Plasma physics, entrepreneurship, and the promise of fusion energy: Bringing it all together!

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Friends of Physics
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Abstract

As the title suggests, this talk will have three main themes. First I will talk about plasma physics as a most challenging intellectual curiosity driven discipline of physics, its early history, how it spawned the field of nonlinear dynamics, and was and is at the forefront of computational science. The next two themes will be intertwined. I will talk about the history of the quest for fusion energy, industrial involvement, and entrepreneurship. This interesting history of the fusion program, with its declassification in the 1950s, includes early efforts originating from Texas, via the Texas Atomic Energy Research Foundation, and the later founding of the Institute for Fusion Studies in 1980. Recent progress in fusion energy science will be highlighted in concert with a brief description of some plasma fusion devices. There has been a recent dramatic sea change in the research landscape of fusion science, as evidenced by a veritable explosion in the number of startup companies in recent years. I will explore the cause and possible ramifications of this sea change.

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Overview

- Plasma physics as a curiosity driven discipline (spawning of nonlinear dynamics)
- Early plasma history quest for fusion energy
- Recent and projected fusion results
- Sea change

The Institute for Fusion Studies

Since 1980, the Institute for Fusion Studies (IFS) has been a national center for theoretical (and experimental) research in fusion energy science and plasma physics. Its primary mission is to contribute to the understanding of physical phenomena important to fusion, and other plasma physics-related areas of science, by performing fundamental research of originality and rigor. Emphasis is placed on tackling scientific issues of long-range significance, and exchanging scientific developments with other fields of research.

DOE Establishment Grant $3M/year + other $\approx$ $5M/year.

What is a Plasma?

Adding Heat:

Solid $\rightsquigarrow$ Liquid $\rightsquigarrow$ Gas $\rightsquigarrow$ Plasma

97% of visible universe is plasma

Dynamics of Charged Particles $\Leftrightarrow$ Electromagnetic Fields

Plasma Physics as Curiosity Driven Science

- Spawned Nonlinear Dynamics
(adiabatic invariants, invariant tori description, integrable field theories, ...)

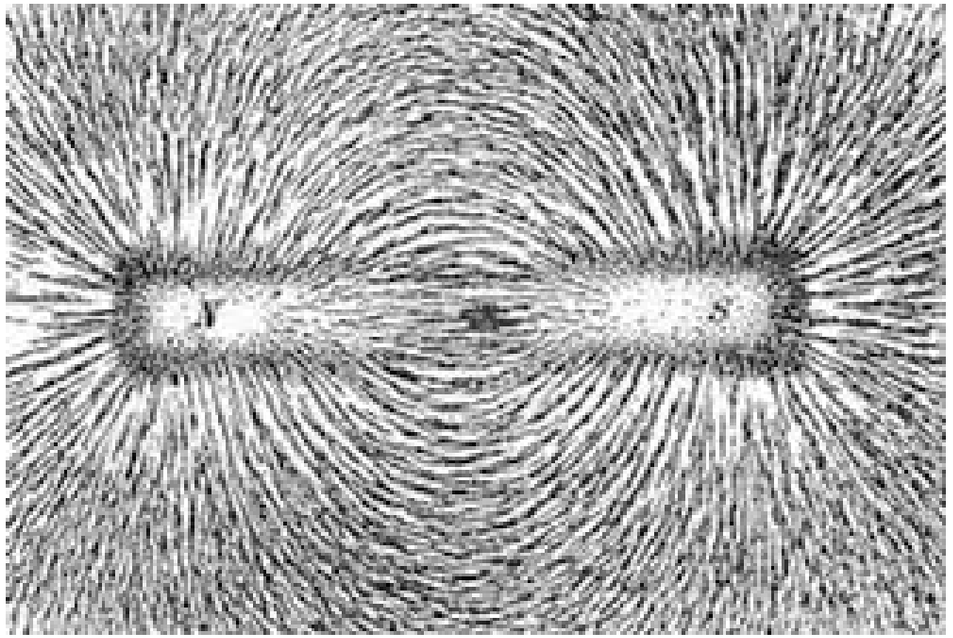
- How do magnetic field lines behave? Particle orbits under electromagnetic interaction. Self-consistency. Celestial mechanics. ...

- Early computational algorithms

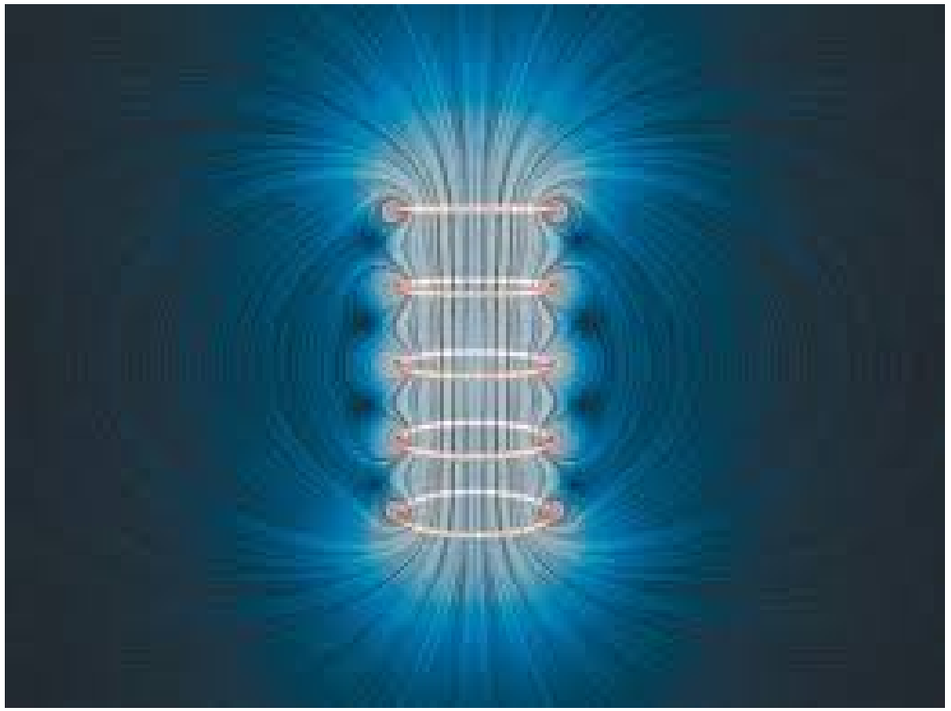
- Challenging mathematical physics

- Difficult science. Multiscale, nonlinear, difficult boundary conditions, ...

