日本天文学会2021年秋季年会

NAGOYA UNIVERSITY

熱的制動放射による宇宙初期でのダークマターハロー形成への制限

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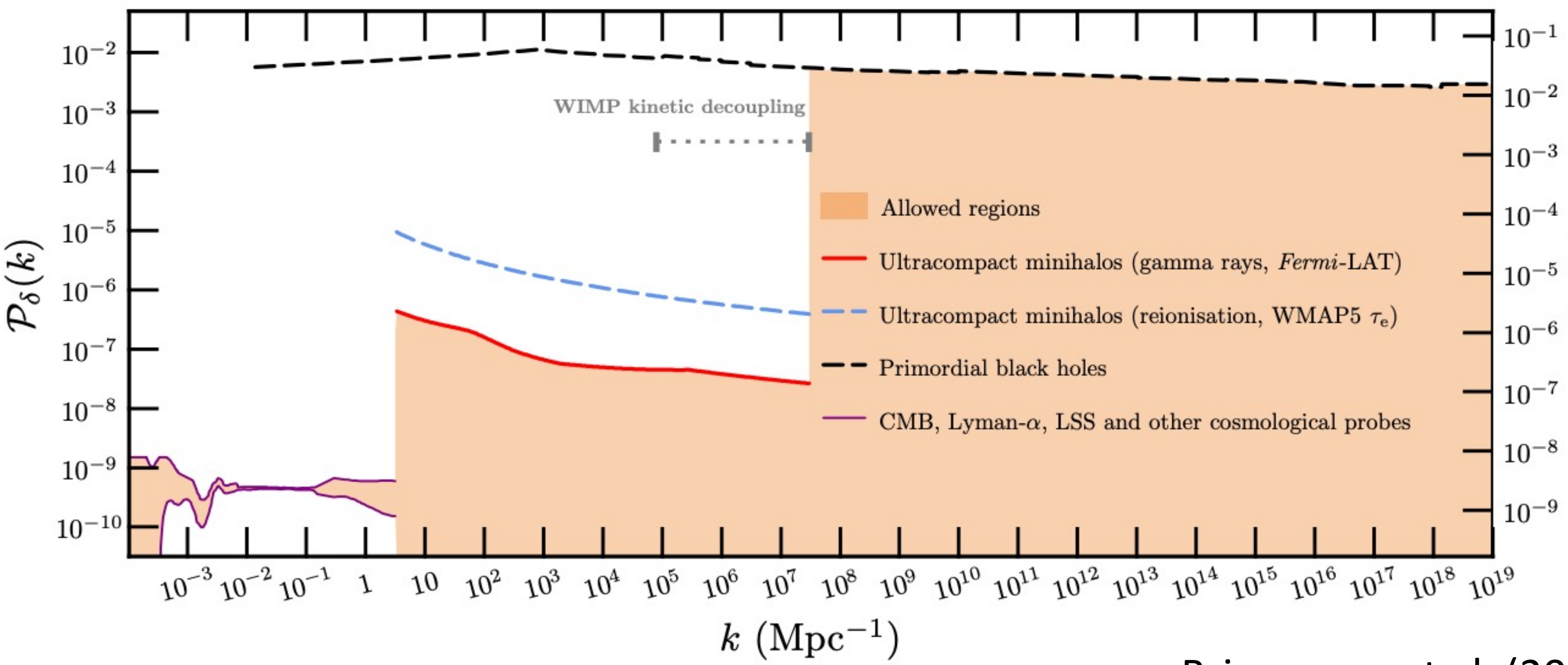
https://arxiv.org/abs/2108.00621

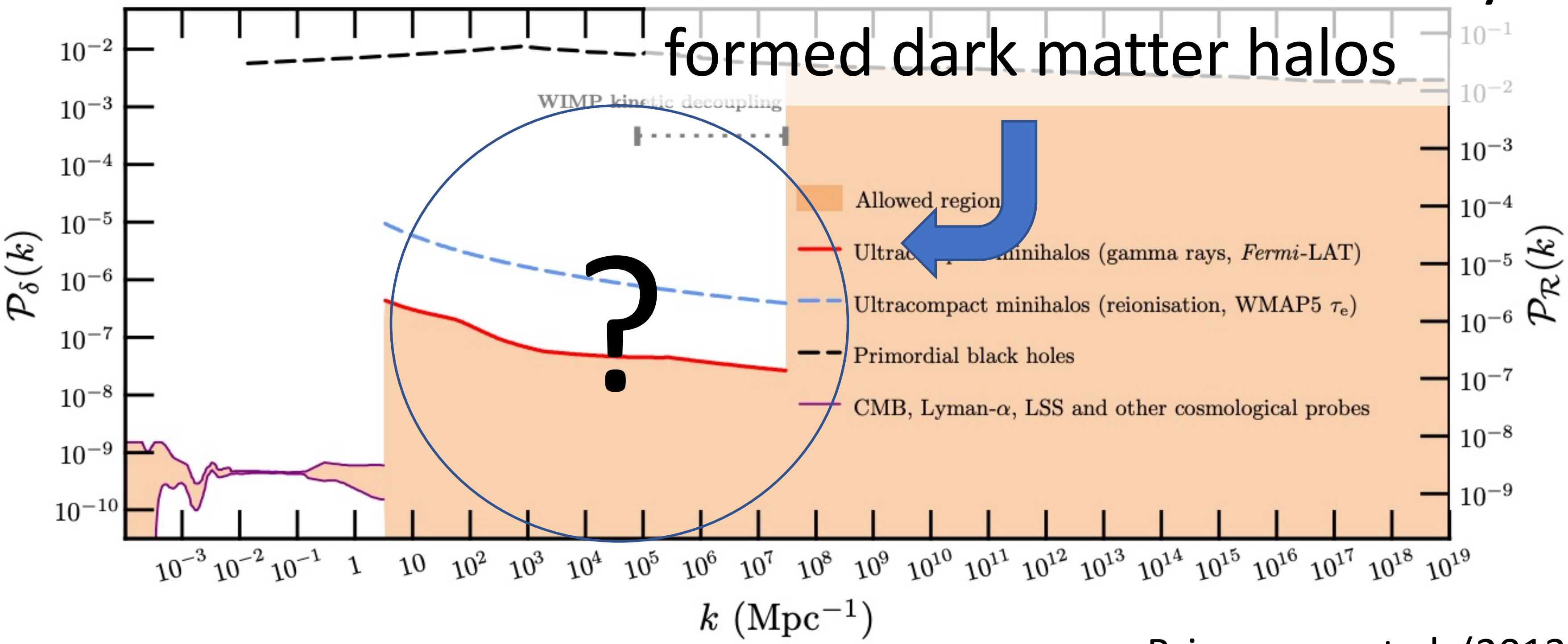
Small-scale perturbation



Bringmann et al. (2013)

