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SIMULATING OUTPUT CURRENTS IN GAS-FILLED CYLINDRICAL PHOTOEMISSION DRIVEN CAVITIES

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Abstract:

This work presents a computational simulation of irradiated gold in a cylindrical photoemission gas-filled cavity [1]. The computation process happens in two steps. First, the electron emission material is irradiated with an input X-ray photon spectrum to produce a photoelectron emission spectrum. The photoelectron spectrum, together with the X-ray time pulse and yield, is then used to characterize the electron emission into the gas-filled cylindrical cavity that is modeled via an electromagnetic (EM) particle-in-cell (PIC) code. The full geometry simulation results are compared to simulations that model the stem and B-Dot as an axial transmission line. This simplified model reduces computation time while reproducing the physics.

Keywords: *Radiation Transport, Photoelectric Emission, Space-Charge-Limited (**SCL**) Emission, Transmission Lines, Anode/cathode Gaps (**A/K**)*

Introduction and Background:

- Pulsed-Power simulations using experimental data from the Z-Machine
- Metal irradiation in an A/K Gap
- Coupled Monte Carlo (MC) and Electro-Magnetic (EM) Particle-In-Cell (PIC) codes
  - MC code generates a photoelectron spectrum used by the EM PIC code to calculate currents and voltages in the cavity
- Presence of a gas leads to plasma formation
- Surface 1 (where X-rays enter): Anode, carbon-coated aluminum
- Surface 2 (bottom emission surface): Cathode, gold
- **B-Dot** Diagnostic: $\mu_0 I = \int \vec{B} \cdot d\vec{l}$ (Ampere's Law), or Bdl Current [1]
  - Current induces a time-varying magnetic field [2]

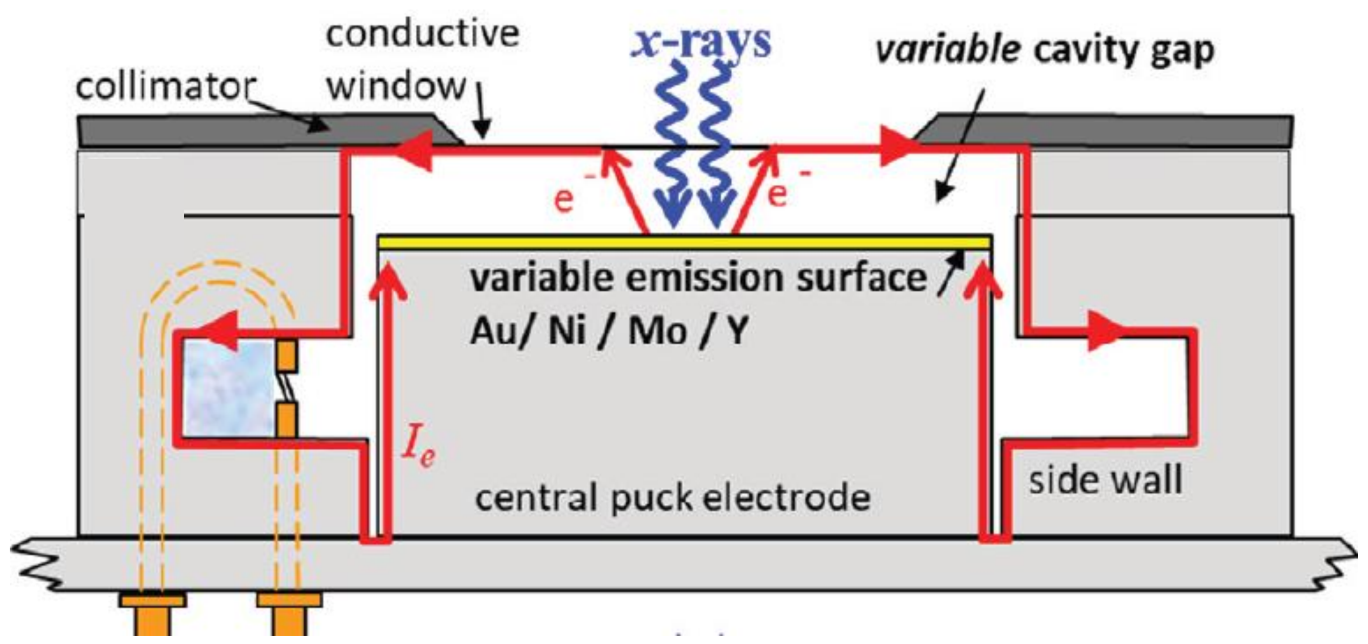

Figure 1: B-Dot sensor schematic. The pulse creates a current, which induces a magnetic field in the sensor circuit, producing a voltage [3]

