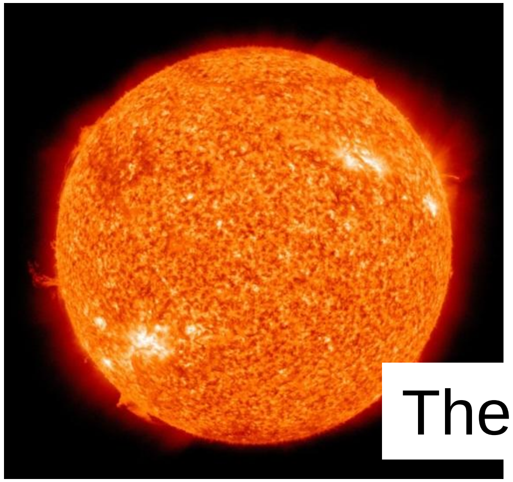
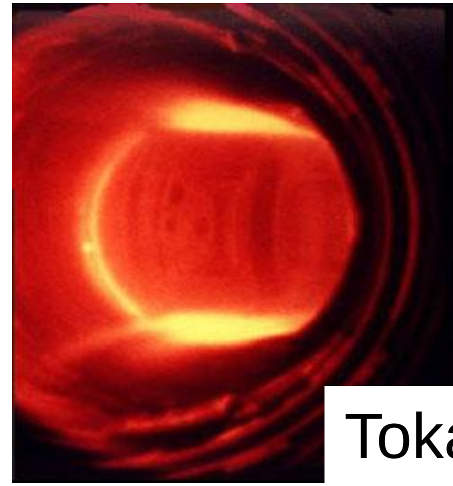


The Sun



Tokamak

# Magnetic Fusion and Tokamaks

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2013 Canadian Workshop on Fusion Energy Science and Technology

Oshawa, August 30th, 2013

NSERC CRSNG

UNIVERSITY OF SASKATCHEWAN

Fedoruk Centre
SYLVIA FEDORUK CANADIAN CENTRE FOR NUCLEAR INNOVATION

# Outline

- Fusion Requirements and Approaches
- Magnetic Confinement Fusion
- How Does a Tokamak Work?
- Progress and Outlook
- Fusion Research at UofS
- Summary

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# Fusion Difficulties

- In order to bring the D and T close enough to make the fusion reaction happen, the repulsive Coulomb force ($1/r^2$) between the positively charged D and T has to be overcome
- Fuels can be heated to high temperatures ( hundreds of millions degrees )
- High temperature fuel (plasma) must be confined

# Requirements and Challenges

- The fuel density must be high enough to generate necessary power in the reactor → $n \sim 10^{21}\ \mathrm{m}^{-3}$
- The confinement time must be high so the fuel fuse before getting lost → $\tau \sim 1\ \text{second}$
- Fusion triple product (Lawson's Criterion)

$$nT\tau \sim 10^{22}\ \mathrm{m}^{-3} \cdot \mathrm{keV} \cdot \mathrm{sec}$$

- Q-value (measure of economy)

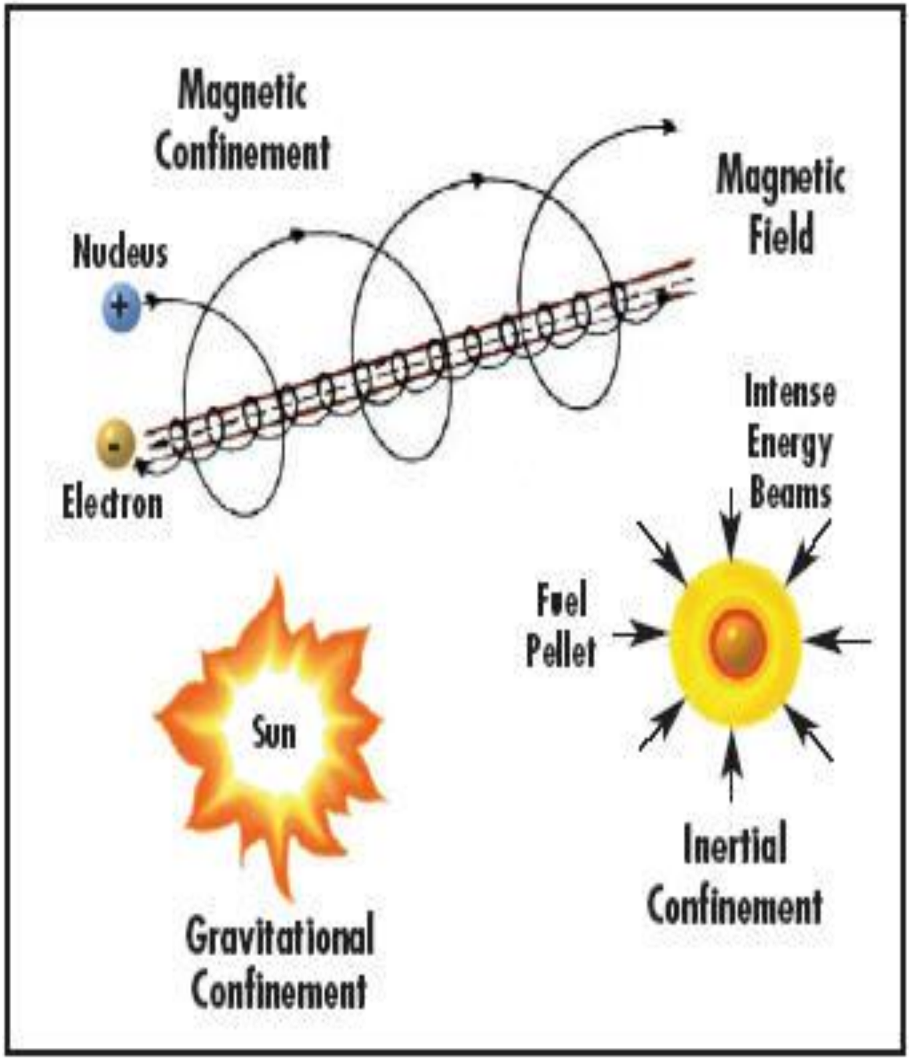
$$Q = \frac{\text{fusion power}}{\text{input power}} \gg 1$$

