Laser driven magnetic reconnection experiments on Shenguang II

Jiayong Zhong

Key Laboratory of Optical Astronomy, National Astronomical Observatories, Chinese Academy of Sciences

Feb 13, 2012, Rochester University
Astrophysics and HEDLP Collaboration Meeting

Collaborators

- NAOC: **Gang Zhao**, Feilu Wang, Huigang Wei, Kai Zhang, Yongli Ping

- IOP/SJTU: **Jie Zhang, Yutong Li**, Quanli Dong, Xun Liu, Shoujun Wang, Xiaoyuan Lin, Lei Zhang, Dawei Yuan, Fei Du, Lin An

- PKU: **Xiaogang Wang**, Jiaqi Wang, Chijie Xiao

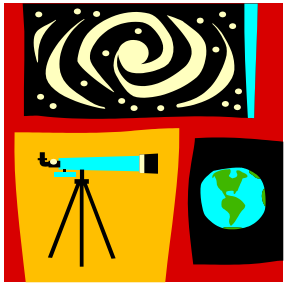
- IAPCM/PKU/ZJU: **Xiantu He**, Hongbo Cai

- We acknowledge the Shenguang II staffs for operating the laser facility, CAEP-RCLF staffs for providing some diagnostics and target fabrication.

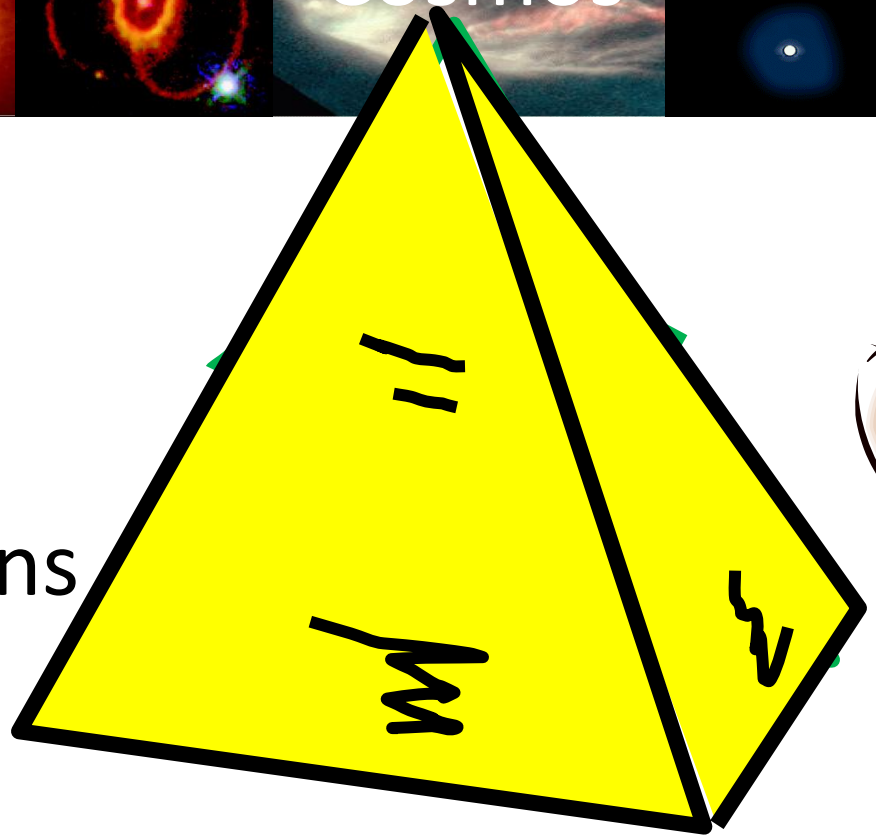
Outline

- High energy density laboratory astrophysics
- Laser driven magnetic reconnection (LDMR)
- LDMR experiments on Shenguang II
- Summary and future collaborations

High energy density laboratory astrophysics



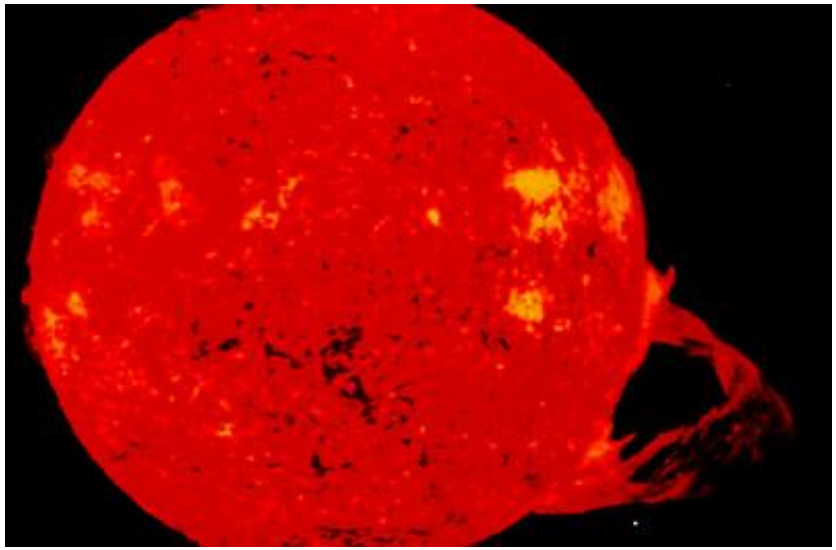
Observations



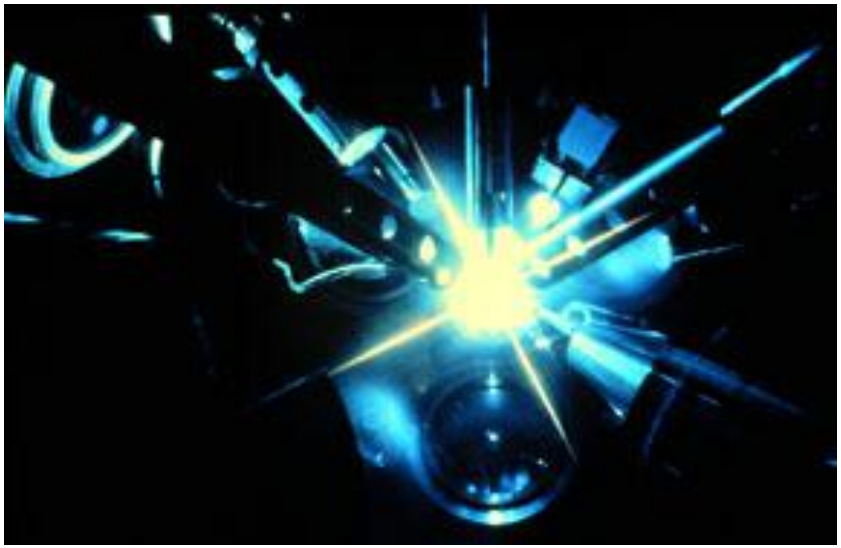
Models

Laboratory Astrophysics -HEDLA

HEDLA



Gravitational confinement fusion



Inertial confinment fusion

- The study of Controlled Fusion opens the field of Laboratory Astrophysics
- Advanced HEDP Facilities are involved in this area: NIF, OMEGA, Z,… …
- In China, 10% shots of Shenguang II for each year are given for the study of LA

— *Many works shown HEDLA is progressing*

- Review Papers:

— Remington, B. A., Arnett, D, Drake, P & Takabe H., *Science* **284**,1488(1999)
— Remington, B. A., Drake, P & Ryutov, *Rev. Mod. Phys.* **78**, 755-807 (2006)

- More Recent progress:

— **Sameness** of physics, Measurement of fundamental material properties: Opacity, EOS (Wei 2008)

— **Similarity** of physical dynamics-exploration of astrophysical phenomenology under controlled lab conditions: Photo-ionized plasmas (Fujioka 2009, 2010), Plasmas jets and reconnections (Zhong 2010)

— **Resemblance** of physics, Shock and glaxy field (Morita 2010, Park 2011, Kuramitsu 2011, Gregori 2012)

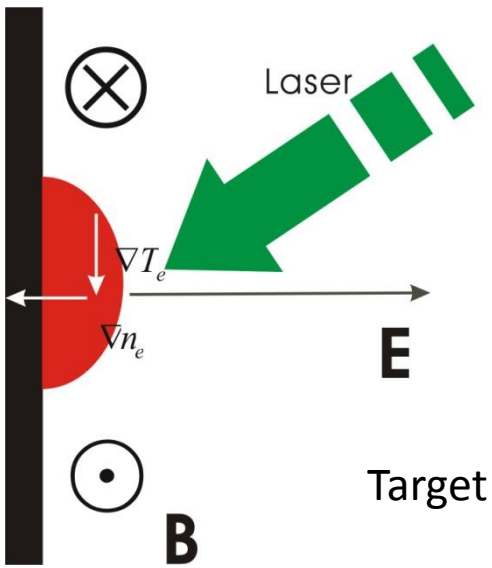
What can be studied in HEDLA?

