Studying high *Re* and Re_m plasmas in the laboratory

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Reynolds number

Ratio of inertial forces to viscous forces

$$\mathrm{Re} = \frac{UL}{\nu}$$

U - velocity scale (m/s)
L - length scale (m)
ν - kinematic viscosity (m^2/s)

What happens at high *Re*?

- Systems can become turbulent
- Turbulent systems have fluctuations on a wide range scales
- Energy is transferred from large scale vortices l_0 to the viscous dissipation scale
  $\boldsymbol{l_v \sim Re^{-3/4} * l_0}$

Re	10^3	10^5
l_0	1 m	100 µm
l_v	5 mm	.01 um

Dimotakis P E 2000 The mixing transition in turbulent flows
J. Fluid Mech. 409 69

Magnetic Reynolds number

Ratio of inertial forces to magnetic diffusivity

$$\mathrm{Re}_m = \frac{UL}{\eta}$$

U - velocity scale (m/s)
L - length scale (m)
η - magnetic diffusivity (m^2/s)

What happens at high Re_m?

- The magnetic field is advected with the fluid flow
- The field lines become “frozen in” to the plasma and are carried with the flow
- Dissipation scale for magnetic fields $\boldsymbol{l_\eta \sim Re_m^{-1/2} Re^{-1/4} l_0}$

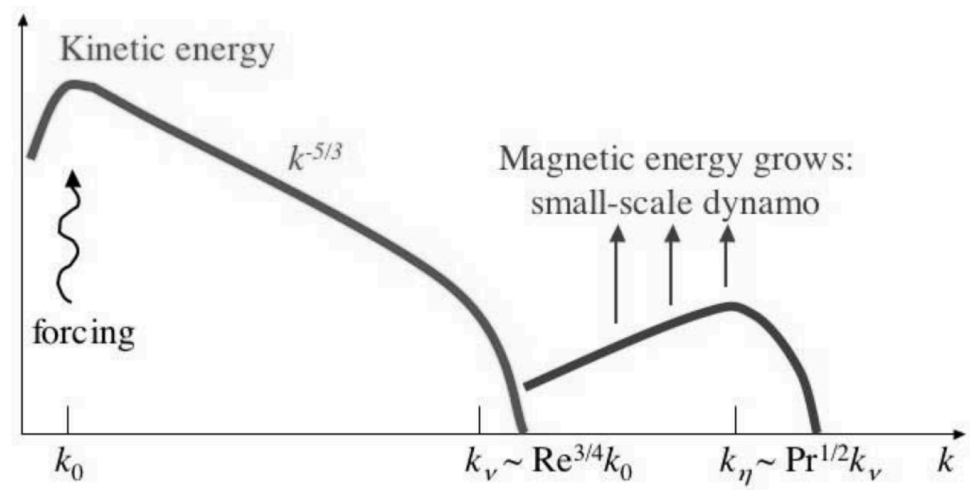
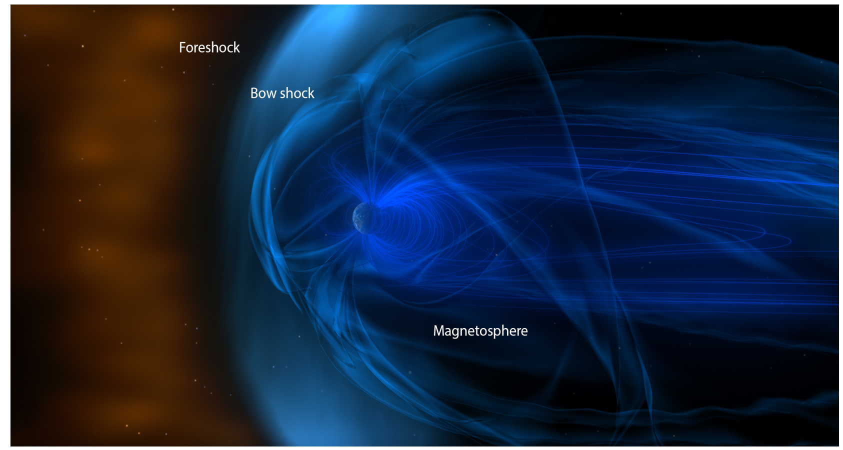


FIG. 1.—Sketch of scale ranges and energy spectra in a large-Pr_m medium.

A. A. Schekochihin, Astrophysical Journal, 2004

Where can high *Re* and Re_m flows be found in nature?

