Comparing two-mode pulsating aurora with GEMINI model output

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Abstract

The ionospheric structure of pulsating aurora bears further investigation, in particular to understand the drivers of pulsating aurora and the impact those drivers have on the electrodynamics of pulsating aurora. This study aims to use the Geospace Environment Model of Ion-Neutral Interactions (or GEMINI) model to investigate pulsating auroral electrodynamics. We compare our simulations with a simplified analytic model from Oguti and Hayashi (1984), as a first step. The GEMINI program was utilized to simulate a simple pulsating aurora structure, modulating the characteristic energy of precipitating electrons and the period of pulsation across a range of hypothetical values. In addition to this, some simulations with modulating field-aligned boundary currents were input to compare with results from the SWARM satellite. This wide array of simulations has revealed the impact of the characteristic energy of precipitating electrons, as well as the period of oscillation, on the peak electron density and the height thereof. These electron density changes drive changes in the Hall and Pedersen conductivities which impacts the overall electrodynamic circuit.

Methodology

- Using Maxwell's equations, the analytical model proposed by Oguti and Hayashi (1984) produces a two-mode current structure that perturbs the background current: a divergence-free twin vortex current combined with a field-aligned pair current flowing opposite the background current system (figure 1)
- This investigation focused on reproducing the current structure, then modulating the characteristic energy of precipitating electrons from between 2 to 16 keV and modulating the period of pulsation from between 4 to 12 seconds, and quantifying the impact these changes had on peak electron density and peak height

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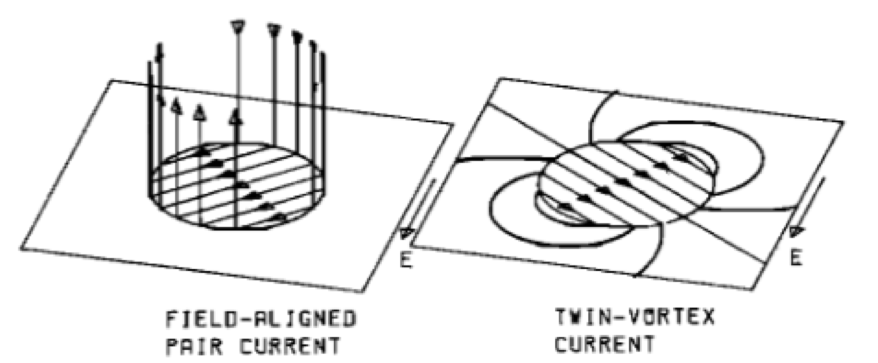

Reproducing Analytical Model

- The potential in the 1984 paper is modeled using the following radial distribution:

$$\Phi^o = (rE + C/r)\cos(\theta) + (D/r)\sin(\theta)$$
$$\Phi^i = (E + C)r\cos(\theta) + Dr\sin(\theta)$$

- With the appropriate boundary conditions based on the field-aligned discharge rate, the current density can be calculated over the domain of interest (Oguti and Hayashi figure 2, my work figure 3)

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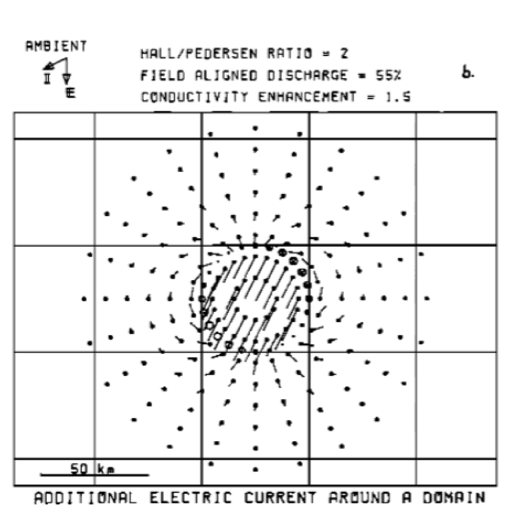

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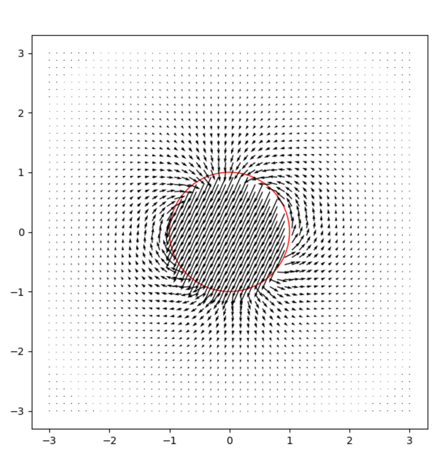

Comparison with Oguti and Hayashi (1984)

