

Particle Acceleration in the Heliosphere

--- Lessons from GEOTAIL

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Particle Acceleration at Flares

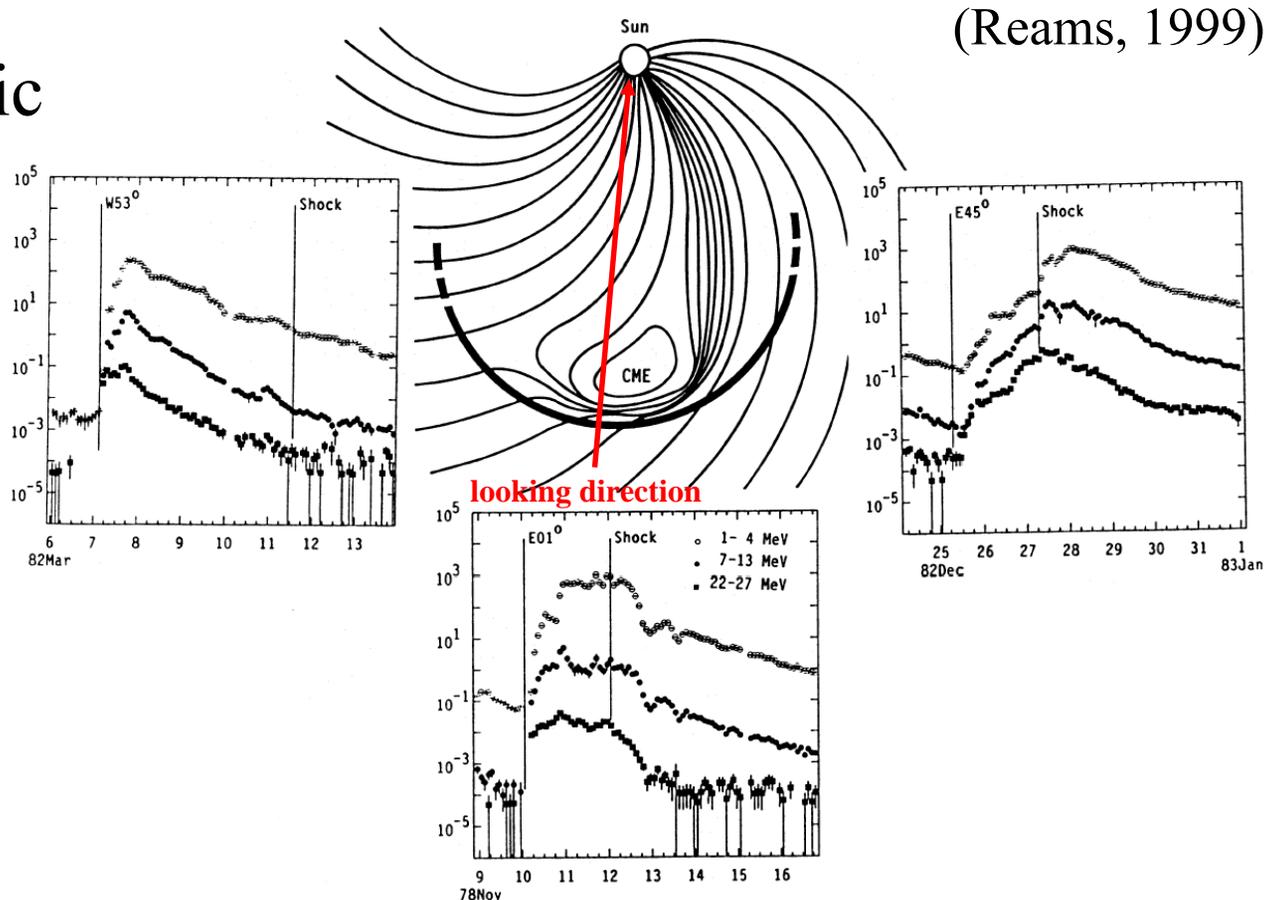
- Many models have been proposed to account for non-thermal electrons of the loop-top sources.
- One of the candidates is the acceleration by shocks.
- However, it is still uncertain under which condition do shocks accelerate particles.

