Application of Optic Flow Method for Imaging Diagnostic in JET

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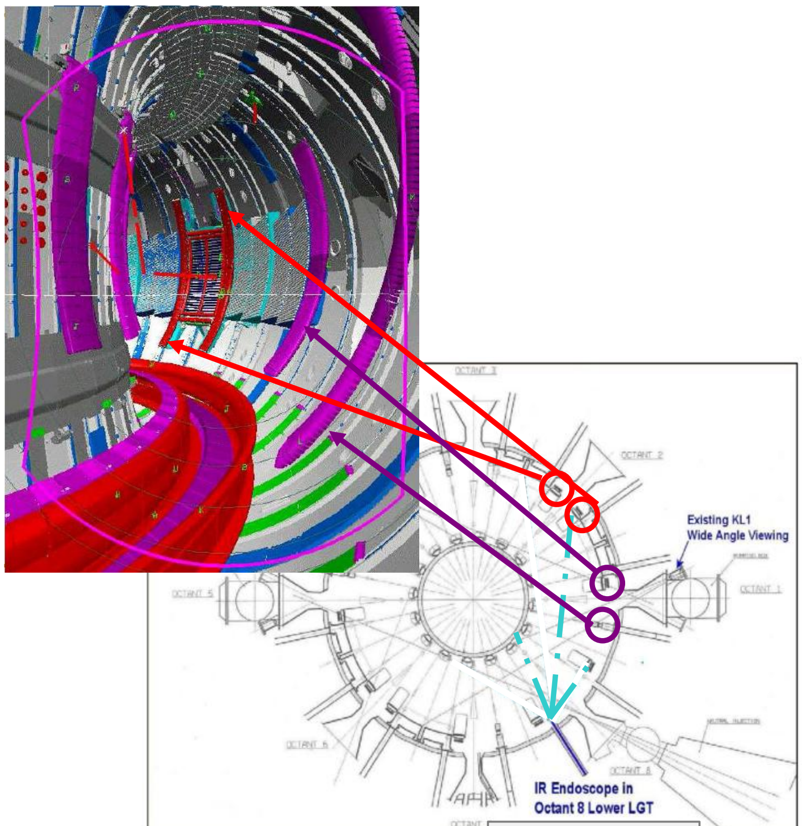
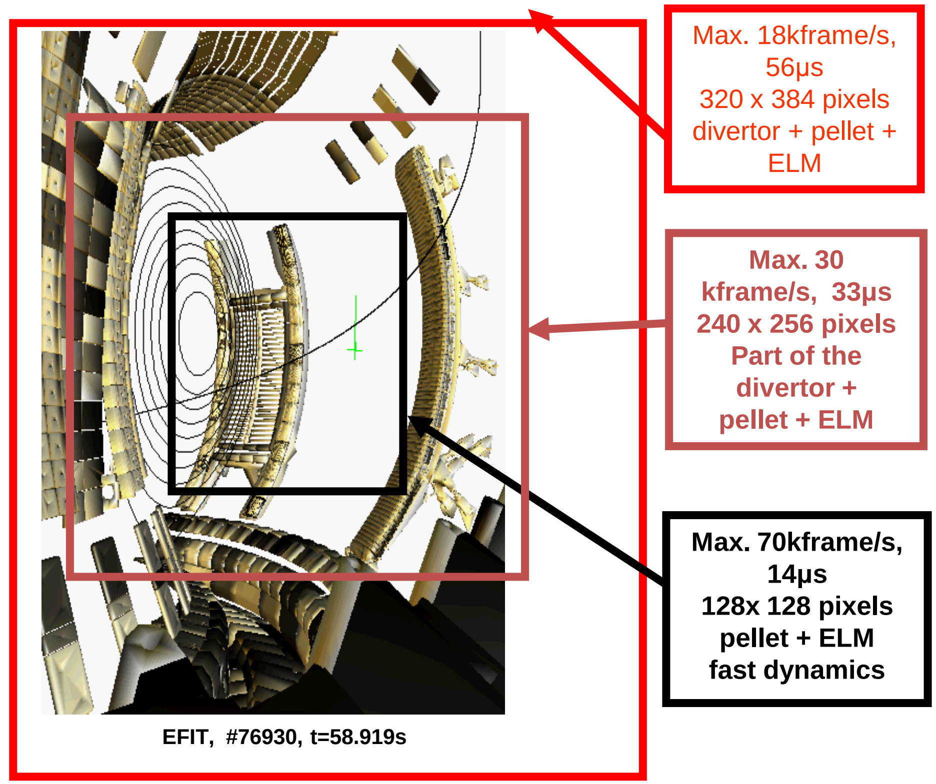
A wide angle view fast visible camera (Photron APX) was recently installed in JET.

