Educating Kids & Exciting Teachers about Science:
A Model from the Plasma Science Community

The Power of the Universe on Earth: Plasma Physics and Fusion Energy

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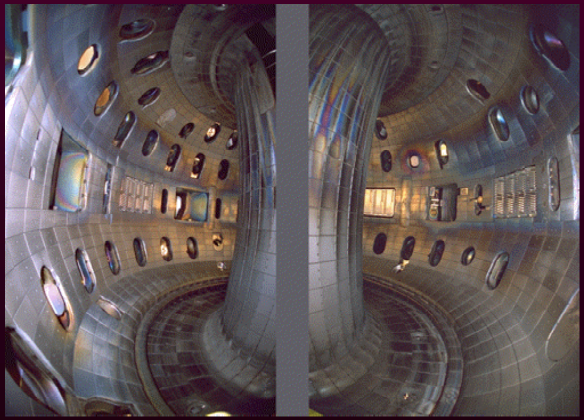
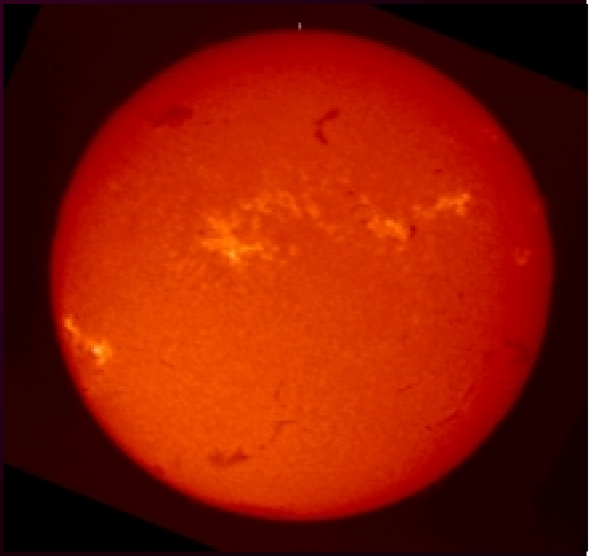


What is a plasma?
Why should we care?
Where are the questions?



March 14, 2000

Science and Education

"…if you tell me I listen … if you teach me I learn … if you involve me I remember …"

(Jim Diaz quoting Ben Franklin)

Outreach and education are intrinsically linked

Stimulate interest and you will stimulate learning

Scientists at all levels must get involved in sharing their science

Plasma Science in Education and Outreach

- Elementary schools
- High schools
- University/College
- Teacher training
- General Outreach

In all of these settings:

Outreach, materials development and direct educational efforts are underway

1999 APS/DPP Outreach/Expo
Courtesy of Carol Danielson

Outline

What is a plasma?

Where do we find them?

Why are we interested in them?

- Astrophysics
- Plasmas all around us
- Fusion energy

Picture courtesy of Jan Curtis
http://climate.gi.alaska.edu/Curtis/curtis.htm

More on fusion energy.

Charged particles moving in a magnetic field.

Turbulence

What is a plasma?

A plasma is an ionized gas.

Plasma is called the "fourth state of matter."

More than 99% of the known mass of the universe is in the plasma state.

'Plasma' was coined by Tonks and Langmuir in (1929):

> "...when the electrons oscillate, the positive ions behave like a rigid jelly..."

Where do we find plasmas?

Examples of plasmas on Earth:

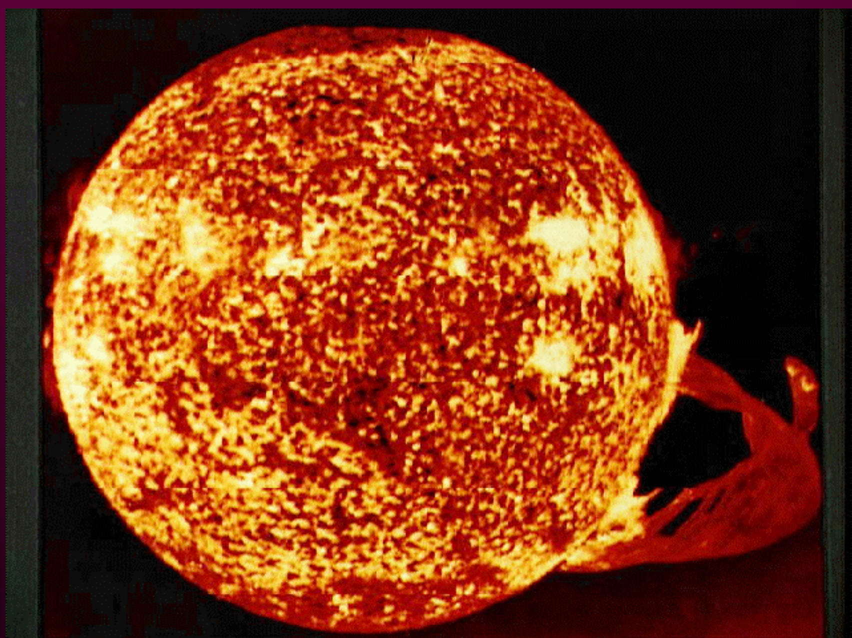
- Lightning
- Neon and Fluorescent Lights
- Laboratory Experiments

Examples of astrophysical plasmas:

- The sun and the solar wind
- Stars, interstellar medium

Astrophysical plasmas

The Sun



http://bang.lanl.gov/solarsys/

Catseye Nebula

http://www.stsci.edu:80/

Astrophysical Plasmas

MyCn18, a young planetary nebula located about 8,000 light-years away

Galaxy NGC 4414, is 19.1 megaparsecs or about 60 million light-years

Pictures courtesy of NASA
http://nssdc.gsfc.nasa.gov/photo_gallery/

Plasmas on Earth

Laboratory Experiments

http://FusEdWeb.pppl.gov/

Lightning

Why are we interested in plasmas?

Fusion Energy

Potential source of safe, abundant energy.

Astrophysics

Understanding plasmas helps us understand stars, stellar evolution and the evolution of the Universe.

Upper atmospheric dynamics

The upper atmosphere is an important plasma.

Plasma Applications

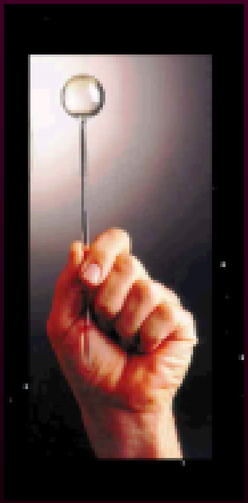
Plasmas can be used to build computer chips and to clean up toxic waste.

