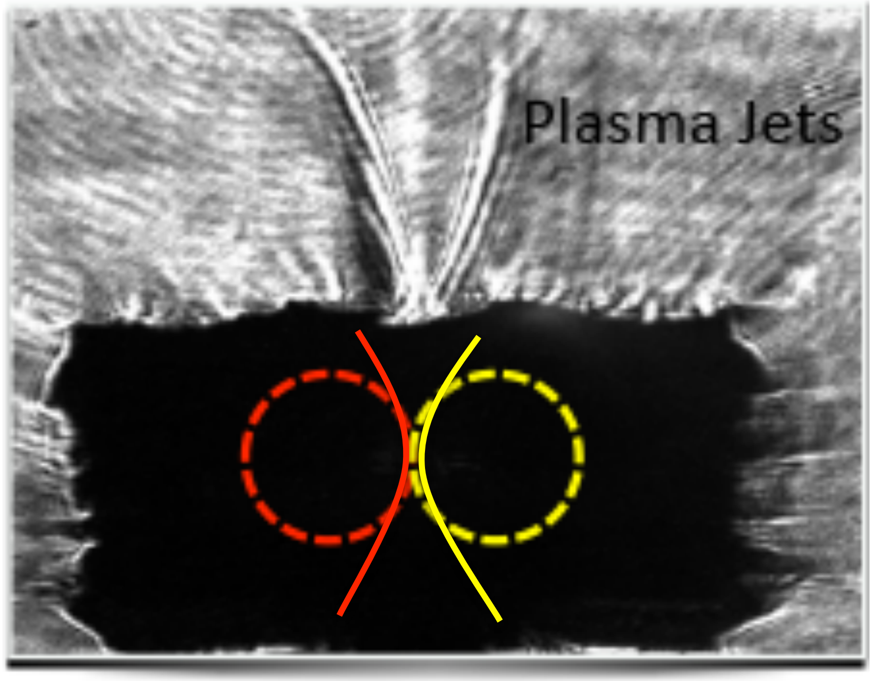
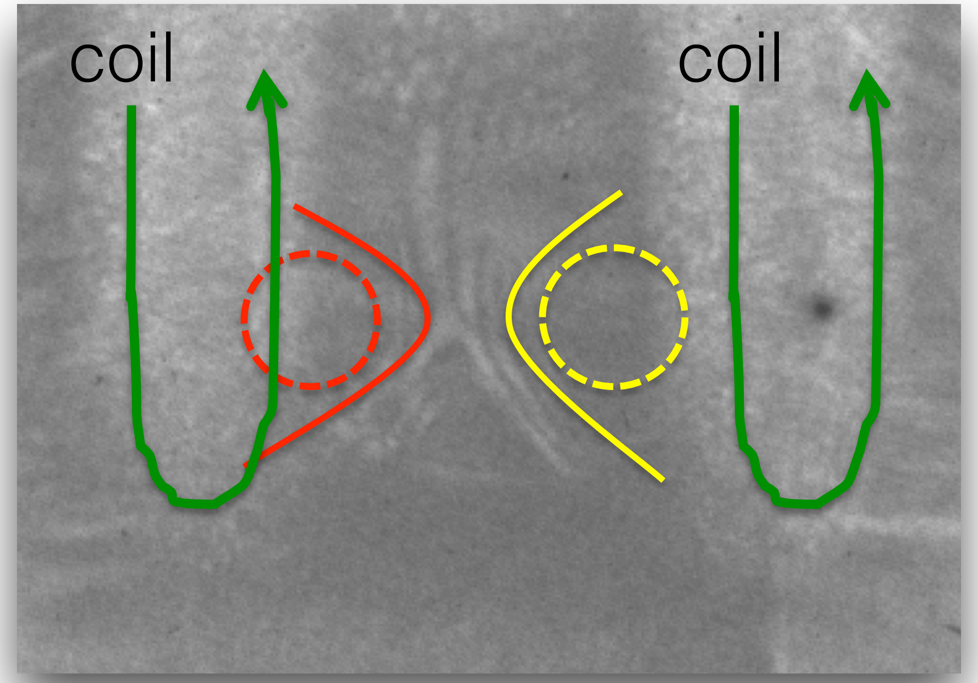
Recent Progresses on laser driven magnetic reconnection experiments





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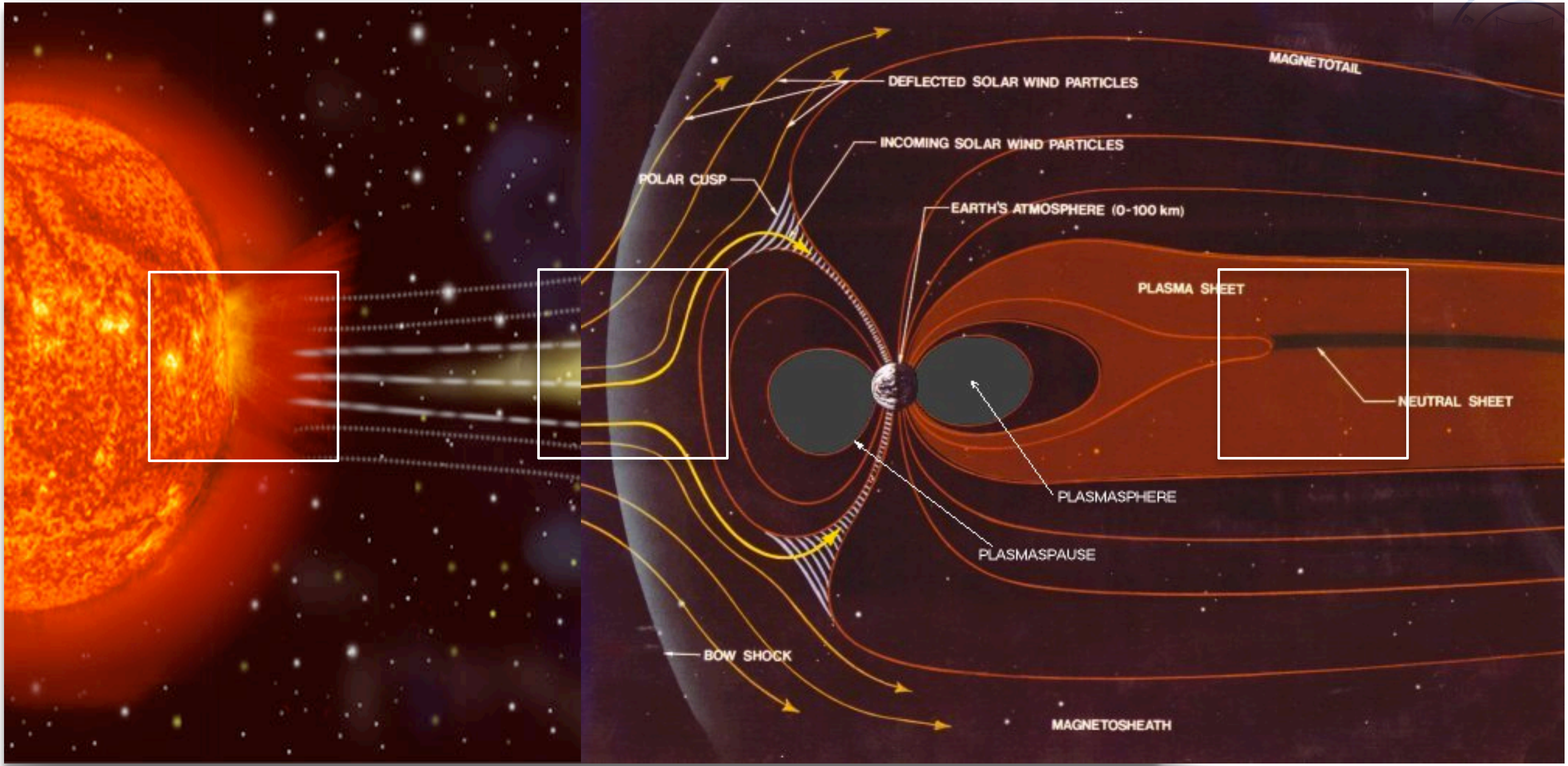
Magnetic Reconnection in Plasmas

