Space Plasma Physics: Five Year Theory Strategic Plan

Presented by

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Plasma Science Applications

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 Plasma Science Applications

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

Space Plasma Physics

Goal

To understand **solar** activities (solar flares, prominence, coronal mass ejection and solar wind) and how these activities affect the plasma dynamics, waves and instabilities, transport of particles, momentum and energy in the **magnetosphere** and **ionosphere**.

Synergy with Fusion Plasma Physics

Have successfully applied our expertise in magnetic fusion theory to several critical areas of space plasma physics. The research experience in space plasma physics has also benefited our study of fusion plasma physics.

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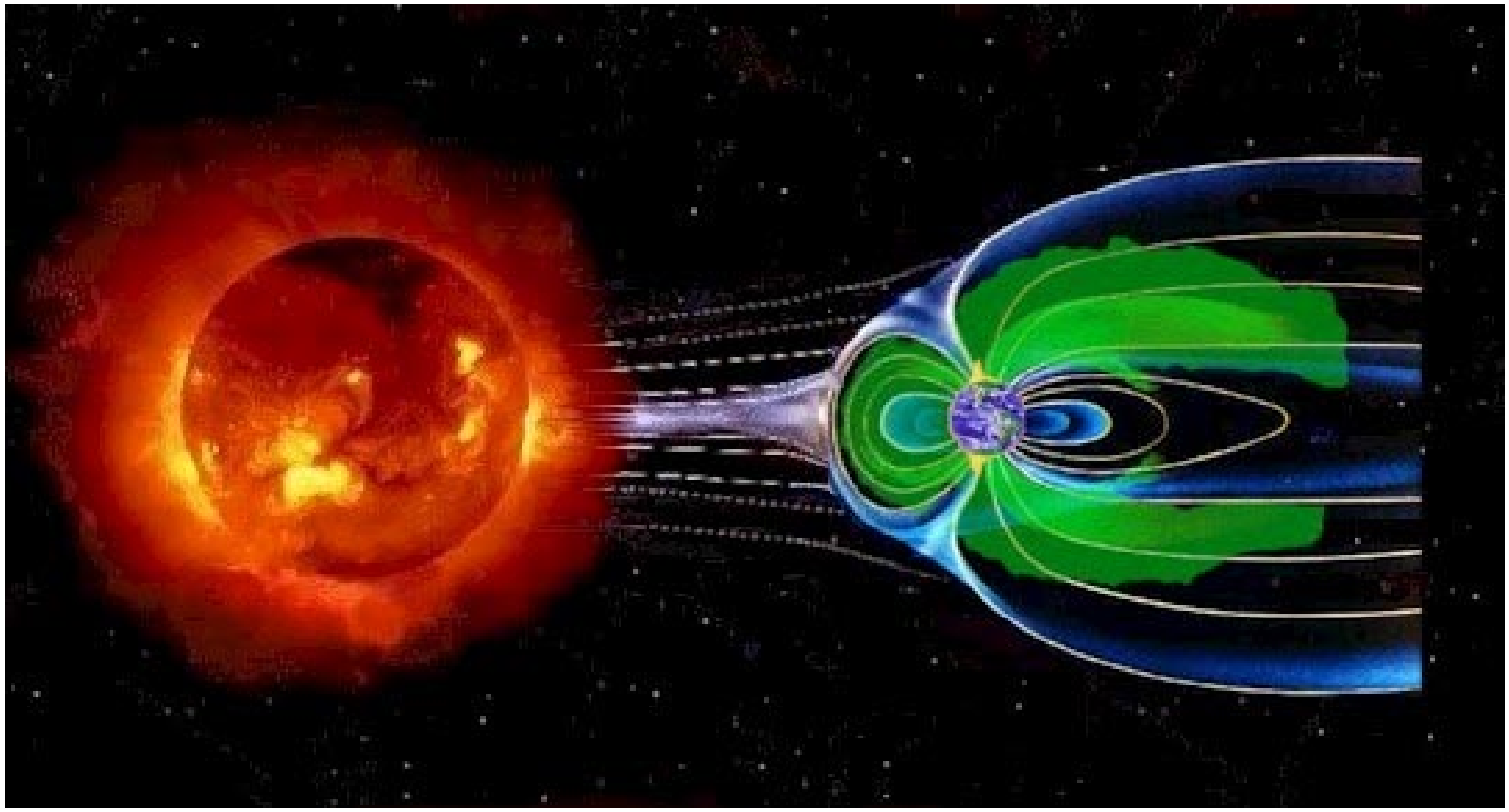
Sun-Earth Connection



