CMB Bounds from Primordial Black Hole Accretion

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May 9, 2023

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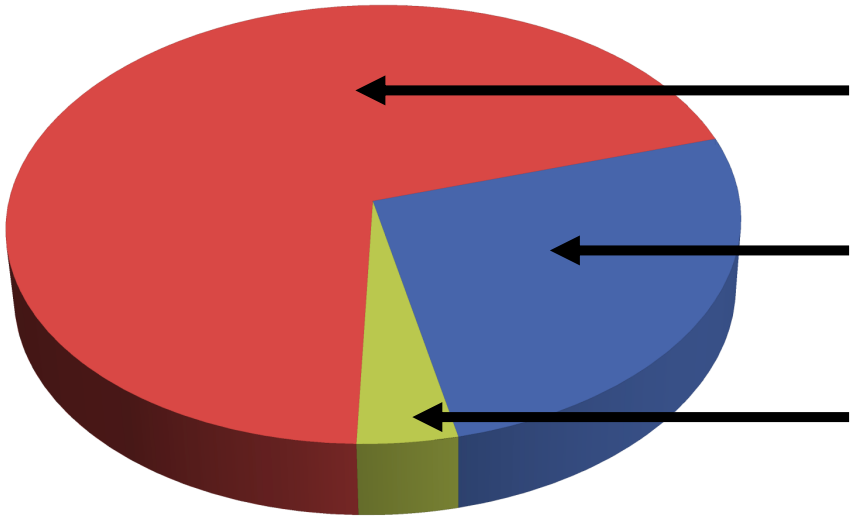
OUTLINE

1. Motivation and Background
2. PBH Accretion and Energy Deposition
3. Ionization and Thermal History
4. CMB Bounds and Preliminary Results

What is Dark Matter?

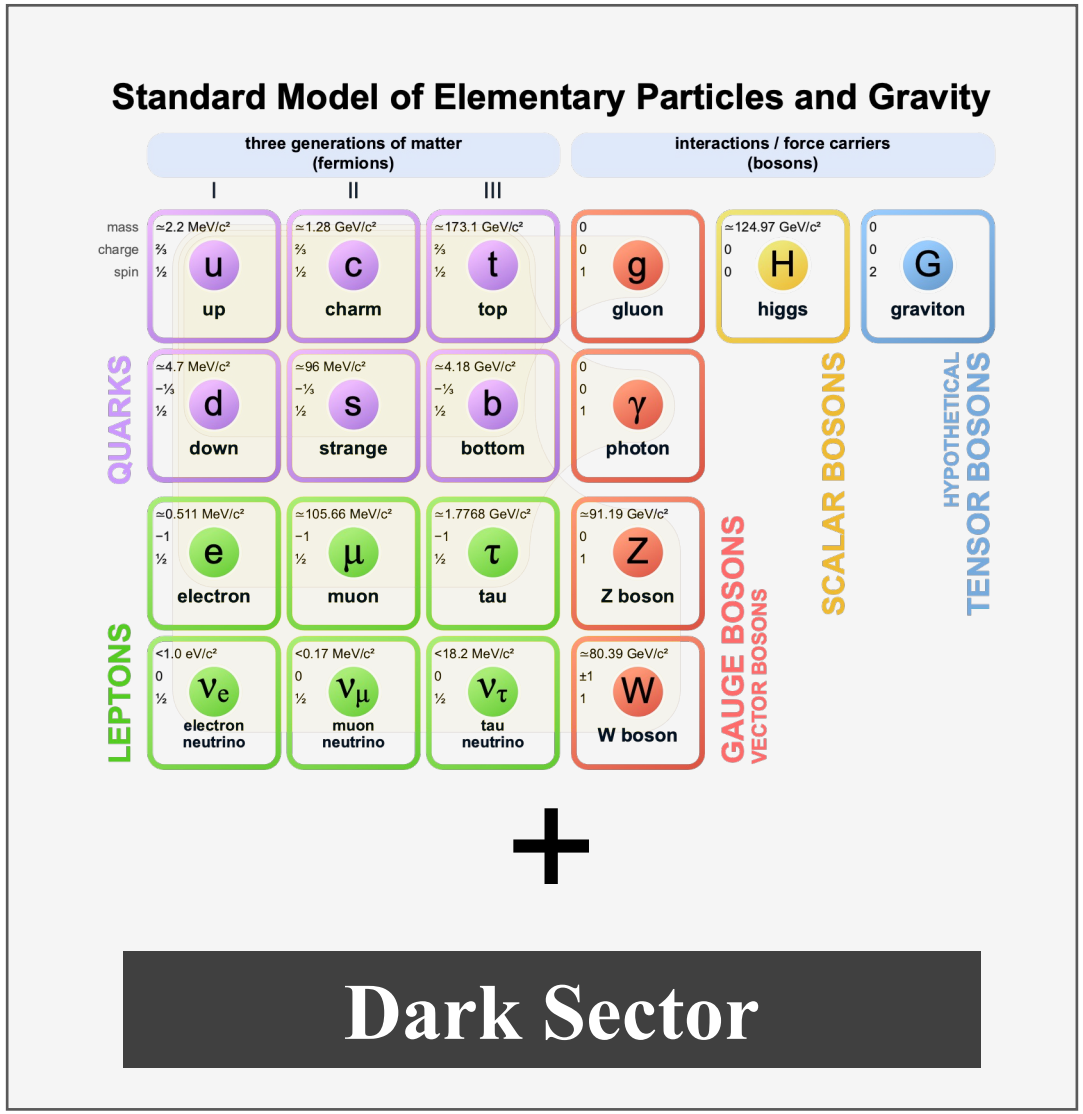


70% Dark Energy

26% Dark Matter

4% Ordinary Matter

- Extensions of the Standard Model are most explored possibility
- **NO DETECTION** of DM particle candidates from experiments (yet)



