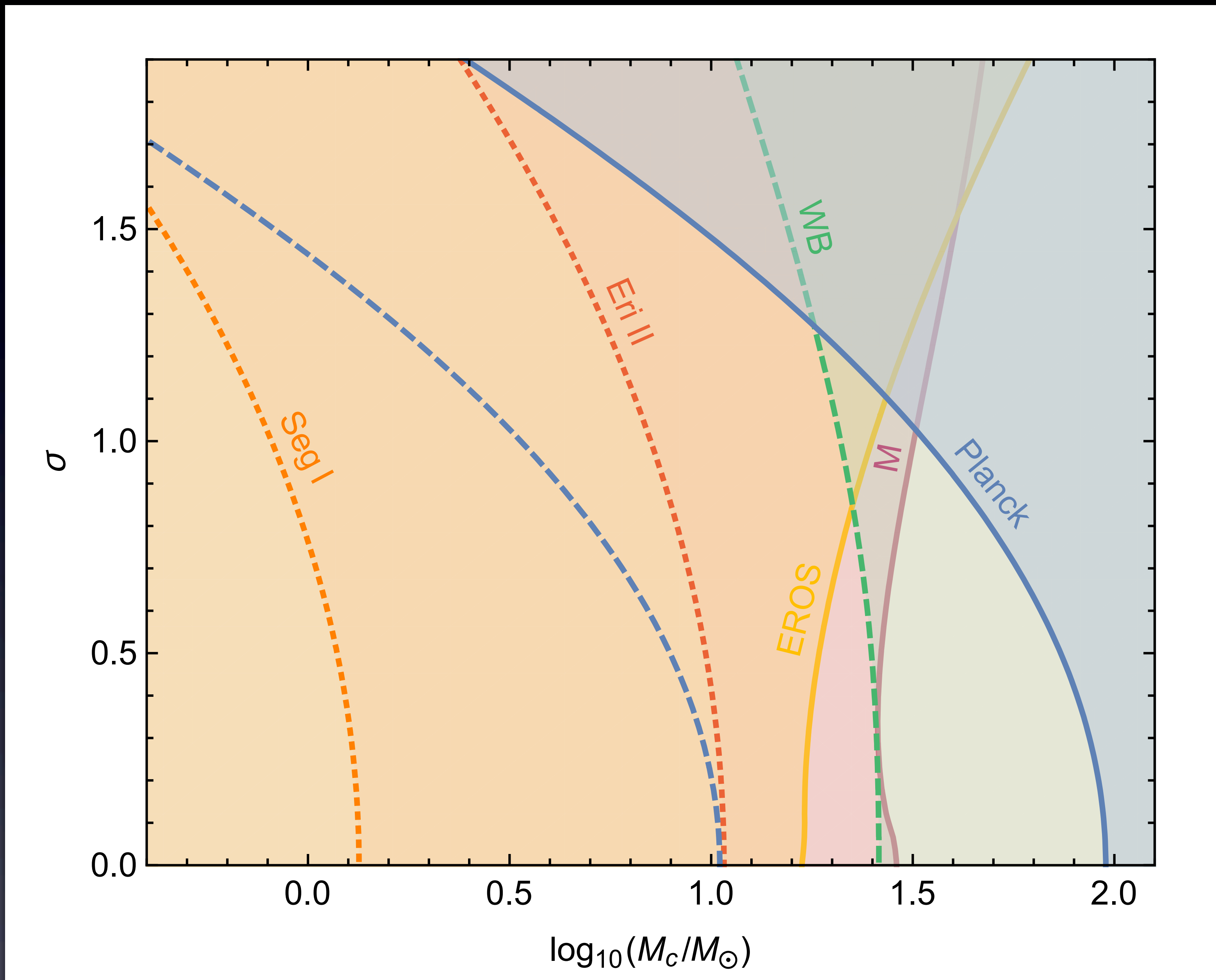

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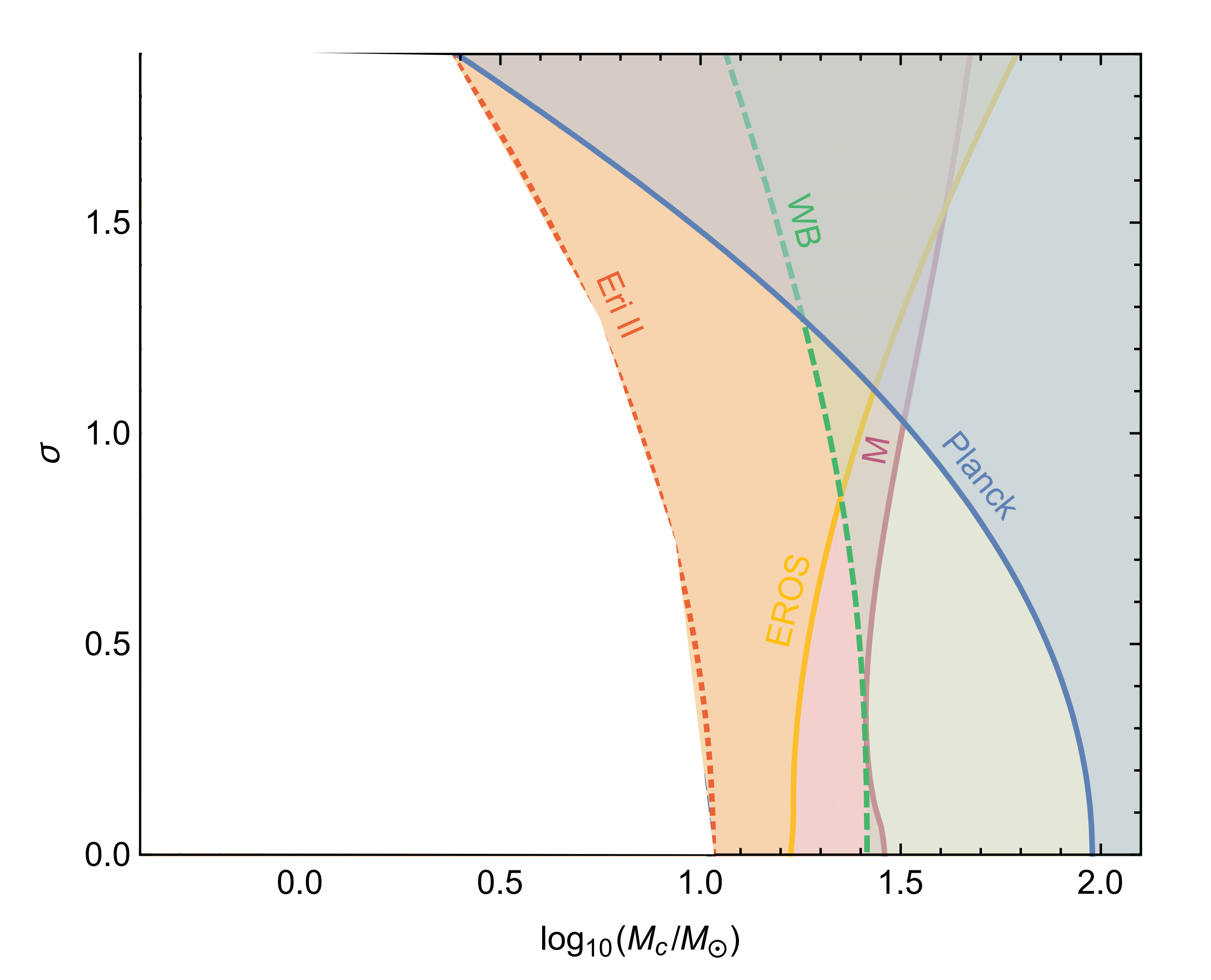

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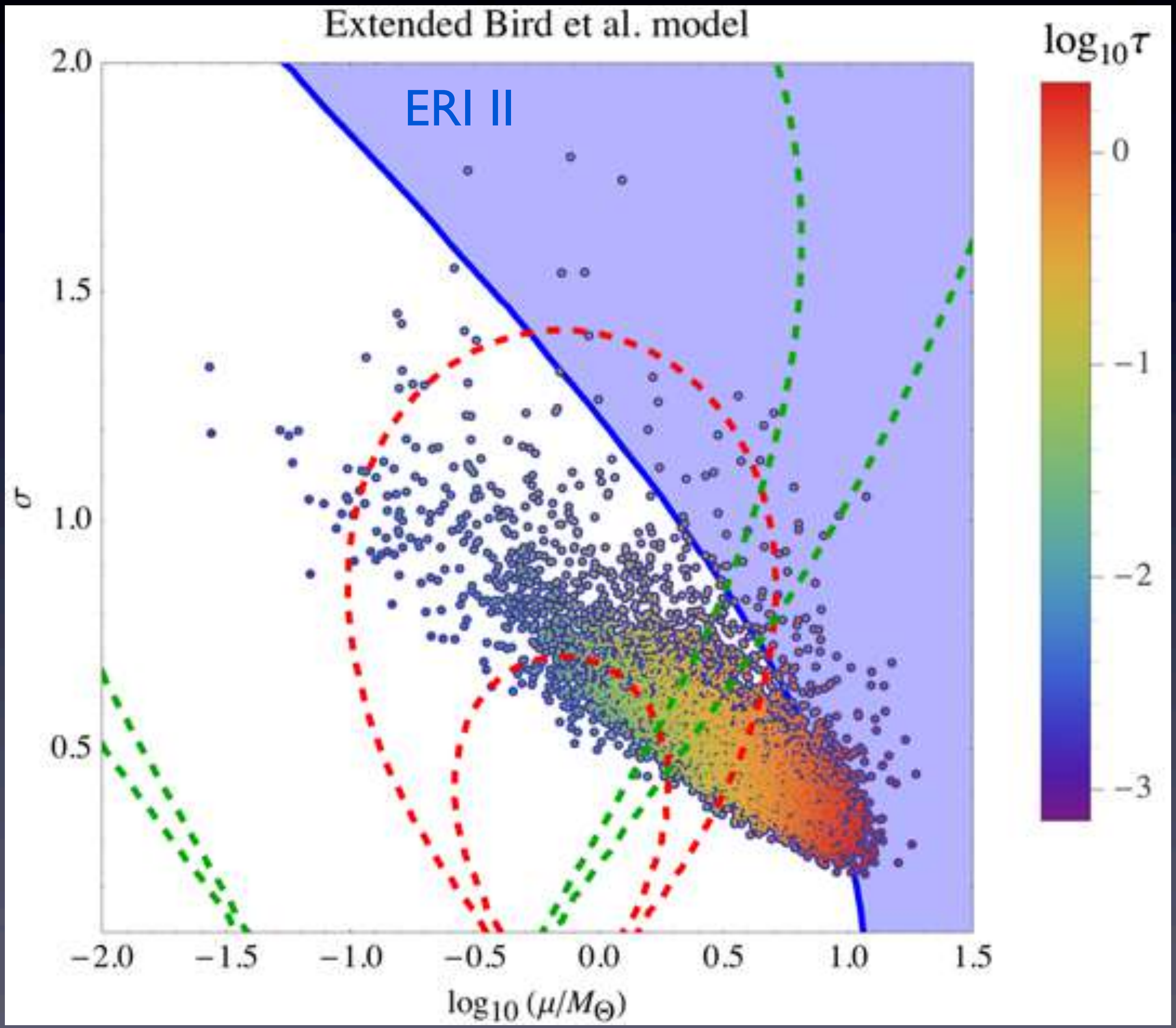
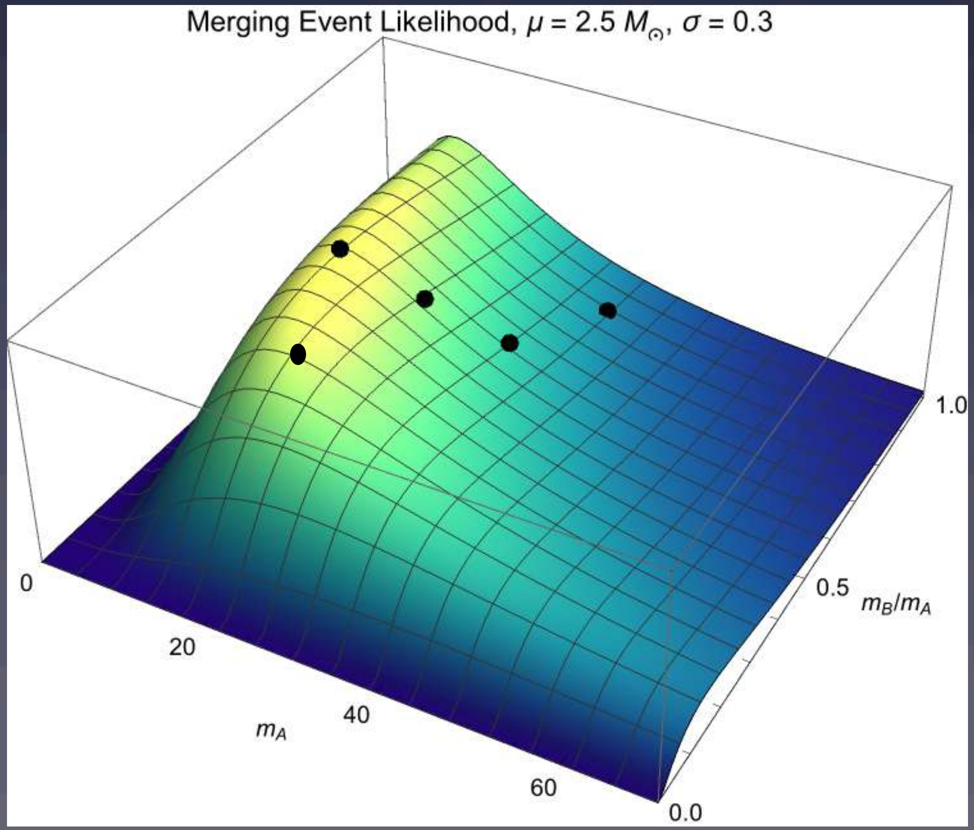
Four hints for PBH-DM