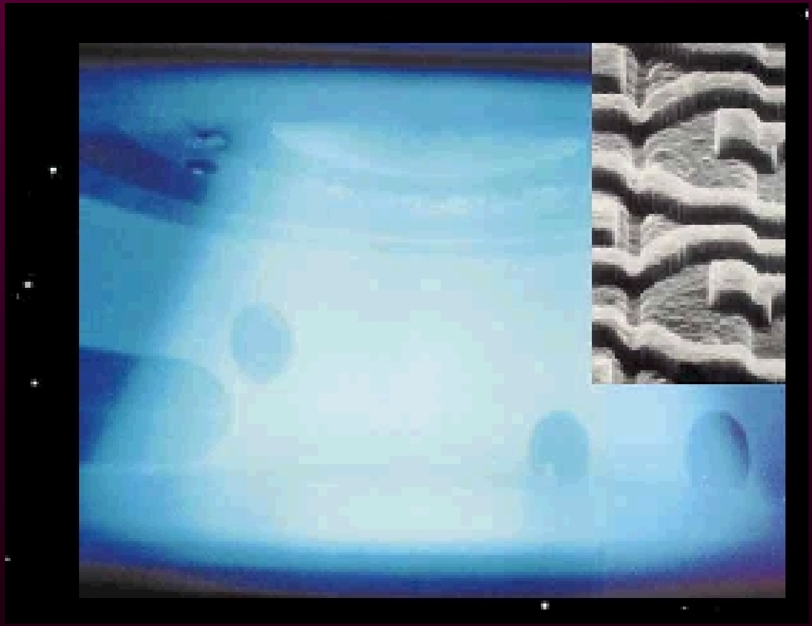
Plasmas around us

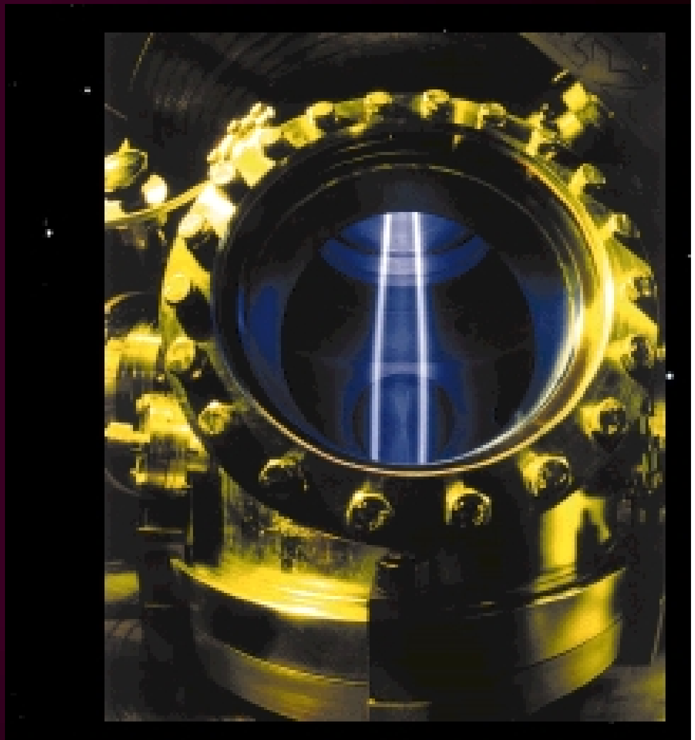
Plasma processing

- Computer chips
- Surface modification

Lighting







Courtesy of University of Wisconsin, Madison
Photographer Bruce Fritz

Pictures from
Plasmas: The 4th State of Matter

Plasmas around us

Plasma displays

Decontamination

Plasma Thrusters

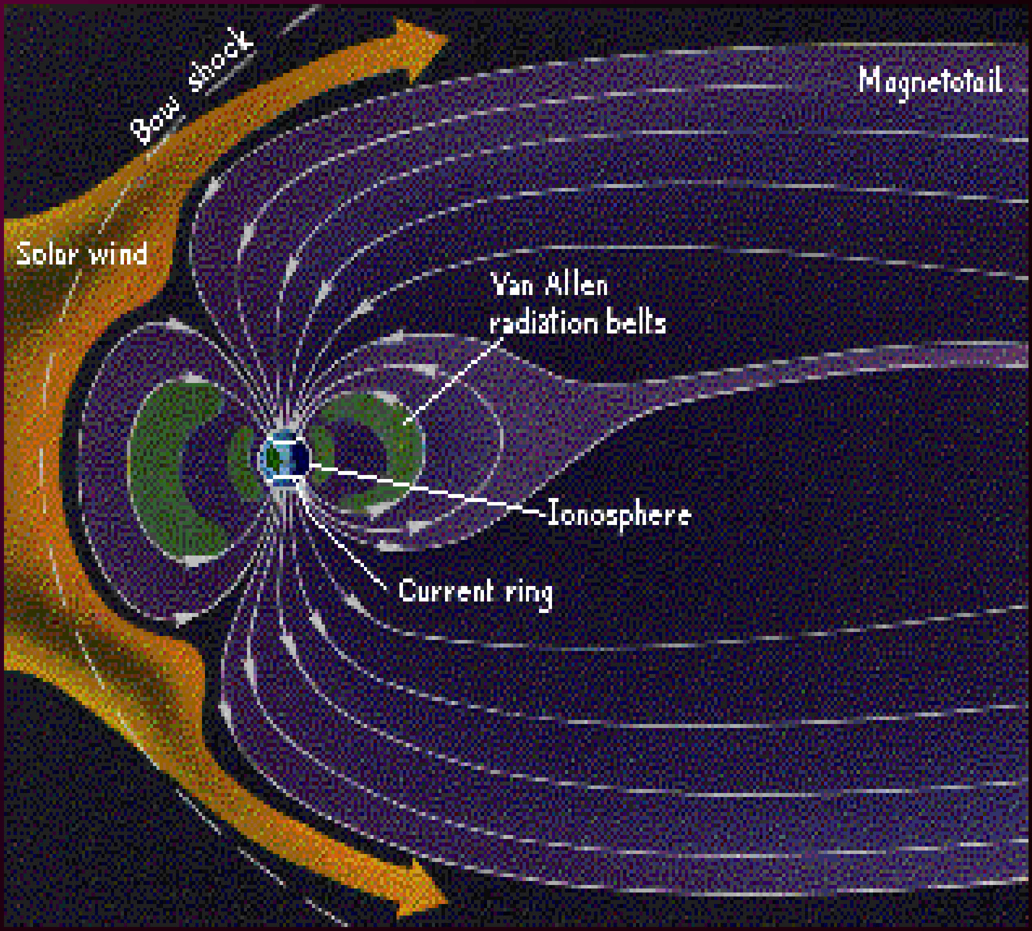
Plasma torch from the
Plasma Technology Research Center

Electrograph Plasma Display
http://www.electrograph.com/detail.asp

The solar wind (a plasma) interacts with the Earth's magnetic field

The sun emits mass in the form of plasma at velocities of up to 500 km/s.

This solar wind causes the Earth's magnetic field to compress creating a shock wave called the Bow wave.



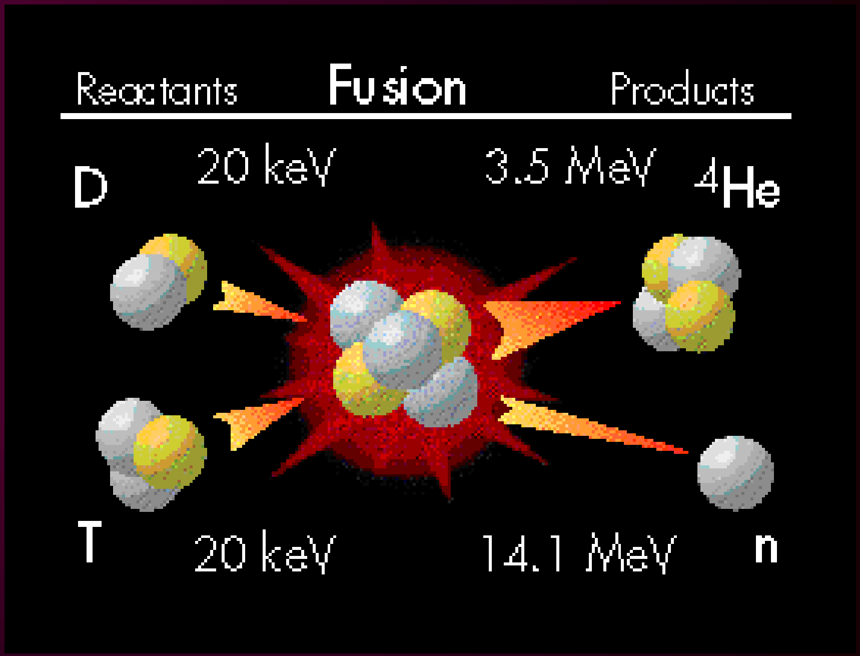
From ***Stars,*** *James Kaler*

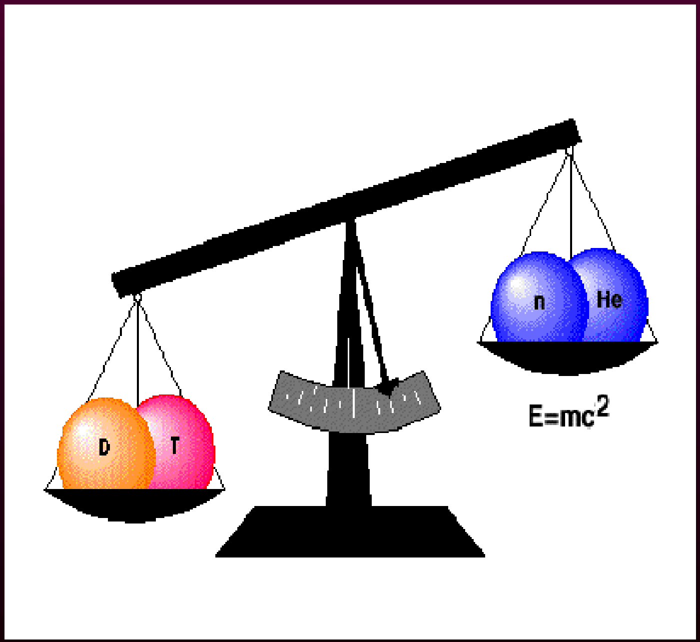
Interactions between the earth's magnetic field and a plasma can have spectacular results

