Continual Assessment Number 4

Introduction

Due to the nature of black holes, direct observations and measurements of black holes are almost impossible do but through the use of Kepler's law and a companion star, measurements such as the mass of a black hole can be measured through indirect observations using the companion star.
The aim of this report is to discover whether or not a black hole lies inside the close binary system GS2000 through the use of Kepler's law for binary systems, the measurement of the orbital period using the transit method and the measurement of the orbital velocity through the use of spectral analysis on the companion star.
As the primary object inside the binary system GS2000 is unknown, we shall henceforth call it a compact object.

In order to determine the first step in our calculation of the mass of the compact object, we should first observe the equation in which the mass can be measured, which is the Kepler's law for binary system, which is derived through Kepler's third law and the equations of circular orbits.

Kepler's law for binary stars is given below :-

$$\frac{Mx^3 \sin^3 i}{(Mx+Mc)^2} = \frac{P\,K^3}{2\pi G} \tag{1}$$

Where Mx is the mass of the compact object, Mc is the mass of the companion star, i is the inclination of the orbital plane, P is the binary period and K is the orbital velocity of the companion star.

Through observing the spectral lines of the companion star, the radial velocity of the companion star can be found. Since the companion star is moving away and towards us when orbiting the compact object, the spectral lines of the companion star will be shifted slightly when moving away and towards us. We can therefore compare the doppler shifted spectral lines to a typical spectral lines of a template star, which can be described as a non moving star that is of a similar stellar type to the companion star. The radial velocity of the companion star is determined by trialling various radial velocities and doppler shifting the template star until the spectral lines of both stars overlap one another.
The use of spectral lines to determine the radial velocities instead of the overall spectrum of both companion and template stars is due to the overall shape of both spectrums are very much unknown and that the overlapping of both spectrums would become much more difficult.
By creating a plot of radial velocity with phase, the orbital velocity can be found by finding the semi-amplitude of the companion star through least squares fitting of the velocity curve.

The mass of the companion star is based on previous papers which state that the mass of the companion star is around $0.7M_{\odot}$ (Perrin, 1976). Along with the mass of the companion star, the binary period was also determined to be 0.3440915 days using the transit method (Chevalier & Ilovaisky, 1993).

Through the use of Monte-Carlo error propagation techniques, we can trial several inclines with the knowledge that the incline of the plane must be greater than 0 degrees, simply do to the fact that the mass of the compact object in equation 1 shoots to infinity as the incline falls to 0 degrees. With this same thought process we can estimate the minimum mass of the compact object by using 90 degrees as the incline of the plane.

Analysis

Cross-Correlations

Using spectral data of the companion star provided by W. M. Keck Observatory, we proceeded to cross-correlate the spectral data of the companion star with a template star. The first hurdle in our cross-correlation was to decide on the stellar type of the template star since the stellar type of the companion star was unknown. Since the Keck Observatory also provided spectral data of several different stellar types in which the absorption lines were clearly visible, we trialled and compared all possible stellar types with the companion star and used chi-squared minimisation to find the closest stellar type to the companion star.