# DYNAMICS OF THE MAGNETIZED CHROMOSPHERE

*SIRAJ HASAN*
*Indian Institute of Astrophysics*
*Bangalore*

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# BACKGROUND

The *quiet* solar atmosphere consists of magnetic and no magnetic regions. Although magnetic fields are four everywhere on the Sun they are dynamically unimportant the interior of supergranulation cells.

Strong magnetic elements occur at the cell boundarie and constitute the *magnetic network*. Vertical tubes pressure equilibrium with the outside medium expa upward to conserve magnetic flux. From a low filling fact (< 1%) in the photosphere the tubes spread to 15% in th layers of formation of the emission features in the H and lines of ionized calcium (at a height of 1 Mm) and to 100 in the so-called *magnetic canopy*.

The remaining quiet Sun outside the network is called the *internetwork*, sometimes also referred to as cell interior.

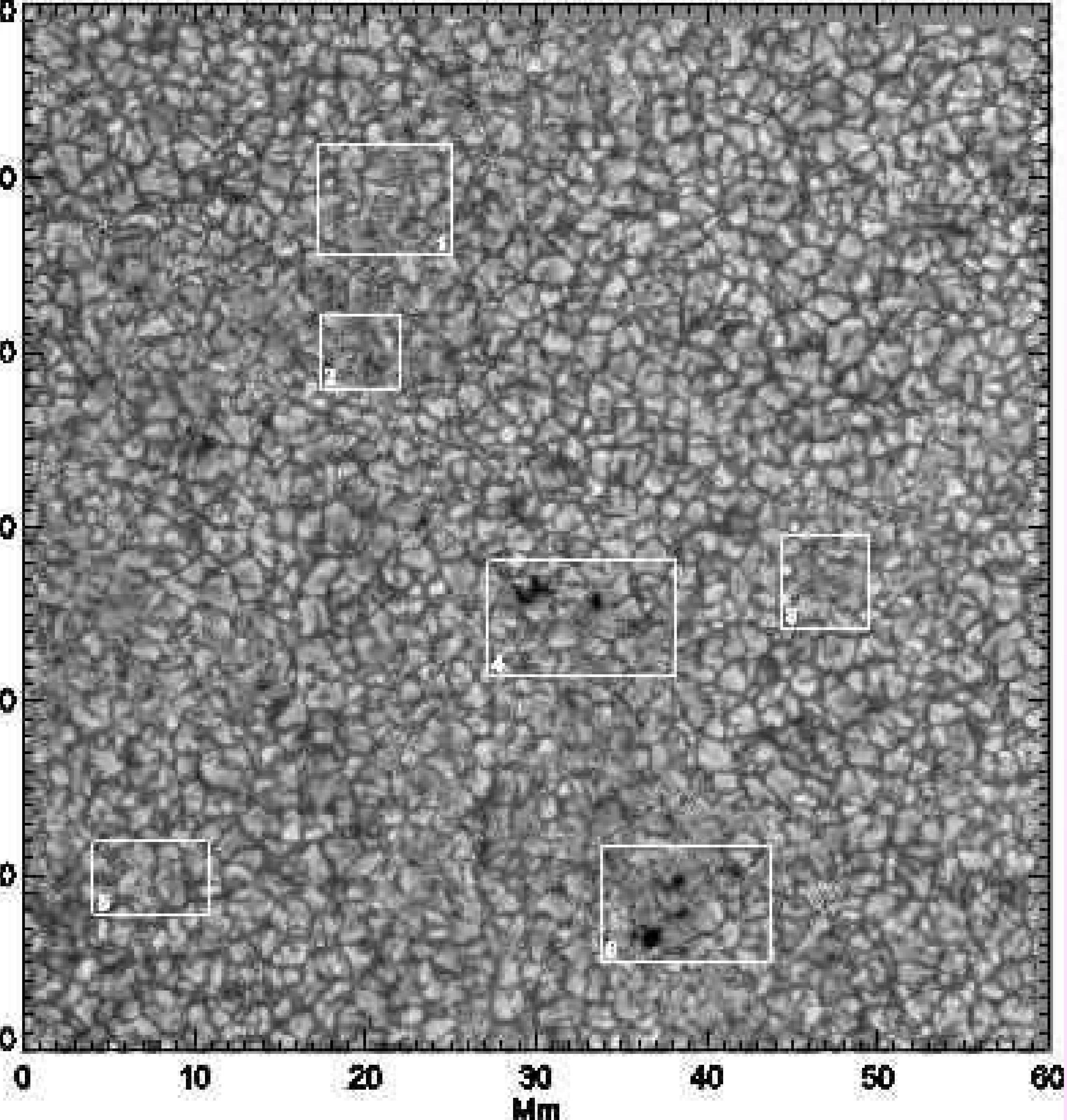
# MAGNETIC NETWORK

The magnetic network consists of vertical magnetic fields clumpe into elements or flux tubes with field strengths in the kilogauss rang and diameters of the order of 100 km (e.g. Frazer & Stenflo) at the *footpoints* located in the photosphere (although Berger et al. 200 suggest that the scenario may be more complex).

