New Astronomy 57 (2017) 59–62

Contents lists available at ScienceDirect

New Astronomy

journal homepage: www.elsevier.com/locate/newast

Some new possible anticipated signals for existence of magnetic monopoles☆

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HIGHLIGHTS

- The model of supermassive object with magnetic monopoles is discussed in detail.
- The signals for existence of magnetic monopoles from recent astronomical observations are proposed.
- Gravitational waves, and the gamma-ray burst may support the existence of the RC mechanism, and the magnetic monopole.

ARTICLE INFO

Article history:
Received 21 January 2017
Revised 23 May 2017
Accepted 26 June 2017
Available online 28 June 2017

Keywords:
Galaxy
Magnetic fields
Black hole physics

ABSTRACT

Most of physicists believe that the existence of magnetic monopoles had been ruled out by experiments. However, experiments only indicated that the flux of magnetic monopoles on the earth is too low to be observed. We summarize some predictions from the model of supermassive object with magnetic monopoles which match up with recent astronomical observations quantitatively. They may be the signals for existence of magnetic monopoles in the supermassive objects, such as one at the Galactic Center.

1. Introduction

In the primordial universe, the electromagnetic interaction between magnetic monopoles and plasma is so strong such that magnetic monopoles might store up in the center of quasars and active galactic nuclei (AGN) during the collapsing process of the original giant nebulae, including at the collapsed core of the Galactic Center (GC). Due to the Rubakov–Callan (RC) effect (Rubakov, 1981; Callan, 1983), magnetic monopoles may catalyze nucleon decay and is invoked as the energy source of quasars and AGN.

Based on a supermassive object infused with primordial magnetic monopoles, the supermassive object with magnetic monopoles (SMOMM) model is has been estimated in our paper (Peng and Chou, 2001). The fact that magnetic monopoles may catalyze nucleon decay (i.e., Rubakov–Callan effect) as predicated by the grand unified theory of particle physics is invoked as the energy source of quasars and active galactic nuclei. Recent study of this model revealed that the radius of the supermassive object located at the Galactic center is much larger than its Schwarzschild radius. We proposed that this supermassive objects could be the source of high-energy gamma-ray radiation, although the emitted radiation may be mainly concentrated in the infrared.

Really, we detailed discussed this question as early as 1985 due to the fact that this is a very interesting question (see our paper Peng (1985)). We discussed the number of monopoles in stellar objects in the paper. We noted that the number of monopoles possibly contained in a stellar object is closely related to the initial physical condition in the primary cloud from which the object was born. For example, in the interior of a protostar (the number density of hydrogen atoms $\sim (10^2–10^4)\mathrm{cm}^3$ and temperature $\leq 10^2$K), the interaction of monopoles with neutral atoms is insignificant, and very few monopoles will be drawn by the neutral matter during the collapse of a primary cloud (molecular or neutral hydrogen). On the other hand, however, the huge primordial clouds (It collapses into quasars and AGNs) in the early universe were in a plasma state with high temperature $\sim 4 \times 10^3$K. The interaction of

☆ This work was supported in part by the National Natural Science Foundation of China under grant nos. 11565020, 10773005, and the Counterpart Foundation of Sanya under grant no. 2016PT43, the Special Foundation of Science and Technology Cooperation for Advanced Academy and Regional of Sanya under grant no. 2016YD28, the Scientific Research Staring Foundation for 515 Talented Project of Hainan Tropical Ocean University under grant RHDRC201701, and the Natural Science Foundation of Hainan province under grant no. 114012.

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http://dx.doi.org/10.1016/j.newast.2017.06.011
1384-1076/

monopoles with plasma is so strong that many monopoles will be drawn into the quasars and AGNs during their formation.

The SMOMM model is based on a supermassive object infused with primordial magnetic monopoles. However, it is believed today that, due to their immense mass ($\sim 10^{20}$MeV/c^2), these monopoles could only have formed in the time interval between the Big Bang and inflation. Then, cosmic inflation would have diluted the monopole population so much that fewer than one would exist today within the observable universe. This argues against the existence of objects containing primordial monopoles. But from the symmetry and beauty of the Dirac equation, Dirac suggested the existence of magnetic monopoles which is the most natural explanation of the quantization of electric charge (Dirac, 1958).