# Types of confinement schemes

**Inertial**

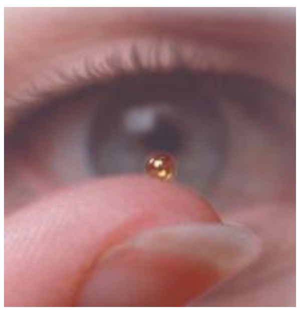
**Magnetic**

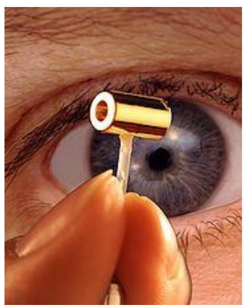
**Gravitation (sun)**



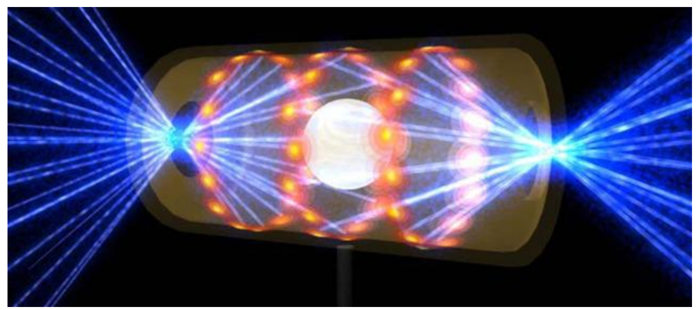
# Inertial Fusion

- Compress the fuel capsule to a very high density in a short period of time using lasers





Tiny fuel cell



Hundreds of laser beams compress the fuel

NIF in USA

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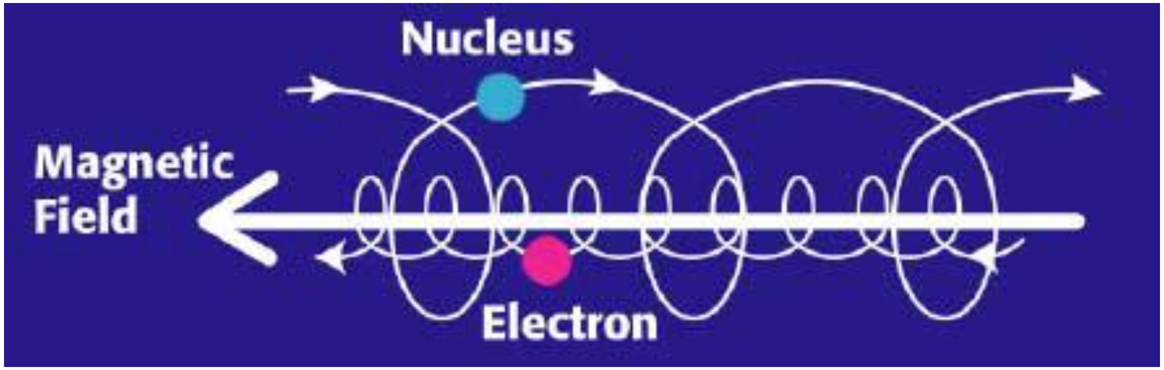
# Magnetic Fusion

- A charged particle makes gyro-motion around the magnetic field lines
  - Cross-field motion is restricted
  - Motion along the field lines is still free (end loss)

