Transient Shocks and Associated Energetic Particle Events Observed by ACE during Solar Cycle 23

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Outline

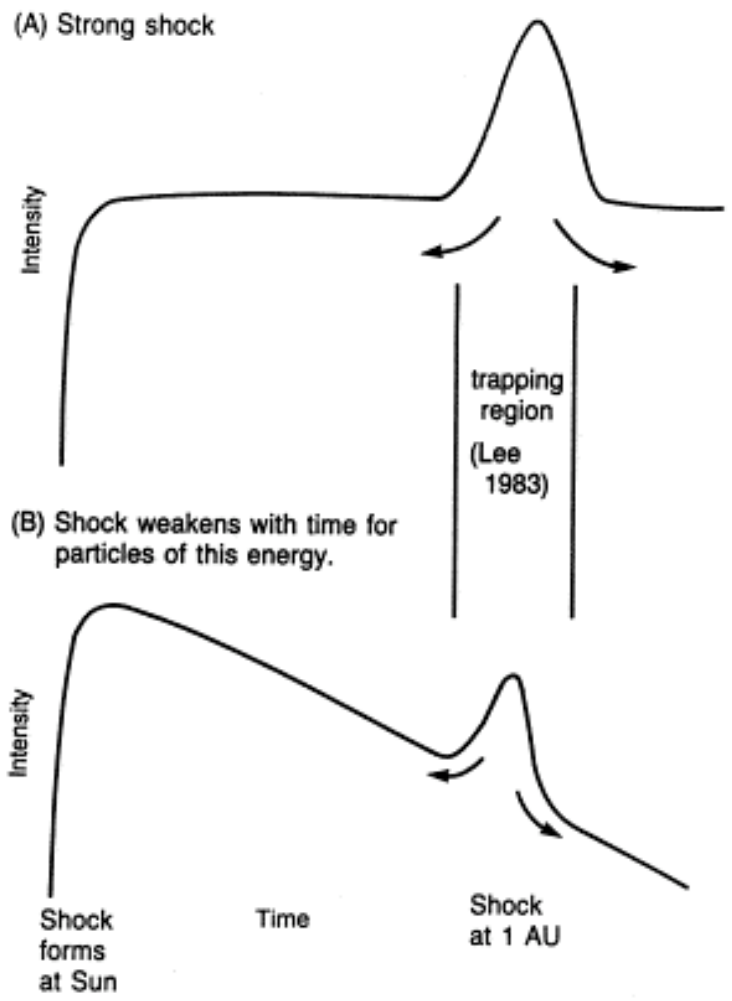
- Introduction
- ACE ESP events survey
  - Time-intensity profiles
  - Spectral evolution
  - Spectral profiles
- Selected ACE/Wind ESP events
- Summary

Energetic Storm Particle (ESP) Events

Energetic Storm Particle (ESP) events are increases of energetic charged particle intensities that are observed upstream and downstream of interplanetary (IP) shocks. ESP events are observed most commonly in ion intensities and have time scales ~hours.

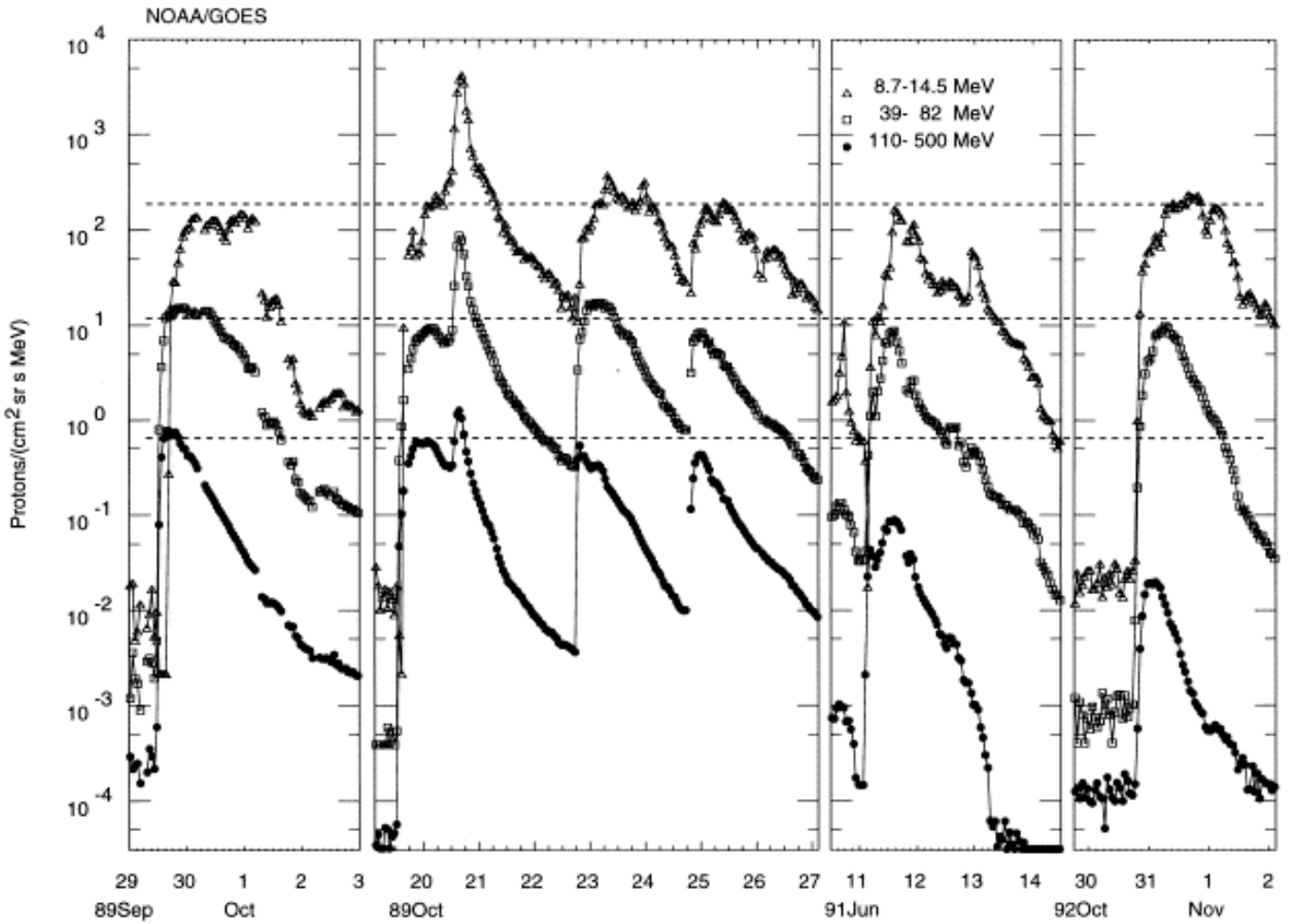
The energetic particle signatures of ESP events have been studied extensively during the 80s (Tsurutani and Lin, 1985; van Nes *et al.*, 1984; Scholer, 1988; Decker, 1981; etc.). Lee [1983] modeled the energetic particles within ESP events with a diffusive shock acceleration model at a quasi-parallel shock, while Decker [1983] successfully applied the shock drift model to explain the shock-spike events.