Can a fast mode shock at the loop-top environment accelerate electrons?

Parameter dependence of electron acceleration at shocks ?

Particle Acceleration at Interplanetary Shocks

- Solar Energetic Particles (SEPs)
- Detailed studies from ion compositions (e.g. Tylka et al., 2005)

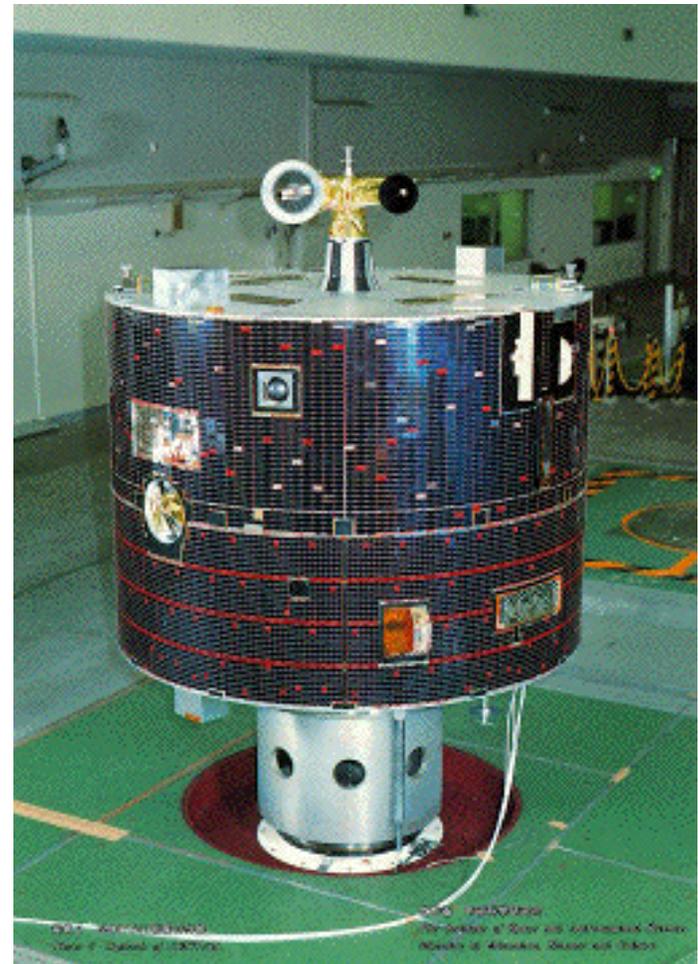


Many studies on ions, but how about electron acceleration ?

To obtain some hint for **electron acceleration**
by shocks in the solar corona and the
heliosphere....

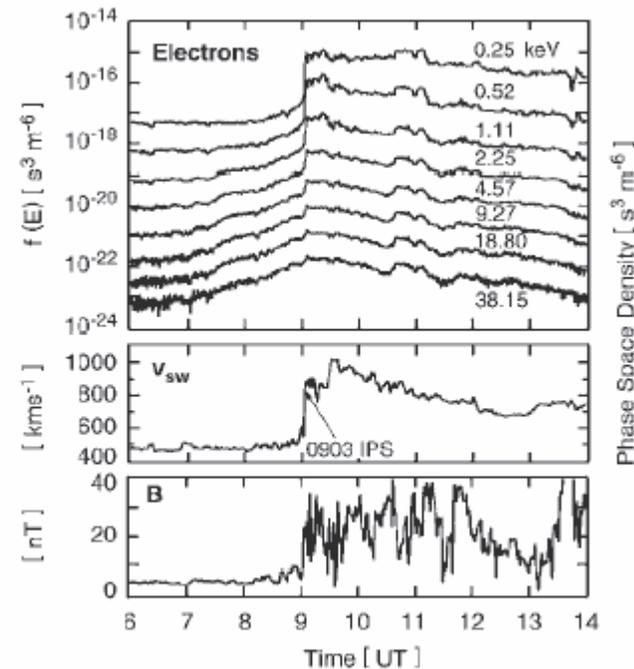
Geotail Spacecraft

- Launched in 1992 as a collaborative project by the ISAS and NASA.
- Designed to investigate distant magnetotail, but 40% of its orbital time is in the upstream side of the magnetosphere.
- Suitable for studying the solar wind, the bow shock, interplanetary shocks, and CMEs.



