

# Waves in the corona

Philip Judge, HAO

- Ideal MHD waves
- Observations
- Their meaning
  - popular interpretations
  - problems
- Conclusions

May 8 2008



NCAR

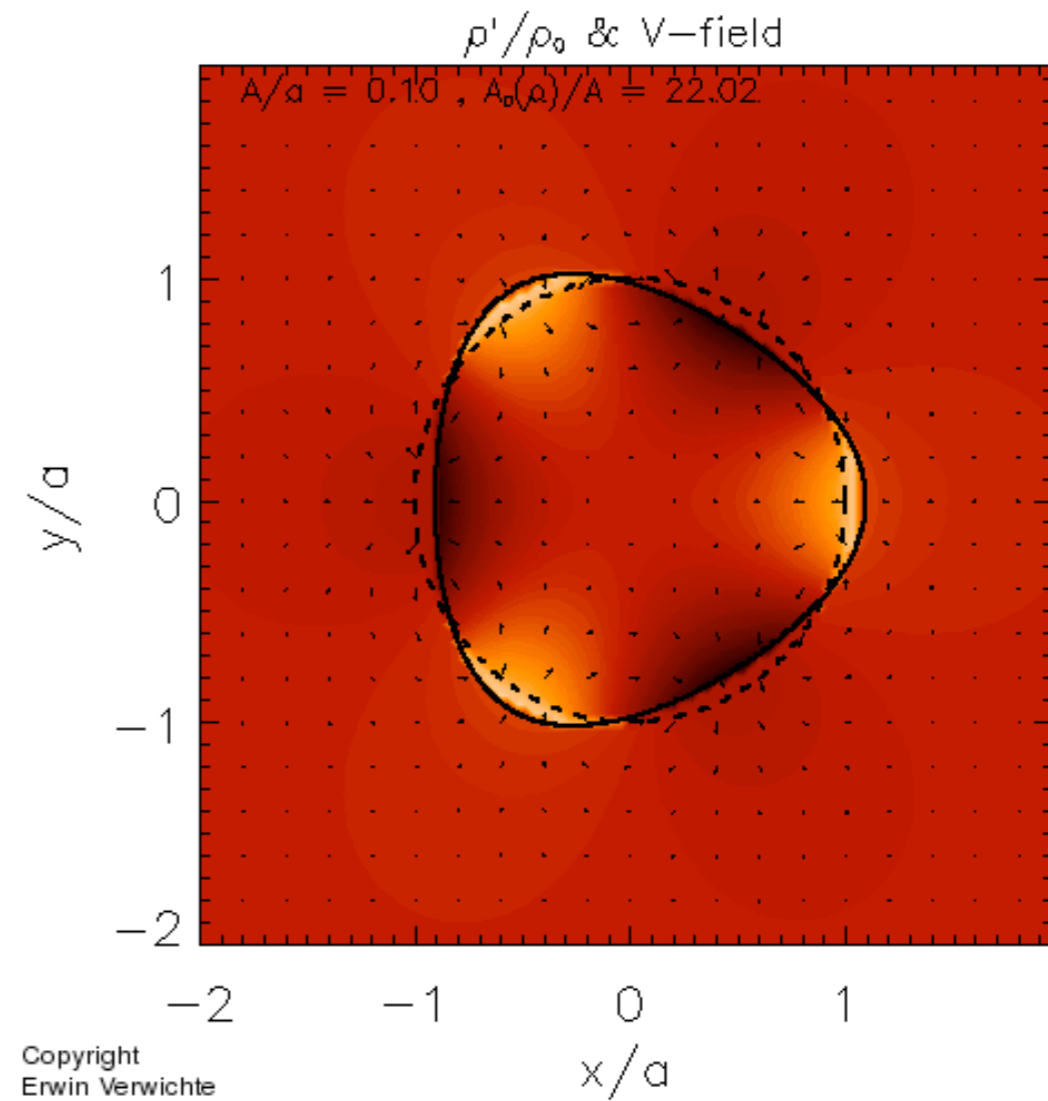
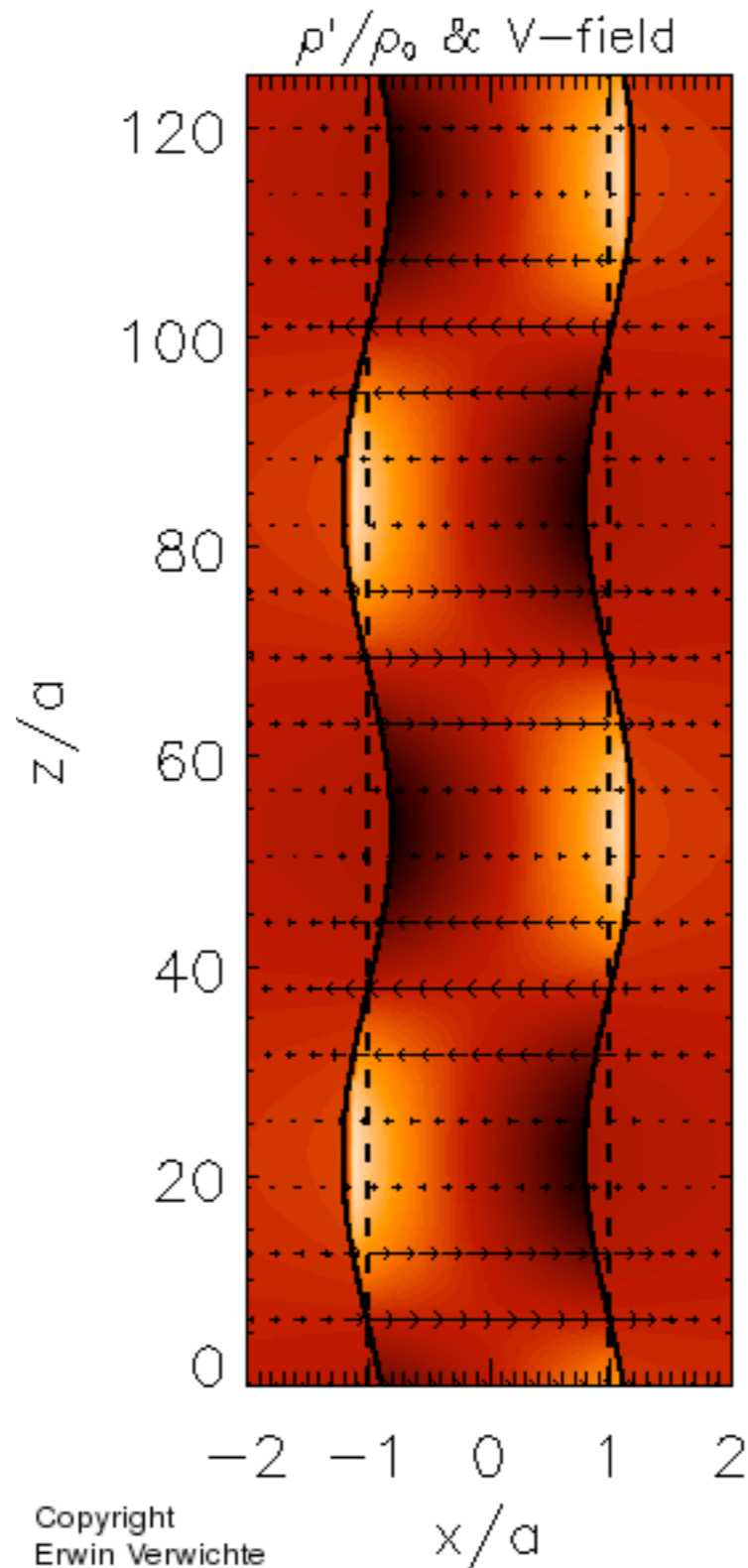
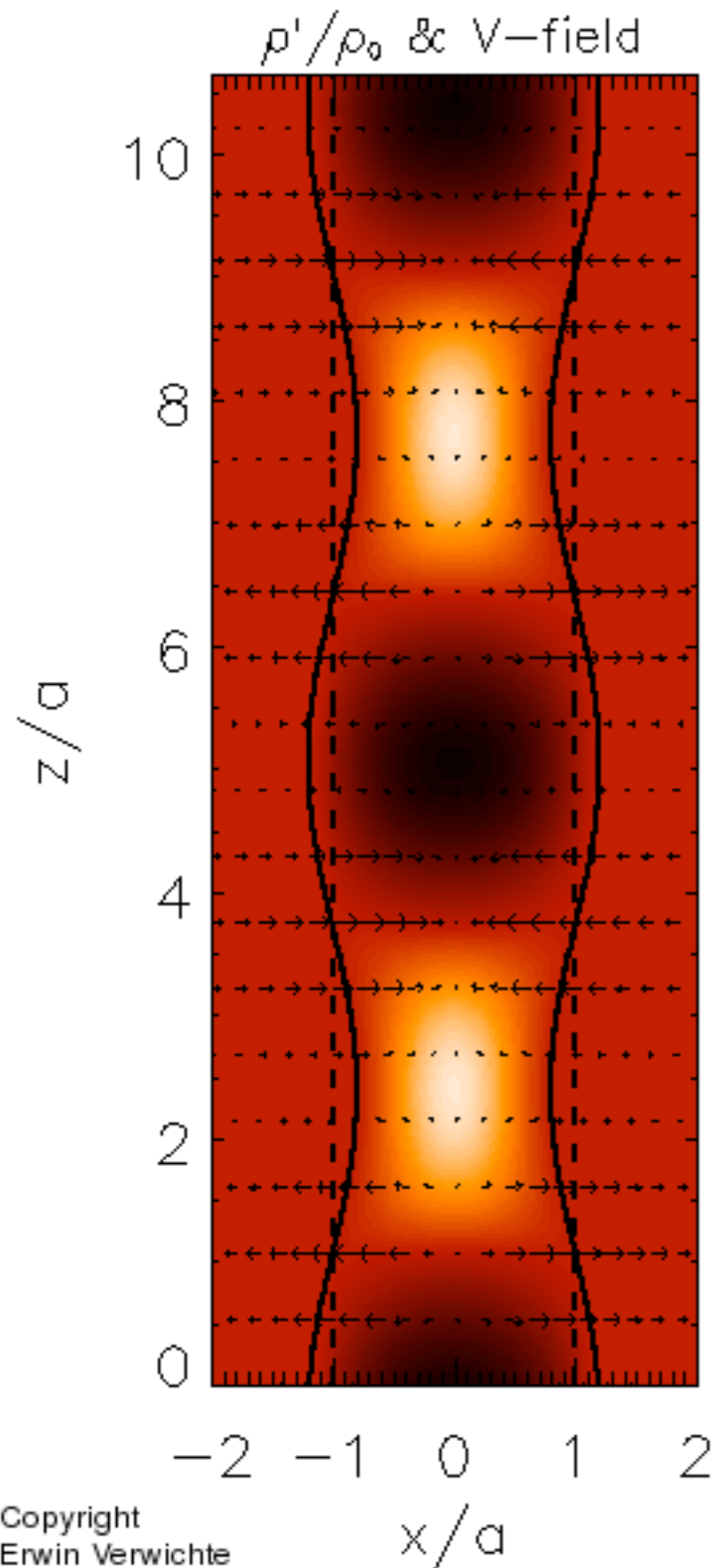
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# Ideal MHD waves

