# A6 subcourse: Experimental General Physics（一般物理実験）

# Frontiers of experimental physics

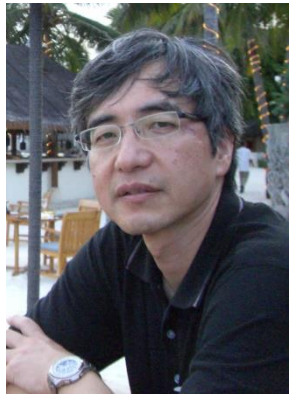
A6 subcourse is interdisciplinary and incubatory.

Both A7 (biophysics) and A8 (astrophysics and astronomy) subcourses have been derived from A6 subcourse.

## Current A6 subcourse members (alphabetical order):

**Hirofumi Sakai（酒井広文）:**
Atomic, Molecular, and Optical (AMO) physics, High-intensity laser physics, Ultrafast Phenomena in atoms and molecules

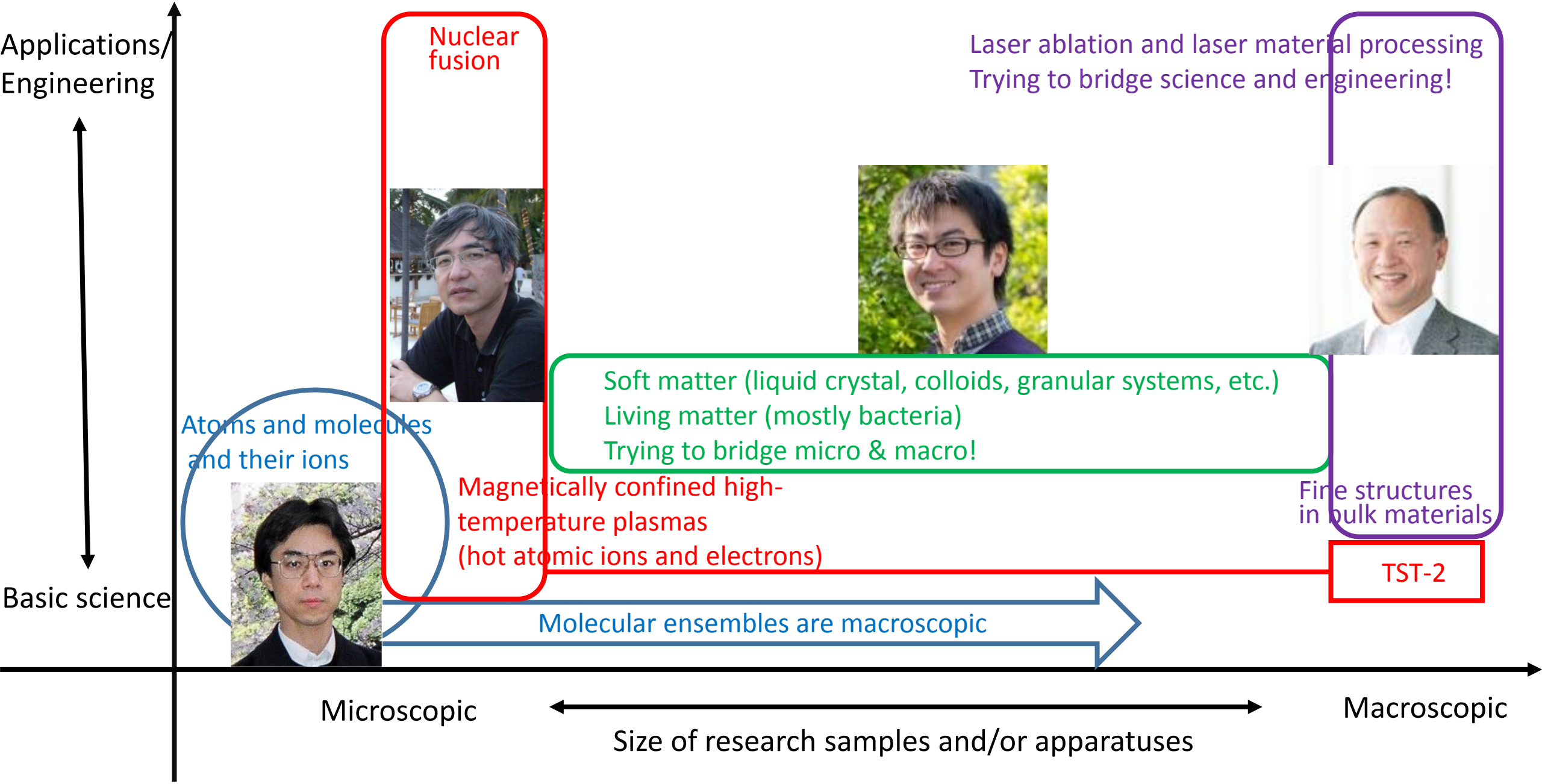
**Yuichi Takase（髙瀬雄一）:**
Physics of magnetically confined high-temperature plasmas, Tokamak plasma formation and plasma current ramp-up using the lower-hybrid wave (LHW) on TST-2 (Tokyo Spherical Tokamak-2)



**Takeuchi A. Kazumasa（竹内一将）:**
Statistical physics of nonequilibrium systems by using soft matter (liquid crystal, colloids, granular systems, etc.) and living matter (mostly bacteria)

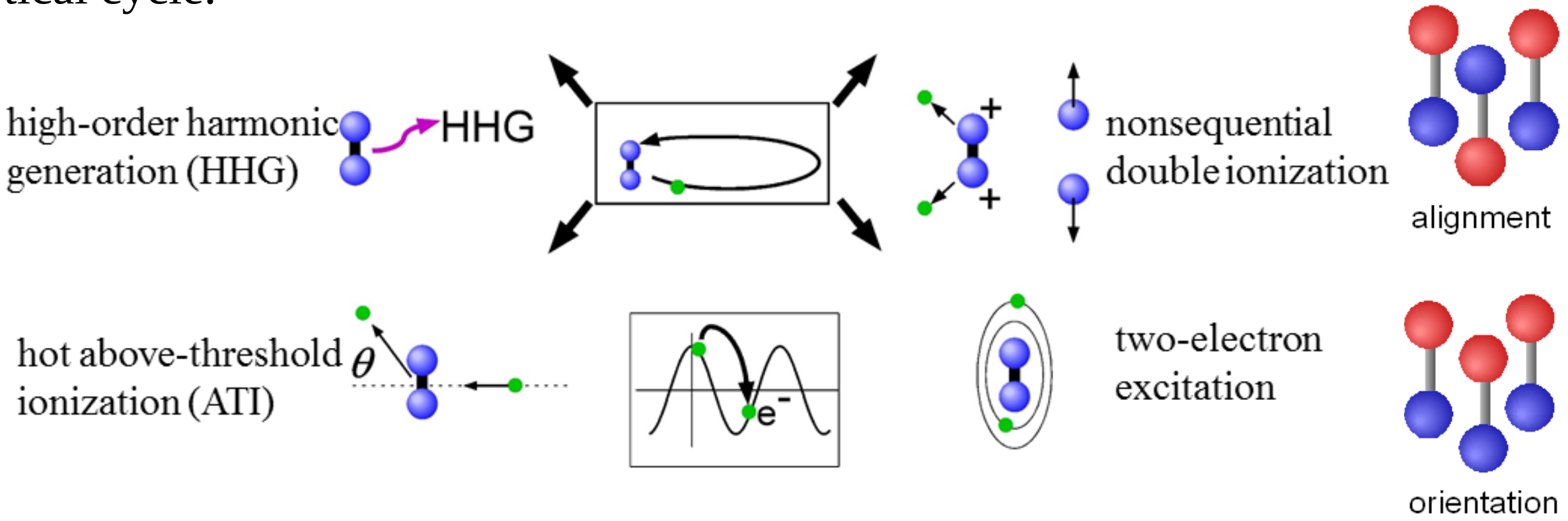
**Junji Yumoto（湯本潤司）:**
Measurements of optical constants in EUV region, Photoemission spectroscopy using ARTOF, Laser ablation and laser material processing

