Three-dimensional Magnetic Reconnections in PROTO-SPHERA

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Università di Roma Tor Vergata

ENEA Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

INAF ISTITUTO NAZIONALE DI ASTROFISICA

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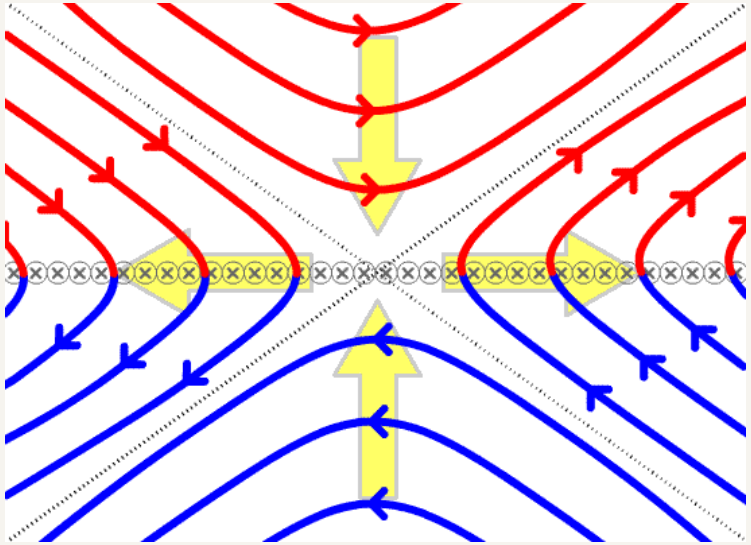
Magnetic Reconnection

❖ Ideal

$$\vec{E} + \vec{v} \times \vec{B} = 0 \longrightarrow \textit{frozen-in} \longrightarrow \frac{\partial \vec{B}}{\partial t} - \nabla \times \left(\vec{v} \times \vec{B}\right) = 0$$

❖ Resistive

$$\vec{E} + \vec{v} \times \vec{B} = \eta \vec{J} \longrightarrow \frac{\partial \vec{B}}{\partial t} - \nabla \times \left(\vec{v} \times \vec{B}\right) = -\frac{\eta}{\mu_0} \nabla \times \nabla \times \vec{B}$$



Acquired from Wikipedia

Magnetic Reconnection: some time scales

- Resistive time scale $\tau_\eta = \frac{\mu_0 L^2}{\eta}$
- Dynamic time scale $\tau_A = \frac{L}{v_A}$
- Lundquist number $S = \frac{\tau_\eta}{\tau_A}$

$$\tau_{Rec} = \tau_A S^\alpha$$

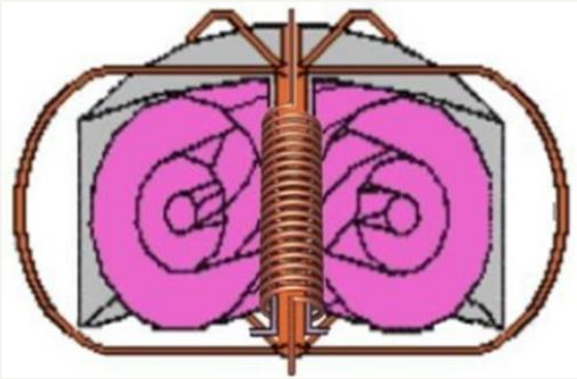
PROTO-SPHERA

PROTOtype of a Spherical Plasma for HElicity Relaxation Assessment

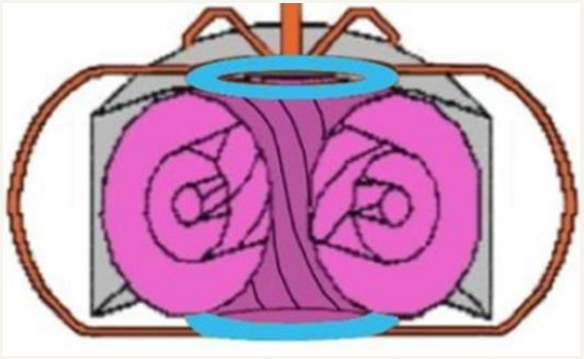
- Simply connected configuration
- Cylindrical vacuum chamber
- Spherical Torus with closed flux surfaces + Screw Pinch
- Uses Reconnections to confine plasma

