Feedback on first assignment

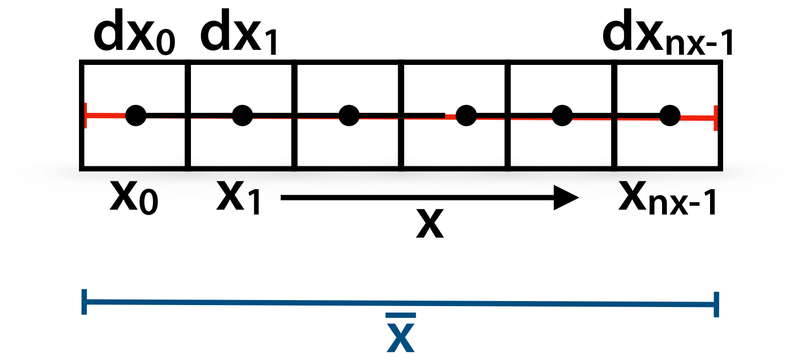
First assignment

Exercise 1.2.4 - 3

- Exercise 1.2.3 (simulation) fine except for a little detail *(sorry if that sounds pedantic but details matter)*:
  - **Computational grid:** The provided models are computed with CO^{5}BOLD (Freytag et al. 2012), which uses a Riemann-type solver (not finite differences)

  ➡ Grid consists of cells, most quantities defined in the cell centres

  ➡ For each dimension: Total extent of computational domain = Total extent of all grid cells



$$\bar{x} = {}^1/_2\, dx_0 + (x_{nx-1} - x_0) + {}^1/_2\, dx_{nx-1}$$

- Ok, to just take the difference between the first and last cell centre but also think about the part of the first and last cell between their centre and the actual model boundary

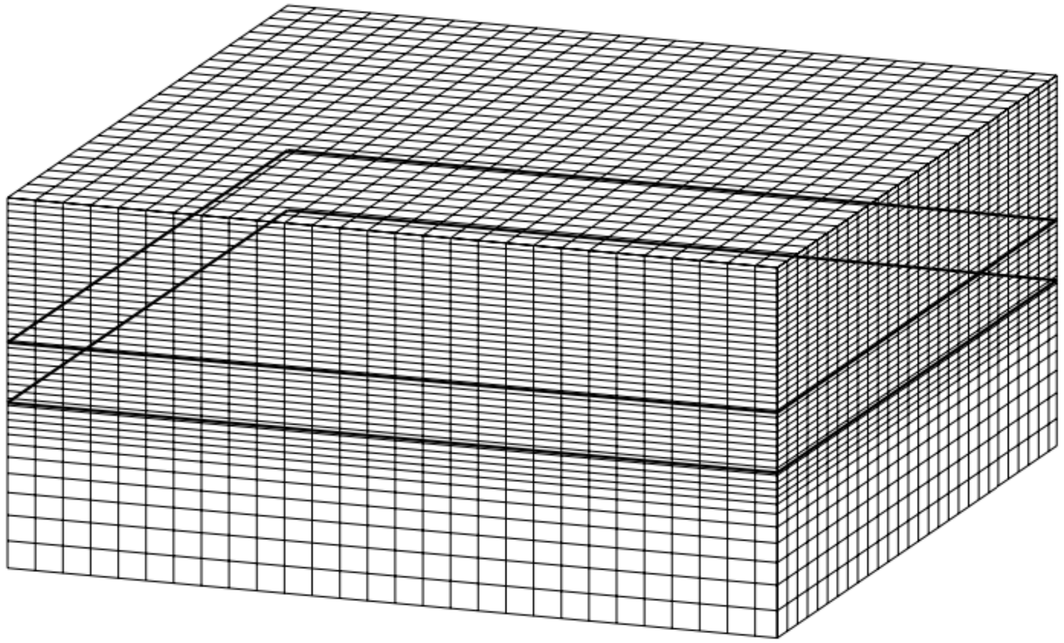
$$\bar{x} = 4725\ \text{km} + 2\ {}^1/_2\ \ 9\ \text{km} = 4734\ \text{km}$$
$$\bar{y} = 4725\ \text{km} + 2\ {}^1/_2\ \ 9\ \text{km} = 4734\ \text{km}$$
$$\bar{z} = 1225\ \text{km} + 2\ {}^1/_2\ \ 7\ \text{km} = 1232\ \text{km}$$

- To be fair … cell sizes only given in vertical direction (dz)
- But grid is equidistant in all directions!

First assignment

Exercise 1.2.4 - 3

- The model provided to you was interpolated onto a vertically equidistant grid.
- Many models are equidistant in horizontal direction but use a varying grid cell size in vertical direction. **WHY?**



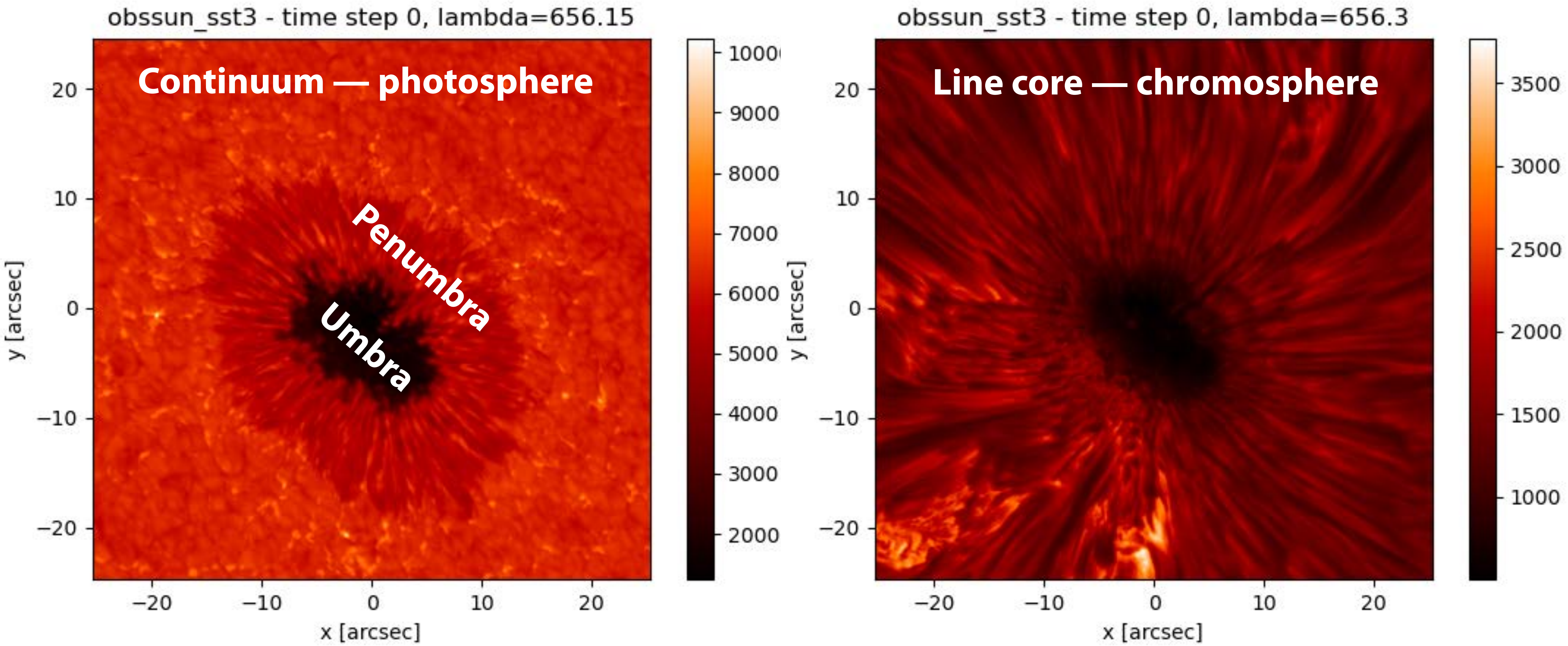
- Important to resolve changes in the relevant quantities such as pressure with enough grid cells
- Remember the stratification and the **pressure scale height**!
  - ➡ Grid cells per pressure scale height
  - ➡ Sufficient to have larger grid cell deeper in the model
  - ➡ Fewer grid cells saves computation time

Exercise: Determine the pressure scale height as function of height in the provided models.

