Boundary conditions and space weather

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Using solar data to predict what will happen at 1 AU requires:

- take a code solving physics (here MHD equations)
- inject the observed values at the bottom boundary (all?)
- run the code

However, all observables cannot be *all* fixed at the boundary
Physics requires a) to respect causality (characteristic formulation) b) to take coronal leakage/feedback into account

The *line-tied* limits says all feed back is reflected (due to very large Alfvén speed ratio)
A more realistic BC is proposed, allowing finite leakage (and feedback) from corona

Some preliminary results are shown (CME-like events driven by surface shear) in axisymmetric solar wind simulations

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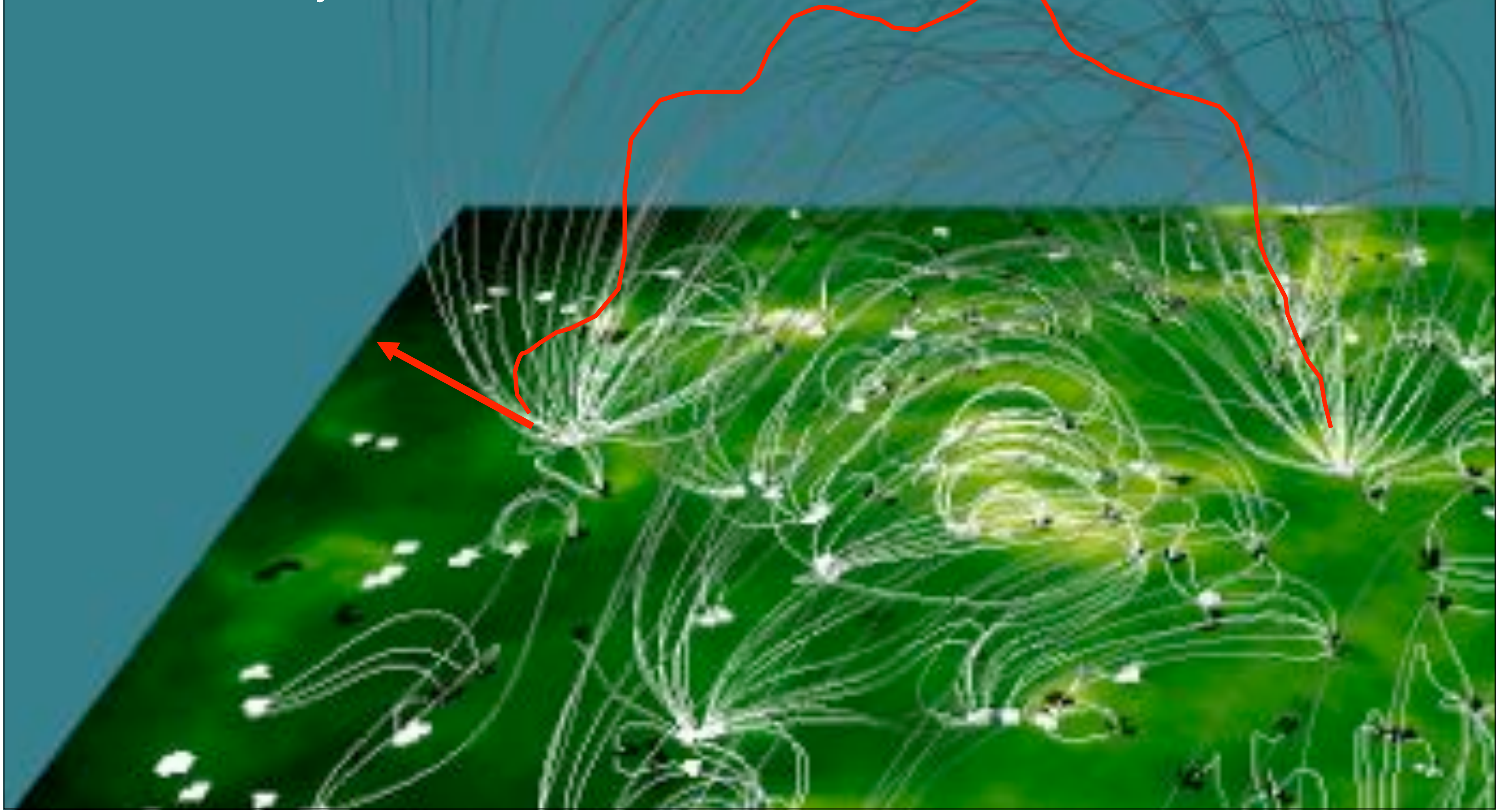
Some keywords

- Feedback
- Heating
- Break-up

boundary conditions issue enters in all three cases

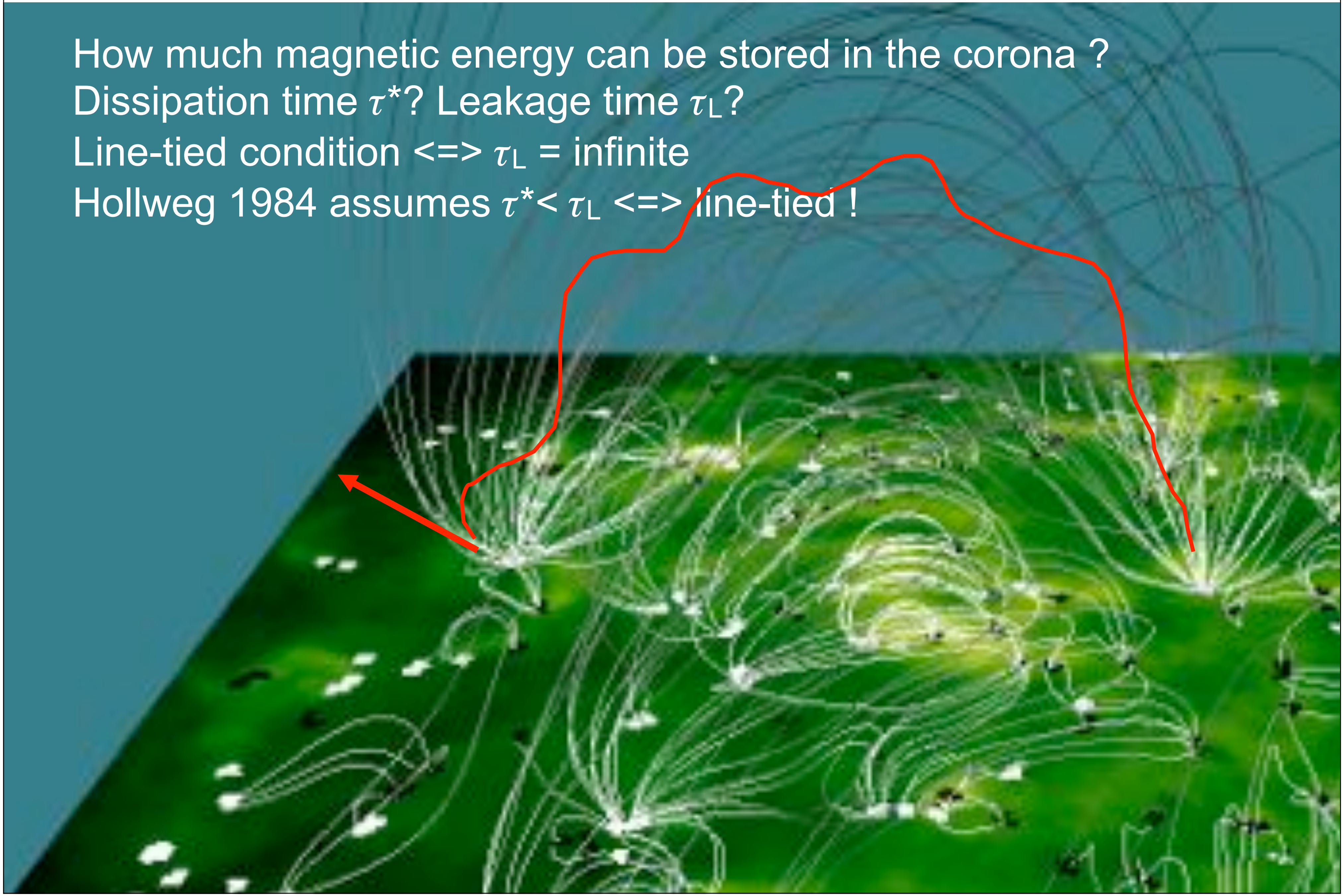
Feedback

Can magnetic loops transport momentum from one point to other point of solar surface?
Is surface dynamics modified due to corona?