Time-intensity Profiles of SEP and ESP



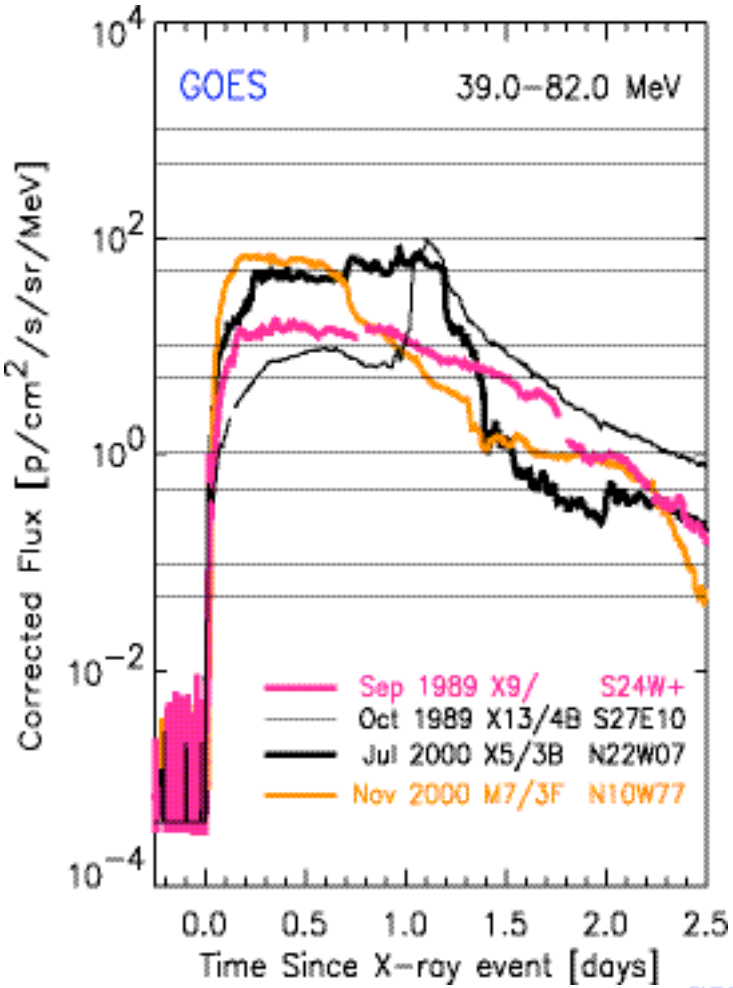
Reames, 1999

SEP and ESP During Cycle 22



Reames, 1999

Large ESP Events

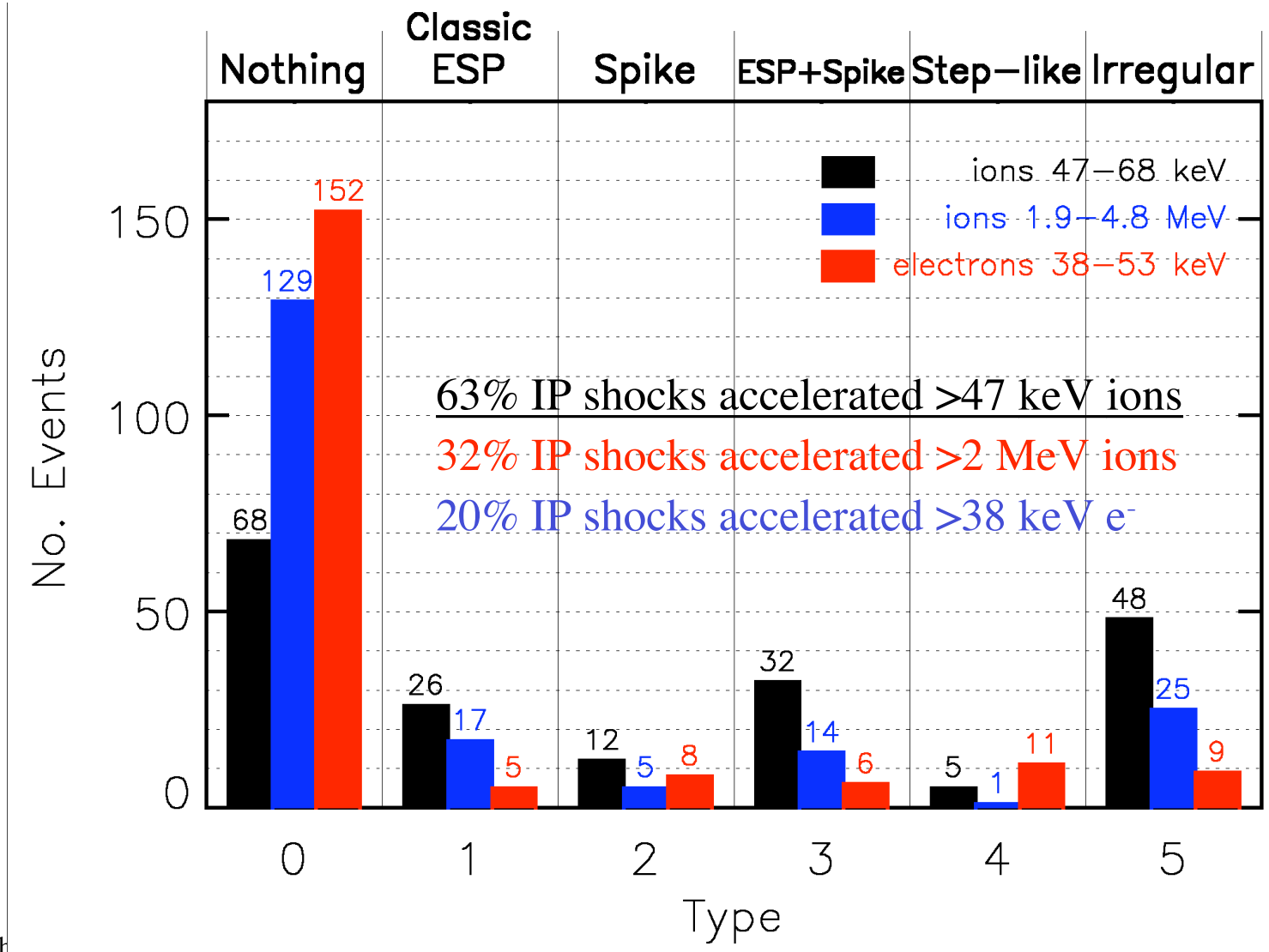


Lario and Simnett., 2003

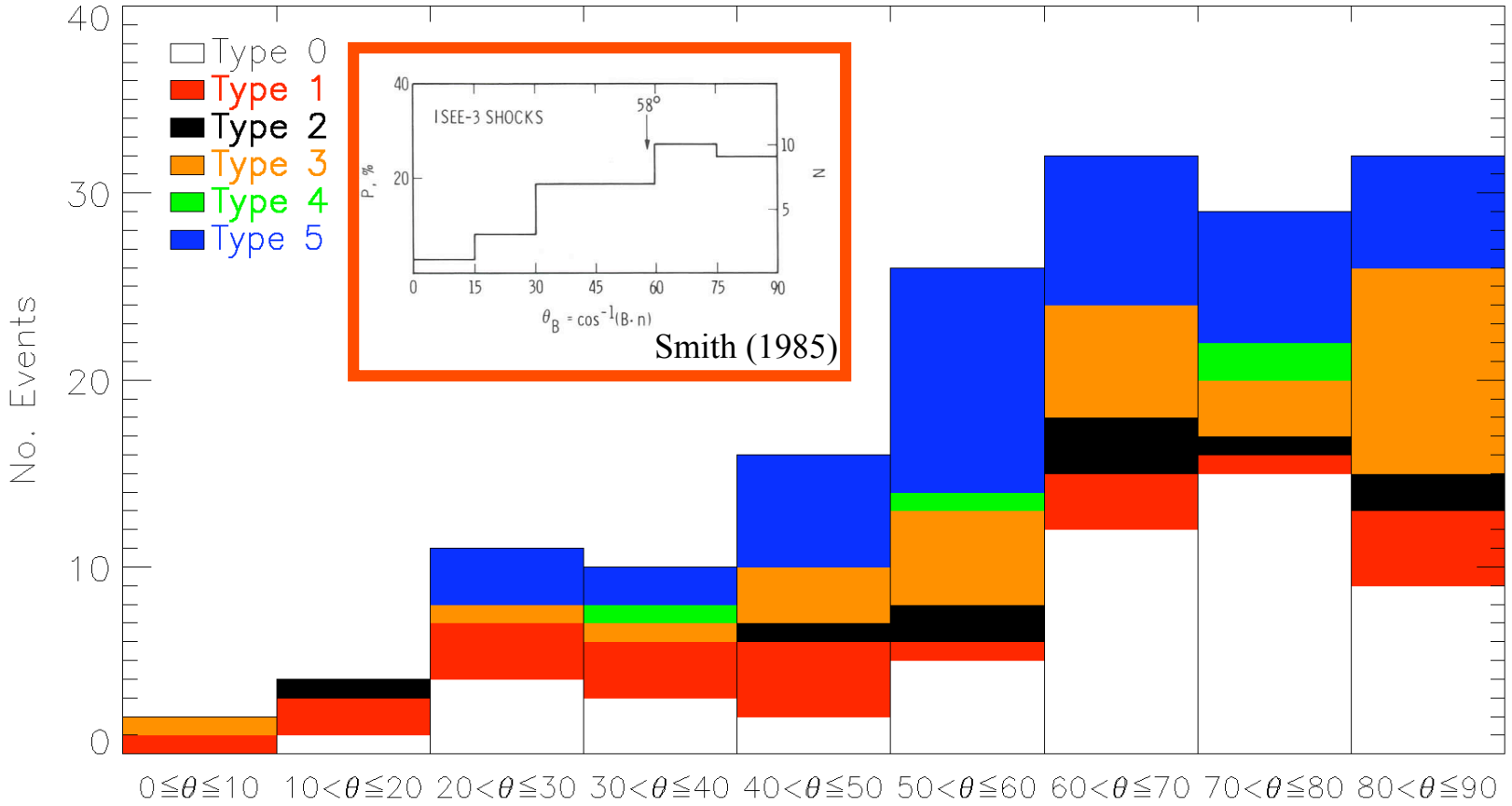
Event Selection

- From February 1, 1998 to October 28, 2003 the SWEPAM and MAG teams identified a total of 298 interplanetary shocks.
- Out of these 298 interplanetary shocks, we have selected 191 shocks that were fast and forward and with clear evidences of being driven by or related to the passage of ICMEs, i.e., we have excluded: reverse shocks, slow shocks, shocks associated with CIRs and shocks associated with other structures such as magnetic holes or stream-stream interactions. A total of 97 shocks.
- We have also excluded those shocks associated with the most intense SEP events (such as the Bastille Day 2000 event, or the November 2001 events). A total of 10 shocks.
- A preliminary list of Wind interplanetary shocks indicate 124 of the 191 shocks were also detected by Wind, 5 ESP events were selected to examine in detail the spatial and temporal variations of these events in the Earth's vicinity.

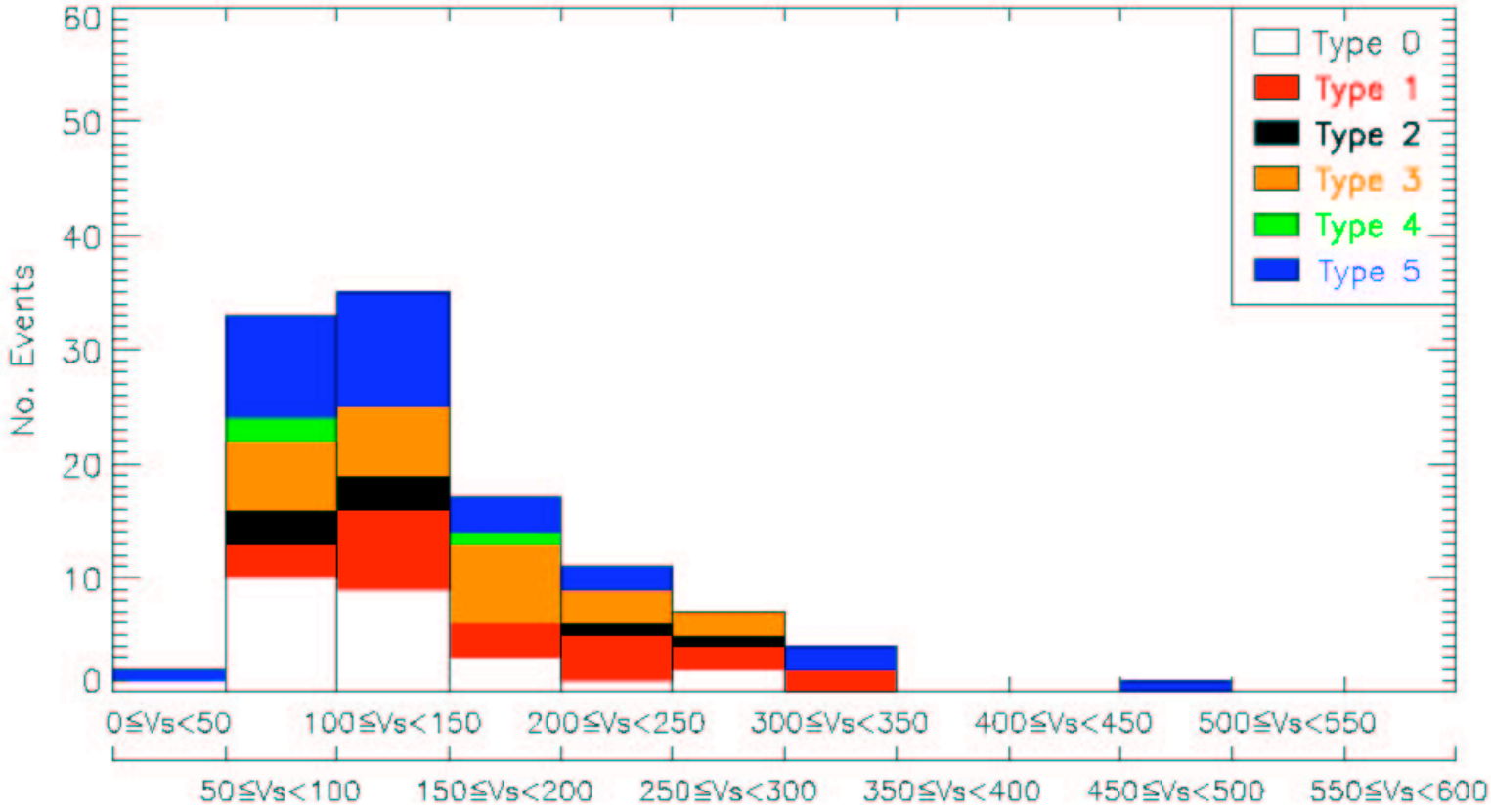
Classification of the 191 ESP events according to their intensity-time profile



Upstream Magnetic Field Direction (θ_{Bn})



