Radiative-transfer modeling of solar prominences

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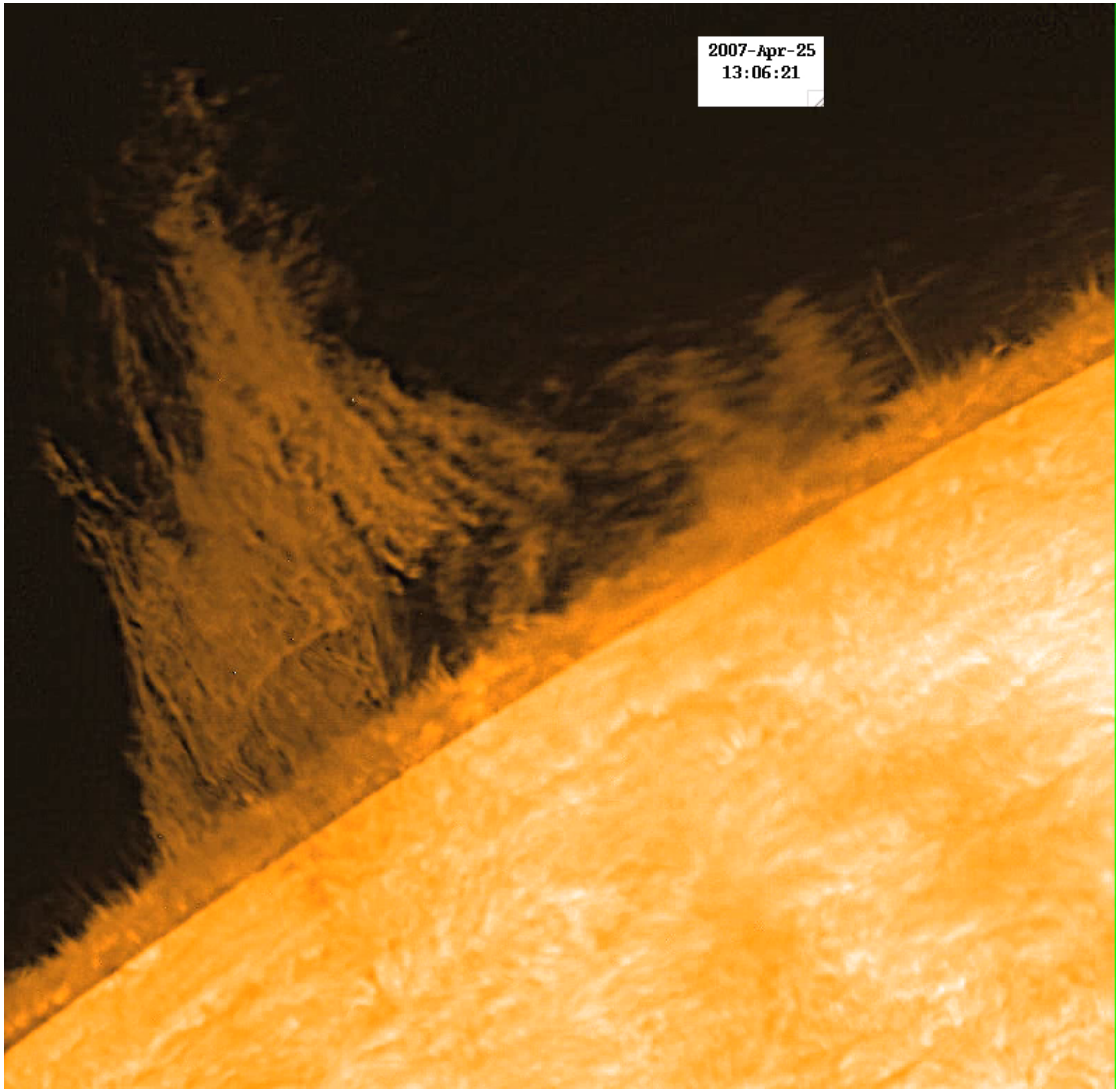
For a review see: Labrosse, N., Heinzel, P., Vial, J.-C. et al. 2010
Space Sci. Rev. 151, No. 4, 243-332

Hinode/SOT



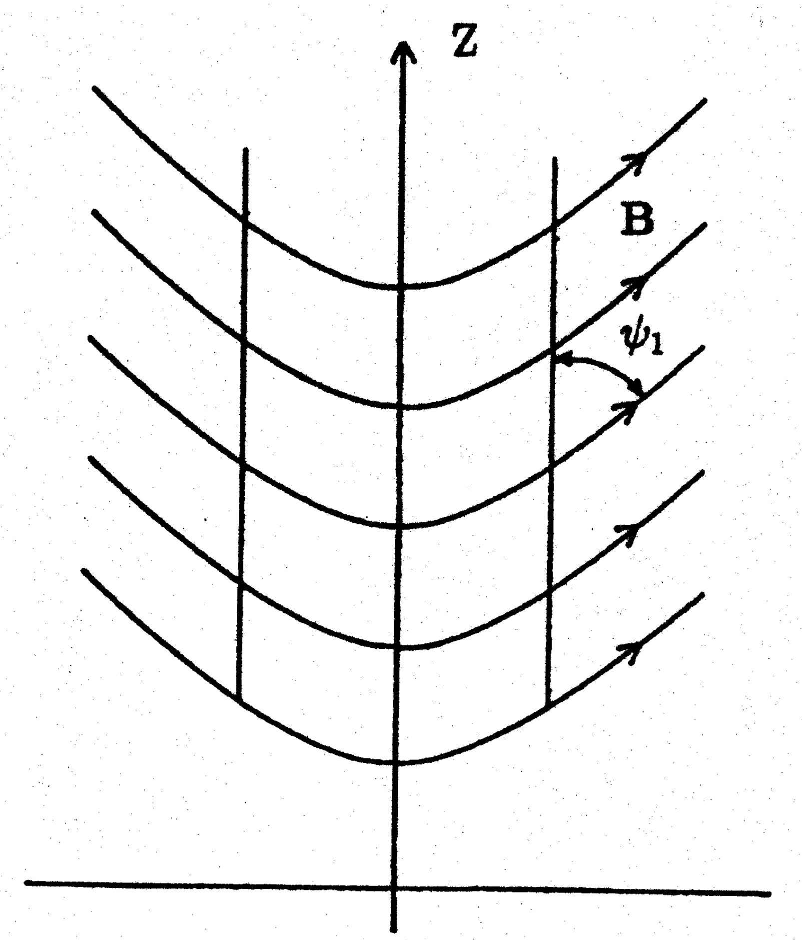
SOT NFI at Hα line center (bandpass 120 mÅ)

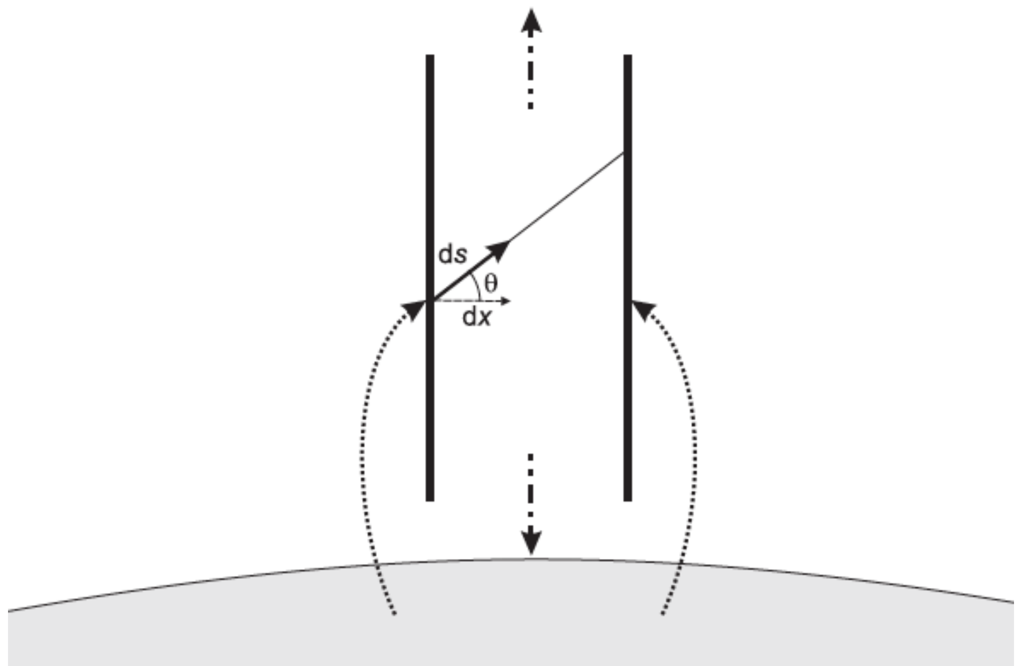
LOS flows < 20 km/sec

Heinzel et al. 2008
Schmieder et al. 2010

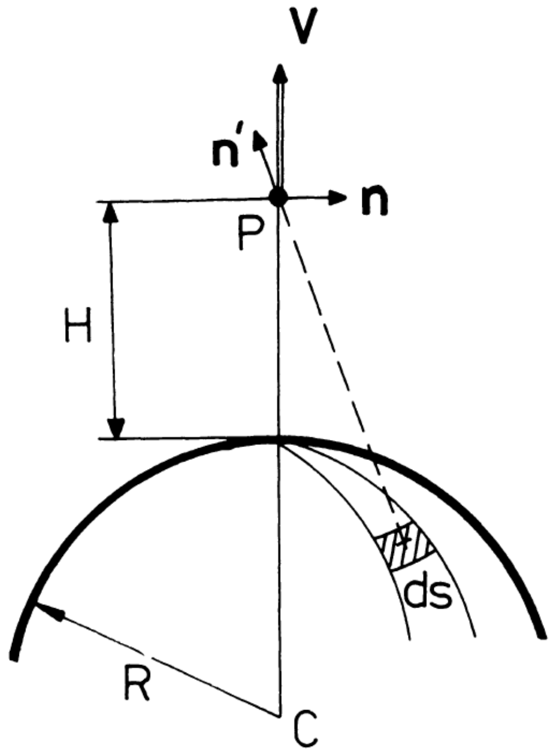
Kippenhahn-Schlüter MHS model

Kippenhahn & Schlüter (1957)