First assignment

Exercise 1.2.4 - 3

obssun_sst3	Sunspot (AR12533), chromospheric spectral line Hα 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

obssun_sst3 - time step 0, lambda=656.3

Continuum — photosphere

Penumbra

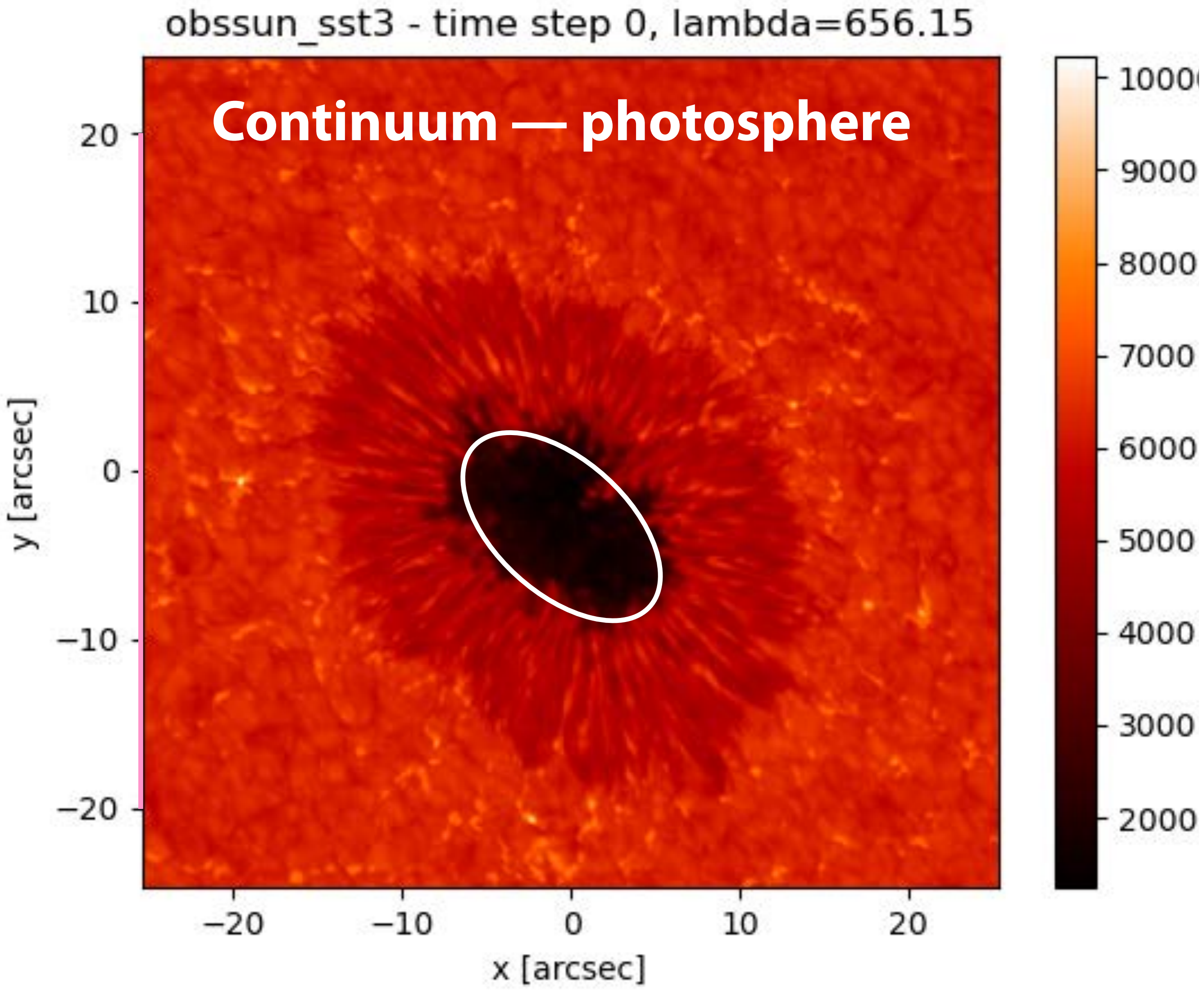
Umbra

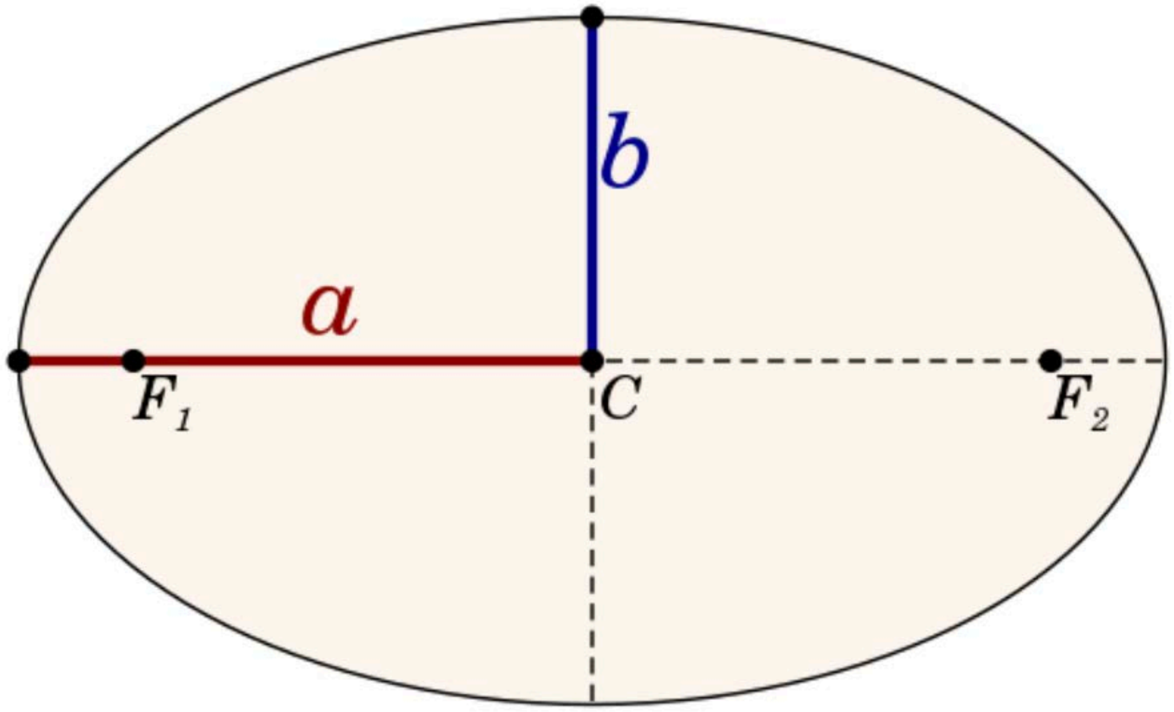
Line core — chromosphere

First assignment

Exercise 1.2.4 - 3

- Ellipse: major axis = longest diameter; minor axis perpendicular to that



