Center for Simulation of Wave Interactions with MHD (SWIM)

PSACI PAC meeting
PPPL
May 24-25, 2006

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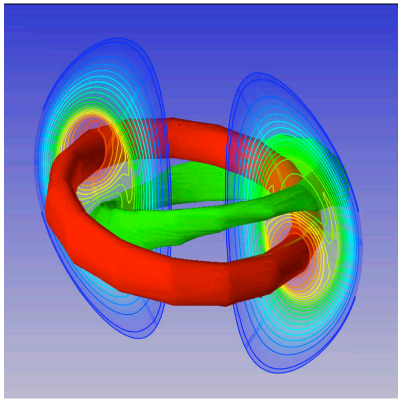
L. Sugiyama – *MIT,* **C. C. Hegna** – *University of Wisconsin,* **H. Strauss** – *N*
H. St. John – *General Atomics,* **G. Bateman, A. Kritz** – *Lehigh Univ.*

- Program logic
- Design approach for SWIM computational Framework
- Physics targets, research issues

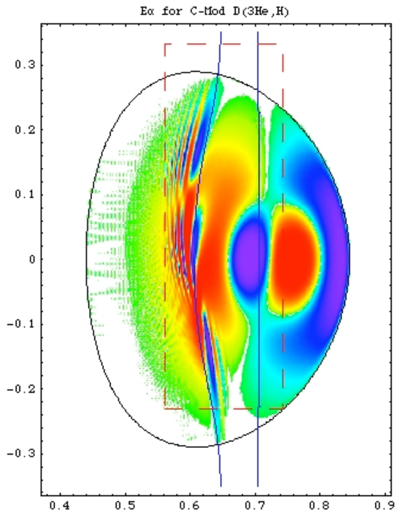
See our fun website at: **www.cswim.org**

SWIM brings together two mature sub-disciplines of fusion plasma physics, each with a demonstrated code base

Extended MHD – CEMM



High power wave-plasma interactions – CSWPI

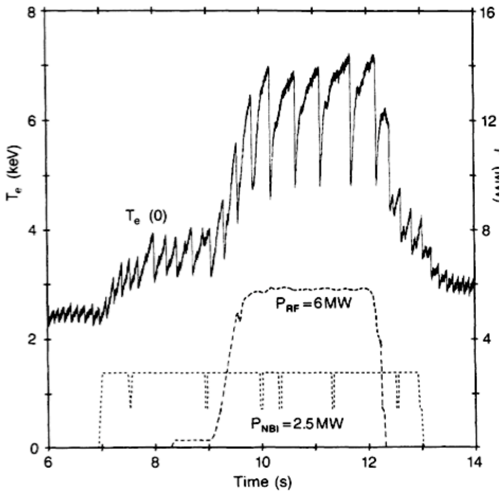


Why couple these particular two disciplines?

- Macroscopic instabilities can limit plasma performance
- RF waves can mitigate and control instabilities

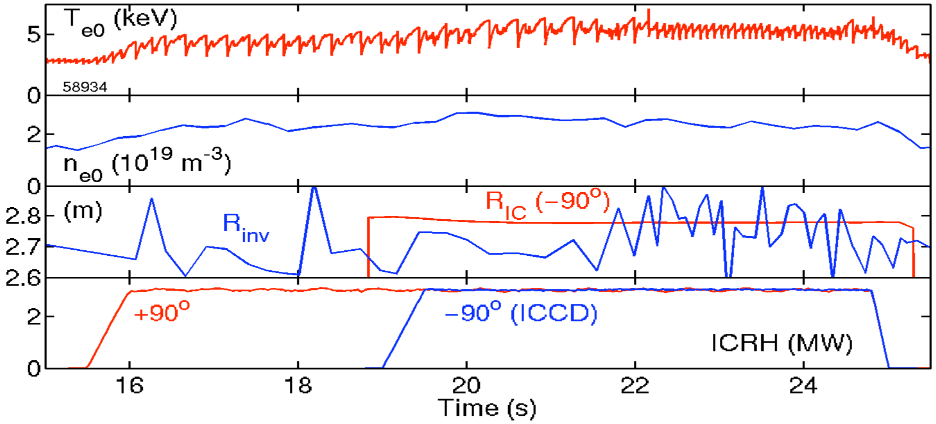
There are several experimentally demonstrated mechanisms by which RF waves can control sawtooth behavior

