

Near Earth Asteroid Orbital Determination of 2009 KD5

ARIANNA, KUDRAT, ROY¹

¹*Summer Science Program, 2025, GCSU*

ABSTRACT

Near-Earth Asteroids (NEAs) are asteroids whose orbits come close to Earth. If they are sufficiently sized (greater than 140 m in diameter), they are classified as potentially hazardous asteroids (PHAs). Therefore, to prevent possible collisions with Earth, it is crucial for scientists to monitor and update the orbits of such asteroids. In this paper, the trajectory of 2009 KD5, an Apollo-type NEA and PHA, was calculated based on three observations made during the span of three weeks from June to July of 2025. Using the observed data, the method of Gauss was applied to predict the future position of the asteroid by defining both its orbit and its orbital elements. Additionally, we used the Monte Carlo method with normally distributed values to estimate the uncertainty and refine the right ascension and declination. The calculated results show that 2009 KD5 has a semi-major axis of 1.046 ± 0.0002 AU, an eccentricity of 0.262 ± 0.0002 , an inclination of $13.489^\circ \pm 0.01^\circ$, a longitude of the ascending node of $104.480^\circ \pm 0.01^\circ$, an argument of perihelion of $294.349^\circ \pm 0.02^\circ$, and a mean anomaly of $250.004^\circ \pm 0.03^\circ$. Using these values, the orbit of 2009 KD5 can be accurately constructed, allowing scientists to assess potential collision scenarios with Earth.

1. INTRODUCTION

Asteroids are remnants of the early formation of the solar system; they are composed of rocks, metals, or a mixture of both. Almost all of the Solar System's asteroids orbit in the Main Belt, a ring of rocky bodies and dust located between the orbits of Mars and Jupiter. Consequently, more than 1.3 million main-belt asteroids have been discovered to date. Although the majority of asteroids are located within the asteroid belt, there are near-Earth asteroids (NEAs) that have orbits that come near Earth. NEAs [W. F. Bottke et al. (2002)] are asteroids with a perihelion distance (q) less than 1.3 astronomical units (AU). Understanding their trajectory is important because some asteroids could pose potential threats to Earth. [J. S. Stuart & R. P. Binzel (2004)] NEAs are classified into four groups, Atira, Amor, Aten, and Apollo based on their perihelion and semi-major axis. Out of the four groups, Apollo asteroids are the most abundant, but they also pose the greatest impact threats to Earth. [G. W. Wetherill (1988)] Apollo asteroids have a semi-major axis greater than 1 AU and a perihelion distance less than 1.017 AU. A notable example of an Apollo asteroid is 2009 KD5. On May 26, 2009, KD5 [M. Hicks et al. (2010)] was discovered via a sky survey in Spain. In 2010, the conducted follow-up time series photometry showed two superposed light-curve periods, a signature often produced by a synchronous binary system. The finding remains unconfirmed, but

suggests that KD5 could be similar in structure to Didymos/Dimorphos. With an estimated diameter of approximately 0.8 kilometers, 2009 KD5 is larger than 97% of known NEAs. Furthermore, asteroid 2009 KD5 has a perihelion distance of 0.722 AU, which is within the NEAs threshold. And, during its 391-day orbital period, KD5 will pass rather closely to Earth (within 0.14 AU) on July 13, 2025. Moreover, during the June to July time frame, 2009 KD5 has an apparent magnitude of 16.8 to 16.0, which means that it will be observable during this time frame using a ground-based telescope (Camera fov: 12' x 16').

In this study we will determine the orbital trajectory of asteroid 2009 KD5 using the Method of Gauss. This method requires collecting three precise astrometric observations. Using the three distinct observations, we can determine the asteroid's right ascension and declination on each day. Thus, we can use its position to compute its six Keplerian orbital elements: semi-major axis, eccentricity, inclination, longitude of the ascending node, argument of perihelion, and its mean anomaly. Using these parameters, we will be able to provide a mathematical description of the orbit of the asteroid, allowing us to predict its future location in the sky. Accurate orbit determination of NEAs like 2009 KD5 are extremely important not only for refining ephemerides but also for assessing impact probability. Apollo-class asteroids, because of their Earth-crossing orbits, are also important to ongoing planetary defense. Using ground-based ob-

servations with techniques like the method of Gauss, our study is able to contribute to that cause.

