A Magnetic-Monopole-Based Mechanism to the formation of the Hot Big Bang Modeled Universe

Qiu-He Peng and Jing-Jing Liu

1 Department of Astronomy, Nanjing University, Nanjing, Jiangsu 210000, China
2 College of Marine Science and Technology, Hainan Tropical Ocean University, Sanya, Hainan 572022, China
liujingjing68@126.com

Chi-Kang Chou
3 National Astronomical Observatory, Chinese Academy of Sciences, Beijing, 100000, China

Received (Day Month Year)
Revised (Day Month Year)

There are some particle physics theories that go beyond the so-called "standard cosmological model" to predict the existence of magnetic monopoles (MMs). The discovery of magnetic monopoles would be an incredible breakthrough in high-energy physics. The existence of MMs in the early Universe has been speculated and anticipated from Grand Unified Theory. If MMs exist, the inverse powers of the unification mass will not suppressed the baryon number violating effects of grand unified gauge theories. Therefore, MM catalyzing nucleon decay is a typical strong interaction. This phenomenon is due to the boundary conditions that must be imposed on the core of MM fermion fields. We present a possible mechanism to explain the formation of the Hot Big Bang Cosmology. The main ingredient in our model is nucleon decay catalyzed by magnetic monopoles (i.e., the Rubakov-Callan effect). It is shown that Hot Big Bang developed naturally, because the luminosity due to the Rubakov-Callan effect is much greater than the Eddington luminosity (i.e., $L_m > 10^4 L_{Edd}$).

Keywords: Cosmology; Rubakov-Callan effect; Magnetic Monopole.

PACS Nos.: 97.60.Bw, 26.30.Jk, 23.40.-s.

1. Introduction

On the standard model of the Hot Big Bang Cosmology, the early Universe is depicted by extrapolating back to a hot and dense initial state of Planck length and

*This work was supported in part by the National Natural Science Foundation of China under grants 11565020, 11965010, and the Counterpart Foundation of Sanya under grant 2016PT43, 2019PT76 the Special Foundation of Science and Technology Cooperation for Advanced Academy and Regional of Sanya under grant 2016YD28, the Scientific Research Starting Foundation for 515 Talented Project of Hainan Tropical Ocean University under grant RHDRC201701, and the Natural Science Foundation of Hainan Province of China under grant 118MS071, 2019RC239.
†Corresponding author.
Planck time derived according to the uncertainty principle. In 1992, the origin of the Big Bang was discussed by Thakur(1992). They developed a singularity-free model of the universe within the framework of the Friedmann-Lemaitre-Robertson-Walker cosmology. Then the Big Bang model on its origin and development have been investigated by Alpher(1999). The standard cosmological model and some related issues have been discussed by some astronomers and scholars(e.g., 3-7). Recently, a macroscopic view of the standard cosmological model was given by Ignat’ev et al., (2018). Khlopov (2018) also discussed the standard models of particle physics and cosmology. Their results showed that the modern Standard cosmological model of inflationary Universe and baryosynthesis is deeply involved particle theory beyond the Standard model. Brian.(2018), also redefined the standard model of cosmology. However, the formation of the Hot Big Bang itself has not been investigated. In this paper, we will present a possible mechanism to explain the formation of the Hot Big Bang Cosmology. The main ingredient in our model is nucleon decay catalyzed by magnetic monopoles (MMs).

The experiment tells us that the magnetic north and south poles cannot be divided into magnetic monopoles (MMs), i.e., isolated magnetic charges. Petrus (1269) discussed this issue in the 13-th century. There are strong theoretical reasons to believe that MMs should exist. Hooft and Polyakov (1974) showed that MMs are an inevitable prediction of Grand Unified Theory of elementary particle interactions, and the same is generally true for more modern theories of everything, such as superstring theory. Therefore, it would be an incredible breakthrough if people could find a MM particle in high-energy physics.

Although magnetic monopole has not been discovered, it plays an important role in the theoretical research of high energy physics. For example, magnetic monopoles provide powerful theoretical tools for studying properties of strongly coupled non-Abelian canonical field theory, such as quantum chromodynamics, and in particular its supersymmetric variants.

Although MMs have not been found, they play an important role in theoretical research of high-energy physics. For example, the MMs give powerful theoretical tools for exploring properties of strongly coupled non-Abelian gauge field theory, such as quantum chromodynamics, and in particular its supersymmetric variants. Therefore, the study MMs and its related problems (e.g., search for MMs) is a hot topic in the field of high-energy physics and astrophysics.