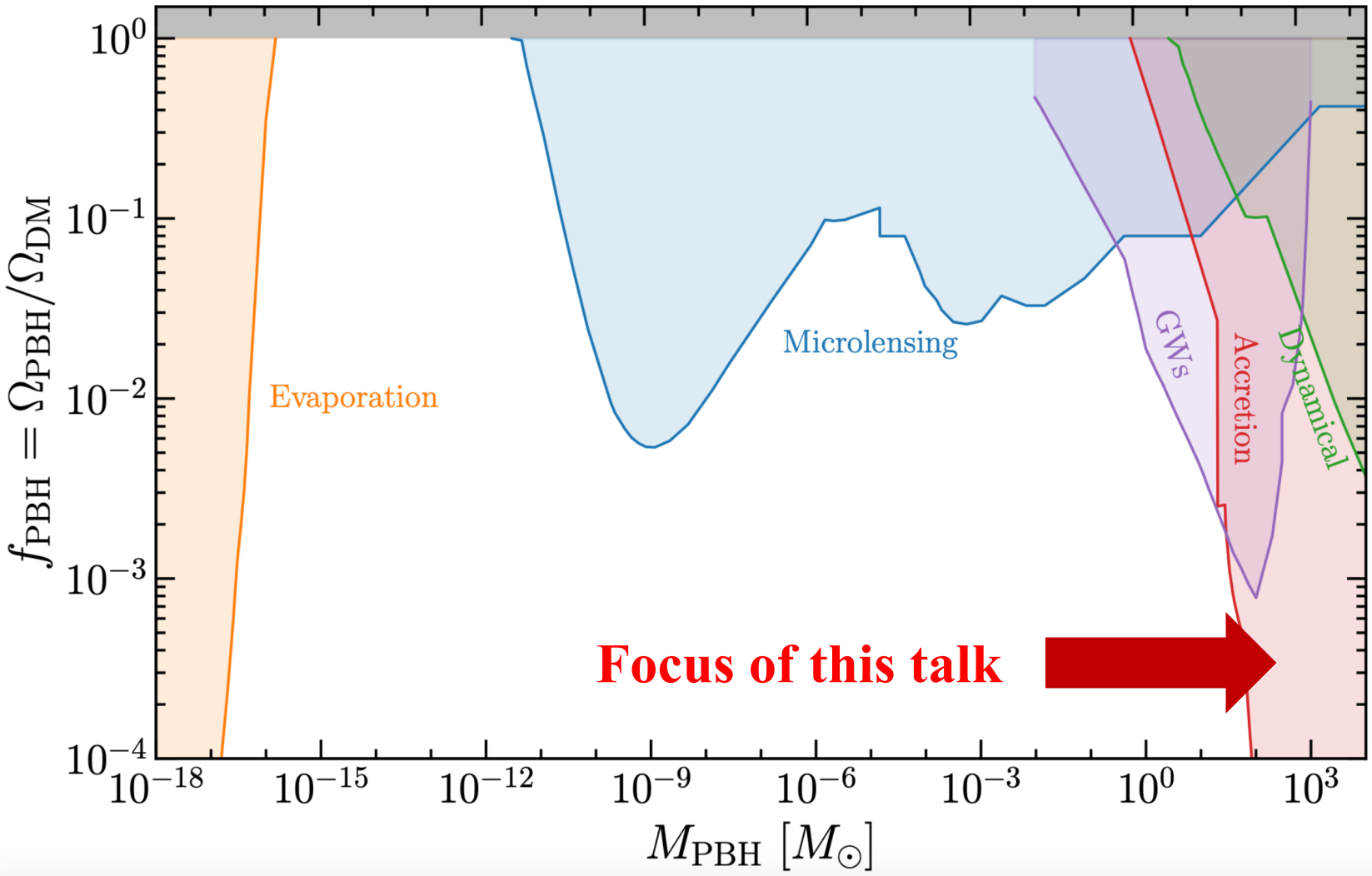
Motivation for PBHs

1. Primordial Black Holes (PBHs) are a macroscopic alternative to particle dark matter

2. PBHs might act as seeds for the formation of super-massive black holes

3. PBHs might explain recent gravitational wave detections of black hole mergers

PBH Abundance Constraints

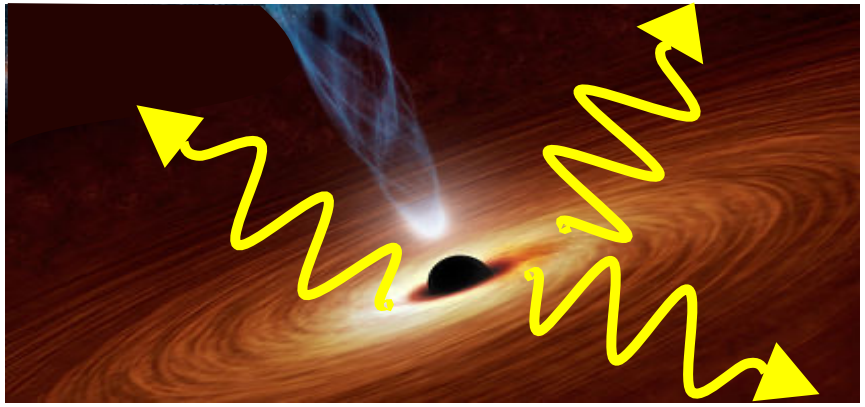


GOAL: TEST THE ROBUSTNESS OF THE ACCRETION BOUND AND APPLY NEW ACCRETION MODEL