2. METHODS AND OBSERVATIONS

2.1. Target Selection

Asteroid 2009 KD5 has an apparent magnitude value that ranges between 16.8 and 16.0, which makes it brighter than the limit of 17. This means that at its brightest it is approximately 2.5 times brighter than the minimum apparent magnitude necessary for viewing. Due to its visibility, the 2009 KD5 is an ideal NEA for observation. Moreover, the 2009 KD5 has an altitude that varies between 45 and 58 degrees. And, since we took our observations at Georgia College and State University (GCSU), which is located at a latitude of 33 degrees, 2009 KD5 is within our viewing range. Due to these various aspects it makes 2009 KD5, ideal for us to observe.

Date (UTC)	Time (UTC)	Right Ascension	Declination	Air Mass
06/12/2025	03:15	17 51 51.11	+06 53 51.2	1.2 Air Mass
06/16/2025	03:15	17 38 30.16	+05 34 16.6	1.2 Air Mass
06/22/2025	03:15	17 09 02.37	+01 53 40.5	1.2 Air Mass

Table 1. Values of observation parameters

2.3. Image Calibration

For our image calibrations, we followed standard CCD reduction procedures. We took seven darks and flats, then calibrated and preformed bias corrections using the same exposure times. Moreover, to account for the differences in temperatures and dark current, we took pictures of darks for each night. Calibration was applied via a master dark, master flat, and master bias, which was created by median-combining the respective sets. Using AstroImageJ, calibrations were applied to all of our images, this ensured consistent photometric quality throughout our dataset.

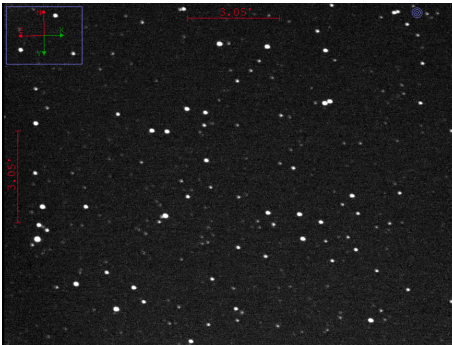


Figure 1. The stacked image processed using AstroImageJ.

2.2. Observing Methods

Asteroid 2009 KD5 was observed using the optical telescope at the Pohl Observatory at GCSU, Milledgeville, which has a latitude of 33 degrees and a longitude of 82 degrees. The telescope is a Plane wave Instruments Corrected Dall-Kirkham (CDK 24) with a focal ratio of f/6.8. Over the course of multiple weeks, we took observations of five second exposures at 4:00 UTC of KD5 at regular intervals. During this time frame, the asteroid was at a relatively high elevation which minimizes atmospheric distortions. (10 - 12 min intervals). Standard calibration procedures were performed, including bias, dark, and flat corrections, in order to reduce instrumental noise. Afterwards AstroImageJ and SAOImage DS9 were used to compare and animate images in order to compare images and locate the asteroid.

2.4. Astrometry

Standard plate solving was performed within the AstroImageJ software. We made sure our images were aligned using WCS from where the RA and Dec direction of the telescope, and afterwards we stacked the images. Using those stacks, we blinked through the images that were taken with 10 minute intervals in order to determine the asteroid's movements. Position of the target asteroid was determined using an api key from astrometry.net by using positions of known stars as reference, fitted to a linear regression.

2.5. Photometry

Photometry was carried out in AIJ using differential aperture photometry. Using reference stars, the stacked images were plate solved in order to determine specific right ascension and declination for specific pixel values. Then, we used SAO Image DS9 in order to map the APASS catalog onto the plate=solved image. Five stars with known brightnesses had their apparent magnitude taken. These values were graphed against the logarithm of the source-sky values (background noise was subtracted out by utilizing an annular at a width around the aperture) taken with AIJ. A linear relationship was established using least squares plate reduction and the

apparent magnitude of KD5 was determined by plotting its measured source-sky value.