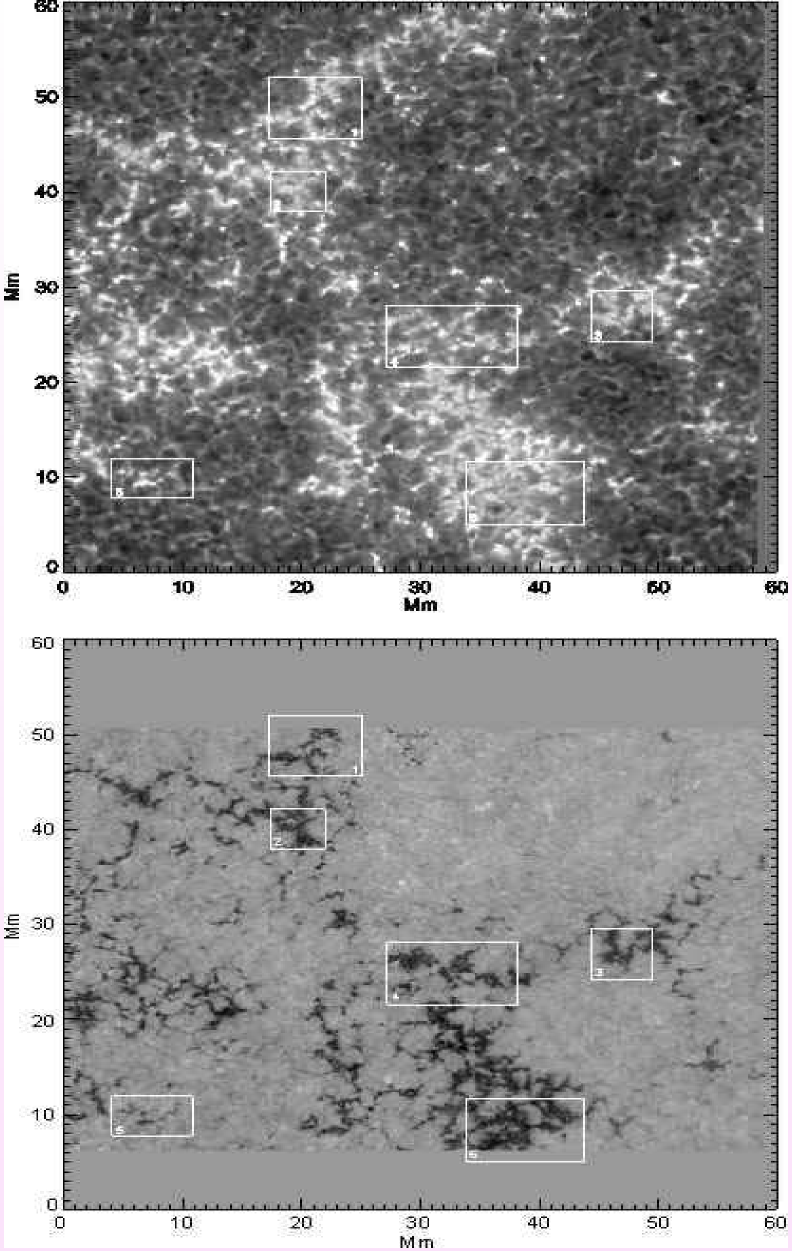
Magnetic elements can be identified with bright points in G-bar (4305 Å) images (e.g. Muller 1994, Berger et al. 1995, 1998, 2004 which are co-spatial with Ca II and TRACE (UV) structures (Rutte 1999).

High resolution observations suggest that these network bright poin (NBPs), located in intergranular lanes, are in a highly dynamical state, due to the buffeting effect of random convective motions (e.g. Muller et al. 1994; Berger & Title 1996).

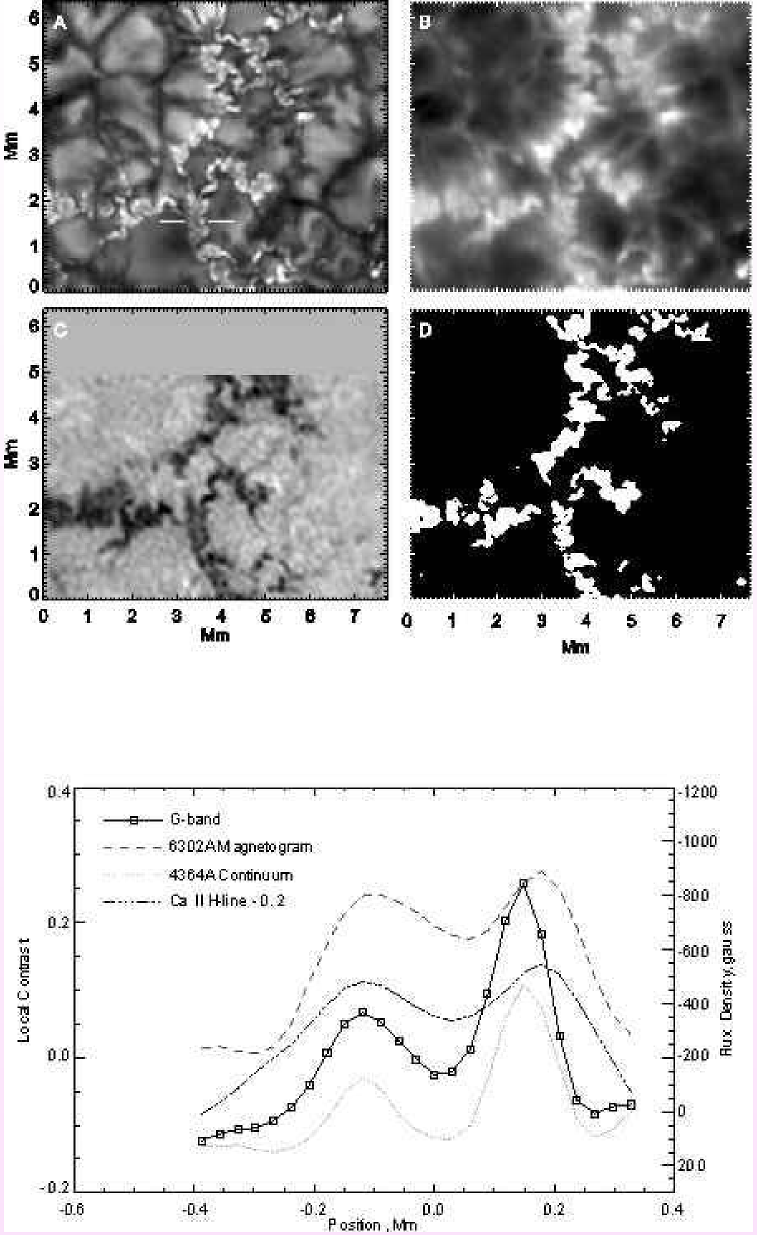
A histogram of the velocities of NBPs shows a mean speed of 1.4 km $s^{-1}$ but there were several instances of motions with speeds as high as 3 km $s^{-1}$ .