- The 1984 model predicts a southwest-directed current flow as a result of the southward electric field, with a Hall-to-Pedersen conductivity ratio of 2 to 1. The current flow is enhanced within the domain because of the stronger particle precipitation (figure 5)
- The boundary of the domain produces the field-aligned current flow - upward on the southwest border, and downward on the northeast border (figure 7)
- GEMINI reproduces the same pair current structure - southwest current flow enhanced within the domain, with field-aligned currents on the northeast and southwest boundaries of the domain (figures 4 and 6)
- The field-aligned pair current is clearly visible in GEMINI's output (middle left), whereas the twin vortex is not immediately visible (figure 8)
- The angle of the current flow varies with altitude: at low altitudes, the Hall term dominates and the flow is majority westward; at high altitudes, the collision frequency decreases and the current flow points southward with the electric field

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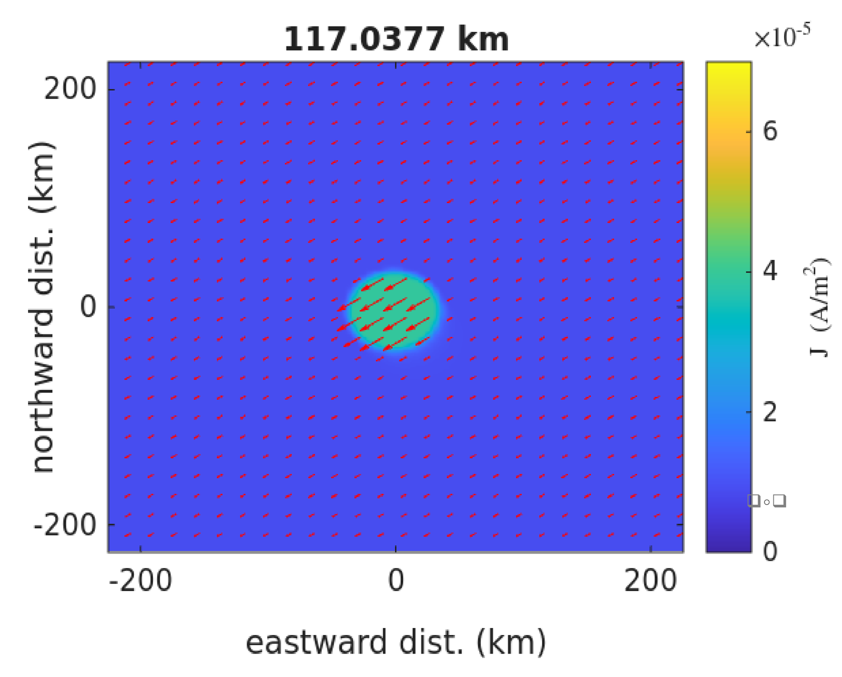

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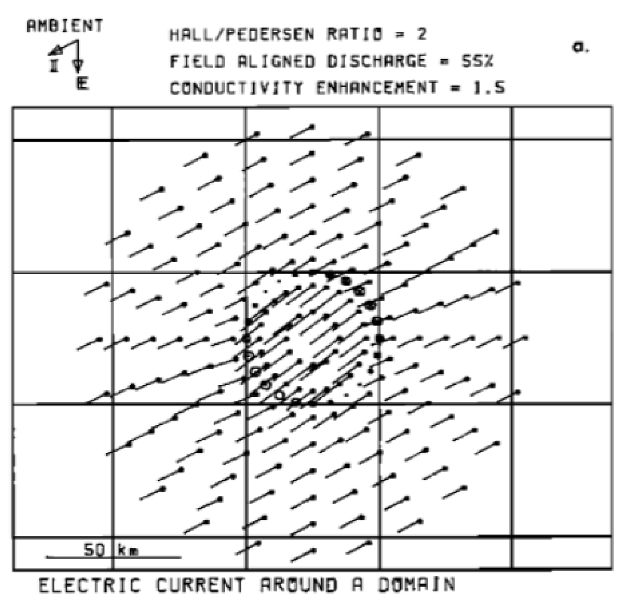

