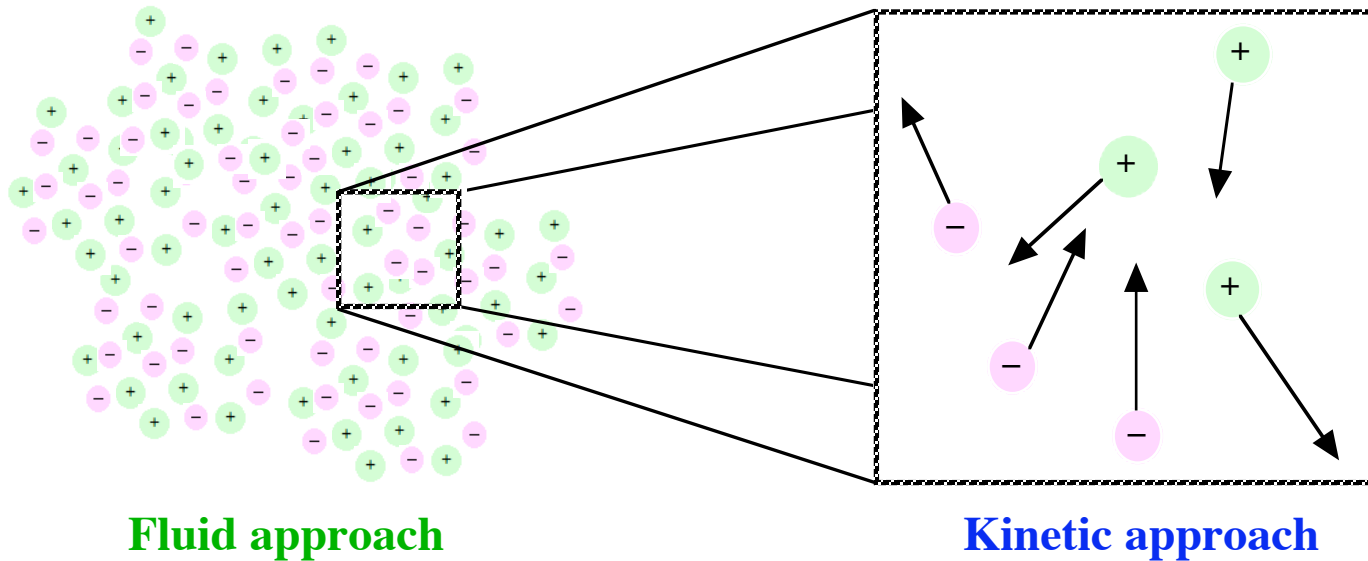


Two approaches to plasma physics

Plasma... composed of many particles

Focus on a selected **local region** → **Kinetic approach**

Focus on the **whole region** → **Fluid approach**



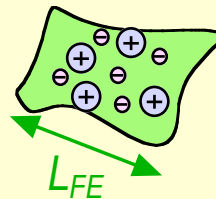
Kinetic approach

→ study **microscale** processes, the behavior of **particles**

Fluid approach

→ study **macroscale** processes, the behavior of **fluid elements***

***Fluid element**... a **virtual** object containing a number of particles; most of the particles **keep staying inside the element** (\Rightarrow typical size $L_{FE} \gg l_{mfp}, r_G$)

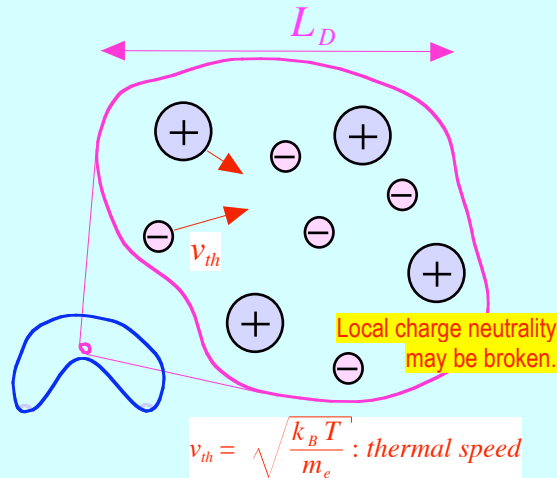


l_{mfp} : mean free path

r_G : gyration radius

Typical scales used in both approaches...

