Cloud Cooling Bounds on Intermediate Mass and Light Primordial Black Holes

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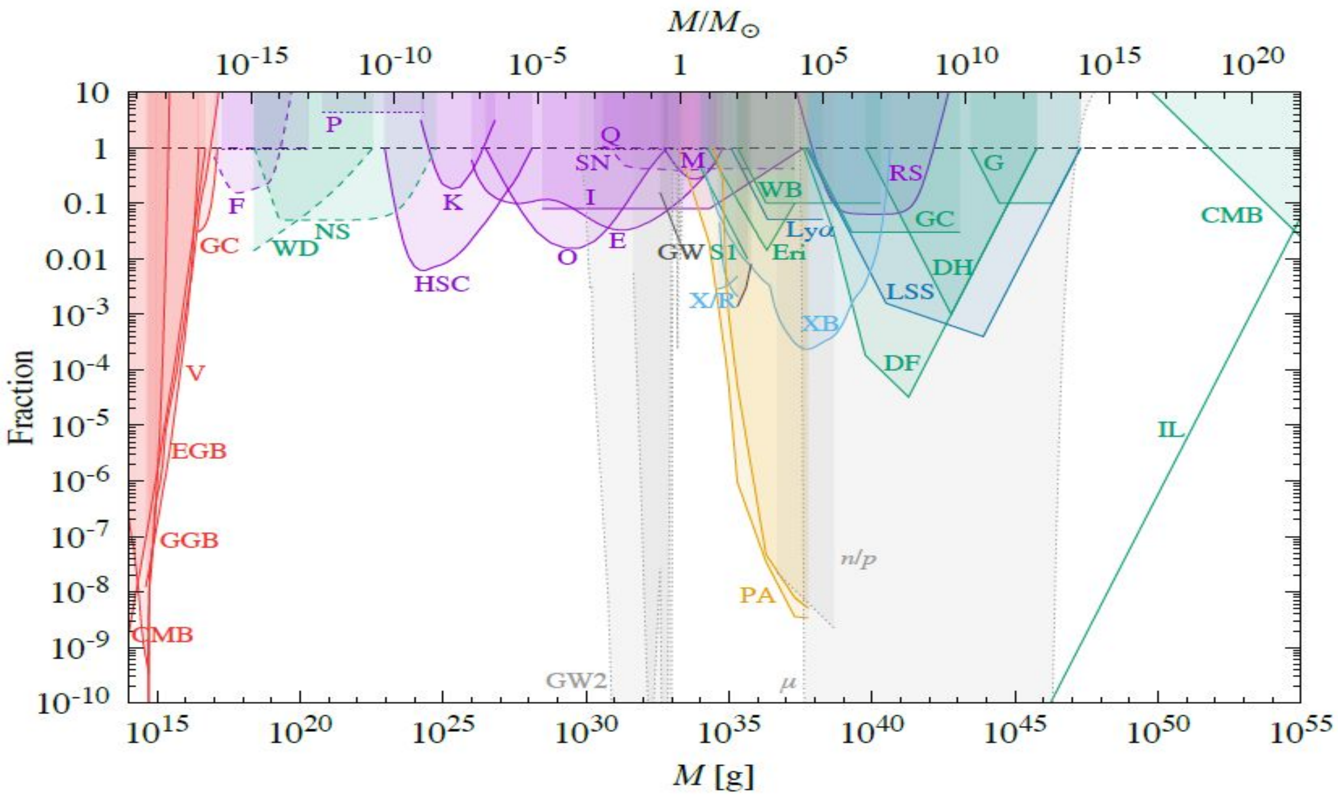
arXiv:2007.02213
arXiv:2009.11837
arXiv:2105.06099
arXiv:2111.08699

PBH Bounds



Carr et al. 2020

PBH Heating Constraint

Thermal Equilibrium

- Require heating rate equal to cooling rate
- Ignore heating from standard sources

Total heating (PBH) vs local heating (particle DM)

$$N_{\mathrm{PBH}}(M) = f_{\mathrm{PBH}} \frac{\rho_{\mathrm{DM}} V}{M}$$

PBH allowed fraction

$$f_{\mathrm{PBH}} < f_{\mathrm{bound}} = \frac{M\dot{C}}{\rho_{\mathrm{DM}} H(M)}$$

