Physics 100 Lab Report 2

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1 Abstract

The purpose of this lab is to use parallax to determine the distance between earth and the dwarf planet Makemake. We took images of Makemake on two different occasions and determined the distance Makemake moved (in terms of viewing angle) to be 367$\pm$5 arcseconds. Combining this result with the geometry of earths orbit, we obtained the distance from Makemake to earth to be 55.5$\pm$0.59 AU, assuming that the movement of Makemake is negligible.

2 Target, Equipment, and Methods

We used the 24 inch telescope in the Student Observatory with Apogee Ap8 CCD camera. Images of Makemake were taken on 04/24/2013 and 05/01/2013 PDT. Makemake was located using J2000 coordinates when it was close to opposition. The camera was cooled to its normal temperature of -40 centigrade each night. Before taking quality images of Makemake, numerous images were taken to correctly locate the position of the dwarf planet. We used images from DSS2 red survey to accurately confirm the location by matching specific and noticeable stars in the field of view. Once the correct location was found, we focused the camera and took 7 exposures moving the camera a little between each exposure. We were careful not to saturate the images. The exposures were later added together to create a combined final image. This process is known as dithering and is used to reduce noise and to expand our field of view to minimize any error in calculating the exact location of the dwarf planet. Bias frames and dark frames were taken at the end of each night, which were later subtracted from the final images to help improve image quality of the combined exposure. The observation details are summarized in Table 1.1.

Time	Conditions	Target	Equipment	Exposure
2013/4/24 11 PM	Full moon, bright sky background, clear/little cloud cover	Makemake	Imaging CCD, no filter	7 exposures for 20 seconds
2013/4/24 11:30 PM	Full moon, bright sky background, clear/little cloud cover	None	Imaging CCD, Dark Frame	20 seconds
2013/4/24 11:35 PM	Full moon, bright sky background, clear/little cloud cover	None	Imaging CCD, Bias Frame	0 seconds
2013/5/1 10 PM	Half-Moon, Warm, clear/little cloud cover	Makemake	Imaging CCD, no filter	7 exposures for 60 seconds
2013/5/1 11:15 PM	Half-Moon, Warm, clear/little cloud cover	None	Imaging CCD, Dark Frame	60 seconds
2013/5/1 11:35	Half-Moon, Warm, clear/little cloud cover	None	Imaging CCD, Bias Frame	0 seconds

Table 1.1 List of Observations

The process spanned over 3 weeks, with the first two weeks devoted to observations and the third week to data analysis. During our first observational session, we had a full moon, which greatly affected the FWHM of our images and made focusing very difficult. The FWHM ranged from 5 to 6 pixels. On our second night of observation, we had a half-moon which improved our FWHM to between 4.8 and 5 pixels. During both observational sessions, no setup changes were made to the telescope. We used a dithering technique to take quality images. We processed our data by subtracting the dark and bias frames from our original exposures and combined our dithered images to create one overall image of Makemake on 2013/4/24 and 2013/5/1.

3 Results and Analysis

3.1 Observational Results

Included below are images from our observational sessions compared side by side with the DSS2 red survey:

04/24/2013 11pm PDT

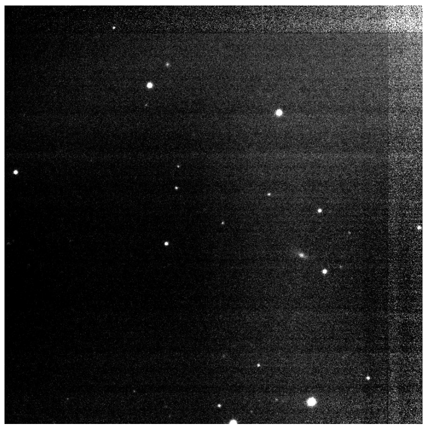


Figure 1: Observed

Figure 2: DSS2 red survey

Zoom in:

Figure 3: Observed

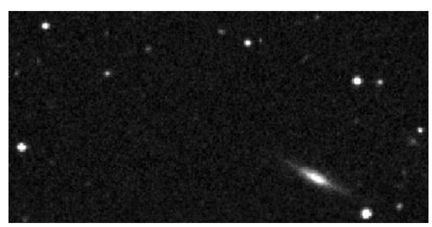


Figure 4: DSS2 red survey

Makemake is clearly visible at about $\frac{1}{3}$ from the left on the observed zoom in image and clearly invisible on the survey image.