The northern lights (aurora borealis)

Photo by David Fritts
http://dac3.pfrr.alaska.edu:80/~pfrr/AURORA/INDEX.HTM

Mass goes into energy in a fusion reaction

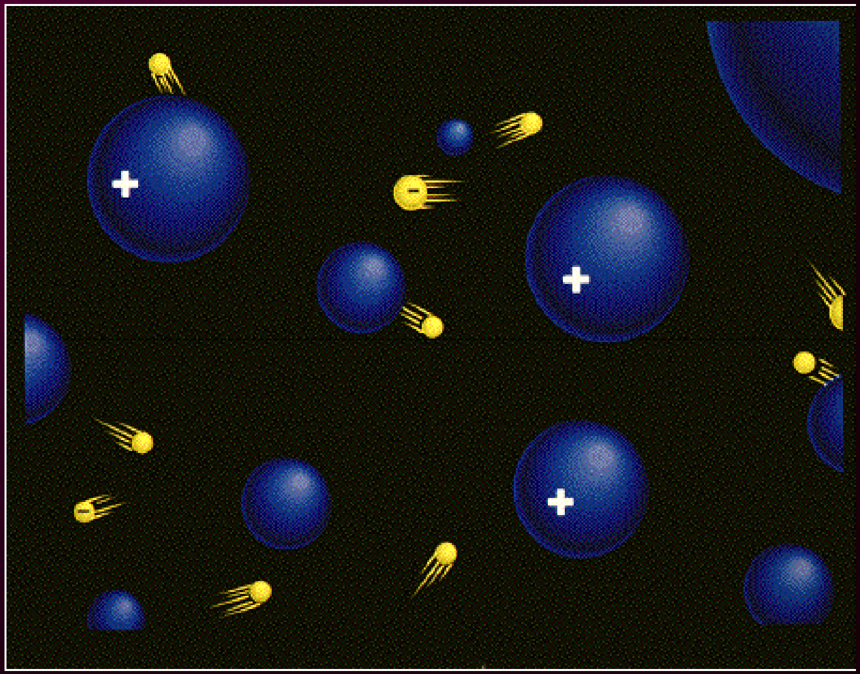




Properties of plasmas

- A collection of positively and negatively charged particles.
- Plasmas interact strongly with electric and magnetic fields.
- Plasmas support many different types of waves and oscillations.

Cartoon of a plasma



http://demo-www.gat.com/

More on Fusion Energy

Much of plasma physics research has been motivated by the goal of controlled fusion energy.

Fusion energy is a form of nuclear energy which is emitted when two light nuclei combine to form a single more stable nuclei.

The sun and stars derive their energy from fusion.

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Why is Fusion power needed?

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Country	Consumption (kW-h/capita)
US	12000
Developed World Avg.	6000
World Avg.	1500
China	500
India	250

1990 Energy use per capita

- Projected change in consumption by increasing to world average

Country	Energy Use 1990 (GW)	Energy Use 2020 (GW)
China	120	500
India	65	450

- If fossil Catastrophe Looms

For more information see:
http://wwwofe.er.doe.gov/More_HTML/Artsimovich/PKKawPaper.html

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Fuel and waste products

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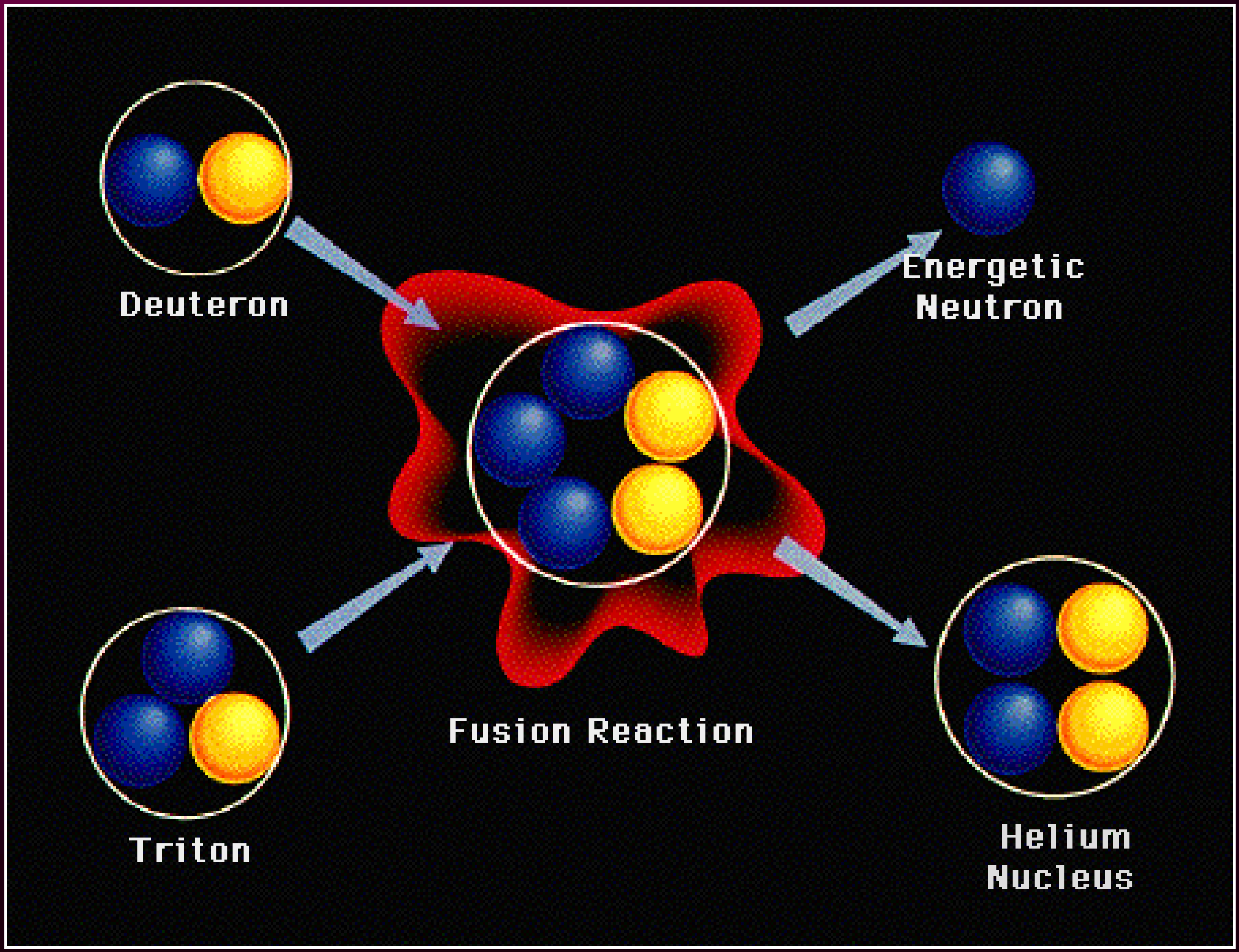
Fuel and waste for coal plants(most readily available energy source) vs D-T fusion plant

DAILY FUEL CONSUMPTION
DAILY WASTE PRODUCTION
1,000 MEGAWATTS

	COAL PLANT	D-T FUSION PLANT
FUEL	9,000 T. COAL	1.0 LB D_2 3.0 LB Li^6 (1.5 LB T_2)
WASTE	30,000 T. CO_2 600 T. SO_2 80 T. NO_2	4.0 LB He^4

