Primordial black holes and the Sunyaev-Zel'dovich effect

Growing black holes, Nepal 2022

Geoff Beck & Justine Tarrant
University of the Witwatersrand

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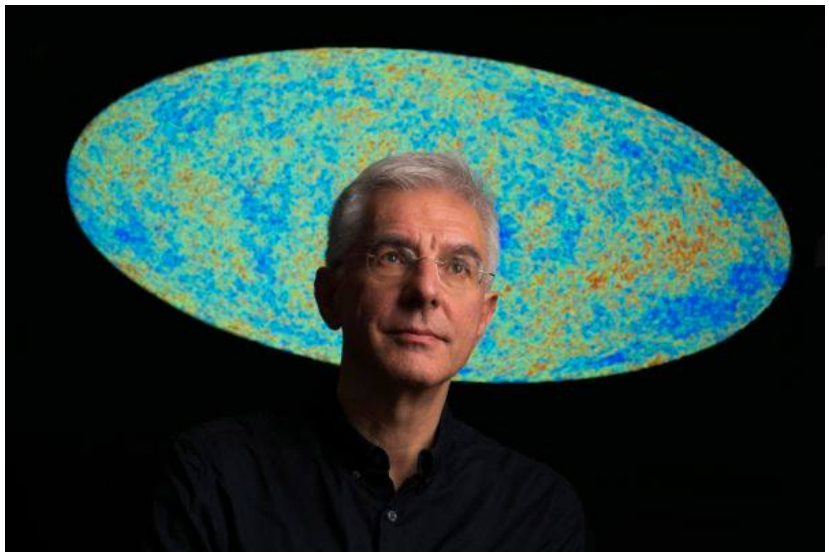
In memory of Sergio Colafrancesco

- A vision for fundamental astrophysics in Africa
  - Done by Africans with African instruments
- Unafraid of "crazy" ideas or being wrong
- I am the last PhD he graduated

