Polar Alignment with Excel

A new method for polar alignment of equatorial mountings using a camera and a spreadsheet

By Jürgen Kahlhöfer
VHS-Sternwarte Neumünster, Germany

1. Short outline of the method

Introduction

A method for polar alignment of equatorial mountings, using a star trail image taken with a turn of the camera, has been described by Hartwig Luethen. [1] Here, a spreadsheet is presented for exact evaluation of the images. Input data are the rectangular coordinates of three stars on the image at both ends of their trails, the right ascension and declination of the stars, the longitude and latitude of the observatory, and the date and time the image was taken. Results are the necessary corrections of azimuth and polar altitude in degrees. These can be converted into the necessary number of turns of the adjustment screws.

In Luethen's original method the star trails were necessary for visual determination of the centre of rotation. Using the spreadsheet, only the ends of the star trails are needed. Therefore alternatively two static images taken at different hour angles can be used.

Features of this method

The method is quantitative and exact. You not only get the direction, but also the exact amount of the necessary correction. In the calculation, an accuracy of 1 minute of arc is attainable. Altitude is corrected for the influence of atmospheric refraction.

The method is simple and safe. If an error has occurred in the identification of a star or a false coordinate has been entered, there will be an error warning. In the case of a severe error the results may be suppressed.

The method is applicable both in the northern and southern hemisphere.

Necessary software

A spreadsheet program (e.g. Microsoft Excel or Open Office) is absolutely necessary. The spreadsheet has been developed in Open Office and converted to Excel format

An image processing program (notably Fitswork, www.fitswork.de) is recommended for the measurement of the coordinates of the stars.

A planetarium program (e. g. Stellarium, www.stellarium.org) helps with the identification of the stars and serves as a source for current right ascension and declination values. The data for a small selection of stars are already provided in the spreadsheet.

Free download of the spreadsheet and instructions:
www.sternwarte-nms.de/ext-links/downloads

2. Practical notes

Preparation

It is advisable, to make oneself familiar with the adjustment screws of the mounting before taking the first image. Which way must I turn the screws to make the polar axis move up or down, eastward or westward? The threads of the screws and their distances from the corresponding axes should also be measured beforehand. They are needed for the conversion of the results from degrees to numbers of turns of the screws.

Stability

It is important, that the camera support must be rigid. A slight inclination of the camera during the turn would deteriorate the accuracy. The author would not trust a small ball head to carry the camera.

A temporary camera support

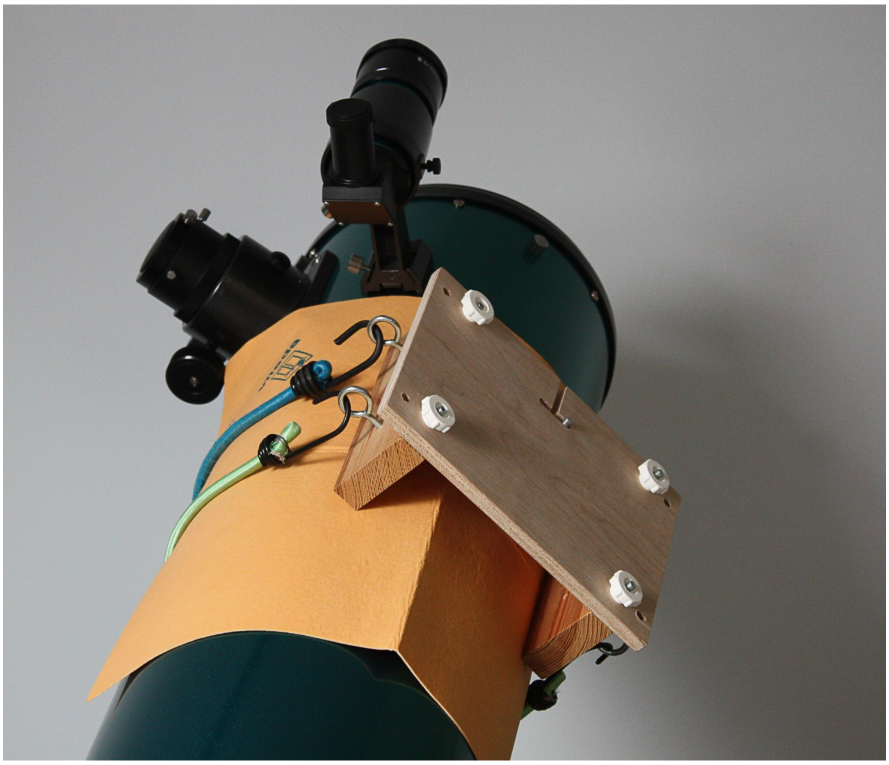

Image 1: The picture shows a simple camera support made of wood. Highly recommended: A window cloth placed under the support has a good frictional resistance on the smooth tube surface. It prevents the camera support from slipping and protects the surface of the tube.

