Overview of the PPPL Theory Department Five Year Plan

presented by

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Princeton NJ

Overview

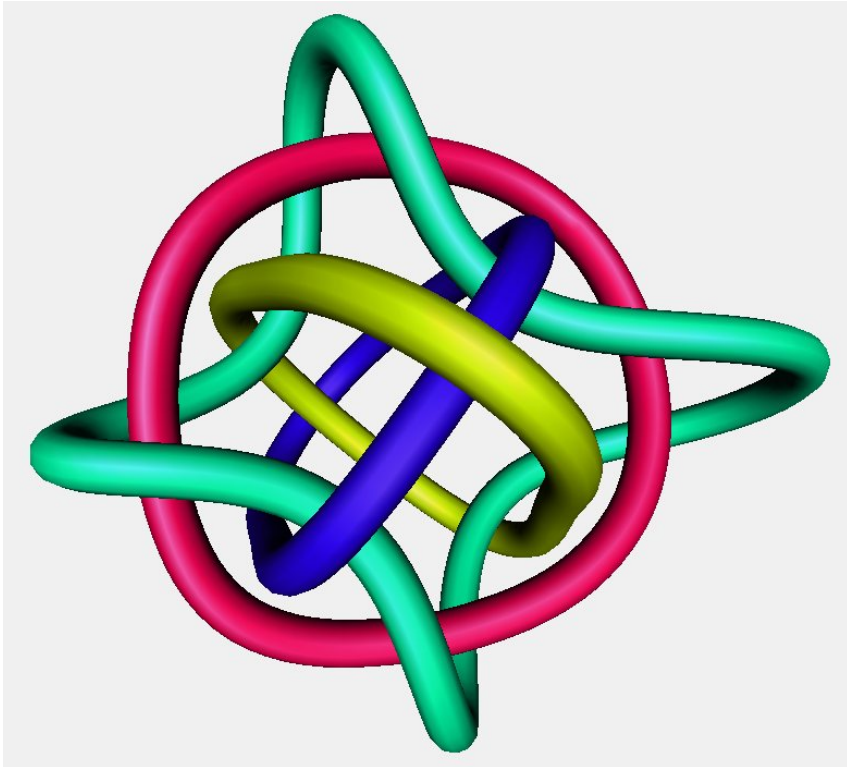
- The program has made significant progress
- Has a well motivated plan to address the most important, scientifically challenging problems facing fusion research
- Uses resources in a cost-effective manner through synergistic collaborations, internal and external
- Has forged strong partnerships with universities, laboratories.
- Well positioned to advance scientific computing in plasma science.
- Continues a long-standing commitment to educational excellence

Outline

- Mission
- Topical areas – highlights
  - MHD, turbulence, wave-particle, boundary
- Project areas
  - Tokamaks, STs, stellarators, FRCs
- Non MFE applications
  - accelerator physics, heavy ion fusion, high energy density physics, laser-plasma-interactions, and space physics
- Synergy and collaborations
- Academics
- Organizational structure – staffing – budget
- Summary

The theory department performs world class research oriented towards enabling the success of the fusion program and to advance scientific understanding

- **Our goal is to strive for Excellence – measured by lasting physics impact**
- **Our activities are mission oriented based on FESAC priorities, ITPA, and project needs**
- **A major goal is to advance plasma science broadly**
- **Our approach reflects synergy and collaborations**



These four themes are strongly interlinked and manifest in all our activities

PPPL Theory addresses FESAC-identified scientific questions in macroscopic plasma physics

- *T1. How does magnetic field structure impact upon fusion plasma confinement?*
- *T2. What limits the maximum pressure that can be achieved in laboratory plasmas?*
- *T3. How can external control and plasma self-organization be used to improve fusion performance?*

Machine design influenced by theory

PBX – access to ballooning stable regime,
NSTX – high beta, impact of reusing a poloidal coil
NCSX – quasi-axisymmetric compact stellarator

Improving the modeling of MHD phenomena

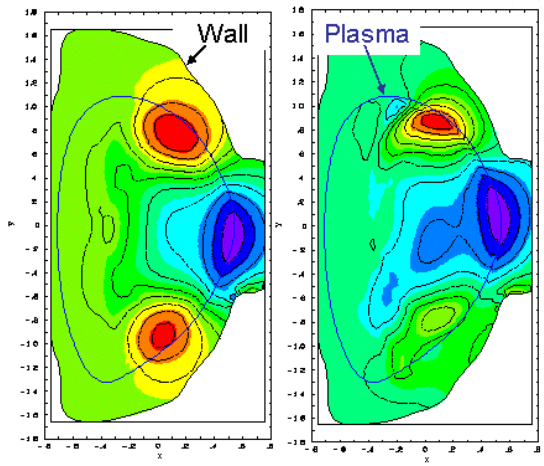
RWM modeling
Sawtooth
Disruption mitigation

