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Tomographic reconstruction of COMPASS tokamak edge turbulence from single visible camera data and automatic turbulence structure tracking

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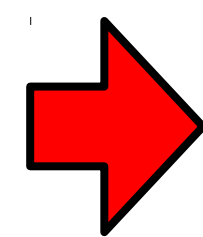
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Poster based on [Cavalier et al. 2019 Nucl. Fusion 59 056025]

A. MOTIVATION

- Importance of turbulence in fusion devices
- Hard to diagnose scrape-of-layer (high fluxes)
- Optical diagnostics popular → visible camera
- Light coming from interaction neutral/plasma
- Gas-puff imaging to have 2D poloidal section
- Not passive diagnostic → perturbation [1]



- Tomography with one camera
- Light coming from neutral naturally present in vessel
- =
- Passive diagnostic
- Just need 1 window + 1 camera

B. TOMOGRAPHIC TECHNIQUE [3,4]

Different from SVD or least-square methods

Goal is to retrieve from a picture I_0 the plasma emissivity S_0 :

$$I_0(x, y) = \int_{s_c}^{+\infty} S_0(\psi(s_{xy}), \theta(s_{xy}), \varphi(s_{xy})) ds_{xy}$$

ψ is a flux coordinate, θ a poloidal coordinate and φ the toroidal angle

3D (space) to 2D (camera chip) problem → Assume constant emissivity along B $S_0(\Psi, \theta, \varphi) \rightarrow S_0(\Psi, \theta)$

- At φ , discretize the poloidal plane so that for ψ_λ an orthogonal basis:

$$S_0 = \sum_{\lambda=1}^{N_\lambda} s_\lambda \psi_\lambda = \sum_{\lambda=1}^{N_\lambda} \langle \psi_\lambda | S_0 \rangle \psi_\lambda \quad \rightarrow \quad I_0 = K S_0 = \sum_{\lambda=1}^{N_\lambda} s_\lambda K \psi_\lambda,$$

- Assuming K is invertible and taking advantage of the adjoint K^* : $\langle K a | b \rangle = \langle a | K^* b \rangle$ we define

$$\begin{aligned} K \psi_\lambda &= \kappa_\lambda \chi_\lambda \\ K^* \xi_\lambda &= \kappa_\lambda \psi_\lambda \end{aligned} \quad \text{With } \kappa_\lambda \text{ such that } \|\xi_\lambda\|=1$$

- From the previous equations and since the ψ_λ is an orthogonal basis, it follows that:

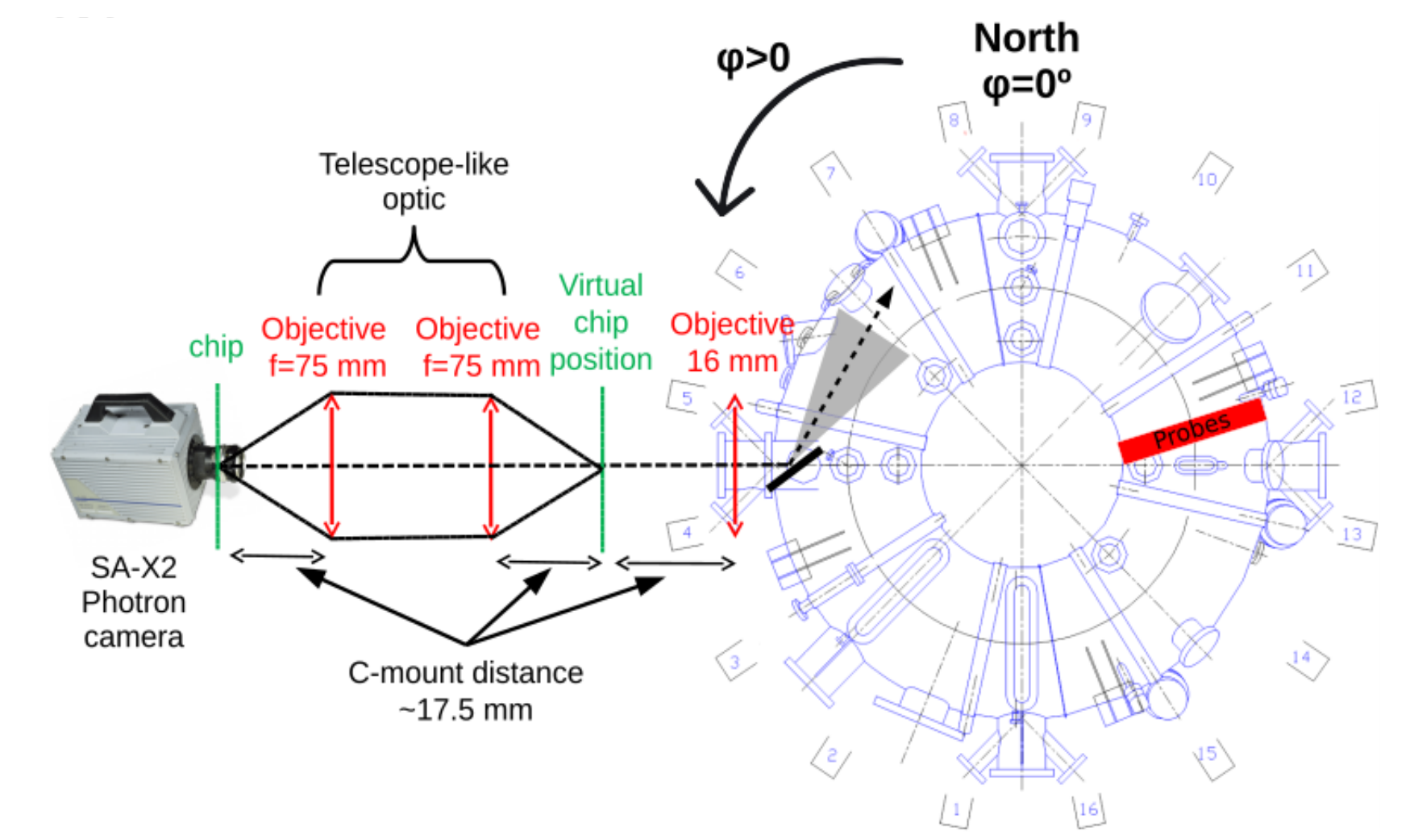
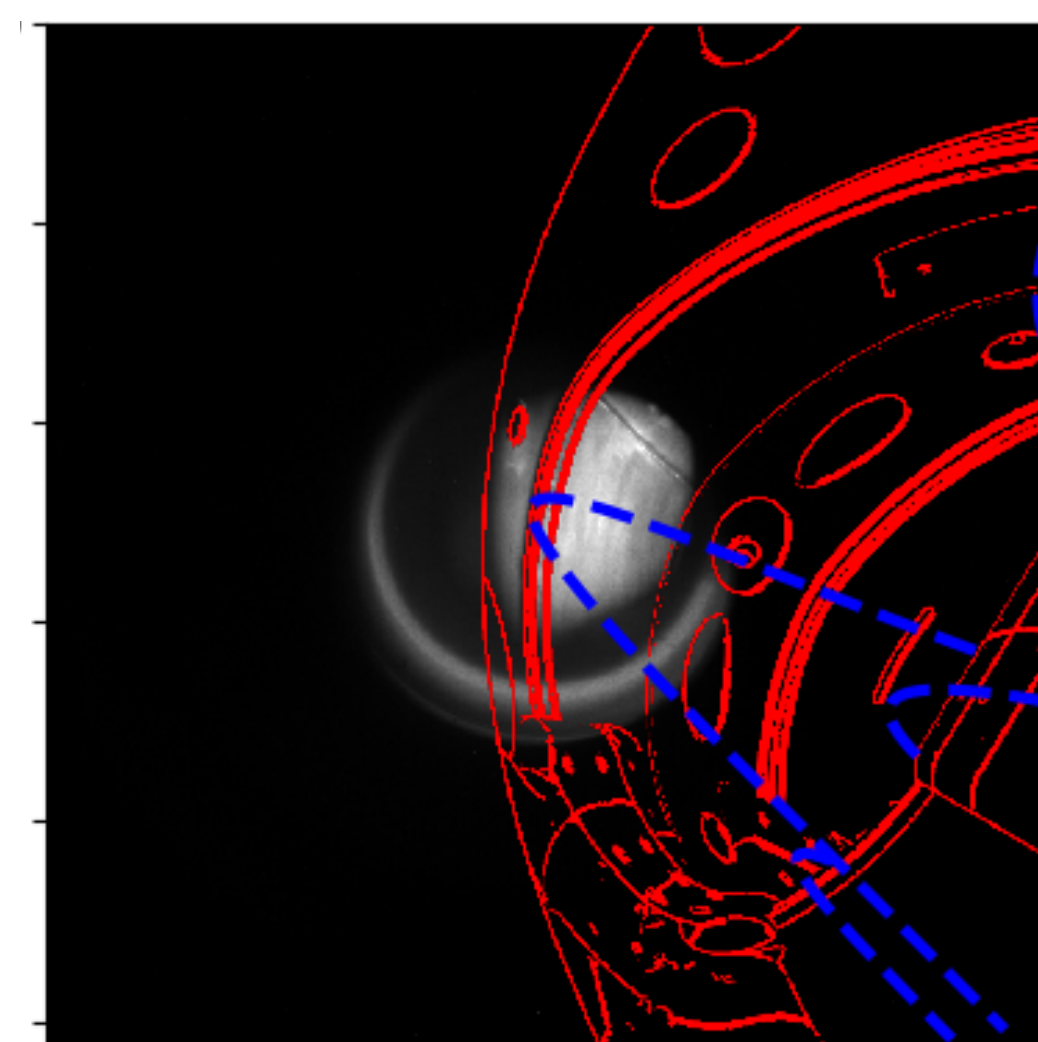
$$S_0 = \sum_{\lambda=1}^{N_\lambda} \langle I_0 | \xi_\lambda \rangle \kappa_\lambda^{-1} \psi_\lambda \quad \text{and} \quad \langle \xi_\lambda | \chi_{\lambda'} \rangle = \begin{cases} 1 & \text{if } \lambda = \lambda' \\ 0 & \text{otherwise} \end{cases}$$

