SOCRAT

NLTE Calculations of the **SO**lar spectrum with **CR**oss influence of solar **AT**mospheric structures

Cassandra Bolduc, Werner Schmutz

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Dorfstrasse 33, CH-7260 Davos Dorf
Phone +41 81 417 51 11, Fax +41 81 417 51 00
www.pmodwrc.ch

Outline

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

Dorfstrasse 33, CH-7260 Davos Dorf
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1. Introduction

1. Why modeling the solar spectrum?
2. Method
3. The COSI model

Dorfstrasse 33, CH-7260 Davos Dorf
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1. Introduction

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

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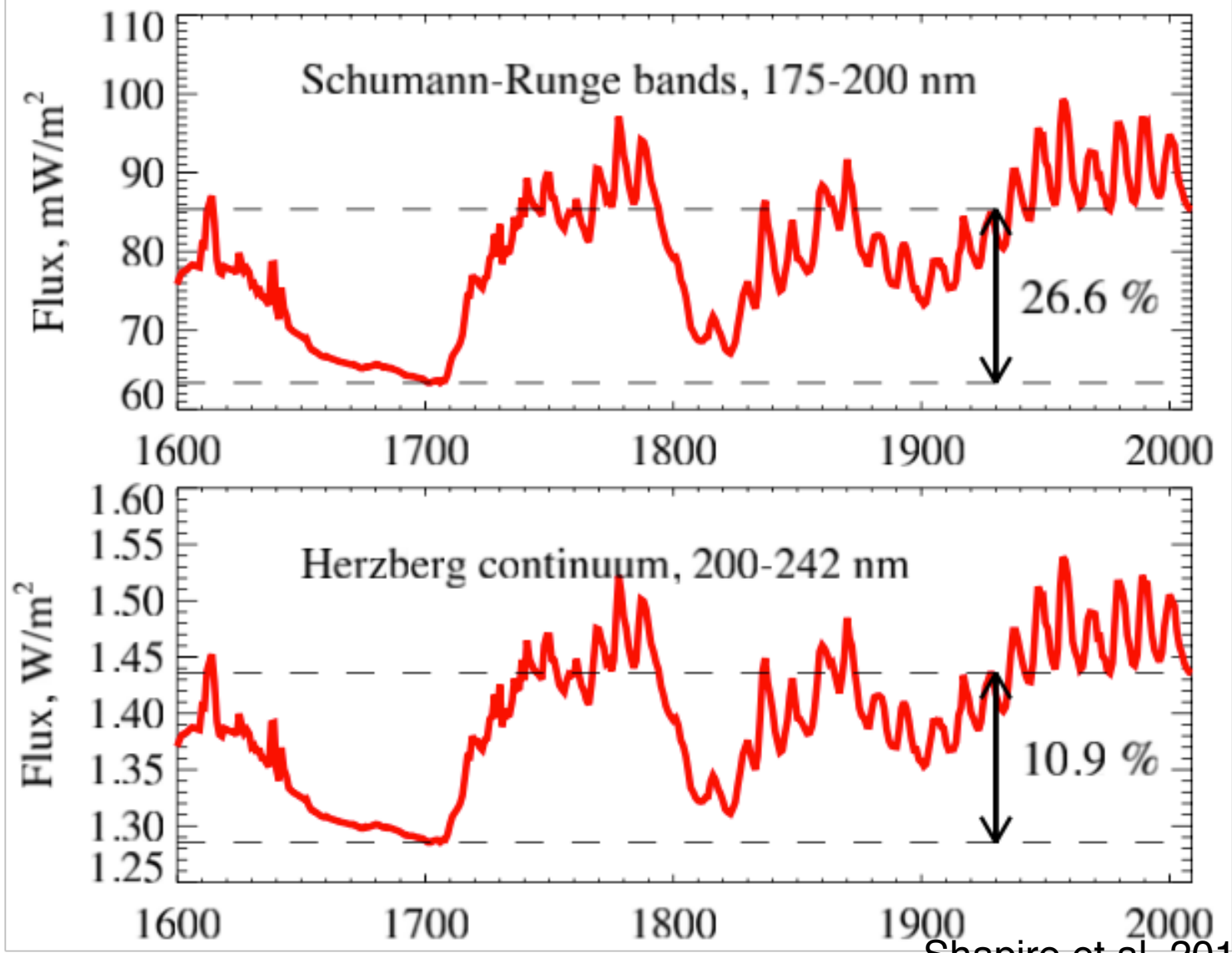

