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Formation and Primary Heating of the Solar Coronal Structures

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S.M. Mahajan, R.Miklaszevski, K.I. Nikol'skaya & N.L. Shatashvili. *Phys. Plasmas*. **8,** 1340 (2001);
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S.M. Mahajan & N.L. Shatashvili. arXiv:0709.1535 (astro-ph), (2007).

Outline

- Solar atmosphere - fields and flows.

- Dynamic finely structured solar atmosphere.

- Corona - observations and inferences. Heating of the Solar Corona.

- Models. History. Present state of art.

- Towards a General unifying model $\Rightarrow$ Magnetofluid coupling.

- Simultaneous Formation and primary heating of the coronal structure.

- Simulation examples.

- Equilibrium analysis.

- Summary and Conclusions.

Dynamic multi-scale Solar Corona

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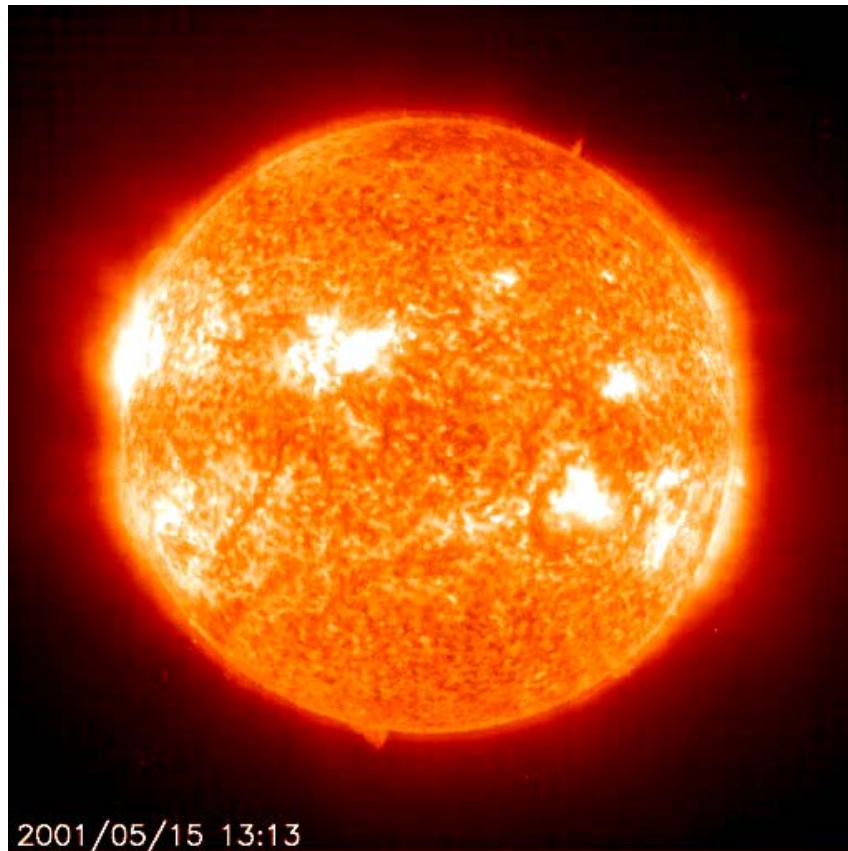
- The solar corona – a highly dynamic arena replete with multi-species multiple–scale spatiotemporal structures.

- Magnetic field was always known to be a controlling player.

Active region of the corona with:
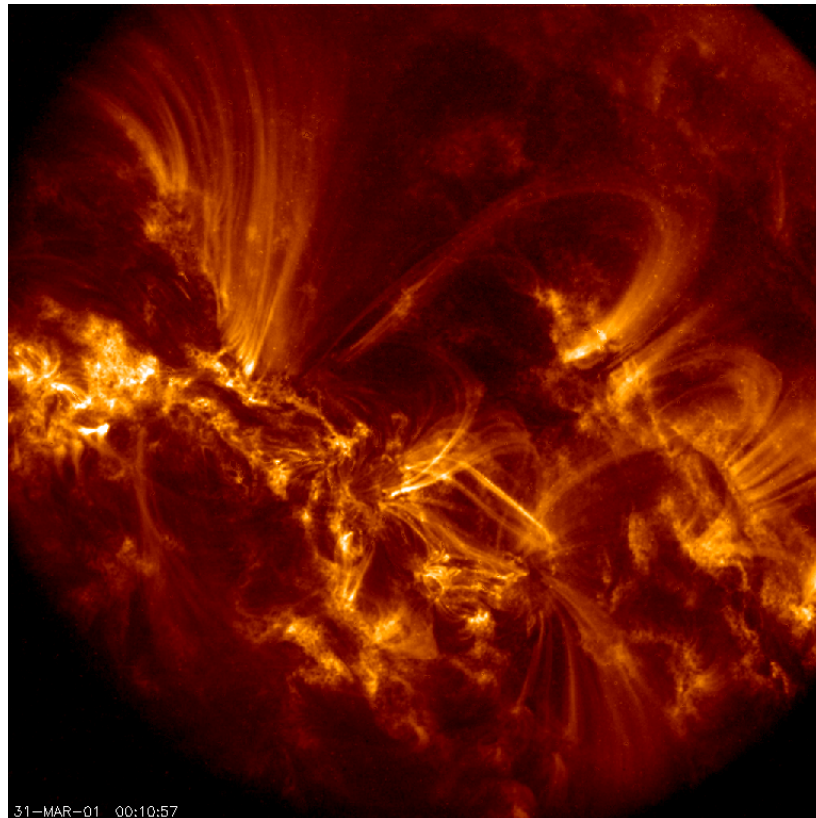
Co-existing dynamic structures:

- Flares
- Spicules
- Different-scale dynamic closed/open structures

Message:

- Different temperatures
- Different life-times

Indication:

- Any particular mechanism may be dominant in a specific region of parameter space.

Richness of the coronal structures

- Observations with high spatio-temporal resolution →

- Enters a major new element – discovery that strong flows are found everywhere in the low atmosphere — in the subcoronal (chromosphere) as well as in coronal regions.

- Directed kinetic energy has to find its rightful place in dynamics: the plasma flows may, in fact, do complement the abilities of the magnetic field in the creation of the amazing richness observed in the coronal structures.

Observations suggest that there are strongly separated scales both in time & space in the solar atmosphere

Loops at different temperatures exist in the same general region and may be co–located to within their measured diameters.

The large line shifts, or **high velocities** (50 ÷ 100 km/s , or even 200 ÷ 300km/s), **are most common at transition region temperatures T ≤ 5 ·10^{5}K**, and seldom appear at 1 MK.

Cool loops in active regions show temporal variability. Characteristic times for the changes may vary.