	1. Sameness	2. Similarity	3. Resemblance
1. Laser-Plasma Interaction			
2. Electron Energy Transport			
3. Hydrodynamics and Shocks	1. Equation of State (Giant Planets)	2. Interaction of Molecular Cloud with Strong Shock by SNR (Morphology)	3. Collision-less Shocks and Particle Acceleration (Origin of Cosmic Ray)
4. Hydrodynamic Instability		4. RT Instability of SN Explosion (SN1987A)	5. Hydro-Instability in Neutrino-Driven SN Explosion 6. RT Instability of Eagle Nebula
5. Atomic Physics and X-ray Transport	7. Opacity (Star Evolution, etc.)	8. Non-LTE Atomic Process in SNR 9. Stellar Jets (Non-Rel.) 10. Radiation Hydro. (Early Galaxy) 11. Photo-ionized Plasmas	12. Vishiniac Instability of SNR 13. X-ray Laser in Universe
6. Laser-Produced Relativistic Plasma			14. Fireball of Gamma-ray Bursts 15. Cosmological Jets (Rel.)

Takabe, Progress of Theoretical Physics Supplement No. 143, 2001

Laser Driven Magnetic Reconnection

MR source—azimuthal self-generated magnetic field

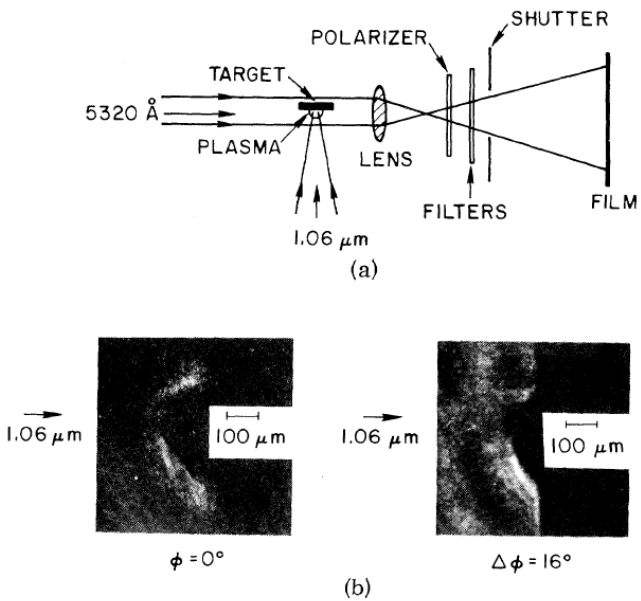


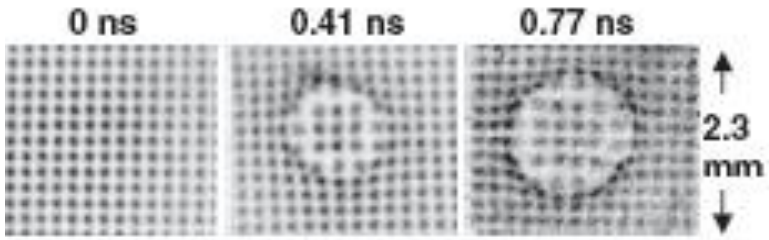
Nonparallel temperature and density gradients

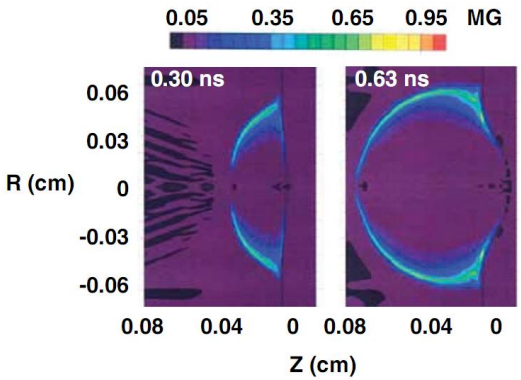
Target

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

The self-generated magnetic field





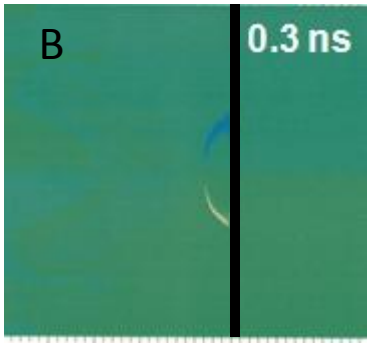


J. A. Stamper et al, PRL, 34,138 (1975)

C. K. Li et al. PRL 99, 055001 (2007)

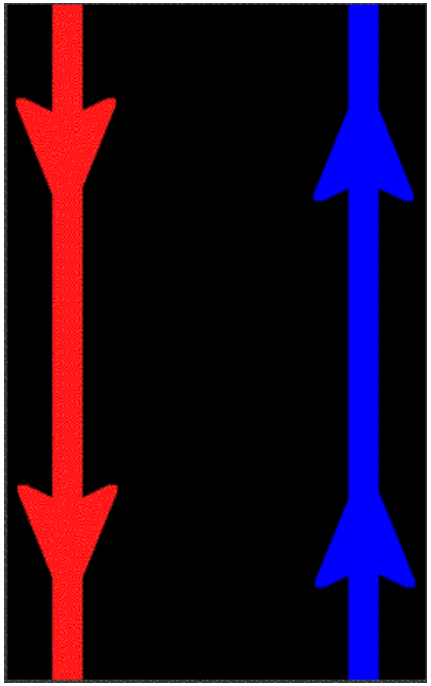
Toroidal B fields are

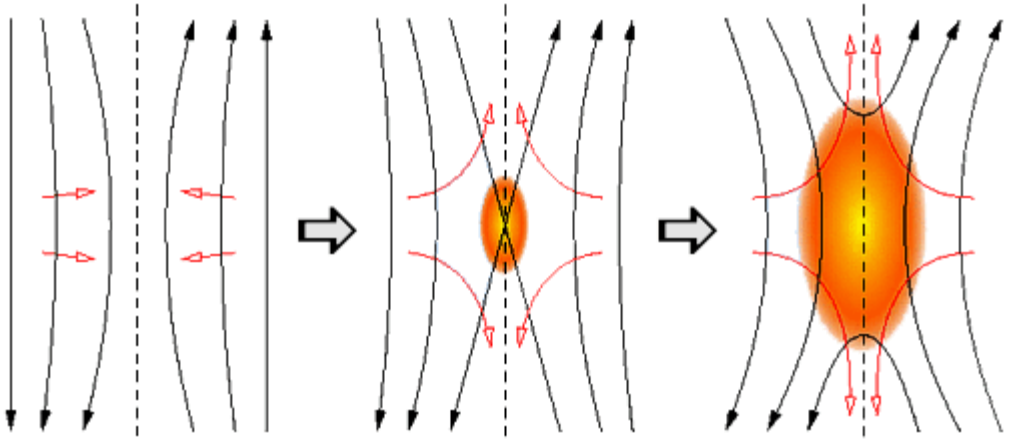
- **Mega Gauss (100 T)**
- **Concentrated on a hemispherical bubble**
- **Surrounding and expanding**



Magnetic Reconnection

What is magnetic reconnection?





During the reconnection a high electric current flows in the diffusion region, which heats up the plasma.