C. EXPERIMENTAL SETUP

Camera details:

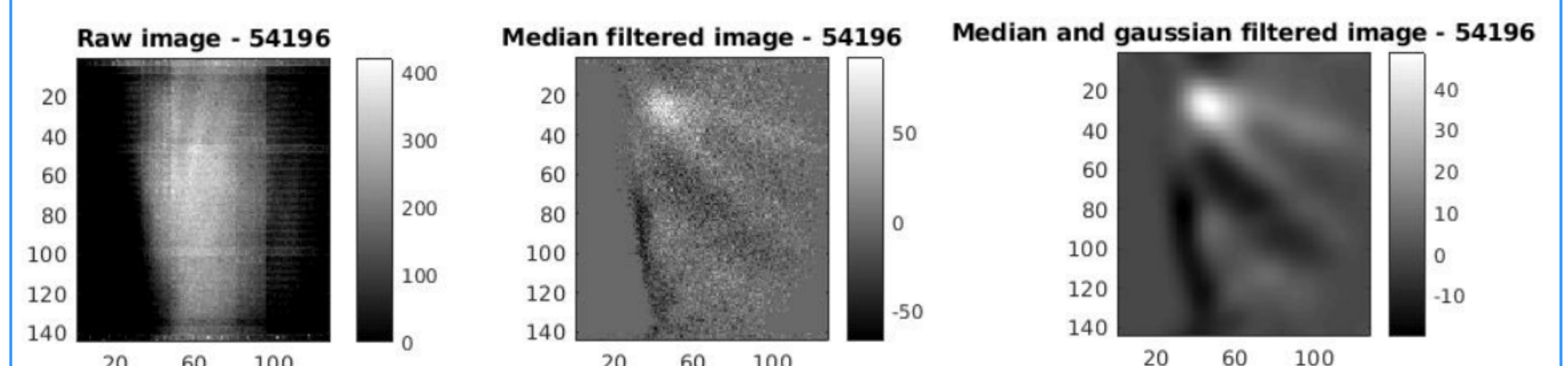
- 12 bits SA-X2 photon camera
- CMOS sensor 20x20 μm^2