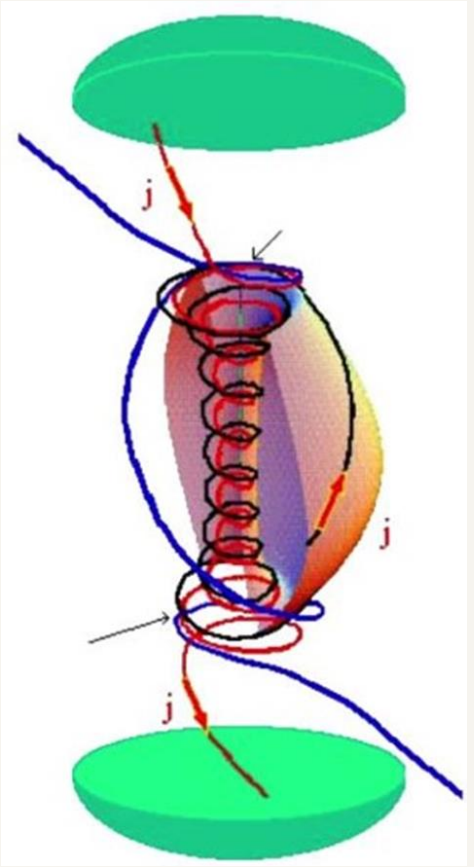
→ **See P. Micozzi Talk**

Tokamak

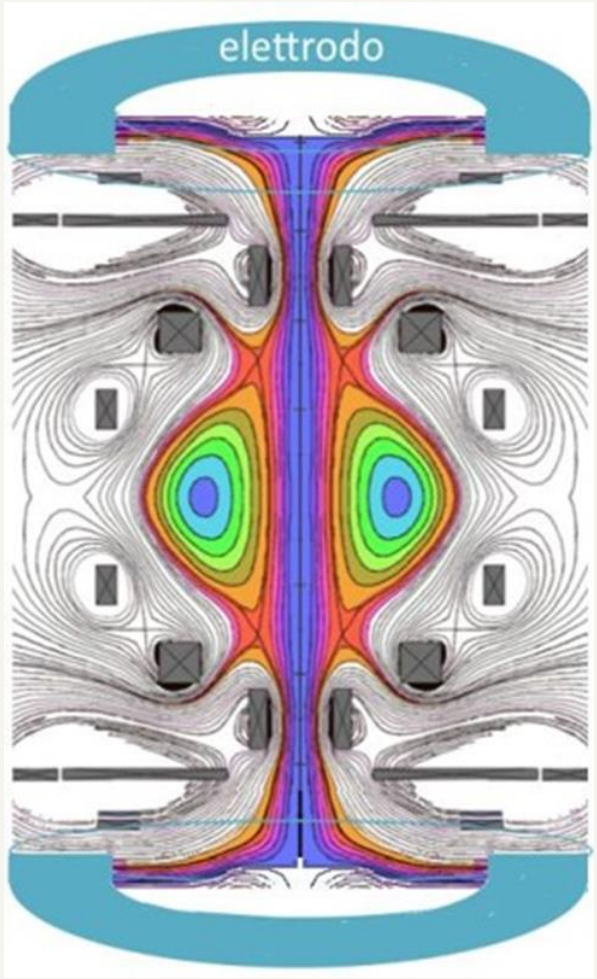


PROTO-SPHERA





PROTO-SPHERA: x-points formation



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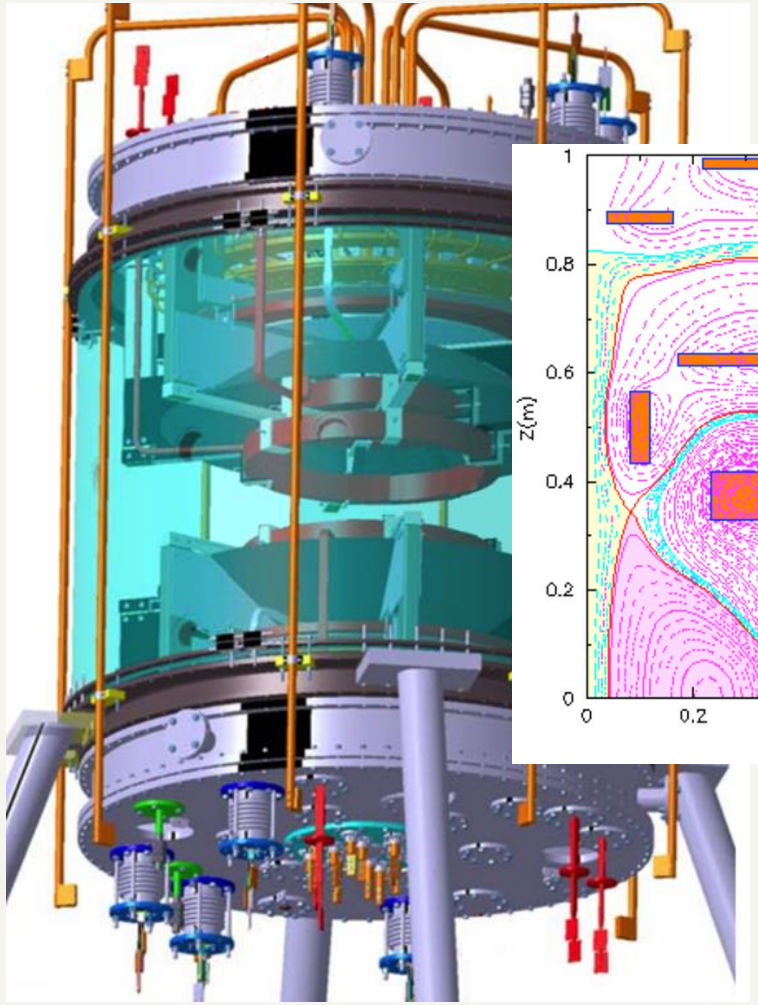
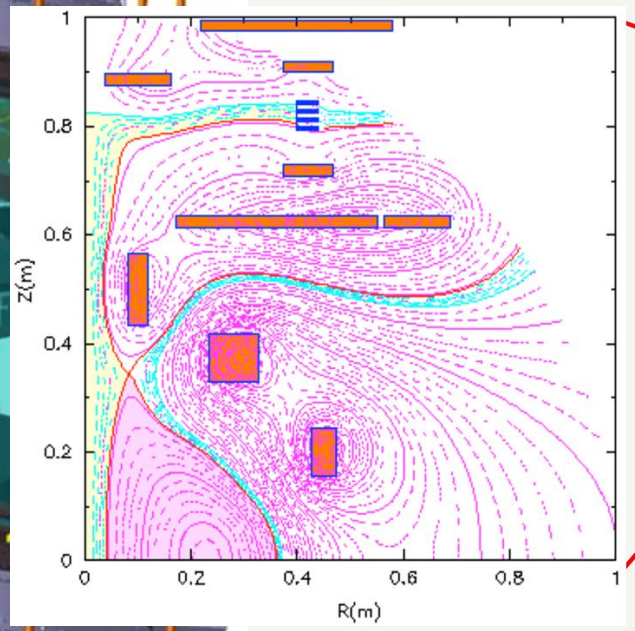
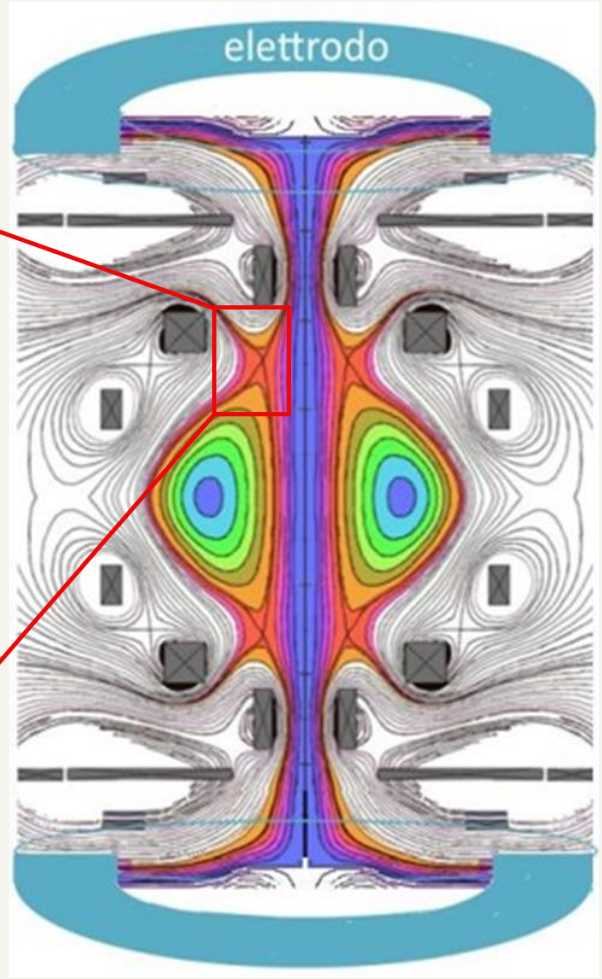


