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FitCoPI: Fitting density and temperature of coronal active region plasma in 3D from single vantage point observations

Background: Knowing the *three dimensional* distribution of plasma density and temperature in a solar active region (AR) is desireable. This would allow for better analysis and deeper understanding of the coronal processes.

Problem: Solar corona is optically thin. => Only line-of-sight integrated intensities can be measured, resulting in just *two dimensional* maps.

Current approaches: Tomographic and stereoscopic methods:

- Observing from two or more vantage points at the same time [1]. *Disadvantage*: Currently restricted to *STEREO* data [2].
- Observing from one point over a certain time, so that one gets different perspectives onto the same structure due to solar rotation [3]. *Disadvantage*: Requires the sun to rotate for a day or so, but processes in an AR are faster (cooling time of 1h, for example).

Our method: Iteratively fitting a 3D atmosphere using EUV/X-ray observations and extrapolated coronal magnetic fields. Smoothing of updates along field lines dissolves problems when loops are crossing each other.

The *FitCoPI* code [4]:

- Take a set of EUV/X-ray images of an AR, taken at (approximately) the same time.
- Extrude the image plane into the third dimension, dividing the volume into cells based on the pixel size (fig. 1)
- Take a magnetic field extrapolation for an AR.
- Place sample points along the field lines. The points monitor density and temperature.
- Map plasma properties on the points into the cells, ending up with a 3D atmosphere of the AR. This allows for synthesizing images.
- *Update densities on the sample points based on intensity mismatches in observed and synthesized images.*
- *Update temperatures on the sample points based on mismatches in the filter ratios in observed and synthesized images.*
- *Key point: Smooth updates along field lines to distinguish two loops where they are crossing each other (fig. 2).*
- *Iterate until reaching a quasi-stable state.*

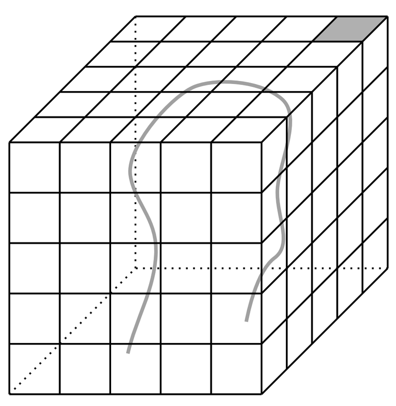


Fig. 1: The observations (top facet) is extruded into the 3rd dimension. A pixel (gray facet) determines the cell size. Extrapolated field lines (gray line) are within the volume.