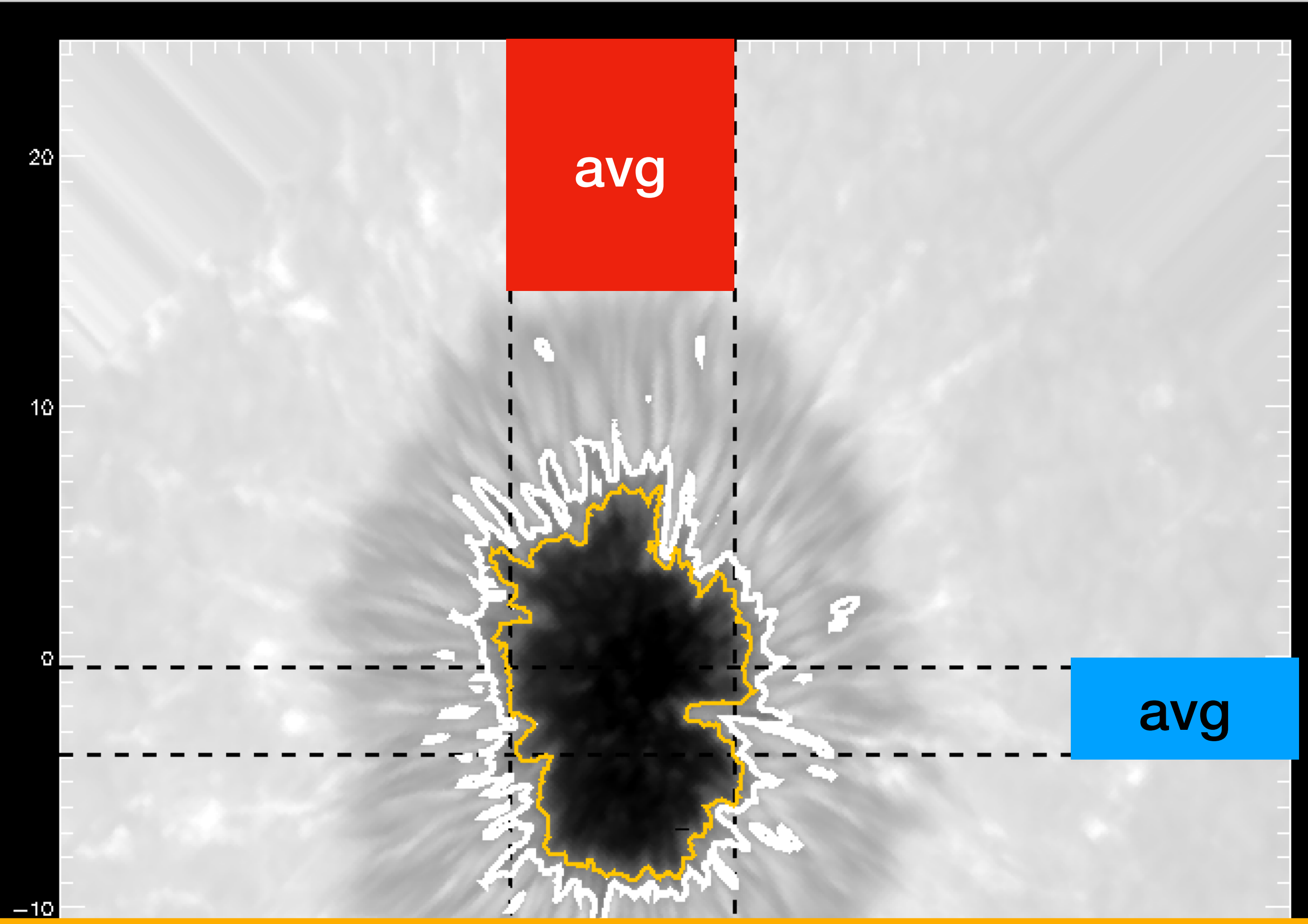


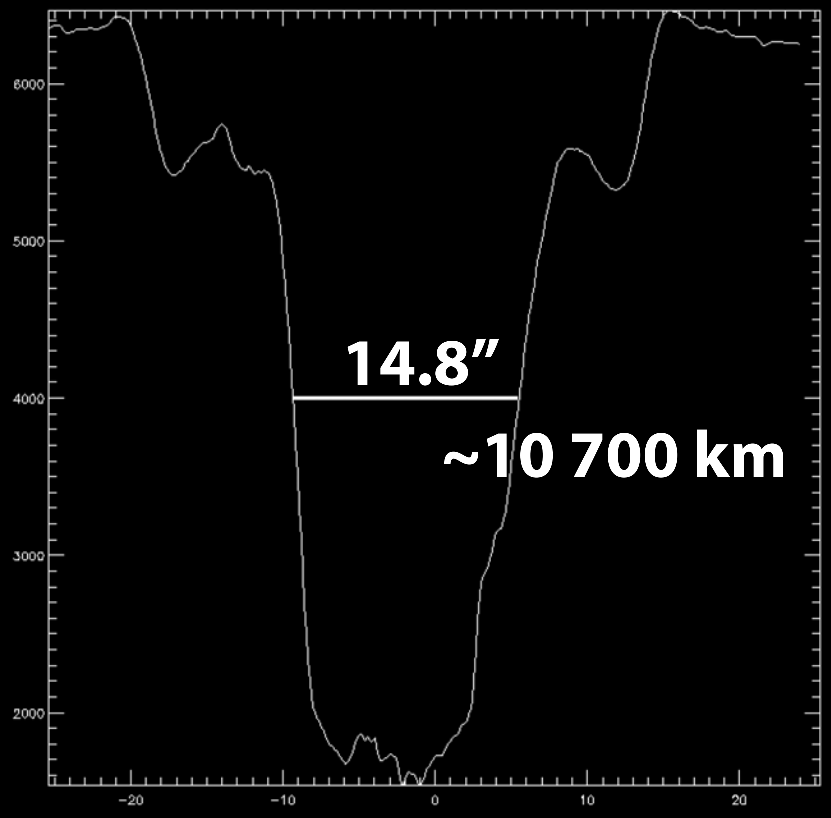
a: semi-major axis

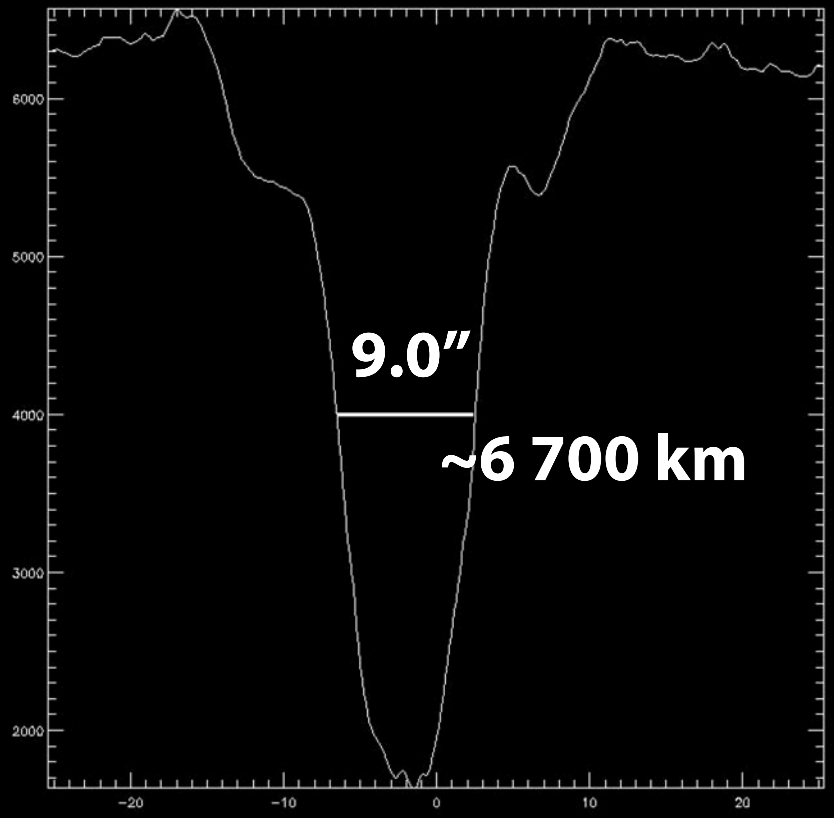
b: semi-minor axis

First assignment

Exercise 1.2.4 - 3







- Exact measurement depends on choice of threshold etc.
- Also, perimeter of umbra varies!
- Just try to be as accurate as possible and describe any major assumption / step that you made to derive the value so that a reader can **reproduce** your result

