Study of Activity in Galaxies due to the Kerr Metric Dynamics in the Galactic Centers' Black Holes leading to Synchrotron Radiation Emissions

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Abstract

Active galaxy observations have shown spectrums with higher flux values in the low radio frequency ranges, which haven't been completely explained yet. Even though the reason for emissions in certain frequencies is attributed to large amounts of mass in the accretion disk, the increasing angular velocity of the Black Hole, due to the falling mass, could also be the cause of traces of galactic activity. The energy of the accreting particles rises significantly due to twisted deformations of space-time generated by a rapidly spinning Black Hole, based on a Kerr metric, thus, the distorted magnetic fields would lead to the production of non-thermal radiation, specifically, synchrotron radiation. This would explain the low energy peaks appearing in the active galaxy spectrum. Measurements can be made with interferometers within intermediate-class radio telescopes in the low radio frequency ranges (UHF). Finding synchrotron emissions in nearby normal galaxy centers raises the possibility of a center black hole with increasing rotation, which can lead to understanding some facts on the evolution of galaxies and allows an analysis on whether galactic activity is a hierarchical process, or a spontaneous event.

1. Introduction

Active galaxies are characterized by certain properties such as bright star-like nucleus, high luminosity, strong emission lines, occasional radio jets and non-thermal spectra with higher indices of luminosity in regions other than the optical. Therefore the main differences between normal and active galaxies are based on their power spectrum. This is, the sum of the spectrum of each star, dust and gas. As a consequence, normal galaxies present peaks in the optical range, according to Planck's thermal radiation distribution, with absorption lines cut into it. On the other hand, active galaxies show a broadband spectrum with higher than normal values in radio and x-ray frequencies, a phenomenon that is still not completely understood. Electromagnetic radiation in these ranges cannot come in such proportions from star formation or interstellar gas and dust. Despite this, we know for sure that the cause for galactic activity resides in a compact region at the center of the galaxy, specifically, around the central Black Hole. The galactic centers that we are studying mainly consist of a central massive rotating Black Hole, with gas and dust irrepressibly accreting onto it and forming a disk around it due to angular momentum conservation. Although there are no exact measurements of a Black Hole's rotation, galactic and stellar evolution strongly suggest that they have an intrinsic angular momentum. When the large amounts of mass from the accretion disk are pulled at tremendous speeds by the large gravitational force of the Black Hole, friction between the particles generates an increase in temperature, which unchains physical reactions that transform the material into plasma, generating a magnetic field. The efficiency of the accretion process leads to the emission of strong galactic jets, which can be observed from the near IR up to Gamma rays. These black holes are considerably massive (greater than 10^6 solar masses), and it has been estimated that this characteristic, along with the large amounts of mass in the accretion disk, are the main factors for galactic activity. But some variables have not been explained yet.

There haven't been strong signs of galactic activity in the Milky Way or the neighboring galaxies, setting them as 'Radiatively inefficient AGNs' because of the radiatively inefficient solutions to the equations that govern the accretion under certain characteristics. This popular model is known as the Advection-Dominated Accretion Flow (ADAF), and explains the accretion of gas onto a Black Hole in a sub-Eddington accretion rate and very high relative opacity [1]. ADAF solutions imply that the accreting matter doesn't form a thin disc, and in consequence, the acquired energy doesn't radiate away efficiently, less than one percent. This may happen if the density of the infalling matter is low and collisions between particles are few. Due to the general characteristics of the Milky Way, low accretion rate and central luminosity, the ADAF model has been widely used to explain the dynamics of our galactic center. On the other hand, recent observations have raised the possibility of a faint galactic jet emanating from the center of our galaxy. "The jet appears to be running into gas near Sagittarius A* producing X-rays detected by Chandra and radio emission due to synchrotron radiation observed by the VLA" [2]. But, "while ADAF may explain the faintness of optical and ultra-violet (UV) emission, its application to explain the compact radio emission from low-luminosity AGN is problematic (…) For Sagittarius A* itself, the standard ADAF model falls short of explaining the cm-wave radio emission by more than an order of magnitude and additional assumptions must be imposed in order to match the spectrum" [3]. So, according to the results of the VLA measurements, there is a mismatch with the ADAF model on the low frequency range that is still not completely explained.

