Wave-Particle Interaction/Energetic Particle Physics: Five Year Theory Strategic Plan

Presented by

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Wave-Particle Interaction/Energetic Particle Physics

FESAC Goal

Advance fundamental understanding of plasma, the fourth state of matter, and enhance predictive capabilities, through comparison of well-diagnosed experiments, theory and simulation.

Five Year Goal of Wave-Particle Interaction Physics

Develop predictive capability for plasma heating, flow and current drive, as well as energetic particle driven instabilities, in power-plant relevant regimes.

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Key Research Areas

- Single particle orbits – particle loss due to effects of field ripple, and particle interaction with MHD perturbations and RF waves
- Collective fast ion driven instabilities
  – linear theory of collective instabilities: TAEs, fishbones, internal kinks (sawtooth stabilization and fishbones), kinetic ballooning modes, interchange modes, and Alfvèn ion cyclotron instability, etc.
  – nonlinear behavior of collective instabilities
  – fast ion transport induced by collective instabilities
- RF Physics – RF wave propagation and power deposition, current drive efficiency, α-channeling, etc.
- Collaboration with other theory teams
- Collaboration between theory and experiments

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Key Accomplishments – Theory and Code Development

- Collective Instabilities
  – Fishbone instability and sawtooth stabilization by fast ions.
  – Invention of toroidicity-induced Alfvén eigenmode (TAE).
  – Theoretical prediction of TAE instability by fast ions which was confirmed in tokamak and stellarator experiments.
  – α driven TAEs in TFTR DT experiments.
  – NOVA-K code for low-n mode stability in tokamaks.
  – HINST code for high-n mode stability in tokamaks.
  – Stabilization of kinetic ballooning instability in low aspect ratio tokamaks (NSTX) by effects of finite ion Larmor radii and trapped electron dynamics.
  – Understanding of observed frequency chirping of TAE and RTAE.
  – Alfvén ion cyclotron instability to explain ion cyclotron emissions (ICE) observed in TFTR and JET experiments.

- Single Particle Orbit
  – Development of an orbit following code, ORBIT and a stochastic orbit diffusion theory of fast ion loss due to TF ripple.
  – Extension of ORBIT to study quasi-linear evolution of energetic particle interaction with TAEs and fishbones in tokamaks.

- Nonlinear Theory and Fast Ion Transport
  – Study of fast ion stochastic transport due to collective modes.
  – Development of a nonlinear hybrid gyrokinetic–MHD simulation code, M3D-K code, based on the kinetic-MHD model.
  – Low-n TAE saturation via nonlinear wave-particle trapping.
  – Development of a kinetic-Fluid Model for high β plasmas with multiple ion species by employing one-fluid equations (continuity equation, momentum equation and generalized Ohm's law including gryroviscosity) with plasma pressure and gyroviscosity tensor obtained from particle distribution functions.

- RF Physics
  – Alpha-channeling for transfering α energy to thermal plasmas
  – Bucket transport for non-stochastic, energy-selective transport of ions
  – Kinetic-fluid model for ion cyclotron wave propagation and power deposition

Key Accomplishments – Collaboration Activities

- Participated in TFTR experiments to study fishbones and sawtooth stabilization, and TAEs in DT and ICRF experiments.
- Participated in JT60U fast particle physics experiments with N-NBI and ICRF fast ions; and performed analysis to understand experimental results
- Studied theory of TAEs and Alfvén ion cyclotron instabilities in NSTX which will be the basis for future experimental proposals.
- Studied fishbones and sawtooth stabilization in collaboration with JET and ASDEX groups on experiments in JET and ASDEX.
- Studied TAEs in DIII-D with UCI and DIII-D groups.
- Studied nonlinear behavior of TAE modes with IFS group.

Planned Research in Theory and Code Development

- Improve the ORBIT code to include effects of equilibrium toroidal field ripples, separatrix in vacuum region and particle interaction with RF field in tokamaks and stellarators.
- Improve the perturbative and non-perturbative NOVA-K codes to include more complete particle kinetic physics.
- Improve the high-n TAE stability code, HINST, to couple with numerical equilibrium and to include thermal particle kinetic effects.
- Study frequency chirping modes, bursting modes and fishbone modes observed in tokamaks and stellarators.
- Study nonlinear interaction of energetic particles with TAEs, fishbone modes, and other MHD modes and energetic particle transport using existing quasi-linear ORBIT and M3D-K codes.