ICRF stabilization on JET



- ICRF heating can produce "monster" sawteeth – period and amplitude increased
- Likely stabilization mechanism – energetic particle production by RF

Sawtooth control on JET with Minority Current Drive on JET

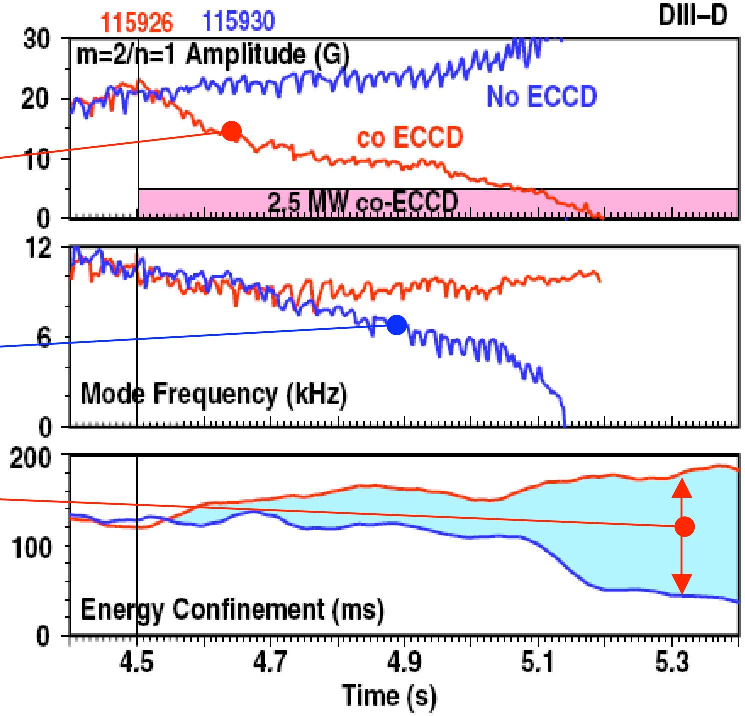


- ICRF minority current drive can either increase or decrease period and amplitude
- Likely stabilization/destabilization mechanism – RF modification of current profile

- Sawteeth can limit plasma performance themselves, or can trigger other instabilities – disruptions, neoclassical tearing modes
- Many physics processes interact – *qualitative* understanding exists but *quantitative* verification and *prediction* is lacking

It has been demonstrated experimentally that suppression of NTM by RF leads to improvement in confinement

- Electron cyclotron current drive drives down mode amplitude
- keeps mode rotating (no drop in frequency)
- improves energy confinement



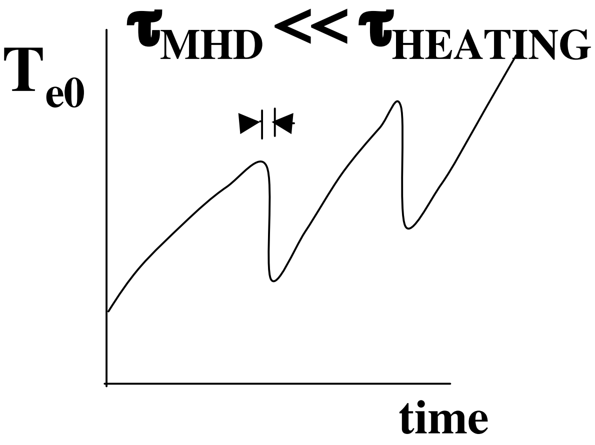
R. Prater
APS 2003

- Empirical scaling of NTM pressure limits in ITER leave no margin in performance
- "Understanding the physics of neoclassical island modes and finding means for their avoidance or for limiting their impact on plasma performance are therefore important issues for reactor tokamks and ITER" – ITER Physics Basis (1999)

SWIM has two sets of physics goals distinguished by the time scale of unstable MHD motion