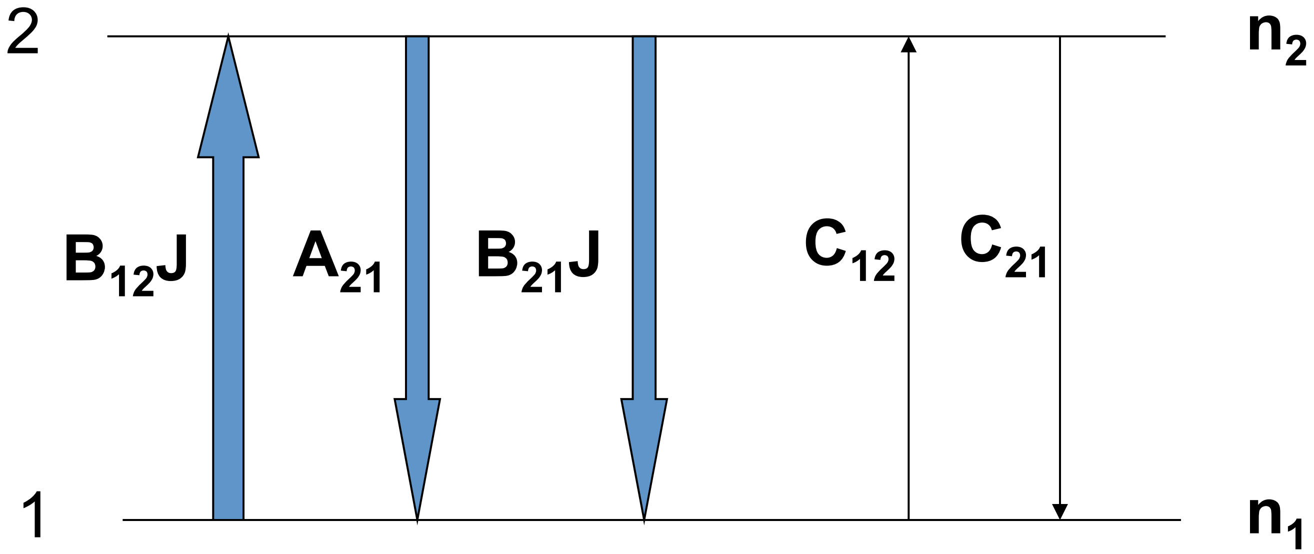


- **isothermal – isobaric slabs**
- **1D slabs in MHS equilibrium**
- **PCTR included**



incident solar radiation

radiative and collisional transitions (two-level atom)



$$\mu \frac{\mathrm{d}I_\nu}{\mathrm{d}\tau_\nu} = I_\nu - S_\nu \, .$$

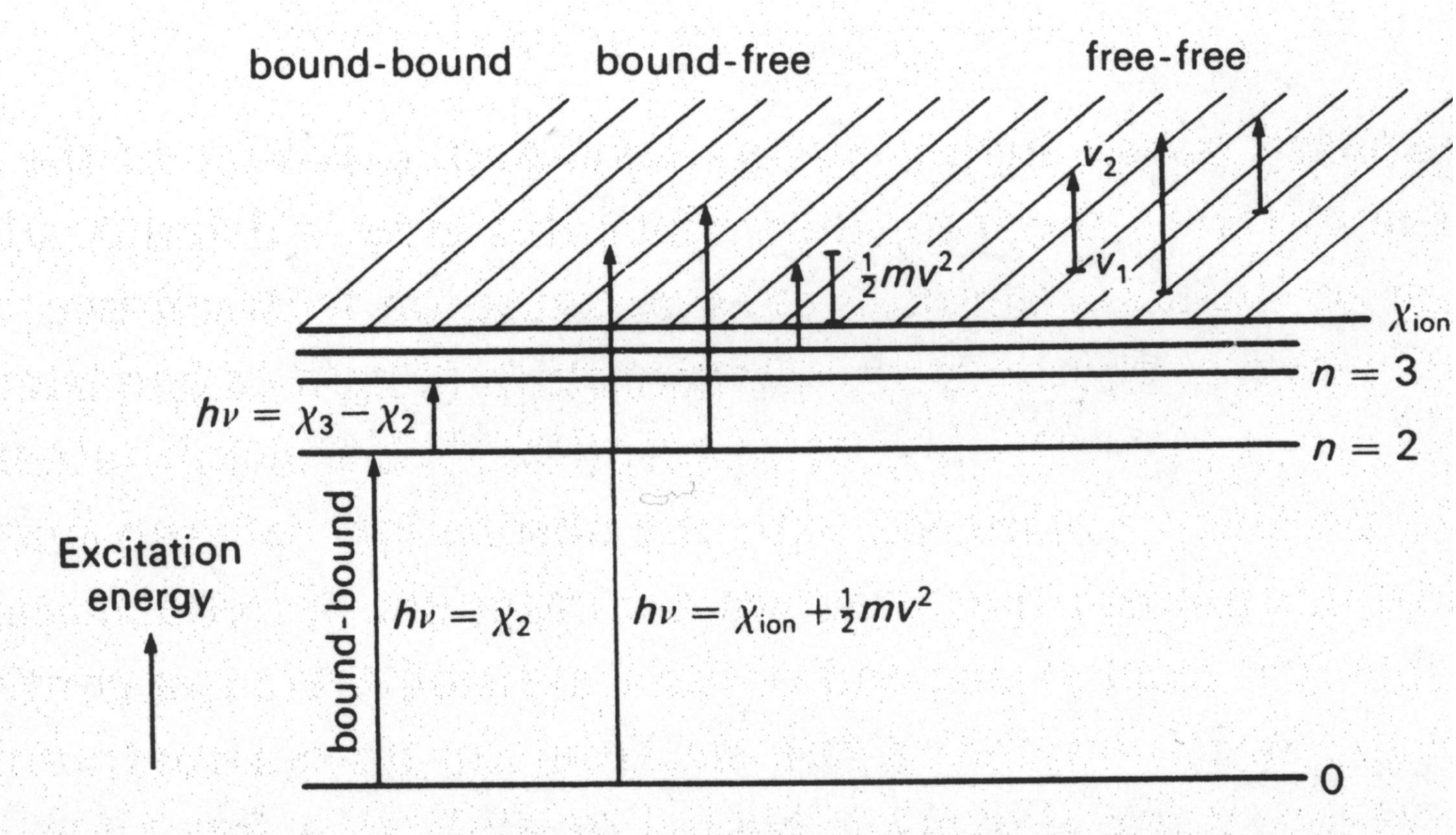
$$S_\nu \equiv \frac{\eta\nu}{\chi\nu} \, .$$

$$n_1 B_{12} \bar{J}_{12} + n_1 C_{12} = n_2 A_{21} + n_2 B_{21} \bar{J}_{12} + n_2 C_{21}$$

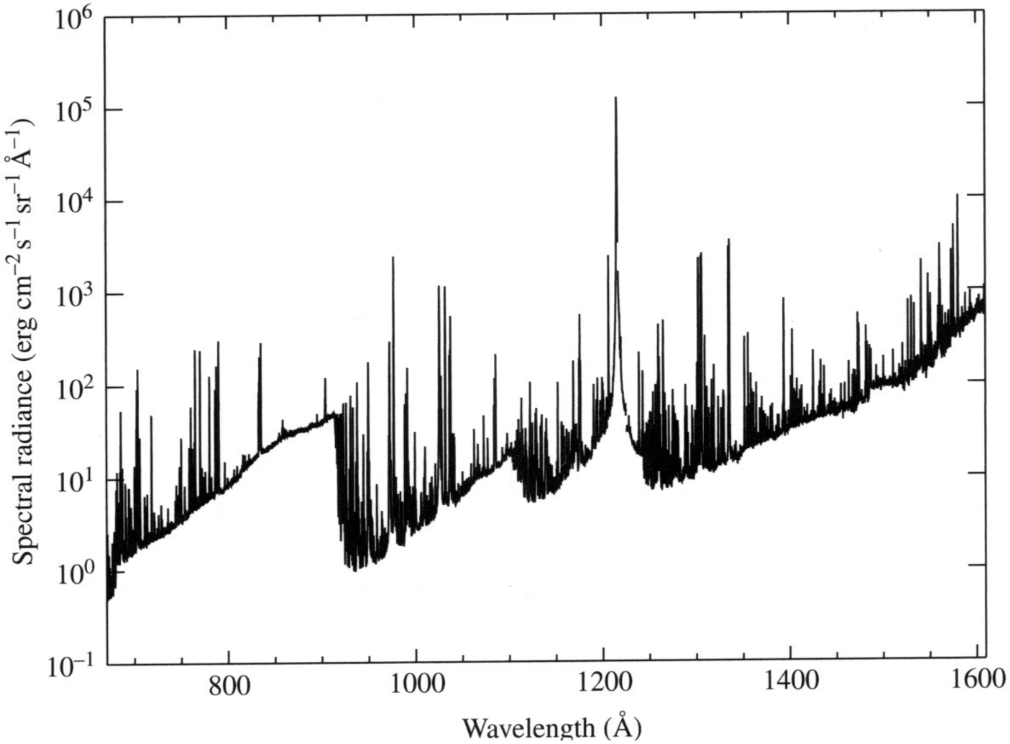
$$S = (1 - \epsilon)\bar{J} + \epsilon B_{\nu_0}$$

$$\epsilon \approx \frac{C_{21}}{(C_{21} + A_{21})}$$

Multilevel atoms



Chromospheric and TR spectrum



SOHO
SUMER

Solution of MHS equations using the column-mass scale

$$dm = -\rho dx$$

$$\frac{\partial p}{\partial m} = g\frac{B_z}{B_x}$$

$$\frac{\partial B_z}{\partial m} = -\frac{4\pi g}{B_x}$$

Solutions:

$$B_z(m) = -\frac{4\pi}{B_x} gm + const$$

$$B_z(M/2) = 0 \Rightarrow const = \frac{4\pi}{B_x} g \frac{M}{2}$$

$$B_z(m) = \frac{4\pi g}{B_x}(\frac{M}{2} - m)$$

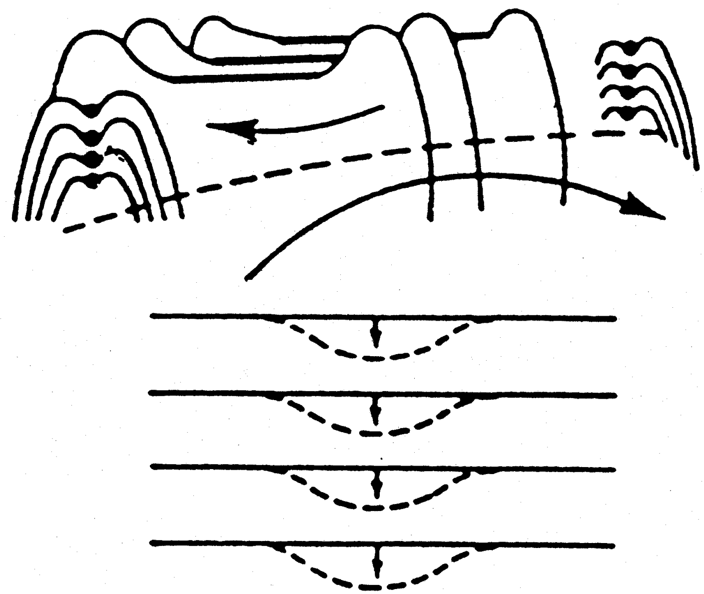
$$\frac{\partial p}{\partial m} = \frac{4\pi g^2}{B_x^2}(\frac{M}{2} - m)$$

