Comment on "MeV magnetosheath ions energized at the bow shock" by S.-W. Chang et al.

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From a study of the May 4, 1998, storm event, *Chang et al.* [2001] (CETAL01) suggested that "ions are accelerated at the quasi-parallel bow shock to energies as high as 1 MeV and subsequently transported into the magnetosheath during this event" and mentioned that "This is confirmed by a comparison of energetic ion fluxes simultaneously measured in the magnetosheath and at the quasi-parallel bow shock when both regions are likely connected by the magnetic field lines" (see their Abstract). After an inspection of the measured energetic ion data, however, one finds that CETAL01 have artificially adjusted the observed ion energy spectrum in the "magnetosheath" (near the cusp) to lower energy which brings it in closer agreement to the flux measured near the quasi-parallel bow shock, making their analysis suspect. In fact, simultaneous measurements indicate that at this time the energetic ion flux near the cusp was about one order of magnitude higher than that near the quasi-parallel bow shock, demonstrating that the quasi-parallel bow shock was not the main source of the energetic ions near the cusp during this event.

CETAL01 stated that "A comparison of Interball and Polar ion spectra can potentially falsify our bow shock source hypothesis and is now the focus of our analysis".

In Figure 11 of CETAL01, accordingly, they compared the energetic ion flux measured by Interball near the quasi-parallel bow shock with that measured by Polar near the cusp during the interval 11:01-11:42 UT on 5/4/98, where their Polar/CEPPAD energetic ion data (open circles in their Fig. 11) were taken only from the ion sensor that was looking 90° from the Polar spin axis. Our Figure 1 replots the Interball data (stars) and the Polar/CEPPAD data (open squares) for the same time interval. Comparing Figure 11 of CETAL01 to our Figure 1, we find that they have artificially moved the CEPPAD ion energy spectrum to the lower energies which reduces the difference between Interball and Polar ion fluxes. This is not the only case where CETAL01 artificially move the observed ion energy spectrum, for in an earlier paper, *Chang et al.* [1998] (CETAL98) artificially moved the MICS (Magnetospheric Ion Composition Sensor) lower energy limit from 1 keV/e to 0.6 keV/e which brought the fluxes into better alignment with "bow shock ion spectra", and in addition, moved the HIT (Heavy Ion Telescope) helium data point below the actual observed value of 0.22 He^{+2} ions $(cm^2\text{-sr-s-keV/e})^{-1}$ at 8:37:40-8:45:00 UT on August 27, 1996 [see Fig. 3 in CETAL98]. Based upon such artificial adjustments of observed data, CETAL01 stated in their introduction that CETAL98 "showed that cusp energetic ion spectra ($<$ 300 keV e^{-1}) matched very well with a large body of bow shock ion spectra".

Yet even after moving the observed CEPPAD ion data, the Interball ion flux was still lower than the Polar ion flux as shown in their Figure 11, so that CETAL01 made another spectral adjustment by increasing the measured Interball ion flux to match the repositioned Polar ion flux to obtain their Figure 13. They called it a "distance correction" and made it central to their argument stating that "an important piece of evidence for the bow shock source is demonstrated in Figure 13". However, it has been reported [*Lee*, 1982] that the proton flux at 13 R_E from the bow shock is almost the same as that at the bow shock at energies larger than 60 keV; that is, no correction is needed to transfer the > 60 keV proton flux at 13 R_E to 0 R_E from bow shock [see Fig. 1 in *Lee*, 1982]. This result was further supported by *Trattner et al.* [1994] who found that there is essentially no correlation between the 67.3 keV proton flux and the distance from the bow shock and that the actual correlation coefficient found was about 0.2. CETAL01 cite these two papers, which suggests that when Interball was at a distance of about 4-6 R_E from the bow shock adjusting the > 60 keV Interball ion flux was unjustified.

Additional evidence that CETAL01 mishandled the ion data is shown in their Figure 14. From its left panel, we observe that the oxygen ion (solid circles) flux of solar wind origin is even higher than the total ion flux at about 20 keV, which is obviously impossible. Also from its right panel, the He^{+2}/O^{+6} ratio has a value of about 3 at energies < 10 keV/e, which is more than one order of magnitude lower than the known ratio value in solar wind [e.g., *Möbius et al.*, 1987], suggesting that either the data was misplotted or was not of solar wind origin.