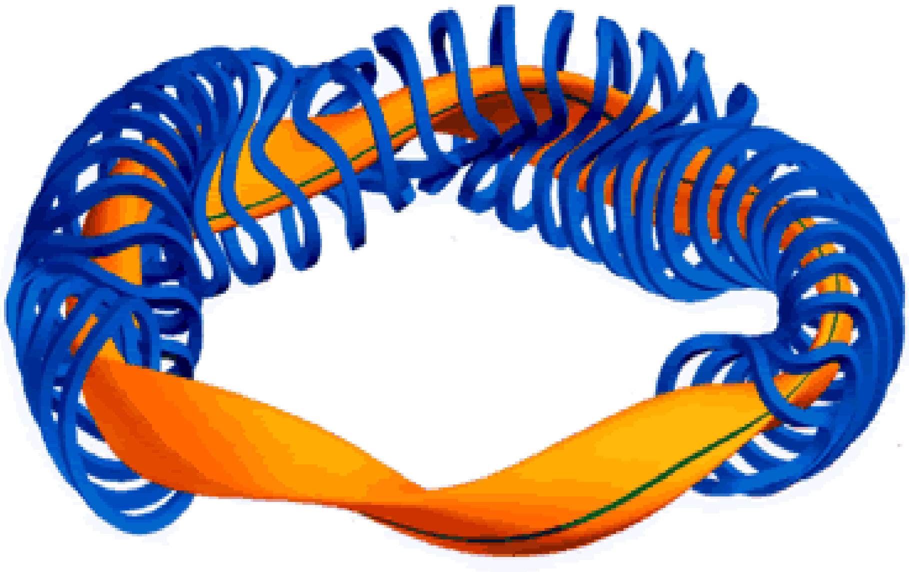



- Closed magnetic field lines are preferred

# Types of Magnetic Fusion Devices

- Magnetic field can be applied externally or induced, partially or wholly, by current flowing in the plasma.
  - Fully applied by external field → Stellarators
  - Fully induced by current in plasma → Reversed Field Pinch (RFP)
  - Applied partially by external coils and partially by the plasma current→ Tokamak, currently the most promising configuration for MCF reactor

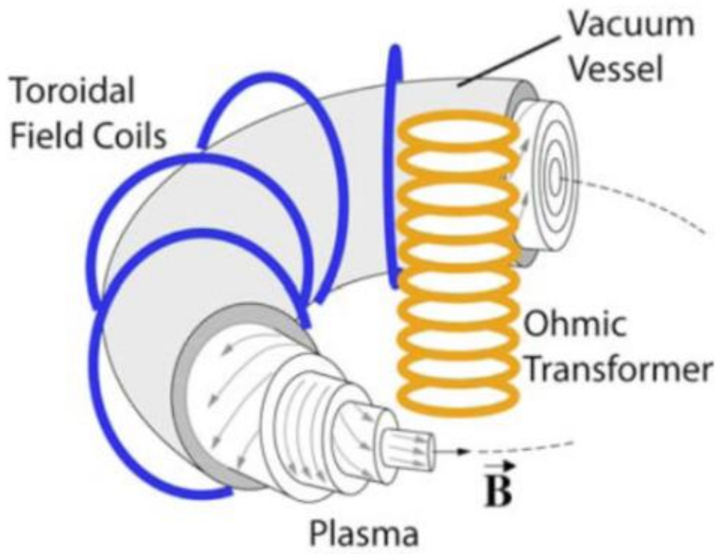
# Stellarator

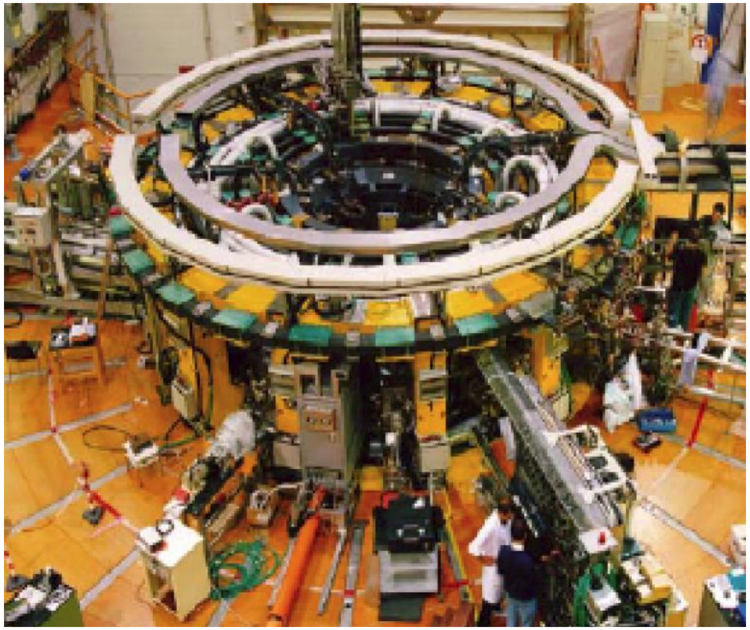


sophisticatedly shaped superconducting coils create the necessary magnetic configurations