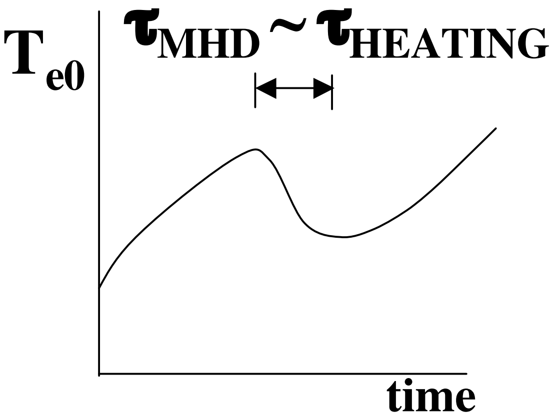
Fast MHD phenomena – separation of time scales

- **Response of plasma to RF much slower than fast MHD motion**
- **RF drives slow plasma evolution, sets initial conditions for fast MHD event**
- **Example: sawtooth crash**



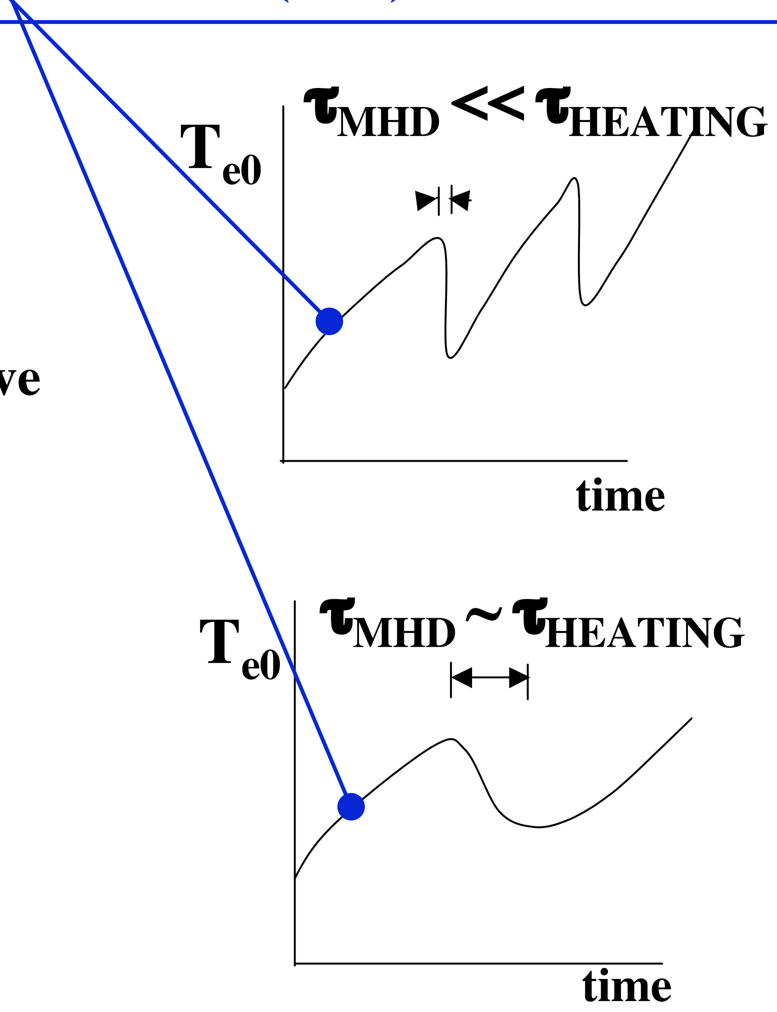
Slow MHD phenomena – no separation of time scales

- **RF affects dynamics of MHD events ⬄ MHD modifications affect RF drive plasma evolution**
- **Deals with multi-scale issue of parallel kinetic closure including RF – a new, cutting edge field of research**
- **Example: Neoclassical Tearing Mode**



We are approaching these regimes in two *campaigns* of architecture development and physics analysis and validation

