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Generation of Modern Satellite Data from Galileo Sunspot Drawings in 1612 by Deep Learning

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Introduction

Generative Adversarial Network (GAN, Goodfellow et al. 2014), which is one of popular deep learning methods, has been widely examined in image generation task. Isola et al. (2017) suggested a general-purpose solution to image-to-image translation problems using conditional Generative Adversarial Networks (cGAN). In this study, we apply an Artificial Intelligence (AI) model, based on the image-to-image translation with cGAN, to solar magnetograms and EUV images.

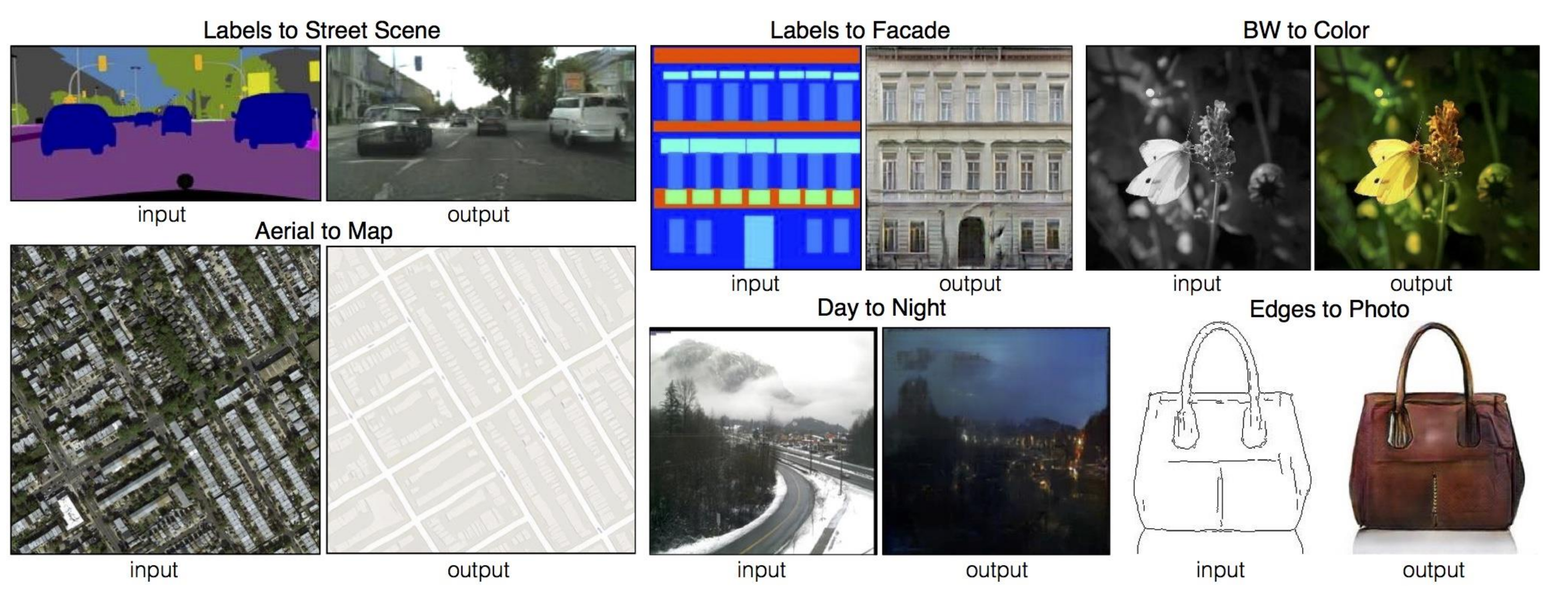
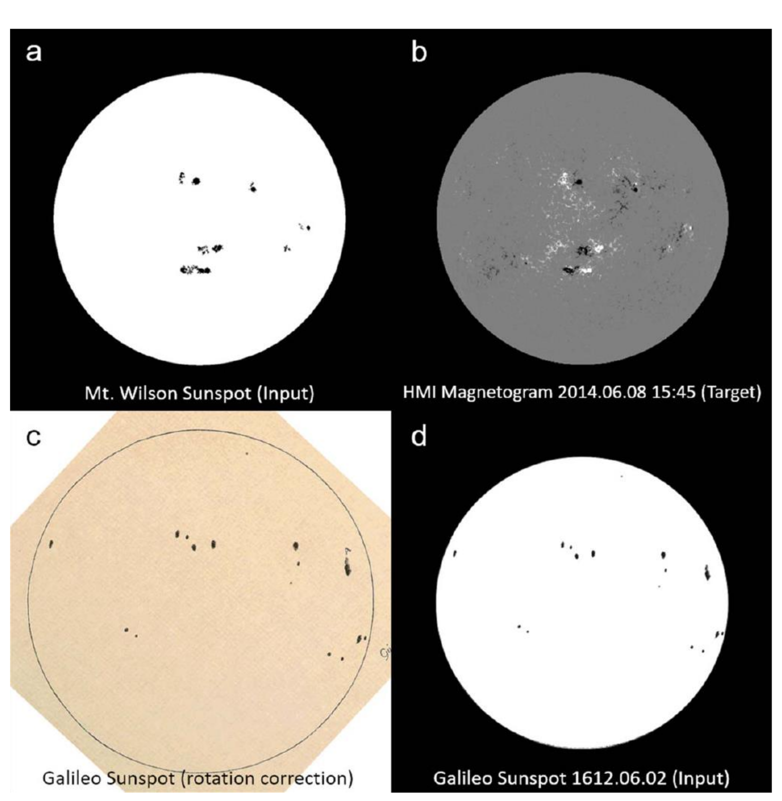