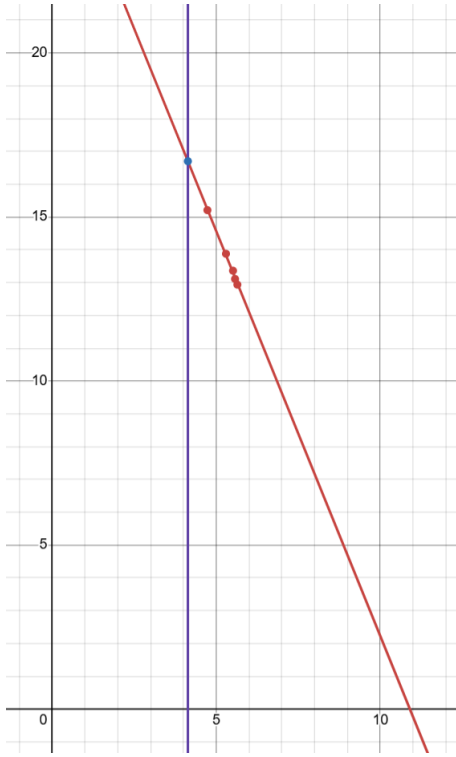


Figure 2. Intersection of the source-sky value for KD5 and the line of best fit, allowing apparent magnitude determination

$$y_1 \sim mx_1 + b$$

REGRESSION PARAMETERS

$$m = -2.46989 \quad b = 26.92107$$

STATISTICS

$$R^2 = 0.9973$$

$$r = -0.9986$$

RESIDUALS

e_1

Figure 3. Least squares best fit line of the five reference stars (apparent magnitude against $\log(\text{source-sky})$)

3. ORBITAL ELEMENTS

Orbital elements are a set of parameters that describe the orbit of an object in a two-body situation. Although there are different ways to represent an orbit mathematically, we used a standard set of six elements commonly used in astronomy to describe the path of our asteroid. These elements define the size, shape, and orientation of the object's orbit, which in most cases is an ellipse

described by the equation:

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$$

Where a is the semi-major axis and b is the semi-minor axis.

Semi-major Axis (a): The semi-major axis is the size of the orbit. For elliptical orbits, it is half the length of the longest diameter of the ellipse. It is the average distance between the orbiting object and the central body (sun).

Eccentricity (e): The eccentricity shows the shape of the orbit, and how it differs from a circular orbit. The closer the eccentricity is to zero, the more circular the orbit. It can be expressed in terms of a (semi-major axis) and b (semi-minor axis):

$$\frac{\sqrt{a^2 - b^2}}{a}$$

Inclination (i): The inclination describes the tilt of the orbit relative to the equatorial plane.

Longitude of the Ascending node (Ω): The ascending node is a point where the asteroid starts moving from south of the ecliptic to the north. Longitude of the ascending node is the horizontal orientation of the point where the orbiting body crosses the reference plane. It is the angle that is measured from the vernal equinox to the ascending node.

Argument of the Perihelion (ω): This is the angle from the ascending node to the perihelion, the point closest to the Sun.

Mean Anomaly (M): The mean anomaly is the angular position of the asteroid in the orbital plane, as if it was orbiting in a circular orbit, viewed from the center of the ellipse. It is measured in degrees from the perihelion point.

The figures below show a visual representation of the orbital elements.

3.1. Method of Gauss

For the method of Gauss, we created Python codes in order to compute the six orbital elements for 2009 KD5. The observations we made provided us with the right ascension (α) and declination (δ) of our asteroid, converted to decimal degrees. In order to find the position (ρ), which is the vector between the Earth and the Sun, we utilized $\vec{r}$, the position vector between the asteroid and the Sun, and $\vec{R}$, the Sun vector. Using these components, and fundamental properties of vectors, we are able to determine the unit vector of ρ .

Using the right ascension (RA) and declination (Dec), we determined the unit direction vector $\hat{\rho}_i$.

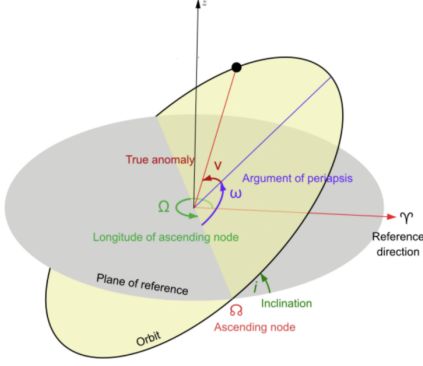


Figure 4. Visualization of all orbital elements except Mean Anomaly

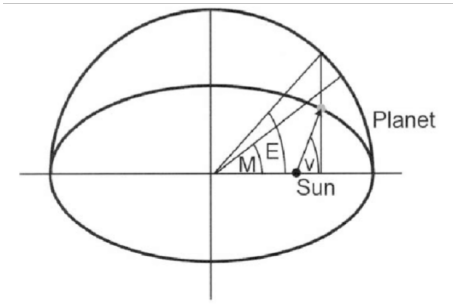


Figure 5. Visualization of the Mean Anomaly

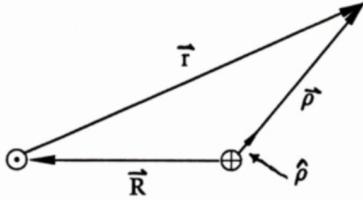


Figure 6. Sum of the Sun vector and position vector.