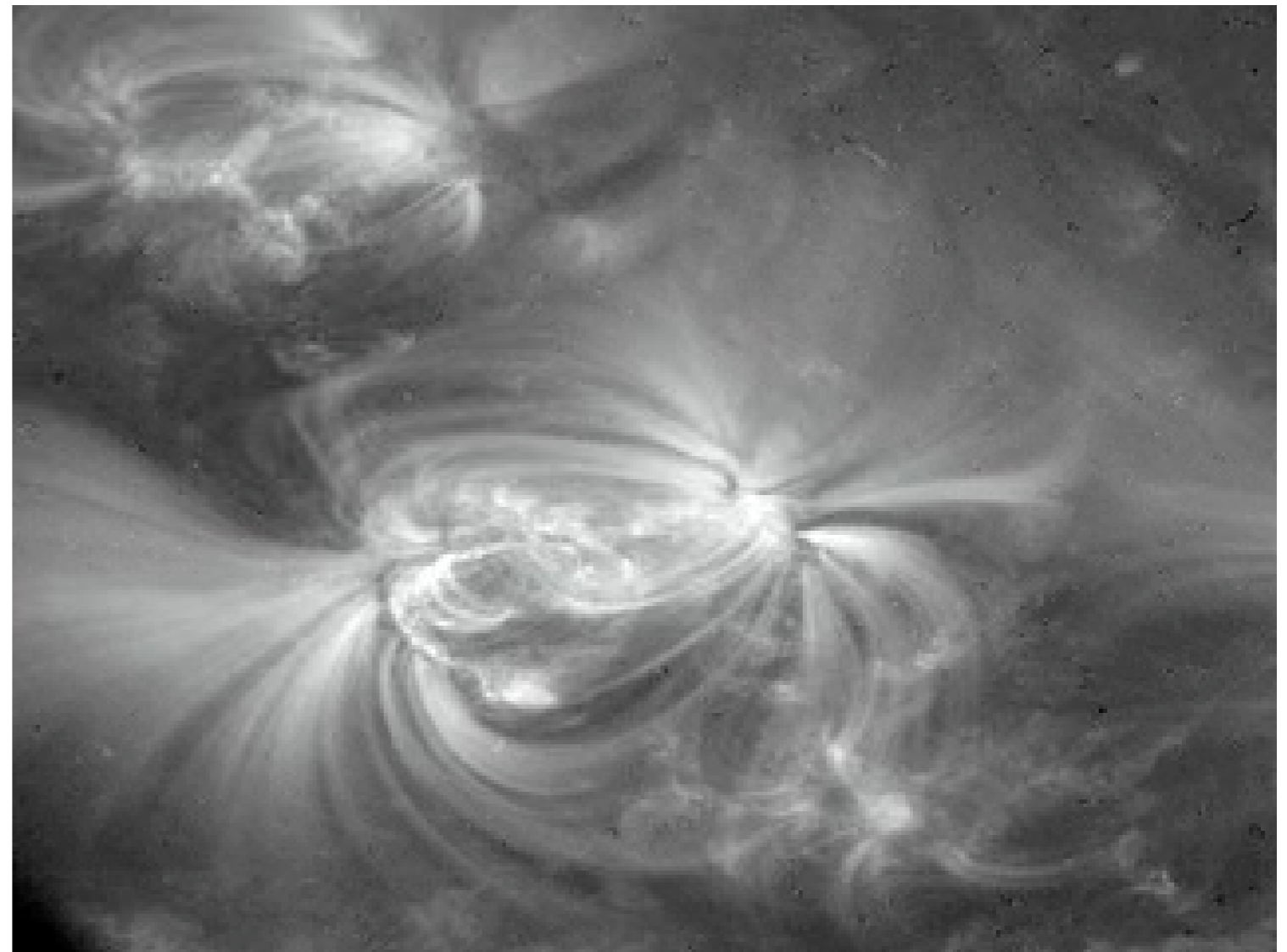
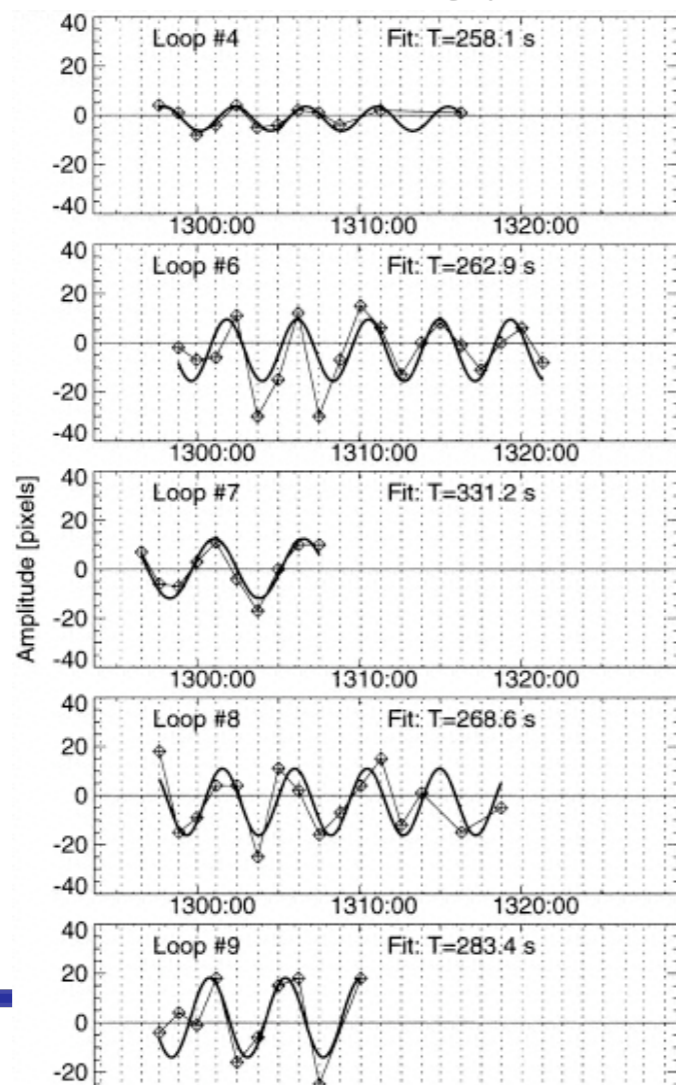
- linearize eq. motion in specific symmetries:
- **Homogeneous**: plane waves (Alfvén 1942...Banos 1955)
  - slow, fast, intermediate (Alfvén)
  - $j \times B \Rightarrow$  asymmetry, decoupling
- **Cylindrical**: Bessel functions (Wilson 1970s...Edwin & Roberts 1983)
  - localized to tubes (finite energy)
  - magnetoacoustic
    - $m=0$  “sausage”,  $m=1$  “kink”,  $m=2$  “fluting”
  - “Alfvén”: torsional
- **General**: nasty coupled set of PDE’s
  - J. Thomas 1983
- Weakly nonlinear: mode conversion, dissipation...
  - Melrose (1977)...