- 270 kfps, 128x144 pixels, 2.1 μs
- Mostly D α
- Resolution 0.4 mm at 28 cm



Data from COMPASS #15487

~1150 ms L-mode $n_e = 3.10^{19} \text{ m}^{-3}$ $I_p = 180 \text{ kA}$

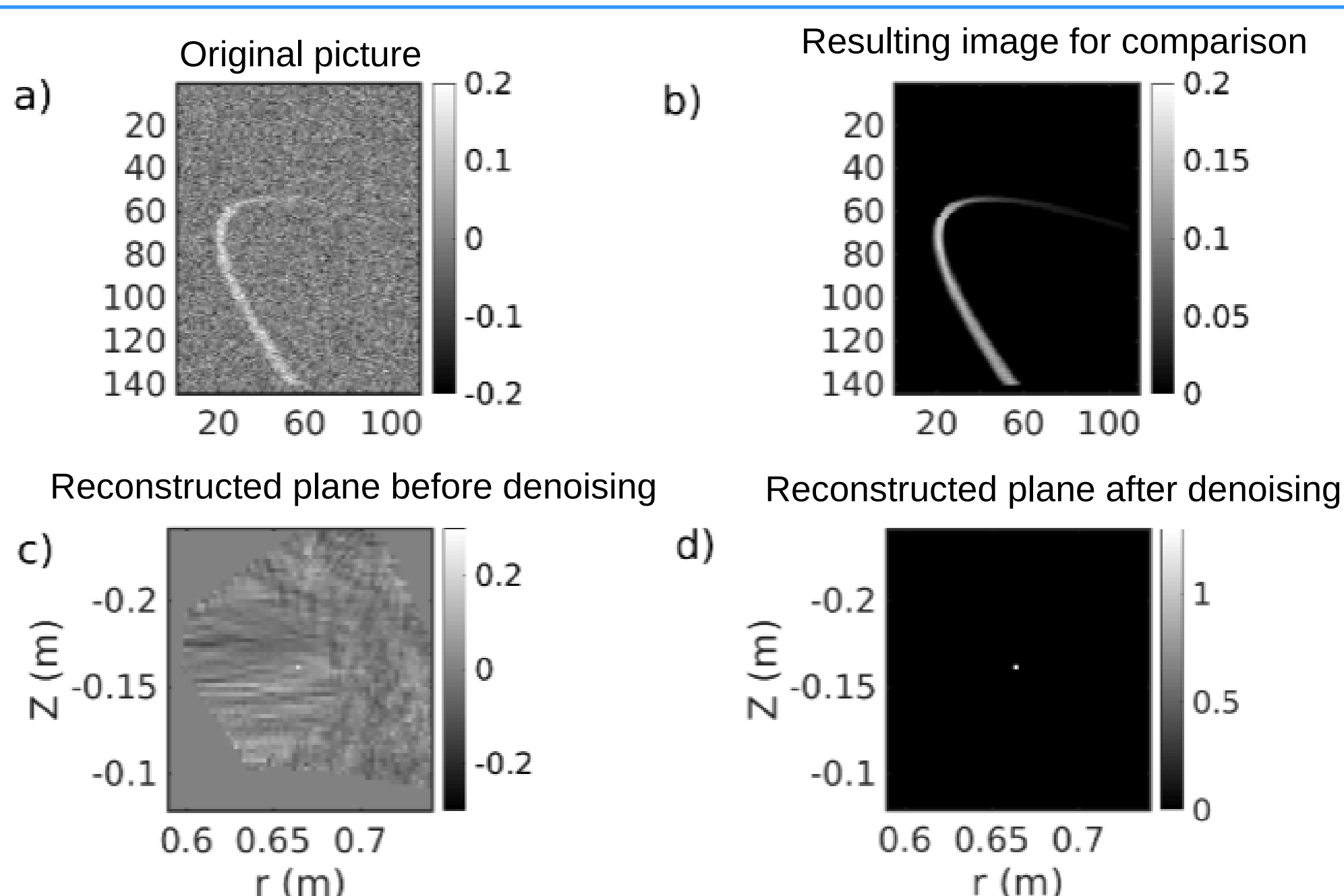


Median filter calculated over 10 frames.
Gaussian filter with 5 pixels standard deviation

