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ERRATUM: "COMPREHENSIVE ANALYSIS OF CORONAL MASS EJECTION MASS AND ENERGY PROPERTIES OVER A FULL SOLAR CYCLE" (2010, ApJ, 722, 1522)

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In our recent paper (Vourlidas et al. 2010, Paper I hereafter), we reported various statistics regarding the masses and energies of coronal mass ejections (CMEs) including the detection of a 6 month CME mass variability. Since then, we have uncovered a processing error in the routines that create the mass images. They failed to take into account the image rotation during the 180° rolls of the *SOHO* spacecraft (see http://soho.nascom.nasa.gov/hotshots/2004_01_04 for more information). Therefore, the mass and energy measurements for those periods did not correspond to the actual CME location. This error affected about half of the events since 2003 June when the spacecraft began rolling for 3 months at a time. We corrected the software error, reprocessed all images and measurements since 2003, and redid the analysis exactly as it was reported in Paper I. The final sample includes slightly more events (7820 CMEs) compared to the 7668 events used in Paper I. We found that the correction affected mostly our discussion on the solar cycle effects (Section 3.5 in Paper I). We describe these changes in detail below and provide updated figures where necessary.

The most significant change is the disappearance of the 6 month signal in the CME mass. The discussion in Section 3.5.2 and Figures 15 and 16 in Paper I are no longer valid. There is still evidence of periodicity in the corrected CME masses but it requires additional analysis before it can be confirmed. Such analysis is beyond the scope of this erratum.

The updated statistics do not show a sharp decline in the CME mass and energy properties in 2003 (Figure 1). We had no explanation for this decline in Paper I and the correction solves this problem. The rest of our results remain valid, however. The

