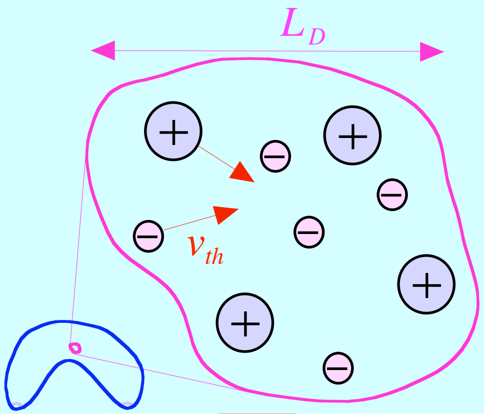
Typical scales in both approaches...

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



$v_{th} = \sqrt{\frac{k_B T}{m}}$: *thermal speed*

Typical scales:

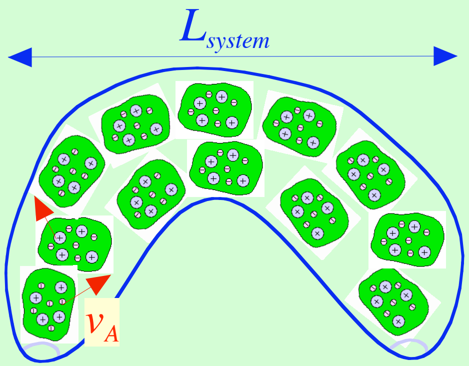
Length... L_D (Debye length)

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)



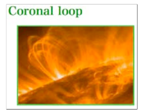
$r_{particle} << L_D << l_{mfp} << L_{FE} << L_{system}$

$r_G << L_{FE}$

Typical scales:

Length... L_{system} (System size)

e.g., 100,000 km ~ 10^8 m for a coronal loop



Time... L_{system} / v_A ($v_A = \frac{B}{\sqrt{\mu_0 n m}}$: *Alfvén speed*)

e.g., 100 s for a coronal loop (v_A ~ 1000 km/s)

Summary of characteristic scales of plasmas

	E-related scale			B-related scale	
Length	mean free path (l_{mfp})	Debye length (L_D)	effective radius (r_{eff})	gyration radius (r_G)	mean interval (l)
Time	collision time ($t_c \sim \frac{l_{mfp}}{v_T}$)	oscillation period ($t_p \sim \frac{L_D}{v_T}$)		gyration period ($t_G \sim \frac{r_G}{v_T}$)	
Physical process	collision	oscillation	collision with a large scattering angle	gyration	
Physical effect	thermalization	neutralization	thermalization	pressure & current in $B_\perp$-plane	
CGS unit	$l_{mfp}^{e-e} \sim \frac{(k_B T_e)^2}{n_e e^4} \frac{1}{\ln \Lambda}$	$L_D \sim \sqrt{\frac{k_B T}{4\pi e^2 n_e}}$	$r_{eff} \sim \frac{e^2}{k_B T}$	$r_G \sim \frac{m c v_T}{e B}$	$l \sim n^{-\frac{1}{3}}$

Additional comments on plasma state, kinetic & fluid approaches

Plasma state... *4th state of a system* in which

it is composed of **many charged particles**

these particles **behave collectively** => *local charge neutrality*

Kinetic approach... *more fundamental approach* in the sense that

it is based on **a real object** (**particle**)

it can be used **even for a non-plasma state** (*each particle behaves independently*)

Fluid approach... *less fundamental approach* in the sense that

it is based on **a virtual object** (**fluid element**)

it can be used **only for a thermal state** (*velocity distribution of particles is given by Maxwellian distribution*)

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 magnetic fields against solar gravity via magnetic buoyancy

