中国科学技术大学
University of Science and Technology of China

Summary of Laser Plasma Session

Jian Zheng

University of Science and Technology of China

3rd Asia-Pacifc Conference on Plasma Physics, Hefei, November 4-8, 2019

Acknowledgements

- Prof. K. Mima and Prof. Y. Mori;
- The speakers who provide summary slide;
- All delegates who attend the laser plasma session

Outline of the Summary

中国科学技术大学
University of Science and Technology of China

1 Overview of Laser Plasma Session

2 Relativistic Laser

3 Inertial Confinement Fusion

4 High Energy Density Physics

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1. **Overview of Laser Plasma Session**
2. Relativistic Laser
3. Inertial Confinement Fusion
4. High Energy Density Physics

Overview of the Laser Plasma Session

Plenary	Semi-Plenary	Invited	Oral	Poster
4	6	35	8	2
Total: 55				

Sub-fields	Invited and Oral
Relativistic Laser	15
High Energy Density Physics	15
Laser Fusion	13

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1 Overview of Laser Plasma Session

2 **Relativistic Laser**

3 Inertial Confinement Fusion

4 High Energy Density Physics

PL-5 (L)		Chang Hee Nam	IBS	Exploration of nonlinear Compton scattering between a laser-accelerated GeV electron beam and a PW laser

LPL-1	Ryosuke Kodama	Osaka University	Exploration of high energy density science in various scales of structures with high power lasers
L-I1	Liming Chen	IOP, CAS	Ultrahigh charge electron acceleration from solid target
L-I2	Yuji Fukuda	QST	Quasimonoenergetic proton bunch via interactions of micron-scale hydrogen cluster targets with PW-class laser
L-I3	Amol Holkundkar	Birla Institute of Technology and Science	Higher harmonics and attosecond pulse generation by laser interaction with atomic clusters via Thomson scattering
L-I4	Ki Hong Pae	GIST	Generation of a high-density high-energy proton jet from the interaction of an ultra-intense laser pulse with a thin solid target
L-I9	Hamad Ahmed	Queen's University Belfast	Accelerator quality beams of high-energy protons guided by intense-laser driven helical coils
L-I10	Akifumi Yogo	Osaka University	Developments of laser neutron source and diagnostics in Japan
L-I11	Kitae Lee	KAERI	Generation of quasi-monoenergetic ion spectra from layered targets irradiated by an ultraintense laser pulse
L-O1	Olivier Zabiolle	Amplitude Laser Group	Towards high repetition rate ultra-intense lasers, latest developments at Amplitude Laser
L-I18	Masakatsu Murakami	Osaka University	Relativistic proton emission from ultrahigh-energy-density nanosphere generated by micro-bubble implosion
L-I19	Wei Lu	Tsinghua University	Ultrafast Intense laser technology and plasma based accelerator research at Tsinghua University

Physics for laser power from 1 PW to 100 PW (Baifei Shen, PL-18)

1. The progress of physics with TW-PW laser

- Electron acceleration （nano wire injection and plasma density modification) and positron generation
- Proton and heavy ion acceleration (light pressure acceleration, shock acceleration and wakefield acceleration)

2. The status of SULF and the planned experiments

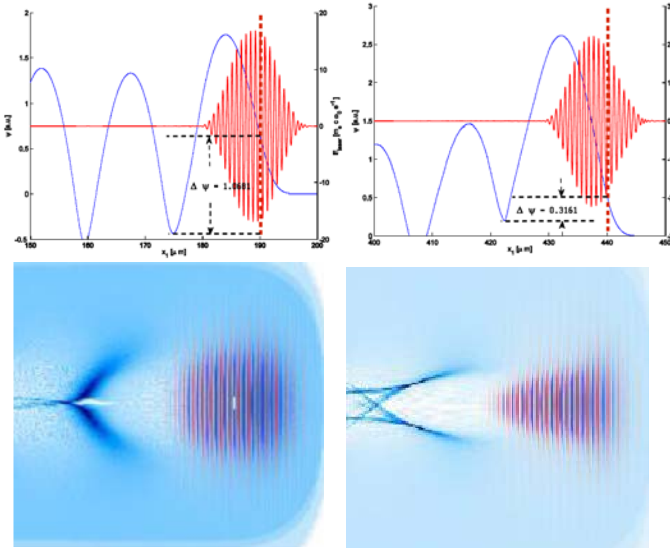
- 10 PW will be ready soon.
- 10GeV electron and 100 MeV proton acceleration are planed.

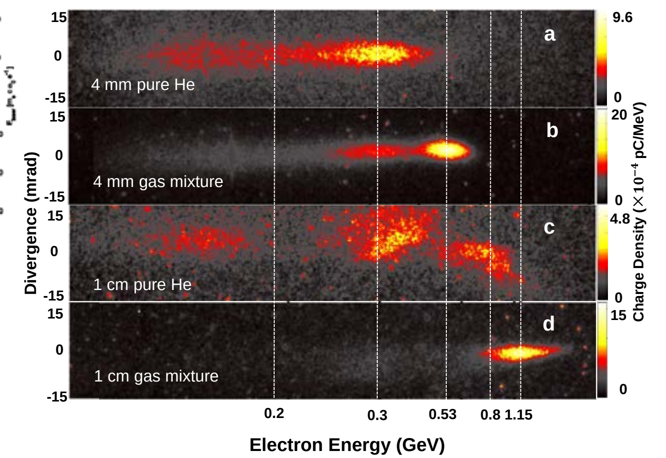
3. The status of SEL@SHINE and the planned experiments

- Experiment for vacuum QED effect is designed.
- XFEL serves as a good probe for high energy density physics experiments.

SJTU-1:High quality ionization injection

1. Control the wake!
Injection length can be controlled within ~100μm, 5% energy spread for a few hundreds MeV electrons.

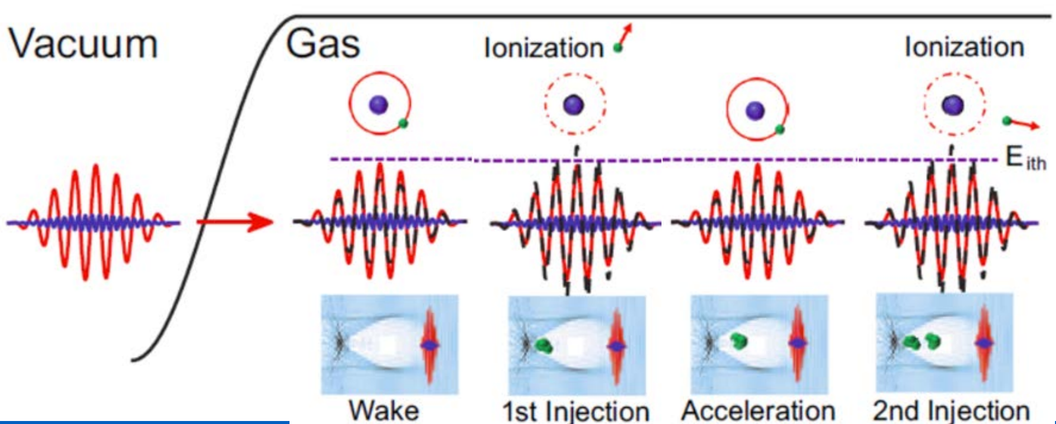


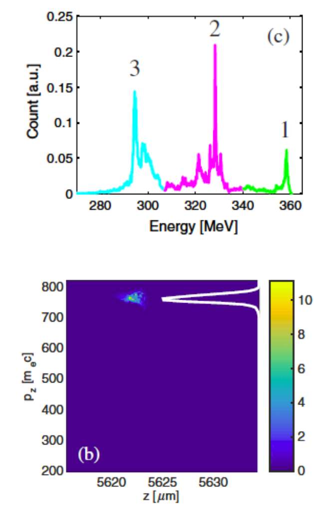


S. Li, N. Hafz, et al., Opt. Express 22, 29578 (2014).
M. Mirzaie, S. Li, N. Hafz et al., Sci. Rep. 5, 14659 (2015)

M. Zeng et al., POP, 21, 030701 (2014).

2. Control ionization!
Injection length can be limited to ~10 μm.
Simulation shows energy spread can be smaller than 0.5%.

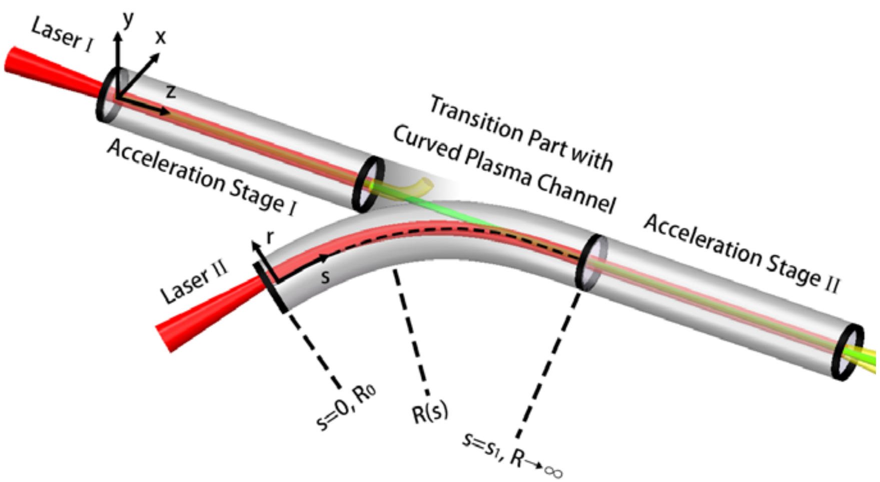


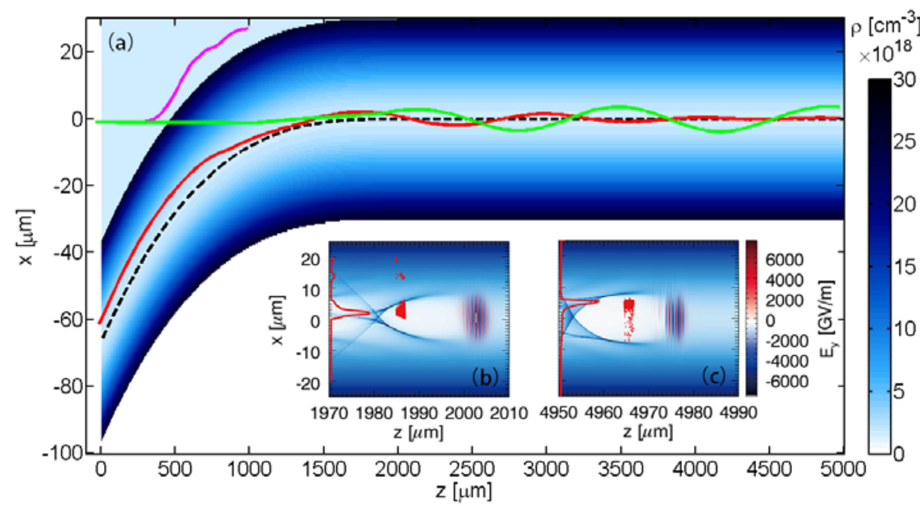


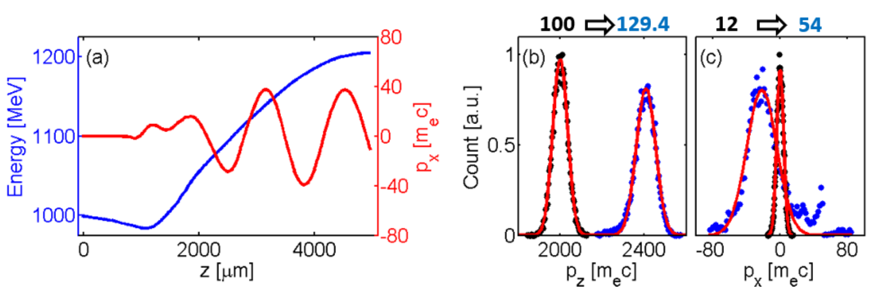
SJTU-2: Curved Plasma channel based LWFA staging

