

Three-dimensional Magnetic Reconnections in *PROTO-SPHERA*

Samanta Macera^{1,2} and the PROTO-SPHERA Group

¹ GSSI, Viale Francesco Crispi 7, 67100 L'Aquila, Italy

² University of Rome Tor Vergata, Via della Ricerca Scientifica 1, 00133 Roma, Italy

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The 21st International Spherical Torus Workshop



PROTO-SPHERA Group

FSN Department, CR-ENEA Frascati

Paolo Micozzi, Alessandro Mancuso^{retired}, Vincenzo Zanza^{retired}, Fabrizio Andreoli, Gerarda Apruzzese, Francesca Bombarda, Luca Boncagni, Paolo Buratti^{retired}, Antonella De Ninno, Francesco Filippi, Donatella Fiorucci, Edmondo Giovannozzi, Luigi Andrea Grosso, Matteo Iafrati, Alessandro Lampasi, Violeta Lazic, Simone Magagnino, Simone Mannori, Francesco Napoli, Valerio Piergotti, Selanna Roccella, Giuliano Rocchi, Alessandro Sibio, Benedetto Tilia^{retired}, Onofrio Tudisco

INAF – IAPS, Via Fosso del Cavaliere 100, 0133 Rome, Italy

Franco Alladio

GSSI, Viale Francesco Crispi 7, 67100 L'Aquila, Italy

Samanta Macera

Pisa University

Francesco Giammanco^{retired}, Danilo Giulietti, Paolo Marsili

Università di Padova e Consorzio RFX and FSN Department, CR-ENEA Frascati

Giuseppe Galatola Teka

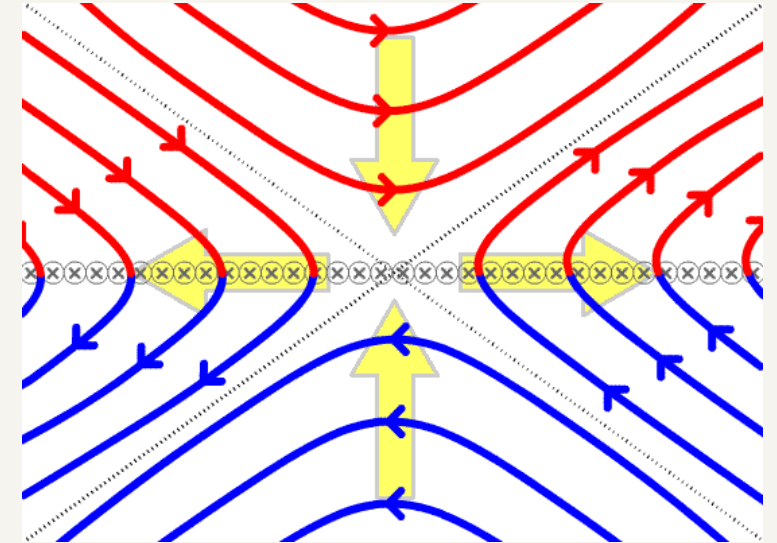
Magnetic Reconnection

❖ Ideal

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

❖ Resistive

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



Acquired from Wikipedia

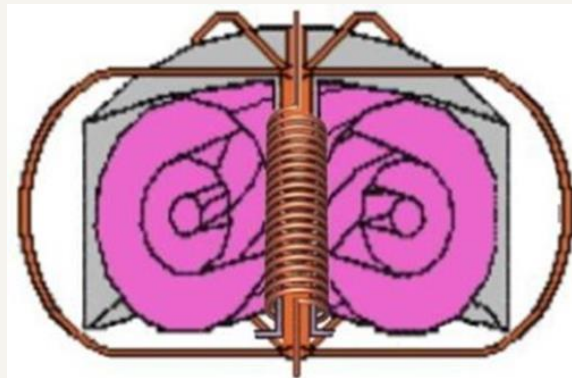
PROTO-SPHERA

PROTOTYPE of a Spherical Plasma for HElicity Relaxation Assessment

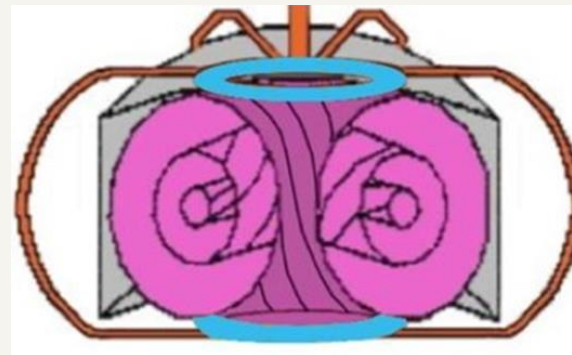
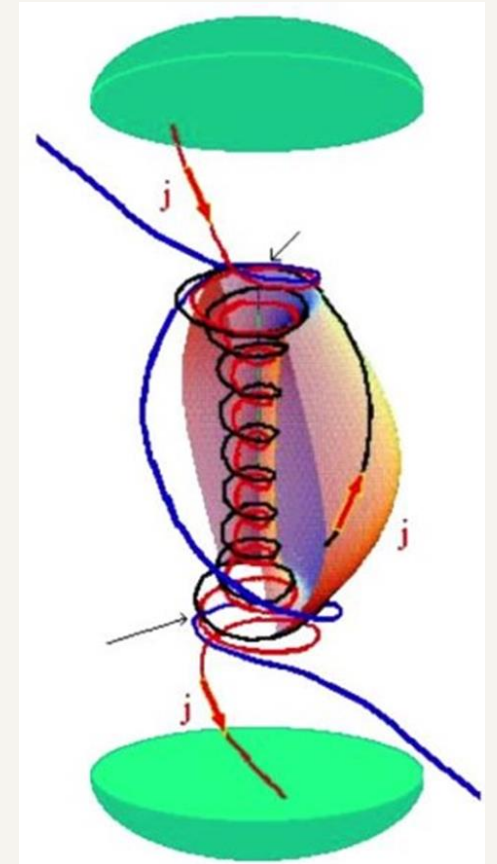
- Simply connected configuration
- Cylindrical vacuum chamber
- Spherical Torus with closed flux surfaces + Screw Pinch
- Uses Reconnections to confine plasma