$$\hat{\rho}_i = \begin{bmatrix} \cos \alpha_i \cos \delta_i \\ \sin \alpha_i \cos \delta_i \\ \sin \delta_i \end{bmatrix}$$

In order to find the Gaussian time intervals, we used $\tau = k(t - t_0)$, where t_0 represents the corresponding Julian date. In our calculations, we assumed $k^2 = \mu = 1$. Using the Julian dates corresponding to our three nights of observation, we calculated the following time intervals:

$$a_1 = \frac{\tau_3}{\tau_0}, \quad a_3 = \frac{-\tau_1}{\tau_0}$$

We computed the initial estimates for the scalar coefficients a_1 and a_3 from the expression:

$$\vec{r}_2 = a_1 \vec{r}_1 + a_3 \vec{r}_3$$

These coefficients allow us to determine the middle position vector $\vec{r}_2$ based on the vectors from the first and third nights.

With the values of a_1 and a_3 determined, we calculated the scalar distances of ρ_1 , ρ_2 , and ρ_3 using the following:

$$\rho_1 = \frac{a_1(\vec{R}_1 \times \hat{\rho}_2) \cdot \hat{\rho}_3 - (\vec{R}_2 \times \hat{\rho}_2) \cdot \hat{\rho}_3 + a_3(\vec{R}_3 \times \hat{\rho}_2) \cdot \hat{\rho}_3}{a_1(\hat{\rho}_1 \times \hat{\rho}_2) \cdot \hat{\rho}_3}$$

$$\rho_2 = \frac{a_1(\hat{\rho}_1 \times \vec{R}_1) \cdot \hat{\rho}_3 - (\hat{\rho}_1 \times \vec{R}_2) \cdot \hat{\rho}_3 + a_3(\hat{\rho}_1 \times \vec{R}_3) \cdot \hat{\rho}_3}{-(\hat{\rho}_1 \times \hat{\rho}_2) \cdot \hat{\rho}_3}$$

$$\rho_3 = \frac{a_1(\hat{\rho}_2 \times \vec{R}_1) \cdot \hat{\rho}_1 - (\hat{\rho}_2 \times \vec{R}_2) \cdot \hat{\rho}_1 + a_3(\hat{\rho}_2 \times \vec{R}_3) \cdot \hat{\rho}_1}{a_3(\hat{\rho}_2 \times \hat{\rho}_3) \cdot \hat{\rho}_1}$$

With the scalar ρ values, we calculated the heliocentric position vectors using:

$$\vec{r} = \rho \hat{\rho} - \vec{R},$$

To estimate the velocity vector for the second day $\dot{\vec{r}}_2$ using a finite difference approximation:

$$\dot{\vec{r}}_2 = \frac{(t_3 - t_2)\vec{v}_{12} + (t_1 - t_2)\vec{v}_{23}}{(t_3 - t_1)(t_3 - t_2)(t_2 - t_1)} \cdot 2(t_2 - t_1)(t_3 - t_2)$$

Using the initial values of the position vector $\mathbf{r}_2$ and velocity vector $\dot{\mathbf{r}}_2$, we can find the initial values of the functions $\mathbf{f}(\tau)$ and $\mathbf{g}(\tau)$:

$$\mathbf{f}(\tau) = 1 - \frac{\tau^2}{2r_2^3} + \frac{(\dot{\mathbf{r}}_2 \cdot \dot{\mathbf{r}}_2)\tau^3}{2r_2^5} + \frac{\tau^4}{24r_2^3} \left[3 \left(\frac{\dot{\mathbf{r}}_2 \cdot \dot{\mathbf{r}}_2}{r_2^2} - \frac{1}{r_2^3} \right) + 15 \left(\frac{\dot{\mathbf{r}}_2 \cdot \dot{\mathbf{r}}_2}{r_2^2} \right)^2 + \frac{1}{r_2^3} \right]$$

$$\mathbf{g}(\tau) = \tau - \frac{\tau^3}{6r_2^3} + \frac{(\dot{\mathbf{r}}_2 \cdot \dot{\mathbf{r}}_2)\tau^4}{4r_2^5}$$

