Rebuttal Letter to the Reviewers and to the Topic Editor

We thank the referees for their careful read and comments. We have addressed all of them and our responses are written below in *italic*.

Reviewer comments by Michael Küppers, 29 Mar 2026

The manuscript is part of a series of papers describing the observations of the SWI instrument onboard JUICE during the Moon-Earth gravity assist. The presentation is clear and accessible for a non-specialist.

It is important to document the in-flight calibration activities and results, in particular for a mission with a long cruise phase like JUICE. Therefore the manuscript deserves publishing.

Overall the paper is well structured and complete. I just have some minor suggestions for improvements the authors may want to consider:

Introduction: There seem to be 4 papers describing different aspects of the SWI observations around the swingby. It maybe useful to shortly describe which aspects are covered in which paper.

> *Agreed. The last paragraph of the Introduction has been changed as follows:*
>
> *This paper is the third of a series of four publications in this special issue ”The first-ever lunar–Earth flyby: a unique test environment for Juice”. The first publication ”Juice/SWI during the Lunar-Earth-Gravity-Assist (LEGA). I. General overview” provides a description of the functional characteristics of SWI and its operational principles; the second publication ”Juice/SWI during the Lunar-Earth-Gravity-Assist (LEGA). II. Instrument operations” describes in detail the concept of SWI's observation modes, the operations planning, and the overall observation strategy of SWI for the Cruise Phase. This paper ”Juice/SWI during the Lunar-Earth-Gravity-Assist (LEGA). III. Observations of the Earth as Calibration target” presents typical data obtained during LEGA and provides an overview of the current status of the ongoing data analysis to better understand the instrument behavior and related systematic measurement errors. Finally the last paper ”Juice/SWI during the Lunar-Earth-Gravity-Assist (LEGA). IV. Antenna pointing and beam characterisation” of the series presents in-flight measurements of the instrument's main beam width, the beam sidelobe level, the antenna pointing, and receiver coalignment.*

Instrument description: ”There are a few things about SWI the reader needs to know to better understand the data presented in this paper”: The phrase sounds a bit strange for a scientific publication. Maybe say something like: ”In this section we shortly summarize the instrument and its measurement principle.”

> *Agreed. The sentence has been changed as suggested.*

Section 3.1: Why are the atmospheric data resampled to lower spatial resolution given that, according to the introduction, one of the sources for differences between data and model are small-scale variations in the atmosphere?

> *The underlying idea behind this resampling is to obtain a kind of climatology table for the Earth's atmosphere, similar to the ”Cospar International Reference Atmosphere 1986”. This atmospheric model is rotation symmetric around the Earth's*

rotation axis and depends only on season and latitude. Such a model simplifies the analysis of the obtained SWI data, because it can only provide a single Earth spectrum to which all SWI data can be compared with. However, SWI observations executed on the 20 August 2024 during the closest approach of JUICE to the Earth show cold spots in the data, which may be caused by scattering in convective clouds. These observations let us add the general note that small scale atmospheric phenomena may cause deviations between the expected and observed brightness temperatures.

Now we have to put numbers on SWI's footprint size during the LEGA observations: when the cold spots have been observed the altitude of the spacecraft was between 8100 km and 10800 km. This corresponds to a FWHM nadir footprint size of 19 to 25 km diameter for the 600 GHz receiver and approximately half of this for the 1200 GHz receiver. Except the limb scan shown in section 4.2 all the data analyzed in this work have not been taken before the 21 August 2024 12:00. The smallest altitude of JUICE was at that time 208500 km, corresponding to a footprint size of 483 km for the 600 GHz receiver resp. 267 km for the 1200 GHz receiver. For all following observations the footprint size ever increased - 24h later it was already 1250 km for the 600 GHz receiver. At such low spatial resolution it is not possible anymore to resolve convective clouds and – as a matter of fact – the cold spots have been seen in SWI's LEGA data set only for the 19th August during closest approach.

The MERRA-2 data are provided with a grid step size of 0.5 degrees in latitude and 0.625 degrees in longitude, corresponding to a rectangle of 55 km times 69 km size at the equator. Such a high spatial resolution definitely justifies the effort to analyze the SWI data using Earth atmospheric data properly chosen in space and time. However, this task is not within the scope of this paper and needs to be scheduled for the future.