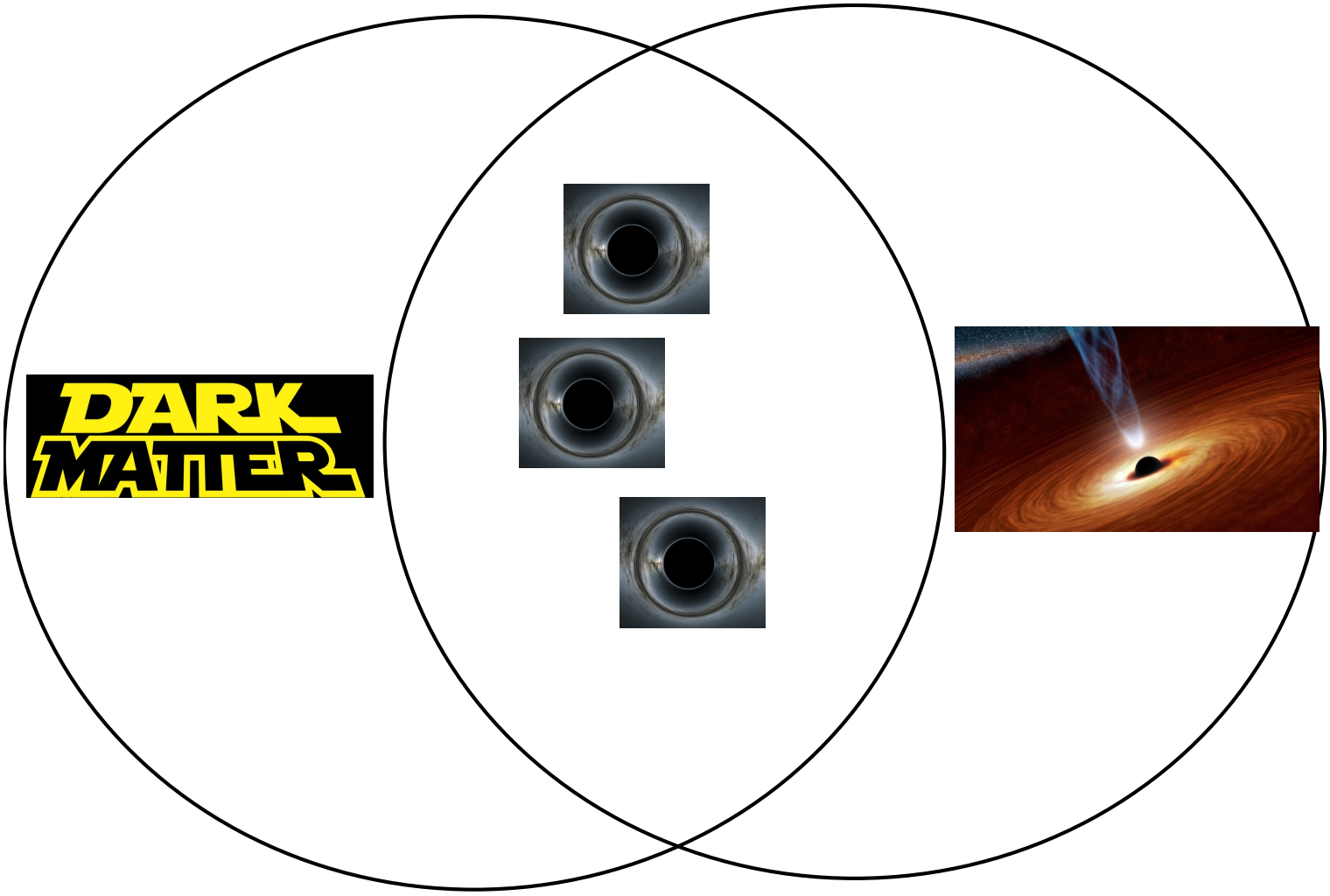


I wasn't sure what to talk about here

- I don't know much about black holes
- But I do know that

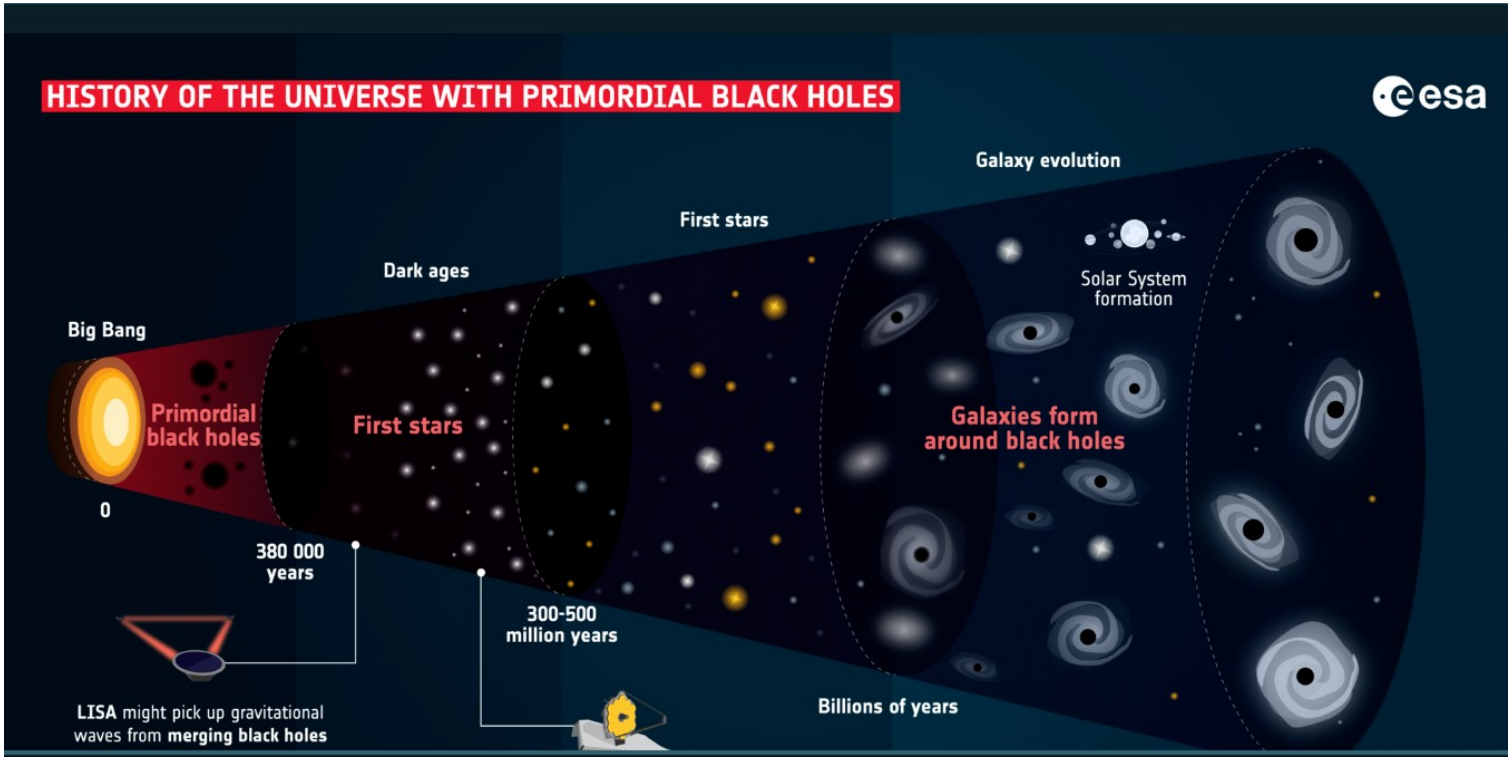