Which lens is suitable?

In the beginning, a focal length of 50mm on a camera with an APS-C format chip may be favourable. When you are close to the pole, you can use a short telephoto lens. (Approx. f = 100mm on a camera with an APS-C-chip or f = 150mm on a full format camera) Focussing should have no play. Make the rattle test: The lens should not rattle when it is shaken. A fixed focal length may be better than a zoom lens, because it has fewer moving parts and less distortion.

Photography

You can use a star trail image taken with a turn of the camera around the polar axis or 2 static images taken at different hour angles. Two static images are easily made, but a star trail image could reveal if the mounting does not go round smoothly. (Uneven self-made horseshoe mount?)

If it is intended to evaluate 2 static images with Photoshop Elements or a similar program, both images should be displayed in landscape format. Therefore it is recommended, to take one image with the camera inclined approx. 30° to the left, the other 30° to the right.

The camera is fixed near the front end of the telescope tube or directly on the mounting and pointed at the celestial pole. It is always recommended to take a static image first. This makes it easier to identify the stars. (Exposure e.g. 15s with f/4 and ISO 1600) An image stabilizer must be switched off. Guiding is not necessary. Before taking the second static image, the hour angle has to be turned approx. 60°.

For a star trail image, the beginning and the end of the star trails must be clearly marked with a few seconds of static exposure. Set exposure time at Bulb (B). Start exposure, wait for some 5 seconds, then start turning (the telescope and) the camera around the polar axis, within about 30 to 60 seconds turn over an angle of at least 30°, not more than 90°, stop turning and continue exposure for a few seconds more.

