Experimental study of self-reformation of collisionless shock using high power laser

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Background

<u>Observational dilemma in space</u>

Extrasolar bodies

--- remote sensing

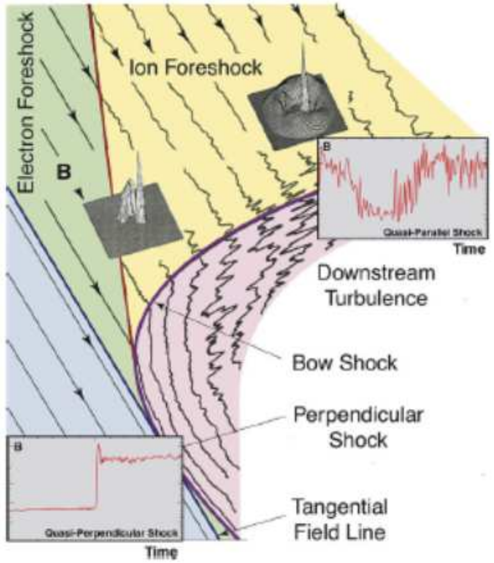
⇔ global/macroscale structures

Solar-Terrestrial system

--- in-situ observation

⇔ local/microscale structures

Burgess et al. [2012]



Multi-scale coupling plays essential roles in many astrophysical plasma phenomena

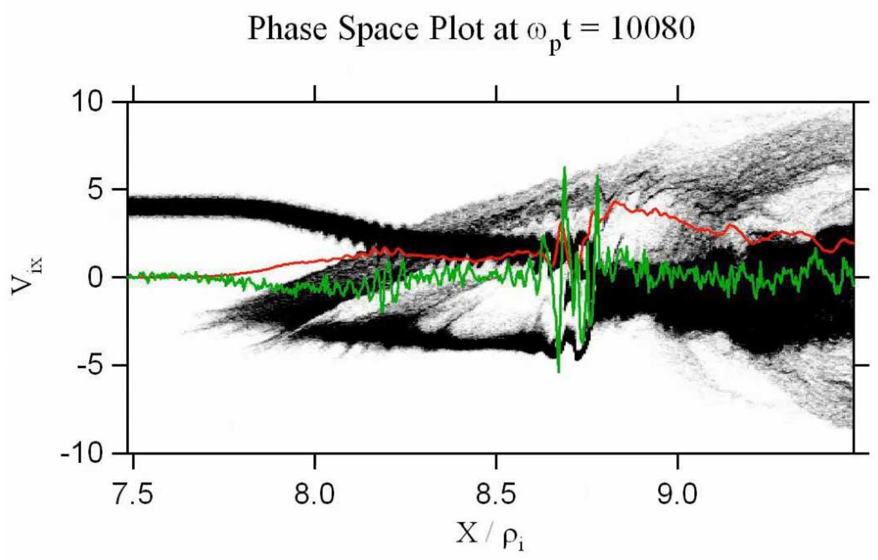
<u>Laboratory astrophysics (potential advantages)</u>

- High controllability and reproducibility
- Simultaneous accessibility to both global/macroscale and local/microscale phenomena

Background & Purpose

Self-reformation of a collisionless shock

- A unique dissipation mechanism of a collisionless shock, contributing to production of nonthermal particles, wave emission, …
- Shock front is cyclically destroyed and reformed when Mach number is sufficiently high, even if upstream plasma is completely steady and homogeneous
- Predicted by numerical simulation in 1980s (e.g., Lembege & Dawson [1987])
- Not yet evidenced by in-situ observations



Purpose:

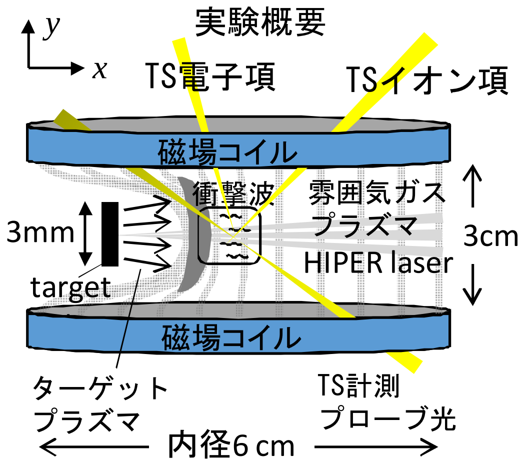
Experimentally demonstrate cyclic nature of the shock reformation by using high power laser experiment