Shapiro et al. 2011

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1. Introduction

2. Method

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

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1. Introduction

2. The COSI model

- COde for Solar Irradiance
- NLTE
- Spherical geometry

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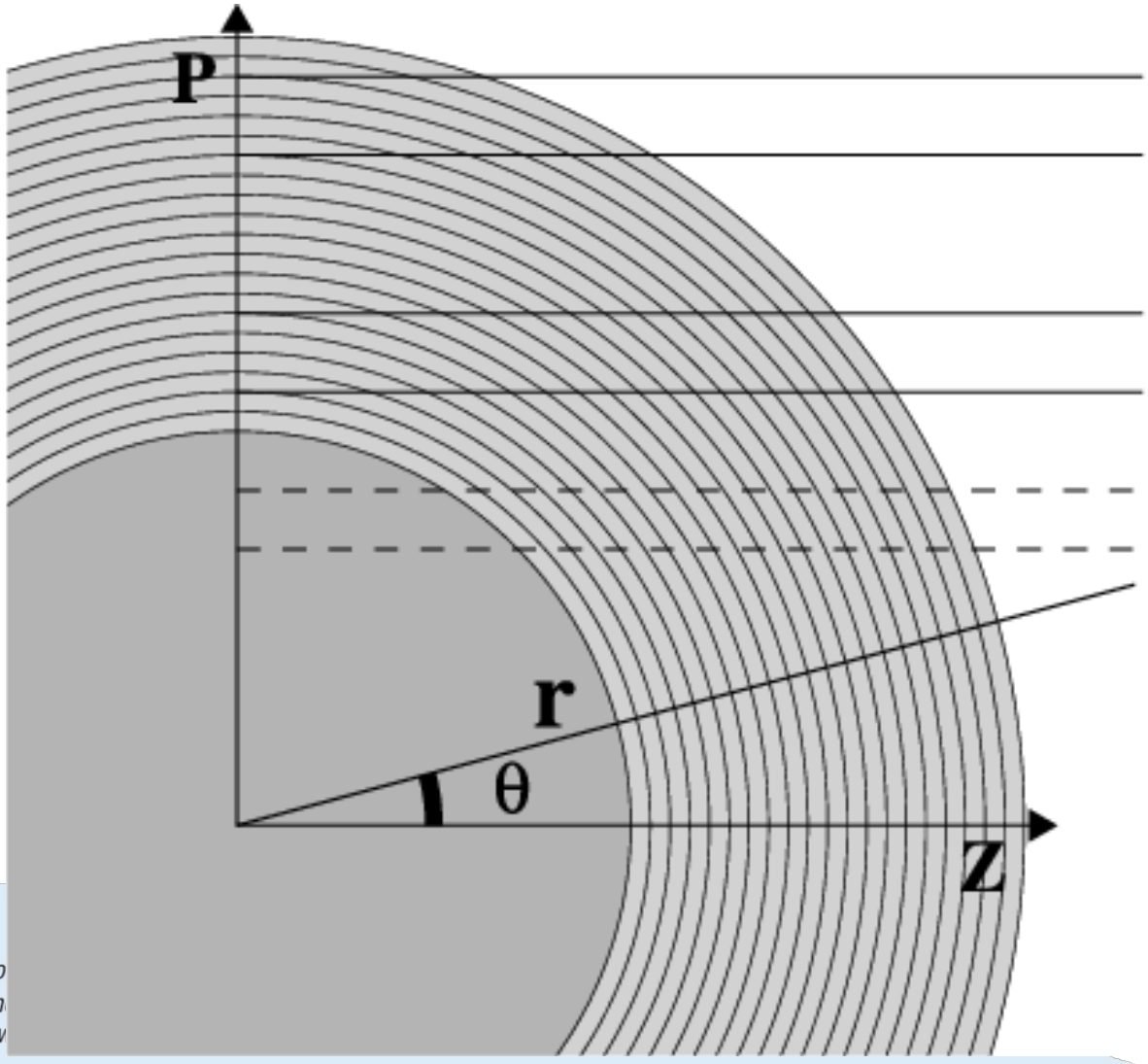
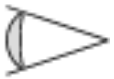
1. Introduction





1. Introduction

2. The COSI model

- COde for Solar Irradiance
- NLTE
- Spherical geometry
- Assumed atmospheric structures
- NLTE Opacity Distribution Functions (ODFs)

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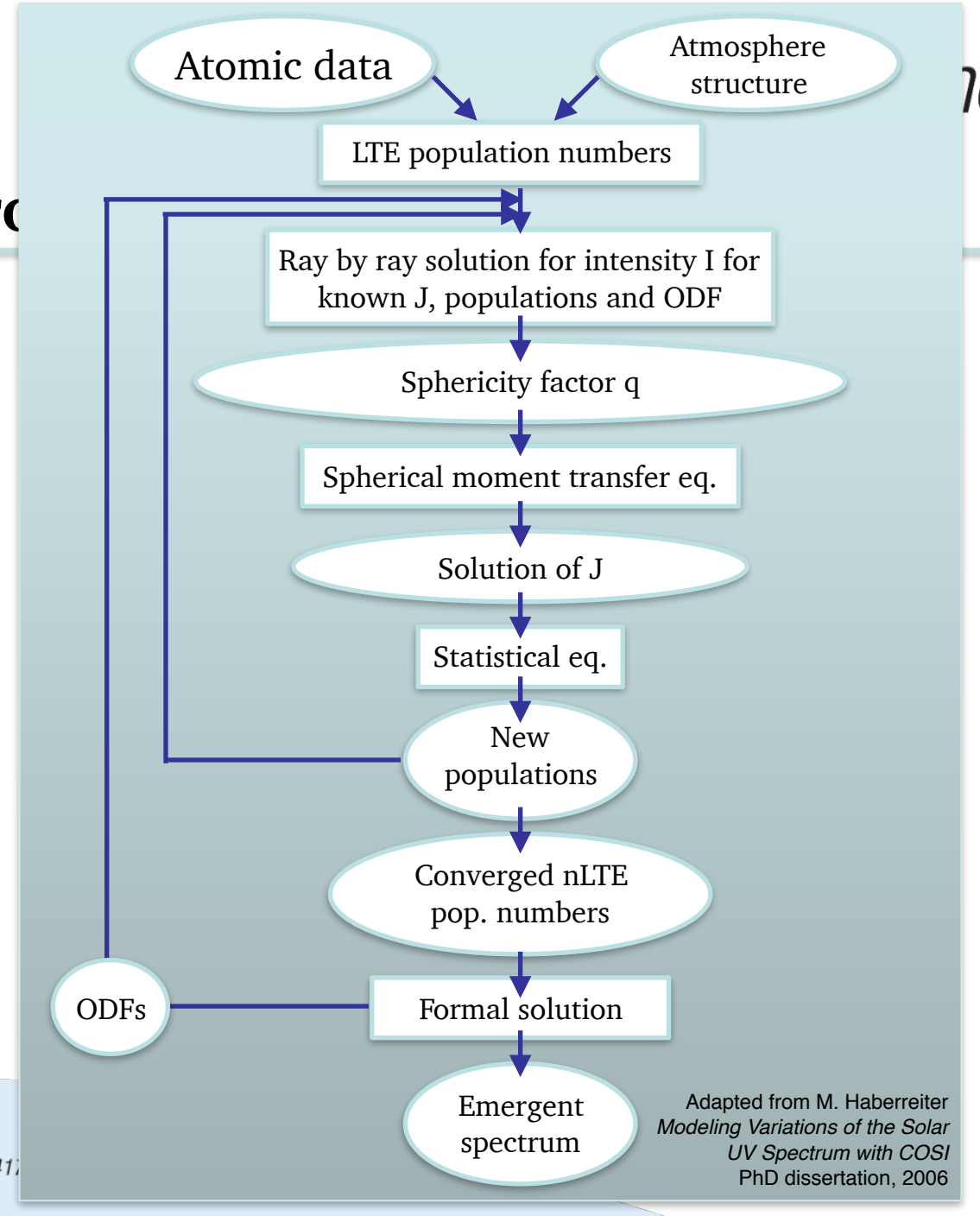
1. Intro