Section 4.1: "Another important thing simplifying the calculation of the expected Earth spectrum is given by the fact that". Maybe simpler "Further simplification of the calculations is possible because . . . "

Agreed. The sentence has been changed as suggested.

Section 4.1.1: "which could be used in this way for the intended analysis" → "which could be analyzed this way"

Agreed. The sentence has been changed as suggested.

Section 4.1.2: "To obtain the wanted nadir viewing spectra". Suggest to remove "the wanted"

Agreed. The sentence has been changed as suggested.

Section 4.1.4: In addition to the values above 1170 GHz in the high frequency receiver, there seems also be a deviation much larger than 4% below 540 GHz in the low frequency receiver. Can you comment on that?

Actually the observed brightness temperature for the local oscillator tuning of 541.800 GHz is 10.45% larger than the expected value. We agree that such a discrepancy needs *an explanation and thus more investigations. Contrary to this data point, the observed brightness temperature for the local oscillator frequency of 536.355 GHz is only 4.2% larger than expected, so that point is not such a big outlier. We agree that the reason for discrepancies larger than 4 to 5% needs to be understood and thus have already started this investigation.*

In general the dominating error source for the absolut calibration into brightness temperatures is the determination of the correct receiver noise temperature for each tuning. Such measurements have been repeatedly executed in space and a first error estimation of these values can be derived from the reproducibility or scatter of the results. This way we could identify already a few tunings, which are not stable and thus are considered as not applicable for science observations. However, the two tunings under consideration here look good, so more work needs to be put into this issue.

Section 4.3.2: Any idea of the reason for the discrepancy at 563.5 GHz? Also, several of the spectra in the low frequency band show discrepancies towards low IF frequencies. In addition, some tunings in the high frequency band show discrepancies (e.g.1218.9 and 1221). Those other discrepancies should be mentioned/discussed as well.

The data point for an LO frequency of 562.95 GHz deviates from the model spectrum (the black line), because actually at this tuning the water vapor transition at 556.936 GHz is observed in the lower sideband. Given an intermediate frequency range of 5.5 to 6.5 GHz this data point belongs to a radio frequency of 556.45 to 557.45 GHz. The broad emission of this transition causes especially at this local oscillator frequency the deviation from the (single sideband) model spectrum. The same effect appears for a local oscillator tuning to 550.980 GHz: in this case the water vapor transition at 556.936 GHz is observed in the upper sideband ranging from 556.58 to 557.48 GHz. Once more this effect also explains the deviation of the expected brightness temperatures from the model spectrum at the local oscillator frequency of 1215.720, 1217.070, and 1221.030 GHz. The green triangles represent always the model brightness temperature +/-6 GHz apart of the local oscillator frequency.

Conclusions: I would remove "Obviously" from the start of conclusion 3.

Agreed. The sentence has been changed as suggested.

Maybe the conclusions should also summarize where observations differ from expected data, the possible reasons, and the foreseen way forward.

We agree that unexpectedly large deviations between the observed data and expected brightness temperatures need to be discussed in more detail. Especially the possible reasons and the way ahead needs to be addressed. Thus the bullet point two in the Conclusions has been changed to:

"2. The system temperatures of both receivers appear to be sufficiently stable to allow a lookup table approach for the total power calibration, which mitigates the limited lifetime problem for the hot load calibration flip mirror. Though this approach works in general very well, there are many observations, which deviate by more than 7% from the expected value. Especially the 1200 GHz receiver displays in the range

of 1170 to 1220 GHz local oscillator frequency deviations of 8 to 12%. Taking into account the fact that the power consumption of the receivers change with the tuning, these large deviations may be caused by different thermal stabilization times of the receiver hardware. So more detailed investigation of the instrument's drift behavior have to be carried out first, to understand how to best mitigate these effects."

Reviewer comments by Vincent Kofman, 15 Apr 2026

Dear authors,

The near-Earth observations clearly have provided great test grounds for the submillimetre wave instrument (SWI). The paper is clearly written and provides interesting examples of the observations taken using the Juice spacecraft. The results are clearly presented and the radiative transfer model reproduces the observations well. Juice/SWI will no doubt be a great asset for studying the Jovian system in the future. This manuscript describes the calibration issues and strategies with the (unexpected) limited life time of the calibration flip mirror, and demonstrates the performance of the methods. I would recommend a few corrections to be made to the manuscript listed below, but recommend this work to be published.