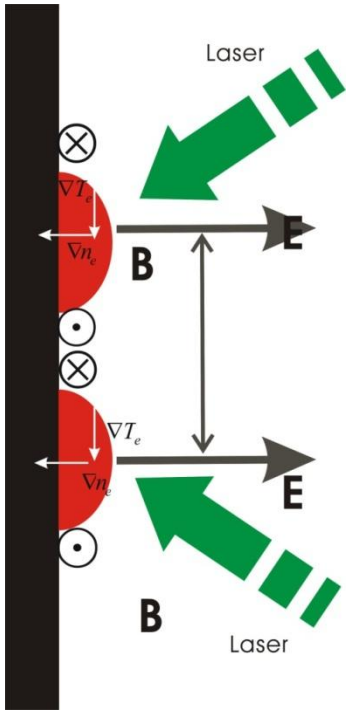
Magnetic reconnection occurs

- **Magnetized plasmas** encountered each other
- **With oppositely pointed B-fields**

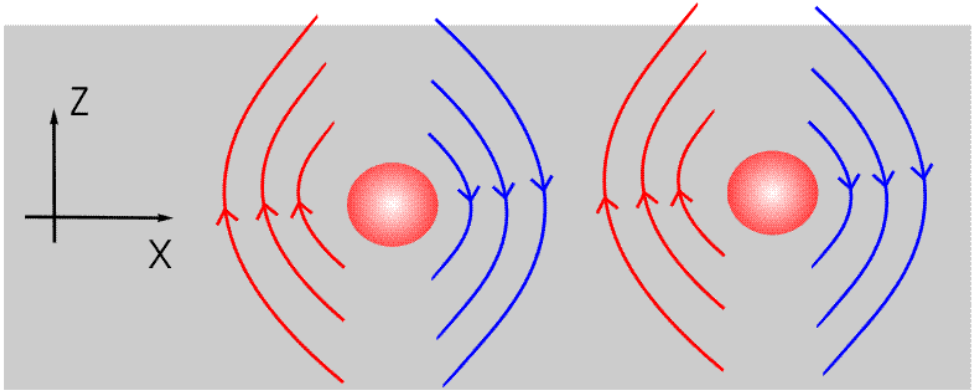
Constructing LDMR

Magnetic reconnection occurs

- **Magnetized plasmas** encountered each other
- **With oppositely pointed B-fields**

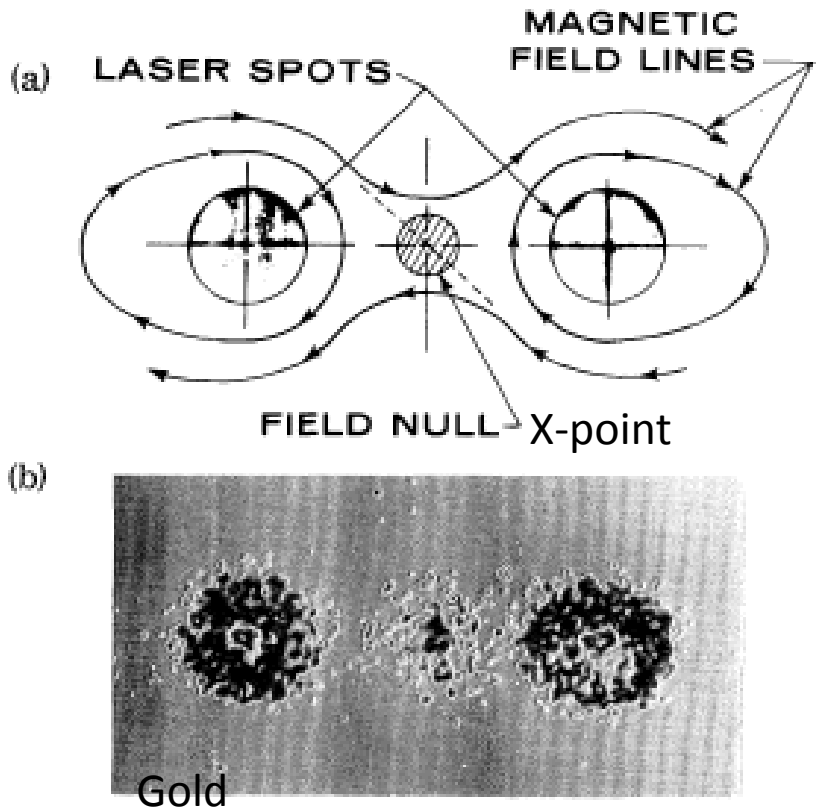


Side view

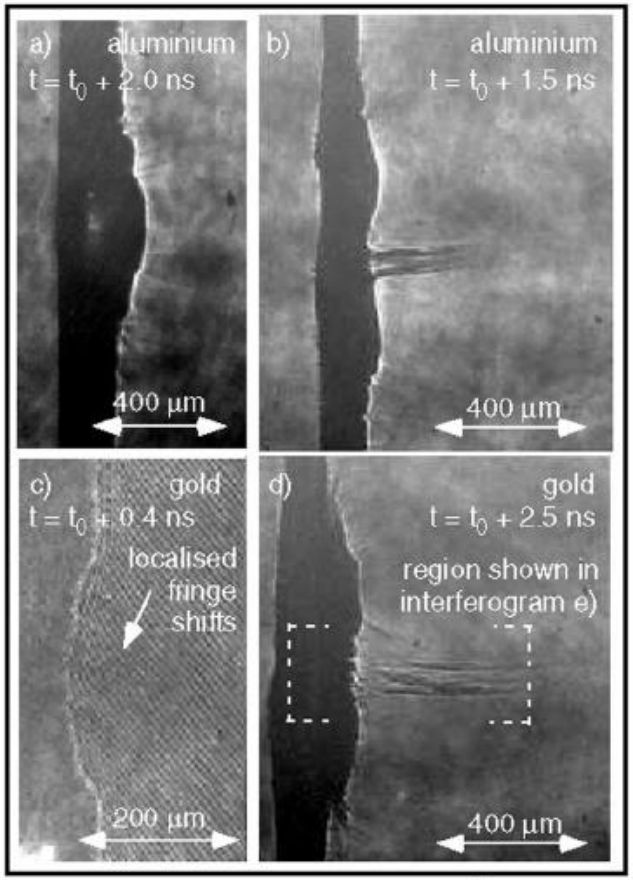


Front view

LDMR Studies

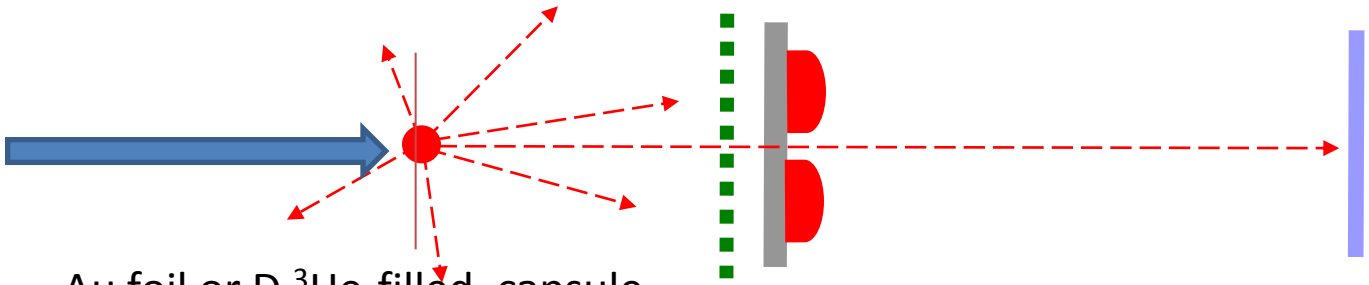


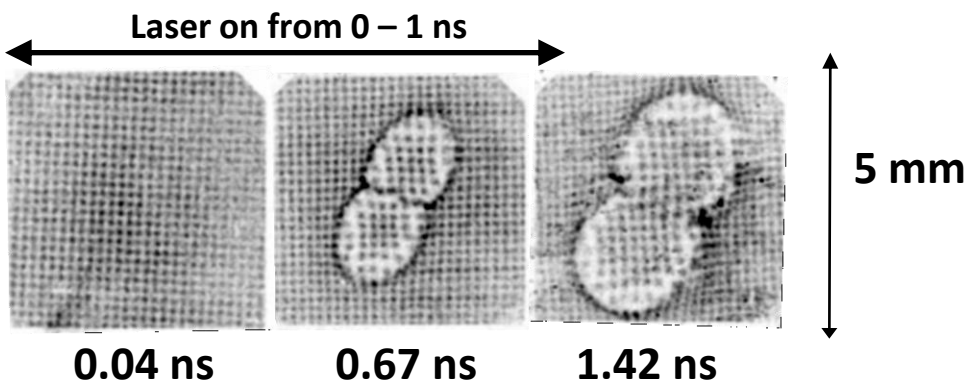
Yates et al., PRL, **49**,1702 (1982)