In recent years, people always discuss the other possibilities, whether magnetic monopole would produce or not. Much literature exists on the creation of monopoles in the modern universe via ultra-high-energy particle collisions in the intense magnetic fields of compact objects. For example, Bonnardeau and Drukier (1979) detailed discussed the creation of magnetic monopoles in pulsars. These magnetic monopoles are believed to create by the very energetic particles in pulsars. These particles can interact between themselves and/or be smashed onto the neutron star surface to produce pairs of magnetic monopoles and antimonopoles. Pazameta also discussed a general-relativistic model of such a monopole-infused object (Pazameta, 2012). They described the final equilibrium state of compact objects infused with magnetic monopoles produced by proton-proton collisions within the intense dipolar magnetic fields generated by these objects during their collapse. Their model could be adapted to construct a physical model of the SMOMM. In any case, it is a fundamental problem in physics whether magnetic monopoles exist or not.

The plan of this letter is as follows. In Section 2, we will sketch the model of SMOMM and its predictions. In Sections 3–5, we will show some predictions of our model in agreement quantitatively or basically with some new astrophysical observations: a strong magnetic field around the GC, the observation of the rate of the emitted positrons, and the frequency of the spectrum peak of the thermal radiation from the GC. In the last Section, we will discuss and try to explain two recent observations with the model of the stars with the magnetic monopoles: the highly super-luminous supernova ASASSN-15lh and the gravitational waves GW150914.

2. The model of SMOMM

The model of SMOMM (Peng and Chou, 2001) suggested that an amount of magnetic monopoles stored up in the center of quasars and AGNs, including at the collapsed core of the GC during the collapsing process of the original giant nebulae in the primordial universe because the electromagnetic interaction between magnetic monopoles and plasma was so strong. Due to the RC effect (Rubakov, 1981; Callan, 1983), nucleon decay may be catalyzed by magnetic monopoles,

$$p + M \rightarrow M + e^{+} + \pi^{0} + \text{debris (85\%)}, \tag{1}$$

$$p + M \rightarrow M + e^{+} + \mu^{+} + \mu^{-} + \text{debris (15\%)}. \tag{2}$$

In this model, the RC effect is invoked as the energy source. In the case of GC, the SMOMM is located at the center with the radius of about 8.1×10^{15}cm $\sim 1.2 \times 10^{4}$R$_S$ (R_S is its Schwarzschild radius). The total mass of the SMOMM is derived to be 2.5×10^{6}M$_\odot$ (now taken as 4.6×10^{6}M$_\odot$) from the observed luminosity of Sgr A*(1×10^{37} ergs s^{-1}).

The gravitational effect around SMOMM in the GC is similar to the model of supermassive black holes. In the black hole model, accretion of matter results in the huge luminosity, but the energy source in the model of SMOMM is supplied by the RC effect.

The main predictions of the model of SMOMM are as follows (Peng and Chou, 2001).

1. The production rate of positrons emitted from the SMOMM in the model is $\sim 6.5 \times 10^{42} e^{+}$/s.
2. High-energy gamma-ray radiation has energy higher than 0.5 MeV. The integrated energy of these radiations would be much greater than both the bolometric luminosity and the energy of positron annihilation line.
3. The radial magnetic field at the surface of the SMOMM is estimated to be $H(R) \sim$ (20–100)G.
4. The strong radial magnetic fields of the high-speed rotating SMOMM transforms a strong electric field for a distant observer in the rest frame. A variety of produced particles (e^{+}, $\mu^{\pm}$, $\pi^{\pm}$) would be accelerated by the strong electric field to very high energy, say $E_\gamma \sim 10^{21}$eV or greater. We predict that these could just be the observed ultra-high-energy cosmic rays which have an initial energy of several hundred MeV produced from the SMOMM.
5. The surface temperature of the SMOMM is derived to be about 121 K and the corresponding spectrum peak of the thermal radiation is at 10^{13} Hz in the sub-mm wavelength regime.