Lower limit

$$f_{\mathrm{bound}} > \frac{3M}{4\pi r_{\mathrm{sys}}^3 \rho_{\mathrm{DM}}}$$

Bhoonah et al. 2018
Wadekar and Farrar 2019

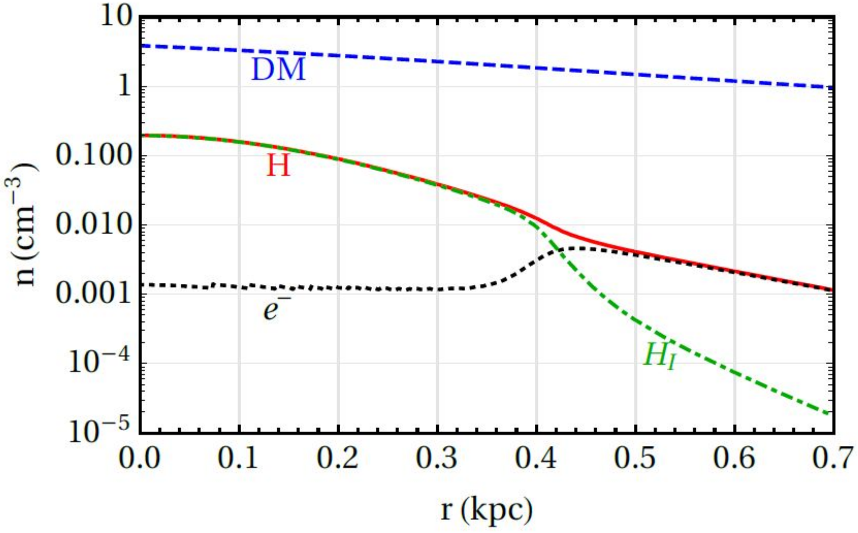
Target System: Leo T

Dwarf Galaxy

- Well-studied and modeled
- No significant star formation
- No coherent rotation detected

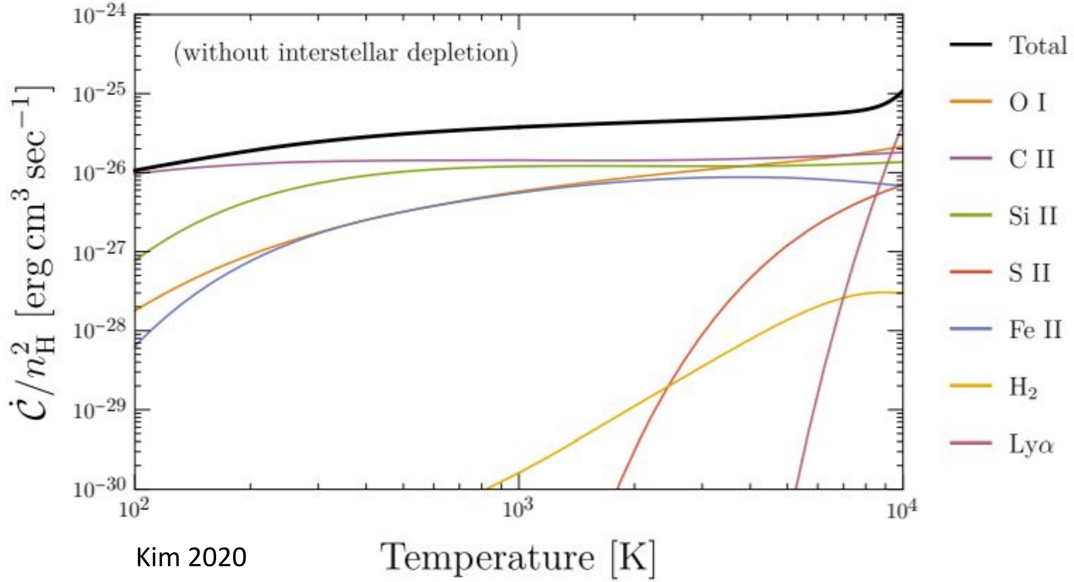
Properties

- Average DM density: 1.75 GeV/cm^3
- Average H1 density: 0.07 GeV/cm^3
- Velocity dispersion: 7 km/s



