# Developing faster and more accurate radiative transfer calculations for solar and stellar applications

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# First project - Introduction

**OODF: Optimized Opacity Distribution Functions for a New Generation of Solar and Stellar Brightness Variability Models**

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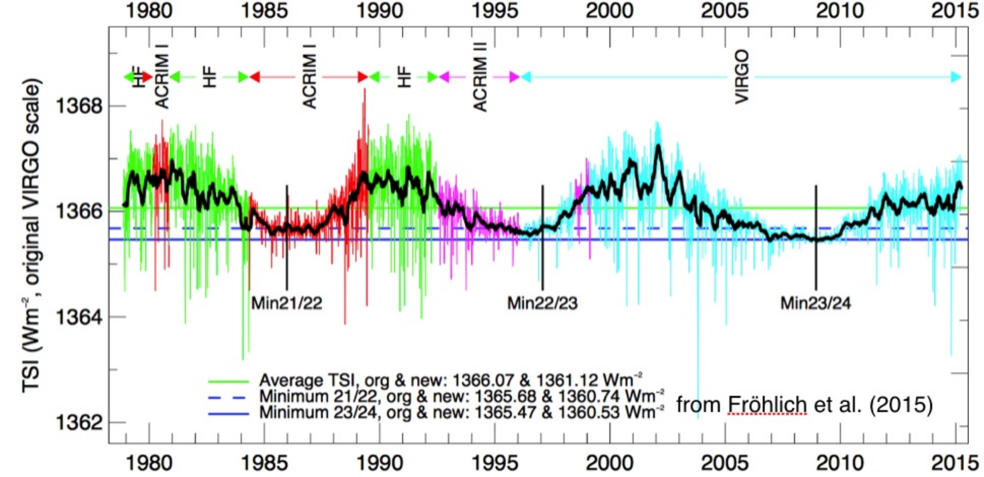
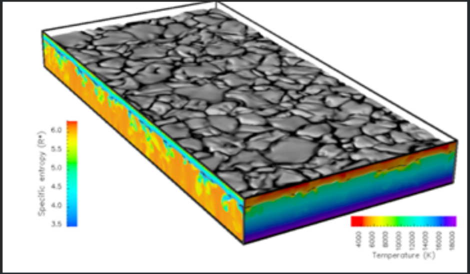
# Total Solar Irradiance