# Tube waves



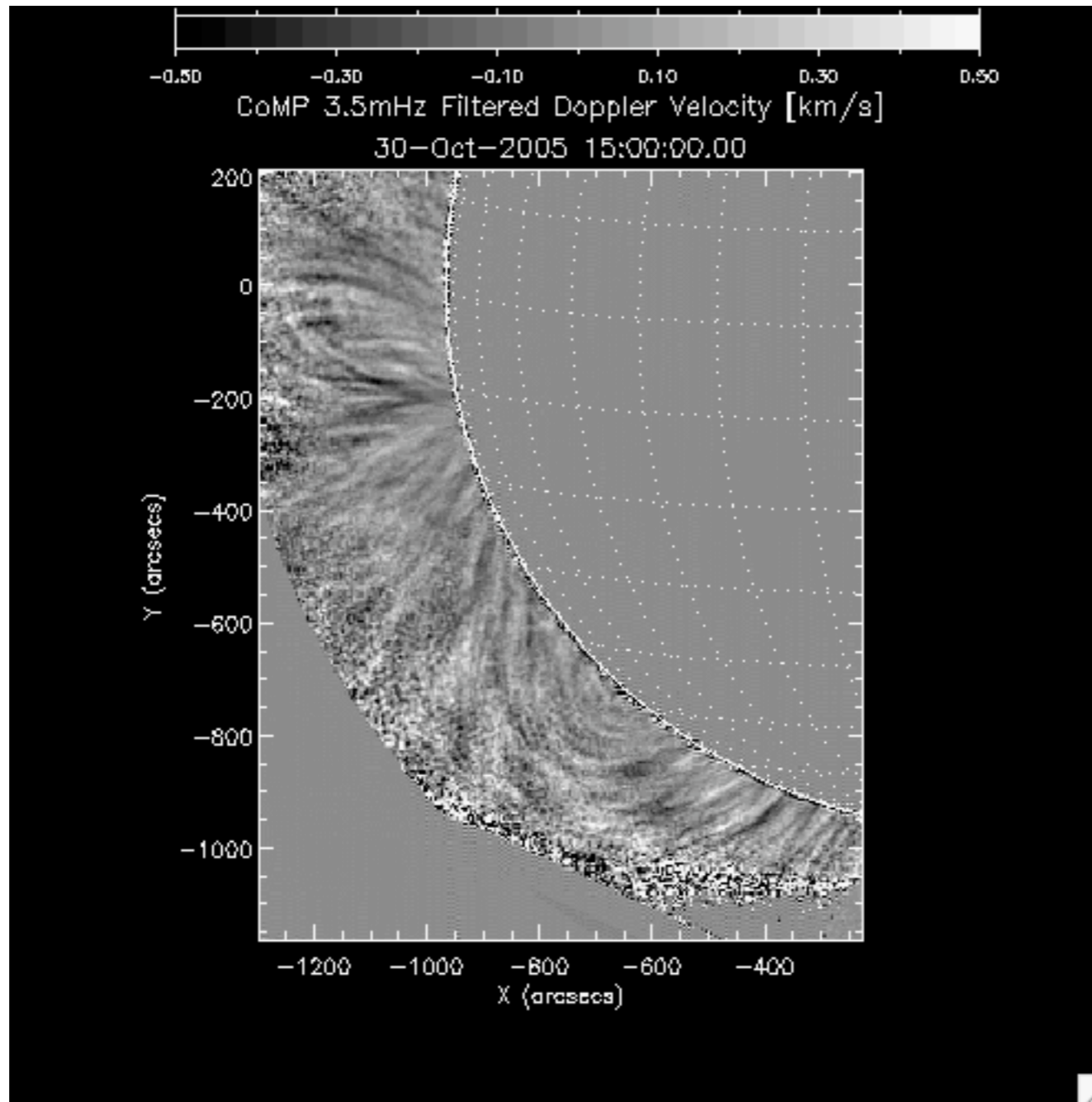
# Flare induced oscillations

- Aschwanden et al 1999
- Damped oscillations
- $P \sim 5$  min, decays 20 min
- $P$  indep. of “loop” length
- “coronal seismology”



# CoMP (Tomczyk et al 2008)

- “Doppler polarimeter” filter instrument
- Alfvénic fluctuations in/around a prominence cavity

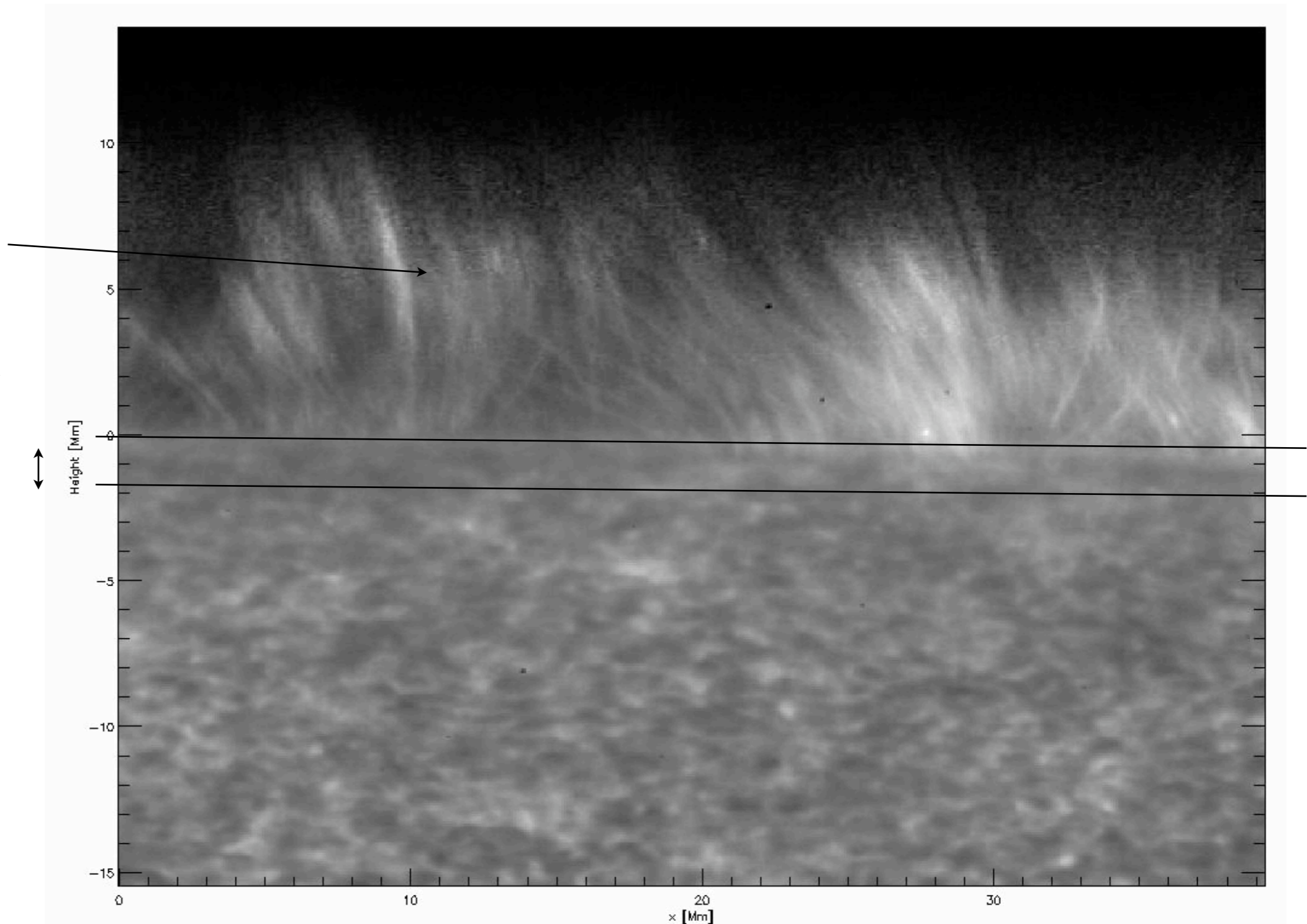


# Oscillating Spicules

- Hinode data (radial filter to enhance spicules, M. Carlsson)
- “base” of the corona (coronal hole in this case)

*spicules arise from within the chromosphere*

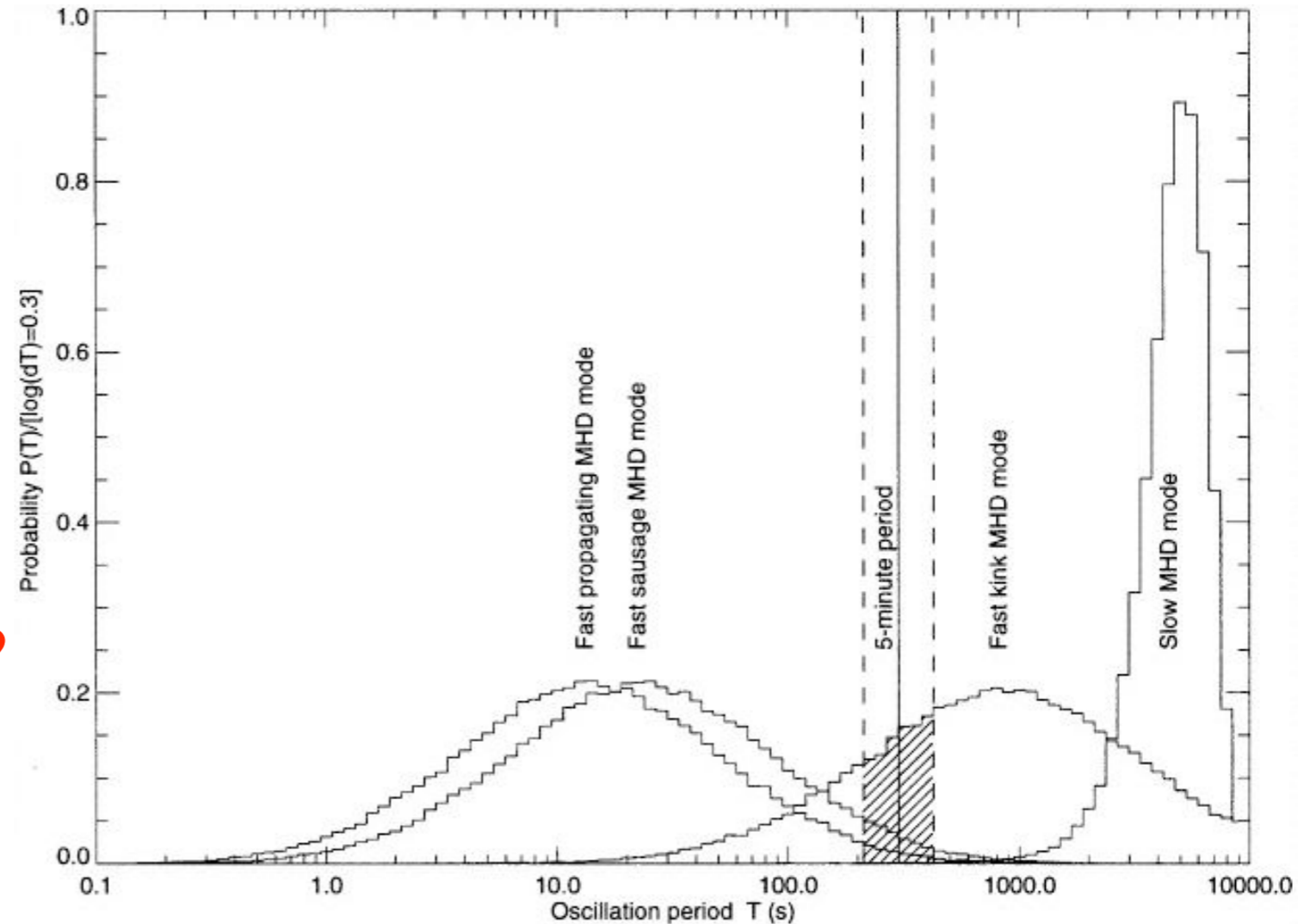
stratified VAL  
chromosphere  
1.5Mm only



# **Some recent work**

# Achwanden et al 1999

- Probabilities of finding standing wave modes at observed frequency
- “kink mode” likely
- But:
  - assumes loop geometry
  - freq. vs. L independence
  - not a standing tube wave
  - **what’s between the loops?**





# Living review:

## Coronal Waves and Oscillations

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### Abstract

Wave and oscillatory activity of the solar corona is confidently observed with modern imaging and spectral instruments in the visible light, EUV, X-ray and radio bands, and interpreted in terms of magnetohydrodynamic (MHD) wave theory. The review reflects the current trends in the observational study of coronal waves and oscillations (*standing kink, sausage and longitudinal modes, propagating slow waves and fast wave trains, the search for torsional waves*), theoretical modelling of interaction of MHD waves with plasma structures, and *implementation of the theoretical results for the mode identification*. Also the use of MHD waves for remote diagnostics of coronal plasma - MHD coronal seismology - is discussed and the applicability of this method for the estimation of coronal magnetic field, transport coefficients, fine structuring and heating function is demonstrated.