Wadekar and Farrar 2019
Faerman et al. 2013

Cloud Cooling



Kim 2020

Cooling rate:

$$\dot{C} = n^2 10^{[\mathrm{Fe/H}]} \Lambda(T)$$

Cooling Function:

$$\Lambda(T) = 2.51 \times 10^{-28} T^{0.6}$$

Wadekar and Farrar 2019
Kim 2020

Cloud Heating Processes

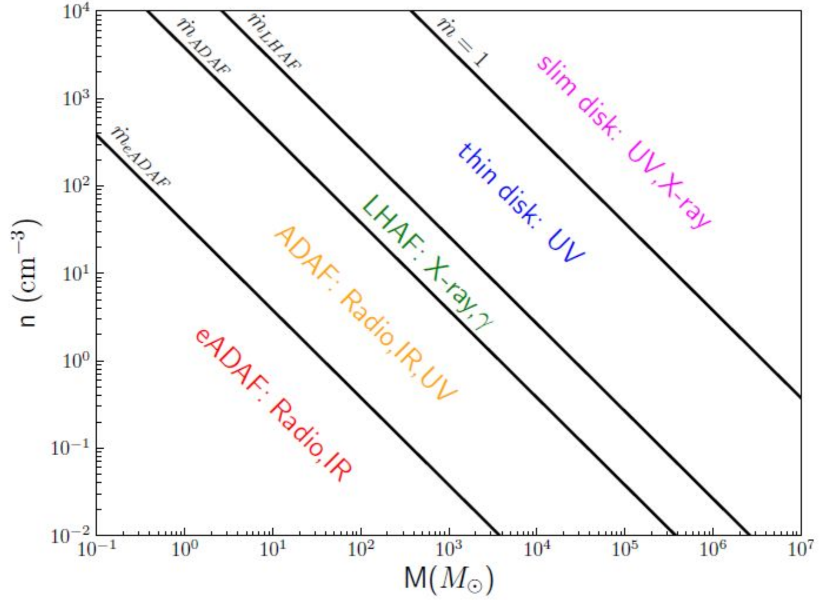