3. A strong magnetic field around the galactic center

The recent observation (Eatough et al., 2013) in 2013 indicated that there is a dynamically important magnetic field near the black hole. In particular, at $r = 0.12$ pc the lower limit of the outward radial magnetic field near the GC is

$$B \geq 8\left[\frac{RM}{66.960\,\mathrm{m}^{-2}}\right]\left[\frac{n_0}{26\ \mathrm{cm}^{-3}}\right]^{-1}\mathrm{mG}, \tag{3}$$

where n_0 is the number density of electrons there, and RM denotes the measurement of the Faraday rotation near the GC. The lower limit of the observed data is in agreement with the prediction 3 in the model of SMOMM because the magnetic field strength decreases as the inverse square of the distance from the source and has $B \approx$ (10–50)mG at $r = 0.12$pc. Up to now no other physical mechanism can produce this strong radial magnetic field.

As analyzed in Zamaninasab et al. (2014), “jet magnetic field and accretion disk luminosity are tightly correlated over seven orders of magnitude for sample of 76 radio-loud active galaxies”. They pointed out that the black hole models “may require significant changes”, and “models of the Galactic Center accretion disk may also need to be revised, as a dynamically important magnetic field has been reported (Eatough et al., 2013) within a distance of $\sim 3 \times 10^{7} r_g$ from the central black hole.”

4. Rate of emitted positrons

New observation (Knödlseder et al., 2003) reported that the measured 511 keV line flux located at the GC at a distance of 8.5kpc converts into an annihilation rate of $(3.4 - 6.3) \times 10^{42}$s^{-1}. “The observed flux is compatible with previous measurements (Share et al., 1999; Cheng et al., 1997; Purcell et al., 1997; Milne et al., 2000; 2001) that have been obtained using telescopes with small or moderate fields-of-view, yet it is on the low side when compared to OSSE measurements” (Knödlseder et al., 2003). Those observations are in agreement with the prediction 1 in the model of SMOMM quantitatively.

5. Frequency of spectrum peak of the thermal radition from the galactic center

A review paper (Falcke and Markoff, 2013) pointed out that the radio flux density S_ν from the GC shows a flat-to-inverted spectrum. i.e., it raised slowly with frequency of the power peaking around 10^{12} Hz in the sub-mm band. The observed power peak is in agreement basically with the prediction 5 in the model of SMOMM.

6. Conclusions and discussions

The agreement of the predictions of our model of the SMOMM with three new astrophysical observations quantitatively or basically issues the signals for existence of magnetic monopoles. We are looking forward to seeing more astrophysical observation which will meet the predictions of our model.

At the beginning of this year two important astrophysical observations were reported: The highly super-luminous supernova ASASSN-15lh and the gravitational waves GW150914. We believe that our model and its development can be suitable to meet the new observations.

The recent observation (Dong et al., 2016) reported the discovery of ASASSN-15lh (SN 2015L), which was interpreted as the most luminous supernova to be found. "At redshift $z - 0.2326$, ASASSN-15lh reached an absolute magnitude of $M_{u,AB} = -23.5 \pm 0.1$ and bolometric luminosity $L_{bol} = (2.2 \pm 0.2) \times 10^{45}$ erg s^{-1}, which is more than twice as luminous as any previously known supernova". "In the 4 months since first detection, ASASSN-15lh radiated $(1.1 \pm 0.2) \times 10^{52}$ ergs, challenging the magnetar model for its engine".

Up to now, the supernova explosion mechanism has not been solved. In a model of a supermassive star with magnetic monopoles, the phenomena of ASASSN-15lh and the superluminous supernova (SLSN) may be explained naturally. Although a few magnetic monopoles may be stored in the core of stars during the process of star formation from a neutral hydrogen nebulae due to very weak interaction between magnetic monopoles and neutral hydrogens, the stars may capture some flight magnetic monopoles in the space (Peng et al., 1985). The flux of the flight magnetic monopoles is

$$\begin{aligned}\Phi_m = n_m v_m &= 10^{-4} c n_B^{(0)} \zeta_m^{(0)} (\frac{v_m}{10^{-4}c}) \\ &\approx 7.5 \times 10^{-19} (\frac{\zeta_\mathrm{m}^{(0)}}{\zeta_S})(\frac{n_B^{(0)}}{1\mathrm{cm}^3})(\frac{v_\mathrm{m}}{10^{-4}c})\mathrm{cm}^{-2}\mathrm{s}^{-1} \\ &\approx 2.5 \times 10^{-4} (\frac{\zeta_\mathrm{m}^{(0)}}{\zeta_S})(\frac{n_B^{(0)}}{1\mathrm{cm}^3})(\frac{v_\mathrm{m}}{10^{-4}c}) \times (100\mathrm{m})^{-2}\mathrm{Yr}^{-1},\end{aligned} \tag{4}$$