- Stars and during star formation, galaxies and galactic evolution, accretion disks, planet formation, magnetosphere and more



Structure of the Earth's magnetosphere

Examples of *Re* and *Re_m* for some astrophysical systems

	Re	Re_m
Intergalactic medium	10^{13}	10^{27}
Magnetized jets	10^{14}	10^{19}
Galaxy cluster	10^{25}	10^{25}
Solar dynamo	10^{11}	10^{8}
Accretion disks	10^{9}	10^{8}

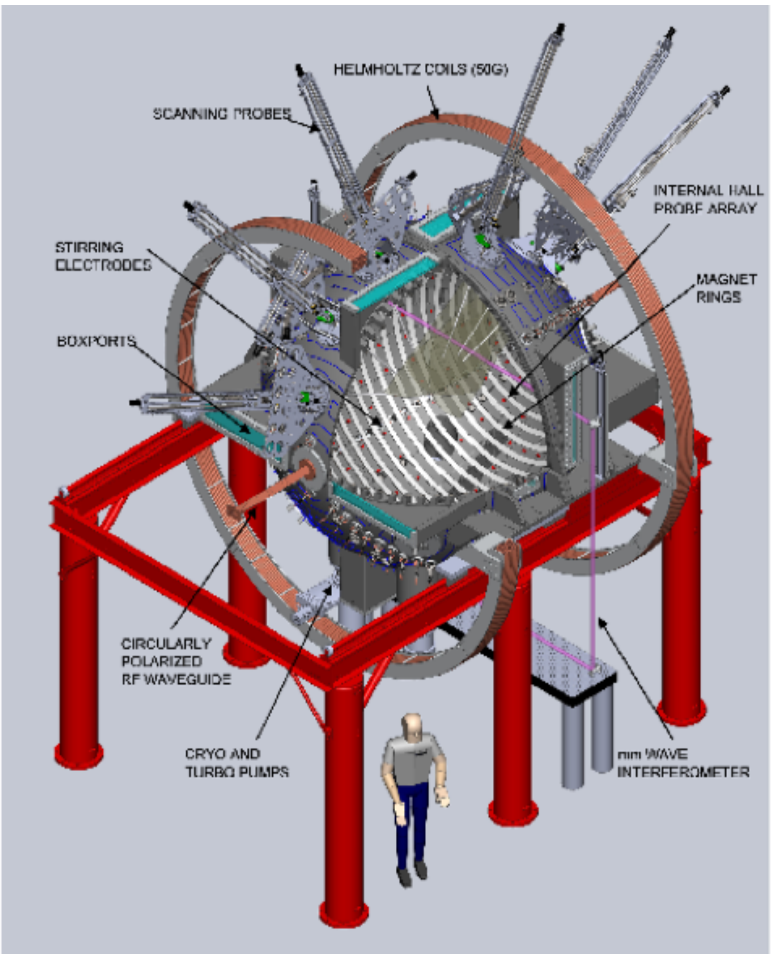
What is the scale, structure, and evolution of these systems and how is it affected by the magnetic field?

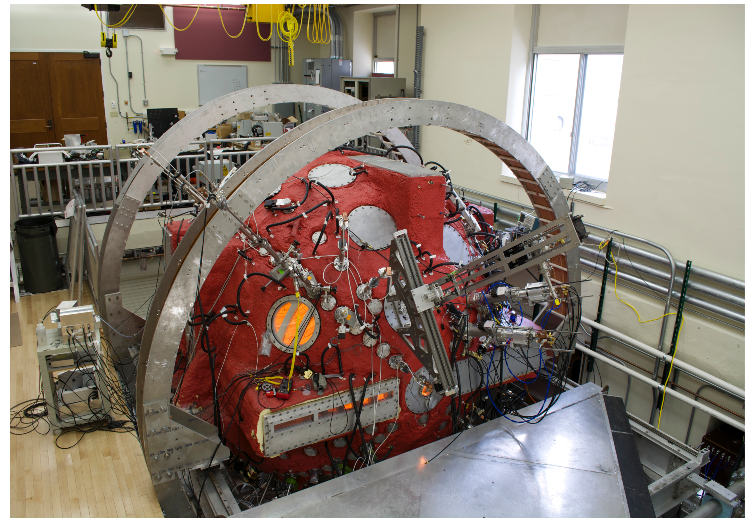
High *Re* and Re_m flows are complex

- There exists an interplay of the velocity and magnetic field vectors and the dissipative parameters, viscosity and resistivity
- Sufficient theory does not exist in this regime
- Computational simulations require significant resources and all scales cannot be resolved and are limited in *Re* and Re_m due to numerical diffusivity
- Experiments can help advance the understand of these systems

How can we study these systems experimentally?

