



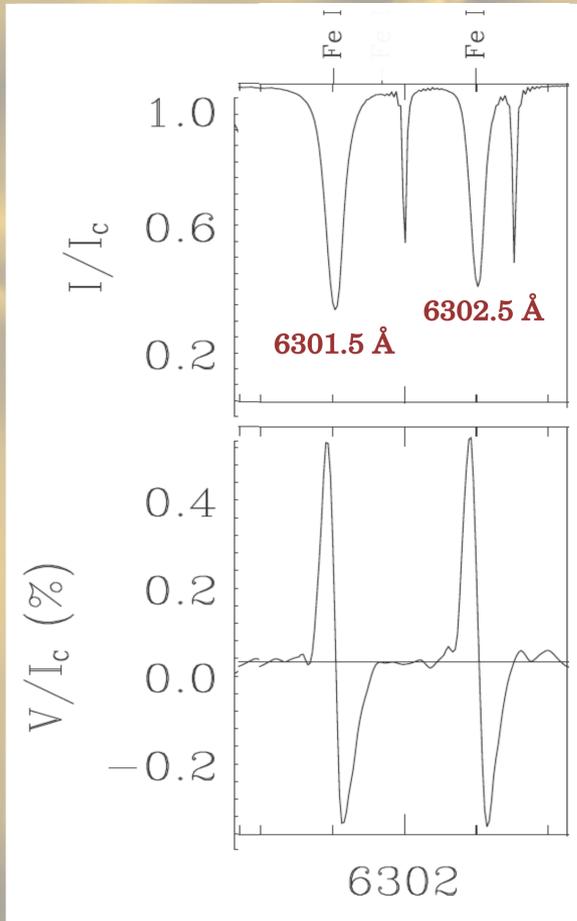
**How wrong are the results of inverting Fe I lines when NLTE and 3D radiative transfer effects are ignored?**

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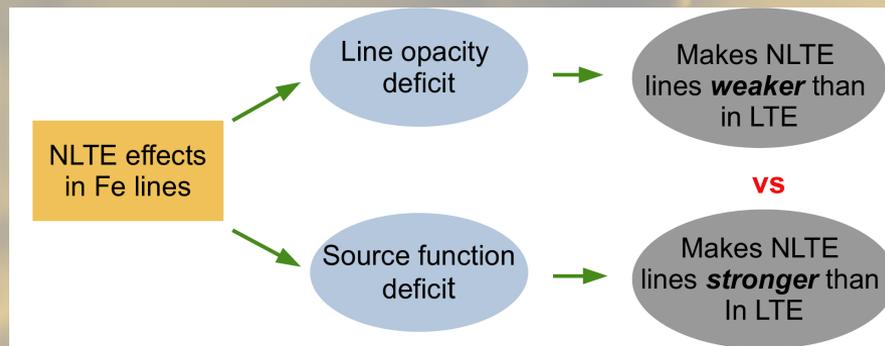
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- Fe I 6301.5 Å and 6302.5 Å are two of the most commonly used spectral lines to probe the solar photosphere by means of inversion codes
- Lites (1972, thesis) showed that the medium and strong Fe lines are affected by Non-Local Thermodynamic Equilibrium (NLTE) effects due to UV-overionization
- But inversions neglect both NLTE and 3D/horizontal radiative transfer effects
- In this work, we investigate the errors introduced in the inverted atmospheres when NLTE and 3D effects are neglected

## Sources of NLTE effects:

- Over-ionization of Fe I atoms into Fe II atoms by UV photons: **opacity deficit**
- Source function departures from the Planck function: **source function deficit**