# Map of research fields of current A6 members



# Sakai group

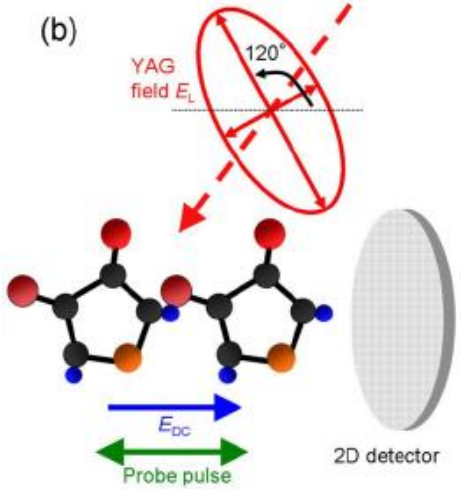
- We are the world-leading group in molecular alignment and orientation techniques and their applications.
- Sakai was awarded “the 23rd Matsuo Foundation Takuma Hiroshi Award” in 2019.
- Some important physical phenomena are caused by electron recollision within one optical cycle.



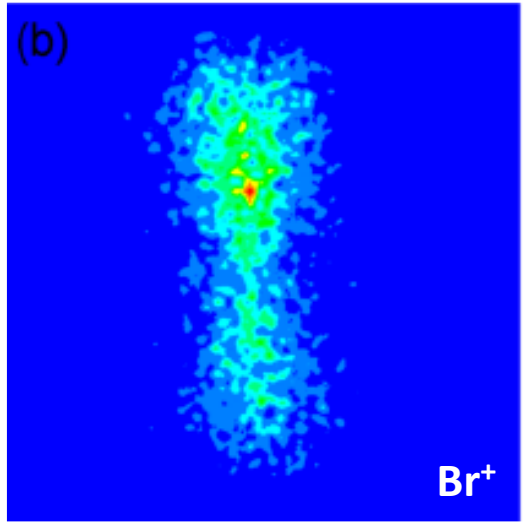

Electronic stereodynamics in molecules is the basis for ultrafast molecular imaging.

# Research highlights

1. Laser-field-free orientation of state-selected asymmetric top molecules
   J. H. Mun *et al*., Phys. Rev. A **89**, 051402(R) (2014).
2. Laser-field-free three-dimensional molecular orientation
   D. Takei *et al*., Phys. Rev. A **94**, 013401 (2016).




3,4-dibromothiophene




3 desired requirements are fulfilled!

(1) Higher degrees of molecular orientation

(2) Three-dimensional molecular orientation

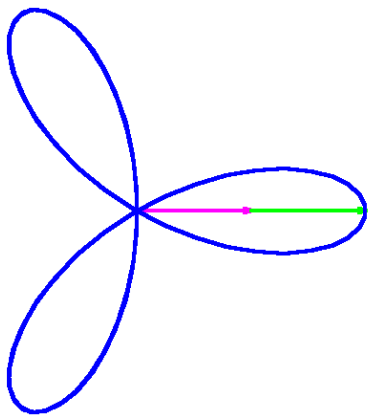
(3) Molecular orientation in the laser-field-free condition

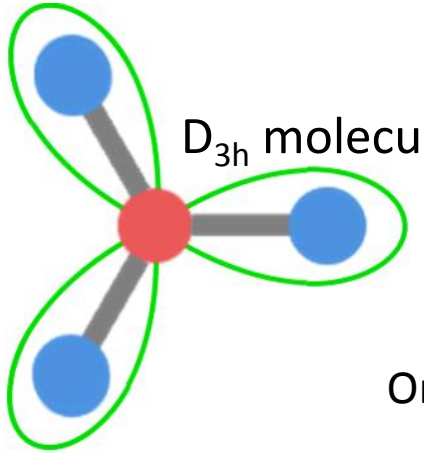
This accomplishment can be regarded as the acme of the molecular orientation technique based on the combined-field, i.e., (DC+AC)-field technique.

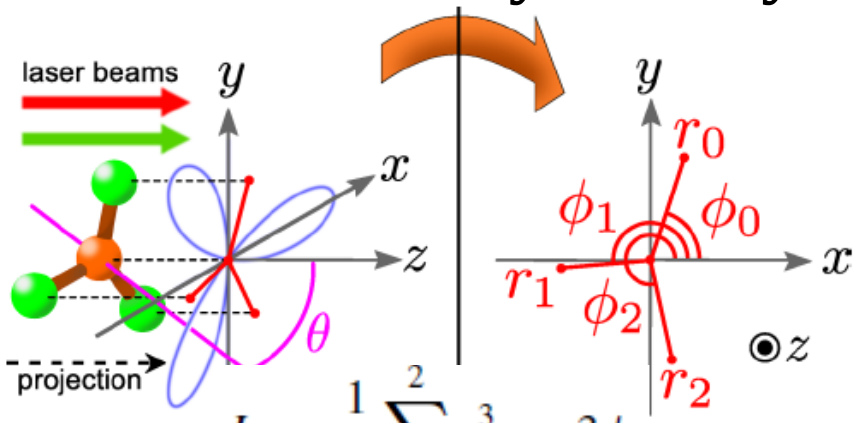
3. Orientation dependence in multichannel dissociative ionization of OCS molecules
   Y. Sakemi *et al*., Phys. Rev. A **96**, 011401(R) (2017).
4. Recipe for preparing a molecular ensemble with macroscopic threefold symmetry
   H. Nakabayashi *et al*., Phys. Rev. A **99**, 043420 (2019).→Future plans