Hint 1: 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



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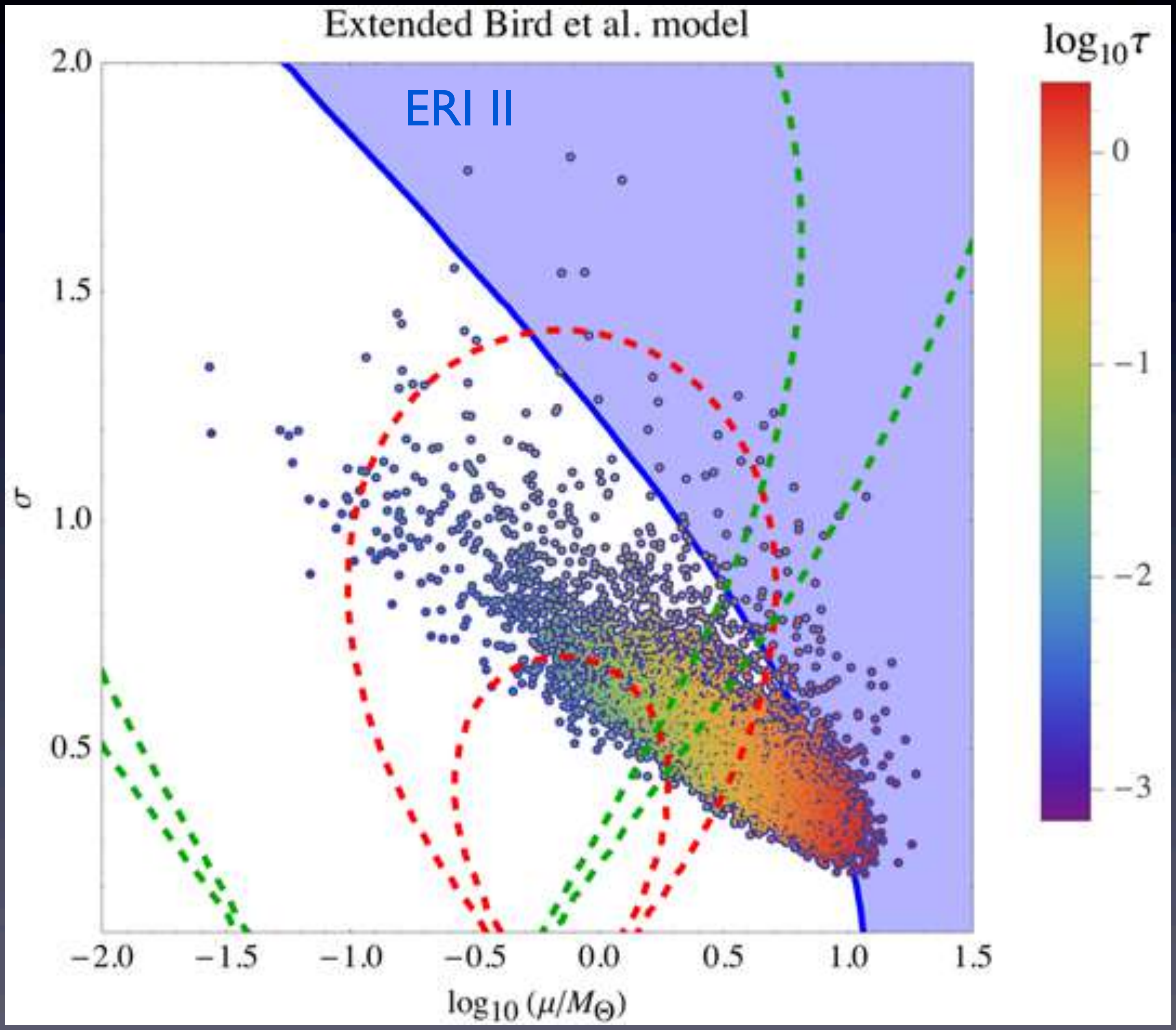
Hint 2: Star clusters and dynamics of faint dwarf galaxies



- 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, missing baryons due to matter accretion
- Re-analysis and N-body simulations in progress...

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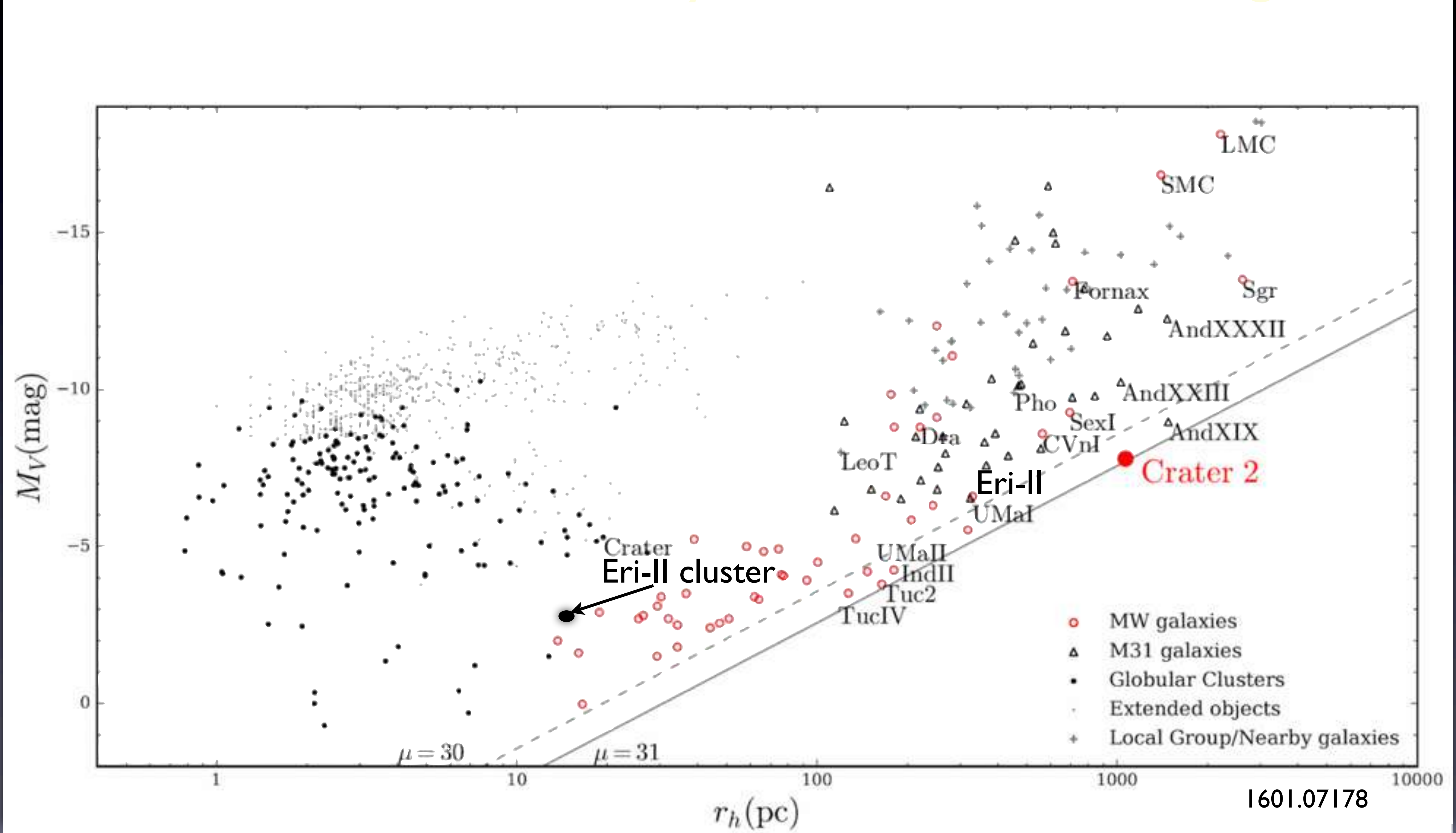

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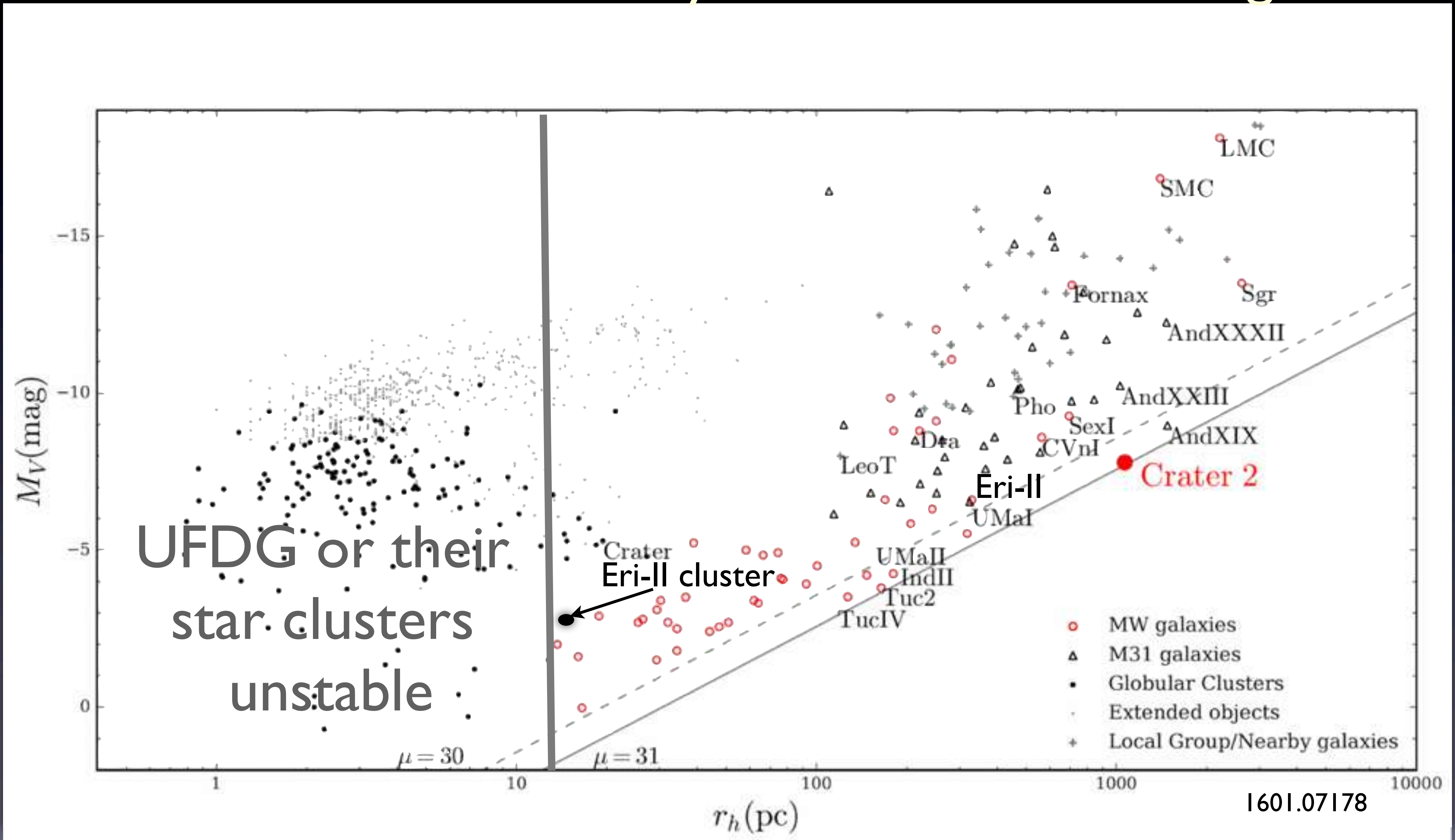