Key Research Areas

- Magnetospheric Physics – to understand 3D quasi-steady structure of magnetosphere; substorm and storm dynamics and associated energetic particle transport; effects of low frequency wave activity and magnetic reconnection on plasma transport across magnetopause; kinetic effects on MHD phenomena; etc.

- Ionospheric Physics – to understand magnetosphere-ionosphere coupling processes: auroral arc formation and dynamics, the role of Alfvén waves and ion cyclotron waves on auroral current and plasma heating and particle acceleration, etc.

- Solar Physics – to understand 3D magnetic field structure and solar wind in solar corona, mechanism of current sheet formation, prominence formation and its magnetic field structure, and eruptive phenomena such as solar flares and coronal mass ejection, etc.

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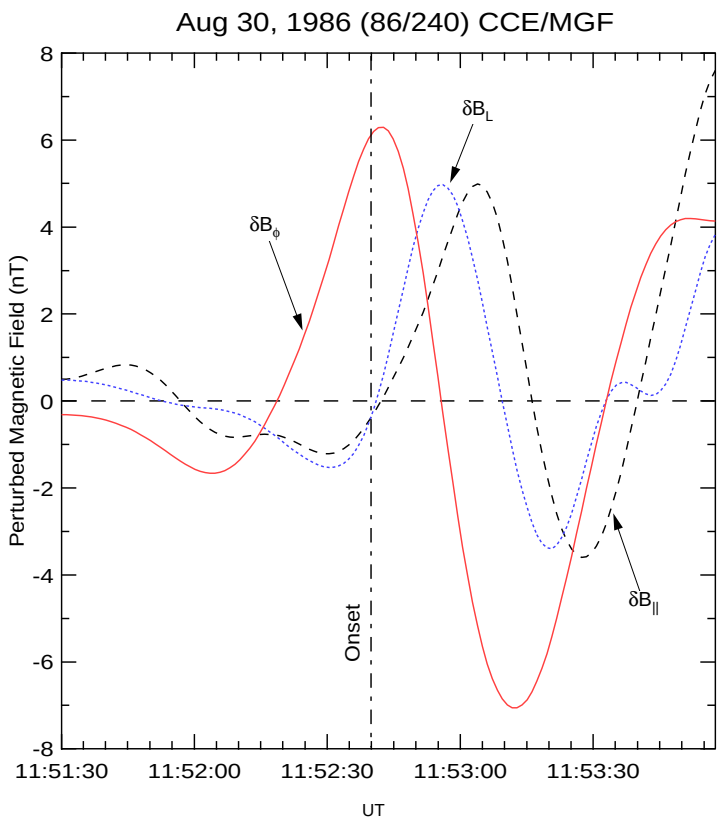
Highlights of Accomplishments:

Magnetospheric-Ionospheric Physics

- Calculated 3D magnetospheric equilibrium by MAG-3D code
- Observed a low frequency instability before substorm onset and developed kinetic ballooning instability (KBI) theory to understand the instability, substorm onset and subsequent current disruption. The KBI theory is applied to low aspect ratio tokamaks.
- Developed kinetic Alfvén wave theory to understand low frequency wave activities and plasma transport across magnetopause.
- Field-aligned structure of Pc 5 waves (about 10 mHz) in the magnetosphere is understood by ballooning-mirror instability.
- Developed a new ion cyclotron wave propagation theory which resolves a decade long controversy between theory and observations over the issue of how Pc 1 waves (about 1 Hz) could propagate from the magnetosphere to the ground along auroral field line.

