LABORATORY EXPERIMENTS ON SHOCKS

XINYAN HUA

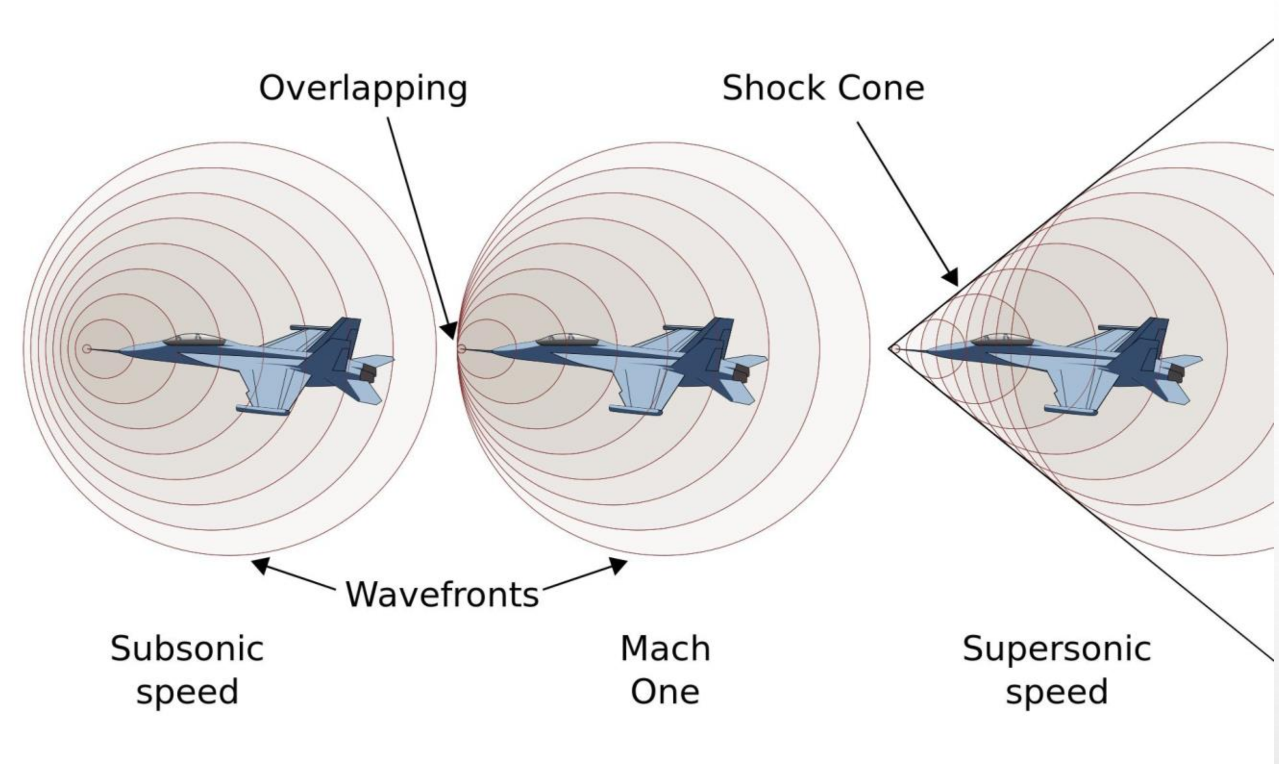
SUPERVISOR: H. FENG; W. CUI

Outline

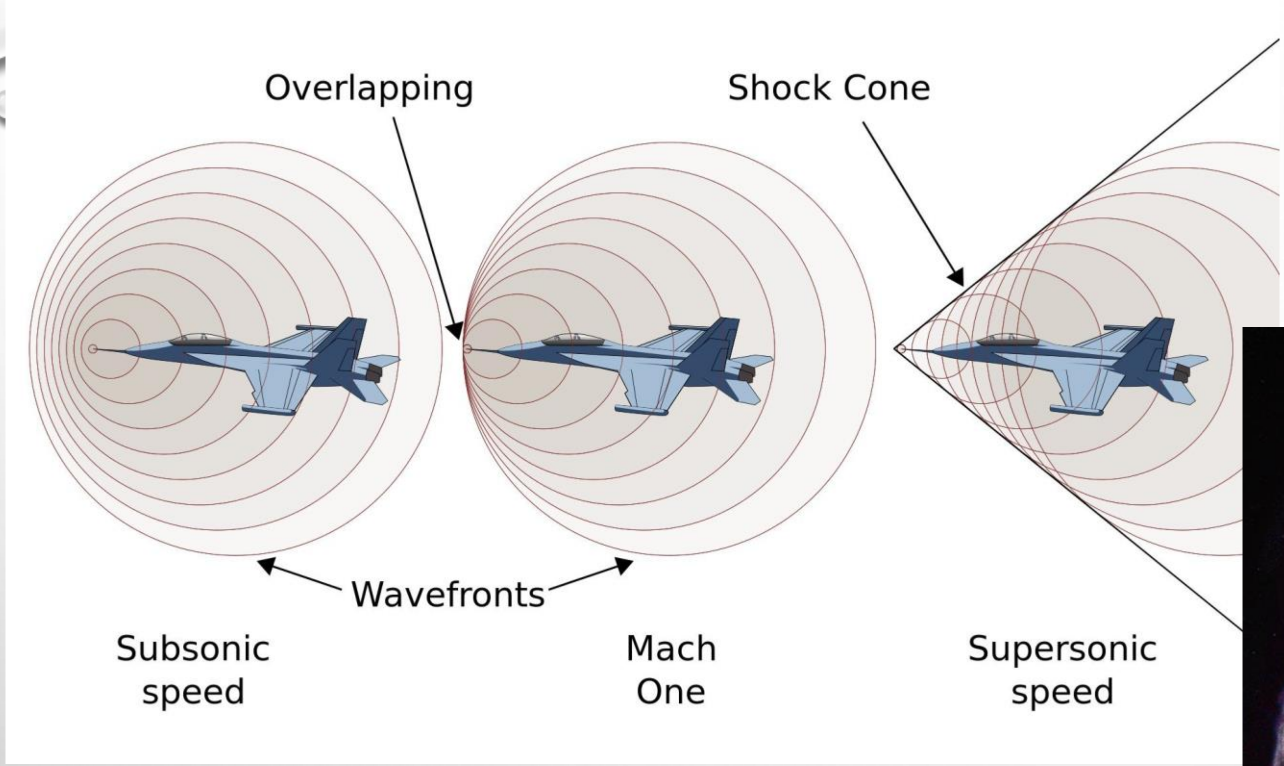
- Introduction of shocks
- Why need to study shocks
- Shock experiments in laboratory
- Summary

