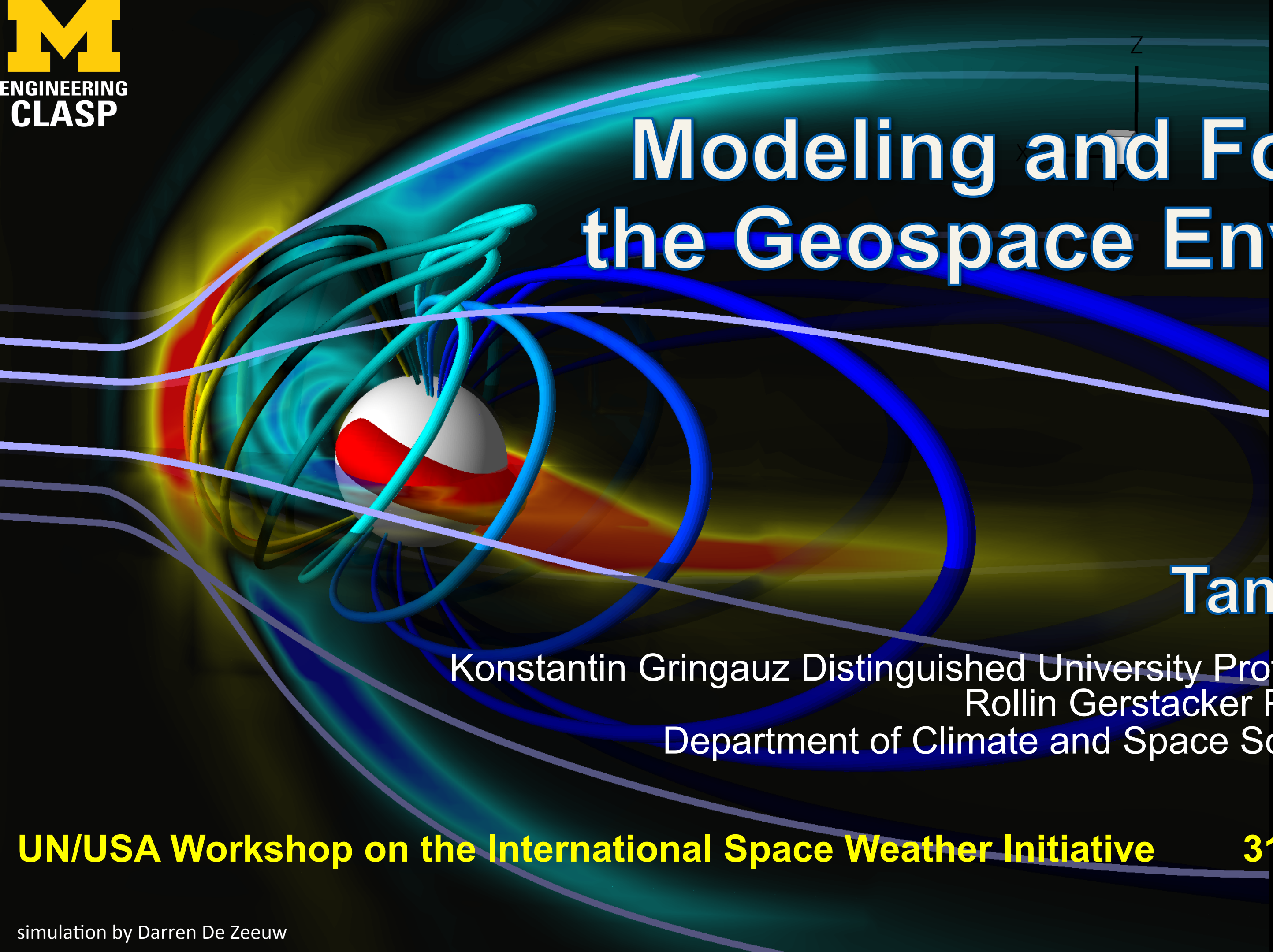


Modeling and Forecasting the Geospace Environment

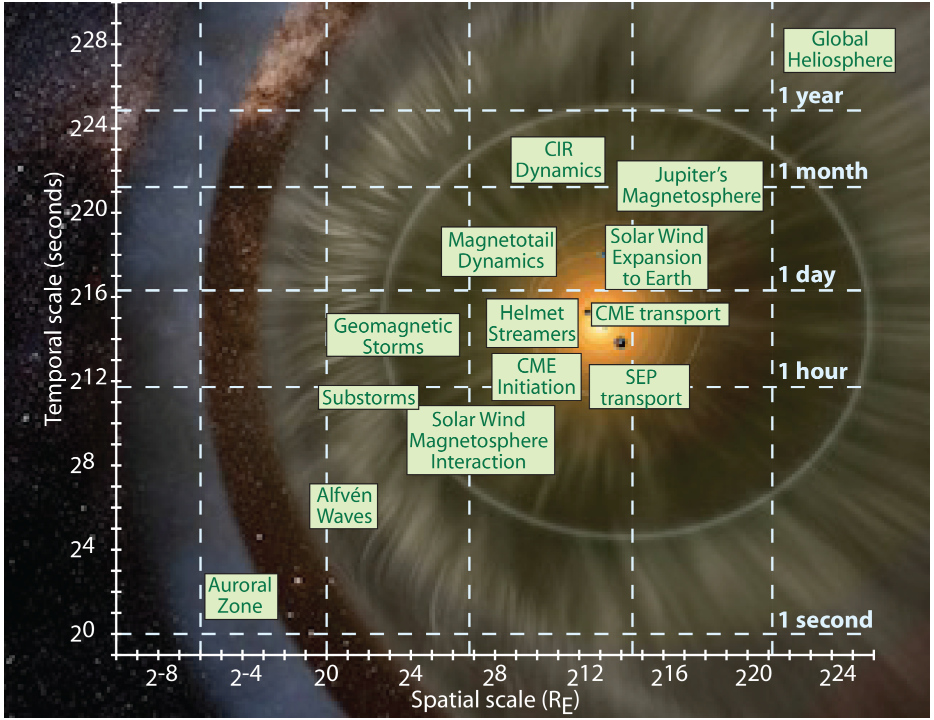
Tamas Gombosi

Konstantin Gringauz Distinguished University Professor of Space Science
Rollin Gerstacker Professor of Engineering
Department of Climate and Space Sciences and Engineering
University of Michigan

