Measurement of X-Ray Flux Emissions Using CHANDRA Supports the Existence of a Supermassive Black Hole in the Andromeda Galaxy

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Abstract

It is hypothesized that one object at the center of the Andromeda (M31) galaxy, called M31*, is a candidate for a supermassive black hole at the galaxy’s center. Evidence shows that the X-ray source at the location of M31* is consistent with a point source and a power-law spectrum with an energy slope 0.9 ± 0.2. In order to evaluate this hypothesis, the X-ray emissions of the M31* object were measured using six 40 kilosecond observations taken by the Chandra X-Ray Observatory. It is hypothesized that data should be consistent with data of other supermassive black holes, as well as consistent in multiple wavelengths, and thus support its proposed status as a supermassive black hole. This can be done by quantifying the flux measurements of the supermassive black hole candidate. Photons in the X-ray wavelength were counted in each observation using the software program DS9 (Deep Space 9). Based on the data of several objects near M31*, it can be evaluated if any other objects are affected by the same unexplained event that altered the flux emissions of M31*. Findings were consistent with those of Garcia et. al.1, supporting the idea that M31* is a strong candidate for the supermassive black hole at the center of the Andromeda galaxy.

Introduction

Super massive black holes act as galactic nuclei, and have relatively low levels of luminosity due to an accretion disk. At the center of the Andromeda galaxy (M31), there is a likely candidate named M31*. Around M31* are three objects: P1, SSS (super soft source), and S1. In order for M31* to be identified as a supermassive black hole, it is necessary to measure emissions from the objects at multiple wavelengths, including radio waves, and in the case of the current study, X-rays. The focus of this work was to determine if the candidate object M31*, at the center of the Andromeda Galaxy, is a supermassive black hole. The Chandra X-ray observatory was used to gather point source X-ray data of objects around M31* in the Andromeda Galaxy.

Only a small amount of the data from a full observation was actually needed from the study, so in order to increase efficiency, CIAO (Chandra Interactive Analysis of Observations) software was able to isolate the four objects near the center of the observation. Once the objects were isolated, their pixels were enlarged in order to ease observation. Astronomical software called DS9 (Deep Space 9) was combined with data analysis of the objects by creating a visual representation of the data. As a single photon hit a pixel, that photon would be recorded and represented on a continuous color scale. The brighter the image appeared in DS9, the more photons had come in contact with the pixel at that point. DS9 also has several other functions, such as automatically counting the number of photons in a region, removing a portion of the data, and automatically centering a region on a light source.

Regions also must be standardized in order to maintain consistency in data analysis. Because the images are taking pictures at differing levels of magnification, a standard size must be developed. Arcseconds (or measurements equal to 1/1,296,000 of sky), are used for this purpose. Their units are then squared, in order to have a unit of area rather than one of angular quantity. This allows for a region to isolate part of an image in a standard way to prevent error that would be caused by measuring areas of sky based on resolution. For example, a region of 1000 pixels could vary from 25 to 0.01 arcseconds of sky, simply based on the level of magnification. In order to allow reproducibility for techniques, regions were consistently used in arcseconds.

Sherpa2 is another data analysis tool that works with DS9 to make models of astronomical data, graphical representations of spectra, and run scripts. By taking the data chosen through DS9, Sherpa can create a model or graphic representation of the data which could be more helpful delineating trends. In order to write a script within the software the commands must be given in a coding language called Python (Python Software Foundation, http://www.python.org). The script involves a list of variables, which include, 1) the relative x and y positions of the four objects; 2) the background interference; 3) the radius of the light source, and; 4) the amplitude of the light being emitted from the source. Based on these variables, a model of the data is created. These variables are manipulated to improve the accuracy of the model, also known as the fit. The accuracy of the fit can be determined from a third image, which filters the background information and compares the fitted model to the data. The closer the sum of the photon counts in this “fit” image is to zero, the more accurate the model. Therefore, as the model and the data cancel out, a perfect “fit” image would be blank.

Webpimms6 is a publically available web program that uses certain input, such as photon counts, the length of the observation, and the distance the object is from the Earth, and systems of equations and algorithms to find other useful information, such as flux. It was used to aid in unit conversion from photon counts.
to flux. Radiative flux is a measurement of the amount of power (light) radiated through a given area that reaches Earth from a certain object, and is measured in ergs per square centimeter per second. Unabsorbed flux is the amount of light which is estimated to be emitted by the object based on its distance from Earth, based on the amount of light measured from Earth. Thus, it is the amount of flux which is not absorbed by objects in between Earth and the energy emitted by the object.

