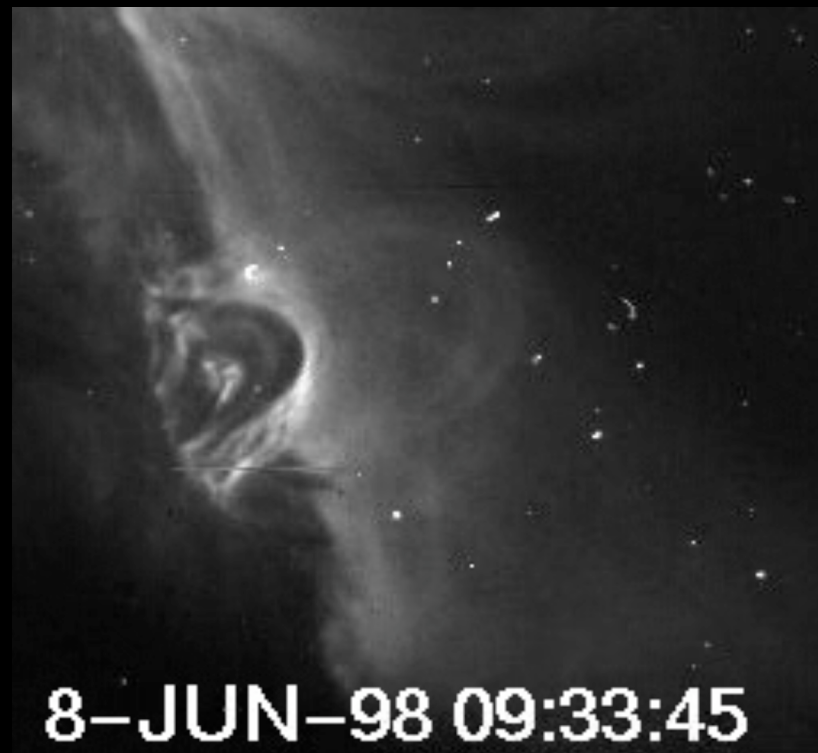


Flux emergence

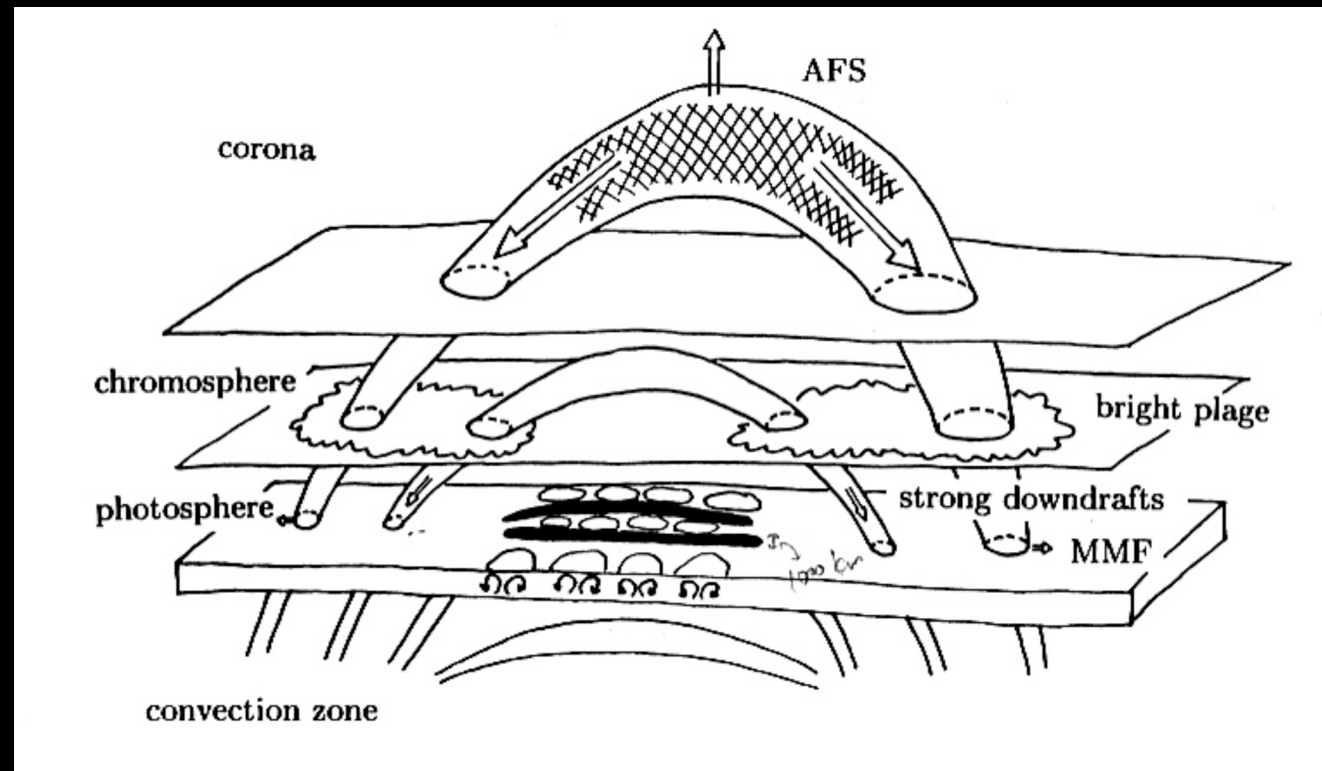
Emergence of magnetic flux from solar interior into solar atmosphere

