

Overview

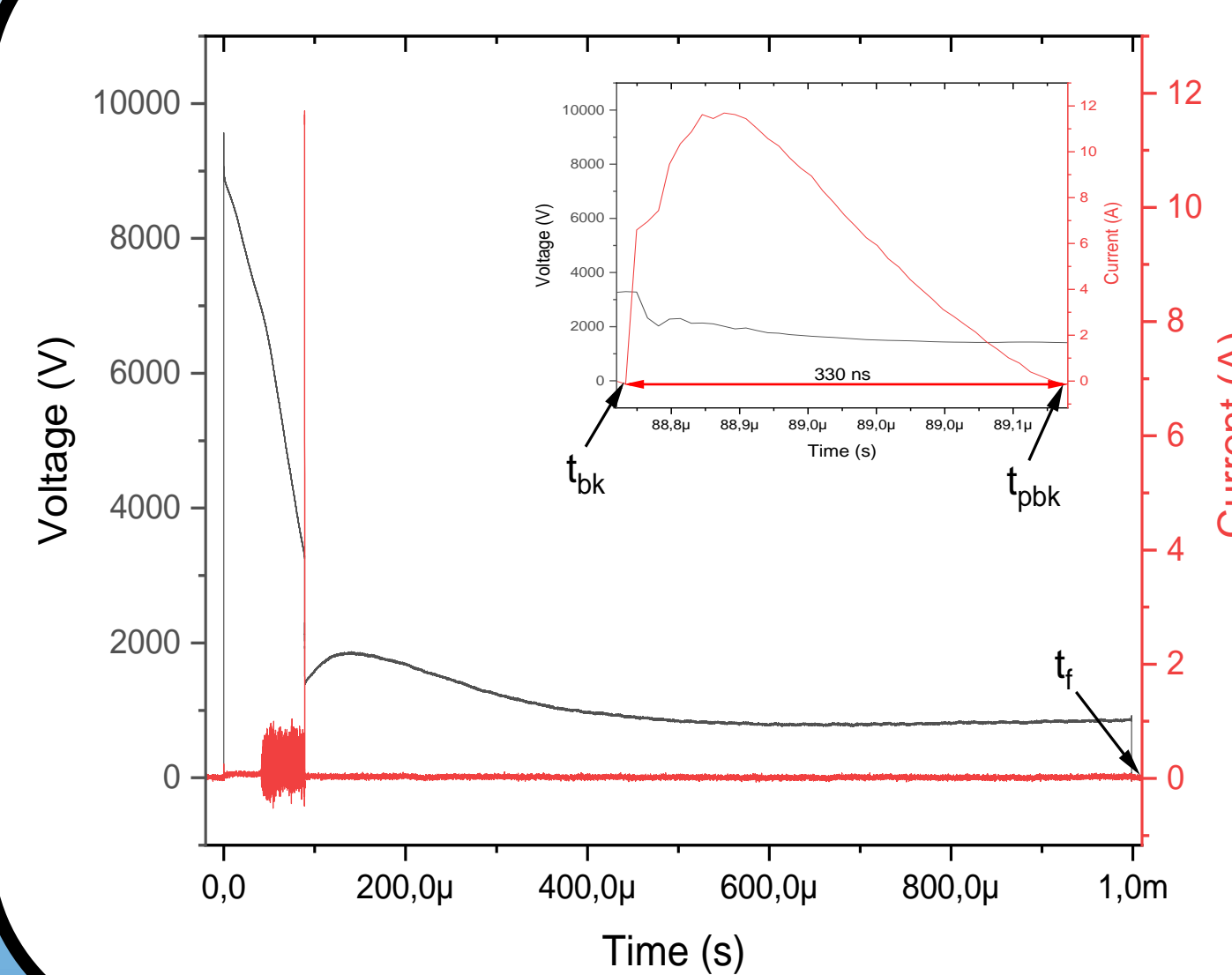
Electrical signals

Objectives

- To convert electrical energy into useful chemical species
 - Environmental applications: water and effluents treatment
 - Material applications: nanomaterial synthesis

Frame of work: a fundamental approach

- To identify and to model the physical & chemical processes involved during an electrical discharge in liquid water:
 - During the pre-breakdown stage (initiation + propagation) → Collaboration with the CWI at Amsterdam but ... COVID ☹️
 - During the breakdown stage
 - During the post-breakdown stage



