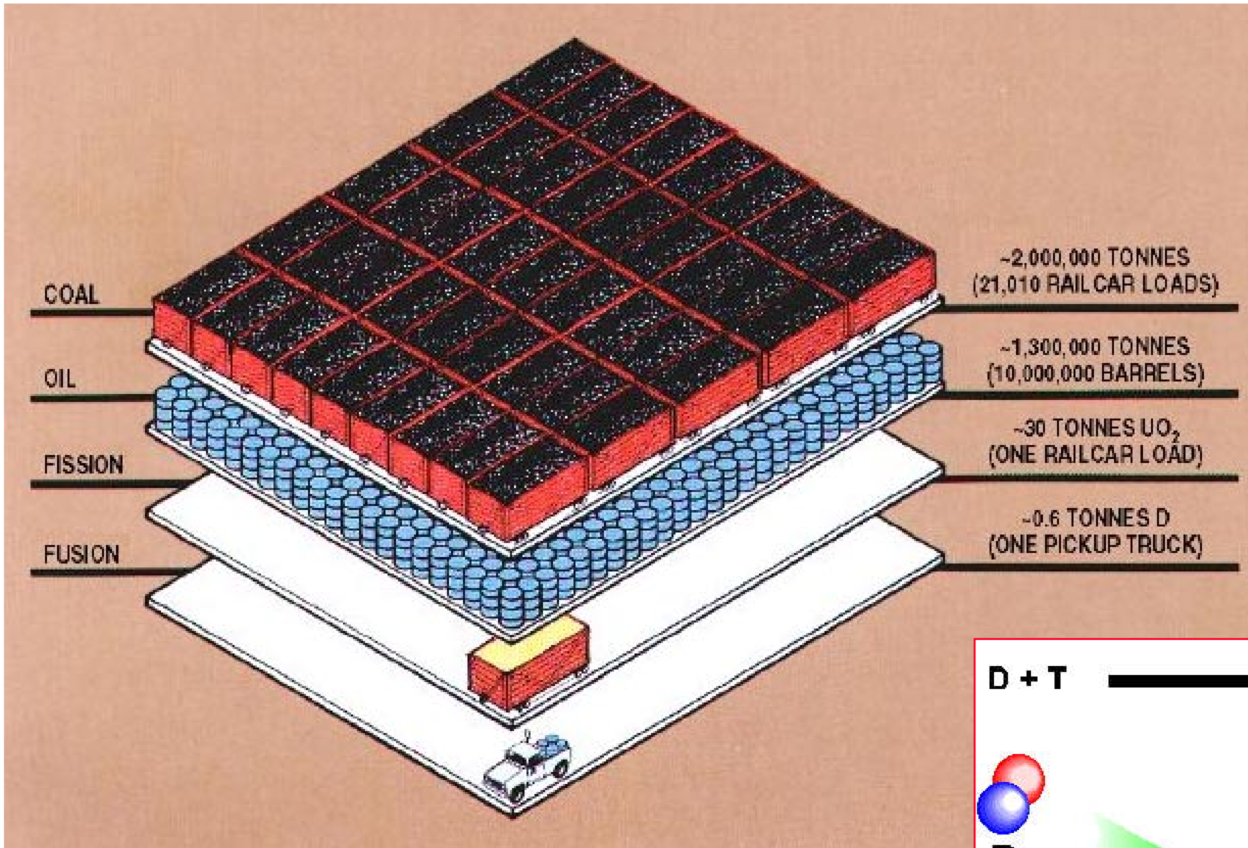
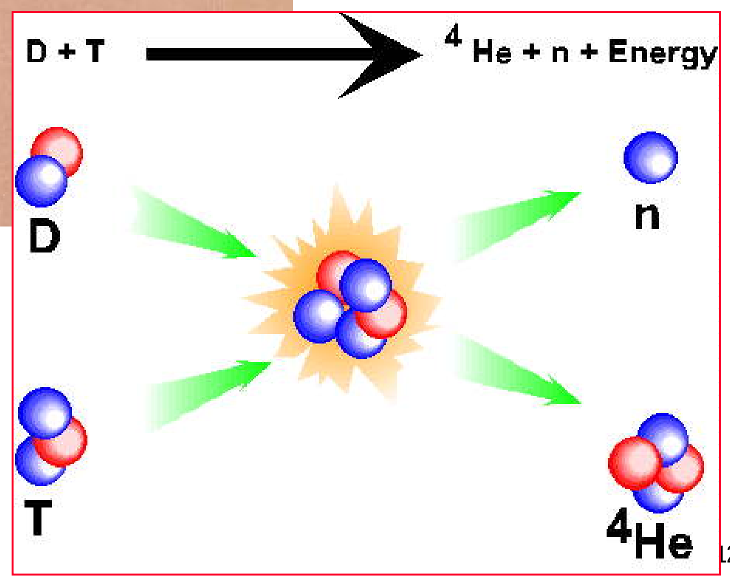
Fusion has great potential as an energy source for the future.