Observation of flux emergence



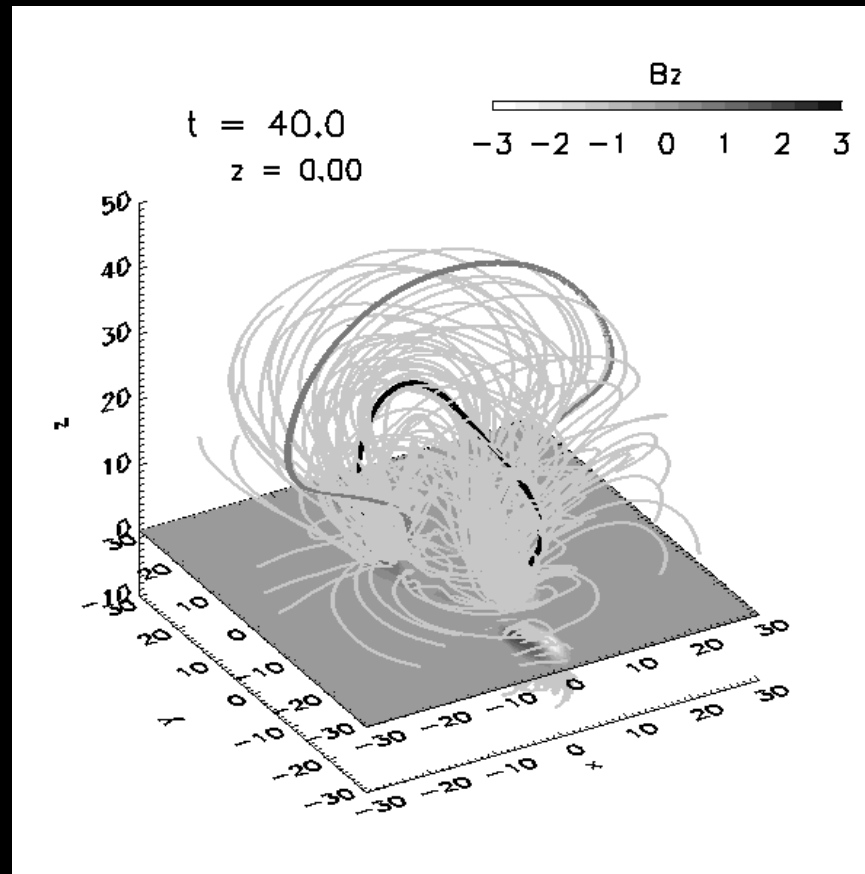
Observed by *TRACE*

Schematic model of flux emergence



Shibata et al. (1989)