Flows are found within loops. The time variable emission over a full range in temperatures in a volume filled with transient loops points to a close connection between regions of various T structures, at least in the range 10^4K ÷ 5 ·10^5K.

- Challenge – to develop a theory of energy transformations for understanding the quiescent and eruptive/explosive events in solar atmosphere.

- Recently developed theory that the formation and heating of coronal structures may be simultaneous

and

- **directed flows may be the carriers of energy** within a broad uniform physics framework opens a new channel for exploration.

How does the Solar Corona gets to be so hot $(\geq 10^6 K)$?

Still an unsolved problem?!

Models galore – never a lack of suggestions – the problem is how to prove or disprove a model with the help of observations.

- Is it the ohmic or the viscous dissipation?

- Or is it the shocks or the waves that impart energy to the particles

- And do the observations support the "other consequences" of a given model?

Towards a General Unifying Model:

Conjecture:

Formation and primary heating of coronal structures as well as the more violent events (flares, erupting prominences and CMEs) are the expressions of different aspects of the same general global dynamics that operates in a given coronal region.

- The plasma flows, the source of both the particles and energy (part of which is converted to heat), interacting with the magnetic field, become dynamic determinants of a wide variety of plasma states $\Longrightarrow$

- the immense diversity of the observed coronal structures.

Magneto-fluid Coupling

V — the flow velocity field of the plasma

Total current $j = j_0 + j_s$. j_s – self-current (generates B_s).

Total (observed) magnetic field — $B = B_0 + B_s$.

The stellar atmosphere is finely structured. Multi-species, multi-scales.

Simplest – two-fluid approach.

Quasineutrality condition: $n_e \approx n_i = n$

The kinetic pressure: $p = p_i + p_e \approx 2\,nT; \qquad T = T_i \approx T_e$

Electron and proton flow velocities are different:

$$V_i = V \; ; \qquad V_e = (V - j\,/\,en)$$

Nondissipative limit: field frozen in electron fluid; ion fluid (finite inertia) moves distinctly.

Heating due to the viscous dissipation of the flow vorticity:

$$\left[\frac{d}{dt} \left(\frac{m_i \mathbf{V}^2}{2} \right) \right]_{\text{visc}} = -m_i n \nu_i \left(\frac{1}{2} (\nabla \times \mathbf{V})^2 + \frac{2}{3} (\nabla \cdot \mathbf{V})^2 \right). \tag{1}$$

Normalizations: $n \to n_0$ – the density at some appropriate distance from surface,
$\boldsymbol{B} \to \boldsymbol{B_0}$ – the ambient field strength at the same distance, $|\boldsymbol{V}| \to V_{A0}$ – Alfvén speed

Parameters: $r_{A0} = GM / V_{A0}^2 R_0 = 2\beta_0 \, r_{c0}$; $\alpha_0 = \lambda_0 / R_0$; $\beta_0 = c_{s0}^2 / V_{A0}^2$;
c_{s0} — sound speed , R_0 — the characteristic scale length ,
$\lambda_0 = c/\omega_{i\,0}$ — the collisionless ion skin depth   **are defined with** n_0 ; T_0 ; $\boldsymbol{B_0}$.

Hall current contributions are significant when $\alpha_0 > \boldsymbol{\eta}$
($\boldsymbol{\eta}$ - inverse Lundquist number)

Important in: interstellar medium, turbulence in the early universe, white dwarfs,
neutron stars, stellar atmosphere.

Typical solar plasma: **condition is easily satisfied.**

Construction of a Typical Coronal structure

Solar Corona — $T_c = (1 \div 4) \cdot 10^6\ K$　　　$n_c \leq 10^{10}\ cm^{-3}$.

Standard picture – Corona is first formed and then heated.

3 principal heating mechanisms:

- By Waves / Alfven Waves,
- By Magnetic reconnection in current sheets,
- MHD Turbulence.

All of these attempts fall short of providing a continuous energy supply that is required to support the observed coronal structures.

New concept:

Formation and heating are contemporaneous – primary flows are trapped & a part of their kinetic energy dissipates during their trapping period.

It is the Initial & Boundary conditions that define the characteristics of a given structure $\quad T_c >> T_{0f} \sim 1 eV$.

Observations → **there are strongly separated scales both in time and space in the solar atmosphere.** And that is good.

A closed coronal structure – 2 distinct eras:

1. **A hectic dynamic period when it acquires particles & energy (accumulation + primary heating)**

   Full description needed: time dependent dissipative two-fluid equations are used. Heating takes place while particles accumulate (get trapped) in a curved magnetic field (*viscosity is taken local as well as the radiation is local),*

2. **Quasistationary period when it "shines" as a bright, high temperature object — a reduced equilibrium description suffices**
   collisional effects and time dependence are ignored.

   Equilibrium: each coronal structure has a nearly constant *T*,
   but different structures have different characteristic *T*-s,
   i.e. **bright corona seen as a single entity will have considerable *T*–variation**

1st Era – Fast dynamic

Energy losses from corona: $F \sim (5 \cdot 10^5 \div 5 \cdot 10^6)$ erg/cm^2 s.

If the conversion of the kinetic energy in the **Primary Flows** were to compensate for these losses, we would require a radial energy flux

$$\frac{1}{2} m_i n_0 V_0^2 \; V_0 \geq F$$

For initial $V_0 \sim (100 \div 900)$ km/s $n \sim 9 \cdot 10^5 \div 10^7$ cm^{-3}

Viscous dissipation of the flow takes place on a time:

$$t_{\text{visc}} \sim \frac{L^2}{\nu_i} \qquad\qquad (2)$$

For flow with $T_0 = 3 \text{eV} = 3.5 \cdot 10^4 \text{ K}$, $n_0 = 4 \cdot 10^8 \text{ cm}^{-3}$

Creating a quiet coronal structure of size $L = (2 \cdot 10^8 \div 10^{10}) \, \text{cm}$
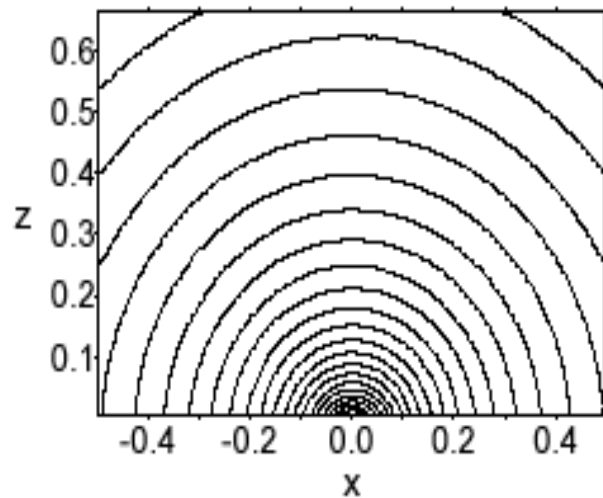
$$t_{\text{visc}} \sim (3.5 \cdot 10^8 \div 10^{10}) \text{ s}$$