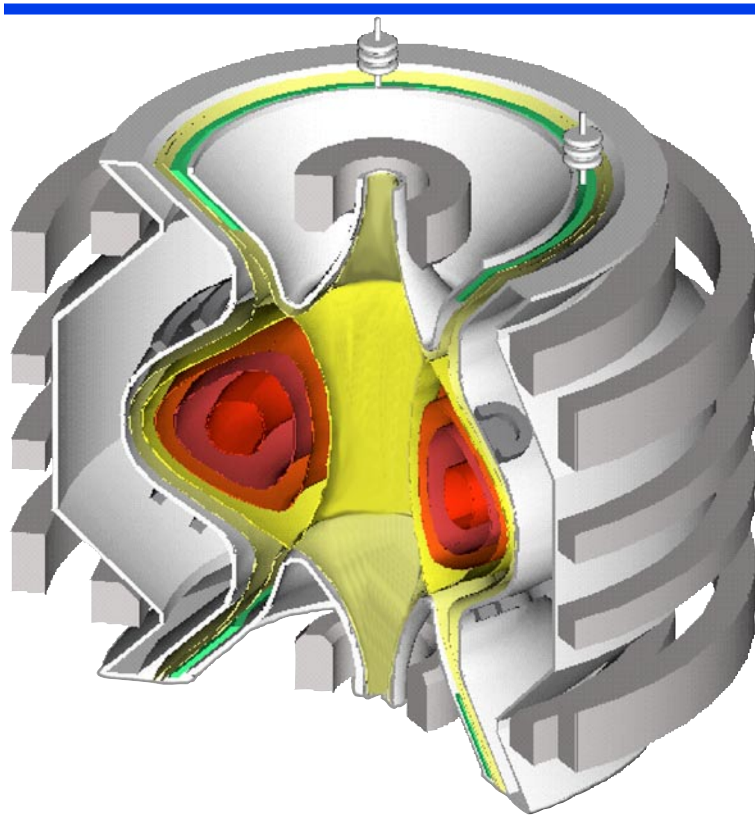


Benefits of fusion
- no greenhouse gases
- no meltdowns
- no proliferation
- no long-term wastes
- plentiful fuel

The challenge is to make fusion energy practical and affordable.



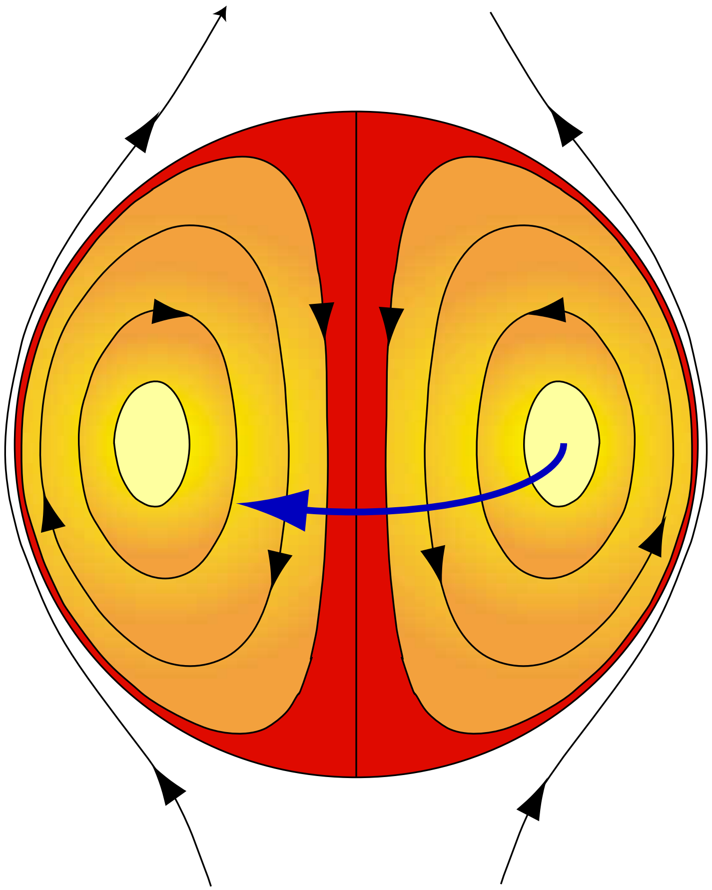
The Spheromak offers a potentially attractive reactor concept and is rich in physics content



