Response to Referee 2 – "MAESTRO instrument operation and performance over two decades in orbit" by Jiansheng Zou et al.

We thank Dr. Dekemper for his comments, which are given below with our responses provided in light blue indented text.

General review

This paper explains the difficulties encountered since the beginning of operations of the ACE-MAESTRO solar occultation UV-VIS-NIR spectrometer. As highlighted in the manuscript, MAESTRO was the only satellite instrument of its kind between 2006 and 2017. Therefore, any effort to improve the mission's geophysical products should be supported. High-quality O3 and aerosol profiles retrieved from MAESTRO's solar occultation measurements would help fill the significant gap in the SAGE time series. A merged, multi-decadal solar occultation dataset would be a valuable tool for the atmospheric science community.

In this context, this work will be particularly useful to researchers outside the core MAESTRO team, as it describes several challenges encountered by the instrument during its lifetime and the in-depth analyses conducted to characterize key acquisition parameters, such as the spectrometer's actual pointing on the solar disk. Any effort to improve understanding of the L1 product (the spectral atmospheric transmittance profiles) will enhance the mission's scientific return. I recommend publishing the manuscript after addressing the minor comments below.

Specific comments:

At the end of the first paragraph of the introduction, it is stated that a paper by Jeffery et al. 2025 concluded to a "good agreement" between "measurement products" from "other instruments"... Even if the cited publication can definitely be consulted by the interested readers, I would prefer that a highlight of the conclusions by Jeffery et al. is given. This would allow to immediately capture the stakes of the work. Two sentences might suffice to point out where problems remain, and from there, explain how the submitted report contributes to improving the situation.

> Agreed. Two sentences have been added to summarize the results and specify the issues addressed in this study. Revised text is given below (replaces lines 39-40 in preprint).
>
> "The latest MAESTRO measurement products have been compared against other instruments in Jeffery et al. (2025), showing good agreement above 20 km for Visible-NIR O_3 data (2.5–7.6% within 20–50 km), slightly poorer agreement for UV O_3 data (2.8–7.6% within 20–45 km), and marginal agreement for UV NO_2 data (<27.2% within

20–40 km), with larger discrepancies below 20 km. In this study we seek to understand the instrument-related differences between UV and Visible-NIR measurements and the altitude dependence of the measured spectral data."

Section 3.1 discusses the "action tables," which, as I understand, are sequences of acquisition settings designed to maintain high-quality radiometric measurements from the bright high Sun to the dim low Sun. However, this discussion occupies too much space in the manuscript. The situation is clear: the "A" set of action tables was poorly calibrated, and the "B" set corrected this. Combining Figures 2 and 3 (panels (a) and (b) only) would allow readers to quickly assess the improvements introduced by the "B" set. I recommend using a logarithmic scale on the left y-axis to better visualize the altitude range of the acquisitions.

Section 3.1 has been reformulated and shortened. Figures 2 and 3 (panels a and b) have been combined for easier comparison. The altitude y-axis is shown on a logarithmic scale. See the revised section below (replaces lines 114-200 in preprint).

3.1 Development of MAESTRO measurement schemes - action tables

MAESTRO's method to capture signals over the extreme dynamic range is described in McElroy et al. (2007) and Nowlan et al. (2007). Crucially, two parameters control the detector readout throughout a measurement sequence: the integration time, i.e., the exposure time of the detector to sunlight and the "grouping" of the 1024 detector pixels. Each group comprises 2^n pixels (n=0−10). Each group is reset simultaneously, and the groups are reset in sequence (all pixels having the same integration time). At the highest intensity, a group is 1 pixel, reset with the shortest integration time (0.148 ms for UV and 0.308 ms for Visible-NIR, as determined by the controller cycle time), and the 1024-pixel array is read out sequentially. At the lowest signal levels with the longest integration time, a single group is the entire 1024-pixel array, and it is reset simultaneously. Between these two extremes, by changing pixel groups (detector modes) and the integration time, the signal-to-noise ratio is optimized throughout the occultation. It takes <330 ms to complete a full spectral measurement for all altitudes (McElroy et al., 2007).