Numerical simulation of flux emergence

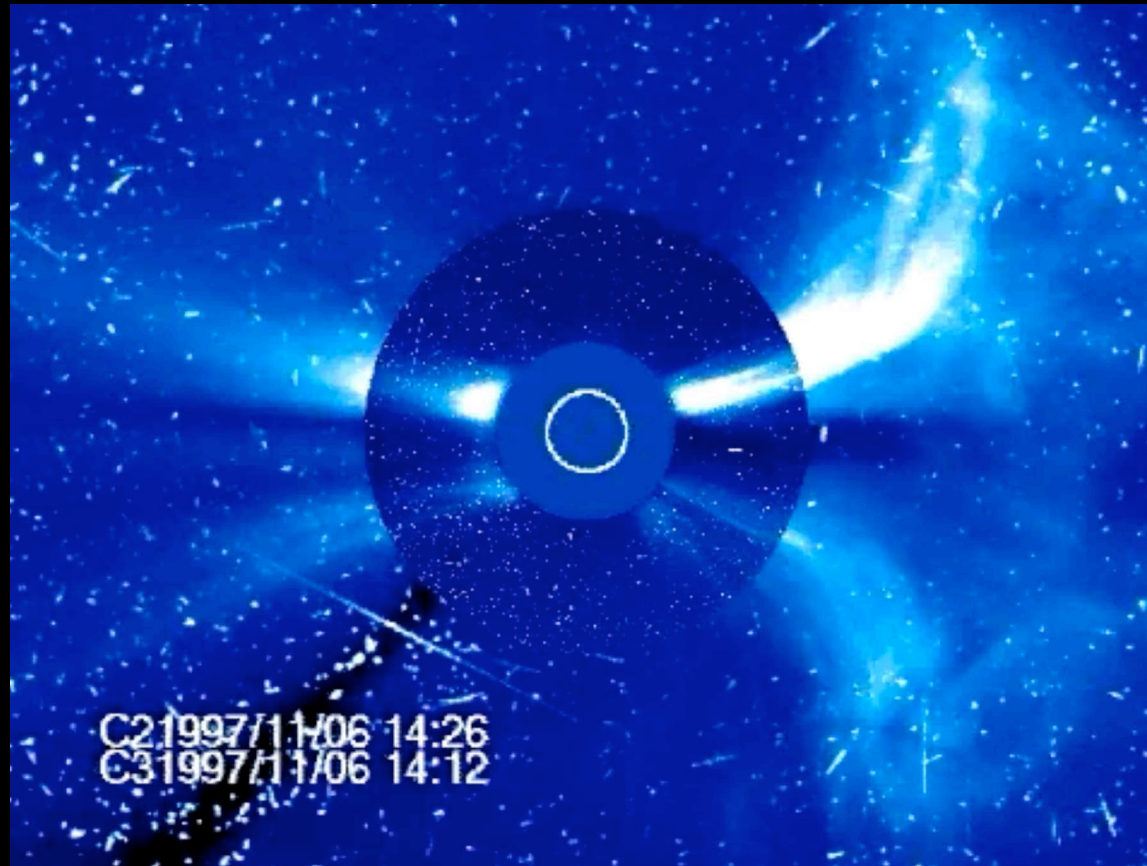


Magara (2004)

