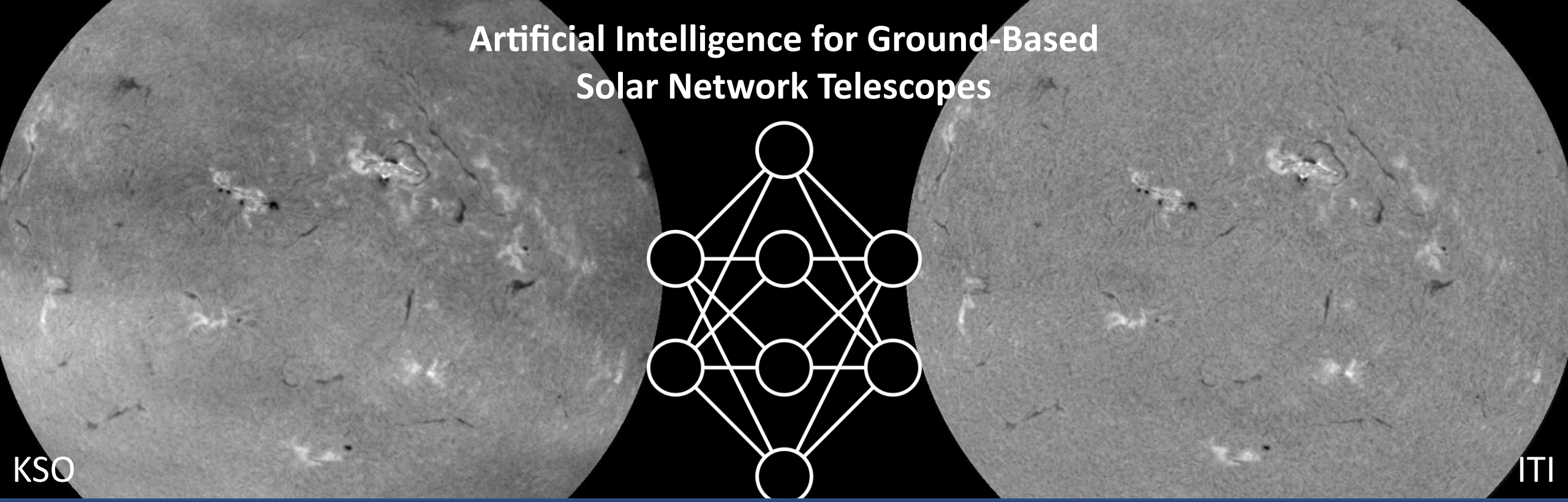
Artificial Intelligence for Ground-Based Solar Network Telescopes



R. Jarolim[1], A. M. Veronig[1,2], W. Pötzi[2], T. Podladchikova[3], A. Diercke[4,5], C. Kuckein[5,6,7], S. J. González-Manrique[6,7,8], M. Ziener and C. Denker[5]

[1]University of Graz, Institute of Physics, Universitätsplatz 5, 8010 Graz, Austria
[2]University of Graz, Kanzelhöhe Observatory for Solar and Environmental Research, Kanzelhöhe 19, 9521 Treffen am Ossiacher See, Austria
[3]Skolkovo Institute of Science and Technology, Bolshoy Boulevard 30, bld. 1, Moscow 121205, Russia
[4]National Solar Observatory, 3665 Discovery Drive, Boulder, CO 80303, USA
[5]Leibniz Institute for Astrophysics Potsdam, An der Sternwarte 16, 14482 Potsdam, Germany
[6]Instituto de Astrofísica de Canarias 38205 C/ Vía Láctea, s/n, La Laguna, Tenerife, Spain
[7]Departamento de Astrofísica, Universidad de La Laguna 38205, La Laguna, Tenerife, Spain
[8]Astronomical Institute, Slovak Academy of Sciences (AISAS) 059 60 Tatranská Lomnica, Slovak Republic