- Develop a general nonlinear kinetic-fluid model/code for high β plasmas including plasma flow and large ion gyro-orbit physics. This new code can be developed from the existing M3D-K code.
- Develop a RF wave propagation and power deposition code for axisymmetric toroidal devices based on kinetic-fluid model.
- Develop a NOVA-K code for non-axisymmetric devices including effects of plasma flow and pressure anisotropy.
- Develop equilibrium codes including plasma flow, pressure anisotropy and field ripple for tokamaks, stellarators and innovative confinement devices.
- Perform code optimization for MPP computers.

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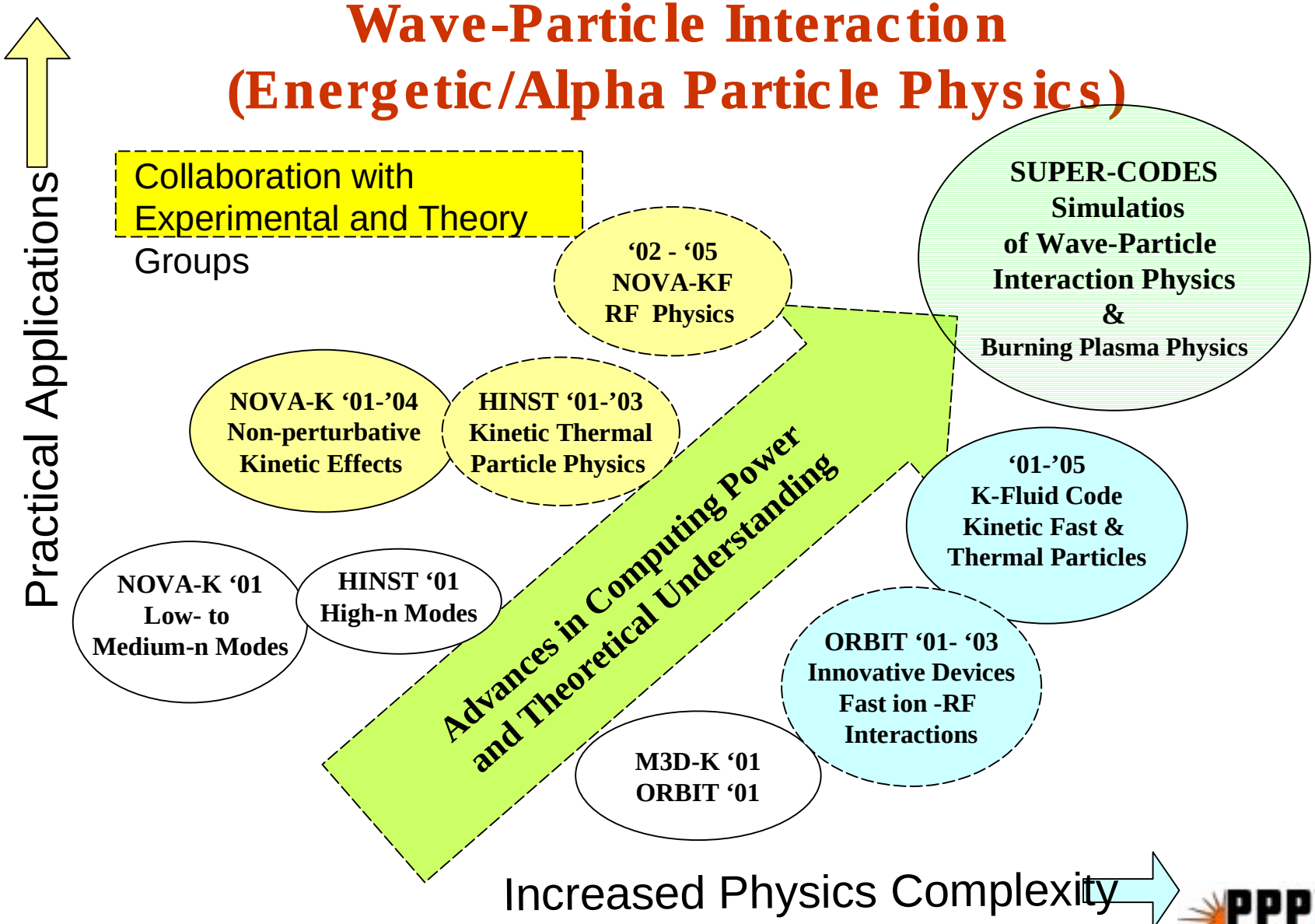
Planned Collaboration Activities

- Study fast particle physics in collaboration with IFS group and other theory groups.
- Participate in joint theory-experimental programs of energetic particle physics and RF physics on NSTX.
- Participate in joint theory-experimental energetic particle physics programs in JT-60U experiments involving 500 keV N-NBI and ICRH fast ions.
- Study α-particle physics in JET in collaboration with JET group.
- Study fishbone modes and sawtooth stabilization in ASDEX in collaborations with ASDEX group.
- Study fast particle physics in stellarators in collaboration with LHD group at NIFS, and the recently observed bursting modes induced by NBI fast ions observed in CHS experiments.