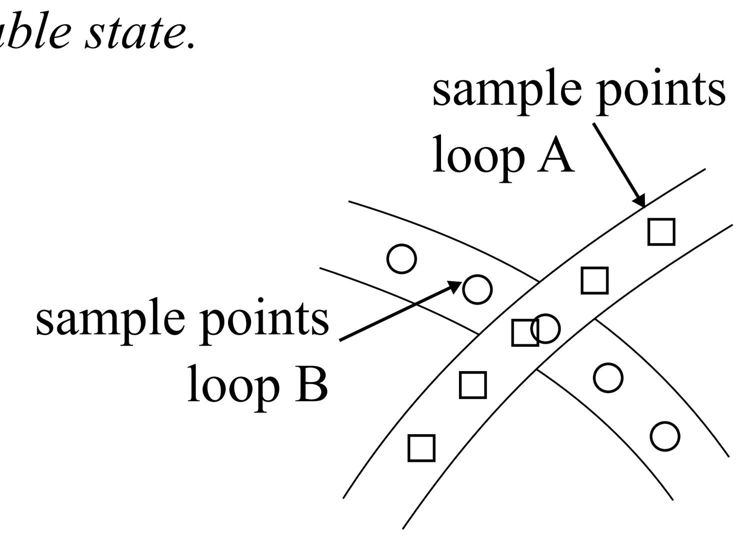
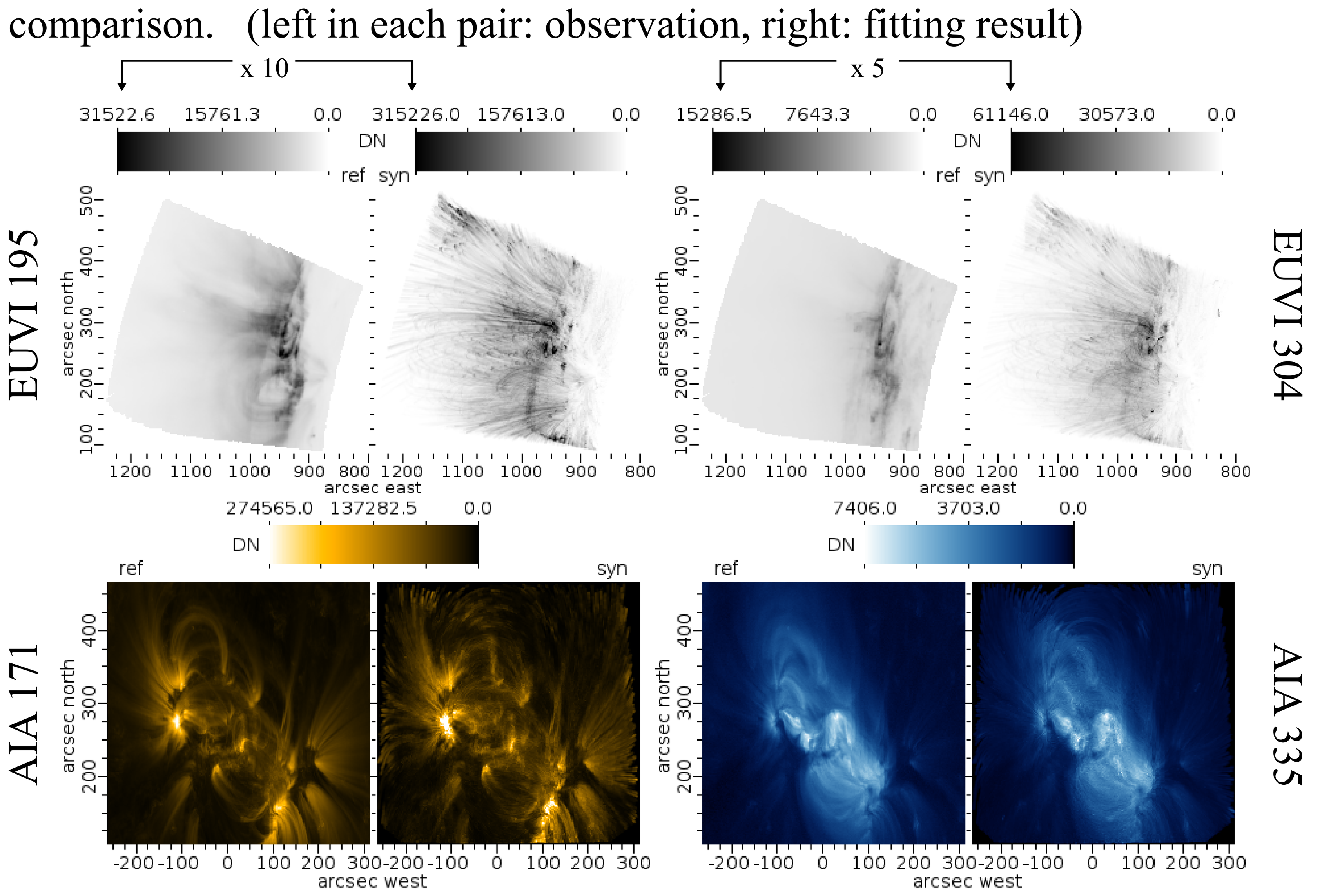


Fig. 2: The plasma properties of the two loops in the crossing point are distinguished by smoothing iterative updates with the neighboring sample points.

