

Reply to Referee #2 on the manuscript "Thermospheric shock waves and lensing of light in the Barium Release, Optical and Radio rocket experiment", by Leyser et al.

We thank the reviewer for the careful reading and constructive comments on the manuscript. We have discovered an error in the data analysis concerning the lensing effect so that we are not convinced of its presence any longer. All text and one figure concerning the lensing has therefore been removed. Also, the reference to lensing in the title has been removed. However, this does not affect the main theme of the manuscript, namely the results on the shock waves themselves. The section Discussion was accidentally numbered as 2.1 and is now given the separate section 3. The section Conclusions has been renamed to Summary, to reflect its content. Below is our response to the comments in the review report.

Introduction:

Information has been added for the original purpose of the BROR experiment as well as the usefulness of optical imaging of barium releases. Some additions to highlight the usefulness of barium-release experiments have been made. A note has been added at the end of the Summary on that the shock wave observations do not interfere with those of the barium clouds, because of different time scales. However, the significance of the observations of the shock waves is still an open question to us, but we feel that the observations are interesting enough to motivate publication.

The line numbers below refer to those of the original manuscript and the referee report, which may be different in the revised manuscript.

Line 12: Local time has been specified.

Line 24: The relevant electric field component has been clarified. It is understood that an electric field has both amplitude and direction.

Line 40-42: A figure showing the geometry of the experiment has been added as figure 1. However, the terminator is difficult to show as its altitude is difficult to depict in the projection of a 3D landscape on a 2D figure. We have instead given additional information on the terminator in the first paragraph in the Introduction.

Observations:

The unfortunate placement of the figures is a feature of the manuscript style used. The figure placements generally are more appropriate in the published version. Additional details of the rocket experiment pertinent to the present study have been added, primarily in the beginning of Observations. Information on the duration of the flight is given in the captions of figures 3, 4 and 6 which state the times after launch for the depicted releases. We have now also added the times after launch for the first and last barium ejection in the first paragraph in Observations, which are a measure of the ballistic flight time.

Figure 1: We have added that it is the ballistic rocket speed that is shown, so the altitude dependence of the speed is approximately the same on the upleg and downleg.

Lines 86, 87: A note on the rocket rotation ($40^\circ/\text{s}$) has been added in the first paragraph of the Observations and that no effect of the rotation can be discerned in the optical data for

the barium cloud nor the shock waves. The direction of the ejecta relative to the rocket has now been more detailed in the second and third paragraph in Observations. This information is repeated where relevant in the Discussion, as in the original manuscript. However, as we know too little about the actual range of directions in which the barium was ejected, we cannot say more than what is already stated (that the ejection occurred approximately in the direction of the rocket nose) and therefore refrain from providing a cartoon of this. In view of the rocket having a much higher speed than that of the ejected remnants relative to the rocket, we only consider the direction of the rocket speed and trajectory in our simplified analysis of the shock wave speed.

Line 96: An additional panel has been added to figure 4 to show the line along which the light intensity curve of the shock is taken.?

Line 98: The video frame rate of 10 fps has been added in the first paragraph of the Observations.

Lines 105-106: All velocities are now given in m/s.

Line 107: The sentence has been reformulated.

Line 118: Done.

Line 147-148: As mentioned above all results related to lensing has been removed.

Line 185: We have reformulated the sentences. With "wind" in the original manuscript we meant the air resistance due to the motion of the rocket. The thermospheric conditions were quiet in this early part of the experiment and the background thermospheric wind is assumed negligible relative to the rocket speed. The conditions developed to the storm only later in the evening. We have now added in the first paragraph of Observations that nearby aurora did not affect the images of the shock waves.

Line 196, 198, 199, 225 to 227: Done.

Line 203: We have added information on the direction of the rocket velocity to clarify.

Lines 235-236: The reviewer is correct in that the frictional force is proportional to the size r . But the deceleration due to this frictional force is inversely proportional to the mass, according to equation (10), and the mass too depends on r . This is why a heavier particle is decelerated less by friction than a lighter particle, although the frictional force is larger on the larger and heavier particle.

Line 236: The sentence has been clarified.

Line 243 (equation 14): The purpose of the paragraph is not to strictly calculate the Reynolds number itself and demonstrate that $Re \ll 1$, but the purpose is only to check for consistency. We are aware that the reasoning is not logical. But if the Reynolds number would not be small with the obtained diameter L , although we had assumed $Re \ll 1$, we would have a problem. The consistency that we checked for is a necessary requirement, although not sufficient. We have reformulated the paragraph to bring this out.

Lines 288-289: As mentioned above, we discovered an error in the data analysis and are not convinced that lensing occurred. All data and discussion on this effect has therefore been removed.

Conclusions: The text is rightly a summary, rather than a conclusion. The section heading has therefore been changed correspondingly. A note has also been added that the shock waves exist during a much shorter time than the barium clouds, so that the possible effect of the shock waves on the barium clouds is likely negligible.