- Wendelstein 7-X, Greifswald, Germany
  - Largest stellarator being built.
  - First plasma 2015

# Reversed Field Pinch



- RFX, Padua, Italy - largest RFP
- MST, Madison, USA
- KTX, Hefei, China – New RFP being built

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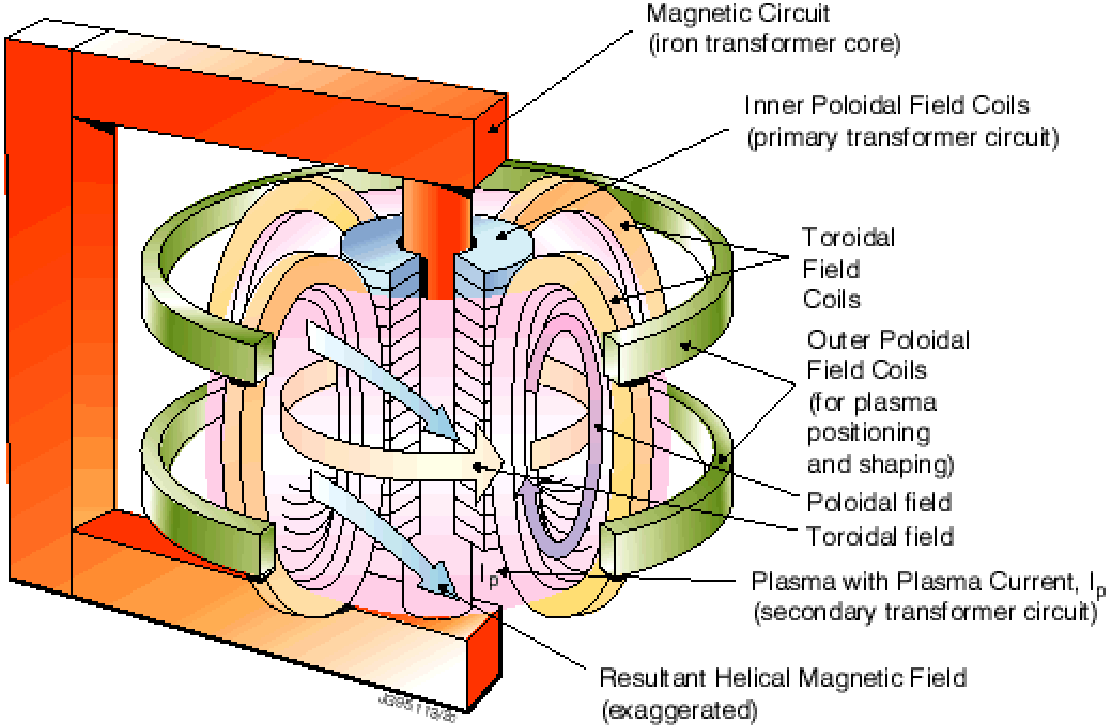
# Tokamak

- Bend solenoid to form closed magnetic field lines
- A transformer drives plasma current
  - Heating
  - Help create helical field lines, a stable field configuration
- Vertical field for equilibrium and shaping




Tokamak: abbreviation of Russian words for toroidal magnetic chamber

# Largest Tokamaks Today

- JET, UK (European Union)
  - R/a=2.96m/1.25m, B=3.45T, I=7 MA
- JT-60U, Japan
  - R/a=3.45m/1.2m, B=4.4T, I=5 MA

# Steady State Tokamak Operation

- Superconducting toroidal coils
- Microwave/neutral beam heating for ignition
- Self-sustained heating by α particles (plus additional heating)
- Tritium breeding
- High boost strap current (plus current drive)