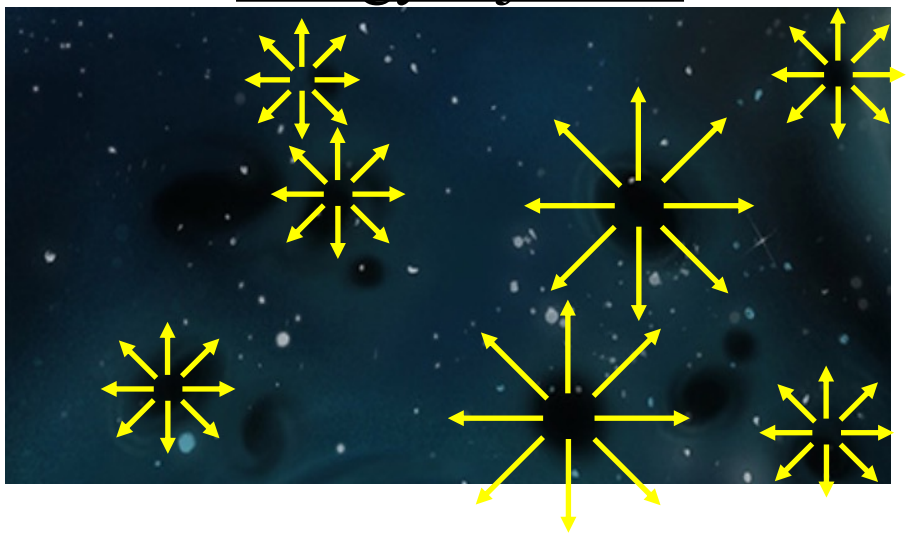
Overview of PBH Accretion

Accretion Rate

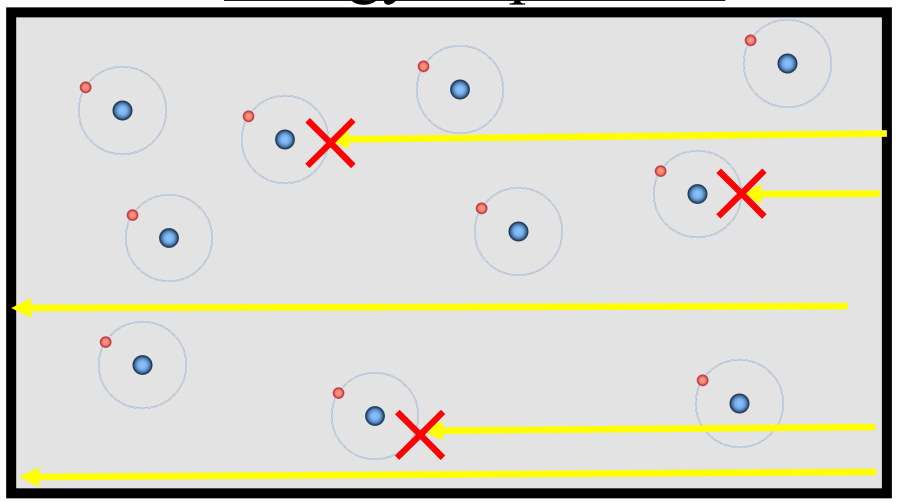
Accretion Luminosity



Energy Injection



Energy Deposition

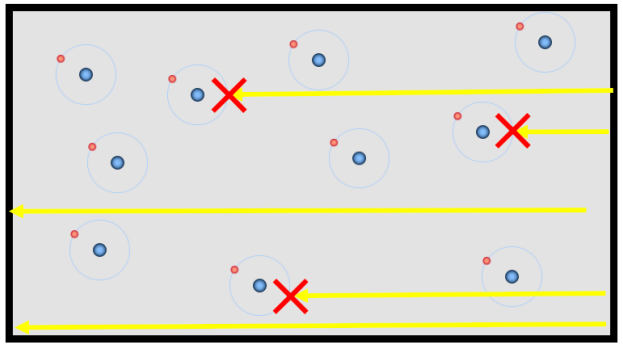


3 DEPOSITION CHANNELS: HEATING, IONIZATION, EXCITATION

Deriving the CMB Bound

Ionization History

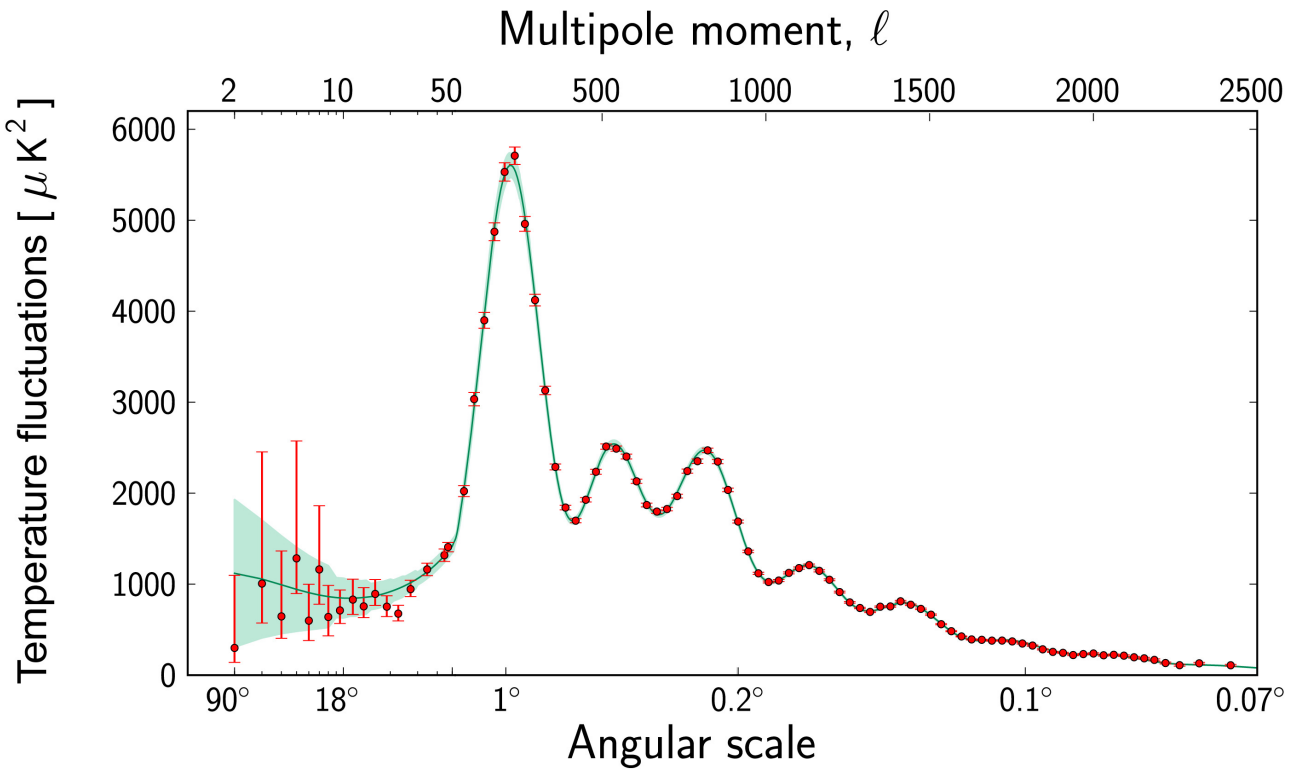
Energy Deposition



x_e

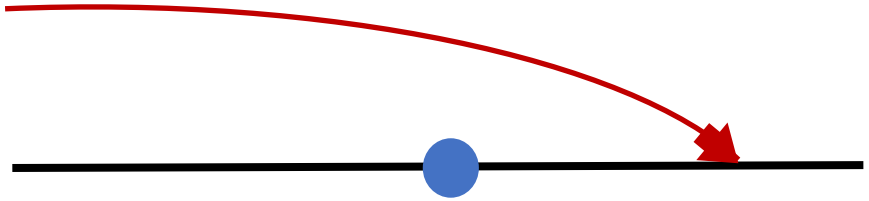
T_m

Thermal History



Accretion Models (BHL)

- Bondi-Hoyle-Lyttleton (BHL) is the "standard" PBH accretion model
- Typically, BHL has been used to compute PBH abundance bounds



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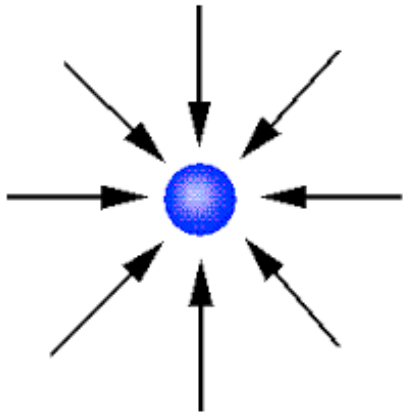

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$$\dot{M}_{\rm BHL} \sim \rho_\infty \frac{M^2}{(v_{\rm rel}^2 + c_{\rm s,\infty}^2)^{3/2}}$$

