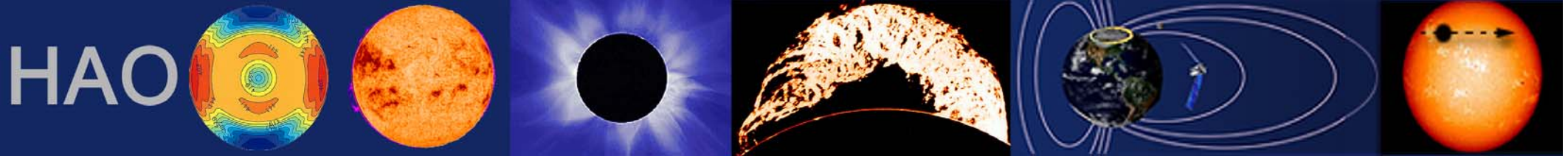

Photospheric Magnetic Fields

Hector Socas-Navarro

Juan Manuel Borrero

High Altitude Observatory

National Center for Atmospheric Research

Index

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Index

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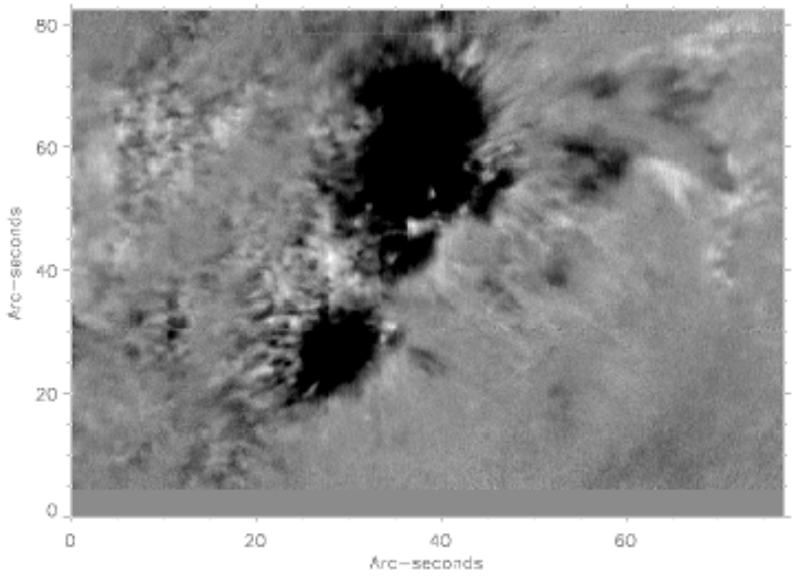
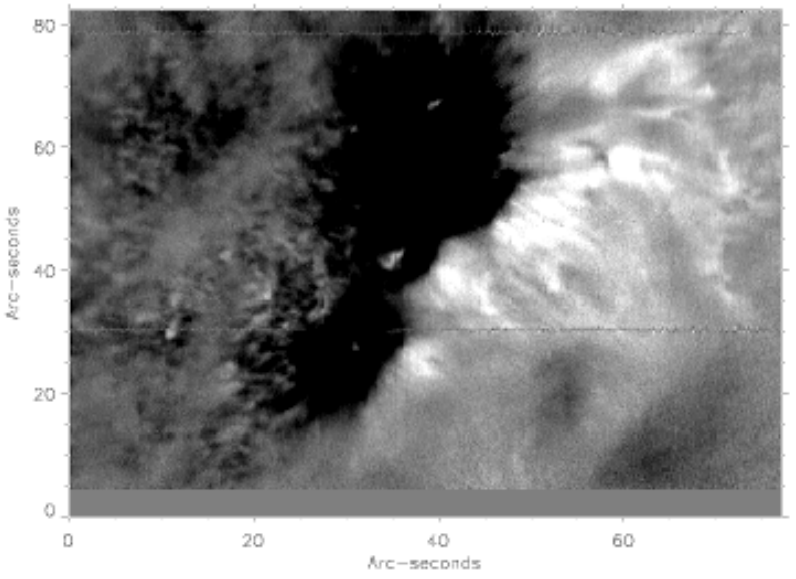
Photospheric magnetometry

- Easier than chromospheric/coronal magnetometry
  - LTE polarized radiative transfer
  - Well-behaved lines -> Polarimeters (Magnetograms) are relatively meaningful
  - A





Photospheric magnetometry

- Degrees of sophistication (Instrumentation+Inversion)
  - Magnetograms
  - Milne-Eddington inversions ("flat" photosphere)
  - Full-LTE, gradients ("3D" photosphere)

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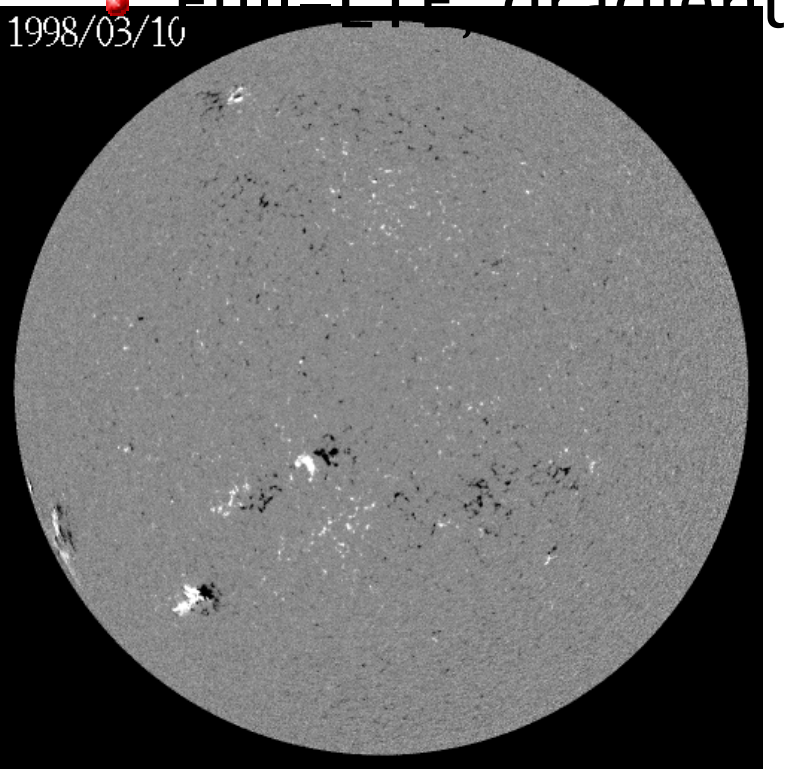

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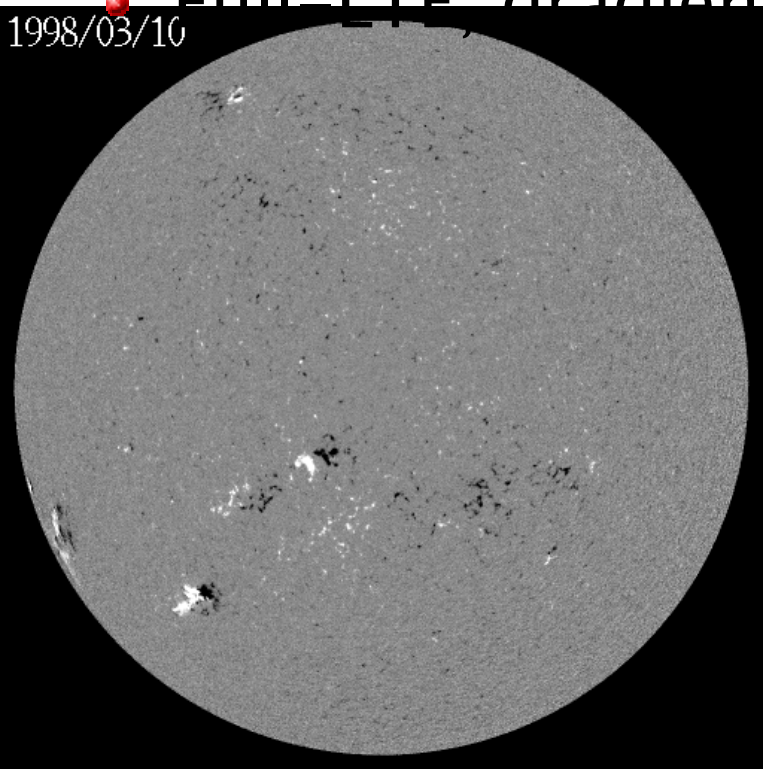