The existence of MMs in the early Universe has been speculated and anticipated from grand unification. The goal of such theories is to unity the strong, weak, and electromagnetic interaction in terms of quarks and leptons within the framework of a gauge field theory based on non-Abelian symmetry group. These theories make two startling predictions: namely, the instability of the proton, and the existence of stable and heavy MMs.

Most of physicists believe that the existence of MMs had been ruled out by experiments. However, experiments only indicated that the flux of MMs on the Earth is too low to be observed. We summarize some predictions from the model of super-
massive object with MMs, which match up with recent astronomical observations quantitatively. They may signal the presence of MMs in supermassive objects, such as one at the Galactic Center. In 2001, we discussed ultra-high-energy cosmic rays from supermassive objects with MMs, as well as high-energy radiation from quasars, active galactic nuclei, and the Galactic Center with MMs. Very recently, some issue on MMs were illustrated by our group (e.g., [22, 27, 28]). We discussed a series of important but puzzling physical mechanisms concerning the energy source, various kinds of core-collapse supernovae explosion mechanisms during central gravitational collapse in astrophysics. The puzzles of possible association of γ-ray burst with gravitational wave perturbation, the heat source for the molten interior of the core of the Earth and the cooling of white dwarfs were also investigated. We have made use of the estimations for the space flux of MMs and nucleon decay induced by MMs, called the Rubakov-Callen (RC) effect, to obtain the luminosity due to the RC effect and also investigated other problems related to supernova explosion (e.g., [30–40, 40–42]).

Rubakov (1981, 1988) and Callan(1983) [43–45] have shown that the fermion wave function is literally sucked into the core because of the potential between the s-wave of a fermion and that of a MM. Due to sucking of the s-wave, the catalysis cross section saturates the uncertainty bound: \( \langle \sigma v \rangle \approx E_F^{-2} \), where \( E_F \) is the Fermi energy. The actual catalysis section depends on the Grand Unified Theory. In SU(5), we know \( M + m \rightarrow M + \pi^- + e^+ \) or \( M + p \rightarrow M + \pi^0 + e^+ \). It is then expected that MM catalysis has great potential to produce astrophysical fireworks, and applications of the \( R - C \) effect to quasars and active galactic nuclei have also made remarkable achievements [27, 46, 47, 67].

In this paper, we will use the R-C effect to explain the formation of the Hot Big Bang. We want to propose a possible mechanism to describe how the Big Bang developed. The main ingredient in our model is the MMs catalyzing nucleon decay with strong cross section of interaction.

2. The Astronomical evidence for both the absence of black holes and the existence of MMs at our Galactic Center

Eatough et al.(2003) reported a measurement of a strong magnetic field around the supermassive black hole at the centre of the Galaxy [49]. We know that at \( r = 0.12 \) pc near the Galactic center (hereafter GC), the minimum value of outward radial magnetic field is \( B > 8 \) mG, which is larger than the Alphen critical value \( B_{\text{Alphen}} \sim 1.3 \) mG. Due to the exists of the strong radial magnetic field, the accretion (plasma) disk is prevented from approaching to the GC, and may not enter in the neighborhood of the GC. As a result, the radiations observed from the accretion disk gas around the black hole of the GC are hardly to emit. It is a difficult situation of the standard accretion disk model of black holes in the GC [27, 49].

Considering the RC effect, the MMs may catalyze nucleon decay, which can be used as an energy source. However, this dilemma in the GC may be naturally
solved by our super-massive star model with MMs. At $r = 0.12$ pc near the GC, the observed outward radial magnetic field strength (i.e., $B > 8$ mG) is in good agreement with our theoretical predictions.

In our model, at least three predictions were quantitatively confirmed by subsequent observations. Firstly, the GC emits large numbers of positrons at a rate about $10^{43} e^+/\text{sec}$ or so. This is consistent with the high-energy astrophysical observations. Secondly, at $r = 0.12$ pc of the super-massive object core, the radial magnetic field strength produced by the MMs condensed is about $B \approx (10 \sim 50)$ mG, which is consistent with the lower limit of the magnetic field strength observed. Finally, for the super-massive stellar object at the GC, we predicted their surface temperatures to be about $123$ K, corresponding to a frequency of $10^{13}$ Hz (at the sub-millimeter range). This frequency predicted is quite close to the observed value (i.e., $10^{12}$ Hz).