Outline

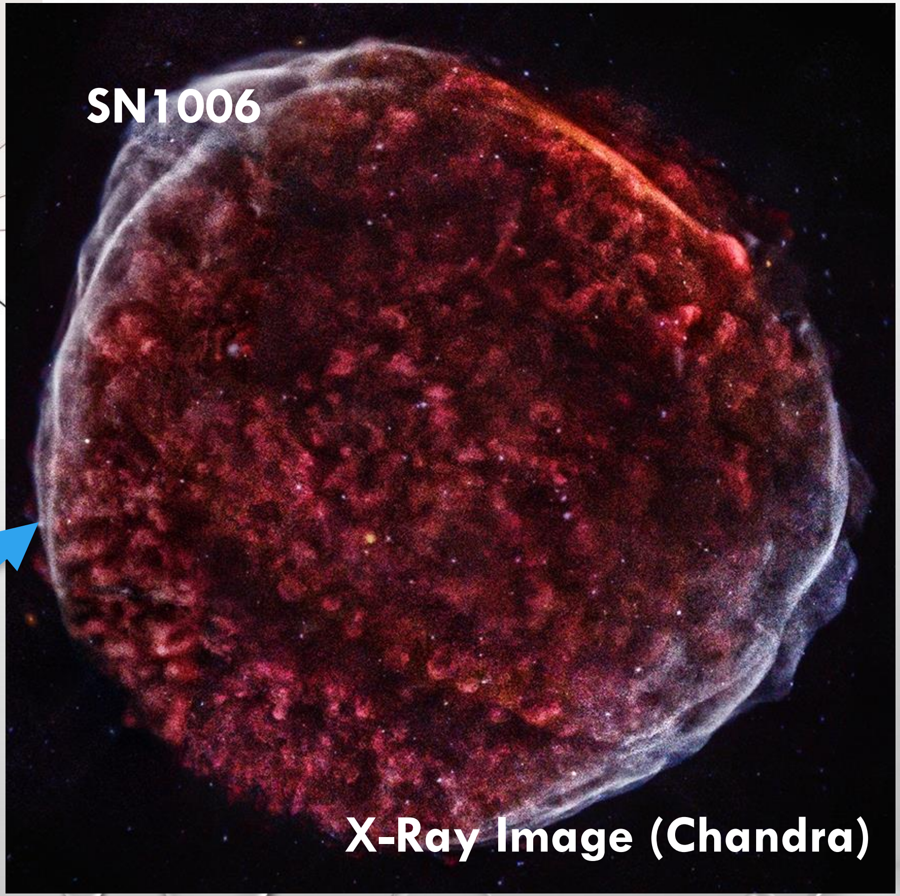
- Introduction of shocks
- Why need to study shocks
- Shock experiments in laboratory
- Summary



Mach number = object velocity / speed of sound


Overlapping
Shock Cone
Wavefronts
Subsonic speed
Mach One
Supersonic speed

Shock front


SN1006
X-Ray Image (Chandra)

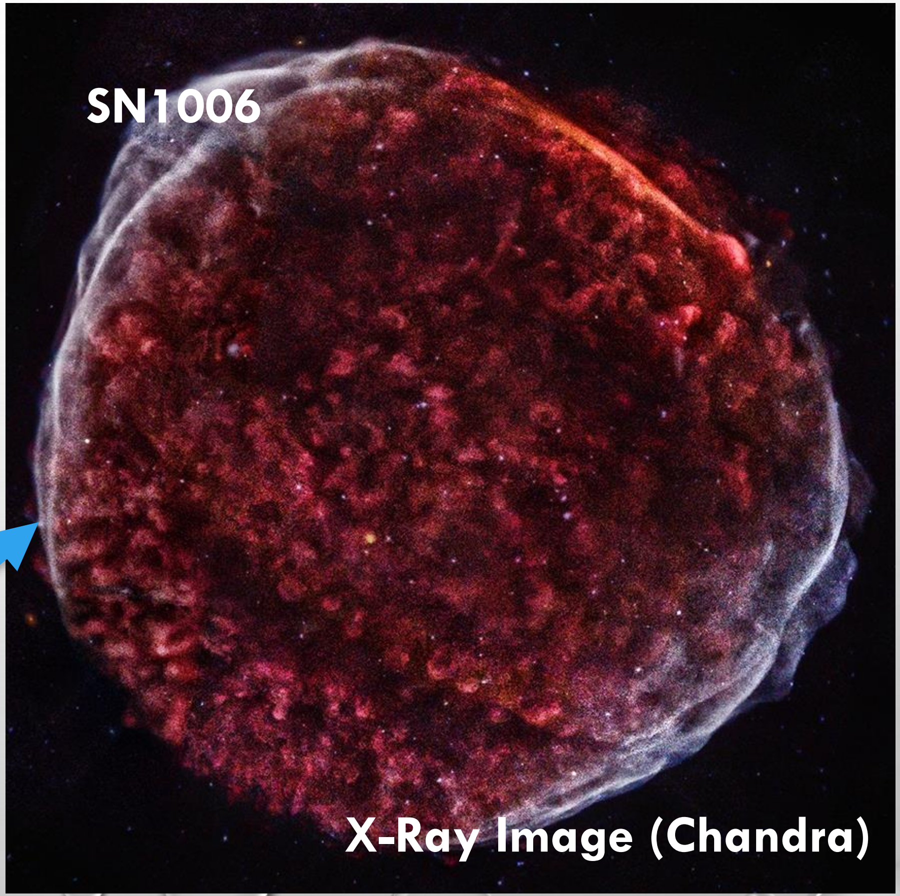
$$l_{Coul} = \frac{m_e^2 v^4}{8\pi n Z^2 e^4 ln\Lambda} \approx 1.4\times 10^4 (\frac{T}{K})^2 (\frac{n}{cm^{-3}})^{-1} cm$$

Coulomb mean free path: ~ 10^{20} cm

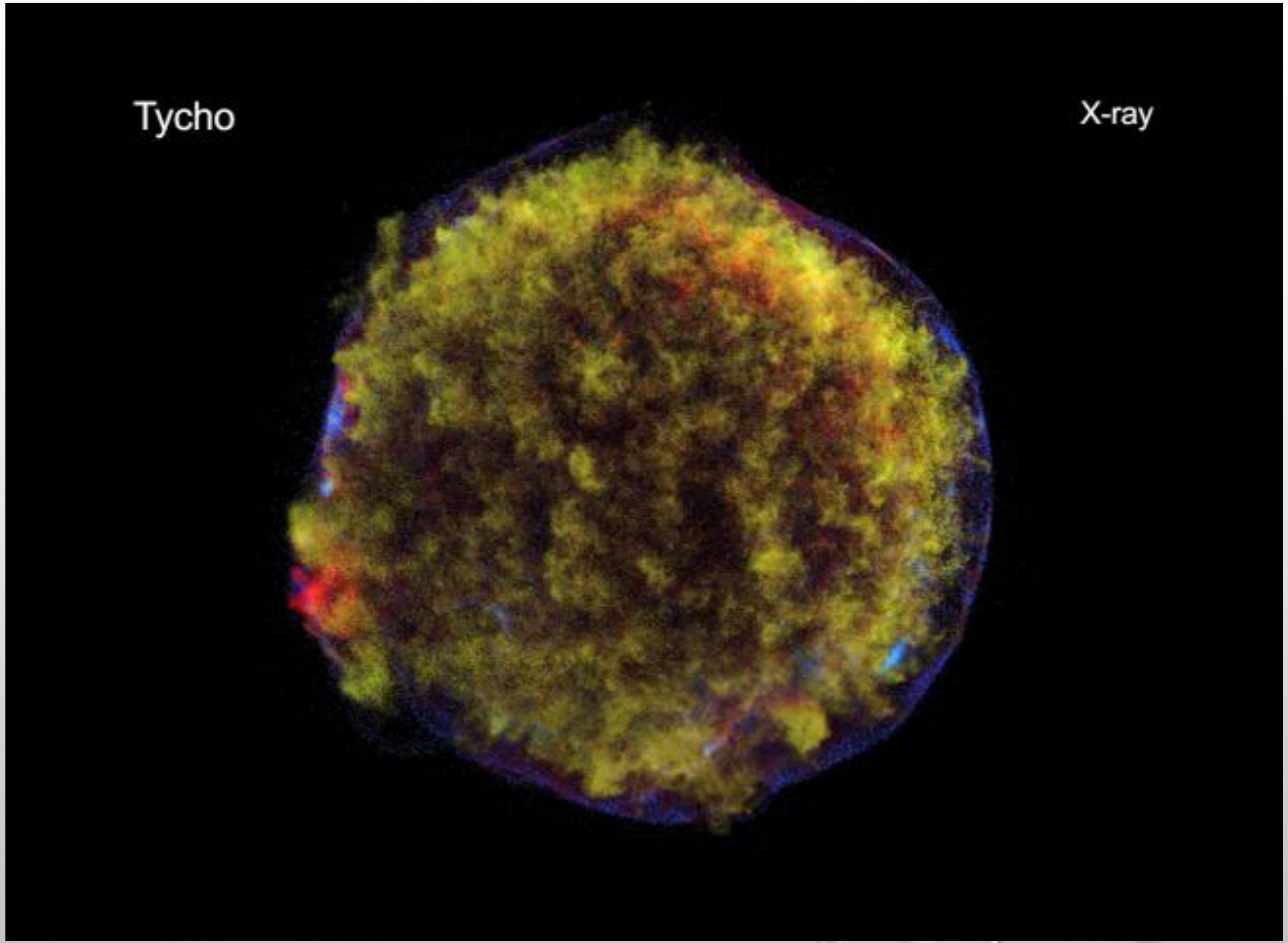
Diameter of SN1006: ~ 10 pc = 3×10^{19} cm