$$p(m) = \frac{4\pi g^2}{B_x^2}(\frac{M}{2}m - \frac{m^2}{2}) + const$$

$$p(m) = 4p_c \frac{m}{M}(1 - \frac{m}{M}) + p_0$$

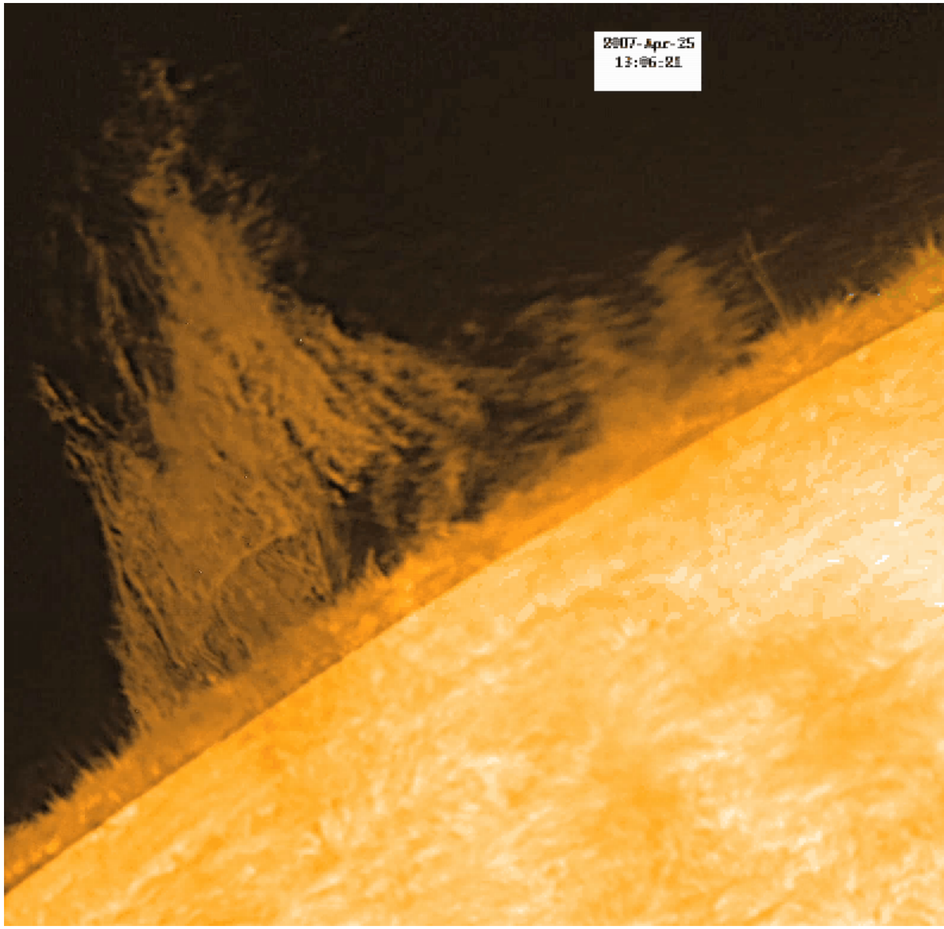
p_0 is the coronal pressure at the slab surface $m = 0$ or $m = M$

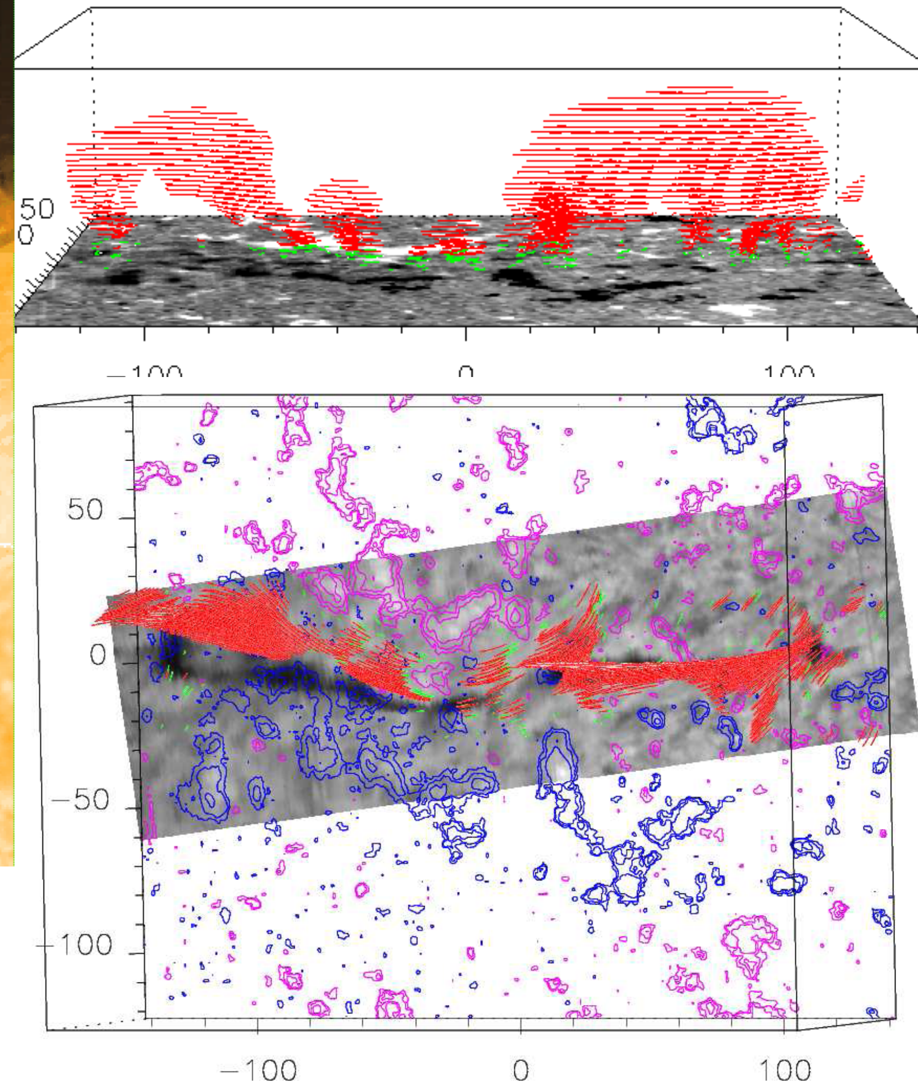
Poland & Mariska scenario



Poland and Mariska (1986)

