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The 2024 Great American Eclipse: first report on the observational campaign

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This is a short report on the observational campaign that has been performed during the total solar eclipse of April 8th, 2024 in U.S. After a short description of the eclipse properties, this report briefly describes the observation site, the instrumentation, and then lists and shows some of the exposures that have been acquired during the totality.

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1. The April 8th total solar eclipse

The main properties of the total solar eclipse (hereafter TSE) that occurred on April 8th, 2024 are shown in Figure 1: the totality path crossed the first Mexico, then the U.S., and finally Canada and also Iceland over a time of about 101 minutes starting around 18:07 GMT on the West Coast of Mexico, and ending around 19:46 GMT on the East Coast of Iceland (see Fig. 1). The maximum expected duration of the totality at the greatest duration point near Durango Mexico (Lat. 25.3° N, Lon. 104.1° W) was 4 minutes and 28 seconds. A list of times for main U.S. cities and towns in the path of totality is provided in Table 1 (courtesy of NOAA).

Figure 1: main characteristics of the April 8th 2024 total solar eclipse (NASA).

Location	Partial Begins	Totality Begins	Maximum	Totality Ends	Partial Ends
Dallas, Texas	12:23 p.m. CDT	1:40 p.m. CDT	1:42 p.m. CDT	1:44 p.m. CDT	3:02 p.m. CDT
Idabel, Oklahoma	12:28 p.m. CDT	1:45 p.m. CDT	1:47 p.m. CDT	1:49 p.m. CDT	3:06 p.m. CDT
Little Rock, Arkansas	12:33 p.m. CDT	1:51 p.m. CDT	1:52 p.m. CDT	1:54 p.m. CDT	3:11 p.m. CDT
Poplar Bluff, Missouri	12:39 p.m. CDT	1:56 p.m. CDT	1:56 p.m. CDT	2:00 p.m. CDT	3:15 p.m. CDT
Paducah, Kentucky	12:42 p.m. CDT	2:00 p.m. CDT	2:01 p.m. CDT	2:02 p.m. CDT	3:18 p.m. CDT
Evansville, Indiana	12:45 p.m. CDT	2:02 p.m. CDT	2:04 p.m. CDT	2:05 p.m. CDT	3:20 p.m. CDT
Cleveland, Ohio	1:59 p.m. EDT	3:13 p.m. EDT	3:15 p.m. EDT	3:17 p.m. EDT	4:29 p.m. EDT
Erie, Pennsylvania	2:02 p.m. EDT	3:16 p.m. EDT	3:18 p.m. EDT	3:20 p.m. EDT	4:30 p.m. EDT
Buffalo, New York	2:04 p.m. EDT	3:18 p.m. EDT	3:20 p.m. EDT	3:22 p.m. EDT	4:32 p.m. EDT
Burlington, Vermont	2:14 p.m. EDT	3:26 p.m. EDT	3:27 p.m. EDT	3:29 p.m. EDT	4:37 p.m. EDT
Lancaster, New Hampshire	2:16 p.m. EDT	3:27 p.m. EDT	3:29 p.m. EDT	3:30 p.m. EDT	4:38 p.m. EDT
Caribou, Maine	2:22 p.m. EDT	3:32 p.m. EDT	3:33 p.m. EDT	3:34 p.m. EDT	4:40 p.m. EDT

Table 1: list of times and main cities in the path of totality (NOAA).

The event was massively followed by public throughout all the countries, and a large number of projects have been conducted for this special event, not only for outreach to the general public, but also to acquire new scientific observation of the inner solar corona. Many “citizen science” projects were also conducted, such as the "Eclipse MegaMovie" project and the "Citizen CATE (Continental-America Telescope Eclipse)" project. In particular in the framework of the latter project a new way to visualize the polarization properties of coronal emission observed during TSEs has been developed (DeForest, Seaton, & West 2022). This method is based on the so-called HSV – Hue, Saturation & Value – color scale, and is able to provide a visualization of the solar corona closer to the "natural" visualization which would be possible to observe with the naked eye if the human eye had a sensitivity to polarization; an example is shown in Fig. 2.

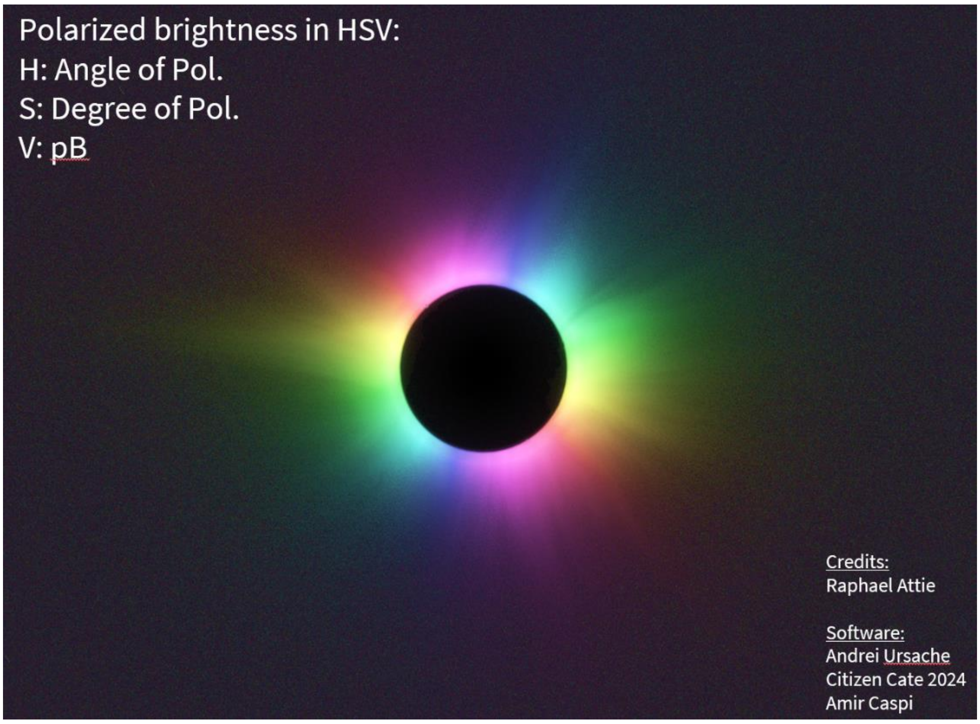


Figure 2: the April 8th 2024 TSE as observed from Mount Katahdin (Maine) by Dr. Raphael Attié – NASA.

2. TSE observation site

Among different possible places in U.S., the final location for the 2024 TSE observations was chosen in order to

- allow the availability of a quiet and not crowded observation area,
- allow possible last-moment displacements along the centre of the totality path,
- have good duration of the totality,
- allow also the attendance after the TSE to the TESS2024 meeting.

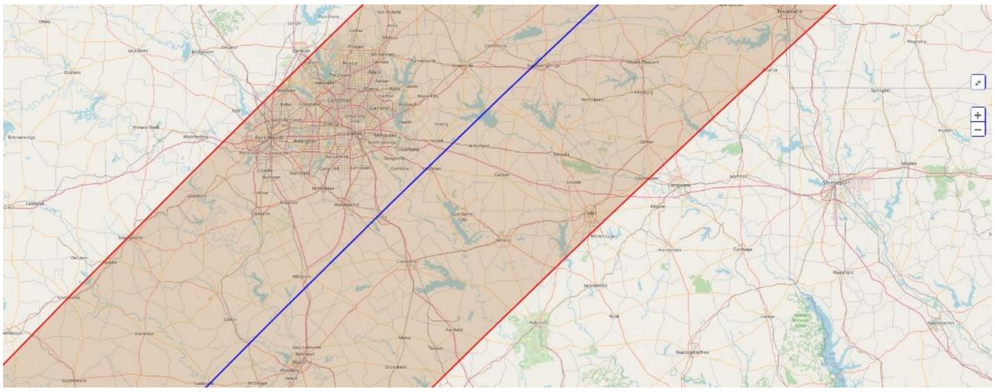
Considering all the above and other conditions, I decided to perform the observations from Balch Springs nearby Dallas TX, the final site of the observations was located at following GPS coordinates:

Latitude:	+32.717570 (32° 43' 3.252" N)
Longitude:	-96.641500 (96° 38' 29.399" W)
Altitude:	145 m
Distance from central line:	29.9 km

A couple of maps (with different zoom) showing the exact location of observations are provided in Fig. 3, as provided by the "eclipse2024.org" interactive map[†]. This interactive map also provides the expected local

[†] https://eclipse2024.org/eclipse_cities/statemap.php

times for the first (C1, beginning of partial eclipse), second (C2, beginning of totality), third (C3, end of totality), and fourth (C4, and of partial eclipse) contacts between the Moon's and the Sun's disks; these times are listed in Table 2, together with local altitude for the Sun centre. The expected total duration of totality in the selected observation site was 4 minutes and 9 seconds.



