Dynamos
Theory and numerical simulations

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Where we are in time

1910- Magnetization of sunspots (Observational)

1920- Dynamo action is introduced

1930- Anti-dynamo theorems

1950- Cyclonic events and the Γ-effect

1960- Mean field eletrodynamics (introduced)

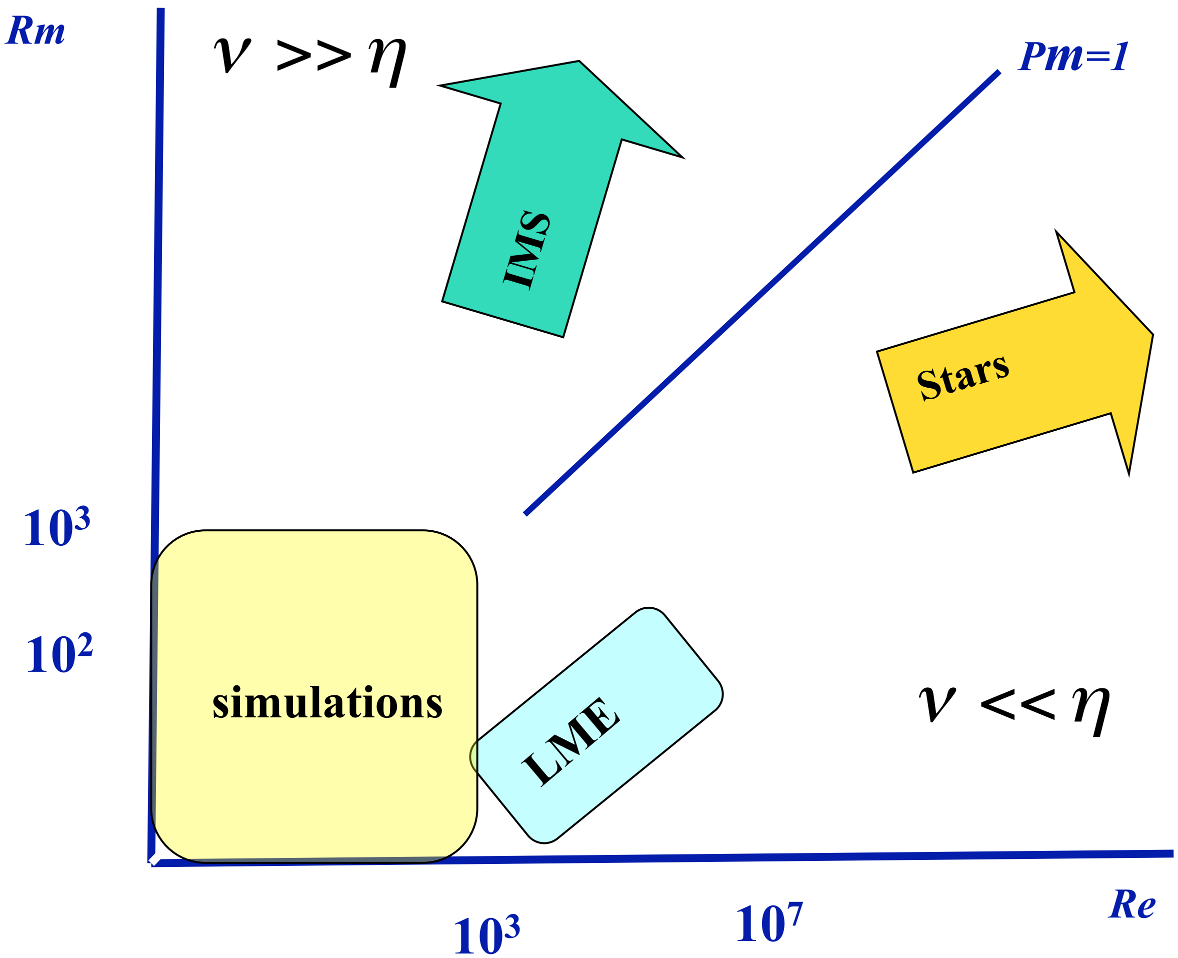
1970- Mean field models

1980- Fast dynamo theory

1990- Numerical dynamos

2010- We are here

Where we are in parameters



Where we are in understanding

Important to distinguish between two problems:

- **Small-scale dynamo**
  - **Generation of magnetic energy.**
  - **Characteristic scale of B smaller than characteristic scale of v**

- **Large-scale dynamo**
  - **Generation of magnetic flux**
  - **Characteristic scale of B larger than (or comparable with) characteristic scale of v**

Where we are in understanding

Another distinction:

- **Kinematic:**
    - $\|B\| \ll \|v\|$ Lorentz force negligible
    - Velocity is prescribed
    - "Eigenvalue problem" for growth rate

- **Non-linear:**
    - Lorentz force important
    - Solve for velocity and magnetic field self-consistently
    - Nonlinear problem for amplitude, spectrum, etc.