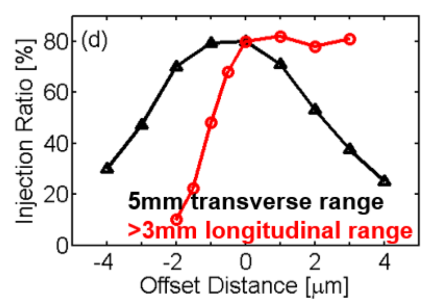
$$i\frac{\partial a}{c\partial t} = \left[-\frac{c}{2\omega_l}\frac{\partial^2}{\partial r^2} + \frac{\omega_l}{2c}\frac{n_0}{n_{cr}}\left(1 + \frac{\Delta n}{n_0}\frac{r^2}{w_0^2}\right) - \frac{\omega_l}{c}\frac{r}{R}\right] a$$

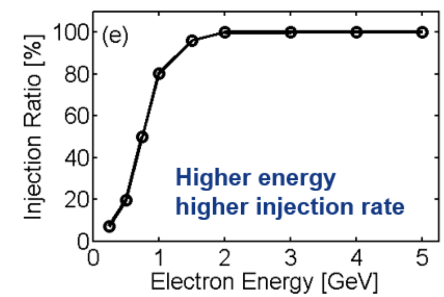
R can be a variable of laser propagation distance.





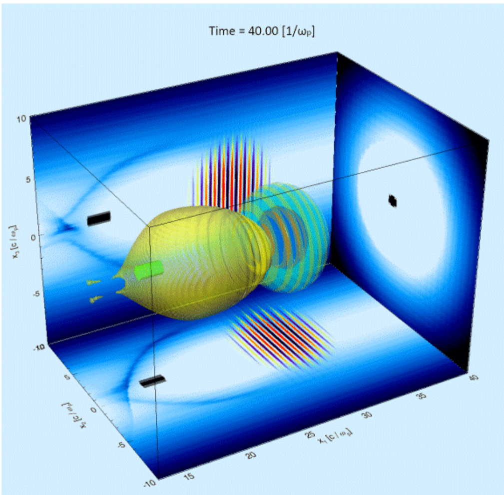




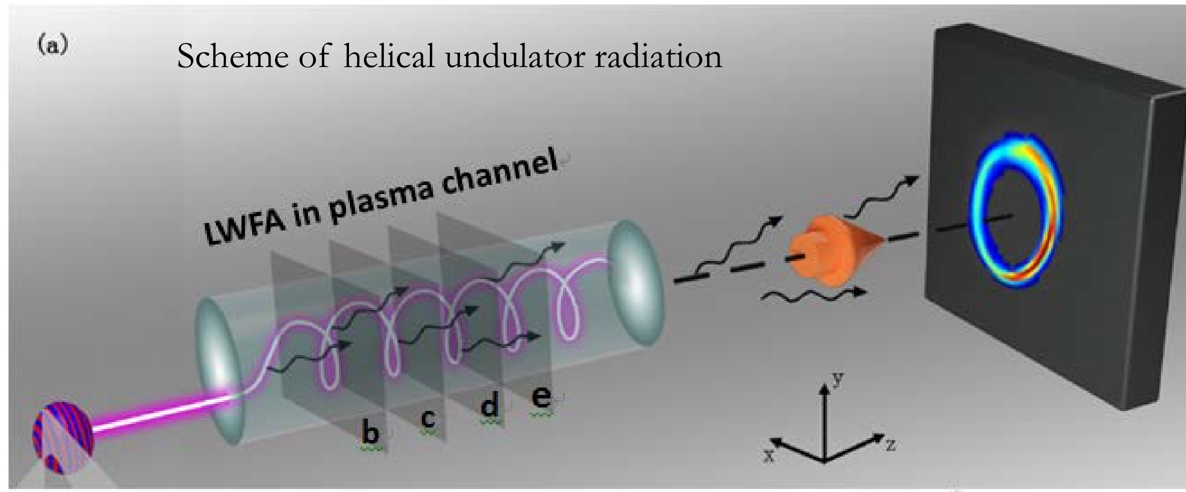


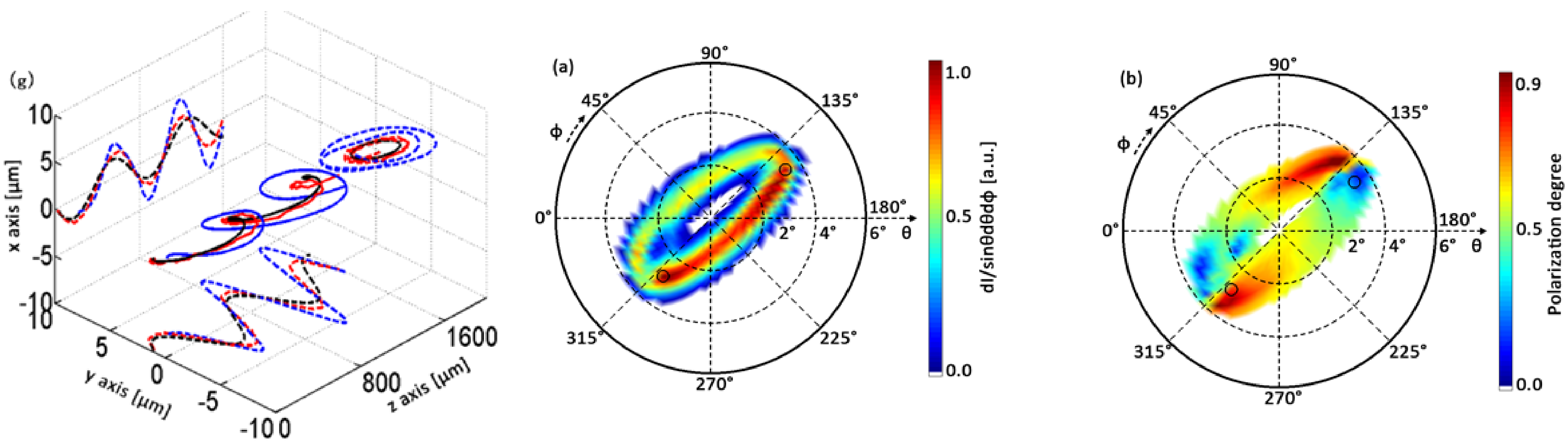
J. Luo, M. Chen, W.Y. Wu, et al. PRL, 120, 154801 (2018)

SJTU-3: Radiation from helical plasma undulator



Laser and e^- beam center trajectories

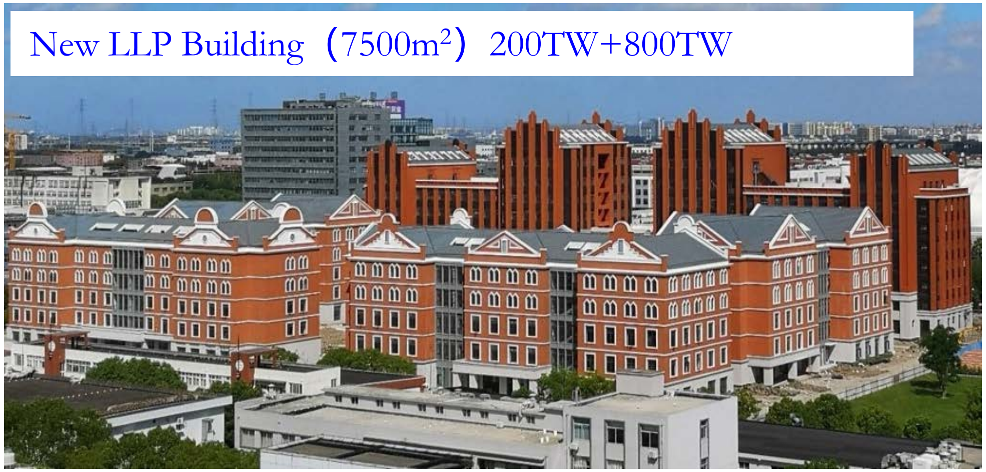




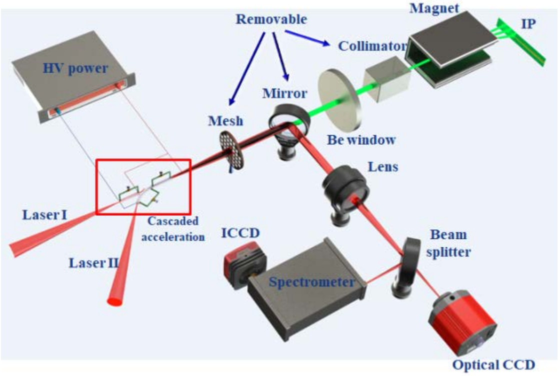
SJTU Future: Two lasers + challenge studies + applications

SJTU Main plans: Upgrade the current 200TW to 200+800TW two-beam system.