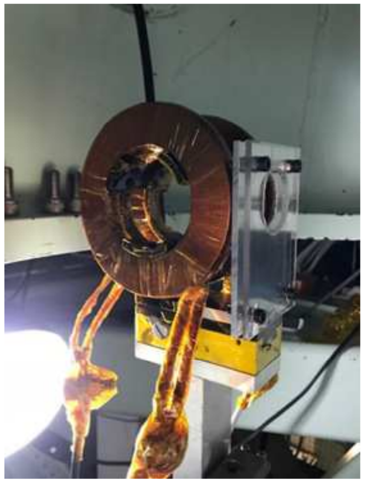
Gekko XII experiment on collisionless shock

← ~ 2m →

- 4 beams × $700J$ at ω ($1053\ nm$)
  Gaussian shape with $1.3ns$ duration
  $2.8mm$ spot, $F/15$ for each beam
- target: Al foil ($3\ mm \times 3\ mm \times 2mm$)
- gas : N_2 ($5\ Torr$)
- magnetic field: capacitor bank (2 sets of $3mF \times 4$)
  $\rightarrow B > 3.5T$

Exp. setup

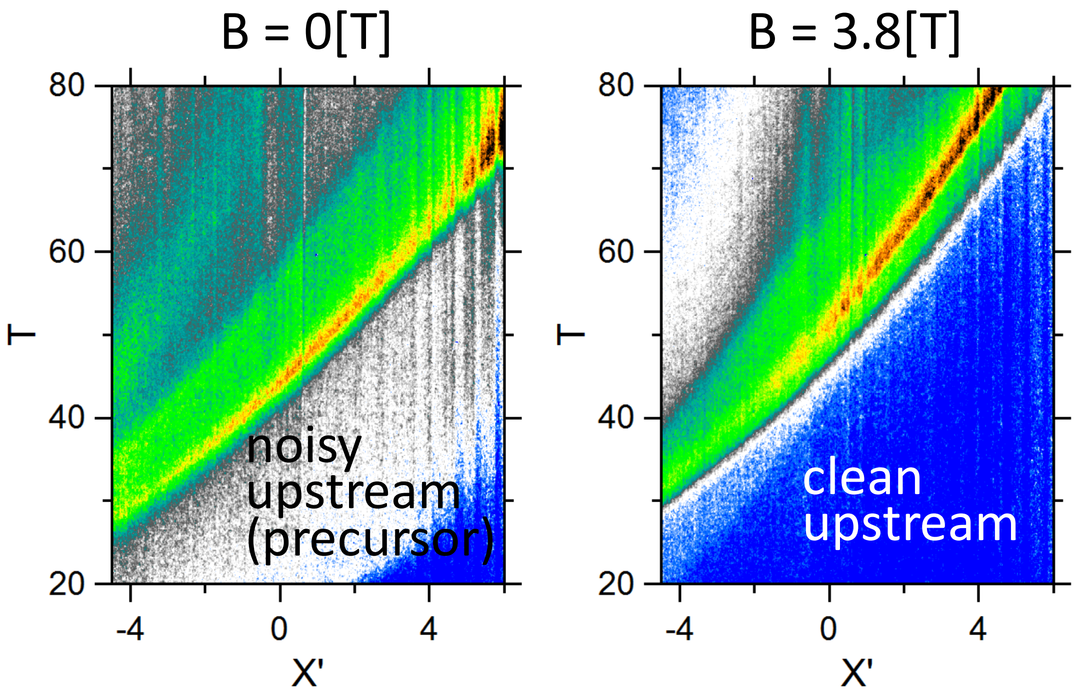


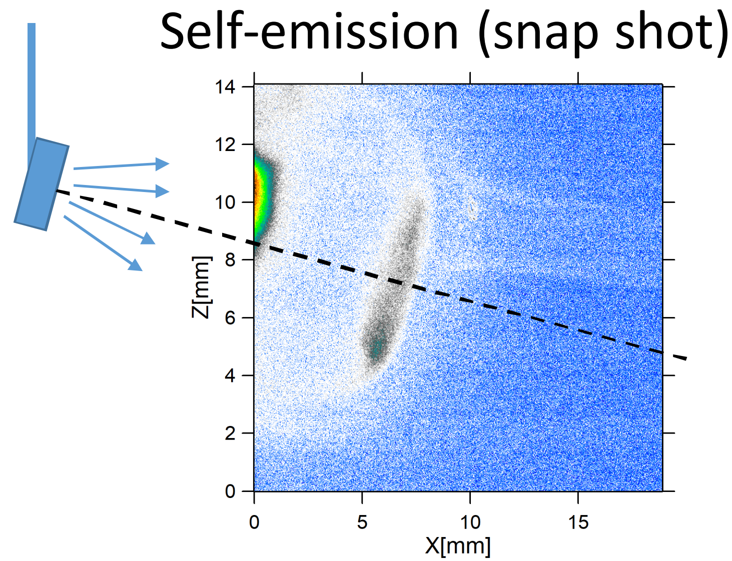