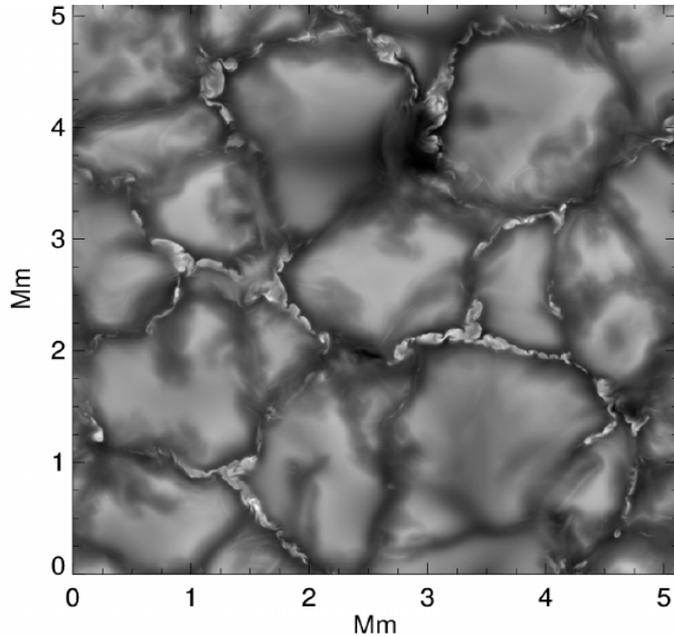


## Sources of 3D effects:

- Mainly due to horizontal gradients in temperature

The 3DNLTE can make the lines stronger/weaker than the LTE line

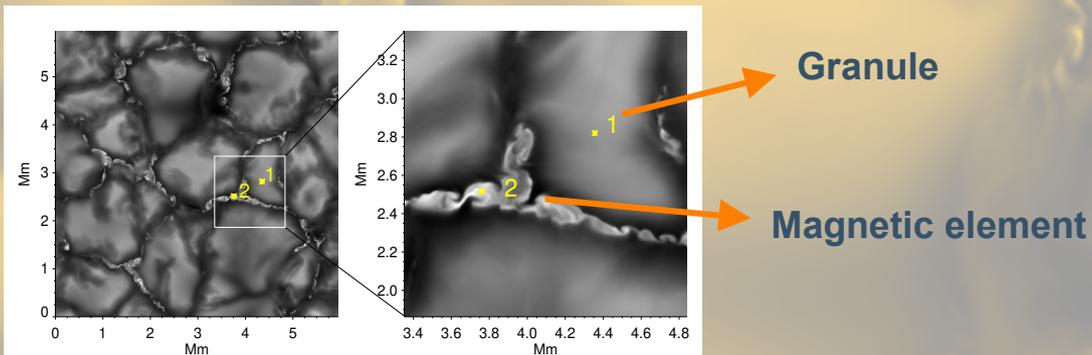
Continuum intensity



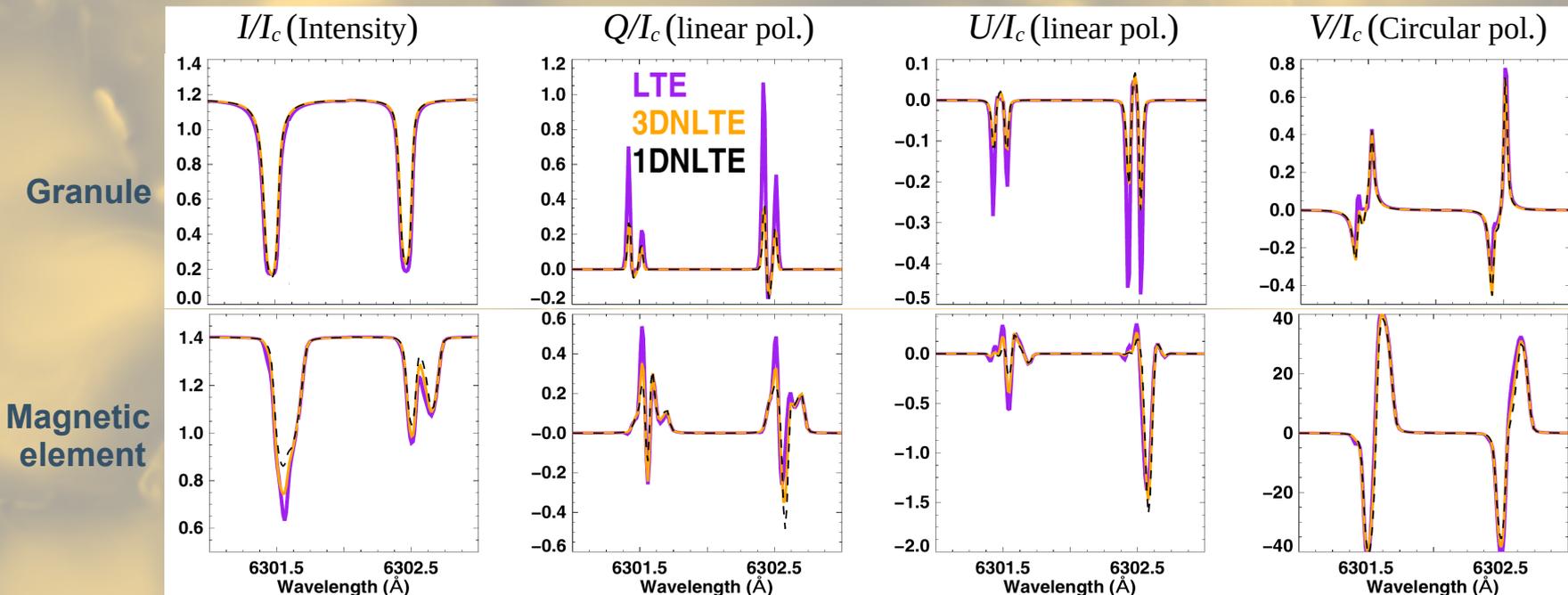
- *We used a MURaM 3D MHD cube*  
Size: 6 x 6 x 2 Mm  
Grid spacing: 5.82 x 5.82 x 7.85 km
- *Synthesized the Stokes profiles using the RH code*
  - Case 1: LTE
  - Case 2: NLTE
  - Case 3: NLTE + 3D