→ **See P. Micozzi Talk**

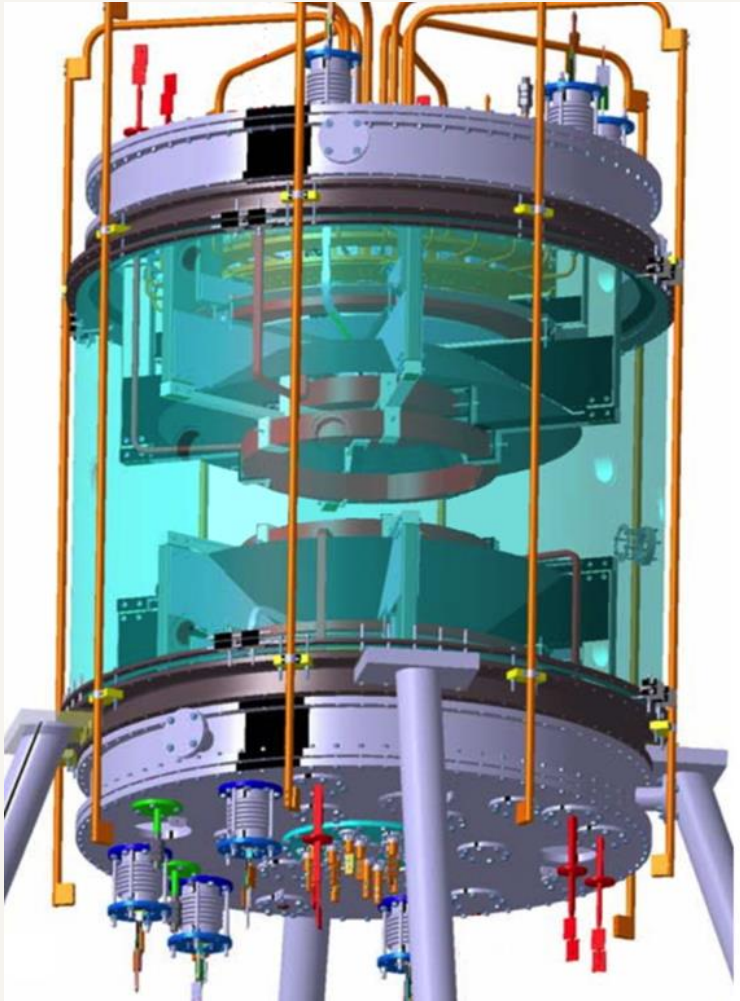
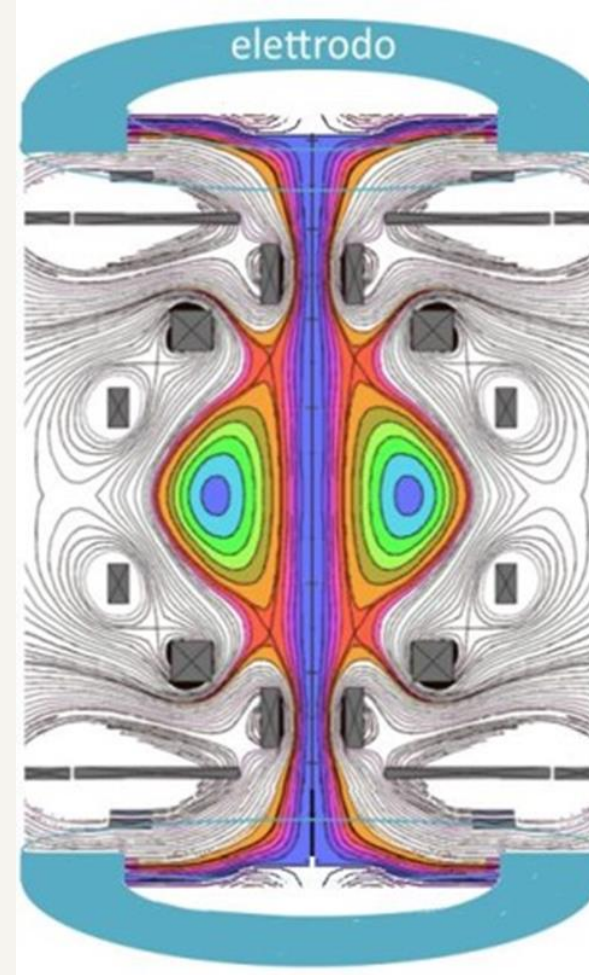
Tokamak