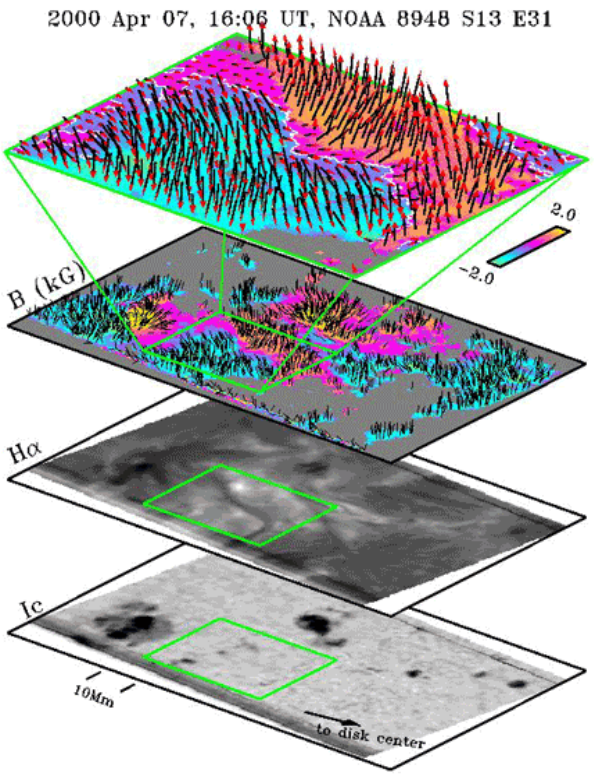

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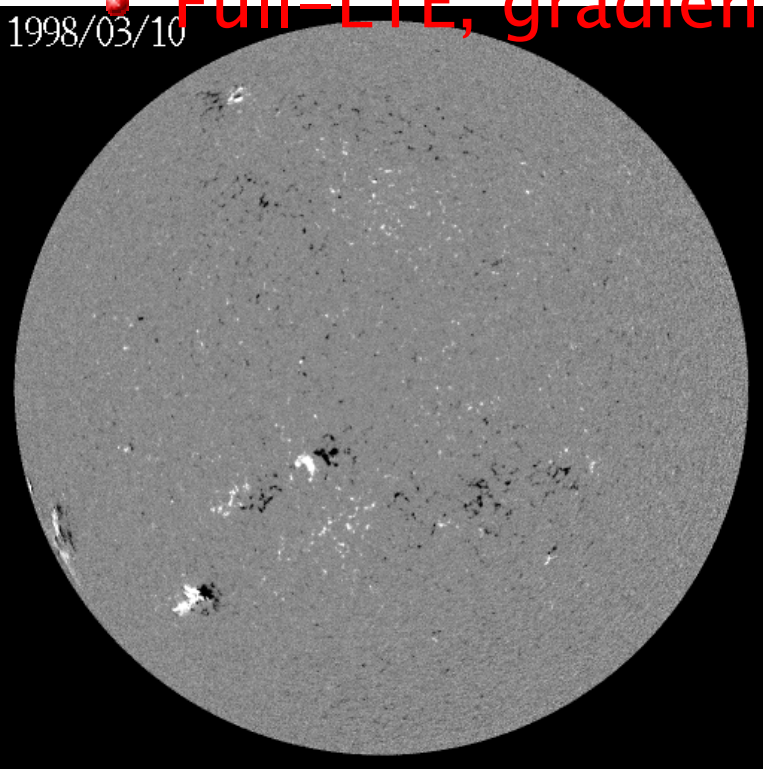
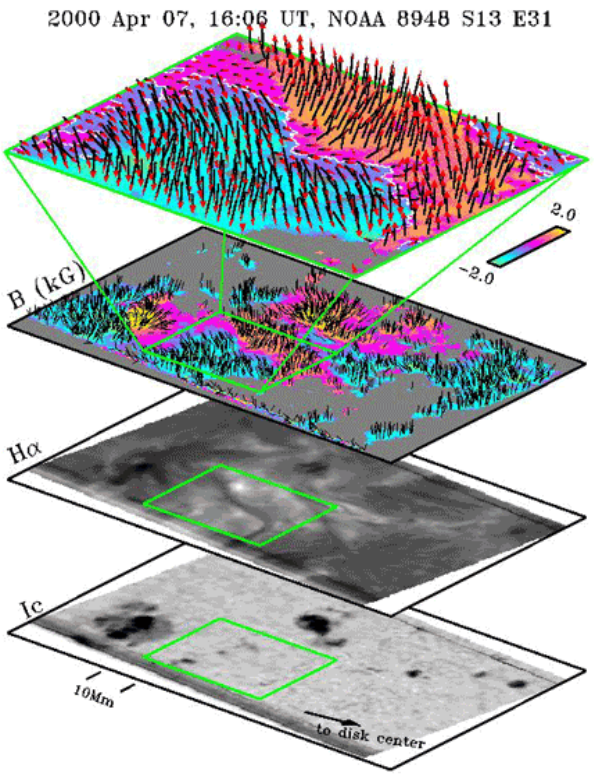
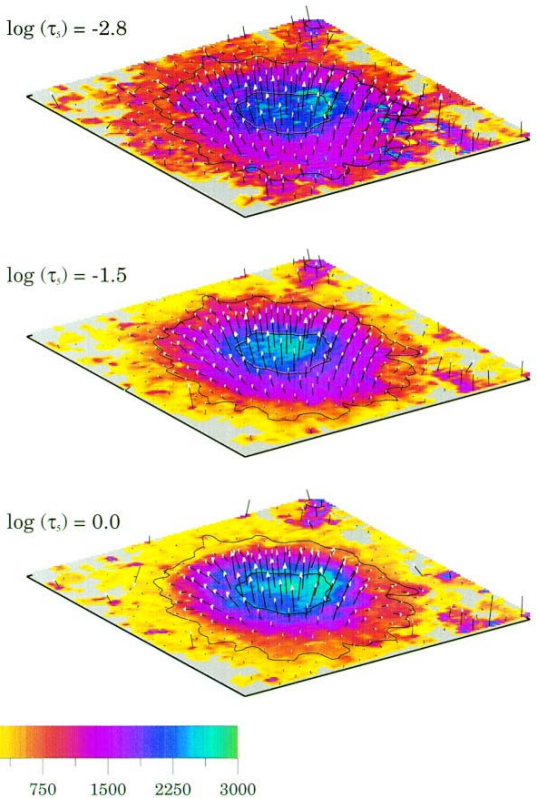
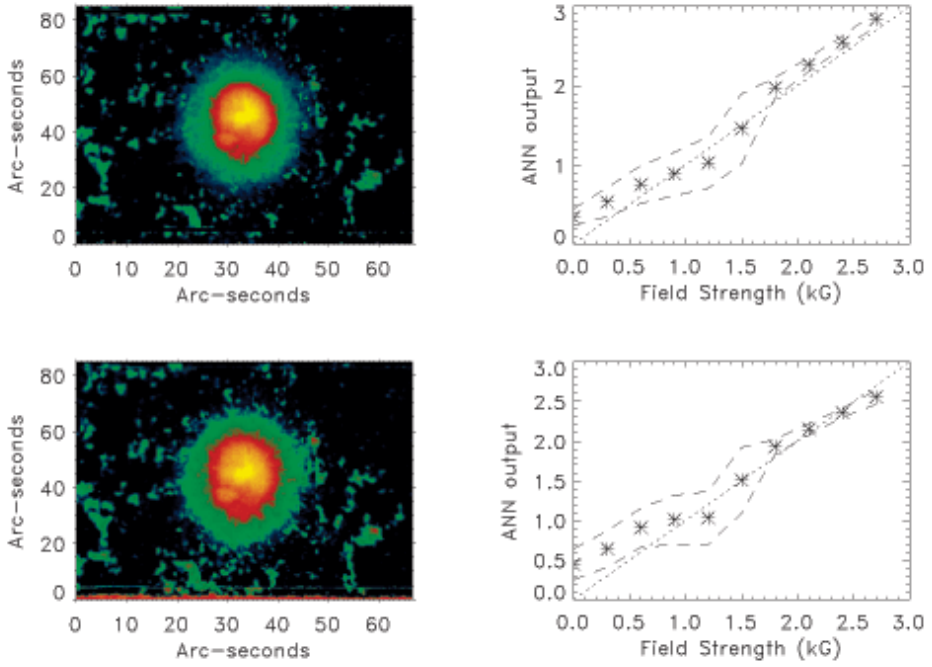






Photospheric magnetometry

- Degrees of sophistication (Instrumentation+Inversion)
  - Magnetograms
    - PCA & Artificial Neural Networks
  - Milne-Eddington inversions ("flat" photosphere)
  - Full-LTE, gradi



Index

- Introduction: Photospheric magnetometry
- The *not-so-quiet* Sun
  - How magnetic is it?
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- Magnetic fields in active regions
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Index

- Introduction: Photospheric magnetometry
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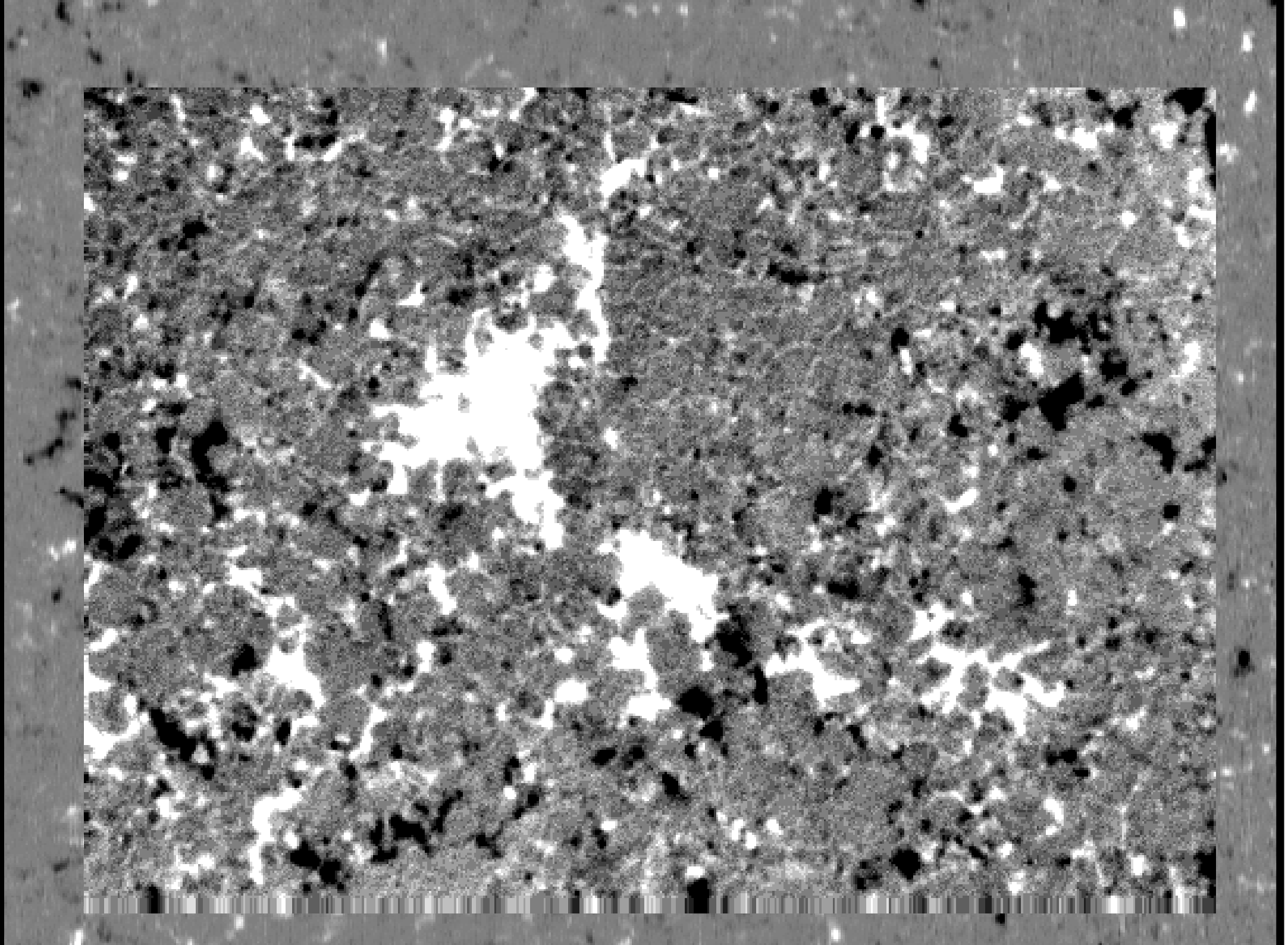