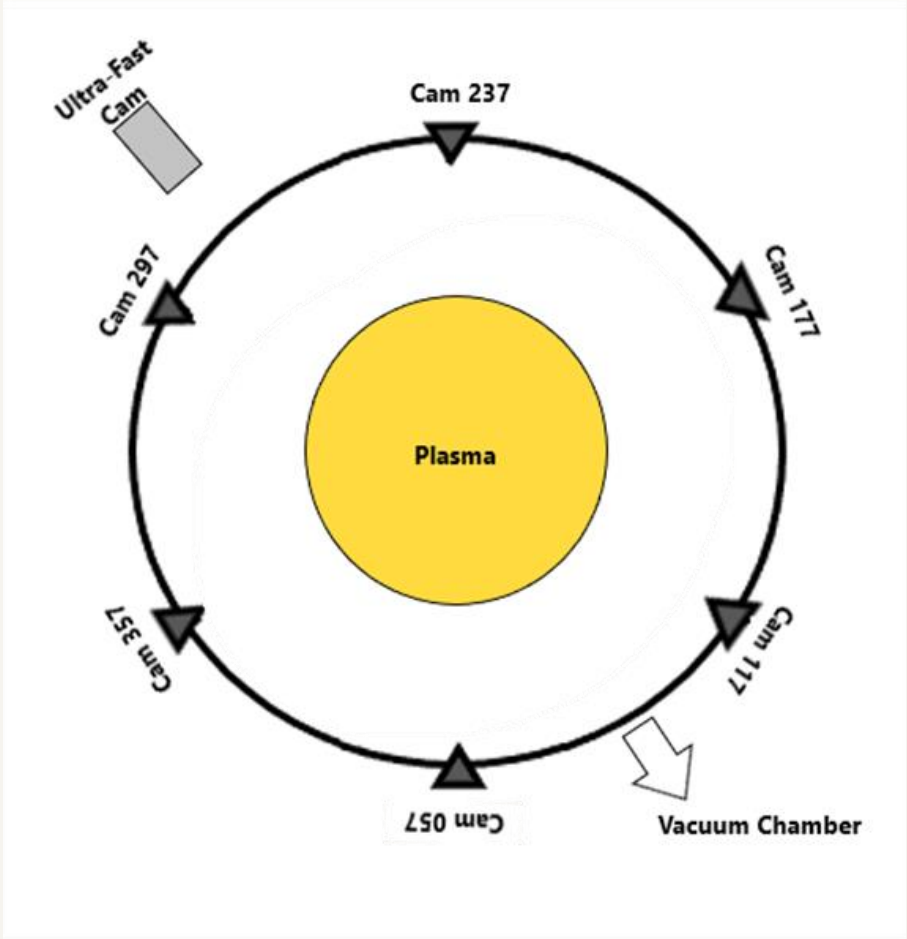




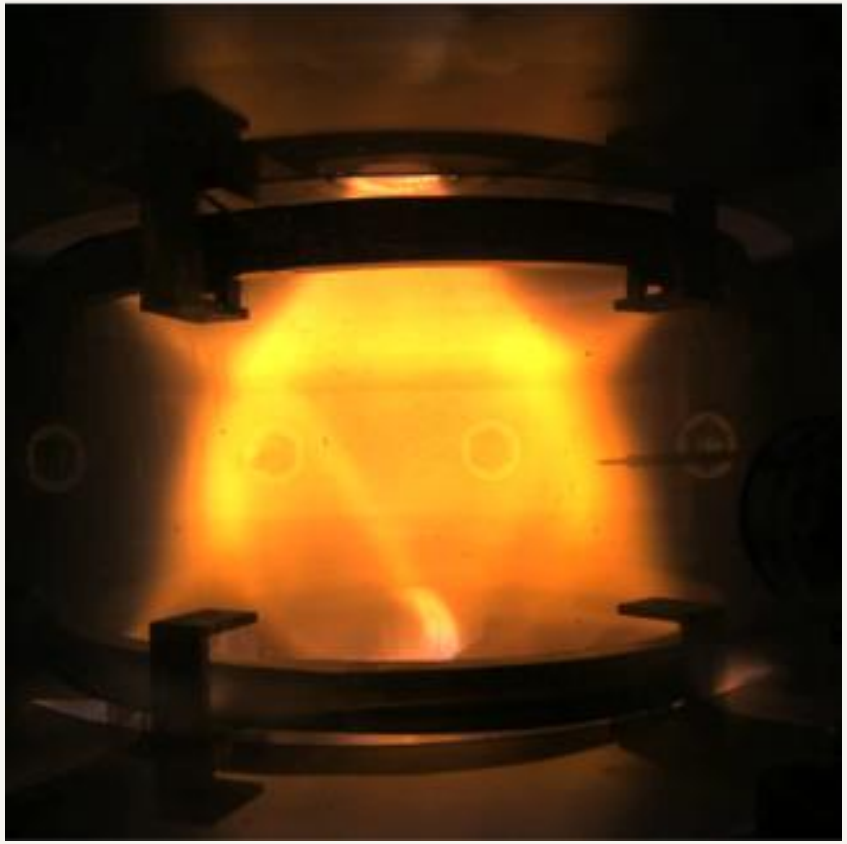
S.Macera,

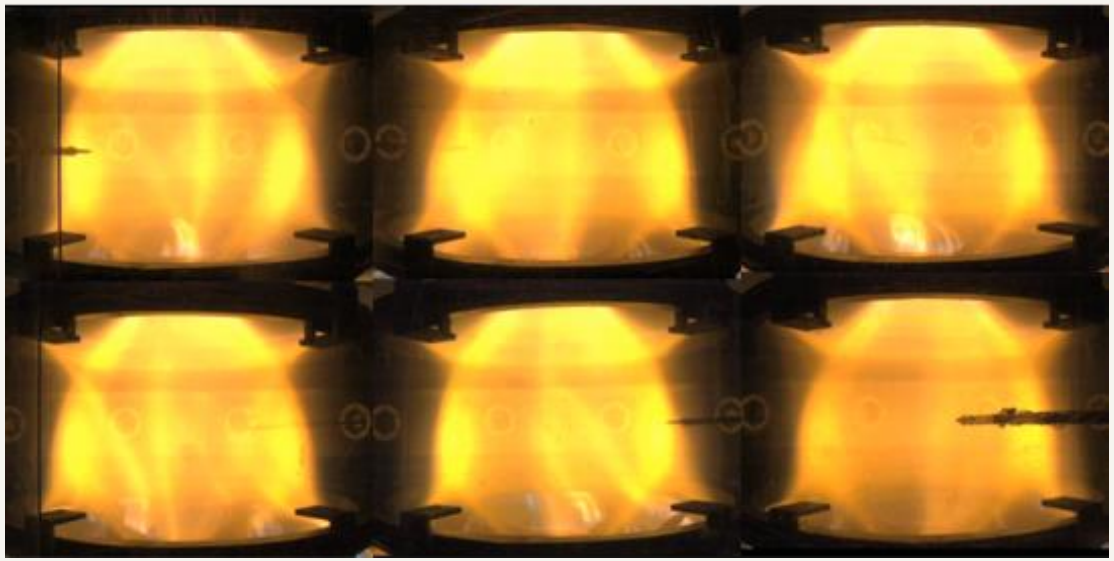
PROTO-SPHERA: Diagnostics

- Hall Sensors
- Langmuir Probe
- 6 Fast Cameras (600 fps)
- 1 Ultra Fast Camera (3600 fps)



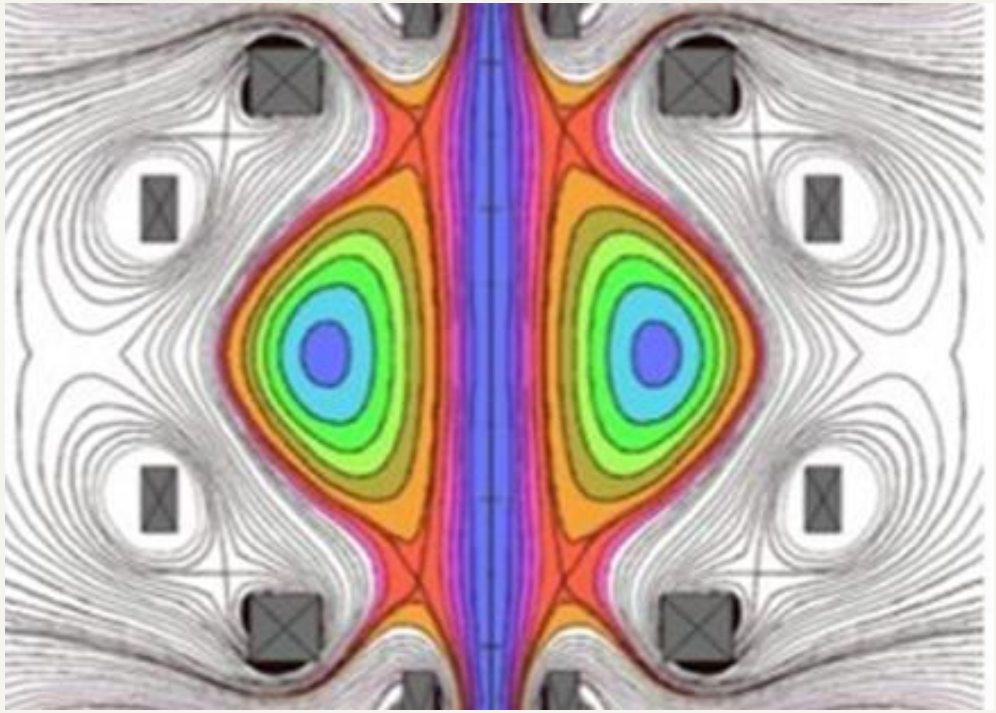
PROTO-SPHERA: Helium shot #2141

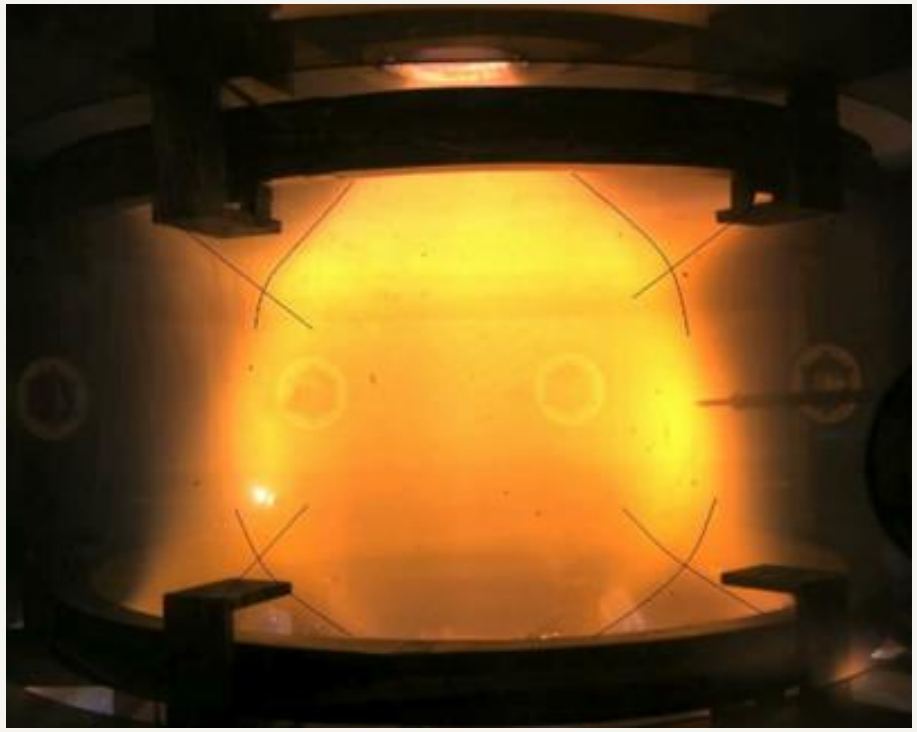




- Reconnections not axisymmetric (as expected)
- Global rotation due to $\vec{E} \times \vec{B}$
- Torus displaced from the equatorial plane

