SOCRAT
NLTE Calculations of the SOLar spectrum with CRoss influence of solar ATMospheric structures

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Outline

1. Introduction
2. Problems
3. The inhomogeneous quiet Sun
4. Existing models
5. 1.5D model with cross-influence of solar atmospheric structures
1. Introduction

1. Why modeling the solar spectrum?

2. Method

3. The COSI model
1. **Introduction**

1. Why modeling the solar spectrum?
   - Better understand the physical properties of the Sun
   - Reconstruct SSI/TSI
1. Why modeling the solar spectrum?
   • Better understand the physical properties of the Sun
   • Reconstruct SSI/TSI

Introduction

Shapiro et al. 2011
1. Introduction

2. Method

- Solve the radiative transfer and statistical population equations iteratively
  - With assumed atmospheric structure (T and $\rho$ as a function of height)
  - And assumed chemical abundances
- Spectral synthesis
- SSI modeling, etc.
1. Introduction

2. The COSI model
   • COde for Solar Irradiance
   • NLTE
   • Spherical geometry
1. Introduction

The COSI model

- COde for Solar Irradiance
- NLTE
- Spherical geometry
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2. The COSI model
   • COde for Solar Irradiance
   • NLTE
   • Spherical geometry
   • Assumed atmospheric structures
   • NLTE Opacity Distribution Functions (ODFs)
1. Introduction

Emergent spectrum

Formal solution

Converged nLTE pop. numbers

New populations

Statistical eq.

Solution of J

Sphericity factor q

Spherical moment transfer eq.

Ray by ray solution for intensity I for known J, populations and ODF

ODFs

Converged nLTE pop. numbers

Formal solution

Emergent spectrum

Adapted from M. Haberreiter
2. Problems

1. Disagreement in the IR between models and observations
2. Missing opacity source in the UV
3. Oxygen crisis
2. Problems

1. Disagreement in the IR between models and observations
2. Problems

1. Disagreement in the IR between models and observations from Thuillier et al. 2014, SOL.
2. Problems

1. Disagreement in the IR between models and observations

From Thuillier et al 2014, Sol.
2. Problems

2. Missing opacity source in the UV
2. Problems

2. Missing opacity source in the UV

From Shapiro et al. 2010
2. Problems

3. Oxygen crisis
2. Problems

3. Oxygen crisis

- 1-D Abundances ≠ 3-D abundances
- 1-D: log $\varepsilon_0 = 8.93 \pm 0.04$
- 3-D: log $\varepsilon_0 = 8.66 \pm 0.05$
2. Problems

3. Oxygen crisis

- Solves the apparent too large O abundance compared to interstellar medium
- Does not match helioseismology results
- These results are model-dependent

3. The inhomogeneous quiet Sun

Credit: Swedish Solar Telescope
3. The inhomogeneous quiet Sun

Credit: Swedish Solar Telescope
3. The inhomogeneous quiet Sun

Uitenbroek & Criscuoli 2011
4. Existing models

  • 1D LTE - 3D NLTE - 1.5D NLTE
  • 1.5D: rays passing through a cube
  • Each has its own temperature structure
  • RT solved independently
  • Output combined
  • Does not take into account the interaction between rays (and disagrees with 3-D simulations)
5.1.5D with cross-influence

- 1.5D
  - Different structures are used independently and summed
  - At each depth point, they "see" each other following the fraction of total area each structure occupies
5.1.5D with cross-influence

- 1.5D
  - At each depth point, they "see" each other following the fraction of total area each structure occupies

\[ I^j_k(z) = I^j_k(z) (1 - e^{-\tau_k(h)}) + e^{-\tau_k(h)} \sum_i \alpha_i I^j_i(z) \]
5.1.5D with cross-influence

- Step 1: Solution of RT, moment eq., lines, Statistical Eq., NLTE for each structure independently
- Step 2: Consider the cross-influence and re-solve moment equation
- Step 3: Return to step 1 with new radiation field
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Step 2: Consider the cross-influence and re-solve moment equation

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5.1D with cross-influence

Solution of J

Spherical moment transfer eq.

Sphericity factor q

Ray by ray solution for intensity I for known J, populations and ODF

LTE population numbers

Atm. 1

Atm. 2

Atm. 3

LTE population numbers

LTE population numbers

Ray by ray solution for intensity I for known J, populations and ODF

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Sphericity factor q

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Solution of J

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Statistical eq.

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ODFs

Emergent spectrum
5.1.5D with cross-influence

• Free parameter $l_k$: characteristic size of a structure
• Case 1: $\tau_k \gg 1$: structure unaffected by its neighbours
• Case 2: $\tau_k \ll 1$: complete redistribution; mixture of all components weighted by their respective filling factor
5.1.5D with cross-influence

• State of the project/outlook:
  • Calculate 3 different atmospheres in parallel and get the same results as when calculated independently.
  • Implement cross-influence
  • Test optically thin/thick regimes; find $l_k$
  • Calculate spectrum in the UV; find the effect of cross-influence on over ionisation, find the effect on the missing opacities
5.1.5D with cross-influence

- State of the project/outlook:
  - Find impact on H- concentrations (main source of opacity in the visible/IR)
  - Calculation in the IR: reproduce UV line simultaneously as CO lines?
The End
4. Existing models