A Few Highlights of Space Science Computational Challenges

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NASA SMD Computational Modeling Capabilities Workshop
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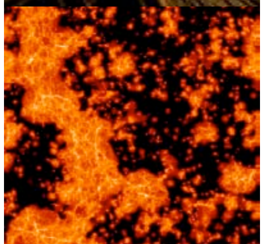
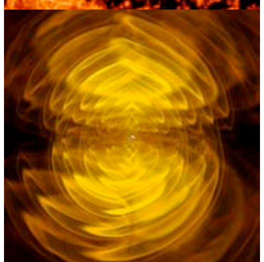
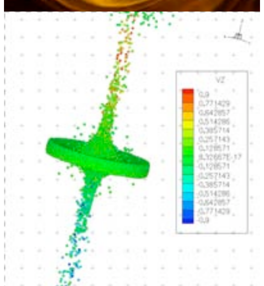
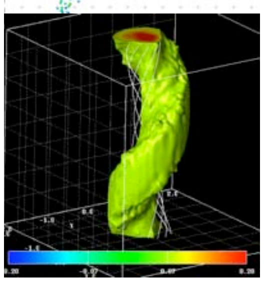
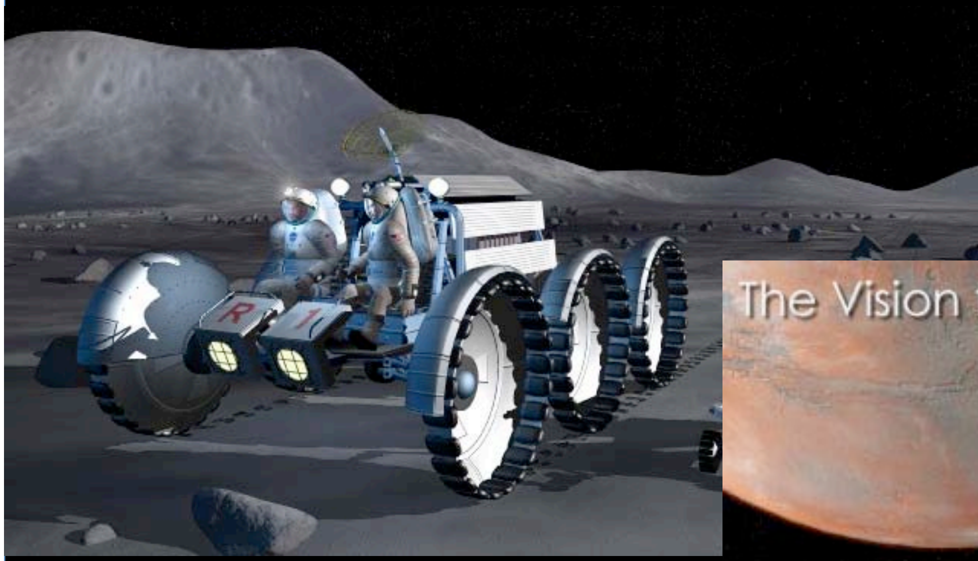
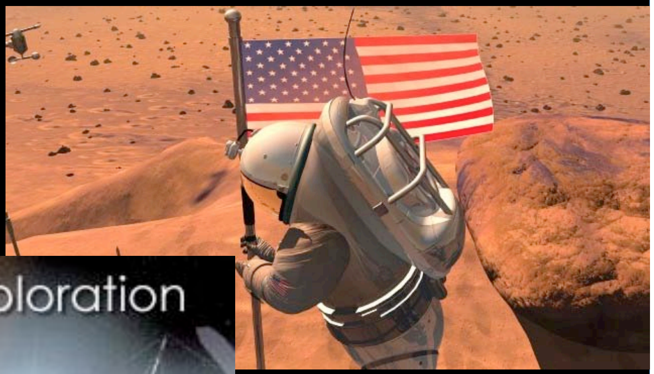





