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New Insight into Magnetic Monopoles in Astrophysical Application

Qiuhe Peng[1], Jingjing Liu[2], Zheng Li[3]

[1]Department of Astronomy, Nanjing University, Nanjing, China
[2]College of Science, Hainan Tropical Ocean University, Sanya, China
[3]Xinjiang Astronomical Observatory, Chinese Academy of Sciences, Xinjiang, China
Email: syjjliu68@hntou.edu.cn

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Abstract

In this paper, we mainly review our previous works on a magnetic-monopole toy model, in which the energy resources come from nucleon decay catalyzed by magnetic monopoles. Utilizing this unified model, we have explained various supernova explosion and gamma ray bursts, extra heat at the centers of white dwarfs and the earth. The unusually strong radial magnetic field near the Galactic Center (GC) is quantitatively consistent with our theoretical prediction in 2001. It may be strong astronomical observational evidence of the presence of magnetic monopoles predicted by particle physics. Using the masses of 100,000 quasars observed by SLOAN with various red-shifts due to the black hole, according to the popular black hole accretion model, we estimate the initial mass of quasars when they born in early universe. It is found that most low-red-shifting quasars have an initial mass of negative or very small values. However, based on our proposed model of super massive stars with magnetic monopoles, the statistical distribution of the initial mass for these quasars should be a reasonable Gaussian distribution. This suggests that the modern model of black holes in the quasars and active galactic nucleus may be unreasonable.

Keywords

Supernovae, Cosmology, Cosmic Microwave Background

1. Introduction

For more than half a century, the black-hole models have been inundated in many fields of astrophysical research [1] [2] [3] [4]. A black hole is defined by the fact that light cannot escape from it. Its only characteristics are the singularity and horizon, where the latter was calculated as early as 1796 by Laplace, who took up an idea of Mitchell of 1783 and called these hypothetical stars "corps obscures". A black hole can be formed by the collapse of a rotating object with angular momentum, forming a Kerr black hole. In addition, the theory of black holes has been enriched and matured by a large number of scientists, such as Einstein, Schwarzschild, Chandrasekhar, Oppenheimer, Wheeler, Hawking and so on, and has reached a consensus in the scientific community. Cygnus X-1 is believed to be the first black hole ever discovered. On April 10, 2019, the first image of a black hole was finally taken. It shows the black hole at the center of galaxy M87, 55 million light-years away, with 6.5 billion solar masses ($M_\odot$). Black holes are invisible because they have an event horizon, a spherical interface called the Schwarzschild radius $R_s = 2Gm/c^2 = 3\ (m/M_\odot)$ km, at which the accreted material emits visible light and powerful bursts. The largest black hole ever discovered is the one at the center of the TON618 quasar, which is $6.6 \times 10^{10} M_\odot$.

According to the existing internationally popular theory of stellar evolution, massive stars with a mass greater than $30M_\odot$ experience long main sequence hydrogen burning stage, red giant star helium burning stage, and then rapidly go through carbon burning, neon burning, oxygen burning, and silicon burning stages. For a massive star with a mass greater than $50M_\odot$, it is possible to enter the oxygen burning phase directly after the helium burning phase.

According to prevailing theories, huge massive black holes may exist at the core of active galaxies nucleus (AGNs, $m > 10^6 M_\odot$). There may be an intermediary mass black hole at the center of some galaxy clusters ($10^3 M_\odot < m < 10^5 M_\odot$). There may also be black holes with star-level mass in some close binary stars ($5M_\odot < m < 100M_\odot$).

The black hole itself is not glowing and cannot be directly observed. However, black holes have a very strong gravitational effect on their outer matter. Attracted by the powerful gravity of a black hole, an accretion disk that rotates around the black hole is approaches the black hole. When matter falls near a black hole, gravitational potential energy is converted to kinetic energy, which is then converted to X-ray radiation by generating thermal energy through collisions between particles in dense matter, or it can be converted into particle momentum by gravitational potential energy, the charged particles moving at high speed in the magnetic field emit synchronous cyclic radiation. Astronomers observe and judge the existence of a black hole and explore its properties by accepting and studying the radiation.

To date, the following astronomical observations have been widely considered to be the most irrefutable and reliable evidence of the existence of black holes. Based on observations and reliable calculations of the large number of star motion orbits orbiting the galactic center (GC), it is determined that the mass of the huge-massive object located at the GC is approximately $4 \times 10^6 M_\odot$. According to the currently popular theory of stellar evolution, such a stable super-massive object cannot be another known object, only a black hole. So far, according to all the consensus theories of physics, except for a new energy source from nucleon decay catalyzed by magnetic monopoles which were proposed by particle physicists in 1980s, there is no physical factor in nature that prevents massive stars and super-massive objects from collapsing into an extremely dense state with a radius of less than (or equal to) the Schwarzschild radius after the end of thermonuclear evolution. This is a sufficient condition for the formation of the black hole.

There could exist magnetically-charged objects, including magnetic black holes with large magnetic charges. Black holes in general relativity have a curvature singularity at $r = 0$ where the theory itself breaks down. The rotating black hole solution in GR *i.e.* the Kerr scenario turns out to be most relevant. By using modifications to Einstein gravity in light of non-linear electrodynamics. Bardeen proposed a black hole scenario in light of astrophysical observations, which evades the singularity at $r = 0$. The Bardeen black hole model is characterized by the monopole charge parameter g and the spin a [5] [6].

Starting from the overweight magnetic monopole proposed in the 1970s in particle physics, we can use the new idea that magnetic monopoles can catalyze nucleon decay into lepton in particle physics (Rubakov-Callan effect, abbreviated as the RC effect) [7] [8] [9] [10] as the main energy source for quasars and AGNs. Since 1985, we have proposed massive star models with magnetic monopoles to replace black hole models. In our model, the gravitational effects of a super-massive object at the core of a galaxy are similar to that of a black hole in the region around it. Combined with the RC effect in particle physics, the central singularity of the black hole theory for the general relativity is avoided. It makes the physics theory of nature become completely self-harmonious and harmonious. This article describes our series of exploratory studies since 1985 and some of scientific predictions [11]-[22] that have since been confirmed by astronomical observations. We will describe the various quasars and AGNs models with magnetic monopoles since 1985 and the five theoretical predictions we made in 2001 about the super-massive object model with magnetic monopoles at the GC. We will raise another fatal question about the black hole model of quasars and AGNs.

