Is the chromospheric transition region stable?

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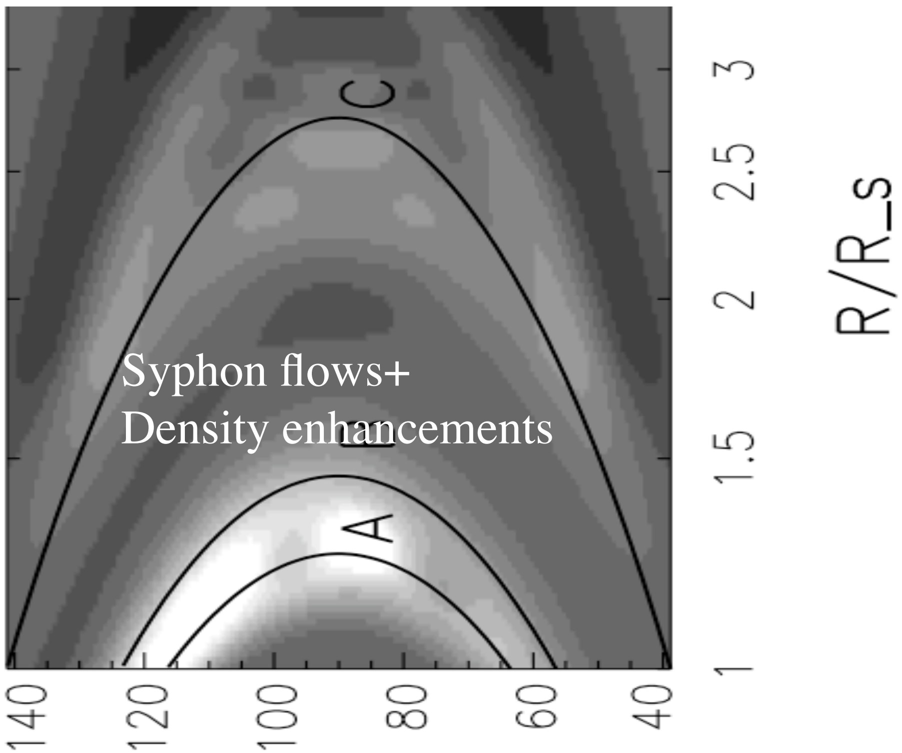
How does the chromospheric transition region (TR) react to impinging waves (from above or below)? How are they transmitted or reflected?

What kind of boundary is it ? Passive or active, transparent or reflective?

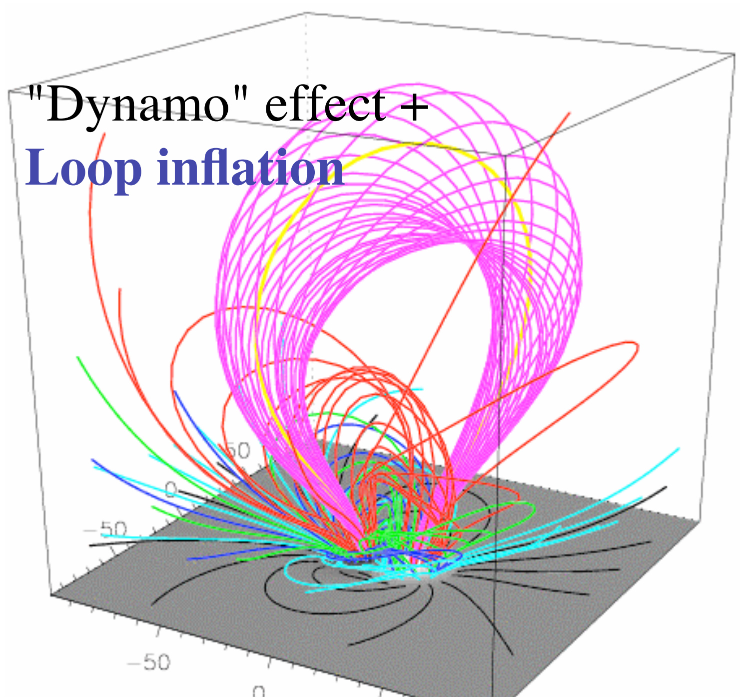
Motivation: The boundary condition dilemma

Axisymmetric MHD solar wind model
(Grappin Léorat Habbal 2003, 2005)

3D MHD, $\beta=0$
(Aulanier, Démoulin Grappin 2005)



(1)Twisting footpoints "transparent"



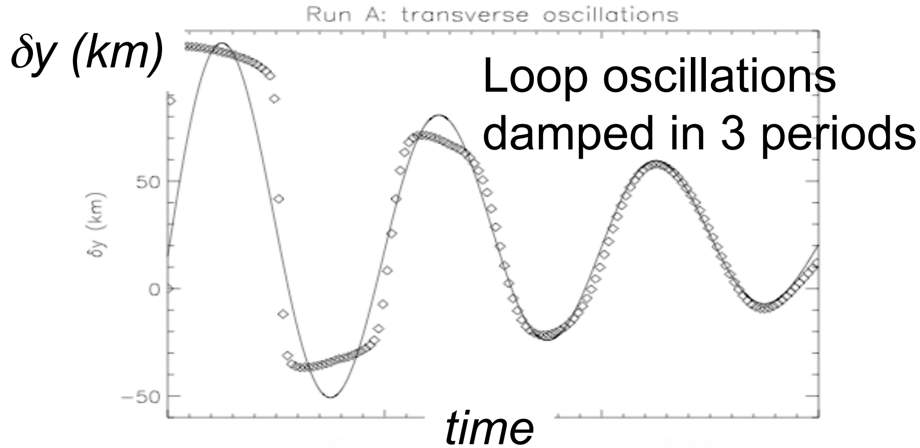
(2)Twisting footpoints "line-tied"

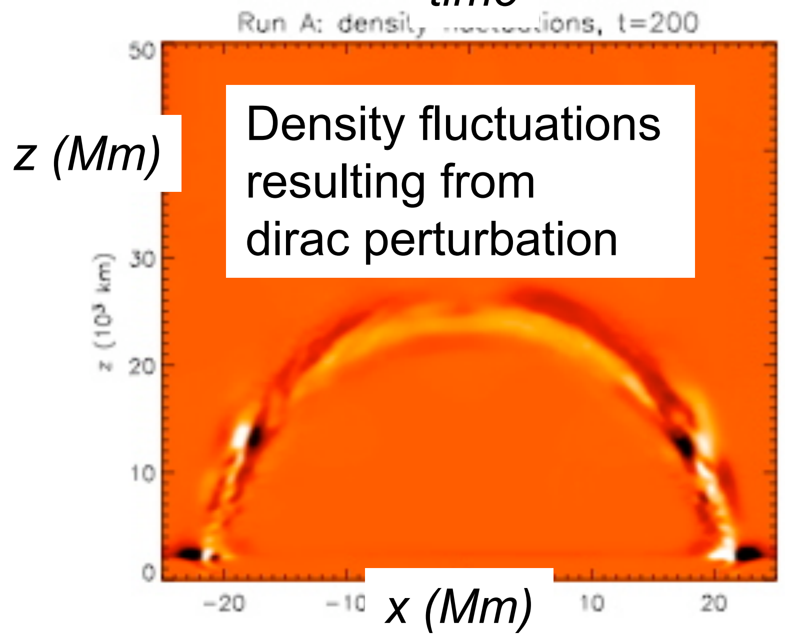
Is the "surface" transparent or rigid/reflective?