Nordita, Stockholm, Sweden
Aug 10 - 14 , 2015

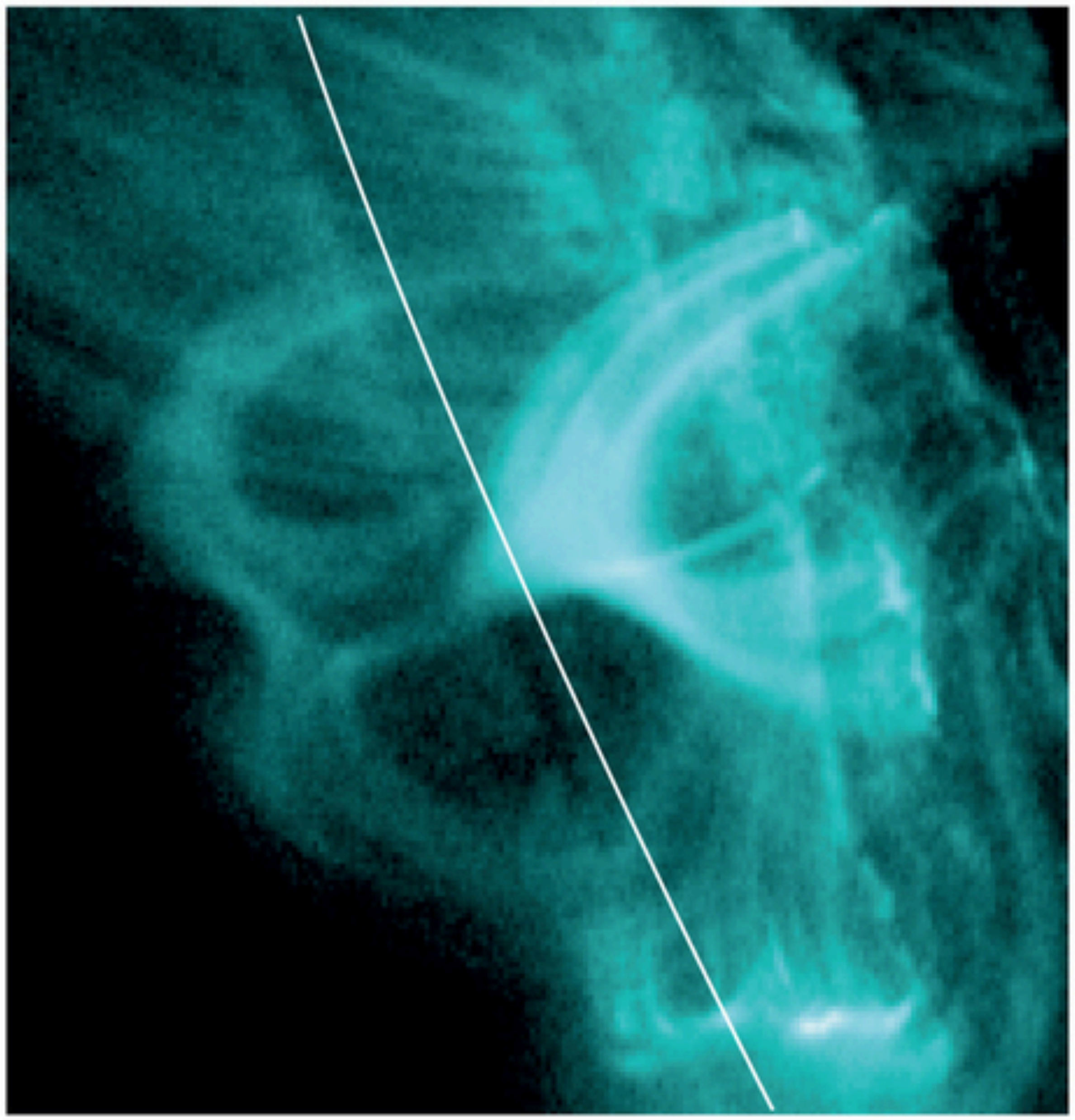
Outline

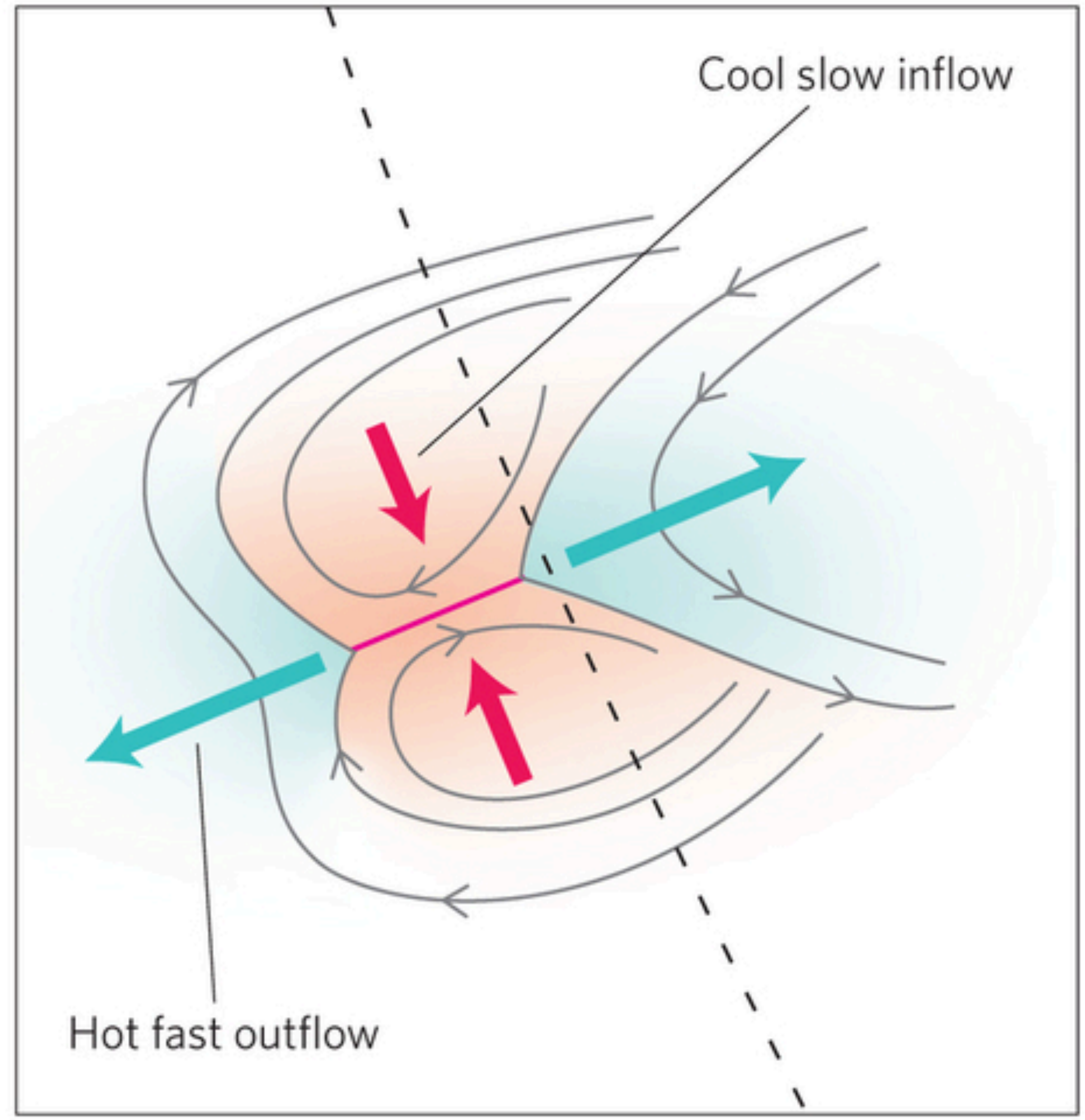
1. Magnetic reconnection Phenomena
2. Magnetic reconnection experiments on SGII
3. Opportunities for Laser driven reconnection
4. Summary

1. Magnetic reconnection Phenomena
- In solar flares and space environment



Observations from NASA's Solar Dynamic Observatory provide compelling evidence for the central role of magnetic reconnection in solar flares.

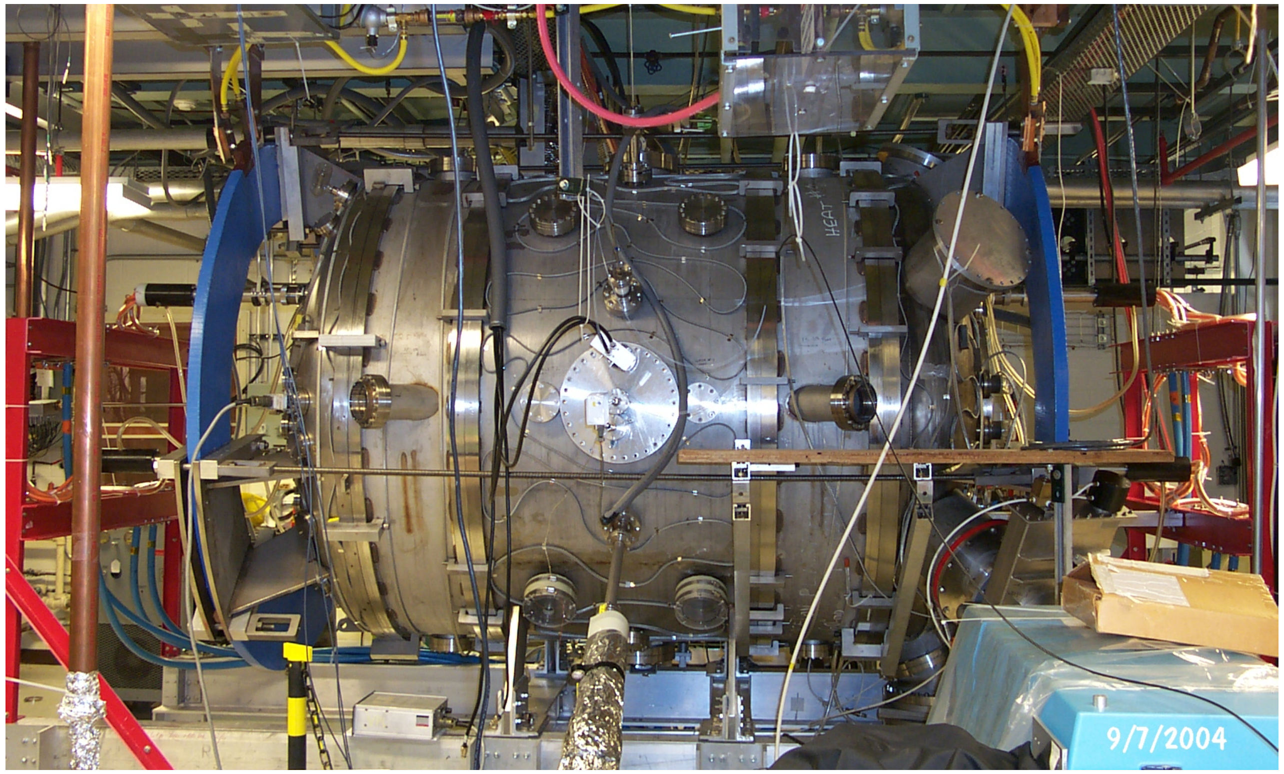


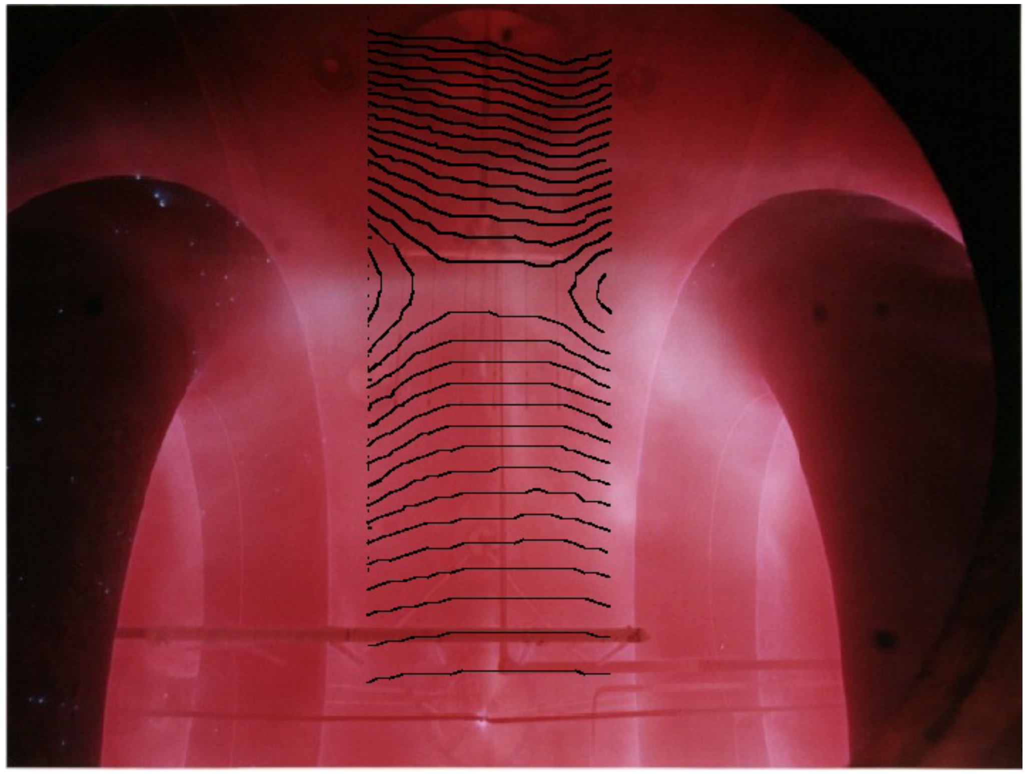


Y. Su et al (2013)

Magnetic reconnection Phenomena
- In Lab plasmas

Magnetically driven systems





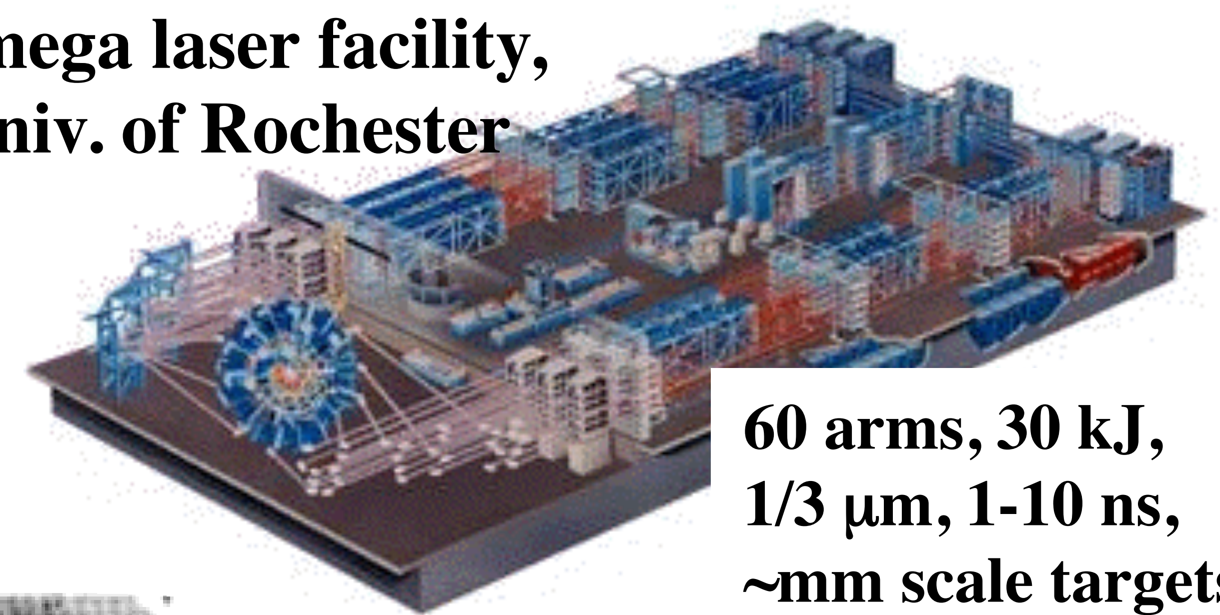
MRX at Princeton for reconnection studies

