# Solar MURI Code Coupling Experiences: Solar Interior - Solar Corona

S. A. Ledvina, W. P. Abbett, G. H. Fisher and J. G. Luhmann

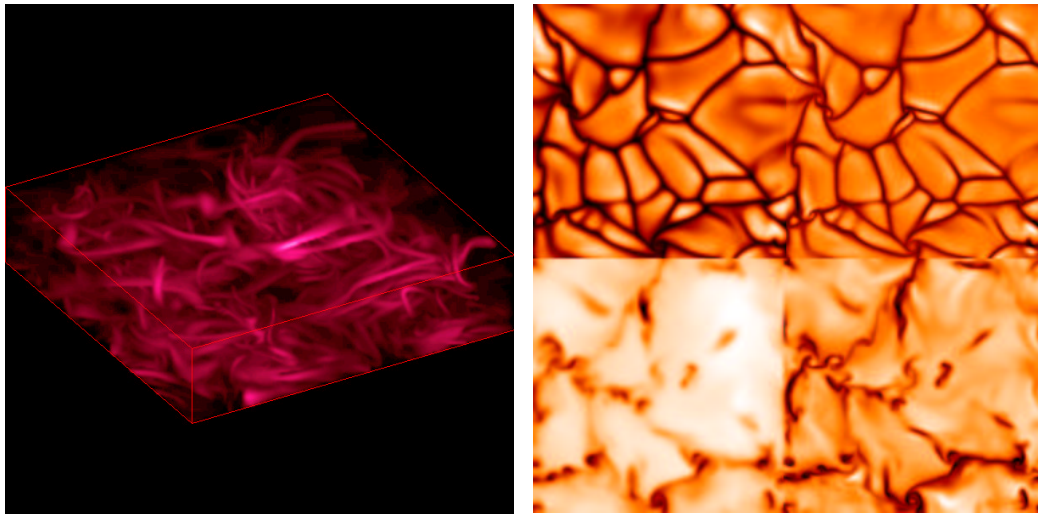
Space Sciences Lab, University of California, Berkeley

# Motivation: To understand how flux emergence effects the global magnetic structure of the solar corona.

- Evolution of the solar corona is influenced by magnetic fields and mass flows at and below the photosphere.
- The corona can affect the deeper layers (Longcope & Welsch, 2000).
- Conditions at the base of the corona are subsonic and subAlfvénic and are strongly affected by backward propagating waves.

## ANMHD: 3D anelastic pseudo-spectral MHD code (Fan, Abbett)

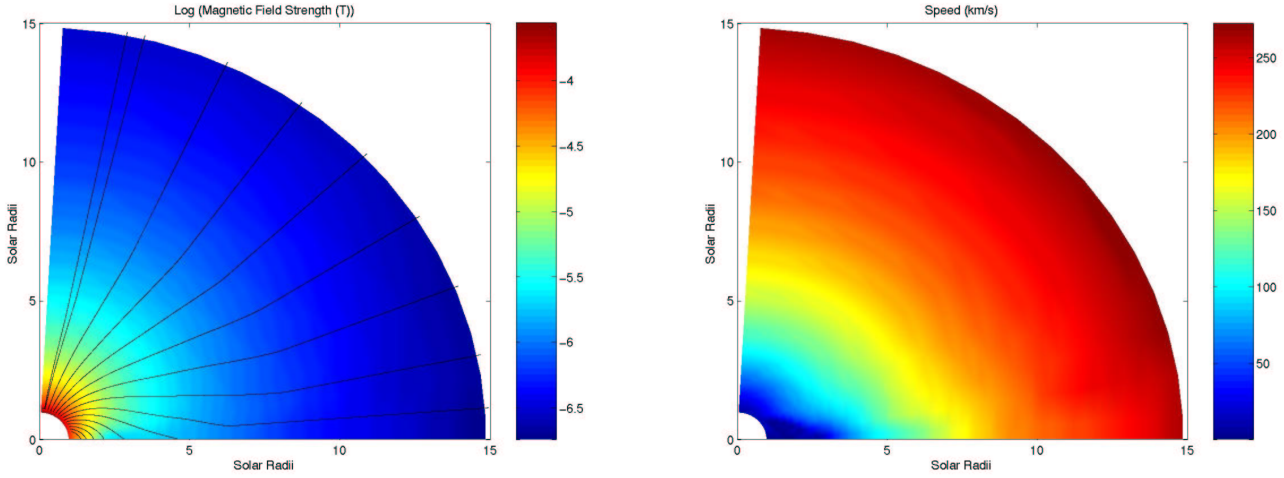
- Valid for $\beta \gg 1$
- Not Courant limited by sound waves (large time steps)
- Good for the solar interior



Magnetic flux tubes within the convection zone (left). Convection cells at various depths (right).

