Applying a couple of solar wind heating mechanisms to heating coronal loops

Bo Li (BBL@SDU.EDU.CN)
School of Space Science & Physics, Shandong University at Weihai,
Weihai 264209, China

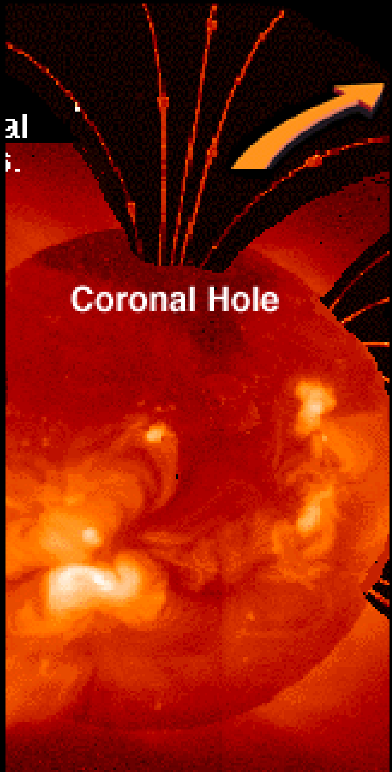
In collaboration with:
Xing Li @ IMAPS, Aberystwyth University, UK

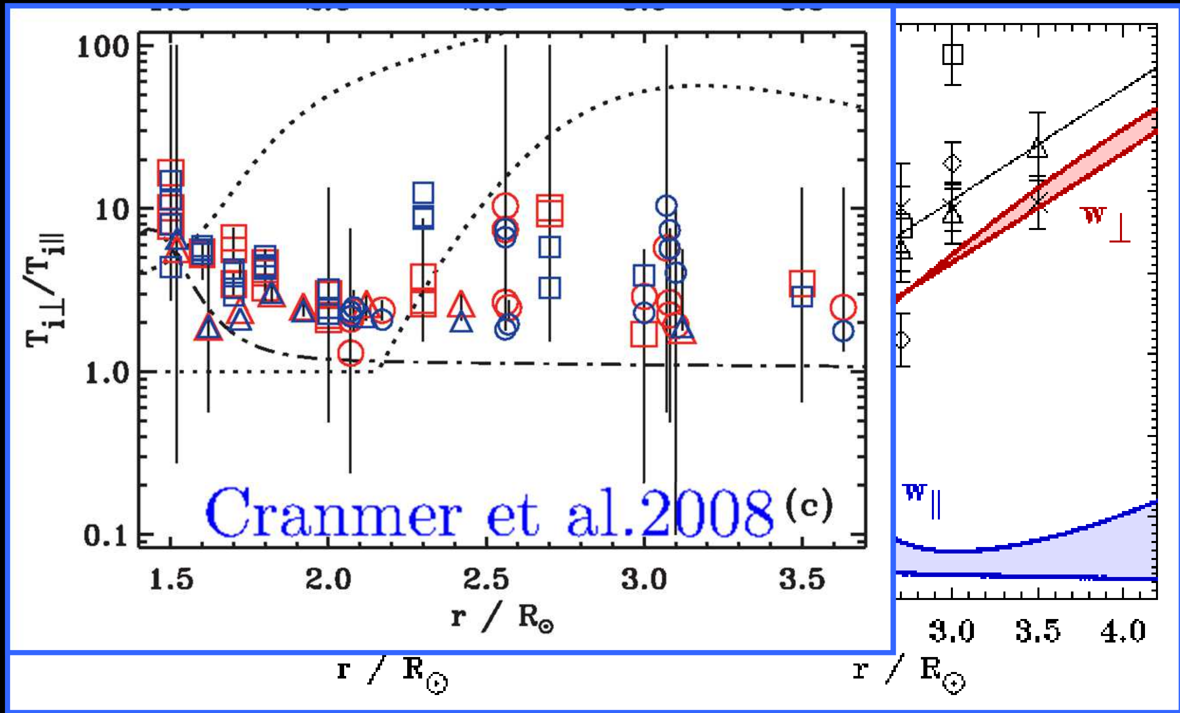
Applying a couple of solar wind heating mechanisms to heating coronal loops

Outline

- Motivations: from wind heating to loop heating
- Models contrasted with TRACE and YOHKOH measurements
- Summary

Observed ion temperature anisotropy





significant ion temperature anisotropy

\+

ions hotter than electrons

?

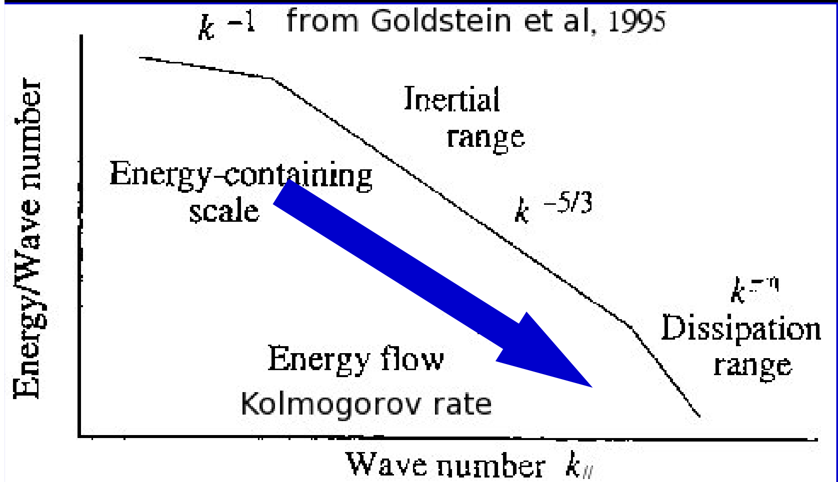
Solar wind heating mechanisms (to name but a few)

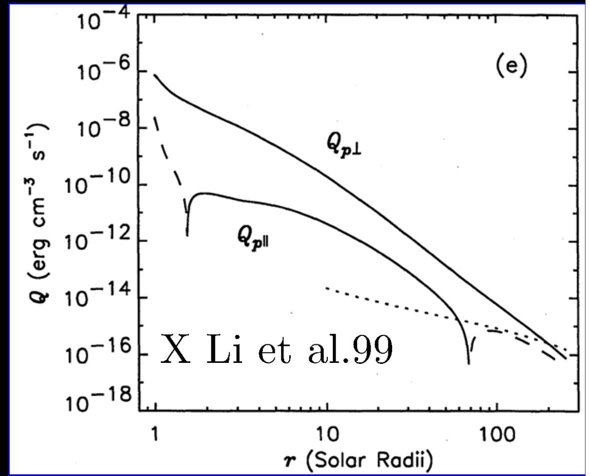
Ion-Cyclotron resonance (review by Hollweg & Isenberg 02)

- parallel cascade (Hollweg 86, X. Li et al.99, B. Li et al.04, 05,11, among others)
- spectrum sweeping (some heritage from Axford & McKenzie 92; Tu & Marsch 97; X Li et al.03; He et al.08)

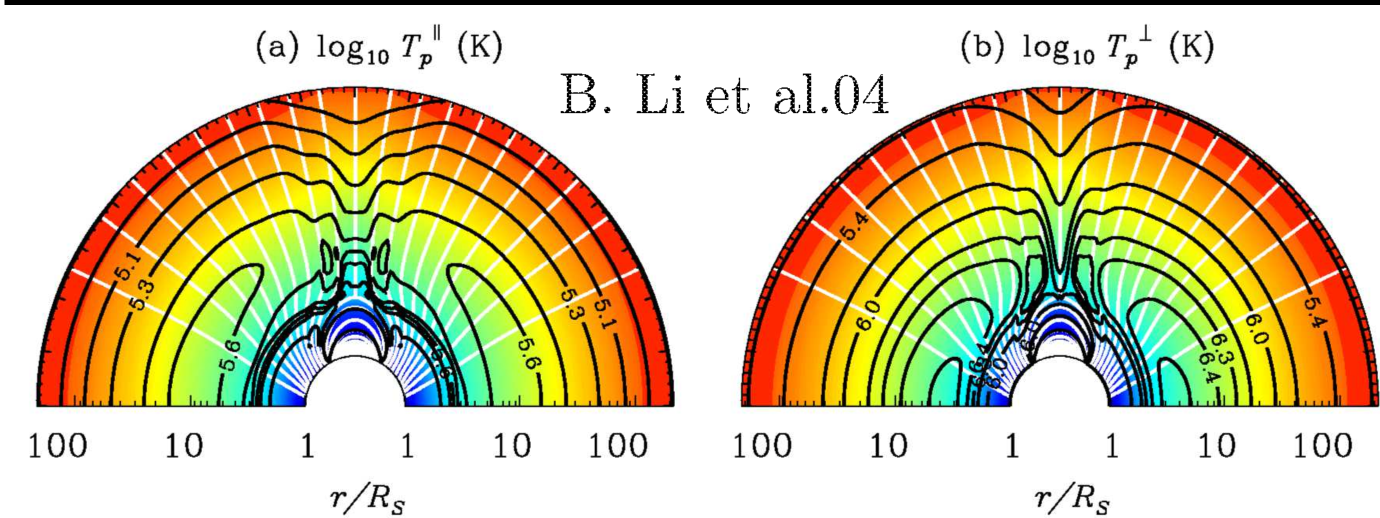
Anisotropic turbulence (originated by Matthaeus et al. 99, developed into fluid model by Cranmer & van Ballegooijen 05, Cranmer et al. 07, 12 Verdini et al. 05, 10; Chandran et al. 11, Li & Habbal 12)

