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# MHD simulation of solar wind using solar photospheric magnetic field data

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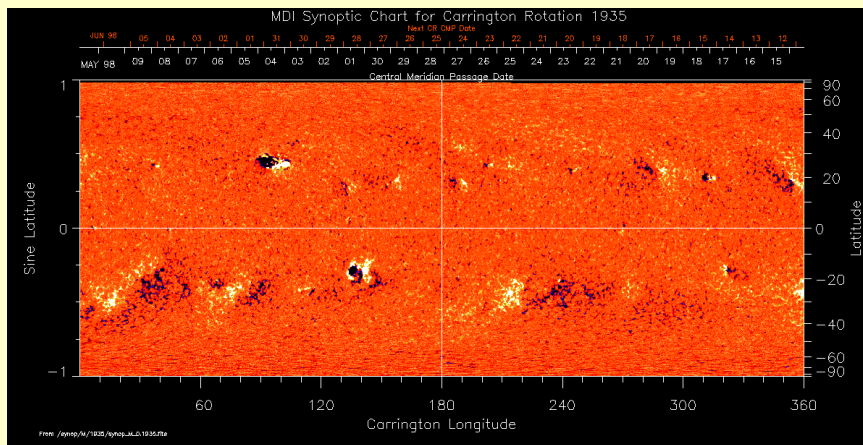
# Introduction

Time-dependent multi-dimensional MHD simulation code is a powerful tool to obtain the trans-alfvenic solar wind structure and simulate the interplanetary disturbance propagation associated with flare/CME events. Magnetic field distribution appearing on the solar surface is a key factor to determine the plasma and magnetic field structure in coronal and interplanetary space. Therefore, to assign the situation to be simulated, solar photospheric magnetic field data must be given to the simulation as boundary values. Many sophisticated simulation models have been made for this approach in decades. We have also developed time-dependent three-dimensional MHD simulation code and will show some results in this paper.

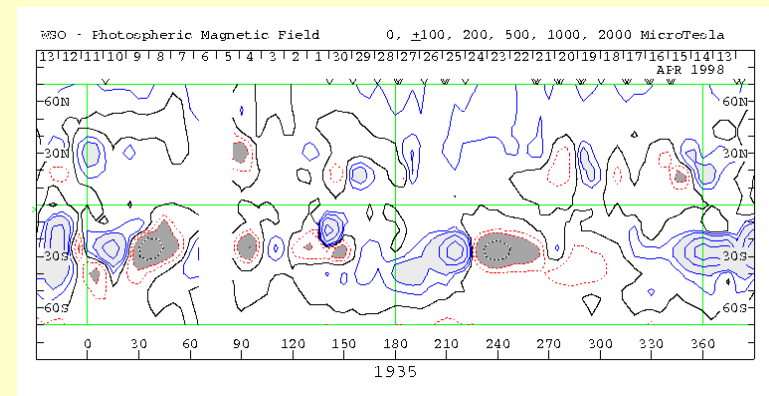
# Solar photospheric magnetic field data

In this paper, we will focus on the MHD simulation of the global solar corona. For this, global map of solar surface magnetic field is needed.

The synoptic map format of solar photospheric magnetic field covering the entire solar surface can be obtained from 27-days observation.



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## Method : simulation code

- Time-dependent three-dimensional MHD code.
- Code is based on TVD-MUSCL method with linearized Riemann solver.
- Difference equation is based on FVM.
- Explicit method for time-increment step.
- Grids are constructed in the spherical coordinate system.
- Variables on the inner boundary sphere at  $1 R_s$  is treated by **characteristic projection method**.