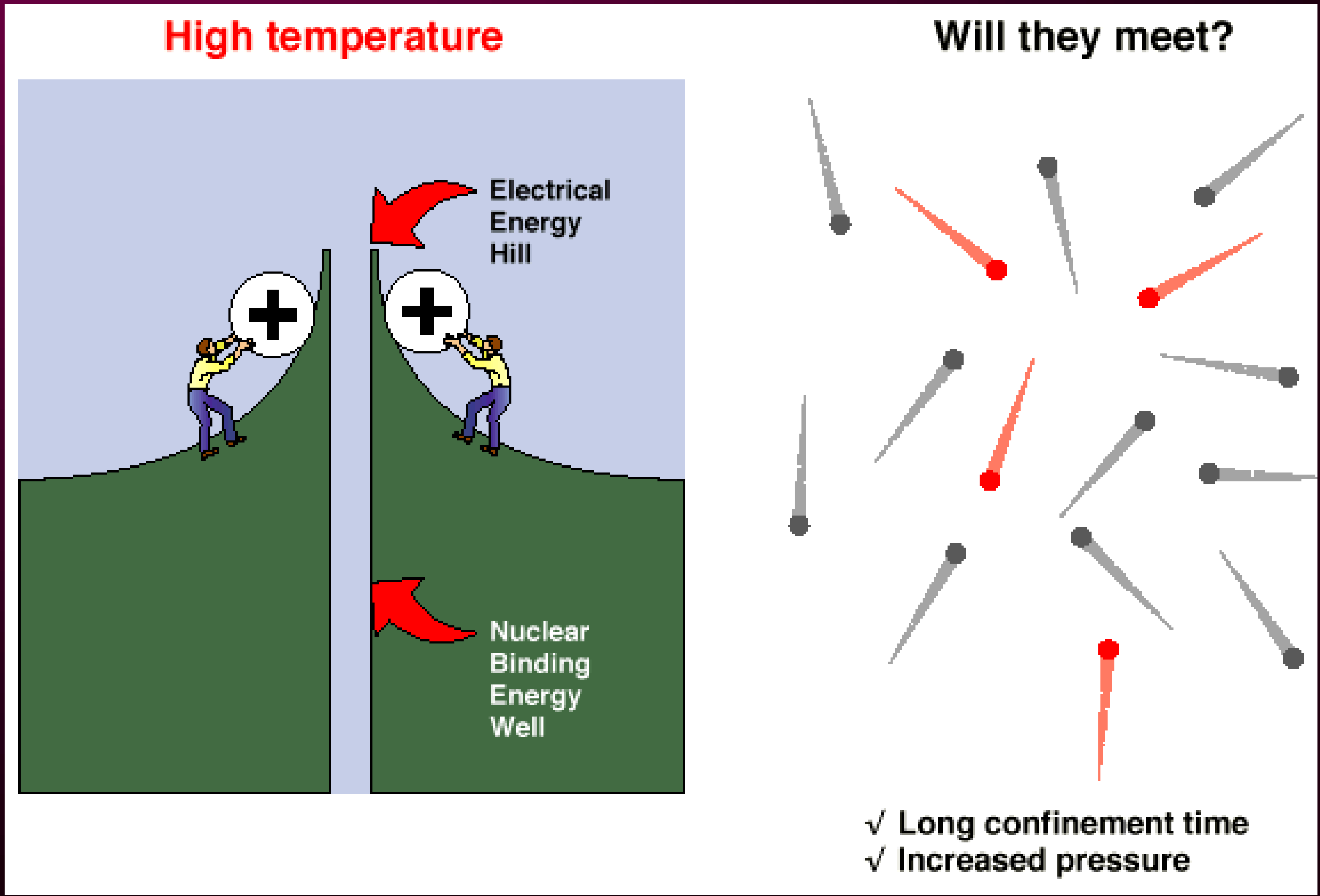
http://www.pppl.gov

Deuterium and tritium combine to form helium, a neutron and fusion energy.



http://FusEdWeb.pppl.gov/

High temperatures and densities are needed

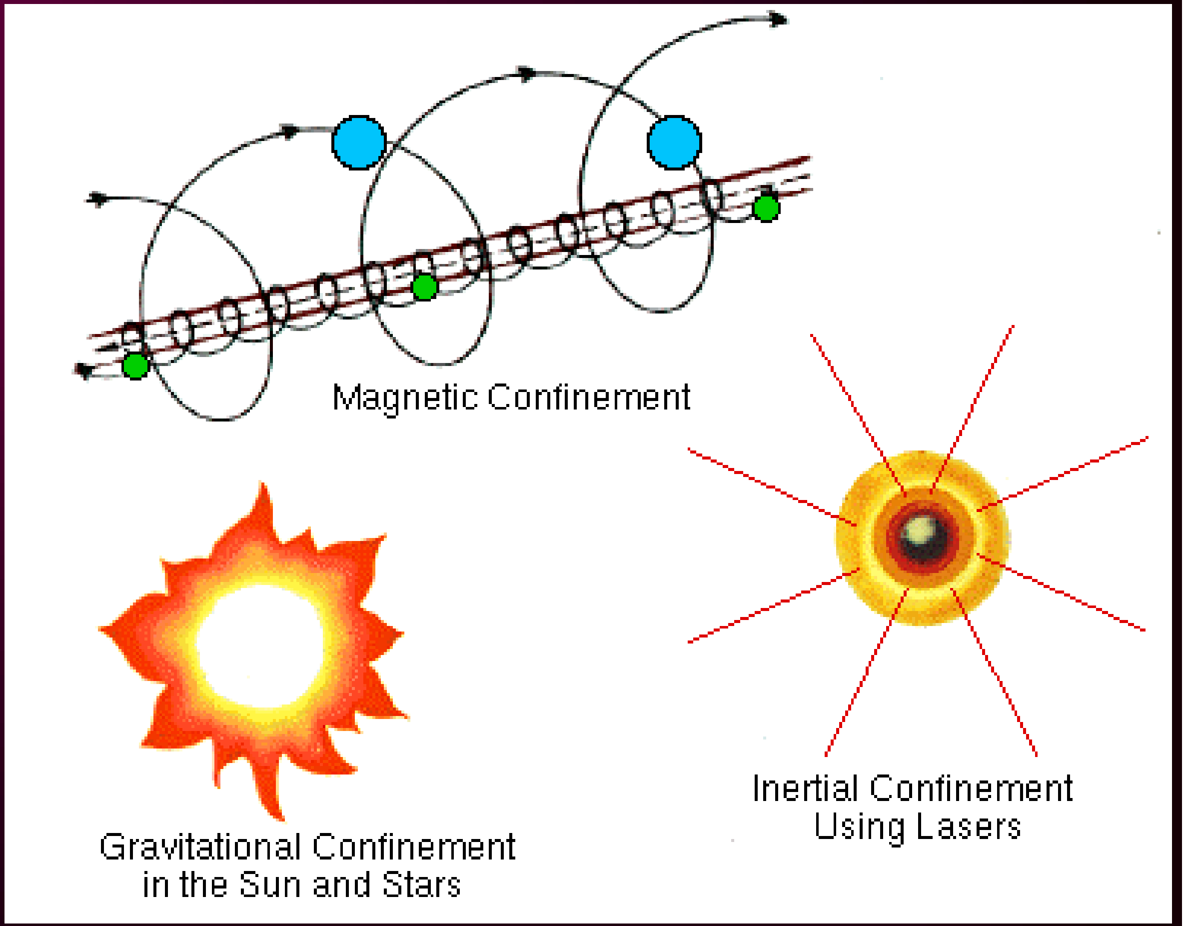


http://lasers.llnl.gov/lasers/education/talk.html

Methods for confinement

Hot plasmas are confined with gravitational fields in stars.

In fusion energy experiments magnetic fields and lasers are used to confine the hot plasma.



http://FusEdWeb.pppl.gov/

What must be achieved to obtain fusion energy?

Contain a high temperature, T, high density, n, plasma for a long enough time, τ, to achieve ignition (power out >> power in).