As proposed by Dirac close to a century ago, the magnetic monopole is a fascinating physical object that could elegantly explain the quantization of electric charges in Nature. Ever since, physicists have been studying magnetic monopoles both from theoretical and experimental directions. On the theory side, especially, the discovery of Polyakov't Hooft monopoles in 1974 [23] has been applied to Grand Unified Theories (GUT) predicting the GUT monopole mass around 10^{17} GeV. For heavier masses above the Planck mass scale, magnetically charged black holes have long been proposed, which can have masses proportional to their magnetic charges [24]. Various experimental methods have been adopted to search for magnetic monopoles, e.g., detecting the quantized jump in magnetic flux when monopoles pass a superconducting quantum interference device [25] and searching for the Cherenkov light generated when the accelerated monopoles pass the large IceCube detector [26] [27]. Magnetic monopoles could also be captured by stars and planets including our Earth, and their annihilations can produce detectable neutrinos and/or heat [28].

As to the magnetic monopole formation mechanism, there are the traditional Drell-Yan (DY) production for magnetic monopoles via quark-pair annihilation through a virtual photon $q\bar{q} \to \gamma^* \to M\bar{M}$, as well as photon fusion $\gamma^*\gamma^* \to M\bar{M}$, proton-pair annihilation $pp \to M\bar{M}$, and collisions of cosmic rays bombarding the atmosphere [29]. Magnetic monopole has a great influence on modern physics, for example, it brings perfect symmetry to electrodynamics. Considering the effect of magnetic monopole, the Maxwell's equations can be written as a covariant form of $\partial_t \tilde{F}^{\mu\nu} = J_m^{\nu}$, and $\partial_t F^{\mu\nu} = J_e^{\nu}$, where $F^{\mu\nu}$ is the electromagnetic tensor, and $\tilde{F}^{\mu\nu}$ is the dual tensor via a symmetry transformation $\tilde{F}^{\mu\nu} = 1/2\,\varepsilon^{\mu\nu\rho\sigma} F_{\rho\sigma}$.

In this review, using the nucleon decay catalyzed by magnetic monopoles as an energy mechanism, we propose a new physical mechanism to drive a core-collapsed supernova explosion, to provide additional energy mechanisms for the high temperature melting state of the Earth's core, and to provide an energy mechanism to explain why white dwarfs stop cooling. Taking the RC effect as the energy source, we also propose a physical reason for driving the Hot Big Bang of the universe.

2. The Significance of Finding Anomalous Strong Radial Magnetic Field near the GC

In 2013, Ref. [30] found a millisecond pulsar near the GC, and reported the detection of an unusually strong radial magnetic field at a distance of about 0.12 pc and an abnormally strong radial magnetic field with a lower limit of 8 mG. This is the most important result we take from this paper. The famous magnetic freezing effect in magneto-hydrodynamics is that when the kinetic energy density of plasma fluid is much lower than the energy density of magnetic field, the magnetic field line will block the passage of plasma fluid. The major conclusion from this unusually strong radial magnetic field is that the accretion disk of the plasma outside of the central region of the Galaxy will be blocked by a strong magnetic field far from the GC (at least $r >$ 0.15 pc) [31] [32] [33].

When the gas and dust flow of the plasma accretion disk do not enter the inner region of the Galaxy (the mass of the huge massive object is $4.6 \times 10^6 M_\odot$), its Schwarzschild radius (Rs) is about 0.1 A.U., and the plasma accretion disk flow is blocked beyond $3 \times 10^5 R_s$. Recently, radiation has been detected that from a range of (5 - 50)R_s away from the GC from the radio wave region to the near infrared, which cannot be produced by the accretion disk material around the GC. Thus, the traditional "massive black hole model" at the GC, which has been popular for half a century, is nonphysical. It does not account for the latest astronomical observations of various radiations from the GC. That is, the GC cannot be a black hole.

In 2019, the international astronomical mainstream and the news media almost reached a climax when they trumpeted the apparent existence of black holes. The researchers from the international team of seven large telescopes were reluctant to cite another paper [34], a statistical analysis of 76 radio galaxies, including M87. The conclusion of the paper is that there may be a strong magnetic field in the galactic center region for these galaxies. A warning that the model of the accretion disk for the black hole may not be suitable is given in the paper. However, the M87 black hole photo does not involve the theory analysis of the question of whether or not it has a strong magnetic field. Of course, we cannot measure its magnetic field directly due to the M87 being too far away. These papers are just theoretical models. It does not serve as definitive observational evidence that the M87 is the black hole.

3. Astronomical Evidence of the Existence of Magnetic Monopoles

A puzzling question is that what is the source of the abnormally strong radial magnetic field ($B > 8$ mG) at a distance of $r = 0.12$ pc from the GC, and what physical factors cause this abnormally strong magnetic field? It has been demonstrated in detail in our paper [30] [31]. If it is based on the generator mechanism, in an interstellar gas environment 0.12 pc away from the GC, it can only generate a magnetic field of at most 0.1 μG. It is 10^5 times weaker than the actual observed magnetic field. This provides a severe challenge to modern physics and astrophysics.

Based on our research on the model of quasars and AGNs with magnetic monopoles and the theoretical predictions, we believe that this abnormally strong radial magnetic field is generated by magnetic monopoles gathered in the core regions of quasars and AGNs. By using the RC effect as energy source, we proposed the magnetic-monopole model of super-massive objects [16] [18] [19] [20]. Our model replaces the black hole model of quasars and AGNs. As pointed out in our paper [21], the radiation pressure generated by the RC effect, resists gravitational collapse and prevents the formation of a black hole from this super-massive object with magnetic monopoles at the GC.

The main ideas of our model are summarized as follows: the gravitational effect of the super-massive object in the GC is similar to that of a black hole. A super-massive object with a sufficient number of magnetic monopoles has neither the black hole horizon nor the central singularity, because the magnetic monopole can catalyze the decay of nucleons, and the reaction rate is proportional to the square of matter density. This makes the physical theory of nature become completely self-consistent. For the super-massive object in the GC, the main predictions of our model are as follows:

1) Generates a large number of positrons with a rate is 6×10^{42} e^+/s. There are very strong 0.511 MeV positive and negative electron annihilation lines in the GC direction.