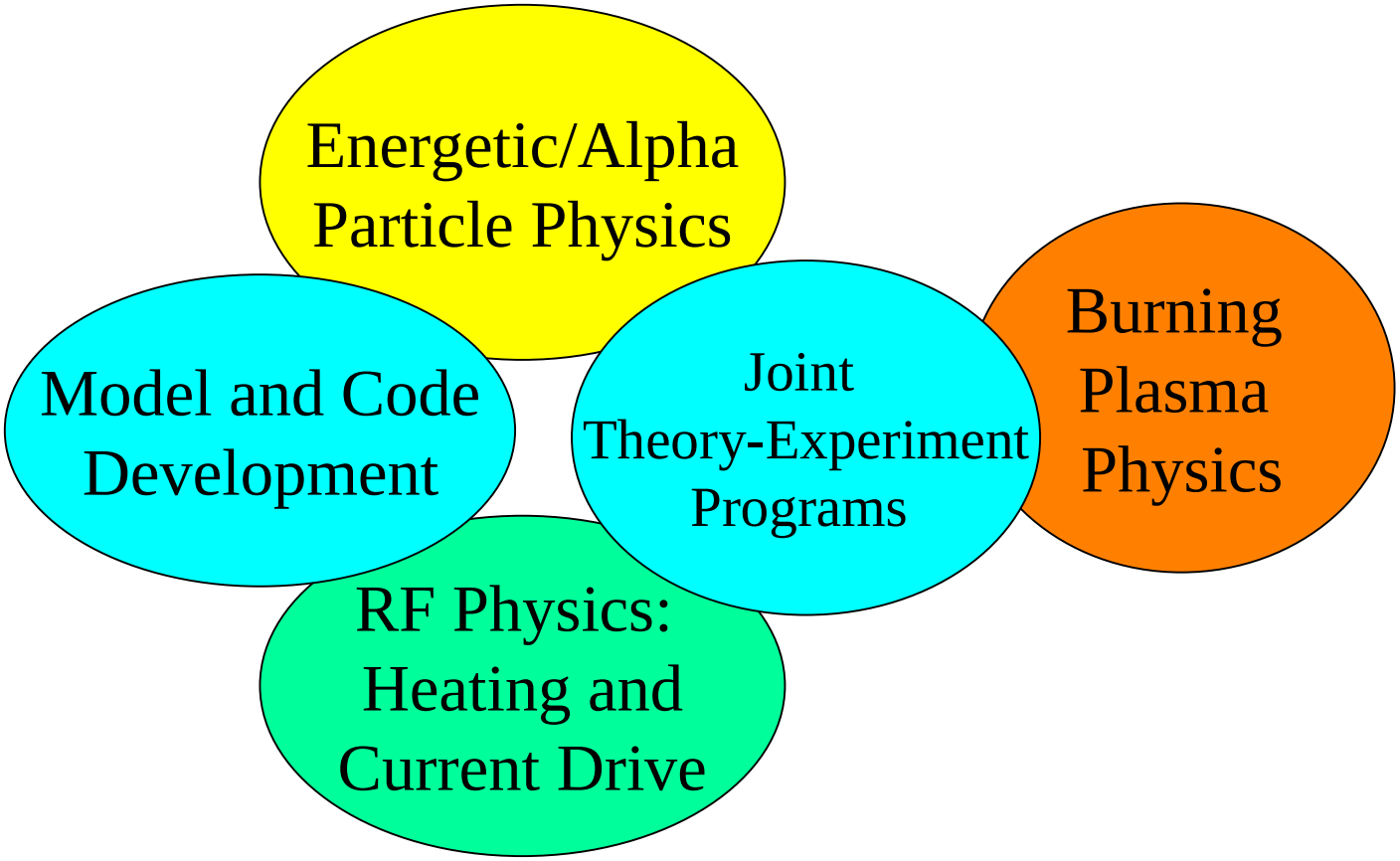
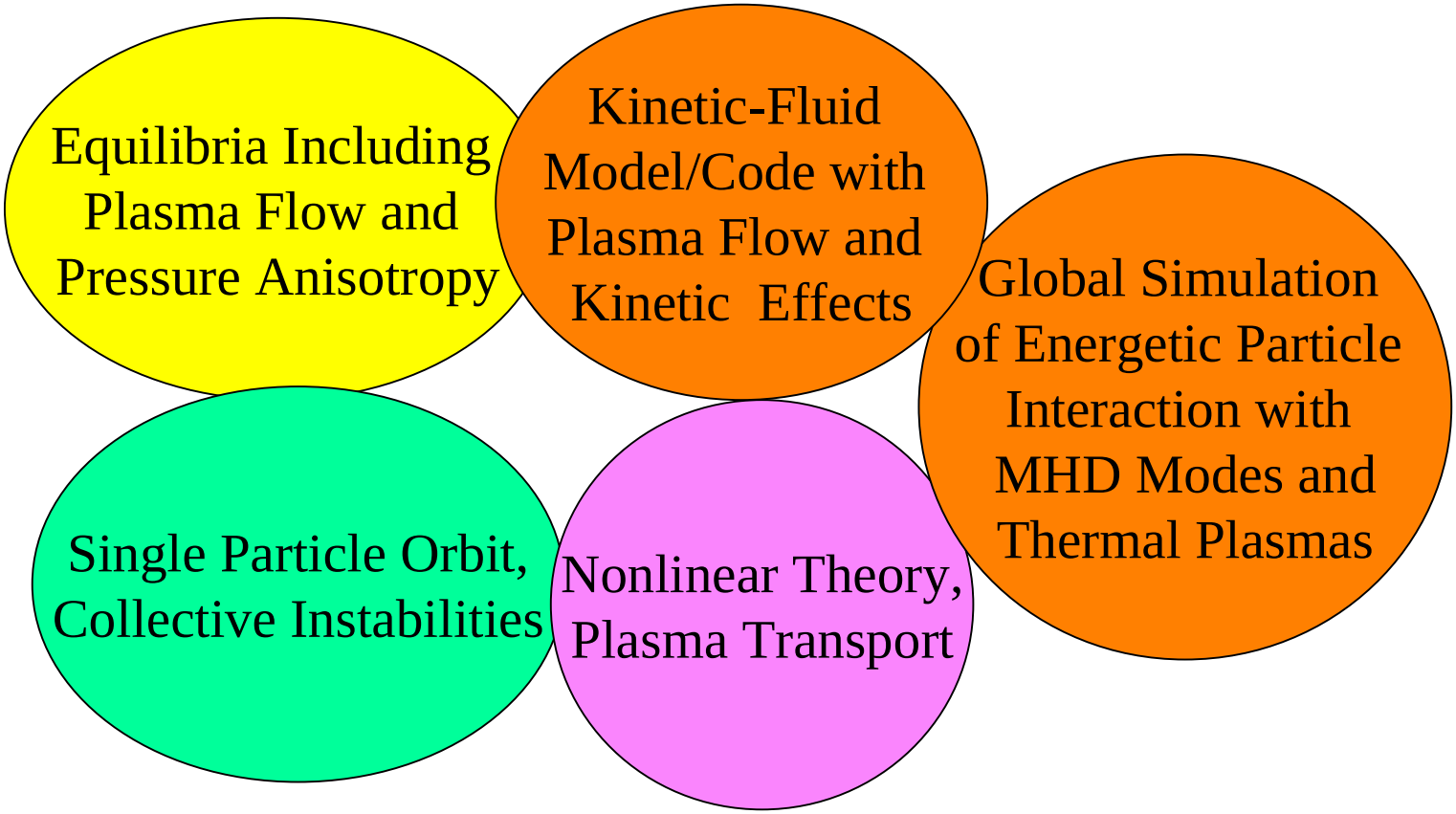
Conclusions

- PPPL theory team has developed the foundation of energetic particle physics.
- PPPL theory team has very productive interaction with TFTR and JT-60U experimental groups.
- PPPL theory team has strong collaborations in theory and experiments of energetic particle physics in US and abroad.
- Strategic plans are in place for an exciting future program.

Wave-Particle Interaction (Energetic/Alpha Particle Physics)



Wave-Particle Interaction Physics



Energetic/Alpha Particle Physics