Advancing plasma science

Evolution of MHD model in numerical simulations
Kinetic effects –stabilize tilt modes in the FRC
Wave-plasma interactions

Applications to a broad range of devices

NSTX, NCSX, Off-site tokamak research



Perturbed Poloidal flux at $\Omega = 0$

Saturates at $\Omega = 0.05 \frac{v_A}{R}$ w/ collisional viscosity

See Jardin's presentation

MHD model improvement

Free boundary RWM

- DIII-D, JET → ITER
- Up-down asymmetry
- 3-d structures

Neo classical tearing modes

- Predictive model
- DIII-D, JET, NSTX → ITER

Pellet Injection

- 3D model – benchmark
- CDX-U, DIII-D, JET -→ ITER

Energetic Particle modes

- DIII-D, JET, NSTX → ITER
- Improved kinetic model
- Non-linear effects

Sawtooth Phenomena

- Energetic particle effects
- Integrated modeling of RF stabilization
- Systematic study CDX-U --- ITER

2005	2006	2007	2008	2009	2010

Concept Improvements | Development | Applications

PPPL PRINCETON PLASMA PHYSICS LABORATORY

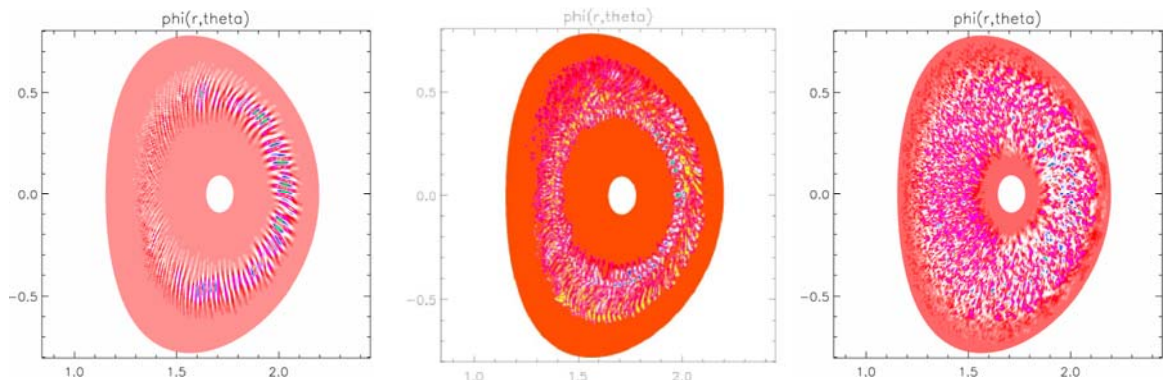
PPPL Theory addresses FESAC-identified scientific questions in multi-scale transport plasma physics

- *T4. How does turbulence cause heat, particles and momentum to escape from plasmas?*

  Predicting non-linear ITG threshold

  Physics of ExB zonal flows

  Physics of turbulence spreading



  Predicting neoclassical transport

  Diagnostic development to investigate turbulence fluctuations

  - MIR, tangential scattering

See Lee's and Hahm's presentations

Analytic theory improvement

non-local transport, shear flow effects, meso-scale physics

Ion thermal transport and zonal flows

- GTC studies of NSTX, DIII-D, JET, JT60U…… ITER
- General geometry Modular – parallel Diagnostics - visualization
- Support for GS2-GYRO - DIII-D, JET → ITER

Electron thermal and Particle Transport

- Comparisons to DIII-D, JET, NSTX → ITER
- Study role of trapped electrons,ETG streamers
- Magnetic flutter transport
- Develop Improved kinetic electron model

Neo classical transport

- GTC-Neo studies of DIII-D, JET, NSTX → ITER
- Stellarator
- NCSX, LHD, W7AS

Integrated simulation

- Improved Edge-Core Coupling, Inclusion of gyrokinetic effects to transport codes
- GK simulation on transport time scale
- Systematic studies of tokamaks and STs ITER