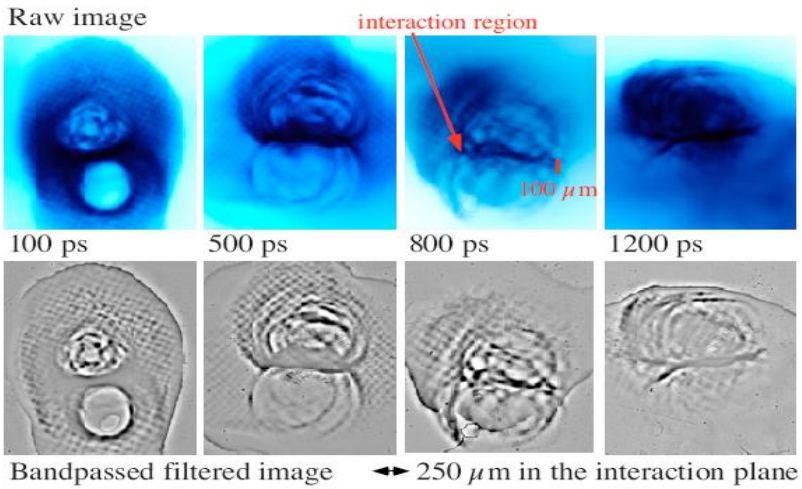


Nilson et al., PRL **97**, 255001 (2006)

LDMR Studies



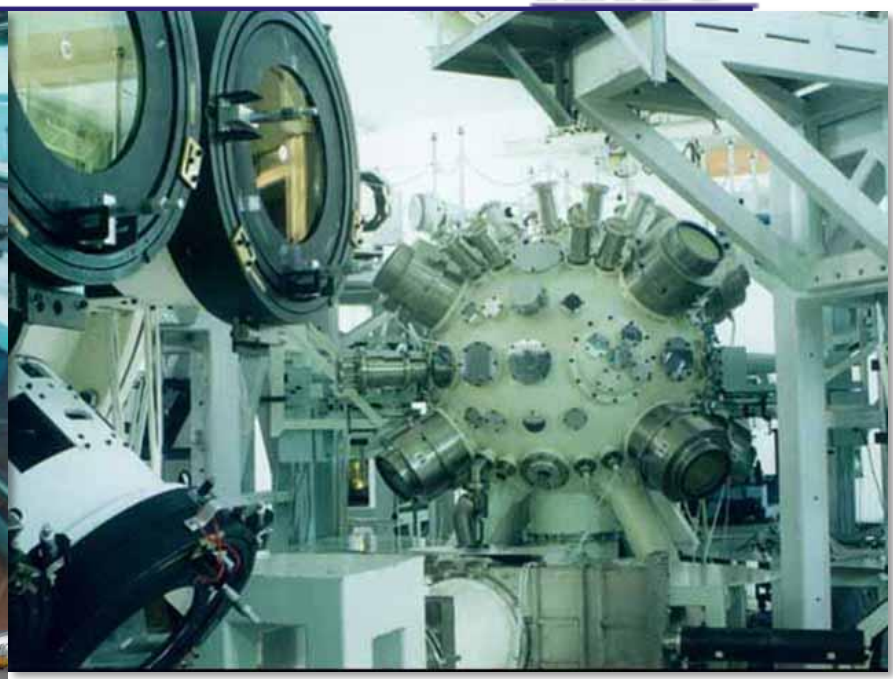




C. K. Li et al., PRL **99**, 055001 (2007)

L. Willingale et al., PoP **17**, 043104 (2010)

LDMR experiments on SHENGUANG II

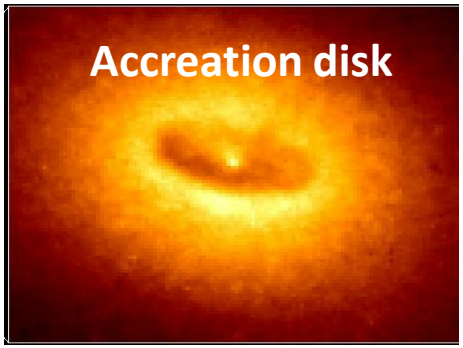


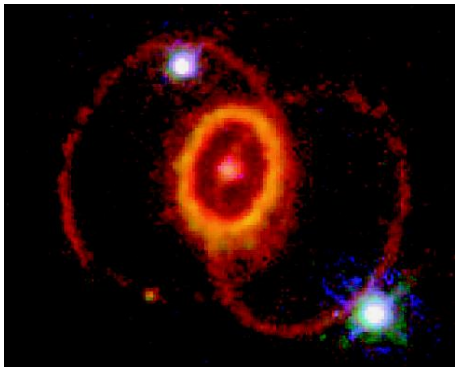
SG II Lasers
Beams: 8
Pulse: 10ps-1 ns
Wavelength: 1052, 532, 256 nm
Energy: 260 J/beam for 3ω
Focus spot: 50-100 μm
Intensity: 1-5$\times 10^{15}$ W/cm^2

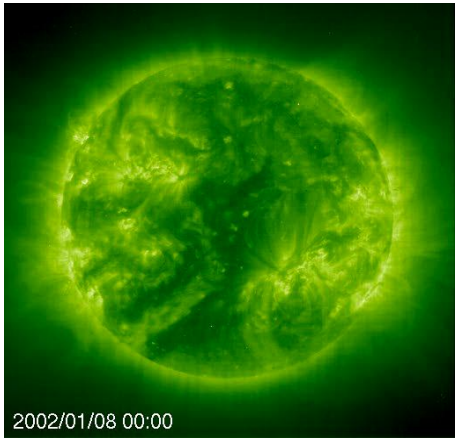
HEDLA topics On Shenguang II

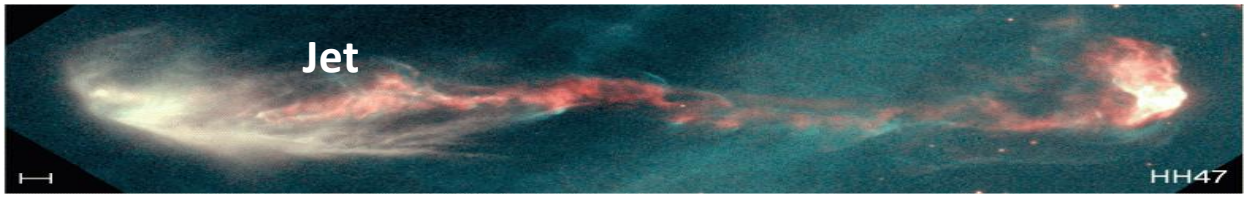
（1） X-ray spectra in astronomical plasmas
（2） Collisionless shock
（3） Opacity
（4） Plasma jets
(5) Laser driven Magnetic reconnections
- Solar flare
- Structure of Diffusion region
- Particles acceleration