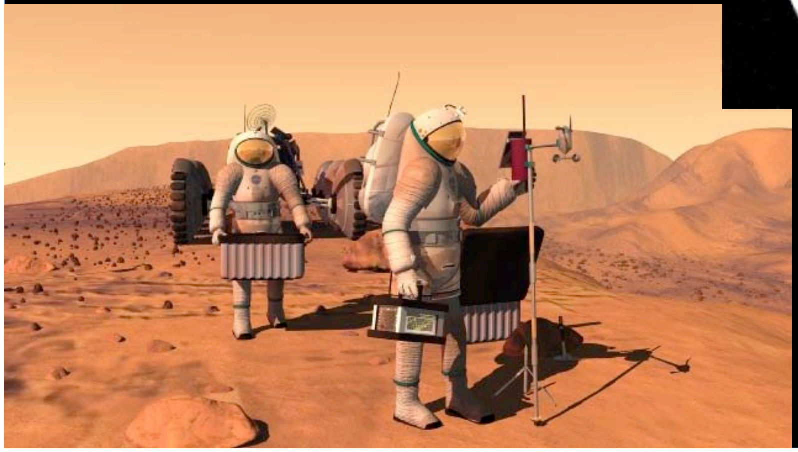
A Few Highlights…

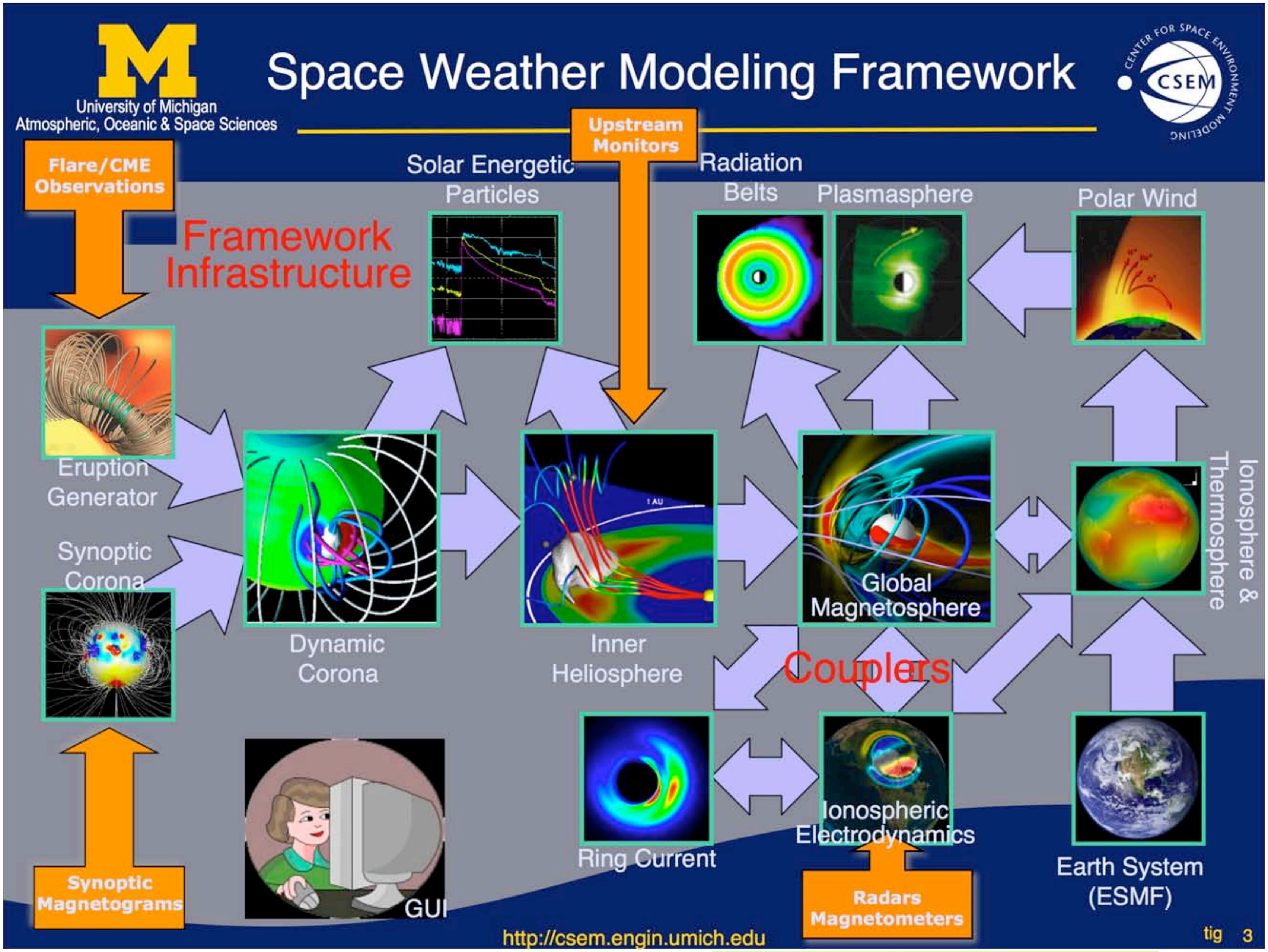
- Space Weather Modeling
- Hydrodynamic simulation of dark matter and gas in galaxies
- Dark Matter Halo of Milkyway
- Relativistic Jets
- Gravitational radiation from black hole binary mergers