2005	2006	2007	2008	2009	2010

Concept Improvements | Development | Applications

PPPL PRINCETON PLASMA PHYSICS LABORATORY

PPPL Theory addresses FESAC identified scientific questions in waves and energetic particle physics

- *T11. How do electromagnetic waves interact with plasma?*
- *T12. How do high-energy particles interact with plasma?*

Codes used to model energetic particle physics –
NOVA, M3D, HYM, HINST

Linear and non-linear physics

Physics validation of theory models – CAE, GAE, TAE,…
NSTX, DIII-D, JET, JT60-U

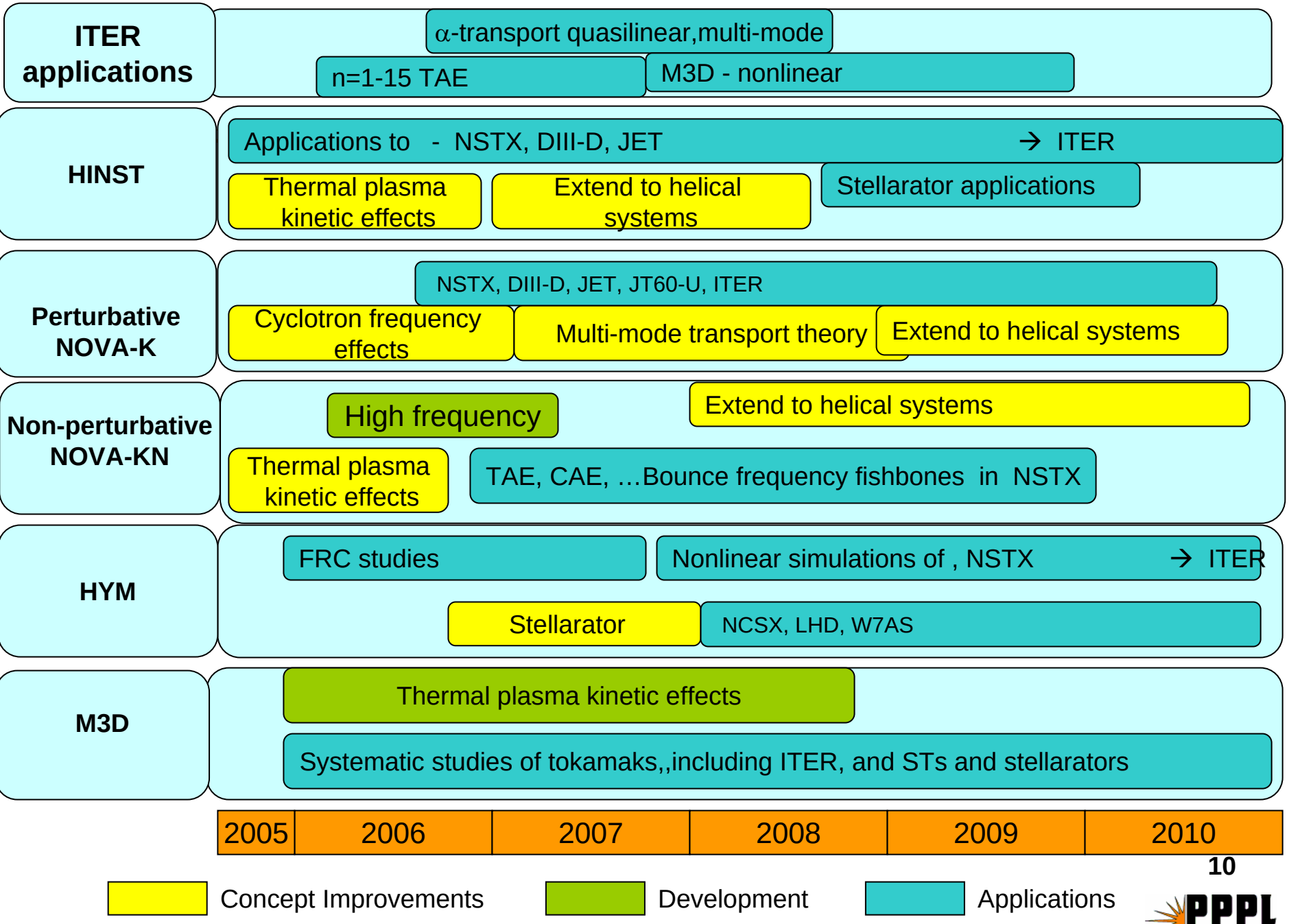
ITER relevance – tasked by ITER team to study impact of TAEs on particle confinement

DoE high level milestone for FY07 led by PPPL

Determine the linear stability properties of ITER to Alfven eigenmodes with toroidal mode number, n, in the range, unity to the high value of fifteen.