Coronal mass ejection

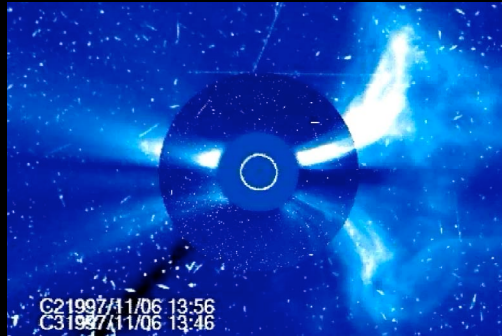
Solar global eruption

Observation of coronal mass ejection

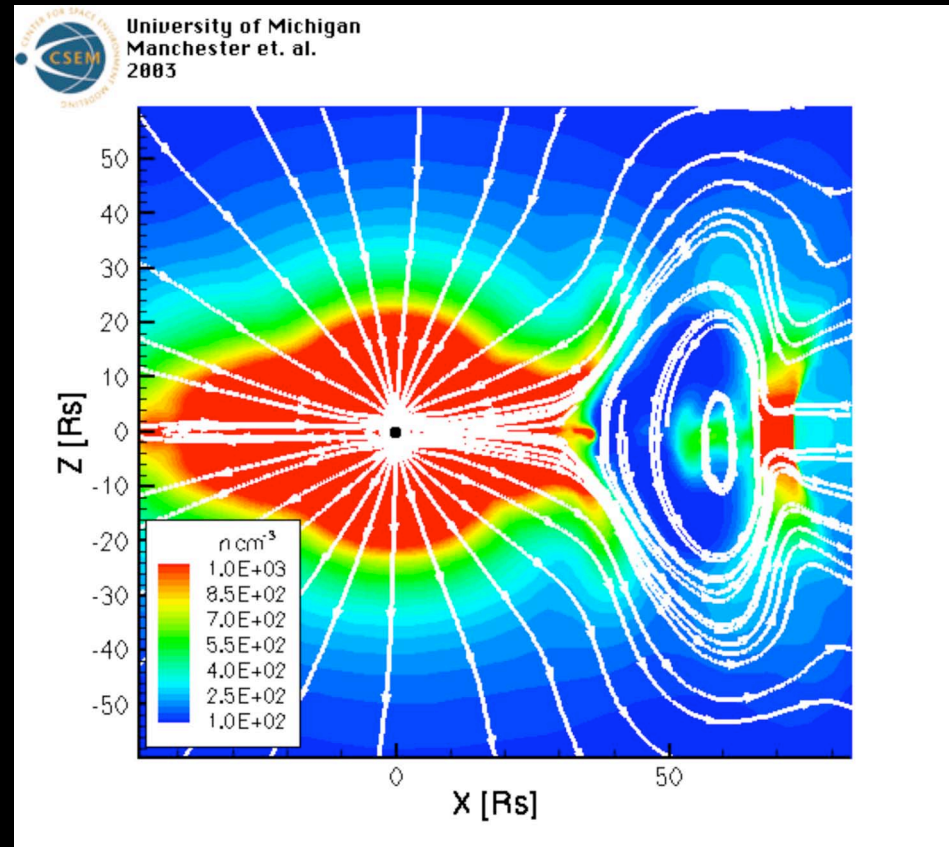


Observed by **SOHO**

Numerical simulation of coronal mass ejection *(from the Sun to the Earth)*



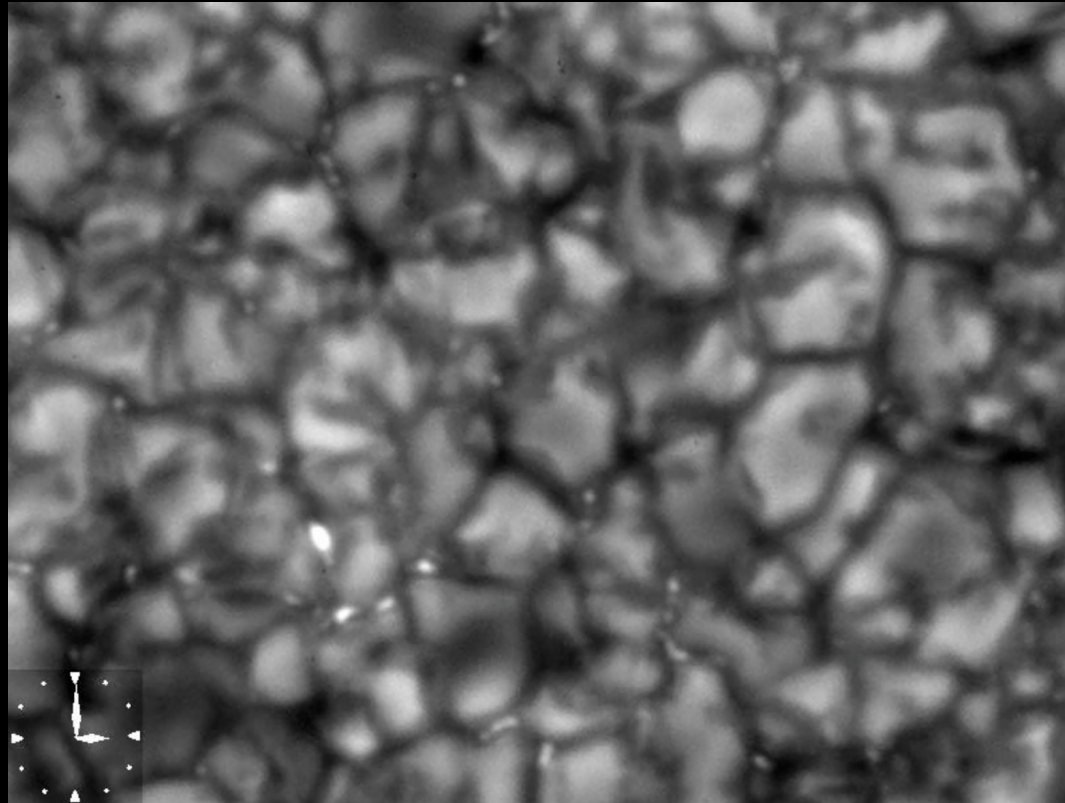
Manchester et al. (2003)



Granulation

Solar surface motion

Observation of granulation in solar surface (photosphere)