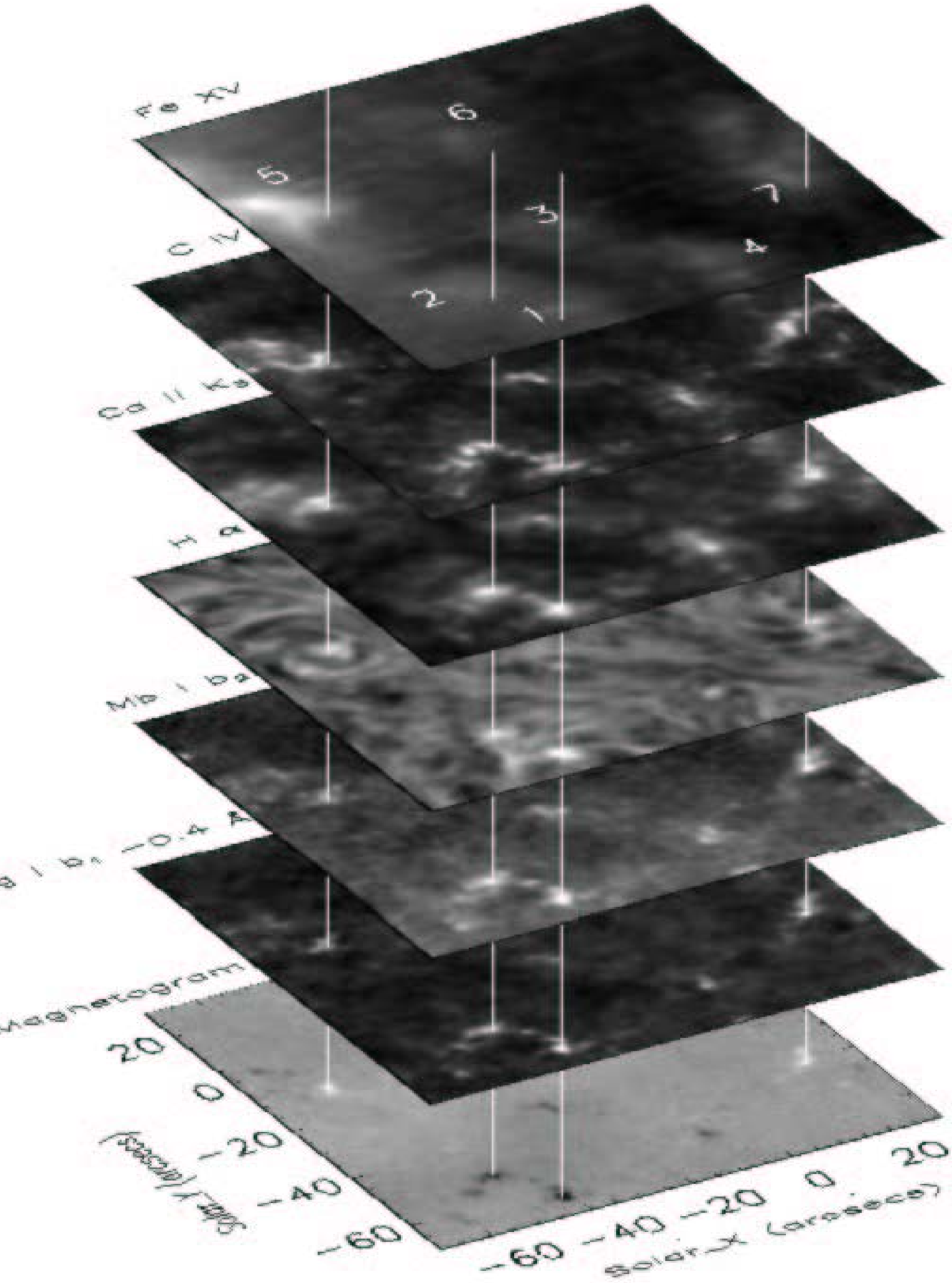
Remnant AR 1036 at heliographic co-ordinates S7 E4 (μ = 0.99) taken on May 25, 2003 in th 436.4 nm G-band continuum band-pass with the Swedish 1-m Solar Telescope on La Palma (Berger et a 2004).



mnant AR 10365 at heliographic S7 E4 (μ = 0.99)
p: Ca II (396.8 nm) H-line bandpass; Bottom: SOUP
lar Optical Universal Polarimeter) Fe I 630.5 nm
gnetogram (Berger et al. 2004)

