

# From setting up a new telescope to optimizing astrometric solutions

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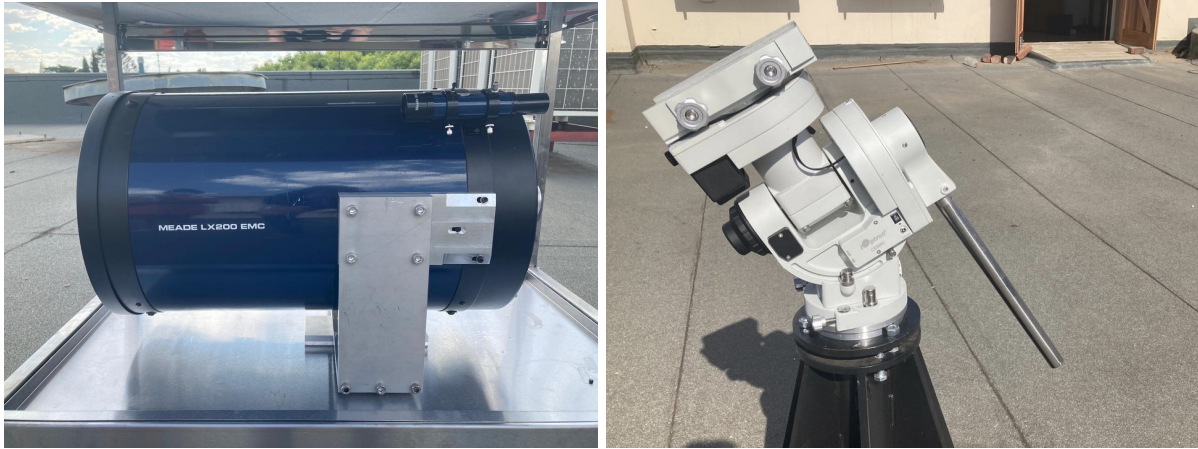
**Abstract.** A new optical telescope has been set up at the North-West University (NWU) Potchefstroom campus, on the roof of the physics building (G5). It is the old 30 cm Meade that used to be at the Nooitgedacht observatory until around 2010 when it was replaced by a 40 cm. We decided to give it a second life, by refurbishing the optical tube and purchasing a new mount. It will mostly be used for public outreach purposes. The project was to set up a new telescope from scratch, starting with a custom made steel pier anchored to the roof, extending an electrical connection, and the balancing plus polar alignment of the telescope. Basically getting all parts, including the software, to function together. We are now in the final phase of making this observatory ready for the public by making the roof safe for the public. For scientific observations, we have tested and optimized methods of plate solving for accurate astrometric solutions. We will discuss how to go from detector coordinates (X, Y) to astronomical coordinates (RA, DEC) on images taken at the Nooitgedacht observatory.

## 1. Introduction

An optical telescope is an essential tool for astronomers, used to collect images of distant objects through their emission, absorption, or reflection of visible light. They have been in existence since the seventeenth century and have been used for many discoveries. Galileo Galilei was credited as the first person to be associated with a telescope, although he did state he was not the first to come up with the invention [1, 2]. This led to the discovery of the four moons of Jupiter and the rings of Saturn. Other scientists began creating and building different types of telescopes, covering the electromagnetic spectrum. Having a site accessible to the public, where people can learn the basics, and get hands-on experience using a small telescope will provide a great opportunities to both upcoming student scientists and the public at large.

## 2. The Roof Observatory

The roof observatory is located at coordinates  $26^{\circ}41'11''S$   $27^{\circ}5'37''E$ . The telescope has a Schmidt-Cassegrain design and is seen in Figure 1. The tube is portable, and easy to assemble and disassemble. It has a 30 cm (12") aperture, with a light-collecting area of  $225\pi$  cm<sup>2</sup> and resolving power of 0.38 arc-seconds [3]. The telescope focal ratio of  $f/10$  makes it ideal for planet and moon gazing. The focal length of the telescope is 3048 mm, and the eyepiece is 40 mm, giving a magnification of 76.2. The mount chosen is an iOptron CEM60, Central Equatorial mount (see Figure 1). The mount has a payload capacity of  $\sim 27$  kg, high precision tracking, and provides a slew speed of  $3.75^{\circ}/\text{sec}$  [4]. The CEM60 comes with an iPolar scope incorporated



**Figure 1.** The image on the left shows the optical tube for the observatory. The image on the right is the iOptron CEM60 mount on the steel pier.

within it. It is used for the polar alignment, while pointing at the celestial pole, it will detect star patterns and guide the alignment process with the provided software. Once the mount has the polar alignment done, we can start to point and track properly.