The wide angle view is appropriate for:

- study of pellet ablation
- large scale instabilities
- plasma wall interactions



installed on the 'visible arm' of the IR endoscope

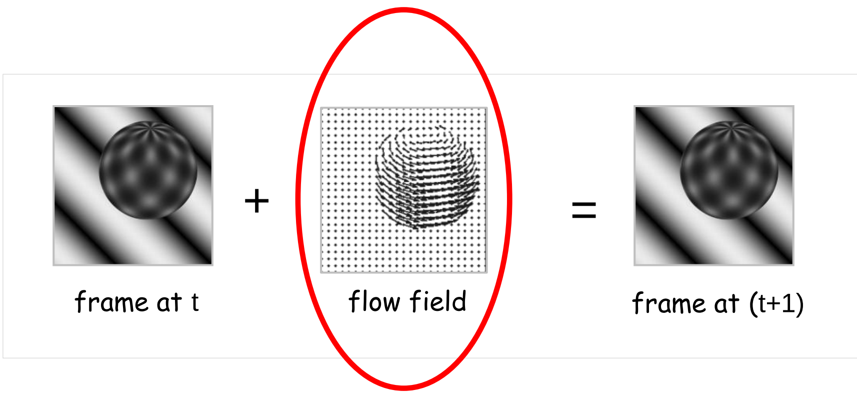


- Time resolution: 10-15μs
- View: full poloidal cross section toroidal extent: ~90 ^{o}

Optic Flow Methods

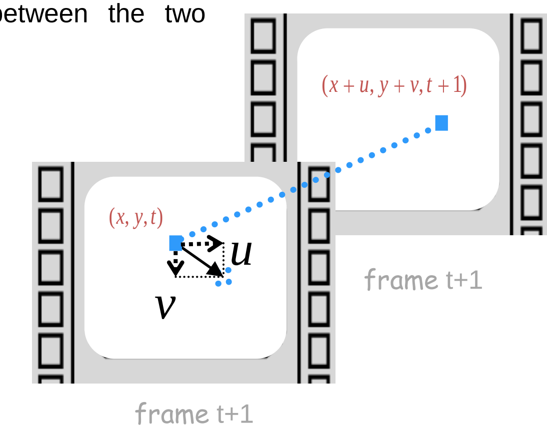
image sequence

attempt to find the vector field which describes how the image is changing with time



The optical flow is a velocity field in the image which transforms one image into the next image in a sequence

a voxel at location (x,y,t) with intensity $f(x,y,t)$ will have moved by u and v between the two image frames:



Basic assumption:

the grey values of image objects in subsequent frames do not change over time:

$$f(x+u, y+v, t+1) - f(x, y, t) = 0$$

small displacements: $f_x u + f_y v + f_t = 0$

ill-posed problem:

- small perturbations in the signal can create large fluctuations in its derivatives

- undetermined set of equations – *aperture problem*

Combined local-global (CLG) method

$$E_{CLG}(w) = \int_{\Omega} \left(\Psi_1\left(w^T J_\rho(\nabla_3 f)\, w\right) + \alpha \Psi_2\left(|\nabla w|^2\right) \right) dxdy$$

Assumes that the unknown optic flow vector is constant within some neighbourhood of size ρ.

- A sufficiently large value for ρ is very successful in rendering the L–K method **robust under noise**.

- in flat regions where the image gradient vanishes, the aperture problem remains present – **non-dense flow fields**

Incorporates a global smoothness assumption for the estimated flow field.

- Larger values for α result in a stronger penalisation of large flow gradients and lead to smoother flow fields.

- At locations with |∇ f| ≈ 0, no reliable local flow estimate is possible, but the regulariser | ∇u|2 + |∇v|2 fills in information from the neighbourhood - the filling-in effect.

Ψ_1, Ψ_2

In order to be able to capture also intrinsic locally non-smooth motion, it is necessary to allow outliers in the smoothness assumption.

Better results at locations with flow discontinuities

Coarse-to-fine multi-resolution Approach

In the case of displacements that are larger than one pixel per frame, the cost functional in a variational formulation must be expected to be multi-modal, i.e. A minimisation algorithm could easily be trapped in a local minimum.