This study will be done collaboratively.

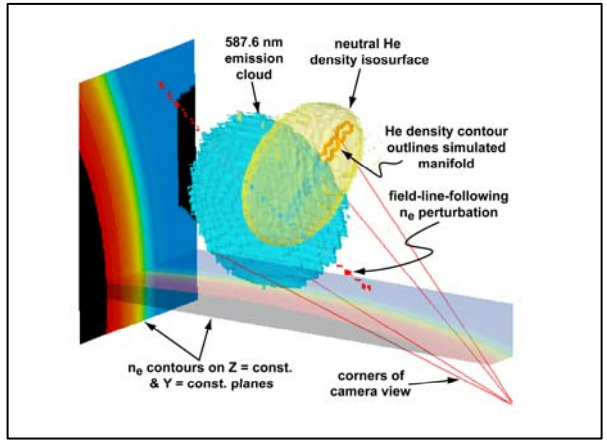
See Gorelenkov's presentation


ITER applications
α-transport quasilinear,multi-mode
n=1-15 TAE
M3D - nonlinear
HINST
Applications to - NSTX, DIII-D, JET → ITER
Thermal plasma kinetic effects
Extend to helical systems
Stellarator applications
Perturbative NOVA-K
NSTX, DIII-D, JET, JT60-U, ITER
Cyclotron frequency effects
Multi-mode transport theory
Extend to helical systems
Non-perturbative NOVA-KN
High frequency
Extend to helical systems
Thermal plasma kinetic effects
TAE, CAE, …Bounce frequency fishbones in NSTX
HYM
FRC studies
Nonlinear simulations of , NSTX → ITER
Stellarator
NCSX, LHD, W7AS
M3D
Thermal plasma kinetic effects
Systematic studies of tokamaks,,including ITER, and STs and stellarators
2005
2006
2007
2008
2009
2010
Concept Improvements
Development
Applications

PPPL Theory addresses FESAC identified scientific questions in multi-phase interface physics

- *T10. How can a 100-million-degree burning plasma be interfaced to its room temperature surroundings?*

- Fast and flexible tool for analyzing experimental data – DEGAS-2
  - Divertor modeling for C-Mod
  - Gas puff imaging on C-Mod, NSTX
  - Enables dynamical analysis – Lodestar
- Lithium as a plasma interface
  - Recycling control
  - Heat spreading



See Stotler's presentation

DEGAS 2 Stellarator Geometry Definition Tools → NCSX Neutral Transport Module

Add Sputtering & Li Data to DEGAS 2 → Model NSTX Li Coating Experiments

Investigation of Liquid Li PFC Concepts

Modeling of NSTX SGI Experiments

Characterize Recycling in NSTX

Center for Plasma Edge Simulation: Edge Turbulence & Transport Simulation

- Add DEGAS 2 modules to XGC
- Update atomic physics & PMI used in XGC / DEGAS 2

GPI Modeling

2005	2006	2007	2008	2009	2010

Edge Plasma Turbulence & Transport Models

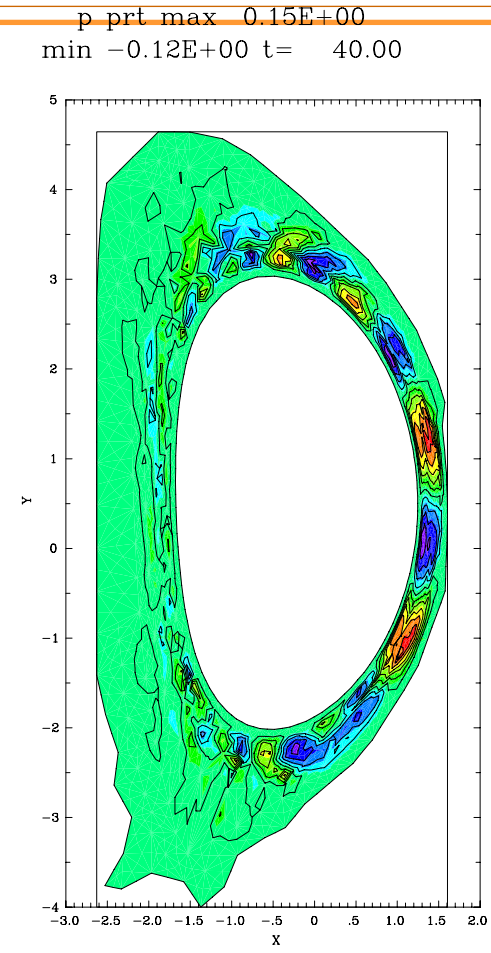
Concept Improvements

Recycling & Fueling Models

PPPL PRINCETON PLASMA PHYSICS LABORATORY

The Department is engaged in ITER/ITPA High Priority Research tasks

- RWM modeling
- Disruption mitigation
- High-n Alfvén eigenmodes
- Turbulence simulations
- ELM simulations
- SOL plasma turbulence



