Extreme Energy Events Project @ ICD 2024
The Solar Flare on may the 10th 2024

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The Solar Flare of May 10, 2024
Using data acquired from various EEE telescopes and POLA-R detectors, we will study variations in muon flux during the Solar Flare event on May 10, 2024.
Data
You have access to (downloadable) datasets from various detectors:

- **BOLO-02 (Bologna): BOLO-02_2024-04-16_2024-05-15_summary_Trending**
- **CAGL-01 (Cagliari): CAGL-01_2024-04-16_2024-05-15_summary_Trending**
- **LAQU-01 (L'Aquila): LAQU-01_2024-04-16_2024-05-15_summary_Trending**
- **VICE-01 (Vicenza): VICE-01_2024-04-16_2024-05-15_summary_Trending**
- **POLA-01 (Ny Alesund): POLA-01_2024-04-16_2024-05-15_summary_Trending**
- **POLA-02 (Bologna): POLA-02_2024-04-16_2024-05-15_summary_Trending**
- **POLA-03 (Ny Alesund): POLA-03_2024-04-16_2024-05-15_summary_Trending**
- **POLA-04 (Ny Alesund): POLA-04_2024-04-16_2024-05-15_summary_Trending**

These datasets are available in both CSV and ROOT formats, covering one month of data collection from April 16, 2024, to May 15, 2024.

Note: You may select which and how many datasets to use in your analysis. This brief guide provides basic steps for analysis using Excel with CSV files **(instructions below are for the English version of Excel)**.

All files contain the same information in the same order; for convenience, we will refer to one specific file: VICE-01_2024-04-16_2024-05-15_summary_Trending.

After downloading all files:

1. Choose the dataset for analysis.
2. Create a copy of the selected file and add the label "orig" (original) to its name.
3. Open the file without the "orig" label (for example, VICE-01_2024-04-16_2024-05-15_summary_Trending).

To open the file with Excel, simply double-click on it.
The file should look as shown in the figure. If data does not appear divided into columns, proceed to manually separate columns via the menu: **Data -> Text to Columns**.

G8 f_x

	A	B	C	D	E
1	#BinStart	RateHitEvents	RateTrackEvents	Pressure	
2	5.46E+08	5.44E+01	4.97E+01	9.98E+02	
3	5.46E+08	5.32E+01	4.88E+01	9.98E+02	
4	5.46E+08	5.54E+01	5.04E+01	9.98E+02	
5	5.46E+08	5.45E+01	4.97E+01	9.98E+02	
6	5.46E+08	5.54E+01	5.09E+01	9.98E+02	

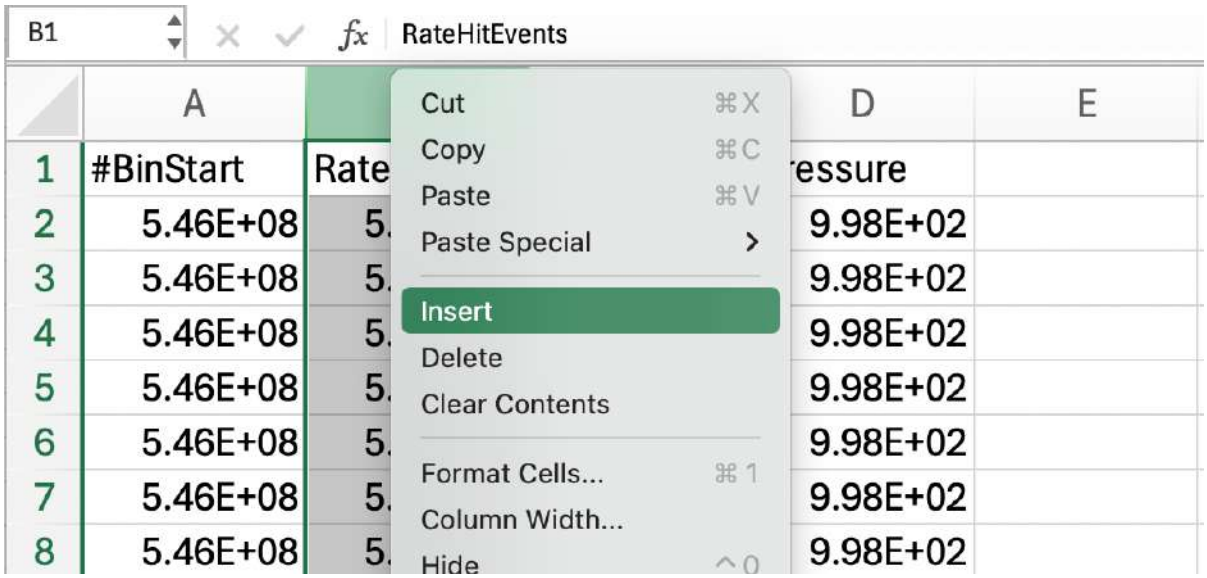
#BinStart: Time in seconds from January 1, 2007.
RateHitEvents: Rate of events where a point is reconstructed in the chambers without checking for a reconstructed track.
RateTrackEvents: Rate of events with a reconstructed track.
Pressure (mbar): Atmospheric pressure.

