The RFP: Its Confinement Status and Future

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Outline

- Status of RFP confinement

- MST opportunities
  - For general science requiring a PoP facility
  - As a PoP fusion facility

Key confinement result

RFP confinement is comparable to tokamak confinement

(although RFP confinement improvement is transient)

The RFP Confinement Problem

Weak toroidal magnetic field

$\Downarrow$

$q < 1$

$\Downarrow$

strong magnetic fluctuations

$\Downarrow$

stochastic field

$\Downarrow$

transport

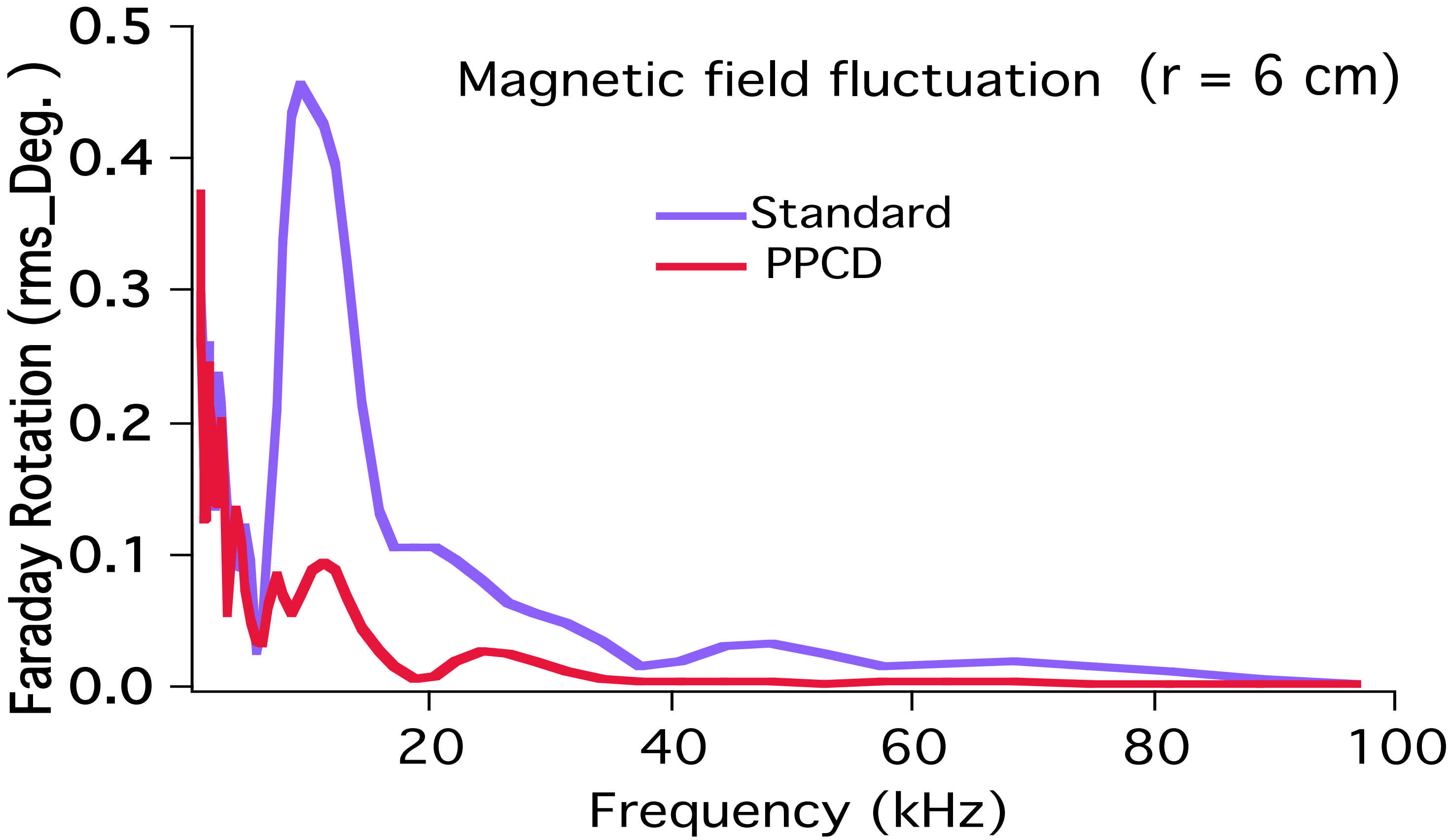
The Solution

- Control the j(r) profile to reduce magnetic fluctuations

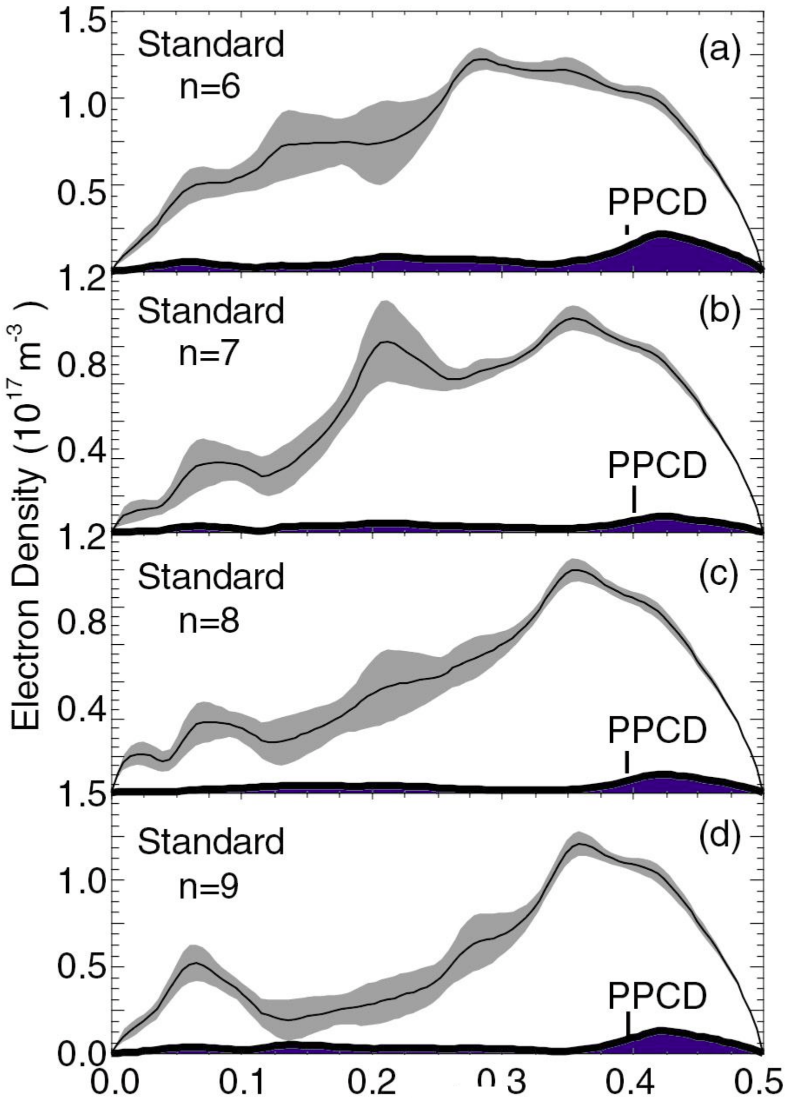
- First implementation: program Ohmic electric field (transient, crude)

Core magnetic fluctuations reduced

Measured by Faraday rotation (UCLA)