- TSI – spectrally integrated solar radiative flux at 1 AU from the sun



# 1.5D simulations

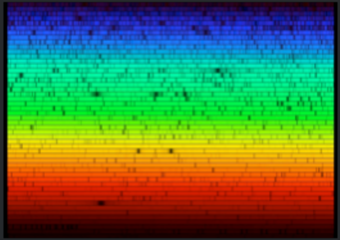
## 3D MHD simulations with MURaM




Structure of the magnetic features

+

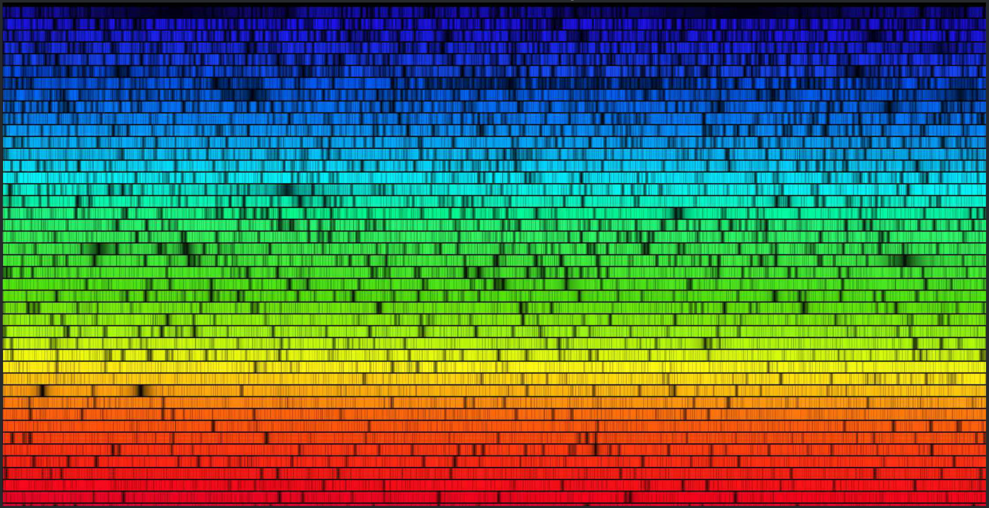
## 1.5D radiative transfer



Spectra of the magnetic features

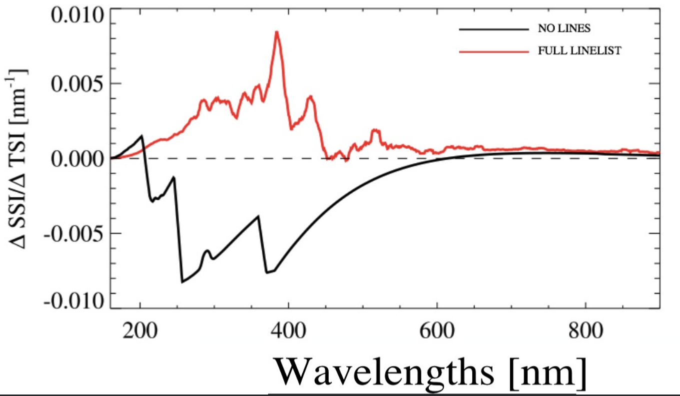
# Spectra of the individual components

## Observed solar spectra

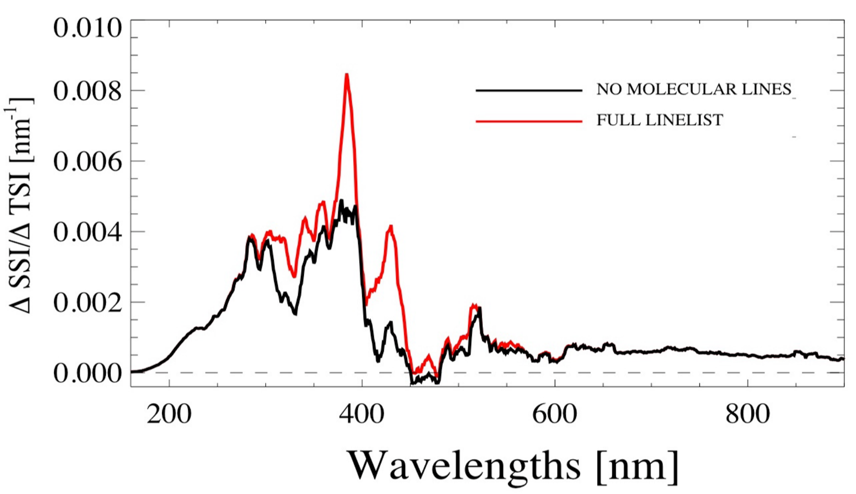


# Importance of lines for variability

- TSI – Total Solar Irradiance, i.e. integrated over wavelengths
- SSI – Spectral Solar Irradiance, depends on wavelength
- △ – difference between the solar minima and maxima

