Revisiting the CMB Accretion bound on PBH abundance

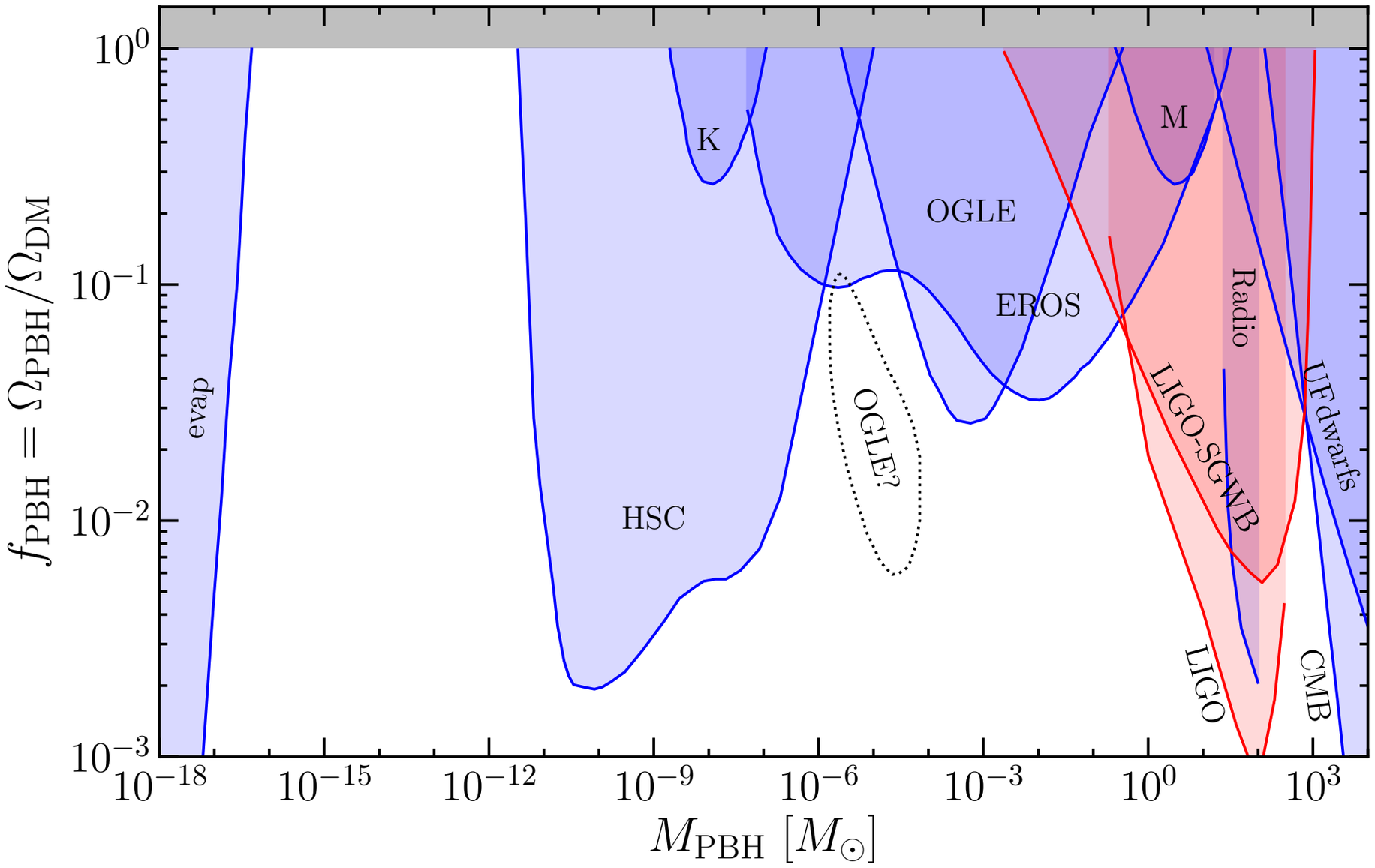
Daniele Gaggero

TeVPA 2023

INFN PISA
Istituto Nazionale di Fisica Nucleare
Sezione di Pisa

Black Holes and Dark Matter - Phenomenology

Constraints on PBHs as DM

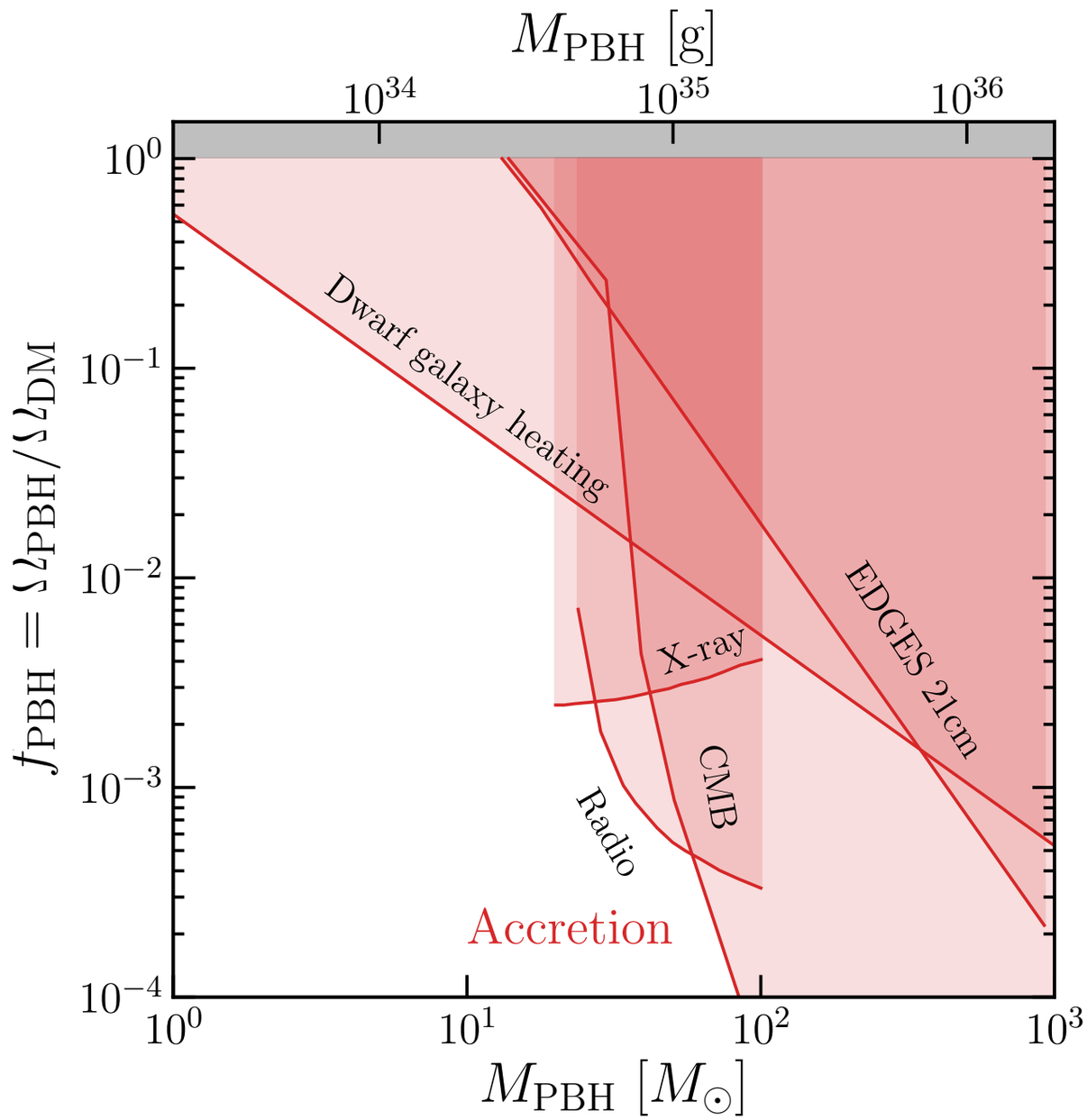


Credit: Bradley Kavanagh, https://github.com/bradkav/PBHbounds

Accretion bounds

Constraints from Accretion of baryonic matter

- *Very strong* especially for high masses
- **Astronomical environments:** X-ray/radio bounds (focus on Galactic center)
- **Cosmological bound** from CMB and 21 cm
- They rely on complicated accretion physics
- Comprehensive assessment of the uncertainties is very much needed!



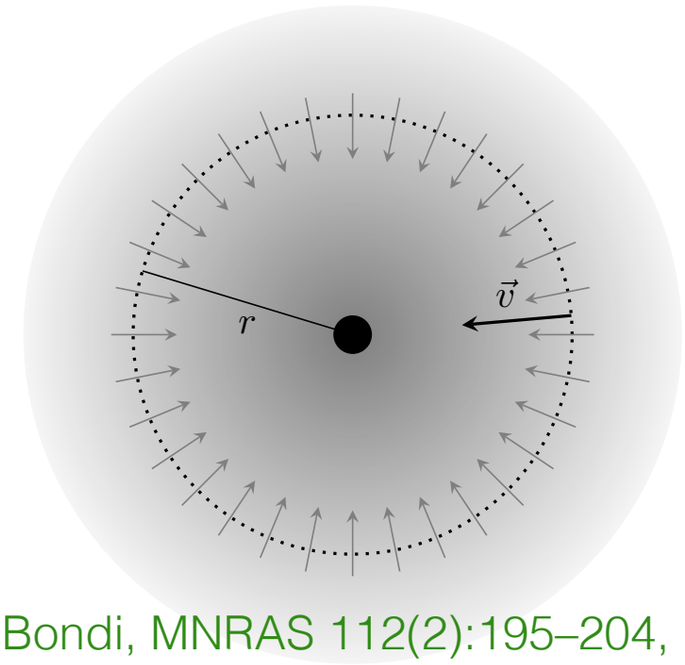
Accretion physics under the spotlight: BHL formalism.

