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Interactive comment

Interactive comment on "A highly miniaturized satellite payload based on a spatial heterodyne spectrometer for atmospheric temperature measurements in the mesosphere and lower thermosphere" *by* Martin Kaufmann et al.

Anonymous Referee #1

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The manuscript entitled: "A highly miniaturized satellite payload based on a spatial heterodyne spectrometer for atmospheric temperature measurements in the mesosphere and lower thermosphere" by Kaufmann et al. describes the design of a miniaturized SHS instrument to measure thermospheric temperature profiles from a CubeSat in low earth orbit, data analysis steps and the expected measurement performance. This manuscript covers a topic that is of significant interest to the community, it is well written, and is well suited for the journal. I recommend the publication of this manuscript after a number of minor comments and one equation error are addressed and corrected.

(1) Abstract: “with a solid angle of 0.65 degrees” The solid angle unit is “steradian”, not degrees. Please correct the specification.

(2) Caption of Figure 2: “‘Barth’ indicates the number of molecules created by the recombination of atomic oxygen.” Judging from the axis label and the rest of the description, I assume that ‘Barth’ indicates the Volume Emission Rate of the airglow component that is resulting from the Barth mechanism, not a number of molecules. Same comment applies to the A-band and B-band description in this caption.

(3) Figure 2: This figure could be improved by (a) omitting the number “2” on the left of the y-axis, (b) adding a “K” after the temperature labels (200, 210) on the top right, and (c) omitting the integral sign and 1 3 0 1 on the top right. It is not clear to me what the latter means.

(4) Page 6, line 2+: “The zero frequency of the fringe pattern is at the Littrow wavelength and the spectral peaks of the neighboring wavelengths are spread or heterodyned around this central wavelength.” This sentence is not quite clear to me. What is meant with “spectral peaks”? Instead, it might be worth pointing out that the heterodyning effect results in the fact that high spectral resolution can be obtained because small wavenumber changes result in fringes with discernable, low spatial frequency, which can be observed with available imaging detectors.

(5) Page 6, line 5+: For completeness, the authors might consider adding a reference to the first satellite borne SHS instrument: Englert, C. R., M. H. Stevens, D. E. Siskind, J. M. Harlander, and F. L. Roesler (2010), Spatial Heterodyne Imager for Mesospheric Radicals on STPSat-1, J. Geophys. Res., 115, D20306, doi:10.1029/2010JD014398.

(6) Page 6, line 13: This equation is incorrect. The right side is missing the grating groove density (see Harlander et al., ApJ, 1992, Equation (1))

(7) Page 7, line 1: It might be worth adding that “position x” is in the direction parallel

to the dispersion plane.

(8) Page 7, line 9: It is not quite clear to me why the authors say that the spectral resolution is limited by the detector resolution (pixels per length?). I do agree that the Nyquist theorem limits the bandpass, as the authors state.

(9) Page 7, line 17: For completeness the authors might consider adding to this sentence: "... by Hilliard and Shepherd (1966) with a Michelson interferometer, and first introduced for SHS by Roesler and Harlander (1990)." The reference is: "Roesler and Harlander, Spatial heterodyne spectroscopy: interferometric performance at any wavelength without scanning, Proc. SPIE 1318, 1990, doi: 10.1117/12.22119."

(10) Table 1: giving the clear aperture in PI times radius squared is a little confusing. I recommend listing the aperture diameter or radius.

(11) The authors might consider giving the field of view dimensions in both directions, so that a reader can verify that the etendue is the product of the field of view solid angle and the aperture area.

(12) Figure 4: The top axis suggests that the detector is 0.8 cm wide, but using a pixel pitch of 5.04 microns and 840 pixels per row only results in a width of about 0.4 cm. Please check.

(13) Figure 4: The caption states: "Note: I will update the figure later on". Please provide the correct figure (in case this is not the correct one), and please include what local time this simulation was made for, since day and night profiles are significantly different.