Artist's concept of a spheromak fusion reactor. About 6m in diameter and 6m tall for a 1000MW unit.

- Simple coil geometry
  - self generated confining fields eliminate need for most complex and massive coils
- Compact
  - possibly 1/10 the size of comparable tokamak
- Steady state
  - plasma dynamo transfers external voltages to the interior

Essential Characteristics of a Spheromak Plasma



- Low-aspect-ratio (R/a) toroidal magnetic configuration.
- Confining magnetic fields produced by currents in the plasma itself.
- Nearly force-free field aligned currents:

$$\lambda = \frac{\mu_0 j}{B} \qquad \nabla \times \vec{B} = \lambda \vec{B}$$

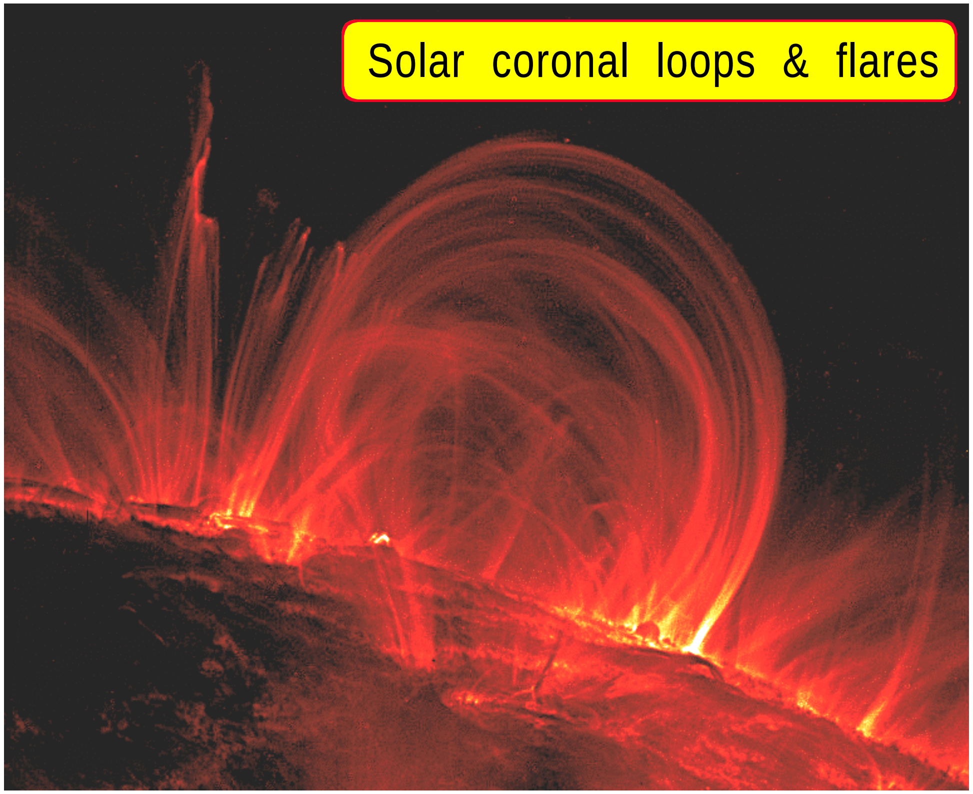
- Magnetic topology:
  - — edge: Poloidal fields & currents
  - — core: Toroidal fields & currents

The physics free-flowing plasma currents that governs spheromak behavior is common to many other situations.

