Prospects for Magnetography in the Chromosphere and Transition Region

Thanks to: Alan Gary, Jack Harvey, Harry Jones, Bruce Lites, Jason Porter, Andy Skumanich, Hector Socas-Navarro, Ted Tarbell

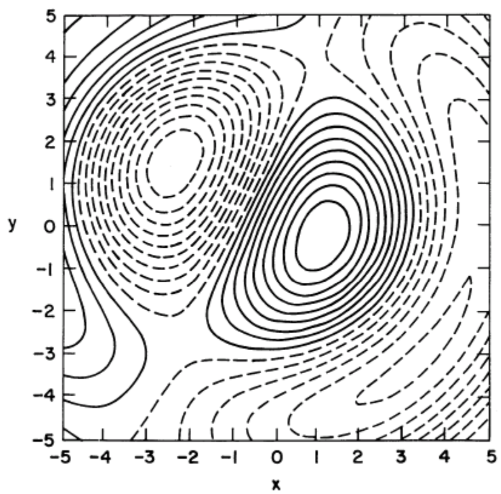
Short Version — Chromosphere

- Gaudy cartoons notwithstanding, we don't understand chromospheric structure and dynamics.
- This is an obstacle to unraveling energy transport to and from the upper atmosphere.
- Measuring ***B*** in the chromosphere is a necessary part of a complete picture.
- Recent progress in NLTE inversion for chromospheric lines opens up observational opportunities.
- It will likely take 5–10 years of ground-based observation and theory for chromospheric magnetography to become a standard tool comparable with photospheric magnetography today …
    - … but the chromosphere will always be harder.

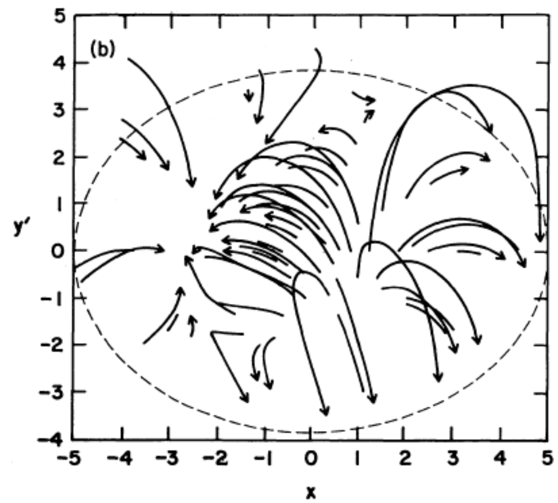
Short Version — Transition Region

- The magnetic structure of transition-temperature structures is unquestionably central to their role in energy transport.
- The possibilities for measurement are real but limited.
- Space is the place.
- Full vector measurements are probably unrealistic.
- What are the questions that a measurement of line-of-sight flux will answer? (Keeping in mind
  - Small filling factor
  - Often optically thin
  - Highly dynamic)

Why It Matters — Chromosphere I.