Adapted from M. Haberreiter
Modeling Variations of the Solar UV Spectrum with COSI
PhD dissertation, 2006

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2.Problems

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

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2.Problems

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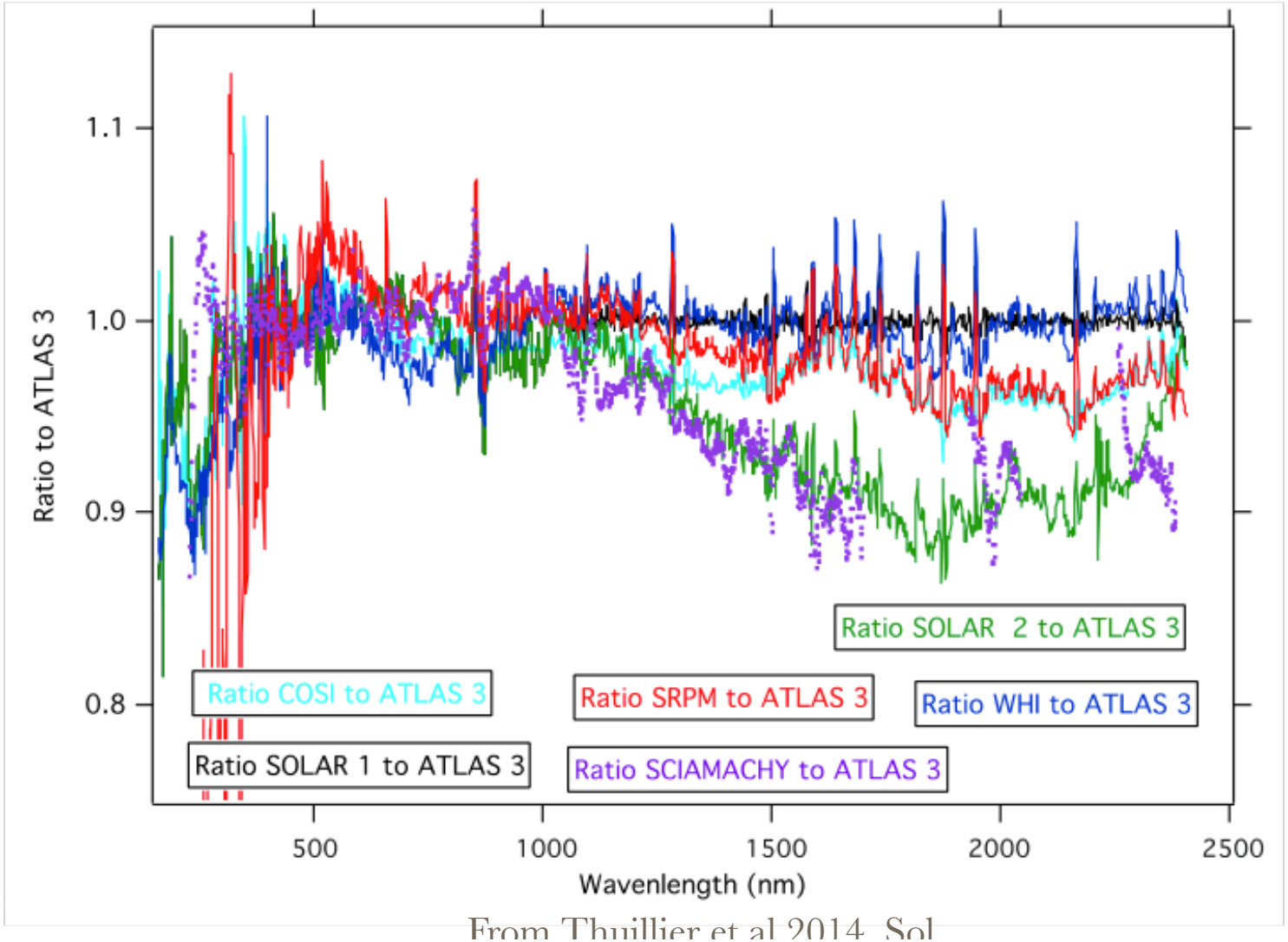

