Parallax Distance Calculation of NEA 2002 KL6

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1 Introduction

On July 18, 2016 students of the Summer Science Program in Socorro, NM and students of the Yale Summer Program in Astrophysics in New Haven, CT took near simultaneous observations of Near-Earth asteroid 2002 KL6. KL6 made its closest approach to Earth on July 22, 2016 and had a high altitude for both campuses. KL6 was an excellent candidate for parallactic distance calculation as it had an instrumental magnitude of 13.7 and remained over 55 degrees away from the Moon at the time of observation.

2 Methods

The parallax data was taken at Etscorn Observatory at New Mexico Tech and at Leitner Family Observatory at Yale University (locations given in Table 1 below). Sets of images were taken at each observatory using 30 second exposure times and the images were reduced using CCDSoft. The right ascension, declination, and time of observation for every image used in this experiment are given in section 4. Astrometry was conducted using the Least Squares Plate Reduction method, which uses reference stars with known right ascension and declination values within the field of view to create a linear model for the right ascension and declination for a given pixel in the image.

Once right ascension and declination values for the asteroid were known at several times for each location, a linear fit model was constructed to determine the right ascension and declination values for the asteroid at any given time within the observational period to better match the data at the two locations. Table 1 below also gives the right ascension and declination from the best-fit line models for 7/18/2016 4:50 UTC. Raw observed data and the linear fits with respect to time can be seen in section 4.

Location	Etscorn Observatory	Leitner Observatory
ϕ	34.0727°N	41.3210°N
L	106.9139°W	72.9220°W
Elev.	1429m	38m
α	287.63695°	287.61685°
δ	35.68493°	35.68223°

Table 1

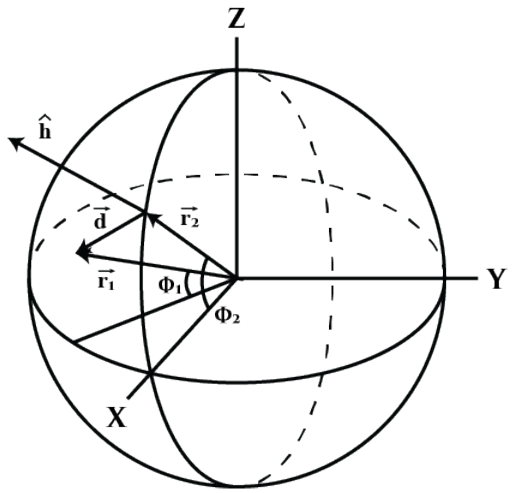

Figure 1: Vector diagram showing the geometry of the two observatories and the orientation of $\vec{d}$ & $\hat{h}$.

The distance to an object using the parallax method is given by Eq(2.1).

$$D = \frac{d\sin(\theta)}{2\tan\left(\frac{X}{2}\right)} \tag{2.1}$$

where $d\sin(\theta)$ is our effective baseline and X is our parallax angle. The parallax angle is given by Eq(2.2) shown below.

$$\sin^2\left(\frac{X}{2}\right) = \sin^2\left(\frac{\Delta\delta}{2}\right) + \cos(\delta_1)\cos(\delta_2)\sin^2\left(\frac{\Delta\alpha}{2}\right) \tag{2.2}$$

From Eq(2.1), d is the straight line distance between our two observatories and is found by first converting the latitude and longitudes of the observatories into Cartesian vectors using the matrix,

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} \cos(\phi)\cos(L) \\ \cos(\phi)\sin(L) \\ \sin(\phi) \end{pmatrix} \tag{2.3}$$

then by using vector subtraction to find the vector $\vec{d}$. Thus,

$$d = \|\vec{d}\| \tag{2.4}$$

The θ from Eq(2.1) is the angle between distance vector $\vec{d}$ and $\hat{h}$, the unit vector from the subpoint to the asteroid. The subpoint is found from making an assumption that the local α and δ at one observatory is the same as the α and δ at the subpoint. The latitude of the subpoint is simply the δ of the asteroid while the longitude of the subpoint is the α of the asteroid minus the LST at Greenwich during the time of observation.

Since the asteroid will be directly at the zenith for an observer at the subpoint, $\hat{h}$ is also the latitude and longitude of the subpoint expressed in a Cartesian unit vector Eq(2.3).