Madison Plasma Dynamo Experiment



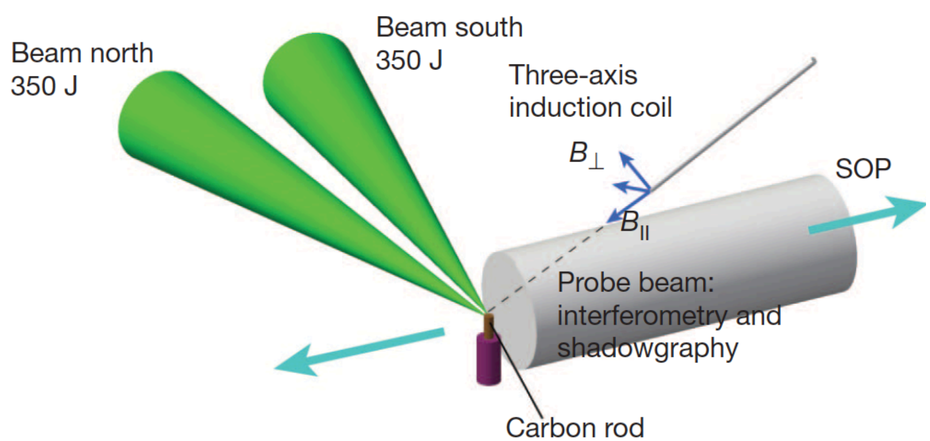


Quantity	Symbol	Value	Unit
Plasma Radius	R_0	1.4	m
Density	n_e	$< 5 \times 10^{18}$	m^{-3}
Electron temperature	T_e	< 20	eV
Ion temperature	T_i	$0.5 - 4$	eV
Peak driving velocity	V_0	< 10	km/s
Ion species	H, He, Ar	1, 4, 40	amu
Pulse length	τ_{pulse}	< 10	sec
Installed Power	P	360	kW
Fluid Reynolds number	**Re**	**< 1000**	
Mag. Reynolds number	**Rm**	**< 1000**	
Mag. Prandtl number	**Pm**	**$0.05 - 10$**	

E.J. Spence, K. Reuter, and C.B. Forest, Astrophys. J. (2009).

How can we study these systems experimentally?