An intersection

- Dark matter could be primordial black holes (PBHs)
- A way to intersect with the conference topic?



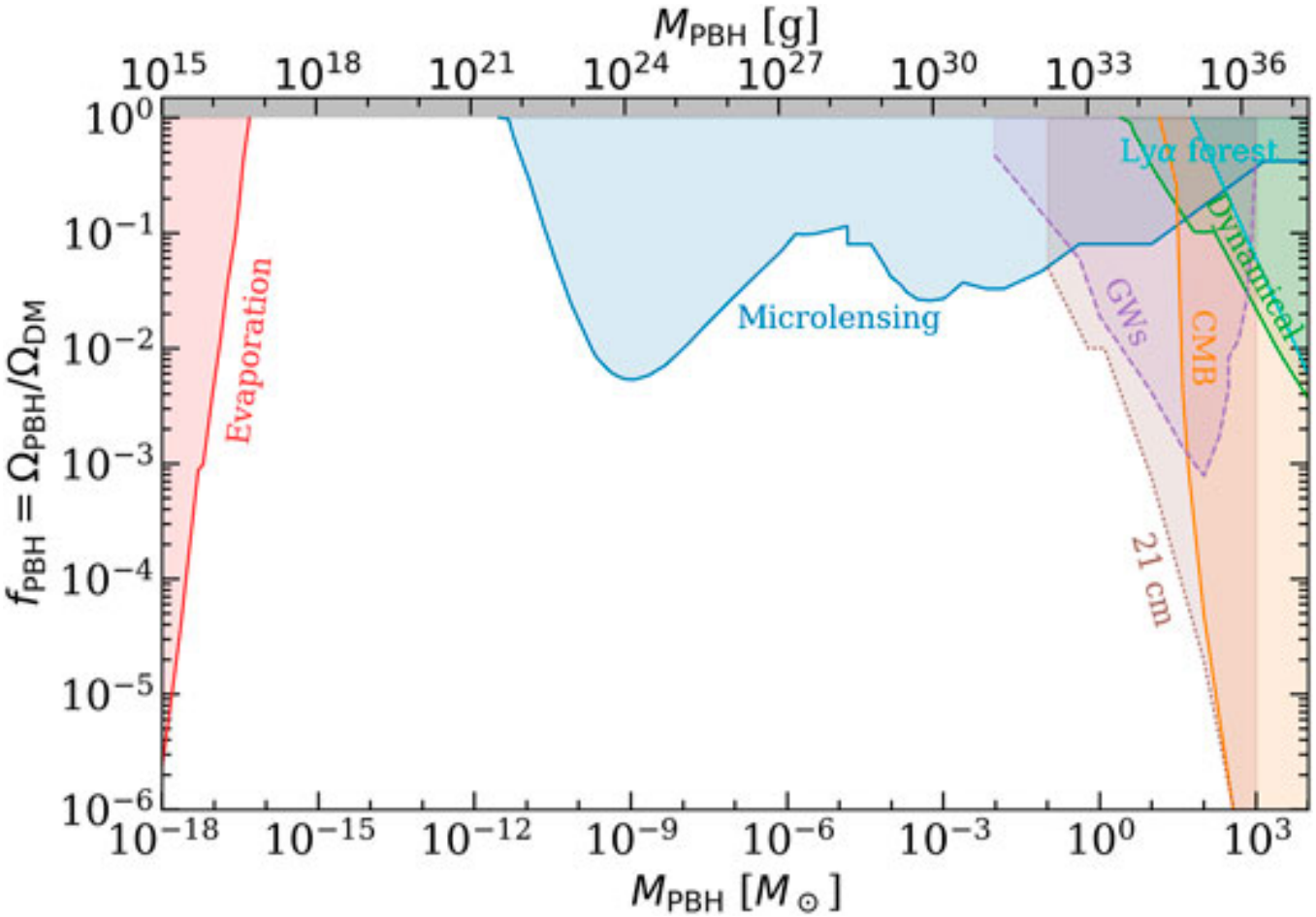
What is a PBH?