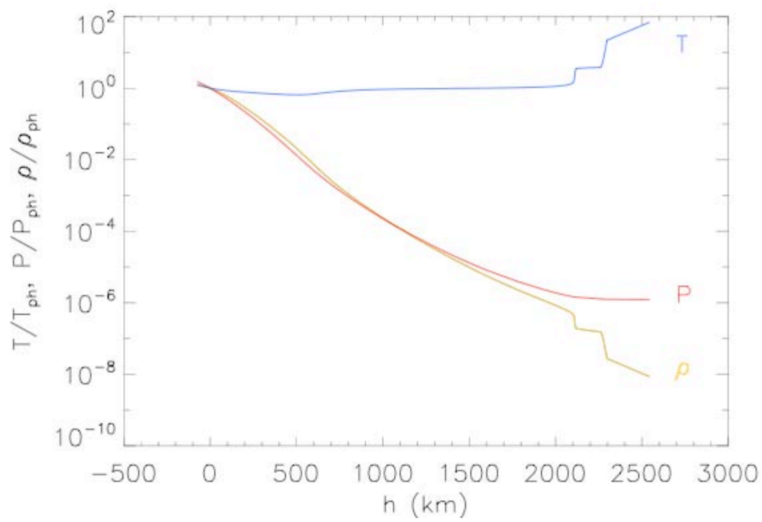
- Emergence of magnetic fields into the solar atmosphere (flux emergence)
  => Forms magnetic structure on the Sun (e.g. sunspot, sigmoid, prominence/filament)

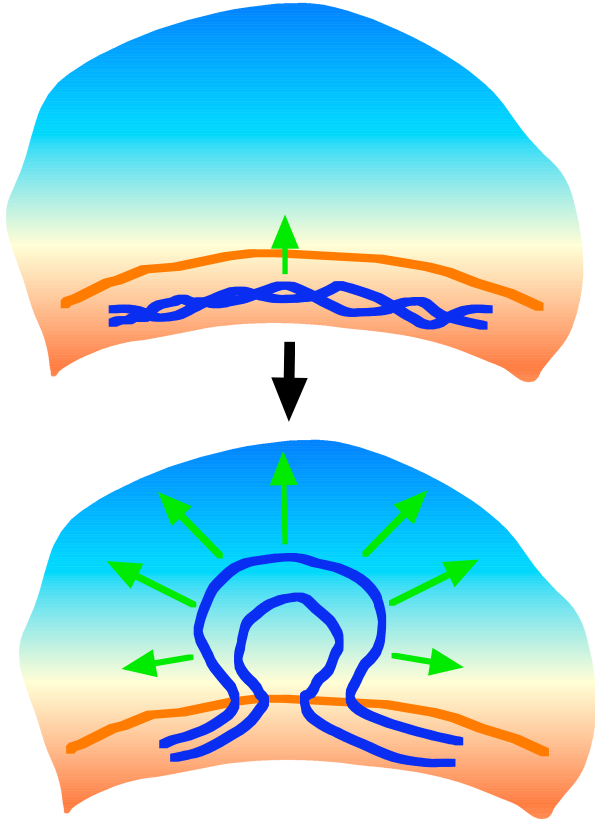
- Diffusion of magnetic fields in the solar atmosphere (release of magnetic energy)
  => Produces explosive phenomena via magnetic reconnection (e.g. flare, jet, coronal heating?)

- 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 emerges to the solar atmosphere and then expands rapidly due to the sharp decrease of gas pressure of a surrounding plasma across the solar surface.





Photosphere	Chromosphere	Corona
P ~ 2×10^5 dyn/cm^2	P ~ 1×10^2 dyn/cm^2	P ~ 2×10^(−2) dyn/cm^2

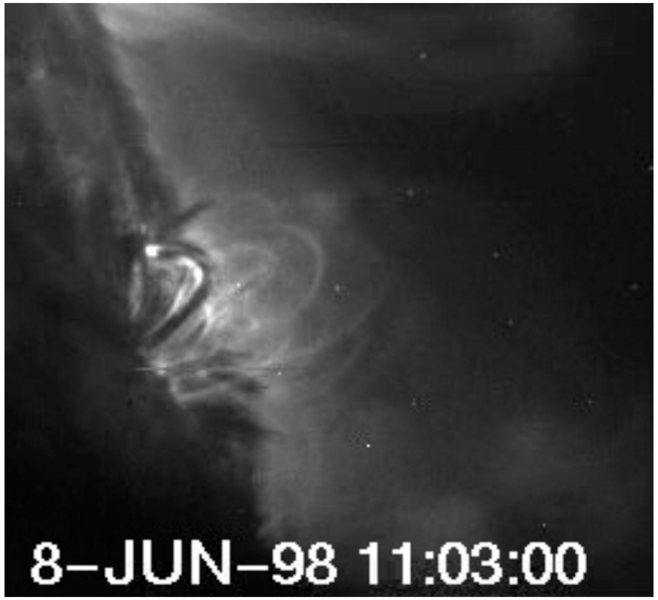
840 km ($0.001\ R_{\odot}$)