Space Weather Modeling: A Critical Component of the Vision for Exploration





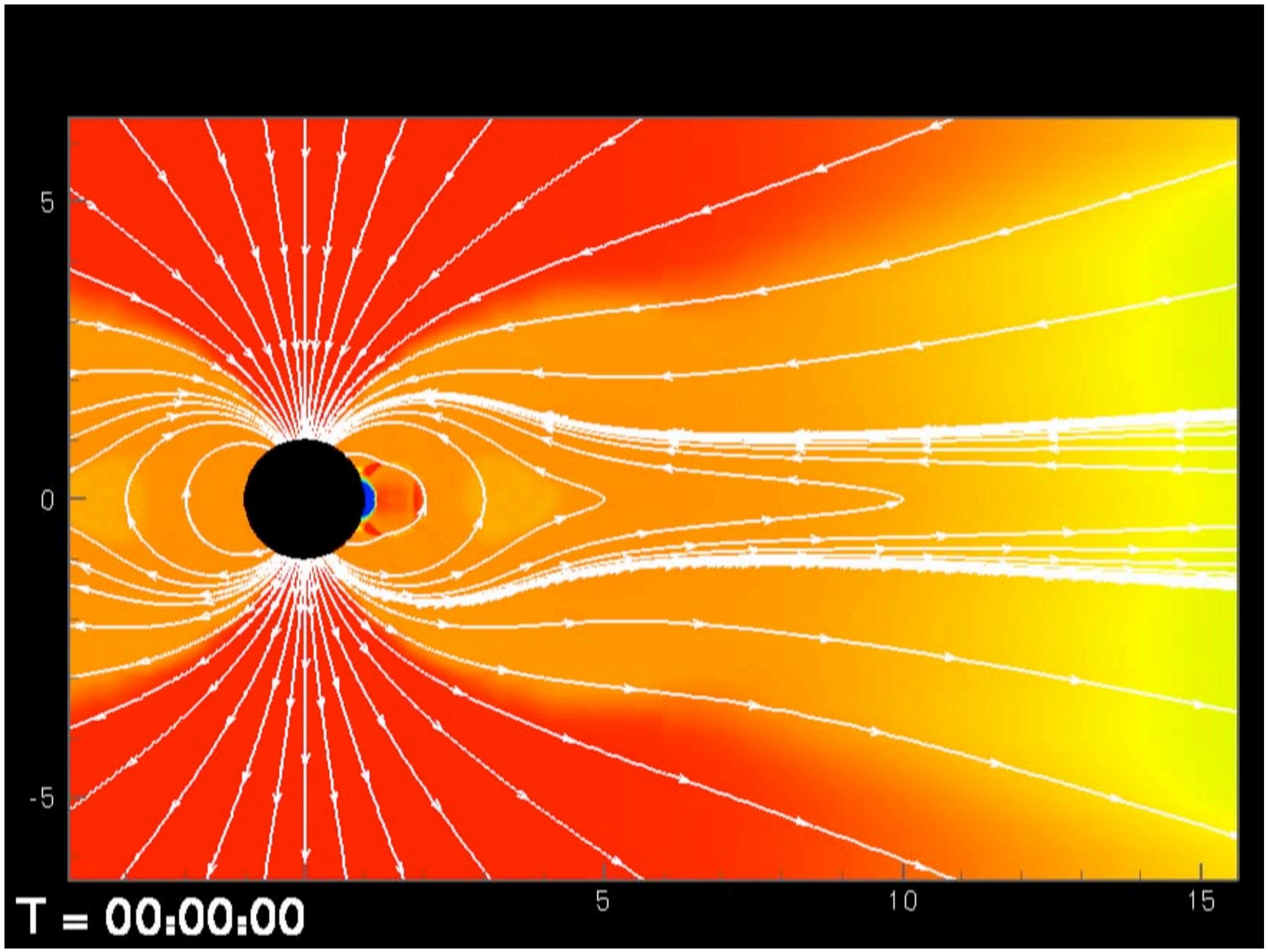




Supported by NASA's Computational Technologies Project

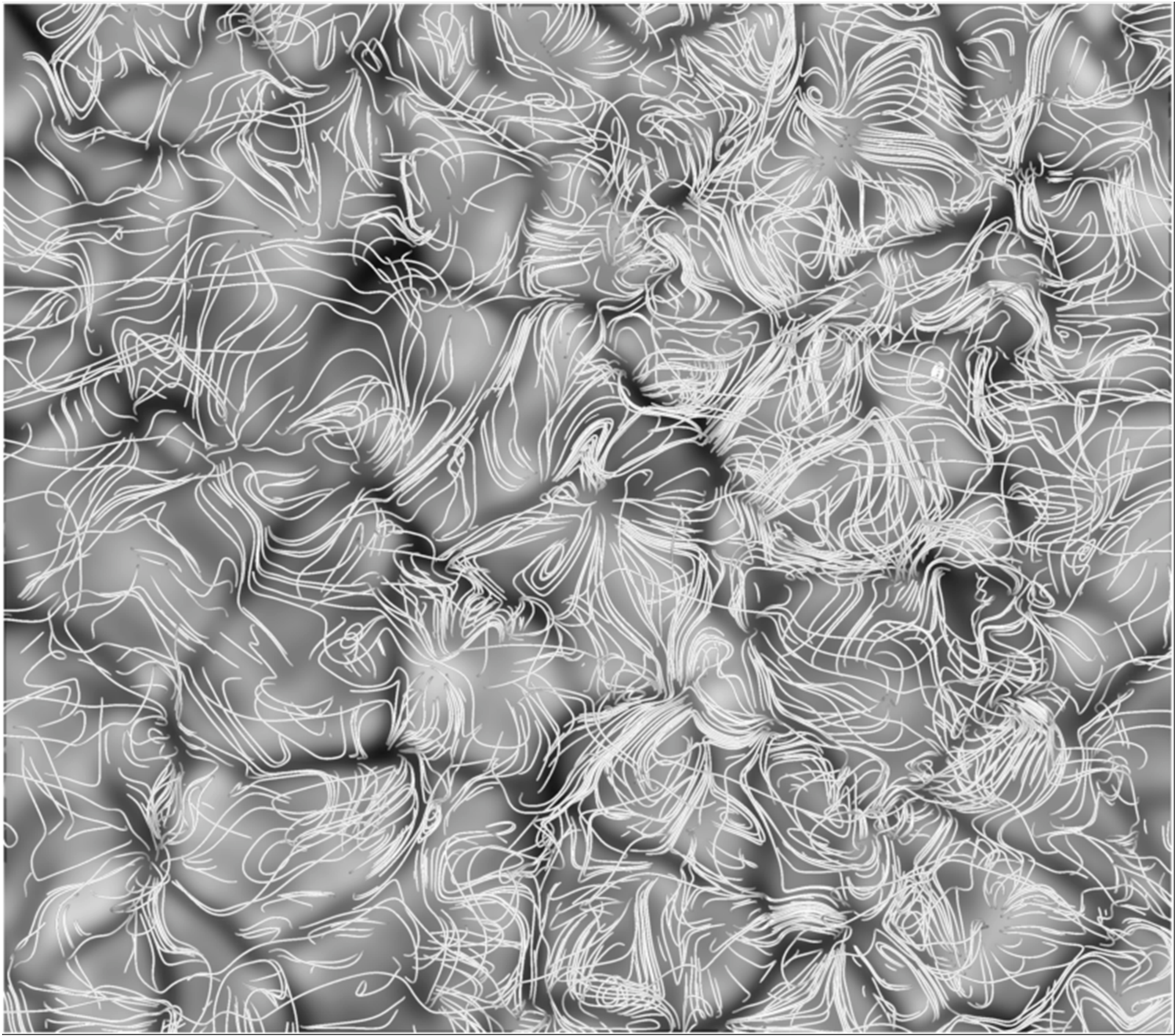
Sun to Mud:

A Simulation of CME Interacting with Earth's Magnetosphere



Courtesy of Gombosi et. al