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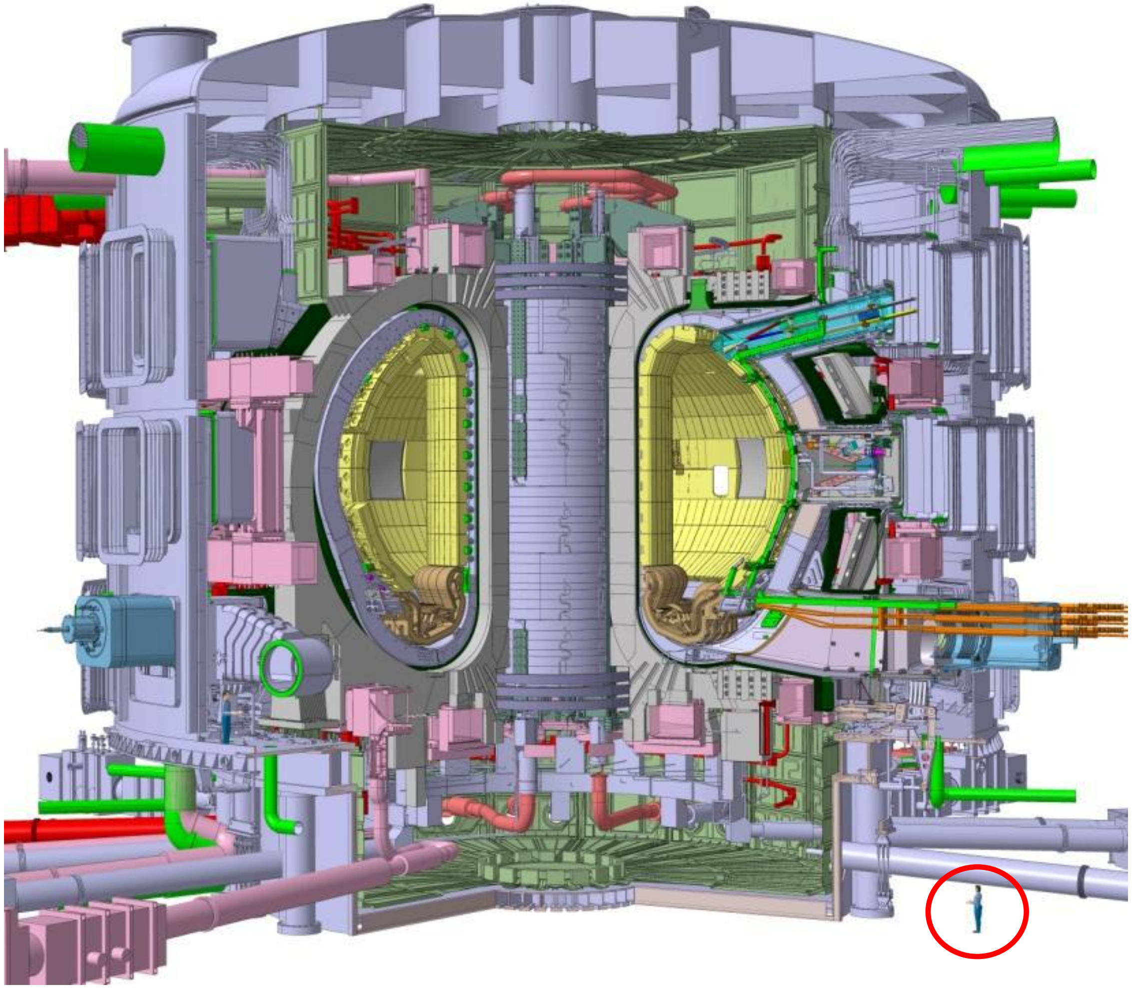
# International Thermonuclear Experimental Reactor (ITER)

- Will be the largest tokamak in the world
- International collaboration with 7 partners
  - China, EU, India, Japan, Korea, Russia, USA
  - Canada is not part of it
- Cadarache, southern France
- Start operation in about 7 years
- Demonstrate net power gain

