The Kinematic Distance to NGC 6309

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Abstract

We present an updated distance measurement to the planetary nebula NGC 6309 (Box Nebula) using the Kinematic Distance Method (KDM). We find the distance to be 4.1 +0.29/-0.38 kpc. This updated approach for calculating the distance to planetary nebulae (PNe) allows astronomers to determine a multitude of other intrinsic features of PNe, such as radius, age, absolute magnitude, and luminosity.

Methods

The Kinematic Distance Method (KDM) utilizes a system of two equations. Firstly, we approximate the galactic rotation curve as roughly flat. From this approximation, we can relate an object's galactocentric circular velocity V_r to the observed radial velocity of the object V_0 (i.e. the component of the velocity which points directly towards or away from the solar system). The equation is:

$$V_r = V_0(\frac{R_0}{R} - 1)sin(l)cos(b)$$

Where *(l,b)* are the galactic coordinates of the object, *R* is the galactocentric radius of the object, and R_0 is the galactocentric radius of the solar system. V_r, V_0, R_0, and *(l,b)* are observable quantities, and thus *R* can be calculated from this equation.

Methods (Continued)

The object, the center of the galaxy, and the solar system form points of a triangle. The Law of Cosines becomes:

$$R^2 = R_0^2 + (dcos(b))^2 - 2R_0dcos(b)cos(l)$$

Where *d* is the heliocentric distance to the object. Utilizing both equations, *d* can be calculated.

Results

We use the following values for NGC 6309 (Box Nebula): V_r = 32 km/s (Vázquez et al 2008, Rubio et al 2015), V_0 = 220 km/s (Zhu 2013, Wenger et al 2018), R_0 = 8.138 kpc (Abuter et al 2019), and *(l,b)* = (9.6548°, +14.8137°) (SIMBAD).

With these values, we calculate two possible distance estimates: 4.1 kpc and 12.6 kpc. Cahn et al 1991 used the comparatively inaccurate Daub method to roughly estimate the distance to NGC 6309. They found approximately d = 2.5 kpc. Because this value is closer to 4.1 kpc than to 12.6 kpc, we conclude that 4.1 kpc is the more accurate distance measurement to NGC 6309.

We generated error bars for our estimate using software created by Wenger et al 2018. The software conducts a Monte Carlo simulation which accounts for uncertainties in the radial velocity estimate, such as uncertainty due to proper motion of the object. The error bars it generated are +0.29 / -0.38 kpc.

Conclusion

Using the distance estimate from the system of two equations and the error bars generated from the Wenger 2018 software, we conclude that the distance to NGC 6309 is 4.1 +0.29/-0.38 kpc. This distance estimate allows us to estimate many intrinsic features of NGC 6309, such as its radius (0.14 pc), its age (27,000 years), its absolute magnitude (-1.6), and its luminosity ($1.3 * 10^{29}$ W).

We hope that future astronomers will utilize the KDM to deepen our understanding of PNe in the Milky Way galaxy.

Acknowledgements

Thank you to Melanie Crowson, Jack Layton, Timothy DeLisle, Thurburn Barker, and Amanda Peake for their help with this project.

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