# Modeling the Space Environment

Dan Welling

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# Why Model?

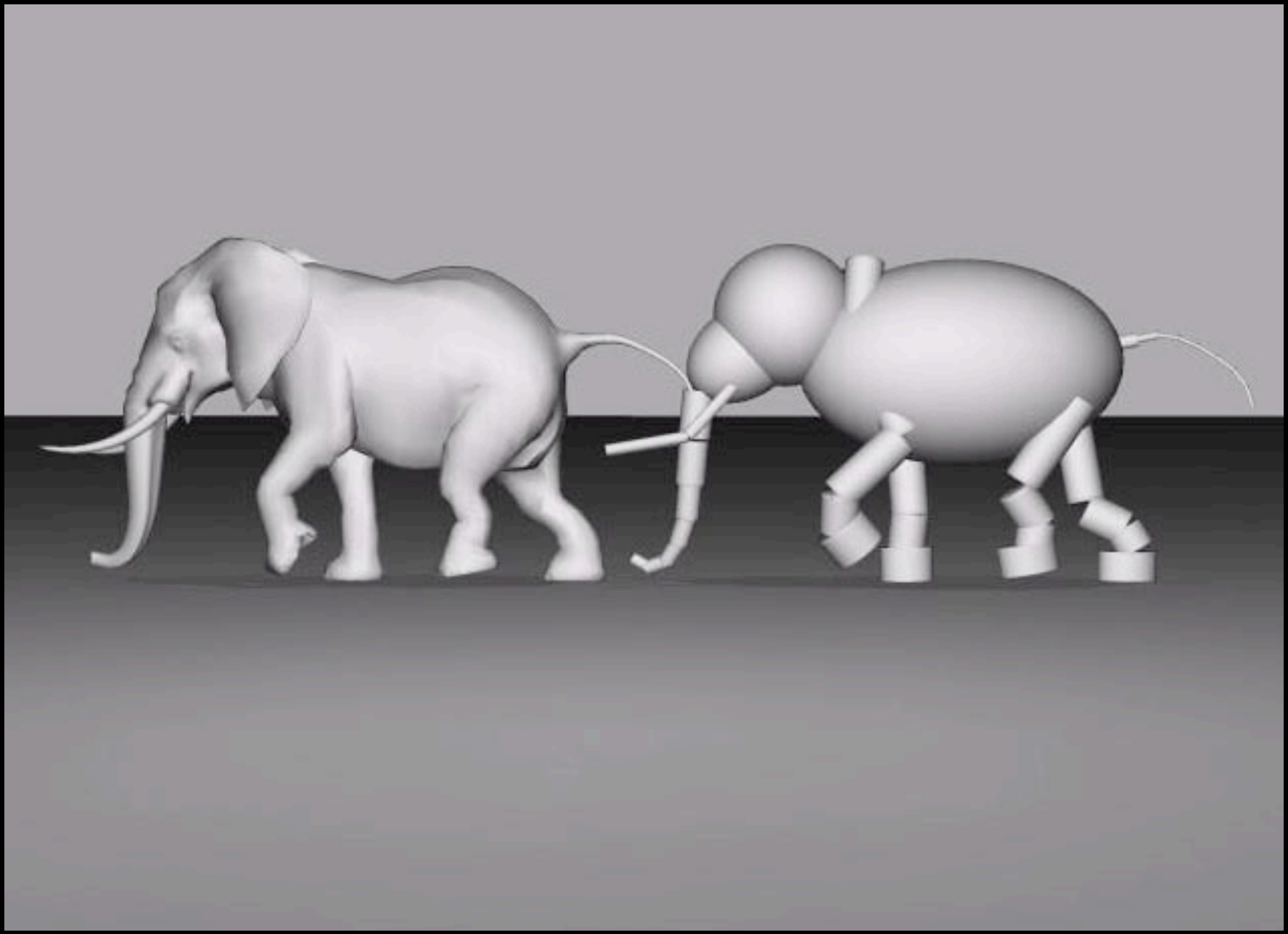
**Models are an attempt to recreate complicated physical systems.**

- Model performance tells us how well we understand a system.
- Give insight to how system works
- Models can reveal interactions and processes that were previously unknown.
- Model results are not limited by instrument coverage