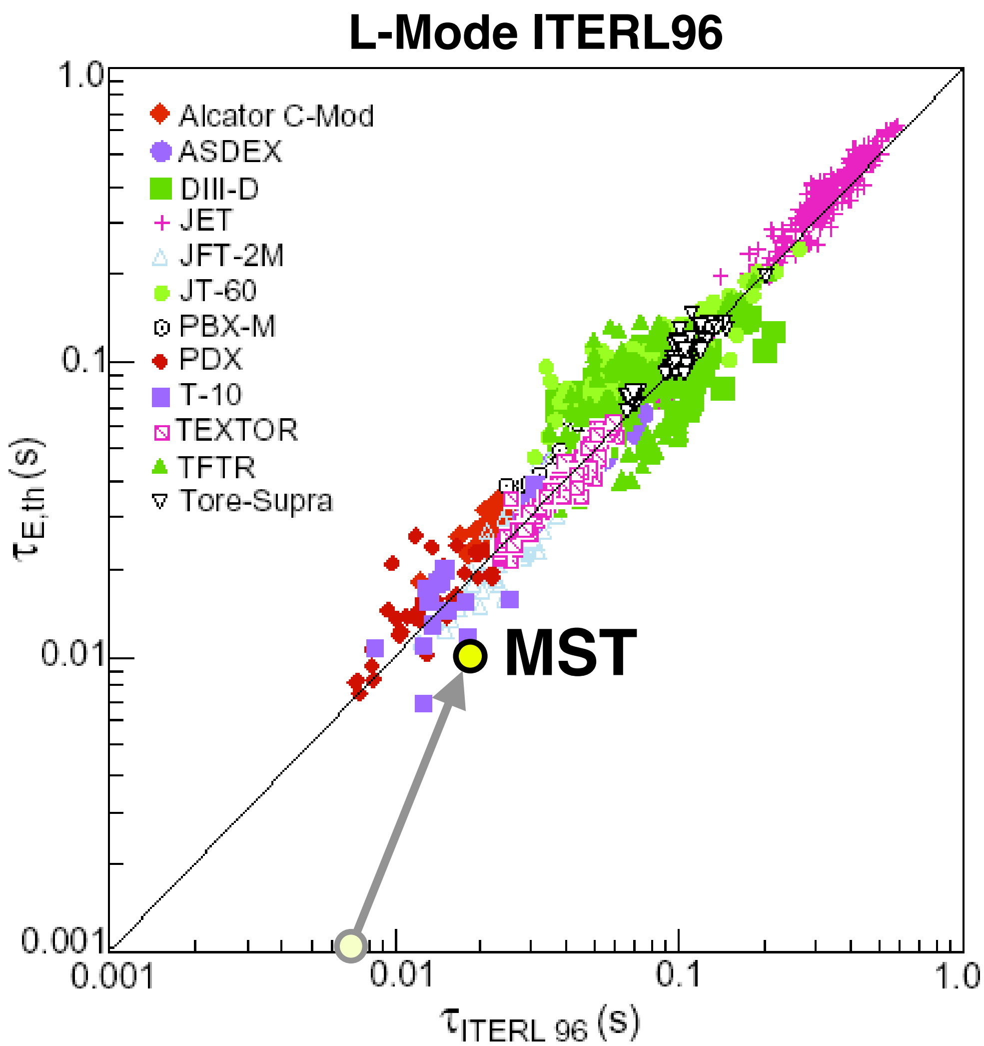
Core density fluctuations reduced

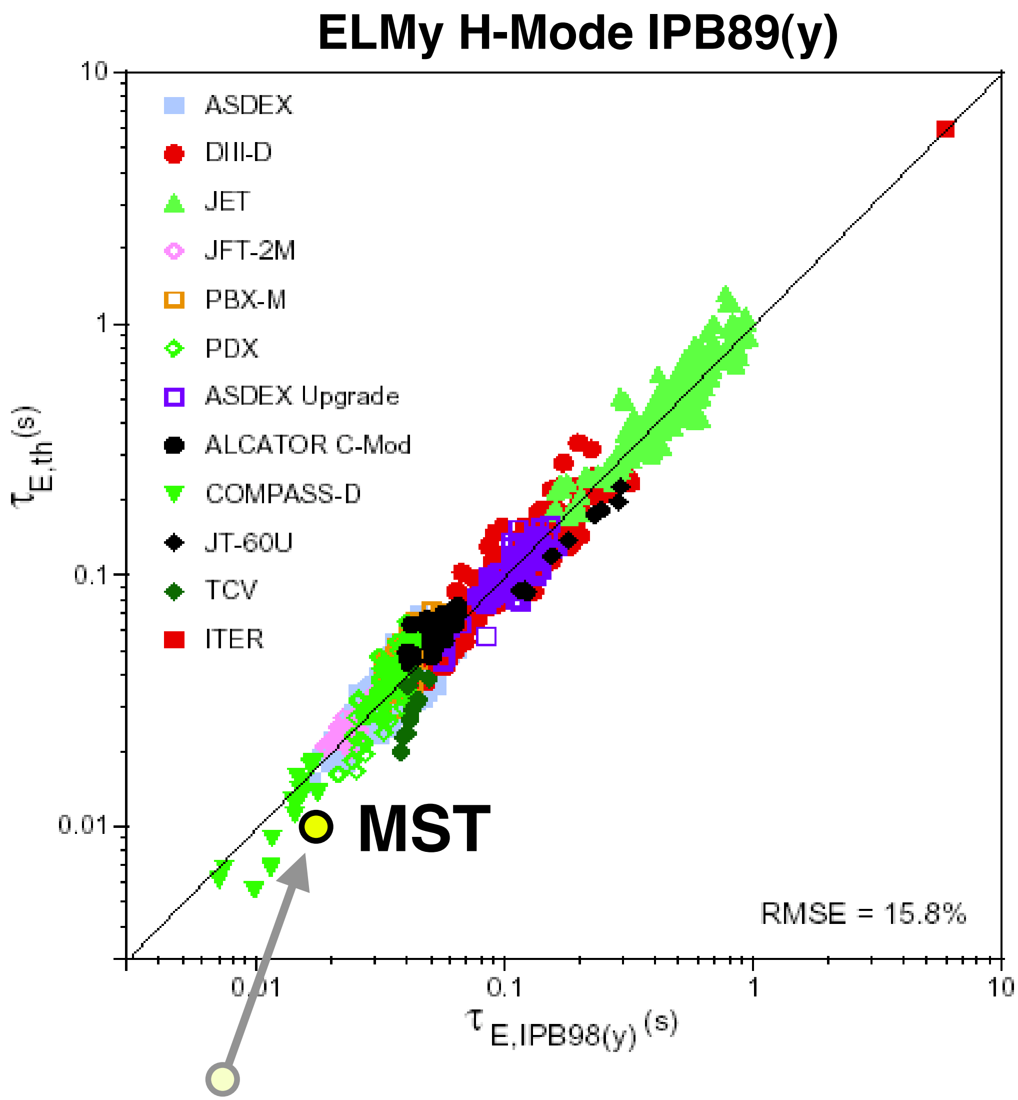


radius

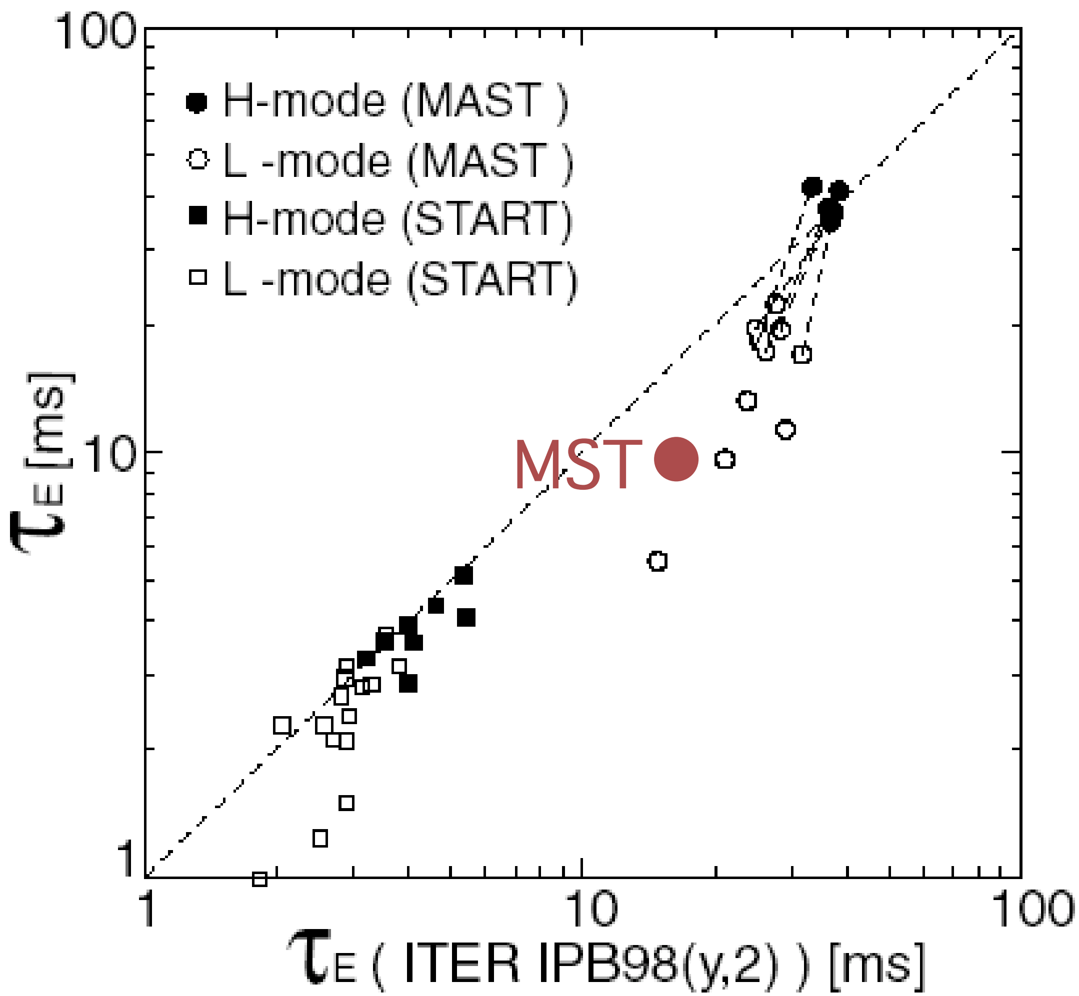