ne= 1-10 x10^{13} cm^{-3}, Te~5-15 eV, B~100-500 G

Magnetic reconnection Phenomena
- In Lab plasmas

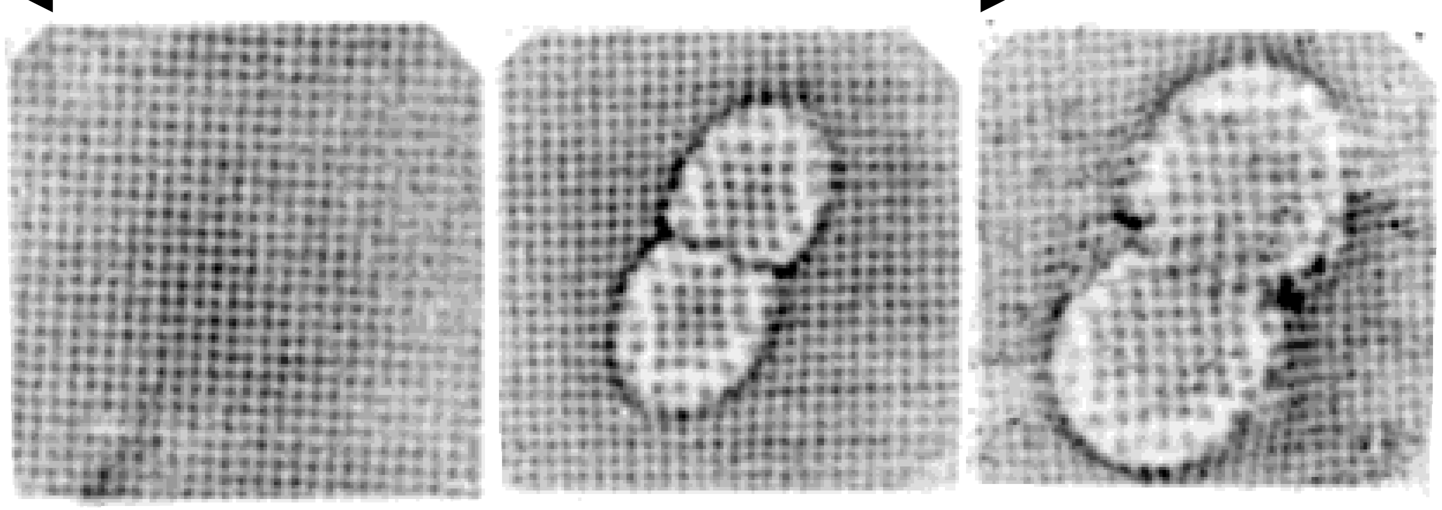
Flow driven systems

Omega laser facility, Univ. of Rochester



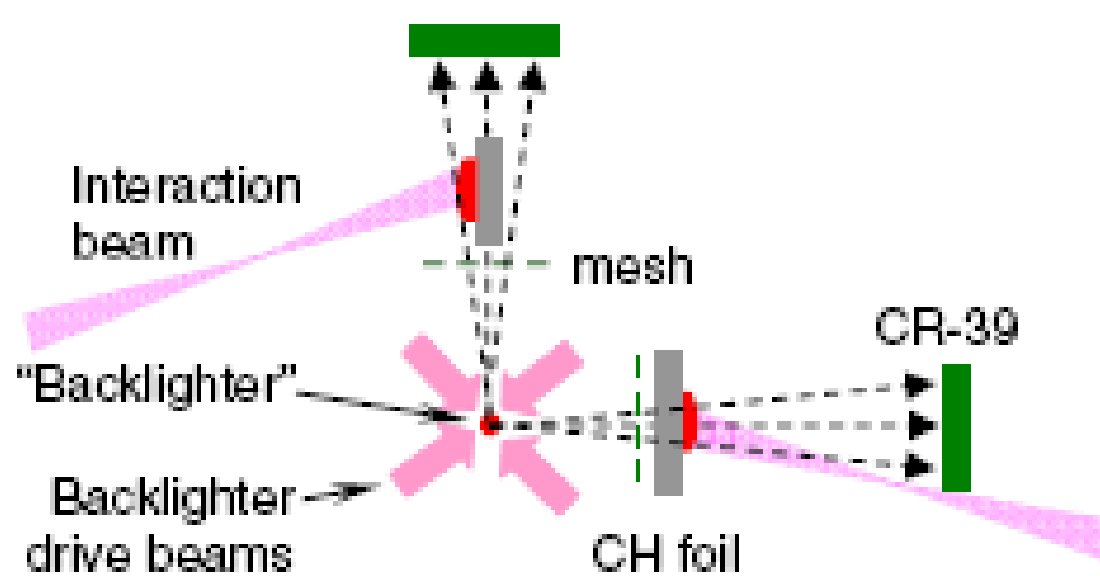
60 arms, 30 kJ, 1/3 μm, 1-10 ns, ~mm scale targets (E/V ~ 10^{14} erg/cm^3)

Laser on from 0 – 1 ns



0.04 ns **0.67 ns** **1.42 ns**

C. K. Li et al. (2007)



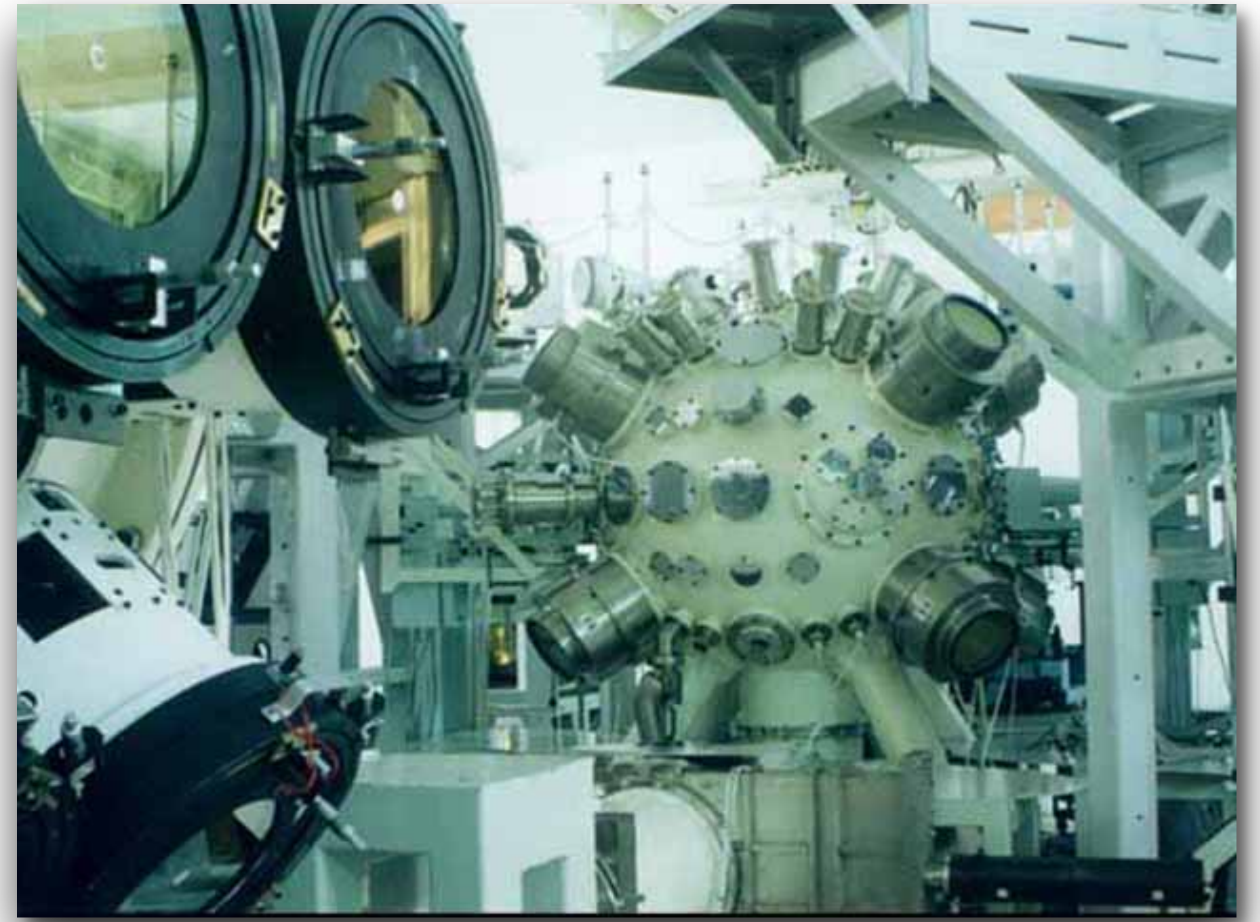
2. Magnetic reconnection experiments on SGII

- What is SGII

SG II Lasers
Beams: 8
Pulse: 1 ns
Energy: 260 J/beam for 3ω
Focus spot: 50-100 μm
Intensity: 1-5×10^{15} W/cm^2

ne= 1-10 x10^{19} cm^{-3}, Te~1keV, B~10^6 G

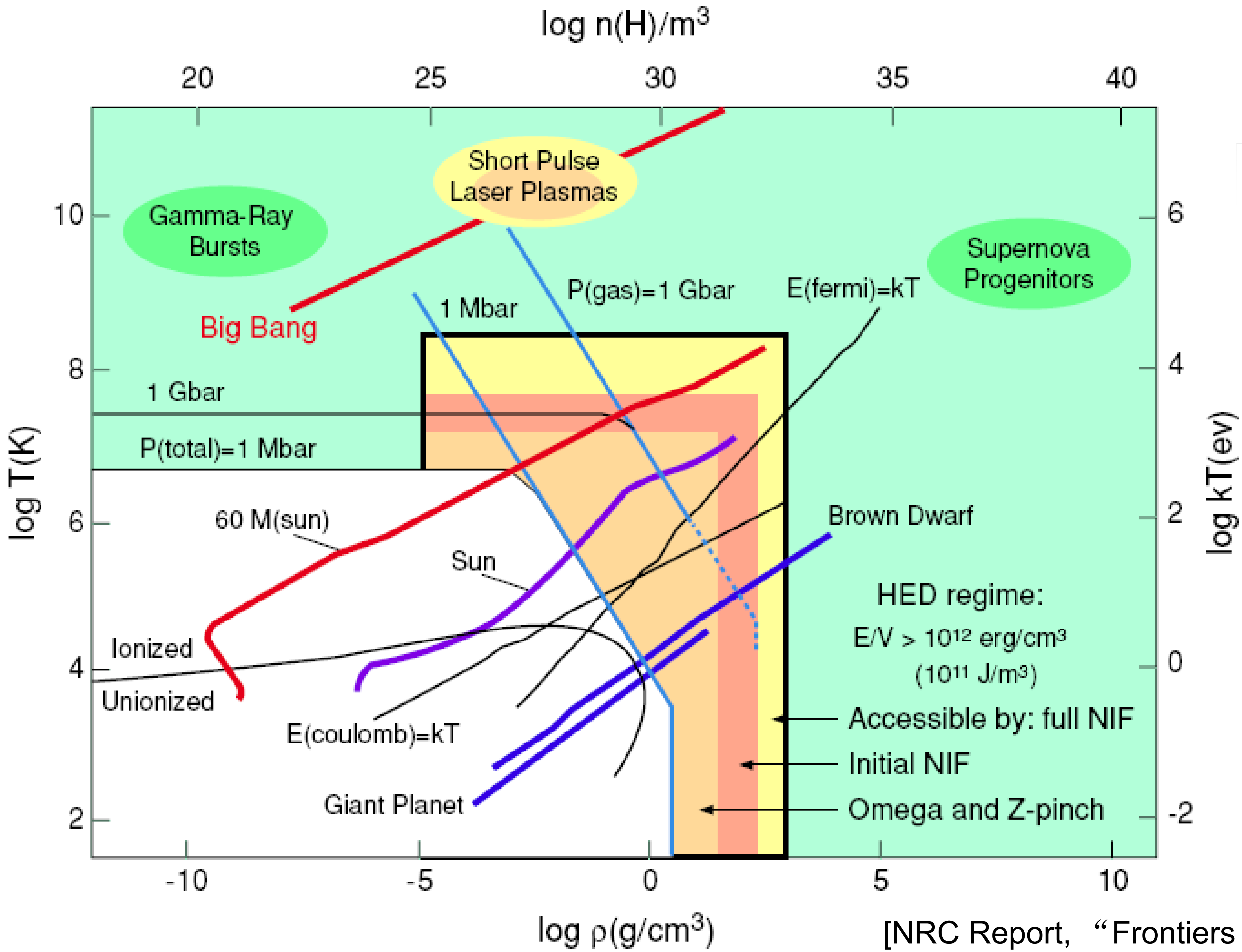
- What is SGII



Diagnostics:
X-rays: pinhole, framing,...
Optical devices:
shadowgraphy,
Interferometry,
Faraday, ...
Particles: EMS, RCF...

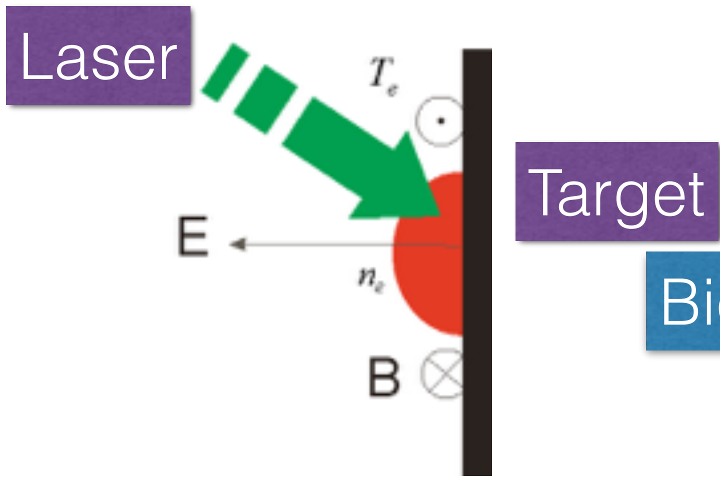
- Like other Advanced HEDP Facilities: NIF, OMEGA, Z,... ...
- SG II is used to study fusion, laboratory astrophysics, ...
- In China, 20% shots of Shenguang II for each year are given for the study of Laboratory astrophysics

High energy density laboratory astrophysics (HEDLA)-similar with IPELS

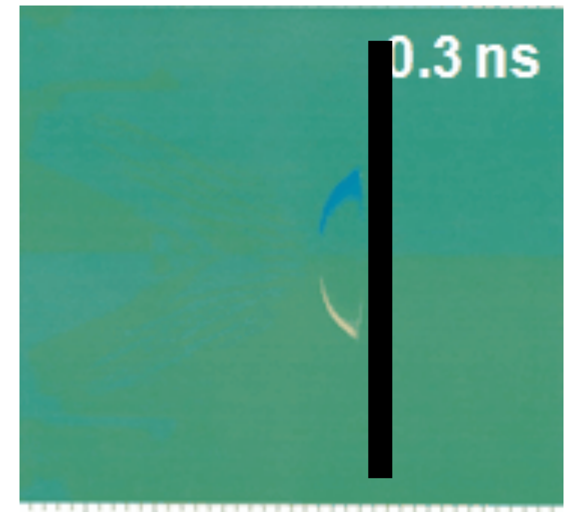


[NRC Report, "Frontiers in HEDP," Ron Davidson et al. (2003), Fig. 1.1

Magnetic field in ns laser plasmas

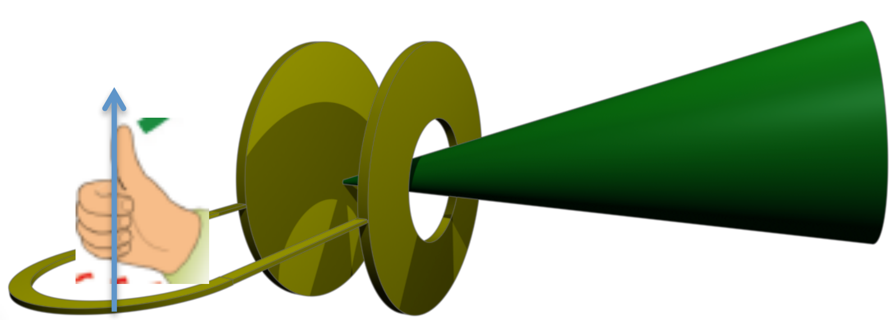


Biemann's battery mechanism



$$\frac{\partial \boldsymbol{B}}{\partial t} \approx -\frac{\nabla n_e \times \nabla T_e}{e n_e} + \nabla \times (\boldsymbol{v} \times \boldsymbol{B}) - \nabla \times (D_m \nabla \times \boldsymbol{B}) + \frac{m_e}{e} \nabla \times \left[\frac{\partial \boldsymbol{v}}{\partial t} + \boldsymbol{v} \nabla \boldsymbol{v} \right] - \frac{\nabla \times \boldsymbol{R}}{e n_e} + \nabla \times \boldsymbol{Q} - \nabla \times \boldsymbol{G}$$