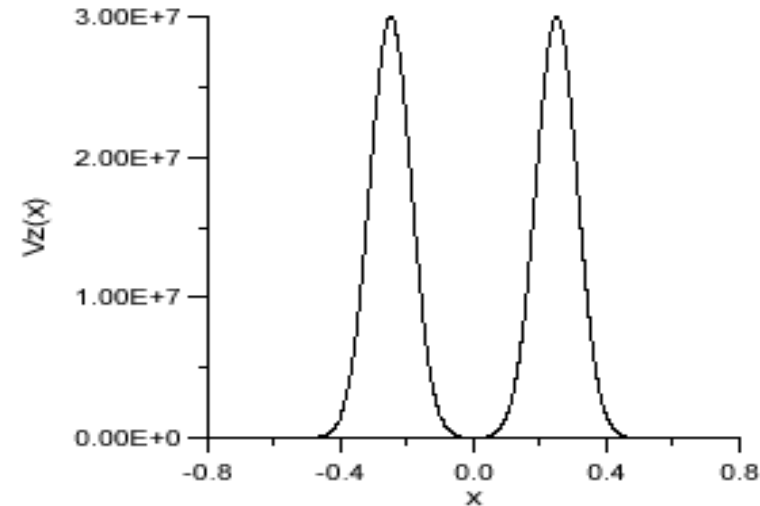**Note:**   (2) is an overestimate. $t_{\text{real}} \ll t_{\text{visc}}.$

Reasons:

1) $\nu_i = \nu_i(t, \mathbf{r})$ will vary along the structure,

2) the spatial gradients of the *V*–field can be on a scale much shorter
   than L (defined by the smooth part of *B*–field).

Initial and Boundary conditions

Contour plots for the vector potential **A**
(flux function) in the $x - z$ plane for a **typical**
arcade- like solar magnetic field

The distribution of the radial component V_z
(with a maximum of **300 km/s at $t = 0$**) for the
**symmetric, spatially nonuniform velocity field.**

2.5D numerical simulation of the general two-fluid equations in Cartesian Geometry.
        Code: Mahajan et al. PoP (2001), Mahajan et al, ApJ (2005).

Simulation system contains: 1) dissipation (local) and heat flux; 2) plasma is compressible ; 3) *Radiation* is local
        (modified Bremsstahlung) - extra possibility for micro-scale structure creation.

Transport coefficients are taken from Braginskii and are local. Diffusion time of magnetic field > duration
                                                of interaction process (would require $T \leq$ a few eV -s).

Hot coronal structure formation
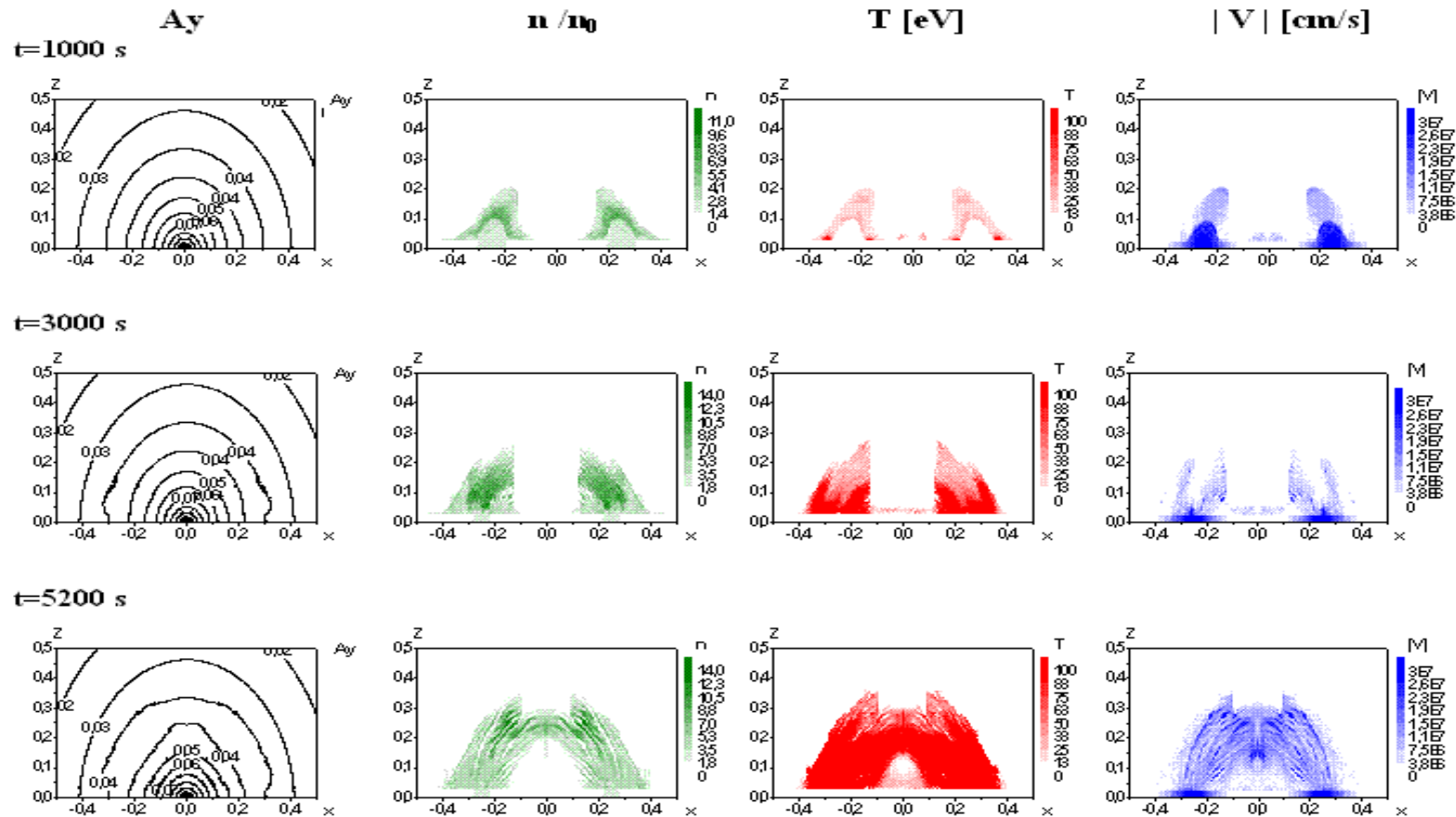
Flow $T_0 = 3$ eV, $n_0 = 4 \cdot 10^8$ cm^{-3}, initial background density $= 2 \cdot 10^8$ cm^{-3}, $B_{max} (x_0, z_0 = 0) = 20$ G.