Shock front width: ~ 0.04pc = 1.2×10^{17} cm

Collisionless Shocks



Tycho's supernova remnant
X-Ray Image (Chandra)

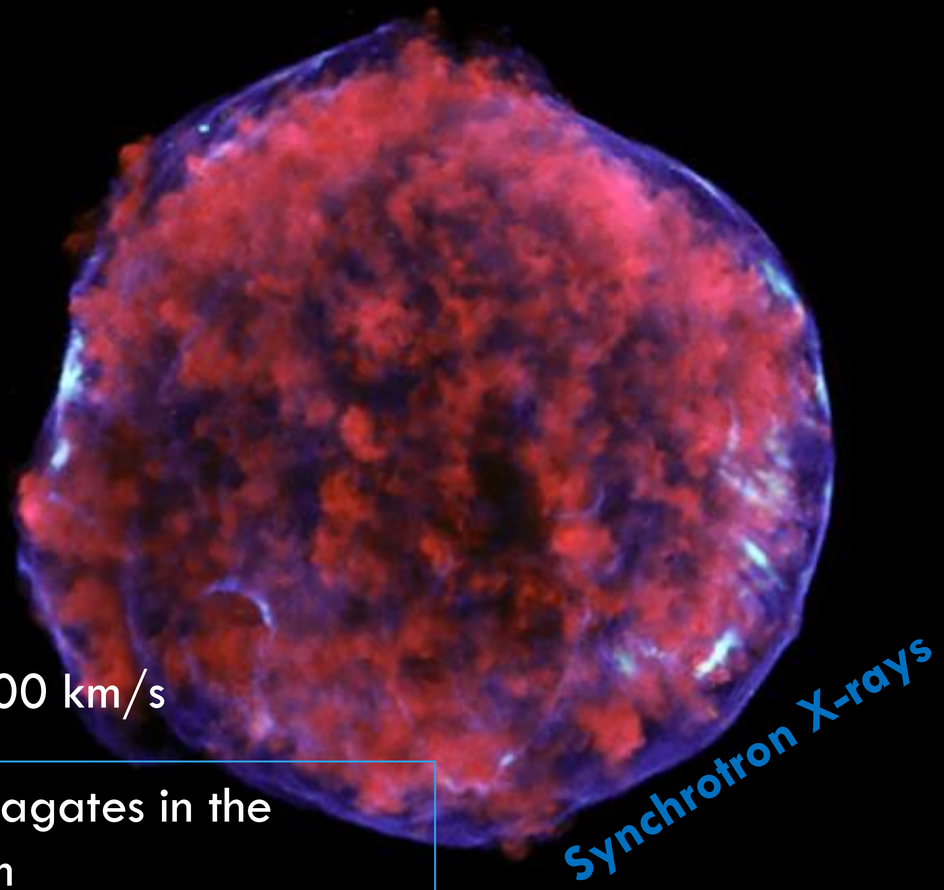


Mechanism driving shocks:
Plasma instabilities

Fermi Acceleration

Tycho

Red: low energy X-Ray
Blue: high energy X-Ray



Shock velocity: 4000 km/s

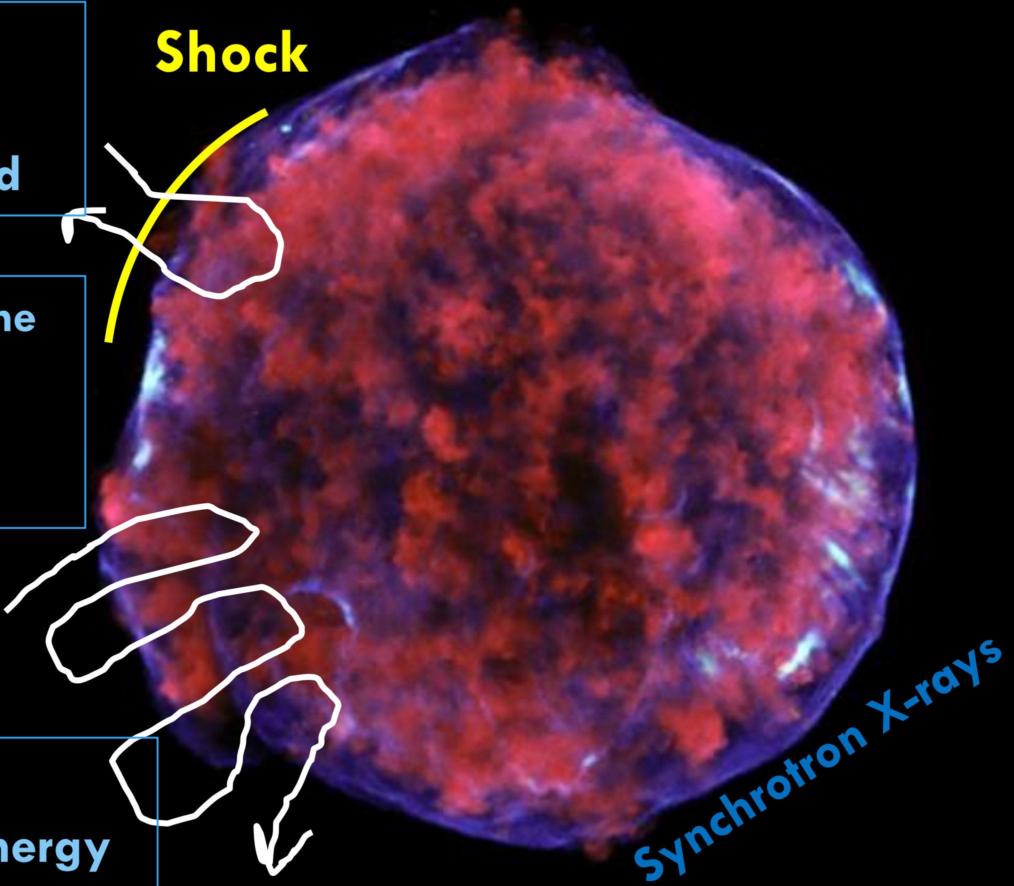
Shock wave propagates in the interstellar medium
TeV electrons producing **synchrotron X-Rays**

Tycho

Red: low energy X-Ray
Blue: high energy X-Ray

"Random Walk" of charged particles in a presence magnetic field

One round trip crossing the shock wave:
Gain 1% of the original energy



1000 round trips:
20000 times bigger energy
eg. 1 GeV → 20 TeV

Outline

- Introduction of shocks
- Why need to study shocks
- Shock experiments in laboratory
- Summary

Outline

- Introduction of shocks
- Why need to study shocks
- Shock experiments in laboratory
- Summary

Why we need to study (collisionless) shocks ?

- Collisionless shocks are associated with extremely high energy particles.
- Shock waves act as cosmic ray accelerator.
- Shock waves and magnetic field ?
- Condition to generate shocks ?