Electron Acceleration at Interplanetary Shocks

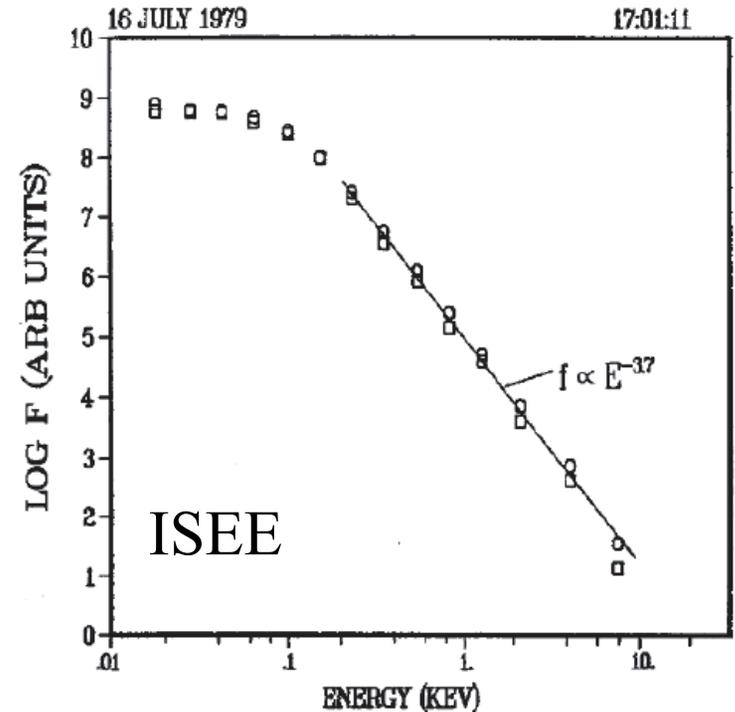
- Though rare, interplanetary shocks associated with super flare events accelerate electrons.
- In the case of 21 Feb. 1994 event, the acceleration mechanism was clearly determined to be the Diffusive Shock Acceleration (Shimada et al., 1999).
- **When and how do shocks accelerate electrons is the outstanding problem for space physics and astrophysics !!**



An example of
shock observation
by GEOTAIL

Electron Acceleration at the Earth's Bow Shock

- Large data set for the bow shock compared to interplanetary shocks.
→ Enables statistical study over wide range of parameters.
- Until today, *Gosling et al., 1989* is the only comprehensive work that studied electron acceleration at the bow shock.