From Thuillier et al 2014, Sol

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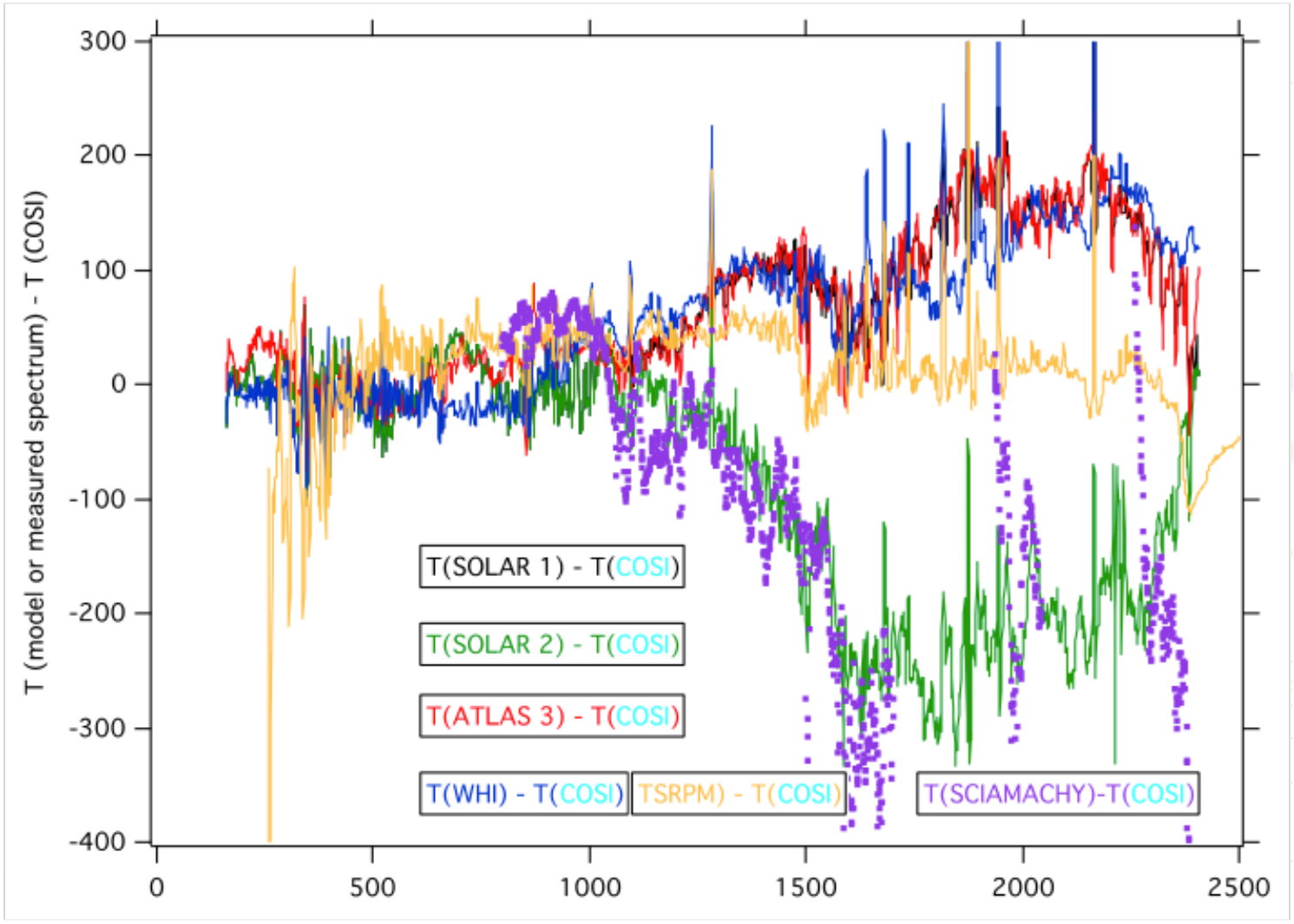

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2.Problems

2.Missing opacity source in the UV

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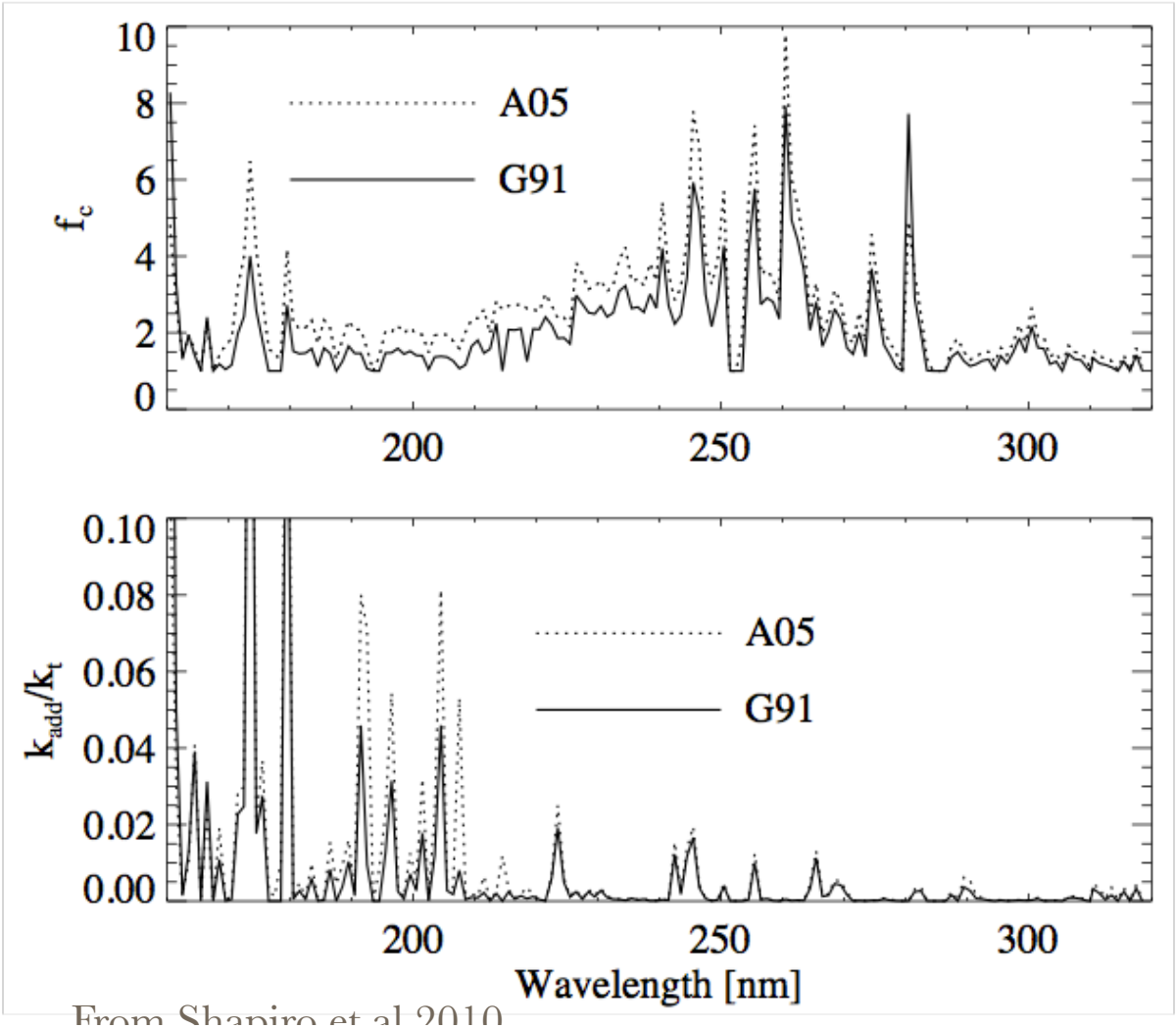
2.Problems