|| cascade

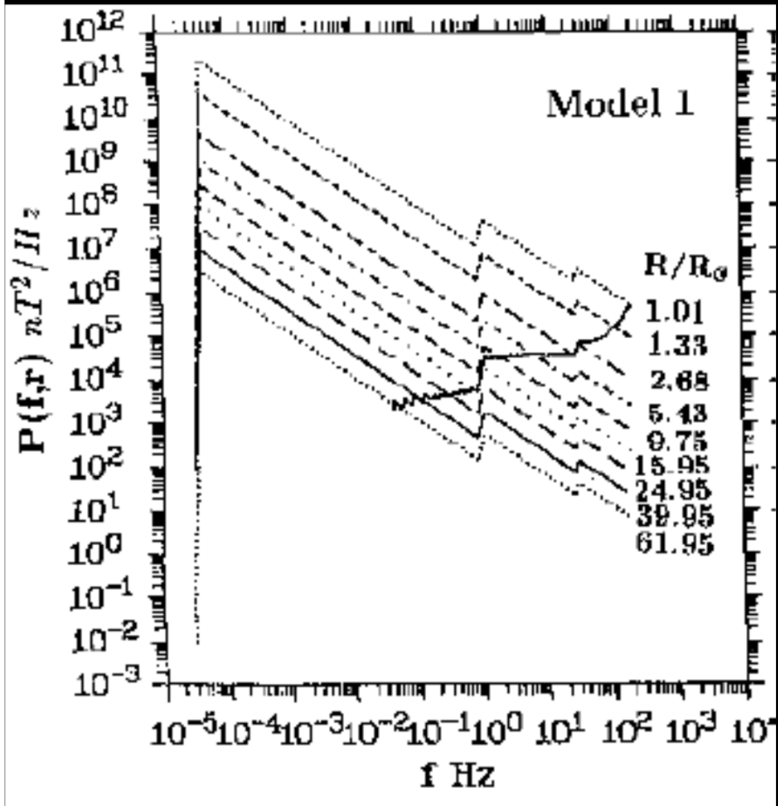


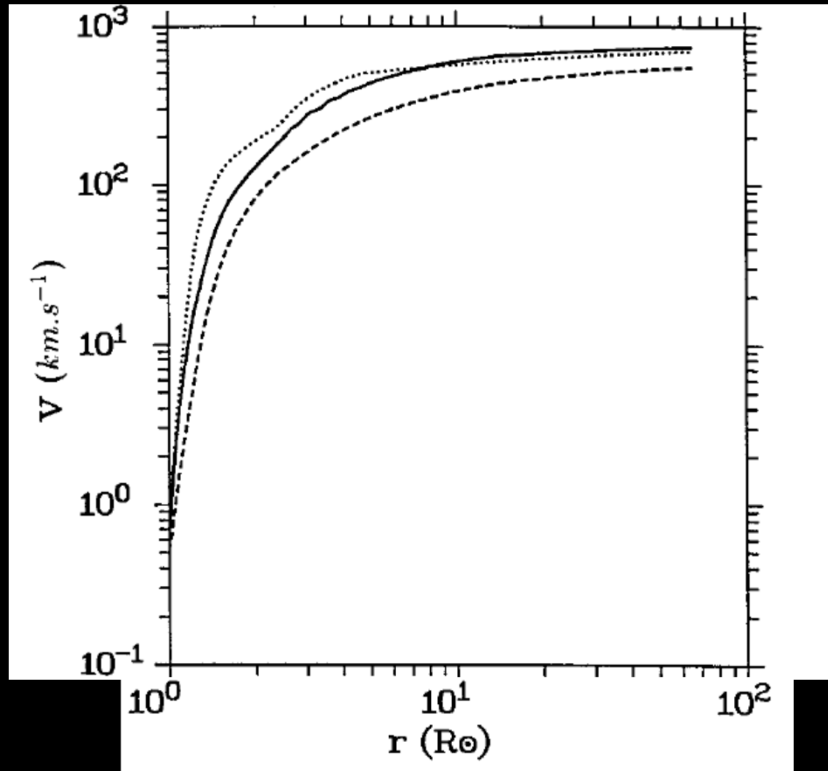


- $Q_{\rm kol} \propto \rho(z^+)^3/L_\perp$
- goes entirely to protons, primarily in $\perp$
- proves a success in reproducing many parameters, $T_\perp/T_\parallel$ in particular



spectrum sweeping





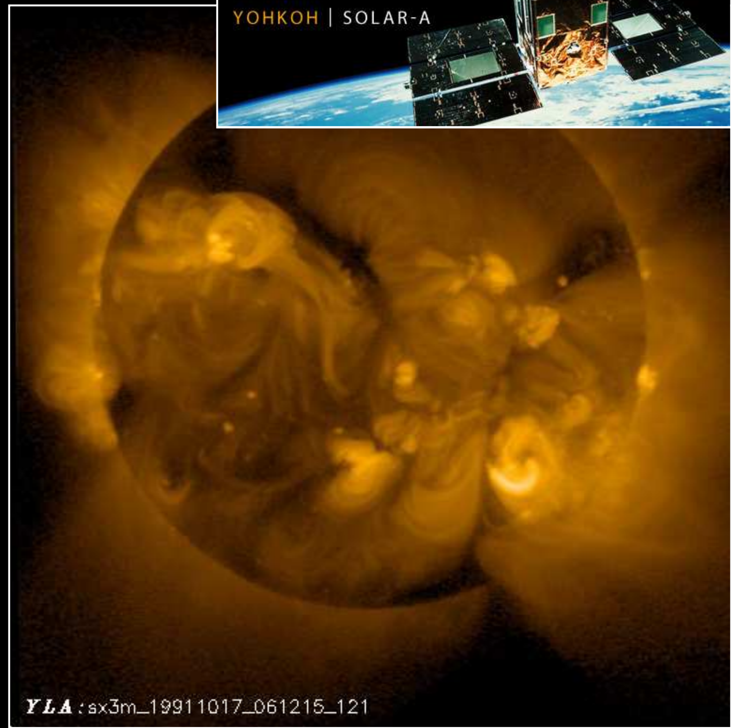
- basic idea: high-freq (kHz) waves launched by mag. recc. at chromospheric network, absorbed with distance as B decreases
- put into a global fluid model model by Tu & Marsch 97
- can produce a TR + fast wind simultaneously (Li et al.03)

Do they apply to coronal loops?

TRACE

YOHKOH/

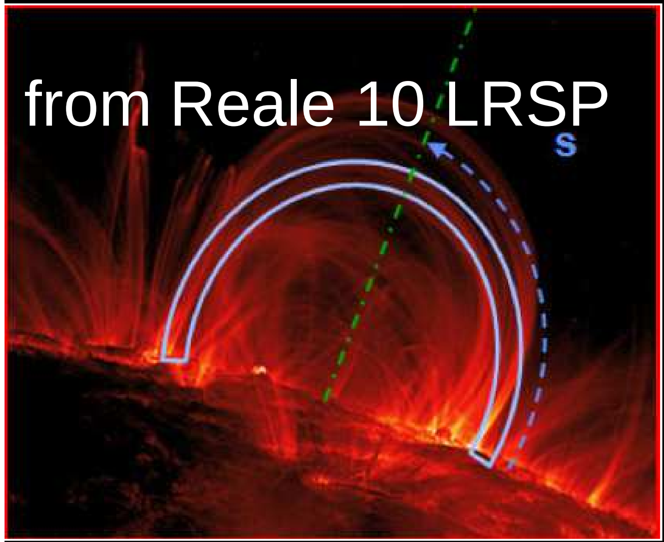
SXT

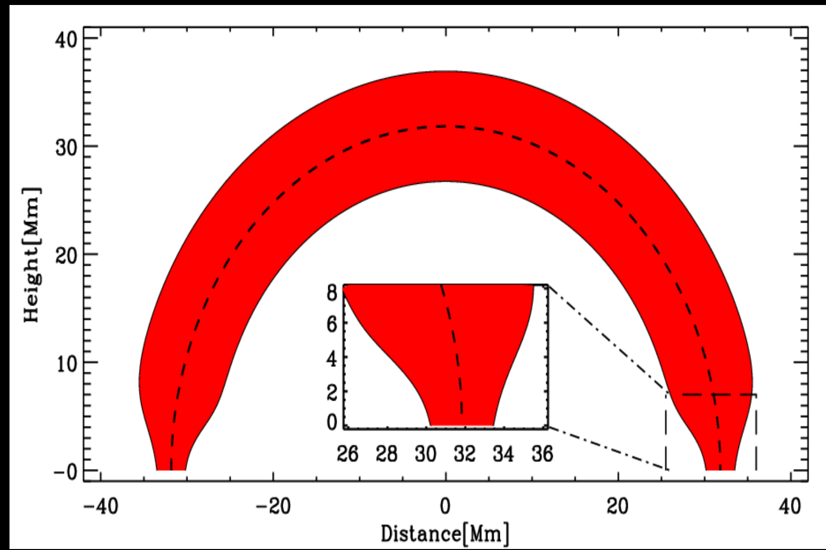


Words of caution

- winds may be fundamentally different from loops
  - winds (collision-dominated → collisionless; TR heating often neglected; open tubes: there is no other end)
  - loops (collision-dominated; TR heating has to be an ingredient; closed tubes: both ends anchored to photosphere: discrete modes)
- uncertainties exist as to
  - how turbulence cascades and dissipates
  - how to properly account for e^- heat flux in TR
- Aim of this presentation
  - present a direct contrast between observations and models constructed using solar wind heating mechanisms

Parallel cascade





$$\frac{\partial\rho}{\partial t}+\frac{1}{a}\frac{\partial(\rho v a)}{\partial s}=0$$

$$\frac{\partial v}{\partial t}+v\frac{\partial v}{\partial s}=-\frac{1}{\rho}\frac{\partial\left(p_e+p_p+p_w\right)}{\partial s}-g_\parallel$$

$$\frac{\partial T_e}{\partial t}+v\frac{\partial T_e}{\partial s}+\frac{2T_e}{3a}\frac{\partial(va)}{\partial s}=\frac{2}{3nka}\frac{\partial}{\partial s}\left(a\kappa_e\frac{\partial T_e}{\partial s}\right)+2\nu_{pe}(T_p-T_e)-\frac{2}{3nk}L_{rad}$$