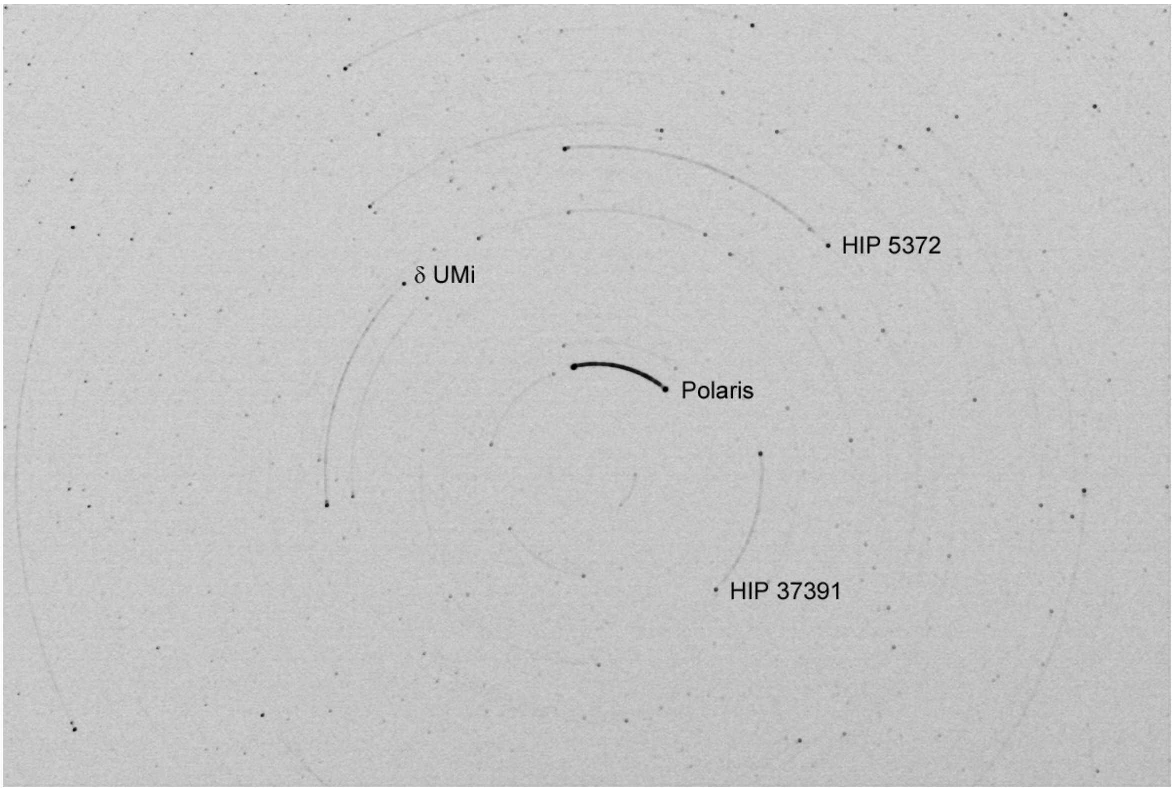

Image 2: A typical star trail image of the north polar region

3. Instructions for use of the Polar Alignment Spreadsheet

The file contains 2 tables, table 1 with example data, table 2 almost empty.

Overview of the spreadsheet

Polar alignment with a turn of a camera		Auxiliary field for adjustment
Entry space		Memory space for data of the mounting
		Memory space for coordinates of observatories
Results		Memory space for star coordinates
Calculation and interim results		Memory space for data of a reference star

The upper part of the left side is the interactive area for input and results. Yellow cells are for input of current data, orange cells are for standard data that are not often changed. Below this you find the lines for results in pale turquoise and a red line for error warnings.

In the lower part of the left side are the formulas for the calculation and the interim results. In this area nothing must be changed. Normally, the sheet is protected against accidental or unauthorized alterations.

On top of the right side is an auxiliary area for the conversion of the results, the necessary corrections of the azimuth and polar altitude, from degrees into the number of turns of the adjustment screws. Some data of metric screws are supplied for convenience.

Below the auxiliary area are some memory spaces for data of mountings, coordinates of observatories and stars and data of a reference star. These spaces are only for storage, data in these spaces are not involved in the calculation. To use the data, they can be copied here and entered in the input cells on the left side.

Siderial time base for conversion of right ascension to hour angle
Line 18

Take it easy! Use the default data of the original spreadsheet. They are applicable all over the world, even in the southern hemisphere. If the data are a few years old, you could make an update, but this is not urgent.

The data for line 18 can be read from a planetarium program, e. g. “Stellarium” (www.stellarium.org), for any location (with its longitude), any star and any time.

Data of the star trail image and observatory
Line 25

The moment of the exposure of the star trail image or 2 static images and the geographical coordinates of the observatory are entered in line 25.

The time of exposure here and the reference time in line 18 may be given in any time zone, but the difference (in hours) between the respective zone and UT has to be entered below. (Positive values for eastern time zones, negative values for western time zones.)

For the geographical coordinates of the observatory an accuracy of 0.1° is fully satisfactory.

The height above sea level in cell G26 plays only a very minor role in the calculation of the atmospheric refraction.

Which stars should be used?

The stars should be easily identifiable (brightness and surroundings) and not too far away from the pole. The author likes the nice little triangle around the North Pole: delta UMi, HIP 5372 and HIP 37391. (Suggestion for the South Pole: chi, tau and zeta Oct) (See also sky charts in the appendix.)