The implications of the facts that these predictions were quantitatively confirmed by astronomical observations are: 1) There is no supermassive black hole at the center of our galaxy; 2) These are the evidences for the existence of MMs.

We would like to declare that the astronomical observations are really the physical experiments in cosmic space, although MMs have not been detected by the physicists up to now.

3. An united model of supernova explosion driven by MMs

Regarding the RC effect as a source of energy, MMs can catalyze the decay of nucleons. Therefore we propose a unified model supernova explosions caused by MMs. The main idea is as follows. Taking the nucleon decay induced by MMs in particle physics and making estimation for the space flux of MMs, we can obtain a formula to estimate the luminosity due to the RC effect.

According to the RC luminosity formula, we discuss the issue that the supernova explosion would develop just when its luminosity is much greater than the Eddington’s luminosity due to RC effect in the star. We present a unified treatment for all kinds of core-collapse supernovae (e.g., SNII, SNIb, SNIc, Ultra-luminous supernova (ULSN)). We will also discuss the gamma-ray burst generation mechanism in detail in our paper. Those weak or/and dark explosions of supernova will be also naturally expressed by our idea due to the fact that its RC luminosity is just greater than the Eddington’s luminosity of the star.

The very important result is that no matter how massive the supernova is, a neutron star (NS) will be formed after supernova explosion due to the $R - C$ effect by a small amount MMs remained in the new born NS. However, this theory does not apply to black holes.

Besides, both the heat source for the core of the Earth and the energy source needed for the white dwarf interior are also solved by the same treatment using the RC effect. The possible association of the short gamma-ray burst detected by the Fermi gamma-ray Burst Monitoring Satellite (GBM) and the LIGO gravitational
wave event (GW150914) may be reasonably explained by our unified model. In the present paper, based on the same idea, we propose further a model of hot big bang cosmology driven by MMs without initial singularity of the Universe.

4. The standard cosmology

A most fundamental feature of the standard cosmology is the expansion of the Universe. The expansion, discovered in the 1920’s, led to Hubble’s law and played a fundamental role in observational cosmology. Almost all the galaxy spectra measured by observers in the world are redshifted, illustrating the universality of the expansion with redshift $z$. For a smaller distance, we can also interpret it as a simple Doppler effect by the redshift $z$. Thus, we have

$$z = \frac{\lambda - \lambda_0}{\lambda_0} = \frac{v}{c},$$

(1)

where the speed of light is much larger than the secession velocity of galaxies. $\lambda_0$ and $\lambda$ are the original radiation wavelength and the observed wavelength, respectively. However, for a larger distance, Eq.(1) must be replaced by

$$1 + z = \frac{\sqrt{1 + v/c}}{\sqrt{1 - v/c}}.$$  

(2)

For large recession velocities of the distant galaxies, the Hubble’s law may be written as

$$v = H d.$$  

(3)

In a homogeneous isotropic Universe, the expansion rate is constant in time and the recession time of the distant galaxies may be obtained as

$$t = \frac{d}{v} = \frac{1}{H_0} \approx 138 \text{ (billion year)},$$

(4)

where $0.4 \leq h \leq 1$, $H_0 \approx 65\text{kms}^{-1}\text{Mpc}^{-1}$, and $H_0^{-1}$ is the age of the Universe. The redshift of galaxies varies linearly with the distance for $z << 1$. In addition, the homogeneous cosmology predicts the existence of the black-body cosmic microwave background radiation and the abundances of helium and the primordial nucleosynthesis of other elements. These are the great achievements of the Lemaitre model and the pioneering theories of the Hot Big Bang.

Now we describe briefly some of the relevant physics for Universe expansion. The radius of the expanding Universe $R$ satisfies $dR(t)/dt > 0$. For homogeneous universe expansion, we have $\rho R^3 =$constant, and $TR =$constant, where $\rho$ denotes the matter density, $T$ is the background temperature. The radiation energy density is denoted by $aT^4$, where $a$ is the Stephen Boltzmann constant, and the rest mass energy density is denoted by $\rho c^2$, then the ratio is written as

$$\Gamma = \frac{aT^4}{\rho c^2}.$$  

(5)
We note that the early Universe could be dominated by matter or radiation. The matter in the Universe consists of both ordinary visible matter that can be detected and dark matter that is invisible. The radiation is mainly comes from the cosmic background microwave radiation. For convenience, we present the following relevant data at the present time