Accretion disk luminosity

- Bondi-Hoyle accretion
- ADAF
- Thin disk
- Optical Depth

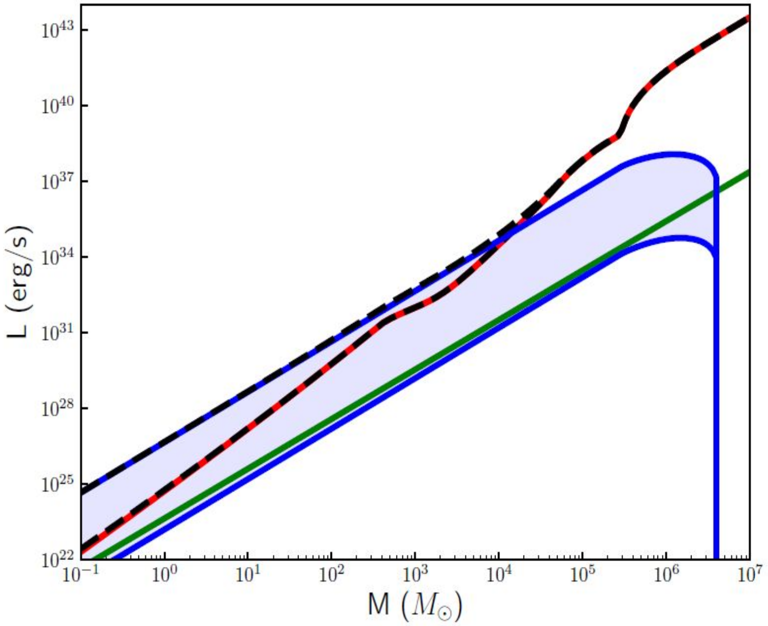
Winds

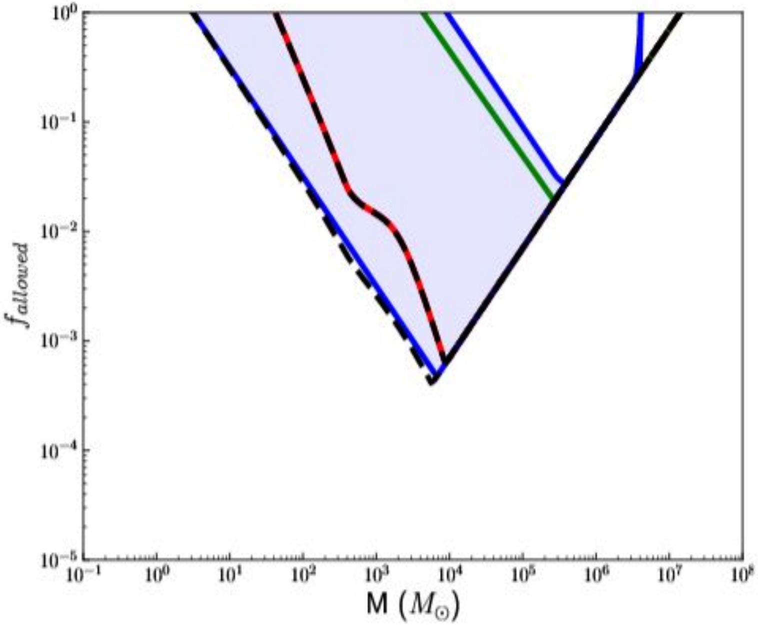
- Stopping Power

Dynamical Friction

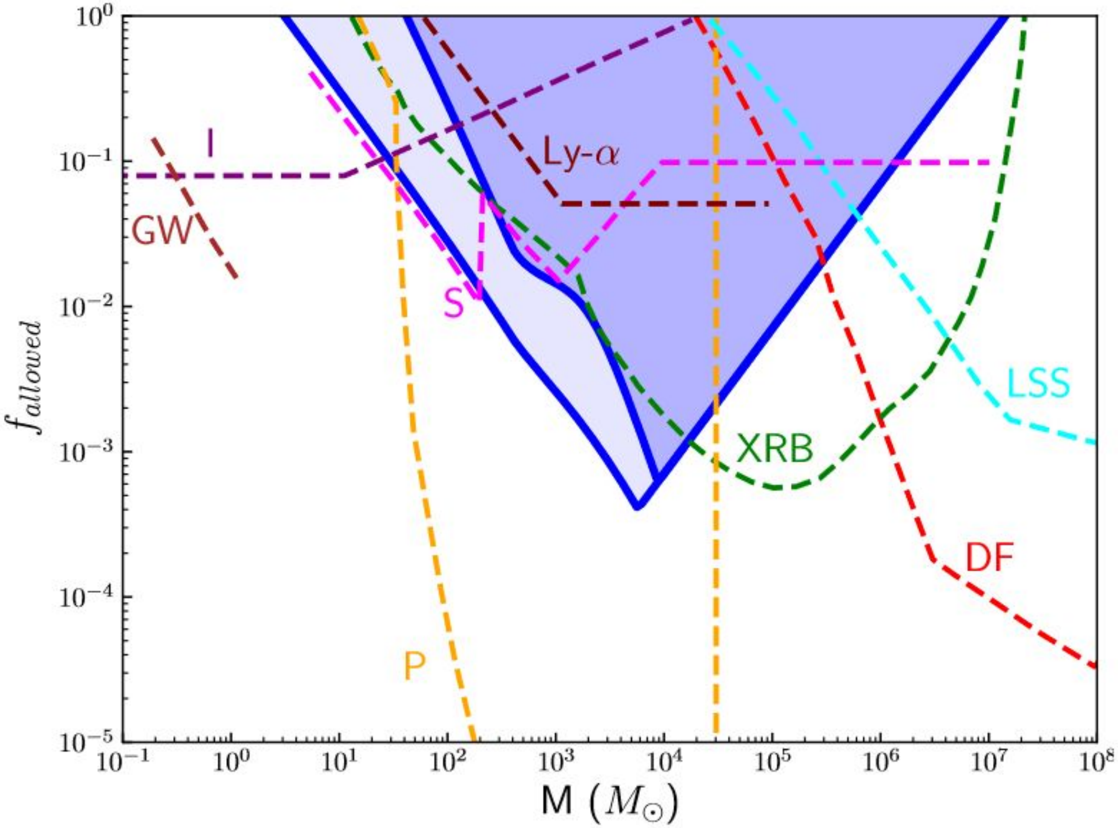


Individual Heating Contributions





Initial Constraints