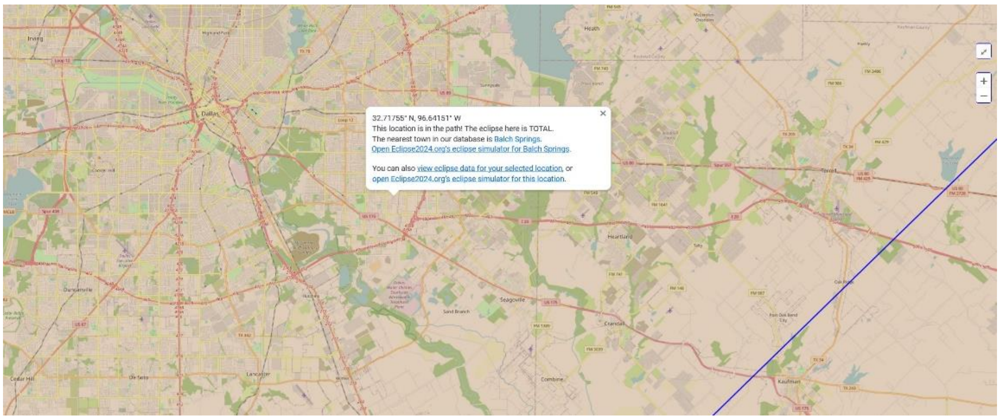


Figure 3: maps (with two different zoom) of the location chosen in Dallas TX for the 8th April 2024 TSE observations with respect to the centre of totality (blue line) and the TSE area (red lines, provided by the "eclipse2024.org" interactive map).

Event	Date	Time (UT)	Time (local)	Altitude
C1	08/04/2024	17:23:24	12:23:24	+60.7°
C2	08/04/2024	18:40:43	13:40:43	+64.7°
C3	08/04/2024	18:44:52	13:44:52	+64.6°
C4	08/04/2024	20:02:52	15:02:52	+56.7°

Table 2: TSE times for the selected location of observations.

3. Instrumentation

The 2024 TSE observations have been conducted by using the same instrumentation successfully employed for the 2017 TSE observations (see Bemporad, Abbo & Benna 2017; Bemporad 2020, Bemporad 2023):

- Canon EOS 1100D DSLR Camera,
- Canon EF 75-300mm f/4-5.6 III Telephoto Zoom Lens,
- Camera tripod (alto-azimuthal mount, no tracking).

The exposures during the partial and total eclipses have been acquired by using the following filters:

- Baader OD5.0 solar filter (filter sheet mounted on a sunshade),
- Hoya 58mm Linear Polarizer Filter (B58PLGB).

The exposure sequences and bracketing have been remotely controlled by using the following hardware and software:

- Neewer LCD Digital Timer Remote Control,
- Samsung Tablet running the DSLR Controller[‡] app.

Moreover, in the occasion of the 2024 TSE, an additional instrumentation has been procured and tested with observations of the moon and the sun before the event, and more in details:

- ALKERIA CELERA CO5S-MP "PolarCam"
- Jintu 500mm f/6.3 Manual Telephoto Lens
- Skymemo-S Equatorial Wedge + Portable Tracking Platform
- Neewer 163 cm tripod + fluid video head

The exposure sequences and bracketing have been remotely controlled by using the following hardware and software:

- Laptop Lenovo IdeaPad 5 Pro 16IAH7 i7-12700H 4.7GHz SSD1000GB
- ALKERIA Vision Studio (v. 1.1.0)
- Microsoft Visual Studio 2022.

For the partial phase I employed the same Baader OD5.0 solar filter also for the above camera, while for the totality a polarizer filter was not necessary anymore considering that the "PolarCam" is equipped with a sensor (SONY IMX 264) incorporating a layer of linear polarizers above the pixels with four different polarization angles (0°, 90°, 45°, and 135°) for each macro-pixel. A detailed list of specifications for the "PolarCam" is given in Fig. 4 (as provided by the ALKERIA S.R.L.[§]).

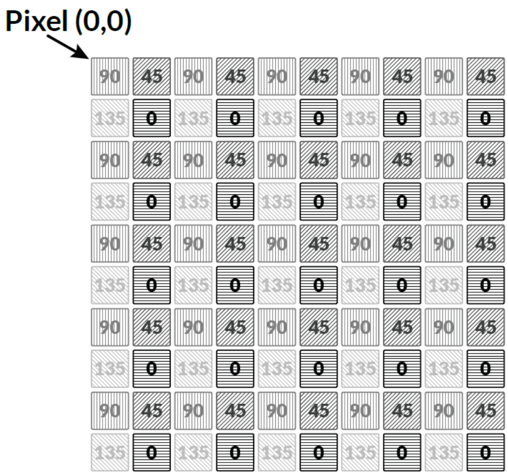


Figure 4: example of distributions of linear polarizer filters over adjacent PolarCam pixels

‡ https://dslrcontroller.com/
§ https://www.alkeria.com/

Specification	CELERA CO5S-MP
Sensor model	SONY IMX264
Sensor type	Mono Polarized
Sensor resolution	2464(W) x 2056(H) (5.01 MP)
Sensor technology	CMOS, global shutter
Sensor format	2/3"
Pixel size	3.45 μm^2 × 3.45 μm^2
Max. frame rate	35 fps
A/D Conversion	12 bits
Synchronization	External trigger, software trigger
Controls	Shutter, gain, virtual angle, LUT, sequencer
Shutter control	17 μs ÷ 5 s (1 μs steps)
Sequencer	Up to 64 pages
Binning factor	None
Readout	Normal, frame combiner
Power supply	3 W max, powered by USB 3.2 Gen 1x1
Inputs/outputs	2 in, 2 out, 1 I/O (RS-422, RS-644, LV-CMOS, LV-TTL)
Lens adapter	C-mount, F-mount
Interface	Single USB 3.2 Gen 1x1
Pixel formats	RAW8, RAW16, RGB24
Weight	131 g (with C-mount adapter)
Size (without adapters)	56 mm x 56 mm x 26.7 mm
Size (with C-mount)	56 mm x 56 mm x 38.3 mm
Size (with F-mount)	56 mm x 56 mm x 67.3 mm
Conformity	CE, RoHS, FCC, IC
Operating temperature	0 ÷ 50 °C (referred to housing)
Software	MaestroUSB3
Link	www.alkeria.com/products/celera-polarization
Warranty	24 months

Figure 5: list of specifications for the ALKERIA CELERA CO5S-MP "PolarCam".

4. PolarCam testing and setup

Before the eclipse campaign, the ALKERIA PolarCam has been tested in many different occasions. The main purposes of these tests were to 1) optimize the C# routine (provided by ALKERIA) managing the sequence acquisition, 2) optimize the sequence of exposures to be acquired for every bracketing, 3) optimize the metadata content attached to each image acquired by the camera, 4) check the proper operation of the 500 mm telephoto zoom with the camera, 5) check the proper operation of the polarized sensor filters, 6) check the possible consequences of misalignments of the tracking platform with the North pole. These listed activities led in summary to the results briefly described as follows:

1. The C# file has been optimized first of all to save the acquired images at the end of each bracketing sequence (and not at the end of the whole acquisition), to save each image in a single TIFF file (and not in a multi-layer TIFF as originally proposed by ALKERIA with 4 images for each one of the 4 polarized filters), to write each file with a filename corresponding to the system acquisition time, to have a definable path for the input directory (where the XML file created with the "ALKERIA Vision Studio" software defining the sequence is located) and for the output directory (where the images are saved); the C# code was developed with "Microsoft Visual Studio 2022" together with the ALKERIA Team, whose support is gratefully acknowledged here;
2. The exposures acquired into a single bracketing sequence was defined by a file "configuration.XML" created as an output of the "ALKERIA Vision Studio" software, different attempts have been performed trying to cover at least two order of magnitudes in the signal, and having the last 3-4 exposures in the sequence with the full Moon saturated; the reason is that the surface brightness of the Moon varies from about apparent magnitude 6.34 near a new Moon, to 3.53 near full Moon, and this interval covers more or less the surface brightness magnitude of the solar corona between 1.3 and 2.0 solar radii (as shown in Figure 8); it was also important to optimize the frame rate for each frame, because the ALKERIA camera has a maximum rate of 25 Hz, but of course each frame

cannot be acquired with a rate higher than $1/t_{exp}$; also it was very important to check that each sequence is acquired in a short amount of time like 1 sec, and also that on the other side the total number of files (considering that each image occupies 9.67 MB) resulting after the sequence acquisition can be recorded on the Laptop SSD memory; the defined sequence is provided in the next paragraph;