……



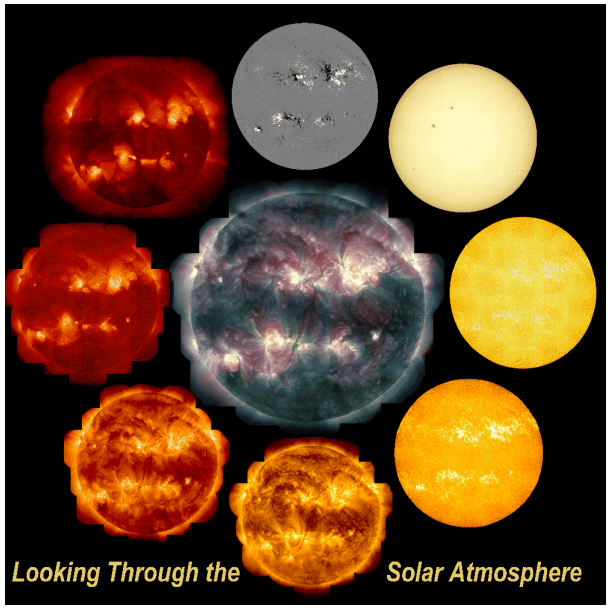


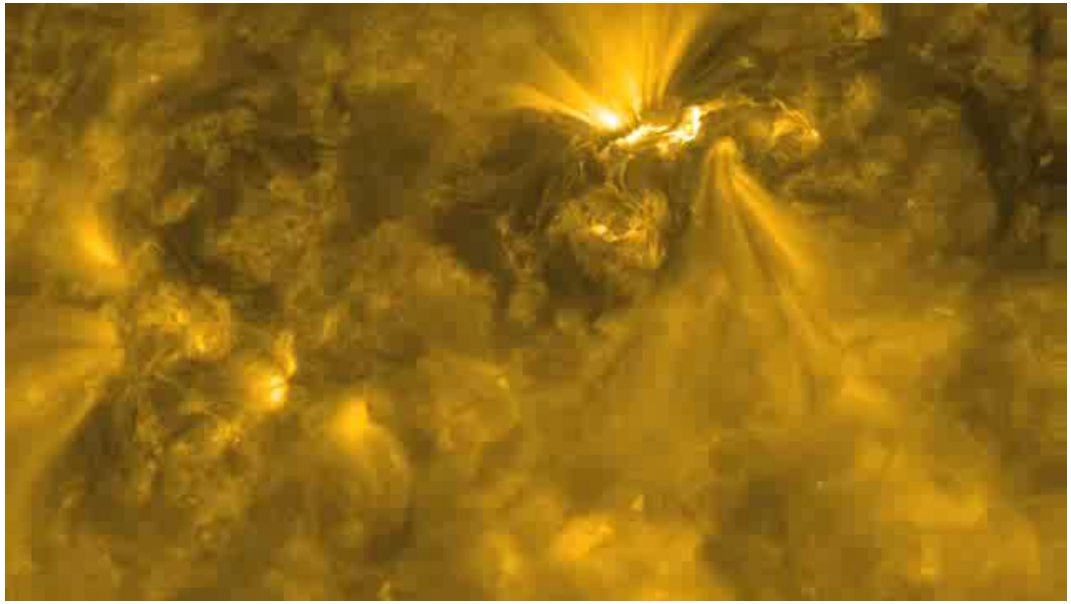




Solar flare

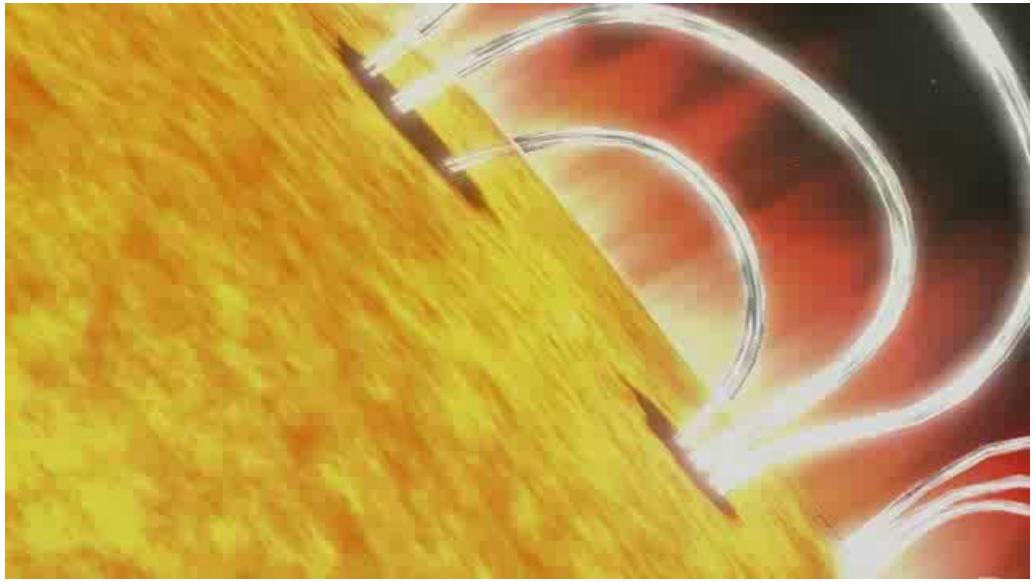
Observations





Http://www.nasa.gov/goddard/

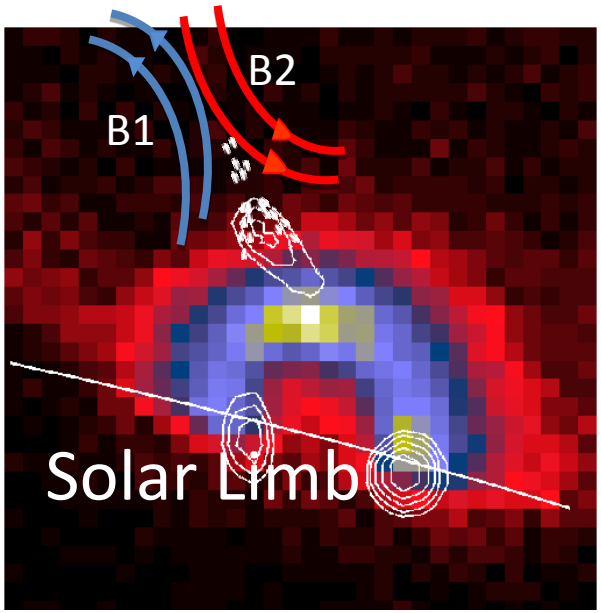
Models



Http://www.nasa.gov/goddard/

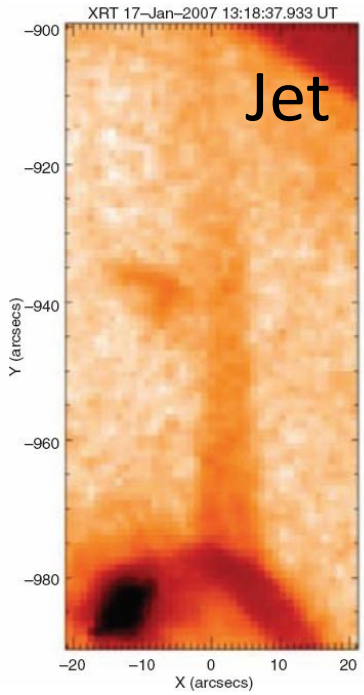
It has shown that the magnetic reconnection model is successful for the explanation of Solar flares.

Some evidences of MR in solar flares



Loop-top X-ray source

（Masuda et al 1994）



X-ray Jet

(Cirtain et al 2007)

Solar flare plasmas

Laser plasmas

Two Plasmas in different systems

Rm = 5×10^{8}

Solar flare Plasmas

Scaling Law
Ryutov 2001

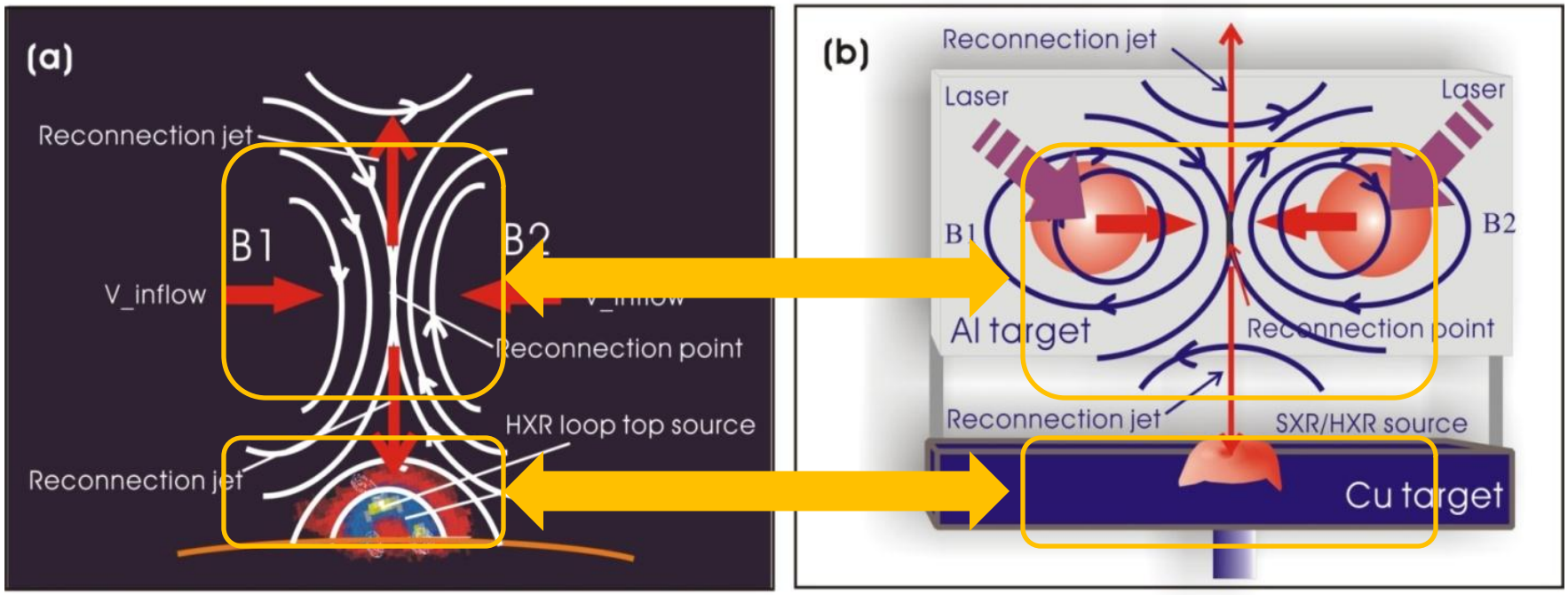
Laser Plasmas

Rm = 4000

Parameters	Laser Plasmas	(After scaling)solar flare
Length (cm)	10^{-1}	10^{-2}–10^{-1}
Time (s)	10^{-9}	10^{-10}–10^{-9}
Pressure (Pa)	10^{7}	10^{7}–10^{11}
Density (cm^{-3})	~10^{19}–10^{20}	10^{19}–10^{21}
Velocity (km s^{-1})	~10^{2}	10^{2}–10^{3}
Magnetic field (G)	~10^{6}	10^{6-7}