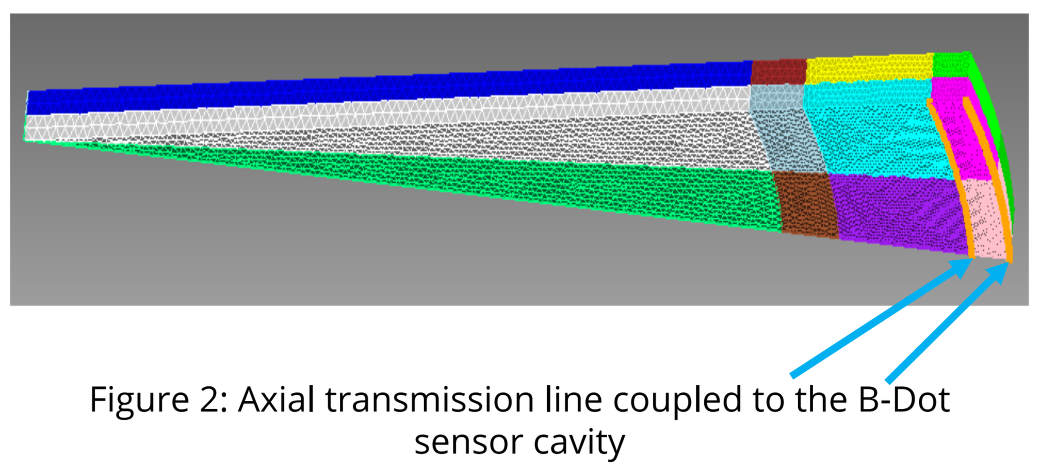

Figure 2: Axial transmission line coupled to the B-Dot sensor cavity

Transmission Line Modeling

- 1 mm gas-filled cavity with a stainless-steel wire array input X-ray spectrum
- The B-Dot diagnostic and the stem of the cavity can be modeled as a transmission line, with Inductance (*L*) and Capacitance (*C*) per unit length
- An axial transmission line replaces the stem and the B-Dot sensor
- *L* and *C* per unit length are calculated using coaxial cable formulae, but *L* is halved as the EM pulse is double counted
- The purpose of modeling the transmission line is to reduce computational resources without sacrificing physics

$$C = \frac{2\pi\varepsilon_0\varepsilon_r}{\ln\left(\frac{b}{a}\right)}\ [F] \qquad L = \frac{\mu_0\mu_r}{2\pi}\ln\left(\frac{b}{a}\right)\ [H]$$

Equations for Capacitance and Inductance for a coaxial cable [4]

- ε_0 is permittivity of free space
- ε_r is relative permittivity
- μ_0 is permeability of free space
- μ_r is relative permeability
- *b* is outer radius, and *a* is inner radius

Methods:

- Filtered 1 keV – 20 keV stainless-steel wire array X-ray input spectrum
- X-ray Source is 500 mm from Gold cathode (Surface 2)
- 3 ns FWHM stainless-steel wire array X-ray pulse
- MC code output is a normalized photoelectron emission spectrum
- The cathode is the dominant electron emission surface
- EM PIC code uses these spectra to compute Bdl current vs time
- **Neon** gas pressure in the cavity is varied at 100 mTorr increments between vacuum and 500 mTorr
- SCL emission is toggled "off" and "on"
- SCL on drives the maximum current through the circuit after the X-ray pulse

