Manual for measuring the parallax of asteroids

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2. Introduction

Las Cumbres Observatory (LCO) operates 25 research telescopes at seven different locations worldwide, including the two Faulkes telescopes on Haleakala/Hawaii and in Siding Spring/Australia, each with a mirror of 2.0 metres in diameter, and thirteen 1.0m telescopes. In addition, there are ten 0.4m telescopes at the locations Siding Spring/Australia, Sutherland/SA, McDonald/Texas, Cerro Tololo/Chile, Haleakala/Hawaii and Teide/Tenerife. All telescopes can be used free of charge for educational purposes.

Using this technical equipment, it is tempting to try to determine the distance of near-Earth objects with simultaneous observations from different observation sites on Earth. With baselines of up to 10,000 kilometres, one should obtain a sufficiently large parallax.

Vividly speaking, our interpupillary distance is increased to up to 10,000 kilometres, and what we observe is digitally fixed so that it can be discussed calmly and objectively in a group or team.

Of course, it is also possible to combine your own telescopes with the LCO telescopes, as Ronald Schünecke demonstrated with the school observatory of the Gymnasium Lippstadt.

The basic idea relates to stereographic vision with the help of two eyes or cameras and the calculation methods of trigonometry. Depending on age and level of education, it is possible to delve deeper into the subject.
The first phenomenological approaches, such as stereo vision, creating one's own stereo images and a stereo view of sky objects should already have a mind-expanding effect for pupils from grade 6: Asteroids are near, while fixed stars are far away.
Rough estimates of the exact distance of asteroids can be made using simple mathematics (methods from trigonometry) to produce amazingly accurate results from as early as grade 9. With stochastics and vector algebra available at college level, results can be achieved that also meet scientific requirements.
This manual assumes that you have received basic instruction in working with the LCO telescopes and that you already may have successfully created observation assignments.

There is a large number of image editing programmes available to astronomers. Here the programme AstroImageJ was chosen as an example.

AstroImageJ is a free but powerful image editing programme that runs with all common operating systems. Therefore, it is also well suited for schools. AstroImageJ can also process the compressed fits.fz files from the LCO archive directly. Both amateurs and professionals use the programme for simple but also complex solutions.

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3. Methods

a. Visualisation and explanation (from grade 6)

Stereographic vision, 3D glasses and films as well as a basic idea of cyberspace are definitely topics for lower secondary school. These can be supplemented with a stereo view into space.

For example, if you superimpose the images of asteroid (2004) Lexell from 02.12.2021 with the 0.4m telescopes from McDonald/Texas and Cerro Tololo/Chile like transparencies, you can clearly see the "Daumensprung" (this is the german word describing the phenomenon that a thumb of the outstretched hand, alternately aimed at with the right and left eye, appears to move in front of the more distant background). If you do this with different asteroids (division of work betwenn small groups of students), you qualitatively convey the different parallaxes or distances of asteroids in addition to image processing.
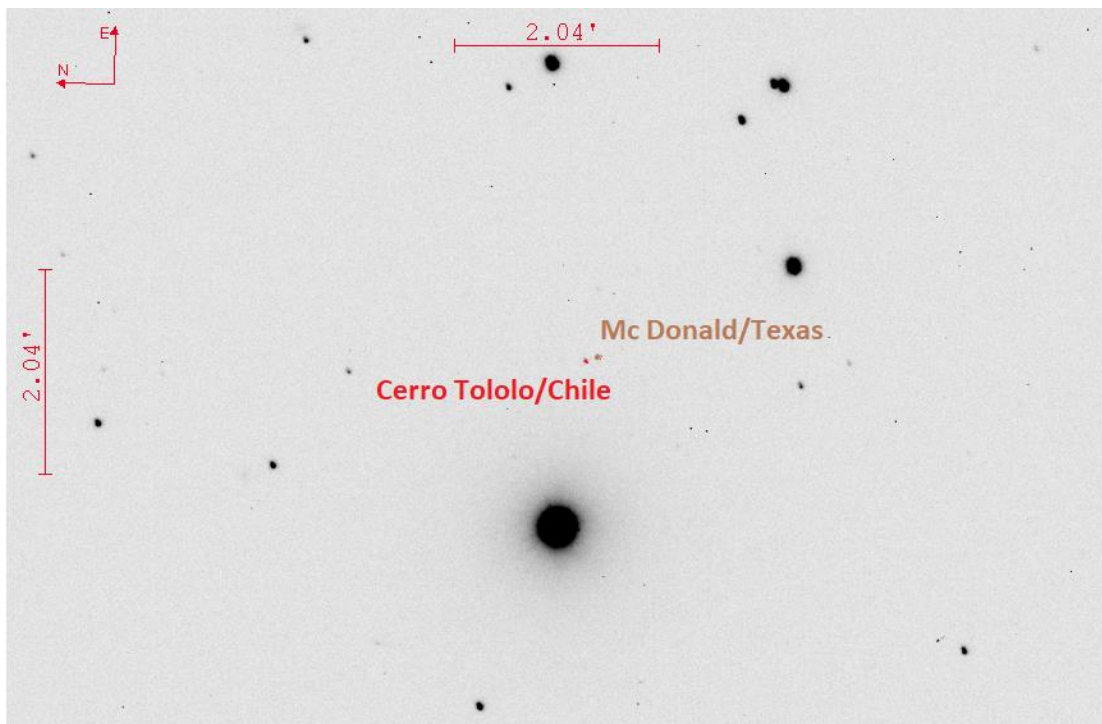

Fig. 1:   Asteroid (2004) Lexell on 02.12.2021 at 01:01UT as seen from McDonald/Texas (brown) and from Cerro Tololo (red). The individual images from the 0.4m LCO telescopes were superimposed like transparencies using the AstroImageJ software .

Astronomical insight:
The stereo view into space shows: Unlike fixed stars, asteroids are moving objects that can come quite close to Earth. They belong to our solar system. The greater the distance, the smaller the parallax.

Notes:
Using the table "Parallax → Distance" in the appendix, lower secondary school students can also estimate the approximate distance without the need of calculation.