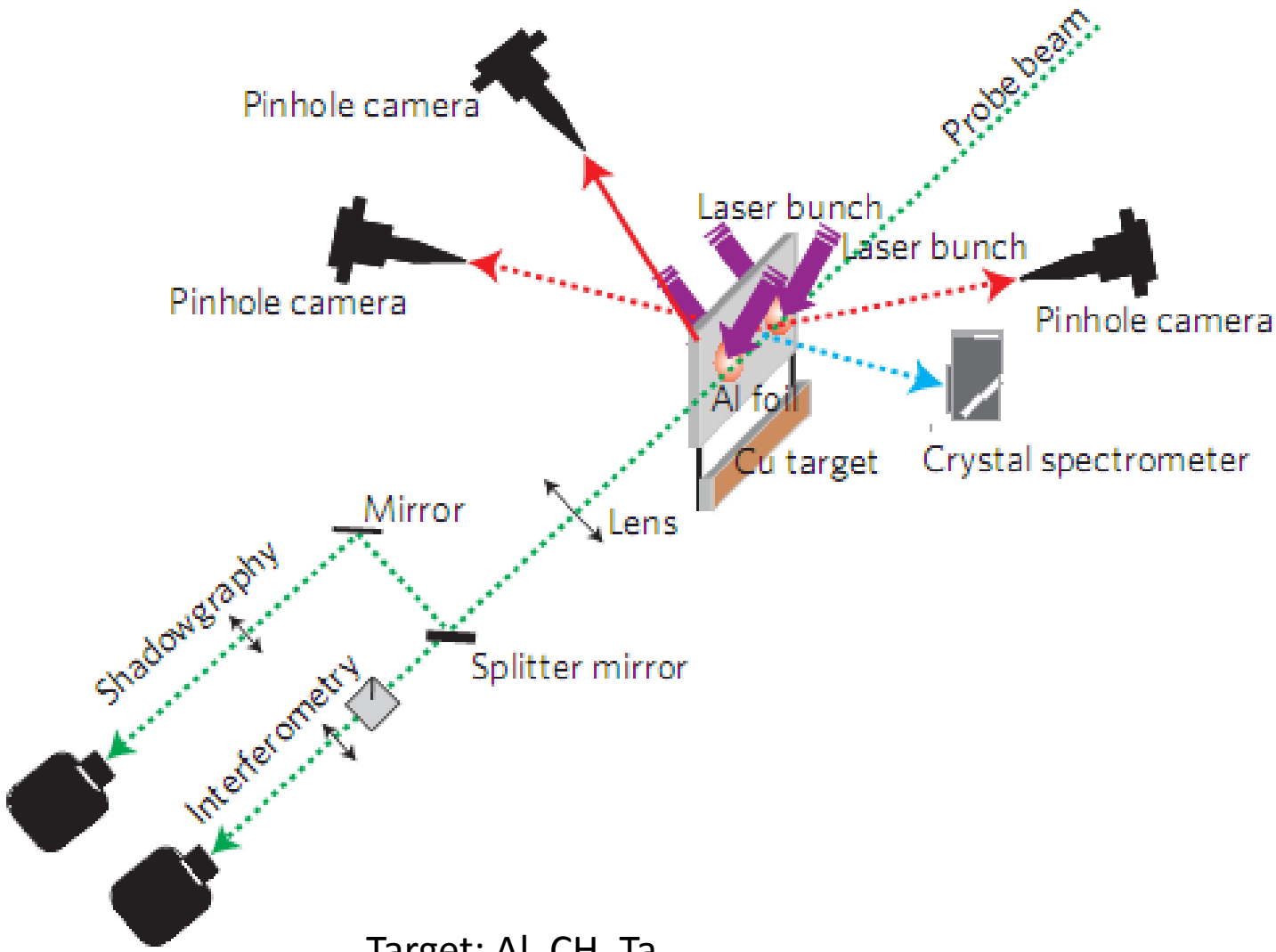
$$v_{激光} = a\sqrt{\frac{c}{b}}v_{太阳},\ t_{激光} = a\sqrt{\frac{b}{c}}t_{太阳}$$

The idea is ……



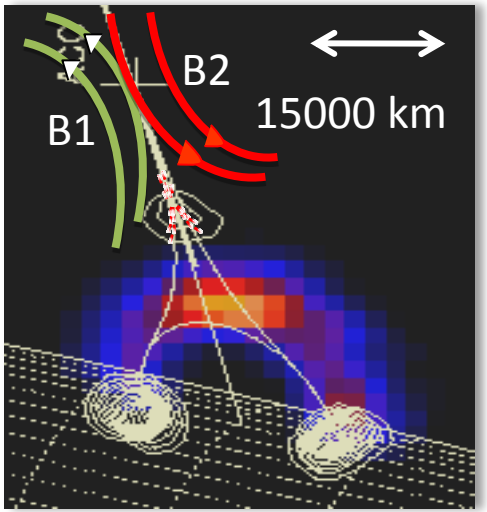
Modelling loop top x-ray source and reconnection outflows