Typical parameters of gas plasma & shock

$\omega_{pe} \sim 6 \times 10^{13}[s^{-1}]$	$c/\omega_{pi} \sim 0.5[mm]$
$\Omega_e \sim 6 \times 10^{11}[s^{-1}]$	$v_A \sim 35[km/s]$
$T_e(\sim T_i) \sim 10[eV]$	$v_{sh} \sim 200[km/s]$
$m_i/m_e = 25704$	$\rho_{ref\_i} \sim 5[mm]$
$Z \sim 3$	$\lambda_{mfp\_ii} \sim 2[cm]$

Results: self-emission streak





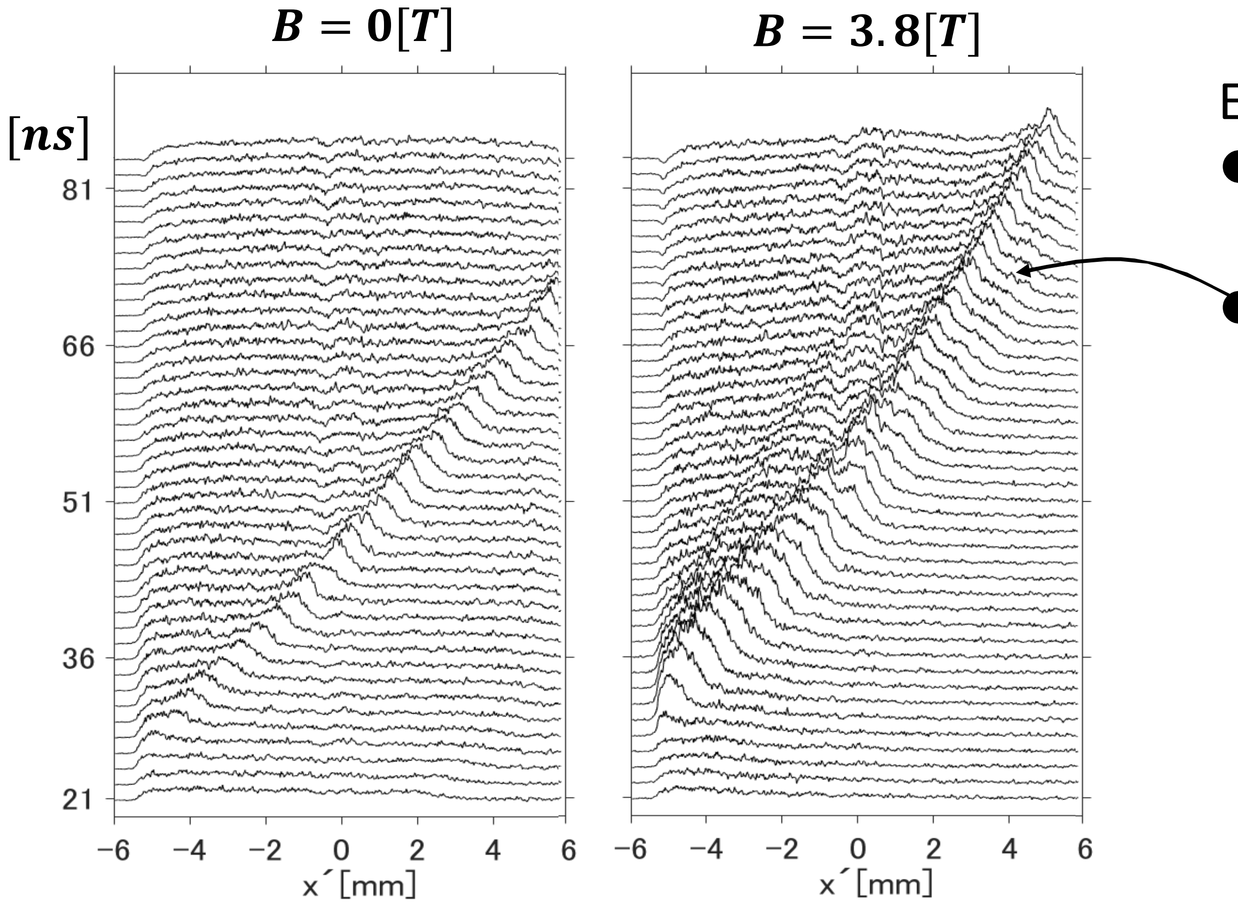
B = 0

- Noisy upstream (precursor)

B = 3.8 [T]