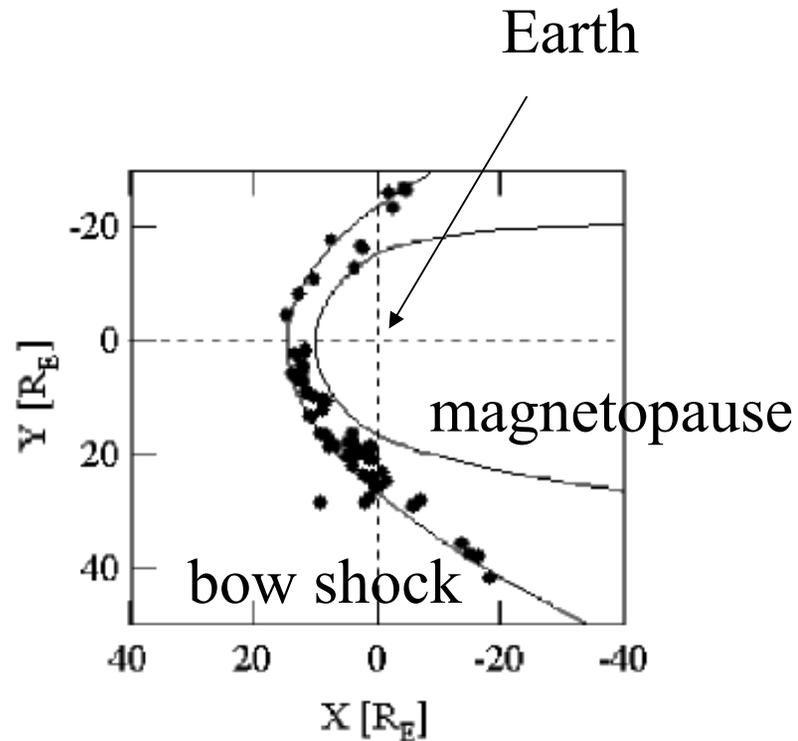
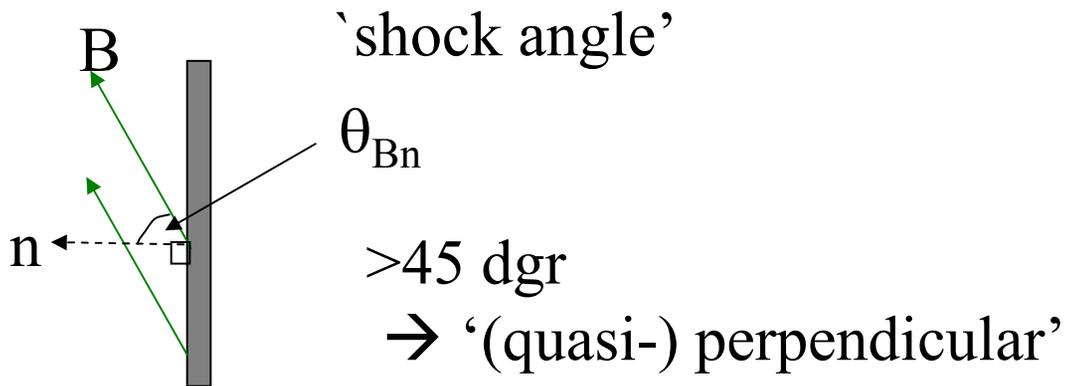


Gosling et al., 1989

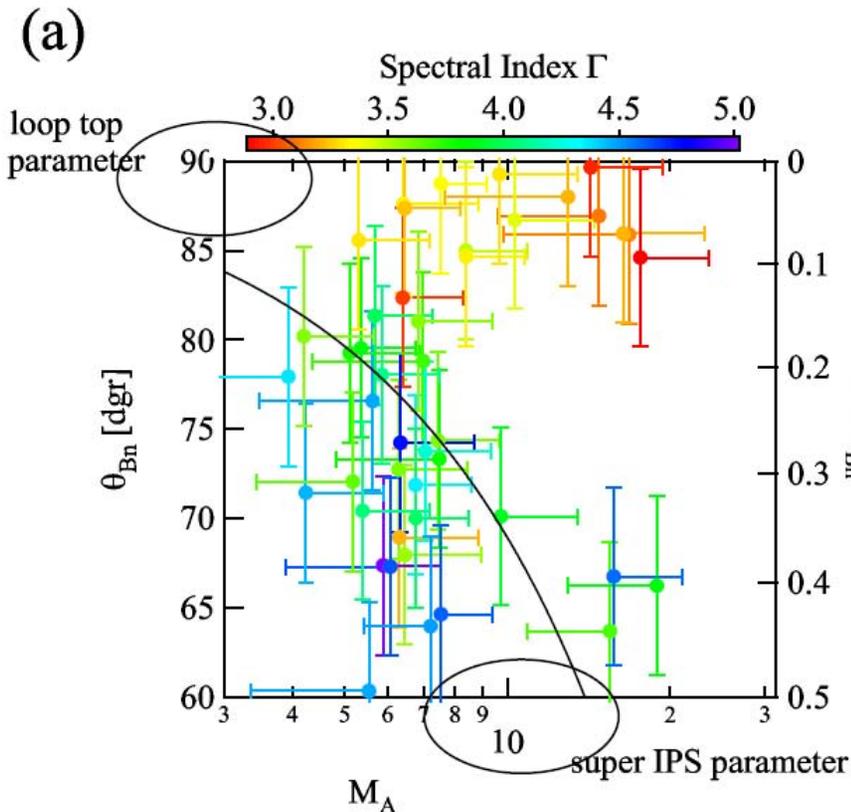
Extend this work using the Geotail data.

