2 day mini-workshop: Axion Cosmology

arXiv:1901.06809

Thermal Sunyaev-Zel'dovich anisotropy due to Primordial black holes

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in collaboration with
Hiroyuki Tashiro (Nagoya Univ.)
Toshiyuki Tanaka (Nagoya Univ.)

We detected primordial black holes !?

Selected for a Viewpoint in *Physics*

PRL **116,** 061102 (2016) PHYSICAL REVIEW LETTERS week ending 12 FEBRUARY 2016

Observation of Gravitational Waves from a Binary Black Hole Merger

B. P. Abbott *et al.**

(LIGO Scientific Collaboration and Virgo Collaboration)

(Received 21 January 2016; published 11 February 2016)

On September 14, 2015 at 09:50:45 UTC the two detectors of the Laser Interferometer Gravitational-Wave Observatory simultaneously observed a transient gravitational-wave signal. The signal sweeps upwards in frequency from 35 to 250 Hz with a peak gravitational-wave strain of 1.0×10^{-21}. It matches the waveform predicted by general relativity for the inspiral and merger of a pair of black holes and the ringdown of the resulting single black hole. The signal was observed with a matched-filter signal-to-noise ratio of 24 and a false alarm rate estimated to be less than 1 event per 203 000 years, equivalent to a significance greater than 5.1σ. The source lies at a luminosity distance of 410^{+160}_{-180} Mpc corresponding to a redshift $z = 0.09^{+0.03}_{-0.04}$. In the source frame, the initial black hole masses are $36^{+5}_{-4} M_\odot$ and $29^{+4}_{-4} M_\odot$, and the final black hole mass is $62^{+4}_{-4} M_\odot$, with $3.0^{+0.5}_{-0.5} M_\odot c^2$ radiated in gravitational waves. All uncertainties define 90% credible intervals. These observations demonstrate the existence of binary stellar-mass black hole systems. This is the first direct detection of gravitational waves and the first observation of a binary black hole merger.

DOI: 10.1103/PhysRevLett.116.061102

Primordial black hole?

What's? → How? → Conclusion

- Primordial black hole
- Thermal Sunyaev-Zel'dovich effect

- Method
- Set up

- Anisotropy spectrum
- PBH abundance

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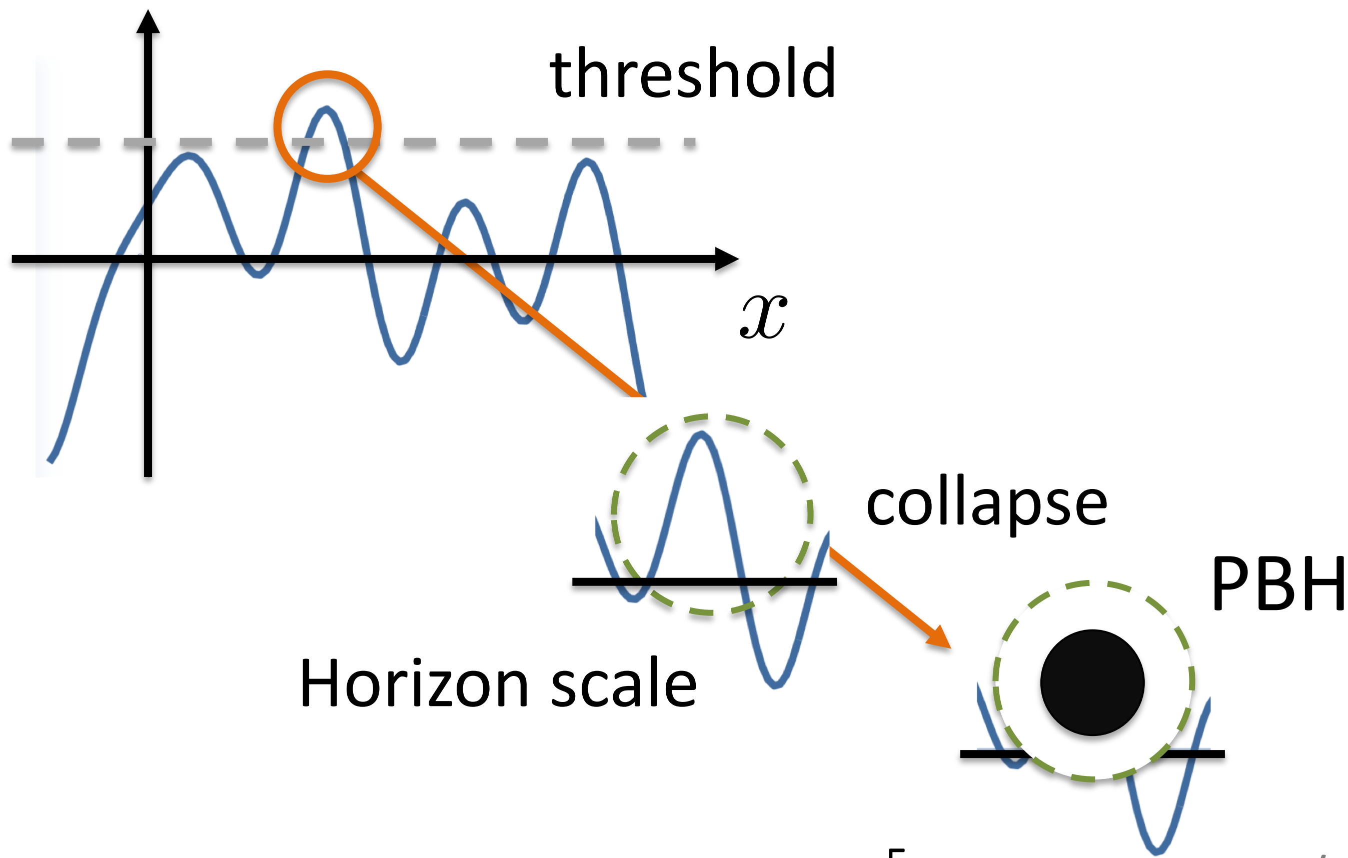
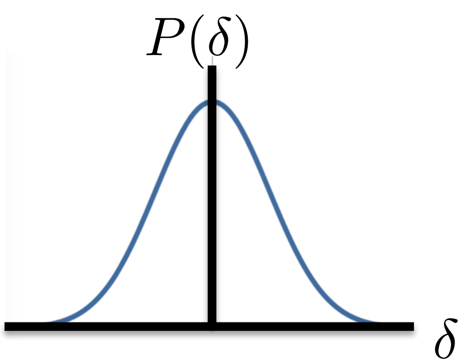
What's primordial black holes (PBH)?