- Clean upstream
- Small precursor in early time

Stack plot

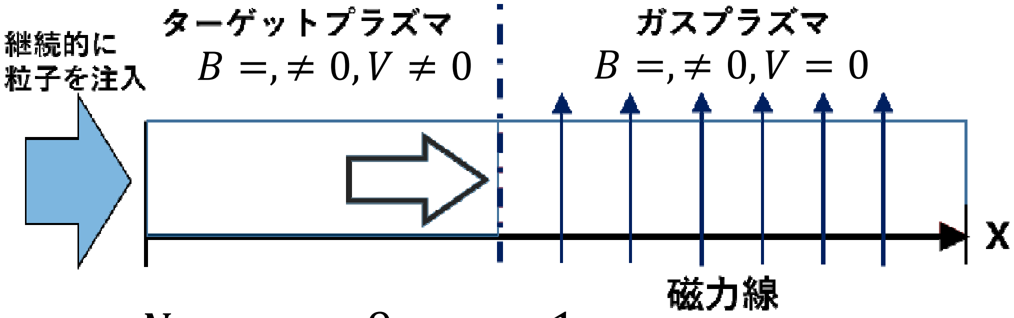


Effect of finite B:

- Relatively smooth transition ($L \sim c/\omega_{pN}$) when B = 0
- Substructure in front of the main peak when B = 3.8[T]

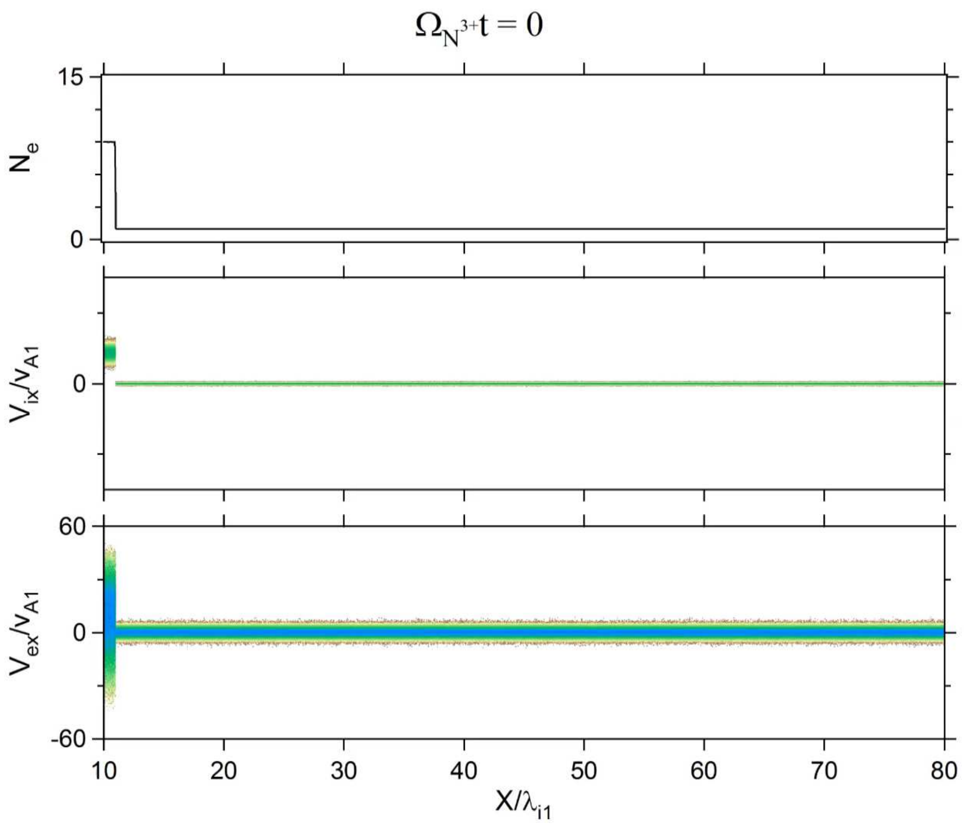
PIC simulation

Initial setting of PIC simulation



N_e	9	:	1	
$V/v_{A,N}$	8.7	:	0	
$T_e(=T_i)$	100	:	1	$(\beta_N = 1)$
Z	2	:	3	
m_i	200	:	100	