MAESTRO uses 19 different combinations of pixel groups and integration times during an occultation measurement, named "action tables", along with their repetition times to collect 80 spectra for atmospheric (0–100 km) and exo-atmospheric measurements (100–150 km and above), for sunrise or the reverse for sunset. It also collects 80 dark-count spectra by taking measurements on the orbit dark side using the same occultation action tables used to measure a zero-irradiance point. Special action tables, such as sun-scans, were created for specific events and tests.

Action tables must account for changes in the observation beta angle, which ranges between 0° and 60°, by specifying measurement durations for the occultations. This can vary from 63 to about 190 seconds. To account for this, the beta angle range is subdivided and the action table timings for the beta angle sub-ranges are generated from the zero-angle table by extending the time intervals between spectral measurements. The

detector modes and integration times for each spectral measurement are kept fixed. The duration of these intervals is based on the centre of the beta angle sub-ranges. Finer sub-ranges lead to more representative measurement durations.

Two sets of action tables were developed for the mission:

Set "A" was defined over five beta-angle sub-ranges with bounds at 0°, 20°, 30°, 45°, 55°, and 60° and used from February 2004 to August 2005. Figures 2a/b show an example of a spectral measurement time sequence from the UV (Fig. 2a) and Visible-NIR (Fig. 2b) spectrometers for observation ss8342 (an observation is catalogued by sunset (ss) or sunrise (sr) and the orbit number) on 1 March 2005 with beta angle 38°. Here, 80 data points of integrated spectrum intensities measured during the sunset occultation are plotted (with a guideline), covering an altitude range from approximately 150 km to near 0 km. The altitude information is taken from the ACE-FTS tangent height data, which are time-tagged (see Sect. 3.7 for a discussion on time-tagging) and cover a range of ~10−120 km. The integration time and the number of repetitions for each row of the action table are shown in the legends of Fig. 2a/b. The integration time for the UV channel varies from 0.148 ms at the high sun to 150.473 ms at the near-zero tangent height, and for the Visible-NIR channel, 0.308 ms to 2.483 ms. The first 20 exo-atmospheric spectra are averaged for the high-sun reference. Between about 50 and 30 km, 8 spectra are recorded; between 30 and 15 km, 15; and below 15 km, 27. Due to the geometric weighting of absorption in the tangent layer relative to that of the layer above in the spherical atmosphere (McElroy et al., 2007), the vertical resolution of the retrieved profiles is about ~1 km, roughly matching the vertical sampling in the troposphere and stratosphere. Set "A" of action tables was found to have an overly high density of data points recorded at low altitudes (below 15 km), as illustrated in Figs. 2a/b, and there are notable mismatches between the measurement time and the variable occultation time within each beta angle sub-range.

Set, "B," was developed with more data points at higher altitudes (above 15 km), fewer at lower altitudes (below 15 km), and with more beta angle sub-ranges covering nine intervals with bounds at 0°, 10°, 25°, 34°, 42.5°, 48.5°, 53.2°, 56.7°, 58.2°, and 59.4°and used from August 2005 to now. In addition, a separate scheme of 20 exo-atmospheric spectral measurements above 150 km was produced and included in the "B" tables. Figures 2c/d show an example of a spectral measurement time sequence for observation ss11053 on 1 September 2005 with a beta angle of 38° using "B" tables. One upper limit occultation measurement is taken at 150 km, and most measurement points are now located within the ozone layer. From 50 km to 25 km, there are 34 points; from 25 km to 20 km, 10; from 20 km to 15 km, 7; and below 15 km, 21. On average, there are 1.5 measurements per 1 km. In Figs. 2c/d, very small spectral intensities at very low altitudes, well below the lowest ACE-FTS measurement altitude, are cut off. Compared to table "A" (Figs. 2a/b) with a similar beta angle, the occultation measurement time for table B (Figs. 2c/d) is longer by about 5 seconds. Hence, the measurements using "B" span a wider altitude range than "A". Figure 3a/b shows the 80 ss11053 spectra (after dark-count calibration) for the UV and Visible-NIR channels. It demonstrates the ability to capture signals across at least three orders of magnitude.