Perturbed pressure

Gorelenkov, Jardin, Lee, Stotler, Nazikian will present details

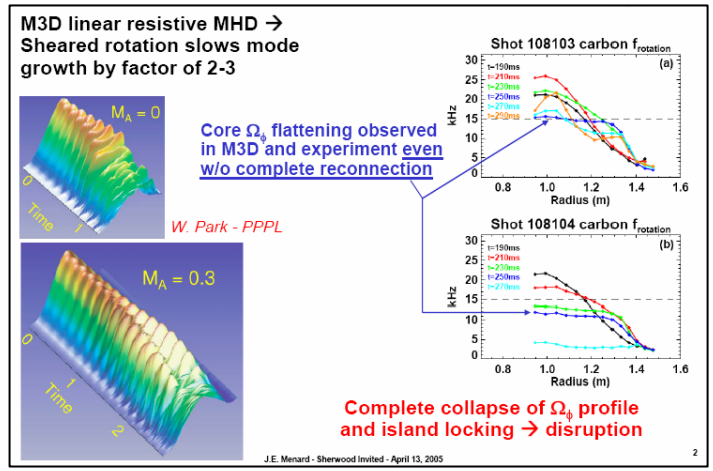
Theory collaboration with NSTX advances the understanding of ST and Tokamak physics

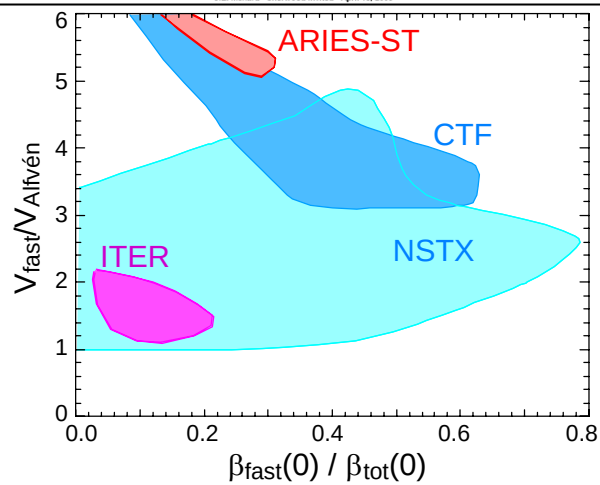
- NSTX challenges the theory models by operating in an extended parameter space
  - Low B_T
  - High β, ρ, $f_{trapped}$
  - Strong shaping
  - Mode coupling
  - Large flow and flow-shear
  - Super-Alfvenic particles

PPPL Theory is well positioned to advance AE physics

Same V_{fast}/V_{Alfven} and strong drive

Rotational stabilization of 1/1





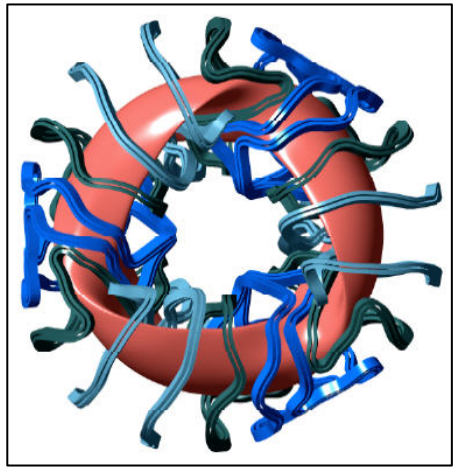
NSTX is an excellent test-bed for theory and modeling

