Long Term Measurements of Solar Wind Fe Charge States

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Solar Wind Fe Charge State Expectations

- Four types (Schwenn, 2006)
  - Fast solar wind (coronal holes)
  - Slow solar wind (near helmet streamers)
  - Slow solar wind (active regions)
  - ICME solar wind
- \(<Q_{Fe}^{\text{slow}} > Q_{Fe}^{\text{fast}}\)
- ICME QFe \(~16+\)
- Small variations in mean charge state compared to SEPs

Von Steiger et al., (2000)
STEREO A Fe Charge States vs. Solar Wind Speed
Latter Half of 2008

- Limited period of time
- Solar wind speed is inversely related to Q Fe
- Examine a longer period, in solar maximum…
Solar Wind QFe from ACE/SWICS 1998-2008

- Two hour averages of solar wind Fe charge states with a 33 day running average (top)
- International Monthly Sunspot number (bottom)
- ICME solar wind may have high Fe charge states (Lepri; Reinard (2005, 2008))
- Fewer occurrences of high charge state solar wind in 2006-2008.
- The mean Fe charge state decreases in 2006-2008.
QFe Histograms: ACE SWICS
1998-2008

QFe is reduced by 2 units from 1998 to 2008
<QFe> from ACE/SWICS and Solar Wind Speed from ACE/SWEPAM

- Mean ACE Fe charge states: 33 day running averages (top)
- Solar wind speed from ACE/SWEPAM (bottom)
- The mean solar wind speed sometimes changes without an inverse change in the mean Fe charge state.
Iron charge states and solar wind speeds:
2007 (DOY 022) - 2009 (DOY 230), STEREO A

- The top trace is the iron charge state, averaged over 2 hour periods.
  - The average charge states typically ranged between 8+ and 11+.
  - A prominent exception occurred during the 2007/143 May 23 ICMEs. The average charge state was ~13+ to 14+.

- The bottom trace is the 2 hour averaged solar wind speed from STEREO A.
  - A long decline below the 2007 levels followed, until August of 2009.
  - Variations in the solar wind speed have decreased compared to early 2007.
Mean Iron Charge State and Solar Wind Speed:

2007 (DOY 022) - 2009 (DOY 230), STEREO A

- The smoothed trendline in the iron charge states is shown in blue (left axis) with the smoothed trendline for the solar wind speed.
- The iron charge state tends to move in the opposite direction to the solar wind speed in a large scale sense.
- The charge state has not completely recovered to the early 2007 levels, even though the average solar wind speed has gone lower than it was in 2007.
Solar Wind Speeds: Recent Solar Min and Max

- **STEREO A:**
  2007/045-2009/230
- **ACE:** 1998-2005.5
- Speeds in the 2007-2009 period (solar min) are typically lower than the 1998-2005 period (solar max)
• The iron charge states are plotted against corresponding solar wind speeds for the 2007-2009 period.

• Variations in charge state are generally related to solar wind speed, but with a broad spread of approximately 1-2 charge units.
Iron Charge States for 4 S/W Speed Ranges

- Histograms of mean iron charge states are plotted for selected intervals of solar wind speed.
- The average charge state declines particularly over the speed range 270-500 km/s, then changes little at higher speeds.
- $<QFe>$ decreases by $\sim 1$ unit over the entire speed range:
  - $260 < \text{S/W speed} < 310 \text{ km/s}$
    - $<QFe> = 9.7$
  - $375 < \text{S/W speed} < 425 \text{ km/s}$
    - $<QFe> = 9.2$
  - $500 < \text{S/W speed} < 550 \text{ km/s}$
    - $<QFe> = 8.7$
  - $700 < \text{S/W speed} < 750 \text{ km/s}$
    - $<QFe> = 8.6$
• NSO/GONG synoptic coronal hole plots for selected Carrington rotations
  – Red/green areas are coronal holes: red negative polarity, green positive polarity
  – Neutral line is in black
• Isolated coronal holes disappear with time
• Polar coronal hole extensions shrink
• Neutral line flattens (less tilted current sheet)

Galvin et al., 2009
Iron Charge States vs. S/W Speed
2007-2009

• One hour sampling intervals are shown.
• Transient or ICME intervals are highlighted (Kilpua et al, 2009 a, b)
  – Small transients: magnetic structures related to sector boundaries in solar wind
  – ICME list (Jian, 2009)
  – Additional ICMEs identified by Kilpua 2009b
• Reinard (2005, 2008) related the Fe charge state to the energetics of the originating solar event such as flare magnitude.
• No ICMEs occurred with $<Q_{Fe}>$ near 16+ 

Galvin et al. (2009)
Summary

• ACE/SWICS mean Fe charge states have declined in the declining phase of the previous solar maximum by ~2 units (1998-2008).
• The decline is partly a result of fewer transient periods of high charge states (fewer ICMEs?)
• Fe charge states are anticorrelated with solar wind speed over short periods, but they may be poorly correlated in long term averages.
• The mean STA Fe charge state in the 2007-2009 period tends to be higher at low speeds than at high speeds by ~ 1 unit.
• Variation of the Fe charge state with speed is small above 500 km/s.
• STEREO A mean Fe charge states have varied inversely with solar wind speed in the 2007-2009 period.
  – Recent Fe charge states are lower for the present low speed regime than they were in 2007.
  – Is this slow solar wind without the high charge state component (~Fe 16+)?
- One hour averages of solar wind speed and iron charge state from STEREO A
- Smoothed lines - 655 hour averages (~Carrington rotation)
STEREO A Fe Charge States vs. Solar Wind Speed

- Average Fe charge state generally shows an anticorrelation with solar wind speed (sources: fast or slow s/w, coronal holes or active region).
- Typical values of charge state are between 9+ and 10+.
- Only one period of high charge states exists: May 22-24, 2007 (ICME).