6000 km ($0.01\ R_{\odot}$)

Flux emergence

↓

a very dynamic process

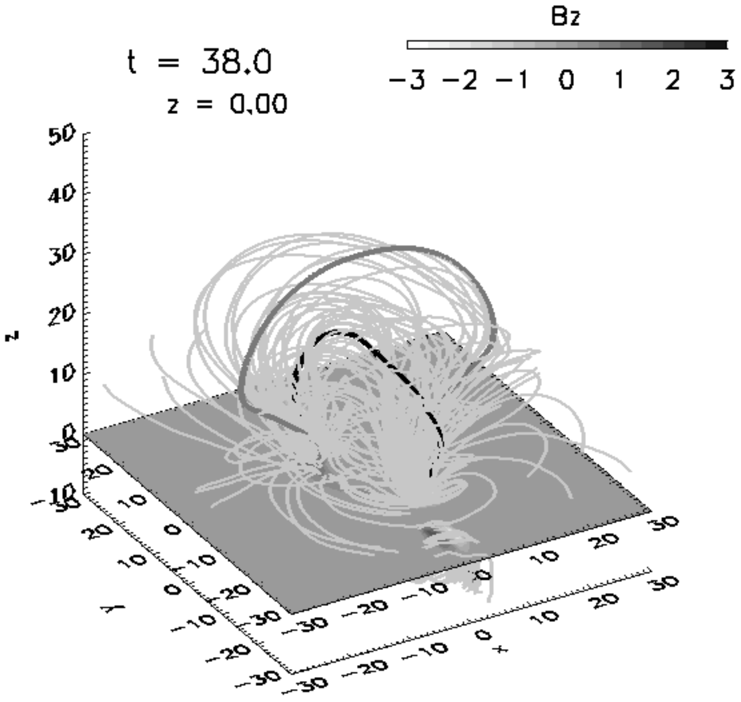


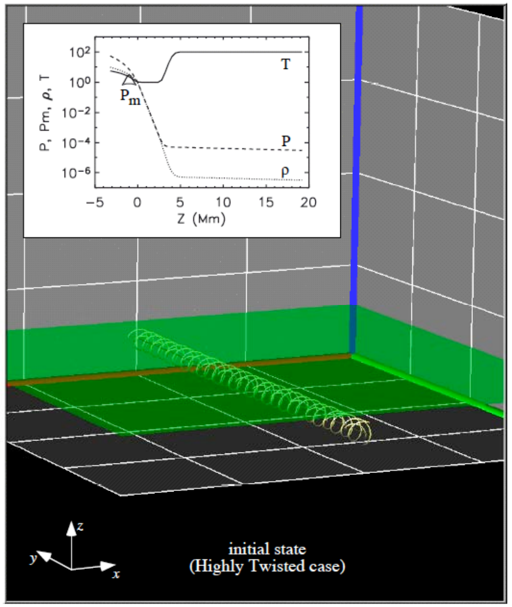
TRACE

Time-dependent model is required for the **theoretical study of flux emergence**.