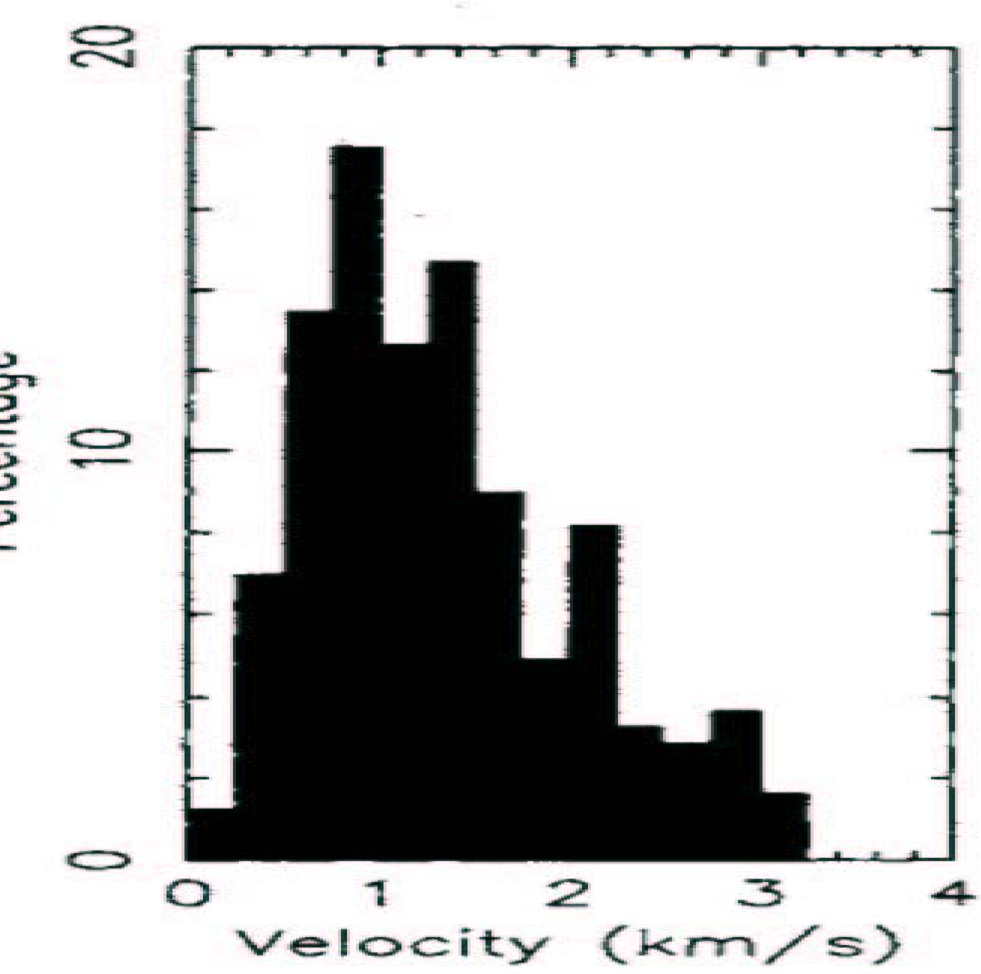


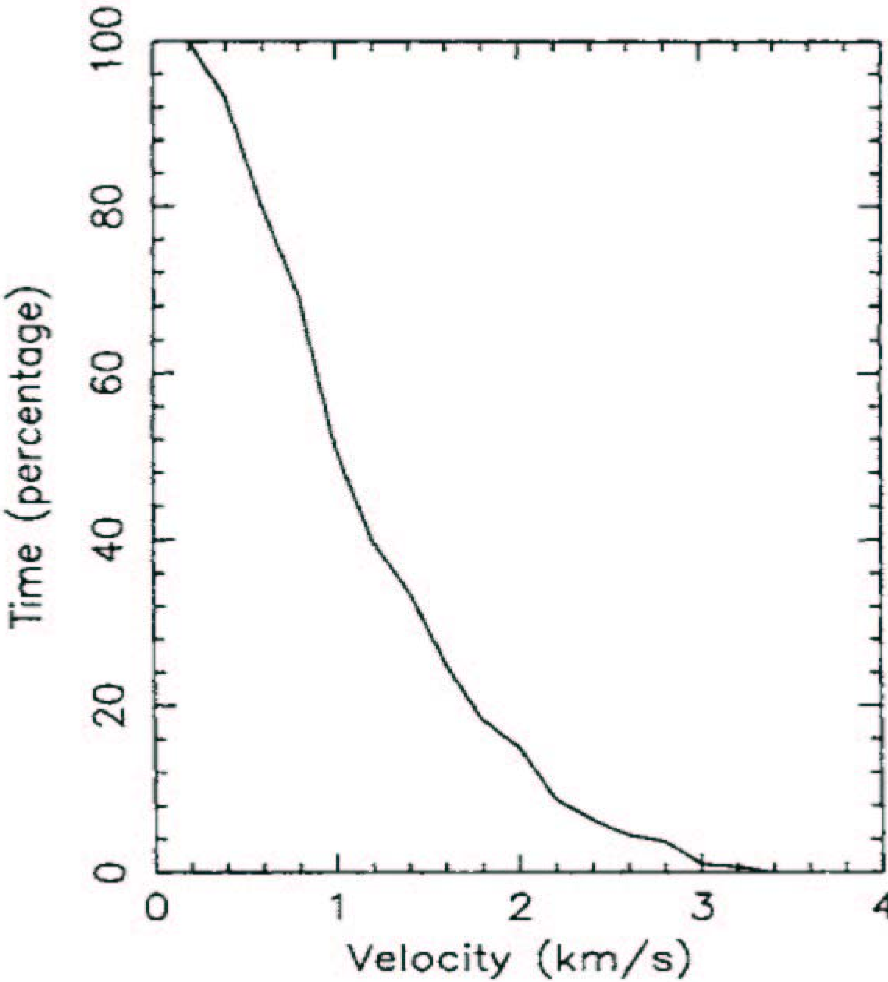
Top: Enlargement of Box 1 from a) G-band filtergram,
b) Ca II H-line filtergram, c) Fe I 630.25 magneto-gram
d) Binary mask of the G-band emission in panel a).
Bottom: Intensity plot along the white lines shown in



Time averaged data of a 10 x 100" field of view in th corona (EIT 284Å), transitic region (CIV 1500Å) and th chromosphere. The botto plot is the correspondir magnetogram. The vertic lines show four stable NBP The chromospheric NBF have a one to one spat correlation with th photospheric magnetic fie and exist throughout th transition region and th corona (after McAteer et a 2003)

# HISTOGRAM OF VELOCITIES COMPUTED ALONG NETWORK TRAJECTORIES (AFTER MULLER ’94)





alculation for 245 values: Mean is 3 km $s^{-1}$, standard deviation is 0.70 n $s^{-1}$