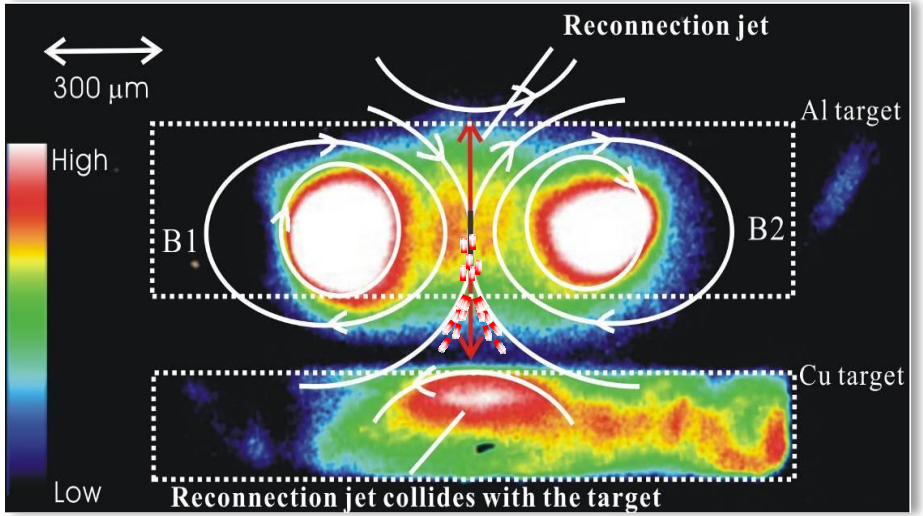
Experimental setup



Target: Al, CH, Ta

Results





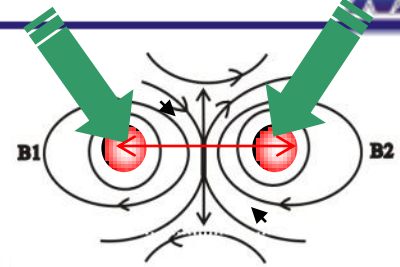
Masuda solar flare in x-rays

X-ray Pinhole images

Zhong et al, Nature Physics, 6, 984 （2010）

—The collision effect on the two plasma bubbles

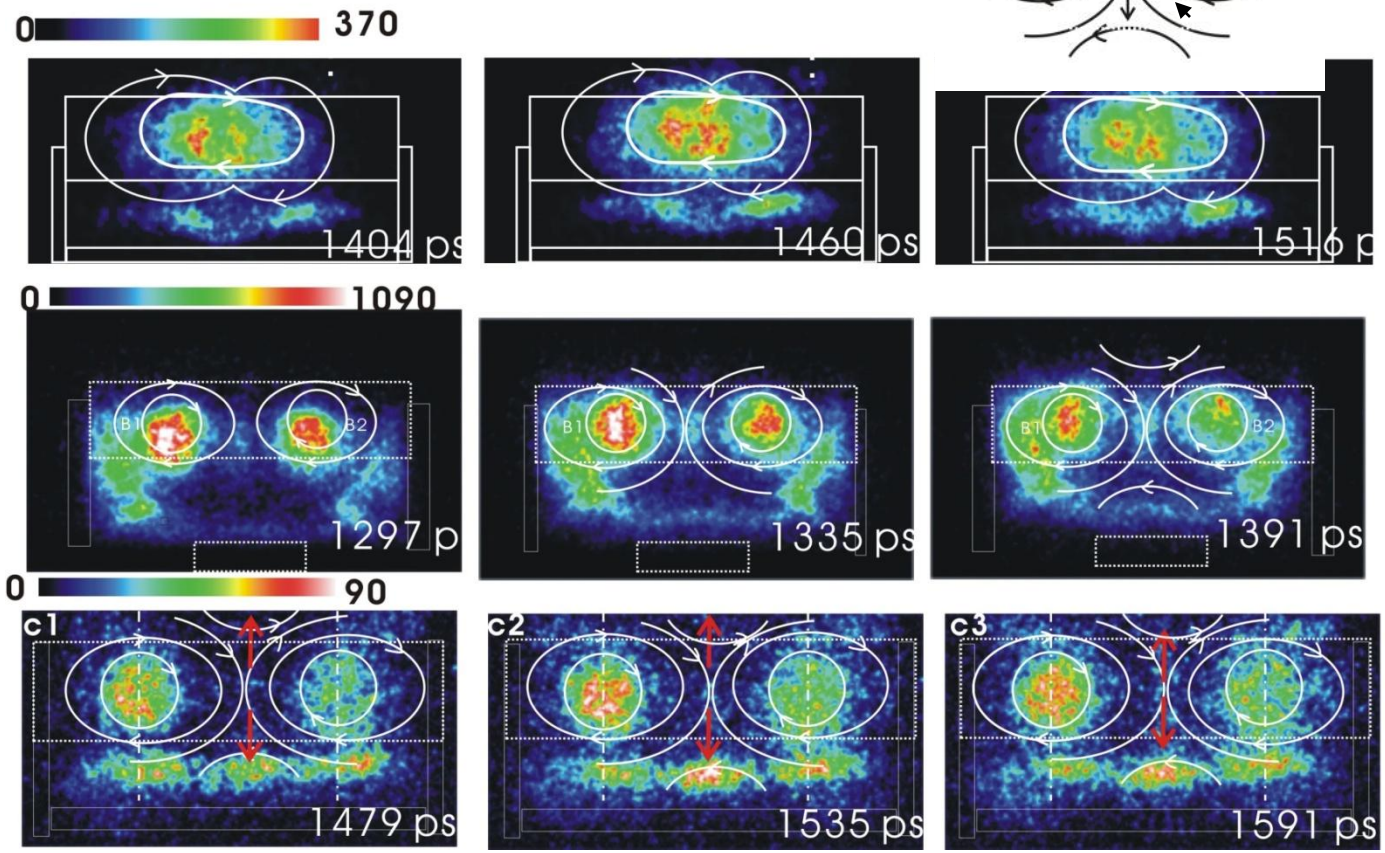
Changing the distance of two plasma bubbles