Correlation between shock parameters and particle signatures



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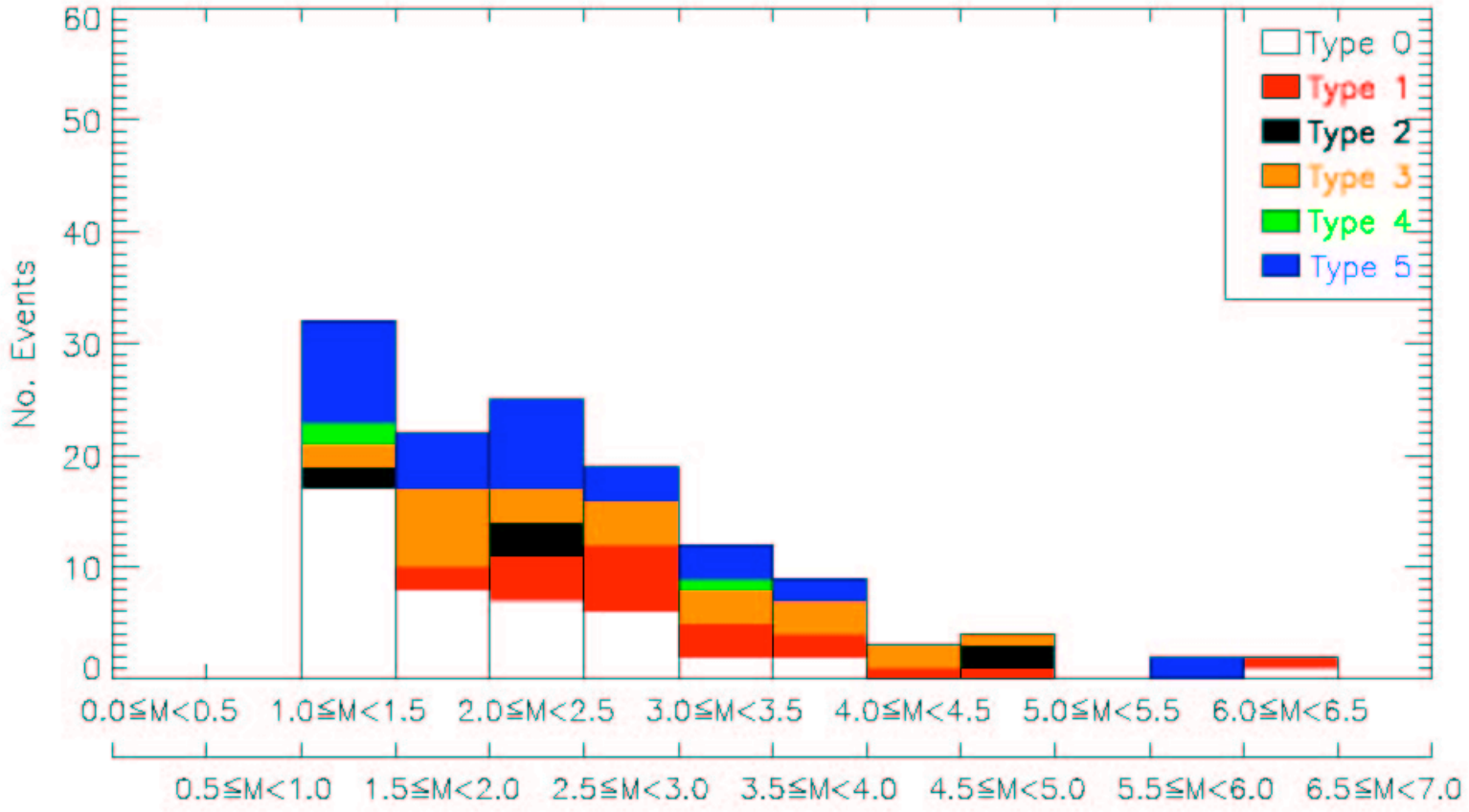

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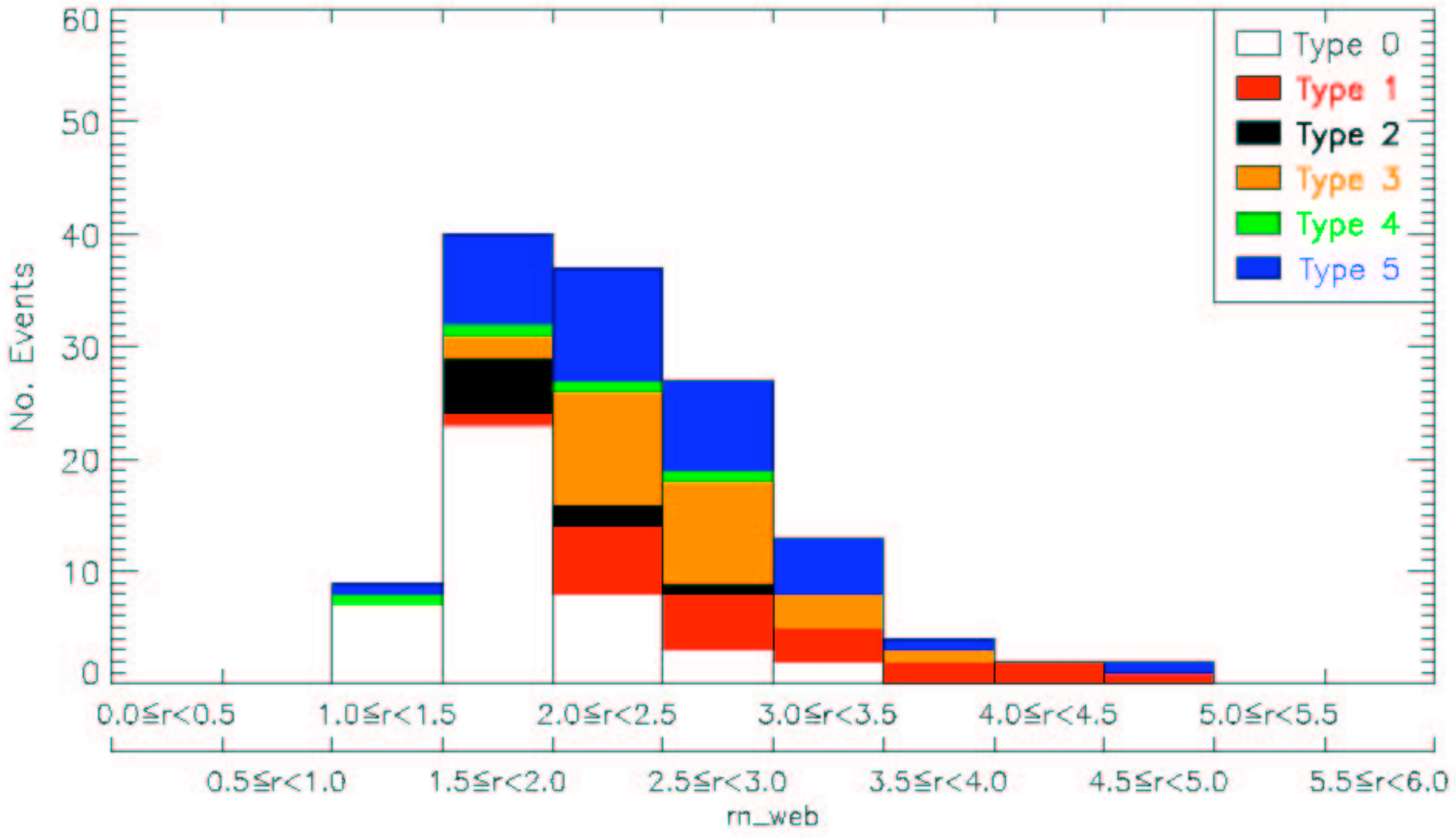
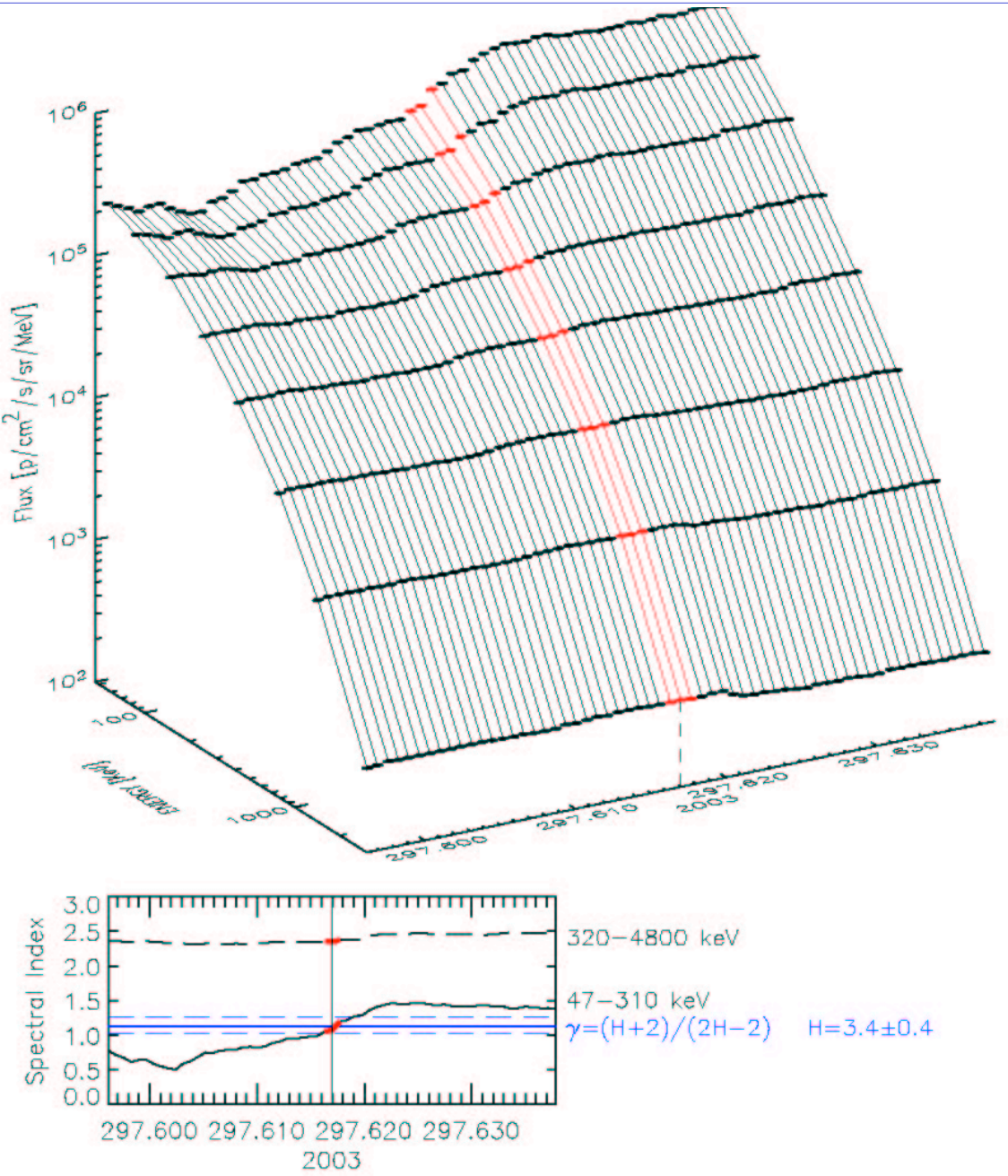
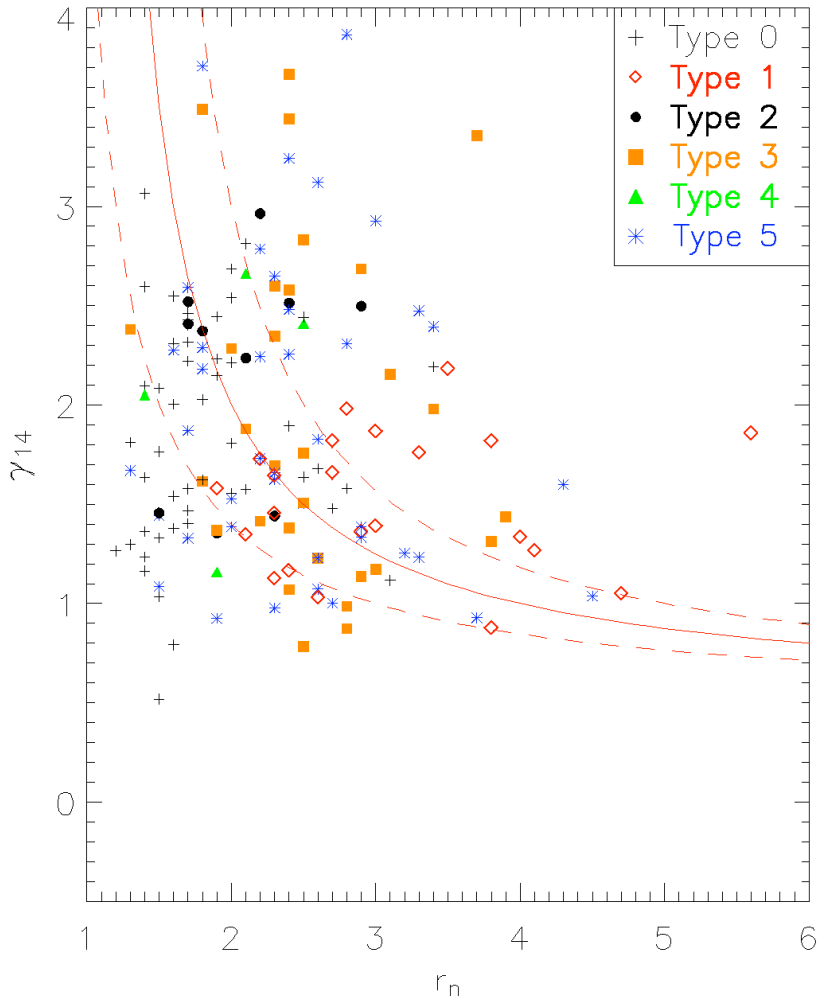