Substorm and Current Disruption



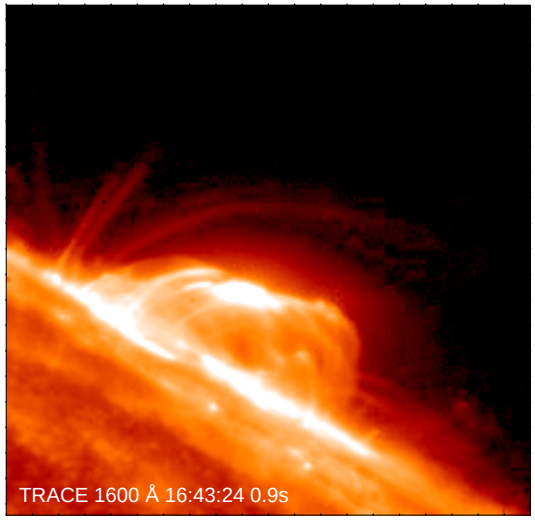
Magnetic field perturbation of low frequency instability measured by AMPTE/CCE satellite

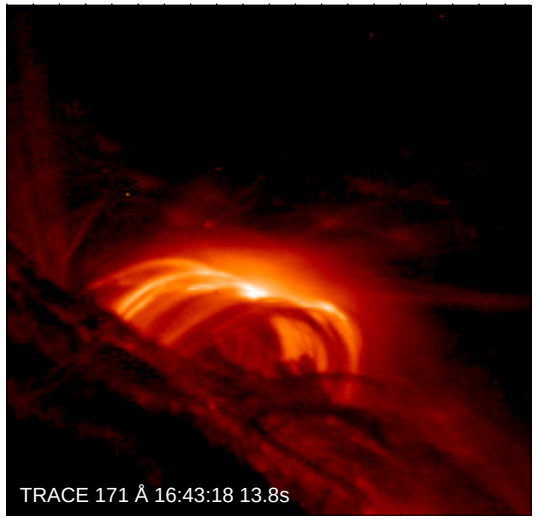
- AMPTE/CCE located at 8.8 R_E near midnight.
- Low frequency instability occured after plasma β increased from 20 to 50 – 70.
- Developed a KBI theory to explain instability observation and subsequent current disruption.

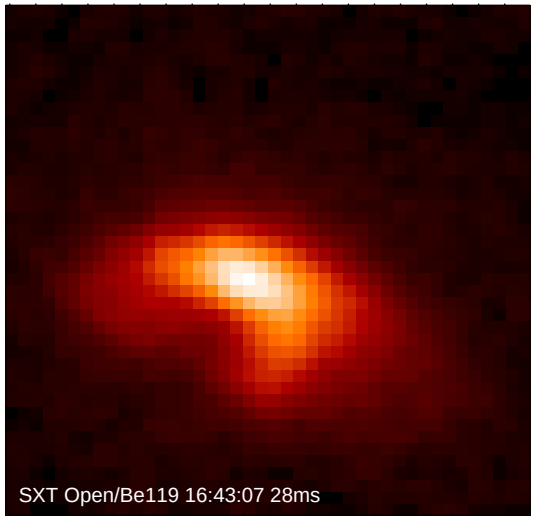
Highlights of Accomplishments: Solar Physics

- Obtained new current sheet and prominence formation mechanism in the solar corona with quadrupolar field geometries.
- Developed a new solar flare model: flare processes consist of magnetic reconnection of arcade magnetic field, generation of magnetic islands, and merging of magnetic islands. The model explains all three phases of flares as well as the Yohkoh satellite observation of two phases of soft X-ray plasma ejecta rising motion.