The *not-so-quiet* Sun

- Some problems:
  - Sensitivity
  - Spatial resolution
  - Signal cancelation (Zeeman only)
  - Vis/IR discrepancy: Sub-pixel PDF

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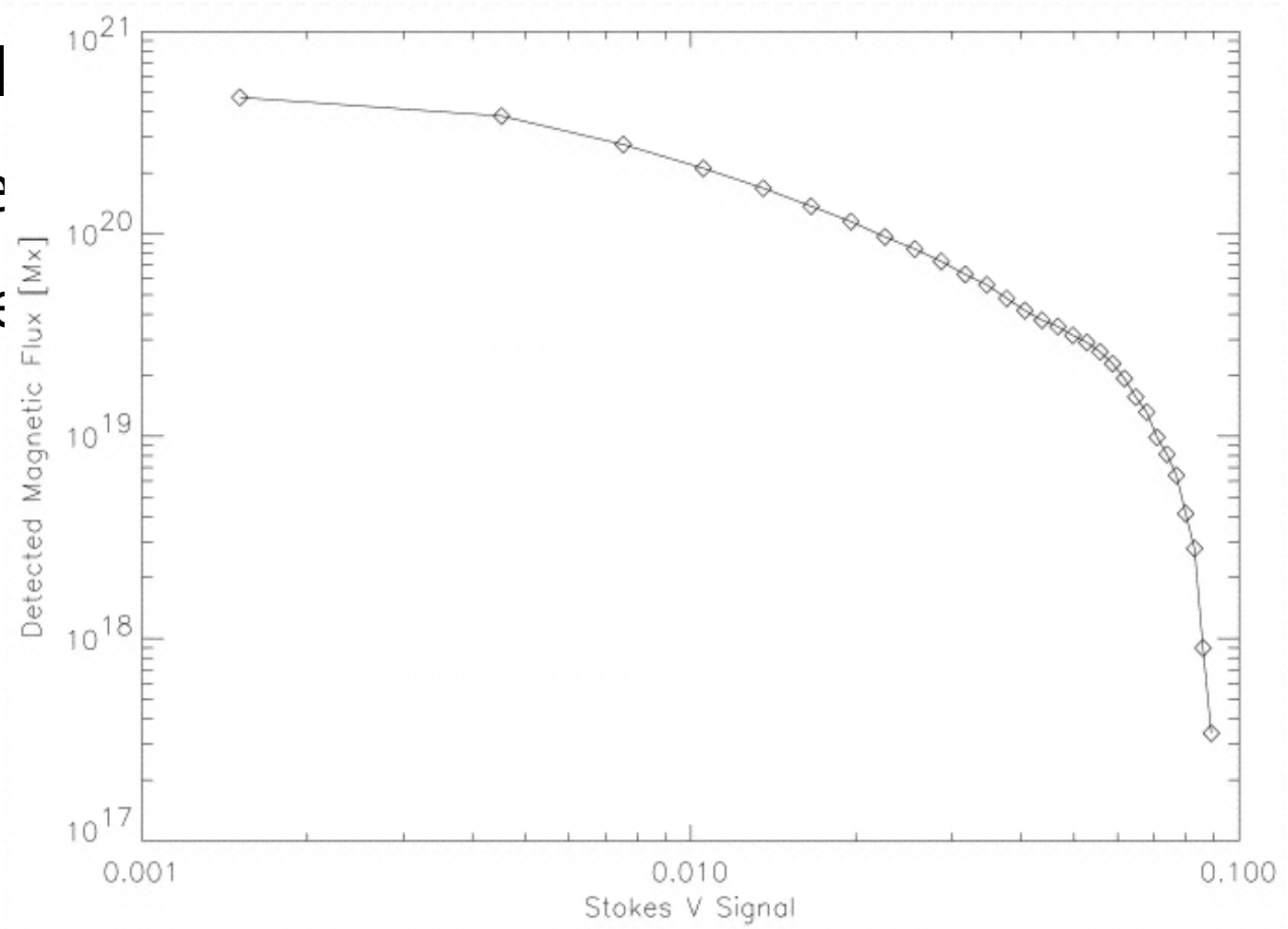

Socas-Navarro & Sanchez Almeida (2002)

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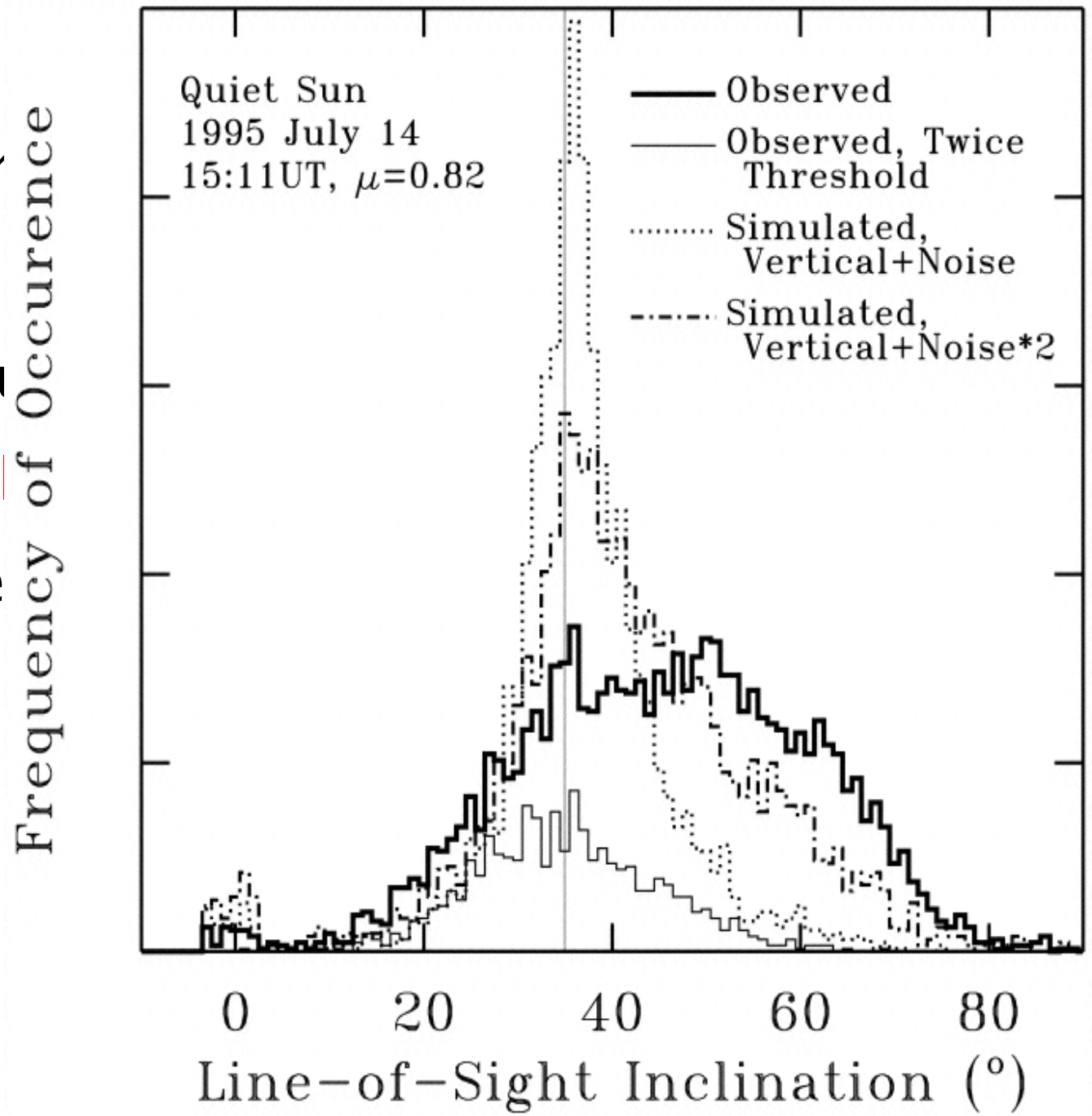

Lites (2002)

