3D Structure of the Sunspot Umbra

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Bruce Lites, *HAO, Boulder*

Sarah Mägli, *ETH Zurich*


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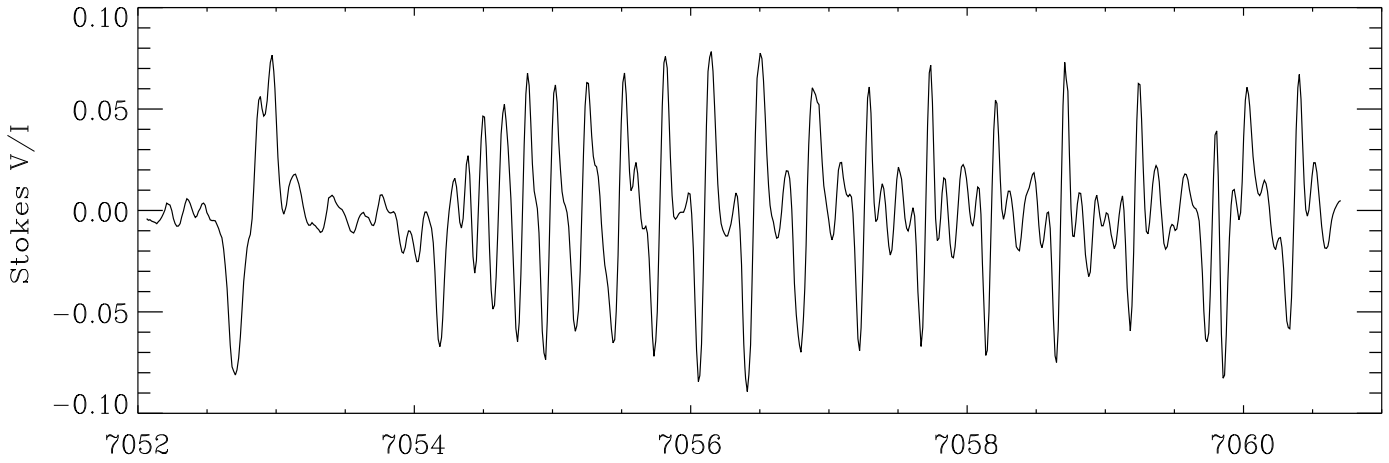
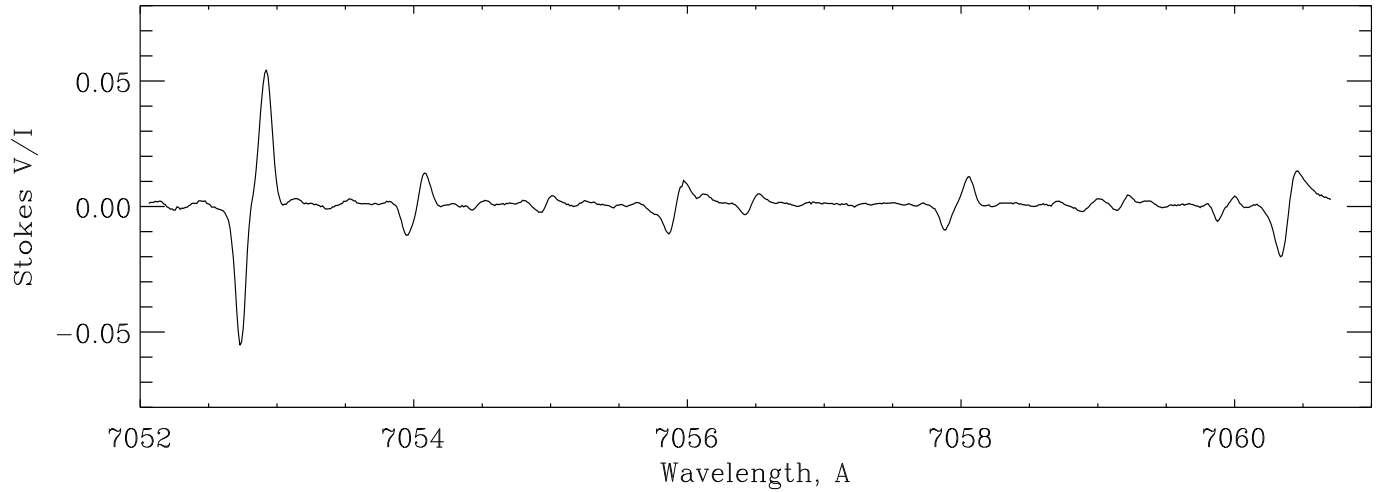
Molecules in sunspot umbra

- Sunspot umbra: TiO

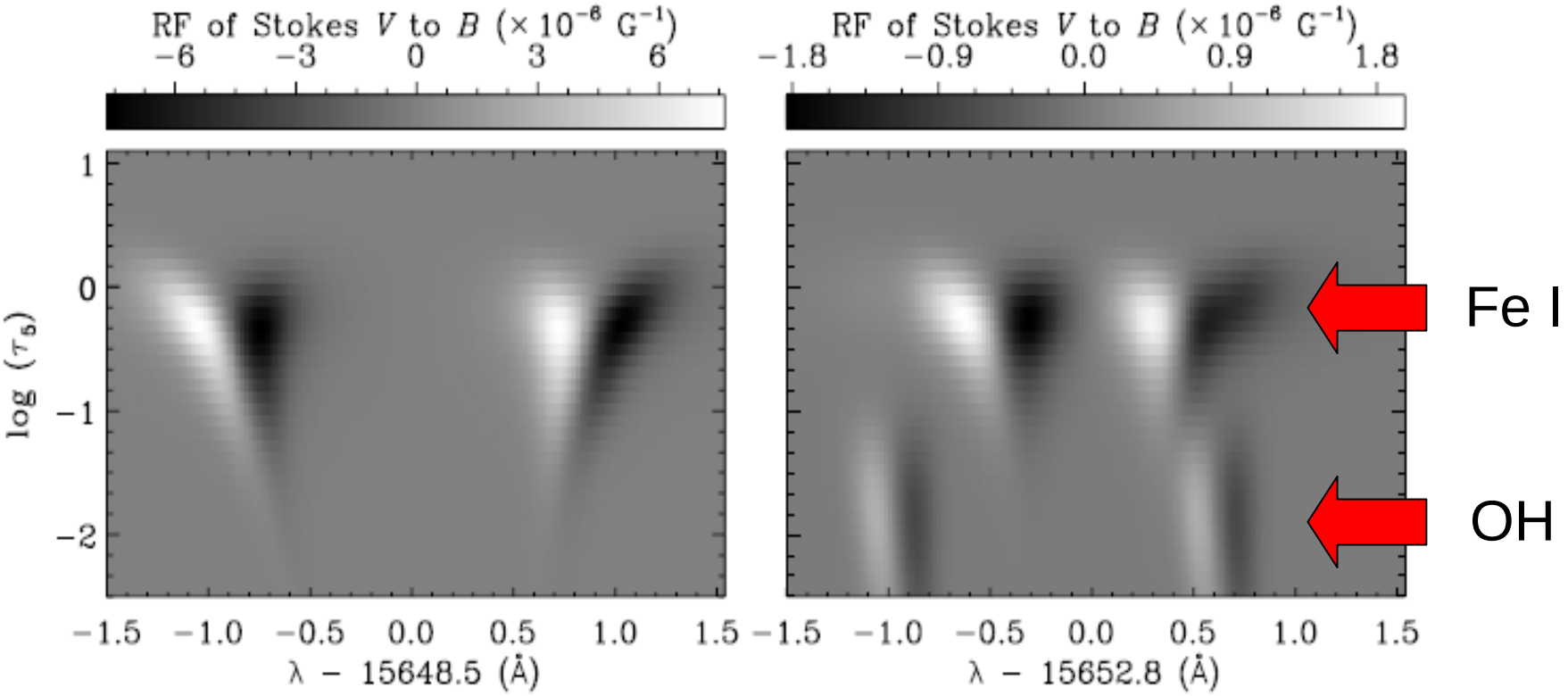


- Sunspot penumbra



Sunspots: 3D structure

- Simultaneous inversion of Fe I and OH lines in the IR



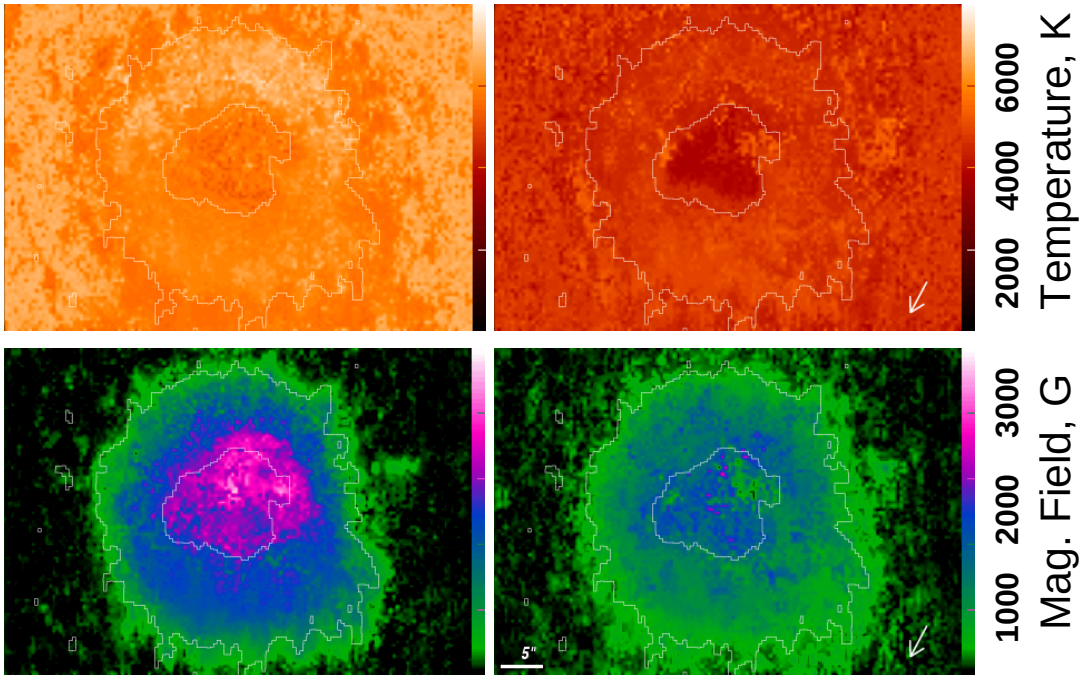
Mathew et al. (2003)

