CSEM–CCMC Collaboration

Tamas Gombosi

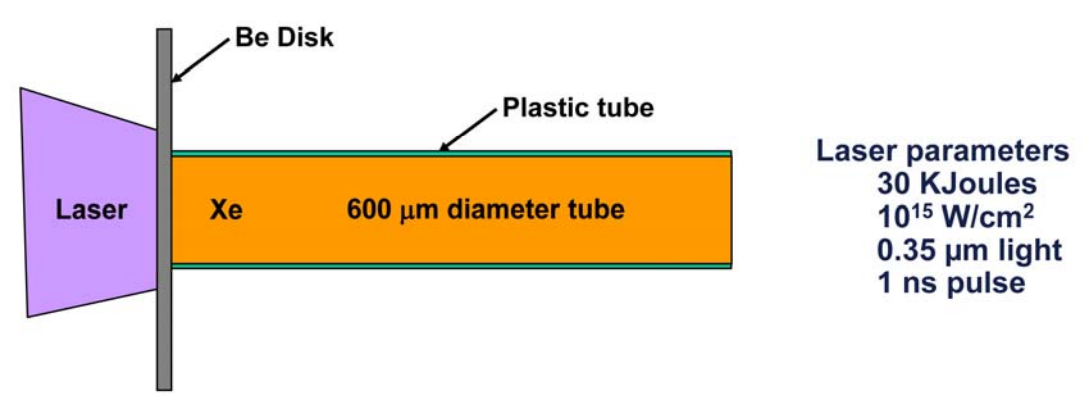
CCMC Workshop
January 25-29, 2010
Key Largo, FL

Center for Space Environment Modeling

- Goal: To develop high-performance, first-principles based computational models to describe and predict hazardous conditions in the near-earth space environment, extending from the Sun to the ionosphere, that run considerably faster than real time on mid-size parallel computers.
- CSEM spans across discipline and departmental boundaries. Its participants combine expertise in
  - modern numerical algorithms,
  - massively parallel computational technologies,
  - high-performance computational physics,
  - solar, interplanetary, magnetospheric, and ionospheric physics.
- CSEM works in close collaboration with other scientists from universities, government laboratories, nonprofit organizations, and industry.

Center for Radiative Shock Hydrodynamics

- CRASH is funded by a $17-million, five-year cooperative agreement from NNSA.
- CRASH is one of five Predictive Science Academic Alliance Program centers.
  - Predictive science is the study of the behavior of complex systems, especially systems where full scale experiments or prototypes are impossible.
- CRASH will develop numerical simulations of laser plasma experiments.
- There is a high level of synergism between CRASH and CSEM.



CSEM/CRASH Team at Michigan

- Developers (5): Darren De Zeeuw, Bart van der Holst, Aaron Ridley, Igor Sokolov, Gabor Toth
- Backseat drivers (4): Paul Drake, Tamas Gombosi, Ken Powell, Quentin Stout
- Alpha users (7): Bruce Fryxell, K.C. Hansen, Chip Manchester, Eric Myra, Aaron Ridley, Martin Rubin, Valerii Tenishev
- Postdocs (4): Xianzhe Jia, Dave Pawlowski, Geeta Vichare, Erdal Yigit
- Collaborators (19): Dennis Bernstein, Steve Bougher, Mike Combi, Krzysztof Fidlowski, Rich Frazin, Natasha Ganushkina, James Holloway, Smadar Karni, Janet Kozyra, Carolyn Kuranz, Ed Larsen, Bram van Leer, Mike Liemohn, Bill Martin, Mark Moldwin, Andy Nagy, Vijayan Najir, Phil Roe, Katsuyo Thornton
- Students (11): Fang Fang, Julie Feldt, Zhenguang Huang, Raluca Ilie, Roxane Katus, Jin Meng, Xing Meng, Dalal Najib, Stav Ofer, Rona Oran, Yiqun Yu

CSEM and CCMC

- Models
  - BATS-R-US was the first model at CCMC (2000)
  - BATS-R-US was the first RoR model at CCMC in 2001
  - BATS-R-US/SWMF is running in an experimental 24/7 real-time mode since 2002
  - SWMF is available at CCMC since 2004
  - SWMF is used for NASA mission support since 2008
- Statistics
  - 1275 RoRs were made with SWMF/BATS-R-US out of 2900 total runs (45%)
  - ~75% of all magnetosphere RoR runs used SWMF/BATS-R-US
- Impact of RoRs
  - ~100 Presentations
  - ~30 Peer reviewed publications
  - 5 Ph.D. dissertations
- CCMC has access to the CSEM CVS repository and there is no “time-lag” between CSEM and CCMC codes.