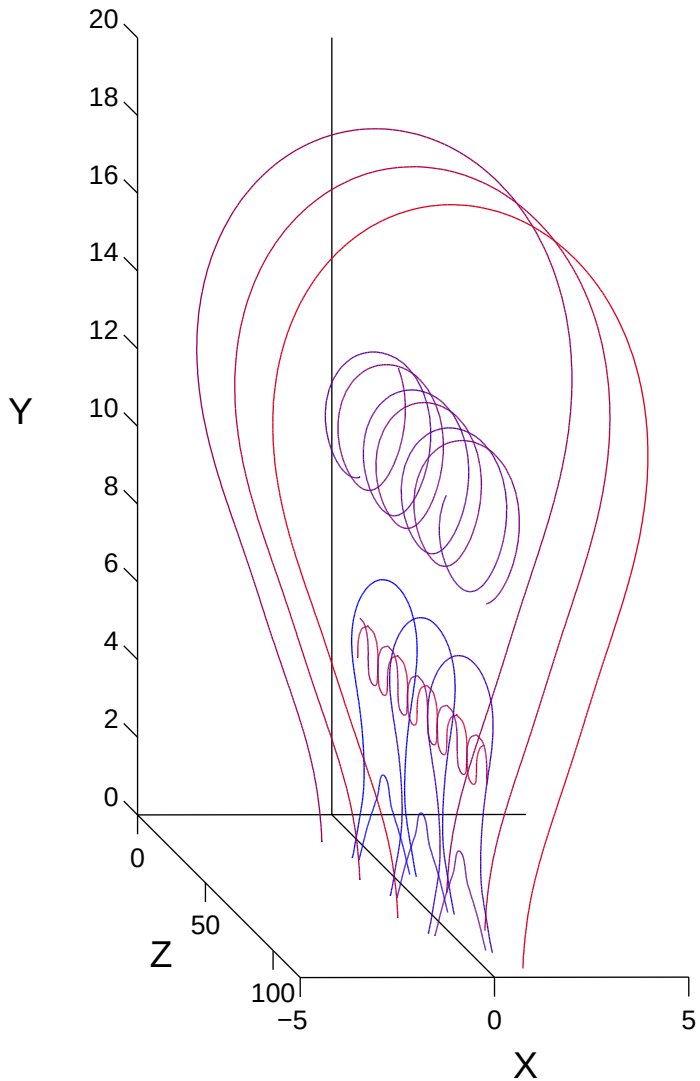
Solar Flare Observed by YOHKOH and TRACE Satellites







A Solar Flare Model



- Magnetic Reconnection in Current Sheet
- Creation and Merging of Magnetic Islands
- Reconnection electric field ($E_z \approx 1\,\mathrm{V/m}$) can accelerate electrons to $> 10^4\,\mathrm{keV}$ in $10^4\,\mathrm{km}$ to produce hard X-ray emission.

Planned High Impact Research Areas

- Magnetospheric and Ionospheric Physics:

  – Develop an improved 3D quasi-steady equilibrium code to study large scale structure of magnetosphere under various solar wind and interplanetary magnetic field conditions.
  – Perform more complete calculation to quantify the substorm onset mechanism.
  – Study magnetotail dynamics and energetic particle injection during substorm.
  – Develop a 3D global kinetic-fluid simulation code for studying dynamics of magnetosphere-ionosphere.
  – Study wave activity, magnetic reconnection and plasma transport at the magnetopause.
  – Study magnetosphere-ionosphere coupling processes of auroral arc dynamics, magnetic field-aligned electric field and current, plasma convection, plasma heating and particle acceleration associated with ion cyclotron wave and Alfvén wave activities.

- Solar Physics:

  – Develop a 3D quasi-steady equilibrium code to study large scale corona and solar wind structure.
  – Develop a 3D resistive MHD code for studying solar eruptive phenomena such as current sheet formation, prominence formation and eruption, solar flare and coronal mass ejection.
  – Study coronal and flare heating mechanism by considering wave-particle interaction physics

- Collaboration:

  Perform analysis of satellite data and theory in collaboration with other space physics groups such as APL/JHU, Dartmouth College, NCAR/HAO, Yohkoh and TRACE solar physics research teams.