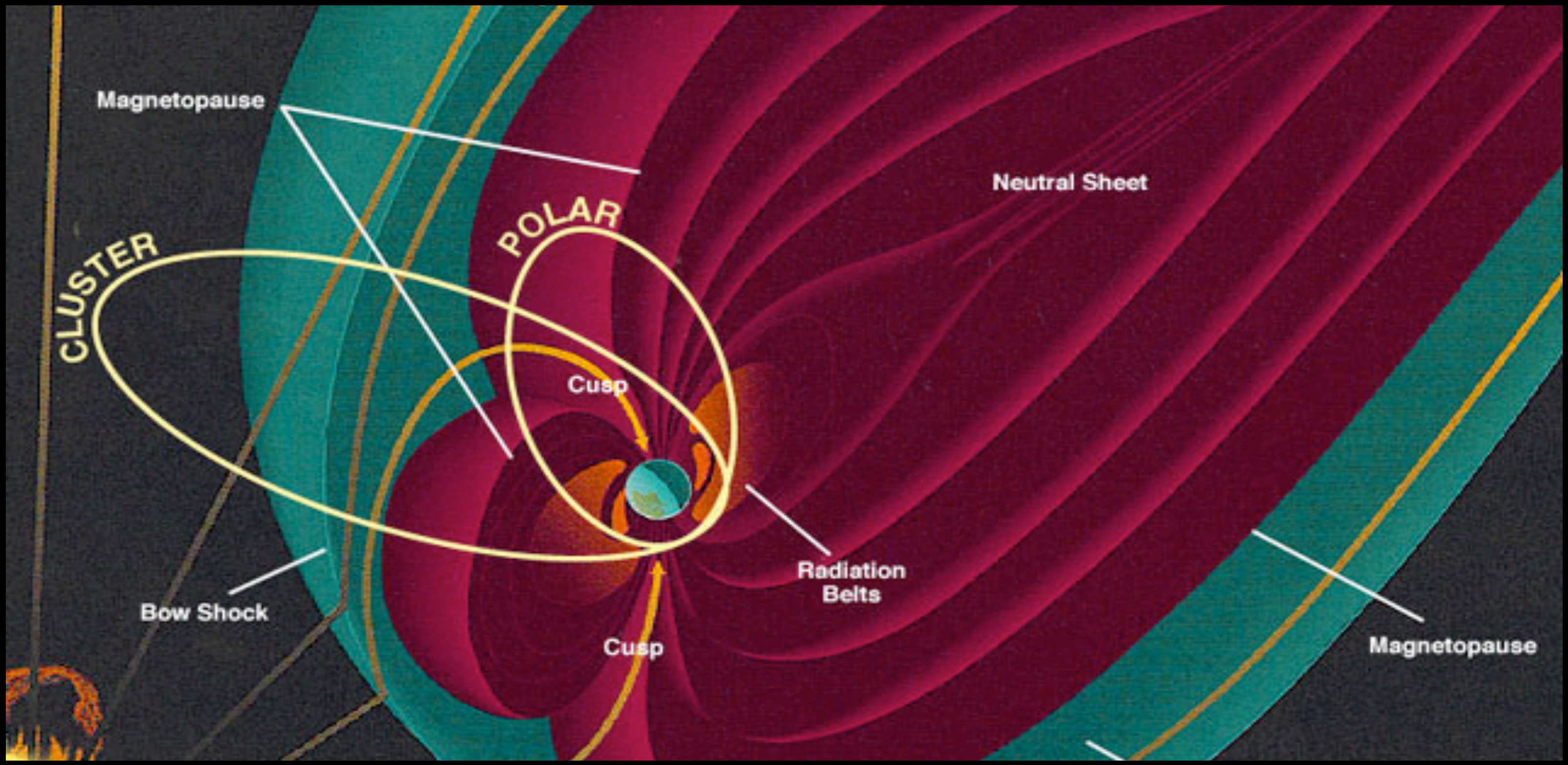
# Model Development

- A “perfect” model would contain all possible physical mechanisms.
- This is unrealistic!
  – The model would take forever to finish using even the most powerful computer.
  – We don’t know all the physics yet!
- Models start with only the most important physical processes.
- Model complexity is limited by computing power.

# Model Development



# Space Environment Modeling




- The space environment is composed of many different interacting domains.
- The important physical processes change from domain to domain.

# MHD Models

- <u>M</u>agneto<u>H</u>ydro<u>D</u>ynamics combines gas dynamic equations with the Maxwell equations.
- Typically treats plasma as a single-species, collisionless fluid.
- Solves for density, momentum, magnetic field and total energy.