CSEM/CRASH Capabilities: Physics

Fluid Equations

- Compressible HD
- Ideal MHD
- Semi-relativistic MHD
- Resistive MHD
- Single-fluid Hall MHD
- Two-fluid Hall MHD
- Multi-species MHD
- Multi-fluid MHD
- Anisotropic pressure
- Heat conduction

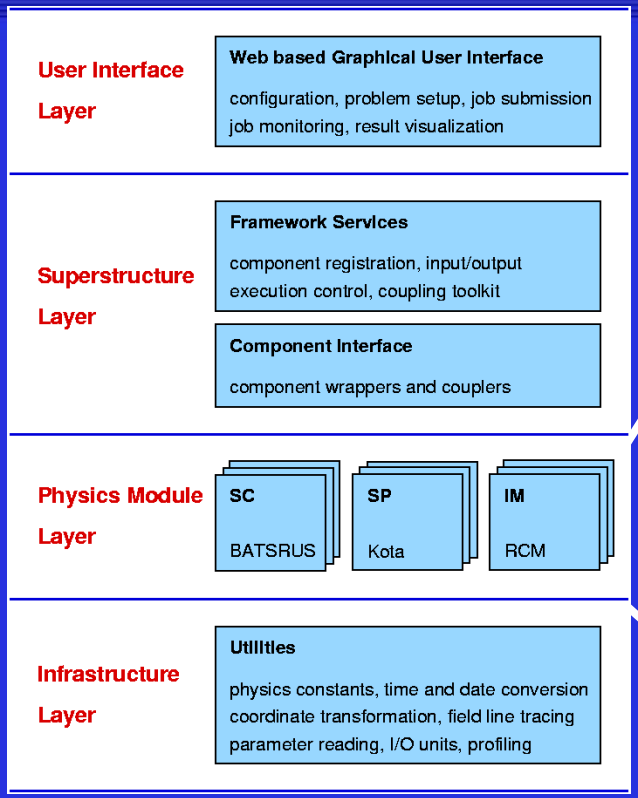
Additional Physics

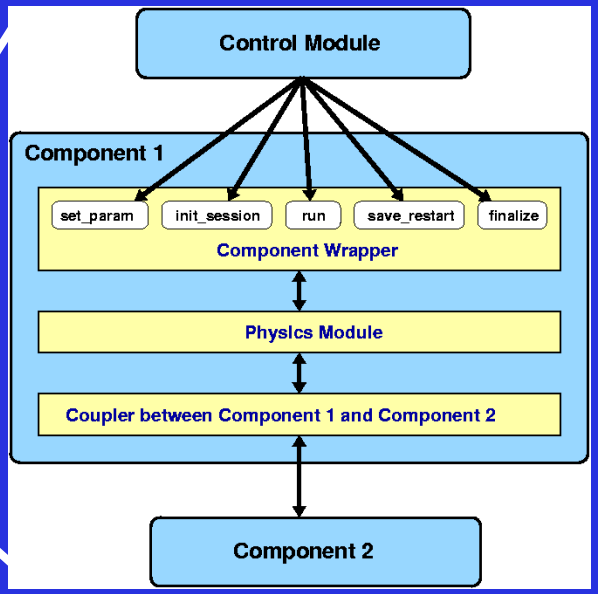
- Multiple materials
- Non-ideal EOS
- Radiation
  - Gray diffusion
  - Multigroup diffusion
- Source terms
  - Gravity, mass loading, chemistry, photo-ionization, recombination, etc…
- Various resistivity models
- Semi-empirical coronal heating
- Alfven wave energy transport and dissipation
- Self-consistent turbulence