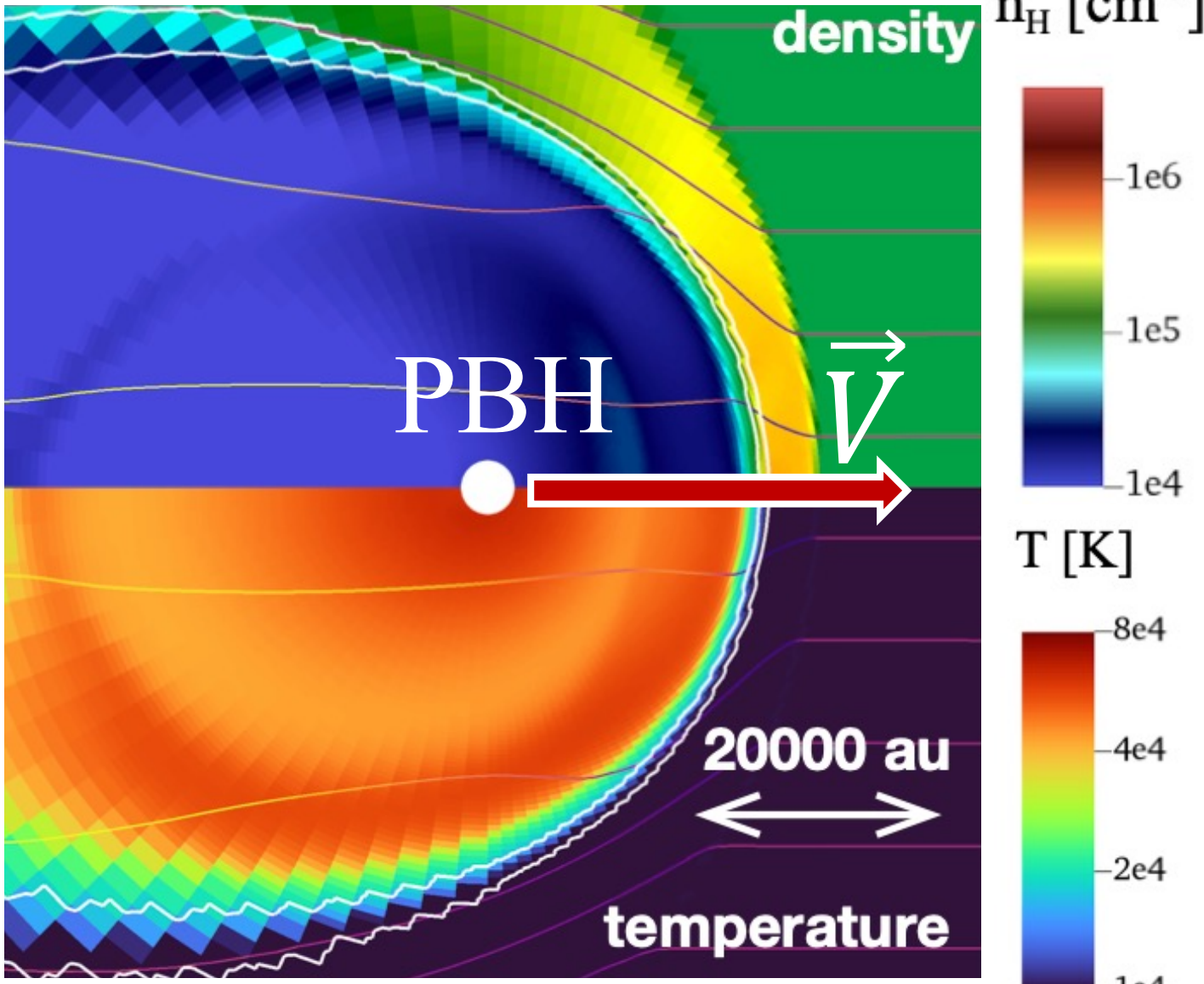
Accretion Models (PR13)

- PBHs form ionization fronts (Sugimura and Ricotti)

Park-Ricotti Model (PR13)