# Simulation code : governing equations

$$\begin{aligned}\frac{\partial \rho}{\partial t} &= -\nabla \cdot (\vec{V} \rho) \\ \frac{\partial(\rho \vec{V})}{\partial t} &= -\nabla(P + \rho \vec{V} : \vec{V}) + (\nabla \times \vec{B}) \times \vec{B} \\ &\quad + \rho(\vec{g} + (\vec{\Omega} \times \vec{r}) \times \vec{\Omega} + 2\vec{V} \times \vec{\Omega}) \\ \frac{\partial \vec{B}}{\partial t} &= \nabla \times (\vec{V} \times \vec{B}) = -\nabla \cdot (\vec{V} : \vec{B} - \vec{B} : \vec{V}) \\ \frac{\partial \varepsilon}{\partial t} &= -\nabla \cdot \left[ \left( \varepsilon + P + \frac{B^2}{2} \right) \vec{V} - \vec{B}(\vec{V} \cdot \vec{B}) \right] \\ &\quad + \rho \vec{V} \cdot (\vec{g} + (\vec{\Omega} \times \vec{r}) \times \vec{\Omega}), \\ \varepsilon &= \rho V^2/2 + P/(\gamma - 1) + B^2/2, \quad \nabla \cdot \vec{B} = 0\end{aligned}$$

The ideal MHD equations described in the frame rotating with the Sun. Specific heat ratio is 1.05 in this study.

# Simulation code: boundary treatment (1)

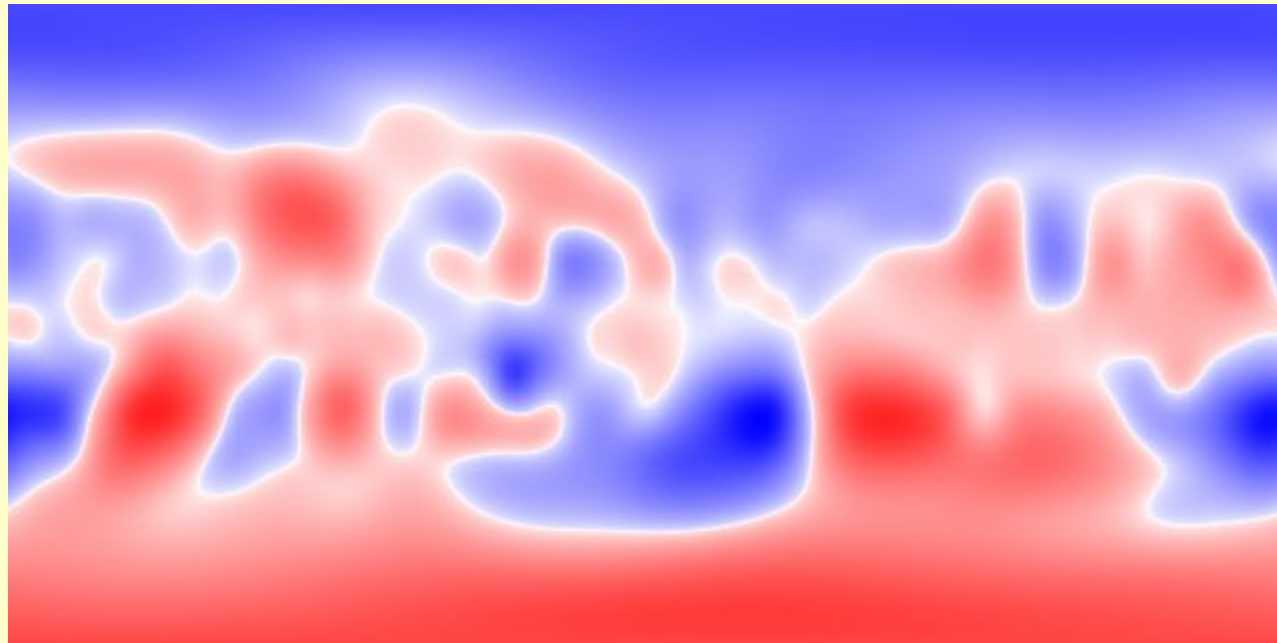
- Radial component of magnetic field are fixed.
- Coupling the assumption above, the horizontal component of plasma flow are assumed to be parallel to that of magnetic field, so that the induction equation for  $B_r$  is satisfied.
- Having three constraints above, we defined **two additional constraints**. Then, the temporal variations of variables on solar surface are calculated in accordance with the concept of characteristic projection method.

