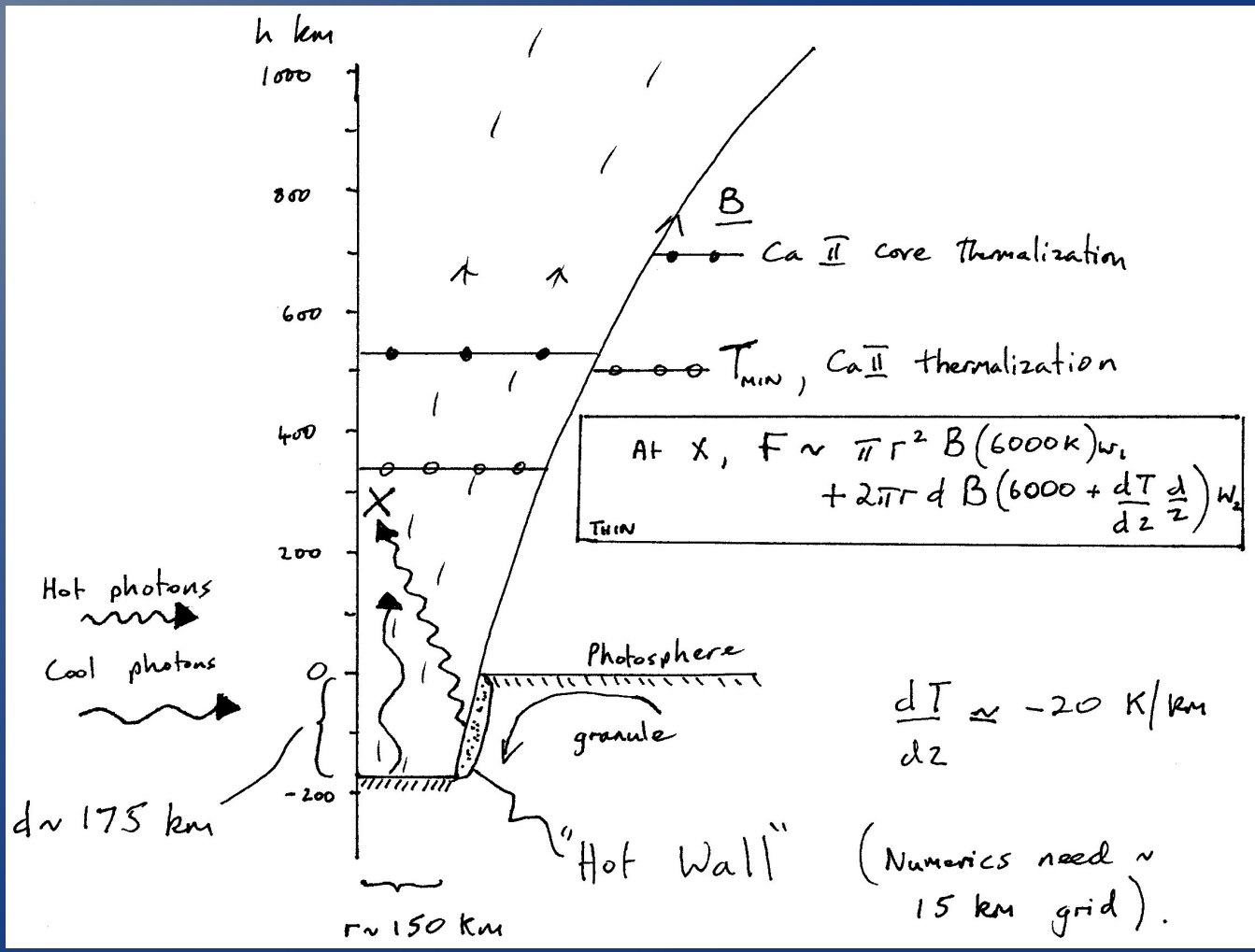
What are the mechanical energy needs of the chromosphere?