## Zeus-3D: 3D fully compressible MHD

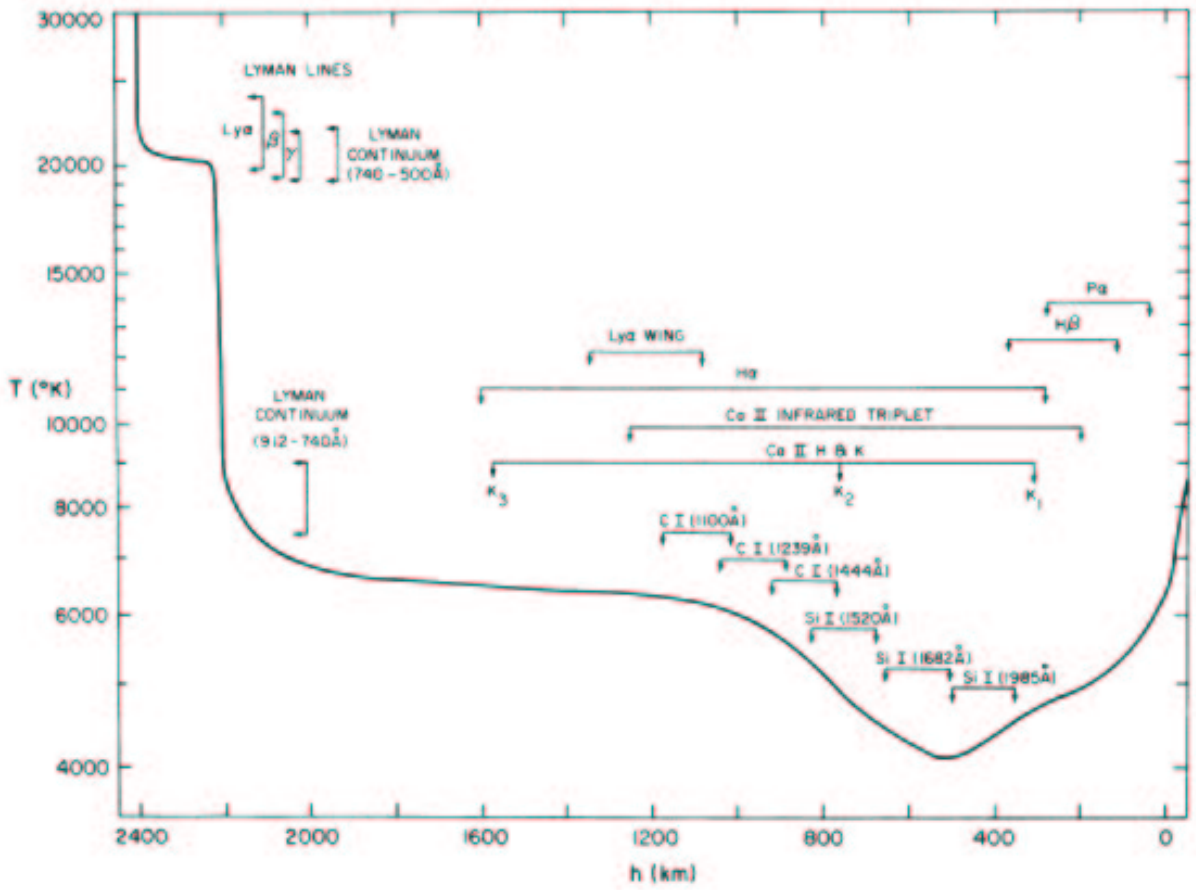
- Robust, well known, community code, with a large user base.
- Flexible, can incorporate additional physics in a straight forward manner.
- Has been widely used in astrophysics applications.




Contours of magnetic field strength (left) and speed (right) for a 3-D simulation of the solar corona.

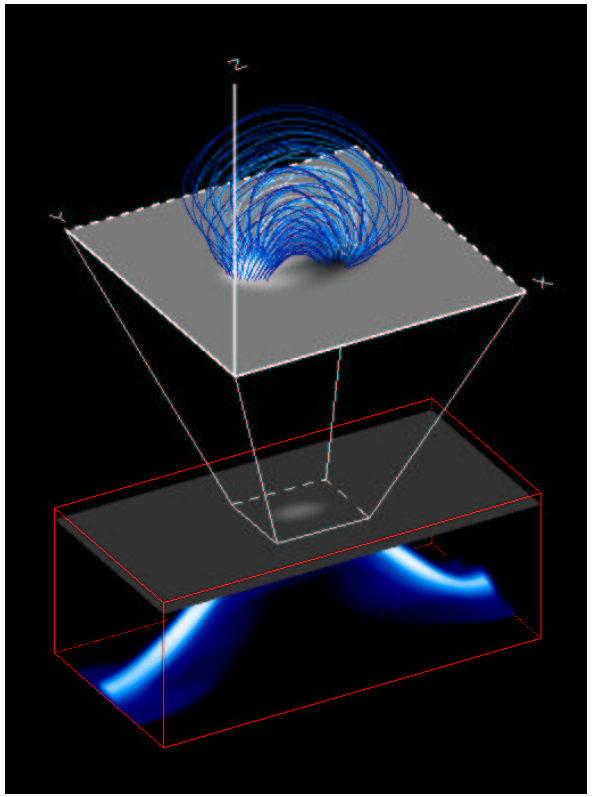
**Coupling the models requires including the transition region.**