05/01/2013 11pm PDT Zoom in:

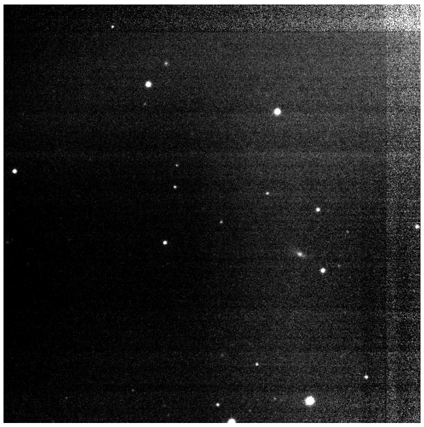


Figure 5: Observed

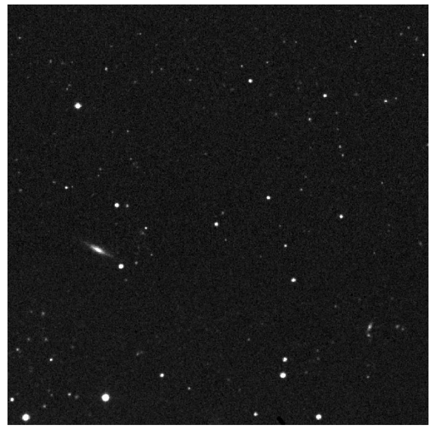


Figure 6: DSS2 red survey

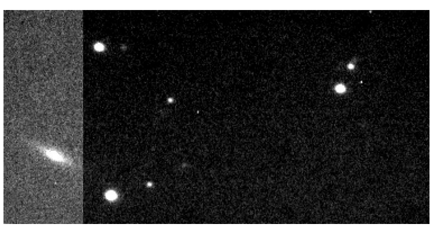


Figure 7: Observed

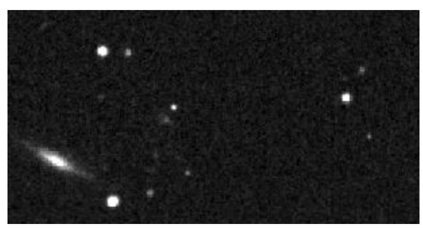
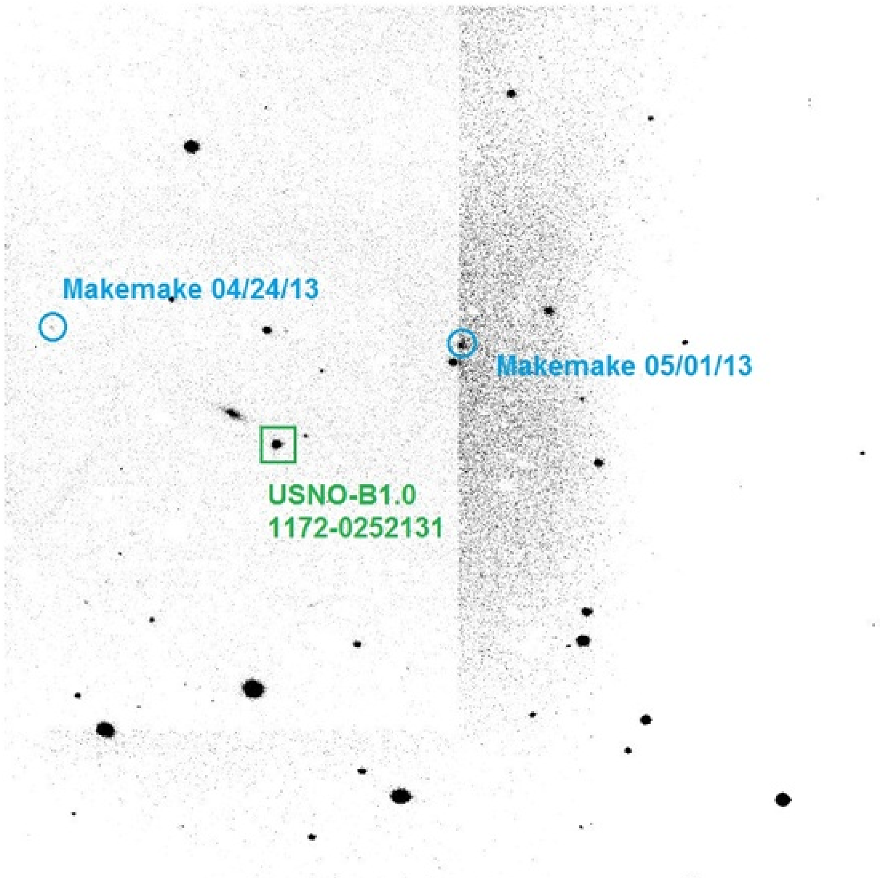


Figure 8: DSS2 red survey

From both a geometry and relative brightness point of view, its easy to confirm that the bright object in the upper right corner of the zoom in observed image is Makemake, not the faint star USNO-B1.0 1172-0252078 (mag. 19) on the survey. The brighter star on the lower left side of the planet is USNO-B1.0 1172-0252081 (mag. 16) and is visible in both images.

The image below was obtained by overlapping the images from both observational sessions:



From the above, we are able to calculate the pixel distance that Makemake moved. Assuming the origin of the coordinate system is the upper left corner of the image:

$$x = 4642 pixels$$

$$y = 422 pixels$$

$$r = 4662 pixels$$

Note that the sky brightness on 04/24 is much higher than on 05/01 and that the contrast of the 04/24 images is much worse than the 05/01 ones. However, the relative flux from Makemake should be similar on both days after subtracting the sky brightness. Using USNO-B1.0 1172-0252131 for comparison (magnitude 15) shown in the green square above.