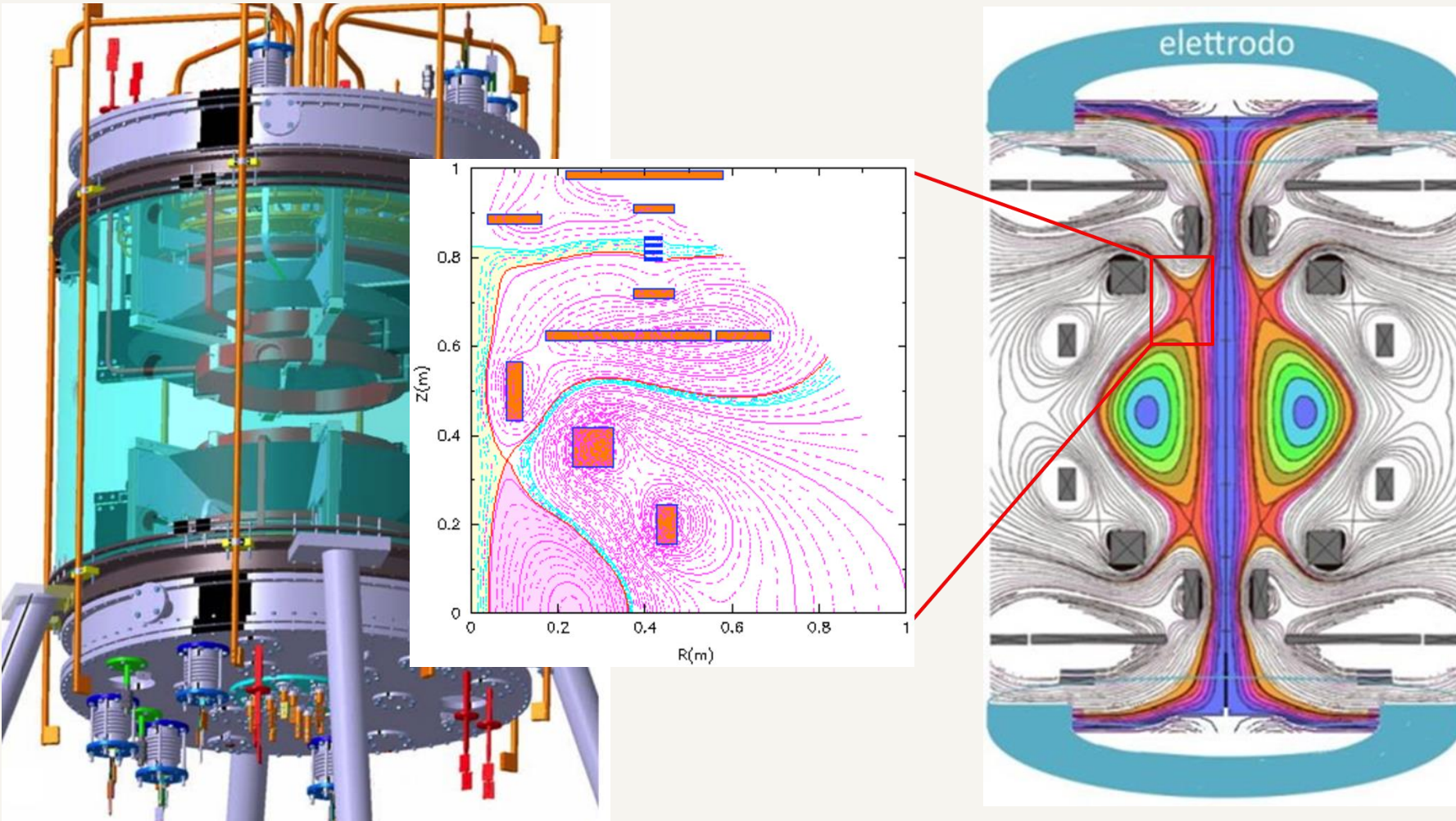
PROTO-SPHERA



PROTO-SPHERA: x-points formation

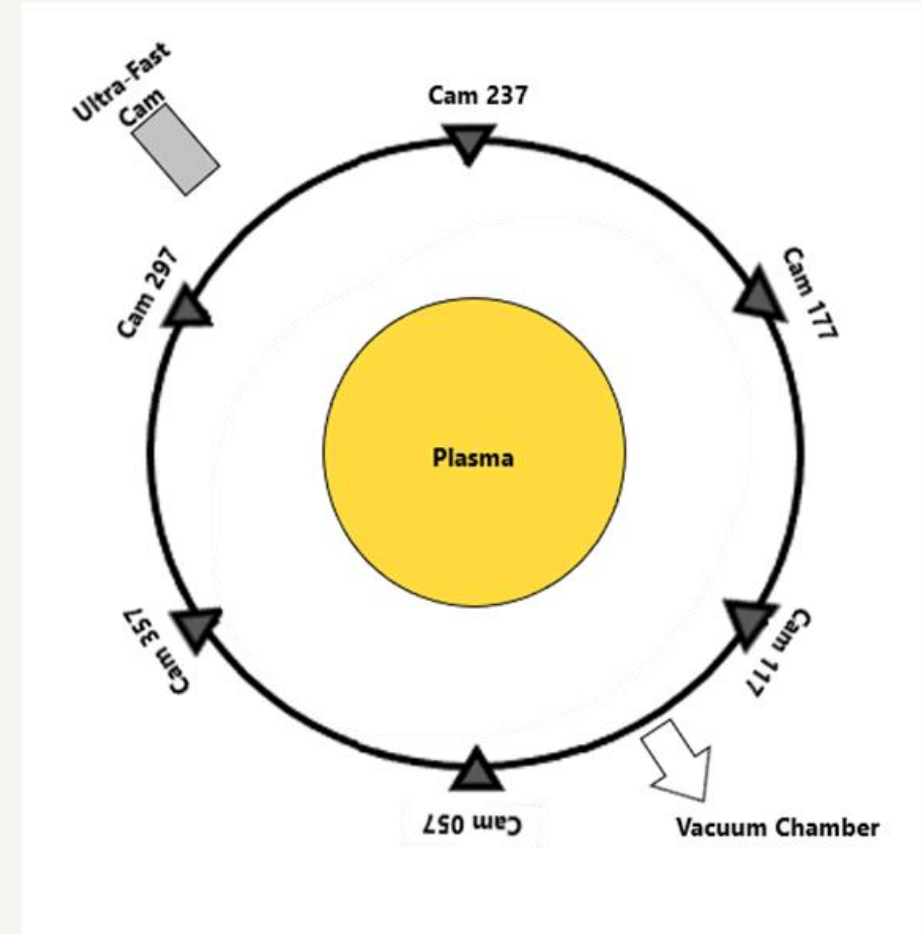


PROTO-SPHERA: x -points formation



PROTO-SPHERA: Diagnostics

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

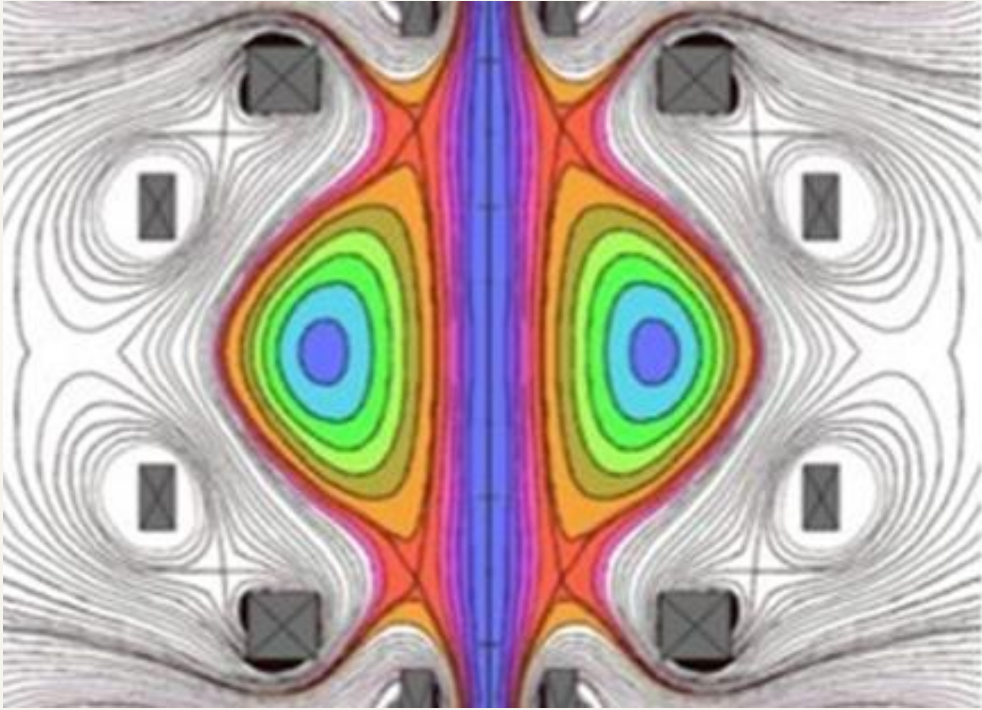
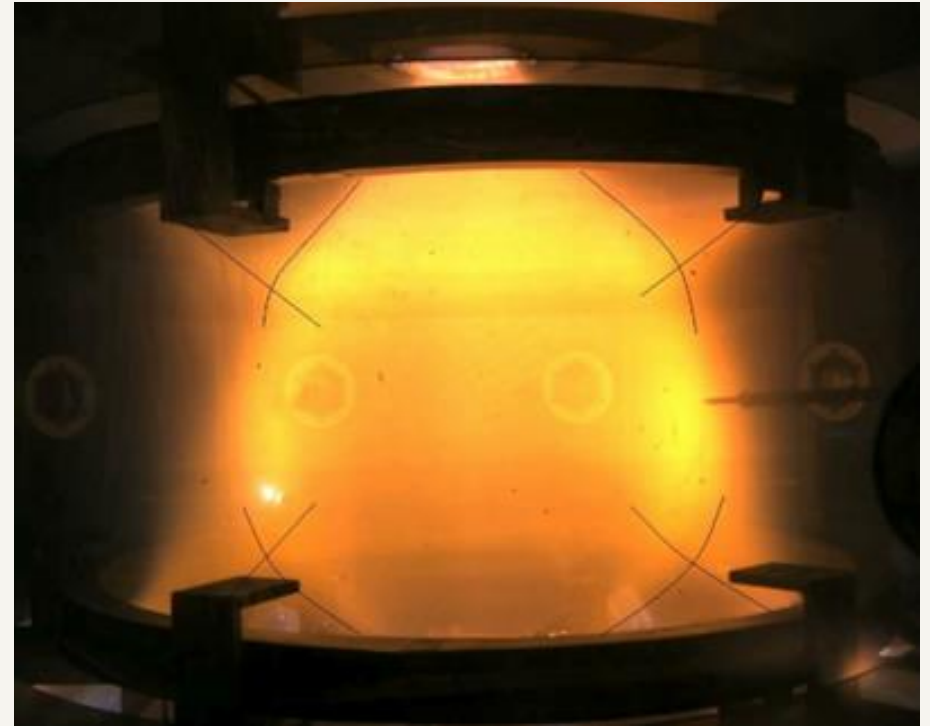


PROTO-SPHERA: Helium shot #2141



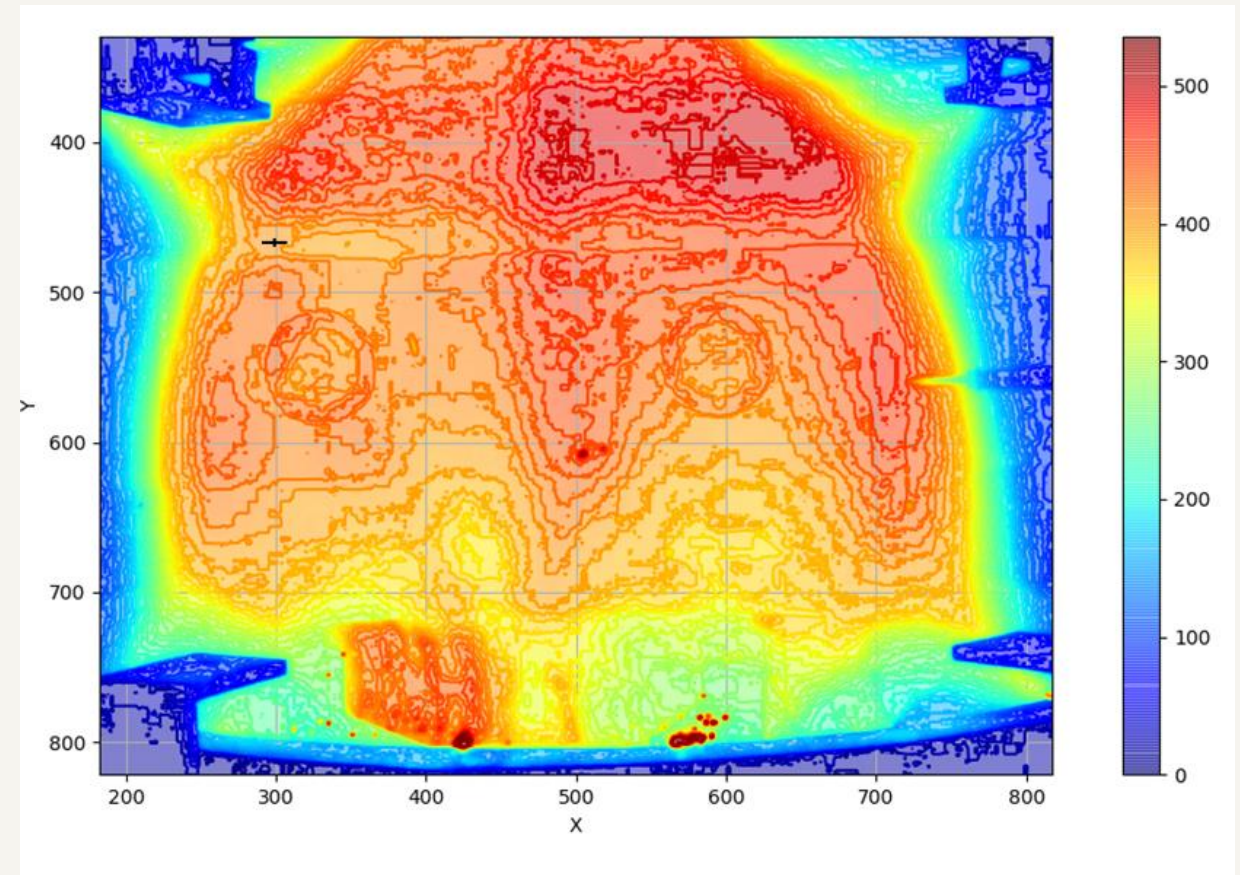
- ❖ Reconnections not axisymmetric (as expected)
- ❖ Global rotation due to $\vec{E} \times \vec{B}$
- ❖ Torus displaced from the equatorial plane