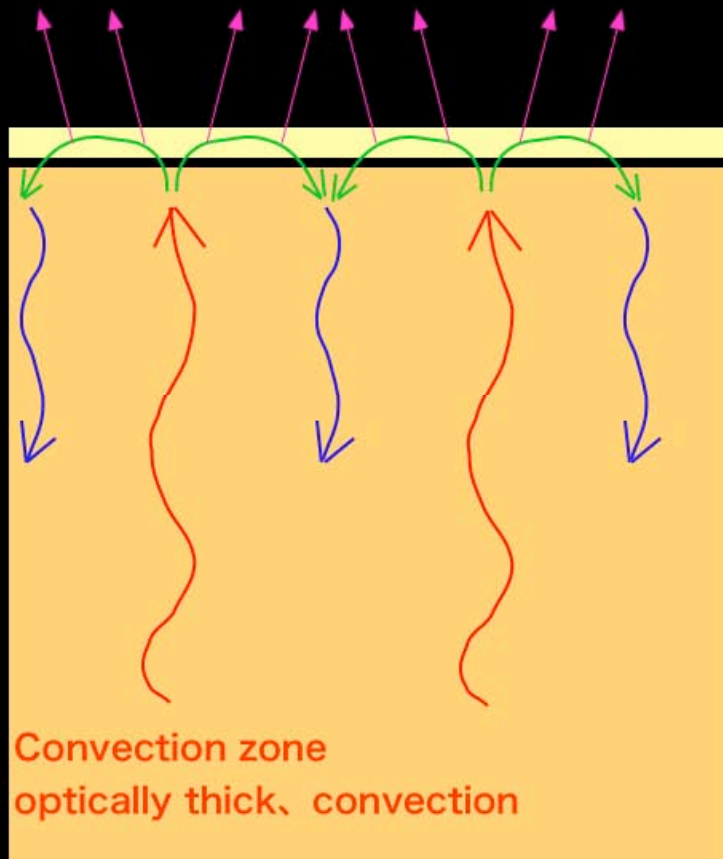


Observed by *Hinode*

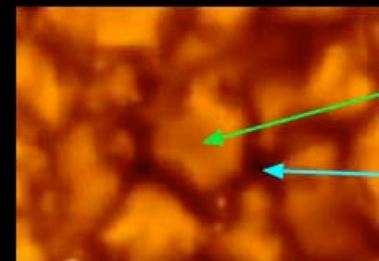
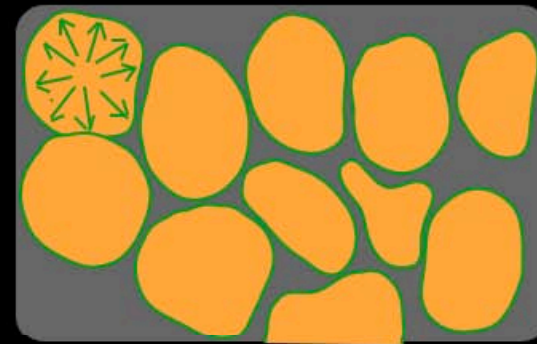
Schematic model of granulation

Photosphere
optically thin, radiation

Side view



Top view



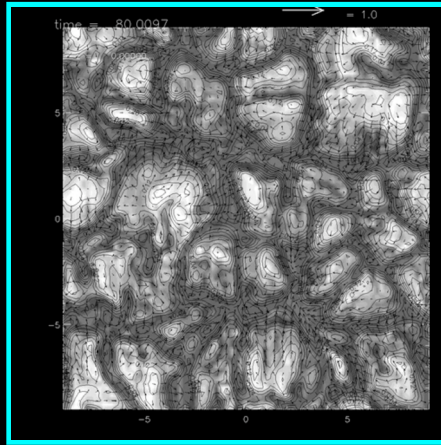
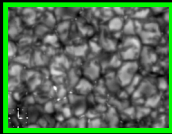
hot