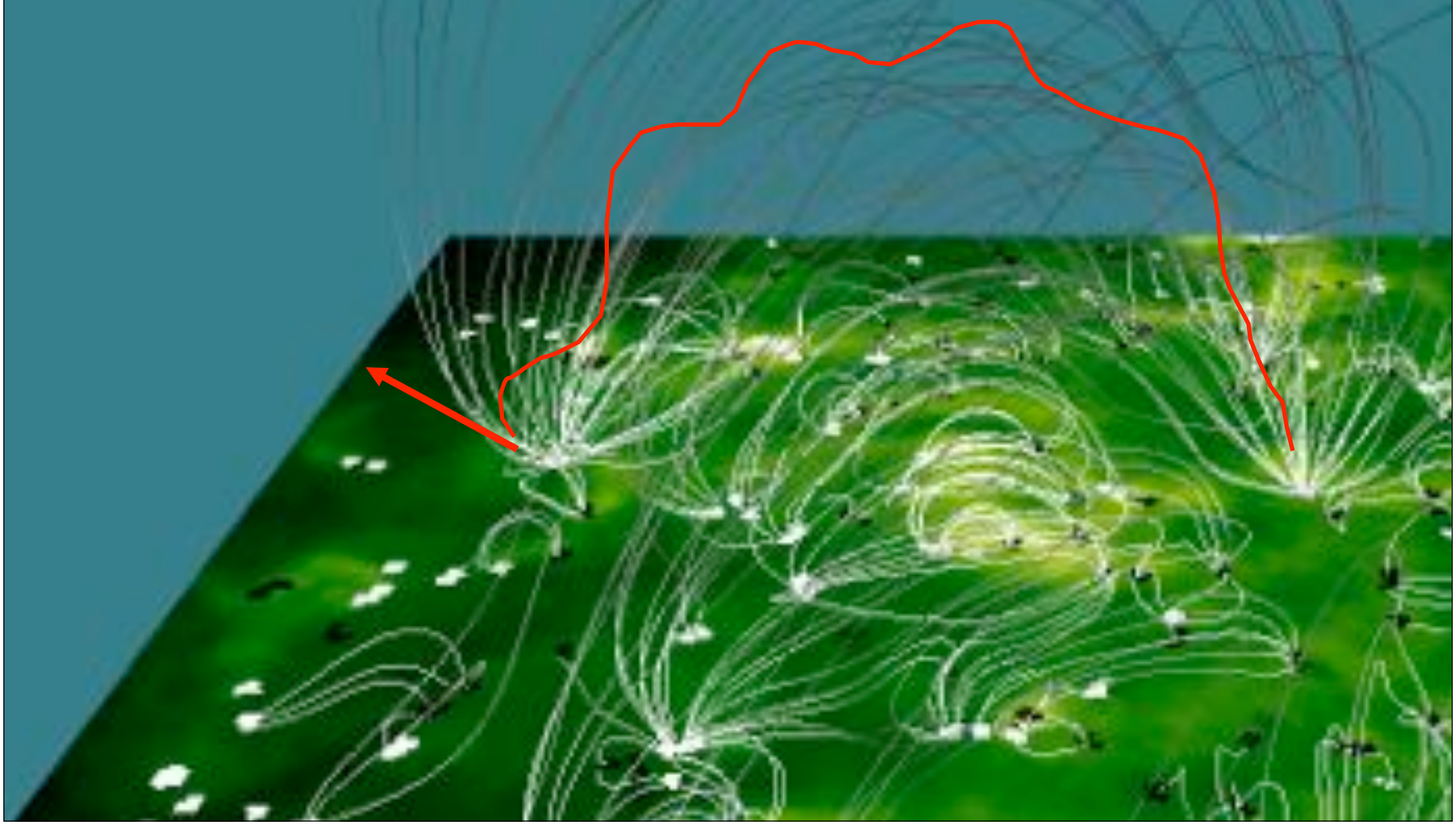
Heating

How much magnetic energy can be stored in the corona ?
Dissipation time τ^*? Leakage time τ_L?
Line-tied condition <=> τ_L = infinite
Hollweg 1984 assumes $\tau^* < \tau_L$ <=> line-tied !



Break-up

Break-up simulation assumes often *infinite* leakage time, allowing unlimited coronal B accumulation => too easy !

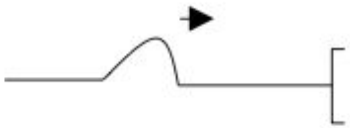


Examining the BC problem (1): Rope with end tied or free

Rope with length [0,1], displacement y:
$\partial_{tt}y = c^2\partial_{xx}y$

Two possible choices at end x=1

a) <u>tied rope: **y=0** at x=1</u>
$y = y^+ + y^-$ & $y^+ = -y^-$

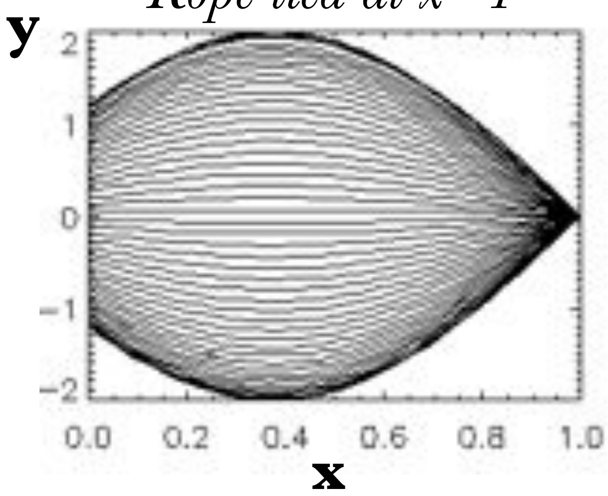


y^- ($t<t°$)

y^+ ($t>t°$)

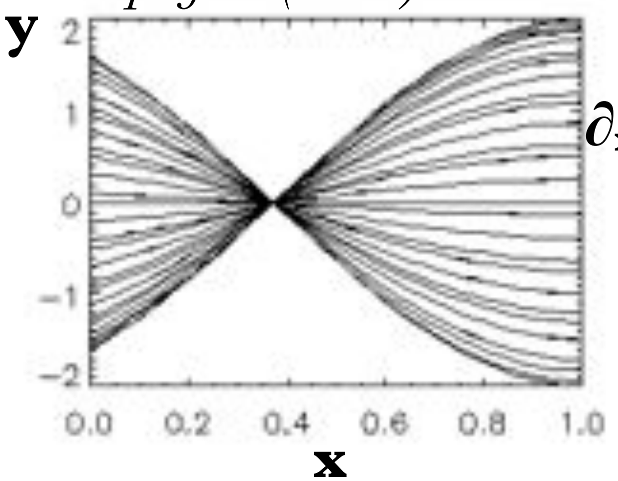
b) <u>free rope</u> : $\boldsymbol{\partial_x y = 0}$
(no force, dissymetric tension at x=1)

Rope tied at x=1



y = 0

Rope free (ends!) at x=1



$\boldsymbol{\partial_x y = 0}$

Examining the BC problem (2): Magnetic field with end tied or free

Uniform field in a finite domain $0 \leq x \leq 1$, uniform density n
Transverse velocity and magnetic field u, $b = \delta B / \sqrt{n}$:
$\partial_t u = V_a \partial_x b$, $\partial_t b = V_a \partial_x u$

