Determining the Relationship Between Black Hole Mass and Location by Analyzing Doppler Shifts in Radio Spectra

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Abstract

For our research project we determined the correlation between the masses of several black holes and their angular elevations above the plane of their host galaxy, the Milk y Way. By using a 4.6-meter radio telescope at the Pisgah Astronomical Research Institute (PARI) ,we were able to take spectra of two local black holes, scanning around the frequency of hydrogen emission (1420 MHz). By analyzing the resulting graphs of intensity vs. frequency offset from the hydrogen line, we used the Doppler shifts in the data to determine the velocity of objects orbiting in the accretion disks of the black holes. However, because we were unable to determine the radii of the accretion disks of the black hole, we could not directly calculate their masses. After consulting astronomical databases, we were able to create a graph of mass vs. magnitude of galactic latitude. From this, we found that there is no discernible correlation between black hole mass and galactic latitude.

Introduction/Background

When humans look into the night sky, the light they see coming from distant stars is a form of electromagnetic radiation. However, the electromagnetic spectrum includes much more than visible light, such as infrared, ultraviolet, and radio. Because hydrogen, the most abundant element in the universe, emits radio waves through spectral-line emission, using radio telescopes is an extremely useful way of gathering information about distant objects in the universe. Radio waves are produced when a hydrogen atom loses energy and falls to its ground state, releasing a photon of a unique wavelength in the process.

Experimental Design

We used a 4.6-meter radio telescope at PARI to take spectra of two black holes in the Milky Way: Cygnus X-1 and V404 Cygni. We scanned over frequencies that ranged from 600 KHz below 1420 MHz and 600 KHz above 1420 MHz. These observations occurred on July 17th 2011 at approximately 11:00 pm. The next day we took spectra over the same frequencies in the same spot in the sky (where the black holes were no longer located) in order to obtain background spectra. By subtracting the background spectra from the initial spectra, we had a more accurate representation of the black holes themselves.

Results

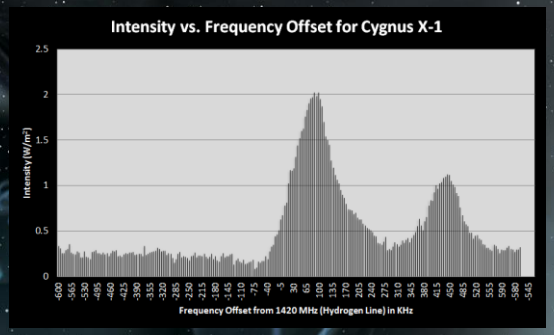


Figure 1: Radio spectrum for Cygnus X-1

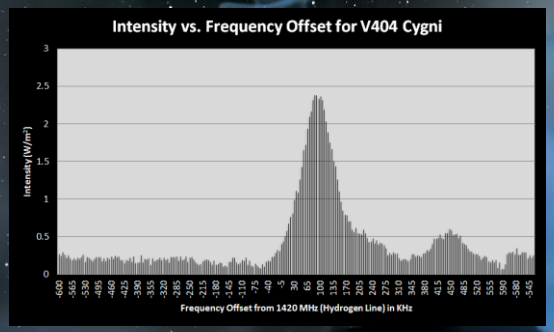
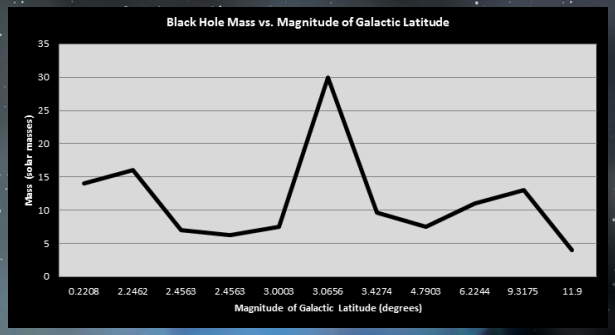


Figure 2: Radio spectrum for V404 Cygni

Figures 1 and 2 show the spectra for Cygnus X-1 and V404 Cygni, respectively. We found that for Cygnus X-1, the first peak occurred at an offset of 95 KHz, while the second peak occurred at an offset of 440 KHz. The midpoint between the peaks was at an offset of 267.5 KHz. For V404 Cygni, we found that the first peak occurred at an offset of 85 KHz, the second peak occurred at an offset of 445 KHz, and the midpoint occurred at an offset of 65 KHz. Using this data, we can determine the velocities of objects orbiting the black holes in their accretion disks, as well as the black hole masses. The graph on the next page shows mass vs. magnitude of galactic latitude for several black holes in the Milky Way. This data was obtained from online astronomical databases.

Thanks You: Mike Castalez, Christi Whitworth, and PARI



Calculations/Discussion

The equation to determine the velocity of an object using its frequency offset is :

$$v = c\left(\frac{\Delta f}{f_0}\right)$$

Using this, we determined that the velocity of the objects orbiting in the black hole's accretion disk for Cygnux X-1 and V404 Cygni were 36 km/s and 38 km/s, respectively. However, we were unable to determine the masses of the black holes because we had no reliable way of determining the radii of their accretion disks. If this data is found, our results can be used to determine the masses of the black holes through simple Newtonian mechanics.

Conclusion

We took radio spectra of two black holes in the Milky Way galaxy: Cygnus X-1 and V404 Cygni. By analyzing the Doppler shifts in the data, we found that objects orbit Cygnus X-1 in its accretion disk at a velocity of 36 km/s, while objects orbit V404 Cygni in its accretion disk at a velocity of 38 km/s. While we were unable to calculate the masses of the black holes ourselves due to a lack of knowledge of the orbital radii of objects in the accretion disks, we were able to use online databases to find the masses and locations of several black holes. For the 11 black holes we analyzed, we found that there is no direct correlation between the mass of a black hole and its angular elevation above or below the plane of our galaxy. Possibilities for future research include analyzing the relationship between black hole mass and radial distance from the center of the host galaxy.