3. It was very important to save in each single image the exact acquisition time (taken from the system time that I synchronized before the eclipse with the UT), the shutter time, and also another metadata information such as the camera temperature for future dark current corrections;
4. During the testing I noticed that at the high expected elevation for the total solar eclipse observations (between 60° and 64°) the 500 mm lens had a problem of stability with the focusing (in practice the weight of the lens itself caused the movement of the focus to rotate), a problem that became critical when I discovered that in the images acquired a little bit off-focus the pattern in the pixels due to different polarization angles in the images was washed out (an effect also confirmed by the ALKERIA Team); I solved the problem by marking on the lens mounting the exact position of the focus for sources at infinity, and by using (as done before for the 2017 TSE) a simple scotch tape to block the focus position on the observation day;
5. Different image sequences have been acquired of different Moon's phases (Figure 6), and also of the Sun; IDL routines were written to perform the preliminary data analysis and measure the first 3 parameters of the Stokes vector (Figure 7) by combining intensities with different polarizer filters (equations 1 and 2 in Reginald et al. 2017); moreover images have also acquired by mounting the linear polarizer filter employed for the 2017 TSE in front of the lens installed over the PolarCam, providing a preliminary estimate of the standard errors in the measurement of the polarization angle which is on the order of 8-16%; observations with the Sun (Figure 9) demonstrate that in the regions of the image where stronger spatial intensity gradients are present (as it happens near the limb of the Sun), some artefact can be introduced in the derivation of degree of linear polarization and polarization angle, always made by assuming that the nearby 4 pixels with 4 different polarizers are observing the same source (see also comments on this in Bemporad 2020).
6. Different attempts were performed to prevent the case where a polar alignment (due for instance to cloudiness) in the nights before the eclipse was not possible; in particular I tested many times that, by selecting the correct value for the equatorial mount azimuth angle (simply related to the latitude of the observation site) and by using a compass to align more or less the axis in the direction of the North, it was possible to keep the Moon's disk inside the field-of-view of the camera over the expected 4 minutes of duration of the totality.

Some Figures related with the above activities are provided in the following pages.

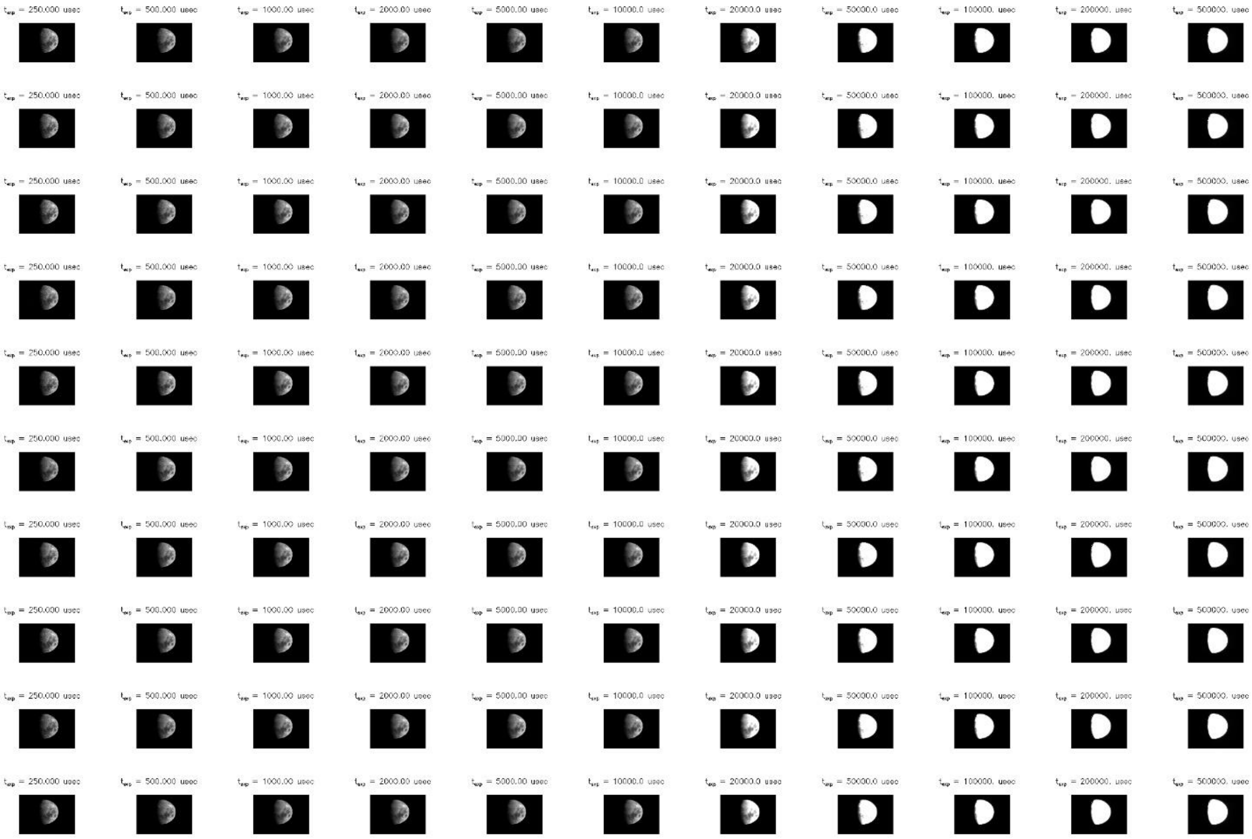


Figure 6: Example of different exposures acquired and normalized for 11 different shutter times (given in μsec).

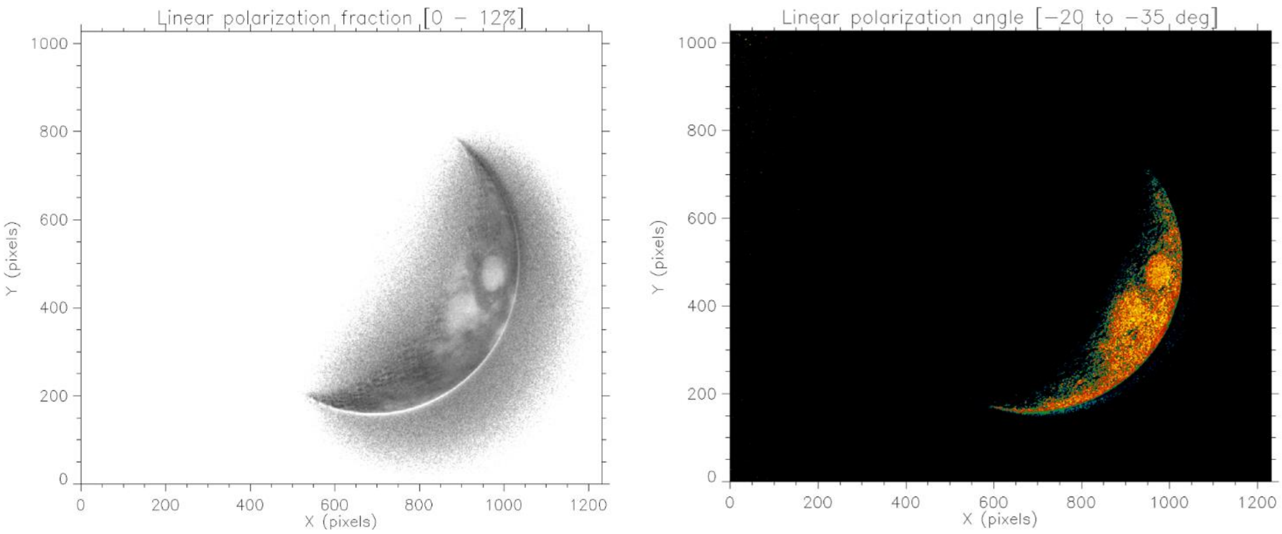


Figure 7: example of Moon's degree of linear polarization (left) and linear polarization angle (right).

