Iron Charge State Distributions in Large Gradual Solar Energetic Particle Events

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Abstract

Ionic charge state distributions of solar energetic particles (SEPs) can provide evidence for their origin and acceleration mechanism. Iron charge state distributions from the ACE/SEPICA instrument will be presented for four large SEP events. Three may be represented by a source at thermal equilibrium, plus a higher charge state component. The equilibrium temperatures and the origin of the higher charge state component will be discussed.

1. Introduction

SEP ionic charge state measurements were reported for many ion species by Luhn et al. (1987). They classified events as either large flare events or 3He-rich events with abundance enhancements for heavy ions. The "large flare" events are now known as gradual events (Reames, 1999) and usually feature a CME-driven shock. They may also include a simultaneous flare. The 3He-rich events are associated with flare acceleration processes.

The average Fe charge state for gradual events was 14.1 charge units. In the 3He-rich events, the Fe charge state was 20.5 units. These average values were interpreted as evidence for the source region temperature. In the gradual events, the source temperature was estimated at 2-4 MK, while in the 3He-rich events, the temperature was estimated at 10 MK.

The ACE/SEPICA instrument (Moebius et al., 1998) has measured Fe charge state in several large events in the 1997-2000 period. In this work, observed Fe charge state distributions will be compared to model distributions derived from equilibrium source temperatures.

2. Observations

SEPICA uses an energy loss/residual energy telescope and electrostatic deflection to directly measure charge states. It covers the energy range from 0.23-0.33 MeV/nuc for Fe in this study. ACE orbits the L1 Lagrange point in the solar

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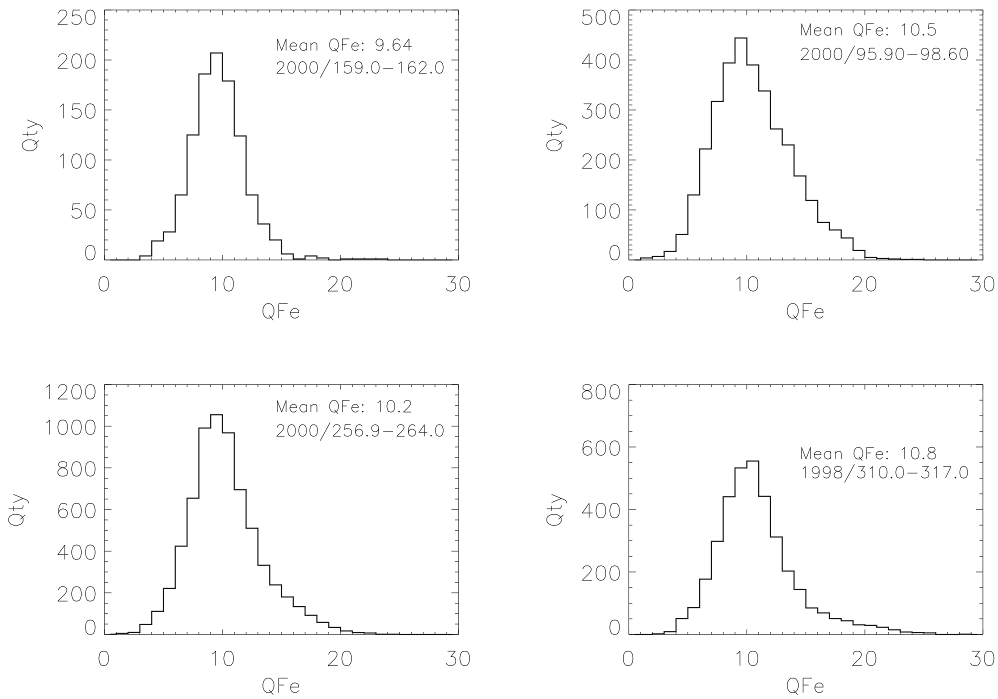

Fig. 1. Iron charge state distributions are shown for four large SEP events as observed by ACE/SEPICA. One is approximately symmetrical, while the other three have tails extending to higher charge states.

wind.

