F-P6

Deep learning for tomographic reconstruction of imaging diagnostics

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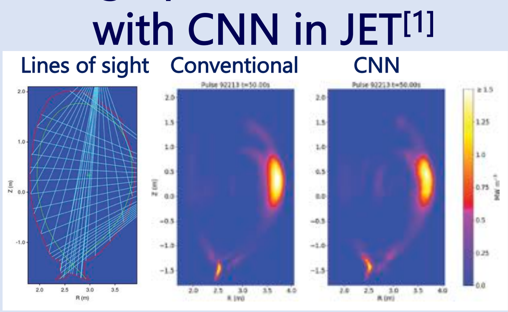
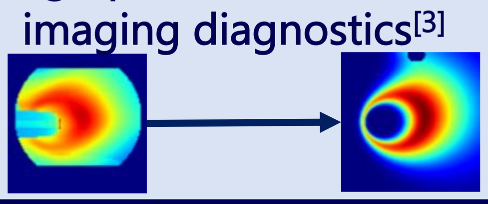
Introduction

- Conventional tomography employs a simple model of internal structure, and the model parameters are easily evaluated by inverting the integrated observables.
- The limited accessibility of diagnostics or the influence of nonlocal optical effects (such as backscatter from the chamber walls) can cause a lack of data, resulting in numerical instabilities in the inversion problem.
- Deep-learning convolutional neural networks (CNNs) have been applied at JET to reconstruct the 2D plasma profile with satisfactory accuracy [1].
- Although the learning process is automatic, numerous manual processes are necessary to design an effective loss function.
- A Generative Adversarial Network (GAN) has been proposed to learn the loss function automatically via an adversarial process [2].
- We have built a method using cGAN and used it to obtain the local emissivity from line-integrated images [3].

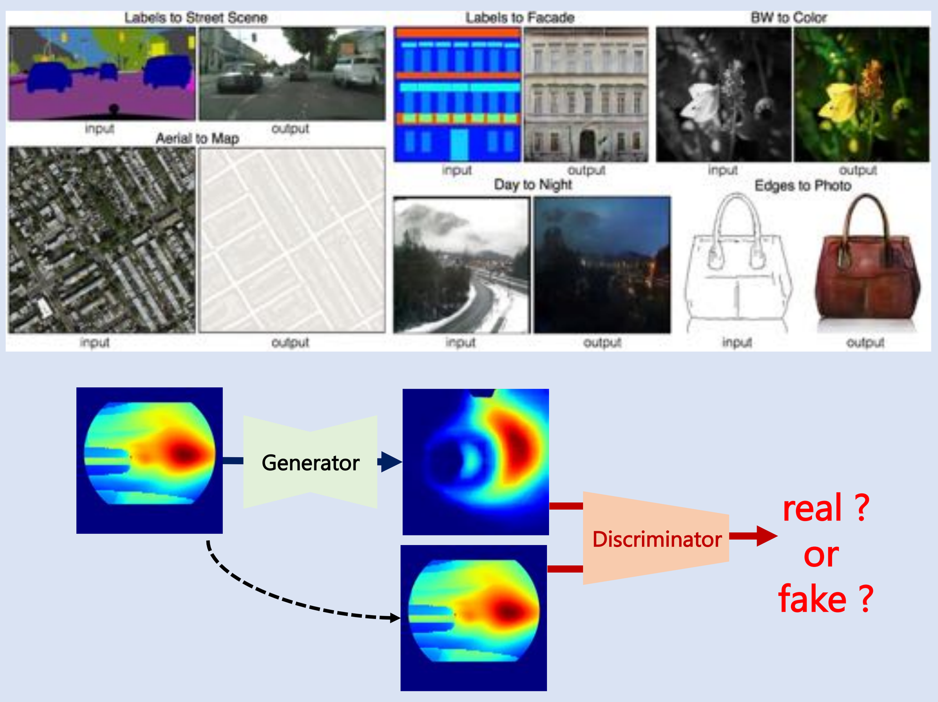
Tomographic reconstruction with CNN in JET[1]



Tomographic reconstruction of imaging diagnostics[3]