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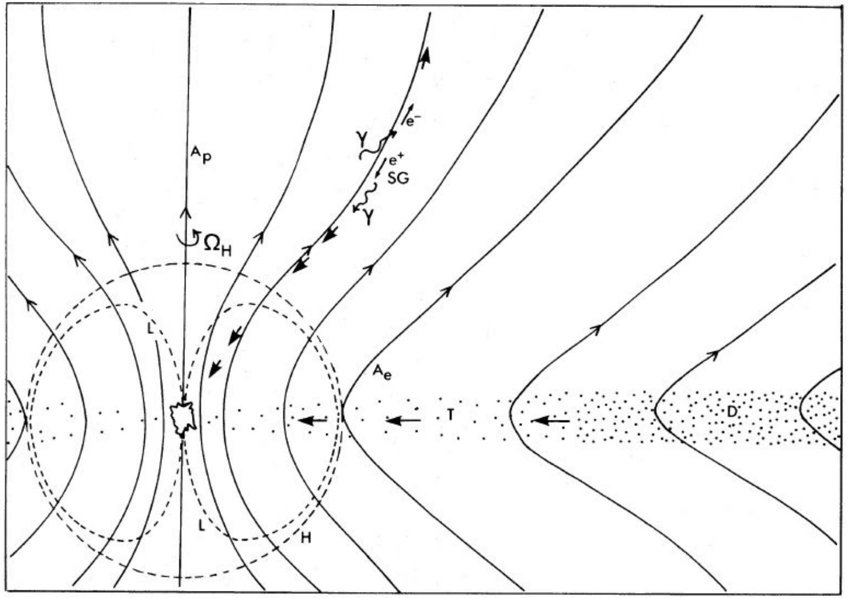
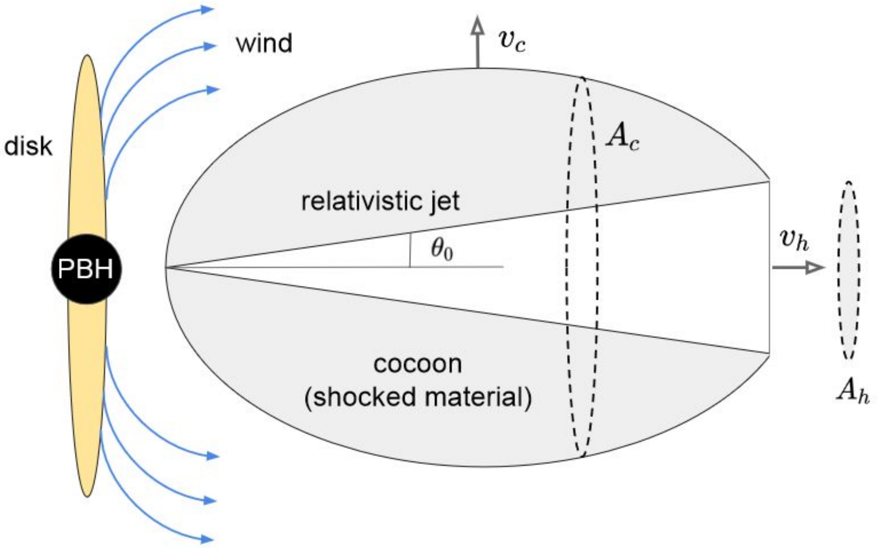
Spinning PBH

- Spin decreases Innermost Stable Circular Orbit (ISCO) radius
- Increased plasma temperature resulting in higher accretion disk emission
- Possibility of Blandford-Znajek jets