Sunspots: 3D structure

- Simultaneous inversion of Fe I and OH lines in the IR

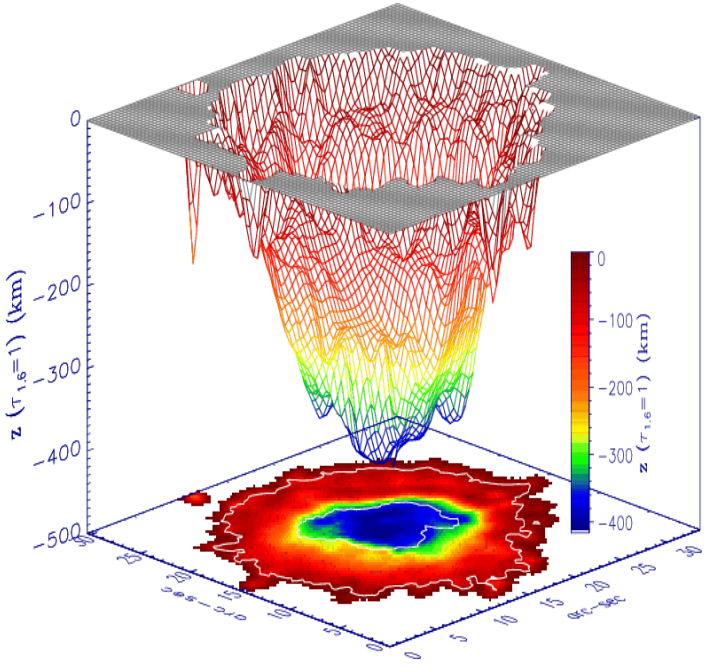
Bottom of photosphere
log $\tau_{0.5}$= 0

Middle photosphere
log $\tau_{0.5}$=–2



Mathew et al. (2003)

Wilson depression
at $\tau_{1.6}$=1

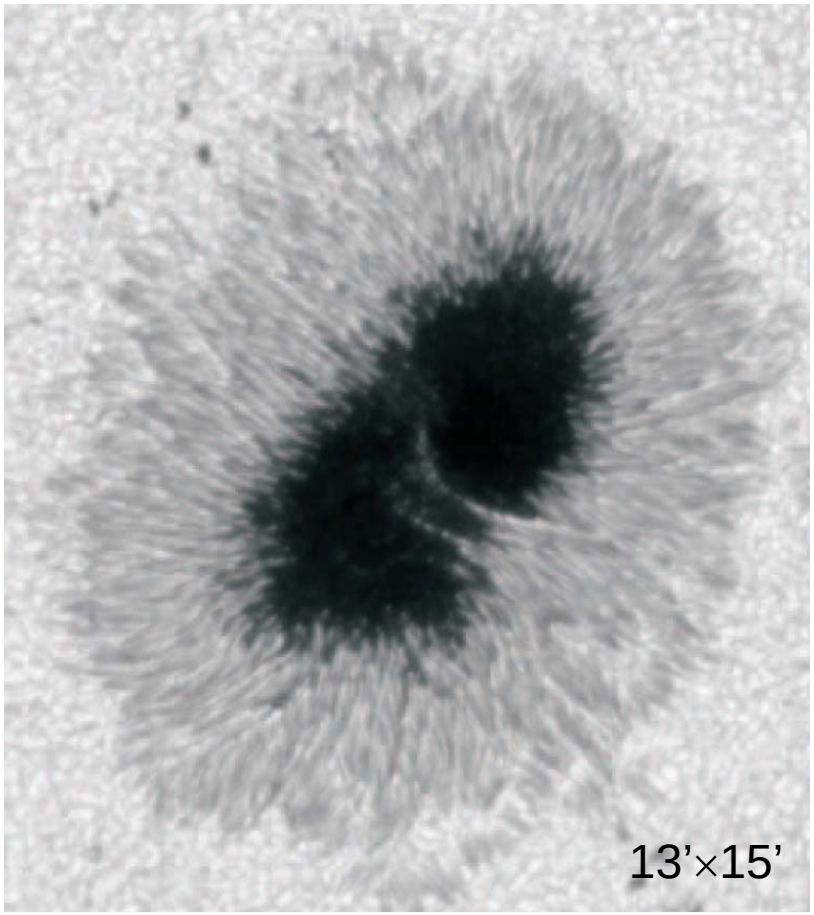


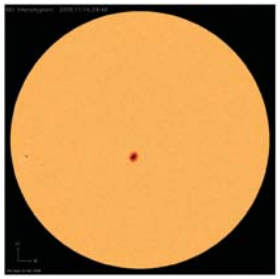
Mathew et al. (2004)

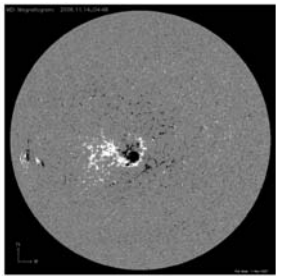
Umbra: 3D structure

- Observations
  - Hinode, Nov 2006
  - Full Stokes spectro-polarimetric imaging
  - 0.3” resolution
  - 6301-6303 Å region
- Inversions
  - Fe I, CaH (B-X, PBR), TiO (γ,γ’, ZR)
  - SPINOR: Polar. RT, chem eq. (Berdyugina et al., 2000-2006)
  - T, B, γ, χ, P, v, etc. (h)
  - Umbra (~30,000 pix)