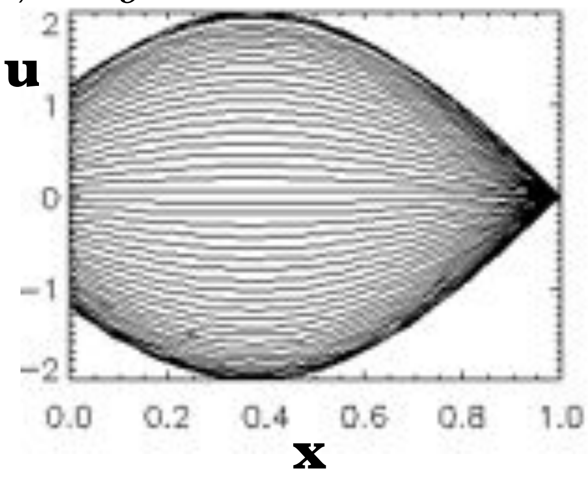
Two possible choices at x=1:

a) <u>line-tied condition: **u=0**</u>
$u = u^+ + u^-$ avec $u^+ = -u^-$

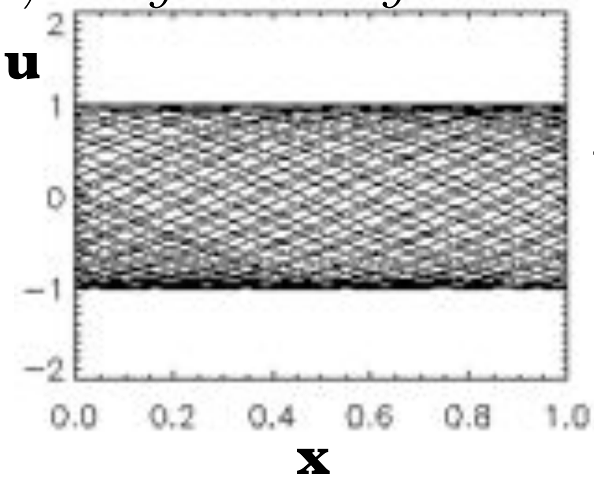
$\mathbf{u^-}$ ($t<t°$) $\qquad$ $\mathbf{u^+}$ ($t>t°$)

b) <u>free condition</u> : $\mathbf{u^+ = 0}$
no reflection !

(a) *"foot" x=1 tied*



(b) *"foot" x=1 free*



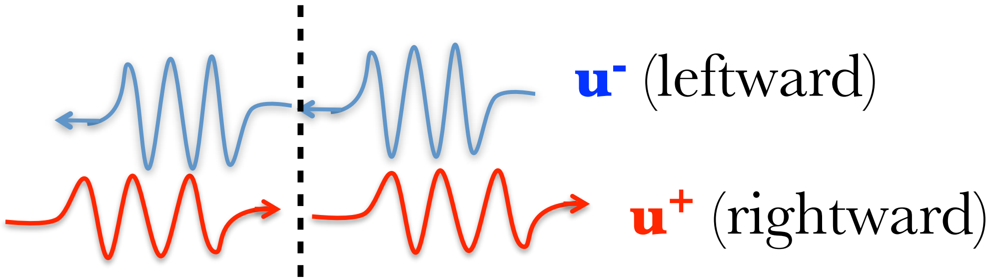
Fixing BC: characteristic form of equations

Solution to old problem (Thompson,1980): how to set BC in a compressible time-dependent gas? (later generalized by Brio&Wu 1988 to MHD)

•Decompose each field in *incoming* and *outgoing* perturbation

$$\boxed{\mathbf{u} = \mathbf{u}^{+} + \mathbf{u}^{-}}$$

NB actually:
$\partial u/\partial t = \partial u^{+}/\partial t + \partial u^{-}/\partial t$



•Specify only *incoming* perturbation u^{+}

Solar physics applications: [del Zanna et al 2002, Suzuki & Inutsuka 2005, Grappin et al 2000-2010, Ofman...]

How to take into account finite coronal leakage/feedback

•<u>Boundary conditions</u> at coronal base on u_ϕ^+, u_r^+, u_θ^+:

•Axisymmetric assumption => (linear) Alfvén waves deal with u_ϕ, B_ϕ

•Transparency for *radial and poloidal components*:

$\partial_t u_r^+ = \partial_t u_\theta^+ = 0$ (transparency for u_r & u_θ - to begin with)

•Semi-reflective boundary for azimuthal (Alfvén) component:

$$\boxed{\partial_t \mathbf{u}_\phi^+ = (1+\mathbf{a})f(t) - \mathbf{a}\partial_t \mathbf{u}_\phi^-}$$

see Hollweg 1984
Grappin Aulanier Pinto 2008
Verdini Grappin Velli 2010

with:

$f(t)$ = photospheric forcing

$a=(1-\varepsilon)/(1+\varepsilon)$ = reflection coefficient

$\varepsilon = V_A^{phot}/V_A^{corona}$ = wave transmission coefficient

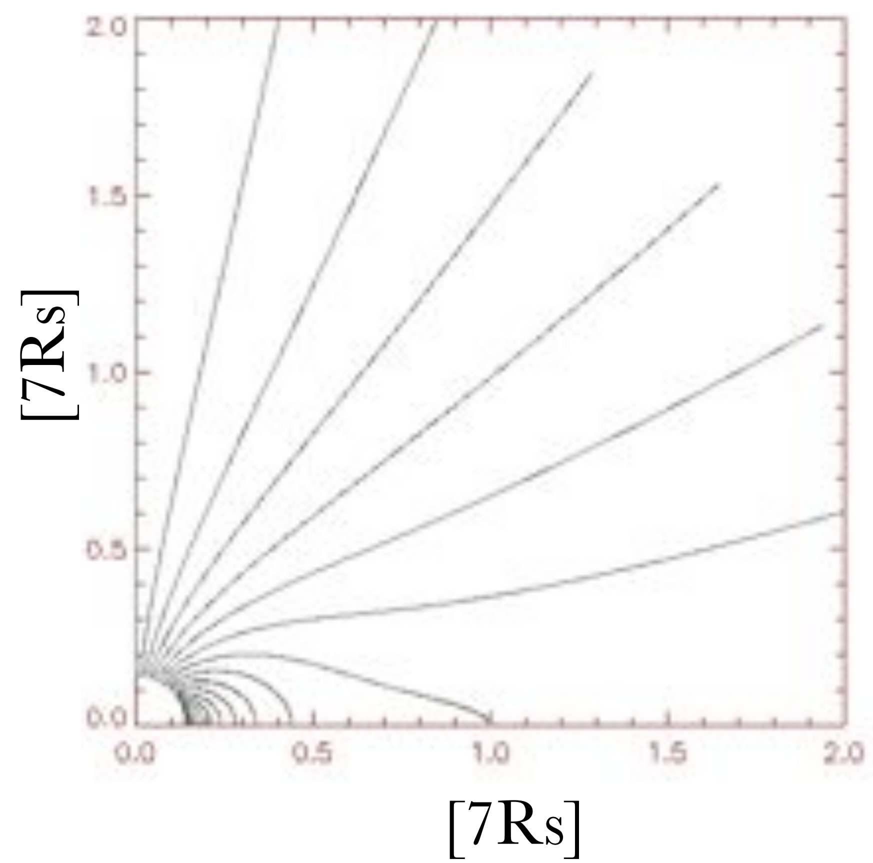
NB

LINE-Tied limit: $\varepsilon=0$, $a=1$: $\partial_t \mathbf{u}_\phi^+ = 2f(t) - \partial_t \mathbf{u}_\phi^-$

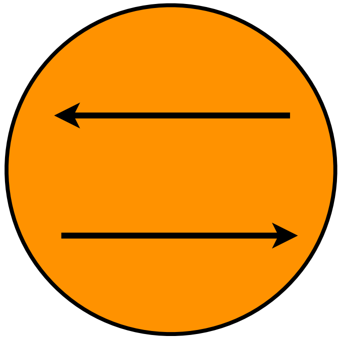
Transparent limit: $\varepsilon=1$, $a=0$: $\partial_t \mathbf{u}_\phi^+ = f(t)$

Application: take a quasi-stationary (slow) solar wind solution...