Continuity equation for steady-state flow

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \rho v\right) = 0$$

Euler equation

$$\rho v \frac{dv}{dr} = -\frac{dP}{dr} - \frac{GM\rho}{r^2}$$

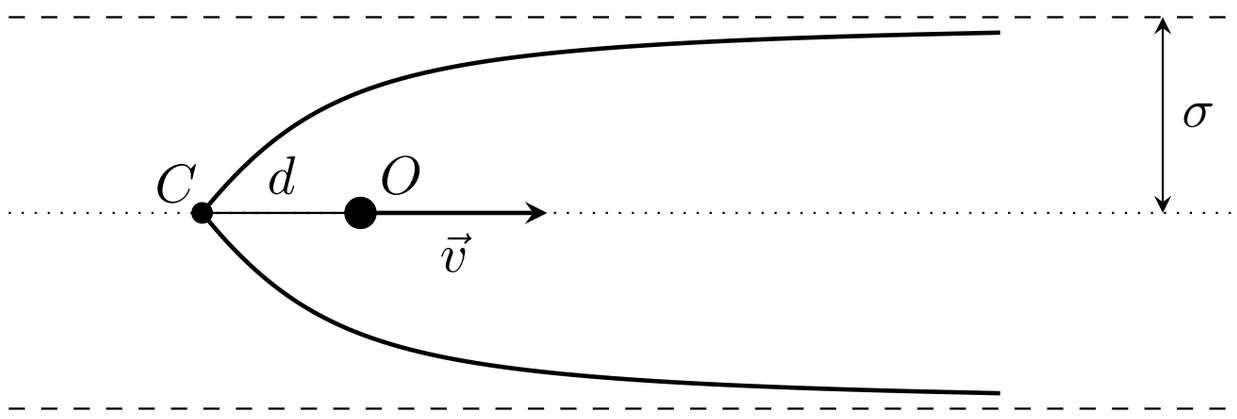


BH at rest: *Bondi* accretion rate

$$\dot{M} = 4\pi r_s^2 \rho(r_s) c_s(r_s) = \pi \frac{(GM)^2 \rho(\infty)}{c_s^3(\infty)} \left(\frac{2}{5-3\gamma}\right)^{\frac{5-3\gamma}{2(\gamma-1)}}$$

H. Bondi, MNRAS 112(2):195–204, 1952

H. Bondi and F. Hoyle, MNRAS 104(5):273–282, 1944



Moving BH: *Bondi-Hoyle-Littleton* accretion rate

$$\dot{M}_{\rm BHL} = 4\pi \frac{(GM)^2 \rho_\infty}{(v^2 + c_\infty^2)^{3/2}}$$

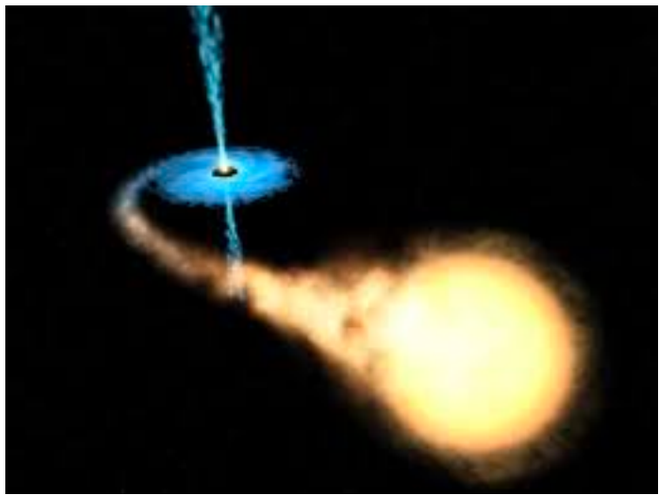
Accretion physics under the spotlight: BHL formalism.

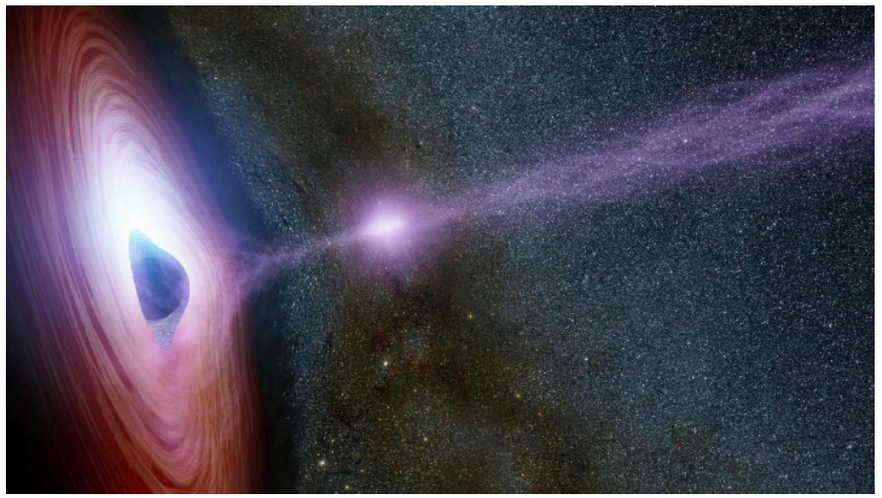
Bondi-Hoyle-Littleton formula needs to be “fudged” because of observational constraints related to local neutron stars, the SMBH at the center of the Galaxy, and AGNs.

$$\dot{M} = 4\pi\lambda(GM_{BH})^2\rho\left(v_{BH}^2 + c_s^2\right)^{-3/2}$$

- Perna et al. 2003, *“Bondi accretion and the problem of missing isolated neutron stars”*
- S. Pellegrini 2005, *“Nuclear Accretion in Galaxies of the Local Universe: Clues from Chandra Observations”* (explanation for the radiative quiescence of supermassive black holes in the local Universe)
- Wang et al. 2013, *“Dissecting X-ray-emitting Gas around the Center of our Galaxy”*

The fudge factor takes into account several effects, including the role of outflows