Our Statistical Study

- 78 'clean' quasi-perp shock crossings
- From Jan 1995 – July 1997

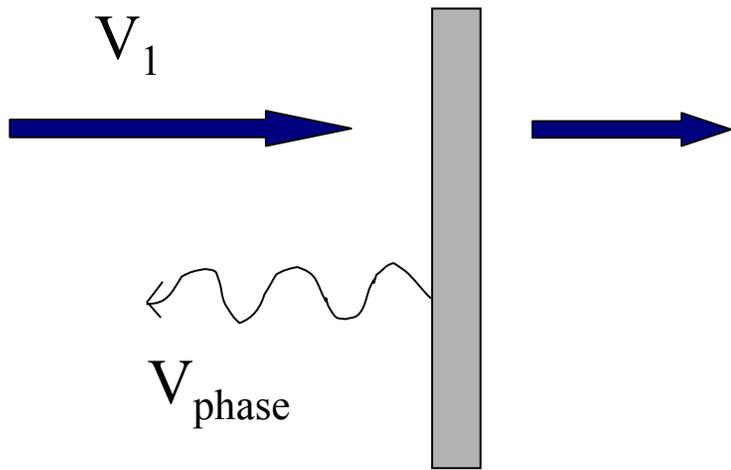


Spectral Index Γ



Hard spectrum
for
large θ_{Bn} and
large M_A

Whistler Critical Mach Number



