Constraining Spinning Primordial Black Holes With Global 21 cm Signal

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Plan of the talk

1. 21 cm signal

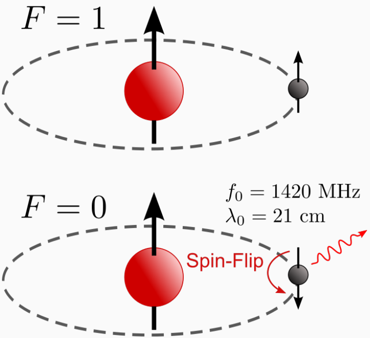
2. Temperature Evolution of gas in presence of spinning primodial black hole

3. Conclusion

21 cm signal

21 cm line

- 21cm signal arises from hyperfine splitting of hydrogen atom due to the interaction of magnetic moment of electron and proton.



$$\mathbf{F} = \mathbf{I} + \mathbf{S}$$

Transition rate of 21 signal

- This transition is highly forbidden because transition rate is $3 \times 10^{-15}\, s^{-1}$ (equivalent to Einstein's coefficient A_{10}).
- Characteristic time scale $=1/$ transition rate $=10^7$years.

Spin temperature

- Relative number density of triplet(n_1) and singlet states (n_0) of HI is

$$\frac{n_1}{n_0} = \frac{g_1}{g_0}\, e^{-\frac{E_{21}}{T_s}}$$

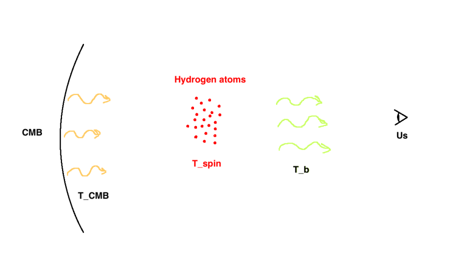
where $E_{21} = 5.9 \times 10^{-6}\, eV = \frac{2\pi}{21\text{cm}}$=0.068 K and $\frac{g_1}{g_0} = 3$.

T_s is the spin temperature.

Brightness temperature

- Under RayleighJeans limit, the specific intensity for a blackbody can be written
$$I_\nu = \frac{2K_B T_B \nu^2}{c^2}$$
T_B quantity is the Brightness Temperature.

Differential brightness temperature



- The intensity of the signal is quantify in differential brightness temperature:

$$T_{21} = T_B - T_{CMB} = \frac{1}{1+z}(T_S - T_{CMB})(1 - \exp^{-\tau})$$

Here τ is the optical depth, which is given by

$$\tau \approx \frac{3\lambda_{21}^2 A_{10} n_H}{16 T_S H(z)} \ ,$$

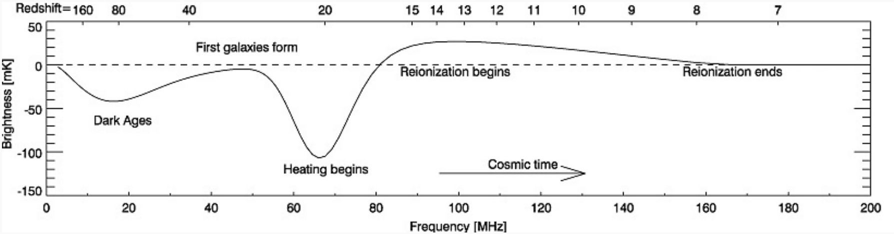
Spin Temperature dependence

- Detectability of T_{21} depends upon the T_S.
- $T_S > T_{CMB}$, we observe 21 cm emission signal.
  $T_S < T_{CMB}$, we observe 21 cm absorption signal.
  $T_S = T_{CMB}$, there is no signal
- Deviation of spin temperature from background temperature can be expressed as

$$T_S^{-1} = \frac{T_{CMB}^{-1} + x_\alpha T_\alpha^{-1} + x_c T_K^{-1}}{1 + x_\alpha + x_c},$$

  where x_α and x_c are coupling coefficient due to scattering of Lyα and atomic collision respectively.
- $T_{CMB} = 2.72K(1+z)$

Evolution of 21cm Signal

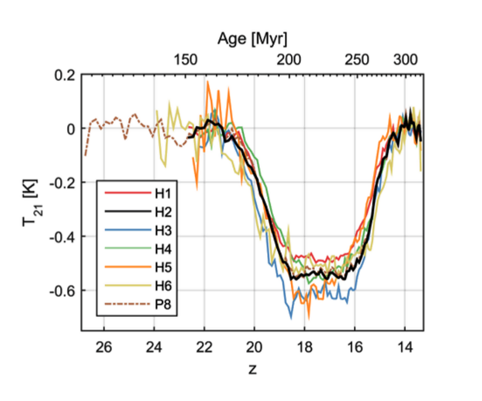


- The standard astrophysics prediction for brightness temperature

$$T_{21}(z = 17) \geq -220\ mK$$

This correspond to gas temperature 6.8 K at z=17.