UN/USA Workshop on the International Space Weather Initiative **31 July – 4 August, 2017**

simulation by Darren De Zeeuw

Space Weather Scales

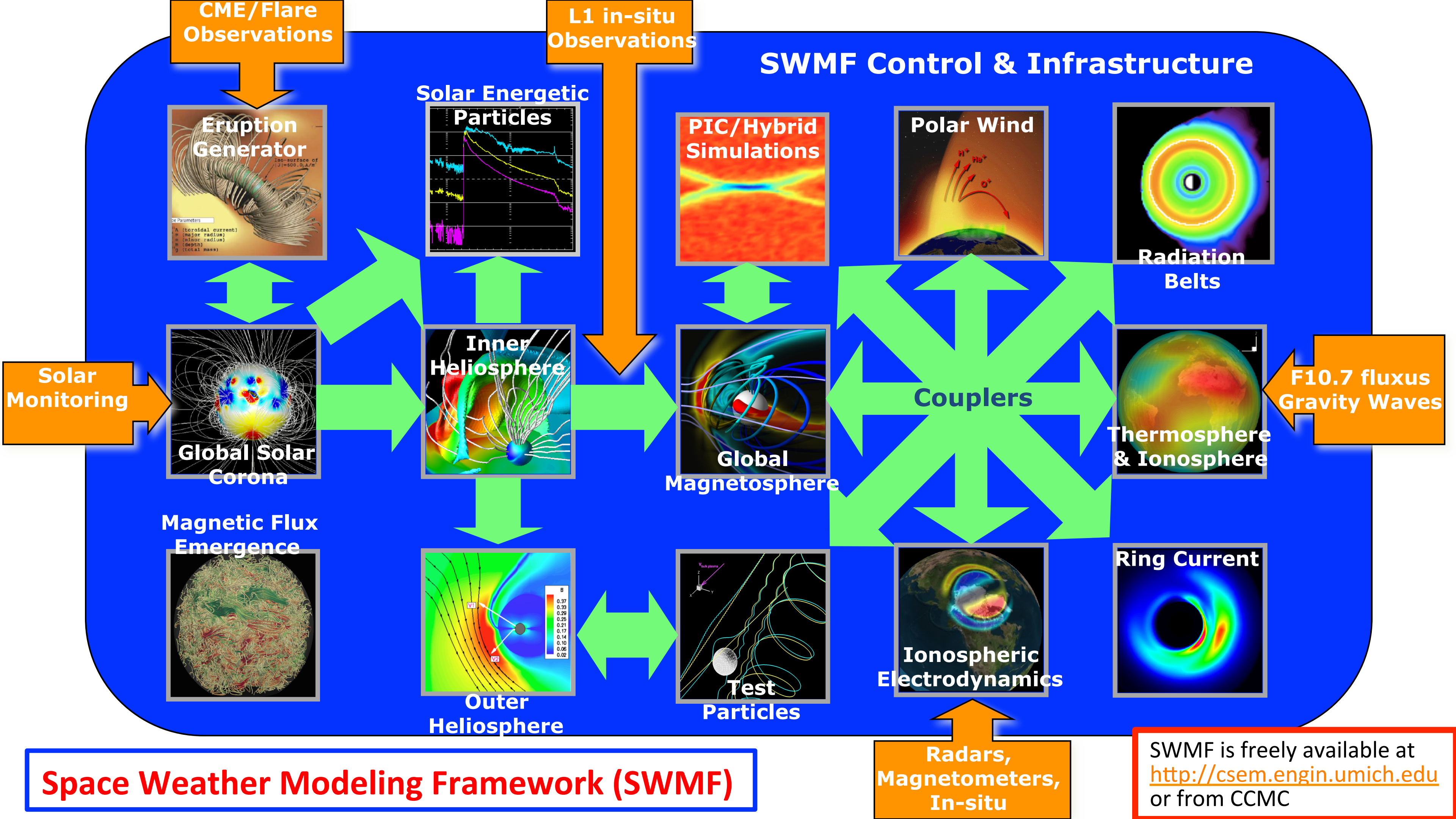


- Multi-scale
  - Temporal range: $2^{28} \sim 2.7\times10^{8}$
  - Spatial range: $2^{28} \sim 2.7\times10^{8}$
  - Cell volume range: $2^{84} \sim 1.9\times10^{25}$
- Multi-physics – from kinetic to MHD
  - Solar interior and dynamo
  - Transition region
  - Corona
  - Heliosphere
  - Magnetosphere
  - Ionosphere-upper atmosphere
  - Ground currents

ENGINEERING CLASP

Tamas I. Gombosi
tamas@umich.edu
http://www-personal.umich.edu/~tamas/

CENTER FOR SPACE ENVIRONMENT MODELING CSEM



Space Weather Modeling Framework (SWMF)

SWMF is freely available at
http://csem.engin.umich.edu
or from CCMC

Multiphysics X-MHDCode: BATS-R-US

Block Adaptive-Tree Solar-wind Roe-type Upwind Scheme

Time-stepping
Local explicit (CFL control) for steady state
Global explicit
Part steady explicit
Explicit/implicit
Point-implicit
Semi-implicit
Fully implicit