The *not-so-quiet* Sun

- Some problems:
  - Sensitivity
  - Spatial resolu
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  - Vis/IR dis
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    - Almeid
    - 2002; I
    - 2004)
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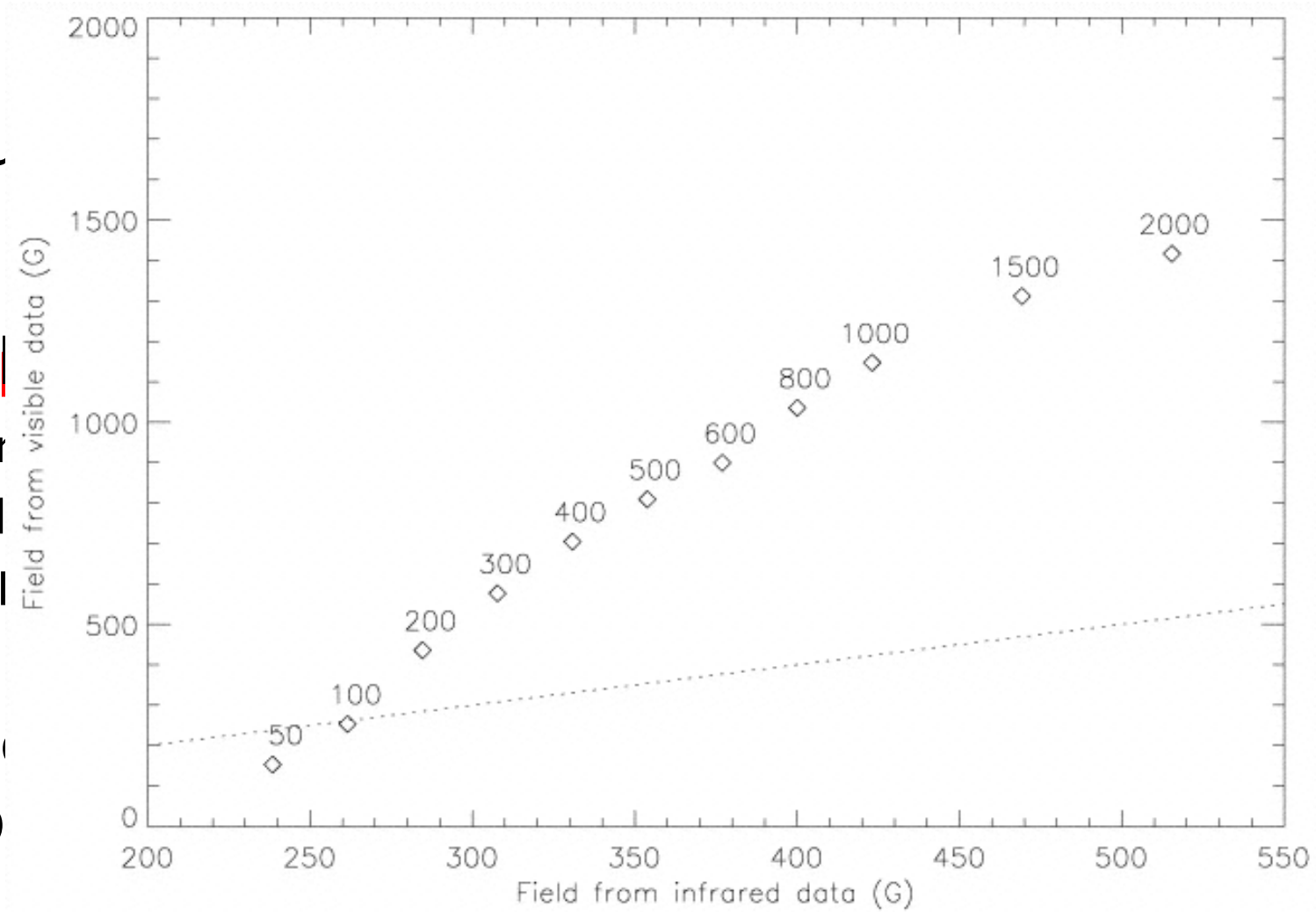
    - (Lin 19



Socas-Navarro & Sanchez Almeida (2003)

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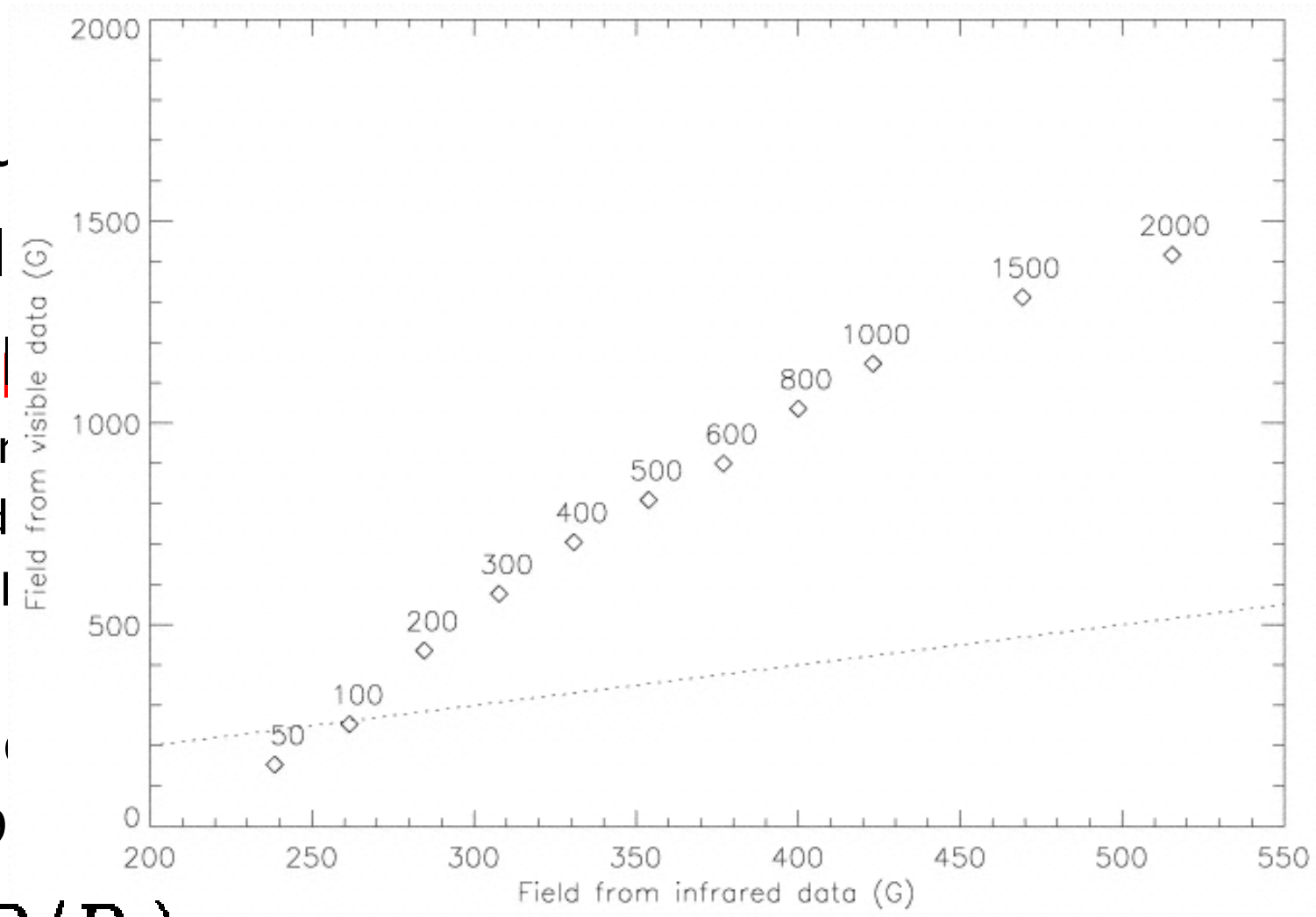


$$P(B) = exp(-B/B_0)$$

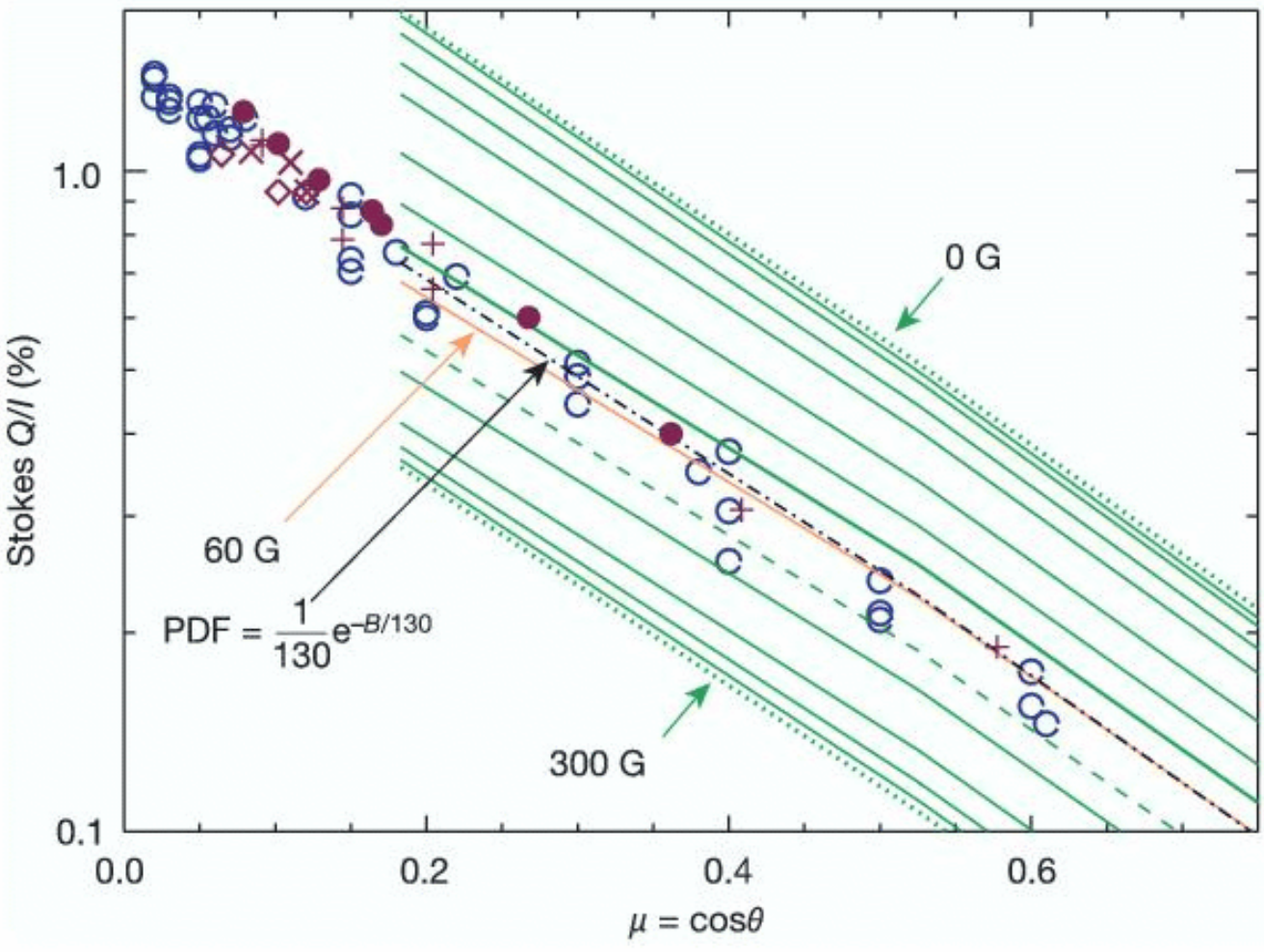
Socas-Navarro & Sanchez Almeida (2003)

