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The interpretation of the CMBR

Yi-Jia Zheng (郑怡嘉)

National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100101, China; *zyj@bao.ac.cn*

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Abstract In the popular ΛCDM model, the cosmic microwave background radiation (CMBR) is thought to be the remnant of the early hot universe. An important precondition of this interpretation of CMBR is: after the last scattering surface formed, the high temperature ionized gases in the universe became low temperature neutral gases and so the universe has been completely transparent to the radiation which comes from the hot early universe. However, observations show that today most gases in the universe are still in a high temperature ionized state. The universe is not completely transparent to the radiation which comes from the hot early universe. According to the famous Sunyaev-Zeldovich effect, if the CMBR comes from the early hot universe and follows a perfect blackbody spectrum, the free electrons in the cosmic plasma will distort the perfect blackbody spectrum of the CMBR. In this case, the observed CMBR cannot be of a perfect blackbody spectrum. This is a fatal flaw in the interpretation of CMBR using the ΛCDM model. In order to overcome this fatal flaw, in this paper it is proposed that in the ΛCDM model frame, a better interpretation of CMBR is: The CMBR is a thermal equilibrium product between the high temperature ionized gases and the cosmic radiation field in the local universe space.

Key words: cosmology: theory — cosmological model — cosmic microwave background radiation

1 INTRODUCTION

Penzias & Wilson (1965) reported that measurements of the effective zenith noise temperature of the 20-foot horn-reflector antenna at the Crawford Hill Laboratory, Holmdel, New Jersey, at 4080 Mc s^{-1}, yielded a value about 3.5 K higher than expected. Later, on a wider frequency spectrum, a similar phenomenon was observed (Fixsen 2009).

It should be noted that the concept of cosmic microwave background radiation (CMBR) in the ΛCDM model cosmological model is different from the directly observed diffuse emission by Penzias & Wilson (1965). The directly observed diffuse emission by Penzias & Wilson (1965) is a composite of a multitude of Galactic, extragalactic and cosmological components. The CMBR is only the residual after some known non-cosmological components are removed from the observed diffuse emission (Planck Collaboration et al. 2014).

After removing known non-cosmological components, the final residue is thought to be the cosmological component, CMBR, and has a perfect blackbody spectrum. So in the ΛCDM model cosmological model, the CMBR is thought to be from the hot plasma of the early universe. It should be noted that when removing known components, a contribution caused by plasma in the local cosmic space has not been considered (Planck Collaboration et al. 2014). Because the plasma in the local cosmic space is very diluted and is hard to observe, it has long been neglected (Fukugita et al. 1998).

The scenario of this interpretation of CMBR in the ΛCDM model cosmological model is:
Just before the last scattering surface formed, the gases in the universe were in a high temperature ionized state and dense enough, and the cosmic ionized gases and cosmic radiation field were in thermal equilibrium, so the cosmic radiation followed a blackbody spectrum of high temperature; After that, due to expansion, the temperature of the universe decreased, and the ionized gases recombined into neutral gases. In this case, the universe became transparent to radiation, so the perfect blackbody spectrum of cosmic radiation which is from the early hot universe remained unchanged; only the temperature of radiation dropped and formed the present observed CMBR (Peebles et al. 2000; Peebles 2017).

It should be noted that an important and necessary precondition for such an interpretation of CMBR is: after the last scattering surface formed, the high temperature ionized gases in cosmic space should be recombined into low temperature neutral gases.

Observations showed that today in the universe most gases still exist in the form of high temperature ionized gases and diffused in space to form cosmic plasma (Wang & McCray 1993; Fukugita et al. 1998; Kaplinghat et al. 2003). This means that in the ΛCDM model cosmological model frame, the precondition of the present interpretation of CMBR is conflicted with observations.

In order to overcome this flaw in the ΛCDM model cosmological model, in this paper it is proposed that thermal equilibrium (between the high temperature ionized gases and radiation field) not only can take place in the early hot universe, thermal equilibrium can also take place in local cosmic space.