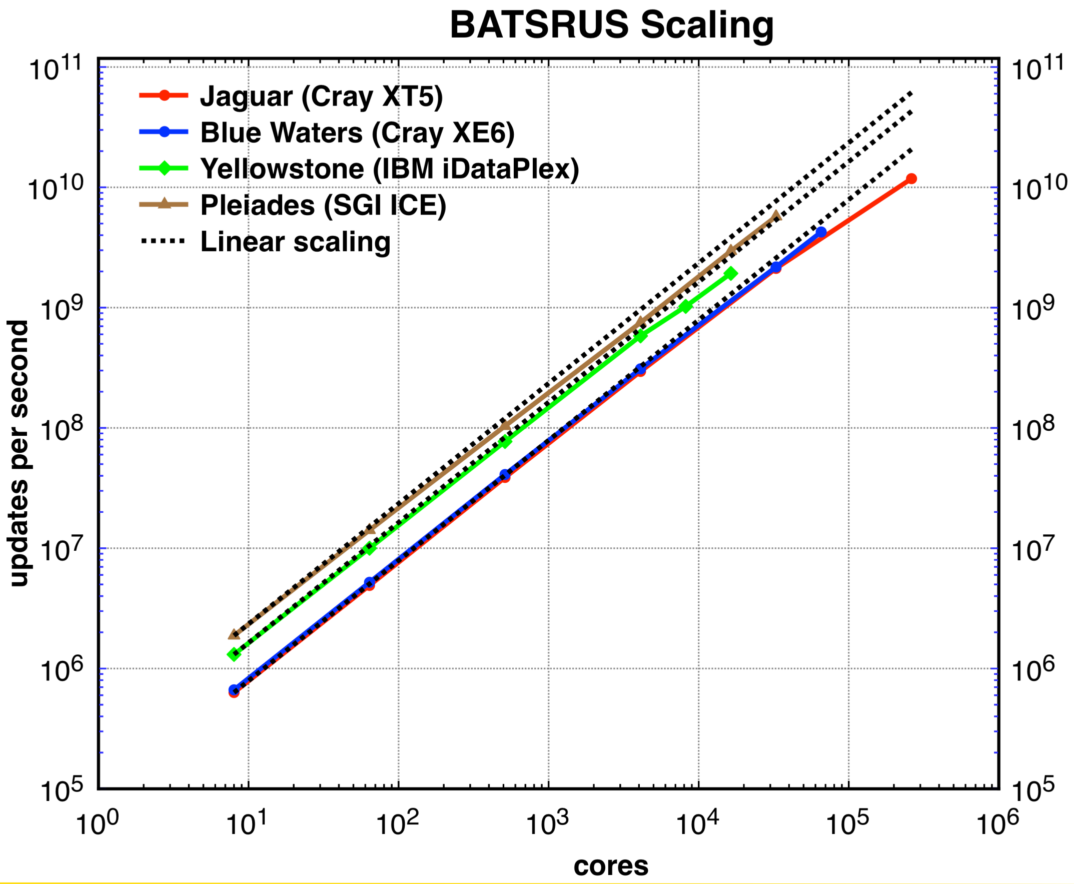
Conservation laws
Hydrodynamics
X-MHD
Ideal & non-ideal
Hall
Anisotropic pressure
Semi-relativistic
Multi-species
Multi-fluid
Ideal & non-ideal EOS

Numerics
Conservative finite-volume discretization
2nd (TVD), 4th (PPM) & 5th (MP) spatial order schemes
Rusanov/HLLE/AW/Roe/HLLD
Splitting the magnetic field into $B_0 + B_1$
Divergence B control
CT, 8-wave, projection, parabolic-hyperbolic cleaning

AMR Library (BATL)
Self-similar blocks
Cartesian grid
Curvilinear grid (can be stretched)
Supports 1, 2 and 3D block-adaptive grids
Allows AMR in a subset of the dimensions

Source terms
Gravity
Heat conduction
Ion-neutral friction
Ionization
Recombination
Charge exchange
Wave energy dissipation
Radiative heating/cooling

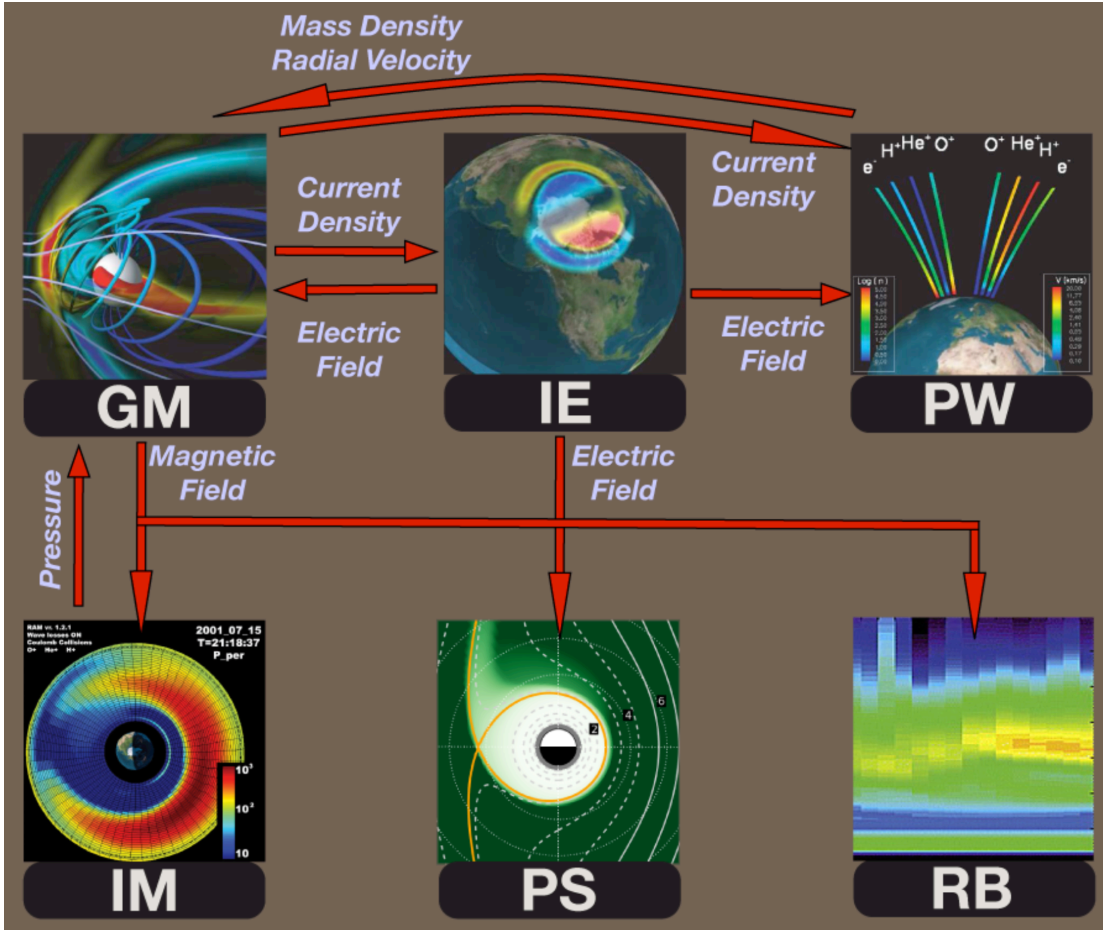
Auxiliary equations
Wave energy transport
Radiation transfer (multigroup diffusion)
Material interface (level set)
Parallel ray-tracing
Tabular equation of state