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b. Rough estimation of distance (from grade 9)

Parallax angle

If you enlarge the area around asteroid (2004) Lexell in Figure 1 very much, you can see and count the individual pixels.
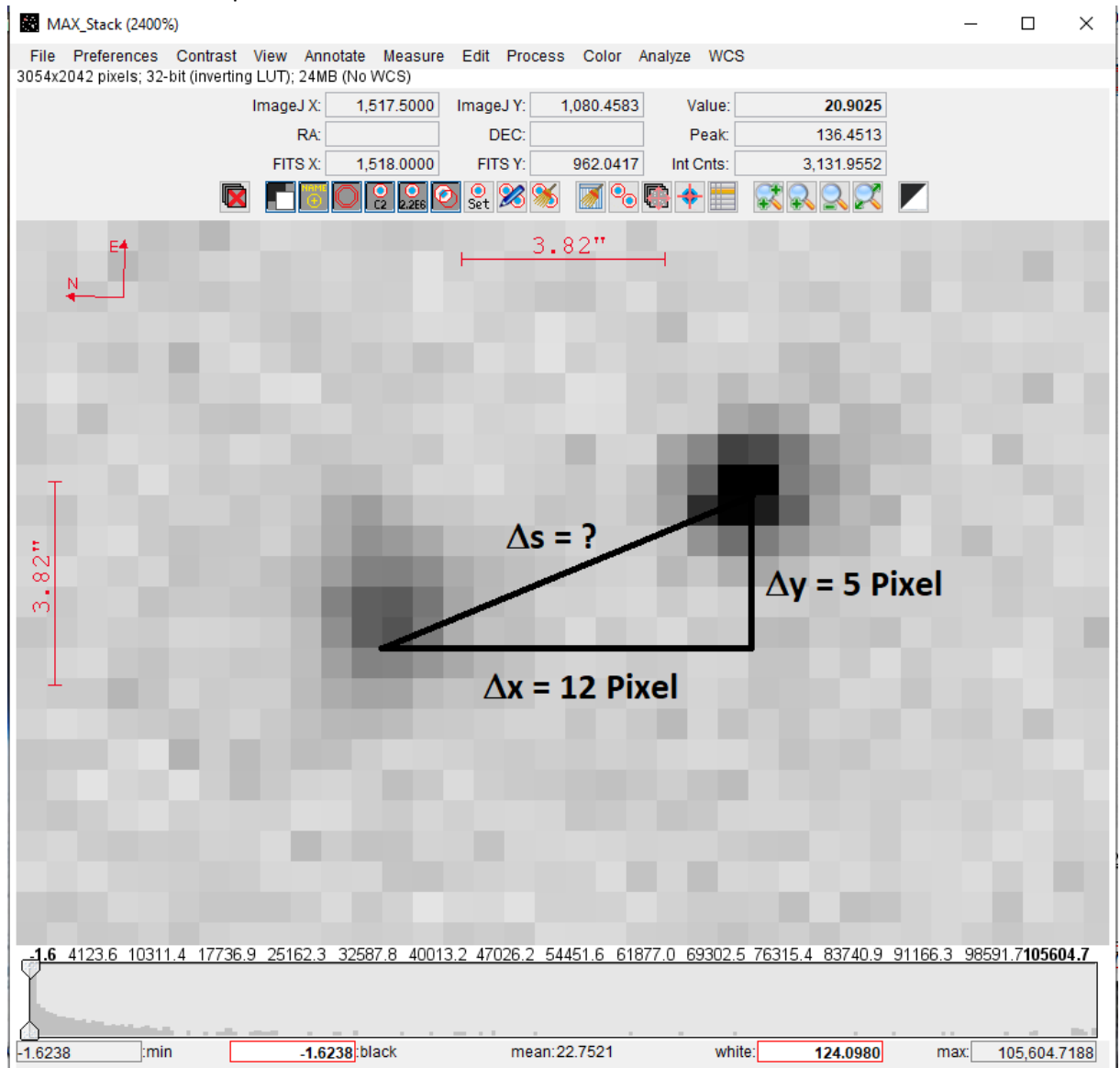
Fig.2: *Very high magnification of Fig. 1 in the area of (2004) Lexell*

The centres are 12 pixels away in the x-direction and 5 pixels away in the y-direction.

According to Pythagoras' theorem, this makes a distance of $s = \sqrt{12^2 + 5^2} = \sqrt{169} = 13.0$ pixels.

In the LCO library you will find that for the 0.4m telescopes 1 pixel corresponds to 0.571" (pixel scale: 0.571"/pix): https://lco.global/observatory/instruments/ .

The parallax angle is therefore =13.0 pix * 0.571"/pix = 7.423" = 0.1237' = 0.00206°.

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c. **Simple trigonometric considerations: Sine or tangent, isosceles triangle**

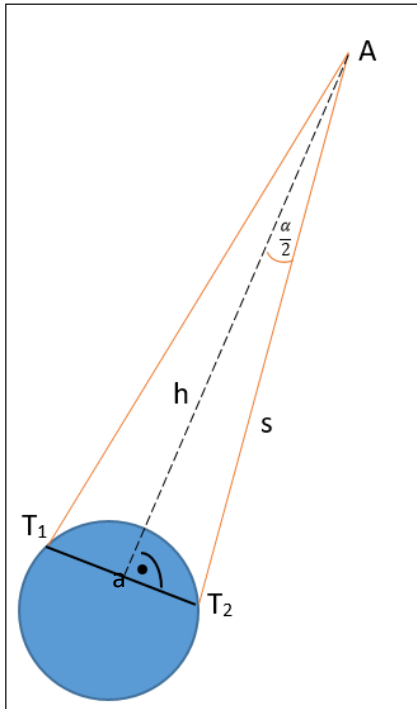If we assume in good approximation that the triangle T_1T_2A (telescope_1, telescope_2, asteroid) i is isosceles and the baseline a between T_1 (McDonald) and T_2 (Cerro Tololo) is 7180km, we obtain using the tangent or sine function:

For the height h of the triangle

$$h = 0{,}5 * a /\tan(\alpha/2) = 199512503\text{km} = 1{,}33\text{AU}$$

or for the legs

$$s = 0{,}5 * a/\sin(\alpha/2) = 199512503\text{km} = 1{,}33\text{AU}.$$

The MPC gives 1.396AU for the distance s on that day. That is, the estimate agrees with a deviation of 0.066AU (4.7%).

Notes:
* You should not do without an error estimate: How reliable is the obtained result?
In each direction one can possibly assume an inaccuracy of +/-2 pixels. It follows that the distance in the image is between 10.4pix < s < 15.7pix , which means 1.11AU< s < 1.66AU:
So s = 1.39+/-0.28AU (+/-19.9%) is a very rough but correct estimate!
* The assumption "isosceles triangle" should be discussed.
Under which circumstances is the triangle T_1T_2A very far from an isosceles triangle? Can such situations really occur here?
In order to answer this heuristically, students can produce scaled sketches (A4 sheet: Earth diameter d = 1.3cm; distance of the asteroid s = 8 to 20cm)
* The distance of the telescopes can of course also be calculated in grade 9. This contribution to the mathematical understanding of geography (longitude and latitude) can be useful as a cross-curricular aspect (see appendix).