r_n


Flux [p/cm^2/s/sr/MeV]
10^6
10^5
10^4
10^3
10^2
Energy [keV]
100
1000
297.600
297.610
297.620
297.630
2003
Spectral Index
3.0
2.5
2.0
1.5
1.0
0.5
0.0
320–4800 keV
47–310 keV
γ=(H+2)/(2H–2)
H=3.4±0.4
297.600 297.610 297.620 297.630
2003

Correlation between shock parameters and particle signatures



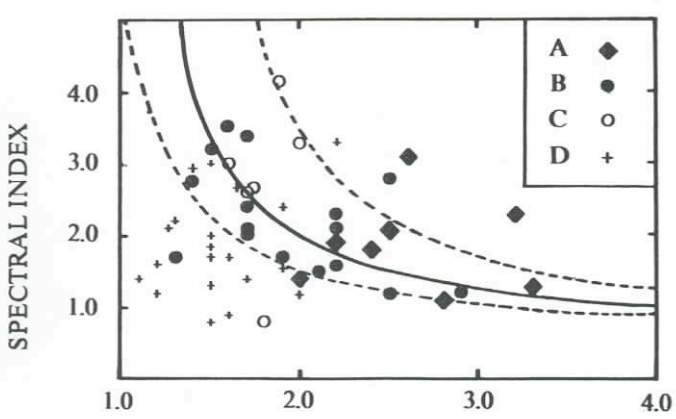
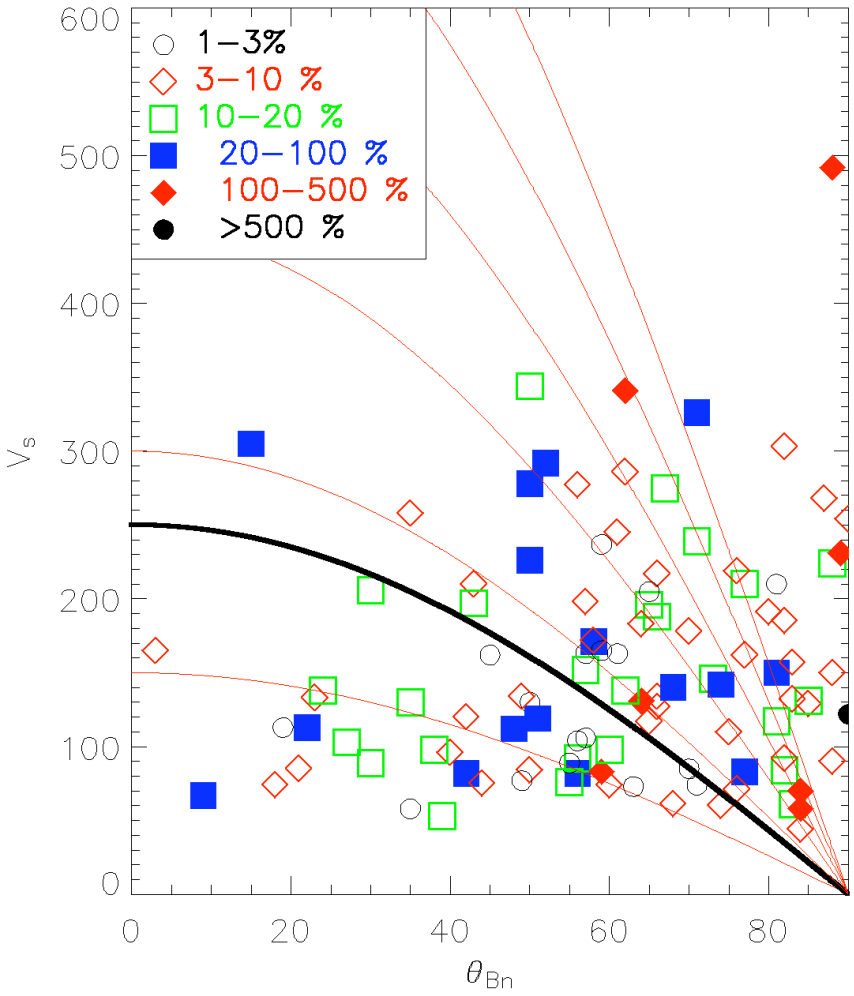


Fig. 12. Spectral index γ plotted as a function of the hydrodynamic shock strength H. The index was derived for the spectrum constructed from the average flux during 10 min immediately after the shock passage. The solid curve indicates the theoretical relation $\gamma = (H + 2)(2H - 2)^{-1}$. Points within the dashed lines are considered to follow the relation, because of the uncertainty of 25% in H. The events from the different classes are distinguished by different symbols.

Correlation between shock parameters and particle signatures



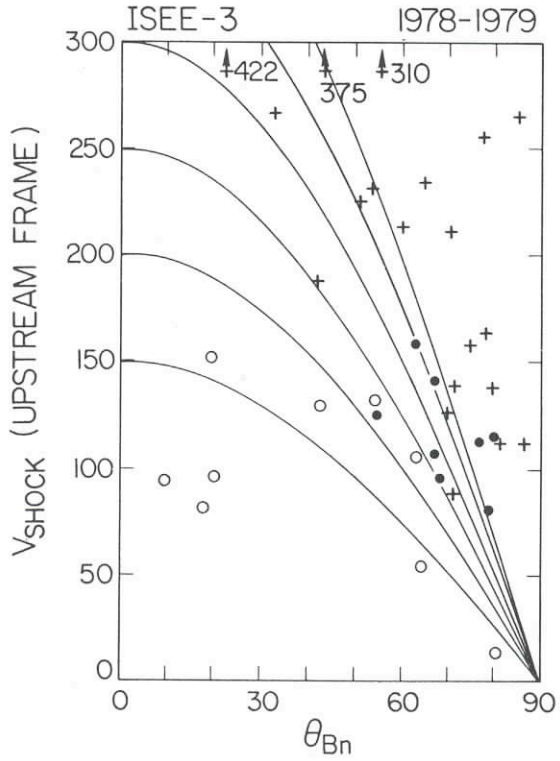
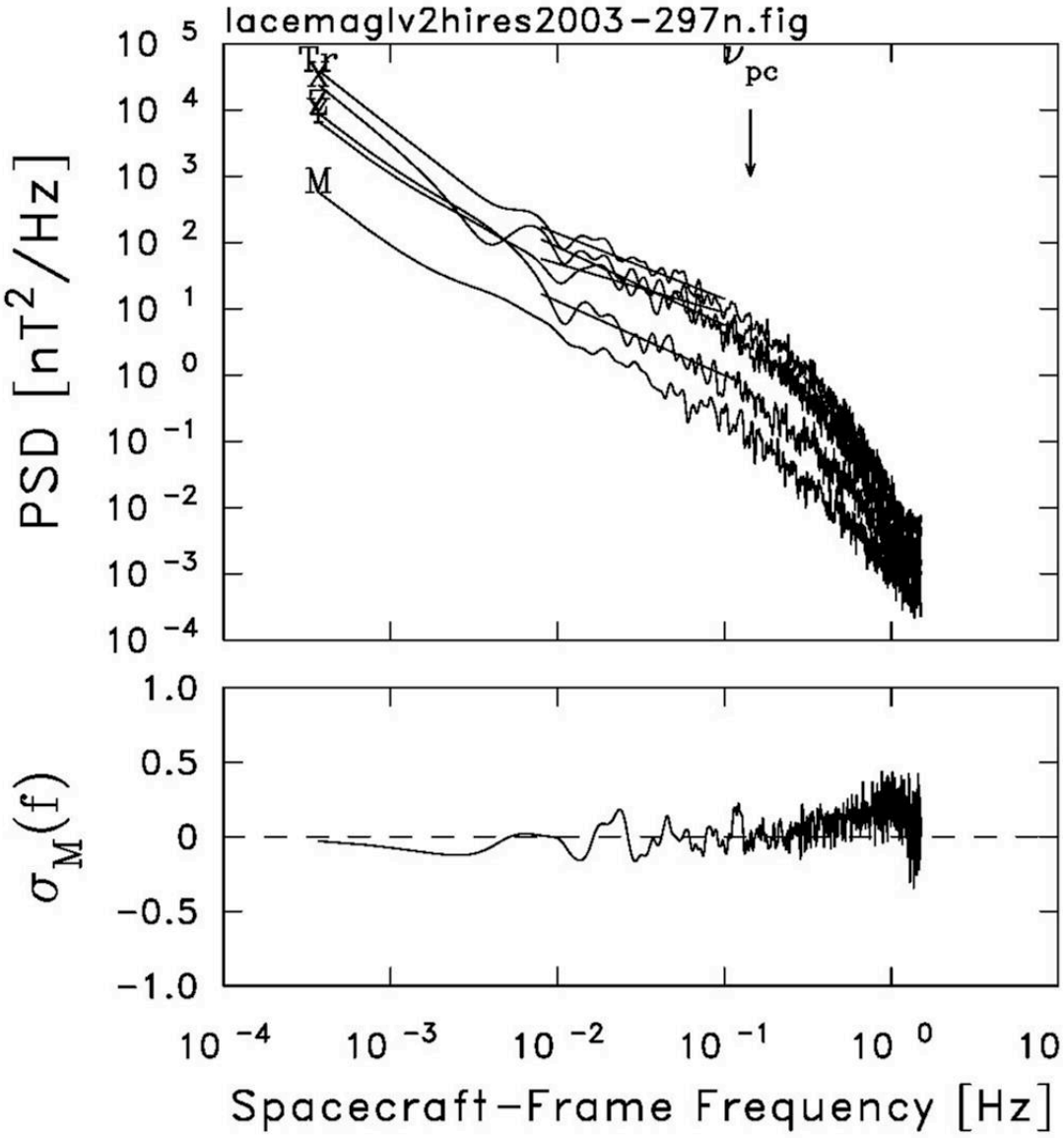


Fig. 8. A scatter plot of the particle flux increases as functions of the shock velocity (V_s) relative to the upstream medium (slow solar wind) and the shock normal angle θ_{Bn}. The particle flux increases (over the upstream ambient) are indicated by the type of event point used. Open circles represent events with little or no effects (less than 20% increases), solid circles are moderate events with 20 - 200% increases, and crosses are large events with > 200% increases. The contours are lines of constant velocity along the upstream magnetic field, $V_{SB} = V_s / \cos \theta_{Bn}$.