- Black holes unrelated to collapsing stars
- Formed Strong density fluctuations or cosmic phase transitions



How to observe PBHs?

- Lensing
- Gravitational wave backgrounds
- Evaporation: Hawking process (mostly photons considered)



How about Hawking radiated electrons?

- Hot electron populations produced by PBHs
- How to go about detecting this? Radio and X-ray?
- How about favourite of Sergio's: the Sunyaev-Zel'dovich effect

Simulated differential observations of the Sunyaev-Zel'dovich Effect: Probing the Dark Ages and Epoch of Reionization

C.M. Takalana[1,2] • P. Marchegiani[1,3] • G. Beck[1] • S. Colafrancesco[1,†]

Beyond the Standard Lore of the SZ effect

S. Colafrancesco

INAF - Osservatorio Astronomico di Roma
Via Frascati 33, I-00040 Monteporzio, Italy
Email: Sergio.Colafrancesco@mporzio.astro.it

The Non-Thermal Sunyaev–Zel'dovich Effect in Clusters of Galaxies

S. Colafrancesco[1], P. Marchegiani[2] and E. P

[1] INAF - Osservatorio Astronomico di Roma via Frascati 33, I-00040 Monte
Email: cola@coma.mporzio.astro.it
[2] Dipartimento di Fisica, Università di Roma "La Sapienza", Piazzale A. Mo

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A high-frequency study of the Sunyaev-Zel'dovich effect morphology in galaxy clusters

D. A. Prokhorov[1⋆], S. Colafrancesco[2], T. Akahori[3], E. T. Million[4], S. Nagataki[5], K. Yoshikawa[6]

[1] *Hansen Experimental Physics Laboratory, Stanford University, Stanford, CA 94305, USA*
[2] *INAF - Osservatorio Astronomico di Roma via Frascati 33, I-00040 Monteporzio, Italy. Email: sergio.colafrancesco@oa-roma.inaf.it*
[3] *Research Institute of Basic Science, Chungnam National University, Daejeon, Republic of Korea*
[4] *University of Alabama, Department of Physics and Astronomy, 206 Gallalee Hall Box 870324, Tuscaloosa AL 35487*
[5] *Yukawa Institute for Theoretical Physics, Kyoto University, Kitashirakawa Oiwake-cho, Sakyo-ku, Kyoto, 606-8502, Japan*
[6] *Center for Computational Sciences, University of Tsukuba, 1-1-1, Tennodai, Ibaraki 305-8577, Japan*

Polarization of the Sunyaev-Zel'dovich effect: relativistic imprint of thermal and non-thermal plasma.

