Image refinement and estimation of intensity contrast degradation at small scale events of Solar observations

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Objectives:

Intensities and contrasts are degraded in observations with limited angular resolution. We perform image refinement and estimations of the degradation of intensities at limited angular resolution, in order to facilitate meaningful analysis of small-scale dynamics. The concept is general, but here we present specific applications on millimeter wavelength for observations with the Atacama Large Millimeter/sub-millimeter Array (ALMA).

Neural Network Architecture

Long Short Term Memory (LSTM) - Suitable to handle long sequences of data. Recognizing patterns at short scales and preserves information over long scales of the data sequence.

Convolutional Long Short Term Memory (Conv-LSTM) - Applying convolutional operations at all gates, which allows to capture spatial features and study their dynamic evolution in temporal domain (see e.g. Shi et al. 2015).

3D MHD Bifrost simulations

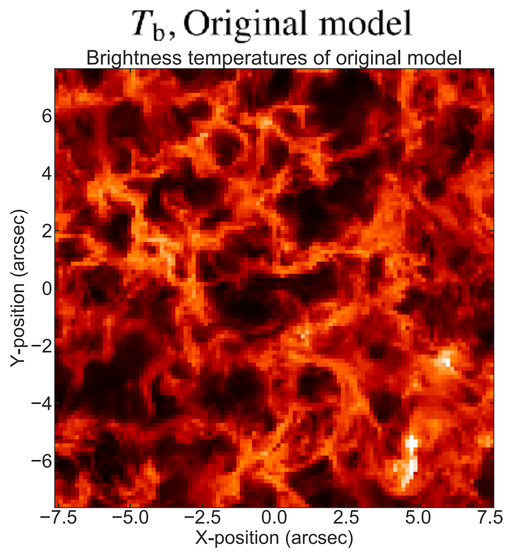
are used for training and validation (never previously seen by the Neural network) of the neural network. The models are re-runs of publicly available simulations (Carlsson et al., 2016), with high cadence and treatment of non-LTE and non-equlibrium hydrogen ionisation (suitable for observables in millimeter wavelengths).

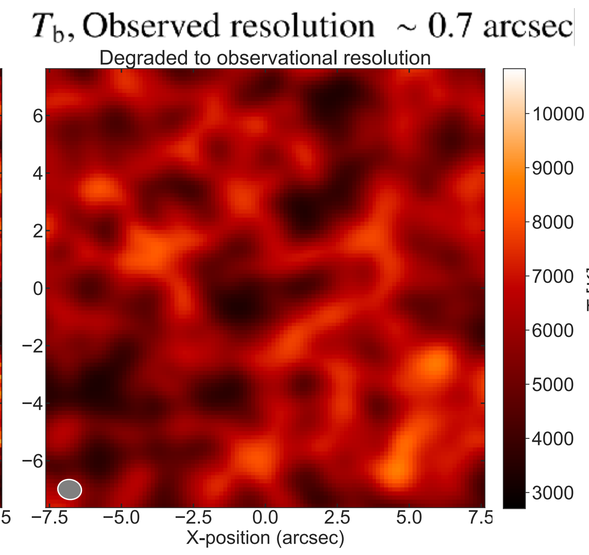
Simulation for:

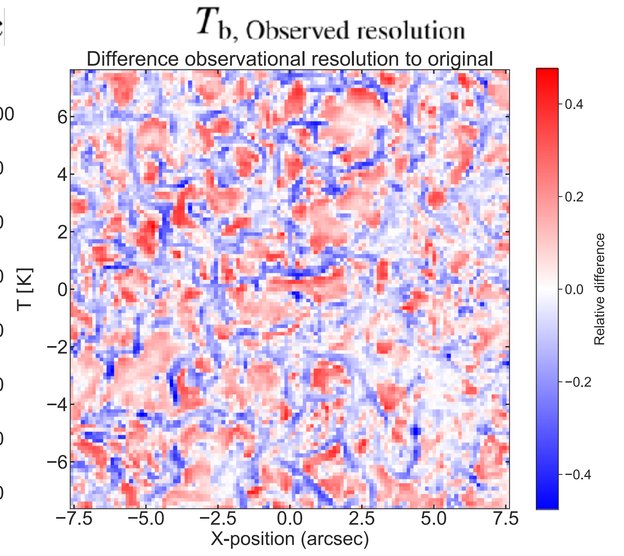
Training data	**Validation data**
- Box size: 33” x 33”	- Box size: 15” x 15”
- 1 s cadence	- 2 s cadence
- 3600 s in total	- 200 s in total

Observables at millimeter wavelengths are obtained from radiative transfer calculations (using ART, de la Cruz Rodríguez, 2021), here shown λ=1.25 mm (ALMA band 6) which are degradation to resolution of ALMA observations ~ 0.7 arcsec (see Eklund et al. 2021 for details) by convolution of the Point spread Function (clean beam).