# Future plans

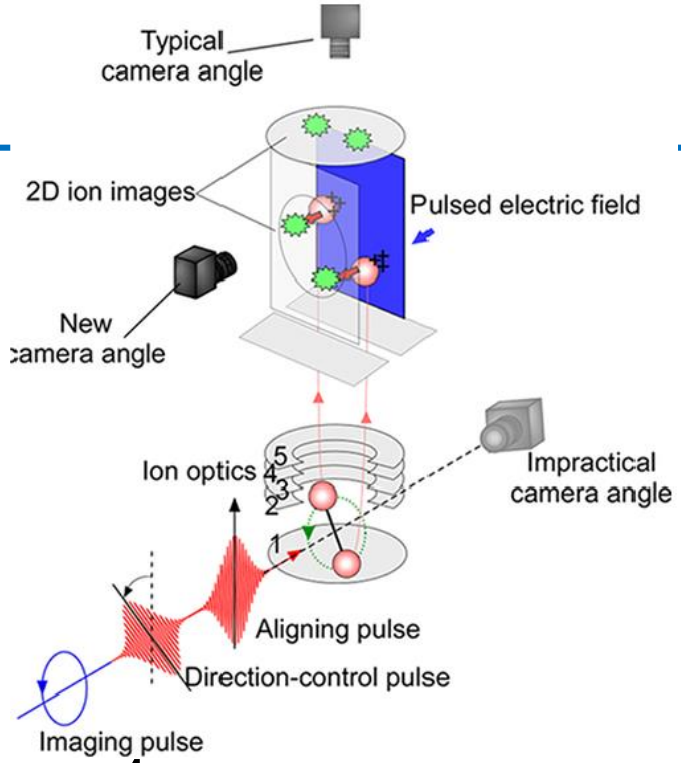
## 1. Forming a gaseous crystal with three-fold symmetry





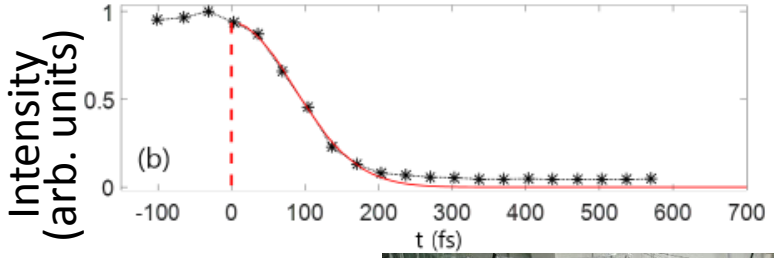

Order parameter: $I_\Delta = \frac{1}{3}\sum_{i=0}^{2} r_i^3 \cos 3\phi_i$




↑Adopted from J. Vis. Exp. **120**, e54917 (2017)

## 2. Field-free molecular orientation with an intense nonresonant two-color laser pulse with a slow turn on and a rapid turn off

(Theory) T. Kanai and H. Sakai, J. Chem. Phys. **115**, 5492 (2001).
(Demonstration) K. Oda *et al*., Phys. Rev. Lett. **104**, 213901 (2010).
(Plasma shutter) J. H. Mun *et al*., Opt. Express **27**, 19130 (2019).




## 3. Development of "electronic stereodynamics in molecules"

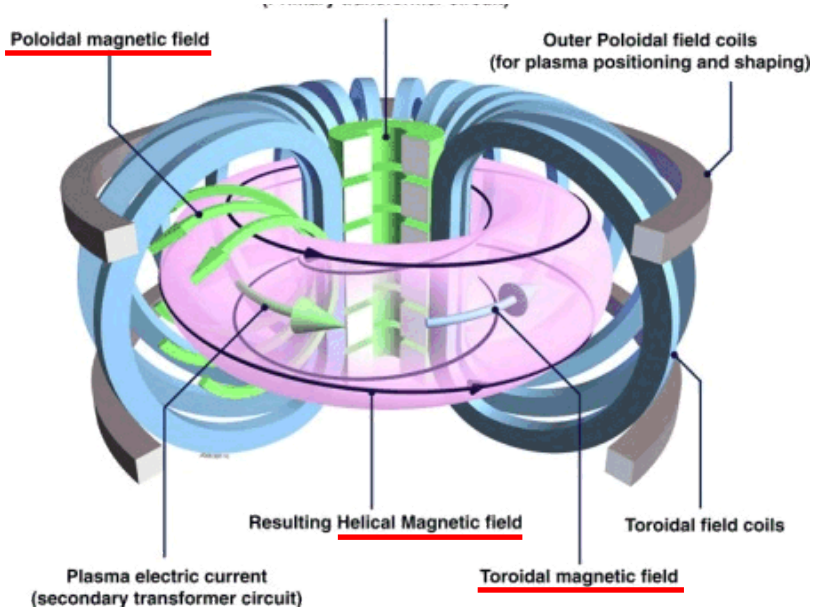
Ex. Y. Sakemi *et al*., "Orientation dependence in multichannel dissociative ionization of OCS molecules," Phys. Rev. A **96**, 011401(R) (2017).

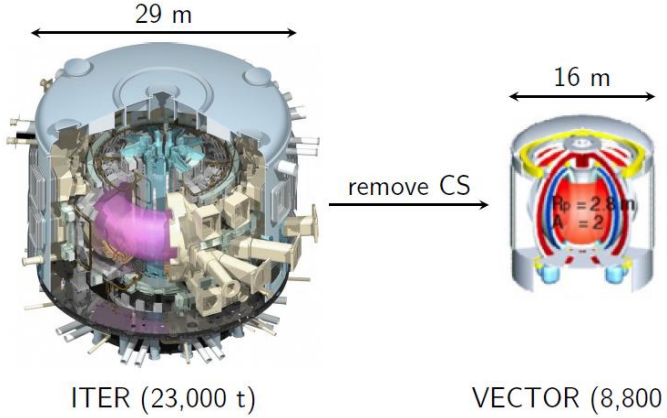
Home-built CO-VIS→

# Plasma Physics and Fusion Research

## Tokamak

**Central Solenoid (CS)**

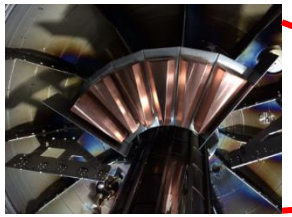


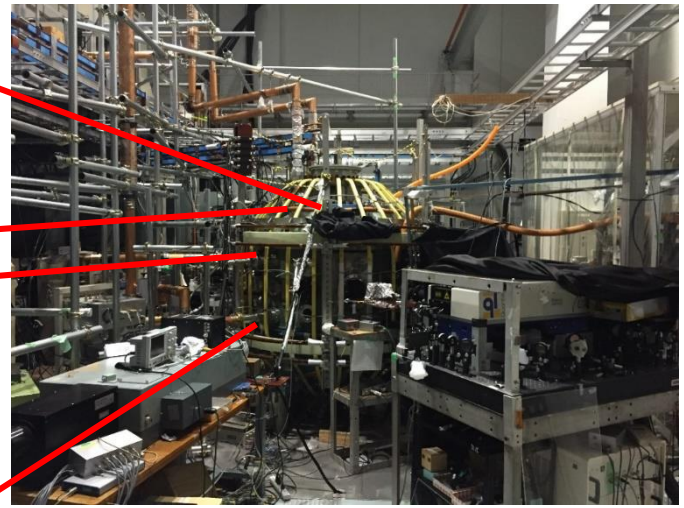

- Removal of the CS may lead to a compact tokamak reactor, but non-inductive plasma current ramp-up is a challenge.
- Plasma current ramp-up using the lower-hybrid wave (LHW) is being investigated in TST-2.