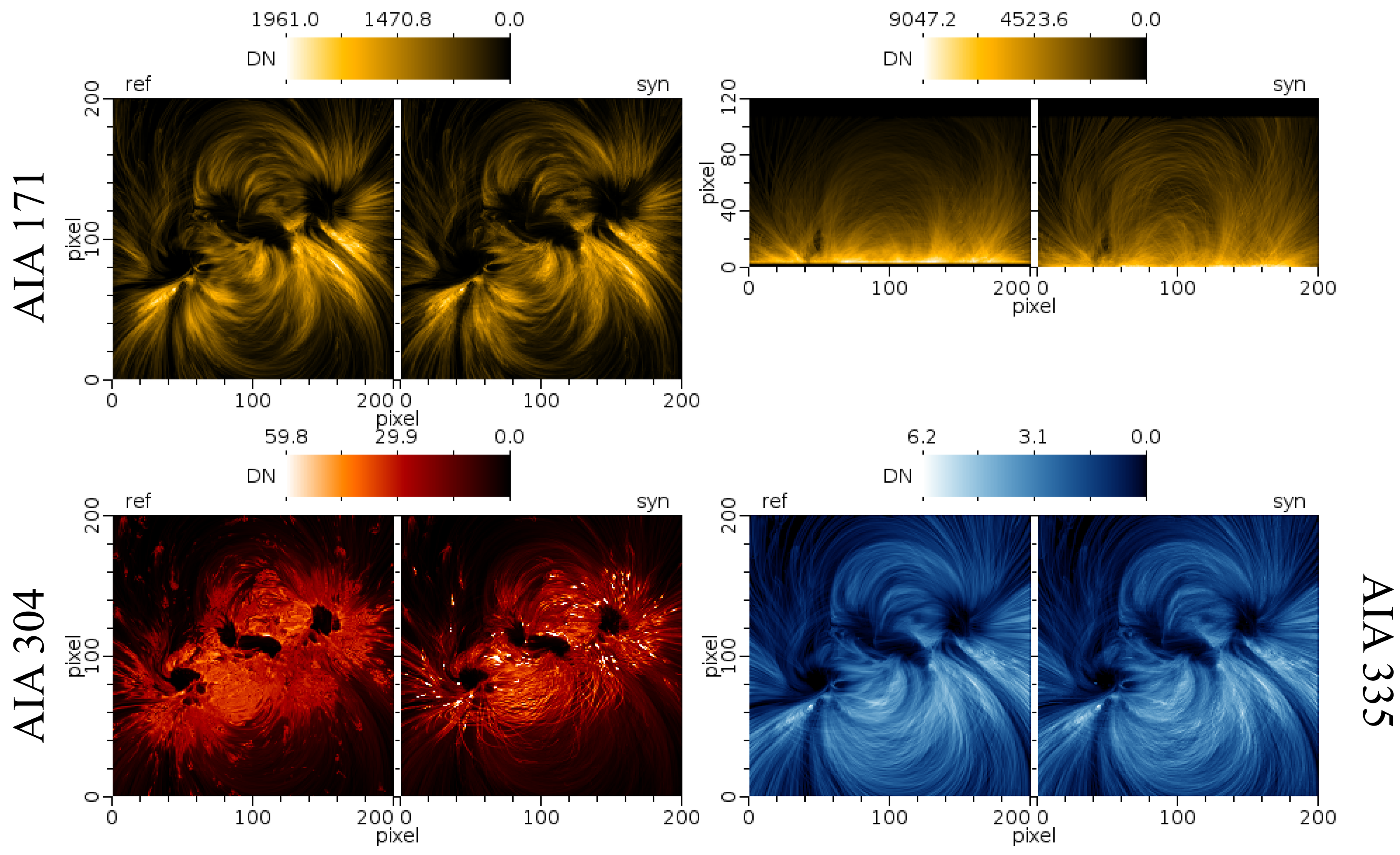
Applying algorithm to AR 11087, 15 Jul 2010, field extrapolated by [7] with their S-NLFFF.