A measure of plasma performance is thus given by:

$$nT\tau$$

density x temperature x confinement time

Two major approaches to fusion (D–T)

Magnetic confinement

Temperature ≈ 10^{8} °C (10 keV)

$\eta\tau \approx 10^{15}$ Atoms ·seconds / cm^{3}

$\tau \approx$ 10 seconds (magnetic "bottle")

$\eta \approx 10^{14}$ Atoms / cm^{3} (10^{-5} times the density of air)

Inertial confinement

Temperature ≈ 10^{8} °C (10 keV)

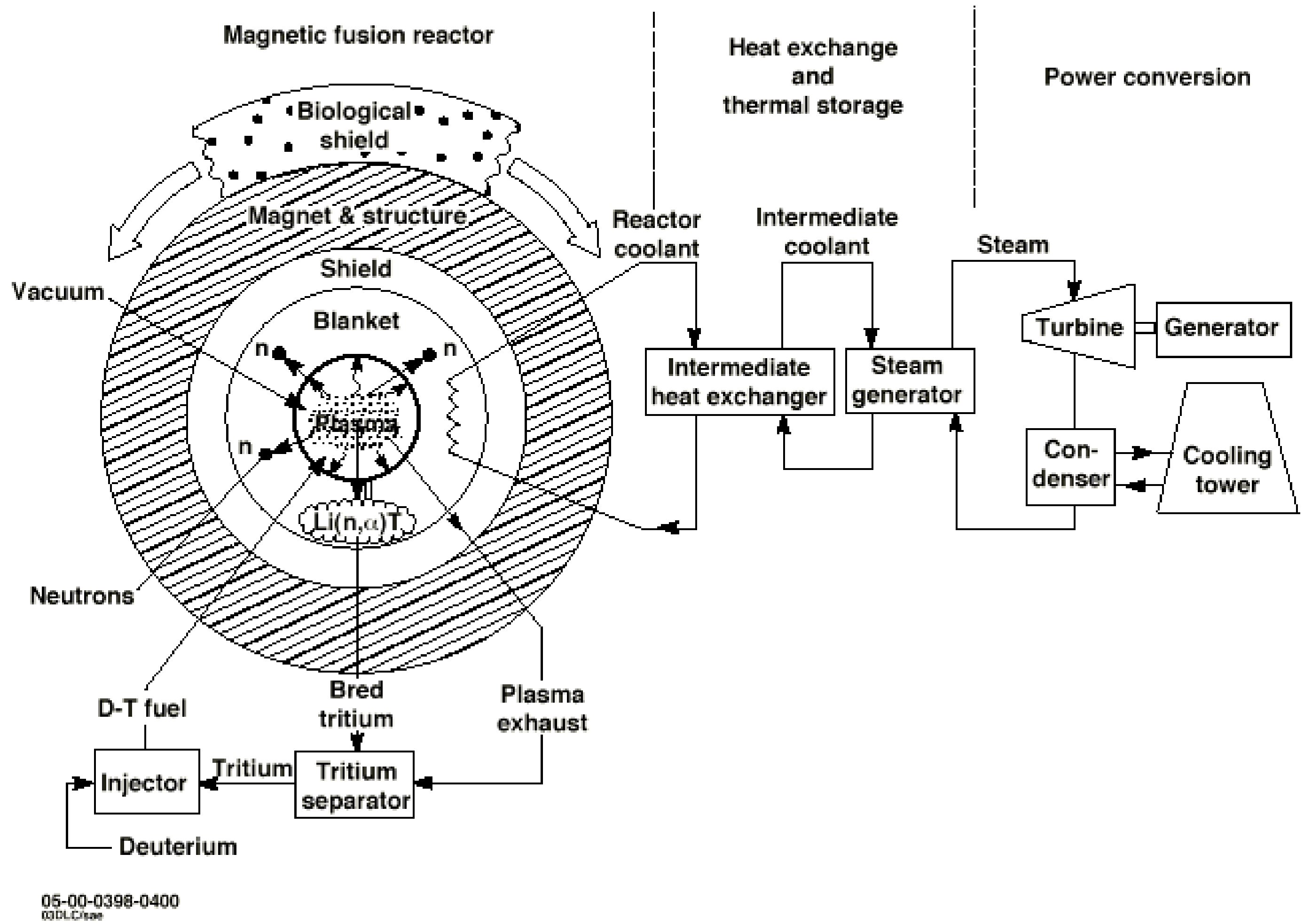
$\eta\tau \approx 10^{15}$ Atoms ·seconds / cm^{3}

$\tau \approx 3 \times 10^{-11}$ seconds (microexplosion, inertial "bottle")

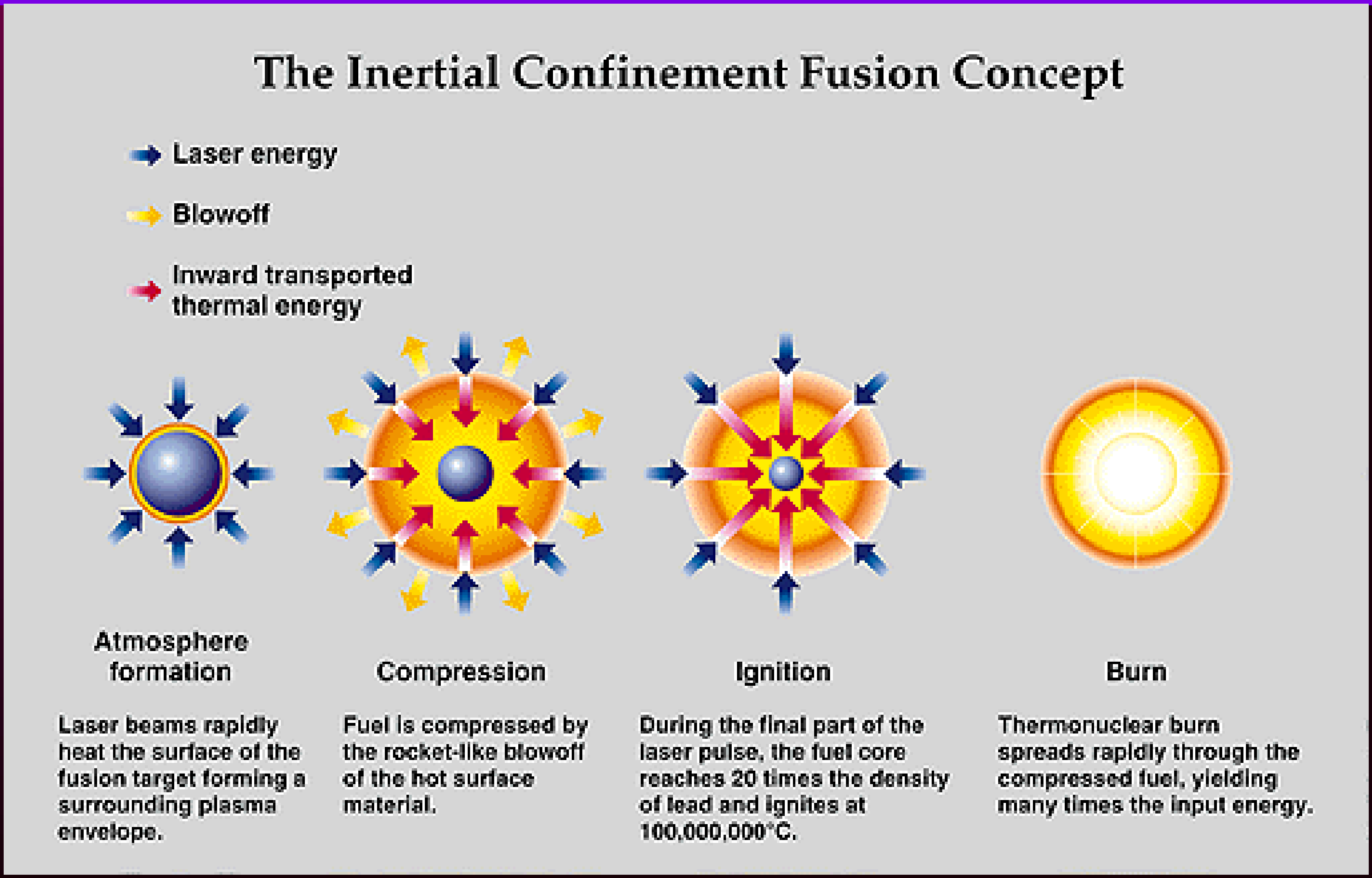
$\eta \approx 3 \times 10^{25}$ Atoms / cm^{3} (12 times the density of lead!