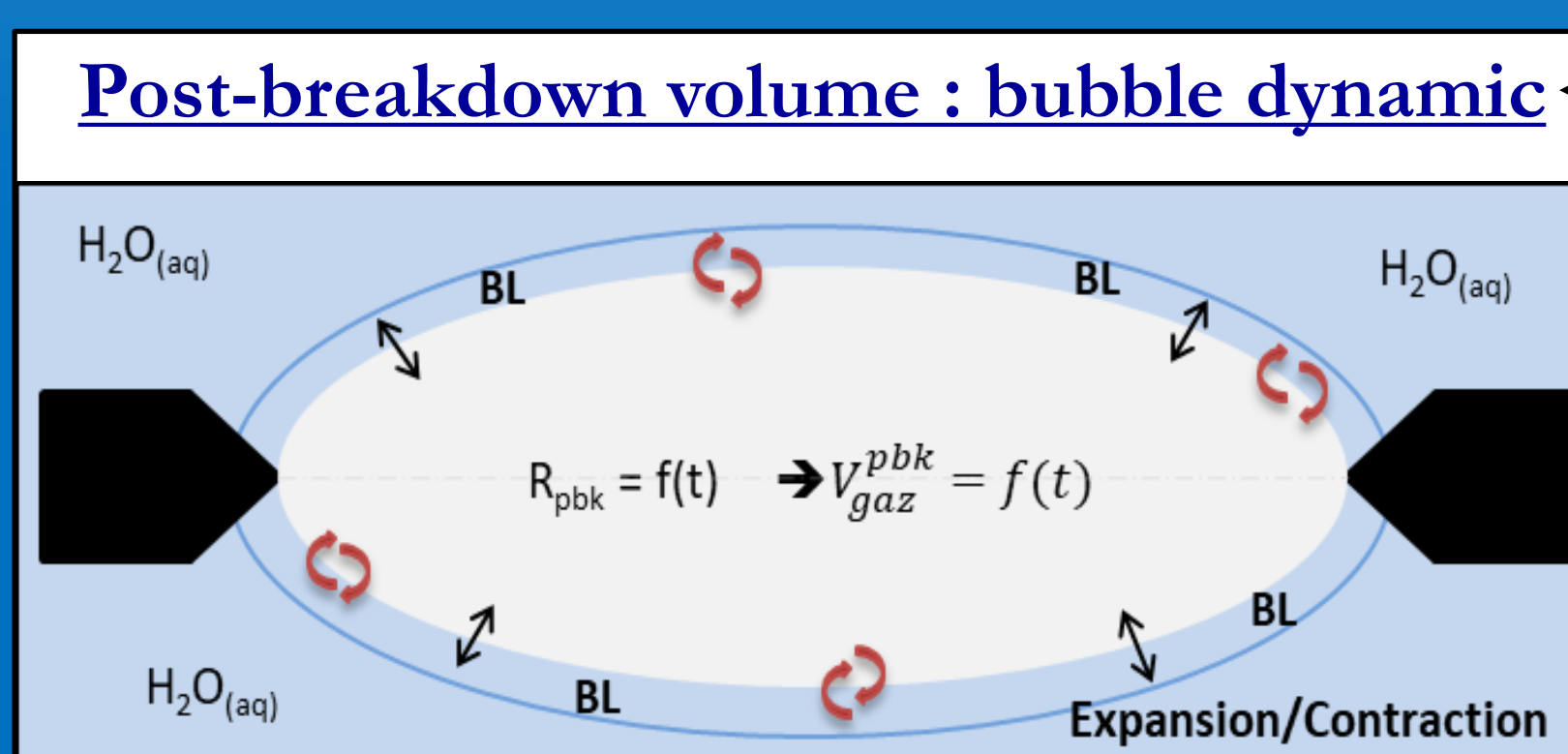
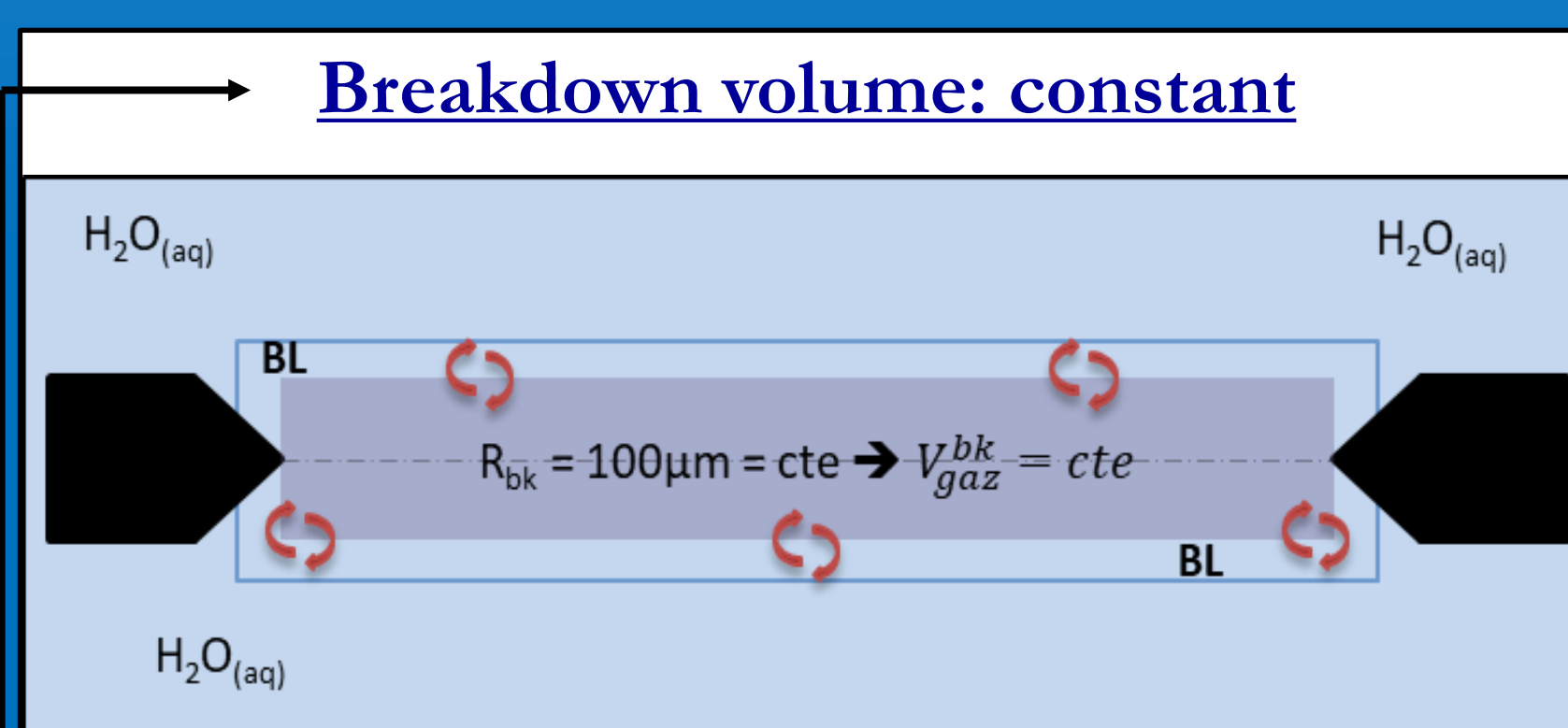
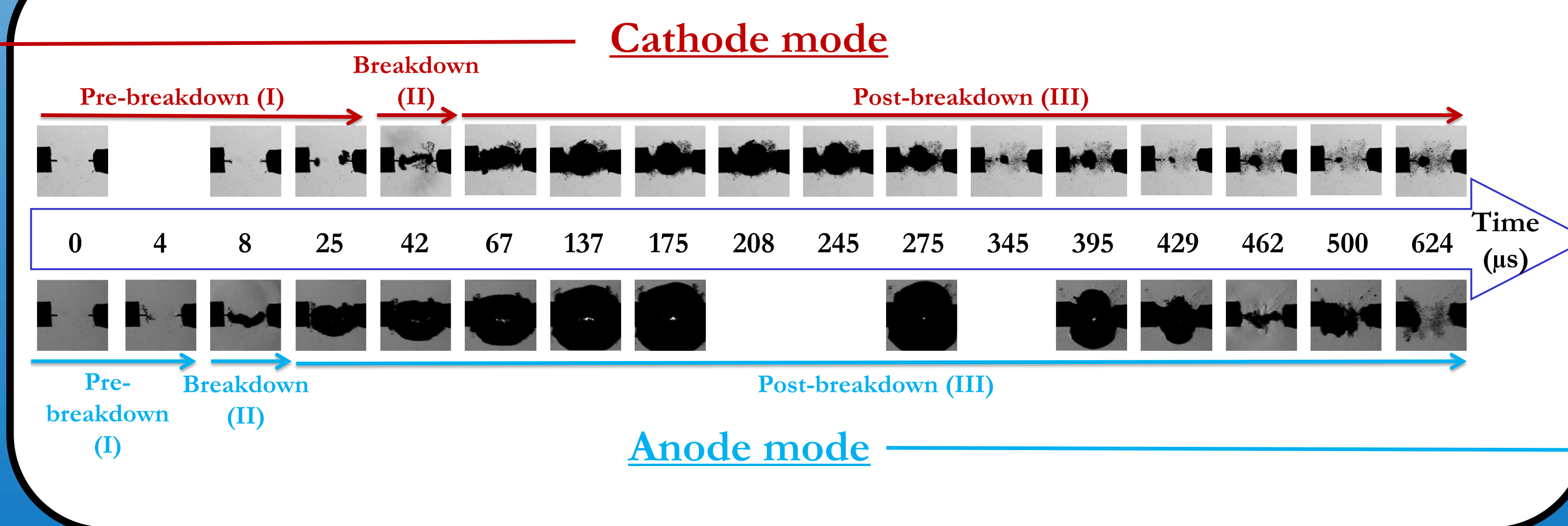
- Electrical pulse**: 12 kV
 - Rising front**: 40 ns
 - Electrode diameter**: 100 μm
 - Electrode gap**: 2 mm
 - [t_{bk}, t_{pbk}]**: 330 ns
 - [t_{bk}, t_f]**: ≥ 1 ns
- Transient current → Vaporization of water [1]
Width of the current peak (330 ns) = power injection time interval