Magnetic field lines



...Apply **constant** shear between south and north foot points

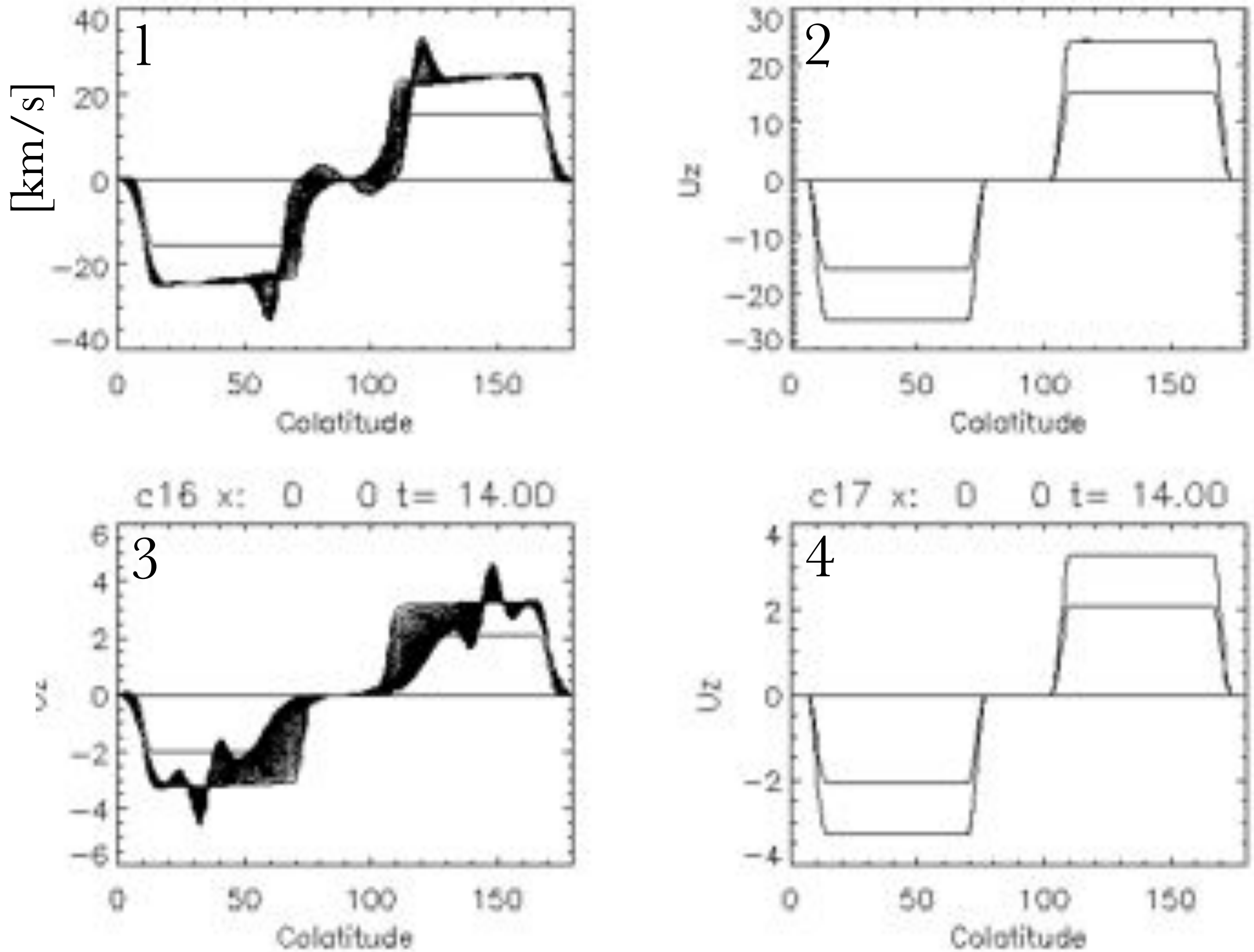


Shear (U_ϕ at coronal base)

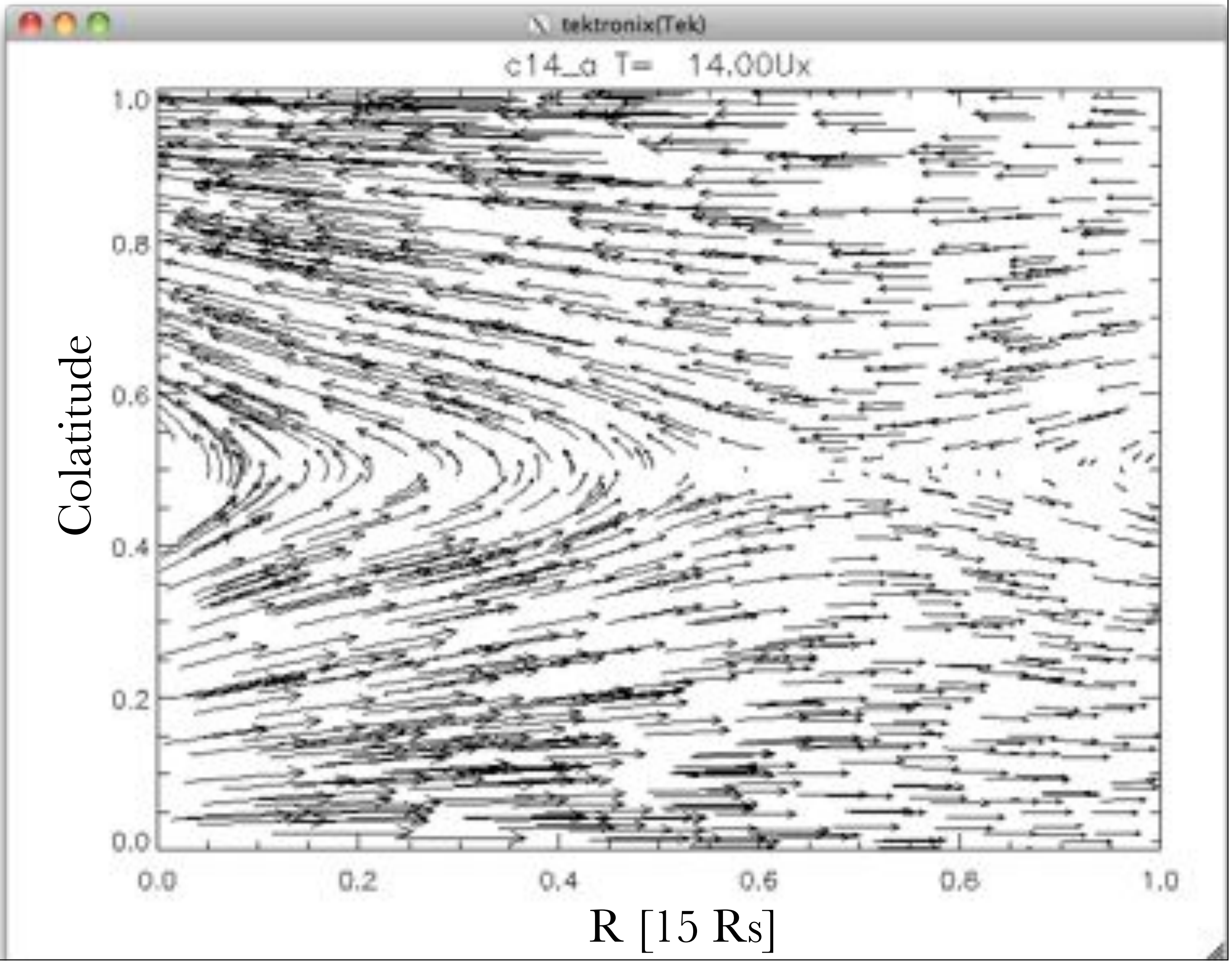
finite leakage (ε=0.01) ***Line-tied***

•*Large shear*

•*Small shear*



... observe interplanetary field reconnection in ecliptic plane (with large shear)