cool

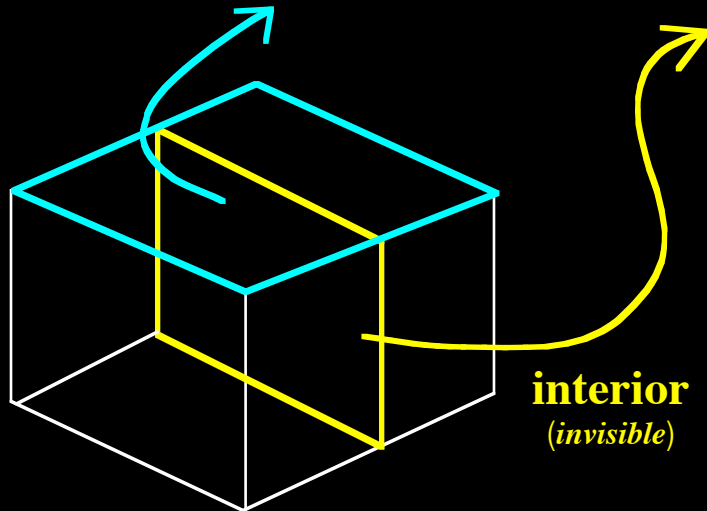
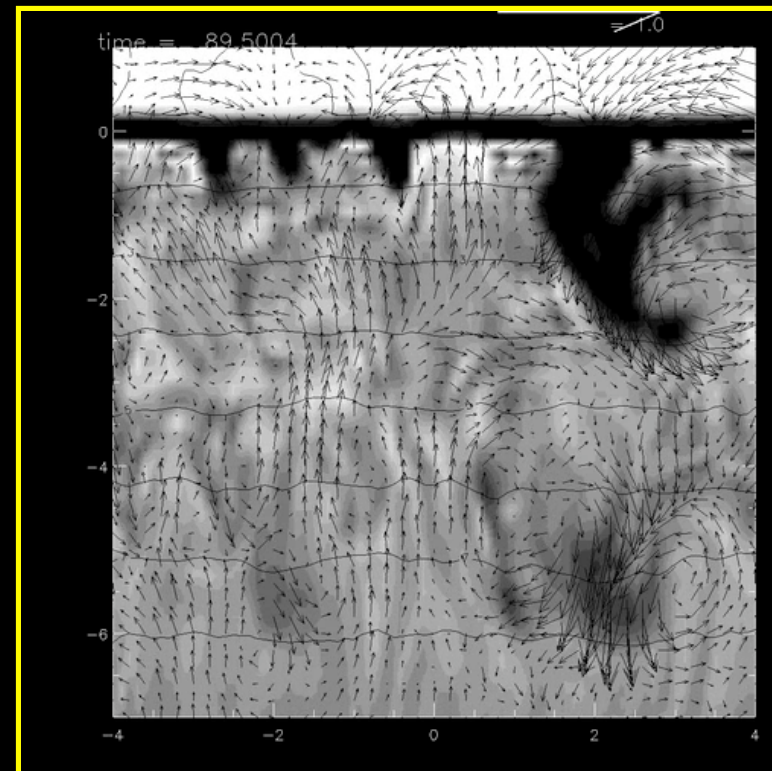
Numerical simulation of granulation

surface

(*visible* => direct
comparison to
observation)



Numerical simulation can tell
invisible solar internal dynamics.

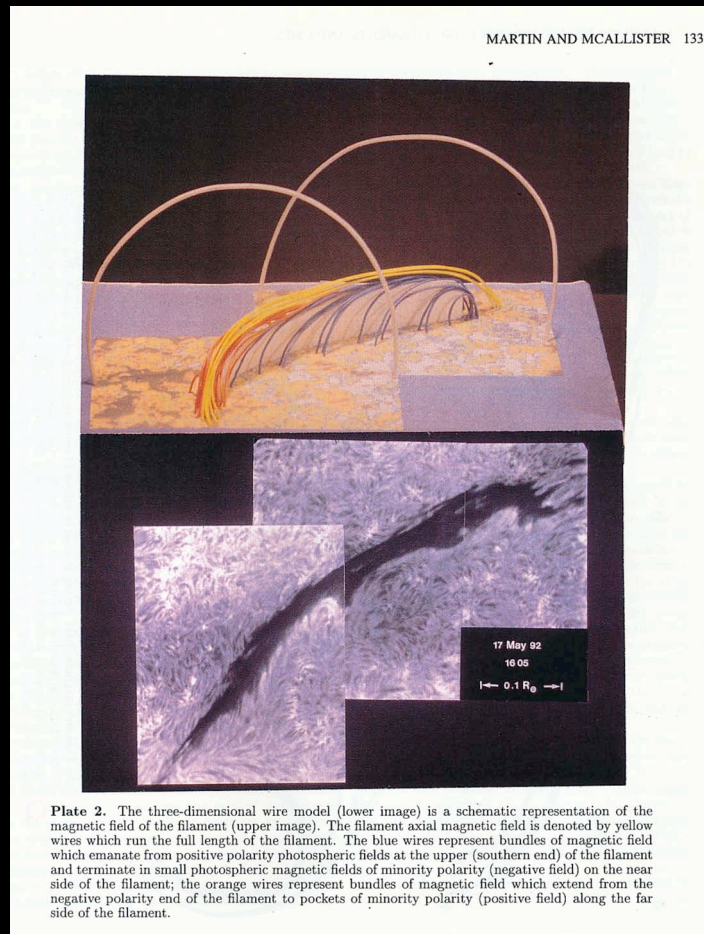


interior
(*invisible*)

Filament (Prominence)