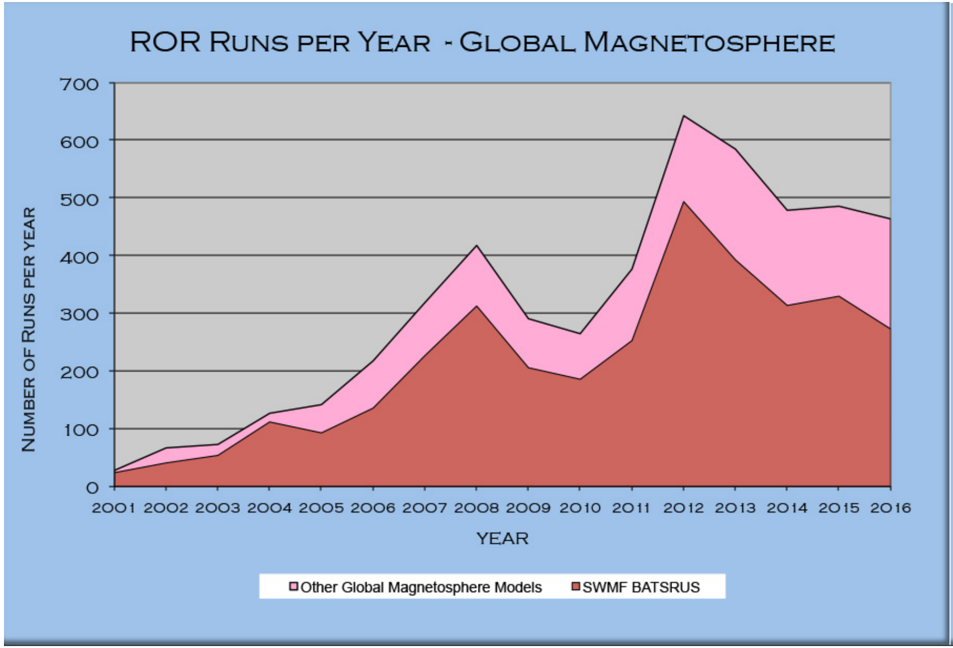
Tamas I. Gombosi
tamas@umich.edu
http://www-personal.umich.edu/~tamas/

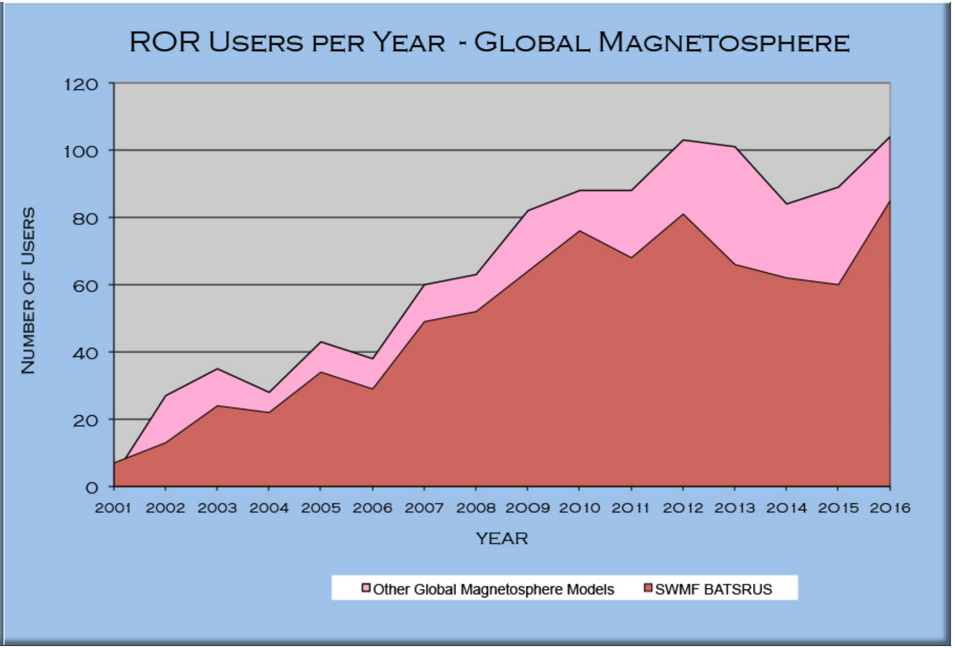
SWMF/Geospace Model

- XMHD options
  - Ideal MHD
  - Resistivity models
  - Single species, mutispecies, multifluid
  - Hall MHD
  - Isotropic or anisotropic temperatures
- Input:
  - Upstream solar wind
  - Date/time (for magnetic axis)
  - F10.7 flux
- Simulated observables:
  - Dst, Kp, regional K, CPCP, individual magnetometers, …
  - Plasma parameters anywhere in the magnetosphere
  - Ionospheric convection