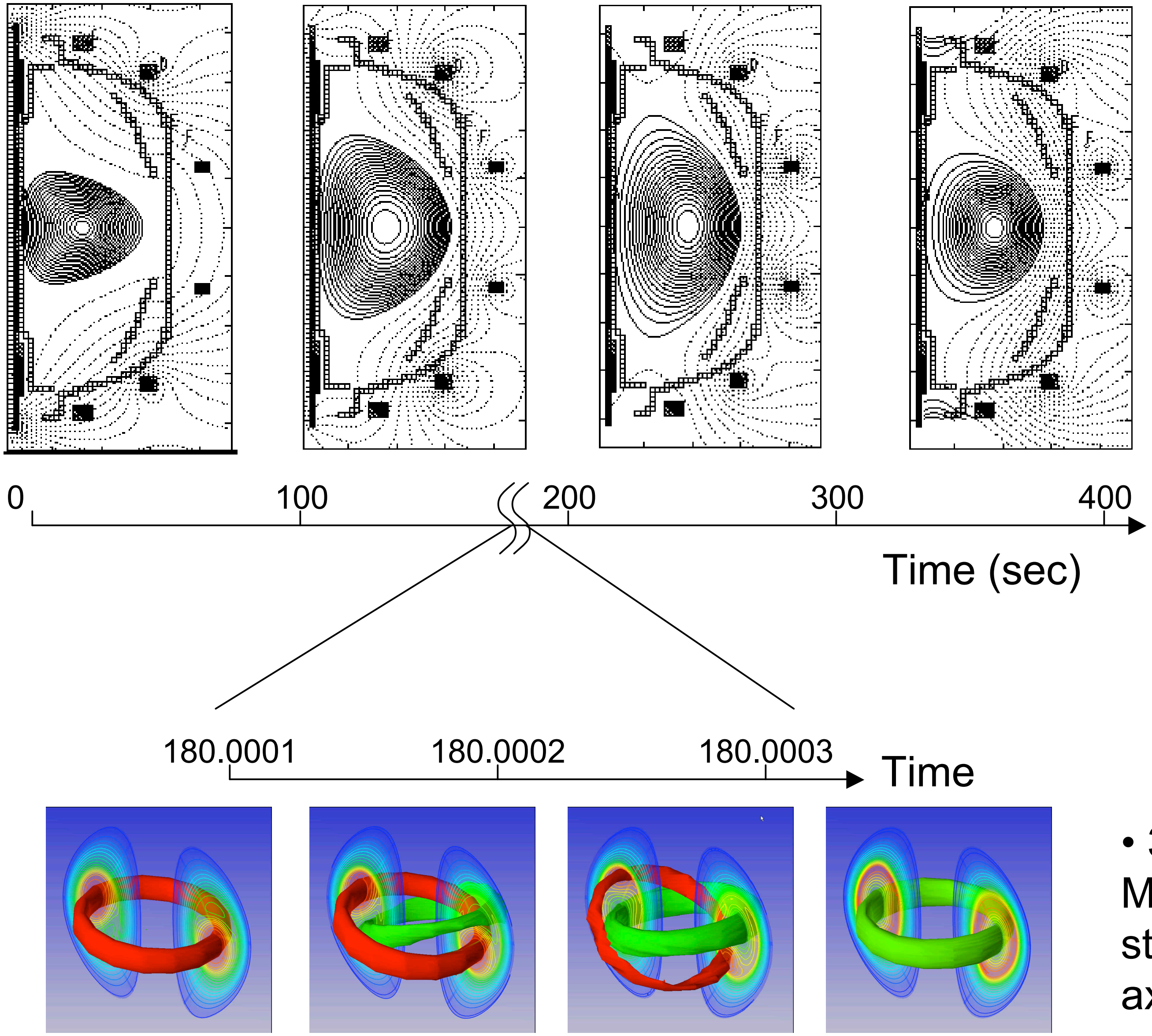
Simulation of plasma evolution requires complete model – Integrated Plasma Simulator (IPS)



- **Heating and current drive sources**
- **Particle sources**
- **Transport**
- **Magnetic field evolution**

Integrated Plasma Simulator will allow coupling of virtually any fusion code, not just RF and MHD, and should provide the framework for a full fusion simulation