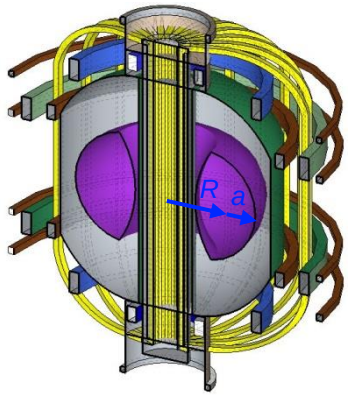
TST-2

top-launch



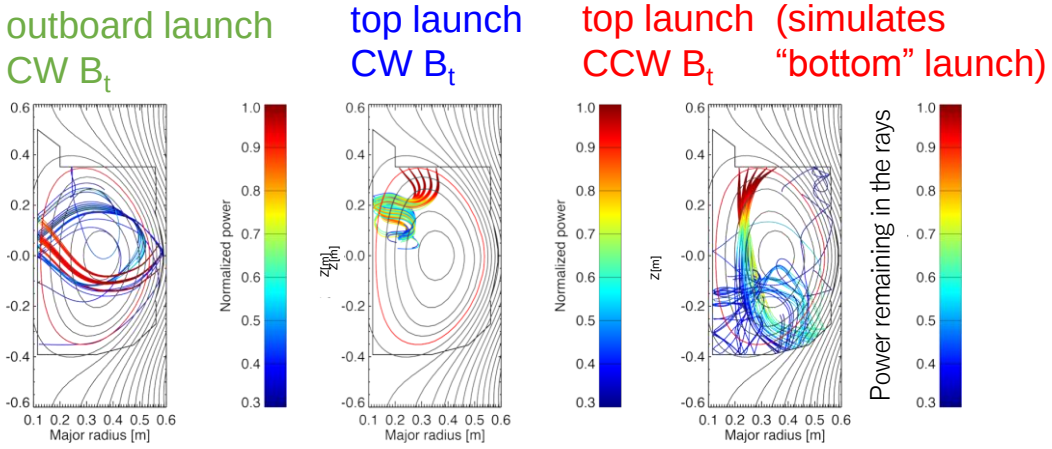
outboard-launch

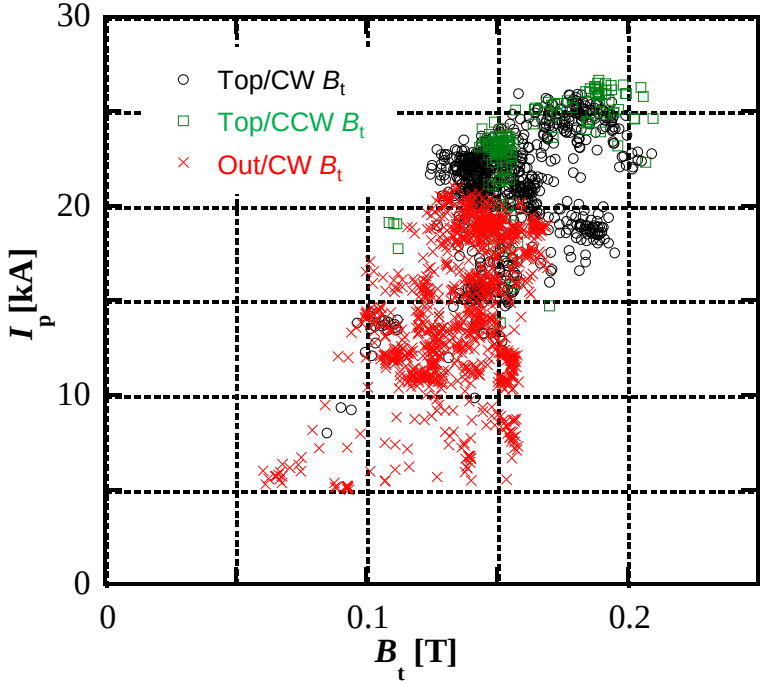





$R_0$ = 0.36 m
$a$ = 0.23 m
$B_t$ = 0.3 T
$I_p$ = 0.1 MA

# Plasma Current Start-up by LHW on TST-2



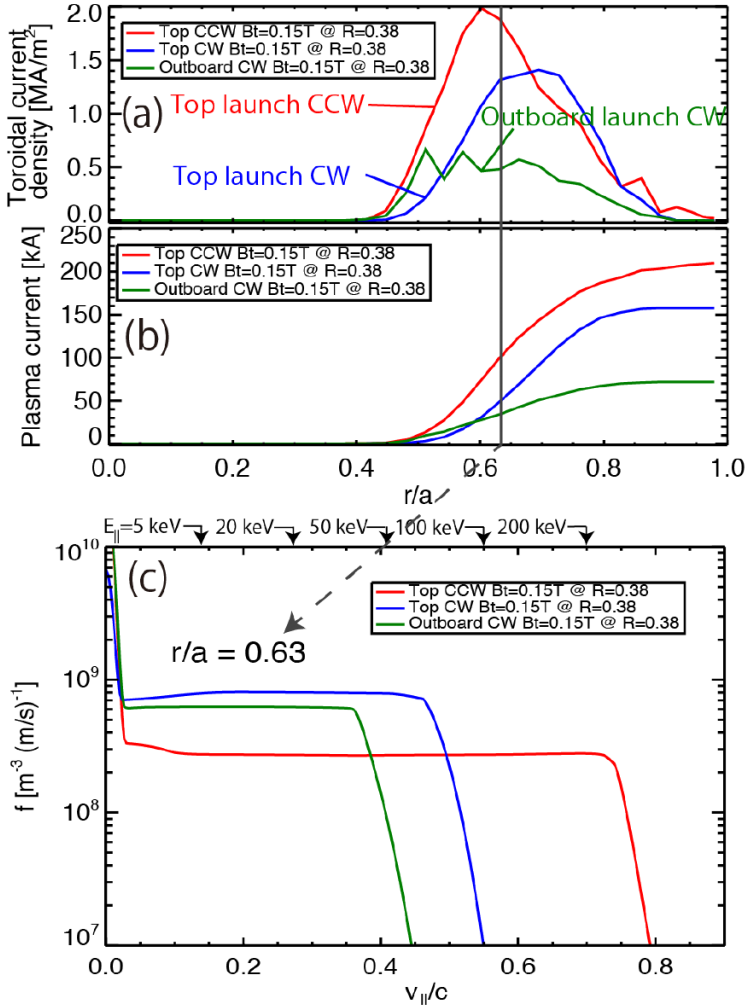

Top-launch CW $B_t$

Top-launch CCW $B_t$
(simulates bottom-launch)

Outboard-launch CW $B_t$

Higher $I_p$ is achieved with top-launch LHW than with outboard-launch, as expected.