Percentage of times a given granule moves faster than a given velocity

# THEORETICAL BACKGROUND

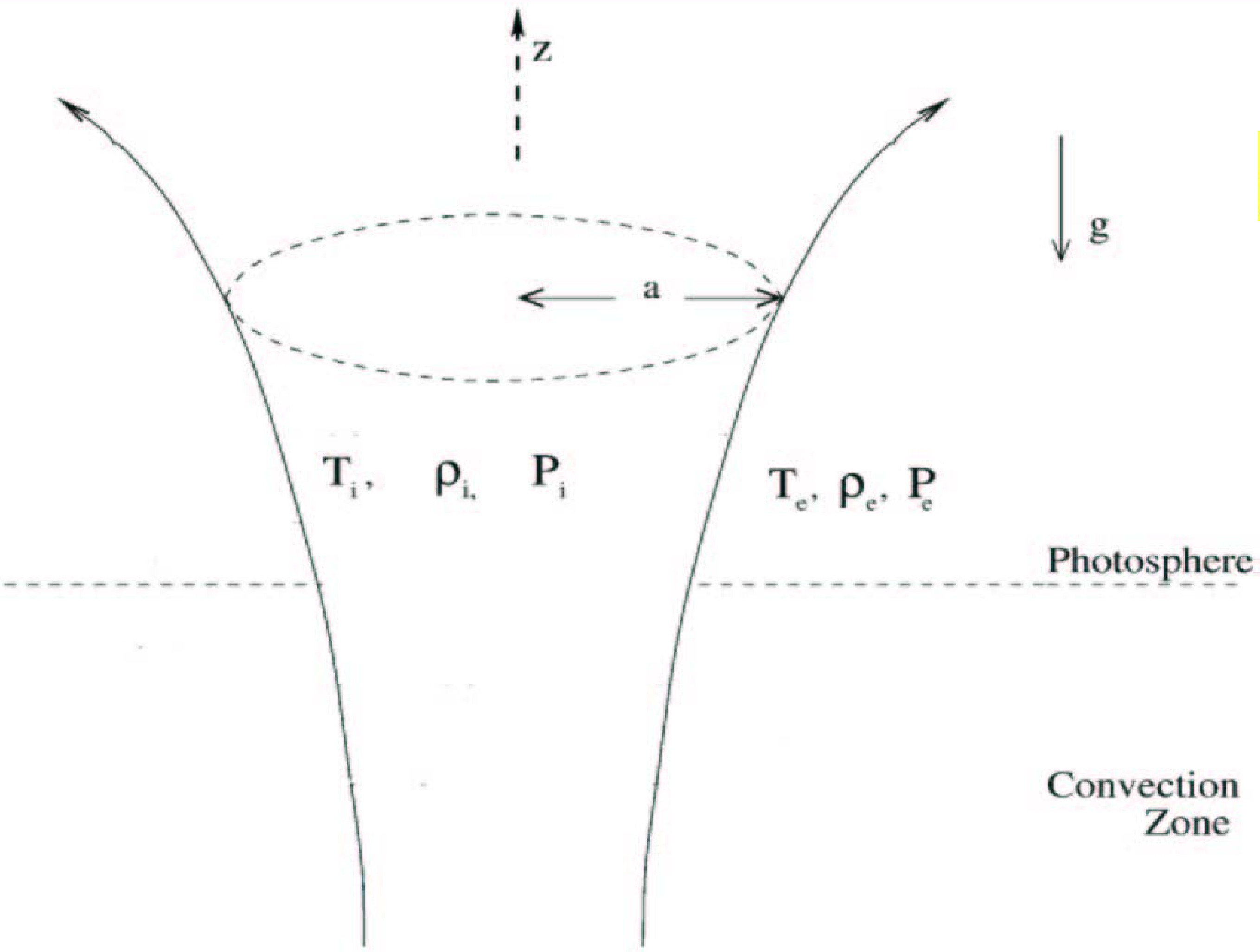
The magnetic field in the network can be idealized in term
of isolated vertical flux tubes which fan out with height, du
to the decrease in pressure with height. A flux tube ca
support various modes (e.g. *kink* or *transverse*, *sausage*
*longitudinal*, *torsional Alfvén* waves etc).

The earliest studies on MHD wave excitation use
extensions of the *Lighthill mechanism*. More recentl
several studied have examined the generation
longitudinal and transverse waves in a flux tube throug
turbulent motions in the convection zone.

An alternative scenario, based on the observations of Muller (1994 is that the excitation of transverse (kink) waves occurs through th footpoint motions of magnetic elements (e.g. Choudhuri et al. 199 Hasan & Kalkofen 1999). Rapid motions with velocities larger than km $s^{-1}$ can excite transverse oscillations which carry adequate energ for coronal heating.

Many numerical simulations of dynamical effects associated with th interaction of magnetic fields and convection have been carried o (e.g. Nordlund & Stein 1989, 1990; Nordlund et al. 1992; Steiner al. 1998, Vögeler & Schüssler 2003; Schüssler et al. 2003; Vögeler al. 2005). The simulations of Steiner et al. clearly show the bendi of flux sheath through the buffeting action of granules. Th interaction can excite MHD oscillations in the magnetic eleme which can propagate upwards and heat the chromosphere ar corona (Spruit 1981; Ulmschneider et al. 1999).

# LUX TUBE IN EQUILIBRIUM WITH THE AMBIENT MEDIUM



**Pressure balance:**

$$p_i + B^2/8\pi = p$$

**Hydrostatic Equilibrium:**

**(isothermal medium)**

$$p = p_0\, e^{-z/}$$

$$B = B_0\, e^{-z/2}$$

**Flux conservatio**

$$A = A_0\, e^{z/2H}$$

ux tube extending vertically through the photo-
here and convection zone

# ENERGY SOURCE FOR HEATING NBPs

Kink waves generated inside flux tubes by the buffeting action granules (Choudhuri et al 1993; Hasan & Kalkofen 1999) or turbule motions (Huang, Musielak & Ulmschneider 1995);

Longitudinal waves generated either by pressure fluctuations insi flux tubes (Ulmschneider et al. 1991); or through nonline conversion of kink waves (Hasan et al. 2003);

Torsional (Alfvén) waves generated inside flux tubes (Nob Musielak & Ulmschneider 2004);

Acoustic waves, generated in the field-free atmosphere surroundi the flux tubes, that can penetrate into the tubes;

Acoustic-like waves generated at the interface of flux tubes and t ambient medium that also penetrate into the flux tubes.