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \overline{u}) = 0$$

$$\rho \frac{\partial \overline{u}}{\partial t} + \rho \overline{u} \cdot \nabla \overline{u} + \nabla p - \overline{j} \times \overline{B} = 0$$

$$\frac{\partial p}{\partial t} + \overline{u} \cdot \nabla p + \gamma p \nabla \cdot \overline{u} = 0$$

$$\frac{\partial \overline{B}}{\partial t} + \nabla \times \overline{E} = 0$$

$$\overline{j} = \frac{1}{\mu_0} \nabla \times \overline{B}$$

$$\overline{E} = -\overline{u} \times \overline{B}$$

# MHD Models

**Strengths:**

- Works on large scale domains
- Speedy!
- Captures large scale magnetospheric fluctuations well
- Does a good job on magnetic field

**Weaknesses:**

- Small scale particle interaction effects are not captured well
- Reconnection occurs due to artificial sources
- Single fluid is bad.

# MHD Models

## Popular MHD Models:

- Lyon-Fedder-Mobarry (LFM)
- Open Geospace General Circulation Model (OpenGGCM)
- Block Adaptive Tree Solar-wind Roe-type Upwind Scheme (BATS-R-US)
- Robert Winglee's Model

# Inner Mag Models

**Inner Magnetosphere Models investigate the ring current, plasma sheet, plasmasphere, and radiation belt.**

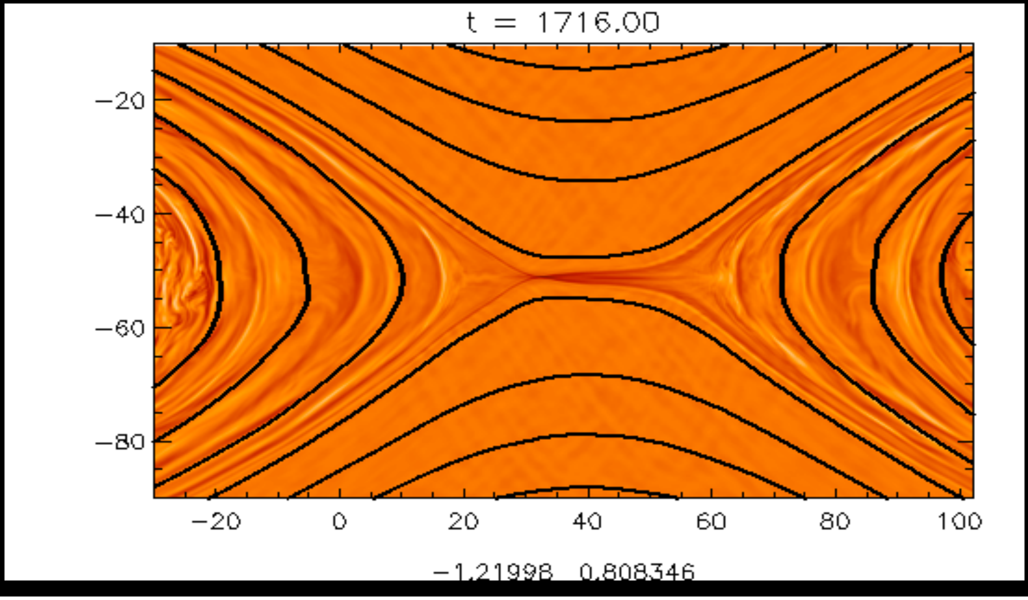
- **All use bounce-averaged kinetic drift physics to model the closed field line inner magnetosphere region.**

**Examples:**

- **Rice Convection Model (RCM)**
- **Ring current Atmosphere interaction Model (RAM)**

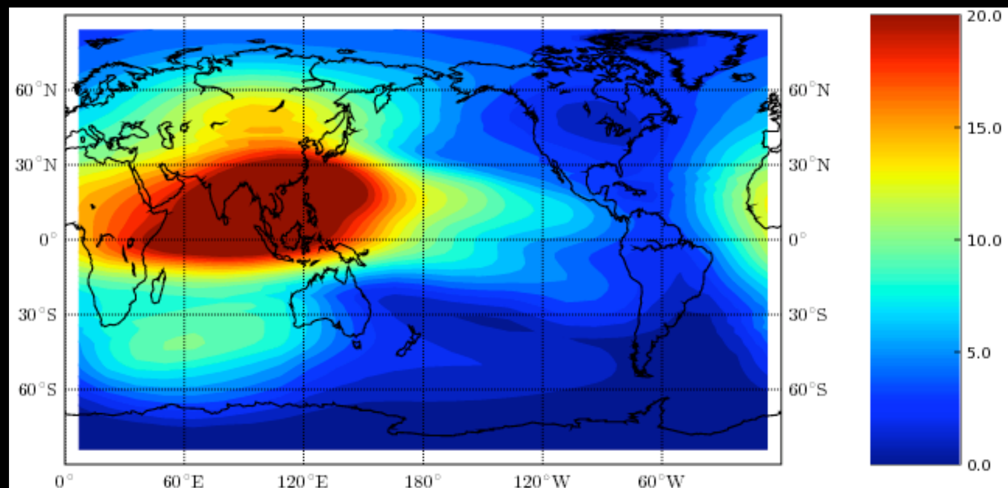
# Particle Models

- Tracks individual particles in system
- Uses Lagrangian and Eulerian formulations of mechanics.
- Two flavors: Test particle and PIC
- Captures small details of system very well!
- Computationally expensive!