ESPM
08-09-2021

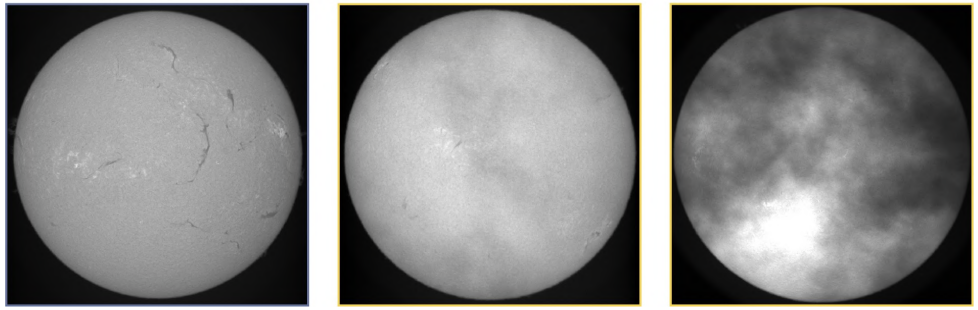
robert.jarolim@uni-graz.at

This research has received financial support from the European Union's Horizon 2020 research and innovation program under grant agreement No. 824135 (SOLARNET).

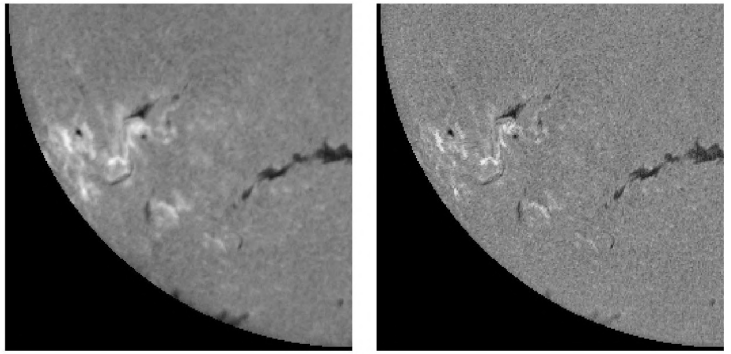
Introduction

- Ground-based observations
  - Merging multi-site observations can provide a continuous data series (**Network telescopes**)
  - Correction of **atmospheric degradations, instrumental** characteristics in real-time required for data **merging**
  - Development of **automated methods** to analyze the data
- Artificial Intelligence - Deep Learning
  - Data-driven method that uses **input-output pairs** to find a **general mapping** function
  - Provides **state-of-the-art results** in image classification, enhancement, segmentation, etc.
- Automated methods for the next generation of network telescopes
  - SOLARNET **SPRING** – ground-based full-disk solar network telescope