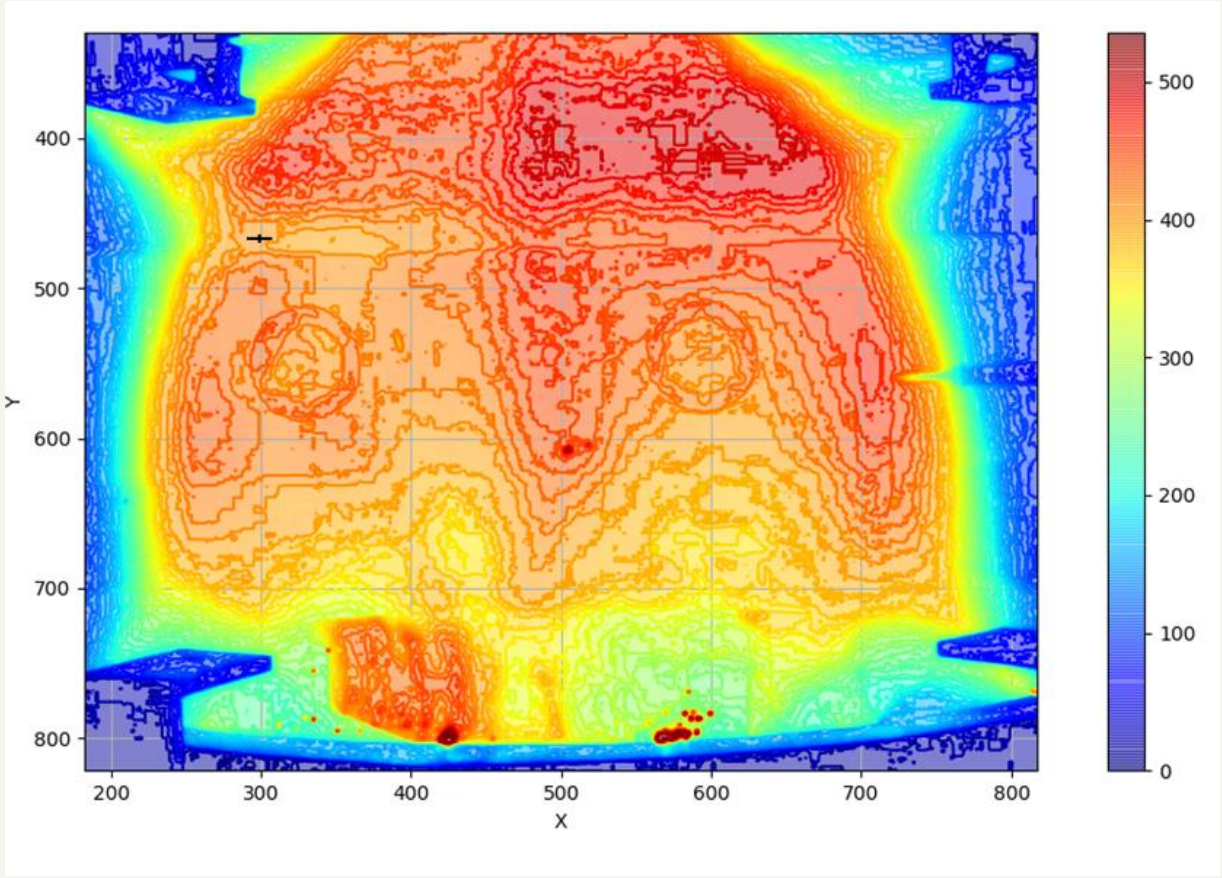
Fast Cameras Data Analysis





Fast Cameras Data Analysis

- Filtered Image (RGB: 100%R 86%G 25%B)
- Gradient of luminosity
- Search for minima



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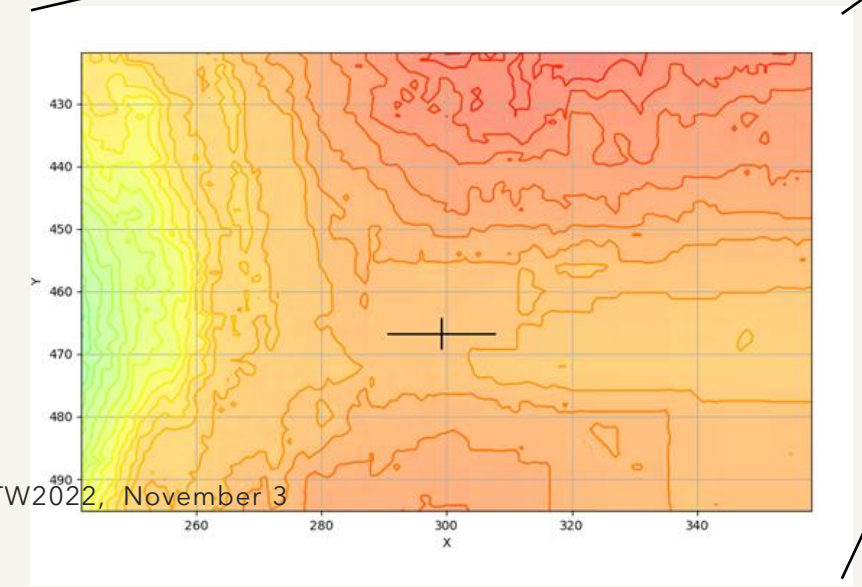
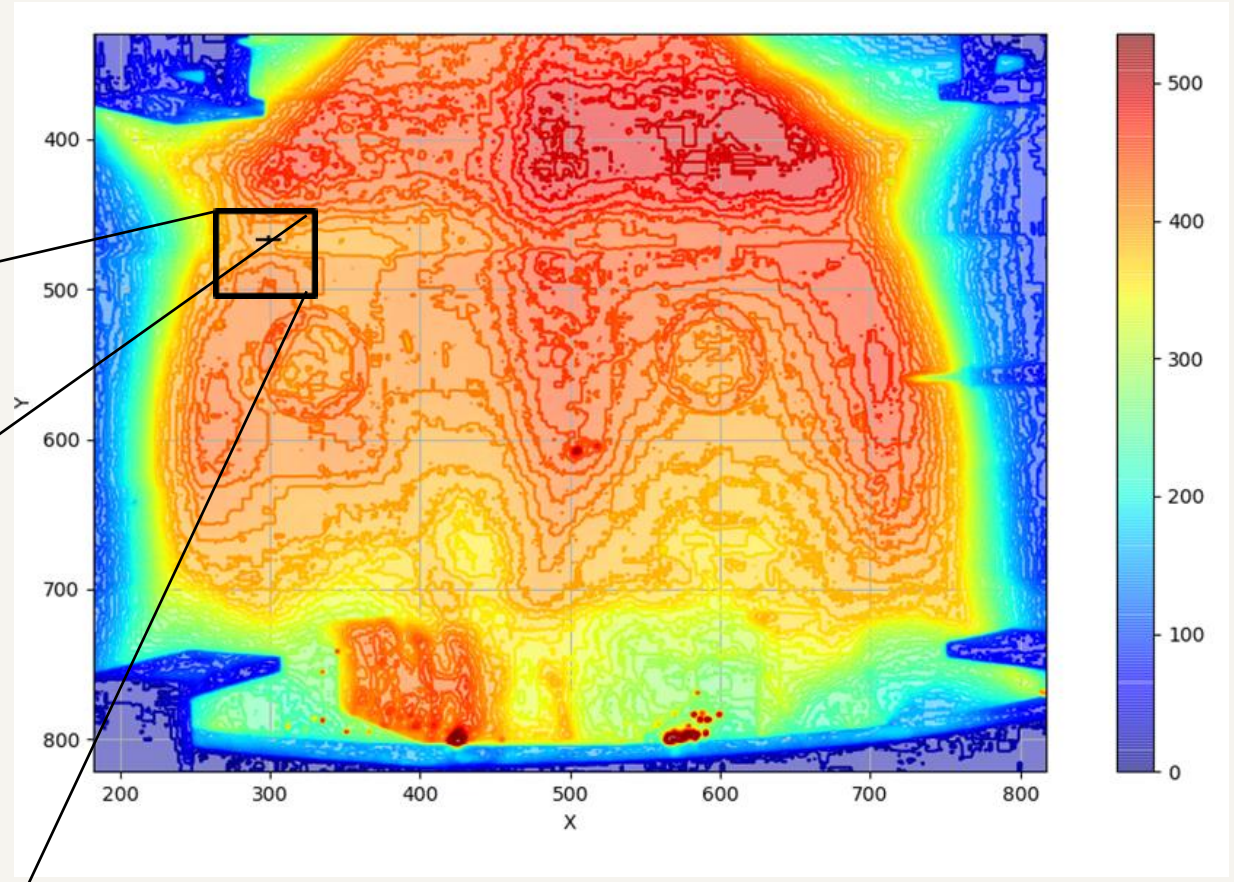
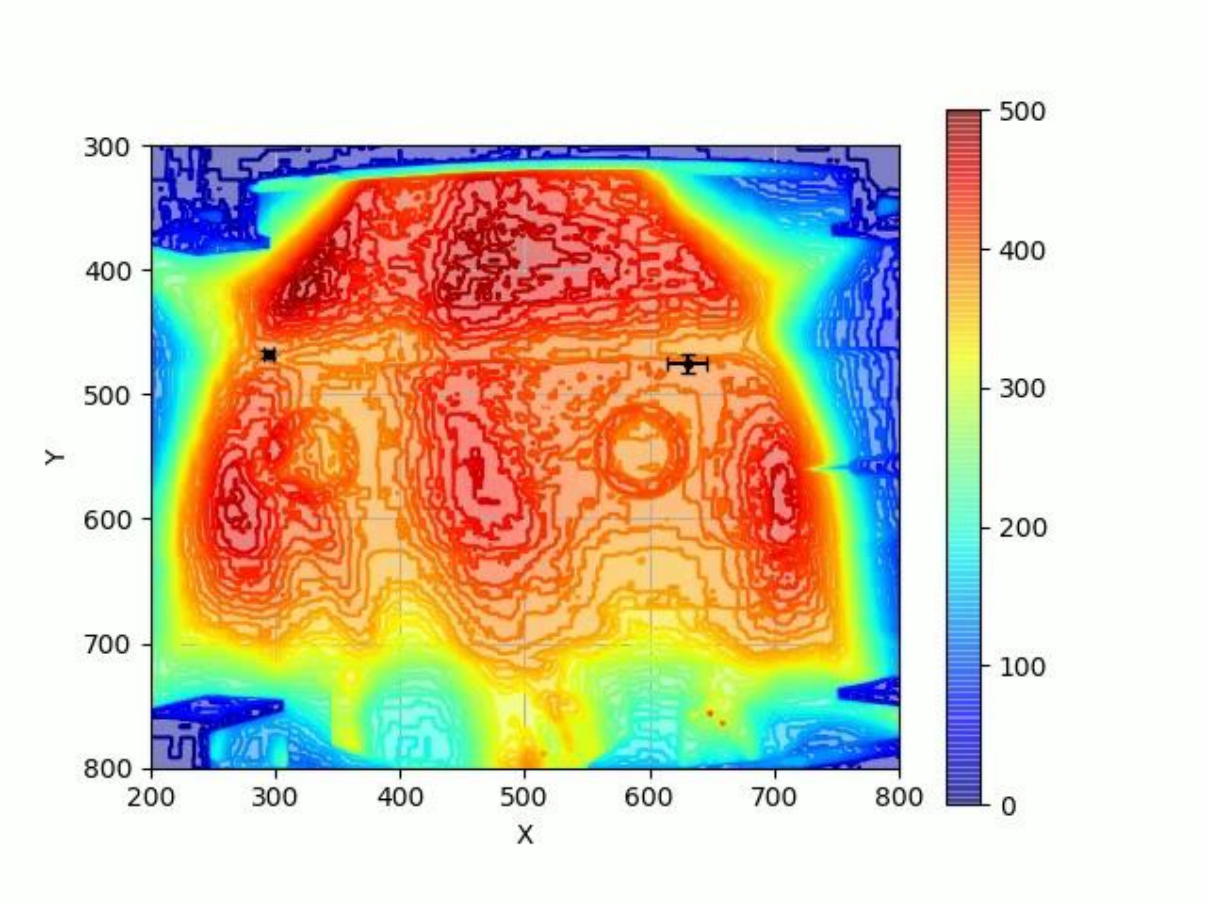