STEP 1: Exercise –

Transforming the #BinStart Variable into a Date

Recommended Path:

1. Add a column to the right of the **Time** column, as shown in the figure.
    - **Figure:** Enter a title for the new column (e.g., "Date").



	A	B	C	D	E	F
1	#BinStart	Date	RateHitEvent	RateTrackEv	Pressure	
2	5.46E+08		5.44E+01	4.97E+01	9.98E+02	
3	5.46E+08		5.32E+01	4.88E+01	9.98E+02	
4	5.46E+08		5.54E+01	5.04E+01	9.98E+02	
5	5.46E+08		5.45E+01	4.97E+01	9.98E+02	
6	5.46E+08		5.54E+01	5.09E+01	9.98E+02	

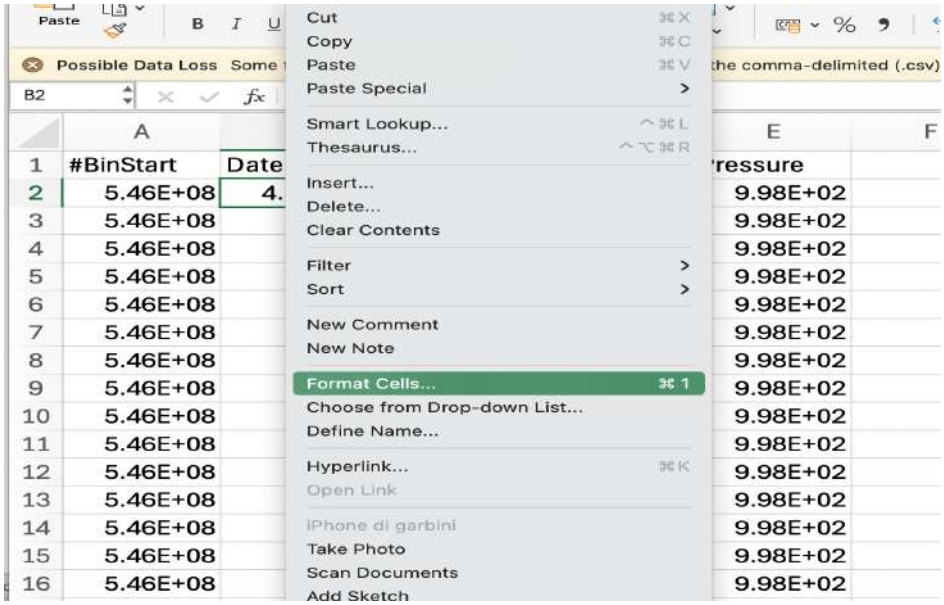
2. Calculate the date corresponding to each **#BinStart**. Referring to the figure, place your cursor in cell B2 and write:

