National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland
20771

TELEPHONE: (301) 286-5256
FAX: (301) 286-1648
E-MAIL: mcollier@pop600.gsfc.nasa.gov

Reply to Attn of: Code 692

5 December 2000

Janet G. Luhmann, Senior Editor
Journal of Geophysical Research
Space Sciences Laboratory
Centennial Dr. at Grizzly Peak Blvd.
University of California
Berkeley, CA 94720-7450

Dear Dr. Luhmann:

Please find enclosed four copies of the revised manuscript number 20.0382 entitled **Observations of Neutral Atoms from the Solar Wind** by Michael R. Collier, Thomas E. Moore, Keith W. Ogilvie, Dennis Chornay, J.W. Keller, S. Boardsen, James Burch, B. El Marji, M.-C. Fok, S.A. Fuselier, A.G. Ghielmetti, B.L. Giles, D.C. Hamilton, B.L. Peko, J.M. Quinn, T.M. Stephen, G.R. Wilson and P. Wurz.

We have carefully considered the comments of both Referees and the following outlines our responses along with the modifications we have made to the originally submitted manuscript:

Referee #1:

1. The Referee points out that two important facts have been established by this paper: (1) The detection technique is now proven viable for the imaging of space ion populations containing H atoms of energies around 1 keV and (2) There is a flux of neutral atoms, about 10^{-4} of the solar flux, in the magnetosphere.

In response, we have added these two facts to the abstract as well as the conclusion section along with the Referee's observation that "This opens a new window for observation and a new topic for investigation in the role of low energy neutral atoms in space plasmas."

2. The Referee states that the original manuscript missed the opportunity to check earlier speculations against the most recent observations. The Referee specifically cites the exchange between Akasofu (1964) and Brandt and Hunten (1966) and the ideas of Gruntman (1994) and Hsieh et al. (1992).

In response, we have divided the original Section 3, Discussion, into two sections, one section entitled Neutral Atom Source and Comparison to Expected Fluxes and another section entitled Geophysical Phenomena and Early CME Warning.

2a. In response to Referee #1's comment 2a, we have added a discussion of Akasofu's proposal that neutral hydrogen atoms may penetrate deep into the magnetosphere and produce an intense ring current and we have added a discussion of Brandt and Hunten's criticism of Akasofu's proposal. Finally, we have added a section that points out that the fluxes observed by LENA are much lower than the fluxes required by Akasofu. As part of our response, we have added the reference Akasofu, PSS, 12, 801-833, 1964. We have also, of course, added the Brandt and Hunten reference [PSS, 14, 95-105, 1966] pointed out by the Referee.

2b. The Referee indicates that the implications of Gruntman [1994] and Hsieh et al. [1992] on using neutral atoms generated in CMEs for early warning against storms should be addressed. In response, we have added a discussion in section 8 entitled "Geophysical Phenomena and Early CME Warning" including the reference the Referee gives as well as an article by Gosling et al. [1991].

3ai. The Referee comments that in the lower panel of Figure 4, the ratio of the H peak to the O peak is about 50 to 1, while in Figure 5 it is about 6 to 1. The Referee points out that if the total counts (area under the curves) is taken into account, the discrepancy is even greater.

In response, we have added the following to the section on the June 8, 2000 event: "There are at least two explanations for the larger oxygen signal in the in-flight data as compared to the calibration data: (i) Because of the viewing geometry and the conclusion that LENA is observing charge exchange in the magnetosheath where the superthermal population is pronounced, LENA may be responding to energies greater than 1 keV. If the sputtered oxygen yield is a strongly increasing function of energy, this could explain the disparity between the in-flight and claibration hydrogen to oxygen ratio. (ii) The start microchannel plate bias level was lower during calibration (1850 V) than in-flight (1950 V) and there is evidence that the oxygen and hydrogen efficiencies vary differently with microchannel plate bias level."

3aii. The Referee comments that in going from the absence of O counts to the presence of O counts, should not the ratio of H/O decrease? It is then asked why the ratio is increasing in Figure 6.