Philip Judge
HAO, NCAR

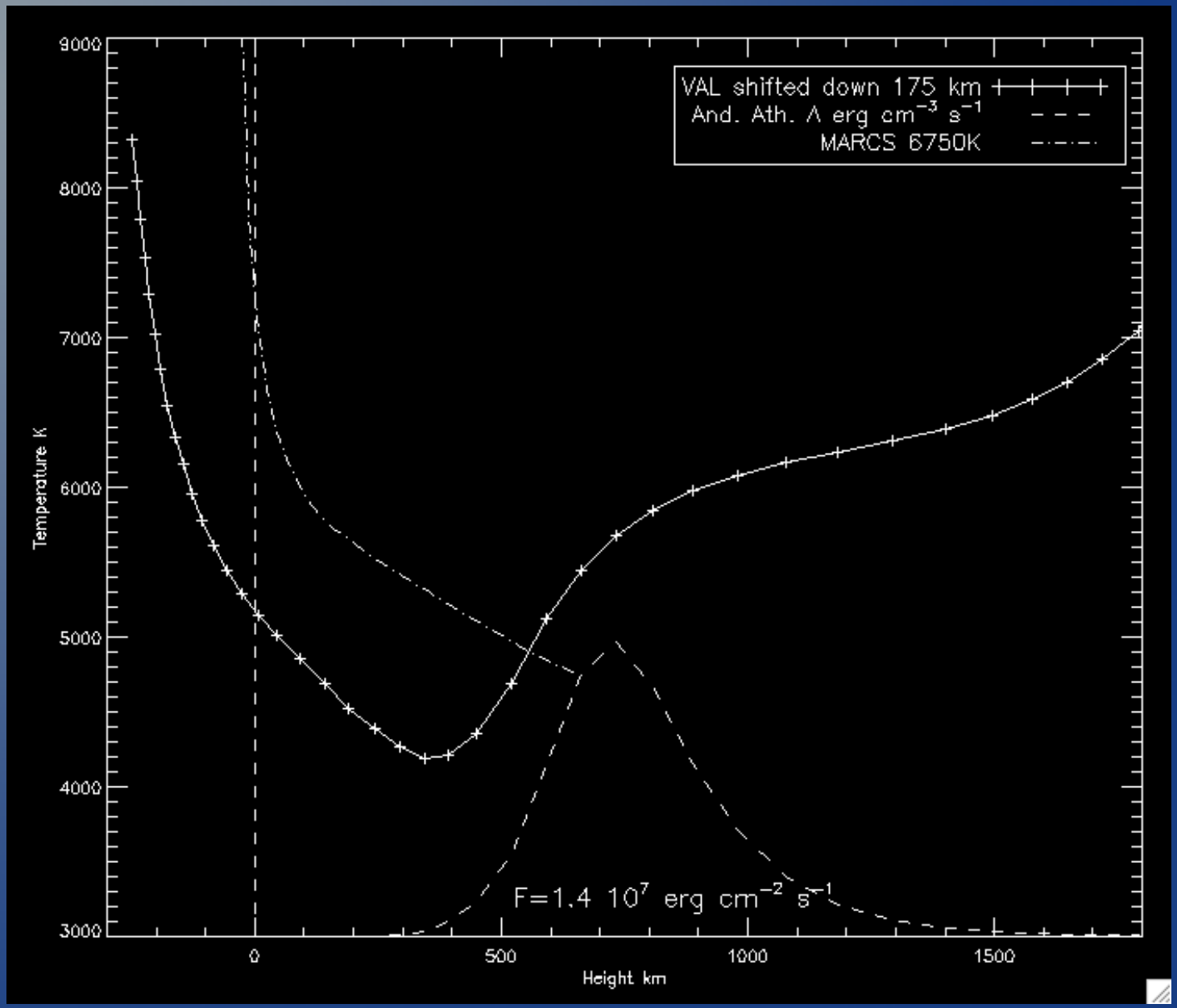
January 2010

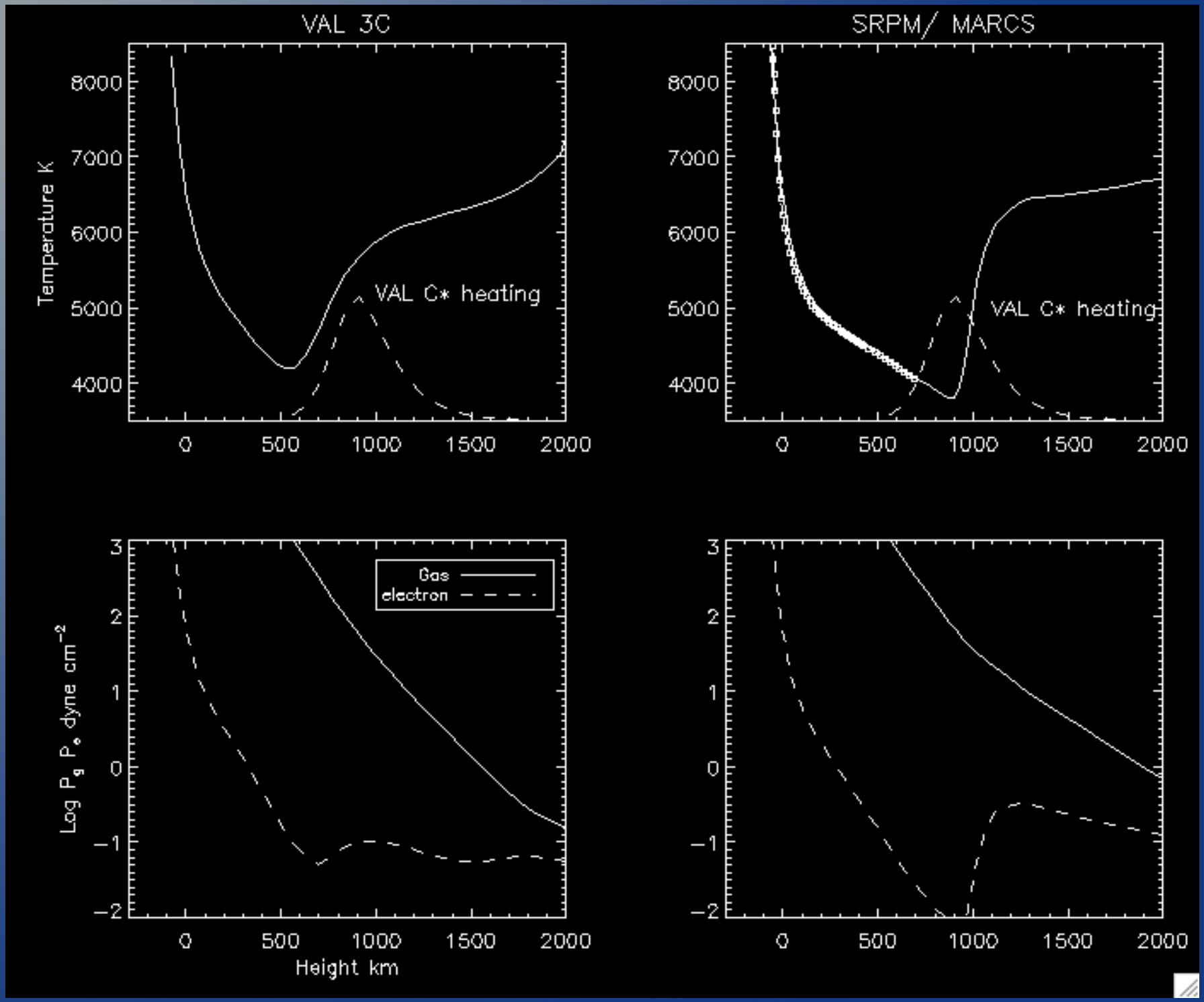


How chromospheric heating requirements are estimated

Models must be used, because chrom radn ~ 10^{-5} photosphere @ similar wavelengths

- *VAL, Anderson & Athay:*
  - *semi-empirical 1D models based on*
  - *Crude (5x5" or worse) observations*
  - *NLTE + Hydrostatic eqm, yields*
- *F ~ 1.4 10^{7} erg/cm /s (model C*),*
  - *From lowest few scale heights*
  - *30-100x corona*


VAL shifted down 175 km
And. Ath. Λ erg cm^{-3} s^{-1}
MARCS 6750K
F=1.4 10^{7} erg cm^{-2} s^{-1}
Temperature K
Height km
9000
8000
7000
6000
5000
4000
3000
0
500
1000
1500


VAL 3C
SRPM/ MARCS
Temperature K
8000
7000
6000
5000
4000
VAL C* heating
0
500
1000
1500
2000
Gas
electron
Log P_g P_e dyne cm^{-2}
3
2
1
0
−1
−2
Height km

Network model problems

Non-unique *T(m)* (VAL3C vs SRPM...)