Small-scale

	Pm>>1	Pm<<1
Kinematic	OK	OK
Nonlinear	OK ?	??

Is there a *Pm* independent regime at small *Pm*?

Large-scale

- Is there a universal mechanism?
  - Probably not
- Is turbulence important?

Yes

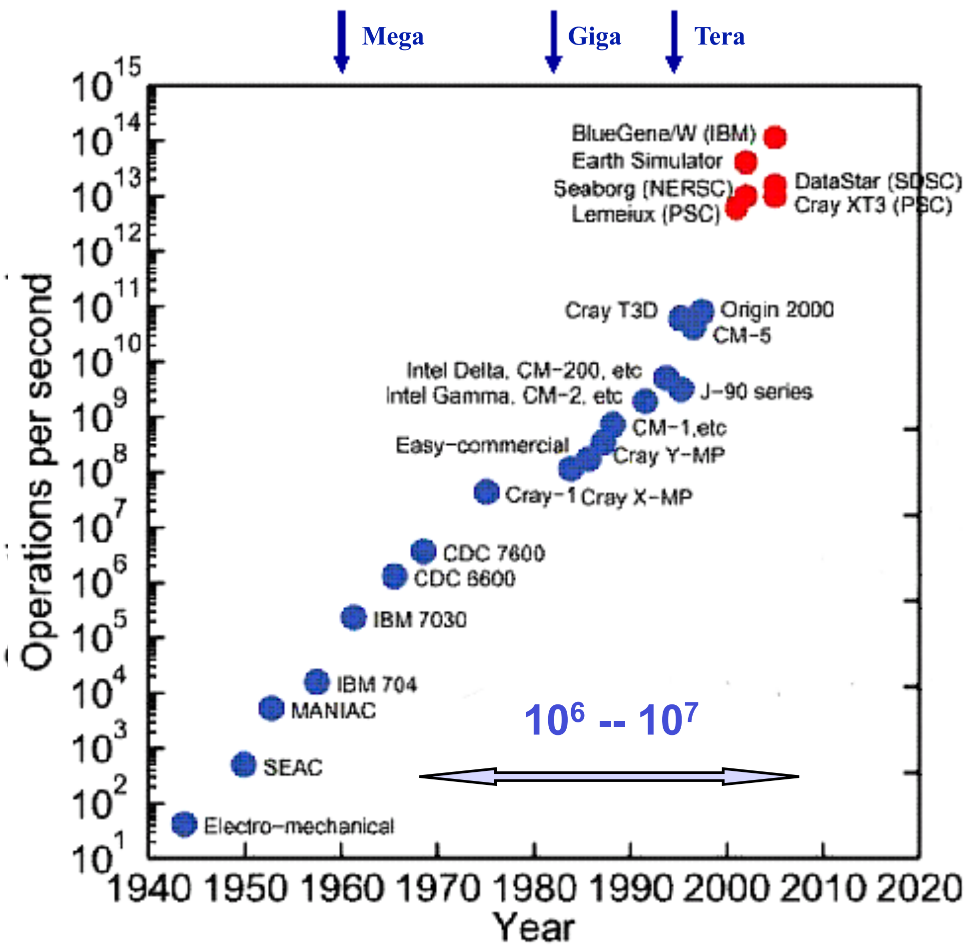
- Boundary conditions
  - Magnetic helicity flux
- Interaction with large-scale flows
  - Shear-current effect
  - Fluctuating α effect

No

- Large-scale flows
- Constraints
  - Rotation
- Magnetically driven/influenced flows

Where we are in computations

Exponential increase in computing power



Cray 2

Facts of life

- Computational resources increase by a factor of 100 every decade
- Computational resources increase as the 4^{th} power of the resolution for a 3D explicit simulation
- Unless innovative algorithms/methods/etc. are introduced resolution increases by a factor of 3.16 per decade
- Magnetic Reynolds number increases by
    - a factor of 10 every decade for smooth flows
    - less for turbulent flows

More fact of life

- Large-scale dynamo problem requires
  - high magnetic Reynolds number
  - scale separation

- Small *Pm* problem requires:
  - scale separation between viscous and magnetic boundary layers
  - good (numerical) representation of rough velocities
  - high magnetic Reynolds number

Advances in either problem may require more than pure numerical brute force alone

Summary

- There are lots of interesting problems in dynamo theory
- Two stand out:
  - What happens at small *Pm*?
  - How are large-scale fields formed/maintained?