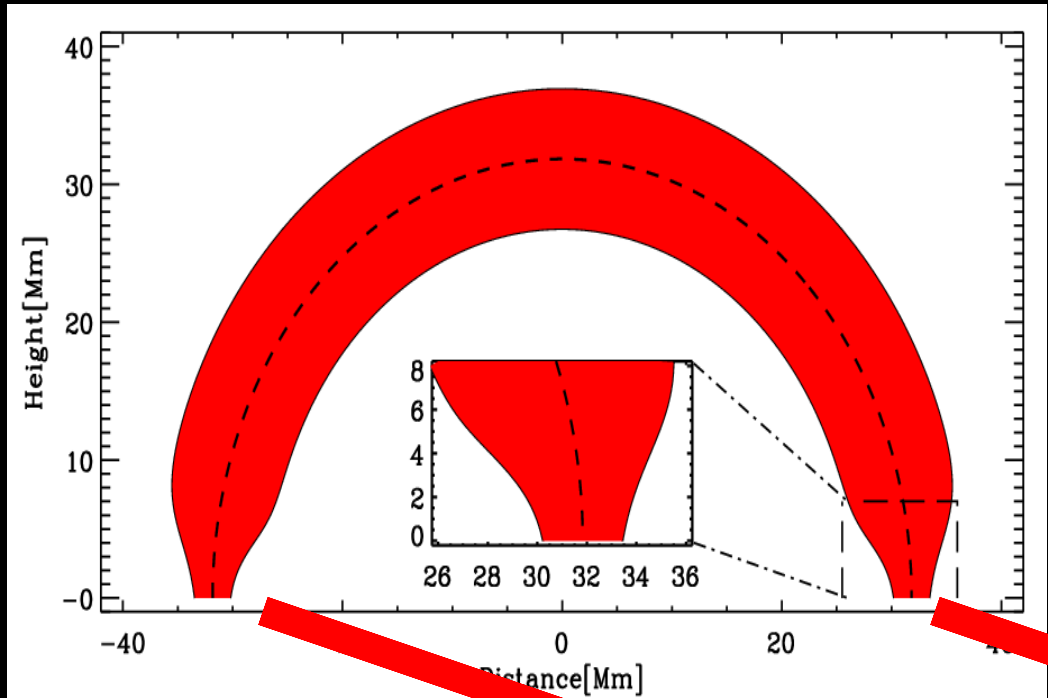
$$\frac{\partial T_p}{\partial t}+v\frac{\partial T_p}{\partial s}+\frac{2T_p}{3a}\frac{\partial(va)}{\partial s}=\frac{2}{3nka}\frac{\partial}{\partial s}\left(a\kappa_p\frac{\partial T_p}{\partial s}\right)+2\nu_{pe}(T_e-T_p)+\frac{2}{3nk}Q$$

$$Q=Q_{\mathrm{Kolmogorov}}$$
$$=\rho\xi^3/l_{\mathrm{correlation}}$$

$$p_w=\rho\xi^2/2$$

$$\frac{\partial p_w}{\partial t}+\frac{1}{a}\frac{\partial}{\partial s}\left[a\left(1.5v+v_A\right)p_w\right]-\frac{v}{2}\frac{\partial p_w}{\partial s}+\frac{Q}{2}=0$$

waves injected at one end

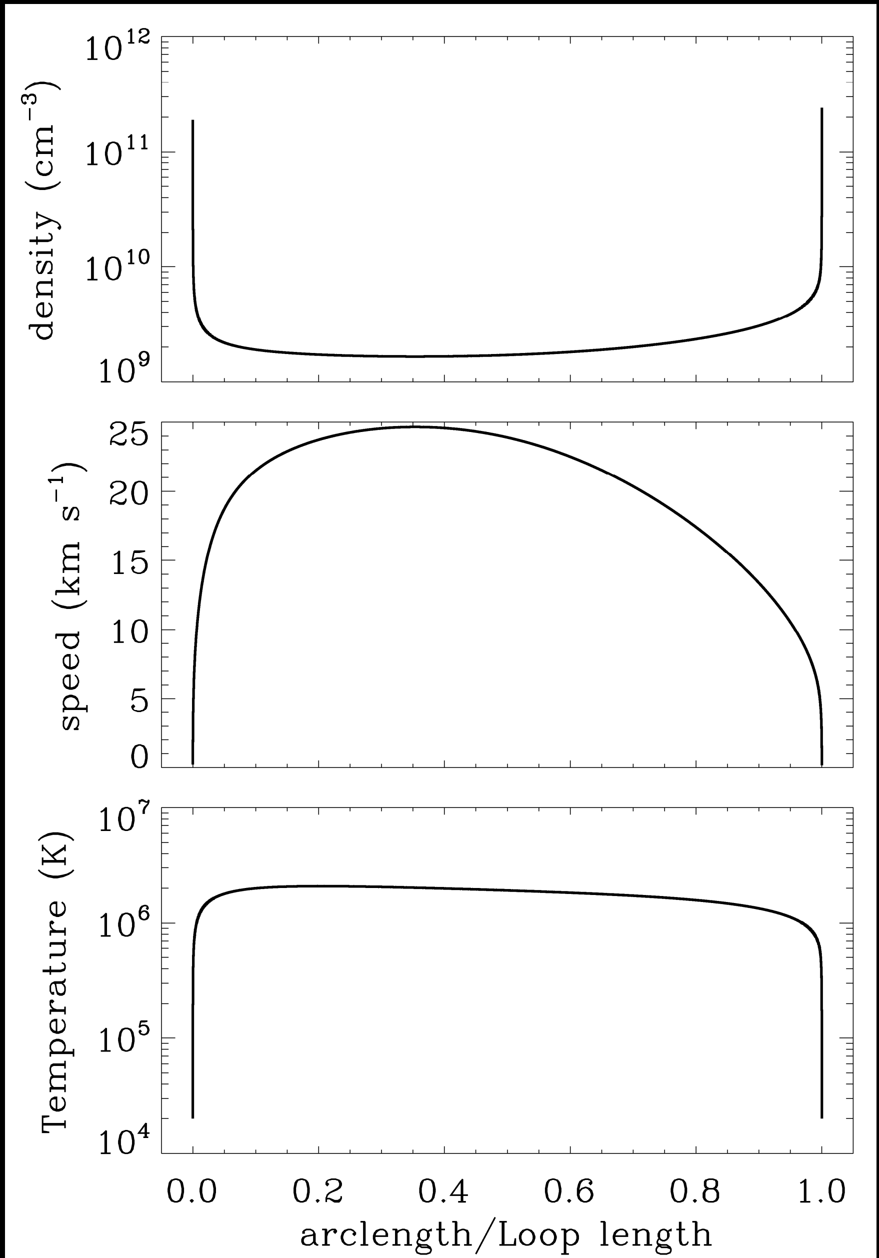


Temperature $= 2 \times 10^4$ K
free boundary for density, speed

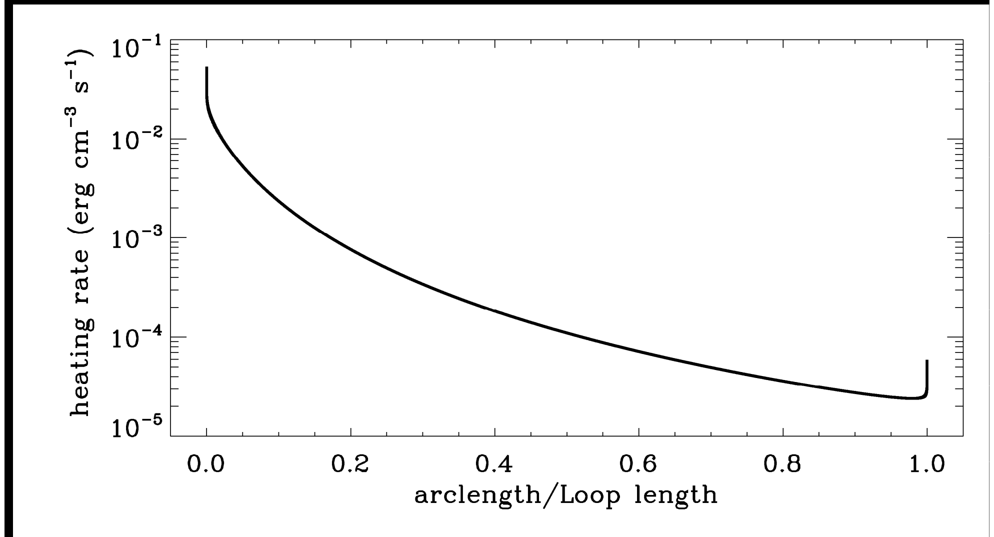
wave amplitude 10 km/s (Chae et al.98)

first developed by Li & Habbal 03; explored in O'Neill & Li 05; Li & Li 06; recently Xie & Li, manuscript

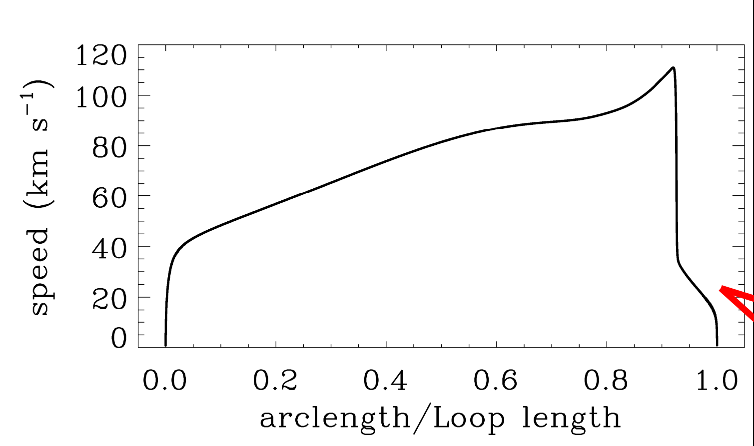
|| cascade: uniform loop



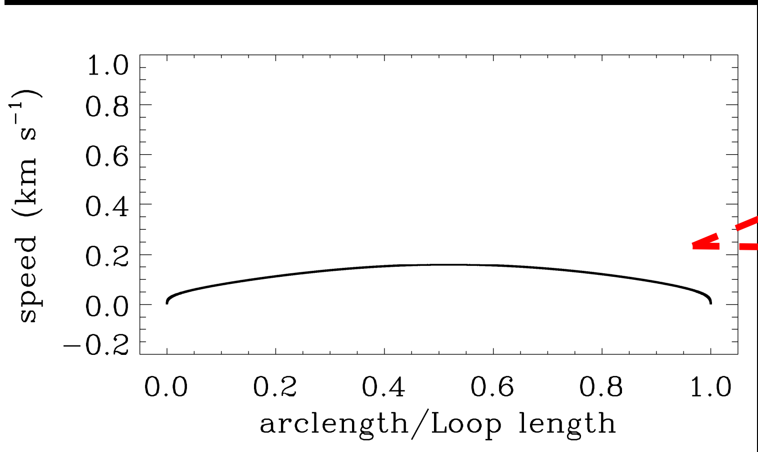
A substantial flow of observed magnitude (~30-40 km/s) results only with asymmetric heating (Li & Habbal 03, Patsourakos et al.04)