Formation of solar plasma cloud

Observation & schematic model of filament

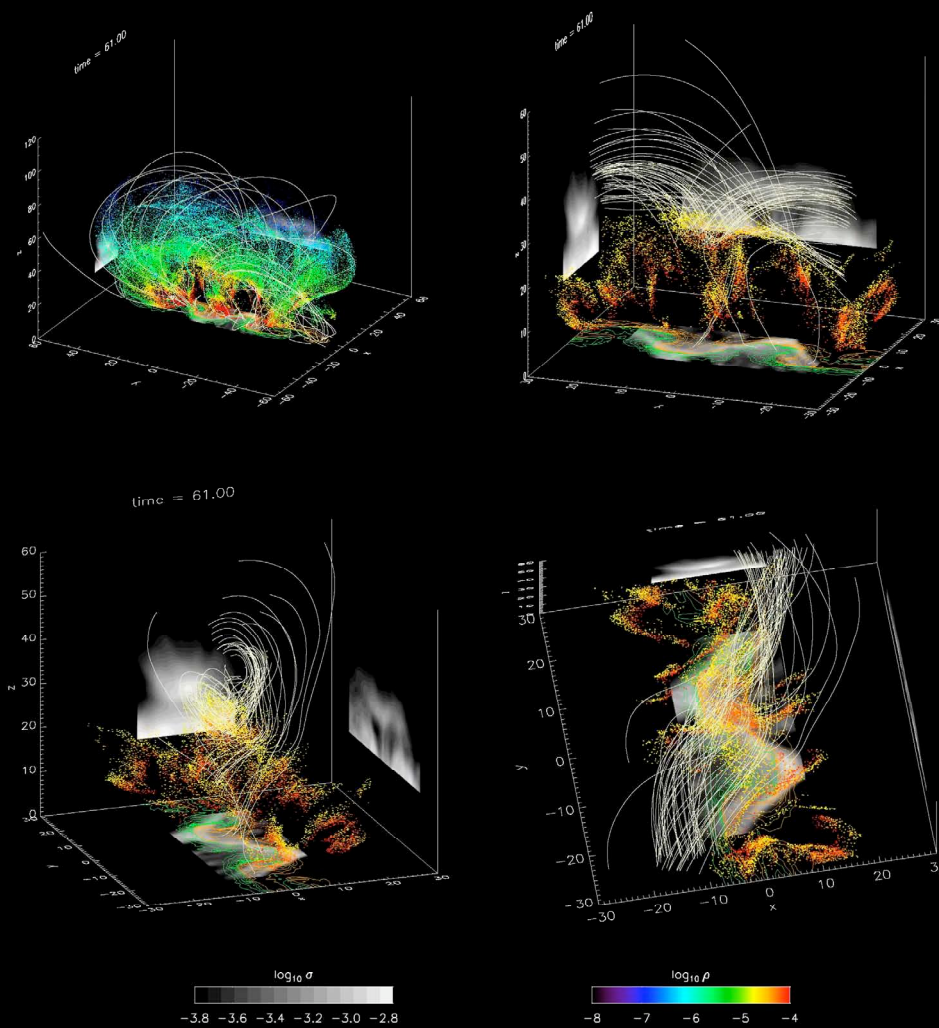


Martin (1998)

Feature	Chirality	
	N	S
1. Filament Channels		
2. Filaments		
3. Coronal X-Ray Arcades		
	Dominant in Northern Hemisphere	Dominant in Southern Hemisphere

Figure 10. One-to-one chirality relationships for (a) fibril patterns, (b) filament spines and barbs, and (c) overlying arcades of coronal loops, are shown in each column. The patterns in the left column are dominant in the northern hemisphere and those in the right column are dominant in the southern hemisphere. Exceptions exist to this hemispheric preference but there are no known exceptions within the sets of chirality relationships. Illustration from Martin (1998).

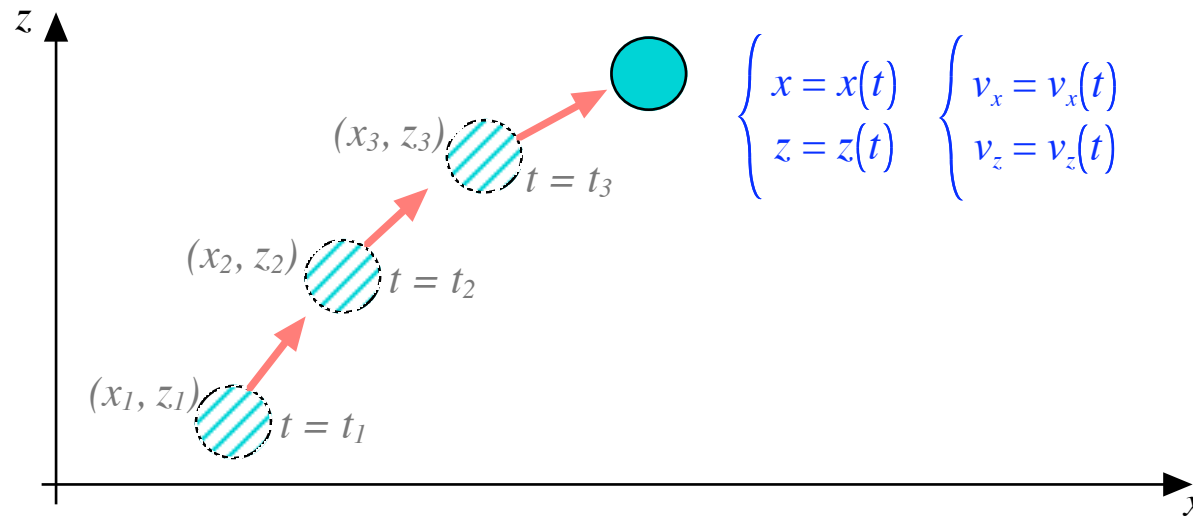
Numerical simulation of solar filament (prominence)