1300-1448 UT



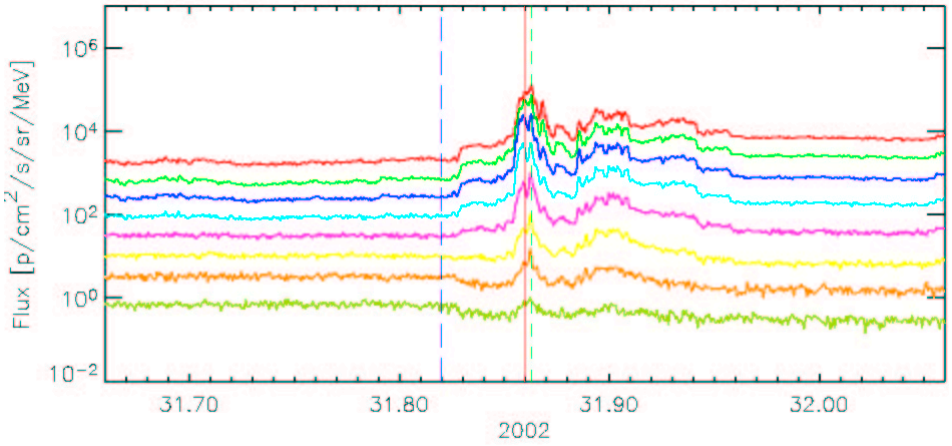
Magnetic field power spectrum

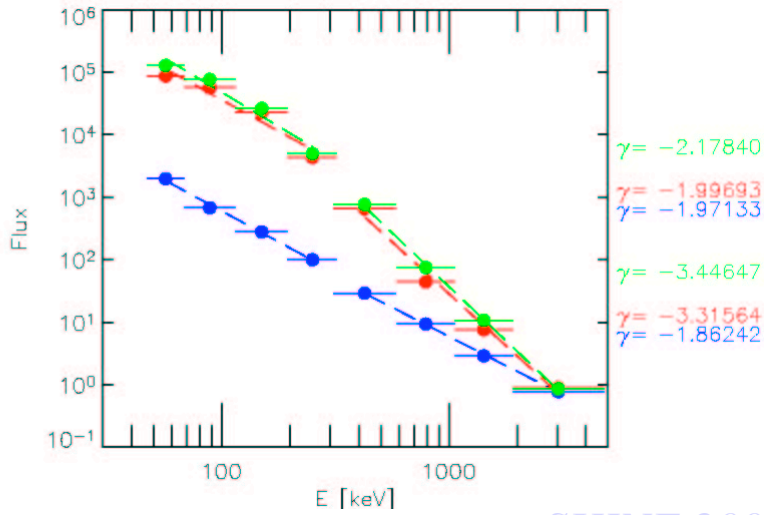
ν_{pc} = proton gyrofrequency

Normalized magnetic helicity spectrum

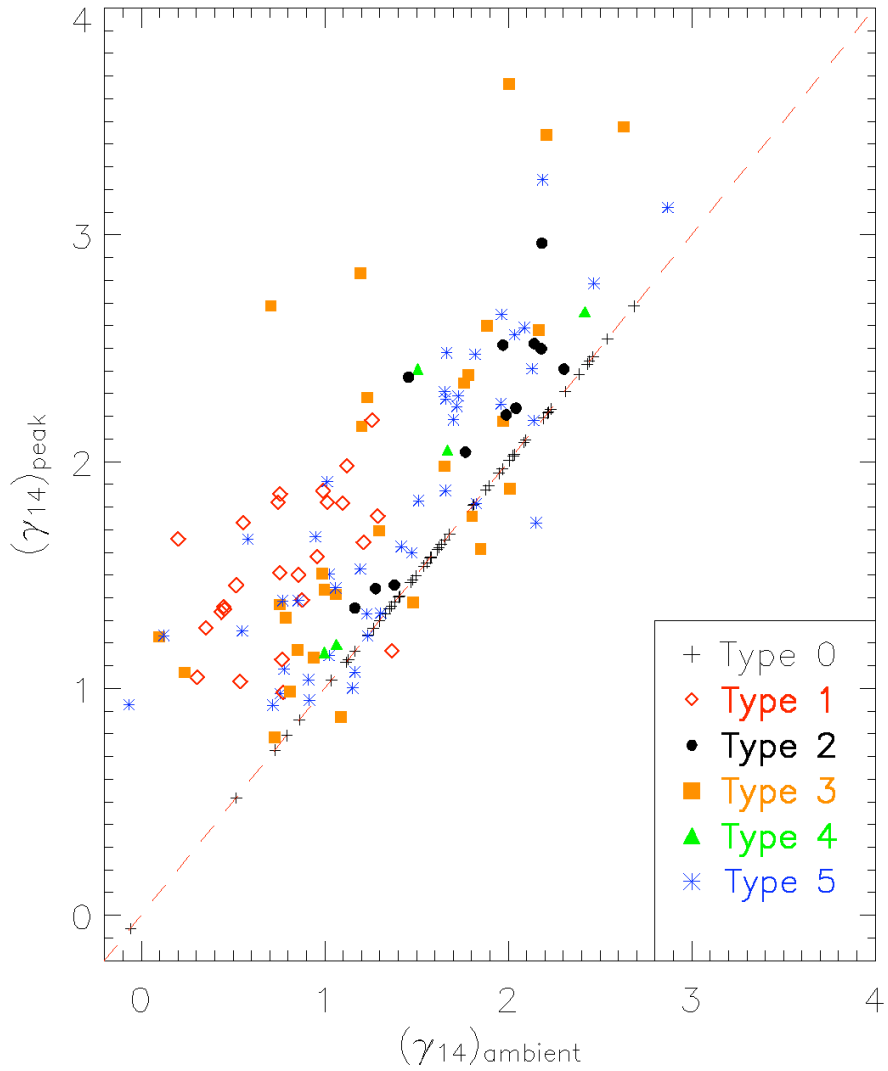
297/2003

Ambient, shock and peak spectra

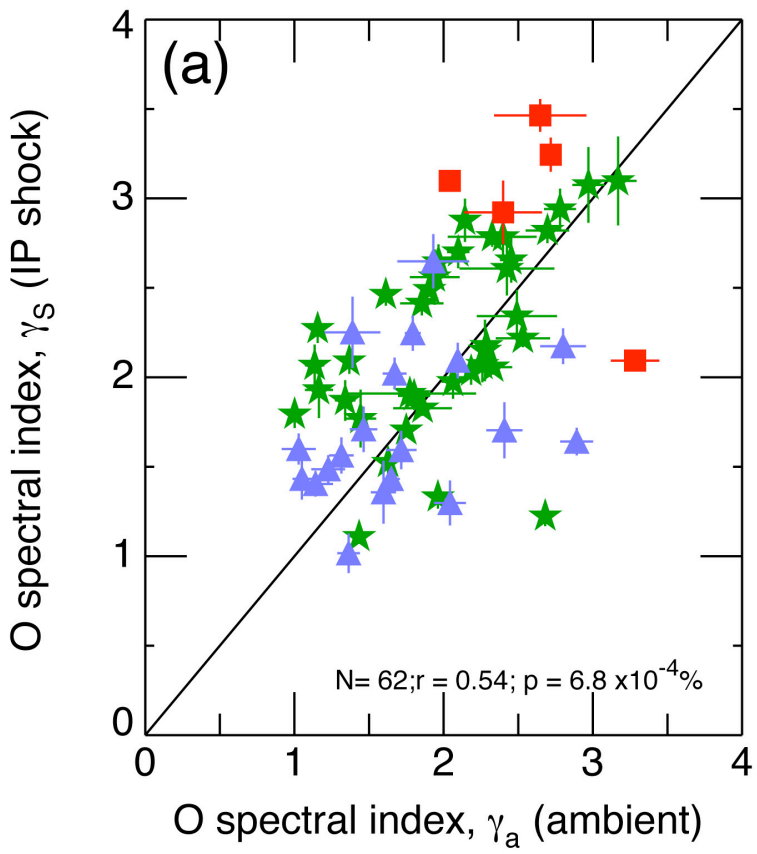