2) Simultaneously emits high-energy radiation with an energy higher than

0.511 MeV, the total integrated energy is not only much higher than the total energy of the annihilation spectrum, but also higher than the luminosity of the central celestial object.

3) The magnetic monopoles gathered will generate a strong radial magnetic field, on the surface of the celestial body (the radius is about 50 A.U. ≈ 8×10^{13} m), and the magnetic field strength is about 20 - 100 G.

4) If we assume that all AGNs within 50 Mpc of the Earth are such supermassive objects with saturated magnetic monopoles, then they may be the source of the observed extreme ultra high energy (energy up to 10^{20} eV) cosmic rays.

5) Its surface temperature is predicted to be ~120 K, and the peak of the corresponding thermal radiation spectrum is about 10^{12} Hz (located in the sub-millimeter wave band).

These predictions of are consistent with subsequent astronomical observations. In particular, these three predictions are quantitatively almost identical to the corresponding astronomical observations.

I) Our prediction of the positron generation rate was almost quantitatively consistent with the 2003 high-energy astrophysics observations [35] of (3.4 - 6.3) $\times 10^{42}$ e^{+}/s. In other words, our theoretical prediction was confirmed by these subsequent observations.

II) Since the radial magnetic field strength decays inversely proportional to the square of the distance, from our prediction (3), it is naturally deduced that $B \approx (10 - 50)$ mG at $r = 0.12$ pc ≈ 3.7×10^{15} m. This is a key prediction that can be verified by astronomical observations in the near future.

III) The astronomical observations since 2010 [36] stated that the peak of the thermal radiation spectrum from the GC direction is ~10^{13} Hz, which is also quantitatively identical to our prediction of (5). The above predictions of (1), (3) and (5) are completely independent, and were confirmed quantitatively by subsequent astronomical observations.

Here we must emphasize that since the accretion disk of plasma on the periphery of the GC is blocked by a strong magnetic field at a considerable distance, it is impossible to reach the inner area of $(5 - 50)Rs$. The various radiations from the GC direction cannot be provided by accretion disks of plasma near the "massive black hole" at the GC. The model of AGNs with magnetic monopoles we proposed may be a reasonable model. Since the prediction of positron generation rate in our model in 2001 is almost exactly consistent with the observation of high-energy astrophysics in 2003.

It is believed that the magnetic flow in space is also very small because the spatial density of magnetic monopoles is very sparse. Since the formation of the Earth, the number of magnetic monopoles captured from space is small (about a few grams of atoms), and they are all concentrated in the core area of the earth.

Therefore, any physical experiment performed by physicists on the Earth's surface (mantle) and any experiment on magnetic monopole capture from space cannot find magnetic monopoles. However, in the large-scale celestial bodies of the universe, for example the super-massive object at the GC, a large number of magnetic monopoles can be gathered. The magnetic monopoles may show more obvious physically observable effects: for example, positrons and other high-energy radiation can be continuously produced by magnetic monopole catalyzing the decay of nucleons. Our predictions are confirmed by astronomical observations providing the existence of magnetic monopoles. These astronomical observations are akin to physical experiments in space.

4. Query into the Black Hole Model of Other AGNs and Quasars

A statistical analysis of 76 radio-noisy active galaxies published in Nature [34] in 2014 also concluded that there is a strong radial magnetic field at the center of these active galaxies, preventing the gas from falling. This makes the basic assumption that the standard accretion disk model of black holes for the AGNs is potentially invalid. For the problem of the original mass of quasars born in the early universe, astronomical observations indicated that the masses of the central bodies of quasars with high red-shift are generally considered to be (10^8 - 10^{10}) $M_\odot$. Wu *et al.* (2015) discovered high red-shift quasars with masses of $10^{10} M_\odot$ [37]. However, the masses of low red-shift quasars and AGNs are generally considered to be (10^6 - 10^8) $M_\odot$. The largest mass of AGNs in the low red-shift region is M87, and its mass is estimated to be (4 - 6) × $10^9 M_\odot$. Astronomers estimated the masses of more than 100,000 quasars and AGNs as possible.

Based on the compilation data of 105,783 quasar masses compiled by [38] and combined with the red-shift values of quasars, it is easy to plot the observed distribution of quasar mass versus distance (see in Figure 1 and Figure 2). However, there are at least two obvious drawbacks to drawing these graphs directly

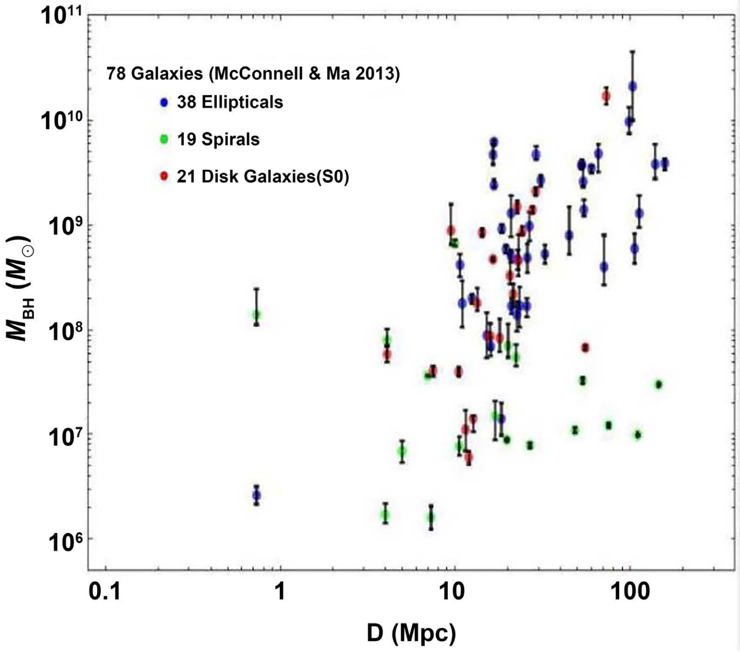

Figure 1. Distance dependence of black hole mass for 76 AGNs [40].