- *del Zanna et al 2005* simulation of a loop system with transition region (with *limited* oscillations)

=> Loop oscillations damped in 3 periods

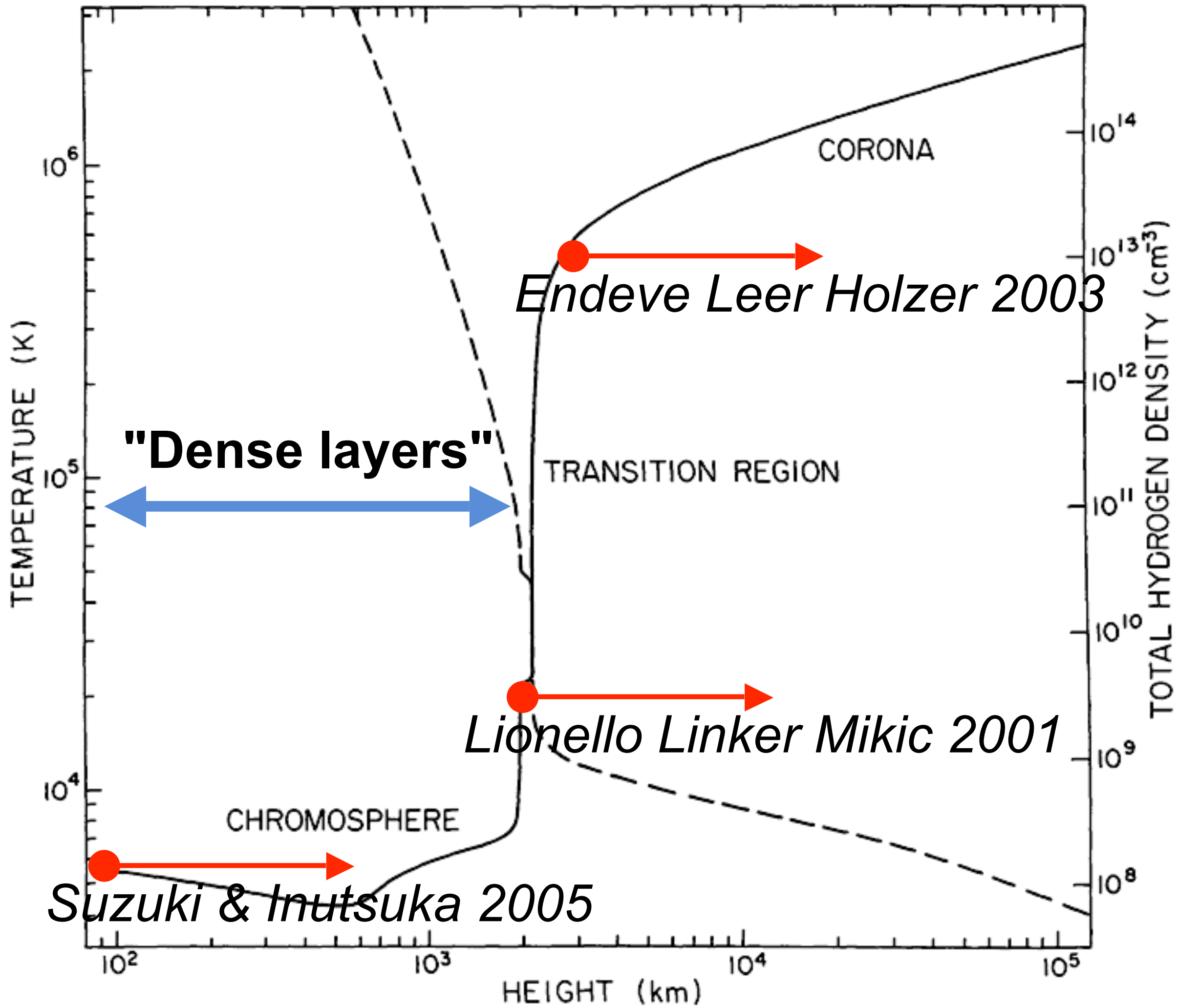
…how much does TR reflectivity depend on the detailed model ?





Solution: transition layer AND wind

How to include
the denser
layers?



Tr

How to ir
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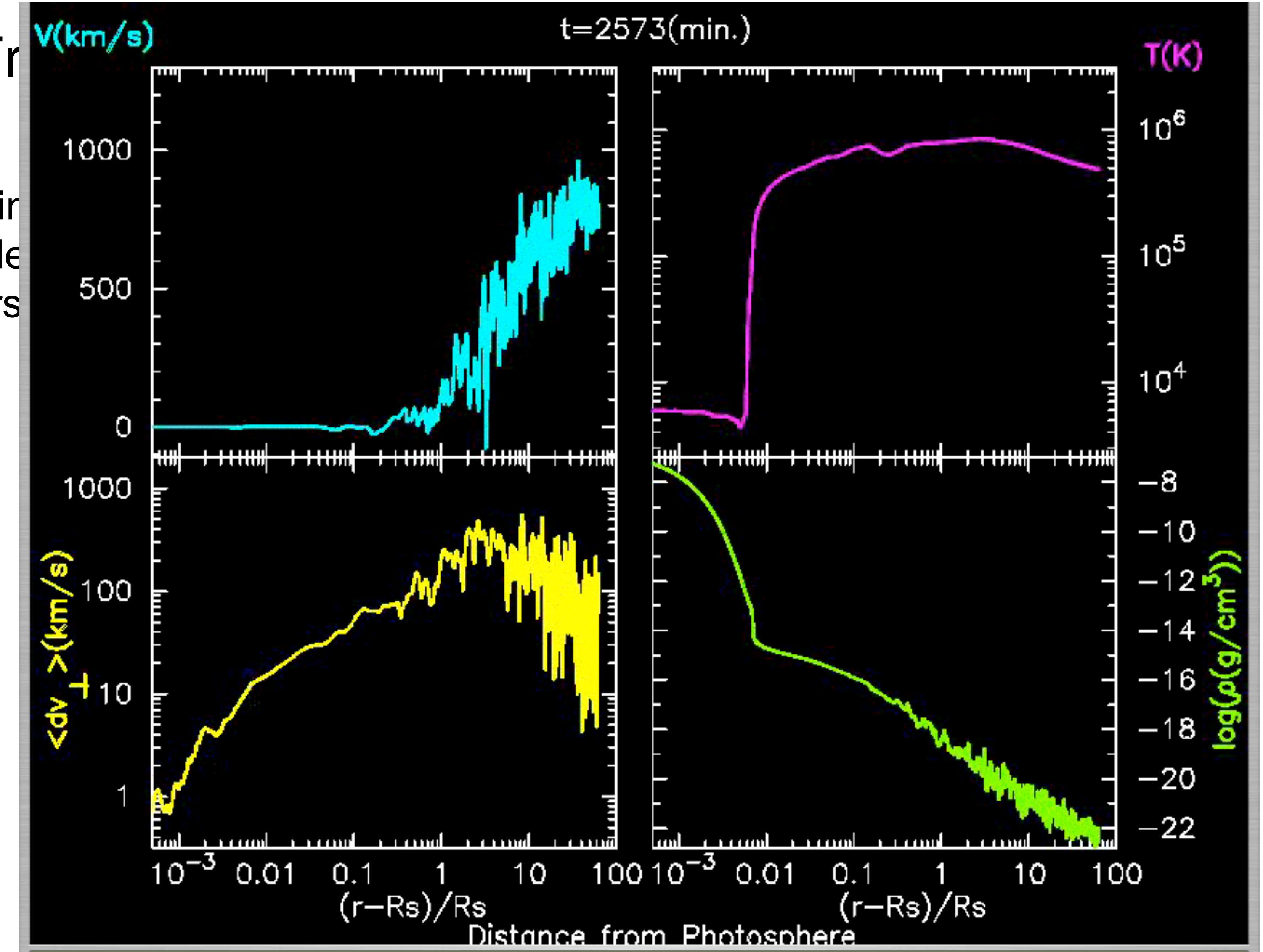
layers



Suzuki & Inutsuka: the example to follow?

Suzuki & Inutsuka: N=14000 grid points

=> impossible to generalize to 2D/3D

=> same with N = 300 points ?