- Narrow region about 500 km wide.
- The physical processes in the region are not understood.
- Steep density and temperature $\left(20000 - 1 \times 10^6 \text{ K}\right)$ gradients.




Temperature vs. height above the photosphere, the transition region begins around 2200 km.

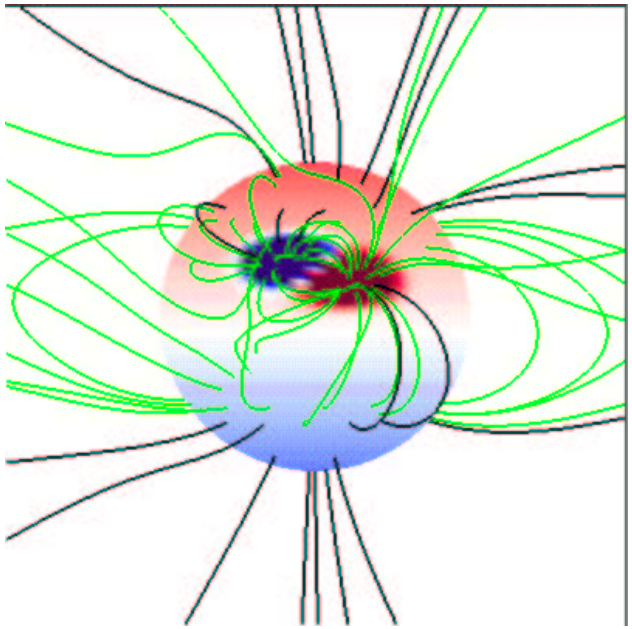
**Including the transition region is an important component in studying emerging flux.**




A flux tube emerging from a ANMHD simulation of the convection zone, through the transition region into the lower corona.

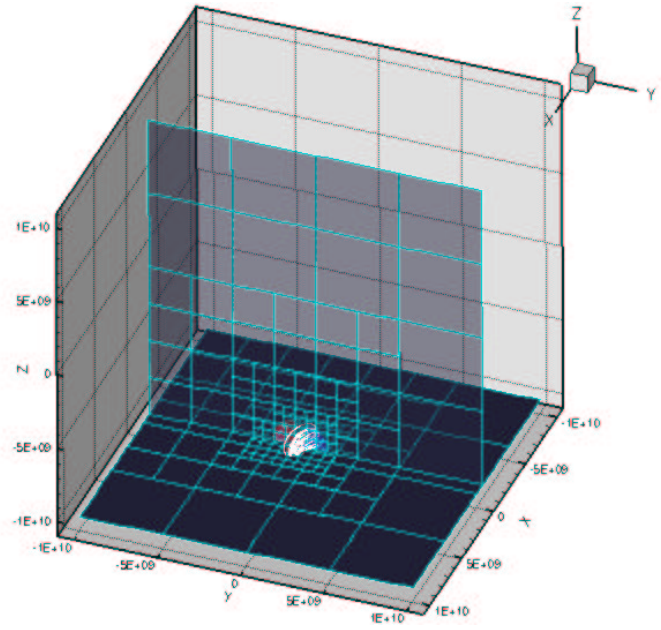
**In order to examine the effect emerging flux has on the global structure of the Corona, high resolution is required.**

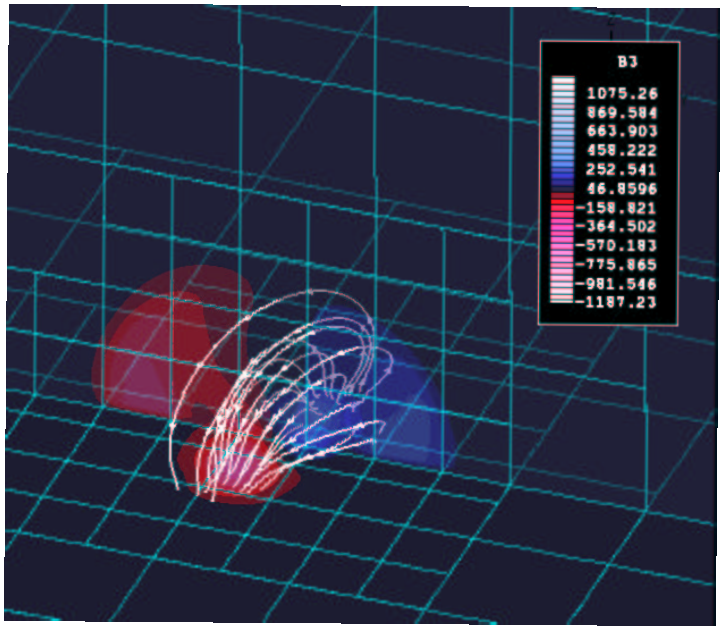
- Nested Meshes
- Adaptive Mesh Refinement