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d. Propaedeutic science work (college level)

exact measurement with or without error estimation,

stochastics: linear regression and standard deviation, σ-environments

vector algebra: cartesian coordinates $\Leftrightarrow$ spherical coordinates, distance between two points in space (Pythagorean theorem 3D); sine and/or cosine theorem, scalar product

astronomy: general understanding of Universal Time and Sidereal Time
Movement of the Earth around the Sun!
Asteroid threat and defence

[in progress]

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4. Suitable candidates

We have gained good experience with bright asteroids located at a distance of up to 2 AU (astronomical units = distance Earth-Sun). At greater distances, the angle of the parallax becomes so small that small measurement errors produce large deviations. At distances below 0.01 AU, it becomes increasingly difficult to find two LCO sites from which to observe the object simultaneously. We have measured asteroids with a distance of 0.01 to 3.71 AU (See Appendix).

Suitable candidates can easily be found on the Near Earth Objects - Dynamic Site (NEODyS-2), sponsored by esa: https://newton.spacedys.com/neodys/index.php?pc=3.2 .
We recommend using the unique number of the asteroids!
Enter

„V magnitude mag" Max = 16 ,
„Distance from Earh au" Max = 2,
„Motion deg/day" Max= 16
and click the [search]-Button.
On 25.11.2021, five candidates were proposed (screenshot on the right):

NEA	V magnitude	Distance from earth	Motion
(4660) Nereus	13.69	0.062	1.572
(163899) 2003SD220	14.6	0.074	1.235
(159857) 2004LJ1	14.64	0.253	1.286
2010LF64	-9.99	0.855	0.458
2010LB67	2.62	1.246	0.813

Fig. 5: Search for candidates with the help of NEODyS-2

Numbers or names can easily be copy-pasted into the Submit Observation form of LCO under "Target":
https://observe.lco.global/create .
There you have to select
„Type" = „Non-Siderial" and
„Scheme" = „MPC Minor Planet"
(see below).
Asteroids that are not numbered usually have an orbit that cannot yet be clearly determined, so they may be difficult to find for beginners. Orbital parameters or celestial coordinates can, of course, also be entered by hand if you happen to have the appropriate knowledge.
If necessary, move "End" generously into the future and then adjust it together with "Start" as **precisely as possible to** the intended **simultaneous observation time.**

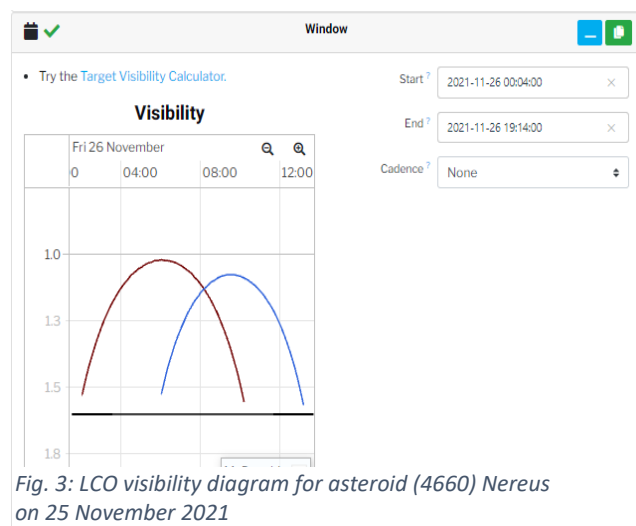Fig. 3: LCO visibility diagram for asteroid (4660) Nereus on 25 November 2021

Fig. 5 shows the visibility of NEA (4660) Nereus on 25 November 2021 for the 0.4m telescopes. Airmasses are plotted on the vertical axis in $1/\sin(\alpha)$, where α is the height of the object above the horizon. Here the value 1.5 corresponds to an altitude of α = 41,8° above the horizon and 1.3 of α

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= 50,3°. You can see that Nereus can be observed around 08:00 UT from McDonald/Texas (brown) as well as from Haleakala/Hawaii (blue). Between 8:00 and 8:08 UT Nereus is more than 50° above the horizon, thus easily observable.

You may also have to consider the distance between the target and the moon, which should not be less than 30°. Backlight shots are always problematic!

5. LCO observation requests

We decide to observe from McDonald/Texas (brown) and Haleakala/Hawaii (blue) at the same time. Between 8:00 and 8:08 UT Nereus is more than 50° above the horizon in McDonald as well as on Haleakala, thus easily observable. We set "Start" and "End" accordingly
In the input mask of LCO (https://observe.lco.global/create), only the following has to be entered under "Target":

- Name: **Nereus** *oder* **4660**
- Type: **Non-Sidereal**
- Scheme: **MPC Minor Planet**

The current orbital parameters are then automatically taken from the Minor Planet Center (MPC) database (see above).

Under "Configuration", one chooses of course

- Instrument: **0.4 meter SBIG**

and under "Instrument Configuration"

- Exposure Time: **10** [sec]
- Exposure Count: **12**
- Filter: **PanSTARRS-w** .

Fig. 4: Description of the target in the LCO job form

This job is expected to last 6:36 minutes, including alignment of the telescopes, and it has to be entered at least three times into the LCO Observation Portal to avoid simultaneous exposures from the two adjacent 0.4m mirrors at Haleakala or McDonald. A specific observing site cannot be chosen in the LCO system.

In addition, the window must be chosen very narrowly, otherwise the images will most likely not be taken simultaneously by different telescopes, but instead one after the other by a single telescope. (This makes sense considering the automatic process optimising the schedule, as the latter saves the time for aligning the telescopes.)

Remarks:

I. The PanSTARRS-w filter is a special white light filter. It roughly corresponds to visible light. Advanced observers can of course also use other filters.
II. Remember that you are dealing with moving objects! The exposure time therefore must not be too long, or otherwise the object will be imaged as a dash. On the other hand, the exposure time depends on the brightness of the asteroids and the weather conditions.

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For orientation, here is a table of the exposure time as a function of the apparent velocity of the asteroid for the 0.4m LCO telescopes:

max. velocity in °/d	max. velocity in '/h bzw. "/min	max. exposure time in s
16	40	2
11	27	3
6,4	16	5
3,2	8,00	10
1,6	4,00	20
1,07	2,67	30
0,80	2,00	40
0,64	1,60	50
0,53	1,33	60

According to Fig. 5, Nereus has an apparent speed (motion) of just under 1.6°/d = 4.00"/min. Consequently, the exposure time should not exceed 20 s.

On the other hand, Nereus has an apparent brightness of just under 14mag. Therefore, the exposure time should be greater than 10s with good seeing.

If the target is too fast or too faint, advanced observers can stack several images.

III. If a number has been assigned to the asteroid, we recommend using it in the LCO input mask. Only the number is unique. Temporary names are either not recognised at all or may be incorrectly assigned to different objects.

