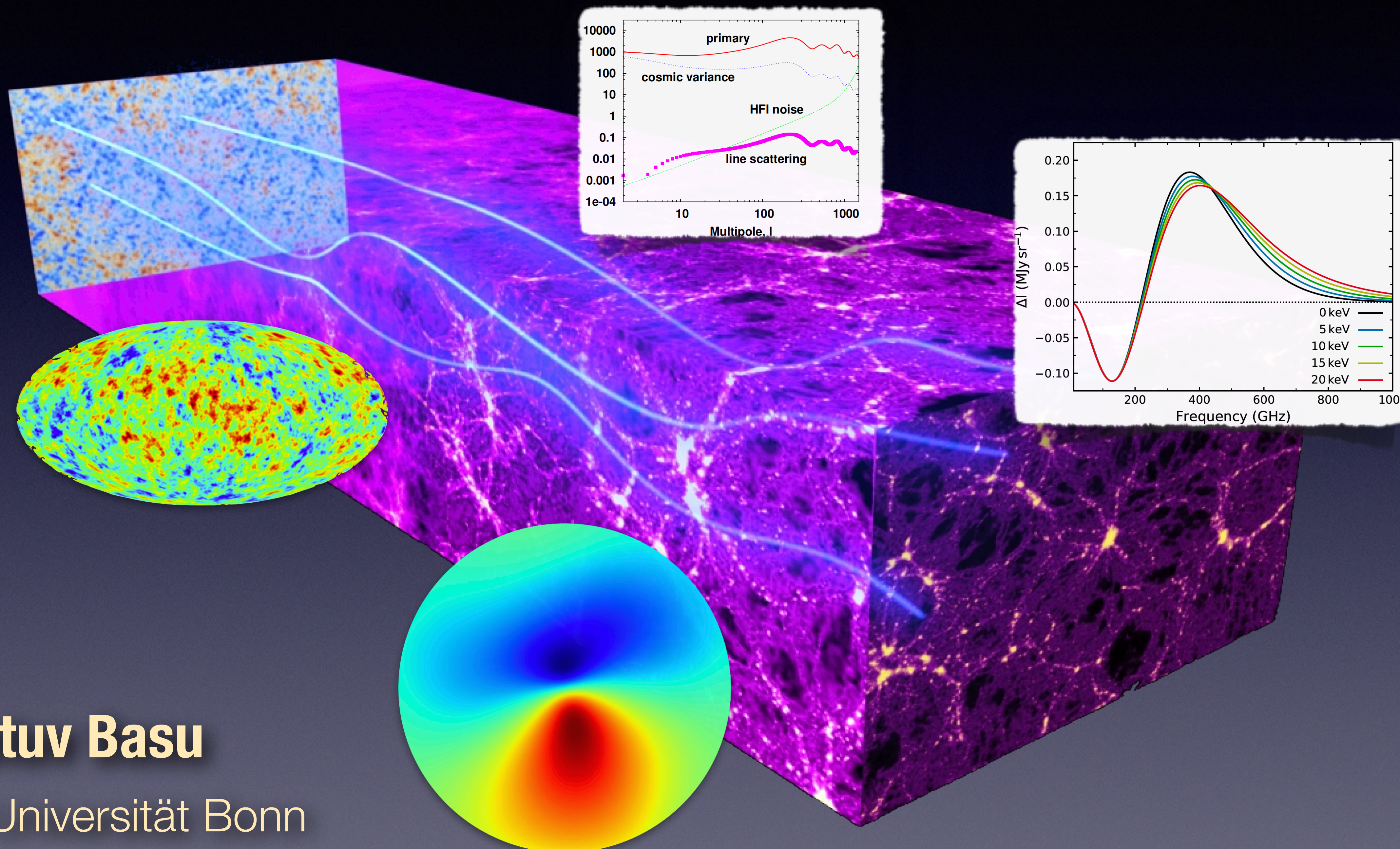
Deep Learning on the CMB:

How to learn more from the oldest light



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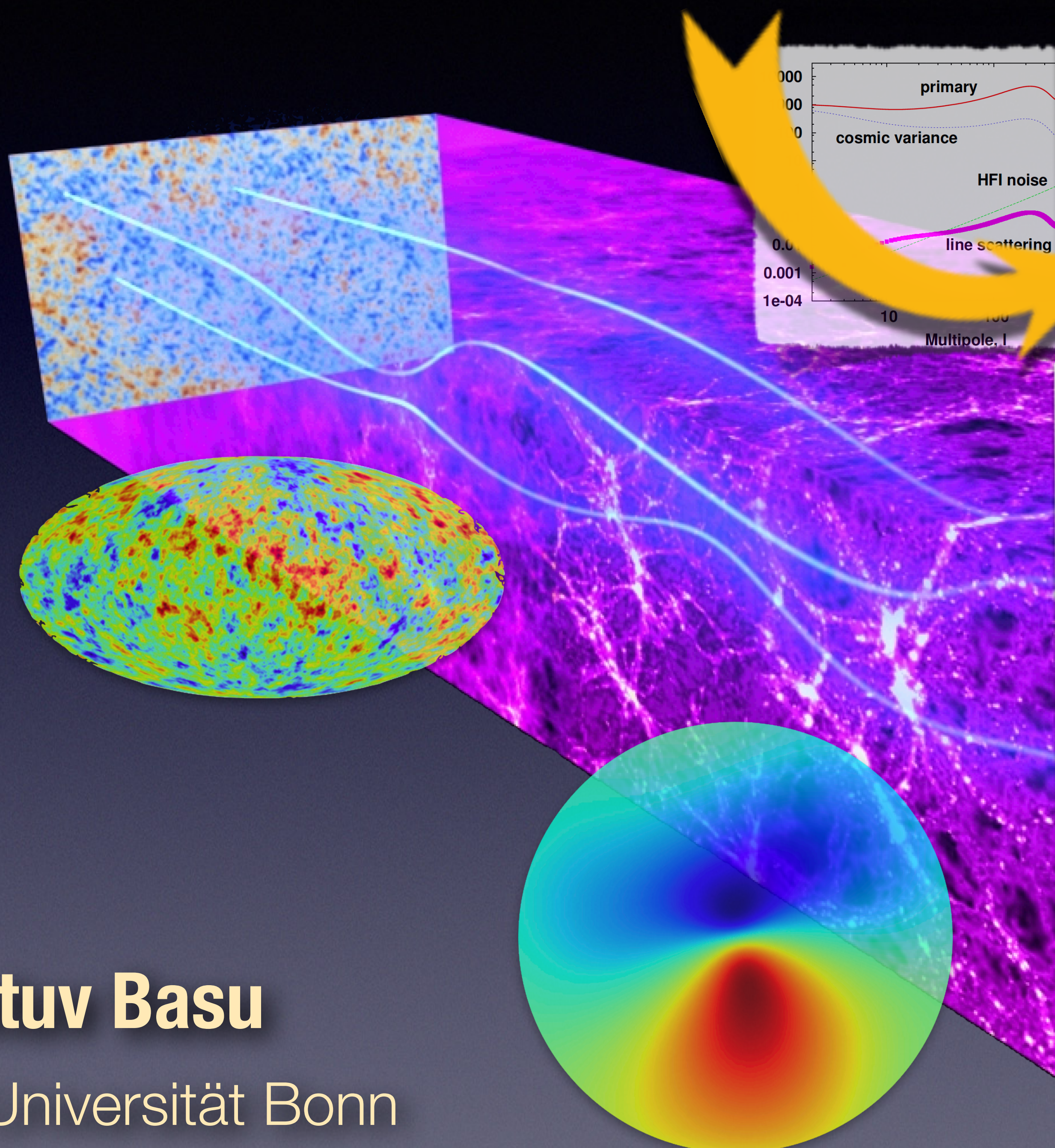