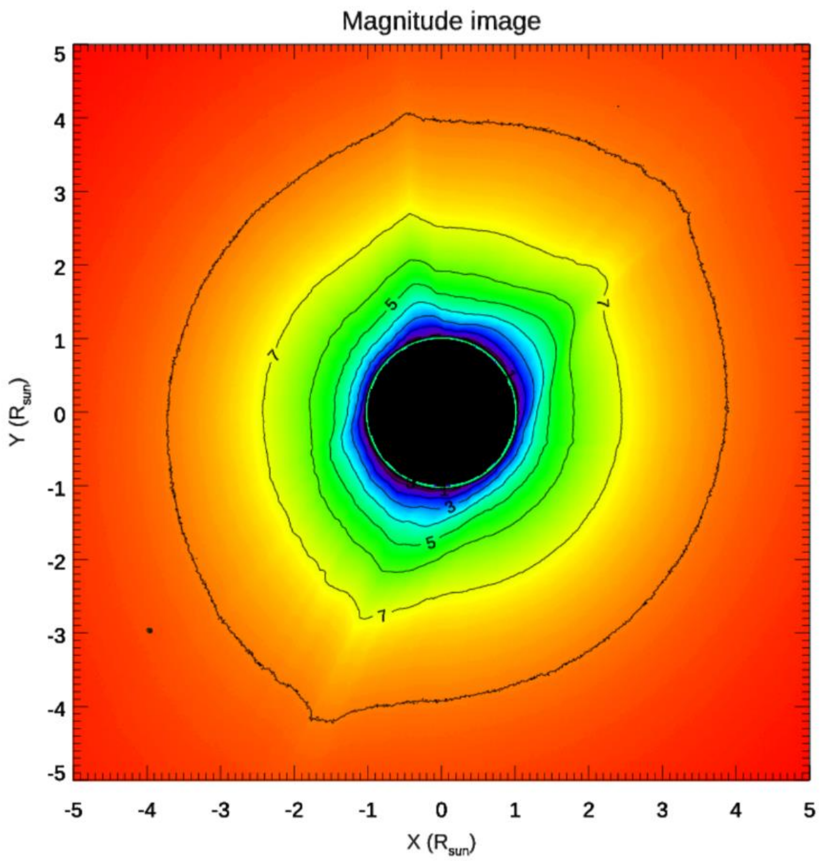


Figure 8: example of surface brightness apparent magnitude of the solar corona as derive with 2017 TSE observations.

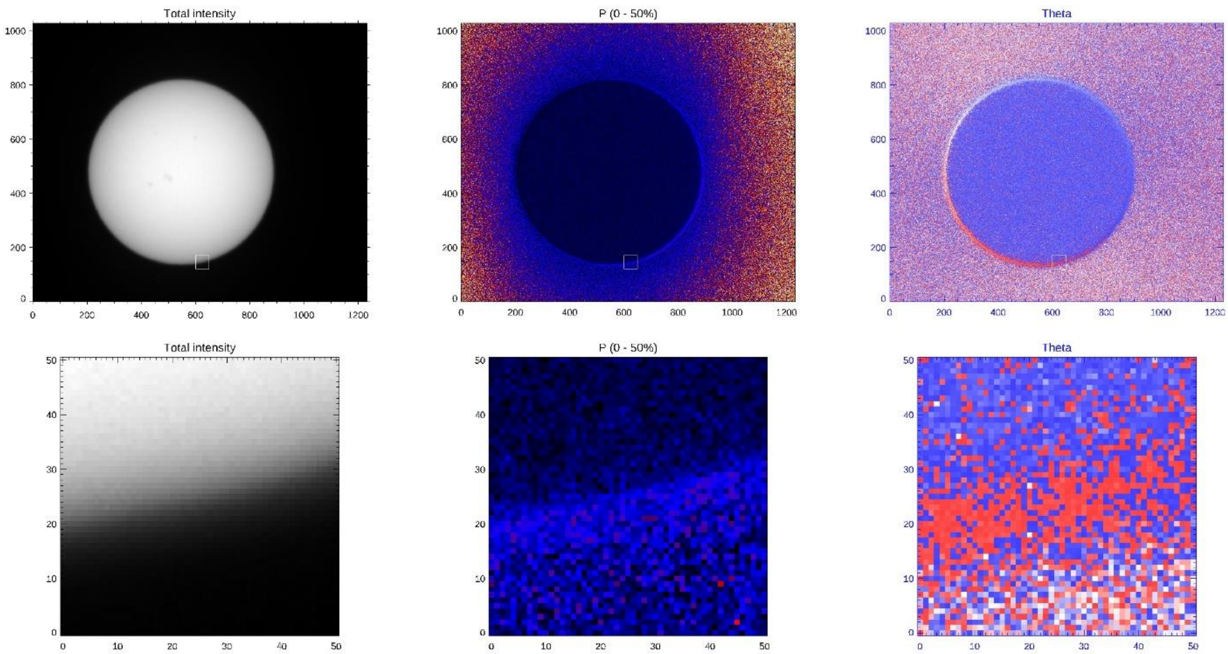


Figure 9: example of PolarCam observations of the solar disk; different columns provide the total intensity (left), degree of linear polarization (middle), and the linear polarization angle (right). The bottom row provides a zoom over the region marked as a white box in the top row.

5. TSE observation sequence

The night before the TSE event was clear, allowing the best possible alignment of the equatorial mount with the North pole. Unfortunately, the day of the TSE event the sky was partly cloudy, making the future analysis of the acquired data much more complicate. An example of the sky conditions approximately 2 hours before the beginning of the partial eclipse is shown in Figure 10. In the following I briefly present the data that have been acquired both with the DSLR camera and the PolarCam.

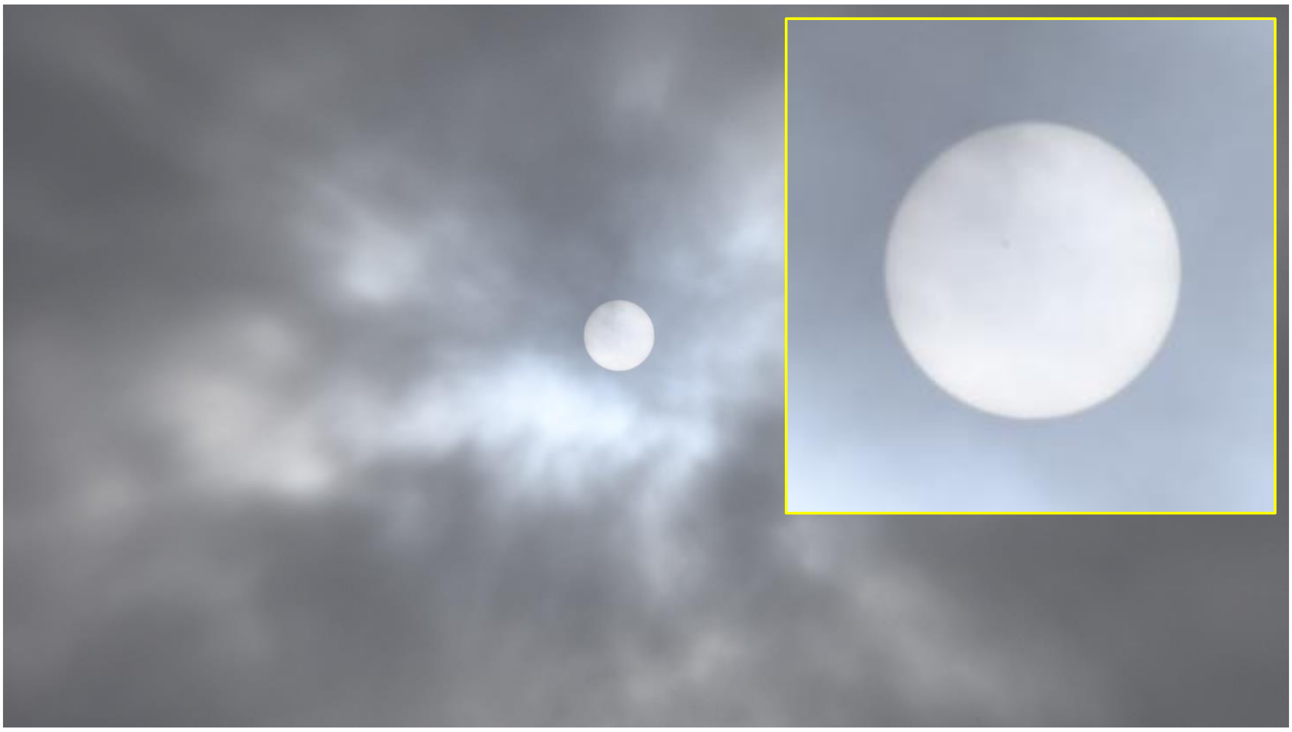


Figure 10: image acquired (without any filter) from the observation site approximately 2 hours before the beginning of the partial solar eclipse, the image shows the biggest sunspot present on the solar disk on April 8th 2024 that was used to optimize the focusing of the camera lenses.