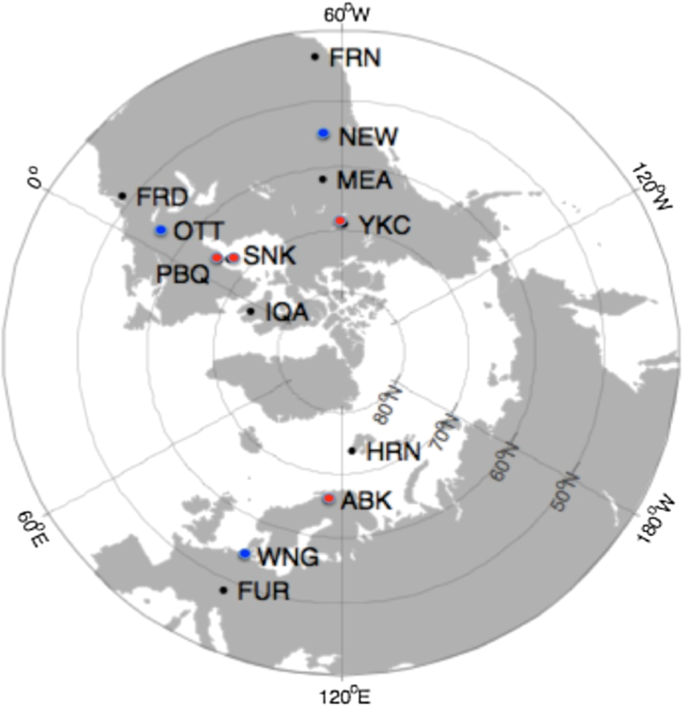
SWMF/Geospace at the CCMC

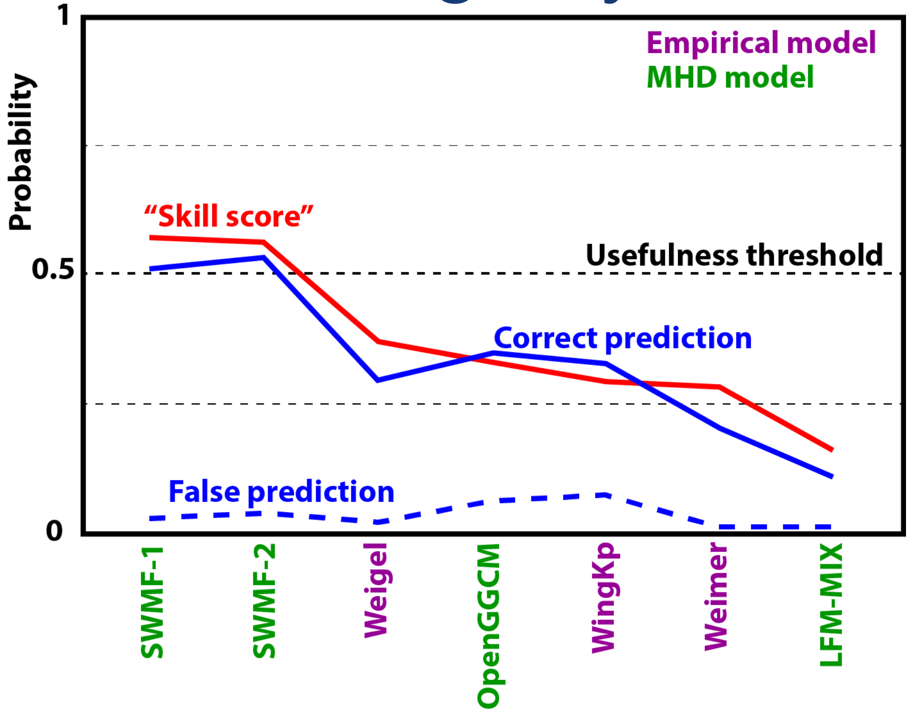




Tamas I. Gombosi
tamas@umich.edu
http://www-personal.umich.edu/~tamas/

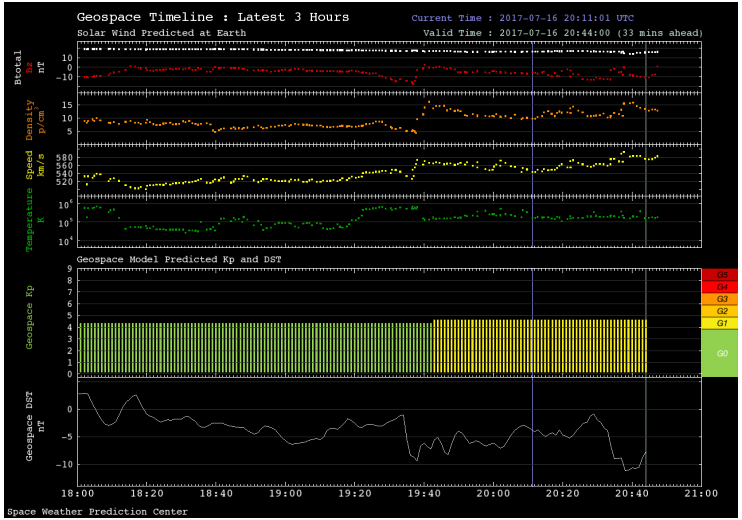
SWPC Geospace Model Challenge by CCMC

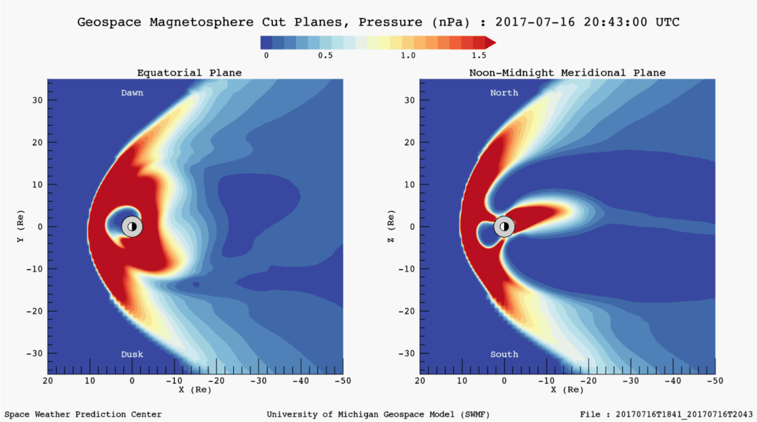


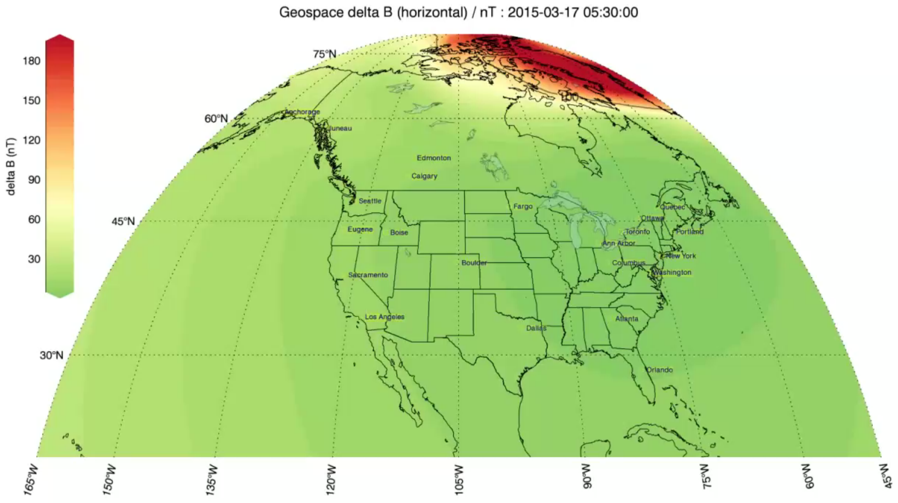


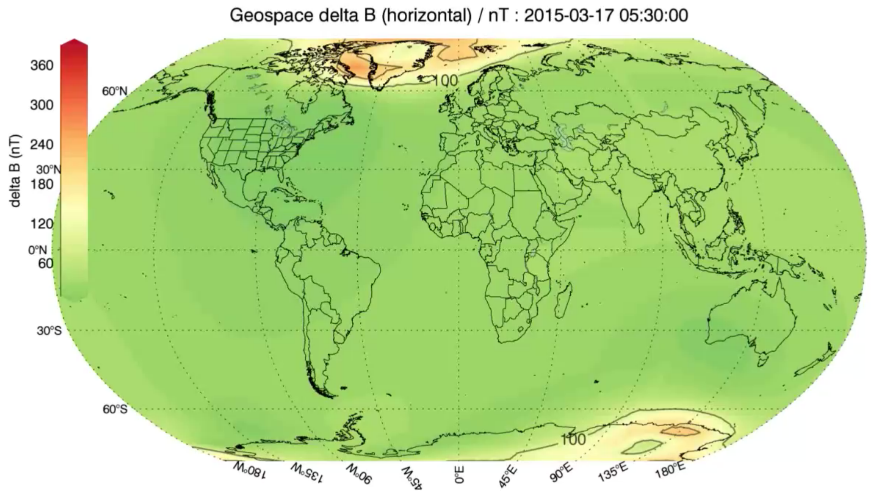
Glocer et al., Space Weather, 2016 (doi: 10.1002/2016SW001387)
Pulkkinen et al., Space Weather, 2013 (doi: 10.1002/swe.20056)

SWMF @SWPC


Geospace Timeline : Latest 3 Hours
Current Time : 2017-07-16 20:11:01 UTC
Solar Wind Predicted at Earth
Valid Time : 2017-07-16 20:44:00 (33 mins ahead)