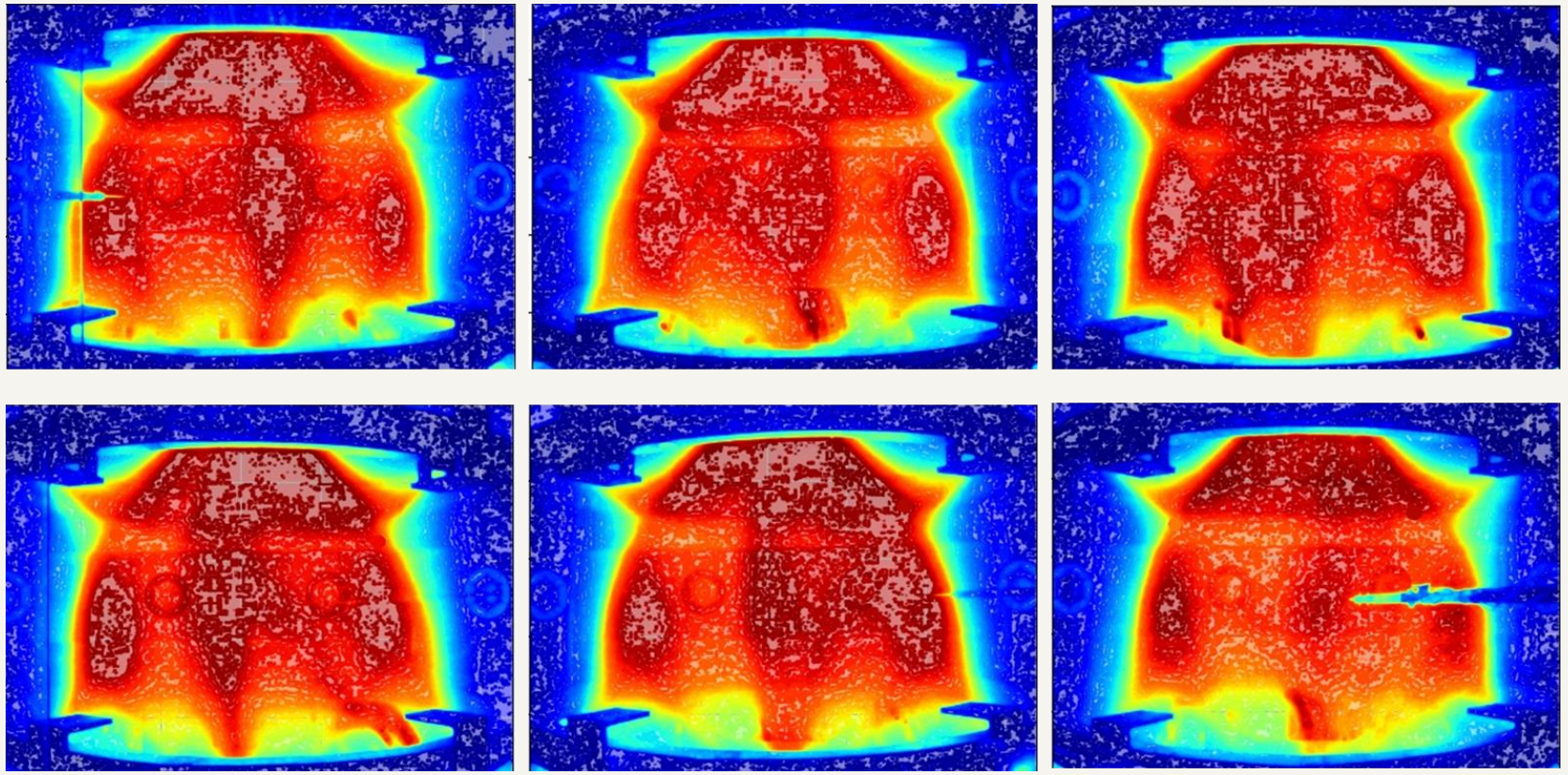


Fast Camera Data Analysis



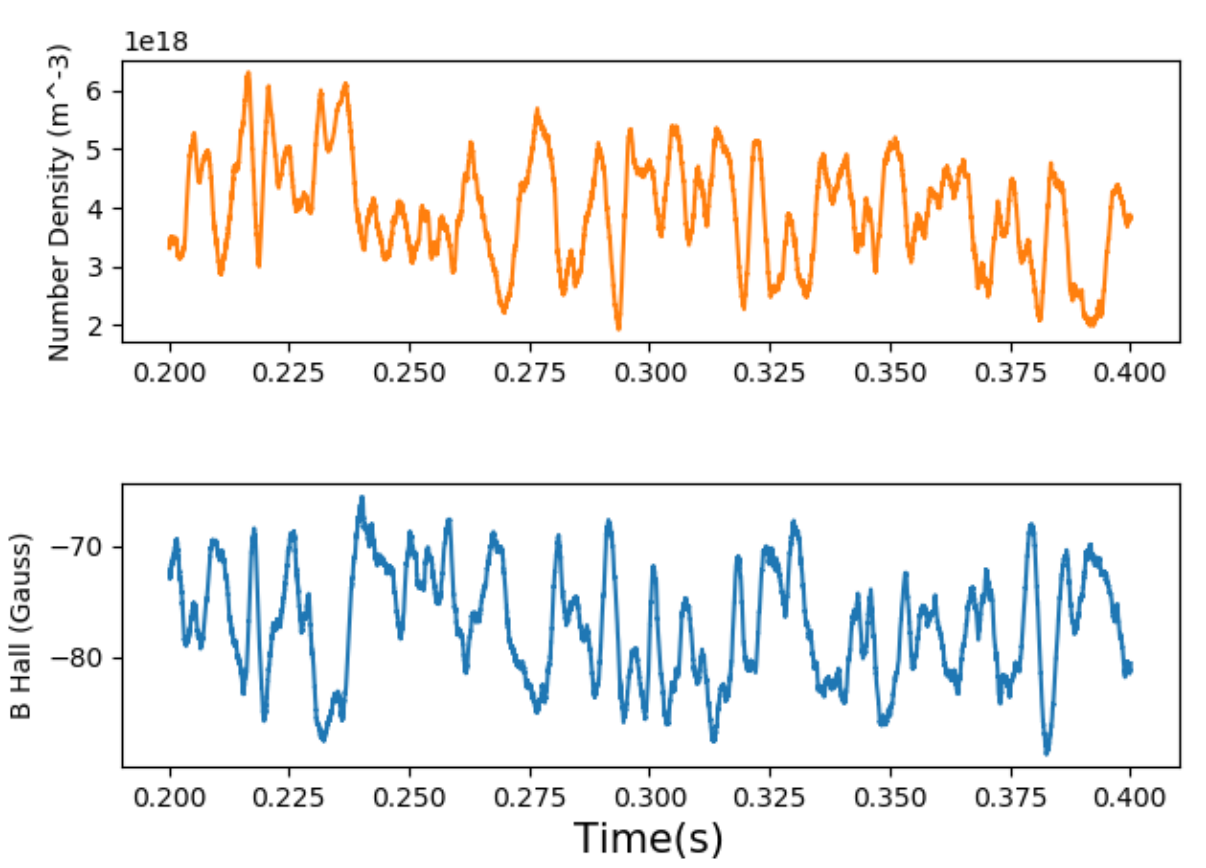
- Closed curves and nestled up in the torus
- X-points oscillations

