Regularization extraction for real-time plasma tomography at JET

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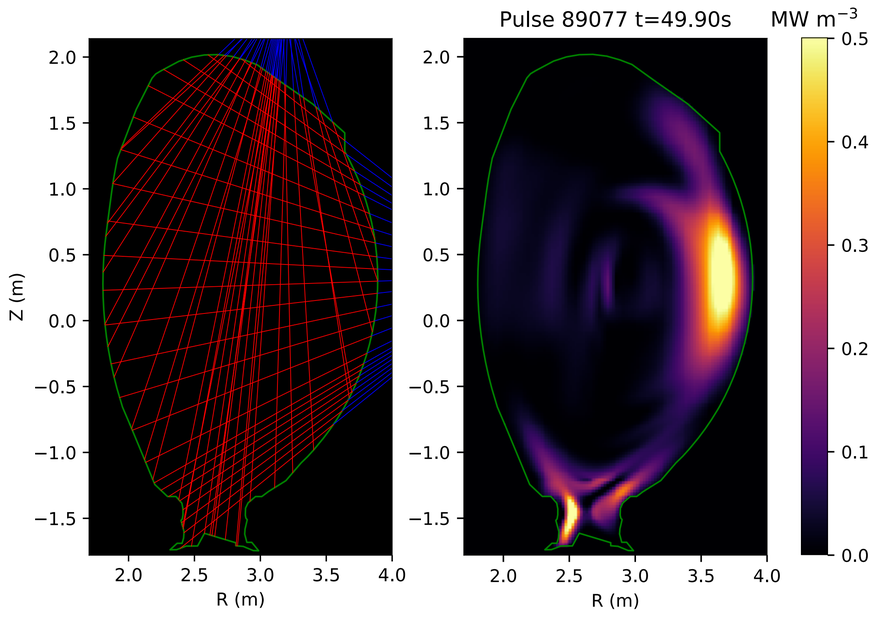
Bolometry 1

- Bolometer system with 56 lines of sight (KB5)
- Current reconstruction method: TOMO5 [1]
  - Smoothing along magnetic flux surfaces
  - Non-negativity constraints
  - Iterative process, several minutes to converge
- Tomograms with 196×115 resolution (22540 pixels)



Tomography 2

- Measuring the line-integrated radiation is a *forward problem*

detector measurements (56×1) → $\mathbf{f} = \mathbf{T} \cdot \mathbf{g}$ ← radiation profile (22540×1)

T_{ij} : how much each pixel j contributes to each detector measurement i (56×22540)

- Reconstructing the plasma radiation profile is an *inverse problem*

radiation profile (22540×1) → $\mathbf{g} = \mathbf{M} \cdot \mathbf{f}$ ← detector measurements (56×1)

M_{ij}: how much each detector j contributes to each pixel i (22540×56)

- 22540×56 = 1.26 million parameters

Data fitting 3

- Given a set of reconstructions $\{\mathbf{g}_1, \mathbf{g}_2, ..., \mathbf{g}_n\}$ together with their corresponding measurements $\{\mathbf{f}_1, \mathbf{f}_2, ..., \mathbf{f}_n\}$
- It is possible to fit $\mathbf{M}$ by minimizing the the mean absolute error