Using the properties of vector dot products, the angle between the geocentric unit vector $\hat{h}$ and baseline vector $\vec{d}$ is given by,

$$\theta = \cos^{-1}\left(\frac{\vec{d}\cdot\hat{h}}{d}\right) \tag{2.5}$$

3 Results, Data Analysis, and Conclusions

Using the data from Table 1 in Eq(2.2) above, the angular difference in the equatorial coordinates of the asteroid between the two locations is $X = 59.56$". We find the coordinates of the subpoint using the α and δ as measured from Etscorn.

The subpoint is at 35:41:05.76° N latitude, 81:17:47.29° W longitude, which corresponds to a geocentric unit vector

$$\hat{h} =< 0.12290796, -0.802883859, 0.5933276 >.$$

The baseline between the two sites is calculated to be 3049 km with a unit vector

$$\hat{d} =< 0.46155188, 0.07459, 0.100034951 >.$$

Projecting the baseline onto the geoecentric unit vector using Eq(2.5) gives a fore-shortened, effective baseline of 3034 km. We estimate an error of about 1" in our angular measurement and 1 km in our baseline measurement, which gives a relative uncertainty of about 1.6% on our final answer. The distance to the asteroid can then be simply calculated using Eq(2.1), which uses the trigonometry in the triangle composed of the two locations on Earth and the asteroid. We calculate a distance to 2002 KL6 of 0.071 ± 0.001 AU. JPL Horizons predicts a range to KL6 of 0.07017 AU. With a relative uncertainty of 1.6% and a percent error of about 0.5%, our calculated value agrees with the predicted value to within our error bars.

The JPL Horizons predicted range is within our uncertainty bound, indicating that our methodology is correct. Our result had a percent error of 0.48%, disregarding significant figures. Potential sources of error include choice of the baseline point and uncertainties in astrometry calculations. Because the earth is not a perfect sphere, parallax calculations do depend on the locations on Earth chosen and are not perfect in determining the range to the asteroid. From our calculations and observations, we can conclude that the parallax is an effective method to determine the range to an asteroid to within reasonable uncertainties. Further exploration can be done with additional data points and location pairs to verify results.

4 Raw Data

Included below are the raw astrometric data from both Etscorn and Leitner Observatories.

JD	**Etscorn RA**	**Etscorn Dec**
2457587.68479	287.58408333	35.65173889
2457587.6898	287.60008333	35.661875
2457587.69182	287.60620833	35.66601667
2457587.69464	287.61495833	35.67116111
2457587.70968	287.663625	35.70153611

Table 2: Etscorn astrometry for 2002 KL6

JD	**Leitner RA**	**Leitner Dec**
2457587.697488	287.6045	35.6747194444
2457587.697894	287.605708333	35.6754
2457587.698299	287.606916667	35.676175
2457587.698704	287.608291667	35.677
2457587.699097	287.609333333	35.6777388889
2457587.699907	287.612166667	35.6793638889
2457587.700312	287.613416667	35.6801388889
2457587.700706	287.614666667	35.6808861111
2457587.701111	287.616041667	35.6817027778
2457587.701516	287.61725	35.6824611111
2457587.701910	287.6185	35.6832416667
2457587.702315	287.619833333	35.6840611111
2457587.702720	287.621125	35.6848083333
2457587.703125	287.622375	35.685575
2457587.703519	287.623666667	35.6863777778
2457587.703924	287.624958333	35.6871527778

Table 3: Leitner Astrometry for 2002 KL6

Below are best fit lines for the Right Ascension and Declination of 2002 KL6 at Etscorn and Leitner Observatories.