# “Consensus” 2008

## Analytic approximate seismology of transversely oscillating coronal loops

M. Goossens<sup>1</sup>, I. Arregui<sup>2</sup>, J. L. Ballester<sup>2</sup>, and T. J. Wang<sup>3</sup>

“There is general consensus that the TRACE oscillations are fast standing kink mode oscillations”

32 “coronal seismology”  
ADS articles since 2000

The authors proceed to develop a theoretical basis for the seismic investigation of coronal magnetic structure, based on the *assumption* that the modes are kinks.

This assumption seems to be rooted in the idea that “**plasma loops**” correspond to magnetic flux tubes. Few question this idea.



# A “news flash”

## •Solar Corona Is Both Hot And Kinky

- Astrophysicists are having a heated debate over the wave structure of the Sun's Corona - a debate which may one day influence solar weather forecasting and the theory behind fusion reactors.
- Last year American scientists thought they had cracked this [coronal heating] paradox with research showing how high-energy Alfvén wave structures could super-heat the Corona.
- The astrophysicists said they could detect Alfvén waves within the Corona - waves that have a corkscrew motion along the magnetic field at supersonic speed.
- However, scientists at the University of Warwick say these are well known and earlier discovered magneto-acoustic kink waves.
- Dr ... explains; "We interpret the data differently. They think they're looking at an Alfvén wave, but in fact they are looking at Kink wave.
- "Moreover, because the scientists from Boulder Colorado identified the wrong kind of wave all of their subsequent calculations are out. And, sadly, it means the question of why the Corona is hot remains unanswered".

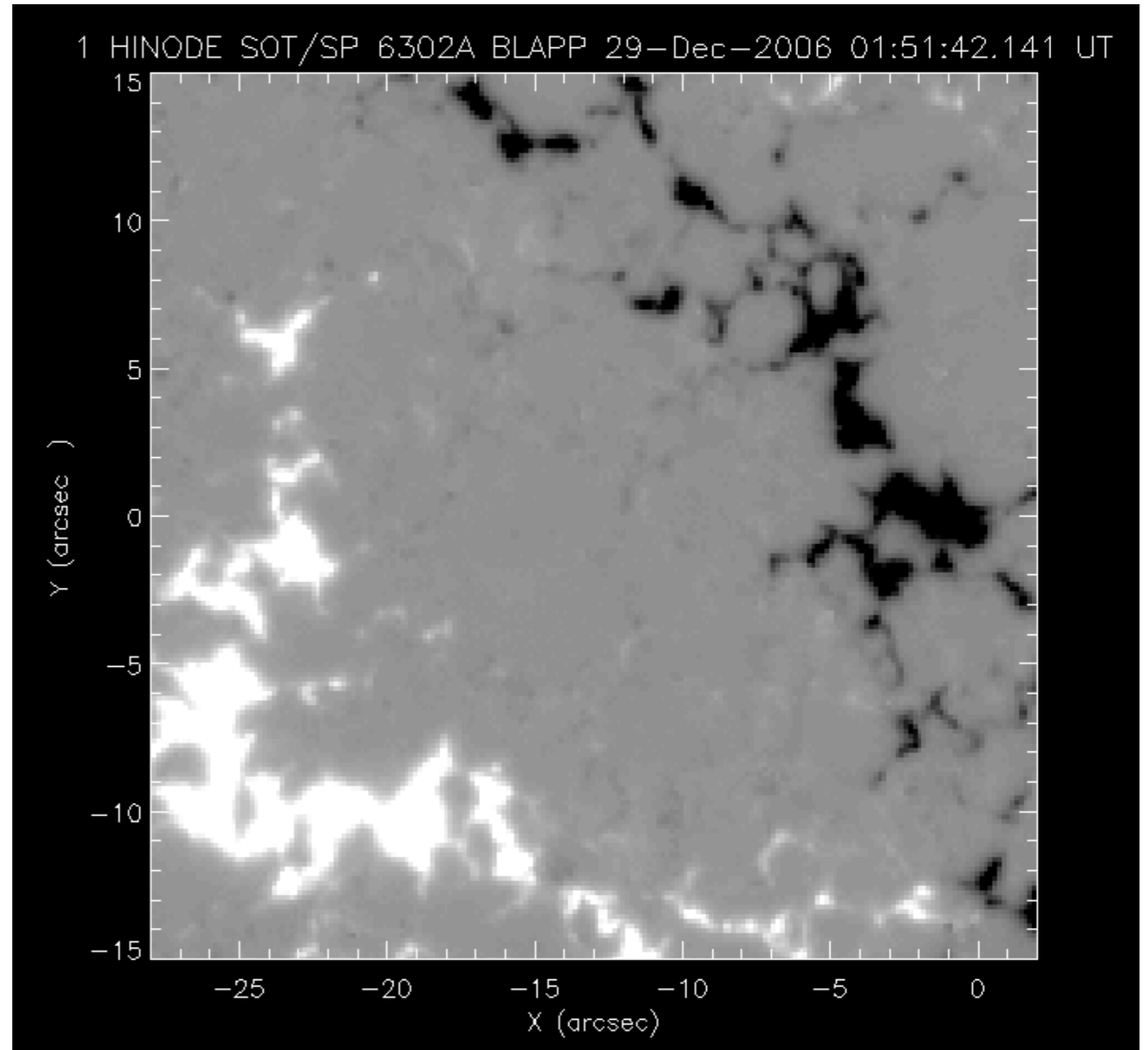


# Some problems



# How does the sun make **cylindrical** plasma loops in the corona?

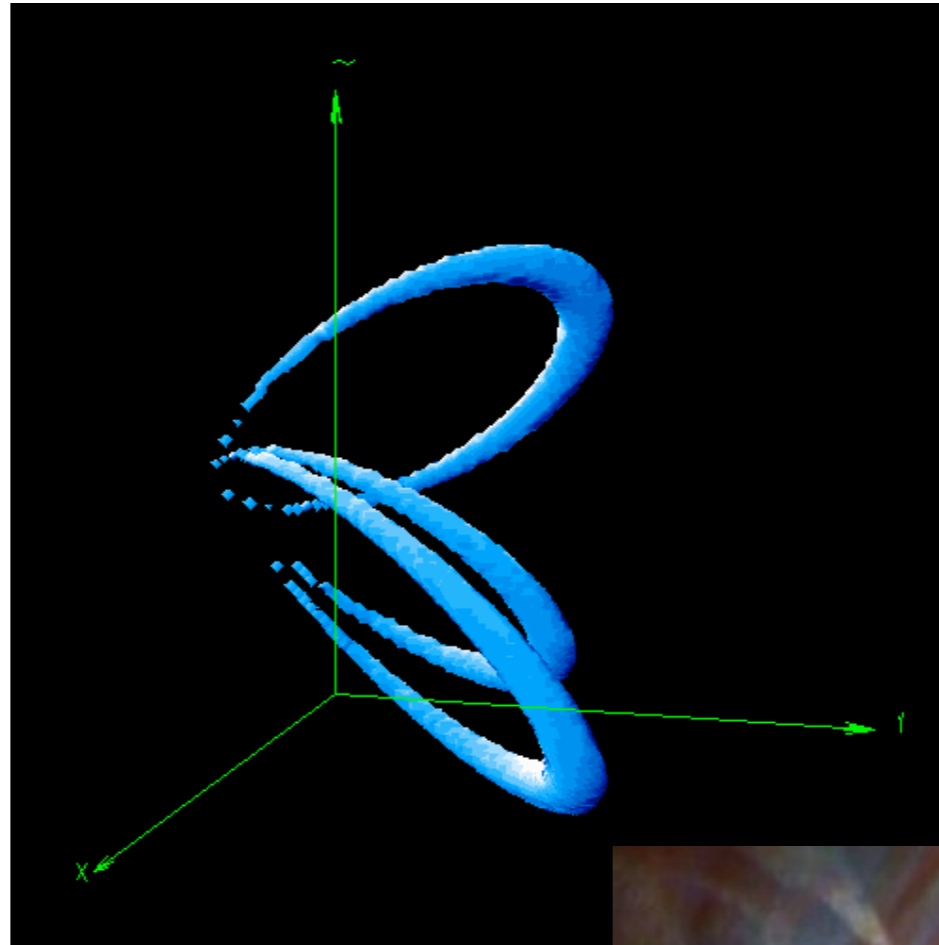
Are we to believe that sources at the surface can lead to ~cylindrical coronal loop structures?