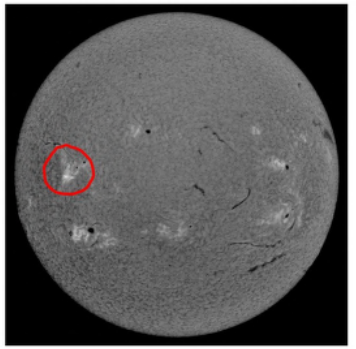
(1) Solar Image Quality Assessment



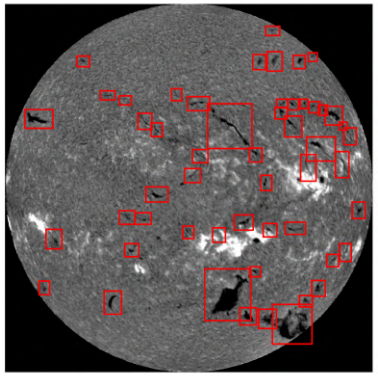
(2) Image Enhancement



(3) Flare Detection



(4) Filament Detection



(5) Coronal Hole Detection

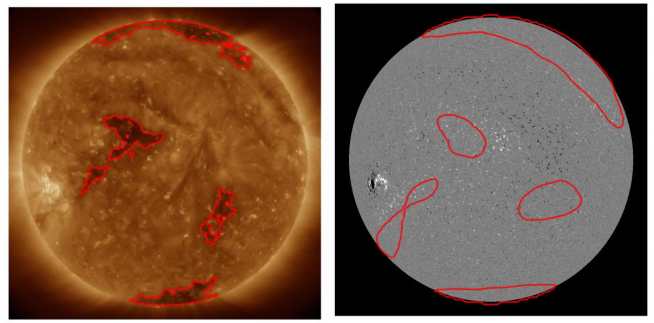
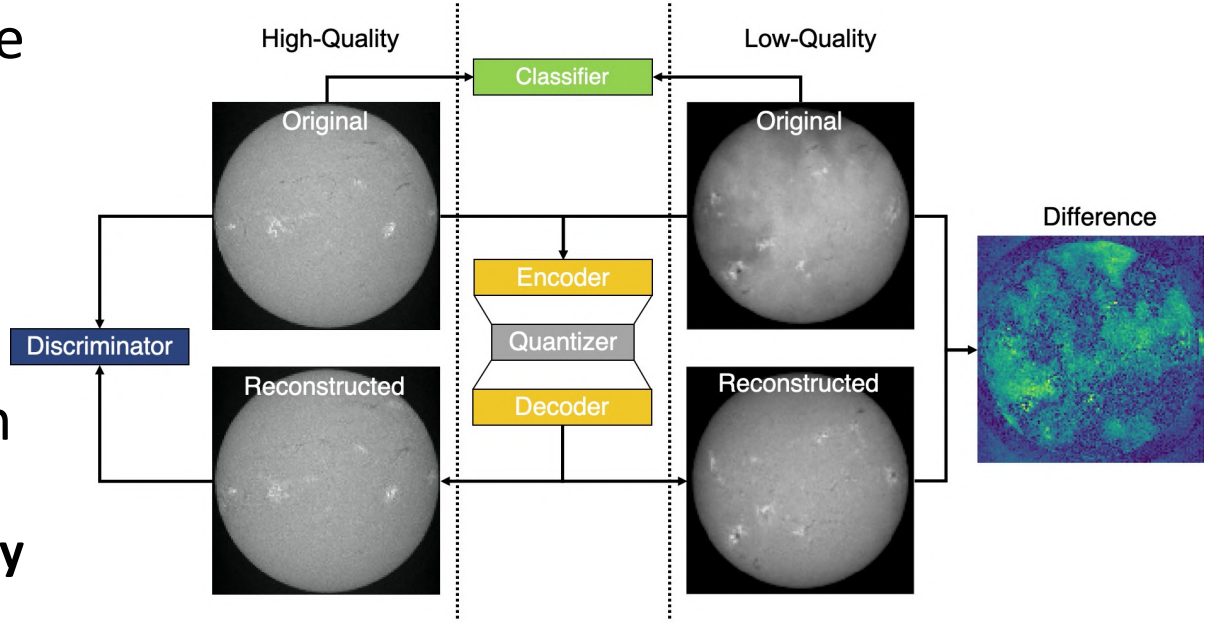
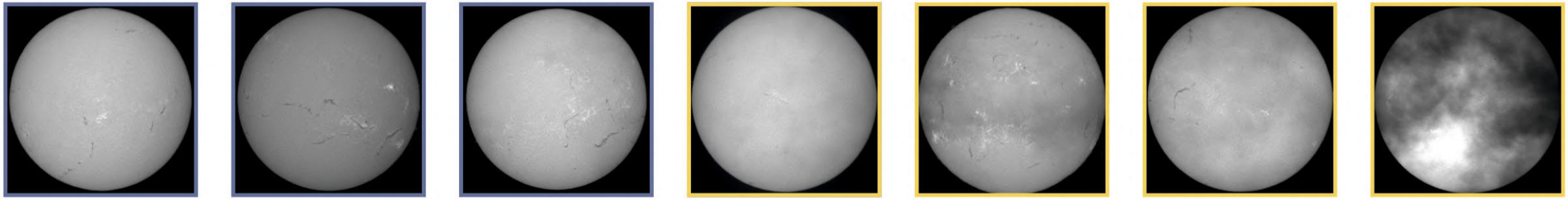


Image-quality assessment (Jarolim et al. 2020)

- **Objective image quality assessment** to provide consistent data stream
  - Quality degradations are **diverse** (e.g., clouds, instrumental errors)
  - **Continuous** quality **metric** for frame selection (multi-site selection)
- Generative Adversarial Network (GAN) to learn the appearance of high-quality observations
  - Quality metric based on **deviation** from **high-quality** image distribution
  - Human-like assessment: **98.5% agreement**



(from: Jarolim et al. 2020, A&A 643 A72)