The *not-so-quiet* Sun

- Open questions:
  - How magnetic is it?
  - Does the flux increase with better resolution/sensitivity?
  - What is the intrinsic field strength?
  - What is the origin of these fields?
  - Systematic exploration still needed

The *not-so-quiet* Sun

- Open questions:
  - How magnetic is it?
    - Sánchez Almeida &
    - Socas-Navarro & S
    - Sánchez Almeida (
    - Domínguez Cerde
    - Khomenko et al (2
    - Lites & Socas-Nava
    - Trujillo Bueno et a
  - Does the flux incr
  - What is the intrins



The *not-so-quiet* Sun

- Open questions:
  - How magnetic is it?
  - Does the flux increase with better resolution/sensitivity?
    - Domínguez Cerdeña et al (2003) -> Factor 2 increase when going from 1" to 0.5" (Speckle polarimetry)
    - Lites & Socas-Navarro (2004) -> No increase when going from 1" to 0.6" (DLSP + AO)
  - What is the intrinsic field strength?
  - What is the origin of these fields?
  - Systematic exploration still needed

The *not-so-quiet* Sun

- Open questions:
  - How magnetic is it?
  - Does the flux increase with better resolution/sensitivity?
  - What is the intrinsic field strength?
    - What is the PDF?
    - Khomenko et al (2003); Trujillo Bueno et al (2004); Domínguez Cerdeña et al (2005)
  - What is the origin of these fields?
  - Systematic exploration still needed

The *not-so-quiet* Sun

- Open questions:
  - How magnetic is it?
  - Does the flux increase with better resolution/sensitivity?
  - What is the intrinsic field strength?
  - What is the origin of these fields?
    - Local dynamo vs Active region dissipation (e.g., Durney et al 1993)
    - Convective collapse (???)
      - Aborted events: Bellot Rubio et al (2001); Socas-Navarro & Manso Sainz (2005)
  - Systematic exploration still needed

The *not-so-quiet* Sun

- Open questions:
  - How magnetic is it?
  - Does the flux increase with better resolution/sensitivity?
  - What is the intrinsic field strength?
  - What is the origin of these fields?
  - Systematic exploration still needed
    - Better coverage; multiple latitudes; coronal holes vs normal corona; etc

Index

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Index

- Introduction: Photospheric magnetometry
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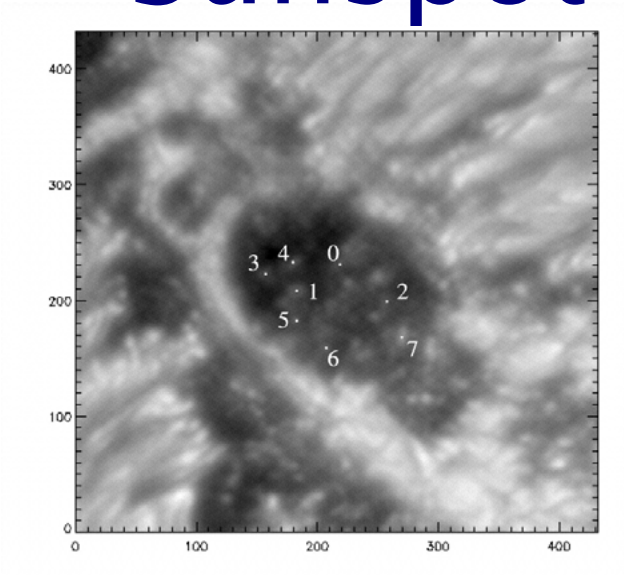
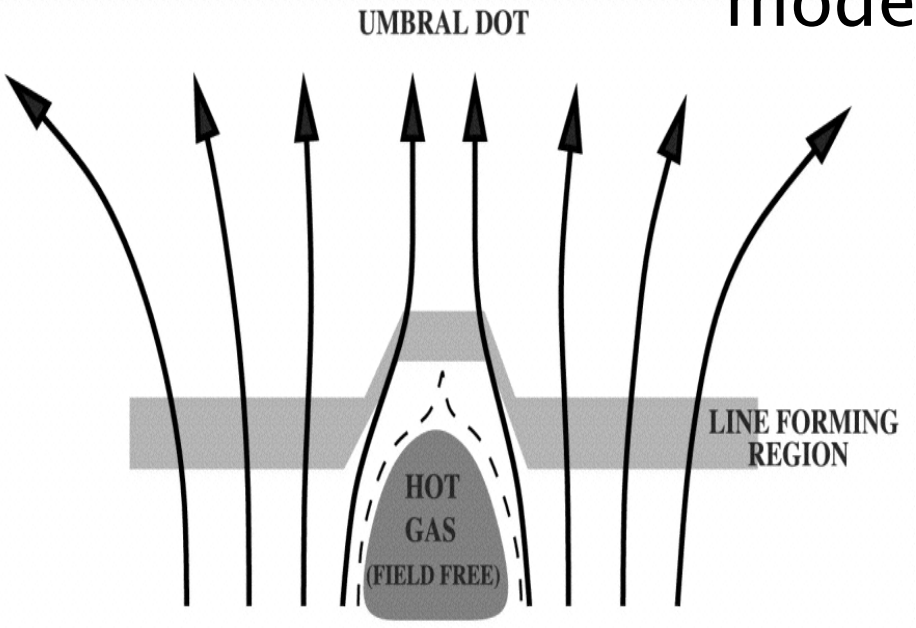
Sunspot umbrae: umbral dots



Socas-Navarro et al. (2004)

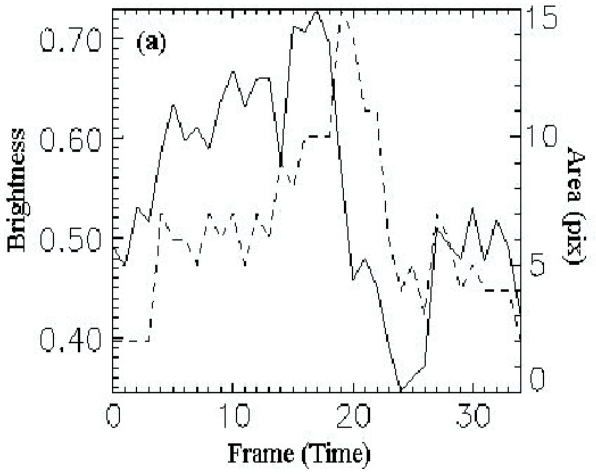
AR 8990; Full Stokes; 0.7 arc sec; LPSP

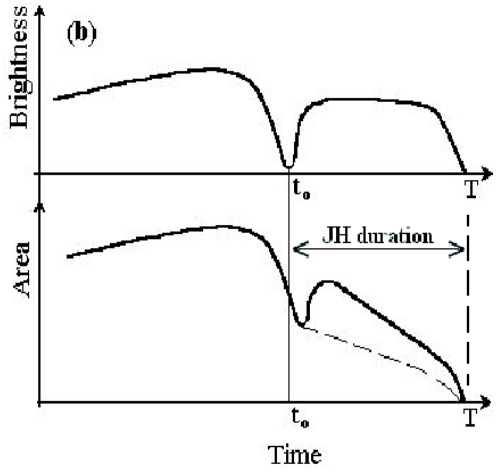
Stokes inversion with LILIA on 8 umbral dots; dark umbral background consistently modelled.



Hamedivafa & Sobotka (2004)

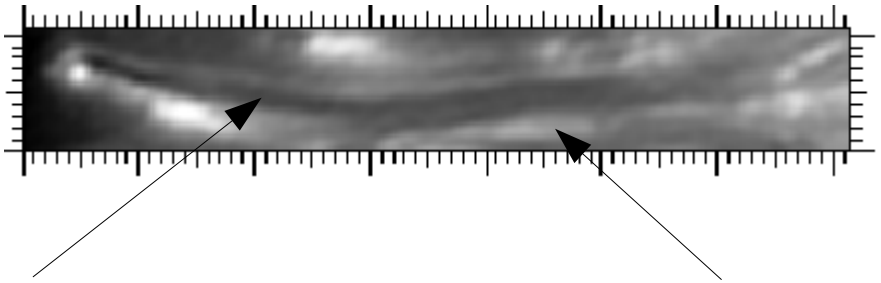
Joule heating in 12% of UDs





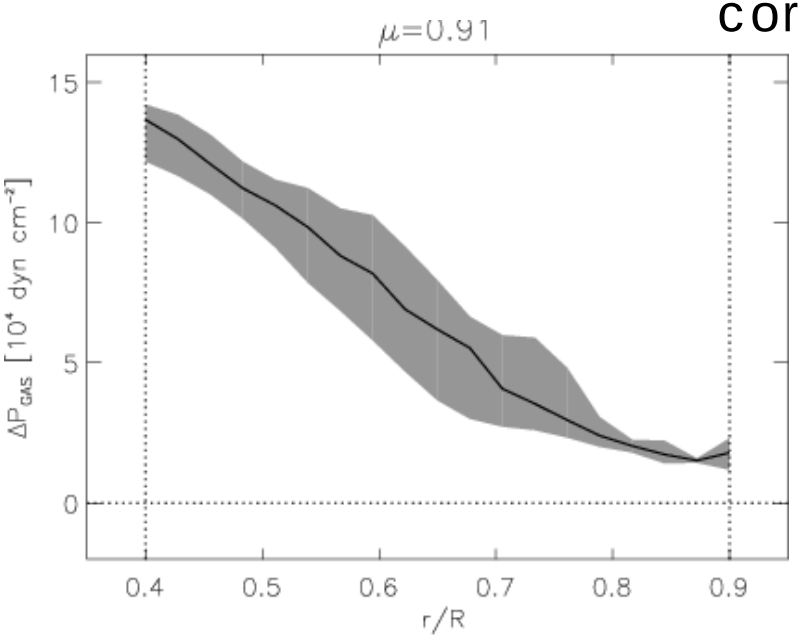
Sunspot penumbra: small scale magnetic field and Evershed flow