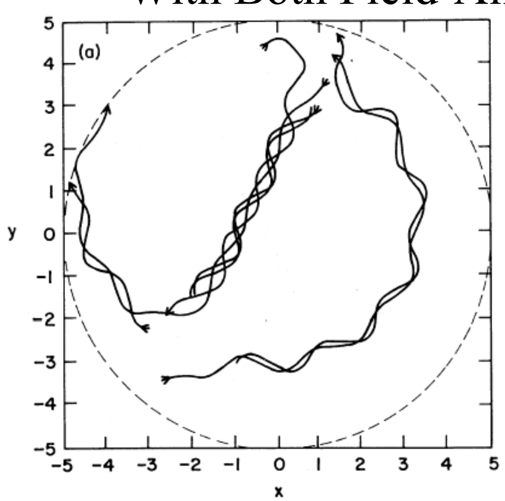
B_z at the Photosphere



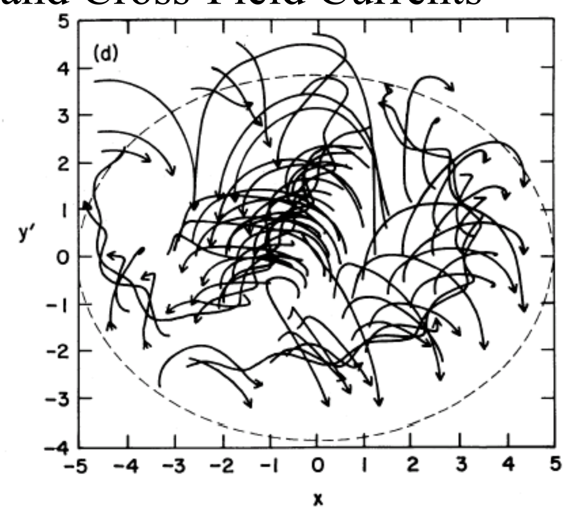
Potential Field

B. C. Low, ApJ 399, 300 (1992)

With Both Field-Aligned and Cross-Field Currents



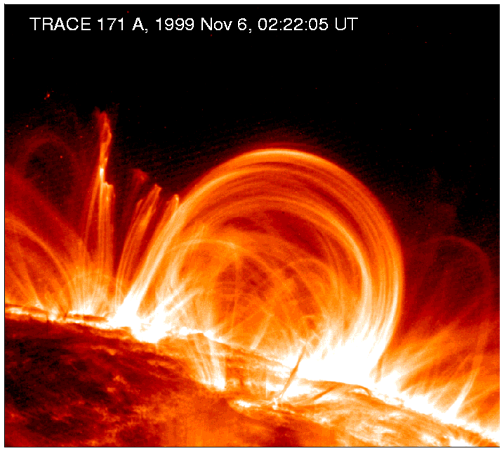
Selected Low-Lying Field Lines

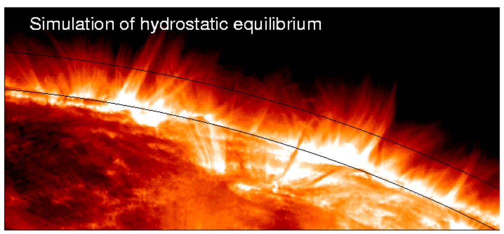


Larger Subset of Field Lines

⇒ Force balance

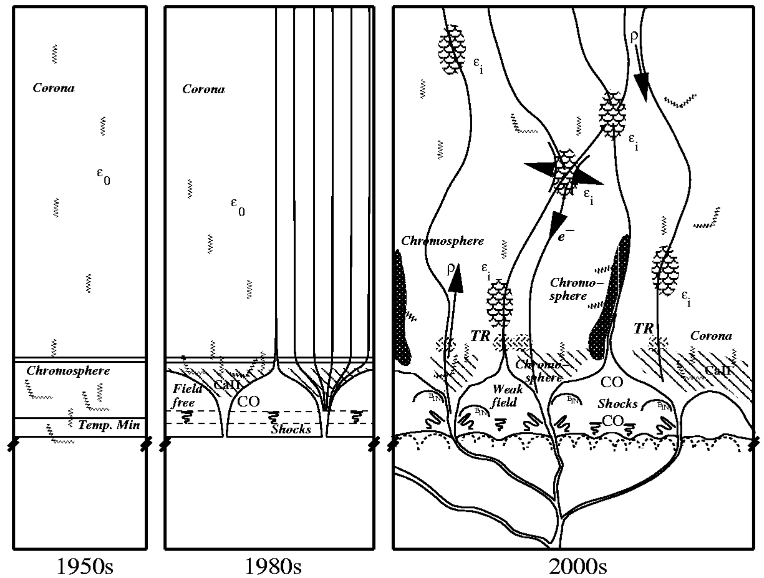
Why It Matters — Chromosphere II.



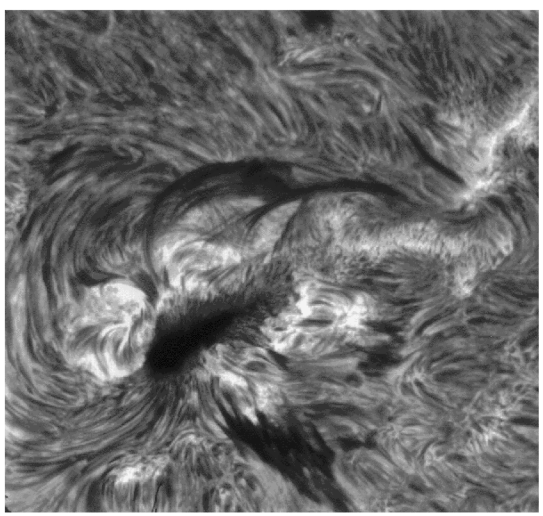


TRACE

$\Rightarrow$ Connecting the Solar Atmosphere



Cartoon Evolution (Schrijver)