Let us try (begin to try…)

First try closed loop model with smooth stratification

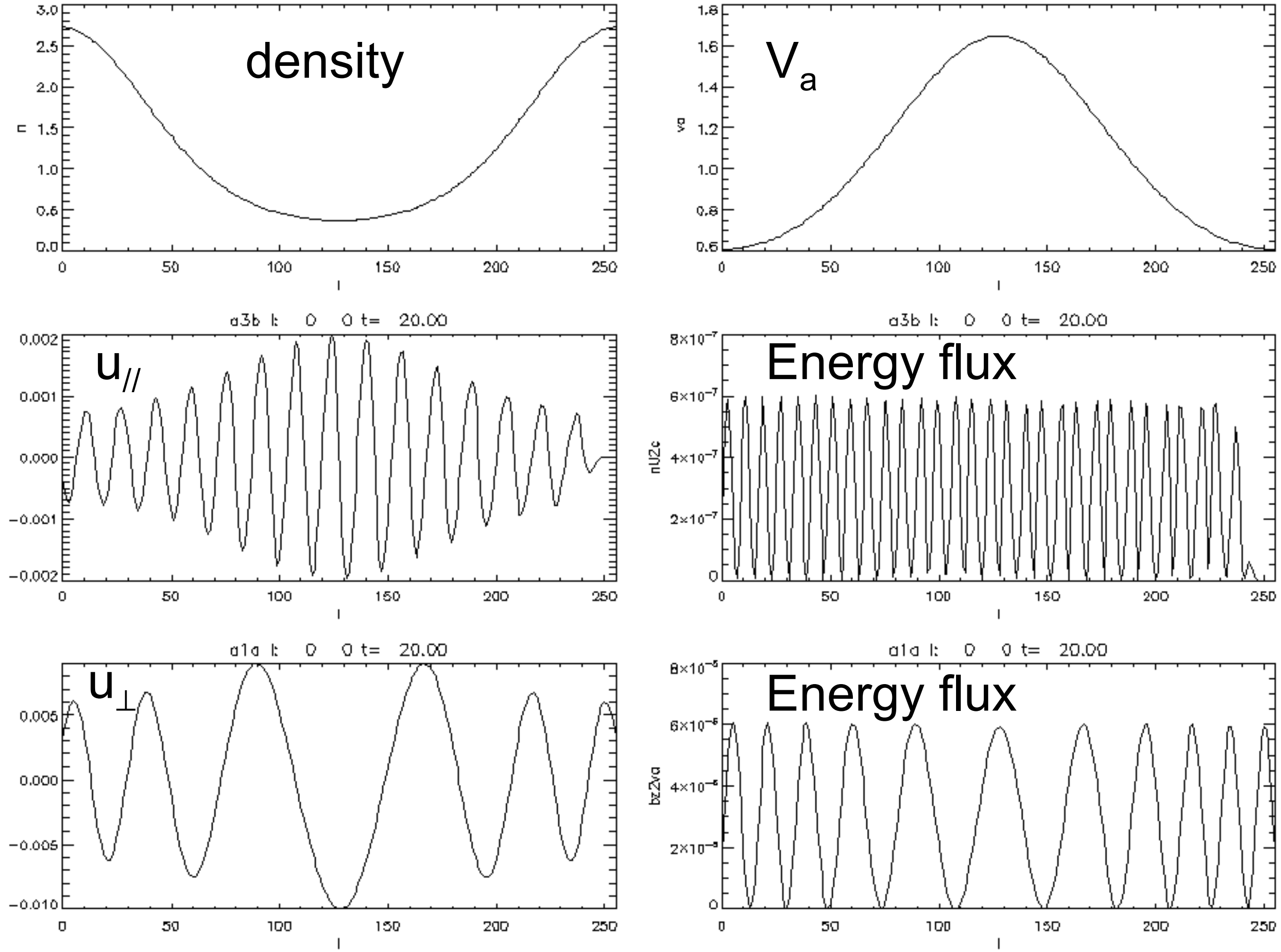
Foot point 1 Foot point 2

Toy loop model: 1D domain, with (//) gravity changing sign

a) Injecting sound wave ===>

b) inj. CPolarized Alfvén wave===>

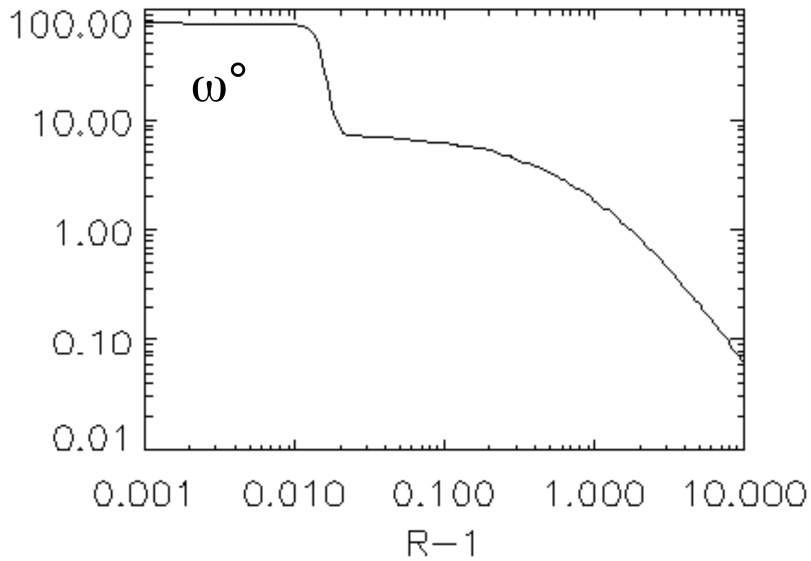
=> Energy flux conservation in both cases



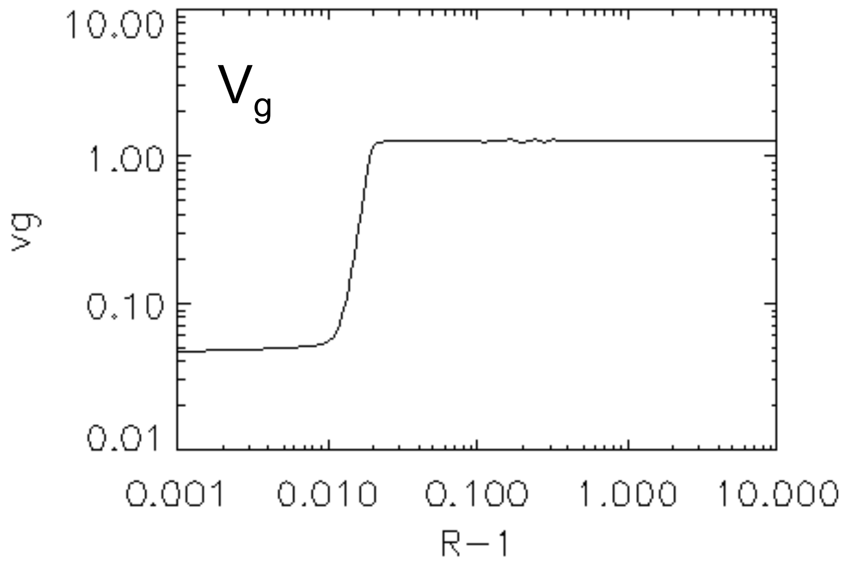
Now build open loop with strong stratification (no B field)

Atmosphere with two temperatures:
0.01 MK, 1 MK

Fréquence de coupure

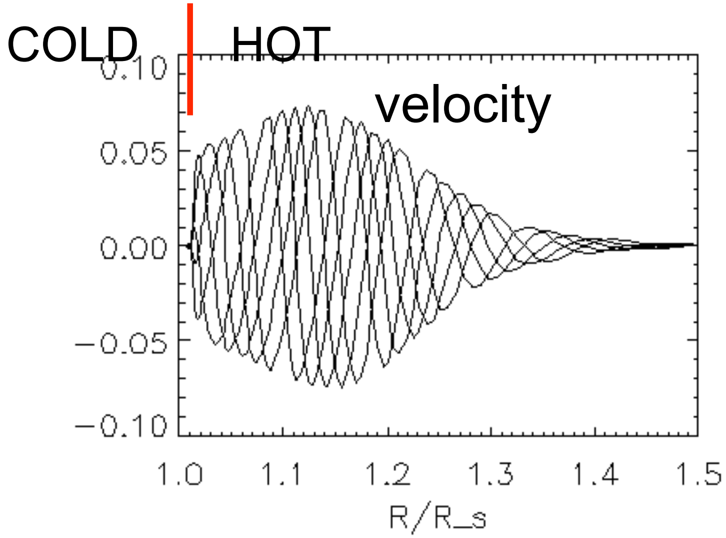


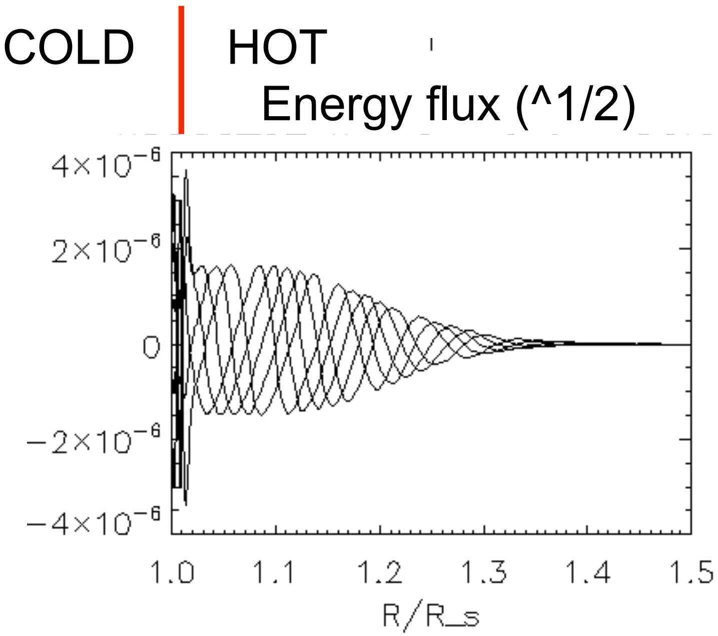
Group velocity
(ω =100)

