

AST5770

Solar and stellar physics

Sven Wedemeyer, University of Oslo, 2026

Assignments

First mandatory assignment

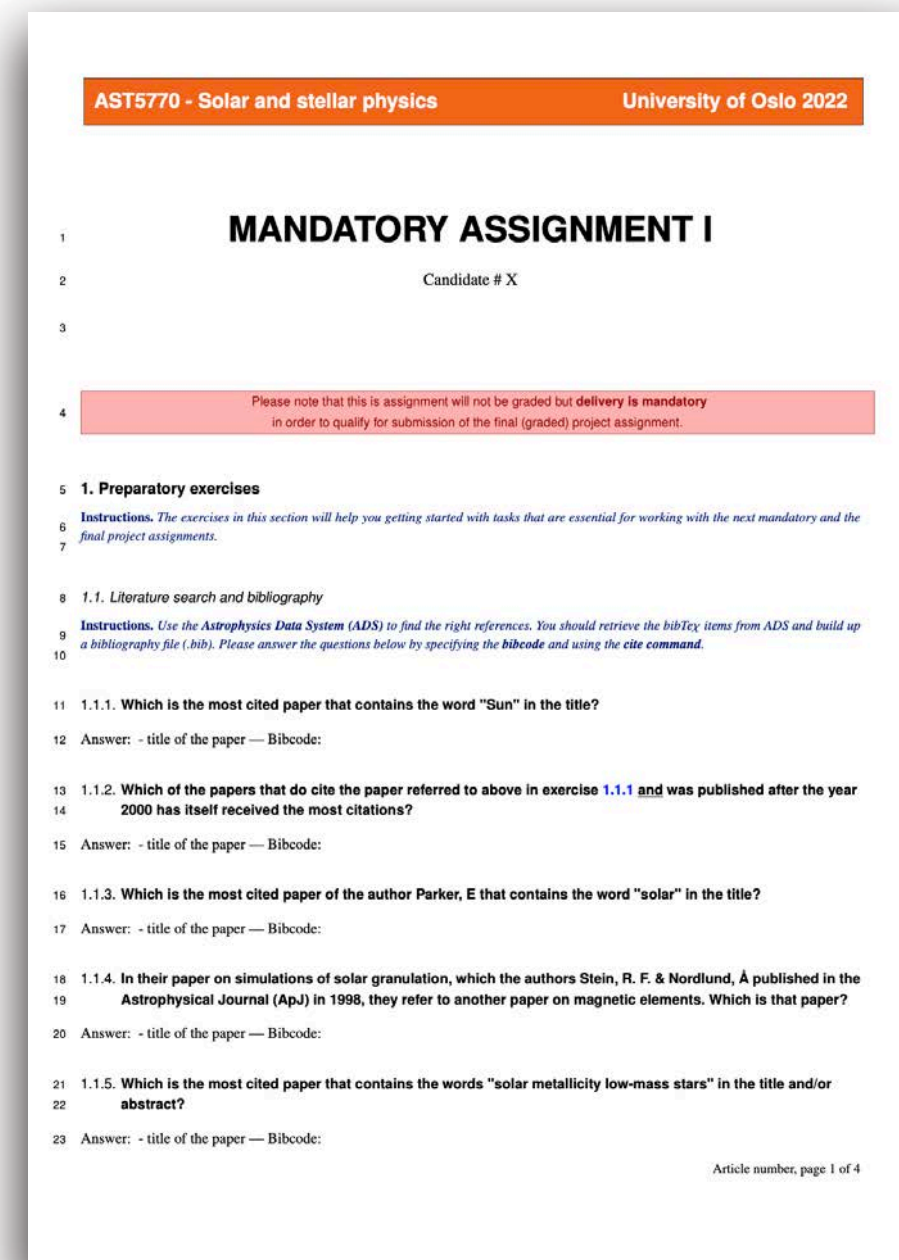
- Delivery via devilry (more information soon)
- Assignments to be prepared using the provided latex templates found on the webpage

- **Preparatory exercises for training**

1. Literature research with ADS
 - Download bibtex items and use them in latex
2. Loading and plotting a reference model (VALC)
3. Use the helioviewer tool
4. First look at the provided observation and simulation data

- **First steps towards the final project assignment**

- Tentative science question, work plan, and reading list
- Important: Just to get started! Can be updated!



Practical information

Data / material for assignments

- **Data:** `/mn/stornext/d19/RoCS/svenwe/lecture/AST5770/data`

- **Everybody please check: Can you access these directories?**

- **On the course webpage**
 - Templates
 - Submission dates and requirements
 - A document with information about data & assignments
 - Evaluation matrix

Practical information

Data / material for assignments

- Main directory: `/mn/stornext/d19/RoCS/svenwe/lecture/AST5770/`
- Sub-directories/content:
 - Data: `data/`
 - Templates 4 assignments: `assignment/`
 - First assignment: `assignment/assign1/`
 - Latex: `assignment/latex/`
 - Further information: `AST5770_manual.pdf`
- Who uses python? Who IDL?
- Note that order of dimensions in data cubes can be flipped!

Literature research

Previously: Astrophysics Data System (ADS)

The screenshot displays the ADS search interface. At the top, the ADS logo is on the left, and navigation links for Feedback, ORCID, About, Sign Up, and Log In are on the right. Below the header, a search bar contains the query 'author:('Vernazza') year:1981'. The search results section shows 'Your search returned 1 results'. On the left sidebar, filters for Authors (Avrett, E., Loeser, R., Vernazza, J.), Collections (astronomy), and Refereed status are shown. The main content area displays a single result: '1981ApJS...45..635V' from April 1981, cited 2172 times. The title is 'Structure of the solar chromosphere. III. Models of the EUV brightness components of the quiet sun.' by Vernazza, J. E.; Avrett, E. H.; Loeser, R. The interface includes buttons for 'Show highlights', 'Show abstracts', and 'Hide Sidebars'. At the bottom, there are pagination controls showing 'Per Page 500' and '1 of 1' results, along with 'prev' and 'next' buttons. A 'Top' link is also present. On the right, a graph area shows 'Too little data to make a useful graph.' for the 'Years' tab.

ads

Feedback ORCID About Sign Up Log In

QUICK FIELD: Author First Author Abstract Year Fulltext All Search Terms

← Start New Search

author:('Vernazza') year:1981

Your search returned 1 results

↓ Date Export Explore

✓ AUTHORS
 > Avrett, E 1
 > Loeser, R 1
 > Vernazza, J 1
 ✓ COLLECTIONS
 > astronomy 1
 ✓ REFEREED
 > refereed 1
 > INSTITUTIONS
 > KEYWORDS
 > PUBLICATIONS
 > BIB GROUPS
 > SIMBAD OBJECTS
 > NED OBJECTS
 > DATA
 > VIZIER TABLES
 > PUBLICATION TYPE

☐ Show highlights Show abstracts Hide Sidebars Go To Bottom

1 ☐ 1981ApJS...45..635V 1981/04 cited: 2172

Structure of the solar chromosphere. III. Models of the EUV brightness components of the quiet sun.
 Vernazza, J. E.; Avrett, E. H.; Loeser, R.

Per Page 500 prev 1 of 1 next Top

Years Citations Reads
 Too little data to make a useful graph.

<https://ui.adsabs.harvard.edu/>

Literature research with SciX

<https://scixplorer.org/>



Astrophysics

▼

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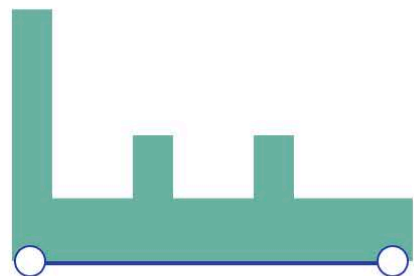
QUICK FIELD: [author](#) [first author](#) [abstract](#) [year](#) [fulltext](#)

Your search returned **15** results

Filters



Year(s)



1972 1981

- [Author](#)
- [Collections](#)
- [Refereed](#)
- [Institutions](#)
- [Award](#)
- [Keywords](#)
- [Publications](#)
- [Bibgroups](#)

Relevance



☐ Select All

Bulk Actions

Explore

[Structure of the solar chromosphere. III. Models of the EUV brightness components of the quiet sun.](#)



1 ☐

Vernazza, J. E.; Avrett, E. H.; Loeser, R.; [show details](#)

1981/04 · The Astrophysical Journal Supplement Series · [cited: 2486](#)



[Structure of the solar chromosphere. II. The underlying photosphere and temperature-minimum region.](#)



2 ☐

Vernazza, J. E.; Avrett, E. H.; Loeser, R.; [show details](#)

1976/01 · The Astrophysical Journal Supplement Series · [cited: 534](#)



[Structure of the Solar Chromosphere. Basic Computations and Summary of the Results](#)



3 ☐

Vernazza, Jorge E.; Avrett, Eugene H.; Loeser, Rudolf; [show details](#)

1973/09 · The Astrophysical Journal · [cited: 393](#)



[Extreme ultraviolet composite spectra of representative solar features.](#)



Vernazza, J. E.; Reeves, E. M.; [show details](#)

Stellar structure — The Sun

Atmosphere

Corona

$>1\,000\,000\text{ K}$

Transition region

$\sim 100\,000\text{ K}$

Chromosphere

$10\,000\text{ K}$

Photosphere

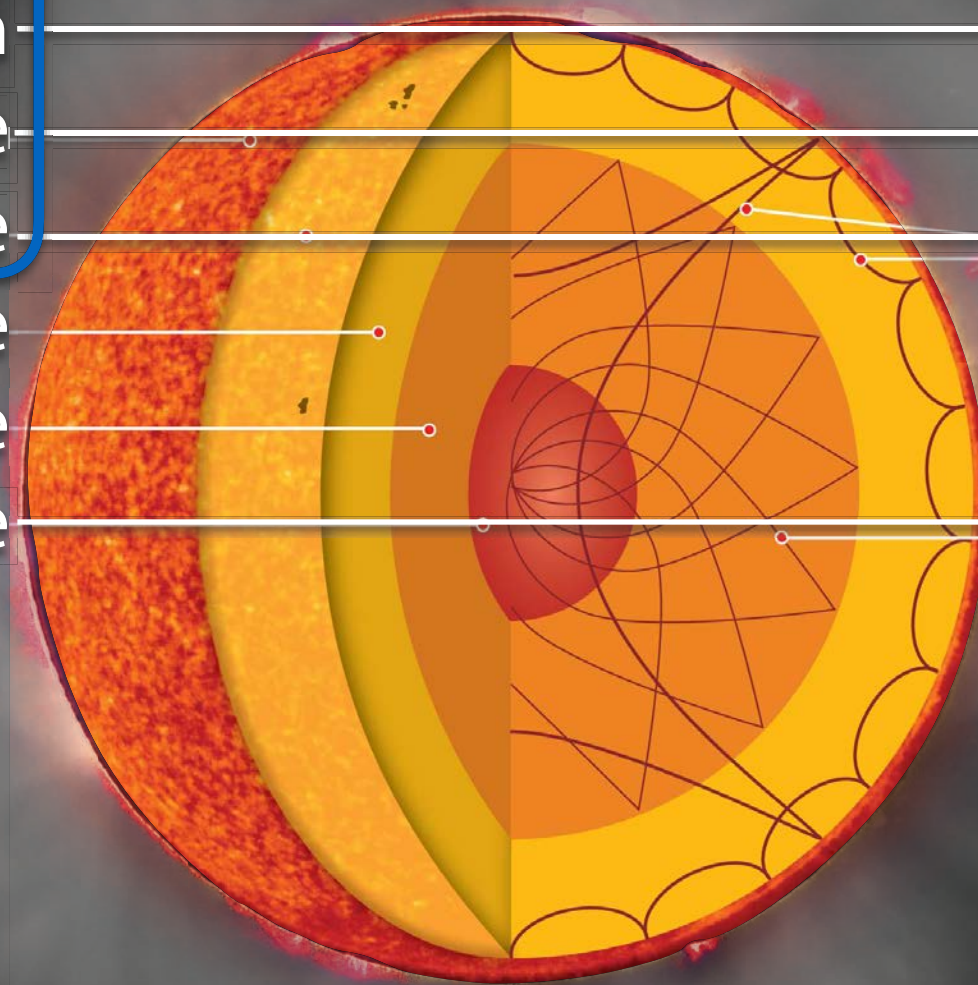
$5\,770\text{ K}$

Convection zone

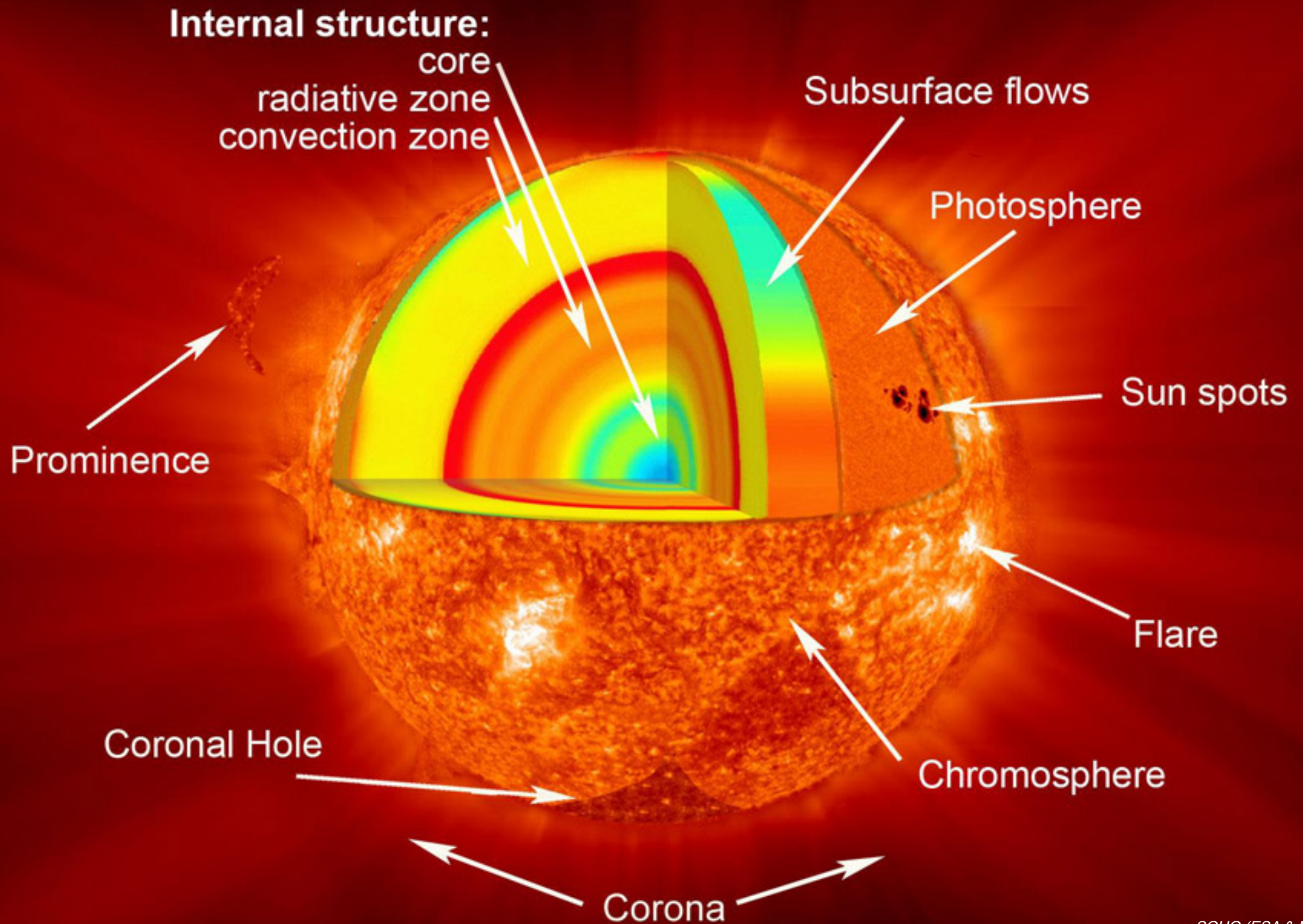
Radiative zone

Core

$15\,000\,000\text{ K}$



The solar atmosphere



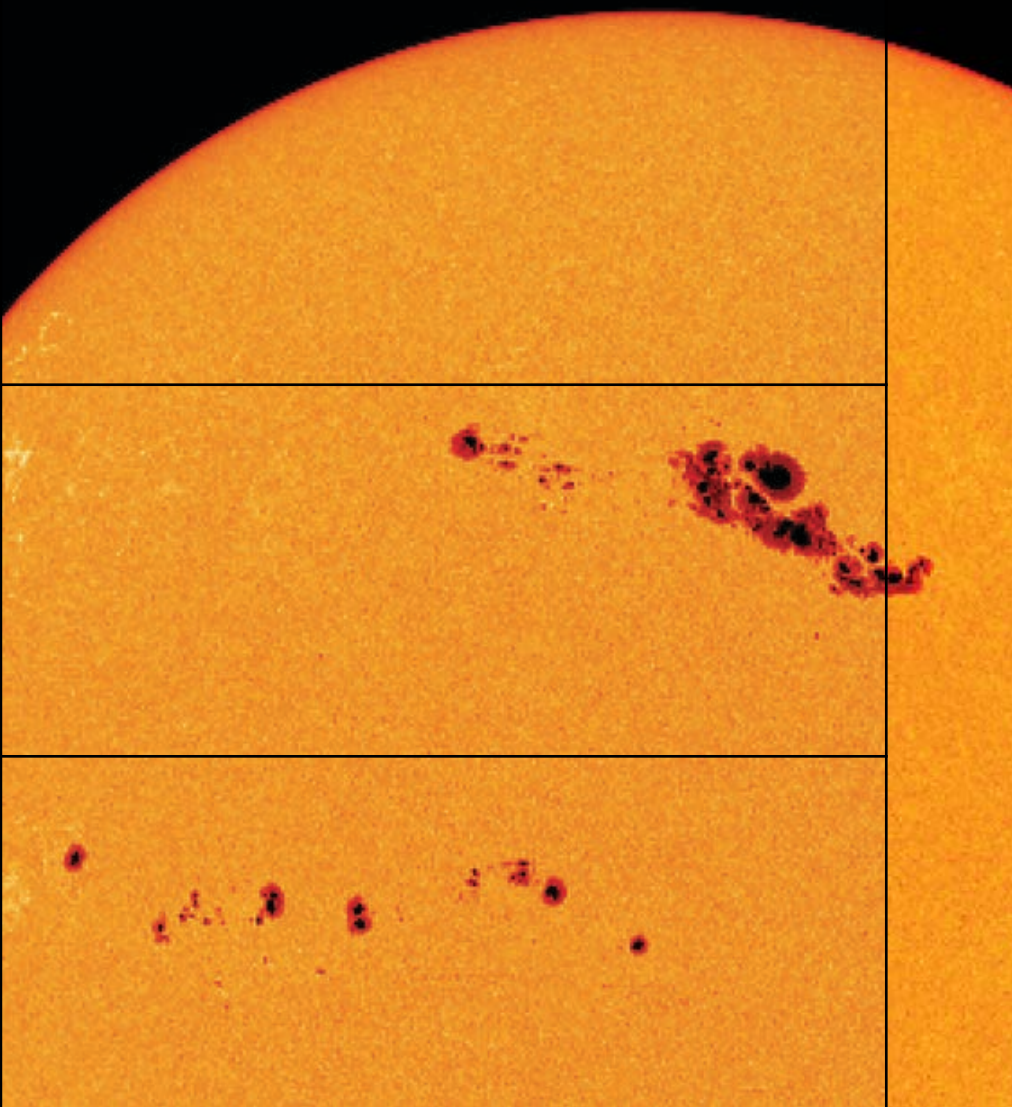
The solar atmosphere

Solar “zoology”

- A plethora of phenomena with different names
- Names often depend on the **region/layer** where phenomenon occurs (if known/limited to that) or the **wavelength** domain in which it is observed
- Names are often given upon discovery without understanding the physical mechanism behind — names not always meaningful
- Careful: Sometimes different names just refer to different aspects of the same phenomenon or observable imprints in different parts of the spectrum

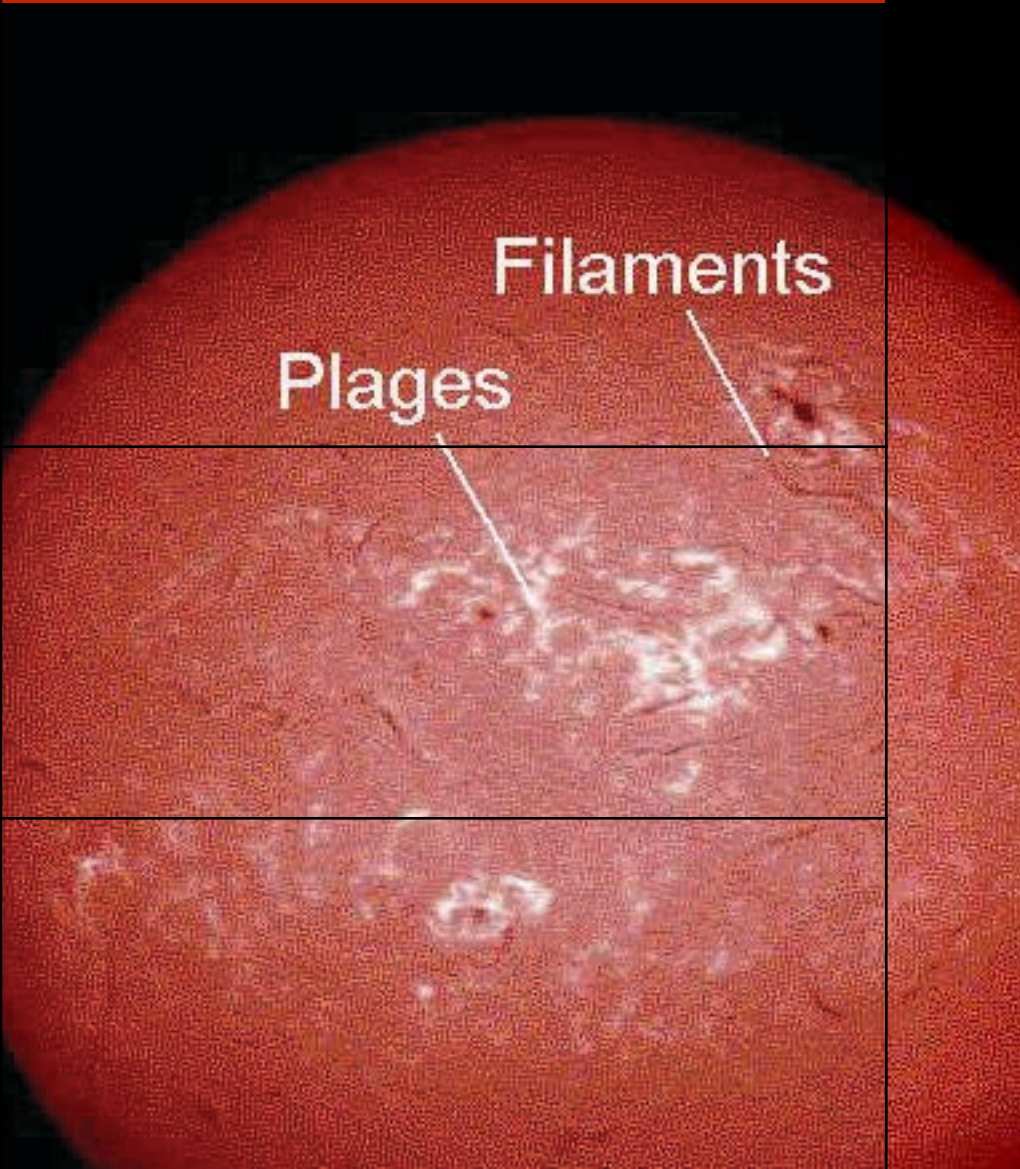
The solar atmosphere

Different regions — photosphere

(Average) magnetic field strength ↓	Active Region (Large) area with strong magnetic field	Sunspot Areas of concentrated very strong field, appear dark	Umbra Central compact part, dark Penumbra Surrounding, filamentary
		Faculae bright (filamentary) areas	
	Quiet Sun Outside Active Regions, weaker magnetic field	Network Concentrations of strong magnetic field, filamentary/mesh-like	
		Inter-network Areas with weak magnetic field inside network cells	