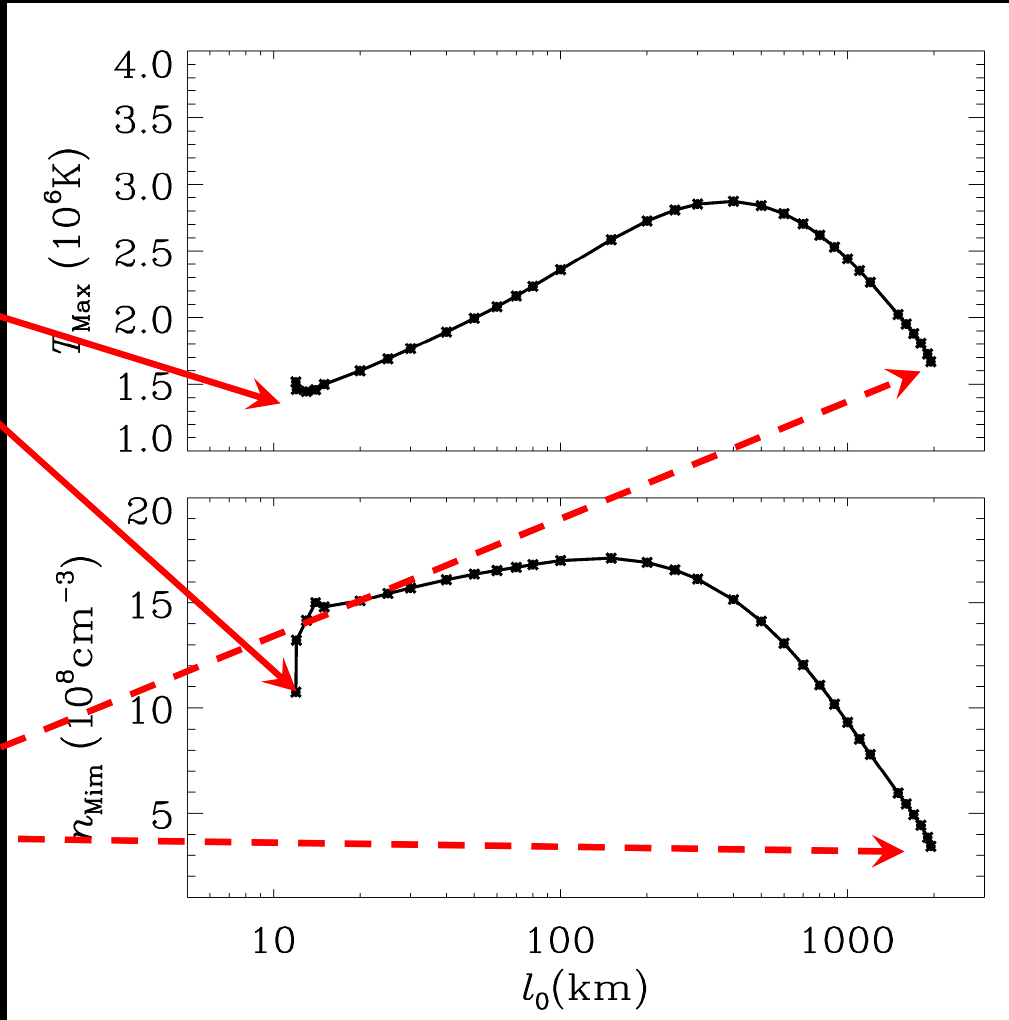
Dependence on base correlation length l_0



shocked loop

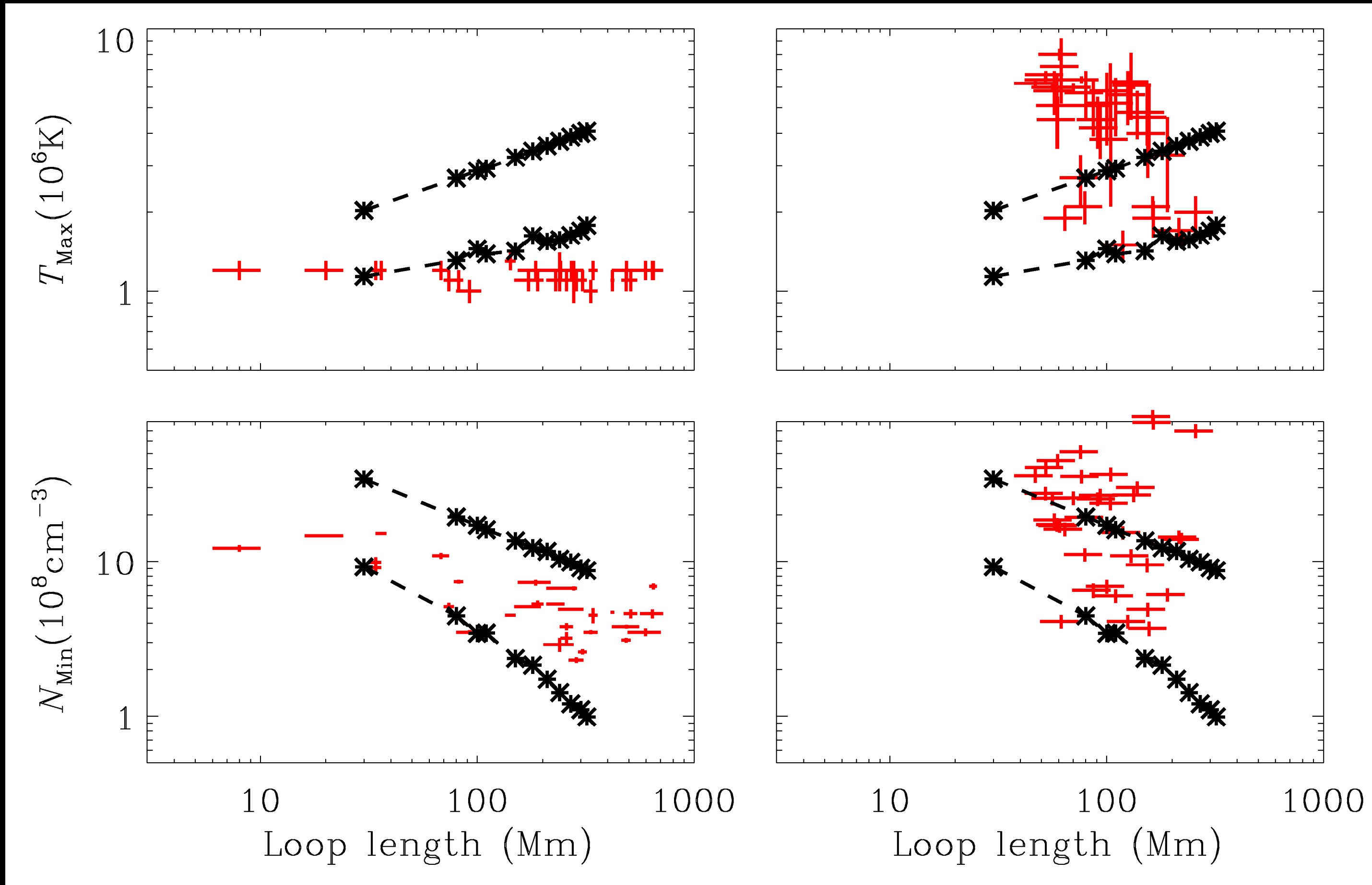


static loop



An observational test

TRACE | YOHKOH/SXT



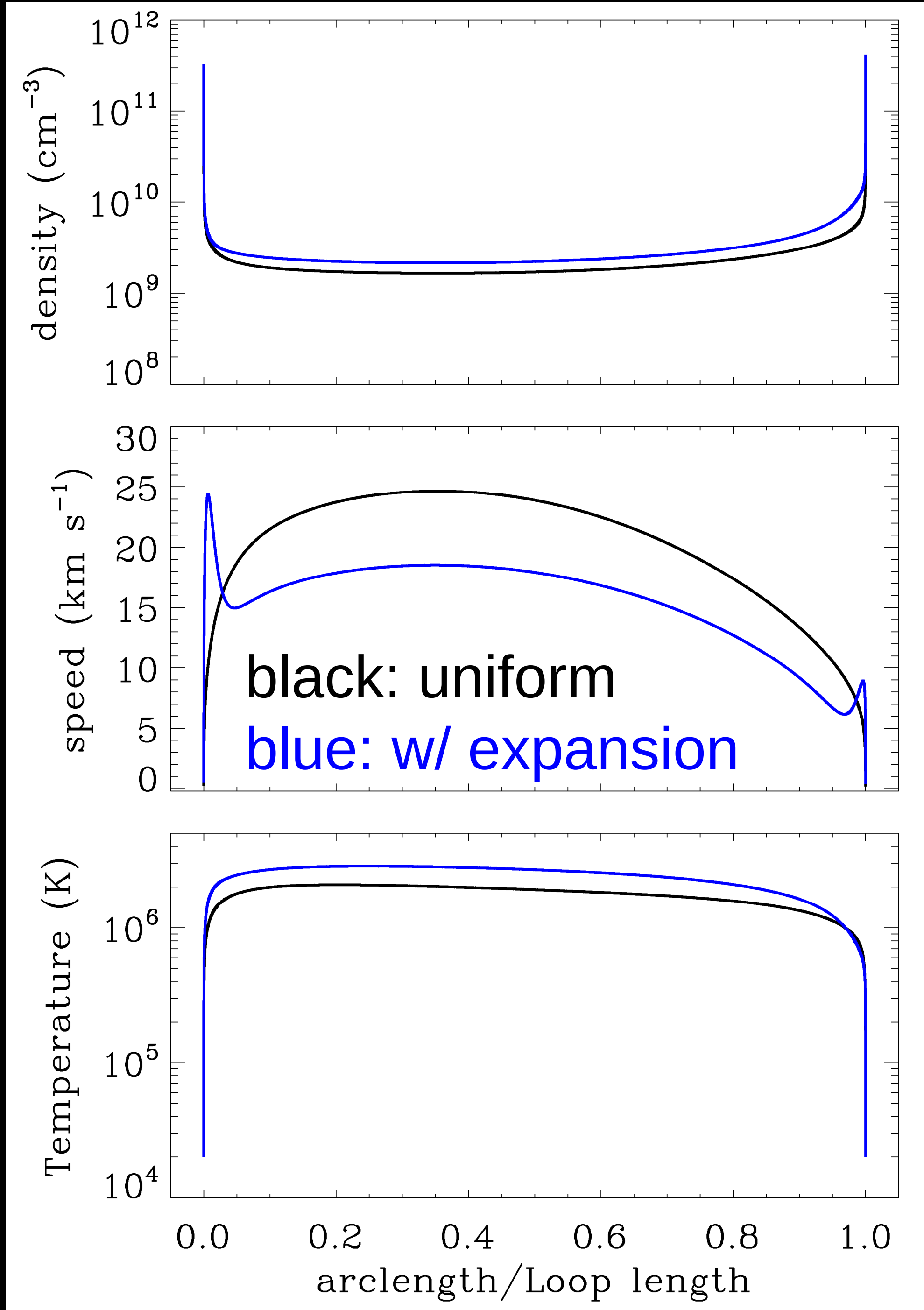
data compiled by Winebarger et al.03

Does loop expansion help?