# Potential “loops”

Localized sources  
produce loop expansion  
( $\text{div } \mathbf{B}=0$ )

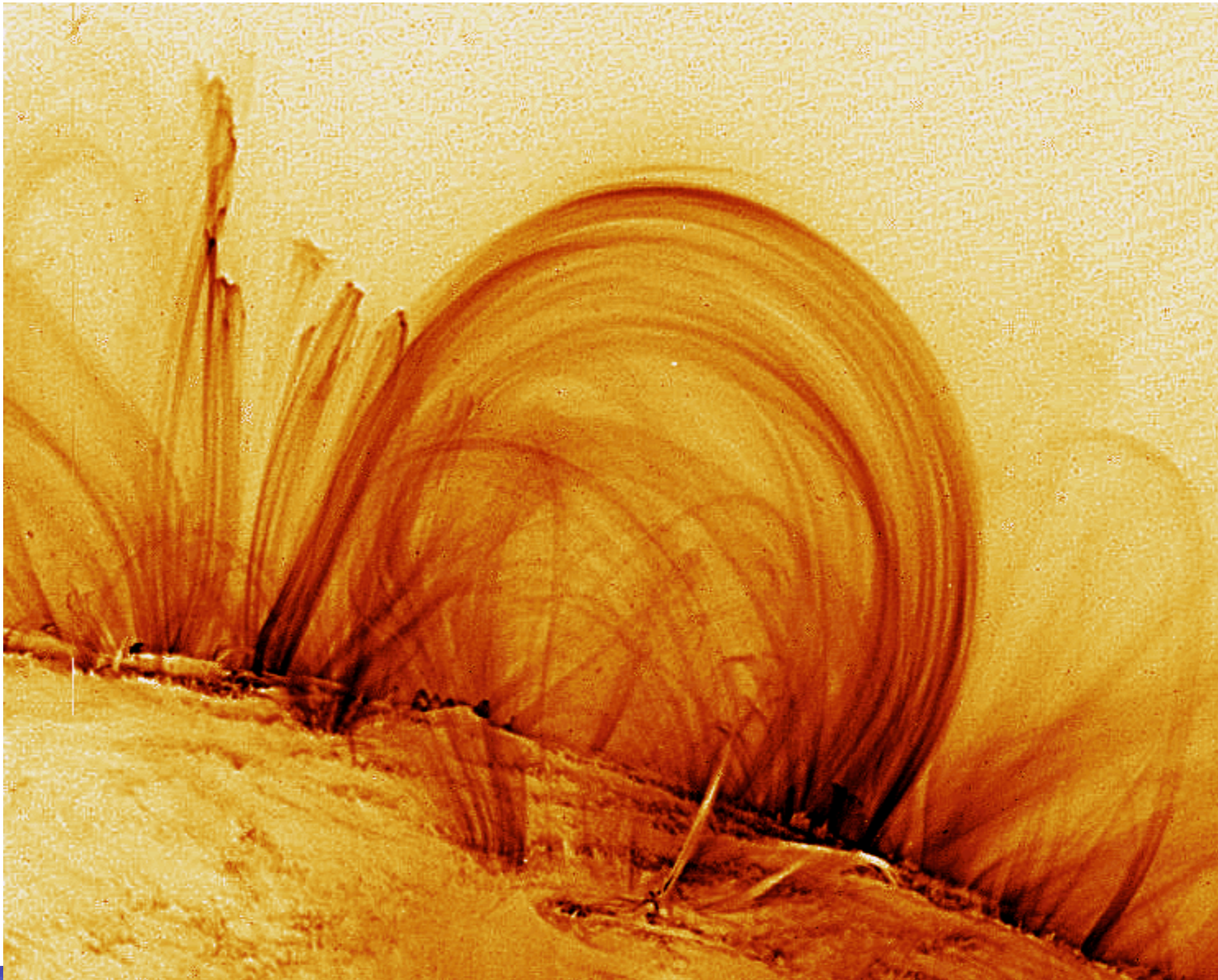
This expansion is  
routinely seen in the  
corona



Oscillating TRACE  
loops appear not to be  
of this ilk

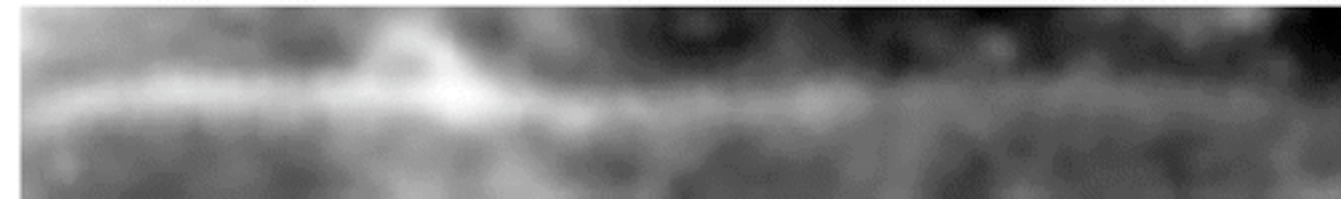
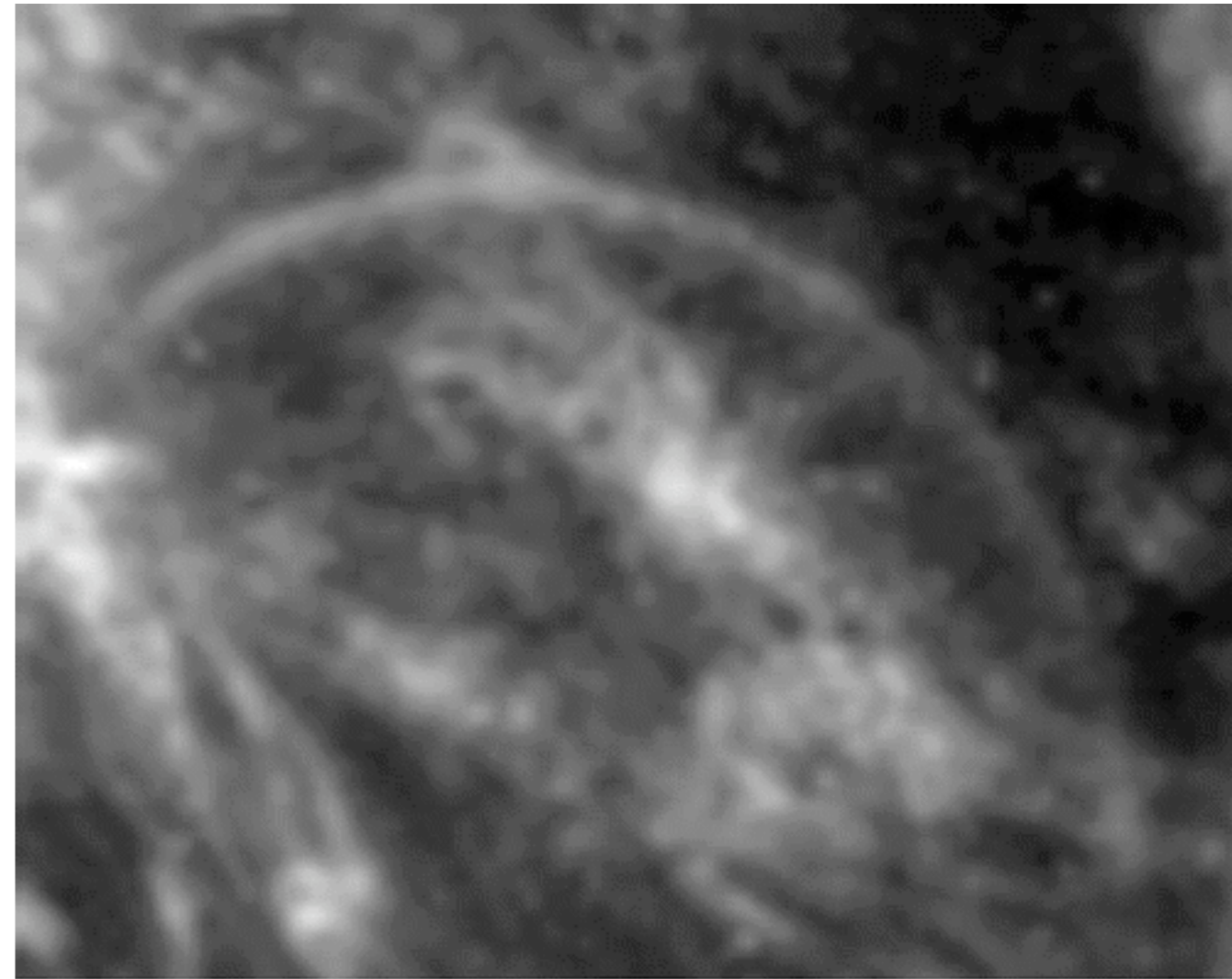
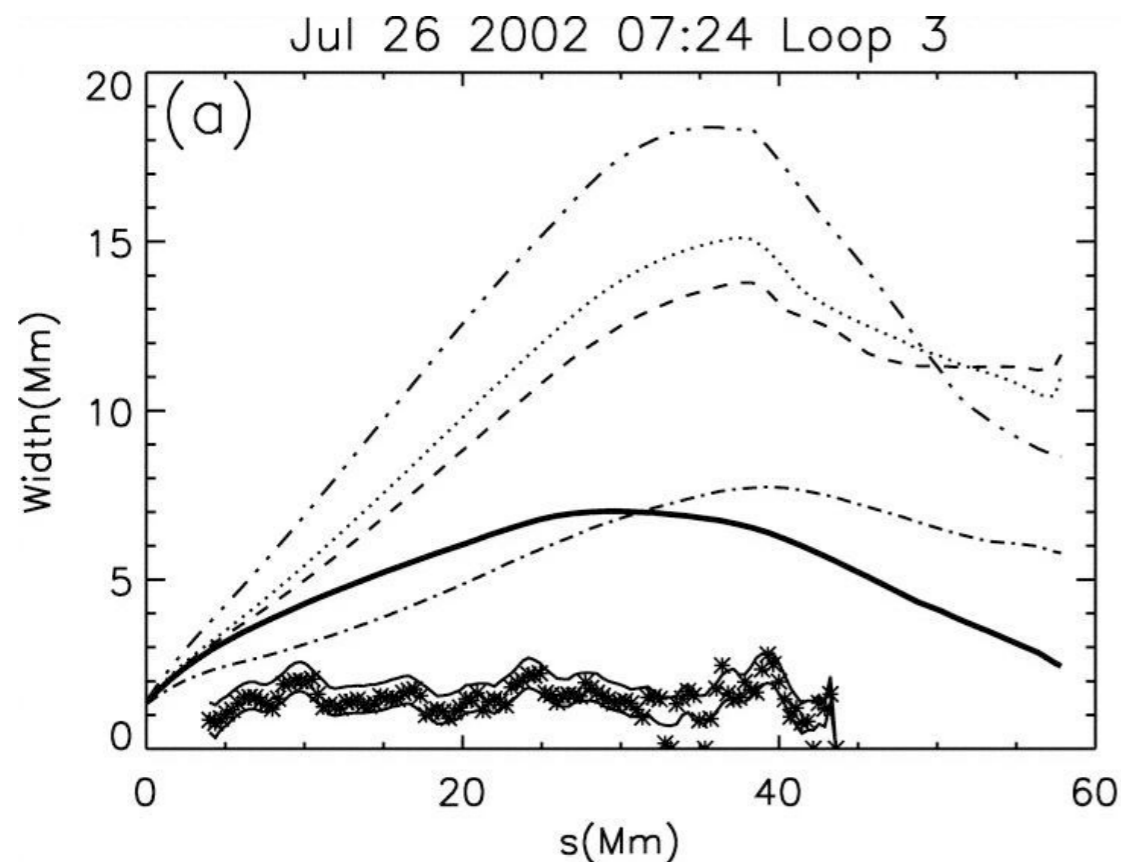