$$\rho_0^M = (0.3 - 0.4) \rho_c = (0.3 - 0.4) \times 10^{-29} \text{ g cm}^{-3},$$  \hspace{1cm} (6)

$$E_0^M = \rho_0^M c^2 = (0.27 - 0.36) \times 10^{-8} \text{ erg cm}^{-3},$$  \hspace{1cm} (7)

$$E_r = aT^4, \quad T_R^0 = 2.7 K, \quad a = 7.56 \times 10^{-15} \text{ erg cm}^{-3}K^{-4},$$  \hspace{1cm} (8)

$$E_r^0 = 4.0 \times 10^{-13} \text{ erg cm}^{-3}, \quad E_r^0 << E_0^M. \quad (9)$$

where the superscript (0) represents the present moment, $\rho_0^M$ is the average density of matter in the Universe at the present moment, $\rho_c$ is the critical density of the corresponding material at the boundary between the closed Universe model and the open Universe model, $E_0^M$ represents the average energy density of matter in the Universe at the present moment, $E_r$ represents the energy density of the radiation field in the Universe, $T_R^0$ represents the temperature of the cosmic radiation field (the cosmic background), and $a$ is the radiation constant.

We note that both the radiation energy density and the matter density decrease with the time during the universe expansion. At the same time, radiation from galaxy spectra are all redshifted during the expansion. The density of radiant energy decays much faster with time than the density of matter, and then radiation is dominated in the early Universe. About several thousand years after the creation of the Universe, it was the dividing line between the radiation-dominated and material-dominated ages. At the dividing line, we have $\Gamma = 1, aT^4 = \rho m c^2$.

Our whole universe was once in a very small volume, higher material density and temperature. When the temperature is higher than $10^{12} K$ or more, the universe was produced by Hot Big Bang. This is from astronomical observations (now the universe is expanding), we obtain that the early universe must be in the hot and dense state. However, people don’t know realistically the physical reason of early universe by hot big bang (i.e., the outbreak mechanism of early universe). The physical reason of the Hot Big Bang theory of the Universe has never been discussed up to now really.

There are many speculations about the Hot Big Bang. For example, when the time extrapolates from the present moment back to the initial singularity ($t = 0$), we have $R \rightarrow 0, \rho \rightarrow \infty, T \rightarrow \infty$, so the Universe will arise singularity. These are very interesting theoretical speculations such as the baby Universe, and the Universe wave function proposed by Hawking based on the uncertainty principle, but the physical reason for the formation of the Hot Big Bang itself has never been investigated. Using the $R - C$ effect we will propose a possible mechanism for the Hot Big Bang in the next section.
5. An oscillating model of the Universe

In history, some oscillating Universe models had been proposed, but the physical reason of the Universe expansion during the oscillation has not been discussed. The continuum and continuum-particle models for both oscillating and ever-expanding model universes are considered, with the consequences of various interactions between the components being traced and the connection with the irreversibility of oscillating models noted by Landsberg & Reeves. Similar to the models above, our model of the Universe is also the oscillating model between the expansion phase due to the Hot Big Bang and the contracting phase due to the gravitational attraction, but we propose the physical mechanism for the Hot Big Bang of the Universe in this paper.

At the present time $t_0$, the radius of the Universe is $R_0$, baryon density $\rho_0$, and the cosmic background temperature $T_0$, then at a later time $t$ during the contracting phase, the corresponding radius of the Universe $R$, the baryon density $\rho$, and the cosmic background temperature $T$ are given by

$$\frac{R}{R_0} = \left(\frac{\rho}{\rho_0}\right)^{-1/3},$$  \hspace{1cm} (10)

$$\frac{T}{T_0} = \left(\frac{R}{R_0}\right)^{-1} = \left(\frac{\rho}{\rho_0}\right)^{1/3}. \hspace{1cm} (11)$$

It is generally estimated and believed that there are $2 \times 10^{11}$ galaxies. Every galaxy is roughly the size of over Milky galaxy with $10^{11}$ stars, then the total number of stars in the Universe is about $2 \times 10^{22} - 4 \times 10^{22}$. The mass of the sun is $2 \times 10^{33} \text{g}$, then the total mass of the Universe of the baryons is $2.0 \times 10^{56} \text{g}$ and the total number of the baryons is $10^{80}$. If the content of the magnetic monopoles of the same polarity contained in the Universe is $\zeta \equiv N_m/N_B = 10^{-20} (\zeta/\zeta_{\text{up}})$, here $N_m$ and $N_B$ are the number of magnetic monopole and baryons, respectively. Here $\zeta_{\text{up}}$ is the Parker upper limit $\zeta_{\text{up}} \approx 10^{-20}$. So the total number of the magnetic monopoles of the same polarity contained in the Universe may be estimated to be $N_m = 10^{61}(\zeta/\zeta_{\text{up}})$. The magnetic monopoles in the high temperature baryon plasma are strongly compressed and moving very fast toward the center via electromagnetic interaction.