Mohammad Shehzad Emritte,[a] Sergio Colafrancesco,[a,1] Paolo Marchegiani[a]

[a]School of Physics, University of the Witwatersrand, Private Bag 3, WITS-2050, Johannesburg South Africa
E-mail: Sergio.Colafrancesco@wits.ac.za, emrittes@yahoo.com, Paolo.Marchegiani@wits.ac.za

Probing the physics and history of cosmic reionization with the Sunyaev-Zel'dovich Effect

S. Colafrancesco[1,2], P. Marchegiani[1,2] and M.S. Emritte[2]

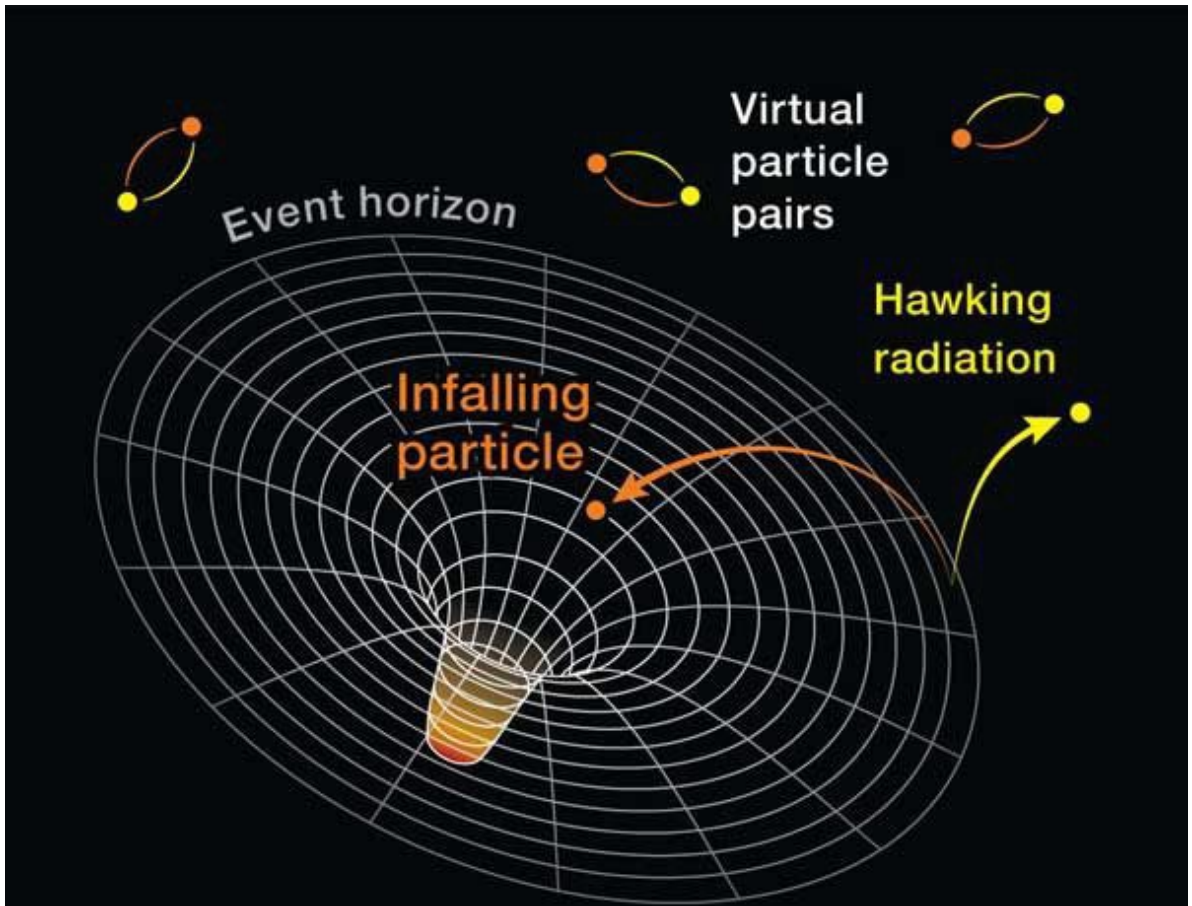
[1] INAF - Osservatorio Astronomico di Roma via Frascati 33, I-00040 Monteporzio, Italy. Email: sergio.colafrancesco@oa-roma.inaf.it
[2] School of Physics, University of the Witwatersrand, Private Bag 3, 2050-Johannesburg, South Africa. Email: sergio.colafrancesco@wits.ac.za