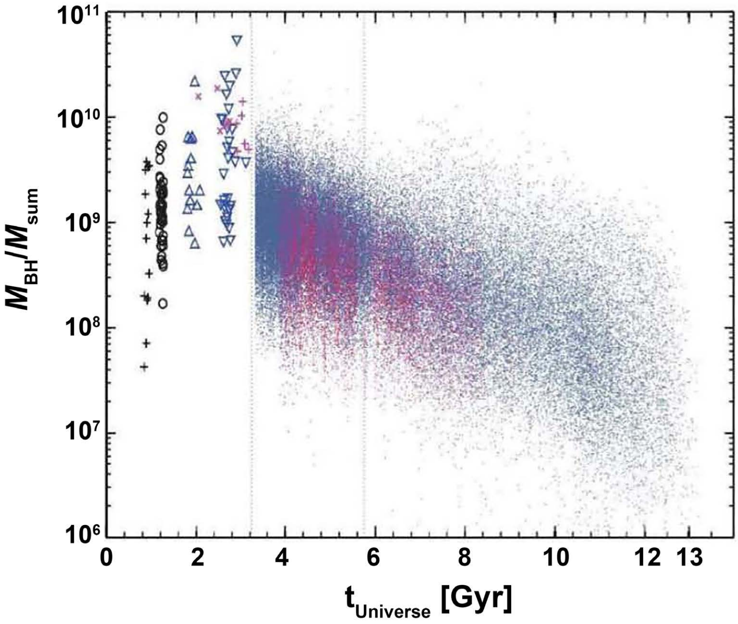

Figure 2. Current observation of the relationship between the mass of quasar black hole and the age of the universe (when receiving quasar luminescence) (see [38]).

from the observed masses of quasars and their red-shifts. 1) For more distant regions with high red-shifts, a large number of low luminosity (corresponding to lower mass) cannot be observed due to the observational selection effect. Therefore, the distribution lacks authenticity. 2) For quasars with different red-shifts, the radiations received today from these different red-shift (distance) quasars are emitted from different eras. Thus, this distribution cannot directly reflect the relationship between the mass and red-shift of quasars when they are born. This direct comparison of the masses of quasars in different eras is meaningless.

After deducting the mass gained by accretion since the birth of black hole, it is surprising to find that the masses of quasar black holes are almost zero or negative within the $Z = (0.2 - 0.3)$ range (see in **Figure 3**), which is impossible. The masses of quasar black holes at $Z = 5.0$ and 6.0 decrease little. Given this apparent contradiction, there have been many explanations, hypotheses or models in the research field in the last 20 years or so that attempt to explain the tendency that the masses of quasars and AGNs decrease with decreasing in their red-shifts. Several common explanations are given as following:

1) The luminosities of low-mass quasars and AGNs are low. It is difficult to observe the high red-shift quasars and AGNs, which are too far away. In fact, these observed selection effects are very complex. Not only are they not well understood, but also the negative value of the original mass distribution function of the quasars and AGNs mentioned above cannot be explained by the observational selection effect.

2) Some scholars have proposed that the accretion disk model near the core of AGNs does not accrete continuously from the beginning to the end, but intermittently. This model cannot overcome the difficulty that the accretion mass of

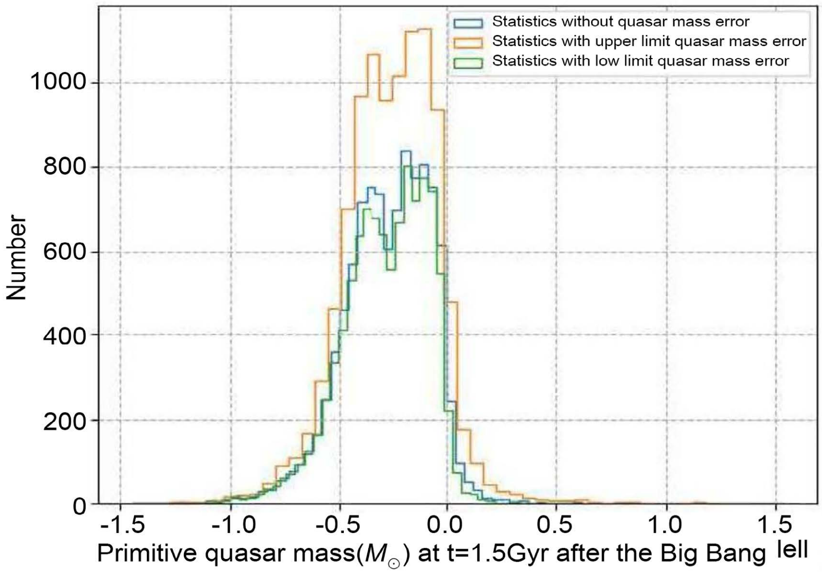

Figure 3. The original mass distribution function (t = 1.5 Gyr) of early universe quasars in the black hole model. 105,783 quasars with different red-shifts are reflected in the observed masses. The data are collected from the paper published by [38].

black hole should be deducted. If the accumulation interval of accretion is short, it has no essential effect on solving the difficult question of excessive accretion mass of black holes that should be deducted; if the accumulated interval of accretion is far greater than the accretion time scale, it is impossible to observe black holes without accretion materials during the accretion pause.

3) In recent years, it has been popular to think that the seed black holes masses are only $(10^5 - 10^6)M_\odot$, and then rapidly accreted and merged to form super-massive black holes. If so, it would be difficult to form a black hole with a mass greater than $10^{10}M_\odot$ in the age of the universe (about 14.6 billion years).

4) In order to intuitively explain the number of quasars with the mass up to $10^9M_\odot$ and the red-shift distribution peak near $Z = (2 - 3)$, some astronomers propose that most quasars and AGNs are formed in the range of $Z = (2 - 3)$. However, this assumption violates the Mach principle that the universe is uniform and isotropic everywhere (modern cosmology is based on this principle).

5) At present, in the mainstream theories in this field, the mass of AGN increases, and the integration process is like a tree graph. Each AGN has its own accretion and remerging. However, even if it can be assumed that in the early universe, the galaxy density was very high, and that the time scale for the merging of two galaxies might be less than 10 million years, the time scale for the merging of two almost point masses of the galactic cores was at least two or three orders of magnitude higher than that of two galaxies merging. If we synthesize super-massive black holes from a series of $10^6M_\odot$ black holes, the timescale must be longer than the age of the universe.

6) Layered model of black hole formation: in recent years, some astronomers have proposed the layered model of black hole formation, which is actually a

combination of the above two types of models (4) and (5). It is still difficult to avoid a long timescale and the Mach principle of cosmology.