Figure 1 shows SEP Fe charge state distributions for four large events: 2000/159, 2000/095, 2000/257, 1998/310. The mean Fe charge state for each event is included. The distributions typically peak near charge state 9+ or 10+. Three have tails extending to charge states of 20+ or more. One (2000/159) appears to be more symmetrical than the other three. A model Fe distribution for a 1.0 MK source is shown in Figure 2. This model was constructed by applying the instrument response function to an Arnaud and Raymond (1992) 1.0 MK Fe distribution. All histograms are in instrument measurement space. Two events are compared to the 1.0MK model in Figure 2. The symmetrical event of 2000/159 is similar to the 1.0MK model, but the 2000/095 event contains an extension to higher charge states. The 2000/095 event cannot be represented by a single temperature source model. The excess represents 21% of the total observed distribution.

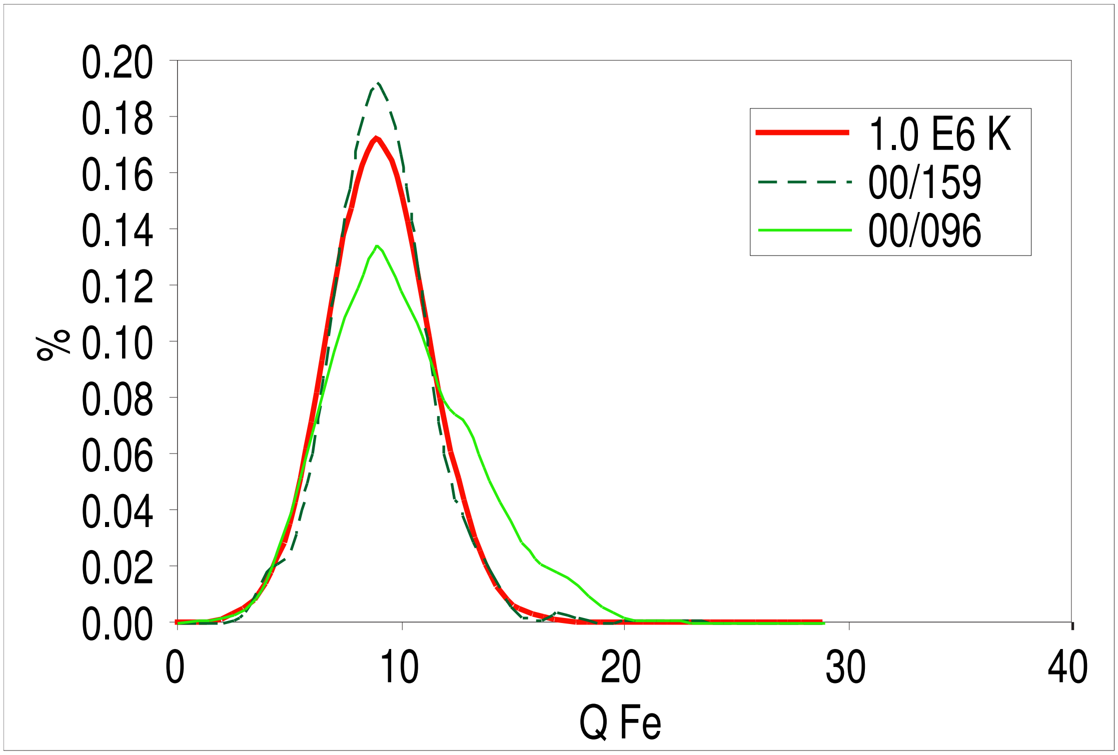

Fig. 2. Two Fe charge state distributions are compared to a model assuming a 1.0 MK source. The 00/159 event is similar to the 1.0MK model, while the 00/096 event has an excess of higher charge state ions.

3. Discussion

Three of the four large events are consistent with a source at thermal eqilibrium, plus a higher charge state component. In these cases, the shape of the charge state distribution provides more information about the source populations than its mean. The higher charge component may originate in a flare acceleration process. This could take the form of a direct contribution by a flare that occurs simultaneously with the CME eruption. Indeed, the symmetrical event (2000/159) originated on the central solar disk, whereas the 2000/095 event occurred at W66 in conjunction with an M-class flare. The latter event should have better magnetic connection to the Earth than the former. Alternatively, the high charge component may be introduced by shock reacceleration of previously accelerated flare ions in the interplanetary medium (e.g., Mason et al., 19xx). The absence of a high charge tail in the 2000/095 disk event may place limits on this mechanism.

4. References

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