In the spheromak, free-flowing currents determine the essential properties of the plasma such as magnetic field topology, pressure, and temperature.

This is also true for

— solar corona
— interplanetary solar wind
— galactic magnetic fields
— other fusion devices

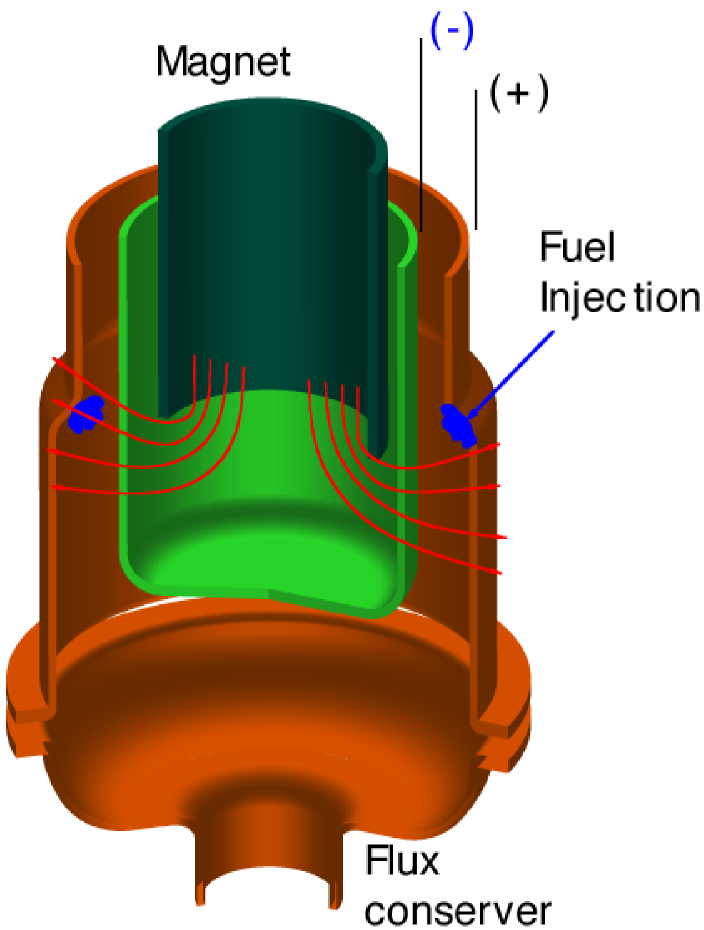


3-d numerical simulation can give us clues to how such systems operate, but computational limits and limited physics content lead to large uncertainties.

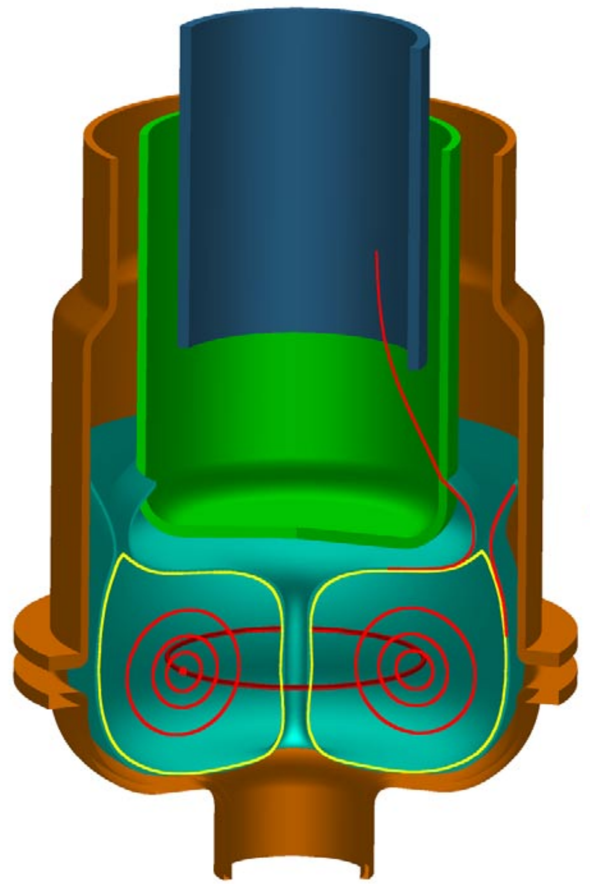
Detailed measurements in actual plasmas will yield better understanding and improved models.

