Chapter 9

Summary, conclusions and outlook

9.1 Summary

In this thesis, we investigated several approaches to model the AR corona on the Sun. Observational constraints and inputs are provided by the SDO of NASA (Pesnell et al., 2012), mainly by the EUV imager AIA (Lemen et al., 2012) and the polarimeter HMI (Schou et al., 2012, chapter 4). Compared to other ways of analysing the physical conditions in the corona (for example Kashyap and Drake, 1998; Hannah and Kontar, 2012; Aschwanden et al., 2013), we intended to achieve a three dimensional model atmosphere rather than two dimensional maps. In contrast to tomographic and stereoscopic methods (like Aschwanden et al., 2000a; Vásquez et al., 2011), we also wanted the model to work for a single instrument and with a single set of observations taken in a short time (a minute or so).

Coronal models incorporate coronal heating. Therefore, if a model is able to reproduce the observed appearance of an AR corona, it can be deduced that the incorporated heating mechanism is likely to act in the observed AR. Such conclusions are desirable as the roles of different mechanisms in coronal heating are still under debate.

In all of the methods we investigated here, extrapolated magnetic fields and the field lines derived from these fields are used as a tracer for the loops. We use non-linear force-free-field models, namely the code by Wiegelmann et al. (2012) and its stereoscopic extension by Chifu et al. (2017). As these extrapolation codes are applicable only to ARs near the centre of the solar disk, we also focus on such ARs.

Goal of all methods is to obtain the physical quantities, electron density, electron temperature and gas pressure, along the field lines. After obtaining these quantities, images can be synthesized from the model atmosphere which can be compared against real observations. Also, the distribution of the quantities can be analysed for which heating mechanism fits best, if not already known.

First, we tried to retrieve the quantities along the loops (or in our case: the field lines) directly from the observations (chapter 6). The method of background subtraction and filter ratio analysis used is described in Aschwanden et al. (2008a). In the core of the AR, loops are heavily criss-crossing in the observed images. We found that this makes, in our opinion, an appropriate background subtraction impossible. The method is, hence, not feasible. We note that Aschwanden et al. (2013) published a code which incorporates an automated detection of loops in AIA observations. They detect the loops directly from the contrasts in the images, without using field lines. However, sometimes they also have problems to detect loops in the cores of near-disk-centre ARs, resulting in some voids without detected loops (compare their figure 11).

Next, we applied static loop models to the field lines (chapter 7). We used the classical model by Rosner et al. (1978) and the model by Serio et al. (1981). We combined them with scalings from Golub et al. (1982) and Schrijver et al. (2004) to close the set of equations. We also applied an isothermal model made by ourselves. Besides the NLFFF we also used a LFFF and a potential field model. None of the models can reproduce the EUV observations, and all have to be rejected.
As a consequence, no statement about the actual heating mechanisms can be made. This is in line with the work by Lundquist et al. (2008a), Warren and Winebarger (2006) and Dudík et al. (2011). They mainly modelled the AR corona with static models fitting X-ray observations. When they synthesized EUV images from their solutions, these images were not able to match observations either. However, the NLFFF produces a rather organic, realistic shaped AR, while the LFFF and the potential field cause the AR to appear very artificial in its morphology. This is contradicting to Lundquist et al. (2008a) who claimed that the difference in the appearance of the modelled AR between using a potential field and a NLFFF is negligible.

Finally, we developed a new code for iteratively fitting the 3D atmosphere using the fields lines and single vantage point observations [Barra, re-submitted to Solar Physics, chapter 8]. The code, labelled Fitting coronal Plasma iteratively FitCoPI, updates the physical properties at each point on the field lines, followed by smoothing the updates. This smoothing allows to discriminate between two loops in locations where they cross each other in the observations. In this early stage, the code is able to reproduce the observations quite remarkably. This is especially true for the observations that are used for the fitting input. Besides of this, though with some larger errors, also observations from other vantage points made at the same time match images synthesized from the fitted atmosphere very well. The errors in density and temperature, determined on the basis of a test case, allow for order of magnitude estimations. Possibilities how to further improve the code are given in [Barra, re-submitted to Solar Physics], too. Warren et al. (2018) published a way to link traced loops in the observations to field lines yielded from field extrapolations. This method allows to gain a 3D atmosphere, too. Their method is, consequently, limited to the loops actually detected, which is difficult in the core. Compared to that, we can gain atmospheric reconstruction everywhere where there is a field line. Also, their method can yield physical properties for only one point along the LOS of each pixel while our method provides a resolution along the LOS. On the other hand, their method can use the well tested DEM analysis for retrieving the densities and temperatures. Both methods may be combined.

9.2 Conclusions

From the results mentioned above, we can draw several conclusions:

- In the core of an AR, background subtraction is nearly impossible. Directly inferring the physical conditions in loops located there is, therefore, not feasible.
- Static models cannot reproduce the EUV emission of an AR.
- The NLFFF should be preferred for extrapolating coronal magnetic fields from vector magnetograms, compared to potential fields and LFFFs.
- The FitCoPI code can already yield a good approximation of the AR corona. As it can be improved, it is an approach which should be pursued further.

9.3 Outlook

Analysing the atmosphere of AR 11087 obtained by the FitCoPI code in terms of signatures of heating mechanisms is pending. In the future, we would like to improve the FitCoPI approach further. Also, more tests on other active regions are planned as soon as possible to further proof the robustness of the method. Once the code can give very precise results, much better than now, time series of three dimensional AR coronas are possible. Such time series would allow to follow the heating and cooling processes very detailed. Especially, the correlation to the dynamics of the magnetic field can be seen. Surely this would provide strong evidence on the heating mechanisms acting, or not acting, or co-acting in the AR, in different parts of it and at different times.