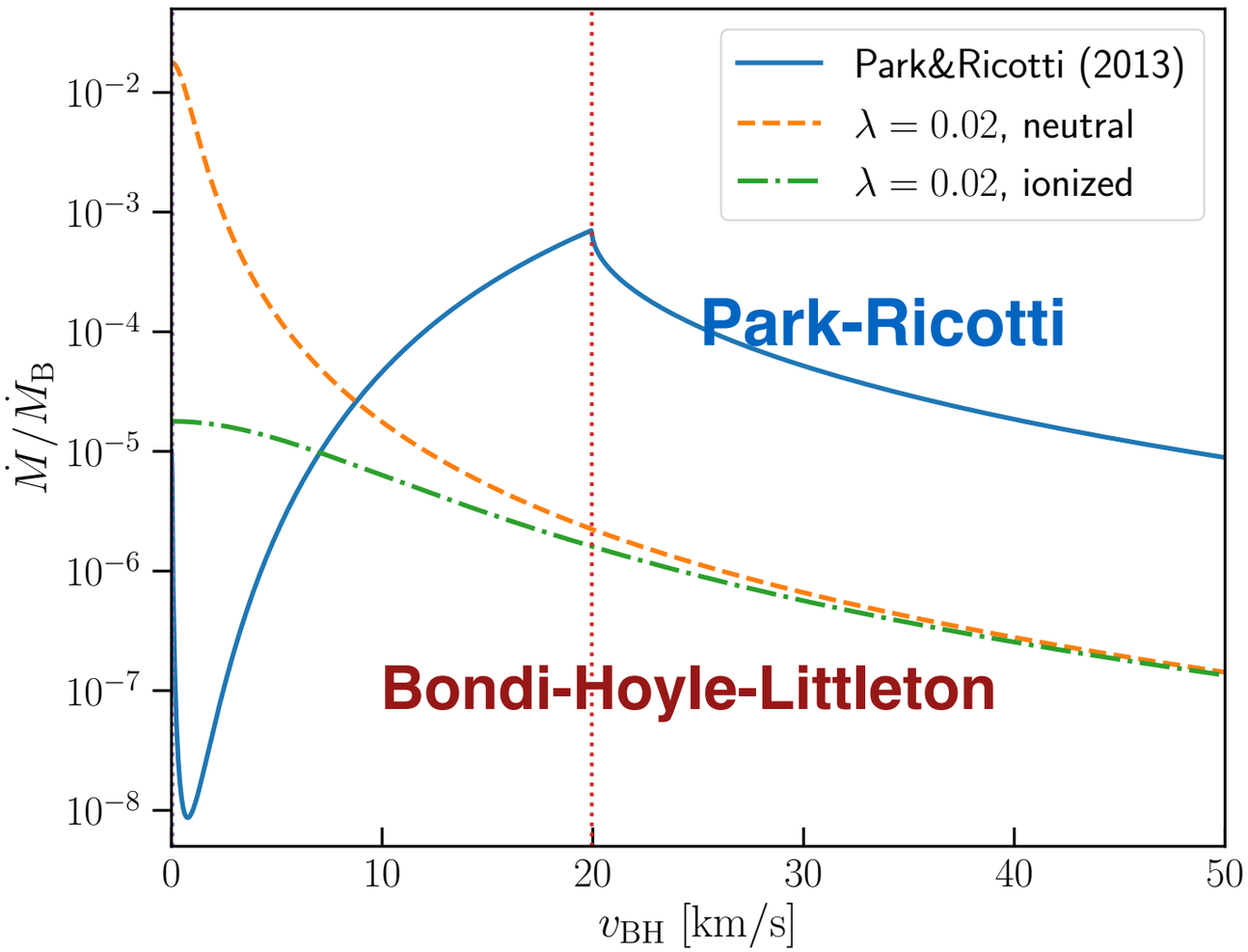


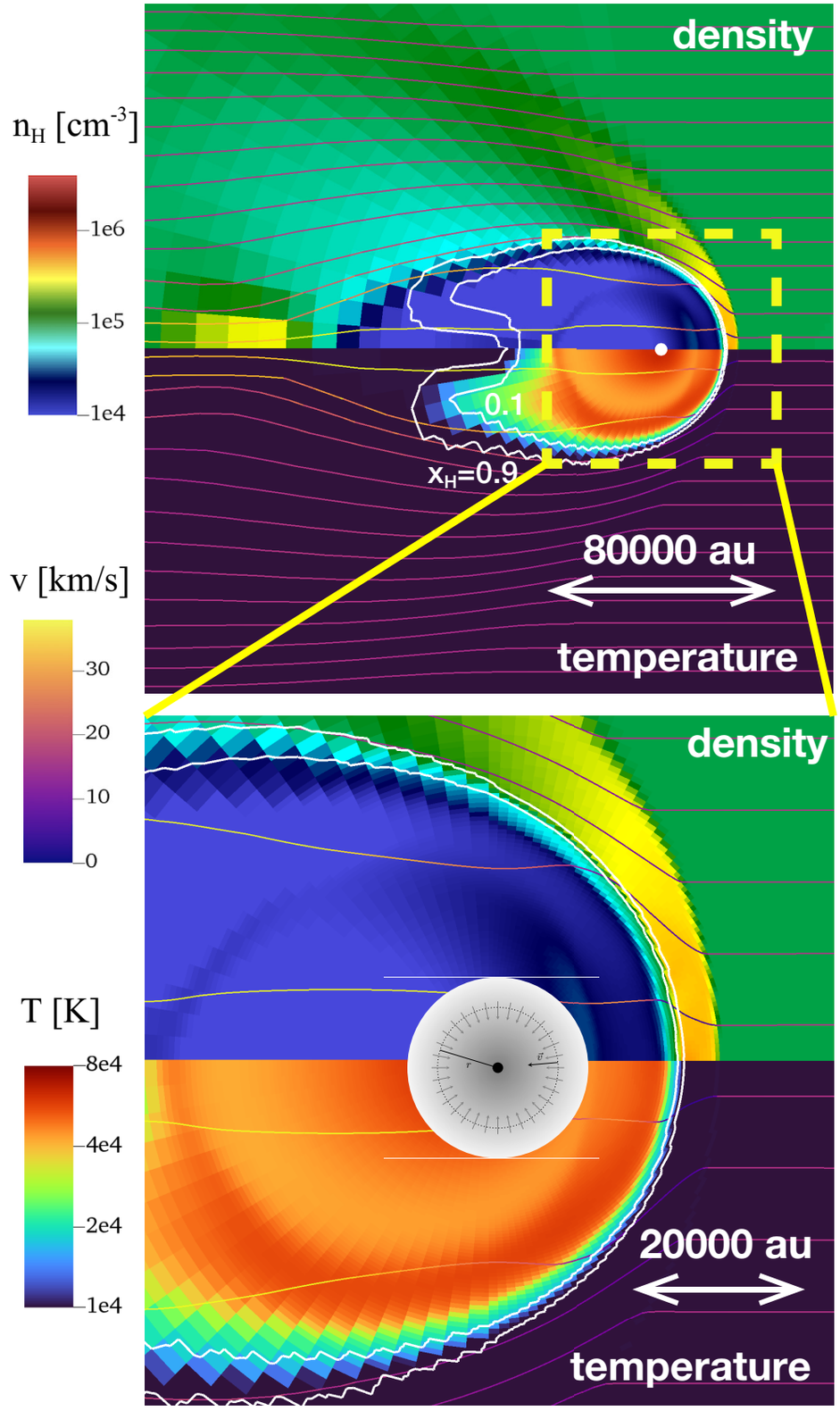


The Park-Ricotti model

- **Park-Ricotti model:** numerical simulations + semi-analytical parametrization in presence of radiative feedback.

- Suppression of the accretion rate at low velocity, due to the formation of an ionized bubble