If we only consider the lowest order interactions between the free electrons and photons, i.e., Compton scattering effects, thermal equilibrium between high temperature plasma and radiation can only be reached in the condition that the number density of the plasma is high enough. In this case, the temperature of the thermal equilibrium is high. Such a thermal equilibrium can only occur in the early hot universe.

If the high order interactions between the free electrons and photons are taken into account, and at the same time, free-free absorption and emission of fully ionized gases are considered, then even if the number density of the plasma is low and the temperature plasma is high, thermal equilibrium between them can also be reached. In this case, the temperature of the thermal equilibrium can be low. Therefore, in local cosmic space, thermal equilibrium between high temperature plasma and radiation can occur.

In order to show that in local cosmic space, the thermal equilibrium between high temperature plasma and radiation can occur, the interactions between the radiation and plasma in local cosmic space need to be reviewed. The interactions between radiation and plasma in local cosmic space include the high order interactions between photons and free electrons, and the free-free absorption and emission processes in fully ionized gases (Spitzer 1962).

2 THE INTERACTIONS BETWEEN RADIATION AND PLASMA IN LOCAL COSMIC SPACE

Observations indicated that in local cosmic space most gases are not in the neutral state but in the form of high temperature ionized state with very low density (Wang & McCray 1993; Fukugita et al. 1998; Kaplinghat et al. 2003); and radiation energy is mainly concentrated in the low frequency band (Allen 1973; Vavryčuk 2018).

In quantum electrodynamics, the interactions between radiation and dilute plasma are usually simplified as the interactions between a photon and a free electron. In discussion of interactions between a photon and a free electron, usually only the lowest order interactions are considered, such as the Compton scattering and inverse Compton scattering (Compton 1923; Zwicky 1929; Sunyaev & Zel'dovich 1980). Figure 1 is a schematic illustrating Compton scattering.

In addition to the lowest order interactions between a photon and a free electron, in fact there are many high-order interactions (Heitler 1954; Gould 1984). A high-order interaction refers to the number of output photons not being equal to the number of input photons. Usually, the cross-section of a high-order interaction is far less than the cross-section of the lowest interaction. For example, the cross-section of double Compton scattering is two orders of magnitude less than the cross-section of normal Compton scattering (Heitler 1954). Therefore, usually high-order interactions are ignored. Figure 2 is a schematic depicting the double Compton scattering.

If a high-order interaction includes the absorption and emission of soft photons (soft photon refers to a photon whose energy tends to zero), the situation will be completely different. For example, if a Compton scattering includes a soft photon k_r (within the range of dk_r), the cross-section of the interaction will be the cross-section of Compton scattering times a factor

$$F(\Delta P)dk_r = \frac{4e^2}{3hc}\frac{(\Delta P)^2}{E^2}\frac{dk_r}{k_r}\,, \tag{1}$$

where ΔP is the momentum change of the target free electron during the interaction between the incident photon and an isolated free electron; E is the energy of the free electron ($m_e c^2$); e is the electron charge; h is the Planck constant (Heitler 1954). Therefore, the calculated cross-section of this type of high order interaction (soft photon process) will go to infinity if the frequency of the soft photon tends to zero. Figure 3 is a schematic demonstrating the soft photon emission in Compton scattering.

The soft photon emission is usually considered a troublemaker. That is the so-called "infrared divergence" problem. For the problem of "infrared divergence", physicists are mainly concerned with how to overcome the difficulties caused by "infrared divergence" (i.e., the computational cross-section of the interaction will approach infinity) (Heitler 1954; Gould 1984). In physics, an infinite factor in the calculated cross section of the interaction of a soft photon process simply implies that the emission of soft photons is an unavoidable consequence during interactions between the photons and electrons in a dilute plasma.