Blandford and Znajek 1977

Winds and Jets as Outflows



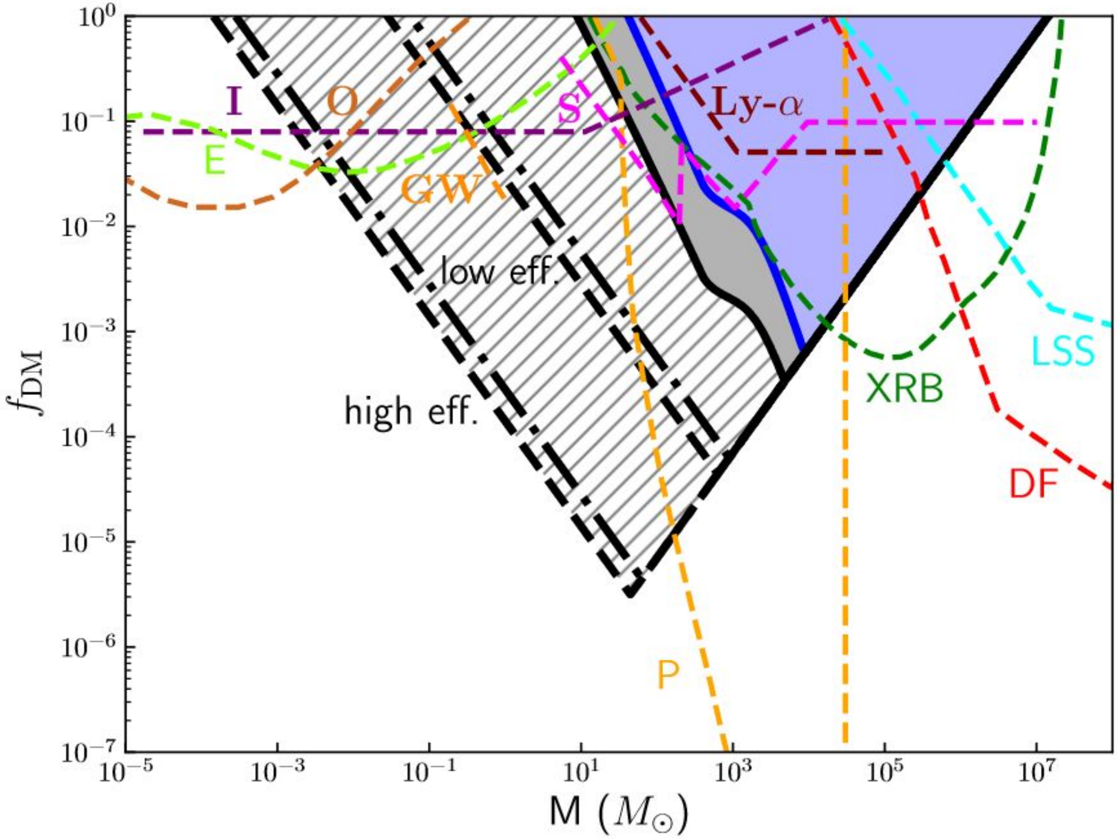
Volodymyr Takhistov

- Parameterized emission with efficiency factor

$$L_{\rm j} = \epsilon_j \dot{M}_{\rm acc}$$

- Magnetically Arrested Disk (MAD) suggest ϵ_j=1 (high eff.)
- Outflows from Quasars suggest ϵ_j=0.005 (low eff.)
- Additional factors from duty cycles, heating efficiency implicitly included

Shock Heating Limits



arXiv:2111.08699

Application to Evaporating PBHs

- Competitive bound for light PBH
- Uses similar cloud cooling argument
- Assumed positrons/electrons were permanently trapped
- We reanalyzed and included spin.