EDGES Signal



- Brightness measurement with 99% confidence interval is

$$T_{21}^{EDGES}(z = 17) \approx -500^{+200}_{-300} \; mK$$

This correspond to gas temperature : $3.26^{+1.94}_{-1.58} \; K$ (Bowman 2018)

- Either decrease T_S or increase T_{CMB} during Cosmic Dawn era.

Temperature Evolution of gas in presence of spinning primodial black hole

Temperature Evolution of Baryon in presence of SPBH

In the presence of Hawking radiation, the thermal evolution of the gas

$$\frac{dT_{\rm gas}}{dz} = 2\,\frac{T_{\rm gas}}{1+z} + \frac{\Gamma_c}{(1+z)\,H}(T_{\rm gas} - T_{\rm CMB}) - \frac{2\;\Gamma_{\rm PBH}}{3\,N_{\rm tot}(1+z)\,H}\,, \quad (1)$$

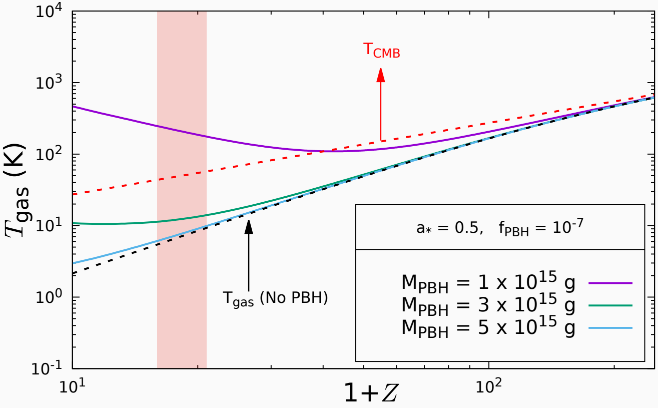
here, $\Gamma_{\rm PBH} = \Gamma^{e^\pm}_{\rm PBH} + \Gamma^{\gamma}_{\rm PBH}$

$$\Gamma^{e^\pm}_{\rm PBH}(z, a_*) = 2\int \left[f^e_c(E - m_e, z)\,(E - m_e) \left(\frac{d^2N_e}{dt\,dE} \right) \right] n_{\rm PBH}\, dE\,, \quad (2)$$

$$\Gamma^{\gamma}_{\rm PBH}(z, a_*) = \int \left[\; f^{\gamma}_c(E, z)\,E\, \left(\frac{d^2N_\gamma}{dt\,dE} \right) \right] n_{\rm PBH}\; dE\,. \quad (3)$$

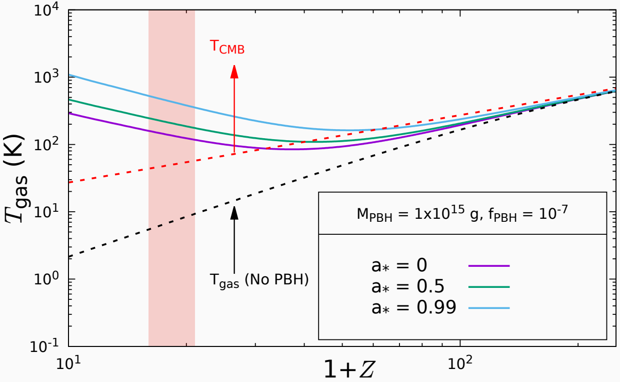
Where $N_{\rm tot}$ is the total number density of the gas.
f^i_c is the the energy deposition efficiency.
$n_{\rm PBH} = f_{\rm PBH}\,(\rho_{\rm DM}/M_{\rm PBH}),\; f_{\rm PBH} = \Omega_{\rm PBH}/\Omega_{\rm DM}$