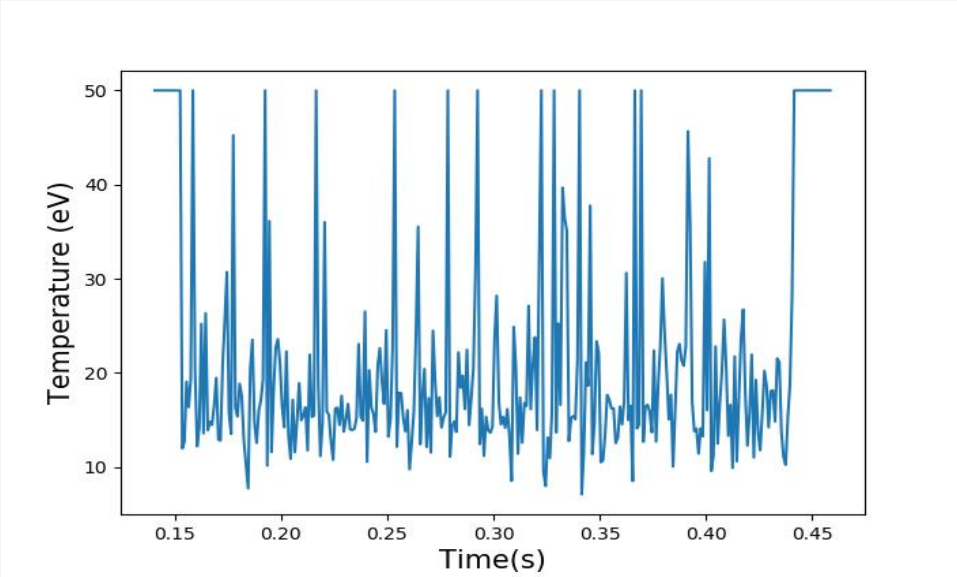
Fast Cameras Data Analysis



- Check: are the X-points at the same height passing from one camera to the next one?

Data Analysis: more datas..





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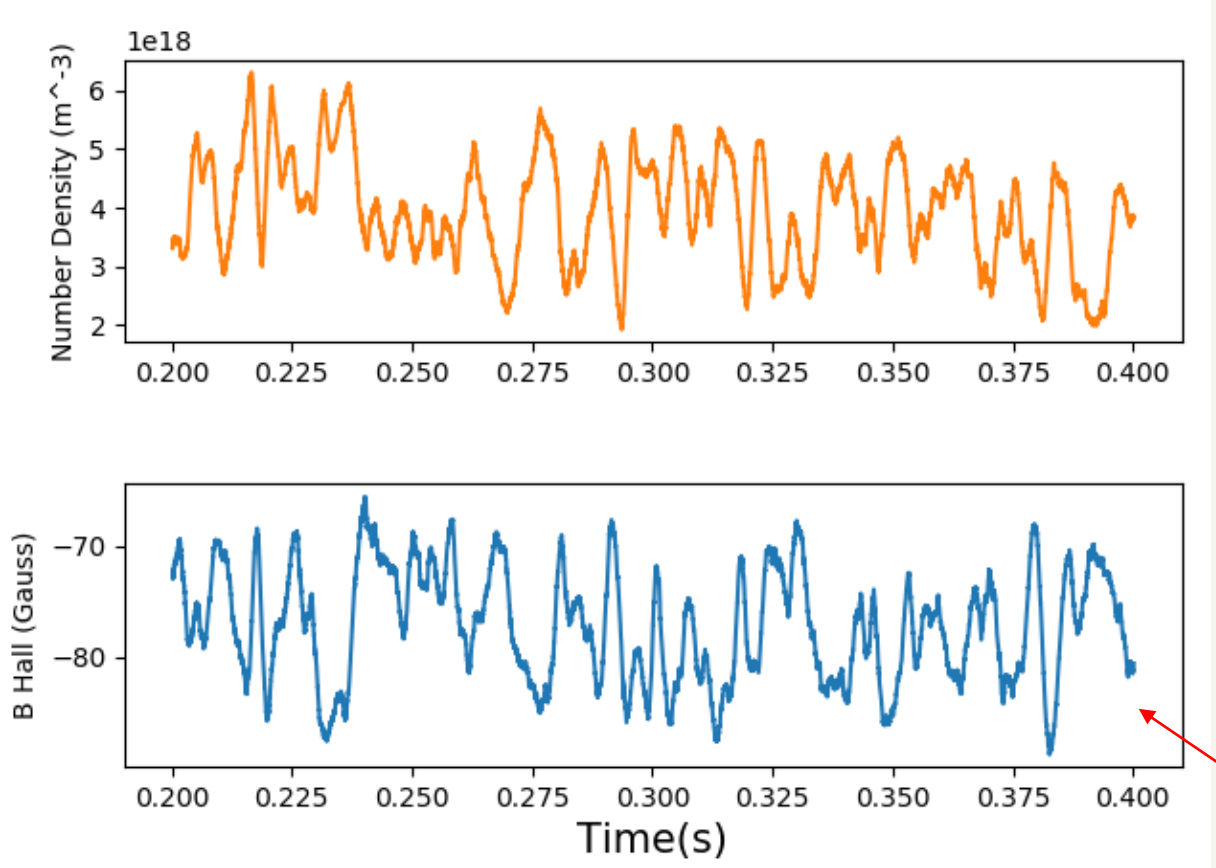