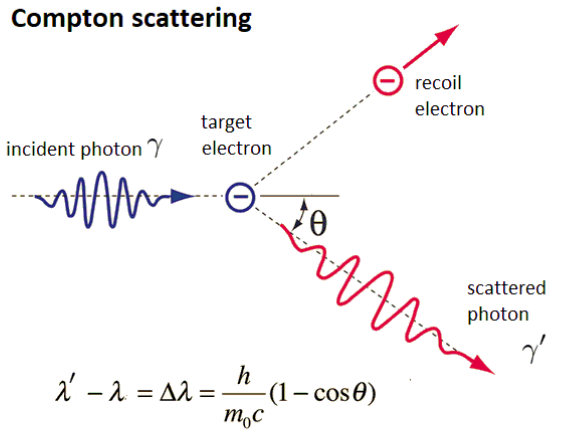

Fig. 1 The sketch illustrates Compton scattering. γ represents the incident photon and γ' signifies the outgoing photon after interaction.

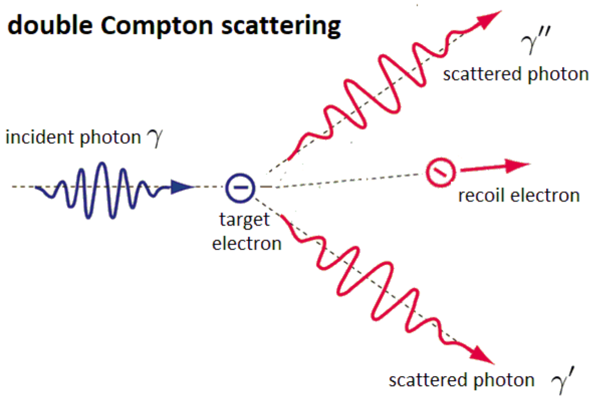

Fig. 2 The sketch depicts double Compton scattering. γ represents the incident photon, γ' and γ'' signify two outgoing photons after interaction.

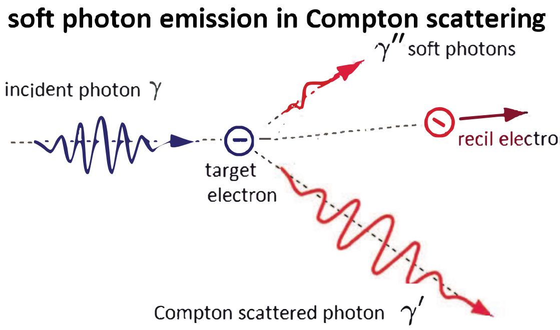

Fig. 3 The sketch demonstrates soft photon emission in Compton scattering. γ represents the incident photon. γ' signifies the Compton scattering photon. Its direction is different from the direction of the incident photon. γ'' corresponds to the soft photon, which also is emitted during the interaction between an incident photon and an isolated free electron.

According to quantum electrodynamics theory, a situation can exist in which the high order interactions with the number of output photons is less than the number of input photons as long as the energy and momentum conservation laws are obeyed in the interaction processes. This means that soft photons can be combined with a normal photon to form a new photon (in this paper it is called the "inverse soft photon process").

Due to the high order interactions between photons and free electrons in high temperature cosmic plasma, a large amount of low frequency radiation will be produced in cosmic space. Finally, after a large amount of high order interactions between photons and free electrons in the cosmic plasma, the cosmic radiation energy density will be mainly concentrated in the low frequency band.

According to Spitzer (1962) and Allen (1973), the free-free absorption coefficient of radiation of plasma is

$$\kappa_s = \frac{4\pi}{3\sqrt{3}} \frac{Z^2 e^6}{h c m^2 v} \frac{g}{\nu^3} N_e N_i \,, \qquad (2)$$

where v = is electron velocity, g = Gaunt factor representing the departure from Kramers' theory, Z = ionic charge, and N_e and N_i are electron and ionic density in cm^{-3}. Mean $\frac{1}{v} = (2m/\pi kT)^{1/2}$ (T = is the temperature of free electrons in plasma).

After allowance for stimulated emission, the effective linear absorption coefficient is

$$\kappa'_\nu = 3.692 \times 10^8 (1 - \exp(-h\nu/kT) Z^2 g T^{-1/2} \nu^{-3} N_e N_i \quad [\kappa'_\nu \text{ in exp cm}^{-1}] \,. \qquad (3)$$

The effective linear absorption coefficient $\kappa'_\nu \propto \nu^{-3}$ means that for low frequency radiation, it is easy to be absorbed and re-emitted by diluted plasma in local cosmic space. The low frequency radiation cannot freely pass through local cosmic space which is filled with diluted plasma.