5.1 Observations with the DSLR camera

As for the 2017 TSE, to perform the observations the DSLR camera has been mounted on the tripod, and the zoom has been set on the maximum available focal length by 300mm. The focus has been optimized manually by looking (with the OD5.0 filter installed) before the beginning of the partial eclipse at the solar limb and at the small sunspot visible on disk on April 8th 2024 (Figure 10). At the time of the observations the seeing was affected by transiting thin visible clouds, with time intervals of clear sky. A picture showing the location of observations and the camera mounted on the tripod is provided in Figure 11.

The observations have been acquired by bracketing the exposures with 14 different exposure times, going from 1/3200 s up to 2.5 s, in order to cover the dynamic range of coronal brightness from the base of the solar corona up to the limits of the camera field of view. Each image has 4272 x 2848 pixels, resulting in a final resolution of about 3.7 arcsec/pixel. For all the exposures the DSLR camera has been set with ISO100, Fnumber 5.6. All the images have been saved only in the RAW format (to minimize the storage time on the local memory), each file is automatically compressed by the camera with lossless compression, and occupies 12.7 MB of memory. A large number of dark frames have been acquired before and at the end of the partial eclipses; flat field images have been acquired at the end of observations. The full sequence of images acquired during the totality is shown in Figure 12: a total of 8 sequences, each one with 14 different exposures, have been acquired. Sequences #1, #7 and #8 have been acquired without any filter, while sequences from #2 to #6 have been acquired with the same linear polarizer employed for the 2017 TSE observations, and with 5 different orientations of the polarizer separated by approximately 45°.

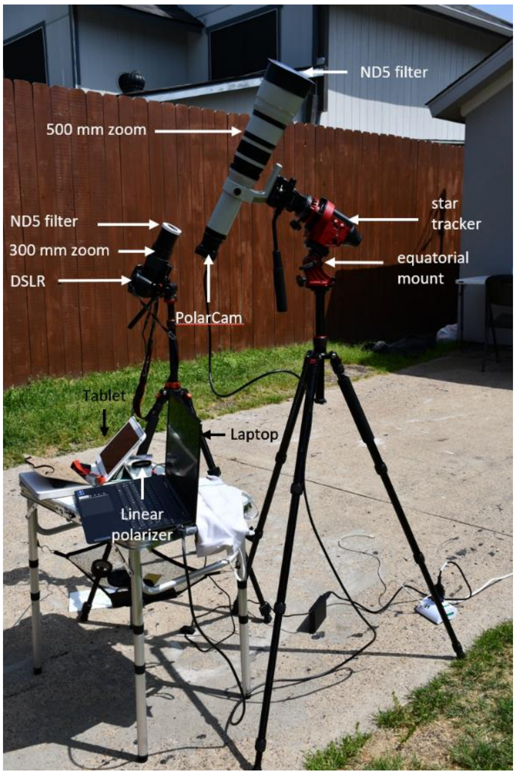


Figure 11: the observation site for the April 8th 2024 total solar eclipse.

Figure 12: the full sequence of images acquired with the DSLR during the totality.

An example of the main astronomical objects that have been identified around the Sun during the totality is shown in Figure 15: in particular the image shown in this Figure has been obtained after flat field correction and dark current removal of the image acquired with exposure time of 1.3 sec during the sequence #1 (hence without any filter). The image has been also "debayered" by selecting only the G pixels among the RGB pixels acquired in the DSLR Bayer filter array, and by interpolating the missing G pixels as explained in Bemporad 2020. Despite the presence of a few thin clouds, the resulting image show not only the clear appearance of coronal streamers, but also the location of ζ Psc A+B double star, the 88 Psc star, and also a faint sungrazing comet SOHO 5008 falling into the Sun. The 3 boxes in Figure 15 show a zoom over these astronomical objects.

A preliminary evaluation of the level of cloudiness during the acquisition of this sequence has been performed by averaging over two areas 100 x 100 pixels, one centred on the Moon's occulting disk, and the other one located in the corona nearby the Moon's occulting disk. Results show that the inner coronal regions are likely not too much affected by the cloud transit. On the other hand, the analysis of images acquired with different orientations of the linear polarizer will be very difficult, because of changing cloudiness conditions from the acquisition of one sequence to another. As an example, **Error! Reference source not found.** shows the relative difference between two images acquired with the same exposure time by 0.6 sec in the sequences #3 and #5, after flat field and dark current corrections and very preliminary coalignment with respect to the Moon's occulting disk. This image (that can be compared with Figure 5 provided in Bemporad, Abbo & Benna 2017) shows that unfortunately the variable cloudiness partially affected the polarized emission detection.

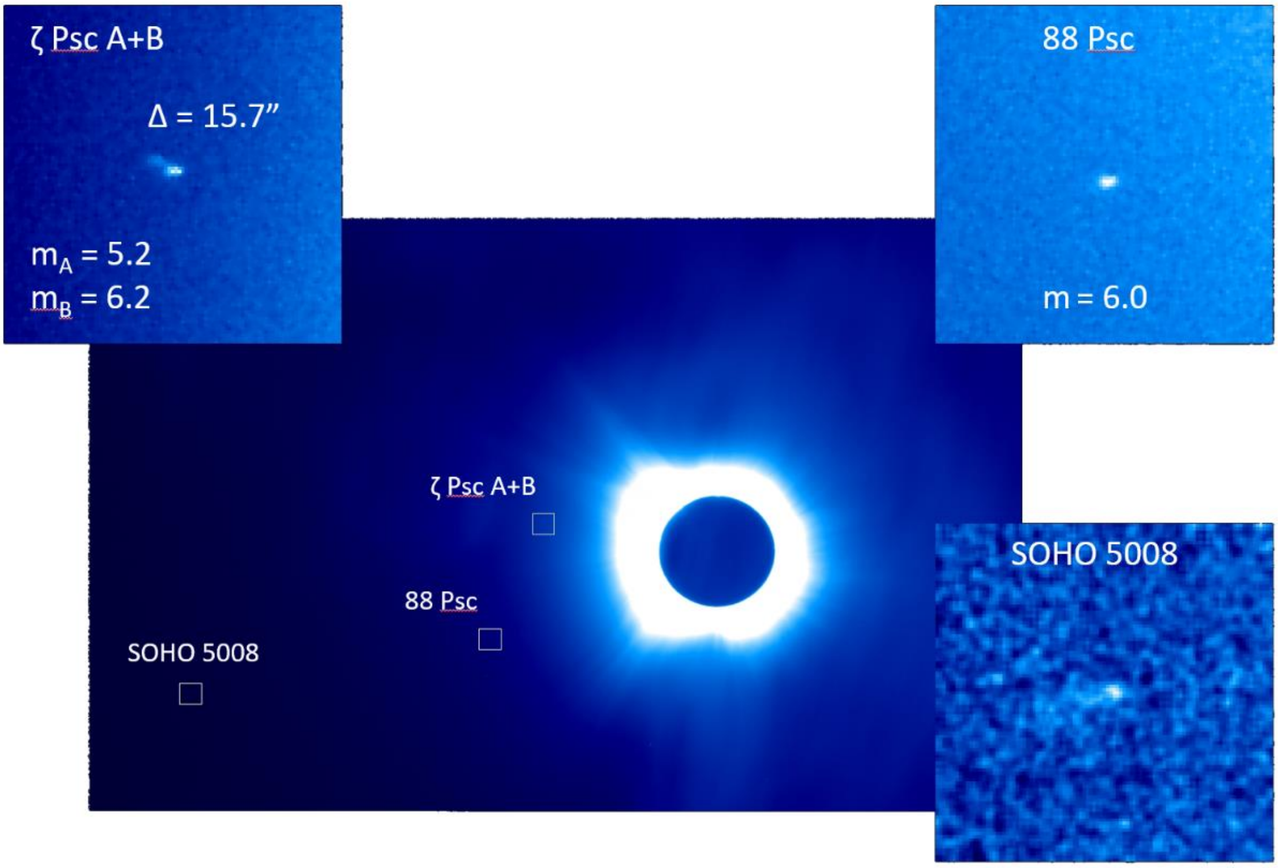


Figure 13: identification of astronomical objects visible in the DSLR camera field of view during the 2024 TSE.