Capacity mechanism



Laser

Target

$$I(t) \propto \frac{T_h \log \left[\frac{E_{laser}}{T_h^2} \right]}{n} \left(1 - e^{\frac{-\eta t}{\mu}} \right)$$

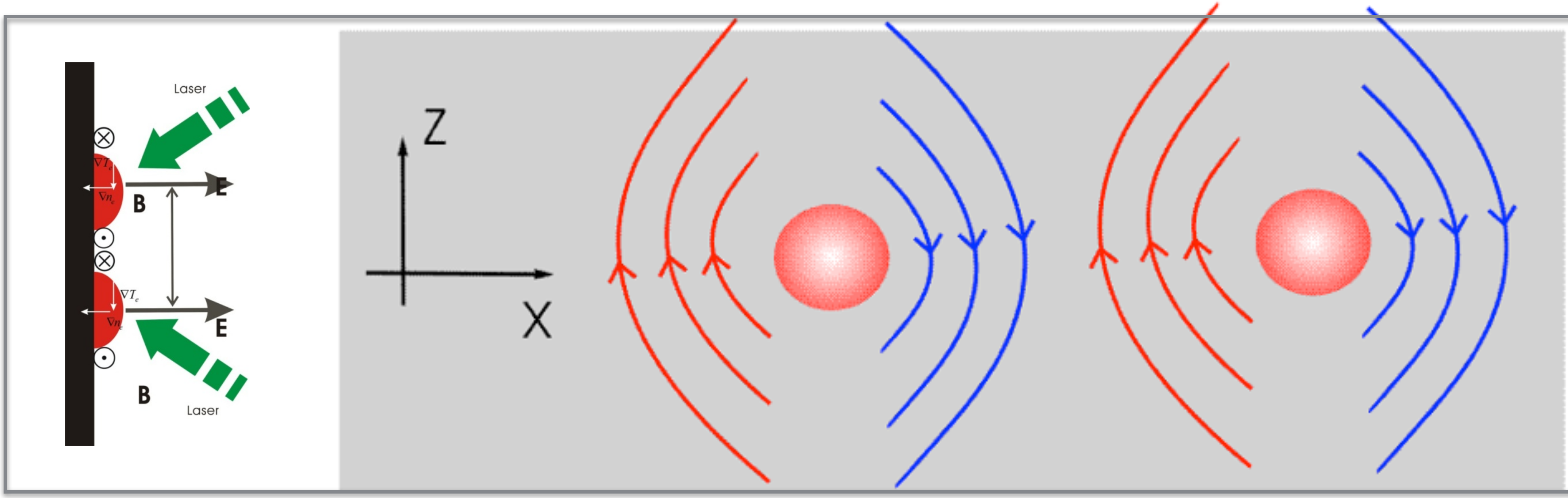
$$B(t) \propto \frac{\mu_0 I(t)}{2a}$$

Laser driven magnetic reconnection opens a new territory of study for magnetic reconnection in a parameter regime not covered before

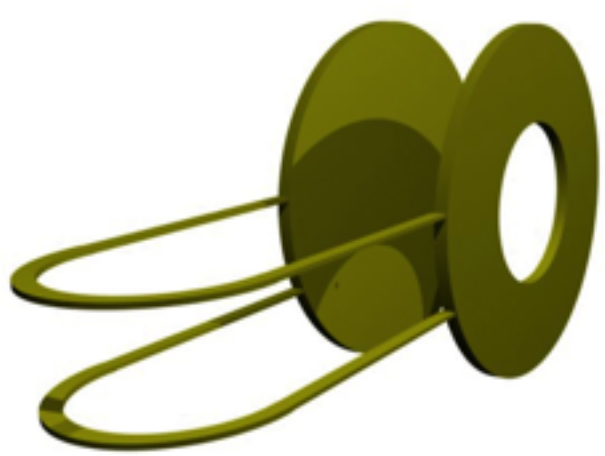
Parameters	Laser-produced plasmas	Coil plasmas
Length (cm)	10^{-1}	10^{-1}-1
Time (s)	10^{-9}	10^{-9}-10^{-8}
Pressure (Pa)	10^{7}	
Density (cm^{-3})	~10^{19}-10^{20}	$<10^{18}$
Velocity ($km\ s^{-1}$)	~100	100-1, 000
Magnetic field (G)	~10^{6}	10^{6-7}

$\beta = 4.03 \times 10^{-11} n T B^{-2}$ 0.001-100

B is frozen in Plasmas

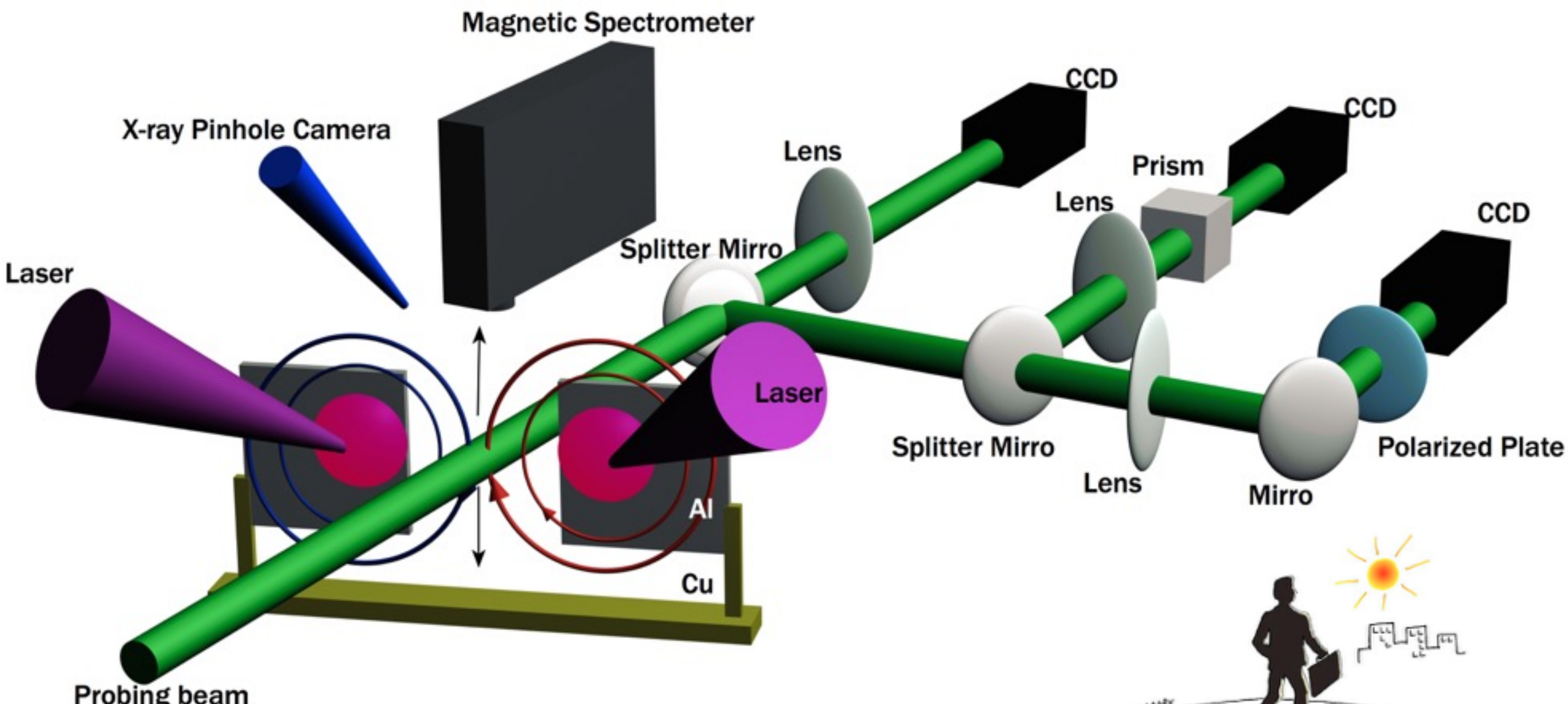


B is separated with Plasmas



The coil will be ionized by the radiation from the laser produced plasmas, while the density is lower.

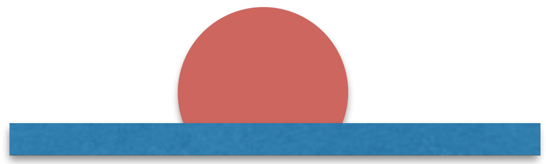
Experiments on Laser-Flow driven MR

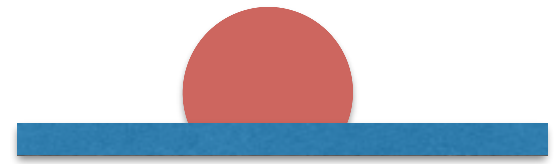


Experimental setup

Experiments on Laser-Flow driven MR

1. Reconnection effects in hydro-interaction



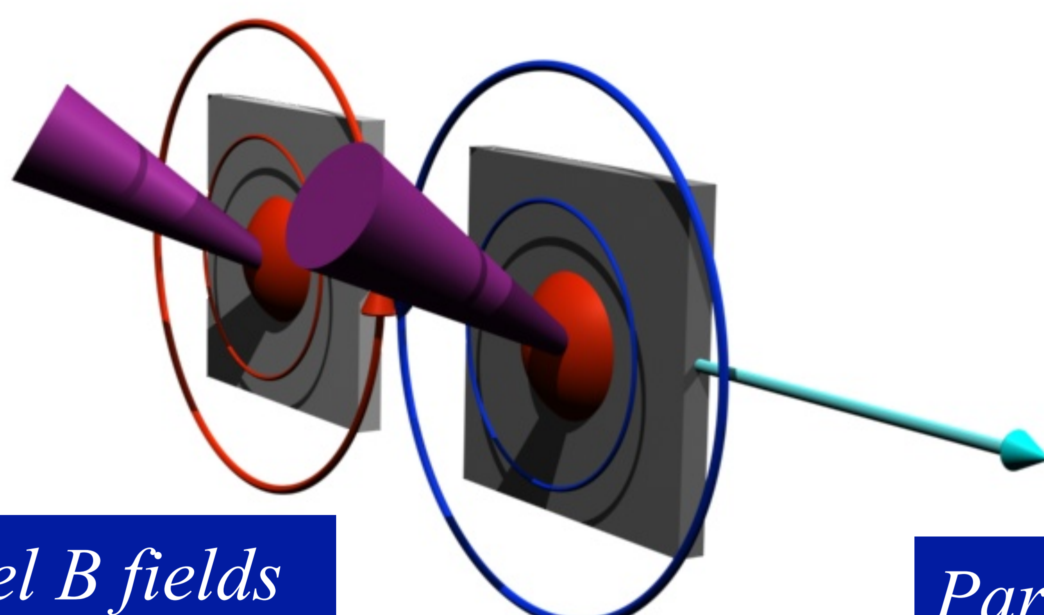


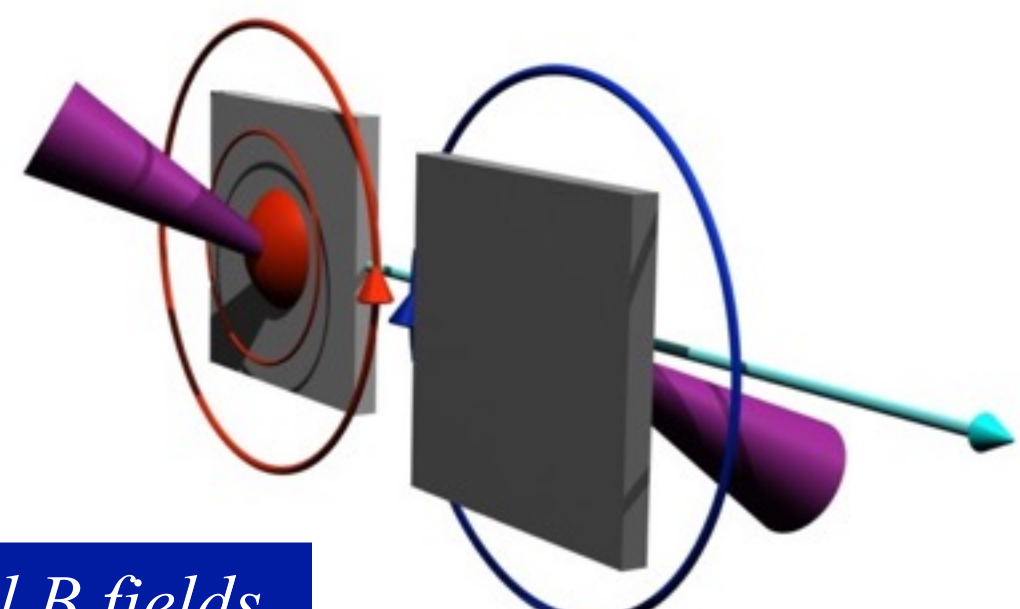
$$\rho\frac{du}{dt} = -\nabla(\frac{B^2}{2} + p) + B\cdot\nabla B$$