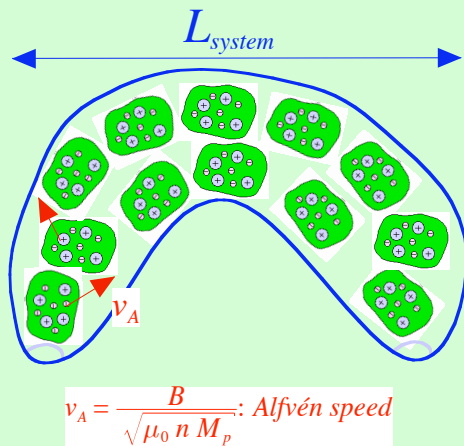
Kinetic approach... particle is a fundamental object (its internal structure is not considered)



Typical scales:

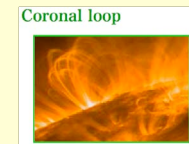
- Length... L_D (Debye length)
e.g. 1 cm for a solar coronal plasma
- Time... $L_D / v_{th} \sim 1 / \nu_p$ (plasma frequency)
e.g. 5×10^{-9} s for a solar coronal plasma

Fluid approach... fluid element is a fundamental object (its internal structure is not considered)



Typical scales:

- Length... L_{system} (system size)
e.g. 100,000 km $\sim 10^8$ m for a coronal loop
- Time... L_{system} / v_A (Alfvén speed)
e.g. 100 s for a coronal loop ($v_A \sim 1000$ km/s)



Characteristic scales of plasmas (particle-based scales)

	E-related scale		B-related scale
Length	mean free path (l_{mfp})	Debye length (L_D)	gyration radius (r_G)
Time	collision time ($\tau_c = \frac{l_{mfp}}{v_T}$)	oscillation period ($\tau_p = \frac{L_D}{v_T}$)	gyration period ($\tau_G = \frac{r_G}{v_T}$)
Physical process	collision	oscillation	gyration
Physical effect	thermalization	neutralization	magnetization
CGS unit	$l_{mfp}^{e-e} = \frac{(k_B T_e)^2}{4 \pi n_e e^4 \ln N_D}$ <small>$\ln N_D \sim 10$</small>	$L_D = \sqrt{\frac{k_B T}{4 \pi e^2 n_e}}$	$r_G = \frac{m c v_T}{e B}$

Emergence of magnetic fields into the solar atmosphere

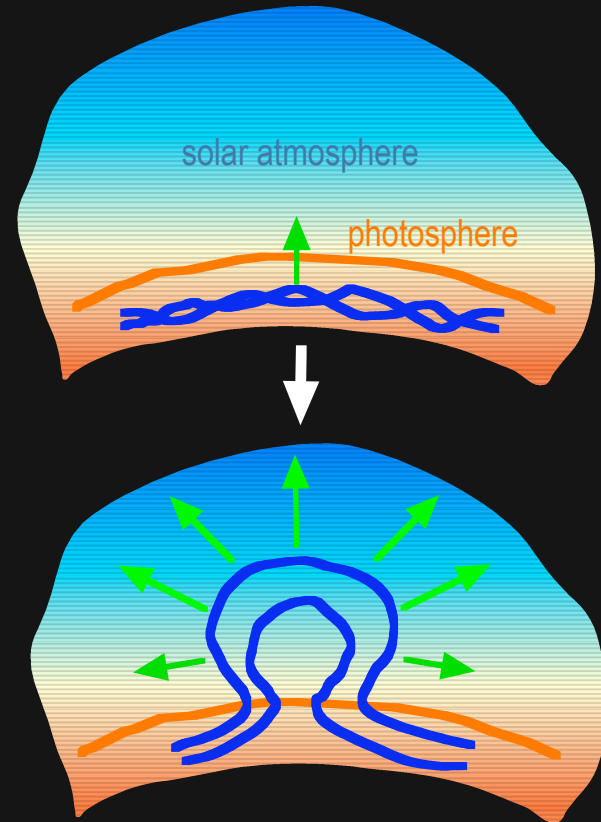
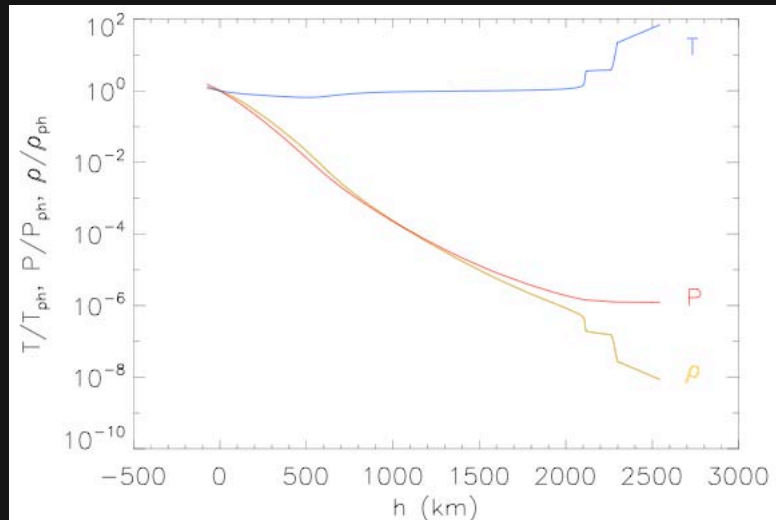
(flux emergence)