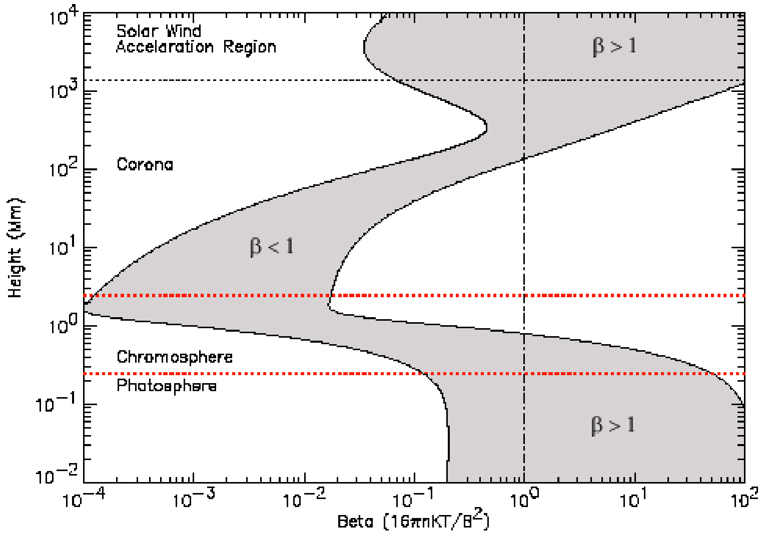
BBSO

Moss, carpet, canopies, fibrils, filaments, spicules, COmosphere, K_{2V} bright points, …

Why It Matters — Transition Region

- Magnetic field in the hot atmosphere: at least *one* data point would be nice!

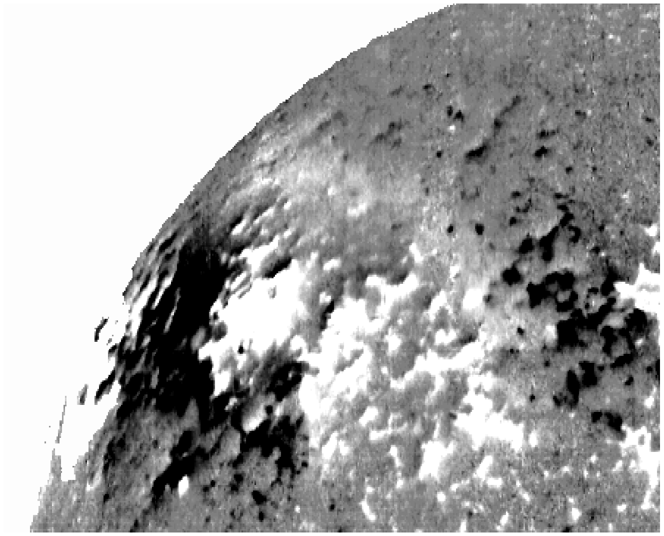
- Genuinely $\beta \ll 1$
  - Extrapolation
  - Free energy, helicity (but …)



A. Gary

- Microflare associated changes
- Flux tube waves?
- Geometry of downward thermal conduction

State of the Art — Chromosphere I.