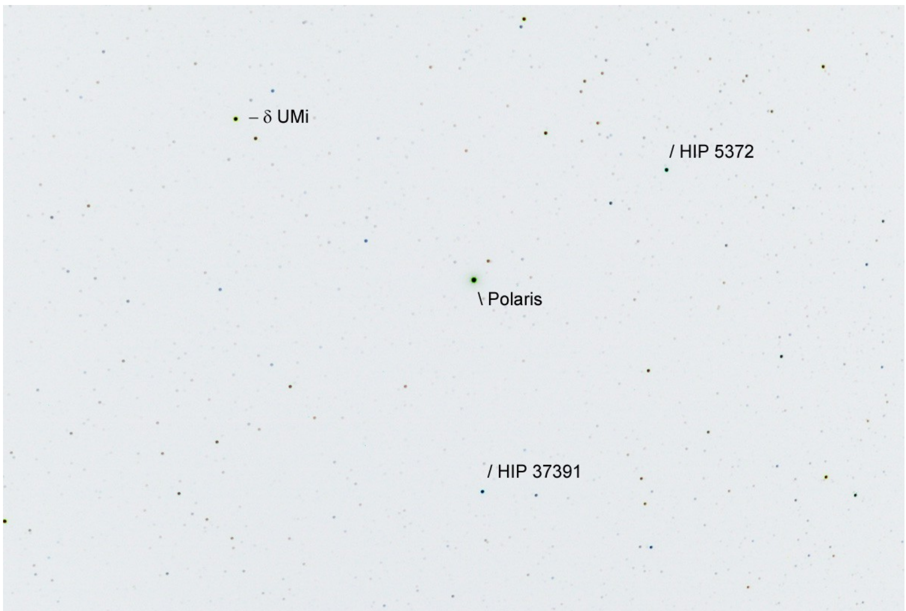

Image 3: Static image of the north polar region (f = 105mm on a camera with a chip of APS-C size)

Coordinates of the stars
Lines 34-36

The right ascension and declination of the stars change slowly due to the precession of the earth's axis. The data should not be older than one year. Do **not** use the data for year 2000. Current data can be found e.g. in „Stellarium". Data for a small selection of stars are provided in the original spreadsheet, but they may be out of date. Table 3 of the spreadsheet offers support for the update of RA and DE data. The declination must be entered as a decimal number. Write decimal numbers with a point or a comma, according to the setting of your computer.

For three stars the rectangular X and Y coordinates are measured at both ends of their trails or on both static images. (X1, Y1 and X2, Y2 for each star) The directions of the X and Y axes, the position of coordinate zero, and the coordinate scale are arbitrary. The axes must only be at right angles and have the same scale. The orientation of the image is also arbitrary, with the restriction that in the case of 2 static images they must have the same orientation, preferably landscape format.

It is recommended to use an image processing program, notably Fitswork, for the measurement of star coordinates. Fitswork (www.fitswork.de) is very accurate for this purpose, because it calculates the centre of the point spread function of the star. And it is comfortable, because the coordinates can be transferred to the polar alignment spreadsheet by copy and paste.

Measurement of coordinates in Fitswork

Start Fitswork, select and open the star trail image or the first static image. In menu Settings / Various check “<L> Show PSF Informations in a separate Window”.

Point the mouse cross at a star, do not click, but press the letter key “L”. The program calculates the centre of the point spread function (PSF) of the star and gives the X and Y coordinates in a separate window “PSF Infos”. Thus measure three stars first only at one end of their trails, preferably in the order in which they are listed in the polar alignment spreadsheet, then in the same order at the other end of the trails or on the second static image.

Mark the X and Y columns in Window “PSF Infos”, copy them with Ctrl C and paste them into the free space of the spreadsheet with Ctrl V. From there, copy and paste the coordinates to the input lines of the appropriate stars.

NOTE: Fitswork gives out decimal numbers with points. If your computer is set to use decimal numbers with comma, the points must be removed. (They could be replaced by commas, but it is easier to remove them and use integer numbers of hundred times the value.)

Results

Lines 39-40 and 42

The results, i. e. the required corrections of the azimuth and the polar altitude in degrees, are displayed in lines 39 to 40. Before you use them, look at line 42 to check if the results are trustworthy. If there was an error in the identification of a star or a faulty coordinate had been entered, there would be a warning in line 42. (The calculated results may be suppressed and replaced by “99.99”). In this case, check your inputs or measure at least one more star and replace the first three stars in turn. If the input data are good, you should find a smiley. The smiley only means that your data look trustworthy. It does not mean that the alignment is well done. The calculated camera rotation angle in line 41 must fit your estimated rotation. If not, the results are not valid. (Error of orientation?)

On top of the right side of the spreadsheet, there is an auxiliary field for conversion of the required corrections from degrees to the number of turns of the adjustment screws. Enter the thread of the screws and the distance of the screws from the appropriate axes, both in mm.

For a user in the northern hemisphere, the required correction of the azimuth refers to the north end of the polar axis and the observer looking north. In the southern hemisphere: south end of the polar axis, looking south. A positive correction goes right, the north end of the polar axis must go east and the south end must go west. A negative correction goes left, the north end must go west and the south end must go east.

The polar altitude is corrected for the influence of atmospheric refraction.

4. Short draft of the mathematics

Only for those who are interested

The X-Y-coordinates of three selected stars are measured at both ends of their trails and entered into the spreadsheet. Imagine a chord between the end points of each star's trail. Calculation begins with a new position for each star on the middle of its chord. The position of the centre of rotation is found as a weighted mean of the intersections of the perpendiculars of the three chords.