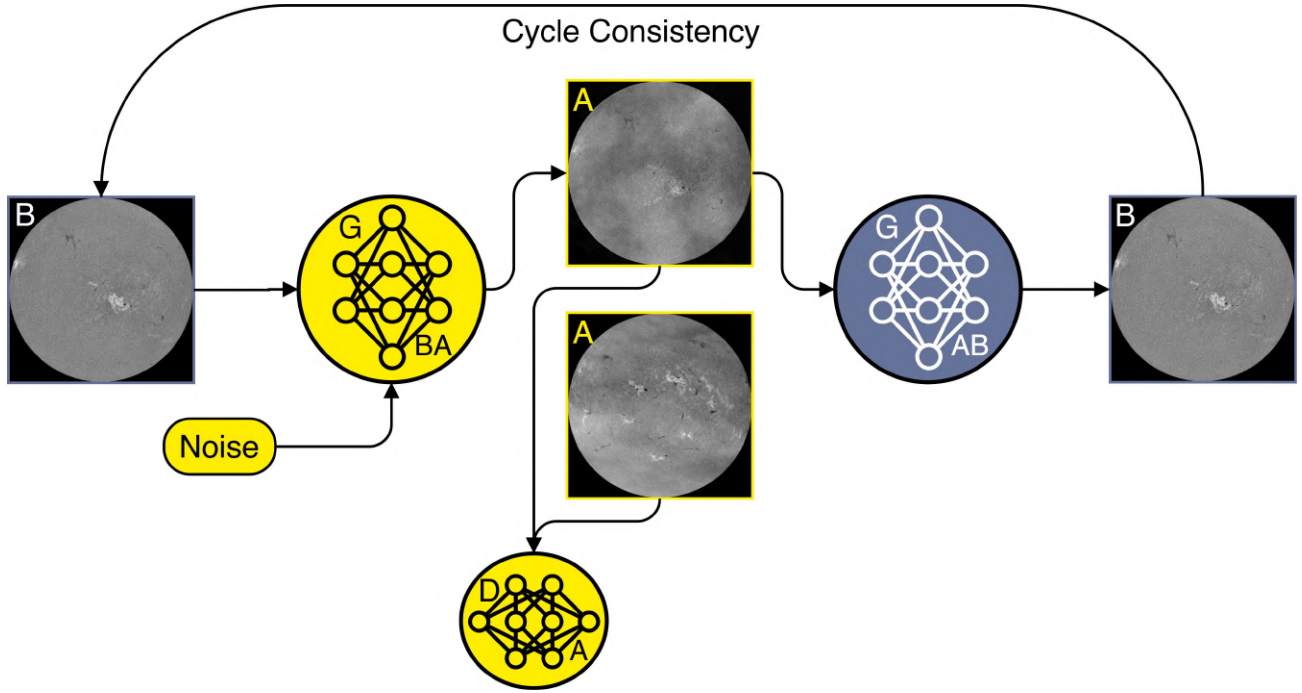


Instrument-To-Instrument translation

(Jarolim et al. 2021b; in prep.)

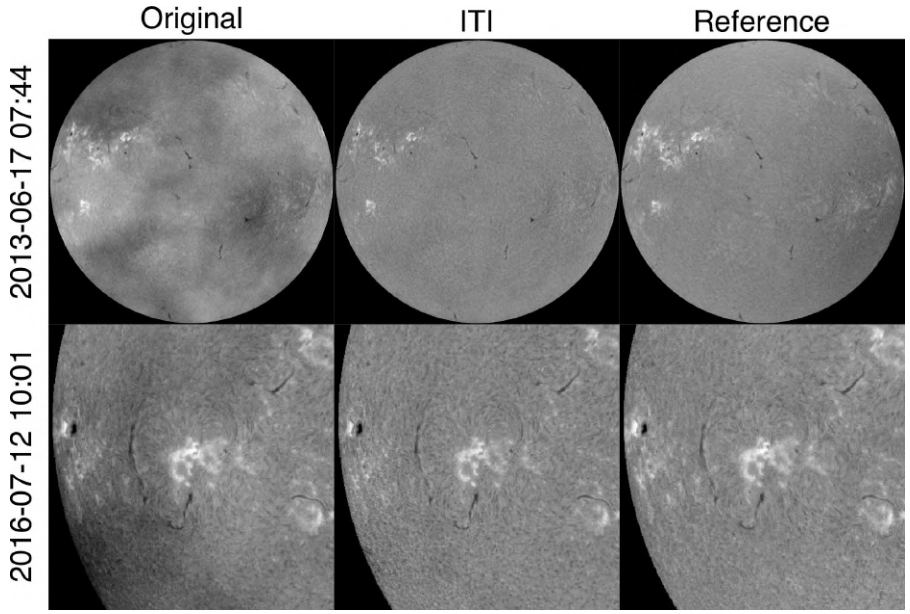
- **General framework** for image enhancement and data series restoration
  - Unpaired image translation (no temporal/spatial overlap required)
  - Infers image enhancement from real high-quality observations