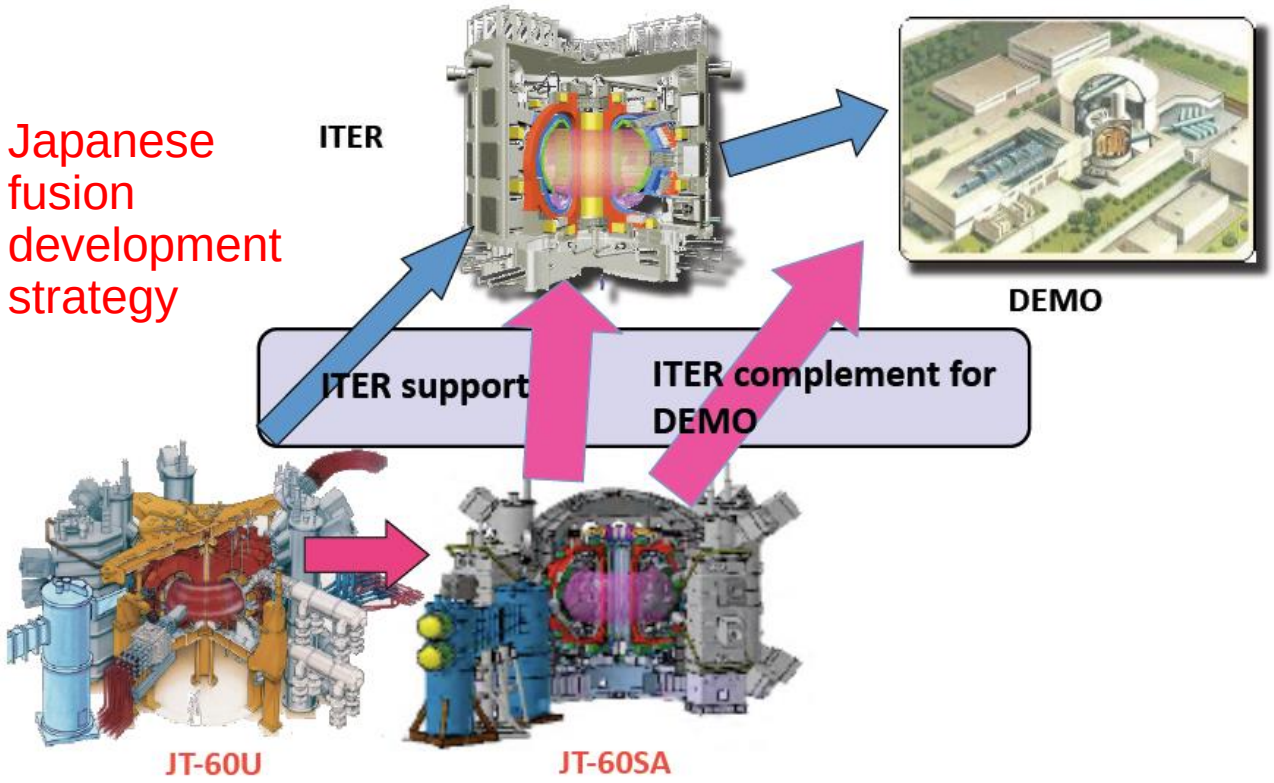
Contrary to expectation, similar $I_p$ is achieved with top-launch LHW with either direction of $B_t$ .




CQL3D (Fokker-Planck) solution

# Contributions to Fusion Energy Development

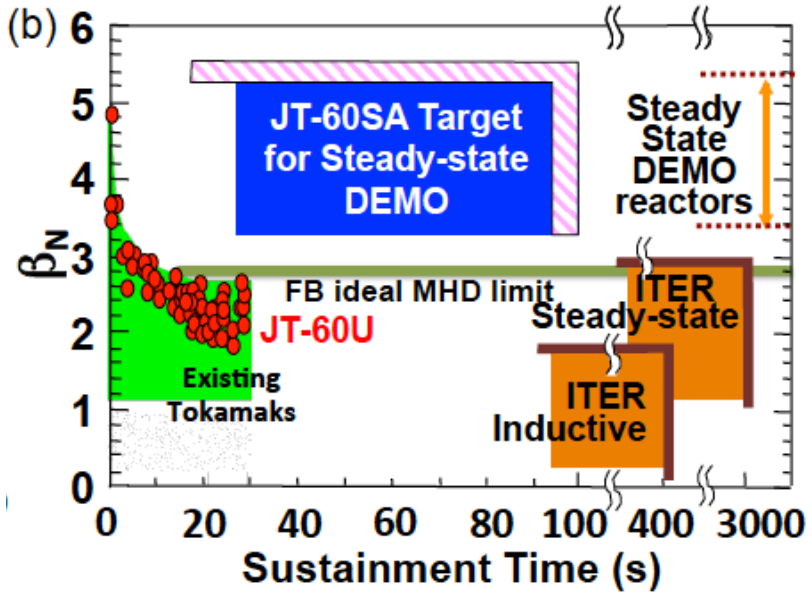
Japanese fusion development strategy




- JT-60SA has a dual mission:
  - ITER support
  - ITER complement:
    "develop advanced tokamak scenarios for DEMO"

- UTokyo group will provide scientific leadership in the JT-60SA project (JA-EU collaboration):
  - Plasma commissioning (2020)
  - High-power heating experiments (2023-)

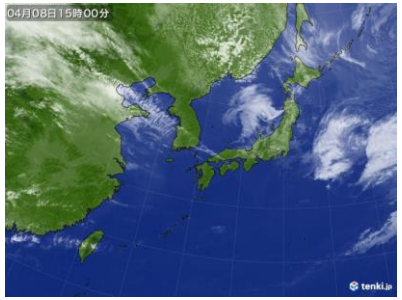
Challenges of advanced tokamak operation:
- sustained high $\beta_N$ with good confinement
- steady-state with high self-driven current fraction

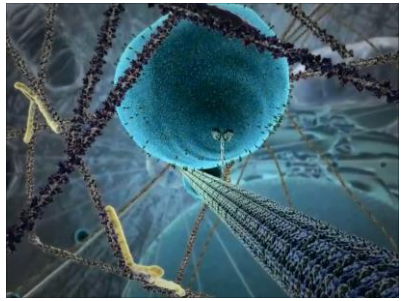


Takeuchi Lab

# "Experimental Statistical Physics Lab using Soft & Living Matter"

Our interests: Physical principles of non-equilibrium systems across disciplines



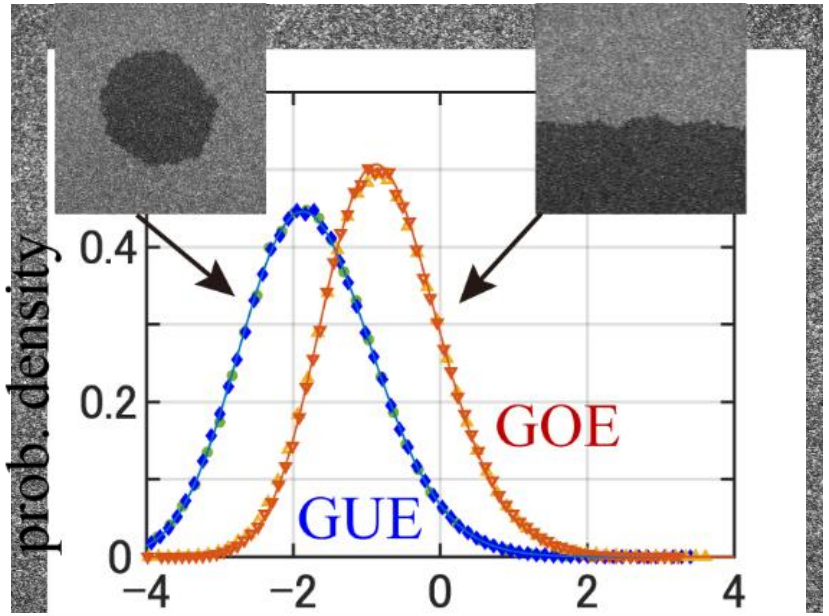


We aim at large-scale, hopefully universal, phenomena. Design experiments & carry out!