We first removed the U-fork anchor of the old alt-azimuth mount from the 30 cm optical tube. A new mount, an iOptron CEM60, was purchased in 2019 and has been with us since July 2020. An adapter was made so that the tube fits on the new mount. In March of 2021, a steel pier was installed on the roof. An electrical connection was brought to the side of the telescope so we can drive the motors and power the computer. The mount came with a 9.5 kg counterweight. This was not enough to balance the telescope; a second counterweight was added and modified to fit the shaft. This was also not enough, so the counterweight shaft was extended by more than 30 cm to achieve balance. To allow proper tracking and operation, the mount was set to an angle of  $26.4^\circ$  corresponding to our latitude.

Figure 2, depicts the telescope's final setup, well balanced and properly polar-aligned. There is still a main broad connection problem preventing perfect pointing. However, this is a documented problem, which will require a firmware upgrade, to be done soon. The telescope can still observe under the current conditions. For the site to be ready, a rolling protective metal cover has been designed and manufactured and should be delivered soon. It will be used during the dry season so that the telescope can be kept outside. It will protect the telescope from dust, humidity, and heat, and will ensure quick access to it throughout the whole of the season, from May to November. It can be rolled away to allow easy access for stargazing.

### 3. Astrometric Calibration

Images taken with a CCD camera on a telescope have an X and Y pixel axis, a grid based on the physical size of the detector. These images can also have the approximate RA and DEC of where the telescope was pointing while imaging the sky. An astrometric solution is the addition of the RA and DEC information, at a sub-pixel level, to the image header. This is called the World Coordinate System (WCS). Before processing any data, basic data reduction has to be done by taking bias, flats, and darks. These tasks can be carried out using AstroImageJ [5]. Once the basic reduction is done, we have to find the astrometric solution, using Astrometry.net [6]. In each image, stars will be detected, and their relative position in X and Y will be compared to



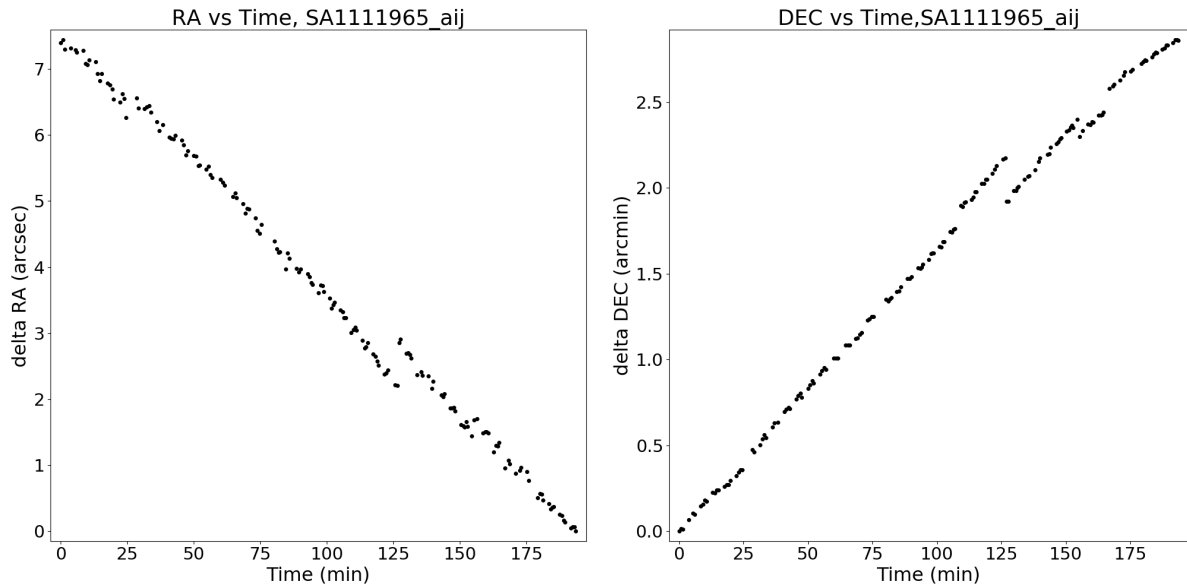
**Figure 2.** The full operating telescope with counterweights, properly aligned and well-balanced.