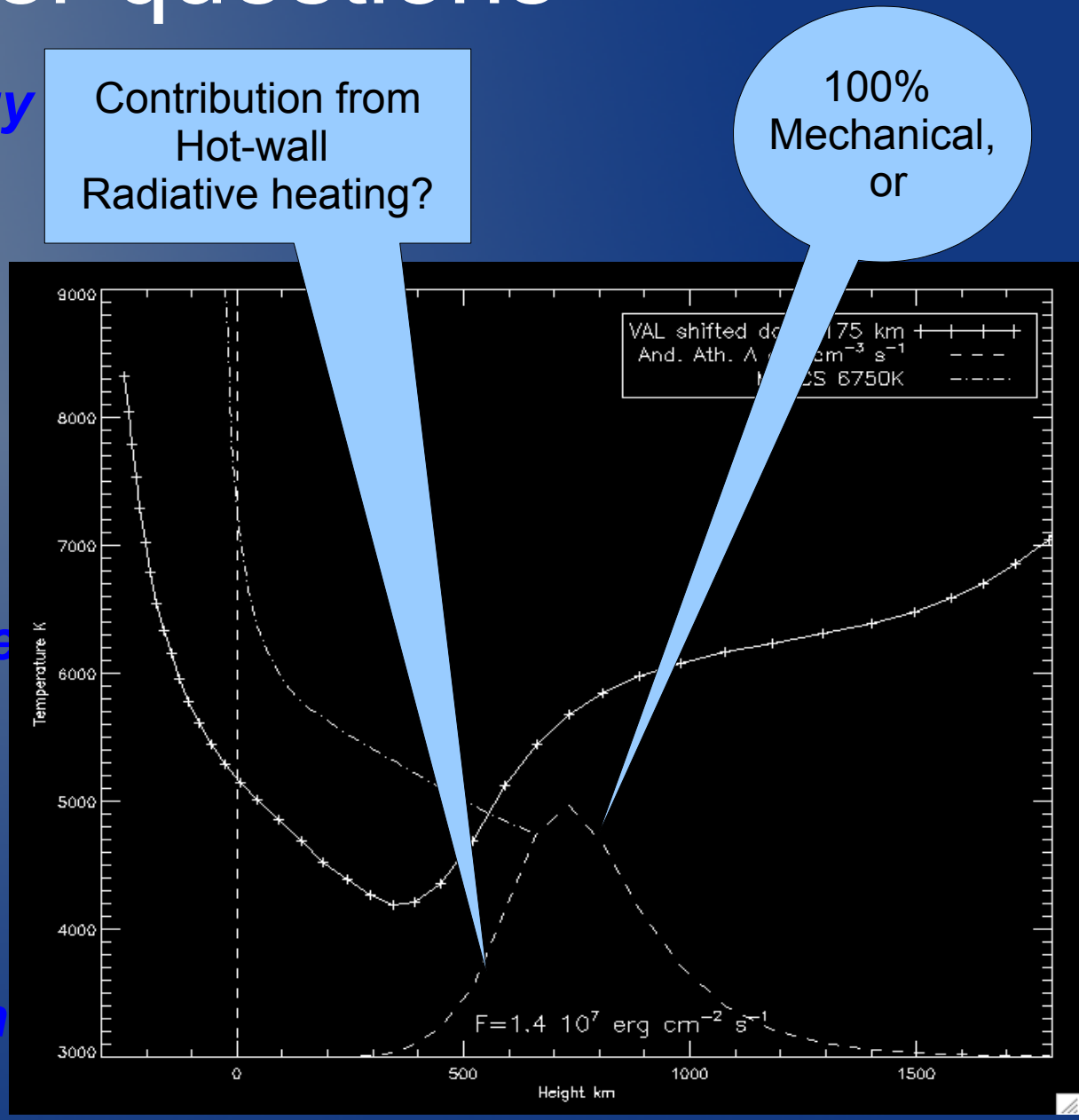
- ***1D models have***
  - *(nearly) identical photospheres to internetwork*
  - *no ”hot walls” so*
  - *no hot radiation at the base*
- *Lower radiative boundary condition is incorrect*