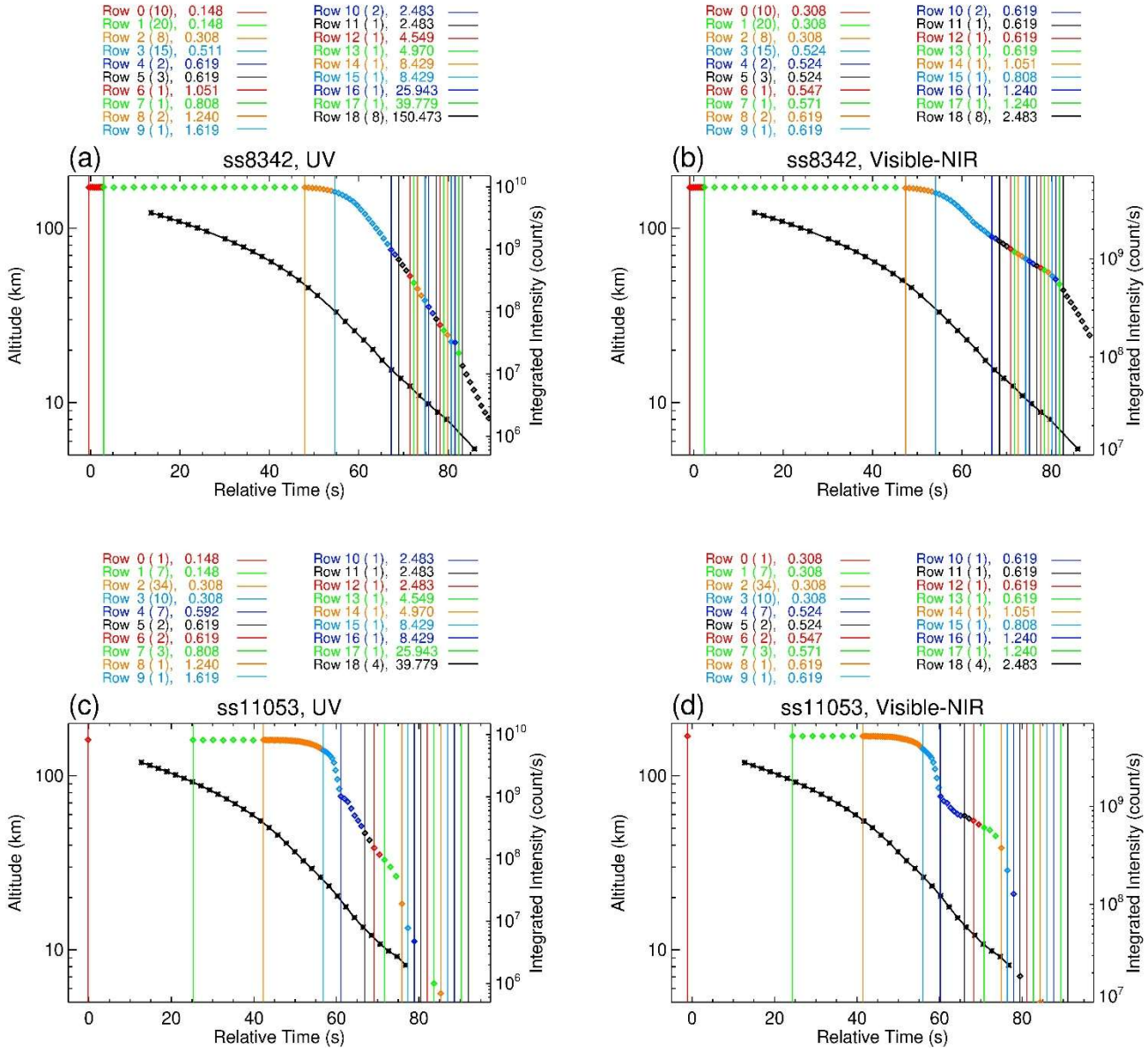

Figure 2 MAESTRO spectral measurements during sunset occultations. Top panels (a, b): Occultation ss8342 on 1 March 2005, with a 30 km altitude tangent point at 01:38:54z, located at 80.004° N, 161.137° W, and a beta angle of 38.099°, using an action table from set "A" applicable to the beta angle range of 30−45°. Panel a (top left): Integrated UV spectrum intensity vs. time, with the colour code specified in the legend above the panel, and the tangent height vs. time curve (black) obtained from ACE-FTS data. MAESTRO and ACE-FTS times are aligned as described in Sect. 3.7. Left y-axis: altitude; right y-axis: integrated spectrum intensity. The coloured text lists the 19 rows of the action table set "A", each marked by a colour code, with the number of repetitions in parentheses and integration time in milliseconds (ms). Vertical lines denote the start time of each row. Panel b (top right): Same as panel a, but for the Visible-NIR channel.