Magnetic Fields



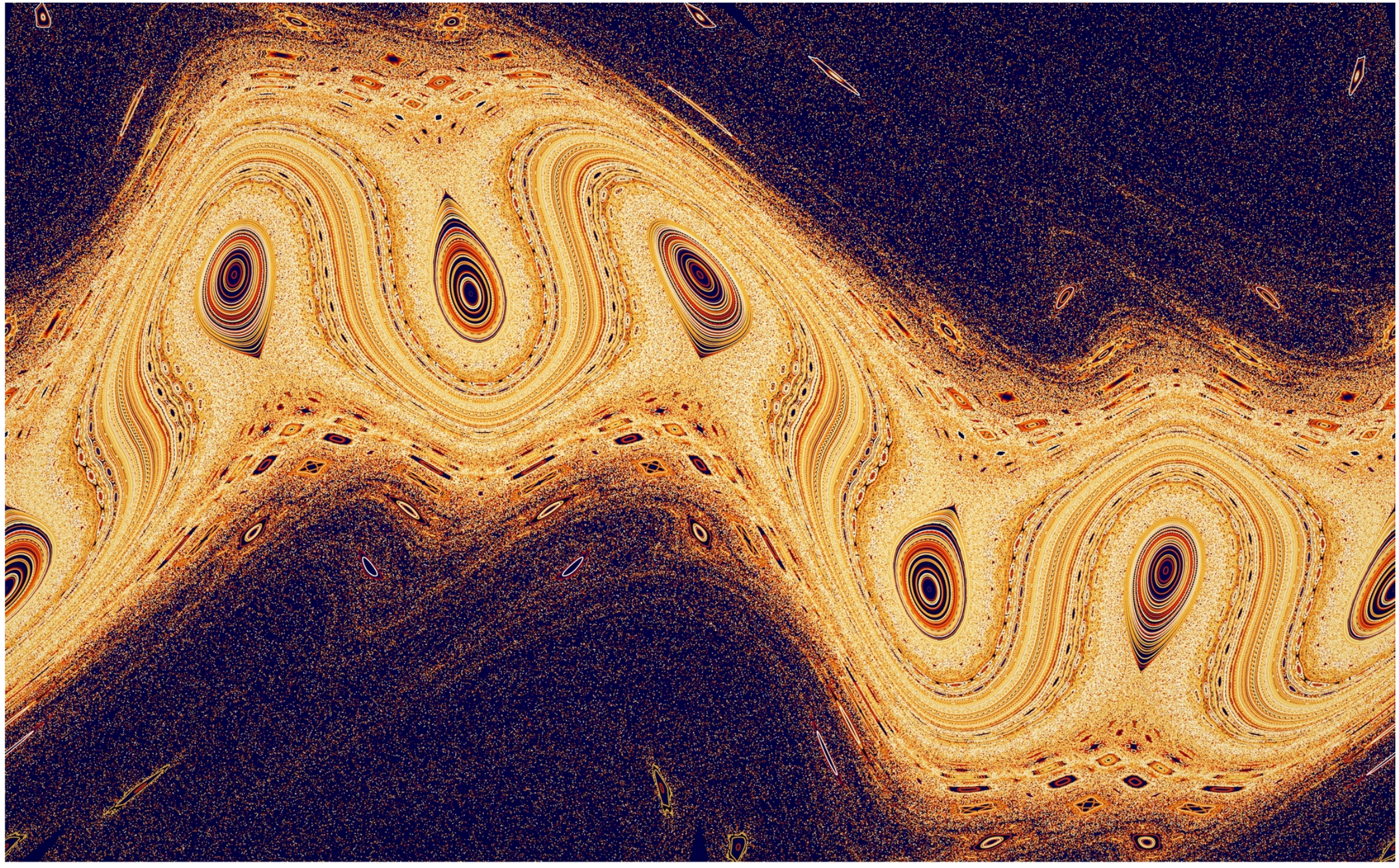
(a)



(b)

FIG. 1. (a) Iron filings depicting **B**-lines. (b) **B**-lines from currents.

Arrows $\rightarrow$ Lines. Space curves $d\mathbf{r}/d\tau = \mathbf{B}$



Self-Similarity and Universal Scaling in Symplectic Maps

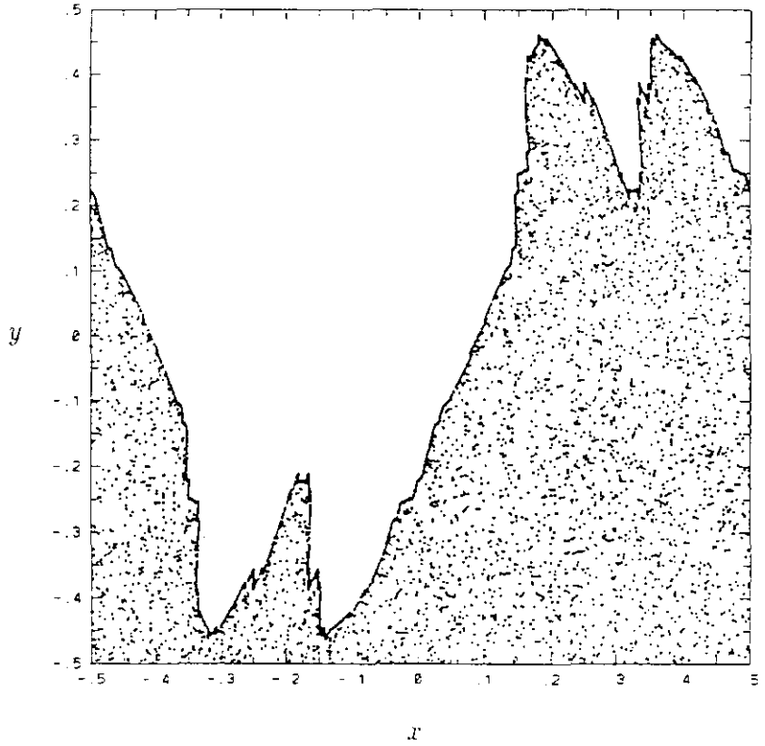


Fig. 13. The standard nontwist map at the critical parameter values, $(a_c, b_c) = (0.686049,\ 0.742493131039)$ for destruction of the $1/\gamma$ shearless orbit.