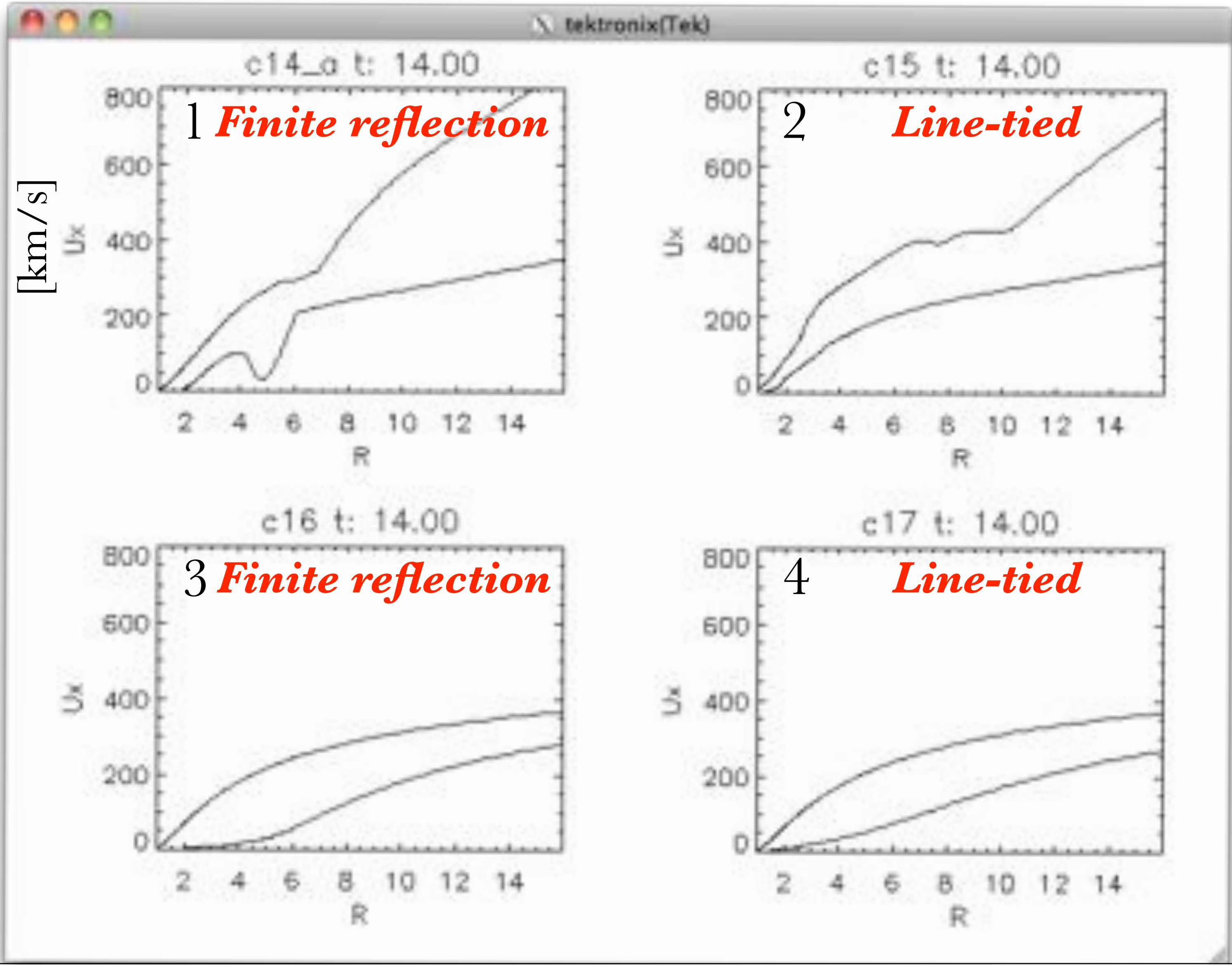


... and corresponding CME-like events (only with large shear)

•*Large shear*
large effect of finite leakage/ reflection

•*Small shear*
no effect of finite reflection

Max and Min radial velocity profiles



Temporal evolution (strong shear)

Equatorial velocity vs time
unit time = 8.4 h

As a rule, line-tied BC (right) lead to larger amplitudes of trailing CME events (first event very close in both cases)

Finite reflection ***Line-tied***

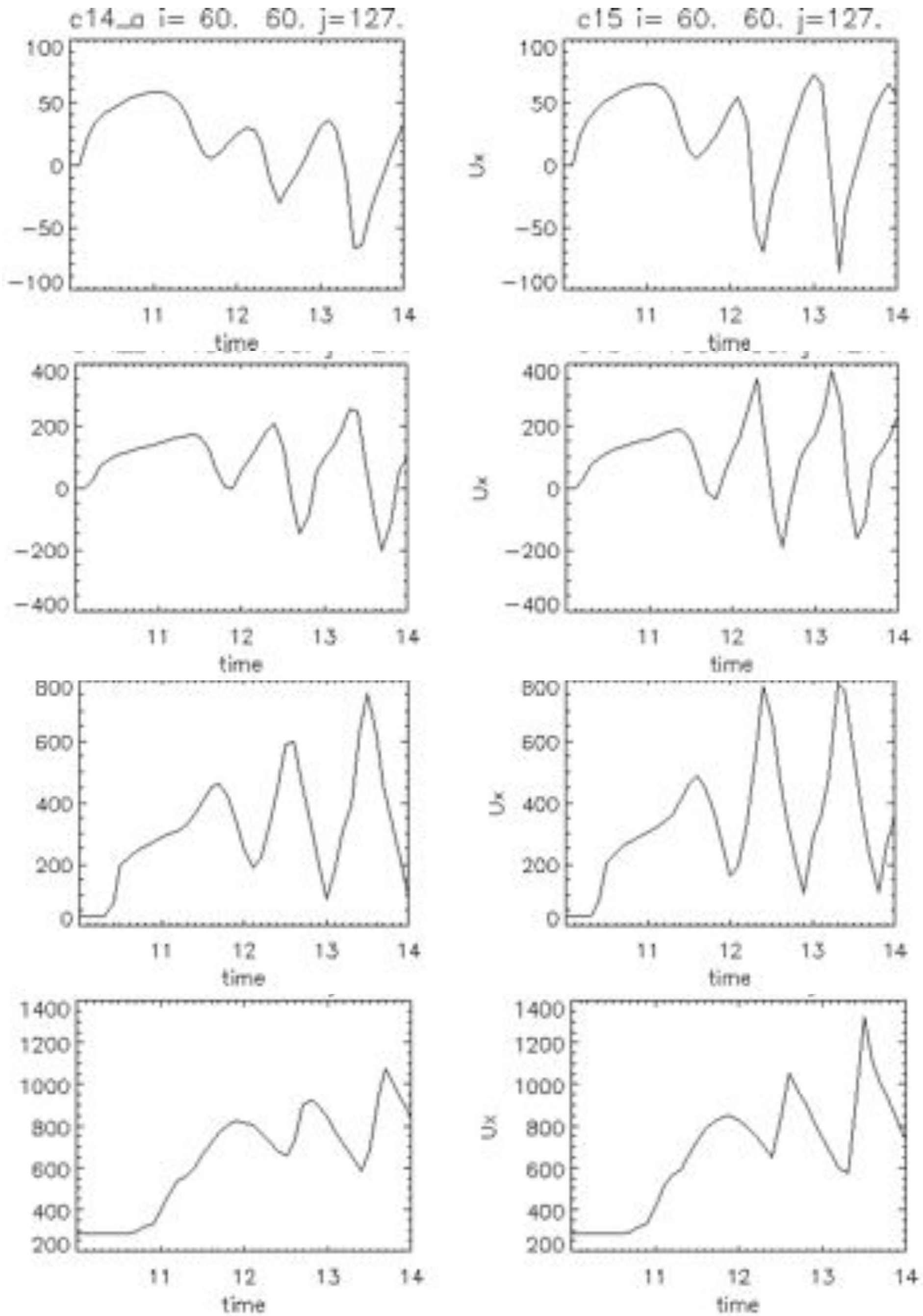
[km/s]