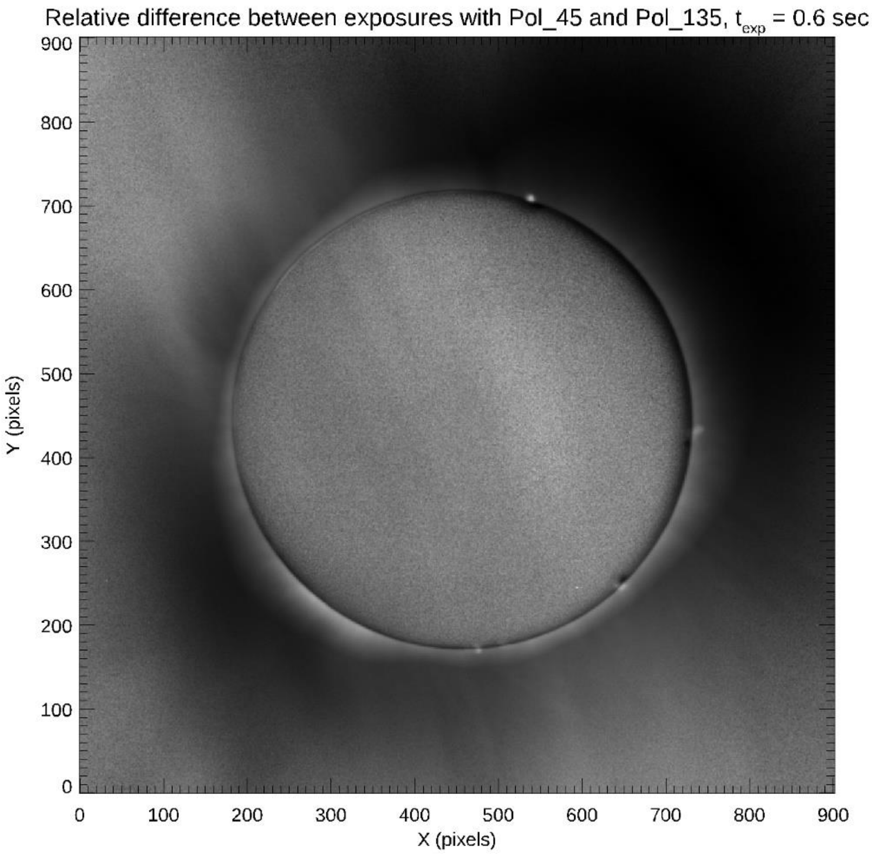


Figure 14: example of relative difference between images acquired with the same exposure times and different orientations of the linear polarizer, after preliminary coalignment.

5.2 Observations with the PolarCam

During the totality, 248 sequences have been acquired, 1 sec each one, and by bracketing 11 different exposure times from 100 µ sec to 200 m sec in each sequence. This corresponds to a total of 2728 images, 9.67 MB each one for a total of 25.7 GB of data. Flatfield and dark current images have been also acquired after the end of the partial phase. Each image has 2464 x 2056 pixels, with a projected pixel size of about 1.4"/pixel, corresponding to 1017 km/pixel on the Sun. Three example images are shown in Figure 15, while a summary of the acquired sequences is showed in Figure 16.

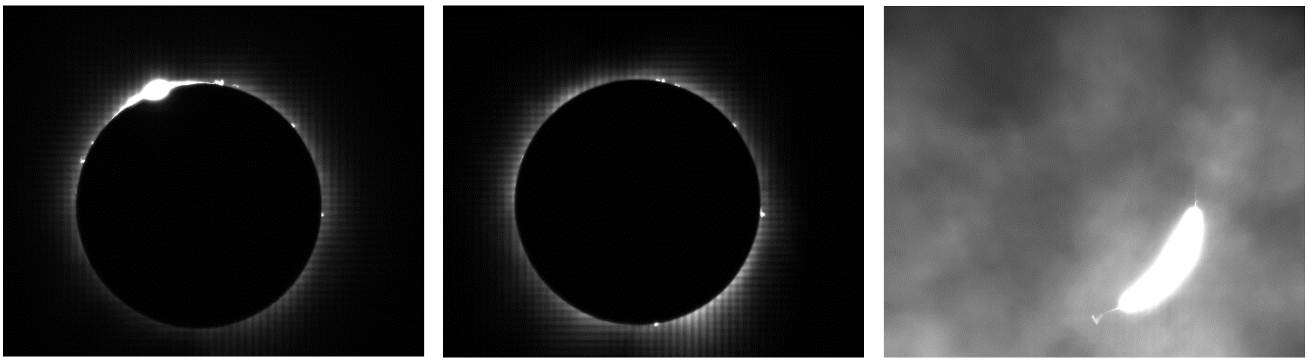


Figure 15: example of 3 images acquired at the beginning of the totality (left), at the centre of the totality (middle), and at the end of the totality (right).

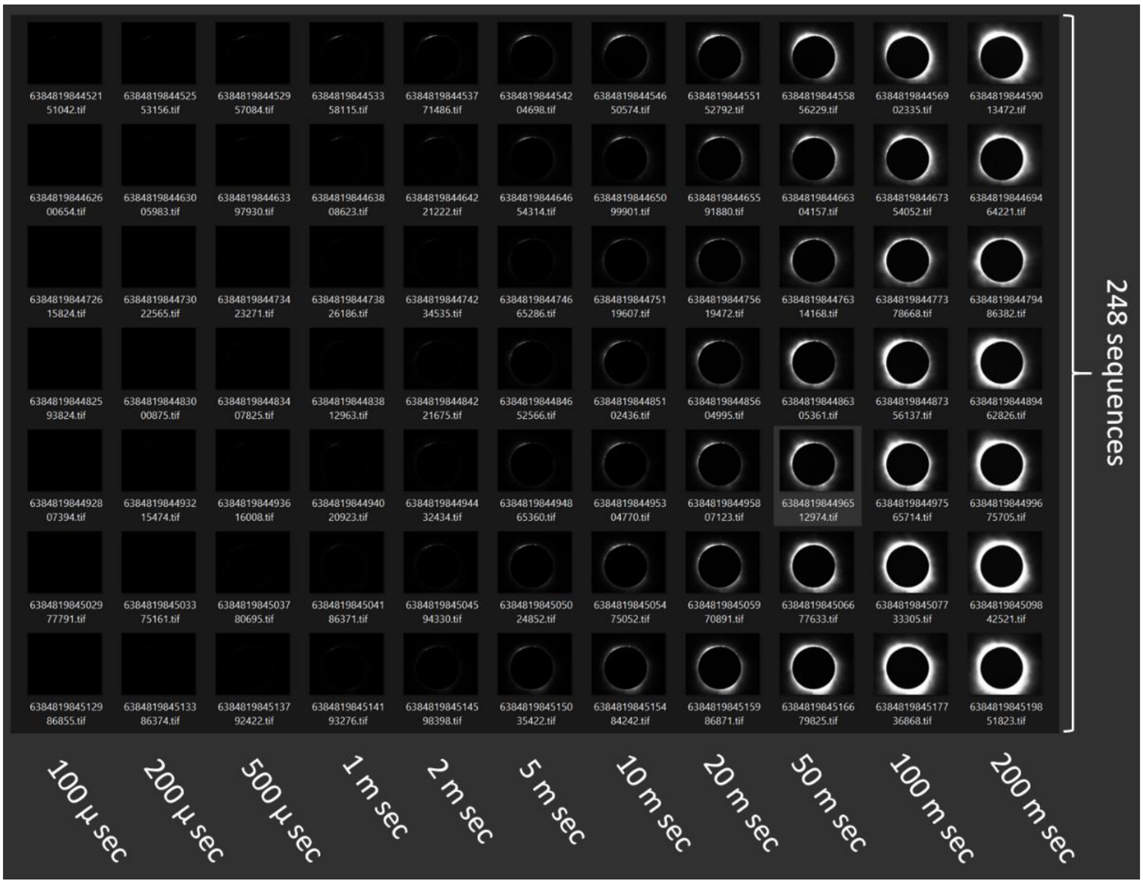


Figure 16: example of images acquired in the full sequence with the PolarCam during the totality.