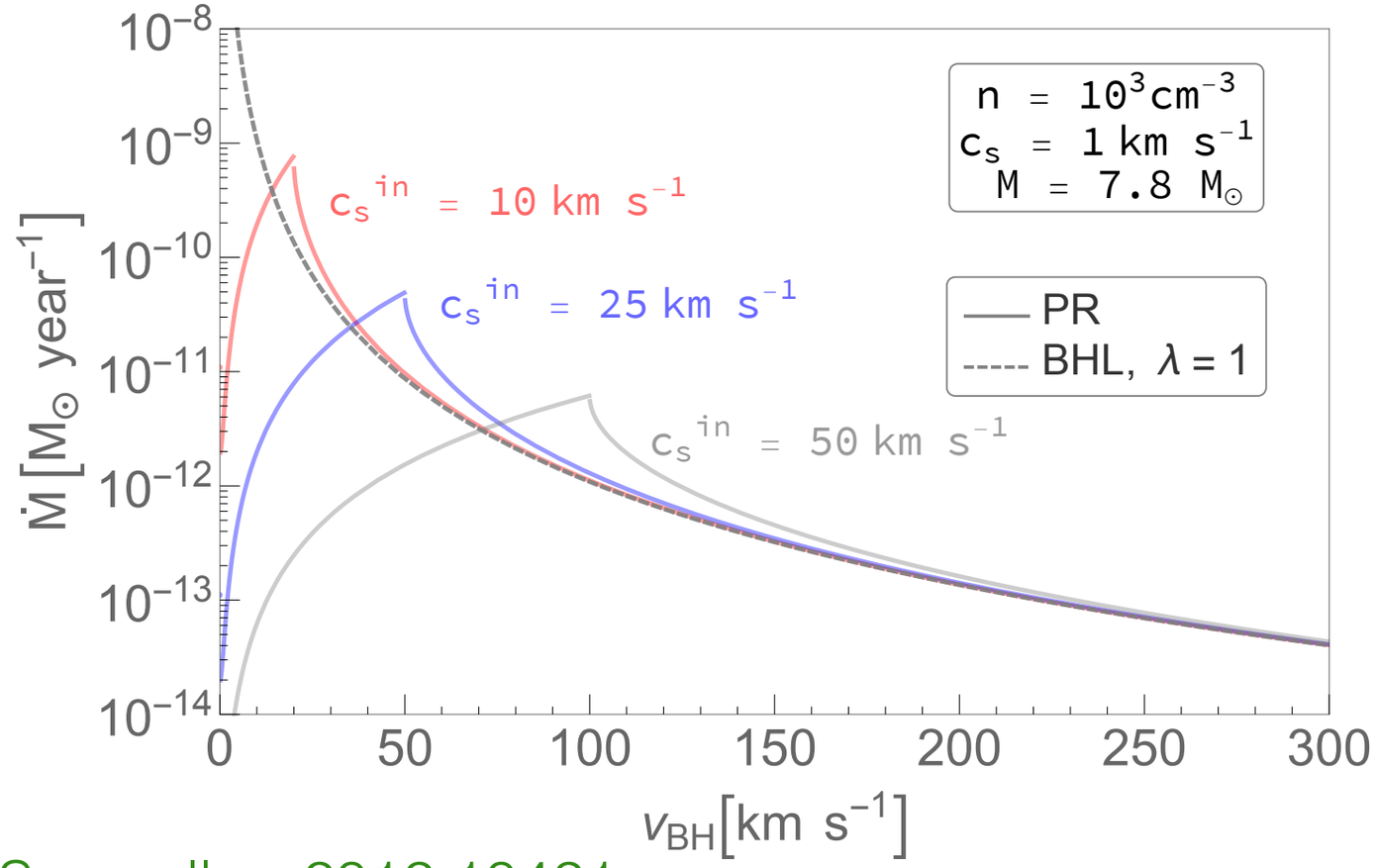




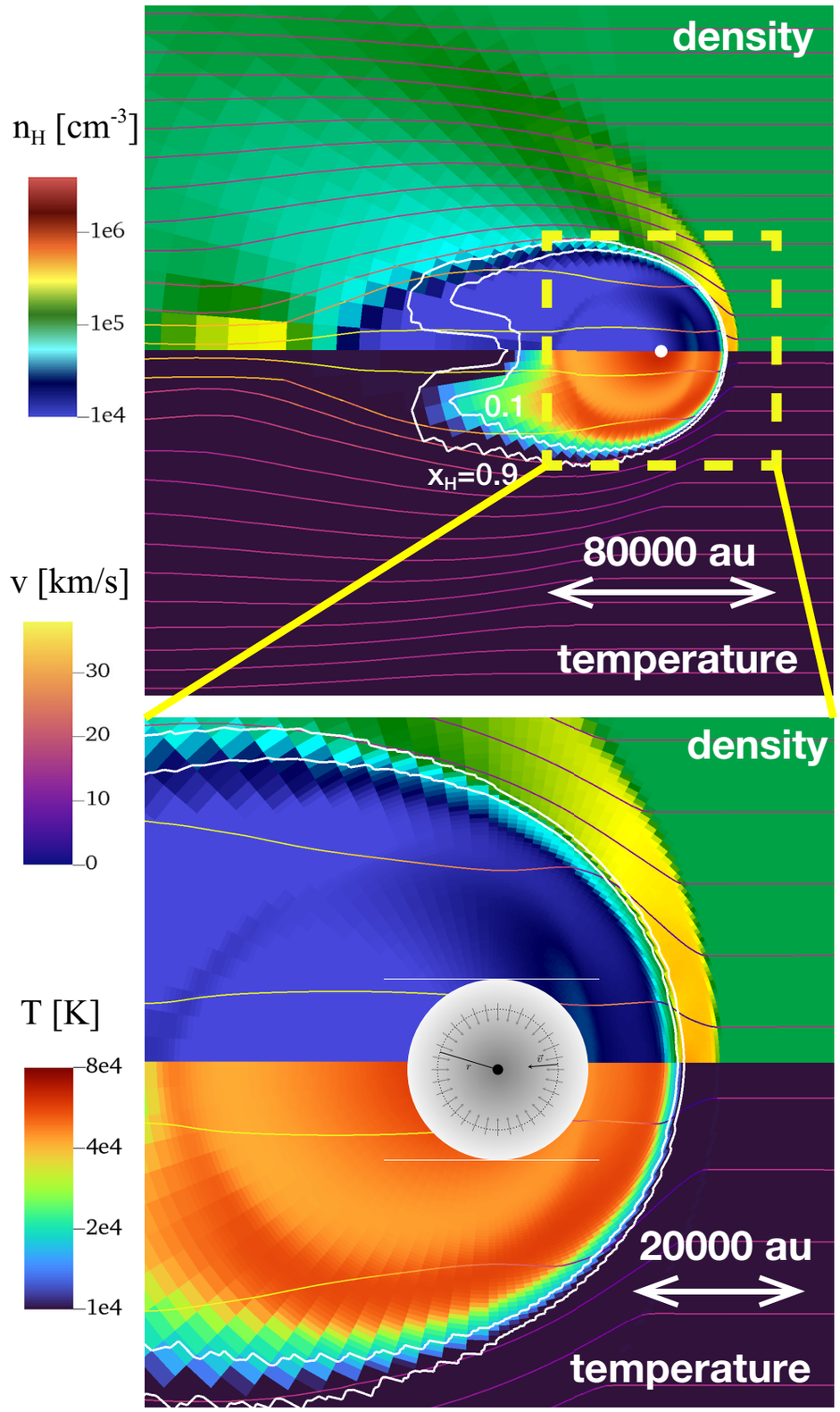
The Park-Ricotti model

- **Park-Ricotti model:** numerical simulations + semi-analytical parametrization in presence of radiative feedback.

- Peaks of accretion rate depends on ionized sound speed



Scarcella+ 2012.10421



The physics behind the bound

- PBHs accrete baryonic matter.
    - The accretion rate Mdot depends on ambient density and PBH - baryon relative speed. **BHL** and **PR** model.
    - Ambient density dilutes with decreasing redshift

$$\rho_\infty = m_\mathrm{p}\, n_\infty \approx m_\mathrm{p}\, 200\,\mathrm{cm}^{-3} \left(\frac{1+z}{1000}\right)^3$$

Poulin+ 1707.04206

    - PBH speed relative to baryons also decreases according to linear theory:

$$\sqrt{\langle v_\mathrm{L}^2 \rangle} \simeq \min\left[1, \frac{1+z}{1000}\right] \times 30\,\mathrm{km/s}\,.$$

Revisiting the Cosmological constraint

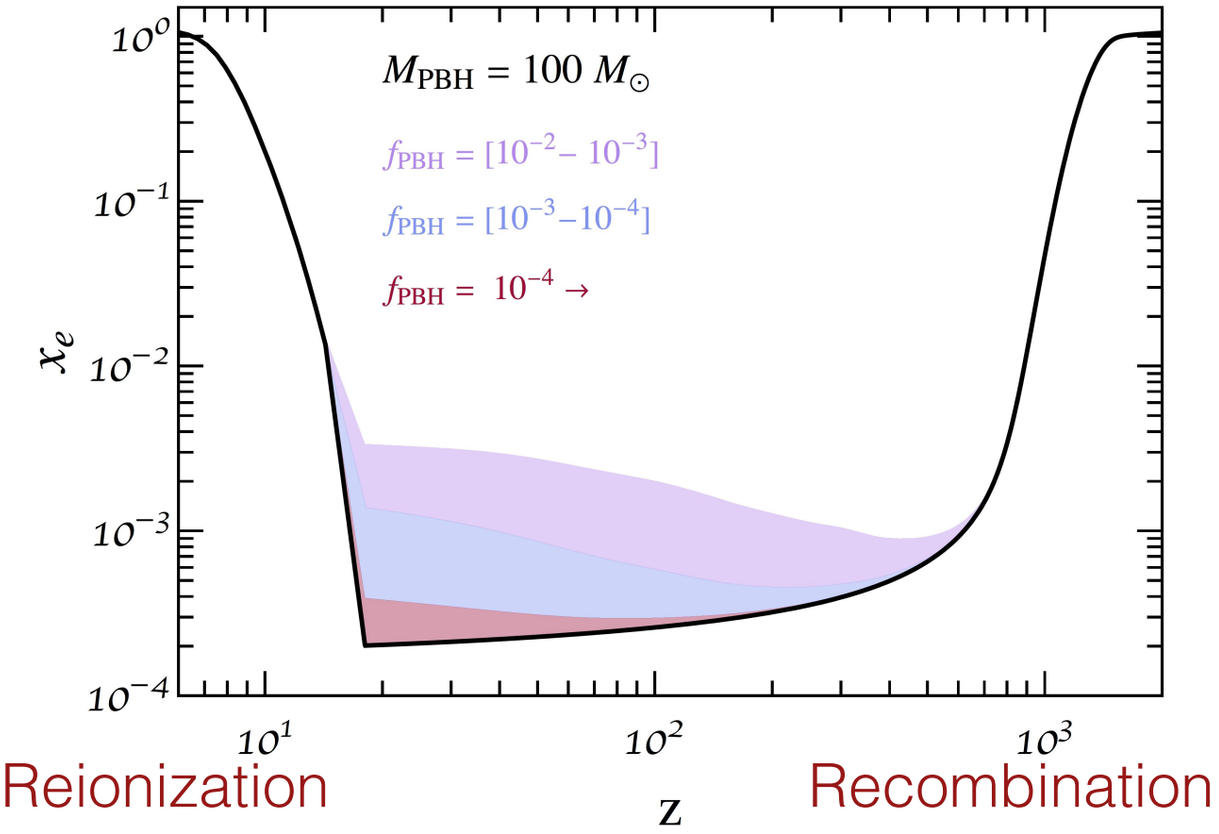
The physics behind the bound

- Accretion disks emits *ionizing radiation* during the Dark Ages (between Recombination and Reionization)*:*
  - IGM is heated up (alteration of T_M)
  - IGM is also partially ionized (alteration of the *free electron fraction* X_e)