Magnetic repulsion

Hydro

Magnetic reconnection





Anti-Parallel B fields

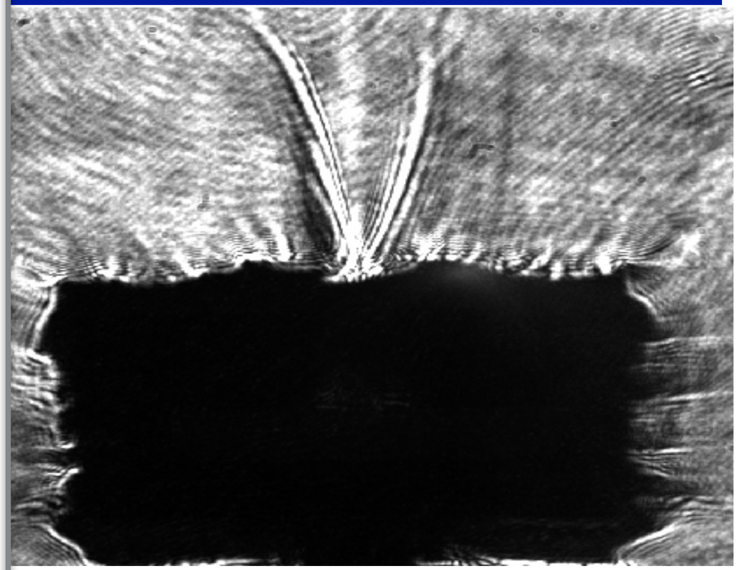
$$\rho\frac{du}{dt} = -\nabla(\frac{B^2}{2} + p) + B\cdot\nabla B$$

Parallel B fields

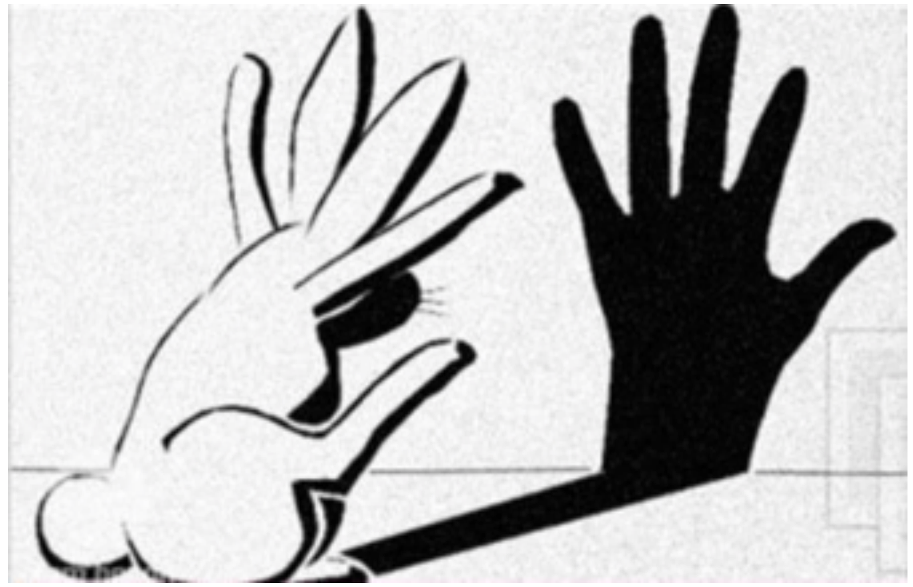
$$\rho\frac{du}{dt} = -\nabla(\frac{B^2}{2} + p)$$

The shadowgraph together with X-ray images show the topology of magnetic reconnection with laser driven flow plasmas, confirmed by MHD simulation.