Fast Cameras Data Analysis



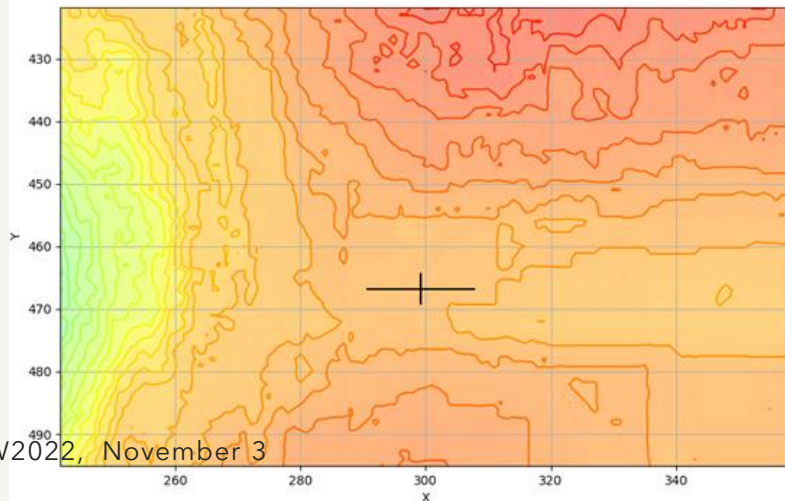
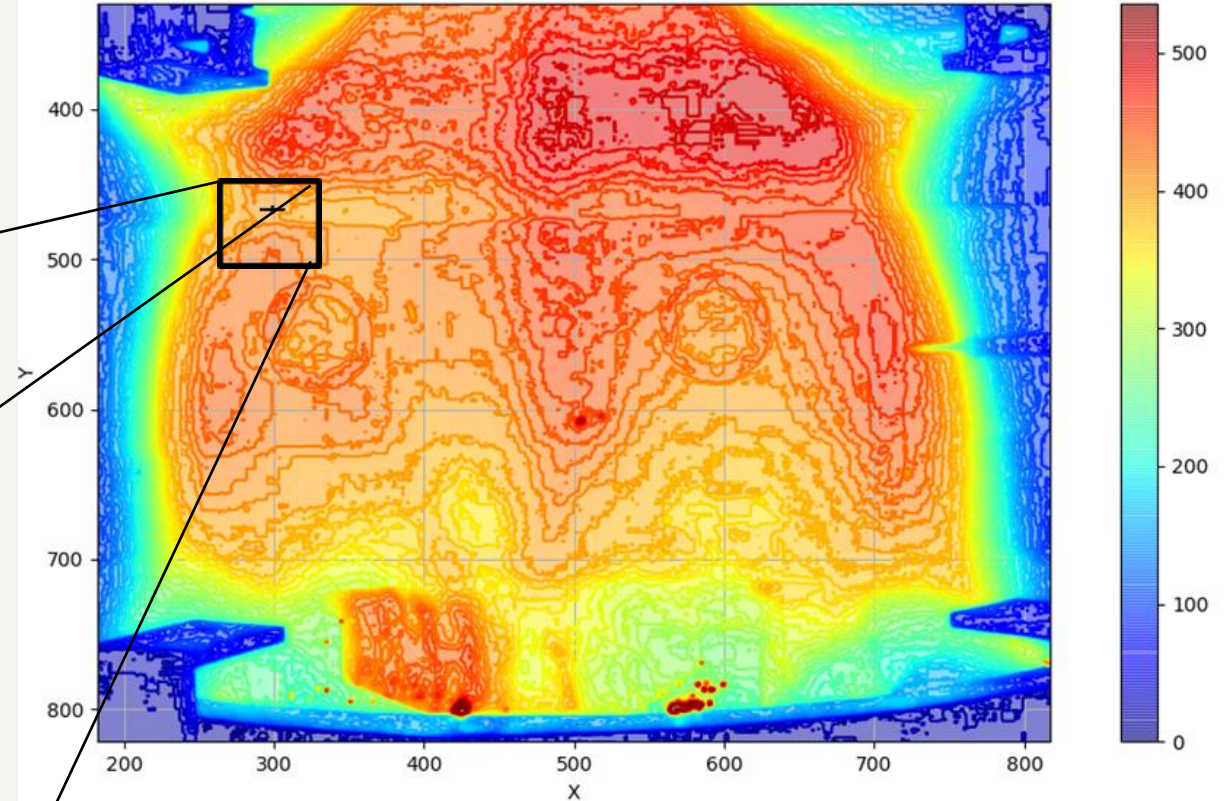
Fast Cameras Data Analysis