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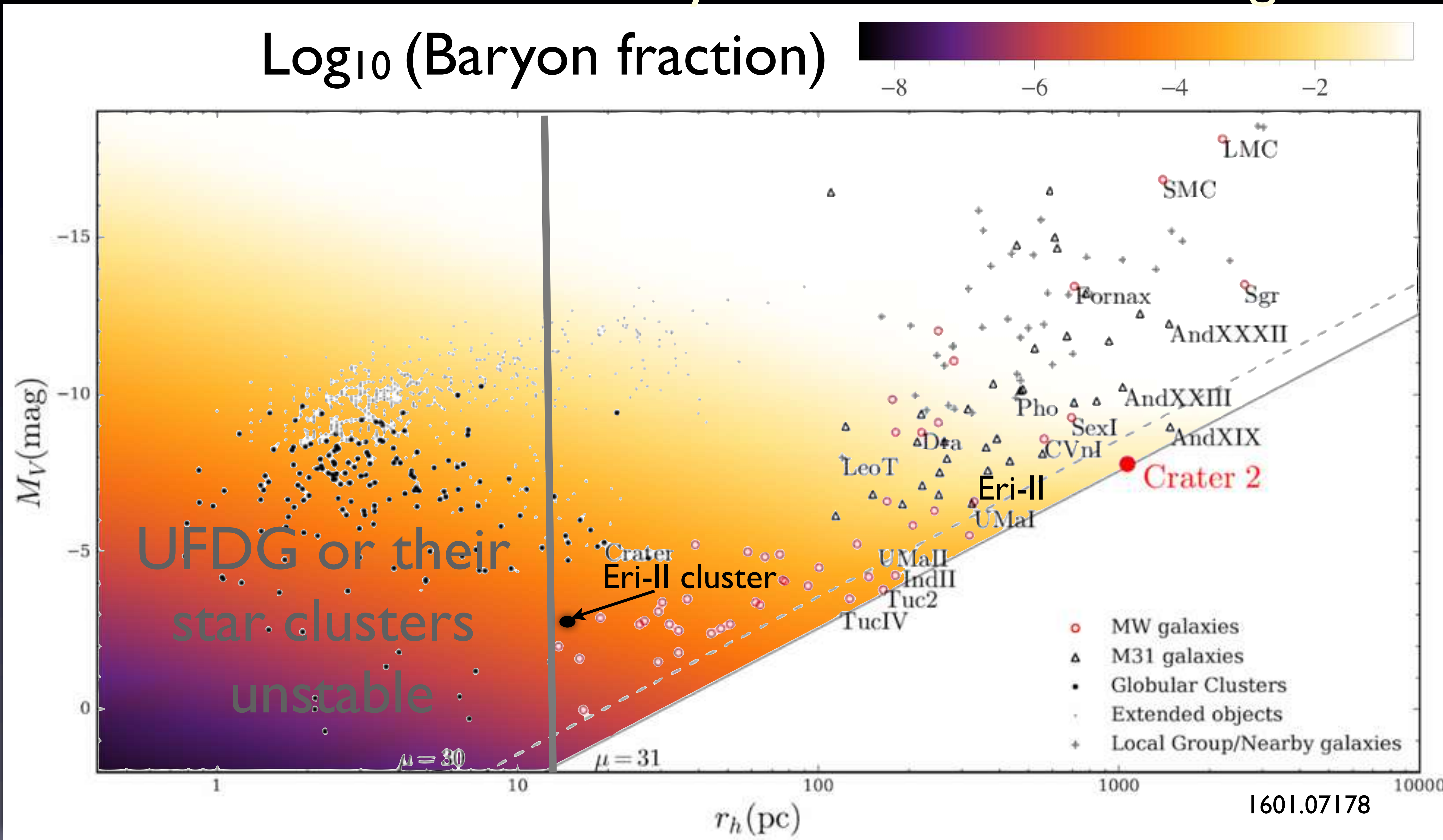

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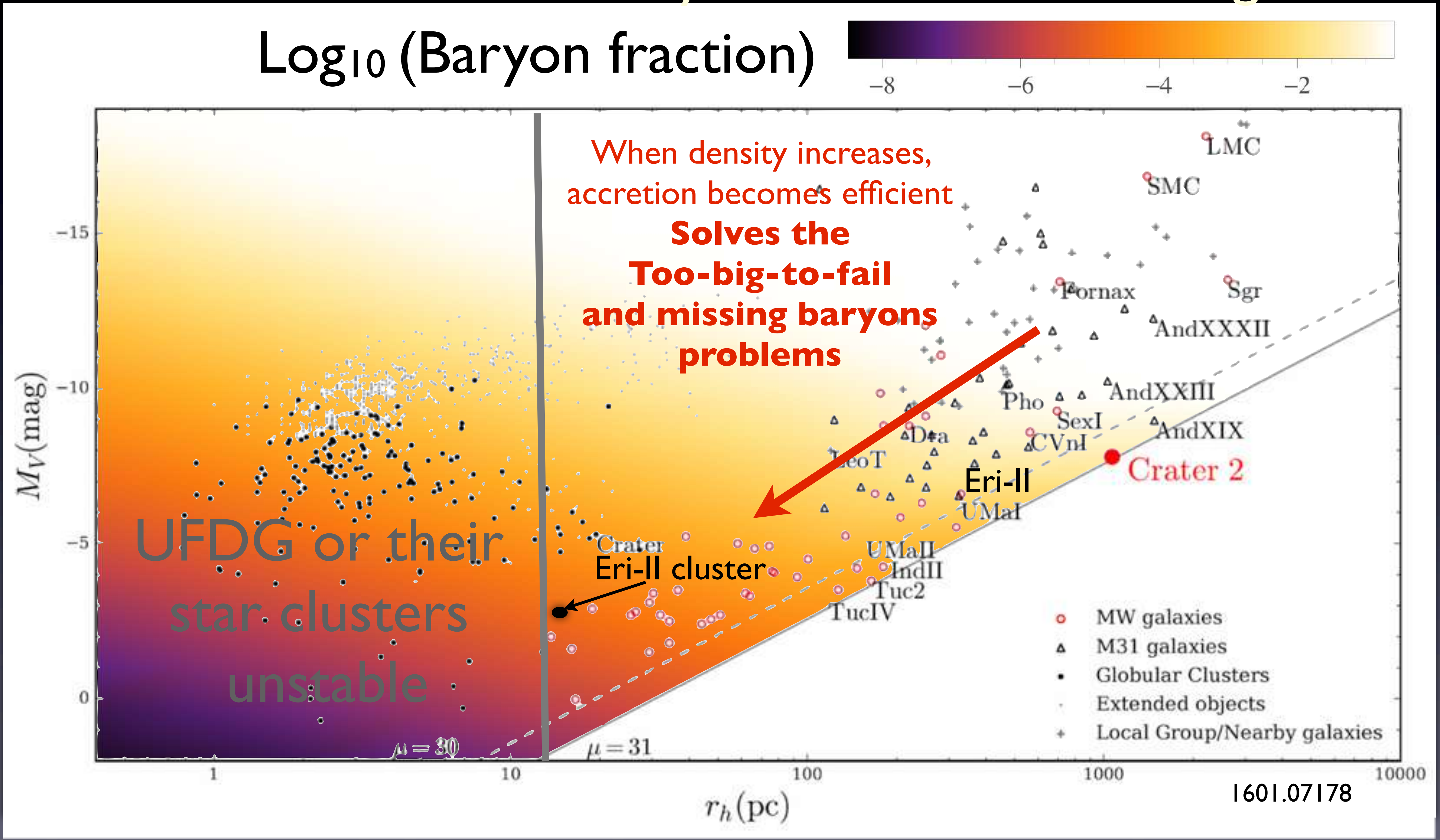

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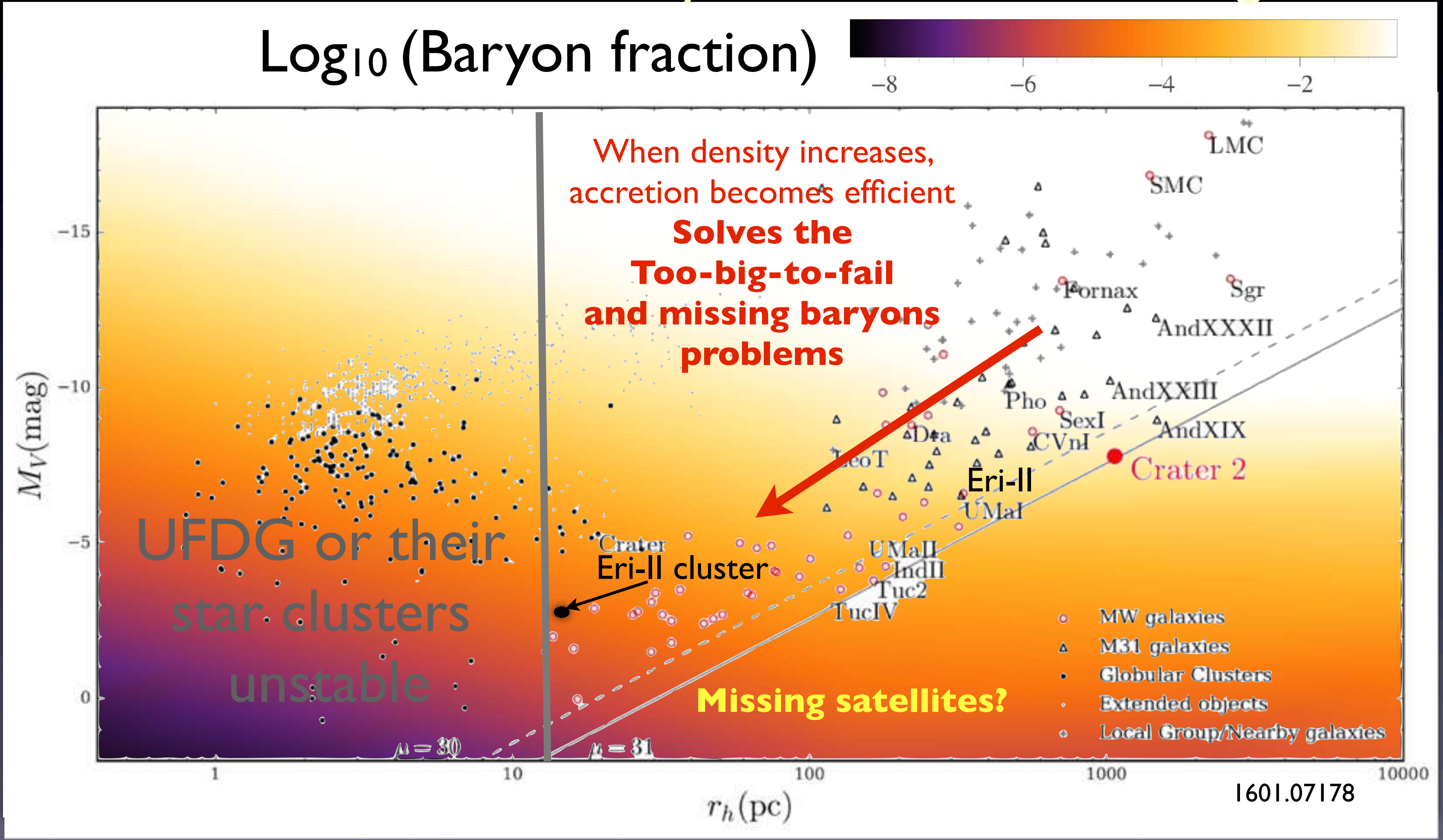