PR13 = Bondi + Ionization Front

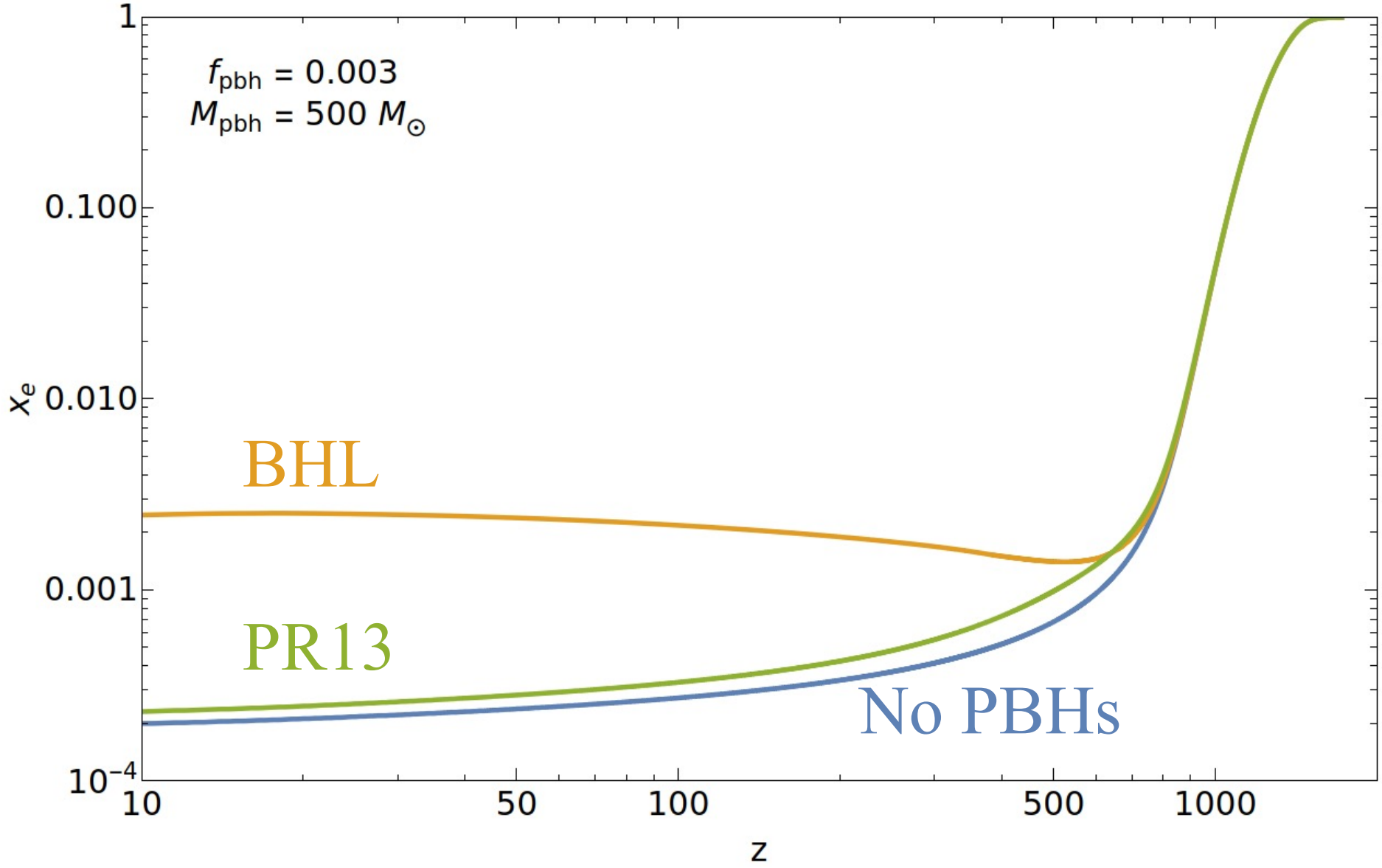
$$\dot{M}_{\mathrm{PR13}} \sim \rho_{\mathrm{in}} \frac{M^2}{\left(v_{\mathrm{in}}^2 + \left(c_s^{\mathrm{in}}\right)^2\right)^{3/2}}$$