- Topological defect turbulence of liquid crystal
- Order formation in bacteria turbulence
- Statistical physics of dense bacteria suspensions
- Model experiments on interacting particle systems by granular matter
- Time-series analysis for large chaotic systems

# Topological Defect Turbulence of Liquid Crystal

macro: growing liquid-crystal turbulence




26V, 250Hz, Speed x5, t=28 200$\mu$m

KPZ: universal fluctuations of growth phenomena and beyond

micro: imaging 3D defect dynamics

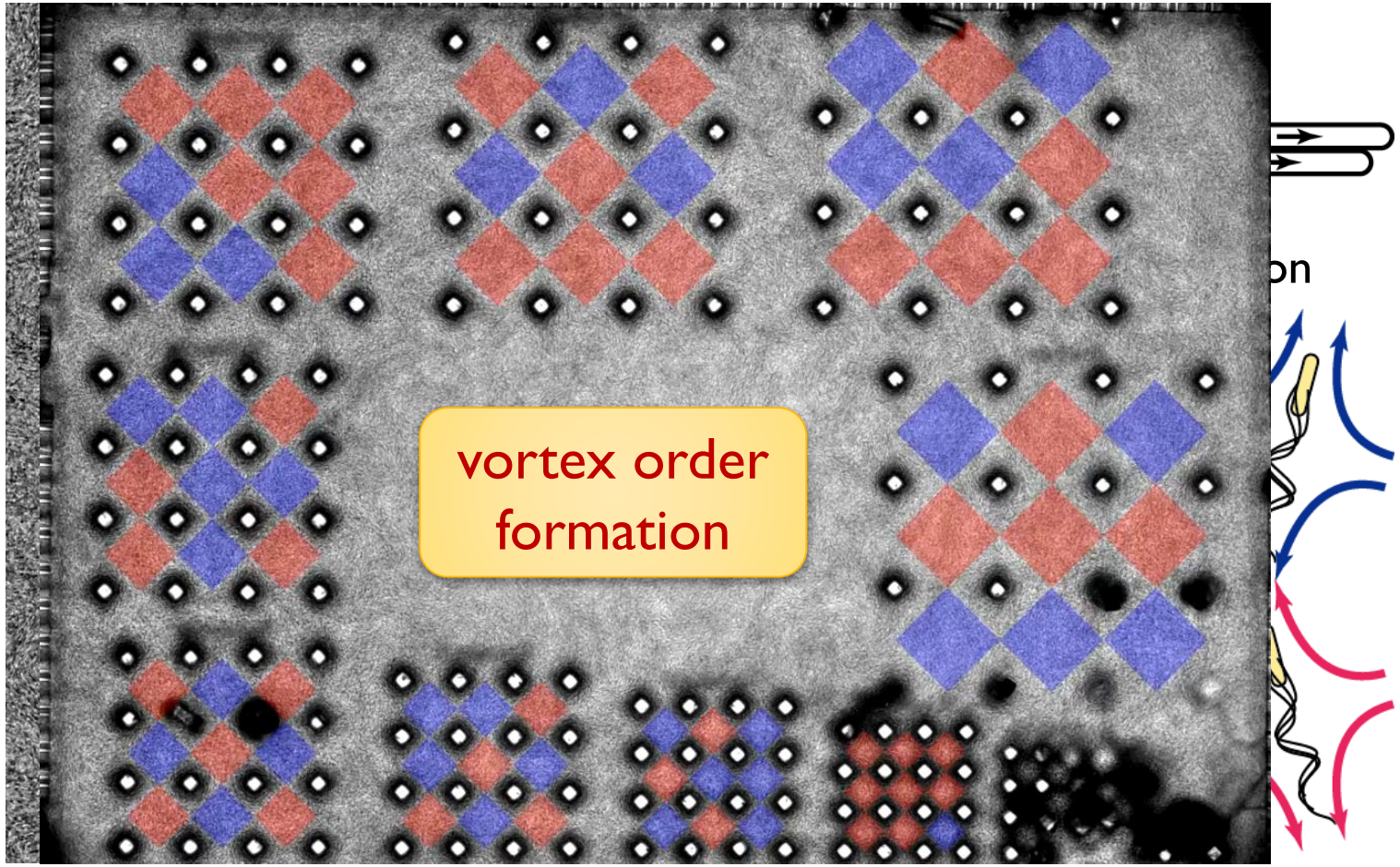
- Unique experiment uncovering KPZ class physics: bridge to KPZ exact solutions (PRL 2010, 2013, 2017a, 2017b, 2020, etc.; MEXT Young Scientist Prize 2018)
- Confocal imaging of defect dynamics, uncovering universal kinetics of reconnections (ongoing; PRESTO 2018-)

We're aiming to bridge micro & macro!

# Statistical Physics of Bacteria Suspensions

Bacteria suspensions are intrinsically turbulent.

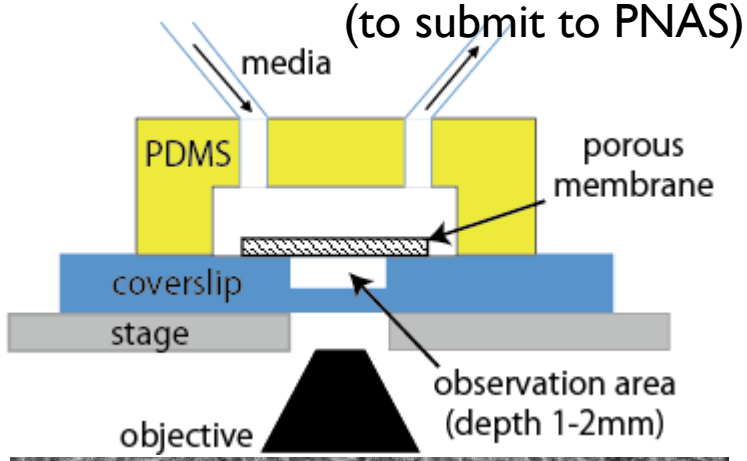
How to make an order? ⇨ Small pillars! (Nat Comm 2018)




*B. subtilis*

new microfluidic device for dense bacteria suspensions

(to submit to PNAS)



*E. coli*, speed x60

# Junji Yumoto

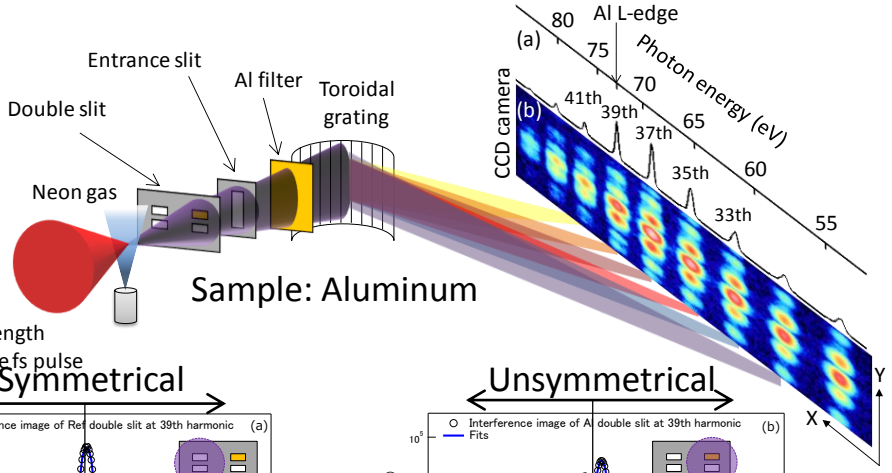
Professor, Department of Physics (2015-)
Director, Institute for Photon Science and Technology (2014-)
Director, UTokyo Research Inst. for Photon Science and Laser Technology (2017-)