$l_0 = 60 \text{ km } L = 10^5 \text{ km}$

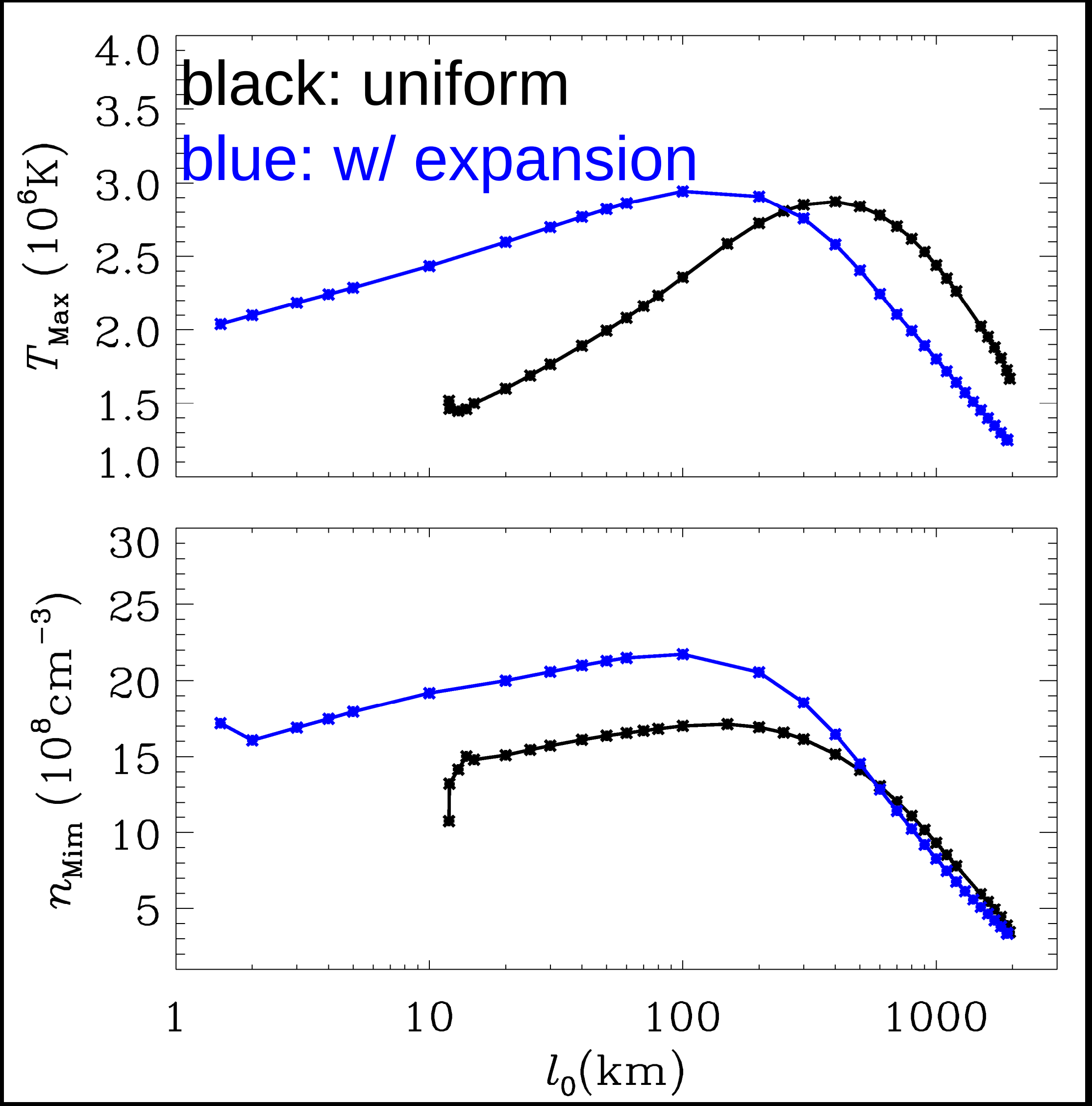
loop expansion constrained by TR measurements (Patsourakos et al.99)