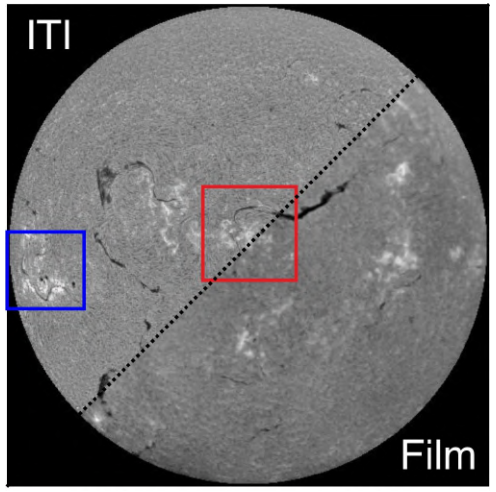
- **Competitive learning** with two Neural Networks
  1. Use high-quality(B) image to create synthetic low-quality(A) image
  2. Verify that synthetic image corresponds to the low-quality domain
  3. Reconstruct original image from synthetic degraded image
  4. Verify reconstruction (cycle consistency)
- Applicable to **real low-quality** observations after training

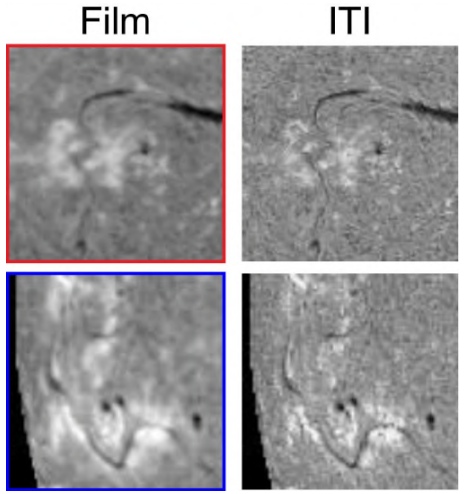


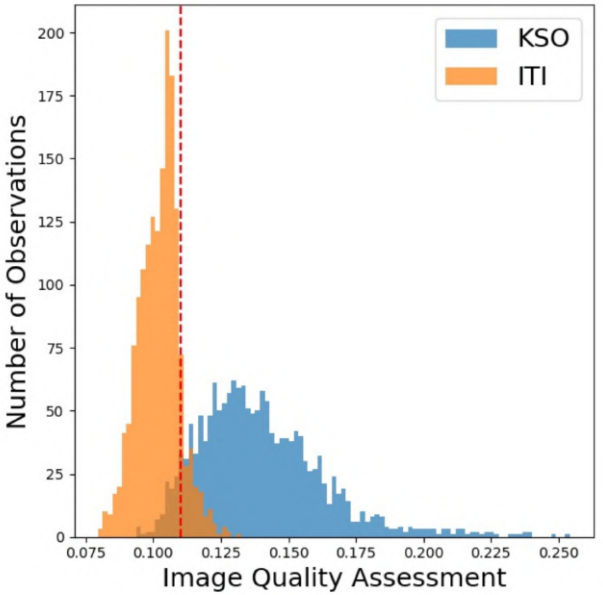
Instrument-To-Instrument translation

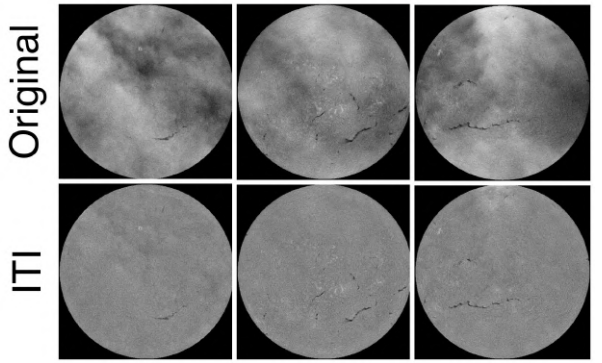
- Real-time correction of **atmospheric degradations**
  - KSO Hα observations
  - Mitigation of clouds
  - Adjustment of saturations
  - Quality increase
- Restoration of **photographic film** scans
  - Adjustment to CCD quality
  - Unified KSO Hα series (1973-now)