Besides its mass, a Black Hole has another important characteristic: its angular velocity. A Black Hole has all its mass compressed into a small space comparable to Planck's length, so, as more mass falls within the event horizon, the rotational speed of the black hole is accelerated to preserve the angular momentum. The spin parameter of the Black Hole is bounded by its mass: increasing mass would increase the energy and, therefore, the angular momentum [4]. A rotating Black Hole's characteristics are explained by the solutions in the Kerr metric, offering implications as a basis for the proposals in this work.

2. Active Galactic Nuclei

All of galaxy components contribute to the behavior of the radiation peaks. The hot gas clouds are the HII regions, which are very bright and are the cause of the emission lines: the [NII], [OII], [OIII], Hα, Hβ and Hγ spectrum lines peaks in the visible range (400 nm – 700 nm). On the other hand, the dust component is relatively cool and doesn't contribute in the optical spectrum: as it absorbs light, it results in optical absorption lines, although, it is optimal for emissions in the far infrared (around 100 μm). The addition of these two features give form to the visible region power spectrum of a galaxy: absorption lines result from stars and emission lines result from hot gas. Moreover, coincidences between absorption and emission lines, and broadened lines, due to Doppler shift effects, need to be considered.

A notable feature in the active galaxy spectrum is the higher flux peaks, especially in the Hβ and Hγ lines. The strong and broad emission lines show that the galaxy contains hot gas, just like an HII region. This implies that the gas must be either extremely hot or in rapid motion. Since at such high temperatures Hβ emissions wouldn't be possible, because any hydrogen would be completely ionized, the broadened lines cannot be thermal, instead, they should be consequence of bulk motions of several thousand kilometers per second. This means, large amounts of kinetic energy in the gas motions: an energetic accreting disc.

As for other regions of the spectrum, differences are also found between normal and active galaxies. Power spectrums are measured in Spectral Flux Density vs. Wavelength (*F_λ vs. λ)* and in logarithmic axes, because both parameters vary by many powers of 10. But in the case of broadband analysis, spectrums plotted in the form λF_λ *vs.* λ (in logarithmic axes) become more useful when we want to analyze separated parts of a broadband spectrum. This is called Spectral Energy Distribution (SED) [5].

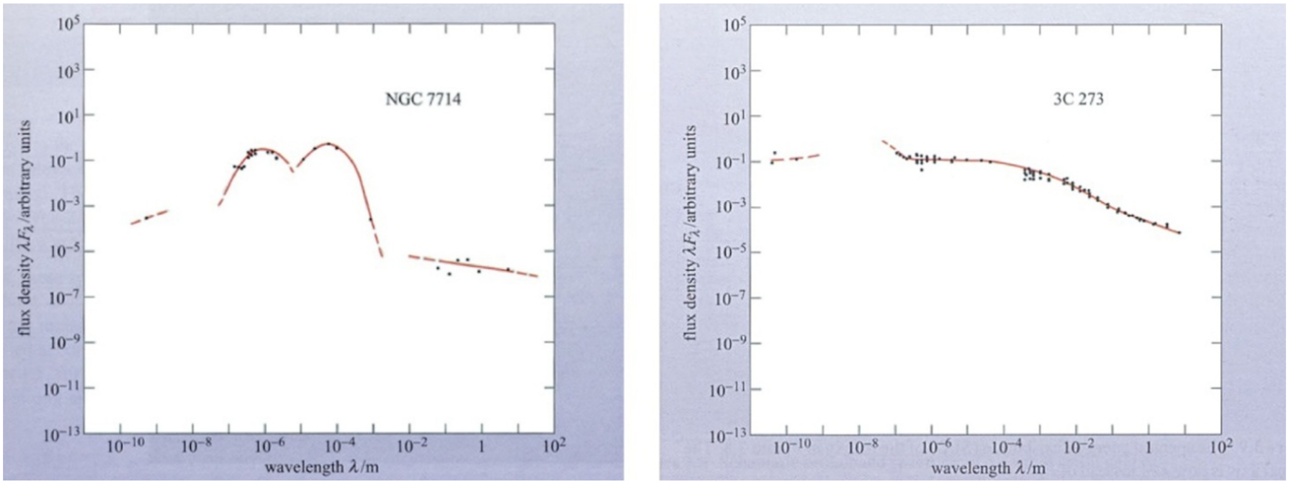

Fig 2. SEDs from a normal galaxy (left) and an active galaxy (right) in the broadband spectrum [5].