Magnetic fields play important roles in producing solar dynamic phenomena.

- **Cyclic amplification of magnetic fields in the solar interior (*dynamo*)**
=> **Produces long-term activity variations** known as **solar cycle**
- **Transport of magnetic fields through the convection zone (*magnetoconvection*)**
=> **Lifts magnetized plasmas against solar gravity** via **magnetic buoyancy**
- **Emergence of magnetic fields into the solar atmosphere (*flux emergence*)**
=> **Forms magnetic structure on the Sun** (e.g. sunspot, prominence/filament, sigmoid)
- **Diffusion of magnetic fields in the solar atmosphere (*release of magnetic energy*)**
=> **Produces explosive phenomena** via **magnetic reconnection** (e.g. flare, jet, coronal heating?)
- **Ejection of magnetic fields into the interplanetary space (*removal of magnetic fields from the Sun*)**
=> **Produces outflow/eruptive phenomena** (e.g. solar wind, coronal mass ejection)

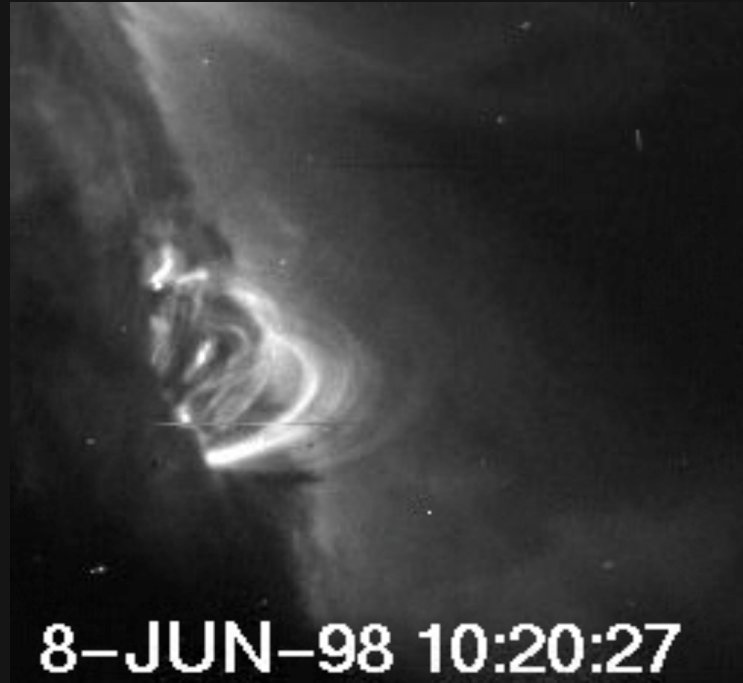
Flux emergence...