Minor comments:

line 6: remove word 'essentially'

Agreed. The word has been removed as suggested.

line 20: Perhaps elaborate on the 'telescope efficiency numbers'.

The sentence ". . . , first of all the telescope main beam efficiency." has been changed to ". . . , first of all the telescope main beam efficiency, which is the ratio of power received in the main beam of the antenna pattern to the total power received by the antenna."

line 40: consider adding a statement like: at the scales and level of details considered (mention beam size on disk?), the databases used (MERRA2) are expected to accurately reproduce the Earth.

Agreed. We think such a statement fits best into the section "3.1 Earth Atmosphere Model" and added here the sentence "Within the scope of the data analysis presented in this work we expect this data base to reproduce the Earth's atmosphere with sufficient accuracy. Taking into account SWI's large footprint size (during the observations taken on e.g. the 21 August 2024 it had a diameter of 500 km to 800 km for the 600 GHz receiver and about half this size for the 1200 GHz receiver), we decided to follow a climatological approach. Thus the data have been resampled the following way:"

line 50: although for this part of the spectrum GHz is the units typically used, perhaps add the wavenumbers and/or microns too. This helps readers less familiar with this part of the spectrum to orient.

We think the frequency information provided in GHz is complete and sufficient, but to help readers less familiar with this part of the spectrum the corresponding wavelength range will be specified in the figure caption.

line 49 & 54: In 49 it is mentioned that the receivers can be operated simultaneously, in 53-54 you mention only one type can be operated at one time. I assume what is meant here is that both receivers can be operated without changing the instrument configuration, but not at the same time. Please clarify.

It is correctly understood that each of the two receivers can be operated standalone or both of them can be operated simultaneously. As spectrometer either only the CTS or only the ACS can be used, but a CTS can never be combined with an ACS. Also e.g. the combination of CTS1 with ACS2 is not possible. This results in the following six possible operational cases:

1. *600 GHz receiver1 in combination with CTS1 - 1200 GHz receiver2 and CTS2 remain powered off.*
2. *1200 GHz receiver2 in combination with CTS2 - 600 GHz receiver1 and CTS1 remain powered off.*
3. *600 GHz receiver1 in combination with CTS1 - 1200 GHz receiver2 in combination with CTS2.*
4. *600 GHz receiver1 in combination with ACS1 - 1200 GHz receiver2 and ACS2 remain powered off.*
5. *1200 GHz receiver2 in combination with ACS2 - 600 GHz receiver1 and ACS1 remain powered off.*
6. *600 GHz receiver1 in combination with ACS1 - 1200 GHz receiver2 in combination with ACS2.*

We have changed the sentence "At any time only one type of these two different spectrometers can be operated: either both receivers use the CTS or the ACS." as follows: "At any time only one type of these two different spectrometers can be operated: either one or both receivers use the corresponding CTS or the ACS. In any case simultaneous operation of a CTS and an ACS is not possible."

line 105: were these in-flight observations?

Yes, these measurements of the receiver noise temperature have been performed in space.

line 140: Can you elaborate on the choice of the latitudinal averages? How does the beam size compare to the 10 deg. averages? This seems to be because you probe above 6 KM, where spatial and temporal variations are much smaller.

Except the limb scan shown in section 4.2 the observations analyzed in this work started on 21 August 2024 12:00 UTC and ended on 23 August 2024 08:00 UTC. In this time interval the altitude of JUICE above the Earth's surface increased from 208500 km to about 780000 km. Correspondingly the footprint diameter in nadir viewing direction increased from about 500 km to 1870 km for the 600 GHz receiver. The footprint size of the 1200 GHz receiver can be considered as half of the 600 GHz *receiver's size. These numbers correspond to a latitudinal extent of 4.5 to 16.8 degrees for the 600 GHz receiver, and half of this for the 1200 GHz receiver. Thus we consider the choice of 10 degree bins in latitudinal coordinates as reasonable.*

Eq 8: Watch type setting in this equation. Currently it looks like there are vertical offsets between different elements of the summation.

The vertical offsets are intended, because the vertically upward shifted summations are the exponents x to the exponential function e^x resp. $\exp(x)$.

line 150: Are there any more applications of this radiative transfer model? Perhaps it could be of interest to refer to these documents.