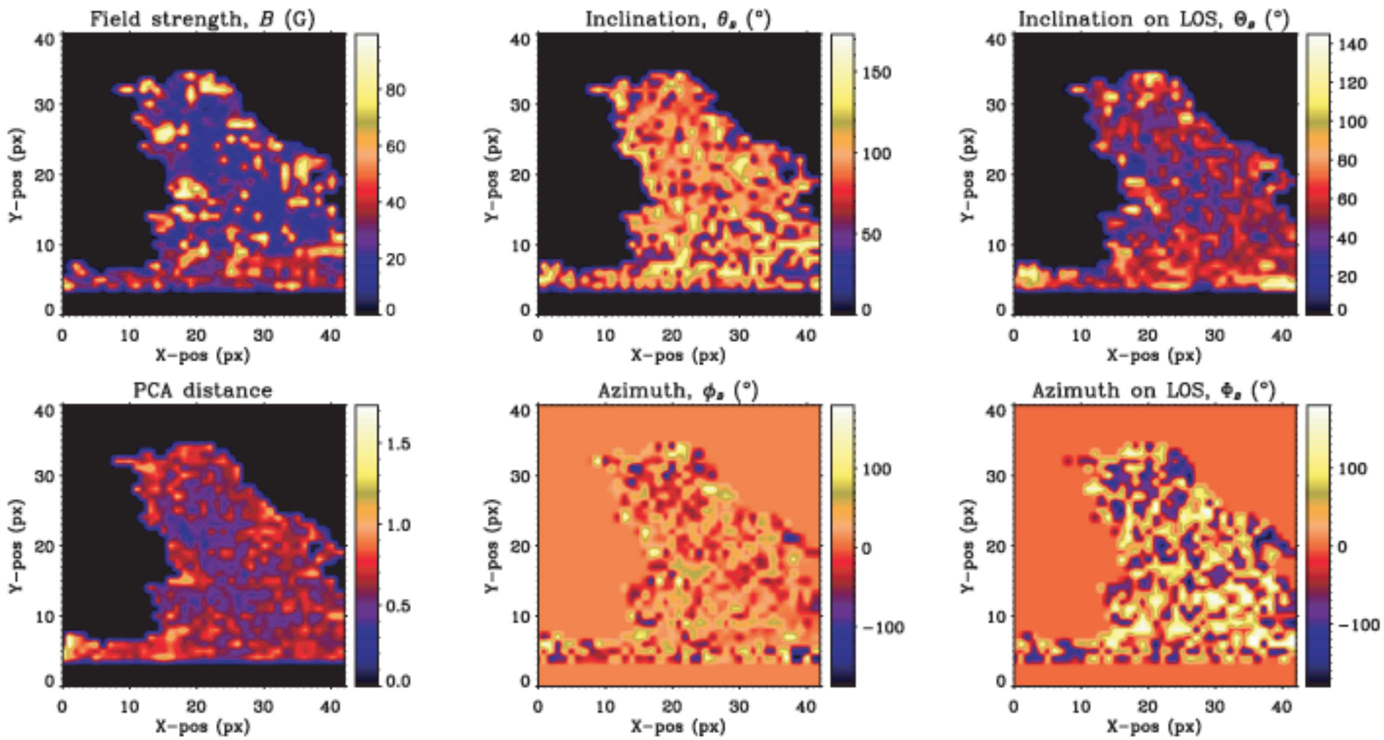
Magnetic-field structure





Dudik et al. 2008

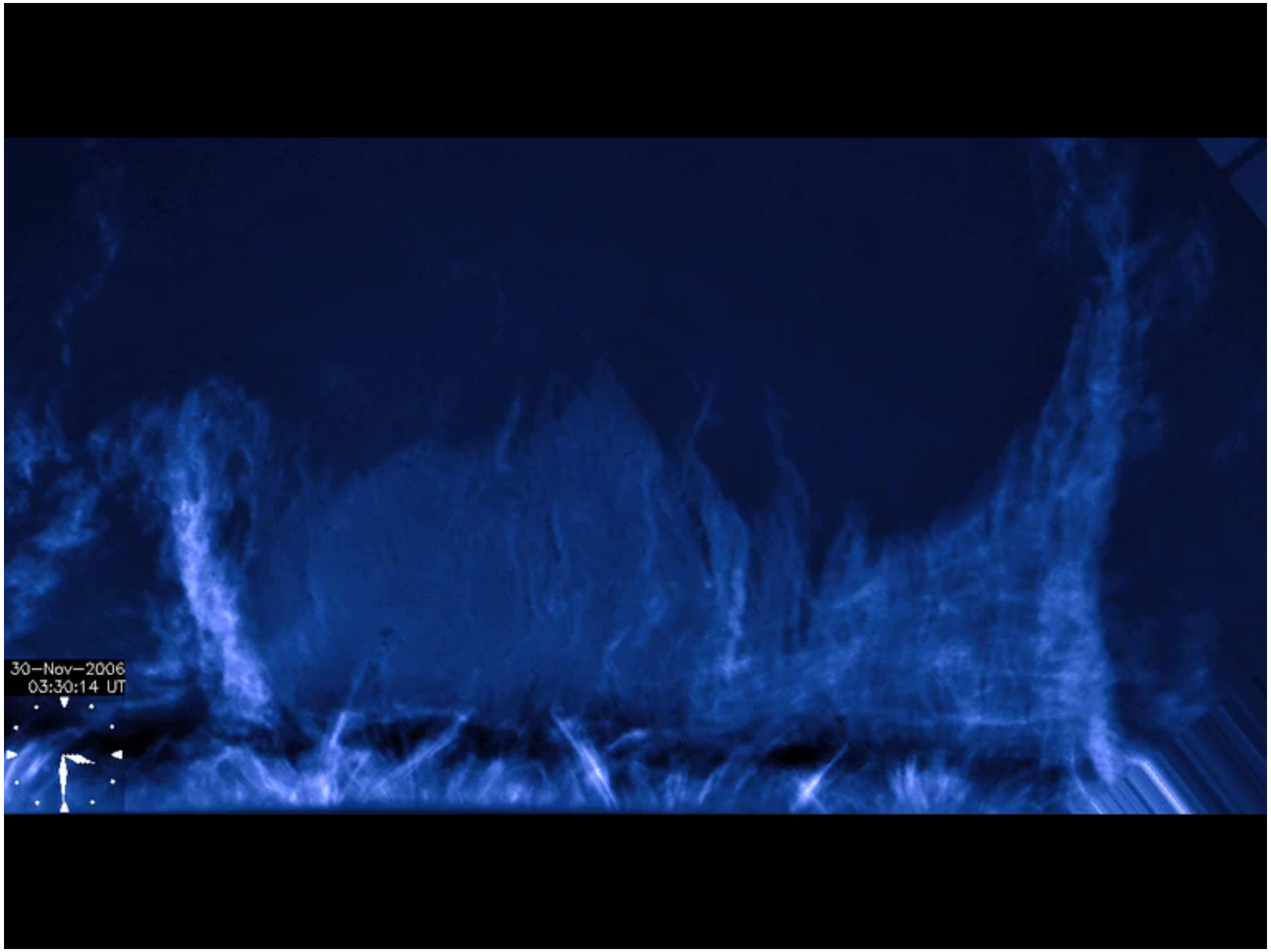
2D maps of the magnetic field



Casini et al. 2003

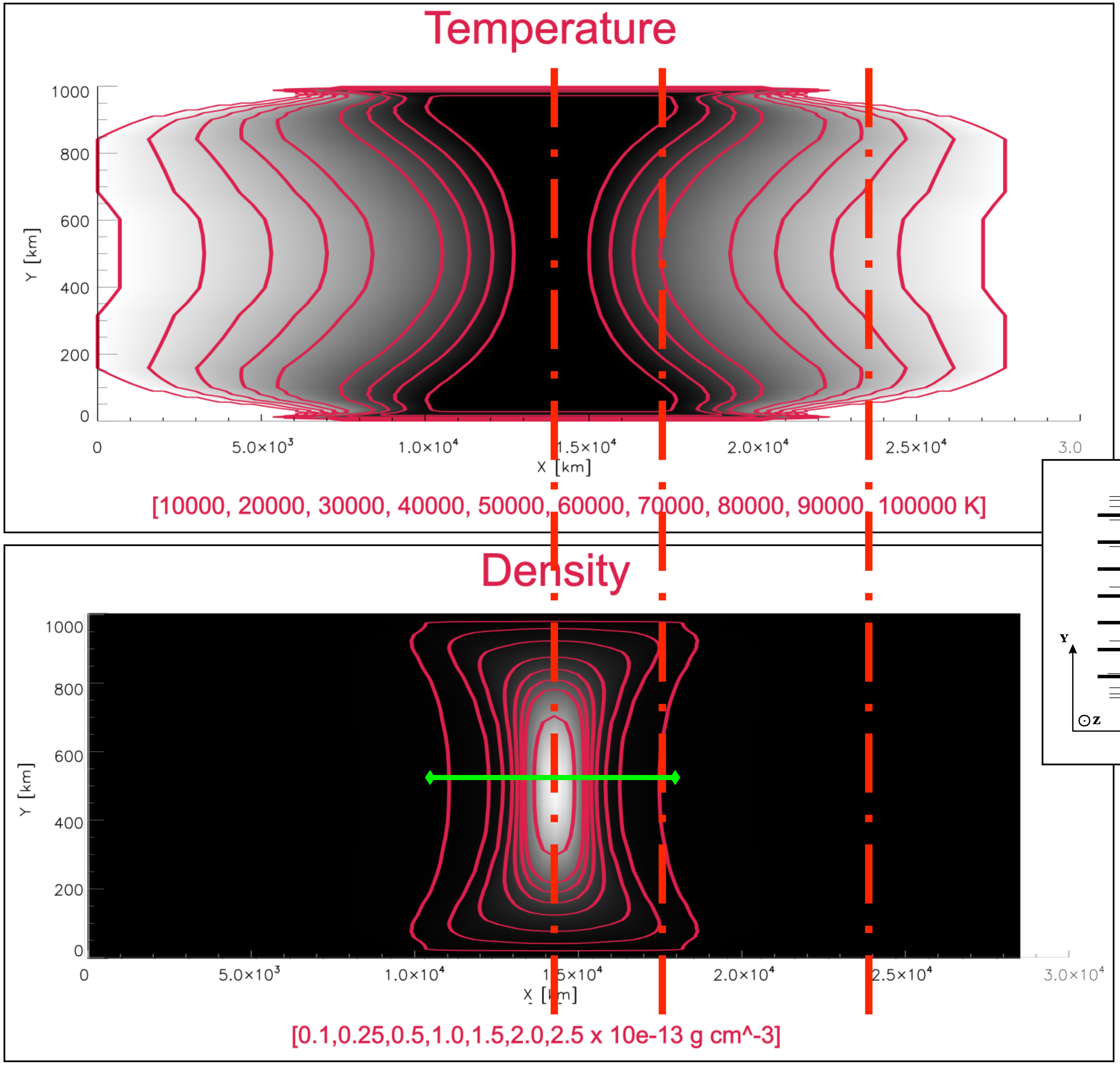
Prominence magnetism and Hanle measurements – see also review by Lopez-Ariste and Aulanier (2007)

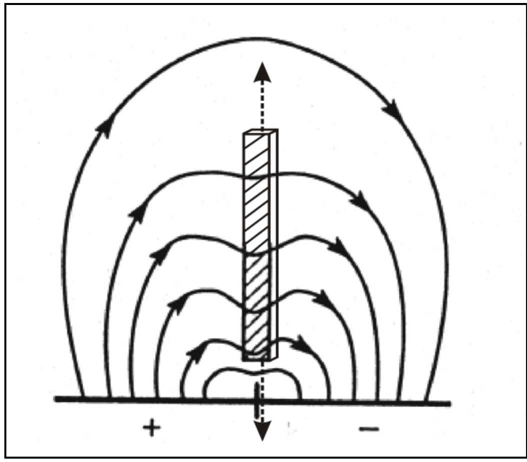
Hinode/SOT CaII H

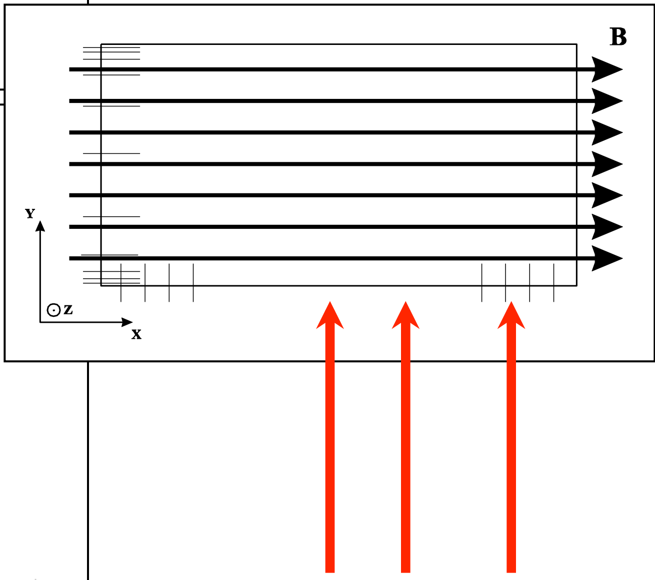


Berger et al. (2008)

Temperature and density variation in $x-y$ plane

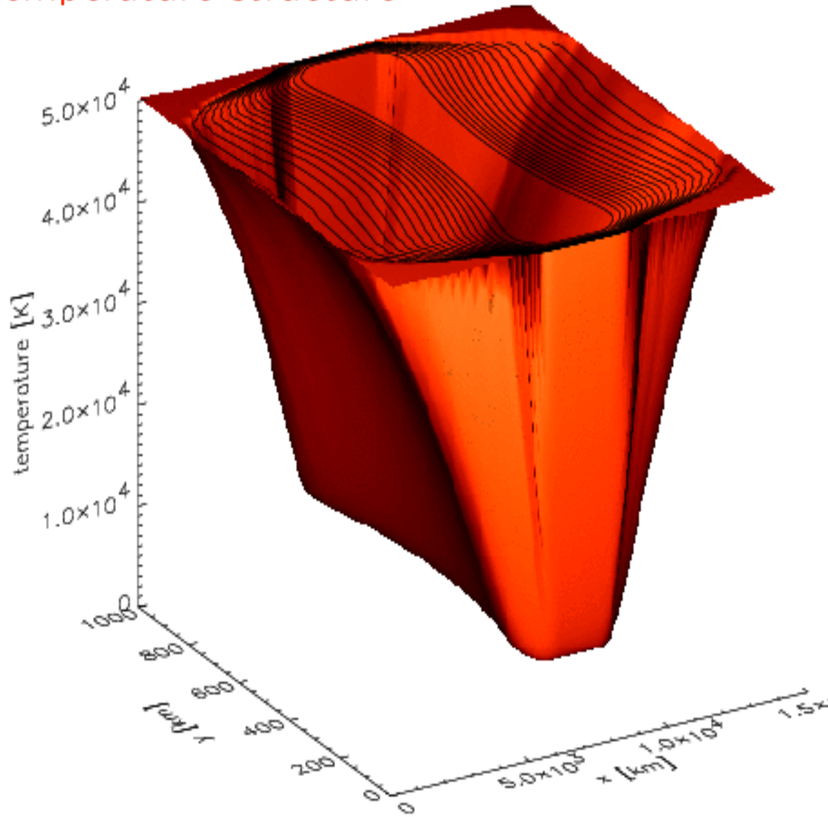




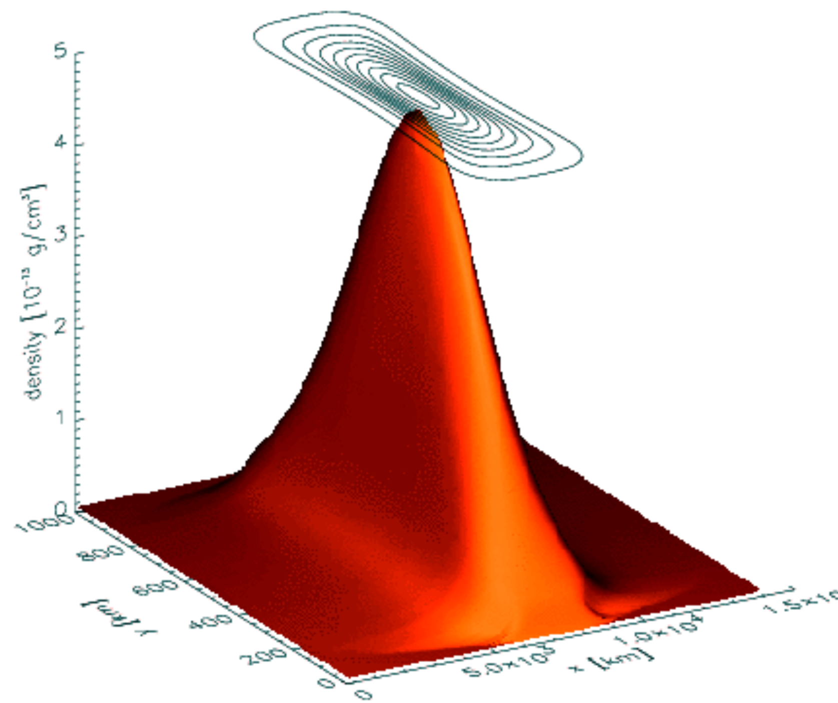


Temperature and density structure

Temperature structure



Density structure



$$T(m,y) = T_{\mathrm{cen}}(y) + [T_{\mathrm{tr}} - T_{\mathrm{cen}}(y)] \left\{ 1 - \right.$$

$$M(y) = M_0 \left(1 - \left|\frac{y}{\delta}\right|^{\gamma_3}\right), \quad \text{for } |y| \le \delta$$

