Orbit Determination
Asteroid 348400 (2005 JF21)
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Abstract
Tracking asteroid 348400(2005 JF21), we calculated values for the six orbital elements that define JF21's heliocentric orbit. We worked with another team that tracked the same asteroid and combined their results with ours to generate accurate orbital elements. We found that JF21's semi-major axis is **2.19726 +/- 0.15047 AU**, eccentricity is **0.53047 +/- 0.028749**, inclination is **10.82301 +/- 0.006151°**, longitude of ascending node is **132.34465 +/- 0.0037859°**, argument of perihelion is **205.92582 +/- 0.0042683°**, and the mean anomaly is **346.55306 +/- 0.034431°**. This data has been sent to the Minor Planet Center to update their databases and improve their prediction models.

1. Introduction
1.1 Background Information
Our research at SSP was geared towards determining the orbital elements of a Near Earth Asteroid. Our subject of study, asteroid 348400(2005 JF21) was labeled by the Minor Planet Center as a potentially hazardous asteroid to Earth. By studying and tracking this asteroid, we have added to the relatively small number of total observations to this asteroid. To determine the orbit, we used an iterative method developed in the 1820s by Gauss. The Gaussian method takes as input three sets of Right Ascension(RA) and Declination(Dec) we calculated through three observation sessions to generate six orbital elements required to define an orbit in space.

1.2 Parameters
The parameters used in this paper to describe orbit related parameters are located in Table 1 and Table 2.

Parameter	Explanation	Parameter	Explanation
α	RA(right ascension)	Ω	longitude of ascending node
δ	DEC(declination)	ω	argument of perihelion
a	semi-major axis	ν	true anomaly
e	eccentricity	U	argument of latitude
i	inclination	M0	mean anomaly

Table 1. Explanations of parameters used in the paper

Parameter	Explanation	Parameter	Explanation
ρ	earth-asteroid vector	**rdot**	sun-asteroid velocity vector
r	sun-asteroid vector	f	f series
R	earth-sun vector	g	g series
τ	time intervals	U	argument of latitude
t	time of observation	M0	mean anomaly

Table 2. Explanations of parameters used in the paper

2. Methods

Observations were taken at the Sommers-Bausch Observatory, CU Boulder, at time intervals that, based on our calculations, added no significant error to our models. An 18" f/8 Cassegrain telescope made by DFM engineering was used with an SBIG STL1301E CCD camera for observations on 2015 July 16 and 2015 July 30, and a 16" f/12 Cassegrain telescope made by DFM Engineering paired with an SBIG STX-16803 CCD camera for observations on 2015 July 23. Images were also taken on the 16'' telescope on 2015 July 19, but were not used in our Orbital Determination(OD) program.

To take images, the telescope first had to be 'snuck up' on to the asteroid by centering and focusing on stars, repeating this process with stars successively dimmer and closer to our asteroid's expected α and δ. Once a dim object was centered and focused, the telescope was slewed to our asteroid's α and δ, and images were taken. For most of the observations, fifteen images were taken in sets of five spaced between ten and thirty minutes apart, depending on how quickly the asteroid was expected to move that night. An ephemeris generated using JPL Horizons was used to determine the asteroid's expected movement. Flats were taken at regular intervals using an illuminated white sheet draped over the telescope. To reduce these images, programs to centroid pixel values for our asteroid in each image, perform centroiding on reference stars in aforementioned images, account for dark current and pixel sensitivity by using flats, find the asteroid's magnitude, and calculate the asteroid's α and δ were created and implemented with our gathered data. Asteroid magnitude was found by using a centroiding program, a Least-Squares-Plate-Reduction program, and a magnitude comparison program to compare the brightness(pixel counts at centroided point) of the asteroid to the brightness of a known star's pixel counts.

Once the α and δ of the asteroid for three observations were determined, they were put into code we produced to determine the orbit of a body using Gauss' method[1].