As a summary, supposing that both quasars and AGNs are born in the early universe, the black hole model of quasars and AGNs presents an inevitable paradox: the masses black hole model of quasars and AGNs presents an inevitable paradox: the masses of the primary "black holes" of most low red-shift quasars and AGNs are negative or very small. We can explain this phenomenon naturally using the RC effect of magnetic monopole, the masses of quasars and AGNs decrease with the decreasing in red-shift. Combining the mass reduction law of quasars with the currently observed mass data of 105,783 quasars compiled by Shen *et al.* [38], we plot the distribution curve of the initial mass (Gauss type) of quasars formed in the early universe under our model with magnetic monopoles in **Figure 4**.

The jet problem of AGN has been considered as the most powerful observational evidence for the black hole model. But, in 2014, Sell *et al.* studied the jets of 12 famous AGNs (including M87) in detail [39]. They believed that these jets were generated by the rapid star formation process (starburst) in the core region of AGN, but had no statistical correlation with the mass of the central black hole.

In 2016, the Bu *et al.* research group of Shanghai Observatory published two consecutive papers on numerical simulation [40]. In both the absence and presence of magnetic field, it turns out that the jets are determined by the gravitational potential of stars near the core of the galaxy, but not related to the mass of the central black hole. In addition, infrared photometric observations of quasars have been popularly used as strong observational evidence for a unified model of AGNs. Unfortunately, around 2004, Fan's team observed that the two quasars with the highest red shift ($Z = 6$) at that time did not detect infrared radiations emitted from hot dust [41] [42].

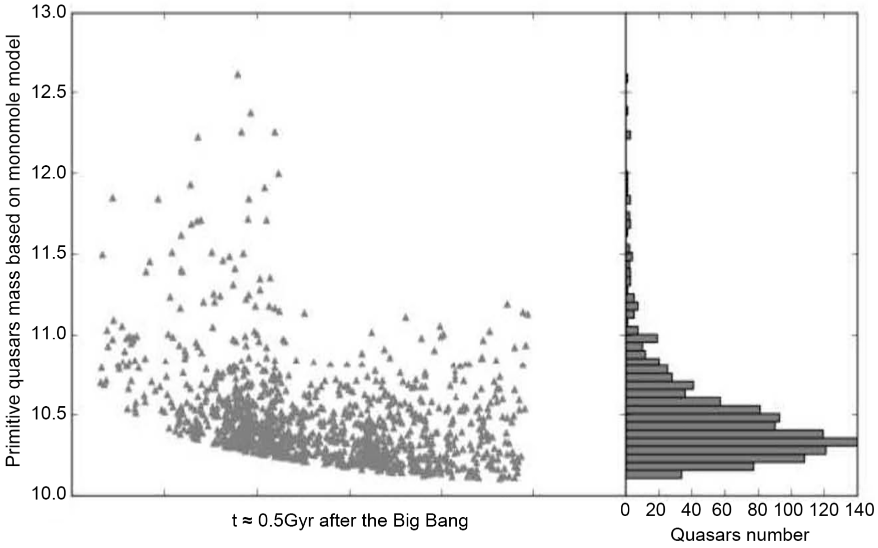

Figure 4. Distribution of the initial mass (in $M_\odot$ logarithm) of quasars formed in the early universe under the super massive star model with magnetic monopoles.

5. Magnetic Monopoles Drive Supernovae Explosion

5.1. Mystery of the Mechanism of Core Collapsed Supernova Explosion

Using the RC effect as the energy source, the problem of supernova explosion, which has been a puzzle in the past hundred years, can be solved very simply. When the thermonuclear evolution of a massive star is over, the core region of a star composed mainly of iron group elements has a high temperature as high as $(3 - 5) \times 10^9$ K and a high mass density above 3×10^6 kg/m^3. In the physical environment, the Fermi energy of the degenerate electron gas is higher than the energy threshold of electron capture process (EC process) on the iron-group nucleus. Then the number of free electrons decreases sharply, due to the EC process, and the degenerated pressure of free electrons drops sharply, which can no longer maintain the dynamic balance of the star. The stellar core would then collapse sharply toward the center.

In the outer part of the Fe core, the collapse speed increases gradually from the outside to the inside. As the star collapses, the density of the stellar center increases rapidly. When the density of the collapsed core exceeds the saturation density ρ_{uuc}, the non-relativistic degeneracy pressure of nucleon system exceeds the degeneracy pressure of relativistic electron gas. The polytropic exponent in the equation of state $p = K\rho^{\gamma}\_$ becomes $\gamma = 5/3$, and the inner core becomes a stable system in thermodynamics. The inner core no longer collapses.

However, due to inertia, the collapse of the inner core is not completely stopped until the center density reaches (2 - 4) ρ_{uuc}. While the material outside the inner core continues to collapse at supersonic speeds, slamming violently into the hard core that suddenly stops collapsing, it immediately creates a strong outward rebound shock not far from the boundary between the inner and outer cores with $E_{\text{shock}} = 10^{44\text{-}45}$ J.

This energy is converted from the self-gravity energy released by collapsing material during the collapse. The temperature behind the shock front rises to above 10^{11} K, and the average thermal energy is as high as 10 MeV, exceeding the binding energy of a nucleon (8.8 MeV) for ^{56}Fe. The nuclei of iron group elements are quickly broken by thermal photons through the process $^{56}\text{Fe} \rightarrow 13\alpha + 4\text{n} \rightarrow 26\text{p} + 30\text{n}$. This photo-induced fission process consumes the energy of rebound shock by $-\delta E/\delta m \approx 192.26$ MeV/^{56}Fe ≈ 1.69 Bethe/0.1$M_\odot$, where 1Bethe = 10^{43} J.

5.2. Causes of Instantaneous Explosion Failure

If the external core mass is not too large, $m_{\text{out-core}} < E_{\text{shock}}/(-\delta E/\delta m)$, the shock wave can rush out of the outer core. And when it completely destroys all the iron nuclei of the outer core, as long as the initial shock energy remains more than 1% of the energy (10^{42} J), the residual shock wave can throw the entire star's mantle and atmosphere into space, forming a supernova explosion. The above image is called instantaneous explosion mechanism.

If the external core quality is too large, $m_{\text{out-core}} > E_{\text{shock}}/(-\delta E/\delta m)$, before the above outward rebound shock wave penetrates the outer core, all the energy of shock wave is consumed in the process of photolysis of iron nuclei. It could not have blown the mantle and atmosphere away, and it doesn't cause supernovae explosion. And because both of the mantle and atmosphere outside of the core will continue to fall to the center, the original outward rebound shock wave turns into an accretion standing shock. That is, in this case, the instantaneous explosion mechanism fails.