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

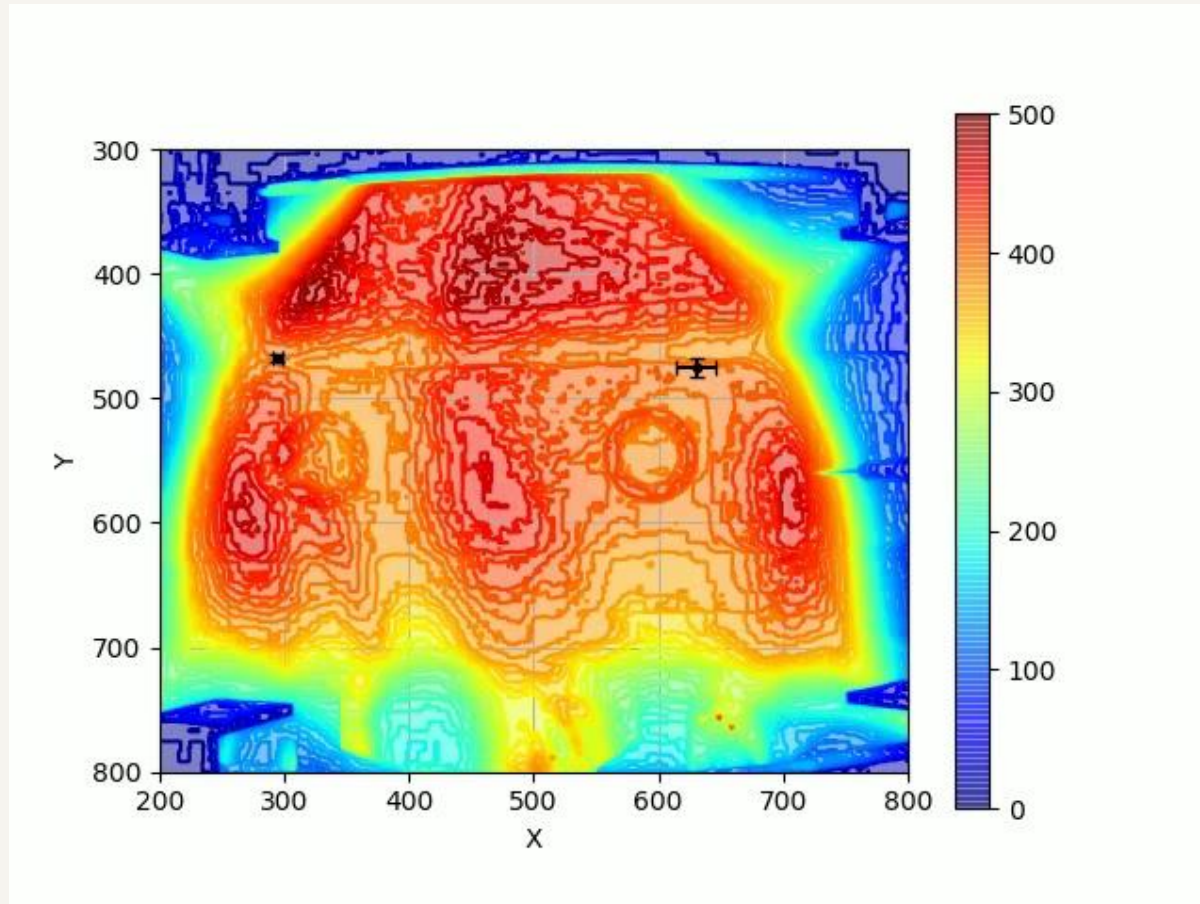


Fast Cameras Data Analysis

- ❖ Filtered Image (RGB: 100%R 86%G 25%B)
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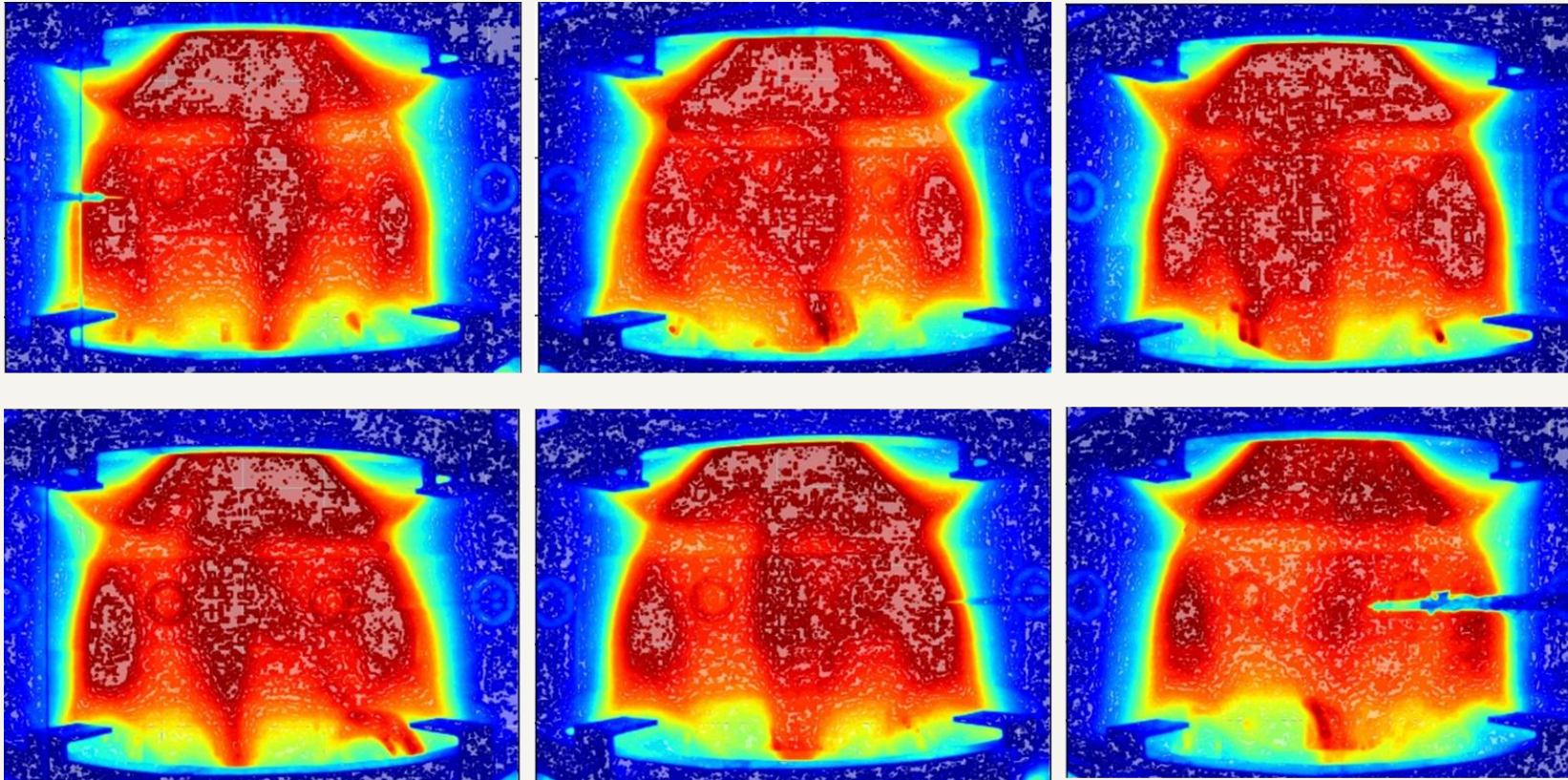


Fast Camera Data Analysis



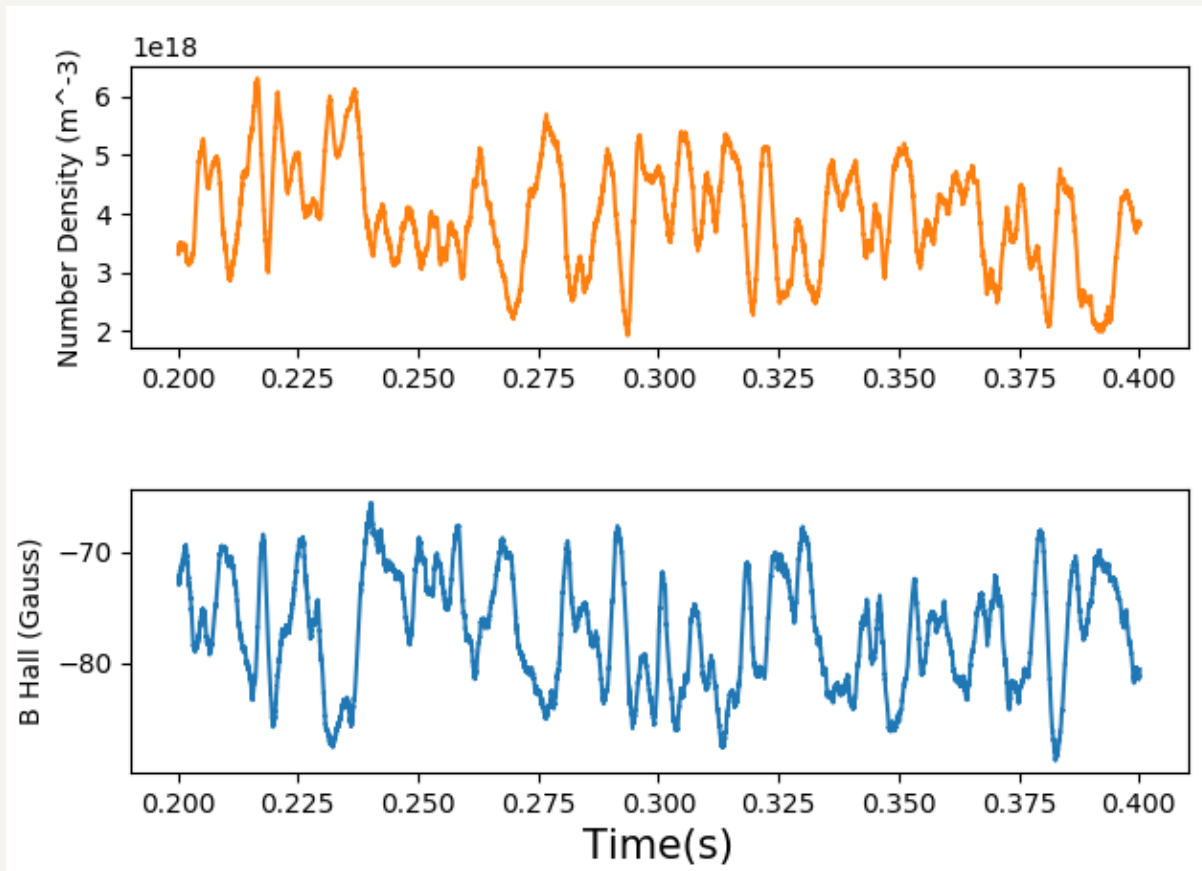
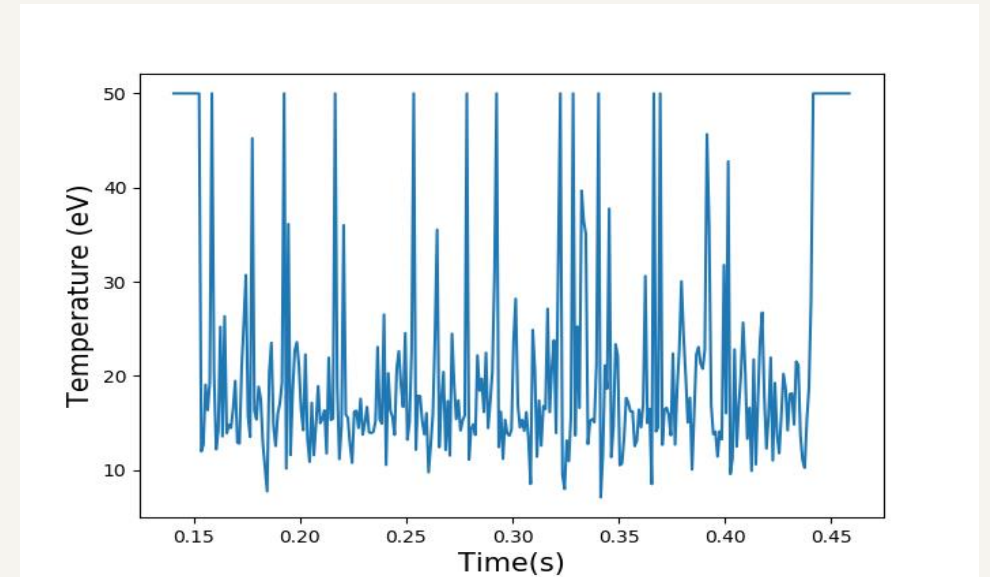
- ❖ Closed curves and nestled up in the torus
- ❖ X-points oscillations