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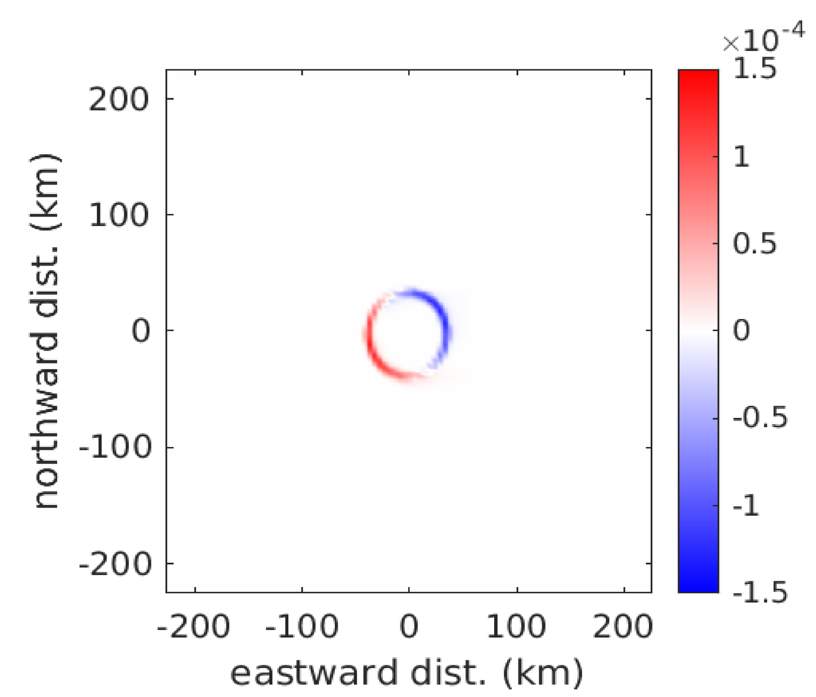

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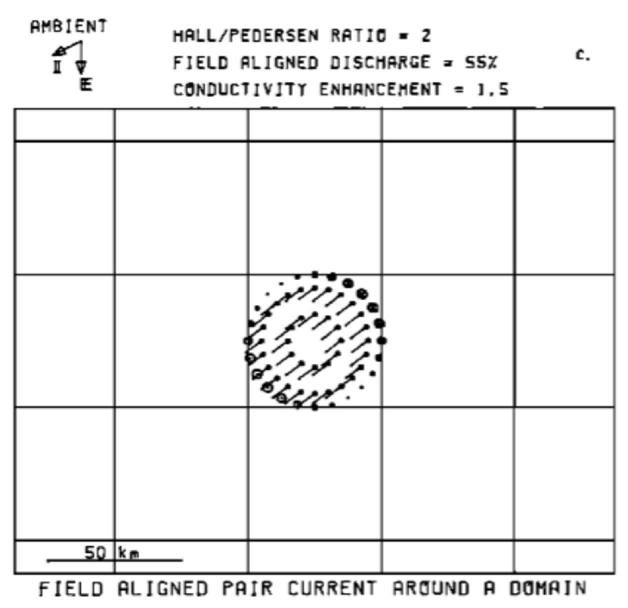

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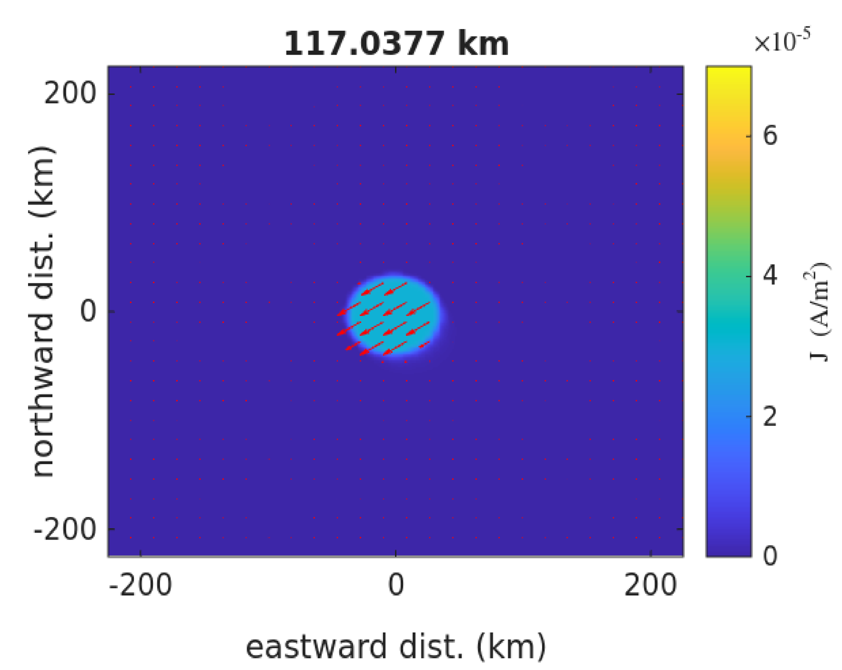