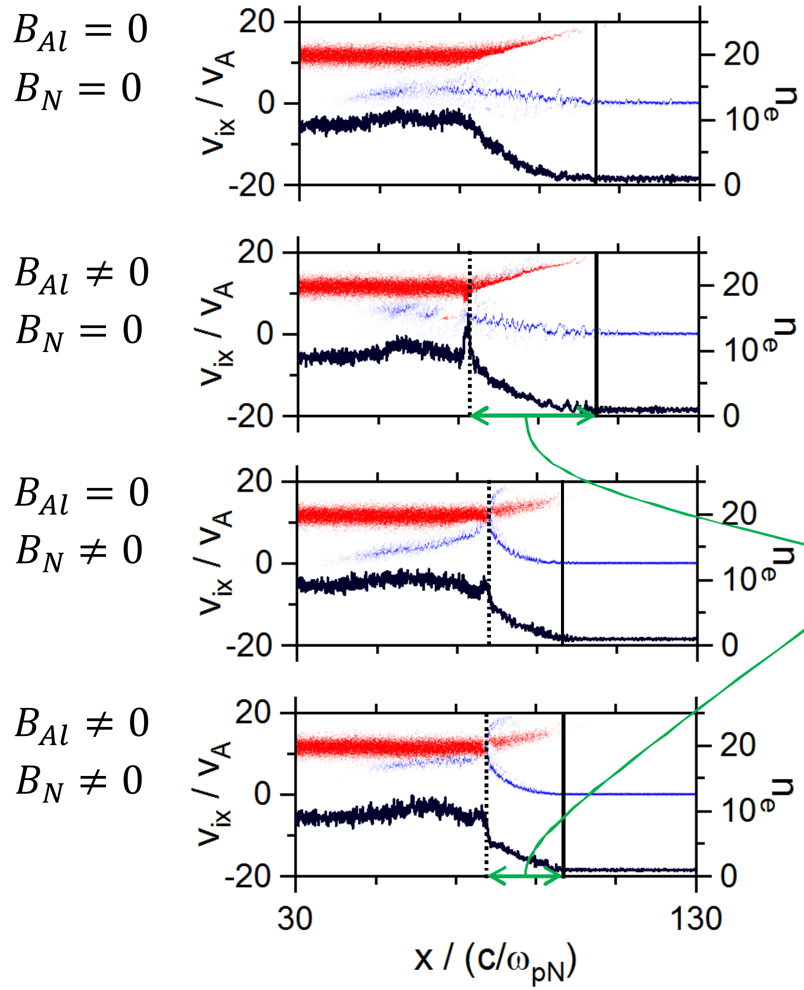
B is a parameter



$$B_{Al} = B_N\left(\omega_{pe,N}/\Omega_{e,N} = 10\right)$$

Electron discontinuity vs density jump

$\Omega_{N^{3+}}t = 1.1\ (\sim 14ns)$



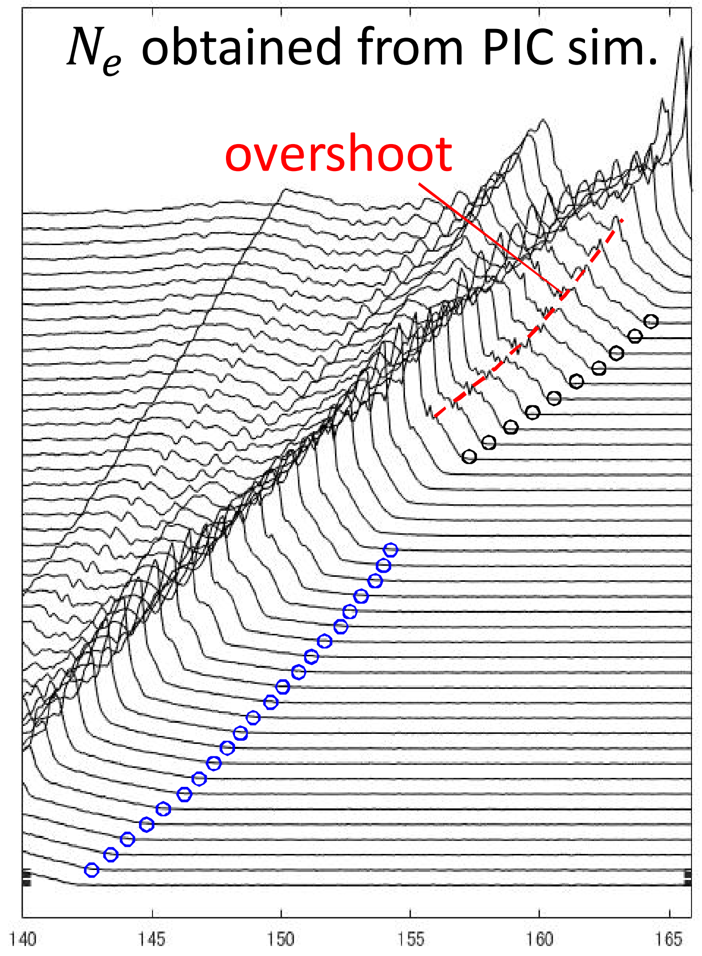
Finite $B_{Al} (\neq 0)$ is necessary to form n_e jump for $B_N = 0$