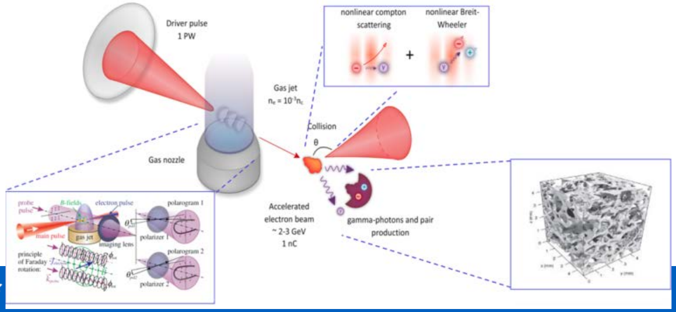
1. Demonstration of high quality two-color laser ionization injection (~0.1% Energy spread, low emittance)
2. Staged laser wakefield acceleration (curved plasma channel, 1GeV→ 1.5GeV)
3. LWFA based nonlinear Thomson scattering sources



Curved plasma channel based controlled radiation and staging studies.



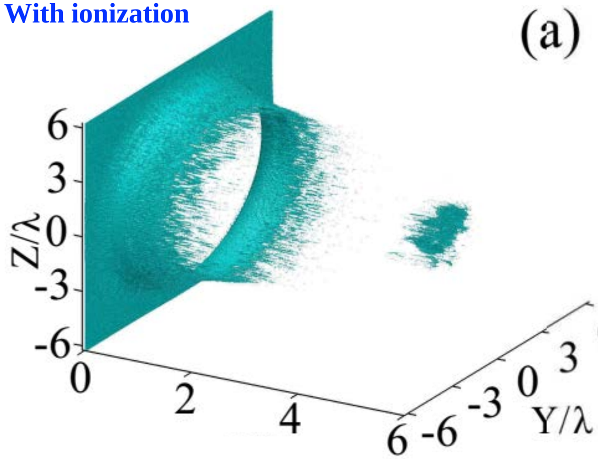
LWFA based electron, photon source & Applications



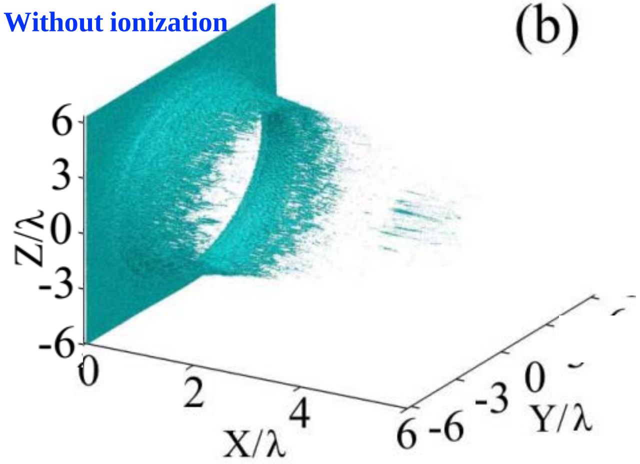
3D PIC simulations verify the method of Ionization-stabilized Laser Ion RPA

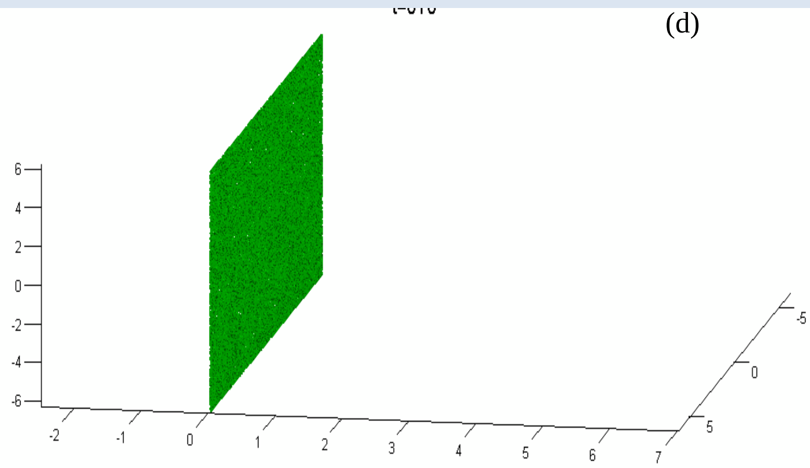
L-O10	Xiaofei Shen (U30 winner)	Peking University	Ionization-stabilized Laser Ion Radiation Pressure Acceleration

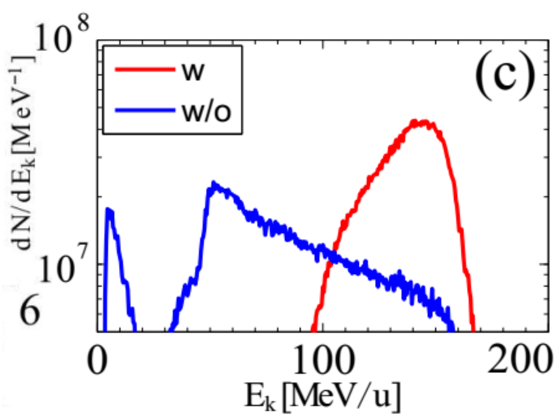
With ionization



Without ionization







X. F. Shen et al., PRL **118**, 204802 (2017)

Electron bunch undergoing extraordinary strong acceleration emulating the behavior of electrons near black holes is found in a certain condition

Probing space-time effect using multi-PW laser plasma interaction via Thomson scattering

Hawking-like shift

Spectral broadening

$$S(\omega,\theta_1,\theta_2)=\int S^D(\omega-x,\theta_1,\theta_2)S^H(x)dx$$

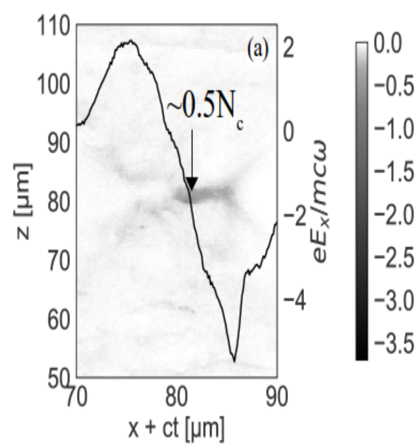
Doppler shift

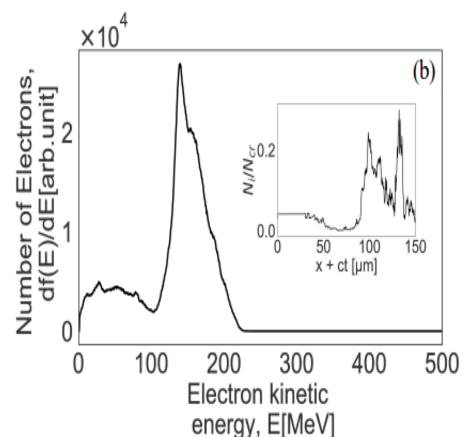
Requirement of electron density

- High density -> to get efficient scattered light
- Strong acceleration -> maximize Hawking-like shi
- Low transverse velocity spread -> minimize Doppler shift

We call it 'super-acceleration'

$I=10^{24}$ W/cm^2
$M/Zm_p=1$
$t=625$ fs
$N_e=5.0\text{x}10^{19}$ cm^{-3}





- High density -> ~0.5Nc
- Strong acceleration -> a0~5
- Low transverse velocity spread -> $\frac{\Delta v}{v}=0.63$

$T_U\approx 0.5$ [eV]

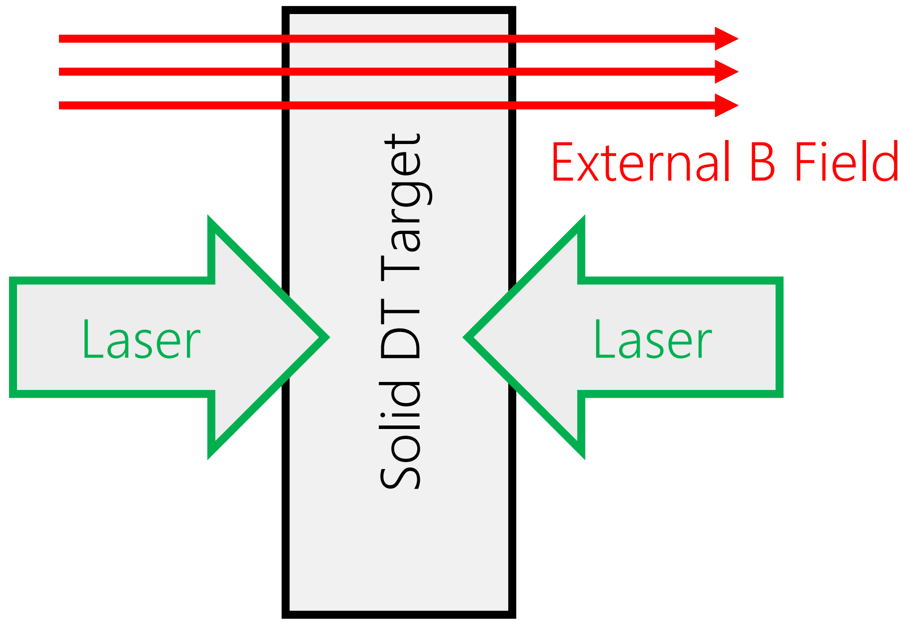
$$\frac{\Delta\omega^S}{\omega^S}=(2T_U/mc^2)$$

$\simeq 0.22\%$ -> might be detectable

Laser-plasma interaction in overdense plasmas under strong magnetic fields

- We propose a new ion-heating mechanism in overdense plasmas by the collapse of standing whistler waves.
- This mechanism could be applicable to various plasma phenomena, not only laser plasmas but also magnetic confinement fusion and planetary magnetosphere.