Example of the modeling research

3-dimensional MHD simulation of an emerging flux tube

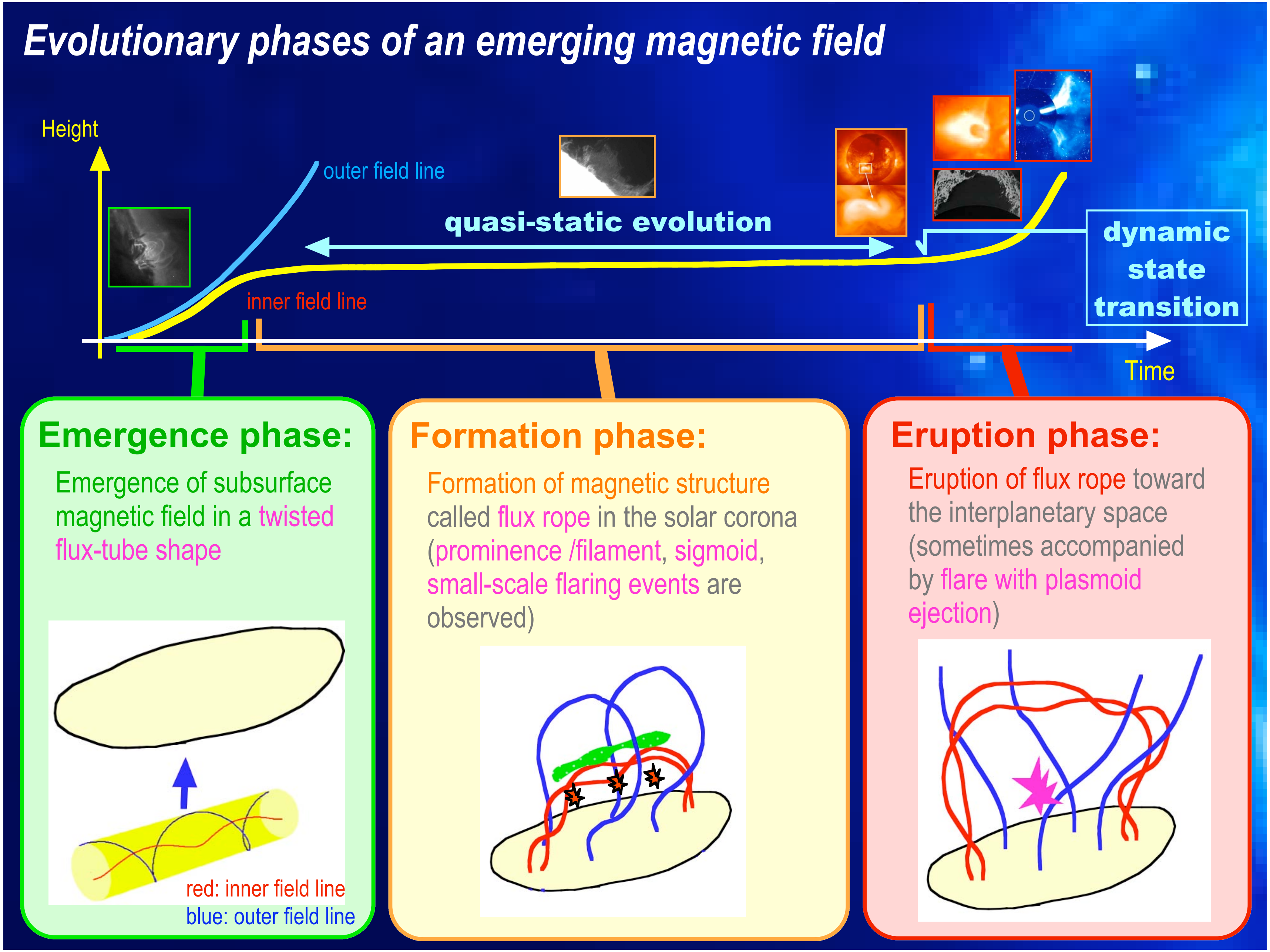




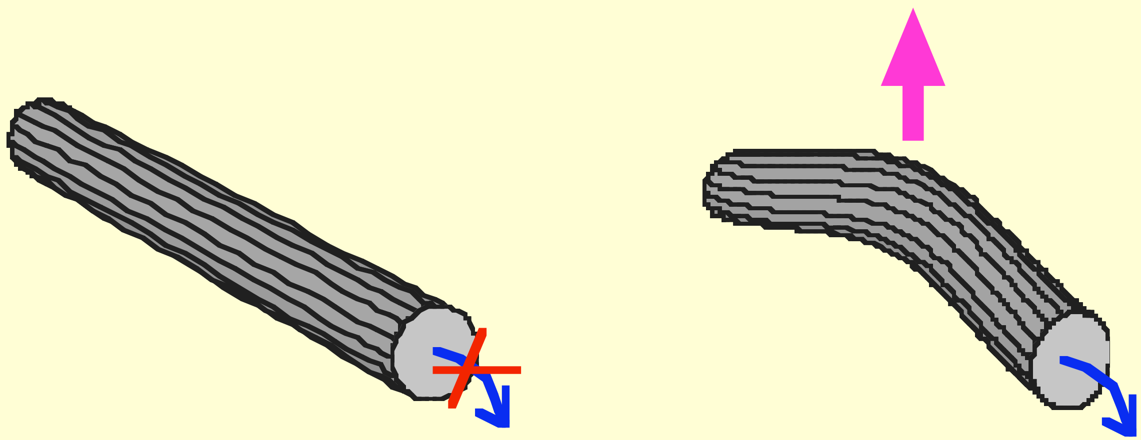
A twisted flux tube is placed below a solar surface.