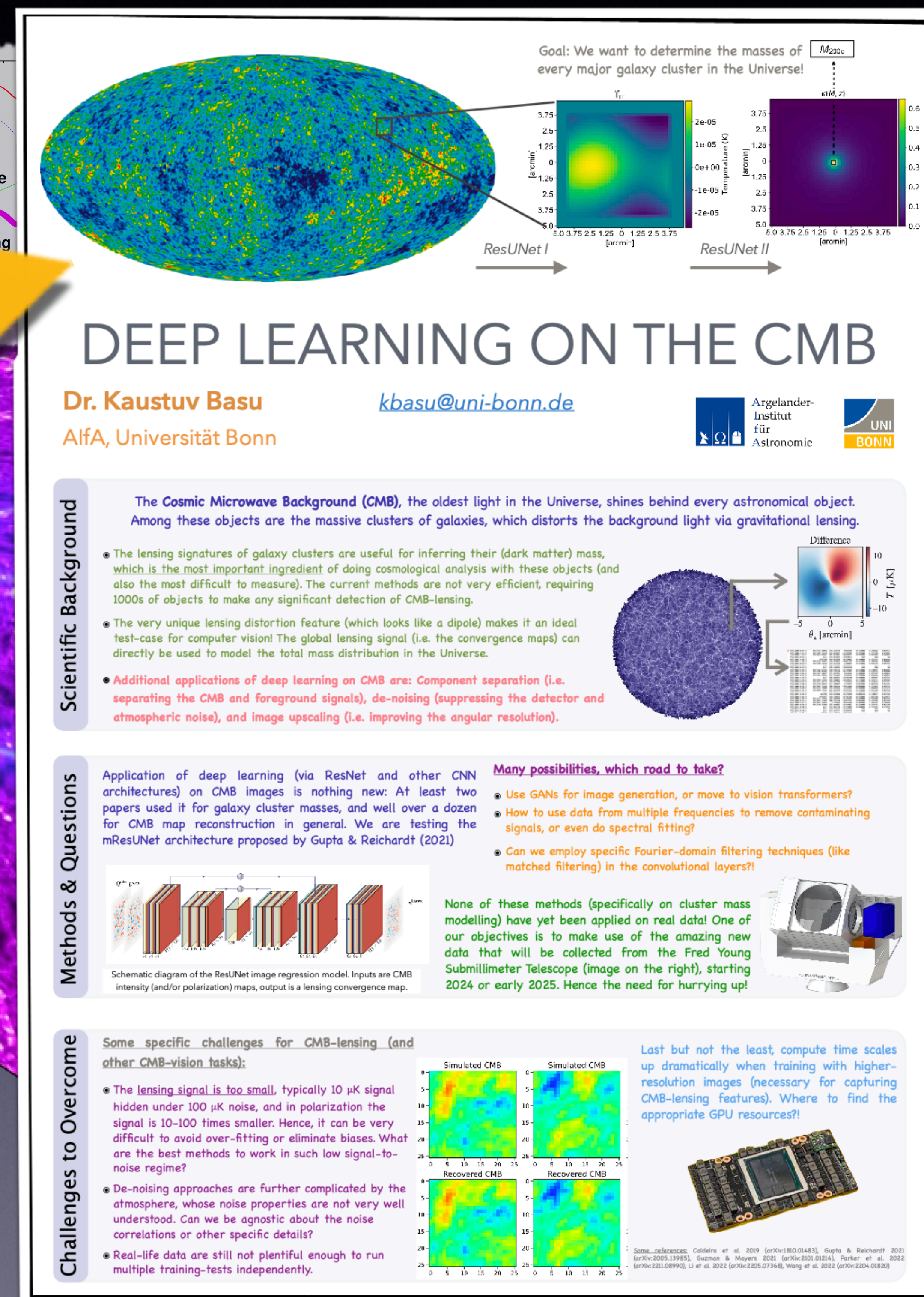

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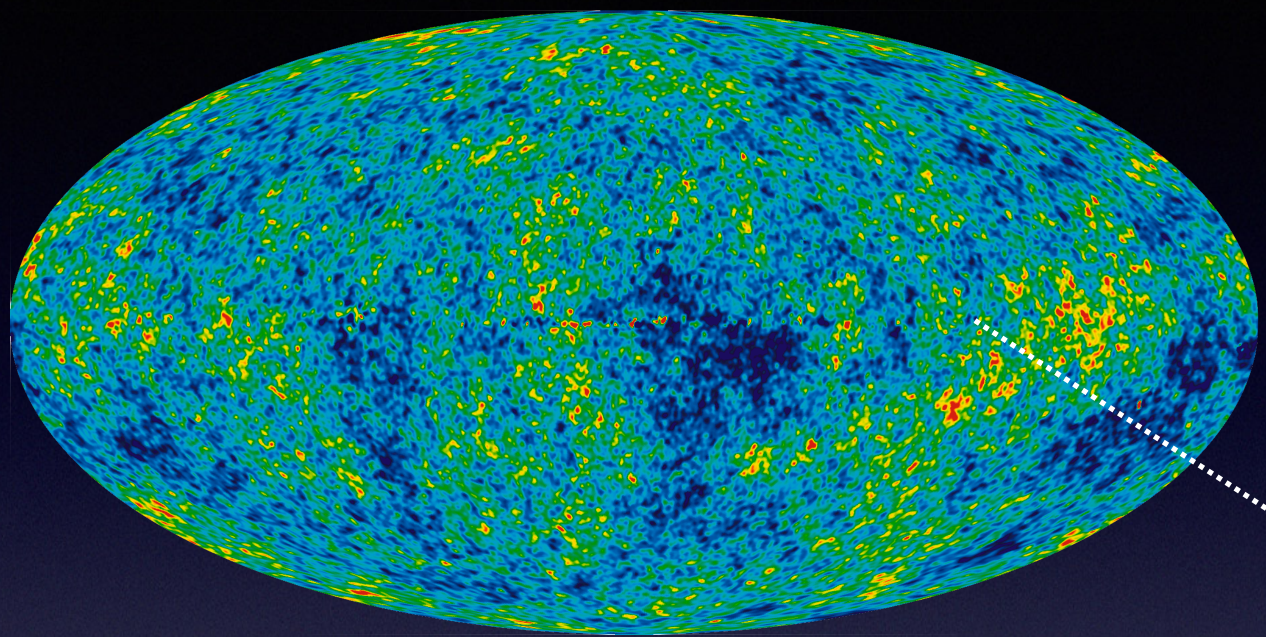
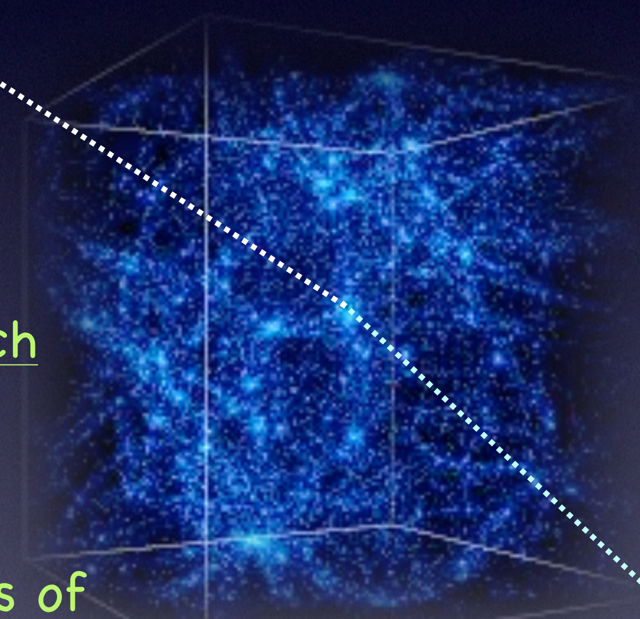
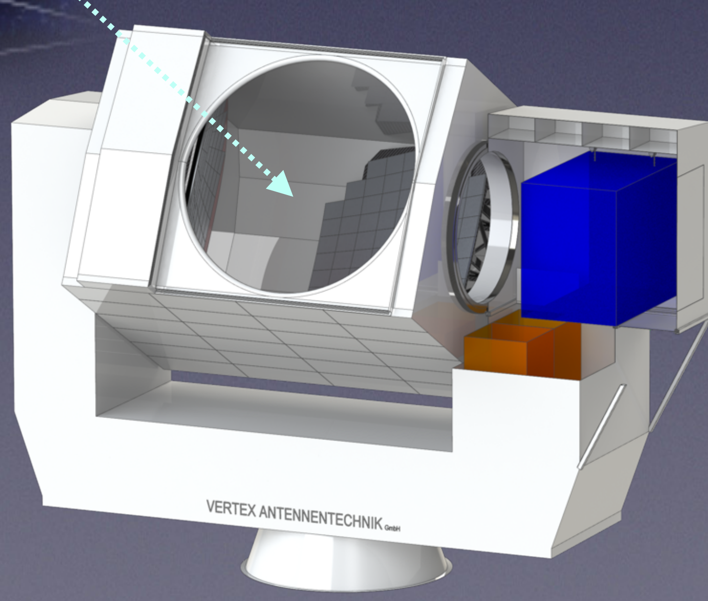
Gravitational lensing of CMB