Cathode mode

Thermal regime

- Pre-breakdown**
 - Initiation by thermal effects
 - Bush structure
 - Vaporization (transient current)
 - Streamer subsonic propagation mechanism
- Breakdown**
 - Highly ionized vapour channel (spark) → LTP formation
 - High current peak (~20 A)
 - Shock wave formation
- Post-breakdown**
 - Formation of pure vapor bubble
 - Expansion until maximum radius
 - Several contraction/expansion cycles

Discharge description



Anode mode

Mechanical regime

- Pre-breakdown**
 - Initiation by pre-existing microbubbles? [2]
 - Filamentary structure,
 - No vaporization, time scale too short
 - Streamer supersonic propagation mechanism
- Breakdown**
 - Highly ionized gas-vapor channel (stronger spark) → LTP formation
 - High current peak (up to 70 A)
 - Shock wave formation (stronger than cathode mode)
- Post-Breakdown**
 - Formation of bubble with few vapor
 - Expansion until maximum radius
 - Collapse without rebounds
 - Shock wave emitted at collapse

Breakdown Kinetic global model

Hypothesis

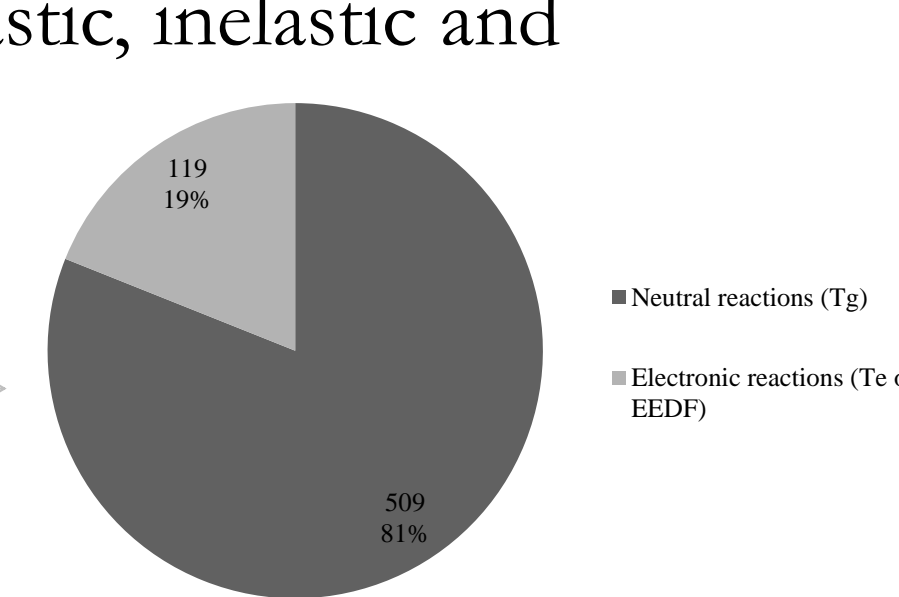
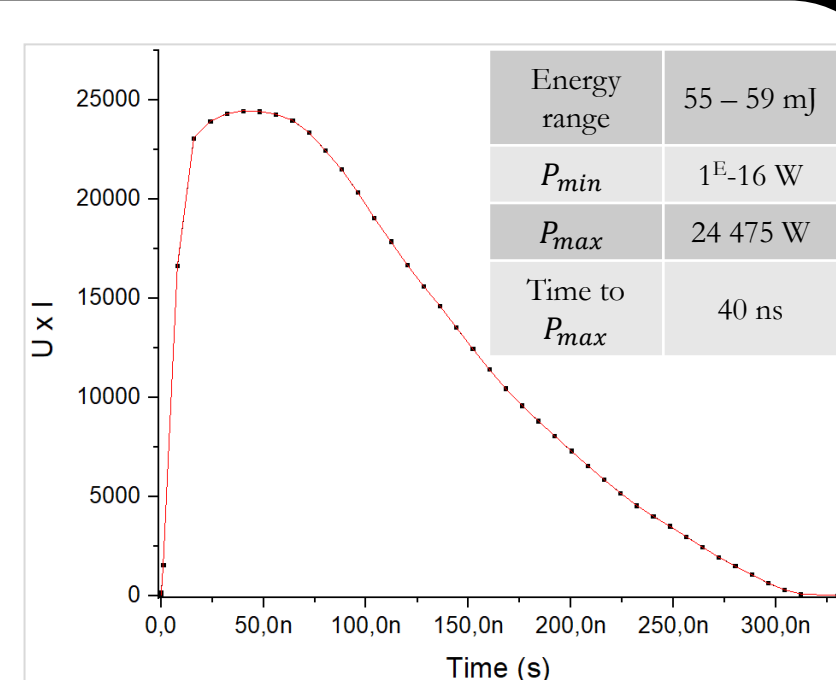
- Heavy species and electrons = Maxwellian EDF
- Injected power determined from electrical signals
- Thermal non equilibrium: T_g and T_e
- Initial composition → Pre-dissociated water vapor and electron seed

