

# AST5770

Solar and stellar physics

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# Scientific Questions

# What can I do with the data?

- **Have a look at the data!** (Also see the document with explanations!)
  - Play around. Plot different things.
- Can I **compare** data regarding a certain physical quantity?
  - **Simulations:**
    - With magnetic field compared to without magnetic field?
    - Different stellar models ( $T_{\text{eff}}$ , spectral type)
  - **Observations:**
    - What are the differences (in terms of intensity) inside a sunspot and outside (Quiet Sun)?
      - ➡ Are there any differences that depend on different magnetic field strength?
    - How does the imaged region look in the spectral line core compared to the continuum?
      - ➡ What are the differences and similarities? What do I learn from that?

# What can I do with the data?

- **Simulation vs observation**

- Can I explain the observations by comparing the synthetic (simulated) intensities with the observed ones?
- By looking at the 3D simulation data, can I explain how the intensity is formed?
  - ➡ Which properties can / cannot be derived from the observations?
  - ➡ What should I be looking for in the observational data?
  - ➡ Can I suggest an explanation of the physical mechanisms with help of the simulation data?

- **Time-dependent simulation**

- Exploit the time domain to understand the physical mechanism that produces the structure and dynamics seen in the model.
  - ➡ Provide / suggest a description (of the essentials) of the physical mechanism

# Scientific questions

## Scientific questions

- What are the properties of solar granulation and what does it tell us about surface convection on the Sun?
  - ➡ Can I determine the velocity field?
  - ➡ What are the differences between Quiet Sun and sunspots?
  - ➡ What does that imply for the role of the magnetic field in structuring the atmosphere?
- What is (3D/height-dependent) magnetic field topology of sunspots?
- How is reversed granulation produced?
- What is the origin of bright points in the Quiet Sun?
- How do the properties of small-scale surface convection change across the main sequence?
- How well do the simulations reproduce the granulation and emergent intensity from the photosphere?
  - ➡ Continuum intensity? Spectral lines?
- What are the physical processes driving magnetic tornadoes?
- How are the global stellar parameters connected and what can I learn from that regarding stellar evolution / populations / structure?

# Important considerations

- Do I have **all the necessary data** to address the scientific question?
  - Yes - How are my data analysis steps?
  - No - How can I adjust the question to make it feasible with the available data?
- This is your **tentative** scientific question! You **can adjust** the question during the next week according to the results of your data analysis.
  - It is important to define a (rough) initial question to have a **direction to start!**
  - Keep playing around with the data. Be curious and advantageous.
  - Never belief results at face value but try to understand why!
- **The aim** is to plan a small research project and summarise the results in a report similar to a scientific journal article.
  - You are not expected to produce novel results!
  - A negative conclusion is a conclusion, too.
  - If no firm conclusion can be drawn, one can suggest possible explanations. In addition, you could suggest future work (observations, simulations) that should be done to answer the question.

# Example 1—Sunspot

## What is (3D/height-dependent) magnetic field topology of sunspots?

- What data do I have?

|             |                                                                                                                                                                                                                 |                      |
|-------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|
| obssun_sst3 | Sunspot (AR12533), chromospheric spectral line $H\alpha$<br>29-Apr-2016 09:43:09 - 11:13:07 UT, ( $\mu = 0.75$ , $[x, y] = [623'', 8'']$ )<br><b>2020A&amp;A...638A..63D,</b><br><b>2021A&amp;A...648A..54R</b> | $[x, y, \lambda, t]$ |
| obssun_sst4 | Sunspot (AR12770), photospheric spectral line Fe I 617.3 nm<br>2020-Aug-07 08:22:21 - 08:59:58 UT, ( $\mu = 0.83$ , $[x, y] = [-446'', 279'']$ )                                                                | $[x, y, \lambda, t]$ |

- Not the same sunspot and slightly different inclination angle (close enough) but the data sets provide different height ranges (sampled from line core to continuum)

### ➡ Height information is imprinted!

- How to start the data analysis?
  - Measure the area of the umbra as a function of wavelength.
  - Width of fibrils?
- Extra data: SDO/HMI magnetogram (can be found and retrieved with jhelioviewer).