$Q \geq 10$

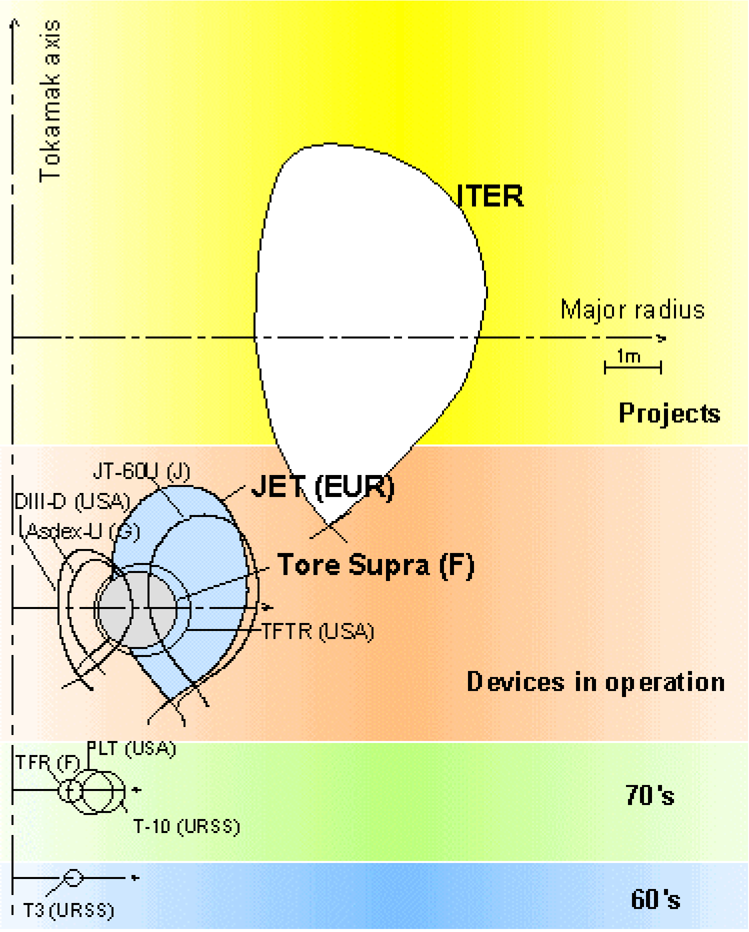
# ITER Project

$a$ = 2.0 m
$R$ = 6.2 m
Q =10
Power:
 500 MW fusion
 73 MW heating



Human size

# Progress

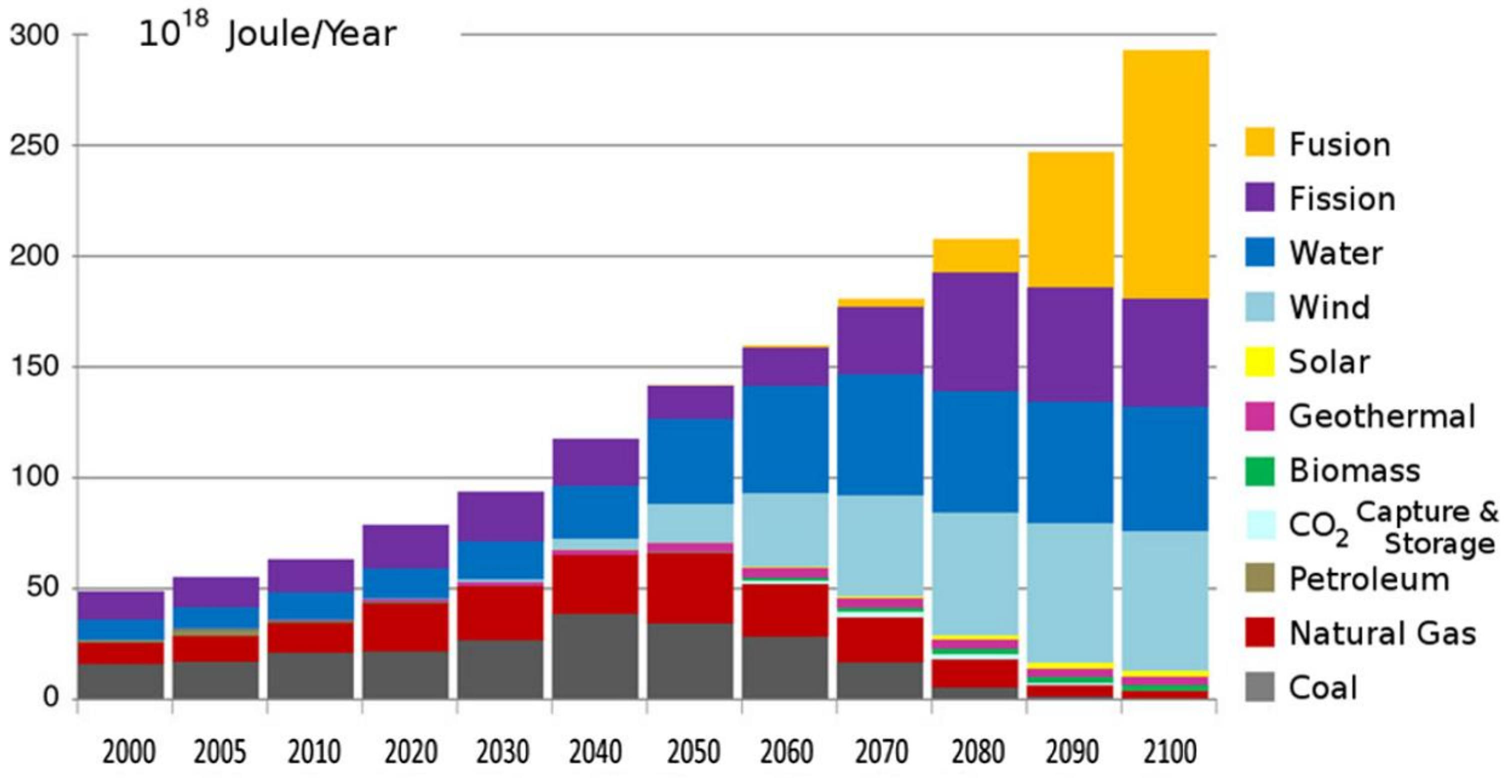

Tokamak axis
ITER
Major radius
1m
Projects
JT-60U (J)
DIII-D (USA)
Asdex-U (G)
JET (EUR)
Tore Supra (F)
TFTR (USA)
Devices in operation
TFR (F)
PLT (USA)
T-10 (URSS)
70's
T3 (URSS)
60's

# Demo - a Step after ITER

- Demo will be a real test reactor between ITER and commercial reactors to address many unkown issues
  - First wall material
  - Materials for structures and coils that is resistant against neutron bombardment
  - Tritium breeding and handling
  - Central fuelling
  - and more …

# When Will We Get a Fusion Reactor?

Electricity consumption




When? – When we really need it

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# Plasma Physics Lab (PPL) at the University of Saskatchewan