BH which forms from collapse of the cosmic fluid in the early universe

$\delta = \delta\rho/\rho$ (in the early universe)

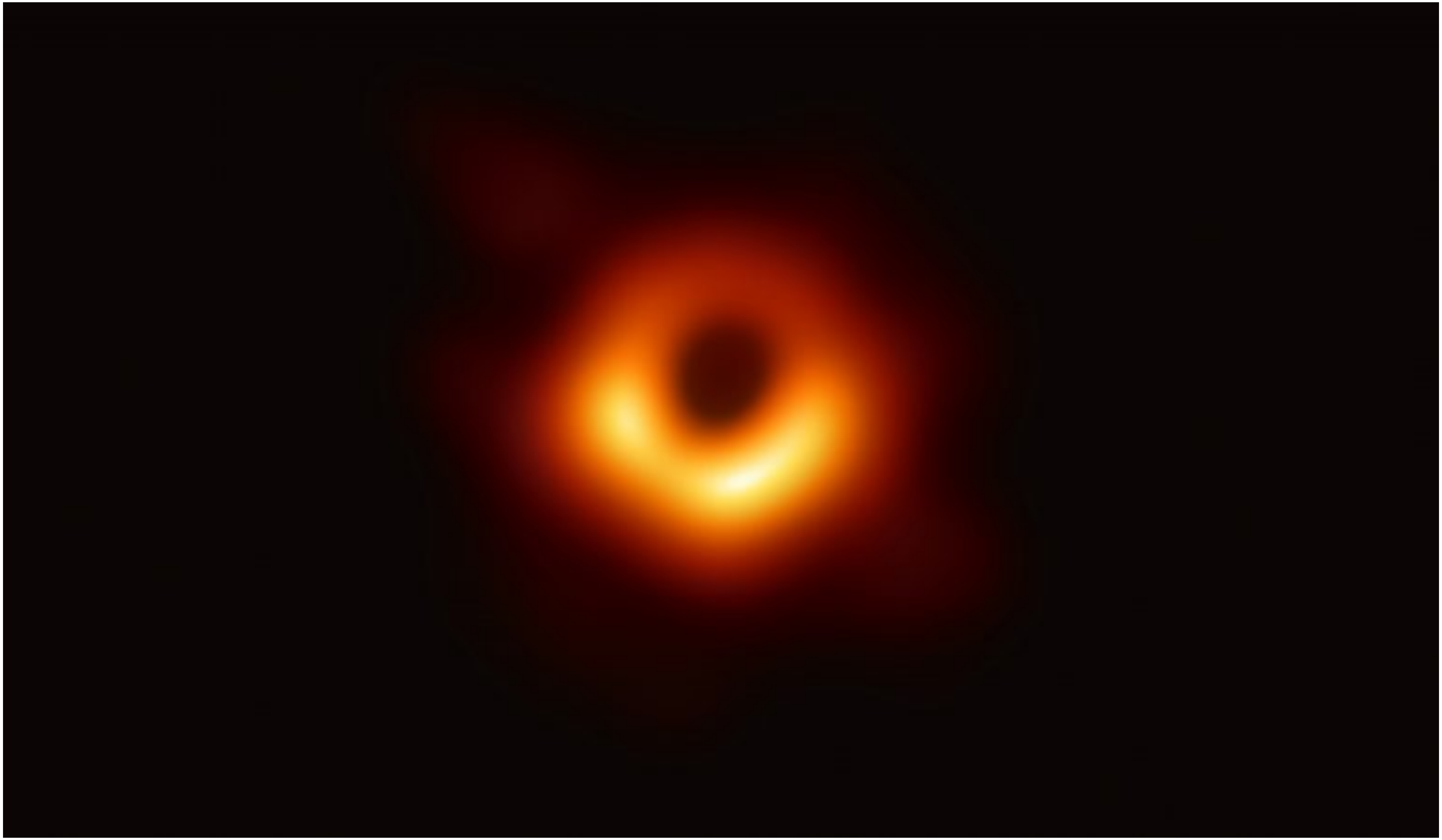


BTW
this fluctuation is...



Gaussian fluctuation

Event Horizon Telescope M87



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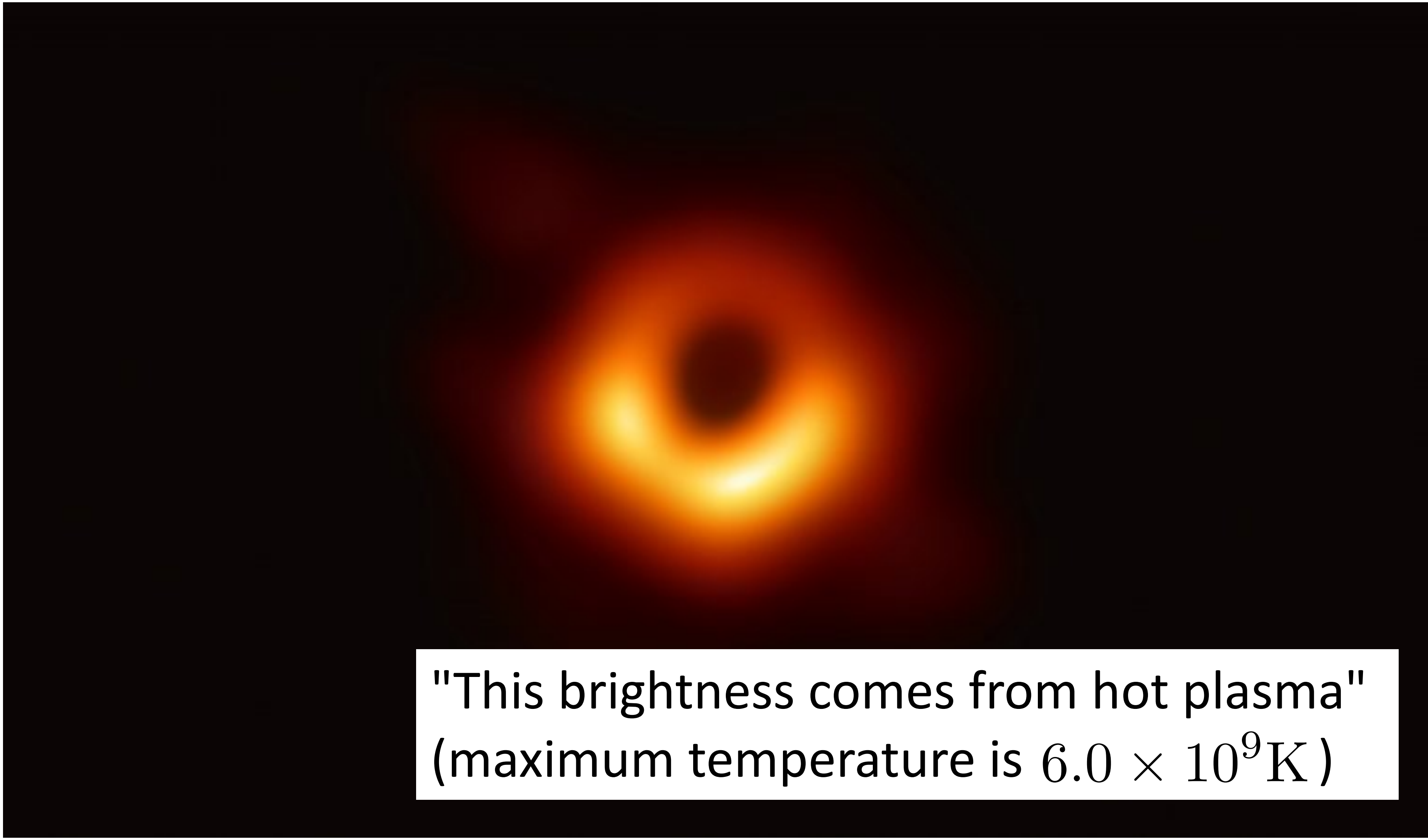
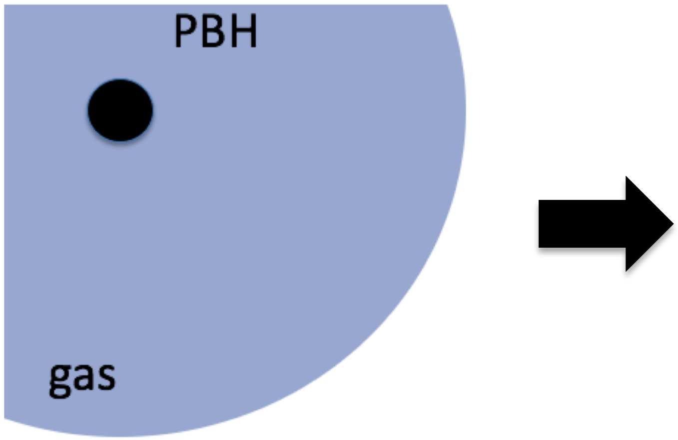