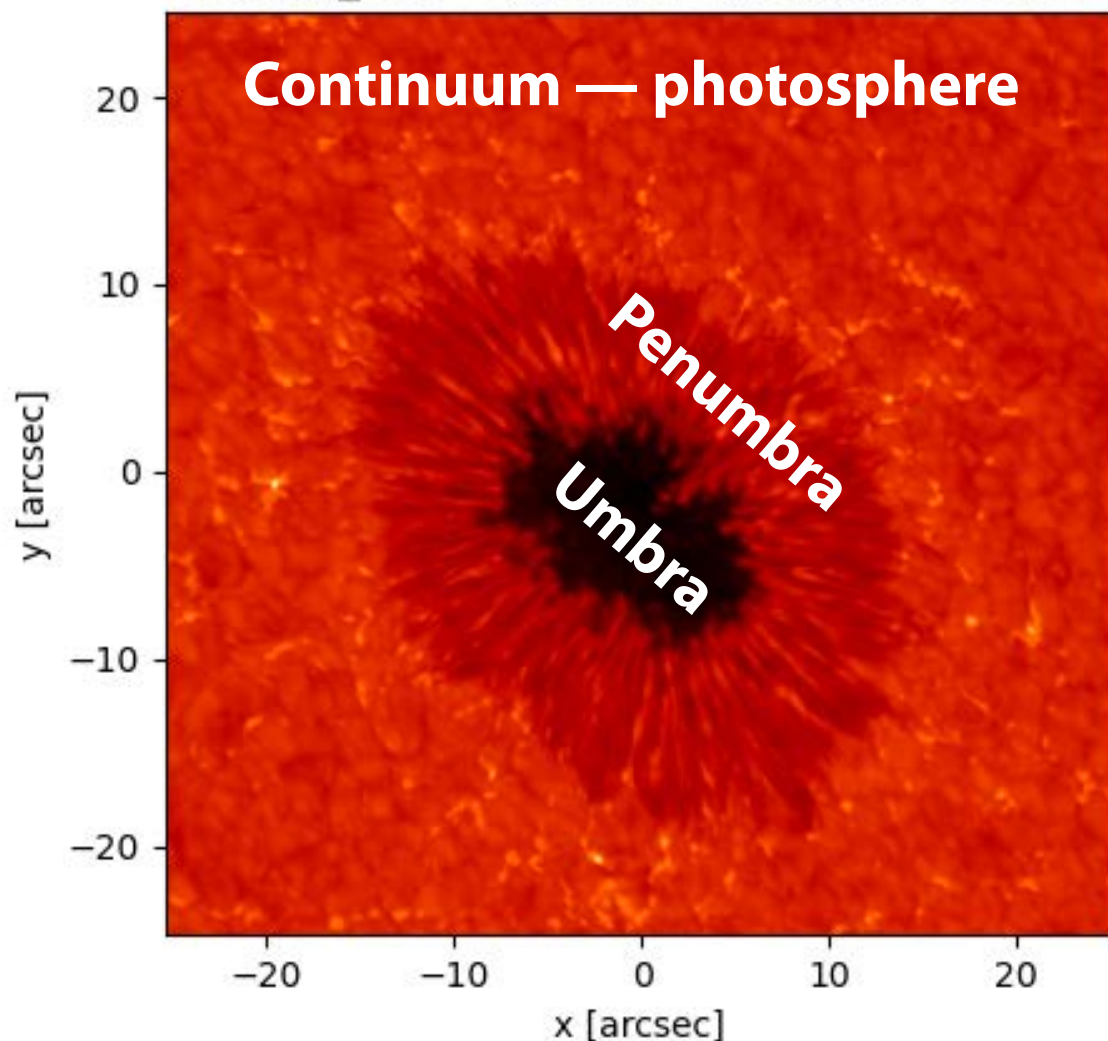
# Example 1 — Sunspot

## Solar observations (SST) — obssun\_sst3

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

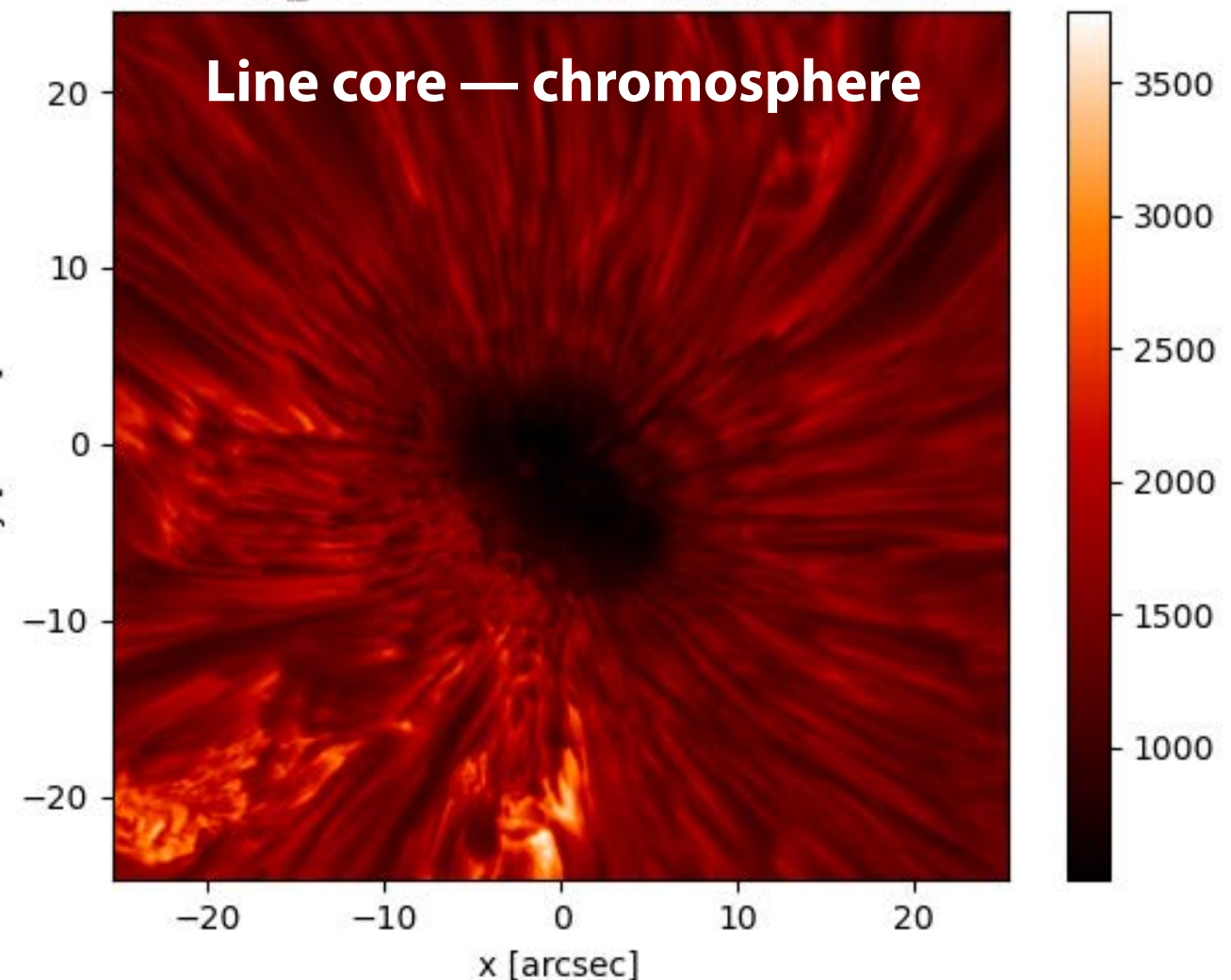
obssun\_sst3 - time step 0, lambda=656.15