Specifically, these calculations quantified the number of photons in the X-ray spectrum that were registered during a 40 kilosecond (ks) observation. By quantifying the flux measurements of the supermassive black hole candidate, it is predicted that unabsorbed X-ray flux data should be consistent with the unabsorbed X-ray flux data of other supermassive black holes, as well as with data in other electromagnetic wavelengths (such as radio), and thus support that M31* is a supermassive black hole. The flux measurements coincide with Garcia et al.'s results and therefore support the hypothesis.

Materials and Methods

The research consisted of six 40 ks (about 11 hours) observations which took place on October 5, 2001, September 1, 2011, September 6, 2011, June 1, 2012, June 6, 2012, and June 12, 2012. In each of the observations, CIAO was used to isolate useful sub-images and to enlarge the pixels to assist in observation. Each of the sub-images is fitted to a model using the data analysis tool Sherpa. Python scripts are modified in certain variables, including 1) the relative x and y positions of the four objects; 2) the background interference; 3) the radius of the light source, and; 4) the amplitude of the light being emitted from the source. These variables are manipulated until the “fit” image is insignificant and approximately zero. Using DS9 the three objects around M31* could be differentiated into P1, S1, (names of stars,) and SSS (the Super Soft Source). The Sherpa model further helped in finding the positions of the objects. DS9 uses a centering algorithm called Centroid that identifies the center of the X-ray source in the x-y plane. Once the center of a source was known, a vector proportion which estimated the positions of other objects based on another, was used which was based on previous observations; other sources can be placed relative to a single centroided search. Once these sources are differentiated, a centered region of one square arcsecond is created around each object. This region is used to measure the number of photons which hit a certain pixel over the 40 ks observation period. Based on the number of photons and an already known and measured distance of the objects using redshift, the X-ray emission can be extrapolated in terms of flux. The numbers of photons are counted, and the counts then are converted to unabsorbed flux using the program Webpimms. The data of the unabsorbed flux is added to a data set of all the observations of the three objects around M31* and graphed by the amount of flux per object against the date of the observation. The graph is then interpreted for correlations which could support that M31* is a supermassive black hole.

Results

The measurements were fitted to ensure compensation for astronomical background noise, or information that is in the observation, but is not relevant to the study. Before the data is fitted, an image of the raw data can be observed. This image is seen in Fig. 1. It can be seen that the positions of the four objects (P1, P2 (M31*), SSS, and S1) can be differentiated.

Once the data was fit, a model was formed and with a fit image to show its accuracy. A specific variable was put in the script to modify the fitting algorithm in order to compensate for background, improving the precision of the data. This can be seen in Fig. 2. with the raw data in the upper left, the model in the upper right, and the fit image in the lower left. Notice how the image from Fig. 1 is represented in Fig. 2. This is because the raw data is compared to the model in order to demonstrate its accuracy.

When the data has been fit it becomes possible to proceed with flux measurement. Based on the model created by the fit, regions are able to be more accurately centered on the objects. These regions are seen in Fig. 3. where each object is assigned a centroided region. This allowed for the count measurements seen in the Table 1.

Data in Table 2 show that the flux of the first observation of M31* in 2001 was zero. This is a conversion of the count data based on distances, seen in Table 1. However, over time the amount of flux increases (Figure 4) continuing through 2012. Figure 5 shows the data of Garcia et al.'s results on M31* up until 2010. The data shown in Figure 4 shows continued support for the results of Garcia et al., further demonstrating the existence of a black hole at M31*. Additionally, M31* also tends to remain the lowest source of X-ray emission, except on June 1 2012 (Figure 6). In regards to other objects, SSS consistently remains the brightest source and the flux coming from P1 remains relatively constant.
Table 2. Amount of Unabsorbed Flux recorded for each of the candidate objects located in the center of the Andromeda galaxy.