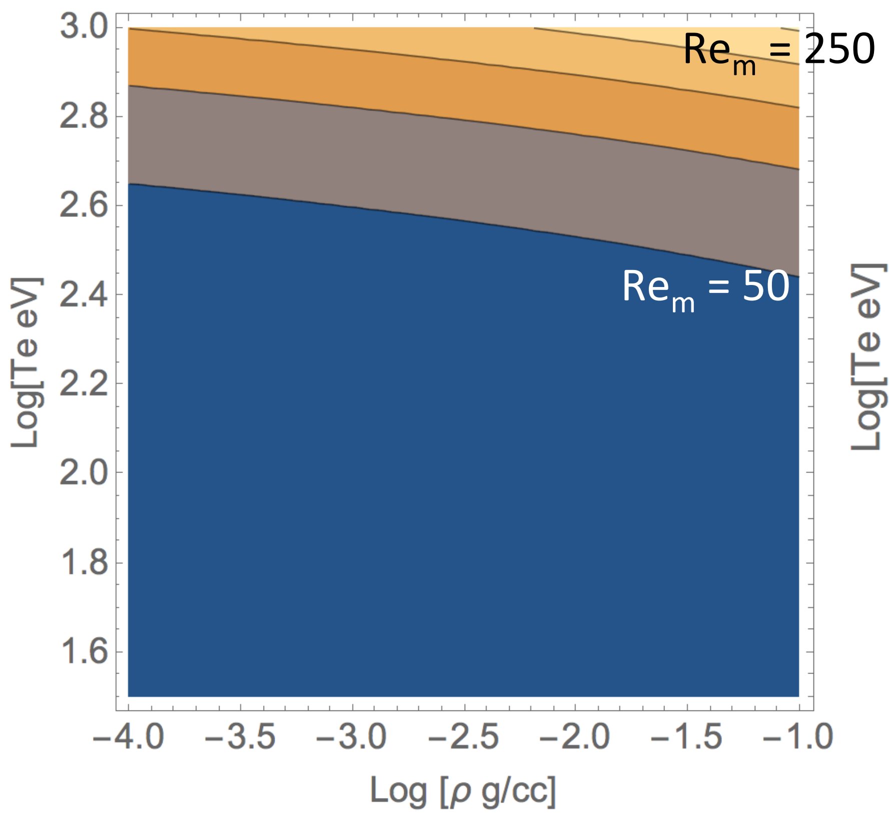
LULI Laser Facility



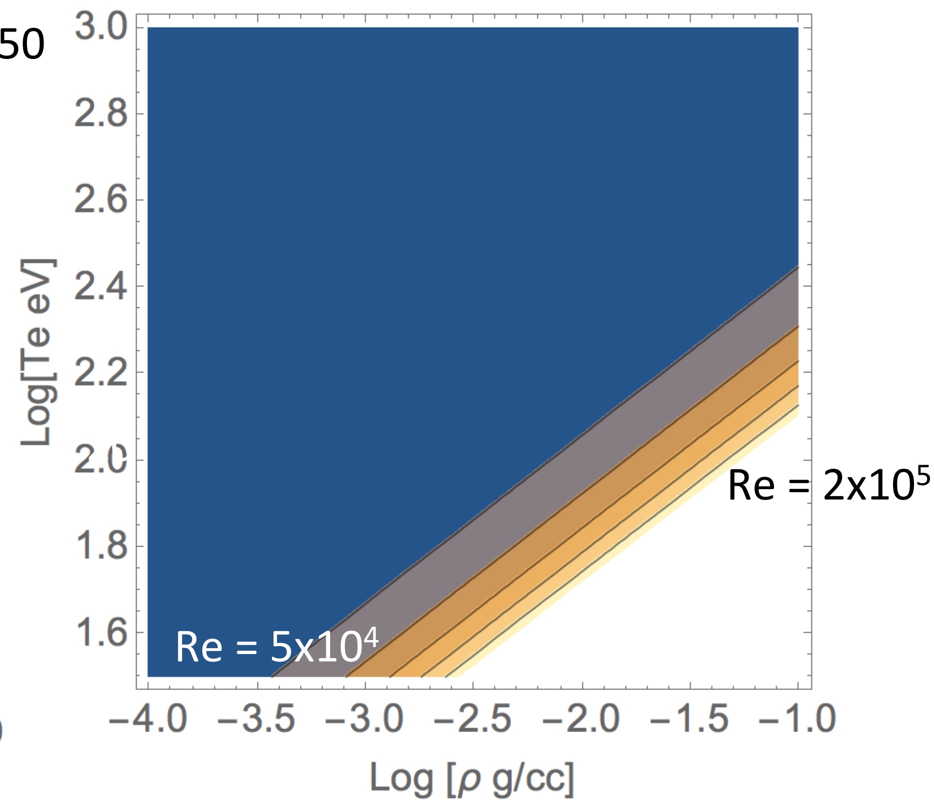
Scaling parameters	Definition	Laboratory (LULI) value
Characteristic length scale of the system	$L \approx 2r/\kappa$	18.8 cm
Characteristic timescale of the system	t	1 μs
Electron temperature	T_e	2 eV
Electron density	n_e	$5 \times 10^{15}\,\mathrm{cm}^{-3}$
Cyclotron frequency	$\Omega_B = \frac{eB}{m_{ion}}$	$4.8 \times 10^4\,\mathrm{s}^{-1}$
Reynolds number	Re	7.9×10^3
Peclet number	Pe	69.0
Magnetic Reynolds number	Re_M	16.5

G. Gregori et al, Nature, **481**, 2012

Can we push for higher still?



Creating higher T flows will increase Re_m



Creating higher ρ flows will increase Re

In many of these astrophysical systems β~1

Ratio of inertial plasma pressure to magnetic pressure

$$\beta = \frac{P_{plasma}}{P_{magnetic}} \sim \frac{\rho U^2}{B^2}$$

Systems highlighted have β > 1

Conclusions

- High Re and Re_m are found in ubiquitous in astrophysical systems
- These systems are difficult to simulate due to wide range of scales and numerical diffusivity
- Madison Plasma Dynamo Experiment and high-energy laser experiments have reached interesting regimes but can be pushed higher
- Higher magnetic fields will decrease β