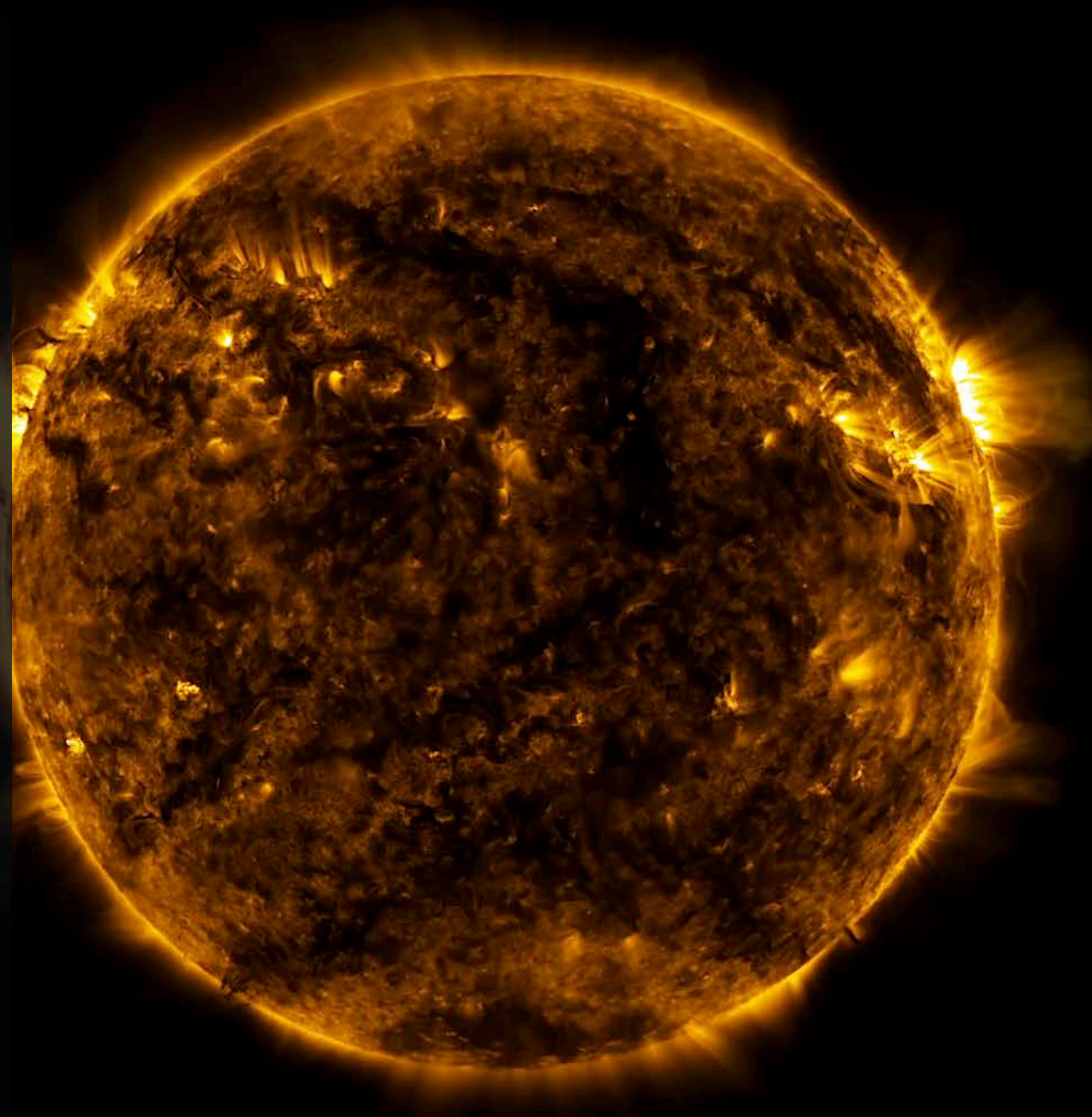
The solar atmosphere

Different regions — chromosphere

(Average) magnetic field strength ↓	Active Region (Large) area with strong magnetic field	Sunspot Areas of concentrated very strong field, appear dark	Umbra Central compact part, dark Penumbra Surrounding, filamentary
		Plage bright area, higher temperature, often proceeds formation of sunspots	
	Quiet Sun Outside Active Regions, weaker magnetic field	Network Concentrations of strong magnetic field, filamentary/mesh-like	
		Inter-network Areas with weak magnetic field inside network cells	

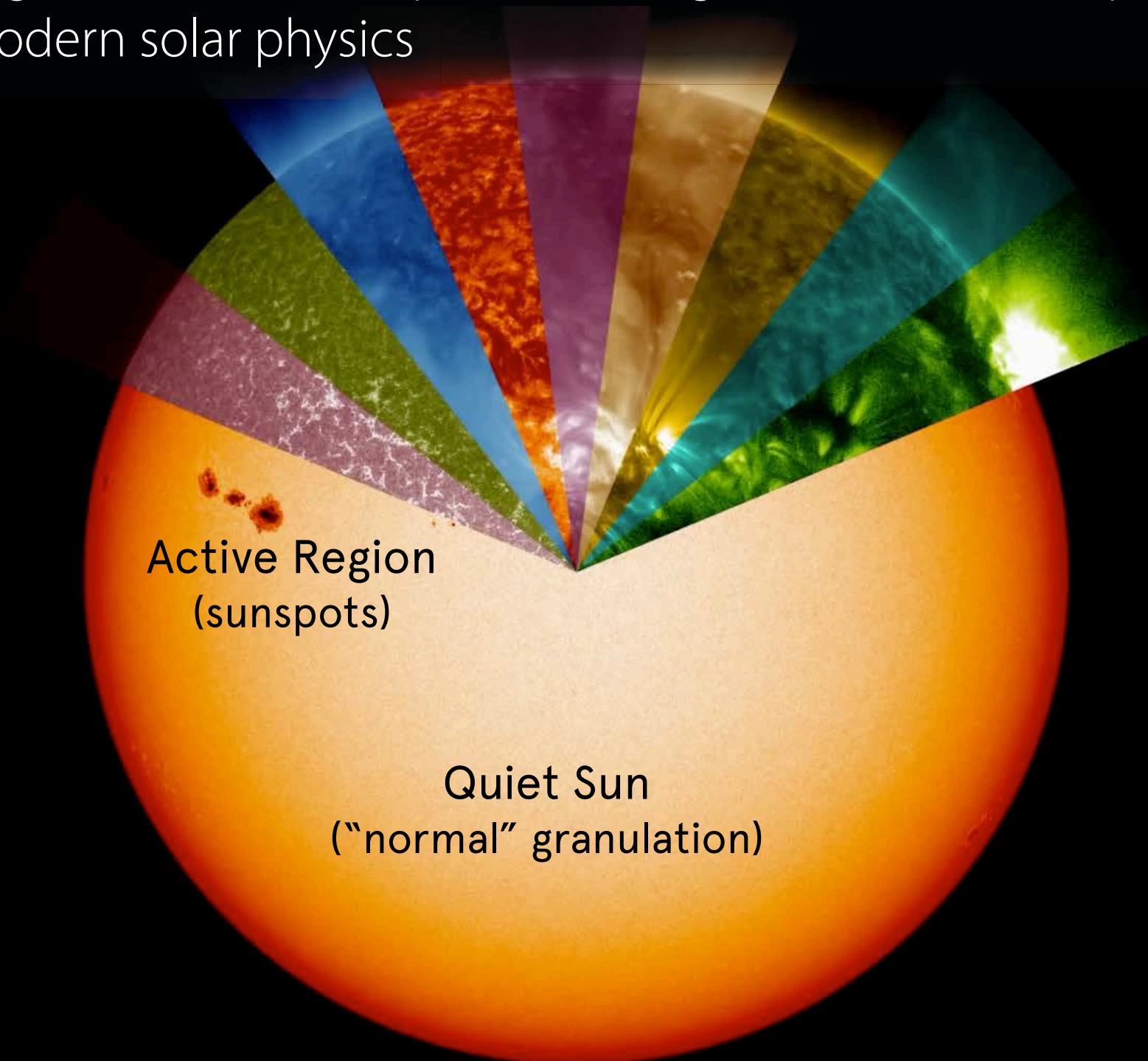
The solar atmosphere

- Solar atmosphere
 - highly dynamic
 - intermittent
 - dynamically coupled
- Structured on large range of spatial scales, down to (at least) 0.1 arcsec
- The Sun is dynamic on short timescales (down to seconds)
- Plethora of processes.
- Great plasma physics "laboratory"



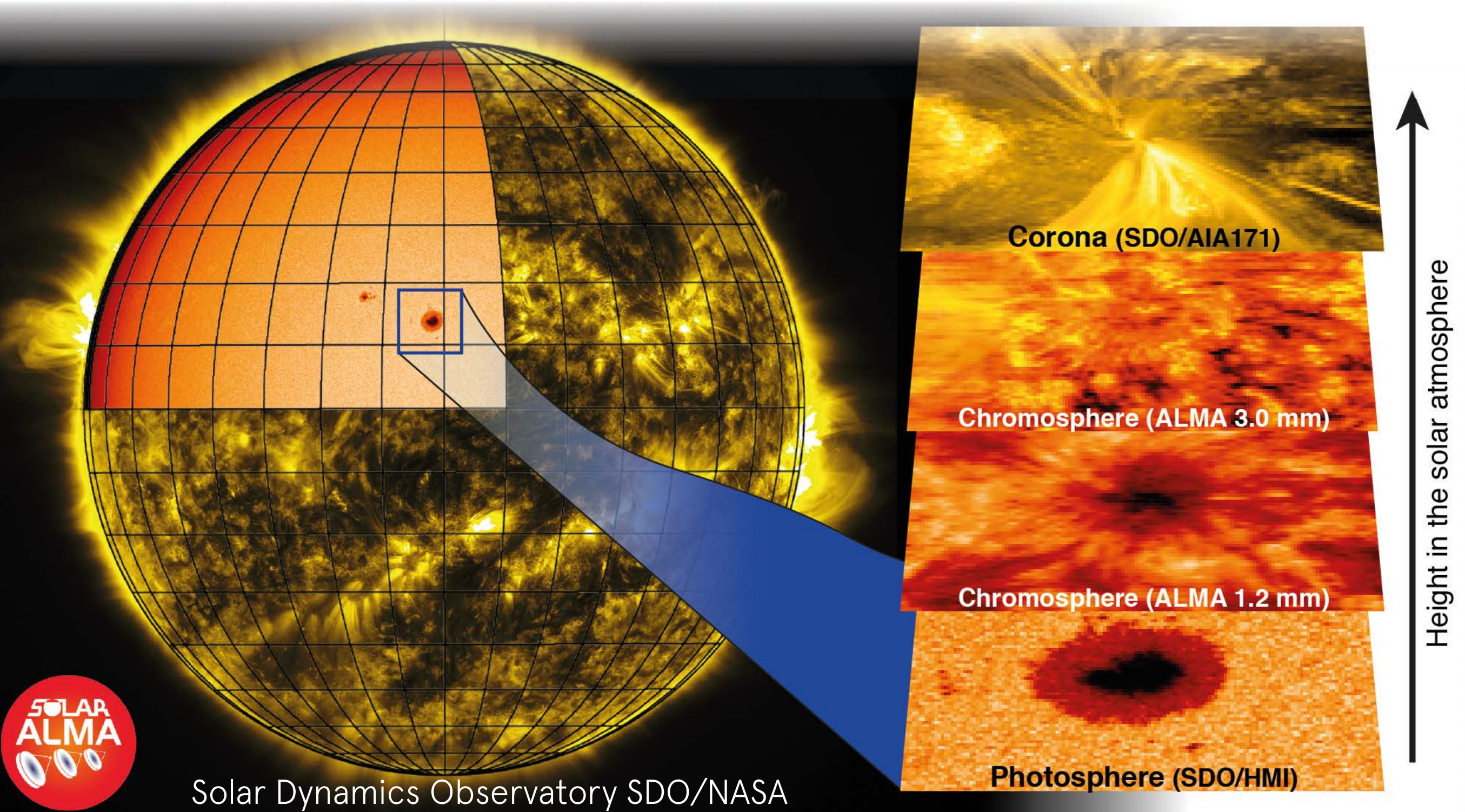
HOW TO OBSERVE THE SUN?

- Different continua and spectral lines probing different plasma properties in different domains/layers
- ➔ Multi-wavelength co-ordinated space-borne/ground-based campaigns as standard in modern solar physics



The solar atmosphere

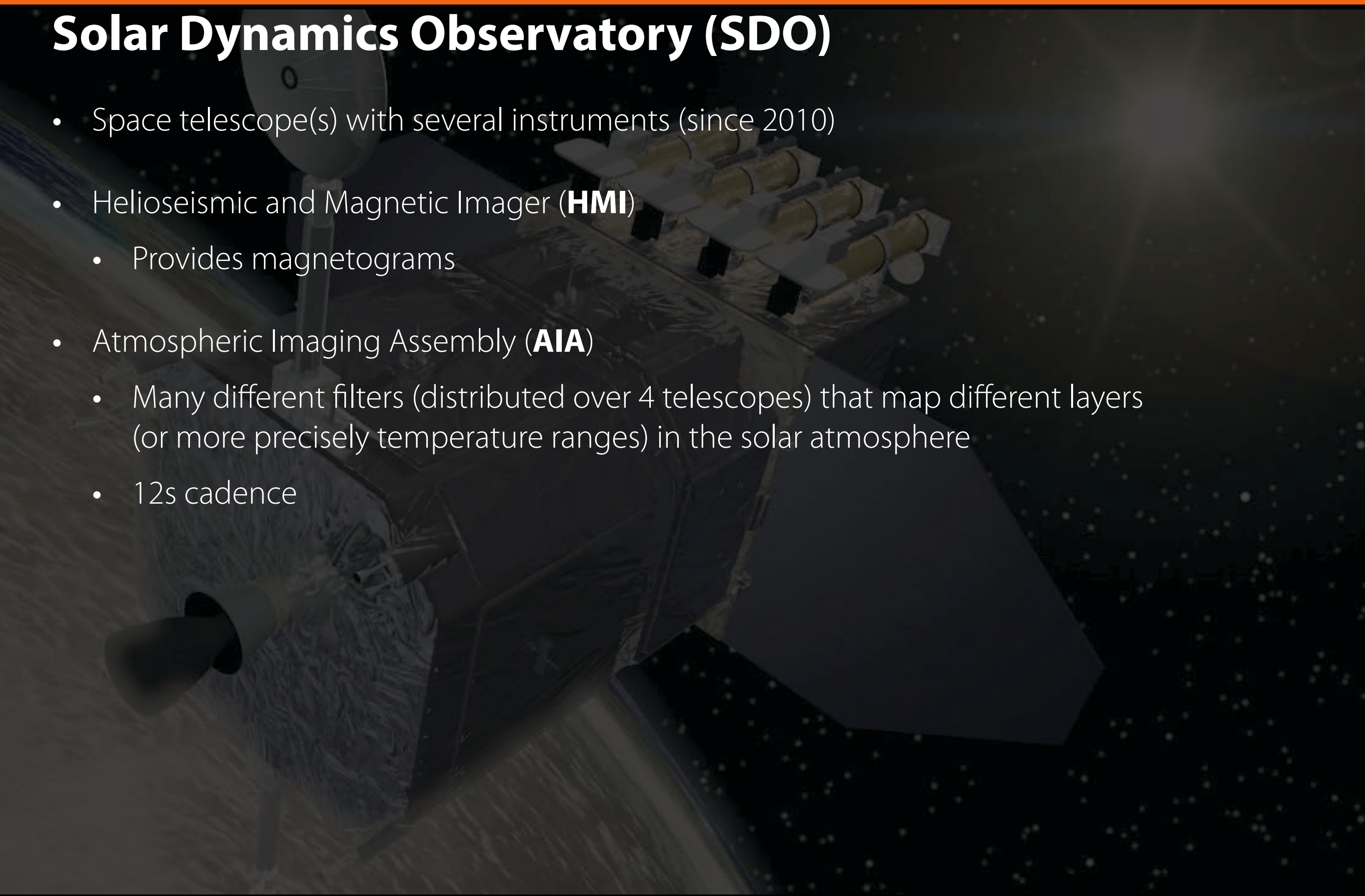
- Multi-wavelength co-ordinated space-borne/ground-based campaigns as standard in modern solar physics



The solar atmosphere

Solar Dynamics Observatory (SDO)

- Space telescope(s) with several instruments (since 2010)
- Helioseismic and Magnetic Imager (**HMI**)
 - Provides magnetograms
- Atmospheric Imaging Assembly (**AIA**)
 - Many different filters (distributed over 4 telescopes) that map different layers (or more precisely temperature ranges) in the solar atmosphere
 - 12s cadence

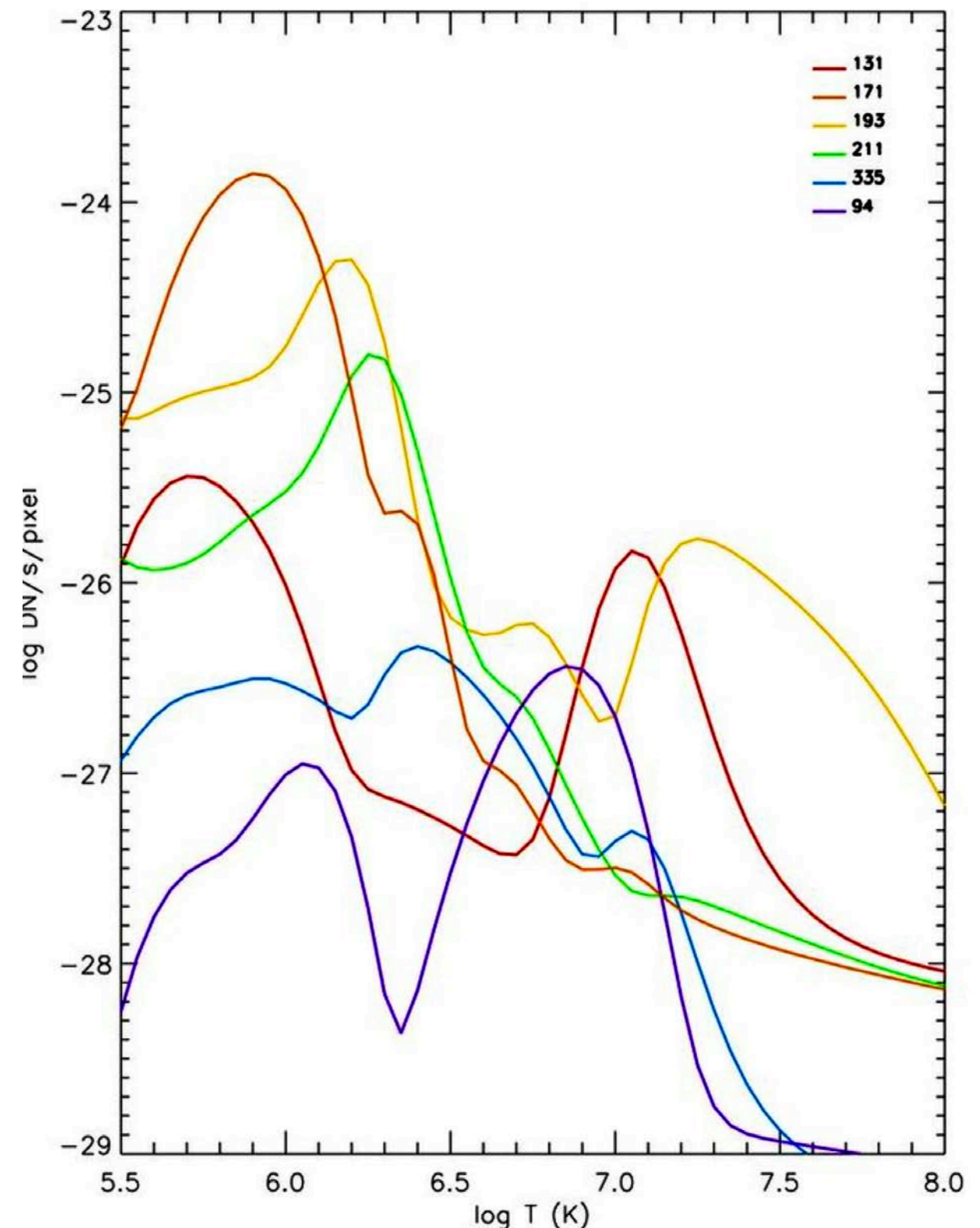


The solar atmosphere

Solar Dynamics Observatory (SDO)

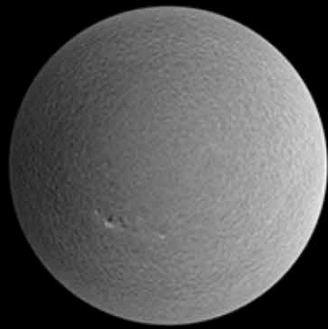
- Atmospheric Imaging Assembly (**AIA**)
- Maps effectively different layers in the chromosphere and corona

Filter	Ions	Log T
131	Fe VIII, XX, XXIII	5.6, 7.0, 7.2
171	Fe IX	5.8
193	Fe XII, XXIV	6.1, 7.3
211	Fe XIV	6.3
335	Fe XVI	6.4
94	Fe XVIII	6.8

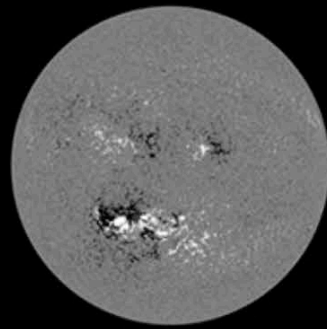


The solar atmosphere

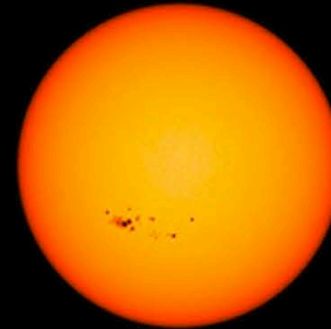
Solar Dynamics Observatory (SDO)



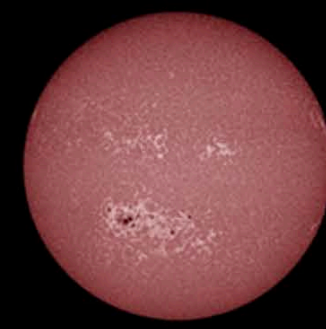
HMI Dopplergram
Surface movement
Photosphere



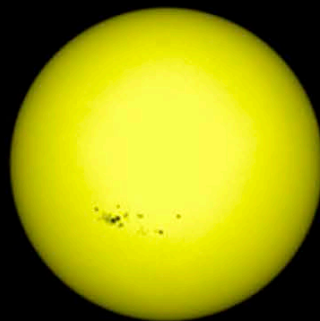
HMI Magnetogram
Magnetic field polarity
Photosphere



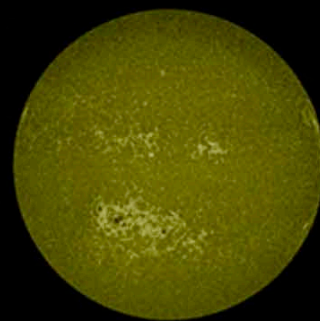
HMI Continuum
Matches visible light
Photosphere



AIA 1700 Å
4500 Kelvin
Photosphere



AIA 4500 Å
6000 Kelvin
Photosphere



AIA 1600 Å
10,000 Kelvin
Upper photosphere/
Transition region



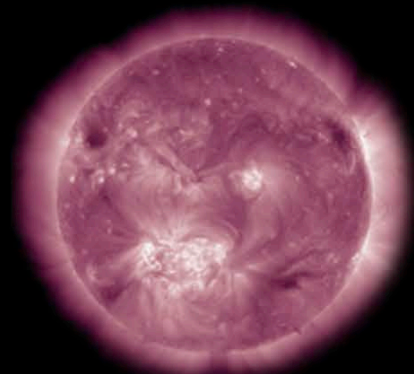
AIA 304 Å
50,000 Kelvin
Transition region/
Chromosphere



AIA 171 Å
600,000 Kelvin
Upper transition
Region/quiet corona



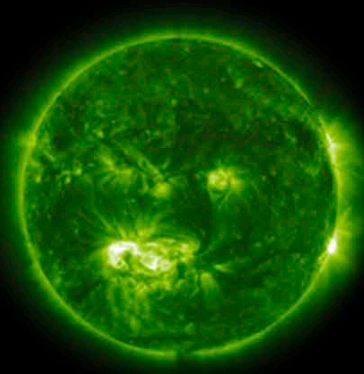
AIA 193 Å
1 million Kelvin
Corona/flare plasma