Much of the primary flow kinetic energy has been converted to heat via shock generation.

# Simulations examples –formation & heating of hot structure

Observations show hot closed structure formation being different for different structures. **In the same region one observes different speeds of formation + heating – we see loop when it is hot.**
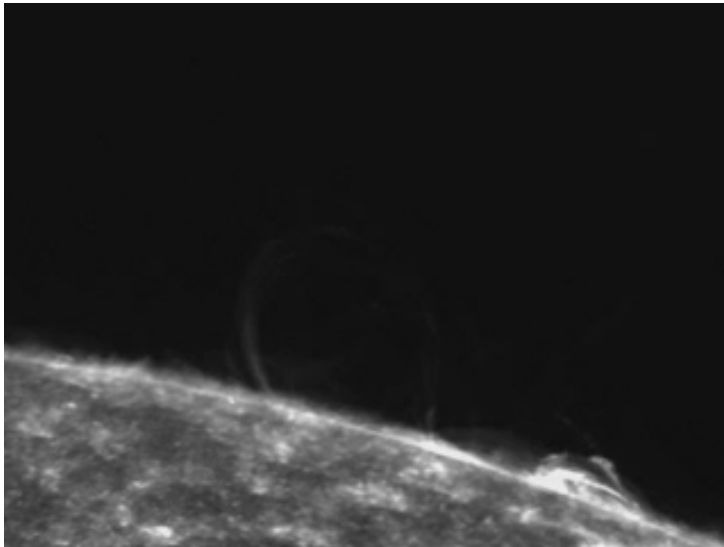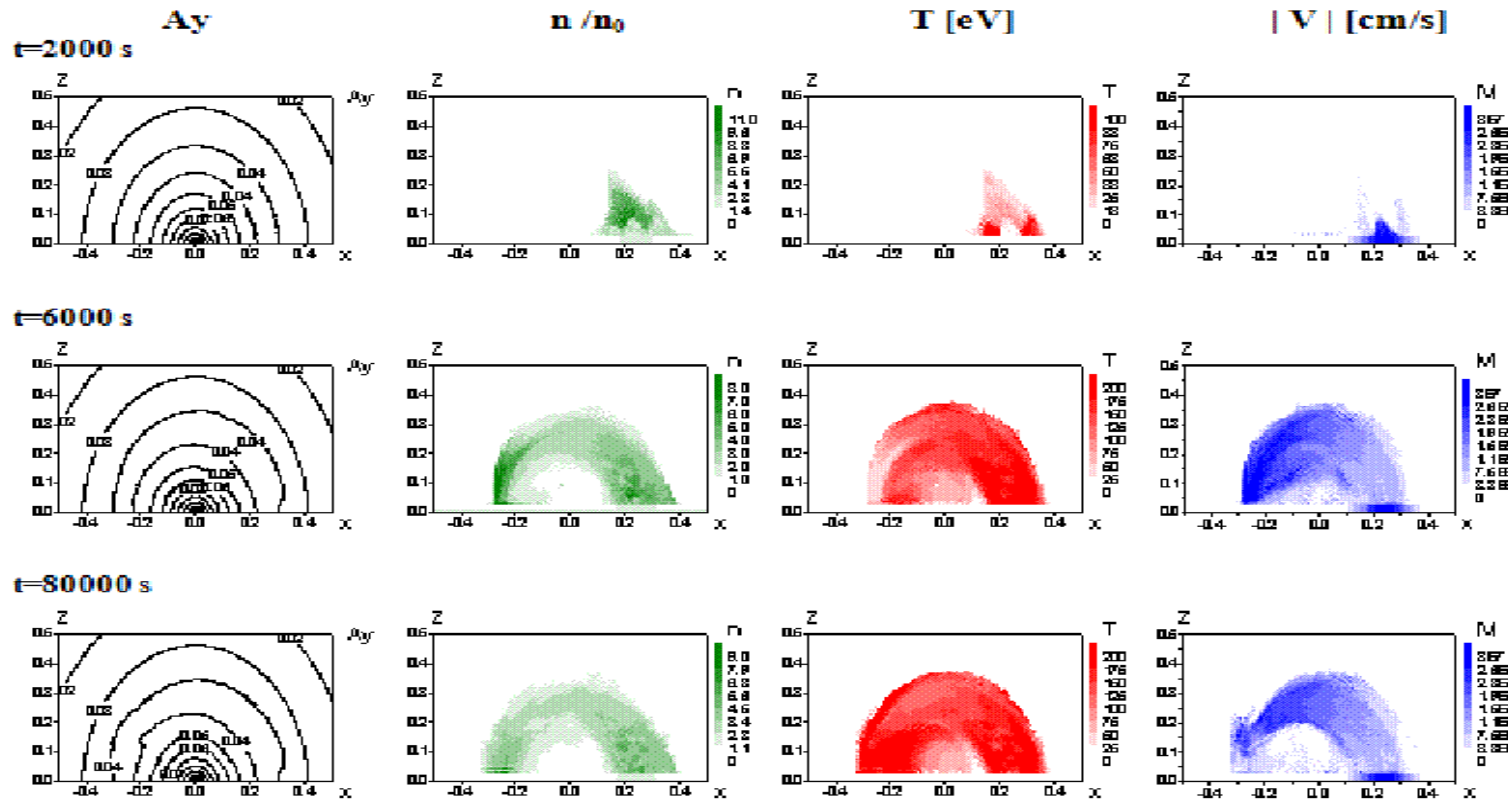
Simulation example 1 – symmetric case: 2 identical constant in time flows interact with closed ***B***-field structure. B_{0max} = 20G, V_{z0max} = 300km/s , T_0 = 3eV.