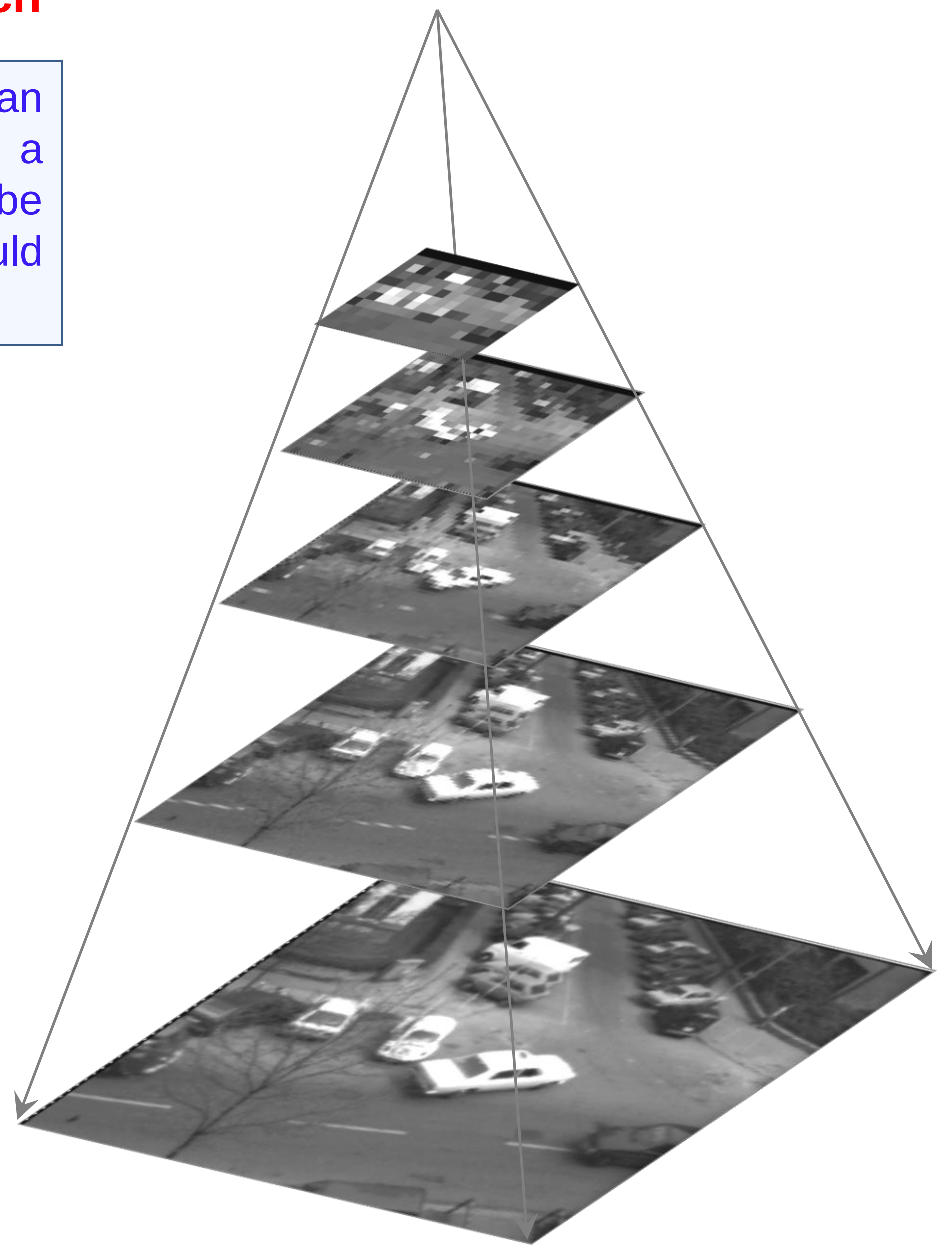
- A pyramid of images is constructed by downsampling and Gaussian smoothing

- Start with solving a coarse version of the problem

the displacements are small and consequently, the linearisation of the constancy assumption is a good approximation.

- Evaluate an increment velocity field (small also) at next resolution level, around the estimate at previous resolution level

compensate the second image for the already computed flow field (the so-called *warping step*)



Sand-Teller bilateral filtering

nonlinear filter that smoothes a signal while preserving strong edges

combines information from regions with similar flow and similar intensities

$$u^{filt}(x,y) = \frac{\sum_{x_j,y_j} u(x_j,y_j)\, w(x,y,x_j,y_j)}{\sum_{x_j,y_j} w(x,y,x_j,y_j)}$$

→ each pixel is replaced by an average depending of its neighbours

The filter weights the neighbours according:

$$w(x,y,x_j,y_j) = \left\{ \begin{array}{l} K\left(\sqrt{(x-x_j)^2+(y-y_j)^2};\sigma_x\right) \\ K\left(I(x,y)-I(x_j,y_j);\sigma_i\right) \\ K\left(\sqrt{(u-u_j)^2+(v-v_j)^2};\sigma_m\right) \\ r(x_j,y_j) \end{array} \right.$$