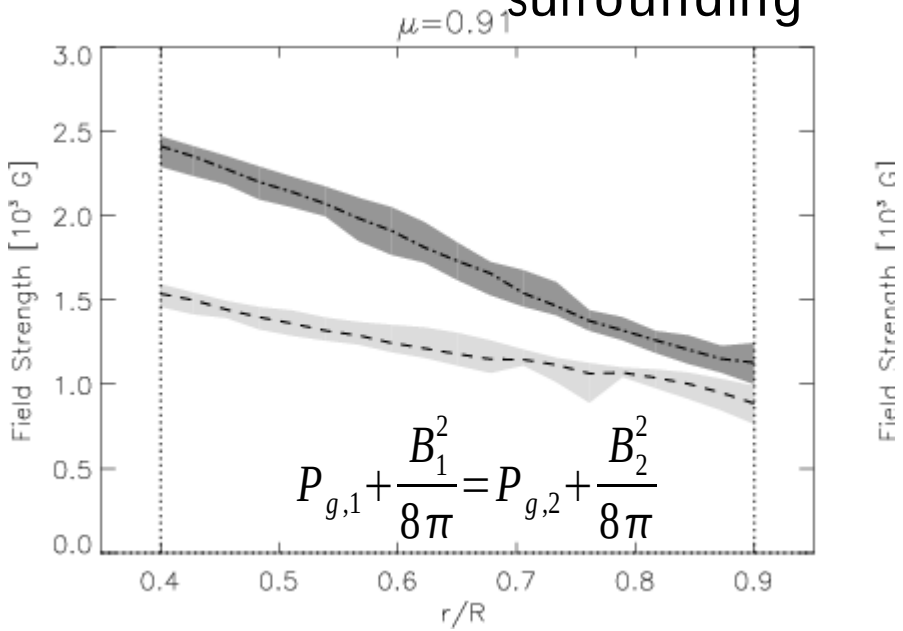
Penumbral strucutre at 0.1 arc sec resolution; Scharmer et al. 2002



Dark core

Magnetic surrounding





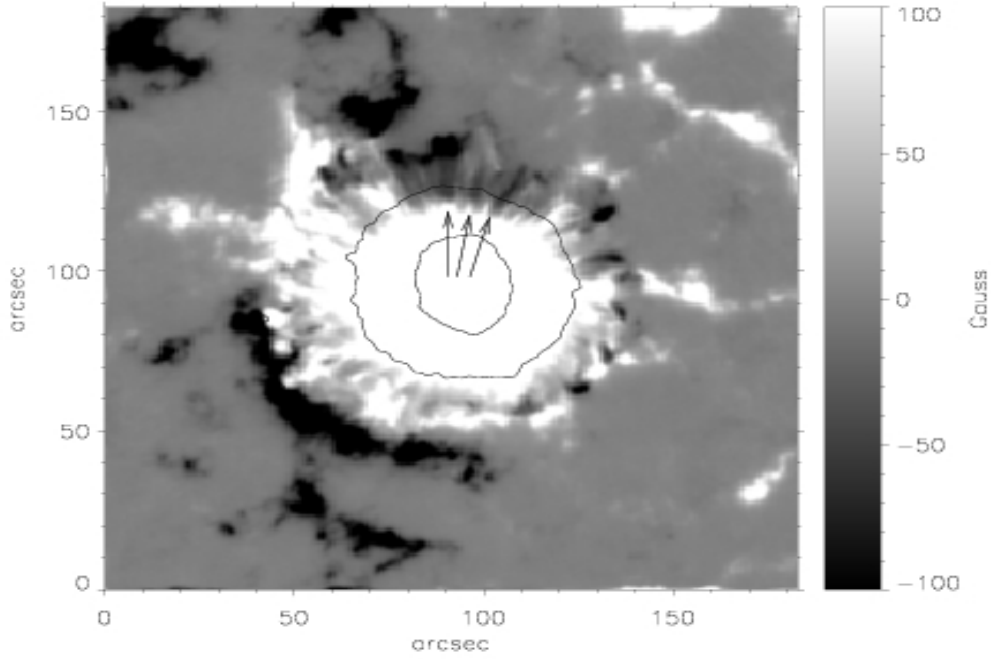
$$\frac{\partial \Delta P_{gas}}{\partial r} < 0$$ Siphon flow ?

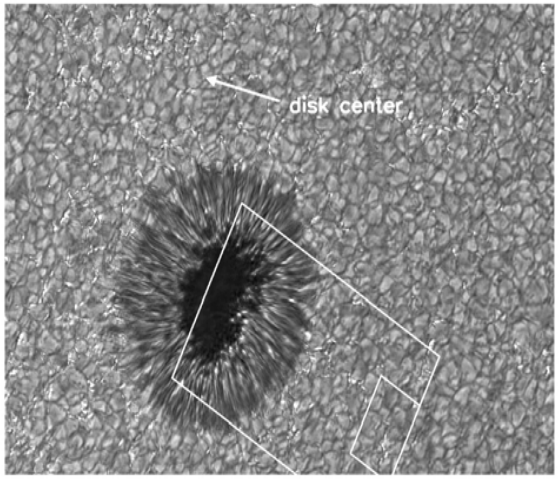
Borrero et al. 2004; A&A, 422:1093

Borrero et al. 2005; A&A, 426:333

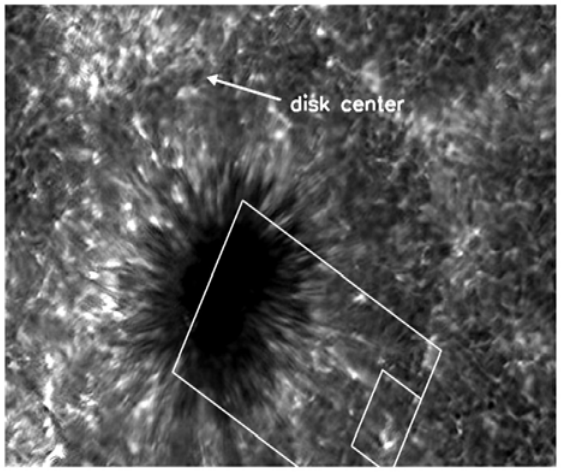
Sunspot moat: MMF's and Chromospheric emission

Sainz Dalda & Martínez Pillet (2005)
MMFs originate well inside the penumbra

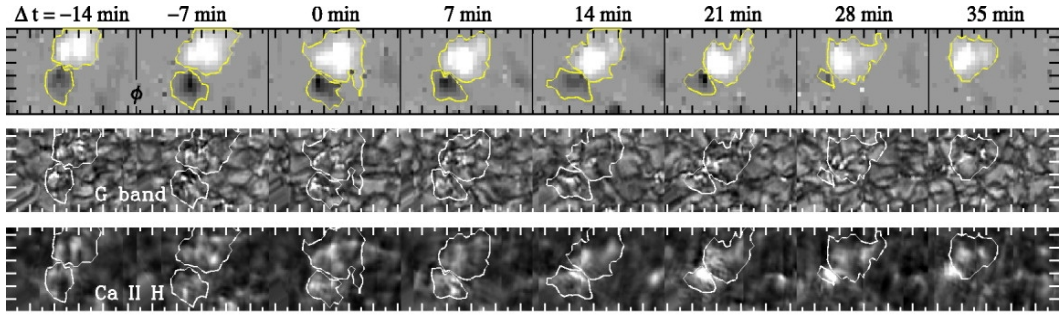




Bellot Rubio & Beck (2005)



Cancellation+strong upflows+Chromospheric emission: magnetic reconnection between opposite polarities?



Sunspots

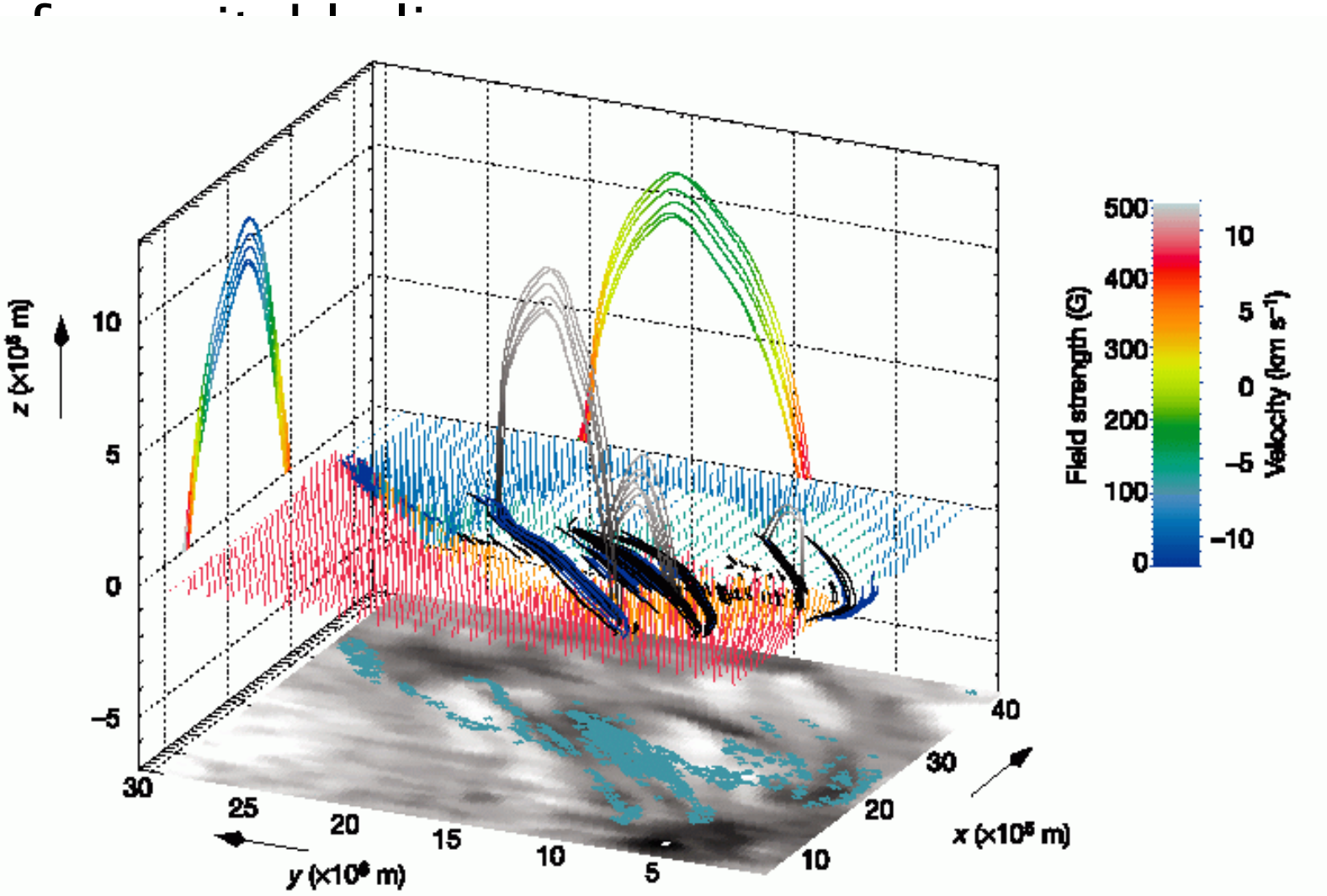
- Recent work points towards a connected view:
  - Umbral dots <--> penumbral grains (Sobotka et al; Rouppe van der Voort et al)
  - Grains are tails of penumbral filaments (Swedish tower movies)
  - Observations (Sainz Dalda & Martínez Pillet) and simulations (Weiss et al; Schlichenmaier et al): Filaments sink below photosphere in outer penumbra and reappear in the moat as MMFs

