Calculation of IES Level 3 Flux from Level 2 Counts

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The Ion and Electron Sensor (IES) uses electrostatic analyzers (ESAs) to differentially measure the energy per charge (E/q) of positively and negatively charged particles. The E/q is measured at 128 different steps from 16 different azimuths and 16 elevations, and if the measured particle mass and charge could be assumed, a velocity space density could also be computed as shown in eq. 1 below. The velocity space density, *f*, is dependent on raw counts from the instrument, C, the speed of measured particles, *v*, the instrument's geometric factor, G, the span of time that particles were counted, Δt, and the instrumental efficiency at which particles were counted, ε. The measured particles speed is inferred from the measured E/q and by estimating the particle's mass, m, and charge, q.

$$f = \frac{2\,{}^{C}/_{\Delta t}}{v^4 * G * \epsilon} \tag{1}$$

$$v = \sqrt{\frac{2 * \left({}^{E}/_{q}\right) * q}{m}} \tag{2}$$

Unfortunately, cometary ions range from H^+ (1 amu) to CO_2^+ (44 amu) in mass, and while most are singly charged, it may not always be the case. In contrast, cometary negative charged particles are much more likely to be electrons, but in at least one case negative hydrogen was observed [Burch et al., 2015]. Consequently, *v* and *f* can vary significantly depending on which species is thought observed.

Our approach to the IES level 3 data product is to distill the level 2 data into its most useful form without making assumptions about the measured particles. Our conclusion from the above discussion is to exclude data dependencies on *v* and leave that to the analysis of future users of the IES data. Therefore, the highest order data product that we can produce is differential flux, DF. We define DF in equation 3 below. Differential flux is computed similarly to velocity space density, with the exception that all dependence on *v* is removed and background signals caused by penetrating radiation and electronic thermal noise are subtracted from the raw counts to define C/Δt'.

$$DF = \frac{{}^{C}/_{\Delta t'}}{G * \epsilon} \tag{3}$$

Our approach to computing each independent variable in equation 3 will be explained in detail in an upcoming paper [Broiles et al., in preparation], but we will briefly explain each below.

In order to compute C/Δt', we must first identify background noise sources. We consider IES' background noise to be relatively small and uniform across energies and directions because it is caused by penetrating radiation and thermal electronic noise. Therefore, we can isolate this signal by looking at data points where we anticipate no real counts. For both the ion sensor and the electron sensor this can be found in directions where there are complete spacecraft blockages. We average data at high energies, in directions with complete spacecraft blockages for each measurement cycle (electrons: Anode 14, elevation step 0, energies greater than 500 eV; ions: Anode 1, elevation step 16, all energies), and subsequently use a rolling average over the adjacent 10 background estimates to smooth the effect of statistical fluctuations in measured background. This approach still allows the background to vary over longer timescales, and removes variable timescale radiation sources such as interplanetary coronal mass ejections and solar flares. Once we have an estimate for the background, it is subtracted from the raw counts to compute C/Δt'.

The geometric factor used here for ions is equivalent to the value described in the IES instrument paper [Burch et al., 2007]. However, for the electron sensor a more precise estimate was computed using flight data from Jan. 1, 2015. Based on previous cometary electron observations Zwickl et al. [1986] found that electrons were isotropically distributed in the rest frame to first order. We summed all of the counts over time to produce a single measurement for each direction and energy for the entire day's data. We then assumed that one direction of the instrument had the ideal geometric factor as described by the Burch et al. [2007] paper. We chose a direction that was generally Sunward point, free of spacecraft blockages, and had minimal deflection voltage applied (Anode 3, elevation step 9). We compare the observed counts at every look-direction to that of our ideal direction at each energy step. Equation 4 describes our method for calculating the calibrated geometric factor, G', using observed counts summed over time, C, at each azimuth step, i, elevation step, j, energy step, k, and the published geometric factor, G [Burch et al., 2007].

Pointing

$$G'_{i,j,k} = \frac{C_{i,j,k}}{C_{3,9,k}} G \qquad (4)$$

Equations 5 and 6 describe our estimate of the uncertainty G' using error propagation of equation 1. Uncertainty in $C_{i,j,k}$ is estimated with Poisson statistics, and G is treated as a known constant. Covariance between counts at azimuth i and elevation j, and azimuth 3 and elevation 9, $\sigma_{ij,39,k}$, is estimated using the series of data that is integrated to calculate $C_{i,j,k}$.

$$\Delta G'^2_{i,j,k} = \sigma^2_{i,j,k}\left(\frac{\partial G'_{i,j,k}}{\partial C_{i,j,k}}\right)^2 + \sigma^2_{3,9,k}\left(\frac{\partial G'_{i,j,k}}{\partial C_{3,9,k}}\right)^2 + 2\sigma_{ij,39,k}\left(\frac{\partial^2 G'_{i,j,k}}{\partial C_{i,j,k}\partial C_{3,9,k}}\right) \qquad (5)$$

$$\Delta G'^2_{i,j,k} = \left(\frac{C_{i,j,k}}{C^2_{3,9,k}} + \frac{C^2_{i,j,k}}{C^3_{3,9,k}} - \frac{2\sigma_{ij,39,k}}{C^2_{3,9,k}}\right) G^2 \qquad (6)$$

Figure 1 shows a comparison of IES flux observations with the application of a constant geometric factor (Figures 1a, 1b) and the new, flight-calibrated geometric factor