## Simulation code: boundary treatment (2)

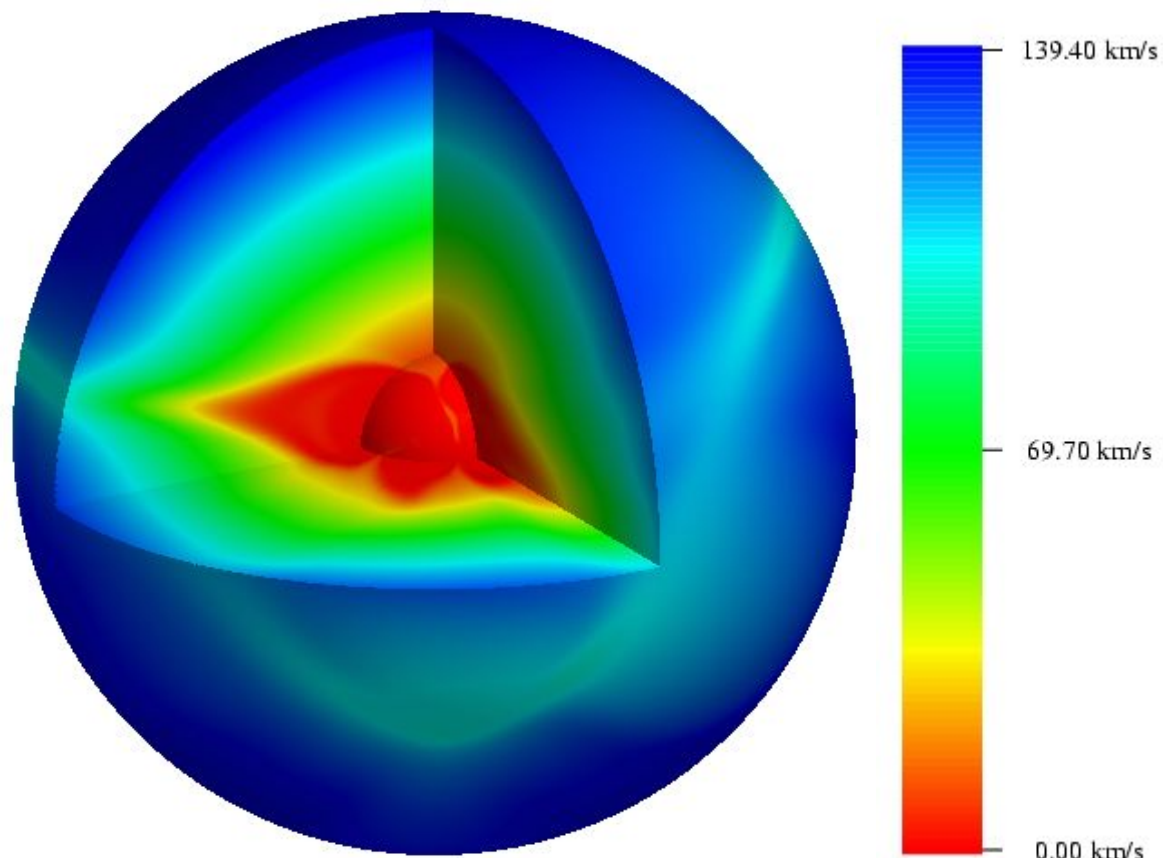
- In this study, the two constraints depends on the radial component of flow speed ( $V_r$ ) .
- For  $V_r < 0$ , reset  $V_r = 0$ , the temporal variations of density (or pressure) and two horizontal component of magnetic field are calculated. Polytropic relation is kept.
- For  $0 < V_r < V_c (= 5 \text{ km/s})$ , the temporal variations of  $V_r$ , and two horizontal component of magnetic field are calculated. Density and temperature (or gas pressure) are fixed.
- For  $V_r > V_c$ , the temporal variations of two horizontal component of magnetic field and plasma density are calculated (temperature is fixed).

## Input data : Boundary magnetic field map

.. is smoothed, so that small polarity spots will be removed. This may not be necessary when spatial resolution of simulation is improved. Relaxation method is used to solve Laplace equation to give an initial potential magnetic field.