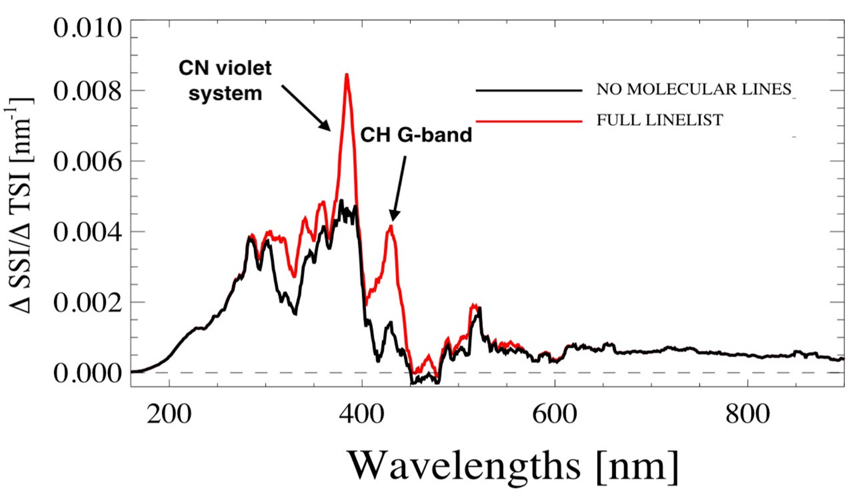


# Importance of lines for variability



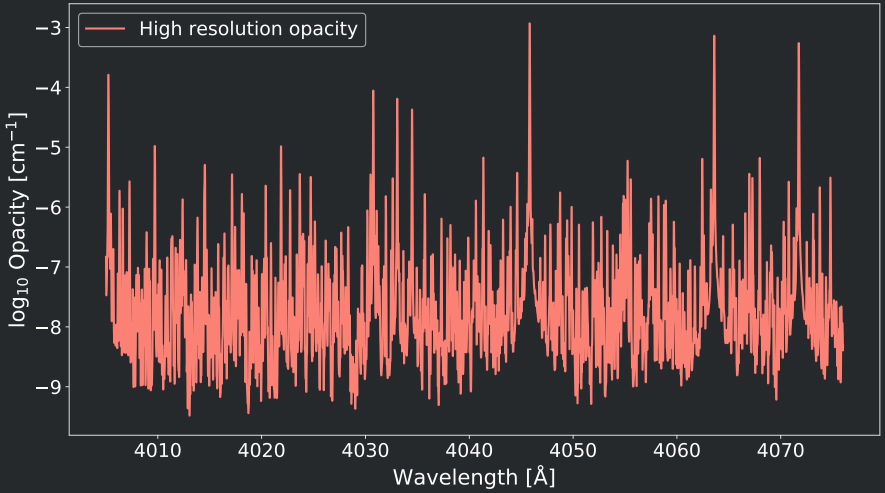
# Importance of lines for variability

- 25% of the variability comes from molecular lines → accurate treatment of lines is crucial