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6. Image processing and evaluation with AstroImageJ (before college level)

As already mentioned above, AstroImageJ is free of charge and runs with all common operating systems. Good introductions and tips can be found, for example, on the Internet or in the manual (see appendix).

The aim of the following is to outline the safest and quickest way from the obtained images to a result. For this purpose, images of asteroid (12) Victoria from 22.06.2021, which can be downloaded from the LCO archive, were used as an easy to evaluate example. Optimisations can be made as desired by the reader. Nevertheless, you should pay close attention to the processing steps and the settings, as the programme sometimes reacts somewhat sensitively to small operating errors or incorrect settings.

Possible evaluation steps:

a. **Load image sequences**
   Download the image sequences of the two telescopes from the LCO archive and unpack them into two well-labelled folders.
   Images of asteroid (12) Victoria from 22.06.2021:
   https://observe.lco.global/requests/2556448 (Cerro Tololo/Chile)
   https://observe.lco.global/requests/2556450 (McDonald/Texas)
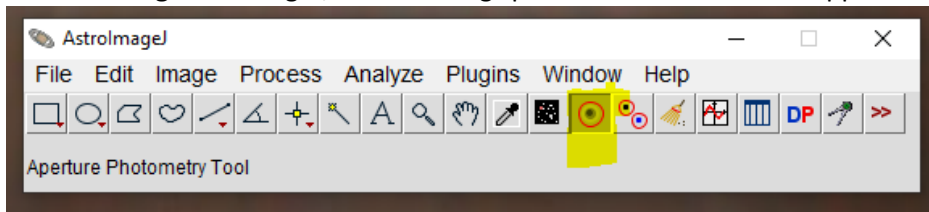   Victoria is the brightly shining object in the centre.

b. **Launch AstroImageJ**
   After **starting** AstroImageJ, the following sparse command window appears:

c. **Settings**
   Set some basic settings with a **right click** on the yellow marked icon above. The window "Aperture Photometry Settings" opens:

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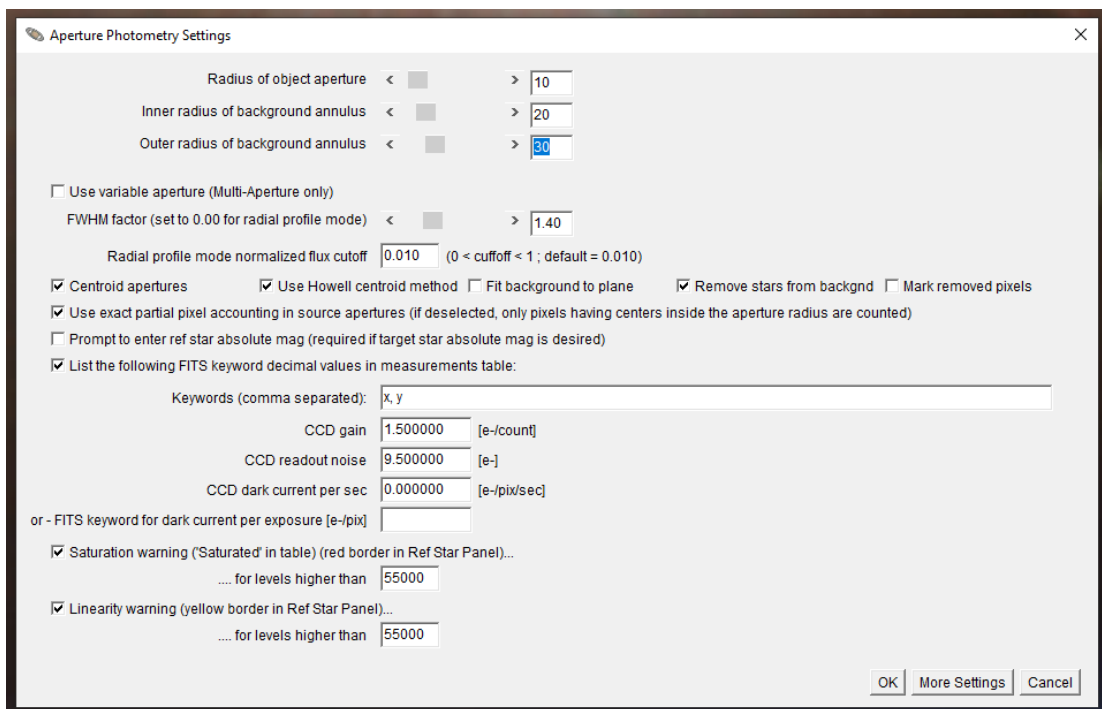
Make sure that the above settings are set. Confirm with [OK].

d. Load image files

Upload one image file each (fits.fz files) of asteroid (12) Victoria taken on 22.06.2021 from McDonald/Texas and from Cerro Tololo/Chile. The images should be as simultaneous as possible:

Menu in the command window: File ➔ Open

The files "elp0m411-kb92-20210621-0094-e91.fits.fz" (McDonald/Texas) (McDonald/Texas) und „lsc0m412-kb26-20210621-0191-e91.fits.fz" (Cerro Tololo/Chile) were loaded.
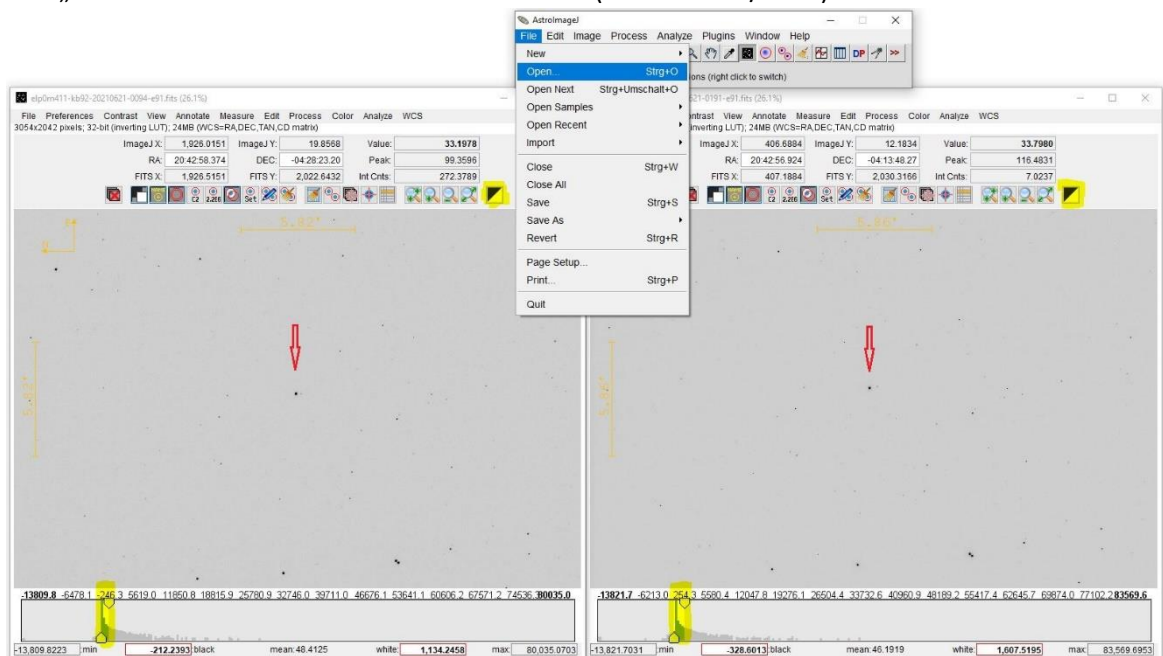
e. Brightness and contrast