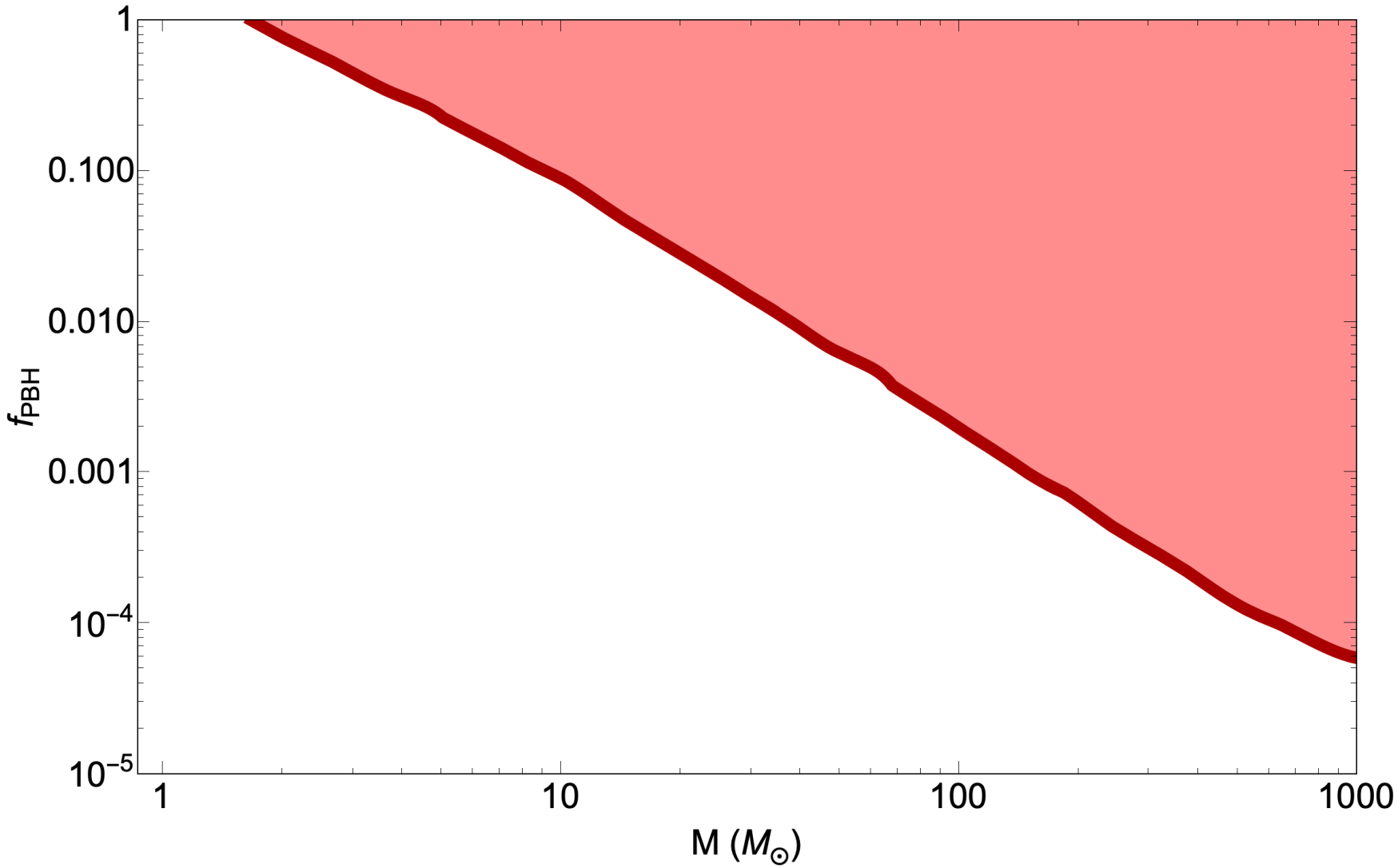
Important Assumptions

- Accretion Model
- Energy Deposition Functions
- Radiative Efficiency
  - Geometry of Accretion Flow
  - Advection
  - Outflows
  - Jets
  - Turbulence
- PBH Velocity Treatment (Linear Theory)
- Averaging Technique
- Speed of Sound in the Ionized Region (PR13)
- Photon Spectra
- …

BHL vs PR13 Free-Electron Fraction



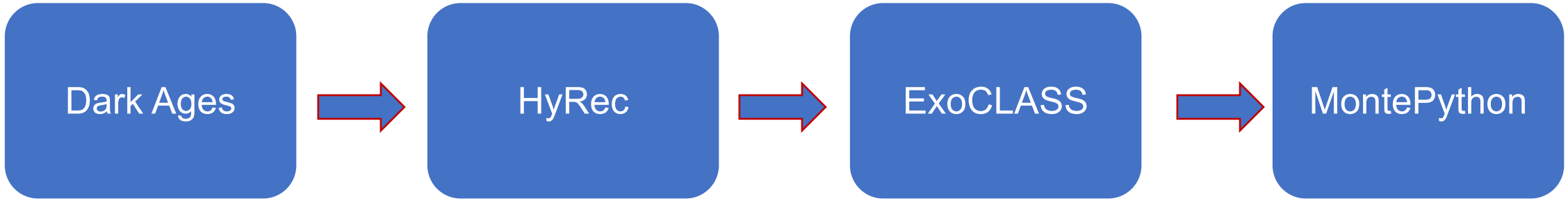
Bounds using BHL Accretion



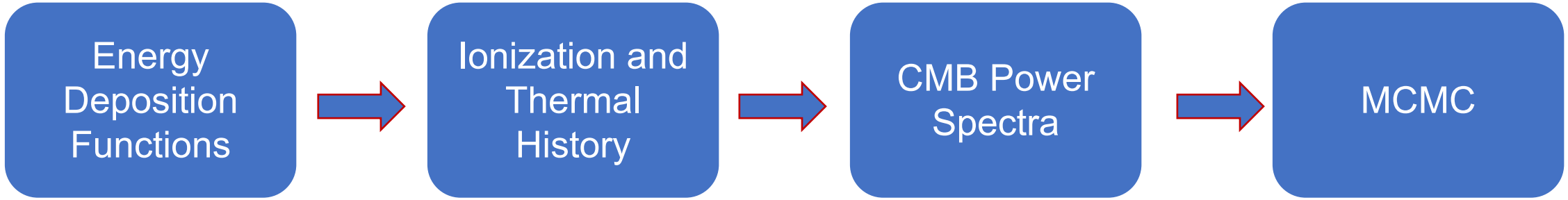
Modified from (Poulin, 2017)