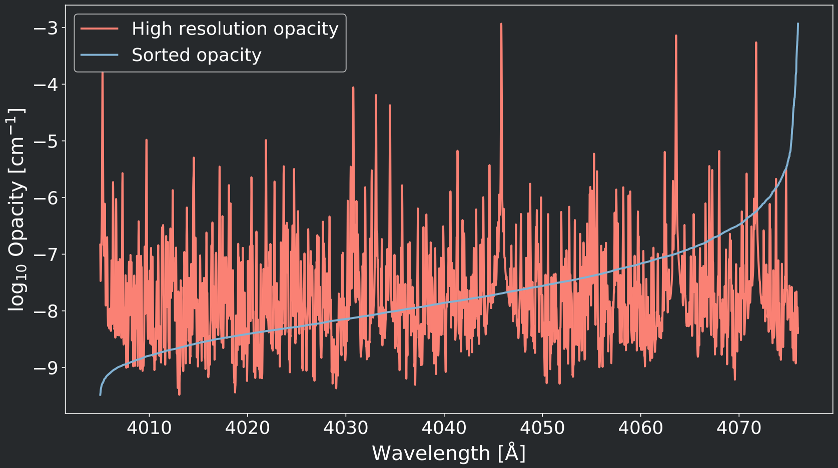
# Generating ODFs

- Start with high resolution opacity



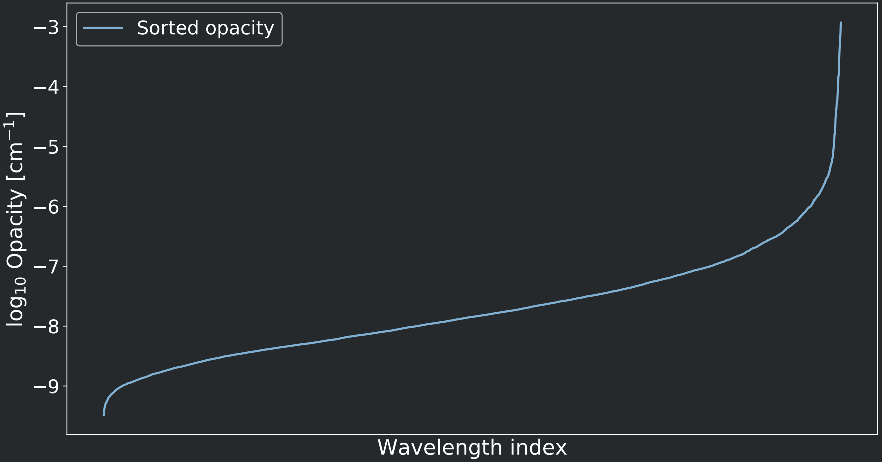
# Generating ODFs

- Sort wavelength points by corresponding values of opacity; monotonically increasing opacity
- Integral is preserved by sorting



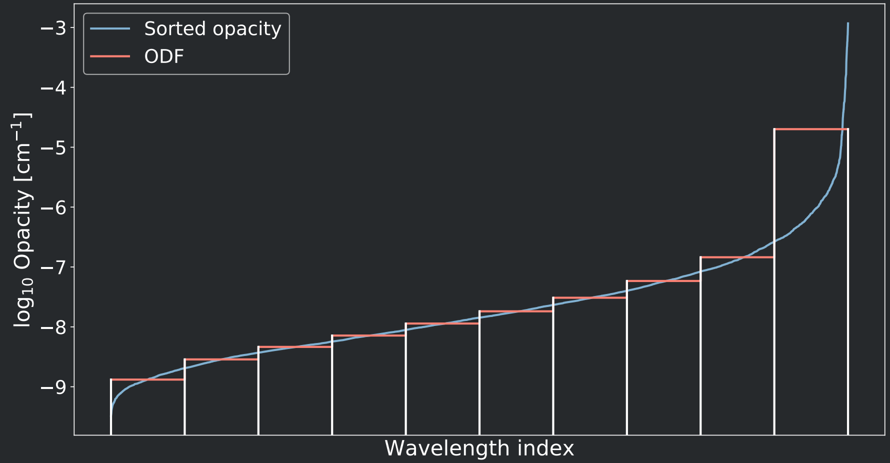
# Generating ODFs

- All wavelength information within the bin is lost



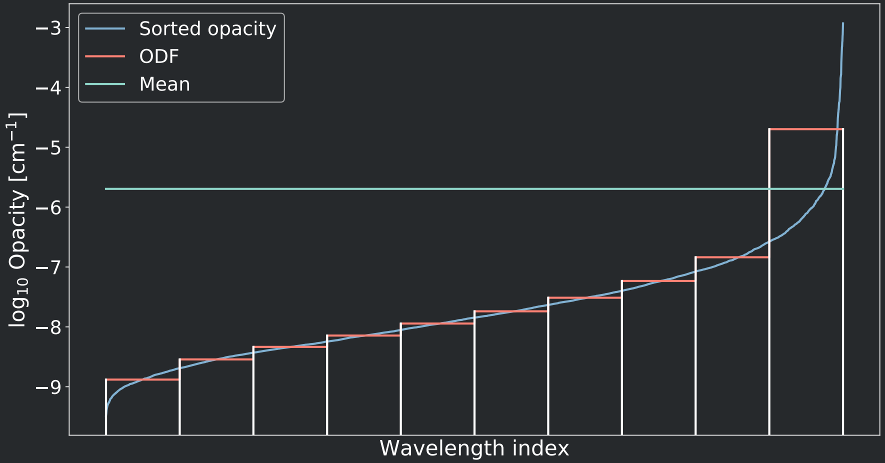
# Generating ODFs - Example with 10 uniform sub bins