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In the new windows, you can adjust the brightness and contrast with the help of the yellow marked button "auto brightness and contrast", top right. Alternatively, you can use the yellow marked sliders at the bottom.

Asteroid (12) Victoria is the brightly shining object in the centre (red arrow).

f. Selecting reference stars

In order to make positions comparable, we need to align the images:
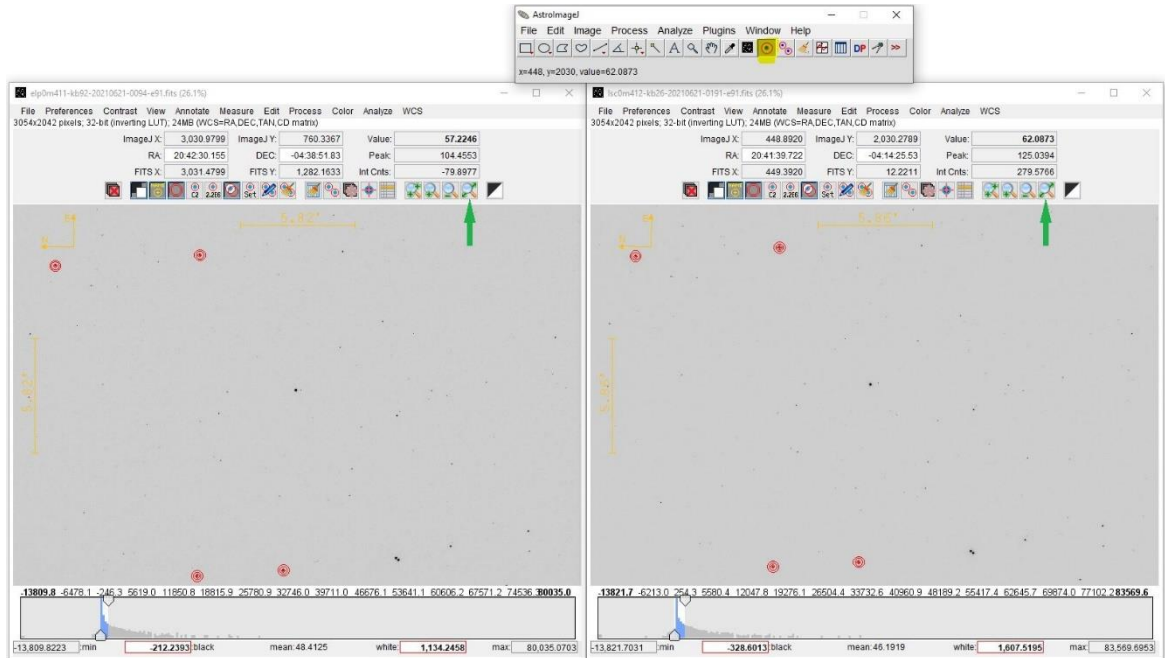
With a **left click** on the yellow marked [icon] symbol at the top of the command window you can mark prominent fixed stars in both image files:

- Zoom: mouse wheel
- move: left mouse button and mouse movement
- select: Linksklick auf Objekt
- whole picture in window: symbol [icon] (green arrow)

Make sure that the same fixed stars have been marked in both images!

g. Alignment of the images

Menu in the command window: Plugin ➔ Astronomy ➔ Align Image

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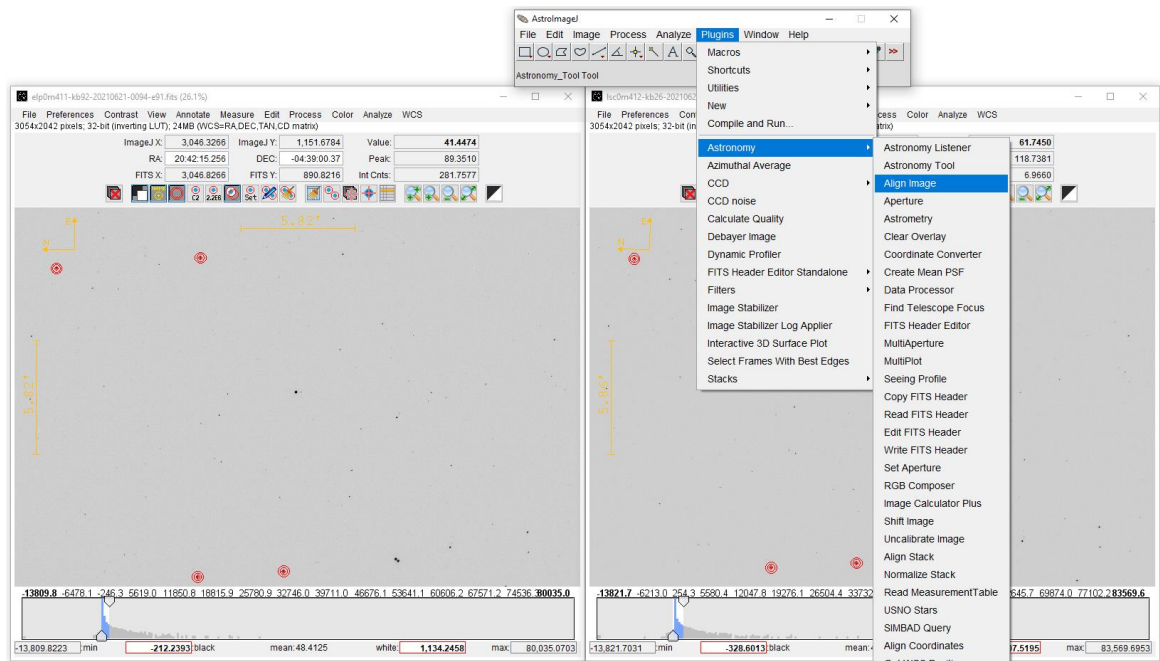
The "Align Image" window opens:
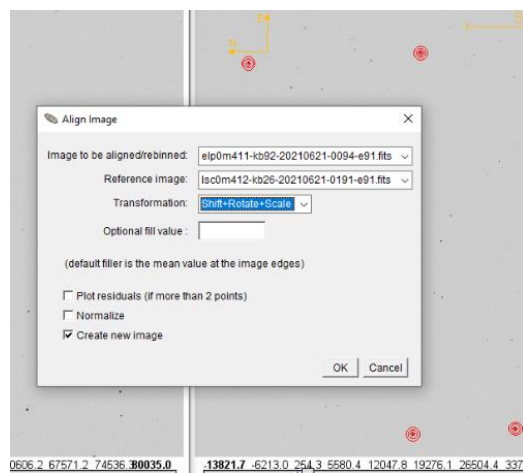
Make sure that "Shift+Rotation+Scale" is selected under **Transformation.**