Goal of this work

Free-free emission from early formed dark matter halos



Bringmann et al. (2013)

Internal structure in a halo

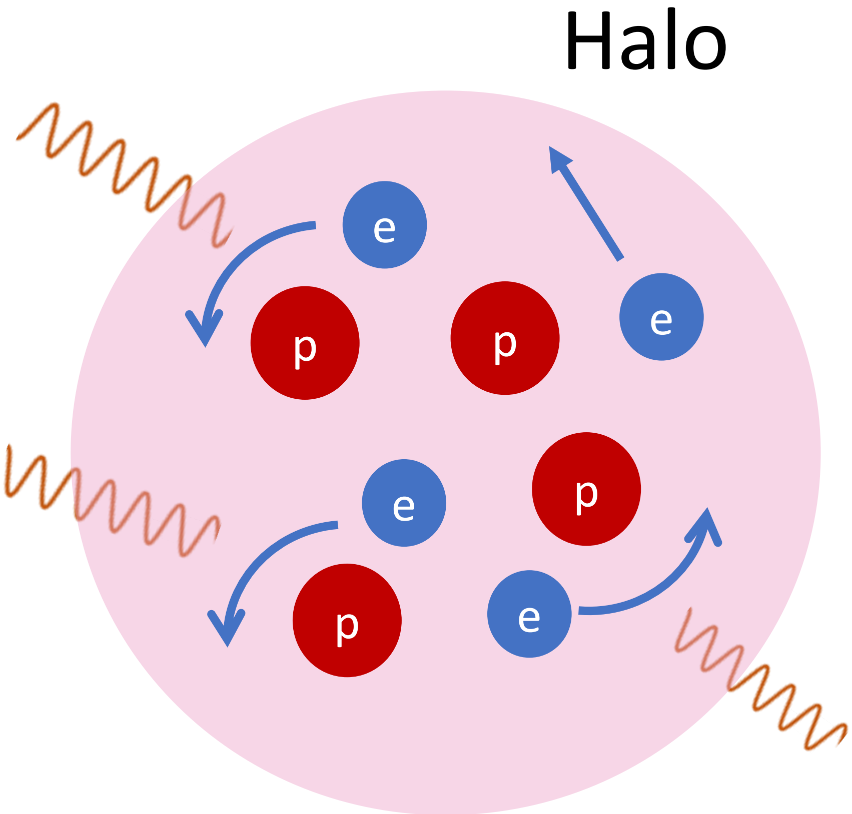
$$\epsilon_\nu^{\mathrm{ff}} = 2.72 \times 10^{-33} n_{\mathrm{b}}^2 x_{\mathrm{e}}^2 T_{\mathrm{halo}}^{-1/2} \exp^{-h\nu/k_{\mathrm{B}} T_{\mathrm{halo}}} \bar{g}_{\mathrm{ff}}$$

$[\mathrm{erg\ s^{-1}\ cm^{-3}\ Hz^{-1}}]$

Hydrostatic equilibrium

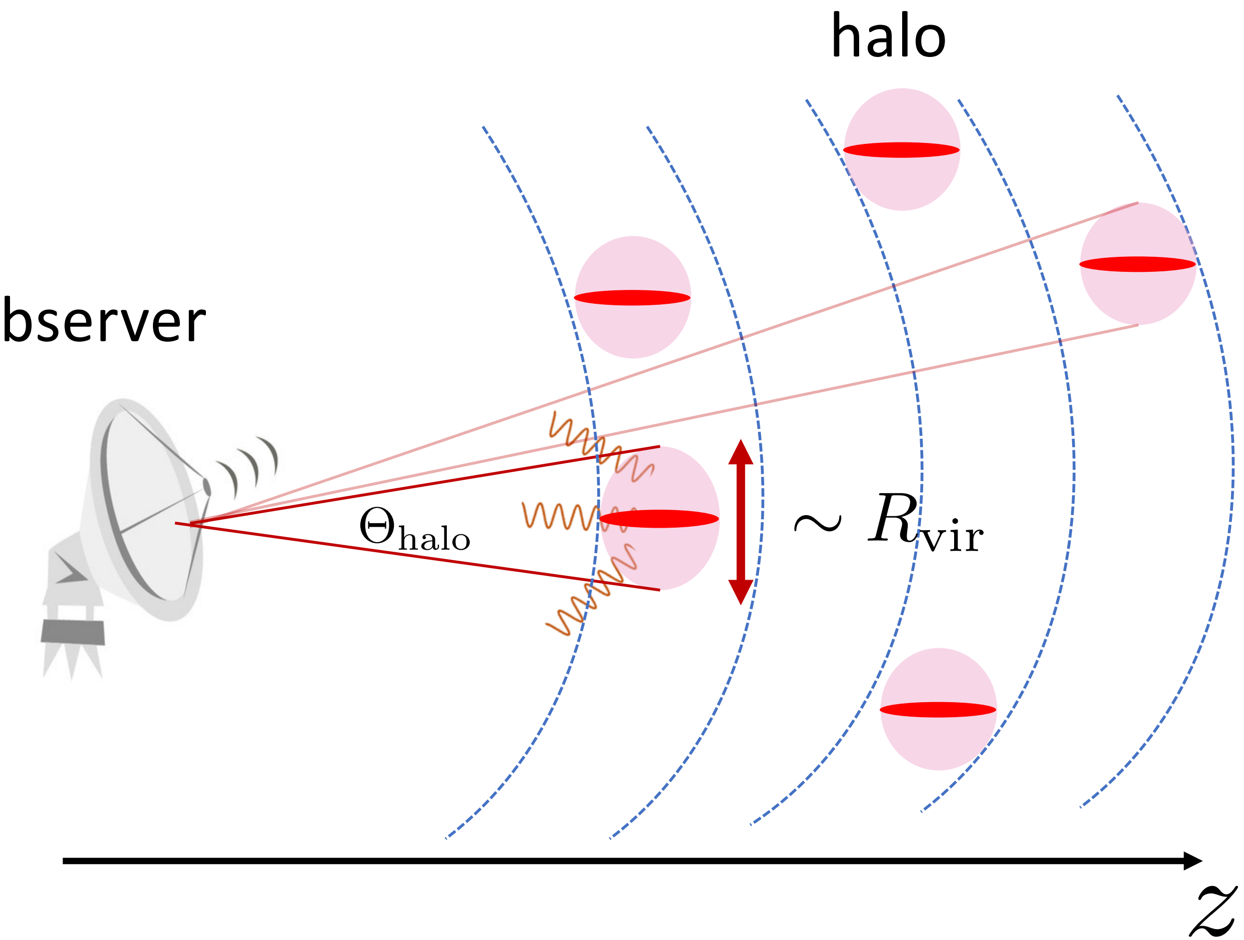
- Dark matter (NFW profile)
- Isothermal gas profile
- Collisional ionization rate
- Gas cooling