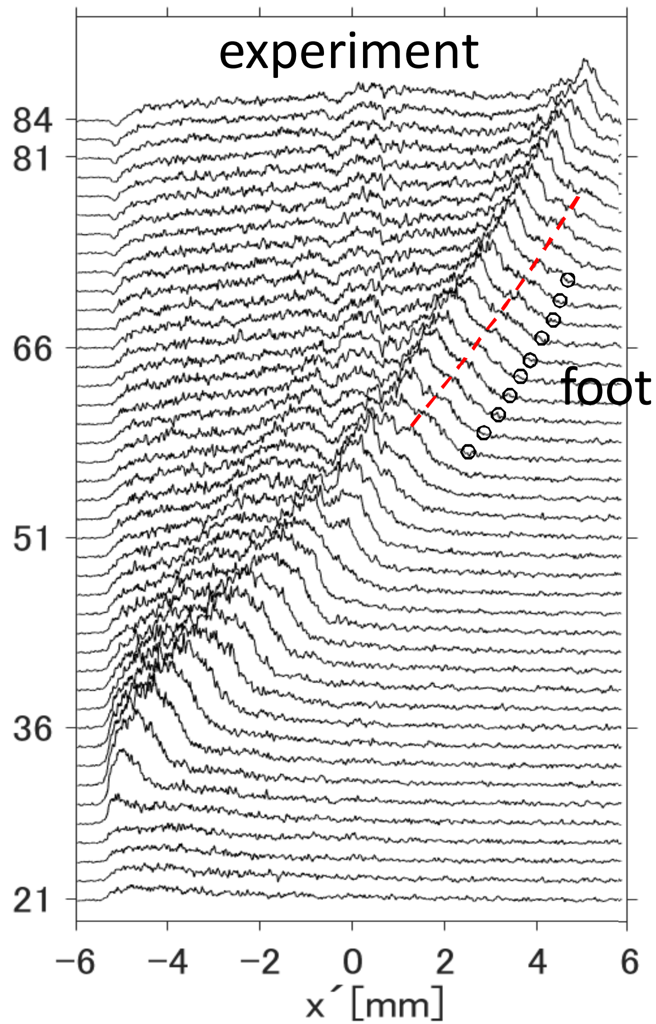
➔ Target (Al) plasma is magnetized probably due to Biermann battery effect

Larger precursor for $B_N = 0$

Precursor due to high speed ions
(Al ions at least in early time)

Magnetic overshoot ?