With [OK] the image "elp0m411-kb92-20210621-0094-e91.fits" is adapted to the image "lsc0m412-kb26-20210621-0191-e91.fits" by means of the marked fixed stars and opened in a new image window.

Close the old image window "elp0m411-kb92-20210621-0094-e91.fits".

h. Create image stack
Using the command
Menu im Kommandofenster: Image ➔ Stacks ➔ Images to Stack
both images are combined into one stack.

Now the "Daumensprung" of asteroid (12) Victoria should become visible.
With the yellow marked slider you can switch between both images. The fixed stars remain "fixed" and the nearby asteroid seems to jump back and forth, depending from which "eye", i.e. telescope, you are looking:

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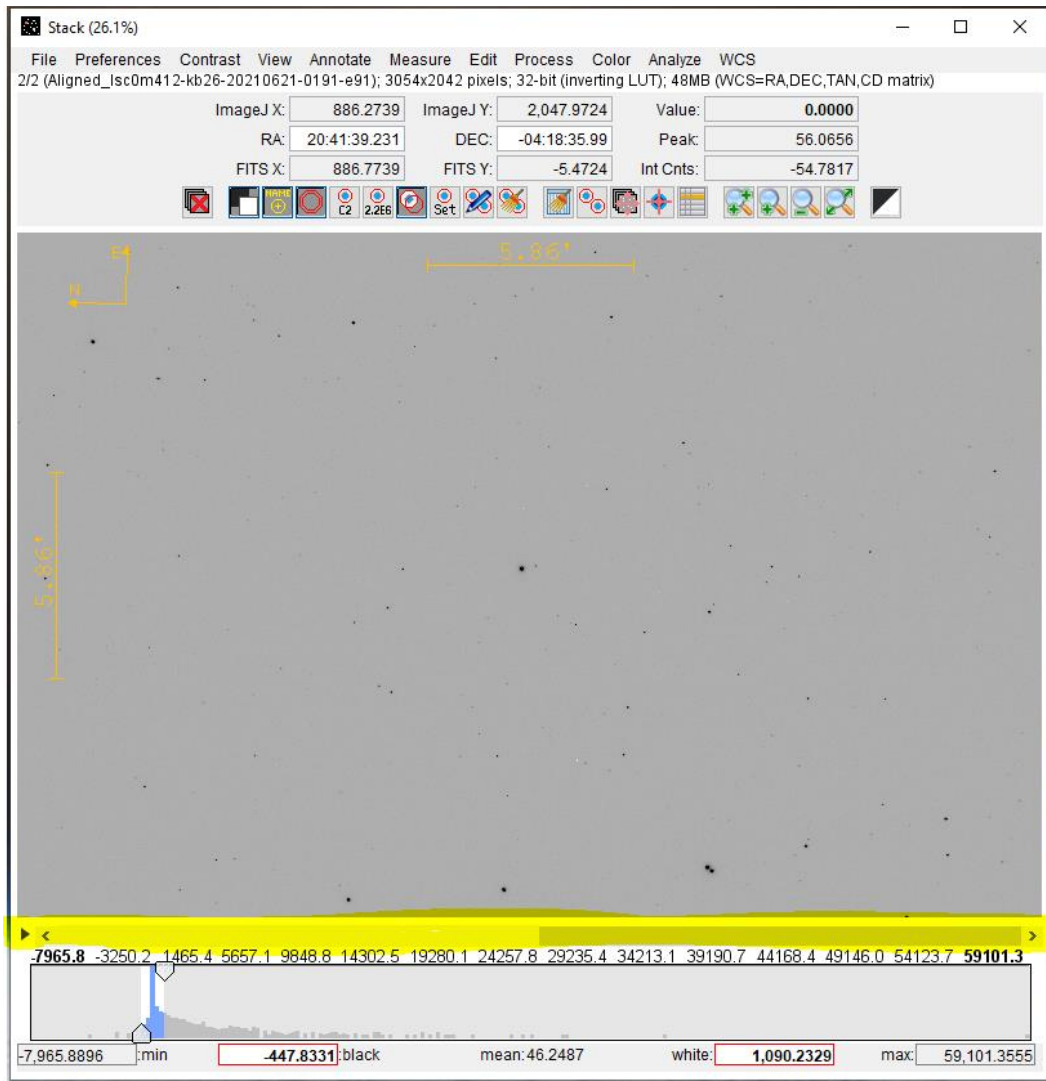
i. Parallax image
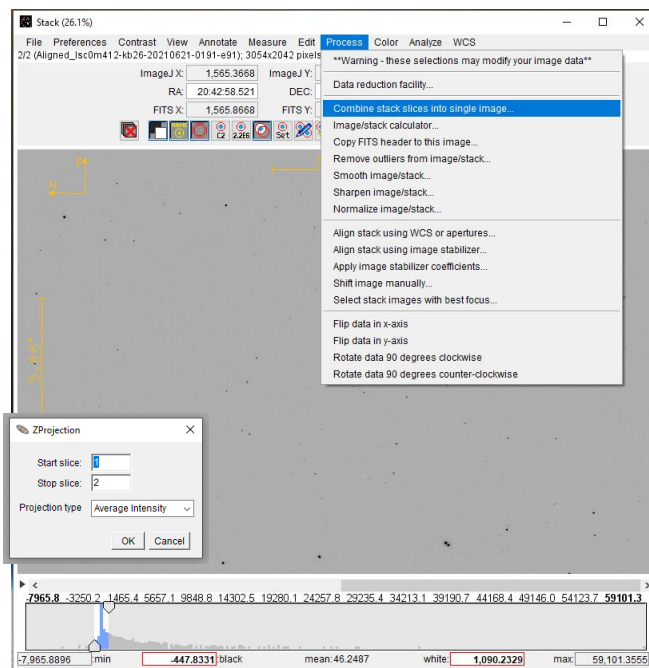
Selection of
Stack-Fenster:
Process ➔ Combine stack slice into single image…

opens the "ZProjection" window:
Start slice: 1
Stop slice: 2
Projection type: Average Intensity
Confirm with [OK].