It is clearly seen that the normal galaxy SED has its peak in the visible spectrum, as the radiation is dominated in large proportion by the HII regions and the dust components. Also, ranges of high and low frequencies have relatively low values of spectral energy. On the other hand, the active galaxy SED presents a slight peak near the range of the visible spectrum, but the spectral energy is higher than usual in the high frequency range and in the low radio frequency range, relative, not only to the visible range peak, but also to the energy values in the normal galaxy SED. This happens as a consequence of radiation energy being released from a specific and dynamic region in the galaxy other than the HII region. These are the so called Active Galactic Nuclei (AGN), which are classified according to the characteristic of their emissions. This work is based on the study of galaxies with central super massive black holes, whose dynamics could provide information about the nucleus emissions, focusing primarily on the low radio frequencies.

2.1 Kerr Rotating Black Holes

Einstein's general relativity field equations suggest variations in the space-time curvature due to the energy-momentum of matter and radiation that are present. It predicts the case when the ratio of an object's mass to its radius becomes considerably large to allow the formation of a region of space from which nothing can escape: a Black Hole. One of the solutions of the Einstein field equations is provided by the Kerr metric. The use of Newman and Janis's null tetrads to obtain Kerr's solution in a frame metric, leads to an appropriate coordinate transformation (t, r, θ, φ) that presents the most useful form to investigate the properties of the solution, the Boyer-Lindquist form [6]:

$$ds^2 = \frac{\Delta}{\rho^2}\left(dt - a\sin^2\theta\, d\theta\right) - \frac{\sin^2\theta}{\rho^2}\left[(r^2 + a^2)d\varphi - a\, dt\right]^2 - \frac{\rho^2}{\Delta}dr^2 - \rho^2 d\theta^2 \tag{1}$$

where

$$\Delta = r^2 - 2mr + a^2 \tag{2}$$

$$\rho^2 = r^2 + a^2\cos^2\theta \tag{3}$$

This solution depends on two parameters: "a" and "m". Here, "m" is identified as the geometric mass in a stationary and axially symmetric solution, being this symmetry valid only under the simultaneous inversion of "t" and "a". This property suggests that the Kerr field emerges from a spinning source, where "a" specifies a spin direction, relate to the angular momentum. According to calculations on the Riemann invariant, the Kerr metric has only one intrinsic singularity when $\rho = 0$, which implies a singularity in the form of a ring of radius "a" lying in the equatorial plane. "The Kerr solution is no longer spherically symmetric and so we no longer expect that there are any curves corresponding to radial null geodesics. This is because, in a loose sense, we expect a rotating source to 'drag' space around with it and consequently drag the geodesics with it (…) The nonlinear field equations couple the source to the exterior field" [6].

On the other hand, by working on the frame metric, the vanishing of the first component (g_{00}) (according to the physically more accurate case $0 < a^2 < m^2$, when the spin is small compared to its mass) results on two surfaces of infinite red shift, which implies the existence of two null event horizons. The region between these two is called the ergosphere (the stationary limit), where the light cones tip over in such extent that photons and particles are forced to orbit the source in the direction of its rotation. Outside the ergosphere, the ionized matter (the plasma) from the accretion disk is attracted by the strong curvature of the Black Hole, swirling around and reaching intense energies. This may lead to intense electric currents whose flow would result in a powerful magnetic field that would act like a giant electromagnet. When a particle from the accreting disk is fired into the ergosphere, where it is propelled in concurrence with the twisted spacetime, it decays into two products, one of which escapes outside the stationary limit. By the quadru-momentum conservation, the energy of the particle that enters the black hole is negative and, therefore, we can conclude that the energy of the escaping particle is greater than the initial energy of the system: the escaping components contain more mass-energy than the originally decayed particle. As a consequence, there is a progressive energy extraction and the angular momentum of the Black Hole is reduced. This is called the Penrose process. Another solution to Einstein's equation is the Kerr-Newman solution which implies a rotating Black Hole with a charge. This scenario is not considered in our work because calculations reveal a very small charge value compared with the mass, to the point where it can be neglected for the purposes of this study.