Primary heating is very fast – hot base is created in few 100s of seconds.
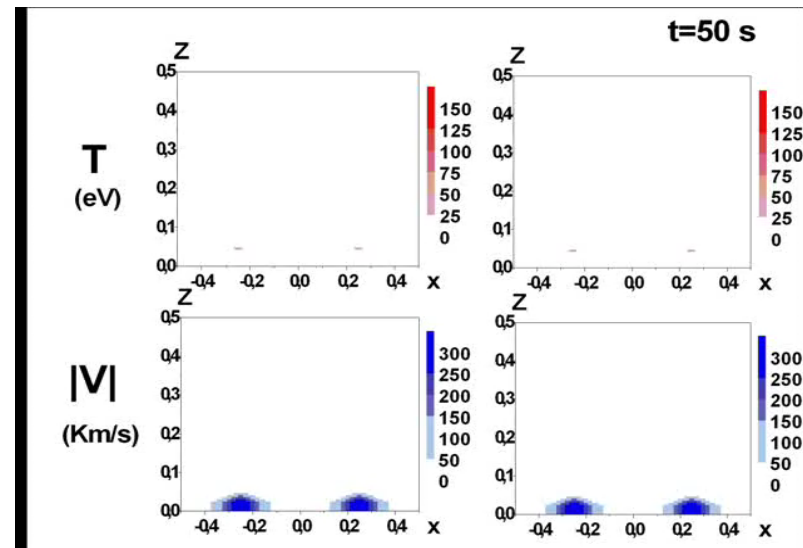
Left Column - no resistivity, right column – local resistivity included with coefficient ~ $2 \cdot 10^{-3}$.
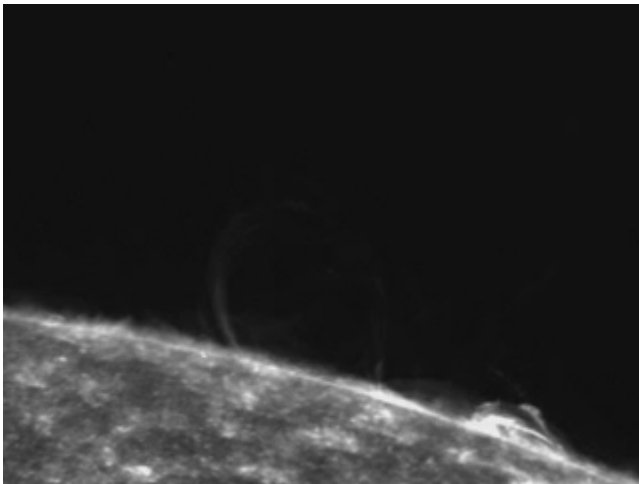
Hot coronal structure formation

The interaction of an **initially asymmetric, spatially nonuniform primary flow**
(*just the right pulse*) with a strong arcade-like magnetic field B_{max} $(x_0 , z_0 =0) = 20$ G.
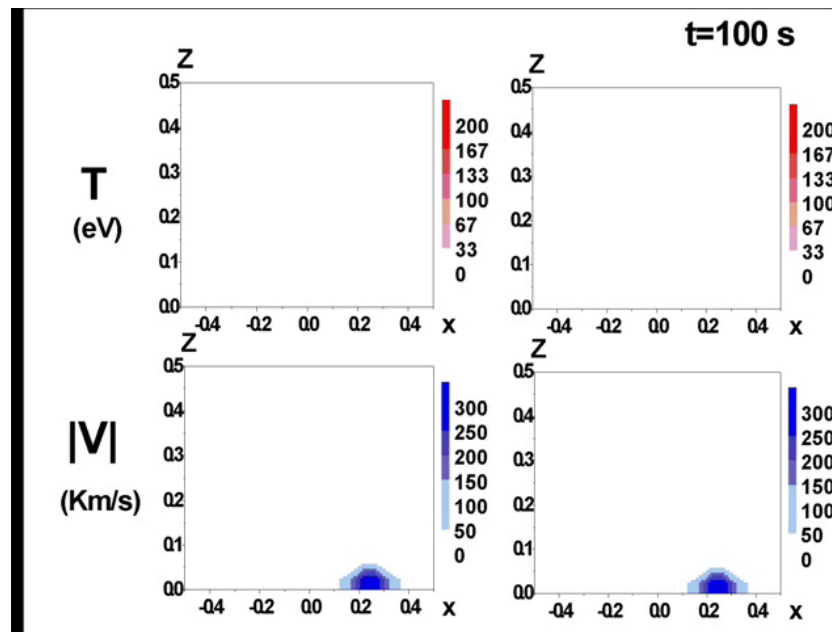
Downflows, and the imbalance in primary heating are revealed

Flows found in the loops

Simulation example 2 – non-symmetric case: 1 flow (constant in time) interacts with closed **B**-field structure. $B_{0max} = 20G$, $V_{z0max} = 300km/s$, $T_0 = 3eV$. **Process of formation + heating is slower than in symmetric case.**
Flow remains along loop, just slowed down.

Observations show that coronal structure **formation + heating is never a symmetric process;** **there are flows inside hot loops.**

Left Column - no resistivity, right column – local resistivity included with coefficient ~ $2 \cdot 10^{-3}$.

Dependence on the initial and boundary conditions

$V_{z0max}(z=0)=150$km/s

$V_{z0max}(z=0)=300$km/s

Left column - constant in time initial flow, **right column** – initial flow has *Life-time = 20000s*; B_{0max} = 10G .
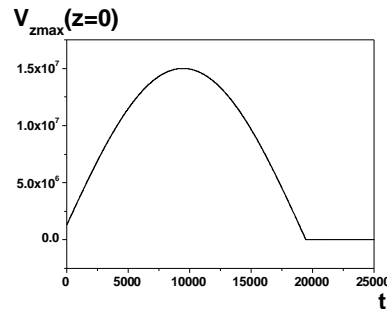
Left column - constant in time initial flow & B_{0max} = 10G; **right column** – initial flow has *Life-time = 10000s* & B_{0max} = 20G .