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j. Evaluation of the parallax image

In the newly created image combination, the distance between the centres of asteroid (12) Victoria can easily be estimated by zooming in and adjusting the brightness or contrast:
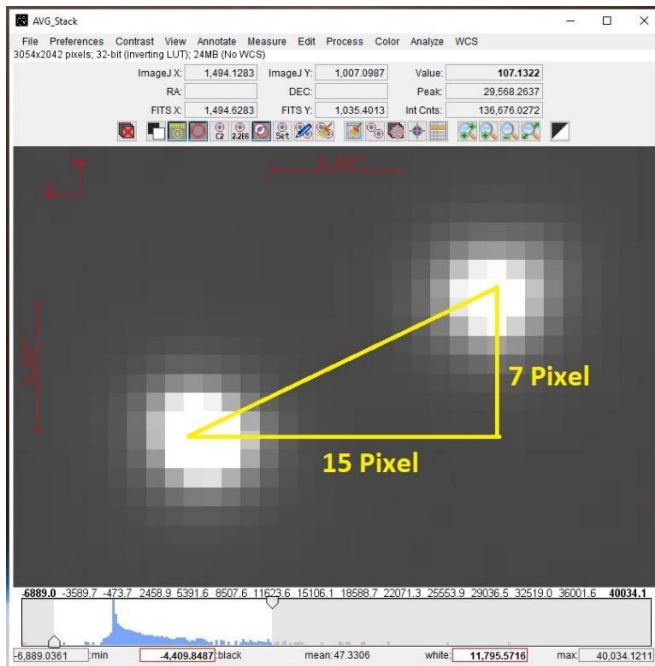
X-direction: 15 pixels (+/- 1 pixel)
Y- direction: 7 pixel (+/- 1 pixel)
According to Pythagoras' theorem, this makes a distance of

$\Delta s = \sqrt{15^2 + 7^2}$ = 16.55 pixels.

In the LCO library you will find that for the 0.4m telescopes 1 pixel corresponds to 0.571" (pixel scale: 0.571"/pix):
https://lco.global/observatory/instruments/ .

The parallax angle is therefore
α = 16,55pix * 0,571"/pix = 9,452"
= 0,1575' = 0,00263°.

If we assume in good approximation that the triangle T_1T_2A (telescope_1, teleskope_2, asteroid) is isosceles and the baseline a between T_1 (McDonald) und T_2 (Cerro Tololo) is 7180km, we obtain using the tangent or sine function:

For the height of the triangle
$$h = 0,5 * a /\tan(\alpha/2) = 156688884km = 1,047AU$$
or for the legs
$$s = 0,5 * a/\sin(\alpha/2) = 156688884km = 1,047AU.$$

In contrast, the MPC gives 0.948AU for the distance s on that day, which means our rough estimate deviates by 0.099AU (10.4%).
In each direction one can possibly assume an inaccuracy of +/-1 pixel. It follows that the distance in the image is between 15.23pix < Δs < 17.89pix, which corresponds to 0.97AU< s < 1.14AU:

The distance s = 1.06+/-0.09AU (+/-8.1%) thus determined may be a very rough estimate, but it misses the MPC value by only a small amount! This is partly due to the fact that the selected shots are about two minutes apart.

k. Optimisation

If one chooses the image "lsc0m412-kb26-20210621-0191-e91.fits" instead of image "lsc0m412-kb26-20210621-0194-e91.fits", the images have a temporal distance of only 7 seconds, and the result improves to 17.46pix < Δs < 20.12pix, which corresponds to a distance that is between 0.862AU< s < 0.993AU:

s = 0.928+/-0.066AU (+/-7.1%) is a rough estimate which includes the MPC value of 0.948AU! The centre of the distance interval thus determined only deviates from the real distance by (0.948-0.928):0.948 = 2.1%, which looks impressively good.

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7. Image processing and evaluation (college level)

[in progress]

8. Appendix

a. Table: Measured asteroids with a distance of 0.01 to 3.71 AU in 2021

No	Date	Asteroid	Note	Side 1	Side 2	Own evaluation: Result in AU	Error in AU	Error	Real Distanz (JPL): Deviation	Requests (1. Side)	Requests (2. Side)	Comments
1	11.01.2021	2021 AZ	(NEO)	C. Tololo 1m0	703 Catalina Sky	0,052240	0,0005	0,96%	0,10%	https://observe.lco.global/requests/2353064 https://observe.lco.global/requests/2353065	https://www.minorplanetcenter.net/db_search/show_object?utf8=✓&object_id=2021+AZ	Extrapolation (12min) ; side result of neo-confirmations (A10ubx8); 2. Side from MPC
2	29.01.2021	313 Chaldeae		Teide 0.4m	Teide 0.4m	1,119	0,066	5,90%	0,97%	https://observe.lco.global/requests/2370807	https://observe.lco.global/requests/2370805	Interpolation
3	07.02.2021	60 Echo		Hawaii 0.4m	Siding Spring 0.4m	1,004	0,0184	1,83%	1,37%	https://observe.lco.global/requests/2382664	https://observe.lco.global/requests/2382663	Interpolation/don't worry, wrong job-name: "#PB - Apophis_A" TO "#PB - Apophis_C"
4	09.02.2021	2020 XU6	(NEO)	Sutherland 0.4m	Teide 0.4m	0,0666	0,0003	0,45%	0,55%(to check!)	https://observe.lco.global/requests/2385370	https://observe.lco.global/requests/2385372	Deviation greater than error! Own error or JPL error!
5	18.02.2021	2020 XU6	(NEO)	Sutherland 0.4m	Teide 0.4m	0,0342	0,0001	0,29%	0,61%(to check!)	https://observe.lco.global/requests/2393589	https://observe.lco.global/requests/2393590	Deviation greater than error! Own error or JPL error!
6	24.01.2021	99942 Apophis	(PHA)	Hawaii 0.4m	Siding Spring 2m0	0,182	0,002	1,10%	0,11%	https://observe.lco.global/requests/2365883	https://observe.lco.global/requests/2361105	Interpolation
7	07.02.2021	99942 Apophis	(PHA)	Hawaii 0.4m	Siding Spring 0.4m	0,147	0,002	1,36%	0,03%	https://observe.lco.global/requests/2382799 https://observe.lco.global/requests/2382801	https://observe.lco.global/requests/2382797 https://observe.lco.global/requests/2382800	Interpolation
8	03.03.2021	99942 Apophis	(PHA)	Sutherland 0.4m	Teide 0.4m	0,1132	0,0007	0,62%	0,18%	https://observe.lco.global/requests/2406141	https://observe.lco.global/requests/2406139 https://observe.lco.global/requests/2406140	Interpolation
9	17.03.2021	99942 Apophis	(PHA)	C.Tololo 0.4m	Teide 0.4m	0,1183	0,0007	0,59%	0,06%	https://observe.lco.global/requests/2419567 https://observe.lco.global/requests/2419568	https://observe.lco.global/requests/2419463	Interpolation
10	21.06.2021	3 Juno		Hawaii 0.4m	C.Tololo 0.4m	2,387	0,119	4,99%	2,36%	https://observe.lco.global/requests/2555141 https://observe.lco.global/requests/2555142	https://observe.lco.global/requests/2555143	Interpolation
11	22.06.2021	12 Victoria		C.Tololo 0.4m	Texas 0.4m	0,9567	0,0167	1,75%	0,92%	https://observe.lco.global/requests/2556448	https://observe.lco.global/requests/2556450	Interpolation
12	09.10.2021	2 Pallas		C.Tololo 0.4m	Hawaii 0.4m	2,114	0,141	6,67%	4,87%	https://observe.lco.global/requests/2675000 https://observe.lco.global/requests/2675001	https://observe.lco.global/requests/2674999	Interpolation
13	11.11.2021	2019 XS	(NEO)	C.Tololo 0.4m	McDonald 0.4m	0,01278	0,00005	0,39%	0,29%	https://observe.lco.global/requests/2706034	https://observe.lco.global/requests/2706036	Interpolation; with σ = 3 (99,5% safety); with σ = 1,64 (90% safety) +/-0,21%
14	20.11.2021	159857 F9857	(PHA)	McDonald 0.4m	Hawaii 0.4m	0,2128	0,00206	0,97%	0,09%	https://observe.lco.global/requests/2712720	https://observe.lco.global/requests/2712718 https://observe.lco.global/requests/2712719	Interpolation. After selecting the sharpest images. Some are shaky.
15	23.11.2021	4660 Nereus	(PHA)	McDonald 0.4m	Hawaii 0.4m	0,0762082	0,000233	0,31%	0,17%	https://observe.lco.global/requests/2714815	https://observe.lco.global/requests/2714623 https://observe.lco.global/requests/2714625	Extrapolation (50s)