- footpoint expansion amounts to momentum deposition, resulting in speed peaks

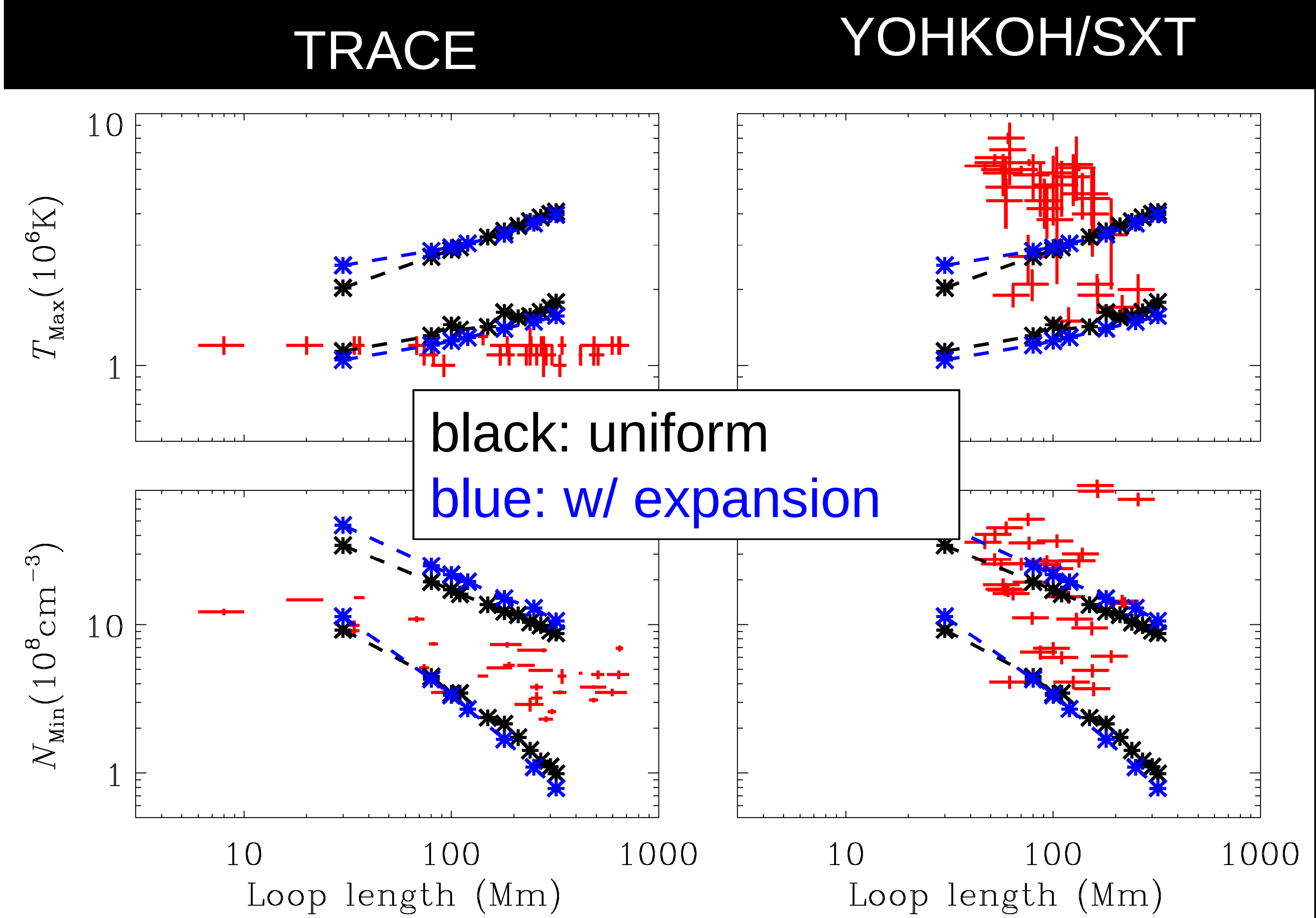


Dependence on base correlation length l_0

loop length 10^5 km

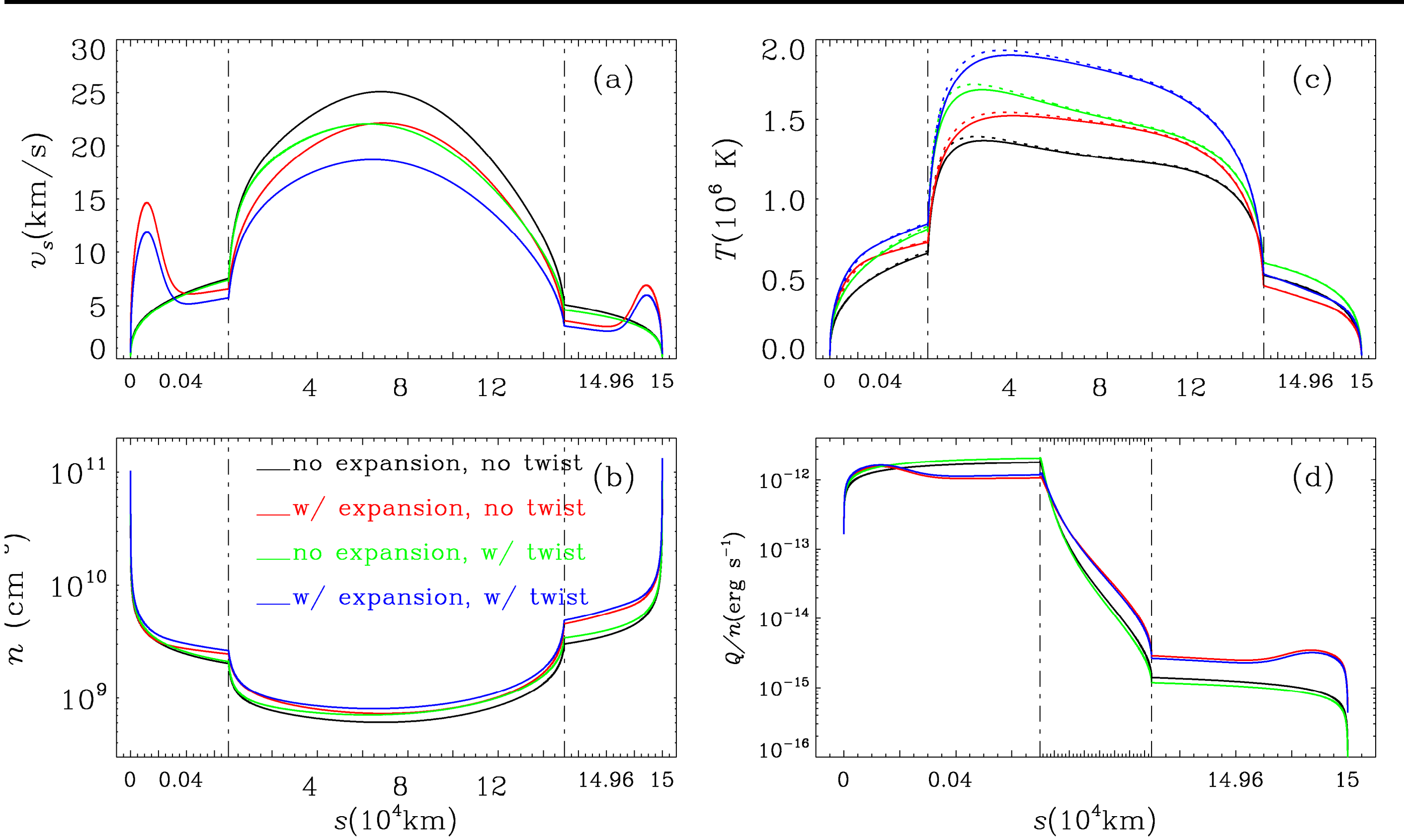


Observational test again



data compiled by Winebarger et al.03

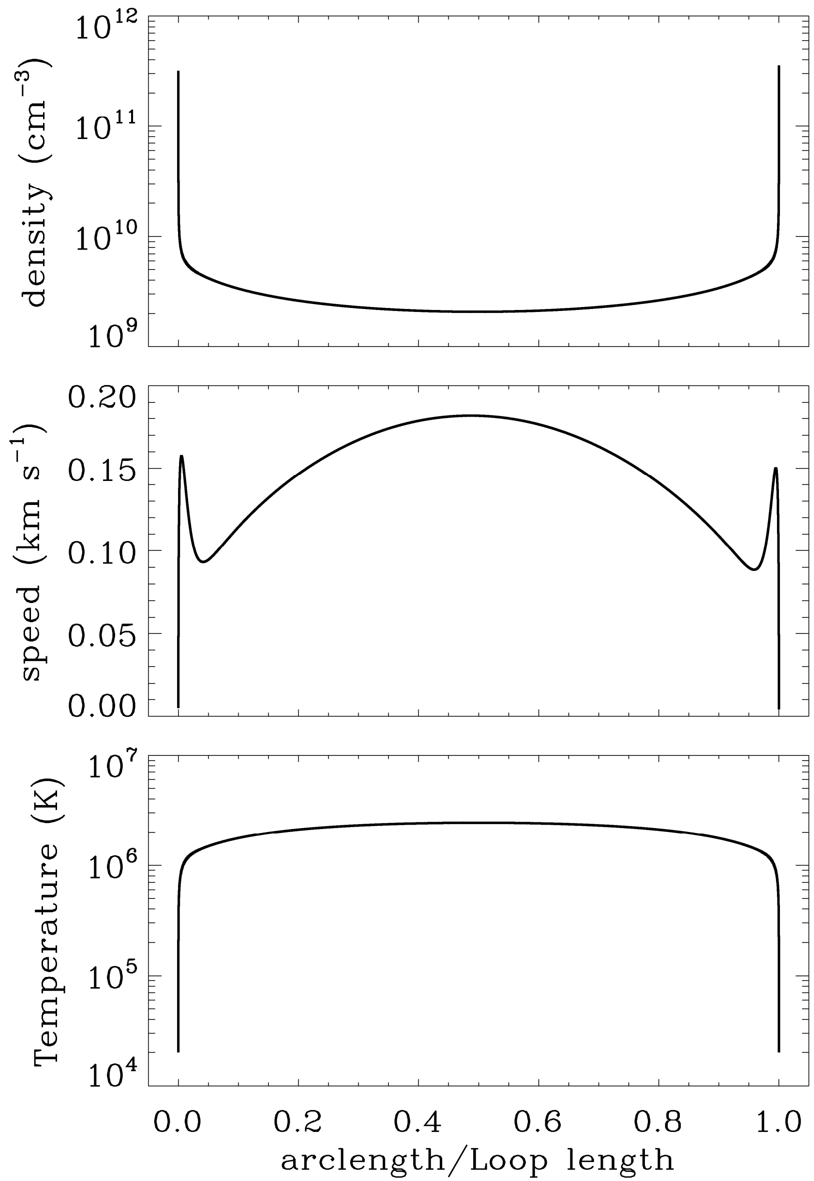
Does magnetic twist help?



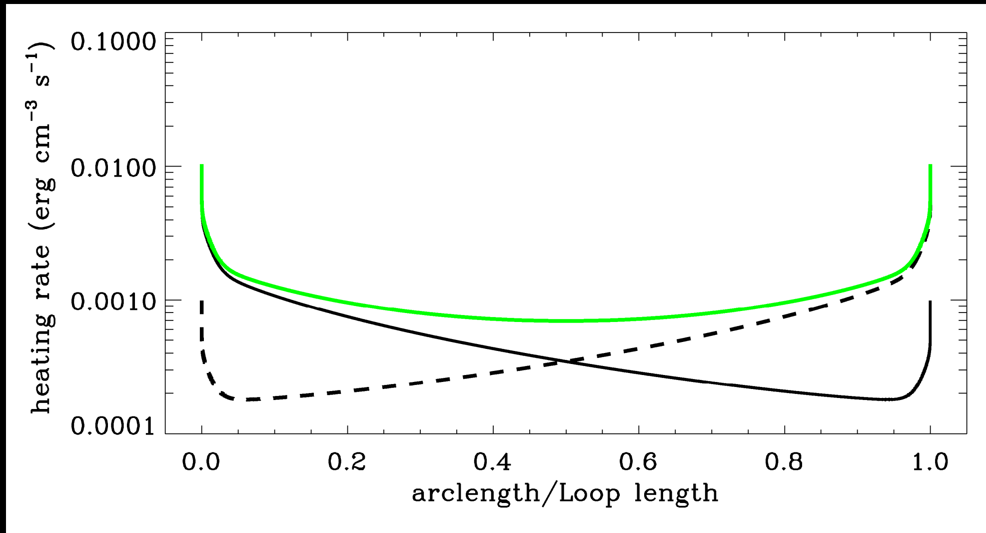
Li & Li 06

- kinetic energy flux; magneto+inertial centrifugal forces associated with azimuthal motion not important
- twist reduces axial thermal conductivity, leading to higher temperature!

Does "waves from both ends" help?

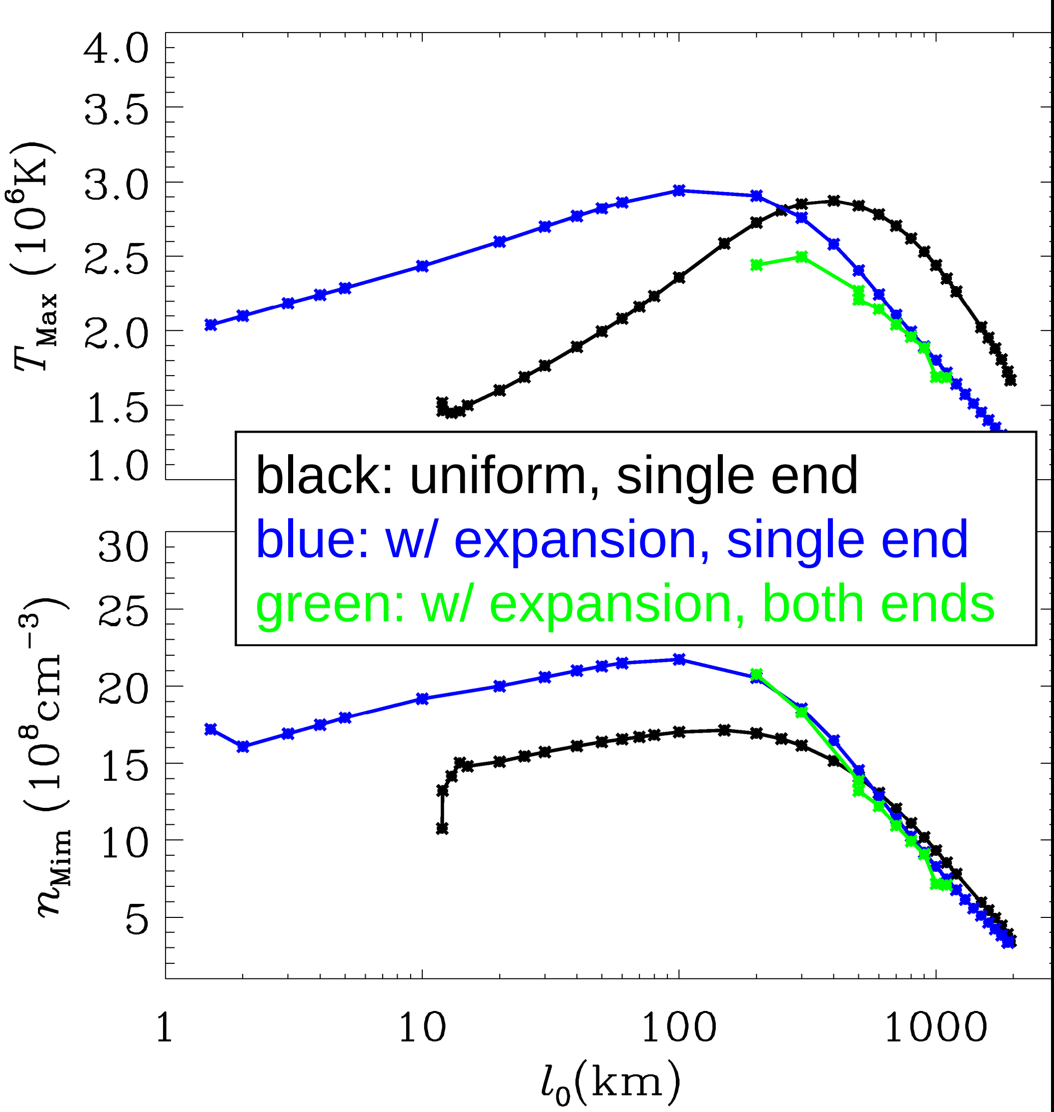


- two wave eqs. solved
- amplitudes at ends chosen such that total fluc. ampl. agree with obs.
- symmetric heating → static loops