Gas temperature-evolution in presence of dark matter: Different mass

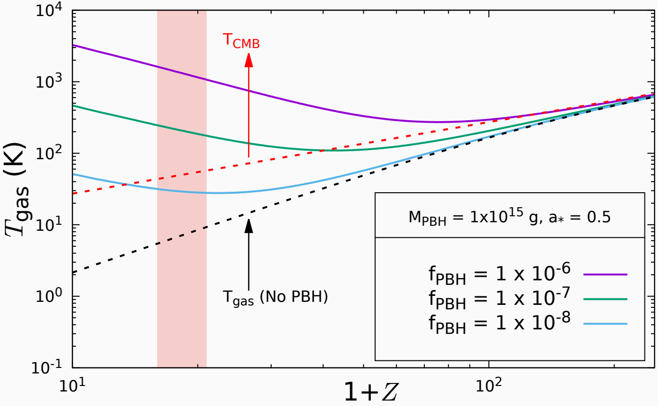


$a_* = J_{\rm PBH}/(G\, M_{\rm PBH}^2)$

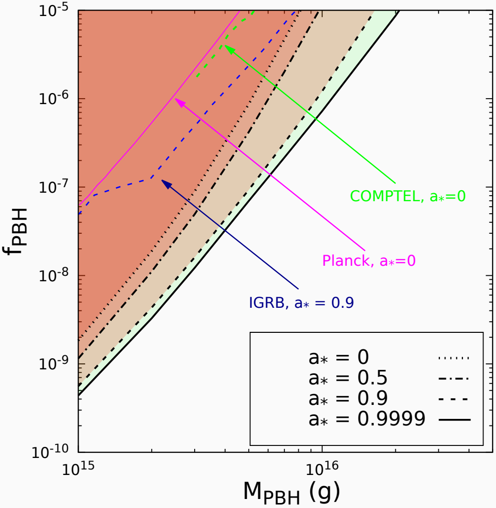
Gas temperature-evolution in presence of dark matter: Different spin of PBH



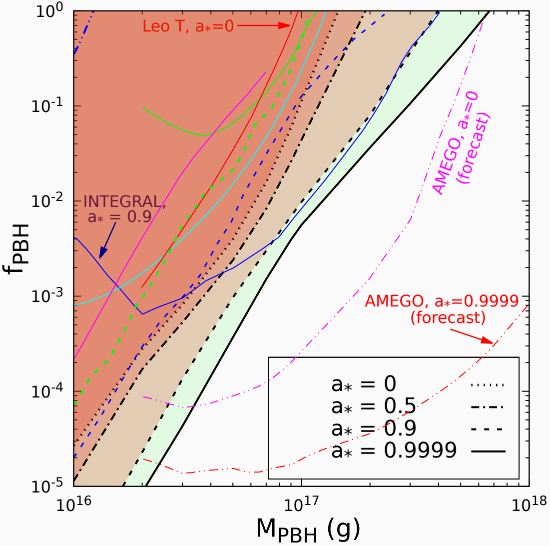
Gas temperature-evolution in presence of dark matter: Different fraction of PBH



Allowed parameter space for SPBH-I



Allowed parameter space for SPBH-II



Conclusion

- Spinning primordial black holes can substantially affect the ionization and thermal history of the Universe.
- Subsequently, it can modify the 21 cm absorption signal in the cosmic dawn era by injecting energy due to Hawking evaporation
- We obatained upper bound on the fraction of dark matter in the form of PBHs as a function of mass and spin, considering that T_{21} does not change more than a factor of $1/4$ from the theoretical prediction based on the ΛCDM framework.
- Our constraints are stringent compared to DSNB, INTEGRAL observation of the 511 KeV line, IGRB, Planck, Leo T and COMPTEL

Thank You

Continue

- Electron fractions evolve as

$$\frac{dx_e}{dz} = \frac{1}{H(1+z)} \frac{\frac{3}{4}R_{Ly\alpha} + \frac{1}{4}\Lambda_{2s,1s}}{\beta_B + \frac{3}{4}R_{Ly\alpha} + \frac{1}{4}\Lambda_{2s,1s}} \Big(n_H x_e^2 \alpha_B - 4(1-x_e)\beta_B e^{-E_{21}/T_C} \Big)$$

- Evolution of relative velocity is given as

$$\frac{dv_{\rm rel}}{dz} = \frac{v_{\rm rel}}{(1+z)} + \frac{D(v_{\rm rel})}{(1+z)H}$$

$$\text{where} \quad D(v_{rel}) \equiv -\frac{dv_{\rm rel}}{dt} = \sum_I \frac{\rho_I}{\rho_b} \frac{\rho_m \sigma_{0,I}}{m_b + m_\chi} \frac{1}{v_{\rm rel}^2} F(r_I)$$

and $F(r_I)$ is given by

$$F(r_I) \equiv \mathrm{Erf}(\frac{r_I}{\sqrt{2}}) - \sqrt{\frac{2}{\pi}} r_I e^{-r_I^2/2}$$