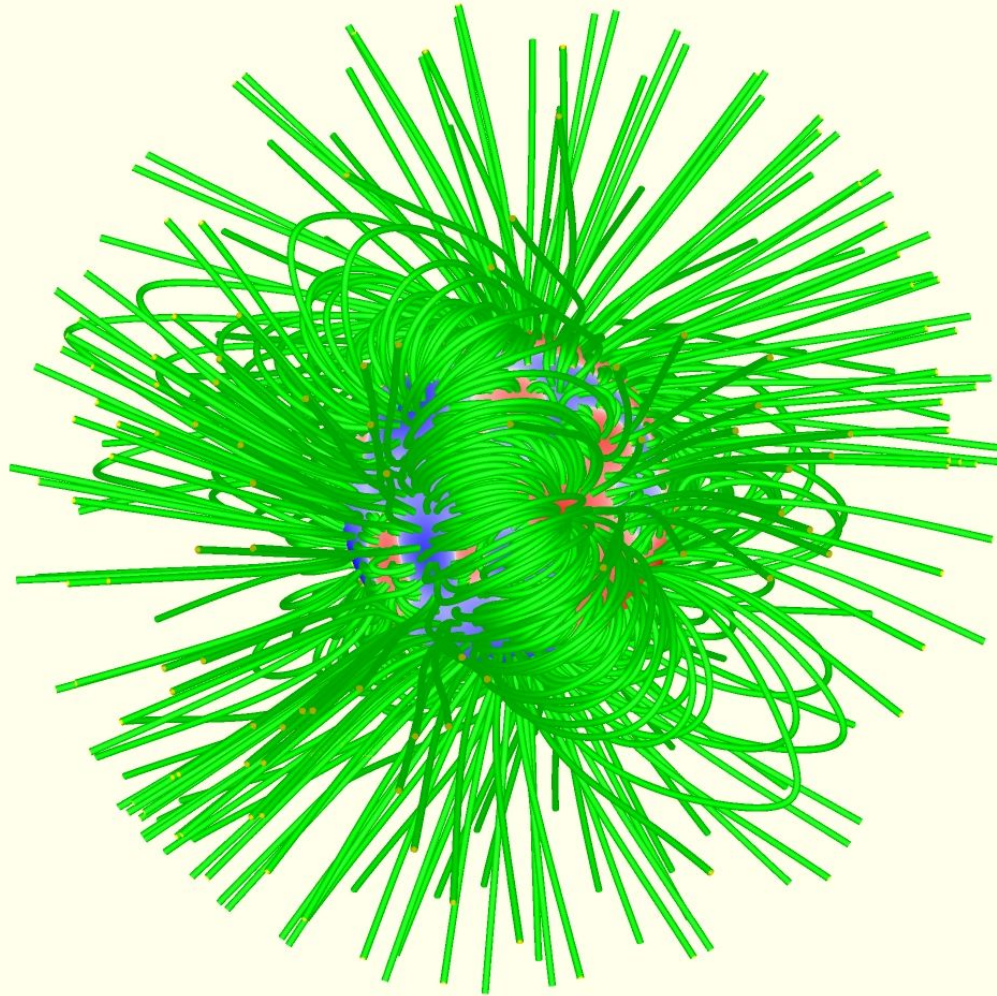


# Simulation results : (1) flow speed

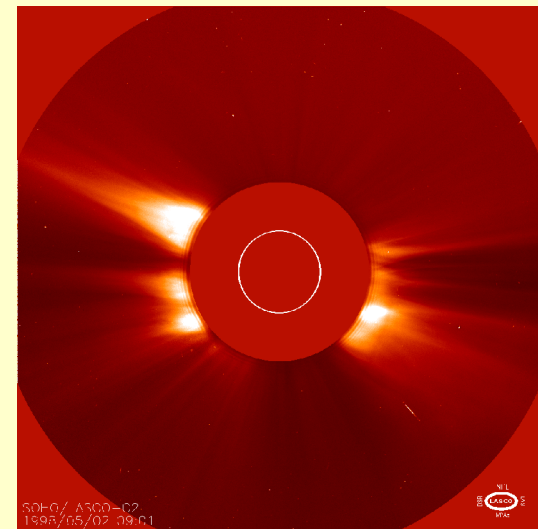


Three-dimensional structure of flow speed at  $r < 5 R_s$ . Cross section parts are showing streamer structures (with red). Cyan color belt appearing on the outer sphere is a slow wind region that locates at/near the heliospheric current sheet.