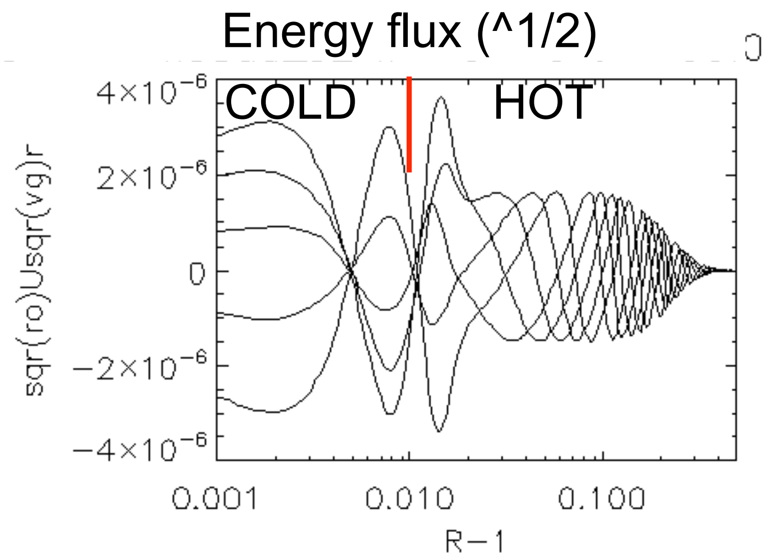


inject pressure waves in open loop

Injecting wave
with frequency 100
(propagative everywhere)
=> Constant energy flux in cold zone
=> Same in hot zone, except for abrupt decrease at
R > 1.1



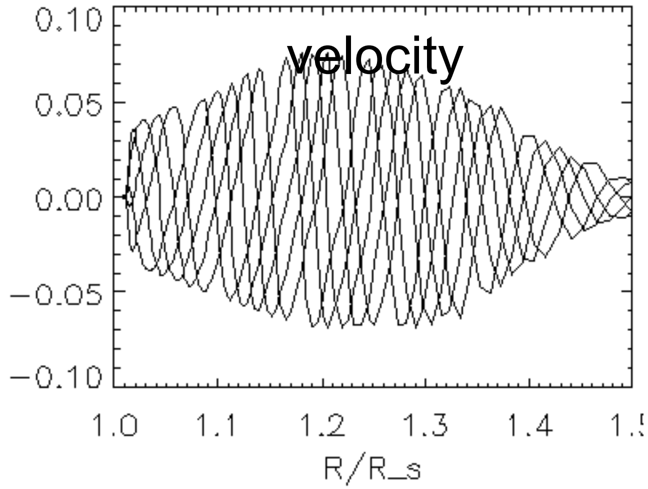




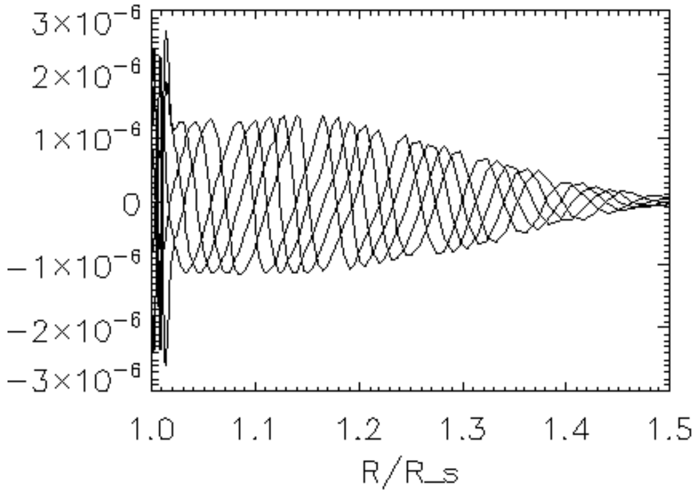
Same with reduced filtering…

Less frequent filtering:

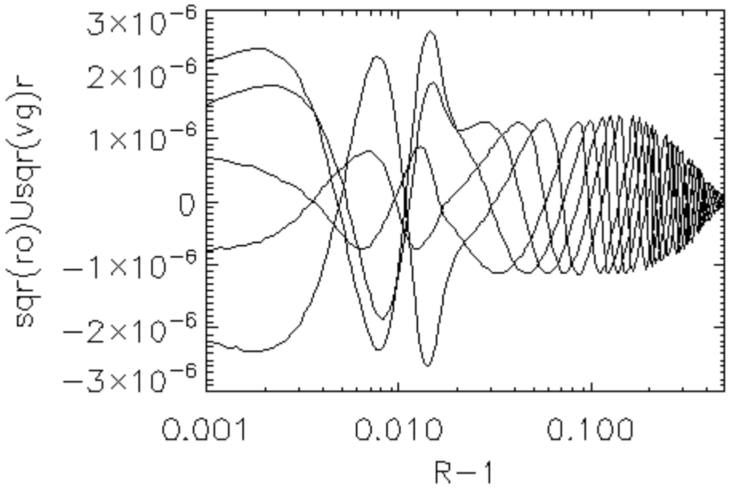
=> wave damping delayed to larger radial distance, where mesh size /wavelength larger than 1/10.



Energy flux (^1/2)



Energy flux (^1/2)

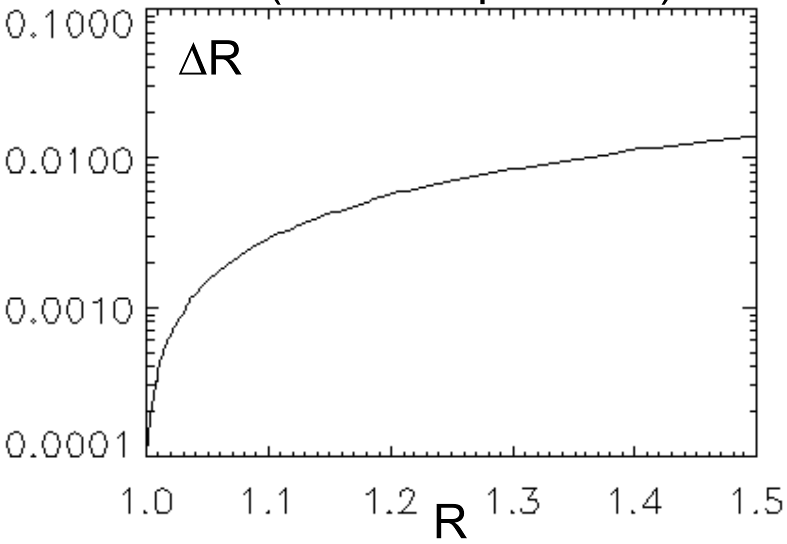


sharing 300 grid points…

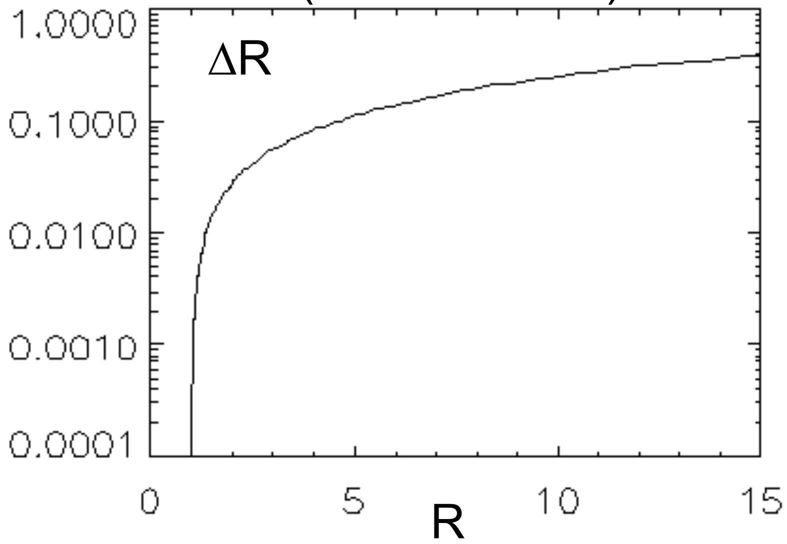
Mesh size has to be small where necessary, but not too small at large distances…