~ 1000 times the density of liquid DT!)

Power Plant Schematic

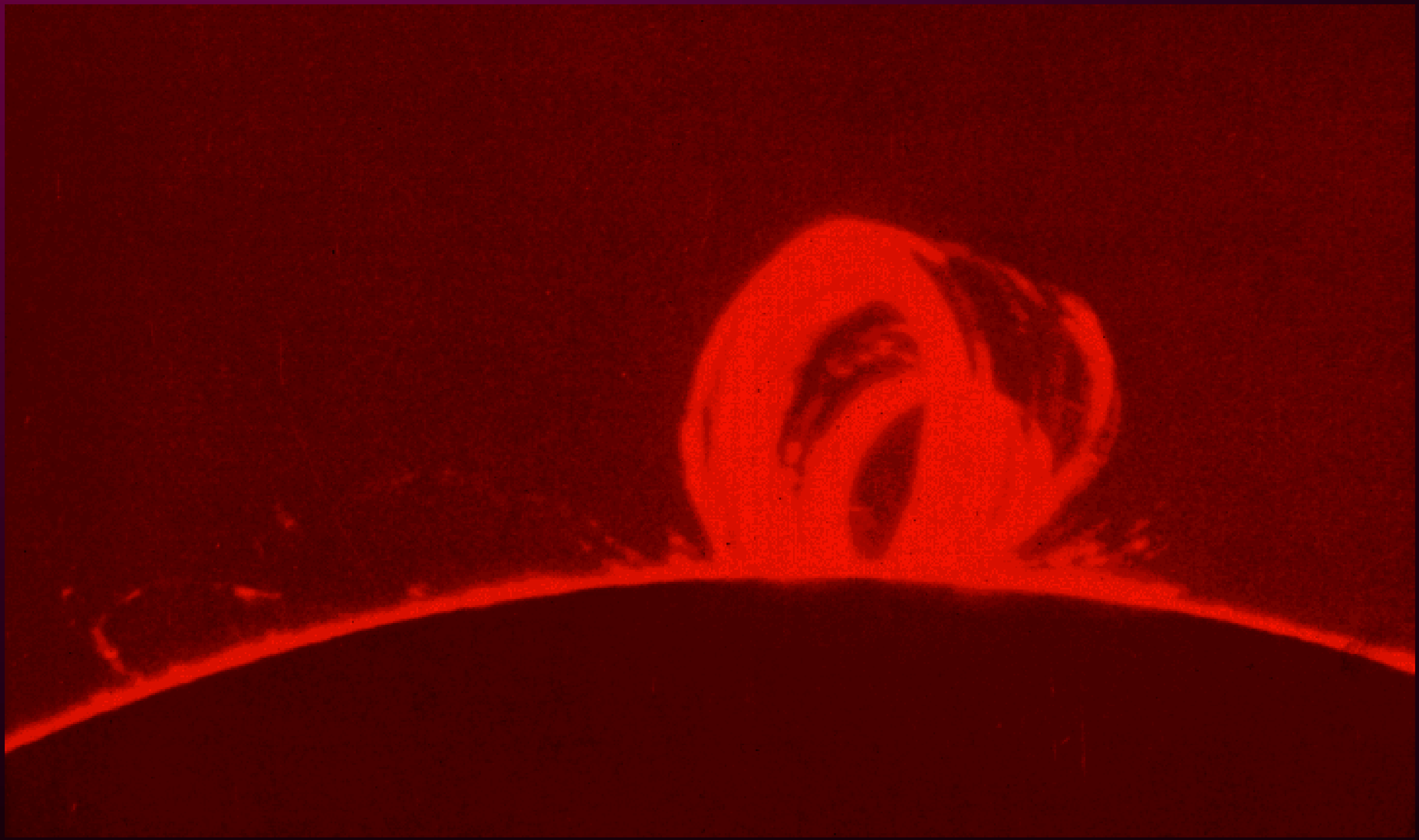


Controlling Fusion using Inertia



http://www-lasers.llnl.gov/lasers/nif/nif_ife.html#fusion

Particles in a Magnetic field

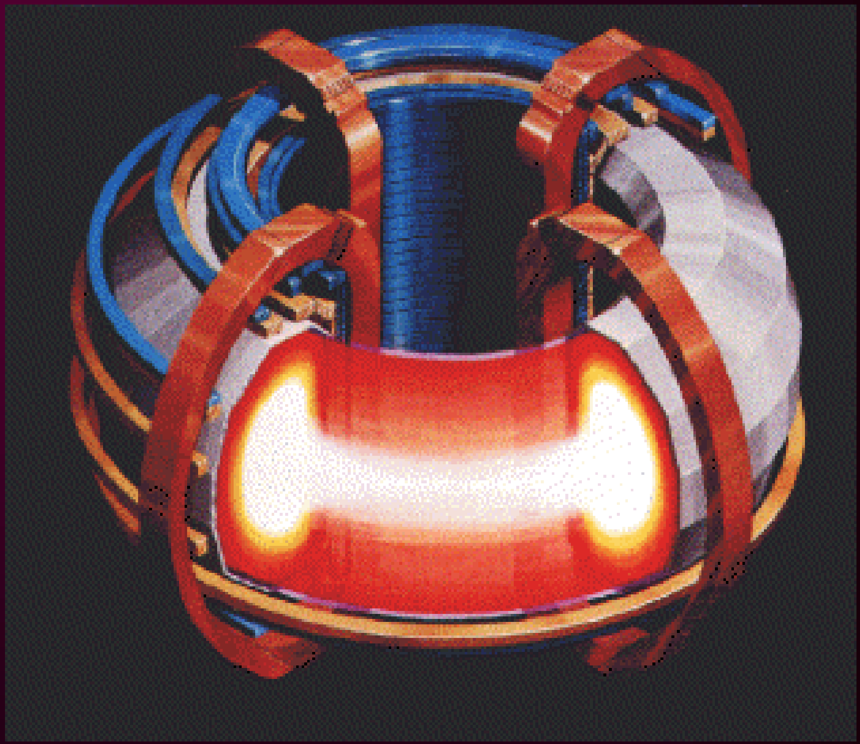


Picture courtesy of NASA http://nssdc.gsfc.nasa.gov/photo_gallery/

Controlling fusion with magnetic fields

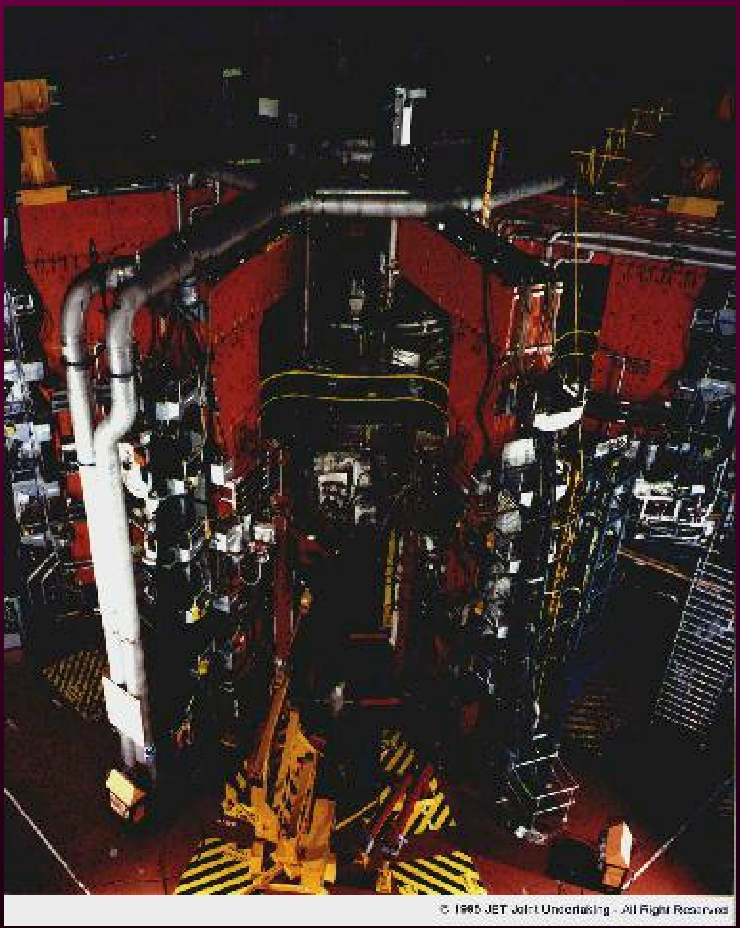
Most magnetic confinement devices in use today have a toroidal shape.