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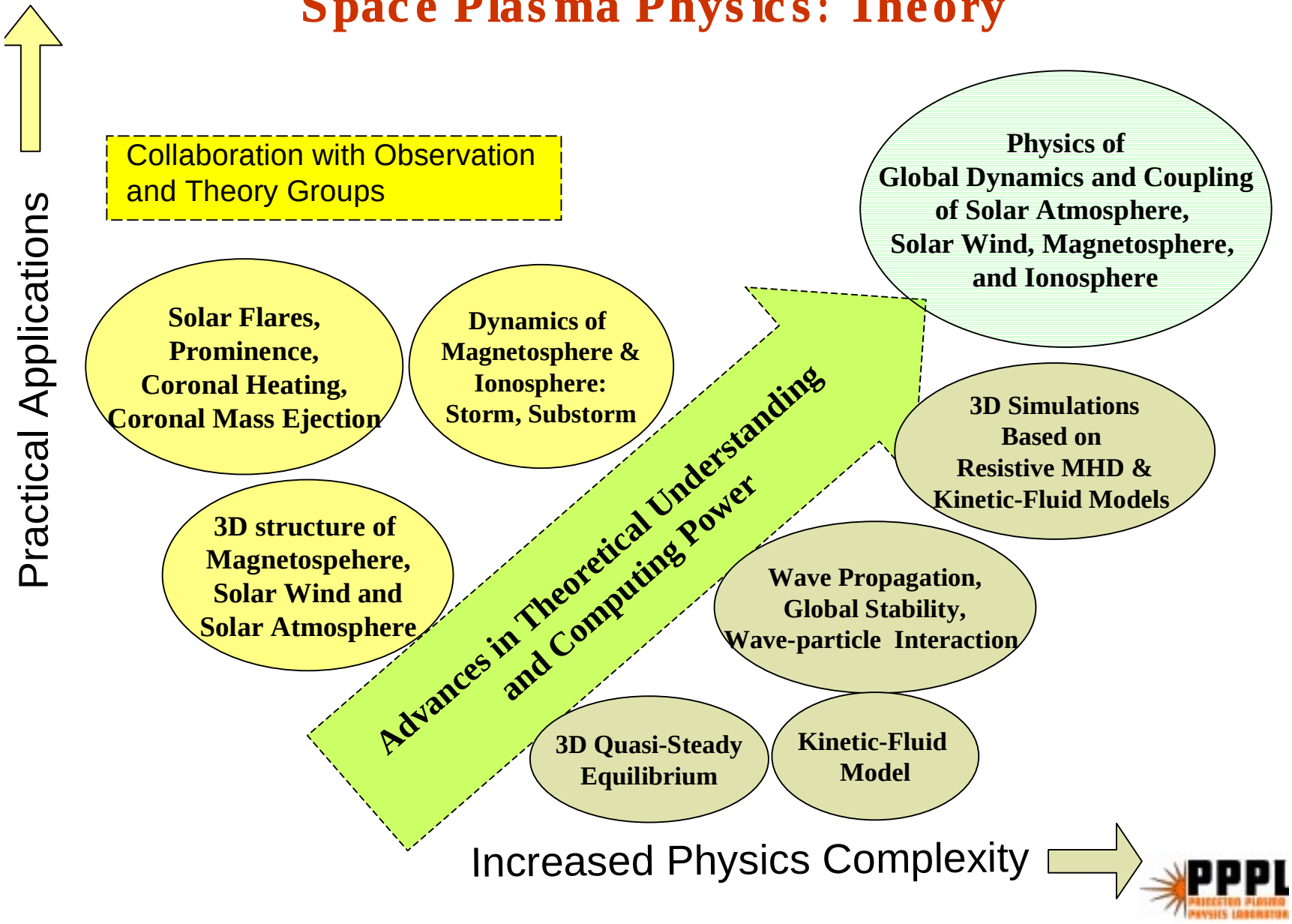