D. VALIDATION

Academic case

=
synthetic filament
+ noise

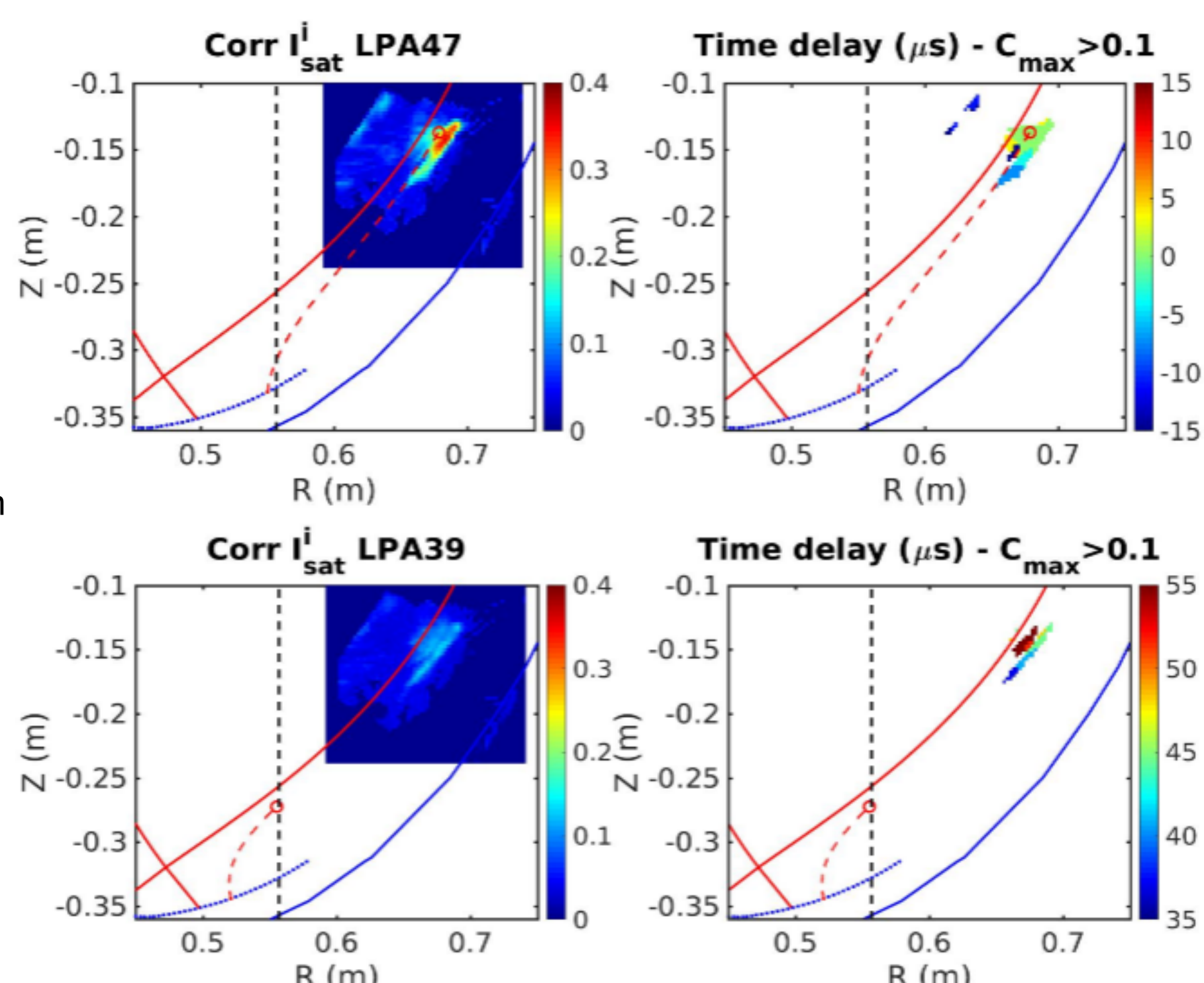


- Validated using data from TOKAM3X [2]: emissivity slowly varying along B lines
- **Experimental validation** by correlation between 10000 images reconstruction and I_{sat} measurement with **Langmuir probes** in the divertor:

- Probes ~2.5m from reconstructed plane

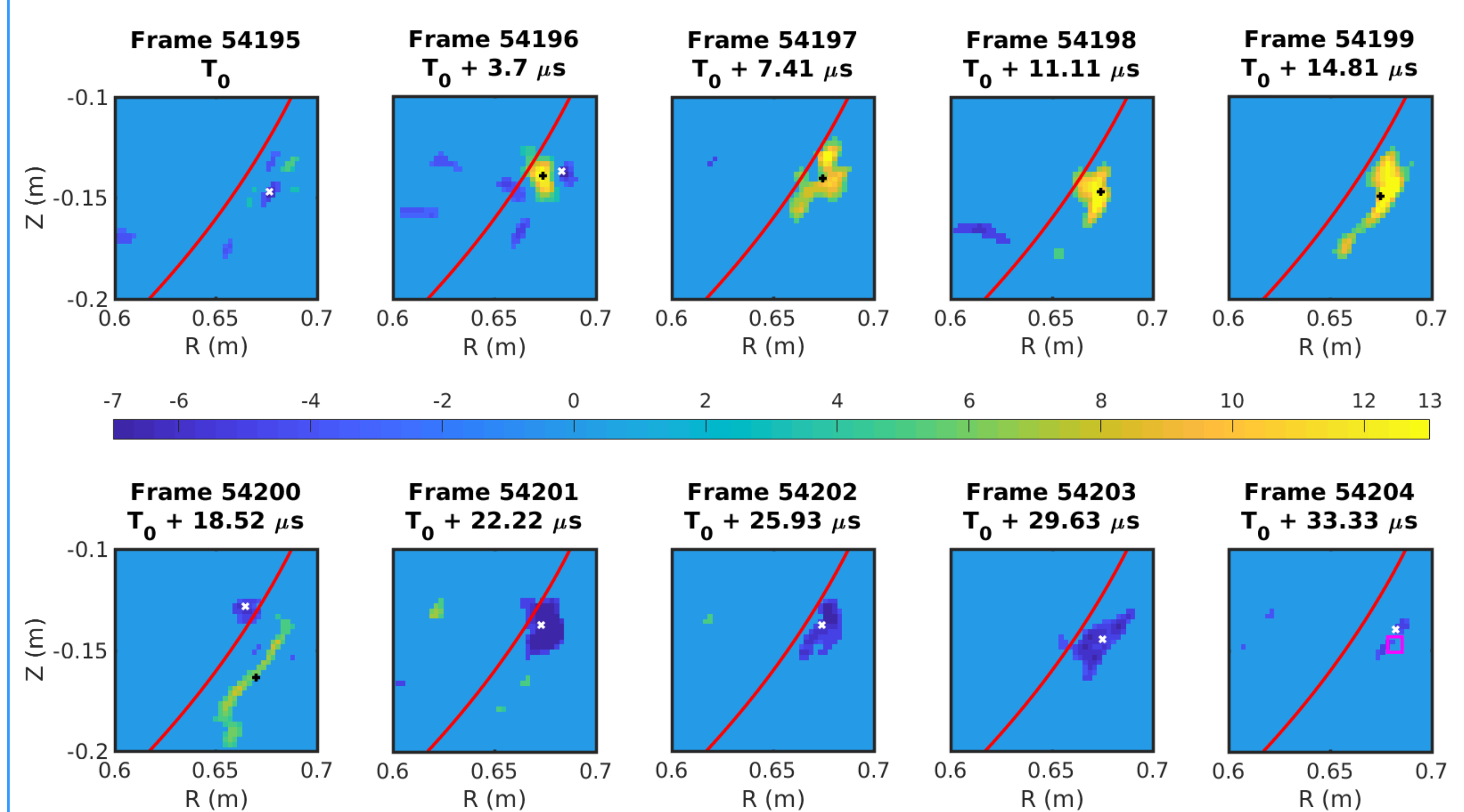
- Time delay on B line = 3.7 μs
→ fast transport along B