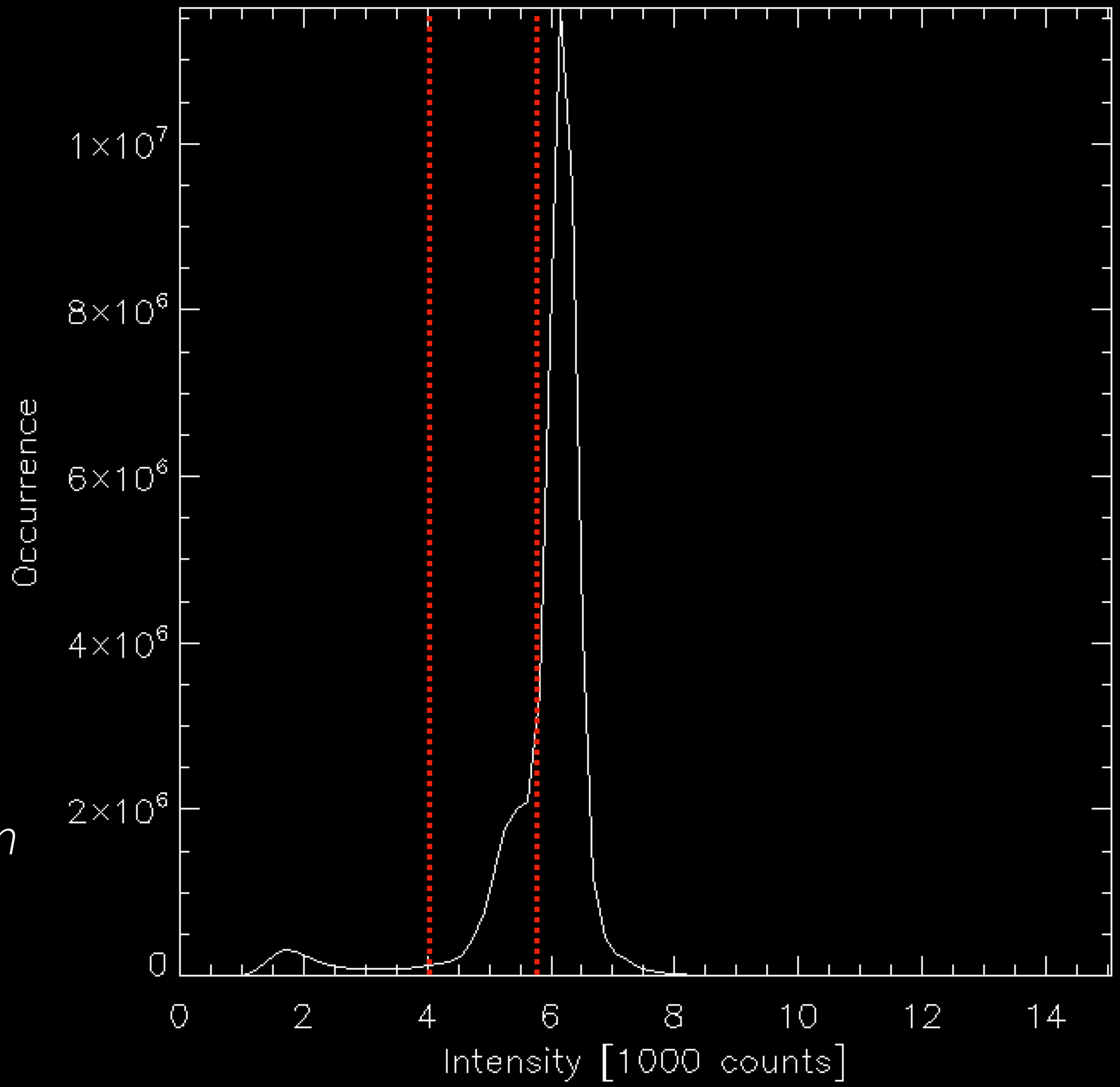
First assignment

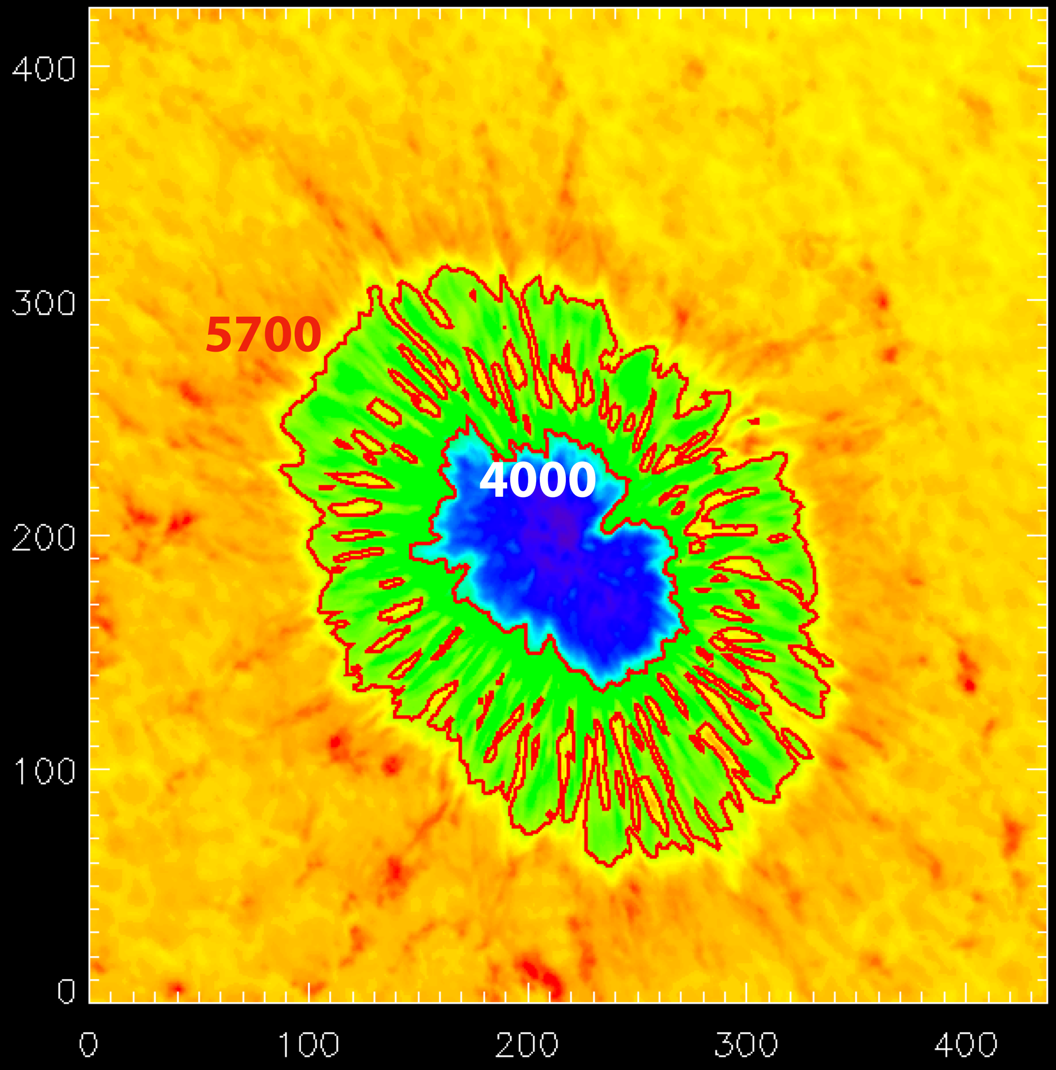
Exercise 1.2.4 - 4

- Three major components
    - Umbra (counts < 4000)
    - Penumbra (counts 4000 - 5700)
    - Surrounding (counts > 5700)

- Thresholds somewhat arbitrary chosen by eye

- *Negative values only in time step 44 (artefacts)*





Second assignment

Tentative science questions and work plan

- Please remember: You do not have to produce completely new scientific results!
- Focus on learning how to carry out a scientific analysis and how to present it in written form similar to a scientific article
- **Advice:**
  - Start realistically and modest with the aim to produce a solid basis.
  - Start with a toned down version of your science question, produce results and figures and describe it in your article (mandatory assignments, continuous writing)
  - If all goes very well, feel free to expand the analysis.

Second assignment

Introduction and background — Aims

- **Aim of a scientific publication:**
  - Present new scientific insights/results that contribute to **advancing the state of knowledge in the scientific field** *(in a way accessible and understandable to other scientists)*

➡ Necessary to identify what of the results goes **beyond** the current state of knowledge

➡ Requires literature research

- What are the relevance and implications of the results in view of the current state of knowledge?

  ➡ Ideally presented connected to existing literature

Accomplished with a good **introduction**:
Background and review of the current state of the art with references to existing literature

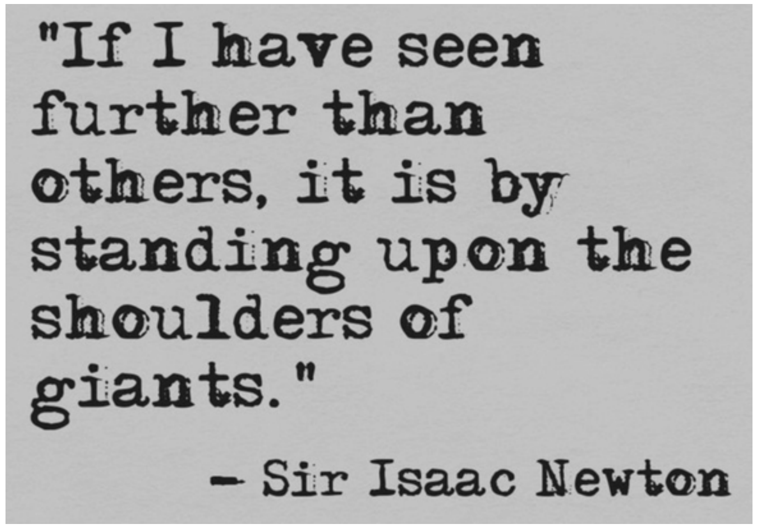
- **For your 2nd assignment (and with the final project assignment:**
  - You are new to all that and writing a comprehensive introduction is a difficult task …
  - … but the best way to learn is to actually *(try to)* just do it!