Simulation Results

- **Primary plasma flows** **are capable of thermalizing during interaction with primary magnetic fields** (that are curved) **to form the hot coronal structure**.
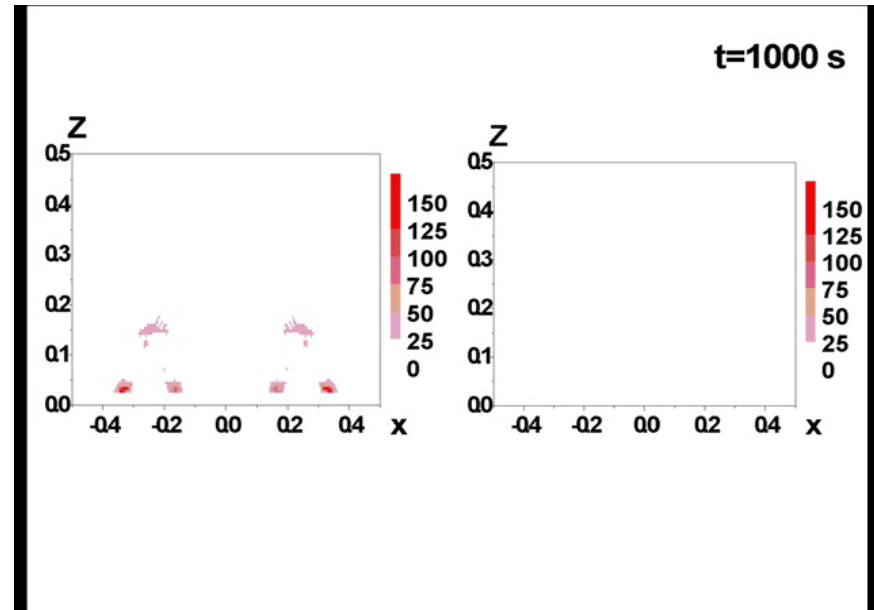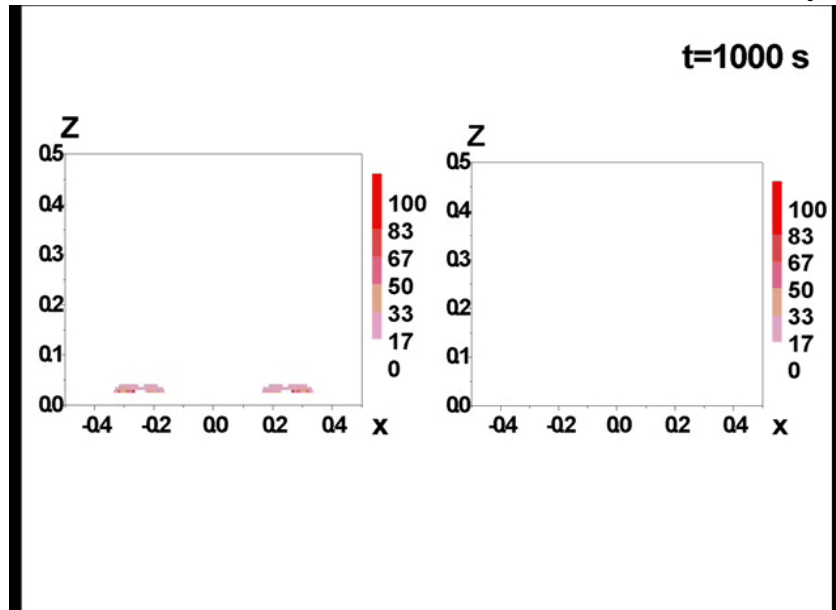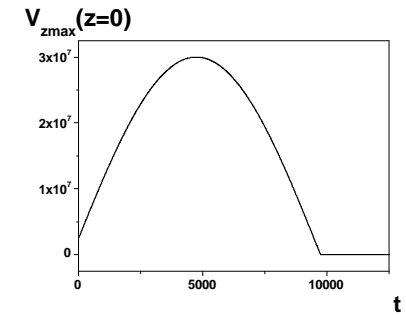
- **Two distinct eras are distinguishable in the life of a hot closed structure** – a fast era of the formation (plus primary heating), and a relatively calm era of in which the hot structure persists in a state of quasi-equilibrium.

- **Parameters of the hot closed structure (in quasi-equilibrium) are fully determined by the characteristics of the primary flow and the ambient magnetic fields**; the greater the primary flow initial velocity and initial magnetic field B_0, the hotter is the coronal base.

- **For the same primary flows the maximum heating is achieved at some height independent of B_0** (in agreement with observations).

- **The greater the resistivity, the shorter is the life-time of the quasi-equilibrium structure**.

- **The formation time of the hot closed structure is strictly dependent on the magnitudes of primary flow & primary magnetic field, as well as their initial time dependence (life-time).**

- The duration of the primary heating is directly determined by the parameters of primary flow and magnetic fields. **Greater the fields, the faster is the primary heating.**

2nd Era – Quasi-Equilibrium

Quasistationary period when
closed coronal structure "shines"
as a bright, high temperature object.
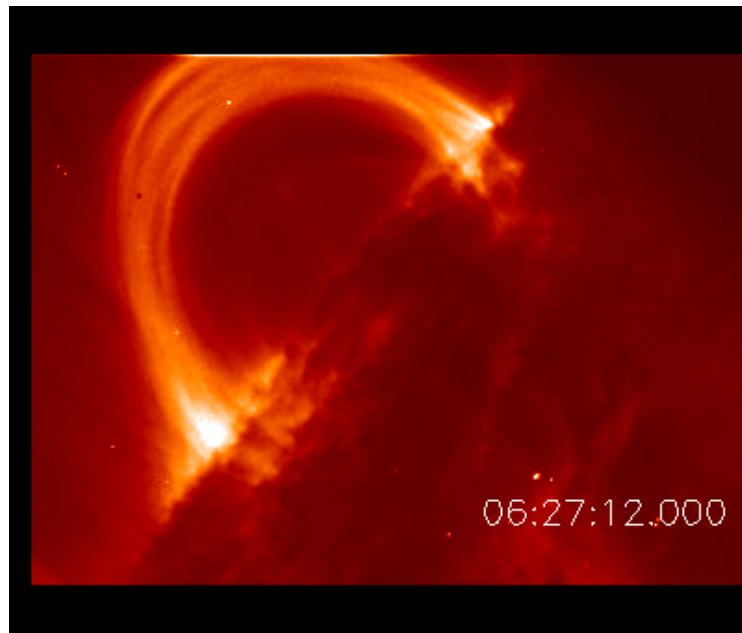
Observations: A loop system may be quiescent for a long time with individual loops living for several hours (2nd era of quasi-equilibrium in the life of the closed coronal structure).

Quiescent periods may be followed by rapid activity (loops are "turned on"/disappear in $\leq$ 10 - 40 min).

In equilibrium each coronal structure has a nearly constant T , but **different structures have different characteristic *T*-s,**

i.e.

bright corona seen as a single entity will have considerable T –variation.

- **The familiar magneto hydrodynamics (MHD) theory (*single fluid*) is inadequate** – The fundamental contributions of the velocity field do not come through.

- Equilibrium states (relaxed minimum energy states) encountered in MHD do not have enough structural richness.

In a two-fluid description, the velocity field interacting with the magnetic field provides:

1. **new pressure confining states**
2. **the possibility of heating these equilibrium states by dissipation of short scale kinetic energy.**

Let us now construct a simple equilibrium theory.

A Quasi-equilibrium Structure

Model: **recently developed magnetofluid theory.**

Assumption: at some distance there exist fully ionized and magnetized plasma structures such that the quasi–equilibrium two–fluid model will capture the essential physics of the system.

Simplest two–fluid equilibria: $T = \text{const} \longrightarrow \text{n}^{-1}\nabla\text{p} \rightarrow \text{T}\nabla\ln\text{n}.$

Generalization to homentropic fluid: $p = \text{const}\cdot\text{n}^{\gamma}$ is straightforward.

