Research Plans on Magnetic Reconnection of the MPPC

Version updated by the German participants on November 26, 2012

I: Research Topics

1. Influence of guide field on magnetic reconnection

Descriptions: The strength of guide field is an important parameter in determine physics of reconnection in laboratory as well as in space/astrophysical plasmas. In fusion plasmas as well as at the Sun, the guide field is typically much larger than the reconnecting field while in Earth's magnetotail guide field is usually small and only sometime can be as large as reconnecting component. At the Earth's magnetopause, the strength of guide field does depend critically on the orientation of the incoming solar wind while at solar corona, guide field is typically regarded as large although most of cases there magnetic field is not directly measured. We plan to study the guide field effects on reconnection both experimentally and theoretically.

1.1 Experimentally, we plan to study guide field dependence of the reconnection rate across a wide range of values from zero in MRX, to small in Vineta, to very large in NSTX and AUG. Reconnection rates are directly measurable in MRX and Vineta through time evolution of 2D magnetic field profile while the reconnection rate is determined from island growth rate based on external Mirnov coils measurements on NSTX and AUG.

Personnel:

- PPPL Postdoc #1 with H. Ji/M. Yamada on MRX-Vineta-tokamaks is being advertised.
- German Postdoc #1 will start Dember 1st 2012 at the IPP Greifswald with O. Grulke on the VINETA experiment.
- German Postdoc #2 with V. Igochine at IPP on AUG-NSTX NTM seeding/error field penetration. To be hired, but a lot of AUG data already existing. Would benefit from close collaboration with theory, may be not purely experimental work., would benefit from collaboration with M3D-C1

1.2 Theoretically, we plan to study guide field effects by using 2-3D electron-MHD (EMHD) and 5-6D PIC simulations at MPS (Buechner, Jain), 5D/6D Vlasov simulations at IPP (Jenko), and 3D Neo-Classical drift MHD code at PPPL (Reiman).

Personnel:

- PPPL Postdoc #2 with A. Reiman NC-drift-MHD modeling being proposed (to be finalized soon)
- Third party funded Ph.D. student by F. Jenko at IPP on 5D/6D Vlasov simulation
- Third party funded Ph.D. student (P. Munoz) by J. Buechner at MPS on 5-6D PIC simulation on micro-turbulence dependence on the guide field strength

2. 3D experimental investigation, EMHD and PIC-code simulation of reconnection and related micro-instabilities

Descriptions: 2D Hall effects have already been proven to be critical to accelerate reconnection rates much above the slow rates predicted by resistive MHD. However, it is unclear whether and how much these 2D pictures can be applied directly to the observations which are 3D by definition. There are indications in measurements from MRX (Dorfman et al.) and from space (Phan et al.) that reconnection processes are indeed 3D. We plan to study 3D effects by combining numerical simulations and experimental measurements.

2.1 Experimentally, we plan to study further the conditions for these 3D reconnection events in MRX and also in Vineta when the time is ripe.

Personnel:

- PPPL Postdoc #1 with H. Ji/M. Yamada on MRX-Vineta-tokamaks is being advertised.
- German Postdoc #1 will start December 1st 2012 at the IPP Greifswald with O. Grulke on the VINETA experiment.

2.2 Theoretically, we plan to investigate 3D electron effects and microturbulence on reconnection by EMHD, PIC, Vlasov codes:

Personnel:

- German Postdoc #3 (N. Jain) started at MPS with J. Buechner on EMHD modeling of 3D impulsive reconnection found at MRX, including guide field dependence
- Third party funded Ph.D. student by F. Jenko at IPP on 5D/6D Vlasov simulation (still to be hired)
- Third party funded Ph.D. students (P. Munoz) by J. Buechner at MPS on 5-6D PIC simulation on micro-turbulence on the guide field strength

3. Drive-dependence of reconnection rate

Descriptions: It is always unclear that magnetic reconnection is a driven process by external sources or a spontaneous process by internal instabilities. Perhaps, both aspects at different degrees are present in the observed reconnection phenomena in nature. In the laboratory, both reconnection at MRX and Vineta will be purely driven while reconnection at NSTX and AUG will have a mixture from both aspects. We plan to focus on the driven nature of reconnection for all 4 experiments. The driven reconnection experiments at NSTX and AUG can be done by imposing external error fields, also known as resonant magnetic perturbation (RMP), to observe the island growth rate.

3.1 Experimentally, we plan to vary drive strength at all 4 devices to observe the responding reconnection rates.

Personnel:

- PPPL Postdoc #1 with H. Ji/M. Yamada on MRX-Vineta-tokamaks is being advertised.
- German Postdoc #1 will start December 1st 2012 at IPP Greifswald with O. Grulke on the VINETA experiment.