# MODEL OF A NETWORK ELEMENT

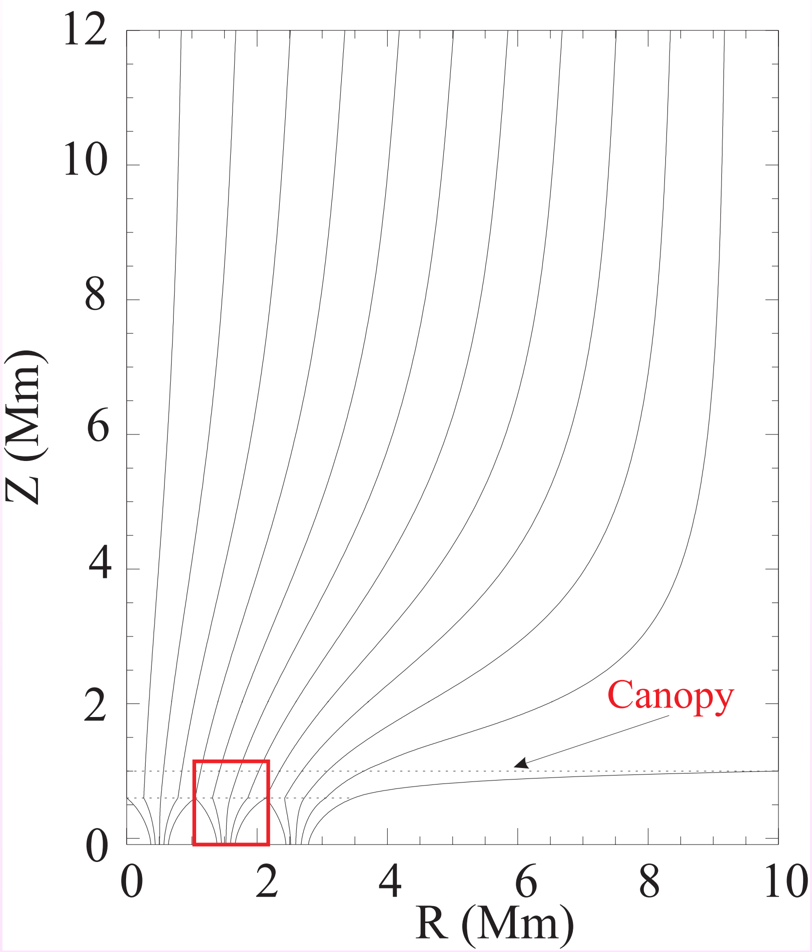
## he network field structure consists of three distinct regions:

Photospheric region up to about 600 km, consisting of individua flux tubes, with a typical diameter of about 100 km in the low photosphere. The flux tubes are rooted in intergranular lanes and are separated from one another by about the diameter of a granule (~ 1000 km). The tubes expand upward and merge with thei neighbours at a height of about 600 km;

Lower chromosphere (600-1000 km) where the merged network flux element expands laterally over the surrounding supergranular cell centre and overlying field free chromosphere;

Upper chromosphere (1000-12000 km), the fully merged magnetic field fills the available volume. At larger heights the field expands primarily in the vertical direction and becomes practically uniform However, at lower heights (1000-2000 km), the field strength varies significantly with horizontally position and the field strength above the tubes is much larger than that above the supergranular cel centre.