- Ultrafast Generation of Thermal Fusion Plasma



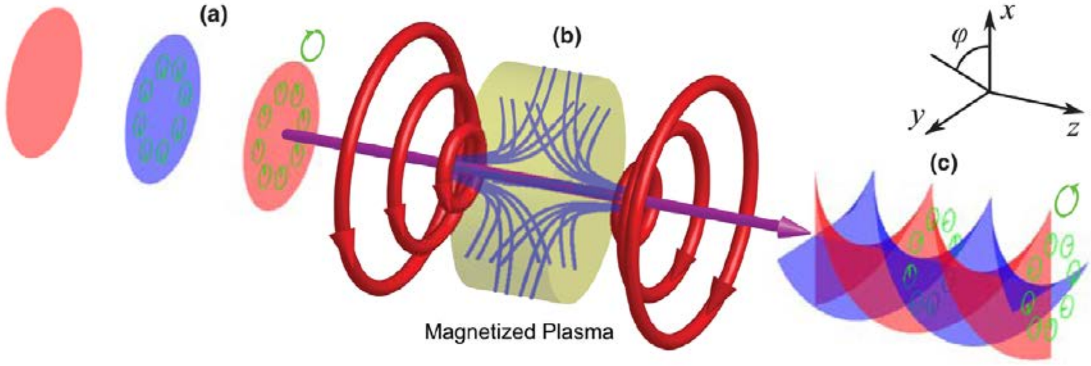
Typical Parameters

$n_{e0}/n_c \sim 30$ $B_{\text{ext}}/B_c \sim 10$ $a_0 \sim 3$

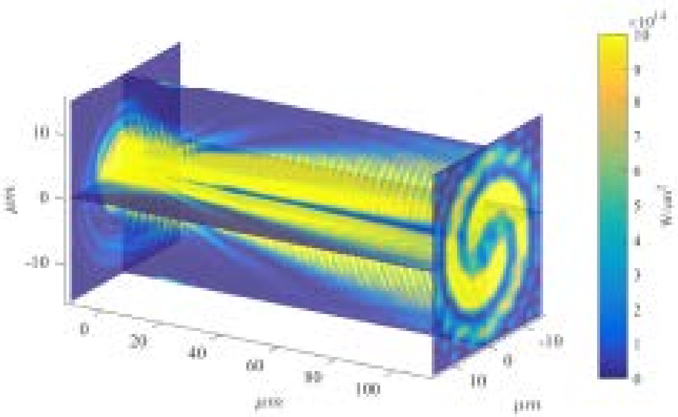
Jia, L-I21

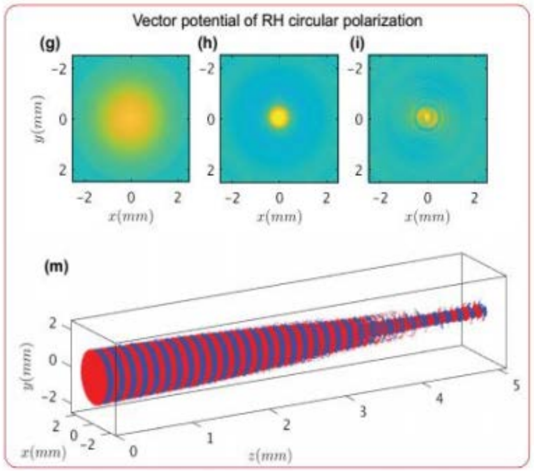
L-I21 Magnetized plasma based q-plate for generation of intense optical vortices

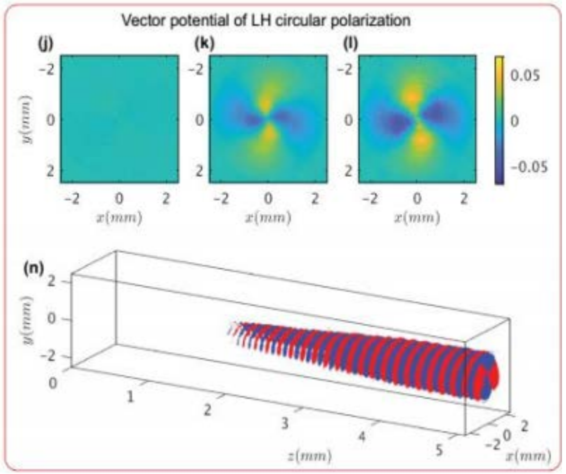
By Qing Jia (USTC), et al.



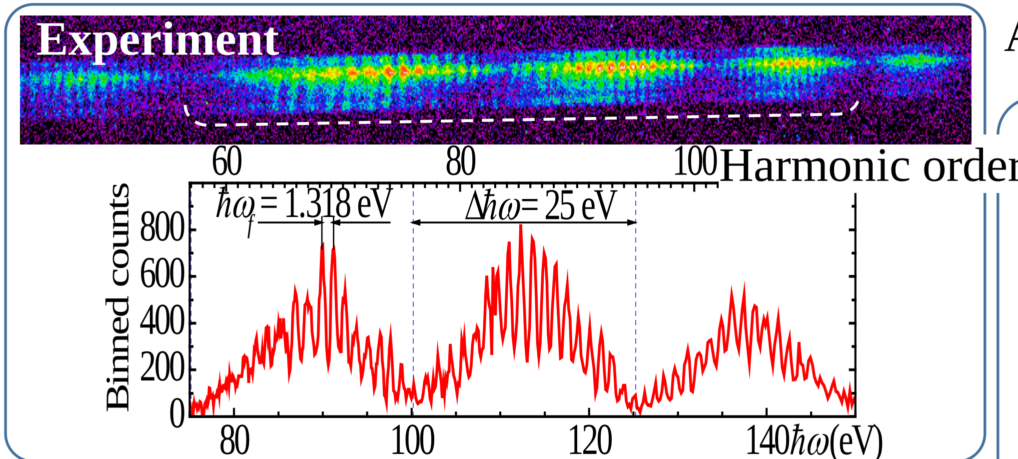
$$E_0(r)\hat{\boldsymbol{e}}_{L,R} \rightarrow E_0(r)\exp(il\alpha)\hat{\boldsymbol{e}}_{R,L}$$





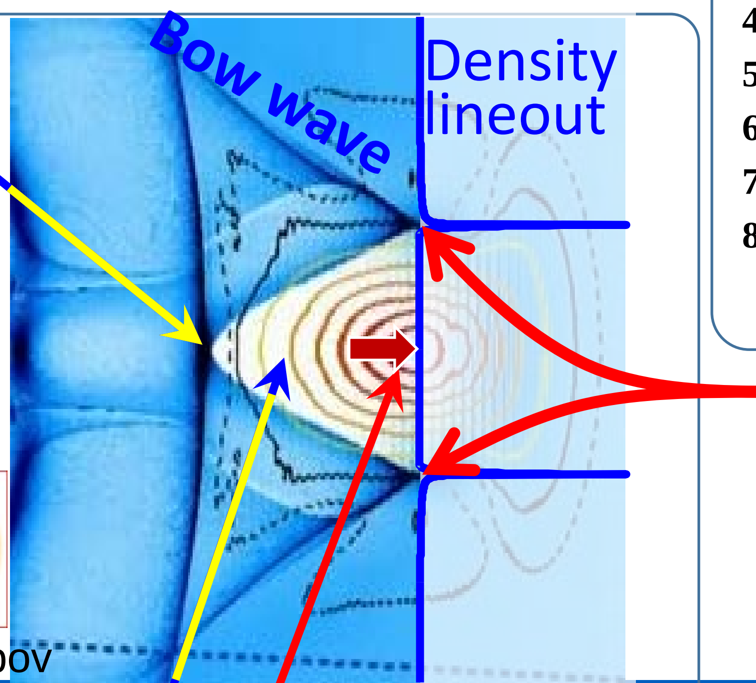


BISER:
Burst Intensification by Singularity Emitting Radiation



Alexander Pirozhkov, Timur Esirk

1. **Surprising experimental discovery:**
   Bright HHG in underdense relativistic plasma
2. **Catastrophe theory based model:**
   Coherent radiation from singularities
3. **Model validated experimentally**
4. **BISER is *Spatially* and *Temporally* coherent**
5. **XUV: μJ, 10^{11} photons, attosecond, *B* ~ 10^{28} S.U.**
6. **Hundreds of harmonic orders, $\hbar\omega$ up to keV**
   S.U. = photons/(mm² mrad² s in 0.1% ba
7. **All travelling wave kinds (EM, GV, AC…)**
8. **BISER = possible FRBs & GRBs progenitor**



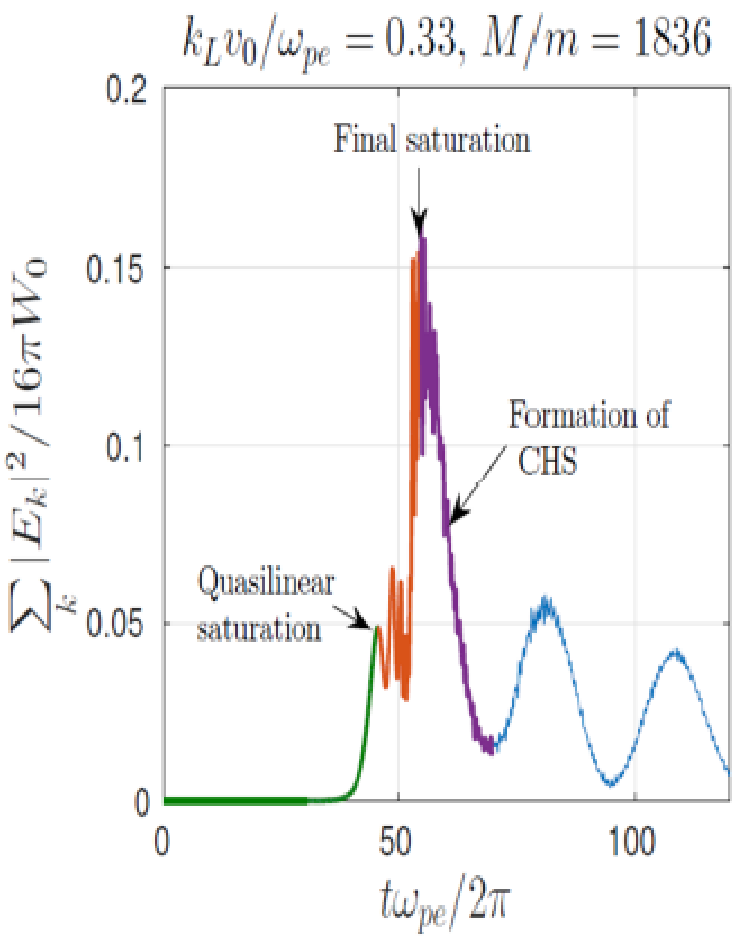
code REMP
T.Esirkepov

Electron density Spikes = Cusp Singularities

X-rays ~ N_e^2

Pirozhkov *et al*. *PRL* **108**, 135004 (2012)
Pirozhkov *et al*. *NJP* **16**, 093003 (2014)
Pirozhkov, Esirkepov, *et al*. *SR* **7**, 17968 (2017)

Summary of Results on Buneman instability (Non-relativistic Case)