**Continuum — photosphere**



obssun\_sst3 - time step 0, lambda=656.3

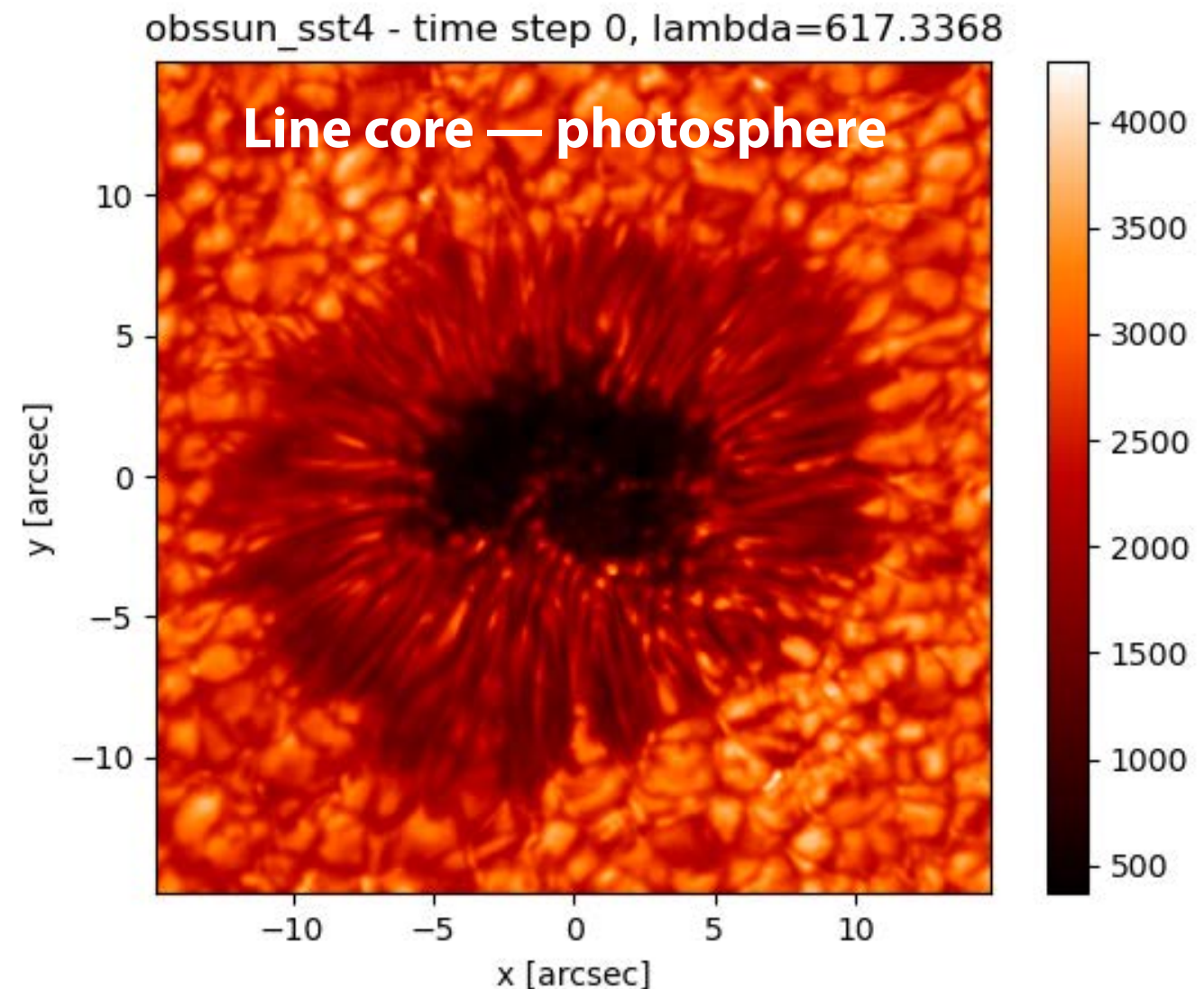
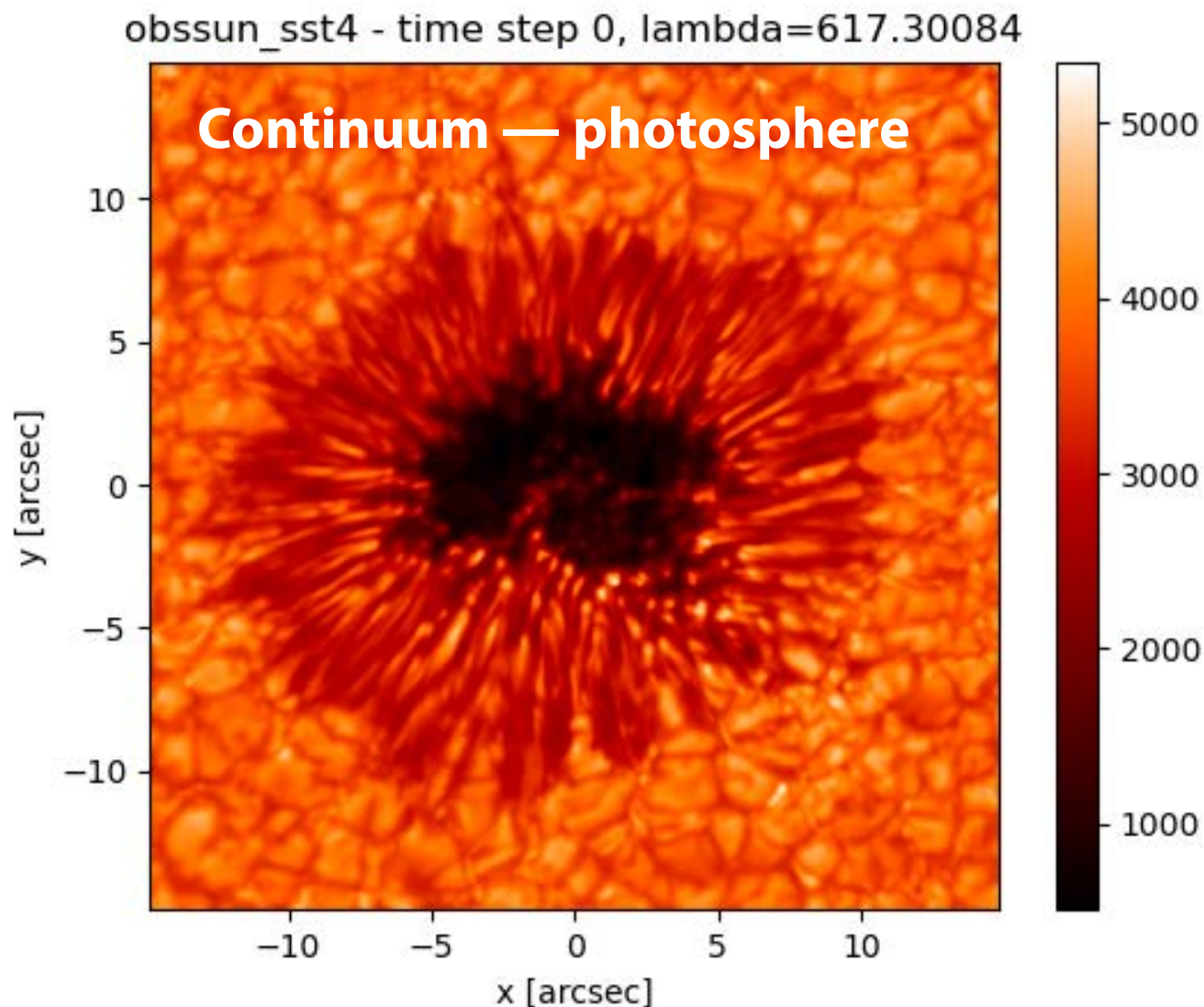
**Line core — chromosphere**