$\Rightarrow$ 3D model







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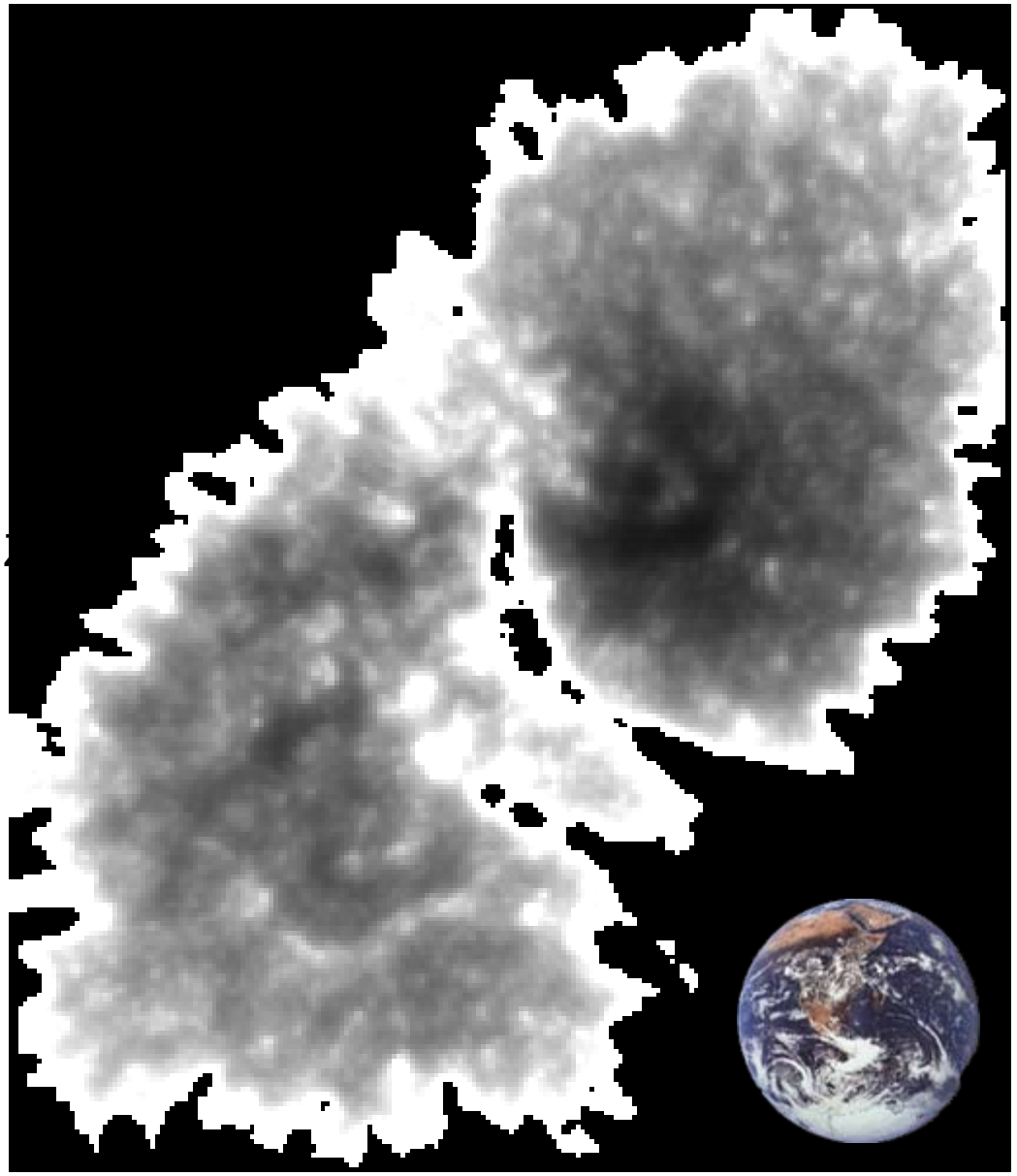
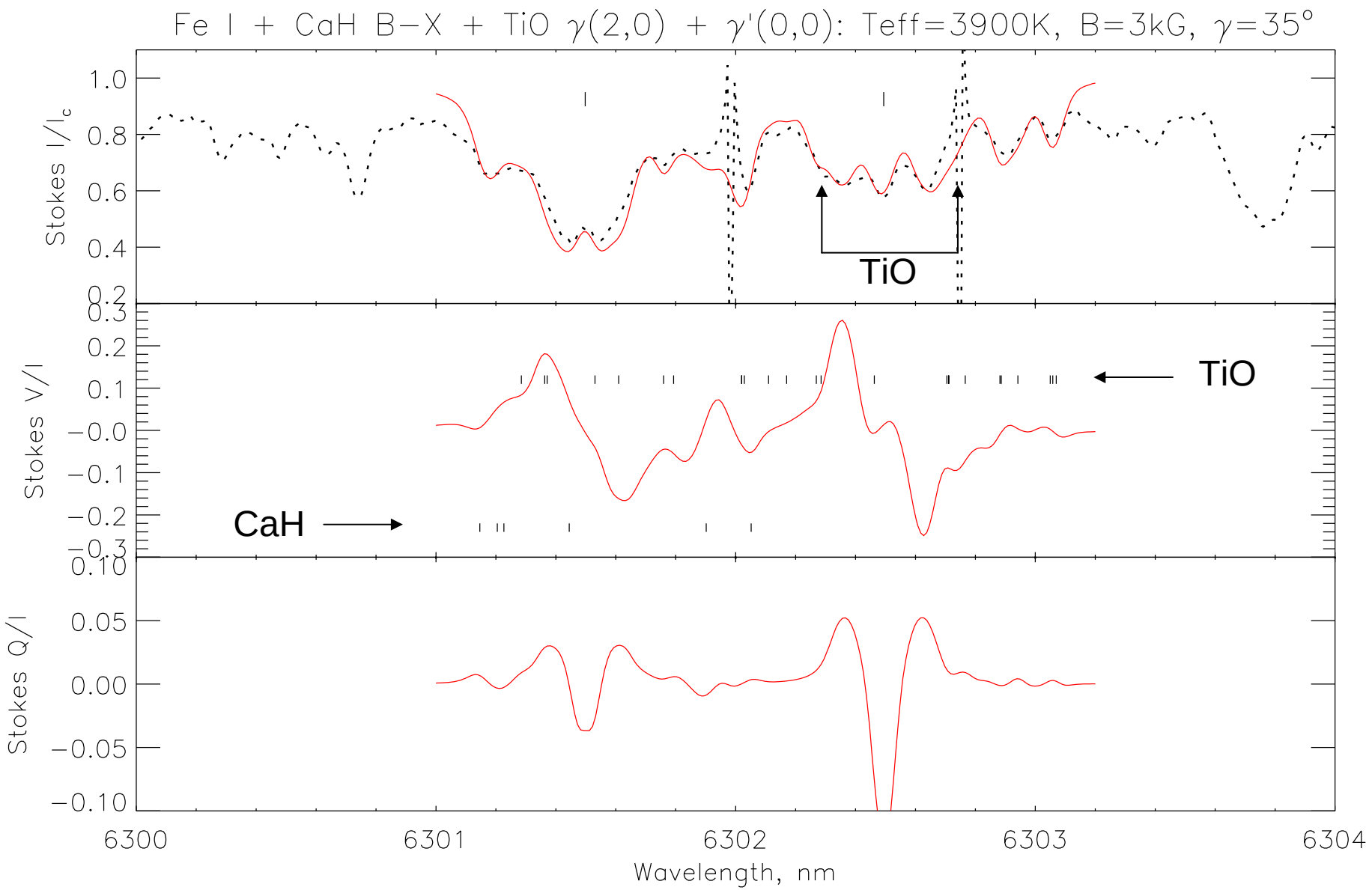
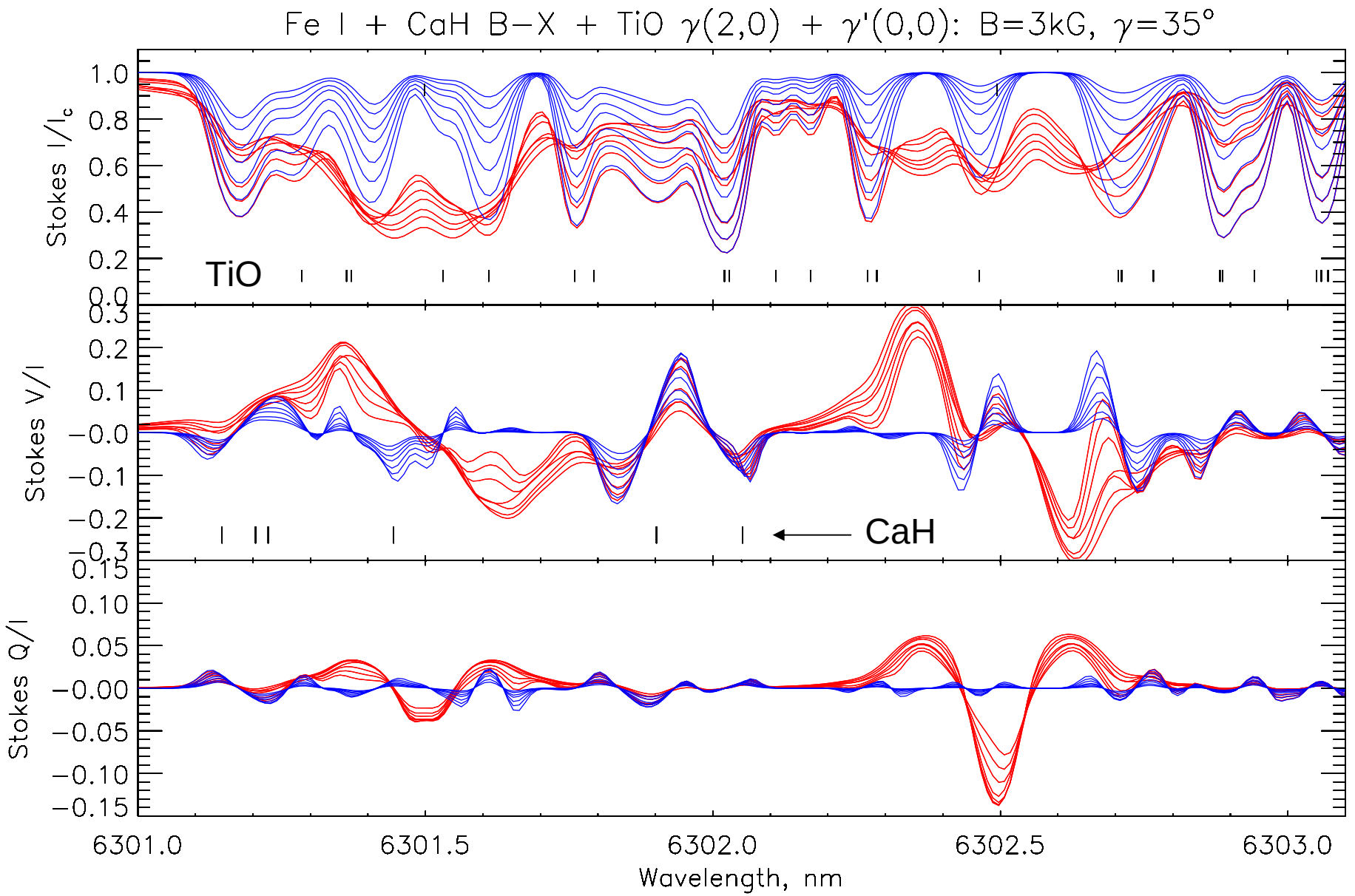