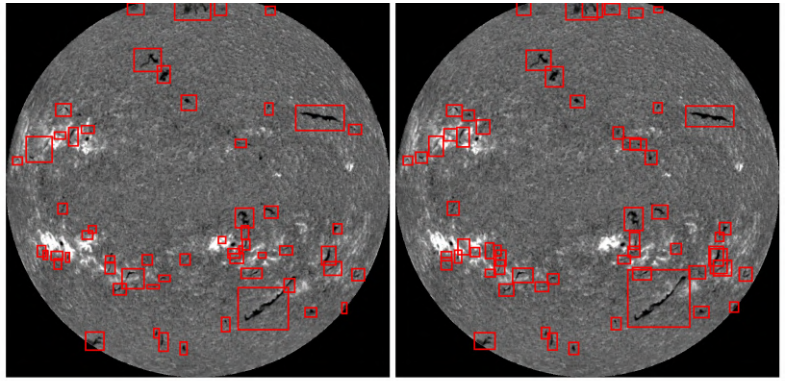
Quality distribution of original and enhanced images

Automated Detection Methods

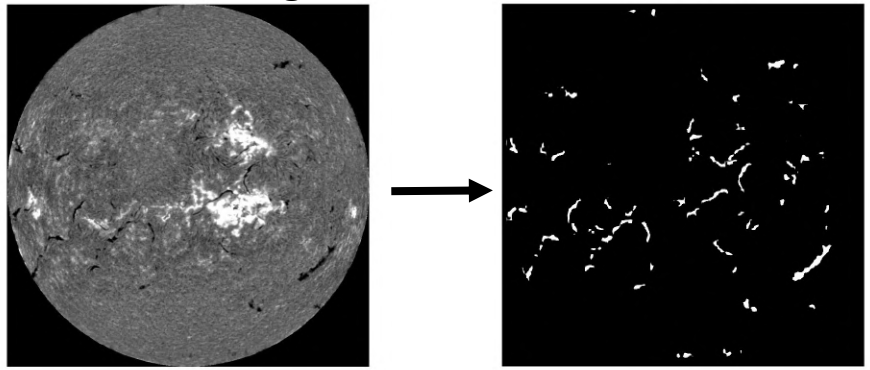
- Solar Flare Detection (in progress)
  - **Spatio-temporal** neural network
  - GONG **Hα** multi-site observations
  - Detection of up to **B-class** flares across the **full disk**
  - **90%** of >C2 flares **verified** with other catalogs
- Automated solar filament detection (Diercke et al.; in prep.)
  - **Hα** ChroTel observations (**962 manually labeled** full-disk observations)
  - Bounding box classification (YOLOv5) → pixel-wise filament segmentation (UNET)
- Provides event **catalogs** and **real-time monitoring** of the Sun