# Example 1 — Sunspot

## Solar observations (SST) — obssun\_sst4

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



# Example 2 — Simulation vs observation

## How well do the simulations reproduce the granulation and emergent intensity from the photosphere?

- This is more a technical question and should be refined into a scientific question.
- However, it would still provide a starting point for a looking at data with the aim to define a more specific question.
- Which data? Simulation and observation only available for the Sun (continuum and spectral line).
- Ideas for a comparison - histograms for the continuum intensity (or Doppler velocity)
  - Histograms different! Why is that? Due to the impact of the telescope (limited spatial resolution)?
    - Can this be verified by convolving the simulation data with a Point Spread Function (PSF) to simulate an artificial observation? (PSF as a Gaussian with a width according the spatial resolution for SST - a telescope 1m aperture.)
- Doppler shifts in the spectral line data - Are the simulations reproducing this well?
  - If yes, can I look into the 3D velocity data in the model and make some conclusions regarding the gas motions due to surface convection?
- Paper for inspiration: <https://ui.adsabs.harvard.edu/abs/2009A%26A...503..225W/abstract>

# Example 2 — Simulation vs observation

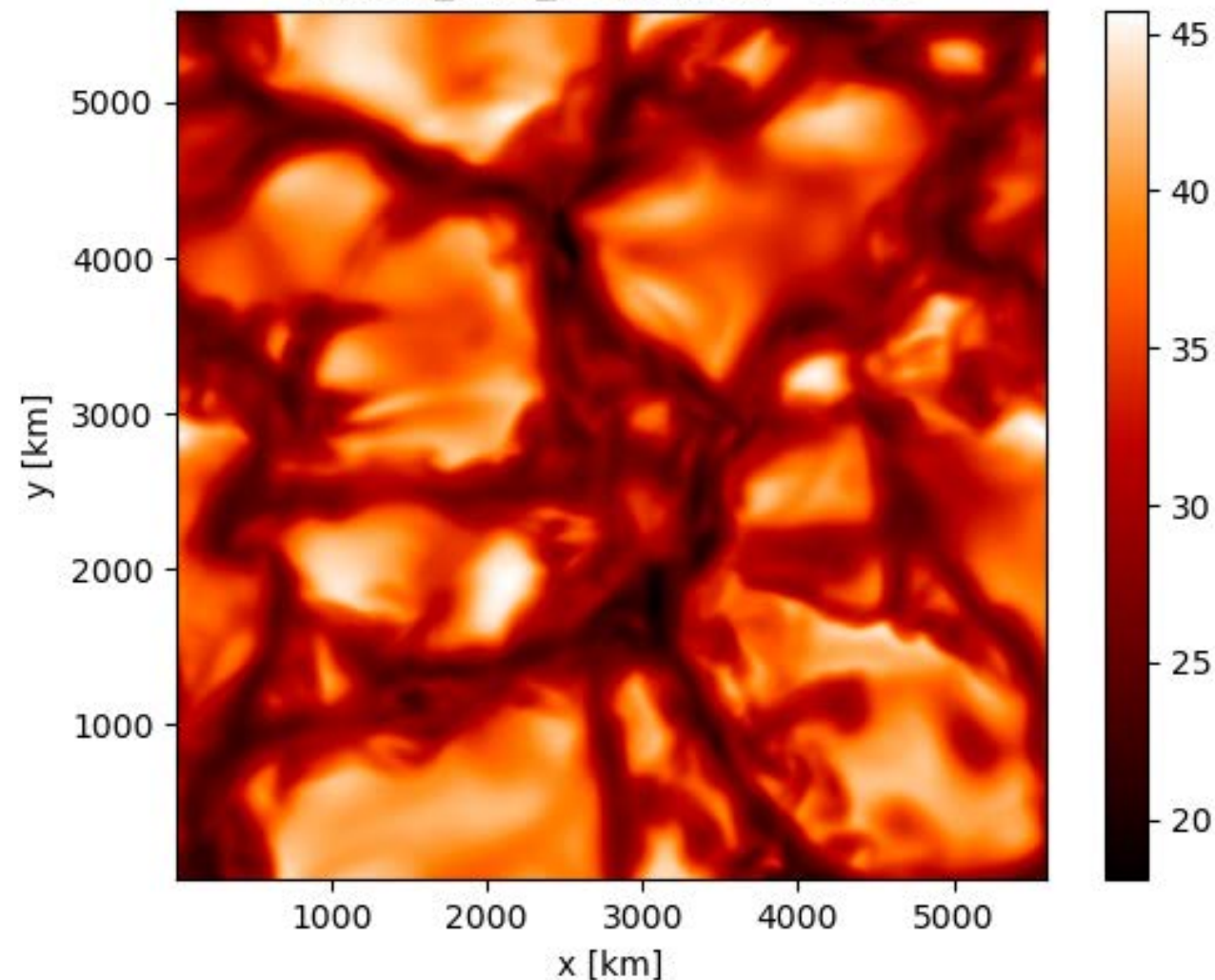
## Solar observations (SST) — obssun\_sst1

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

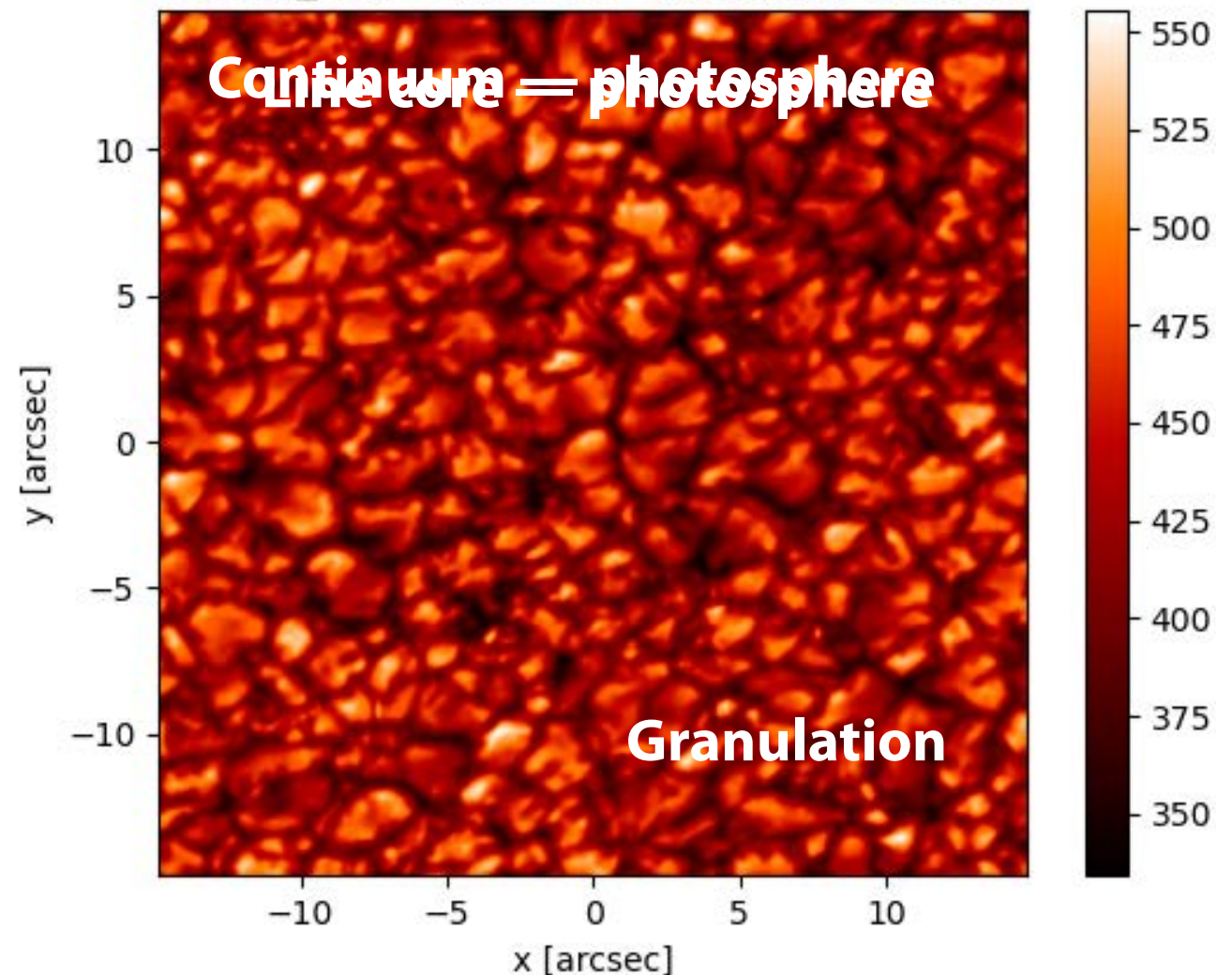
- Simultaneous with dataset obssun\_sst2!