2.Missing



From Shapiro et al 2010

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2.Problems

3.Oxygen crisis

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2.Problems

3.Oxygen crisis

- **1-D Abundances ≠ 3-D abundances**

  (Asplund et al 2004, A&A 417:751)

- 1-D: log ε_0=8.93 ± 0.04
- 3-D: log ε_0=8.66 ± 0.05

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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 (Ayres et al. 2006 ApJ 165:618)

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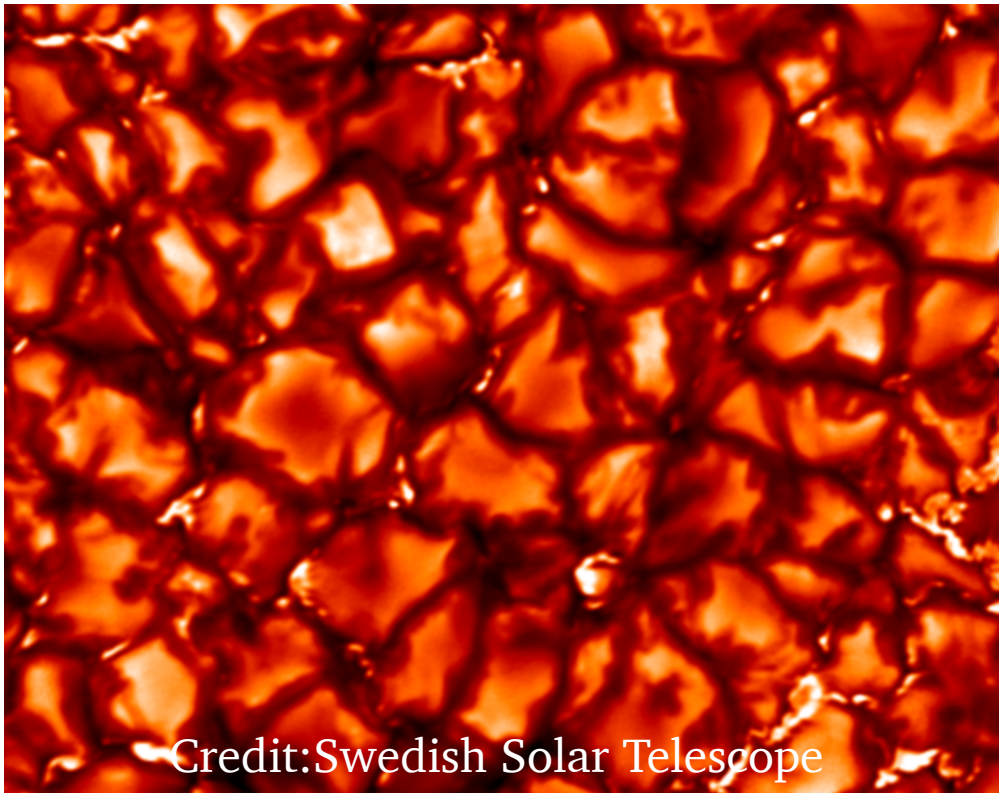
3.The inhomogeneous quiet Sun



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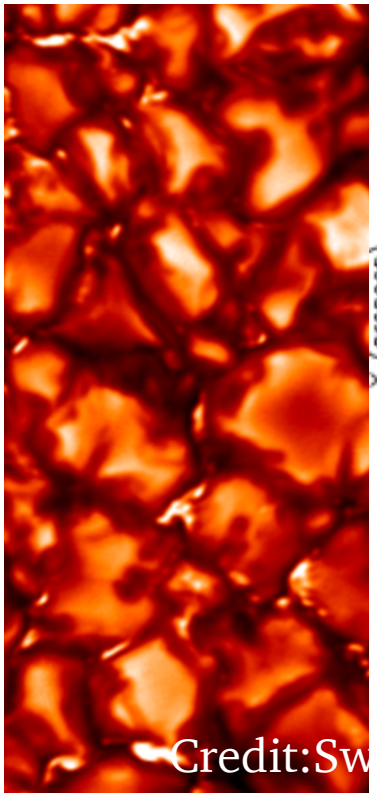
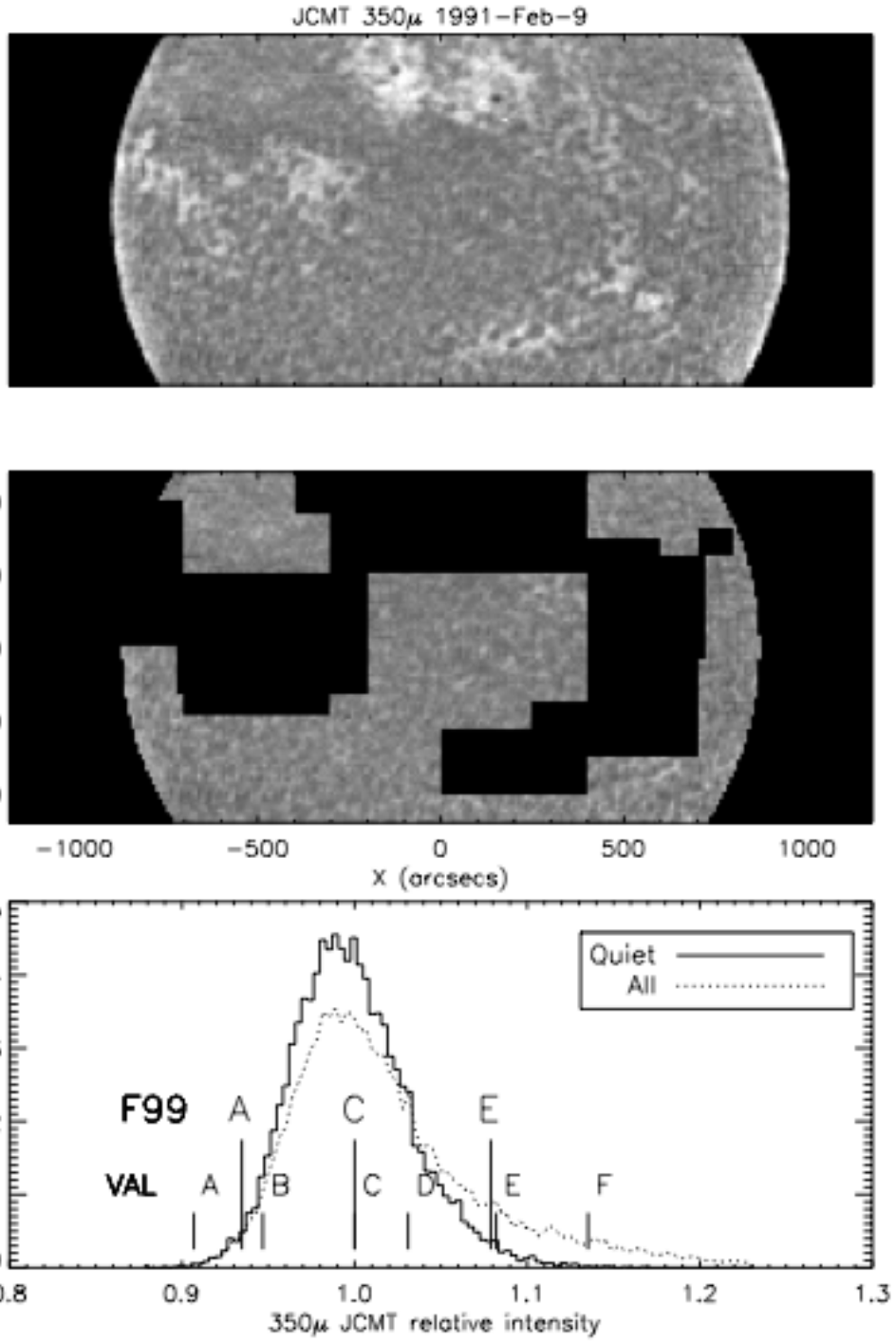
3.The