The key to the success of a transient explosion mechanism is whether its outer (iron) core is massive enough. So far, for all reasonable model calculations, the instantaneous explosion mechanism is unsuccessful, because the mass of the core is too large. Thus, the instantaneous explosion mechanism is a failure.

5.3. Delayed Neutrino Explosion and Its Difficulties

In order to overcome the difficulty of instantaneous explosion of supernova, Wilson *et al.* proposed the mechanism of delayed neutrino explosion [43] [44]. Their reason is that the surface temperature of the initial neutron star formed from the collapsed core of the supernova explosion is as high as 10^{11} K, which will inevitably emit a very powerful neutrino flow with a total energy of 10^{45} - 10^{46} J. The outwards explosion of the outer layers of the supernova (initially at speed ~10^4 km/s) is driven by this powerful neutrino flow.

However, there are two key unsolved problems in the mechanism of neutrino delayed explosion:

1) What are the specific physical processes that produce such powerful neutrino flow? The problem was soon solved better than before. Our research group proposed a phase transition process in the nuclear mater: from two-flavor quarks ((u, d) quark) transfer into three-flavor quarks ((s, u, d) quark) in the core of the newborn neutron stars formed in a supernova collapsed core with a high temperature [45]. The phase transition process is $u + e^- \to d + \nu e$, $u + e^- \to s + \nu e$, and $u + d \to u + s$. The average energy is about 10 MeV and the total energy is more than 10^{45} J. Due to the negative entropy gradient in the core, the Schwarzschild convection of internal and external matter will make the powerful neutrino flow out and reach the surface of the neutrino sphere quickly in a second. Our proposed the quark phase transition process greatly facilitates the neutrino delayed explosion mechanism.

2) Even if a strong stream of neutrinos were present on a very short scale, could their interaction with matter produce such a strong neutrino recoil pressure making the supernova explosion? Moreover, the initial velocity of the explosive material ejection is as high as 10^4 km/s, so can the total explosive energy can reach 10^{42} J?

Since 1985, a number of outstanding astrophysicists have joined forces to discuss neutrino fluid dynamics and consider neutrino transport processes in detail. Since neutrinos interact with matter weakly (the cross section is about 100,000 -

440,000 m^{-2}), the neutrino flow recoil pressure generated by the neutrino flow absorbed by the neutrino stream radiating outwards by the collapsing matter is too weak. It is impossible to turn inward collapsing matter back toward outward explosion.

5.4. Mechanism of Supernova Explosion Driven by Magnetic Monopole

Although the number of magnetic monopoles captured from space by precursor massive stars of supernova since birth is small, only a few hundred grams of molecules (6 × 10^{23} magnetic monopoles for one gram of molecule), these overweight monopoles are concentrated in the stellar core. In the stellar core, the ratio of magnetic monopole to nucleon number density (called magnetic monopole content) should not exceed Newton saturation value ς_n [32]. The luminosity of the RC effect is estimated as

$$L_m = V_c n_m n_B \left\langle \sigma v \right\rangle m_B c^2 = V_c \varsigma_n \left(n_B\right)^2 \left\langle \sigma v \right\rangle m_B c^2, \quad (1)$$

where the number density of the magnetic monopoles $n_m = \varsigma_n n_B$, and V_c is the volume of the core area where the magnetic monopole is concentrated. Equation (1) shows that the RC luminosity is proportional to the square of the nucleon number density n_B in the core region. When the density of the precipitously falling material far exceeds the density of the nucleus, the RC luminosity increases sharply with the square of the nucleon number density. As long as this kind of RC luminosity is far beyond the Eddington luminosity L_{Edd}, which is the luminosity limit of the stable stars, it will inevitably lead to a violent explosion of the supernovae. That is to say the supernova explosion must happen when $L_m \gg L_{Edd}$.

If the density of the collapsed core is not very high, although its RC luminosity is higher but not much higher than the Eddington luminosity, then it will present a weak explosion of the supernova (for example, the Cas A supernova that exploded in 1668) or dark burst supernova. For example, the Chandra satellite detected a gaseous nebula G1.9 + 0.3 located in the constellation Sagittarius. it is inferred that it is a supernova remnant that exploded 110 years ago, according to the observation of the expansion rate of the gaseous nebula.

According to Blasting News, NASA astronomers officially reported a news for observations of the star N6946-BH1 at 2019: the star began to brighten up in 2009, but suddenly disappeared in 2015. Recently, astronomers used the Hubble Space Telescope and the Spitzer infrared telescope to make new observations. The star, it was found, had indeed disappeared without a trace. Simulations have led some to believe it turned into a black hole and the mass of this star is estimated as 25$M_\odot$. It may be a dark matter explosion, but nobody knows the physics behind it.

Using the mass-radius relation of degenerate compact stars $R \propto m^{-1/3}$, we deduced that the mass density of the supernova collapsed core (a degenerate neutron star) is proportional to the square of the mass of the star, $n_B/n_{nuc} \propto$

$(m/20M_\odot)^2$, The correlation between the peak luminosity of the supernova explosion and the mass of the supernova can be deduced

$$
\begin{aligned}
L_m^{peak} &= 5.0\times10^{37}\left(\frac{m}{20M_\otimes}\right)^{2\beta+1}\left(\frac{\varsigma}{100}\right)\left(\frac{T_c}{10^{11}\ \mathrm{K}}\right)^{1/2}\ \mathrm{J/s} \\
\varsigma &= \left(\frac{\sigma}{10^{-34}\ \mathrm{m}^2}\right)\left(\frac{\phi_m^0}{10^{-2}\phi_m^{up}}\right)
\end{aligned}
\qquad (2)
$$

where $\beta = 1.0$ - 1.5, and the value of uncertainty $\varsigma = 100$, which is estimated by using the RC effect to explain the measured data of outward heat flow from the Earth's core.

The relationship between the peak luminosity of the explosion with the mass of supernovae shows that it is roughly consistent with the mass estimates $M = 8$ - $25M_\odot$, 30 - $60M_\odot$, 70 - $100M_\odot$, and $M > 120$ - $150M_\odot$ of the supernovae precursors of type II (SNII), type Ib (SNIb), type Ic (SNIc), and super-bright supernovae (SLSN), respectively.