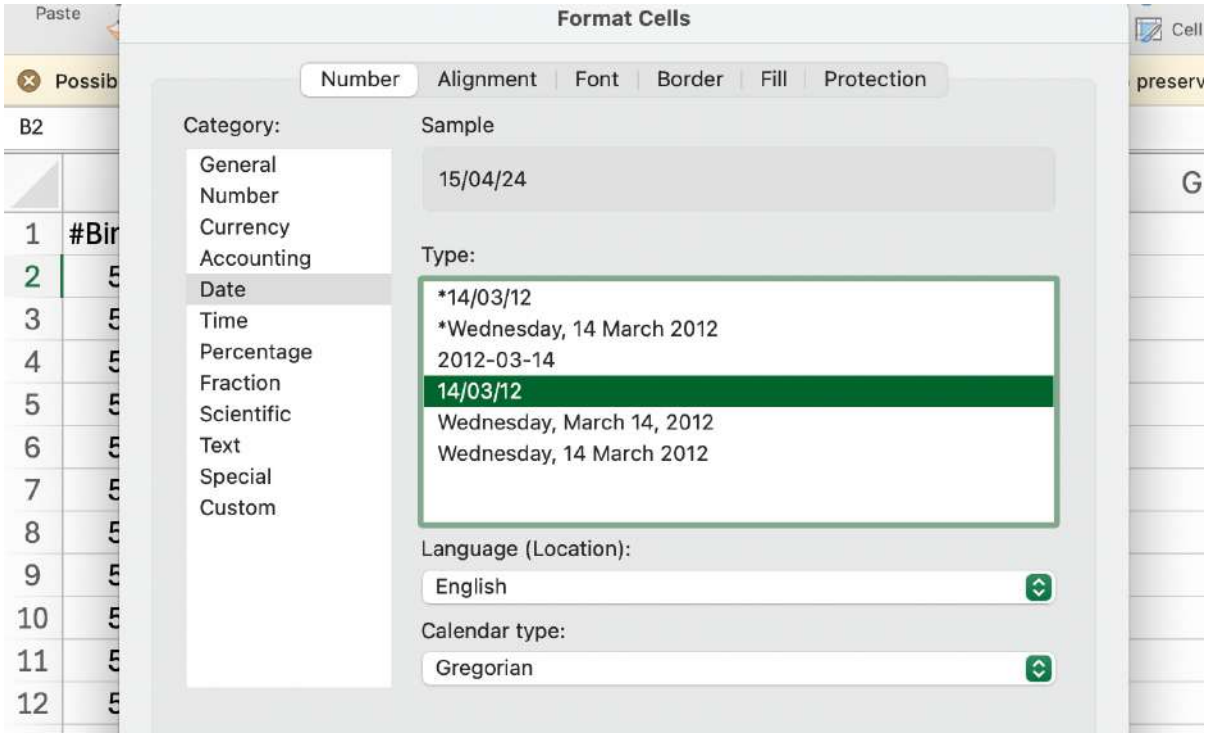
=(A2/86400)+DATE(2007,1,1) and press **Enter to confirm. The DATE function is used for Excel in English; in Italian Excel, use the DATA function with arguments separated by a semicolon.**

	A	B	C	D	E
1	#BinStart	Date	RateHitEvent	RateTrackEv	Pressure
2	5.46E+08	4.54E+04	5.44E+01	4.97E+01	9.98E+02
3	5.46E+08		5.32E+01	4.88E+01	9.98E+02
4	5.46E+08		5.54E+01	5.04E+01	9.98E+02
5	5.46E+08		5.45E+01	4.97E+01	9.98E+02
6	5.46E+08		5.54E+01	5.09E+01	9.98E+02
7	5.46E+08		5.56E+01	5.08E+01	9.98E+02

Select column B and apply a **Date** format for cell display.

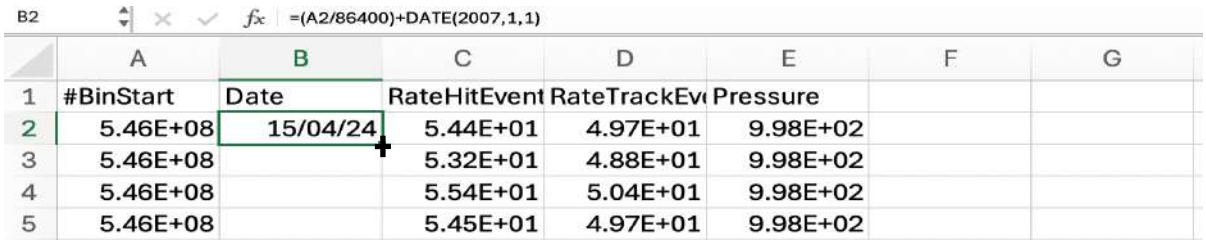
- Choose **Format Cells** and then select **Date** to pick the date format. In the example, we select **day/month/year (dd/mm/yy)** format.