- *Inverted the Stokes profiles using SPINOR LTE code*
  - Ref. model: LTE inv. of LTE profiles } **consistent**
  - Test model: LTE inv. of NLTE profiles } **Not consistent**
  - Test model: LTE inv. of NLTE + 3D profiles } **consistent**

Test model – Ref. model = Errors due to the neglect of NLTE/3D effects

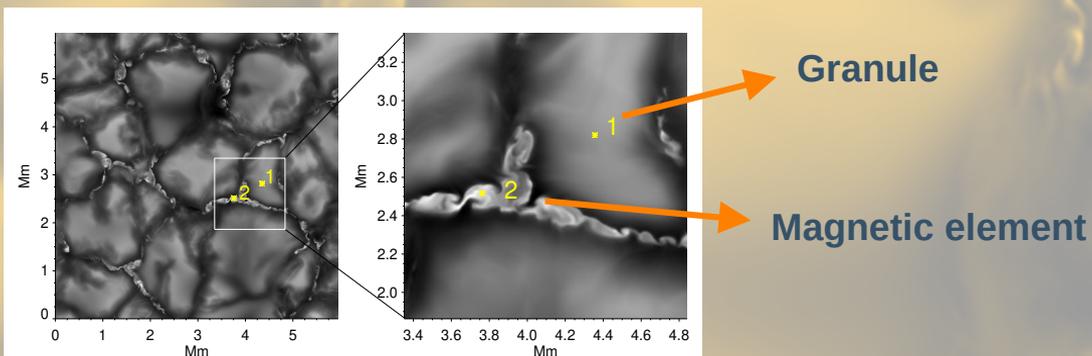
# Differences in Stokes profiles



- The NLTE and 3D effects alter the depth of intensity profiles and the amplitude of polarization profiles.
- The NLTE effects are stronger than 3D effects