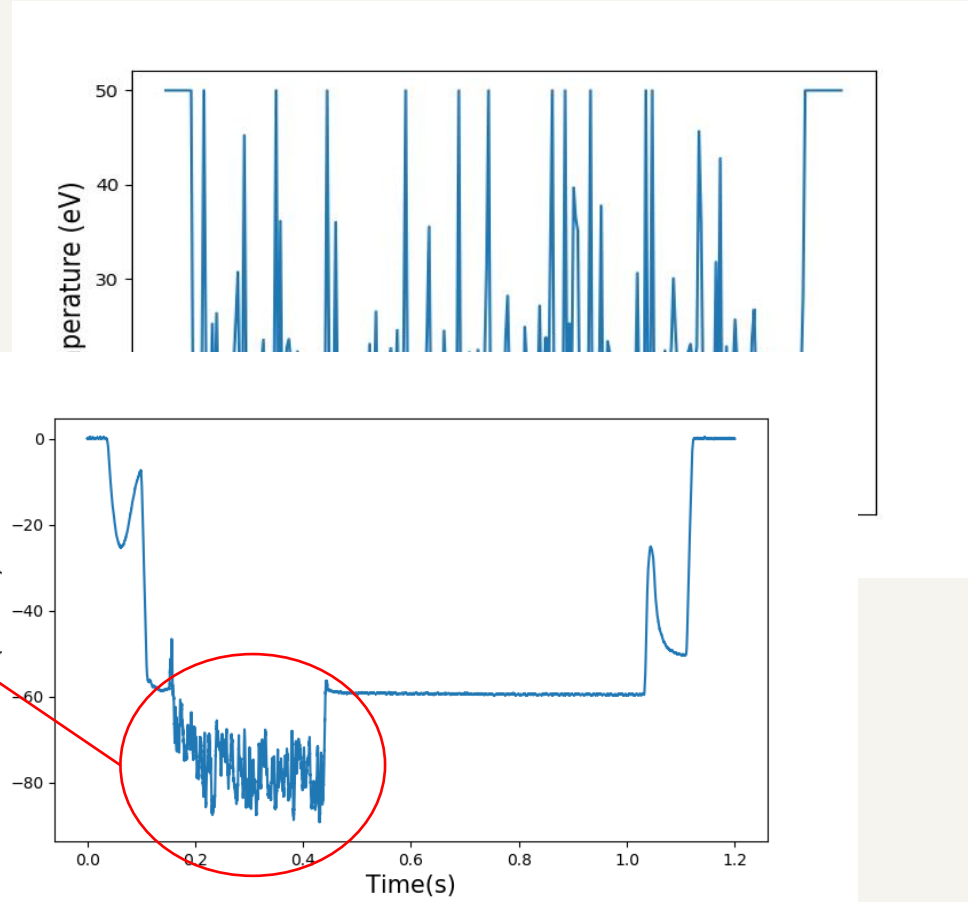

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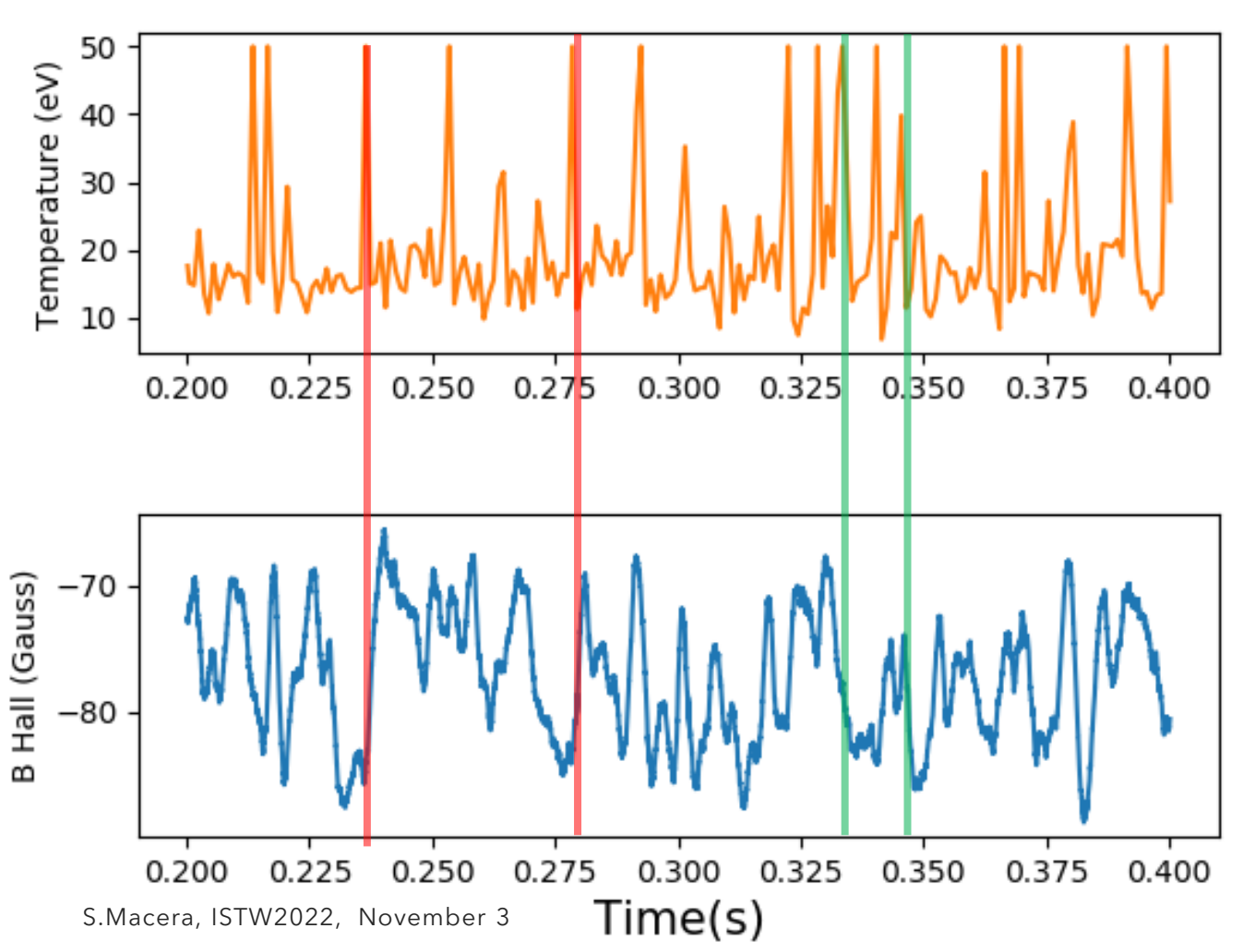
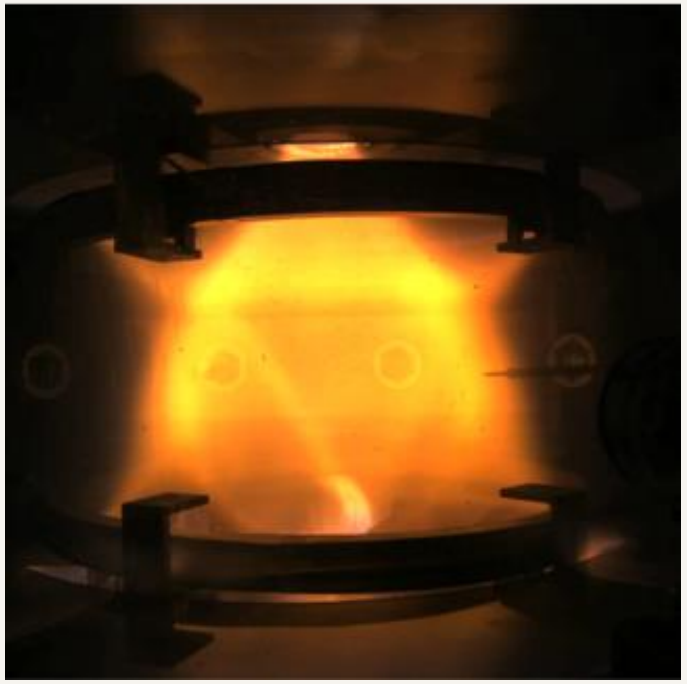
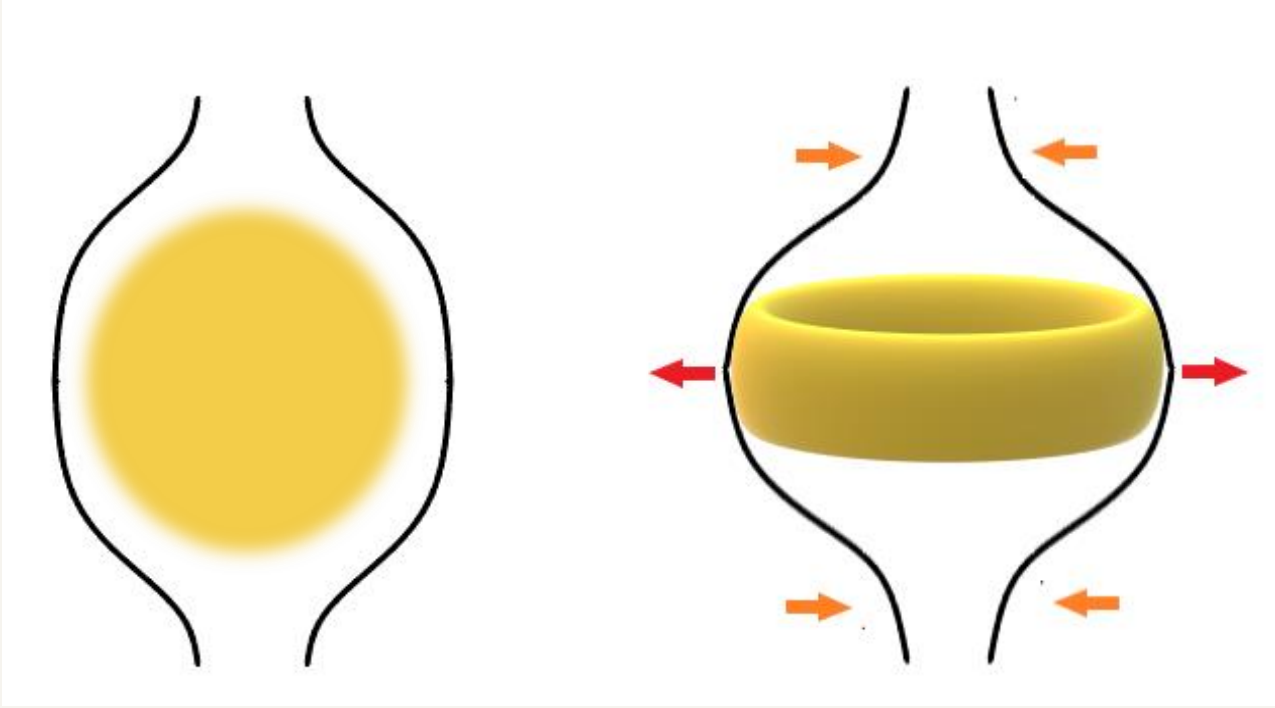


- Extimated toroidal current ≈ **5 kA** with a current between the electrodes of **10 kA**
- From B oscillations → current input of almost 20% of the total current in the torus, i.e. **1 kA**
- Average temperature of **20 eV** with spikes which correspond to sudden increase or decrease of B

→ Reconnections push the current both inside and outside the torus.