- Approximate the sorted opacity with a step-wise function



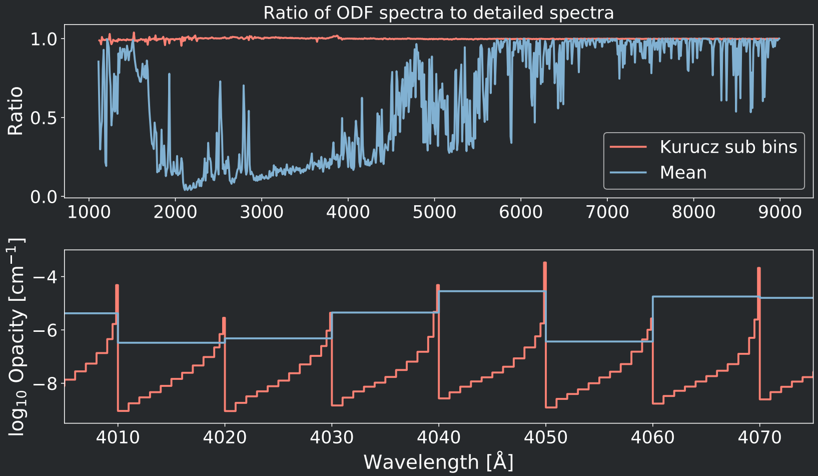
# ODF generation process

- Mean is skewed by extreme values



# ODF performance analysis

- Synthesize spectra with **NESSY** radiative transfer code using ODFs from 1000-9000Å in 10Å bins
- Compare the fluxes from the ODF spectrum with the high resolution spectrum in the bins



## Possible solutions

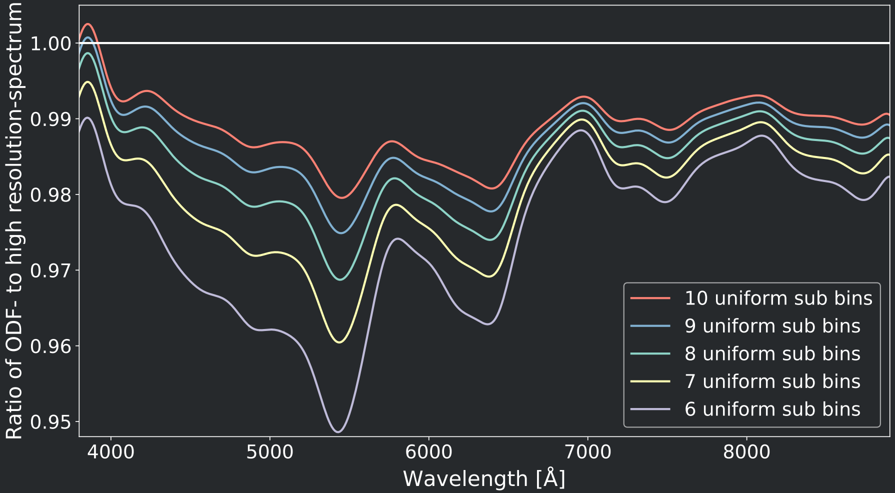
Number of calculations $\mathrm{n_{cal}} = \mathrm{n_{bins}} \times \mathrm{n_{subbins}}$

decrease $\mathrm{n_{cal}}$ by

- decrease the number of sub bins per bin
- increase bin size $\rightarrow$ decrease $n_{bins}$