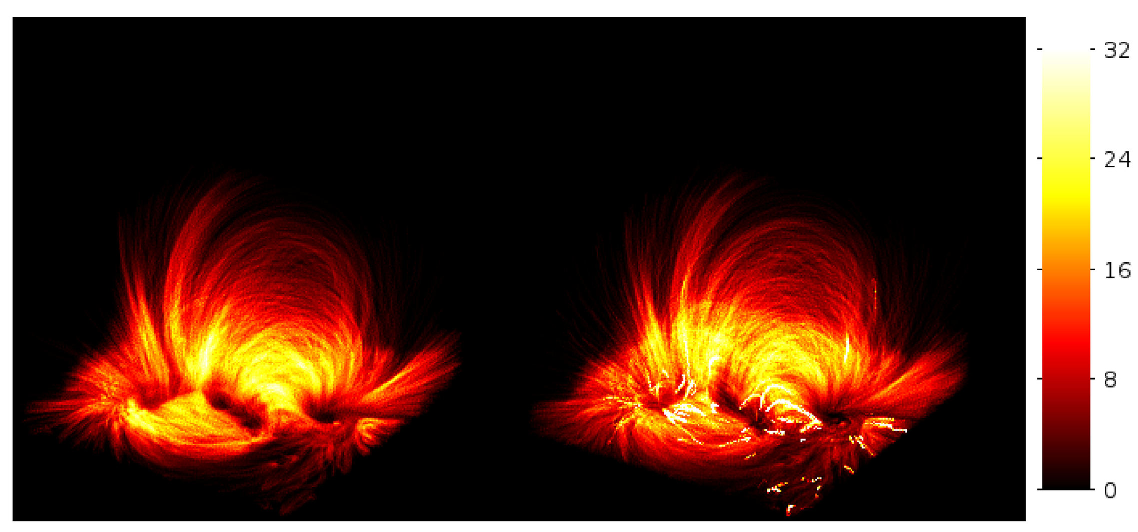
- SDO/AIA as input. Reduced to 200 x 200 pix for computational reasons.
- STEREO A/EUVI [8] images synthesized from results => independent comparison. (left in each pair: observation, right: fitting result)

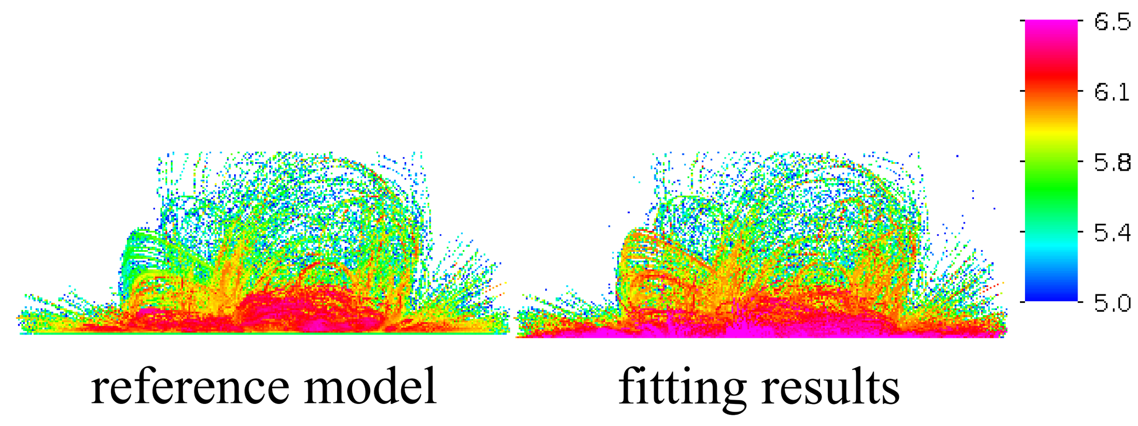


Test on model AR: Field of AR 11158, 14 Feb 2011, extrapolated with NLFFF [5] + simple loop model. Advantage: We now plasma properties and can compare fitting results against model.

Synthesized SDO/AIA [6] images of the model AR serve as input "observations" . (left in each pair: model, right: fitting result)







Discussion:

- *FitCoPI* can reproduce observed images very well.
- For the test model: relative density-error about 60%, relative error in log *T* about 4%.
- EUVI images are a bit brighter. But: Intensities are sensitive to errors in temperature. Structure of AR is still captured.
- Coronal temperatures reach down to photosphere due to smoothing. Results are not applicable here.
- On the other hand, good reproduction of the corona.
- Advantage of our method: Single vantage point is sufficient, the cadence of available 3D atmospheres is determined by the observing instrument.
- Disadvantages: Smoothing reduces spatial resolution a bit.
- Here: Relatively simple implementation of the approach. Improvements may resolve currently remaining problems.

Conclusion: The approach, here implemented by our *FitCoPI* code, is an appropriate ansatz which should be pursued further.

Bibliography:

[1] Aschwanden et al.; ApJ 680, 1477 (2008)
[2] Kaiser et al.; SSR 136, 5 (2008)
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[4] Barra; submitted to SoPh
[5] Wiegelmann et al.; SoPh 281, 37 (2012)
[6] Lemen et al.; SoPh 275, 17 (2012)
[7] Chifu et al.; ApJ 837, 10 (2017)
[8] Howard et al.; SSR 136, 67 (2008)