Astrometry from CCD Images

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Abstract

Astrometry is used to measure properties of celestial objects such as their position on the sky, their movement and their velocities. In this experiment, we used a charged coupled device(CCD). The CCD used mapped the sky on 2D plane. Observations were made using the Dunlap Institute Telescope located in New Mexico, United States. The object of interest for this experiment is 30 Uania which is an asteroid. We will measure the plate constants of the CCD using a data collection of stars field in order to correct for the sheerness of the CCD pixels and then we apply it to the data from 30 Uania over the course of three nights to measure the velocity of this asteroid.

1 Introduction

2 Experimental Procedure

2.1 Equipment

We used the Dunlap Institute Telescope(DIT) which is a 50-cm robotic telescope dedicated to search for optical counterparts of gamma-ray bursts. The telescope was located at New Mexico on Mt. Joy(32:54:10 N +105:31:46 W). The telescope is equipped with a 4096 $\times$ 4096 pixel CCD array and the resultant field of view is approximately 36 $\times$ 36 arc minutes. Pixel size of this CCD is 9μ. This CCD operated in binning mode to collect the data. Binning is useful since it reduces the size of the resultant FITS file and reduces the effect of read-out noise. For 2 $\times$ 2 binning the resultant array is 2048 $\times$ 2048 pixels.

3 Analysis

3.1 CCD Calibration

In order to have good images from the CCD we need to calibrate it. A good image is one that is dark subtracted and divided by flat frames. Therefore, in order to use the data from the CCD, we subtracted the dark data from the actual data. Dark data was taken with the same exposure time as the actual data while the shutter was closed. Dark current is produced due to the noise in the CCD and it might come from the thermal energy of the electrons; therefore, CCDs are kept in cool places in order to reduce the noise. We also divide the dark subtracted data by the flat frames. Flats are morning and evening twilight sky images that are used to normalize the image. Another factor to consider are the bias frames, which are zero second exposures that provide a measure of digital offset when the signal is zero. Here, the bias is assumed to be zero for this long exposure with DIT.

3.2 Detection of Stars

Next step is to find the stars from the CCD image of NGC7331 taken with DIT. The way we did it was to write a python program to check all of the pixels and find the ones that have intensity higher than a specific number, which for me was higher than 20000 ADU. It considered each pixel and then compared it with the pixel on the left, right, bottom and top of it and if it had higher intensity, considered it as a maxima point.This way the program found all of the maxima points; however, there was a problem. For the larger stars, the code put more than one dot on the object since the object consisted of more than one pixel and the code put dots on each of the pixels of the star. Therefore, we need to find the centroids of these maxima points in order for the code to only point to the centroid of the stars and to put only one dot on each star. In order to calculate the centroids, we modified the code so that now it only takes the maxima points and considers a small box around each of the stars and for the maxima points in the specified box finds the centroids. This way we would only have one dot pointing to each star instead of a few. This is shown in figure 1.

3.3 Matching Stars and Standard Coordinates

We need to see if the centroids we found are actually stars; therefore, we used our centroids with an image of NGC7331 from USNO-B1.0 Catalog which is the US Naval Observatory. The USNO-B1.0 catalog lists positions, proper motions and magnitudes in various optical bands over the entire sky. The data are from scans of photographic plates from the Palomar 48-inch Schmidth taken during the last 50 years. This catalog provides all-sky coverage down