	A	B	C	D	E	F	G
1	#BinStart	Date	RateHitEvent	RateTrackEv	Pressure		
2	5.46E+08	15/04/24	5.44E+01	4.97E+01	9.98E+02		
3	5.46E+08		5.32E+01	4.88E+01	9.98E+02		
4	5.46E+08		5.54E+01	5.04E+01	9.98E+02		
5	5.46E+08		5.45E+01	4.97E+01	9.98E+02		
6	5.46E+08		5.54E+01	5.09E+01	9.98E+02		
7	5.46E+08		5.56E+01	5.08E+01	9.98E+02		

Repeat for entire B column.

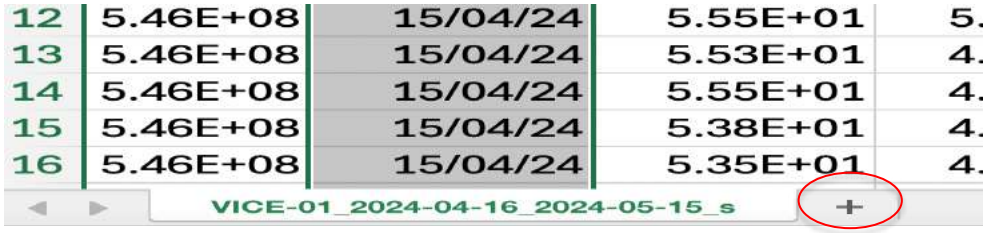


Double clinck on the bottom right corber of cell B2:

STEP 2: Correction for Barometric Effects

To correct the rates for pressure effects (barometric effect):

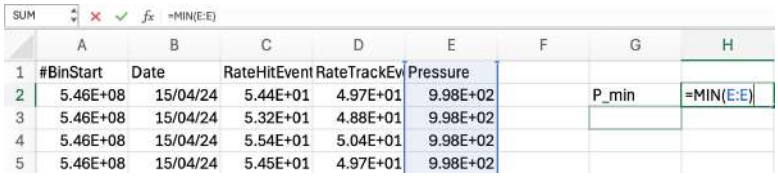
1. Add a new tab in Excel and rename it "BarometricCorr".



2. Give a name to the new tab: right click and rename (BarometricCorr)

To study the correlation between rate and pressure, in the newly created worksheet, we proceed to calculate the average rate (HitEvents or TrackEvents) for the recorded pressure values. Here's how to proceed:

1. Determine the minimum and maximum pressure values observed during the period in question; do this in the initial worksheet.



	A	B	C	D	E	F	G	H
1	#BinStart	Date	RateHitEvent	RateTrackEv	Pressure			
2	5.46E+08	15/04/24	5.44E+01	4.97E+01	9.98E+02		P_min	990
3	5.46E+08	15/04/24	5.32E+01	4.88E+01	9.98E+02		P_max	=MAX(E:E)
4	5.46E+08	15/04/24	5.54E+01	5.04E+01	9.98E+02			

	A	B	C	D	E	F	G	H
1	#BinStart	Date	RateHitEvent	RateTrackEv	Pressure			
2	5.46E+08	15/04/24	5.44E+01	4.97E+01	9.98E+02		P_min	990
3	5.46E+08	15/04/24	5.32E+01	4.88E+01	9.98E+02		P_max	1016
4	5.46E+08	15/04/24	5.54E+01	5.04E+01	9.98E+02			