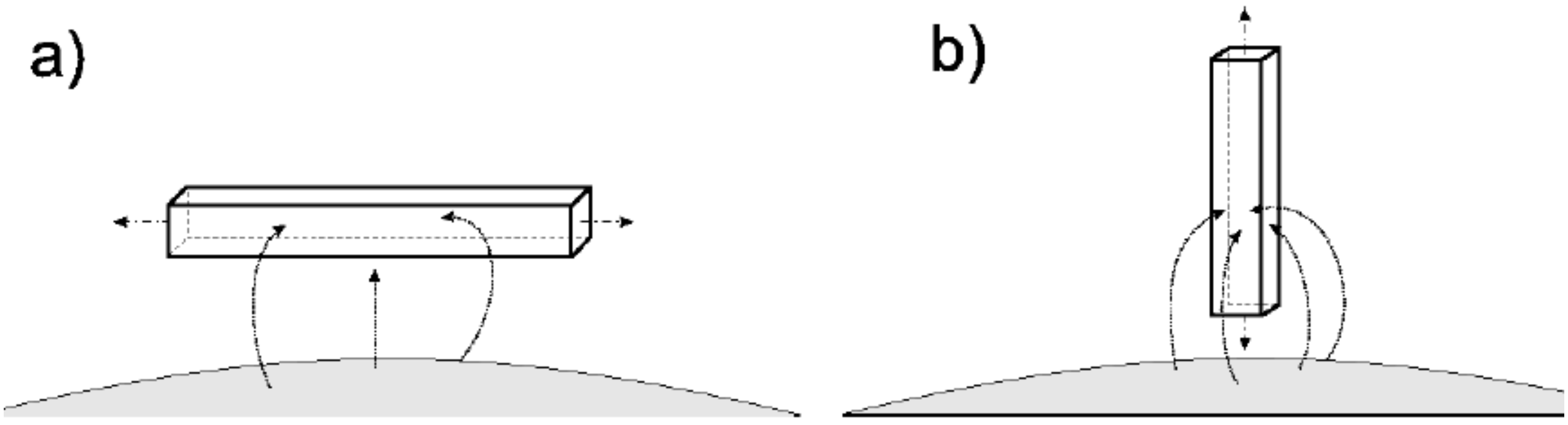
$$M(y) = 0, \quad \text{for } |y| > \delta$$

The central temperature $T_{\mathrm{cen}}(y)$

$$T_{\mathrm{cen}}(y) = T_{\mathrm{tr}} - (T_{\mathrm{tr}} - T_0)\left(1 - \left|\frac{y}{\delta}\right|^{\gamma_2}\right), \quad \text{for } |y| \le \delta$$

$$T_{\mathrm{cen}}(y) = T_{\mathrm{tr}}, \quad \text{for } |y| > \delta$$

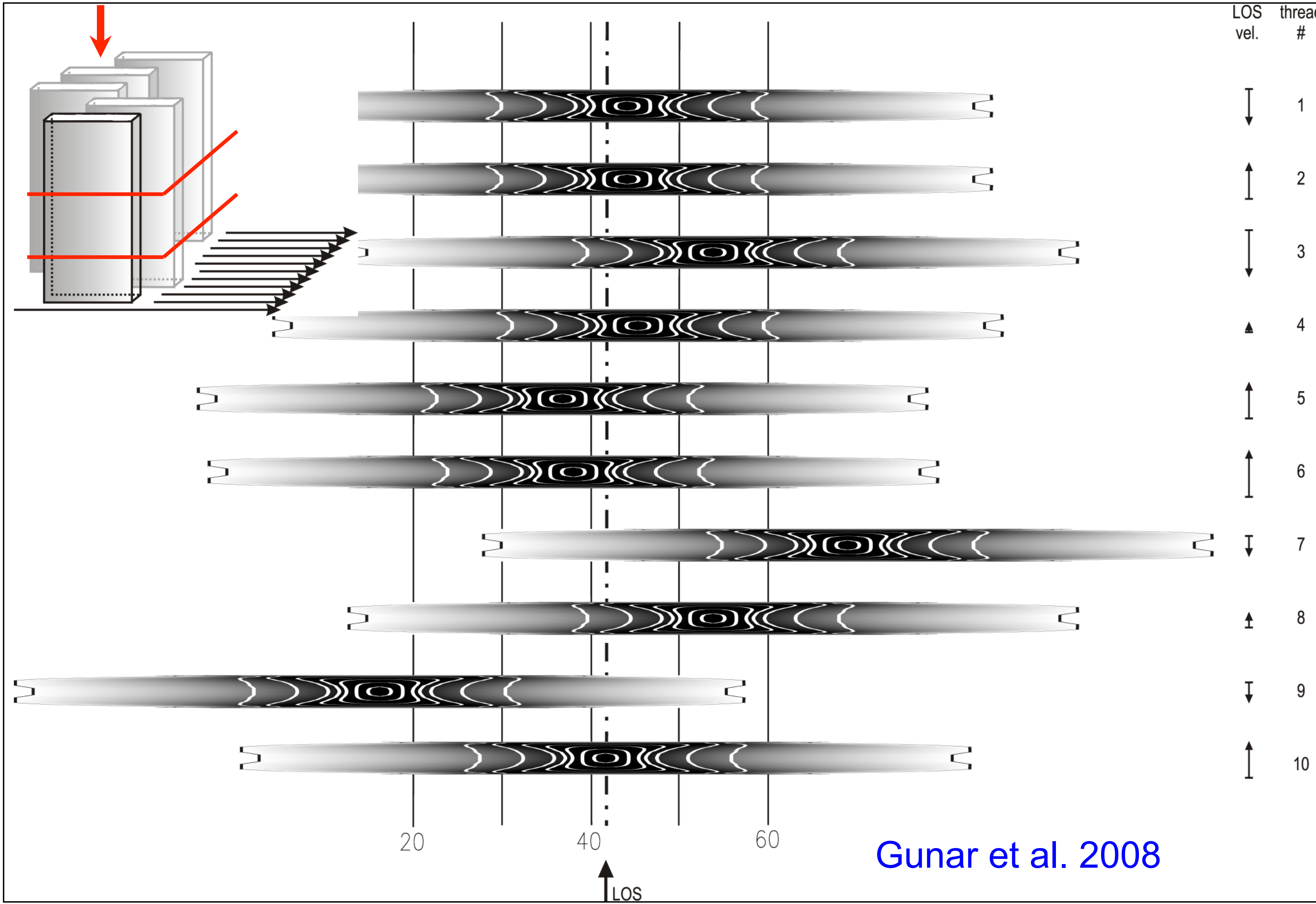
γ_1 and γ_2 are chosen parameters.



2D models

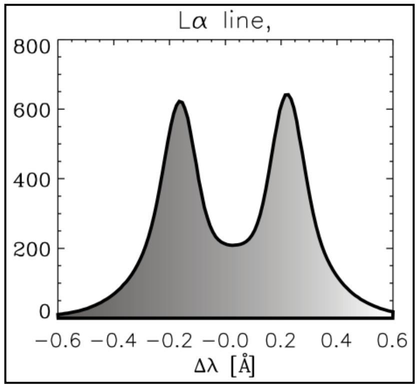
Heinzel and Anzer (2001)

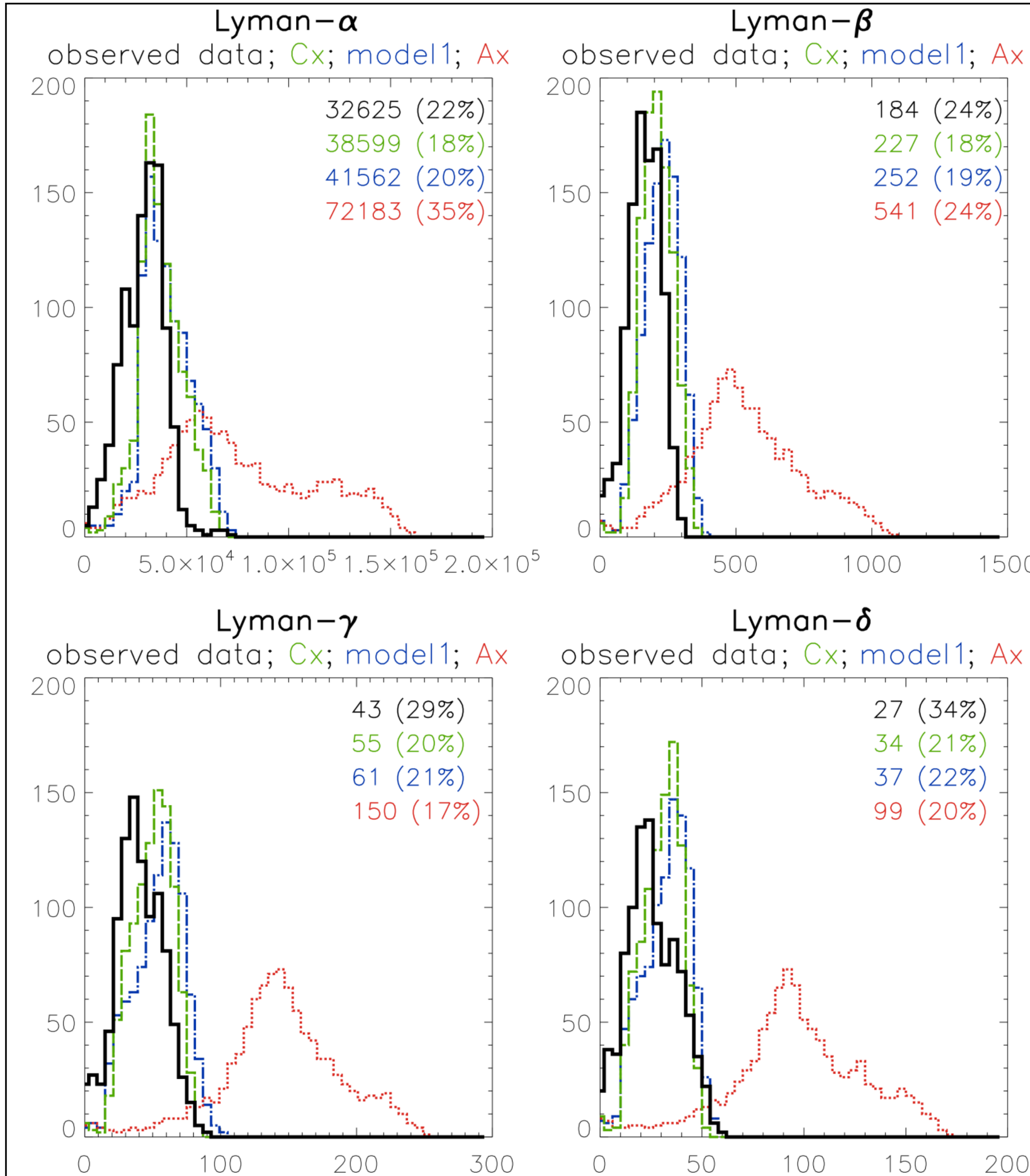
2D multi-thread models with LOS velocities