Bottom panels (c, d): Occultation ss11053 on 1 September 2005, with a 30 km tangent point at 00:47:12z, 79.265° S, 152.432° W, and with a beta angle of -38.037°, using an action table from set "B" applicable to the beta angle range of 34−42.5°. Otherwise, the same layout and conventions as the top panels.

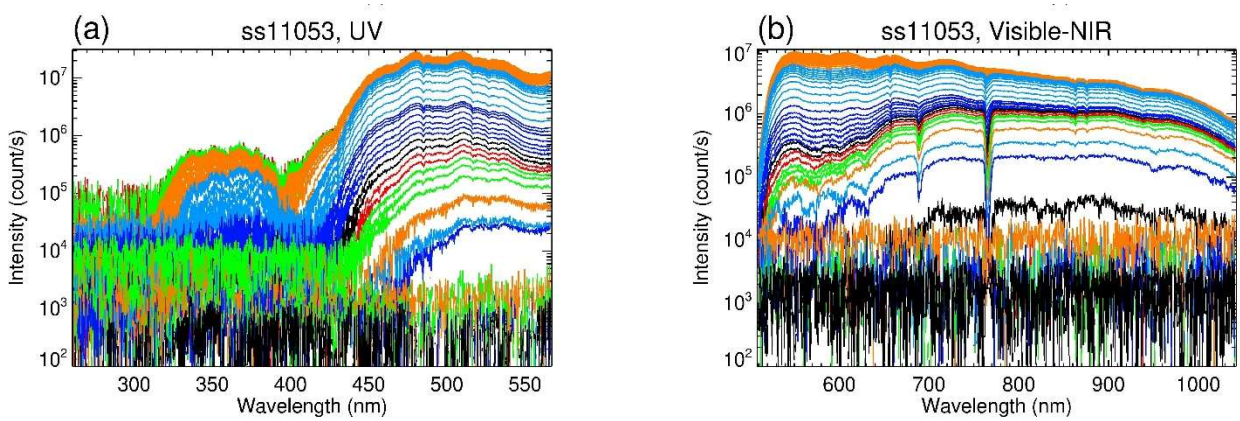

Figure 3 The 80 UV (left) and Visible-NIR (right) spectra produced for occultation ss11053 using action table "B" with the same colour code indicated in Figs. 2c and 2d.

What the manuscript does not clearly explain is the "tic" and "pixel grouping" concepts. I could not fully grasp whether the detector pixels are exposed to sunlight for only 0.2 µs, with the exposure repeated up to 1,024 times, or if other exposure durations can be commanded. I also recommend converting exposure times to "seconds" or "milliseconds" instead of "tics," as currently done in lines 157–158. Finally, in the caption of Figure 2, could you clarify whether the geodetic coordinates refer to the tangent point or the spacecraft's location?