where n_m is the number density of the magnetic monopoles, v_m is the average velocity of the flight magnetic monopoles in space, $n_B^{(0)}$ is the number density of the baryons in the interstellar space, and $\zeta_S = G m_B m_m / g_m^2 \simeq 1.9 \times 10^{-25}$ denotes the Newton saturation value of $\zeta_m = N_m/N_B$, where N_m is the total number of the flight magnetic monopoles and N_B is the total number of nucleons. $\zeta_m^{(0)}$ is the value of ζ_m in the interstellar space, and its upper limit is $\zeta_m^0 \le 10^{-20\pm1}$ (Parker, 1970; Lazarides et al., 1981). After formation of stars the total number of the magnetic monopoles captured by the stars from space is estimated to be

$$\begin{aligned}N_m = 4\pi R^2 \Phi_m T &\approx 3 \times 10^{24} \left(\frac{\zeta_\mathrm{m}^{(0)}}{\zeta_S}\right)\left(\frac{n_B^{(0)}}{1\mathrm{cm}^3}\right) \\ &\times \left(\frac{v_\mathrm{m}}{10^{-4}c}\right)\left(\frac{R}{10^3 R_\odot}\right)^2\left(\frac{T}{10^7\mathrm{Yr}}\right).\end{aligned} \tag{5}$$

where R is the radius of the star, T is the age of the progenitor of the supernova. The captured superheavy monopoles are gathered at the core of the stars.

Due to the RC effect, the luminosity produced by the nucleon decay catalyzed by magnetic monopoles in the core of the stars is

$$L_m = N_m \langle \sigma v \rangle n_B^{(c)} m_B c^2, \tag{6}$$

where $\sigma \sim 10^{-25}$–10^{-26} cm^2 is the cross section of the RC effect (Rubakov, 1981; Callan, 1983), v is the thermal velocity of the nucleons, and $n_B^{(c)}$ is the central number density of the baryons for the star. The temperature would reach 10^{11}K in the collapsed core of the supernova, i.e., $v/c \ge 0.1$. Thus,

$$\begin{aligned}L_m \sim (10^{42} - 10^{43}) &\left(\frac{n_B^{(c)}}{n_\mathrm{nuc}}\right)\left(\frac{\sigma}{10^{-26}\mathrm{cm}^2}\right) \\ &\times \left(\frac{R}{10^3 R_\odot}\right)^2\left(\frac{T}{10^7\mathrm{Yr}}\right).\end{aligned} \tag{7}$$

This luminosity is enough to explain the supernova explosion, when the density of the supernova core is greater than the nuclear density (n_nuc).

As long as we assume that the initial mass of the progenitor of the SLSN is greater than $150M_\odot$, then its radius before the supernova explosion was greater than $10^4 R_\odot$, and the life of the supermassive star is only 10^5–10^6 Yr. Thus, the luminosity produced from the nucleon decay catalyzed by the magnetic monopoles in the collapsed core of the supernova, where the density of the core is much greater than the nuclear density, will be greater than 10^{42}–10^{43} ergs. This luminosity is enough to make the SLSN exploding, so that the SLSN is explained naturally.

On September 14, 2015 two detectors of the Laser Interferometer Gravitational-Wave Observatory (LIGO) simultaneously observed a transient gravitational-wave signal (GW150914) (Abbott et al., 2016). This is the first direct detection of gravitational waves which was commonly explained as the first observation of a binary black hole system mergering to form a single black hole. On December 26, 2015, a second gravitational-wave event, GW151226, was observed by the twin detectors of LIGO (Abbott, 2016).

On February 16, 2016, Connaughton et al. (2016) reported that the Fermi Gamma-ray Burst Monitor (GBM) had revealed the presence of a weak transient source above 50 keV, 0.4 s after the GW event: "This weak transient lasting 1 s does not appear connected with other previously known astrophysical, solar, terrestrial, or magnetospheric activity. Its localization is ill-constrained but consistent with the direction of GW150914" (Connaughton et al., 2016). They also note that the electromagnetic signal from a stellar mass black hole binary merger is not expected if the GBM transient is associated with GW150914. Based on their measurement of the fluence seen by GMB, a luminosity of $1.8^{+1.5}_{-1.0} \times 10^{49}$ erg s^{-1} is derived in hard X-ray emission between 1 keV and 10 MeV.