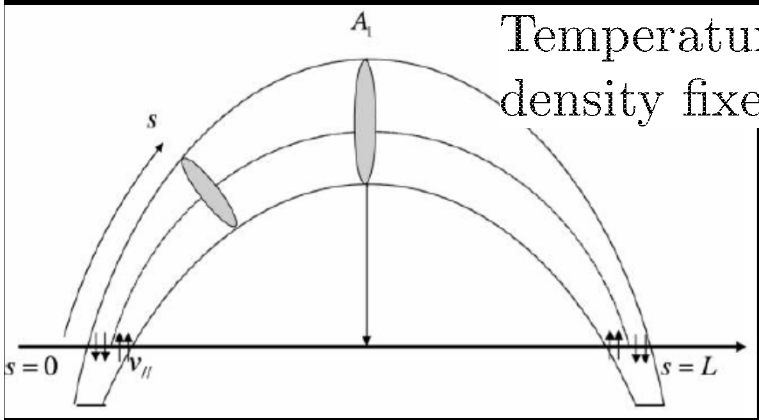
$$l_0 = 700 \text{ km } L = 10^5 \text{ km}$$

Dependence on base correlation length l_0

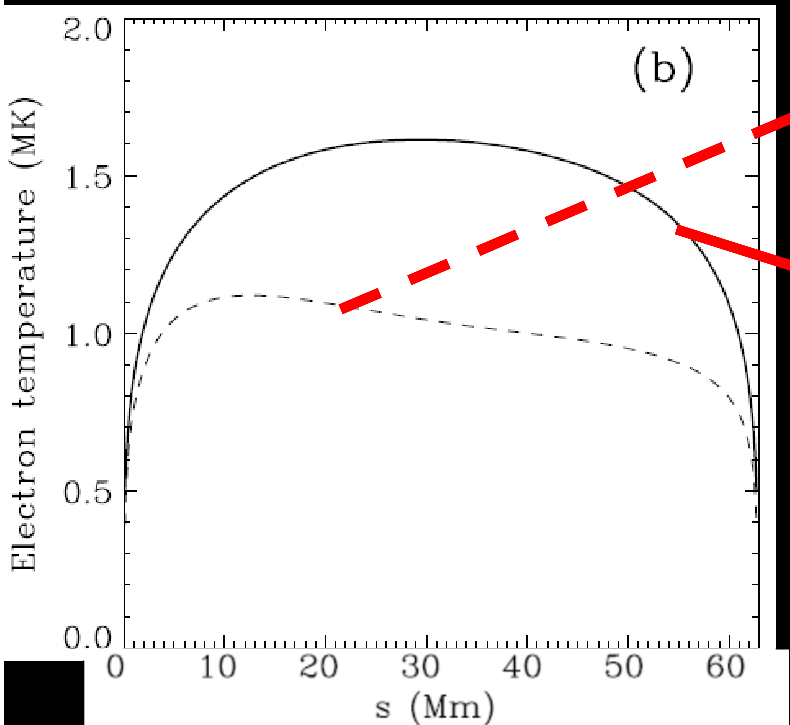


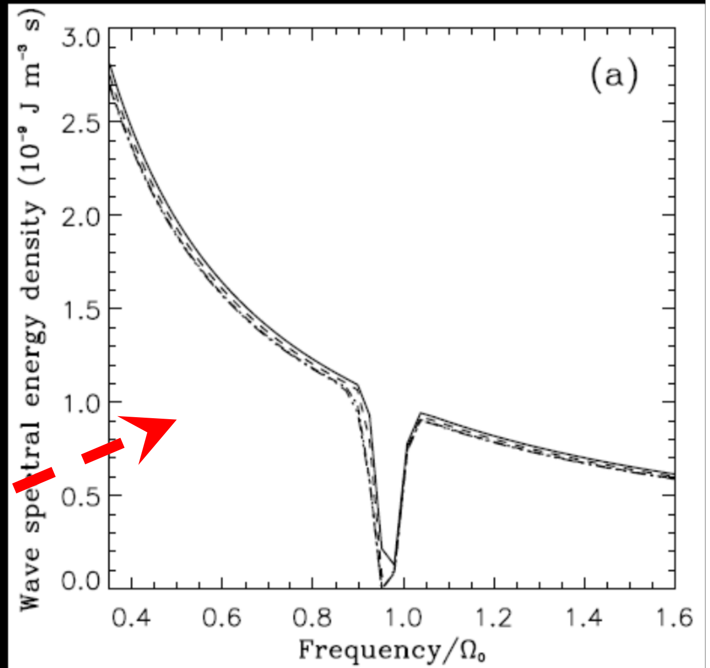
$L = 10^5$ km

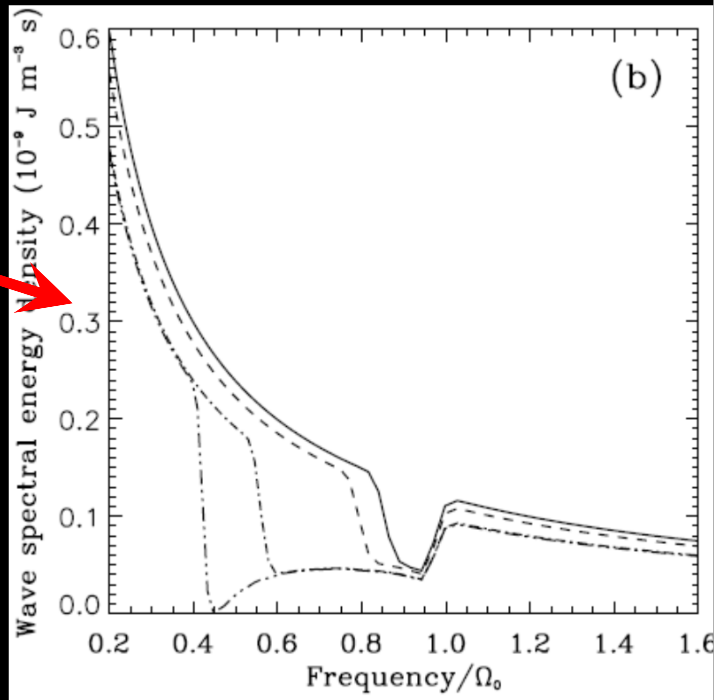
Spectrum sweeping



Temperature $= 2 \times 10^5$ K
density fixed 5×10^9 cm^{-3}

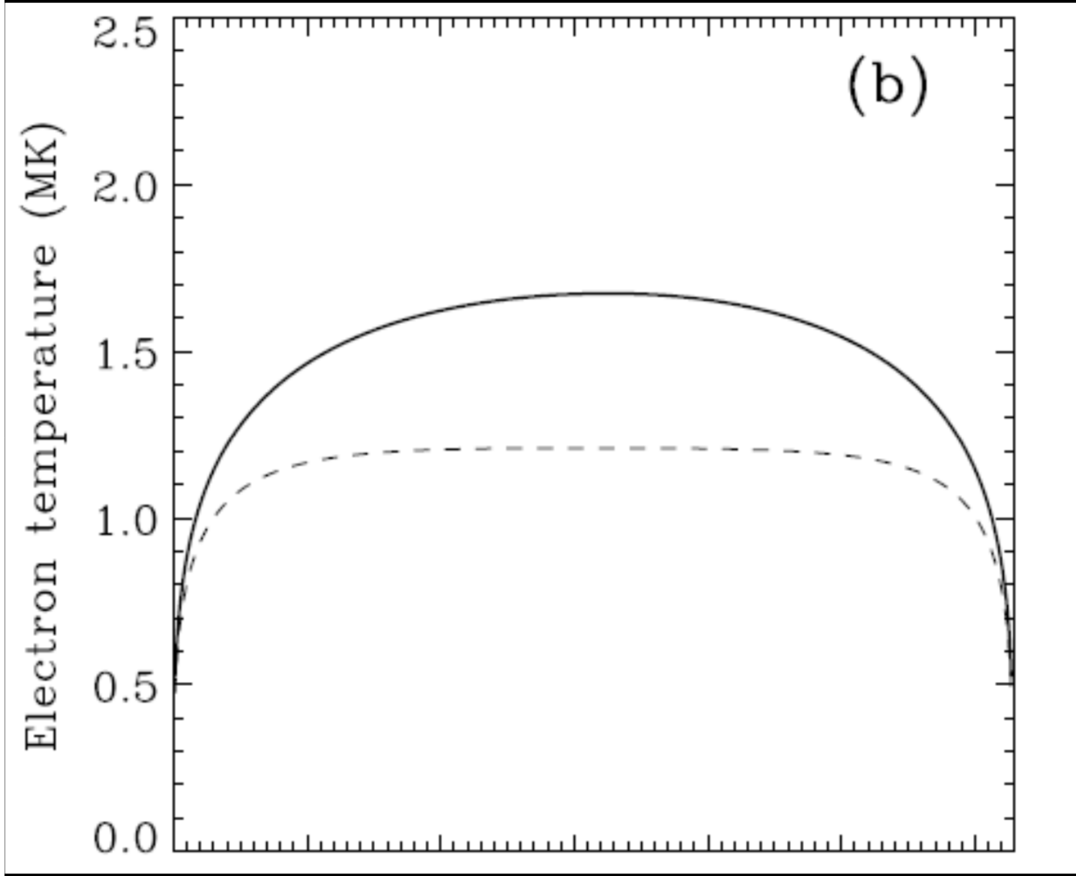






Bourouaine et al.08

Does “waves from both ends” help



solid: strong expansion

dashed: weak expansion

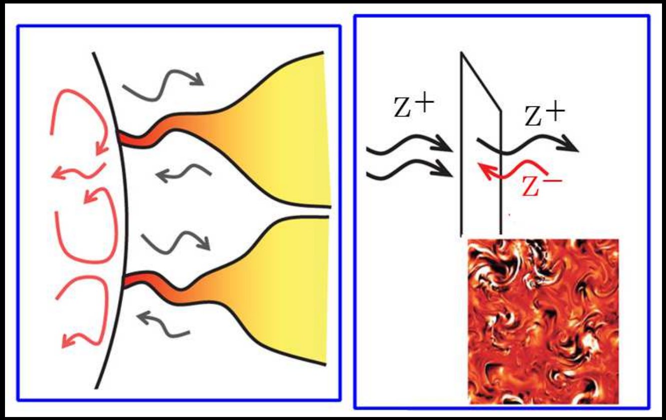
Summary of preliminary results

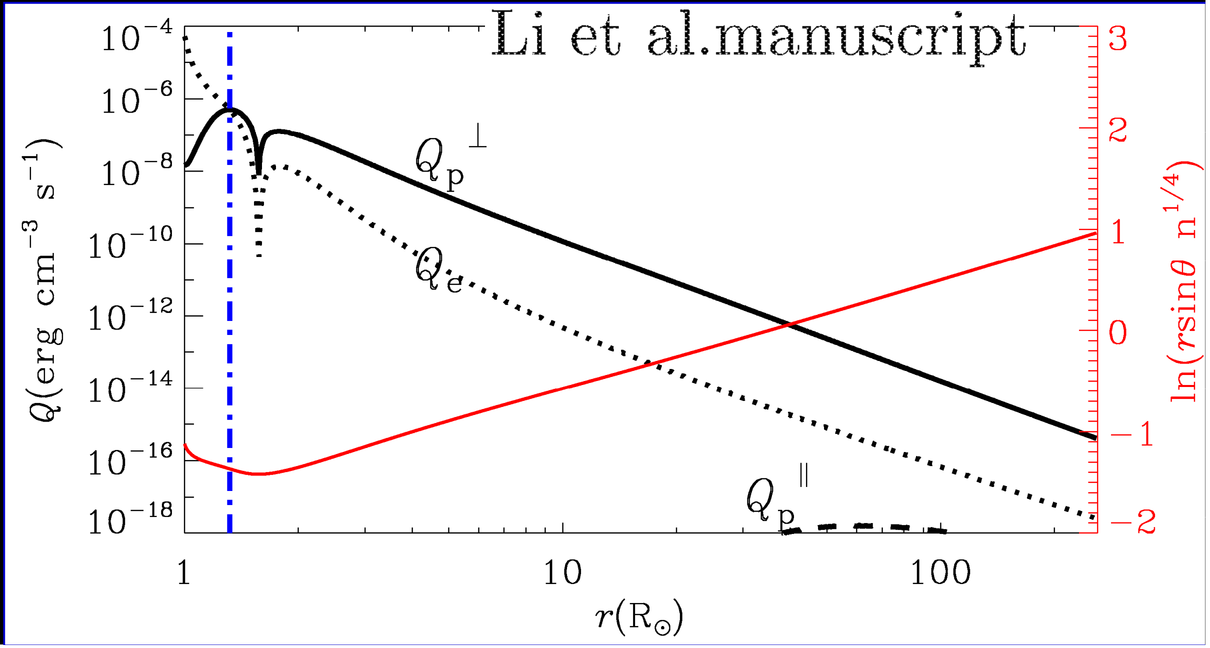
- A couple of solar wind heating mechanisms have been applied to heating coronal loops
- Observational test shows parallel cascade help explain some Yohkoh/SXT loops, but not TRACE EUV loops
  - Magnetic twist won't help
  - "Injection from both ends" won't help