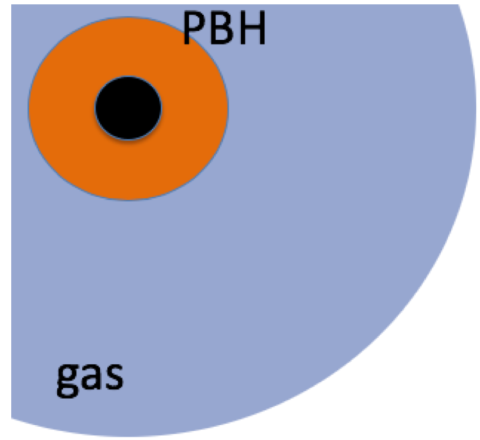
"This brightness comes from hot plasma"
(maximum temperature is $6.0 \times 10^9 \mathrm{K}$)

What's happening around a PBH?

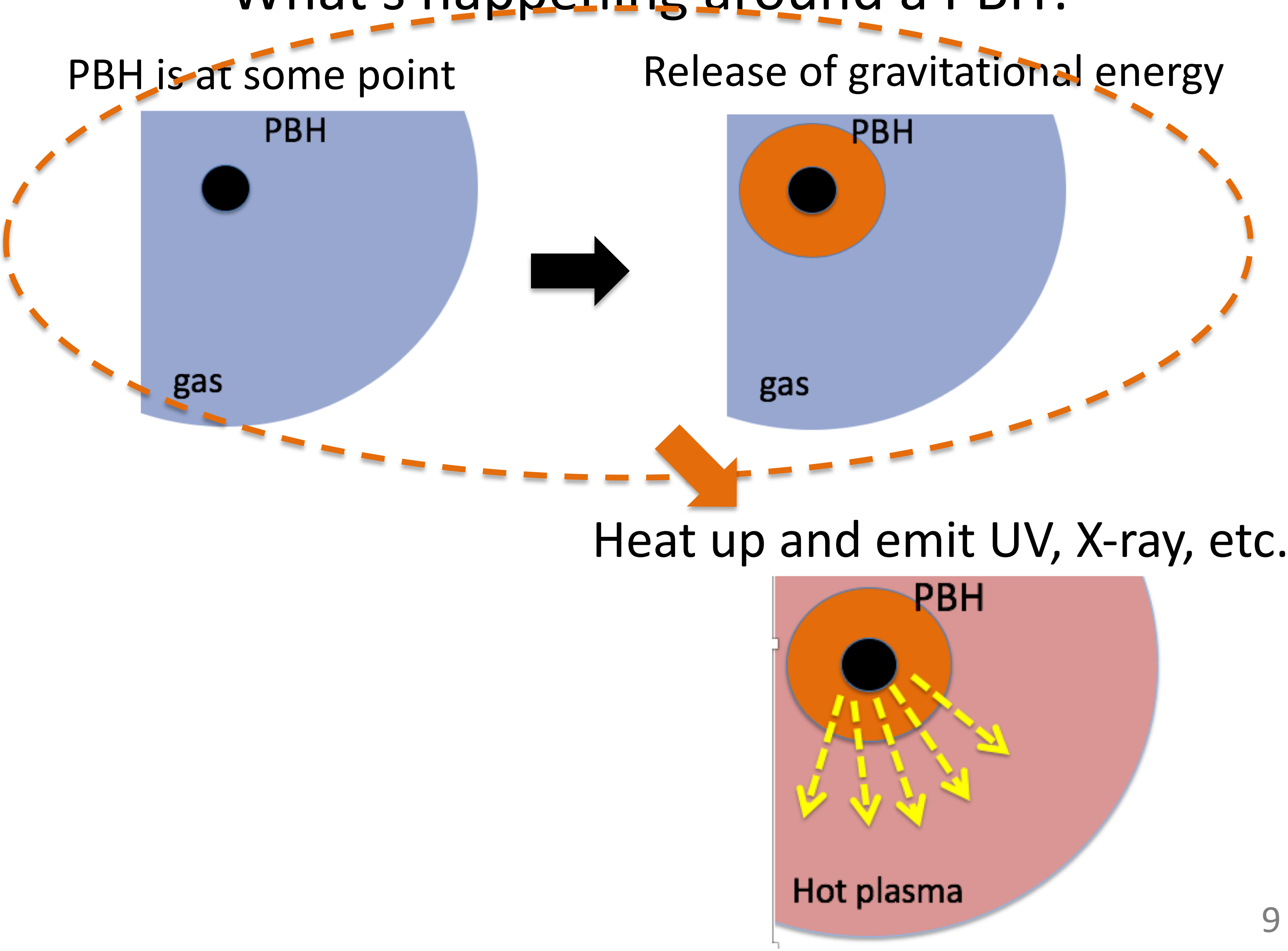
PBH is at some point



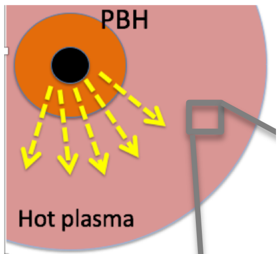
Release of gravitational energy



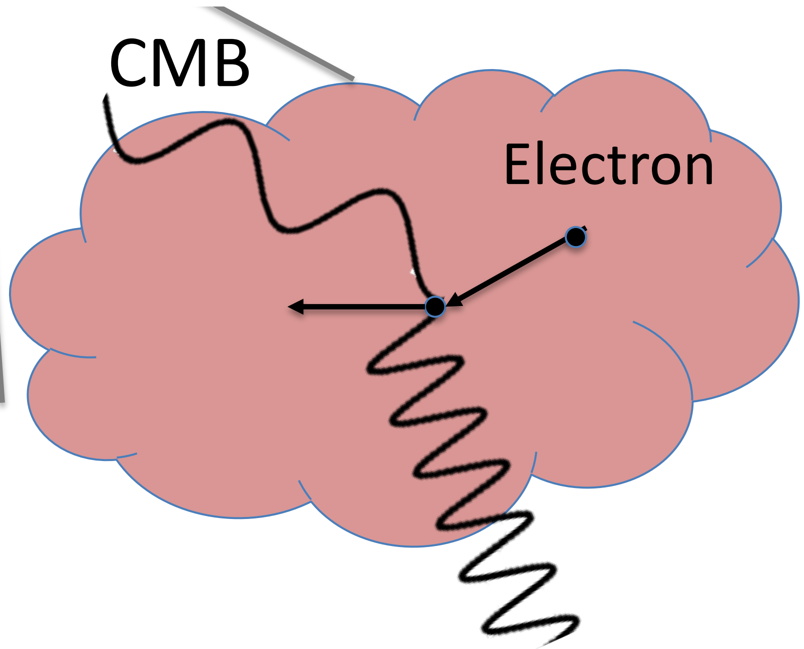
What's happening around a PBH?