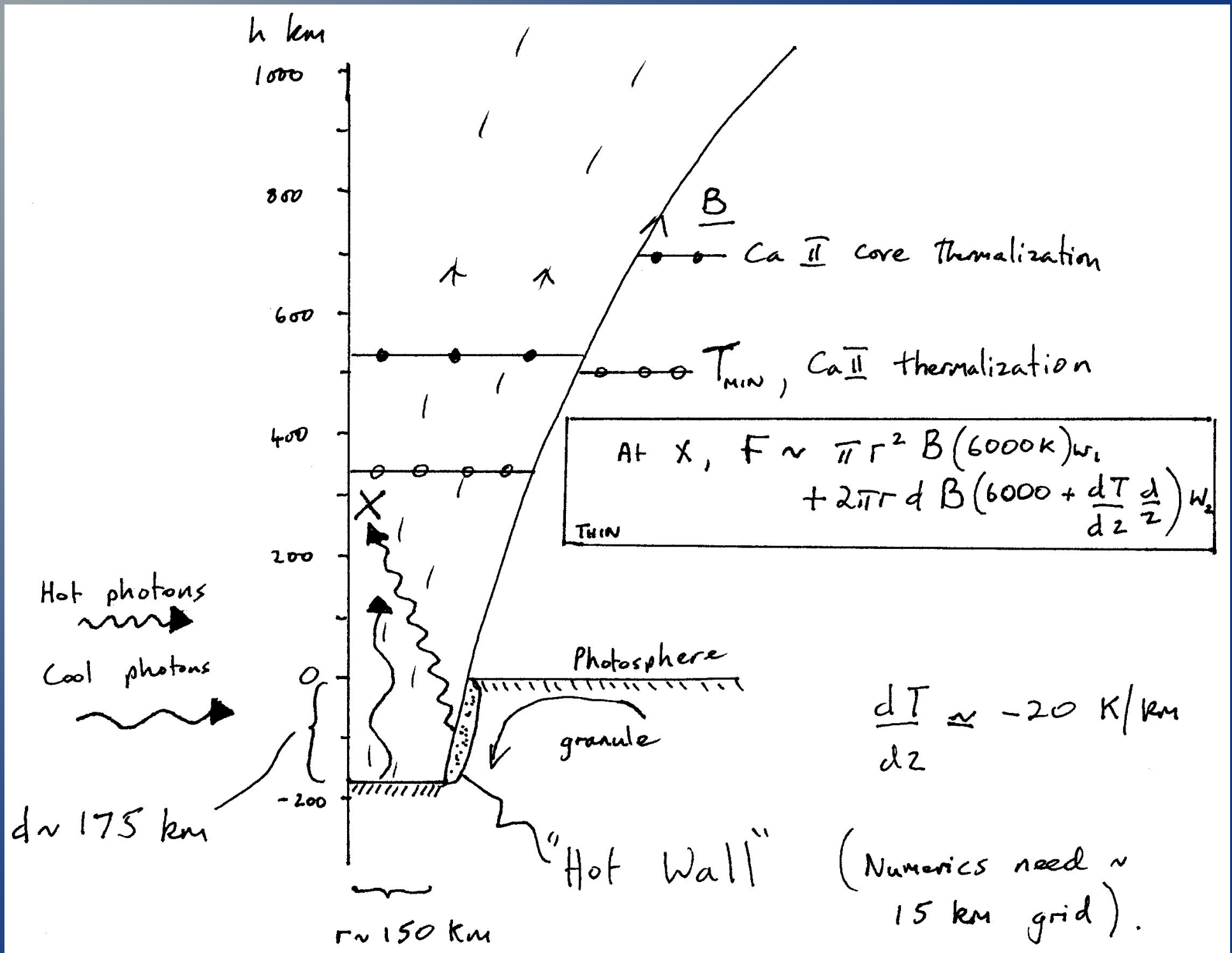
Flying Dutchmen...

- *Uitenbroek- chromospheric lines re-radiate some hot wall photospheric radiation*
  - *Is the lower network chromosphere simply this?*
  - What about thermal sub-mm continuum data?
  - Can hot wall radiation make a chromosphere-like temperature increase without mechanical heating?
- *Rutten (2009) most network emissivity in Na I, Ca II 8542, Ca II H ... stems from photospheric ... view-pipe photon escape ... not much [mechanical] heating is seen in these images*
  - Do Ca II 8542 and H/K cores form too high?

Further questions

- ***Has the mechanical energy needed for the chromosphere been overestimated?***
- ***If so***
  - ***By how much?***
  - ***Is the upper chromosphere the only place where heating is common?***
- ***cf. Rutten, Uitenbroek***
  - ***Spectrum formation***

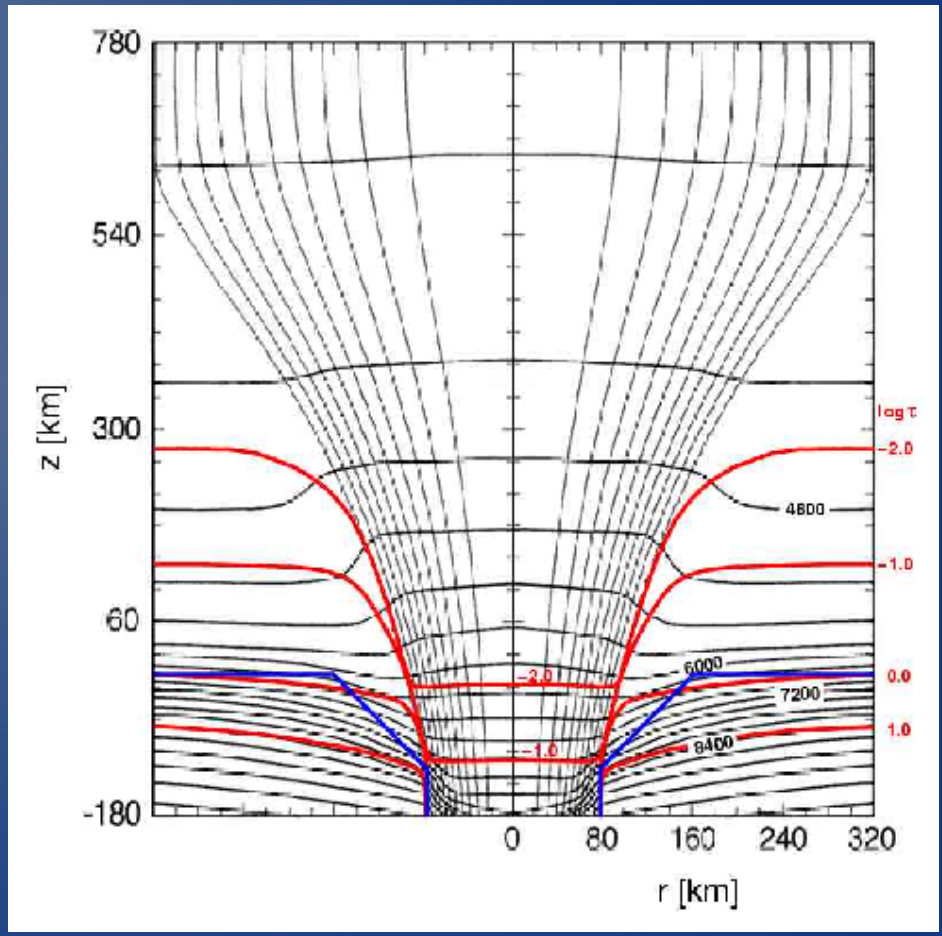



h km
1000
800
600
400
200
0
-200
B
Ca II core Thermalization
T_{MIN}, Ca II thermalization
X
At X, $F \sim \pi r^2 B(6000K) W_1 + 2\pi r d B\left(6000 + \frac{dT}{dz}\frac{d}{2}\right) W_2$
THIN
Hot photons
Cool photons
Photosphere
granule
$d \sim 175$ km
"Hot Wall"
$r \sim 150$ km
$\frac{dT}{dz} \simeq -20$ K/km
(Numerics need ~ 15 km grid).