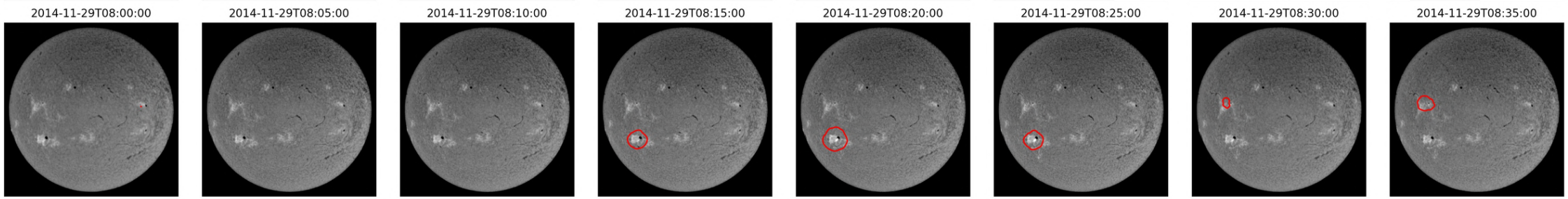
Manual Labels

Model Prediction



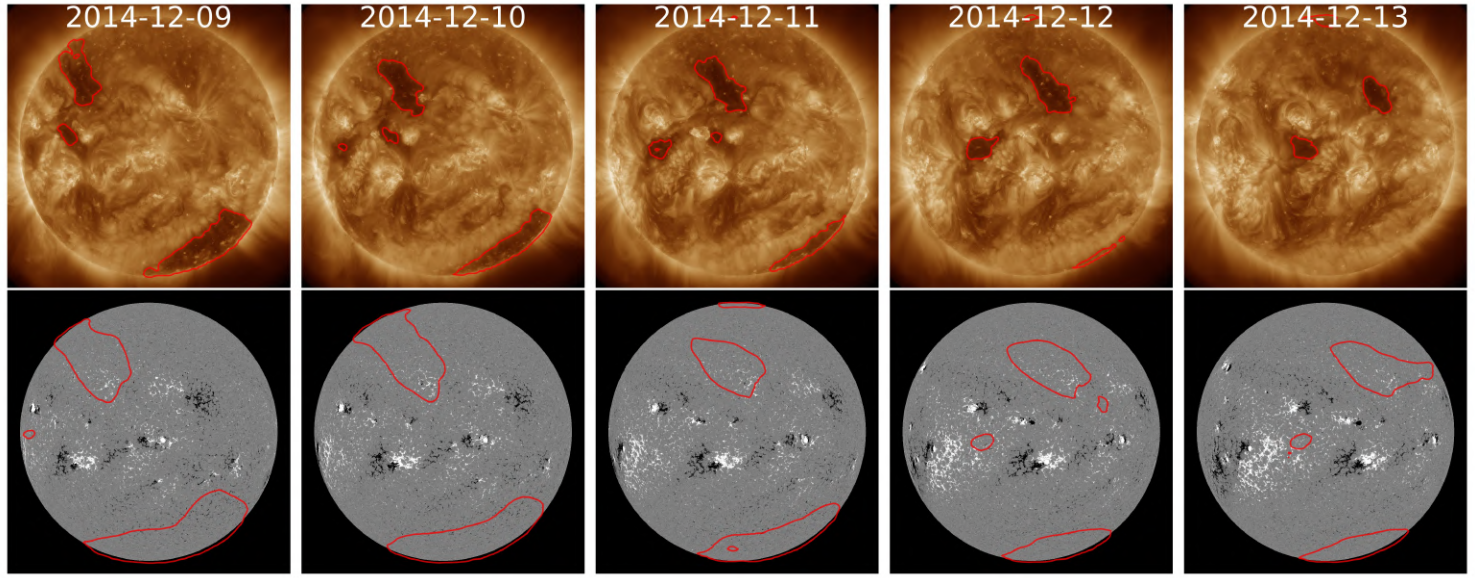
Segmentation Model





Extended detection capabilities (Jarolim et al., 2021a)

- **Coronal holes** appear as dark structures in satellite-based EUV and X-ray filtergrams
  - Ground-based observation limited
  - Neural networks can learn to perceive data differently than humans
- Use EUV segmentation maps for training
  - **LOS magnetograms**: 66.3%
  - **SDO/AIA 304 Å** channel: 83.9%
  - (accuracy of detected CHs)



Example of coronal hole detection from LOS magnetograms (bottom) and reference detections from the SDO EUV channels (top).
(from Jarolim et al. 2021a, A&A *652 A13; CHRONNOS*)

Supplementary Material/References

- Videos available online
  (https://indico.ict.inaf.it/event/794/contributions/9678/)
  1. Image quality assessment for a full observing day
  2. ITI translation for SDO/HMI → Hinode/SOT continuum
  3. Coronal hole detections for the different SDO channels + magnetogram
- Updates
  - https://www.researchgate.net/profile/Robert-Jarolim
  - https://twitter.com/JarolimRobert
- References

  - Jarolim R, Veronig AM, Pötzi W, Podladchikova T. (2020). Image-quality assessment for full-disk solar observations with generative adversarial networks. *Astronomy & Astrophysics*, *643*, A72. (https://doi.org/10.1051/0004-6361/202038691)
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  - Jarolim R, Veronig AM, Pötzi W, Podladchikova T. (2021b). Instrument-to-Instrument translation: A deep learning framework for data set restoration of solar observations. Manuscript in preparation.
  - Diercke A, Jarolim R, Kuckein C, González-Manrique SJ, Ziener M, Veronig A and Denker C. Automatic Extraction of Polar Crown Filaments Using Machine Learning Techniques. Manuscript in preparation.