Second assignment

Introduction and background — Aims

- **The purpose(s) of an introduction:**
    - Introduce the topic (within the scientific field) of your work
    - Provides the context of your work
    - Clearly states the aim/addressed scientific question of the paper and motivates it with respect to he current state in the field/literature
    - Clearly states what is new and thus goes beyond the current state of knowledge
    - Provide an overview of the structure and content of the paper

- *By reading the introduction, a reader should be able to understand why the paper is relevant (and worth reading) and how it will advance the reader's knowledge about the addressed topic.*



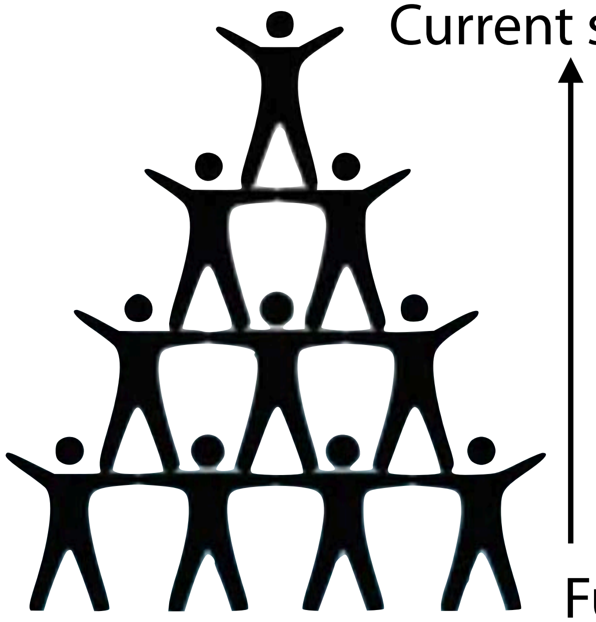
"If I have seen further than others, it is by standing upon the shoulders of giants."

– Sir Isaac Newton

Second assignment

Introduction and background — Level

Don't …



Current state of (advanced) knowledge

Fundamental ("common") knowledge

Reliable research needs systematic order and detail

"Shoulder of giants" = accomplishments of generations of scientists before you

➡ To be honoured in your introduction (at the appropriate level)

- **But at which level to start?**
- Depends on your target audience! How would you explain the interior structure of a star to school child? How to an adult? How to an astrophysicist?
- How "far down the conceptual ladder" do I have to go?
- Specific scientific articles typically start off at a high level already.

Get a "feeling" for this from reading scientific articles!

Second assignment

Introduction and background — Level & balance

- The introduction provides a **concise and balanced** overview of the **relevant** literature
- The introduction should not be expanded into a complete review over many pages!
  - Restrict to the aspects relevant for the new results you are presenting and do cite the most relevant articles.
  - *Complete overviews are given in review paper (which are written for that purpose)*
- Textbook knowledge and statements that are considered "common knowledge" should not be explained in detailed and do not need a specific reference
  - ***Example:*** *In a scientific article, it is not needed to state the radiative transfer equation in its form as presented in countless textbooks and thus no reference is needed. However, if the equation is used in an uncommon form that was published by other authors, then that paper must be cited (and the equation be given if necessary/useful for explaining the new results).*

- **Be fair and balanced.** Some topics are debated with papers stating opposing views. Make sure to cite both cites and argue carefully and fair if you result supports rather one side than the other. Also make sure not only cite papers by your "friends".
  - Be nice and fair if you need to criticise / prove other people's work wrong.

Second assignment

Introduction and background — How to do it?

Gather information

Start reading literature and take notes

- Try to **note** important statements that are **relevant** for your science question and clearly connect them to the source you got them from
- It might be difficult to separate the most relevant from less relevant in the beginning but not get tempted to note all details.
- Look for **references** that are made in these papers that are most relevant for science question.
- Retrieve these new publications and read.

Connect & filter

Make a **mind map** (or some other helpful way) to organise the retrieved information

Try to create a **“red thread”** that connects the most relevant information starting from the general background to your specific science question
(You can start by ordering keywords in your latex doc).

Now fill in the relevant information bits in more **detail** in your own words with **references**

- Do not care about language yet. Do not stop if you don’t remember the English word, just use the Norwegian one for now.

Write

Order the content: First, work on the individual passages and move them around until they match your wanted “red thread”. Remove text that seems to be irrelevant/does not fit.

Language editing: Start from the beginning of the text and rewrite in a consistent way, sentence by sentence. Repeat as often as needed.

Second assignment

Introduction and background — style

- **Scientific articles are written in a particular language/style**
  (very different from other types of literature/written media)

➡ **IMPORTANT: Read scientific articles** and pay attention to how they are written:

  - How are things expressed in terms of language?
  - How are the sentences and paragraph connected?

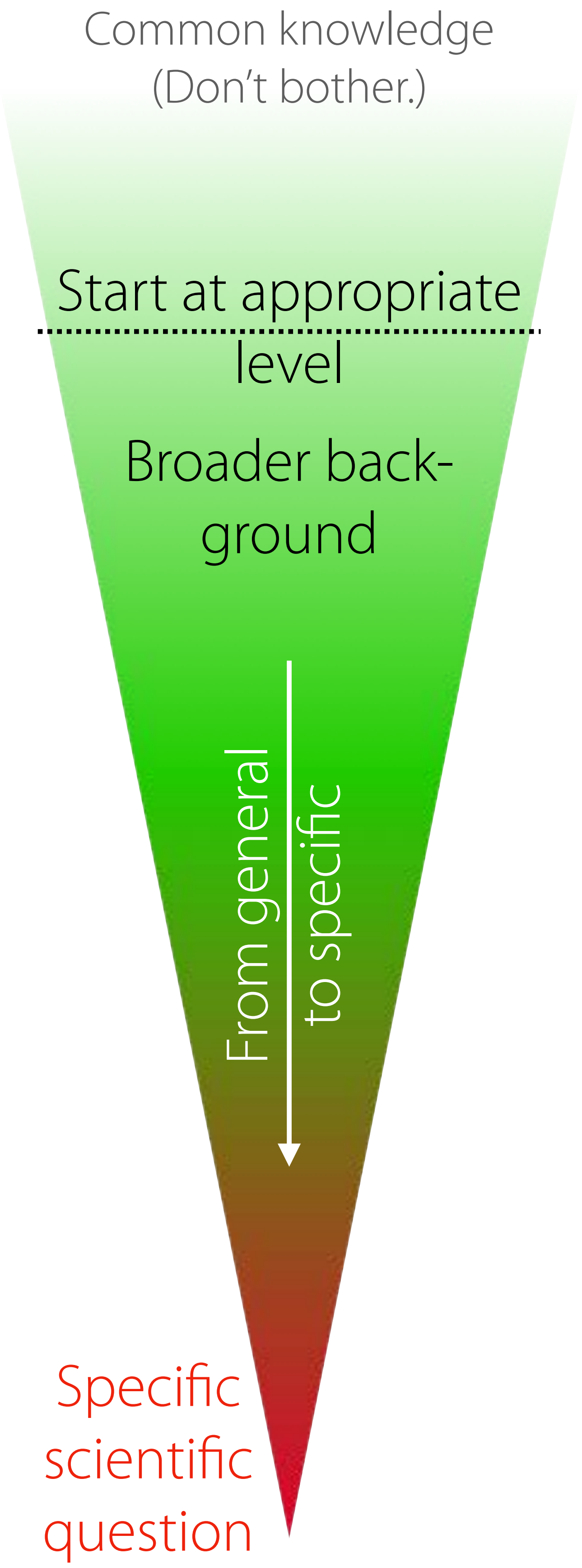
- **Learn by writing yourself.**
  - Try to adopt the style you see in professional scientific articles.
  - Just **get started** and work on a first draft. **Iterate** and improve the text again and again until it is consistent and meets the/your style requirements.
  - You will get **feedback** after delivery of the assignment, which you can use to improve the introduction for the final project assignment.

Second assignment

Introduction and background — structure

- **From general to specific — Tell a (logical) "story".**
  - Start with the general topic and cite papers with general results (finding good review articles may help here)
  - Narrow down towards the specific topic/question of your paper and cite papers that are directly related to your work

- Make sure to mention the following
  - **Motivation:** What is new here and/or why was it necessary to do this study?
    - New method or observational opportunity/better data?
    - Shortcoming in previous research (knowledge gap) that is filled now?
  - Outline your **methodology**/approach including any important ("top level") assumption that is made (but not all details)
  - Possible restrictions/limitations of the results/conclusions
- Optionally, end with an overview of the different sections, describing each with 1-2 sentences



Common knowledge
(Don't bother.)

Start at appropriate level

Broader background

From general to specific

Specific scientific question

Second assignment

Introduction and background — your assignment

- **Your assignments are not scientific journal articles.**

➡ A bit more relaxed regarding the level.