Using these functions, we can find more accurate values for the area covered over day 1 a_1 and day 3 a_3 using the following formulas:

$$a_1 = \frac{g_3}{f_1g_3 - f_3g_1}, \quad a_3 = -\frac{g_1}{f_1g_3 - f_3g_1}$$

Now, we are able to loop through again with our new a_1 and a_3 values, resolving for the position vector ρ of our asteroid at each of the three days. After doing so, we continue by resolving for $\vec{r}$, narrowing down our $\vec{r}_2$ vector and allowing us to calculate new values for $\mathbf{f}(\tau)$ and $\mathbf{g}(\tau)$. We continue calculating a_1 and a_3 and repeat until $\vec{r}_2$ converges.

$$\left| \frac{r_{2,n} - r_{2,n-1}}{r_{2,n}} \right| < 10^{-10}$$

3.2. Calculation of Orbital Elements

In this section, we briefly explain the formulas used to calculate the orbital elements from the position and velocity vectors. We define each variable only when it appears for the first time.

a — Semi-Major Axis was calculated using: v - magnitude of the velocity vector, r - magnitude of the position (radius) vector, and μ - standard gravitational parameter.

$$a = \frac{1}{\frac{2}{r} - \frac{v^2}{\mu}} \quad (1)$$

e — Eccentricity was calculated using the angular momentum vector $\vec{h} = \vec{r} \times \vec{v}$, where h is it's magnitude.

$$e = \sqrt{1 - \frac{h^2}{a\mu}} \quad (2)$$

i — Inclination was computed using the z-component of the angular momentum vector:

$$i = \cos^{-1} \left(\frac{h_z}{h} \right) \quad (3)$$

Ω — Longitude of the Ascending Node Calculated from the x and y components of $\vec{h}$:

$$\Omega = \cos^{-1} \left(\frac{-h_y}{\sqrt{h_x^2 + h_y^2}} \right) = \sin^{-1} \left(\frac{h_x}{\sqrt{h_x^2 + h_y^2}} \right) \quad (4)$$

ω — Argument of the Perihelion

$$\omega = \nu - u \quad (5)$$

Where u is the argument of latitude:

$$u = \cos^{-1} \left(\frac{r_x \cos \Omega + r_y \sin \Omega}{r} \right) = \sin^{-1} \left(\frac{r_z}{r \sin i} \right) \quad (6)$$

And ν is the true anomaly, computed using:

$$\nu = \sin^{-1} \left(\frac{a(1 - e^2)}{he} \times \frac{\vec{r} \times \dot{\vec{r}}}{r} \right) \quad (7)$$

M — Mean Anomaly

$$M = E - e \sin E_1 \quad (8)$$

Where E is the eccentric anomaly:

$$E = \cos^{-1} \left(\frac{ae + r \cos \nu}{a} \right) \quad (9)$$

$$= \sin^{-1} \left(\frac{r \sin \nu}{a\sqrt{1 - e^2}} \right) \quad (10)$$

3.3. Monte Carlo Simulations

Using Monte Carlo simulations, we observed how the orbital elements varied when we slightly changed the values of our RA and DEC. We used random RA and DEC values within the range of their standard deviations, assuming they follow a normal distribution of our orbital elements.

Using the standard deviation formula, we calculated our standard deviations for RA and DEC based on our 3 nights of observations:

$$\sqrt{\frac{\sum (x_f - x_i)^2}{N}}$$

Then, we used the `np.random.normal()` function to generate new random values of RA and DEC within the range of our initial RA and DEC.

By repeating this process many times, we gained multiple values for each orbital element and recorded our results. Then, we created a histogram for each orbital element to visualize the distribution of our outcomes.

3.4. Visualization of the Orbit

The orbit of KD5, defined by the six orbital elements, can be mapped out along with orbits of planets. In Figure 7, we see that the orbit of KD5 is shown in white and displayed with the known orbits of Mars (red), Earth (blue), Venus (purple), and Mercury (pink). The orbit of KD5 shown here utilizes the values shown on JPL.