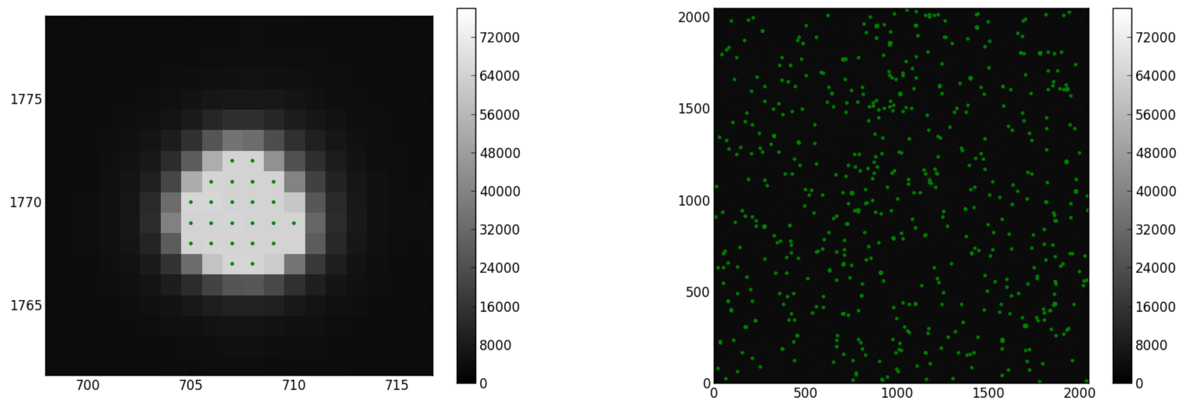


Figure 1: The image on the right shows the maxima points that correspond to the pixels that have intensities higher than 20000 ADU. The image on the left is a random zoomed in part of the right hand side plot in order to show that some of the dots shown on the right image are actually more than one dot. Therefore, we need to find the centroids in order to eliminate the extra dots for one star and only assign one dot to each star.

about magnitude 21 and astrometric accuracy of 0.2 arc second at J2000 and is adequate for the purpose of this experiment. Figure 2 shows NGC7331 from USNO catalog. °

We now have the position of the observed stars from the CCD in pixel x and y and in right ascension and declination from the USNO-B1.0 Catalog. The USNO-B1.0 coordinates are on the celestial sphere, whereas the stars in the CCD image are on a plane, which is the projection of the celestial sphere. Therefore, we need to compare the stars we fond wight he ones in the catalog. As a result, we need to have a common coordinate system and in order to do so, we need to transform the celestial sphere coordinates of the catalog into plane coordinates. The transformation formula are given below:

$$X = -\frac{\cos\delta\sin(\alpha-\alpha_0)}{\cos\delta_0\cos\delta\cos(\alpha-\alpha_0)+\sin(\delta)\sin\delta_0} \tag{1}$$

$$Y = -\frac{\sin\delta_0\cos\delta\cos(\alpha-\alpha_0)-\cos\delta_0\sin\delta}{\cos\delta_0\cos\delta\cos(\alpha-\alpha_0)+\sin\delta\sin\delta_0} \tag{2}$$

In order to calculate α_0 and δ_0, we subtracted the minimum from the maximum value of right ascension and declination and then divided by two so that α_0 and δ_0 are at the centre. The values we used for α_0 and δ_0 are 0.17100700000000302 and 0.14132499999999837 respectively. Then we plotted the same data from USNO-B1.0 in standard coordinates using equations 1 and 2. Figure 3 shows the image obtained.