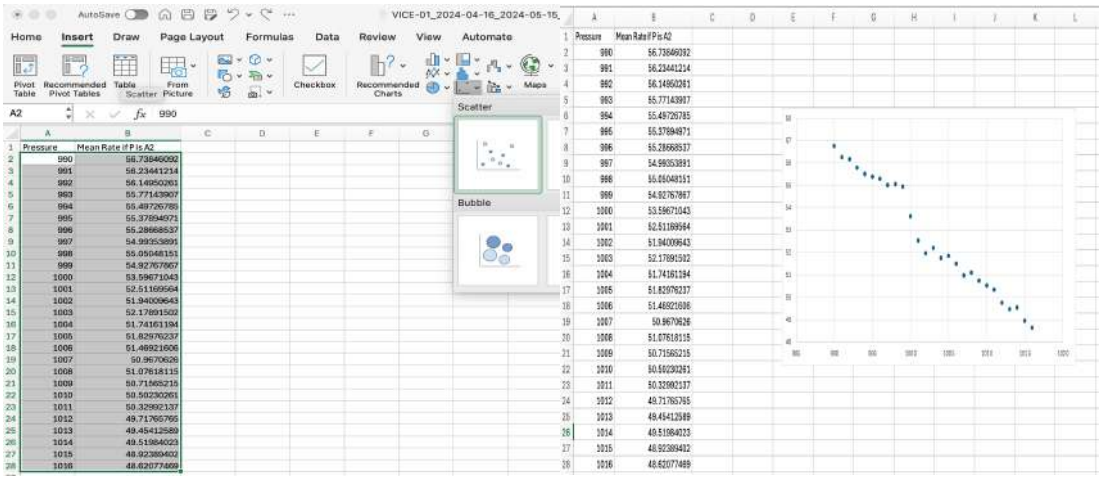
2. In the new tab created, we build the Pressure column to be populated with pressure values from the minimum identified in the previous step to the maximum, with a step of 1 mbar.

3. We now need to calculate the average value of the average rate for each pressure value. There are several ways to do this, but our suggestion is to use the AVERAGEIF function in Excel: this function returns the arithmetic mean of all the cells in a range that meet a specified criterion. The syntax is AVERAGEIF(range; criteria; [average_range]). The arguments of the AVERAGEIF function are as follows:

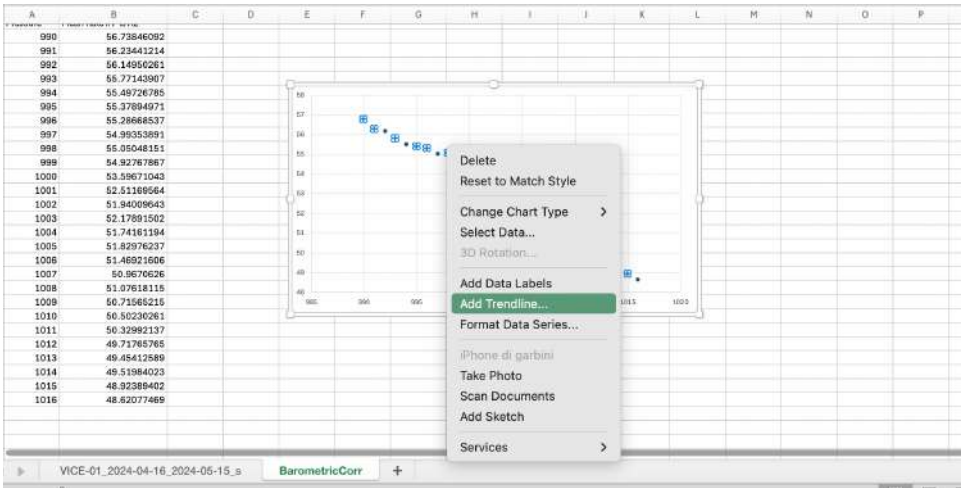
   • **Range:** One or more cells to calculate the average of, including numbers, names, arrays, or references that contain numbers. In our case, these are the measured pressure values, so column E of the initial worksheet.
   • **Criteria:** Criteria in the form of numbers, expressions, cell references, or text that determine which cells will be averaged. The criteria can, for example, be expressed as 32, "32", ">32", "apples", or B4. In our case, the criterion for calculating the average is that the pressure (Range) must be equal to the pressure value of the cell being examined.
   • **Average_range:** The actual set of cells to average. If omitted, the range value is used. In our case, we want to average the rate column (for example, column C of the initial sheet). In this case, for each Pressure value in the current sheet (column A), we insert the formula in column B: =AVERAGEIF(initial sheet column E, pressure value of the Pressure cell, initial sheet column C). For the correct syntax, see the figure.