The quiet Sun magnetic field in the model chromosphere



Magnetic field generated through the action of a convective surface dynamo.

Fieldlines drawn (in both directions) from points located 700 km above the visible surface.

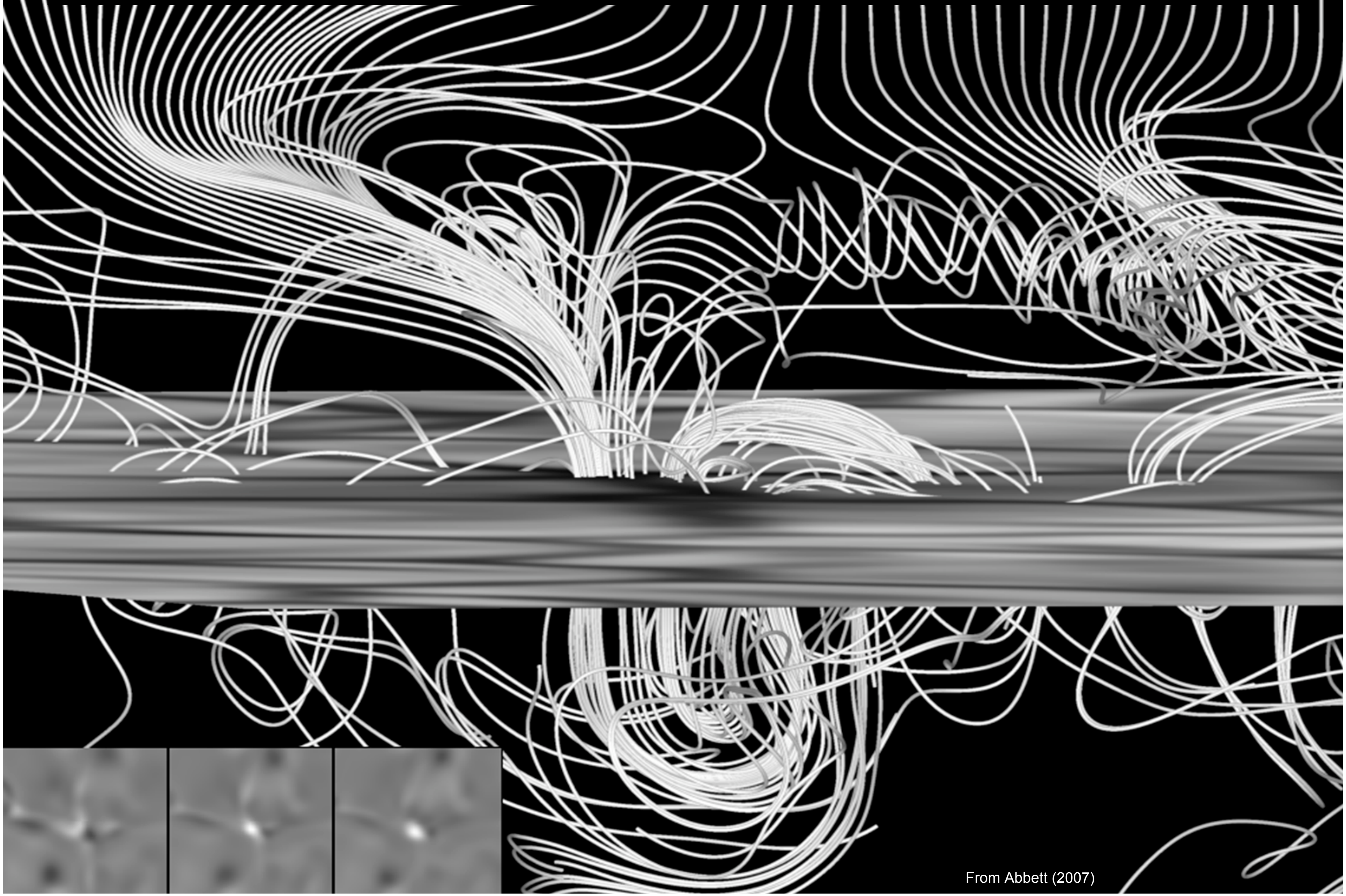
Grayscale image represents the vertical component of the velocity field at the model photosphere.