$$M_{\text{ph}}^w \equiv \frac{V_{\text{phase}}}{V_A} = \frac{1}{2} \sqrt{\frac{m_p}{m_e}} \cos \theta_{Bn}$$

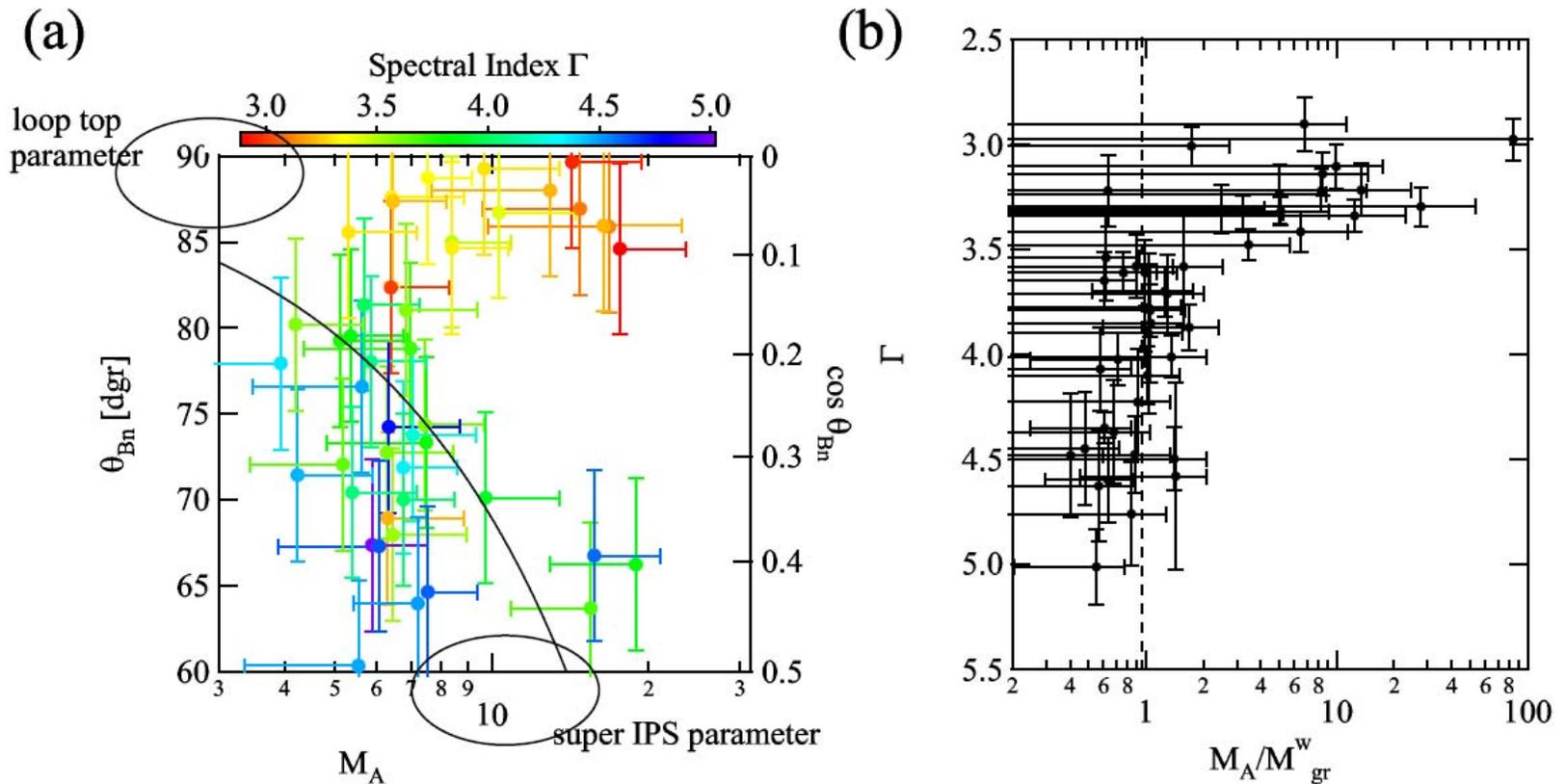
$$M_{\text{gr}}^w \equiv \frac{V_{\text{group}}}{V_A} = \sqrt{\frac{27}{64} \frac{m_p}{m_e}} \cos \theta_{Bn}$$