AIA 211 Å
2 million Kelvin
Active regions



AIA 335 Å
2.5 million Kelvin
Active regions



AIA 094 Å
6 million Kelvin
Flaring regions

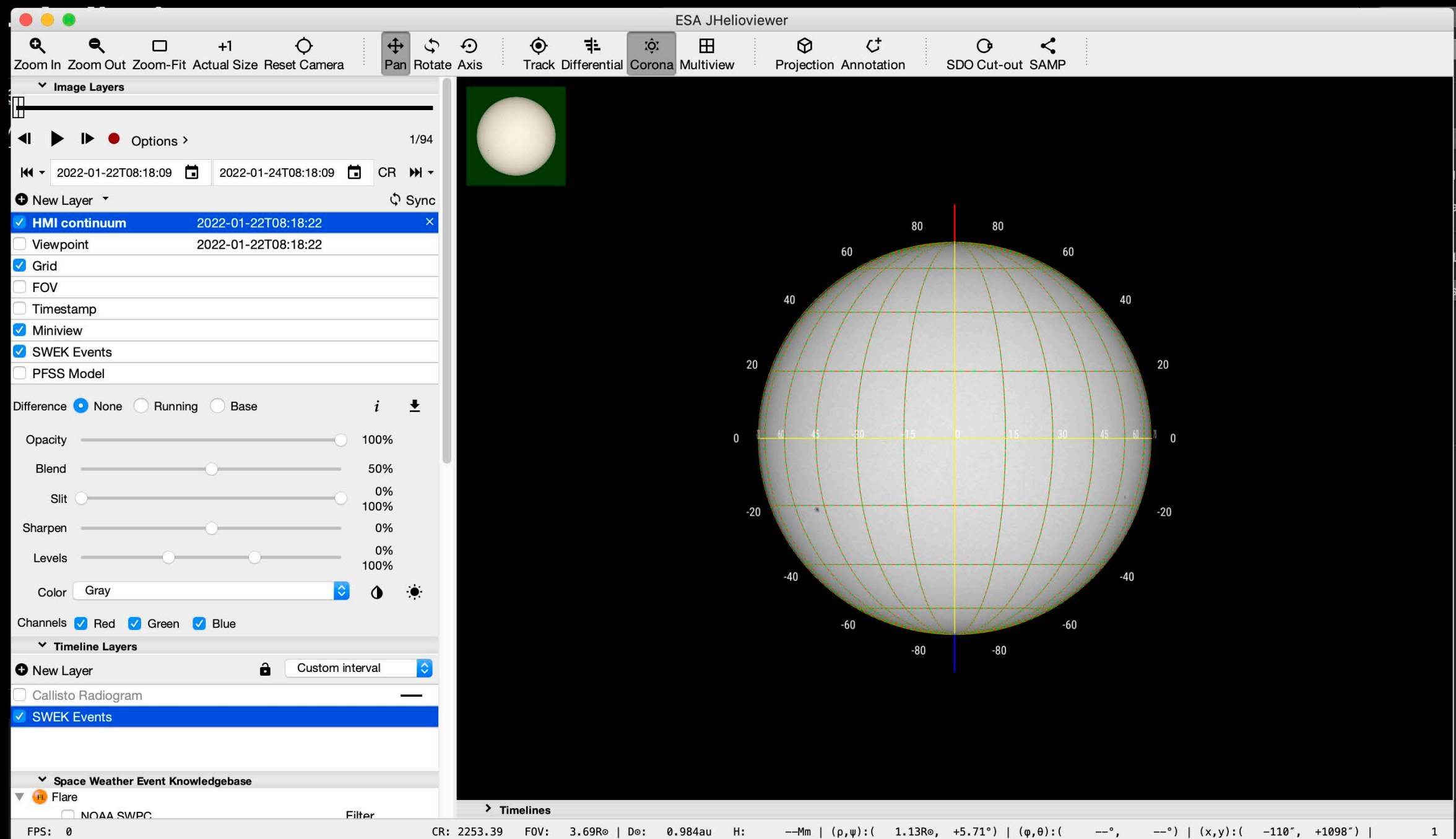


AIA 131 Å
10 million Kelvin
Flaring regions

Preview - The solar atmosphere

Interactive exploring — helioviewer

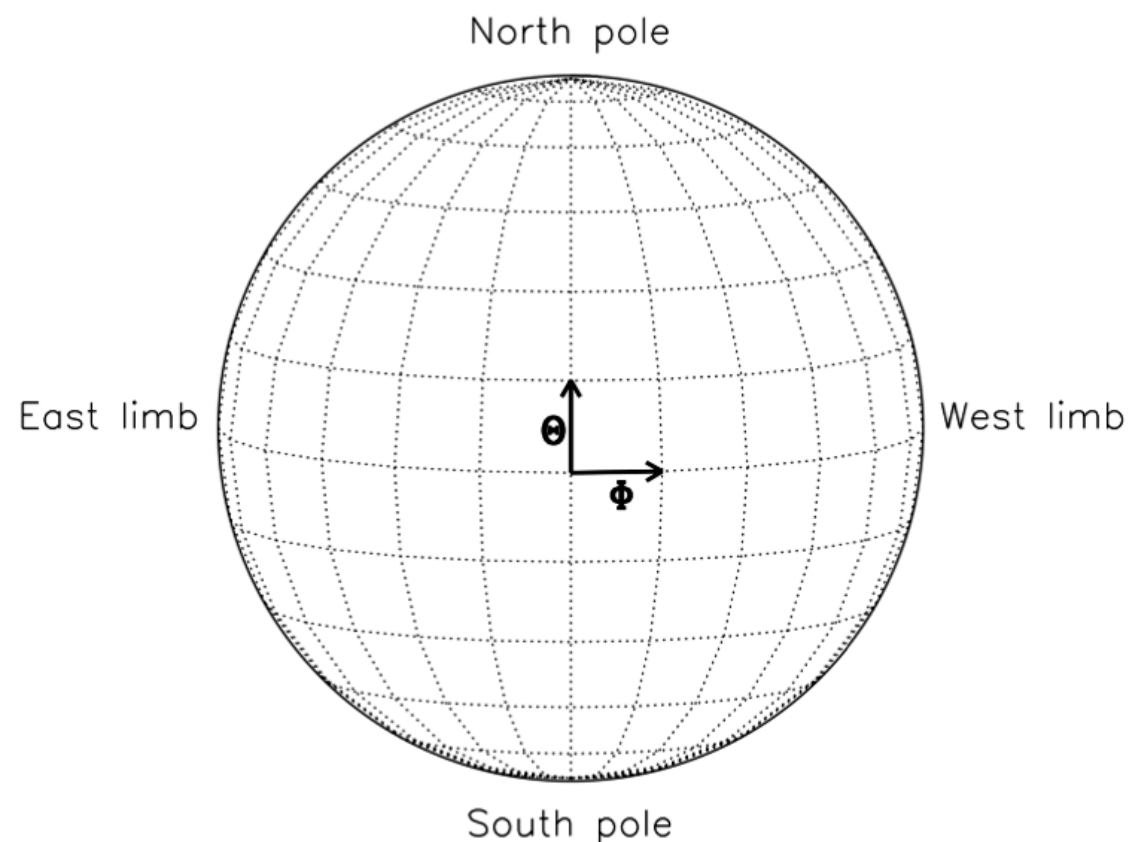
- web-based version: <https://helioviewer.org/>
- downloadable application: <https://www.jhelioviewer.org/> (has more functions)



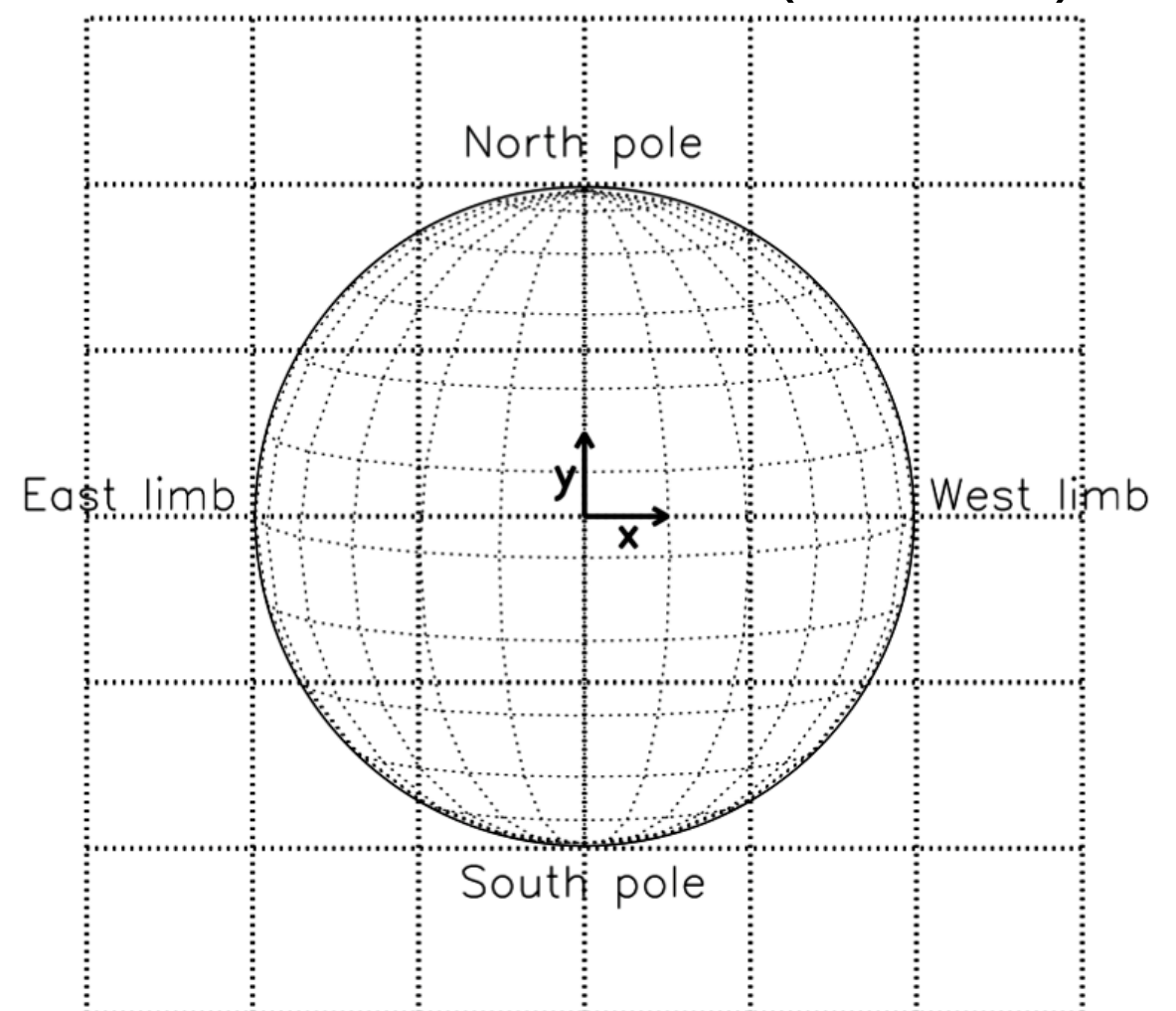
Solar coordinate systems

- RA/Dec does not make sense for relative coordinates on the Sun as the Sun itself is moving with respect to the sky background
- Relevant coordinates for the Sun shown at the bottom of the helioviewer window!

Heliographic coordinates (Stonyhurst)



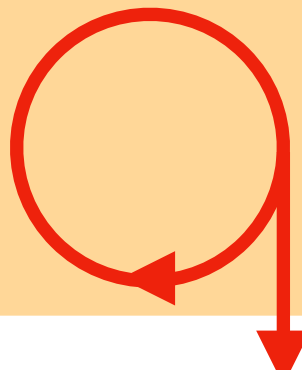
Heliocentric coordinates (Cartesian)



See <https://fits.gsfc.nasa.gov/wcs/coordinates.pdf>

The solar atmosphere

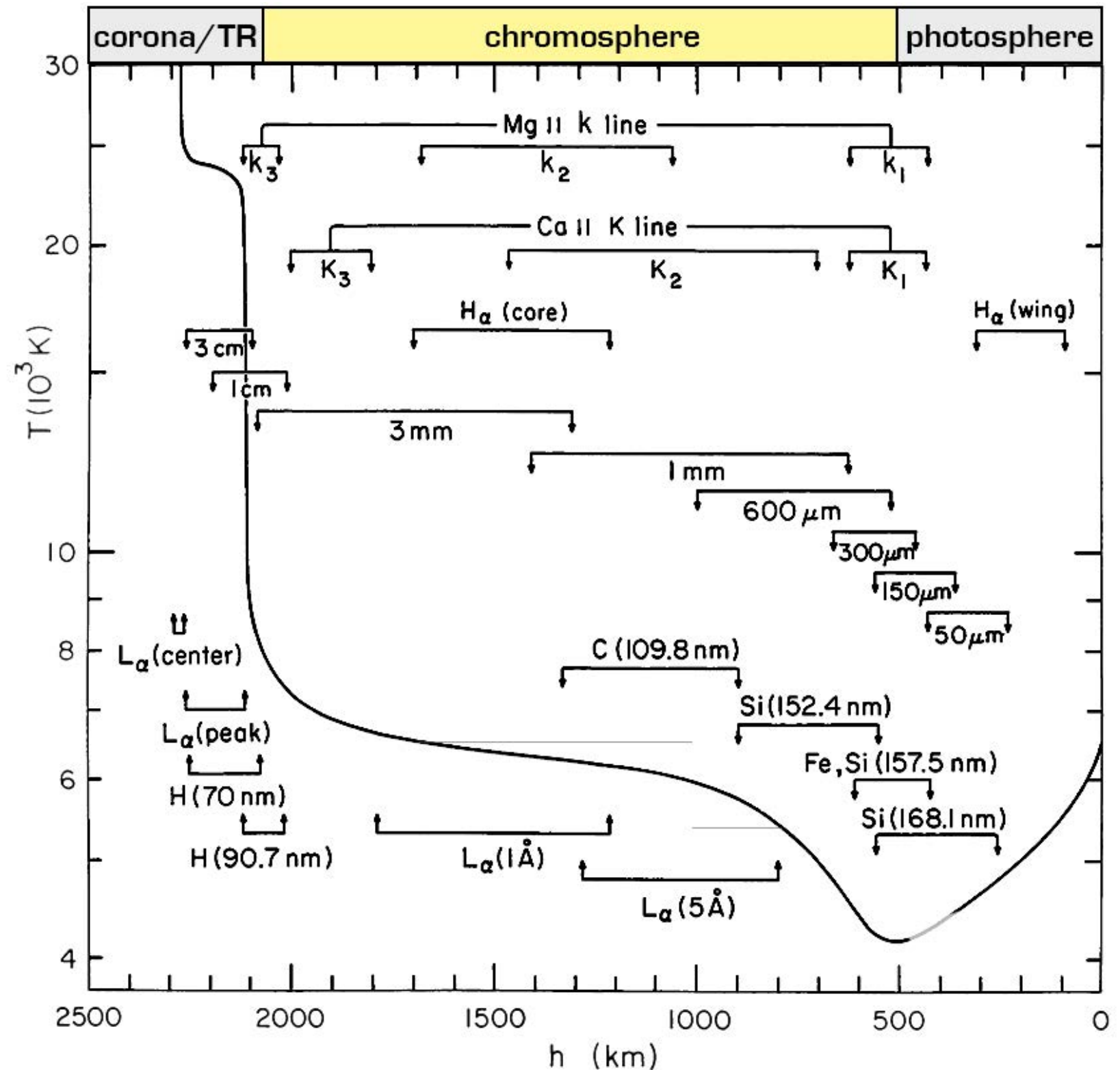
Semi-empirical model atmosphere

- Semi-empirical models
 - Starting with a model atmosphere that describes the stratifications of relevant properties such as gas temperature, density etc.
- 
 - Calculate the emergent intensity for different continua and spectral lines
 - Compare to observations
 - Adjust the model atmosphere
- Repeat until the observations are (overall) reproduced as accurately as possible
- **Very well known: VAL: Vernazza, Avrett, Loeser (1981)**
 - One-dimensional!
 - Several models and updates/modifications
 - Widely used as a reference

The solar atmosphere

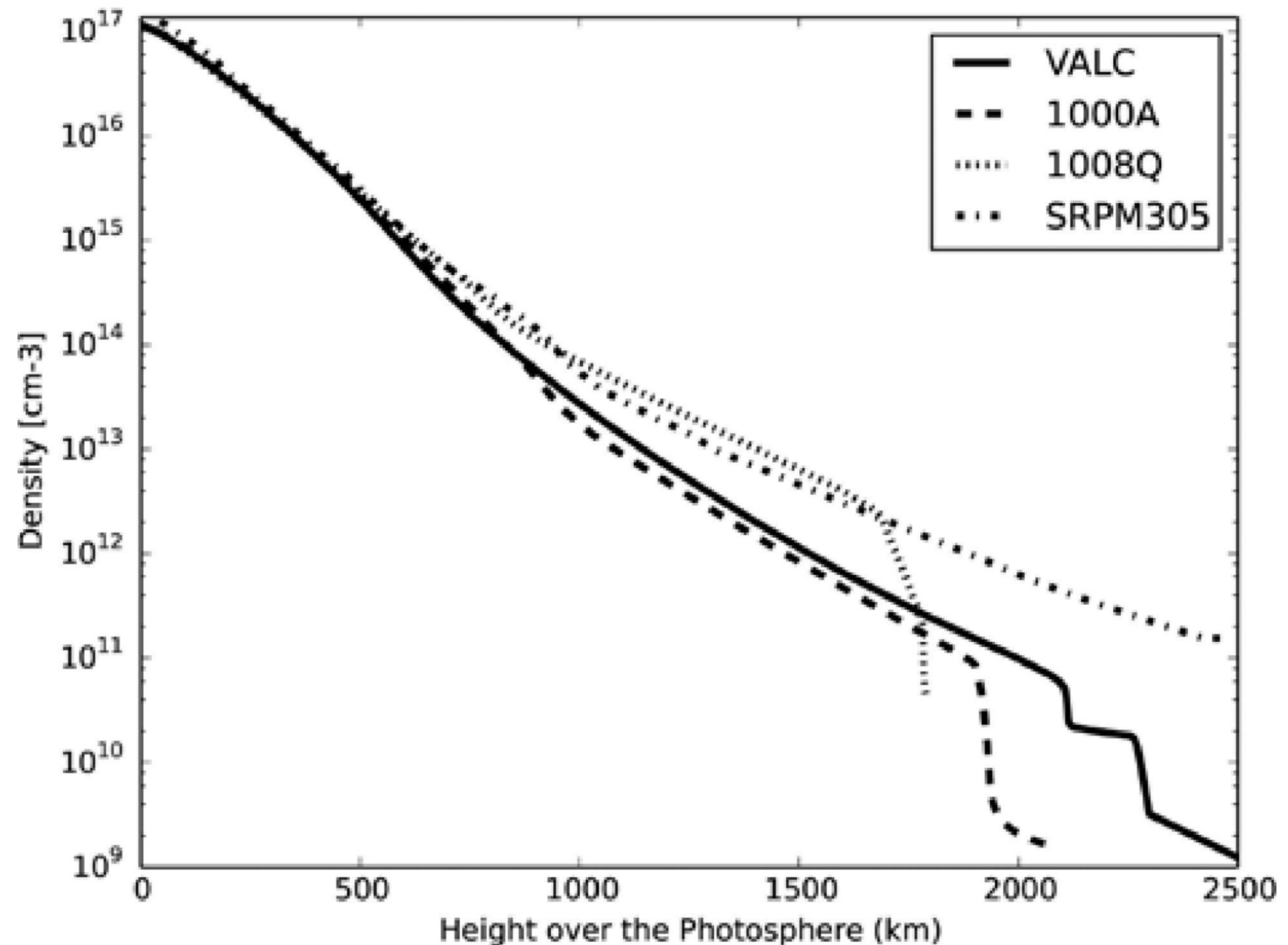
Semi-empirical model atmosphere

VAL: Vernazza, Avrett, Loeser (1981)



The solar atmosphere

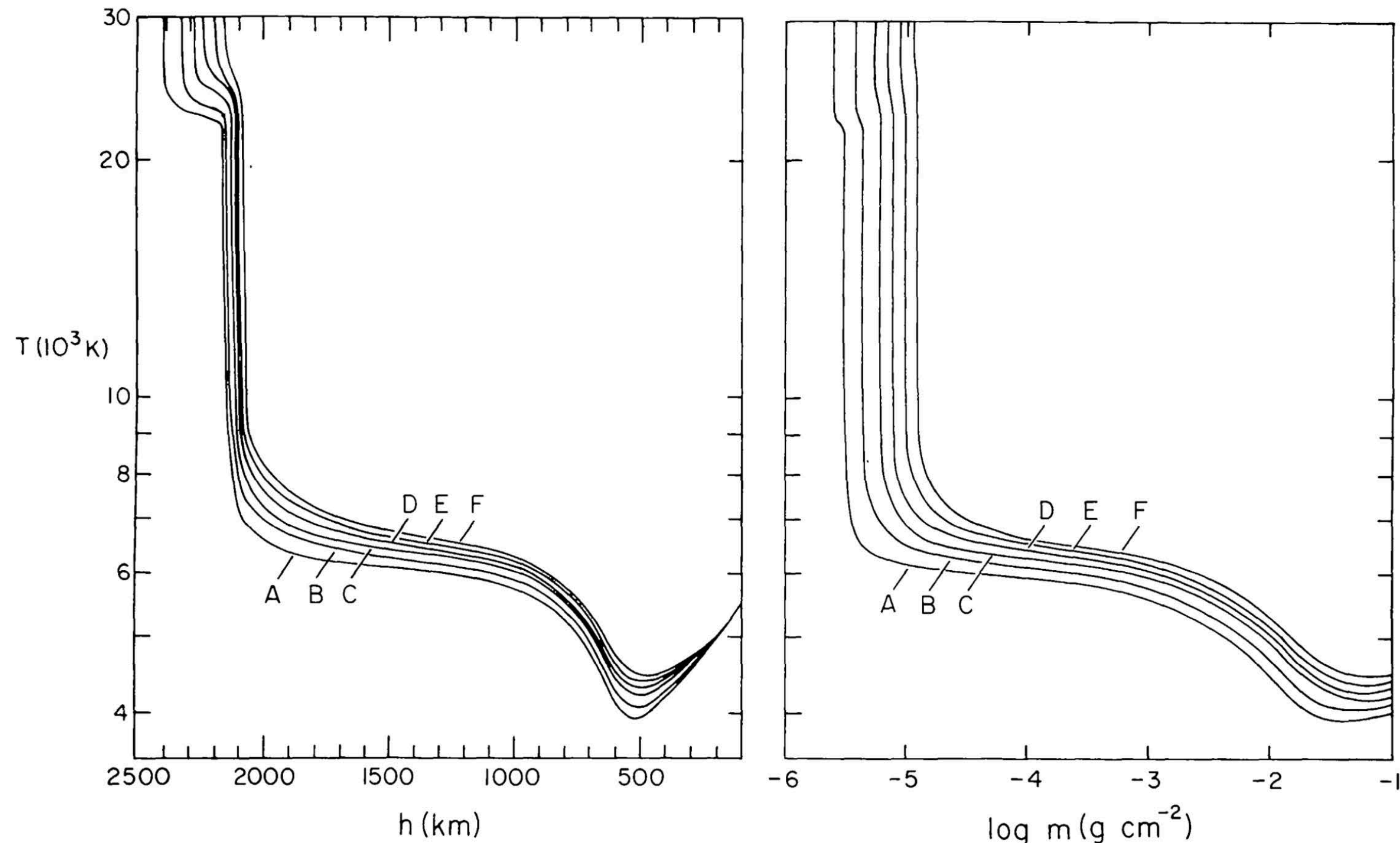
Semi-empirical model atmosphere



VAL: Vernazza, Avrett, Loeser (1981)

The solar atmosphere

Semi-empirical model atmosphere VAL: Vernazza, Avrett, Loeser (1981)