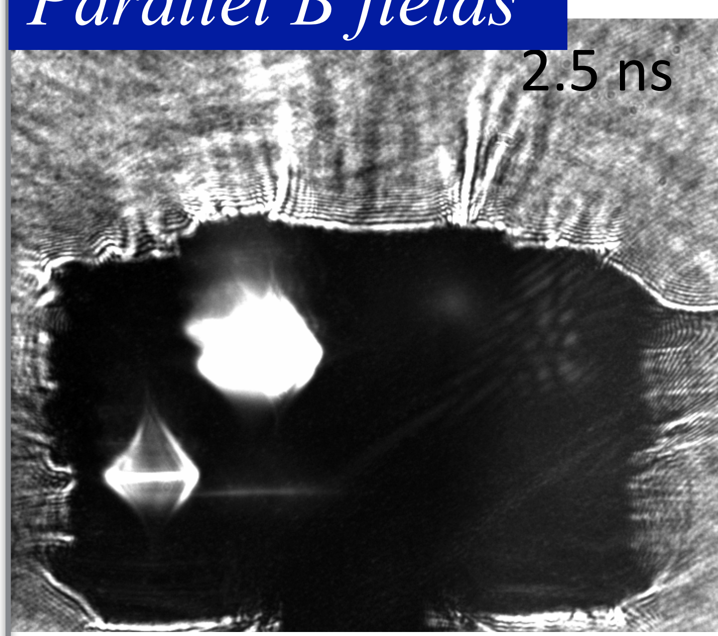
Anti-Parallel B fields



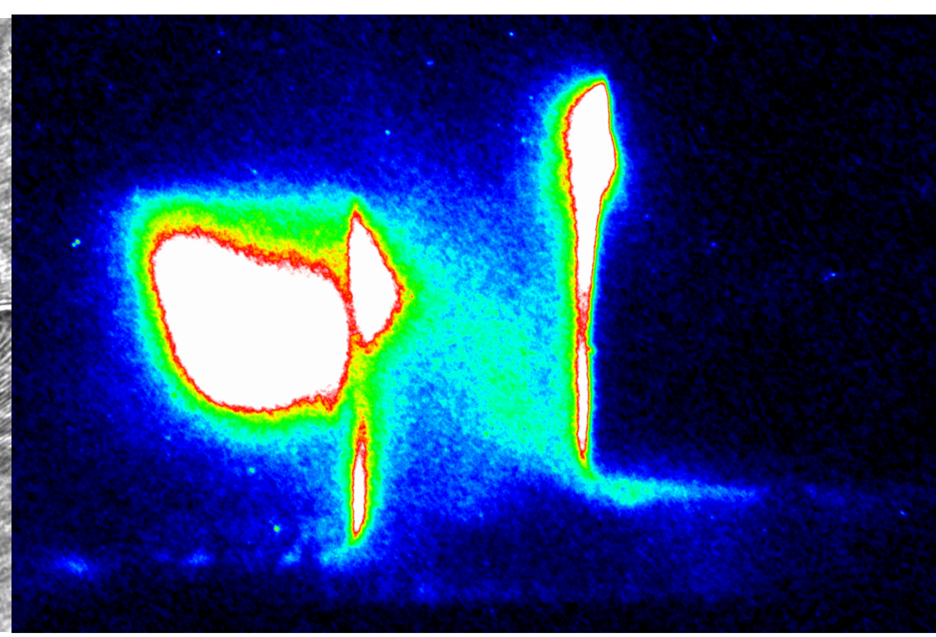
Optical shadows



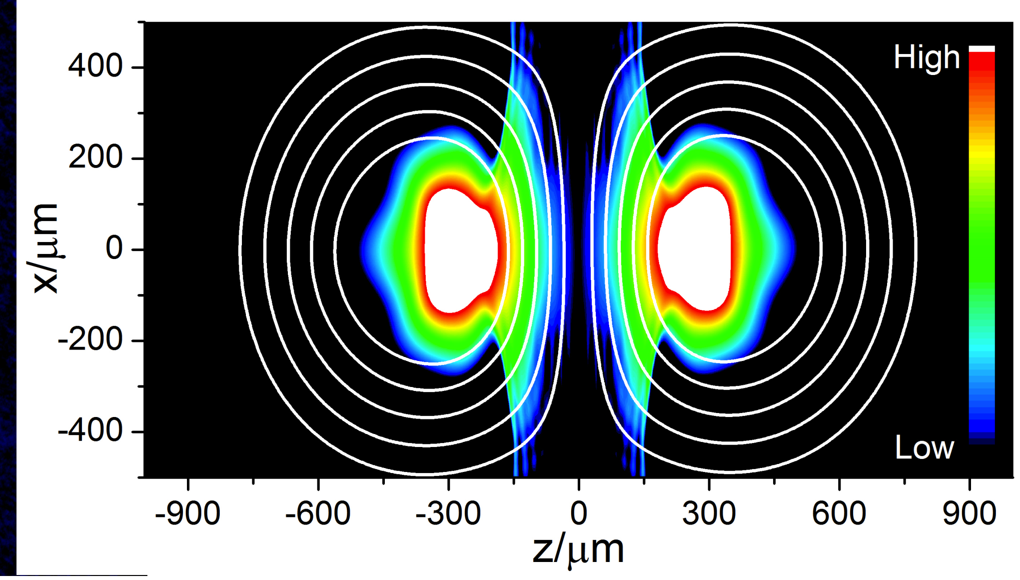
Parallel B fields



Optical shadows



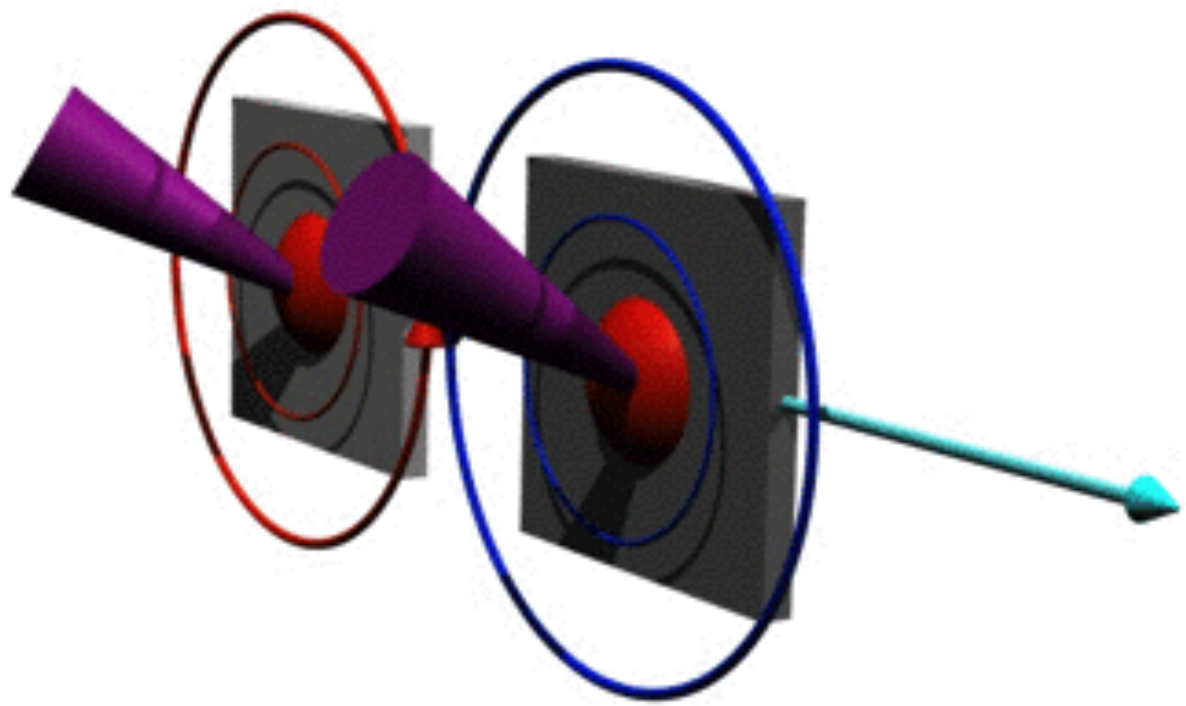
X-ray image

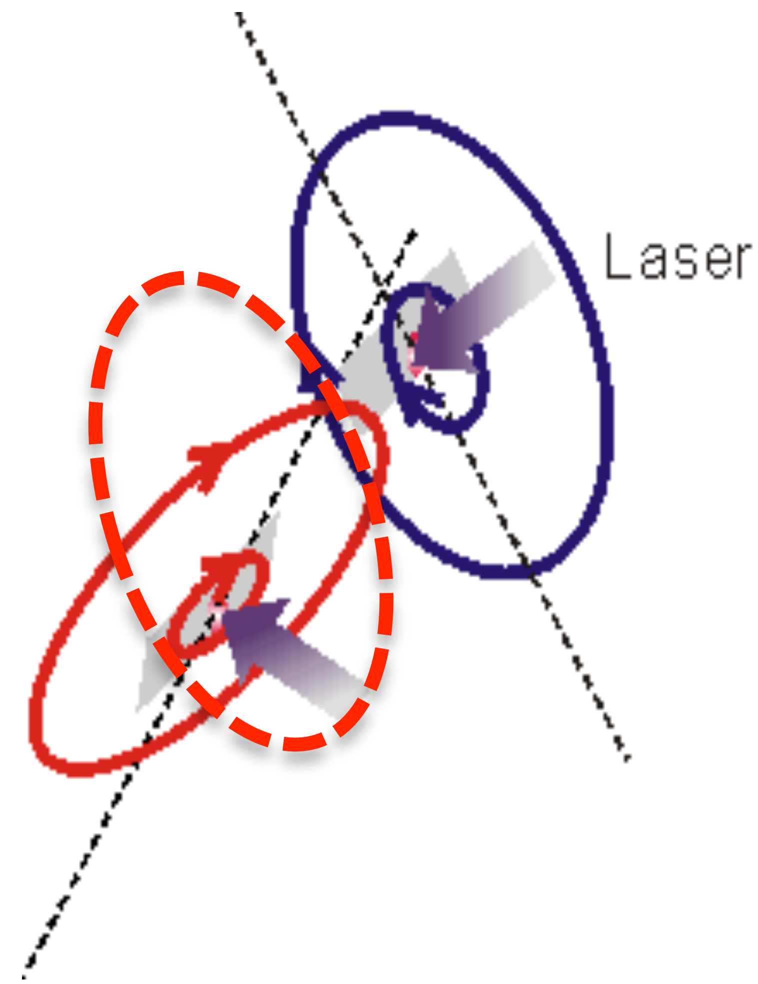


MHD simulation

Experiments on Laser-Flow driven MR

2. Reconnection effects for guide fields

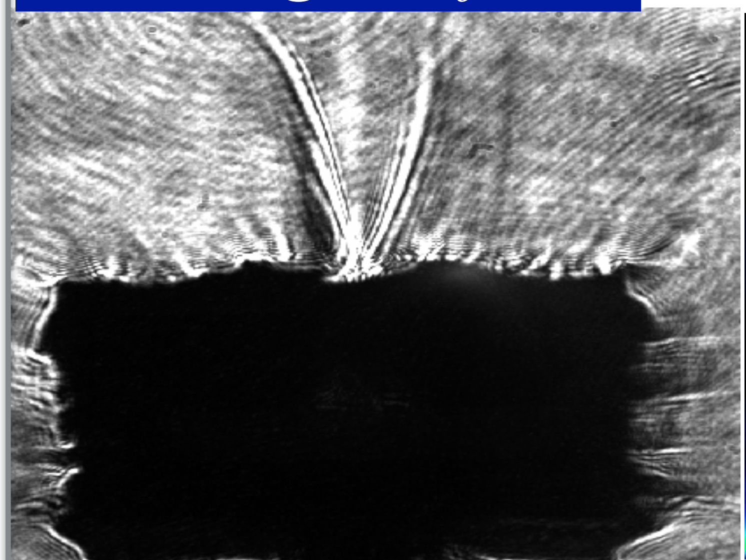




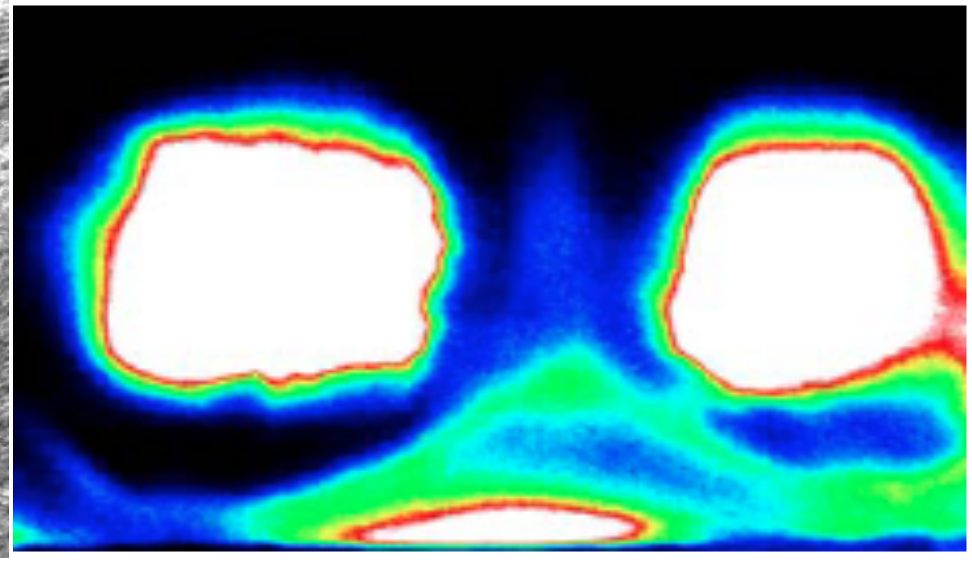
The toroidal magnetic field on the target will produce a magnetic field component at the reconnection plane which is similar provide an applied guide field with the level of the reconnection field.

Guide field do affect the reconnection both for the current sheet and outflows.