The Cosmic Microwave Background (CMB) is the remnant of the hot, early phase of the Universe.
On their journey to our telescopes, the CMB photons get deflected by gravitational lensing (and scattering).





- Lensing of the CMB by galaxy clusters is useful for inferring the total (dark matter) mass of clusters, which is the most important ingredient of doing cosmological analysis with these objects.
- Current methods are not very efficient, requiring 1000s of objects to make any significant detection of CMB-lensing.



Additional applications of deep learning on the CMB:

Component separation (i.e. separating the CMB and foreground signals), de-noising (suppressing the detector and atmospheric noise), and image upscaling (i.e. improving the angular resolution).

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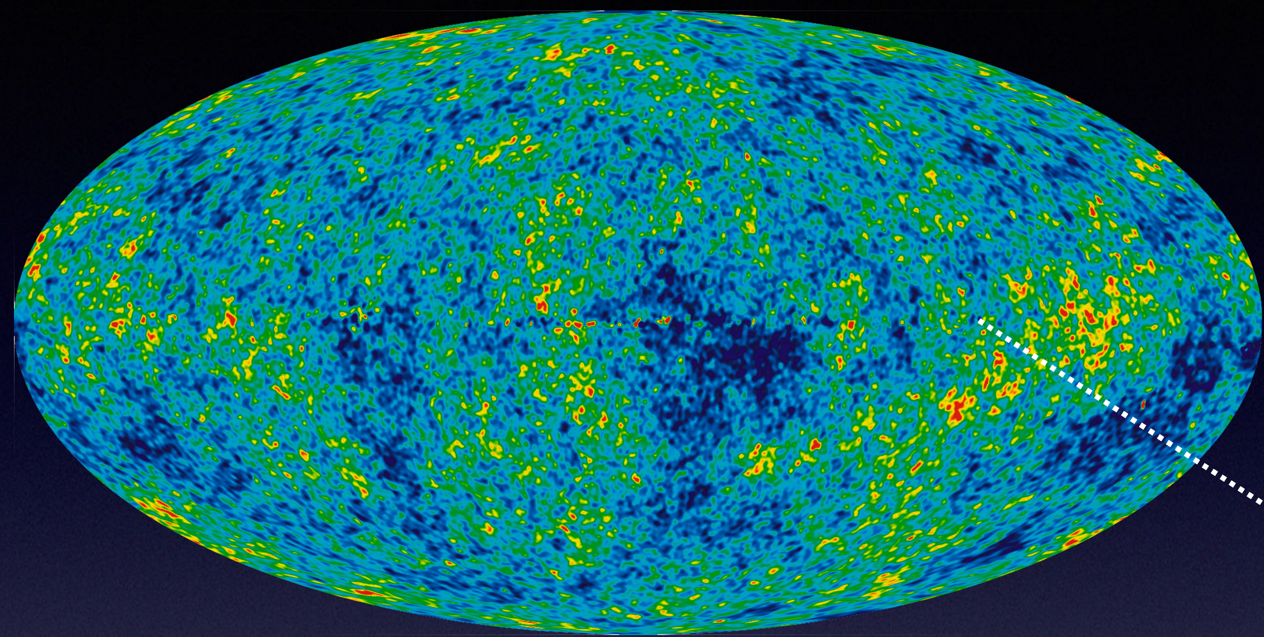