In response, we have added the following to the section detailing the analysis of the June 8, 2000 event: "The calibration results suggest the relative amount of oxygen increases with increasing hydrogen atom energy, at least up to 1 keV. However, as shown in Figure 6, the relative amount of oxygen appears to go down after the shock. Although it is clear that the ratio does show the transition, there are at least three possible reasons why the H/O ratio increases, rather than decreases, across the shock: (i) As stated earlier, LENA was only calibrated to 1 keV at which energy the sputtered oxygen appeared (it was not statistically present at 300 eV). Thus, it is not known how the yield of sputtered oxygen versus hydrogen varies with incident atomic hydrogen energy. It is possible that the yield of sputtered oxygen to hydrogen may decrease at higher energies explaining the behavior of Figure 6. (ii) During the June 8, 2000 event, simulations indicate that LENA is monitoring the magnetosheath in which case the behavior shown in Figure 6 reflects the location in the magnetosheath LENA is sampling. Thus, it is possible that although the solar wind speed increases across the shock, the location LENA is observing in the magnetosheath may be characterized by lower energies, depending on how the magnetosheath reconfigures. (iii) There is an upper limit to the transmission energy for particles traversing the optics. Thus, it may be the case that the higher energy neutral hydrogen produces higher energy sputtered oxygen which may be beyond the upper limit of the passband producing an apparent increase in the H/O ratio seen in Figure 6."

3b. The Referee states that the text and Figures one through six give the impression that the hydrogen flux arrives from the sunward direction within a ninety degree field-of-view centered about 180 degrees in the spin plane. The Referee then points out that figure seven shows a ninety degree field-of-view that does not even include the sunward direction and asks for some clarification.

This is certainly an issue that was not clear enough in the original manuscript. Hopefully, we have made it more clear in the revised version by adding another event, the May 24 event, during which the Sun was within LENA's field-of-view along with adding a section detailing the simulations done on charge exchange within the magnetosheath.

In addition, we have added the following to the Section entitled "Overview of LENA Sun Pulse Observations": "One notable feature is the bright yellow/orange streak which begins near 180 degrees and drifts through all angles. This "sun pulse" (as it will hereafter be reffered to) appears at the spin angle closest to the direction of the Sun. On this particular day, the Sun was within LENA's +/- forty-five degree field-of-view so that the Sun pulse is actually in the direction of the Sun. On the June 8, 2000 event, the spin direction about 180 degrees away from the Earth is closest to the Sun and so the Sun pulse appears there during the event, even though the Sun is outside LENA's field-of-view. It was apparent early in the mission that not only did the signal from the Earth respond to solar wind pressure variations, but that the intensity of the Sun pulse did, as well."

The Referee mentions that a discussion of the rise in the neutral flux at the time of the shock in spin angles outside of the sun pulse is needed in order to make the paper complete. This is an issue that Fuselier et al. [2000] have addressed in their paper, so in response we have added the following to the Section on the June 8, 2000 event: "Fuselier et al. [2000] discuss the brightening around the Earth direction at 09:11 and suggest it may be due to high energy (several keV) neutral hydrogen resulting from ion outflow at the arrival of the shock."

4. We have attempted to make the conclusions and potential impacts clear through our response to question 3 above.

5. The new version of the manuscript seeks to clarify many of the issues that the Referee raises and aims to allow readers outside the specialty to appreciate these results.

6ai. The Referee points out that "neutral particles" may refer to neutrons and neutrinos as well as neutral atoms. Consequently, we have changed "neutral particles" in the introduction to "neutral atoms".

6aii. The Referee states that the referenced sentence gives the impression that the LISM neutral atoms originate from dust grains. In response, we have re-written the referenced sentence to read "These charge-exchanging neutrals may be interstellar neutral atoms, they may originate from dust grains [Holzer, 1977; Schwadron et al., 2000] or they may be part of the Earth's geocorona."

The Referee requests a reference in the discussion of potential charge exchange at Venus. In response, we have added a reference to Bauske et al. [1998] and have included a more elaborate discussion. Please see the response to Referee #2's specific comment number 4 for more information.

6bi. The Referee suggests that the space mission Wind should be represented by "WIND" as SOHO and ACE are presented throughout the paper. In response, we have changed all cases of "Wind" to "WIND".

In addition, the Referee requests that we cite references from which the reader could find the observation of the same CME by ACE, SOHO and WIND. Although it is a bit early for such references to appear in the standard published literature, we have added the following in the way of references to the discussion: [Space Weather News for June 8, 2000, http://www.space-weather.com; ACE data available through Dr. P. Wurz].

6bii. The Referee requests that the identification of the "bright streak" in Figure 1 (now Figure 5) be made in a more coherent manner. In response, we have added Section 4, "Overview of LENA Sun Pulse Observations", which describes the Sun pulse observations in more detail and makes the discussion of Figure 5 more clear.

6biii. The Referee requests that the parenthetical remark be rephrased. In response, we have added the following in place of the sentence containing the parenthetical: " As mentioned in Section 3 entitled "LENA Instrument Operation," the LENA UV response is a result of the ionization of particles by photons, as light does not penetrate to the microchannel plates (see Fig. 1). Thus, the instrument UV response scales with pressure at or near the conversion surface, and the response to UV based on calibration data scaled to the ambient pressures expected on orbit show that LENA has a negligible UV response in orbit."