Spheromak plasmas formed using coaxial injection

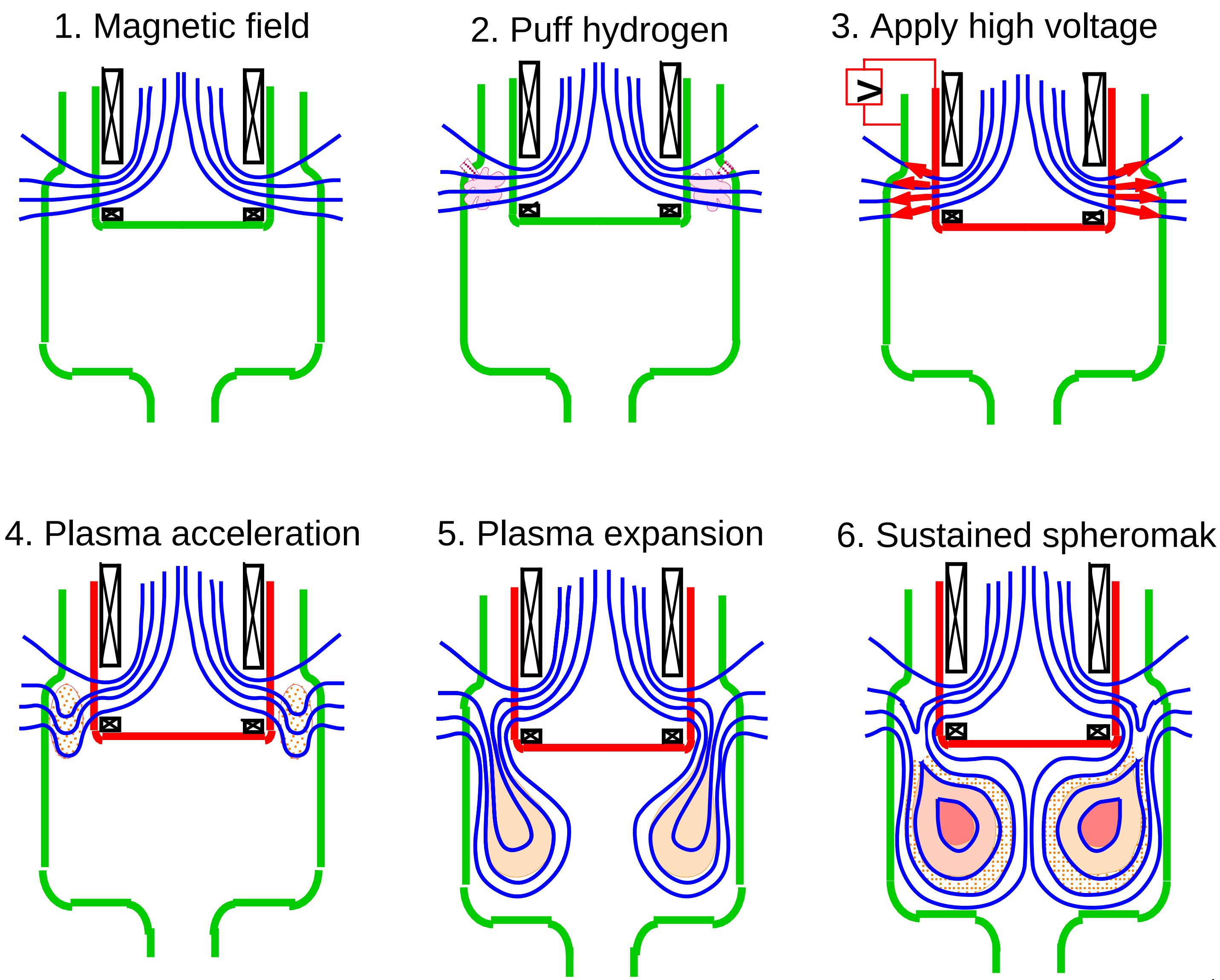
Initial Vacuum Fields



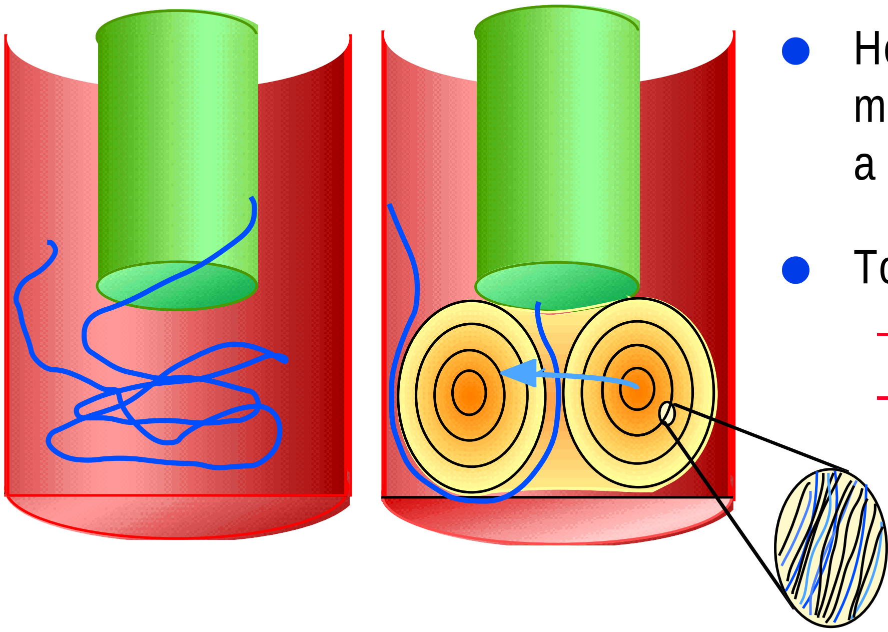
Fully-formed spheromak



Typical spheromak formation sequence



Present research on SSPX: What processes govern magnetic field generation and energy transport?



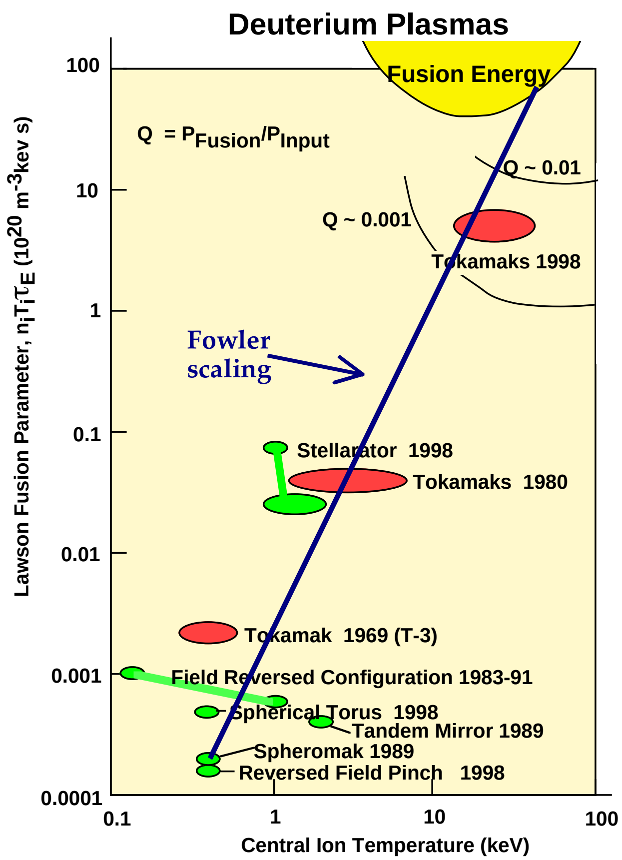
- How are internal fields and currents maintained against resistive decay without a transformer?
- Toroidal current can result from either
  - open field lines connecting electrodes
  - small-scale turbulent fluctuations producing time-average toroidal electric field via a plasma dynamo

    $E = -\langle \tilde{v} \times \tilde{B} \rangle$

- What fluctuation level is needed to sustain the plasma?
- How do fluctuations affect energy transport?