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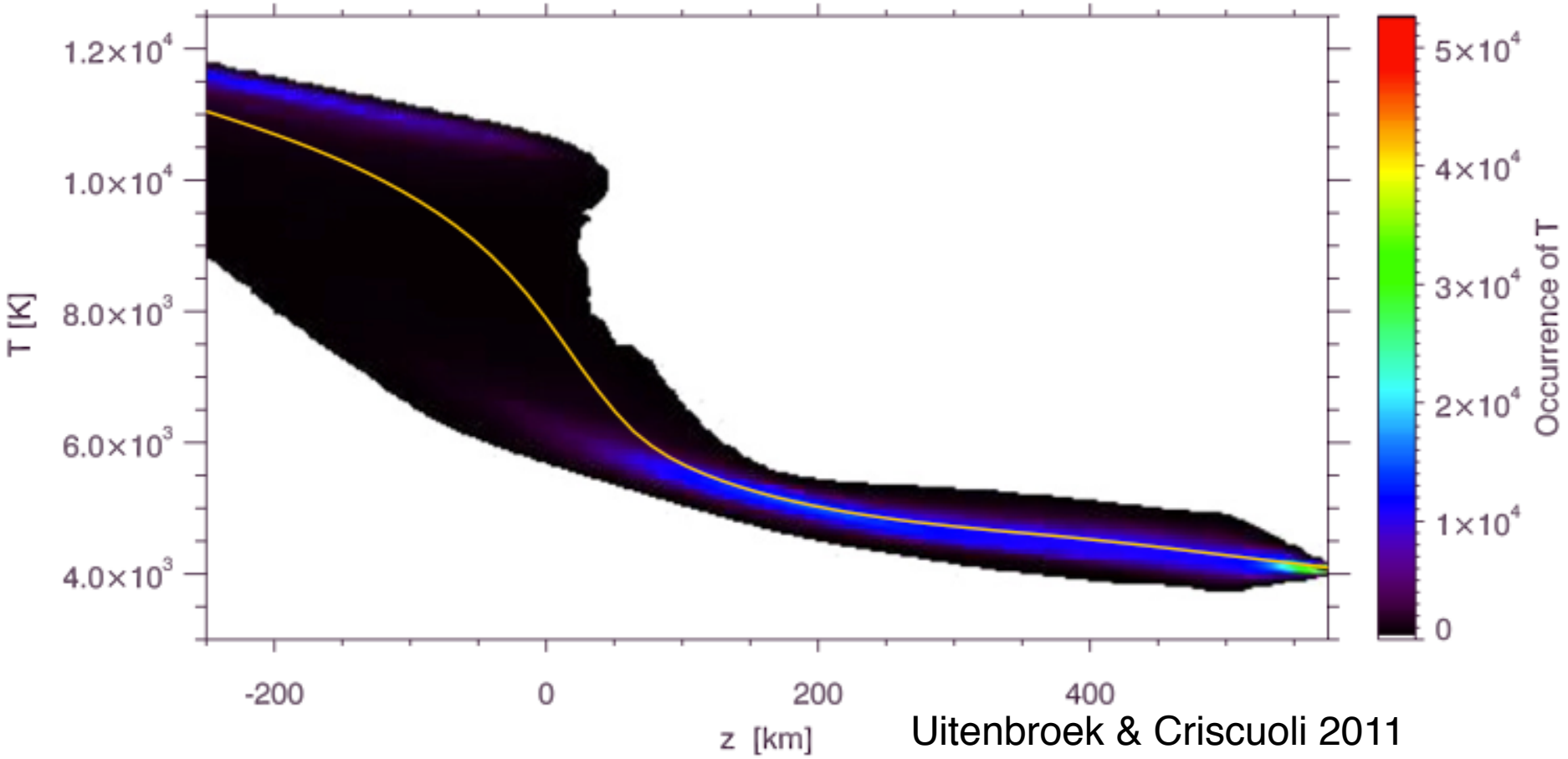
3.The inhomogeneous quiet Sun