Four hints for PBH-DM

Hint 2: Star clusters and dynamics of faint dwarf galaxies

- Dynamical heating of cusps due to two-body interactions
- Relaxation time scale:

$$t_{\rm rel} \approx \frac{r}{v} \frac{N_{\rm PBH}}{8 \ln N_{\rm PBH}}$$

- **Cusps heated in ~10 Gyrs up to a radius ~ 1kpc**
- Naturally solves the **core-cusp problem**

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] Msun (1504.07246)
- 24 micro-lensing of quasars by galaxies: between 15% and 25% of halo compact objects in range [0.05-0.45] Msun (1702.00947)
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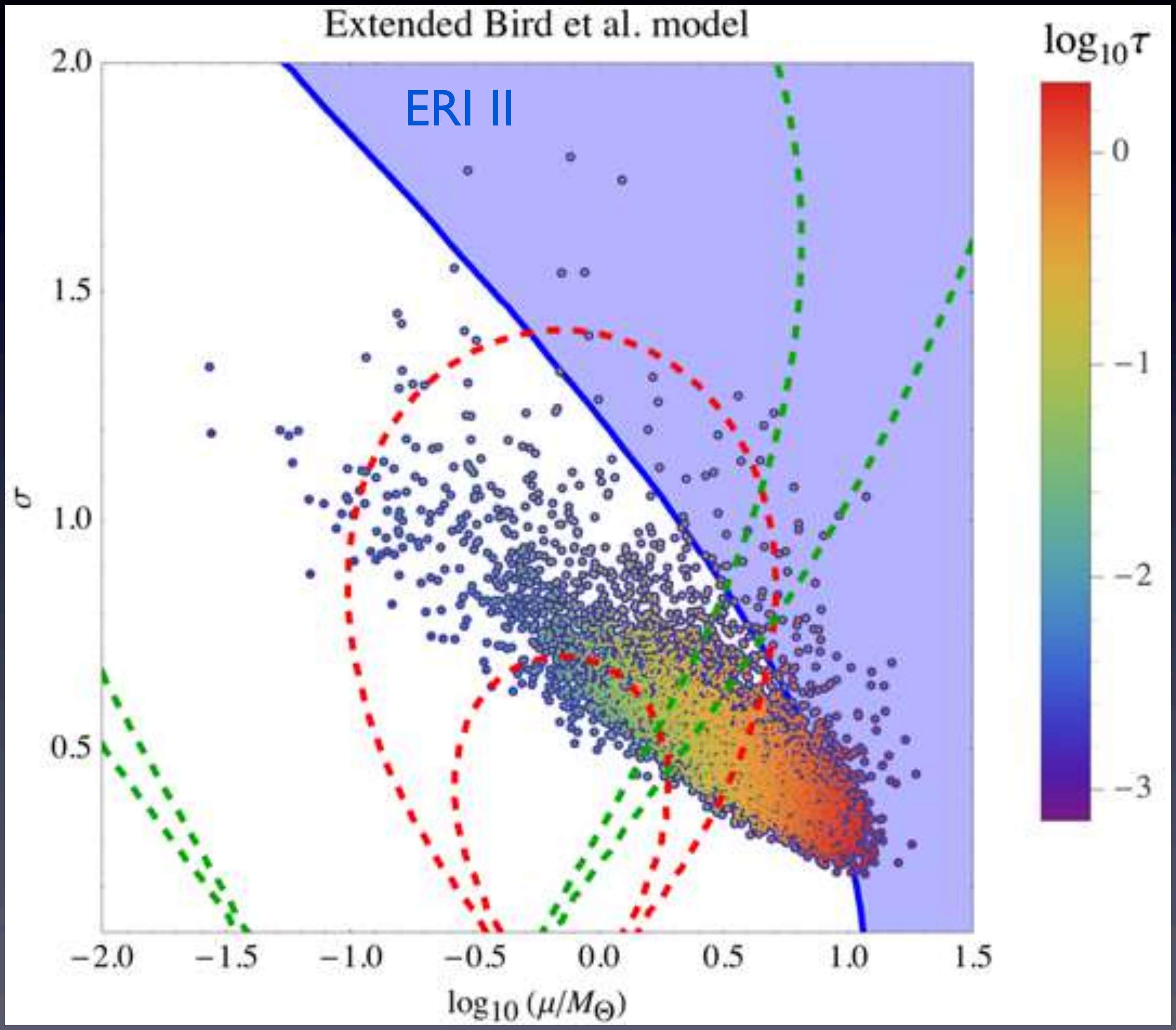

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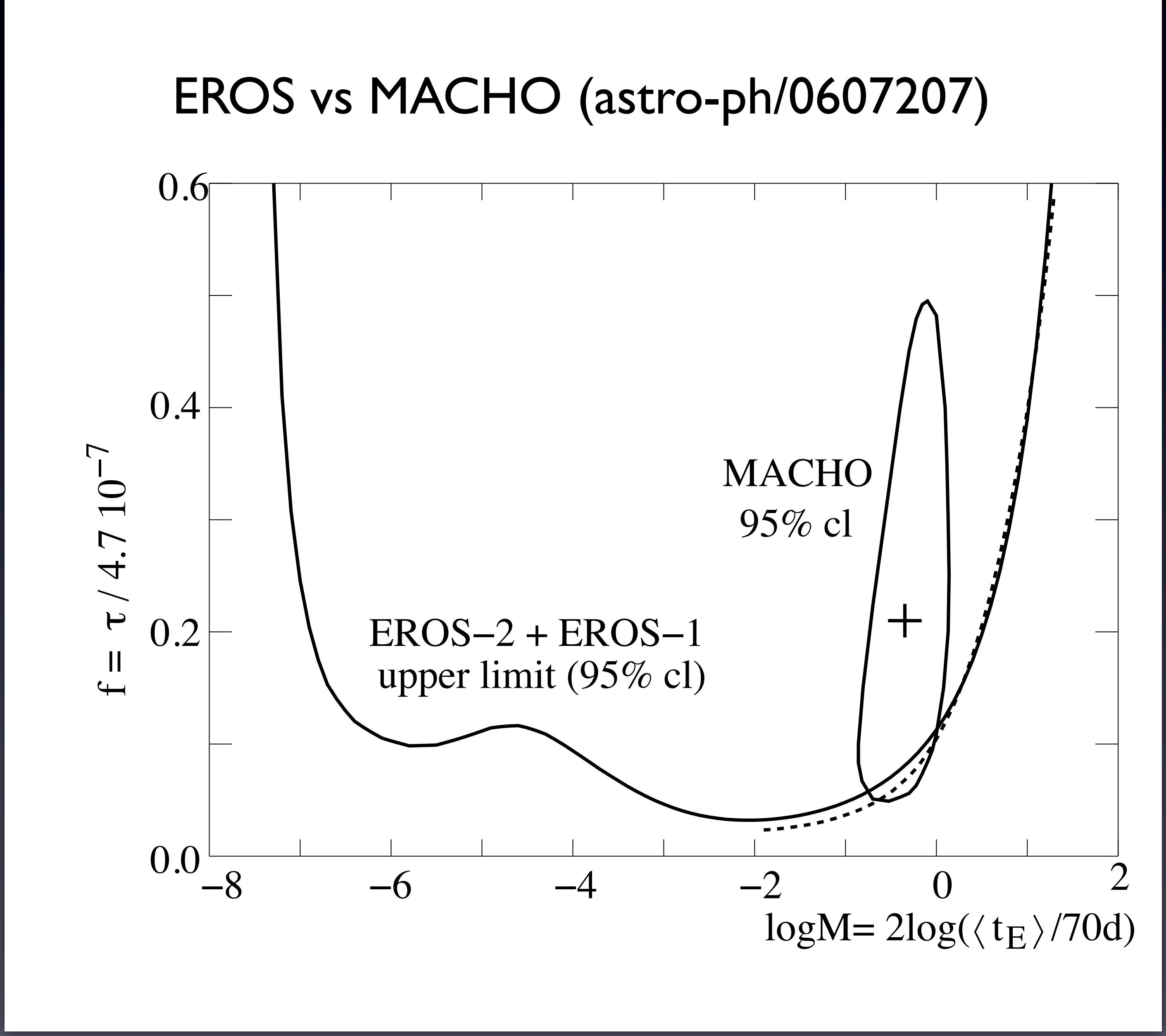

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Hint 4: Spatial correlations in CIB and X-ray background

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

A. Kashlinsky[1],

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 μm 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 Chandrashekar 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)
- 21cm signal (SKA)
- CMB (Planck, S4, LiteBird)
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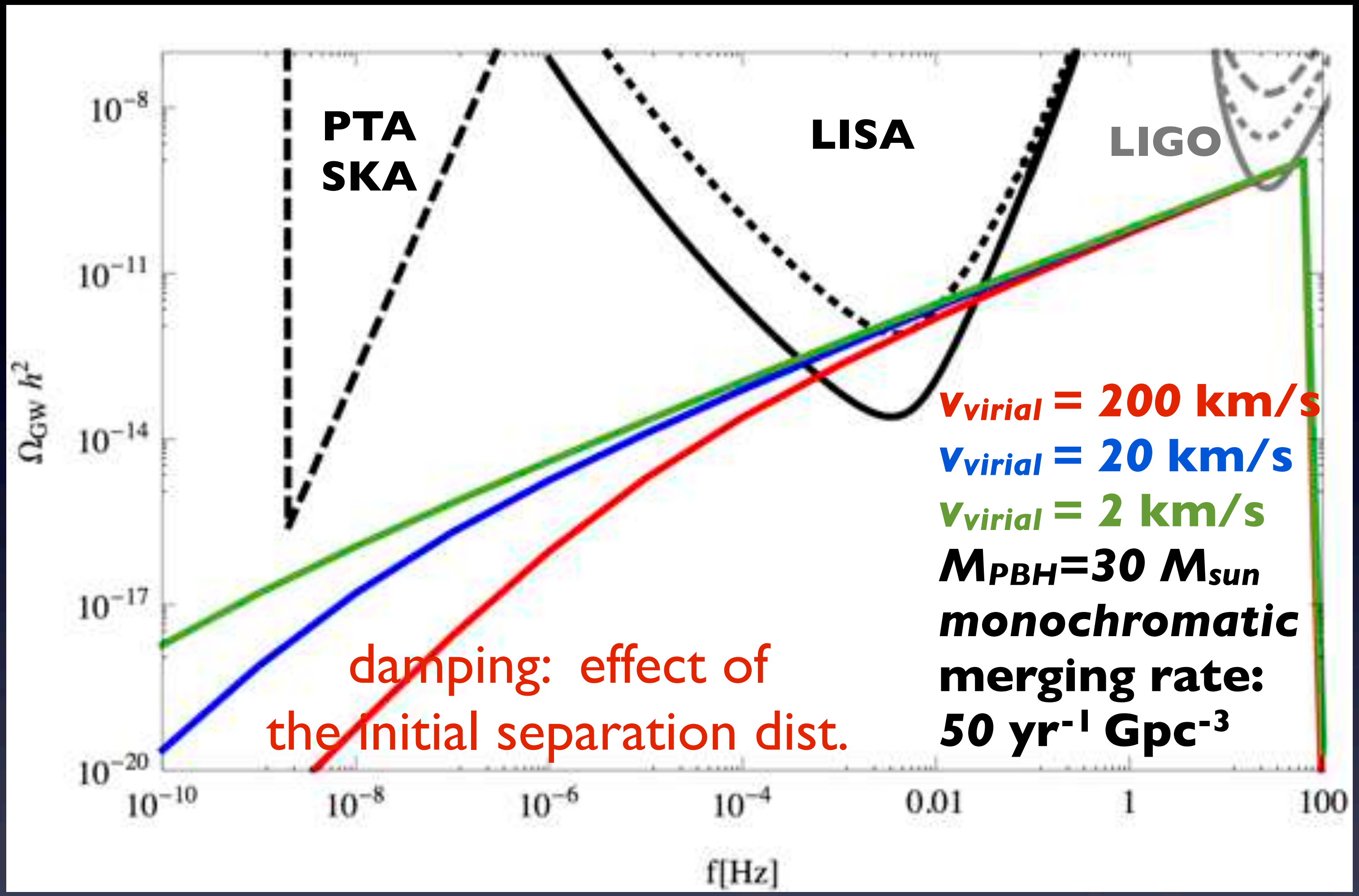

Clustering allows to distinguish stellar and primordial origins SC, JGB, 1610.08479