Hotter, cleaner plasmas have lower resistivity and should need smaller fluctuations $\Rightarrow$ better confinement.

Performance Characteristics of Previous Spheromaks



- Best spheromak performance was in 400eV in decaying CTX spheromak plasma.
- T_e < 100eV in sustained spheromaks.
- Predicted spheromak performance assuming confinement improves with Te (Fowler, 1994 & 1996)
- Ideal stability must be considered, but is not limiting.

Key Issues for Spheromak Development

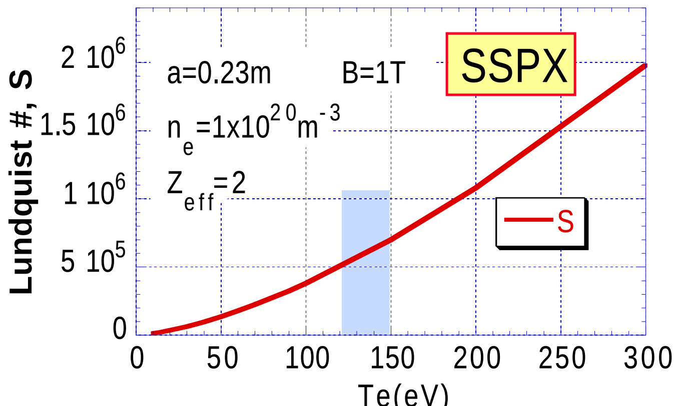
Issue	Timescale	SSPX	National PoP Program		Enhanced Perform	Reactor Exp	Success to take Next Step
			PoP	Supporting Experiments			
Energy confinement	Now	**X**	**X**	x	**X**	x	T_e ~ few hundred eV, favorable τ_E scaling with S.
Drive efficiency	Now / Intermed	**X**	**X**	**X**	**X**	x	$I_{tor}/I_{inj} \geq 3$ & increasing with Te & R
Particle control	Intermed	x	x	x	**X**	x	$I/N \sim 10^{-14}$ A-m
Global stability & beta limits	Intermed	x	**X**	**X**	**X**	**X**	$\beta > 10\%$ with $R_{wall}/2a \geq 1.05$
Power handling and PWI	Longer term		x	**X**	**X**	**X**	$P_{wall} < 20 MW/m^2$, $Z_{eff} < 1.6$
Ignition physics & burn control	Long term					**X**	Controlled fusion reactions

x: will gain information, but not a primary focus for extensive study
X: main subject of experiment – favorable results needed to move to next step.

Turbulent transport due to magnetic fluctuations proportional to $\left|\tilde{B}/B\right|^2$

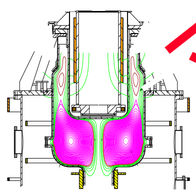
Expect that magnetic fluctuations proportional to Lundquist # : $\left|\tilde{B}/B\right|^2 \propto S^{-\alpha}$

$$S = \frac{\tau_R}{\tau_A} \propto BT^{3/2}$$



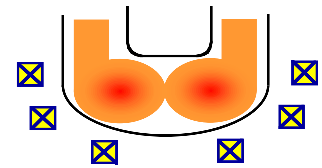
The path for spheromak development

SSPX



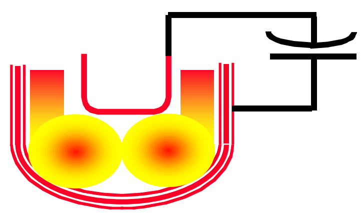
- sustainment physics
- confinement physics
- dynamo studies
- magnetic turbulence

Long-pulse spheromak Experiments



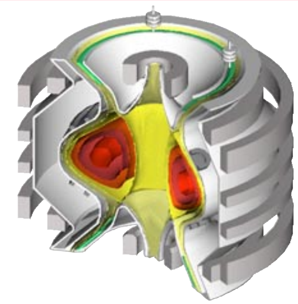
- Stability and control
- Beta limits
- Particle control
- Auxiliary heating

High power pulsed Spheromak Experiments



- Confinement scaling
- Beta limits
- Plasma-wall interactions

Steady-state Reactor



- ignition/burn physics
- alpha confinement
- power handling

Pulsed Reactor