The spin measurement of black holes in active galactic nucleus

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Abstract. Spin as one of the two parameters describing black holes. Measuring the spin of black holes is very important in black holes research. In this paper, we introduce the method to measure the spin of AGNs which is the X-ray reflection method, including both specific content and precautions. Based on this method, we select 25 aim objects and give the spin number. The spins mainly focus on 0.5~1. The selection effect is shortly discussed in this paper. Gravitational waves may be next major technology to measure the spin of AGNs. Gravitational waves method is also briefly introduced in this paper.

1. Introduction

In 1963, Roy Kerr has given the mathematical description of an isolated and uncharged spinning black holes [1]. And it is also provided that axisymmetric black holes have only two independent parameters [2]. So it is all determined by two parameters—Mass and Angular Momentum. Further, we define an unitless parameter “\( a_* \)” equivalent to \( \frac{cJ}{GM^2} \) (\( c \) is the speed of light; \( J \) is the angular momentum of the black hole; \( G \) is the Newton’s constant of gravitation and \( M \) is the mass of the black hole. And the in this Unit system we set \( c \) and \( G \) equal to 1). We call the “\( a_* \)” spin of black holes.

In general, black holes can be classified by Mass. From small to large, they are Primordial black holes, Stellar Mass black holes, intermediate-mass black holes and supermassive black holes (SMBHs). The standard is the mass compared with the mass of the Sun. As the other parameter to describe the black holes, spin (especially the spin of SMBHs) is the major point we study in this paper.

SMBHs are founded in active galactic nucleus (AGNs). Because of the characters of the AGN, the X-ray reflection method is suitable to measure the spin. The reason will be discussed in following parts.

Academic research about how to measure the spin of AGNs is pretty meaningful. First, if we can get that specific number of the black holes spin, we can get the explore the gravity theory by calculate deviations of the inferred gravitational field from the predictions of general relativity [3]. Second, measuring the spin can help us know more about the growth process. In future, as the computer technology depends higher, computer models of cosmological galaxy formation may give us a function of how the AGNs formed and the distribution of SMBHs with galaxy mass or type and time since the Big Bang [3]. Last, power jets are a phenomenon found in AGNs. The idea that jets are powered by the magnetic extraction of black hole spin energy has been put forward [4]. While rapidly spin SMBHs are both founded in AGNs with or without powerful jets. So current spin measurement of AGNs may also provide an insight into the physics of relativistic jet production [3]. Based on these, the measurement of the SMBH spin is pretty necessary and meaningful.

There are still some remaining questions about the spin measurement. One of them is the selection effect. We will see the spin number seems more tending to 0.5~1.0. This phenomenon we call it selection effect. This paper will briefly discuss the effect.
In this paper, we will first introduce the method of how to measure the spin of the SMBHs, in which includes the form process of accretion disk; the specific content of X-ray reflection method. Then we will select the observe aim AGNs. And updates the spin number by 10th August,2020. Finally, I analyse the result gotten from the aim AGN. And then give the conclusion and discussion.

2. X-ray reflection method

The accretion disk is a structure mainly composed of diffused gas, which itself rotates around a rotation axis, and exhibits the characteristics like disk. The accretion disk is a gas disk that surrounds the central celestial body. At present, the black hole-accretion disk model is a widely accepted standard model of the AGNs. In this model, the center of the AGN is a supermassive black hole, and the surrounding gas is drag toward the black hole by the gravity of the black hole. While the gas retains the original angular momentum, so the accretion disk surrounding the central SMBH is formed [5]. Black holes convert the gravitational potential energy of gas into radiation energy through accretion.

There is an innermost stable circular orbit (ISCO) in the accretion disk. In the Schwarzschild black hole, the radius of the ISCO is three times the Schwarzschild radius. Outside the ISCO, matter can exist stably and the ionization degree is relatively low; inside the ISCO, the matter ionization degree is relatively high. The gas flows rapidly toward the central black hole. The material density is very low. The ISCO size has a functional relationship with the AGN spin parameter [6]. In this way, what we only need to do is obtaining the radius of ISCO by analysing the spectrum.

Electromagnetic radiation generated by the accretion disk is mainly in the visible and ultraviolet bands. In the process of outward propagation, the photons in the radiation will get on the inverse Compton scattering with high energy electronics and result in the X-ray hard power law spectrum. Then the high energy photons produced from inverse Compton scattering will interact with substances in the accretion disk again and generate reflection spectrum. The spectrum includes the characteristic spectral lines of the contained elements after being excited by photons. Due to the high iron abundance in the accretion disk, we will observe obvious iron fluorescence characteristic spectral lines in the obtained spectrum. In addition, due to the Doppler effect and relativistic effect, the Fe Kα spectral line obtained in the Kerr black hole will be broadened and distorted. Taking into account the gravitational redshift effect, if the ISCO radius is closer to the central black hole, the gravitational redshift effect will be more obvious. In this way, we can get the positions of the ISCO through the spectral profile under the influence of the redshift effect. Then we can get the spin of SMBHs. In general, these is the specific content of using the X-ray reflection method to measure the spin of SMBHs [7-9].