$R=2R_s$

$R=3.2R_s$

$R=5.4R_s$

$R=16R_s$



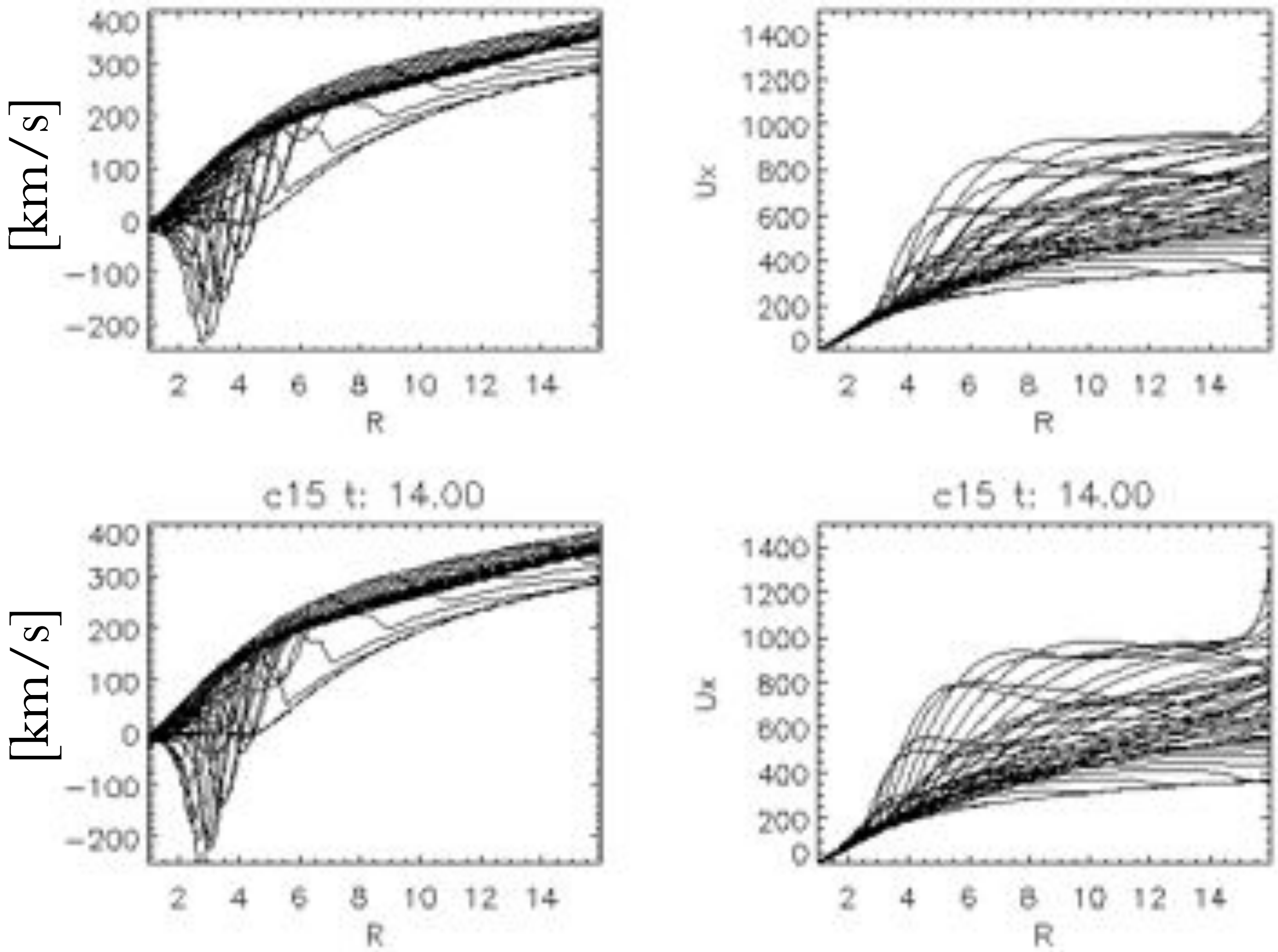
Statistics of CME-like events (case of strong shear)