- Spectrum sweeping may work
  - but TR heating should be more properly accounted for
  - but a detailed test needs to be done
- Anisotropic turbulence
  - seems worth pursuing but z- and z+ should be properly treated
  - has yet to be incorporated into a fluid model
  - has yet to be tested observationally

BACKUP SLIDES

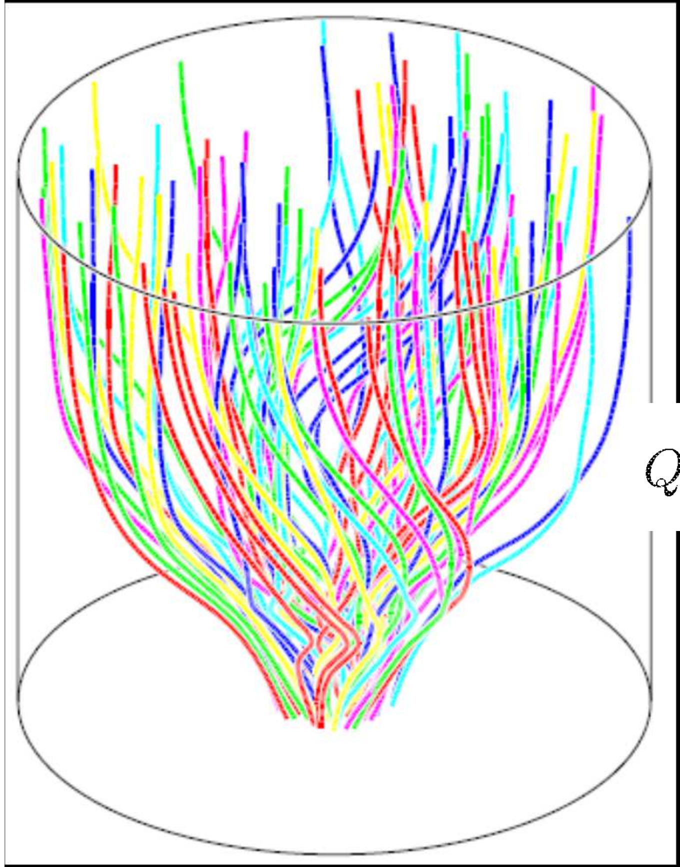
Anisotropic turbulence

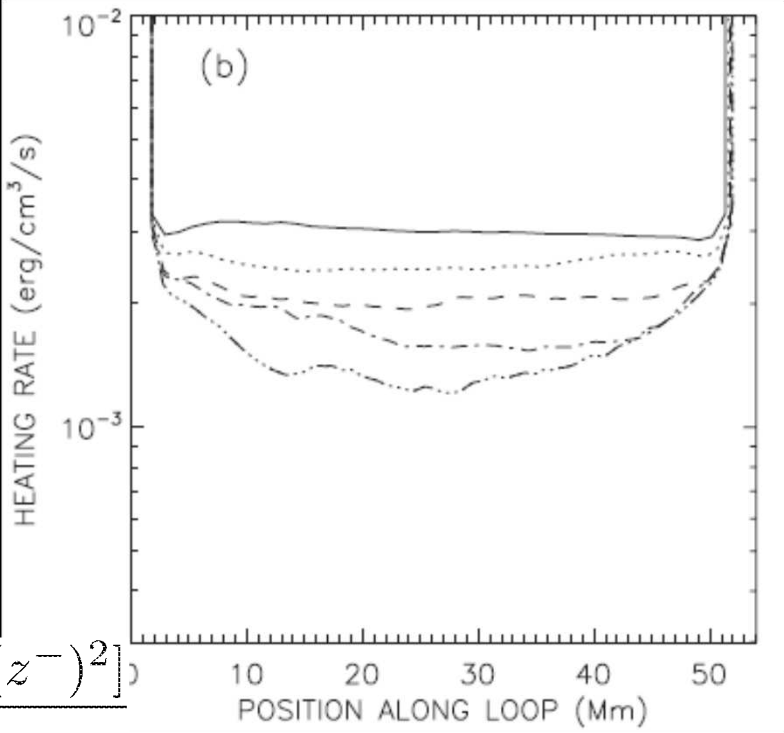
- $Q \propto \frac{\rho[z^-(z^+)^2+z^+(z^-)^2]}{L_\perp}$
- successful in reproducing fast (Chandran et al.11) and slow wind parameters (Li & Habbal 12)
- turbulence proceeds in the way characterized by critical balance
- dissipated turbulence energy goes to e & p heating



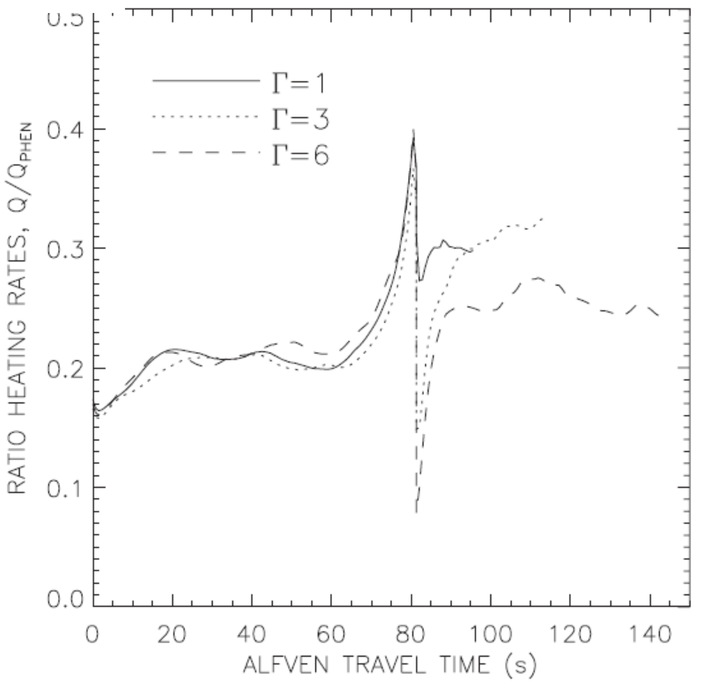


Anisotropic turbulence





$$Q \propto \frac{\rho[z^-(z^+)^2 + z^+(z^-)^2]}{L_\perp}$$



van Ballegooijen et al.11