→ spatial proximity

→ image similarity

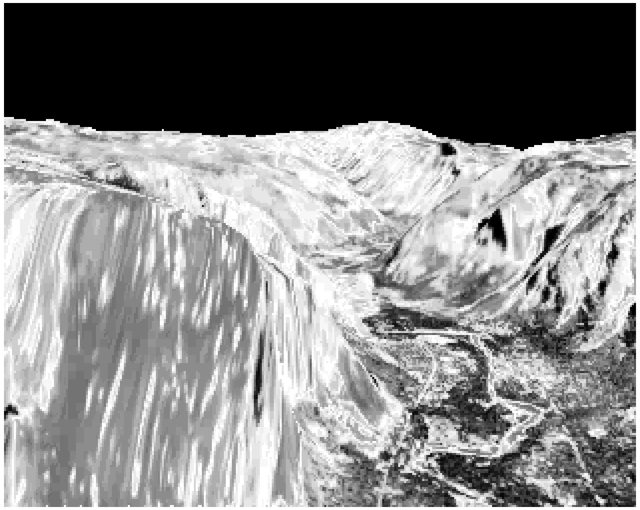
→ motion similarity

→ occlusion labelling

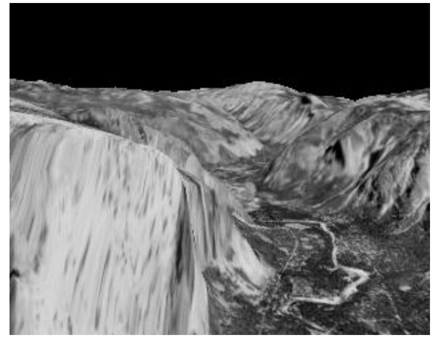
Tests on numerical data

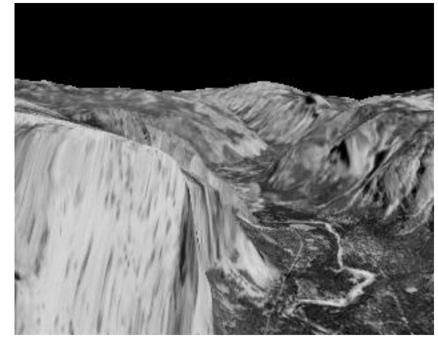
- Yosemite without clouds -

Michael J. Black, Brown University
http://www.cs.brown.edu/~black/

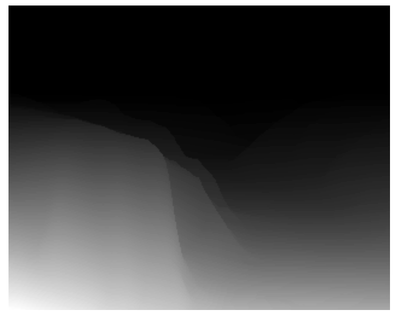


AVI Movie

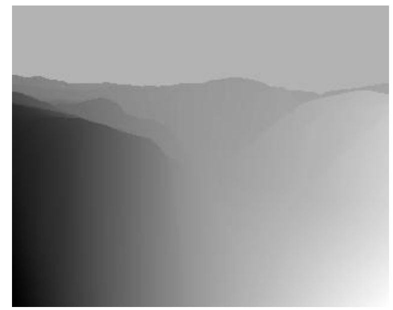




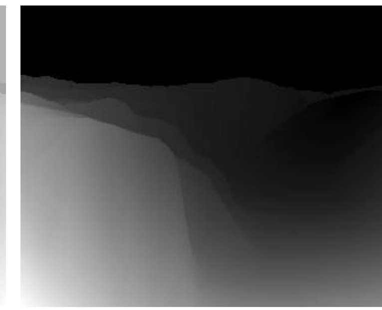
Real optic flow



u



v



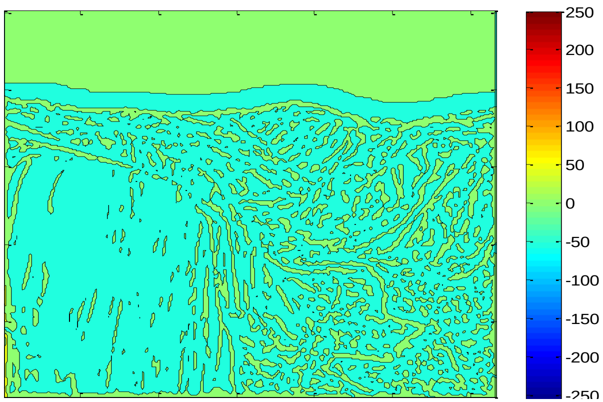
$\sqrt{u^2 + v^2}$

Determined optic flow