# MODEL OF A NETWORK ELEMENT

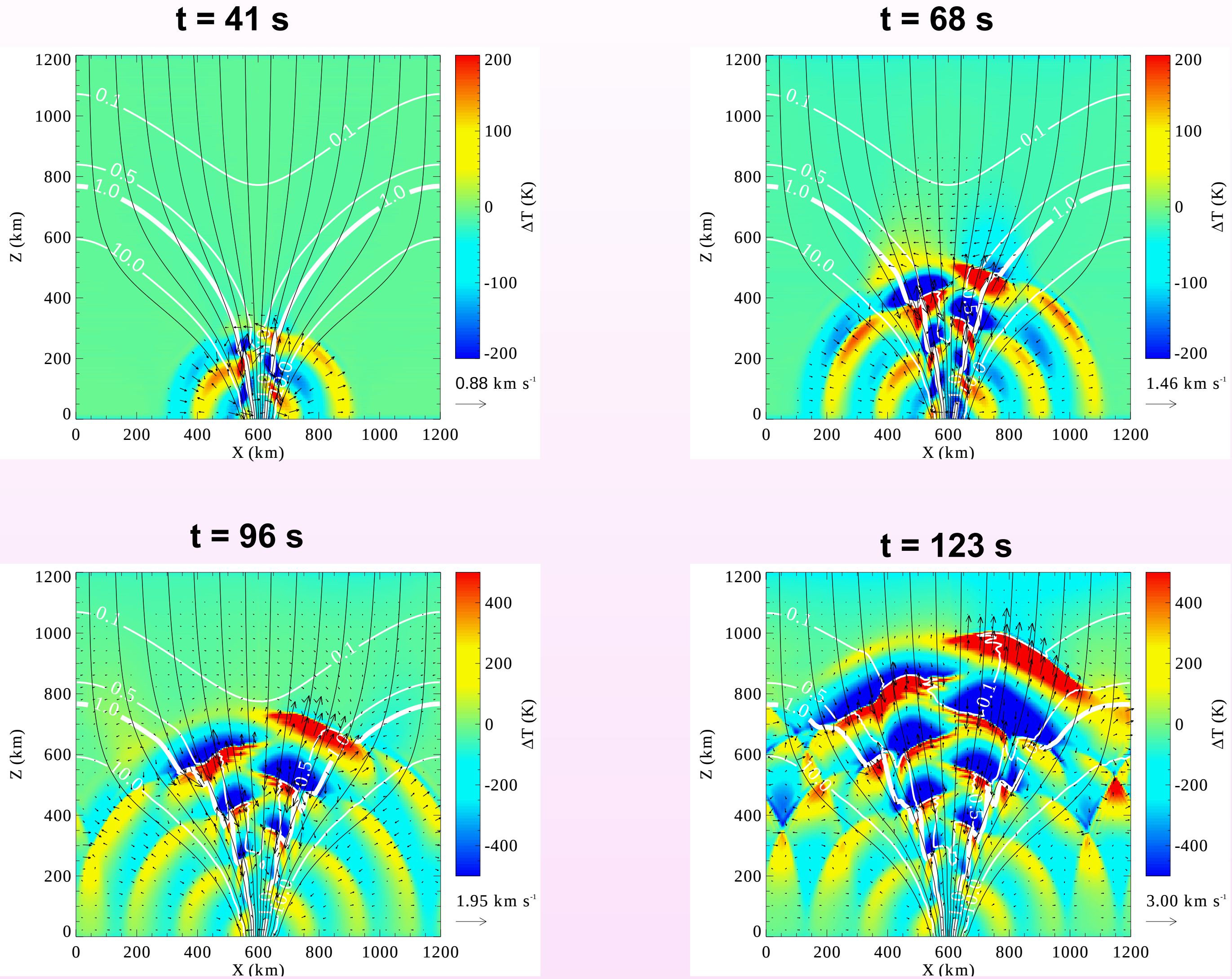


**twork element (typical flux tube ~ 3 $10^{19}$ Mx) as a collection of smaller flux tubes spatia parated from each other in the photosphere. Neighbouring tubes within the network eleme rge into a monolithic structure at a height of about 600 km. The outer edge of this tube form *gnetic canopy*. A second merging occurs when neighbouring network elements come together anopy height (after Cranmer and van Ballegoiijen 2004).**

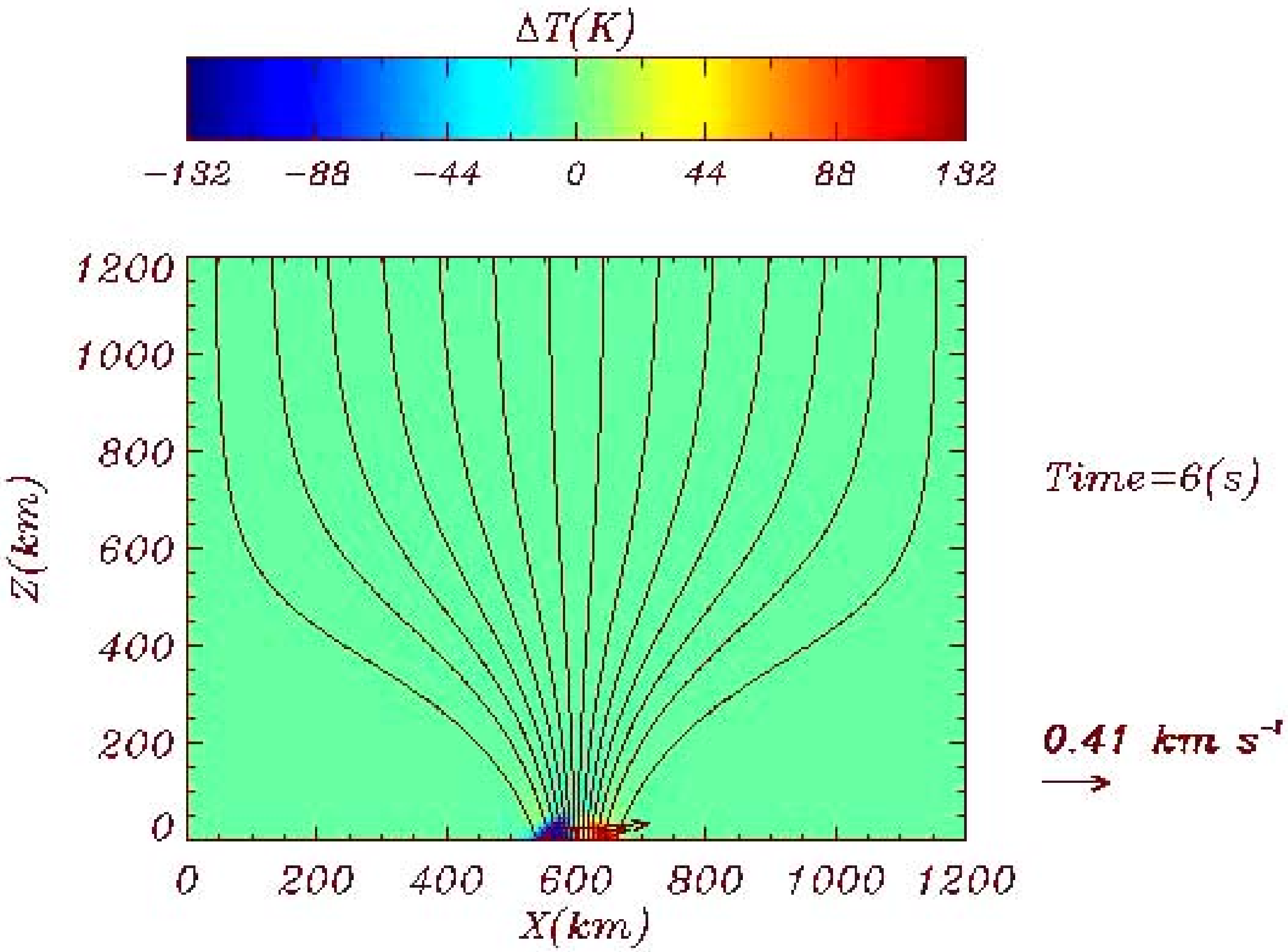
# ARAMETERS ON THE TUBE AXIS & AMBIENT MEDIU

| | Tube Axis | | Ambient Medium | |
|---|---|---|---|---|
| Variable | Base | Top | Base | Top |
| Temperature | 4800 K | 8200 K | 4800 K | 8200 K |
| Sound speed | 7.1 km s$^{-1}$ | 12 km s$^{-1}$ | 7.1 km s$^{-1}$ | 12 km s$^{-1}$ |
| Alfvén speed | 11 km s$^{-1}$ | 92 km s$^{-1}$ | 0.3 km s$^{-1}$ | 52 km s$^{-1}$ |
| Magnetic field | 1400 G | 100 G | 70 G | 100 G |
| β **(ratio of gas to magnetic pressure)** | 0.5 | 0.02 | 600 | 0.06 |