It should be noted, in "Physics of Fully Ionized Gases" (Spitzer 1962), the existence of various positively charged particles (ions) in the plasma is taken into account. However, the existence of various positively charged particles (ions) in the plasma is not taken into account in high order interactions between photons and free electrons.

Therefore, both the high order interactions between photons and free electrons and the theory of "Physics of Fully Ionized Gases" (Spitzer 1962) are the theoretical basis of why in local cosmic space radiation fields and high temperature ionized gases can reach thermal equilibrium.

3 FOR CMBR AND ISOLATED SOURCES, THE MEANINGS OF HIGH ORDER INTERACTIONS ARE COMPLETELY DIFFERENT

For radiation from isolated radiation sources, the optical depth is an important parameter. In the calculation of optical depth of an isolated source, if the optical depth is mainly determined by the Compton scattering effect caused by diluted cosmic plasma, then in this case, the effect of high order interaction caused by diluted cosmic plasma can be neglected. The isolated sources can still be observed well, but Planck Collaboration et al. (2014) mentioned that free-free absorptions and emissions indeed are physical processes which affect the data processing to get CMBR (see subsect. 8.2 in Planck Collaboration et al. 2014).

The "soft photon process" and "inverse soft photon process" in the high order interactions between photons and free electrons are analogous to the free-free absorption and emission processes in "Physics of Fully Ionized Gases" (Spitzer 1962). However, there are some differences between them. In "Physics of Fully Ionized Gases" (Spitzer 1962), the existence of various positively charged particles (ions) in the plasma is taken into account.

Observations by *Planck* indicate that the directly observed diffuse emission is a composite of a multitude of Galactic, extragalactic and cosmological components. The CMBR in the ΛCDM cosmological model is the residue after some known non-cosmological components are removed. It should be noted that among known components that can be removed, the contribution caused by diluted plasma which has diffused in local cosmic space has not been considered (Planck Collaboration et al. 2014).

Early in 1926, Eddington believed that in interstellar space in the Galaxy there is a low temperature radiation field with a blackbody spectrum. The temperature of the radiation field can be inferred according to the Stefan-Boltzmann law. Using radiation from stars, Eddington estimated the radiation density in interstellar space in the Galaxy. Eddington inferred that the temperature in interstellar space of the Galaxy is 3.18 K (Eddington 1926).

This temperature is a little higher than the temperature of the CMBR in the cosmological model. Observations by Planck Collaboration show that the radiation of the Galaxy indeed can approximately be seen as blackbody emission with intensity varying with position and is the most important non-cosmological component (please refer to fig. 1 and subsect. 8.2 in Planck Collaboration et al. 2014).

This means that Eddington's idea is reasonable and it can be extended to a larger local cosmic space. That is, the CMBR in the cosmological model can be a thermal equilibrium product in local cosmic space which has not been removed in the data processing (Planck Collaboration et al. 2014), and so the CMBR does not need to come from the hot early universe directly.

Though in thermal equilibrium in the Galaxy, many physical processes play a role, Perlmutter et al. (1999) demonstrated that in local cosmic space the thermal dust emission can be neglected. Because most gases in the local universe are in a fully ionized state (Fukugita et al. 1998), free-free absorption and emission caused by diluted plasma are the best physical processes which can reasonably be extended to a larger local cosmic space.

Due to the huge Hubble redshift (~ 1000, please refer to Peebles et al. 2000; Peebles & Ratra 2003), the photons that come from the early universe have become low frequency photons. They are easily absorbed and re-emitted by diluted plasma in local cosmic space. Therefore, the observed CMBR cannot come from the early hot universe directly; the observed CMBR can only be the product of thermal equilibrium of local cosmic space. However, radiation from the early hot universe can contribute its energy to the radiation energy density in local cosmic space. In this case, the free-free absorption of diluted cosmic plasma plays an important role.