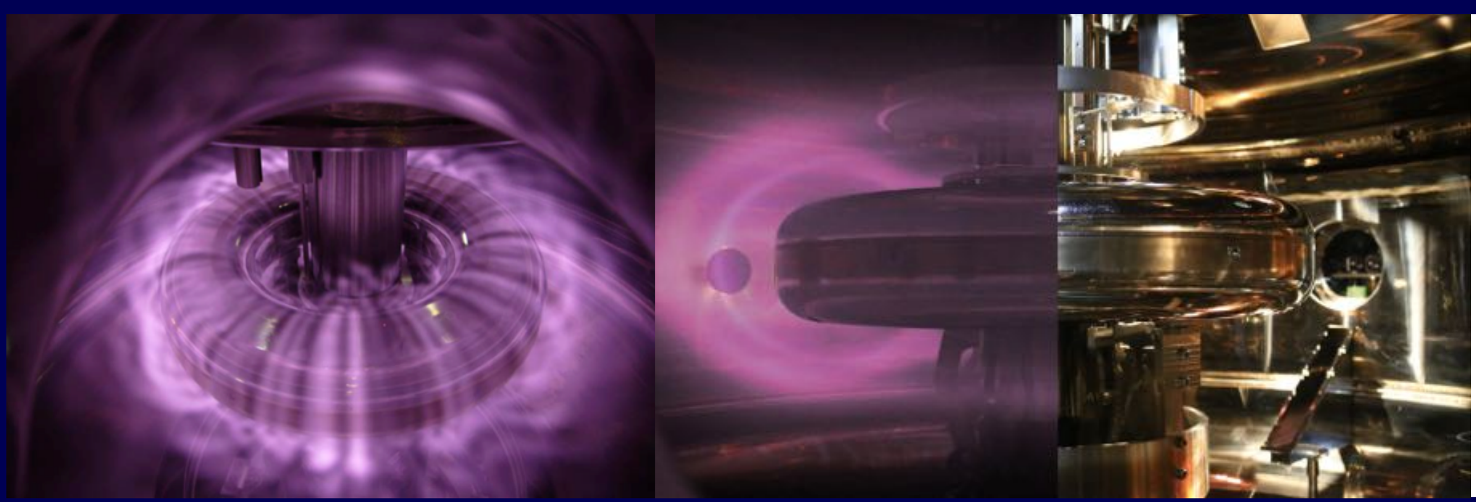


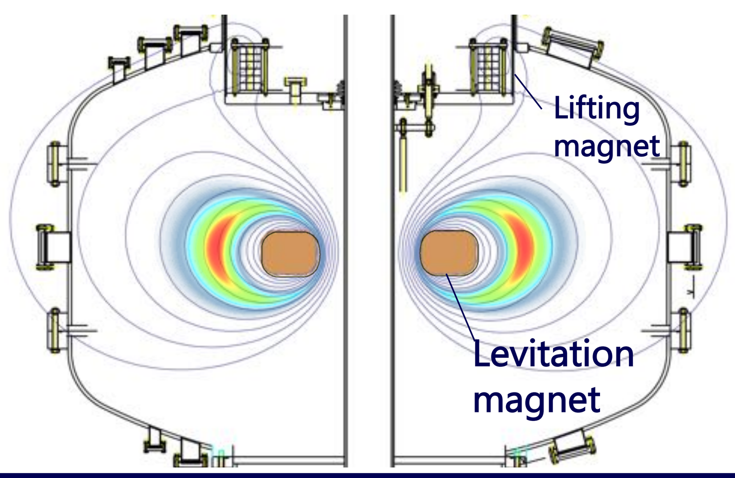
Generative Adversarial Networks



- ✓ A GAN learns a loss that tries to classify whether output images are real or fake, while simultaneously training a generative model to minimize this loss.
- ✓ A "conditional GAN" (cGAN) learns a conditional generative model, applying the same generic approach to problems that would traditionally require very different loss formulations [4].
- ✓ We used the TensorFlow 1.13.1 implementation of cGAN named "pix2pix" [4].