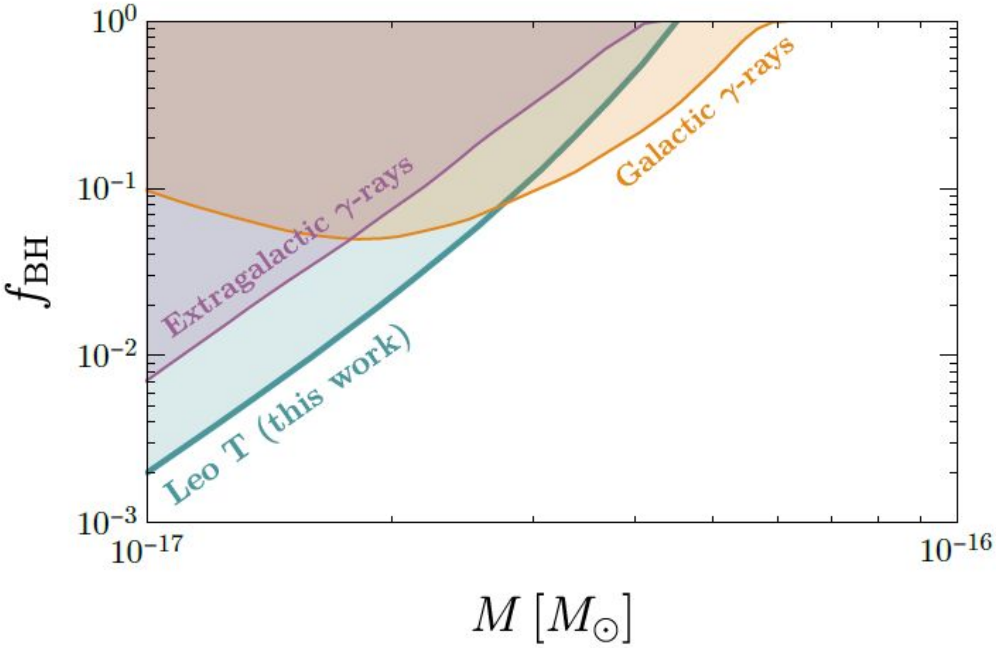
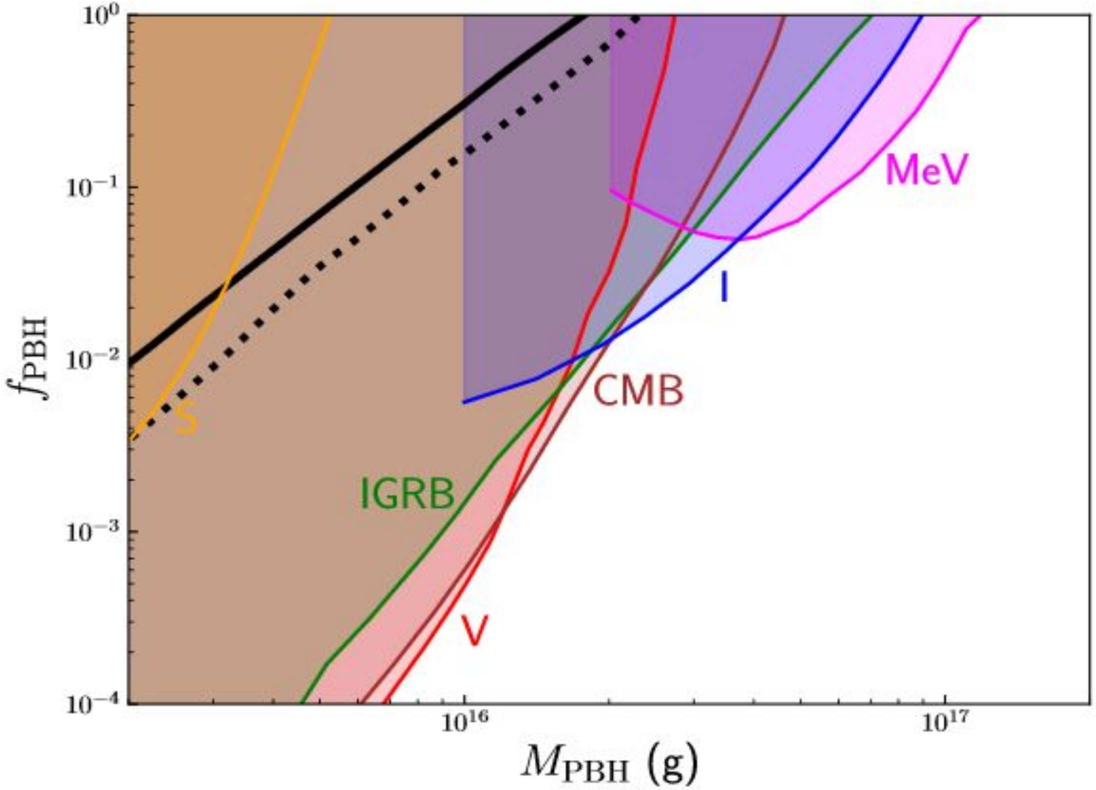


Figure taken from Kim 2020

Light PBH Constraints



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Conclusions

1. New competitive bound on intermediate mass from cloud cooling. This bound is cosmology independent and complementary to other bounds.

2. Spinning black holes have increased emissions resulting in more stringent bounds

3. Outflows from winds or jets can form shocks, efficiently heating the jets.

4. Without the assumption of ion trapping, the bound on light PBH from Hawking evaporation is much weaker than previously claimed.

Questions?