Imagine another rectangular X-Y-coordinate system in the sky, the celestial pole being the zero point of this system. The current positions of the three selected stars in the sky are calculated from their declinations and hour angles. Hour angles are the differences of siderial time and right ascension. Siderial time is calculated from a reference value and elapsed time.

The triangle formed by the three stars in the sky is connected to the celestial pole, the triangle on the image to the centre of rotation. Now by a coordinate transformation the triangle on the image is superimposed on the triangle in the sky. This reveals the deviation of the centre of rotation from the pole. From the deviation in the X-Y-plane, the coordinates of the centre of rotation in a 3D horizontal system are calculated and at last the current settings of the azimuth and altitude of the polar axis and the required corrections. The altitude is corrected for the influence of atmospheric refraction.

Three stars for accuracy, safety and convenience

Two stars would be sufficient for the calculation of the centre of rotation and its deviation from the pole. With three stars the accuracy may be improved. Moreover, three stars open a possibility to check the input data for correctness. The triangle of stars in the image should be similar to the triangle in the sky. That means their angles should be equal. If there was an error in the identification of a star or a faulty coordinate had been entered, the triangles would not match. Nevertheless a rough superposition of the triangles will always be carried out, but an error warning will be displayed if it does not match. In severe cases the results will be suppressed and replaced by “99.99”.

If the X and Y axes are swapped or the direction of one of them is reversed, the coordinates would suggest that the triangle in the photo is a mirror image of the triangle in the sky. This is checked and corrected automatically. For the user the directions of the axes are arbitrary, mistake impossible.

5. Final remarks

The author and friends have used this method successfully in the northern hemisphere, but we have had no opportunity to use it in the southern hemisphere. For the south only a simulated test with an image of the south polar region copied from Stellarium has been carried out. Therefore I would appreciate some feedback if you have used the method in the southern hemisphere.

Good luck and clear skies

Jürgen Kahlhöfer

Literature:

[1] Luethen, Hartwig: Scheinern war gestern. Sternkieker 43: 109-110, (2006)
(Magazine of GvA Hamburg)

[2] Kahlhöfer, Jürgen: Polar Alignment with Camera and Spreadsheet. Sky and Telescope
Vol. 136, no. 3, p. 36 (Sept 2018)