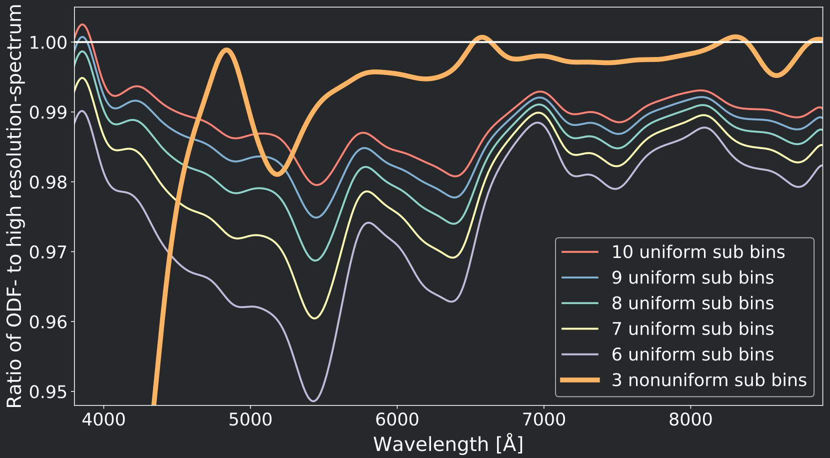
# Analysis of different ODFs

- Uniform ODFs

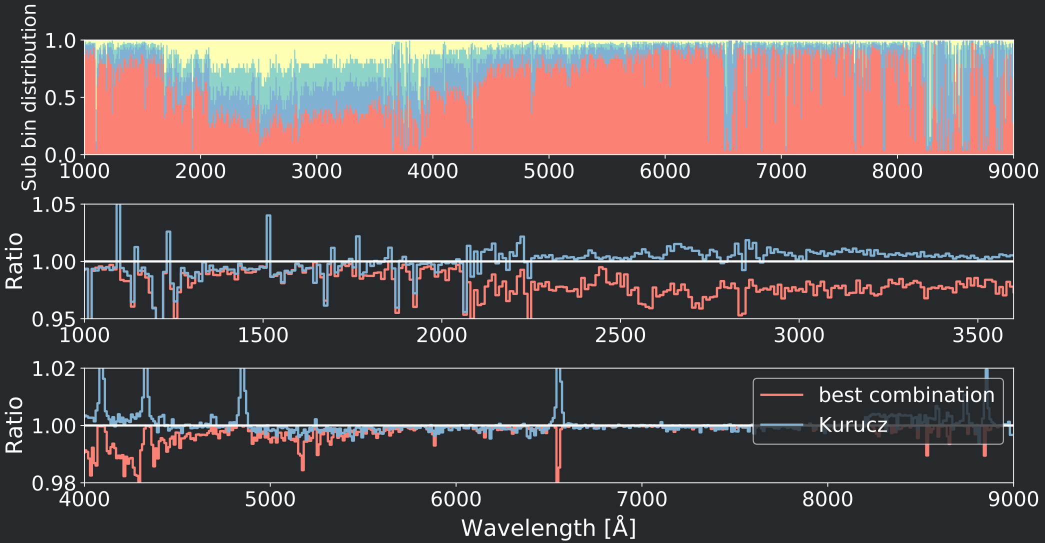


# Analysis of different ODFs

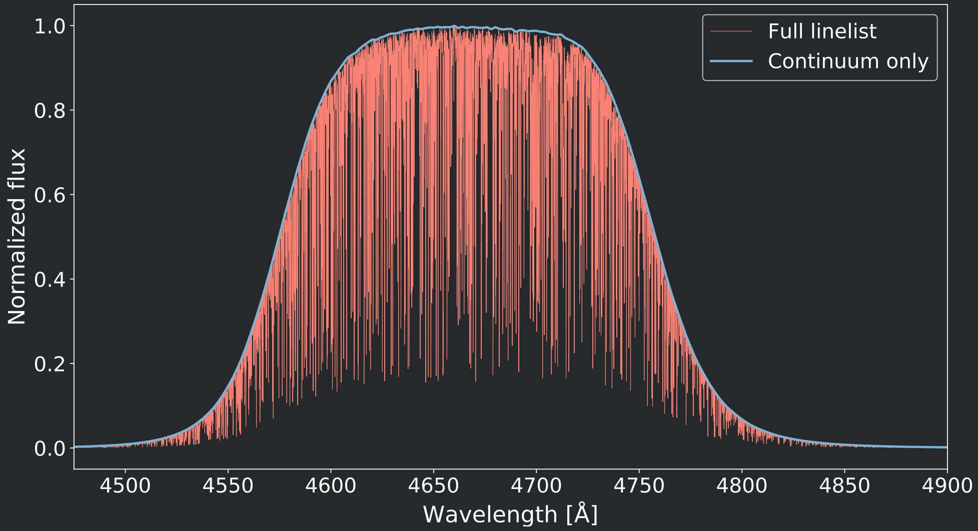
- Nonuniform ODFs
- The last sub bin is crucial after 5000Å