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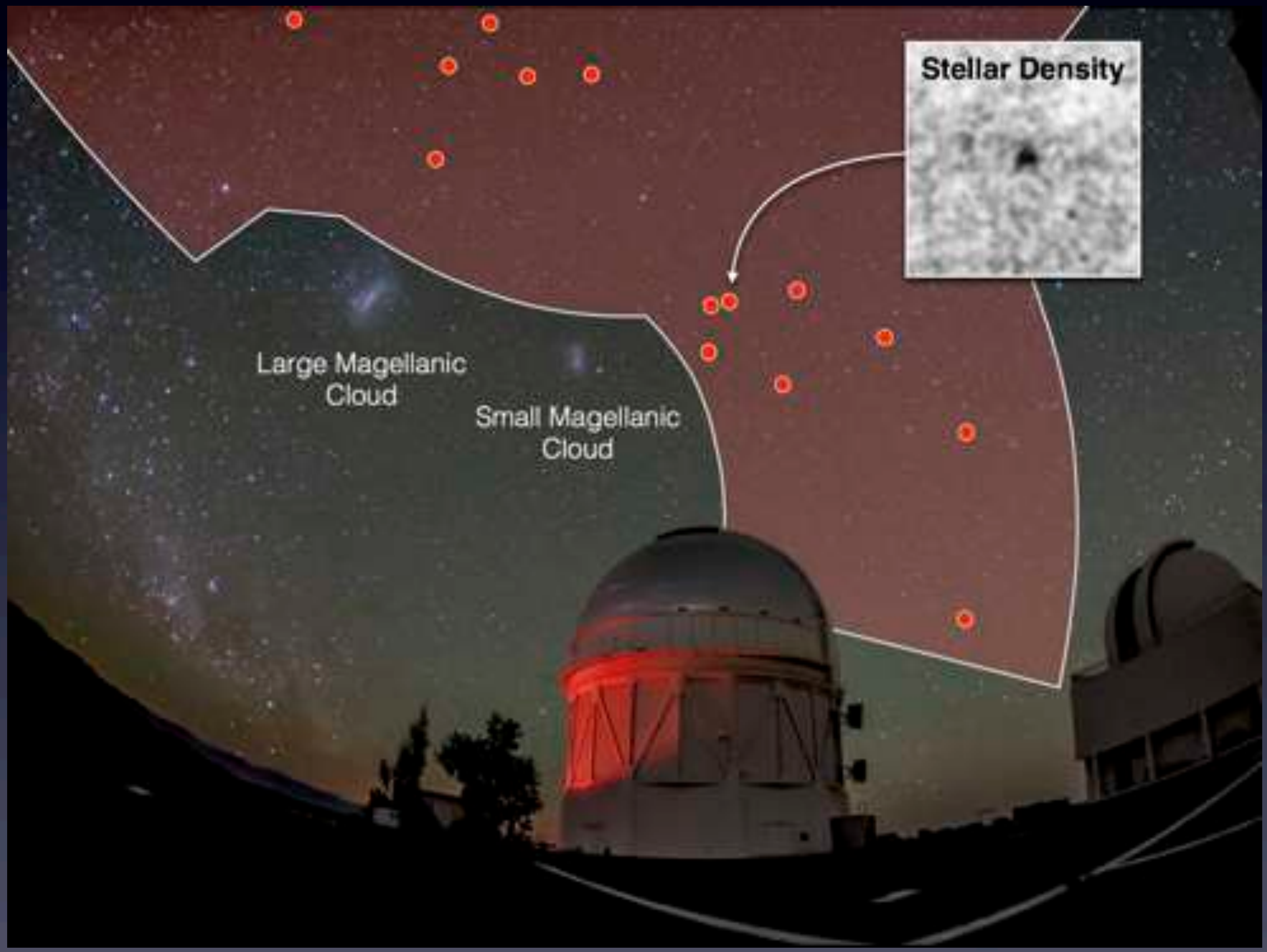

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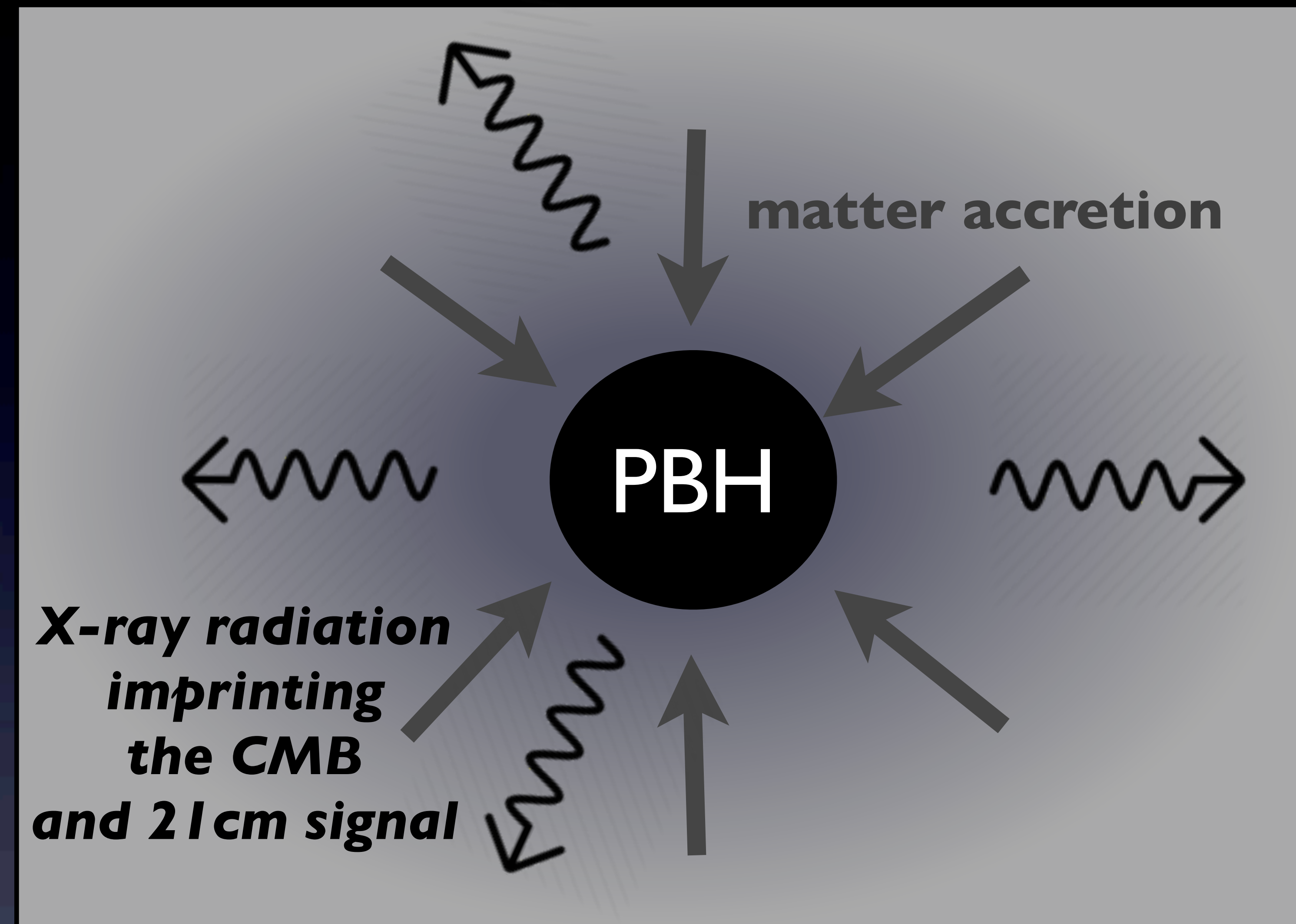

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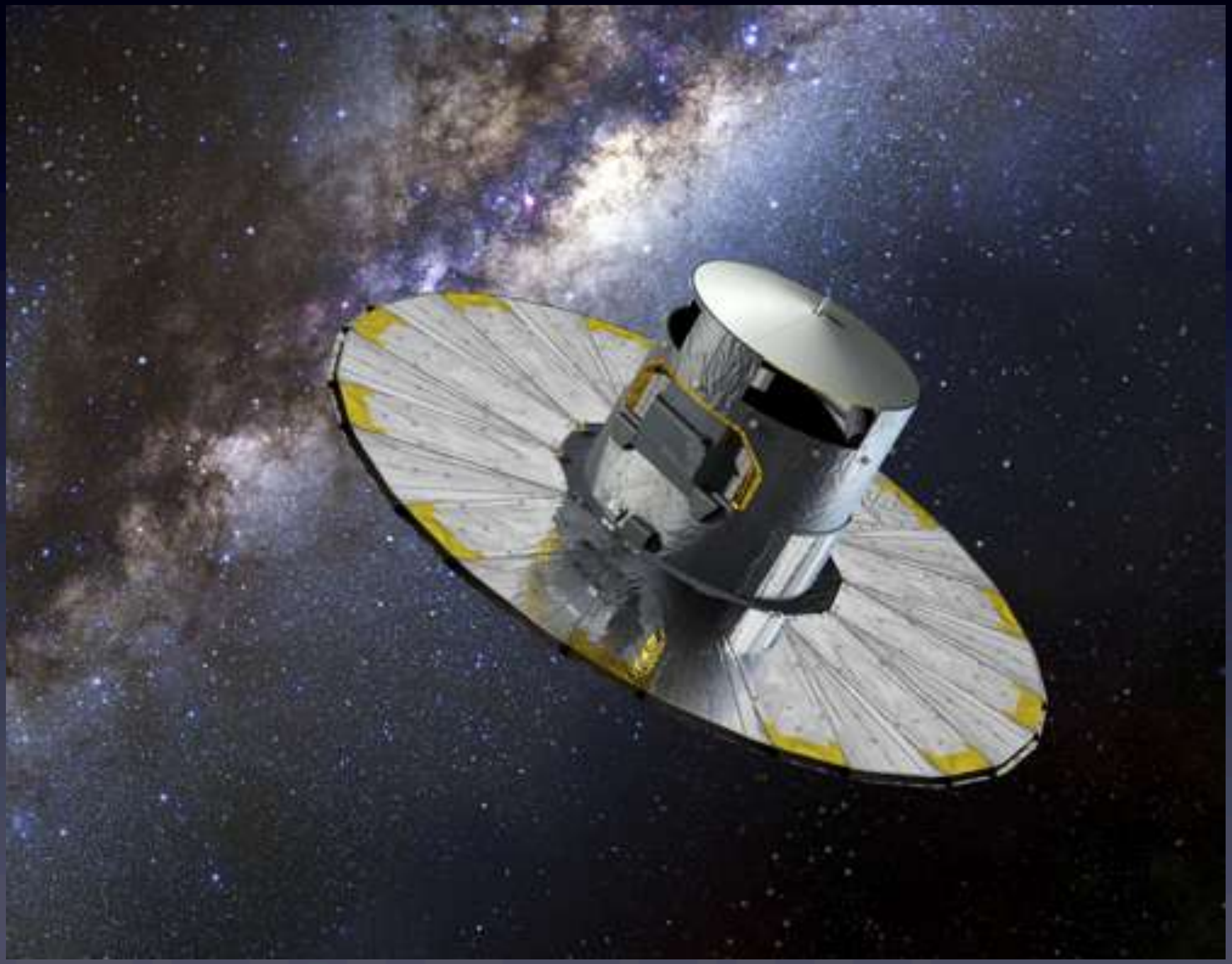