catalog data that has full WCS information to try to find a match. This information is saved in the fits files header. Astrometry.net can be installed locally on a computer without requiring internet access, or used via an online interface from AstroImageJ. The online version is slower and has access to fewer options, but it works very well and without any configuration. We aimed to compare the suitability of the two different methods.

We used the star field SA1111965 in UBVRI, which contained approximately 225 FITS images collected over a three-hour long session. We used AstroImageJ to process the data and get our first astrometric calibration. We then did the same with our local installation of Astrometry.net, playing with some parameters in both methods until we were satisfied with the results. The first round of plate-solving with AstroImageJ produced 114 fits over 13.30 hours, and the second round gave an additional 49 fits over 163 runs over approximately 6.23 hours. Running the files using Astrometry.net installed locally returns 179 successful files for 0.27 hours. The software returns 100 times faster results. Same scenario when using Astrometry.net in combination with the sextractor software for source finding, slightly longer to run (0.37 hours) with more successful files solved (196). These results can be seen in Table 1.

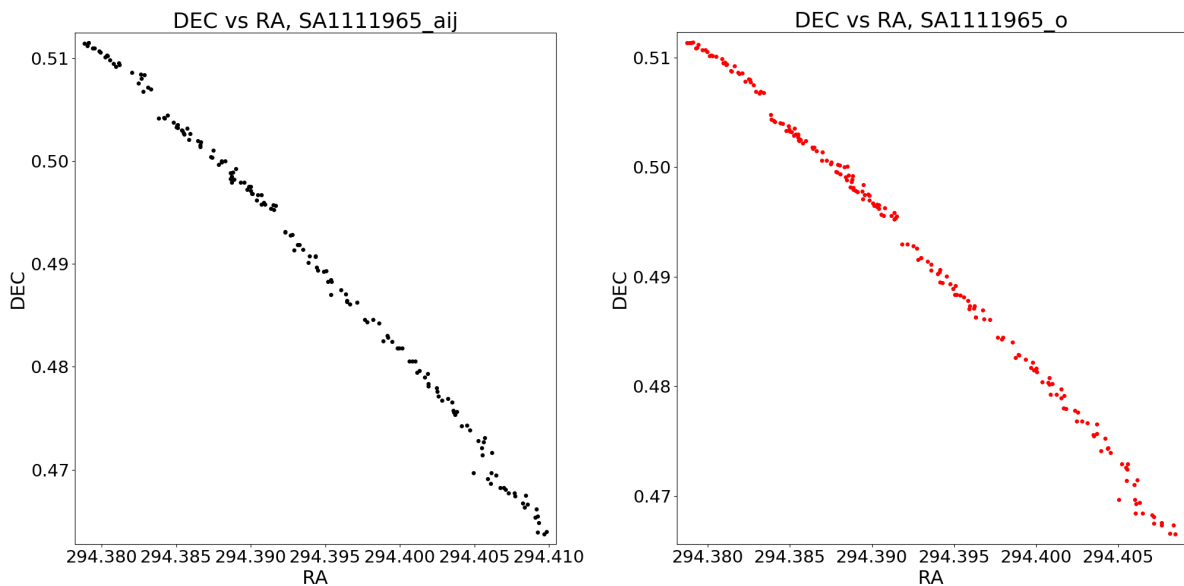
**Table 1.** Summary of plate-solving methods.