1. *At the quasilinear saturation point (Hirose et, al.)*

$$\sum_k \frac{|E_k|^2}{16\pi W_0} \approx \left(\frac{m}{M}\right)^{1/3}$$

2. *At the final saturation point (Ishihara et. al.)*

$$\sum_k \frac{|E_k|^2}{16\pi W_0} \geq 0.11$$

First time verified using PIC simulation

3. *After the final saturation formation of coupled holes solitons are seen.*

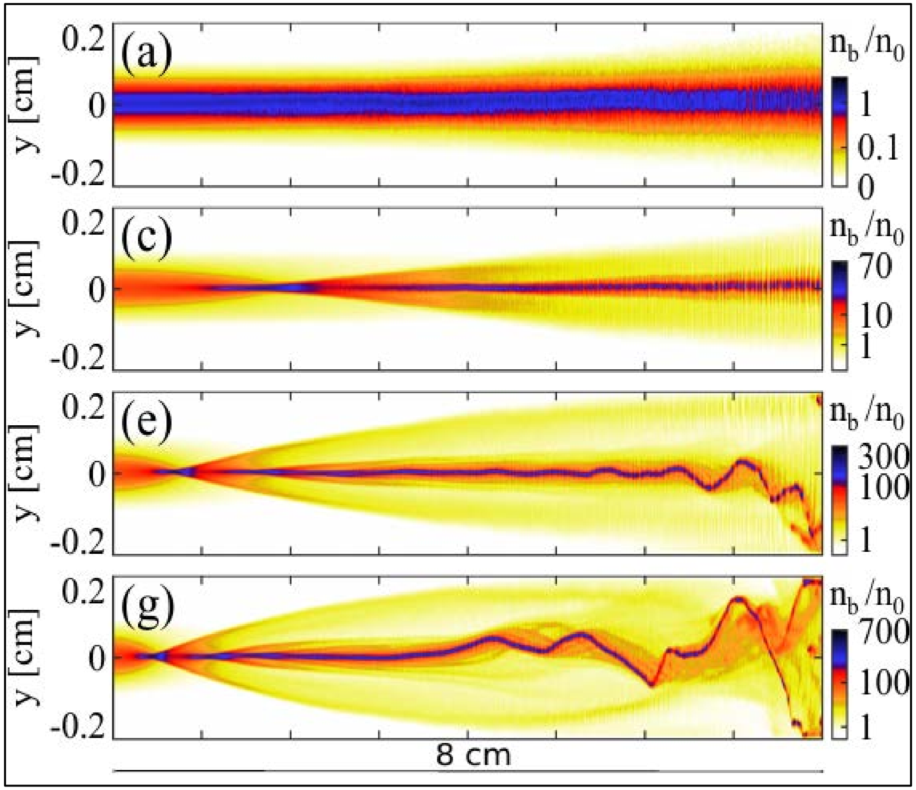
Seen in PIC simulation

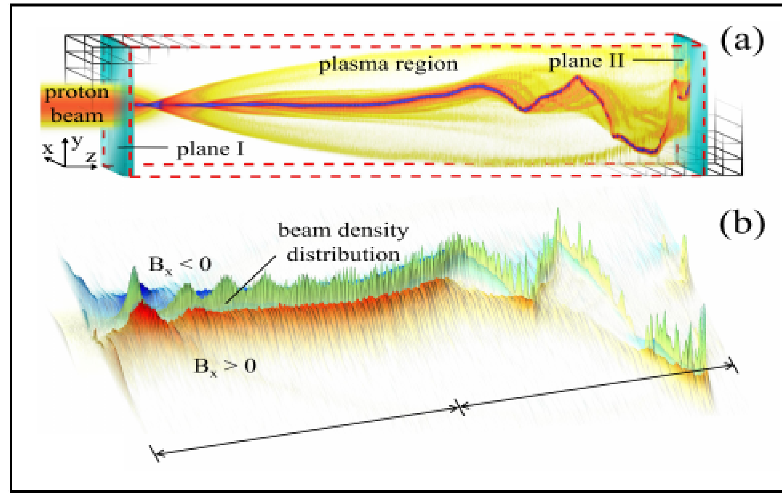
Found to be consistent with Saeki's model

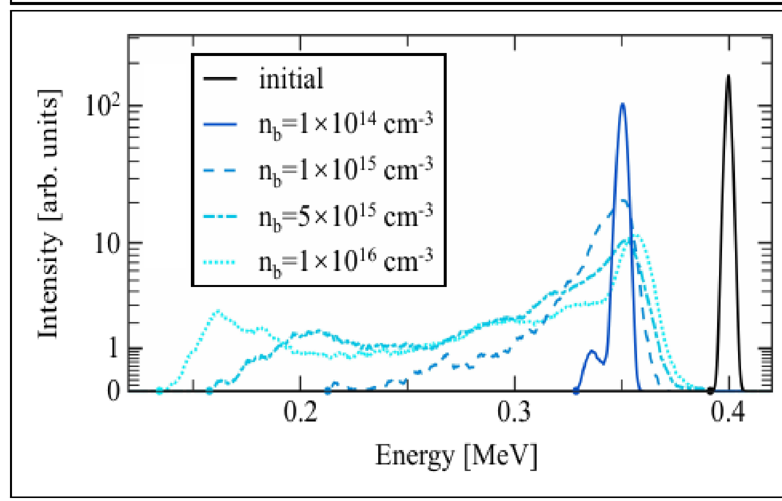
Roopendra Singh Rajawat and Sudip Sengupta; Phys. Plasmas 24, 122103 (2017)

Particle-in-Cell Simulation for the Transport of Particle Beams in Large Plasmas

D. Wu, Zhejiang University, Email: dwu.phys@zju.edu.cn







Energy Loss of Particle Beams in Plasmas:

- Low density beam, consistent with single particle stopping power model

- High density beam, collective electromagnetic effects becomes important.

Wu, L-O7

Smilei)

Open-source
PIC code

Collaborative, user-friendly
GitHub • python interface

Educational resources
online documentation • tutorials

High-performance
MPI-OpenMP • load balancing • vectorization

Physics
ionisation • collisions • strong-field QED

Advanced solvers
high orders • multi-geometries • laser envelope

maisondelasimulation.fr/smilei

M. Grech
F. Perez
T. Vinci

J. Dérouillat
M. Lobet

MAISON DE LA SIMULATION

A. Beck
F. Massimo
I. Zemzemi

... and many more

Derouillat et al., CPC 222 *(2018)*

Perez, L-I28

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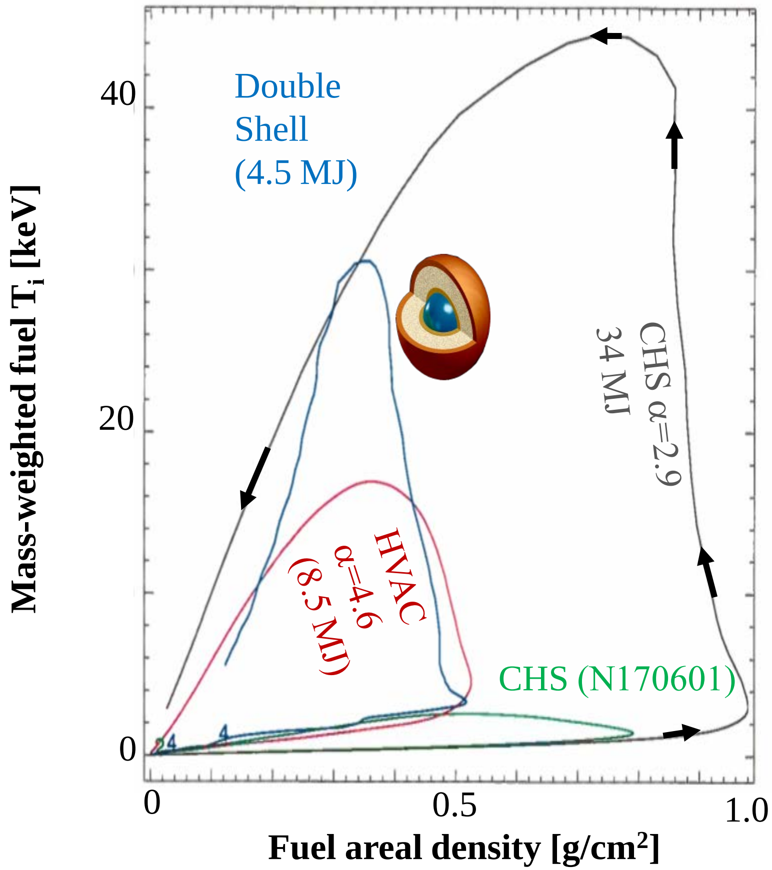
LPL-2	Chuansheng Liu	University of Maryland	Raman scattering: A summary of five decades of theory, experiment and simulations
LPL-3	Dimitri Batani	University of Bordeaux	Progress in shock ignition
LPL-5	Ke Lan	IAPCM	Progress in spherical hohlraum studies and experimental campaign on high energy laser facilities in China

L-I14	Qiong Li	IAPCM	The Application of Simulated Annealing Method in the Chemical Free Energy Model
L-I15	Hideo Nagatomo	Osaka University	An optimum design of a cone-inserted target implosion for reactor scale Fast Ignition
L-I16	Hongbo Cai	IAPCM	Study of the kinetic effects in indirect-drive inertial confinement fusion hohlraums
L-I17	Feng Wang	Laser Fusion Research Center	Progress of ICF Diagnostic techniques and experimental results based on Shenguang laser facility in China
L-I22	Keisuke Shigemori	Osaka University	The role of hot electrons on ultrahigh pressure generation relevant to shock ignition conditions
L-I23	Xiaohu Yang	National University of Defense Technology	Transport of ultra-intense laser-driven fast electrons in dense plasmas
L-I24	Leejin Bae	CoReLS, IBS	Investigation of relativistic electron transport in solid targets irradiated by ultrahigh intensity laser pulses
L-O5	Hui Cao	IAPCM	Laser repointing scheme for spherical hohlraum with 6 laser entrance holes on the SG Facility and the National Ignition Facility
L-O6	Kai Li	IAPCM	Escape of α-particle from hot-spot for inertial confinement fusion

Amendt, L-I34

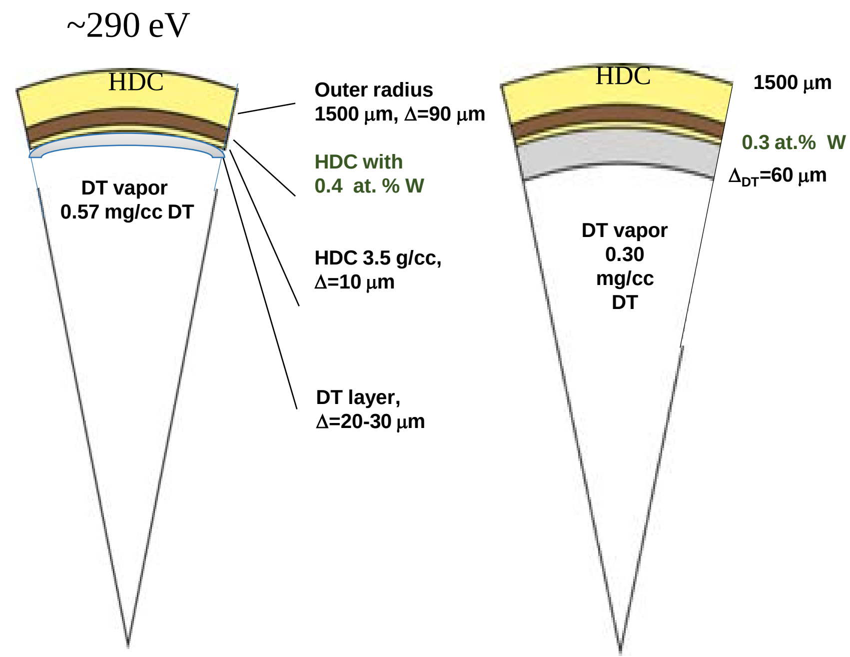
High-Volume and -Adiabat Capsule ("HVAC") novel ignition path features ≅ 2x lower fuel compression requirement (ρR ~ 0.5 g/cm^2) than CHS ignition mode