$$L = \frac{1}{n} \sum_i |\mathbf{g}_i - \mathbf{M} \cdot \mathbf{f}_i|$$

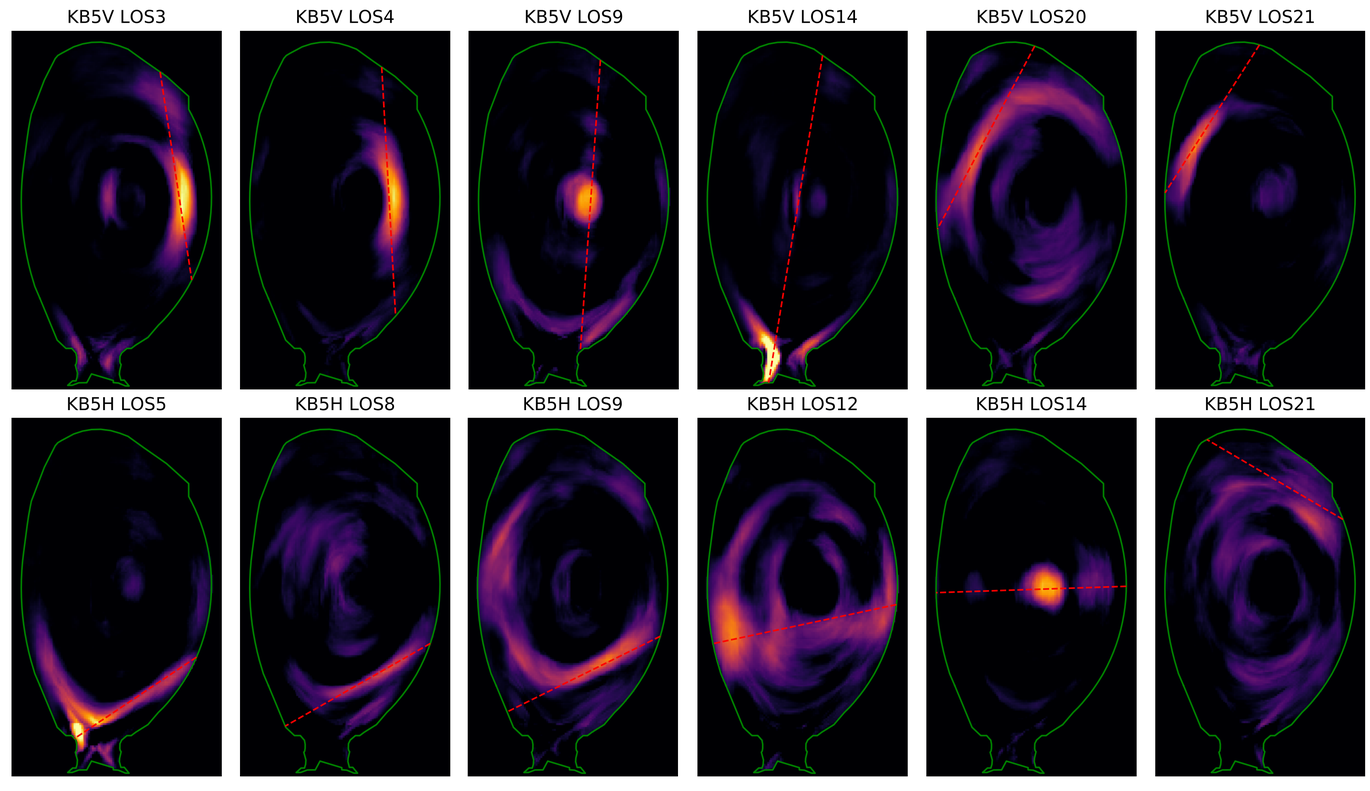
- Using gradient descent with learning rate η

$$\mathbf{M} \leftarrow \mathbf{M} - \eta \cdot \nabla L$$

- Can be accelerated with momentum [2]
- Implemented with a machine learning framework (Theano) running on an Nvidia Titan X GPU
- Reaches a loss L = 0.006 MW/m^3 after 10^6 iterations (53 min)

Regularization patterns 4

- Each column j of $\mathbf{M}$ indicates how detector j contributes to the reconstruction