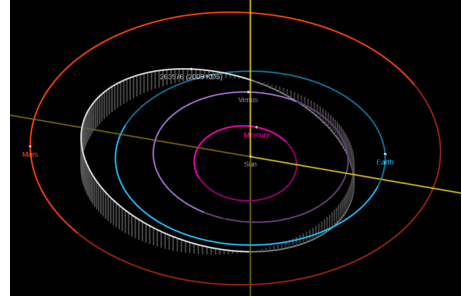
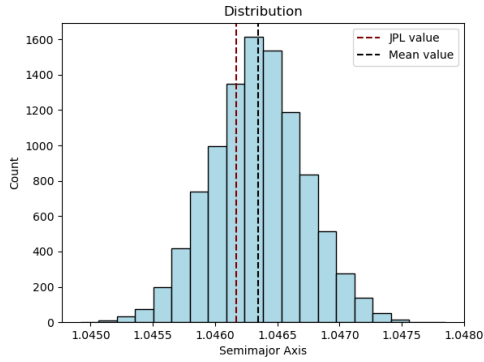
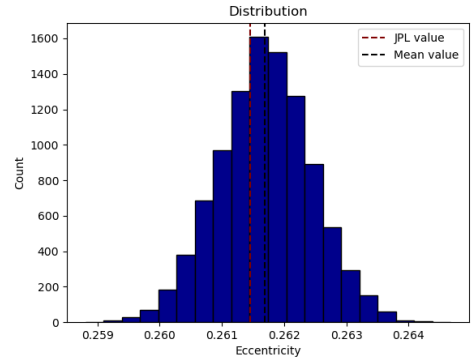
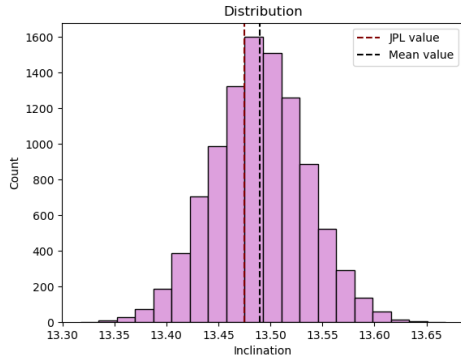
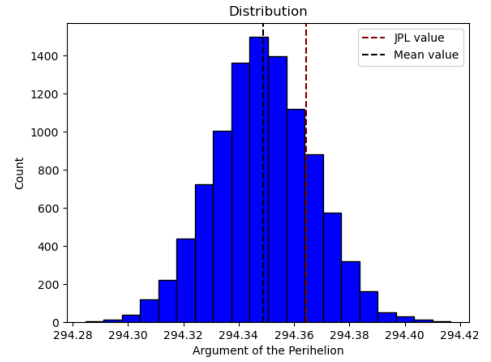
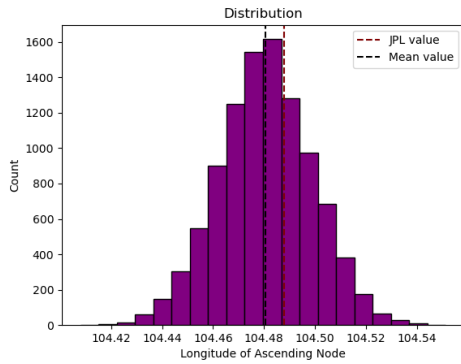
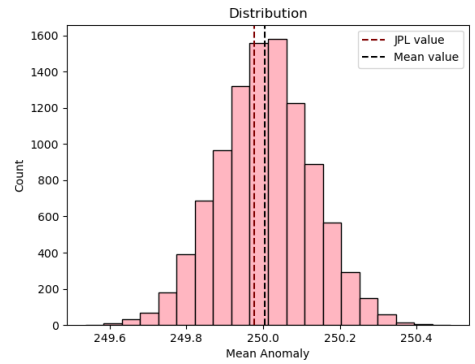


Figure 7. Visualization of the orbit for KD5 (white), compared with the orbits of planets

(a) Monte-Carlo of Semi-major axis (a).(b) Monte-Carlo of Eccentricity (e).(c) Monte-Carlo of Inclination (i).(d) Monte-Carlo of Argument of perihelion (ω).(e) Monte-Carlo of Longitude of ascending node (Ω).(f) Monte-Carlo of Mean anomaly (M).**Figure 8.** Monte Carlo simulation histograms of orbital elements.