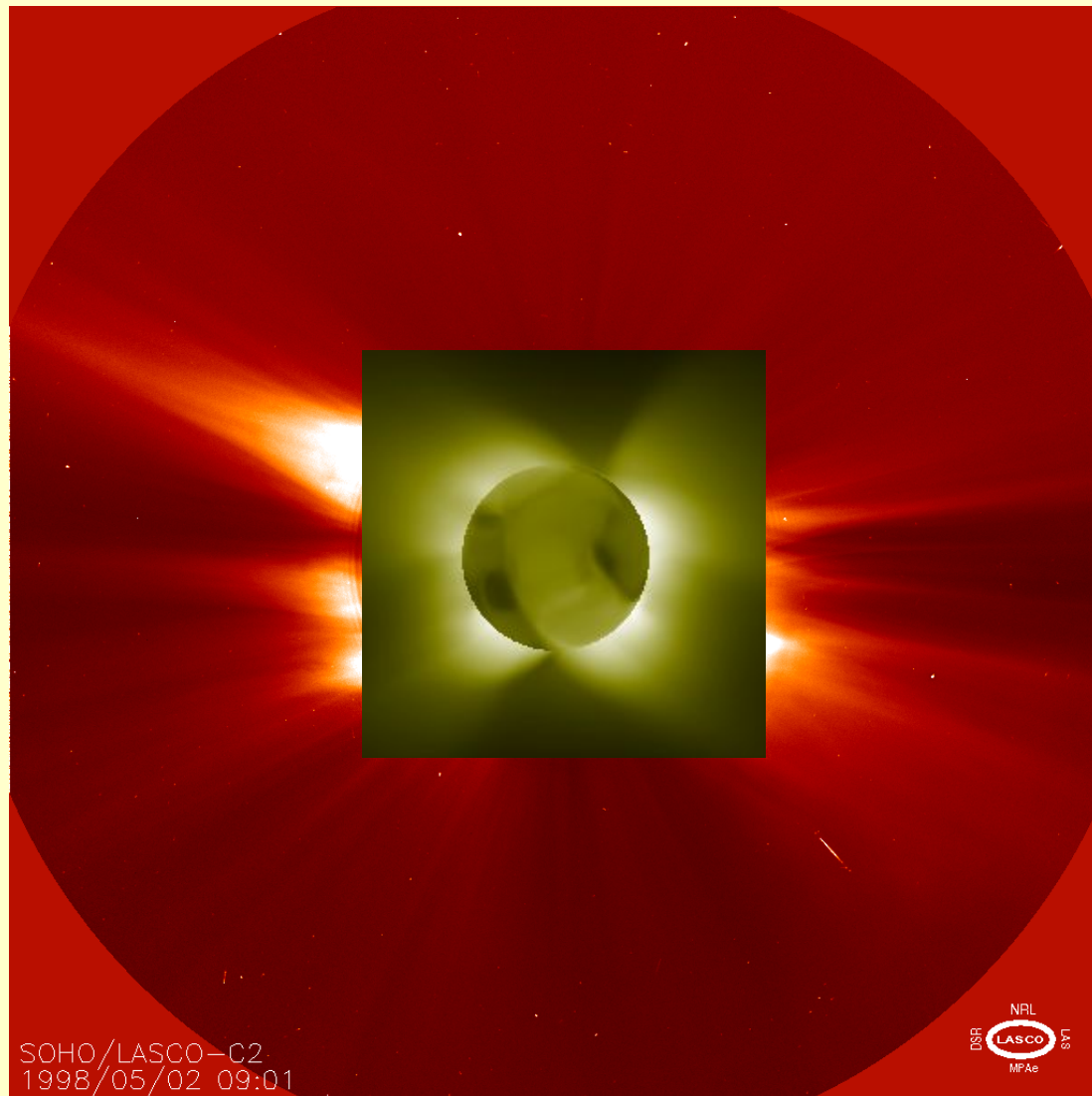
# Simulation results : (2) field lines



Magnetic field lines near the Sun (left).