Gas density profile



Schematic view: Solid angle of a halo

$$dI_\nu^{\rm sky}(z,M) = \left(\int_z^\infty dz_{\rm f} I_\nu^{\rm ind}(z,z_{\rm f},M)\frac{\Theta_{\rm halo}}{4\pi}\frac{d^2N_{\rm halo}}{dz_{\rm f}dz}\right)dz$$



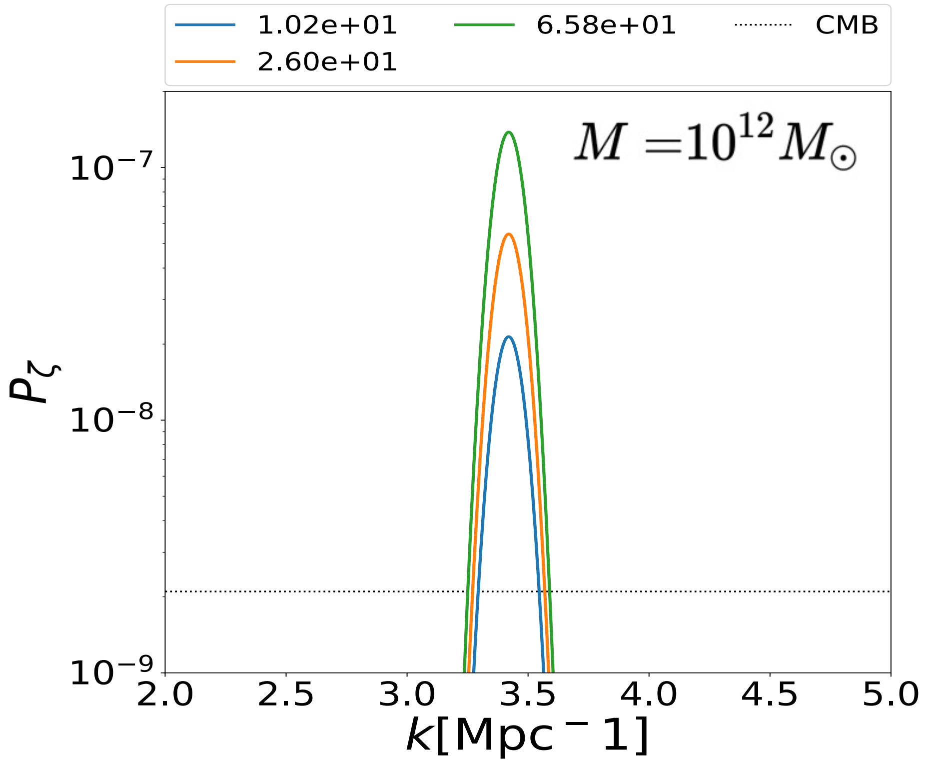
Sky-averaged free-free emission of halos in a redshift shell

Number density of halos

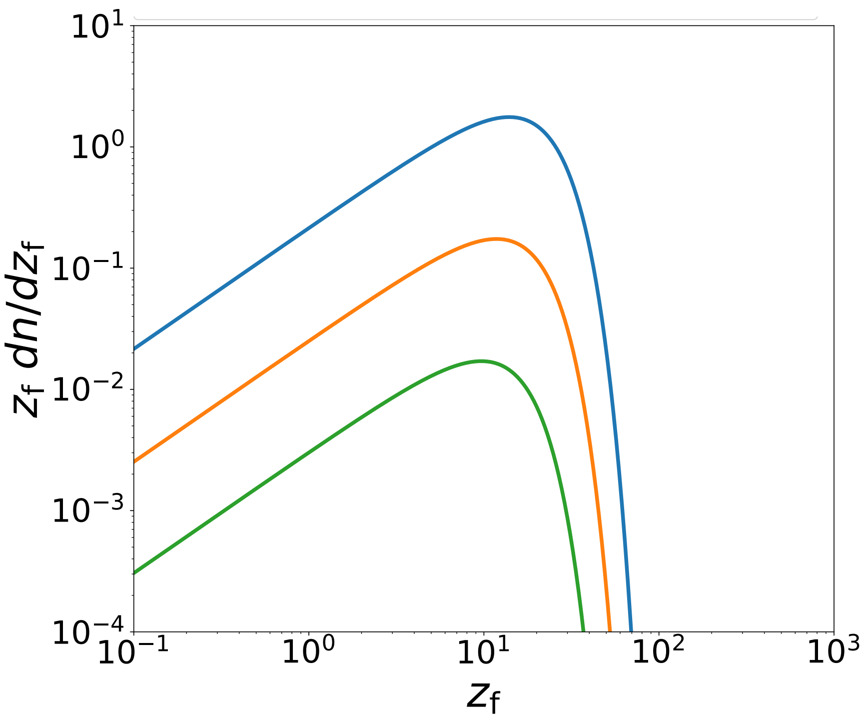
$$dI_\nu^{\rm sky}(z,M) = \left(\int_z^\infty dz_{\rm f} I_\nu^{\rm ind}(z,z_{\rm f},M)\frac{\Theta_{\rm halo}}{4\pi}\frac{d^2N_{\rm halo}}{dz_{\rm f}dz}\right)dz$$

$$\frac{d^2N_{\rm halo}}{dz_{\rm f}dz} = 4\pi r^2\frac{dr}{dz}\frac{dn_{\rm halo}}{dz_{\rm f}}(A_\zeta)$$