Radiative equilibrium 2D/3D

- Spruit 1976 LTE+diffn. approx
- Steiner 1990 LTE+scattering
  - Lines+continuum
  - ODFs with assumptions
- Skartlien 2000 Multigroup
  - LTE opacity
  - S=thermal+coherent scattering
  - lines+continuum
- Others (CO5BOLD,..) grey
- *Not clear what detailed treatments will give, but coherent scattering restricts photon transfer*

- Steiner 1990



Observational tests (sub-arcsecond)

If radiative heating/scattering, then

- photosphere/low chromosphere brightnesses must be correlated
- Spatio-temporal variations must be in phase
- Presence of thermal emission (mm) from low chromosphere implies heating
- Low chromosphere must be diffuse relative to the photosphere

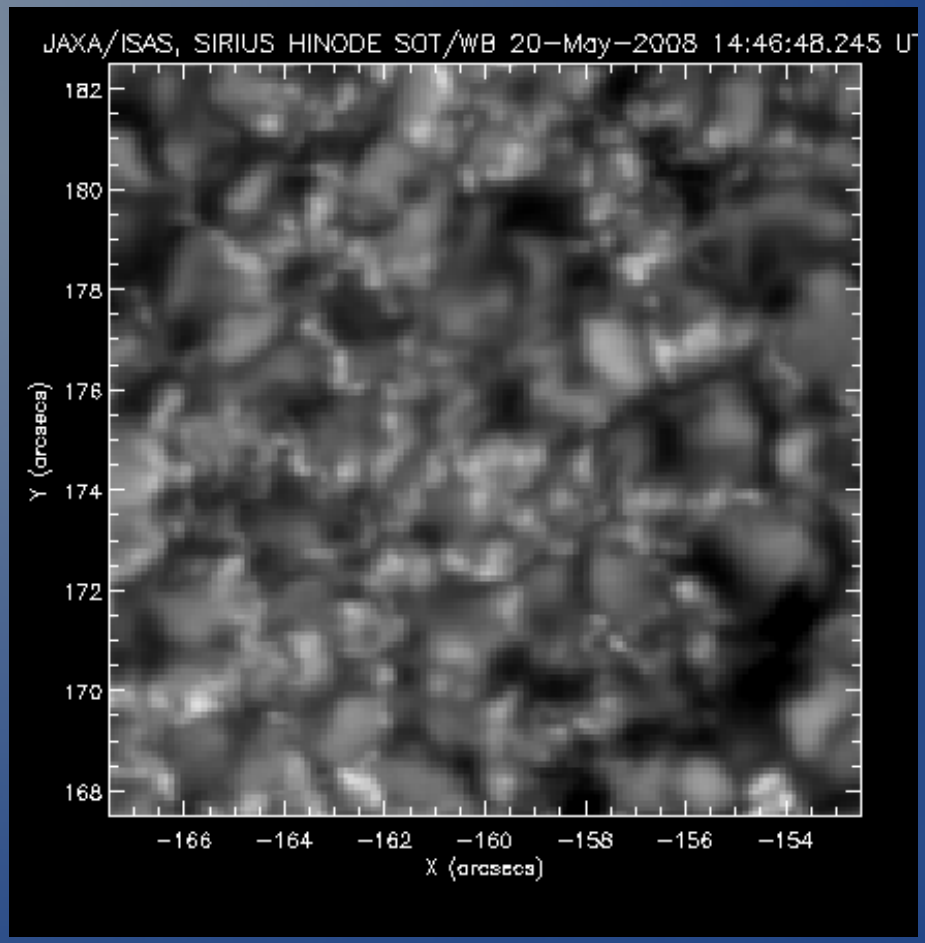
Hinode/IBIS Judge et al, in prep.)

Hinode

Magnetogram
G-band

IBIS

Ca II 8542
chromosphere
wing-core



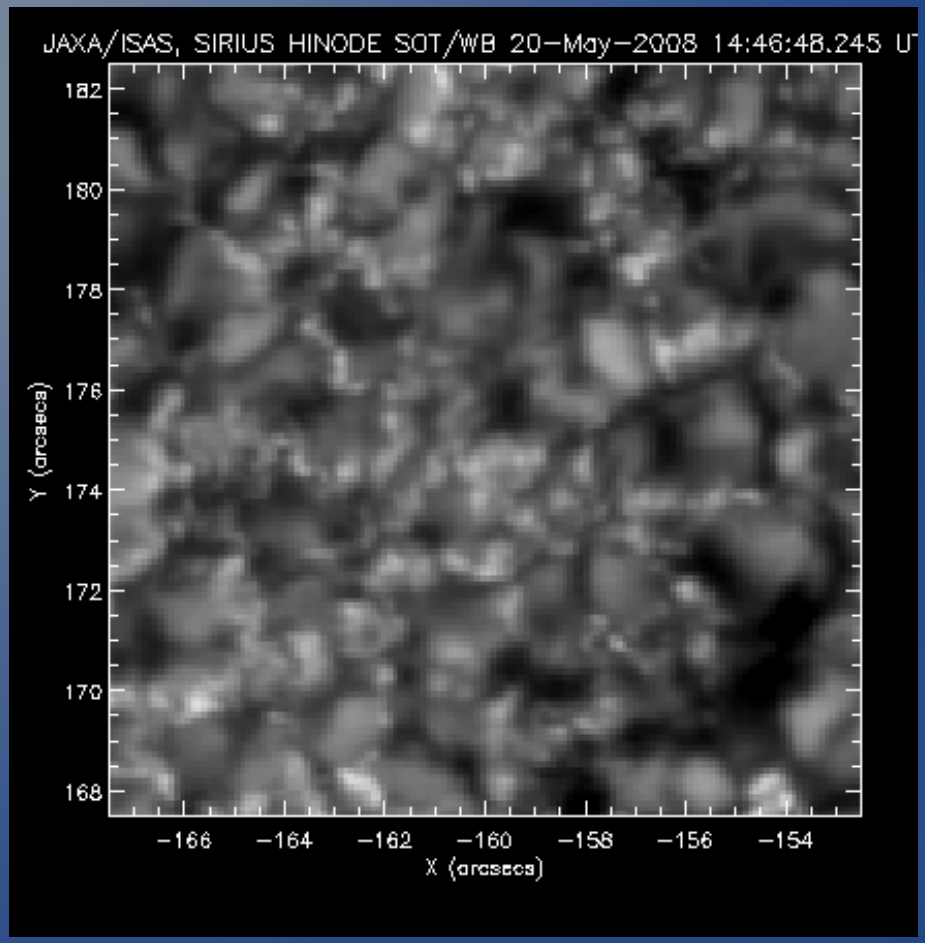
Hinode/IBIS Judge et al, in prep.)