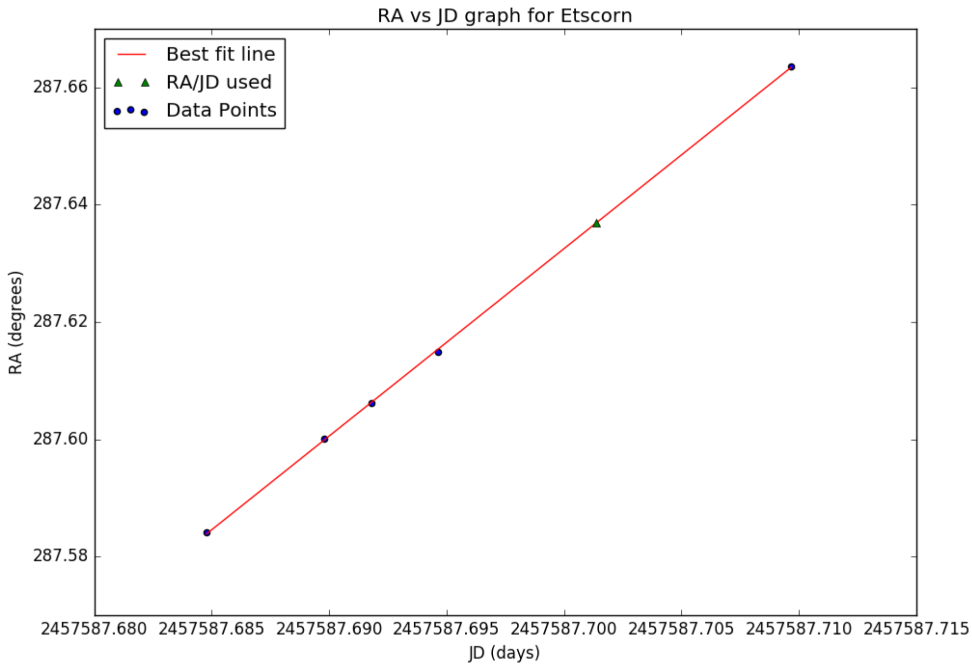

Figure 2: RA vs Julian Date of 2002 KL6 at Etscorn

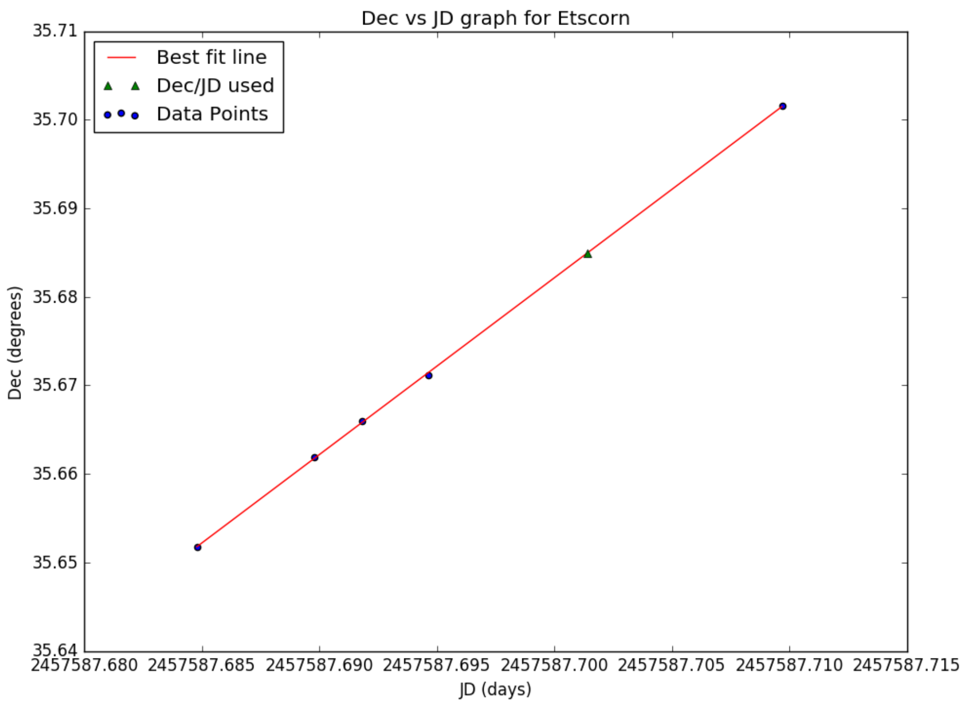

Figure 3: Declination vs Julian Date of 2002 KL6 at Etscorn

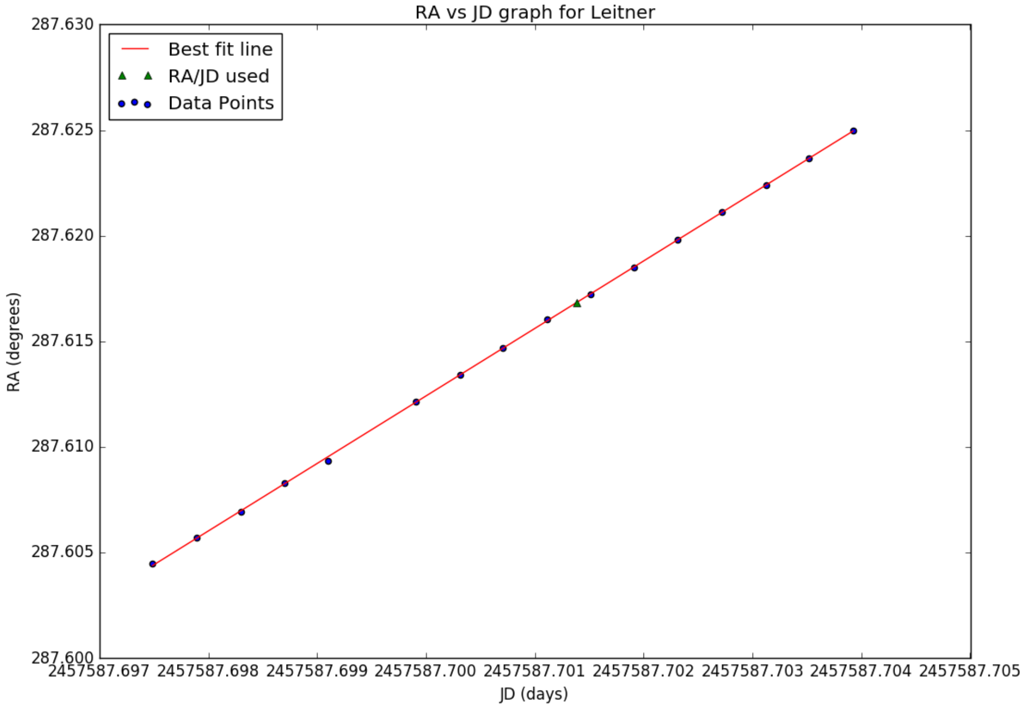

