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SOLARNET

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INTRODUCTION

SOLARNET – High Resolution Solar Physics Network- is an European Project founded by the Horizon 2020 (the biggest EU Research and Innovation programme between the years 2014 to 2020).

The project integrates the major European researchers and infrastructures in the field of high-resolution solar physics, among which the ICTEA institute is included.

The ICTEA along with the MOMA group, works in AO reconstructors employing Artificial Neural Networks (ANNs). Its good results in night-time observations allowed them to be part of the Solarnet project.

One of the main goals of this project is to define the exploitation of the future 4-meter European solar Telescope (EST). It includes design the EST key elements to the required level of definition and validation for their final implementation.

Horizon 2020 European Union Funding for Research & Innovation

EST - European Solar Telescope -

The EST (1) is a 4-metre solar telescope that will be located in the Canary Islands, Spain. It is expected to be built in the year 2027 and to begin operating by the year 2030. It will be the largest solar telescope ever built in Europe. Instruments to be used in the observations of the Sun, will allow to study the activity processes that take place on it. Some of the activities that can be studied are:

- Observation of the Sun's atmospheric layers coupling . Through imaging, spectroscopy and spectropolarimetry instrumentation, it will be able to determine the magnetic, thermal and dynamic properties over many layers.
- Understanding the processes that influences the plasma physics in the Sun.
- Relevancy of the magnetic activity of the Sun on life from Earth.

For all of the tasks, the EST is required to use visible and near-infrared instruments simultaneously. The principal design includes:

- A 4-meters circular aperture (current solar telescopes are restricted to 1-meter apertures).
- Diffraction limited image quality of 1-arcmin circular field of view (FoV).
- AO and MCAO adaptive optics systems integrated into the main telescope light path.

All the science instruments of EST should operate simultaneously to maximize the efficiency; for that the EST must be optimized to give a high throughput.

Artist impression of the future EST. Extracted from [2]