CSEM/CRASH Capabilities: Numerics

- Time integration Schemes
  - Local time-stepping for steady state
  - Explicit (with Boris correction)
  - Explicit/implicit
  - Semi-implicit
  - Point-implicit
- Grids
  - Block-adaptive tree
  - Cartesian
  - Generalized grids including spherical, cylindrical, toroidal
- TVD Solvers
  - Roe
  - HLLD
  - HLLE
  - Artificial-wind
  - Rusanov
- Limiters
  - Koren (3rd order)
  - MC
  - Beta
- Div(B) control
  - 8-wave
  - Hyperbolic/parabolic scheme
  - Projection
  - Staggered grid (CT)
- Ray tracing
  - Fast & parallel
- Synthetic images
  - White light coronagraph
  - EUV LOS (171Å, 195Å, 284Å)
  - X-ray radiographs
- Tomography

CSEM/CRASH Capabilities: SWMF

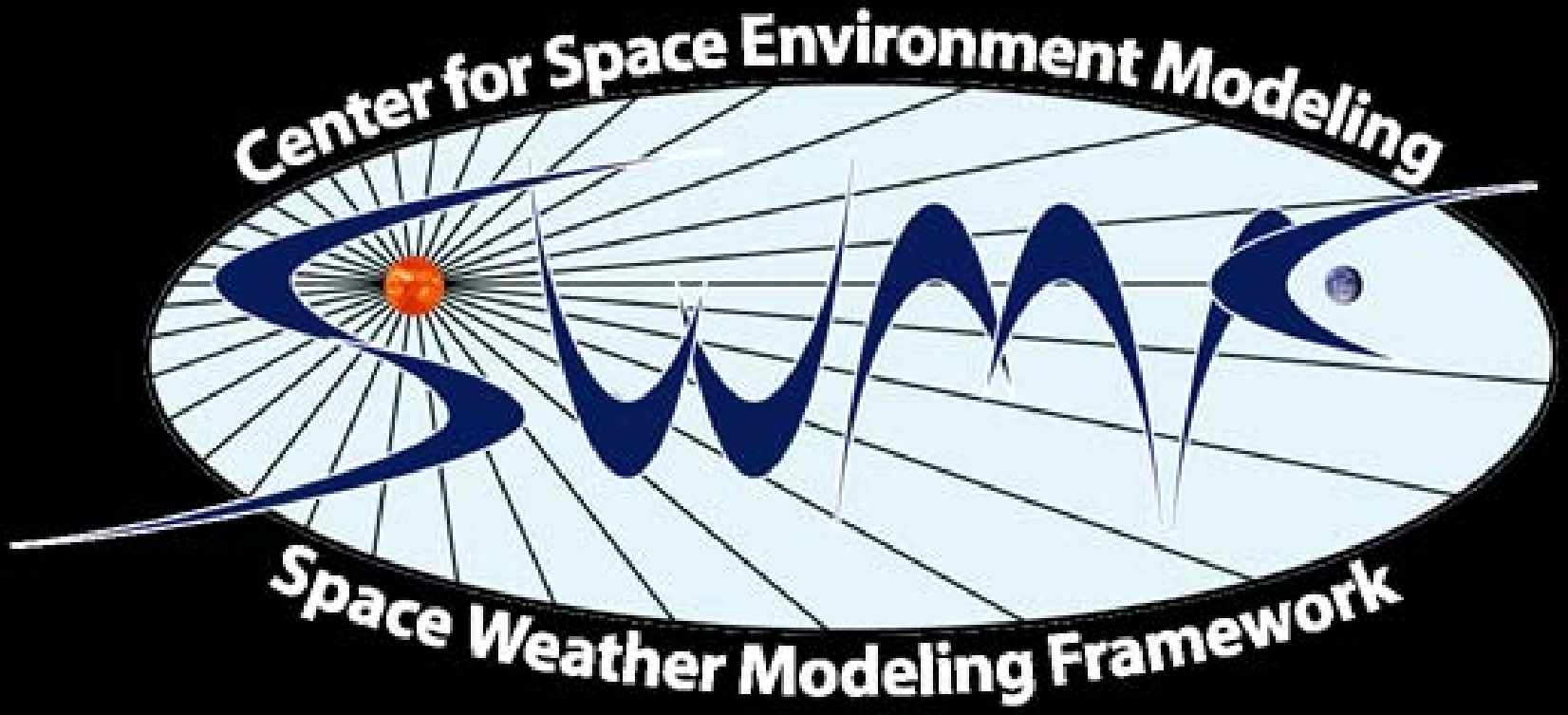




- Source code:
  - 250,000 lines of Fortran in the currently used models
  - 34,000 lines of Fortran 90 in the core of the SWMF
  - 13,000 lines of Fortran 90 in the wrappers and couplers
- User manual with example runs and full documentation of input parameters
- Fully automated nightly testing on 9 different machine/compiler combinations
- SWMF runs on any Unix/Linux based system with a Fortran 90 compiler, MPI library, and Perl interpreter

Education and Outreach

- Ph.D. and postgraduate education
- Undergraduate education (UROP, REU)
  - Summer internships
  - Historically minority institutions
    - Northern Michigan University
    - Howard University
- RET
- K-12
  - Museums (Ann Arbor Hands-on Museum)
  - AMNH/Hayden Planetarium
  - Lectures/class visits