Umbra: Spectrum synthesis

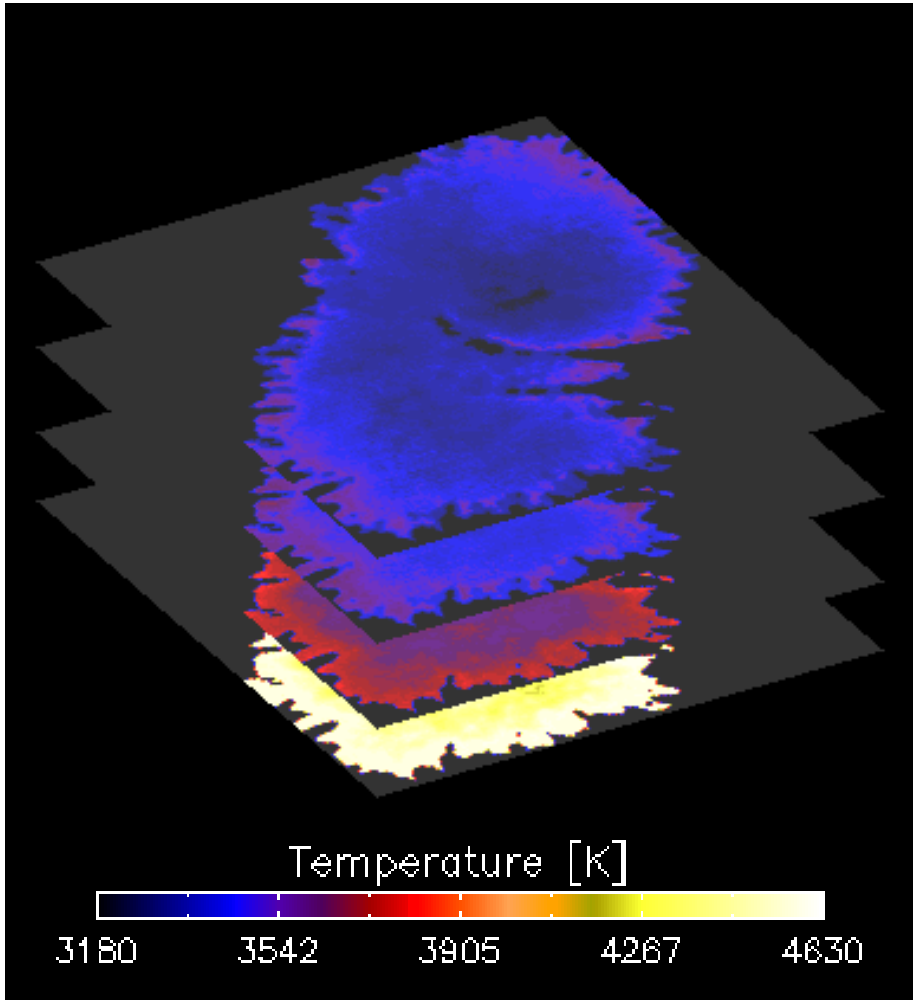


Umbra: Spectrum synthesis

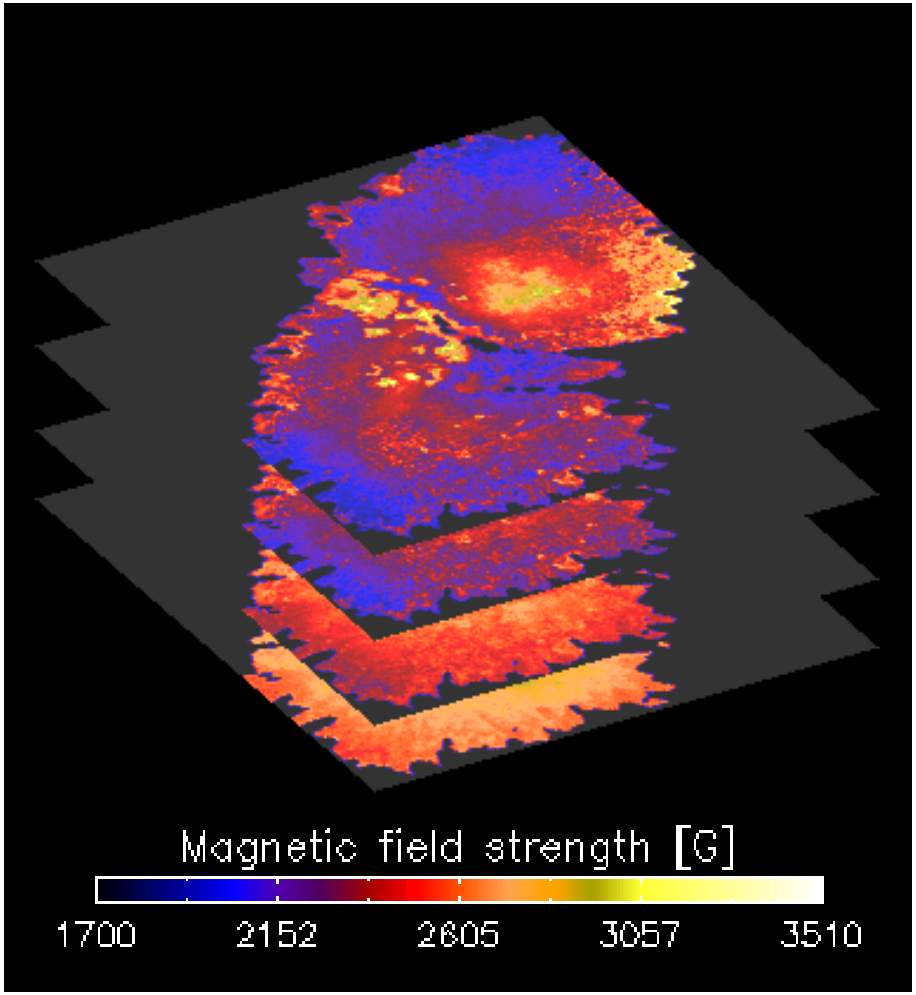


Umbra: 3D structure

- Temperature

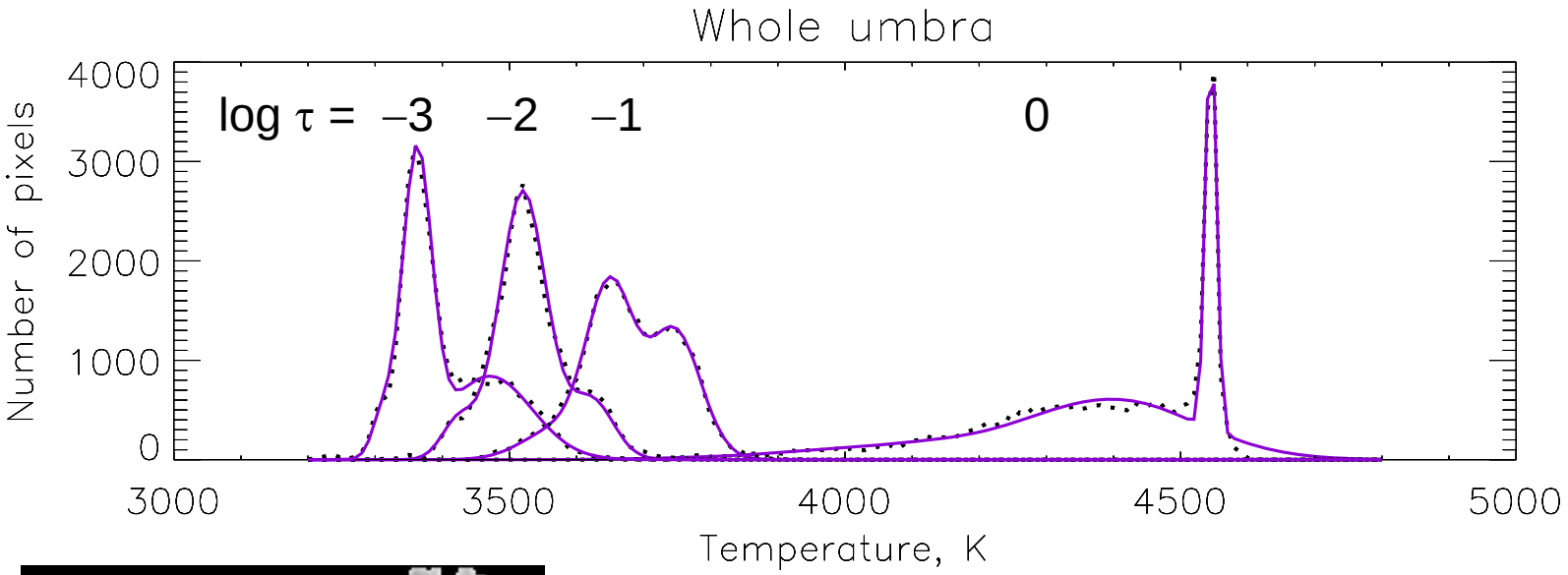


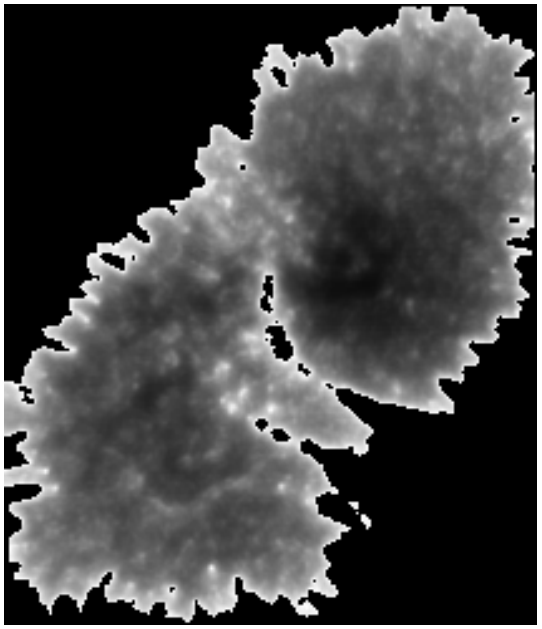
- Magnetic field strength

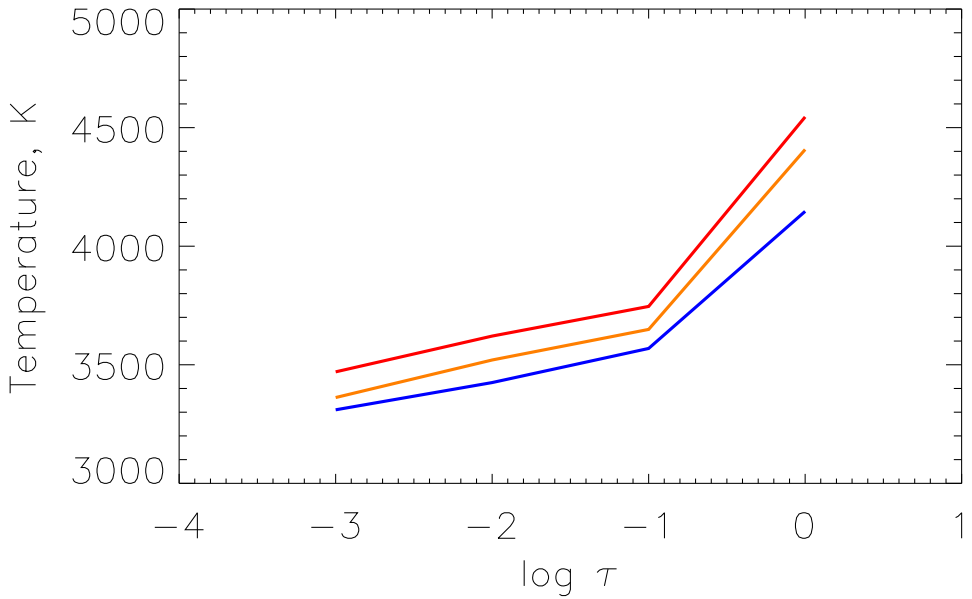


log τ = 0, –1, –2, –3

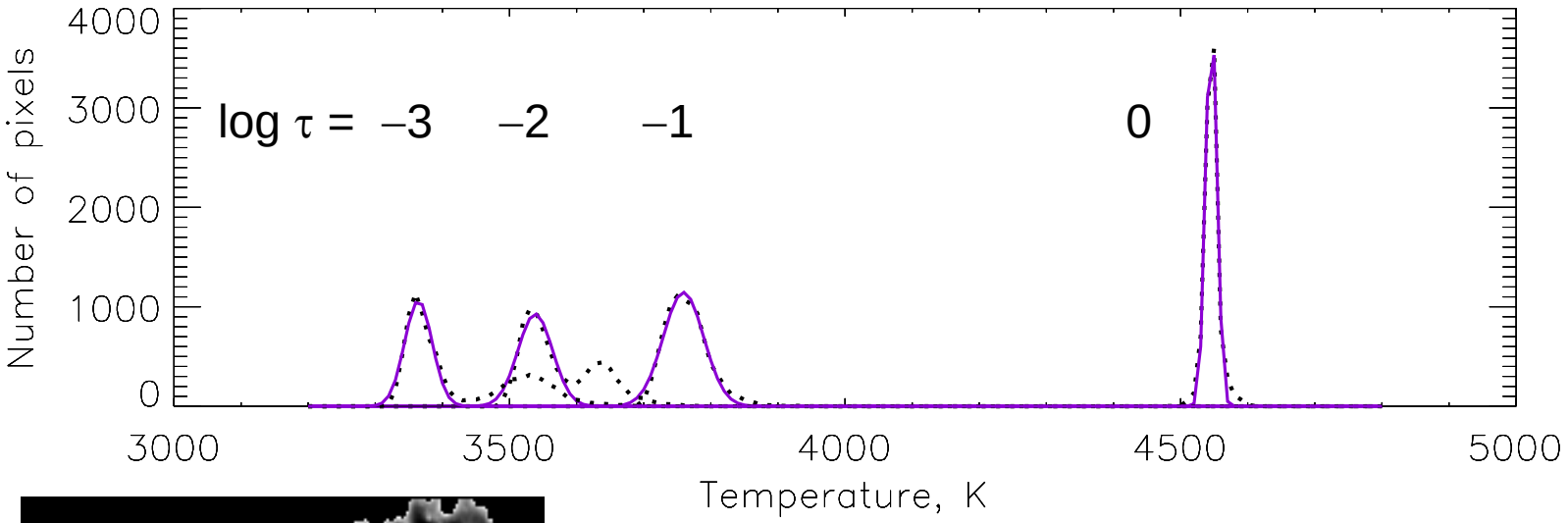