PBHs and electrons

- If we believe in Hawking radiation we have

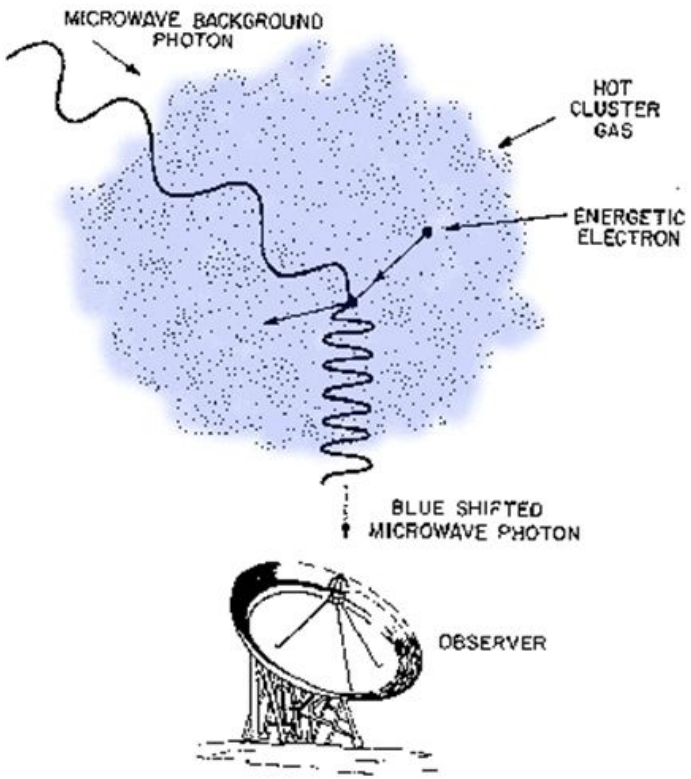
$$T_{\rm BH} = 1.06 \left(\frac{10^{13}\ {\rm g}}{M_{\rm BH}} \right)\ {\rm GeV}\ . \tag{1}$$

- Lots of electrons per PBH per second?



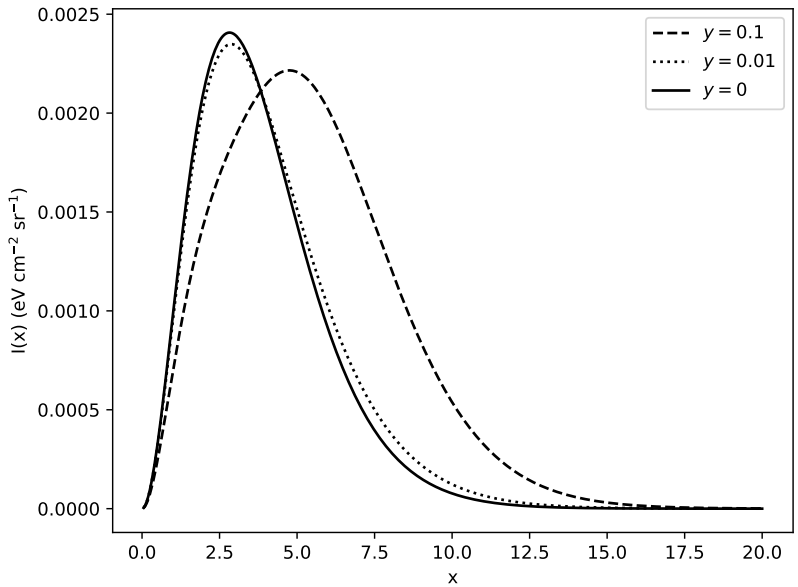
How does the SZ effect work?

