STRUCTURE AND DYNAMICS OF THE COOL CORONA

Hardi Peter

► Part I  **Coronal models**
  – a small ejection driven by increased heat input
    (with Sven Bingert, Philippe Bourdin & Pia Zacharias @KIS)

► Part II  **Hinode / EIS Observations**
  – asymmetric flows in active regions
    → consequences for coronal mass cycle (?)

► Part III  **Brief outlook**
  combining coronal models with observations

The Pencil Code
Brandenburg & Dobler (2002)
Comp Phys Comm 147, 471

- high-order finite-difference modular code for compressible 3D MHD
- efficiently under MPI on distributed-memory clusters

- Box: up to $512^3$ grid : $50 \times 50 \times 30$ Mm$^3$
  horizontally periodic, open top
- non-uniform mesh
- horizontal motions in photosphere as driver
  $\rightarrow$ field line braiding (Parker 1972)
- full energy equation (heat conduction, rad. losses) $\rightarrow$ important for spectral diagnostics

formation height of $10^5$ K emission
horizontally periodic, open top
non-uniform mesh
horizontal motions in photosphere as driver
$\rightarrow$ field line braiding (Parker 1972)
full energy equation (heat conduction, rad. losses) $\rightarrow$ important for spectral diagnostics
Synthetic spectra at each grid point of the 3D model:

- $T$, $n$: emissivity (CHIANTI atomic data base)
- $\nu$: line-of-sight $\rightarrow$ Doppler shift
- $T$: line width

integration along line of sight:

$\rightarrow$ line profiles

$\rightarrow$ maps of spectra
A recent experiment...

integration trough box (side view)
50 Mm x 30 Mm

small AR / two pores (50 Mm x 50 Mm):

B_{vert} @ lower boundary
...with a “gas blob”

integration trough box (side view)
50 Mm x 30 Mm
Ejection of gas driven by “low TR” heating event

or chromospheric

integration trough box (side view)
50 Mm x 30 Mm

\[ \int_{\text{los}} \frac{j^2(x,y,z,t)}{\langle \int_{\text{los}} j^2 \, dy \rangle_{\text{time},x}} \, dy \]

\[ \int_{\text{los}} \frac{j^2(x,y,z)}{\langle j^2(x,y,z) \rangle_{\text{time}}} \, dy \]
Strong heating before ejection

Heat conduction back to surface
→ leads to pressure increase in upper chromosphere
→ drives upward motion

\[ j^2 \]
High-density blob deforming $B$

- comet-tail shaped current
  $\rightarrow$ blob deforms $B$ (not low beta)

- bright in TR emission
- dark in coronal emission $\quad \{ T \approx \text{some } 10^5 \text{ K} \}$

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$\text{C IV (154.8 nm)}$
$\text{O VII (103.2 nm)}$
$\text{Ne VIII (77.0 nm)}$
$\text{Mg X (62.0 nm)}$
The blob: ballistic ejection

- Field lines and trajectory
- Constant acceleration: \( \approx 200 \text{ m/s}^2 < g_{\text{Sun}} \)
- Accumulated mass
- B vs. trajectory angle

\( x \text{ [Mm]} \)
\( y \text{ [Mm]} \)
High-resolution experiments (≥1024³):

- **higher spatial resolution:**
  → resolve smaller structures / current sheets

- **larger computational domain**
  → fit whole AR into box (→ SDO)

**vertical cut: \( j^2 \) – fine expanding current sheets

**good scaling of Pencil code for coronal model**
Part II
Origin of asymmetric coronal line profiles


high-velocity upflows in coronal plasma:

► signature of nanoflare heating
(Klimchuck & Patsourakos 200x)

► upflows in type-II spicules
(McIntosh, De Pontieu 2009)

is there real observational evidence for this?
Is there really a high-velocity component?

Single Gaussian fit:

clear indication of excess emission in blue wing


Double Gaussian fits:

broad component to account for line wing sound speed @ ≈ 2 MK: ≈ 200 km/s

blue component only when constraining fit

Single and double Gaussian fits

in general: narrow core and broad wing component

Fe XV
(284 Å)
Distribution of shifts and width for 2\textsuperscript{nd} spectral component in general:

- **broad 2\textsuperscript{nd} component** (median: FWHM \approx 140 km/s!)

  relation width \sim shift  
  \rightarrow heating \sim acceleration (?)

- **there is a high-velocity component**
  - “normal” line width
  - shift \approx 130 km/s  
  \rightarrow in restricted areas only!

high-velocity components

bad fits
Could high-velocity components be ubiquitous?

NO!
Could high-velocity components be ubiquitous?

**NO!**

$$R = \frac{\chi_{\text{forced}}}{\chi_{\text{free DGF}}}$$

- force the double Gaussian fit to have high-velocity component

**result:**

- free double Gaussian fit (with mostly broad 2\textsuperscript{nd} component)
- is more significant than
- constrained double Gaussian fit (with high-velocity component)
Acceleration in coronal funnels

▶ TR emission lines are asymmetric, too

→ broad components

*basically unshifted*

width: \( \xi \propto T^{1/4} \)

could be (slow mode) wave?


▶ coronal line(s) fit into this picture!

→ broad components

*show strong shifts* \((20–60 \text{ km/s})\)

→ signature of mass supply to corona at about \(100,000\) K?

consistent with various studies of Tu, Marsch, et al.

▶ plus some areas with high velocity outflows

Part III
A brief outlook

- **SDO observations as test for model prediction of structure and dynamics**
  - HMI observation as lower boundary
  - Compute resulting coronal emission
  - Compare to actual AIA observation

- **Investigate feeding of coronal plasma in the transition region**
  - How is plasma fed into the corona?
  - How to model the mass cycle: chromosphere ↔ corona → solar wind

- Interaction of open and closed structures in 2D and 3D models

- Mass balance in 3D models