<b>Astrometry.net (via AstroImageJ) online</b>						
	Time(hrs)	Total	Success	Still fail	New success	Seconds/solve
round 1	13.30	225	114	111	114	420.00
round 2	6.23	225	163	62	49	457.96
<b>Astrometry.net, local with ImageXY</b>						
	0.27	225	179	46	179	5.36
<b>Astrometry.net, local with sextractor</b>						
	0.37	225	196	29	196	6.73



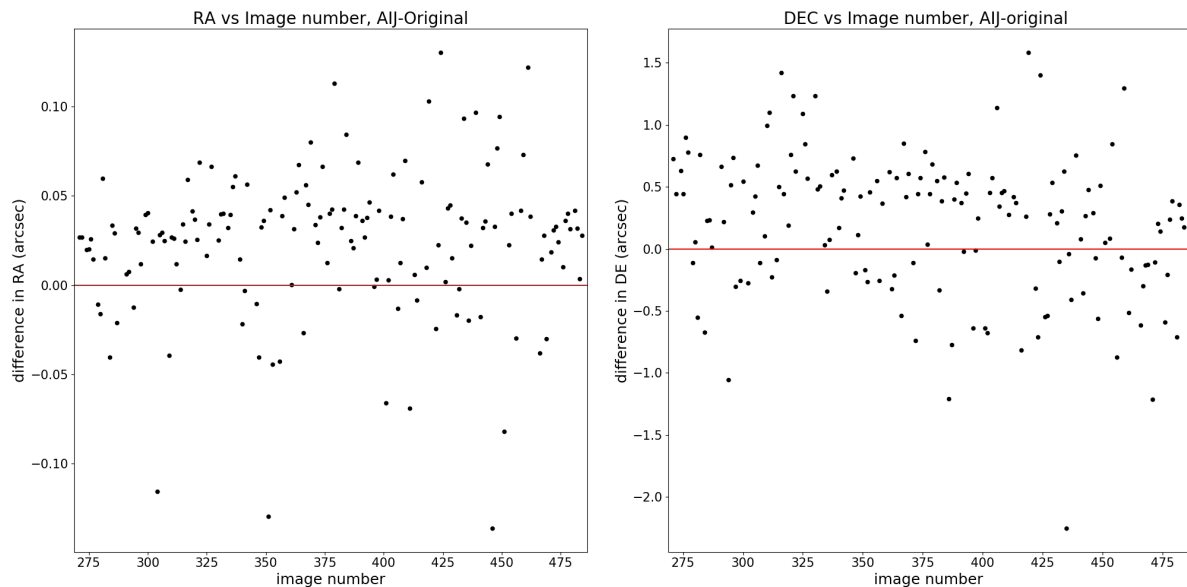
**Figure 3.** The drift in RA (left-side) and DEC (right-side) with time using AstroimageJ.

To examine the drift in the RA and DEC of the reference pixel with time for each image, Figure 3 was constructed using the RA and DEC of the reference point (CRVAL1 and CRVAL2) and time taken from the FITS header. The drift seen in the figure is the slow movement of the telescope over time. According to the estimates, the drift in RA and DEC with time is 0.0421 and 0.0144 arcseconds per minute respectively. The jump in the sequences corresponds to the time when we manually re-centered the field. A spacial distribution plot of RA vs DEC was then constructed for both methods, as seen in Figure 4.



**Figure 4.** Images shows comparison in RA and Dec of AstroImageJ on the left and Astrometry.net on the right-side.

While not totally identical, they are more or less the same for both methods. In both cases, there is a slow drift of the reference pixel of the image, corresponding to our imperfect guiding / tracking. A plot of that difference per image processed by the two different methods can be seen in Figure 5. There is no systematic difference observed, therefore both methods are comparable. Considering the time difference in processing the solutions, and the higher rate of success, a local installation of astrometry.net is preferable.



**Figure 5.** The images shows the difference between AstroImageJ (left-side) and Astrometry.net local (right-side) for each individual image.

#### 4. Conclusion

In summary, we have a new telescope on the roof that is well-balanced and polar aligned, and almost ready for the public. We have also developed a method to do astrometric calibration on images taken at the Nooitgedacht observatory without an internet connection. Our best method is using the optional sexttractor software to do the source detection on a local installation of astrometry.net.

#### Acknowledgement:

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