The low-chromosphere acts as a dynamic, high-β plasma except along thin rope-like structures threading the atmosphere, connecting strong photospheric structures to the transition region-corona interface.

Plasma-β ~ 1 at the photosphere only in localized regions of concentrated field (near strong high-vorticity downdrafts

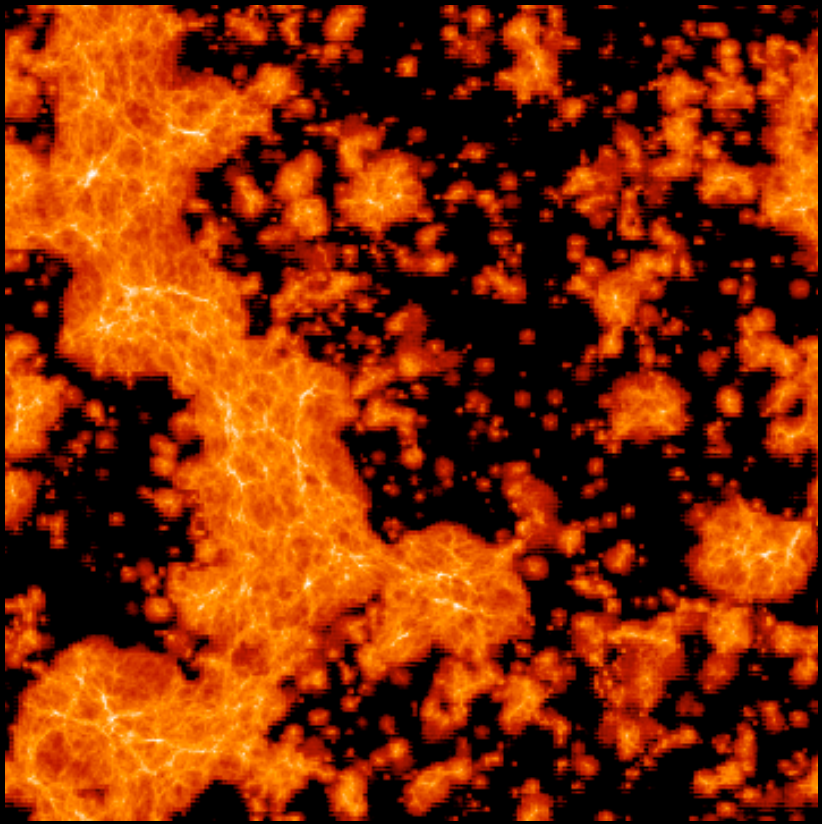
From Abbett (2007)

Flux submergence in the quiet Sun and the connectivity between an initially vertical coronal field and the turbulent convection zone



From Abbett (2007)

Radiative Transfer Hydrodynamic Simulations



Dark matter

- Dynamic range achieved on Columbia 22 in May 2008 is 2.4x 10^{10}
- Dynamic range in mass desired is 10^{12}
- Both RAM and CPU limited

Gasdynamics

- Spatial dynamic range achieved on Columbia 22 in May 2008 is 1536
- Spatial dynamic range desired is 8192
- Both RAM and CPU limited

Radiative transfer

- Ray tracing grid achieved on Columbia 22 in May 2008 is 512^3
- Ray tracing grid desired is 2048^3
- Both RAM and CPU limited