The Ring Trap 1 (RT-1) experiment





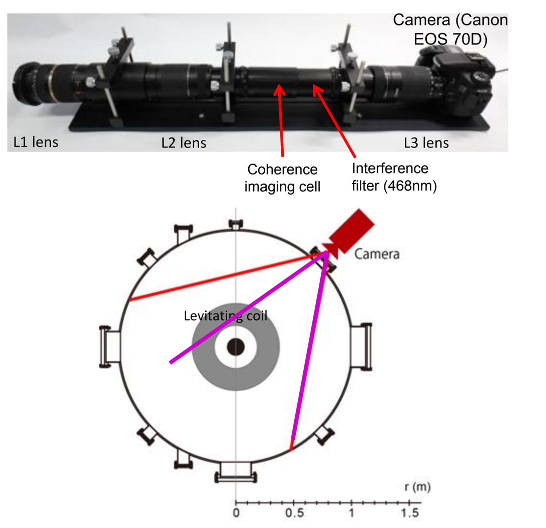
The Ring Trap 1 (RT-1) device is a laboratory magnetosphere that is realized by a levitated superconducting ring magnet in vacuum [5, 6].

- ✓The levitated coil weights ~100kg, which is made of Bi-2223 superconductor
- ✓Radius of levitated coil：r=0.375 m
- ✓Radius of vacuum chamber：R=1.0 m

Generating pairs of local-emissivity and line-integrated images that simulate the experimental system

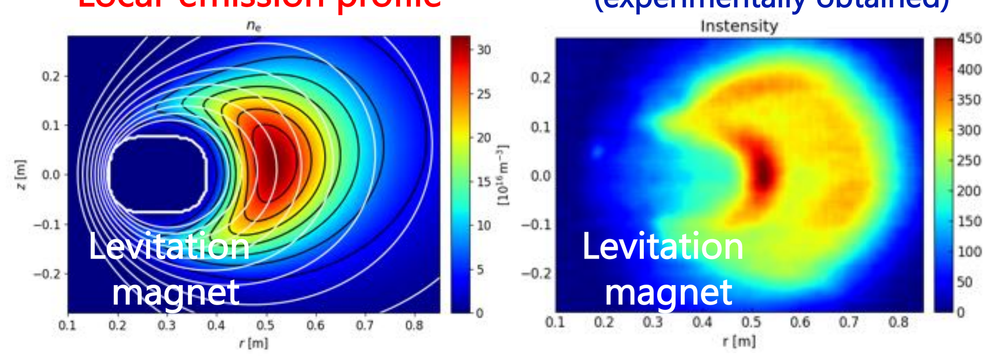
1

Coherence Imaging Spectroscopy for 2D profile



Model function of Local-emission profile

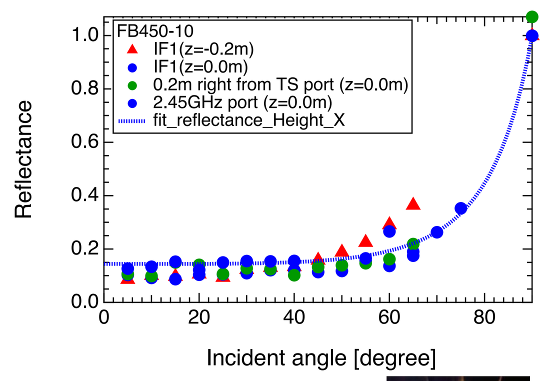
HeII (468.7 nm) emission profile (experimentally obtained)



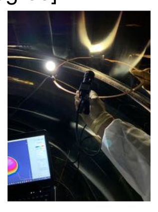
$$n_e(r,z) = n_0 \exp\left(-a\left(\frac{\psi(r,z)-\psi'}{\psi_0}\right)^2\right)\left(\frac{B(r,z)}{B_{z=0}}\right)^{-b}$$

ψ: Magnetic flux
ψ': ψ at r where n_e becomes maximum at z=0
ψ_0: ψ at wall of vacuum vessel (r=1.0m)
B: Magnetic field strength
$B_{z=0}$: Magnetic field strength at z=0