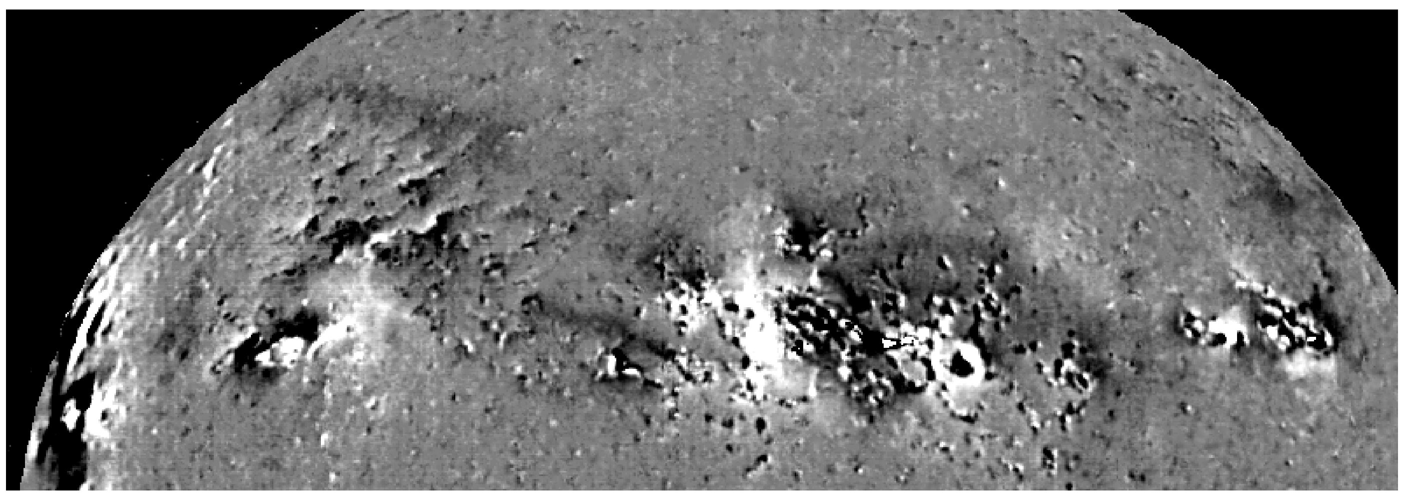


$\Rightarrow$ Large spatial scales

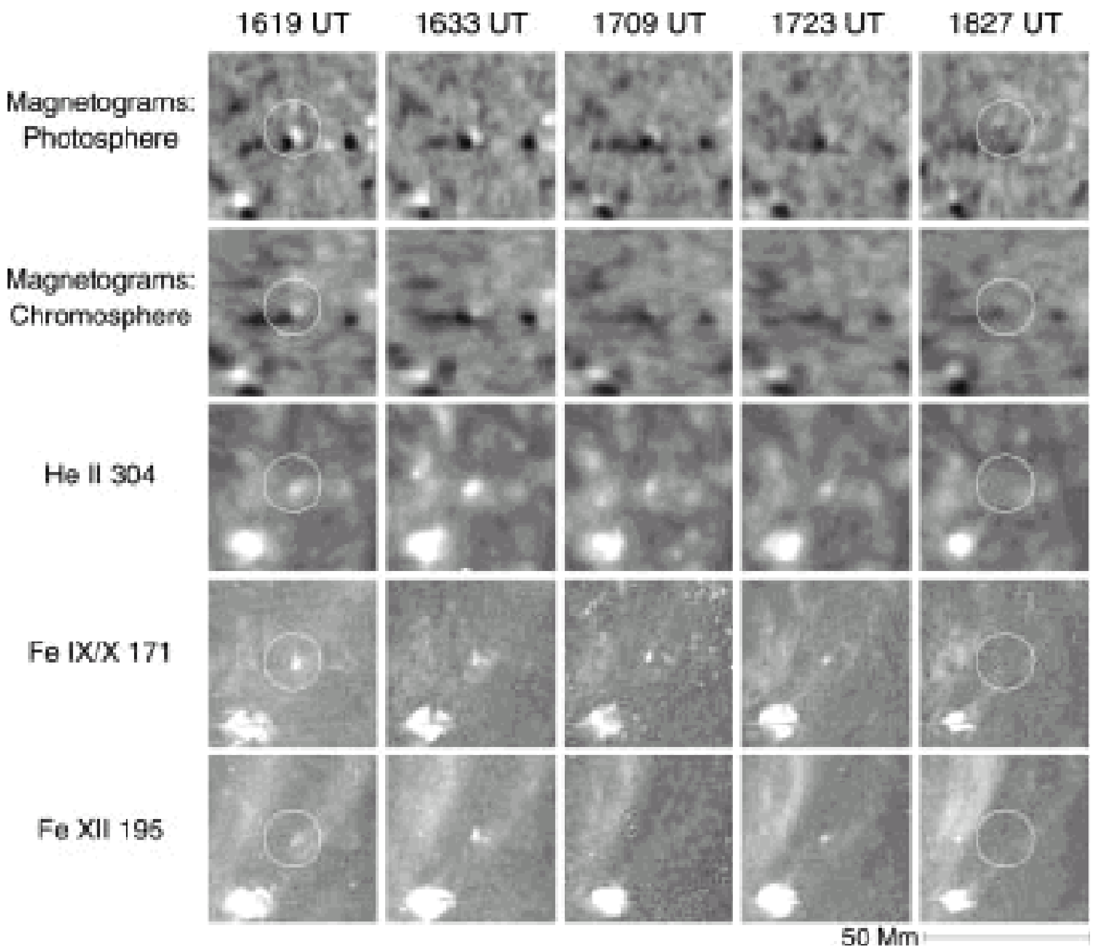
• axial field in filament channels

• unipolar, quasi-vertical connections between active regions

J. Harvey



State of the Art — Chromosphere II.