Large magnetic fields are created by driving currents through coils wrapped around the torus.

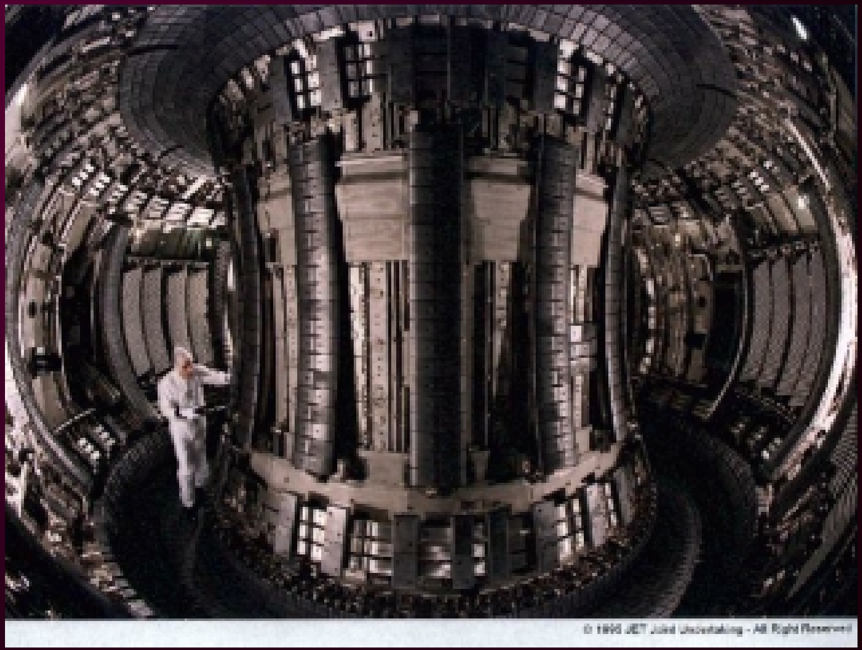


http://demo-www.gat.com/

Joint European Torus:
the largest confinement device ever built



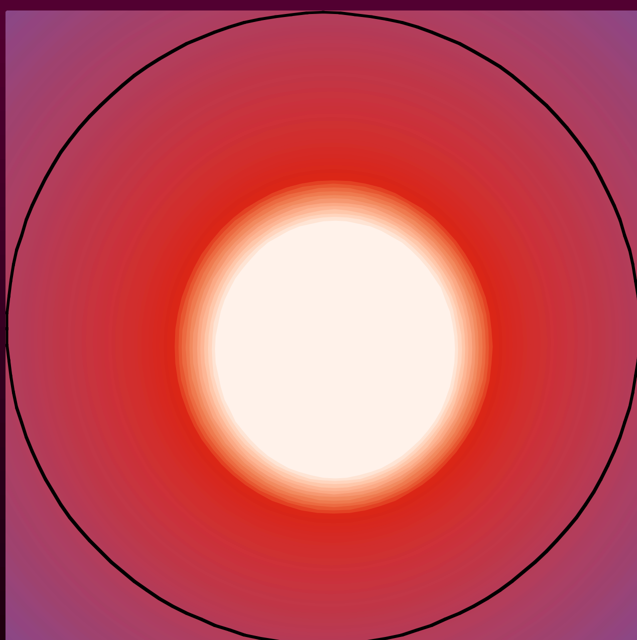
http://www.jet.uk/

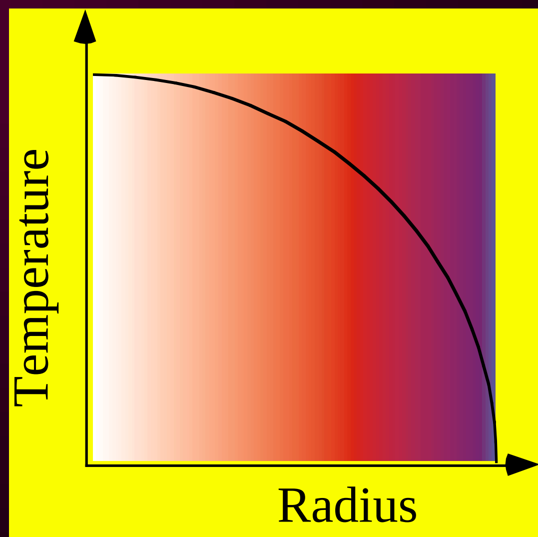


http://www.jet.uk/

Need to control temperature and density

We need the core hot enough for fusion, yet the edge cool enough not to melt the walls





But nature abhors gradients

Whenever a slope (gradient) gets too steep, nature finds a way to flatten it out

- Mountains get eroded
- sand and snow avalanche
- turbulence grows to flatten steep slopes in plasmas

We need to control the turbulence

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Turbulence moves things down the slope

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The turbulent swirls (eddies) move the heat and density toward the edge