A magnetic flux tube emerging into solar atmosphere expands rapidly due to sharp decrease of gas pressure across solar surface (photosphere).



Photosphere	Chromosphere	Corona
$P \sim 2 \times 10^5 \text{ dyn/cm}^2$	$P \sim 1 \times 10^2 \text{ dyn/cm}^2$	$P \sim 2 \times 10^{-2} \text{ dyn/cm}^2$
840 km (0.001 R_\odot)		6000 km (0.01 R_\odot)

Flux emergence... a very dynamic process

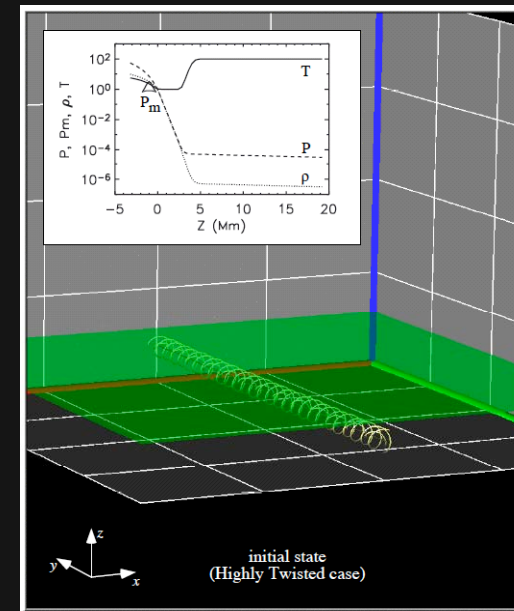
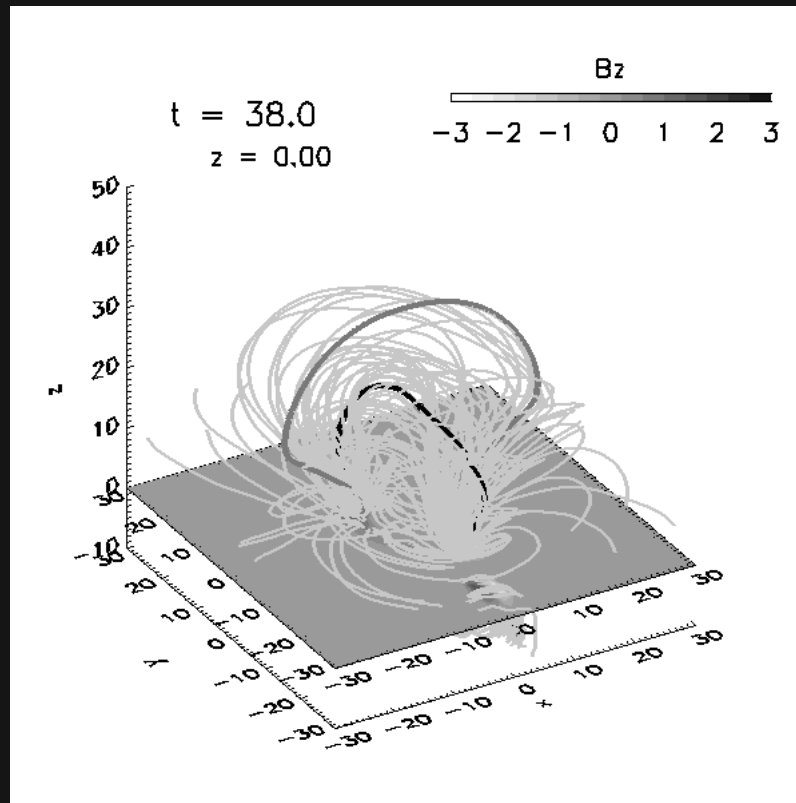


Observed by *TRACE*

A dynamic, time-dependent model is required to study this process.

A typical example of the model:

3-dimensional MHD simulation of an emerging flux tube



A twisted flux tube is initially placed below a solar surface.

The flux tube then starts to rise via magnetic buoyancy.

After emerging to the surface, the flux tube expands rapidly to form magnetic structure on it.