Computing the Bound

PROGRAMS

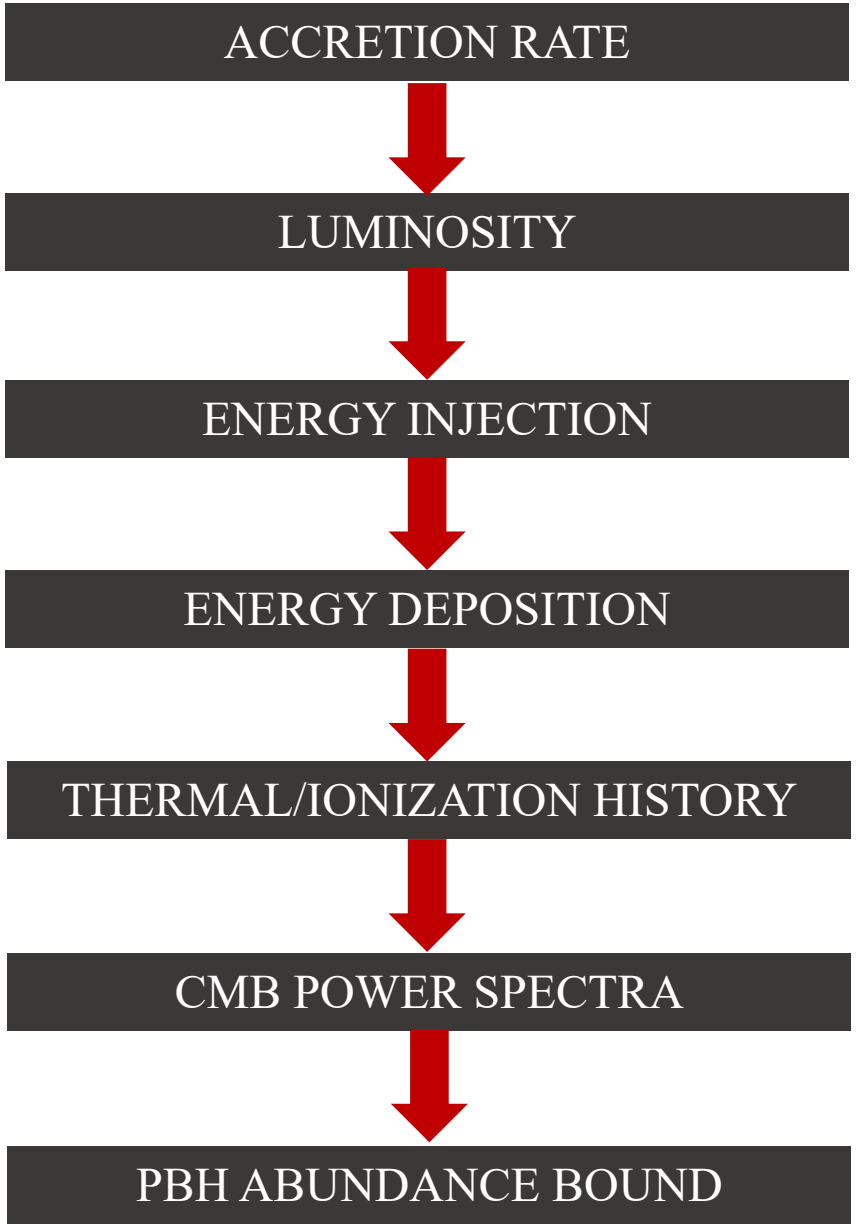


MAIN TASK



Summary

- Computing PBH abundance bounds rely on many assumptions
- PR13 is suppressed compared to BHL
- Expect a **relaxation** in the bound
  (results coming soon!)



REFERENCES

Ali-Haïmoud, Yacine, and Marc Kamionkowski. "Cosmic Microwave Background Limits on Accreting Primordial Black Holes." Physical Review D 95, no. 4 (February 24, 2017): 043534. https://doi.org/10.1103/PhysRevD.95.043534.

Edgar, R. G. "A Review of Bondi--Hoyle--Lyttleton Accretion." New Astronomy Reviews 48, no. 10 (September 2004): 843–59. https://doi.org/10.1016/j.newar.2004.06.001.

Facchinetti, Gaétan, Matteo Lucca, and Sébastien Clesse. "Relaxing CMB Bounds on Primordial Black Holes: The Role of Ionization Fronts." arXiv, December 15, 2022. http://arxiv.org/abs/2212.07969.

Galli, Silvia, Tracy R. Slatyer, Marcos Valdes, and Fabio Iocco. "Systematic Uncertainties In Constraining Dark Matter Annihilation From The Cosmic Microwave Background." Physical Review D 88, no. 6 (September 3, 2013): 063502. https://doi.org/10.1103/PhysRevD.88.063502.

Green, Anne M., and Bradley J. Kavanagh. "Primordial Black Holes as a Dark Matter Candidate." Journal of Physics G: Nuclear and Particle Physics 48, no. 4 (April 1, 2021): 043001. https://doi.org/10.1088/1361-6471/abc534.

Park, KwangHo, and Massimo Ricotti. "ACCRETION ONTO BLACK HOLES FROM LARGE SCALES REGULATED BY RADIATIVE FEEDBACK. III. ENHANCED LUMINOSITY OF INTERMEDIATE-MASS BLACK HOLES MOVING AT SUPERSONIC SPEEDS." The Astrophysical Journal 767, no. 2 (April 8, 2013): 163. https://doi.org/10.1088/0004-637X/767/2/163.

Piga, Lorenzo, Matteo Lucca, Nicola Bellomo, Valentì Bosch-Ramon, Sabino Matarrese, Alvise Raccanelli, and Licia Verde. "The Effect of Outflows on CMB Bounds from Primordial Black Hole Accretion." Journal of Cosmology and Astroparticle Physics 2022, no. 12 (December 1, 2022): 016. https://doi.org/10.1088/1475-7516/2022/12/016.

Poulin, Vivian, Pasquale D. Serpico, Francesca Calore, Sebastien Clesse, and Kazunori Kohri. "CMB Bounds on Disk-Accreting Massive Primordial Black Holes." Physical Review D 96, no. 8 (October 24, 2017): 083524. https://doi.org/10.1103/PhysRevD.96.083524.

Scarcella, Francesca. "Black Hole Phenomenology and Dark Matter Searches," n.d.

Stöcker, Patrick, Michael Krämer, Julien Lesgourgues, and Vivian Poulin. "Exotic Energy Injection with ExoCLASS: Application to the Higgs Portal Model and Evaporating Black Holes." Journal of Cosmology and Astroparticle Physics 2018, no. 03 (March 12, 2018): 018–018. https://doi.org/10.1088/1475-7516/2018/03/018.

Trotta, Roberto. "Bayesian Methods in Cosmology," n.d.