Uitenbroek & Criscuoli 2011

4. Existing models

- Study by Holzreuter & Solanki 2013, A&A, 558:A20.
  - 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)

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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

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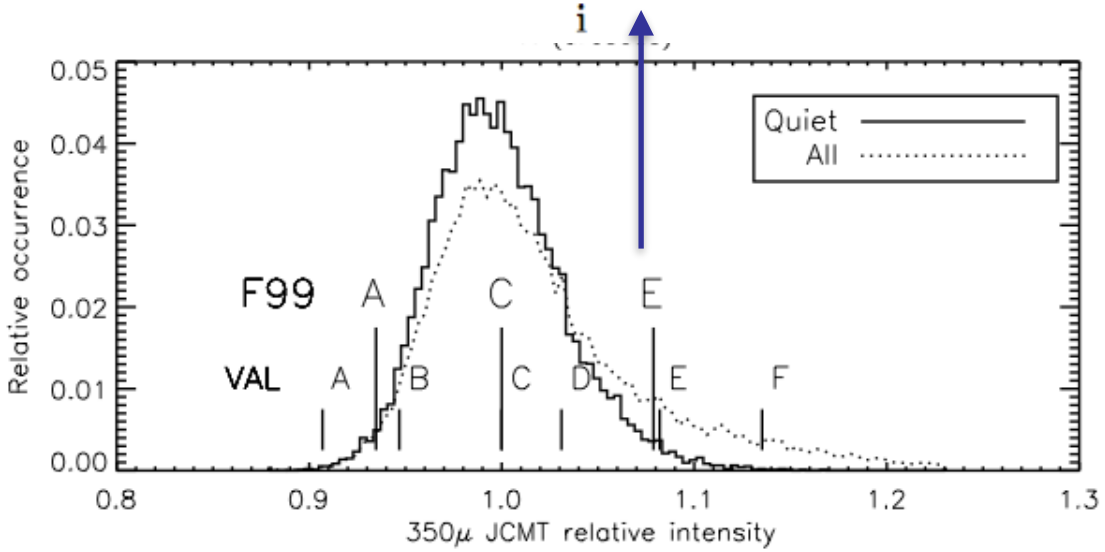
5.1.5D with cross-influence

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

$$I_k^j(z) = \mathring{I}_k^j(z)\left(1 - e^{-\tau_k(h)}\right) + e^{-\tau_k(h)} \sum_i \alpha_i \mathring{I}_i^j(z)$$



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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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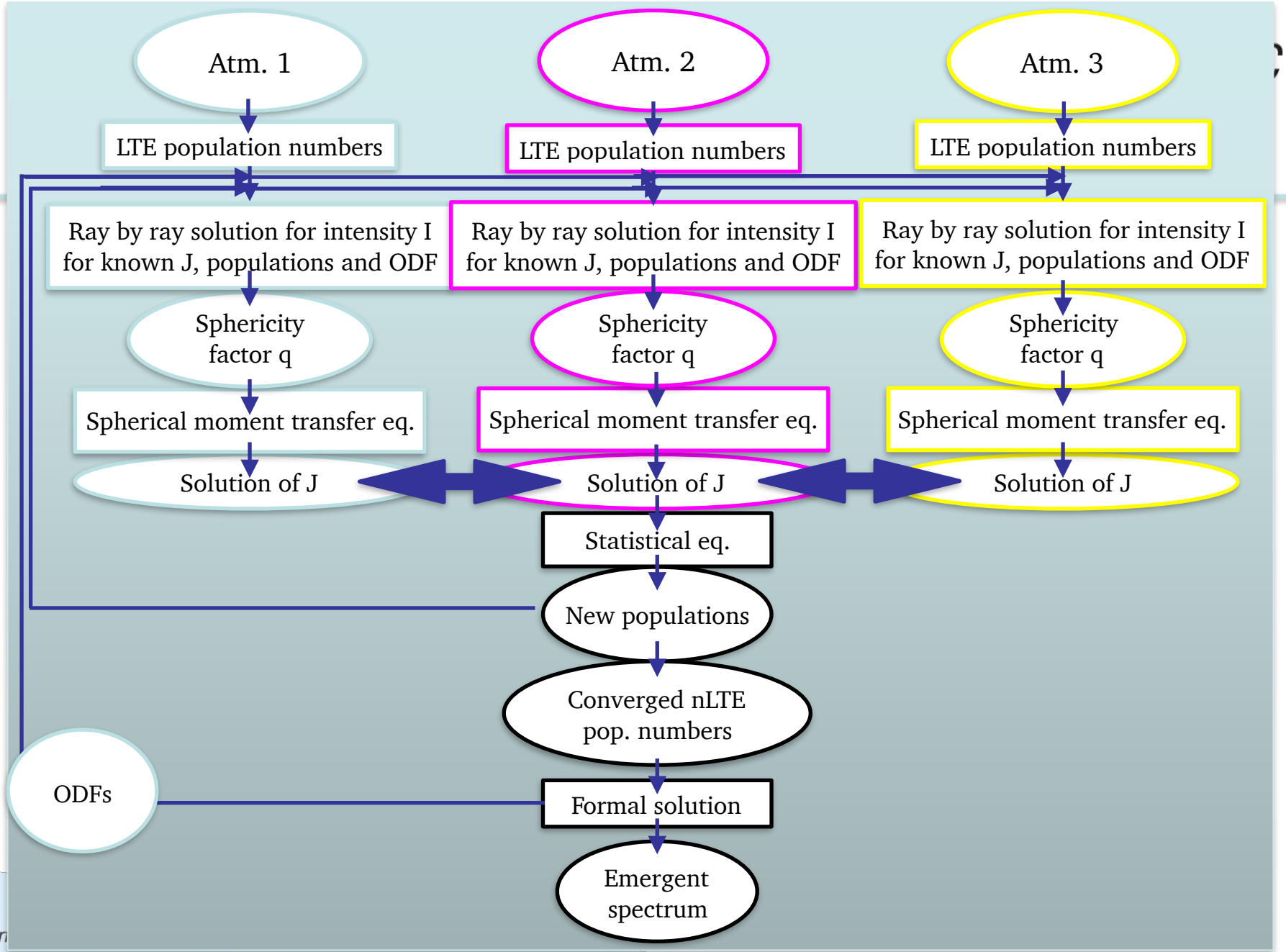

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5.1.5D with cross-influence

- 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

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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

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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?