'Super Critical'
if $M_A > M^w$

Kennel, 1985;

Krasnoselskikh et al., 2002

Spectral Index Γ



Oka et al., in preparation

Mechanism of Acceleration ?

- Speculation:

Different acceleration mechanism

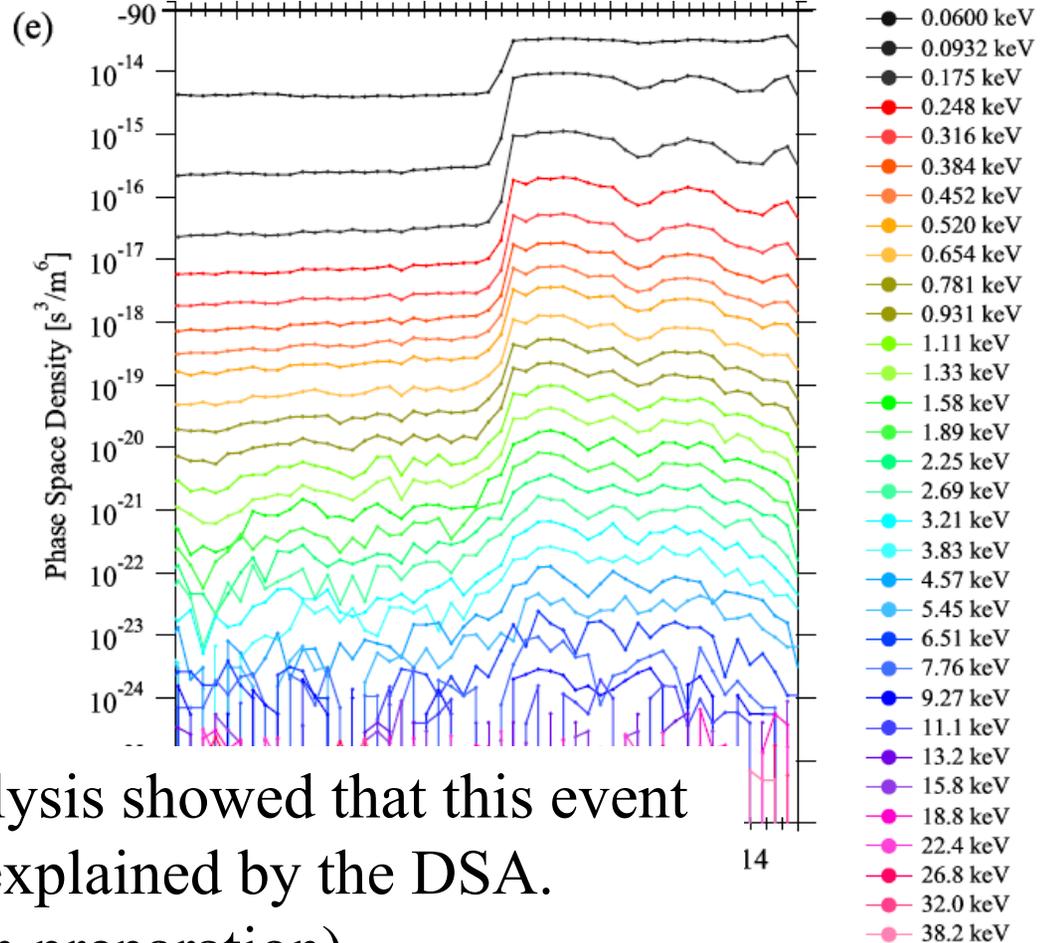
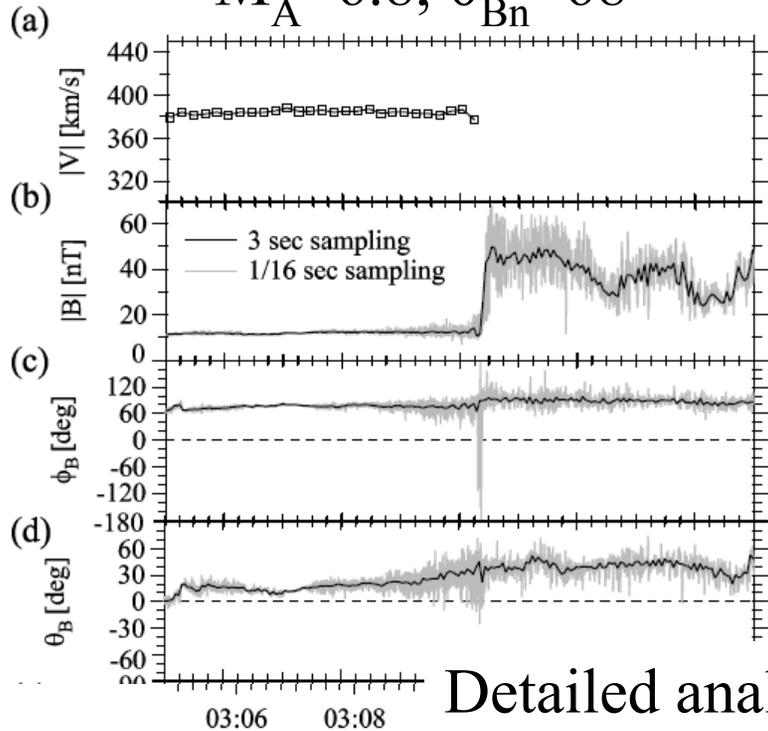
for super- and sub- critical shocks ?

- Sub-critical case : Diffusive Shock Acc. ?
- Super-critical case : Any other efficient way ?