TRAJECTORY in FUEL T_i - ρR SPACE



HVAC CAPSULE

CENTRAL HOT-SPOT (CHS) CAPSULE



- Double shell and HVAC rely on volume ignition of *entire* fuel

Volume ignition mode uses high fuel adiabat α, which large capsules can support due to high margin in rugby hohlraum

Toward laser fusion mini-reactor CANDY, pellet injection R&D are on-going

MORI, L-I37

Pellet injection system

(1) Beads (w/ fusion reaction)

For neutron generation

Achieved 10 Hz, > 2000 beads

Laser illumination ratio > 70%

KOMEDA SR2013, MORI FST2019

(2) Spherical shells (test bed)

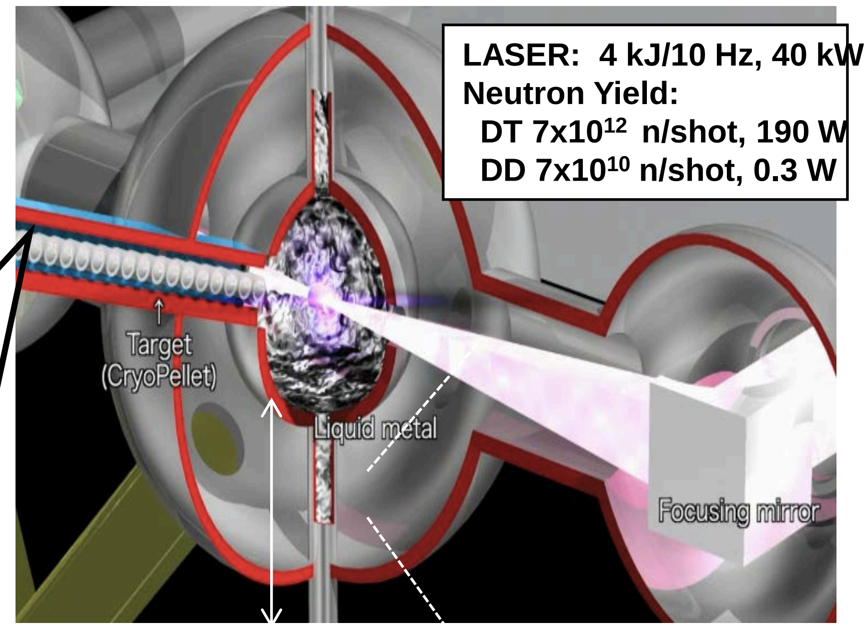
For fuel implosion and fast heating

Achieved 0.5 Hz, 7 shells

MORI NF2019

CANDY (2010~): Demonstration of Laser Fusion Energy Conversion

Kitagawa PFR 2013
Kitagawa J. Phys Conf. Ser. 688 2016



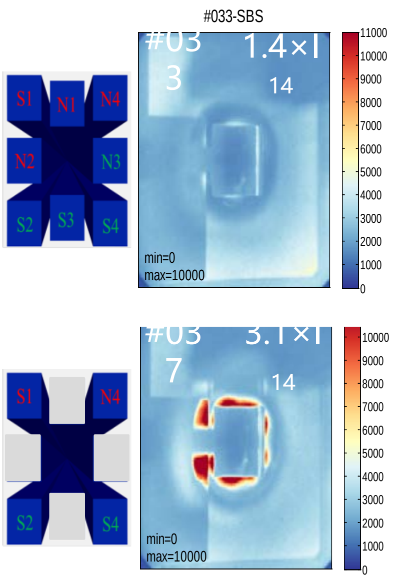
Summary

Yang, L-I35

- A new experimental platform *octuplet* has been developed to study LPI under laser configurations close to the future.
- The effects of several laser parameters on LPI have been studied.

Under current experimental conditions

- Changing single beam's F# while maintaining the whole octuplet's has little effect on LPI.
- Mitigation of LPI is not observed with multi-color beams. ($\delta\lambda$ = 0.3nm @ 351nm)
- LPI depends strongly on the intensity of a single beam rather than the overlapped intensity, offering the potential to mitigate LPI in the future !



The scattered light returns to each beam aperture

TPD can be stimulated at a laser intensity much lower than the normal-incidence threshold

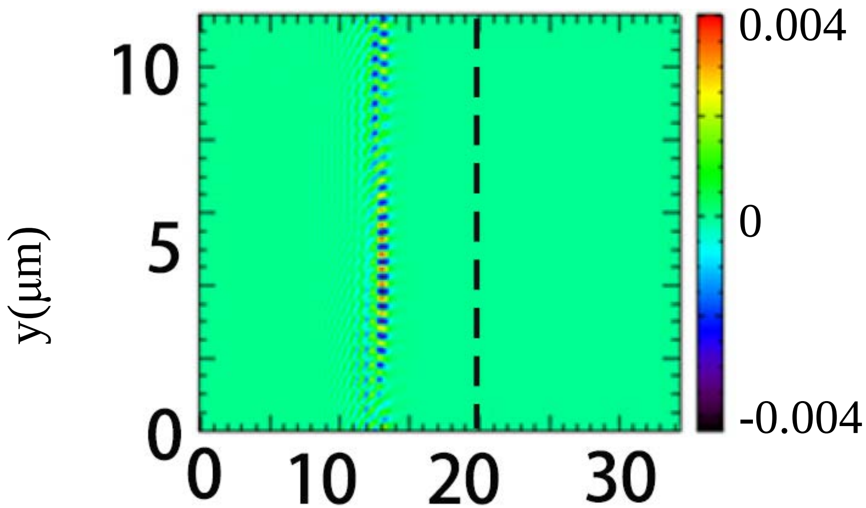
Yan, L-I36

$$I = 1 \times 10^{13} W/cm^2$$
$$T_e = 3keV$$
$$L = 100\mu m$$
$$\lambda = 0.351\mu m$$
$$\eta = 0.0014 \ll 1$$

θ=60.8°

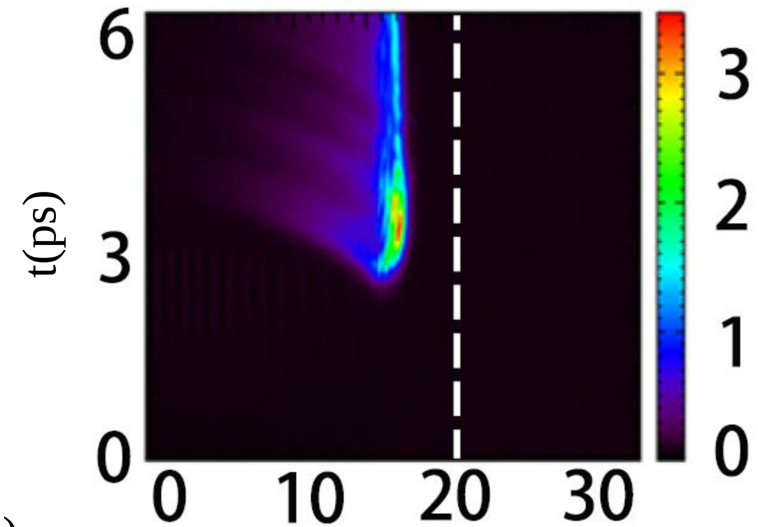
LTS

Electron density fluctuation



OSIRIS

<E_y^2>



x(μm)

$$Normal-incidence\ threshold:\ \eta = I_{14} L_\mu \lambda_\mu / (T_{keV}\, 82)$$

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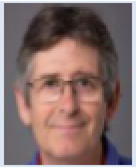
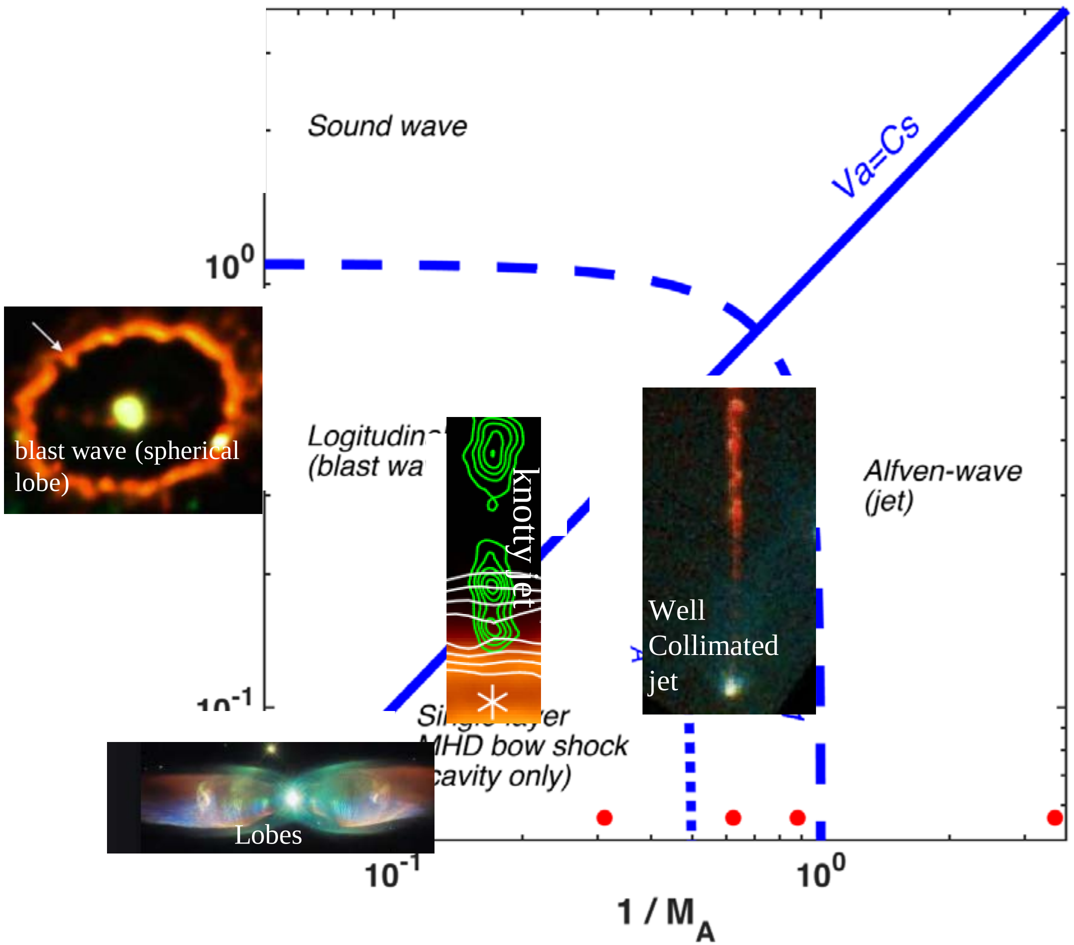
PL-17 (L)		Michel Koenig	Ecole Polytechnique	Overview of Laboratory Astrophysics Experiments at LULI
PL-21 (L)		Hitoki Yoneda	University of Electro-Communications	Progress of inner-shell ionized hard x-ray laser pumped by intense XFEL pulses