Hinode

Magnetogram
G-band

IBIS

Ca II 8542
chromosphere
wing-core



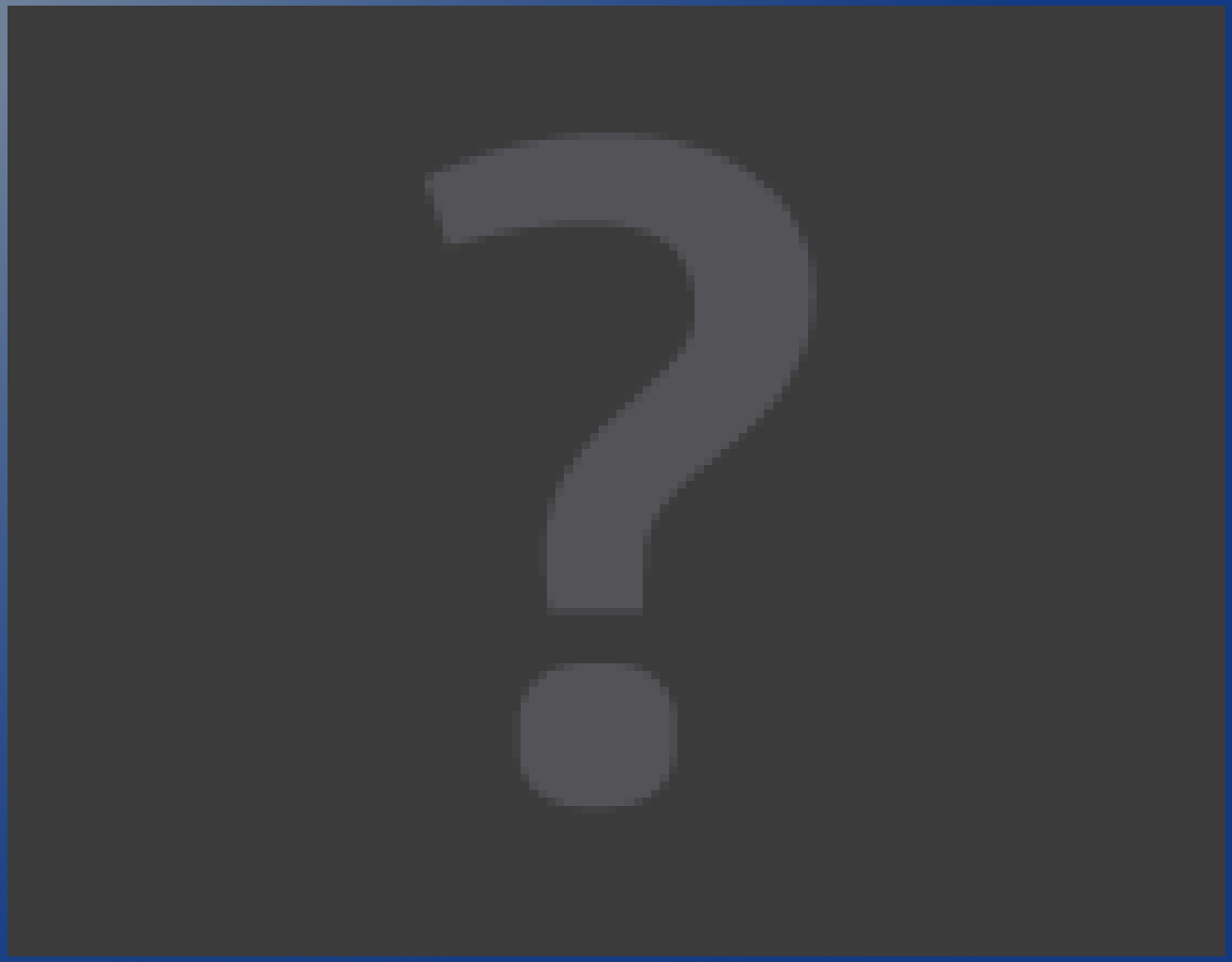
Ca II 8542

Core is clearly uncorrelated with photospheric hot walls

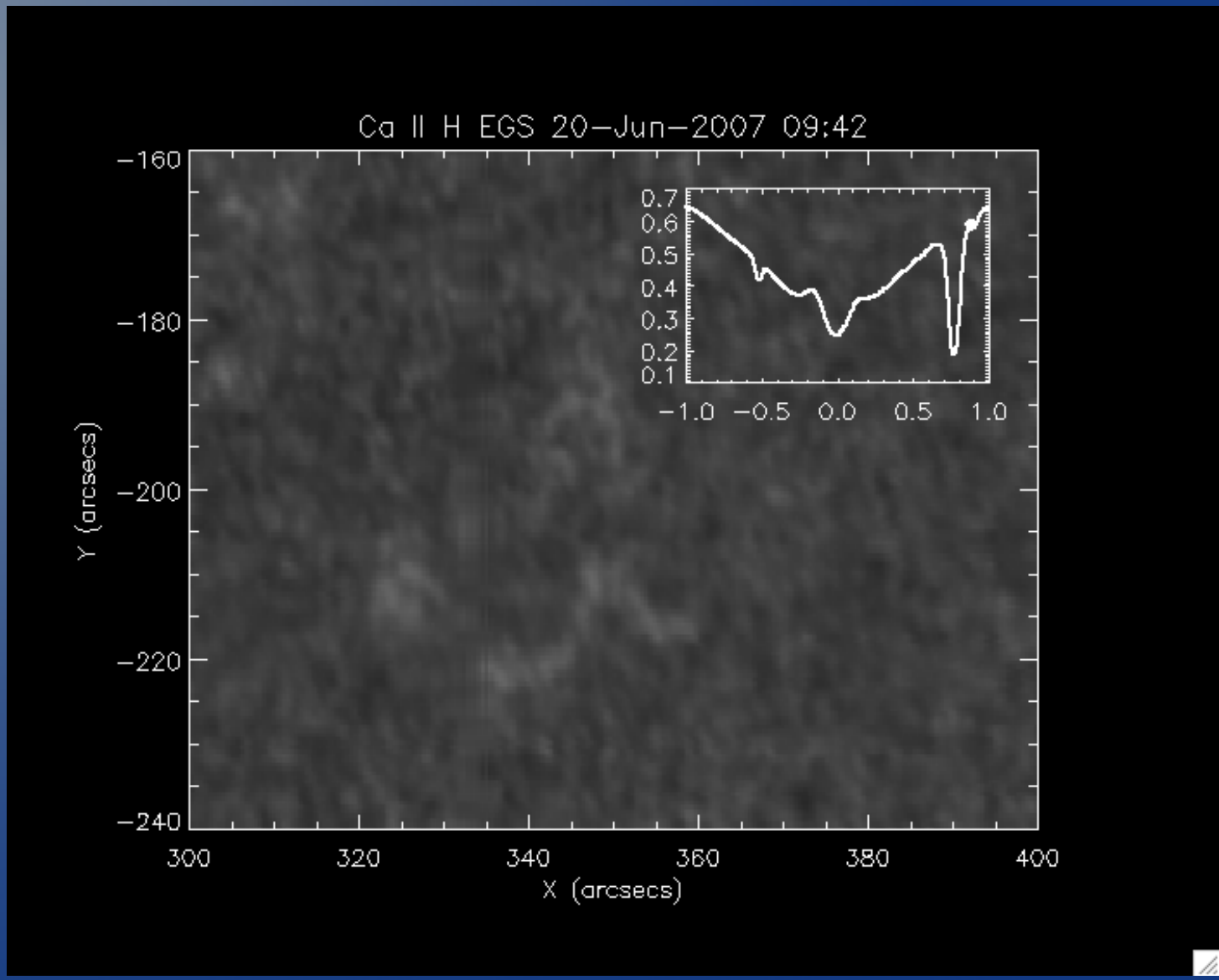