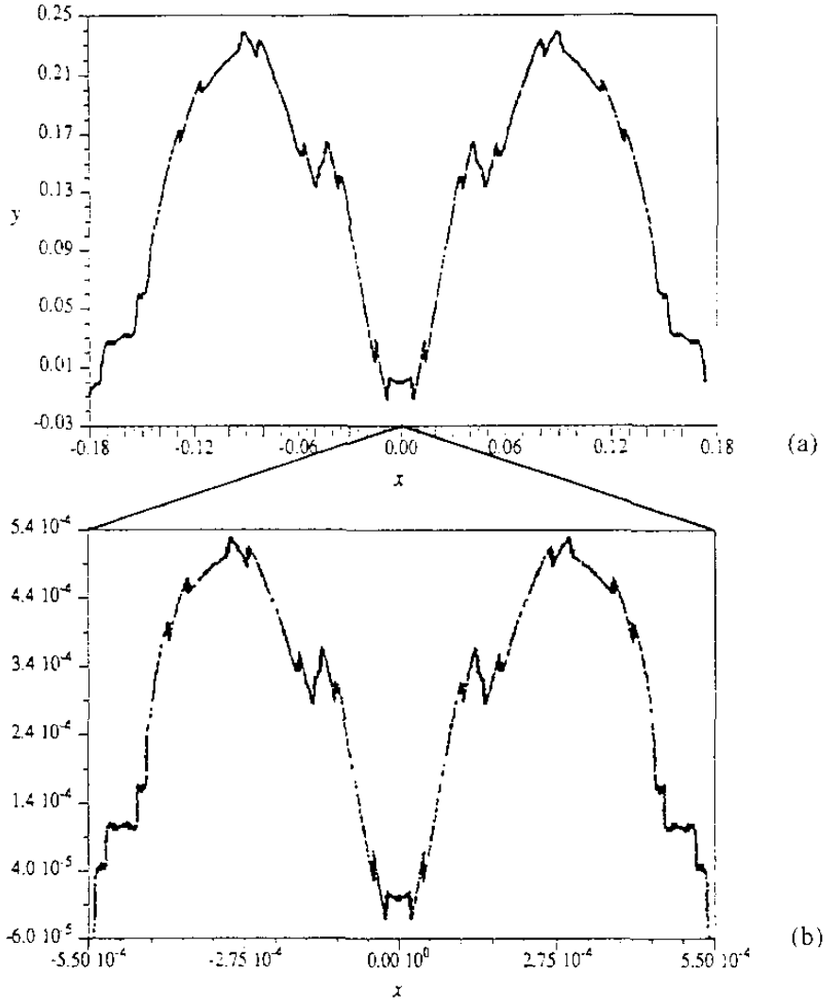


Fig. 15. Self-similar structure of the $1/\gamma$ shearless curves at criticality. In case (a) the shearless curve has been plotted in symmetry-line coordinates. Case (b) is a magnification of (a) by a factor of 321.92 in the x-direction and 463.82 in the y-direction.

Some Early Plasma History

- Irvine Langmuir 1920's (plasma as red and white corpuscles) @ General Electric Corp.
- Hannes Alfven 1940-50s ... Nobel Prize in Physics (1970)

  Power in the north, people south $\Rightarrow$ power transmission.
- Princeton Project Matterhorn (Lyman Spitzer and John Wheeler) 1951

  Wheeler @ UT 1976-1986. Coined the name Stellarator
- General Atomics (GA) in La Jolla, CA (General Dynamics - aerospace and defense) 1955
- The Texas Atomic Energy Research Foundation, 1957
- Fusion declassified 1958

May 1957

GA and the Texas Atomic Energy Research Foundation begin a four-year, $10,000,000 research program in controlled fusion.

TAERF

The Texas Atomic Energy Research Foundation (TAERF) was created in 1957. The composed of 11 Texas power companies, joined with General Atomics (outgrowth of General Dynamics Corp.) to create a nuclear fusion research project. In 1959, the University of Texas sponsored a seminar on nuclear fusion to generate local interest among students and faculty. Throughout the 1970s, the Texas Atomic Energy Research Foundation supported the Texas Tokamak fusion laboratory (Fusion Research Center), with funding from the U.S. Department of Energy and the Edison Electric Institute.

What is Fusion?