The $R - C$ luminosity produced due to catalyzing nucleon decay by the MMs is given as

$$L_M = \frac{4\pi}{3} r_c^3 n_m n_B (\sigma v_T) m_B c^2 = N_m n_B (\sigma v_T) m_B c^2,$$

$$= 10^{75} \left(\frac{\sigma_{\text{nucl}}}{10^{30} \text{cm}^2}\right) \left(\frac{\zeta}{\zeta_{\text{up}}}\right) \left(\frac{\sigma_{\text{em}}(RC)}{10^{-30} \text{cm}^2}\right) \text{ ergs/s}. \hspace{1cm} (12)$$

When the total mass of the Universe is compressed into supermassive body, the corresponding Eddington luminosity is given by

$$L_{\text{Edd}} = 10^{38} \left(\frac{M}{M_\odot}\right) \approx 10^{61} \text{ ergs/s} \hspace{1cm} (13)$$
If the whole Universe is compressed such that
\[
\left( \frac{n_B}{n_{\text{nuc}}} \right) \left( \frac{\zeta}{\zeta_{\text{up}}} \right) \left( \frac{\sigma(\text{RC})}{10^{-30} \text{cm}^2} \right) > 10^{-10},
\]
i.e.,
\[
\left( \frac{n_B}{n_{\text{nuc}}} \right) > 10^{-10} \left[ \left( \frac{\zeta}{\zeta_{\text{up}}} \right) \left( \frac{\sigma(\text{RC})}{10^{-30} \text{cm}^2} \right) \right]^{-1},
\]
Then \( L_m > 10^4 L_{\text{Edd}} \) and the whole Universe must violently explode outward leading naturally to the Hot Big Bang. From Eq.(10), we may estimate the radius of the Universe at the Hot Big Bang to be
\[
R \approx 3 \times 10^{-12} R_0 \left[ \left( \frac{\zeta}{\zeta_{\text{up}}} \right) \left( \frac{\sigma(\text{RC})}{10^{-30} \text{cm}^2} \right) \right]^{1/3},
\]
i.e.,
\[
R \approx 3 \times 10^{-2} \left[ \left( \frac{\zeta}{\zeta_{\text{up}}} \right) \left( \frac{\sigma(\text{RC})}{10^{-30} \text{cm}^2} \right) \right]^{1/3} \text{ pc},
\]
where we have used the present radius of the Universe \( R_0 \approx 10^{10} \text{ pc} \) and the present average baryon density given from Eq.(6). The temperature at the Hot Big Bang also can be estimated to be
\[
\frac{T}{T_0} \approx 3 \times 10^{11} \left[ \left( \frac{\zeta}{\zeta_{\text{up}}} \right) \left( \frac{\sigma(\text{RC})}{10^{-30} \text{cm}^2} \right) \right]^{-1/3},
\]
where \( T_0 = 2.7 \text{ K} \).

In the traditional standard Hot Big Bang Cosmology, it is extrapolated back to the initial singularity of the Universe. This is done purely by theoretical speculation. Our model of the Hot Big Bang is obtained in terms of the Rubakov-Callan luminosity and no other theoretical arguments or anticipations are required. In our model, the expansion phase may finally end followed by the contraction phase due to gravitational attraction.

6. Summary and Discussions

In this paper, we have used the \( R-C \) effect to explain the formation of the Hot Big Bang and presented a possible mechanism that can delineate the details of how the Big Bang developed. The main ingredient in our description of the Hot Big Bang is MMs catalyzing nucleon decay with strong interaction cross section. Our results showed that whether the Universe is in an accelerating expansion phase needs further discussion. On the other hand, the direct observational evidence on the dark energy is also lost by the observational error analyses of SNIa. Our model of the Hot Big Bang is obtained in terms of the Rubakov-Callan luminosity and no other theoretical arguments or anticipation are required. In our model, the expansion phase may finally end followed by the contraction phase due to gravitational attraction.