## ZeusAMR

- Combine Zeus-3D with paramesh (MacNeice et al., 2000)
- Structured block adaptive AMR
- Conservation laws enforced at block boundaries

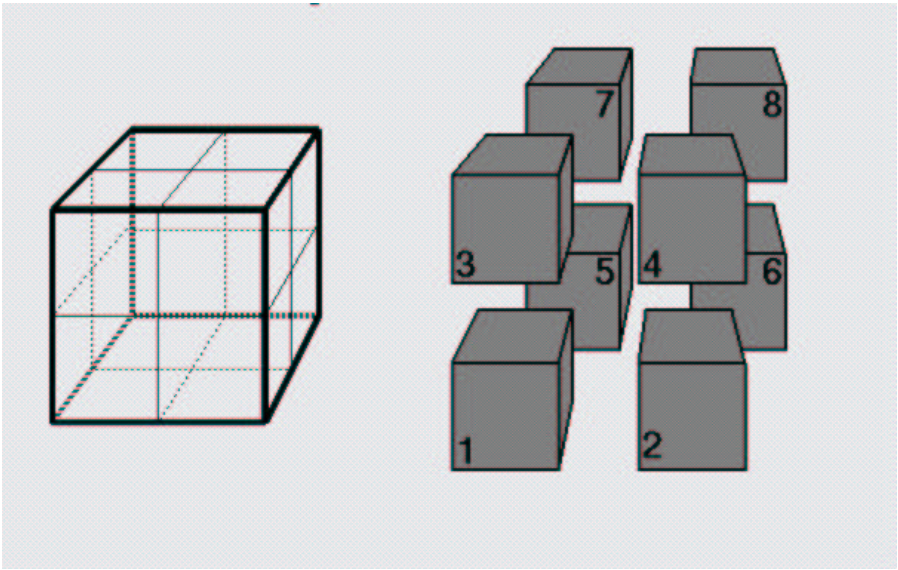



An AMR test of an emerging flux tube into a ZeusAMR corona.

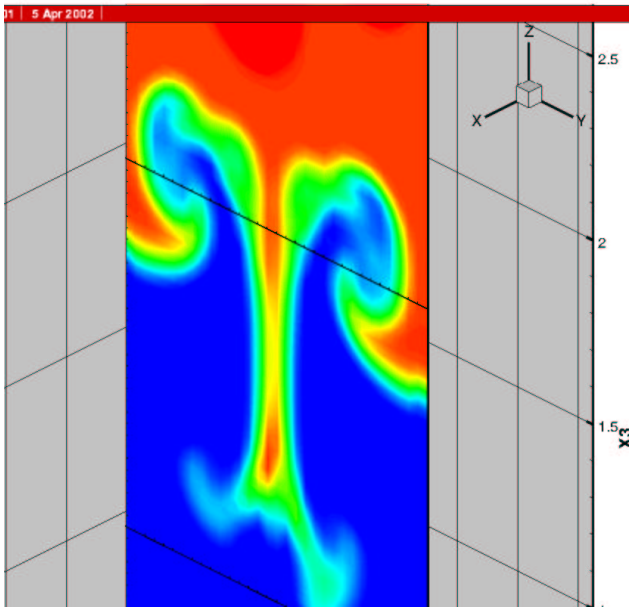
## Need to self-consistently couple both codes, can we use paramesh to accomplish this?

- At the lowest level paramesh is a domain decomposition tool that communicates between neighboring blocks.
- Let code A run on block 1 and code B run on the other blocks.



## Example: Rayleigh-Taylor Instability

- Top block code A, $\rho = 20$, $P = 700$ and $g = 1$ small velocity perturbation at lower boundary.
- Bottom block code B, $\rho = 1$, $P = 700$ and $g = 1$



# Physical Issues with Coupling the Codes:

| ANMHD | ZeusAMR |
|---|---|
| Entropy per unit volume | Internal energy per unit volume |
| No sound wave propagation | Sound waves |
| Solves for perturbations to background fields | Solves for complete fields |
| Pressure perturbations travel at an infinite speed | Pressure perturbations propegate at the sound speed |

Additional issues include handling the transition region and several computational issues (location of the variables on the grid, load balancing units etc...).