3. Results

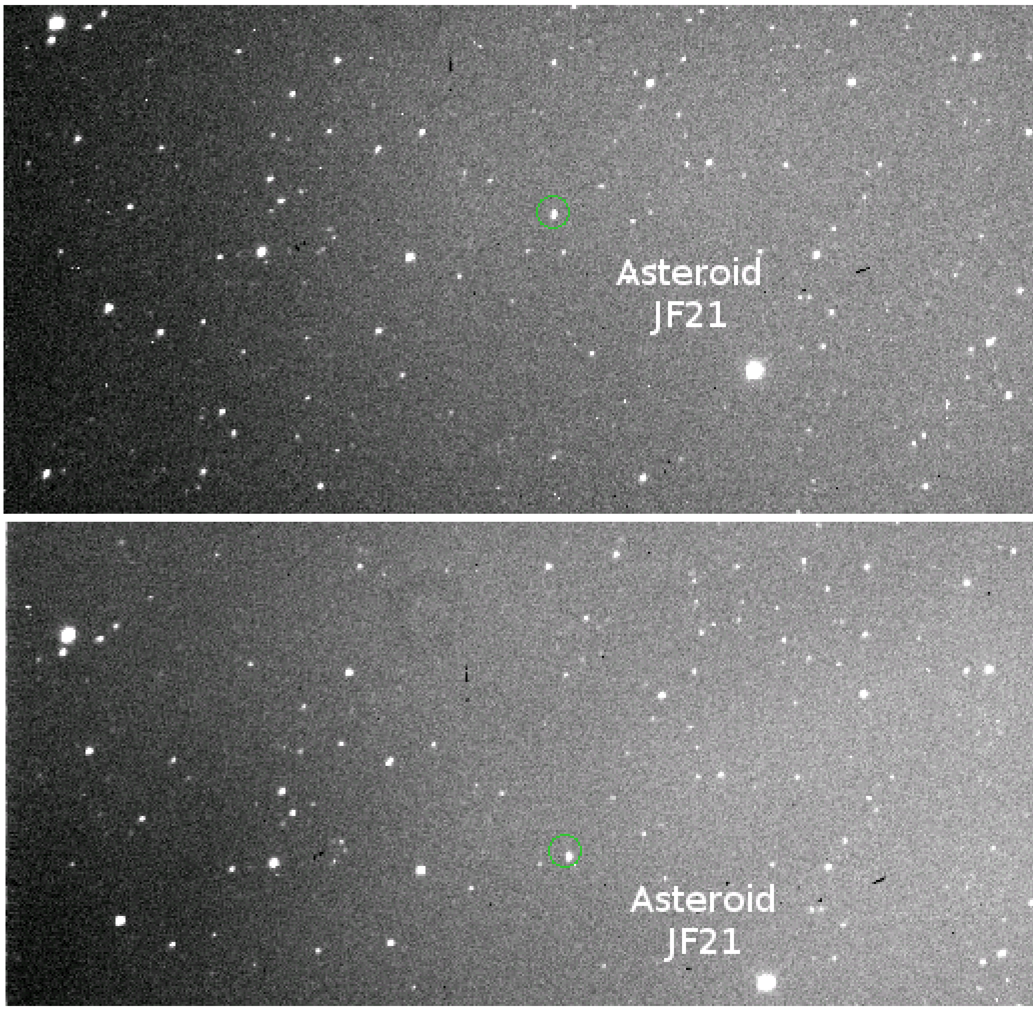

Fig.1. Observations were taken from the Sommers-Bausch Observatory, CU Boulder, at relatively equally spaced intervals. An 18" f/8 Cassegrain telescope was used with an SBIG STL1301E CCD camera.

The images(Figure 1) above were taken on 2015. 7. 30 06:38:14 in UTC with the 18" telescope in Sommers Bausch observatory(Boulder, CO, US). The bottom image is the first image taken in the set, while the top image is the 6th image in the same set. By blinking the images, the asteroid can be found. We have identified the asteroid in the images above by circling it.