Chromospheric magnetometry

- Challenging because:
  - There are few suitable lines
  - Interpretation/inversion complicated by NLTE effects

Chromospheric magnetometry

- Challenging because:
  - There a
  - Interpr
- Two viab
  - Observ



Solanki et al (2003)

Chromospheric magnetometry

- Challenging because:
  - There are few suitable lines
  - Interpretation/inversion complicated by NLTE effects

- Two viable approaches:
  - Observations of He I 10830: Milne-Eddington inversion

    (e.g., Solanki et al 2003)

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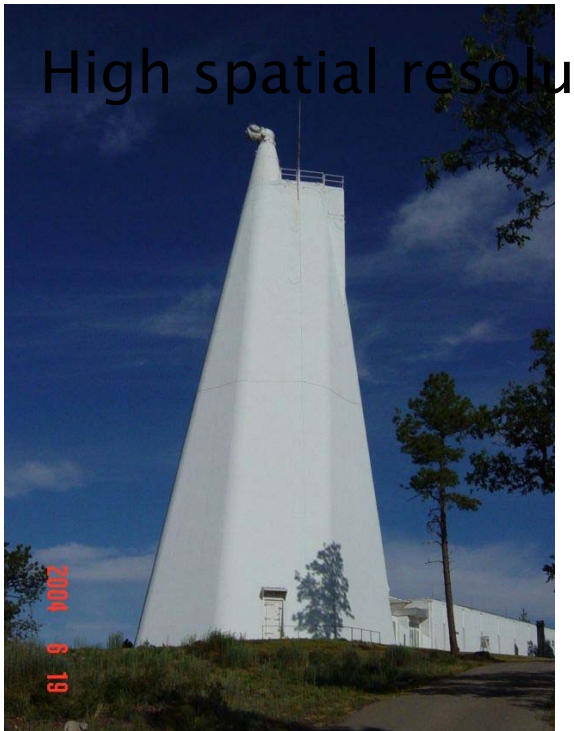
  - There are few suitable lines
  - Interpretation/inversion complicated by NLTE effects

- Two viable approaches:
  - Observations of He I 10830: Milne-Eddington inversion (e.g., Solanki et al 2003)
  - Observations of Ca II infrared triplet: Full NLTE inversions

Chromospheric polarimetry with SPINOR

Spectro-Polarimeter for INfrared and Optical Regions

- Versatile achromatic spectro-polarimeter at the DST (Sac Peak)
- Simultaneous visible and near-infrared operation
- 2 vis+1 ir camera
- High spatial resolution (~0.6") using new high-order AO

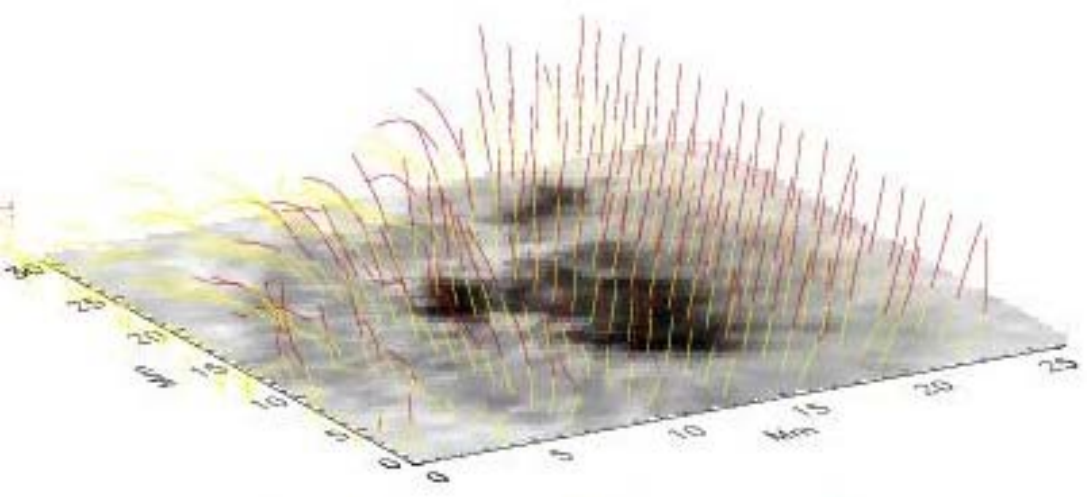


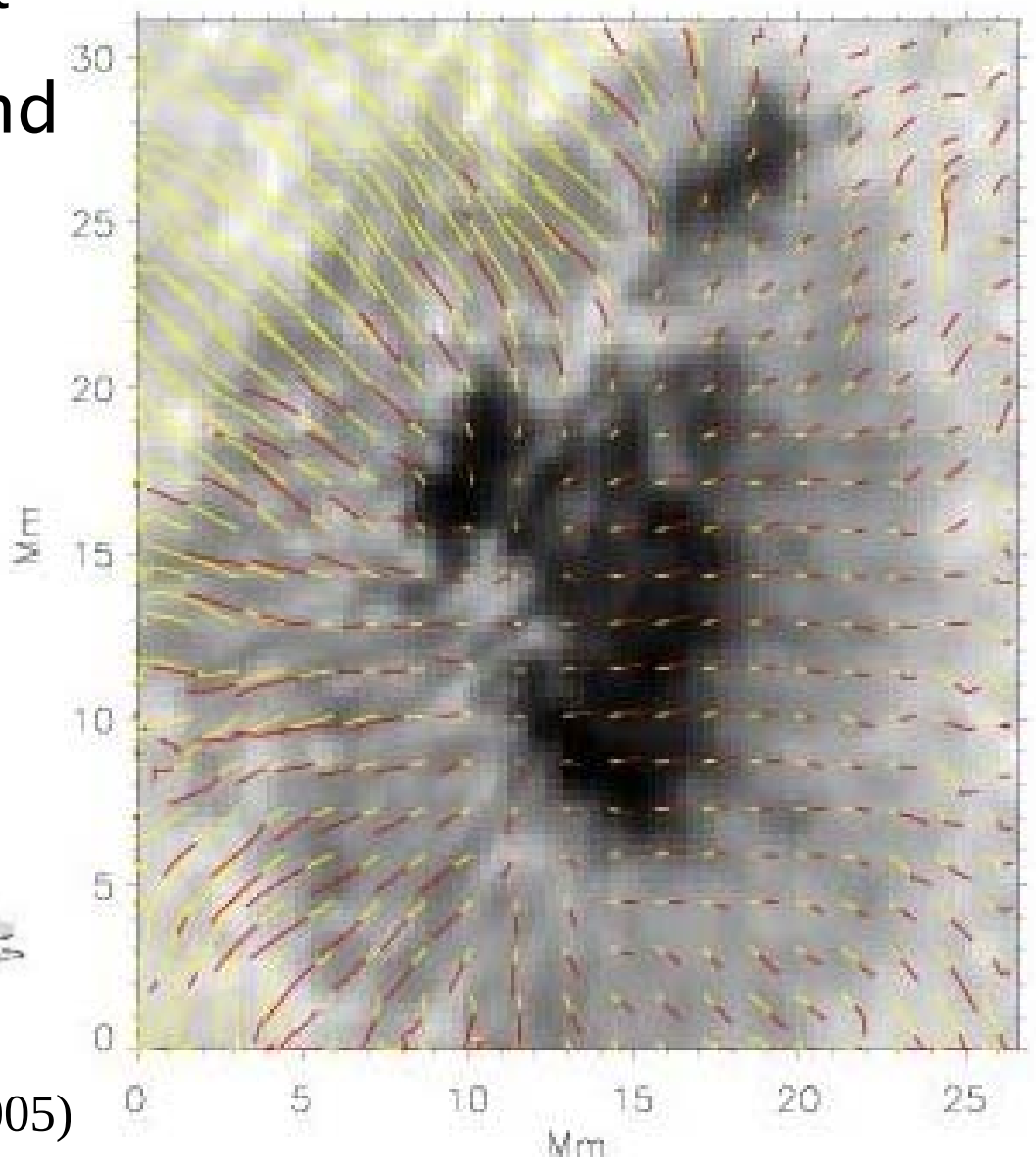
Chromospheric polarimetry with SPINOR

- 3D tomography of a sunspot (phot+chrom) using 2 FeI and 2 CaII lines

  yellow: 0 – 800 km

  red: 800 – 1600 km





Socas-Navarro (2005)