Figure 1. Image-to-Image translations between two domains by Isola et al. 2017.

Data

We use the Mt. Wilson Observatory sunspot drawings from 2011 to 2015 for input data. First, we align the sunspot drawings with the corresponding SDO magnetograms and EUV/UV images. Then, we remove manually all letters and lines except for sunspots. In order to use relatively clear sunspot drawings, we make 8-bit scale images as follows (Figure 2a): 255 for solar disk and 0 for umbra, penumbra, and outside of solar disk.

We use SDO/HMI line-of-sight magnetograms and SDO/AIA seven wavelength images (94, 131, 171, 193, 211, 304, and 335 Å) for target data. Magnetic flux densities are considered within ±1000 Gauss. We use an AIA image with the range of 0 (DN s^{-1}) for minimum and 2^6 -1 ~ 2^{13} -1 (DN s^{-1}) for maximum.



For application of our model, we use the 35 Galileo sunspot drawings (Galilei et al. 1613) processed by Al Van Helden and Owen Gingerich from 2 June to 8 July 1612 (images available at galileo.rice.edu). Figure 2c is the Galileo sunspot drawing with rotation correction on 2 June 1612 and Figure 2d is an input image for our model.

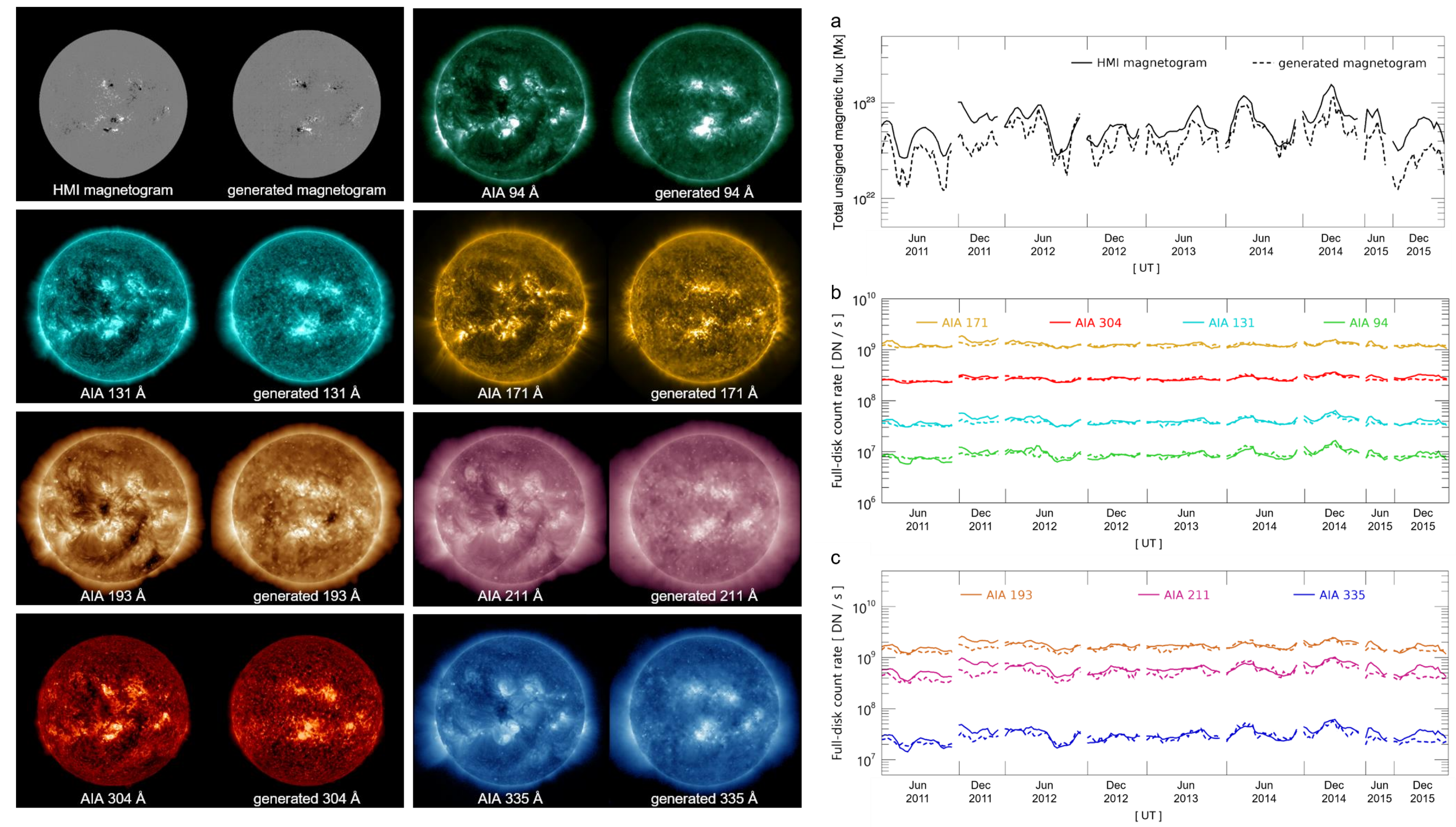
◀**Figure 2. An example of input and target images for test and application.**