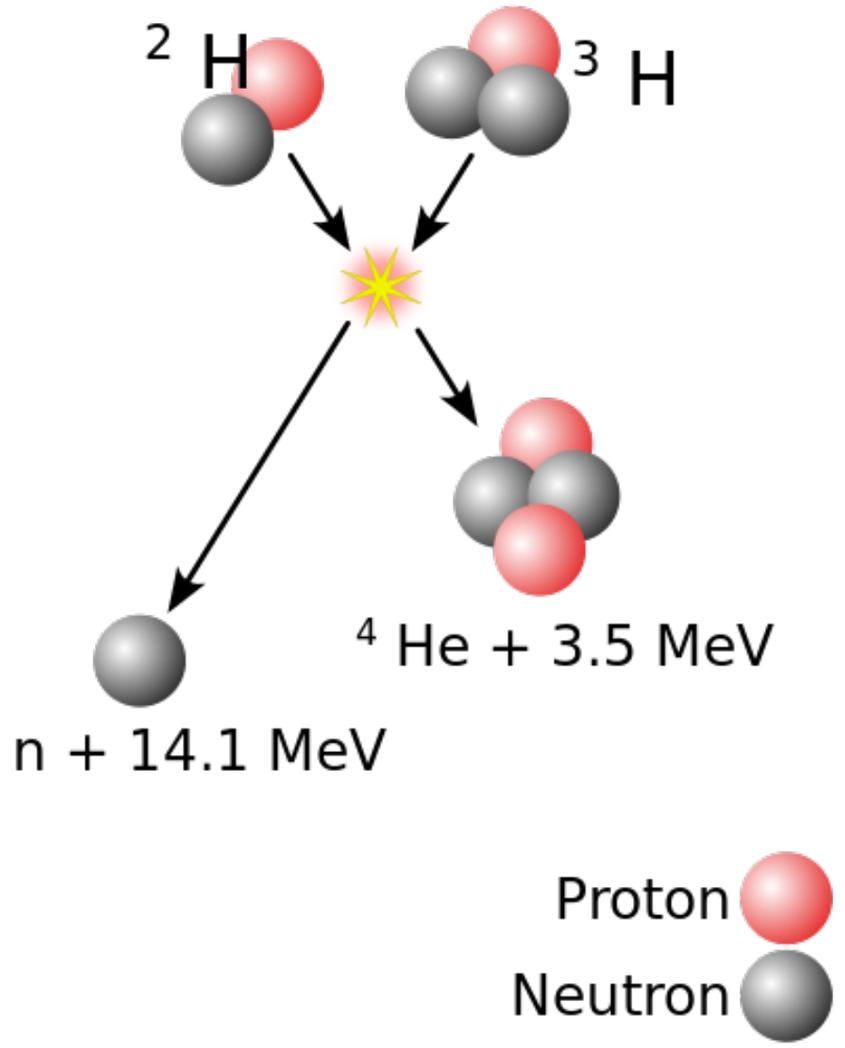
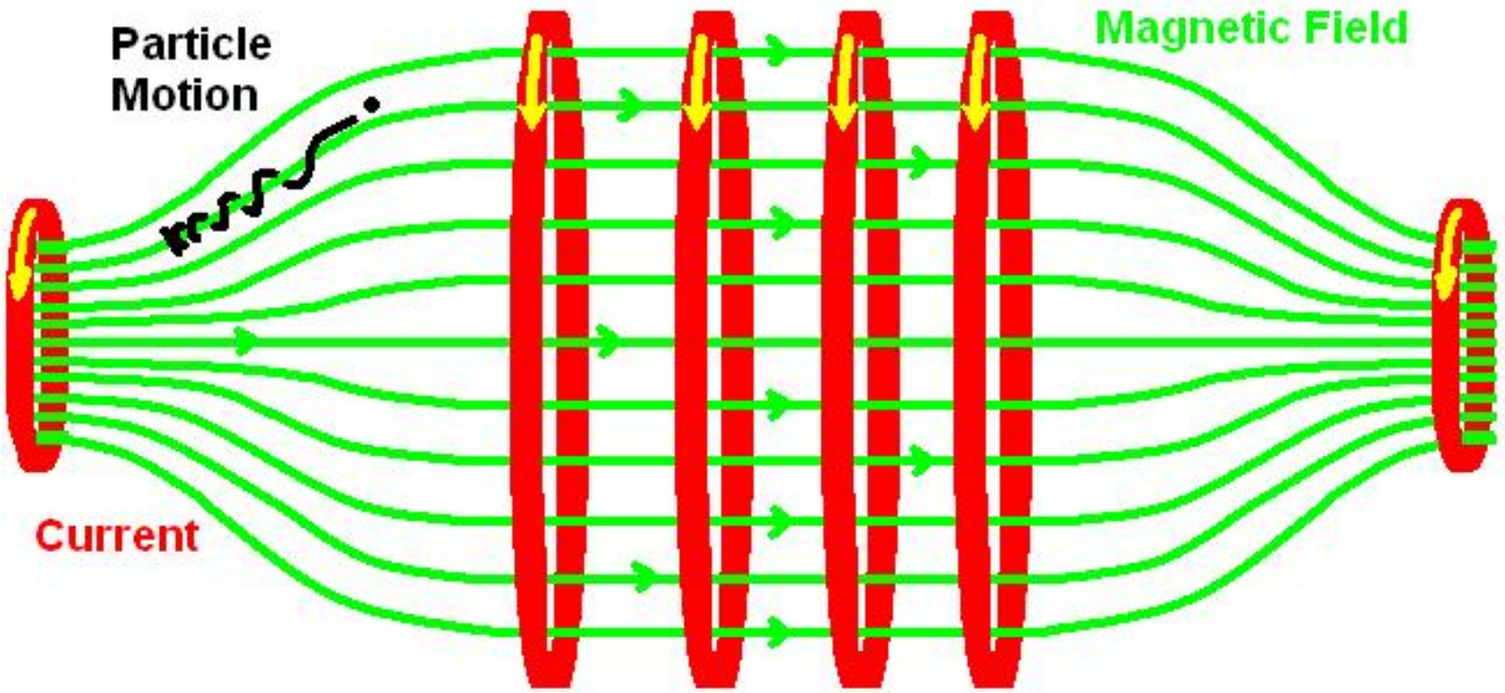
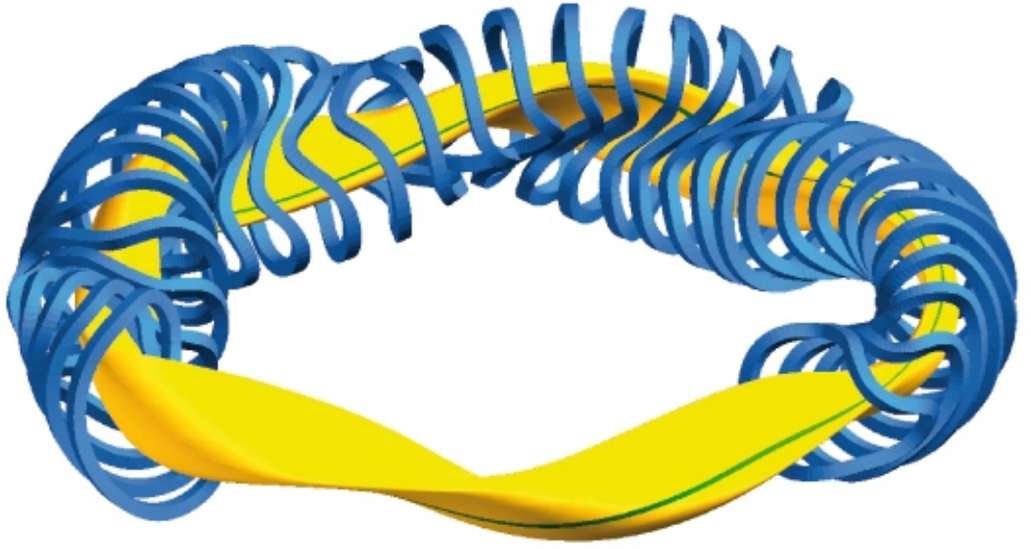