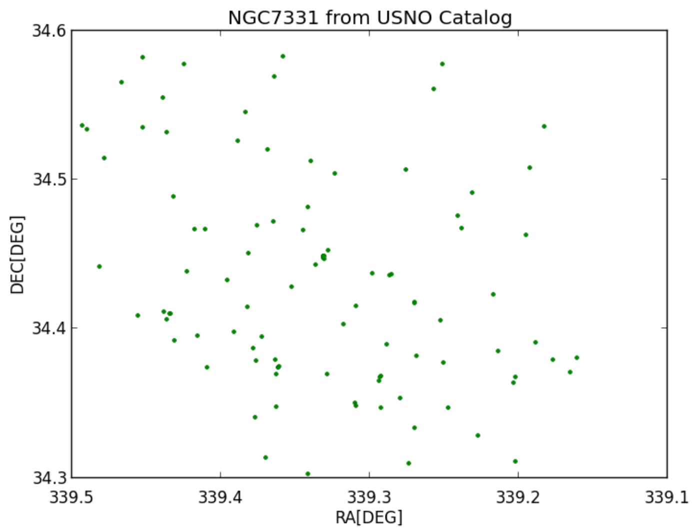
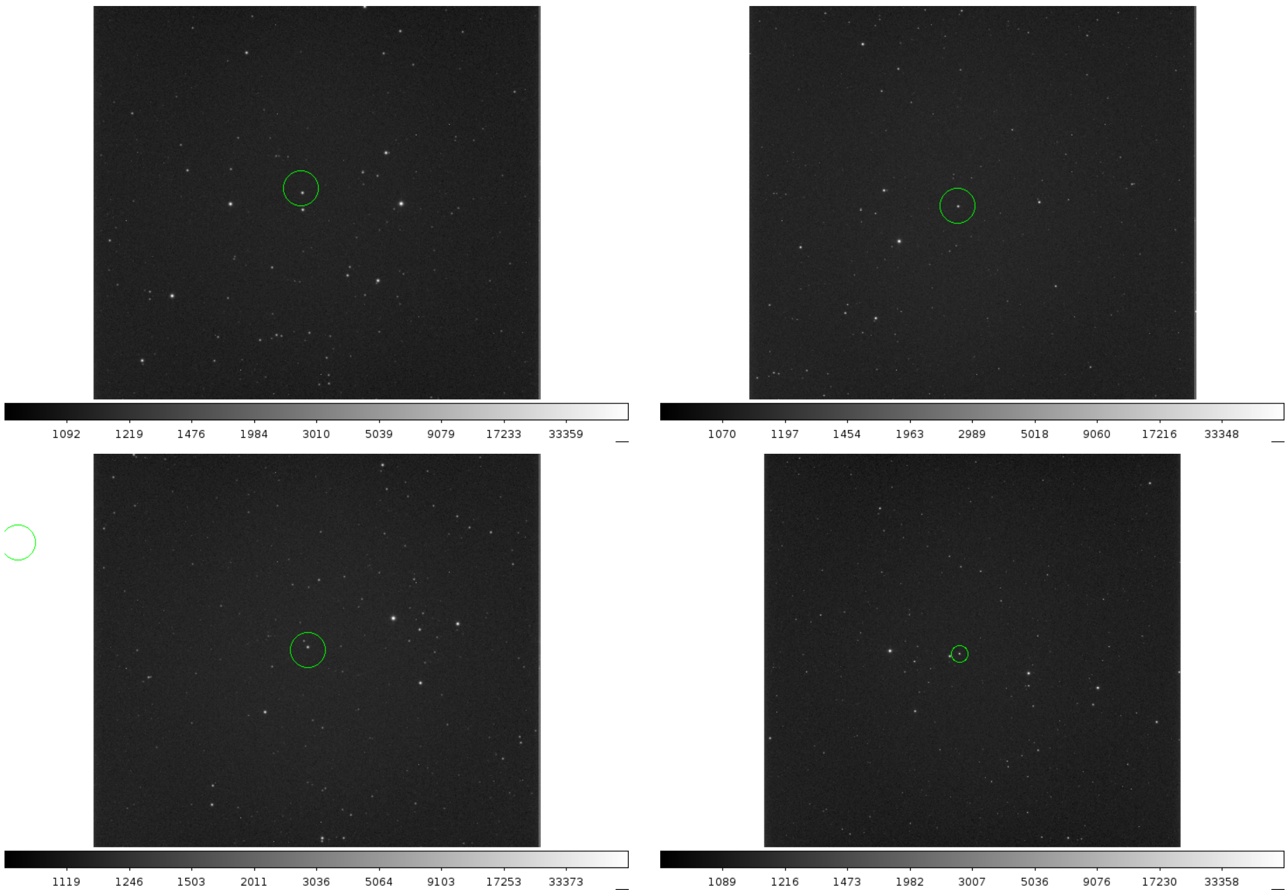


Figure 2: USNO catalog
The catalog position of USNO-B1.0 catalog stars within 30 × 30 arc minute square field centred at the positions of NGC7331(RA = 339°.325 ; DEC = 34°.444 at apoch J2000). Only stars with magnitude greater than 15 are plotted.

4 Detection of Asteroid

Now that we have the plate constants, we can transform the coordinates of the objects detected on the CCD onto the spherical plane. In other words, we are able to find the right ascension and declination of the asteroid using the plate constant we found in previous parts of this experiment. Therefore, we can measure the position of the asteroid on the sky from different nights and calculate its velocity and proper motion through the sky. Data from Asteroid 30 Urania was taken in 5 almost consecutive nights. We used DS9 program in order to detect the asteroid from the background stars. The way we found the asteroid is that we opened the FITS files in DS9 application and log scaled them so that we can find the stars. Then the way we found the asteroid is that we looked at the pattern of the stars and figured out which bright dot is in one image but not in the others. Therefore, the asteroid is found in all four images. We know the a and y pixel numbers of the position of the asteroid on the CCD and using the plate constants we found previously from NGC7331, we converted the pixel numbers to right ascension and declination coordinate. From the position of the asteroid on the sky, we measured the differences in the positions in order to calculate the proper motion. The position results are listed in table 1.


1092
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1984
3010
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1070
1197
1454
1963
2989
5018
9060
17216
33348
1119
1246
1503
2011
3036
5064
9103
17253
33373
1089
1216
1473
1982
3007
5036
9076
17230
33358

Figure 3:

5 Conclusion