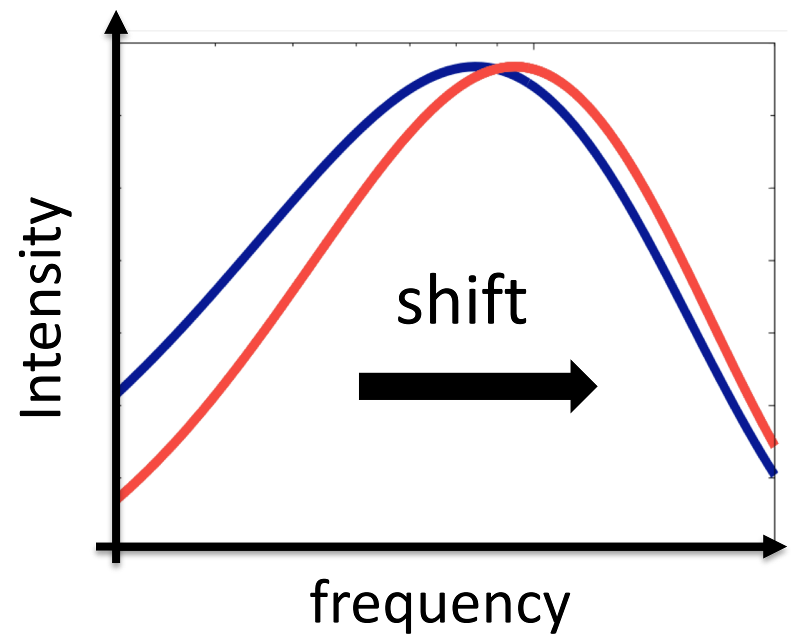
What's thermal Sunyaev-Zel'dovich (tSZ)?



Scattering CMB photons and electron in hot plasma



distortion of CMB energy spectrum



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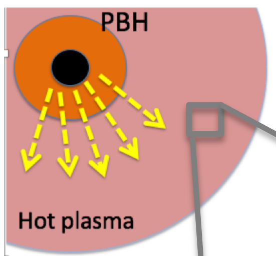

Scattering CMB photons
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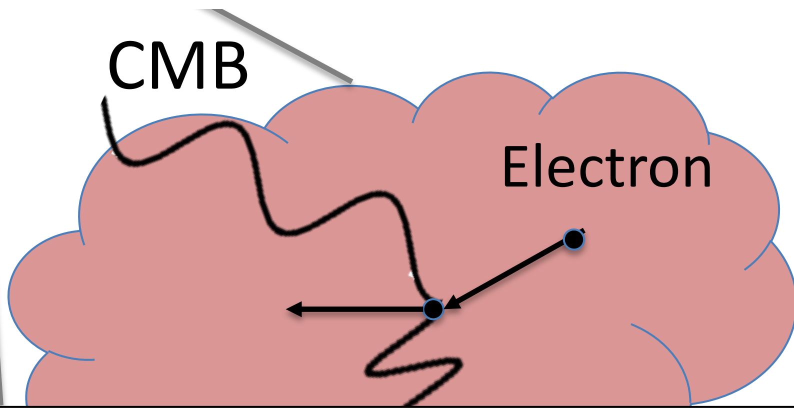
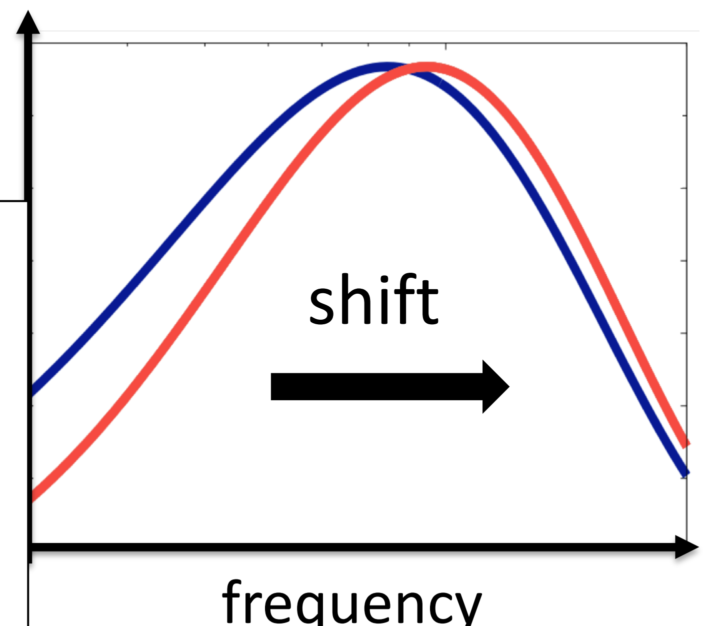


distortion of
CMB energy spectrum



The extent of the shift

→Compton y-parameter

$$y = \frac{c\sigma_{\mathrm{T}}}{m_{\mathrm{e}}c^2}\int dt\ n_{\mathrm{H}} x_{\mathrm{e}} k_{\mathrm{B}} T_{\mathrm{gas}}$$

