Deep Learning the SKA

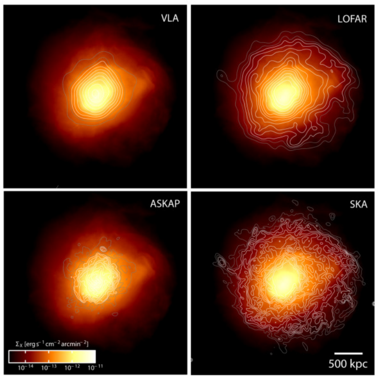
The Square Kilometer Array Project

Dr. Philipp Denzel (denp)
Dr. Elena Gavagnin (gava)
Prof. Frank-Peter Schilling (scik)

Zürcher Hochschule für Angewandte Wissenschaften

The stunning images taken by optical instruments like the iconic Hubble Space Telescope are famous the world over, but there are many details they cannot see. Radio astronomy reveals parts of the invisible sky. By detecting radio waves emitted by a wide range of astronomical objects and phenomena, radio telescopes provide a totally different view of our Universe. As the world's largest radio-frequency interferometer, **SKA** will transform our understanding of the Universe, tackling some of the most fundamental scientific questions of our time.

Image credits: IllustrisTNG Collaboration



In January 2022 Switzerland became a full member of the SKAO. **SKACH**, the Swiss SKA consortium, is responsible for managing the Swiss contribution to the SKAO and aims to deliver cutting-edge Swiss solutions to key science goals, big data research, and technology. This endeavor is led by a board consisting of a strong contingent of Swiss institutions, amongst them ZHAW. Our team's (denp, gava & scik) mission is to deploy various generative deep learning models to explore compressed representations of the SKA data, which will lead to scientific insights and contribute to SKACH's cause.

SKA1-Mid

the SKA's mid-frequency telescope

Location: South Africa

Frequency range: **350 MHz** to **15.4 GHz** with a goal of 24 GHz

197 dishes (including 64 MeerKAT dishes)

Maximum baseline: **150km**

SKA-mid

Data transfer rate: **8.8 Terabits** per second

Total collecting area: **33,000m²** or **126 tennis courts**

Compared to the JVLA, the current best similar instrument in the world:

4x the resolution | **5x** more sensitive | **60x** the survey speed

SKA1-Low

the SKA's low-frequency telescope

Location: Australia

Frequency range: **50 MHz** to **350 MHz**

131,072 antennas spread between **512 stations**

Maximum baseline: **~65km**

Compared to LOFAR Netherlands, the current best similar instrument in the world

25% better resolution | **8x** more sensitive | **135x** the survey speed

The **SKAO** is a next-generation radio astronomy facility, involving partners around the globe, that will lead to groundbreaking new insights in astrophysics and cosmology. It will be operated over three sites: the Global Headquarters in the UK, the mid-frequency array in South Africa (*SKA-mid*), and the low-frequency array in Australia (*SKA-low*). The two telescopes under construction will combine the signals received from thousands of small antennae spread over a distance of several thousand kilometers to simulate a single giant radio telescope capable of extremely high sensitivity and angular resolution, using a technique called aperture synthesis.

Hydrodynamical simulations have been instrumental in the study of the Universe and particularly galactic dynamics. Highly tuned on a vast range of scales, they produce realistic galaxy models from first principles. With the latest suites of large-scale simulations, extracted mock observations have become almost indistinguishable from actual ones (see image above). This realism is driven by a substantial increase in data, which makes the application of deep learning methods especially suited.
In the image above, a simulation of a galaxy's synchrotron emission profile is shown with contours at resolutions of previous state-of-the-art radio interferometers in comparison with the expected performance of the SKA. Thus, by mapping out the sky with SKA the previously unresolved large-scale structure of the Universe (see image below) and the related mystery of dark matter can be studied.

SKAO

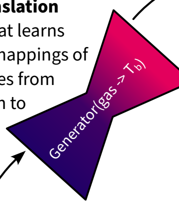
These are the projected coordinates of the SKA-mid stations, arrayed in a spiral pattern.