|            |     |      |      |          |     |     |
|------------|-----|------|------|----------|-----|-----|
| simsts_G2V | G2V | 5770 | 4.44 | 0,<br>50 | Sun | S18 |
|------------|-----|------|------|----------|-----|-----|

simsts\_G2V\_0G lambda=600.0



obssun\_sst1 - time step 0, lambda=617.276



# Example 3 — Magnetic tornadoes

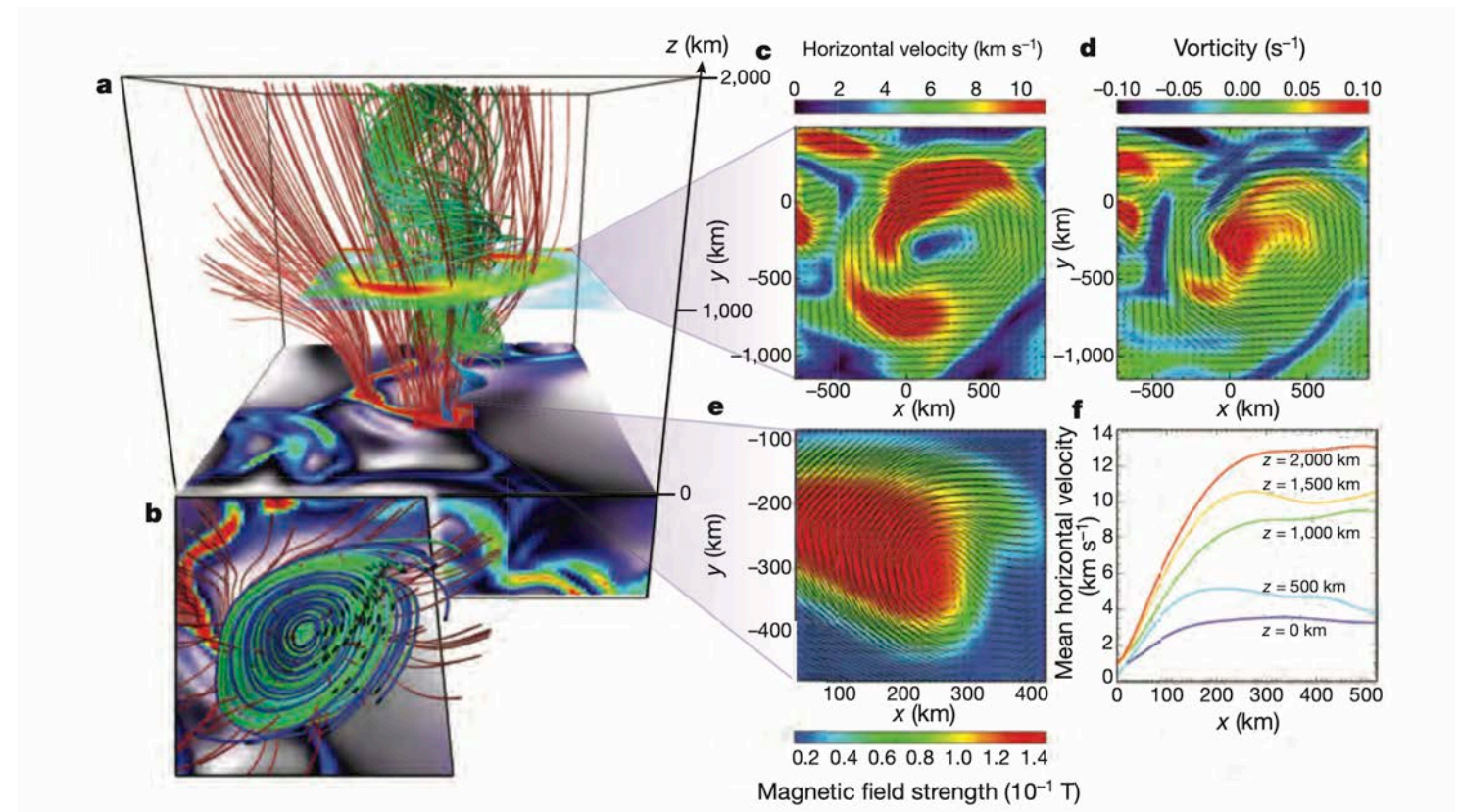
## What are the physical processes driving magnetic tornadoes?

- **Time-dependent data**

- Careful: More data to handle! But also a lot of possible results to work with!