Outline

- Introduction of shocks
- Why need to study shocks
- Shock experiments in laboratory
- Summary

Outline

- Introduction of shocks
- Why need to study shocks
- Shock experiments in laboratory
- Summary

Shock experiments in laboratory

Laser-produced collisionless shocks

- USA: Livermore (LLNL), Los Alamos (LANL), Rochester (LLE), Berkeley, UT, Michigan
- UK: Didcot (Rutherford lab), Aldermaston (AWE)
- France: CEA (CESTA, Saclay), Ecole Polytechnique (LULI, LOA), CELIA
- Germany: Garching, Jena, Munich, Dresden, Dusseldorf
- Czech Republic: PALS
- Japon: Osaka (ILE), Kyoto (JAERI)
- South Korea: GIST
- Russia: Moscou (Lebedev, MEPHI), Arsamas
- China: Pekin, Shanghai

Shock experiments in laboratory

Plasma diagnostics in high power laser experiments

Velocities: particle diagnostics (spectrometers, Thomson parabola), Doppler

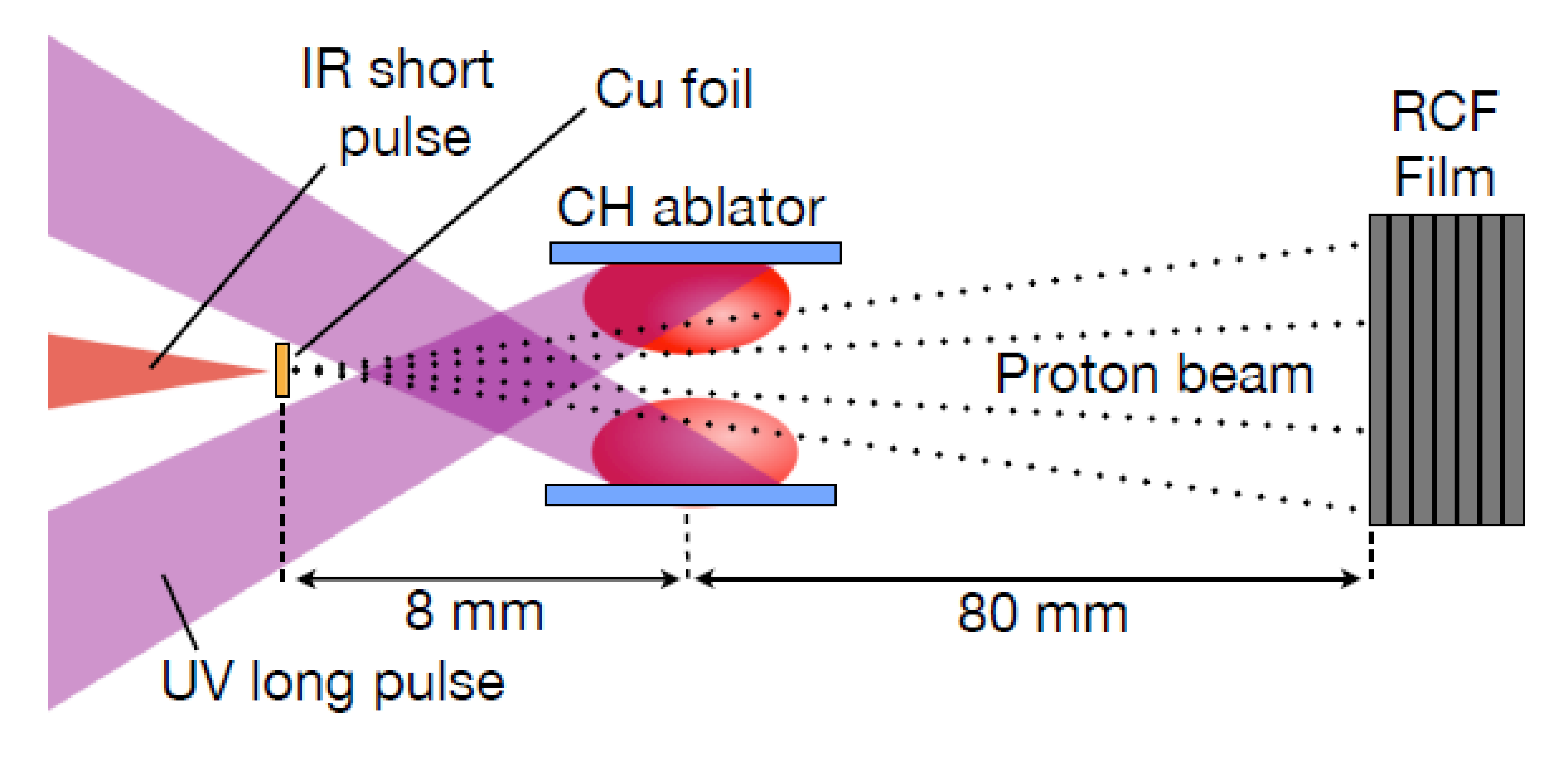
Magnetic fields: proton radiography, polarimetry, faraday rotation, B dots

Densities: interferometry, X-ray radiography, shadowgraphy

Temperatures: spectroscopy, Thomson scattering

Shock experiments in laboratory

Laser-produced collisionless shocks

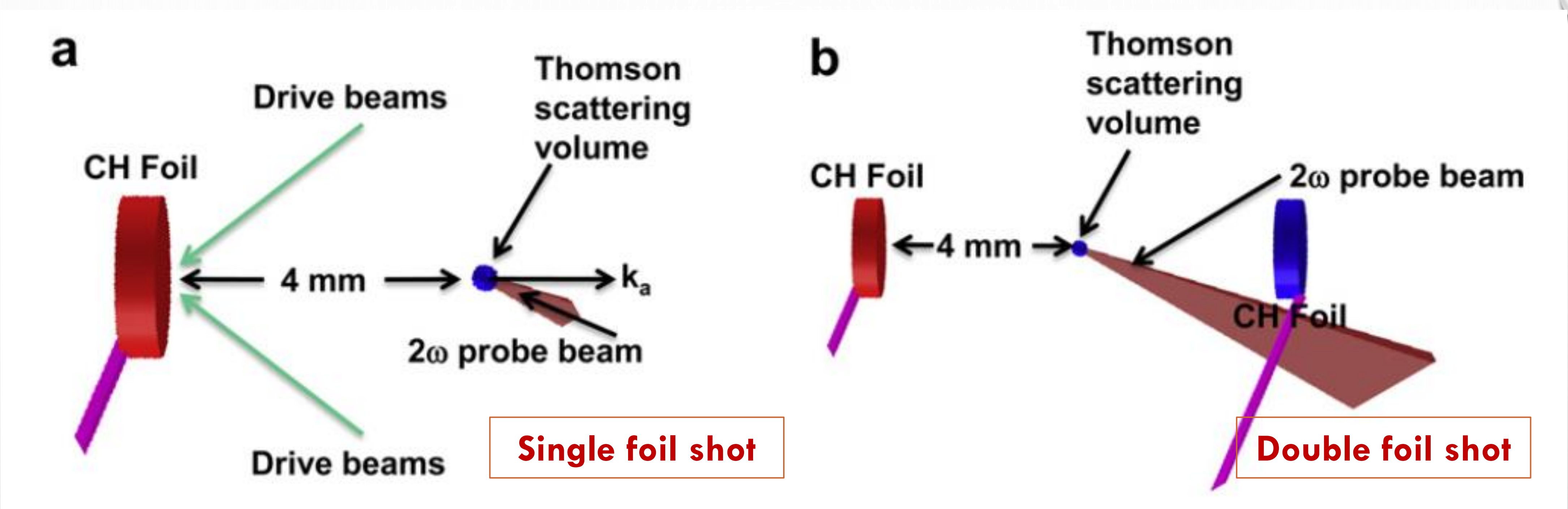


Shock experiments in laboratory

- Collision mean free path λ
- Spatial scale of the interacting flows l_{int}
- Scale needed to generate plasma instabilities l^*