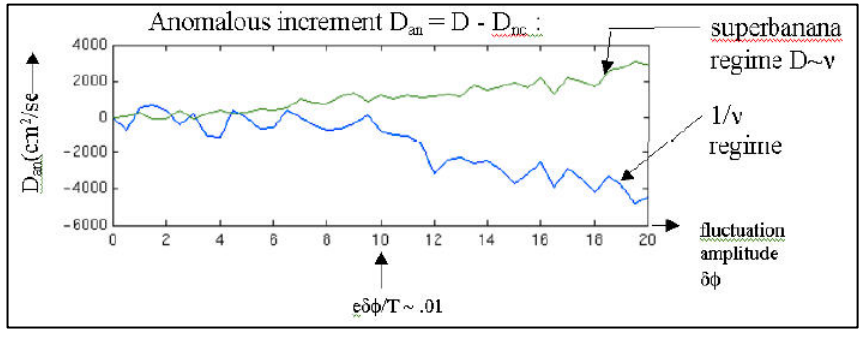
See Kaye's presentation

Theory is contributing strongly to the world-wide stellarator program

- Theory played a major role in designing NCSX
- Flexibility studies demonstrated that the proposed coil set produces a range of useful configurations to experimentally explore stability and transport properties
- Modeling of W7-AS yielded insight into the role of flux surface quality in determining β-limits
- Transport modeling shows that in some regimes of collisionality, ν, turbulent fluctuations can decrease the total radial transport, the opposite of tokamak-based intuitions.

NCSX plasma and modular coils.





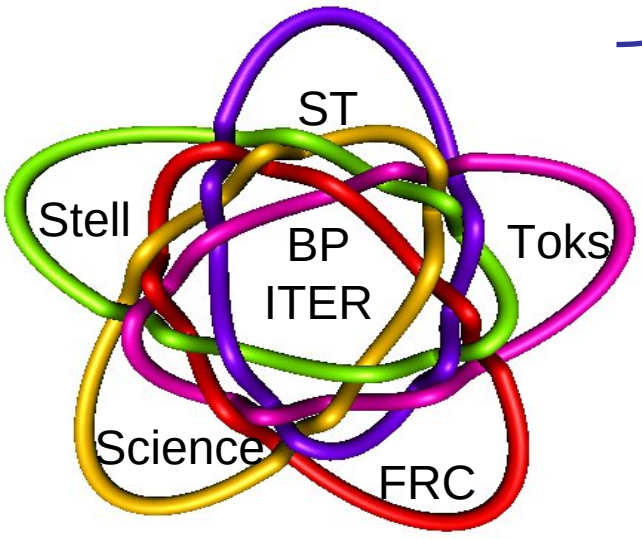
New transport regimes in compact stellarators

See Zarnstorff's and Reiman's presentations

The department consists of interlocking teams, addressing multiple topics

- MHD
- Turbulent transport
- Wave-particle physics
- Boundary physics
- Advanced simulation

- Tokamaks
- Spherical torii
- Stellarators
- FRC
- Plasma science
  - Ion beam physics
  - Space plasma



See Belova's, Qin's and Johnson's presentations

PPPL Theory contributes to non-MFE plasma science

FESAC: *Advance the forefront of plasma science across a broad range of applications, synergistically with the development of fusion science.*

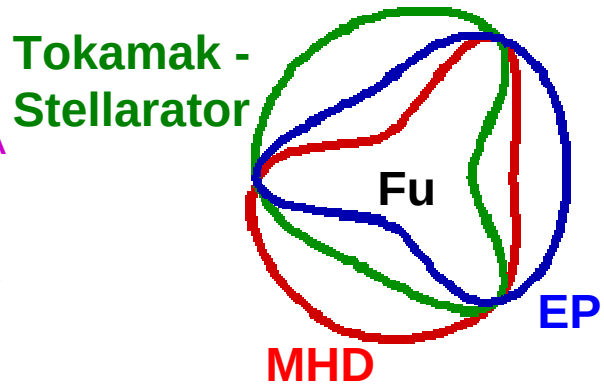
- Nonneutral Plasmas and Accelerator Physics
  - one-component nonneutral plasmas confined in a Paul trap
  - nonlinear collective processes in intense beam propagation – BEST code
- Innovative Concept Development
  - Dense plasma; high field wave-particle interactions
- Space plasma physics – NASA, NSF
  - Solar atmosphere, ionosphere and magnetosphere
  - Accretion disk and astrophysical plasmas

Qin and Johnson will present details

Two examples of synergy in our activities

- Development of the Neo-classical transport code GTC-NEO
  - Neo-classical transport theory – Wang, Hinton, Tang
    - Impurities – Hinton, GA
  - Guiding center Lagrangian – White, Zakharov
  - Generalized magnetic coordinates – Manickam, Zakharov
  - Will be extended to GTC
- Theory department members are involved in multiple projects