DATA	Training	Evaluating	Generation
Input [image size: 512 x 512]	Sunspot drawing from Mount Wilson Observatory		Galileo sunspot drawings
Output [image size: 512 x 512]	SDO/HMI magnetograms & SDO/AIA EUV images		AI-generated
Number of images	1,046 pairs for 8 filter images (2011.01.01~2015.12.31)	204 pairs for 8 filter images (2014.09.15~2014.12.31)	35 drawings (1612.06.02~1612.07.08)

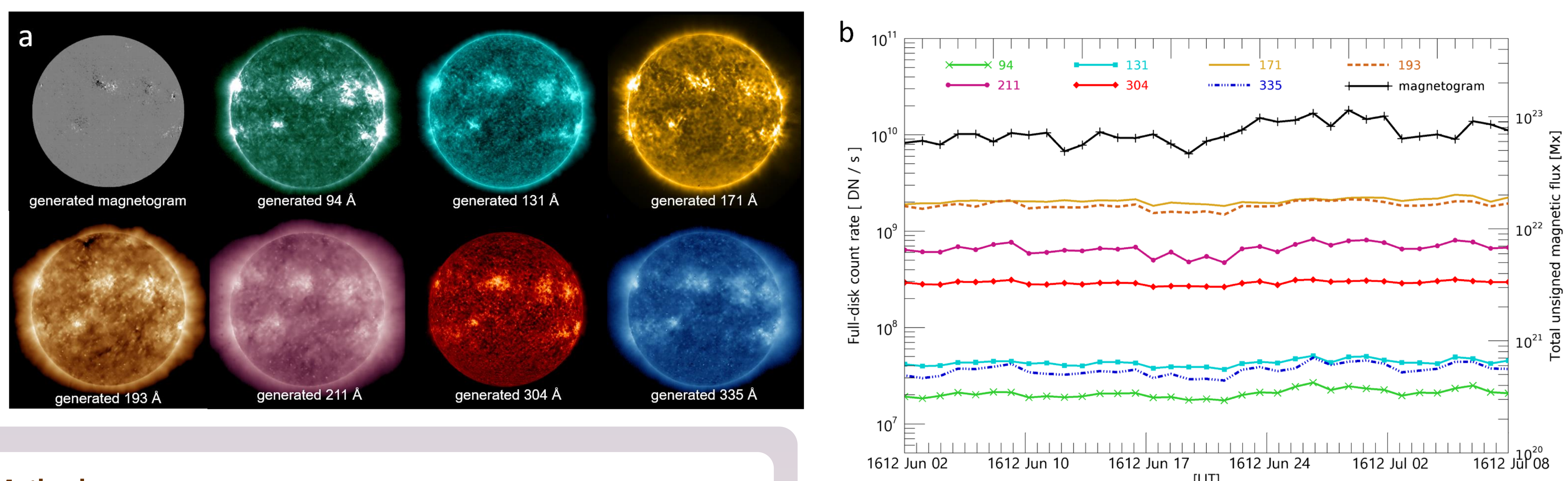
Result

Figure 4 shows eight pairs of target image and AI-generated one at 15:45 UT on 2014 June 8.A comparison between target and AI-generated magnetograms shows that the bipolar structures of the HMI magnetograms are approximately restored.