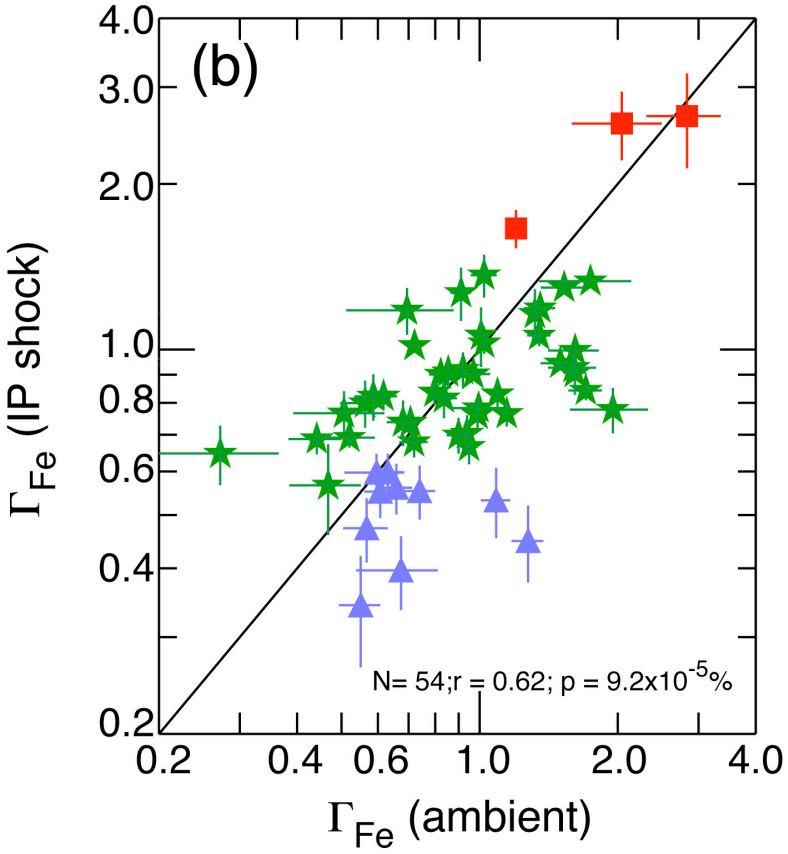


Correlation between ambient and peak spectra



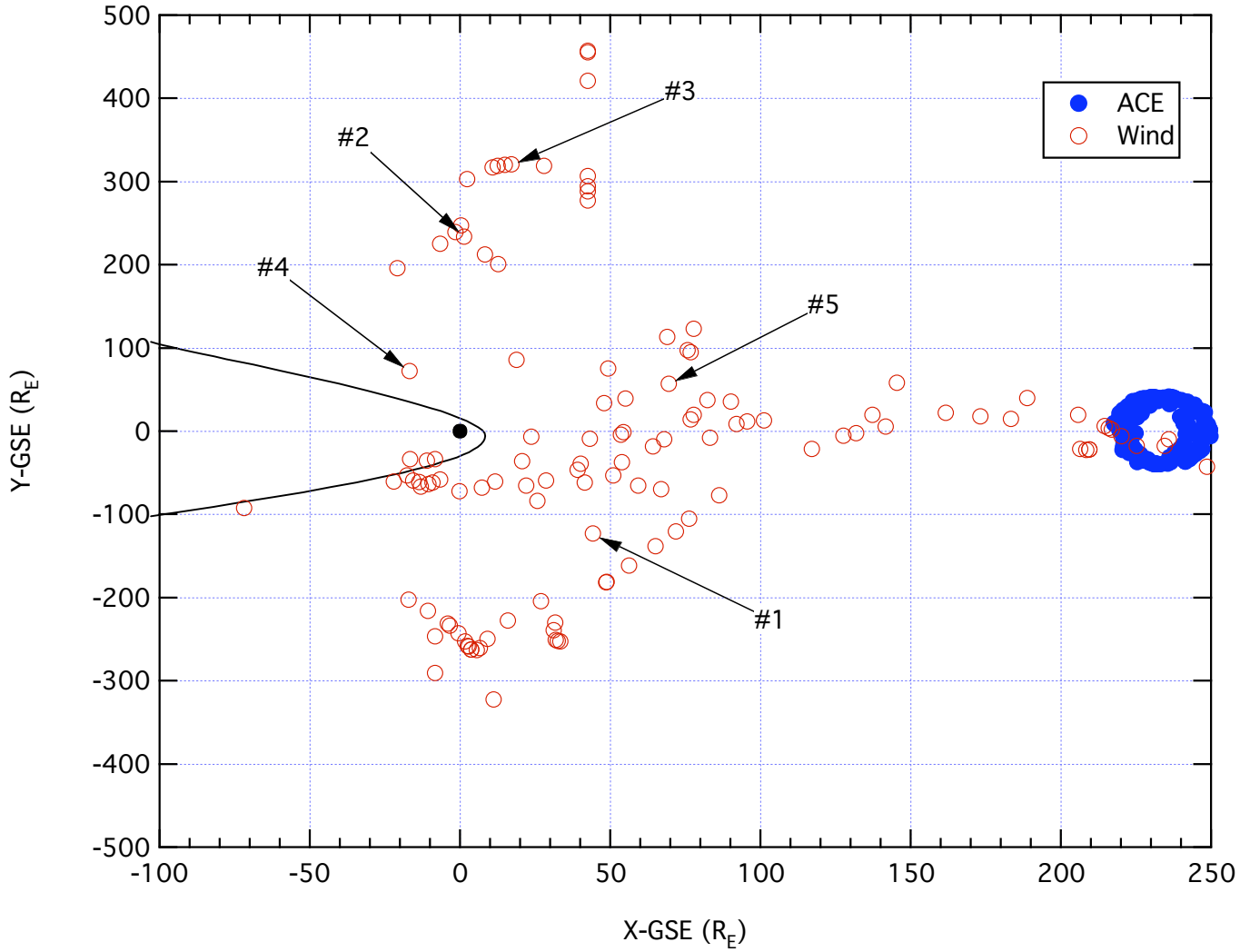
Heavy Ion Spectral Signature



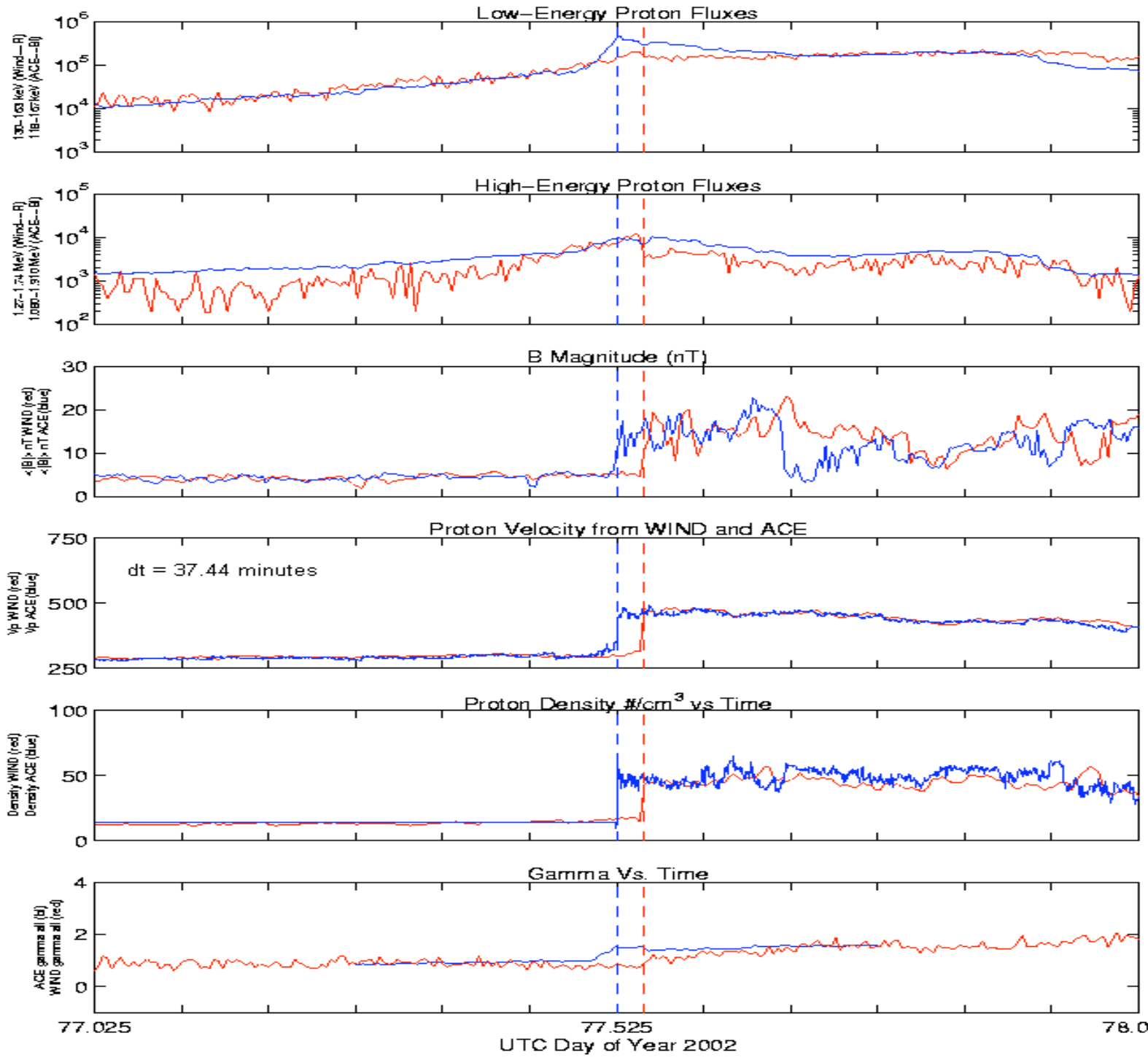


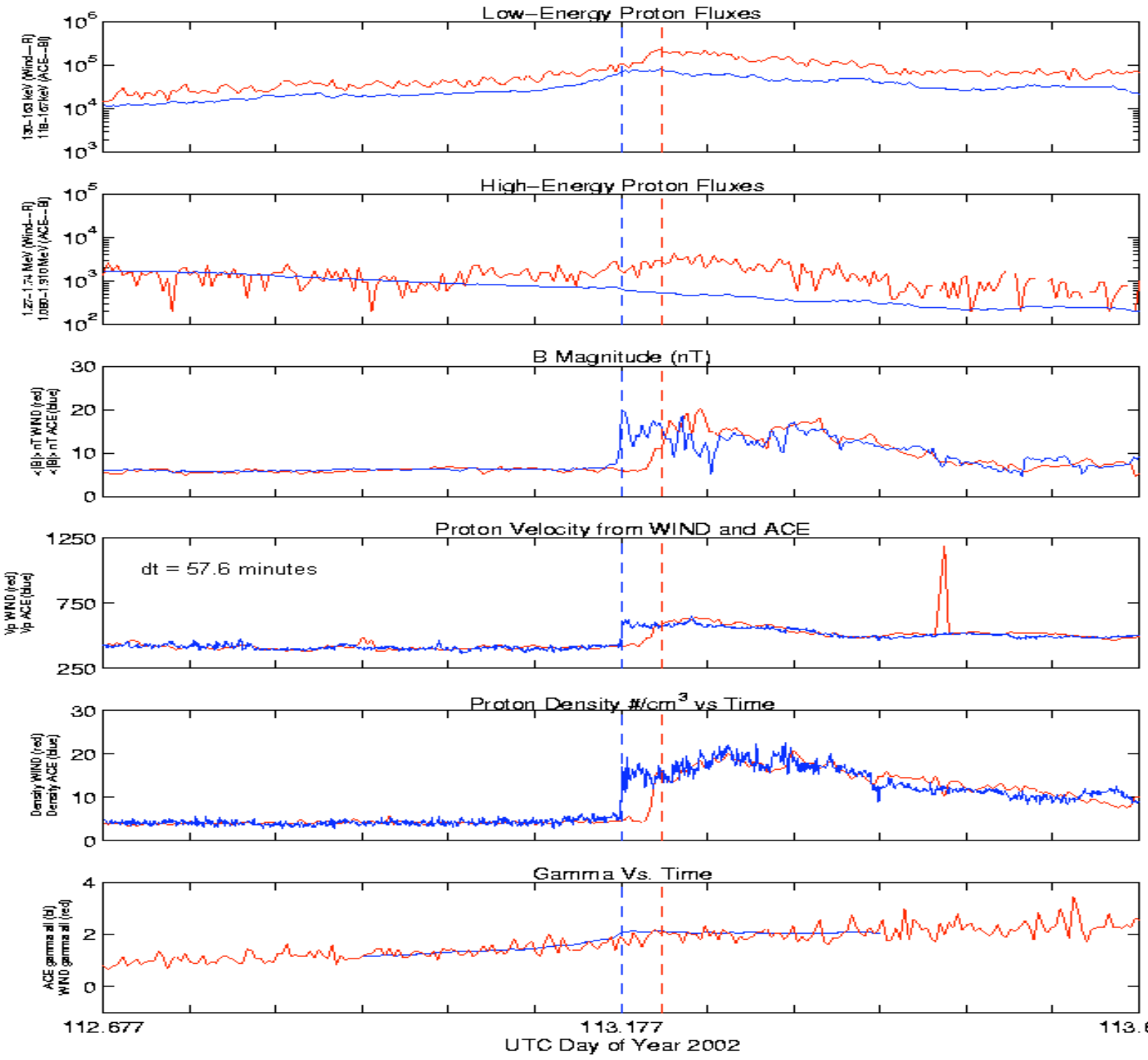
Desai *et al.*, 2004