RA/Dec	Calculated Value	Uncertainty
α (right ascension)	17.64103611	0.3355782756766465(arcsec)
δ (declination)	5.567166667	0.3447534384521171(arcsec)

Table 2. Declination and Right ascension values

Orbital Element	JPL Horizon Value	Calculated Value	Percent error
a (semi-major axis)	1.04616783 AU	1.046340574375595 AU	0.01651235910480737%
e (eccentricity)	0.2614517041749367	0.2616859705997761	0.08960217933124555%
i (inclination)	13.47466253028116°	13.489005508168269°	0.10644406013788209%
ω (argument of perihelion)	294.3644519261626°	294.3491017809172°	0.005214673560262958%
Ω (longitude of ascending node)	104.4879864687798°	104.48081562998912°	0.00686283565509575%
M (mean anomaly)	249.976439423053°	250.00402204595633°	0.011034089039305308%

Table 3. Orbital Elements with percent error from JPL values

Orbital Element	Calculated Value	Uncertainty
a (semi-major axis)	1.046340574375595 AU	0.0001727469884971189(AU)
e (eccentricity)	0.2616859705997761	0.0002342664248394244
i (inclination)	13.489005508168269°	0.014342977887109143°
ω (argument of perihelion)	294.3491017809172°	0.015350145245406566°
Ω (longitude of ascending node)	104.48081562998912°	0.007170838790671041°
M (mean anomaly)	250.00402204595633°	0.027582622903224774°

Table 4. Orbital Elements with Monte Carlo uncertainties

The presented tables contain our computed orbital elements values and their comparison with their reference data. Table 2 shows our results along with their percentage errors compared to JPL Horizons values, and Table 3 shows the uncertainties for each value. Finally, we created histograms using the Monte Carlo method, which help us visualize the range of uncertainties for each element.

4. CONCLUSION/DISCUSSION OF RESULT

After carefully completing all steps in calculating the orbit of 2009 KD5, we found that our results closely match the orbital elements provided by NASA’s JPL Horizons system. The comparison between our calculated values and the JPL data is shown in the table above. Additionally, all of our percentage errors are less than 0.11%, with very small discrepancies in the semi-major axis, eccentricity, inclination, and angular elements. These small differences may be due to a combination of observational and process-related factors. One major source of uncertainty is incorrect centroiding, the process of determining the exact center of the asteroid in CCD images. This was affected by the use of an in-

appropriate exposure time. So, rather than showing up as a sharp point on our image, the asteroid left trails in the images, making precise centroiding more difficult. Additionally, slight shifts in the telescope during observation may have caused streaks to form into the frames, further reducing accuracy in our positions.

Despite these limitations, the close values between our computed orbital elements and those from JPL showcases the reliability of the Method of Gauss.

5. REFLECTION

Arianna:

Throughout this project, I feel like I have learned a significant amount about coding. I did not have much previous experience with coding; however, over the course of this project, I had the opportunity to develop these skills. One thing that went unexpectedly well was collecting our data. Our team was exceptionally lucky: each time we observed, we were able to collect data. However, we really struggled with lowering our percentage error. Although our code was working, the orbital elements we were outputting for our asteroid were incorrect (correcting our input values was extremely tedious

and stress inducing). Overall, I am thankful for the experience of working in a high-pressure environment, as it pushed me to improve significantly in both my time management and coding skills. **Roy:** Over the course of this project, I learned a lot of things. Starting with the data collection, working with the observatory telescope was very exciting. Figuring out how the software worked and how that controlled what we were viewing was very cool, and it was fun to take photos, not only of our asteroid but also getting to take images of the Dumbbell nebula (M27) and the Eagle nebula (M16). Besides collecting data, it was very interesting to learn about data reduction, figuring out how to correct inherent differences in order to get workable data and a good representation of the amount of light actually collected. I had some experience working with AIJ before this project, however using the data reduction facility and learning how to use SAOImageDS9 were new experiences. Although I had experience coding, learning the syntax and oddities of python was difficult, especially gaining an understanding of mutable vs non-mutable data types. We were very lucky in that we were able to get all of our data from GCSU's observatory without losing any observing time, and glad everything went relatively smoothly. The same cannot be said for our code, as we kept running into bugs and errors in conversion. Debugging was something I struggled with, especially for OD5. However, I am glad that the process of linking everything together was relatively quick. As a whole, this project was a great learning experience and I always felt supported even when I was struggling. **Kudrat:** During this project, I learned a lot. I gained valuable experience, especially in coding. Starting with zero background in programming, I learned how to use Python and create different functions. The most excit-

ing part of the project was the observations, it was an unforgettable experience for me. Using the telescope and collecting data was truly special. One thing that went particularly well was our observations. We were the luckiest team every time we observed, the weather was good. In fact, we were the first team to complete three full nights of observation. The thing I struggled with the most was, of course, Python. But with the help of my team and other participants, I managed to get through it and gradually learned how to code. As an individual, the biggest improvement I made was learning how to ask for help. I struggled a lot in the beginning, but with the support of others, especially my team. I was able to overcome many challenges and learn a great deal. In terms of teamwork, I learned how to collaborate with others to solve problems and delegate tasks effectively. Overall, this research was a life-changing experience for me, both academically and socially.