Another problem in CETAL01 concerns the location of Polar in geospace at 11:01-11:42 UT on 5/4/98. CETAL01 stated that "Polar was in the undisturbed magnetosheath according to the plasma and magnetic field data; that is, Polar was located farther into the magnetosheath than that suggested by the model" (shown in their Fig. 9). In contrast to CETAL01, during 11:01-11:42 UT, Polar was in an extremely disturbed magnetic field region with $\Delta B \sim B$ and a field strength peak of about 120 nT. Their Figures 1 and 2 reveal a D-shaped ion velocity distribution, suggesting that Polar was on open magnetospheric field lines at the time. In other words, it suggests that magnetic field lines at the location of Polar were connected with the cusp at this time. Their Figures 1 and 2 further reveal that Polar ion flux was peaked at about 150°-180° pitch angles. Since from 11:01 to 11:42 UT, the Polar spin axis was pointing approximately anti-parallel to the local magnetic field direction, the Polar ion sensor looking at a direction of 130° from the spin axis corresponded to a pitch angle also of about 130°, and the 90° look-direction corresponded to a pitch angle approximately around 90° as well. Our Figure 1 shows that the 130° Polar ion flux (solid circles) was higher than that of the 90° Polar ion flux (open squares), and was about one order of magnitude higher than the Interball ion flux (stars) when Interball was near the bow shock. If "Polar is likely to be very well connected to Interball by magnetic field lines", as claimed by CETAL01, then our Figure 1 demonstrates that the quasi-parallel bow shock was not the main source of the energetic ions observed by Polar near the cusp.

Our Figure 2 compares ion fluxes measured by POLAR (solid line) and Interball (dotted line) over three energy ranges ($\sim$ 65-90 keV, 120-160 keV, and 420-580 keV) from 11:00 to 12:30 UT, where the shaded area indicates the time interval when Interball was magnetically connected to the quasi-perpendicular bow shock and the white areas indicate periods when Interball was magnetically connected to the quasi-parallel bow shock. From 11:00 to 11:45 UT for each of the energy ranges POLAR measured higher fluxes by about one order of magnitude than Interball did. Furthermore, the time profiles of fluxes measured by both POLAR and Interball seem to track fairly closely, and the ion time signatures (peak and valley) were detected first by POLAR then by Interball, all of which suggest that POLAR was closer to the energetic ion source region than Interball. The similar temporal variations of the energetic ion fluxes (our Fig. 2) and the similar ion energy spectral shapes (our Fig. 1), measured by both Interball and Polar, suggest that most of these energetic ions were from the same source. Since Interball was closer to the center of the parallel bow shock (see their Fig. 9), the fact that the higher energetic ion flux (or phase space density) was observed by POLAR argues strongly that the main source for these energetic ions observed by both spacecraft was not arriving from the quasi-parallel bow shock.

We note that when the bow shock, which was magnetically connected to Interball, changed at 11:47 UT from quasi-parallel to quasi-perpendicular, the 65-89 keV ion flux measured by Interball did not change until much later. The top panel of their Figure 1 indicates that from 12:03 to 12:20 UT on 5/4/98, the solar wind ion pressure reduced to the average value (about 3 nPa), and the bow shock position shown in their Figure 9 relaxed sunward even closer to the Interball location. No significant enhancement of energetic ion flux was observed by Interball during this time even though Interball was located almost at the quasi-parallel bow shock. In brief, our Figure 2 reveals that the energetic ion flux ($\sim$ 60-600 keV) observed by Interball near the bow shock was independent of bow shock geometry, and this is additional evidence to indicate that most of these energetic ions were not accelerated at the quasi-parallel bow shock.

CETAL01 also criticized *Chen and Fritz* [1999], saying "... the Geotail and Polar ion flux comparison by *Chen and Fritz* [1999] for this storm event can be wrong." After checking the paper of *Chen and Fritz* [1999], one finds that this paper made no comparison of Geotail and Polar ion fluxes for this storm event.