3. Synchrotron radiation

The study of low frequency radiation is useful because there is no need of high resolution radio telescopes or highly privileged locations for its operation. The above explanation of the Kerr Black Holes dynamics, leads us to assume that there are non-thermal radiation emissions from the center of the galaxy. This would be Synchrotron radiation, a non-thermal electromagnetic radiation generated by charged particles, mainly electrons, moving along curved helical trajectories due to the strength lines in a magnetic field, at high relativistic speed. As it has been explained, these emissions can be produced by the electron proliferation from the Black Hole's ergosphere and the distorted magnetic fields. The characteristics of the Synchrotron radiation make it simple to measure in UHF frequencies. This happens because the frequency spectrum of this radiation emission mechanism behaves as a power law:

$$\mathrm{I}(\nu) \propto \nu^{-\alpha} \tag{4}$$

Where the spectral intensity is a function of the frequency and α is the experimental spectral index. As the velocity of the particles is close to that of light, the radiation is concentrated in a narrow cone directed along the line of movement. The acceleration of the electrons emits radiation in the radio wavelength. As a result, a graphic would show that the highest intensity peaks in the spectral distribution of the total radiation correspond to the lowest radio frequencies (as low as UHF and even VHF).

4. Discussion

The behavior of the active galaxies SED leads to a different analysis of the AGNs dynamics due to the significant non-thermal emission intensities in the spectrum distribution. For this type of emissions to be possible, severe distortions of the core's magnetic fields and proliferation of ionized particles are needed, and a massive accretion disk accreting into a stationary Black Hole is not enough to create the necessary conditions in terms of temperature and energy. Moreover, recent publications [2] discuss the detection of Synchrotron radiation coming from the center of our galaxy, which still does not have a concrete explanation and do not match the model of 'Radiatively inefficient AGNs' granted to the Milky Way [4]. So, the proposal is based on the need for a strong distortion of space-time in the vicinity of the Black Hole and this would be basically produced due to an enormous amount of angular momentum of the Black Hole. This is where the Kerr metric implications play an important role.

According to Kerr's solution, the subsequent accretion, likely to be through a thin disk, remains stable over long times and the angular momentum of the Black Hole increases rapidly (the added angular momentum per unit mass is always proportional to the accreting mass) [4]. Therefore, there is a metric frame that is increasingly dragged and twisted, leading the ionized particles from the inner accretion disk to such speeds that will cause significant increases in energy, ejecting the plasma electrons to relativistic speeds. The electric currents generated, along with the frame metric drag, alter the system's magnetic fields to the point of intensifying and curving their force lines. Jointly, the decay of the particles in the ergosphere leads to the ejection of new particles with more energy than the original. Among them, there are relativistic electrons that will add to the initial proliferation. Note that the ergosphere could eject other particles that generate radiation in other frequency ranges, which increases the argument of the active galaxy broad bandwidth spectrum, but these other processes are not discussed as they don't fall within the observation plan. The already distorted magnetic fields from the Black Hole converge with the electron proliferation and produce the consequent Synchrotron radiation emissions from the galactic center.

The extracted energy from the ejected particles in the ergosphere causes an increasing decay of the angular momentum of the Black Hole. This would indicate that there is a growing period that leads to activity in the nucleus of galaxy that will then gradually decrease. Therefore, we can estimate that the activity could present a Gaussian behavior throughout the galaxy's life. Following the consequences produced by a rotating Black Hole in terms of Synchrotron radiation, measurements in low frequencies could provide useful evidence. This is because the spectral flux density from Synchrotron emission rises exponentially as the frequency decreases (order of Megahertz, UHF band).

5. Conclusions and Future Work

Black Holes generally have an intrinsic angular momentum, whose consequences are studied by the Kerr metric. The implications of this general relativity solution lead to a strong possibility of non-thermal emission from the galactic center: Synchrotron radiation. The temporal evolution of a Kerr Black Hole leads to a proposal of a Gaussian nuclear activity evolution model in galaxies if the Synchrotron radiation hypothesis is proven true. This could also explain the very low frequency peaks on the active galaxy spectrum. Evidence of faint emanations from local normal galaxies could be considered as signs of activity transitions due to the angular momentum of the galactic center.

The Institute for Radio Astronomy of the Pontificia Universidad Catolica del Peru is working on an observation program to perform this experiment. An 8 meter dish radio telescope is near completion and will have the ability to reach frequencies in the order of Gigahertz, more than enough for the observation of Synchrotron emissions. Very large base interferometry is also being programmed with other observatories. Experimental procedures, within the galactic local group, will be performed in order to give new insights on this proposal.

6. References

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