Compromise: ensure correct resolution for waves in region where heating by wave dissipation is required

Mesh size
(zoom as previous)

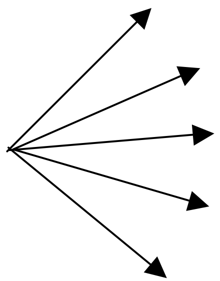


Mesh size
(entire domain)

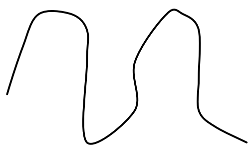


Energy equation (1): *adiabatic*

$DP/Dt = -\gamma P \mathrm{div} u$ (γ=5/3)

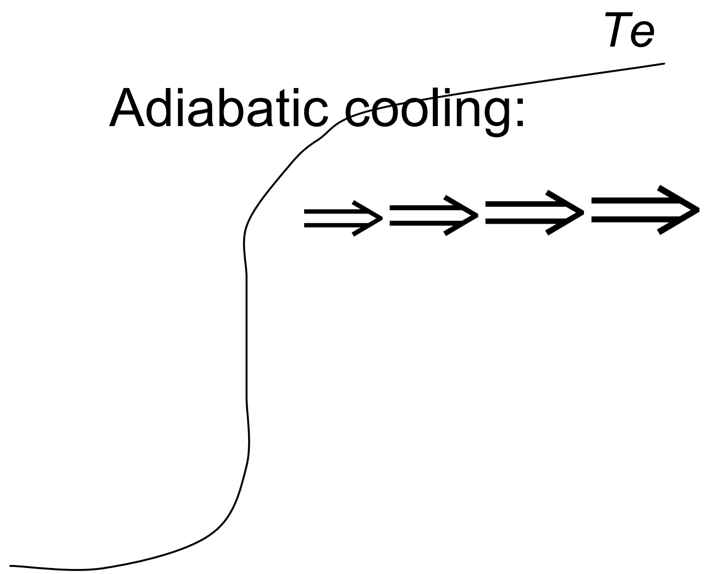


divu>0 (wind)
=> systematic adiabatic cooling



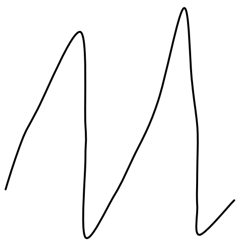
Also:
divu>0 and <0 (pressure wave)
=> reversible cooling/heating

Adiabatic cooling:



Energy equation (2): adiabatic + *mechanical heating*

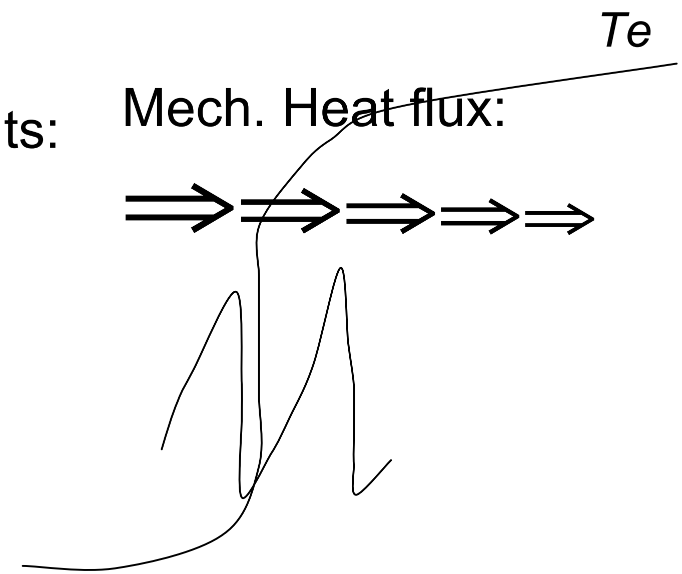
$DP/Dt = -\gamma P \mathrm{div} u - (\gamma-1)\{\mathrm{div} F_m\}$ $(\gamma=5/3)$



- Reality: dissipation of gradients:
  $\mathrm{div} F_m = \eta J^2 + \mu(\omega^2 + \mathrm{div} u^2)$

- *Model: prescribed flux:*
  $F_m = f° (R_s/r)^2 \exp(-(r-R_s)/R_s)$

Mech. Heat flux:



Energy equation (3): adiab. + mech. heating + *conduction*

$$DP/Dt = -\gamma P \mathrm{div}u - (\gamma-1)\{\mathrm{div}F_m + \mathrm{div}F_c\} \qquad (\gamma=5/3)$$

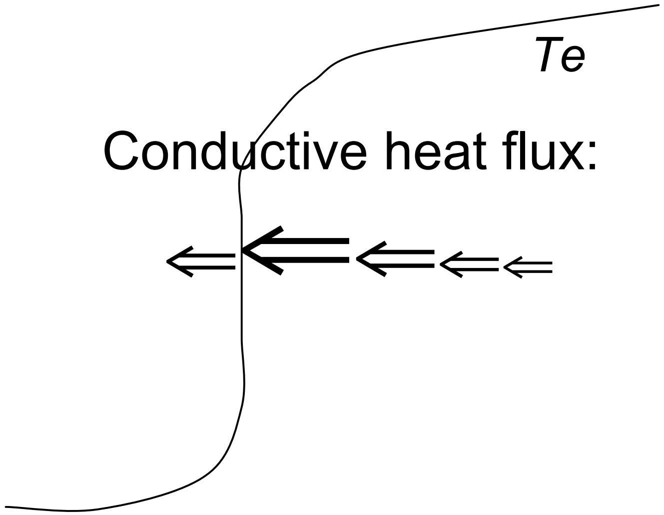
Conductive heat flux:

$F_c = \kappa° T^{5/2} \partial T/\partial r$

=> $F_c = \kappa° \partial/\partial r(T^{N(T)})$ with $2 \leq N(T) \leq 7/2$

cf. *Linker Lionello Mikic Amari 2001*

+ additional reduction factor: parameter t_c

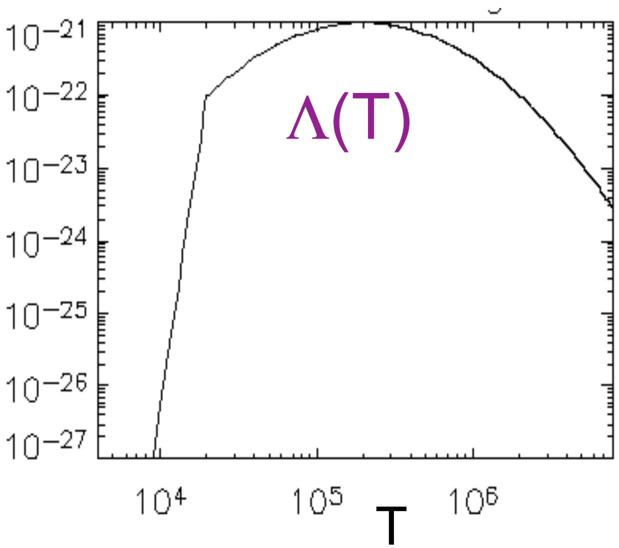


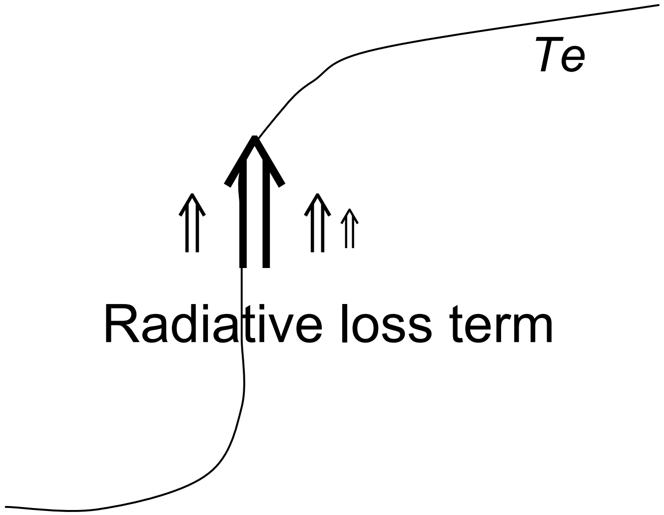
Energy equation (4): adiab. + mech. heating + conduction + *radiative cooling*

$$DP/Dt = -\gamma P \mathrm{div} u - (\gamma-1)\{\mathrm{div}F_m + \mathrm{div}F_c + n^2\Lambda(T)\} \qquad (\gamma=5/3)$$