- Any textbook material that you found extremely helpful for explaining the scientific background?

  ➡ Ok to add a concise description.

- The level is appropriate if any other student in this course can understand all of the background of your science case from reading your introduction!

  ➡ It is encouraged to let the others read and comment on your text.

- An introduction of a scientific article typically does not include figures.
  - For your assignments: Ok to add figures under the condition …
    - … the figure is really helpful for introducing your science question.
    - … the figure and all graphical elements are described in a figure caption.
    - … the source is acknowledged (or reference given).

Second assignment

Introduction and background — Examples

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Astronomy & Astrophysics

EMISSA (Exploring Millimeter Indicators of Solar-Stellar Activity)

I. The initial millimeter–centimeter main-sequence star sample

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ABSTRACT

Context. Due to their wide wavelength coverage across the millimeter to centimeter (mm–cm) range and their increased sensitivity, modern interferometric arrays facilitate observations of the thermal and non-thermal radiation that is emitted from different layers in the outer atmospheres of stars.
Aims. We study the spectral energy distribution ($S_{\rm obs}(\nu)$) of main-sequence stars based on archival observations in the mm–cm range with the aim to study their atmospheric stratification as a function of stellar type.
Methods. The main-sequence stars with significant detection in mm bands were identified in the ALMA Science Archive. These data were then complemented with spectral flux data in the extreme ultraviolet to cm range as compiled from various catalogues and observatory archives. We compared the resultant $S_{\rm obs}(\nu)$ of each star with a photospheric emission model ($S_{\rm mod}(\nu)$) calculated with the PHOENIX code. The departures of $S_{\rm obs}(\nu)$ from $S_{\rm mod}(\nu)$ were quantified in terms of a spectral flux excess parameter ($\Delta S/S_{\rm mod}$) and studied as a function of stellar type.
Results. The initial sample consists of 12 main-sequence stars across a broad range of spectral types from A1 to M3.5 and the Sun-as-a-star as reference. The stars with $T_{\rm eff} = 3000$–7000 K (F–M type) showed a systematically higher $S_{\rm obs}(\nu)$ than $S_{\rm mod}(\nu)$ in the mm–cm range. Their $\Delta S/S_{\rm mod}$ exhibits a monotonic rise with decreasing frequency. The steepness of this rise is higher for cooler stars in the $T_{\rm eff} = 3000$–7000 K range, although the single fully convective star ($T_{\rm eff} \sim 3000$ K) in the sample deviates from this trend. Meanwhile, $S_{\rm obs}(\nu)$ of the A-type stars agrees with $S_{\rm mod}(\nu)$ within errors.
Conclusions. The systematically high $\Delta S/S_{\rm mod}$ in F–M stars indicates hotter upper atmospheric layers, that is, a chromosphere and corona in these stars, like for the Sun. The mm–cm $\Delta S/S_{\rm mod}$ spectrum offers a way to estimate the efficiency of the heating mechanisms across various outer atmospheric layers in main-sequence stars, and thereby to understand their structure and activity. We emphasise the need for dedicated surveys of main-sequence stars in the mm–cm range.

Key words. stars: chromospheres – stars: atmospheres – stars: activity – stars: statistics – submillimeter: stars

1. Introduction

The millimeter to centimeter (mm–cm) waveband (≈10–1000 GHz) offers a unique but so far not systematically used way to explore the atmospheric structure of main-sequence stars. As the activity of a star is closely linked to the physical state and dynamics of the plasma in its atmospheric layers (e.g. Noyes et al. 1984; Pace 2013), the mm–cm waveband thus provides complementary means of assessing stellar activity. Because it is so far the only spatially resolved main-sequence star with a large wealth of data and because it consequently is the star we understand best theoretically, the Sun is a good template star that provides insight into the most relevant emission mechanisms in the mm–cm band. The results for the Sun may be transferred to other Sun-like stars of spectral type (FGK type; White 2004) with possible implications for a wider range along the main sequence. In the Sun, the mm continuum (≈30–1000 GHz) is primarily produced by thermal free-free emission, whereas non-thermal contributions are only expected to become significant under extreme conditions like strong magnetic field enhancements and flares. The height of the layer above the photosphere from which the continuum emission originates increases with decreasing observing frequency (see Wedemeyer et al. 2016, and references therein for solar mm radiation). Like for the Sun, the emission in the mm–cm waveband can be expected to originate primarily from different (optically thick) atmospheric layers at different heights in the chromosphere to transition region in Sun-like stars (FGK type). A recent study of α Cen A&B (G2V & K1V) across 17–600 GHz revealed a brightness temperature $T_{\rm B}(\nu)$ for both stars that decreased with frequency and is thus consistent with a chromospheric temperature rise as expected for these spectral types (Trigilio et al. 2018).

For high-mass main-sequence stars (OBA type), the outer atmospheric structure is expected to be quite different from that of Sun-like stars. It is expected that the average temperature rise as seen in the chromosphere and corona of Sun-like stars is absent in high-mass stars. This is primarily because unlike Sun-like stars, OBA stars are not expected to have an outer convection zone that generates and drives dynamic phenomena that play a vital role in generating the hot outer atmospheric layers in Sun-like stars (see e.g. Donati & Landstreet 2009, for a review). Observations of α CMa (A1V; White et al. 2019) and

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α PsA (A4V; Su et al. 2016) show indeed no significant chromospheric emission. Rather, the mm flux as observed with the Atacama Large Millimeter/submillimeter Array (ALMA) seems to be consistent with purely photospheric emission (for α CMa, see White et al. 2019).

Using the Rayleigh–Jeans approximation, the spectral flux density, S_ν, can be converted into the brightness temperature $T_{\rm B}$, as described by

$$S_\nu = \frac{2\,k\,T_{\rm B}\,\nu^2}{c^2}\,\Omega_{\rm s}, \tag{1}$$

where k is the Boltzmann constant and $\Omega_{\rm s}$ is the solid angle subtended by the star. The latter is given as $\Omega_{\rm s} = \pi R_*^2/D^2$, where R_* is the radius of the star and D is the distance to it. Because the emission primarily originates from optically thick layers in the mm range, the brightness temperature spectrum, $T_{\rm B}(\nu)$, is closely related to the temperature in the continuum-forming layer at a height $z(\nu)$ in the atmosphere. Consequently, the observable brightness temperature spectrum ($T_{\rm B}(\nu)$) is a proxy to the atmospheric temperature stratification, $T(z(\nu))$ (see e.g. the semi-empirical models for the Sun by Vernazza et al. 1981). Systematic mm–cm observations of main-sequence stars of different spectral types and ages will therefore provide important constraints for the evolution of stellar atmospheric structure and activity. Comparing these observations with magnetic field properties will help to better understand the connection between atmospheric structure, activity, and magnetic field as predicted by various models (e.g. Kim & Demarque 1996; Garraffo et al. 2018) and inferred from multi-parameter studies of stars in different surveys (e.g. Donati & Landstreet 2009; Vidotto et al. 2014; Lund et al. 2020; Feinstein et al. 2020).

However, only a few main-sequence stars have been detected in the mm–cm range so far compared to the wealth of detections in the IR to X-ray range. The low detection rate so far is a direct consequence of the low expected flux densities of even the nearest Sun-like stars, which are lower than ~100 µJy (1 Jy = 10^{-26} W m^{-2} Hz^{-1}) in mm bands and well below 100 µJy at cm wavelengths (White 2004). A reliable detection at a single frequency therefore requires an instrument capable of providing a sensitivity of about a few tens of µJy within a reasonable integration time of a few hours at most and over a spectral bandwidth of typically ~10 GHz. In addition, a significant fraction of main-sequence stars belong to binary systems with separations that can be as small as a few arcseconds and/or have debris disks with an inner edge close to the star (see e.g. Gao et al. 2014; Moerchen et al. 2007; Lisse et al. 2007). An example of the former case is the α Cen A&B system at a distance of 1.3 pc with an angular separation of just 4″ (Liseau et al. 2016). ϵ Eri at a distance of 3.2 pc is an example of a star with a debris disk that has an inner edge at ~10″ from the star. Consequently, in order to measure the stellar flux without contamination from a companion or a disk, the angular resolution of an observation must be high enough to separate the star from these potential components. The required angular resolution for observations in the mm–cm bands warrants the use of interferometric arrays. Because it is the most sensitive telescope with the largest number of baselines and a large collecting area in mm bands, ALMA[1] is currently the only telescope that meets the requirements in the mm range. In the cm bands, the Australia Telescope Compact Array[2] (ATCA) and the Expanded Very Large Array (JVLA, Perley et al. 2011) are examples of new-generation arrays that can provide such data.