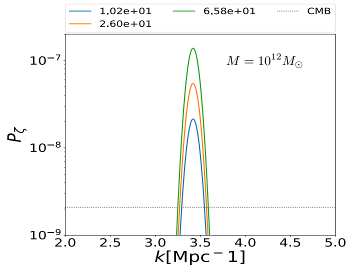
r : comoving distance from z=0 to z



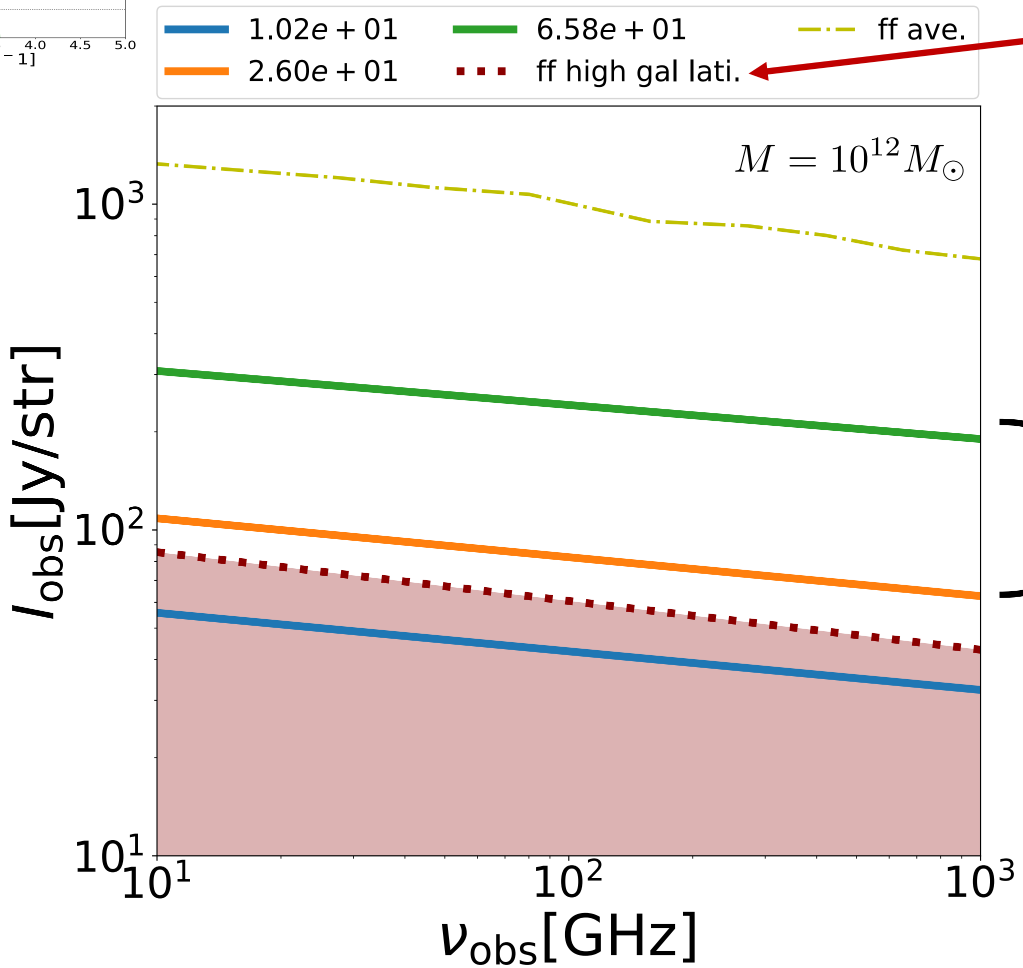
Press-Schechter theory

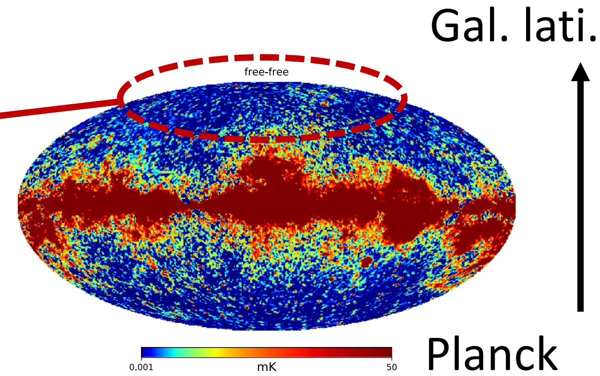


Global signal of free-free emission of early-formed halos



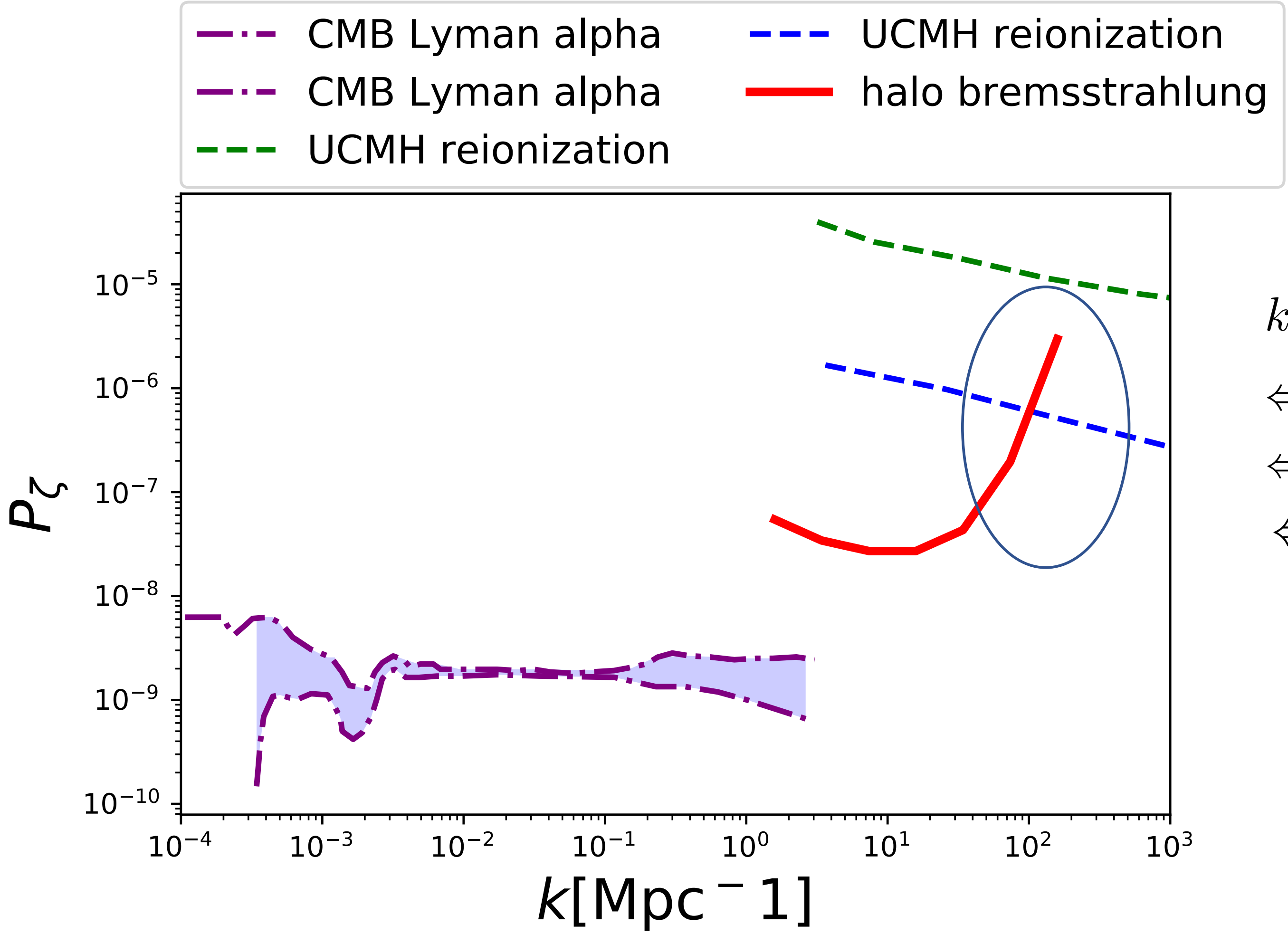
$$I^{\rm sky}_{\nu_{\rm obs}} = \int dz \, \frac{1}{(1+z)^3} \frac{dI^{\rm sky}_{\nu_{\rm em}}(z, M)}{dz},$$





Excluded by the observation of free-free emission in the high galactic latitude region

Constraint of primordial power spectrum



$k \geq 10^2 \mathrm{Mpc}^{-1}$

$\Leftrightarrow M \lesssim 10^8 M_\odot$

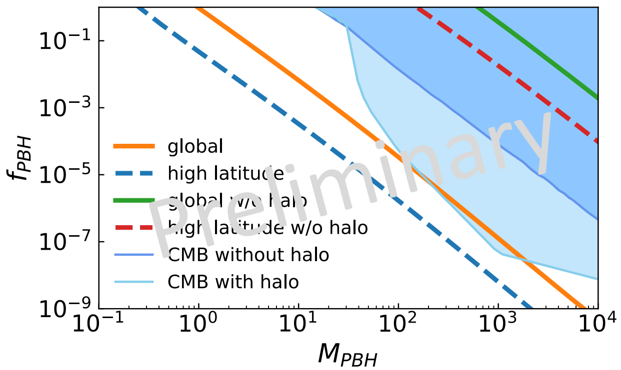
$\Leftrightarrow T\mathrm{vir} \lesssim 10^4 \mathrm{K}$

$\Leftrightarrow x\mathrm{e} \ll 1$

Summary & next work

- We estimate the free-free emission intensity by early-formed halos
- Compared the existing observation of the free-free emission intensity, we put the constraint for the primordial power spectrum as $P_\zeta \lesssim 10^{-8}$ at $1 \lesssim k[\mathrm{Mpc}^{-1}] \lesssim 100$

We are also calculating free-free emission from the PBH gas accretion scenario and updating the abundance constraint.



https://arxiv.org/abs/2108.01916

Back-up slides…

Question

- Gas profileの違い
- DM profile の違い
- UCMHとの違いー＞簡単にはdm profileの違い
- なんでhalo free free emission
- メリット

Concentration parameter

Diemer & Joyce 2019

APPENDIX B: ANALYTICAL MODEL OF MASS-CONCENTRATION RELATION

Following Diemer & Joyce (2019) we model halo concentration using analytical approximation:

$$c = C(\alpha_{\rm eff}) \times \tilde{G}\left(\frac{A(n_{\rm eff})}{\nu}\left[1 + \frac{\nu^2}{B(n_{\rm eff})}\right]\right), \quad \text{(B1)}$$

where $\tilde{G}(x)$ is the inverse function of

$$G(x) = \frac{x}{[f(x)]^{(5+n_{\rm eff})/6}}. \quad \text{(B2)}$$

Here, $f(x) = \ln(1+x) - x/(1+x)$ is the mass function of the NFW profile, and $\nu = \delta_{\rm c}/\sigma(M)$ is the height of the density peak.