Species and energy balance equations

- Continuity equation solved for each species
- Total energy equation (including losses by conduction)
- Electron energy balance → Production and consumption through elastic, inelastic and superelastic collisions

Kinetic scheme

- 31 species involved in 628 volume reactions
- Includes three-body and pressure dependent reactions



Post-breakdown Modeling approach

1. Radius evolution

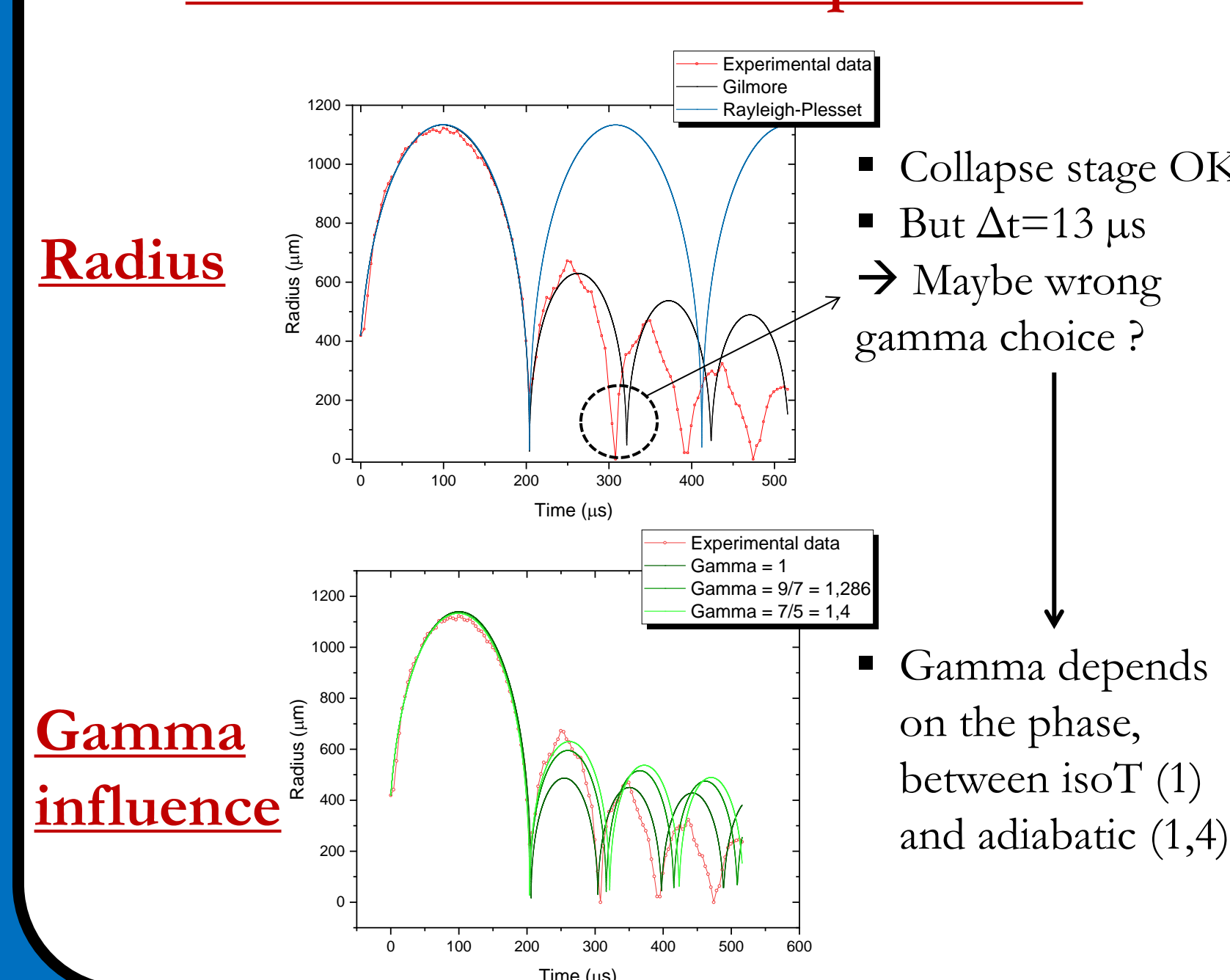
- Rayleigh-Plesset: incompressible
- Gilmore: compressible

Bubble interface (liquid side) → P_L(t) = P_B(t) - (4μ_LṘ / R) - (2σ / ρ_∞R)