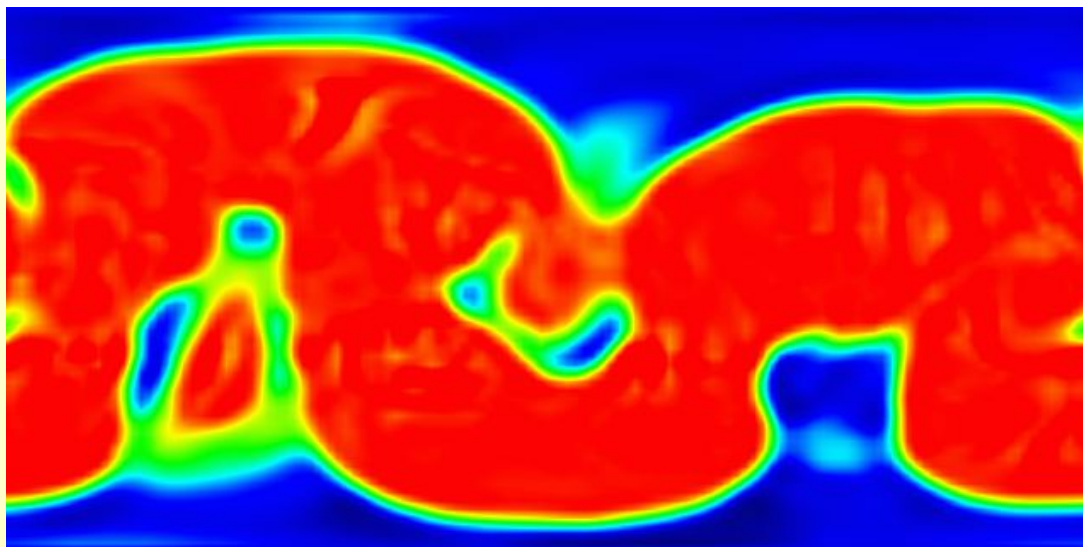
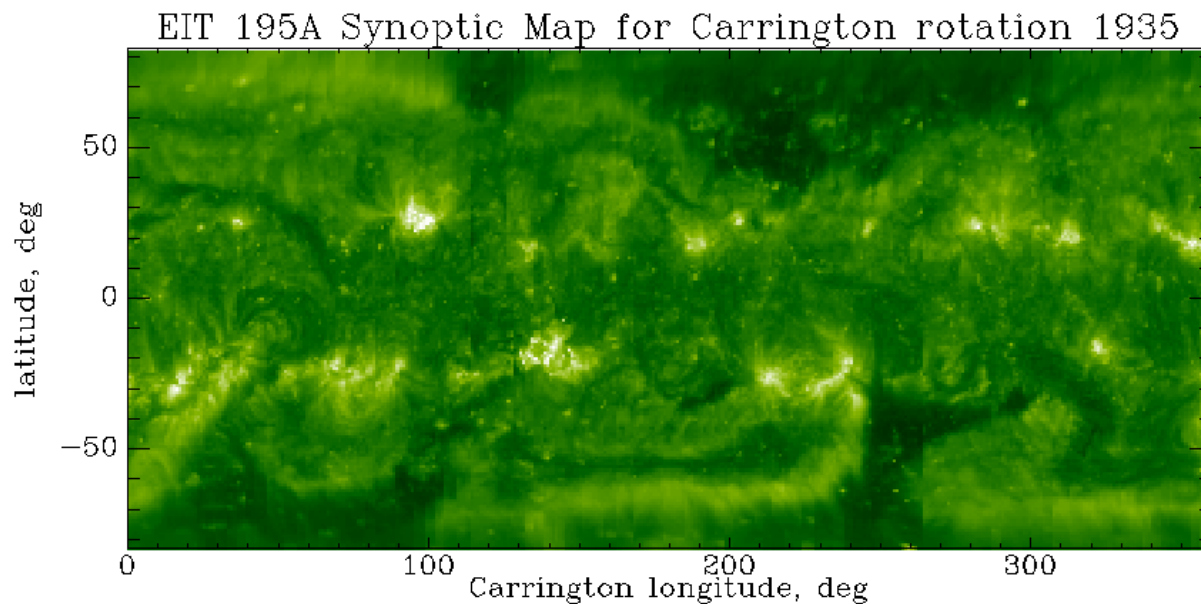


# Simulation results : (3) density



Superposition of LoS integration of simulated density with contrast enhanced (inner), and LASCO C2 image (May 02, 1998).