FIR interferometry

relate to tokamak database



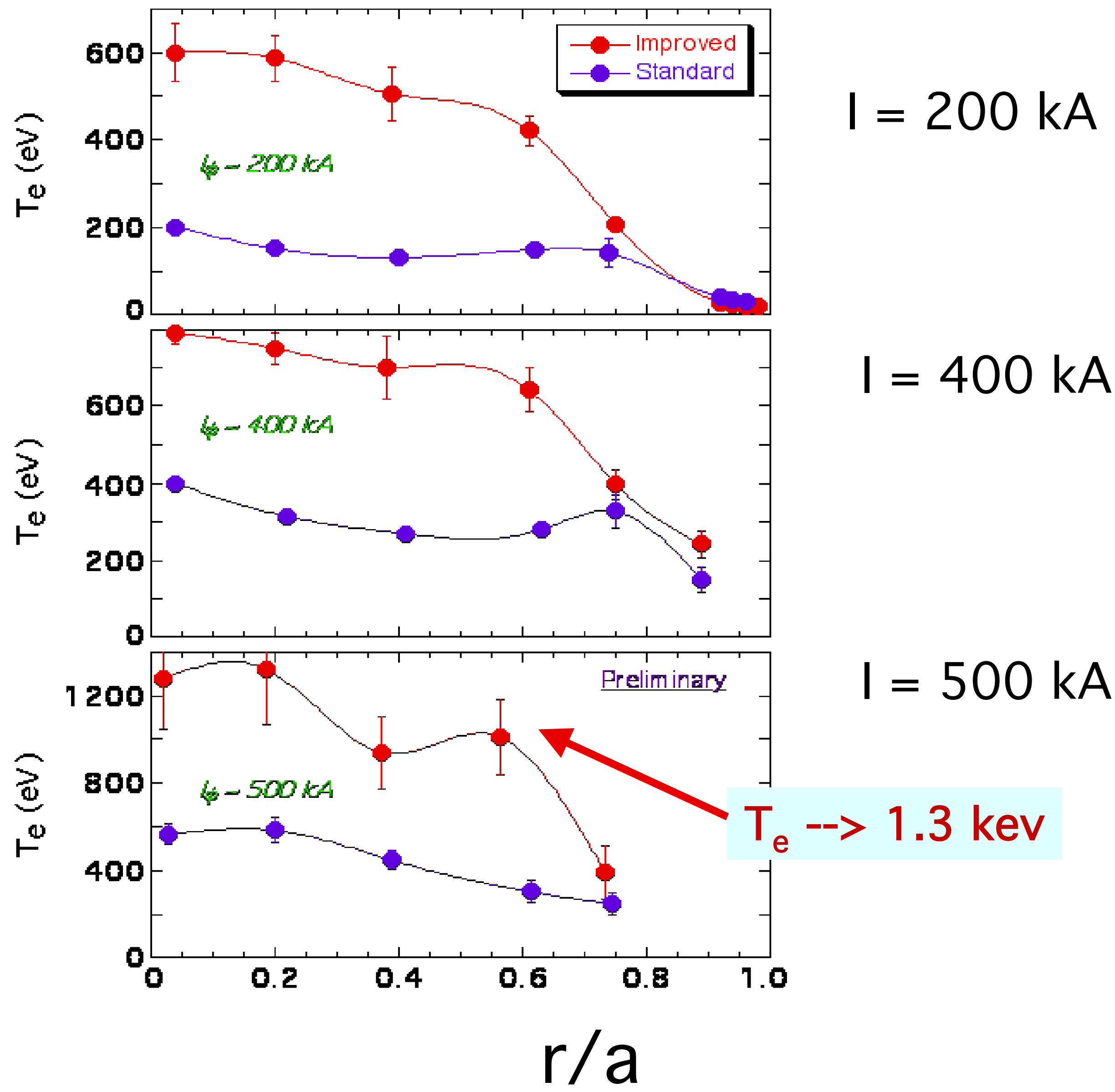

ELMy H-Mode IPB89(y)
ASDEX
DIII-D
JET
JFT-2M
PBX-M
PDX
ASDEX Upgrade
ALCATOR C-Mod
COMPASS-D
JT-60U
TCV
ITER
MST
RMSE = 15.8%
$\tau_{E,th}$ (s)
$\tau_{E,IPB98(y)}$ (s)
10
1
0.1
0.01
0.01
0.1
1
10