The temperature of the CMBR produced in local cosmic space can be estimated by estimation of the radiation energy density in local cosmic space. The estimated radiation energy density in local cosmic space in Vavryčuk (2018) can be used as a reliable reference.

4 SUMMARY AND DISCUSSION

●1. Observations have affirmed that today in the universe most gases still exist in the form of high temperature ionized gases and diffused in space to form cosmic plasma. Only because in the ΛCDM model, on theoretical grounds, it is difficult to see how there could be much mass in void plasma. The existence of uniform and dilute cosmic plasma has long been neglected by astrophysicists (Wang & McCray 1993; Fukugita et al. 1998; Kaplinghat et al. 2003).

Although the free electron density of dilute cosmic plasma is smaller than that in galaxy clusters, along the line of sight, in local space in the dilute cosmic plasma, the total free electron number is much larger than the total number in any galaxy cluster along the line of sight. According to the famous Sunyaev-Zeldovich (S-Z) effect, if the CMBR comes from the early universe, the spectral distortion caused by cosmic plasma should be much more serious than the S-Z effect caused by any galaxy cluster. In this case, CMBR cannot be a perfect blackbody spectrum.

•2. Though the famous S-Z effect considers the interactions between low frequency photons and free electrons in hot plasma, the interactions are simplified as a simple sum of interactions between a low frequency photon and a free electron. Therefore, it can be utilized to explain some effects in astrophysics. However, it is hard to apply the simplified theory to explain some other important effects in astrophysics caused by interactions between low frequency photons and free electrons in hot plasma. For example, according to “Physics of Fully Ionized Gases” (Spitzer 1962), low frequency radiation is easier than high frequency radiation to be absorbed and re-emitted by diluted plasma. According to Equations (2) and (3), the existence of various positively charged particles (ions) in the plasma plays an important role in these effects.

Due to the high order interactions between the photons and free electrons in high temperature cosmic plasma, a large amount of low frequency radiation will be produced in cosmic space. Finally, after a large amount of high order interactions between the photons and free electrons in the cosmic plasma, the cosmic radiation energy density will be mainly concentrated in the low frequency band. The low frequency photons are easily absorbed and re-emitted by diluted plasma. Therefore, in the large local cosmic space, which is filled with dilute high temperature cosmic plasma, low frequency radiation can reach thermal equilibrium with dilute high temperature cosmic plasma, and the temperature of the thermal equilibrium can be low. The temperature of the thermal equilibrium is determined by the radiation energy density according to the Stefan-Boltzmann law. The spectrum of radiation follows that of a blackbody spectrum with a low temperature (Eddington 1926).

•3. Due to the huge Hubble redshift ($\sim$1000, please refer to Peebles et al. 2000; Peebles & Ratra 2003), photons that come from the early universe have become low frequency photons. They are easily absorbed and re-emitted by diluted plasma in the local cosmic space. Therefore, the CMBR cannot come from the early hot universe directly; the CMBR can only be the product of thermal equilibrium of local cosmic space. However, radiation from the early hot universe can contribute its energy to the radiation energy density in local cosmic space.

•4. The temperature of the CMBR produced in local cosmic space can be determined by estimation of the radiation energy density in the local cosmic space. The estimated radiation energy density in local cosmic space in Vavryčuk (2018) can be regarded as a reliable reference.

•5. Due to the effective linear absorption coefficient being $\kappa'_\nu \propto N_e N_I$, the temperature of the radiation field in local cosmic space will fluctuate with fluctuation of the plasma density.

5 CONCLUSION

Because the effective linear absorption coefficient in plasma is proportional to ν^{-3}, it is reasonable to believe that for low frequency photons, the huge local cosmic space, filled with dilute plasma, can be viewed as a blackbody. Due to the huge Hubble redshift ($\sim$1000 Peebles et al. 2000; Peebles & Ratra 2003), high frequency photons of thermal radiation from the early hot universe already became low frequency photons and cannot pass through the dilute plasma in local cosmic space freely. Therefore, observed CMBR cannot come from the early hot universe directly. Observed CMBR can only be the product of thermal equilibrium between the radiation and plasma in local cosmic space.

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