The solar atmosphere

Semi-empirical model atmosphere

TABLE 12
ATMOSPHERIC PARAMETERS FOR MODEL C

VAL Model C (1981)

	h	m	τ_{500}	T	V	n_H	n_e	P_{total}	$\frac{P_{\text{gas}}}{P_{\text{total}}}$	σ
	(km)	(g cm ⁻²)		(K)	(km s ⁻¹)	(cm ⁻³)	(cm ⁻³)	(dyn cm ⁻²)		(g cm ⁻³)
1	2543	5.257-06	0.	447000	11.28	1.005+09	1.205+09	1.440-01	.9896	2.349-15
2	2298	5.365-06	3.712-08	141000	9.87	3.205+09	3.839+09	1.470-01	.9752	7.494-15
3	2290	5.373-06	3.969-08	89100	9.82	5.041+09	5.961+09	1.472-01	.9614	1.179-14
4	2280	5.389-06	4.491-08	50000	9.76	9.038+09	9.993+09	1.477-01	.9318	2.113-14
5	2274	5.404-06	4.952-08	37000	9.73	1.201+10	1.318+10	1.481-01	.9102	2.808-14
6	2271	5.413-06	5.234-08	32000	9.71	1.378+10	1.498+10	1.483-01	.8976	3.222-14
7	2267	5.427-06	5.657-08	28000	9.70	1.567+10	1.677+10	1.487-01	.8840	3.665-14
8	2263	5.443-06	6.124-08	25500	9.68	1.718+10	1.812+10	1.491-01	.8738	4.017-14
9	2255	5.476-06	7.110-08	24500	9.64	1.797+10	1.881+10	1.500-01	.8698	4.203-14
10	2230	5.583-06	1.030-07	24200	9.49	1.862+10	1.943+10	1.530-01	.8718	4.355-14
11	2200	5.716-06	1.426-07	24000	9.33	1.932+10	2.009+10	1.566-01	.8645	4.517-14
12	2160	5.902-06	1.977-07	23500	9.08	2.051+10	2.120+10	1.617-01	.8778	4.795-14
13	2129	6.055-06	2.427-07	23000	8.87	2.163+10	2.219+10	1.659-01	.8801	5.058-14
14	2120	6.101-06	2.562-07	22500	8.81	2.231+10	2.276+10	1.672-01	.8789	5.216-14
15	2115	6.128-06	2.640-07	21000	8.78	2.403+10	2.402+10	1.679-01	.8710	5.619-14
16	2113	6.140-06	2.674-07	18500	8.77	2.732+10	2.620+10	1.682-01	.8539	6.390-14
17	2109	6.172-06	2.754-07	12300	8.74	4.092+10	3.306+10	1.691-01	.7839	9.569-14
18	2107	6.193-06	2.801-07	10700	8.72	4.673+10	3.535+10	1.697-01	.7552	1.093-13
19	2104	6.228-06	2.877-07	9500	8.71	5.239+10	3.705+10	1.706-01	.7277	1.225-13
20	2090	6.416-06	3.243-07	8440	8.60	6.127+10	3.799+10	1.758-01	.6986	1.433-13
21	2080	6.564-06	3.507-07	8180	8.55	6.541+10	3.780+10	1.798-01	.6891	1.530-13
22	2070	6.722-06	3.770-07	7940	8.50	6.960+10	3.783+10	1.842-01	.6808	1.628-13
23	2050	7.066-06	4.299-07	7660	8.42	7.705+10	3.792+10	1.936-01	.6701	1.802-13
24	2016	7.732-06	5.203-07	7360	8.22	9.075+10	3.811+10	2.118-01	.6616	2.122-13
25	1990	8.322-06	5.903-07	7160	8.01	1.033+11	3.858+10	2.280-01	.6600	2.417-13
26	1925	1.015-05	7.717-07	6940	7.63	1.380+11	4.028+10	2.780-01	.6620	3.227-13
27	1785	1.647-05	1.212-06	6630	6.92	2.601+11	4.771+10	4.511-01	.6772	6.082-13
28	1605	3.407-05	1.958-06	6440	5.85	6.386+11	6.005+10	9.334-01	.7262	1.493-12
29	1515	5.144-05	2.420-06	6370	5.26	1.048+12	6.456+10	1.409+00	.7595	2.450-12
30	1380	1.012-04	3.286-06	6280	4.51	2.273+12	7.600+10	2.774+00	.8051	5.315-12
31	1280	1.747-04	4.084-06	6220	3.92	4.200+12	7.486+10	4.786+00	.8423	9.822-12
32	1180	3.112-04	5.075-06	6150	3.48	7.865+12	8.108+10	8.527+00	.8694	1.839-11
33	1065	6.299-04	6.861-06	6040	2.73	1.711+13	9.349+10	1.726+01	.9136	4.000-11
34	980	1.098-03	9.148-06	5925	2.14	3.147+13	1.041+11	3.008+01	.9440	7.359-11
35	905	1.840-03	1.239-05	5755	1.70	5.546+13	1.049+11	5.043+01	.9628	1.297-10
36	855	2.632-03	1.553-05	5650	1.53	8.135+13	1.064+11	7.210+01	.9691	1.902-10
37	755	5.577-03	2.537-05	5280	1.23	1.864+14	8.838+10	1.528+02	.9784	4.358-10
38	705	8.333-03	3.288-05	5030	1.09	2.935+14	7.664+10	2.283+02	.9821	6.864-10
39	655	1.276-02	4.452-05	4730	.96	4.794+14	8.085+10	3.495+02	.9852	1.121-09
40	605	2.013-02	7.022-05	4420	.83	8.119+14	1.112+11	5.516+02	.9881	1.899-09
41	555	3.270-02	1.456-04	4230	.70	1.382+15	1.733+11	8.958+02	.9912	3.232-09
42	515	4.878-02	3.014-04	4170	.60	2.096+15	2.495+11	1.336+03	.9934	4.902-09
43	450	9.378-02	1.017-03	4220	.53	3.989+15	4.516+11	2.569+03	.9949	9.327-09
44	350	2.481-01	5.626-03	4465	.52	9.979+15	1.110+12	6.798+03	.9954	2.334-08
45	250	6.172-01	2.670-02	4780	.63	2.315+16	2.674+12	1.691+04	.9936	5.413-08
46	150	1.433+00	1.117-01	5180	1.00	4.917+16	6.476+12	3.926+04	.9854	1.150-07
47	100	2.118+00	2.201-01	5455	1.20	6.866+16	1.066+13	5.804+04	.9801	1.606-07
48	50	3.056+00	4.395-01	5840	1.40	9.203+16	2.122+13	8.274+04	.9748	2.152-07
49	0	4.279+00	9.953-01	6420	1.60	1.166+17	6.433+13	1.172+05	.9702	2.727-07
50	-25	4.991+00	1.683+00	6910	1.70	1.261+17	1.547+14	1.368+05	.9688	2.949-07
51	-50	5.747+00	3.338+00	7610	1.76	1.317+17	4.645+14	1.575+05	.9697	3.080-07
52	-75	6.534+00	7.445+00	8320	1.80	1.365+17	1.204+15	1.790+05	.9711	3.192-07

Data for assignments

Overview

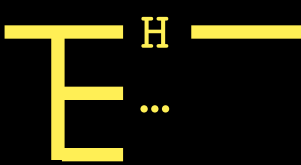
- Data: `/mn/stornext/d19/RoCS/svenwe/lecture/AST5770/data`

<code>ref</code>	Reference model, solar atmosphere (Vernazza et al. 1981), model C
<code>obs_sunspec</code>	Observed spectrum of the Sun (Neckel & Labs 1994)
<code>obssun_sst1</code> <code>obssun_sst2</code> <code>obssun_sst3</code> <code>obssun_sst4</code>	Observations of the Sun with the Swedish 1-m Solar Telescope (SST)
<code>obs_starcats</code> <code>obs_starcats/SED</code>	Catalogue with stellar parameters Spectral Energy Distribution for different stars
<code>simsts_F5V</code> <code>simsts_K2V</code> <code>simsts_K8V</code> <code>simsts_G2V</code> <code>simsts_K5III</code> <code>simsts_M3V</code>	3D numerical simulations for different stellar types, 1 snapshot each • Volume data • Continuum intensity • Spectral line data
<code>simstut_G2V</code>	Time series of 2D slices extracted from a 3D numerical simulations of the Sun

Data for assignments

Reference model

- Semi-empirical atmospheric model of the Sun by Vernazza, Avrett, and Loeser (1981)
- Provided: Model C for Quiet Sun conditions (referred to as **VAL C**)
- For comparison and/or as reference for observational and simulation data sets.
- `/mn/stornext/d19/RoCS/svenwe/lecture/AST5770/data/ref/ val81c.h5`
- HDF5 the following tags:

DESCRIPTION  _data

H

I

M

N_E

N_H

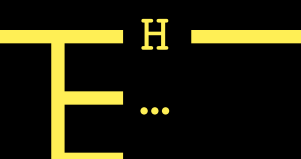
P_TOTAL

PFRAC

RHO

T

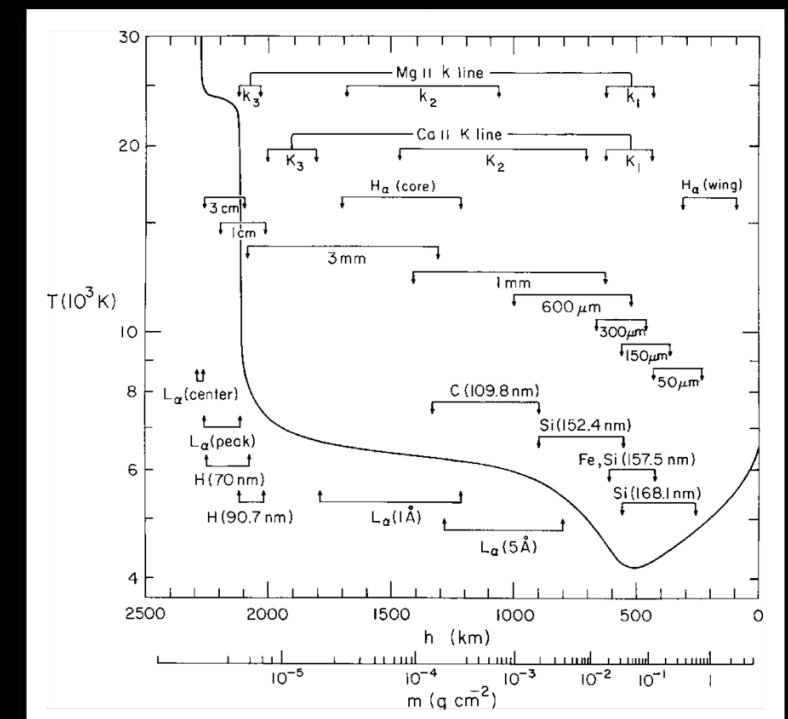
TAU500

UNIT  _data

V

H

z : Geometrical height above the photospheric level with $h=0\text{km}$ where the continuum optical depth $\tau_{500}=1$



Data for assignments

Reference model

- Semi-empirical atmospheric model of the Sun by Vernazza, Avrett, and Loeser (1981)
- Provided: Model C for Quiet Sun conditions (referred to as **VAL C**)
- For comparison and/or as reference for observational and simulation data sets.
- `/mn/stornext/d9/svenwe/lecture/AST5770/data/ref/val81c.h5`

Data for assignments

Solar spectrum

- Data from Neckel and Labs (1984) - measurement spectrum of the Sun (function of wavelength)
- Flux: at solar disc-centre (**FC**) and averaged over the solar disc (**F**), wavelength (**LC**)
- Intensity: at solar disc-centre (**IC**) and averaged over the solar disc (**I**), wavelength (**LC**)
- `/mn/stornext/d19/RoCS/svenwe/lecture/AST5770/data/obssun_spec/obssun_spec_NL94.h5`
- HDF5 the following tags:

DESCRIPTION

F

FC

I

IC

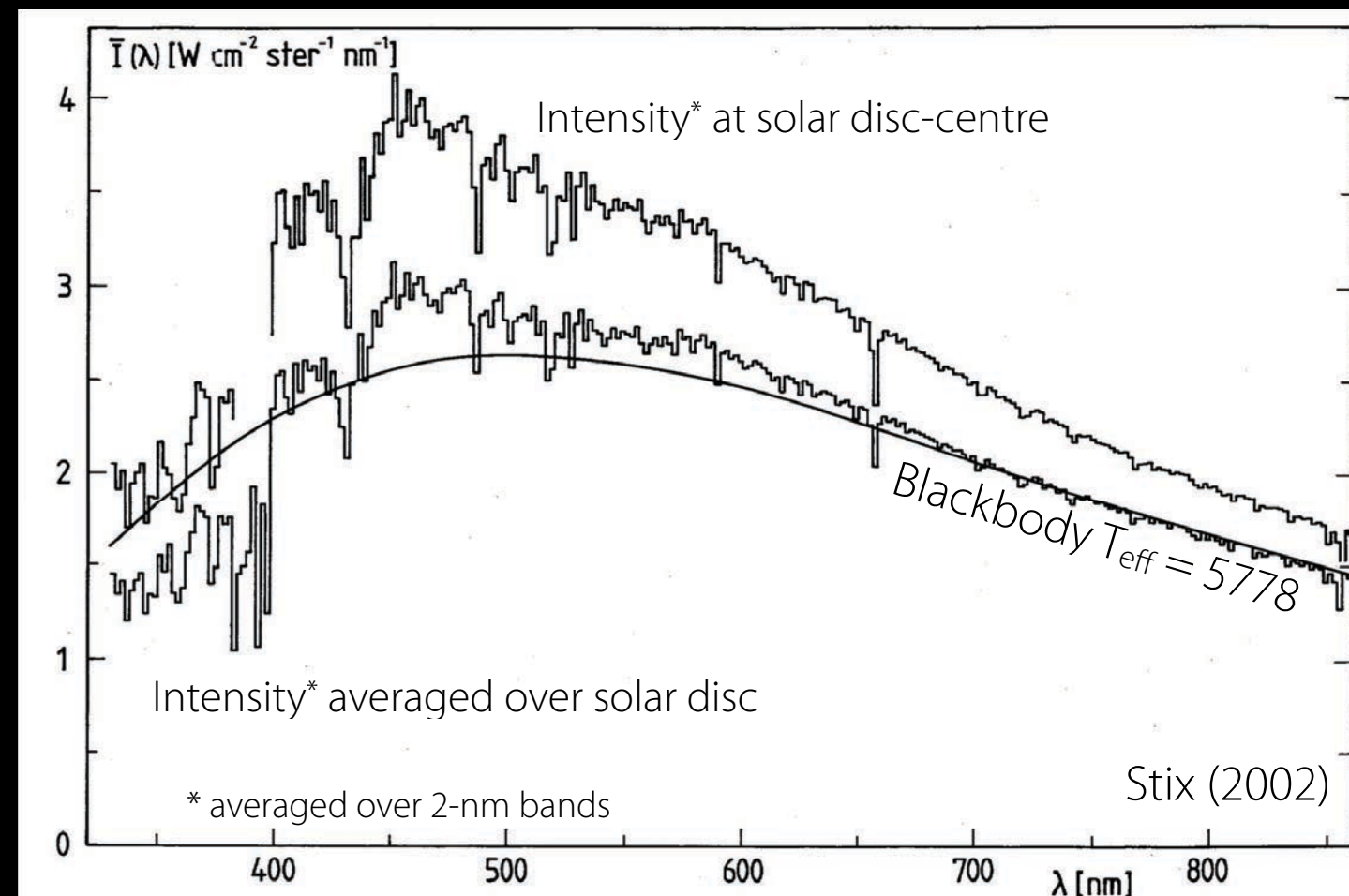
LF

LI

TAGS

TLF

TLI



Data for assignments

Data / material for assignments — solar observations

Solar observations with Swedish 1-m Solar Telescope (SST)/CRISP, time series of images		
obssun_sst1	Quiet Sun, photospheric spectral line Fe I 617.3 nm 2015-Oct-11 08:44:29 - 09:18:16 UT ($\mu = 0.78$, $[x, y] = [-590'', 47'']$)	$[x, y, \lambda, t]$
obssun_sst2	Quiet Sun, chromospheric spectral line Ca II 854.2 nm 2015-Oct-11 08:44:15 - 09:18:01 UT ($\mu = 0.78$, $[x, y] = [-590'', 47'']$) Note: Data contains some weak artefacts that need to be dealt with.	$[x, y, \lambda, t]$
obssun_sst3	Sunspot (AR12533), chromospheric spectral line H α 29-Apr-2016 09:43:09 - 11:13:07 UT, ($\mu = 0.75$, $[x, y] = [623'', 8'']$) Drews and L. Rouppe van der Voort (2020), L. H. M. Rouppe van der Voort et al. (2021)	$[x, y, \lambda, t]$
obssun_sst4	Sunspot (AR12770), photospheric spectral line Fe I 617.3 nm 2020-Aug-07 08:22:21 - 08:59:58 UT, ($\mu = 0.83$, $[x, y] = [-446'', 279'']$)	$[x, y, \lambda, t]$

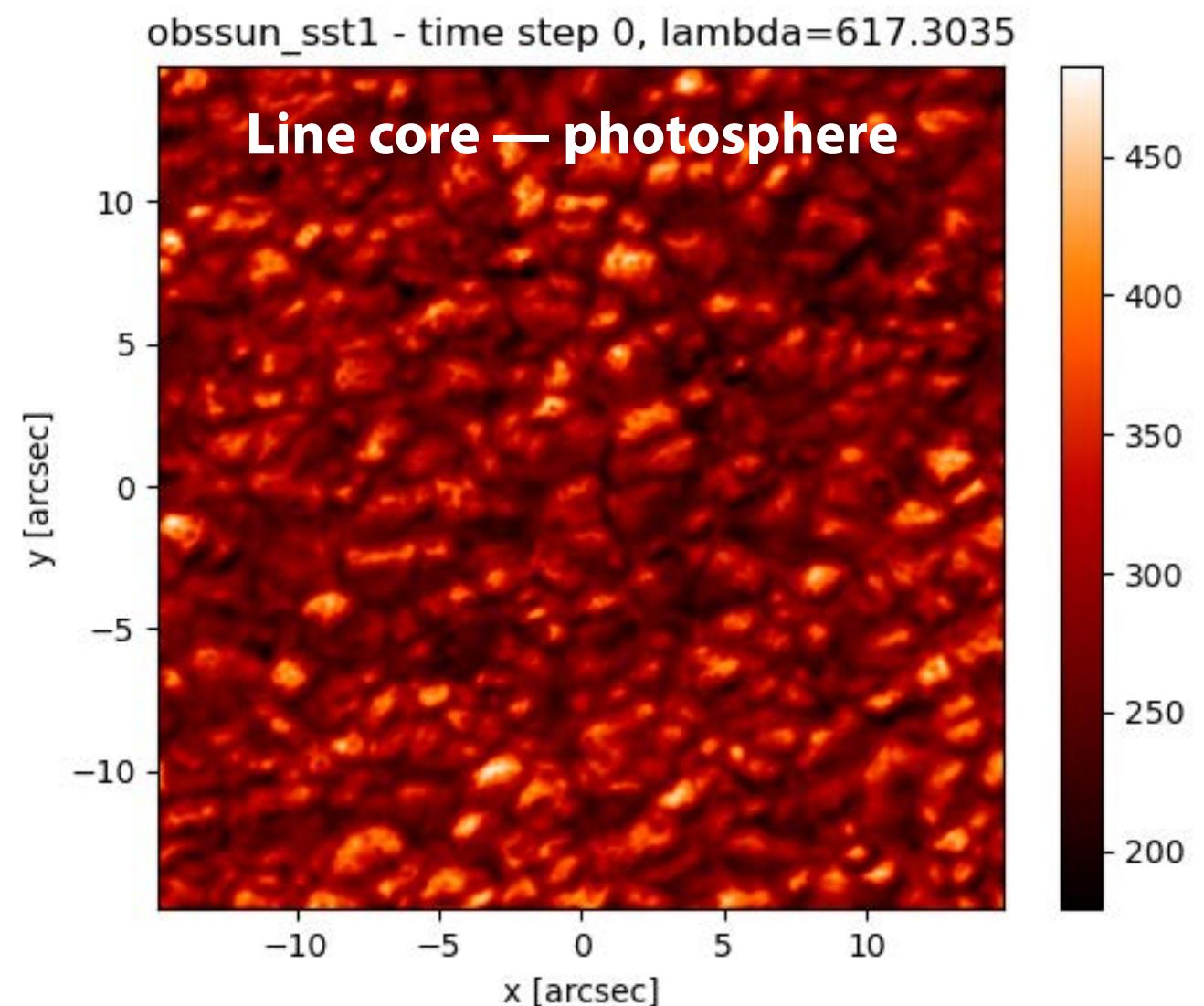
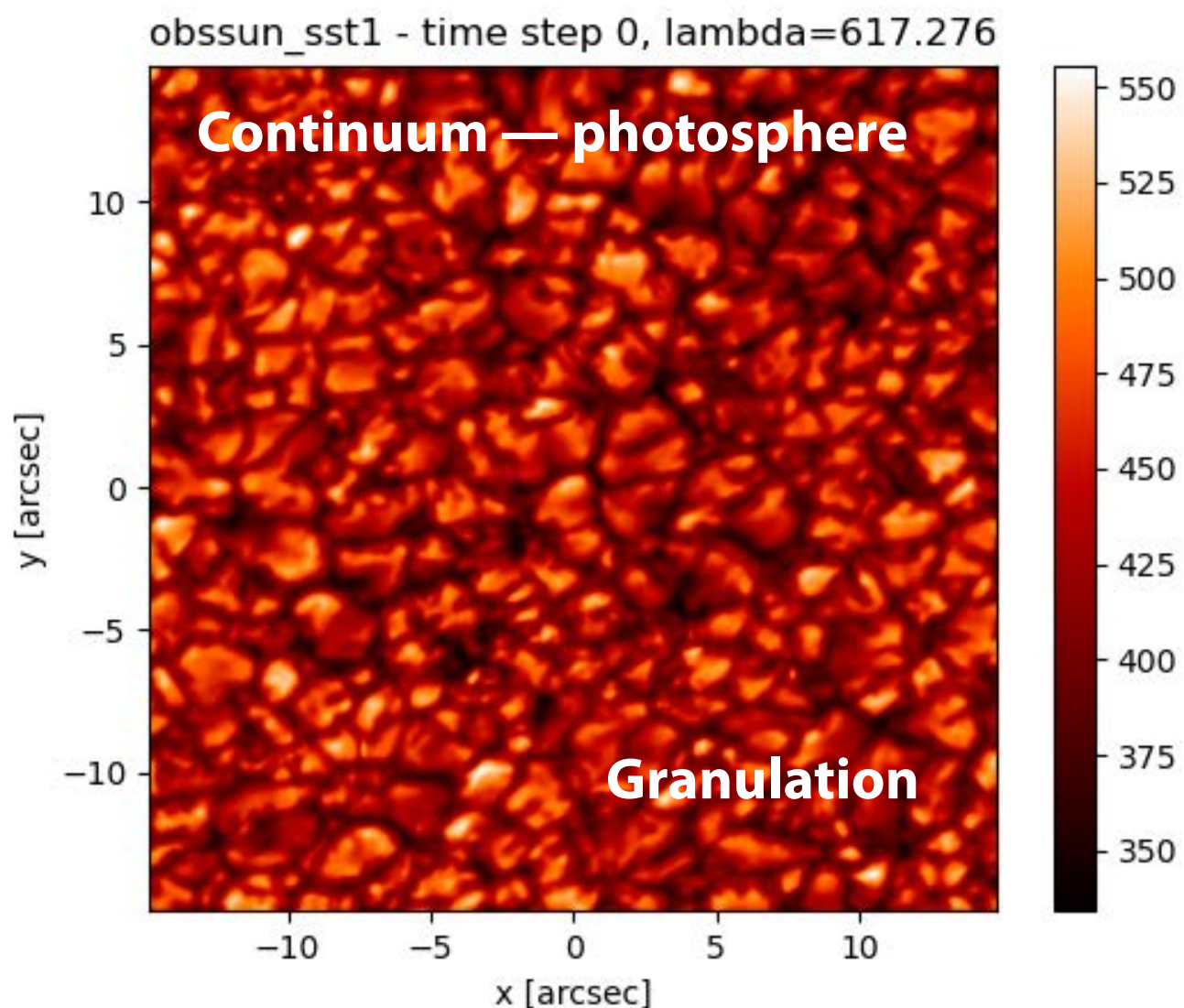
- Swedish 1-m Solar Telescope (SST)
- Time series for different continua and spectra are offered for different solar targets.
- Intensity in units of instrumental counts (no absolute physical units!)
- Files are in HDF5 format and contain a **description**, coordinates (relative within the provided field of view), wavelengths, and time.

Data for assignments

Solar observations (SST) — obssun_sst1

obssun_sst1	Quiet Sun, photospheric spectral line Fe I 617.3 nm 2015-Oct-11 08:44:29 - 09:18:16 UT ($\mu = 0.78$, $[x, y] = [-590'', 47'']$)	$[x, y, \lambda, t]$
-------------	--	----------------------

- Simultaneous with dataset obssun_sst2!