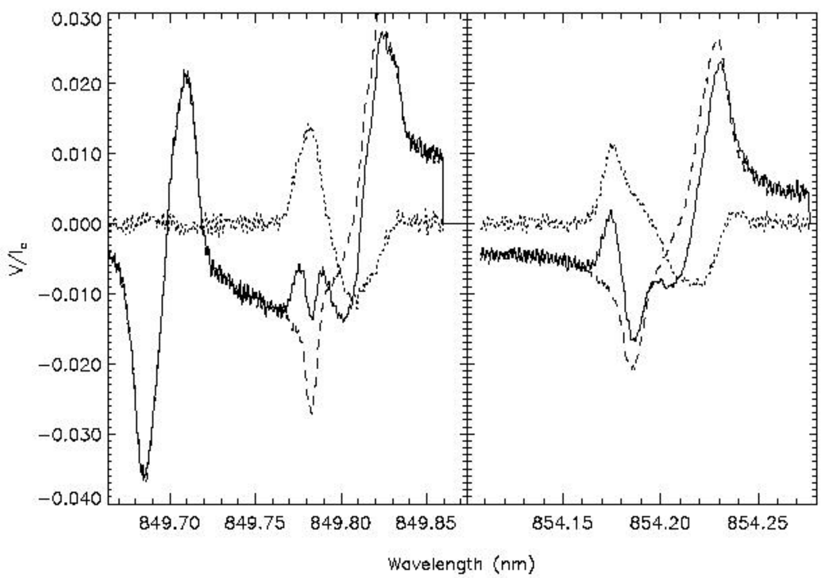
⇒ Temporal Differences

K. Harvey, Jones, Schrijver, Penn (1999)

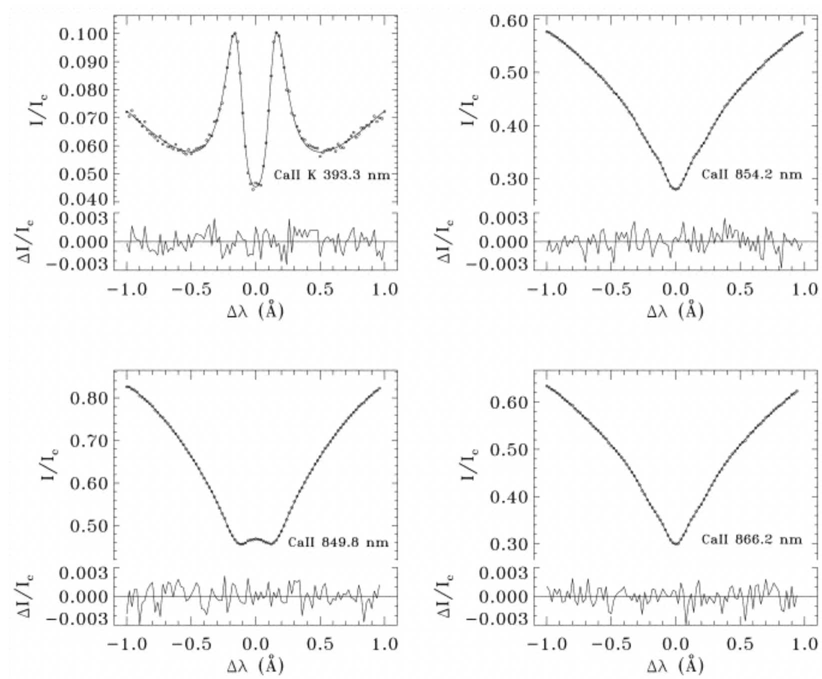
Figure 1. Section of the photospheric and chromospheric magnetograms showing the cancelation of a positive polarity (white) magnetic element with a negative network (black) observed on 16 June 1998 *(white circles*). Note the more rapid disappearance of the positive (white) pole earlier in the chromosphere than in the photosphere. The bottom three sets of panels show the corresponding EIT images in He II 304 Å and TRACE images in Fe IX/X 171 Å and Fe XII 195 Å.

State of the Art — Chromosphere III.

⇒ Quantitative inversion



Two magnetic components in a sunspot umbra



Inversion of synthetic data (VAL-C reference)

H. Socas-Navarro et al.

State of the Art — Transition Region

SMM/UVSP (Tandberg-Hanssen et al., 1981)