Toy Model



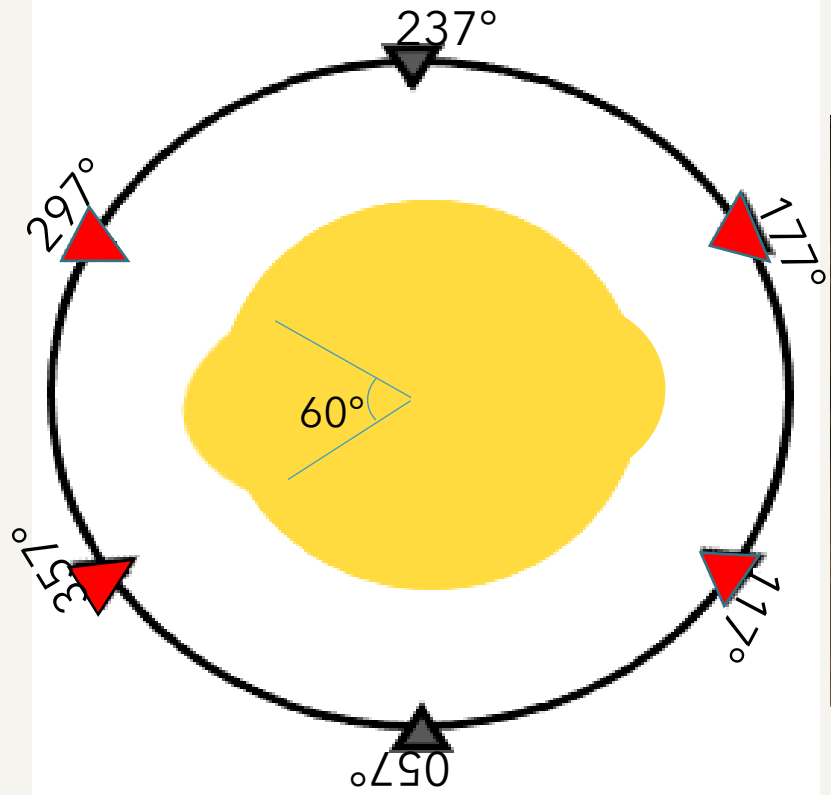


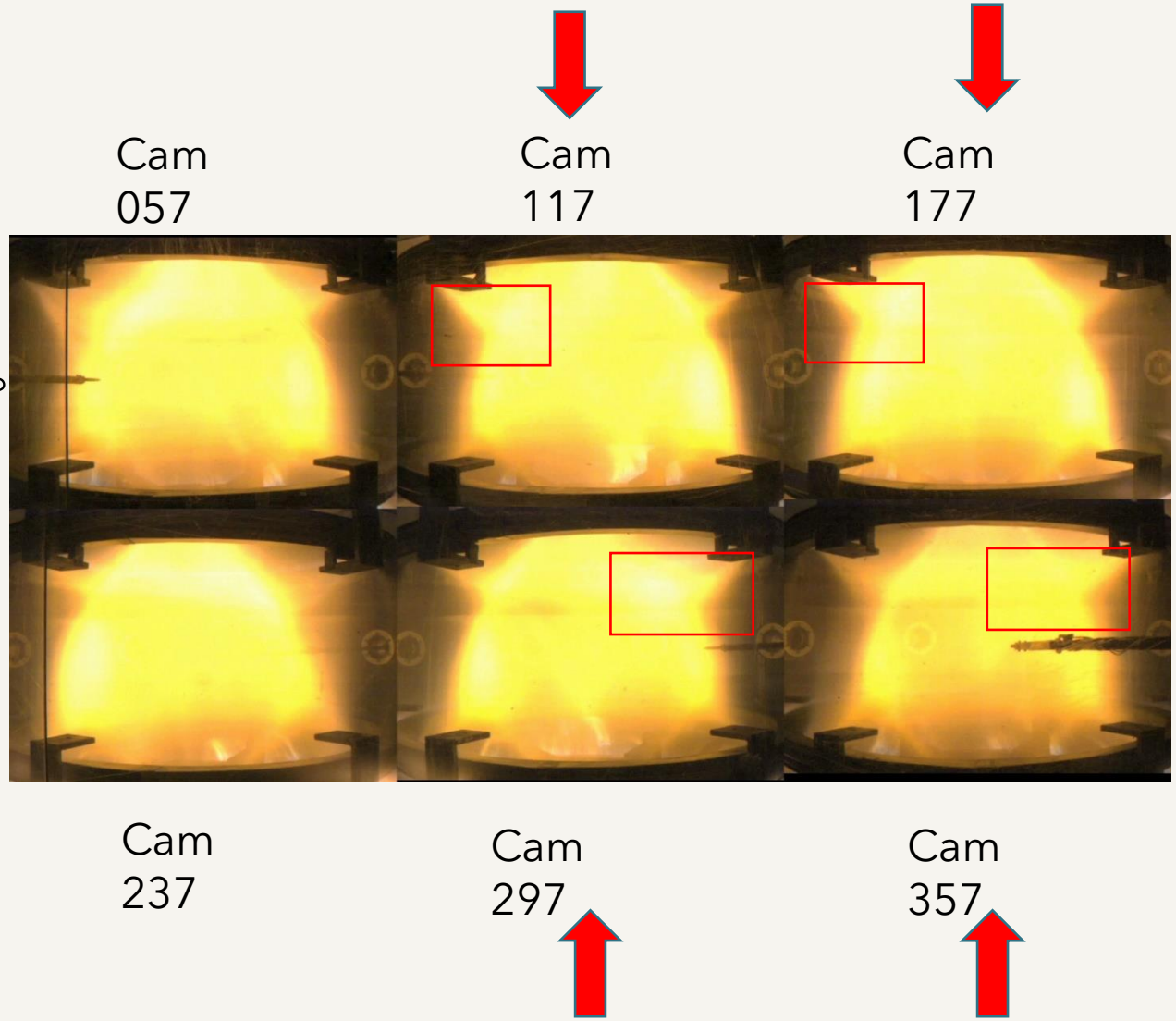
- Less dense
- Lower diameter
- Higher distance btw x-points

Current input = Reconnection

- Higher density
- Higher diameter
- Lower distance between x-points

Toy Model


237°
297°
177°
357°
117°
057°
60°


Cam
057
Cam
117
Cam
177
Cam
237
Cam
297
Cam
357

Reconnections

- The deformations observed near the X points (high or low) last for few milliseconds.
- Deformations accompanied by an increase in brightness (in the same area) and temperature peaks
- Temperature peaks also correspond to abrupt changes in the magnetic field → Reconnection episodes
- Currents are sent in and out of the torus due to reconnections
- From the oscillations of B-field and density we can estimate the duration of this episodes $\tau_{oscillations} \approx 10\, ms$

Reconnection

- PROTO-SPHERA plasma is more compatible with a collisional model
- Estimated reconnection rate from the Sweet-Parker model: $\tau_{SP} \approx 0{,}5\ ms \rightarrow \tau_{Rec}^{SP} \approx 3\ ms$

  $S \approx 30$

  $\tau_A \approx 0{,}1\ ms$
- Observed oscillations' period: $\approx 10\ ms$
- Problems with sampling frequencies!

Hall sensor signals: average at 500 Hz $\approx$ milliseconds → It is not possible to observe the "single" magnetic reconnection

We only observe cumulative effects

Conclusions

- The plasma widens and tightens due to Magnetic Reconnection phenomena
- Reconnections are responsible for current input and output, with predominance of input episodes
- Reconnection phenomena are localized in a zone which extends over almost 60° (azimuthal direction)
- Current diagnostics cannot provide more useful infos on magnetic reconnection
- X-rays or soft-X-rays diagnostics could confirm our interpretation of the temperature spikes as particles accelerated by reconnection
  - Deformation of the Maxwellian distribution → Non-thermal particles accelerated by reconnections


Thank You for your attention