SOLAR ADAPTIVE OPTICS

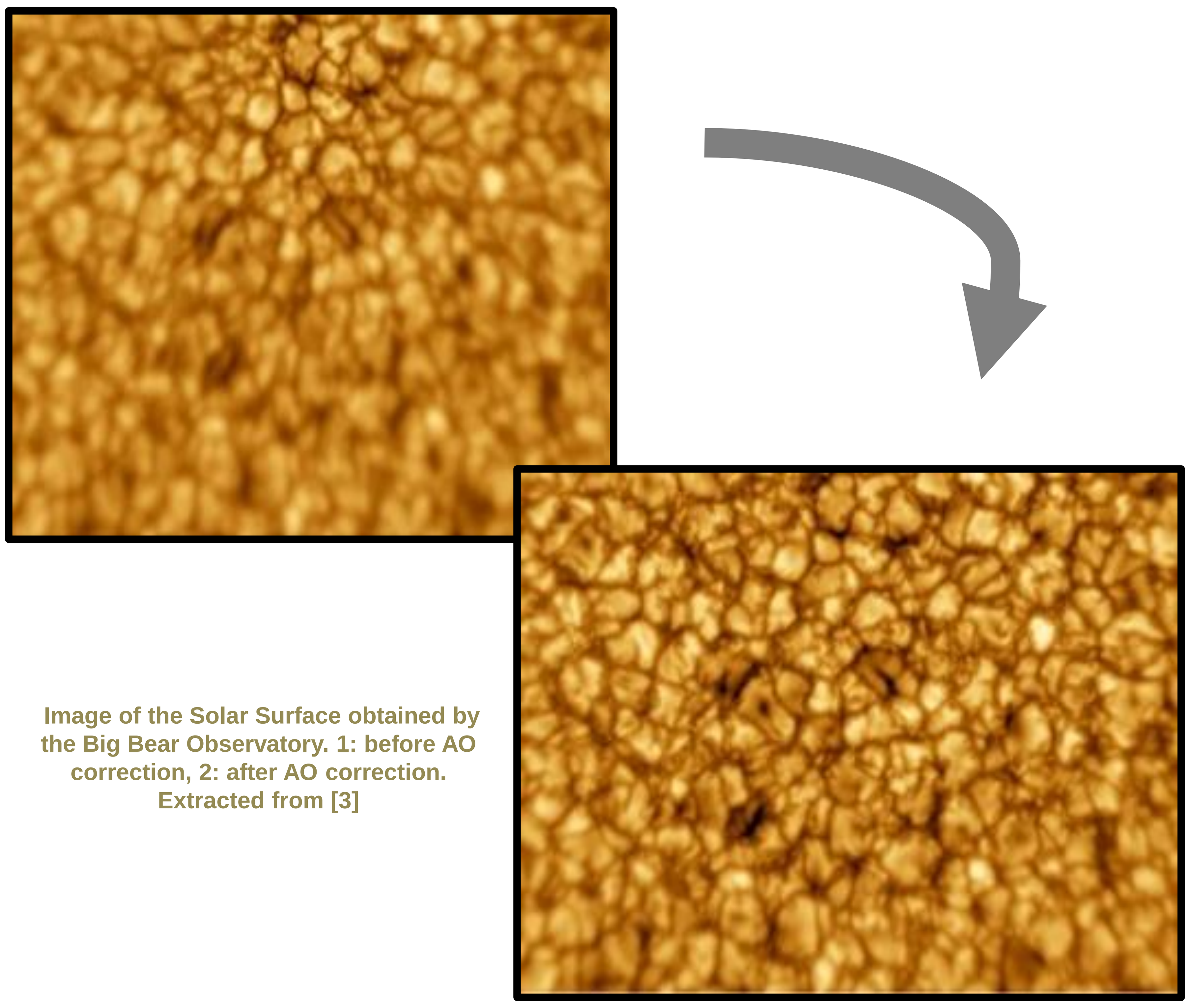


Image of the Solar Surface obtained by the Big Bear Observatory. 1: before AO correction, 2: after AO correction. Extracted from [3]

Atmosphere turbulence produces aberrations on the incoming light from astronomical sources (including Solar light). In grounded telescopes this effect makes difficult to obtain diffraction limited images.

The atmosphere have different refraction indexes due to their diverse air density. The sections of the atmosphere are moving continuously by random winds. The effect on the incoming light is similar as it had passed through a large number of different lenses, so when it arrives at the telescope, the received Wavefront is distorted. In an ideal case, in absence of atmospheric turbulence, the received Wavefront should be flat, however it is not the case regardless the grounded telescope is place.

Adaptive Optics (AO) is a technique that measure the atmospheric turbulence effects, estimates a correction and employs diverse instruments to correct the distortions suffered by the light, obtaining better images of the astronomic object, near the diffraction limit, in real-time. This is the most difficult objective, due to the continuously and randomly variation of the atmosphere. It is employed both in night-time observations and in day-time observations (that is the case of the Sun).

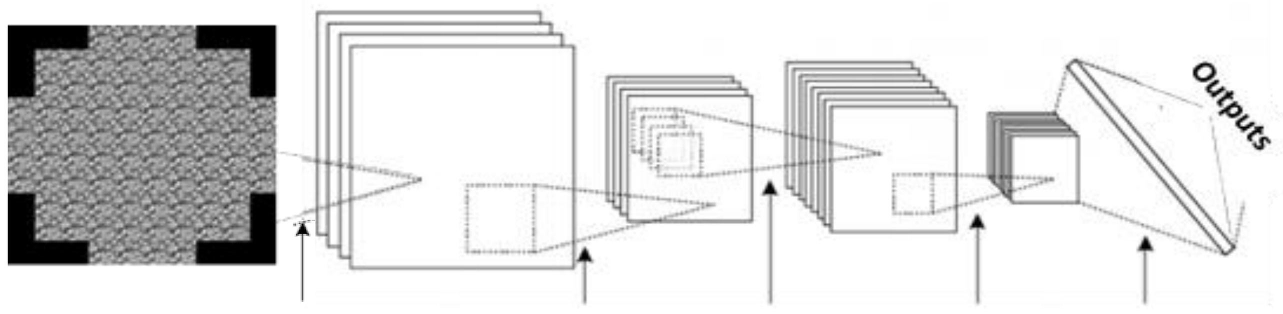
The main components of an AO System are:

- **Wavefront Sensors (WFS):** The most used is the Shack-Hartmann WFS (SH-WFS). One AO System must have at least one WFS to measured how aberrated the Wavefront is. A modification of the SH-WFS with image correlations is used for Solar AO.
- **Reconstructor and control system:** Based on the outputs of the WFS, the reconstructor system must estimate how is the original received Wavefront. This may be performed by estimating the atmospheric turbulence and reversing the distortions suffered by the incoming light. The control system performs the calculations to make the corrections, considering that it must take few milliseconds.
- **Deformable mirror (DM):** It is the system that makes the corrections. It consist in a mirror whose surface shape can be modified (normally using piezoelectric materials). The surface shape is given by the control system at each moment. The received Wavefront is sent to the mirror to recover a flat Wavefront.

CONVOLUTIONAL NEURAL NETWORKS

Artificial neural networks (ANNs) are computer models inspires by the human brain operation, both in their communication and in their learning. The MOMA group works in the generation of a reconstructor system that employs ANNs. Current developments [4,5] are based on Convolutional Neural Networks (CNNs) or Fully Convolutional Networks (FCNs).

CNNs and FCNs have as main advantage that images can be the input of the network instead of arrays. The input of the reconstructor is directly what the WFS is watching, without any loss of the received information in the pre-processing of the data. The outputs of the network are the positions of the DM surface, in the case of CNNs, or another image with the reconstruction of the atmosphere turbulence at each moment in the case of FCNs.



Scheme of the operation of a Solar AO reconstructor based on CNN's. The input image is what a SH-WFS (10x10 subapertures) is seeing at that moment.

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