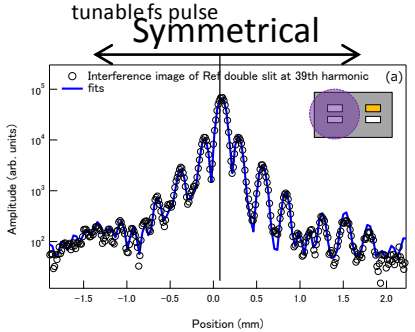
| | |
|---|---|
| 1984 | Doctor of Eng. (Keio University) |
| 1984 | NTT Basic Research Labs. |
| 2006 | Director, NTT Basic Research Labs. |
| 2009 | Vice President, NTT Electronics |
| 2011 | President, NEL America, Inc. (New Jersey) |
| 2014 | Professor, Institute for Photon Science and Technology |
| 2015 | Professor, Department of Physics |

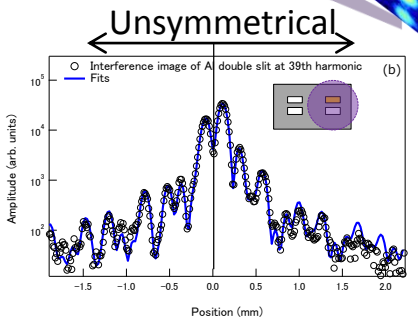
**Research Fields**

- Laser Physics
- HHG / Vacuum UV Generation
- Measurements of Optical Constants in EUV Region
- Photoemission Spectroscopy using ARTOF
- Laser Ablation & Laser Material Processing
- THz Spectroscopy

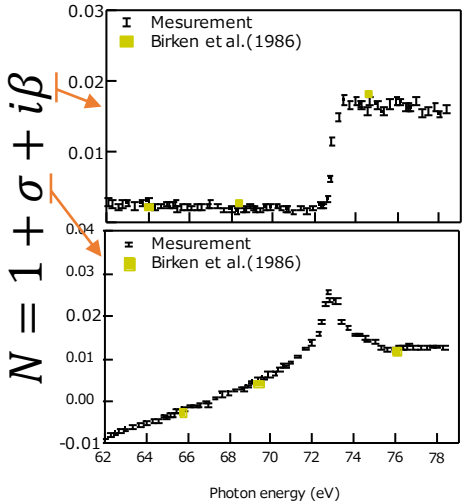
# Direct measurement of refractive index in EUV

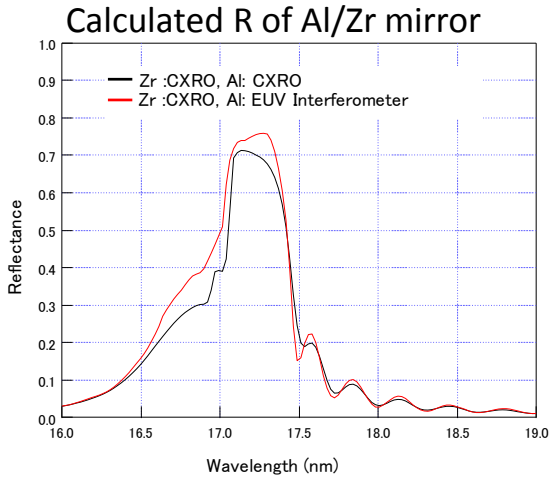



Asymmetry occurs due to a optical path length change and attenuation of the sample transmitted light



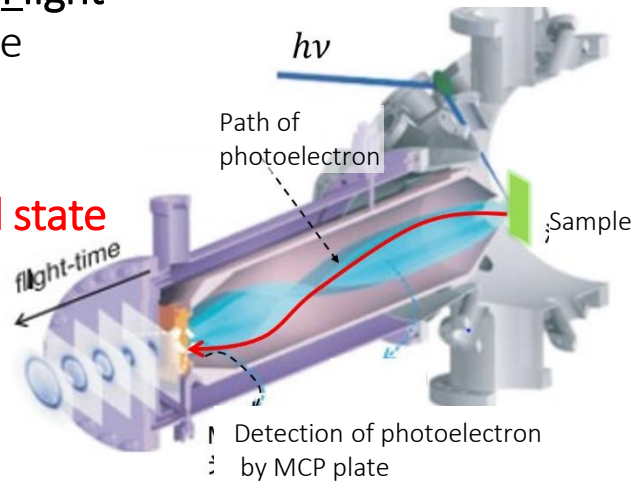




# Photoemission spectroscopy using ARTOF

ARTOF : Angle-Resolved Time-of-Flight

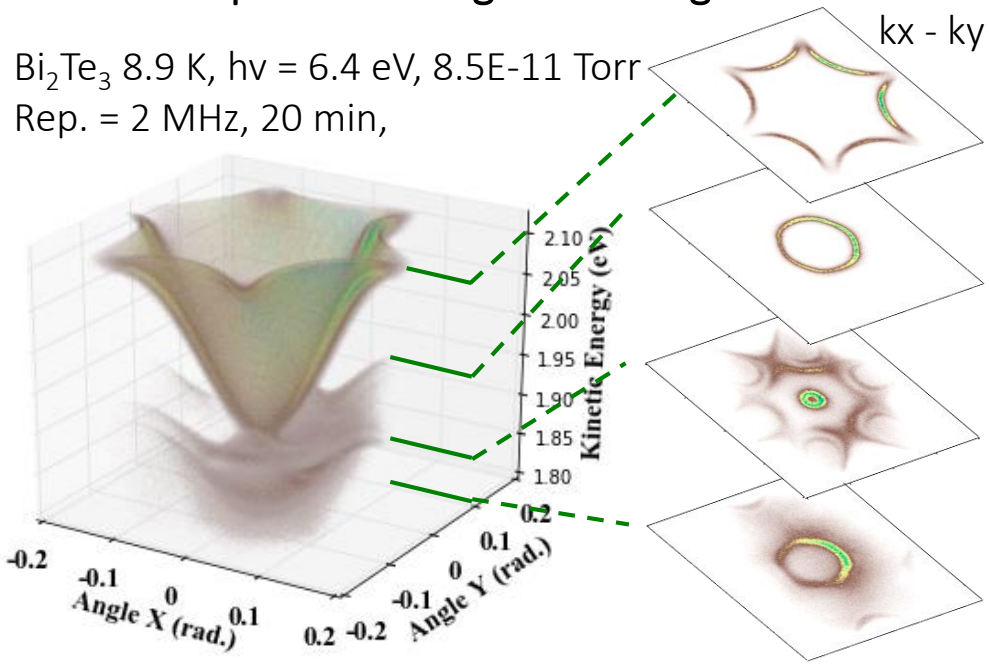
1. 2D wavenumber space image
2. Large taking angle
   =high acquisition efficiency
   >Observation of Unoccupied state