Based upon the artificially adjusted ion data, CETAL01 concluded that "The bow shock source of magnetosheath energetic ions for this event strongly supports the bow shock model of cusp energetic ions [*Chang et al.*, 1998] and is inconsistent with the model of local acceleration in the cusp [*Chen et al.*, 1998]." The observational data shown above demonstrate that the conclusion of CETAL01 is faulty because spectra were consistently lower well away from the magnetopause, with less phase space density, because the ion fluxes temporally followed the changes seen first near the cusp, and because the spacecraft were often not magnetically connected to the quasi-parallel bow shock. A local acceleration mechanism, such as that proposed by *Chen and Fritz* [1998], remains the only consistent explanation for these observations.

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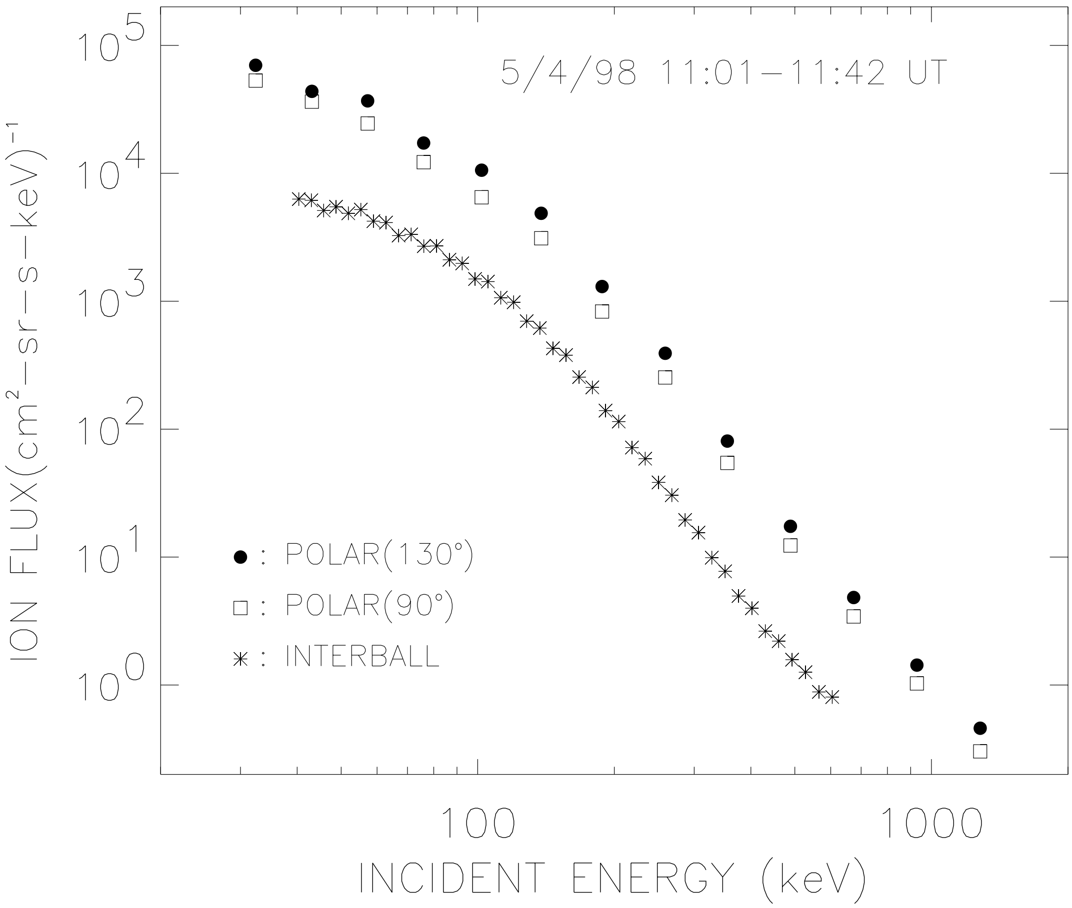
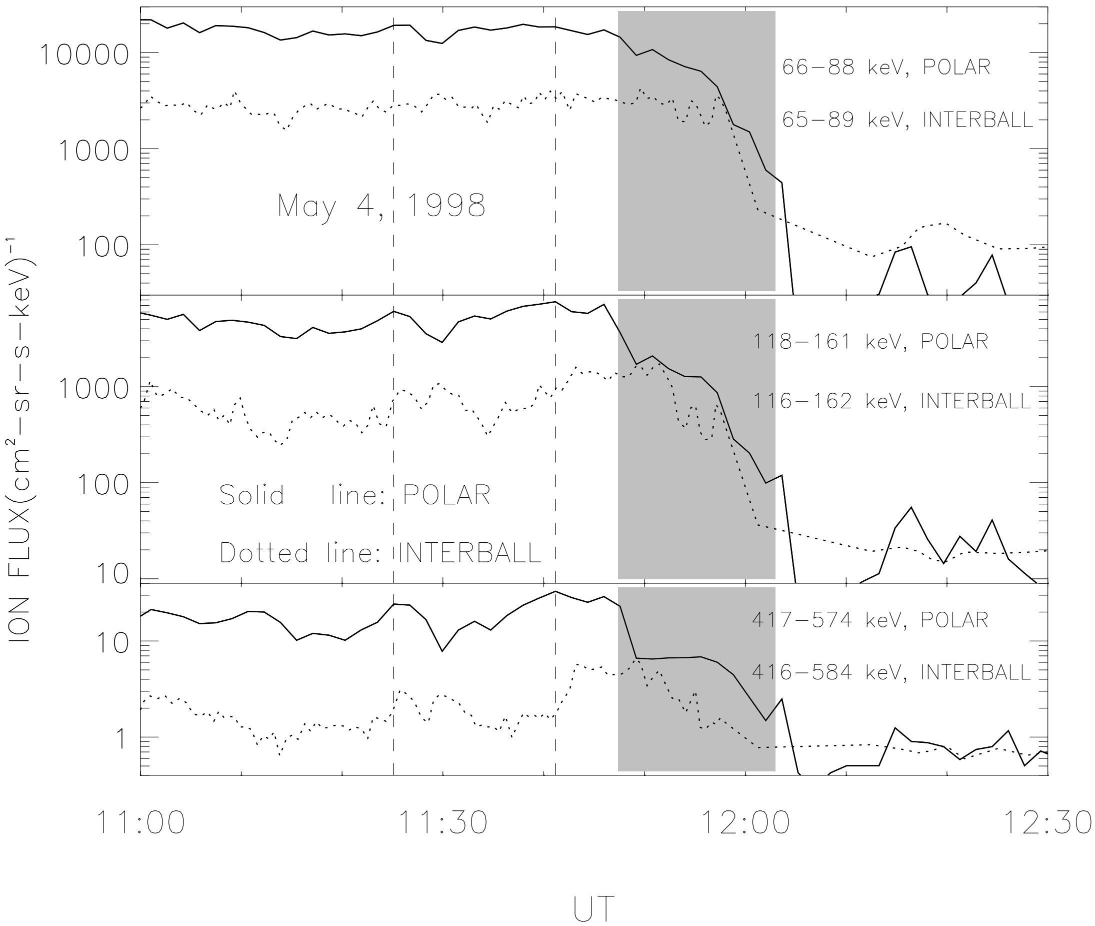