Mena+ 1906.07735

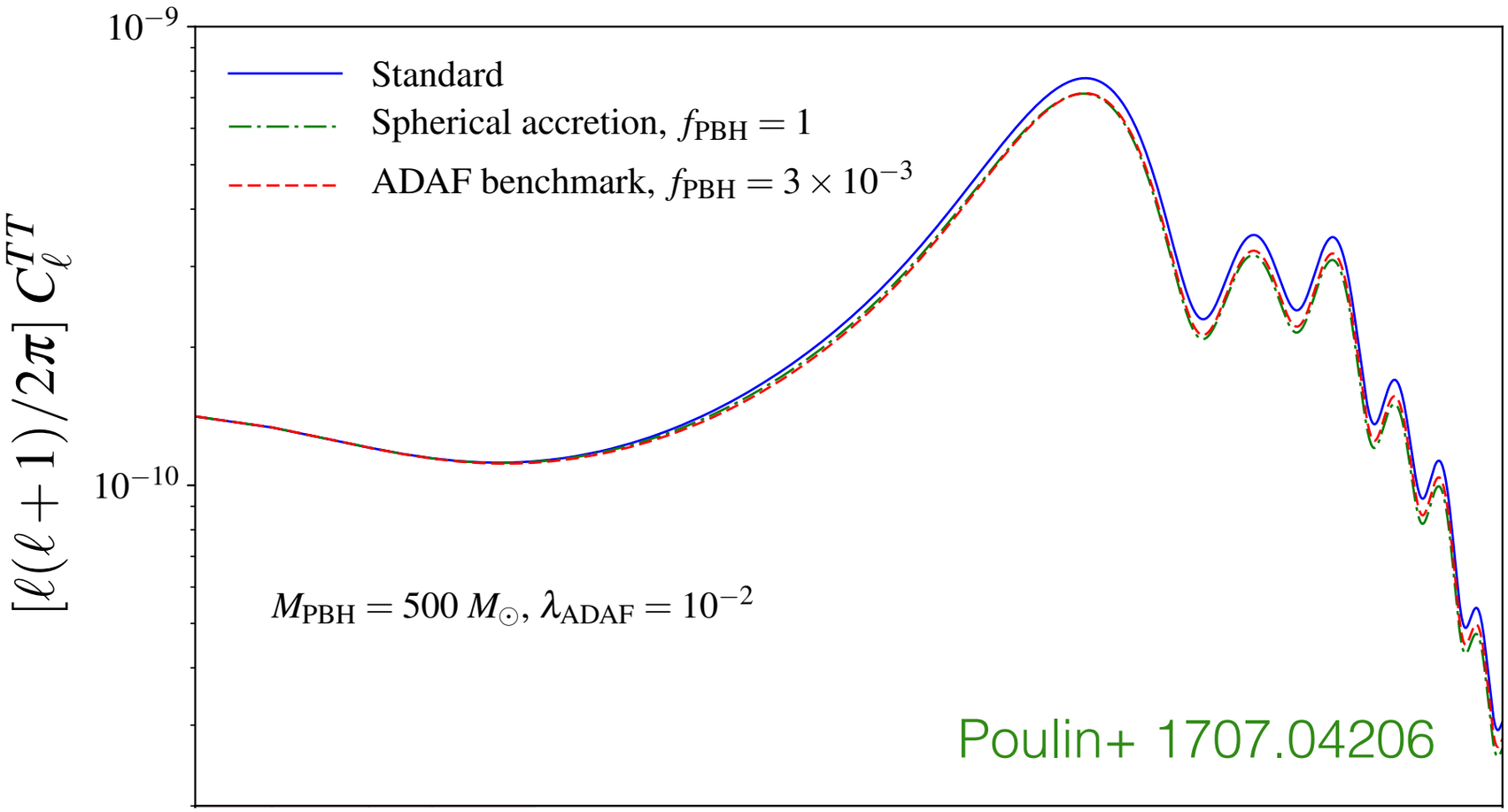
$$\frac{dx_e(z)}{dz} = \frac{1}{(1+z)H(z)}(R(z) - I(z) - I_X(z)) \ ,$$
$$\frac{dT_{\rm M}}{dz} = \frac{1}{1+z}\left[2T_{\rm M} + \gamma(T_{\rm M} - T_{\rm CMB})\right] + K_h \ .$$

Stocker+ 1801.01871



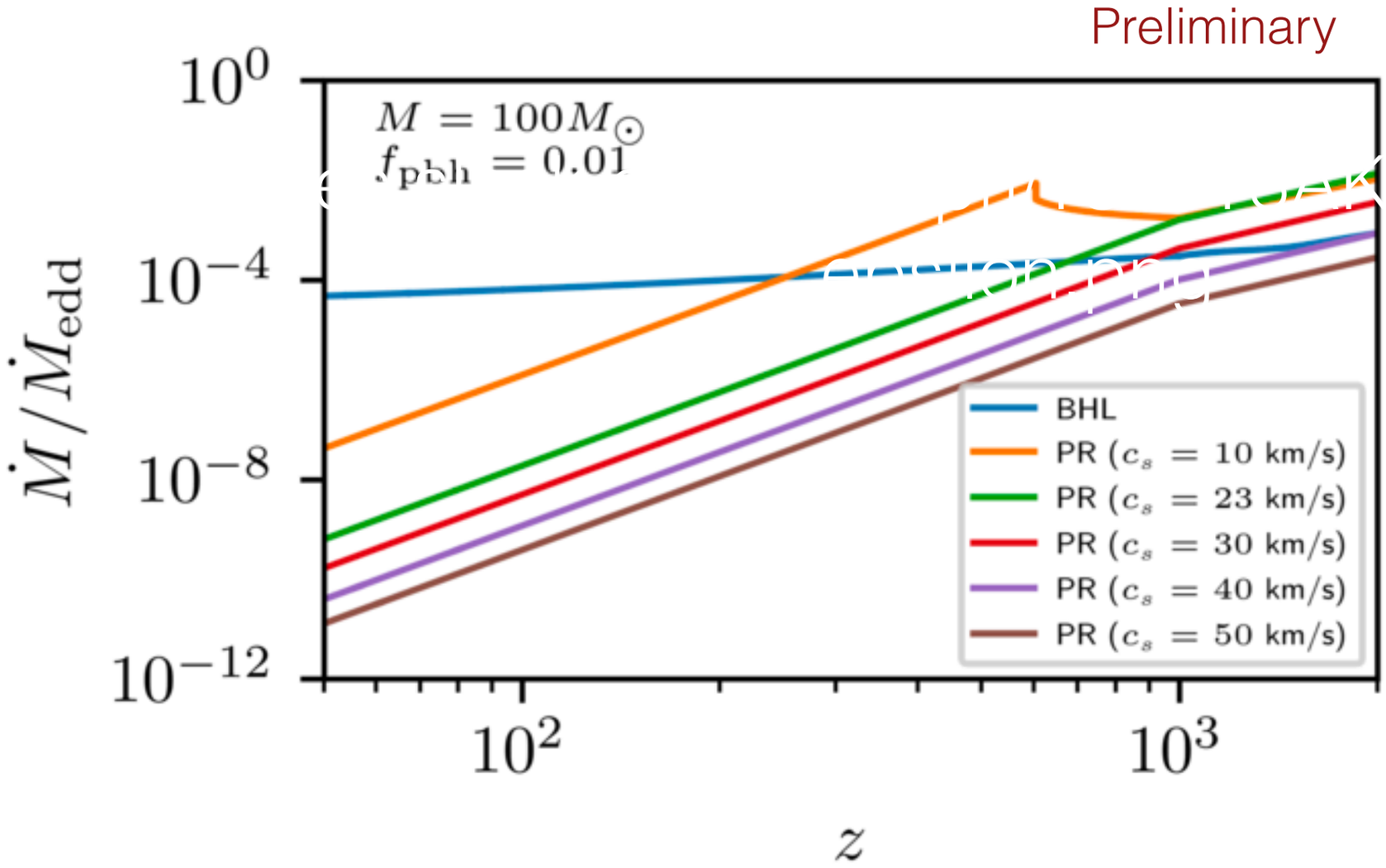
The physics behind the bound

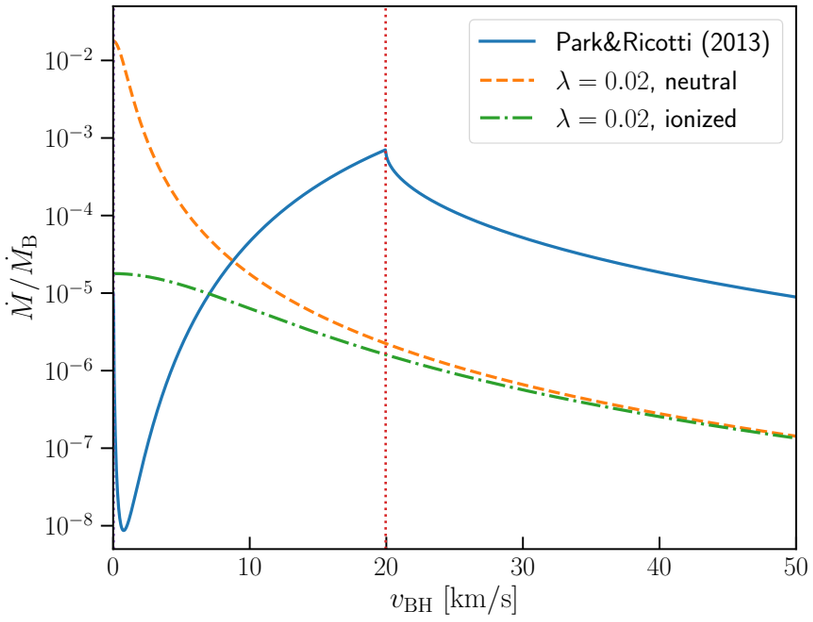
- Impact on CMB anisotropy is due to the alteration of the visibility function and the recombination optical depth



Revisiting the Cosmological constraint: Results

- Accretion rate **suppression** around PBHs is very relevant
- Dependence on the ionized sound speed
- May weaken the bound