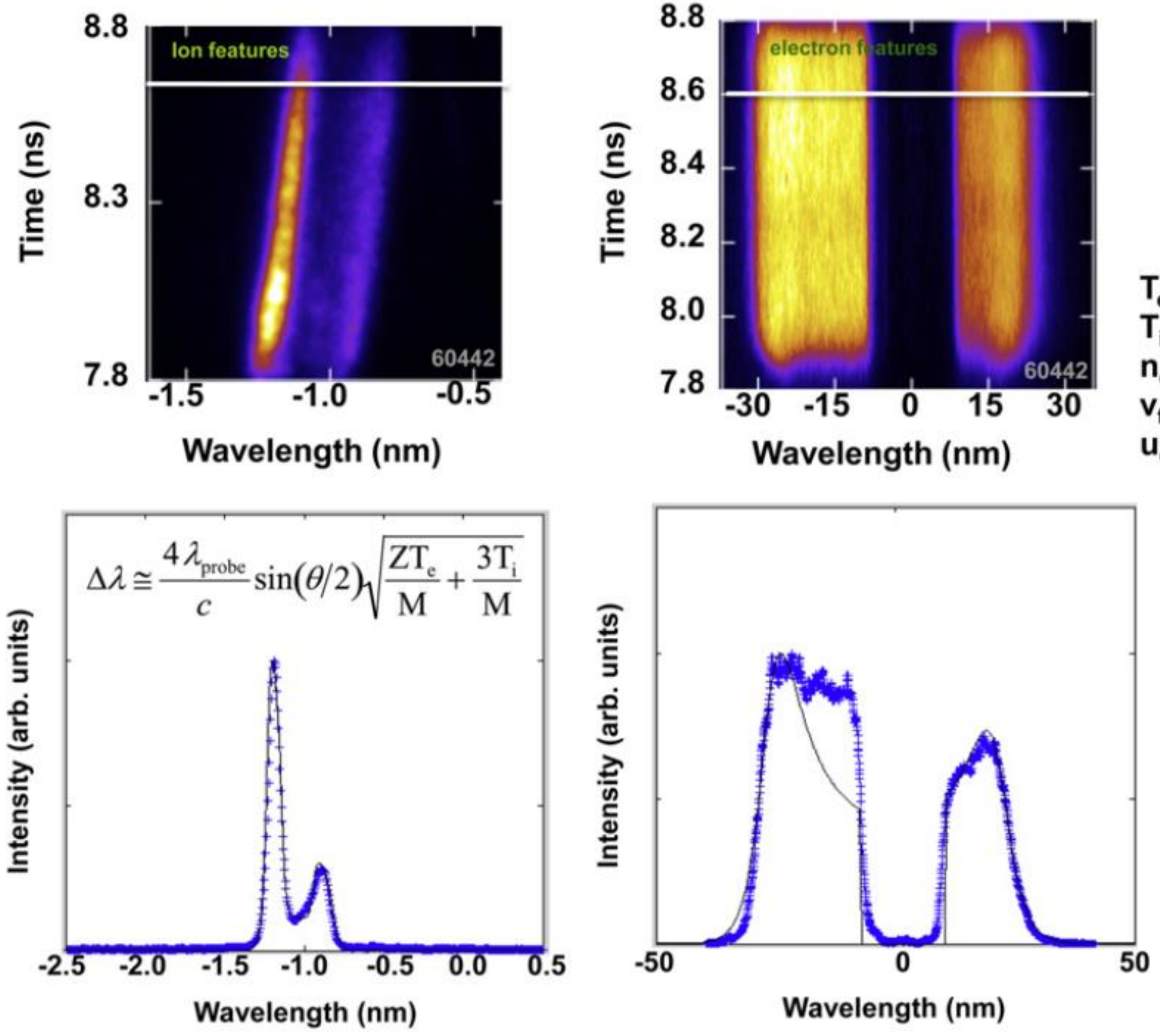
Conditions: $\lambda \gg l_{int} \gg l^*$

Shock experiments in laboratory

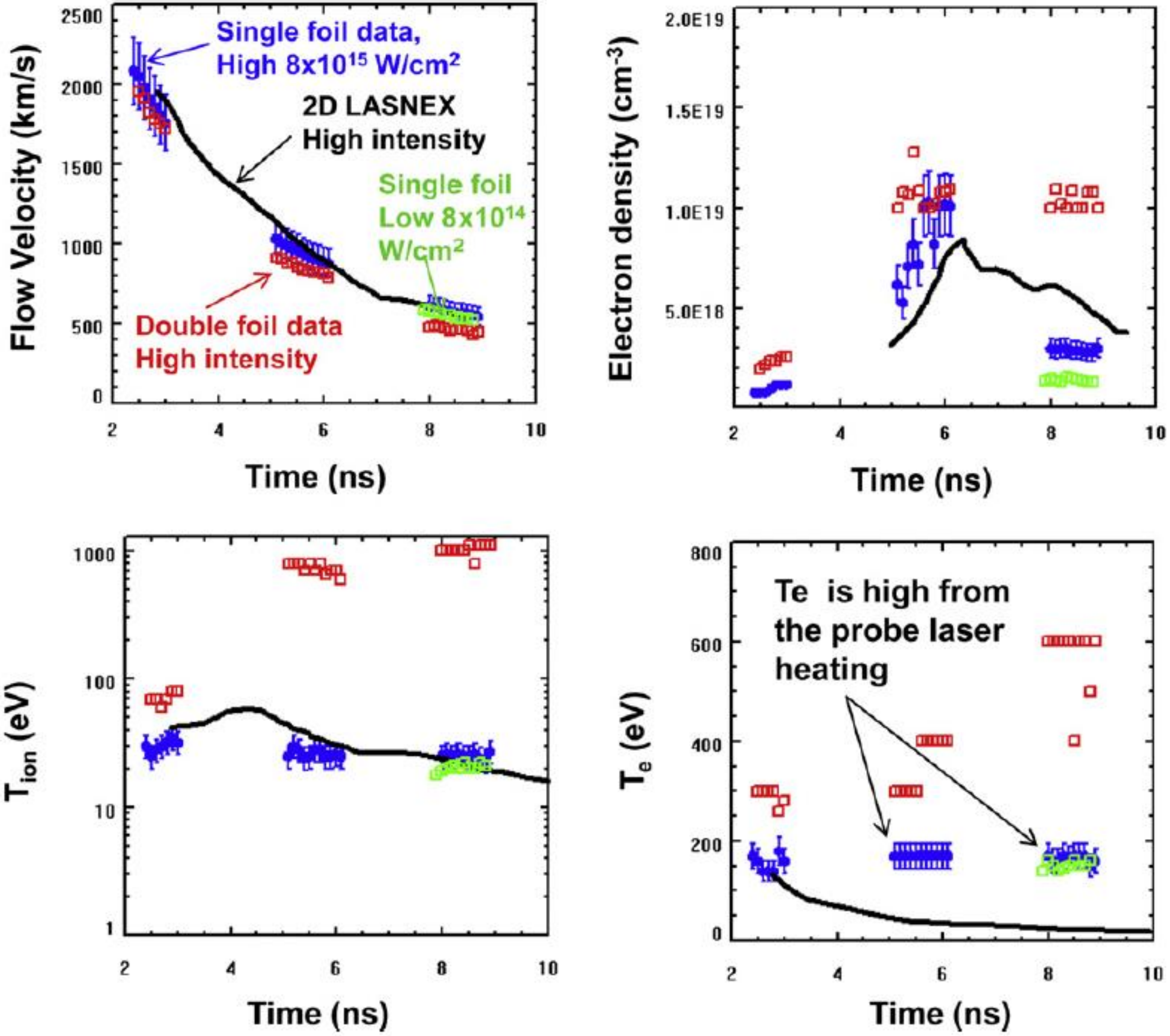


- Heater-drive beams: 5 kJ in a 1 ns square pulse shape
- Probe beam: 0.53 micrometer wavelength
- Thomson scattering is measured from the electron feature and the ion feature

Single foil shot



T_e = 170 eV
T_i = 26 eV
$n_e = 3.1 \times 10^{18}$ cm^{-3}
$v_{flow} = 5.7 \times 10^{7}$ cm/s
$u_{drift} = 1.2 \times 10^{8}$ cm/s