Btotal Bz nT
Density p/cm³
Speed km/s
Temperature K
Geospace Model Predicted Kp and DST
Geospace Kp
G5
G4
G3
G2
G1
G0
Geospace DST nT
18:00
18:20
18:40
19:00
19:20
19:40
20:00
20:20
20:40
21:00
Space Weather Prediction Center

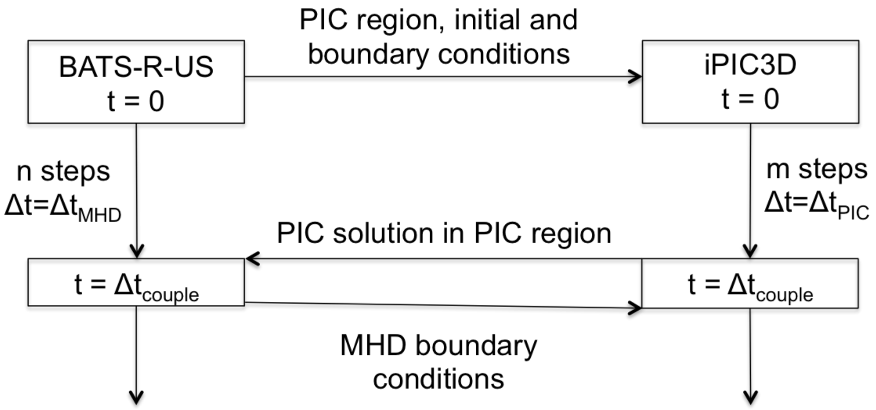

Geospace Magnetosphere Cut Planes, Pressure (nPa) : 2017-07-16 20:43:00 UTC
Equatorial Plane
Dawn
Dusk
Noon-Midnight Meridional Plane
North
South
X (Re)
Y (Re)
Z (Re)
Space Weather Prediction Center
University of Michigan Geospace Model (SWMF)
File : 20170716T1841_20170716T2043


Geospace delta B (horizontal) / nT : 2015-03-17 05:30:00
delta B (nT)
75°N
60°N
45°N
30°N

