Compact Torus Panel

FRC and Spheromak

Status report

Theme 5 Workshop

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CT Research Thrusts (1)

Research Thrust: Determine the scientific feasibility of magnetic fusion in a toroidal magnetic configuration within a simply-connected geometry and with no toroidal-field coils or solenoid

Four Sub-thrusts are proposed:

The first two Research Sub-Thrusts for CTs focus on the Tier 1 issues for the FRC and spheromak.

- **Satisfactory resolution of these issues will enable a broader attack on the physics issues**
- **This will position the CTs to propose Proof-of-Principle level experiments to lead community-wide research.**

The second two Research Sub-Thrusts address integrated research in physics for the ITER era.

CT Research Thrusts (2)

Extend the stable regime of the FRC to large *s*

Sub-Thrust 1: Study FRC stability for a wide range of *s,* the ratio of plasma radius to the Larmor radius:

- **Closely coupled experiments and theory/simulations addressing stability at large *s*.**
- **Research on existing experiments will contribute important understanding**
- **At least one new experiment or significant-upgrade of an existing experiment to operate in the high-*s* regime**
  - **A means of forming and sustaining the FRC, with neutral beams to inject energetic ions, and appropriate conducting walls.**
  - **Significant diagnostic capability, providing data for detailed comparison with simulations**
- **Simulation codes that contain an expanded physics basis and numerical capability to enable a predictive capability**

CT Research Thrusts (3)

Understand how to form and sustain a spheromak in a way that is compatible with good confinement

Sub-Thrust 2: Spheromak formation and sustainment compatible with good confinement:

A multicomponent thrust including

- **Exploratory experiments to test new, potentially transformative ideas**
- **A new experiment, with increased capability compared to past experiments, to test new concepts in a high-quality, well diagnosed environment.**
- **Simulations to explore new concepts, to understand how they would be implemented in a larger experiment, and to interpret experiments**

CT Research Thrusts (4)

Achieve the ITER-era goal for FRCs — a sustained or long-pulsed plasma at kilovolt temperatures, with favorable confinement scaling

Sub-Thrust 3: Understand the integrated impacts of FRC physics in the fusion-plasma, high-beta regime using NBI or RF, addressing transport, current drive, fast particles, heating and other important physics:

An integrated physics thrust, including

- **A flagship facility to develop an understanding of FRC physics at a level at least sufficient to meet the ITER-era goal**
- **Theory and simulations closely-coupled to experiment**
- **Sufficient understanding to evaluate scenarios for advanced-fuel reactor concepts**

The research can make a fundamental contribution to overall fusion research by investigating:

- **The effectiveness of high energy ions for stabilizing global MHD modes in toroidally confined plasmas**
- **The efficiency of current drive methods**
- **The effects of natural divertors on plasma confinement and stability**

CT Research Thrusts (5)

Achieve the ITER-era goal for spheromaks — a sustained or long-pulsed plasma at kilovolt temperatures, with favorable confinement

Sub-Thrust 4: Understand the integrated impacts of spheromak physics in the fusion-plasma regime, including transport, beta limits, and particle balance and density control:

- **An integrated experiment and theory/simulation program**
- **A flagship facility to develop an understanding of spheromak physics at a level at least sufficient to meet the ITER-era goal**
  - **A high-quality vacuum environment**
  - **Neutral-beam and/or rf for heating, current drive and profile control**
  - **An extensive set of diagnostics**
- **Small experiments to explore specific physics issues and technology improvements to improve physics understanding and performance**
- **Extensive theory and computational support**
  - **Provide an understanding of fusion/plasma physics in a parameter regime with $q < 1$**
  - **Develop simulation capability to be used as a engineering design tool**
  - **Ideally integrated into a fusion-program wide FSP effort**

Contributions to fusion/plasma science

- Extend MHD and other science to:
  - Low q, $0.2 < q < 1$
  - Ultra low aspect ratio, < 2
  - High beta $0.1 < \beta < 1$
  - Kinetically-dominated plasmas
  - Effect of sheared flow on stability and confinement
- Plasma self-organization and magnetic relaxation
  - Connects to space and astrophysical plasmas
- Non-inductive start-up and sustainment of plasmas using helicity injection
- Translatable plasmas including
  - Separating formation from burning
  - CT fueling

Brainstorming Cross-cutting science opportunities for CTs

Start-up and sustainment

Spheromak

- Solenoid-free startup and sustainment
- Helicity injection and self-organization
- Particle bootstrap currents scale differently

FRC

- Low-frequency rf current-drive
- Power and particle control

Extending the transport physics regime

Spheromak

* $0.2 < q < 1$

- Beta > 0.1
- Low aspect ratio

FRC

- B-toroidal <<B-poloidal
- Beta ~ 1
- Low aspect ratio
- Highly-elongated equilibria for prolate FRCs can be compared with oblate FRCs

Cross-cutting science opportunities for CTs

Energetic particles

Spheromaks

- Particle orbits in low-aspect, q<1 geometry
- Effects on tearing modes

FRCs

- Role of betatron orbits in current drive and stability
- Stabiliztion of MHD modes

Stability

Spheromak

- Reversed shear and shear stabilization in bad curvature

FRC

- Heating of thermal particles by nonlinear dynamics - stochastic orbits - including effects on stability

Power and particle control/ Heat removal

Spheromak and FRC

- Natural divertor (field lines leave plasma volume w/o being blocked by toroidal-field coils)

Cross-cutting science opportunities for CTs

Plasma flows

Spheromak

- Significant role in spheromak formation

FRC

- Shear stabilizing mechanism for interchange instability
- Particle loss and end-shorting drives rotation

Self organization

Spheromak

- Minimum state of magnetic energy at conserved helicity
- Role of flows in relaxation

FRC

- High-beta relaxed state

RF heating and current drive

Spheromak

- High $\omega_{pe}^2/\omega_{ce}^2$ regime

FRC

- Low-frequency current drive via rotating magnetic fields
- Access at high beta