Thank you
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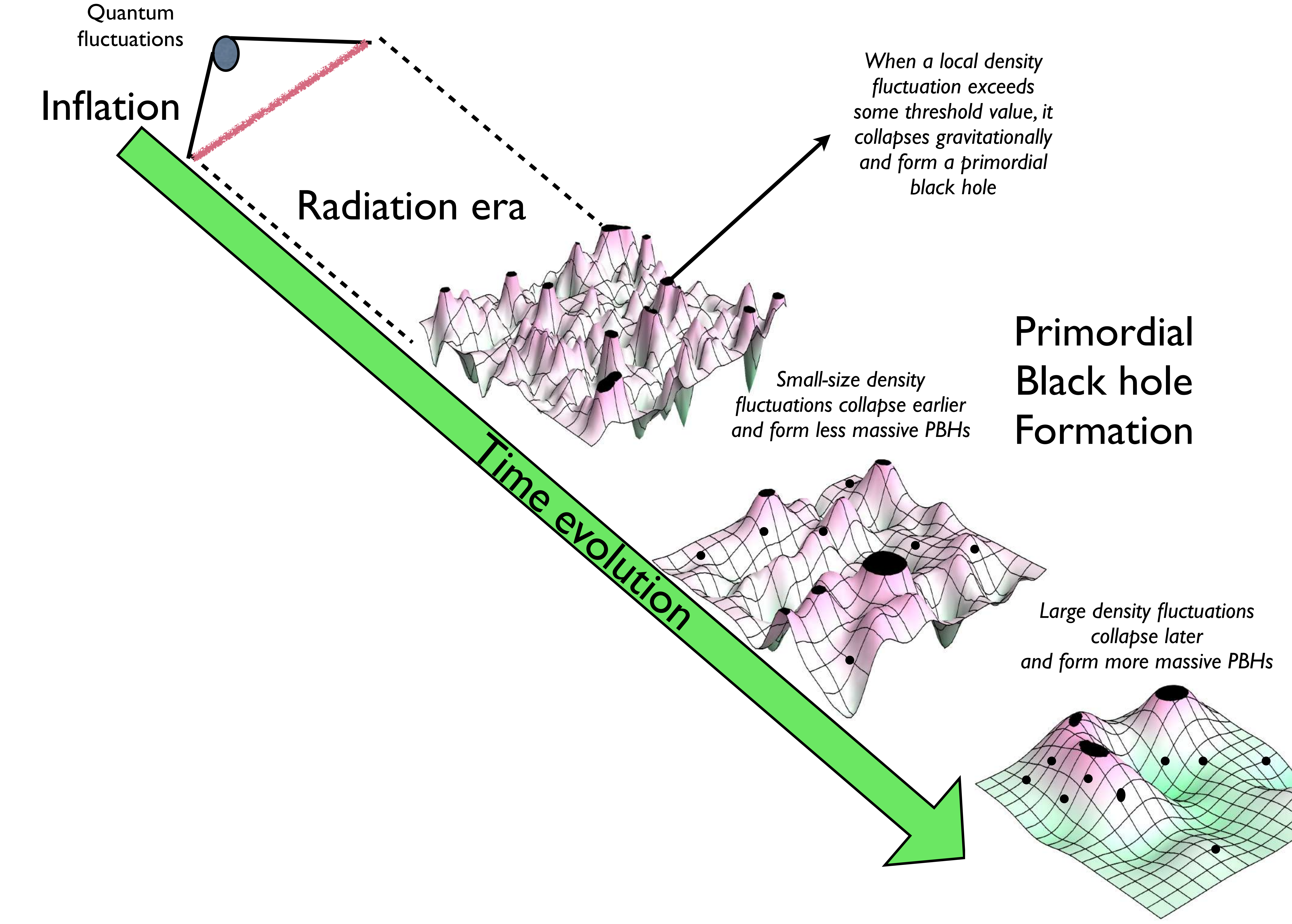
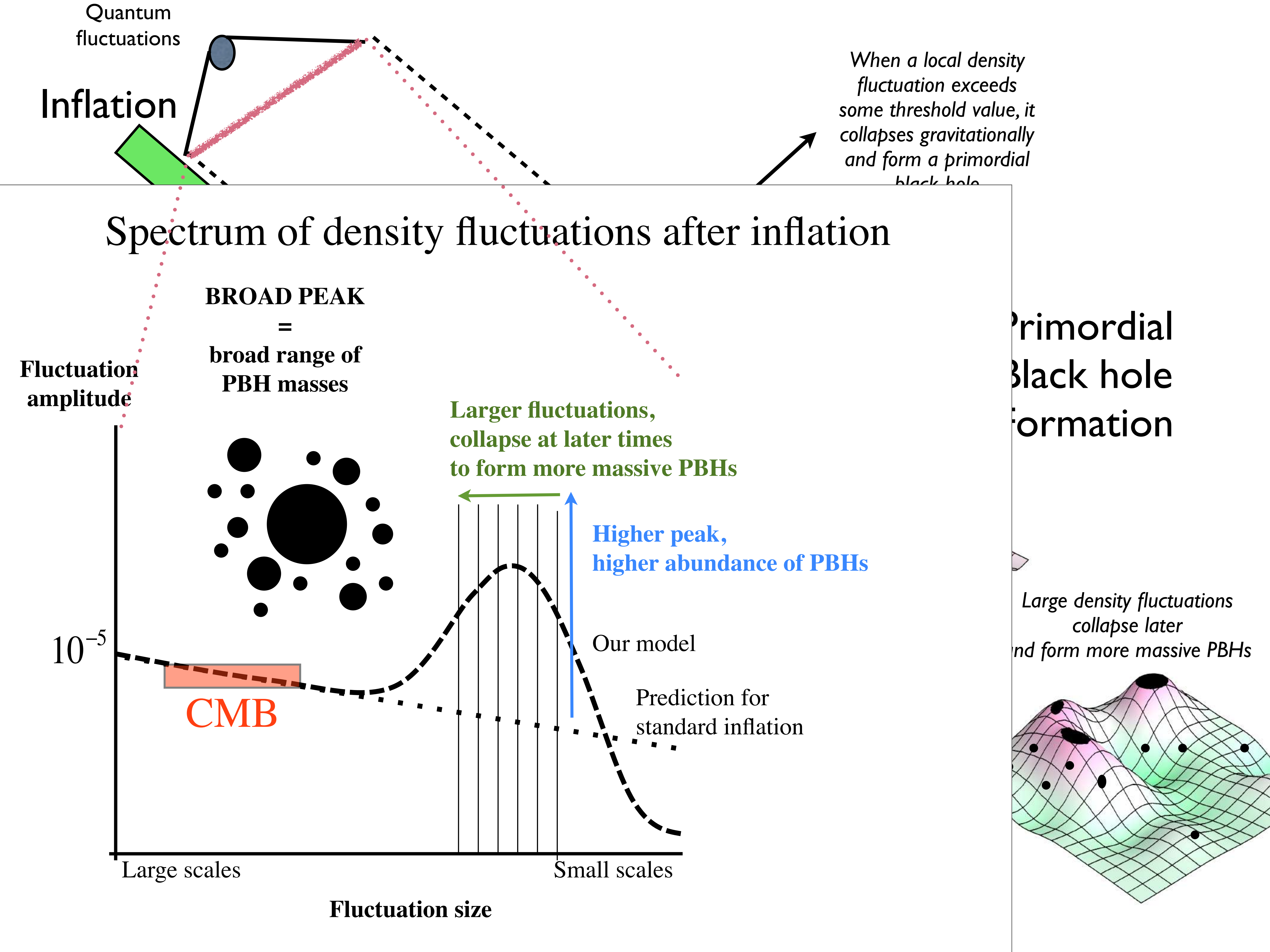

Quantum fluctuations
Inflation
Radiation era
When a local density fluctuation exceeds some threshold value, it collapses gravitationally and form a primordial black hole
Primordial Black hole Formation
Small-size density fluctuations collapse earlier and form less massive PBHs
Time evolution
Large density fluctuations collapse later and form more massive PBHs



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Spectrum of density fluctuations after inflation
BROAD PEAK = broad range of PBH masses
Fluctuation amplitude
Larger fluctuations, collapse at later times to form more massive PBHs
Higher peak, higher abundance of PBHs
Our model
Prediction for standard inflation
10^{-5}
CMB
Large scales
Small scales
Fluctuation size
rimordial
lack hole
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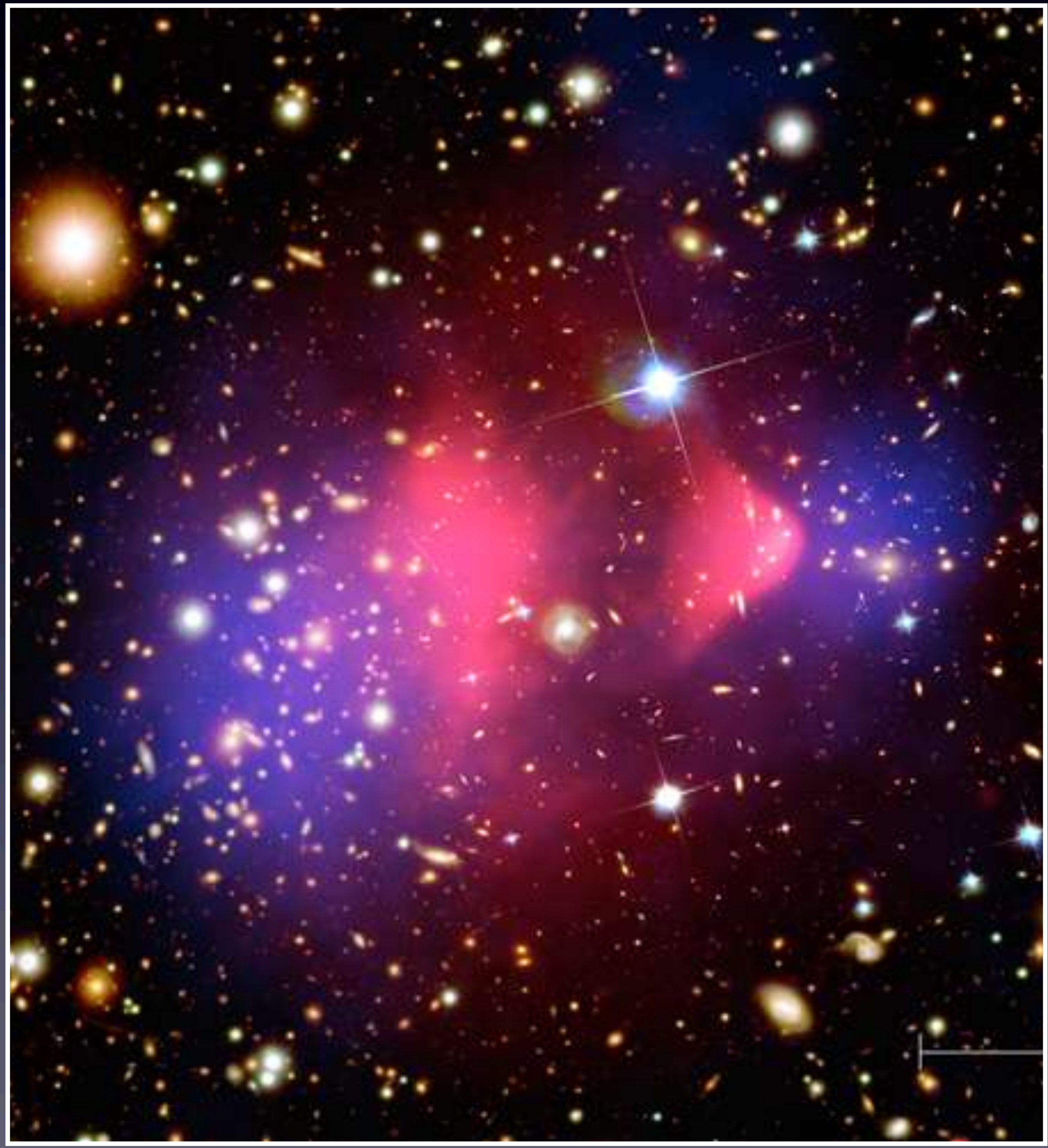
A good Dark Matter candidate