- Over 40 years history of fusion research
- Operates the STOR-M tokamak, currently the only tokamak device in Canada
- A member of the IAEA Coordinated Research Project - Research Using Small Tokamaks

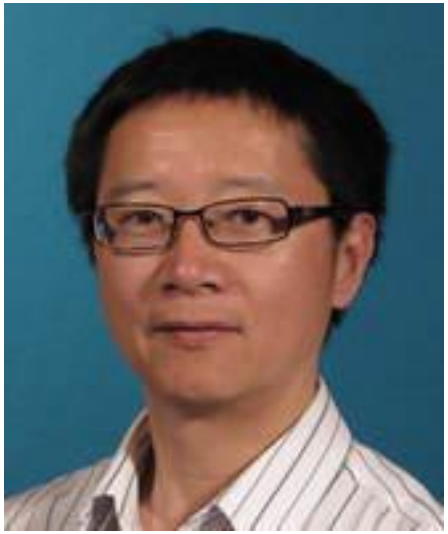
# History

- Established by Dr. Skarsgard in late 50s
- First Canadian tokamak STOR-1M (early 80s)
- STOR-M (built in 1987, still active)
- Compact torus injector added (90s)
- Plasma processing (90s)
- Plasma focus (2013, just started)
- Both theoretical and experimental work

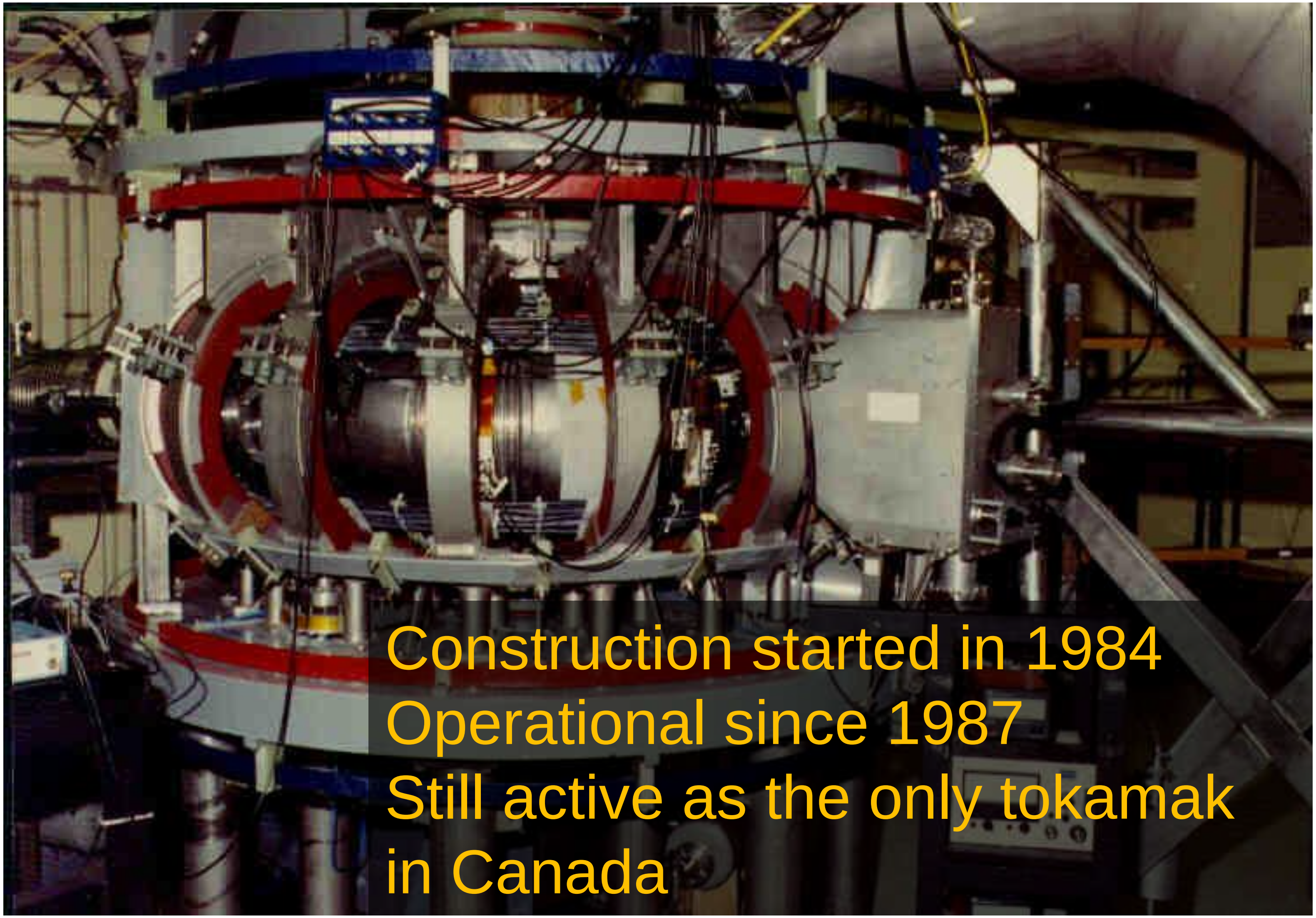
# Professors with PPL (now)