FIG. 4. Nuclear fusion is a reaction in which two or more atomic nuclei, e.g. deuterium and tritium (hydrogen isotopes), combine to form one or more different atomic nuclei and subatomic particles (neutrons or protons) and the release of energy. Nuclear fusion powers our sun and the stars.

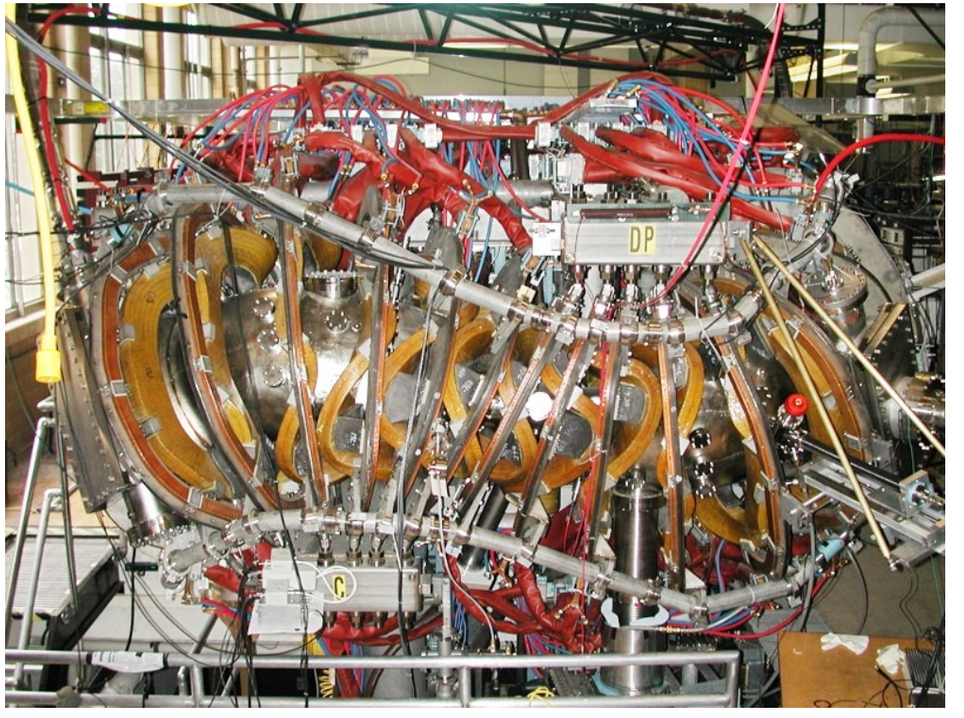
Devices - Magnetic Bottles

Basic Magnetic Mirror Machine:



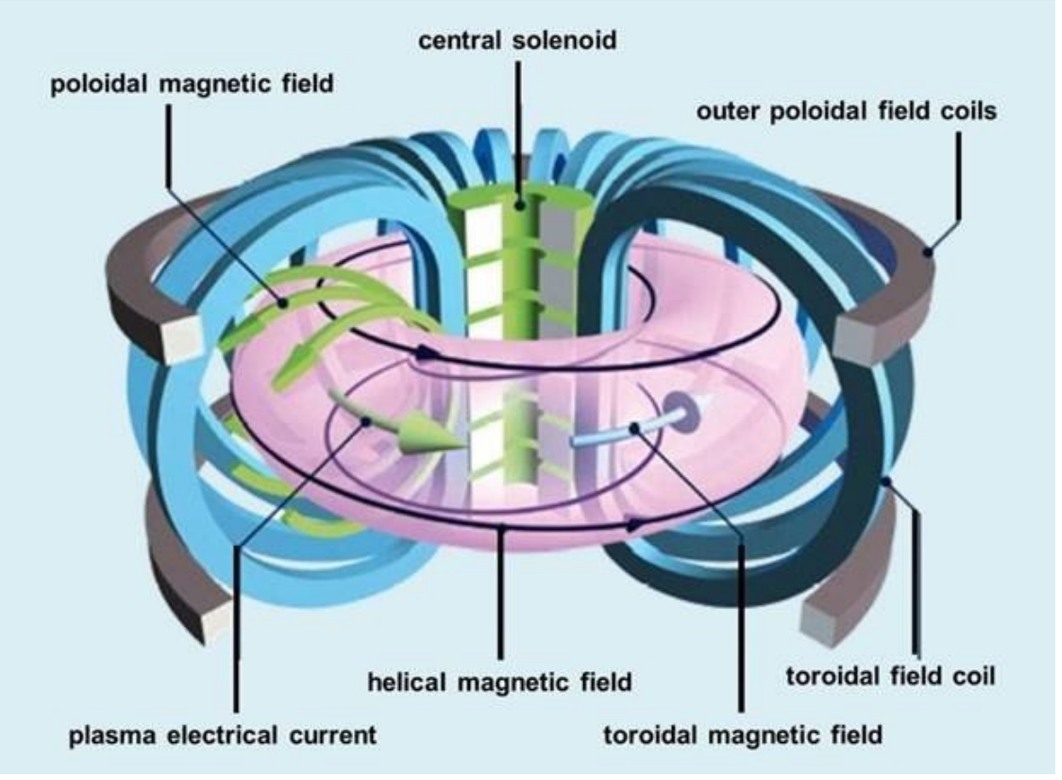


(a)



(b)

FIG. 2. (a) Depiction of German Stellarator W7X in Greifswald. (b) HSX in Madison, WI.