(14) Page 9, line 14+: Depending on the field of view orientation with respect to the satellite velocity direction, the scene is scanned through the field of view, which, for a 60 second exposure, can be significant. It might be worth pointing that out.

(15) Page 9, line 18: Please add that the 66mm are the diameter, since some dimensions are given as radius and some as diameter throughout the paper.

(16) Figure 5: The first sentence of the captions claims that the figure includes the filter, the second sentence says that it is not shown. Please clarify.

(17) Page 11, line 11: It might be worth mentioning the Modulation Transfer Function of the detector optics here, since it will potentially influence the modulation of the higher frequency fringes.

(18) Page 11, line 16: The authors state: "... 80 photons/s at every spectral point within the interferogram." I think what they mean is "... 80 photons/s at every pixel recording the interferogram." The interferogram is in "spatial" space, not in "spectral" space.

(19) Page 12, line 9: The authors state: "Although the dark current at a detector temperature of 20C is a factor of 2.4 larger than the expected atmospheric signal in the nightglow maximum, it does not deteriorate the data processing significantly." This is not clear to me. An additional signal that is 2.4 times larger than the shot noise limited, targeted signal, will increase the noise by a factor of sqrt(3.4), or 80 percent for every interferogram point. I would not call that insignificant.

(20) Page 13, line 14+: It is not clear to me why the first step is required, since all non-uniformities are covered by performing the second step, including the detector non-uniformities.

(21) Page 13, lines 24: Do the authors mean: "Due to the highly compact design of the *front* optics and the use of spherical lenses only...", since assessing the effects of the interferometer and detector optics are discussed in the following paragraph?

(22) Page 14, line 9: If I understand this method correctly, it aims to determine the same fringe phases for each rising and falling fringe edge by finding a constant intensity level. This works, if the fringes have a constant offset (non-modulated part), flatfielding has been performed and a correction for modulation efficiency has been performed, prior to finding these edges. If this is what was done here, please include these caveats.

(23) Page 14, line 18+: I suggest reworking the following for clarity from: "total power

in each wave" to "total power for each spectral element".

(24) Page 14, line 20: "known good enough" should be "known well enough"

(25) Page 14, line 21: Using a Hilbert transformation to determine the envelope of the modulated part of the interferogram is fundamentally the same idea as the methods described in Englert et al. 2004 & 2006, where the corresponding complex/imaginary interferogram is generated from the real interferogram. It might be worth pointing that out. In addition, it is not quite clear to me why the authors do not use the fringe phase that can easily be determined using the Hilbert transform to determine the phase distortion. Since it does not rely on the above caveats, it appears to be a more resilient method than using the constant intensity level to find constant phase positions, as described immediately above this section.

(26) Page 14, line 21: The reference Liu et al. 25 (2017) is not yet published as of the submission of this manuscript and could not be accessed by the reviewer. Please, at least, include the final citation.

(27) Section 7: Please mention that this method explicitly requires a-priori information. It would be beneficial if you could comment on whether this is similar to fitting the line strengths of the known lines to the spectrum obtained with an FFT. The FFT does not destroy information, so all additional information has to be from a-priori knowledge.

(28) If the authors have a 3D design image of the instrument design, it would benefit the paper to include it, rather than just stating that there is a design that fits into 3.5 liters. (optional)

(29) From Figure 4, I assume that the instrument will observe the limb between tangent point altitudes of 60km and 120km. Can you please comment on the case in which the airglow extends above 120km during the day? Presumably, the temperature retrieval for at least the highest altitudes will be affected.

(30) Please comment on any thermal effects that are likely to be encountered on orbit,

including thermoelastic distortion of the optics, which can affect the focus of the fringes and therefore the modulation transfer function, depending on fringe frequency (larger effect on high frequency fringes), which might have a significant effect on the relative line strength determination.

(31) It is not clear to me how a 3.5 liter instrument will fit into a 3U CubeSat. Are the authors thinking of further miniaturization?

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