Fast Cameras Data Analysis

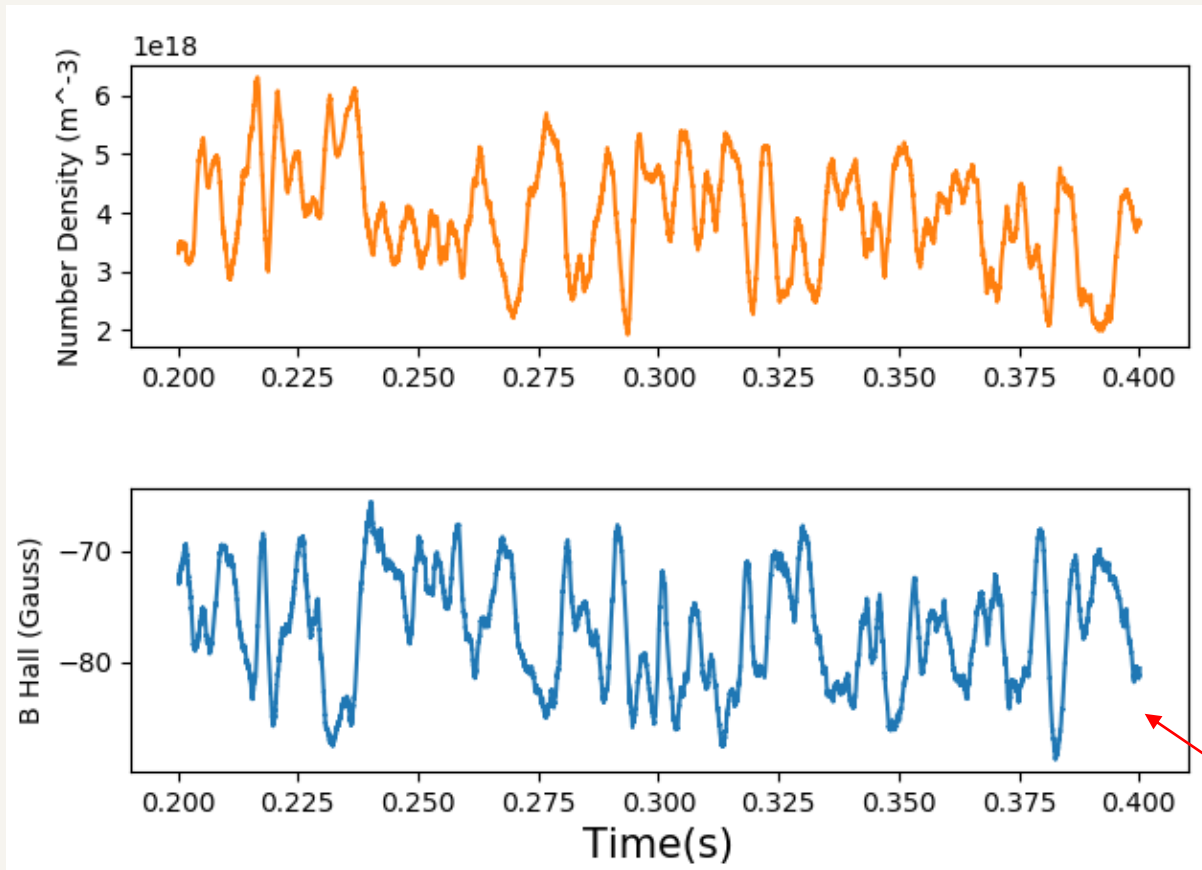
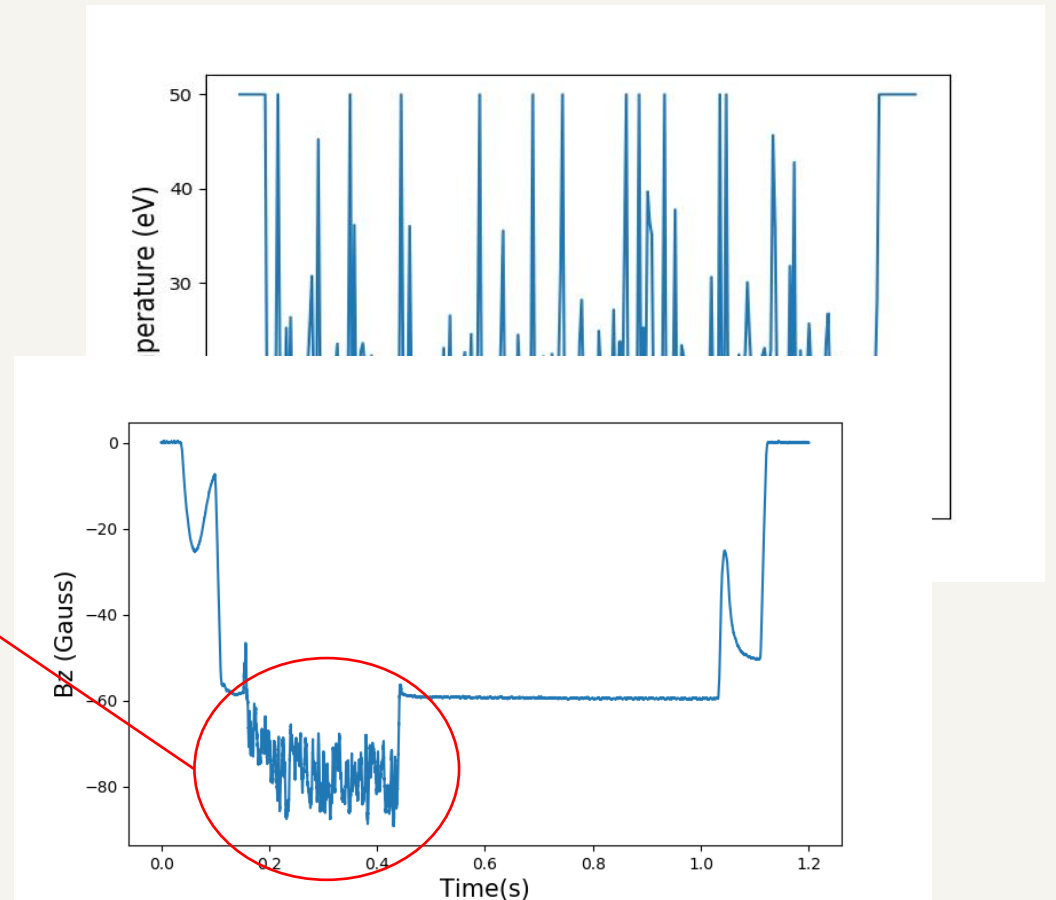


- ❖ Check: are the X-points at the same height passing from one camera to the next one?