Variables $n_{\rm eff}$ and $\alpha_{\rm eff}$ are defined as

$$n_{\rm eff}(M) = -2\left.\frac{d\ln\sigma(R)}{d\ln R}\right|_{R=\kappa R_{\rm L}} - 3 \quad \text{(B3)}$$

and

$$\alpha_{\rm eff}(z) = -\frac{d\ln D(z)}{d\ln(1+z)}. \quad \text{(B4)}$$

The latter is the effective exponent of linear growth $D(z)$. The former reflects the effective slope of the power spectrum, where $\sigma(R)$ is the rms density fluctuation in spheres with Lagrangian radius $R_{\rm L}$ multiplied by a free parameter κ. Halo mass M is directly related to $R_{\rm L}$ as,

$$M = \frac{4\pi}{3}\rho_m R_{\rm L}^3, \quad \text{(B5)}$$

where, $\rho_m(z=0)$ is the mean density at $z=0$.

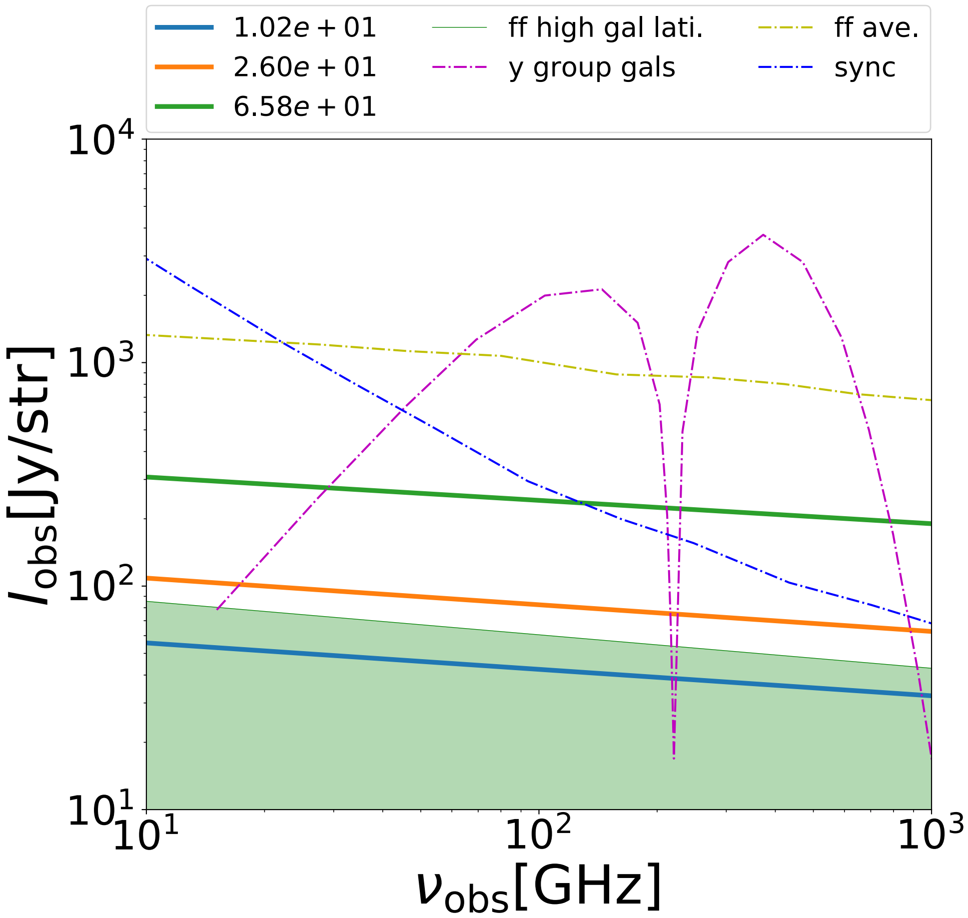
Terms $A(n_{\rm eff})$, $B(n_{\rm eff})$, and $C(\alpha_{\rm eff})$ have the following form:

$$\begin{aligned} A(n_{\rm eff}) &= a_0\left(1 + a_1(n_{\rm eff}+3)\right) \\ B(n_{\rm eff}) &= b_0\left(1 + b_1(n_{\rm eff}+3)\right) \\ C(\alpha_{\rm eff}) &= 1 - c_\alpha(1-\alpha_{\rm eff}), \end{aligned} \quad \text{(B6)}$$

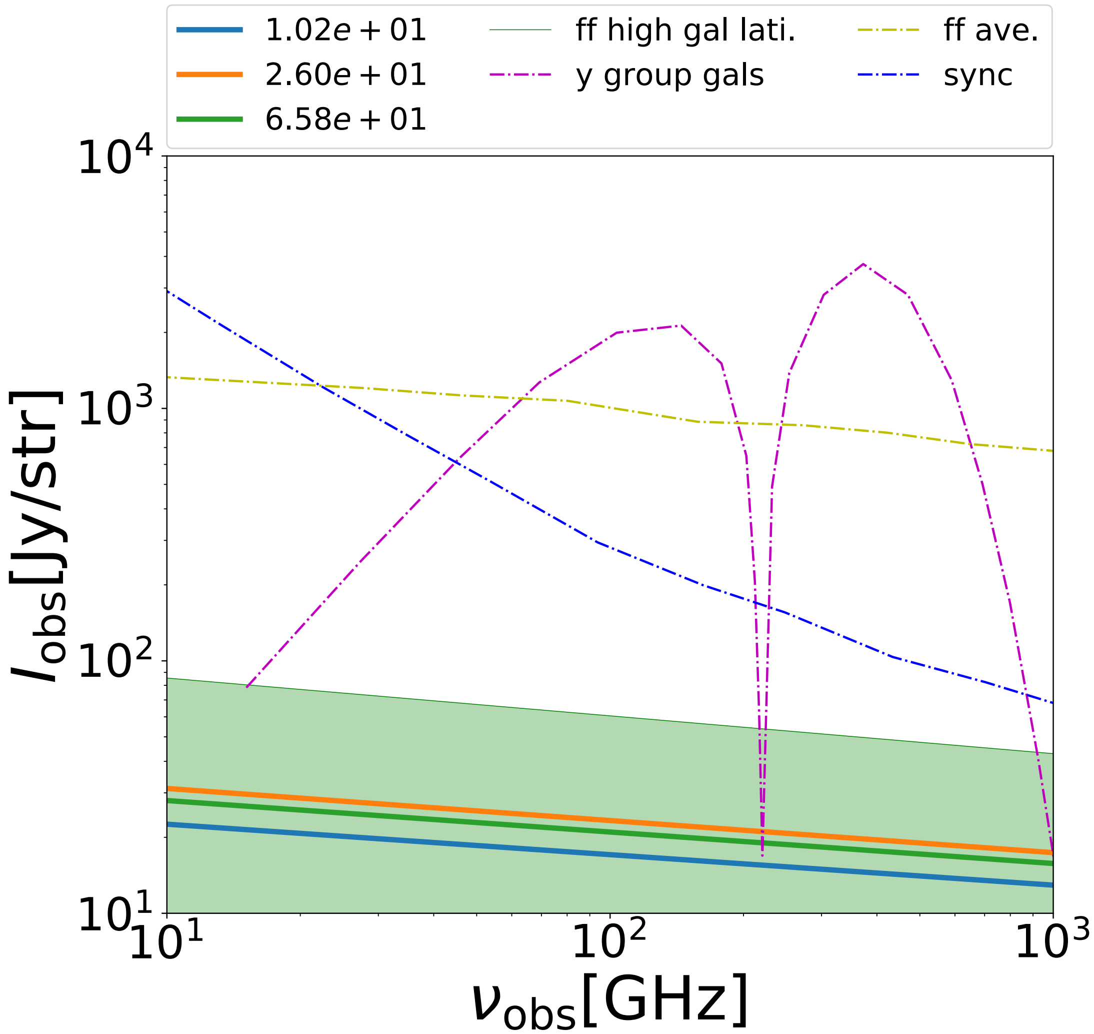
with free parameters, a_0, a_1, b_0, b_1, and c_α.