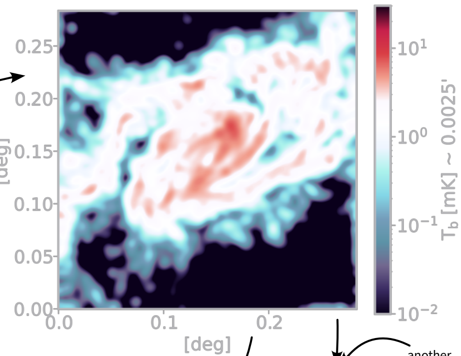
Deep learning is particularly apt to scale up to big-data datasets and extract the more abstract, physical principles that underlie complex observations such as by the SKA.
We explore the (inverse) mapping between astrophysical, hydrodynamical simulations and mock images from simulated SKA visibilities (tomographic data cubes). We aim to measure the performance of various state-of-the-art generative deep learning model types such as variational autoencoders (VAE), diffusion models, generative adversarial networks (GAN), and flow-based models on a dataset of recent AREPO IllustrisTNG simulations (see lower left image).

Brightness temperature T_b is a tracer for the brightness of neutral hydrogen gas and can be measured by radio telescopes. Here, you see what generic radio telescope observations could look like, generated using a CycleGAN deep learning model (preliminary results).

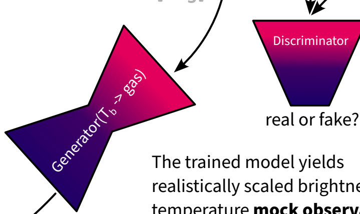
CycleGAN schema

A *CycleGAN* is an adversarial **image-to-image translation** network that learns invertible mappings of input images from one domain to another.

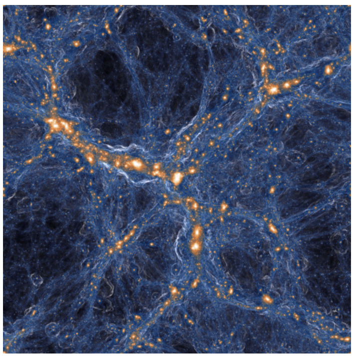




another "real" image

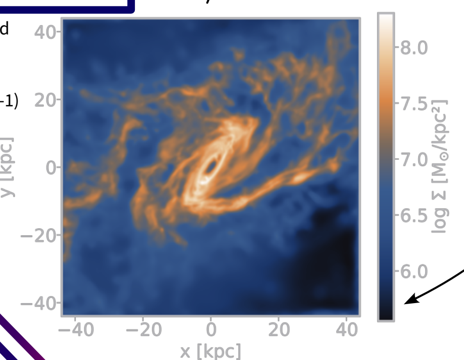


real or fake?

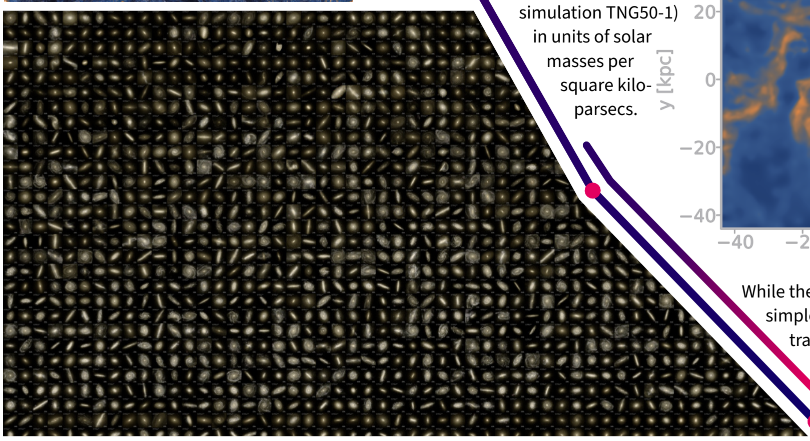


The IllustrisTNG simulation dataset

Log Σ is the 2D projected **gas density** (taken directly from the simulation TNG50-1) in units of solar masses per square kilo-parsecs.



The trained model yields realistically scaled brightness temperature **mock observations** from gas maps projected from astrophysical simulations.



While the CycleGAN model achieves good results, it still encompasses only a rather simple mapping, consisting mainly of a scaling operation and a fast Fourier transform. **In the future**, we plan to learn the mapping to a complex simulation of the SKA instruments, which is computationally much more challenging. Moreover, we are currently testing other generative models, such as PINN (Physics-informed neural net) models, flow-based models, and VAEs.

11/01/2023
Online version of this poster can be found here.