# (in)Famous TRACE post-flare loops



# Are all plasma loops magnetic flux tubes?

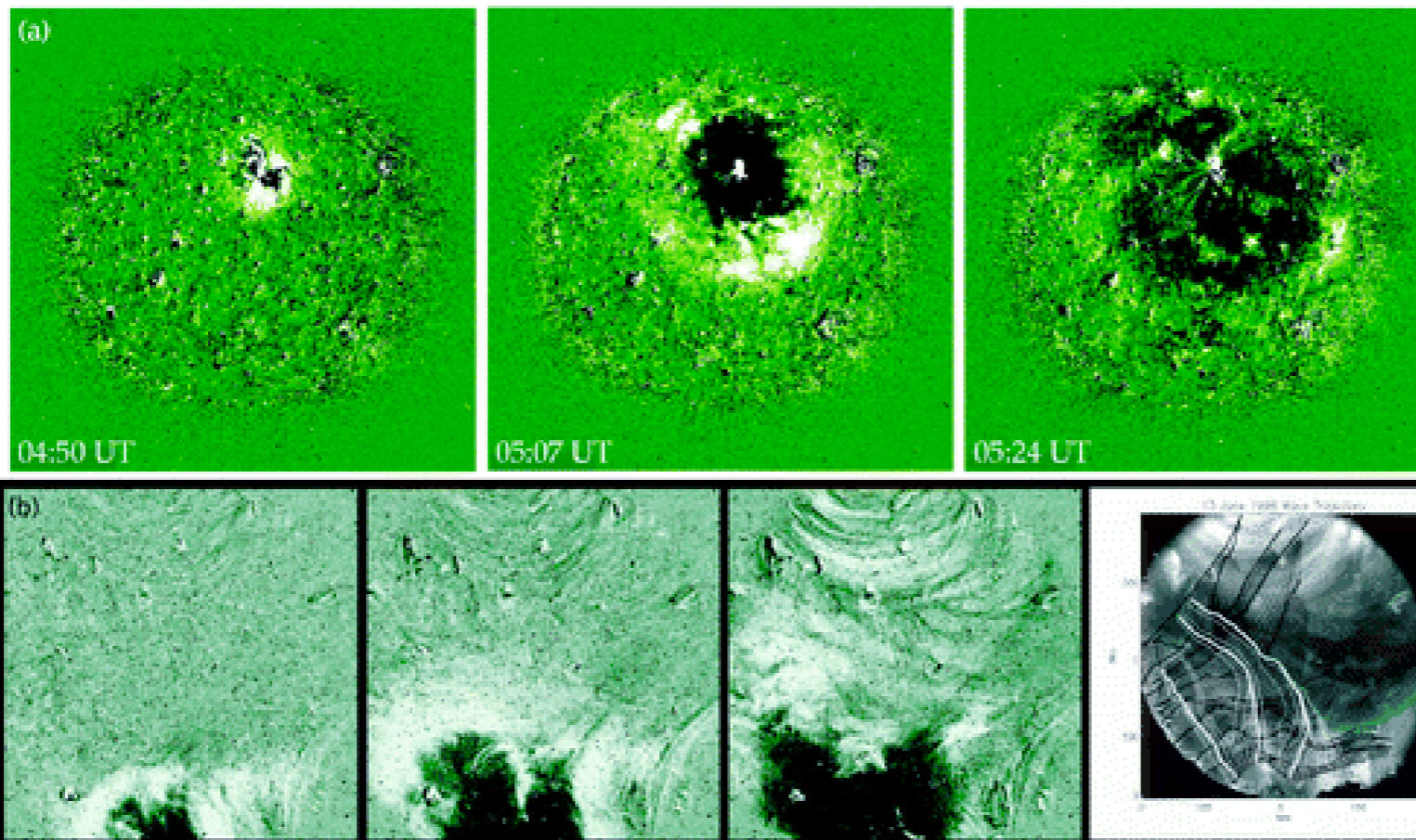
- “Plasma loops in the solar corona” - carefully chosen book title by Bray, Cram, Loughhead, Durrant (1991)
- Curious observations TRACE
- Klimchuk and colleagues:
  - **linear f-f** extrapolations





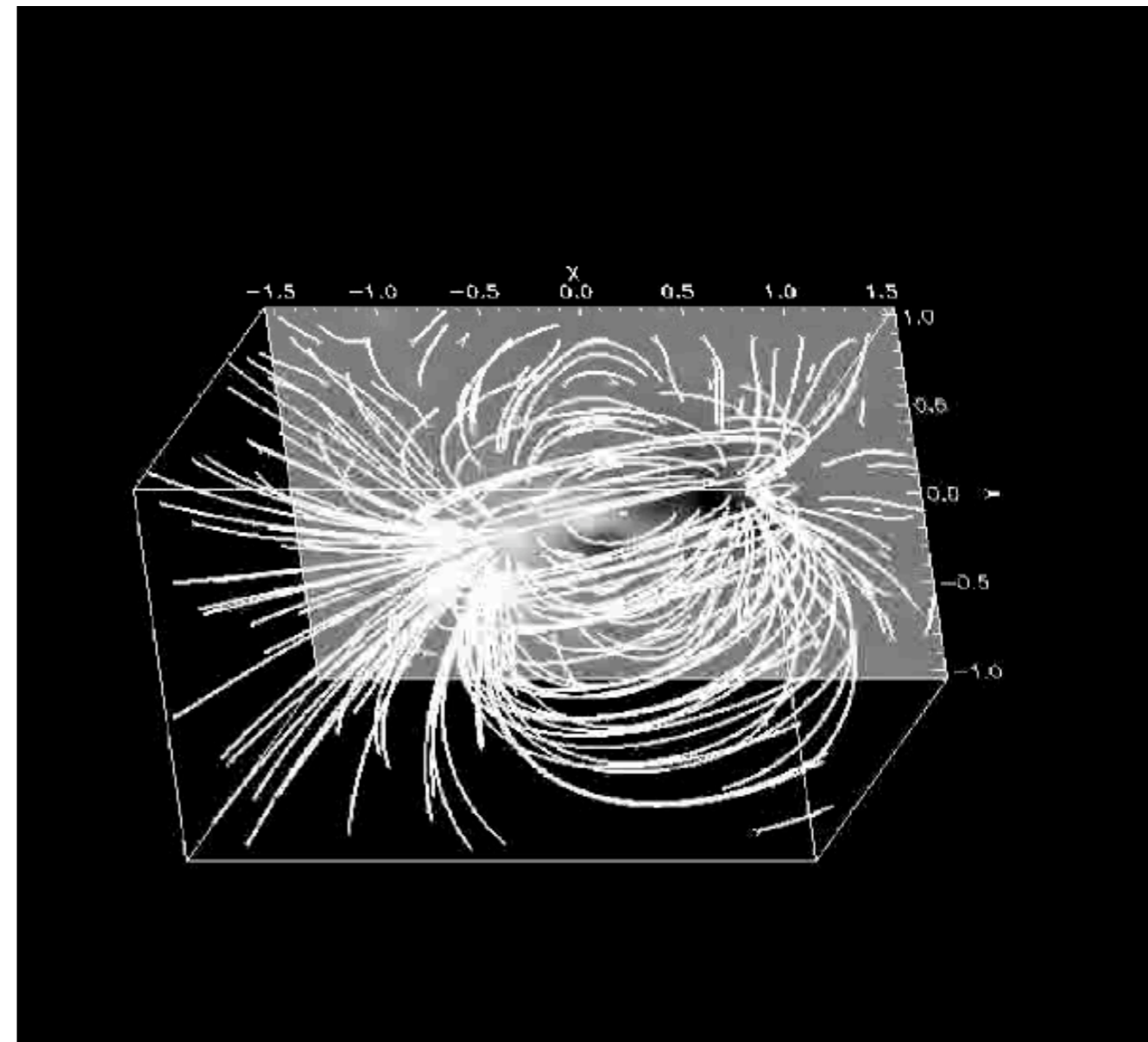
# Moreton and EIT waves

- Chromospheric manifestations of (weakly nonlinear) fast wave propagation. They “see” a homogeneous medium
- Wills-Davey, Deforest, Stenflo (2007):
  - “ Morphologically, EIT waves appear as single-pulse fronts. To date, there has only been one observation of a pulse wave (in this case, a Moreton wave) that appears to include multiple fronts...
- corona is **non-refracting**: remarkable constancy of propagation speed



# TRACE oscillations revisited

- What are TRACE oscillations? Kinks? Body oscillations?
- Ofman (2007)- potl field, stratified atmosphere:
  - No loops here
  - qualitative agreement w/obs
- Occam's razor=> body oscillations
  - plasma loops may trap waves
  - no evidence for this yet
- EIT waves+ this work
  - corona seems homogeneous
  - contrast with TRACE loops
  - WL data...