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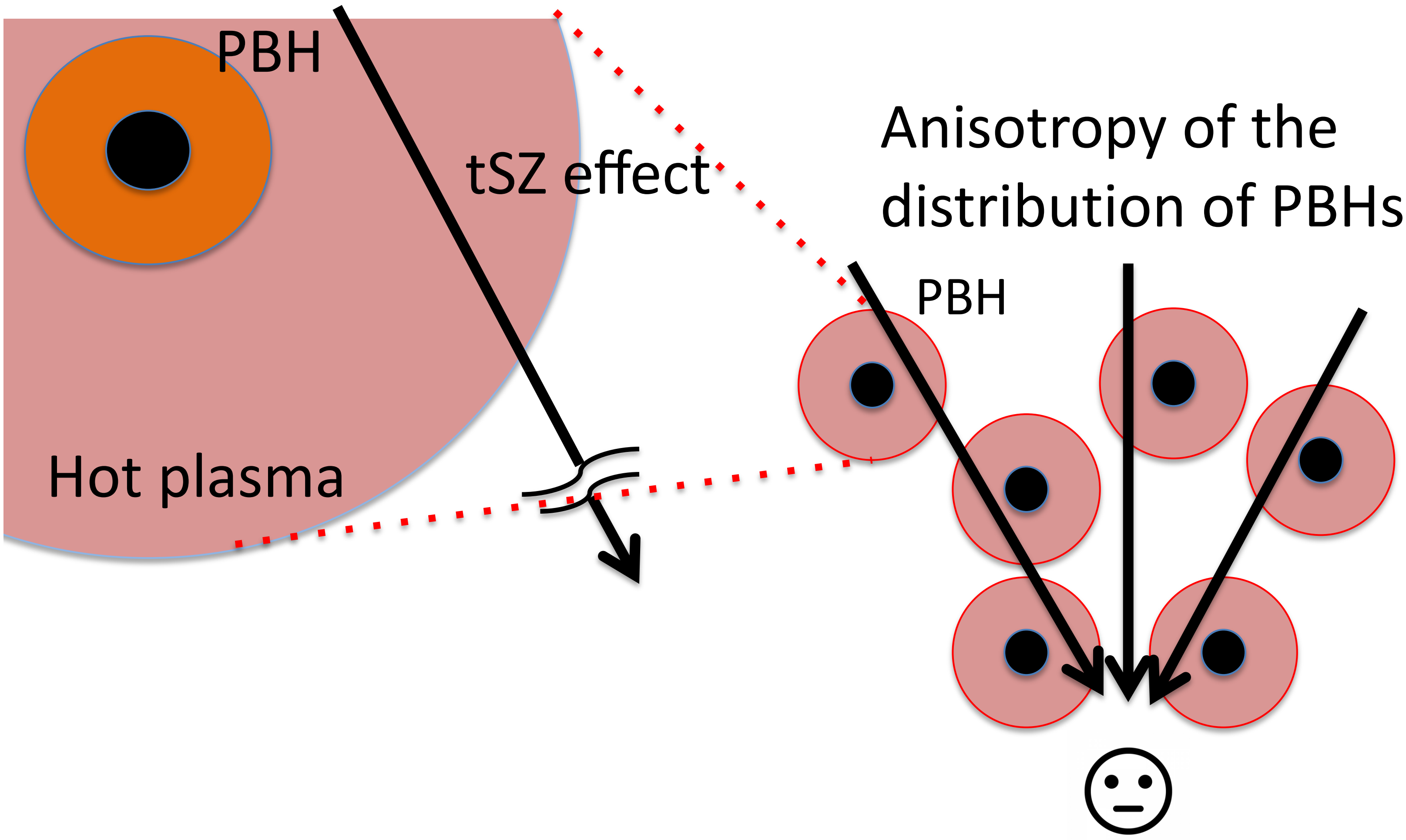
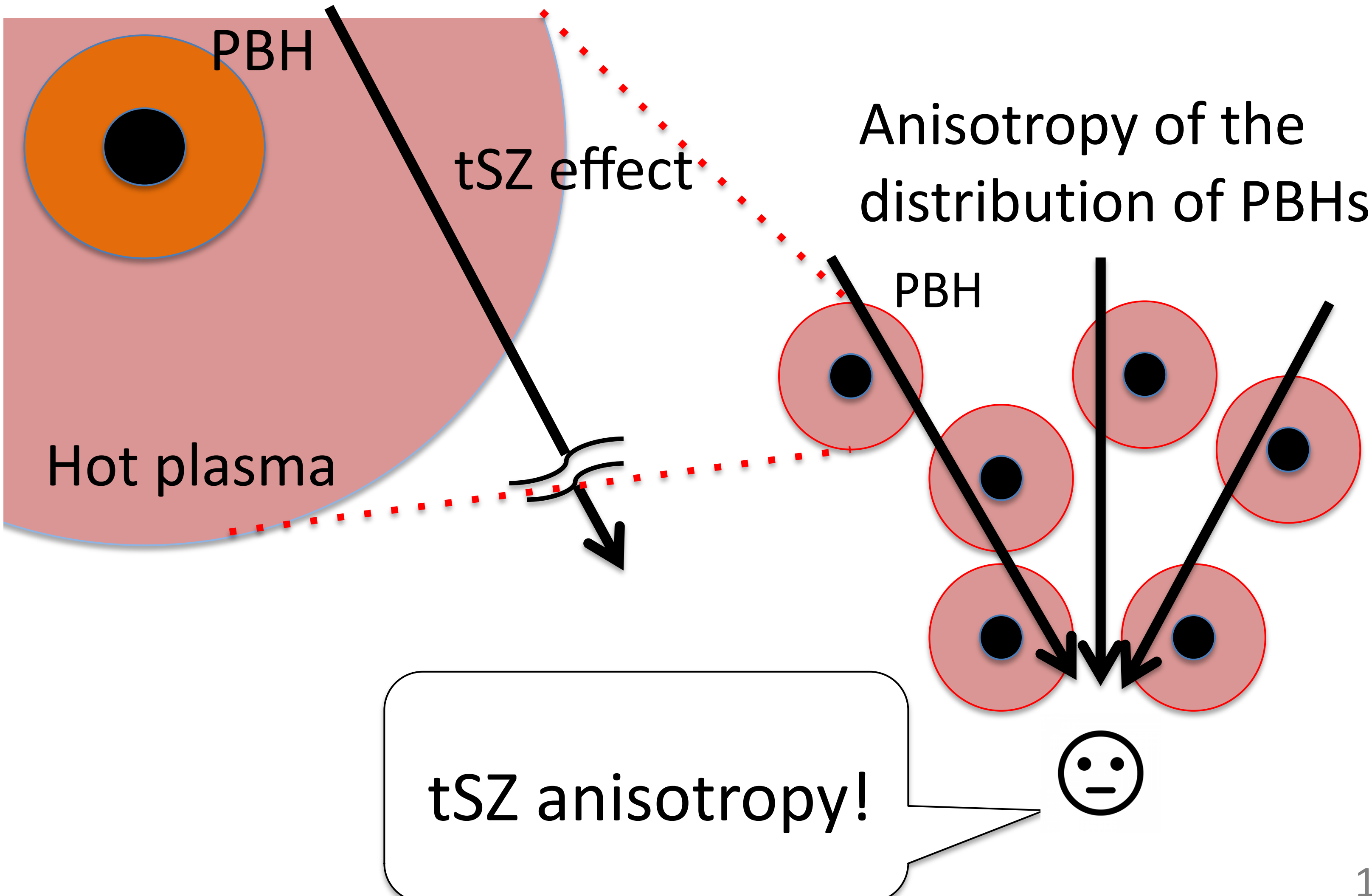
How does the anisotropy yield?



How does the anisotropy yield?



Calculation set up

Time: z=[10,200]
Initial condition : the profiles of Intergalactic medium at z=200
Parametrize the luminosity from (around) PBH as a free parameter "epsilon", $L_{\rm PBH} = \epsilon L_{\rm Edd}$

Equations:

Ionized rate Recombination rate

$$\frac{dx_{\rm HI}}{dt} = -k_{\rm HI,\gamma} + \alpha_{\rm B} n_{\rm H} x_{\rm e} x_{\rm HII}$$

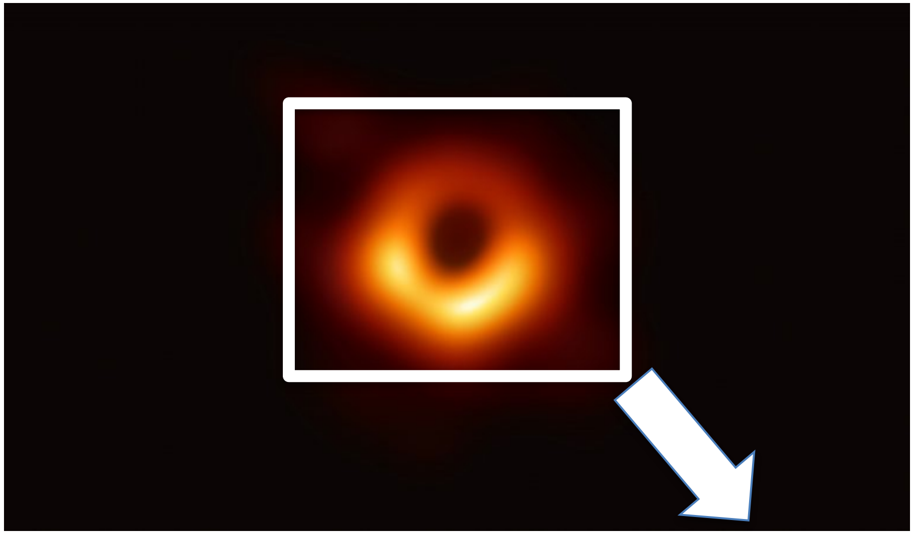
Heating rate

$$\frac{dT}{dt} = (\gamma - 1)\frac{\mu m_{\rm p}}{k_{\rm B}\rho}\left(\frac{k_{\rm B}T}{\mu m_{\rm p}}\ \frac{d\rho}{dt} + \Gamma - \Lambda\right)$$