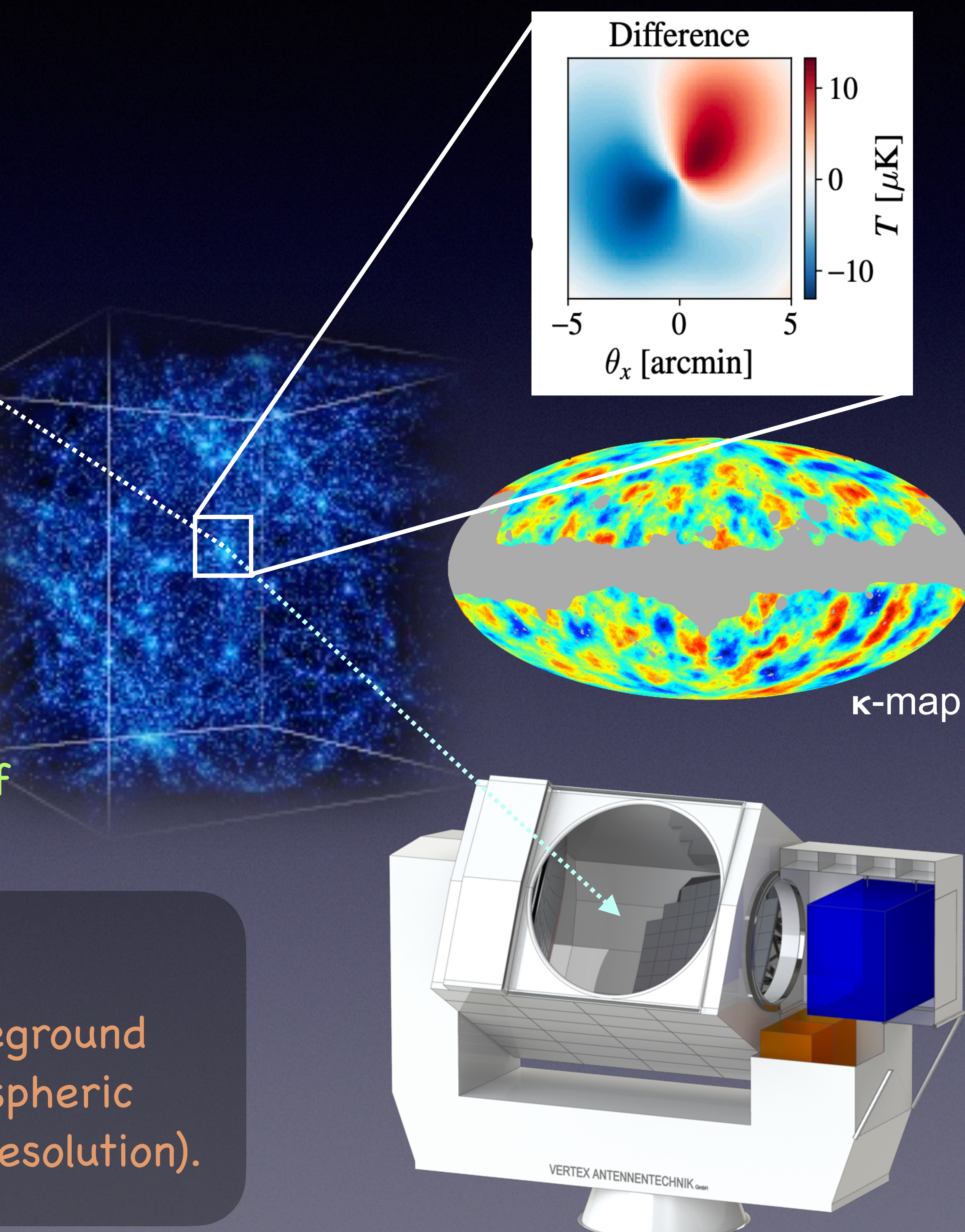

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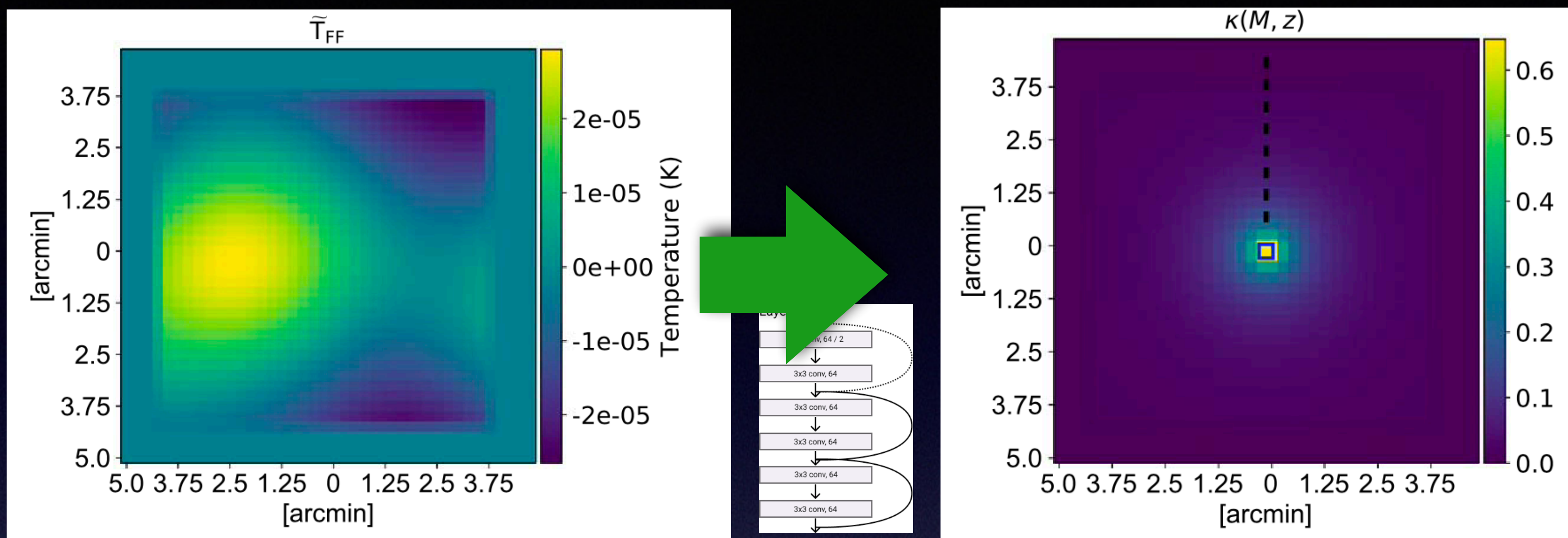
Our work with ~~Skynet~~ ResNet

How to determine the masses of every major galaxy cluster in the Universe (via CMB-lensing)?