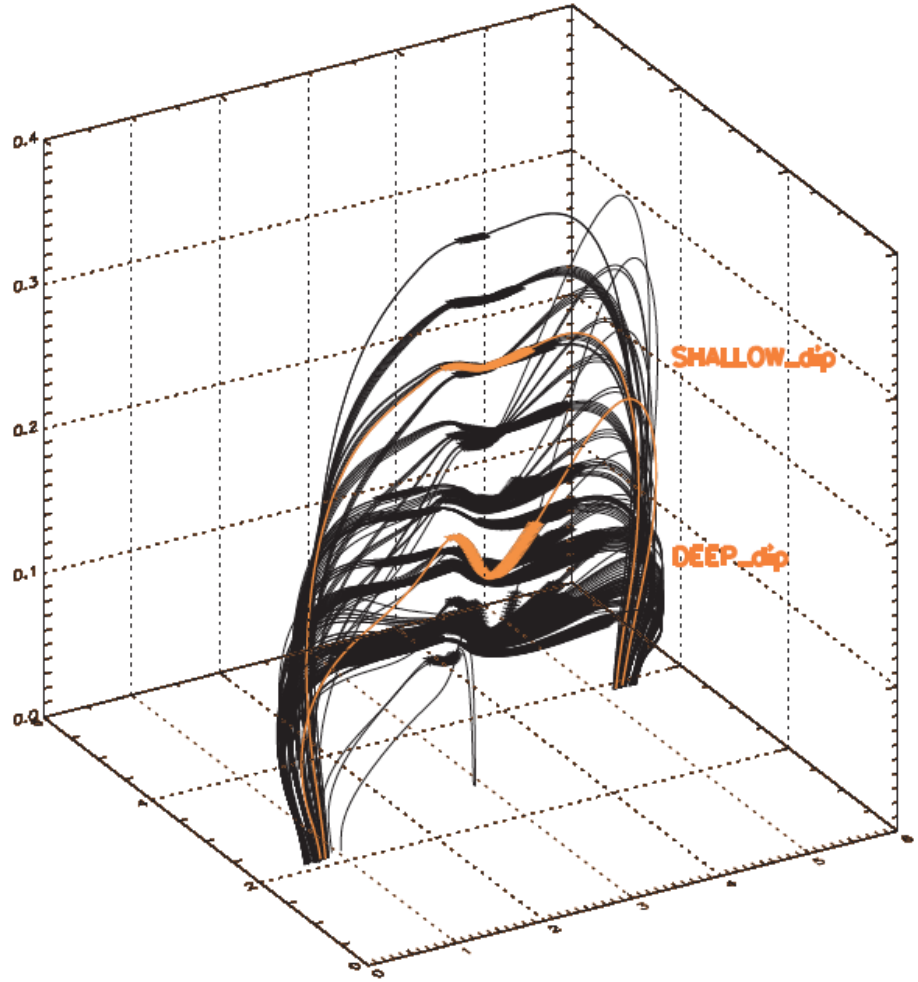
Gunar et al. 2008

Integrated Intensities





Gunar et al. 2010



3D NLFF magnetic dips (Gunar et al. 2012)

Radiative equilibrium

$$\int_0^\infty H_\nu \mathrm{d}\nu = \text{const} = \frac{\sigma}{4\pi} T_{\text{eff}}^4 \tag{1}$$

H_ν is the *radiation flux* (first-moment of the radiation intensity). The **total flux** must be conserved.

Equivalently, we can write:

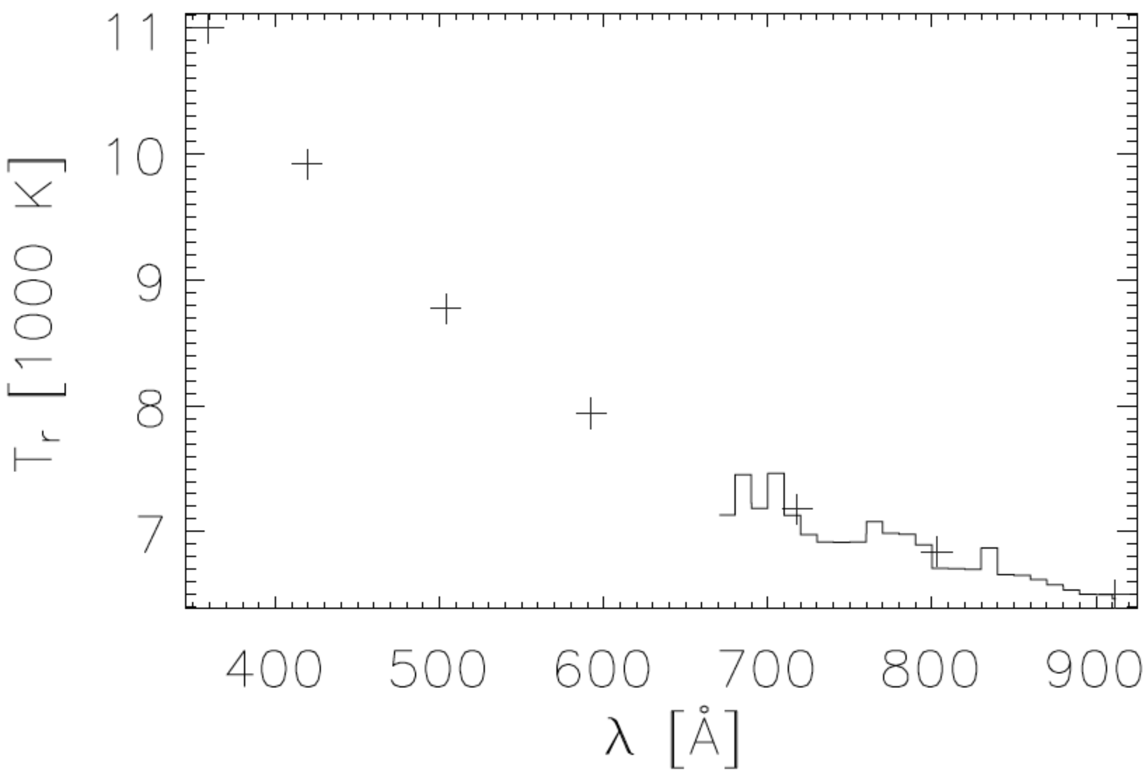
$$\int_0^\infty (\chi_\nu J_\nu - \eta_\nu)\mathrm{d}\nu = \int_0^\infty \chi_\nu (J_\nu - S_\nu)\mathrm{d}\nu = 0 \tag{2}$$

This integral is also called the *net radiation loss function*. J_ν is the *mean radiation intensity* or zeroth moment.

$$L = 4\pi \int_0^\infty (\eta_\nu - \chi_\nu J_\nu) \mathrm{d}\nu$$

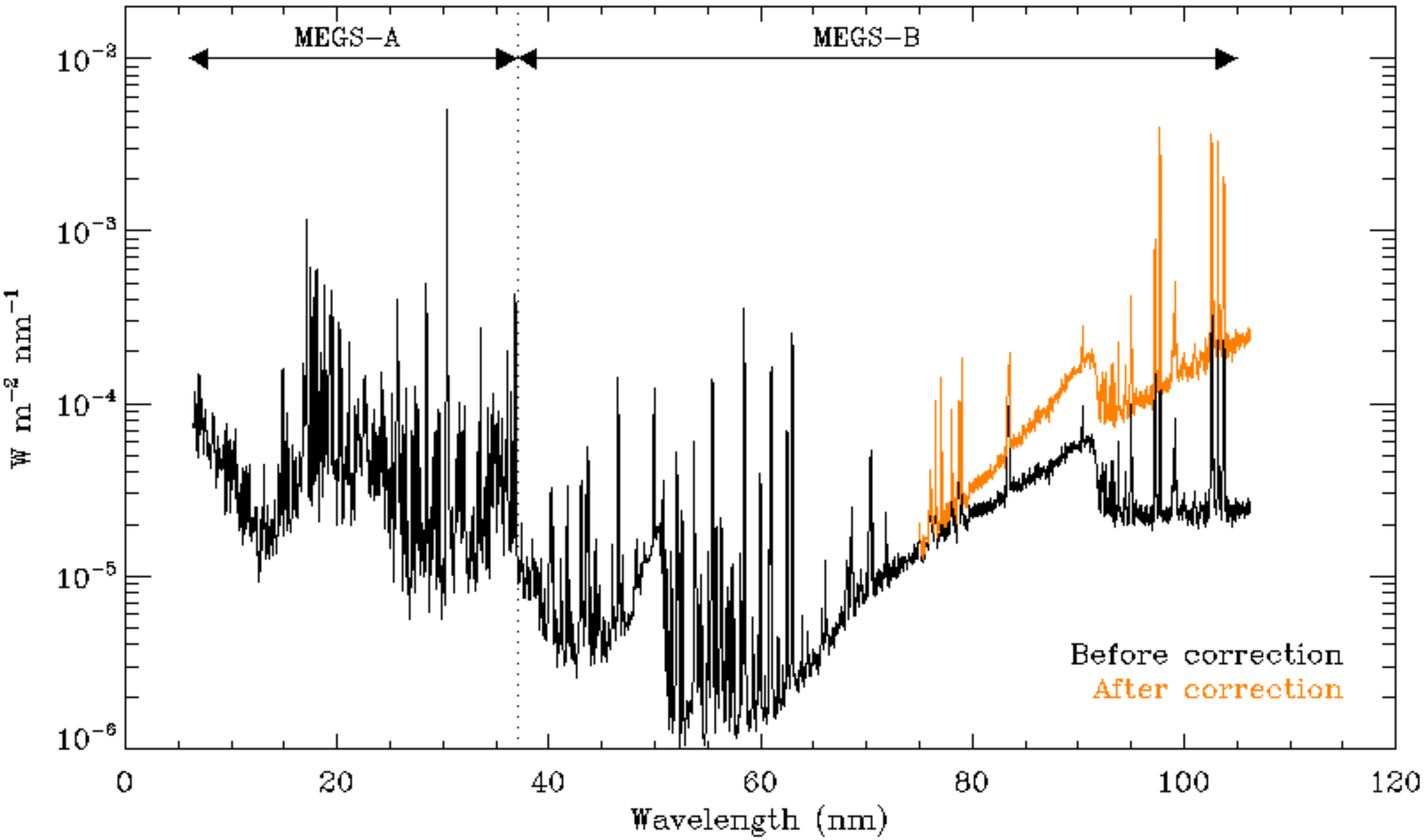
$$L = h\nu \left[n_j \left(A_{ji} + B_{ji} \bar{J}_{ij} \right) - n_i B_{ij} \bar{J}_{ij} \right]$$