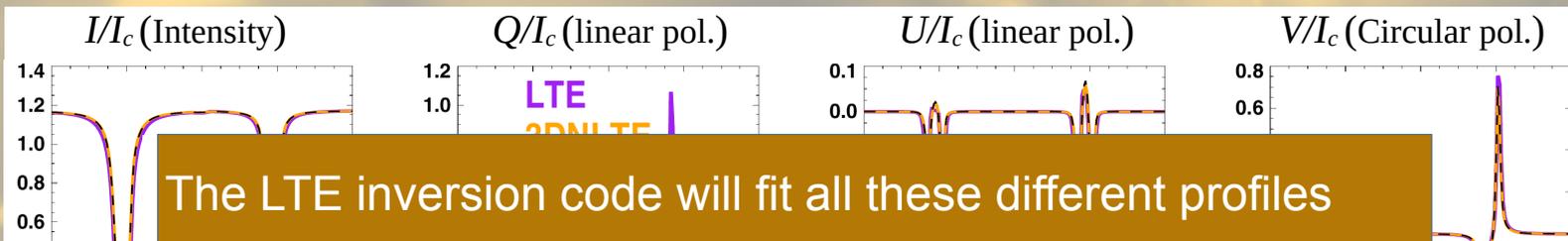


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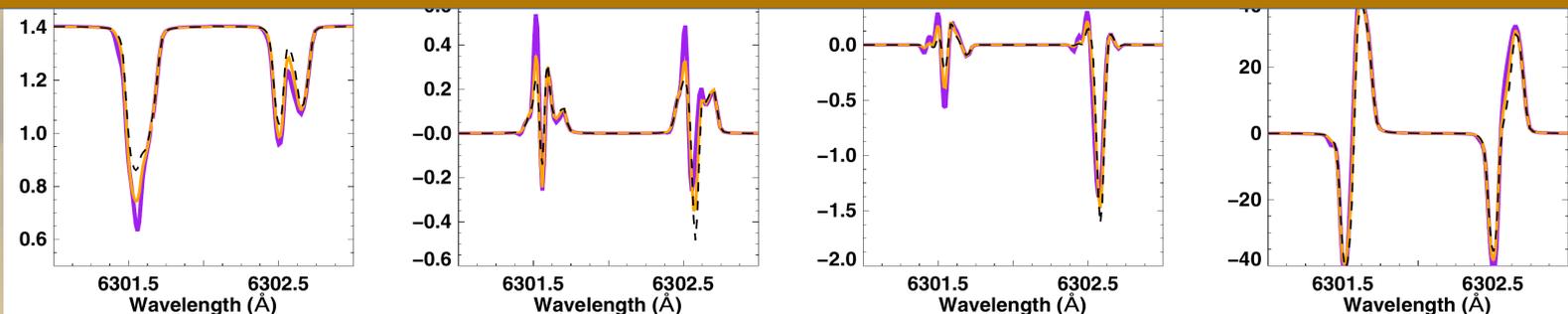
Granule