Radiative loss:

approximate fit to *Rosner Tucker Vaiana 1978*





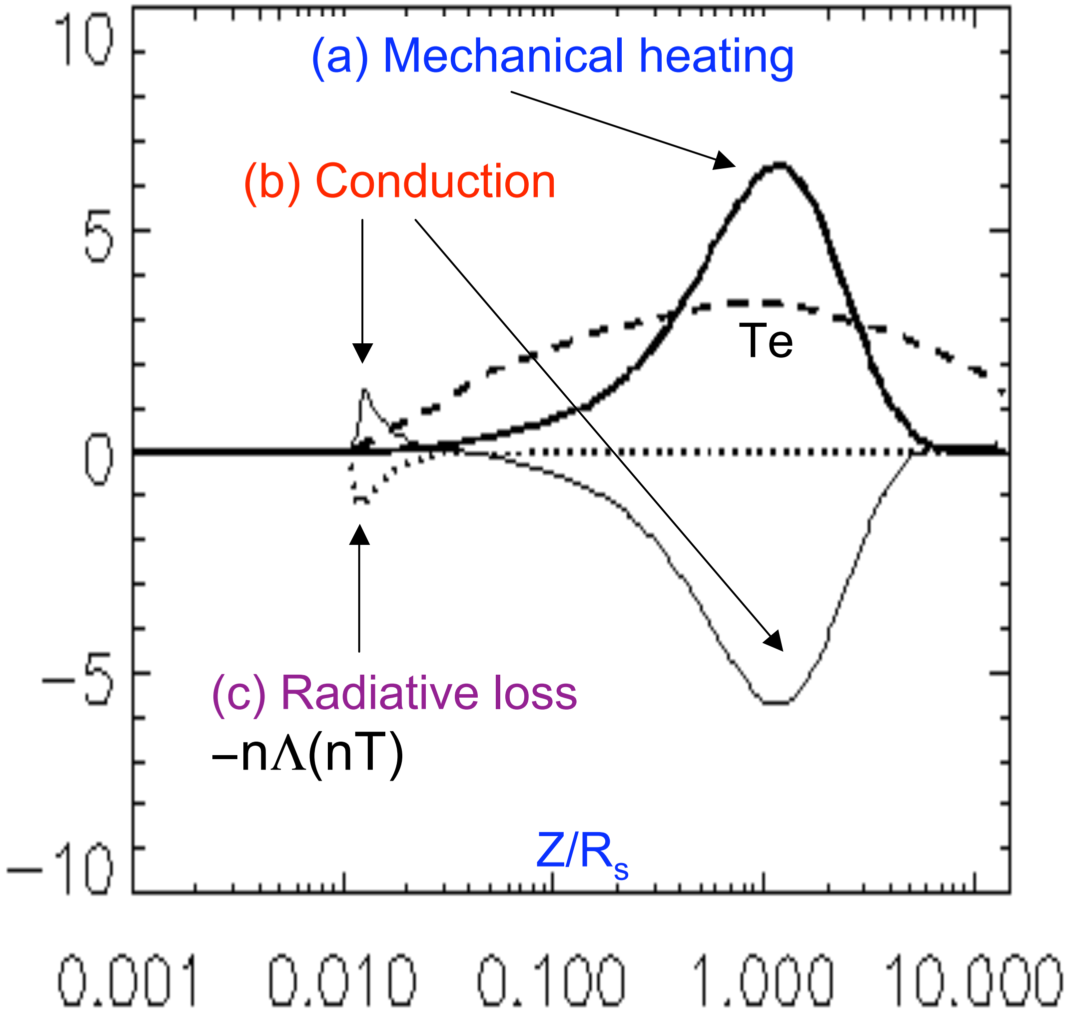
Stationary wind: energy balance per particle

Energy equation
for *temperature* (=P/n):

$D(P/n)/Dt = -(\gamma-1)(P/n)\mathrm{div}u$
$-(\gamma-1)\{$

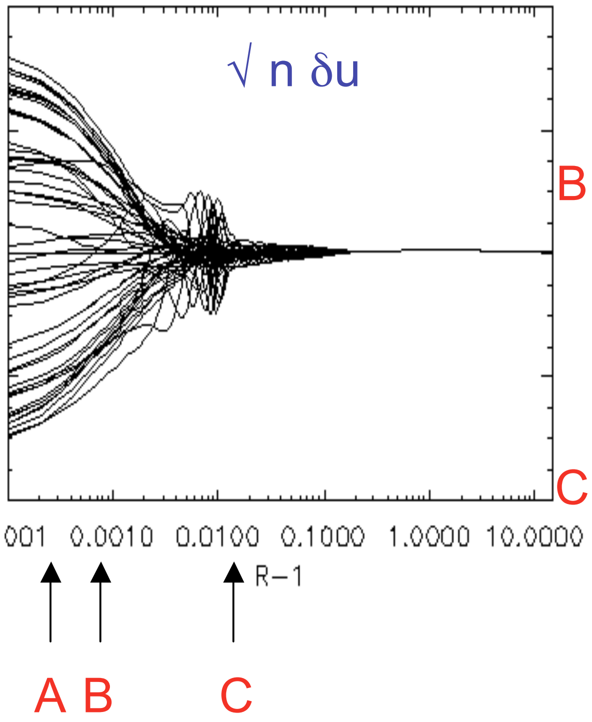
$(1/n)\mathrm{div}F_m$ (a)
+
$(1/n)\mathrm{div}F_c$ (b)
+
$n\Lambda(T)$ (c)