from Ishiyama et al. 2020

Exp gas density profile



Homogeneous gas density profile



Solid angle of a halo & number density

$$dI_\nu^{\rm sky}(z,M) = \left(\int_z^\infty dz_{\rm f} I_\nu^{\rm ind}(z, z_{\rm f}, M) \frac{\Theta_{\rm halo}}{4\pi} \frac{d^2 N_{\rm halo}}{dz_{\rm f} dz} \right) dz$$

Gas profile in a halo

$$\rho_{\rm g}(r) = \rho_{\rm g,0}\exp\left[-\frac{\mu m_{\rm p}}{2k_{\rm B}T_{\rm vir}}\left(V_{\rm esc}^2(0) - V_{\rm esc}^2(r)\right)\right]$$

$$V_{\rm esc}^2(r) = 2\int_r^\infty \frac{GM\left(r'\right)}{r'^2}dr' = 2V_c^2\frac{F(yx)+yx/(1+yx)}{xF(y)}$$

$$F(x) = \ln(1+x) - x/(1+x)$$

Collisional ionization fraction

$$x_{\mathrm{e}}(T_{\mathrm{halo}}) = \frac{C_{\mathrm{coll}}}{C_{\mathrm{coll}} + A_{\mathrm{rec}}}$$

$$C_{\mathrm{coll}} \approx 5.85 \times 10^{-9} T_4^{1/2} \mathrm{e}^{-T_{\mathrm{H}}/T_{\mathrm{halo}}} n_{\mathrm{H}} (1 - x_{\mathrm{e}}) \ \mathrm{cm}^3/\mathrm{s}$$

$$A_{\mathrm{rec}} = -\alpha_{\mathrm{H}} n_{\mathrm{H}} x_{\mathrm{e}}$$

$$\alpha_{\mathrm{H}} = 1.14 \times 10^{-13} \frac{a T_4^b}{1 + c T_4^d} \ \mathrm{cm}^3/\ \mathrm{s}$$

$a = 4.309$, $b = -0.6166$, $c = 0.6703$, $d = 0.5300$, and $T_4 = T_{\mathrm{halo}}/10^4\mathrm{K}$.

Gas cooling

$$T_{\rm halo}(M, z, z_{\rm f}) = T_{\rm vir}(M, z_{\rm f}) \exp\left(-\frac{\Delta_t(z, z_{\rm f})}{t_{\rm C}}\right)$$

$$\Delta_t \approx \frac{2}{3}\left(\frac{1}{H(z)} - \frac{1}{H(z_{\rm f})}\right)$$

$$t_{\rm C}(z) = \frac{3m_{\rm e}c}{4\sigma_{\rm T}aT_\gamma^4} = 1.4 \times 10^7 \left(\frac{1+z}{20}\right)^{-4} {\rm yr}$$

Press schechter theory

$$\frac{dn_{\rm halo}^{\rm com}}{dz_{\rm f}} = 2\frac{\rho_{\rm m,0}}{M}\frac{\delta_c}{(2\pi\mathcal{A}_{\rm mat})^{1/2}}\exp\left(-\frac{\delta_c^2(1+z_{\rm f})^2}{2\mathcal{A}_{\rm mat}}\right)$$

$$\frac{\mathcal{A}_{\rm mat}}{(1+z_{\rm f})^2} = \int {\rm dlog}k\ \mathcal{P}_{\rm mat}(k, z_{\rm f})W(kR_{\rm halo}(M))$$

Relation of density and curvature perturbation

$$\delta(k,a) = \frac{2}{5}\frac{k^2}{\Omega_m H_0^2}\zeta(k)\mathcal{T}\left(\frac{\sqrt{\Omega_r}k}{H_0\Omega_m}\right)a$$

$$\mathcal{T}(\chi) = \frac{45}{2\chi^2}\left(-\frac{7}{2}+\gamma_E+\ln\left(\frac{4\chi}{\sqrt{3}}\right)\right)$$

$$\mathcal{A}_\zeta = \frac{(\Omega_r/\Omega_m)^2\mathcal{A}_{\rm mat}}{81\left[-\frac{7}{2}+\gamma_E+\ln\left(\frac{4\sqrt{\Omega_r}k_s}{\sqrt{3}H_0\Omega_m}\right)\right]^2}.$$

Cutoff redshift

$$1 + z_{\mathrm{cut},>\mathrm{M}} = \sqrt{\frac{6.16\times10^{-9}}{\delta_c^2}\,\frac{81\left[-\frac{7}{2}+\gamma_E+\ln\left(\frac{4\sqrt{\Omega_r}k_s}{\sqrt{3}H_0\Omega_m}\right)\right]^2}{(\Omega_r/\Omega_m)^2}}$$