The flux tube starts to rise via magnetic buoyancy.

After emerging to the surface, the flux tube expands rapidly.


Evolutionary phases of an emerging magnetic field
Height
outer field line
quasi-static evolution
inner field line
dynamic state transition
Time
Emergence phase:
Emergence of subsurface magnetic field in a twisted flux-tube shape
red: inner field line
blue: outer field line
Formation phase:
Formation of magnetic structure called flux rope in the solar corona (prominence /filament, sigmoid, small-scale flaring events are observed)
Eruption phase:
Eruption of flux rope toward the interplanetary space (sometimes accompanied by flare with plasmoid ejection)

Three-dimensional effect:



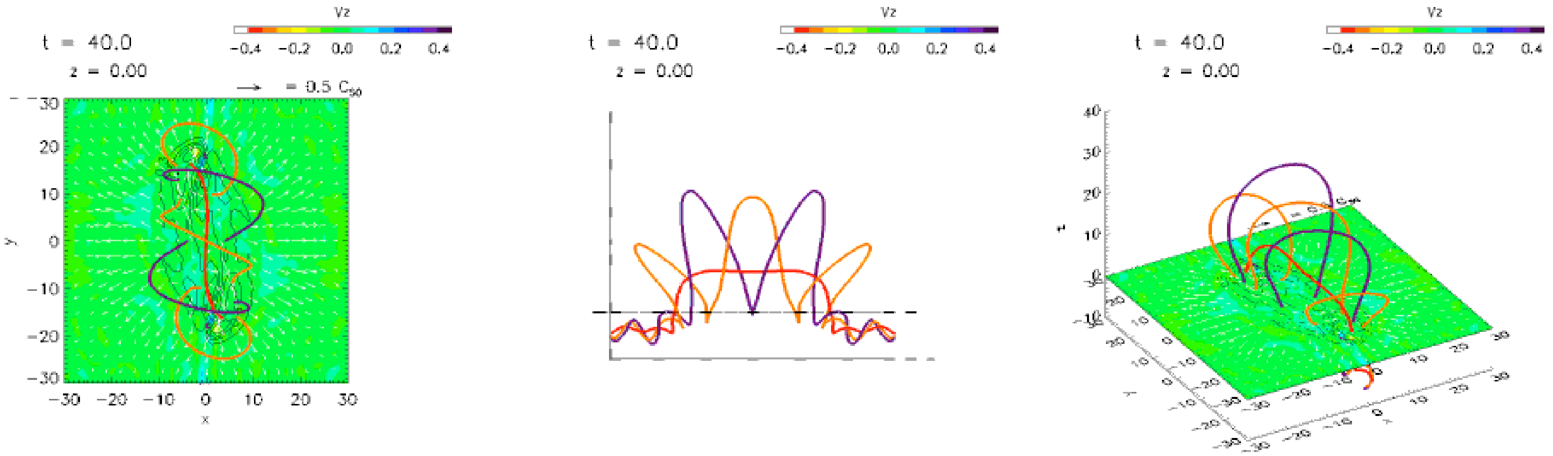
It enables a flux-tube plasma to drain along the axis of an emerging flux tube, thereby enhancing magnetic buoyancy.

2D case (straight axis)... the axis does not emerge （Magara 2001）

3D case (curved axis)... the axis does emerge （Fan 2001; Magara & Longcope 2001）

Three-dimensional evolutoin of emerging field lines

Magara & Longcope (2003)



red... inner field line (axis of flux tube)
purple, orange... outer field lines

Flux-tube axis does emerge into a solar atmosphere (**3D effect**).
Ω-part of outer field lines emerges, whereas their U-part does not emerge.