=> non-radiative heating dominates in the upper chromosphere

Schmidt (Judge et al, in prep.)

Ca II H chromosphere

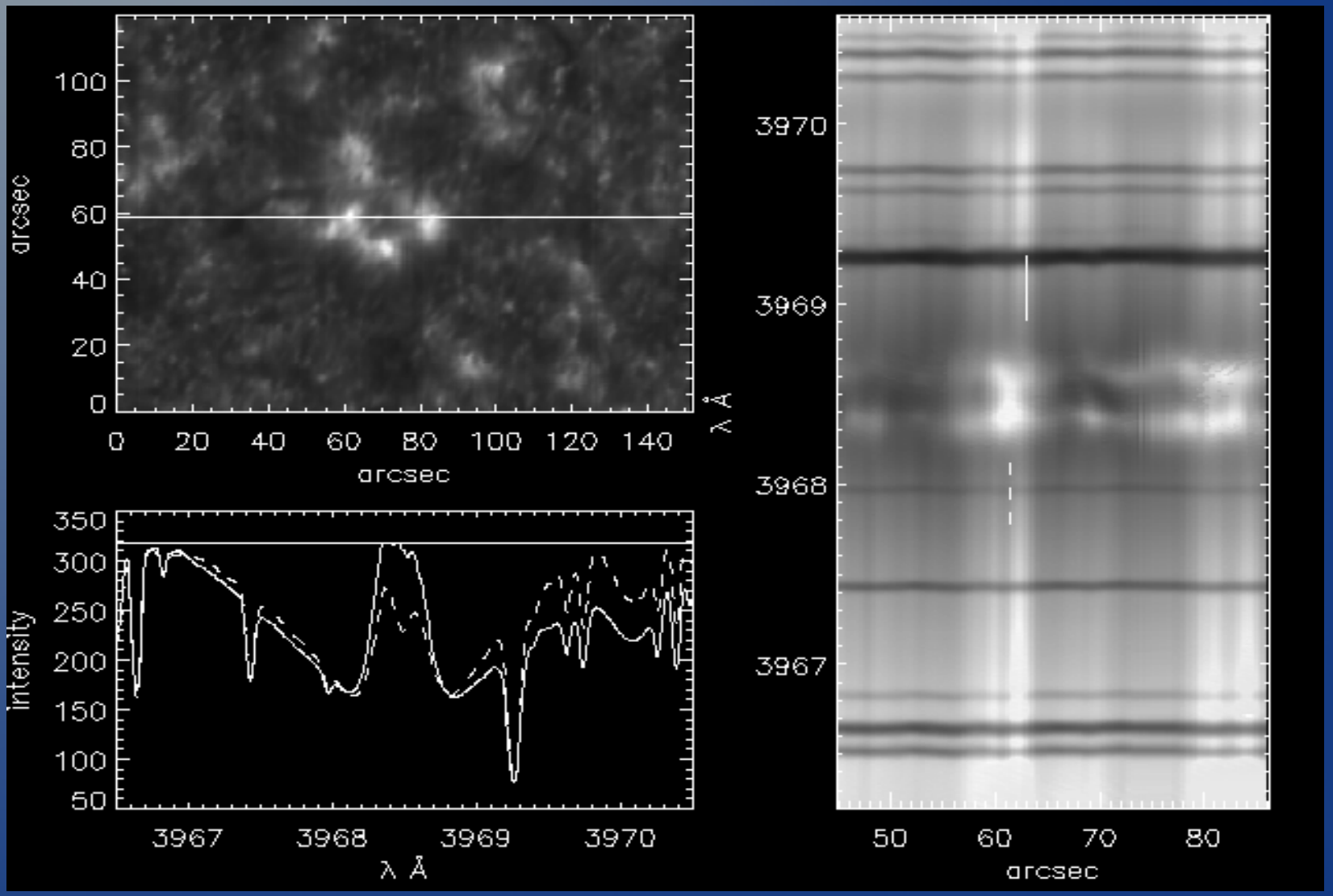


Schmidt (Judge et al, in prep.)