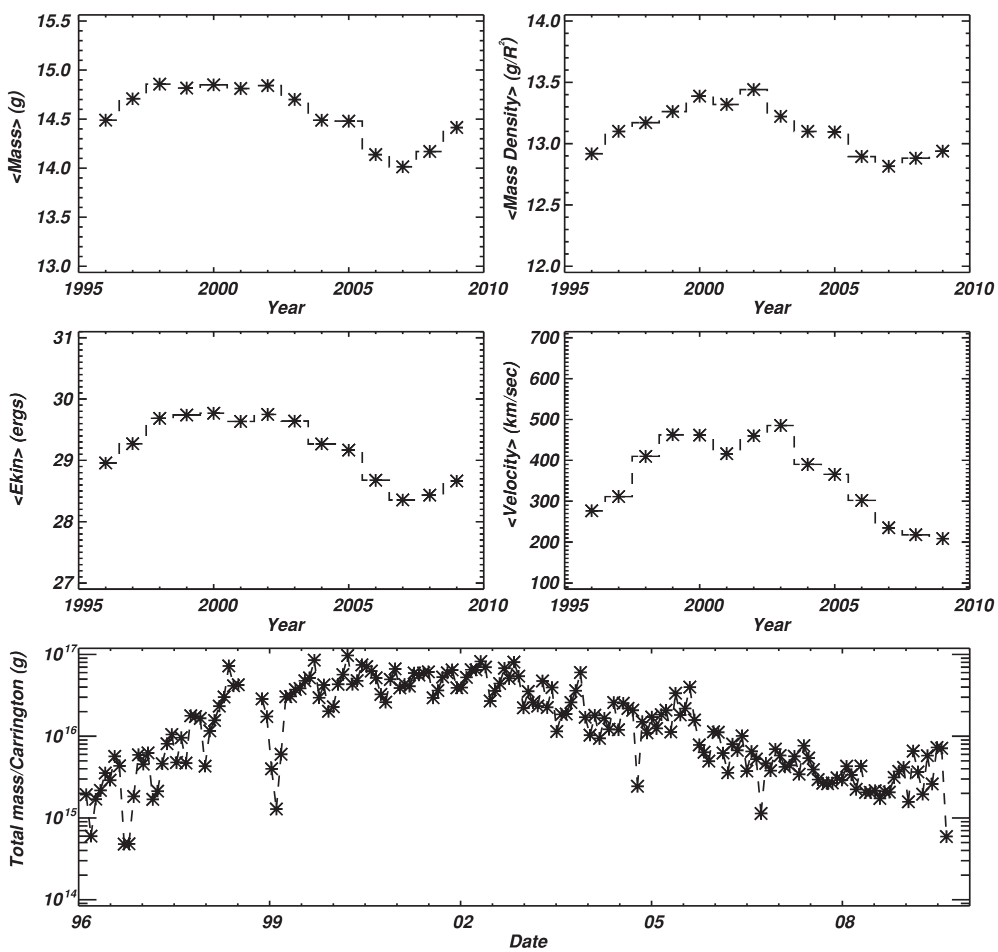

Figure 1. Solar cycle dependence of the CME mass and kinetic energy. Top left: log CME mass. Top right: log CME mass density in g $R_\odot^{-2}$. Middle left: log CME kinetic energy. Middle right: CME speed. All four plots show yearly averages. Bottom panel: total CME mass per Carrington rotation. The data gaps in 1998 and the drop in 1999 are due to spacecraft emergencies. (This figure is an update of Figure 14 in Paper I.)

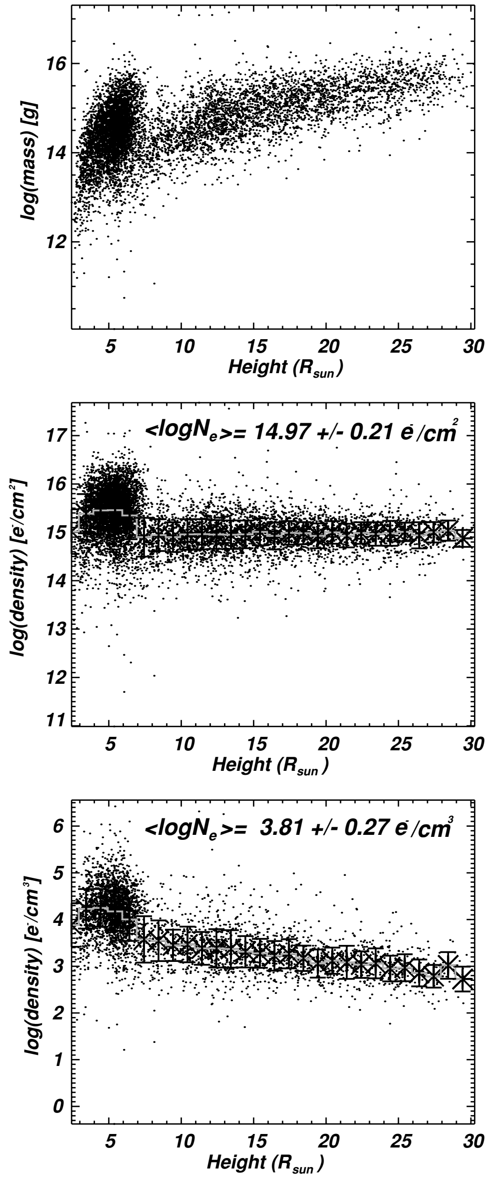

Figure 2. Top: scatterplot of the logarithm of maximum CME mass vs. the height where it was measured. Two populations are present: CMEs reaching maximum mass $<7\ R_\odot$ and CMEs with maximum mass $>7\ R_\odot$. The former are discussed in Paper I. Middle: scatterplot of the logarithm of CME surface density (e cm^{-2}) vs. height. The two populations are clearer here. The CME density is constant above $\sim 10\ R_\odot$. A histogram (gray line) with $1\ R_\odot$ bins is calculated and the average density (asterisks) and standard deviation (error bars) in each bin are overplotted. The small spread of the CME density values above $\sim 10\ R_\odot$ is quite remarkable. Its average value is shown on the plot. The height spread is mostly due to the noise and flatness of the mass measurements at those heights which tend to shift around the height of the maximum mass. Bottom: CME volume density vs. height. The density is derived assuming an LOS depth equal to the projected width. The slow decline of the density toward the outer FOV is consistent with the reduced signal-to-noise ratio at these heights. There is no evidence of material pileup. (This figure is an update of Figure 11 in Paper I.)

decline in 2003 can still be seen in the mass density and mass per Carrington rotation statistics which remain anti-correlated to the CME speeds.