- German Postdoc #2 with V. Igochine at IPP on AUG-NSTX NTM seeding/error field penetration. NTM triggering by external field perturbations on AUG hard to achieve, fast ramp up of coil currents not yet possible.

3.2 Theoretically, we plan to model penetration process of error field at tokamaks

Personnel:

- PPPL Postdoc #2 with A. Reiman NC-drift-MHD modeling being proposed (to be finalized soon)

3.3 Task for the or January 2013 meeting in Garching: Organize a discussion about characterization of the drive in different case (astrophysics, tokamaks, reconnection experiments)

4. RMP penetration and NTM seeding

Key questions: what decides reconnection threshold and rate as a function of perturbation amplitude, rotation speed, distance from the coils etc?

4.1 Experimentally, systematic dependences of RMP penetration on plasma parameters such as plasma density are of crucial importance to guide theoretical research. In addition to AUG, DIII-D data are also suggested to be resourceful. In a later year at MRX, plasma flow can be imposed on MRX to study the effects of flow shear on reconnection rate.

Personnel:

- German Postdoc #2 with V. Igochine at IPP on AUG-NSTX NTM seeding/error field penetration, see above.
- PPPL Postdoc #1 with H. Ji/M. Yamada on MRX-Vineta-tokamaks is being advertised.

4.2 Theoretically, a variety of modeling efforts can be coordinated.

Personnel:

- PPPL Postdoc #2 with A. Reiman NC-drift-MHD modeling being proposed (to finalized soon)
- Third party funded PPPL postdoc by J. Menard and J.K. Park using MARS
- Third party funded Ph.D. student at IPP Garching by S. Günter/K. Lackner 2-fluid modeling via XTOR (code ready, first comparison to AUG experiment planned for coming months)
- IPP Garching: 2 fluid simulations with JOREK planned (difference to XTOR: separatrix can be modeled), to be done by IPP postdoc, extensive benchmarks with M3D-C1 should be performed

5. Magnetic field in 3D and its dissipation

Key questions: Can we determine the magnetic structure in realistic 3D space? How does this relate to the Parker problem and the quasi-separatrix layer (QSL) concept? How do different boundary conditions (periodic, infinite, line-tied) affect reconnection? How is the magnetic energy dissipated and how to bridge the gap from micro to macro scales in describing this process? What is the role of 3D flux ropes that are spontaneously generated in the thin current sheets?
A central problem to be addressed is to what extent we can actually compare results from laboratory experiments to solar observations. Even if the structures produced in the lab and observed on the Sun look alike, they do not necessarily have to be governed by the same physical processes. This investigation will necessitate a strong interaction between solar observations and lab experiments interlinked by modeling efforts.

5.1. Observational approach.

Using solar observations we will investigate the interaction of flows and magnetic structures. This includes prominence-cavity systems, supra-arcade downflows, current sheets and (reconnection) jets. The main question here is how the magnetic configuration changes and which conditions lead to the instabilities. Another topic is field-aligned flows, how they relate to the underlying magnetic structure and what drives them. For these investigations we will use high-resolution imaging data (AIA), stereoscopic information (STEREO), and spectroscopic measurements (EIS/Hinode, IRIS).

Personnel:

- German postdoc #5 (D. Schmit) with D. Innes at MPS on solar prominence cavity systems (starting January 2013).
- D. Innes on the structure and evolution of solar jets
- H. Peter on field-aligned flows maybe together with a third-party funded PhD student.
- Third-party funded student (L. Guo) with A. Bhattacharjee on supra-arcade downflows

5.2 Experimental approach.

Using laboratory experiments we plan to study the 3D nature of eruptions at MRX related to solar flares and more quiescent active region loops. This would allow a direct comparison of the energy transport and flow in lab structures to solar observations. The same applies to dynamics within the current sheet developing in the experiment. Special emphasis will be on the problem to what extent lab experiments and solar observations are actually comparable.

Personnel:

- Third-party funded MRX student to study 3D eruption relevant to solar flares
- Third-party funded MRX student (TBD) to study 3D flux ropes

5.3. Modeling approach.

We plan to investigate the 3D structure and evolution of the magnetic field and its dissipation through a variety of theoretical and numerical models. Forward 3D MHD models including the synthesis of coronal emission will allow a direct comparison to solar observations. We also plan to perform simplified 3D MHD models to investigate the buildup of magnetic energy before solar eruptions and maybe to study the processes in the laboratory. Analytical and numerical models will be employed to investigate details of the 3D reconnection process, such as the enhancement of reconnection by inter-diffusion or multiple islands.