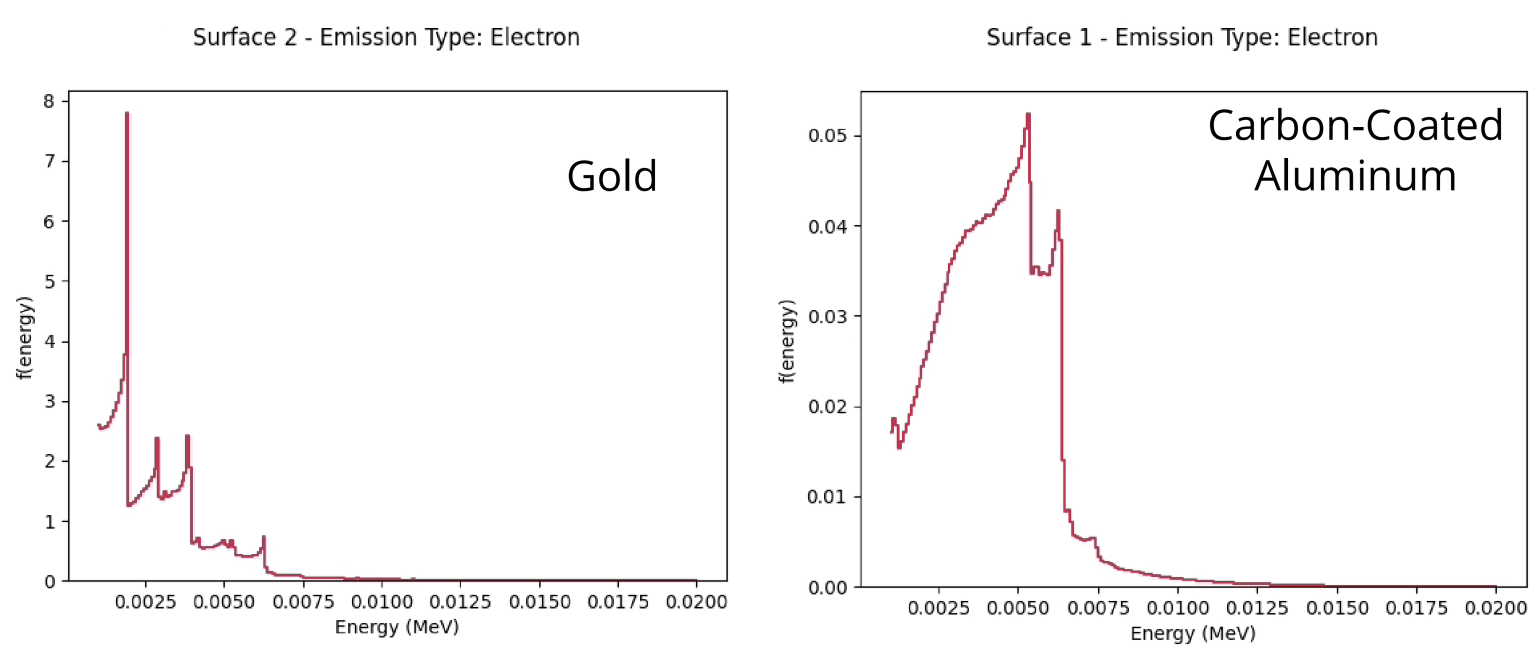

Figure 3: Normalized photoelectron emission distribution for a stainless-steel wire array photon radiation spectrum on the Au (left) and carbon-coated Al (right)

Results:

- 1 mm cavity gap, where the Transmission Line (**TL**) solutions are compared to the full geometry simulation (**3D**) [5]
- *L* and *C* are calculated using coaxial cable equations, but analytically matched *LC* values produce better results
- Vacuum case ran to match rise time and fall time

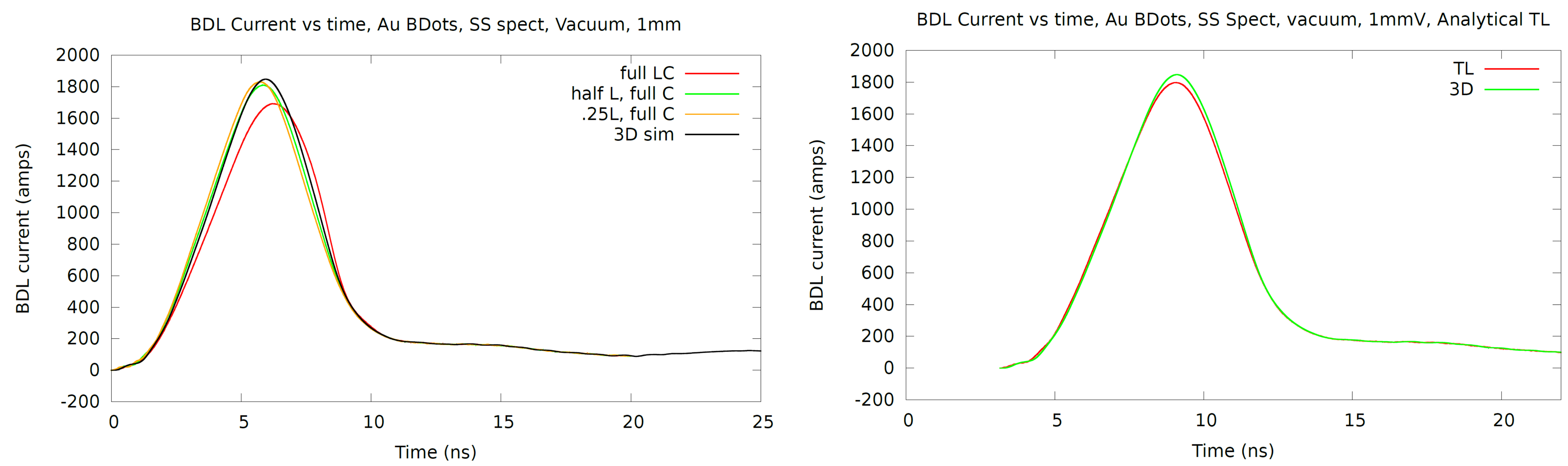

Figure 4: Bdl Current vs time comparing TL and 3D simulations at vacuum pressure. The TL intrinsic LC values are calculated and then analytically matched to the 3D output