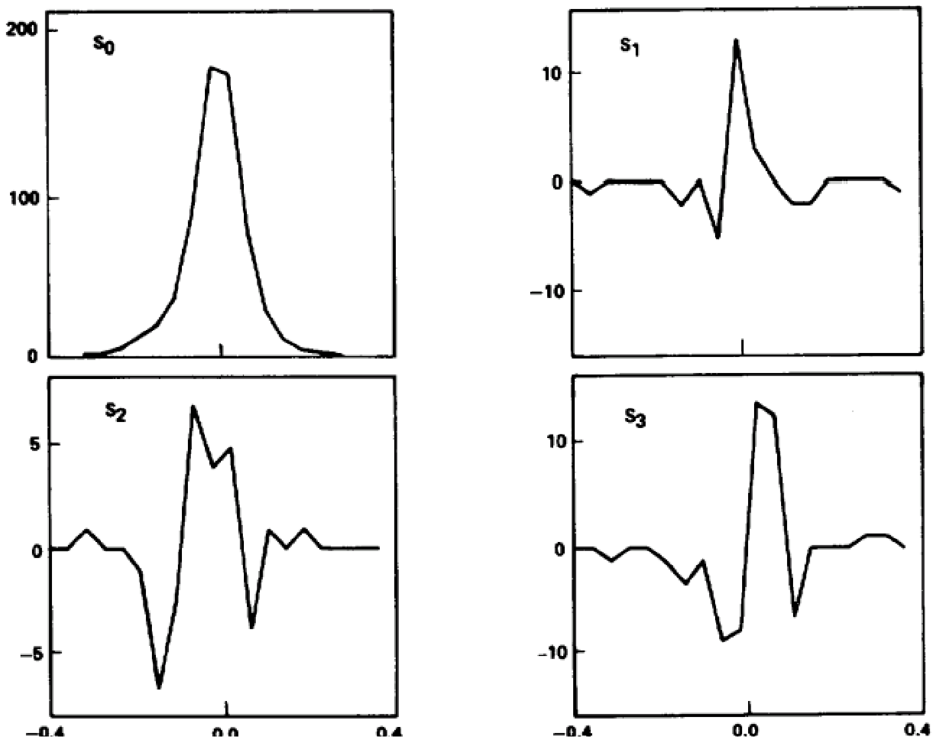
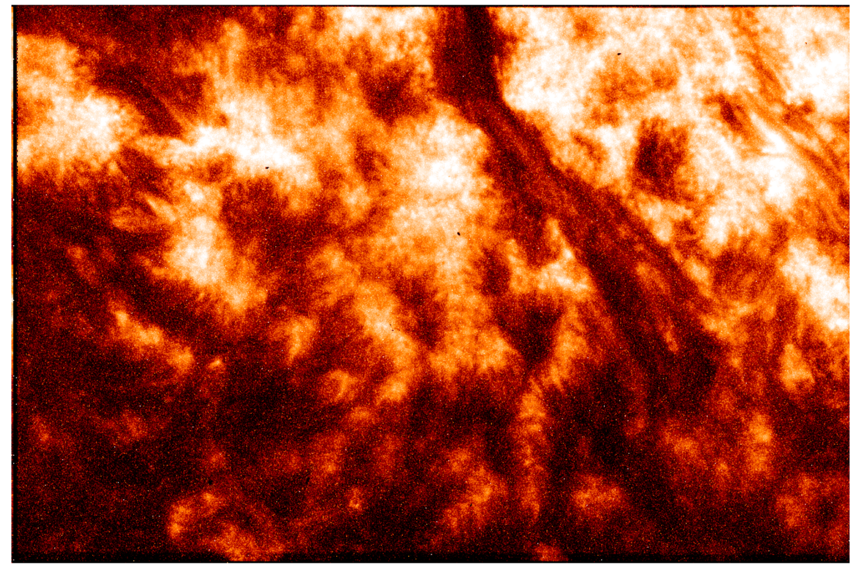


FIG. 2.—The four Stokes parameters, S_0, S_1, S_2, and S_3, measured in the C IV, 1548 Å line above sunspot in AR 2396 on 1980 April 14. Ordinates are in units of counts per 1.024 s, abscissae in angstroms.



NRL VAULT Rocket, Lα, 1999

→ C IV, 2001

Challenge — Transition Region

$I = I_p e^{-v^2} =$	Gaussian emission profile (or emission core of a deep absorption line)
$V = -v_B \cos\gamma \quad \partial I / \partial v =$	Stokes V for weak splitting
$V_{\max} = 0.858 \quad I_p v_B \cos\gamma =$	Peak magnitude of Stokes V
$Q = -\left(v_B \sin\gamma\right)^2 \partial^2 I / \partial v^2 =$	Stokes Q for weak splitting
$Q_{\max} = 0.223 \quad I_p (v_B \sin\gamma)^2 =$	Peak magnitude of Stokes Q

The C IV lines are 1548.2 Å ($g_{eff} = 0.65$) and 1550.8 Å ($g_{eff} = 0.75$).
The λ1548 line is about twice as strong as λ1550 and has an observed FWHM ≈ 200–390 mÅ or $\Delta\lambda_E \approx$ 120–230 mÅ.