Integrated Plasma Simulator (IPS) interfaces to non-linear XMHD codes for detailed analysis of fast events

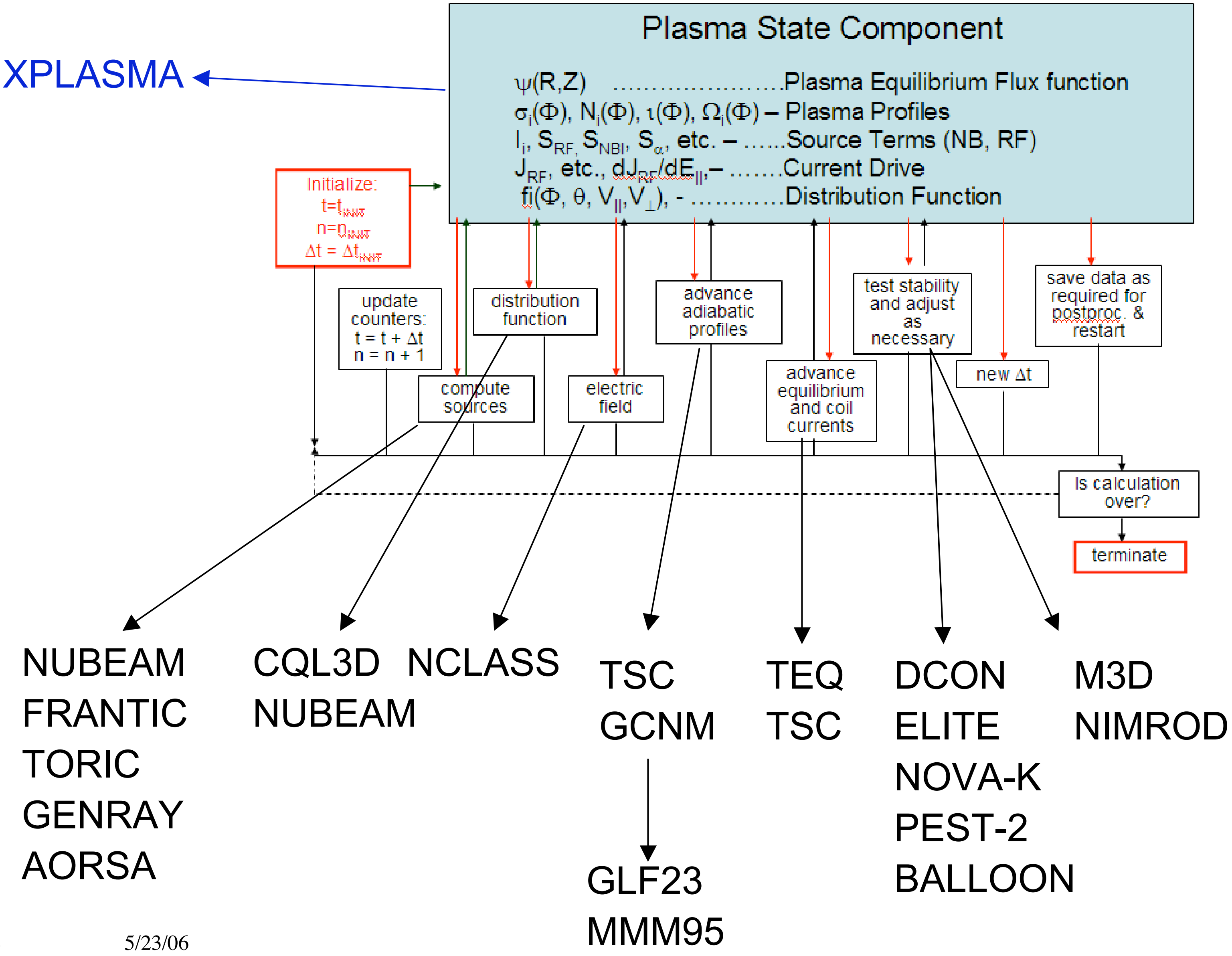


- Plasma evolves through a series of 2D axisymmetric equilibrium states

- Instabilities occur as instantaneous events on IPS time scale

- 3D Extended MHD simulation starts and ends in axisymmetric state

IPS design – Component based architecture, Plasma State component plays a central role, components implemented using existing fusion codes