Cooling rate

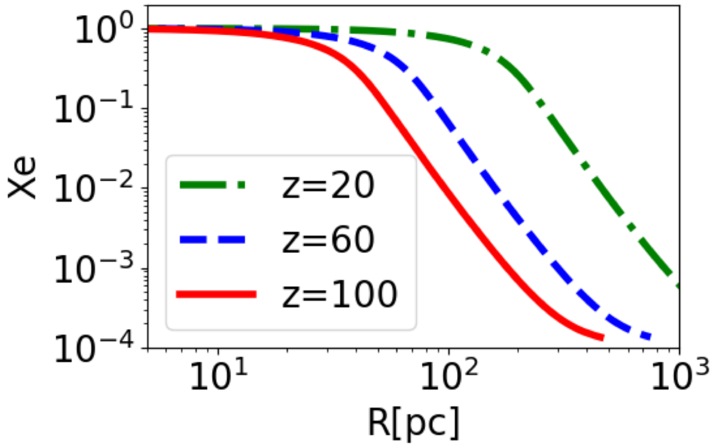
$$y = \frac{c\sigma_{\rm T}}{m_{\rm e}c^2}\int dt\ n_{\rm H} x_{\rm e} k_{\rm B} T_{\rm gas}$$

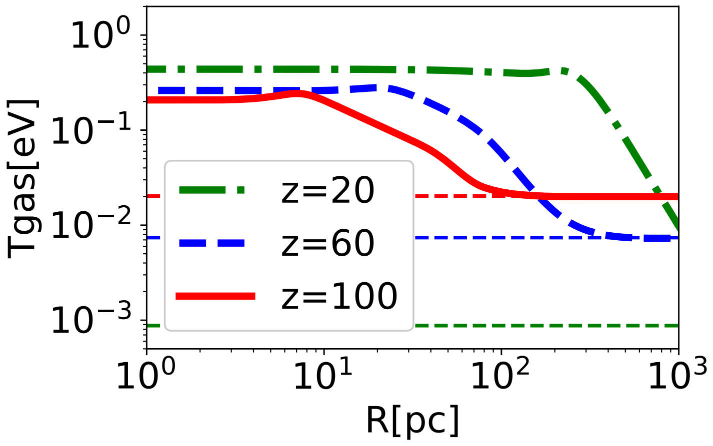
The profiles of gas around a PBH



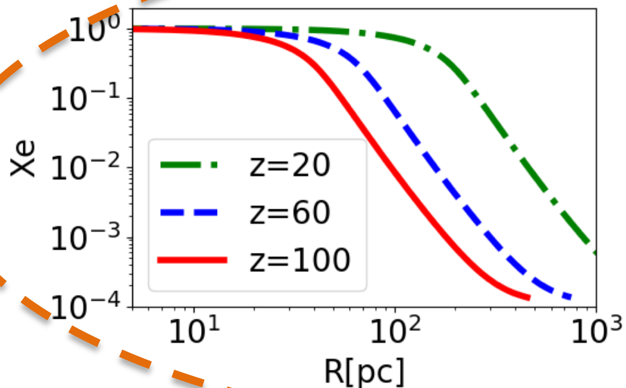
$$M_{\mathrm{PBH}} = 10[\mathrm{M}_\odot]$$

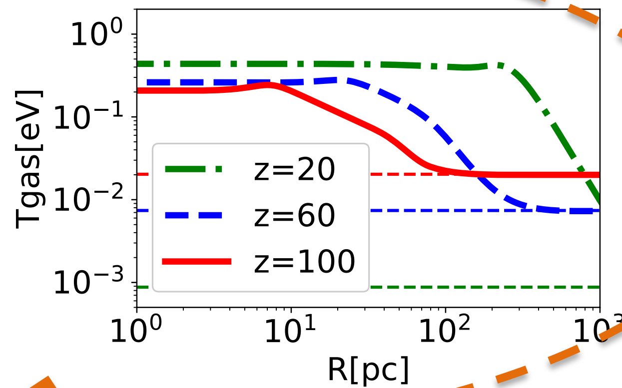
$$\epsilon = 10^{-4}$$

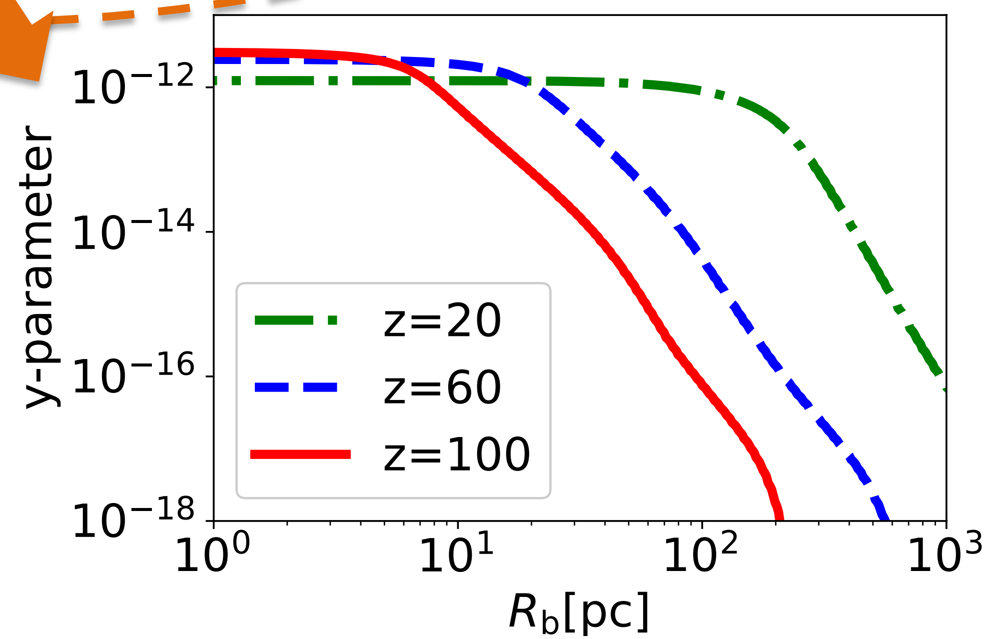




The profiles of gas around a PBH







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tSZ angular power spectrum

Sunyaev & Zel'dovich 1969
Cole & Kaiser 1988
Komatsu & Kitayama 1999

$$C_l^{TT} = g(x)^2 C_l^{yy} = g(x)^2 (C_l^{yy(1P)} + C_l^{yy(2P)})$$

One-PBH term

$$C_l^{yy(1P)} = \int dz \frac{dV}{dz d\Omega} n_{\rm PBH}(M, z) \times (y_l(M, z))^2$$

Two-PBH term

$$C_l^{yy(2P)} = \int dz \frac{dV}{dz d\Omega} P(k = \frac{l}{d_{\rm M}(z)}) \times (n_{\rm PBH}(M, z) y_l(M, z))^2$$

y_l : Fourier component of y

$$\frac{\Delta T}{T_{\rm cmb}} \simeq \left(\frac{x}{\tanh(x/2)} - 4 \right) y \equiv g(x) y \qquad x = cp/k_{\rm B} T_{\rm e}$$

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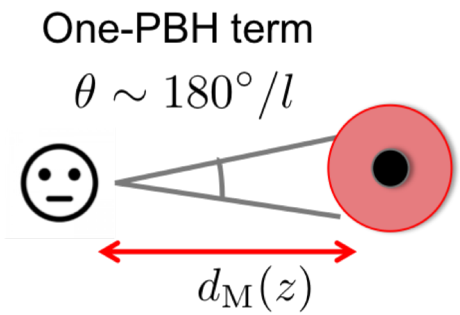