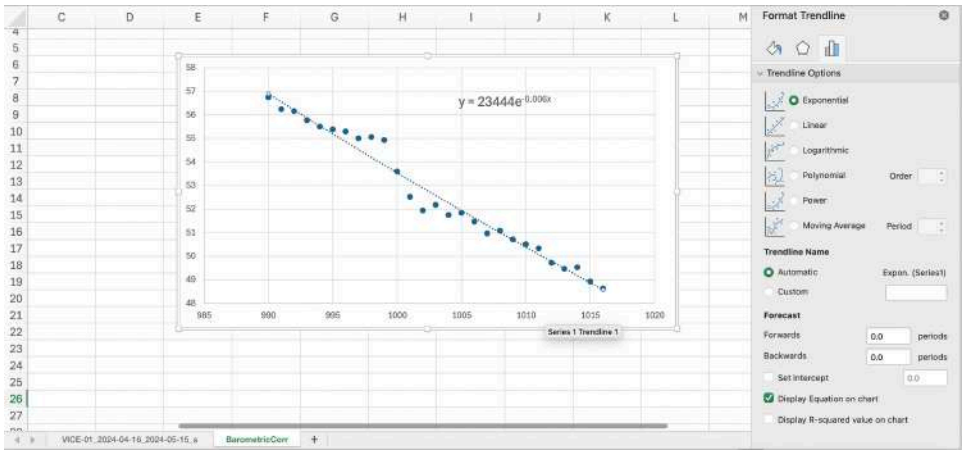
And repeat the operation for the entire column A of the Pressure sheet.

4. The obtained values are placed in a scatter plot with pressure on the x-axis and average rate on the y-axis:



5. We add a trendline, specifically an exponential fit:





From the fit, we obtain the Barometric coefficient $\alpha = 6x10^{-3}$, which allows us to correct the rates to account for the effect of atmospheric pressure. Using the formula:

Rate_Corr = Rate_nonCorr * EXP(α * (Pmis - P_ref))

Where Rate_nonCorr is the measured rate, α is the obtained barometric coefficient, Pmis is the measured pressure, and P_ref is a reference pressure that we assume to be 1000 mbar. Therefore, in the first worksheet, we add the Rate_Corr column: Insert these two values in cells J4 and J5 of the original worksheet.

	A	B	C	D	E	F	G	H	I	J	K
1	#BinStart	data	RateHitEven	RateTrackEv	Pressure						
2	5.46E+08		5.44E+01	4.97E+01	9.98E+02						
3	5.46E+08		5.32E+01	4.88E+01	9.98E+02						
4	5.46E+08		5.54E+01	5.04E+01	9.98E+02				alpha	6.00E-03	
5	5.46E+08		5.45E+01	4.97E+01	9.98E+02				P_ref	1000	
6	5.46E+08		5.54E+01	5.09E+01	9.98E+02						
7	5.46E+08		5.56E+01	5.08E+01	9.98E+02						

E poi in colonna F calcoliamo il Rate corretto (i "$" sono utilizzati per mantenere costanti i valori di alpha e P_ref).

F2 =C2*EXP(J4*(E2-J5))

	A	B	C	D	E	F
1	#BinStart	Date	RateHitEvent	RateTrackEv	Pressure	Rate_Corr
2	5.46E+08	15/04/24	5.44E+01	4.97E+01	9.98E+02	5.38E+01

And we extend it to the entire set of measurements.
We now have the rates corrected for barometric effect.

Note: Charts and columns must include units of measurement and be readable. Having a dataset for a month allows for a good evaluation of the barometric coefficient.