Most of the studies of main-sequence stars in radio wavebands used frequencies below 10 GHz so far, much of which have been on active M dwarfs (see, Güdel 2002, for a review). This is because the flares, especially in active M dwarfs and Sun-like stars, cause coherent radio emissions brighter by several orders of magnitude than the background free-free emission at low radio frequencies (e.g. Bastian 1994; Lim et al. 1996; Crosley & Osten 2018; Villadsen & Hallinan 2019; Davis et al. 2020; Zic et al. 2020). At high frequencies, the flaring rates are low and the emission $T_{\rm B}$ is also much lower, requiring sensitivity limits that are hard to achieve with earlier-generation arrays even for the nearby stars (Bastian 1990; White 2004). However, a few M dwarfs were detected close to 10 GHz by the VLA, namely UV Cet and EV Lac (Osten et al. 2005; Guedel 2006). More recently, the quiescent and flare emission from the nearby M dwarf Proxima Cen was studied with ALMA (e.g. Anglada-Escudé & Butler 2012; MacGregor et al. 2018, 2021). Villadsen et al. (2014) presented the first detection of thermal emission in the cm band using JVLA from Sun-like stars, τ Cet, η Cas A, and 40 Eri A. τ Cet was also observed with ALMA by MacGregor et al. (2016), but the emission was partly contaminated by the edge-on disk emission. Using high-resolution ALMA observations, Booth et al. (2017) were able to distinguish the emission from the K-dwarf ϵEri from its debris disk unlike the IR-band observations of the star (Lestrade & Thilliez 2015; Chavez-Dagostino et al. 2016). Bastian et al. (2018), Rodríguez et al. (2019), and Suresh et al. (2020) extended this up to 2 GHz using the EVLA. The closest binary system α Cen A&B is another repeatedly observed pair of stars that has been observed across all available bands of ALMA, except band 10. The observations were carried out during two different observing cycles separated by 2 yr (Liseau et al. 2013, 2015, 2016; Liseau 2019). A recent study by Akeson et al. (2021) at ≈340 GHz reported similar flux for the binary stars as Liseau et al. (2016). Trigilio et al. (2018) modelled the mm–cm spectrum of α Cen A&B using various scaled solar atmospheric models and demonstrated the existence of a solar-like chromosphere that becomes hotter with increasing distance from the surface. The authors also added 17 GHz flux data points from ATCA to the existing spectra. Following a similar modelling approach as White et al. (2020), they modelled their observations of F-type stars, γ Lep and γ Vir A& B, at ≈233 and 344 GHz. Other F dwarfs that have reliable detection in the mm band are 61 Vir (Marino et al. 2017a) and ηCrv (Marino et al. 2017b). Of the more massive stars, the closest A-type stars, α CMa and α PSa, are the most frequently studied. The former was studied across the ≈30–210 GHz range and the spectrum was modelled by White et al. (2019). The latter garnered more interest primarily due to its circumstellar disk, which was well resolved with ALMA (e.g. Su et al. 2016; White et al. 2017a; MacGregor et al. 2017; Matrà et al. 2017).

We present an initial version of a database of mm–cm fluxes for main-sequence stars detected by ALMA supplemented with other observations from the extreme ultraviolet (EUV) to the radio band. The Sun is included as a fundamental reference. The resulting observed spectral energy distribution (SED) for each star is then compared to the SED calculated with the PHOENIX model (Hauschildt & Baron 1999) to reveal possible chromospheric contributions. The method and initial data set are described in Sect. 2. The resulting SEDs and $T_{\rm B}(\nu)$ are presented in Sect. 3. Section 4 presents the inferences from a comparison of the model and observed SEDs for stars of different types, followed by our conclusions and outlook in Sect. 5.

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[1] `https://almascience.nrao.edu/about-alma/alma-basics`
[2] `https://www.narrabri.atnf.csiro.au/observing/users_guide/`

Second assignment

Introduction and background — Examples

1988ApJ...330..474P

The Astrophysical Journal, **330**:474–479, 1988 July 1

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NANOFLARES AND THE SOLAR X-RAY CORONA[1]

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ABSTRACT

Observations of the Sun with high time and spatial resolution in UV and X-rays show that the emission from small isolated magnetic bipoles is intermittent and impulsive, while the steadier emission from larger bipoles appears as the sum of many individual impulses. We refer to the basic unit of impulsive energy release as a *nanoflare*. The observations suggest, then, that the active X-ray corona of the Sun is to be understood as a swarm of nanoflares.

This interpretation suggests that the X-ray corona is created by the dissipation at the many tangential discontinuities arising spontaneously in the bipolar fields of the active regions of the Sun as a consequence of random continuous motion of the footpoints of the field in the photospheric convection. The quantitative characteristics of the process are inferred from the observed coronal heat input.

Subject headings: hydromagnetics — Sun: corona — Sun: flares

I. INTRODUCTION

The X-ray corona of the Sun is composed of tenuous wisps of hot gas enclosed in strong (10^2 G) bipolar magnetic fields. The high temperature ($2–3 \times 10^6$ K) of the gas is maintained by a heat input of about 10^7 ergs cm^{-2} s^{-1} (Withbroe and Noyes 1977), most of which is lost by radiation as EUV and X-rays. It is observed that the surface brightness of the active X-ray corona is essentially independent of the dimensions of the confining bipole (Rosner, Tucker, and Vaiana 1978) from the normal active region with a scale of 10^{10} cm down to the X-ray bright points at 10^9 cm, and in some cases even down to the small bipoles of 2×10^8 cm at the limit of resolution of present observational instruments.

The heat source that causes the X-ray corona has proved elusive. There is a direct equation between magnetic field strength and heat input (Rosner, Tucker, and Vaiana 1978; Golub *et al.* 1980), and given a source of heat of about 10^7 ergs cm^{-2} s^{-1} the formation of the corona is straightforward: The heated gas expands upward from the top of the chromosphere with a pressure scale height of $1–1.5 \times 10^{10}$ cm; the density of the rising gas increases to about 10^{10} atoms cm^{-3}, at which point radiative losses balance the heat input. The gas pressure is then 6–9 dyn cm^{-2}, the speed of sound is $2–3 \times 10^7$ cm s^{-1}, the magnetic pressure (10^2 G) is typically 4×10^2 dyn, and the Alfvén speed is 2×10^8 cm s^{-1}. The magnetic field is essentially force-free.

The traditional view has been that the convection below the visible surface of the Sun produces sound waves, gravitational waves, and magnetohydrodynamic waves which propagate upward into the overlying atmosphere where they dissipate and deposit their energy as heat in the ambient gas (Bierman 1946, 1948; Alfvén 1947; Schwarzschild 1948; Parker 1958; Whitaker 1963). More recently it has become clear that all but Alfvén waves are dissipated and/or refracted before reaching the corona (Osterbrock 1961; Stein and Leibacher 1974; Sturrock and Uchida 1981; Priest 1982). Presumably, then, it is primarily Alfvén waves that reach the active X-ray corona. The problem is that Alfvén waves are disinclined to dissipate in the corona. Indeed, it is just that disinclination that allows them to penetrate the chromosphere and transition region to reach the corona. Various ideas have been proposed to facilitate dissipation (cf. Hayvaerts and Priest 1983; Hollweg 1984, 1986, 1987; Kuperus, Ionson, and Spicer 1981; Ionson 1984; Lee and Roberts 1986; Davila 1987). The basic point is that in order to provide the necessary heat input without violating the observed upper limit of 25 km s^{-1} on the wave amplitudes (Cheng, Doschek, and Feldman 1979) the Alfvén wave must dissipate within about one period, which is reminiscent of the disintegration of a turbulent eddy (Hollweg 1984, 1986).

Alternatively it has been suggested (Parker 1979, 1983*d*, 1986*c*, 1988) that the X-ray corona is heated by dissipation at the many small current sheets forming in the bipolar magnetic regions as a consequence of the continuous shuffling and intermixing of the footpoints of the field in the photospheric convection. Insofar as the field is concentrated into separate individual magnetic fibrils at the photosphere, each individual fibril moves independently of its neighbors, producing tangential discontinuities (current sheets) between neighboring fibrils at higher levels where they expand against each other to fill the entire space (Glencross 1975, 1980; Parker 1981*a*, *b*; Sturrock and Uchida 1981). There is, however, a more basic effect, viz., a *continuous* mapping of the footpoints spontaneously produces tangential discontinuities (Syrovatsky 1971, 1981; Parker 1972, 1979, 1982, 1983*a*, *b*, *c*, *d*, 1986*a*, *b*, *c*, 1987*a*; Yu 1973; Tsinganos 1982; Tsinganos, Distler, and Rosner 1984; Moffatt 1985, 1986; Vainstein and Parker 1986). The discontinuities appear in the initially continuous field at the boundaries between local regions of different winding patterns. The tangential discontinuities (current sheets) become increasingly severe with the continuing winding and interweaving, eventually producing intense magnetic dissipation in association with magnetic reconnection (Parker 1983*d*, 1986*c*).