Time (UTC)	USNO-B1.0 1172-0252131	Makemake	Ratio
2013-04-25 060000	297	29	0.098
2013-05-02 050000	3672	467	0.13

Table 3.1.1 Total flux after subtracting sky brightness (cnts)

The two ratios agree within an order of magnitude. This confirms that our observed object is indeed the same one in the two observations.

The observed positions of Makemake in geocentric equatorial coordinates and the time of the two observations are shown in the table 3.1.2 below.

Time (UTC)	R.A.	D.
2013-04-25 060000	12h 43' 38"	+27° 12' 51"
2013-05-02 050000	12h 43' 12.6"	+27° 12' 52"

Table 3.1.2 Observed Positions of Makemake

Our plate scale was calculated to be 0.787 arcseconds/pixel. Makemake was observed to move 466 pixel, corresponding to 367 arcseconds, or 0.0018 radians.

3.2 Using Parallax to find the Distance to Makemake

The heliocentric ecliptic coordinate of the Earth at the two observations were obtained from an Ephemeris of the sun:

Time (UTC)	X (AU)	Y (AU)	Z (AU)
2013-04-25 060000	-0.8239455	-0.5295904	-0.2295842
2013-05-02 050000	-0.7516255	-0.6160211	-0.2670574

Table 3.2.1 Heliocentric Ecliptic Coordinates of Earth at Time of Observation

We obtain the distance the Earth moved during the two observations:

$$\Delta x = 0.07232AU$$

$$\Delta y = -0.0864307AU$$

$$\Delta z = -0.0374732AU$$

thus,

$$\Delta r = 0.118763AU$$

The unit vector in this direction is (0.608943, -0.727757, -0.315529). The unit vector in the direction of Makemake is on average (-0.848783, -0.162125, 0.503271). The inner product of these two vectors will give us the angle between the Earth's movement and Makemake, which is about 123.8°. Using the small angle approximation,

$$d \times 0.001779 \approx \Delta r \cos(123.8^\circ - 90^\circ)$$

we obtain that r≈55.5 AU.

3.3 Error Analysis

Since we obtained d from the equation

$$d = \Delta r_e \cos(\cos(\delta_e)\cos(\alpha_e)\cos(\delta)\cos(\alpha)+\cos(\delta_e)\sin(\alpha_e)\cos(\delta)\sin(\alpha)+\sin(\delta_e)\sin(\delta))/\theta_m$$

where δ_e , α_e are the heliocentric equatorial coordinates of the Earth; α is the distance that the Earth moved. We can know these quantities to high precision since we looked these up from the ephemeris. The larger uncertainties are due to δ,α, which are the geocentric equatorial coordinates of Makemake, and θ_m, the observed angular displacement of Makemake over a week. We set the uncertainty on δ to be half of the difference in the two observed δs of Makemake. We can also get α this way. So the uncertainty on δ is $7.3 * 10^{-5}$ radians, and the uncertainty on α is $1.65 * 10^{-3}$ radians. Assuming we have an uncertainty on the separation of the two observations of 5 pixel, our uncertainty on the angualr displacement of Makemake is about $1.9 * 10^{-5}$. Our Total uncertainty can be expressed as:

$$\sigma = \left[(\sigma_m \frac{\partial f}{\partial \theta_m})^2 + (\sigma_\delta \frac{\partial f}{\partial \delta})^2 + (\sigma_\alpha \frac{\partial f}{\partial \alpha})^2 \right]^{\frac{1}{2}}$$

This uncertainty is calculated to be 0.59 AU, with the dominant error being σ_m, the uncertainty of observing the angular displacement of Makemake.

4 Discussion and Conclusions

We have successfully identified Makemake in the two observations we made. We have also calculated the distance to Makemake from Earth using parallax. This distance is 55.50.59 AU. Makemake has a perihelion of 38.5 AU and an Apehelion of 53 AU, so the distance we calculated is reasonable. The main uncertainty comes from the accuracy with which we can measure the angular position and displacement of Makemake. We speculate that a longer period between observations will give us higher accuracy. In addition, we assumed that Makemake moved relatively slowly compared to Earth since it is a distant planet. More than two observations are needed to determine the speed of Makemake.

5 References

"Equatorial Rectangular / Ecliptic Coordinates of the Sun." National Astronomical Observatory of Japan. 1994. http://eco.mtk.nao.ac.jp/cgi-bin/koyomi/cande/sun_rect_en.cgi

"ESO Online Digitized Sky Survey.http://archive.eso.org/dss/dss

"Makemake." Wikipedia. 24 May, 2013. http://en.wikipedia.org/wiki/Makemake_(dwarf_planet)