The popular view of indirect observational evidence for the accelerating expansion of the universe comes from the comparison of theoretical simulations of the
accelerating expansion of the universe and the deviation observation of the isotropy of the cosmic microwave background temperature using WMAP satellite observation data. The popular idea of indirect observational evidence for the accelerating expansion of the Universe comes from the comparison of theoretical simulations of the Universe accelerating expansion and the Universe with the observational data of WMAP satellite for the deviation observation of the isotropy of the cosmic microwave background temperature using WMAP satellite observation data. In recent years, the results of some research groups are in line with our ideas. For instance, Nielsen et al. (2016) analyzed recent observations of a group SNIa. Their conclusions did not support the accelerating expansion of the Universe. More recently, David et al. (2017) also did not support the idea of the accelerating expansion of the Universe.

As is well known, the 2011 Nobel prize awarded to three astronomers (i.e., Riess, Schmist and Perlmutter), because they proposed the accelerating expansion of the Universe, which was confirmed by astronomical observations. The method of this paper is based on Guy et al. (2007). All these researches are based on the SNIa standard candle assumption. In fact, although the average error provided by the UNION2 was only 0.16 m because 685 SNIa completed big samples. We used the observational data of the 685 SNIa from UNION2 to reexamine and analyze the average error and found that the average total observational error of SNIa is obviously greater than 0.55 m, so we can not decide whether the Universe is accelerating expansion or not. In our oscillating model of the Universe, the expanding matter is gradually decelerating during the Universe expansion process. When the kinetic energy of the expanding matter is lower than the potential energy of the whole Universe relative to the expanding matter, the Universe expansion contracts.

Acknowledgments
We would like to thank Prof. Daniel Wang, Prof. Y.F. Huang, Prof. P.F. Chen and Prof. J. L. Han for their help to inform us some new information of observations. This work was supported in part by the National Natural Science Foundation of China under grants 11565020, 11965010, and the Counterpart Foundation of Sanya under grant 2016PT43, and 2019PT76, the Special Foundation of Science and Technology Cooperation for Advanced Academy and Regional of Sanya under grant 2016YD28, the Scientific Research Starting Foundation for 515 Talented Project of Hainan Tropical Ocean University under grant RHDRC201701, and the Natural Science Foundation of Hainan Province of China under grant 118MS071.