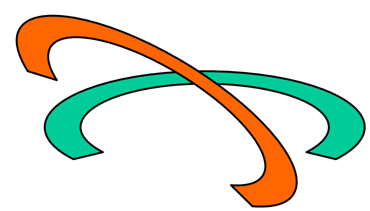
C IV λ1548 $\Delta\lambda_E$=120 mÅ	**100 G**	**500 G**	**1000 G**	**3000 G**
V_{max}/I_p	5.2e-4	0.0026	0.0052	0.016
Q_{max}/I_p	8.2e-8	2.0e-6	8.2e-6	7.4e-5
Q_{max}/V_{max}	1.1e-4	5.6e-4	0.0011	0.0033

Approaches — Chromosphere

Line (nm)	Plus	Minus
Ca II triplet (849,854,866)	C-response, λ, ~ unblended, 5-level + CRD OK	Δg_{eff}, λ
Ca II H & K (393, 397)	C-response	RT
Mg I $b_{1,2,}$ (518,517)	Δg_{eff}	C-response, RT
Mg II h & K (279,280)	C-response, λ	RT, λ
Na D_2 (590)		C-response
Hα (656)	C-response	everything else
Hβ (486)		
He I (1083)	C-response	weak, blended

Stokes profiles

Geometry $\longleftrightarrow$ Radiation Field



What Will Solar-B Do?
(in this area)

- Chromosphere
  - Vector polarimetry in Mg b with the FPP tunable filter
    - ~ 75 mÅ bandpass
    - Low photon flux in the line core, will require long integrations to reach good S/N (~1000:1)

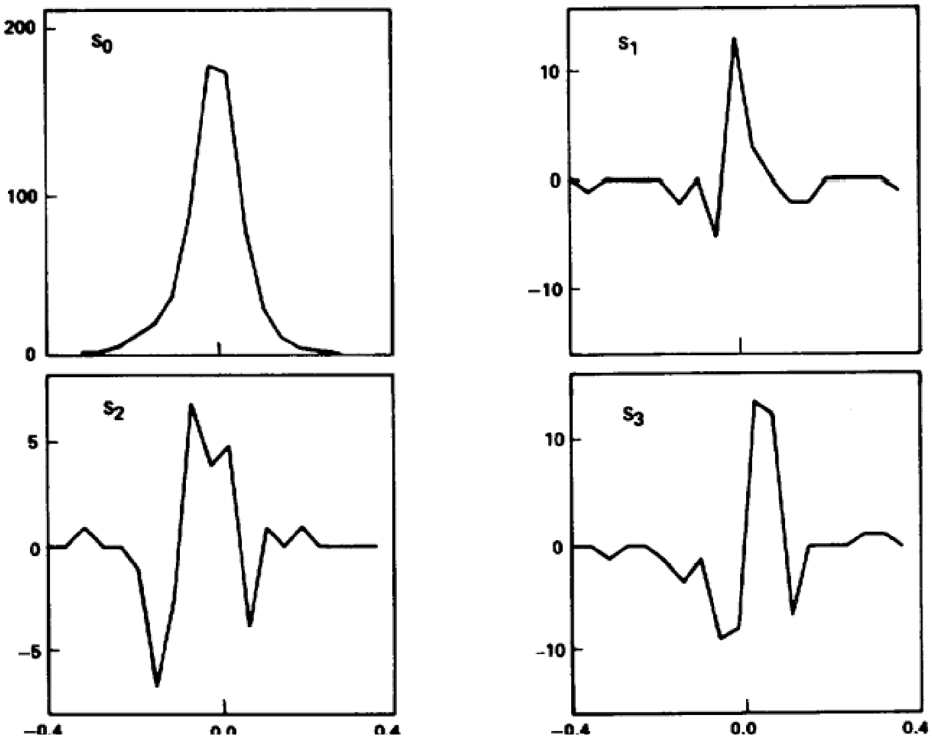
- Transition Region
  - Not Solar-B; need a proof-of-concept such as SUMI

What Will Ground-Based Telescopes Do?

- DST, THEMIS, Gregor, NSST et al.
  - Create a mature technique with a recognized body of results
- Solar-C et al.
  - Hanle effect measurements of prominences and filaments
- ATST
  - Flux, flux, flux
  - Push to high angular resolution

State of the Art — Transition Region

SMM/UVSP (Tandberg-Hanssen et al., 1981)