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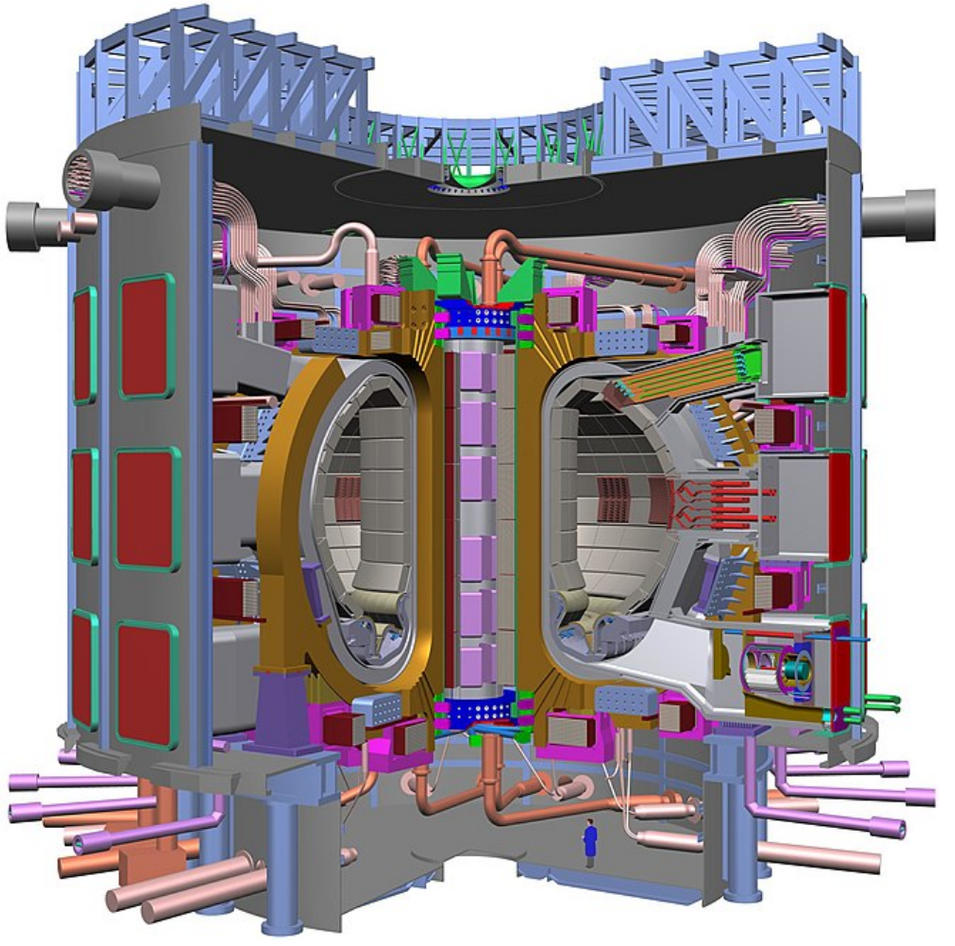
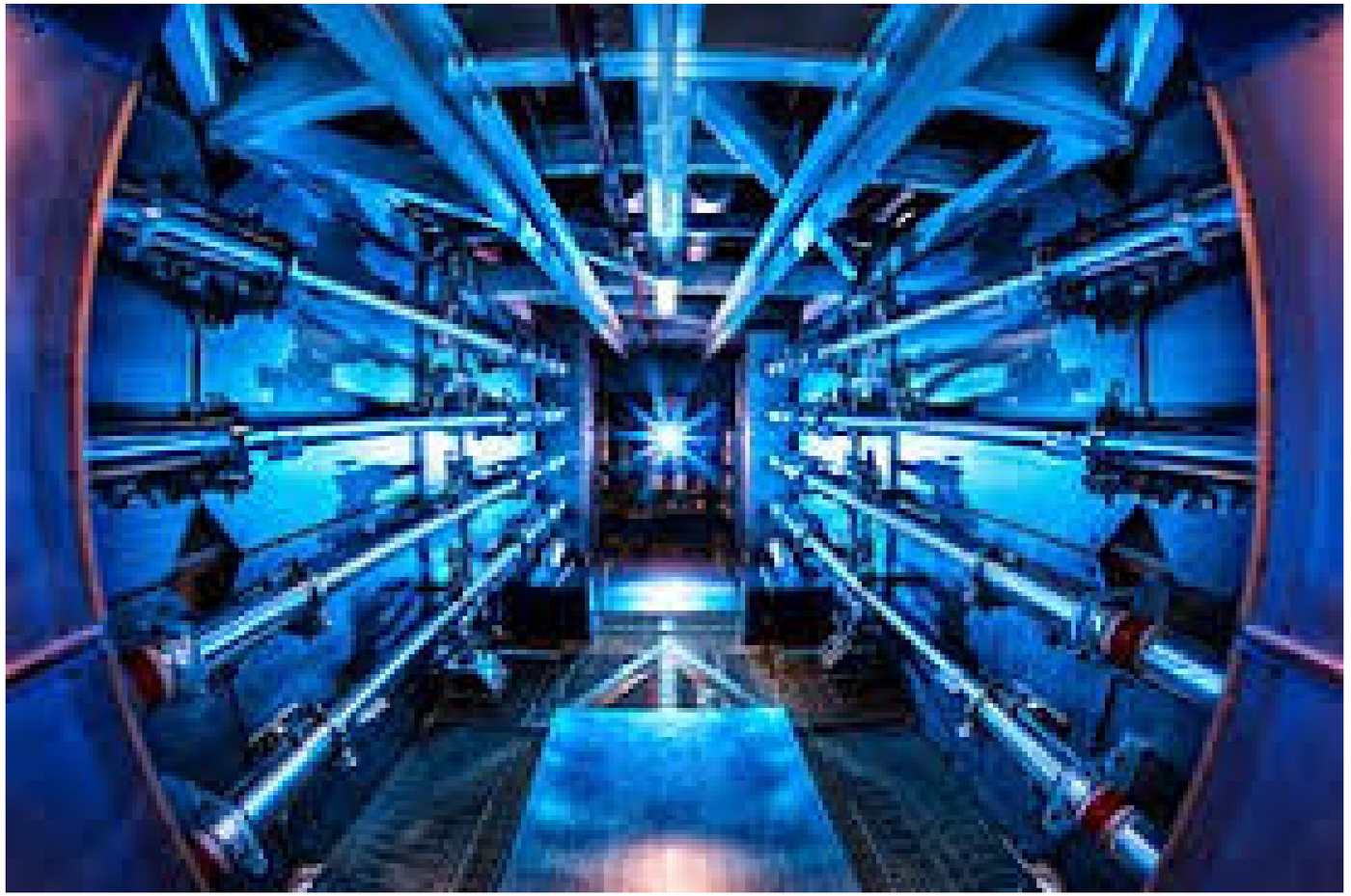