# Coronal inhomogeneities: T vs n

- Many “tube wave” advocates assume plasma loop= flux tube AND a density homogeneity ( $V_A \sim B \rho^{-1/2}$ )
- EUV/X rays: very sensitive to T and  $\rho$
- WL prom. cavity (Koutchmy, November 1991 eclipse)

NOVEMBER & KOUTCHMY

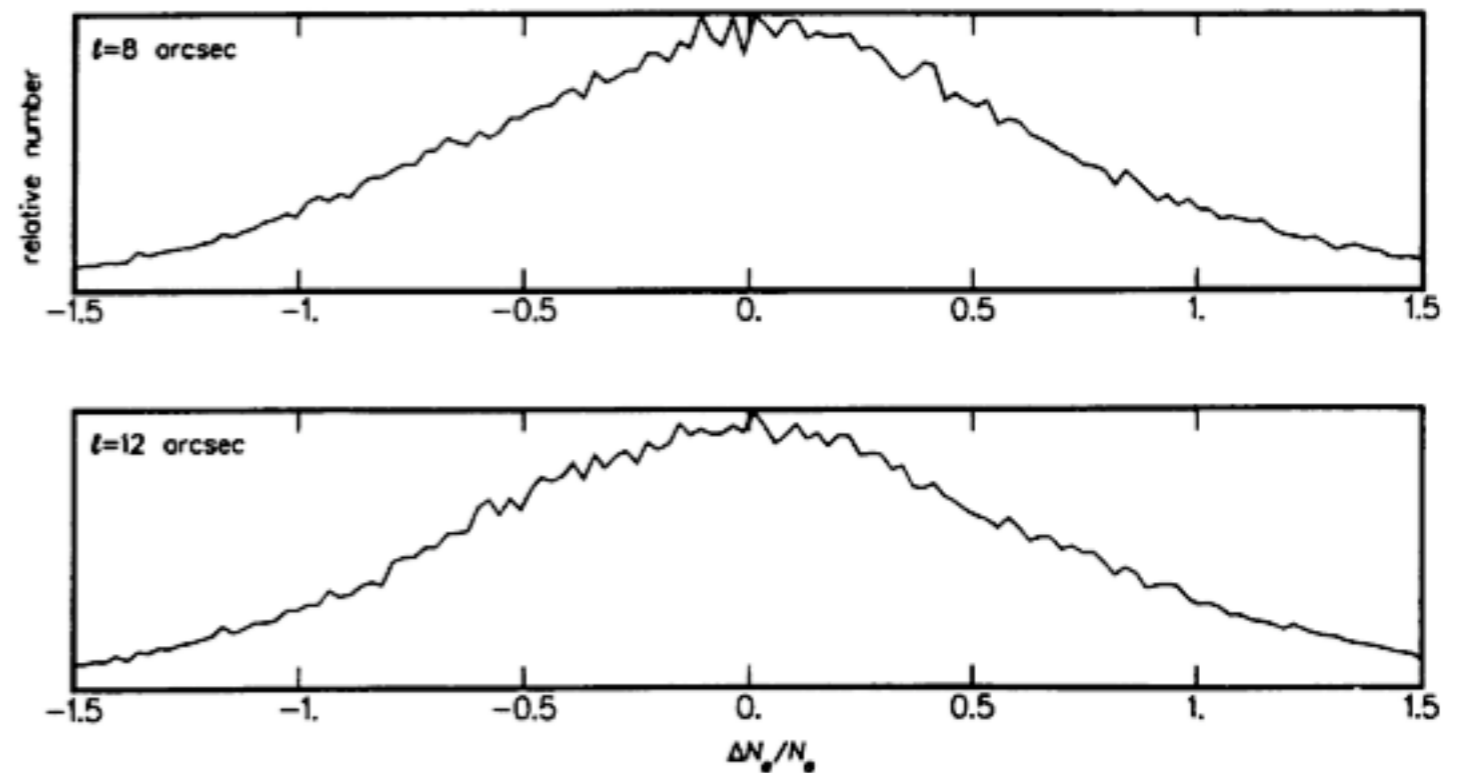
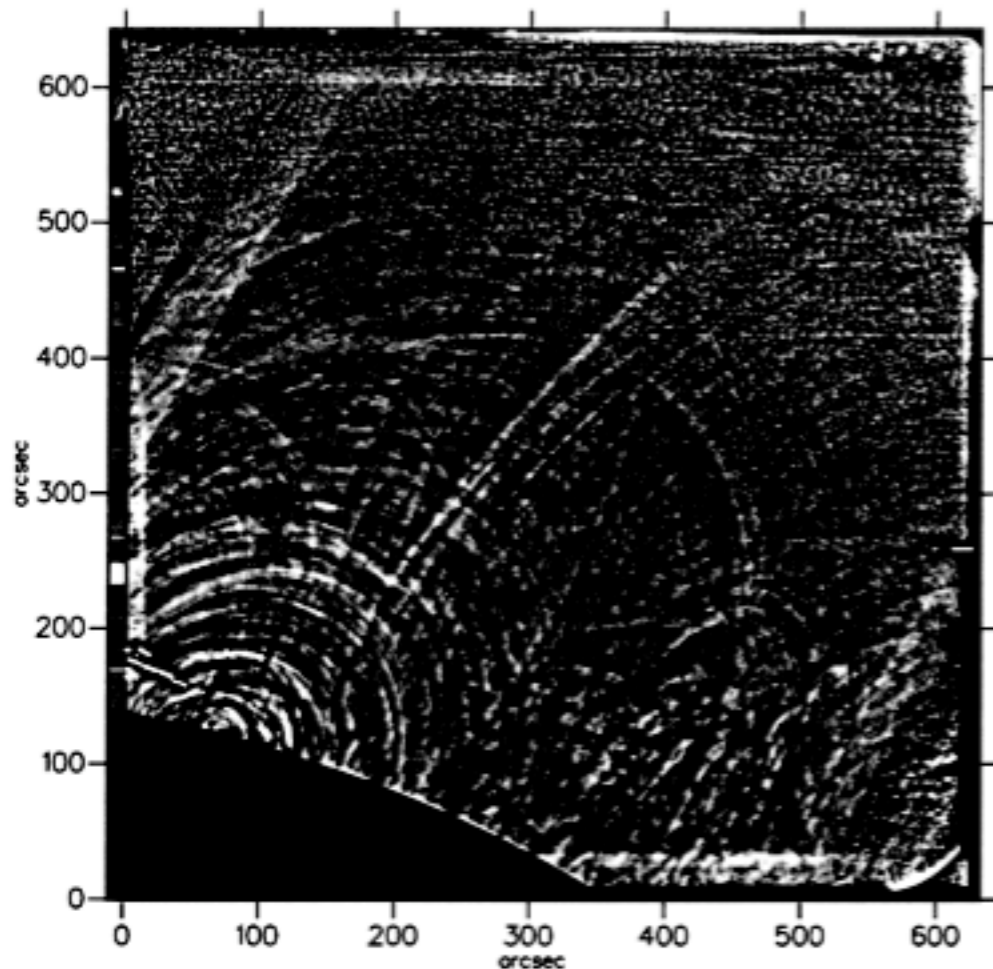
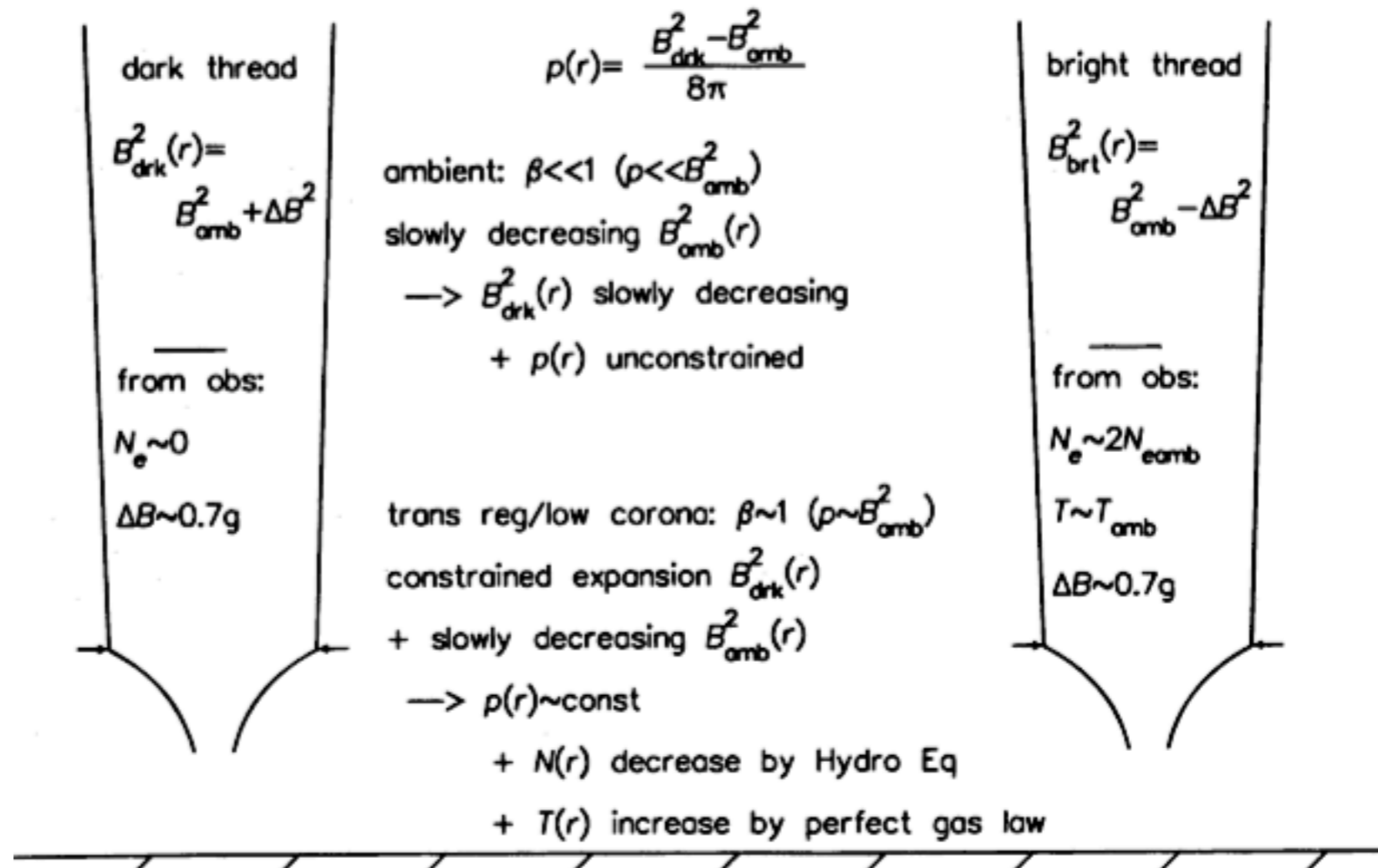