- Time delay always = 0 at location connected to probe
→ signal well reconstructed

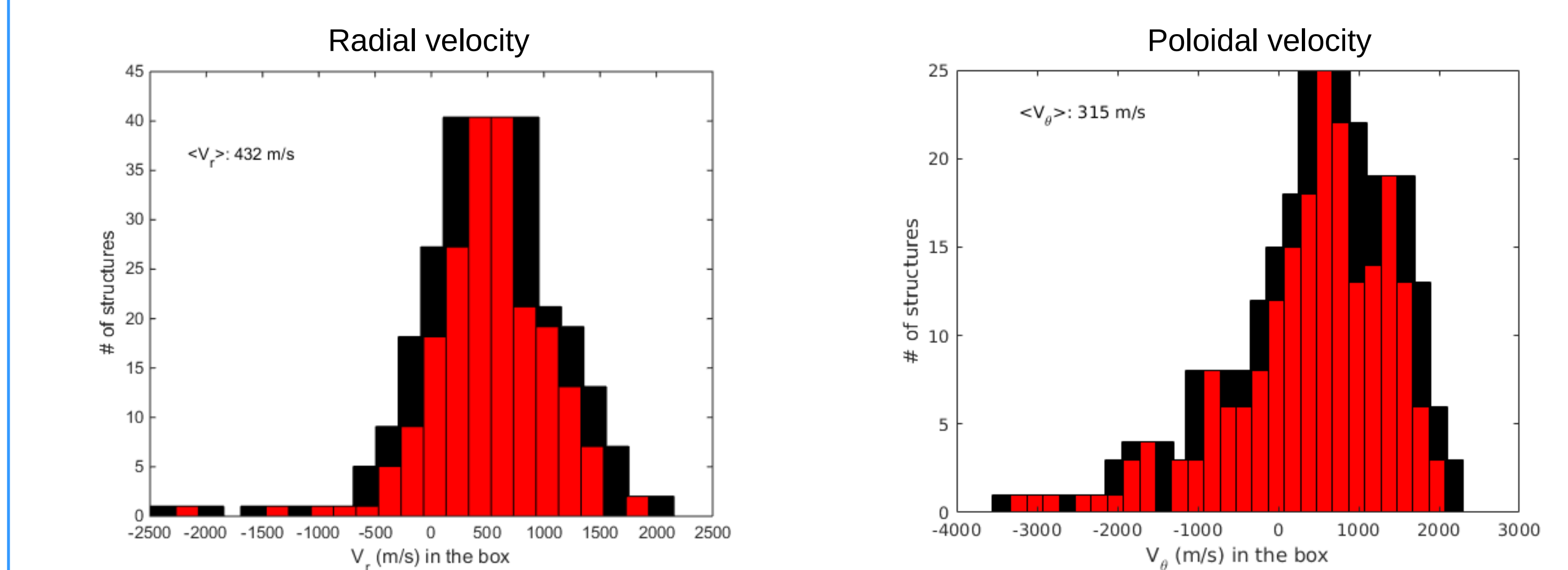


E. STRUCTURE TRACKING

- Example of blob evolution: $T_0 = 1150 \text{ ms}$ → tracking by TRACK software [4]



- Complex turbulent dynamic: 626 positive structures tracked at least 5 images



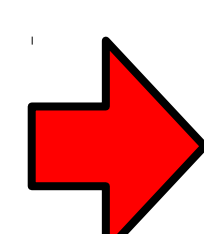
TRACK provides positions, velocities, size, aspect ratio → lot of infos and great statistics

CONCLUSION

- No perturbations
- No need to install in-vessel gas-puff
- Good alternative to GPI

BUT

- Lower signal to noise ratio than GPI
- No control on neutral influx



- Compare statistics from this method and from standard GPI

REFERENCES

- [1] S. J. Zweben et al. Review of Scientific Instruments **88** 041101 2017.
- [2] Jordan Cavalier et al. 2019 Nucl. Fusion **59** 056025 (16p)
- [3] Nguyen Van Yen et al. 2012 Nuclear Fusion, **52** 013005 (11p)
- [4] Track software. <http://www.aprex-solutions.com/>