Yes, indeed there have been more applications of this code! It has been used since 1993 for the analysis of ground-based microwave sounding of the Earth's atmosphere and especially for the analysis of planet observations using the HIFI instrument of the Herschel Space Observatory. The following reference have been added to the manuscript:

1. *C. Seele and P. Hartogh: "Water vapor of the polar middle atmosphere: Annual variation and summer mesosphere Conditions as observed by ground-based microwave spectroscopy", Geophysical Research Letters Vol. 26 Iss. 11 (1999), pp. 1517-1520*
2. *P. Hartogh et al.: "First results on Martian carbon monoxide from Herschel/HIFI observations", Astronomy & Astrophysics Vol. 521 (2010), L48, DOI 10.1051/0004-6361/201015159*
3. *P. Hartogh et al.: "Herschel/HIFI observations of Mars: First detection of O2 at submillimetre wavelengths and upper limits on HCl and H2O2", Astronomy & Astrophysics Vol 521 (2010), L49, DOI 10.1051/0004-6361/201015160*
4. *L. Rezac et al.: "New determination of the HCN profile in the stratosphere of Neptune from millimeter-wave spectroscopy", Astronomy & Astrophysics Vol. 563 (2014), A4, DOI 10.1051/0004-6361/201323300*

line 165: Since 2008, several updates of HITRAN have been released. I recognize that code development and implementation of new databases are tedious, but this could be relevant if more of the observations will be analyzed in more details.

In order to evaluate the effect of migrating from the outdated HITRAN-2008 catalog to the current version HITRAN-2024 version the important model spectrum of Figure 8 (black line) has been re-computed using the HITRAN-2024 version. The relative deviations between the shown model spectrum and the updated spectrum are within +/-0.5%. These deviations are small compared to the expected errors of the SWI observations and thus do not change the results presented in this work.

Fig 4. Does the *'S'* represent the South Pole? I see that this is the case as described in the caption of figure 5. Please ensure that the caption of Figure 4 reflects this as well.

Yes, the 'S' indicates the South Pole. The caption of Fig.4 has been changed accordingly.

Fig. 9 Clarify what the different traces are in the figures.

Each trace corresponds to a single spectrum taken with an integration time of 1.5 seconds. Because SWI's viewing direction slowly crosses the Earth's limb from space towards the center of the Earth during this observation, each spectrum has been taken at a different tangential height, which leads to an increasing pressure broadening for each individual spectral line. The red lines are the expected (not fitted) spectra calculated for the corresponding viewing geometry of each individual spectrum.

Fig. 10: Please indicate the units on the vertical axis, even though are are normalized

An axis name "normalized intensity (dimensionless)" has been added to the figure.

line 334: The statement here indicates the methods used here are advantageous compared to another approach, presumably plotting simulated spectra separated by wavelength versus the double sideband together. Without an actual example however, it is not clear how 'this spectral scan demonstrates clearly'. Perhaps rephrase to something along the lines of: "it is apparent from the figures that the simulated spectra, with their double sideband signals combined, reproduce the signals from the observations well."

The statement has been changed as follows: "This spectral scan demonstrates clearly the complexity of observed spectra, when spectral lines arise simultaneously from both sidebands and appear combined in the intermediate frequency. For example the spectrum taken with a local oscillator frequency of 1221.030 GHz is the combination of a set of ozone transitions originating at a sky frequency of 1213 GHz and a water vapor transition originating at 1229 GHz. It is apparent from the figures that the simulated spectra, with their double sideband signals combined, reproduce the signals from the observations well."

line 340: It is tough to follow the different transitions over the frequency range between the different panels. The specific ozone transition could be highlighted in the figures to guide the readers eye.

Agreed. The figure has been updated to indicate in addition the different molecules with additional color markers.

Further changes

The title of the paper has been changed to harmonize it within the series of four SWI papers for this special issue: the word *(LEGA)* has been added and the words *Calibration Target* has been changed to *calibration target*.

In the section *Acknowledgements.* the following sentence has been added: *A. Murk acknowledges support from the ESA Prodex program and the Swiss National Science Foundation under the Grant No. 200020-165744.*

The reference *Hartogh et al. (2026a, in preparation)* has been removed, because this paper has not been submitted, yet.