STEP 3 of the exercise: Estimating the decrease in the rate coinciding with the solar flare.
Having corrected the rates for the barometric effect, we can highlight rate variations due to other possible phenomena.
As the first step, we create a graph of the rate as a function of time. In these cases, it is useful to create a graph averaged over time intervals of a few hours (in our example, 2 hours).

a) From the first sheet, extract the first and last value of #BinStart (Start and Stop, cells H8 and H9 in the following figure).
b) Calculate the time interval between these two values (Duration, cell I10):

	A	B	C	D	E	F	G	H	I	J
1	#BinStart	Date	RateHitEvent	RateTrackEv	Pressure	Rate_Corr				
2	5.46E+08	15/04/24	5.44E+01	4.97E+01	9.98E+02	5.38E+01			P_min	990
3	5.46E+08	15/04/24	5.32E+01	4.88E+01	9.98E+02				P_max	1016
4	5.46E+08	15/04/24	5.54E+01	5.04E+01	9.98E+02				alpha	0.006
5	5.46E+08	15/04/24	5.45E+01	4.97E+01	9.98E+02				P_ref	1000
6	5.46E+08	15/04/24	5.54E+01	5.09E+01	9.98E+02					
7	5.46E+08	15/04/24	5.56E+01	5.08E+01	9.98E+02					
8	5.46E+08	15/04/24	5.36E+01	4.90E+01	9.98E+02			Start	545609574	
9	5.46E+08	15/04/24	5.39E+01	4.88E+01	9.98E+02			Stop	548201305	
10	5.46E+08	15/04/24	5.47E+01	5.01E+01	9.98E+02			Duration	2591731	
11	5.46E+08	15/04/24	5.54E+01	5.00E+01	9.98E+02			Interval	7200	
12	5.46E+08	15/04/24	5.55E+01	5.07E+01	9.98E+02					
13	5.46E+08	15/04/24	5.53E+01	4.97E+01	9.98E+02					

c) Create a new worksheet.
d) In columns A and B of the new worksheet, build time intervals of two hours (7200 seconds); be careful not to exceed the last time value of the dataset.
e) Calculate the midpoint (convert it into a date): this step allows us to relate a time value (the midpoint of the time interval) and the average rate (to be calculated as indicated below) for that specific interval.

C2 Insert Function =DATE(2007,1,1)+(A2-3600)/86400

	A	B	C	D
1	Start Time Interval	Stop Time Interval	Date of Ttime interval start	
2	545609574	545616774	15/04/24 21:12	
3	545616774	545623974		
4	545623974	545631174		

f) Now we need to calculate the average rate within the time interval. In this case, we suggest using the Excel function (in the English version) AVERAGEIFS (in Italian, MEDIA.PIÙ.SE), which returns the arithmetic mean of all cells that meet multiple criteria. The syntax is:

AVERAGEIFS(average_range; criteria_range1; criteria1; [criteria_range2; criteria2]; ...)

The arguments are as follows:

• **average_range**: One or more cells to calculate the average of, including numbers, names, arrays, or references that contain numbers.

• **criteria_range1, criteria_range2, ...**: criteria_range1 is required, while subsequent criteria ranges are optional. It defines 1 to 127 ranges to evaluate the associated criteria.

• **criteria1, criteria2, ...**: criteria1 is required, while subsequent criteria are optional. It defines 1 to 127 criteria in the form of numbers, expressions, cell references, or text that determine which cells will be averaged. Criteria can be expressed as 32, "32", ">32", "apples", or B4, for example.

We want to calculate the average rate (column F of the first sheet) when the time value (#BinStart in the first sheet) is greater than the lower limit of the time interval and less than the upper limit of the time interval. So, in each cell of column D of the new sheet, the formula will be of the type:
AVERAGEIFS(First Sheet Column F, First Sheet Column A > lower time interval limit, First Sheet Column A < upper time interval limit)
More precisely:
AVERAGEIFS('VICE-01_2024-04-16_2024-05-15_s'!F, 'VICE-01_2024-04-16_2024-05-15_s'!A, ">"&A2, 'VICE-01_2024-04-16_2024-05-15_s'!A, "<"&B2)

g) Graph the average rate vs Date

Suggestions for the analyses

- Identify (if visible) the period of the solar flare (during which a decrease in the rate should be observed, due to the Forbush effect).
- Compare the behavior of the rate corrected for barometric effect and the rate uncorrected for barometric effect for the same detector, commenting on the result in terms of the Forbush effect.
- Comparison between multiple detectors: in this case, it is useful to normalize the rates using the formula:
- rate_norm = (Average rate in the i-th time interval) / (Average rate of all time intervals)