# High-speed imaging of titanium cathode spots in a Vacuum Arc Thruster

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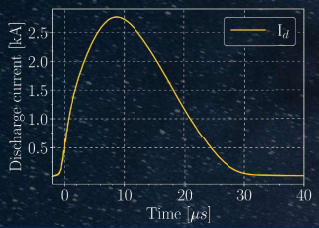
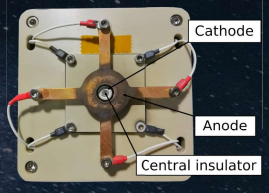
## Vacuum Arc Thruster - PJP

- Miniature space thruster
- Developed and manufactured by COMAT
- Solid propellant
- Pulsed vacuum arc discharge

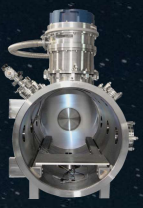



- Vaporization and ionization of metallic elements
- Plasma expansion leads to thrust generation in the opposite direction
- Plasma generation from the cathode: **cathode spots**



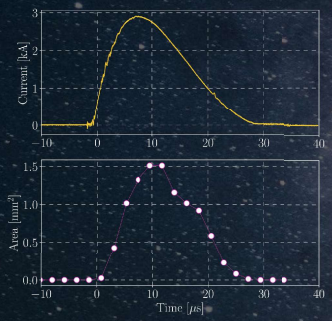

## Experimental arrangement

- 130L capacity vacuum chamber
- 1 primary pump
  2 turbomolecular pumps
- $10^{-6}$ mbar while thruster operation



- Camera: Phantom TMX 7510
- Sampling period 2.2 µs
- Maximum resolution at 450k fps : 256 x 128
- Stochastic phenomenon: arc dynamics changes from pulse to pulse
  - Using a triggered iCCD leads to inaccuracies
  - Importance of single shot measurements


## Active spot surface




- High degree of similarity between the evolution of the surface and $I_d$
- Spearman rank order coefficient of 0.95 in average
- Linear augmentation of the number of active spots with the augmentation of $I_d$
- Rich dynamics, but repeatable values from one pulse to the other

| Parameter | Averaged Value | σ |
|---|---|---|
| Surface [mm²] | 0.345 | 0.078 |
| Max surface [mm²] | 1.124 | 0.230 |
| $r_s$ | 0.948 | 0.048 |

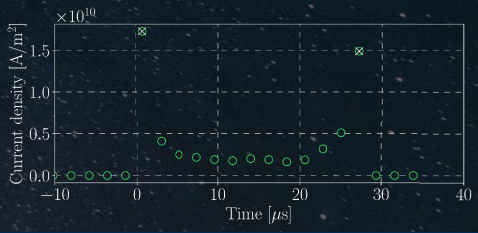
Averaged values over the 150 films

## Current density

- Spots tracking using a modified PTV algorithm
  - Each spot can sustain a limited j
  - Explains the linear relation between $I_d$ and active spot surface
- Over the whole dataset: j = **4.3 ×10⁹ A/m²**
- In accordance with the "Large spot" model

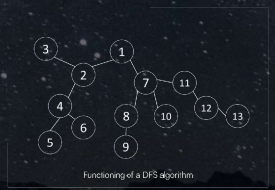
Possible underestimation here

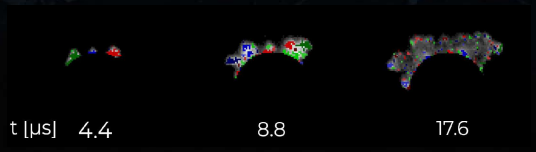
- Low camera resolution
- Dense and rapidly expanding plasma just over the spot (high brightness)
- Fractal spot model




## Clustering

- Detection of spots clusters with a depth-first search (DFS) algorithm
- Average cluster size: 1.83 × $10^{-2}$ mm²
- Maximum size reached around 5 µs: avg 0.3 mm²
- Largest clusters at the beginning of the discharge
  - Due to their inherent self avoiding walk motion

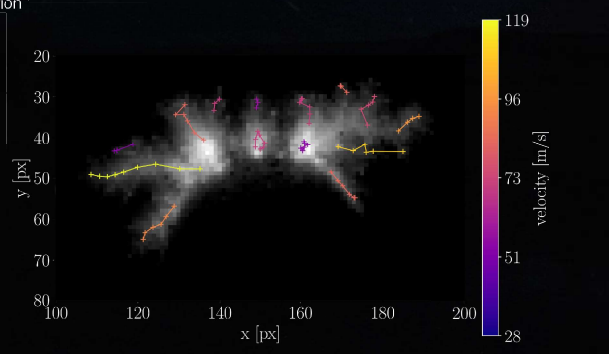



## Motion tracking

*First, to stress the point, the cathode spot is not moving: it only appears to move.*
- Andre Anders

- Spots tracking using a modified PTV algorithm
  - Random walk behavior
  - Emergence of new spots during the discharge
- Accurate 2D tracking: spots trajectories and velocities
- Spots velocities ranging from 20 to 123 m/s
- Average velocity around 60 m/s, higher than in low current vacuum arcs
- No correlation between velocity and propagation direction
- Discharge current responsible of velocity magnitude
- External electric field is not the main driver for the acceleration




## Conclusion and perspective

- New insights into cathode erosion dynamics
- Propellant use can be optimized by matching the cathode dimension and the discharge parameters
- Next experimental campaigns will be focused on seeking correlation between spot dynamics and instantaneous thrust


New vs worn cathode