FIG. 14.—Histogram of  $\Delta N_e/N_e$  for three thread diameters  $\ell$

# Coronal inhomogeneities: (continued)

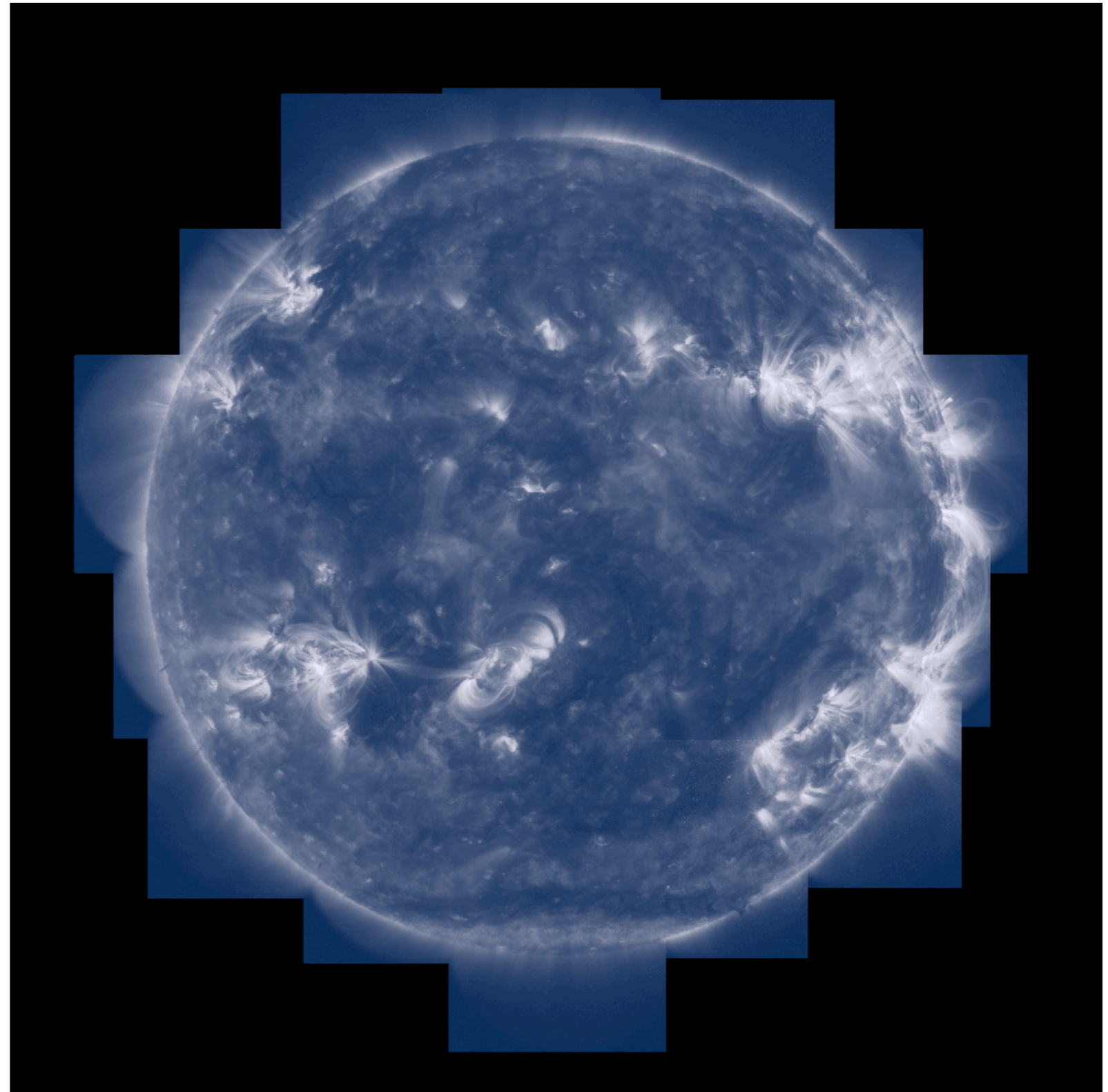


“Threads” mostly have  $\delta\rho/\rho \sim 1$ ,  $\delta V_A/V_A \sim 1/2$ , widths  $w \sim 1-5\text{Mm}$ .

Plasma loops not so common considering the volume integrations-  
fractional volume  $\sim n \cdot w^2 \cdot L / Vol \sim 200 \cdot 10 \cdot 400 / (400^2 \cdot 900) \sim 0.5\%$

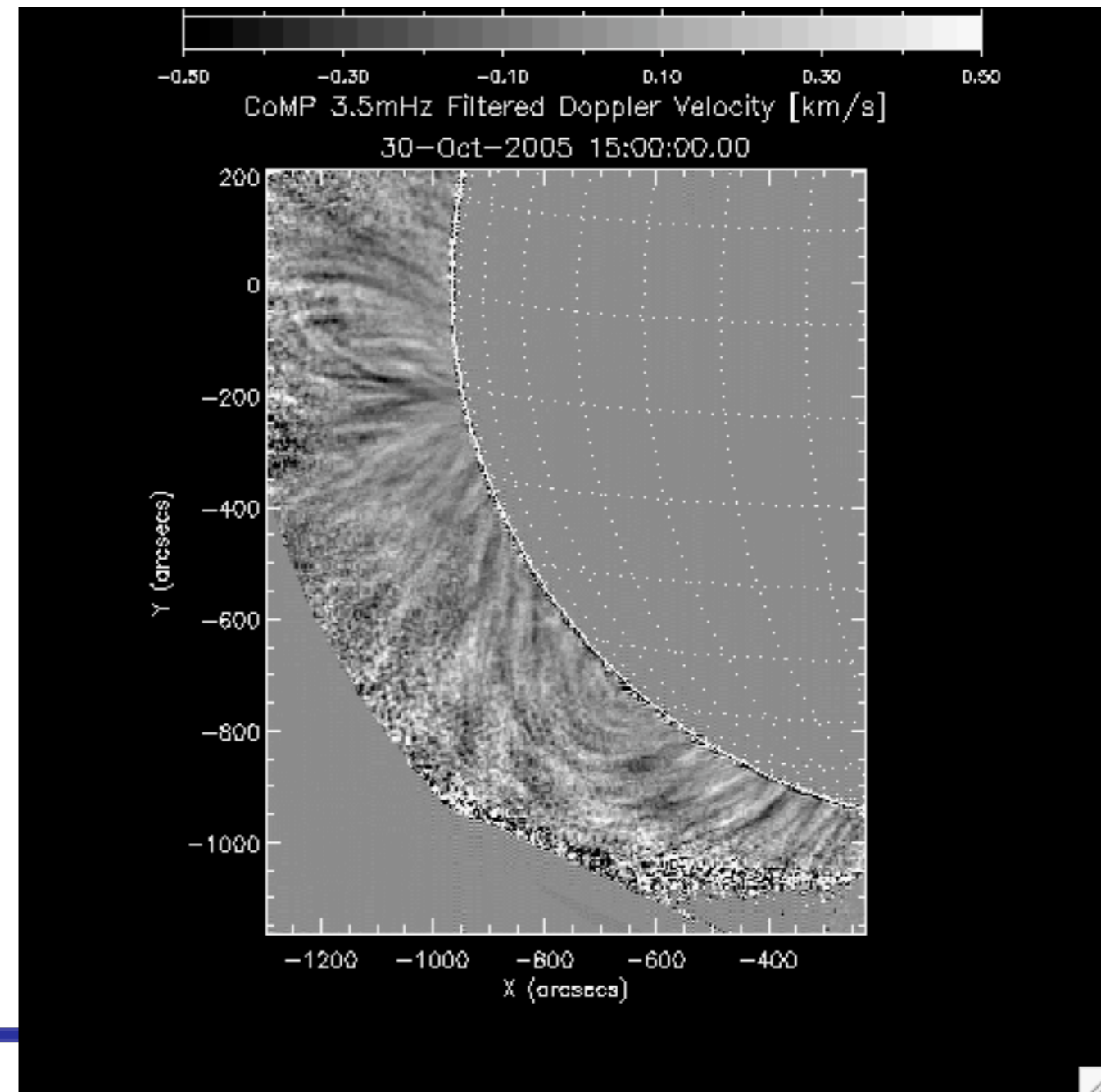
# Some waves see the corona as relatively homogeneous

- In spite of TRACE:
- $\delta\rho/\rho \sim 1, \delta V_A/V_A \sim 1/2$
- tube waves supported but
  - only in small volumes
  - trap wave energy?
- explains
  - EIT wave fronts
  - Loop flare response
  - CoMP data?



# Meaning of CoMP data

- Is CoMP seeing tube waves?
- Given Koutchmy data and Hinode spicules
  - collective mode (Parker 1991)
  - $\Rightarrow$  no phase mixing
  - possibly kinks (cf. TRACE)
- BUT
  - kinks are “Alfvenic” anyway
  - $\delta\rho/\rho_0 \sim 1$
  - $V_{kink} \sim V_A$
  - no big deal for seismology
- More analysis and data needed



# Conclusions

- No “definitive” modes identified- cf. much literature.
- **caveat**, many people believe
  - **plasma loops = flux tubes, the basis of coronal seismology**
  - so then **“Alfven waves = torsional tube waves”**
- TRACE oscillations are likely global AR relaxations
- CoMP + Hinode/CFHT: oscillations may be kinks
  - kinks are physically “Alfvenic” (tension=restoring force) but
  - collective mode, no phase mixing, instead resonant absorption
  - < 1% of the coronal volume is being detected as threads!
  - the 99% other stuff IS IMPORTANT (even in QS)
  - Alfven waves may still be present in 99% of the volume
  - CoMP may be observing the 99% where oscillations are transformed by integrations along LOS, into **linewidths**
  - if so, sufficient power is present to heat the corona.