  For example: G. Fu has contributed to development and applications for
  - Linear eigenvalue wave-particle physics – NOVA
  - Stellarator ideal MHD stability – TERPSICHORE
  - Time dependent wave-particle physics – M3D-K
    - Linear, non-linear, tokamak, *stellarator*
  - NCSX, NSTX, TFTR, DIII-D, QPS, JET, JT60-U



PPPL Theory has benefited from External Collaborations and would like to expand such activities

Theory participates in Collaborative activities in many ways

- Individual collaborators
- Multi-institutional teams
  - Topical SciDAC centers, Proto-FSP SciDAC centers. ISIC centers, Fusion Collaboratory, PTRANSP,
- US National labs
- Universities
- Experiments – both domestic and international
- Other agencies – NASA, NSF

We are requesting funds to support incoming collaborations - $100K

Theory is a strong contributor to Princeton's excellent academic program

- Princeton Teaching faculty - 9
  - **Davidson, Fisch, Hammett, Jardin, Krommes, Qin, Reiman, Tang, White**
- **Current graduate students – 18**
- **Recent theory Ph. D.s (2000-2005) (All – 224)**
  - **Felice, Schekochin, Strasburg, Clark, Zaharia, Morrison, Stowell, Dodin, Son**
- **Recent external awards(2000-2005) -14**
  - **Early Career Presidential – 3, Rosenbluth – 1 , DOE Postdoc – 5 ,**
  - **APS Excellence in Pl. Phys. – 2, Other – 3**
- **Princeton University Awards(2000-2005)**
  - **Honorific – 7**
  - **Ray Grimm – 2**
  - **Carl Oberman – 4**

The Theory Department is fortunate to have a highly capable and well-recognized staff.

- The department publishes its work in refereed journals –
- Web of Science references
  - 2002: 164
  - 2003: 173
  - 2004: 159
  - 2005 121 through August
- Twenty scientists have been recognized as APS Fellows.
- Past five years awards include:
  - Nat Fisch received the E. O. Lawrence medal. Maxwell prize at APS
  - Frank Cheng received the APS award for Excellence in Plasma Physics Research
  - Ron Davidson received the Particle Accelerator Science and Technology Award;
  - Hong Qin received the Presidential Early Career award for Scientists and Engineers;
  - John Krommes, Doug McCune and Alan Reiman were recognized as Distinguished Lab Fellows.

Theory FTE distribution by topical area

30 research scientists, 7 computational scientists

MFE		FTEs
Macroscopic stability	M3D theory and simulation	4
	Stellarator	4
	Experimental modeling	1
	FRC	1
Transport & turbulence	Turbulence simulations	4
	Analytic theory	4
	Experimental modeling	1
	Turbulence simulations	4
Wave-particle physics		3
Edge physics		2
CPPG	TRANSP	3
	MHD	2
	Turbulence	1
	Visualization	1
IFE/HED		3
Space-plasmas		2
Teaching		1
Management		1
TOTAL		37

PPPL PRINCETON PLASMA PHYSICS LABORATORY

OFES theory funding is strongly leveraged by project funds and other resources

OFES Theory funding	FTEs
Tokamaks and Alternates	9.75
Field Reversed Configurations*	0.52
Scientific Computing	6.20
SciDAC Initiatives	
RF Waves	0.33
MHD – CEMM	0.60
Turbulence – GPS	0.98
FSP -- MHD+RF	1.23
FSP – Edge+Core	0.75
Subtotal	20.36