We estimate total unsigned magnetic flux (TUMF) and full-disk count rates (CR) of the evaluation data for both generated and real images and their temporal variations are given in Figure 5.



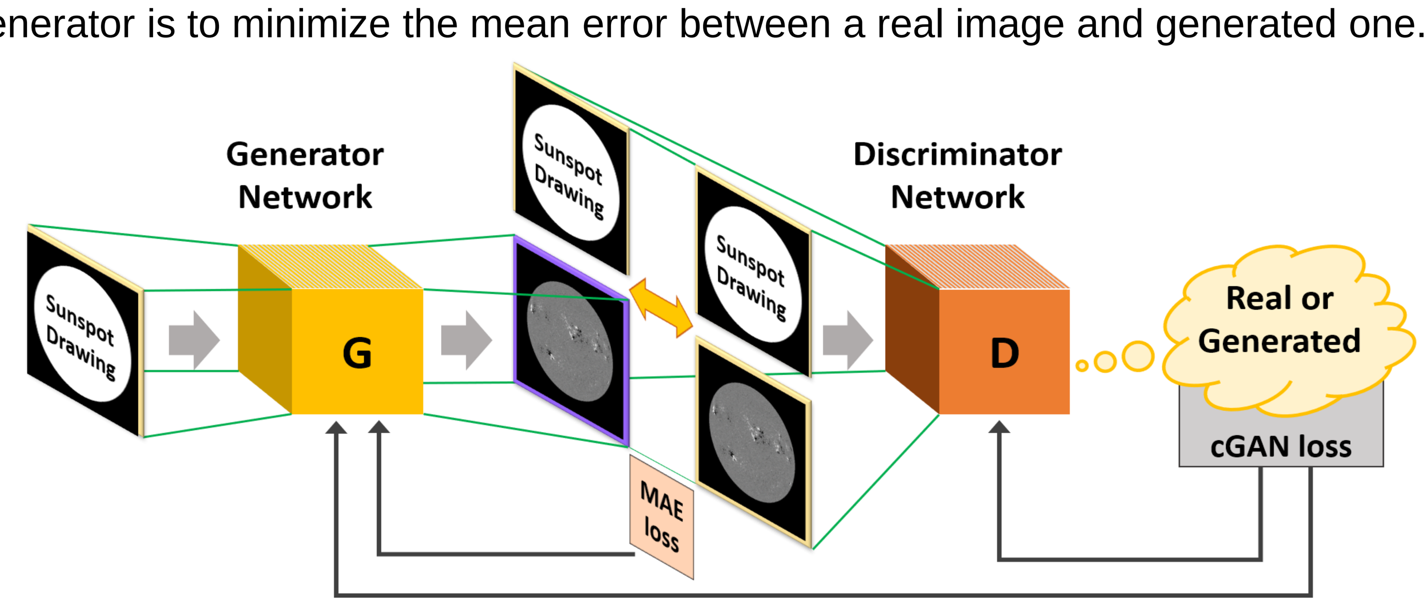
▶ **Figure 4. Left: Comparison between real SDO images and the generated ones at 15:45 UT on 8 June 2014. Right: Temporal variations of the total unsigned magnetic flux (a) and full-disk count rates (b and c) from 2011 to 2015.**



▲ **Figure 5. Results of our model when the Galileo sunspot drawings are used for input data. (a), AI-generated magnetogram and UV/EUV images from the Galileo sunspot drawing on 2 June 1612. (b), Total unsigned magnetic flux and full-disk count rates estimated from the AI-generated Galileo magnetogram and UV/EUV images from 2 June to 8 July 1612.**

Method

We adopt a deep learning model based on the pix2pix. Our model consists of two networks, one is discriminator, and the other is generator. The rule of the discriminator is to distinguish the real pair from the generated pair and that of the generator is to minimize the mean error between a real image and generated one.



▲ **Figure 3. Our Proposed model structure.**

Conclusion

We proposed a new attempt to generate modern satellite data and their related physical parameters from historical sunspot drawings. We demonstrated the validity of this attempt using modern data sets: Mount Wilson sunspot drawings and SDO data. Finally, our model produces modern satellite images and related physical values from Galileo sunspot drawings. This study is expected to offer more information on the long-term evolution of solar magnetic fields and their related studies such as long-term variation of solar irradiance.