The causes of various types of core-collapsed supernova explosions are driven by magnetic monopole catalytic nucleons decay as energy. No matter how massive a supernova precursor is, the remnant of a core collapsed supernova explosion is a neutron star, not a black hole. In other words, stellar black holes cannot be formed by supernova explosions. The reasons are as follows [32].

In supernova explosion, the mass density in the core of the supernova is close to or more than the nuclear density. The RC effect of the supernova core produces such a high RC luminosity and radiation pressure that the entire material in the core, including nucleons and magnetic monopoles, is ejected in the hot plasma state. The magnetic monopoles in the core region are also ejected by electromagnetic interaction with the plasma material. The mass density of the stellar core decreases sharply, and so does the number of monopoles in the core, so the RC luminosity and radiation pressure will decrease significantly. After that, the material ejected at less than escape velocity, including some monopoles, starts falling back toward the star's center. It causes the central mass density to increase rapidly again. The magnetic monopoles in the star's core continue to catalyze nucleon decay, producing the RC luminosity and the corresponding radiation pressure that resists the collapse of falling material. Since the RC luminosity $Lm \propto \varsigma(n_B)^2$, the mass density at the stellar center will not only never approach infinity, it will be far below the nuclear density. The remnant star will eventually reach a stable equilibrium: the RC luminosity in its inner core must be far lower than the Eddington luminosity of this remnant star.

It is popular to guess that the upper limit mass of neutron stars is about $2.5M_\odot$. This is the case without considering the physical factors of the RC effect. According to our model, no matter how massive a neutron star is, it doesn't collapse into a black hole because of the RC effect. Supernova remnants are special objects, similar to neutron stars. The mass density of the inner core is not high, because the residual monopoles constantly catalyze nuclear decay, providing energy and generating so much radiation pressure that the star does not collapse into a black hole. Another important conclusion can be drawn from our analysis: there may be no upper limit to the mass of neutron stars that collapsed after supernova explosions into massive or supermassive neutron stars with the above special structure.

Recently, LIGO detected gravitational waves, a physical experiment in space that proved Einstein's prediction of general relativity, a major event in recent years. If the gravitational wave strength of GW170104 exceeds GW150914, and the mass of the corresponding two merging compact stars is larger, and if we do not see the electromagnetic counterpart, then our theoretical model is difficult to explain. Now, it happens to be the opposite, the gravitational wave intensity of GW170104 is much weaker than that of GW150914, the mass of the corresponding two merging compact stars is much smaller, and no electromagnetic counterpart is observed, so it is in line with our theoretical framework.

6. Query to Why Earth's Core Is in a State of High Temperature Melting

The Earth's core is in a state of high temperature ($T = 6 \times 10^3$ K) melting. The total heat stored in the earth's core is about $E_T \approx 7.0 \times 10^{29}$ J. The rate of heat transfer from the Earth's crust (the latest geophysical data in 2010) is $J_r \approx 4.7 \times 10^{13}$ J/s. Within 500 million years, the total heat released by the radioactive element uranium in the earth is only $E_U \approx 1.0 \times 10^{27}$ J $\approx 1.5 \times 10^{-3}$ E_T. If there is no energy source, the heat will be exhausted within 500 million years.

Radioactive elements are far from likely to provide the hot-melt state of the Earth's core. The temperature of Earth's interior is 6000 degrees, and thermonuclear reactions can't be ignited. Additional sources of energy need to be sought. Since the Earth was formed 4.5 billion years ago, the number of free flying magnetic monopoles captured by the Earth from interstellar space is about

$$N_m = 5.0\times10^{17}\left(\frac{\varsigma_m}{10^{-20}}\right)\left(\frac{n_B}{1\text{cm}^3}\right)\left(\frac{v_m}{10^{-4}c}\right)\left(\frac{m_m}{10^9 m_p}\right)^{-1} \text{J/s}\,. \tag{3}$$

The RC luminosity produced by these magnetic monopoles in the core of the Earth is

$$L_m = 3.0\times10^8\,\xi\,, \tag{4}$$

where $\xi = \left(\frac{\varsigma_m}{10^{-20}}\right)\left(\frac{\sigma}{10^{-34}\ \text{m}^2}\right)\left(\frac{n_B}{1\ \text{cm}^3}\right)\left(\frac{v_m}{10^{-4}c}\right)\left(\frac{m_m}{10^9 m_p}\right)^{-1}$.

The above uncertainty factor $\xi = 100$ can be estimated based on the latest geophysical data in 2010. Therefore, the physical cause of the unknown energy source is simply the nucleon decay catalyzed by magnetic monopoles.

7. New Energy Sources of White Dwarfs

White dwarfs (WDs) are stars whose inner thermonuclear reactions have been extinguished. They are dead stars and are cooling. The mass of the white dwarf is about the same as that of the sun, with a radius of about 10^4 km. A crystal of carbon, oxygen, and silicon compounds with electron degeneracy is in the interior of a WD. For most of WDs, their central temperatures $Tc < 10^7$ K, and their surface temperatures $T_e = (3 \times 10^3 - 4 \times 10^4)$K. The total thermal energy contained in the white dwarf is about $E_T \approx 10^{40}$ J. According to the black-body radiation, the luminosities of WDs are estimated as

$$L = 4\pi R^2 \sigma T_{eff}^4 \approx \left(10^{-4} - 10\right) \times 10^{24}\ \text{J/s}\,. \tag{5}$$

It can be estimated that the cooling time scale of WDs is about 500 million years. Why are there no late M-type and N-type WDs with surface temperatures lower than 2×10^3 K? What are their specific heat sources? So far, there has been little discussion of these issues.

A primordial star with low mass, $m < 8M_\odot$, evolved into the DW after passing through the main sequence stage of hydrogen burning and the red giant stage of helium burning. The RC luminosity produced by the nucleons decay catalyzed by magnetic monopoles of the DWs is estimated as

$$L = 4\pi R^2 \phi_m t \approx 10^{33} \xi \left(\frac{t_{RG}}{10^7\ \text{yr}}\right)\left(\frac{R_{RG}}{10^{-2} R_\otimes}\right)^2 \text{J/s}\,. \tag{6}$$

It can be estimated $\xi = 100$ from the study of the melting state of the Earth's core. As long as $\left(\frac{t_{RG}}{10^7\ \text{yr}}\right)\left(\frac{R_{RG}}{10^{-2} R_\otimes}\right) \approx \left(10^{-4} - 10\right)$. The RC luminosity may explain the long-term non-cooling energy sources of WDs. This constraint for WDs is basically consistent with observations.