L-I12	Dominik Kraus	Helmholtz-Zentrum Dresden-Rossendorf	Ionization dynamics in CH plasmas at Gbar pressures
L-I13	Mrityunjay Kundu	IPR	Short pulse laser cluster interaction: unification of resonances
L-O3	Atur Kumar	IPR	Excitation of magnetosonic solitons in with high power, pulsed CO2 laser in an overdense gas-jet target

Outflow Morpholo

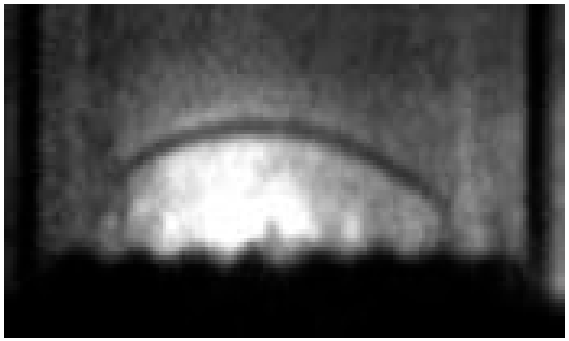


Found that it's the external Alfvenic Mach number determining the outflow morphology, which converting from well-collimated jet to knotty jet and finally to less-collimated lobe

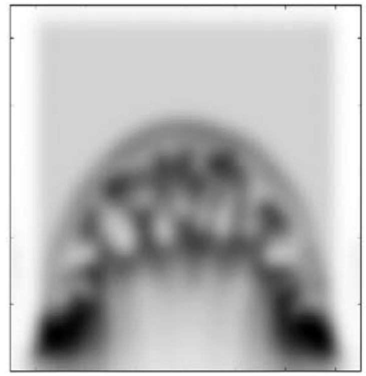
Summary of X-ray radiography results

Mabey, L-I39

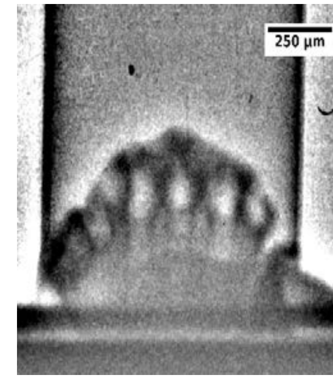
CCD / Image plate – currently used X-ray detectors



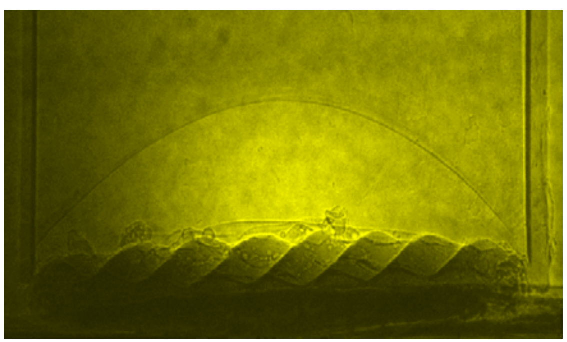
Static RTI modulated target (experiment)

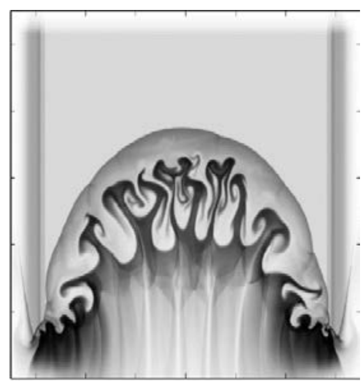


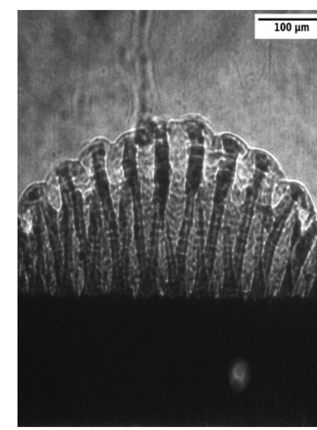
Driven target (simulation)



Driven target

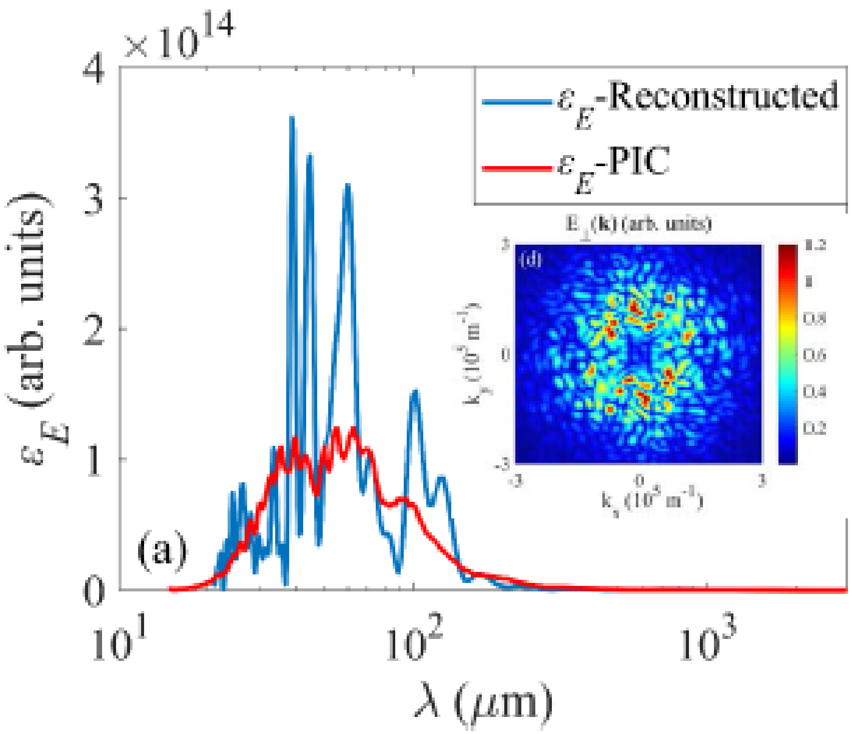






Lithium Fluoride – a new X-ray detector

Ability : providing the average strength and main wavelength of both E and B fields



3D-PIC simulation

$|E_\perp|_{rms} = 3.1\times10^9$ V/m $\lambda_{|E|} = 27$ μm

$|B_\perp|_{rms} = 23$ T $\lambda_{|B|} = 35$ μm

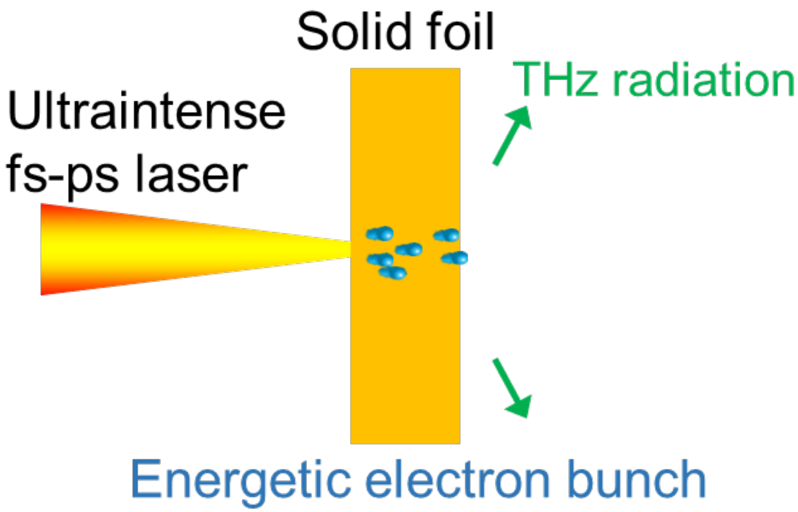
Reconstructed from proton radiography

$|E_\perp|_{rms} = 3.6\times10^9$ V/m $\lambda_{|E|} = 24$ μm

$|B_\perp|_{rms} = 18$ T $\lambda_{|B|} = 48$ μm

Spectrally-tunable THz pulses with the highest pulse energy (>100mJ, world record reported in lab) are generated from relativistic picosecond laser-foil interactions

Liao, L-I40



Theoretical model

Electron emission and ion acceleration can induce THz radiation.

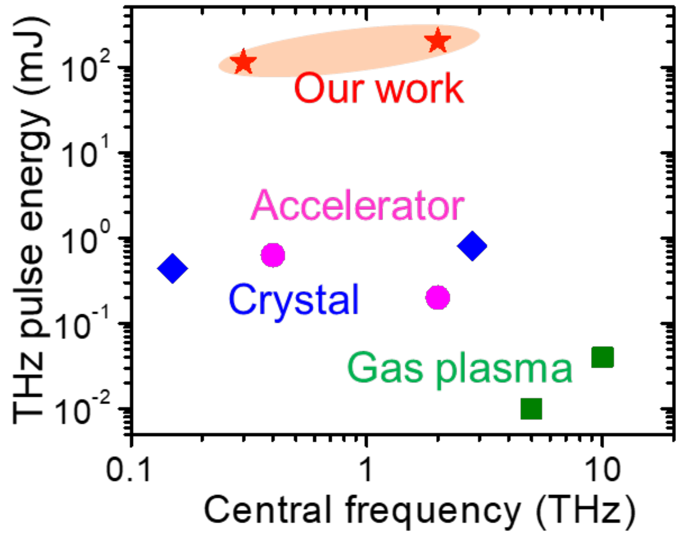
☺ ps duration → Coherent at THz

☺ nC-μC charge → High power

Experiment @ Vulcan

- Sub-TW-level THz pulses are obtained;
- THz spectra can be controlled by tuning laser or target parameters;
- THz radiation is used as an *in-situ* diagnostic of the escaping and sheath electrons.