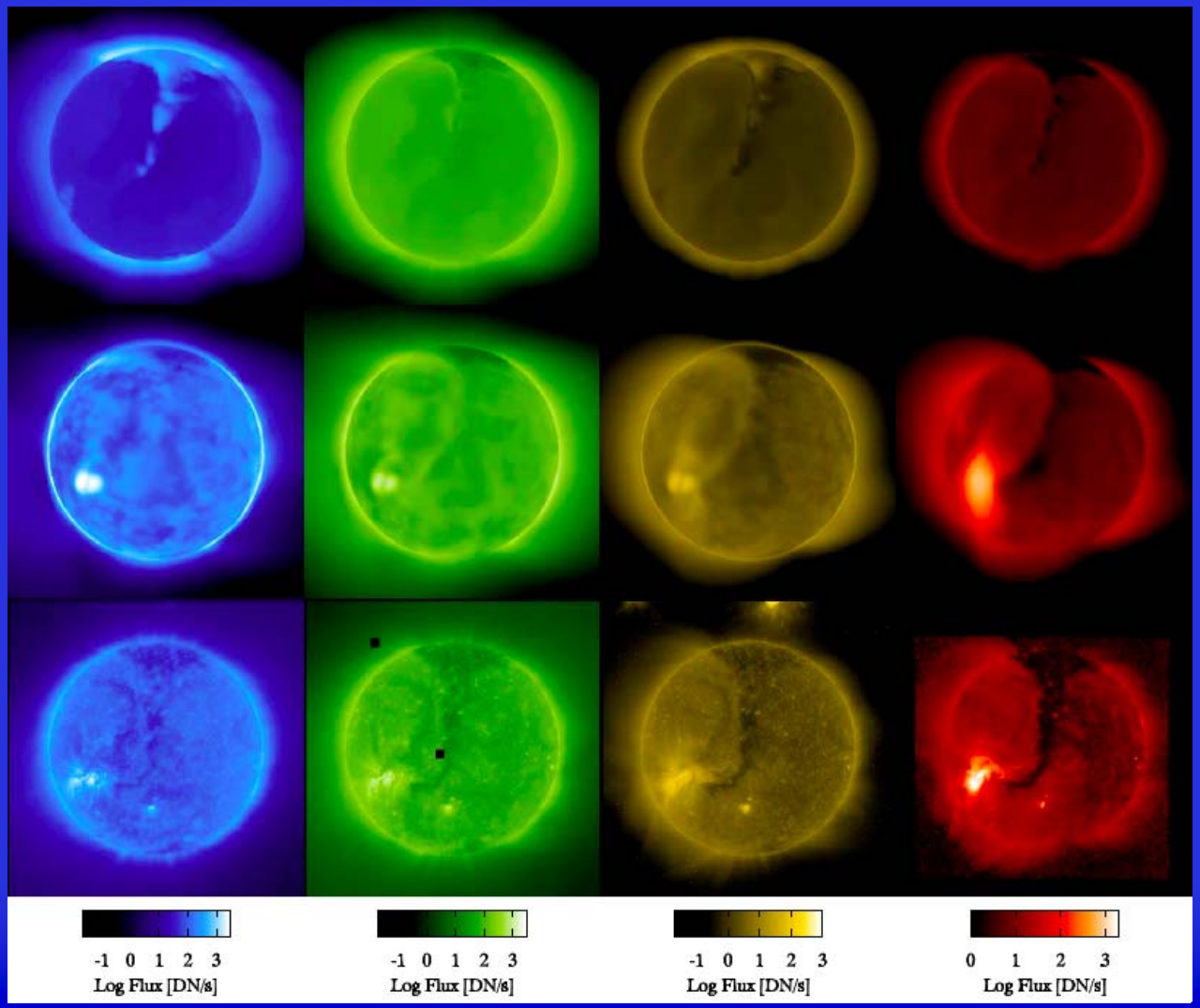

Center for Space Environment Modeling
SWMF
Space Weather Modeling Framework

SWMF Modules

Domain		Name	Description
Eruption generator	EE	Unstable flux rope	Erupting unstable magnetic flux rope
Low corona	LC	BATS-R-US	Υ=5/3 + single fluid + h_e + radiative losses + Exp heating + from chromosphere (T=20,000K, n_e=10^{12}) to 1.5 R_s
Solar corona	SC	BATS-R-US	LOS magnetogram + WSA + MHD with variable Υ
	SC	BATS-R-US	Υ=5/3 + two fluids (e, i) + h_e + self consistent Alfvén wave heating (with 4D TURB)
Solar wind	IH	BATS-R-US	Ideal MHD
Outer heliosphere	OH	BATS-R-US	Ideal MHD + 4 neutral fluids
Solar wind turbulence	TB	4D TURB	Solves for $I_{\pm}(t,\mathbf{r},\omega)$ + 2-way coupling of wave turbulence to MHD plasm
SEP	SP	FLAMPA	Solves for F(t,**r**,v) along magnetic field lines
Global magnetosphere	GM	BATS-R-US	Ideal MHD, resistive MHD, Hall MHD, Multifluid MHD, Boris correction, $p_{\|}$ & $p_{\perp}$
Radiation belt	RB	RBE	Bounce averaged kinetic equation for relativistic electrons with azimuthal drifts