Application of deep learning (via ResNet and other deep-neural architectures) on CMB is not new. At least two papers used it for galaxy cluster mass, and well over a dozen papers or CMB map reconstruction.

No application on real data so far!

We are using the mResUNet model proposed by Gupta & Reichardt (2021), implemented in PyTorch.

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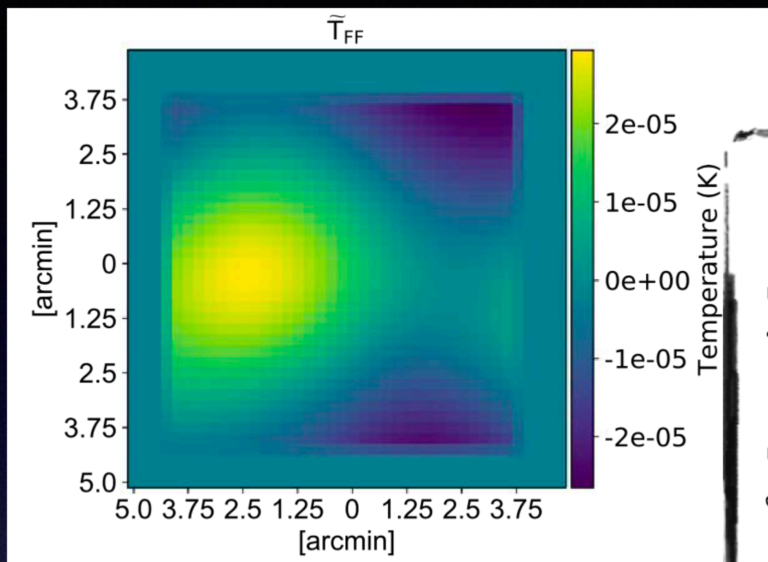