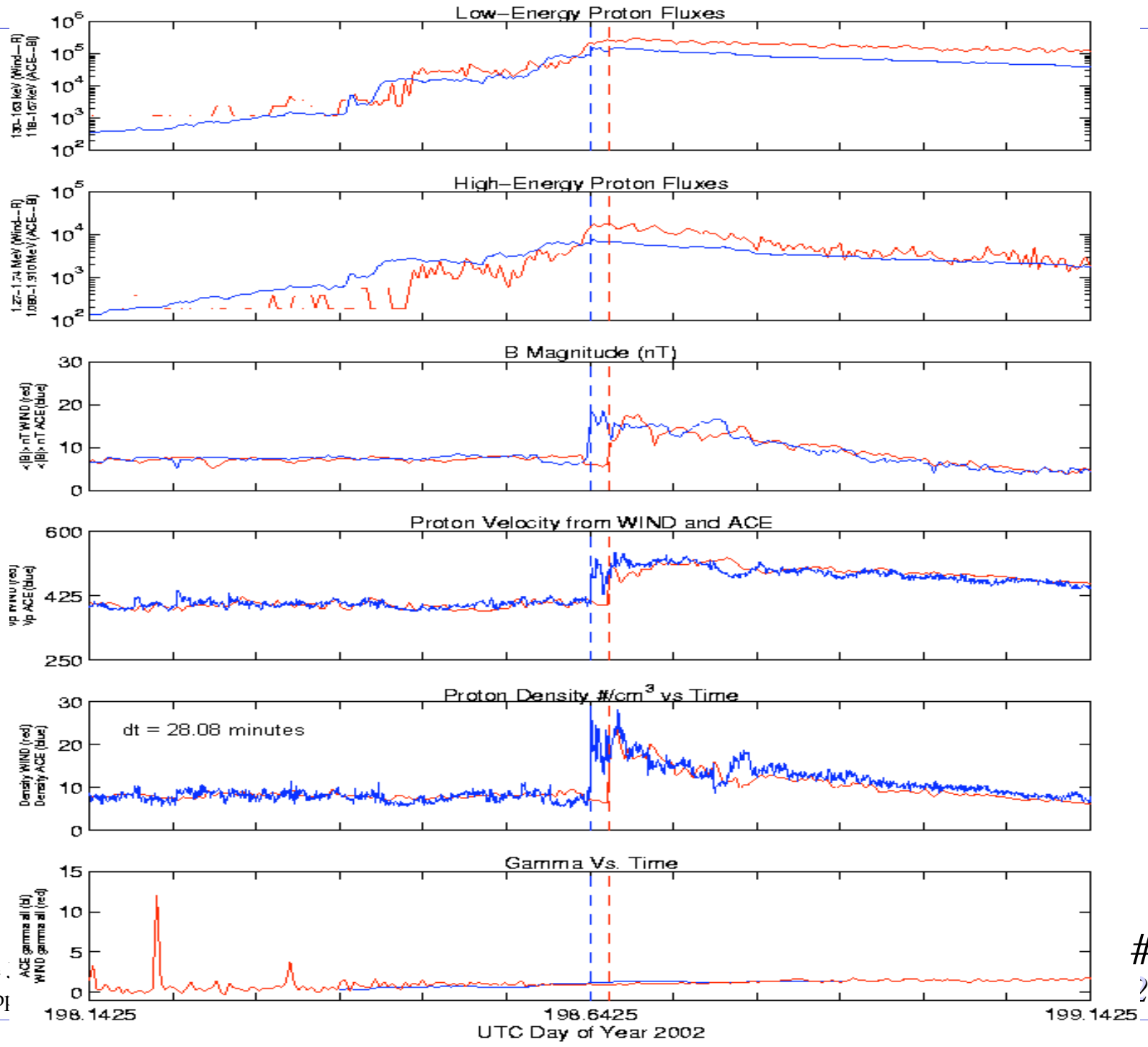
ACE Wind Locations



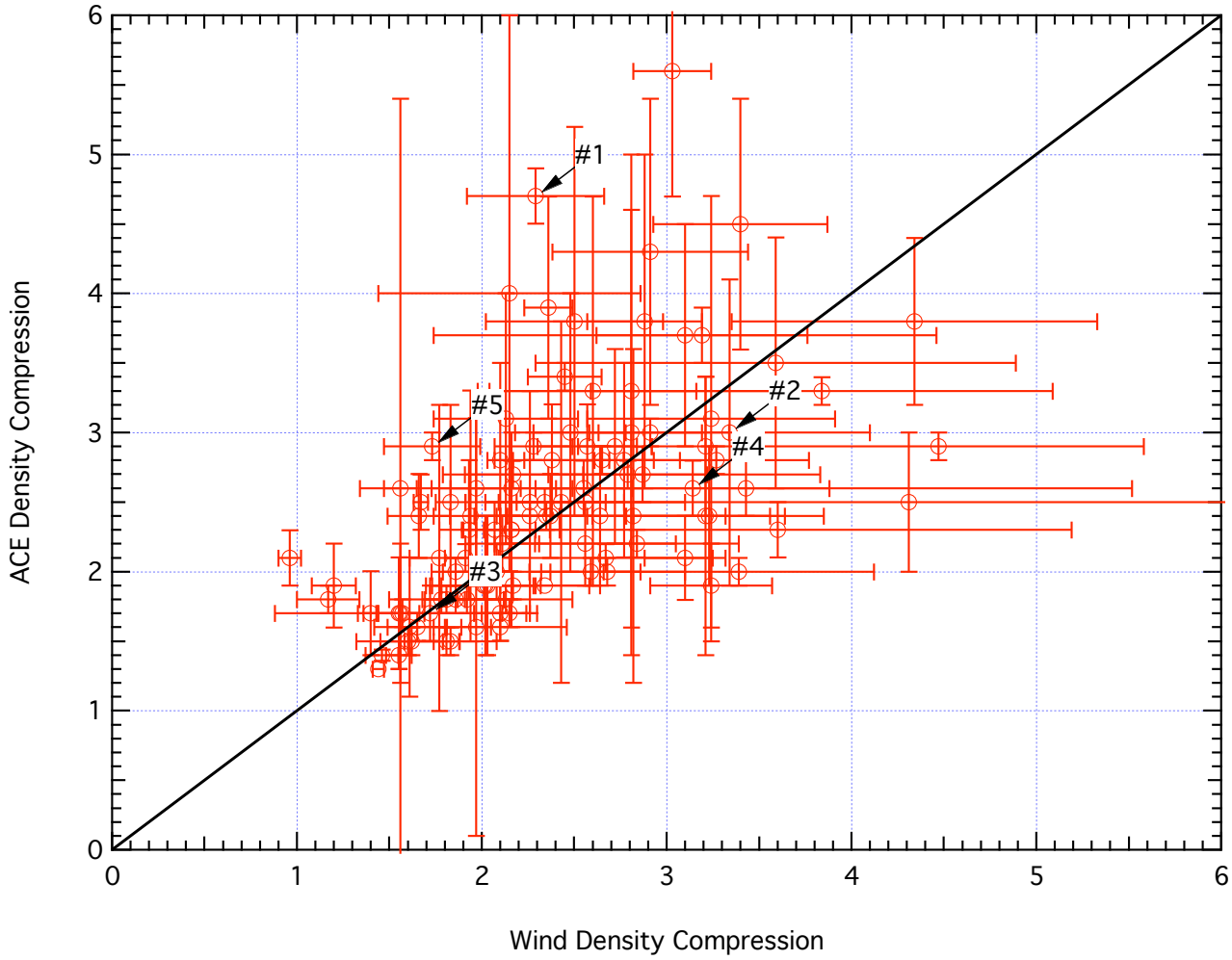
128 events


Low–Energy Proton Fluxes
High–Energy Proton Fluxes
B Magnitude (nT)
Proton Velocity from WIND and ACE
dt = 37.44 minutes
Proton Density #/cm3 vs Time
Gamma Vs. Time
77.025
77.525
78.025
UTC Day of Year 2002