<table>
<thead>
<tr>
<th>Date</th>
<th>S1</th>
<th>SSS</th>
<th>P1</th>
<th>P2(M31*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/5/2001</td>
<td>9.6E-14</td>
<td>1.8E-13</td>
<td>2.5E-13</td>
<td>0.00E+00</td>
</tr>
<tr>
<td>9/1/2011</td>
<td>6.0E-14</td>
<td>1.7E-13</td>
<td>1.0E-13</td>
<td>9.0E-15</td>
</tr>
<tr>
<td>9/6/2011</td>
<td>1.6E-13</td>
<td>1.0E-13</td>
<td>3.2E-13</td>
<td>3.6E-14</td>
</tr>
<tr>
<td>6/1/2012</td>
<td>1.7E-14</td>
<td>1.2E-13</td>
<td>2.6E-13</td>
<td>1.2E-13</td>
</tr>
<tr>
<td>6/6/2012</td>
<td>7.9E-14</td>
<td>1.8E-13</td>
<td>1.6E-13</td>
<td>4.3E-14</td>
</tr>
<tr>
<td>6/12/2012</td>
<td>2.2E-13</td>
<td>8.7E-14</td>
<td>8.4E-14</td>
<td>6.4E-14</td>
</tr>
</tbody>
</table>

Figure 2. The raw X-ray data from Chandra (upper left); the model created using the Python Script using Sherpa (upper right); and the “fit” image (bottom left). X-axis represents photon counts.

Figure 3. DS9 image with 4 centroided regions. X-axis represents photon counts.

Figure 4. The graph shows the photon count rate of the black hole candidate, M31*, on a particular date.

Figure 5. The data from Garcia et. al.4 on M31* based on the date. Black plots represent data taken from ACIS satellites, while those in red are measurements from the HRC. Also the arrows (or carets) represent points in which measurements of the count rate was zero. Notice that the results in Fig. 4 are consistent with the results in Fig. 5. Before 2006 the count rate was consistently zero or at most very low. However, after 2006 the count rate is consistently higher in both cases.

Figure 6. Shows the number of photon counts of an object on a particular date of observation. Each color represents a different object.
Discussion

Research on black holes has been conducted as far back as 1915, when Karl Schwarzschild used general relativity to find a solution which described a mass that was so dense it would cause light to be absorbed. In 1958, David Finkelstein identified the Schwarzschild surface as an event horizon, or the edge of effect of a black hole. After that, research in the field has exploded. In 1971, Lyndon-Bell and Rees hypothesized that at the center of galaxies there lies a supermassive black hole. These black holes can be observed by their emissions of various radiation which is emitted by high amounts of friction in the accretion disk surrounding the black hole. This hypothesis gives way to modern research, more specifically, a candidate for the supermassive black hole at the center of the Milky Way’s sister galaxy, Andromeda.

By looking at the trends in the flux for M31*, the observations taken before 2006 are much lower than those taken after this date. This result further confirms and replicates the former observations of Garcia et al., in which after an anomalous spike in flux in 2006, the flux lowered and then plateaued at a point higher than the original flux measurements prior to 2006. As seen in Fig. 4, the flux has increased significantly from the original observations in 2001. These results in Fig. 4 can be seen to mirror those in Fig. 5, the results of Garcia et al., demonstrating that the results support each other. Not only that, but with the more recent data the increase in flux emissions is still happening. It is possible that the cause of the original spike is also responsible for the increase in average flux after 2006. Unlike older data, these observations were gathered only using ACIS satellite data, rather than both the ACIS and HRC satellite data.

Experimental error may lie in the assumptions that all observations were exactly 40 ks. It is a more realistic expectation that these observations had some minor range, slightly differing from exactly 40 ks. Another assumption that was made was that the distances between the Earth and each of the objects were the same. Of course because those objects occupy different points in space, this is untrue; however, the relatively small differences in distances were treated as negligible.

In Fig. 6 all sources of X-ray emissions remain relatively constant other than M31* (seen in blue) which increases over time. This would support the idea that the two objects are acting independent of one another. Although there was a spike in 2006 for M31* and an increase in flux after that, P1 remains relatively constant.

This constancy suggests that the cause of the change in flux from M31* also does not affect the flux from P1; they seem to be acting independently. This interesting phenomenon, as seen in Fig 1. suggests that the two objects are extremely close in proximity, even merging. Therefore, because the fluxes of the objects are independent of one another, despite their close proximity, the cause of the change in flux of M31* must have only affected M31*, and not P2. There also appears to be no correlation with the changes in flux of S1. This would support that whatever activity caused this increase in flux (perhaps the swallowing of a gas cloud or cluster of stars), would be an activity unique to black holes, and not the stellar objects in the vicinity.

In conclusion, the flux emissions of the candidate do appear consistent with those of a supermassive black hole, and support its candidacy. This is important as the behavior of one of the most important known objects in the sister galaxy to the Milky Way is now better understood.

References


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