Umbra: Fine structure

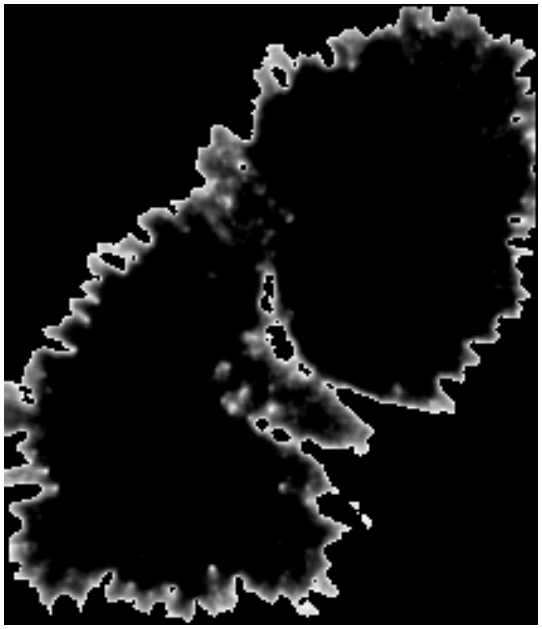


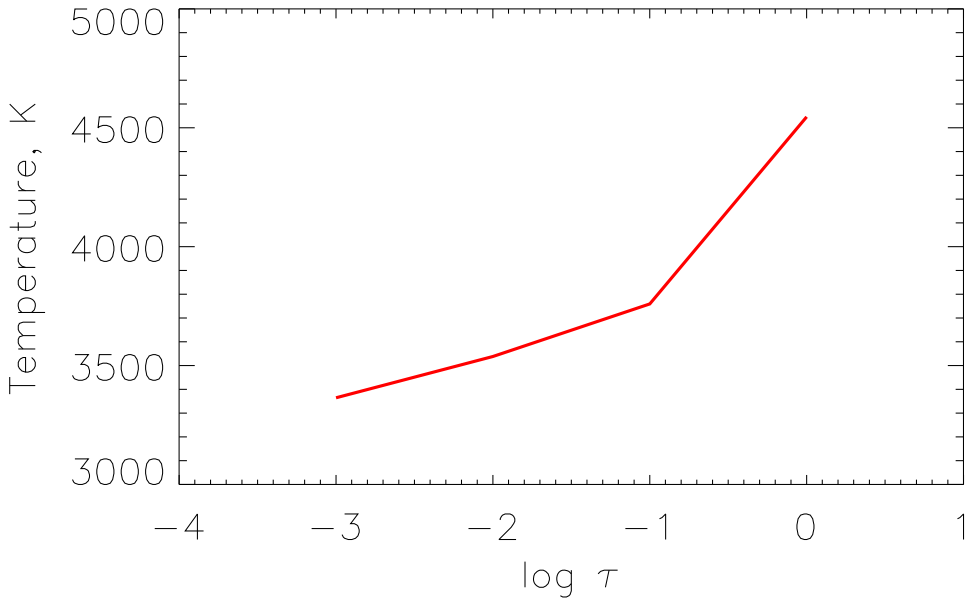




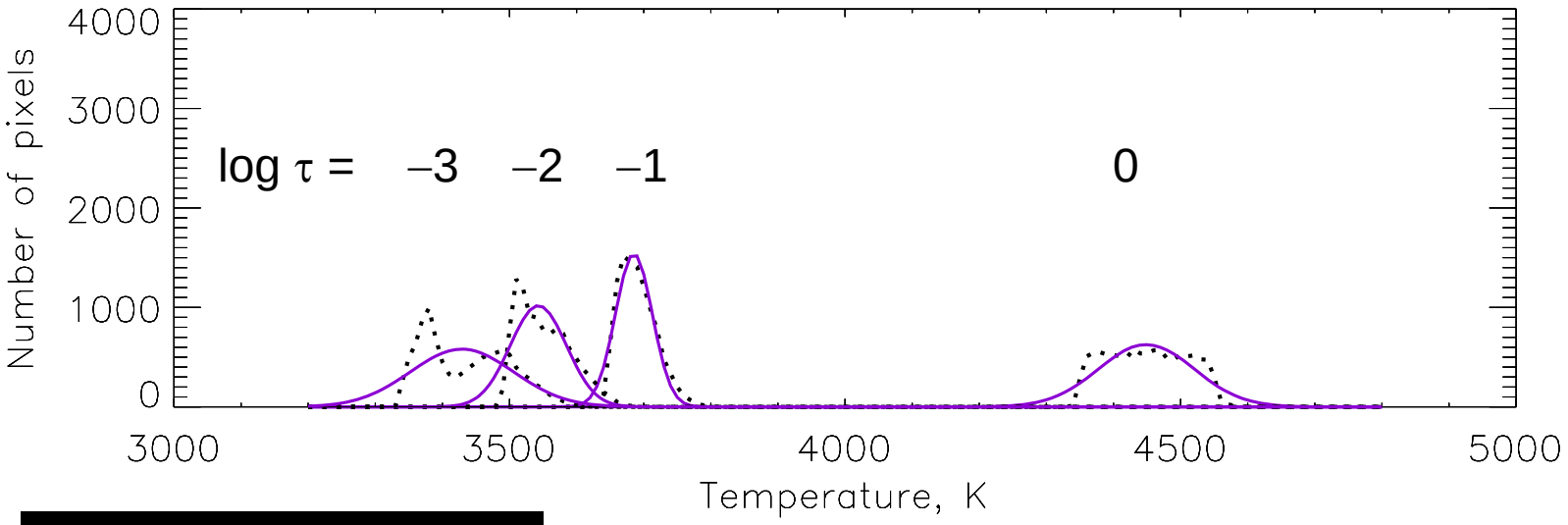
Penumbral edge

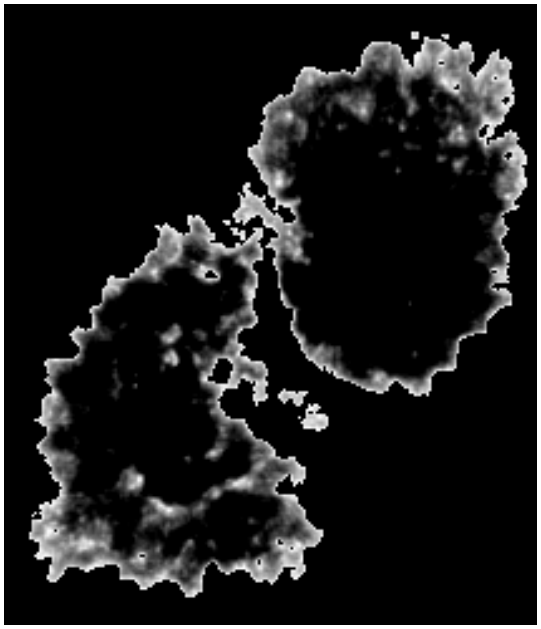


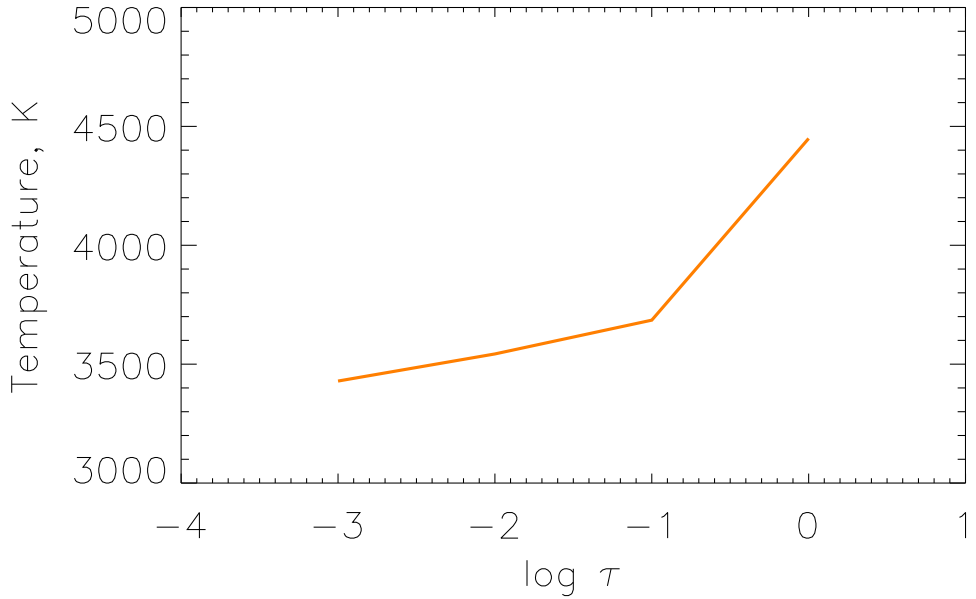




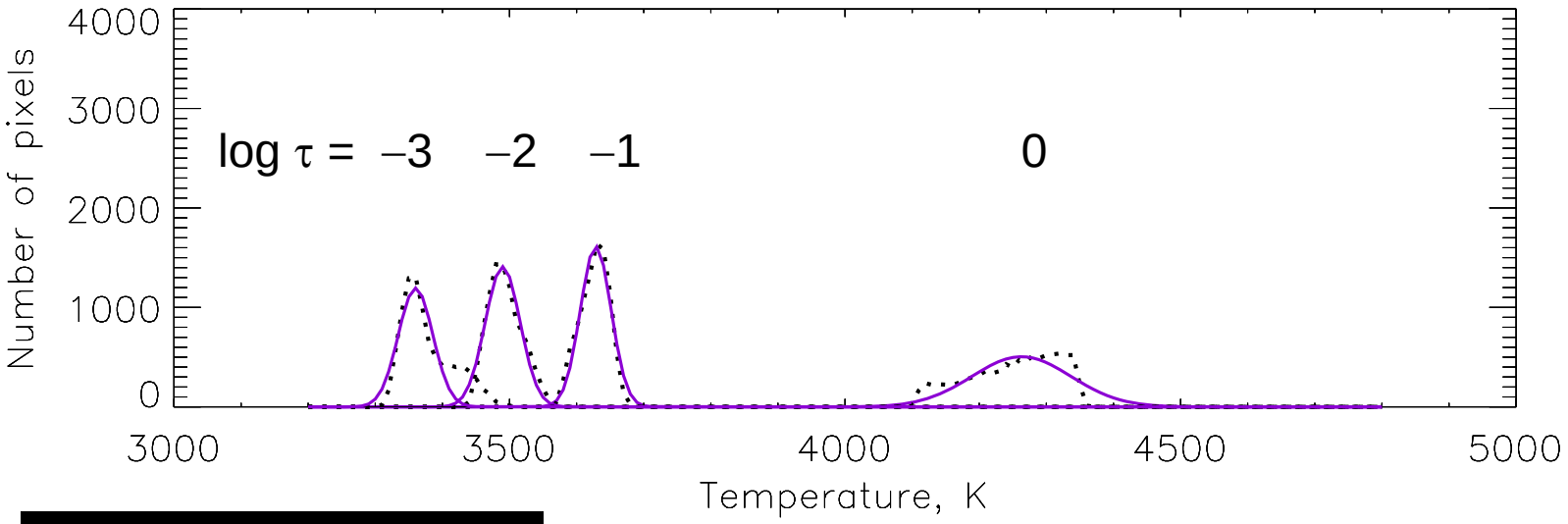
Peripheral Umbral Dots

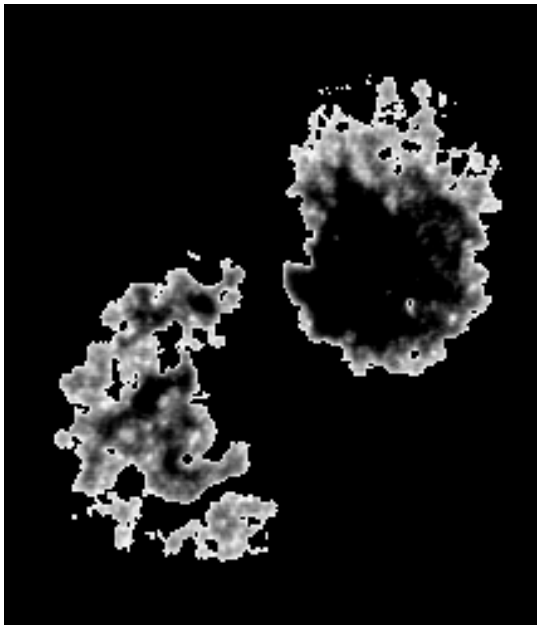