→ Detailed Event Analysis

A sub-critical shock

February 11, 1995
 $M_A \sim 6.8$, $\theta_{Bn} \sim 68^\circ$

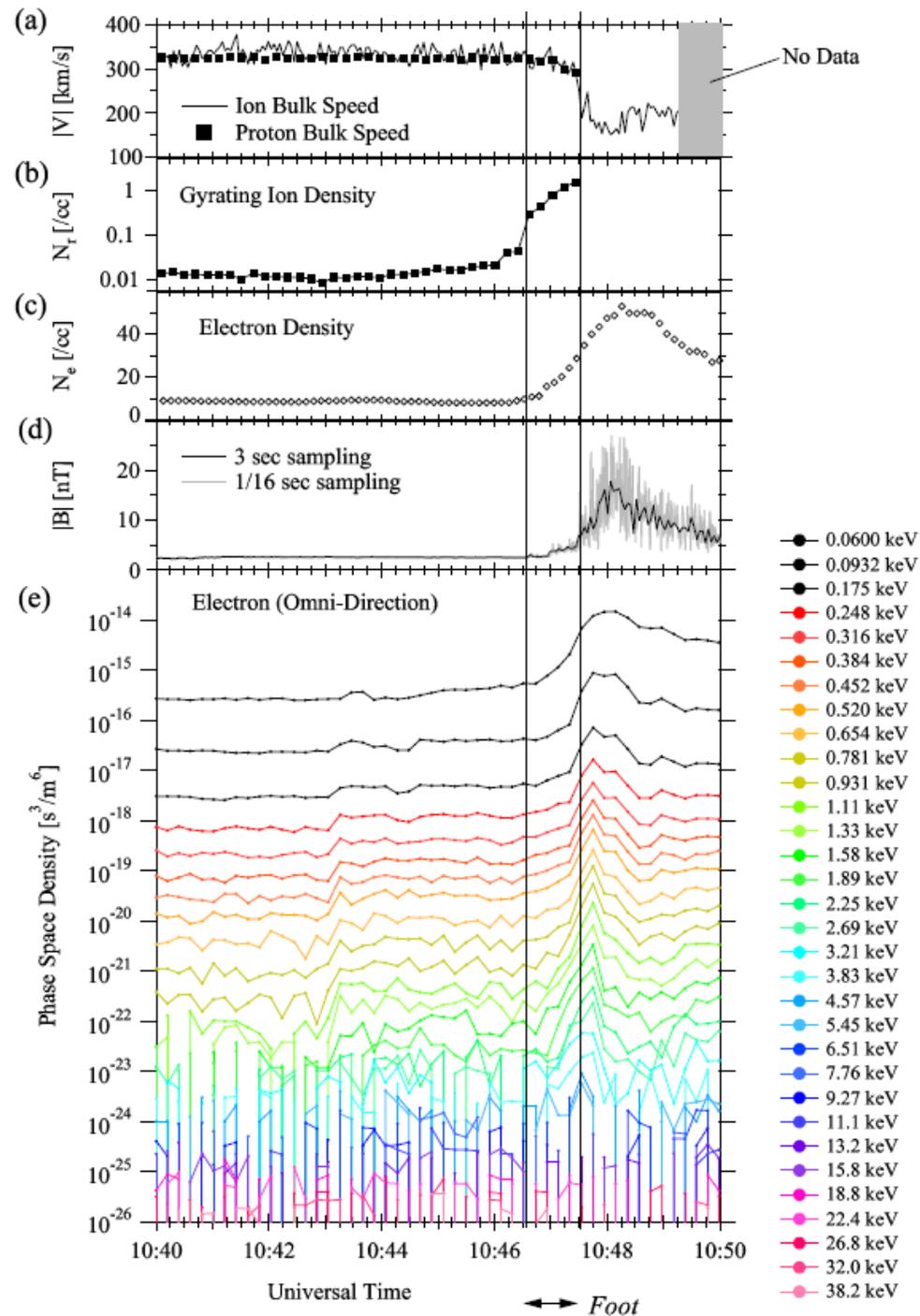


Detailed analysis showed that this event can be well explained by the DSA.
(Oka et al, in preparation)

A super-critical shock

- 1 July 1996
- $M_A \sim 14$, $\theta_{Bn} \sim 86$ dgr
- Candidates of acceleration
 - Drift acceleration
 - Ripple acceleration
 - 1st order Fermi
 - 2nd order Fermi
 - Surfing

Oka et al., in preparation



Summary

- Recent Geotail results showed that electron acceleration at shocks is regulated by the whistler critical Mach number which is a function of both Alfvén Mach number and shock angle.
- It is important to check this parameter dependence at other shocks.
- To test the shock acceleration model for the hard X-ray sources at solar flares, we need detailed and accurate information of the loop-top environment → **Solar B**
- For IPSs, we need larger set of examples of electron acceleration for interplanetary shocks → **STEREO**
- We are looking forward to collaborate with other S/C (ACE, WIND, Cluster, and future missions such as MMS/SMART, MagCon, and SCOPE).