As given above, Section 3.1 has been reformulated, with emphasis on the concept of grouping the 1024 detector pixels. The unit "tic" has been removed and replaced with milliseconds. In addition, the geolocation shown in Figure 2 now explicitly refers to the tangent point at an altitude of 30 km.

Section 3.2 and 3.3 tackle one of the most difficult aspects of the mission: the determination of the pointing of the spectrometer, and how it compares with ACE-FTS. The topic is complex but the authors have succeeded in showing the large efforts put into getting the pointing right (or at least understood). In particular, this is a pretty neat example of the synergistic use of the three payloads on the Scisat satellite. My main remarks concern the figures. First, I'm questioning the interest for the readers to have the x-axes of Fig 4 expressing scanning time. I would have expected the axis to show the commanded pitch or yaw angles offset. That would allow to reconnect with the physical angular dimensions of the solar disk and the slit acceptance angles. Second, the discussion on the differences of co-alignement of the fields of view of the MAESTRO

channels and ACE-FTS is difficult to follow. While the supporting figure 6 is quite clear, the statement that it is "indicating that as the satellite moves in elevation during an atmospheric scan, errors will arise in the normalized spectra" is unclear. Could you explain what is meant by the satellite elevation move ?

Figure 4 has been modified to include additional top x-axes indicating the sun tracker mirror displacements, in degrees, for the elevation and azimuth scanning directions. See revised figure below.