Now, fundamental to any theoretical idea on the energy input to the corona is the mechanical work done on the magnetic field by the photospheric convection. Thus, far, observations have failed to detect either the expected wave motion or the expected shuffling and intermixing of the footpoints. The principal observational difficulty is the continuing inability to resolve the individual magnetic fibrils [with diameters of about

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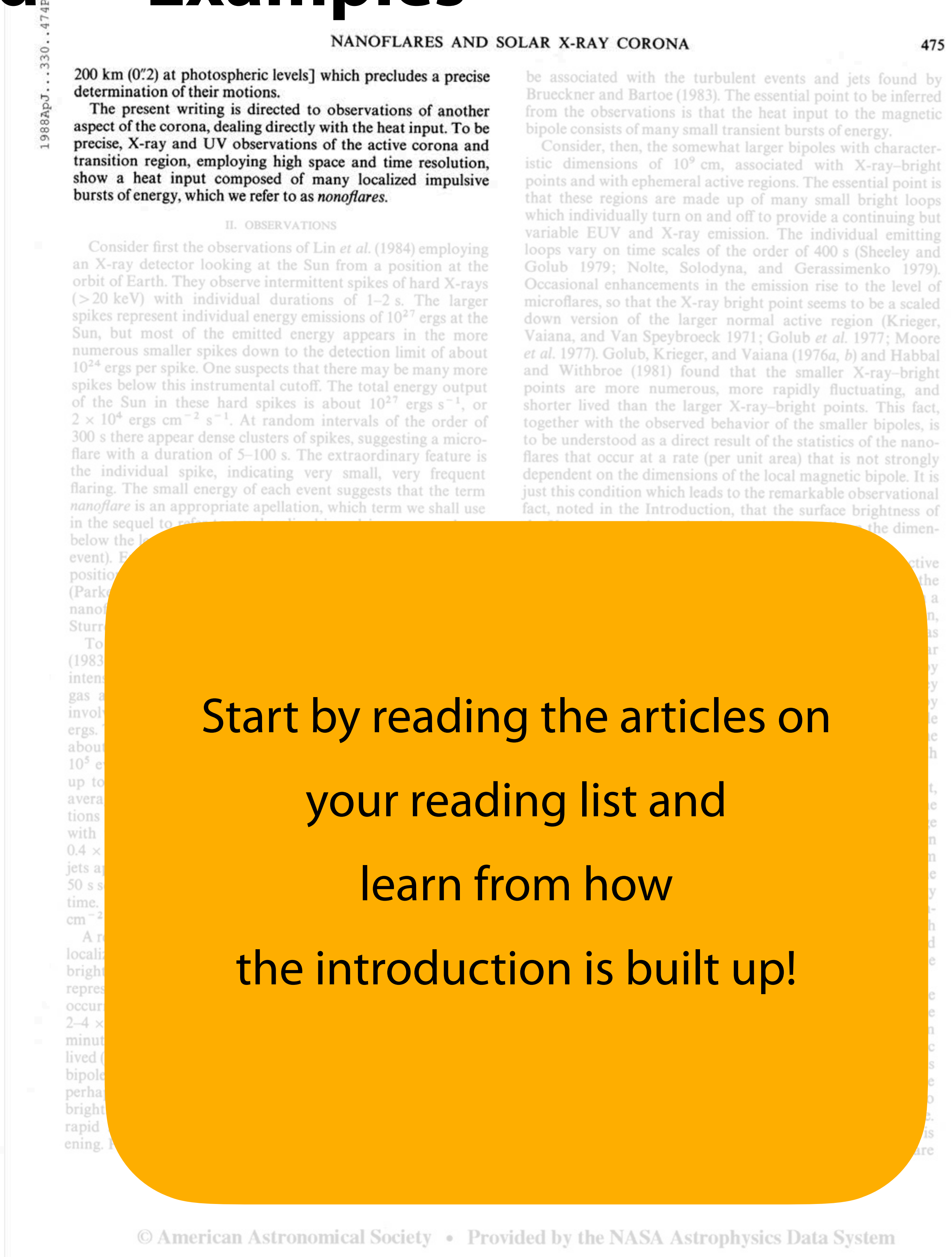

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200 km (0".2) at photospheric levels] which precludes a precise determination of their motions.

The present writing is directed to observations of another aspect of the corona, dealing directly with the heat input. To be precise, X-ray and UV observations of the active corona and transition region, employing high space and time resolution, show a heat input composed of many localized impulsive bursts of energy, which we refer to as *nonoflares*.

II. OBSERVATIONS

Consider first the observations of Lin *et al.* (1984) employing an X-ray detector looking at the Sun from a position at the orbit of Earth. They observe intermittent spikes of hard X-rays (>20 keV) with individual durations of 1–2 s. The larger spikes represent individual energy emissions of 10^{27} ergs at the Sun, but most of the emitted energy appears in the more numerous smaller spikes down to the detection limit of about 10^{24} ergs per spike. One suspects that there may be many more spikes below this instrumental cutoff. The total energy output of the Sun in these hard spikes is about 10^{27} ergs s^{-1}, or 2×10^4 ergs cm^{-2} s^{-1}. At random intervals of the order of 300 s there appear dense clusters of spikes, suggesting a microflare with a duration of 5–100 s. The extraordinary feature is the individual spike, indicating very small, very frequent flaring. The small energy of each event suggests that the term *nanoflare* is an appropriate apellation, which term we shall use

be associated with the turbulent events and jets found by Brueckner and Bartoe (1983). The essential point to be inferred from the observations is that the heat input to the magnetic bipole consists of many small transient bursts of energy.

Consider, then, the somewhat larger bipoles with characteristic dimensions of 10^9 cm, associated with X-ray–bright points and with ephemeral active regions. The essential point is that these regions are made up of many small bright loops which individually turn on and off to provide a continuing but variable EUV and X-ray emission. The individual emitting loops vary on time scales of the order of 400 s (Sheeley and Golub 1979; Nolte, Solodyna, and Gerassimenko 1979). Occasional enhancements in the emission rise to the level of microflares, so that the X-ray bright point seems to be a scaled down version of the larger normal active region (Krieger, Vaiana, and Van Speybroeck 1971; Golub *et al.* 1977; Moore *et al.* 1977). Golub, Krieger, and Vaiana (1976*a*, *b*) and Habbal and Withbroe (1981) found that the smaller X-ray–bright points are more numerous, more rapidly fluctuating, and shorter lived than the larger X-ray–bright points. This fact, together with the observed behavior of the smaller bipoles, is to be understood as a direct result of the statistics of the nanoflares that occur at a rate (per unit area) that is not strongly dependent on the dimensions of the local magnetic bipole. It is just this condition which leads to the remarkable observational fact, noted in the Introduction, that the surface brightness of

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  (includes sources like (text)books, other scientific articles, theses, webpages etc.)
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  ➡ Unfair and often illegal — not ok
  - Quoting text word by word (with or without quotation marks) is plagiarism
  - Presenting a published result/idea (that is not common knowledge) in own words without citing the source is plagiarism.
  - Copying text from you own published texts without reference = **self-plagiarism**, also not ok!
  - Careful: Today articles/theses are checked automatically for plagiarism.
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  - Not worth it, unnecessary and easily **avoidable**!

Second assignment

Plagiarism and how to avoid it!

- **Plagiarism = copying** text without explicitly acknowledging the source
  - Not worth it, unnecessary and easily **avoidable**!

- *"… but it is so much easier to copy nice text than coming up with new text myself…"*

- **How to avoid it then?**
  - You find a sentence/paragraph that you wish you could use it in your article. What to do?
    1. Copy the text and immediately mark the text in quotation marks with a different colour and write the source before/behind it. *Make sure the highlighting does not disappear accidentally.*
    2. **Rephrase** the most relevant part in your own words and make sure it is clear that this statement/idea originates from the mentioned source.
  - **Example** from the paper by Nordlund et al. (2009): *"The typical size of granules, and other convective cells deeper inside the convection zone, is set by mass conservation and is a few times the local scale height."*
    - Rephrased in your paper, e.g.: *According to Nordlund et al. (2009), as a result of the conservation of mass, the typical size of convective cells including granules at the surface is a few times the local scale height.*