energy resolution ΔE
2.4 meV




Photoemission spectrum image with a high resolution

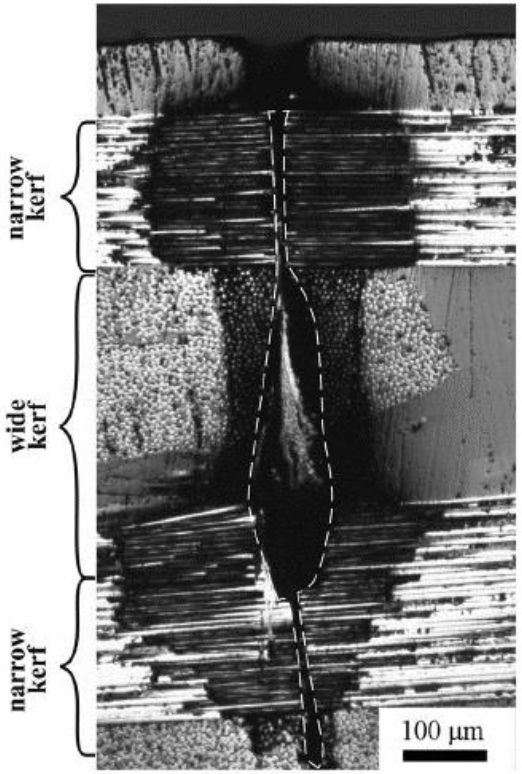
$Bi_2Te_3$ 8.9 K, hv = 6.4 eV, 8.5E-11 Torr
Rep. = 2 MHz, 20 min,



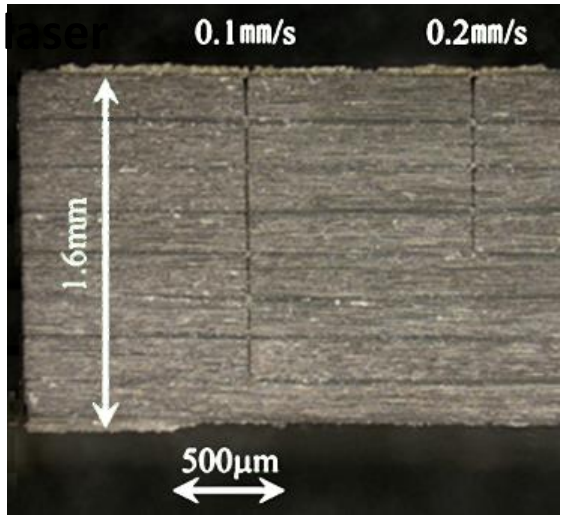
# Laser Ablation & Laser Material Processing

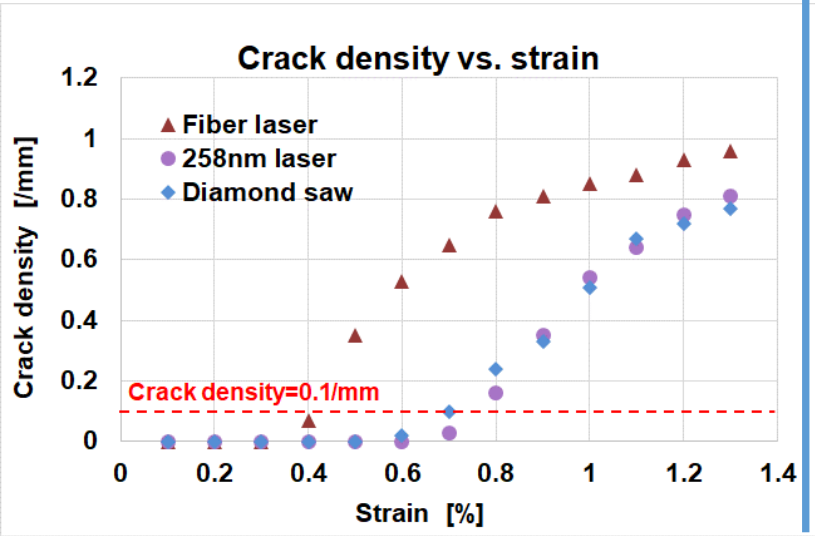
## Laser Cutting of CFRP

**Using 532nm laser**




**Using 258nm ns-pulsed**

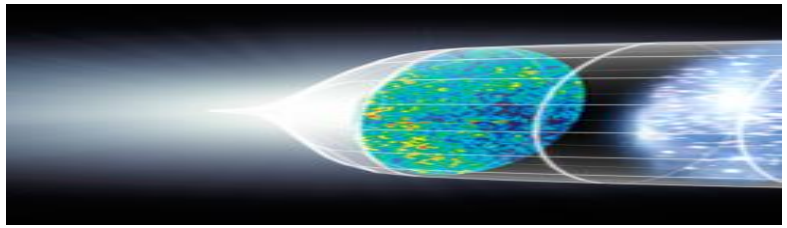
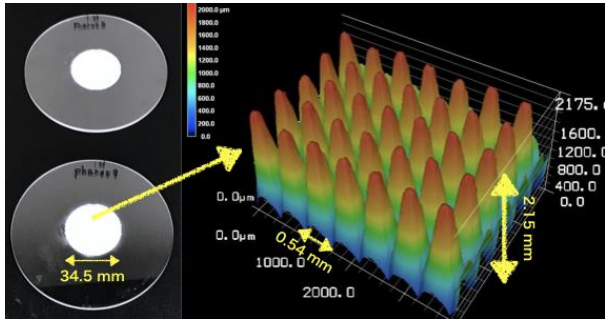
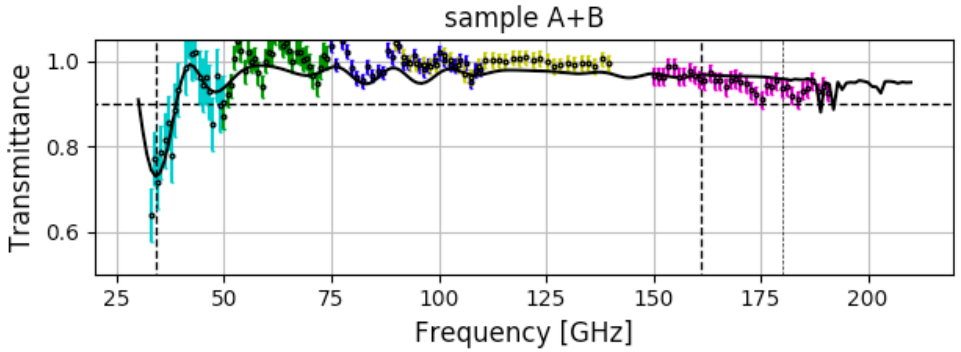



## Moth-eye Structure on Sapphire

-Wideband polarization modulator unit for LiteBIRD-

**LiteBIRD** Collaboration with IPMU, UTokyo



**Laser microscope Image of moth-eye structure**