# Best sub bin combinations using 4 sub bins

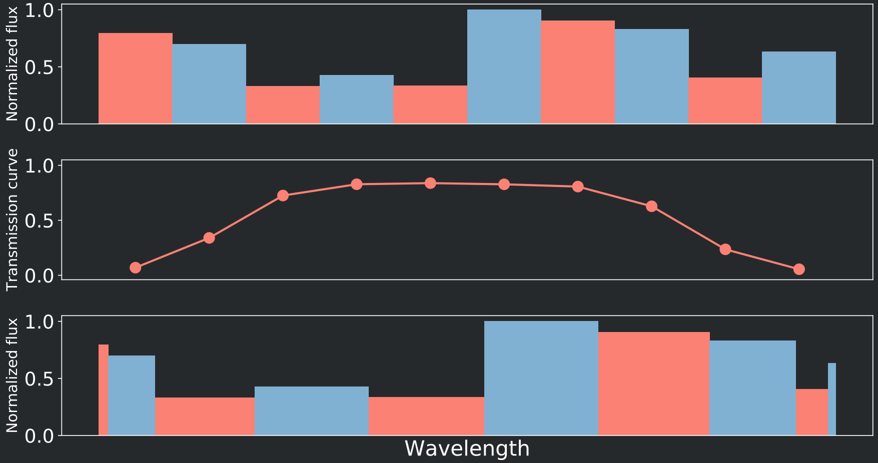


# Strömgren *b*


1.0
0.8
0.6
0.4
0.2
0.0
Normalized flux
4500
4550
4600
4650
4700
4750
4800
4850
4900
Wavelength [Å]
Full linelist
Continuum only

# OODF treatment of filters

- ODF approach can be generalized to take into account any shape of transmission function
- Achieved by transforming the wavelength grid according to the transmission function



# Speedups in the case of Strömgren *b*

- Interval length (transmission curve > 1%): ~400Å

High resolution: 80 points per Å ~ 32 000 points

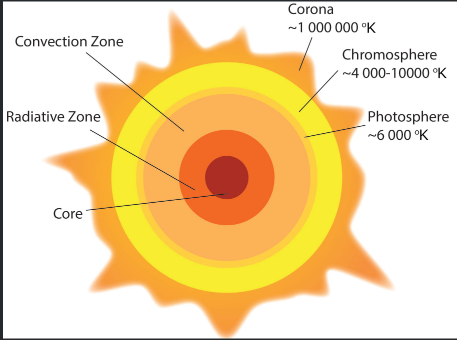
ODF: 12 points per 10Å ~ 480 points
speedup 67 times

OODF: 4 points for the whole bin
speedup ~8 000 times

# MSc project - Introduction

Title: **Fast Approximate non-LTE Treatment of the Chromosphere**

- The aim of the magnetohydrodynamic group at my institute is simulating the Sun from the upper part of the convection zone and up




http://www.phy.cuhk.edu.hk/elearning/Solar_eclipse/Solar_structure.html

MSc project - Fast approximate non-LTE treatment of the chromosphere

**Current solutions:**

- Currently used solution: pre-tabulated cooling rates derived from 1D RADYN radiation-hydrodynamic simulations