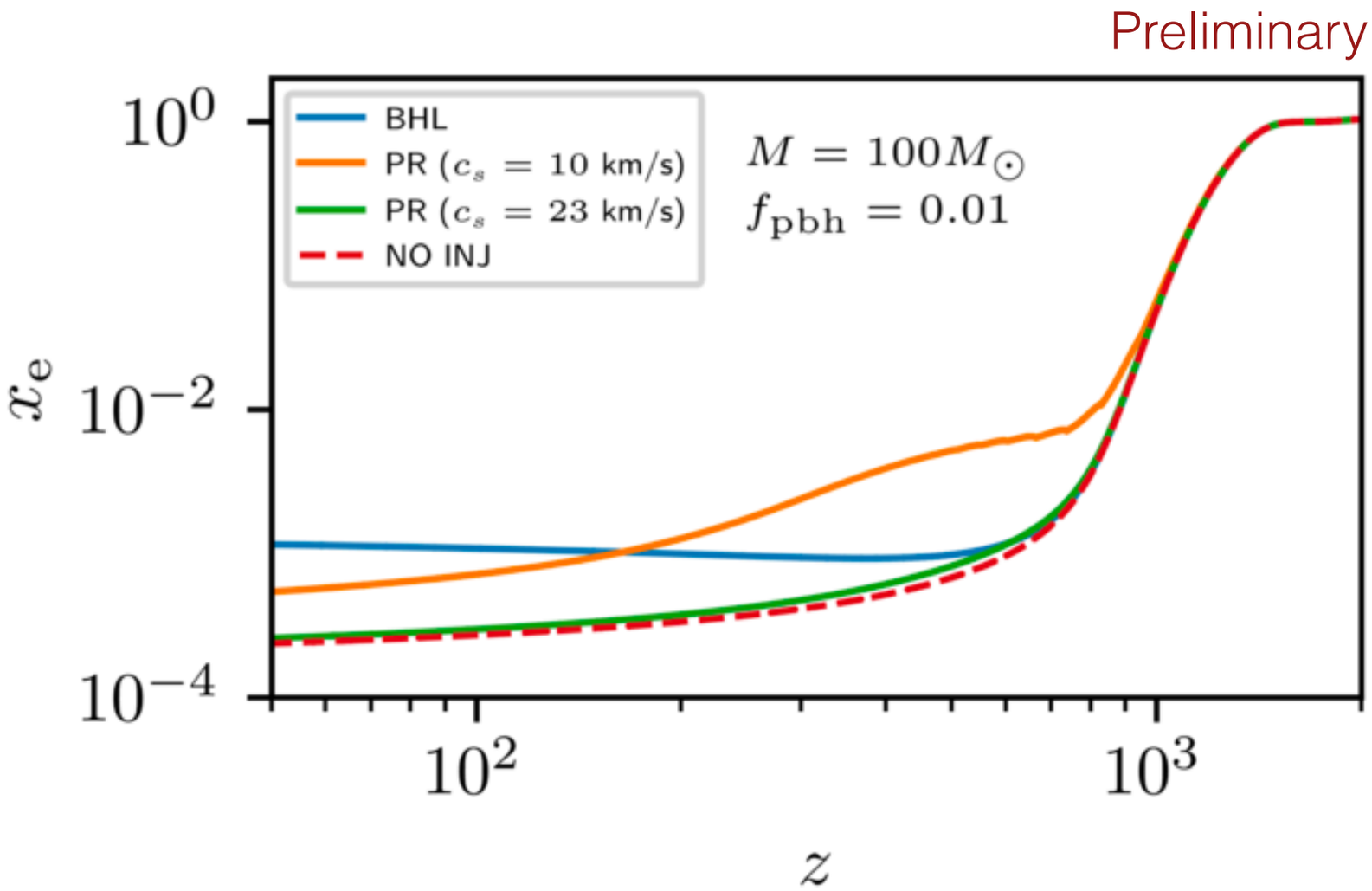


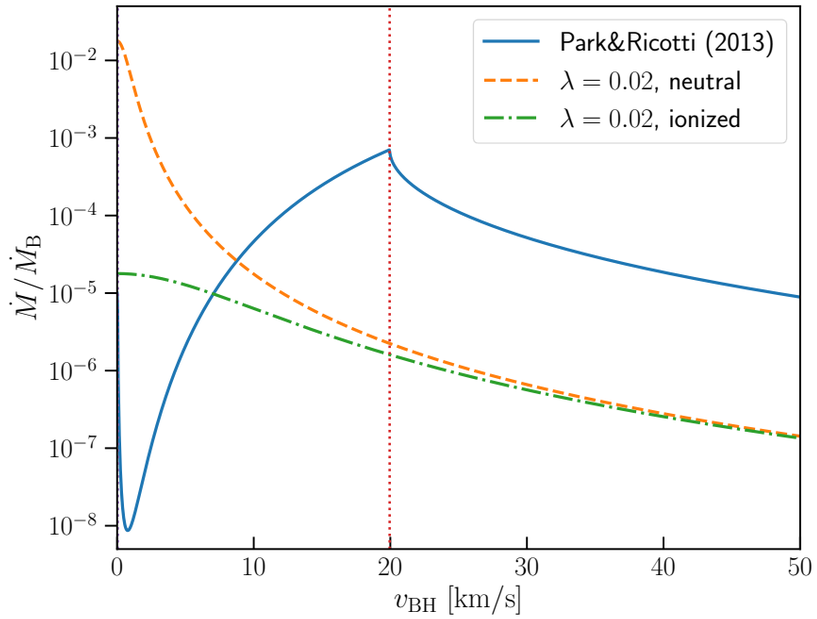


Dominic Agius, DG, Rouven Essig, Francesca Scarcella, Gregory Suczewski, Mauro Valli, *in preparation*

Revisiting the Cosmological constraint: Results

- Accretion rate **suppression** around PBHs is very relevant
- Dependence on the ionized sound speed
- May weaken the bound

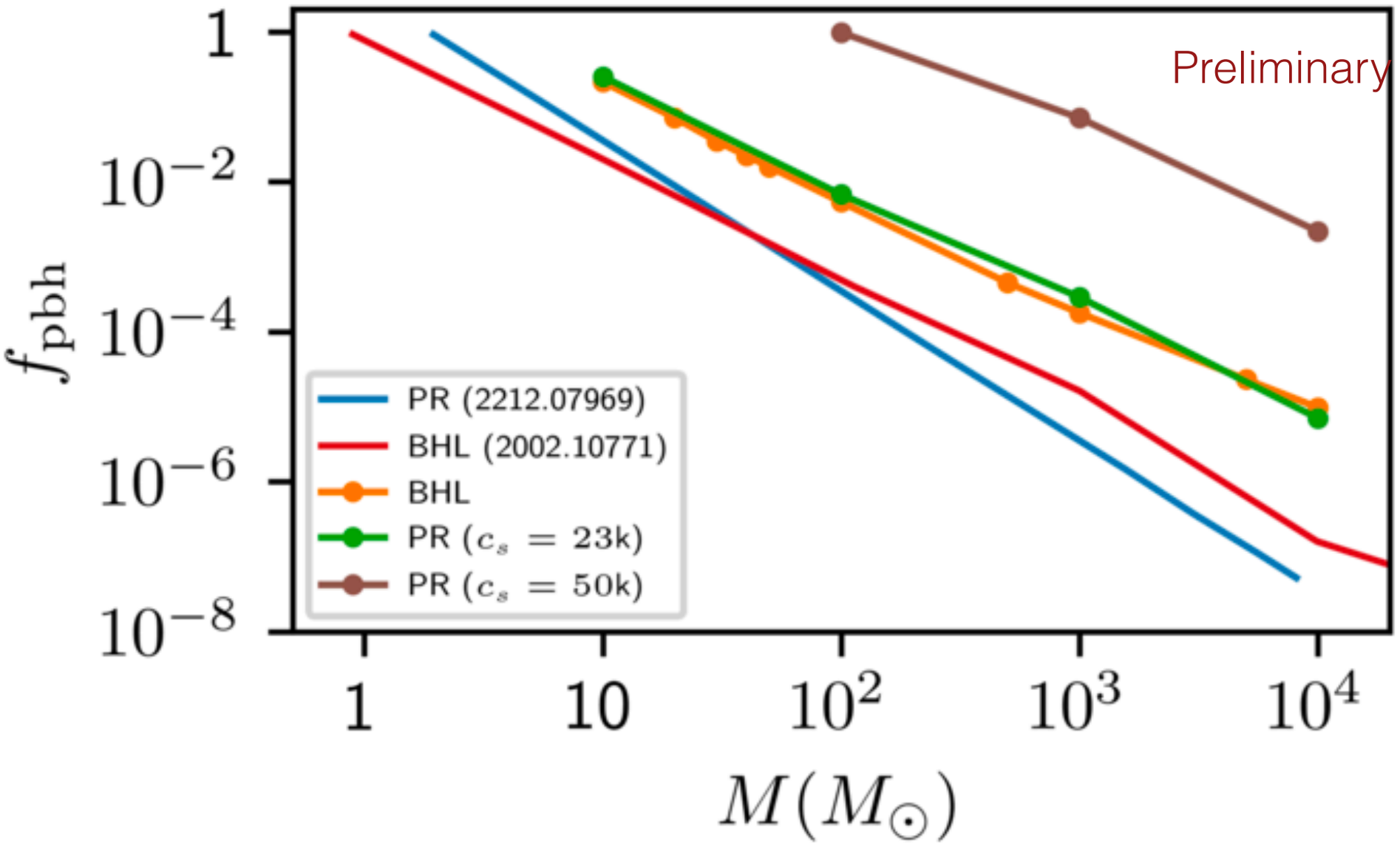




Dominic Agius, DG, Rouven Essig, Francesca Scarcella, Gregory Suczewski, Mauro Valli, *in preparation*