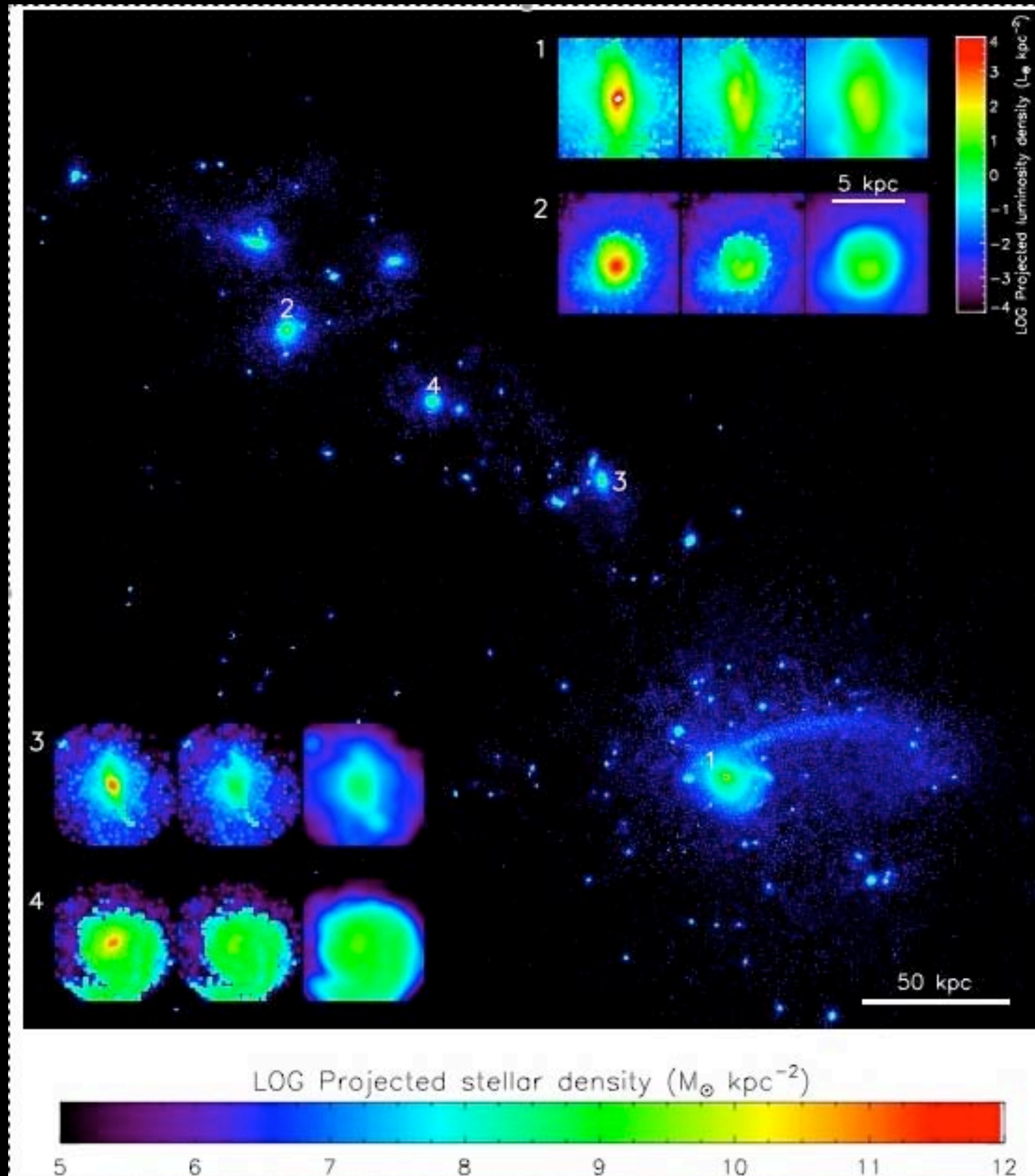
Courtesy of Renyue Cen/Princeton

Ultra-high resolution galaxy formation

Dark matter and gas

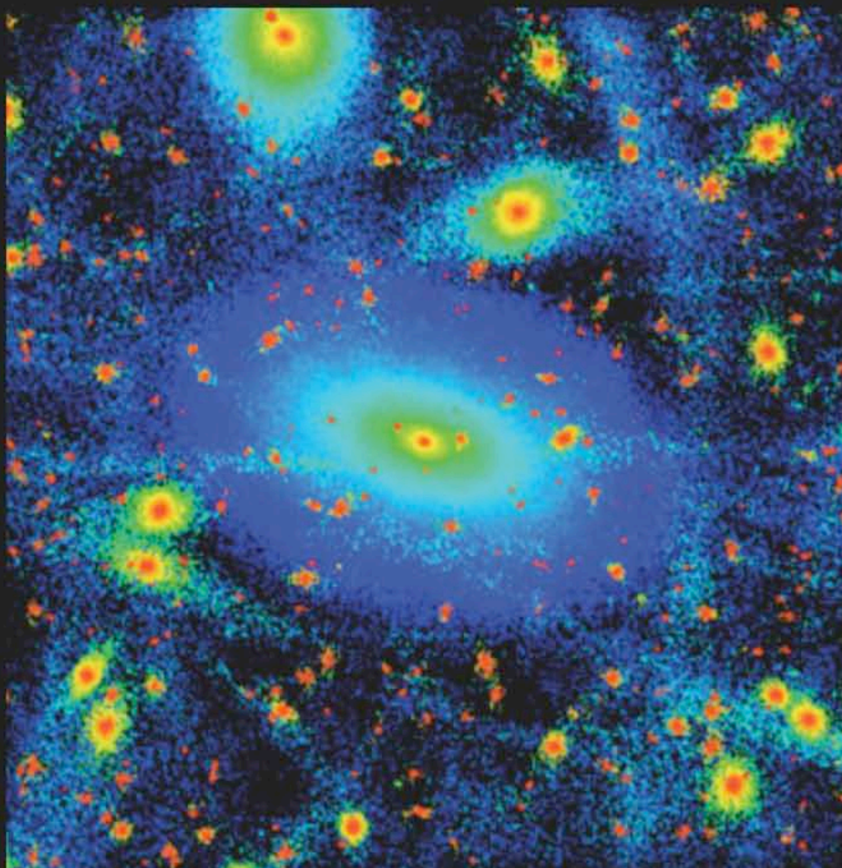
- Dynamic range achievable on Columbia 22 now is 4.2x 10^{10} , giving spatial resolution of 2-3pc at redshift z=3, marginal for resolving interstellar medium, requiring a few month of C22

- Mostly CPU limited, 10-100x Columbia 22 w/ fast communication would allow us to do grand simulations of galaxy formation that are able to resolve ISM, spiral structures,bulges, & interaction between galaxies and the intergalactic medium



Courtesy of Renyue Cen/Princeton

"Via Lactea II", a billion particle simulation of the dark matter halo of the Milky Way galaxy PI: Piero Madau (UC Santa Cruz)

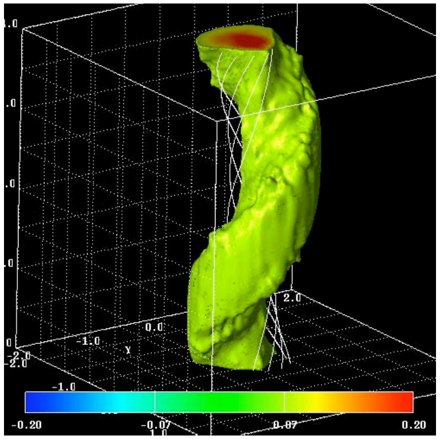