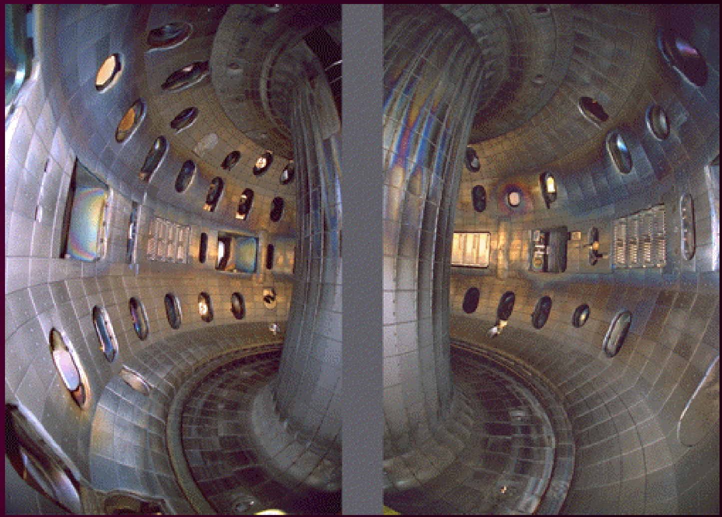
Challenges on the path to Fusion

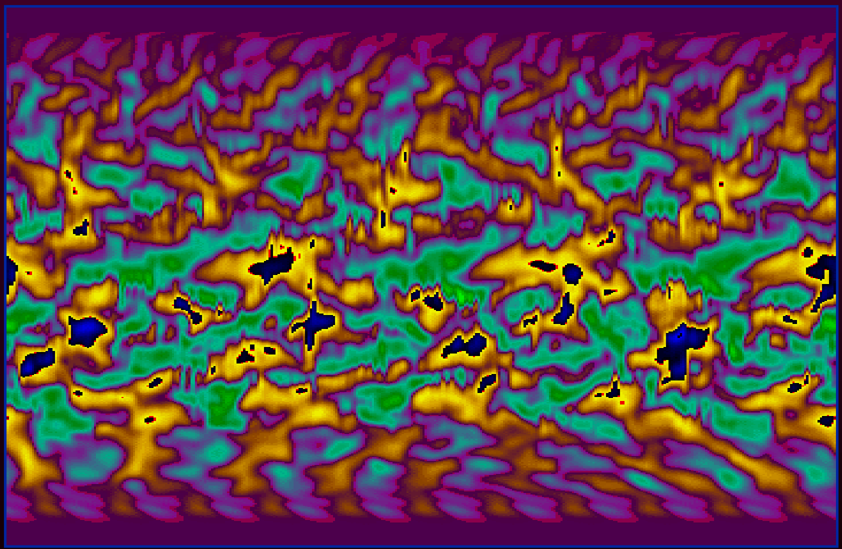
Heating

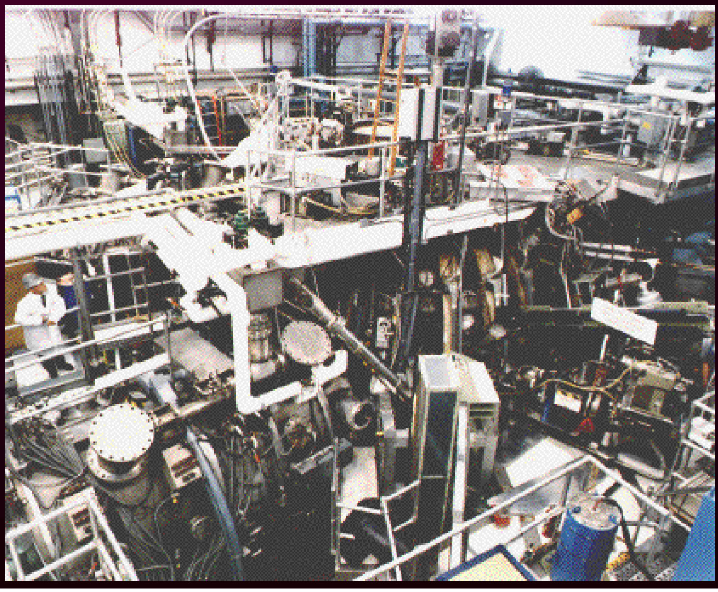
Fueling

Confinement

Plasma physics is on the leading edge of technology

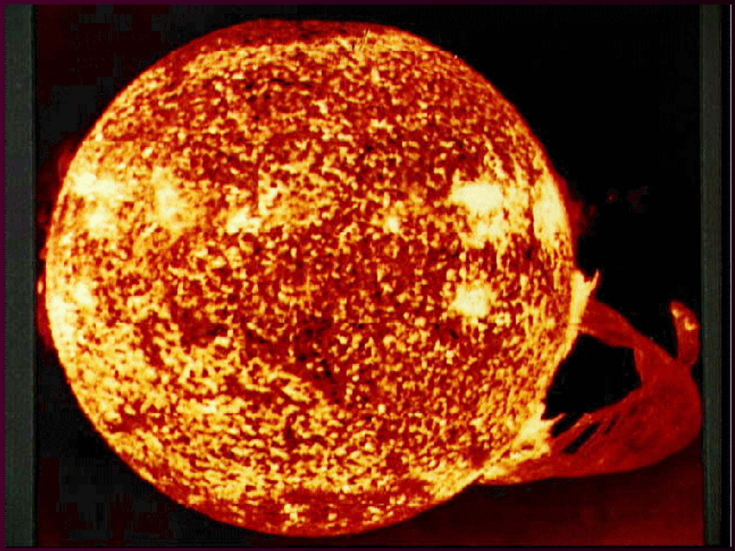






Turbulence is everywhere in nature

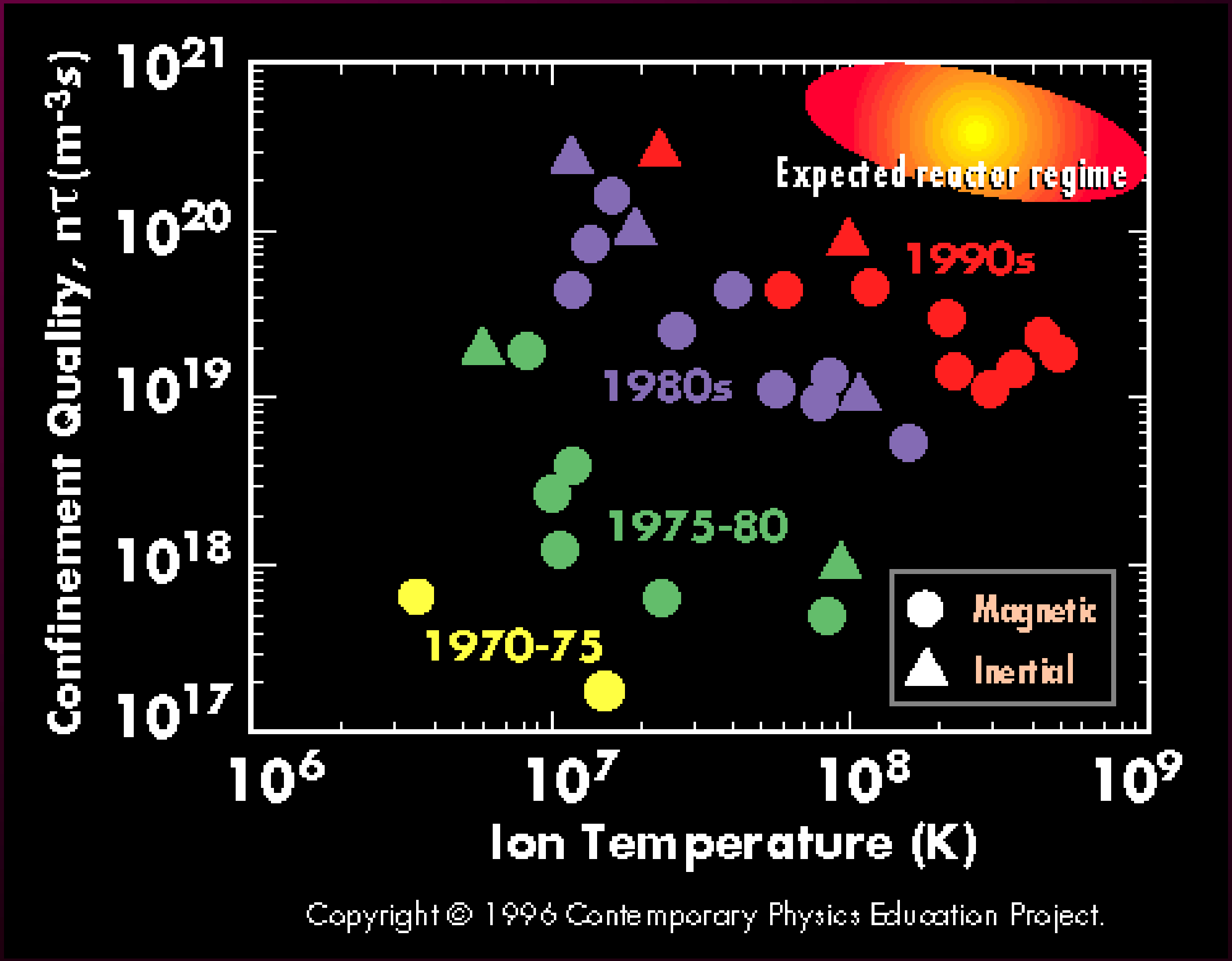
Turbulent transport is one of the main methods for relaxing gradients



ftp://mojave.wr.usgs.gov/pub/spurr/Spurr.html

http://info.pitt.edu/~maarten/work/soapflow/soapjpgs/dense.turb.JPG

Progress towards fusion energy



http://FusEDWeb.pppl.gov/CPEP/Chart_pages/6.Results.html

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Summary

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Plasmas are ubiquitous in our world

Science can indeed be both **fun** and **important**

Important discoveries and developments come from unexpected places so….

- We must encourage people (especially young people) to explore the world around them

Stimulating interest stimulates learning which stimulates discovery and innovation which stimulates the economy

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Web References

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Fusion energy and plasma educational sites

http://FusionEd.gat.com/	General Atomics
http://FusEdWeb.pppl.gov/	Princeton Plasma Physics Laboratory
http://lasers.llnl.gov/lasers/education/ed.html	Lawrence Livermore National Laboratory
http://www.jet.uk/	Joint European Torus
http://www.ornl.gov/fed/fedhome.html/	Oak Ridge National Lab
http://www.ornl.gov/fed/theory/Theory_Home_page.html	
http://ffden-2.phys.uaf.edu	My home page at the Univ. of Alaska - Fairbanks

Astrophysics sites

http://umbra.nascom.nasa.gov/spd/	NASA Space Science
http://www.seds.org/billa/tnp/	The Nine Planets
http://www.stsci.edu:80/	Space Telescope Science Institute
http://bang.lanl.gov/solarsys/	Views of the Solar System
http://www.gi.alaska.edu/	Geophysical Institute (Aurora and Sprite info)
http://www.sec.noaa.gov/	NOAA Space weather site

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