6biv. The Referee points out that the description would be more lucid if the ACE/EPAM counting rate as a function of time were shown in Figure 3. In response, we have added another figure to the paper which directly compares the ACE/EPAM data and the LENA data. We have also modified the fifth paragraph of the Observations section accordingly. Because this involves adding an additional data set to the paper, we have also added Edmond Roelof as a coauthor to the paper because of his contribution related to ACE/EPAM data.

The Referee also indicates that the "data" does not peak, but rather the counting rate contained in the data that peaks. In response, we have modified the appropriate sentence to read "The counting rate contained in the LENA data peaks shortly after the shock's passage and slowly decreases for about an hour thereafter."

6bv. The Referee wants us to make it clear that the distance which is being compared to the 40 R_E scale length is the distance between WIND and IMAGE. The concern is that IMAGE is a new mission and many readers may not be familiar with its orbit around the Earth.

In response, we have modified that section of the paper to read "The WIND spacecraft at this time was about 41 R_E upstream and about 27 R_E off the Sun-Earth line in the minus y GSE direction. The IMAGE spacecraft, which has an apogee of about 8 R_E, is always within a few R_E in the GSE y direction of the Earth so that the distance between WIND and IMAGE perpendicular to the Sun-Earth line is well within the ~40 R_E scale length inferred by Collier et al. [1998] for interplanetary magnetic field correlations, making it likely that WIND was a reliable interplanetary monitor."

6bvi. The Referee comments that the dependence of the H/O ratio on incident energy of H is a crucial piece of information lacking and that the identification of

1 keV as the incident energy of H is consequently very uncertain. All that the Referee says here is, of course, correct. Unfortunately, all the information we have from calibration is that the sputtered oxygen is not present at 300 eV and is present at 1 keV. The simulation results, however, do suggest that the energies are of the order of 1 keV.

In response, we have changed our wording in the paper to indicate that the data suggest that the energy of these neutral particles is greater than 300 eV, consistent with solar wind energies.

6bvii. The Referee states that the peak to the left of the H peak in Figure 5 (now Figure 10) needs a little more discussion. The Referee indicates that some possible causes should be suggested. In response, we have added the following to the end of the paragraph: "One possibility, because this peak occurs at a lower time-of-flight than the hydrogen peak is that it results from ringing in the start electronics. If the stop signal is associated with the ringing, rather than the original, signal, the apparent time-of-flight will be shorter. The higher microchannel plate bias level produces a higher gain which may cause the ringing to be high enough to trigger on."

The Referee also requests that we unify the name referring to the "bright streak", "sun pulse", "sun signal" and "enhancement in the solar direction." In response we have indicated in the Section entitled "Overview of LENA Sun Pulse Observations" after we introduce the Sun pulse using the spectrogram of May 24, 2000 that we will thereafter refer to the streak as the "sun pulse". This is most natural because among team members we refer to it as the "sun pulse." The term gives us a bit of hesitation, however, because it may mistakenly give the impression that the sun pulse is due to light.

6bviii. The hydrogen to oxygen ratio questions raised in the Referee's question 3 have been addressed by adding significant discussion to Section 5, "Observations from the June 8, 2000 Event." See our response to question 3 above for a more detialed discussion.

6ci. The Referee states that the reference to the observation prior to 26 May 2000 needs more clarification. In response, we have added the following paragraph to Section 4 entitled "Overview of LENA Sun Pulse Observations": "In the next section, we will discuss in detail observations similar to the May 24 event made by LENA on June 8, 2000. The major difference was that this event occurred after May 26 when the LENA data suggest the component of the neutral solar wind due to charge exchange upstream of the bowshock moved outside of LENA's field-of-view. Nevertheless, LENA still observed a sun pulse which is due to charge exchange with the geocorona. June 8 was chosen for detailed analysis to complement other LENA data analysis efforts focussed on this event."

6cii. The Referee expresses concern about the arrival direction of the signals and the field-of-view shown in Figure 7 (now Figure 4). To address these concerns, we have added Section 4 which describes an overview of LENA Sun pulse observations and Section 6 which talks about some magnetosheath charge exchange simulations and the expected LENA response.