200 μm

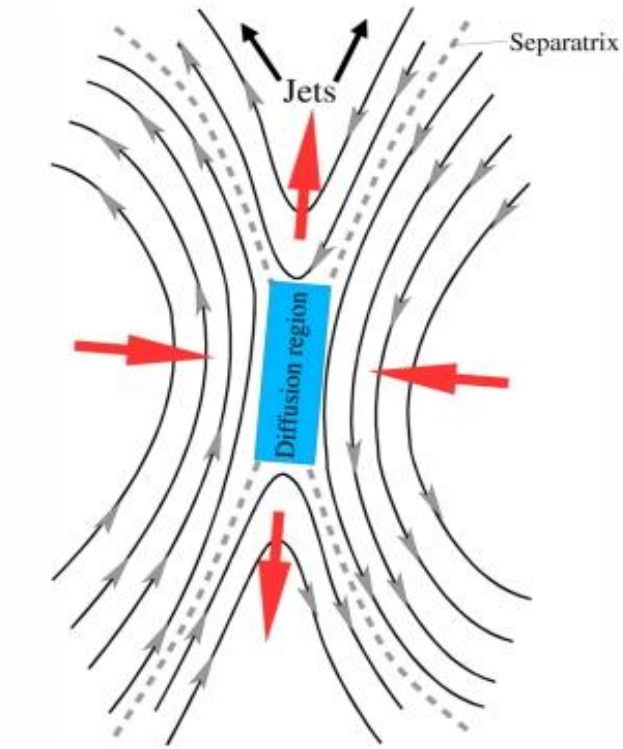
400 μm

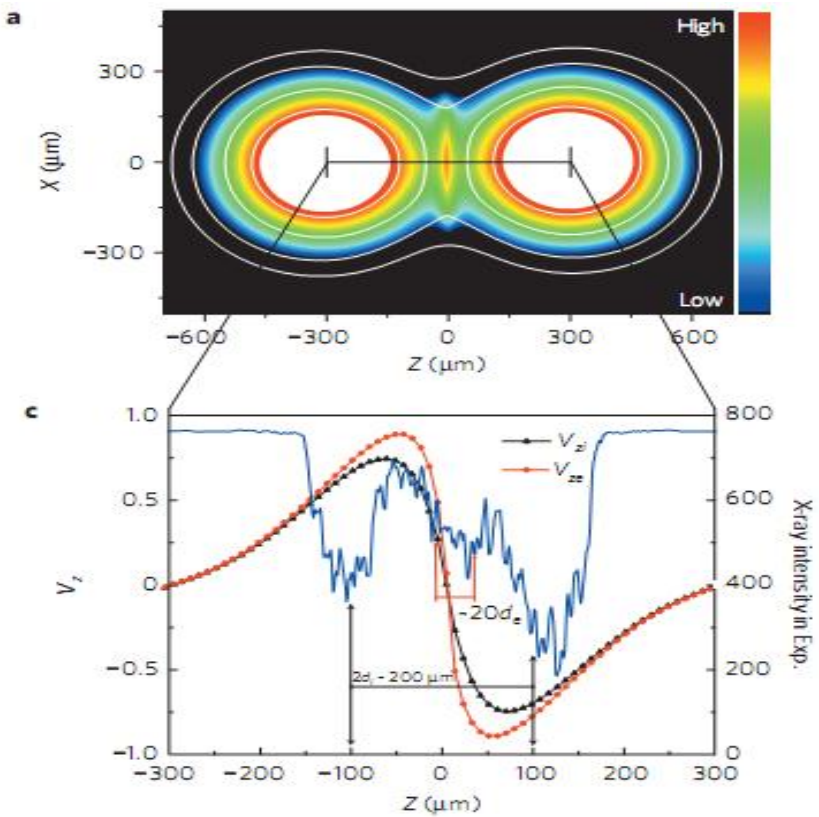
600 μm



X-ray framing images for interaction of two plasma bubbles

— The structures of diffusion region

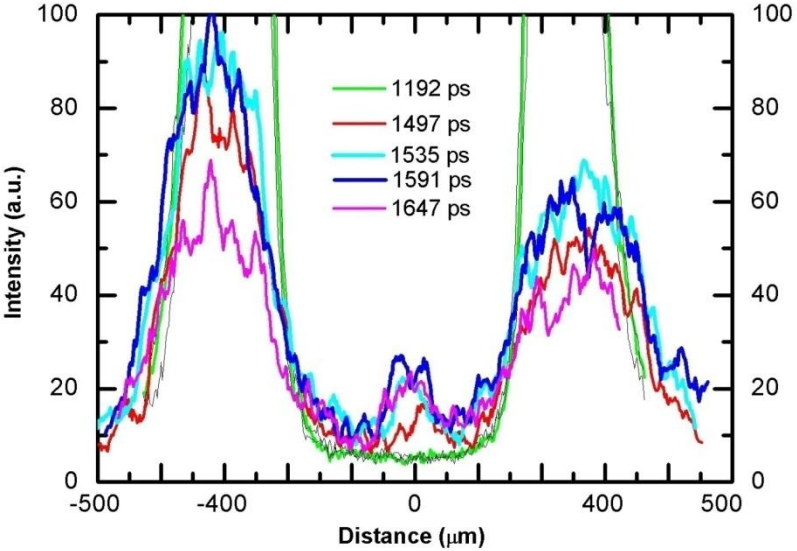


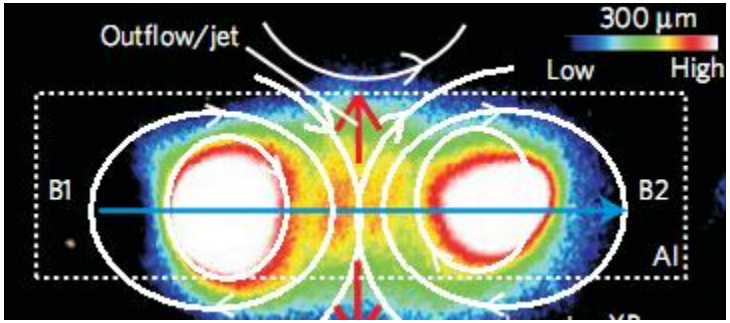


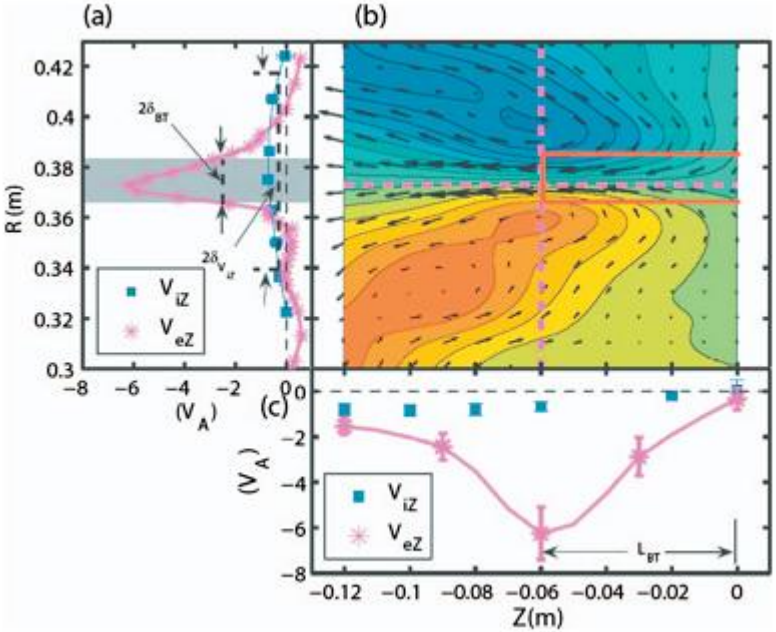
Two- dimensional/3-component Hall MHD Simulations

Two X-ray patterns denoted by black arrows is on the order of the ion inertial length.

— The structures of diffusion region



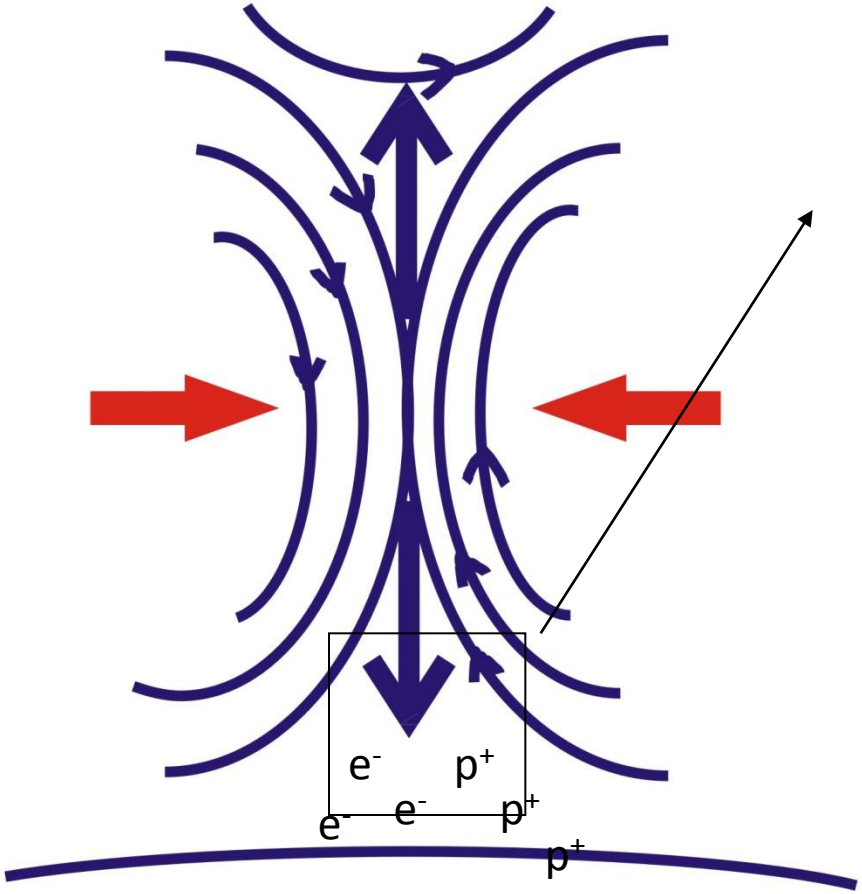


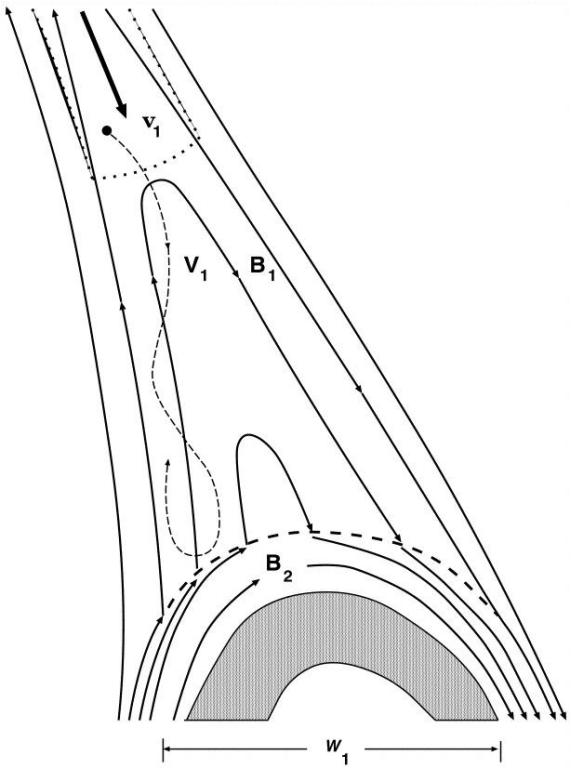


Ren, Y et al. Phys. Rev. Lett. 101,085003(2008)

- **Ion difussion region with the width of ~d_i**
- **Electron difussion region with the width of ~10d_e**

• *Particles acceleration*





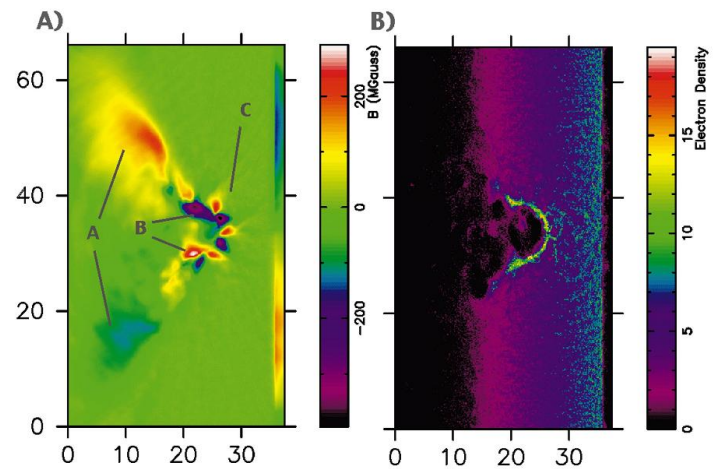
Summary and future collaborations

— Laser driven magnetic reconnection is an active research area which parameter space has not been previously accessible in experiments.

— With help of scaling law we can simulate a lot of astrophysical phenomena related MR, such as solar flare, accretion disk et al.

— In future experiment , We will continue checking the MR related to particles acceleration et al.

— The magnetic field in short pulse is Much higher than ns lasers, giga Gauss, in which we can touch the relativistic MR area.



Wagner et al.PRE 70, 026401 (2004)

Thank you!

Welcome to visit the National Astronomical Observatories, CAS