Polar wind	PW	PWOM	Solves for H^+, He^+ and O^+ along a set of open field lines between 200 and 8000 km
Ring current	IM	RCM	Energy dependent drift model for the flux-tube content of e, H^+ and O^+
	IM	Fok Ring Current	Bounce averaged non-relativistic kinetic model for H^+ and O^+
	IM	HEIDI	Bounce averaged energy dependent drift model for e, H^+, He^+ and O^+
Plasmaphere	PS	DGCPM	Single continuity equation for the low energy plasma content of a moving flux tube
Ionospheric potential	IE	RIM	Solves the potential distribution in a height integrated ionosphere
Upper atmosphere	UA	GITM	3D dynamic ionosphere/thermosphere model with energetics and chemistry

New Low Corona Model

EIT 171Å EIT 195Å EIT 284Å SXT AlMg



CR1913

Old SC model synthesis

New LC model synthesis

Observation: Aug 27, 1997

More About CSEM Contributions to CCMC

- Tuesday:
  - Bart van der Holst: SWMF Solar/Heliopshere (10:30 - 10:55 am)
  - Gabor Toth: SWMF Magnetosphere (5:00 - 5:25 pm)
  - Aaron Ridley: SWMF Ionosphere/RIM/GITM (6:55 - 7:20 pm)
- Friday:
  - Igor Sokolov: 4D Solar Wind Turbulence Model (9:10 - 9:30 am)