Email: juergen.kahlhoefer@sternwarte-nms.de

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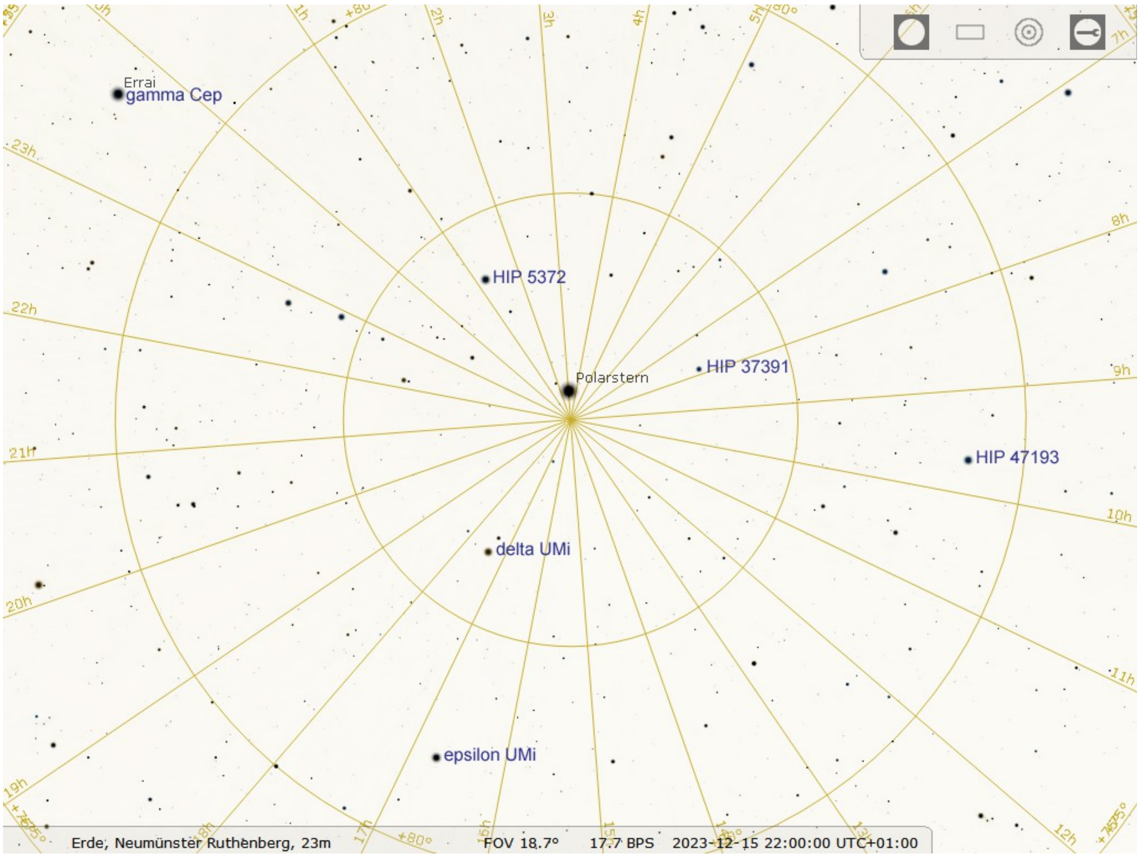
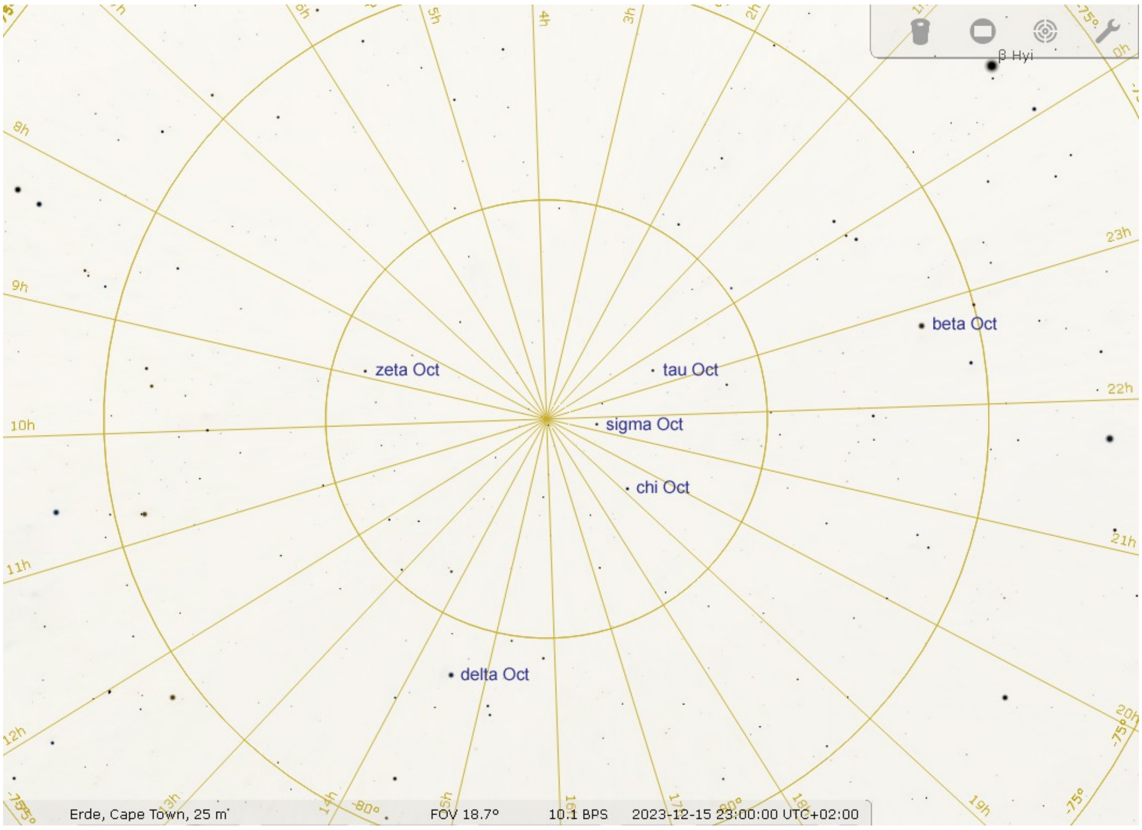


Sky chart of the north polar region



Sky chart of the south polar region

from Stellarium, inverted and annotated