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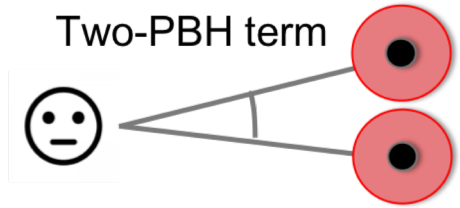

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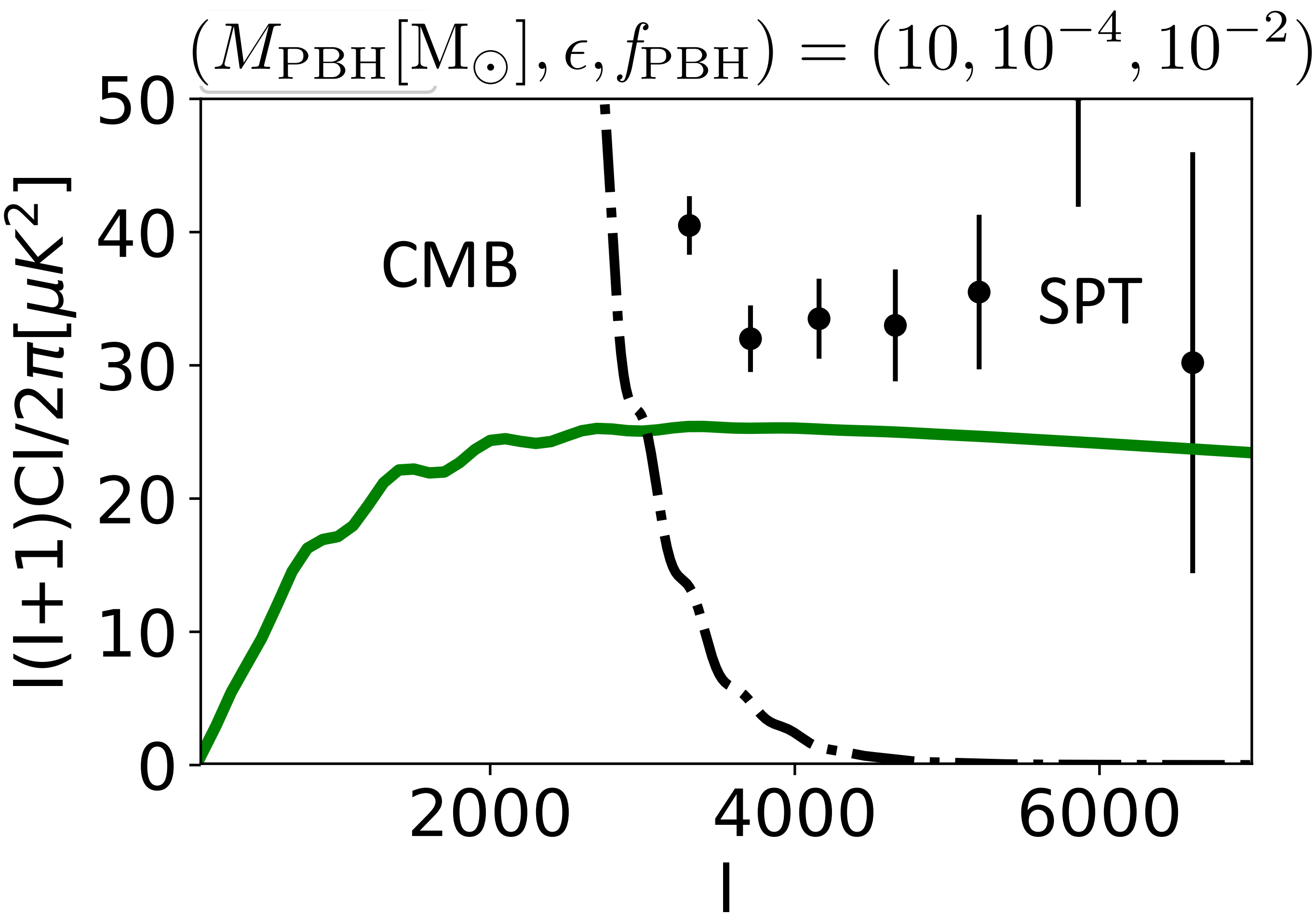
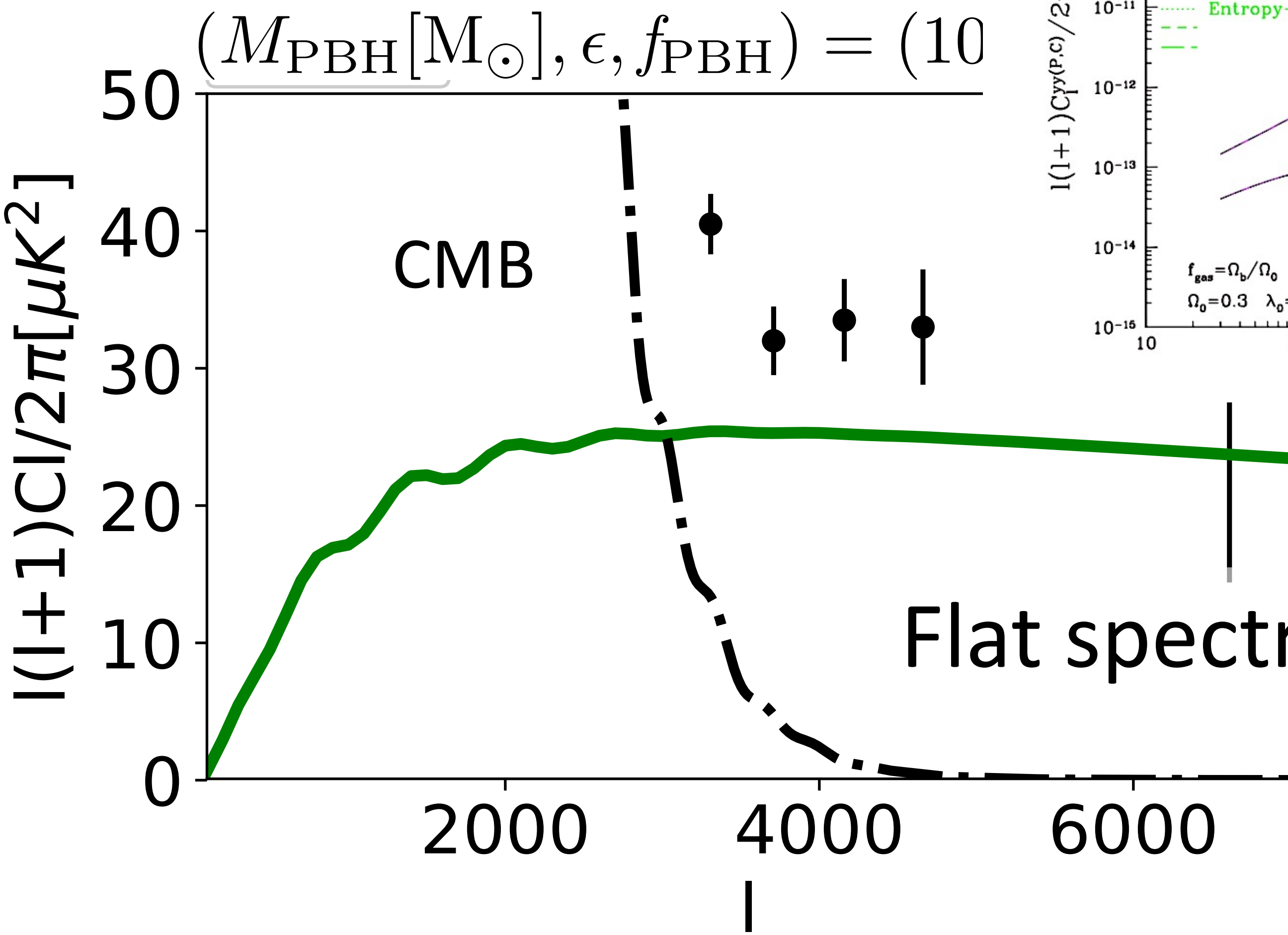
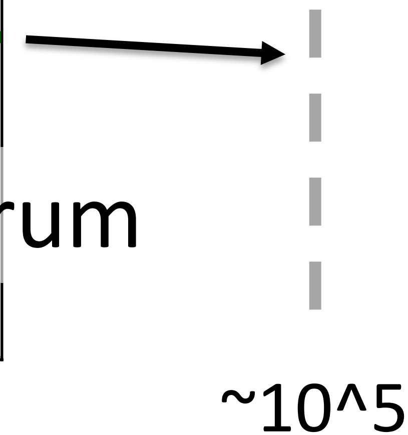
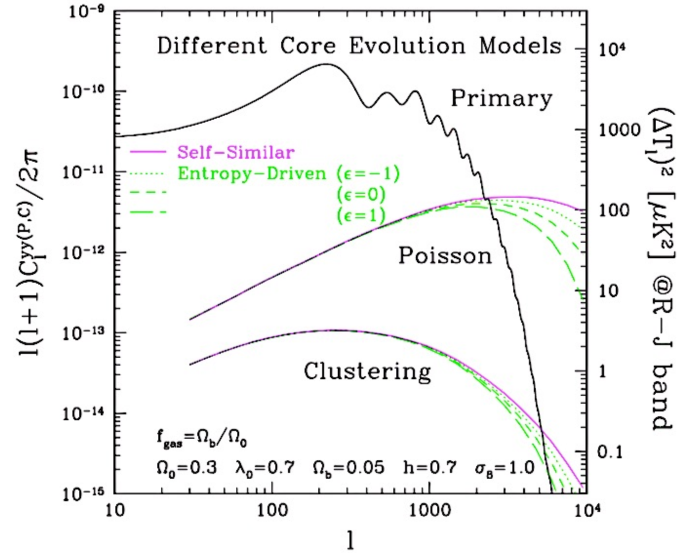