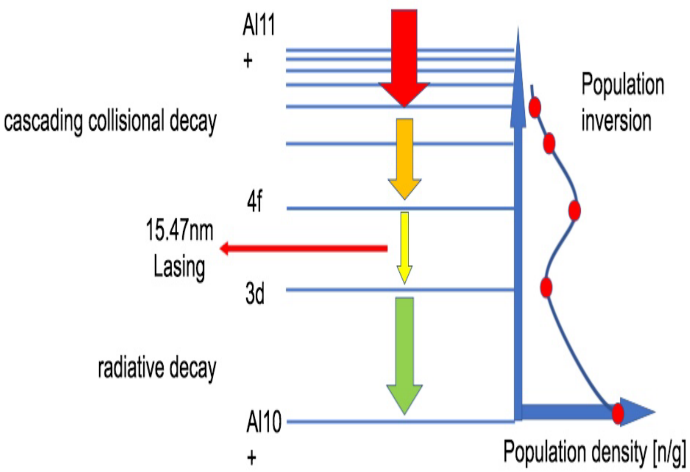
Comparison with other THz sources

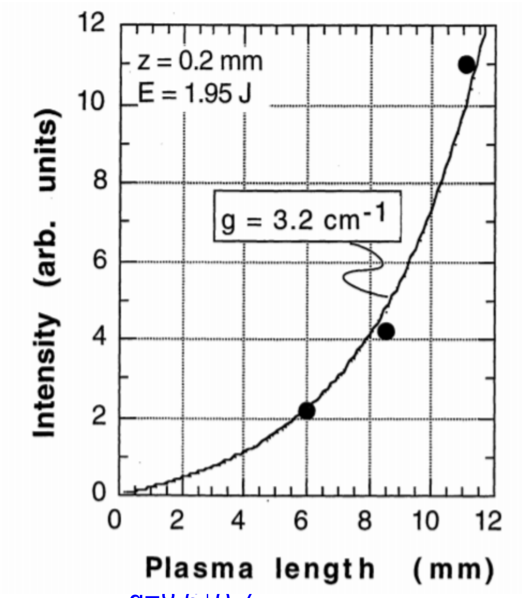


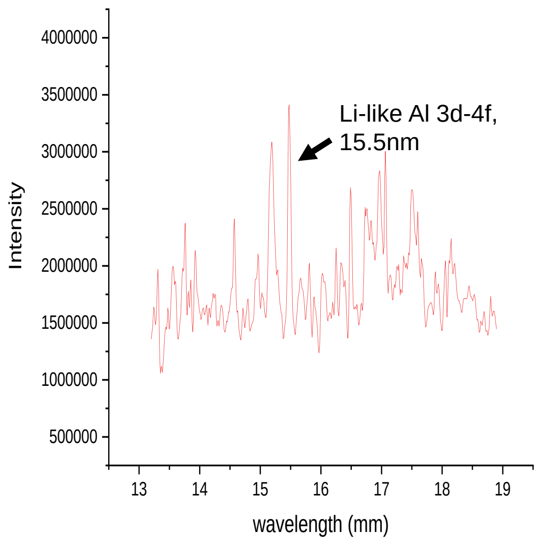
Lithium-like aluminum ion recombination plasma X-ray laser at 15.5 nm

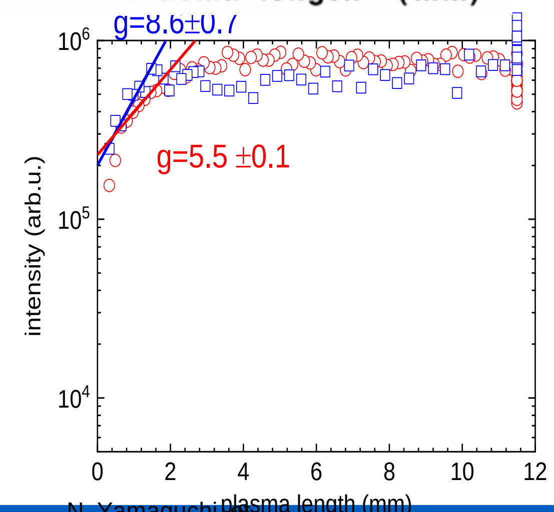
L-P1	Jiahao Wang	Hiroshima University	Lithium-like aluminum ion recombination plasma X-ray laser at 15.5nm

Technology







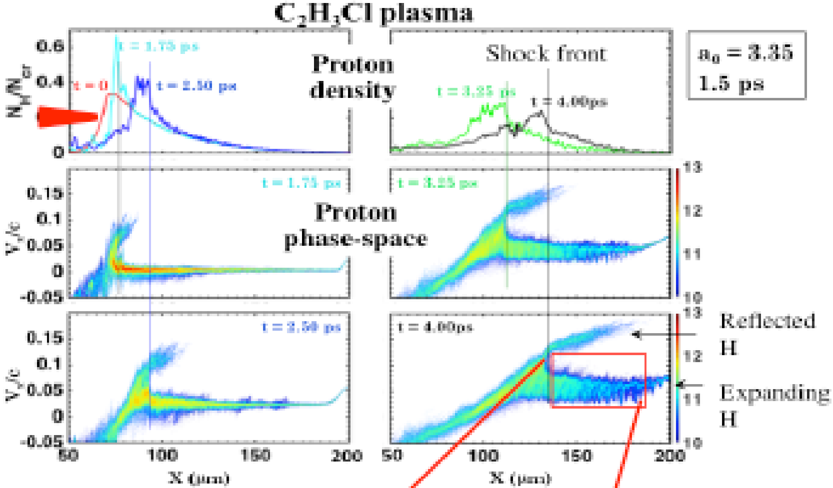


Recombination plasma soft X-ray laser (Li-like Al ion)

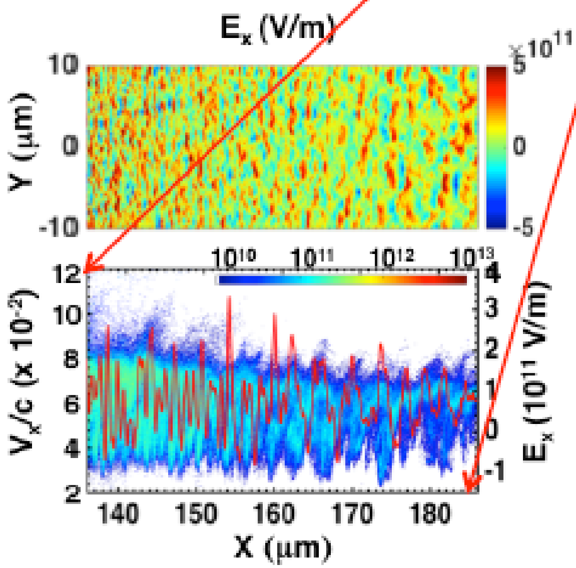
N. Yamaguchi et. al.

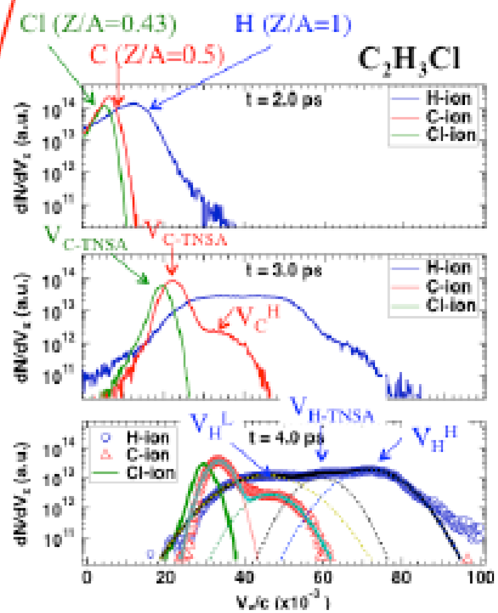
L-I-8 Y. Sakawa (Osaka-U, Japan) Ion acceleration by high-intensity laser-driven electrostatic collisionless shock

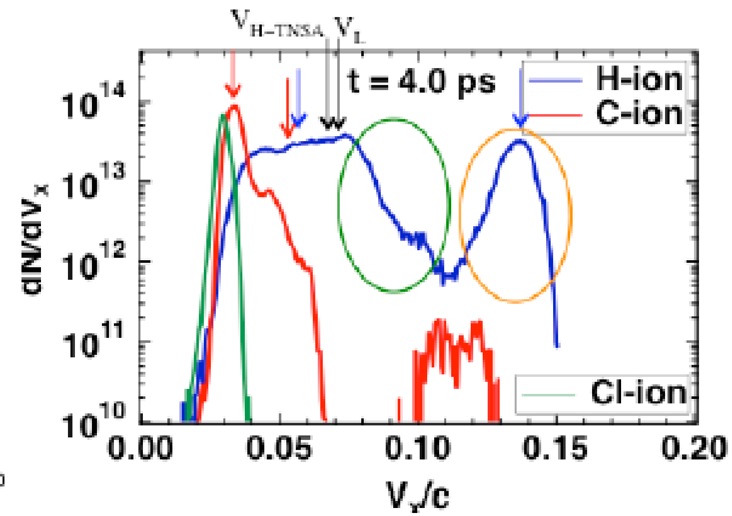
ILE, Osaka U



- 2D PIC simulation study of proton acceleration via electrostatic collisionless shock in multi-ion species plasma, such as C_2H_3Cl
- Z/A dependence of ion expansion velocity V_{TNSA} under DC ambipolar electric field E_{TNSA} → excitation of Es Ion Two-stream Instability (EITI)
- EITI b/w expanding C^{6+} & H^+ leads to a lower-velocity component in H^+
  EITI b/w expanding H^+ & reflected H^+ leads to a higher-velocity component in H^+
  → results in more H^+ to be accelerated by the shock







Conclusions

- Newly established ultrahigh power laser facilities make relativistic plasma physics the most active research field, in particular, laser-plasma accelerator, ultra-bright sources, nonlinear quantum electrodynamics, etc;
- New schemes for laser fusion are proposed, and ignition physics still is the key issue for inertial confinement fusion.
- High-energy-density physics is a very diverse and active field, including laboratory high-energy-density astrophysics, warm dense matter physics. Novel diagnostic techniques are essential for new physics.


Thank you for
your attention!