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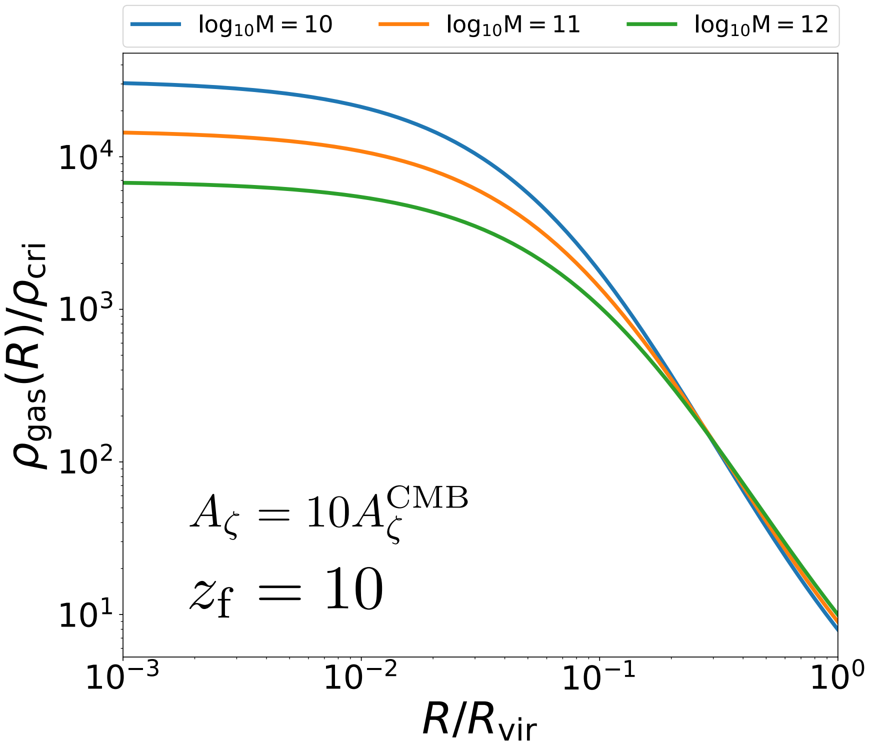
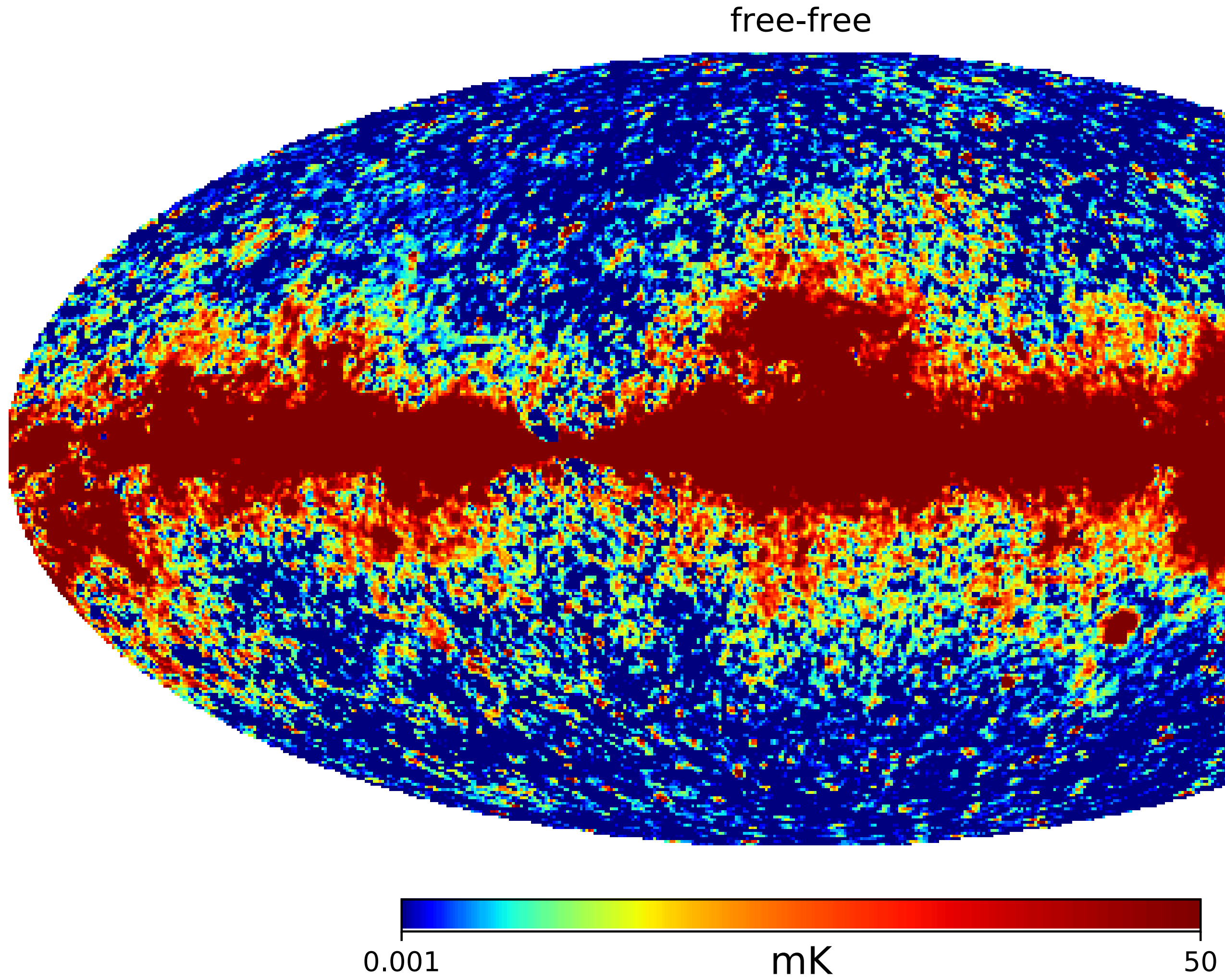


zf: formation redshift

Free-free emission



Planck

Free-free emission