$u_{\det}$

$v_{\det}$

$\sqrt{u_{\det}^2 + v_{\det}^2}$

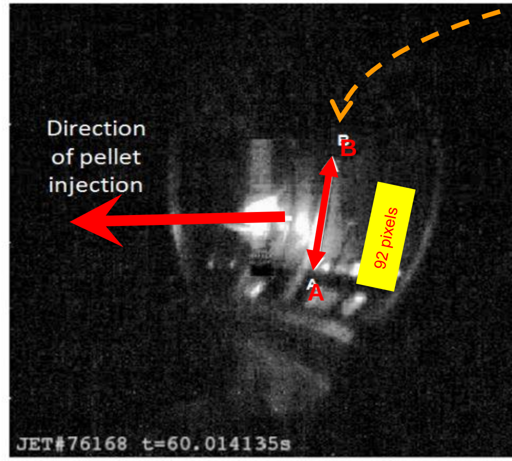


Difference between Image (n+1) and its reconstruction

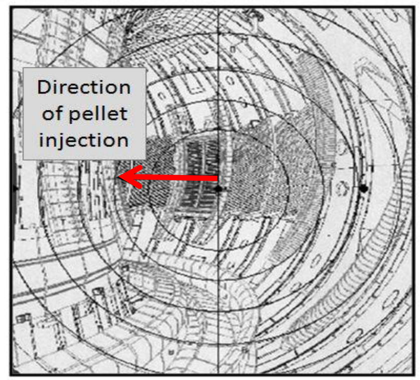
Pellets

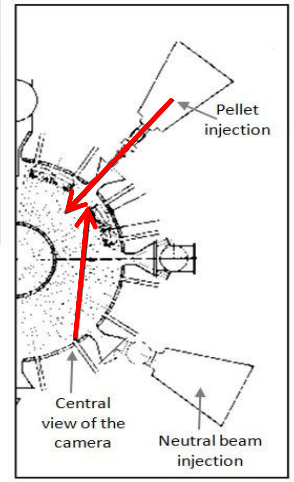
SHOT: 76168 / start time=60.011246 s.

AVI Movie



ICRH antenna, located on the central view of the camera was used for converting pixels in meters



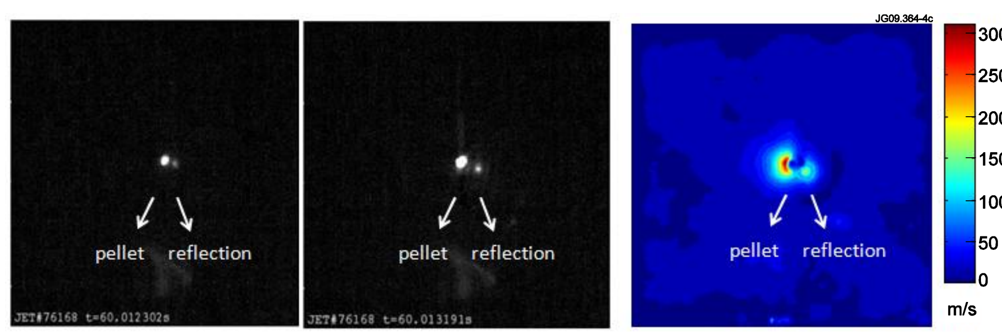


Average speed for all shots with the same pellet parameter settings:

$$215 \pm 28 \ m/s$$

Speed of pellet determined by optic flow method:

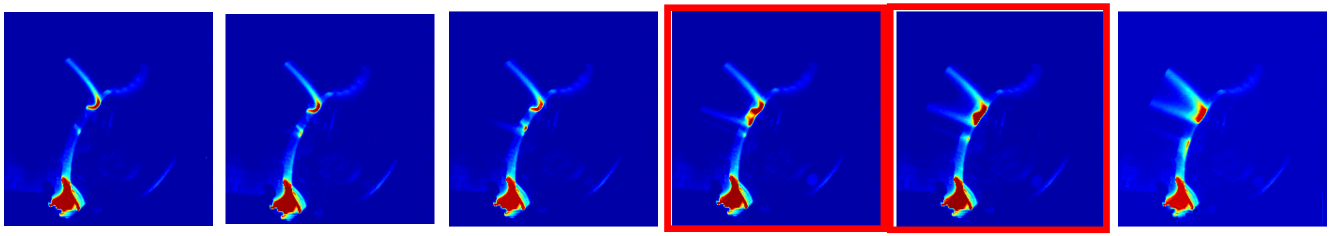
$$\approx 240 \div 262 \ m/s$$

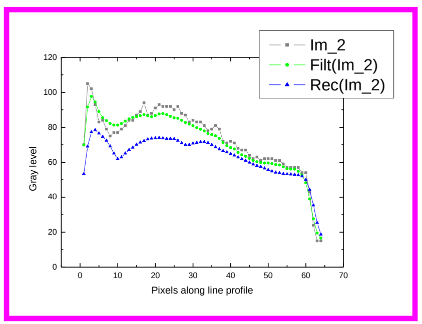


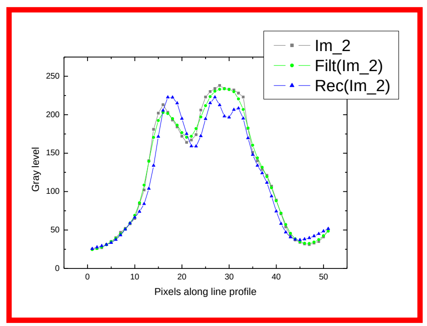
MARFE
“multi-faceted asymmetric radiation from the edge”

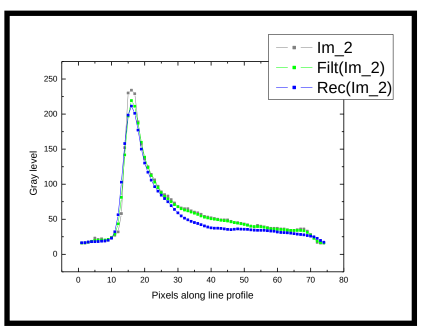
- normally develops in fusion devices close to the density limit.

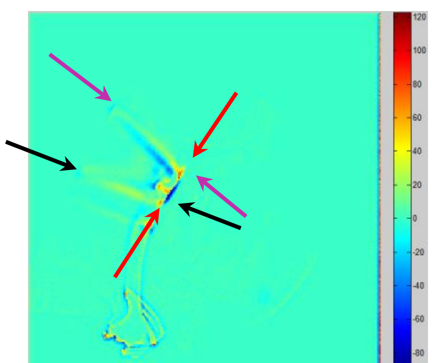
- MARFEs are considered the result of thermal instabilities excited under critical conditions through different mechanisms:
  - impurity radiation
  - recycling of neutral particles
  - anomalous transport of charged particles and energy