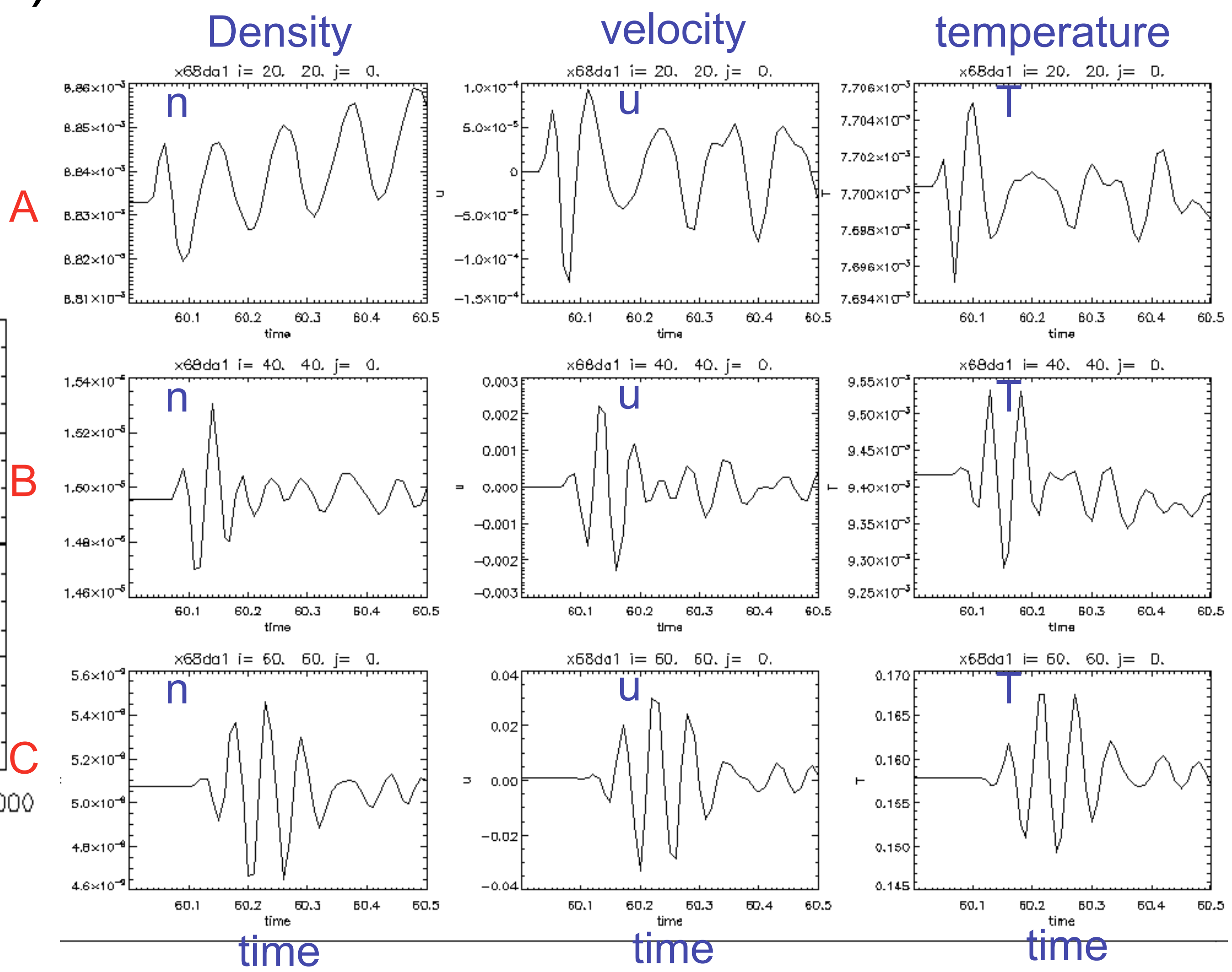
$\}$



Detailed response to monochromatic wave (evanescent case)

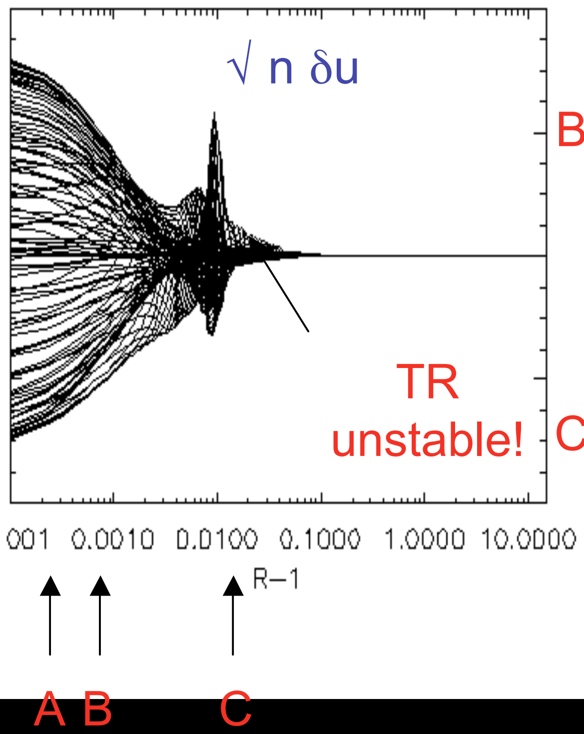
1.Low amplitude wave (38 cm/s)