Revisiting the Cosmological constraint

BHL vs PR: the **"Unexpected robustness"** of the bound



See also
Facchinetti+
2212.07969

Made with `Cobaya+CLASS` (modified to account for energy injection)
`2018 low-l Planck TT.EE, high-l Planck TT.TE.EE, lensing, ACT, BAO`

Revisiting the Cosmological constraint

Other uncertainties to be assessed

- Evolution of the DM-baryon velocity
  (see for instance the discussion in Poulin+ 1707.04206*)*

- Luminosity of the accretion disks around PBHs

- Energy deposition functions
  (Galli+ 1306.0563; Slatyer 1506.03812, Liu+ 2303.07366)

Conclusions

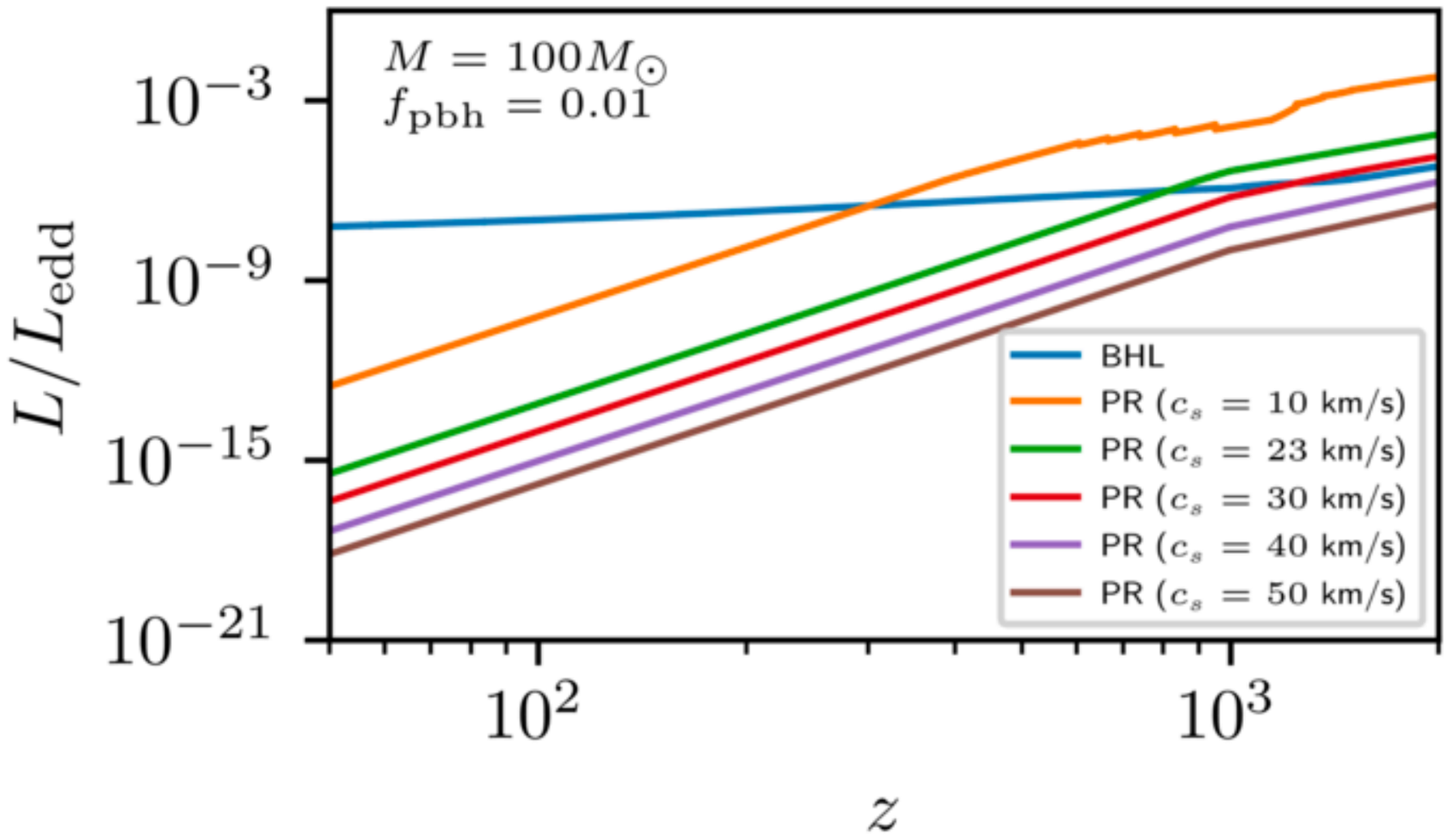
- Revisitation of the **Cosmological bound on the PBH abundance**

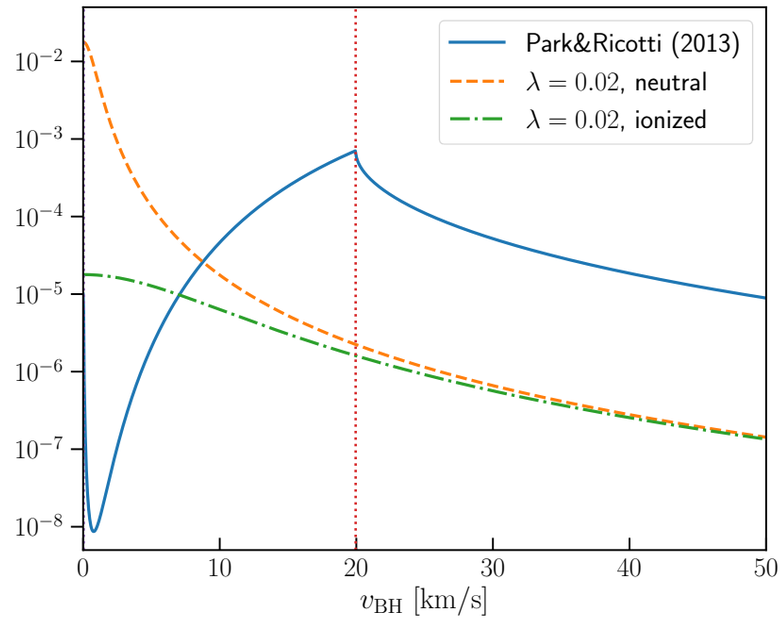
  - Very strong at high masses.
  - Assessment of uncertainties is needed.
  - Different models of accretion predict very different time evolution of *Xe*.
  - The bound is not heavily affected.
  - More investigation on DM-baryon relative speed and radiative efficiency is needed.

Revisiting the Cosmological constraint: Results

- Accretion rate **suppression** around PBHs is very relevant
- Dependence on the ionized sound speed
- May weaken the bound