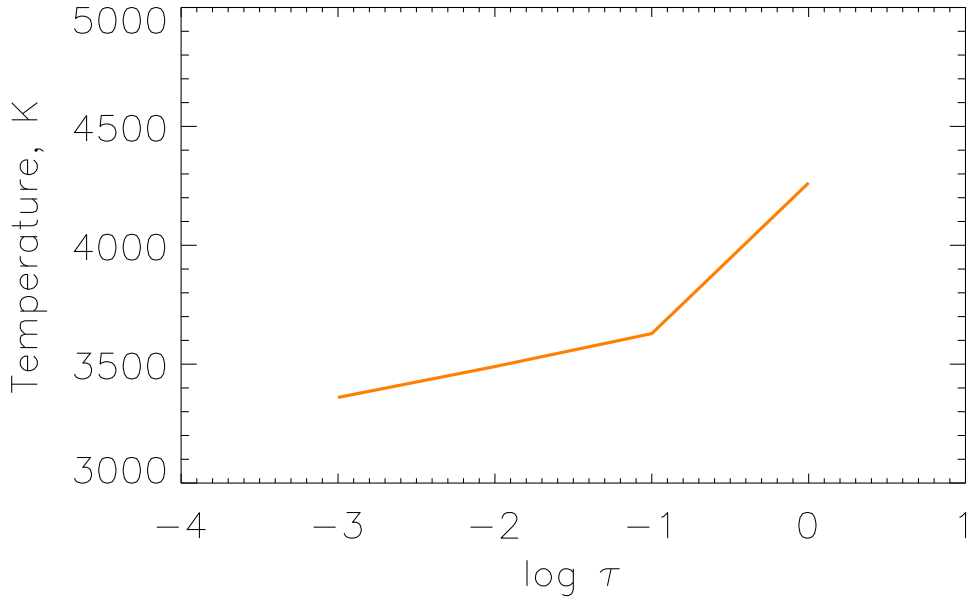




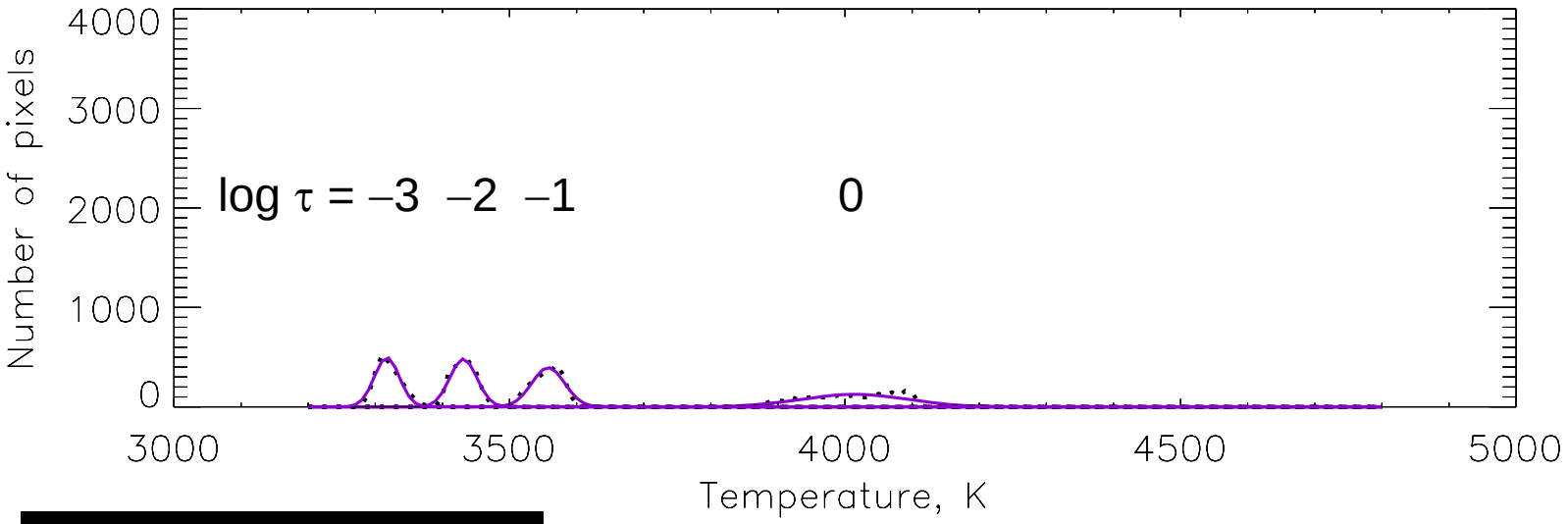
Central Umbral Dots

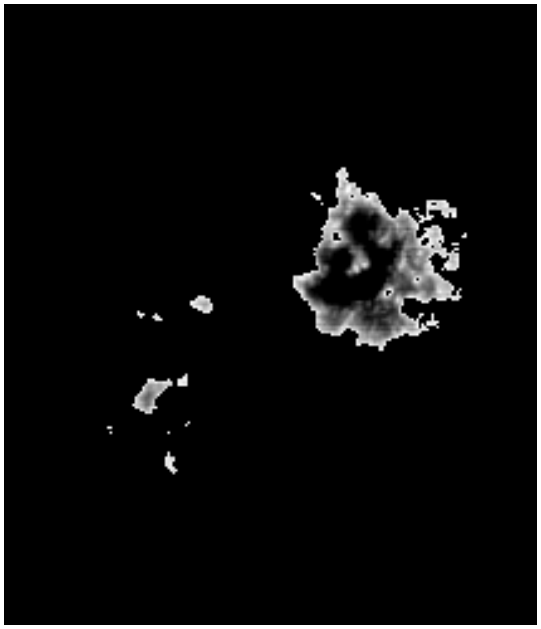


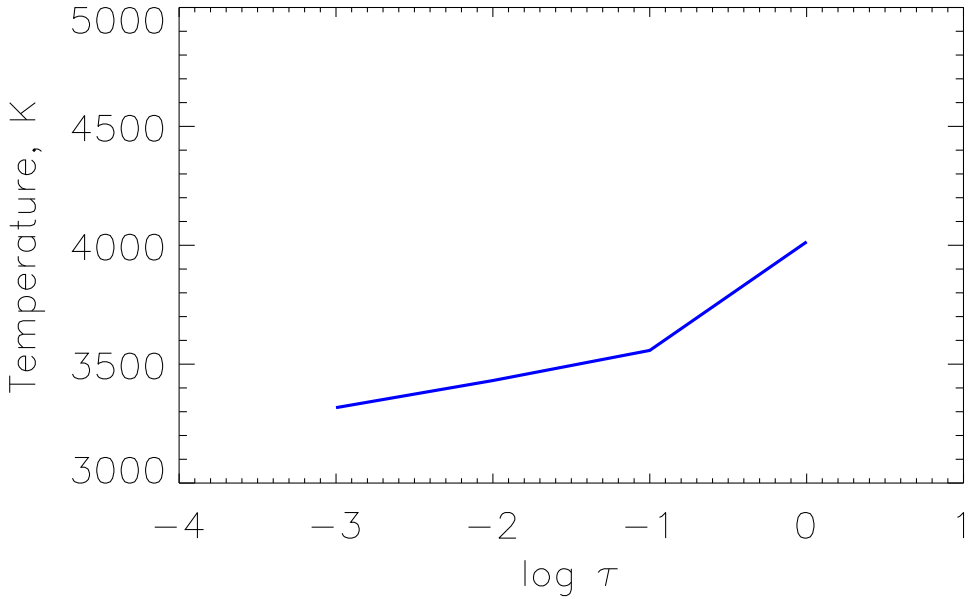




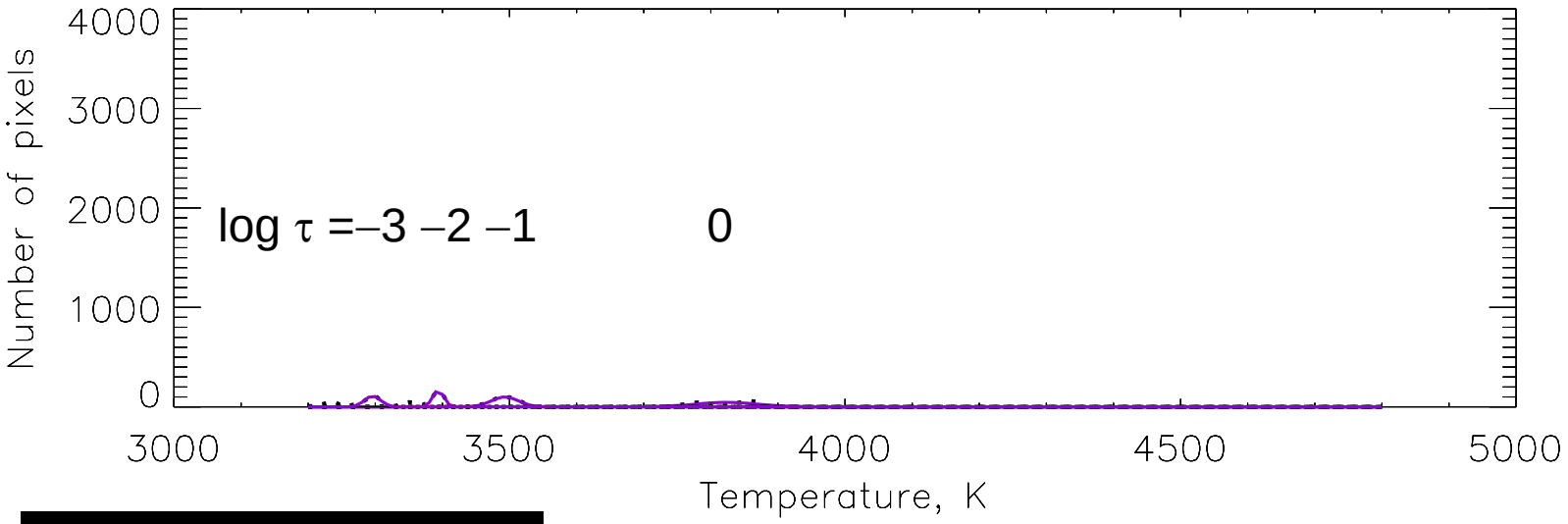
Dark Umbra

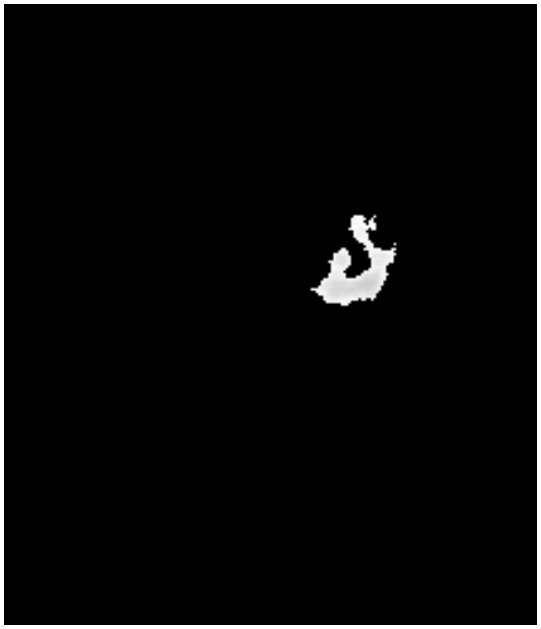

Number of pixels
4000
3000
2000
1000
0
log τ = –3 –2 –1
0
3000
3500
4000
4500
5000
Temperature, K