8. The Physical Mechanism of the Hot Big Bang of Universe

8.1. Gamow's Model Hot Big Bang (HBB) for the Universe

In 1924, Hubble found that the receding (*i.e.* moving away from the Earth) speed of a distant galaxy is proportional to the galaxy's red-shift

$$L = \frac{\lambda - \lambda_0}{\lambda} = \frac{v_r}{c} = \text{Hd}\,, \tag{7}$$

which is the law of Hubble-Lemaitre. That is to say, the spectral lines of all distant extragalactic nebula are shifted in the infrared direction, or these galaxies are moving away from us, and the farther the galaxy is from us, the faster it recedes. This shows that the universe is expanding. It is clear from the laws of thermodynamics that the early universe was in a very hot, dense state.

In 1948, Gamov and Alpher first proposed that the universe originated from a violent Hot Big Bang (HBB) about 15 billion years ago [46]. The violent explosion of the universe led to the expansion of space. With the expansion of space, matter became sparse and its temperature decreased. The 1960s' discovery of the Cosmic Microwave Background (CMB) radiation with $T0 = 2.7$ K confirmed the model of HBB for the universe. As for the physical reasons for the existence of HBB in the universe, this is an unknown question and one that has not been explored in depth.

Based on this, cosmologists have come up with a popular mainstream standard cosmological theory: back in time 14.6 billion years ago, all the matter in the universe could have clustered at almost a geometric point (with infinite density of matter and infinite temperature)—the original singularity of the universe. To avoid singularities that cannot be understood in physics, Hawking and others have proposed various theories such as quantum cosmology, baby cosmology and cosmic wave function. In addition, it is found that there are three major contradictions in the standard cosmology theory, which are difficult to understand (space straightness, horizon and magnetic monopole).

In order to overcome these contradictions, Guth proposed in 1982 that in the very early period of the birth of the universe (about 10^{-35} seconds), there was an accelerating expansion of the universe [47] [48] [49]. The theory has been improved and updated over the decades, falling into a trap that is difficult to extricate itself. The culprit pressing the cosmic accelerator goes by the name "dark energy", which is an appropriately enigmatic moniker for something that remains so poorly understood. Another possibility is that the accelerated expansion arises not from a substance but from a modified form of gravity, one that behaves differently on cosmic scales of time and space.

8.2. RC Effect as Energy Source of Driving HBB for the Universe

Similar to the supernova explosion mechanism, the RC effect with the nucleon decay catalyzed by magnetic monopoles is used as the energy source of driving the HBB of the universe. It is estimated that there are a total of 2×10^{11} galaxies in the universe, and each galaxy (estimated by the Milky way) contains about 2×10^{11} stars. The total number of stars in the universe is about 10^{23} due to the solar mass of 2×10^{30} kg. The total mass of the whole universe is about 2×10^{53} kg, and the total number of baryons is about 10^{80}.

The total number of magnetic monopoles contained with the same polarity in the universe is $N_m \approx 10^{60}(\varsigma/\varsigma^{up})$. When baryon matter is in a high temperature plasma state, these magnetic monopoles compress rapidly towards the center of the universe with a saturation rate. The corresponding RC luminosity is given as

$$L_m = N_m n_B \langle \sigma v \rangle m_B c^2 = 10^{68} \left(\frac{\overline{n}_B}{n_{nuc}}\right)\left(\frac{\varsigma}{\varsigma^{up}}\right)\left(\frac{\sigma}{10^{-30}\,\mathrm{cm}^2}\right) \mathrm{J/s}\,. \tag{7}$$

When the whole matter of the universe is compressed into an extra-massive object, its Eddington luminosity is given by $L_{Edd} = 10^{31}\ (m/M_\odot)$ J/s. As long as the ratio

$$\frac{\overline{n}_B}{n_{nuc}} > 10^{-10}\left[\left(\frac{\varsigma}{\varsigma^{up}}\right)\left(\frac{\sigma}{10^{-30}\ \mathrm{cm}^2}\right)\right]^{-1}, \tag{8}$$

so $L_m > 10^4 L_{Edd}$, which will inevitably lead to an extremely violent thermal explosion in the whole universe driven by RC effect. We also proposed an oscillation model of the universe: The universe is shrinking because of gravity. As the center mass density is more than the nuclear density, the RC luminosity far exceeds the Eddington luminosity of the whole universe, which will inevitably lead to the HBB of the universe. Gravity causes the expansion of the universe to slow, stop and eventually contract. This universe shrinkage process alternates repeatedly with the HBB of the universe, followed by an explosion process driven by magnetic monopoles.

Our model is only a different model of black hole (black hole without singularity), which can be used to avoid the original singularity of the universe that cannot be understood and verified by astronomical observation.

9. Summary

Here we give a summary of this paper. Firstly, we find that the astronomical observation of the fairly strong radial magnetic field at the distance r = 0.12 pc from the GC is quantitatively exactly consistent with our theoretical prediction on the radial magnetic field produced by the huge supper-massive object with magnetic monopoles. Secondly, there are given five scientific predictions in our work [31] on the model of super-massive stars with magnetic monopoles at the GC. All of the five predictions are consistent with astronomical observations. The predicted positron emission rate from the GC is exactly confirmed quantitatively by the later space satellite observation. The predicted peak frequency of thermal radiation from the GC is also confirmed basically by the infrared radiation observations. Thirdly, using the RC effect as a main energy source, we have explored the mechanism of core collapsed supernova explosion, and why the Earth's core is in the state of high temperature melting. A similar mechanism can be applied to why cold WDs with surface temperatures below 2×10^3 K have not been observed. In other words, it addresses why the white dwarfs whose internal thermonuclear burning has long since been extinguished do not cool further. Finally, it addresses the physical mechanism of the HBB of the early universe which led to the observable universe expanding. Our model with magnetic monopoles at the GC addresses these major and difficult problems that have confused astrophysicists for the past 100 years.

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Conflicts of Interest

The authors declare no conflicts of interest regarding publication of this paper.

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