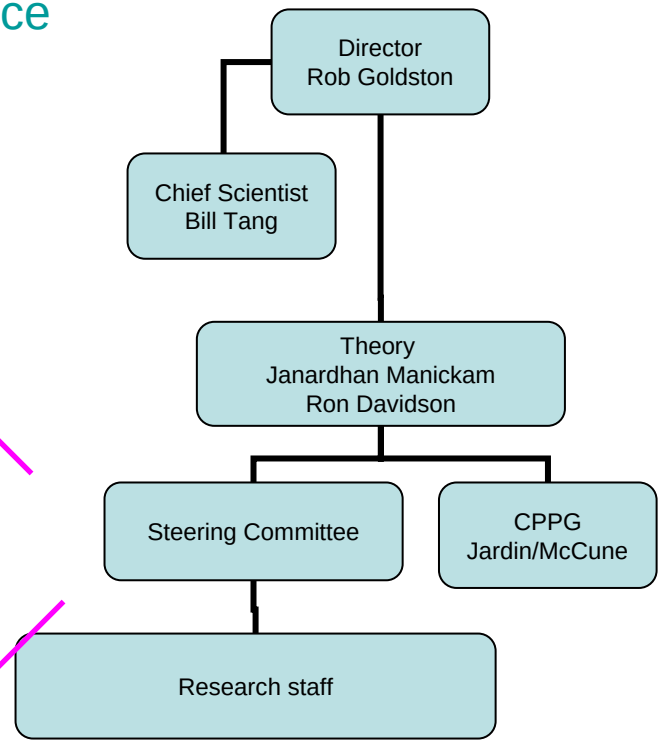
Other Project funding	
MFE	
NSTX & NCSX	4.07
Offsite & University Res.	3.90
OASCR	2.90
IFE/HEP	2.10
Work for others/Space Plasmas –NASA, NSF	2.50
Teaching	0.63
Management	0.80
Subtotal	16.9

TOTAL = 37

Organization

- Theory Department reports to the Director's Office
- Head (Manickam*)
- Deputy Head (Davidson*)
- Steering Committee
  - Davidson – High energy density
  - Fisch – Academic affairs
  - Gorelenkov – Wave-particle interactions
  - Hahm – Analytic theory/edge physics
  - Jardin* – Macroscopic stability/CPPG
  - Johnson – Space plasma
  - Lee – Turbulence simulations
  - McCune - CPPG
  - Reiman – Stellarator physics
  - Valeo – Computer division interface
  - Tang*+ – ex-officio, SFG

*Council member, +Director's Office



Communication is an important element of the department's operations

- Steering committee meets fortnightly
  - Lab Management news
  - Meetings' Calendar
  - Department activities and issues
  - Group leaders' input
- Department meetings are held once a month
  - Lab Management news
  - Department activities and issues
  - Staff input
- Monthly micro-seminar (2 slides)
  - Informal presentation of research activities
- Sub-group meetings

Computing facilities at PPL are at full capacity and need upgrades

- Supercomputing – Offsite – NERSC, ORNL
- Clusters – Onsite – 3 M cpu-hours/year
  - SGI-Altix – 16 processor, 6 processor
  - Mix of 211 dual processor nodes
    - most recent – 24 dual-CPU-64bit AMD Opteron dual processors with low latency Infinaband interconnect – similar to Jacquard
  - Attrition of older processors requires replacement
    - Improvements of cache size and interconnect

Requesting 350 $K/year

We are preparing for the future

- As the world program invests in ITER, we are preparing for it by:
  - Engaging our colleagues in identifying ITER relevant issues – Ongoing activities: ITPA, technical expert groups, BPO
  - Examining our program to ensure that we address them – reflected in Five Year Plan

- We need to:
  - Keep our computing capability up to date - $
  - Enhance our collaborations by attracting researchers to spend time at PPPL - $
  - Train the next generation of researchers, re-institute our dormant postdoc program in a phased manner - $

These require additional funds

Proposed budget addresses baseline needs with a modest increase for incoming collaboration, postdocs and maintenance of computing capability

Baseline Funding Source – annual	FY06	FY07	FY08	FY09	FY10
Tokamak Theory	2401	2401	2473	2547	2623
Alternates Theory	1698	1698	1749	1801	1855
FRC Theory* (ICC support)	208	208	214	220	227
Scientific Computing	2046	2046	2171	2236	2303
SciDAC – three year cycle					
Wave plasma	280	280	288	297	306
CEMM – MHD	255	255	263	271	279
Gyrokinetic	320	320	330	340	350
SWIM – MHD+RF	585	585	585	585	585
Edge core	225	225	225	225	225
Total Baseline Request	**8018**	**8018**	**8298**	**8522**	**8753**
Incremental Requests					
Computer equipment	350	360	371	382	394
Collaborations	100	103	106	109	113
Post-Docs	199	398	410	422	435
Total Incremental request	**649**	**861**	**887**	**913**	**942**
Total request	**8667**	**8879**	**9185**	**9435**	**9695**

SUMMARY

The PPPL Theory Department is a significant national and international resource for Plasma Sciences, and

- Has a strong record of accomplishments
- Has developed a well motivated five year plan which address the most important, scientifically challenging problems facing fusion research
- Uses its resources in a cost-effective manner through synergistic collaborations
- The program deserves strong support
- The modest up-ticks requested are necessary and should be funded