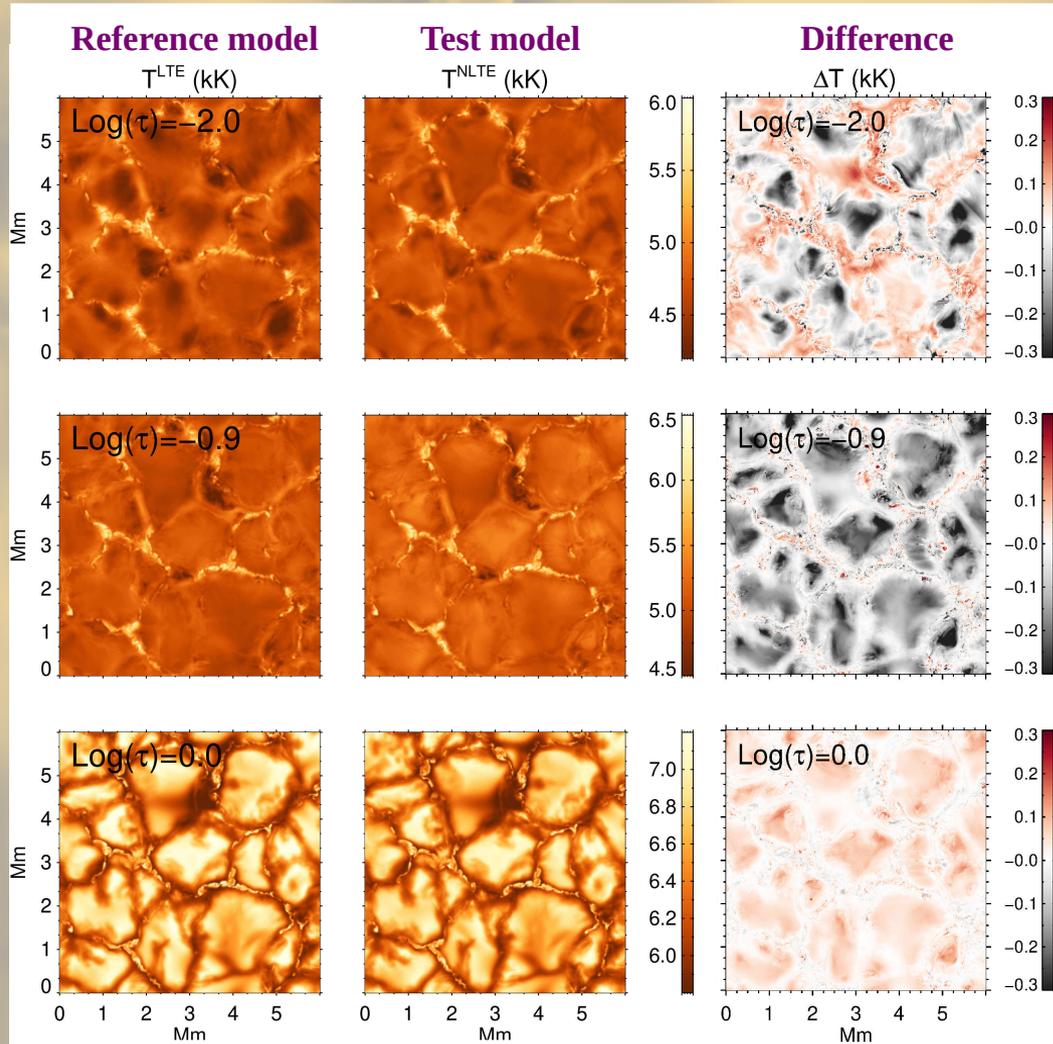


The LTE inversion code will fit all these different profiles

It will compensate for the NLTE/3D effects by tweaking atmospheric parameters

Magnetic element





## Reference model

$T^{\text{LTE}}$  : temperature maps from the LTE inversion of LTE profiles

## Test model

$T^{\text{NLTE}}$  : temperature maps from the LTE inversion of 1DNLTE profiles

## Difference:

$$\Delta T = T^{\text{LTE}} - T^{\text{NLTE}}$$

*Similar analysis was done also for the 3D case*

Atmospheric parameter, X	Relative error (1DNLTE) $\Delta X/X$ can be as high as	Relative error (3DNLTE) $\Delta X/X$ can be as high as
Temperature	13%	5%
LOS velocity	50%	20%
Magnetic field	50%	20%

- Neglecting the NLTE effects will introduce errors in the inverted atmosphere which can be as high as 13% in temperature, 50% in LOS velocity and magnetic field.
- While the NLTE effects are prominent in regions of strong vertical gradients in the atmosphere, the 3D effects are more localized to regions surrounded by strong horizontal gradients in temperature
- The errors introduced due to the neglect of 3D RT effects are not as large as the errors when NLTE effects are neglected completely. They are less than 5% in temperature, and less than 20% in LOS velocity and magnetic field. Hence
- Most importantly, all these errors survive spatial and spectral degradation
- Our findings have wide-ranging consequences since many results derived in solar physics are based on inversions of Fe I lines carried out in LTE

**Ref:**

**Smitha, H. N.; Holzreuter, R.; van Noort, M.; Solanki, S. K. 2020, A&A, 633, A157**

**Smitha, H. N.; Holzreuter, R.; van Noort, M.; Solanki, S. K., 2021, A&A, 647, A46**