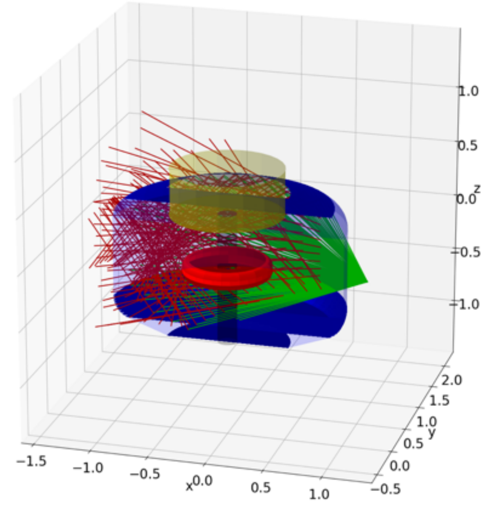
Reflectance of chamber walls of RT-1



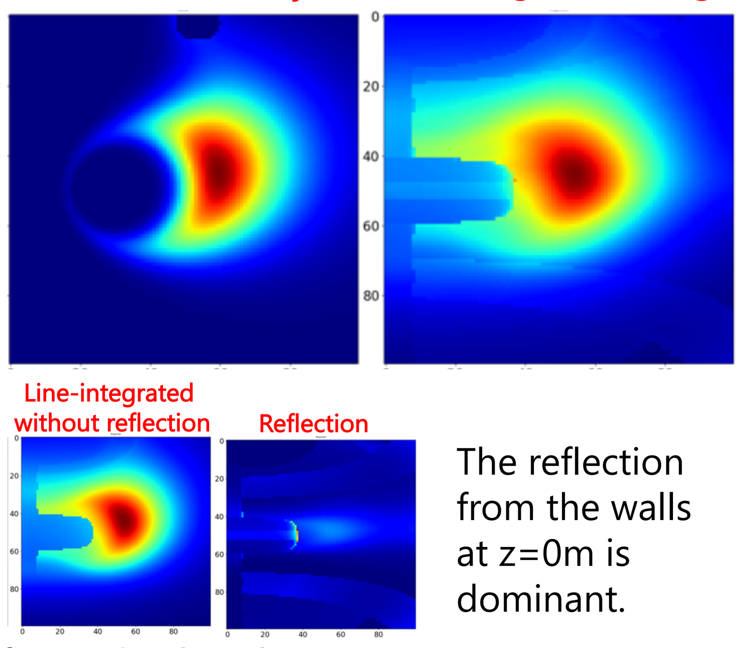
Measurement of reflectance of chamber walls



3D Ray tracing of the CIS optics



Local emissivity   Line-integrated image



The reflection from the walls at z=0m is dominant.

- ✓ We applied this reconstruction technique to the He II 468.6 nm imaging diagnostic of Coherence Imaging Spectroscopy (CIS) [7] from RT-1.
- ✓ To train the network to reconstruct images, we generated pairs of local-intensity profiles and line-integrated images that simulate the optics of the CIS system.
- ✓ We generated the local emissivity using typical model functions for the electron-density and temperature profiles of RT-1 [8].
- ✓ We generated the line-integrated images from the local emissivity, assuming toroidal symmetry for the RT-1 plasmas.
- ✓ We took account of reflections from the chamber walls and the levitation magnet (L-magnet).
- ✓ We also employed the CIS optics to simulate the results, using the optical-engineering program ZEMAX.

Training the generative model which generates the local-emissivity profiles from the line-integrated images