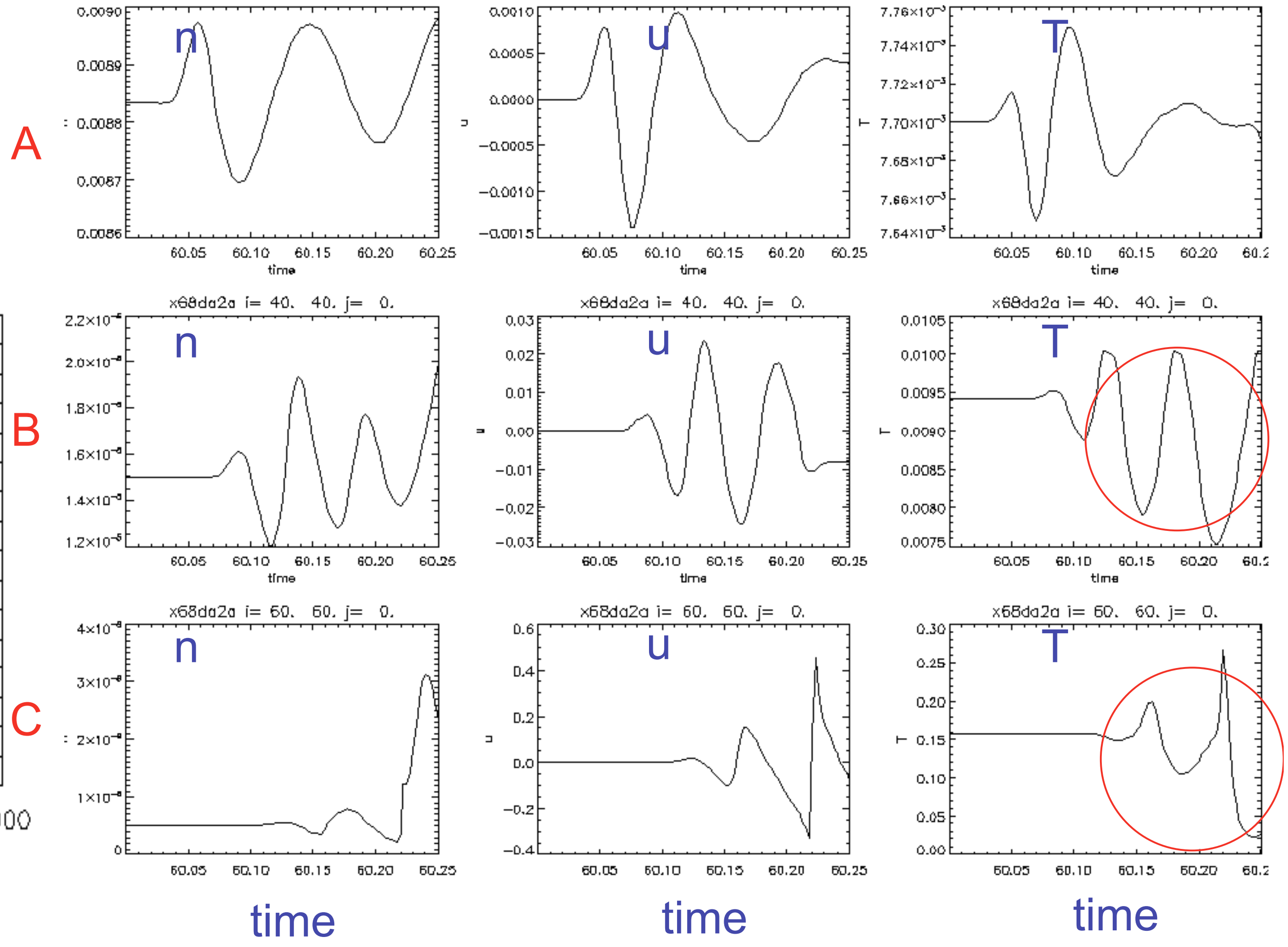




Increasing amplitude => TR unstable

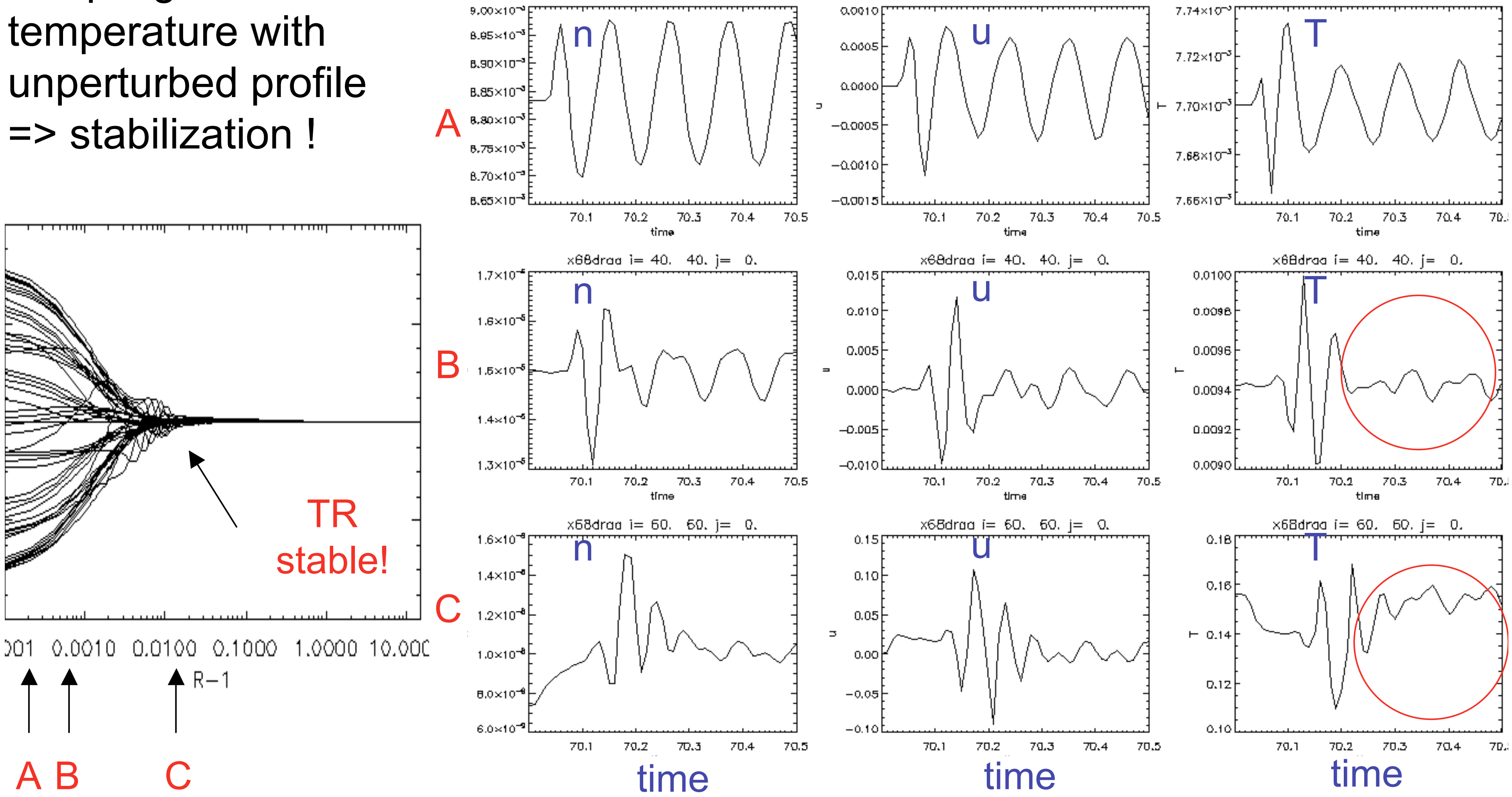
2.Large amplitude evanescent wave (38m/s) => TR instability





Switching to temperature relaxation => TR stable

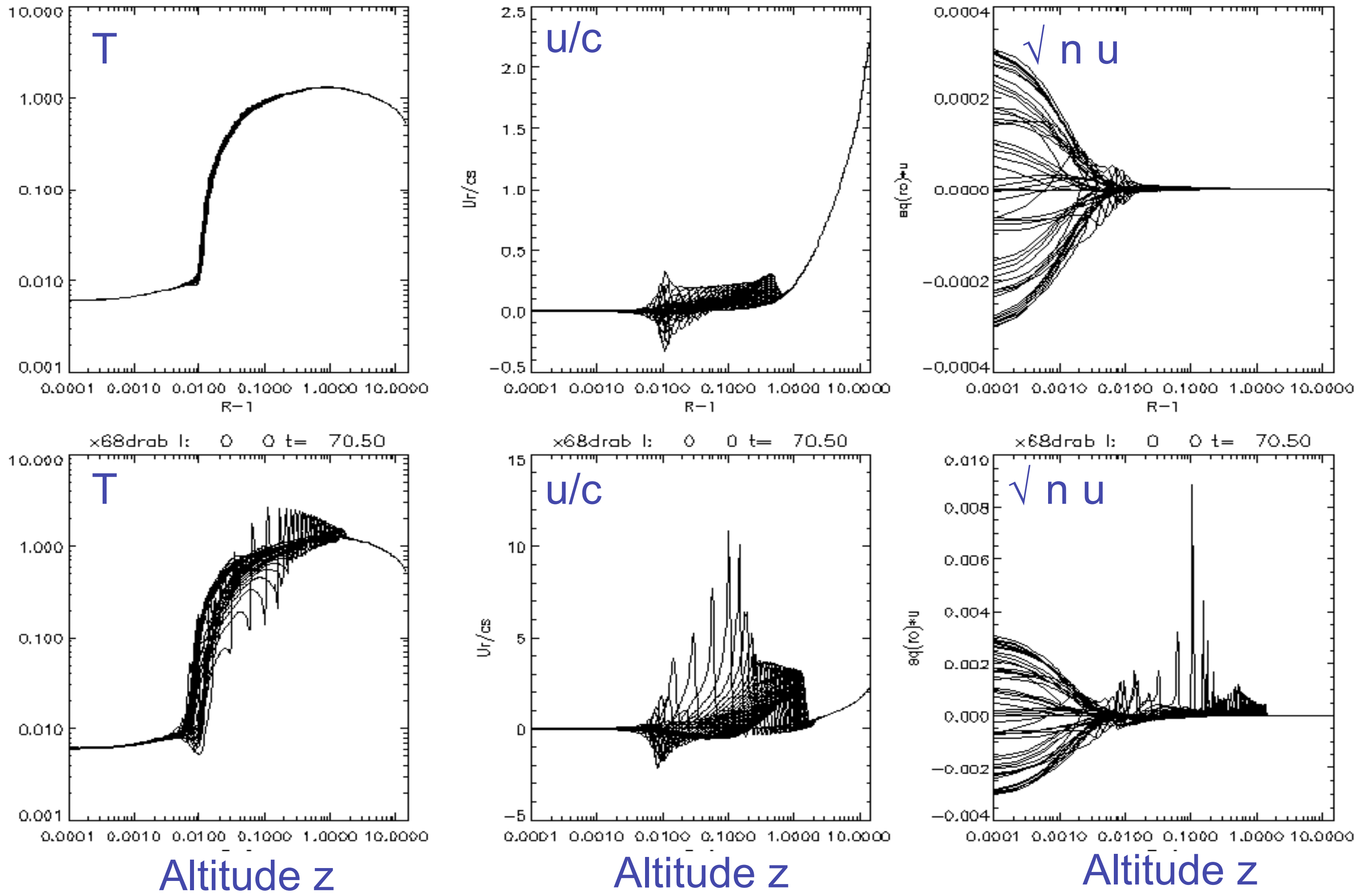
Coupling temperature with unperturbed profile => stabilization !



Temperature relaxation with wave amplitude x 10: still stable

A large amplitude (38m/s)

B very large amplitude (380m/s)



Discussion (1)

A transition region is built by solving an energy equation with convection, mech. heating, radiative cooling.
The domain includes corona and solar wind up to 15 solar radii, using 300 mesh points.
TR is shown to be unstable to waves with moderate amplitude at frequencies ≈ cut-off frequency.
However, stability is recovered if the temperature is "frozen" by relaxation terms.
Close examination shows that average properties of perturbed TR are very different from unperturbed one: this explains the stabilization by relaxation. (See e.g. turbulent viscosity, turbulent pressure…)

=> A first conclusion is that not only do parameters (as TR size…) matter, but also the energy equation.

Discussion (2)

How to interprete the TR instability? Two remarks:

•In our energy model the mech. energy flux and the wave flux are independent, so the TR can absorb the wave energy without bound.

In a self-consistent model, the process would clearly saturate.

Particularly interesting are works with self-consistent viscous/ohmic heating (Suzuki & Inutsuka 2005, Gudiksen et Nordlund, 2003) which show a TR never really at rest.

Also, observations show ubiquitous upward and downward flows which could be the 3D form of the 1D instability studied here.

Future work will be to recover self-consistent coronal heating with the same reduced number mesh points (1.5 MHD) and then to generalize to 2D/3D MHD.

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