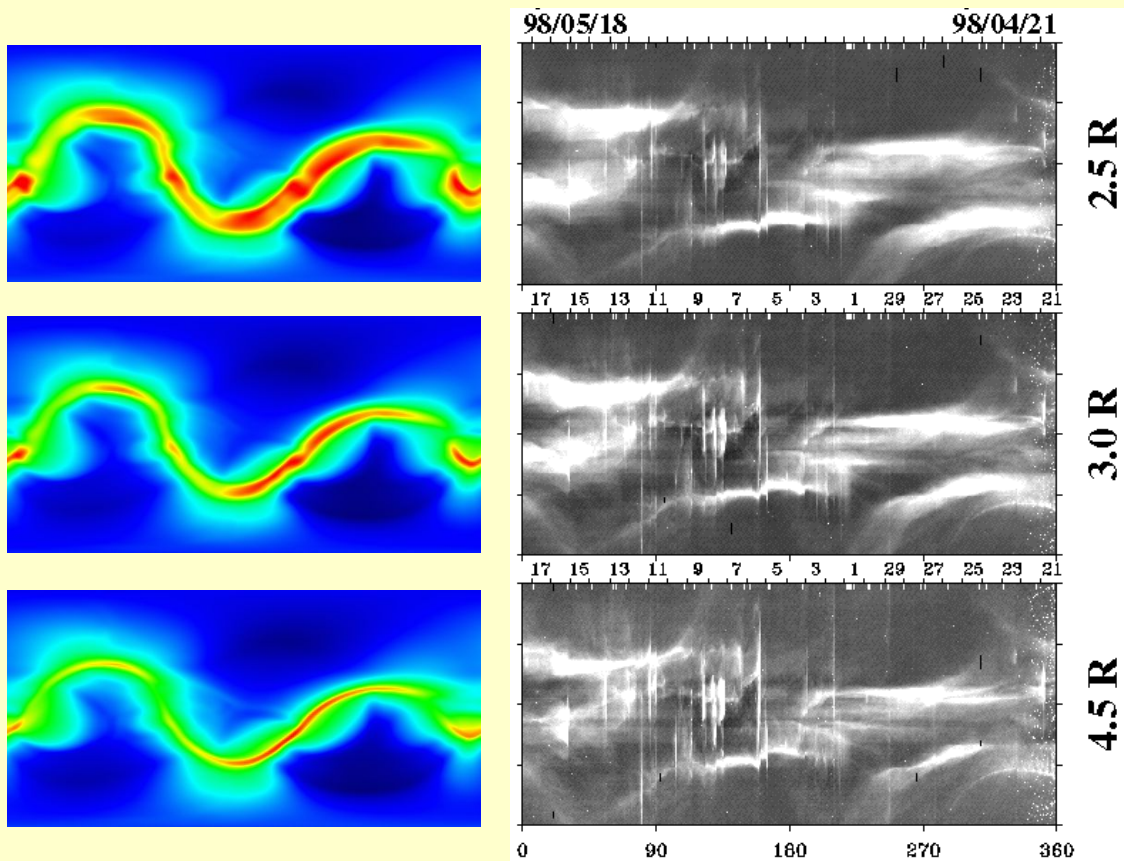
# Simulation results : (4) coronal hole



Synoptic map of EIT 195 A (above) and the simulated flow speed map at  $1.1 R_s$  (below).

The regions with red ( $< 0.2 \text{ km/s}$ ) -- yellow ( $< 1 \text{ km/s}$ ) correspond the closed filed regions where plasma are stagnated.

# Simulation results : (5) streamer



Velocity map obtained with simulation (left) and C2/LASCO synoptic map (right ; constructed at NRL) at various heights.

Colors of velocity maps are controlled with maximum and minimum values in each map. Therefore, the color tables are not identical.

# Remarks

- Some results of our MHD simulation of solar corona/solar wind using observational solar photospheric magnetic field data are shown.
- In our code the characteristic projection method is applied to treat to boundary values, so that the steady state of solar corona are obtained.