Figure 4: RA vs Julian Date of 2002 KL6 at Leitner

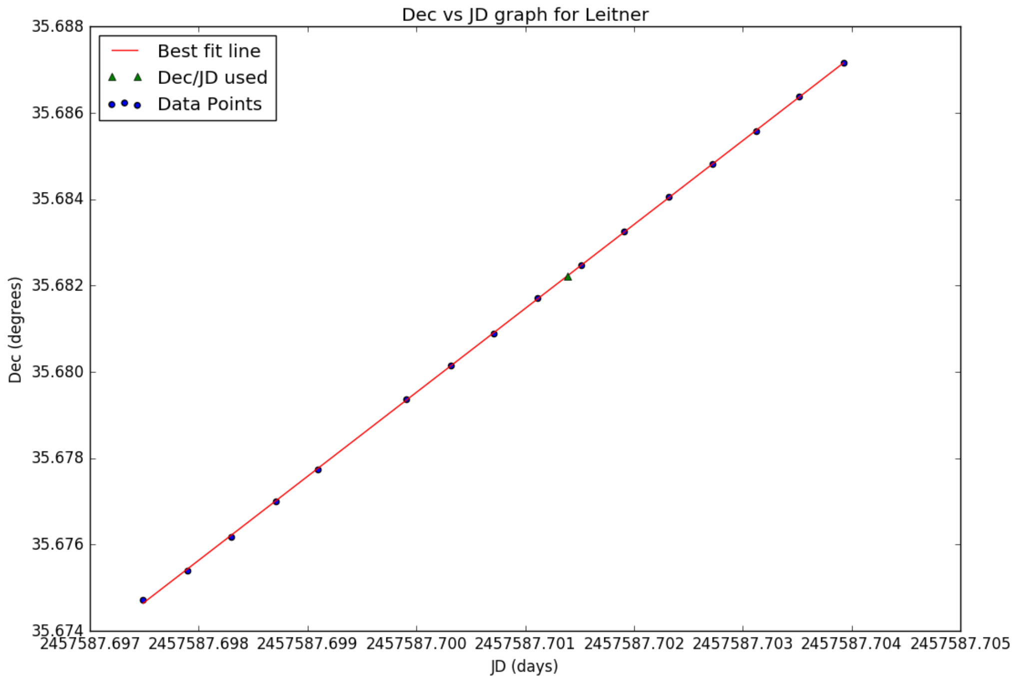

Figure 5: Declination vs Julian Date of 2002 KL6 at Leitner

5 Authors

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