- Ne fill gas added between vacuum and 500 mTorr
- SCL "on" simulations have current outputs long after the initial X-ray pulse
- The true tail of the experiment should be between SCL "off" and "on"
- We are able to run longer finer mesh solutions, and reproduce similar physics

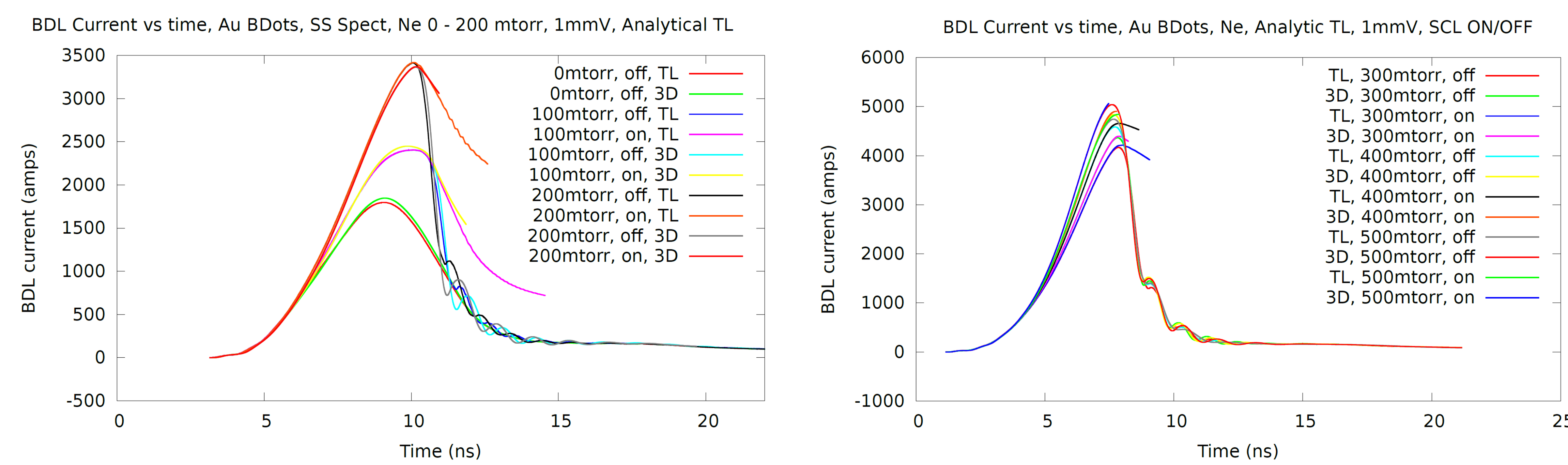

Figure 5: Bdl Current vs time for Ne fill gas between 0 and 500 mTorr for a 1mm Au B-Dot system, with SCL emission toggled on/off. TL are outputs for the return circuit modeled as a Transmission Line, and 3D are outputs for the full simulation

Conclusion:

- Bdl current output and SCL emission was modeled for cylindrical end irradiated photoemission driven cavity with a gold cathode at Neon gas pressures ranging from vacuum to 500 mTorr
- Modeling the B-Dot and the stem as a transmission line produces similar current outputs to the full simulations
- As pressure increases, the current outputs from the analytically matched LC values match in both transmission line and 3D simulations
- Future work is to model the B-Dot as a transmission line for highly space-charge limited cavities

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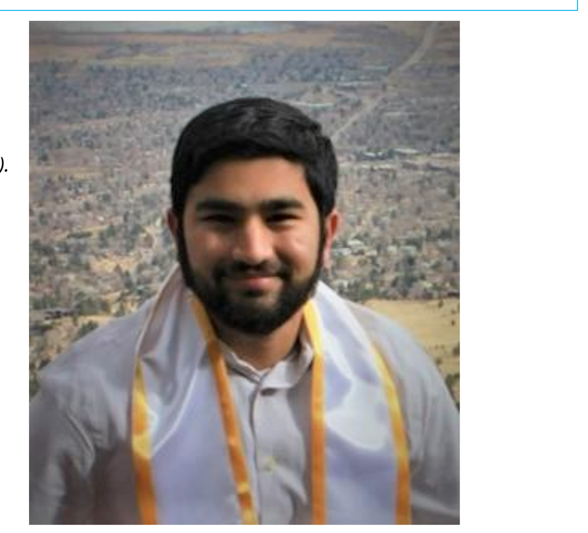
Acknowledgements: A special thank you to Scot Swan, Elaine Rhoades, and Dolores Black for helping with simulations and edits.



SAND2023-03751D

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