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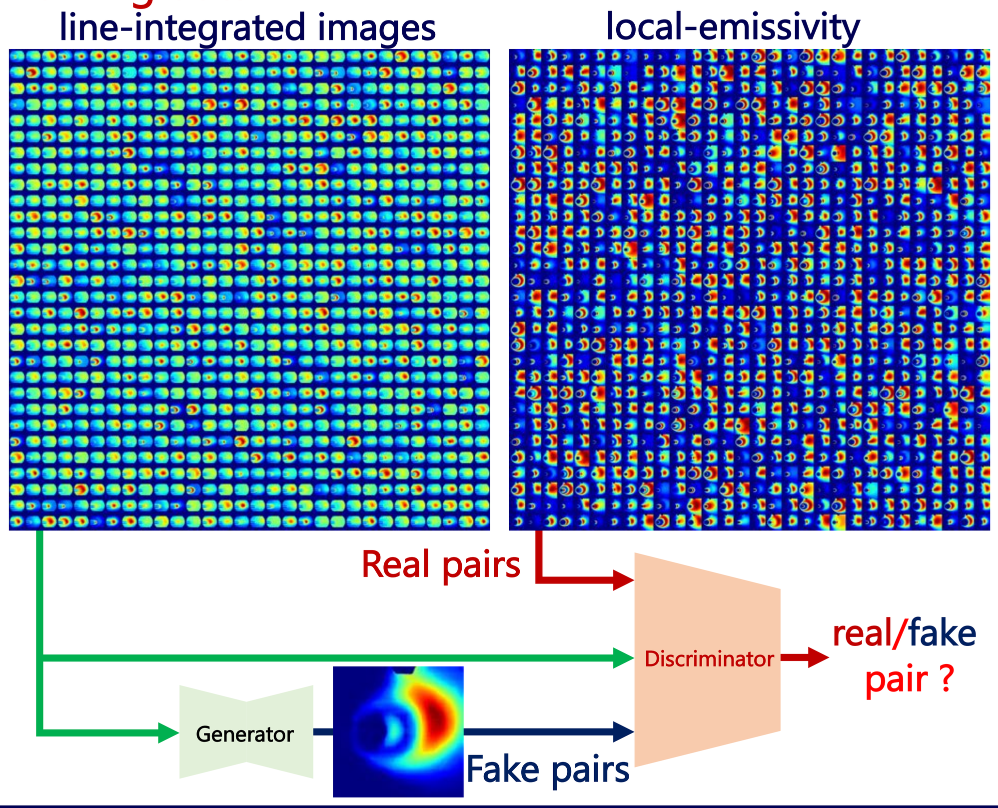
Training data



- ✓ We selected a total of 6500 pairs of images randomly as input for the training, which spanned one million iterations.
- ✓ We also generated another set of 1300 samples using the same strategy, which we employed as a validation set to avoid overfitting.
- ✓ Note that this particular reconstruction was not part of either the training set or the validation set.
- ✓ They show that the network can produce reconstructions with high accuracy.