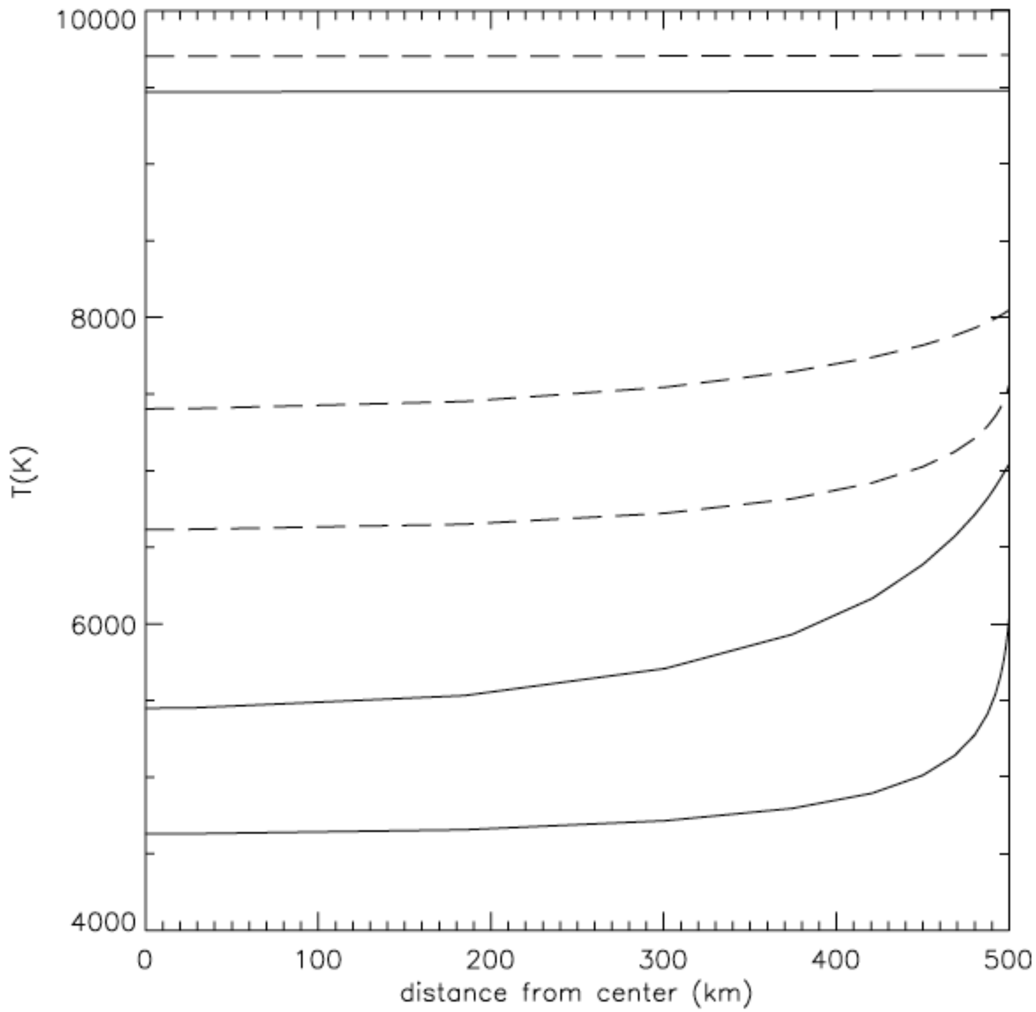
$$\boxed{\frac{\mathrm{d}T}{\mathrm{d}t} = \frac{2}{5} \frac{L}{n_\mathrm{H}(1 + A_\mathrm{He} + y)k}}$$



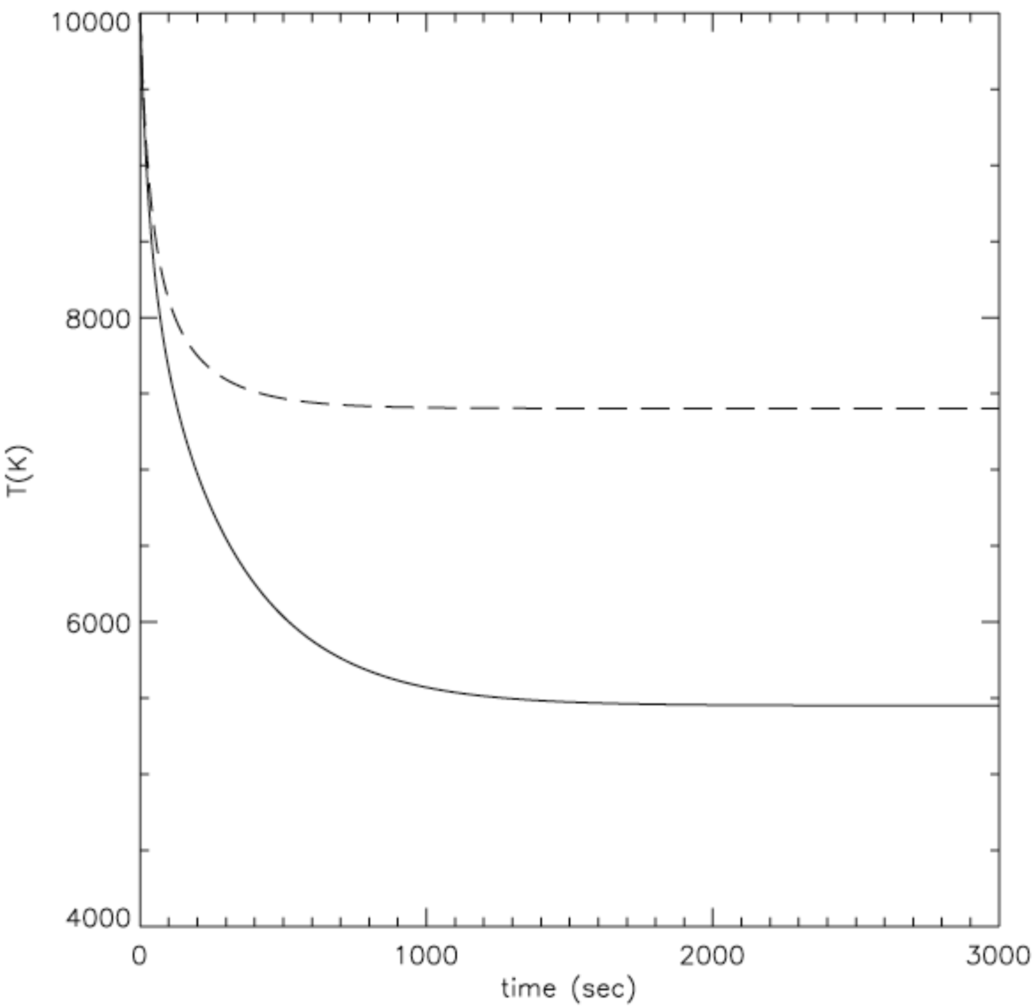
11
10
9
8
7
T_r [1000 K]
400
500
600
700
800
900
λ [Å]

SDO/EVE quiet-Sun spectrum





Heinzel and Anzer (2013)