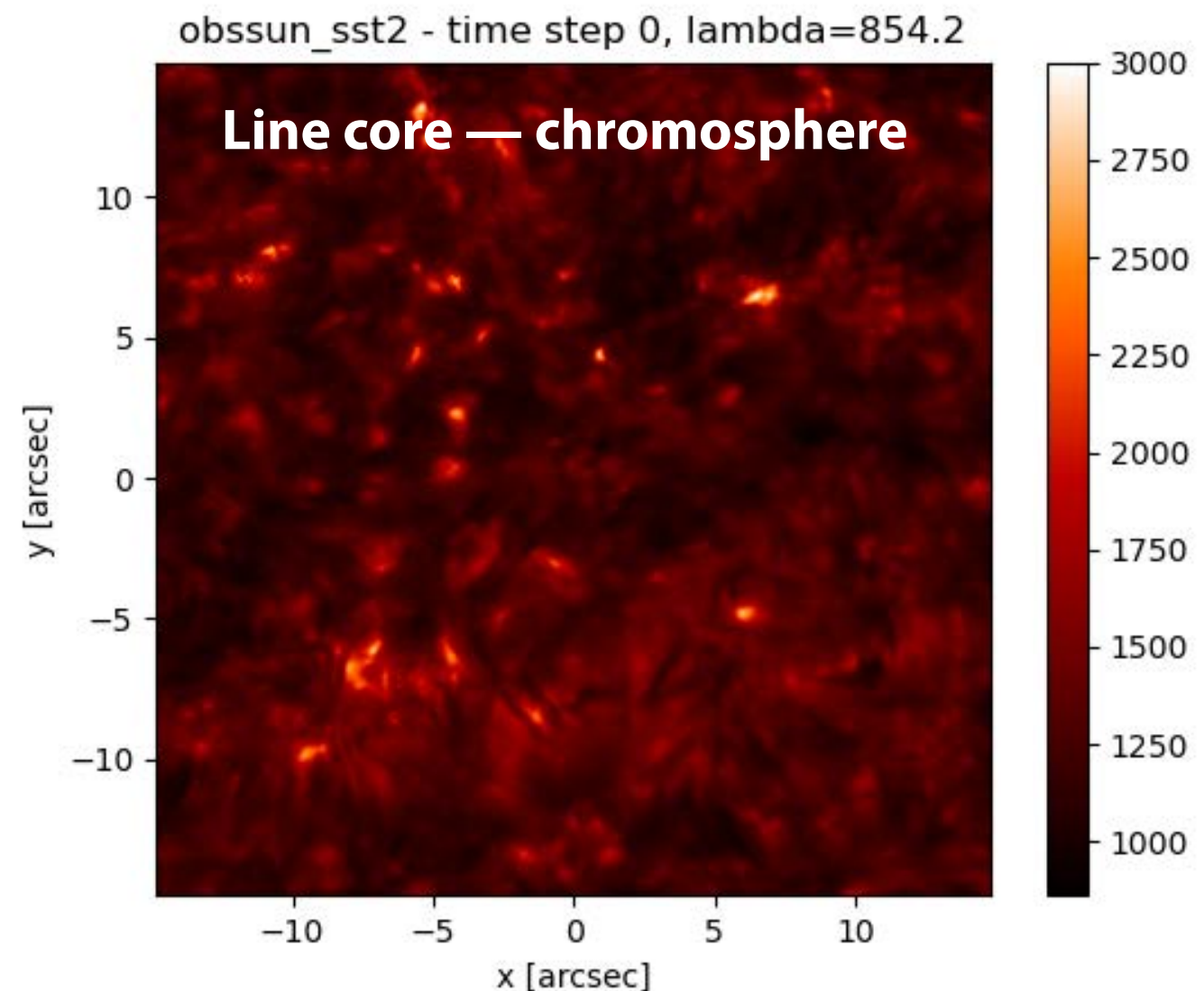
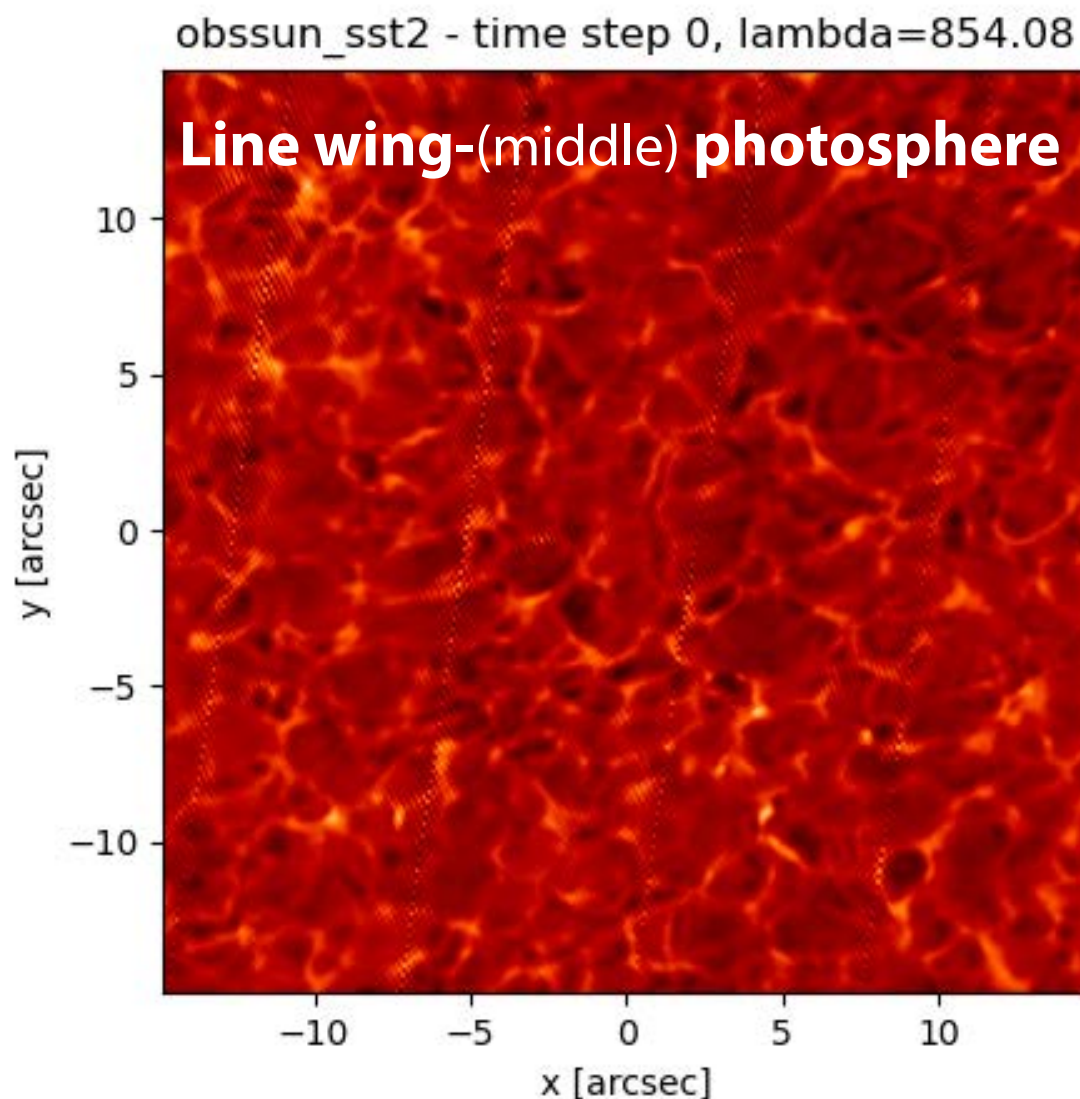


Data for assignments

Solar observations (SST) — obssun_sst2

obssun_sst2	Quiet Sun, chromospheric spectral line Ca II 854.2 nm 2015-Oct-11 08:44:15 - 09:18:01 UT ($\mu = 0.78$, $[x, y] = [-590'', 47'']$) Note: Data contains some weak artefacts that need to be dealt with.	$[x, y, \lambda, t]$
-------------	---	----------------------

- Simultaneous with dataset obssun_sst1!



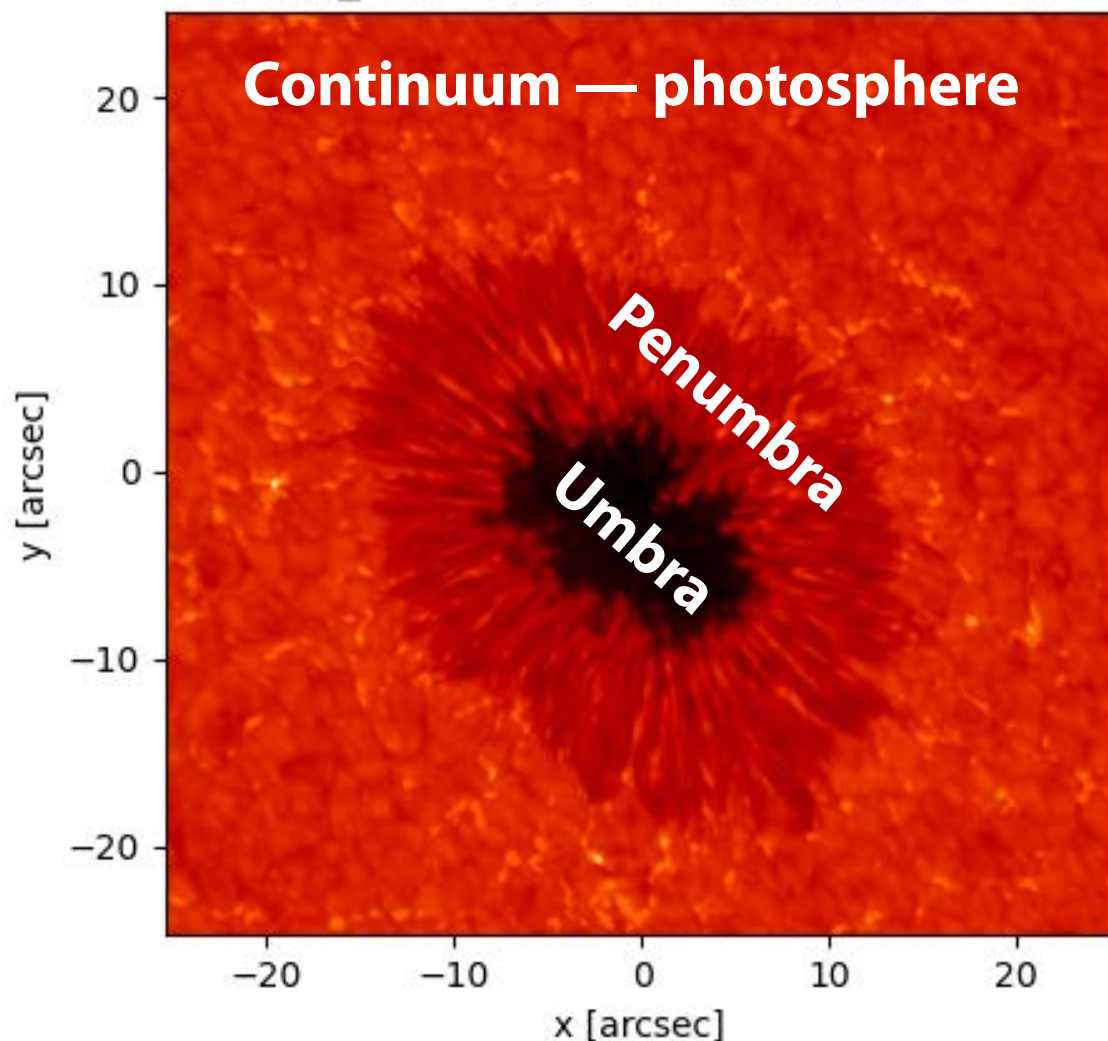
Data for assignments

Solar observations (SST) — obssun_sst3

obssun_sst3	Sunspot (AR12533), chromospheric spectral line H α 29-Apr-2016 09:43:09 - 11:13:07 UT, ($\mu = 0.75$, $[x, y] = [623'', 8'']$) Drews and L. Rouppe van der Voort (2020), L. H. M. Rouppe van der Voort et al. (2021)	$[x, y, \lambda, t]$
-------------	---	----------------------

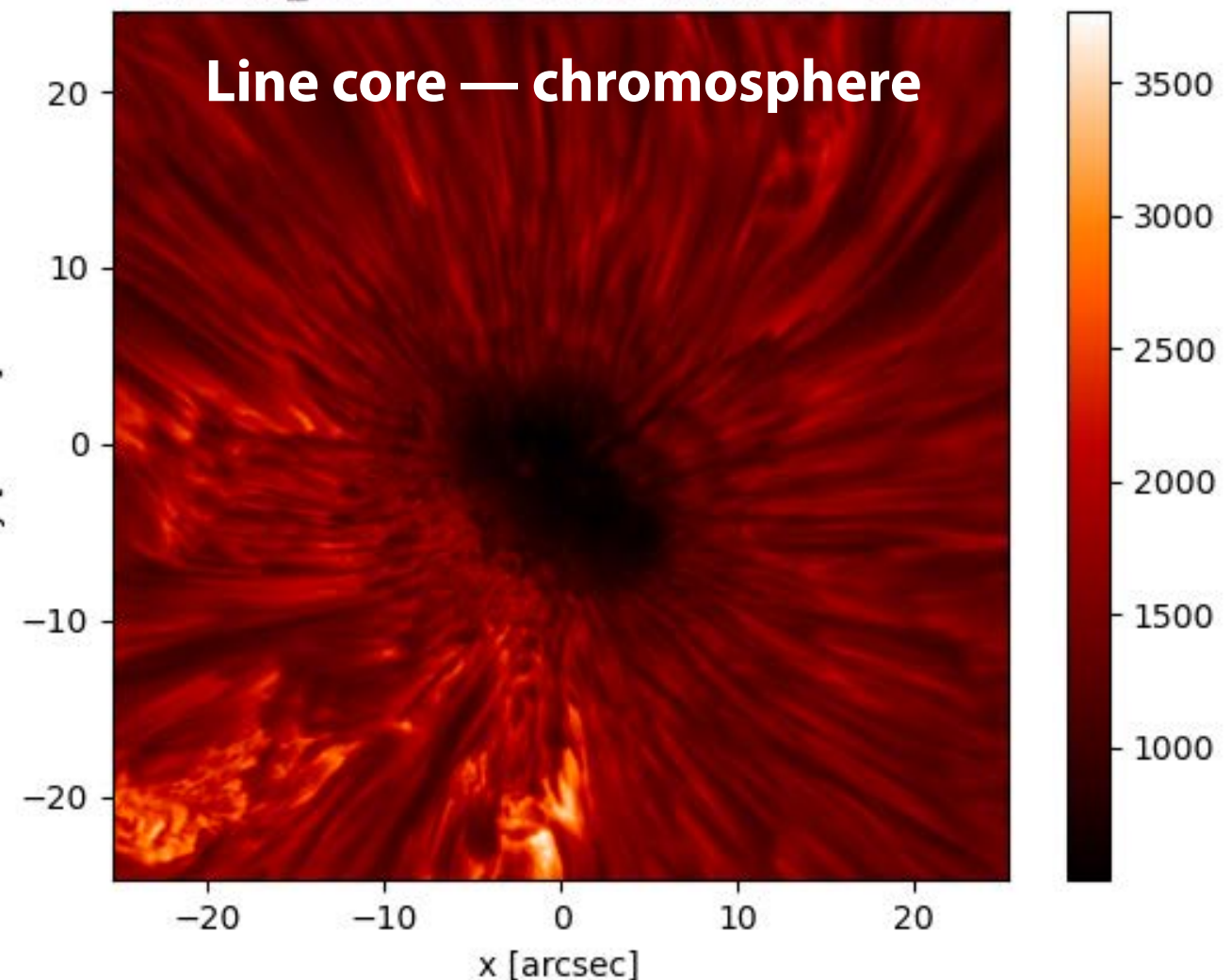
obssun_sst3 - time step 0, lambda=656.15

Continuum — photosphere



obssun_sst3 - time step 0, lambda=656.3

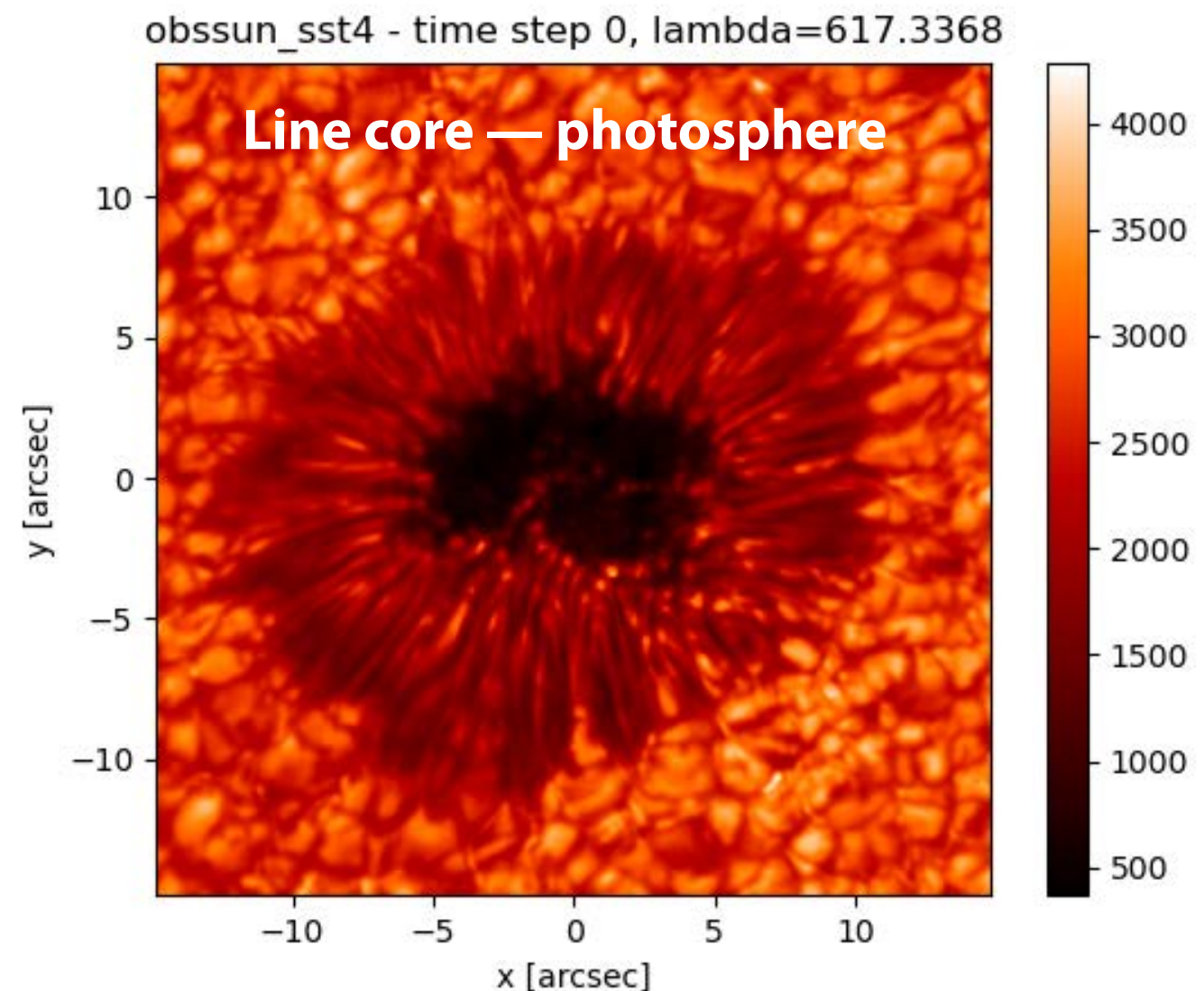
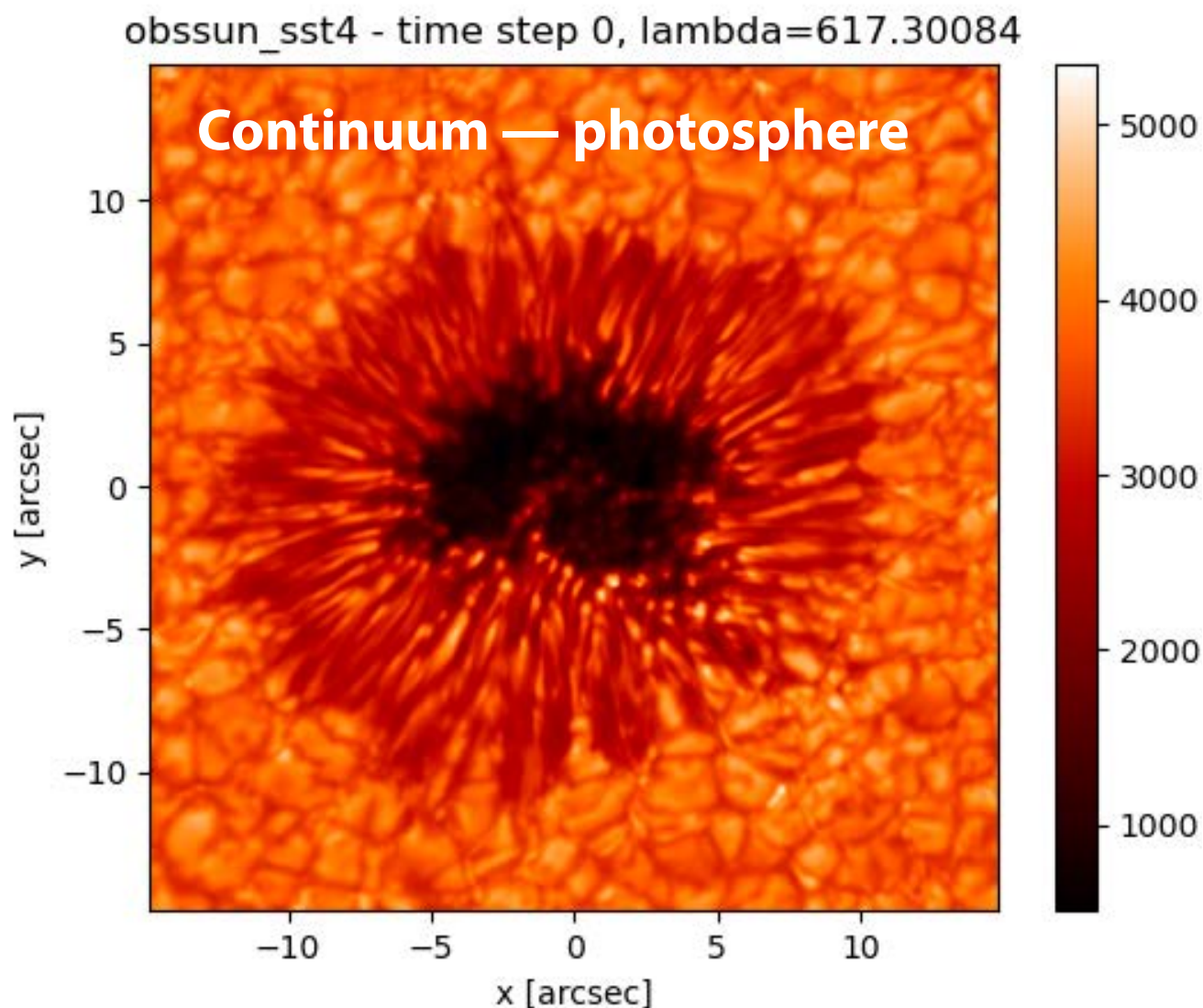
Line core — chromosphere



Data for assignments

Solar observations (SST) — obssun_sst4

obssun_sst4	Sunspot (AR12770), photospheric spectral line Fe I 617.3 nm 2020-Aug-07 08:22:21 - 08:59:58 UT, ($\mu = 0.83$, $[x,y] = [-446'', 279'']$)	$[x, y, \lambda, t]$
-------------	---	----------------------

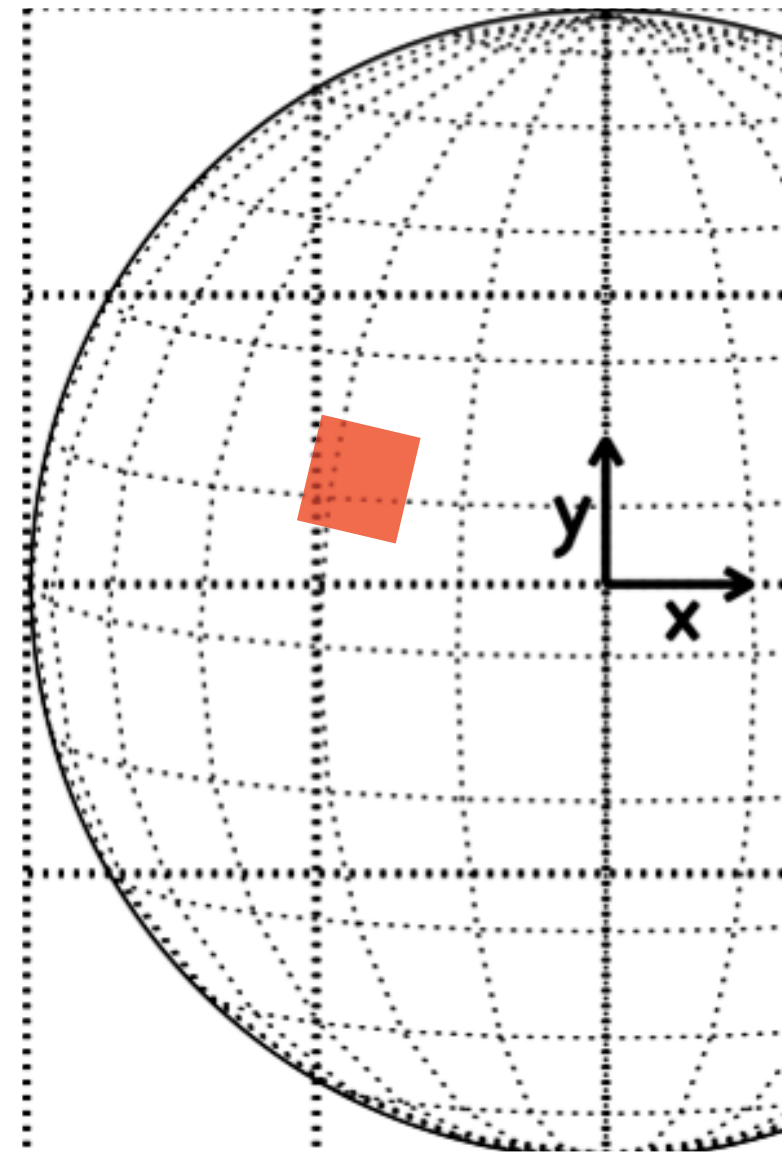


Data for assignments

Solar observations — coordinates

- **Caution: Coordinates and rotation!**
- The coordinates are approximate for the telescope pointing
- Typically near the centre of the field of view (FOV)
- Typically at the beginning of the observation
- Can **differ** from the correct(ed) helioprojective coordinates by a **few arcseconds!**
- The FOV can be **rotated** with respect to the helioprojective coordinate frame
- Usually: FOV is **co-aligned** with a reference image, e.g. SDO
 - SDO coordinates are corrected
 - Co-alignment easier if there are prominent features in both images (e.g. a sunspot)
 - Co-alignment can be hard and unreliable in absence of prominent features!
 - **“Fun” experiment:** Compare the SST FOVs with SDO
 - Correct co-alignment is not expected for the project assignment!