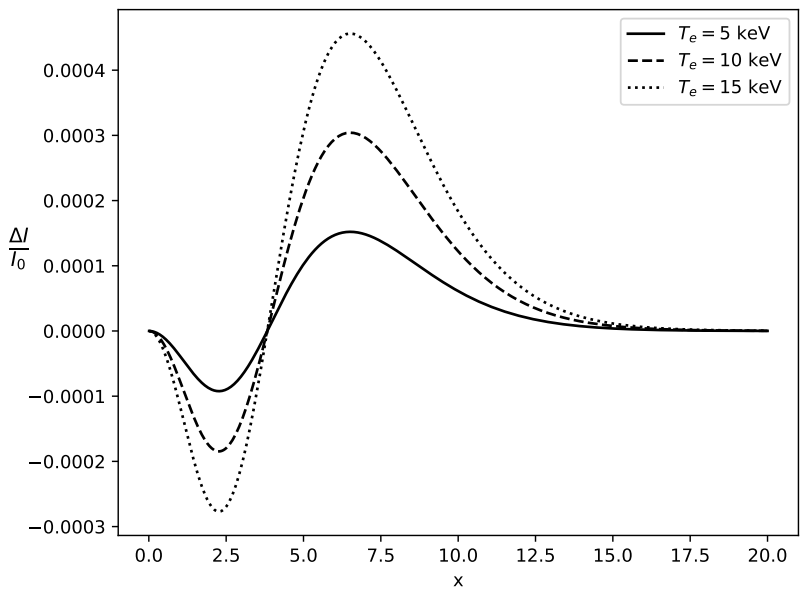
- CMB photons scattered by hot electrons
- Makes the CMB look hotter



Thermal and non-relativistic

$$
\begin{aligned}
x &= \frac{h\nu}{k_B T_{\mathrm{CMB}}} \,, \\
\Delta I(x) &= I_0 y_c g_{sz}(x) \,, \\
y_c &= \int \frac{T_e}{m_e} n_e \sigma_T dl \,,
\end{aligned}
\tag{2}
$$





The nuts and bolts

- We can compute our electron distribution (diffusion insignificant)

$$n_{e,\mathrm{PBH}}(r) = \frac{\rho_{\mathrm{PBH}}}{m_{\mathrm{PBH}} b(E)} \int dE' \frac{\Gamma(E')}{\exp\left[E'/T_{\mathrm{PBH}}\right] + 1} \, .$$