- ADS: 2012Natur.486..505 W, 2014PASJ...66S..10W;

- Review paper: <https://ui.adsabs.harvard.edu/abs/2023SSRv..219....1T/abstract>



- How to analyse the temporal evolution?
  - Movies ... but how to visualise this in an article? Sequence of images?! (See next slide)
  - Measure a quantity (e.g., diameter of ring-link shape; average horizontal velocity) as function of time and plot that?

Observations!

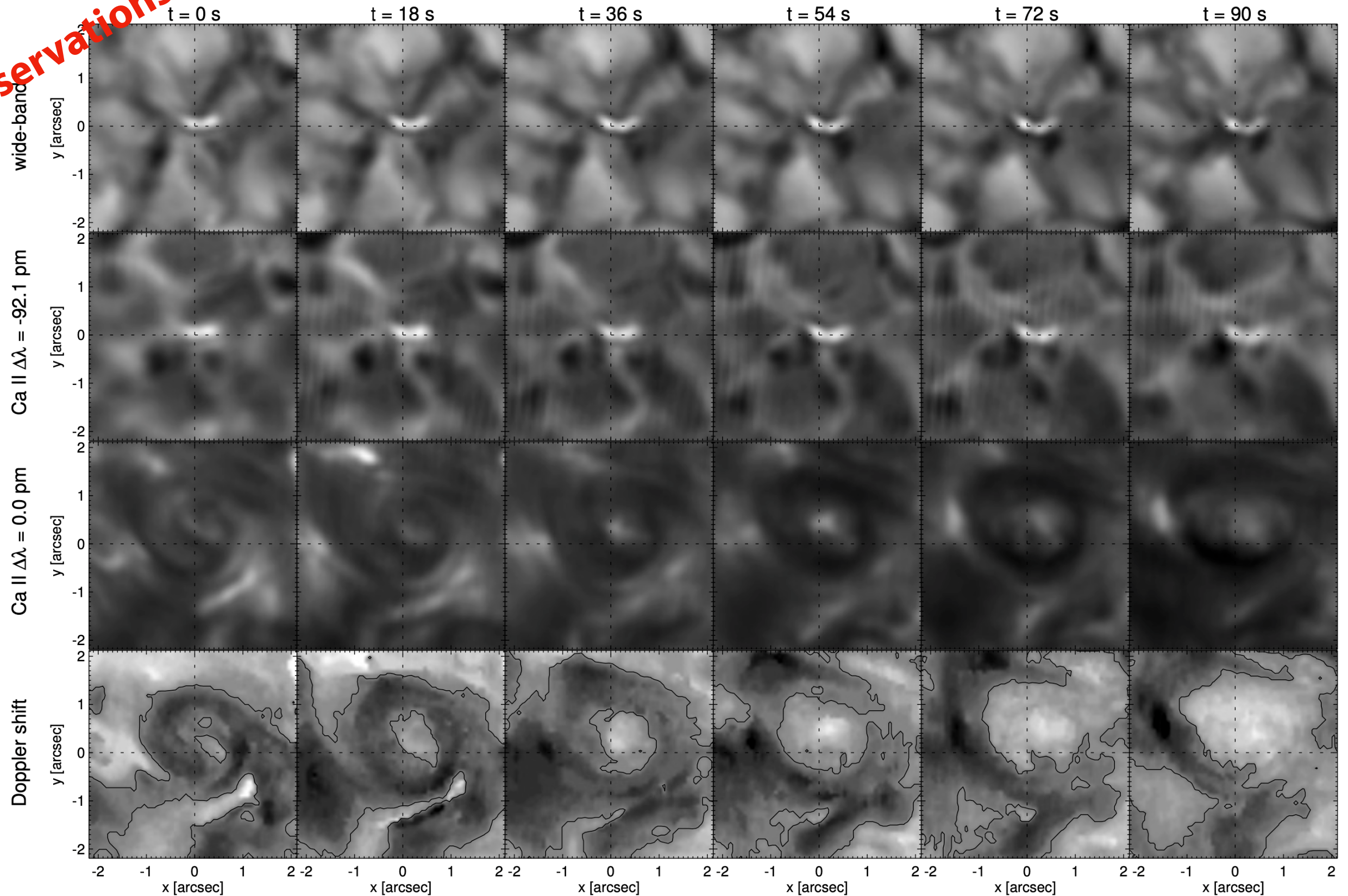


**Fig. 1.** Temporal evolution of a swirl event as seen in close-ups of intensity maps in the wide-band (top row), Ca line wing (upper middle), Ca line core (lower middle), and Doppler shift (bottom). The columns from left to right show every other time step ( $\Delta t = 18$  s). The black contours in the bottom row mark a zero Doppler shift. The grey scale of the Doppler shift is from -5.5 to +5.5 km/s with negative values corresponding to blueshifts and thus upflows. The temporal evolution is presented in a movie provided as online material.