The **dimensionless equations:**

$$\frac{1}{n}\nabla \times \mathbf{b} \times \mathbf{b} + \nabla\left(\frac{r_{A0}}{r} - \beta_0 \ln\ n - \frac{V^2}{2}\right) + \mathbf{V} \times (\nabla \times \mathbf{V}) = 0, \quad (3)$$

$$\nabla \times \left[\left(\mathbf{V} - \frac{\alpha_0}{n}\nabla \times \mathbf{b}\right) \times \mathbf{b}\right] = 0, \quad (4)$$

$$\nabla \cdot (n\mathbf{V}) = 0, \quad (5)$$

$$\nabla \cdot \mathbf{b} = 0, \quad (6)$$

The system allows the following **relaxed state solution**

$$\mathbf{b} + \alpha_0 \nabla \times \mathbf{V} = d\, n\, \mathbf{V}, \qquad\qquad \mathbf{b} = a\, n\, \left[\mathbf{V} - \frac{\alpha_0}{n} \nabla \times \mathbf{b} \right] \qquad (7)$$

augmented by the **Bernoulli Condition**

$$\nabla \left(\frac{2\beta_0 r_{c0}}{r} - \beta_0 \ln n - \frac{V^2}{2} \right) = 0 \qquad (8)$$

a and *d* — dimensionless constants related to **ideal invariants**:

the Magnetic and the Generalized helicities

$$h_1 = \int (\mathbf{A} \cdot \mathbf{b})\, d^3x \qquad (9)$$

$$h_2 = \int (\mathbf{A} + \mathbf{V}) \cdot (\mathbf{b} + \nabla \times \mathbf{V}) d^3x \qquad (10)$$

The system is obtained by minimizing **the energy** $E = \int (\mathbf{b} \cdot \mathbf{b} + n\mathbf{V} \cdot \mathbf{V})\, d^3x$
keeping h_1 and h_2 invariant.

Equations (7) yield

$$\frac{\alpha_0^2}{n} \nabla \times \nabla \times \mathbf{V} + \alpha_0 \, \nabla \times \left(\frac{1}{a} - d\,n\right) \mathbf{V} + \left(1 - \frac{d}{a}\right) \mathbf{V} = 0 \qquad (11)$$

which must be solved with (8) for n and $\mathbf{V}$.

Equation (8) is solved to obtain ($g(r) = r_{c0}/r$) .

$$n = \exp\left(-\left[2g_0 - \frac{V_0^2}{2\beta_0(T)} - 2g + \frac{V^2}{2\beta_0(T)}\right]\right) \qquad (12)$$

The variation in density can be quite large for a low β_0 plasma if the gravity and the flow kinetic energy vary on length scales comparable to the extent of the structure.

Model calculation – temperature varying but density constant ($n = 1$) .

The following still holds (where $\boldsymbol{Q}$ is either $\mathbf{V}$ or $\boldsymbol{b}$):

$$\alpha_0^2 \, \nabla \times \nabla \times \mathbf{Q} + \alpha_0 \, \left(\frac{1}{a} - d\right) \nabla \times \mathbf{Q} + \left(1 - \frac{d}{a}\right) \mathbf{Q} = 0 \qquad (13)$$

Analysis of the *Curl Curl* Equation, Typical Equilibria

The existence of **two, rather than one** (as in the standard relaxed equilibria) **parameter in this theory is an indication that we may have found an extra clue to answer the extremely important question:**

why do the coronal structures have a variety of length scales, and what are the determinants of these scales?

$$\alpha_0 \sim 10^{-7} - 10^{-8} \quad \text{for typical densities} \quad (\sim (10^7 - 10^9\, \text{cm}^{-3}) \quad .$$

Suppose: a structure has a span $\epsilon R_\odot$, where $\epsilon \ll 1$. For a structure of order $1\epsilon \sim 10^{-3}$, .

The ratio of the orders of various terms in Eq. (13) are $(|\nabla| \sim L^{-1})$

$$\frac{\alpha_0^2}{\epsilon^2}: \quad \frac{\alpha_0}{\epsilon}\left(\frac{1}{a} - d\right): \quad \left(1 - \frac{d}{a}\right)$$
$$(1) \qquad\quad (2) \qquad\qquad (3)$$

The following two principle balances are representative:

(a) The last two terms are of the same order, and the first $\ll$ them:

$$\epsilon \sim \alpha_0 \frac{1/a - d}{1 - d/a} \tag{14}$$

For our desired structure to exist ($\alpha_0 \sim 10^{-8}$ for $n_0 \sim 10^9$ cm^{-3}):

$$\frac{1/a - d}{1 - d/a} \sim 10^5 \tag{15}$$

which is possible if *d/a* tends to be extremely close to unity.

For the first term to be negligible, we would further need

$$\frac{\alpha_0}{\epsilon} \ll \frac{1}{a} - d \qquad \Rightarrow \qquad \epsilon \gg \frac{10^{-8}}{1/a - d} \tag{16}$$

easy to satisfy as long as neither of $a \approx d$ is close to unity.

Standard relaxed state: flows are not supposed to play an important part.
Extreme sub–Alfvénic flows: a ~ d >> 1.

The new term introduces a qualitatively new phenomenon:

$\nabla \times (\nabla \times \mathbf{b})$ is a singular perturbation of the system; its effect on the standard root (2) ~ (3) >> (1) will be small, but it introduces a new root for which the $|\nabla|$ must be large (short length scale!)

For a and d so chosen to generate a 1000km structure

$$d/a \sim 1 + 10^{-4}, \qquad d \simeq a = -10, \qquad |\nabla|^{-1} \sim 10^2 \, \mathrm{cm},$$

an equilibrium root with variation on the scale of 100cm will be automatically introduced by the flows.

Even if flows are weak $(a \simeq d \simeq 10)$, the departure from $\nabla \times \mathbf{B} = \alpha \mathbf{B}$ can be essential: **it introduces a totally different (small!) scale solution** $\Rightarrow$ fundamental importance in understanding the effects of viscosity on the dynamics of structures.

Dissipation of short scale structures $\rightarrow$ primary heating.

(b) The other balance: we have a complete departure from conventional relaxed state: **all three terms are of the same order**

$$\epsilon \sim \alpha_0 \, \frac{1}{1/a - d} \sim \alpha_0 \, \frac{1/a - d}{1 - d/a} \tag{17}$$

which translates as:

$$\left(\frac{1}{a} - d\right)^2 \sim 1 - \frac{d}{a}, \qquad \qquad \frac{1}{a} - d \sim \alpha_0 \, \frac{1}{\epsilon} \tag{18}$$

For a **1000km structure**, $\quad \alpha_0 \cdot 1/\epsilon \sim 10^{-5} \quad$ and $\quad$ *a ~ d ~ 1*

we would need the flows to be almost perfectly Alfvénic!

Such flow conditions are in the weak magnetic field regions.

(1)   Alfvénic flows are capable of creating entirely new kinds of structures – quite different from the ones that we normally deal with.