# Flow pattern and Temperature perturbation: *Periodic excitation*

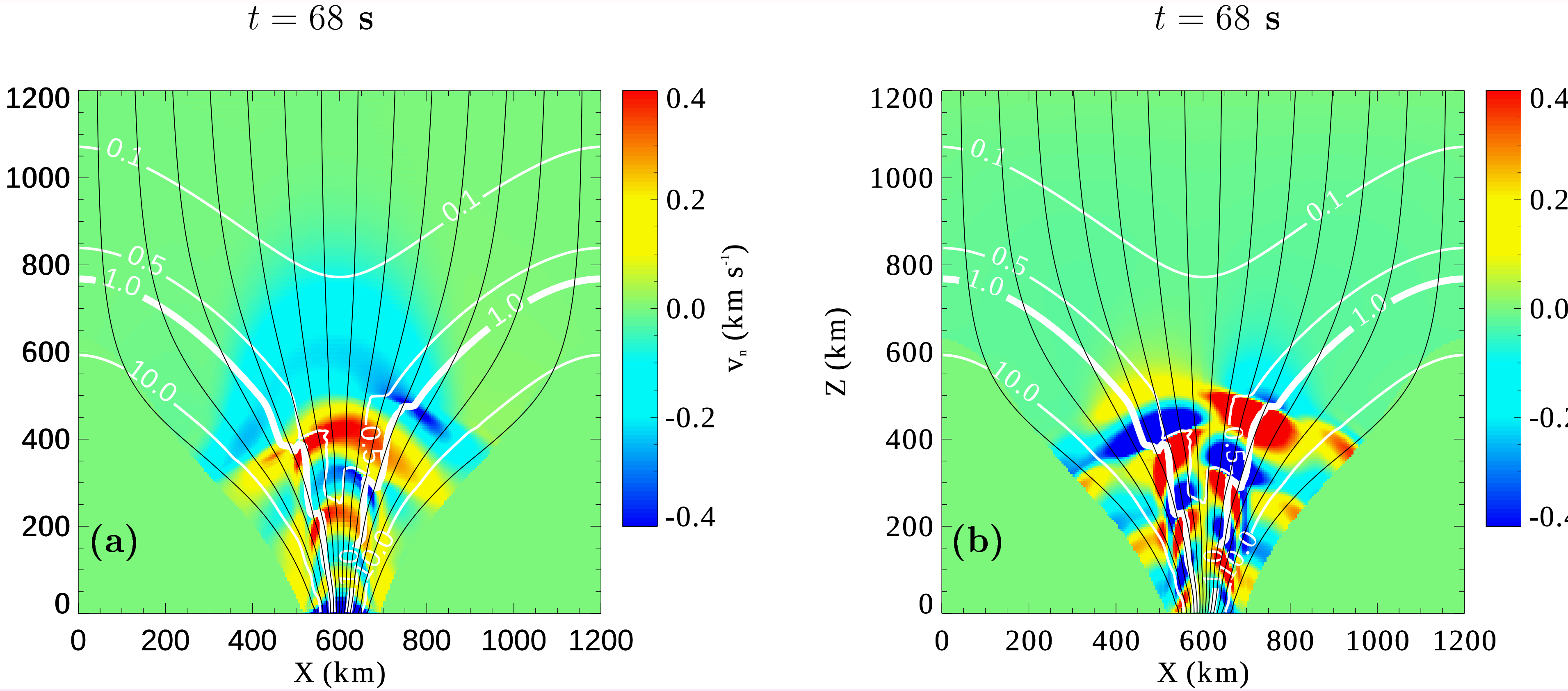


w pattern (arrows) and ΔT at a) 41 s, b) 68 s, c) 96 s and d) 123 s in a network element due to a hori-zontal iodic motion at the lower boundary with an amplitude of 750 m s$^{-1}$ and a wave period P=24 s. Thin black curve note the field lines and white curves are contours of constant β – the thick white curve corresponds to β=1.0.


ΔT(K)
−132
−88
−44
0
44
88
132
1200
1000
800
600
400
200
0
Z(km)
0
200
400
600
800
1000
1200
X(km)
Time=6(s)
0.41 km s⁻¹

**Mov**

# VELOCITY COMPONENTS IN A NETWORK ELEMENT



**locity components a) $V_n$, normal to the field, and b) $V_s$, along the field at $t$ = 68 s in a
twork element due to a horizontal motion at the lower boundary with an amplitude of
0 m s$^{-1}$ and a period of $P$ = 24 s. The thin black curves are the magnetic field lines an
e white curves denote contours of constant β, corresponding to β=0.1, 0.5, 1.0 (thick
rve) and 10.**

# Discussion

Horizontal motion of the flux tube at the lower boundary
a source of acoustic waves at the interface, and in th
ambient medium they propagate isotropically.

Near the axis, fast modes propagating upwards at the loc
Alfvén speed are generated. The fast mode shows a
asymmetry in propagation since the Alfvén speed is large
on the axis and decreases horizontally. The increase
separation in the vertical direction between the colo
peaks shows the increase in wave-length with height.

Away from the axis (where $\beta \geq 1$), the compressions ar
decompressions of the gas generate acoustic like mode
(180° out of phase on opposite sides of the tube axis) th
are guided along the field lines.

These waves steepen with height and heat the upp
atmosphere of the flux tube.

# SUMMARY

This investigation marks the beginning of recent attempts to study the dynamics the magnetic network that go beyond the 1-D *thin tube approximation* and use more realistic treatment that is representative of the field structure in the network.

Impulsive transverse driving motions at the lower boundary lead to pressu perturbations in the field free medium at the tube interface. This is an efficie mechanism for generating vortical motions and longitudinal pulses in the tube. T observational signature associated with vortex formation would be the prediction simultaneous upward and downwards motions on opposite sides of flux tubes

Periodic motions at the lower boundary generate fast and slow waves inside t flux tube. Modes generated in the β>1 region of the tube, undergo mo conversion as they propagate upwards.

A new feature of this work is the identification of an effective mechanism acoustic wave emission at the tube edge. This can have interesting consequence these waves, propagating isotropically will impinge on neighbouring flux tubes a excite waves in them.

An efficient method has been demonstrated by which transverse motions transferred into longitudinal ones ------- the latter steepen with height, form shoc and heat the chromosphere.

# THANK YOU