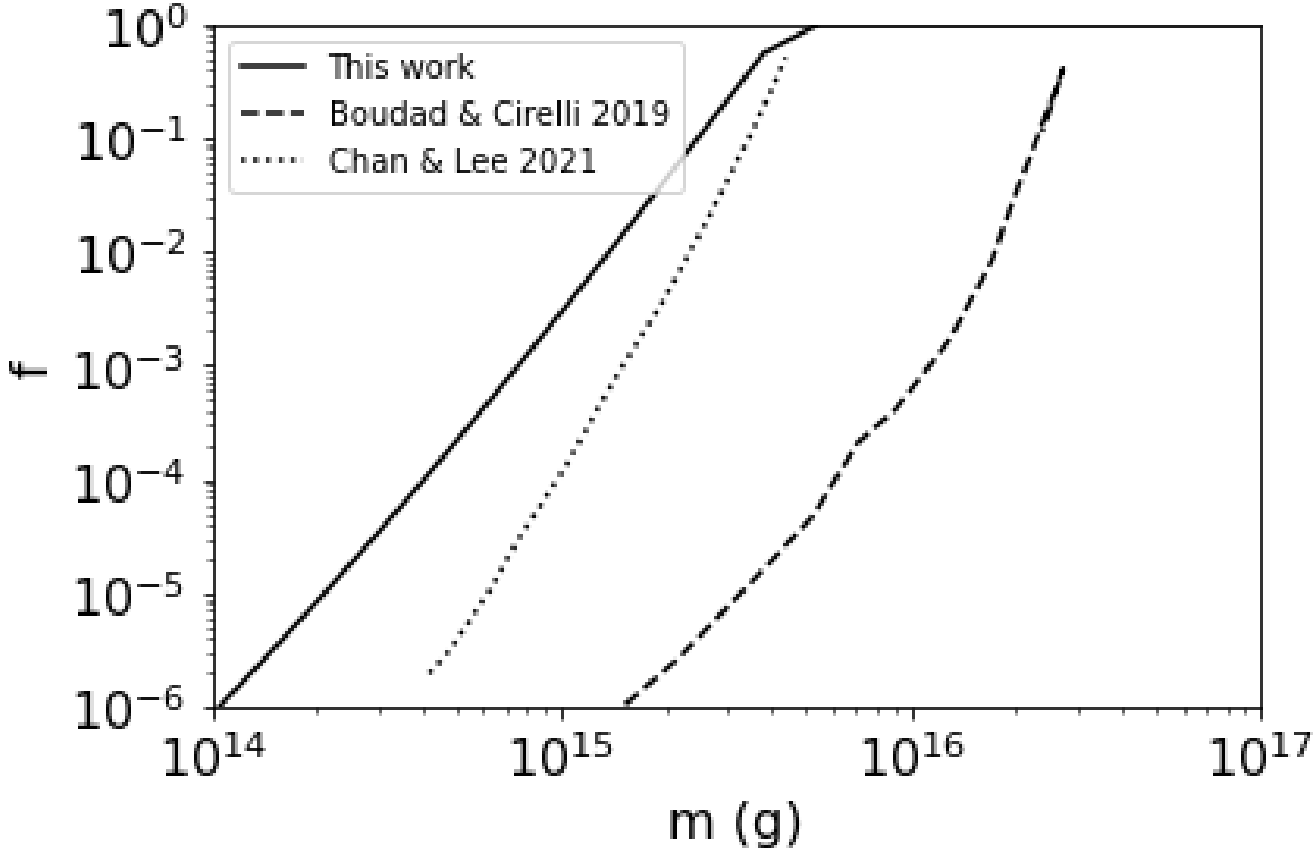
- Note that $\rho_{\mathrm{PBH}} = f \rho_{\mathrm{DM}}$ where f is the fraction of PBH DM
- We can compare in the Coma cluster where the thermal electrons follow

$$n_e(r) = 3.49 \times 10^{-3} \left(1 + \frac{r^2}{64000 \ \mathrm{kpc}^2}\right)^{-0.981} \ \mathrm{cm}^{-3} \, .$$

- and have temperature ~ 15 keV.

Results

- Chan & Lee 2021 depend on galactic centre environment
  - Uncertainties and diffusion assumptions
- Boudad & Cirelli 2019 do just have better limits
  - From particle flux at Voyager positions



Summary

- Lower mass PBH's produce enough hot electrons for a powerful SZ effect
- For $m_{\rm PBH} \lesssim 2 \times 10^{15}$ g they can outshine Coma
  - If PBH's are all DM
- Thus we rule out large populations of PBHs at these masses
- This was just a rough computation, can improve
  - Relativistic SZ effect
  - Beyond monochromatic PBH distribution
  - Other targets?
  - Combine with X-ray/radio electron signatures?
- With the universe as our instrument we can do surprising things
- I think Sergio would have enjoyed this use of the SZE