# Example 3 — Magnetic tornadoes

## What are the physical processes driving magnetic tornadoes?

S10-4

Publications of the Astronomical Society of Japan, (2014), Vol. 66, No. SP1

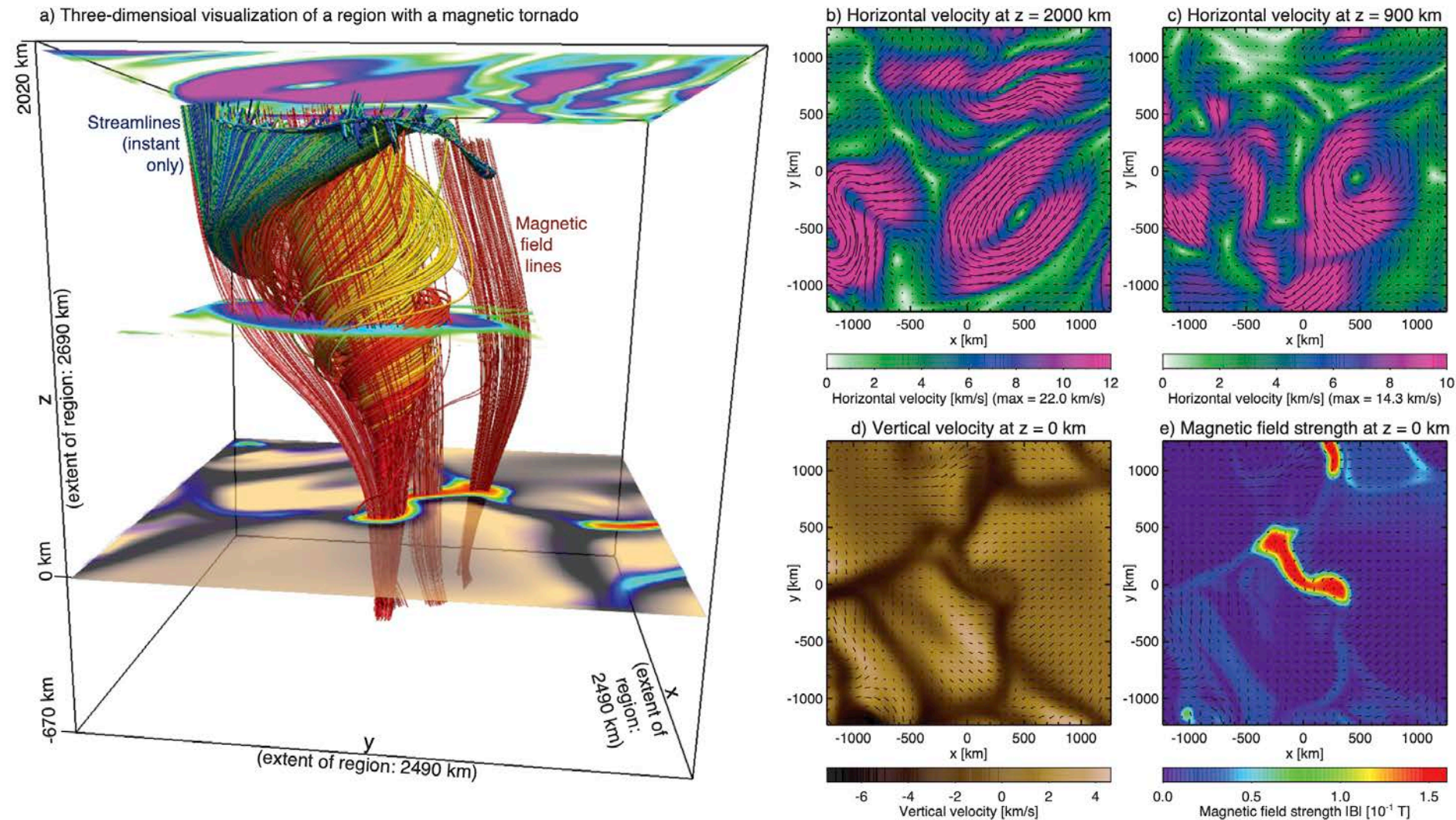


**Fig. 2.** Visualisation of a close-up region in the numerical model by Wedemeyer-Böhm et al. (2012) exhibiting a magnetic tornado. The (red) mostly vertical lines in panel (a) represent the magnetic field, whereas the spiral lines (red–yellow–green–blue) represent the instant streamlines of the plasma in the magnetic tornado. The lower plane shows the granulation pattern of the solar surface at a height  $z = 0$  km (gray–yellowish shades) overlaid with the magnetic footpoints (blue–green–red), whereas the swirl signature (pink ring) can be seen on the top ( $z = 2000$  km) and at an intermediate level ( $z = 900$  km). Please note that the displayed magnetic field lines and streamlines only refer to a single instant in time. The magnetic field rotates in time and the velocity field evolves, too. Consequently, individual (charged) particles do not cross any magnetic field line but do follow the rotating magnetic field lines. The resulting trajectories are shown in figure 3. This image was produced with VAPOR (Clyne & Rast 2005; Clyne et al. 2007). The planes are shown in more detail in panels (b)–(e): (b) horizontal velocity at  $z = 2000$  km, (c) horizontal velocity at  $z = 900$  km, (d) vertical velocity at  $z = 0$  km (with negative velocities for downflows), and (e) absolute magnetic field strength at  $z = 0$  km, all overlaid with streamlines rendering the horizontal flow field in that instant of time. (Color online)

# Example 4 — Statistics

**How are the global stellar parameters connected and what can I learn from that regarding stellar evolution / populations / structure?**

- **Statistical study**

- A desperate way to start: The everything-against-everything plot
  - Just a scatter - no clear correlation ...
  - A notable trend - probably some physical reason for that! (Teff vs L, mass vs radius etc).
  - Linear trend? Can I fit a linear relation to that? Can I interpret this relation?
  - Can I identify groups of data points? Why would there be groups? What do these stars have in common?

- **Spectral energy distribution**

- How well does a black body spectrum fit?
- What do I learn from the deviations for certain wavelength ranges? (See, e.g., <https://ui.adsabs.harvard.edu/abs/2021A%26A...655A.113M/abstract>)