relate to current spherical tokamaks,



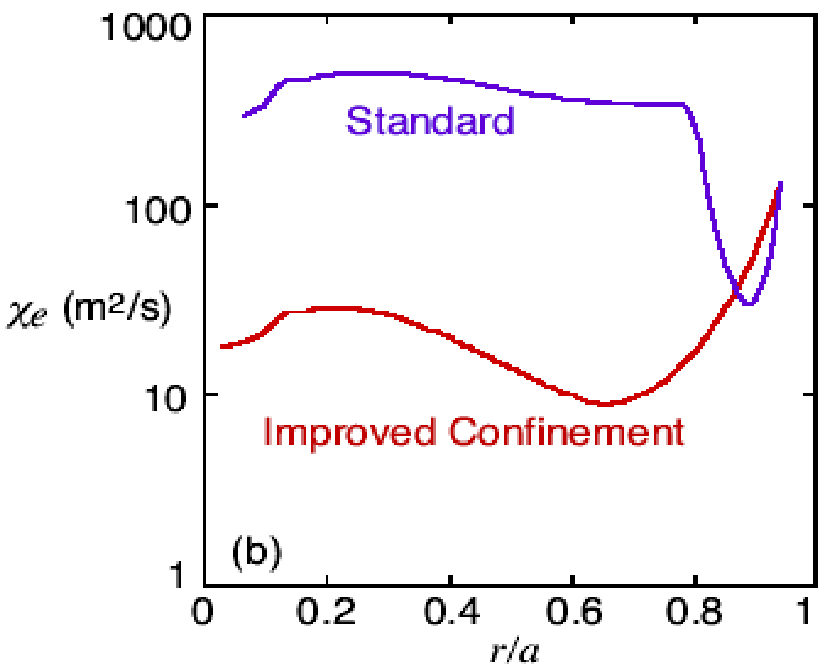
from MAST PRL

T_e increases everywhere



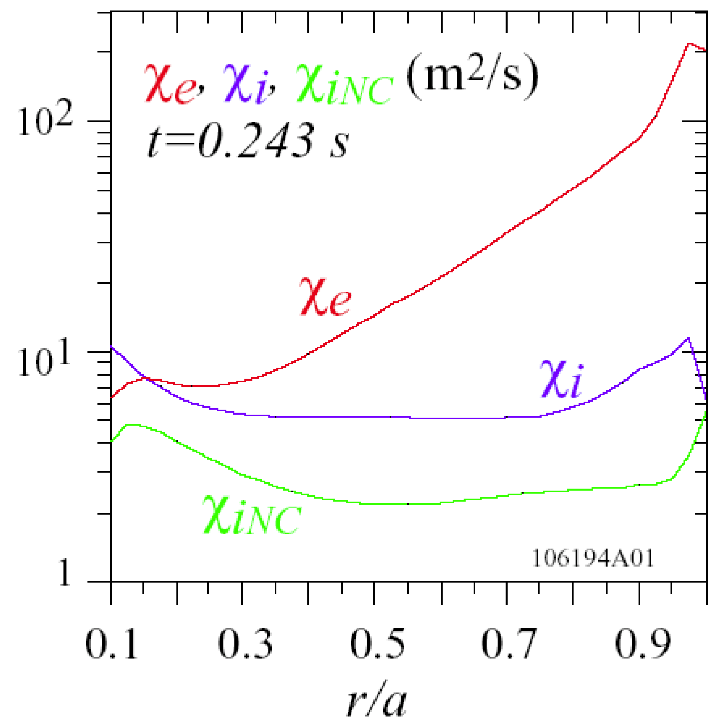
MST electron thermal diffusivity similar to ST

MST



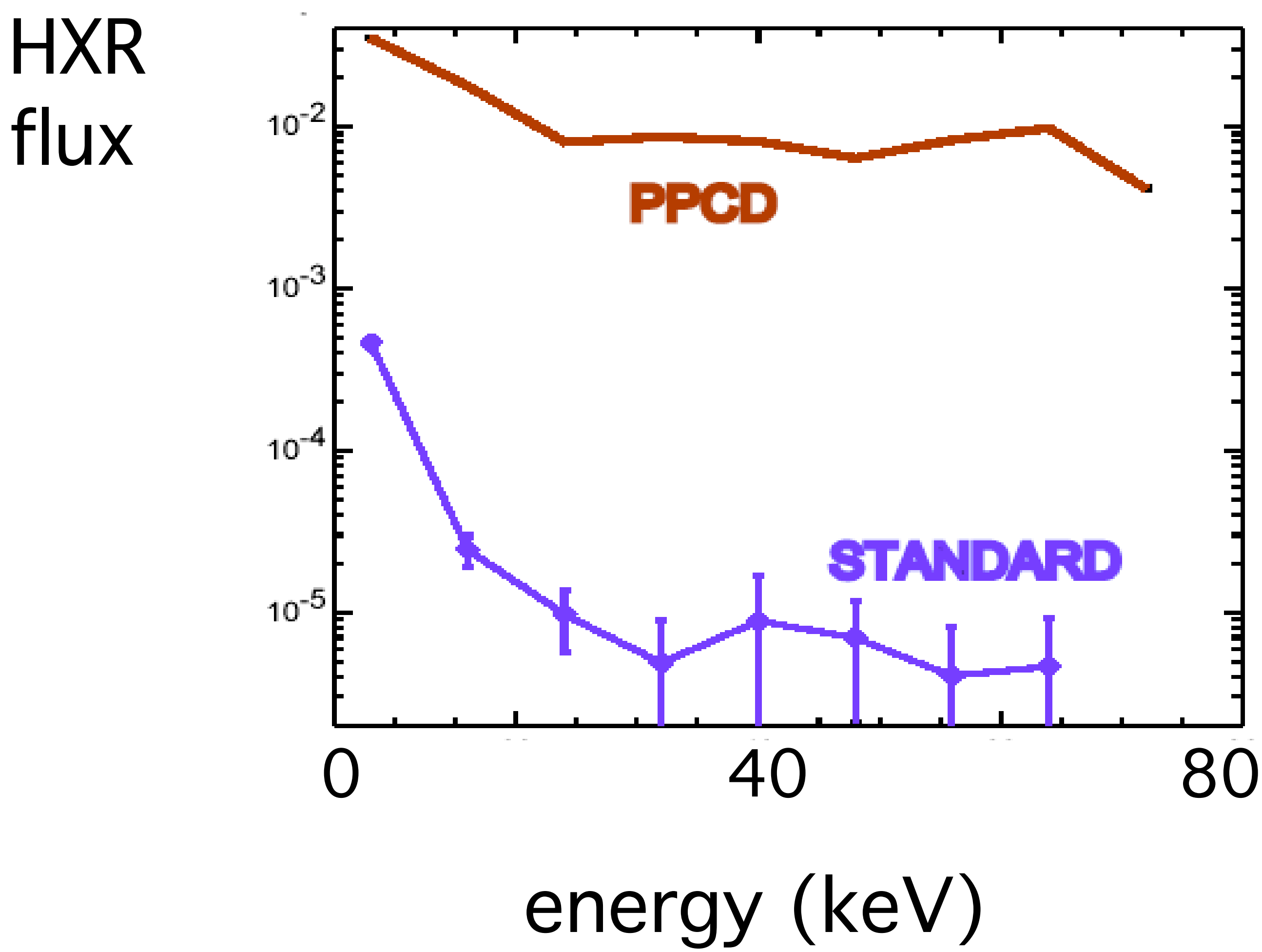
not best case (by 2x)