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



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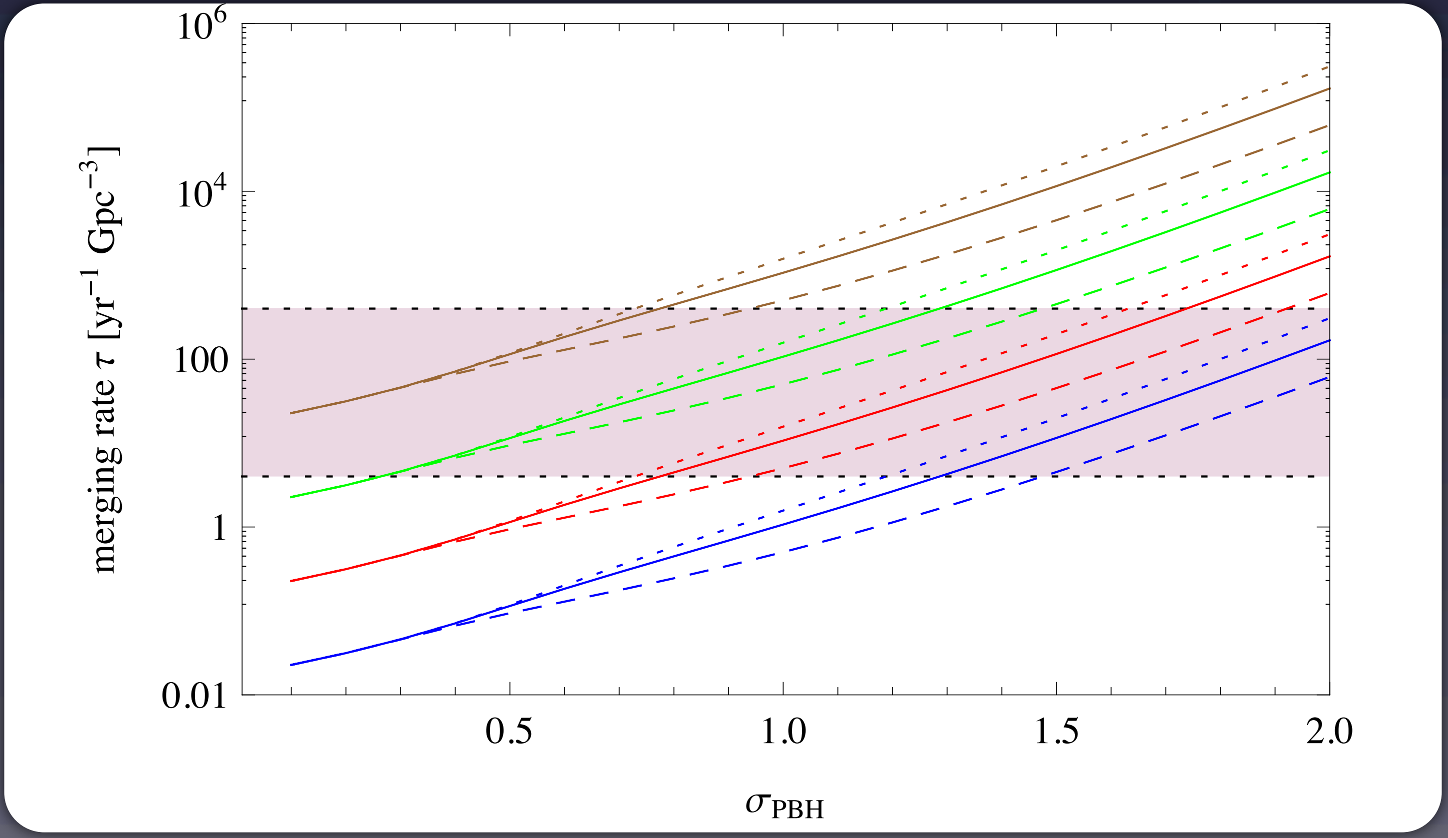

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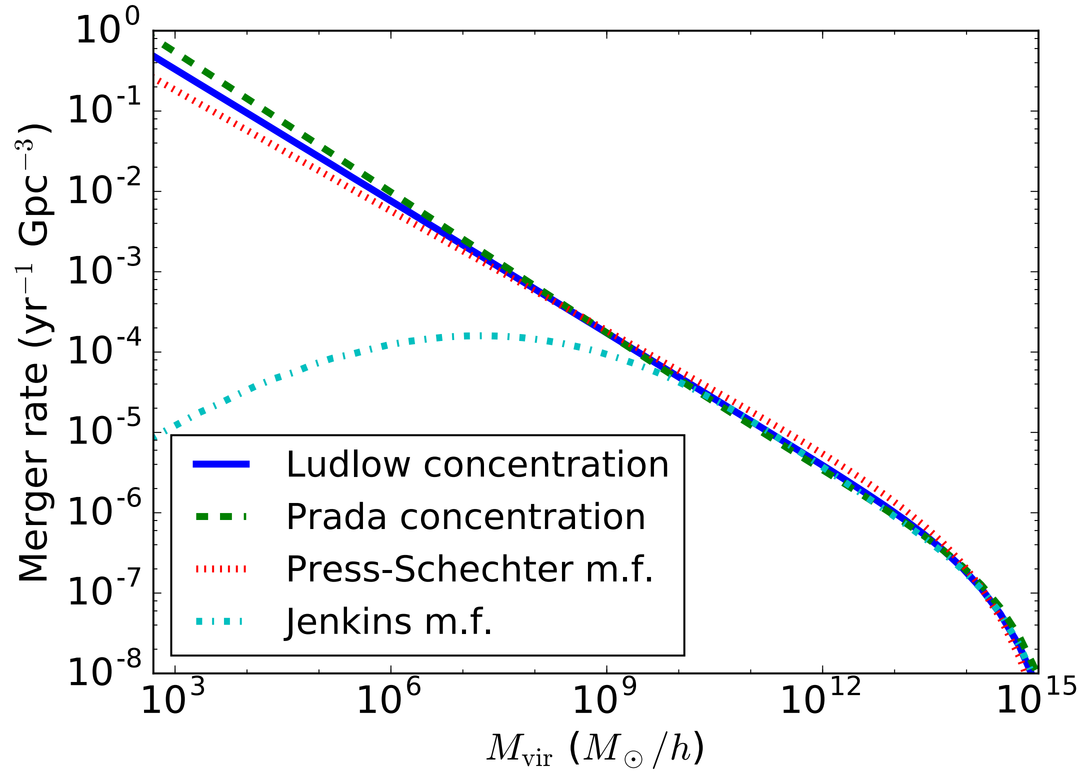

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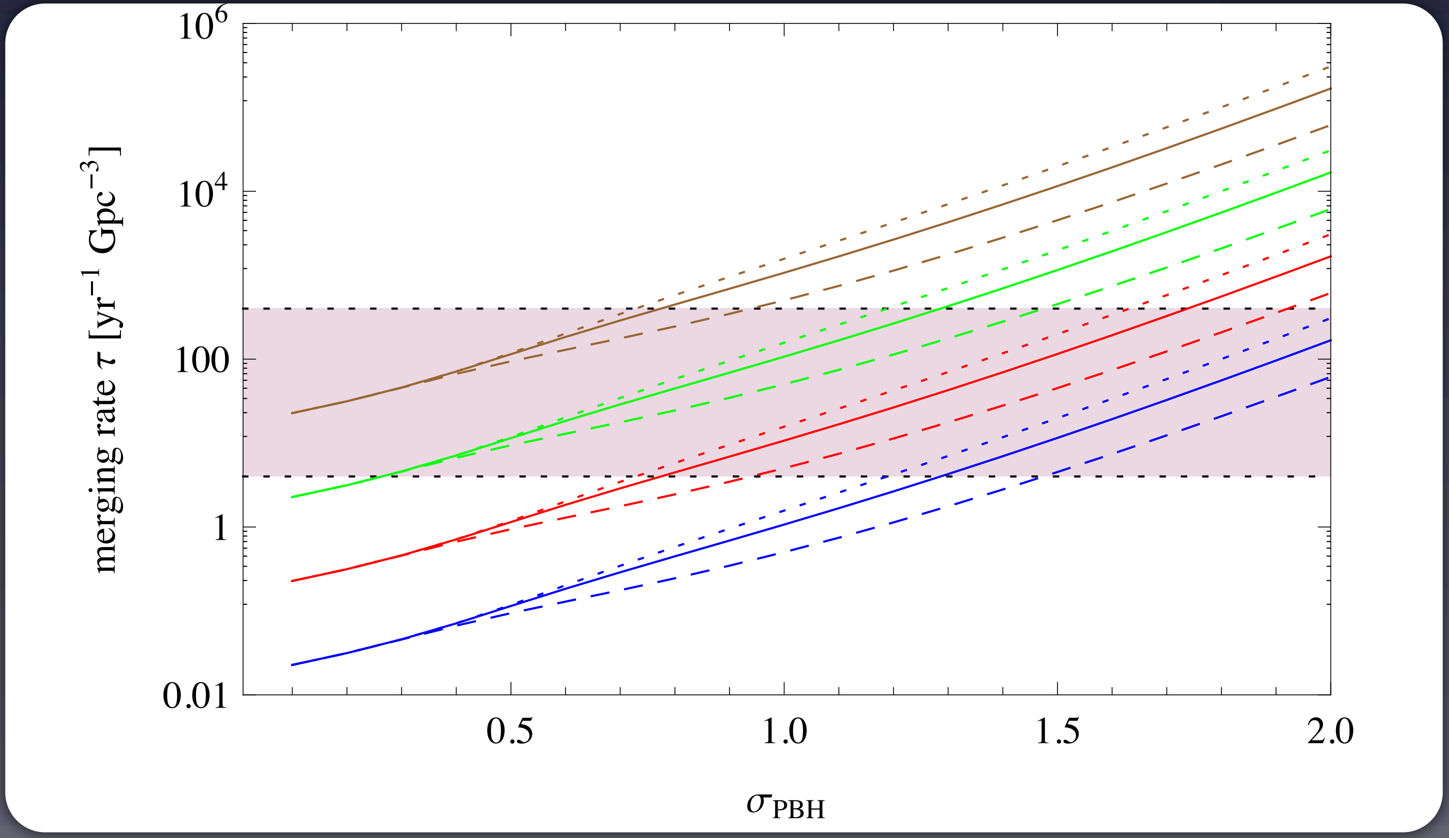

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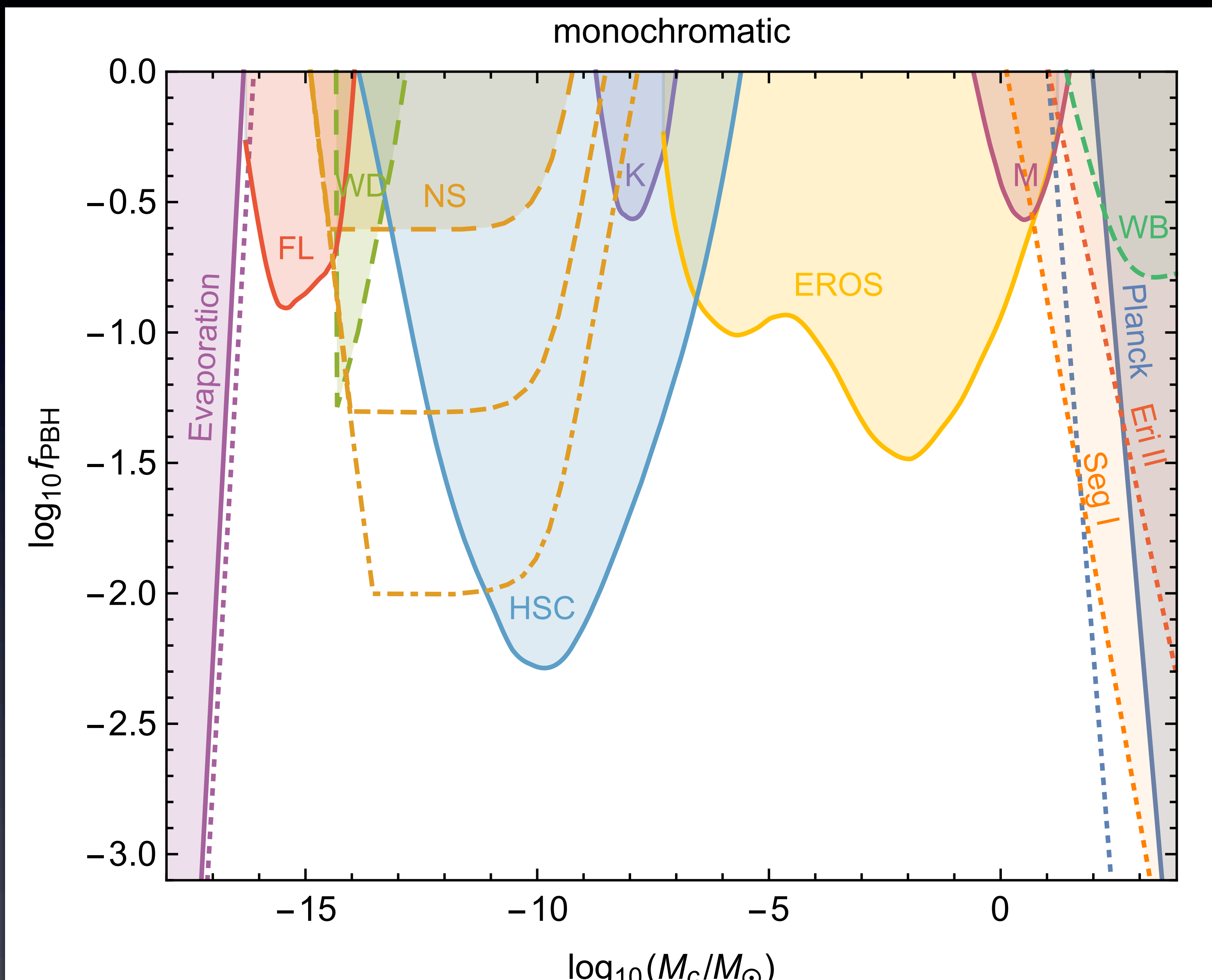