Preliminary

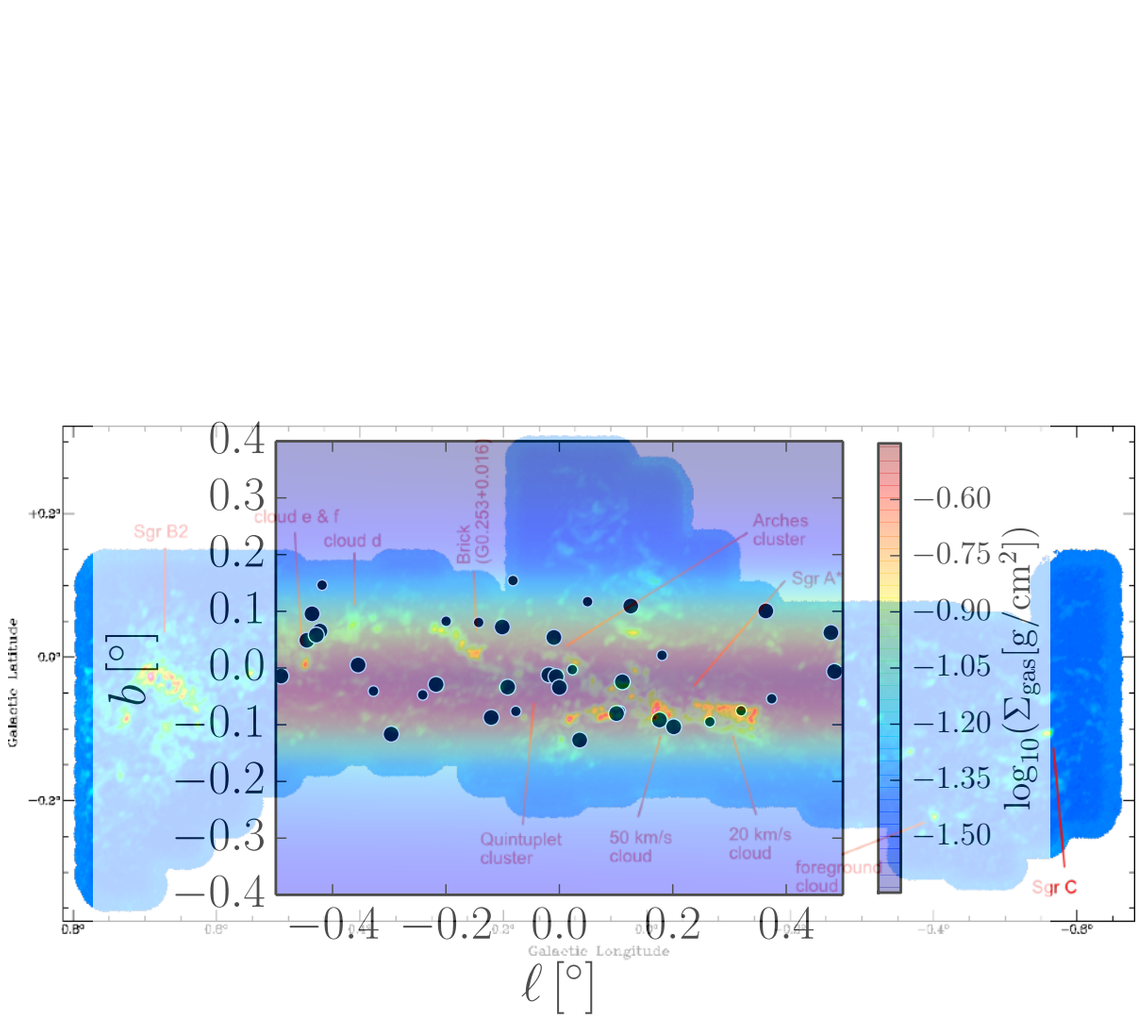


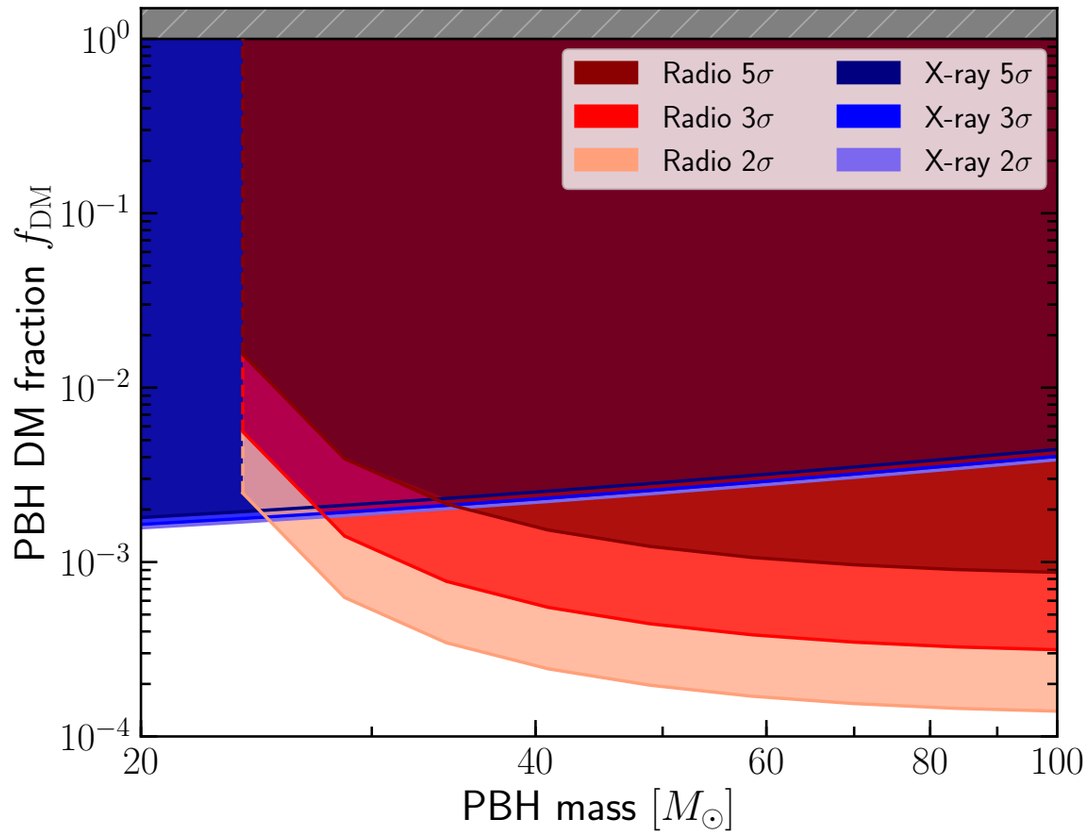


Dominic Agius, DG, Rouven Essig, Francesca Scarcella, Gregory Suczewski, Mauro Valli, *in preparation*

Revisiting the Astronomical constraint

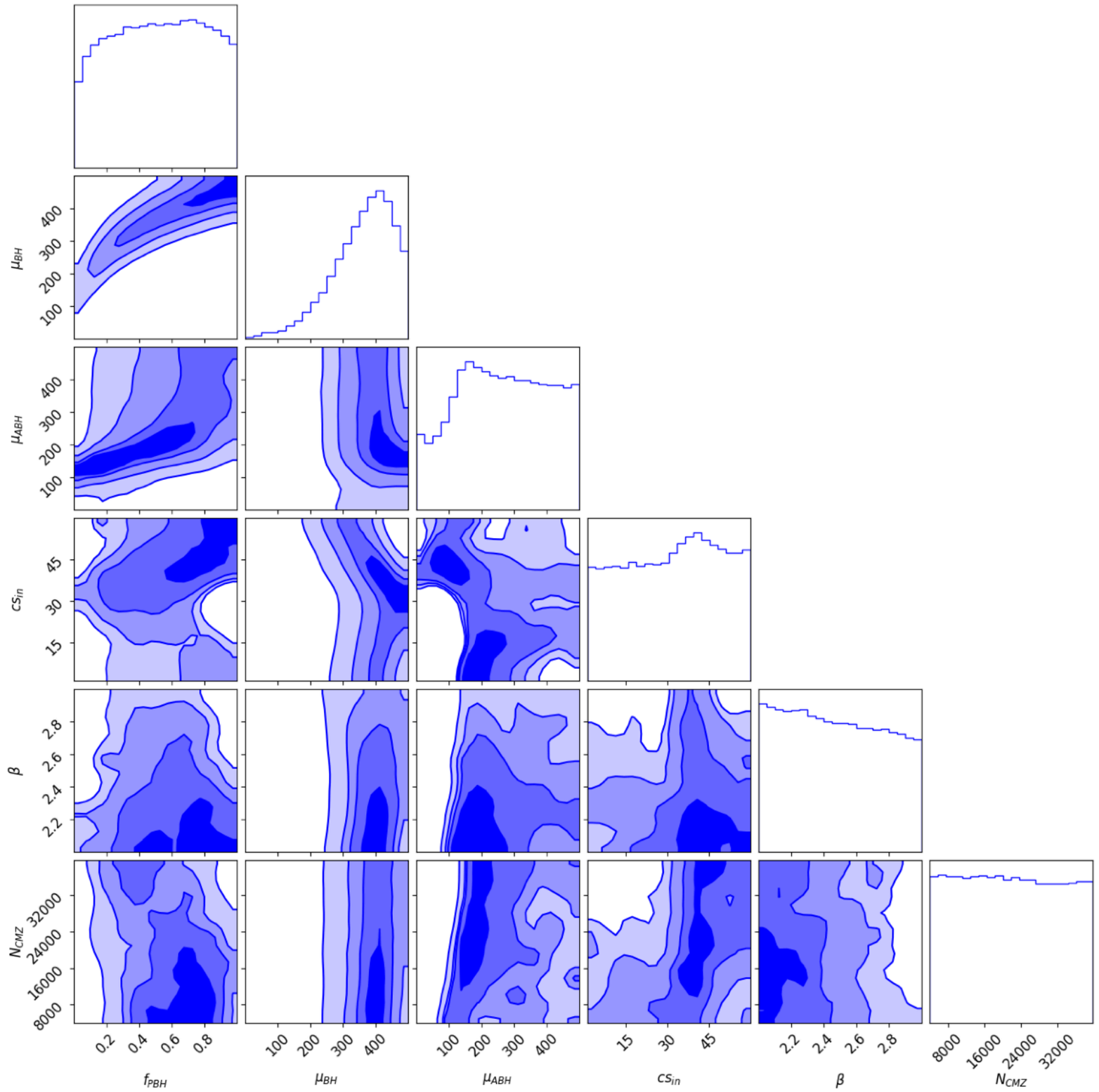
- Focus on Galactic Center region - rich of gas
- If PBHs exist, they accrete gas and emit
- We require not to overshoot data from X-ray and radio point source catalogues
- Both BHL and PR already considered





J. Manshanden, **DG**, R. Connors, G. Bertone, M.Ricotti, 1812.07967

Revisiting the Astronomical constraint



DG, Juan García-Bellido, Francesca Scarcella, Tejas Satheesh, *in preparation*

Revisiting the Astronomical constraint