Input, output, and target images for the network

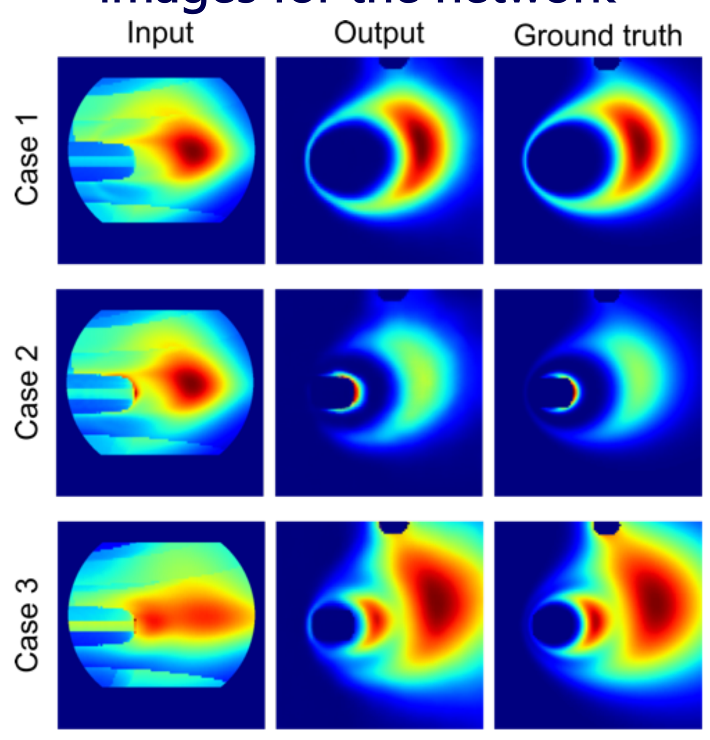


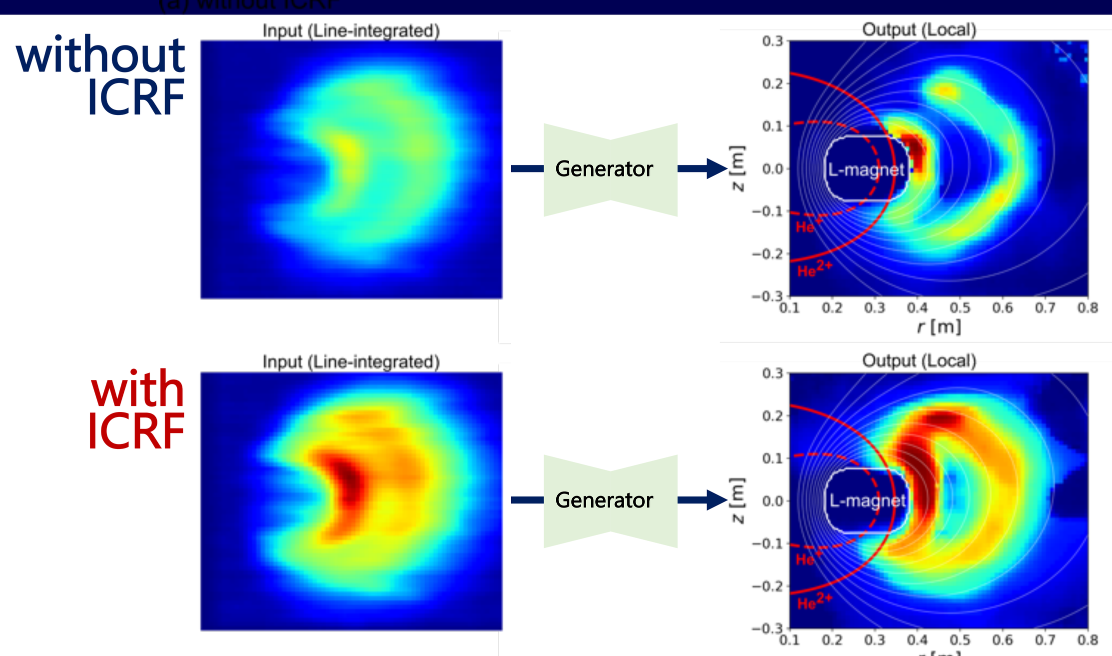
Image-quality metrics
- Structural similarity (SSIM)
- Normalized root-mean-square error (NRMSE)
- Peak signal-to-noise ratio (PSNR)

	SSIM	NRMSE	PSNR [dB]
Mean	0.9393	0.0631	25.957
Std. dev.	0.0224	0.0165	2.546

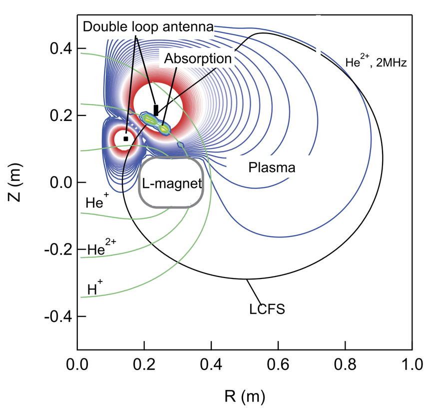
※ Here, SSIM reaches a maximum value of 1.0 when the two images are equal (Note that one can recognize the difference between two images if the SSIM value is less than 0.9).

Application for the He II-emission imaging diagnostic

3



Contours of the E_θ excited by the double-loop antenna



- ✓ We applied it to images obtained by the CIS from RT-1.
- ✓ For helium plasmas, the CIS measured the spectral intensity, ion temperature, and flow velocity of He^+.
- ✓ The 10 kW input power of electron-cyclotron heating (ECH) sustained the target plasma.
- ✓ We applied 9.4 kW of ion-cyclotron-resonance-frequency (ICRF) heating to the double-loop antenna 0.1 sec after the start of the ECH injection and maintained it up to the termination of the discharge.
- ✓ The He^+ intensity increases, especially along the magnetic field lines near the L-magnet.
- ✓ This result corresponds that the heated He^+ ions around the double-loop antenna on the high-field side near the center stack move to the upper region of the L-magnet along the magnetic field lines.

Summary

We have developed a new tomography method using a cGAN and have demonstrated its efficiency by converting a line-integrated image into local emissivity.

- Calculation of the line-integrated image from the local emissivity is generally easier than the calculation of the opposite relation.
- In the present work, we have taken into account backscattering from the chamber walls, which makes even the line-integrals involved; hence conventional inversion methods do not apply.
- This method can be applied to other diagnostics in other machines where reconstruction is difficult because of restrictions on measurements or complexities of the inversion problem.

References

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