In another paper Lyutikov (2016) analyzed the physical requirements in some detail that the possible observation of the electromagnetic signal contemporaneous with GW150914 imposes on the circum-merger environment, and found that the required physical parameters at the source exceed by many orders of magnitude what is expected in realistic astrophysical scenarios. He concluded that Fermi GMB signal contemporaneous with GW150914 is unrelated to the black hole merger.

The merger of two black holes can produce the GW only, not the gamma-ray burst simultaneously. However, in our model of stars with magnetic monopoles, the merger of two supermassive neutron stars with the magnetic monopoles, (they cannot collapse to black holes through the RC effect), whose mass density reaches to $(10^5 - 10^6)\rho_\mathrm{nuc}$ at the center core, not only produces the GW, but also produces the gamma-ray burst whose luminosity may reach 10^{49}ergs/s through the RC effect. After we have finished this paper, Racusin et al. (2016) reported on June 15, 2016 that they had made observations of the event GW151226 and candidate LVT151012 with both the Fermi Gamma-ray Burst Monitor and the Large Area Telescope (LAT). No electromagnetic counterparts were detected by either GBM or LAT. We are looking forward to the future detections of the GW which may accompany with the gamma-ray burst. If yes, it at best supports the existence of the RC mechanism, and so implies the possibility of magnetic monopole existence.

Acknowledgment

We would like to thank the anonymous referee for carefully reading the manuscript and providing some constructive suggestions which are very helpful to improve this manuscript. We also thank Professor Daniel Wang, Professor Y.F. Huang, Professor P.F. Chen and Professor J. L. Han for their help to inform us some new information of observations.

References

Abbott, B.P., et al., 2016. Phys. Rev. Lett. 116, 241103.
Abbott, B.P., Abbott, R., Abbott, T.D., et al., 2016. Phys. Rev. Lett. 116, 061102.
Bonnardeau, M., Drukier, A.K., 1979. Nature 277, 543.
Callan, C., 1983. Nucl. Phys. 212, 391.
Cheng, L.X., Leventhal, M., Smith, D.M., et al., 1997. ApJL 481, 43.
Connaughton, V., Burns, E., Goldstein, A., et al., 2016. arXiv:1602.03920.
Dirac, P.A.M., 1958. The Principle of Quantum Mechanics. Clarendon Press, Oxford, 1958.
Dong, S., Shappee, B.J., Prieto, J.L., et al., 2016. Science 351, 257.
Eatough, R.P., Falcke, H., Karuppusamy, R., et al., 2013. Nature 591, 391.
Falcke, H., Markoff, S.B., 2013. Classical Quantum Gravity 30, 244003.
Knödlseder, J., Lonjou, V., Jean, P., et al., 2003. Aap 411, 457.
Lazarides, G., Shafi, Q., Walsh, T.F., 1981. Phys. Lett. B 100, 21.
Lyutikov, M., 2016. arXiv:1602.07352.
Milne, P.A., Kurfess, J.D., Kinzer, R.L., Leising, M.D., 2001. Gamma-Ray Astrophys. 587, 11.
Milne, P.A., Kurfess, J.D., Kinzer, R.L., Leising, M.D., Dixon, D.D., 2000. Am. Inst. Phys. Conf. Ser. 510, 21.
Parker, E.N., 1970. ApJ 160, 383.
Pazameta, Z., 2012. ApSS 339, 317.
Peng, Q., et al., 1985. Sci. Sin. 970, 977.
Peng, Q., Chou, C., 2001. ApJ 551, 23.
Peng, Q., Lie, Z., Wang, D., 1985. Sci. Sin. (Ser. A) 28, 970.
Purcell, W.R., Cheng, L.-X., Dixon, D.D., et al., 1997. ApJ 491, 725.
Racusin, J. L., Burns, E., Goldstein, A., et al., 2016. arXiv:1606.04901.
Rubakov, V., 1981. JETP Lett. 33, 644.
Share, G.H., Leising, M.D., Messina, D.C., Purcell, W.R., 1999. ApJL 358, 45.
Zamaninasab, M., Clausen-Brown, E., Savolainen, T., Tchekhovskoy, A., 2014. Nature 510, 126.