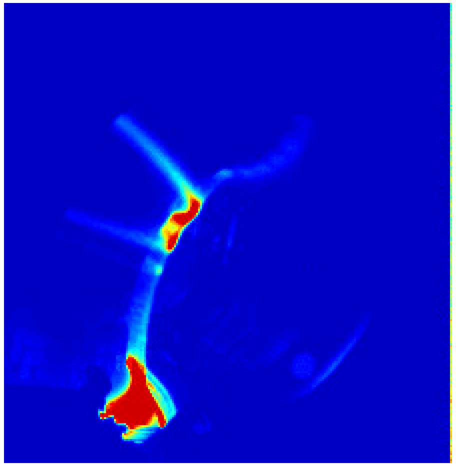










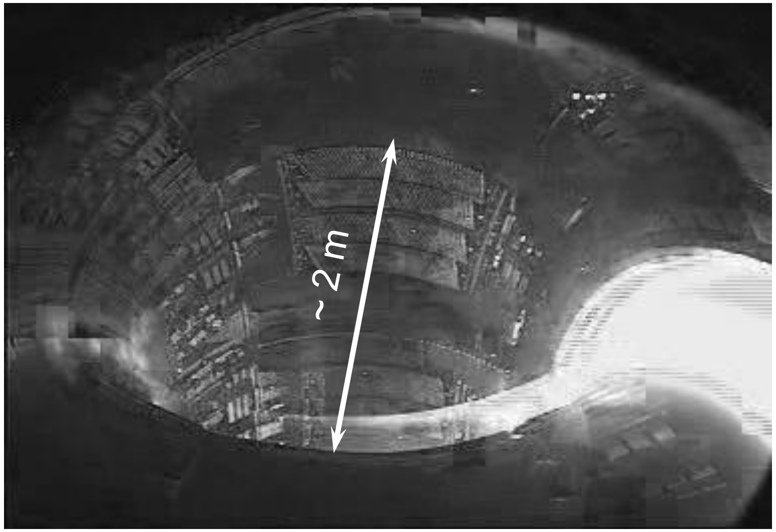


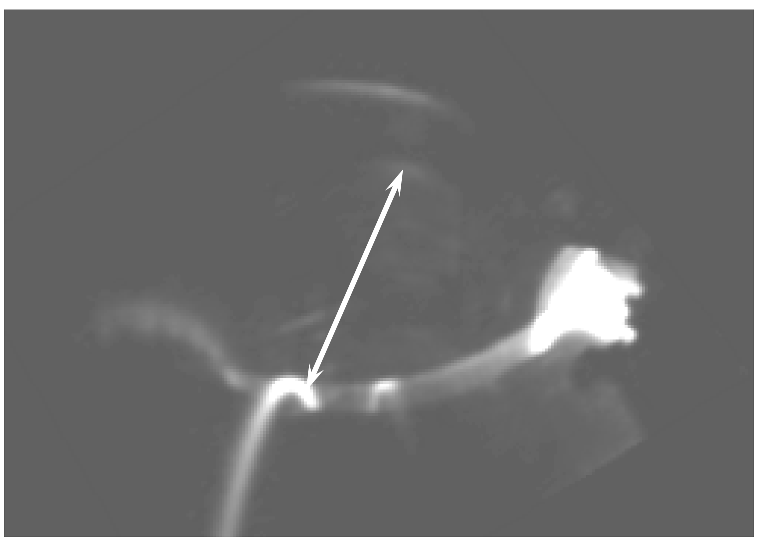
AVI Movie

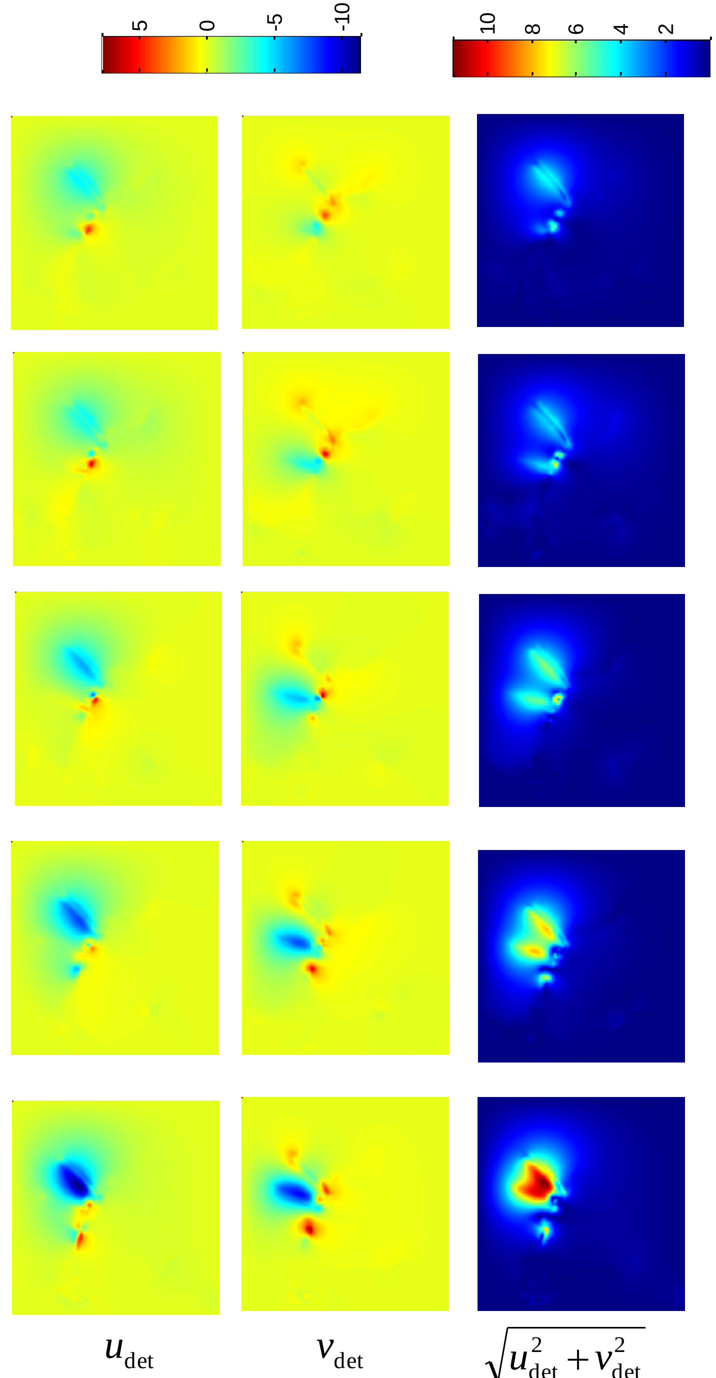
shot 70050 start time: 53.840073 s

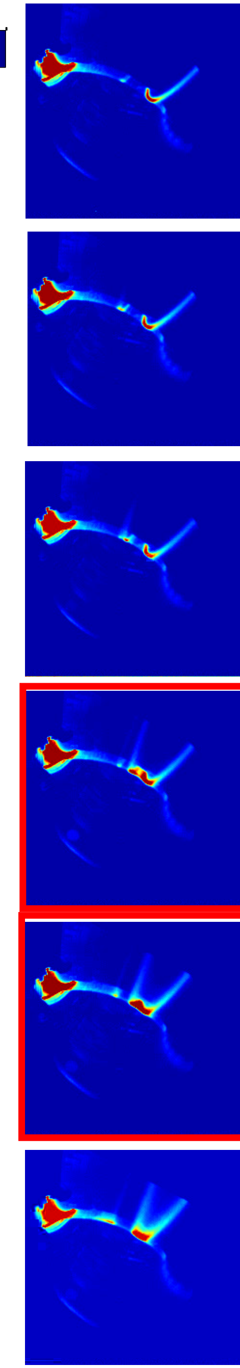
Image units to absolute value conversion:

76.8 pixels = 2.05 m









3.1 pix
2500 m/s

2.9 pix
2400 m/s