b. Linear distance between LCO telescopes (table)

Distanz a in km	Cerro Tololo/Chile	Haleakala/Hawaii	McDonald/Texas	Siding Spring/Australien	Sutherland/SA	Teide/Teneriffa
Cerro Tololo/Chile	0	9512	7178	10310	7814	8031
Haleakala/Hawaii	9512	0	5154	7645	12677	10895
McDonald/Texas	7178	5154	0	10956	11709	7676
Siding Spring/Australien	10310	7645	10956	0	9755	12667
Sutherland/SA	7814	12677	11709	9755	0	7334
Teide/Teneriffa	8031	10895	7676	12667	7334	0

Combinations marked in red do not make sense!

c. Calculating the distance between two places on earth
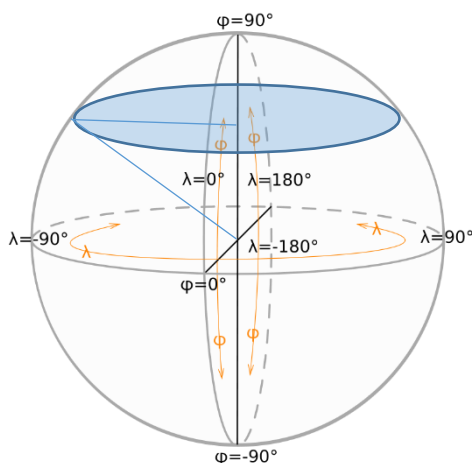
Essentially, this is about transforming spherical coordinates (longitude λ and latitude φ) into Cartesan coordinates and determining the distance of two points in 3D space:

$x = R_E * \sin \varphi * \cos \lambda$

$y = R_E * \sin \varphi * \sin \lambda$

$z = R_E * \cos \varphi$

$\Delta x = x_2 - x_1$

$\Delta y = y_2 - y_1$

$\Delta z = z_2 - z_1$

$a = \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2}$

This provides a good opportunity to get an idea of our habitat, planet earth (life on a sphere).

Parameters are:

- λ Longitude of observation site
- φ Latitude of observation site
- R Distance of the observation point from the center of the earth

Manual for measuring the parallax of asteroids

d. Table: Parallax ⇔ Distance s in km oder au

Parallaxe in "	Faktor k
2	103132,4
3	68754,9
4	51566,2
5	41253,0
6	34377,5
7	29466,4
8	25783,1
9	22918,3
10	20626,5
12	17188,7
14	14733,2
16	12891,6
18	11459,2
20	10313,2
25	8250,6
30	6875,5
35	5893,3
40	5156,6
45	4583,7
50	4125,3
55	3750,3
60	3437,7
65	3173,3
70	2946,6
75	2750,2
80	2578,3
85	2426,6
90	2291,8
100	2062,6
120	1718,9
130	1586,7
140	1473,3
160	1289,2
200	1031,3
250	825,1
400	515,7
600	343,8
800	257,8

If the **distance a** of the two telescopes is known in km, the **distance s** to the asteroid in km is obtained from the following formula:

$$s = k * a .$$

In addition, the distance in au is given by:

$$s = k * a/1.54E8 .$$

Manual for measuring the parallax of asteroids

e. Some help for AstroImageJ

- AstroImageJ: download and instructions
  https://www.astro.louisville.edu/software/astroimagej/

- AstroImageJ: Guide
  https://www.astro.louisville.edu/software/astroimagej/guide/AstroImageJ_User_Guide.pdf

- Youtube-Tutorials: AstroImageJ
  a) AstroImageJ Introduction:
     https://www.youtube.com/watch?v=bi4T_wgNYNk
  b) Obtaining a Light Curve Using AstroImageJ:
     https://www.youtube.com/watch?v=EfMPl2SaSjM
  c) AstroImageJ (AIJ): Processing ExoPlanet Transits (Start to Finish):
     https://www.youtube.com/watch?v=GW--rE5O-c8
  d) AstroImageJ Photometry (LCO)
     https://www.youtube.com/watch?v=joAO7NqEy4w
  e) Robotic Telescope Project: Basic analysis of exoplanet transit data in AstroImageJ
     https://www.youtube.com/watch?v=uVb5CE_syd0
  f) Robotic Telescope Project: Extended analysis of exoplanet transit data in AstroImageJ
     https://www.youtube.com/watch?v=_UR78qRGscc