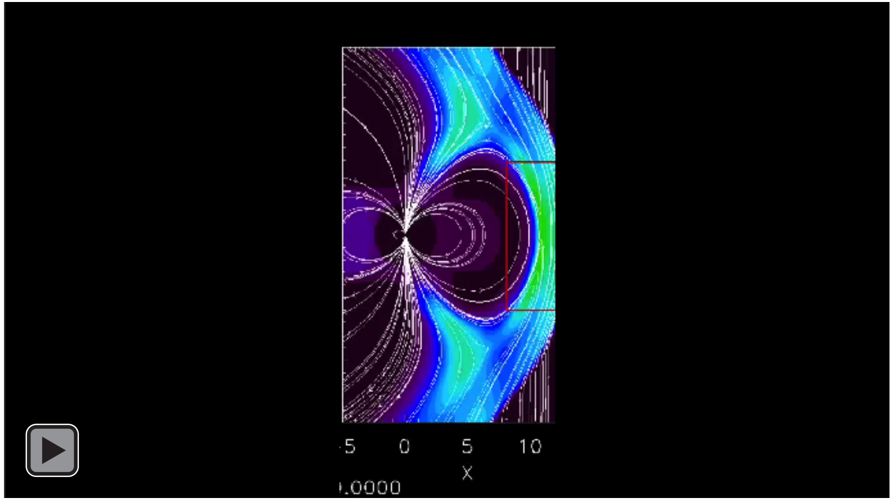

Geospace delta B (horizontal) / nT : 2015-03-17 05:30:00
delta B (nT)
60°N
30°N
0°N
30°S
60°S

Next Step: MHD-EPiC

- Combines the efficiency of the global fluid code with the physics capabilities of the local PIC code
- MHD provides the initial state and boundary conditions for PIC
- PIC overwrites the overlapped MHD cells
- Details
  - Multi-ion MHD. Separate electron pressure.
  - Different PIC and MHD grids including non-Cartesian AMR MHD grids.
  - Different PIC and MHD time steps
  - Multiple PIC domains
  - Efficiency and robustness

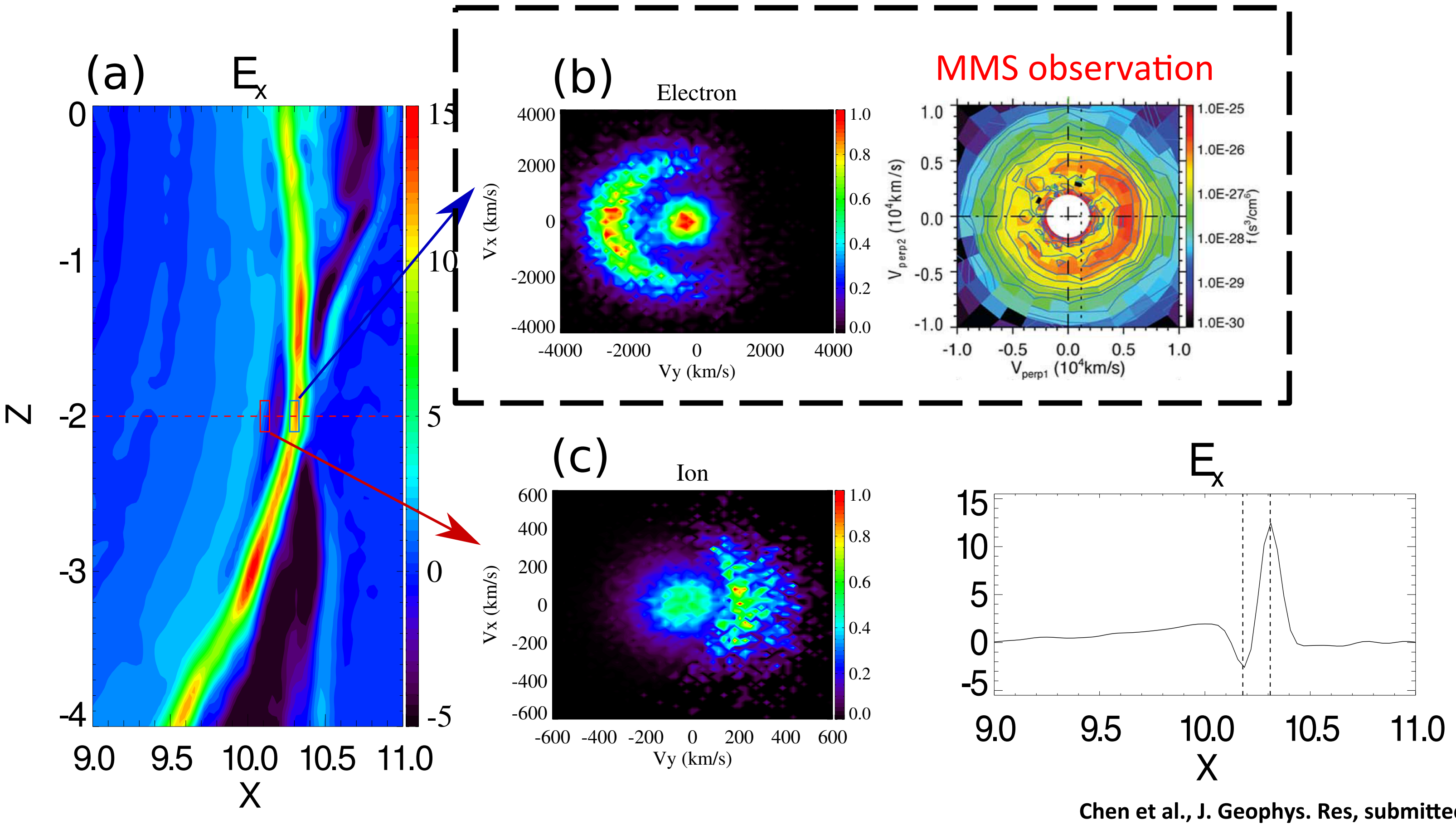


p [nPa]



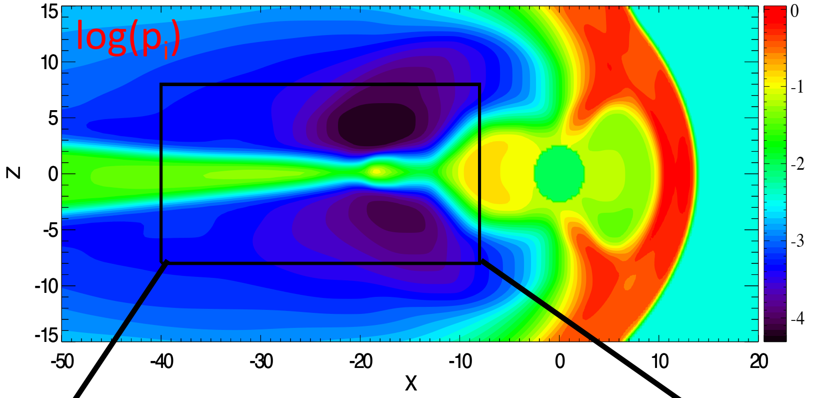
Daldorff et al., J. Comp. Phys., 2014 (doi: 10.1016/j.jcp.2014.03.009)
Toth et al., J. Geophys. Res., 2016 (doi:10.1002/2015JA021997)
Chen et al., J. Comp. Phys., 2016 (doi: 10.1016/j.jcp.2015.11.003)