Blue: single foil shots

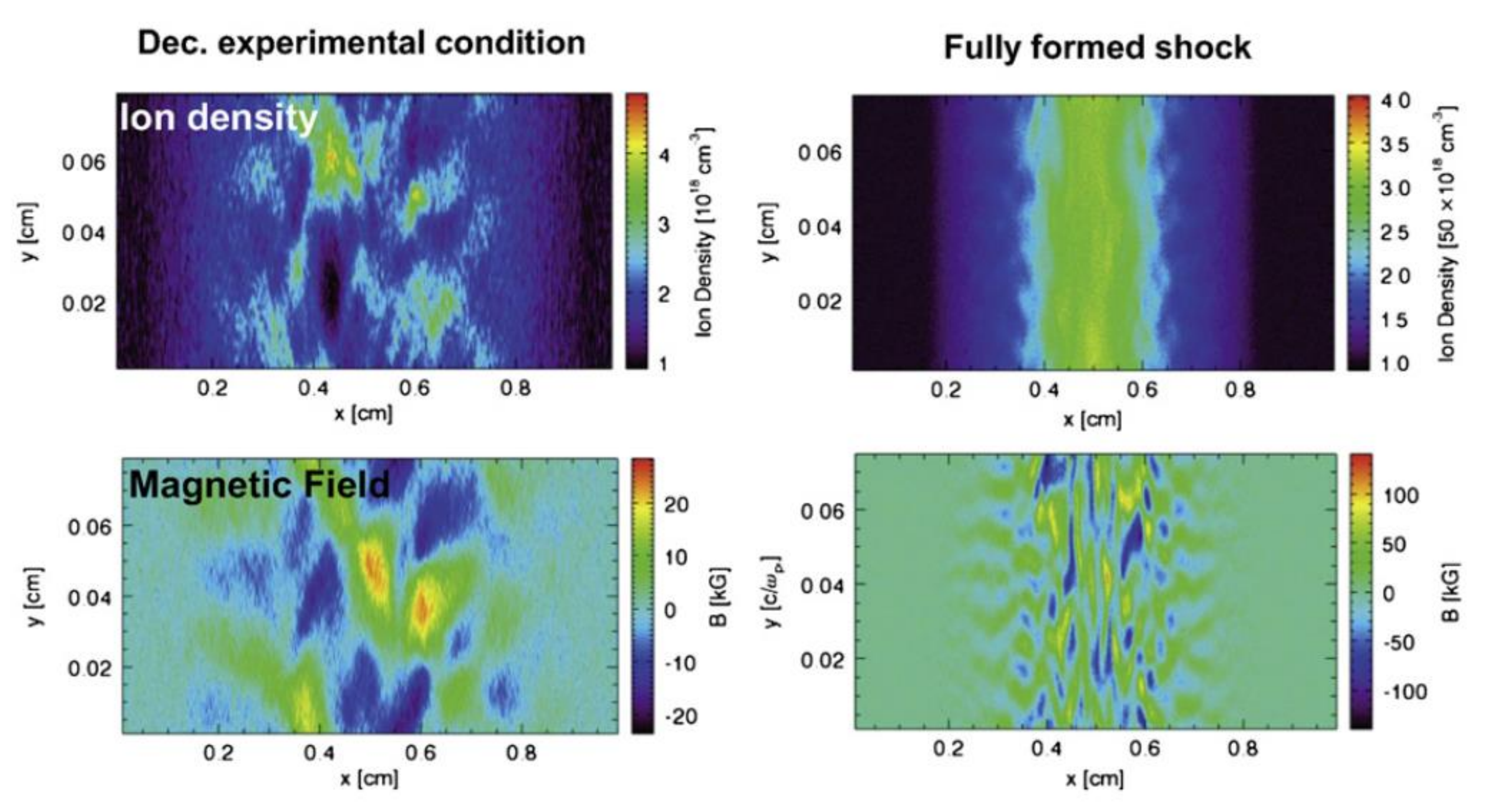
Red: double foil shots

Green: single foil with 10 times

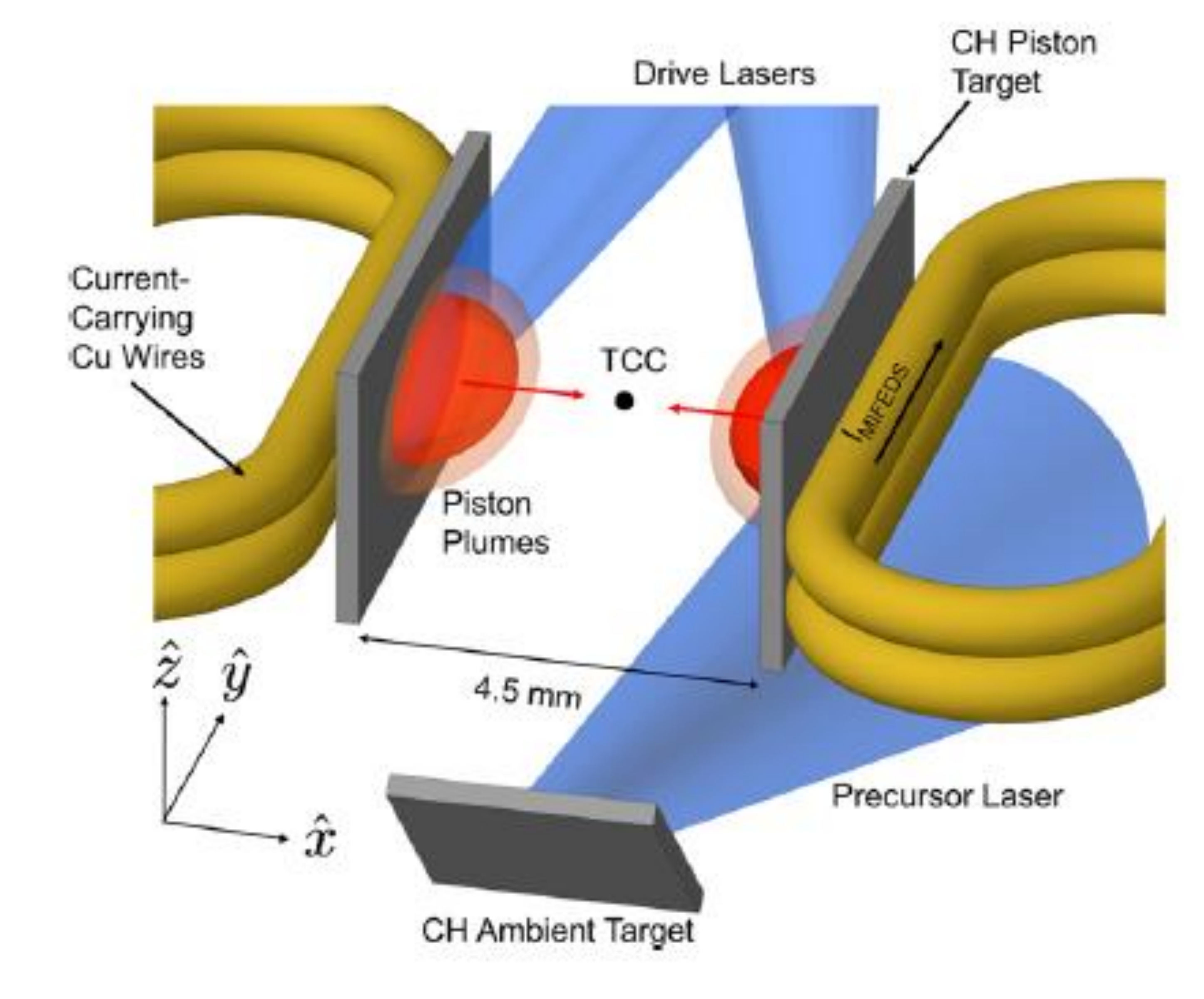
lover driven laser intensity

Solid line: 2D simulations

Shock experiments in laboratory

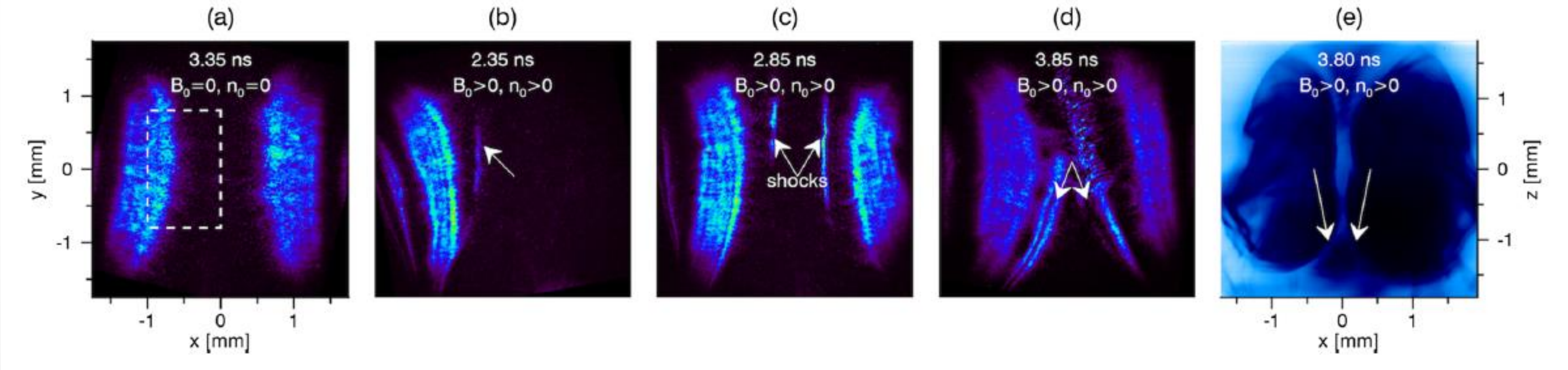


Shock experiments in laboratory



- Two opposing plastic piston targets irradiated by a $5 \times 10^{13}\ W/cm^2$ drive beam (351 nm, 1.5 kJ, 2 ns)
- Ambient CH target irradiated by a $9 \times 10^{12}\ W/cm^2$ beam (351 nm, 100 J, 1 ns)
- An externally imposed background magnetic field $B_{peak} \sim 8\,T$