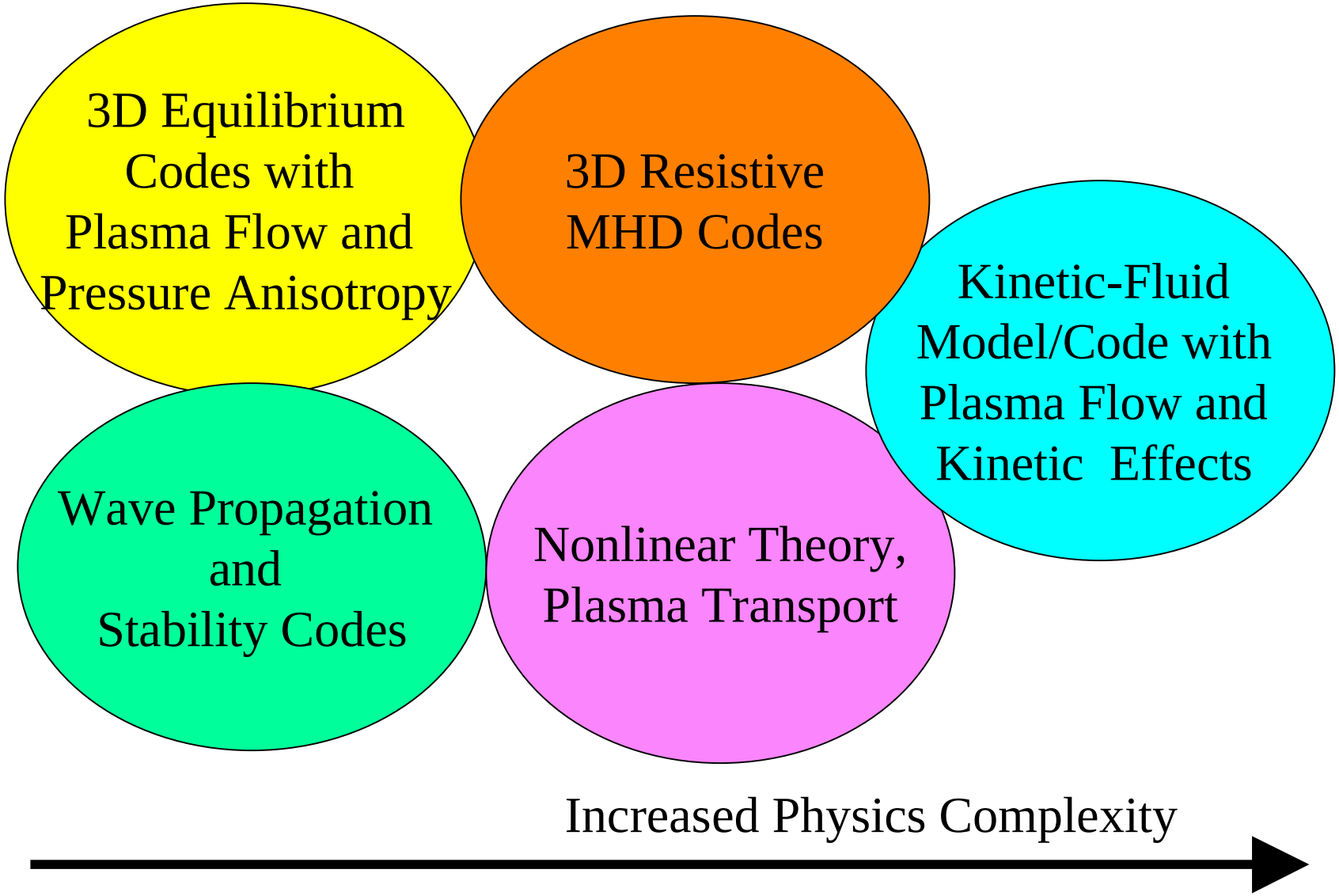
Conclusions