The Neural Network is given sequences of the degraded data with temporal span of 100s and a spatial extent of 2 x 2 arcsec and is asked to estimate the non-degraded highly resolved data. The Neural Network regards small scales and is therefore applicable independently on the large scale structures.

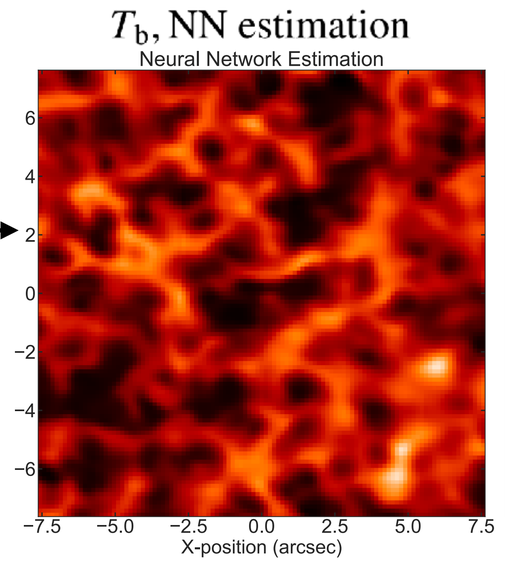


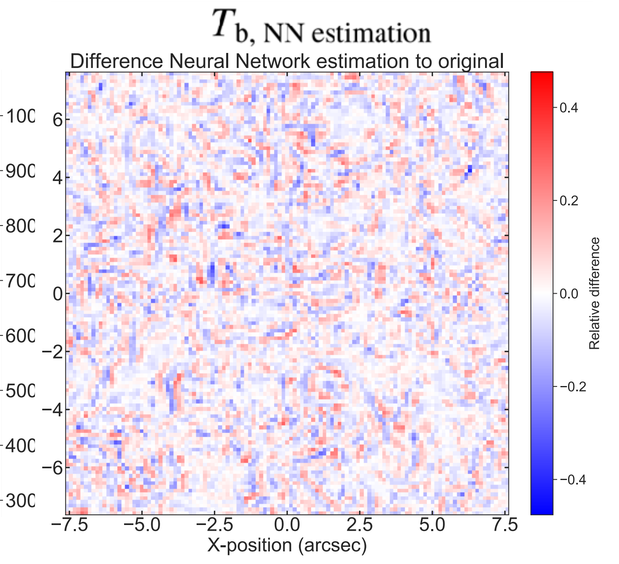


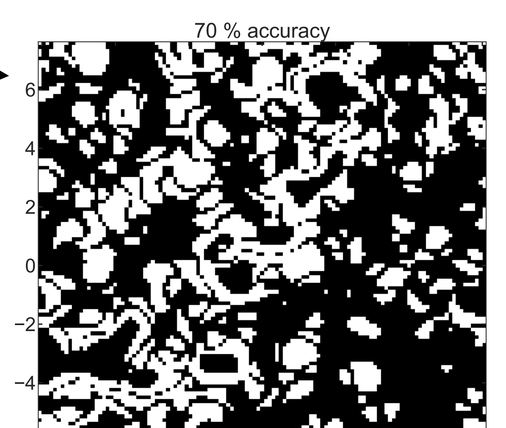


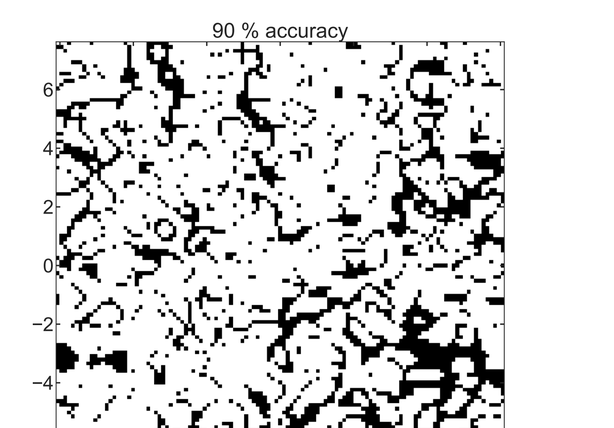
Estimations from Neural Network:

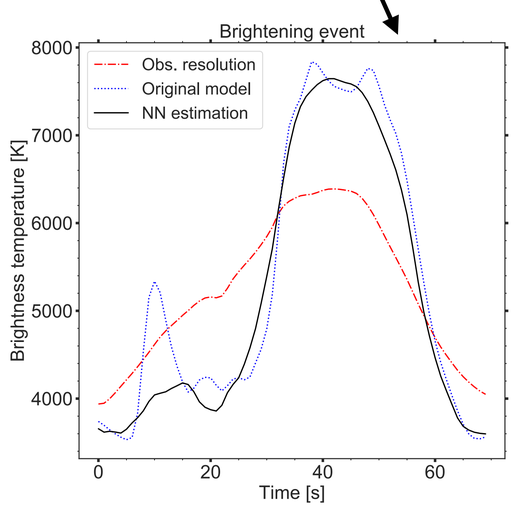
- Refined images of intensities with improved contrasts over the field of view, for each time step.
- Locations with high accuracy in field of view of obsevational data. The locations where intensities shown at observational resolution (0,7 arcsec) are at least 70 % accurate (left) or 90 % accurate (right), in comparison to the original high resolution model (0,066 arcsec).
- Analysis of small-scale brightening events. (see Eklund et al. 2020, 2021 for details). The brightening events (left) are mostly underestimated at observational resolution (middle). The Neural Network performs accurate estimation of their actual magnitudes (right), as given at high resolution.

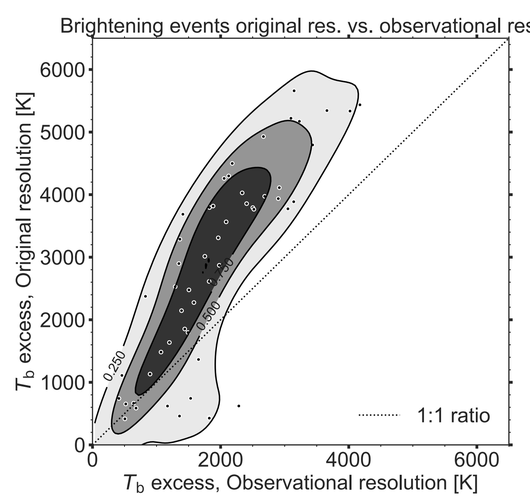


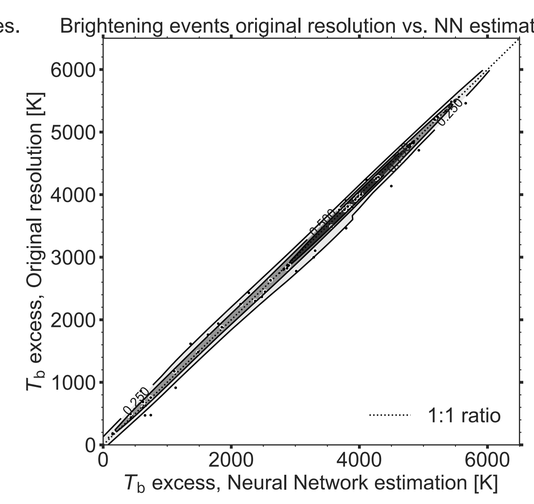




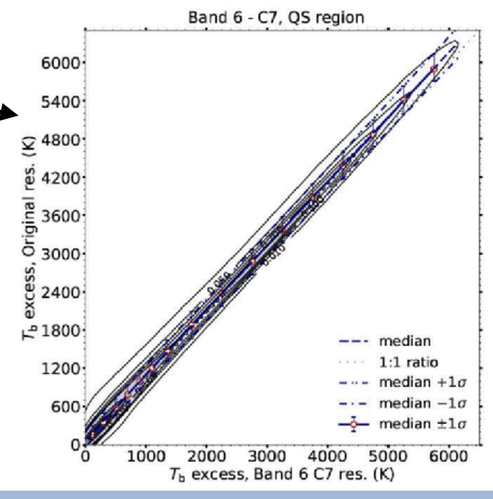








- Comparing to results of Eklund et al. 2021, Neural Network estimation on brightening events corresponds to observations at resolution of approximately 0.12 arcsec.



Conclusions:

Neural Network provides estimations on observational data with limited angular resolution and provides:

- **Locations of high and low accuracy for each time step.**
- **The sign and magnitude of the inaccuracy, i.e. if the intensity at the degraded (observational) resolution appears lower or higher than at high resolution and to what magnitude.**
- **Refined map of intensities and brightness temperatures**

The estimations provide a very useful tool to select location for in-depth analysis and meaningful interpretation of the data.

References:

- Eklund et al., 2020, A&A, 644, A152 https://ui.adsabs.harvard.edu/abs/2020A%26A...644A.152E/abstract
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- de la Cruz Rodriguez et al., 2021, *https://github.com/SolarAlma/ART*
- Shi et al., 2015, arXiv150604214S

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