The focusing of the PolarCam was almost perfect, and very nice observations of the visible solar prominences have been acquired, as it is shown in the example snapshots provided in Figure 17. In particular this Figure

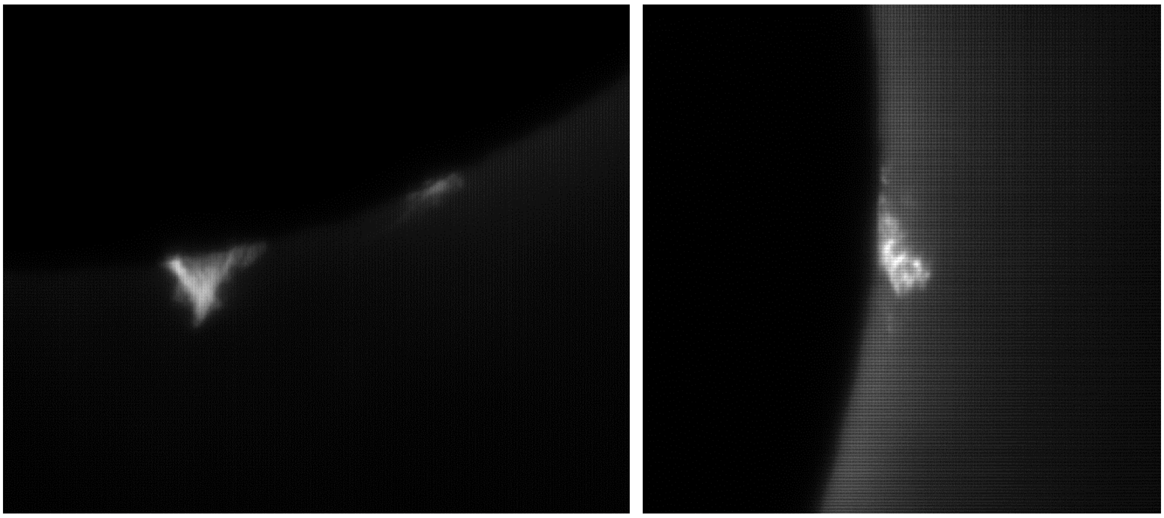


Figure 17: two examples of prominence observations acquired with the PolarCam

also shows a clear periodic pattern, which is due to the nearby pixels in the PolarCam having different orientations of the linear polarizer, as described by Figure 4.

6. Preliminary analysis of PolarCam data

Results from a very preliminary data analysis have been obtained by separating in each image the 4 different pixels with the 4 different orientations of the linear polarizer, and by applying equations 1 and 2 in Reginald et al. 2017. In particular, by considering 8 exposures acquired with 8 different exposure times from 1 msec up to 200 msec, and by combining the 4 different 1232 x 1028 pixel images each one corresponding to different orientations of the linear polarizers, the degree of linear polarization (DOLP) and the angle of linear polarization (AOLP) images have been obtained as follows:

$$S = \begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix} = \begin{pmatrix} I_0 + I_{90} \\ I_0 - I_{90} \\ I_{45} - I_{135} \\ I_{\mathrm{LHC}} - I_{\mathrm{RHC}} \end{pmatrix}. \qquad \begin{aligned} \mathrm{tB} &= S_0, \\ \mathrm{DOLP} &= \frac{\sqrt{(S_1^2 + S_2^2)}}{S_0}, \\ \mathrm{pB} &= \sqrt{(S_1^2 + S_2^2)}, \\ \mathrm{AOLP} &= \frac{1}{2} \times \arctan\left(\frac{S_2}{S_1}\right). \end{aligned}$$

where [S_0, S_1, S_2, S_3] are the 4 components of the Stokes vector, and the only component that with the available data cannot be measured is S_3 corresponding to the measurement of circular polarization. After normalization for different exposure times, the result values of the total brightness tB (arbitrary units), of DOLP and AOLP are provided in Figure 18, Figure 19, and Figure 20, respectively. The results show a very good determination of these quantities, and in particular of AOLP which seems to be not affected by any possible residual of clouds.

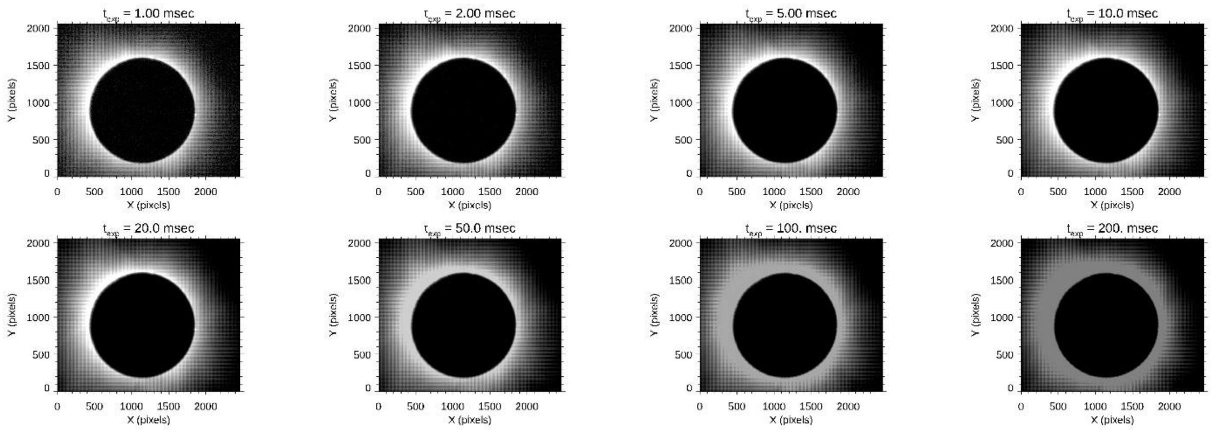


Figure 18: examples of preliminary results for the total brightness tB as obtained from PolarCam data analysis (see text).

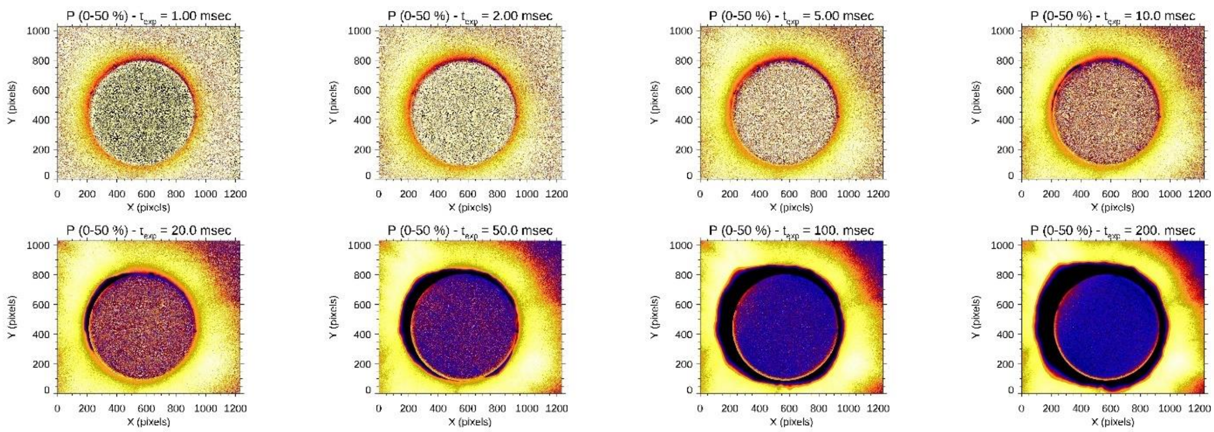


Figure 19: examples of preliminary results for the DOLP as obtained from PolarCam data analysis (see text).

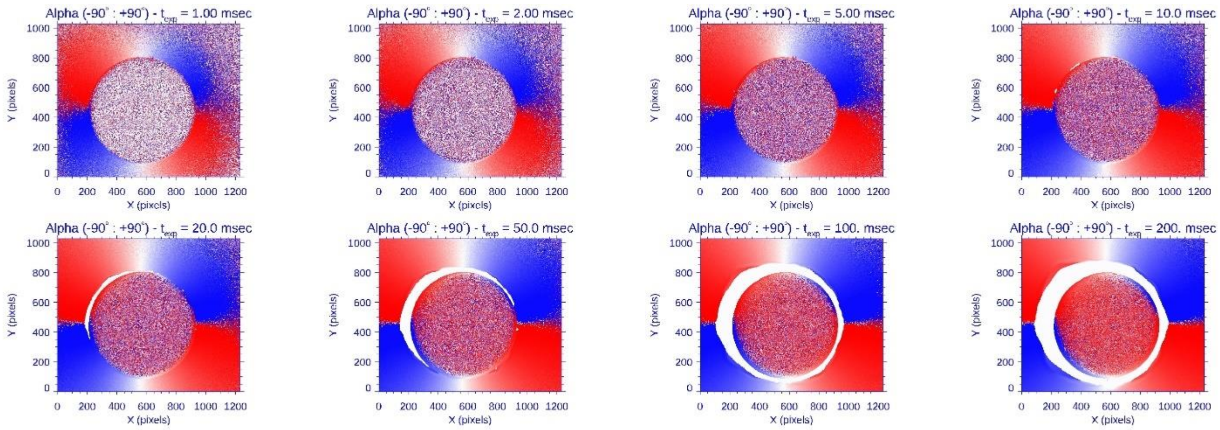


Figure 20: examples of preliminary results for the AOLP as obtained from PolarCam data analysis (see text).