6ciii. The Referee asks how the geocoronal H density based on Wallace et al. [1970] compares to that from the later model of Rairden et al. [1986]. We have examined that issue and included the following in the section entitled "Neutral Atom Source and Comparison to Expected Fluxes": "The geocoronal density, equation 1, is based on the results of Wallace et al. [1970] using, for convenience, an exponent of 3 rather than 3.07. The range of Wallace et al.'s data is about 3-15 R_E. Equation 1 is also very close to the more recent results of Rairden et al. [1986] in which a fit to their data over the range 2-11 R_E with the functional form above gives an 11 R_E density of 11.3 cm^{-3} and a power law exponent of 2.92. So equation 1 seems reasonable given the order-of-magnitude spirit of the calculation."

6d. The Referee wants the conclusion section re-written to reflect the above changes. In response, we have added a paragraph detailing the Referee's comments in (1) above. In addition, other changes have been made in the Conclusions section to reflect modifications in the revised manuscript.

Referee #2:

1. The Referee points out that we identify higher-energy neutrals by considering the detailed characteristics of the instrument output. They further state that this might be understood only by the readers intimatley familiar with the LENA design and performance. The Referee suggests that a description of what exactly the instrument measures and how these count rates relate to the incoming ENA fluxes is needed. In response, we have added a section to the revised manuscript, Section 3, which discusses the LENA instrument operation.

The Referee also suggests that the major instrument performance characteristics, including field-of-view, could be presented in tabular form. In response, we have added Table 1 to the manuscript which summarizes the important LENA parameters for the study discussed in this paper including field-of-view, calibrated energies and energy response among other characteristics.

2. The Referee states that the observation geometry (including the old Figure 7) should be presented before the measurement results are shown and discussed. In response, we have added Section 4 entitled "Overview of LENA Sun Pulse Observations" to make it clear that LENA still observes charge exchange processes in the magnetosheath even when the Sun is not in the LENA field-of-view. In addition, we have moved what was originally Figure 7 to the front of the discussion in Section 5 entitled "Observations from the June 8, 2000 Event".

The Referee states that the observation geometry does not seem to support the identification of the observed signal as presented in the article. Perhaps we were not perfectly clear in the original version of the manuscript that LENA is probably observing charge exchange in the magnetosheath, so that the observed geometry is consistent with observing solar wind neutrals even though the Sun is not within LENA's +/-45 degree field-of-view. To support this contention and make the article more lucid, we have added the results of a simulation showing what LENA should observe if the signal were charge exchange of solar wind ions with the Earth's geocorona in the magnetosheath. The results of the simulation are described in the text and shown in Figure 12.

3. The Referee points out that the neutral component should also be present in the quiet solar wind and asks if there are any signatures in the quiet solar wind and whether such signatures would be below instrument sensitivity. The answers are "yes" and "no" respectively, and we have addedSection 4 entitled "Overview of LENA Sun Pulse Observations" in an attempt to make this clear. In this new section, we discuss "many clear and consistent features... apparent in the LENA data immediately upon reaching science level operations." One of these is, of course, the sun pulse.

With regard to Referee #2's other specific comments:

1. The Referee points out that two major review papers on ENAs, namely Williams et al. [Rev. Geophys., 30, 183, 1992] and Gruntman [Rev. Sci. Intsrum., 68, 3617, 1997] would help the readers to put the presented work into context. In response, we have added the Williams et al. [1992] reference to the Section entitled "Introduction." We have also added the Gruntman [1997] reference to both the section on "Neutral Atom Source and Comparison to Expected Fluxes" and to the section on "Historical Context."

2. The Referee states that the reference to Akasofu is misleading because it was soon shown by Brandt, Hunten and Cloutier that the Akasofu mechanism would probably be insignificant. In response we have added a discussion of both Akasofu's mechanism and the objections of Brandt and Hunten [1966] and Cloutier [1966], along with these references, in the section entitled "Geophysical Phenomena and Early CME Warning."

The Referee states that Fahr [Astrophys. Space Sci., 2, 496, 1968] and Holzer [1977] should be credited for the clear identification of the processes leading to the neutral component of the solar wind. In response, we have added a section, Section 2, to the paper which describes the historical context of the ideas on the neutral solar wind. In this section, we detail, among others, the references of Fahr [1968] and Holzer [1977].

The Referee also points out that Dessler et al. [JGR, 66, 3631, 1961] were the first to invoke solar wind charge exchange on the exospheric neutrals. In response, we have added the following to Section 2, Historical Context: "Historically, the idea that solar wind protons would interact with the Earth's geocorona dates back at least forty years to Dessler et al. [1961] who considered this mechanism a potential source of background hydrogen atom flux for observations of proton ring current decay by charge exchange with hydrogen atoms." We have also added the Dessler et al. [1961] reference to the References section of the paper.

Finally, the Referee states that the solar wind ENA story is described by Gruntman [1997]. In response, we have added this reference to the section on Historical Context and pointed out the particularly enlightening section of this paper dealing with the historical development of NAI instrumentation.