(b)

FIG. 3. (a) Tokamak depiction. (b) ITER 2013-2035

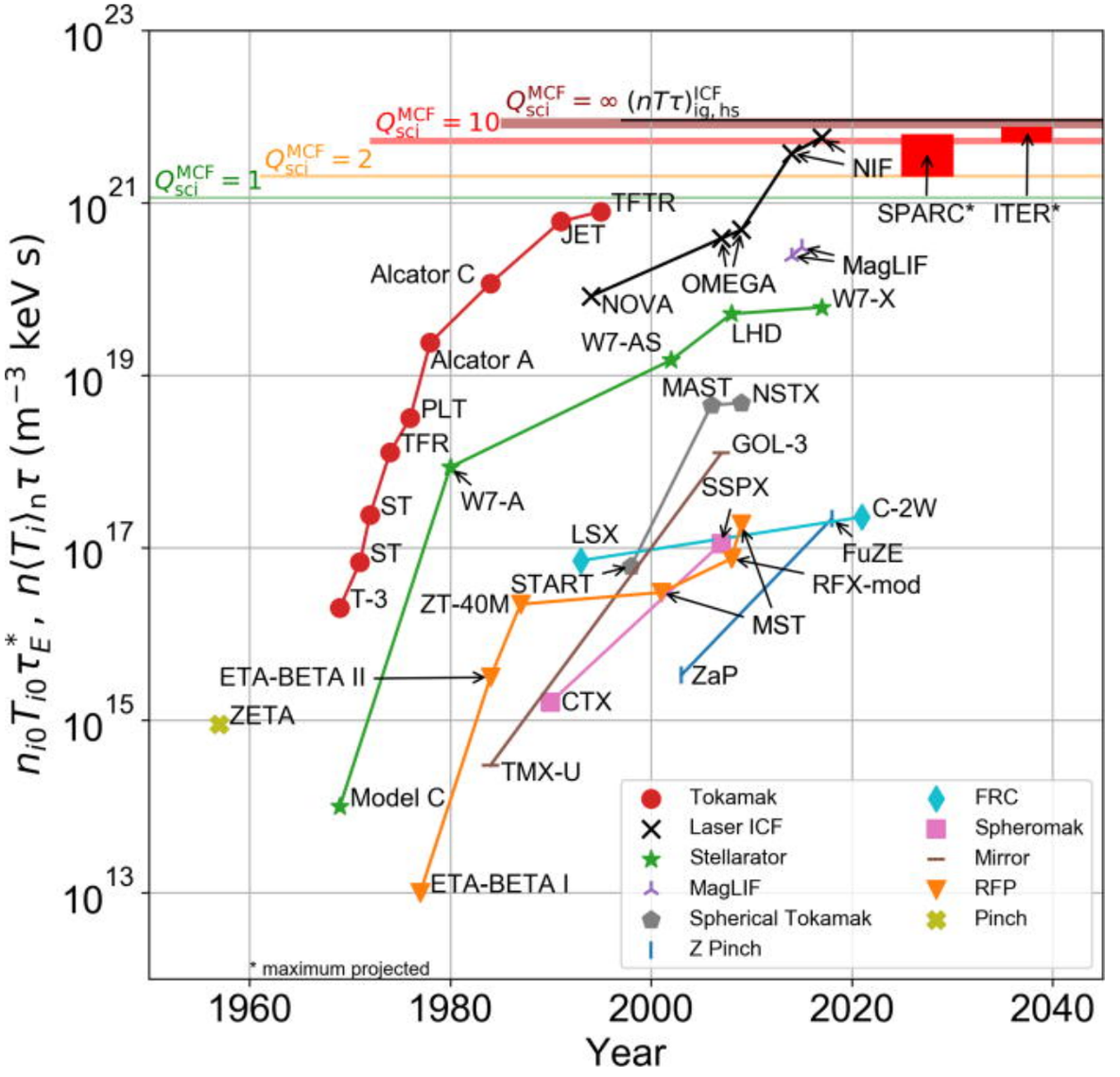


National Ignition Facility inertial confinement fusion (ICF vs. MFE)

Progress?

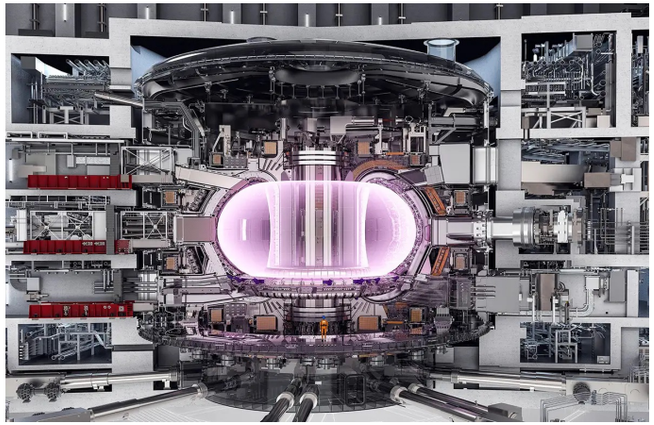
Goodness =

How Much × How Hot × How Long



Why so Difficult?