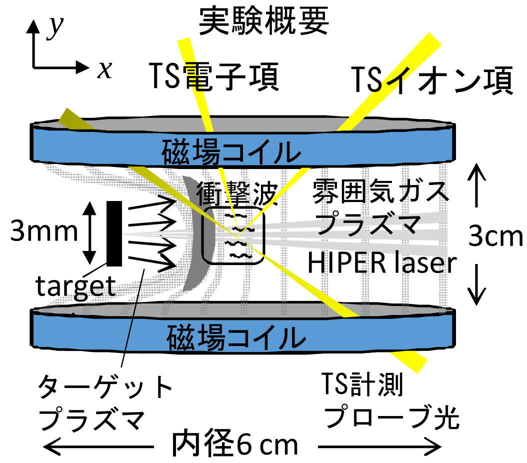


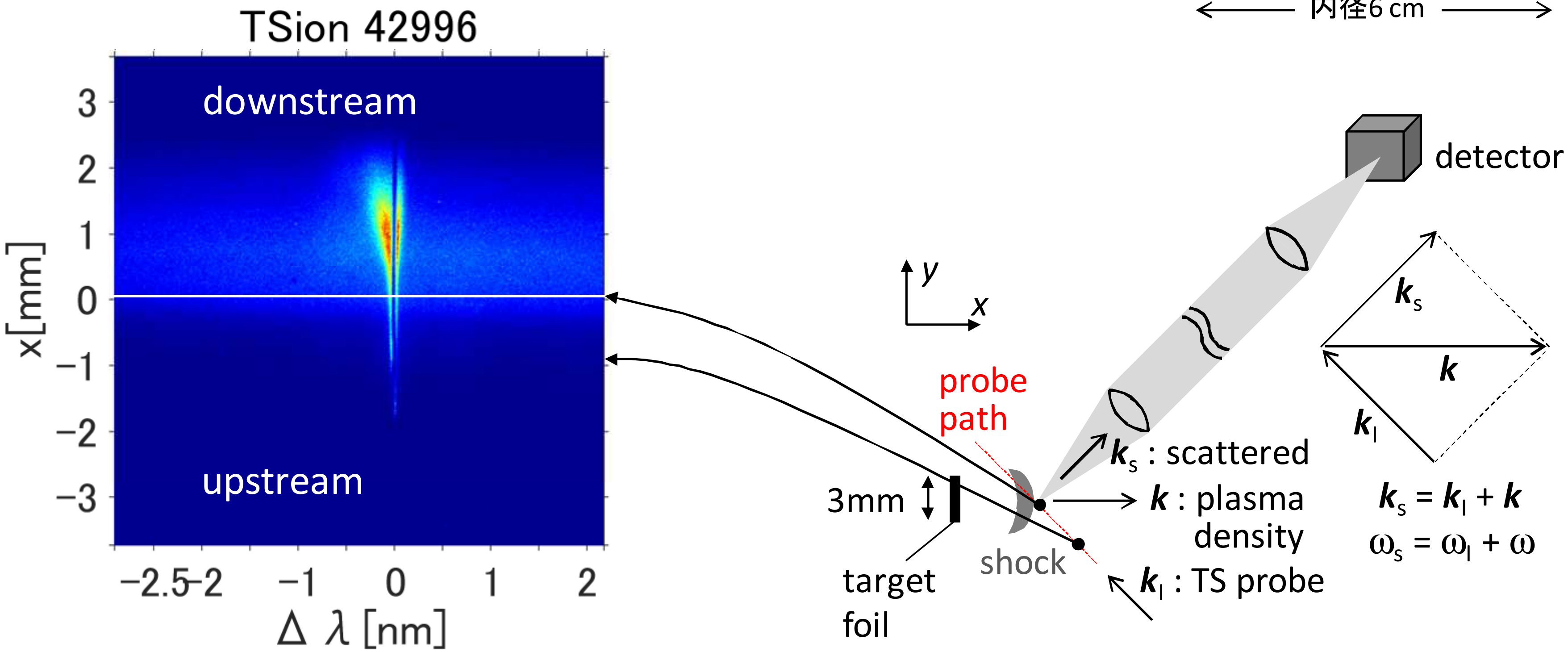


- Internal structure of magnetized shock is detected

Thomson scattering measurement

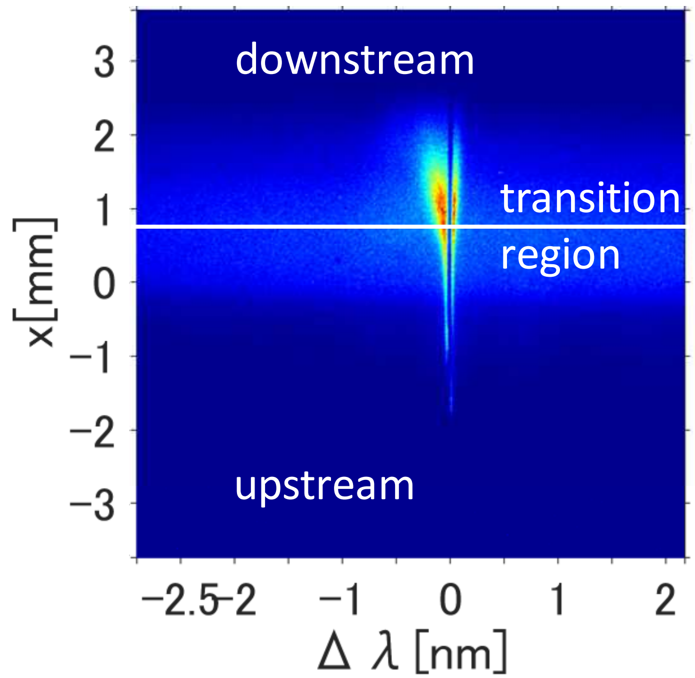
Incident probe laser light is scattered by local plasma electrons
Scattered wave spectrum reflects local plasma state
→estimate local quantities such as $n_e, T_e, T_i, Z, v_d, \ldots$