	Observation 1	Observation 2	Observation 3
α(RA in decimal hours)	18.04103	18.01159	18.05721
δ(Dec in decimal degrees)	+05.69428	+03.97716	-05.88931
α(RA in H:M:S)	18:02:27.707	18:00:41.724	18:03:25.956
δ(Dec in H:M:S)	+05:41:39.41	+03:58:37.78	-05:53:21.52
time (Julian Date)	2457214.84861	2457220.71271	2457233.77921
time (Y-M-D H:M:S UT)	2015-7-11 08:21:60	2015-7-17 05:06:18	2015-7-30 06:42:04
signal-to-noise ratio(SNR)	80	145	70
Magnitude	13.7 (in V filter)	13.2 (in V filter)	11.5 (in red filter)

Table 3. α, δ, t, magnitude, signal-to-noise for three observations

Using our OD program, orbital elements were generated and compared to the JPL Horizon's values. The percent errors were also calculated and showed in the table below. (Table 4)

Asteroid (348400 (2005 JF))			
orbital elements	Values from JPL	Calculated Values	Errors(%)
a (AU)	2.2234580	2.19725	-1.178382
e(degree)	0.5363051	0.5305	-1.087334
i(degree)	10.871454	10.8230	-0.013456
Ω(degree)	132.3092436	132.3092	0.00984
ω(degree)	205.9905267	205.9258	-0.017974
M0(degree)	345.9997895	346.55306	0.153687

Table 4. orbital elements got using our OD

Table 6. Applied ephemeris generation to the fourth observation compared to RA, Dec generated by another group,

	Computed	Actual
α(in decimal hours)	17.18501	18.01630
δ(in decimal degrees)	1.16209	-01.55190
α(H:M:S)	17:11: 6.029	18:0:58.680
δ(H:M:S)	1: 9: 43.53	-1:33:6.84
t (JD)	2457220.71271	2457220.71271
t(Y-M-D H:M:S UT)	2015-7-17 05:06:18	2015-7-17 05:06:18

Table 6.

4. Discussion

The data used in the orbit determination of 2005 JF21 used three observations from the other team working with the same asteroid (Team 10) and one observation obtained using our own measurements. This is because most of the data we gathered were unable to produce any results that seemed consistent with the asteroid's orbital elements as given by JPL Horizons, but created an even more accurate model than just using the other group's data. Using four permutations of three observations, four sets of orbital elements for 2005 JF21 were produced. The results that had the lowest deviation from the accepted values were the ones reported here as our official results. Uncertainties were generated by using the Jack-knife method of estimating uncertainty. For each set of orbital elements obtained by the four different sets of observations, standard deviations of each orbital element were produced and reported here.

The semi-major axis and eccentricity values obtained in the orbit determination were consistent with the JPL Horizons values within the generated uncertainties. Although the inclination, the longitude of ascending node, the argument of perihelion, and the mean anomaly values were not consistent with the JPL Horizons values within the given uncertainties, the inclination values (calculated versus previously accepted) were within 0.049 degrees, the longitude of ascending node values were within 0.036 degrees, the argument of perihelion values were within 0.065 degrees, and the mean anomaly values were within 0.56 degrees. The error that resulted in these values that differed from the previously accepted values originated from the absence of corrections such as topocentric vector correction and parallax correction. Additionally, errors that originated from the semi-major axis and eccentricity values propagated to the other generated orbital elements. Overall, the values obtained in the orbit determination were fairly consistent with the previously accepted values from JPL Horizons. Due to the asteroid's moderate eccentricity and semi-major axis, there is a low chance that asteroid poses an immediate threat to Earth. More research on this asteroid could be done to more precisely determine and continually monitor the orbital elements of the asteroid with additional corrections.

5. References

[1]https://en.wikipedia.org/wiki/Gauss%E2%80%93Seidel_method : accessed 8/2/15
[2]All of Dr. Fu's lecture notes

6. Acknowledgements

We thank the University of Colorado Boulder for having us here and letting us use their facilities, the donors and alumni of SSP who contributed both their time and money to make this research possible, we thank our fellow students for working with and supporting us throughout the project, but most importantly, we thank the adults who worked with us patiently day and night for five weeks. Thank you, Dr. Mason, Dr. Fu, Dr. Fallscheer, Isabella, Ioana, Joni, Andrew, and Reilly. We owe you a lot. Especially for that trip to Steak and Shake.

7. Appendices

7.1 Appendix 1

Below are the α, δ of three observations generated by our OD.