NSTX



From Wilson, ICC conference, likely not best case

Electrons confined to 100 keV



Fokker-Planck modeling (CQL3D) implies

- Runaway electron density ~ 2%
- Electron travel distance ~ 100 km
- Diffusion coefficient ~ 5 m^2/s
- Magnetic surfaces are likely well-formed

MST beta values are increasing

$$\beta = \frac{\langle p \rangle_V}{\langle B^2 / 2\mu_o \rangle_S}$$ ~ 15% in MST (probably transport limited)

The "engineering beta" $\frac{\langle p \rangle_V}{\langle B^2 / 2\mu_o \rangle_{coil}}$ is higher than 15%

MST Confinement Summary

(at I = 200 kA)

	standard		PPCD
T_e	200 eV	----->	600 eV (1.3 keV @ 500kA)
Beta	9%	----->	15%
Ohmic power	2 MW	----->	1 MW
τ_E	1 ms	----->	10 ms
χ_e	50 m^2/s	----->	5 m^2/s

magnetic field no longer stochastic

But,

- The ultimate limit to transport in the RFP is not yet understood

- Confinement improvement is not sustained

(although the projected PoP parameters are already nearly obtained transiently)

- MST is presently *intermediate* between a CE and PoP experiment

- We must sustain and thereby validate the improved confinement

- We must discover the ultimate RFP confinement

- This requires the PoP program approved by FESAC

For refined, sustained plasma control:

- RF (LH, EBW)
- Oscillating field current drive
- Neutral beam injection
- Pellet injection (ORNL)

for current drive and heating;
all are being initiated in stages

MST as a PoP program in plasma physics

Proposal to NSF for

A Center for Magnetic Self-Organization in Laboratory and Astrophysical Plasmas

- To study high temperature plasma physics issues common to lab and cosmos
- Links lab and astrophysical scientists
- Links experiment, theory, computation
- Links four experiments (MST, MRX, SSPX, SSX)
- 24 participants from 7 institutions