$[-590'', 47'']$



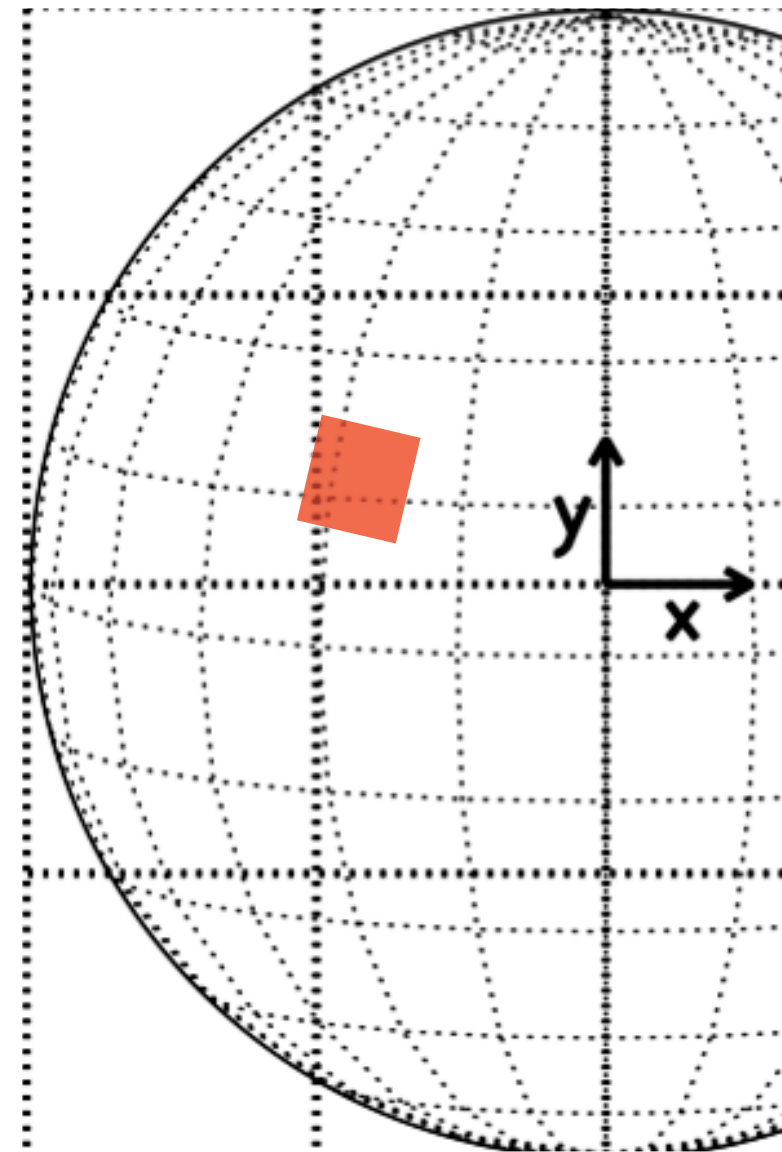
Data for assignments

Solar observations — coordinates

- **Caution: Coordinates and rotation!**

- The coordinates are approximate for the telescope pointing
- Typically near the centre of the field of view (FOV)
- Typically at the beginning of the observation
- Can **differ** from the correct(ed) helioprojective coordinates by a **few arcseconds!**
- The FOV can be **rotated** with respect to the helioprojective coordinate frame
- In addition:
 - The FOV of different telescopes vary
 - SST $\sim 60'' \times 60''$ (Note: smaller close-up regions are provided for the assignments)
 - Sun rotates! Following the same feature on the Sun needs following of the solar rotation (slow but notable after 1h)
 - The quality of images can vary over time ("seeing" due to Earth's atmosphere)

$[-590'', 47'']$



Data for assignments

Stellar catalogue

- `obs_starcatalog/obs_starcatalog.p` contains catalogue with (mostly empirical) parameters for 79 stars
- Can be loaded as a table in python. Some hints: `AST5770_manual.pdf`

Name	Sp Type	SIMBAD MAIN ID	RA	DEC	Distance	B-V	Mass	Radius	Teff	L _{bol}	Period	Vsini	Age	Log R' _{HK}	[Fe/H]	Log L _X	Log R _x	log g	B _V	R ₀	U	V	R	I	J
			deg	deg	pc		M _{sun}	R _{sun}	K	L _{sun}	d	Km/s	Myr			Erg/s		cgs	G						
GJ 1111	M6	G 51-15	127.4556042	26.7760389	3.5805	2.066	0.1	0.11	3293	0.0013	0.46	7.3	200		-0.12	27.61	-2.75	3.36	51.5	0.005		14.81	14.736		8.235
Proxima Cen	M5.5V	NAME Proxima Centauri	217.43	-62.68	1.3	1.886	0.12	0.15	2990	0.003	89.8	2.7	4850	-4.29	-0.07	26.82	-3.98	3.17	200	0.63	14.21	11.13	9.45	7.41	5.357
GJ 1156	M5	V* GL Vir	184.7474811	11.1260831	6.4722	1.83	0.14	0.16	3467.33	0.0021	0.49	8.7	5000		0.11	27.69	-3.29	3.18	64.9	0.005		13.9	13.55		8.525
EQ Peg B	M4.5	BD+19 5116B	352.9693164	19.9371906	6.2477	1.65	0.25	0.25	3309	0.0077	0.4	28.5	950	-4.5		28.19	-3.25	3.04	364	0.005		10.44	12.165		7.101
V374 Peg	M4	V* V374 Peg	330.3046894	28.3069075	9.1041	1.718	0.28	0.28	3432.62	0.01	0.45	39.1			-1.83589	28.36	-3.2	2.99	493	0.006		11.99	11.602		7.635
EV Lac	M3.5	V* EV Lac	341.7072156	44.3339881	5.0502	1.412	0.32	0.3	3742.19	0.0115	4.37	6.9	300	-3.97	0	28.37	-3.32	2.99	406	0.068		10.26	9.89		6.106
YZ CMi	M4.5	V* YZ CMi	116.1673917	3.5524542	5.9874	1.62	0.32	0.29	3542.23	0.011	2.77	6.5		-4.26	0.29	28.33	-3.33	3.02	480	0.042	13.761	11.225	9.958	8.263	6.581
V2247 Oph	M1	EM* SR 12	246.8313	-24.6945528	112.3166	1.545	0.36	2	3828.93	0.236	3.5	19.874675	1.4		-0.254	30.11	-3.14	1.39	142	0.016		13.28	12.15	10.855	9.424
EQ Peg A	M3.5	BD+19 5116A	352.9673833	19.9372944	6.2614	1.52	0.39	0.35	3585	0.018	1.06	17.5	950	-4.18		28.83	-3.02	2.94	282	0.02		10.173	9.946		6.162
AD Leo	M3	BD+20 2465	154.9011708	19.8700361	4.966	1.544	0.42	0.38	3859.05	0.0192	2.24	3.34	25	-4.33	0.2	28.73	-3.18	2.9	152	0.047		9.52	9.19		5.449
CE Boo	M2.5	BD+16 2708	223.6218214	16.1010631	9.9324	1.5	0.48	0.43	3806.34	0.0335	14.7	3.5	130	-4.319	-0.15	28.4	-3.7	2.85	91.6	0.288	12.86	10.15	9.116	7.872	6.633
TYC6349-0200-1	K6	HD 358623	314.0114111	-17.1816122	45.9306	0.978	0.54	0.54	4270	0.244	3.39	15.6	21		-0.1			2.71	34.1			10.625	10.18	8.847	7.849
OT Ser	M1.5	V* OT Ser	230.4705439	20.9777589	11.4445	1.3629	0.55	0.49	3802.66	0.017	3.4	4.8	70	-4.27	-0.1	28.8	-3.4	2.8	81	0.097	12.662	10.003	8.993	7.843	6.61
GJ_2006A	M3.5Ve	GJ 2006 A	6.96	-32.55	34.8	1.5	0.552	0.558	3150	0.046	3.9	6.2	6		-0.5	29.53	-2.72	2.69	4.02			12.95	11.79	10.29	8.88
GJ 49	M1.5	BD+61 195	15.6619519	62.3450481	9.8556	1.463	0.57	0.51	3777	0.048	18.6	2.49	1200	-4.668	0.49	28	-4.3	2.78	16.3	0.352		9.6	8.7	7.88	6.23
DS Leo	M0	V* DS Leo	165.6597572	21.9671392	11.9365	1.437	0.58	0.52	3911.91	0.056	14	2.89	710	-4.37	0.03	28.3	-4	2.77	23.9	0.267	12.246	9.572	8.638	7.634	6.522
HIP 12545	K6	BD+05 378	40.3578681	5.9884503	44.4373	1.25	0.58	0.57	4166.67	0.262	4.83	40	21		0.3			2.69	78.5			10.271	9.88	9.3	7.904
DT Vir	M0.5	BD+13 2618	195.1940975	12.3757311	11.5132	1.45	0.59	0.53	3965.42	0.051	2.85	9.75	600	-3.994	-0.339	28.92	-3.4	2.76	76.6	0.092	12.314	9.75	8.785	7.653	6.437
HIP 76768	K6	HD 139751	235.1182958	-18.6961711	38.1494	1.24	0.61	0.6	4572.53	0.162	3.64	8	120		0.3			2.67	54.2			10.07	9.953	8.637	7.73
DN Tau	M0	V* DN Tau	68.8640625	24.2497028	128.2199	1.36	0.65	1.9	3964	0.534	6.32	12.3	1.7		-1.005	30.08	-3.41	1.7	317	0.027	13.56	12.32	11.79	10.95	9.139
TYC6878-0195-1	K4	CD-26 13904	287.936125	-26.069125	59.0713	1.05	0.65	0.64	4566.78	0.367	5.72	9.8	21		-0.371			2.64	31.7			10.2	9.55	9.09	8.081
HD 201091A	K5V	* 61 Cyg A	316.7248019	38.7494403	3.4972	1.069	0.66	0.62	4327	0.164	34.2	1.1	3600	-4.704	-0.03	28.22	-4.53	2.67	2.68	0.786	7.5	5.21	4.19	3.54	3.12

- `obs_starcatalog/obs_starcatalog.p` contains catalogue with (mostly empirical) parameters for 79 stars
- Can be loaded as a table in python. Some hints:

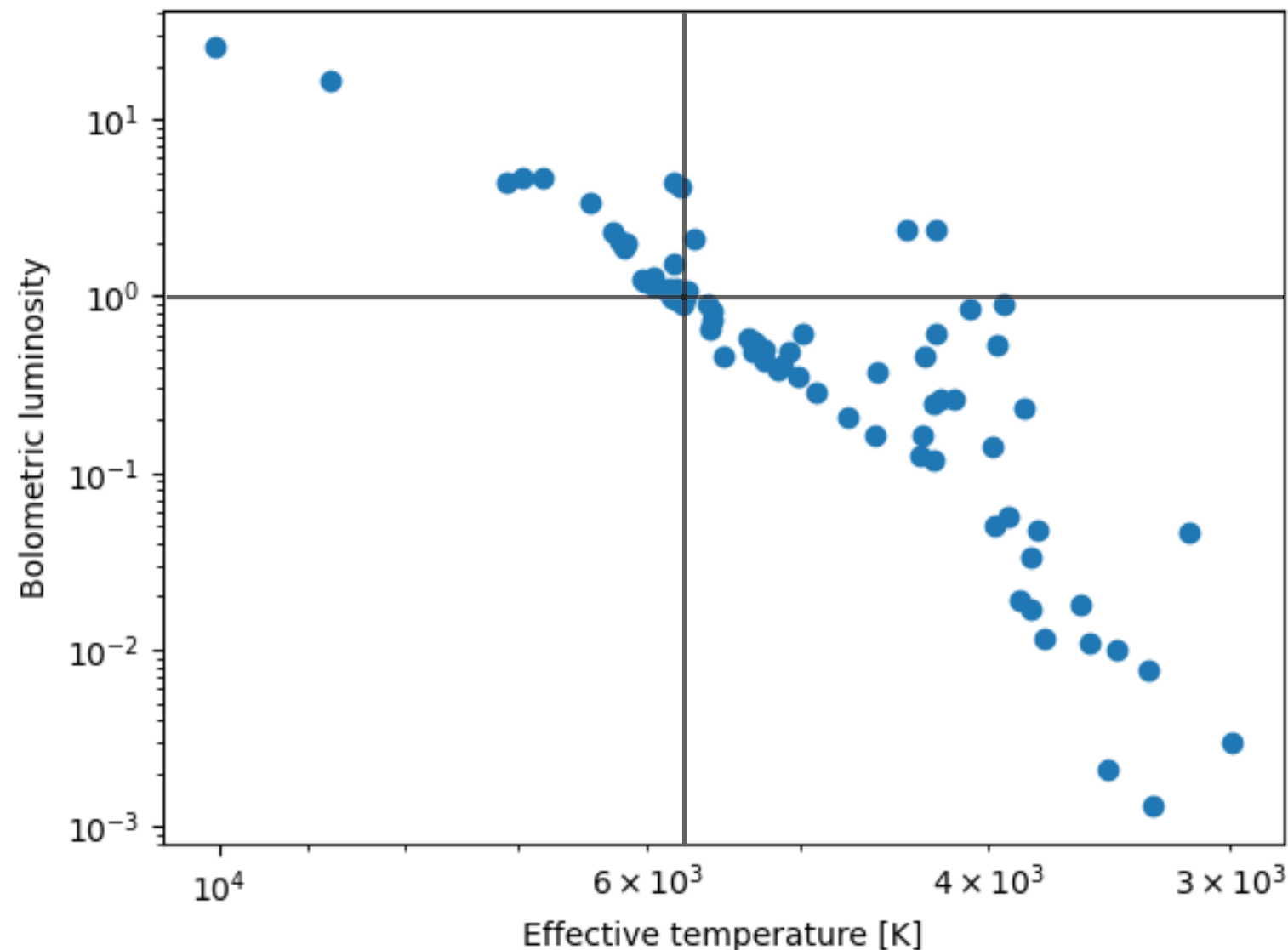
- For some stars fluxes at selected frequencies (mm-radio range)

[illegible]

Data for assignments

Stellar catalogue

- `obs_starcatalog/obs_starcatalog.p` contains catalogue with (mostly empirical) parameters for 79 stars
- Can be loaded as a table in python. Some hints: `AST5770_manual.pdf`
-



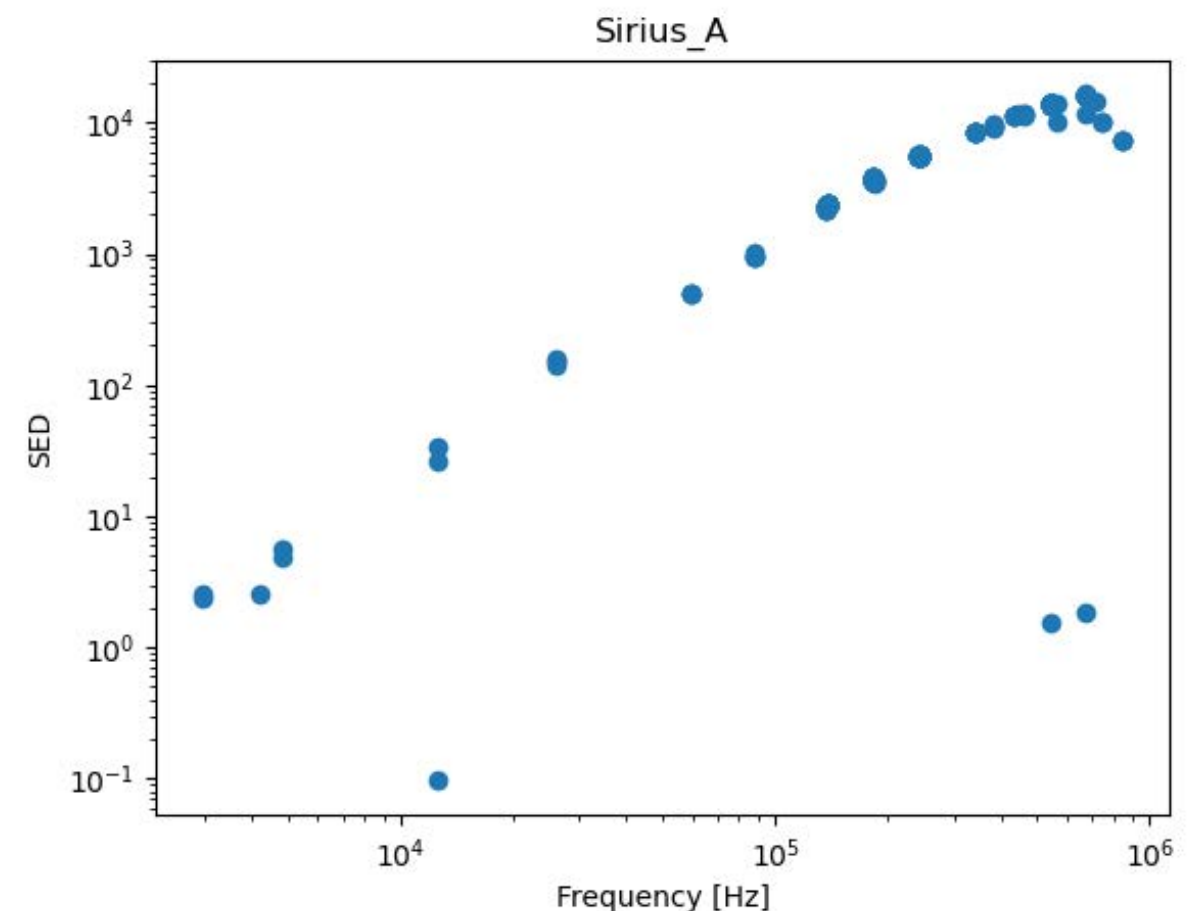
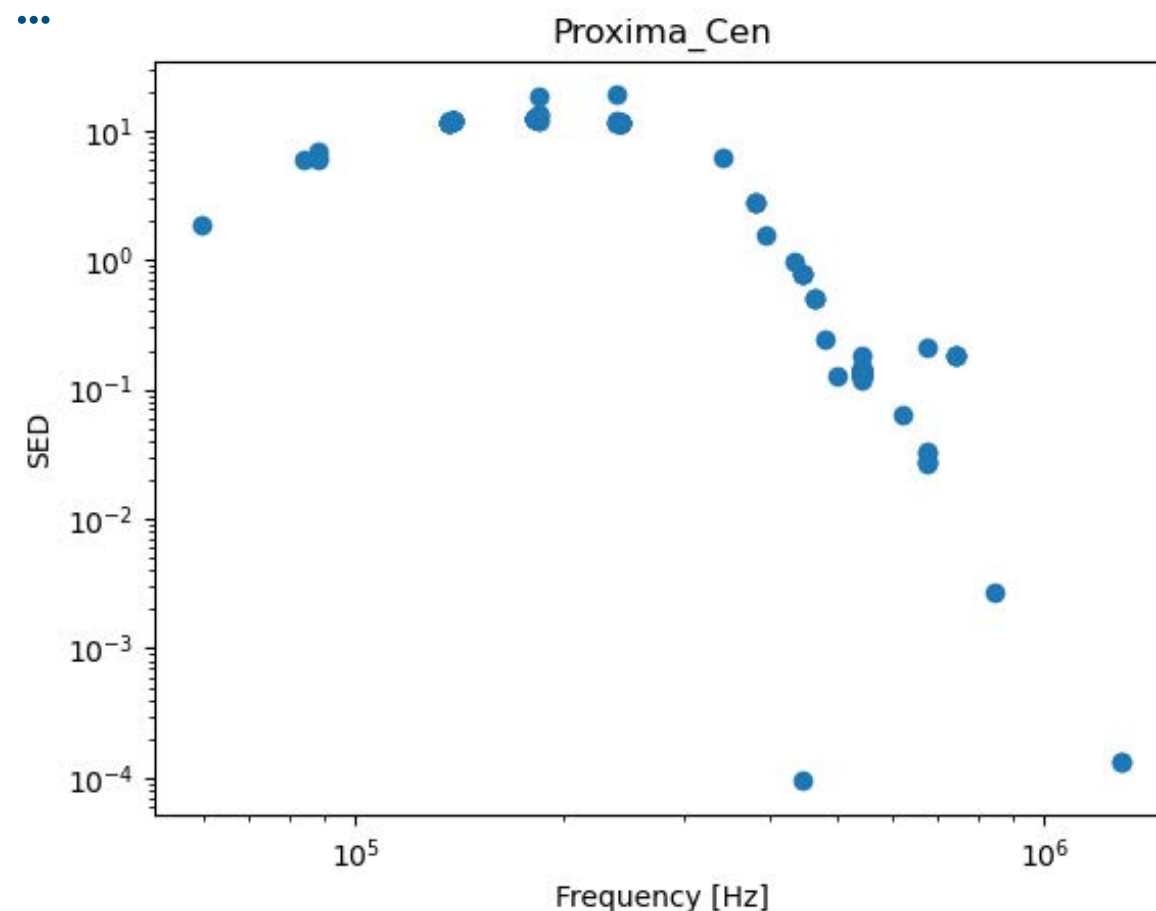
Data for assignments

Stellar observations — Spectral Energy Distribution (SED)

- `obs_starcats/SED` contains files for all 79 stars with SEDs
- Can be loaded in python. Some hints: `AST5770_manual.pdf`

```
from astropy.io.votable import parse_single_table
sed = parse_single_table(datafile).to_table()
list(sed.columns)
freq=sed['sed_freq']
flux=sed['sed_flux']
error=sed['sed_eflux']
```