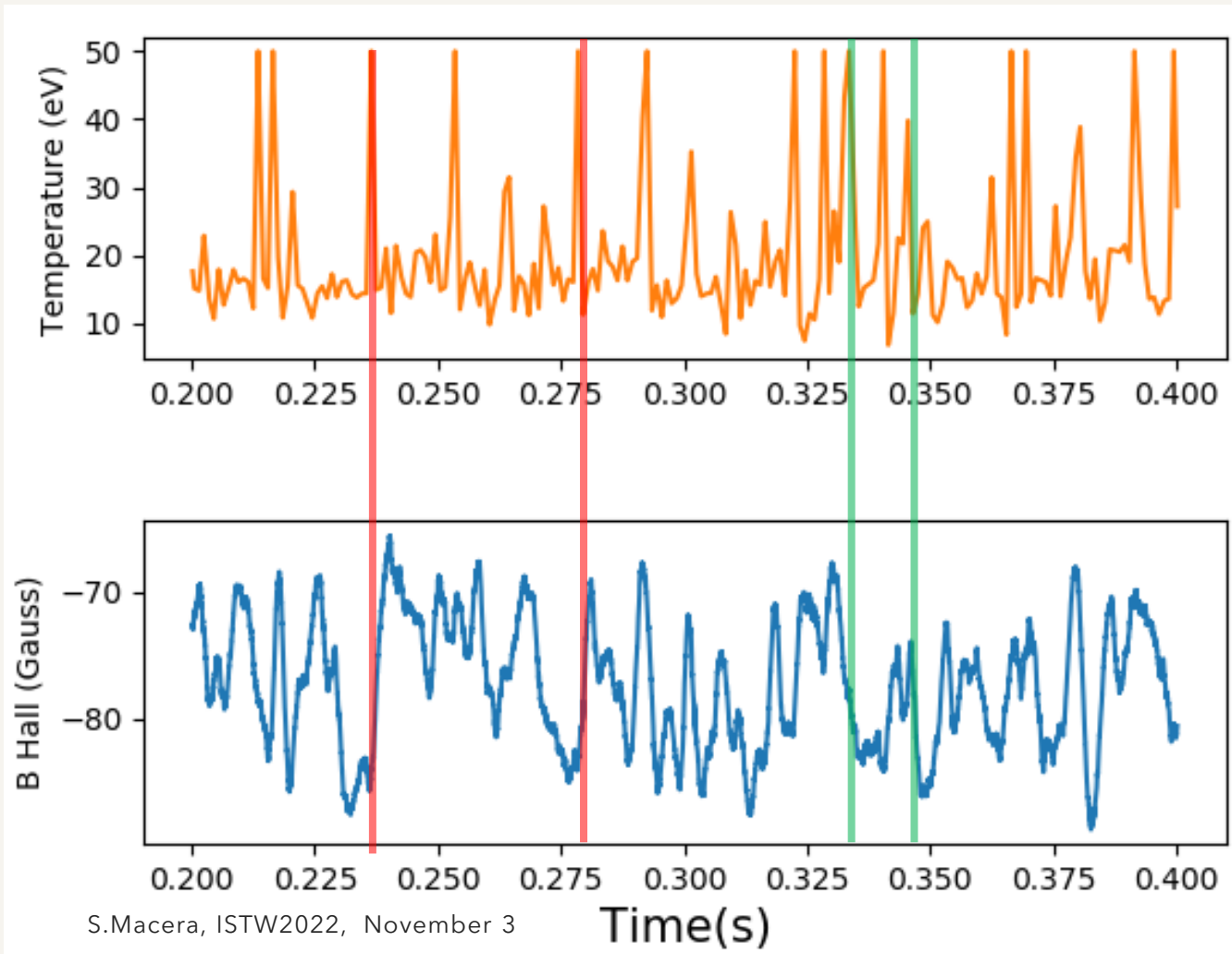
Data Analysis: more datas..



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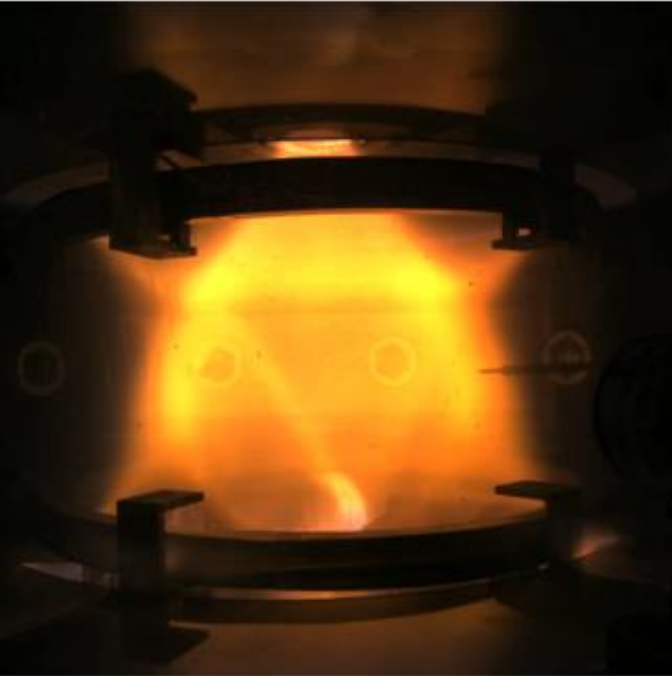
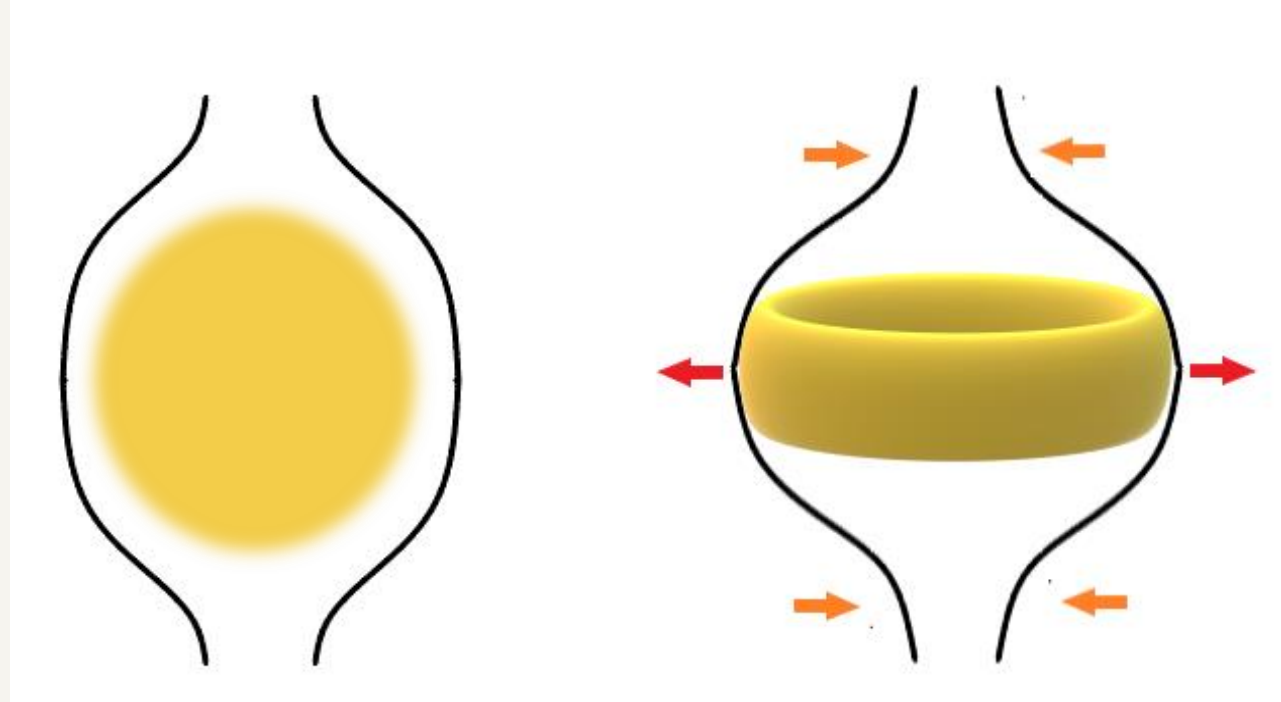


Data Analysis: more data...