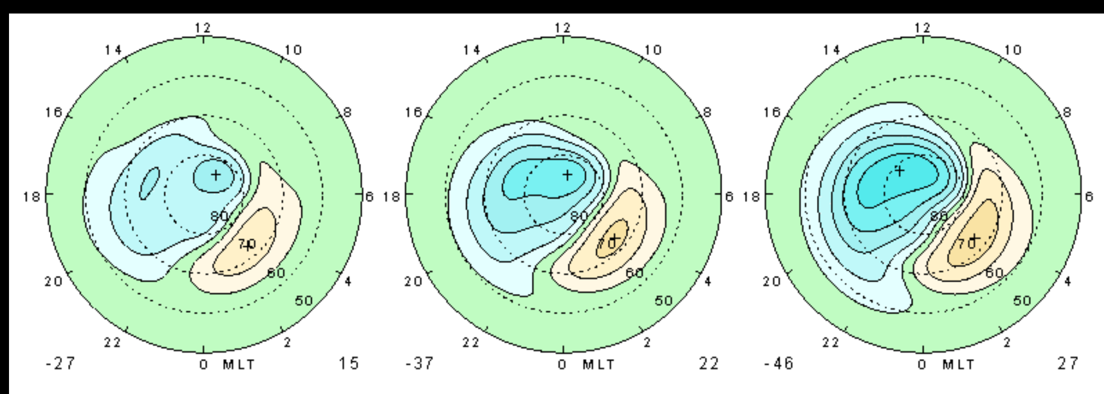


# Data Driven Methods

**Assimilative Models - Uses data to improve your solution.**




**Empirical Models - Uses trends in data to create a function to predict a system's response to a given driver.**



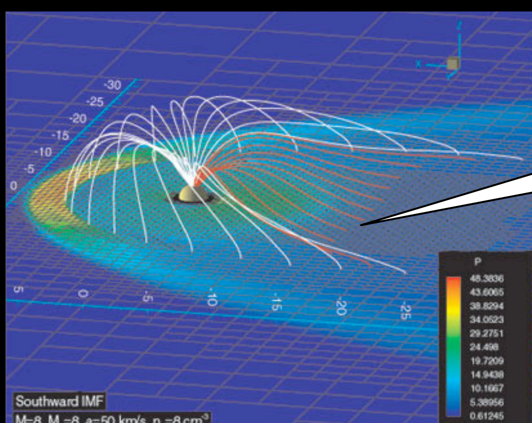
# Expanding Model Capabilities

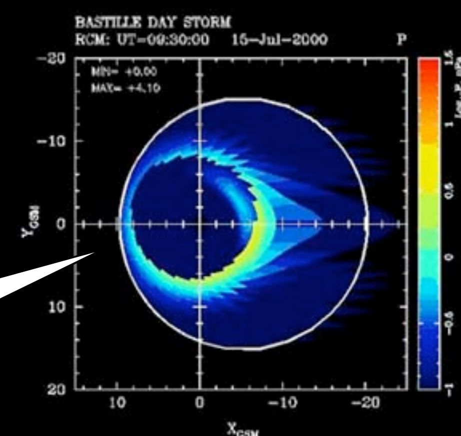
- By adding more physics, codes become more capable (but potentially much slower!)
  - Example: Multi-fluid MHD
  - Example: Hall MHD
- Hybrid models
- Alternatively, you can “couple” two codes together.

# Coupling

- Each model independently creates a solution for its own domain.
- Periodically, the domains are “coupled”: solutions from one model is used to adjust the solution of another.
- The strengths of one model is shared with the others, creating a more accurate solution.

Hey, your B-field sucks. Use mine.




Thanks. Here’s a realistic thermal pressure for you.

# Wrap-Up

- Modeling is especially important in the magnetosphere where data is sparse!
- The near-Earth environment requires many modeling methods to accurately recreate!
- The end goal is to create a Global Geospace Circulation Model!