★ See also: `obs_starcats_SED_info.txt`



Numerical simulation

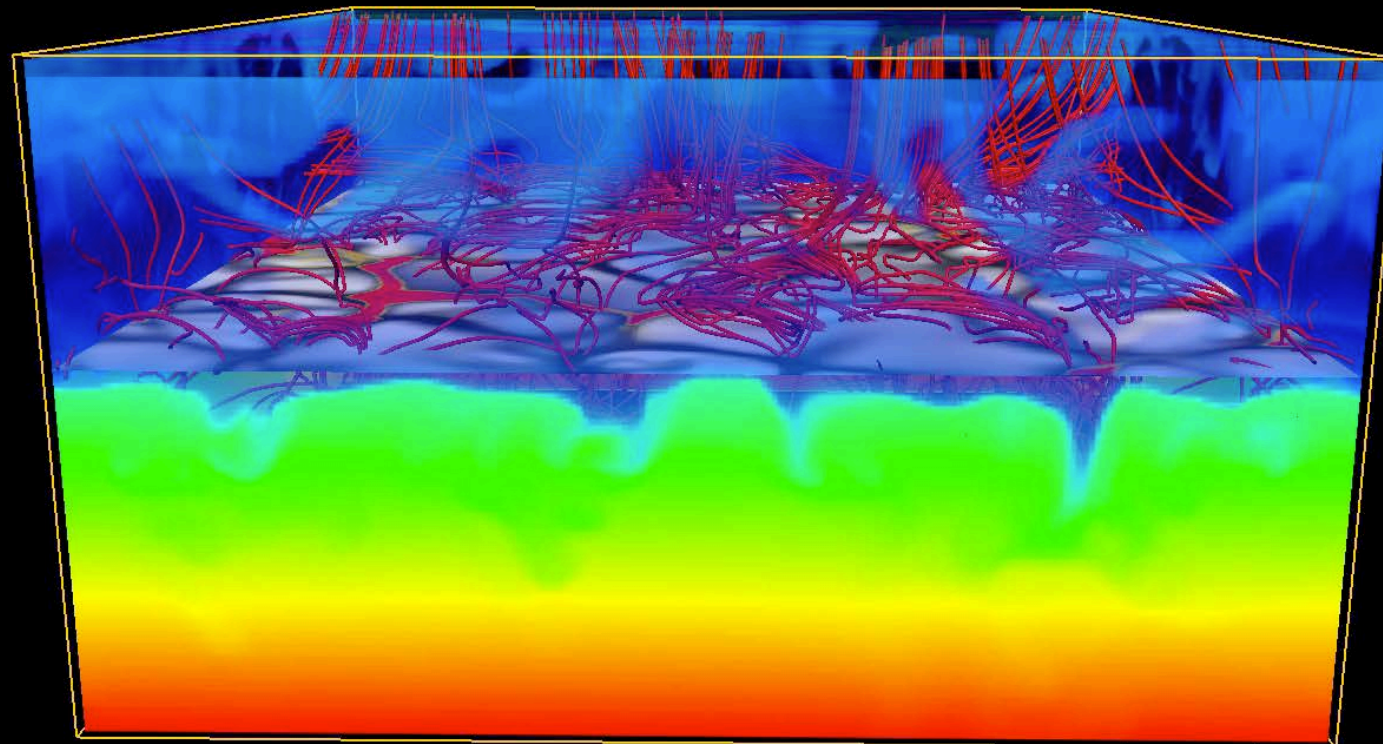
3D radiation magnetohydrodynamics

- Complicated spatial structure of the solar atmosphere requires modelling in 3D
- Small part of the atmosphere plus upper convection zone to drive dynamics self-consistently
- Computational grid, advanced time step by time step
- Solving equations of (magneto)hydrodynamics with “realistic” equation of state plus radiative transfer (simplified with pre-calculated opacity look-up tables)

Numerical simulation

3D radiation magnetohydrodynamics

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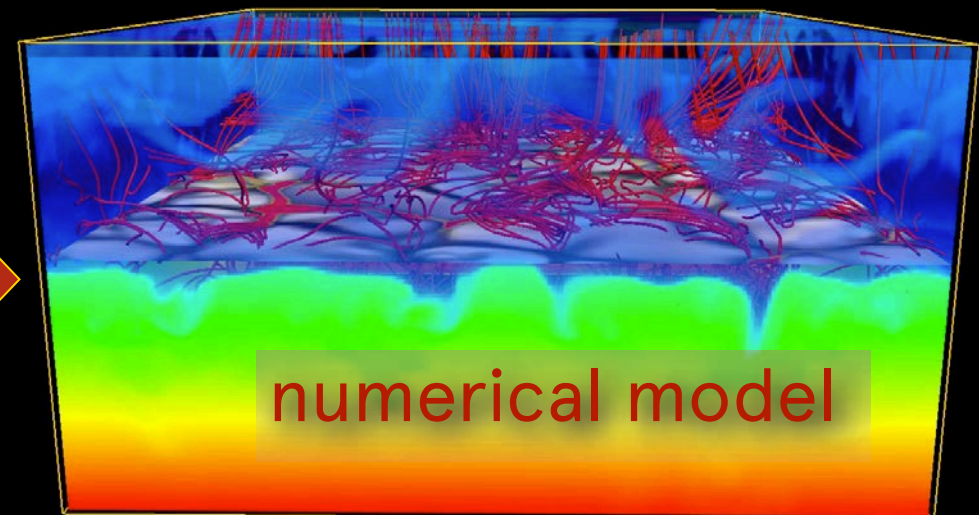
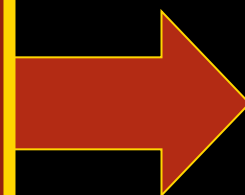


The solar atmosphere

Synthetic observations — radiative transfer

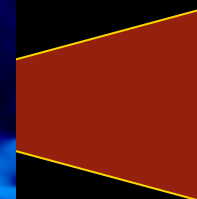
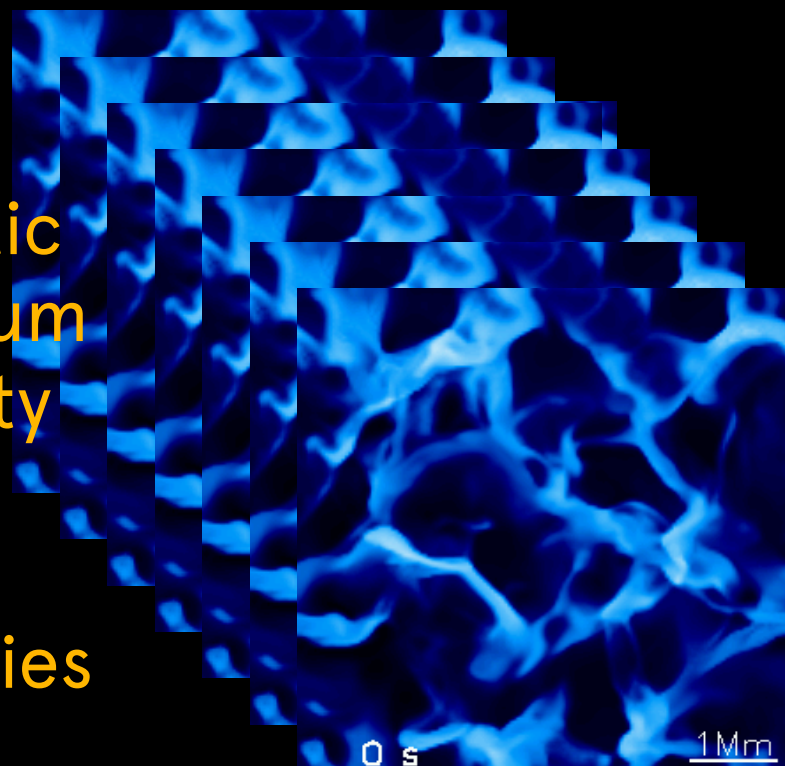
- Predictions by means of synthetic intensity maps calculated from 3D radiation magnetohydrodynamic simulations

3D radiation magneto-
hydrodynamic code



numerical model

synthetic
continuum
intensity
maps
+
time series



intensity
synthesis
code

3D radiative transfer calculations

Numerical simulations

Overview

- Different 3D simulation data for different spectral types are available
- names starting with simsts, only one snapshot per model is available.
- For most spectral types: two models for same spectral type but with different initial magnetic field strength B_0
- See `AST5770_manual.pdf`

ID	Spectral type	T_{eff} [K].	$\log g$	$ B_0 $ [G]	Description	Ref.
MHD simulations for different stellar types, single snapshots only						
simsts_F5V	F5V	6500	4.5	0, 50		S18
simsts_G2V	G2V	5770	4.44	0, 50	Sun	S18
simsts_K2V	K2V	5000	4.5	0, 50		S18
simsts_K8V	K8V	4000	4.5	0, 50		S18
simsts_M3V	M3V	3240	4.5	100	Red dwarf star, similar to AD Leo	W13a
simsts_K5III	K5III	4010	1.5	0	Red giant star, equivalent to Aldebaran (α Tau); Data: 1 time step,	W17
MHD simulations for the Sun, short time series						
simsut G2V	G2V	5770	4.44	50	Sun, time series ($\Delta t = 10$ s)	W13b

Numerical simulations

Overview

- HDF5 files

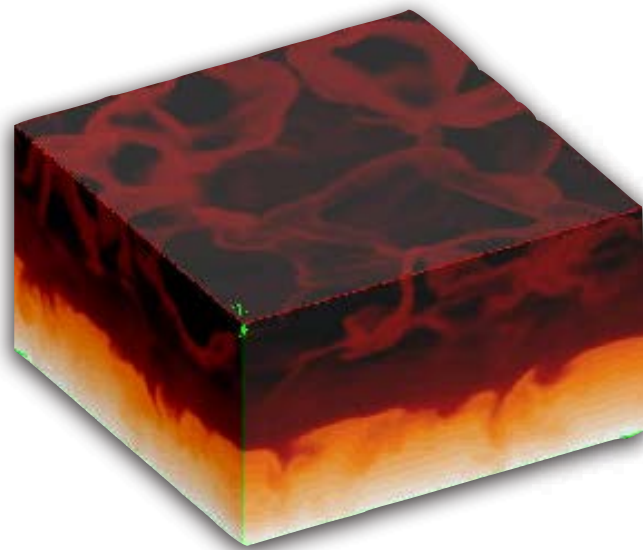


Table A.4: Quantities contained in the simulation data files.

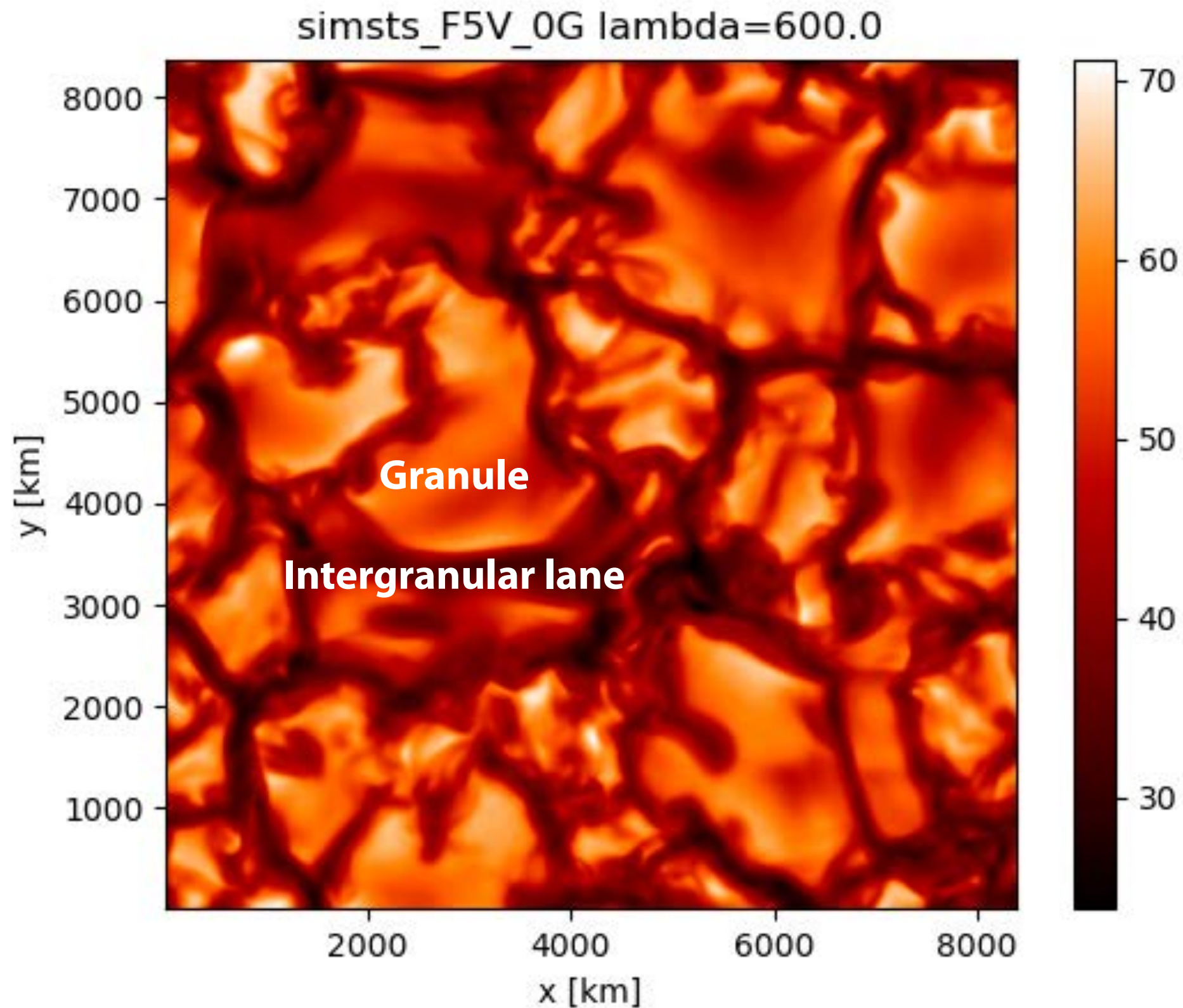
Entry	Description	Unit	Dimension
X	x axis	cm	1D
Y	y axis	cm	1D
Z	z axis	cm	1D
DZ	z extent of grid layer	cm	1D
TIME	time	s	1D or scalar
RHO	Mass density	g/cm^3	3D
TGAS	Gas temperature	K	3D
PGAS	Gas pressure	dyn/cm^2	3D
KAPPA	Absorption coefficient		3D
VX	Velocity x-component	cm/s	3D
VY	Velocity y-component	cm/s	3D
VZ	Velocity z-component	cm/s	3D
The following entries are only available for MHD models.			
BX	Magnetic field x-component	G	3D
BY	Magnetic field y-component	G	3D
BZ	Magnetic field z-component	G	3D
In addition, all files contain the following useful information.			
DESCRIPTION	Description of the data entries		
UNIT	Physical units of the data entries		

Numerical simulations

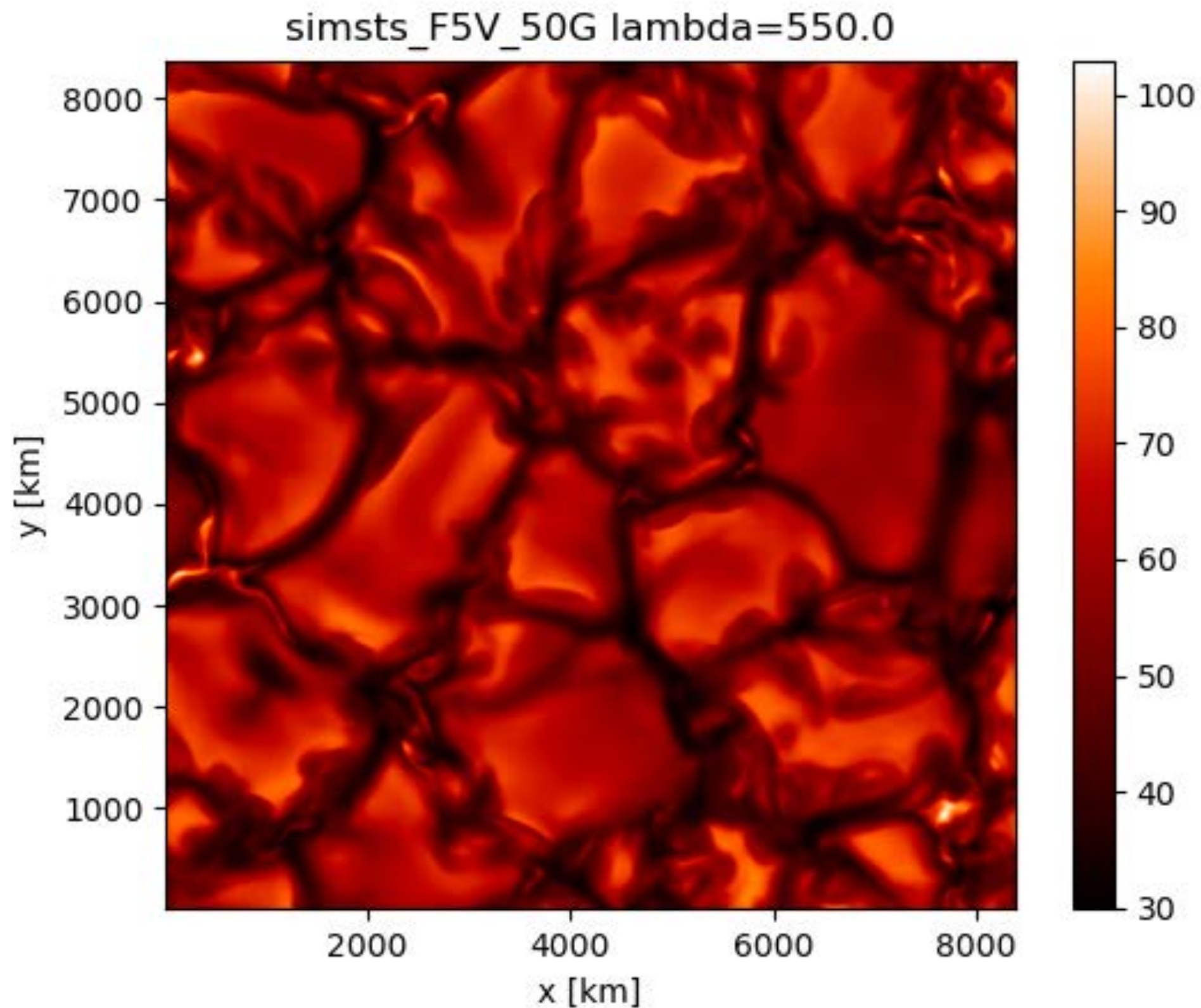
Overview

- Synthetic observables in each folder:
 - ***_continuumintensity.h5**: continuum intensity for wavelengths 300 nm — 5.0 μm
 - theoretical continuum: under assumption of local thermodynamic equilibrium, no spectral lines.
 - ➡ Differences with respect to real observations should be expected
 - intensity data provided as function horizontal coordinates (x and y, identical to those in the files described above) and wavelength λ .
 - See the description and unit tags.
 - ***_lineintensity_FeI6173.h5**: intensity for the Fe I 6173 line (neutral iron, 617.3 nm)
 - difference with respect to the continuum intensity files: spectral line files contain intensity as function of wavelength across a narrow region around the nominal central wavelength λ_0 of the line.
 - In addition, the theoretical continuum at λ_0 (calculated as if there was no line)