- PPPL space plasma physics group has made fundamental contributions in several critical space plasma physics issues.
- Our space physics research is synergistic with the development of magnetic fusion plasma science.
- PPPL space physics group has strong collaborations in theory and satellite data analysis in US and abroad.
- Strategic plans are in place for an exciting future program.

Space Plasma Physics: Theory



Theory and Code Development

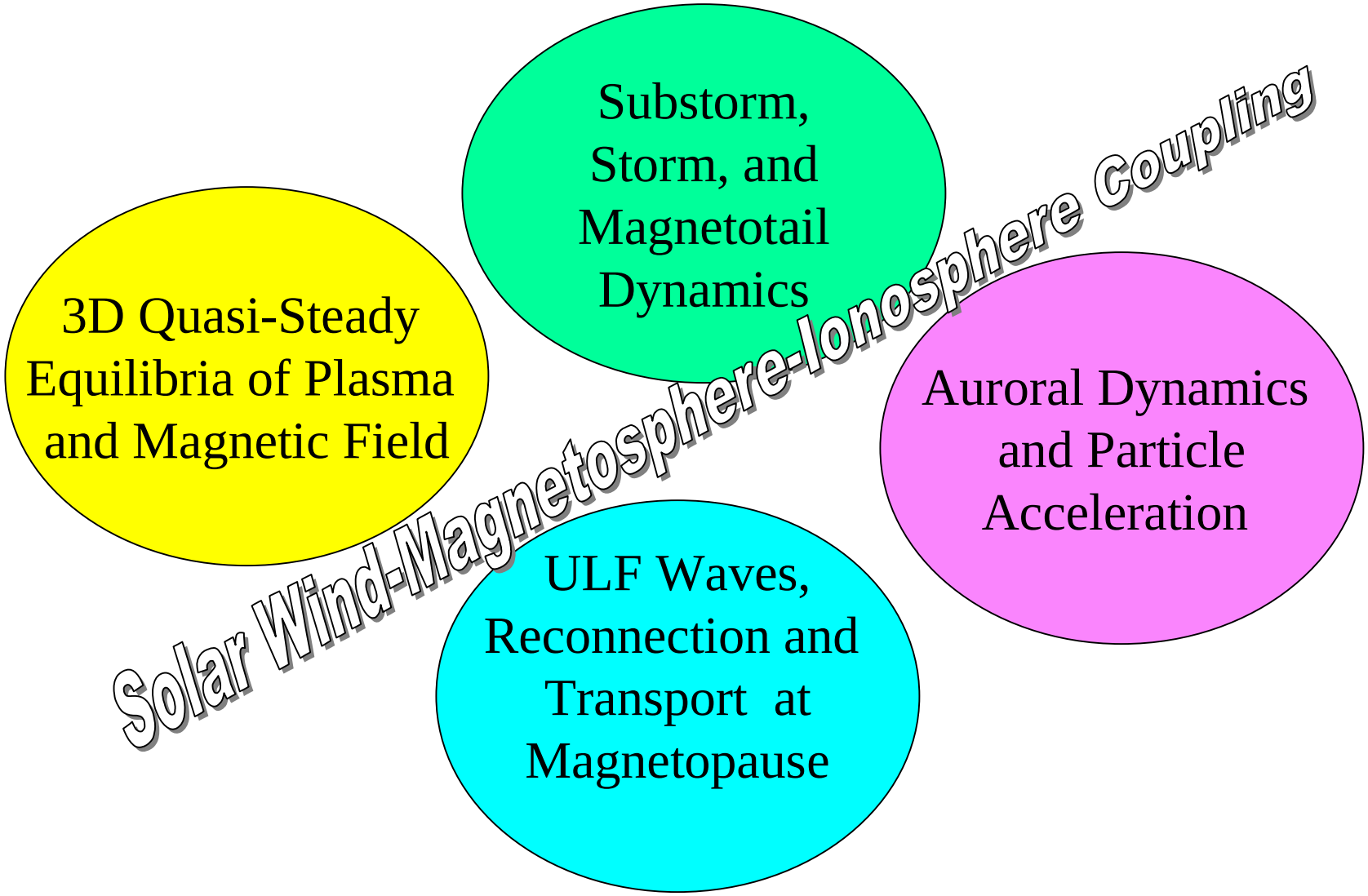


Solar Physics

Solar Flares & Eruption,
Coronal Heating

3D Structure of
Magnetic Fields,
and Current Sheets

Coronal Mass Ejections,
Solar Wind,
Interplanetary Shocks

Formation and Stability
of Solar Prominence

Magnetospheric/Ionospheric Physics