When using the X-ray reflection method, there are some matters needing attention. The soft excess is a very important part of the AGN reflection spectrum. Below the 1KeV band, the radiation flux is twice more than the 2-10KeV radiation flux. At the same time, the power exponent of the power law spectrum rises rapidly, so we will observe an obvious bump at the low energy of the reflection spectrum. This phenomenon is particularly obvious in Type I AGN. The soft excess has yet had a good explanation. The interpretation of the soft excess in the future may result in higher measurement accuracy of reflection method [10]. In addition, we also shall pay attention to whether there are any restrictions on the actual observation object, whether the actual situation conflicts with the ideal model of the X-ray reflection method. These are the matters that needs attention in the actual measurement.

3. Spin results of some SMBHs

Vasudevan [11] quoted the table in Reynolds [7] and updated one data in that table. We update the spin of SMBHs in 24 AGNs in Table 1 and add another aim object (Mrk 766).
Table 1. Summary of the spin of 25 AGNs

| AGN            | Spin  | Reference |
|---------------|-------|-----------|
| Ton S180      | 0.92±0.03 | Wa13[12] |
| Mrk 359       | 0.66±0.30 | Wa13[12] |
| Mrk 1018      | 0.58±0.56 | Wa13[12] |
| 1H0419-577    | > 0.89  | Wa13[12] |
| Ark 120       | 0.64±0.11 | Wa13[12] |
| Swift J0501.9-3239 | > 0.99  | Wa13[12] |
| Mrk 110       | > 0.89  | Wa13[12] |
| RBS1124       | > 0.97  | Wa13[12] |
| Mrk 841       | > 0.52  | Wa13[12] |
| Ark 564       | 0.96±0.01 | Wa13[12] |
| NGC 3783      | > 0.88  | Br11[13] |
| IRAS 00521-7054 | > 0.77  | Wa19[14] |
| Mrk335        | > 0.91  | Ga15[15] |
| Mrk766b       | > 0.92  | Bu18[16] |
| NGC 1365      | > 0.84  | Ri13[17] |
| 3C120         | > 0.95  | Lo13[18] |
| 1H0707-495    | > 0.97  | Zo10[19] |
| Mrk 79        | 0.7 ± 0.1 | Ga11[20] |
| NGC 4051      | > 0.99  | Pa12[21] |
| IRAS13224-3809| > 0.987 | Fa13[22] |
| MCG-6-30-15   | 0.989±0.009 | BR06[23] |
| ESO 362-G18   | > 0.92  | AG14[24] |
| H1821+643     | > 0.4   | Re14[25] |
| NGC 4151      | > 0.9   | Ke15[26] |
| Swift J2127.4+5654 | 0.6 ± 0.2 | Mi09[27] |

* IRAS 00521-7054 consistent with more recent result
b We replace the Fairall 9 with Mrk 766
c Spins are quoted with 90 per cent error ranges.

Obviously, the ratio of spin values above 0.5 is too high. From the perspective of actual observation, due to the limitation of observation, AGN with higher brightness will be easier to observe, which itself in turn requires at least part of the corona to lie at h < 10R_g [11, 28]. Therefore, this tendency may be due to insufficient sample or the sample is not representative. If we can get more spin of representative samples. The selection effect can be more understood.

4. Discussion and Conclusion
The content of this article mainly revolves around measuring the SMBHs spin. In the introduction, the significance of measuring SMBHs in AGN spin is discussed. 1. Measuring the spin parameters of black holes can be used to verify whether the gravitational theory is correct and how the error can be corrected. 2. The measurement of SMBH spin can help us have a better understanding of the formation of AGN, and it will also be helpful for the measurement of the distribution of SMBHs in universe. 3. The measurement of SMBHs in AGNs spin will provide new insights into the study of jets of AGNs. Then I introduce the method of measuring SMBHs spin—the X-ray reflection method. The main process of the X-ray happening in AGNs and the way to get the spin are both introduced.
After that, we quote the measured spin values of 25 AGNs (updated to 2020.8.10), and we summarize and analyse the obtained results.

The discovery of gravitational waves also provides a brand-new probe for detecting celestial bodies, which can also be applied to the research of detecting the SMBHs spin in AGNs. The current SMBH spin measured by gravitational waves is based on the system of two black holes coupling. The process of two black holes coupling is generally divided into three stages. The gravitational waves radiated by each stage will carry the black hole self-selected information (including the initial and the final stable state). The advantage of gravitational wave detection is that the information carried is less disturbed and more accurate. However, with the current technology, it is difficult to accurately extract the information carried. This is also one of the focuses of the future development of astronomical detection technology.

5. Reference

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