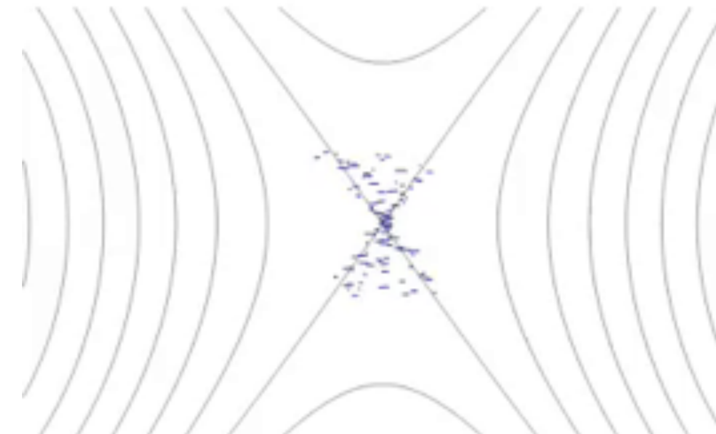
Without guide field



Optical shadows

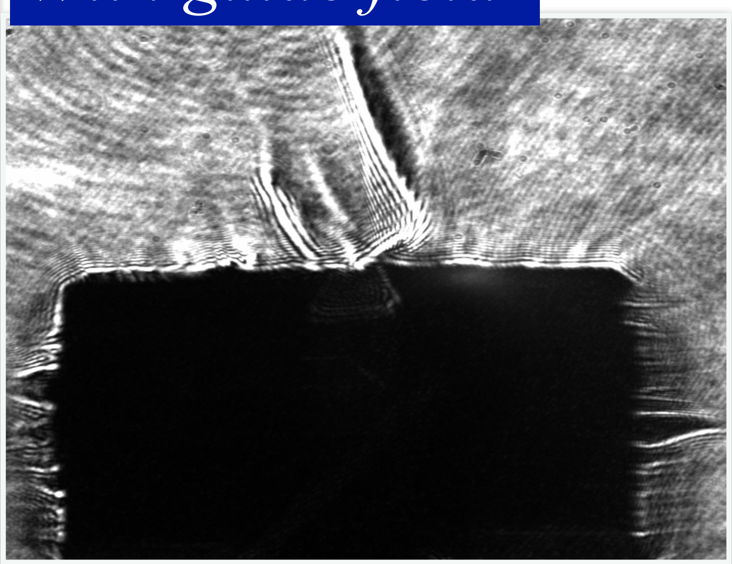


X-ray image

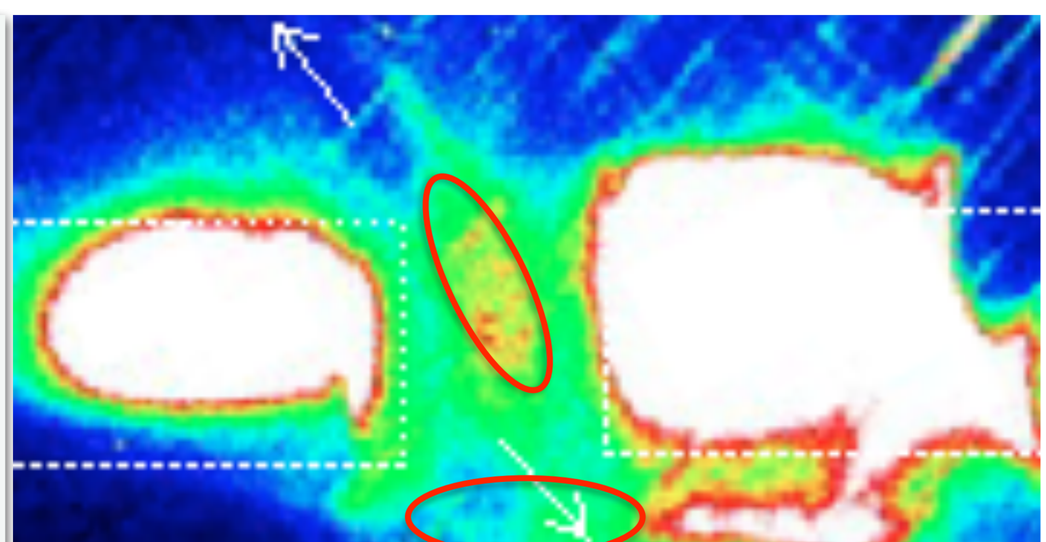


MHD +test particles simulation

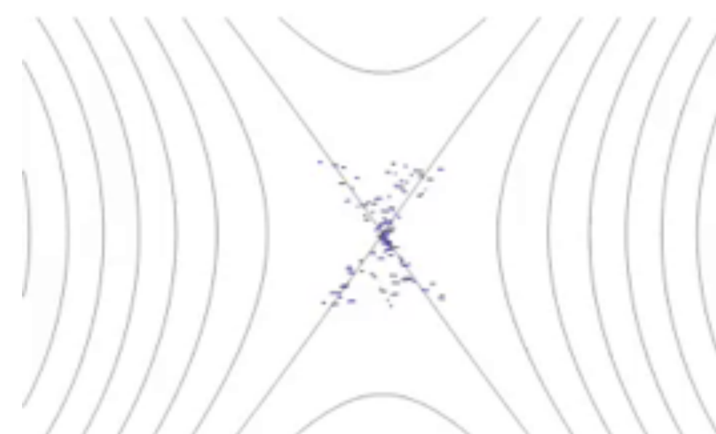
With guide field



Optical shadows

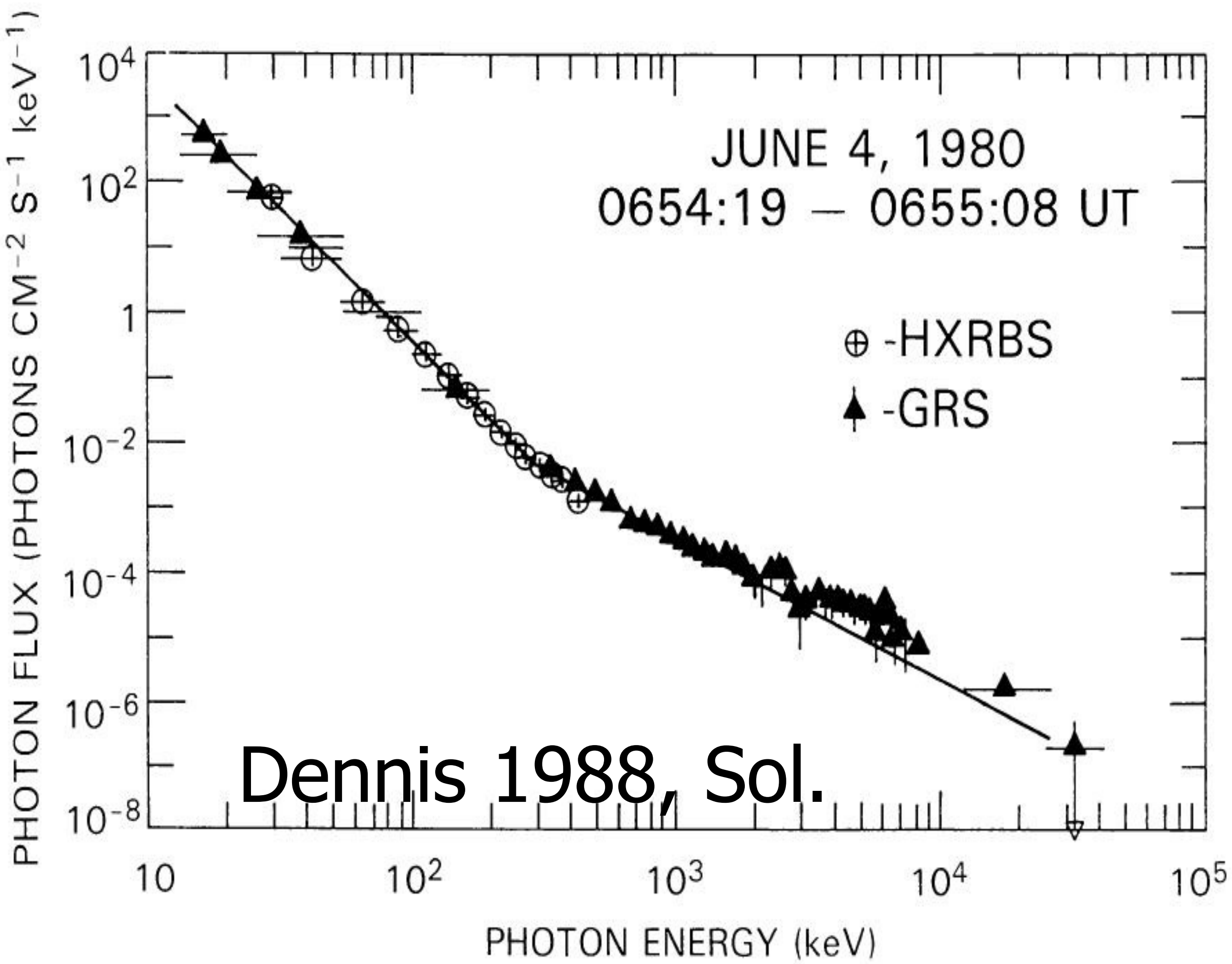


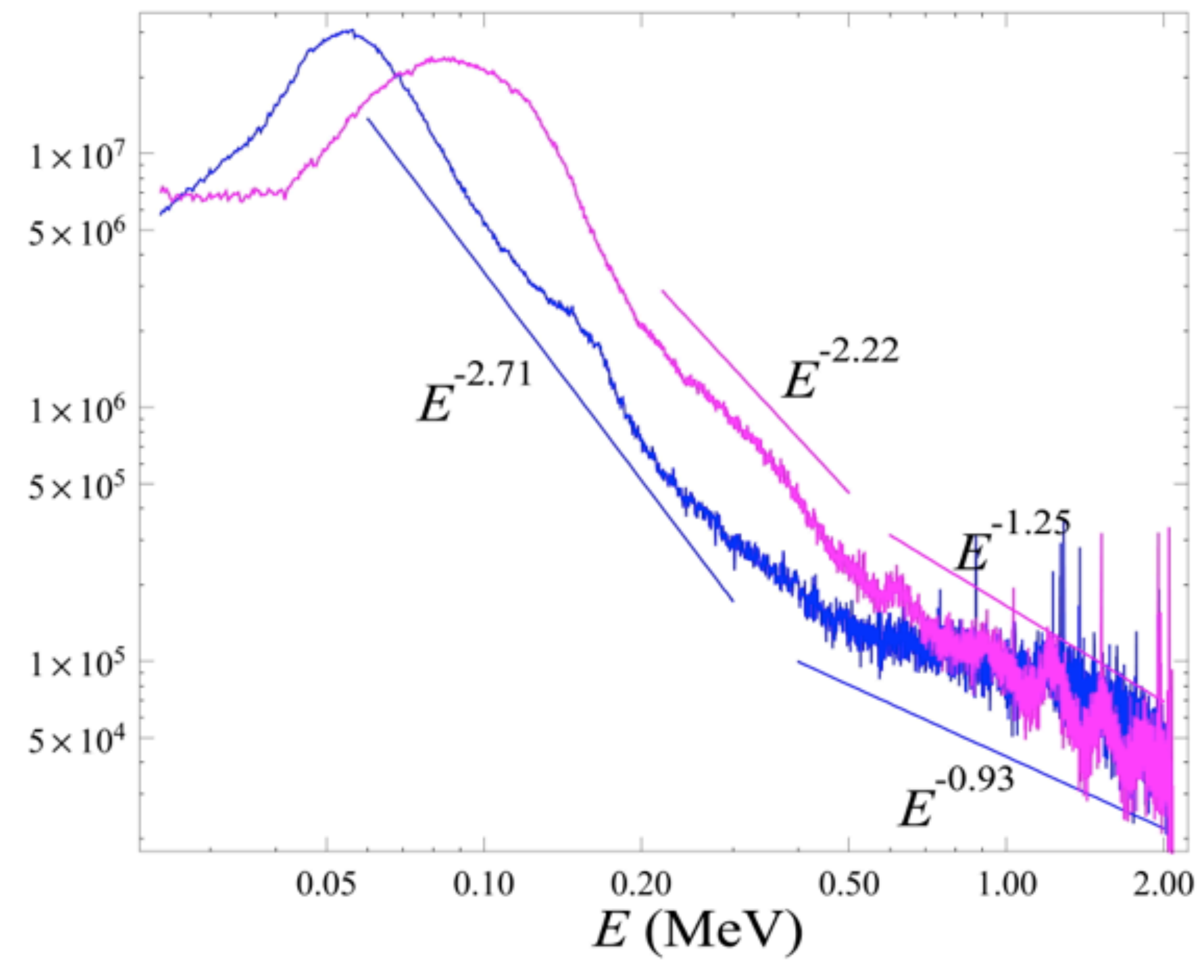
X-ray image



MHD +test particles simulation

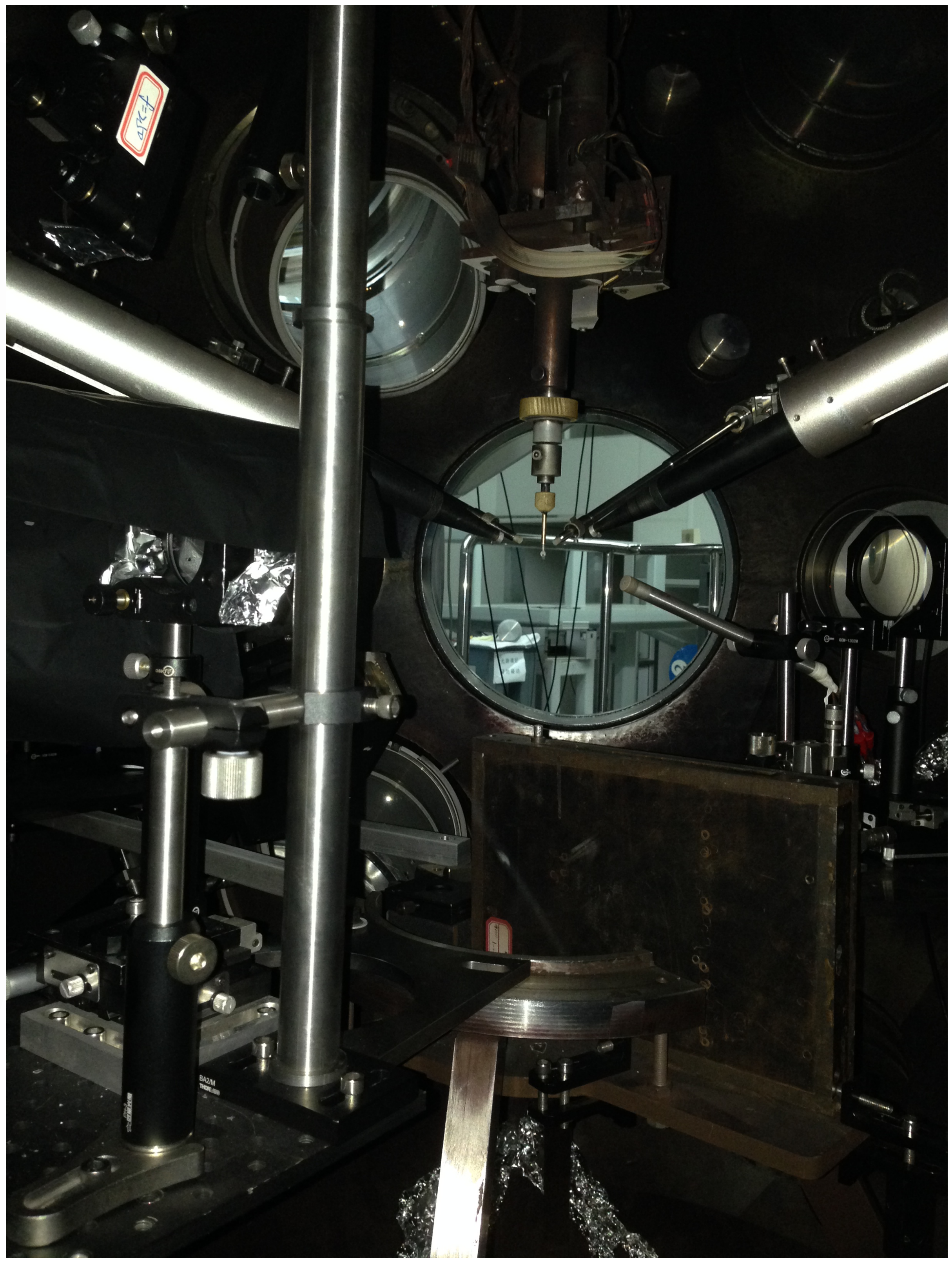
The observed energy spectra of energetic electrons shows the similar distribution with the one observed in space plasmas.

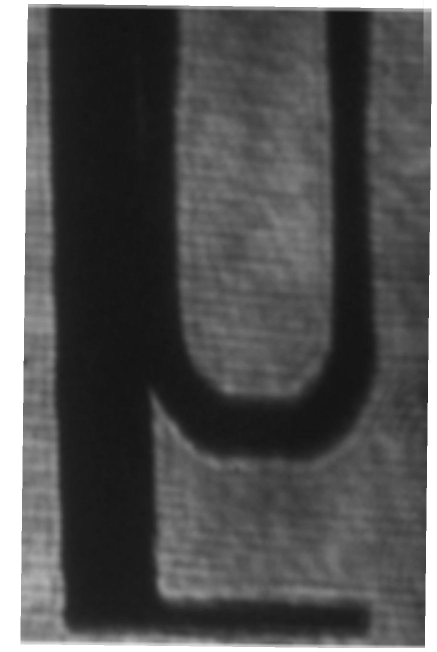




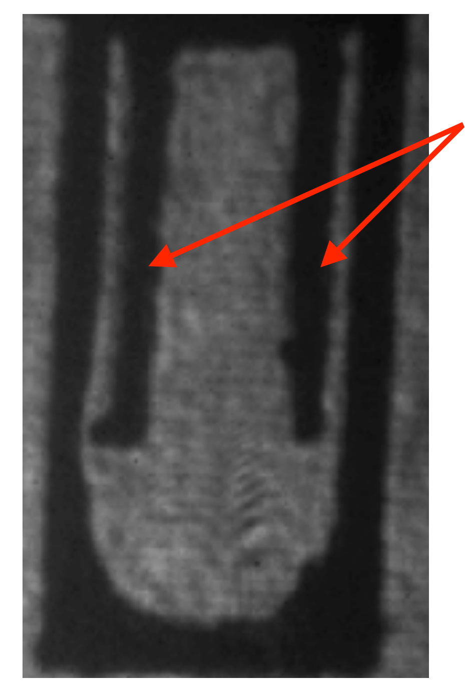
The spectra are obviously of the so-called Kappa distribution that is quasi-Maxwellian at low and thermal energies, while its non-thermal tail decreases as a power law at high energies, as generally observed in space plasmas.