3.2 pix
2600 m/s

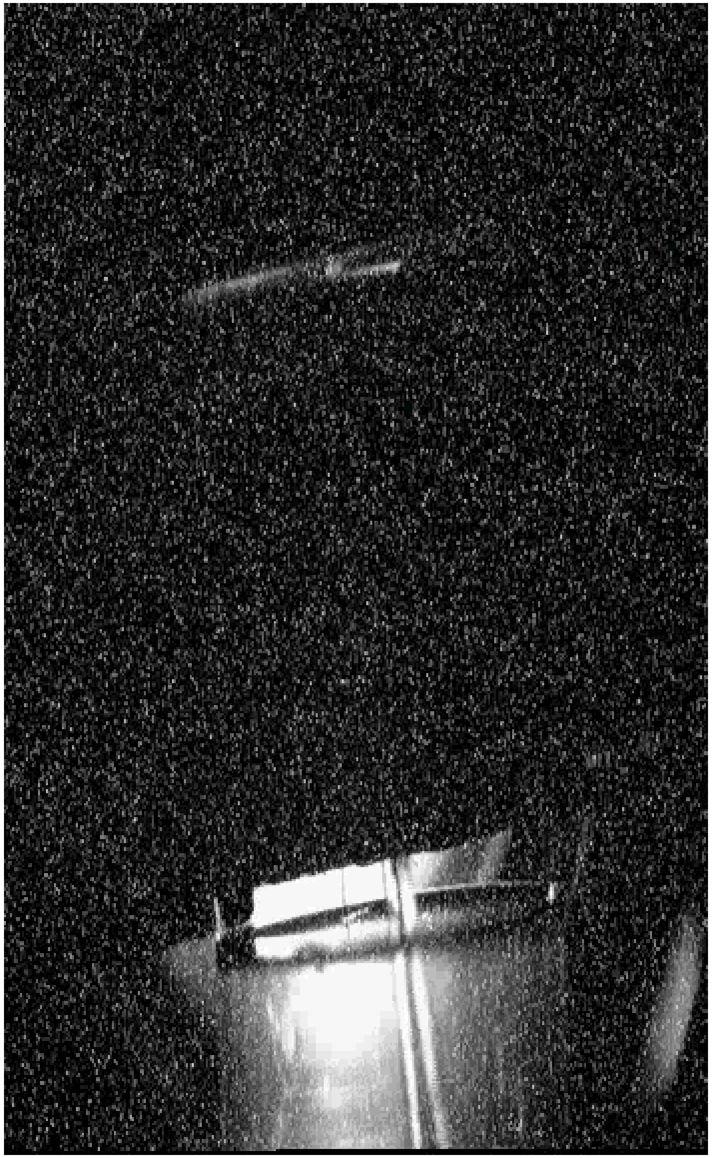
4.7 pix
3900 m/s

6.4 pix
5300 m/s

Future work:

- ➢ Evaluate the ice extrusion velocity based on the image sequences provided by a CCD camera viewing the ice at the exit of the nozzles of the extrusion cryostat.

image sequence showing the extruded deuterium ice in case of JET pulse #76379



AVI Movie