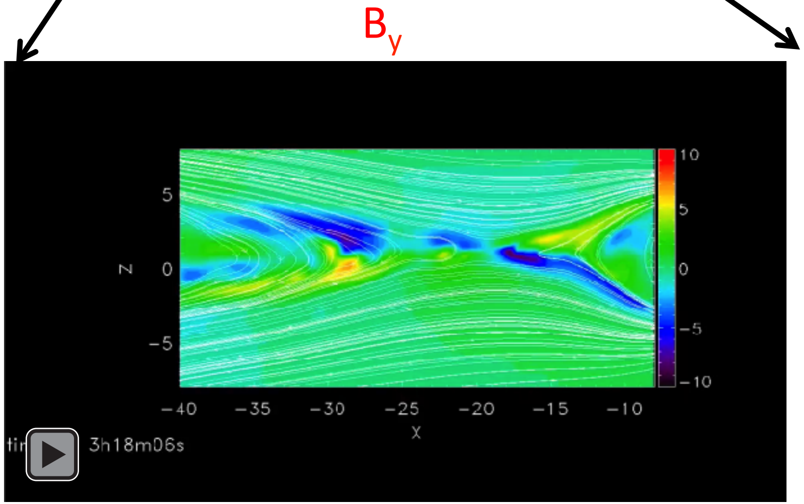
Crescent Distribution & Electric Field

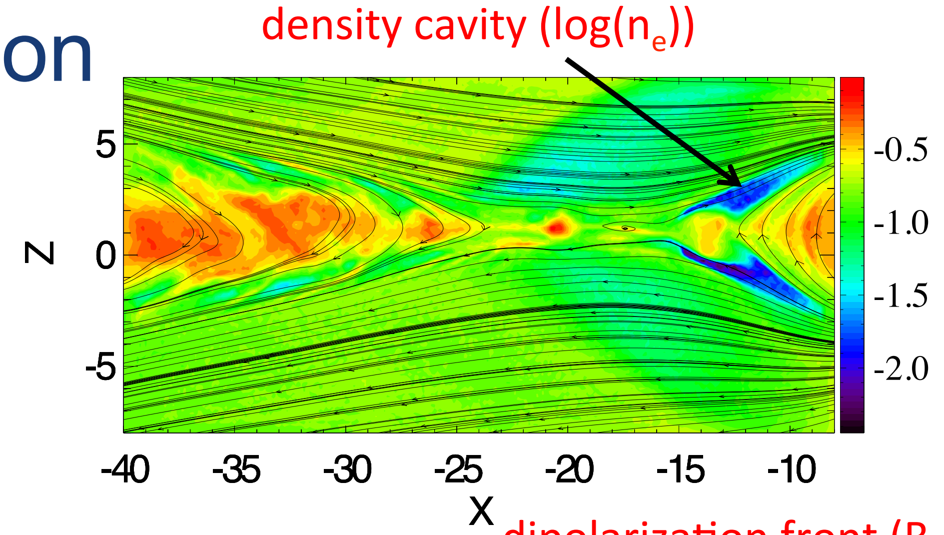


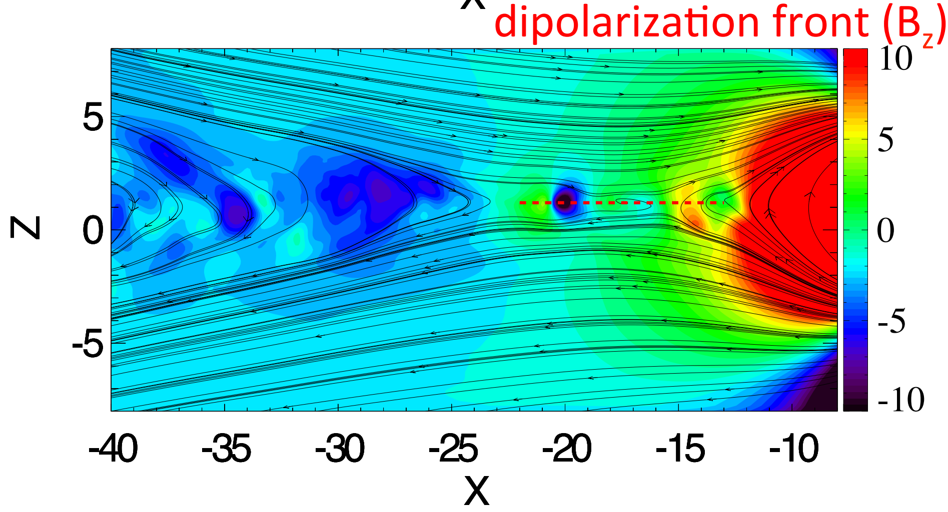
Chen et al., J. Geophys. Res, submitted, 2017

Magnetotail Reconnection









Chen et al., J. Geophys. Res, submitted, 2017

Summary

- Over the last decade physics-based global geospace models became a bridge between experiment and basic theory and now they represent the “third pillar” of geospace research
- Geospace models are widely used by the space weather community via CCMC
- SWMF/Geospace has been transitioned to NOAA/SWPC and it is will enter operations in September 2017
- SWMF and all its components are available for download (after registration) at http://csem.engin.umich.edu
- The next challenge in geospace models is incorporating kinetic physics where needed (MHD-EPiC)

Tamas I. Gombosi
tamas@umich.edu
http://www-personal.umich.edu/~tamas/