By repeating the same analysis for all the exposures acquired during the totality with the same exposure time by 10 msec, and by averaging over a small 3x3 pixels are located in the inner corona approximately at the projected heliocentric distance of 1.1 R_{sun}, I obtained the plots shown in Figure 21; because no changes are expected in the solar corona over the 4m 9s of totality, the observed variations can be entirely ascribed to the changing level of cloudiness. These plots show that there are time intervals that can be considered not significantly affected by clouds.

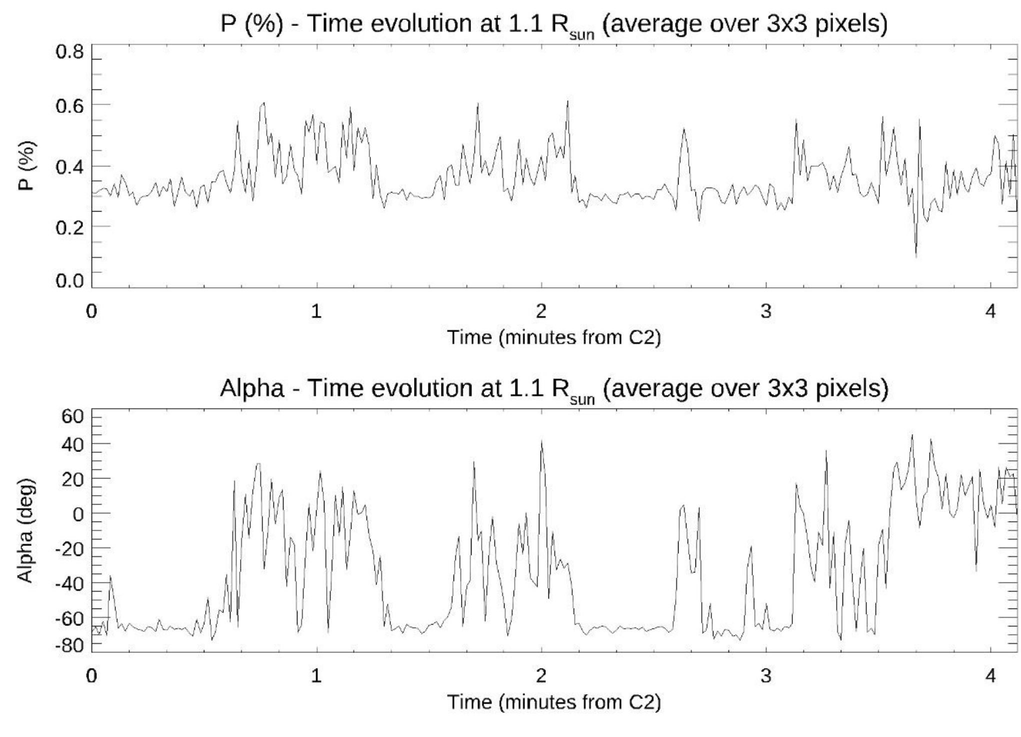


Figure 21: time evolution of DOLP (top) and AOLP (bottom) during the totality.

In summary: despite some level of cloudiness the observational campaign organized in the occasion of the 2024 TSE was fully successful and a big amount of very high quality data have been acquired both with the DSLR camera and with the PolarCam. The analysis of these data in now on-going. The acquired data have been also already presented in the occasion of a seminar held at the INAF-Turin Astrophysical Observatory on May 9th and titled **"The 2024 total solar eclipse as seen from Dallas: first look at the data"**. An image providing a combination of two images acquired with the DSLR camera and the PolarCam (together with an EUV image of the Sun acquired by the SDO/AIA instrument) is given in Figure 22.

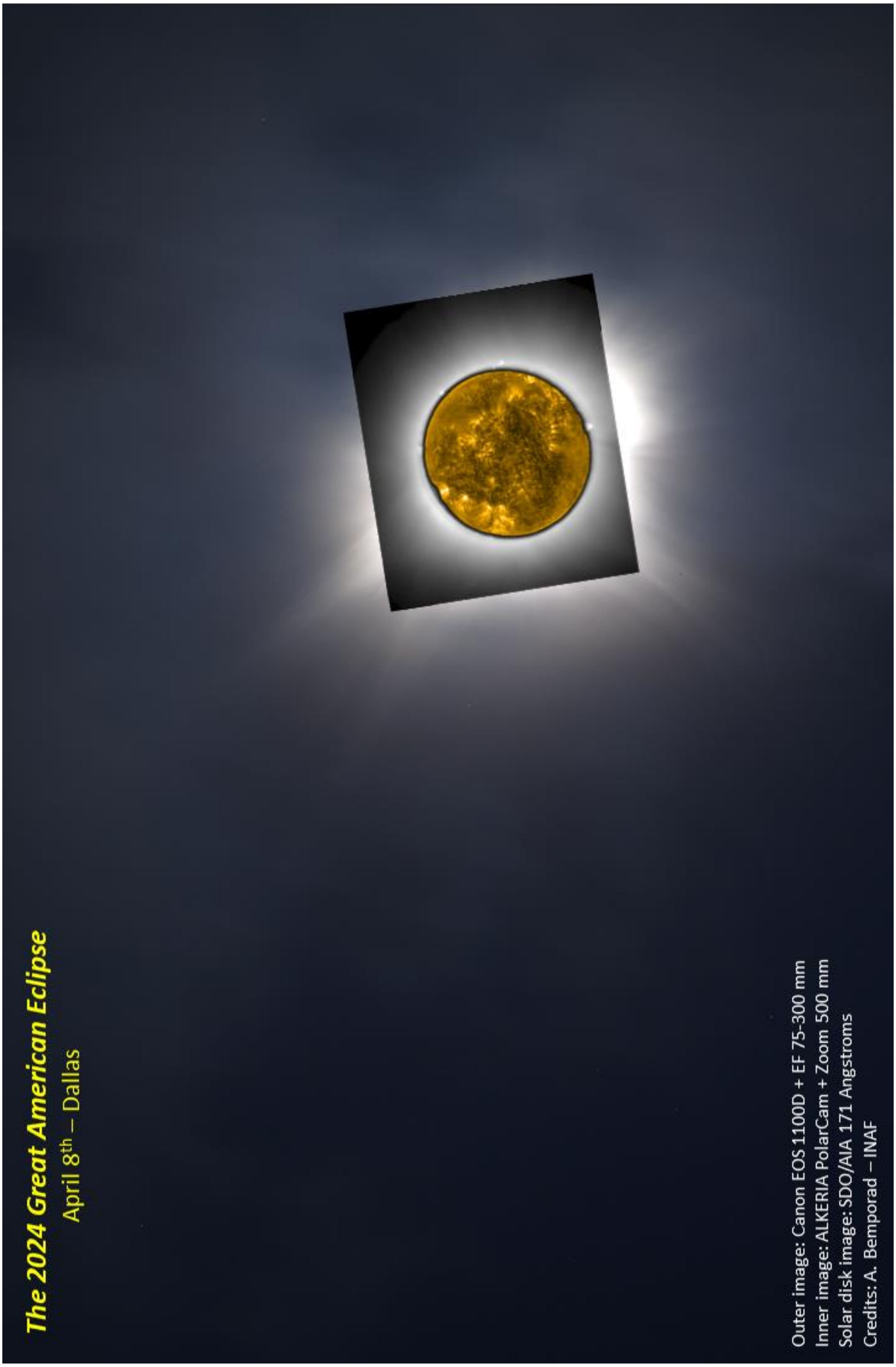


Figure 22: composition between images acquired with the DSLR camera (Canon EOS 100D + EF 75-300 mm - outer image), the ALKERIA PolarCam (+ Zoom 500 mm – inner image), and a solar disk image by SDO/AIA 171 Å.