XPLASMA

Plasma State Component

$\psi(R,Z)$ ....Plasma Equilibrium Flux function

$\sigma_i(\Phi)$, $N_i(\Phi)$, $\iota(\Phi)$, $\Omega_i(\Phi)$ – Plasma Profiles

I_i, S_{RF}, S_{NBI}, S_α, etc. – ......Source Terms (NB, RF)

J_{RF}, etc., $dJ_{RF}/dE_{||}$, – ....Current Drive

$fi(\Phi, \theta, V_{||}, V_\perp)$, - ....Distribution Function

Initialize:
$t=t_{INIT}$
$n=n_{INIT}$
$\Delta t = \Delta t_{INIT}$

update counters:
$t = t + \Delta t$
$n = n + 1$

distribution function

compute sources

electric field

advance adiabatic profiles

advance equilibrium and coil currents

test stability and adjust as necessary

new Δt

save data as required for postproc. & restart

Is calculation over?

terminate

NUBEAM
FRANTIC
TORIC
GENRAY
AORSA

CQL3D
NUBEAM

NCLASS

TSC
GCNM

GLF23
MMM95

TEQ
TSC

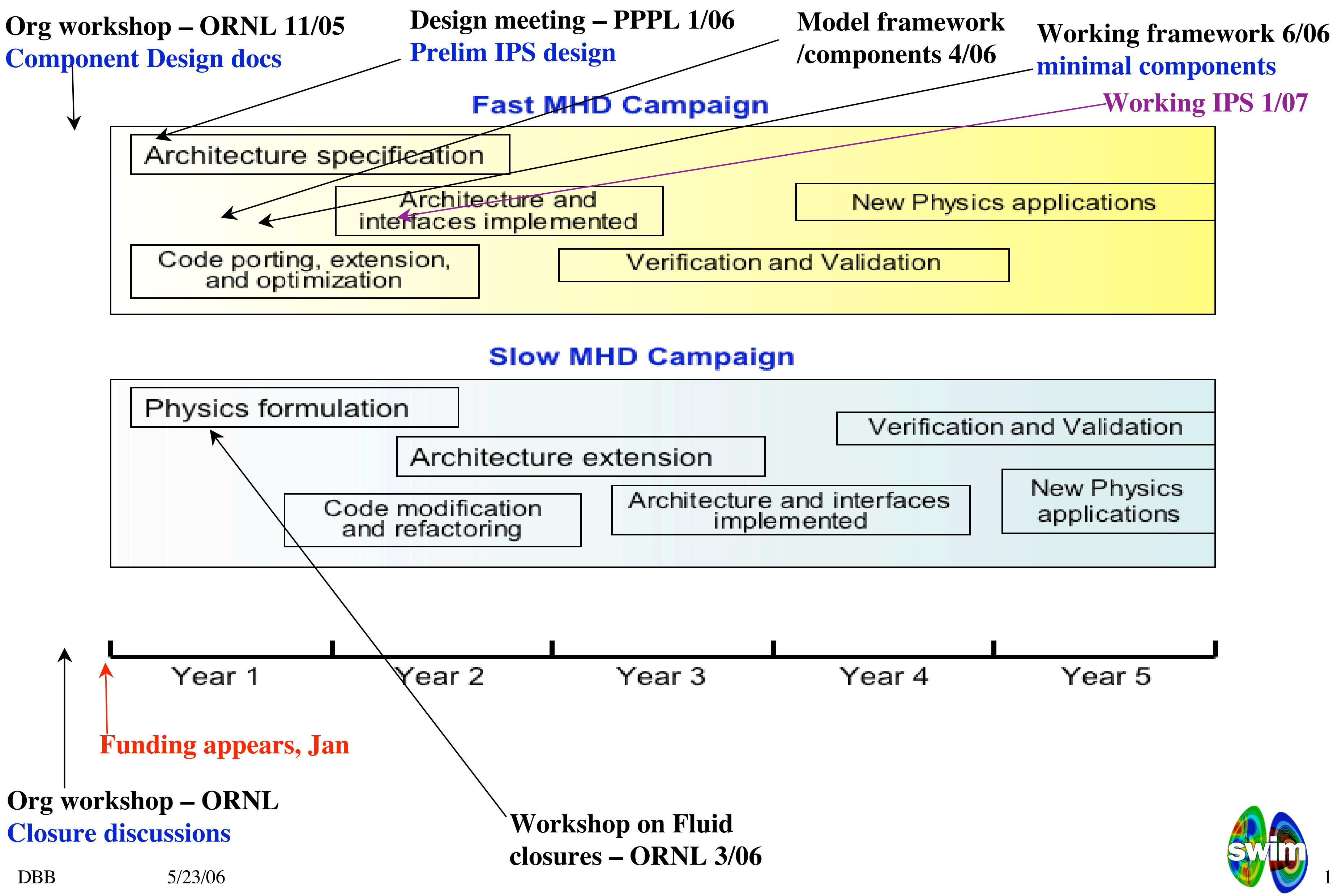
DCON
ELITE
NOVA-K
PEST-2
BALLOON

M3D
NIMROD

Overall Project Strategy

- **Leverage previous investments to maximum possible extent**
  - **Fusion SciDAC projects, predictive TRANSP, NTTC**
  - **Computer Science – SciDAC ISICs, Fusion Grid, user interaction system from LEAD weather prediction system, data management methods from Common Instrument Management Architecture CIMA, authentication technology from myProxy**
- **Component-oriented architecture *(but not formal component system like CCA)***
- **Design for flexibility and extensibility by abstracting interfaces at a high level – include *multiple codes* in each component from the beginning**
- **Start with a strictly *file-mediated exchange* of data between application components**
  - **No changes needed to the application component code; SWIM overall interactions handled by scripting**
  - **Allows isolating of any bugs or problems**
  - **Eliminates issues of re-entrancy and overall system state consistency**
- **Highest end computer systems handled from the start, not as an afterthought**
  - **Porting codes to Cray XT3 at ORNL**

SWIM Work-plan and Timeline



Org workshop – ORNL 11/05
Component Design docs

Design meeting – PPPL 1/06
Prelim IPS design

Model framework /components 4/06