ACKNOWLEDGMENTS

We would like to thank Georgia State and College University for allowing us to use their telescope. We are also deeply grateful to Dr. Donovan Domingue, Dr. Merida Batiste, and Dr. Hasitha Mahabaduge for teaching various aspects of astrophysics, mathematics, physics and providing us with a solid foundation for our research project. Our sincere thanks go to our wonderful TAs, Fatima, Rithwik, Thomas, and Delaney, for their invaluable assistance with coding, guidance during observations, and support during stressful moments. Finally, we thank Mrs. Chan for her continuous care and support, and for helping make this Summer Science Program experience possible.

REFERENCES

- Bottke, W. F., Morbidelli, A., Jedicke, R., et al. 2002, *Icarus*, 156, 399, doi: [10.1006/icar.2001.6788](https://doi.org/10.1006/icar.2001.6788)
- Cole, A. S., Steffen, A., Pfaffhuber, K. A., et al. 2013, *Atmospheric Chemistry & Physics*, 13, 1535, doi: [10.5194/acp-13-1535-2013](https://doi.org/10.5194/acp-13-1535-2013)
- Collins, K. A., Kielkopf, J. F., Stassun, K. G., & Hessman, F. V. 2017, *Astronomical Journal*, 153, 77, doi: [10.3847/1538-3881/153/2/77](https://doi.org/10.3847/1538-3881/153/2/77)
- Giorgini, J. D., & Group, N. J. S. S. D. 2024, JPL HORIZONS System, <https://ssd.jpl.nasa.gov/horizons/app.html#/>
- Hicks, M., Rhoades, H., Somers, J., et al. 2010, *The Astronomer's Telegram*, 2709, 1
- Joye, W. A., & Mandel, E. 2003, in ASP Conference Series, Vol. 295, *Astronomical Data Analysis Software and Systems XII*, ed. H. E. Payne, R. I. Jedrzejewski, & R. N. Hook (Astronomical Society of the Pacific), 489–491
- Lang, D., Hogg, D. W., Mierle, K., Blanton, M., & Roweis, S. 2024, *Astrometry.net*, <https://astrometry.net/>
- Milani, A., Carpino, M., Hahn, G., & Nobili, A. M. 1989, *Icarus*, 78, 212, doi: [10.1016/0019-1035\(89\)90174-7](https://doi.org/10.1016/0019-1035(89)90174-7)
- NASA CNEOS. 2025, Center for Near Earth Object Studies (CNEOS) - Close Approaches, <https://cneos.jpl.nasa.gov/ca/>
- Roquette, J., Bouvier, J., Alencar, S. H. P., Vaz, L. P. R., & Guarcello, M. G. 2017, *Astronomy & Astrophysics*, 603, A106, doi: [10.1051/0004-6361/201630337](https://doi.org/10.1051/0004-6361/201630337)

Space Reference. 2025, 263976 (2009 KD5) Asteroid Facts,
<https://www.spacereference.org/asteroid/263976-2009-kd5>

Stuart, J. S., & Binzel, R. P. 2004, *Icarus*, 170, 295,
 doi: [10.1016/j.icarus.2004.03.018](https://doi.org/10.1016/j.icarus.2004.03.018)

Tonry, J. L., Denneau, L., Heinze, A. N., et al. 2018, *PASP*,
 130, 064505, doi: [10.1088/1538-3873/aabadf](https://doi.org/10.1088/1538-3873/aabadf)

Wetherill, G. W. 1988, *Icarus*, 76, 1,
 doi: [10.1016/0019-1035\(88\)90138-8](https://doi.org/10.1016/0019-1035(88)90138-8)

Wikipedia contributors. 2023a, File:Orbit1.svg —
 Wikipedia, The Free Encyclopedia,
<https://en.wikipedia.org/wiki/File:Orbit1.svg>

Wikipedia contributors. 2023b, Orbital elements —
 Wikipedia, The Free Encyclopedia,
https://en.wikipedia.org/wiki/Orbital_elements