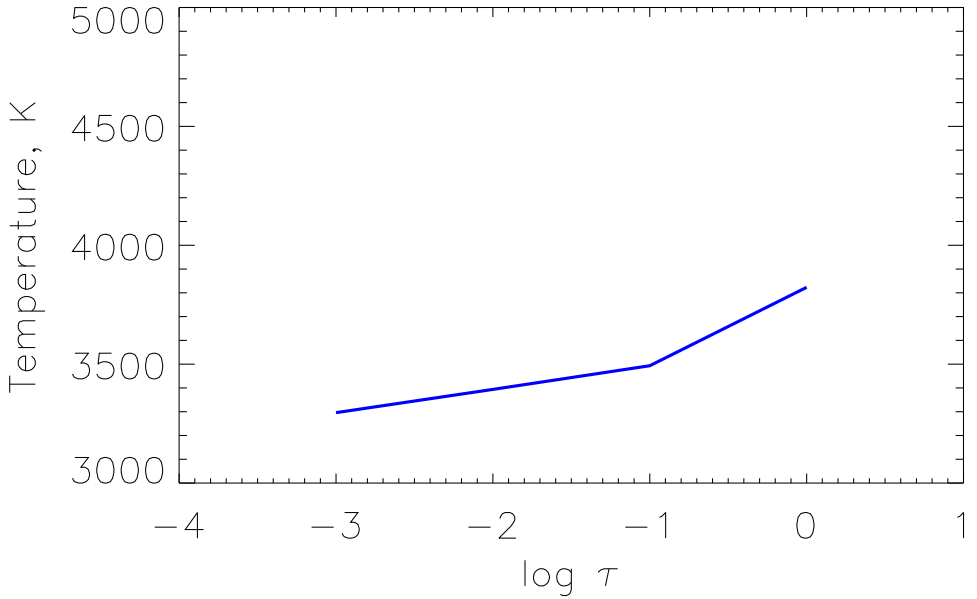



Temperature, K
5000
4500
4000
3500
3000
–4
–3
–2
–1
0
1
log τ

Darkest Umbra

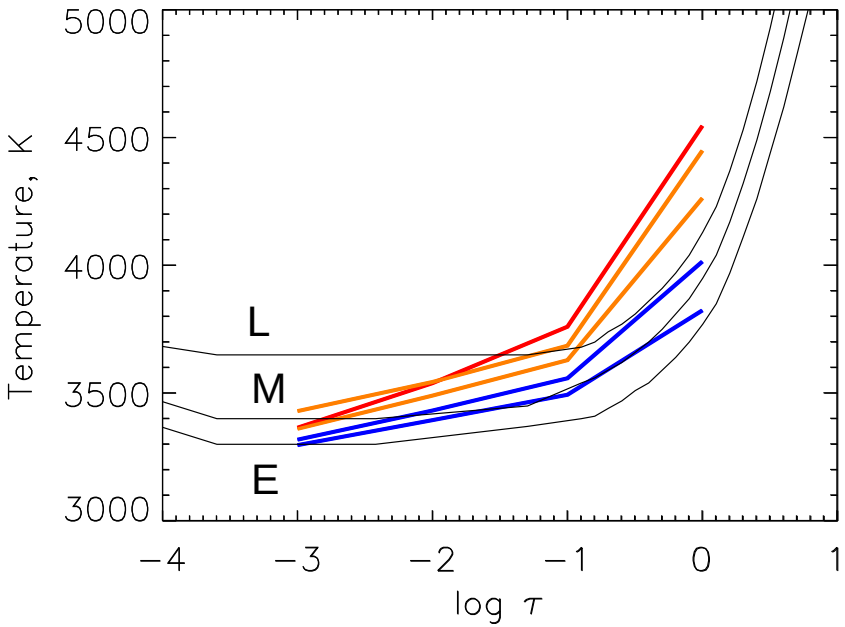




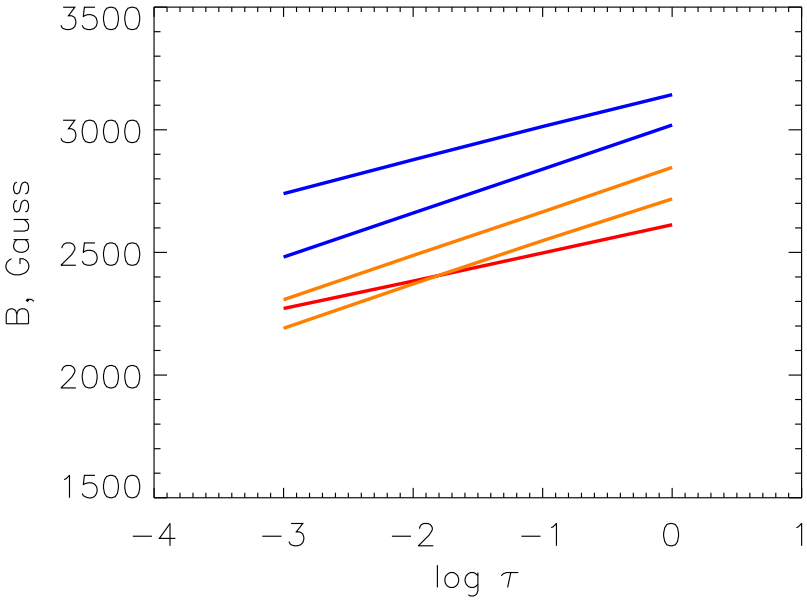


Umbra: Average models

- Temperature



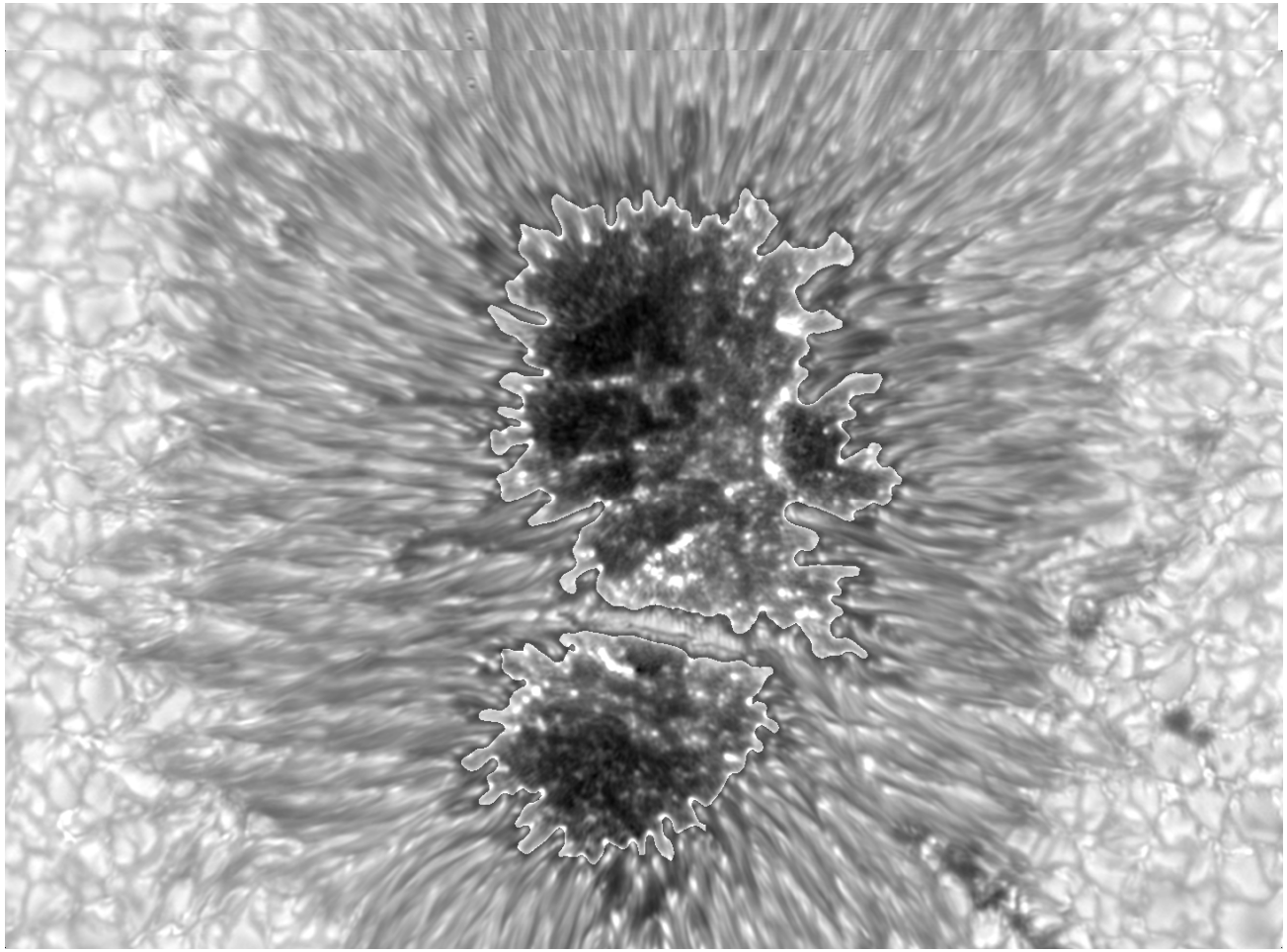
- Magnetic field strength



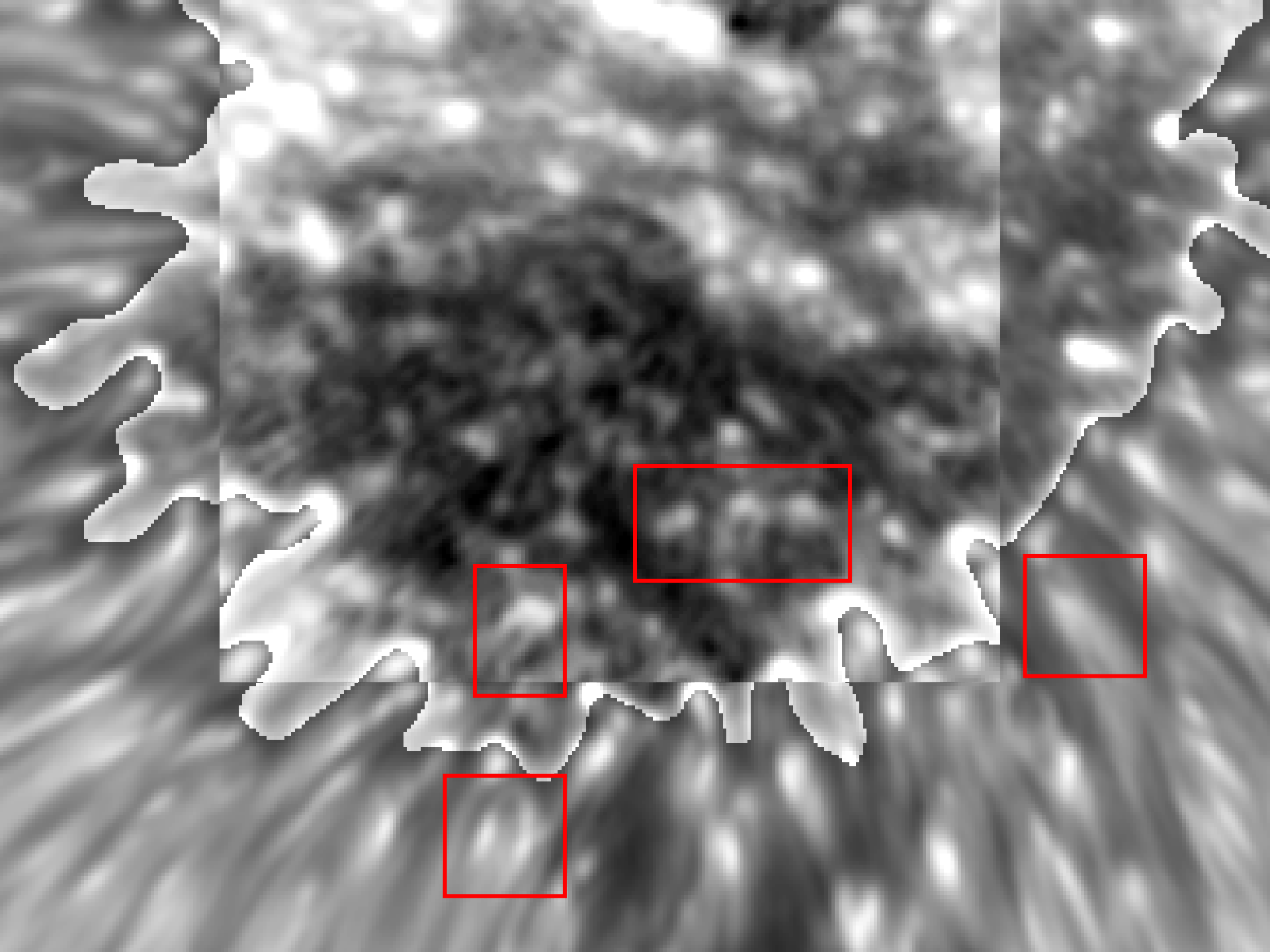
Penumbral edge
Umbral dots
Dark core
Maltby et al. (1986), umbral cores

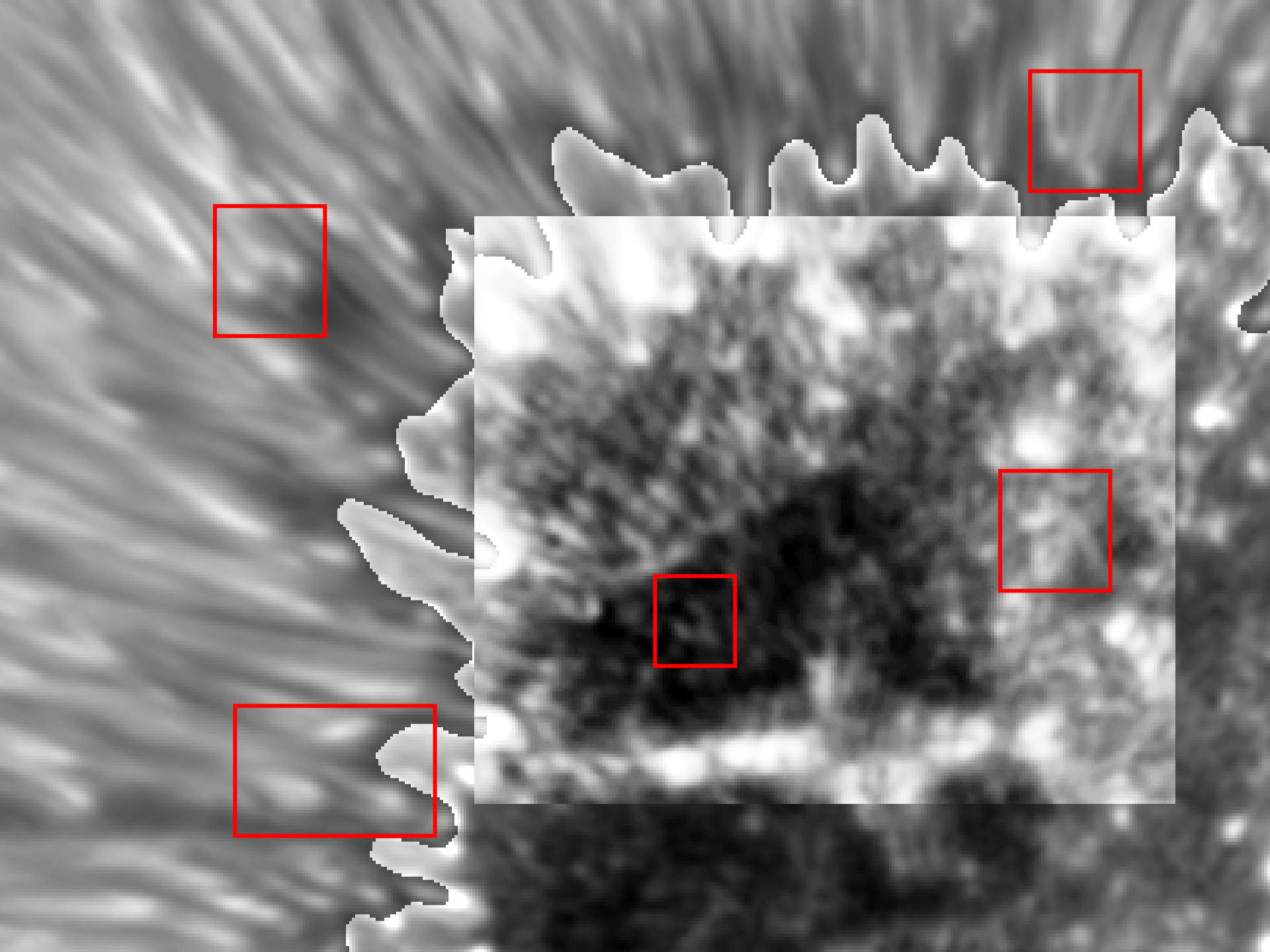
Umbral dots: Filamentary structure?

- TiO band filter



SST, Berger & Berdyugina (2003)
Zakharov et al. (2005)





Summary

- Atoms and molecules probe different heights in spots $\Rightarrow$ 3D structure!
- Molecular blends (TiO) can mimic a larger splitting of Fe I 6302 lines
- Temperature gradient in deeper layers is steeper for warmer structures
- Umbral ”dots” w/r to dark umbra:
  - Peripheral: $\Delta T_p = +450K$, $\Delta B_p = -300G$ ($\log \tau = 0$)
  - Central: $\Delta T_c = +250K$, $\Delta B_c = -200G$
- Umbral ”dots” seem to have a filamentary structure similar to penumbral filaments
- Darkest part of the umbral nucleus: T = 3800K, B = 3150G ($\log \tau = 0$)
- Outlook: A homogeneous sample of sunspot inversions to investigate the internal structure depending on the spot size

Thank you!