Working framework 6/06
minimal components

Working IPS 1/07

Fast MHD Campaign

Architecture specification

Architecture and interfaces implemented

New Physics applications

Code porting, extension, and optimization

Verification and Validation

Slow MHD Campaign

Physics formulation

Verification and Validation

Architecture extension

Code modification and refactoring

Architecture and interfaces implemented

New Physics applications

Year 1

Year 2

Year 3

Year 4

Year 5

Funding appears, Jan

Org workshop – ORNL
Closure discussions

Workshop on Fluid closures – ORNL 3/06

Project outcomes

What do we propose to develop?

- A flexible framework for coupling leading terascale RF and MHD codes
- An unique integrated tool for analyzing and optimizing scenarios for present experiments and ITER
- Greatly expanded capability for coupling and optimizing multi-scale and multi-physics codes for fusion on a range of HPC platforms

If we are successful what will be the significance?

- Understanding of interaction of RF waves with MHD and reliable capability to predict and interpret experiments using RF to control MHD events
- A computational architecture with wide community acceptance and use and that is capable of scaling to a full fusion simulation
- Solution of one of the key multi-time-scale issues of fusion simulation → non-local response of plasma to perturbed fields due to rapid flow along field lines
- Better ability to operate and benefit from ITER

Summary

- Our objective is that the community adopt the SWIM architecture as the backbone for computational fusion research

- The component-oriented architecture, with a flexible control level, will allow coupling of virtually any fusion code, not just RF and MHD, and should provide the framework for a full fusion simulation

- Addressing ultra-scale computing from the start

- Three physics goals
  - Unique Integrated Plasma Simulator for comprehensive long-time simulation of tokamak discharges
  - Sawtooth instability stabilization and destabilization
  - Neoclassical tearing mode stabilization

Backup Slides