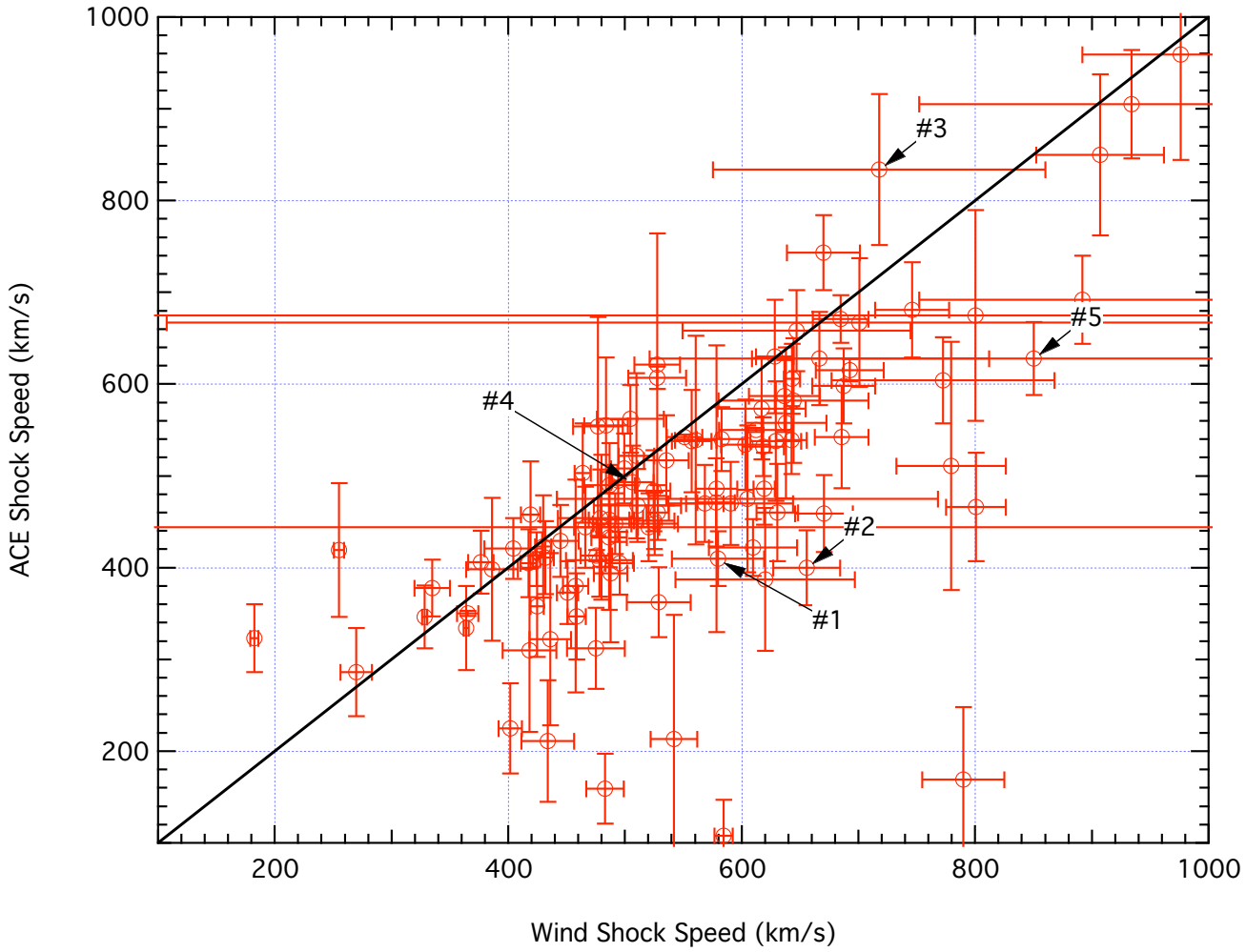

Low–Energy Proton Fluxes
130–103 keV (Wind–R)
118–187keV (ACE–B)
High–Energy Proton Fluxes
1.27–1.74 MeV (Wind–R)
1.060–1.910MeV (ACE–B)
B Magnitude (nT)
<|B|> nT WIND (red)
<|B|> nT ACE (blue)
Proton Velocity from WIND and ACE
dt = 57.6 minutes
Vp WIND (red)
Vp ACE (blue)
Proton Density #/cm3 vs Time
Density WIND (red)
Density ACE (blue)
Gamma Vs. Time
ACE gamma all (blu)
WIND gamma all (red)
112.677
113.177
UTC Day of Year 2002


Low–Energy Proton Fluxes
High–Energy Proton Fluxes
B Magnitude (nT)
Proton Velocity from WIND and ACE
Proton Density #/cm3 vs Time
dt = 28.08 minutes
Gamma Vs. Time
198.1425
198.6425
199.1425
UTC Day of Year 2002

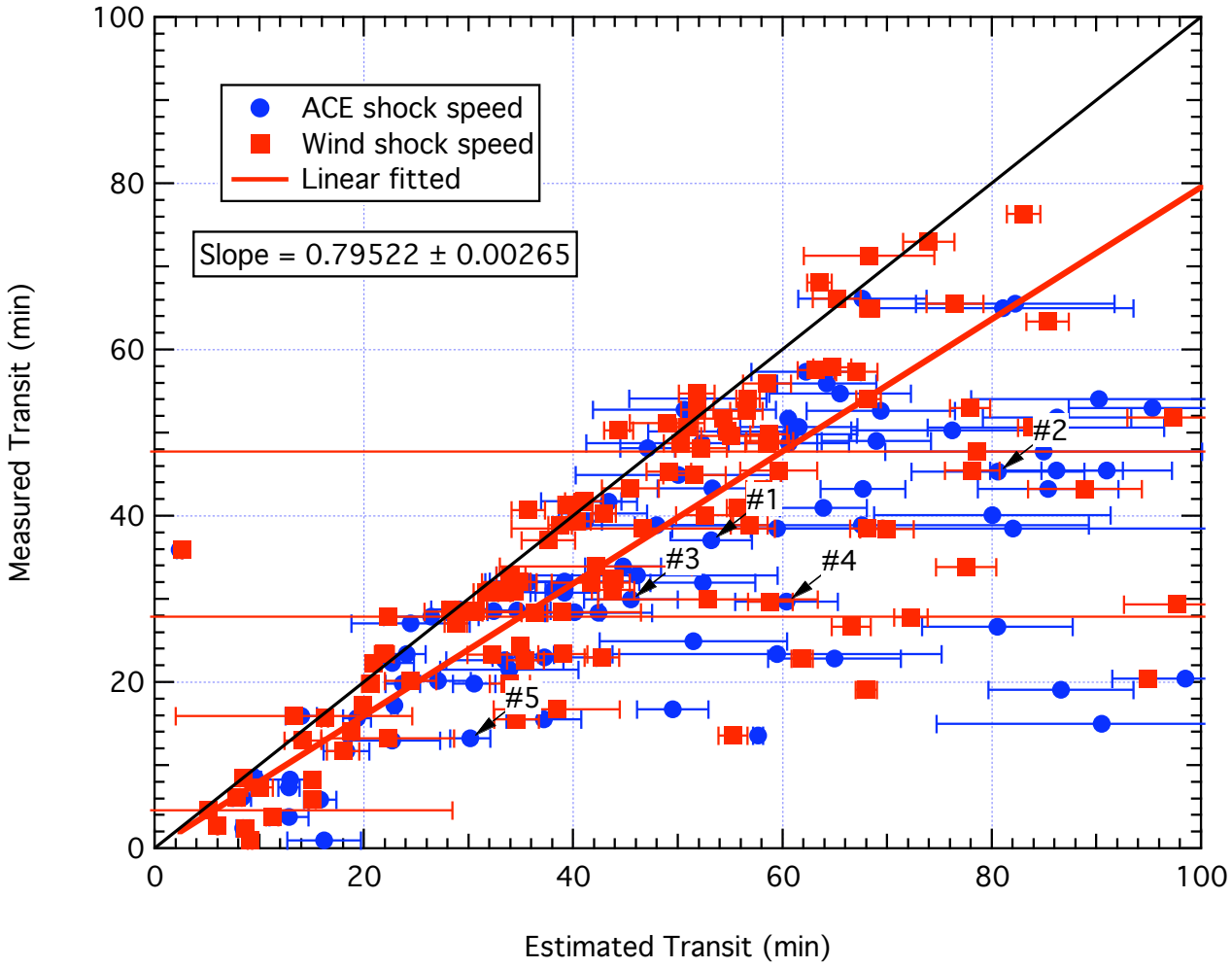
Shock Compression Comparison



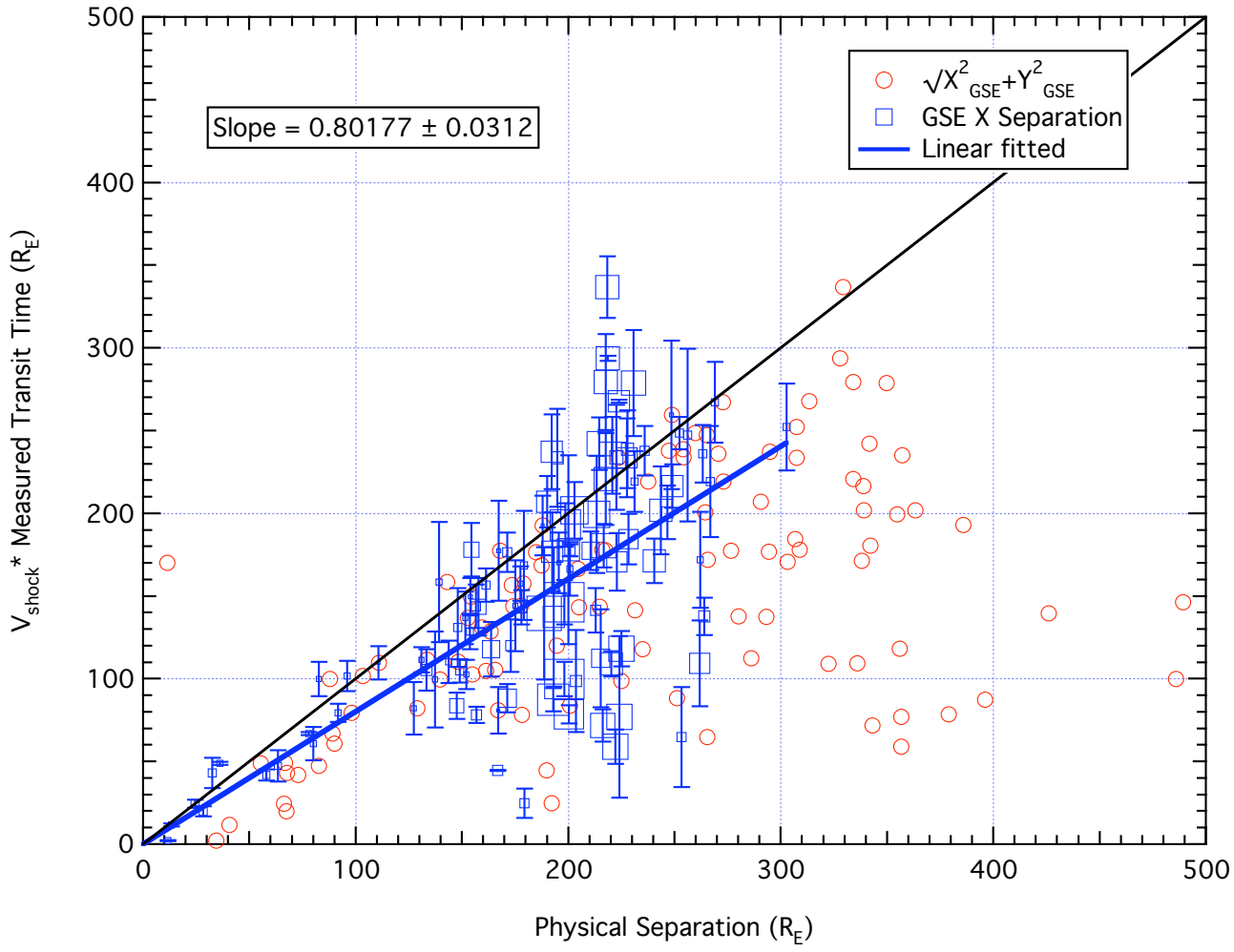
Shock Speed Comparison



Shock Travel Time vs Observed Transit Time



Physical Separation vs Inferred Separation



Summary

- We classified 191 ESP events detected on ACE according to:
  1. Energetic ion and electron time-intensity profile
  2. Spectral index
- 63% of transient forward IP shock accelerated ions at >47 keV, while only 32% IP shock accelerated ions at >1.9 MeV
- The spectral index of energetic ion:
  1. Monotonically increased across the shock; or
  2. Fluctuated across the shock crossing
- Most of the ion spectral index do not follow the diffusive shock theoretical prediction for an equilibrium spectrum (many shock interactions)
- Ion spectra often soften at the shock
- We studied 5 ESP events using particles, field, and plasma instruments on both ACE and Wind
- The particle intensity and spectra index were very similar at the two spacecraft despite the fact that they were in time separate by more than 400 R_E

Summary (continue)

- The agreement between the calculated transits times using the fitted shock speeds on ACE with the actual measured transit times is good only up to ~30 minutes
- The disagreement between estimated transit time and measured transit time increase when the GSE Y separation were large (> 200 R_E)
- This implies a) the shock may not be spherically symmetric at 1 AU, or; b) the shock may not propagate radially, or both
- There is relatively good agreement between the fitted shock speed and density compression ratio for the same shock on Wind and ACE