	Observation 1	**Observation 2**	**Observation 3**
α(in decimal)	18.04103	18.01159	18.05721
δ(in decimal)	+05.69428	+03.97716	-05.88931
α(H:M:S)	18:2:27.707	18:0:41.724	18:3:25.956
δ(H:M:S)	+05:41:39.41	+03:58:37.78	-05:53:21.52
t (JD)	2457214.848611	2457220.71271	2457233.77921
t(Y-M-D H:M:S UT)	2015-7-11 08:21:60	2015-7-17 05:06:18	2015-7-30 06:42:04
signal-to-noise	80	145	70
Magnitude	13.7 (in V filter)	13.2 (in V filter)	11.5 (in red filter)

7.2 Appendix 2

Using the OD program, initial f and g coefficients, and initial **r** and **rdot**, **r**, **r dot**, f,g were iterated 68 times.

Initial F and G coefficients:
f1, g1: 0.998524264176 -0.100836322801
f3, g3: 0.992658963207 0.224244012946
initial **r**: <0.417109, -1.4144, -0.329777>
initial **rdot**: <0.869461, 1.39894, -0.140565>

Revised f1, g1, f3, g3 (The values were generated before iteration):
f1, g1: 0.998622186454 -0.100841483061
f3, g3: 0.991419394727 0.224116815472

Iteration	Revised f1	Revised g1	Revised f3	Revised g3
1	0.998622186454	-0.100841483061	0.991419394727	0.224116815472
10	0.997028340344	-0.100780195613	0.983767702675	0.223522879137
20	0.996868458707	-0.100774282614	0.983066089782	0.22347064806
30	0.996855633444	-0.100773809184	0.983010178723	0.223466501816
40	0.996854509515	-0.100773767701	0.983005281575	0.223466138766
50	0.996854410296	-0.100773764042	0.983004849283	0.223466106718
60	0.99685440153	-0.100773763717	0.983004811088	0.223466103883
70	0.996854400749	-0.10077376369	0.983004807686	0.223466103635

	r		**rdot**
1	<0.416004, -1.05011, -0.355105>		<0.884756, 0.733142, 0.056786>
10	<0.415936, -1.02774, -0.35666>		<0.886127, 0.692144, 0.0685244>
20	<0.41593, -1.02601, -0.35678>		<0.886233, 0.688972, 0.0694339>

30	<0.41593, -1.02586, -0.356791>		<0.886242, 0.688695, 0.0695134>
40	<0.41593, -1.02585, -0.356792>		<0.886243, 0.68867, 0.0695204>
50	<0.41593, -1.02584, -0.356792>		<0.886243, 0.688668, 0.0695211>
60	<0.41593, -1.02584, -0.356792>		<0.886243, 0.688668, 0.0695211>
70	<0.41593, -1.02584, -0.356792>		<0.886243, 0.688668, 0.0695211>

7.3 Appendix 3

Orbital elements	**Values from JPL**	**Calculated Values**	**Errors**
a (AU)	2.2234580	2.1972572	-1.1783818346
e(degree)	0.5363051	0.5304736	-1.0873335244
i(degree)	10.871454	10.8230127	-0.0134561357
Ω(degree)	132.3092436	132.3092436	0.00983613260
ω(degree)	205.9905267	205.9258206	-0.0179738958
M0(degree)	345.9997895	346.5530639	0.15368734449

7.4 Appendix 4:

A table that shows the "computed" (your ephemeris) and the "actual" (their data) RA and dec and time, with RA in both h,m,s and decimal degree form, dec in both dms and decimal degree form and time in both UT and Julian day form. Clearly label the headings of this table.

	Computed	**Actual**
α(in decimal hours)	17.1850080928	18.01630
δ(in decimal degrees)	1.1620918083	-01.55190
α(H:M:S)	17:11: 6.029	18:0:58.680
δ(H:M:S)	1: 9: 43.53	-1:33:6.84

t (JD)	2457220.71271	2457220.71271
t(Y-M-D H:M:S UT)	2015-7-17 05:06:18	2015-7-17 05:06:18

7.5 Appendix 5:

Orbital elements	**Calculated Values**	**Uncertainty**
a (AU)	2.1972572	0.1504737
e(degree)	0.5304736	0.0287498
i(degree)	10.8230127	0.0061508
Ω(degree)	132.3092436	0.0037859
ω(degree)	205.9258206	0.0042682
M0(degree)	346.5530639	0.0344310