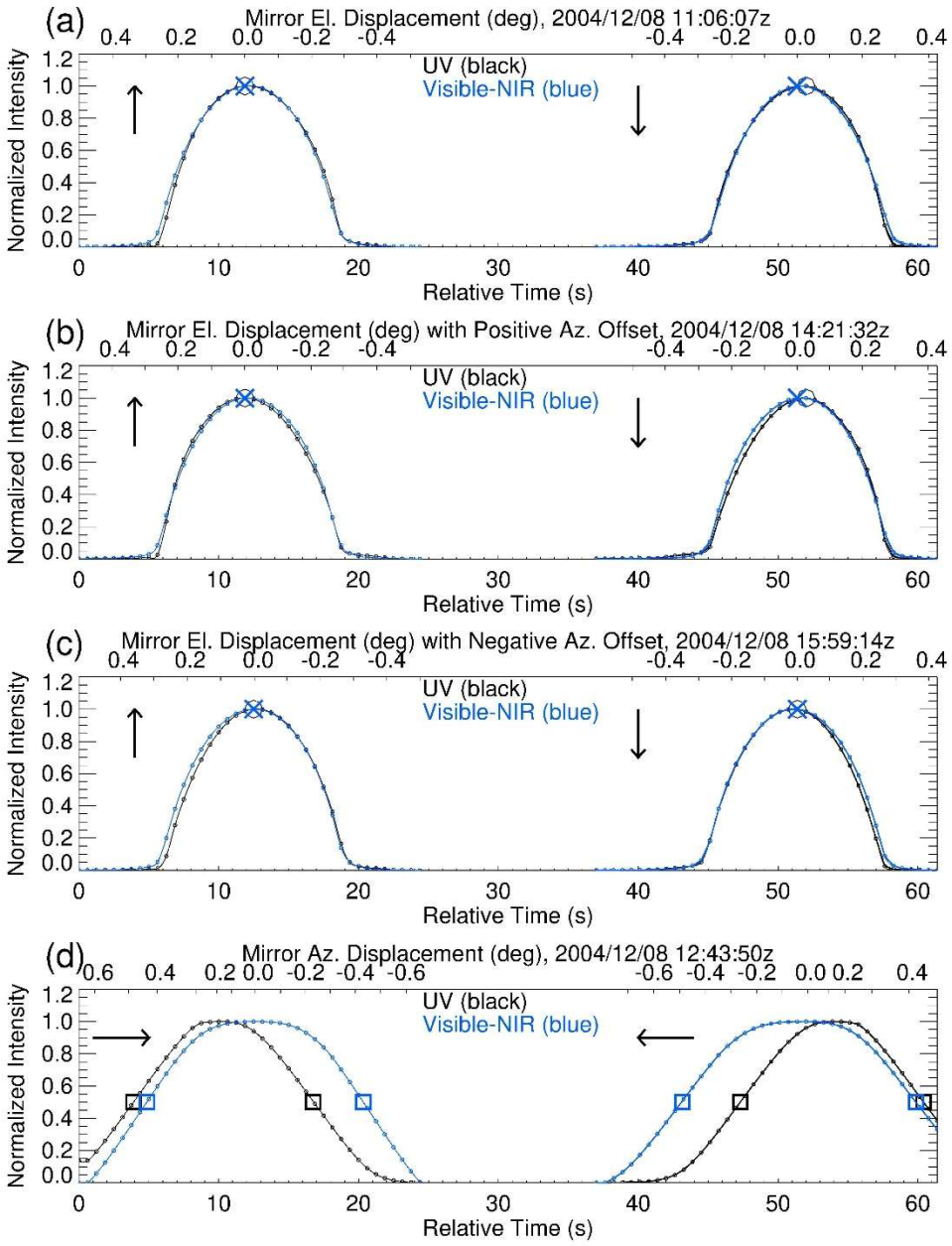

Figure 4: From top to bottom, the integrated intensities from the MAESTRO UV (black) and Visible-NIR (blue) spectra recorded during the sun-scans. The top x-axes correspond to the sun tracker mirror displacements, in degrees, scanning in the elevation (El.)

direction (a), in the elevation direction with positive (b) and negative (c) azimuth (Az.) offsets, and in the azimuth direction (d). The maximum intensities during the elevation scans are marked with an "x" for UV and a circle for Visible-NIR. Half-maximum intensities during the azimuth scans are marked with squares. The vertical arrows indicate upward and downward elevation scans, while the horizontal arrows indicate azimuth scans to the left and right.

The statement has been revised to emphasize the difference between the UV and Visible-NIR slits and the impact on the retrieved data, as below from Sect. 3.2 (lines 280-282 in preprint):

"It is also shifted in azimuth (to the right in Fig. 6) so that the slit does not encompass the Sun, resulting from an inaccurate alignment of the UV detector array that was not detected during ground testing. This misalignment is likely one reason why the MAESTRO UV O_3 data are slightly poorer than the Visible-NIR O_3 data (Jeffery et al., 2025), as the incoming irradiance does not originate from a fully complete source.".

Section 3.5.1 analyzes the impact of the star tracker failure on the satellite's attitude. The evidence presented in Figure 13 convincingly shows that the failure did not significantly affect the spacecraft's attitude control during solar occultations. However, the final sentences of the last paragraph in this section are confusing: if the primary effect on the L1 data is the change in the orientation of the slits during the solar occultation, why isn't this addressed as a standalone point in the paper? Additionally, the use of "high" and "low altitudes" in line 439 is unclear. Could you clarify this?

The final sentences in Section 3.5.1 have been modified. A clear change in the orientational angle with altitude is observed (e.g., from 30 to 10 km, as shown in Fig. 13). However, it remains uncertain whether this variation is physical and would therefore affect the level 1 transmittance calculations, or whether it arises from known Imager artifacts. See the revised sentence from Sect. 3.5.1 below (lines 437-440 in preprint).

"Therefore, the difference in rotation between the two periods is much less than other factors; instead, the dominant feature is the drift with altitude (e.g., from 30 to 10 km as shown in Fig. 13), and the effect of the failure on rotation is minimal. This apparent rotational drift in the satellite attitude may contribute to errors in the transmittance calculations, however, it may instead be related to a known Imager artifact (Gilbert et al., 2007), which a future study will assess."