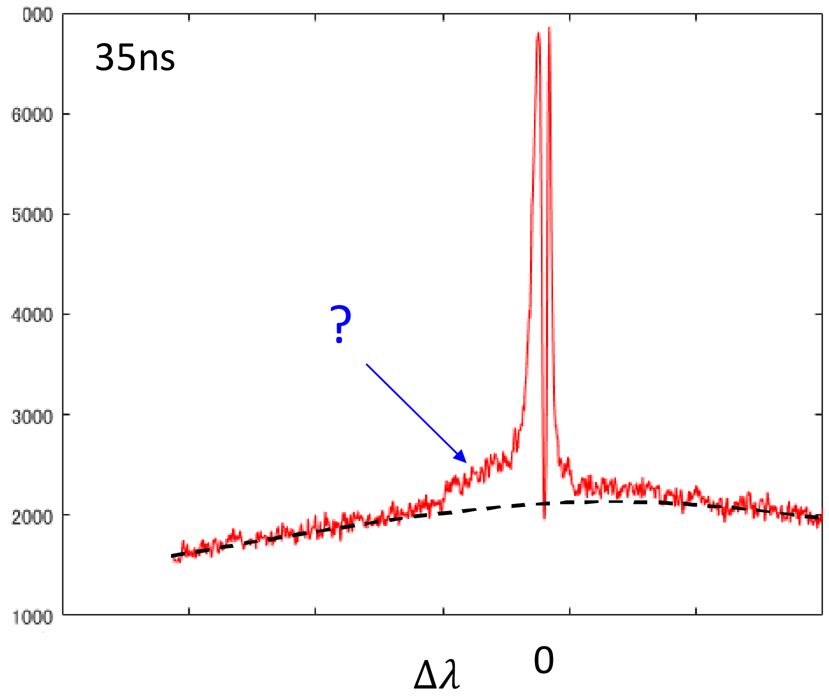


Thomson scattering measurement

TS data at the time when precursor is visible



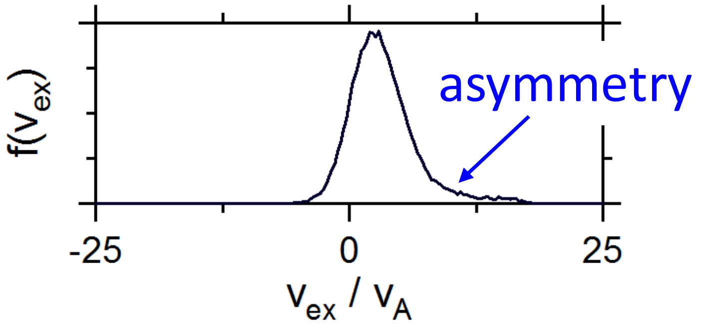
$I \sim N_e(k(\omega))$



- Asymmetric spectrum in the precursor

Thomson scattering measurement

- Asymmetric distribution function of electrons in precursor (PIC simulation)



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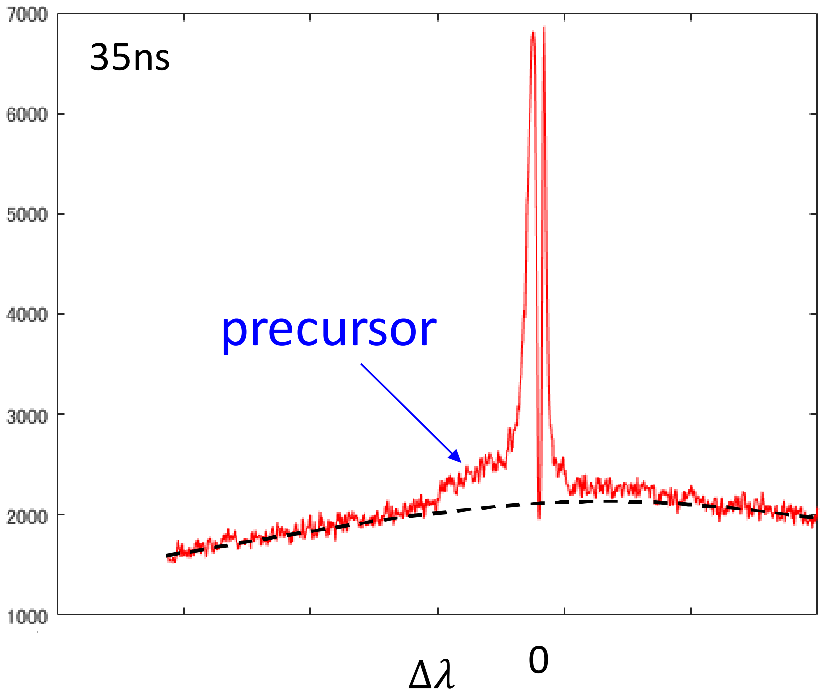

In the foot similar electron distribution function is realized

➔ Self-reformation may lead to periodic change of the asymmetric TS spectrum

Summary

- Magnetized collisionless shock is reproduced by performing Gekko XII experiment
- Internal structure of the magnetized shock is observed by streaked self-emission for the first time
- Precursor is detected by using TS measurement

Issues

- A number of snap shots of TS measurement at different timing to extract cyclic feature of shock front (reformation)
- Improvement of accuracy of the PIC simulation for better comparison with the experiment