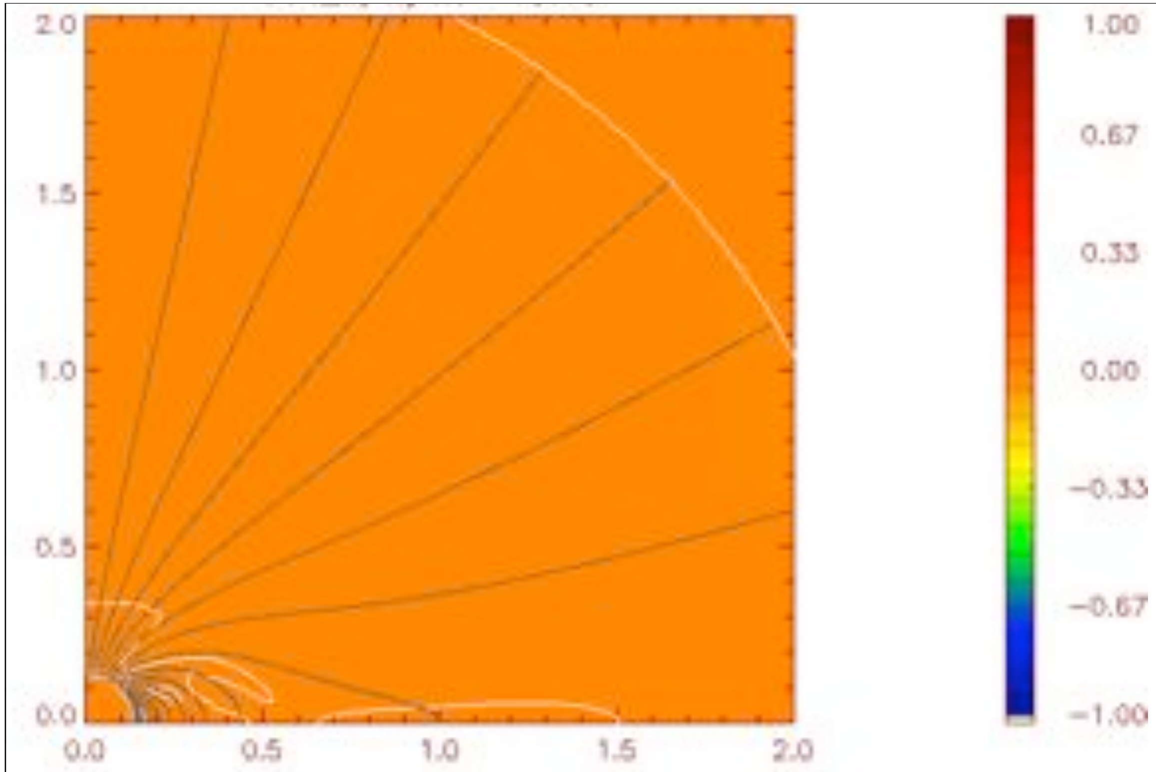
34 hrs statistics

Min radial velocity ***Max radial velocity***

Finite leakage/reflection

Line-tied



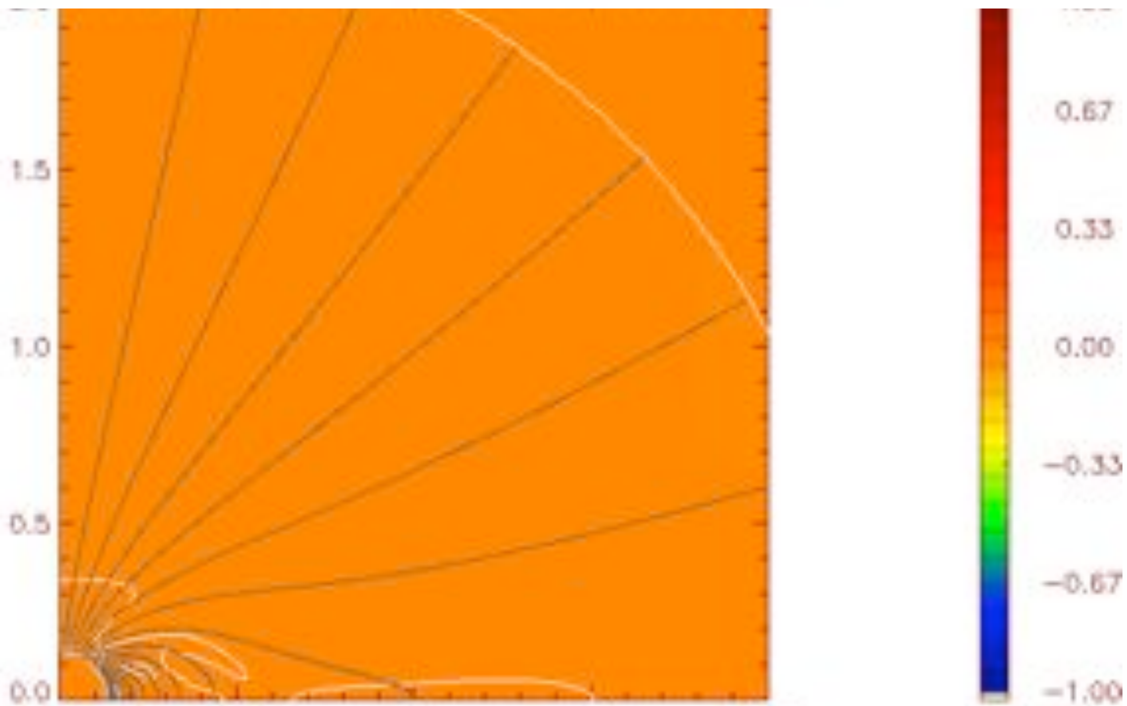


Comparison

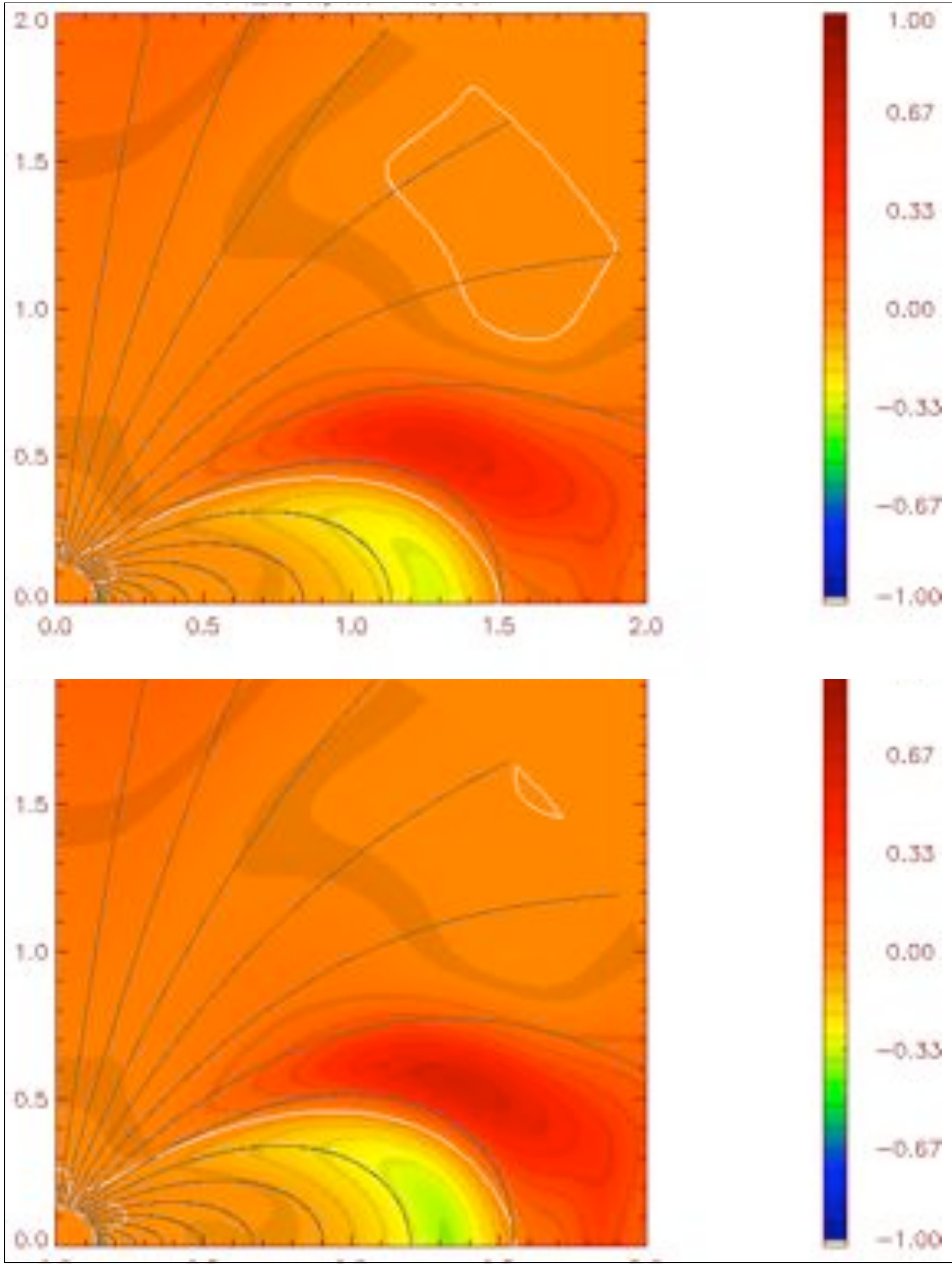
Relative density variation due to shear

1. finite leakage BC

34 hrs total time span



2. Line-tied



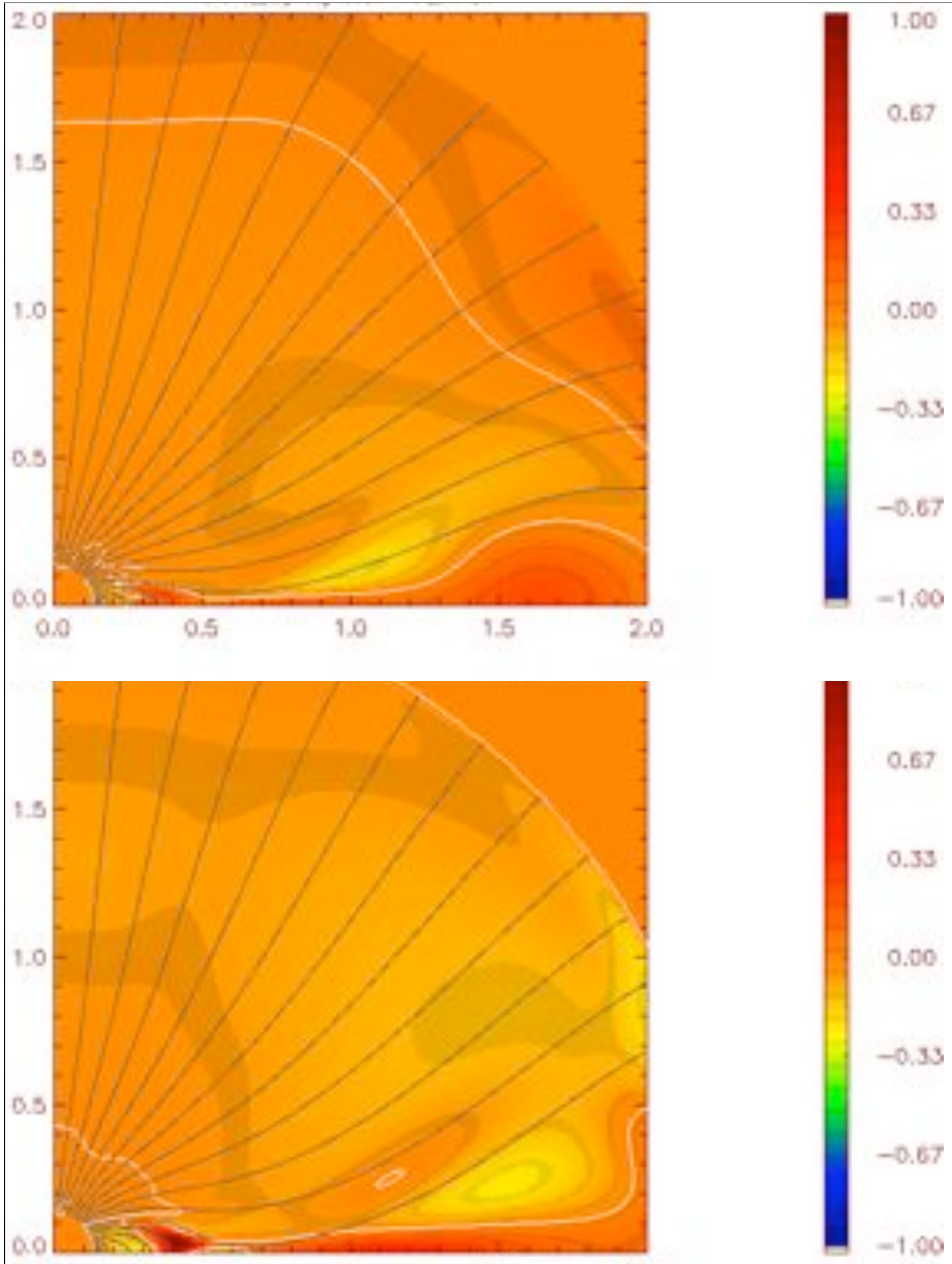
Comparison

Relative density variation due to shear

1. finite leakage BC

First "CME" very similar in both simulations

2. Line-tied



Comparison

Relative density variation due to shear

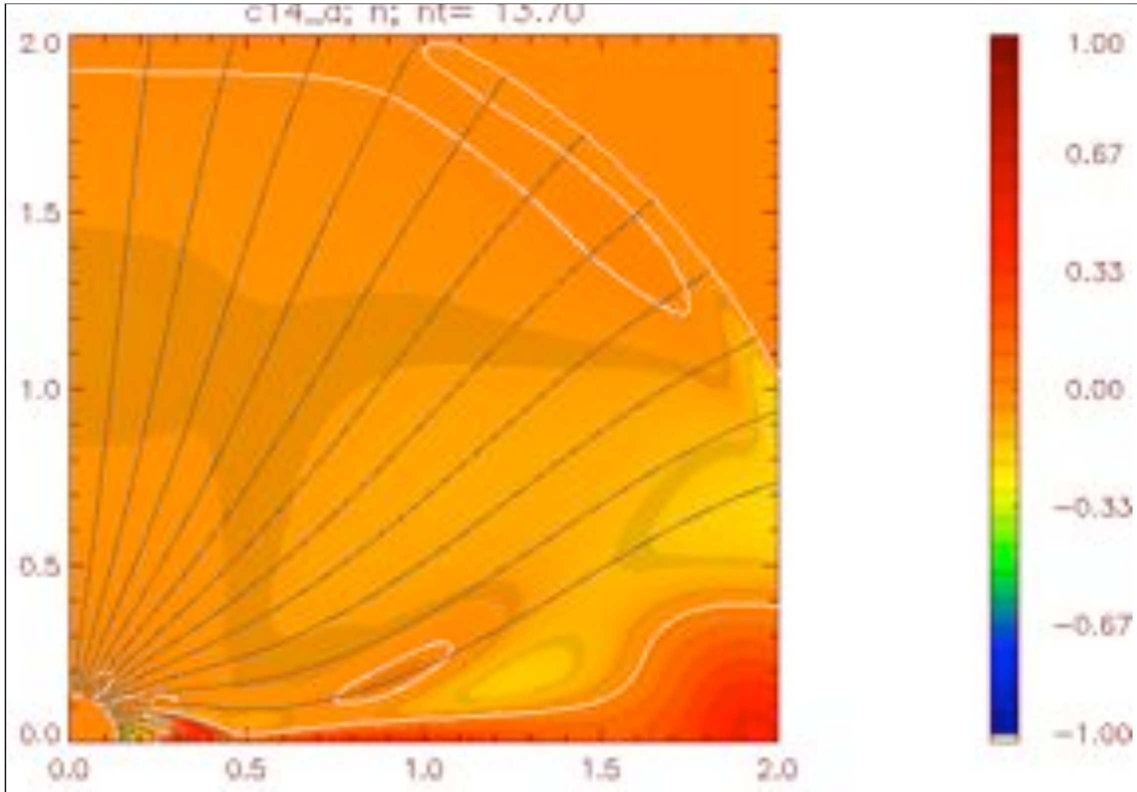
1. finite leakage BC

... but second "CMEs" differ by timing and amplitude

2. Line-tied

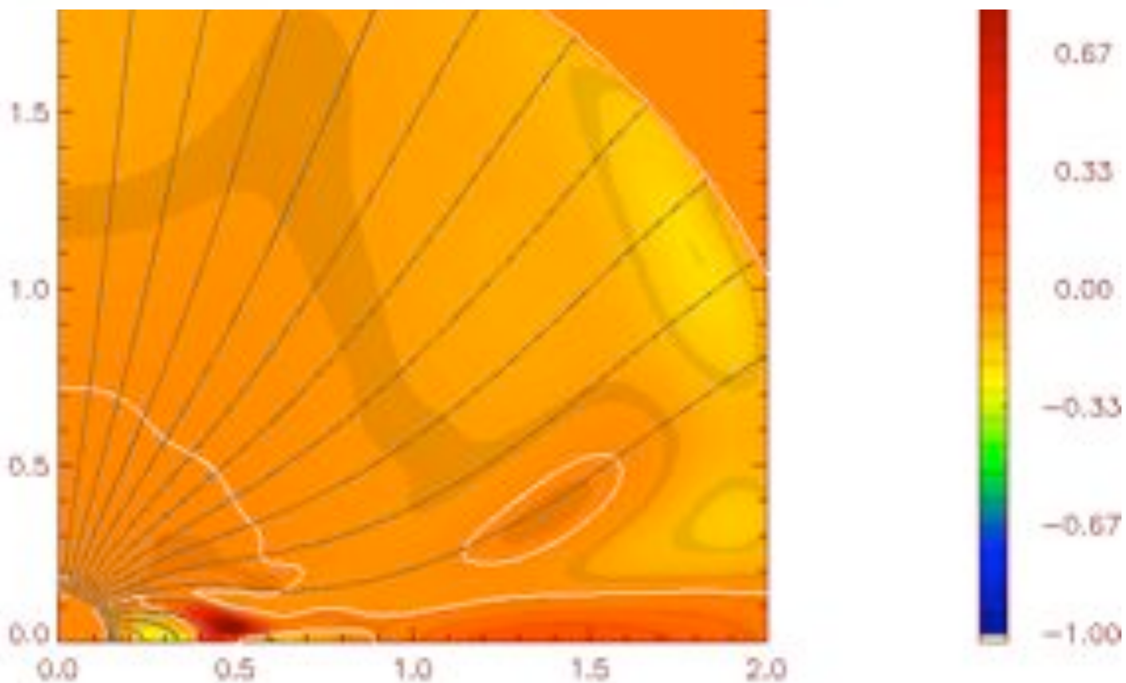
Comparison

Relative density variation due to shear



1. finite leakage BC

Same for third "CME"



2. Line-tied

Discussion: basic principles

Bases *(Grappin Aulanier Pinto 2008*, modèle de boucle 1.5D, cisaillement constant); trois cas selon le paramètre ε et le temps de fuite correpondant ($t_L = L/Va°$):

(a) $\varepsilon <<1$, $t>>t_L$ (temps long)

$b_{couronne}/B° = b_{phot}/B° = U°/Va°$

(b) $\varepsilon <<1$, $t<<t_L$ (temps court)

$b_{couronne}/B° << U°/Va°$

(c) $\varepsilon=0$ (Line-tied)

$b_{cour}/B° = t\, U°/L = U°/Va° \times (t/t_L)$

=> pas d'équilibre en l'absence de dissipation

Applications

Calcul 1 (temps de fuite finie): <=> (a) (presque, quand on calcule les échelles de temps)

Calcul line-tied: (b) ou (c)? (en tout cas, $t<<t_L$, c'est sûr

En tout cas le modèle prédit de fortes différences entre les deux calculs, qu'on ne retrouve pas : donc ce n'est pas le bon modèle !

Faut-il en conclure que les boucles fermées n'ont aucune importance pour déclencher les quasi-CME dans ces calculs et que tout se passe à l'interface zones ouvertes/fermées?

Conclusion

We propose a simple method to include a non-zero coronal leakage, valid for Alfvén polarization in the low frequency limit.

Finite-leakage & line-tied BC are compared for CME-like events driven by large shear:
•finite leakage leads as expected to atmospheric feedback modifying surface shear
•as a result, differences are observed in timing/amplitude of the events

A more convincing assessment of BC would need:
•a line-tied simulation using exactly the same velocity boundary input as the one found in the simulation with leakage.
•comparing with simulations including strongly stratified layers

NB most works do NOT use actually the causal (characteristic form) of BC, either line-tied or else, including the most "applied" space weather published works