2007 INCITE award: A single simulation starting about 20 million years after the Big Bang and calculating the gravitational interactions of 1.1×10^9 particles of dark matter over 13.7 billion years. Run on 3000 "cores" using 10^6 cpu hours on the "Jaguar" Cray XT3 supercomputer at the ORNL. Previous, pathbreaking simulation, "Via Lactea I", run for 3×10^5 cpu hours on NASA's Project Columbia.

"The Via Lactea Project", the most extensive suite of cosmological simulations ever carried out of the assembly and lumpiness of the Milky Way's halo, seeks clues to the nature of the dark matter and the assembly of galaxies.

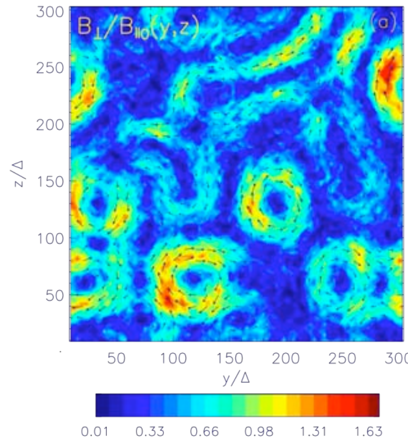
Computational Studies of Relativistic Jets (PI: Ken Nishikawa)

3D RMHD Simulations for Current Driven Instability



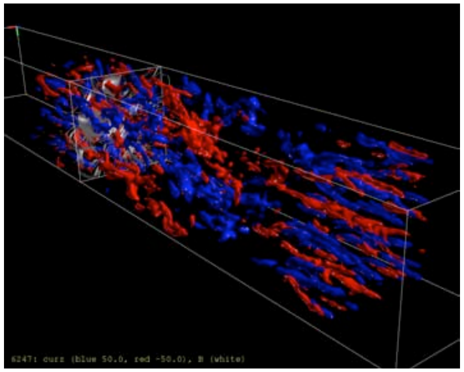
Color: Isovolume density,Lines: magnetic field
(Mizuno et al. 2008)

Production of Magnetic Turbulence by Cosmic Rays Drifting Upstream of Supernova Remnant Shocks