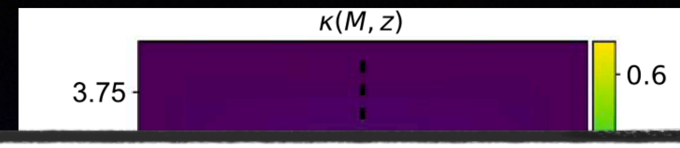

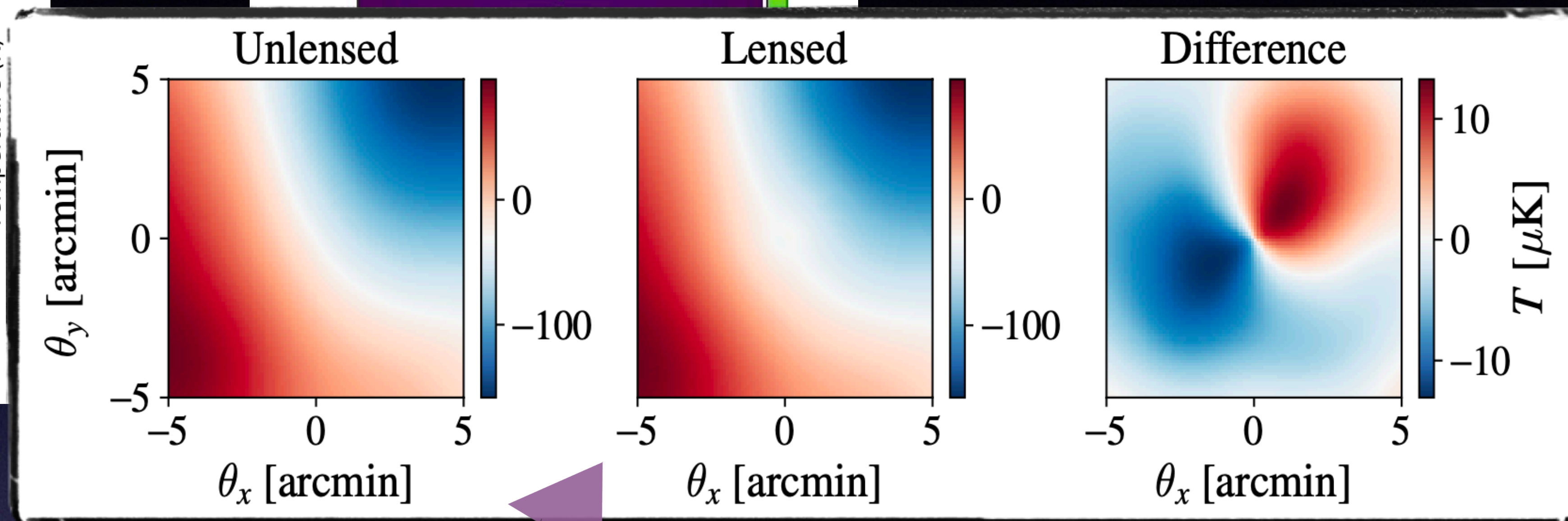

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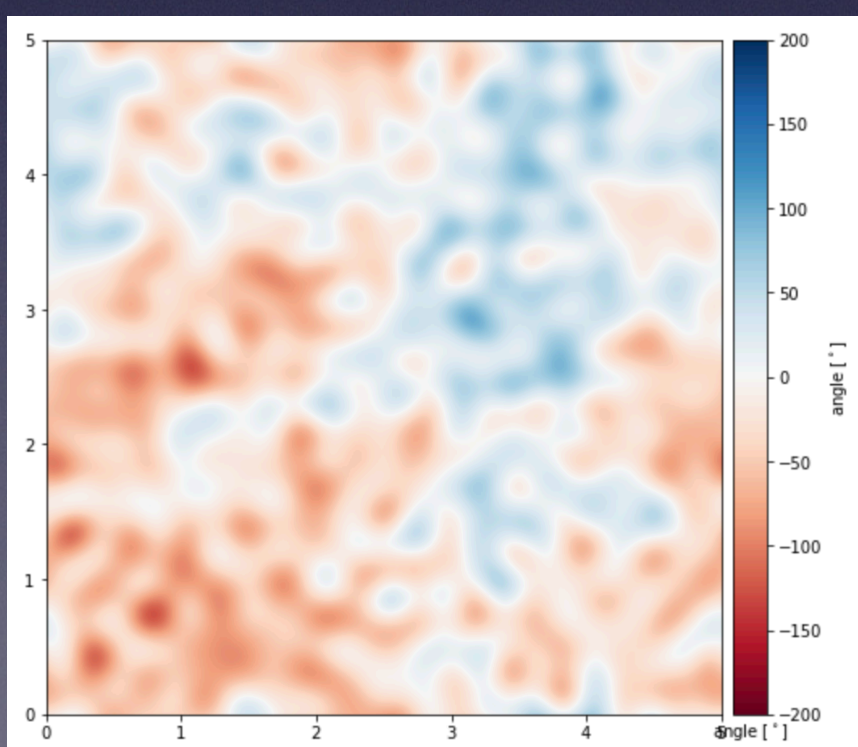
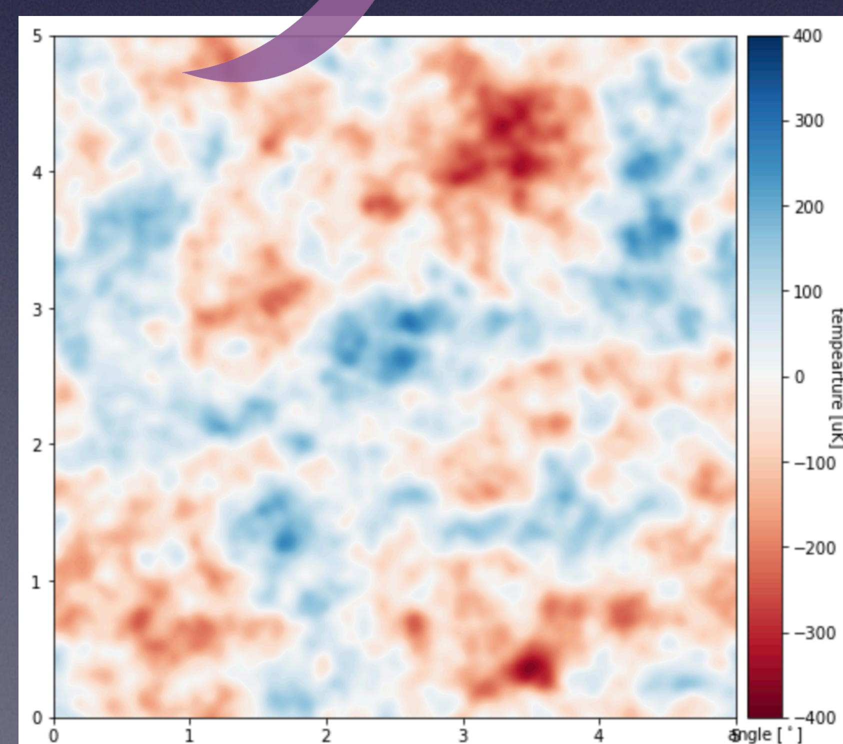


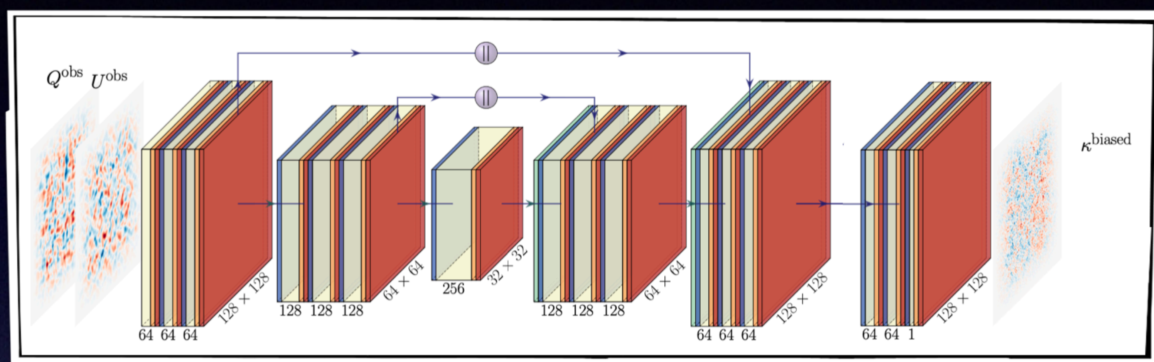


The lensing signal is too small, typically 10 μK signal hidden under 100 μK noise, and in polarization the signal is 10-100 times smaller. What are the best methods to work in such low signal-to-noise regime?

De-noising is further complicated by the atmosphere, whose noise properties are not very well understood. Can we be agnostic about the noise correlations or other specific details?