- Plasma Physicists in PPL



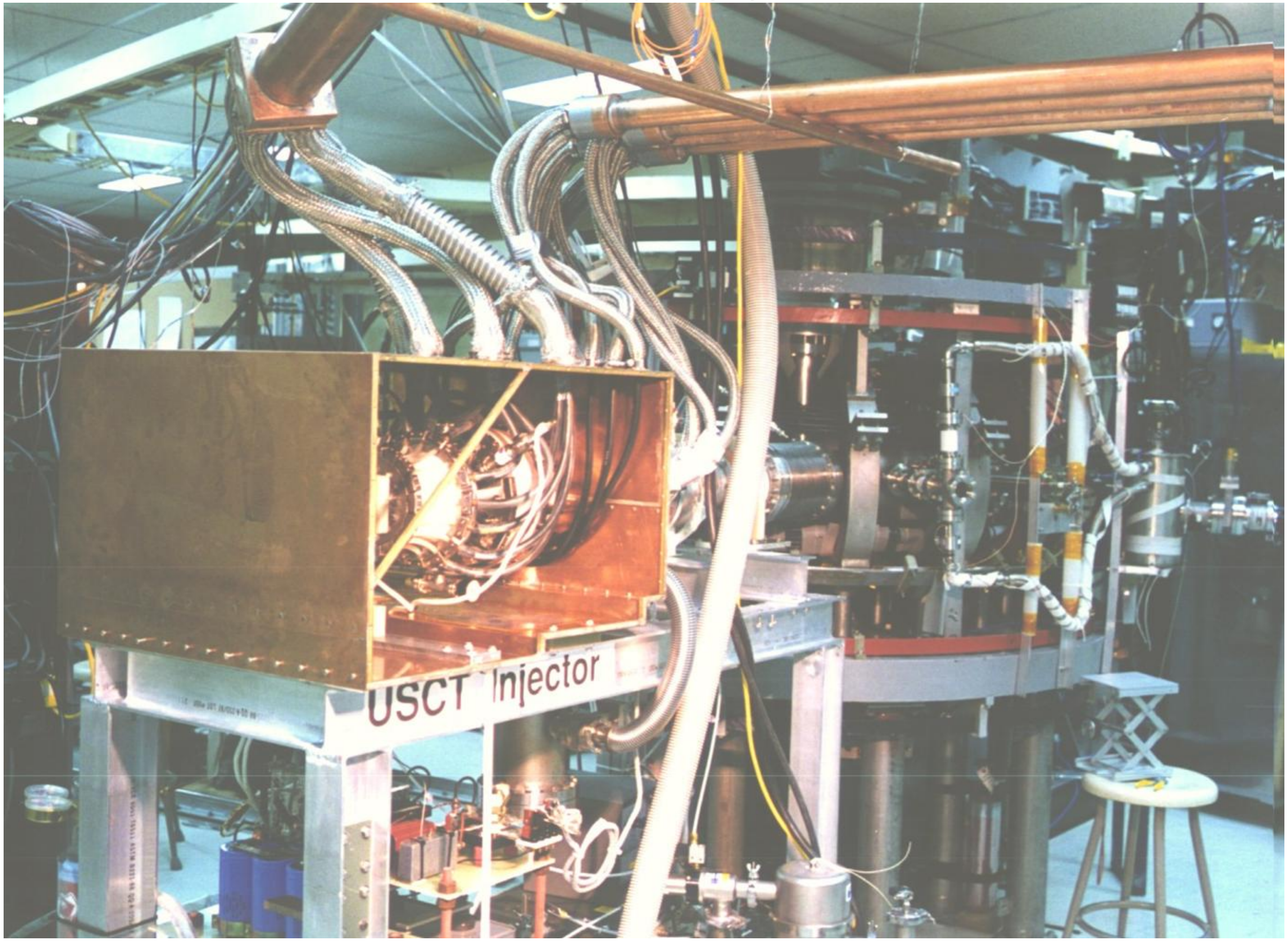



# STOR-M Tokamak



Construction started in 1984
Operational since 1987
Still active as the only tokamak in Canada

# Compact Torus Injector for Fuelling Studies



# STOR-M Research Topics

- Anomalous transport
- Improved confinement
  - By electrode biasing, current pulse, CT injection
- AC operation
- CT injection (fueling)
- Stability studies (by Resonant magnetic perturbation)

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# Summary

- Tokamak is a front-runner among the fusion configurations
- Significant progresses have been made
- ITER is an important milestone in fusion research
- Fusion is a long-term and strategically important research for energy securities

# Thank you!