3. The Referee considers the statement "... by the fact that the geocoronal density at the magnetopause is comparable to that of the solar wind..." to be an ambiguous statement. In response we have re-written that section to read "The potential importance of charge exhange on the exospheric neutrals may be motivated by the realization that the neutral density at the nominal magnetopause (~10 R_E) is in fact comparable to the average solar wind density (~10/cm^3), so that the neutral density at this radial distance is not small [Rairden et al., 1986].

4. The Referee comments that "the statement on the possible importance of the atmosphere of Venus should be supported by (simple) numerical estimates."

In response, we have added the following paragraph to Section 1, Introduction, of the revised manuscript: "The effect of solar wind charge exchange on the exosphere of Venus may be estimated by noting that the fraction of the solar wind density that is neutralized due to an interaction over a characteristic scale length of L is ~σnL where σ is the charge exchange cross section and n is the neutral density. Adopting a neutral density of about 10^5 cm^{-3}, a characteristic scale length of about 0.1 R_v = $6x10^7$ cm and a cross section σ~10^{-15} cm^2, we get a neutral solar wind fraction of about $6x10^{-3}$, easily a large enough flux for LENA to observe [Bauske et al., 1998].

In addition, we have added the reference Bauske et al., A three-dimensional MHD study of solar wind mass loading processes at Venus: Effects of photoionization, electron impact ionization, and charge exchange, *J. Geophys. Res., 103*, 23,625-23,638, 1998.

5. The Referee suggests that the count rate dependences should be preceded by a description of what exactly the instrument measures and how these count rates relate to the incoming ENA flux. In response, we have added Section 3 to the revised manuscript which details the LENA instrument operation. See also our response to Referee #2, General Comment #1.

6. The Referee points out that there is another potentially important and much brighter source of photons that may trigger the detectors, namely the solar Lyman alpha line. This is true and we have been unable to get any Lyman alpha data for this time period. We have, however, added the following to the section in which we discuss the SOHO UV data: "Note however that this does not include the potentially important hydrogen Lyman-alpha line at 122 nm. We anticipate, though, that the wavelength ranges shown reflect the behavior of the Lyman-alpha, at least qualitatively."

7. The Referee points out that the time-of-flight spectrum would be understood only by someone intimately familiar with the LENA instrument design and performance. In response, we have added Section 3 entitled "LENA Instrument Operation" which describes in detail the operation of the LENA instrument and, in particular, the time-of-flight unit.

8. The Referee points out that the narrowing of the energy range to greater than one keV is not justified in the text. The calibration, as described, provides only the threshold of 300 eV. This is correct and we have modified the manuscript to reflect this.

9. The Referee points out that a detailed description of the instrument field-of-view and its angular sensitivity is needed because of the unfavorable observation geometry on the June 8, 2000 event. In response, we have added a table, Table 1, that describes the LENA instrument characteristics. In addition, we discuss these issues in the section entitled "LENA Instrument Operation" and discuss the effect of LENA's field-of-view on the observations in Section 4 entitled "LENA Sun Pulse Observations."

10. The Referee asks how the Wallace et al. results compare to those of Rairden et al. on DE-1. This was also a question that Referee #1 raised and in response the Rairden et al. data were fit to the functional form of equation 1 with similar results, so the the Wallace et al. and Rairden et al. results agree well. For more discussion, please see section 6ciii of the response to Referee #1 above.

Other Modifications:

1. To reflect the addition of the simulation results to the paper, we have modified the abstract by adding the following sentences: "LENA observes these particles from the direction closest to the location of the Sun even when the Sun is not directly in LENA's 90 degree field-of-view. Simulations suggest these neutrals are the result of solar wind ions charge exchanging with exospheric particles in the magnetosheath." We have also modified the last sentence to read "These results show that low energy meutral atom imaging provides the capability to directly monitor the solar wind and/or magnetosheath from inside the

magnetosphere and that there is a continuous and significant flux of neutral atoms originating from the solar wind inside the magnetosphere."

2. We mention in the section describing the June 8, 2000 event the RPI data suggesting that IMAGE did exit the magnetosphere during this time period and acknowledge Jim Green in the Acknowledgments section.

3. We have provided at the end of the Introduction a brief overview of the 10 Sections in the paper.

4. On of Referee #2's suggestions was to strengthen the discovery aspect of the paper. In response we have added to the conclusion the statement that "We have reported possibly the first detection of hydrogen atoms of energy >300 eV consistent with solar wind type energies from the magnetopause and interplanetary space."

With Sincerity,

Michael R. Collier