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**My work:**

- Escape probability methods

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**My work:**

- Escape probability methods $\rightarrow$ problem with going from 1D to 3D
- Scharmer method: *A new approach to multi-level non-LTE radiative transfer problems, Scharmer's et al (1985)*
  - Eddington Barbier approximation + core saturation approximation

# Conclusions

**First project**

- We developed a novel method for fast spectral synthesis.
- Found optimal sub bins for different wavelength regimes.
- Can be tailored for different filters: Strömgren $b + y$, Kepler, PLATO and others.
- Significant speed up relative to standard methods by a factor of at least two orders of magnitude.

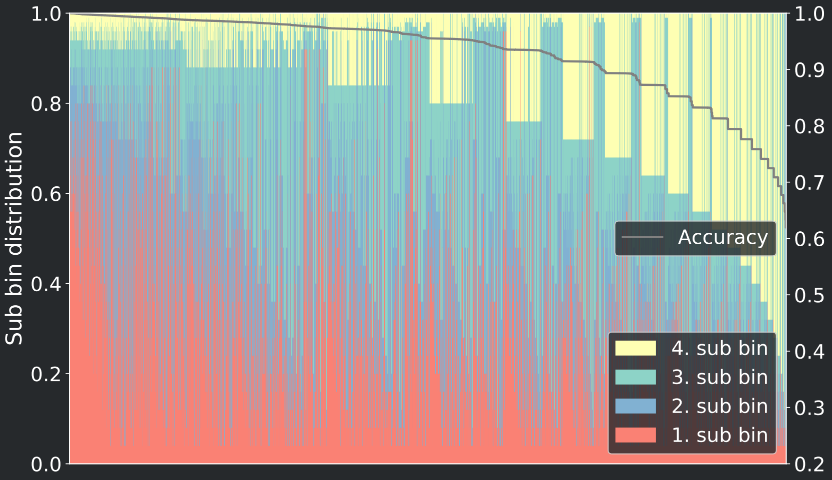
**Second project**

- Escape probabilities: try the 1.5D approach.
- Scharmer: implement the method into RH
- Compare both methods above to the pre-tabulated cooling rates.

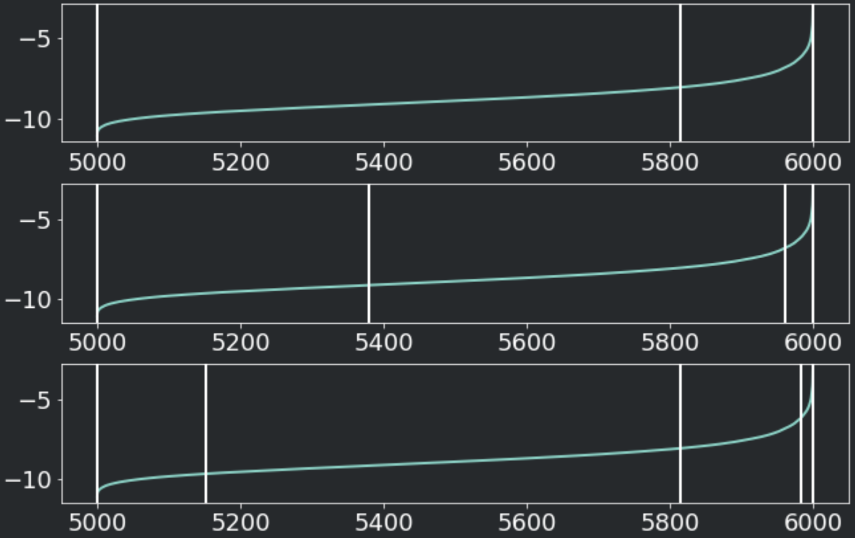
# Backup slides beyond

**Here be dragons!**

# Best combinations of 4 sub bins for Strömgren *b*



# Formula: value weighted by the derivative



# Ascending vs descending sort