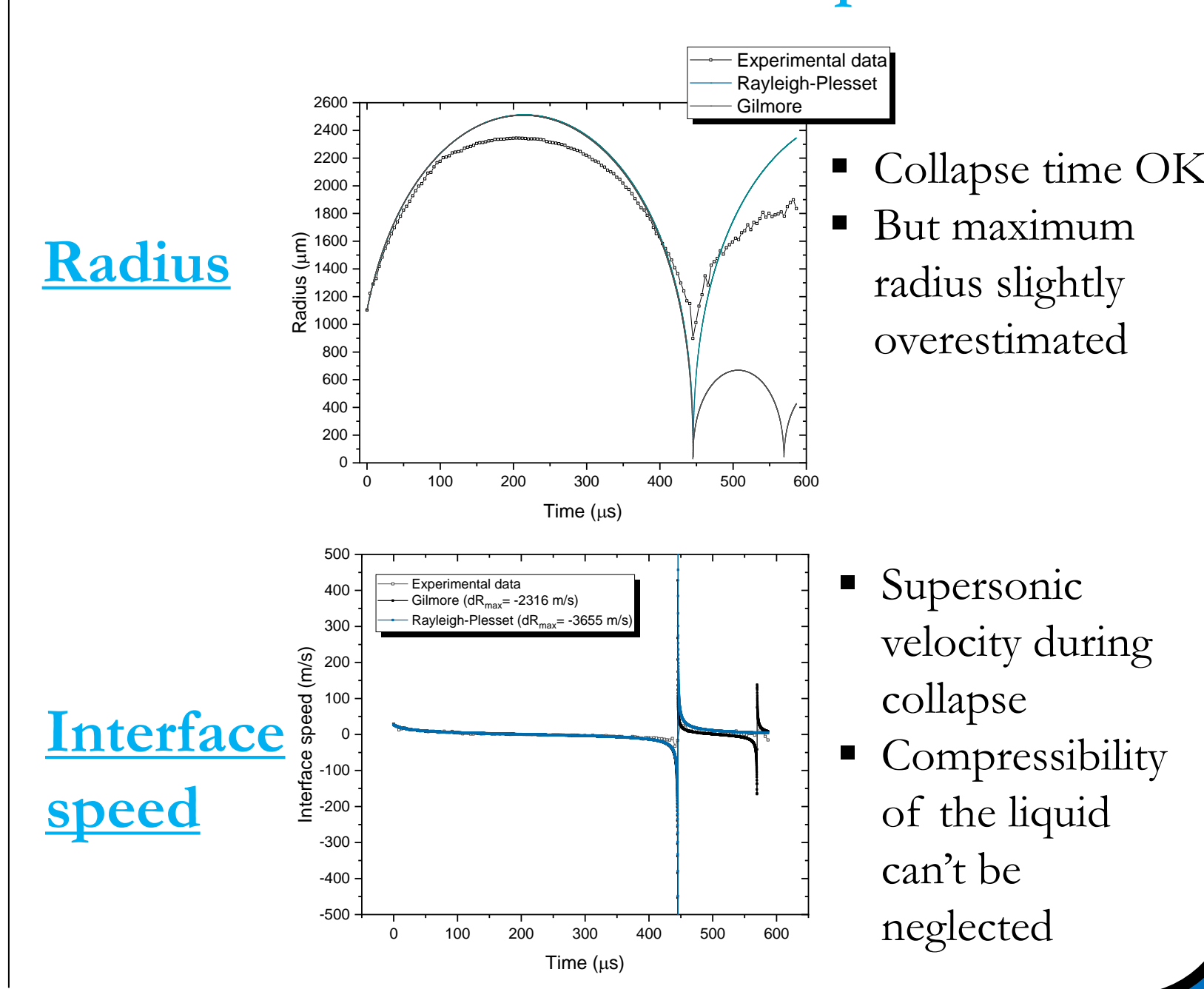
2. Pressure evolution

$$P_B(t) = P_V(T_{\infty}) + P_{g0} \times \left(\frac{R_0}{R}\right)^{3\kappa} \leftarrow \text{Bubble interior}$$

