An unmagnetized plasma dynamo experiment

Mark Nornberg
Cary Forest, Cami Collins, Mike Clark,
John Wallace, Jon Jara-Almonte, Noam Katz,
Fatima Ebrahimi, Ivan Khalzov, Alex Rasmus,
Erik Spence, David Weisberg, Ellen Zweibel
Driving a vigorous shear flow in a liquid metal inevitably leads to turbulence

- Liquid metals are inviscid, resistive fluids
  - A dynamo requires $Rm \sim 100$, which implies $Re \sim 10^7$ in sodium
  - Strongly sheared flows are unstable and drive a turbulent cascade
  - Turbulence efficiently dissipates both large-scale flow and magnetic flux
  - Practical limitations in power required to drive flow constrain experiments to studying near-marginal dynamos ($Rm \sim Rm_{crit}$)
Turbulent dissipation can be overcome by adjusting the boundary conditions

- Constraining the turbulent driving scale
- Augmenting the field amplification of the fluid with iron

Riga
Madison

VKS-Cadarache
Another option is to use a viscous, highly-conducting plasma
A hot, unmagnetized plasma provides certain advantages and challenges

- Diffusivities are adjustable (variable $P_m$)

$$Rm = 1.5 T_{e,eV^{3/2}} V_{km/s} L_m$$
$$Re = 8 \mu^{1/2} n_{10^{18} m^{-3}} V_{km/s} L_m / T_{i,eV^{5/2}}$$

- Rapid rotation can achieve $Rm \sim 1000$

- Diagnostics

- Compressibility, stratification, buoyancy

- Plasma Effects beyond MHD: neutrals, two-fluid, kinetic effects
To take advantage of these properties of a plasma, we need a confinement scheme.

Madison Plasma Dynamo Experiment

$T_e = 20 \text{ eV}$
$\mathcal{n}_e = 10^{17} - 10^{19} \text{ m}^{-3}$
$V = 0 - 20 \text{ km/s}$
$L = 1.5 \text{ m}$

$R_m > 1000$
$Re \sim 1 - 10^4$
$P_m \sim 0.001 - 100$
The vessel manufacture is complete and undergoing vacuum testing
Multipole Magnetic Field can be used to stir plasma at edge (cross field currents produce torque and ExB rotation)

Arbitrary

\[ V_\phi (r = a, \theta) \]

Flow drive in unmagnetized core is accomplished through viscous coupling to edge
Two Vortex Plasma Dynamo Flow can be driven at boundary (spherical Von Karman Flow)

- Plasma $Rm=300$, $Re=100$
  - $Te=10$ eV
  - $U=10$ km/s,
  - $n=10^{18}$ m$^{-3}$
  - Hydrogen

Small Scale Dynamo at $Pm > 1$

- $Rm = 1000$
- $Re = 400$
- Plasma
  - $T_e = 14$ eV
  - $T_i = 1.4$ eV
  - neon
  - $U = 10$ km/s
  - $n = 3 \times 10^{17}$ m$^{-3}$
Summary

- We have an exciting opportunity to create a plasma dynamo
  - Can create both a laminar dynamo well above marginal stability and a turbulent dynamo
  - Can address compressibility, two-fluid, and kinetic effects

- Support from
  - DOE Major Research Instrumentation program
  - NSF Astro & Physics
  - CMSO
Parameter space covered by density and power control

- 10^{17} \text{ m}^{-3}
- 10^{18} \text{ m}^{-3}
- 10^{19} \text{ m}^{-3}

- helium
- argon

- 80 kW
- He, 10 km/s
- Ar, 10 km/s
- He, 2 km/s
- Ar, 2 km/s
Neutral drag can be reduced with sufficient input power.