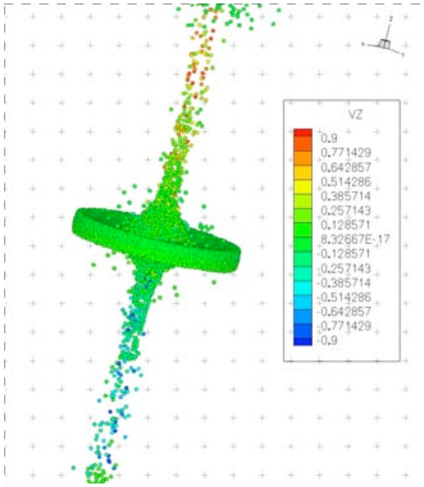
perpendicular magnetic field
generated by cosmic ray ions
(Niemiec et al. 2008)

Evolution of Current filaments generated by the Weibel instability



current filaments merged nonlinearly
Nishikawa et al. 2008)

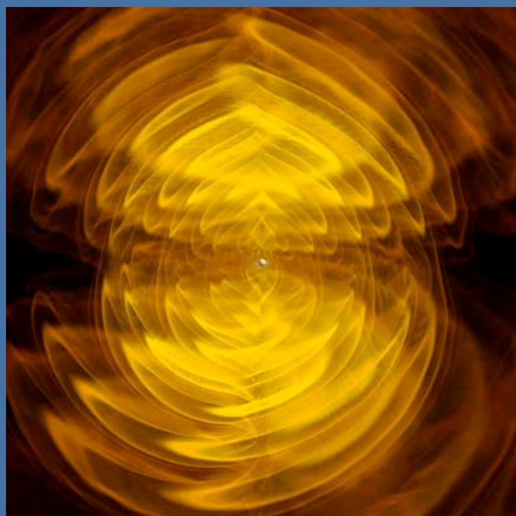
Jet generation from black hole using GRPIC code



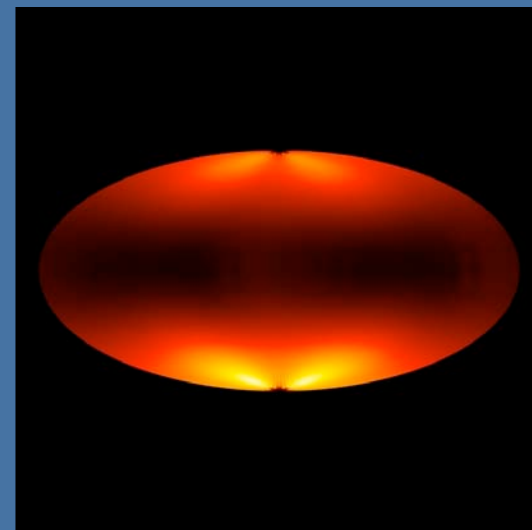
electrons and positrons
ejected from BH
(Watson et al. 2008)

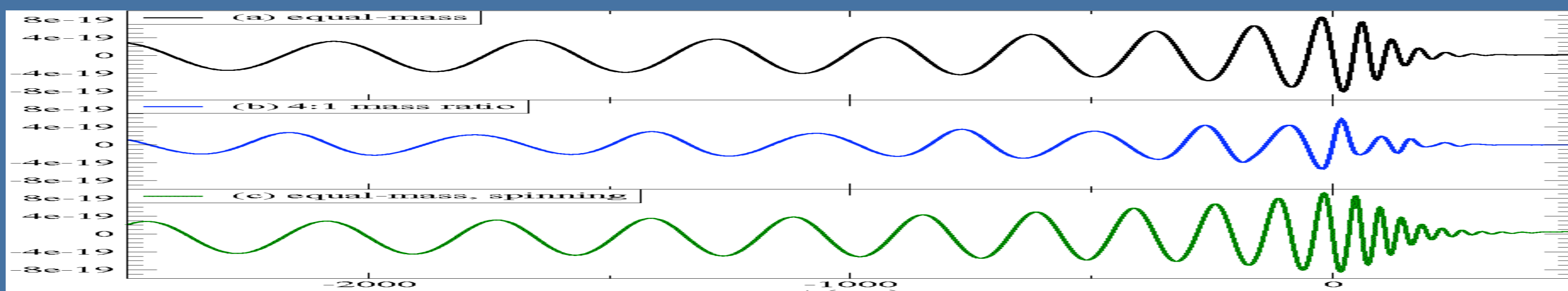
Gravitational radiation from black hole binaries

John Baker, Darian Boggs, Joan Centrella, Bernard Kelly, Sean McWilliams, James van Meter



Simulations of the gravitational radiation from mergers of spinning black holes (left) has led to the discovery of large asymmetries in the radiated energy-momentum (Aitoff map, right) leading to astrophysically significant recoil "kicks".





Analysis of waveforms from black holes of various spins and mass ratios (above) will be important for LISA. The above simulations ran on as many as 500 processors. Further exploration of parameter space with larger spins and mass ratios will require higher resolution.

Defining the Future

- Science drivers
- Models/Applications that drive the computing requirements
- Computing Requirements
- Programming and Analysis Environment