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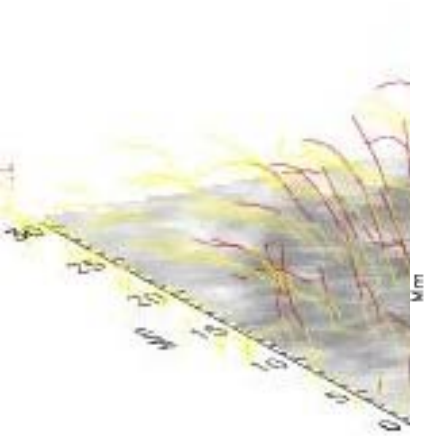
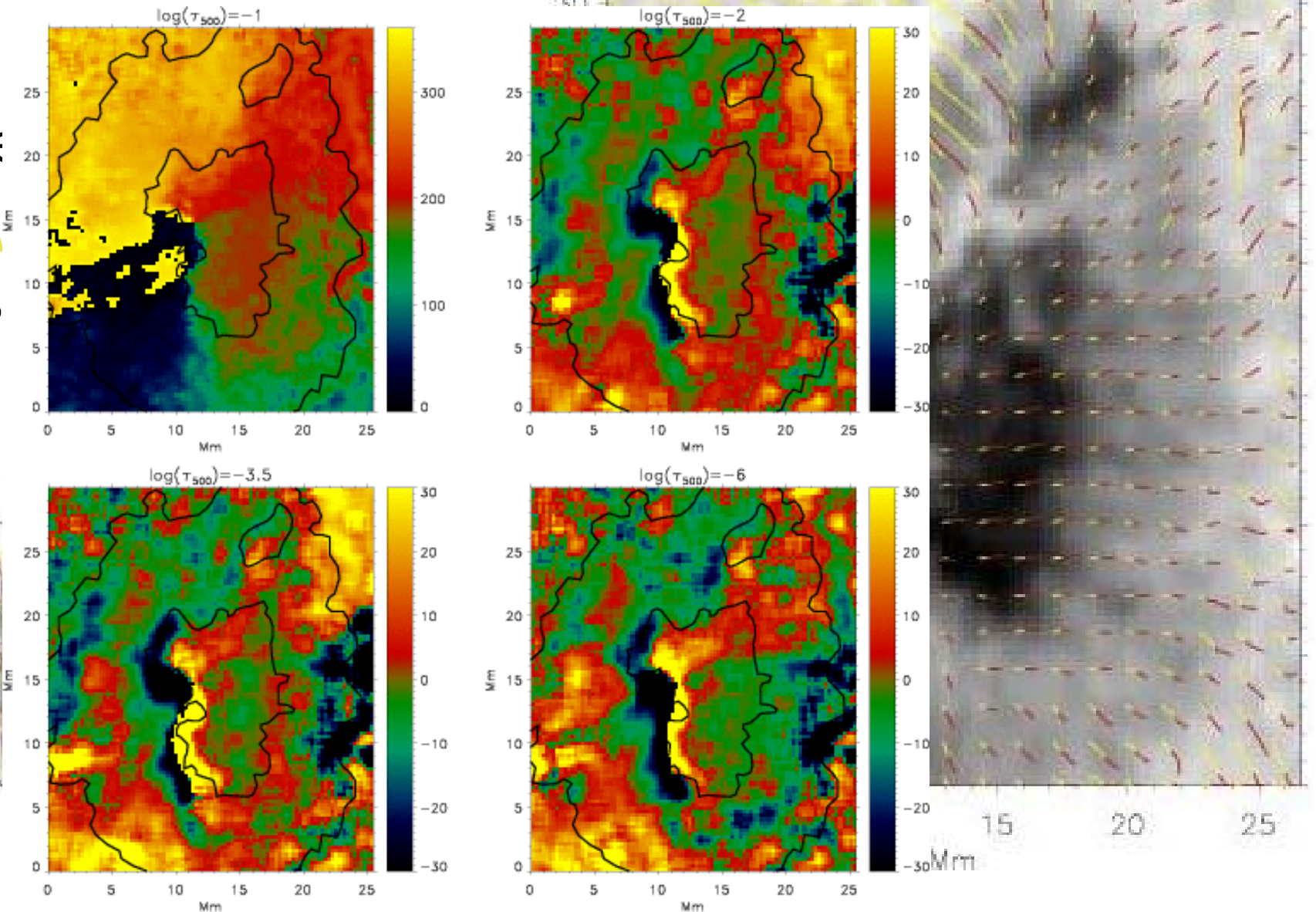
(phot+ch

2 CaII line

yellow

red: 8





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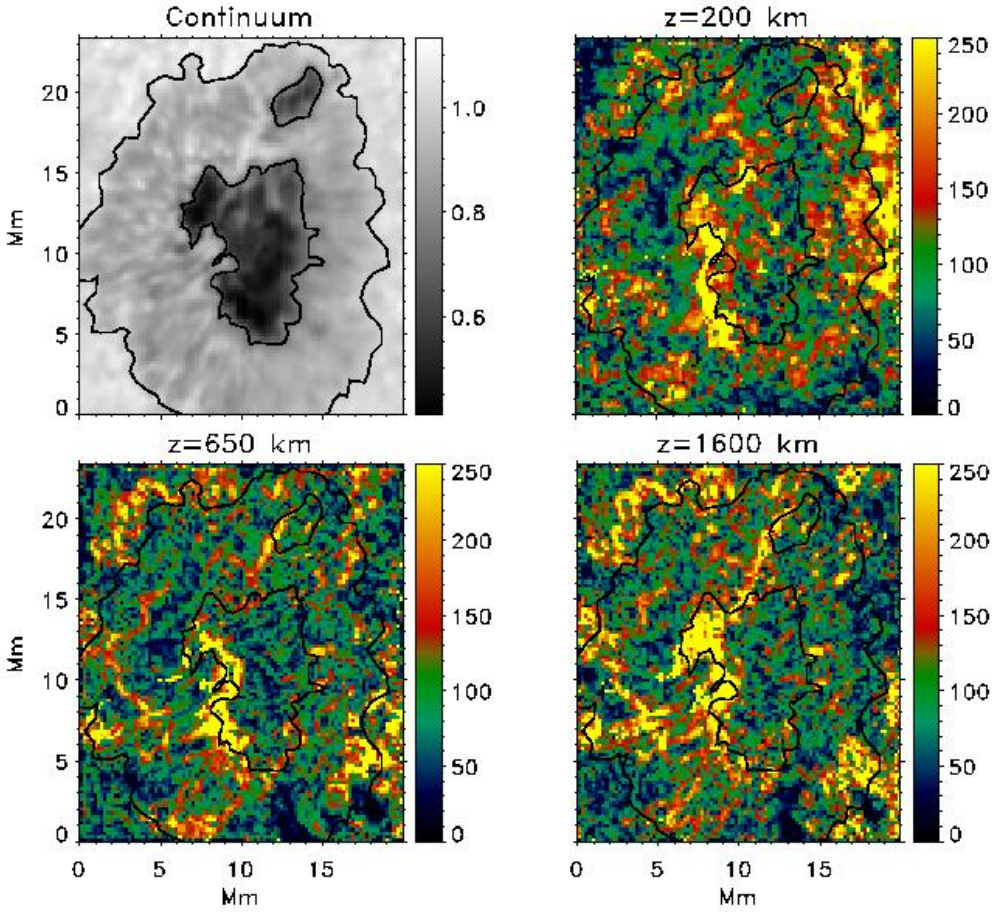
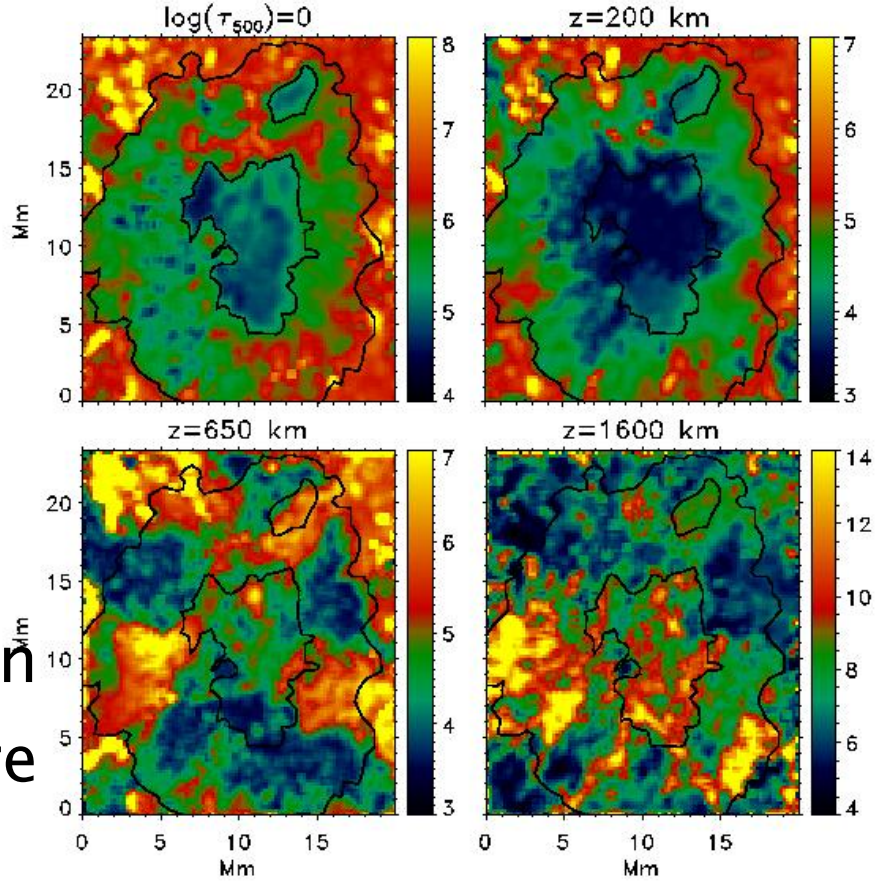


Empirical determination of vector current densities.

$$\vec{j} = \nabla \times \vec{B}$$



Relation (or lack thereof) between currents and temperature

Index

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Conclusions

- The quiet Sun
  - Importance?
    - Amount of flux not yet clear but ...
    - ...there's more in the quiet Sun than in all active regions during solar maximum!!
  - The search for the PDF continues
- Active regions
  - Understanding the fine structure -> Spatial resolution
  - Active region evolution
  - Solar-B will provide both in Aug '06