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The End

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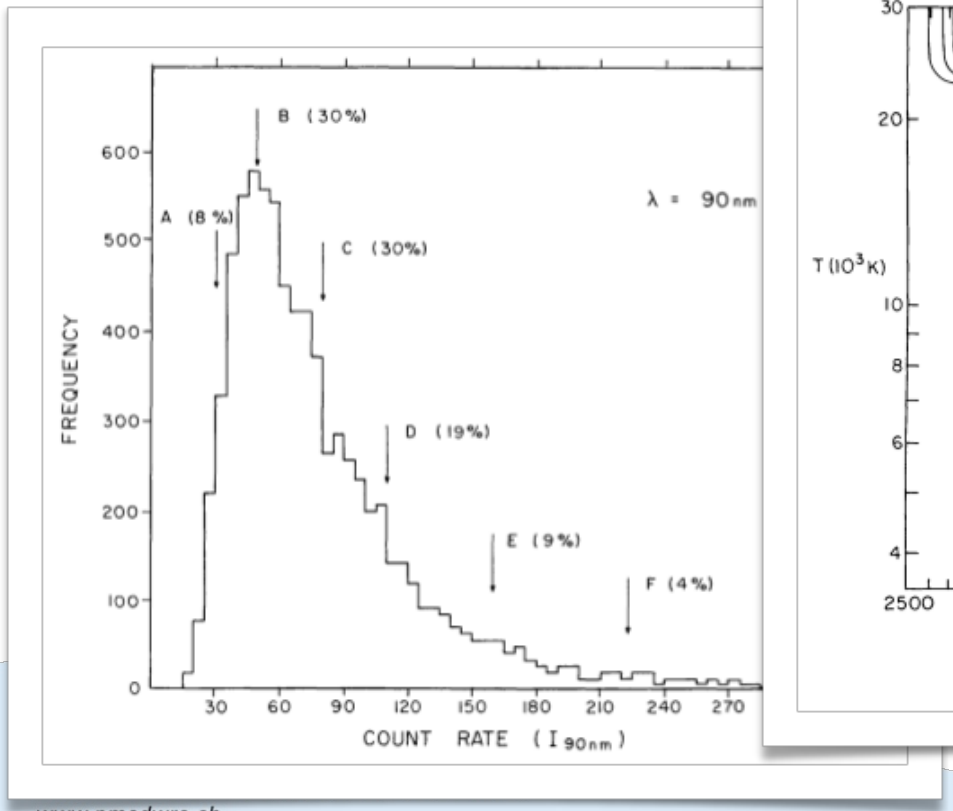
4.Existing models

Existing model: Vernazza et al. (1981) ApJ SS, 45:635.



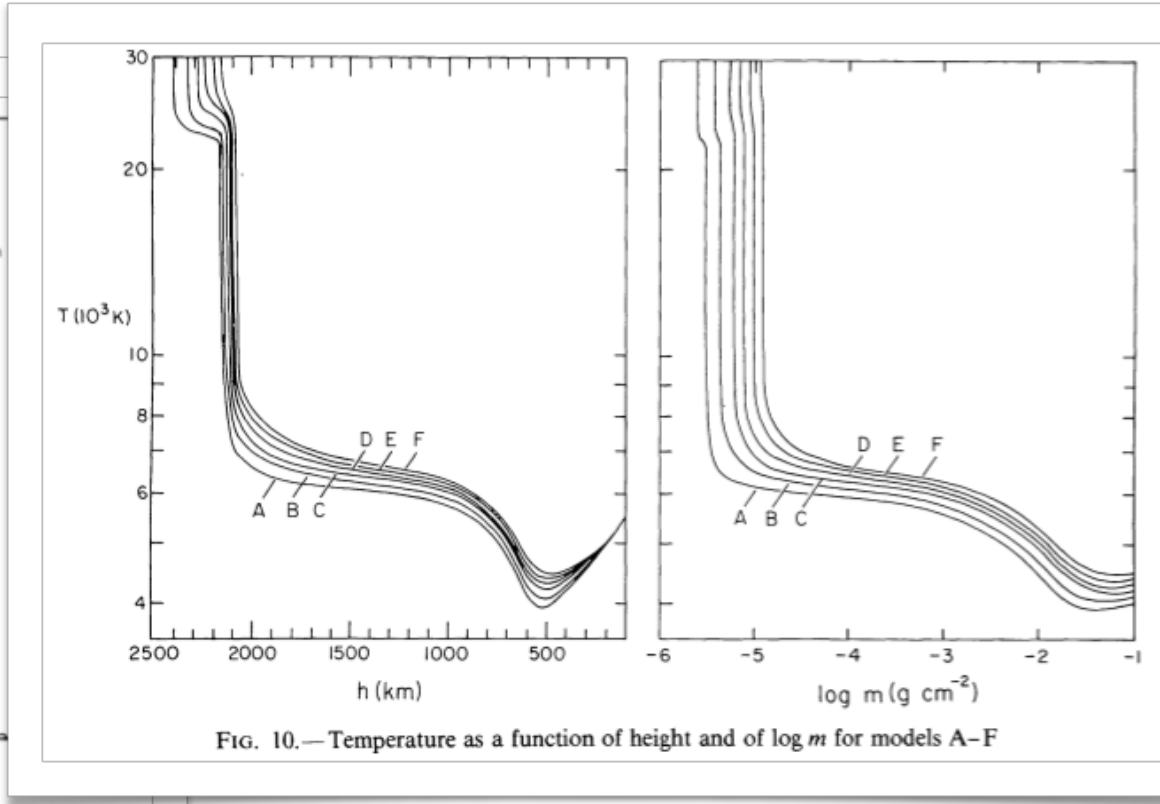


FIG. 10.—Temperature as a function of height and of log m for models A–F