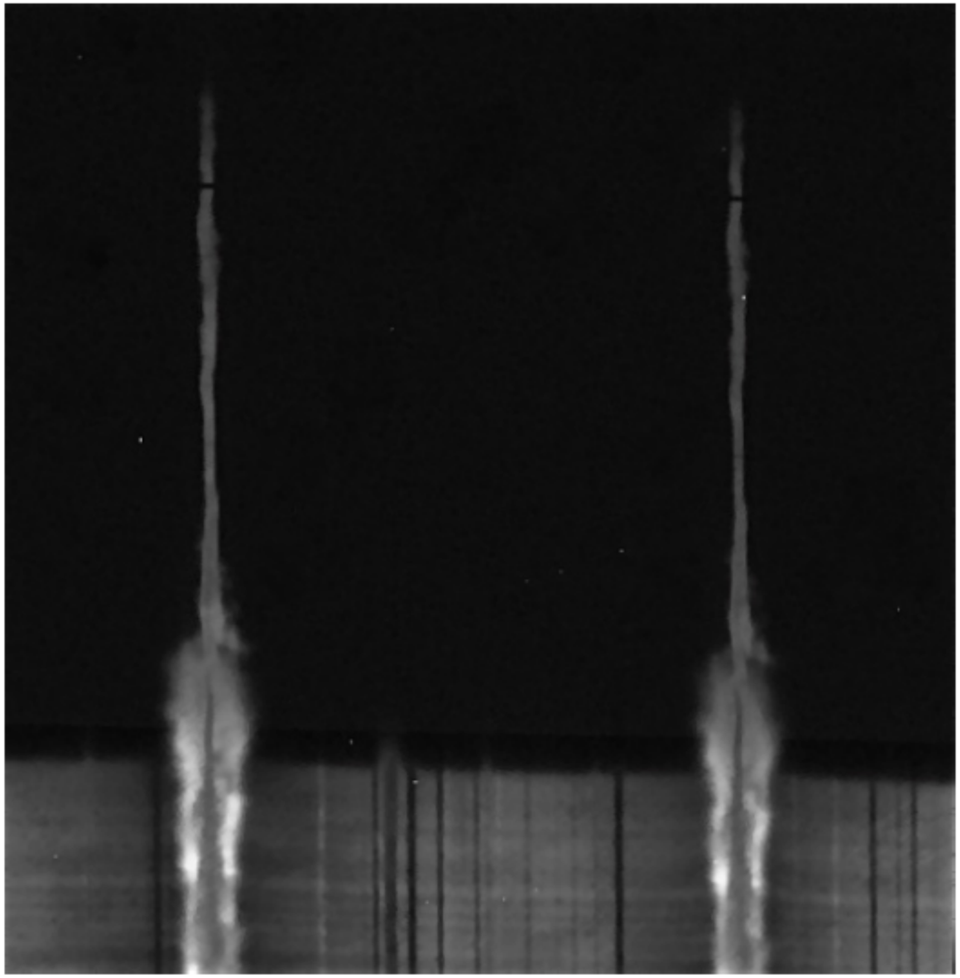


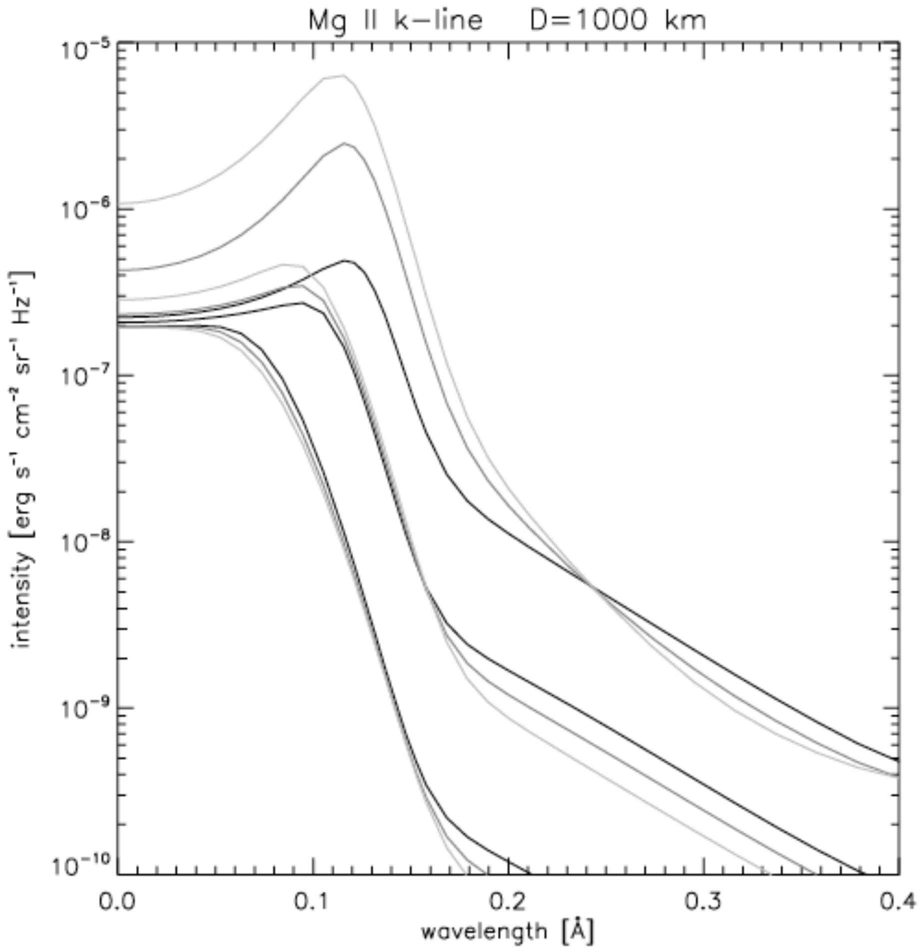
10000
8000
6000
4000
T(K)
0
1000
2000
3000
time (sec)

p[dyn cm^{-2}]	0.01	0.1	0.5	Model
D=200 km	9750 (9760)	7990 (8180)	7010 (7560)	HI losses only
D=1000 km	9700 (9710)	7400 (8050)	6620 (7550)	
D=5000 km	9480 (9570)	6780 (8020)	6340 (7550)	
D=200 km	9530 (9530)	6770 (7270)	5040 (6030)	HI + Ca II losses (updated)
D=1000 km	9470 (9480)	5460 (7030)	4690 (6010)	
D=5000 km	9200 (9300)	4960 (7000)	4360 (5990)	
D=200 km	8280 (8280)	6080 (6530)	4960 (5720)	HI, Ca II + Mg II losses
D=1000 km	8140 (8190)	5260 (6370)	4680 (5710)	
D=5000 km	7650 (7920)	4880 (6360)	4430 (5690)	

Heinzel, Vial and Anzer (2014)

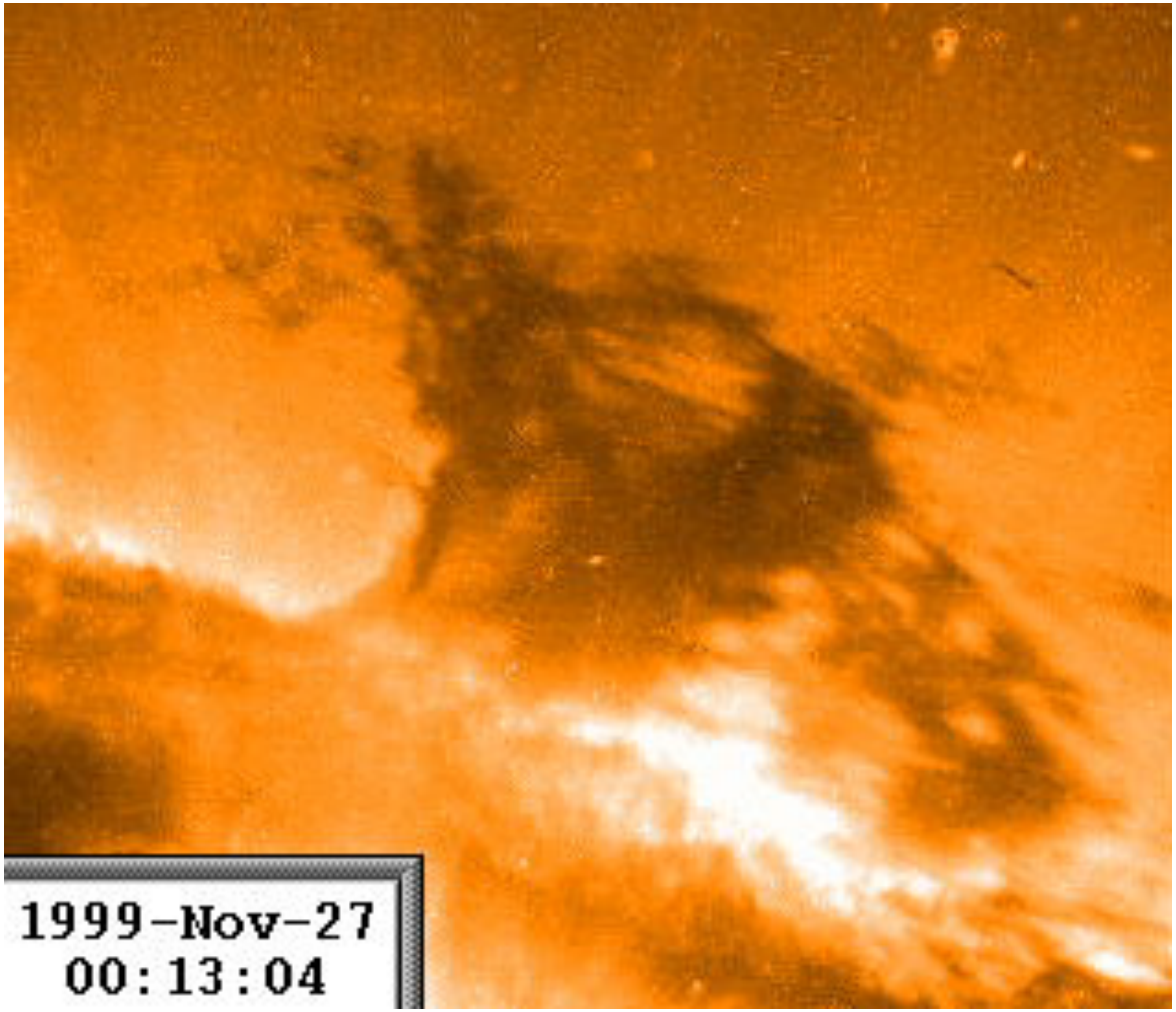
I R I S
MgII k and h lines



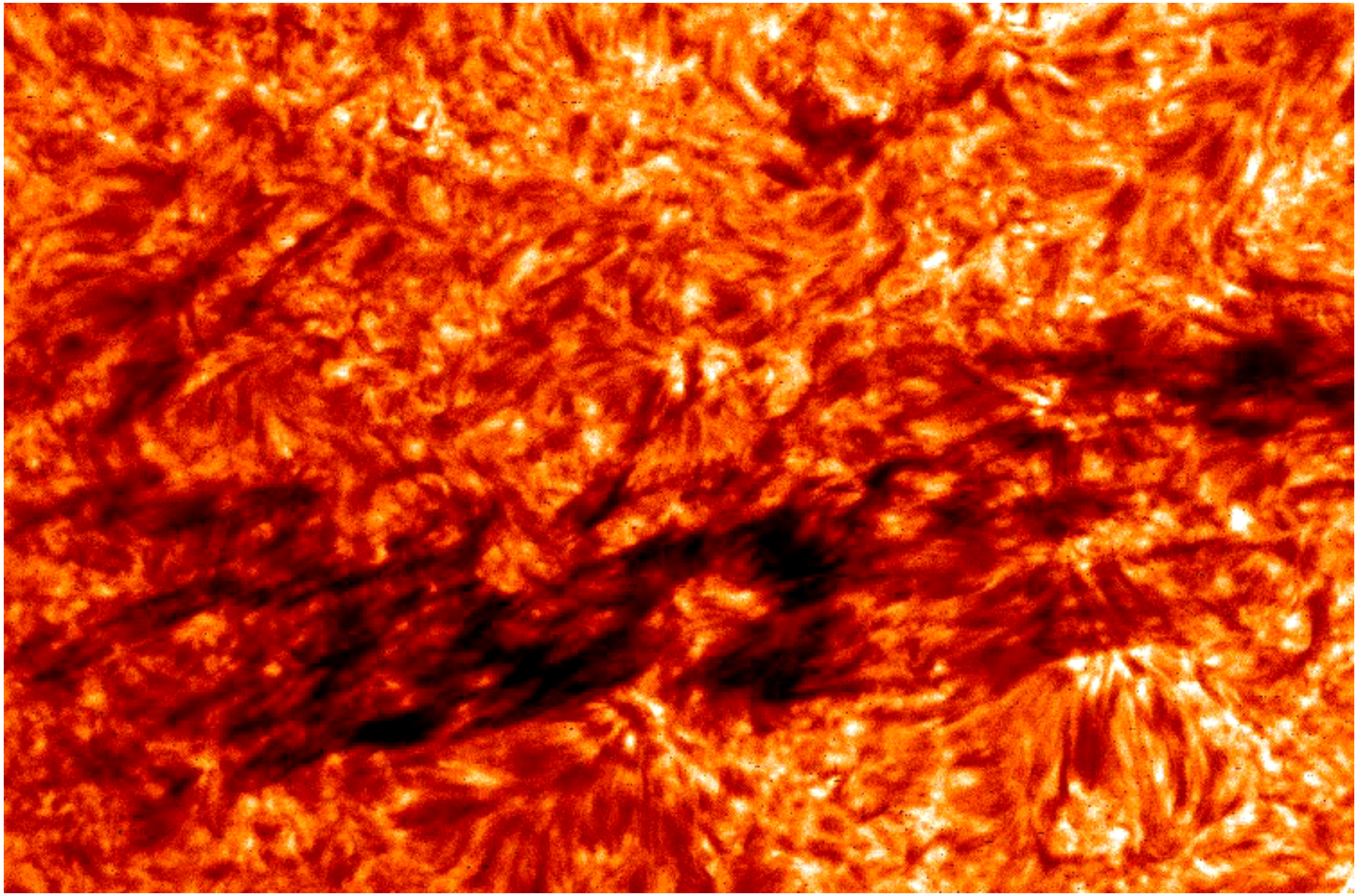


Heinzel, Vial and Anzer (2014)

TRACE 171



Hα disk observations



Lin et al. (2003, 2005)

$$\frac{dn_i}{dt} = \sum n_j (R_{ji} + C_{ji}) - n_i \sum (R_{ij} + C_{ij})$$

$$\frac{dn_i}{dt} = \frac{\partial n_i}{\partial t} + \frac{\partial n_i V}{\partial x}\,.$$