(2)   Though they also have two length scales, these length scales are quite comparable to one another.

(3)   Two length scales can become complex conjugate giving rise to fundamentally different structures in *b* and **V** .

Curl Curl Equation – Double-Beltrami states

With $\quad p = (1/a - d)\quad$ and $\quad q = (1 - d/a)\quad$, $\quad$ Eq. (13) $\implies$

$$(\alpha_0 \nabla \times - \lambda)(\alpha_0 \nabla \times - \mu)\mathbf{b} = 0 \tag{19}$$

where $\quad \lambda\,(\lambda_+)$ and $\quad \mu(\lambda_-)$ are the solutions of the quadratic equation

$$\alpha_0 \lambda_\pm = -\frac{p}{2} \pm \sqrt{\frac{p^2}{4} - q}. \tag{20}$$

If $\quad G_\lambda$ is the solution of the **Beltrami Equation** (a_λ and a_μ are constants)

$$\nabla \times \mathbf{G}(\lambda) = \lambda \mathbf{G}(\lambda), \qquad then \tag{21}$$

$$\mathbf{b} = a_\lambda \mathbf{G}(\lambda) + a_\mu \mathbf{G}(\mu) \tag{22}$$

is the general solution of the double *curl* equation. Velocity field is:

$$\mathbf{V} = \frac{\mathbf{b}}{a} + \alpha_0 \boldsymbol{\nabla} \times \mathbf{b} = \left(\frac{1}{a} + \alpha_0 \lambda\right) a_\lambda \mathbf{G}(\lambda) + \left(\frac{1}{a} + \alpha_0 \mu\right) a_\mu \mathbf{G}(\mu) \tag{23}$$

Double curl equation is fully solved in terms of the solutions of Eq. (21).

Double Beltrami States

- **There are two scales in equilibrium** unlike the standard case.

- **A possible clue for answering the extremely important question:**
  why do the coronal structures have a variety of length scales, and what are the determinants of these scales?

- **The scales could be vastly separated** – are determined by the constants of the motion – the original preparation of the system.
  These constants also determine the relative kinetic & magnetic energy in quasi-equilibrium.

- **These vastly richer structures can & do model the quiescent solar phenomena** rather well – construction of coronal arcades fields, slow acceleration, spatial rearrangement of energy etc.

An Example of structural richness

Closed Coronal structure: the magnetic field is relatively smooth but the velocity field must have a considerable short–scale component if its dissipation were to heat the plasma. Can a DB state provide that?

Sub–Alfvénic Flow: $a \sim d \gg 1 \implies \lambda \sim (d - a)/\alpha_0 \, d \, a \; ; \; \mu = d/\alpha_0 \, .$

$$\mathbf{V} = \frac{1}{a} a_\lambda \mathbf{G}_\lambda + d a_\mu \mathbf{G}(\mu) \tag{24}$$

$$\mathbf{b} = a_\lambda \mathbf{G}_\lambda + a_\mu \mathbf{G}(\mu) \tag{25}$$

while, the slowly varying component of velocity is smaller by a factor ($a^{-1} \approx d^{-1}$) compared to similar part of *b*-field, the fast varying component is a factor of d larger than the fast varying component of *b*-field!

Result: for an extreme sub–Alfvénic flow (e.g. $|\mathbf{V}| \sim d^{-1} \sim 0.1$) ,

$$\frac{|\mathbf{V}(\mu)|}{|\mathbf{V}(\lambda)|} \simeq 1 \tag{26}$$

the velocity field is equally divided between slow and fast scales.

Summary and Conclusions

- The **structures which comprise the solar corona can be created by particle (plasma) flows observed near the Sun's surface**

- **The primary heating of these structures is caused by the viscous dissipation of the flow kinetic energy.**

- It is during trapping and accumulation in closed field regions, that the relatively cold and fast flows thermalize (*due to the dissipation of the short scale flow energy*) leading to a bright and hot coronal structure.

- **The formation and primary heating of a closed coronal structure (*loop at the end*) are simultaneous.**

- The **heating** caused by the dissipation of flow energy **may, in addition, be augmented by one or several modes of secondary heating**. In our model, the **"secondary heating" may occur to simply sustain** (against, say, radiation losses) **the hot bright loop**.

- **The emerging scenario, then, is not the filling of some hypothetical virtual loop with hot gas.** The **loop**, in fact, is created by the interaction of the flow and the ambient field; its **formation and heating are simultaneous & "loop" has no ontological priority to the flow**.

More: generalization of the theory for global approach

- Dissipation of short–scale component of velocity field may provide **a primary** (**during very formation**) and **a secondary** (**supporting**) **heating** for the coronal structure (**closed, open**).

- The active regions demand 82% of the heating requirement, the quiet-Sun regions 17.2%, and CHs merely 0.4% .

- Total energy budget of the coronal heating problem is dominated by the heating requirement of active regions - **heating is split in 2 regions**: **closed and open field regions.**

- **CH** (**dynamically created and not given**)**:** heating is strongly linked to contemporaneous acceleration of plasma and field opening - no accumulation but continuous upward motion of accelerated plasma and **dynamical field opening + heating / cooling!**

- CH - primary heating effects could be less important if CH was a given simple open field quasi-steady structure.

- **Recent observations:** CHs are exhibit closed structures inside, low at the surface $\implies$
  the new approach of sequence of events - several phases of acceleration / heating / opening / escape.

- **CH - two-fluid effects (DB approach) play key role** – ion temperature $T_i \sim 2 \cdot 10^5 K \div 2 \cdot T_e$ in CHs (could be due to viscosity effects!).
  CH's open field region is generally cooler than closed coronal structures.

- *Heating in CHs goes more into protons than electrons, because it is conveyed by the ion-cyclotron resonance rather than by currents (Hollweg 2006).* In this model CH – a given quasi-steady formation and this assumption can be argued.

Dynamic processes in Solar Atmosphere involving flows

At any quasi-equilibrium stage of the accelerating plasma flow [*acceleration scenario could be one of many*], the **nascent intermittent flows will blend & interact with pre–existing closed field structures on varying scales**.

"New" **flows** could be trapped by other structures with strong / weak magnetic fields and **participate in creating different dynamical scenarios** (when dissipation is present) **leading to**:

1) **Formation & heating of a new structure of finely structured atmosphere** [see (Mahajan et al. 1999; Mahajan et al. 2001)].

2) **Explosive events/prominences/CME eruption** [see (Ohsaki et al. 2001; Ohsaki et al. 2002; Mahajan et al. 2002a)].

3) **Creation of a dynamic escape channel** (providing important clues toward the creation of the solar wind [see (Mahajan et al. 2002b; Mahajan et al. 2003)]).

4) **Instabilities, and wave-generation could also be triggered.**