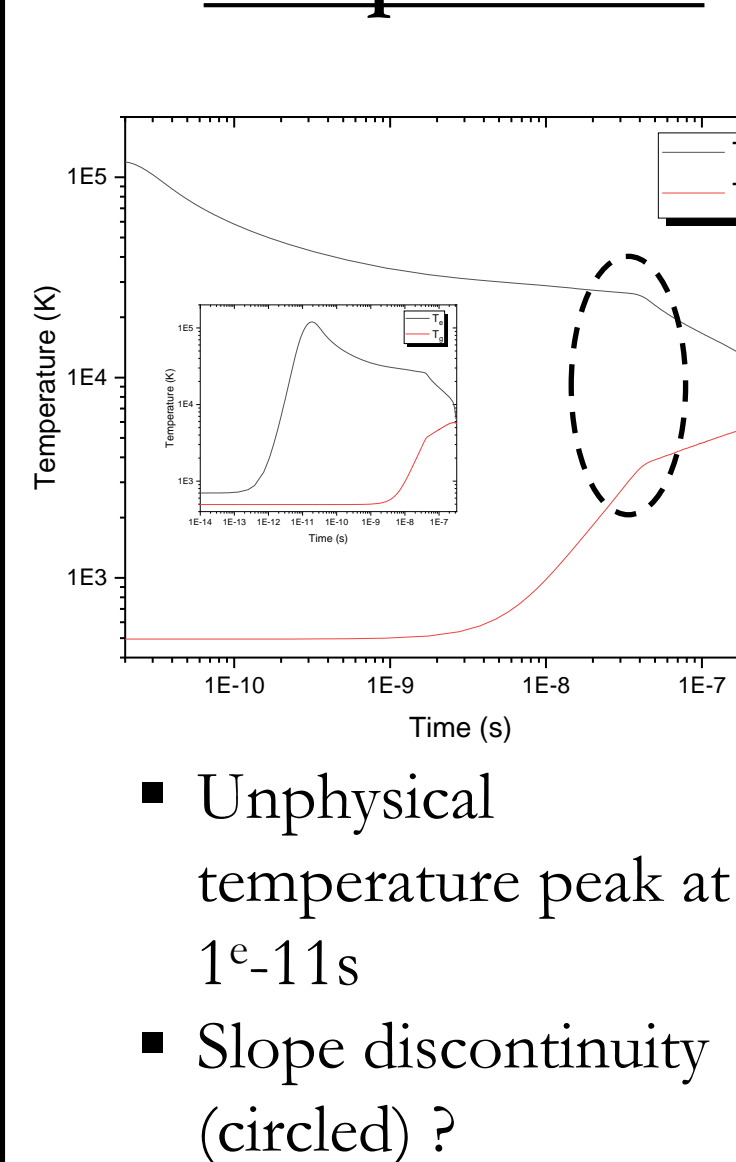
Cathode mode: thermal processes



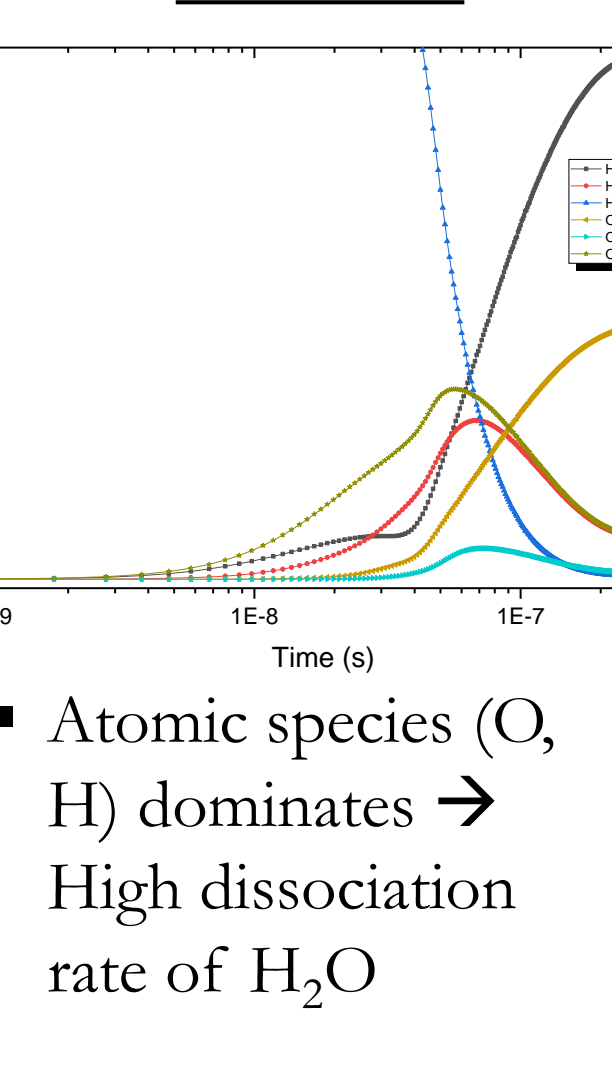
Anode mode: mechanical processes



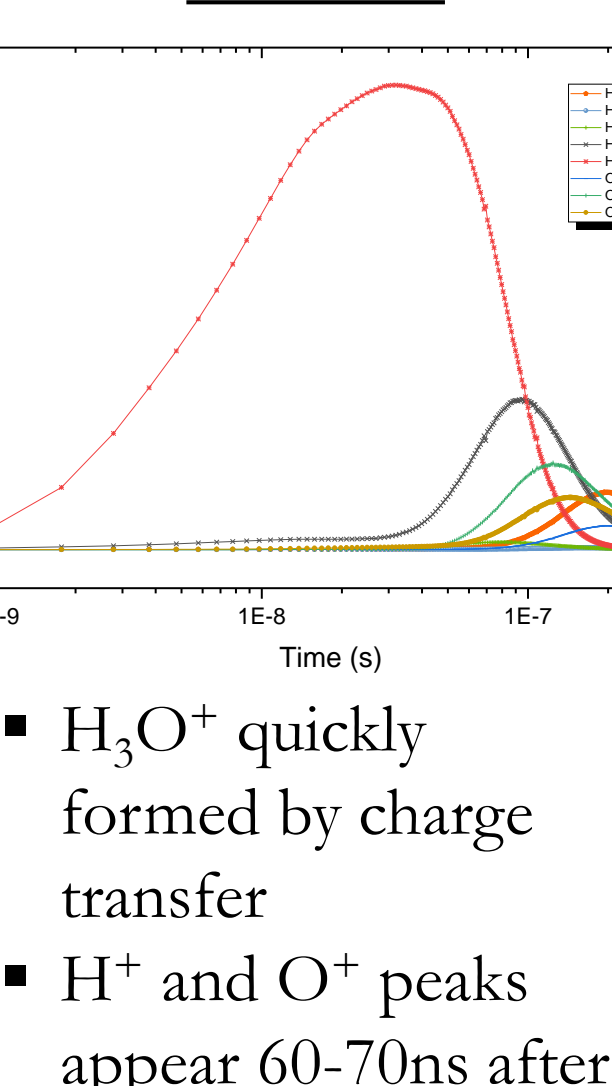
Temperatures



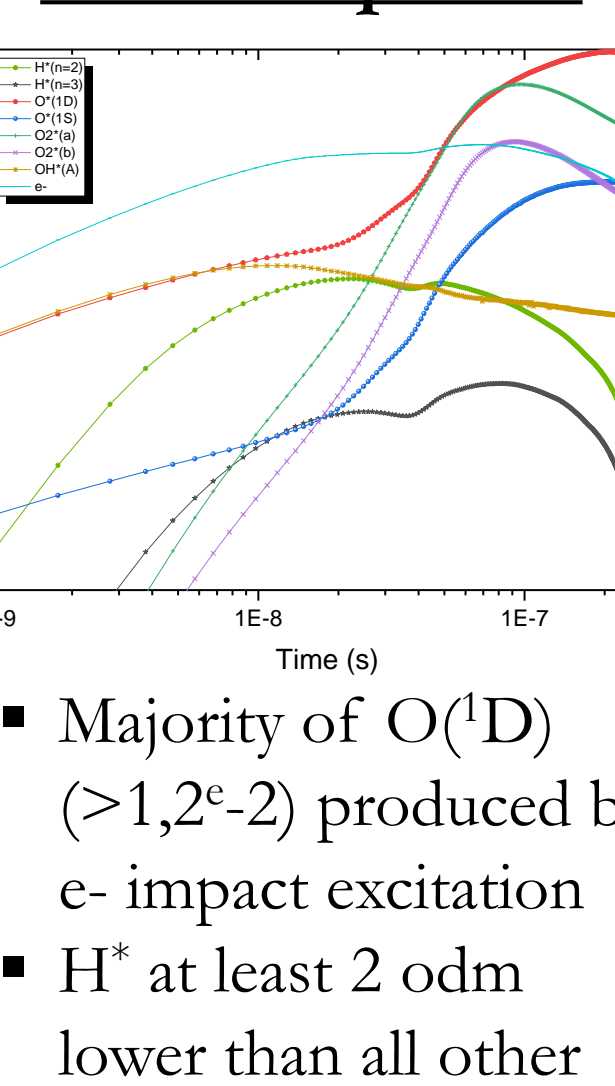
Molar fractions: neutrals



Molar fractions: cations



Molar fractions: excited species

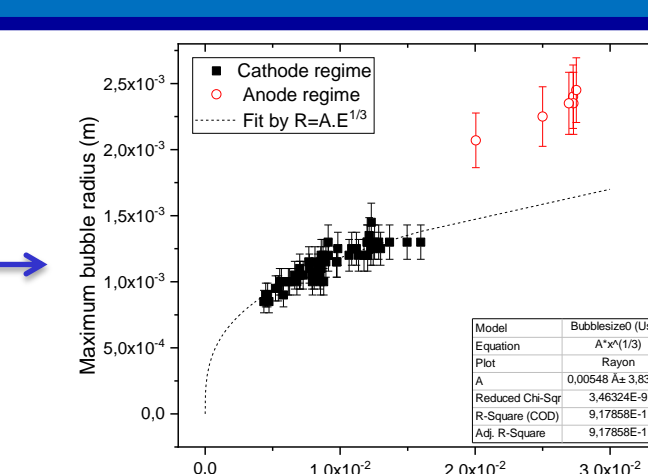


On progress results ...

- To reduce the kinetic scheme identifying the most significant production and destruction pathways for the species of interest → PumpKin software
- To couple the post-breakdown radius evolution with chemistry and diffusion already implemented in the global model

Conclusion and outlook

Validation of Kattan-Denat hypothesis for cathode stage II (22) by plotting E_T^{II} = A × R_M³



The model breaks for anode because it is not initiated by thermal processes

We need a new energy model for anode regime!

References

- Rond et al., « Time-resolved diagnostics of a pin-to-pin pulsed discharge in water: pre-breakdown and breakdown analysis », J. Phys. D: Appl. Phys. 51 335201 (2018)
- J. Qian et al., « Microbubble-based model analysis of liquid breakdown initiation by a submicrosecond pulse », Journal of Applied Physics, vol. 97, n° 11, p. 113304, juin 2005
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