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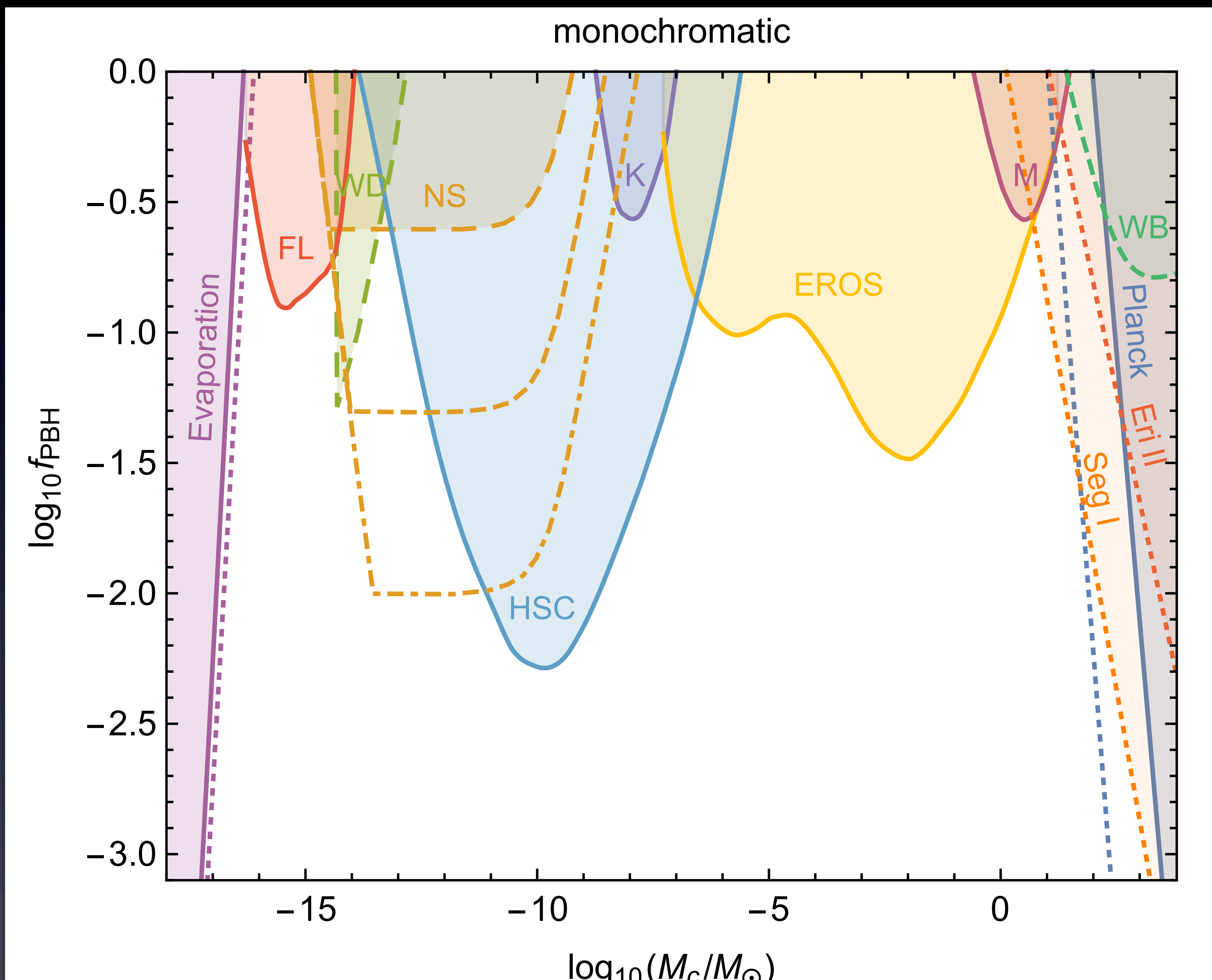
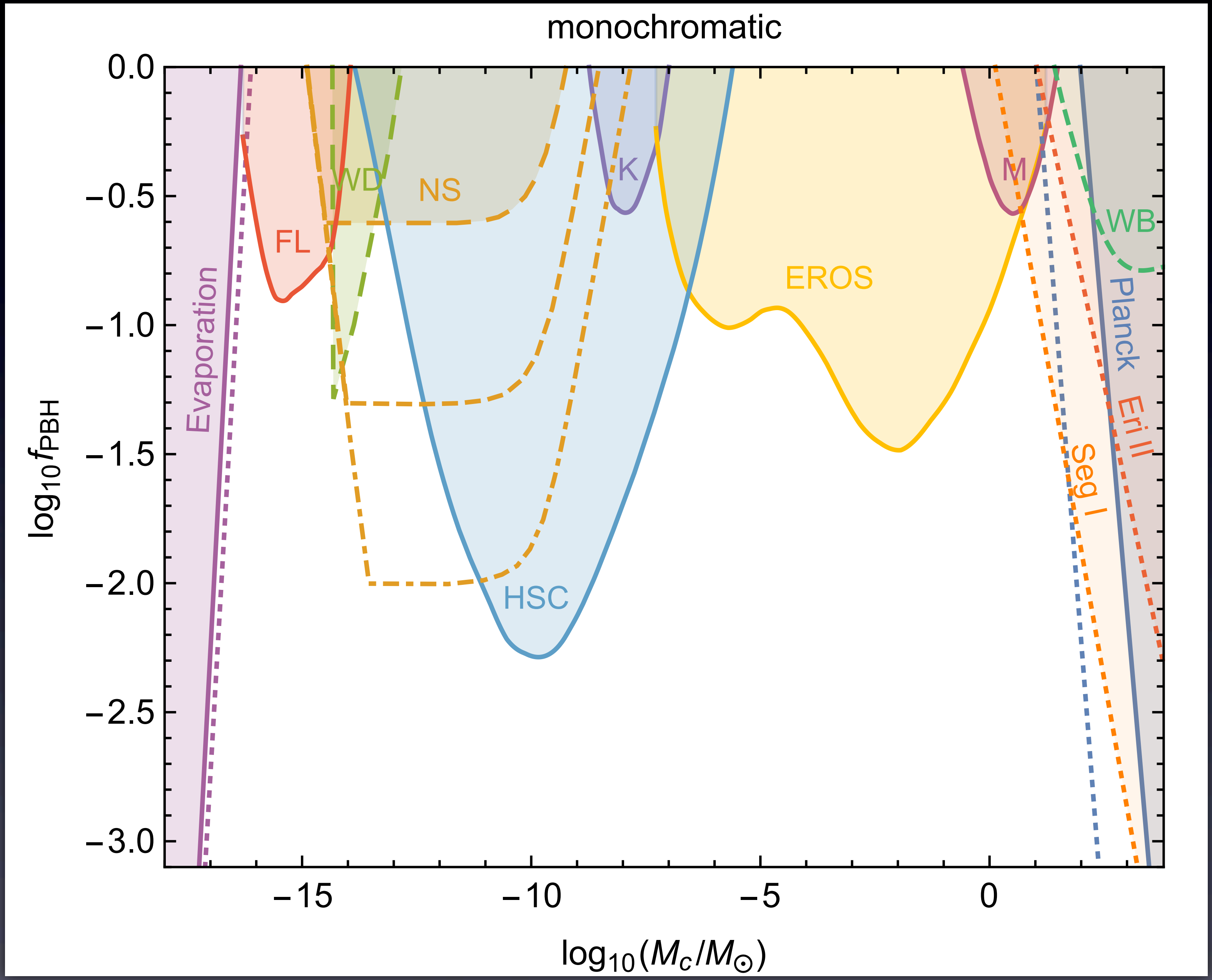


Monochromatic spectrum:
PBH-DM looks excluded in the whole mass range

B. Carr et al., 1705.05567

Constraints on PBH abundances

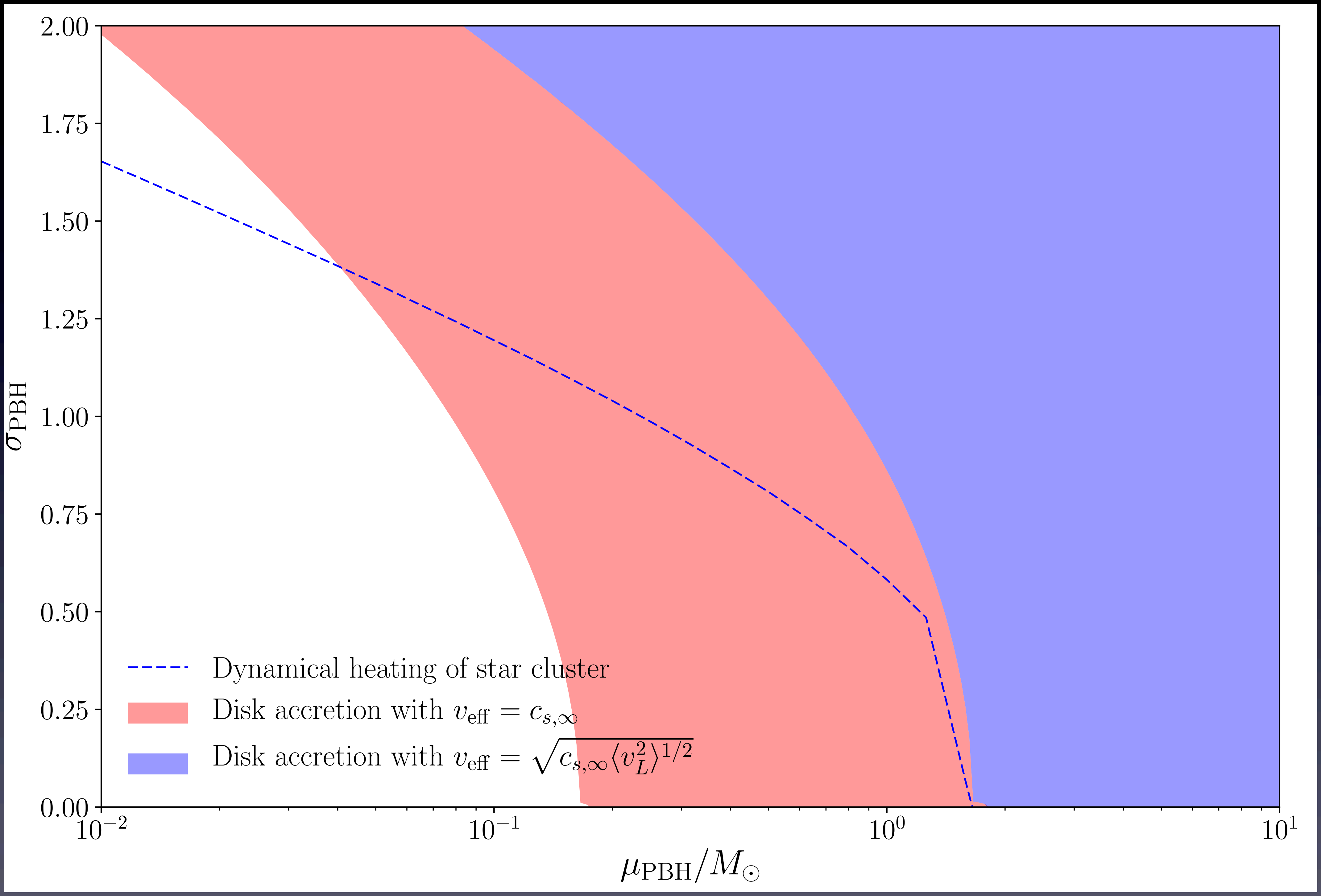


B. Carr et al., 1705.05567

Monochromatic spectrum:
PBH-DM looks excluded in the whole mass range

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

Constraints on PBH abundances



Poulin, Serpico, Calore, SC, Kohry 170704206

CMB very sensitive to the relative PBH/baryon velocity