Figure 1. Ion energy spectra observed by Polar with a look-direction of 130° (solid circles) and 90° (open squares) from Polar spin axis and by the Interball (stars) at 11:01-11:41 UT on May 4, 1998.

Figure 2. Time profiles of the ion fluxes measured by Polar (solid line) and Interball (dotted line) over three energy intervals ($\sim$ 65-90 keV, top panel; 120-160 keV, middle panel; and 420-580 keV, bottom panel) at 11:00-12:30 UT on May 4, 1998. The shaded area indicate times when Interball was magnetically connected with the quasi-perpendicular bow shock, and the white areas indicate periods when Interball was magnetically connected with the quasi-parallel bow shock.


5/4/98 11:01–11:42 UT
ION FLUX(cm^2–sr–s–keV)$^{-1}$
10^5
10^4
10^3
10^2
10^1
10^0
●: POLAR(130°)
□: POLAR(90°)
✳: INTERBALL
100
1000
INCIDENT ENERGY (keV)


10000
1000
100
66-88 keV, POLAR
65-89 keV, INTERBALL
May 4, 1998
1000
100
10
118-161 keV, POLAR
116-162 keV, INTERBALL
Solid line: POLAR
Dotted line: INTERBALL
10
1
417-574 keV, POLAR
416-584 keV, INTERBALL
ION FLUX(cm²-sr-s-keV)⁻¹
11:00
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