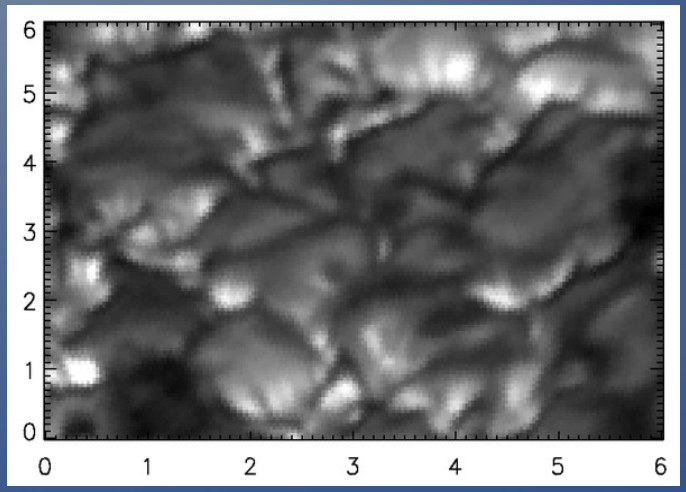
Ca II H Photosphere-chromosphere

Schmidt (Judge et al, in prep.)

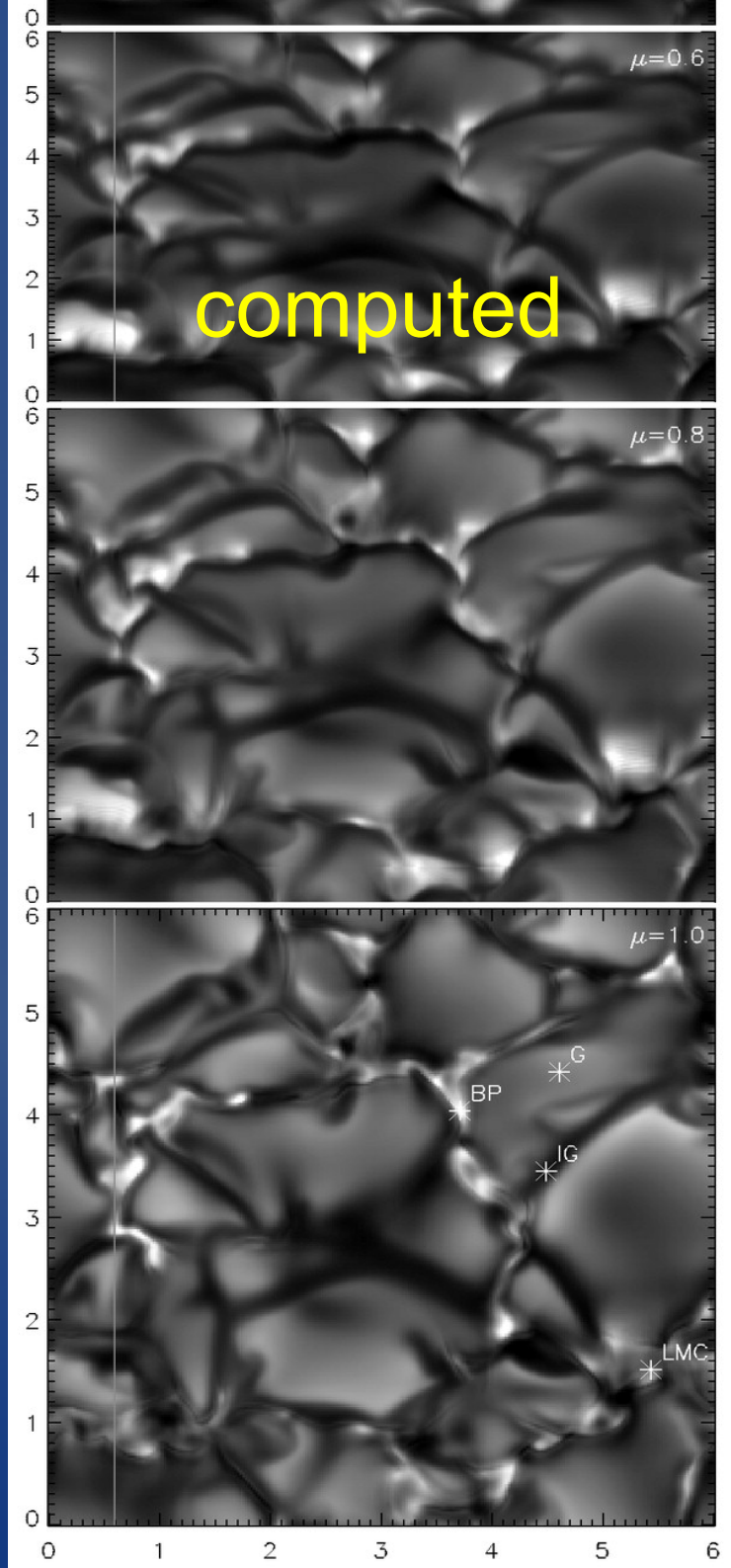


Carlsson et al 2004

Observed mu=0.6



G band photosphere



Conclusions

- *Models are needed to study chromospheric energetics*
- *1D models so far yield best (only?) estimates of heating*
- *In network, plage, 1D models will overestimate mechanical heating, as hot wall radiation can heat/scatter from low chromosphere. Not inconsistent with:*
  - *Plausible physical arguments*
  - *Existing 2D calculations (coherent scattering)*
  - *High resolution observations of Ca II lines*
- *Worth a 2D magnetostatic RE calculation*
- *Is the low chromosphere radiatively heated? (cf. Carlsson-Stein internetwork)*