MFE Spatial Scales



atomic mfp

electron-ion mfp

skin depth

system size

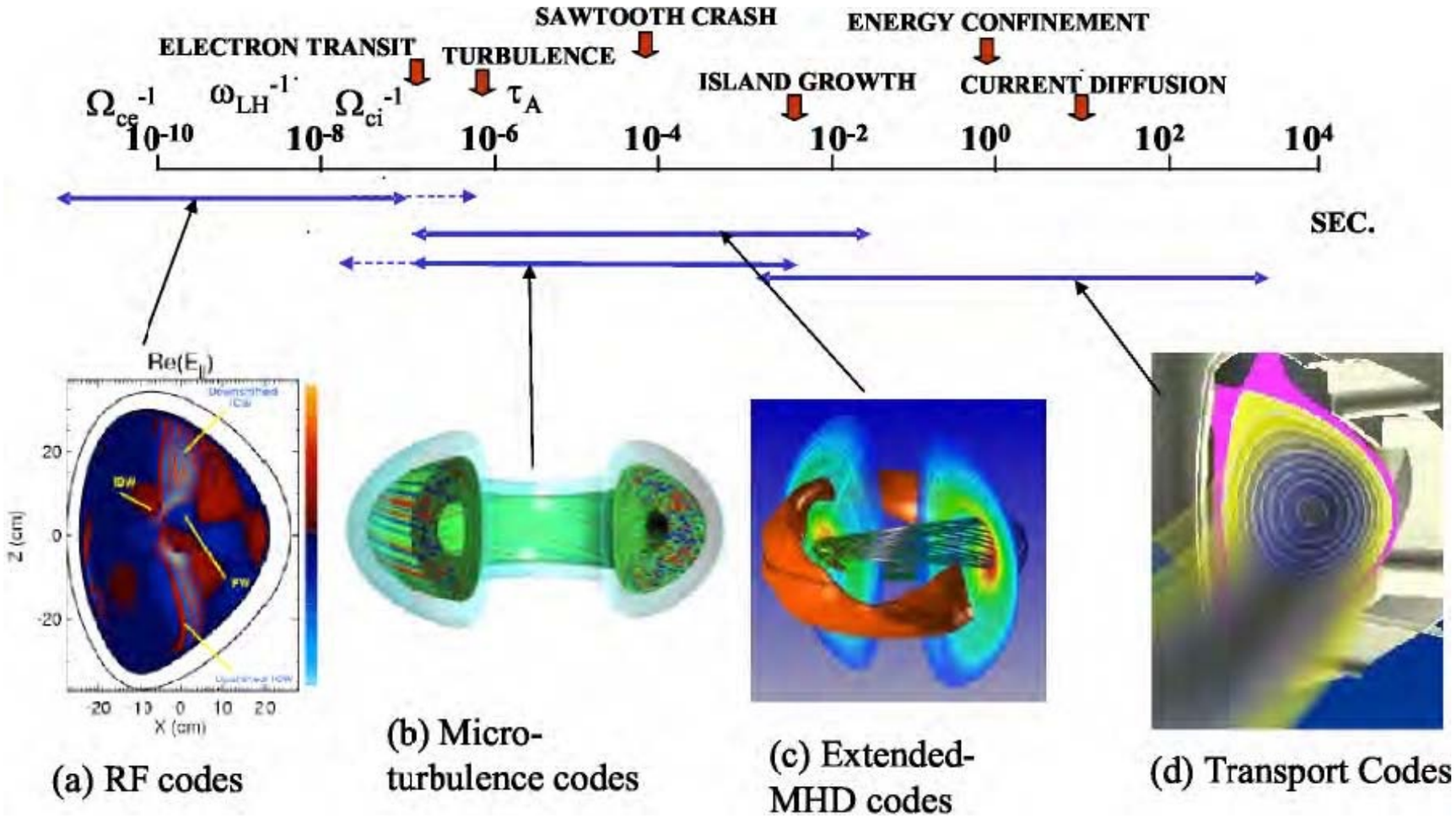
tearing length

ion gyroradius

debye length

electron gyroradius

MFE Time Scales



Sea Change! (past ≈ 5 years)


Proxima
Fusion

STELLAREX

HelicityEspace

nearstar
FUSION

generalfusion

HELION

TYPE ONE
ENERGY

SHINE

BLUE LASER
FUSION

LPP FUSION

MIFTi

EXO FUSION

Commonwealth
Fusion Systems

ZAP ENERGY

tae
TRON

LONGVIEW FUSION
ENERGY SYSTEMS

FOCUSED
ENERGY

KYOTO
FUSIONEERING

THEA ENERGY

REALTA
FUSION

Tokamak Energy

HB11
ENERGY
LASER BORON FUSION

first light

AVALANCHE

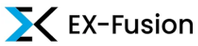
acceleron

PrincetonSATELLITE
SYSTEMS

LaserFusionX

GAUSS
FUSION

XCIMER ENERGY
CORPORATION

fuse

EX-Fusion

SPARC

Helical
Fusion

MarvelFusion

RENAISSANCE
FUSION

nT-tau
Compact Fusion Power

Why?

High T_c Superconductivity

- Nobel Prize in Physics in 1987 30+ years for technology to blossom
- Superconductivity $\rightarrow$ 10$\times$ bigger magnetic fields
- Bigger magnetic fields $\rightarrow$ better confinement in variety of devices
- Decision to revisit. ARPA-E.

Advanced Research Projects Agency - Energy
U.S. Department of Energy

The Advanced Research Projects Agency-Energy (ARPA-E) advances high-potential, high-impact energy technologies. Funding that encouraged private-sector investment.

Promising Results

- Ignition with NIF
- W7X Results

How Long to Fusion?

How Long to Fusion?

- I don't know! Science vs. Engineering.
- Power on the grid in 10 years?