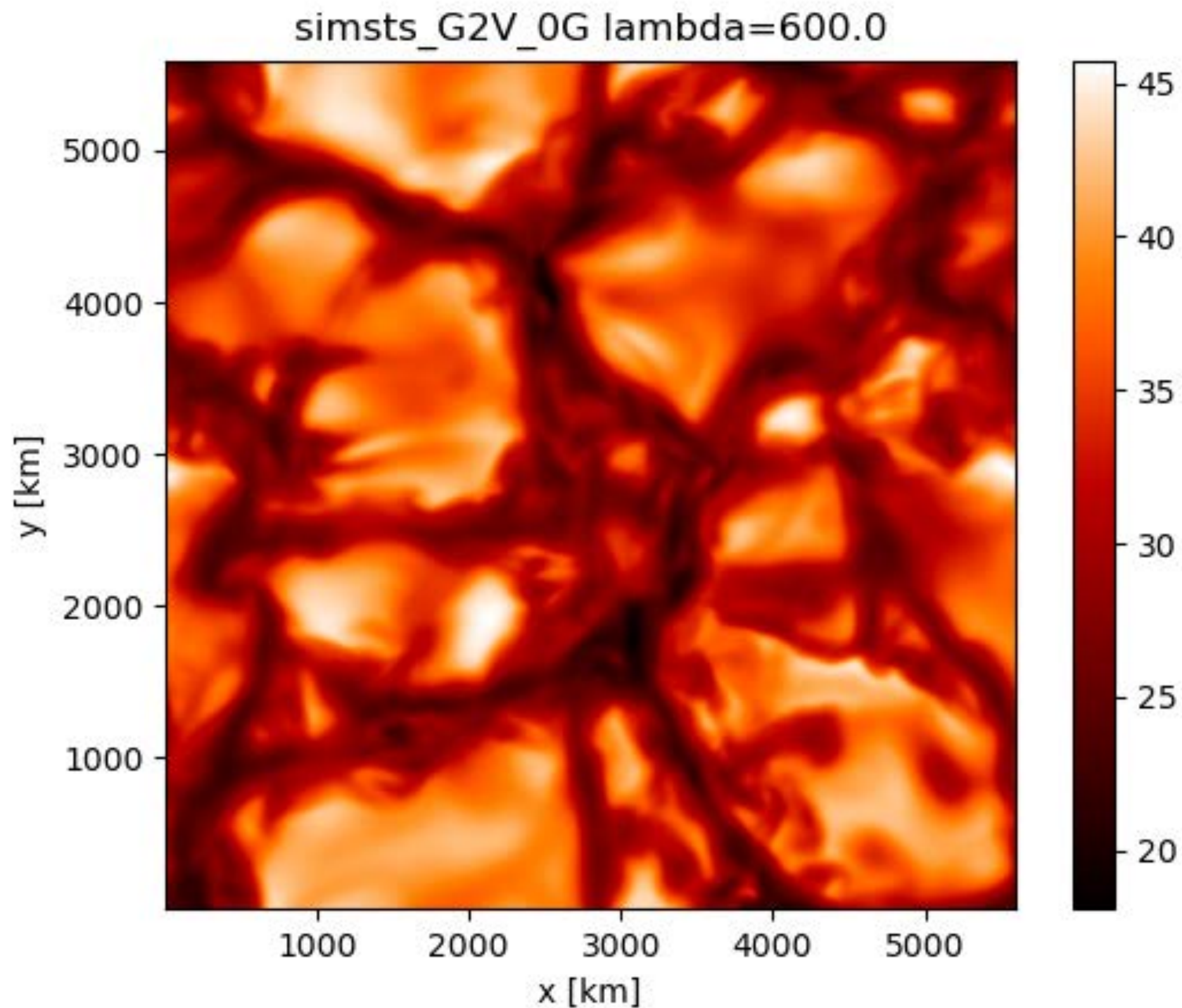
Numerical simulations



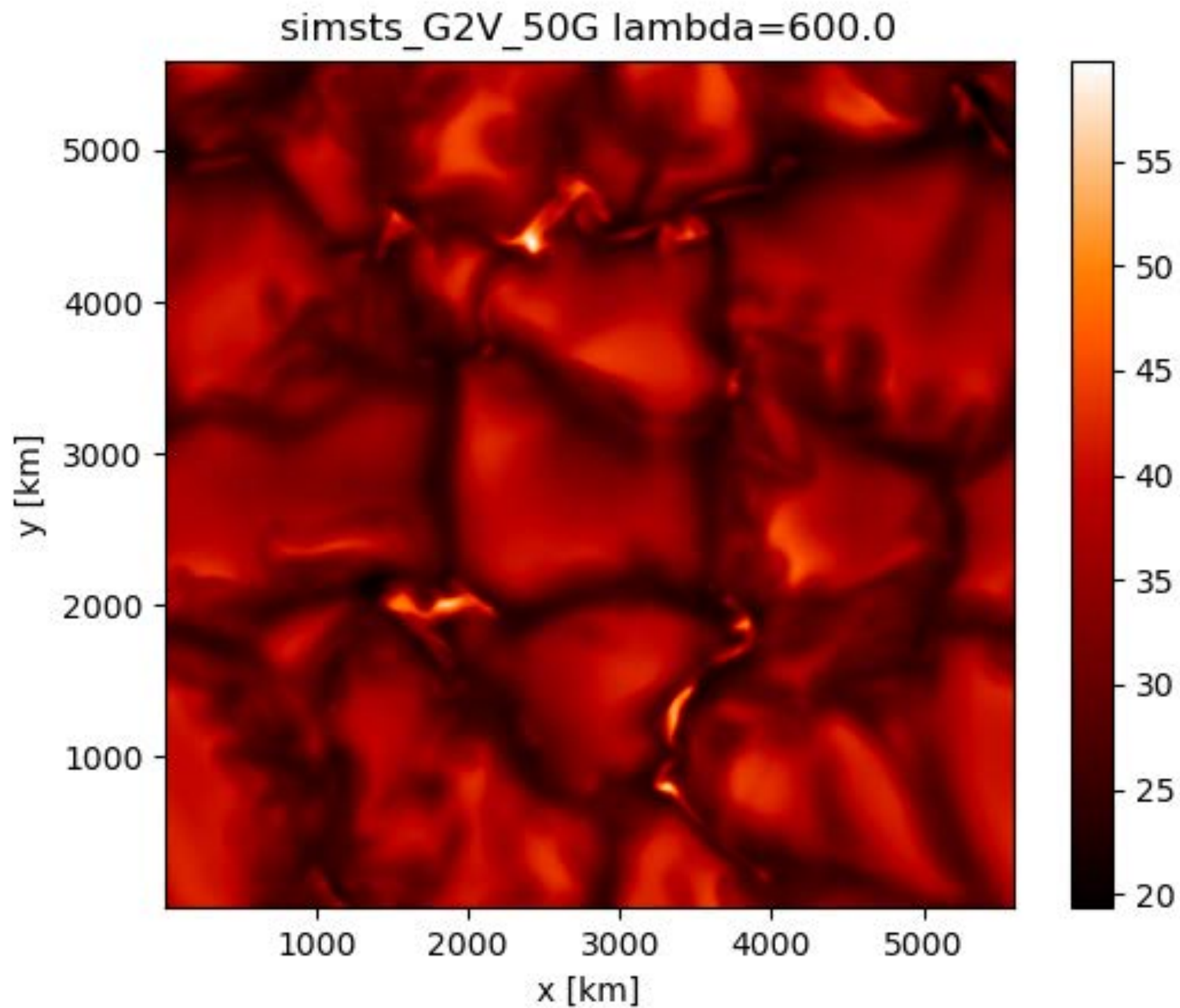
Numerical simulations



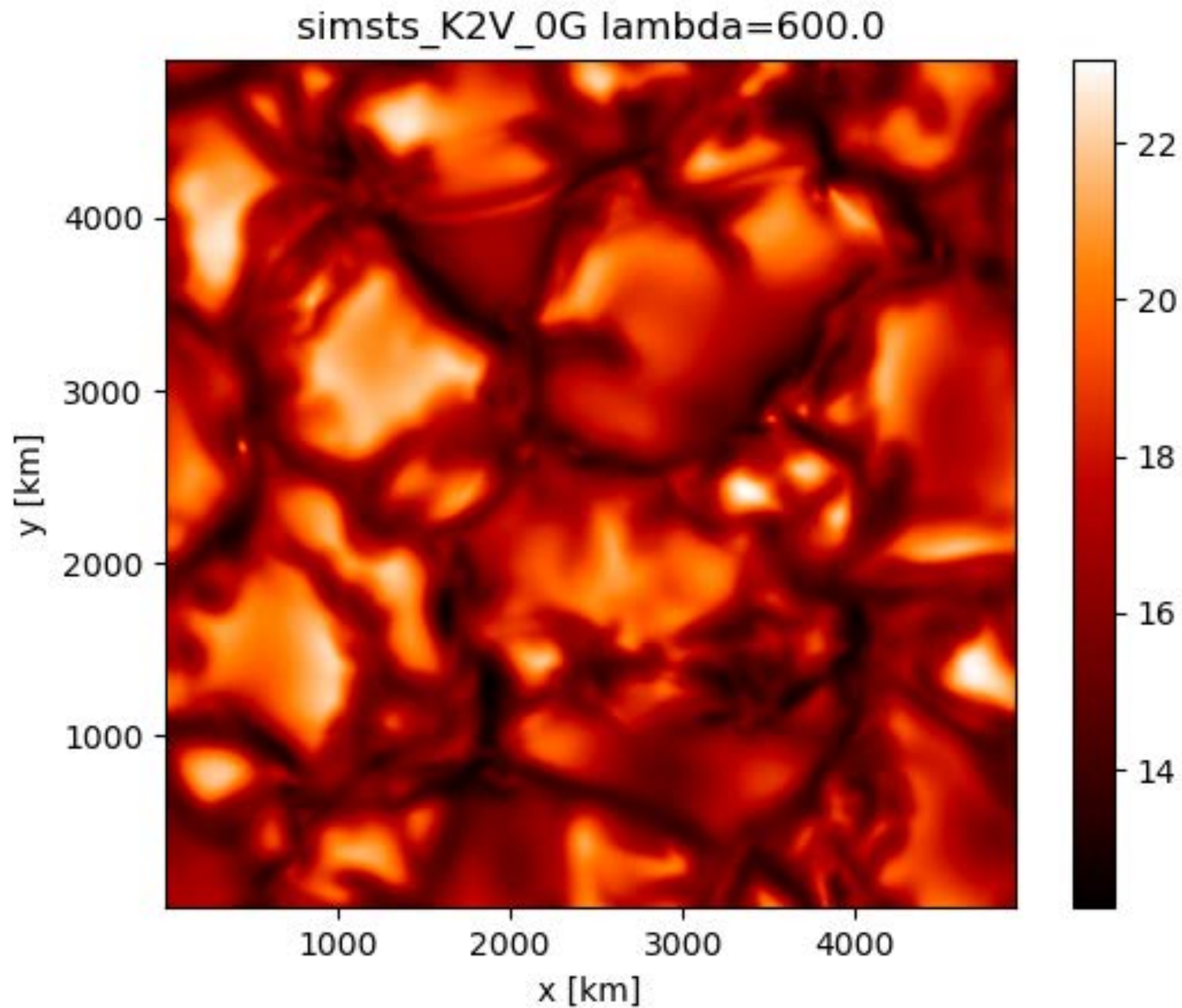
Numerical simulations



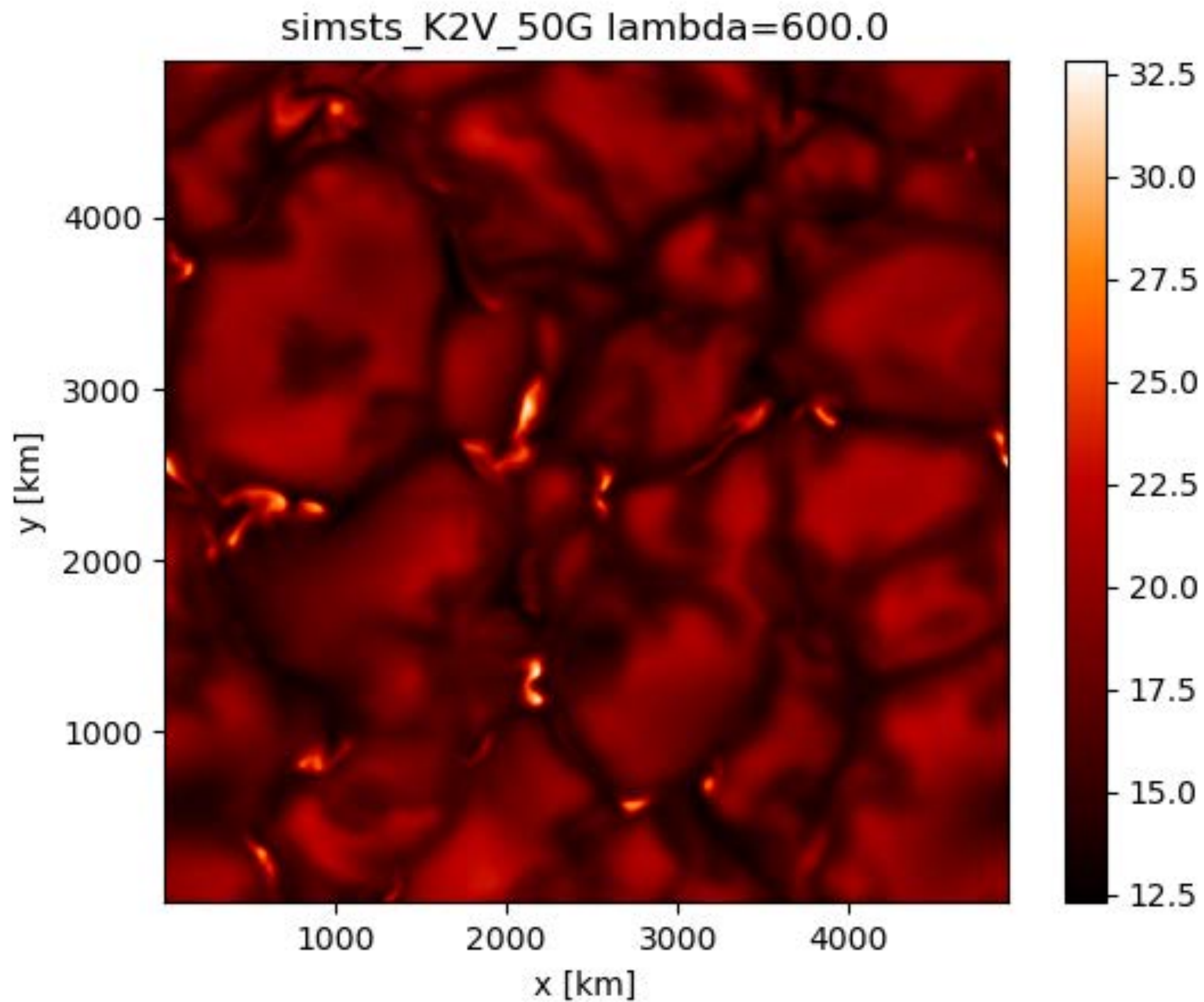
Numerical simulations



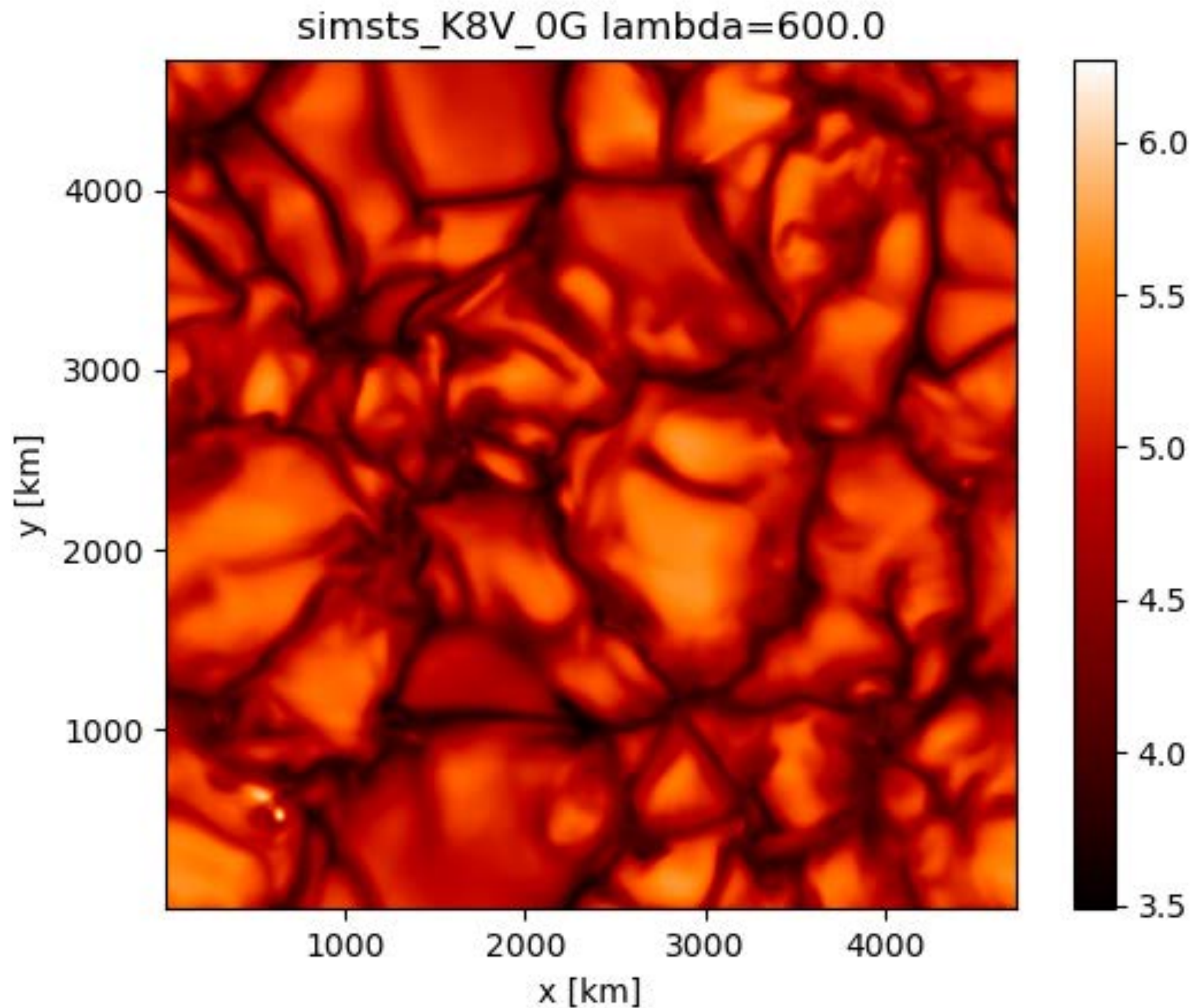
Numerical simulations



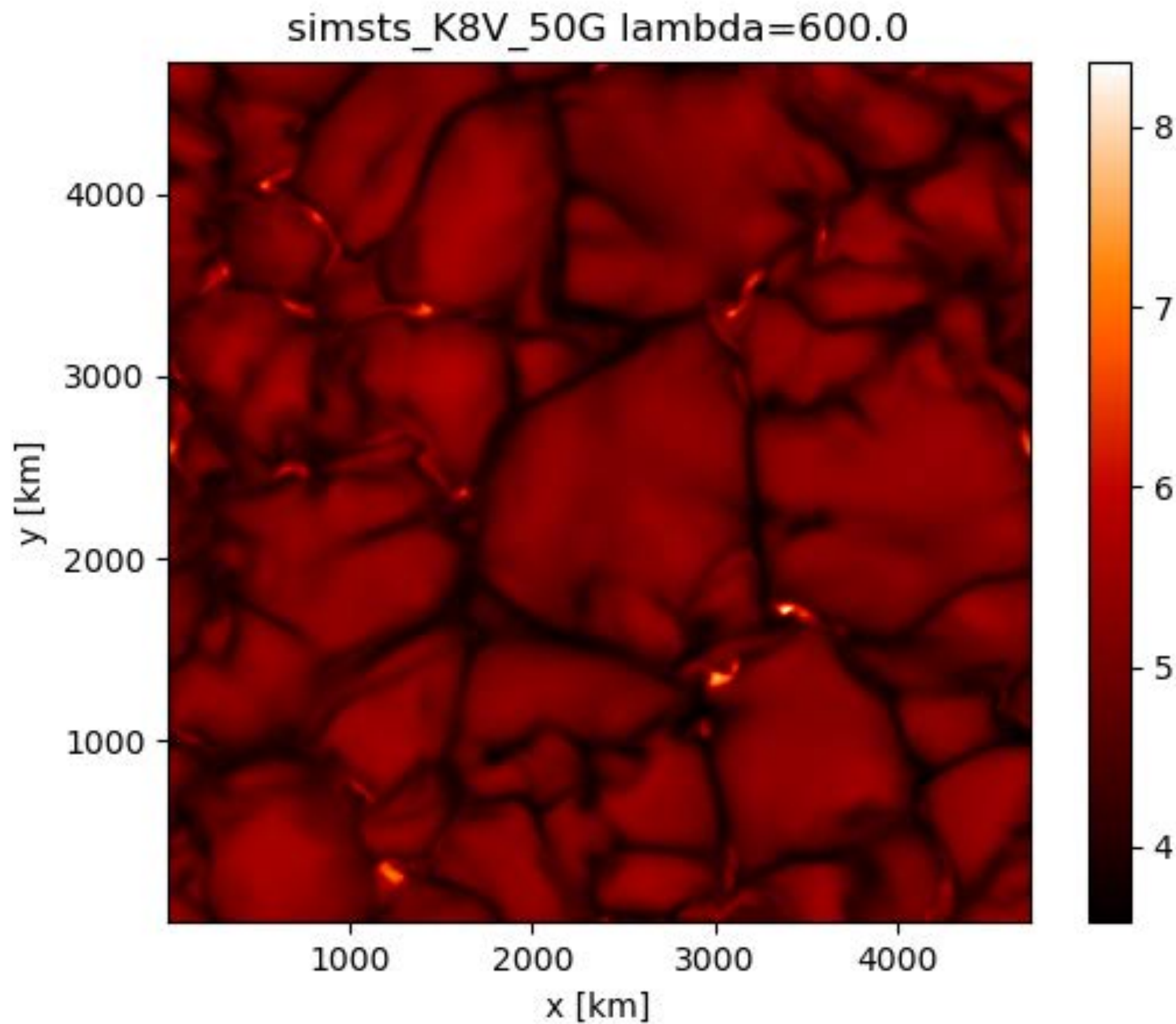
Numerical simulations



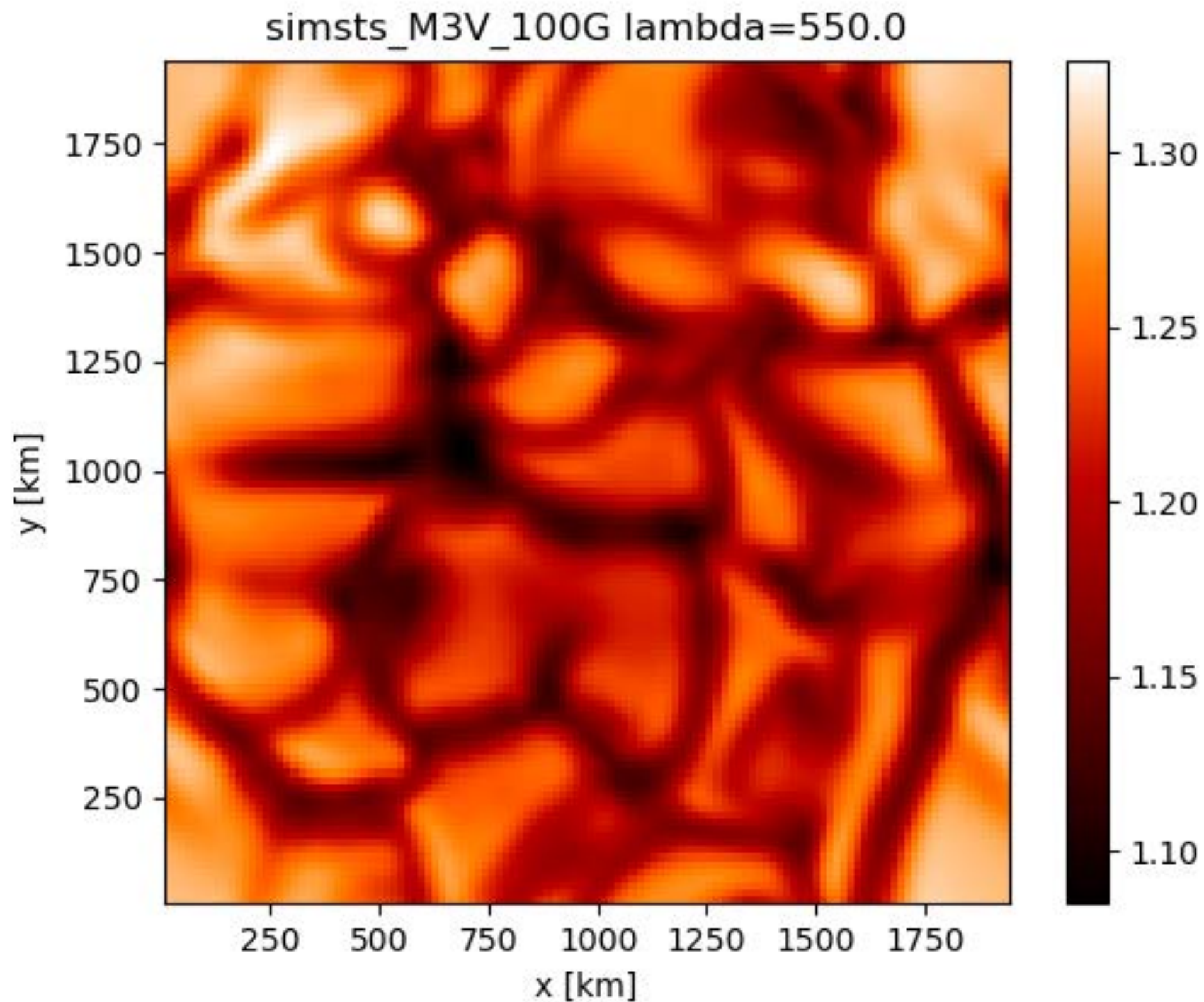
Numerical simulations



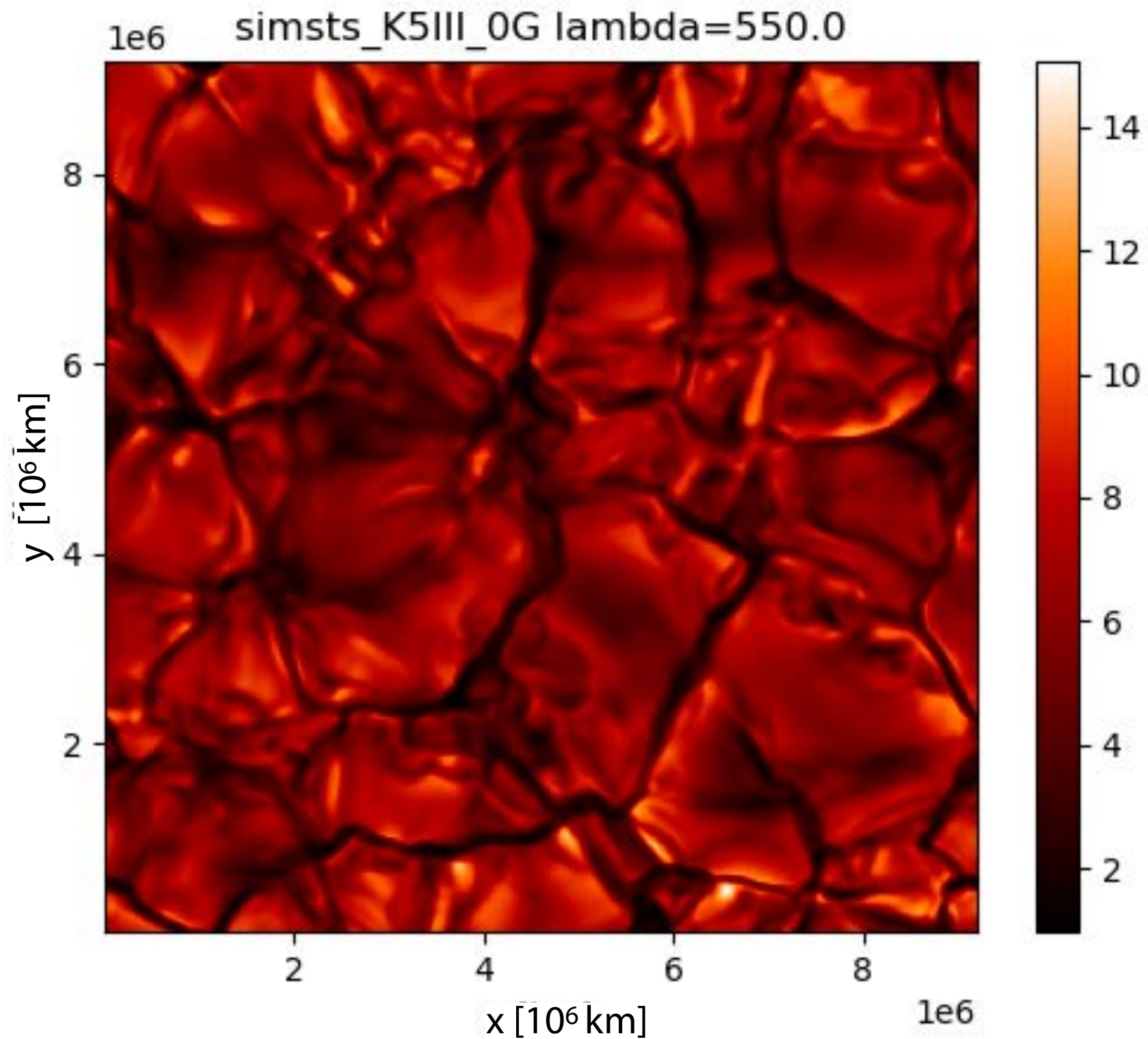
Numerical simulations



Numerical simulations



Numerical simulations

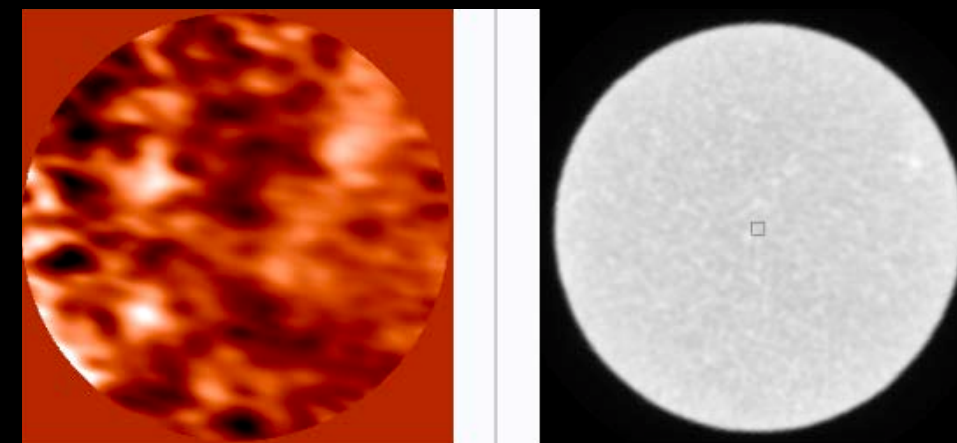


Data for assignments

More ...

- **Currently more data in preparation**

- Global 3D model of a giant star
- ALMA observations of the Sun (SALSA - <http://sdc.uio.no/salsa/>)



- **Own ideas for projects? Need other data?**

➡ Talk to us!

- When using computers at ITA:

- Do not store large data sets in your home directory, use data directories
- Do not compute on the login servers (login, tsih2), use other machines such as beehive