References
1. R. K. Thakur., Ap&SS., 190, 281(1992)
2. R. A. Alpher., Odessa Astronomical Publications, 12, 10(1999)
3. A. Mercik, S. Mercik., Physics, 04, 4024(2006)
4. P. Jain., S. Mitra., MPLA, **25**, 167(2010)
5. M. Shaposhnikov, PPN, **41**, 862(2010)
6. M. Bellini, PhLB, **709**, 309(2012)
7. D. G. Figueroa., C. T. Byrnes., PhLB, **767**, 272(2017)
8. Y. G. Ignat’ev, D. Y. Ignatyev., A. R. Samigullina., GrCo., **24**, 1489(2018)
9. M. Y. Khlopov., , arXiv181109222(2018)
10. A. R. Brian., Redefining Standard Model Cosmology, 2018, Published by Intech Open, London, United Kingdom, ISBN: 978-1-83880-864-8
11. P. Peregrinus., The Letter Of Petrus Peregrinus On The Magnet, A.D. 1269.
12. G. ’t Hooft., Nucl.Phys. B., **79**, 276(1974)
13. A. M. Polyakov., JETP Lett., **20**, 194(1974)
14. M. Duff., R. R. Khuri., & J. Lu., Phys.Rept. **259**, 213(1995)
15. M. Shifman., & A. Yung., Rev.Mod.Phys. **79**, 1139(2007)
16. R. Abbasi., Y. Abdou., M. Ackermann., et al., PhRvD, **87**, 2001(2013)
17. N. Vandewalle., S. Dorbolo., NJPh., **16**, 3050(2014)
18. T. Fuji., A. C.Pierre., ICRC., **34**, 319(2015)
19. A. Aab., P. Abreu., M. Aglietta, PhRvD., **94**, 2002(2016)
20. A. Pollmann., EPJWC., **168**, 04010(2018)
21. D. Bazeia., M. A. Marques., R. Menezes., PhRvD., **97**, 5024(2018)
22. Q. H. Peng., J.J. Liu., Chih-Kang. Chou., IAUSS., **337**, 390(2018)
23. S. Nakosai., S. Onoda., JPSJ., **88**, 3701(2019)
24. M. Frank., A. Antoshkin., C. Dukes., et al., E.ICRC., **36**, 888(2019)
25. Q. H. Peng, C. K. Chou, ASPC, **241**, 133(2001a)
26. Q. H. Peng, C. K. Chou, ApJ, **551**, 23(2001b)
27. Q. H. Peng, J. J. Liu, Z. Q. Ma, NewA., **57**, 59(2017a)
28. Q. H. Peng, J. J. Liu, C. K. Chou, Ap&SS, **362**, 222(2017b)
29. Qiuhe Peng,Yiming Hu, Kun Wang, et al., Journal of Astrophysics and Astronomy, **35**, 253(2014)
30. J. J. Liu, MNRAS., **433**, 1108(2013)
31. J. J. Liu, MNRAS., **438**, 390(2014)
32. J. J. Liu, et al., ApJS, **224**, 29(2016a)
33. J. J. Liu, et al., RAA, **16**, 83(2016b)
34. J. J. Liu, et al., RAA, **16**, 174(2016c)
35. J. J. Liu, et al., RAA, **17**, 107, eprint [arXiv:1707.03504](2017a)
36. J. J. Liu, et al., ChPhC, **41**, 510(2017b)
37. J. J. Liu, et al., RAA, **18**, 8, eprint [arXiv:1711.01955](2018a)
38. J. J. Liu, et al., EPJC, **78**, 84(2018b)
39. J. J. Liu, et al., Ap&SS, **363**, 185(2018c)
40. Z. F. Gao., X. J. Zhao., D. L. Song., N. Wang., Astron. Nachr., **335**, 653(2014)
41. Z. F. Gao., N. Wang., Y. Xu., et al., Astron. Nachr., **336**, 866(2015)
42. Z. F. Gao., N. Wang , H. Shan., X. D. Li., et al., ApJ, **849**, 19(2017a)
43. V. A. Rubakov, Soviet Journal of Experimental and Theoretical Physics Letters., **33**, 644(1981)
44. V. A. Rubakov, Reports on Progress in Physics., **51**, 189(1988)
45. C. Callan, Nucl. Phys. B., **212**, 391(1983)
46. Q. H. Peng, C. K. Chou, Astrophys. J., **551**, 23(2001a)
47. Q. H. Peng, C. K. Chou, ASPC., **241**, 133(2001b)
48. Q. H. Peng, J. J. Liu, C. K. Chou, Ap&SS., **361**, 388(2016)
49. R. P. Eatough, H. Falcke, R.Karuppusamy, Natrue, 501, 391( 2013)
50. J. Knödlseder, V. Lonjou, P.Jean, et al., A&A., **411**, 457(2003)
51. H. Falcke, S. B. Markoff, CQGra., 30, 4003(2013)
52. G. Lemaître., ASSB., 47, 49L(1927)
53. G. Gamow, & M. F. R., The Scientific Monthly., 51, 373(1940)
54. G. Gamow, Physical Review., 70, 572(1946)
55. G. Gamow, Nature., 162, 680(1948)
56. G. Gamow, Vistas in Astronomy., 2, 1726(1956)
57. R. A. Alpher, R. Herman, Nature., 162, 774(1948)
58. R. A. Alpher, R. Herman, Gamow, G. A., Physical Review., 74, 1198(1948)
59. R. A. Alpher, R. C. Herman, Physical Review., 75, 1089(1949)
60. R. A. Alpher, J. W. Follin, R. C. Herman, Physical Review., 92, 1347(1953)
61. P. T. Landsberg, G. A. Reeves., Astrophy. J., 162, 432(1982)
62. E. N. Parker, Astrophy. J., 160, 383(1970)
63. S. Weinberg, J. Silk, BOOK REVIEW: Cosmology, Classical and Quantum Gravity,
    (Oxford University Press, 2008)
64. J. T. Niehen., A. Guffanti., S. Sarkar., Nature Scientific Reports, 6, 35596(2016)
65. C. David F., Open Astronomy., 26, 111(2017)
66. Q. H. Peng, Y. M. Hu, K. Wang., et al., JApA, 35, 253(2014)
67. Q. H. Peng, J. Zhang, Z. Q. Luo, Y. Liang, JPhCS., 665, 2073(2016)
mean dispersion