The correction also improved the visibility of the solar cycle variation overall. Figure 1 shows a clear minimum in CME mass, mass density, and kinetic energy in 2007. These quantities return to their 1996 values by mid-2009. Compared to the discussion in Section 3.5 in Paper I, the discussion on the mass and energy behavior needs to be updated as follows. (1) The CME mass reached a minimum in 2007 (10^{14} g) which was a factor of 2.8 lower than in 1996 (2.8×10^{14} g) and returned to its 1996 value by 2009 (2.6×10^{14} g). (2) The CME kinetic energy reached a minimum of 2.3×10^{28} erg in 2007 which was 3.6 times lower than the 1996 value of 8.3×10^{28} erg and it was still 1.8 times lower in 2009 (4.6×10^{28}). (3) There is no evidence for the transition to the solar cycle in the CME speeds. They continue to fall. The average speed in 2009 was 208 km s^{-1} compared to 276 km s^{-1} in 1996.

Finally, the corrected masses and slightly larger number of events have resulted in some small changes in the overall CME properties (Table 2 and Figure 11 in Paper I). The corrected values are shown in Table 1 and Figure 2.

None of the other figures or conclusions of the original paper are affected in a significant way by the corrections after 2003. To avoid any confusion and clarify the results of our work, we provide below the final conclusions identifying the ones that have been unchanged by this erratum. This list supersedes the conclusions of Paper I.

Table 1
Mass and Energy Properties of CMEs (1996–2009)

	LASCO			Solwind
Property	Histogram Peak	Median	Average	Average
Mass ($\times 10^{14}$ g)	4.4	4.6	13	17
E_K ($\times 10^{29}$ erg)	0.9	2.6	20	43
E_{mech} ($\times 10^{29}$ erg)	8.4	10.0	42	...
Total mass ($\times 10^{18}$ g)	...	...	10.0	3.9
Mass flux ($\times 10^{15}$ g day^{-1})	...	...	2.1[a]	7.5
Duty cycle	...	...	94%	61.7%

Note. [a] 1996–2003: 2.7×10^{15} g day^{-1}. 2003–2009: 1.4×10^{15} g day^{-1}.

1. We identify the existence of two populations in the mass CME data: the "normal" CMEs which reach a constant mass beyond 10 $R_\odot$, and the "pseudo" CMEs which reach a mass peak below 7 $R_\odot$ before they disappear in the C3 field of view (FOV). (Unchanged from Paper I.)
2. The average CME mass density is remarkably constant for the "normal" CMEs at $\rho = 10^{12.86\pm0.21}$ g $R_\odot^{-2}$. Therefore, one can estimate the mass of any CME, within a factor of three, simply by multiplying this density with the projected area of the CME, in $R_\odot^2$, as measured in the images at heights >10–15 $R_\odot$. The CME volumetric density, calculated under the assumption of line-of-sight width equal to the observed width, is $\sim$6457 cm^{-3} and suggests that most of the CME mass originates in the high corona, if CMEs expand adiabatically.
3. The mass and energy distributions become log-normal only for measurements at around 10–15 $R_\odot$. The implication is that measurements at lower heights provide an incomplete picture of the event and will bias statistical studies. Coronagraphs with FOVs at or beyond 15 $R_\odot$ are essential for CME studies. (Unchanged from Paper I.)
4. We show the first complete solar cycle behavior of the CME mass, density, and energies. The statistics reveal a decline in the CME mass and mass density from 2003 onward, while the CME kinetic energy and speed follow with a delay of a year. The mass and energy reach their minimum values in 2007 but the speeds continue their downward trend even during 2009.
5. We show that the CME properties also vary between cycles. CMEs seems to be less massive (by almost a factor of 10) compared to cycle 21 measurements. The CME mass and mass density in 2009 are close to their 1996 values but the kinetic energy is a factor of 1.8 lower and CME speeds are 32% less than in 1996. These observations provide additional evidence for the unusual minimum of cycle 23.
6. The LASCO duty cycle is $\sim$94%. (Unchanged from Paper I.)
7. Instrumental errors and assumptions on the composition of the plasma are insignificant compared to the projection errors below. (Unchanged from Paper I.)
8. CME masses and potential energies may be underestimated by a maximum of two times, and the kinetic energies by a maximum of eight times (mostly due to the speed projection). (Unchanged from Paper I.)

CME masses and energies available through the CDAW CME Catalog have been corrected as of 2011 January 15.

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REFERENCE

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