topics

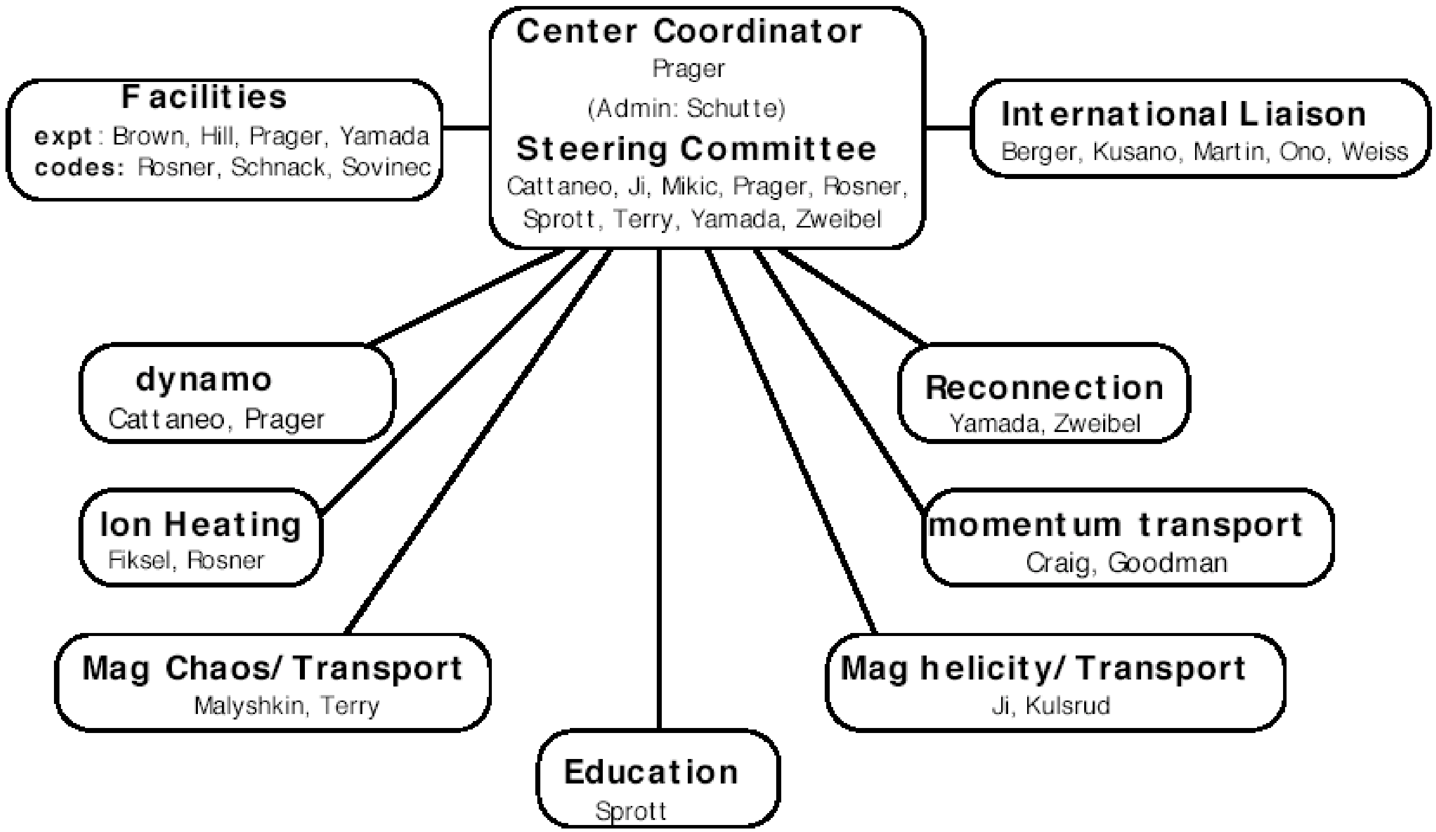
- Dynamo
- Reconnection
- Magnetic helicity conservation and transport
- Angular momentum transport
- Ion heating
- Magnetic chaos and transport

	LABORATORY	ASTROPHYSICS
DYNAMO	RFP field sustainment, Spheromak field sustainment, RFP sawtooth crash/relaxation	Solar magnetic field cycles, Earth magnetic field, Stellar magnetic field cycles, Accretion disk flux conversion
RECONNECTION	Merging plasmas, Spontaneous reconnection in RFP and spheromak, Sawtooth oscillation, Forced reconnection during helicity injection	Earth magnetosphere, Solar flares, Star formation, Protostellar disks, Particle acceleration to ultra-relativistic energy
HELICITY CONSERVATION AND TRANSPORT	Relaxation/dynamo in RFP, Relaxation/dynamo in spheromak, Merging reconnection, Helicity injection experiments	Disruptions in coronal loops, Solar flares, Helicity in solar wind, Fast dynamo
ANGULAR MOMENTUM TRANSPORT	Momentum redistribution in the RFP, Momentum generation in tokamaks	Accretion disks of white dwarfs, Accretion disks of black holes, Accretion disks of AGN, Differential rotation in the Sun, Disks of non-accreting stars
ION HEATING	RFP in steady-state, RFP during relaxation events, Merging reconnection expts, Spherical tokamak with neutral beam injection	Solar corona and wind, Earth magnetosphere, Accretion flow onto black holes
MAGNETIC CHAOS AND TRANSPORT	Transport in RFP, Transport in spheromak, Transport during forced reconnection, Kinetic dynamo in RFP, spheromak	Alfven waves in solar corona, Heating in solar corona, Cosmic ray transport in galactic magnetic field

Participants

Institution	Participant	Department	Expertise
University of Chicago	F. Cattaneo	Mathematics	Astro, comp
	T. Linde	Astronomy & Astrophysics	Astro, comp
	L. Malyshkin	Astronomy & Astrophysics	Astro, theory
	R. Rosner	Astronomy & Astrophysics	Astro, theory, comp
Princeton University	J. Goodman	Astrophysical Sciences	Astro, theory
	H. Ji	Plasma Physics Lab	Lab, expt
	R. Kulsrud	Astrophysical Sciences	Lab & astro, theory
	M. Yamada	Plasma Physics Lab	Lab, expt
University of Wisconsin	J. Cassinelli	Astronomy	Astro, theory, observ
(The lead institution)	D.Craig	Physics	Lab, expt
	D. Den Hartog	Physics	Lab, expt
	G. Fiksel	Physics	Lab, expt
	C. Hegna	Engineering Physics	Lab, theory
	A. Lazarian	Astronomy	Astro, theory
	S. Prager	Physics	Lab, expt
	J. Sarff	Physics	Lab, expt
	C. Sovinec	Engineering Physics	Lab, comp
	C. Sprott	Physics	Education, outreach
	P. Terry	Physics	Physics
Individual Participants			
Swarthmore College	M. Brown	Physics	Lab, expt
Lawrence Livermore	D. Hill		Lab, expt
Science Applic Int Corp	Z.Mikic		Astro, comp
Science Applic Int Corp	D. Schnack		Astro and lab, comp
U. Colorado	E. Zweibel	JILA/ astrophys.& Planetary Sci.	Astro, theory

Management Structure



status

- Selected (from pre-proposal) to submit full proposal (12 out of 44 pre-proposals)
- Chance of NSF funding: about 25%?