- Estimated toroidal current $\approx$ 5 kA with a current between the electrodes of 10 kA
- From B oscillations $\rightarrow$ 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
 - $\rightarrow$ Reconnections push the current both inside and outside the torus.

Toy Model

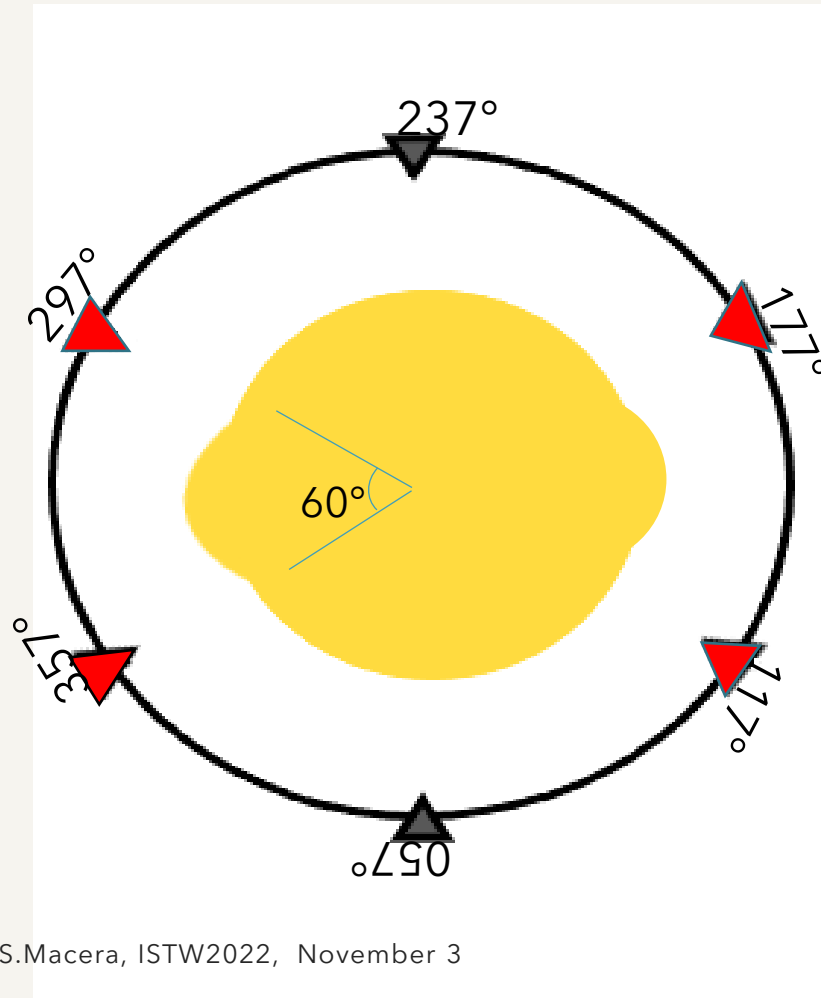


Current input = Reconnection

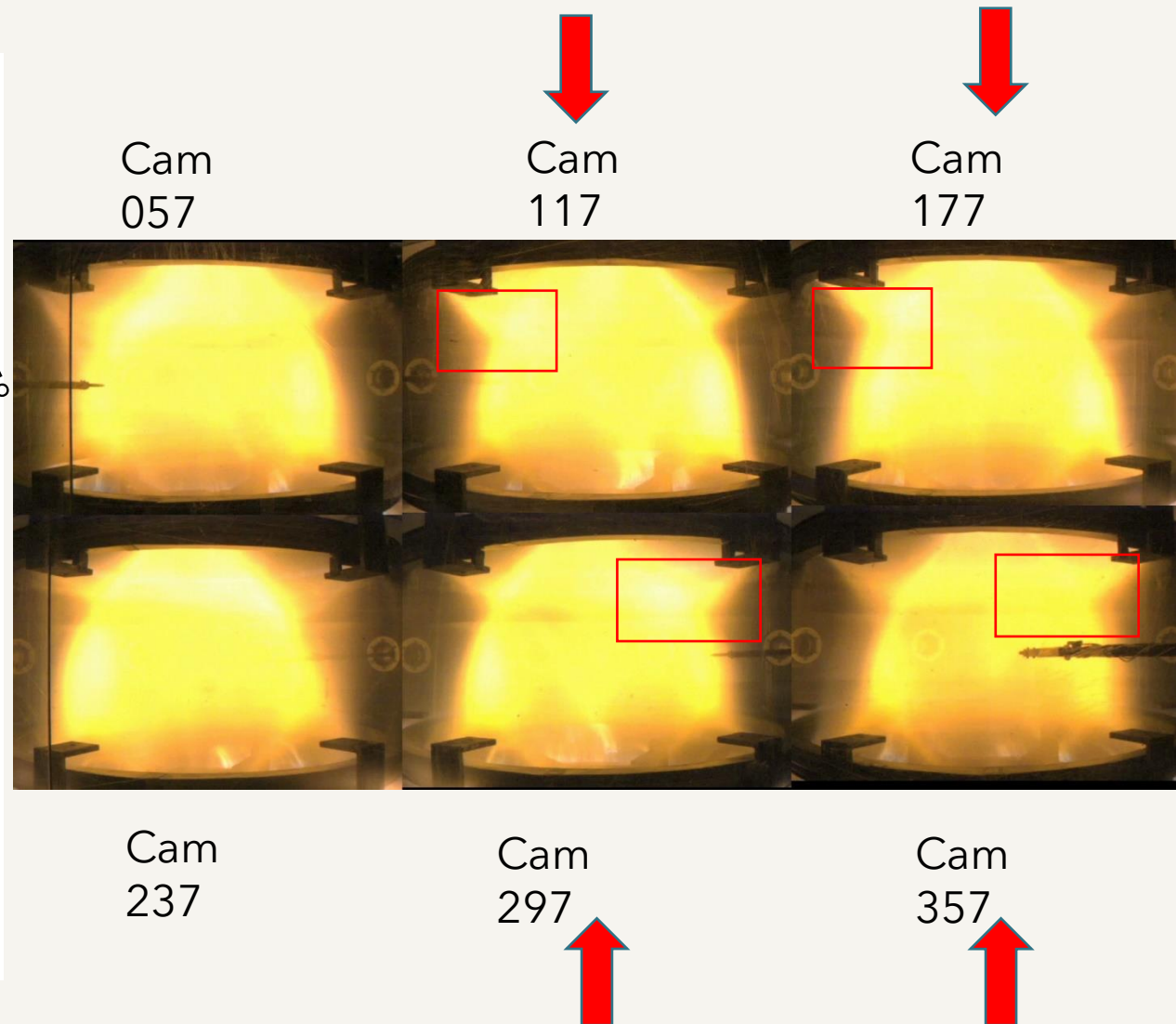
- Less dense
- Lower diameter
- Higher distance btw x-points

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

Toy Model



S.Macera, ISTW2022, November 3



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 $\tau_{oscillations} \approx 10 \text{ ms}$

Reconnections

❖ PROTO-SPHERA plasma is more compatible with a collisional model

❖ Estimated reconnection rate from the Sweet-Parker model:

$$\rightarrow \tau_{Rec}^{SP} \approx 0,5 \text{ ms}$$

$$S \approx 30$$

❖ Observed oscillations' period: $\approx 10 \text{ ms}$

$$\tau_A \approx 0,1 \text{ ms}$$

❖ Problems with sampling frequencies!

Hall sensor signals: average at 500 Hz $\approx$ milliseconds $\rightarrow$ 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