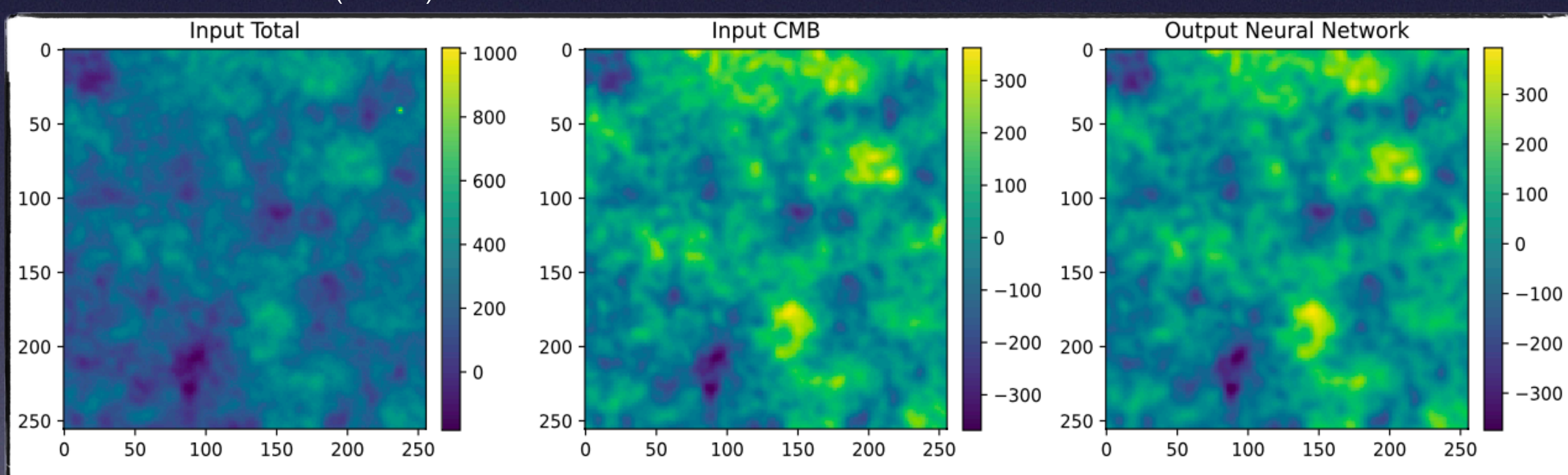
Challenges to solve (& questions to the experts)

We want to move further and make high-resolution CMB maps for upcoming sky surveys, removing the astrophysical foregrounds along the process. This poses many questions:



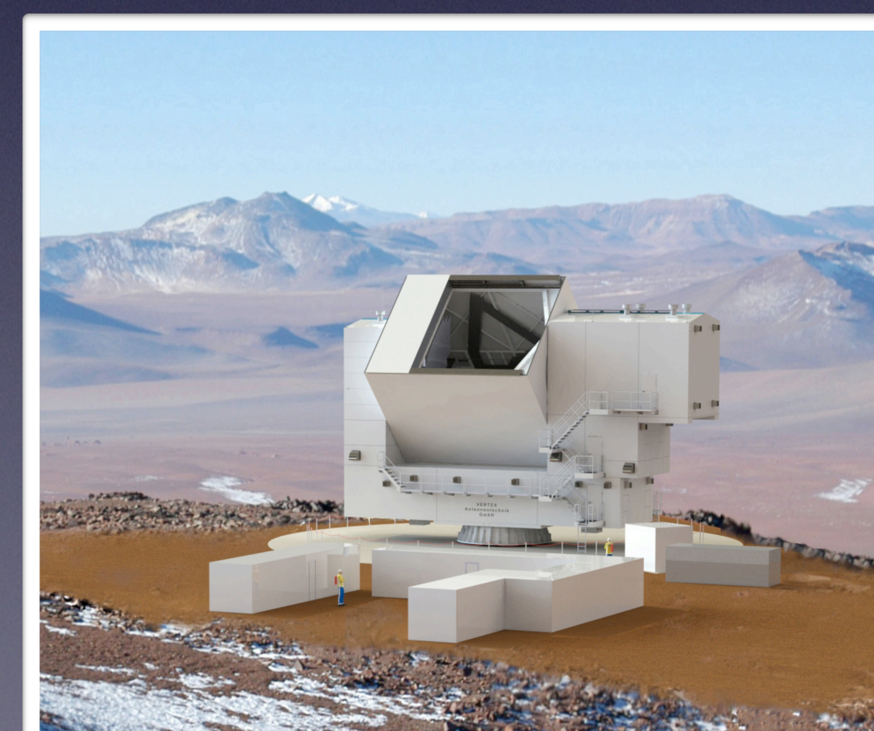
Adapted from Guzman & Mayers (2021)

CENN: Casas et al. (2022)



- Use GANs for image generation, or move to vision transformers?
- How to use data from multiple frequencies to remove contaminating signals (or even to do spectral fitting) ?
- Can we employ specific filtering techniques (like matched filtering) in the convolutional layers? Can we speed-up the whole learning process by running ResNet in the Fourier domain??

Rendition of the Fred Young Submillimeter Telescope (FYST) at Chilean Atacama desert at 5600 meters altitude



None of these approaches have yet been applied on real data! One of our objectives is to make use of the amazing new data that will be collected from the Fred Young Submillimeter Telescope (image on the right), starting 2024 or early 2025.