Shock experiments in laboratory

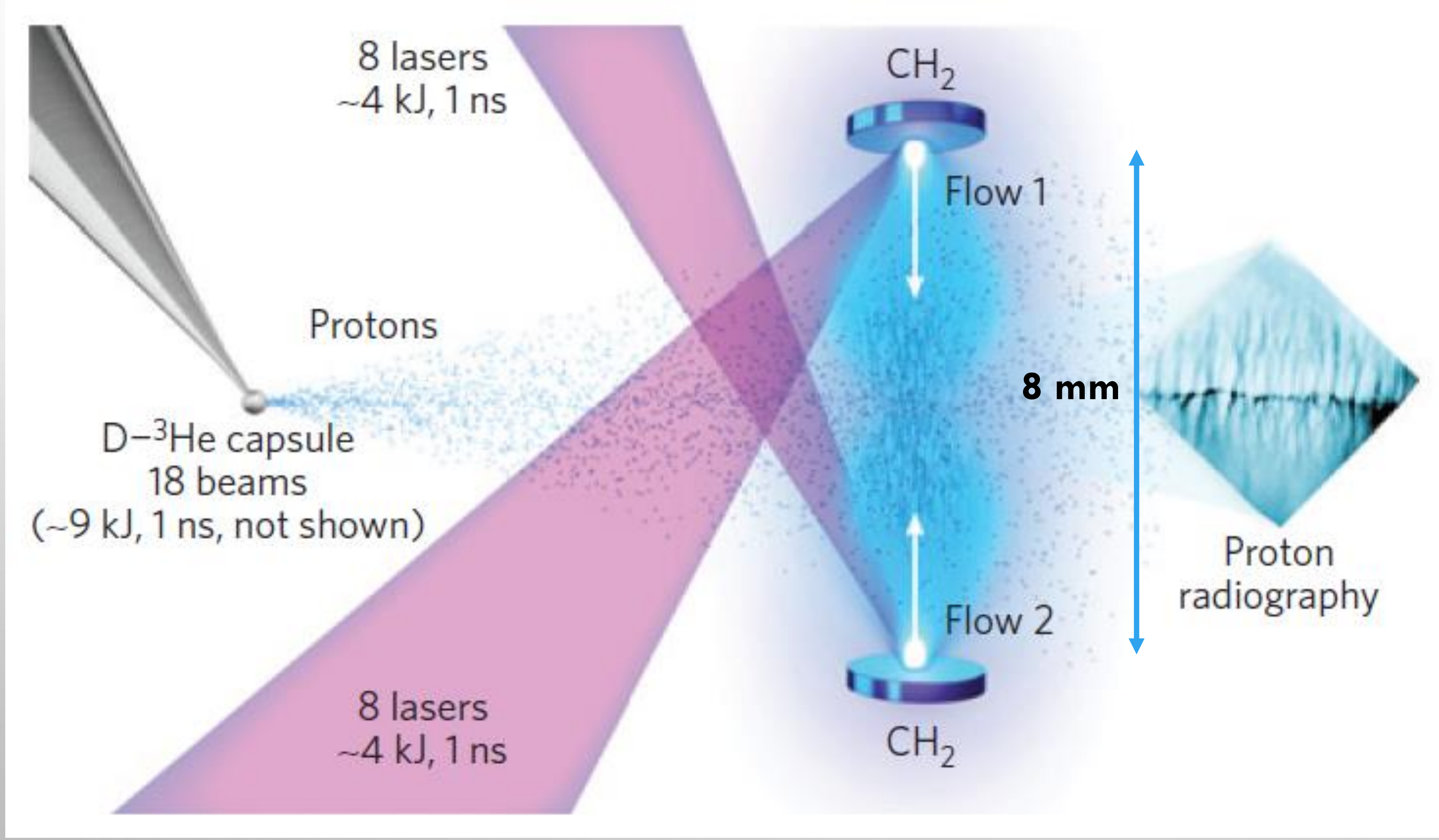


$n_0 \sim 6 \times 10^{18}\ cm^{-3}$

Wide bands: piston plasma plums

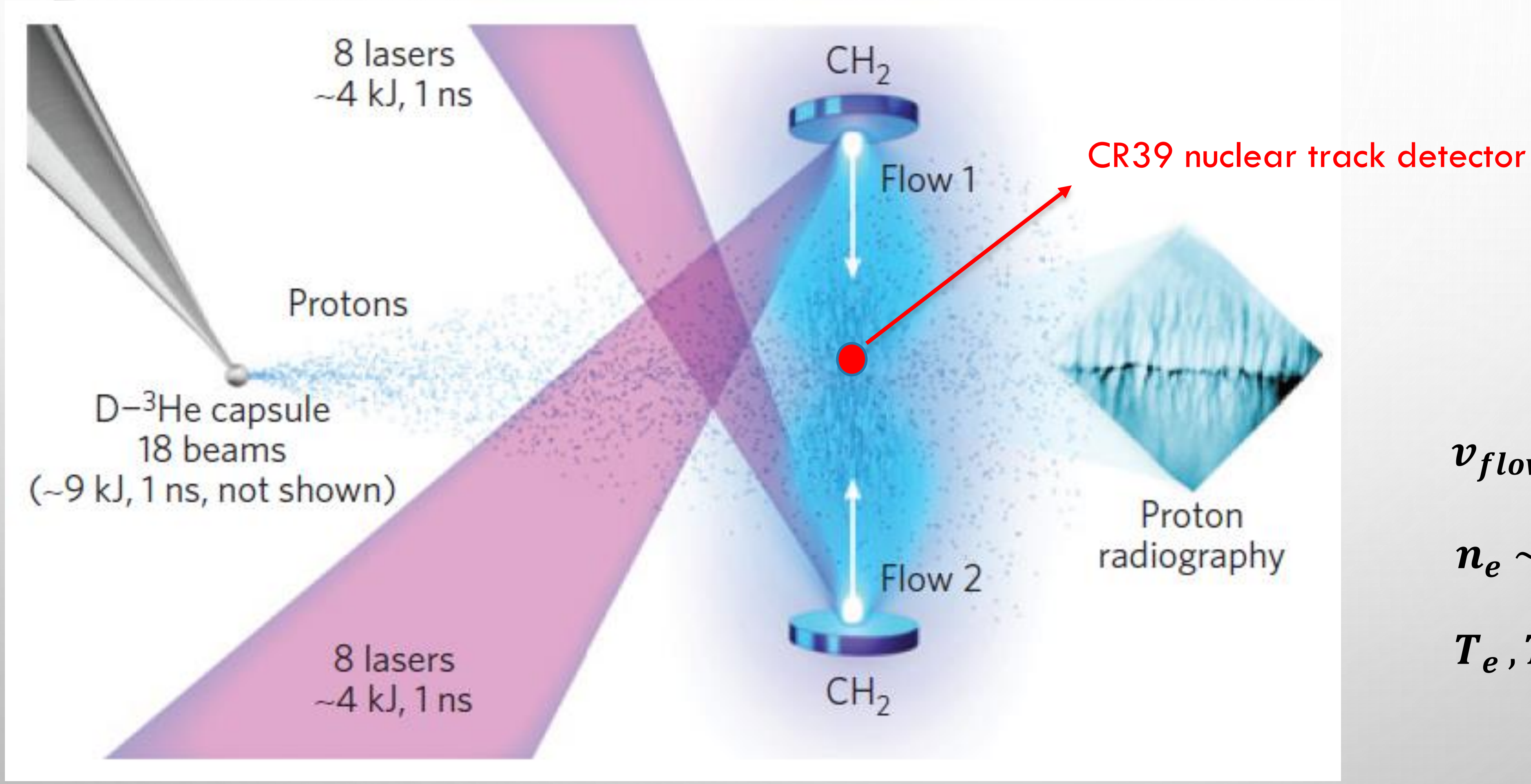
Narrow bands: shocks (strong density gradients, piston and ambient plasma interact)

Shock experiments in laboratory



- 2 foils irradiated simultaneously
- Plasma flows interact near the midplane
- Plasma flow velocity 1000-2000 km/s
- Electron density $n_e \sim 5 \times 10^{18}$ per cube centimeter
- Electron and ion temperature < 200 eV
- Proton imaging to detect magnetic fields
- Protons at 3MeV (from D-D reactions) and at 14.7MeV (from D-3He reactions are produced

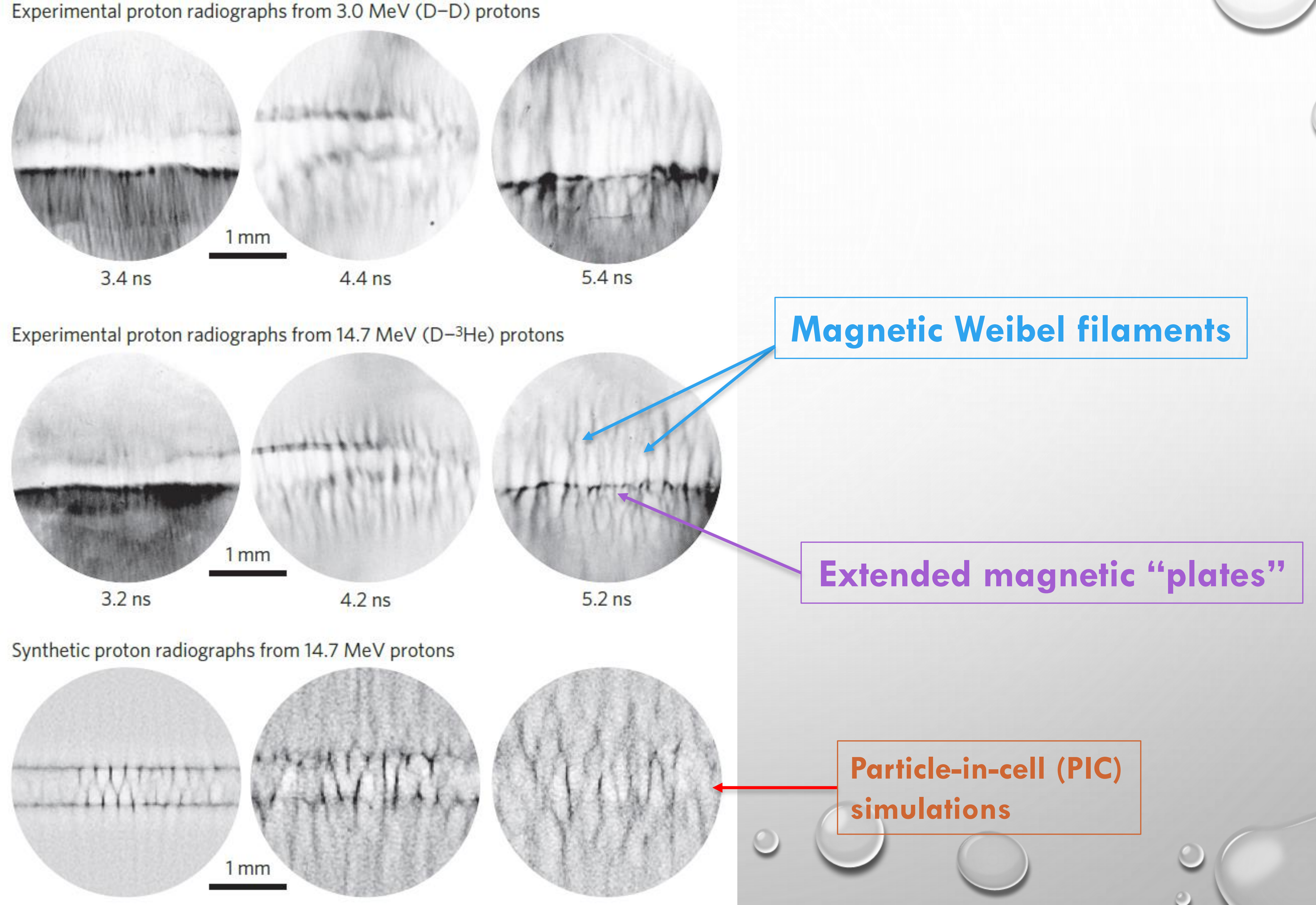
Shock experiments in laboratory



$v_{flow} \sim 1000 - 2000\ km/s$

$n_e \sim 5 \times 10^{18}\ cm^{-3}$

$T_e , T_i\ < 200\ eV$



Experimental proton radiographs from 3.0 MeV (D–D) protons
1 mm
3.4 ns
4.4 ns
5.4 ns
Experimental proton radiographs from 14.7 MeV (D–³He) protons
1 mm
3.2 ns
4.2 ns
5.2 ns
Synthetic proton radiographs from 14.7 MeV protons
1 mm
Magnetic Weibel filaments
Extended magnetic “plates”
Particle-in-cell (PIC) simulations

Outline

- Introduction of shocks
- Why need to study shocks
- Shock experiments in laboratory
- Summary

Outline

- Introduction of shocks
- Why need to study shocks
- Shock experiments in laboratory
- Summary

Summary

- In astronomy shocks are collisionless
- Shock waves act as cosmic ray accelerator
- In laboratory, high power laser can produced collisionless shocks
- Shocks can generate magnetic fields