Magara (2021)

Comparison between mechanics and fluid dynamics

Mechanics



In mechanics, we **do NOT consider the internal structure of an object**, just considering its **position** and **velocity**.

The **equation of mechanics** is given by a *differential equation* where **time** is the **only independent variable** (**ordinary differential equation, ODE**).

$$\begin{cases} m \frac{dv_x}{dt} = F_x(x(t), z(t), v_x(t), v_z(t), t) \\ m \frac{dv_z}{dt} = F_z(x(t), z(t), v_x(t), v_z(t), t) \end{cases} \quad \begin{cases} v_x(t) = \frac{dx}{dt} \\ v_z(t) = \frac{dz}{dt} \end{cases}$$

Fluid dynamics

In fluid dynamics, we **DO consider the internal structure of an object**, such as the **distribution of temperature** in the object, which depends on not only **time** but also **position**. The temperature is therefore expressed as a **function of time and position**:

$$T = f(x, z, t)$$

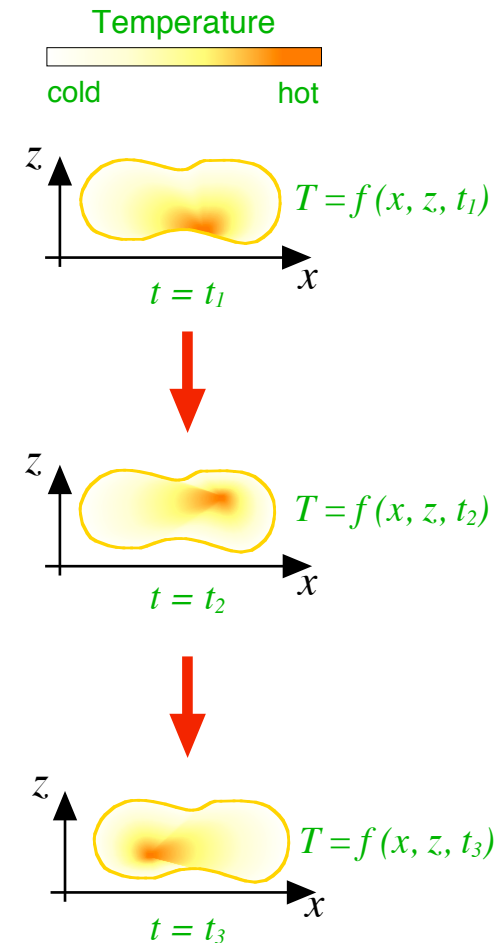
Temperature field

Field... continuously distributed in space-time

The **equation of the temperature field** is given by a **differential equation** where **time** and **position** are **independent variables**.

$$\frac{\partial T}{\partial t} = \kappa \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial z^2} \right)$$

... **partial differential equation (PDE)**



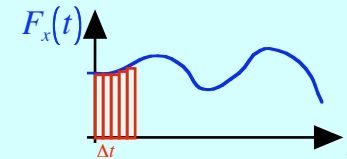
Integration of differential equation (mechanics vs. fluid dynamics)

Mechanics

$$\frac{dv_x}{dt} = \frac{1}{m} F_x(t) \dots \text{Ordinary Differential Equation (ODE)}$$

Integration with respect to t leads to a solution.

$$v_x(t) = \int \frac{dv_x}{dt} dt = \frac{1}{m} \int F_x(t) dt$$



For numerical integration we introduce **grids** to time coordinate.
(discretization)

Fluid dynamics

$$\frac{\partial T}{\partial t} = \kappa \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial z^2} \right) \dots \text{Partial Differential Equation (PDE)}$$

Integration with respect to t does **NOT** lead to a solution.

$$T(x, z, t) \neq \int \frac{\partial T}{\partial t} dt$$