Experiments on Laser-magnetically driven MR



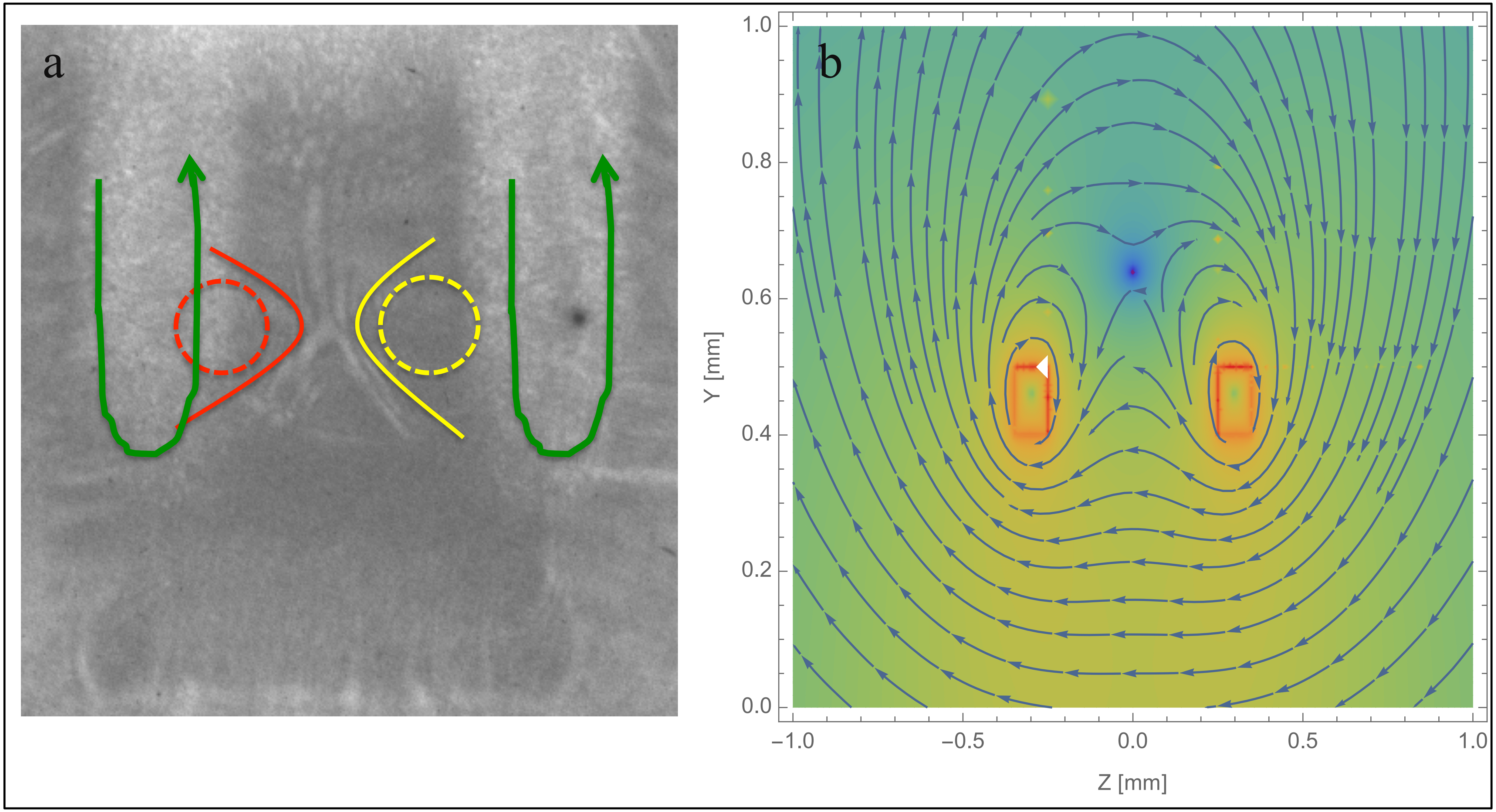


Side view



Front view

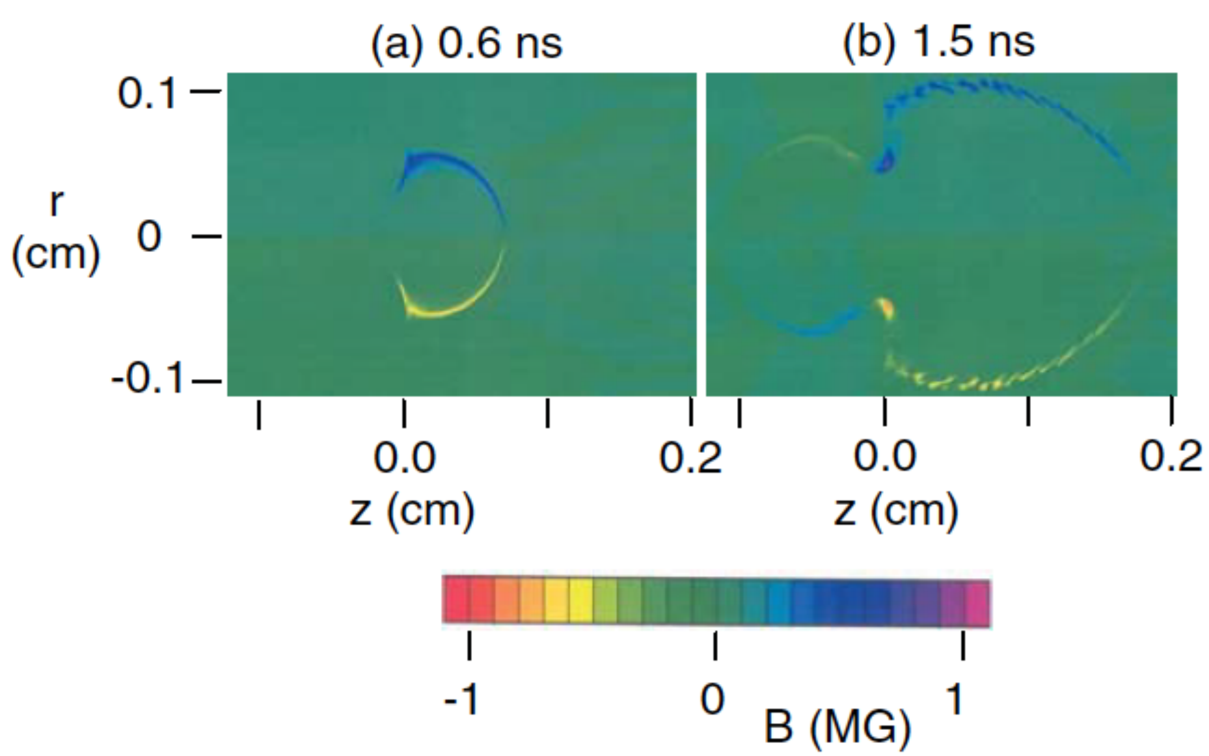
Shadowgraphy shows the shape of plasmas exhibiting with a X-type reconnection. A magnetostatics computer code Radia is applied to construct magnetic topology of the present coil target.



Opportunities for Laser driven reconnection

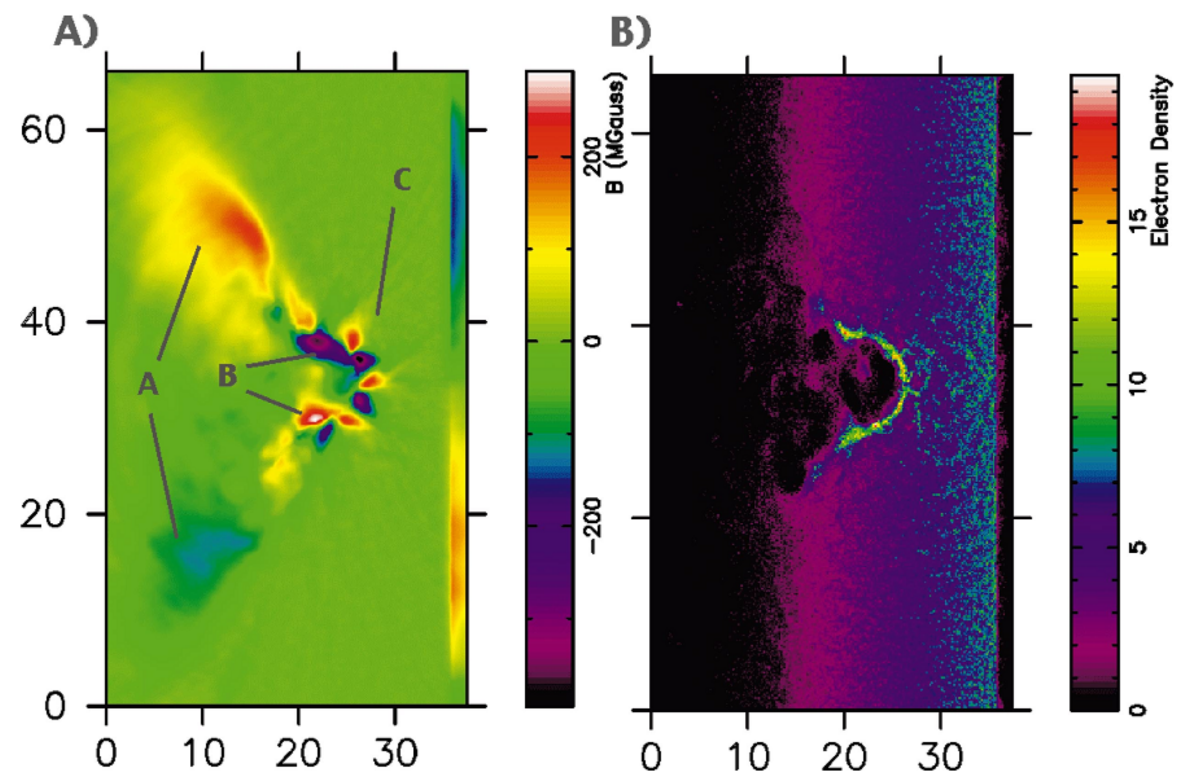
Magnetic fields from "long pulse" laser to "short pulse" laser

ns lasers



C.K. Li et al 2007

fs lasers



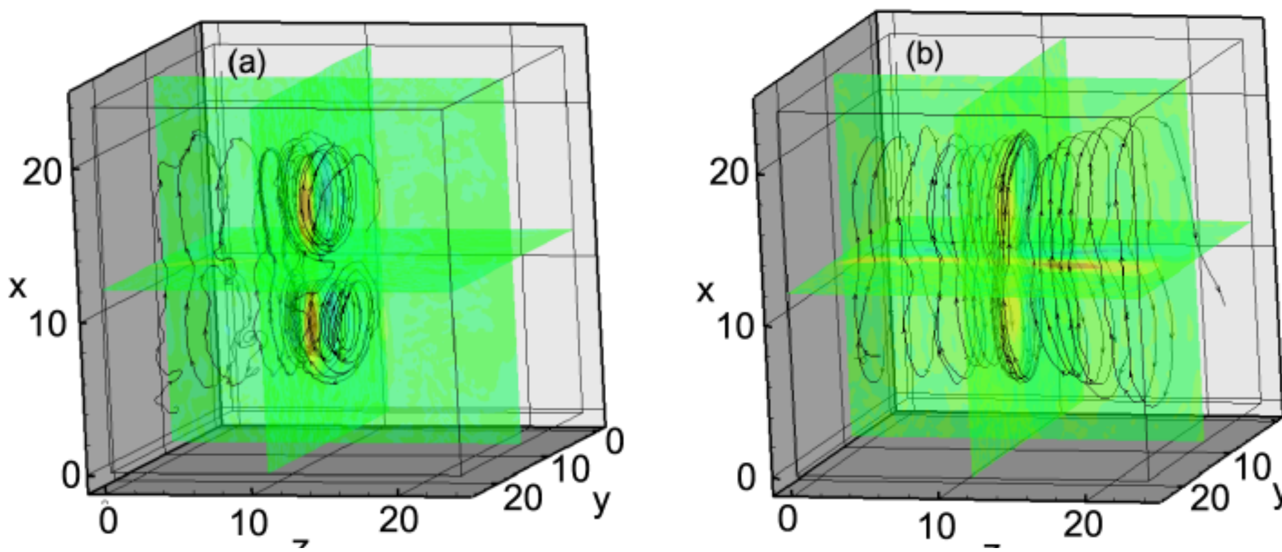
U. Wagner et al 2004

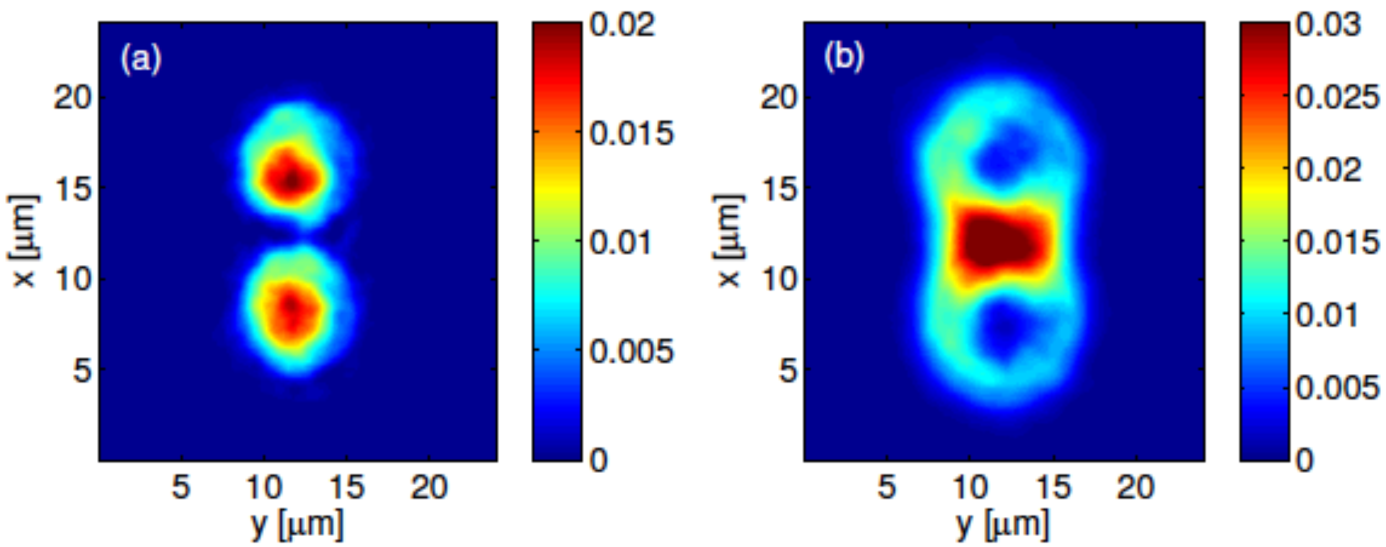
10^6 Gauss to 10^9 Gauss

Opportunities for Laser driven reconnection

Before

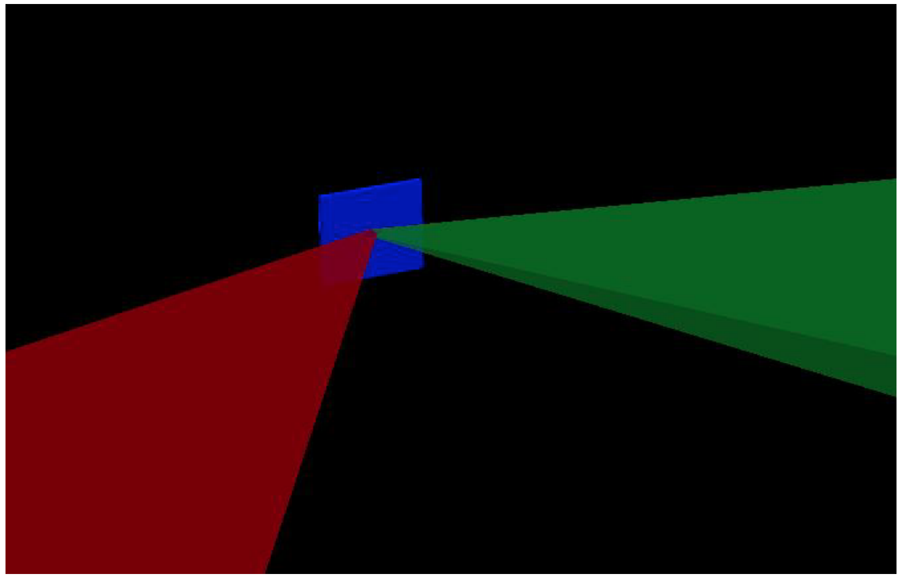
After





Three-dimensional fast magnetic reconnection driven by *two ultraintense femtosecond laser pulses* is investigated by relativistic particle-in-cell simulation

Omega EP



Key challenges:

- co-time of multi beams
- effect from beam itself
- diagnostic …

Summary

- Magnetic reconnection is a basic dissipation process in laboratory, space and astrophysical plasmas.
- Some basic reconnection physics is being studied in *flow driven systems, such as guide field, electron acc.*
- New opportunities for HED experiments to study reconnection.
- Relativistic intensity short pulse lasers are hoping to perform the reconnection experiments with GG-B field.
- With special target, such as capacity target, realizing *magnetically driven systems* and *flow driven systems*, enable to extend a large rang of parameter space for reconnection.