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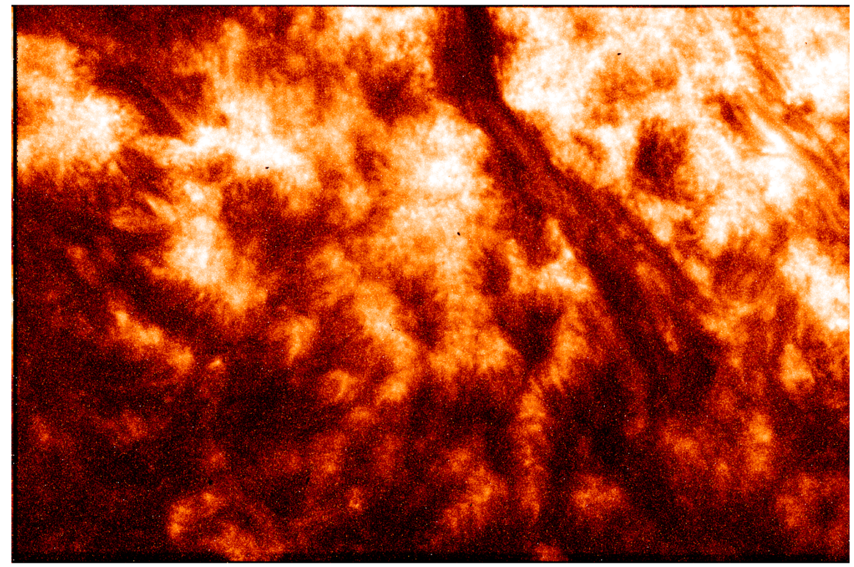


NRL VAULT Rocket, Lα, 1999

→ C IV, 2001

Beyond Solar-B

- Scientific prerequisites:
  - Demonstrate that chromospheric magnetography is a mature and powerful tool.
  - Sharpen the case for limited measurement of the transition plasma.
- ATST and friends
- Comprehensive TR instrument suite with polarimetry
- 2-meter class space telescope
  - For angular resolution better than Solar-B but not diffraction-limited

Summary: Magnetography in the Chromosphere and Transition Region

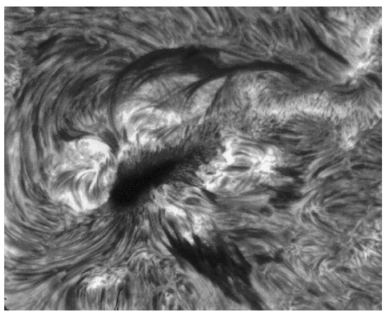
Why?

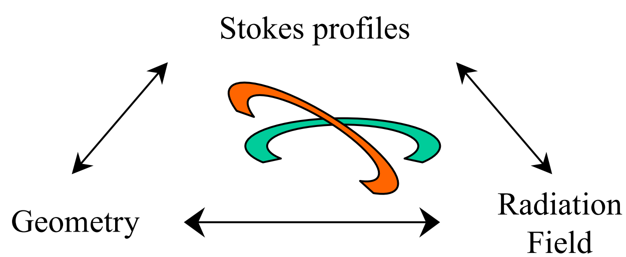
- Unravel energy transport to and from the upper atmosphere
- Measure ***B*** where atmosphere is most nearly force-free

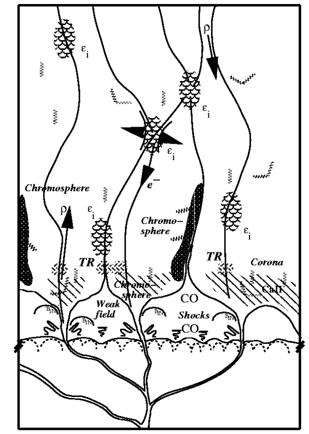
Key Challenge in the Chromosphere

- Interpreting polarimetry of NLTE lines formed in a three-dimensionally inhomogeneous, dynamic atmosphere

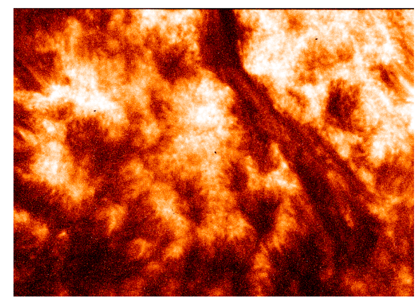
BBSO
Hα



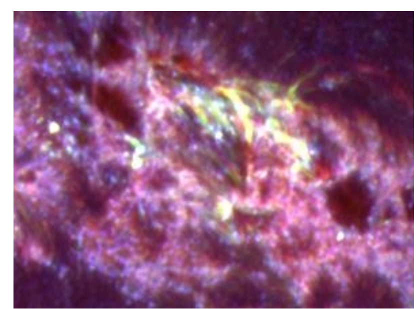




Complex Structure and Energy Transport (Schrijver 2000)



VAULT Lα (1999)



TRACE UV including C IV (1998)

Key Challenges in the Transition Region

- Weak polarimetric signal (full vector field unrealistic)
- Isolating questions that line-of-sight flux measurements can answer

How?

- Chromosphere: large ground-based telescopes, Solar-B
- Transition region: begin with rocket proof of concept