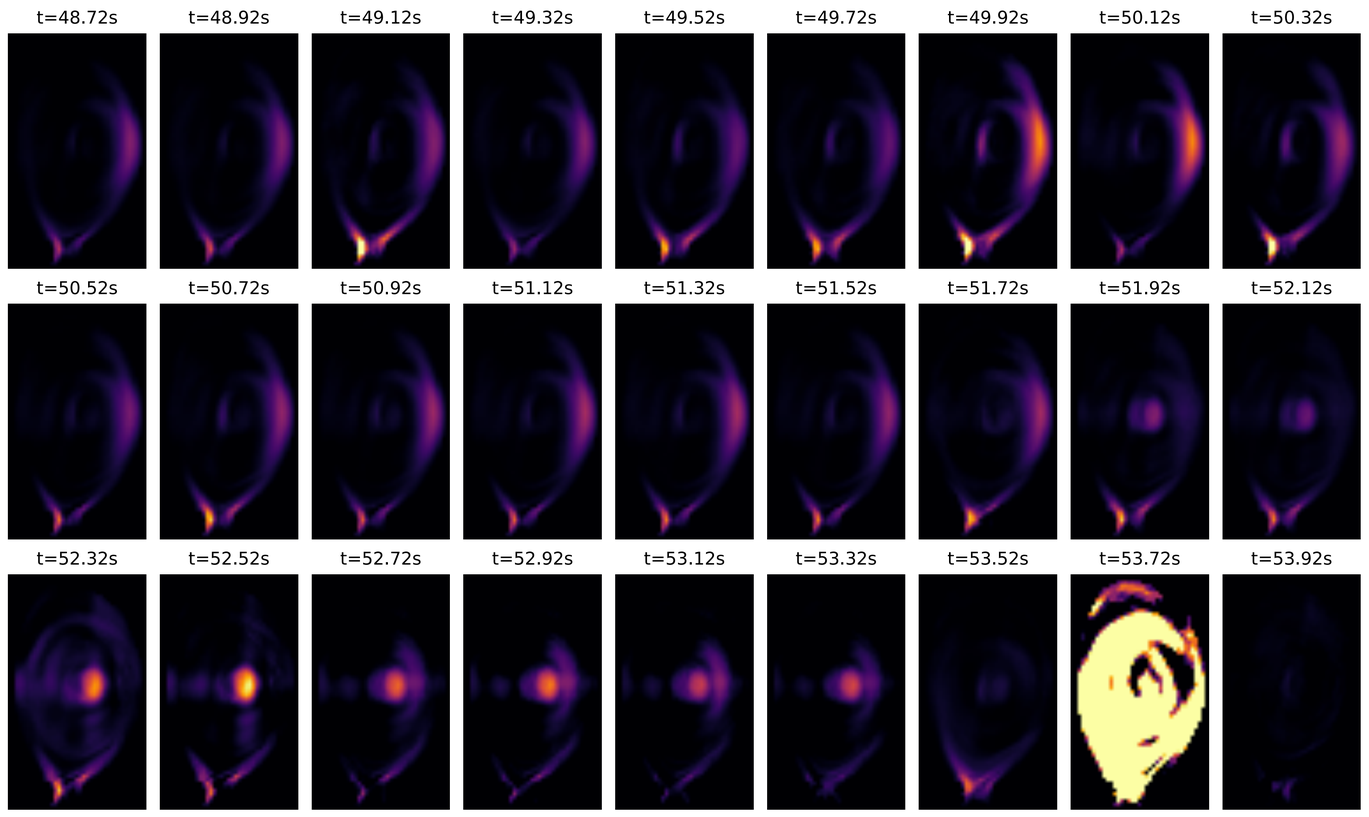
- Regularization patterns resemble smoothing along magnetic flux surfaces

Quality of the reconstructions 5

- Dataset of 800 reconstructions, carefully chosen to avoid artifacts and malfunctioning detectors
- Data divided into 90% for training and 10% for validation, with validation loss of 0.007 MW/m^3 after 10^6 iterations
- Quality metrics on the validation set: SSIM = 0.948 , PSNR = 38.2 (dB) , NRMSE = 0.0435
- The quality of the reconstructions is similar to that obtained with more complex models, namely deep neural networks [3], but error is slightly larger

Full-pulse reconstruction 6

- Calculating $\mathbf{g} = \mathbf{M} \cdot \mathbf{f}$ takes < 0.4 ms on standard quad-core CPU
- Since KB5 sampling rate is 5 KHz (0.2 ms), real-time tomography becomes possible



[1] L. Ingesson et al., Nucl. Fusion 38, 11, 1675 (1998)
[2] I. Sutskever et al., ICML'13 (2013)
[3] D. R. Ferreira et al., arXiv:1802.02242 (2018)

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