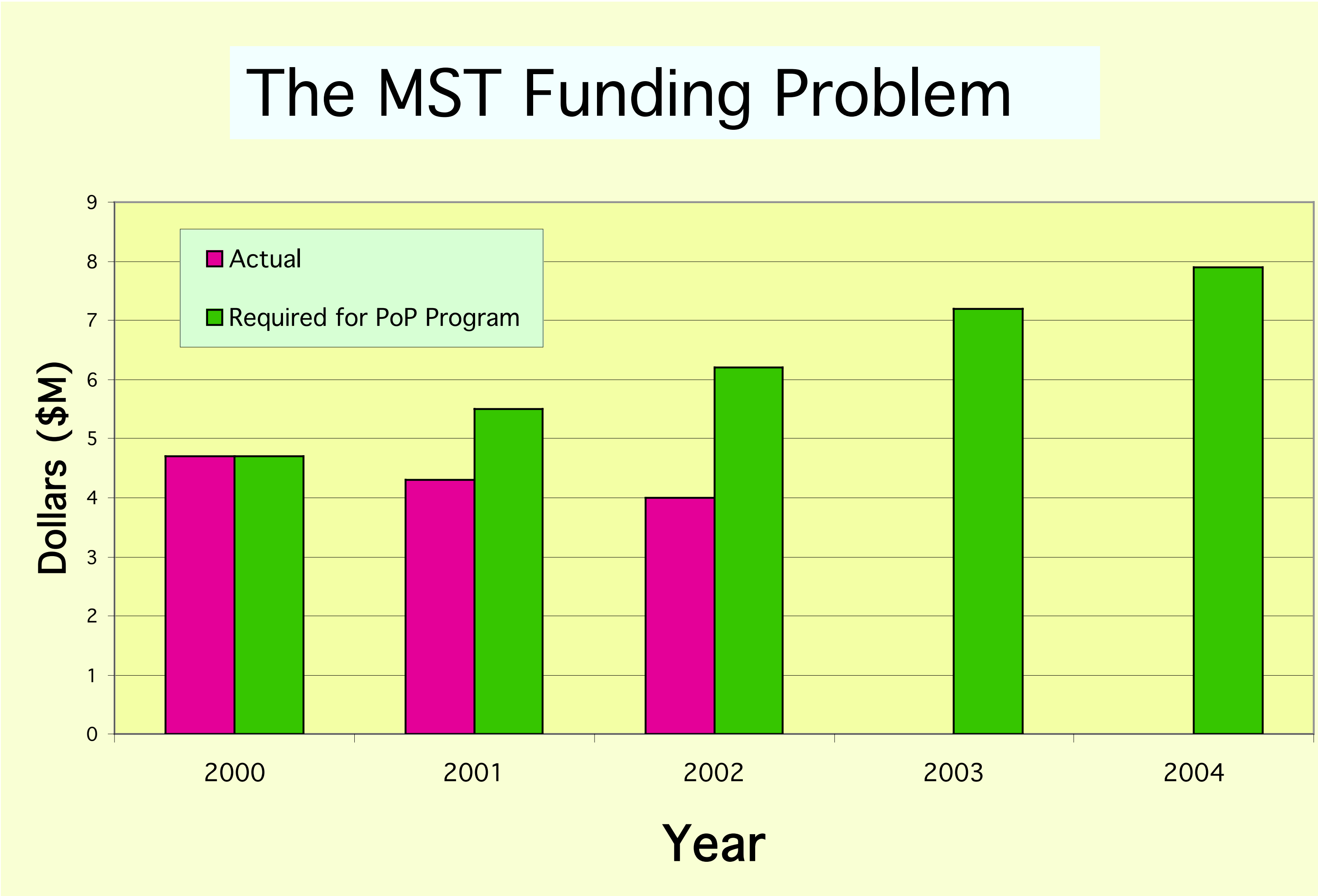
- Validates idea that fusion research contributes to general science
- A PoP facility is needed for general plasma science (comphensive diagnostics and physics)
- An opportunity to exploit

The RFP PoP program is easy to convey to policy makers

- An appealing scientific idea: control magnetic chaos
- Relevance to fusion: low field, high pressure
- Strong connection to broader science/astrophysics
- World leadership
- Extreme cost effectiveness ($8M/yr)
- University participation at the PoP level
- Approved by rigorous review process

MST Collaborators

- RPI - Heavy ion beam probe
- UCLA - FIR interferometry/polarimetry
- Novosibirsk - neutral beam diagnostics and heating
- ORNL/GA - lower hybrid/ EBW injection (help in planning expts)
- ORNL - pellet injection
- University of Saskatchewan - SXR, NBI expts
- Aries group- system studies
- RFX, Italy - Laser impurity injection, SXR, data analys
- TPE-RX, Japan -PPCD expts
- Pegasus, HSX - Thom scat, HXR detection, dnb


The MST Funding Problem
Actual
Required for PoP Program
Dollars ($M)
0
1
2
3
4
5
6
7
8
9
2000
2001
2002
2003
2004
Year

Summary

We are scientifically well-positioned to implement the 1999 FESAC recommendation to move forward with an RFP proof-of-principle program.

MST Physics Group

Wisconsin: A. Almagri, J. Anderson, B. Chapman, P. Chattopadhyay, D. Craig, D. den Hartog, G. Fiksel, C. Forest, J. Goetz, K. McCollam, R. O'Connell, S. Prager, J.Reardon, J. Sarff,*(students: T. Biewer, A. Blair, S. Castillo, M. Cengher, S. Choi, D. Ennis, M. Wyman)*

UCLA: D. Brower, W. Ding, S. Terry

RPI: K. Connor, D. Demers, P. Schock

Novosibirsk:V. Davidenko, A. Ivanov