Personnel:

- German postdoc #4 (S. Bingert) with H. Peter at MPS on MHD modeling including the synthesis of coronal emission.
- Third-party funded PhHD student at MPS (J. Skala) with J. Büchner on MHD models of solar eruptions.
- Analytic models of reconnection by A. Boozer (of what?).
- Analytic and numerical modeling by A. Bhattacharjee with Y.-M. Huang (of what?).

6. Subgrid modeling in MHD

Key questions: which subgrid models can be used to reproduce the observations in the lab, on the Sun and in astrophysics in general? How do they compare for different codes? Available models include (1) isotropic resistivity and viscosity, valid for unmagnetized and collisional plasmas, (2) Braginskii's transport coefficients, valid for magnetized, collisional or semi-collisional plasmas (3) Anomalous resitivity, valid for increased momentum exchanges between electrons and ions due to localized micro-instabilities (4) Anomalous electron viscosity (or hyper-resistivity), valid for increased momentum transport within the electron fluid.

Personnel:

- German postdoc #4 (S. Bingert) with H. Peter at MPS on subgrid MHD modeling, MRX flare experiment modeling, compare with IRIS observations
- Princeton astro postdoc by J. Stone (Need to check)
- PPPL Postdoc #2 with A. Reiman NC-drift-MHD modeling being proposed (to be finalized soon)

7. Sawtooth reconnection at tokamaks

Key question: what is the trigger mechanism? How does it modified by two-fluid and kinetic effects? Is it 3D? How does it affect NTM? Is there a third (thermal diffusion) time scale?

7.1 Experimentally, existing and new data from AUG on both magnetic field (MSE diagnostics) and electron temperature (ECE diagnostics) will be examined and studied.

Personnel:

- German Postdoc #2 with V. Igochine at IPP on AUG-NSTX NTM seeding/error field penetration: comparison of M3D-C1 code results to experiment

7.2 Theoretically, both the M3D-C1 code and a separate two-fluid code will be used.

Personnel:

- A German student (Isabel Krebs) will visit PPPL, funded by German side first and by PPPL later, will use M3D-C1 supervised by S. Jardin on thermal crash; NTM triggering, sawtooth triggering by 1/1 perturbations, relations between sawtooth and snakes
- 3D 2-fluid modeling by A. Bhattacharjee with a research scientist (Q: what's status of this project?)

8. MHD relaxation processes in tokamak and space/solar plasmas

Key questions: are nonlinear ballooning processes at tokamak edges related to sub-storms? Do MHD relaxations involving magnetic helicity transport common to CHI (Coaxial Helicity Injection) processes and solar flare processes?

8.1 Experimentally, ELM/CHI data from NSTX/AUG/DIII-D and observationally, solar data by MPS scientists should be useful.

Personnel:

- German Postdoc #2 with V. Igochine at IPP on AUG-NSTX NTM seeding/error field penetration: comparison of M3D-C1 code results to experiment
- Third party funded personnel to assess NSTX/DIII-D data by J. Menard and R. Raman at PPPL
- Third party funded personnel to asses solar data at MPS

8.2 Theoretically, relaxations can be studied using MHD models

Personnel:

- Third party funded scientist (F. Ebrahimi) by A. Bhattacharjee using NIMROD code (Q: Status?)
- Third party funded scientist (?) Günter and Hölzl using JOREK code (Q: Status?)

Part II: Possible cross-cutting research with other topics within MPPC

1. With Turbulence group
   with Frank Jenko on turbulence and reconnection

2. With MRI group
   reconnection in MRI dynamo/turbulence

3. With Energetic Particle group
particle acceleration and heating due to reconnection

Part III: Summary of MPPC postdocs/students

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- German Postdoc #1 will start December 1st 2012 at IPP Greifswald with O. Grulke on Vineta experiment.
- German Postdoc #2 with V. Igochine at IPP on AUG-NSTX NTM seeding/error field penetration: comparison of M3D-C1 code results to experiment
- German Postdoc #3 (N. Jain) started at MPS with J. Buechner on EMHD modeling on 3D impulsive reconnection found at MRX, including guide field dependence
- German postdoc #4 (S. Bingert) with H. Peter at MPS on subgrid MHD modeling, MRX flare experiment modeling, compare with IRIS observations
- German postdoc #5 (D. Schmit) with D. Innes at MPS on modeling of solar filamented plasmoids and ion/electron distributions