tSZ angular power sp

c.f. tSZ anisotropy by clusters







Komatsu & Kitayama 1999

→the suggestion of the existence of PBHs

Constraint of PBH abundance from this work

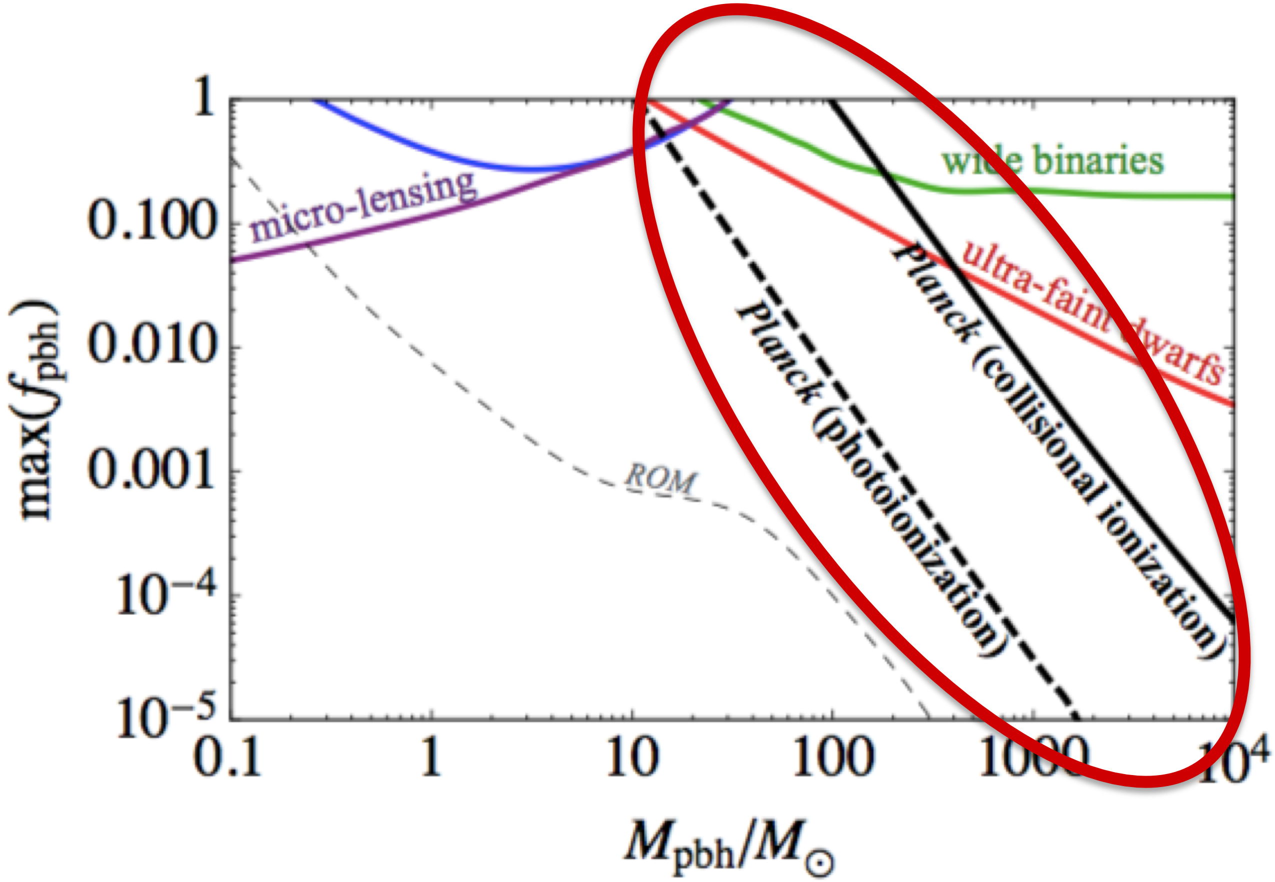
Compared this signal to the SPT data,
we can get…

$$f_{\rm PBH} < 10^{-3}\left(\frac{\epsilon}{10^{-2}}\right)^{-1}$$

However, in the previous work
about the CMB optical depth induced by PBHs,

$$f_{\rm PBH} < 10^{-9}\left(\frac{\epsilon}{10^{-2}}\right)^{-1}$$

The unfortunate constraint of PBH abundance



→This work does not give a new constraint on the PBH abundance

Y. Ali-Haïmoud and M. Kamionkowski (2017)

Future work (Discussion)

- In axion cosmology,
  Are there some mechanisms to change the thermal history of Universe like this work?

- Let’s discuss the relation between PBH and axion.

Summary

We calculate the tSZ angular power spectrum
of CMB temperature induced by PBHs.

In future SZ anisotropy measurements,
the detection or non-detection of the flat spectrum
gives useful information about the existence of PBHs.

Unfortunately, tSZ anisotropy induced by PBHs
does not give a new constraint on the PBH abundance.

Fin.