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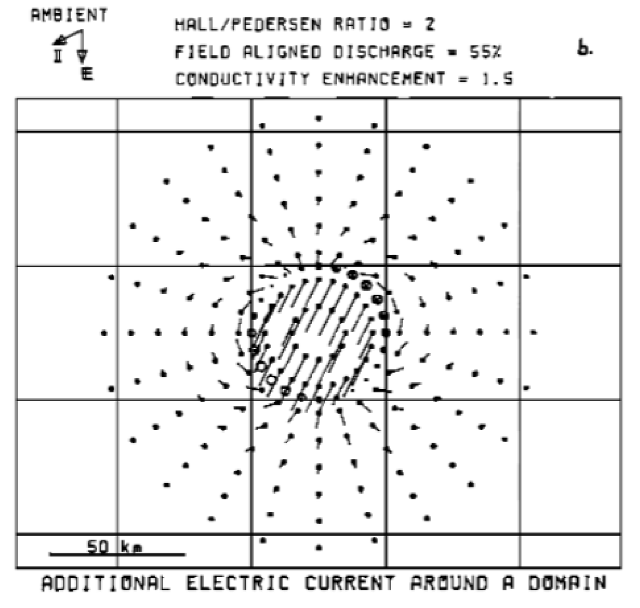

Characteristic energy and period dependence

- The input precipitation varies sinusoidally over the specified period, from background levels to the characteristic energy per unit area as a boundary condition
- Increasing the characteristic energy lowered the altitude of the peak electron density to altitudes in the 90-100 km range (figure 10)
- Increasing the period of pulsation produced a widening of the peak electron density between the peak and troughs of pulsation (figure 11)
- The range of values (figure 12) aligns with observations from EISCAT data reported by Hosokawa and Ogawa (2015) (figures 13 and 14)

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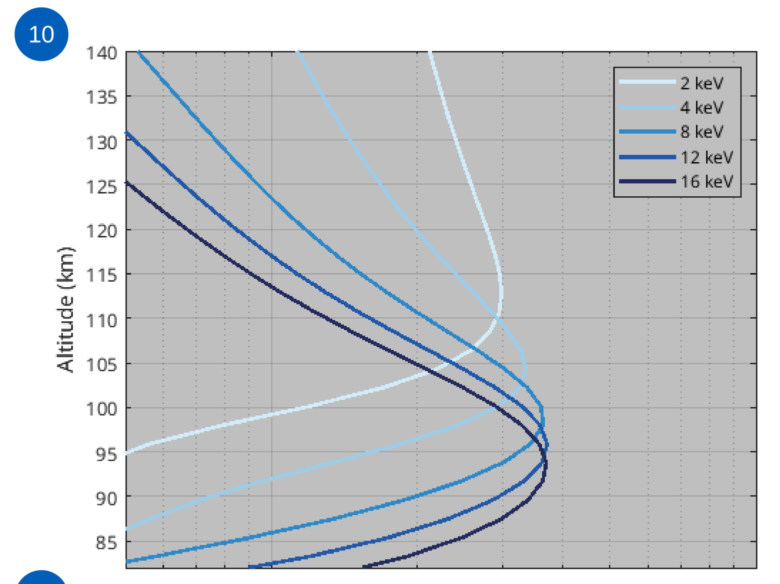

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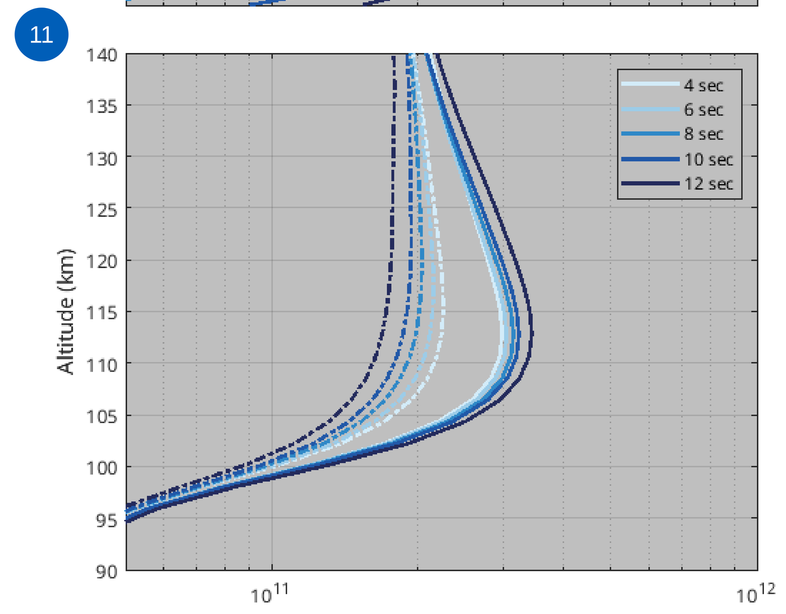

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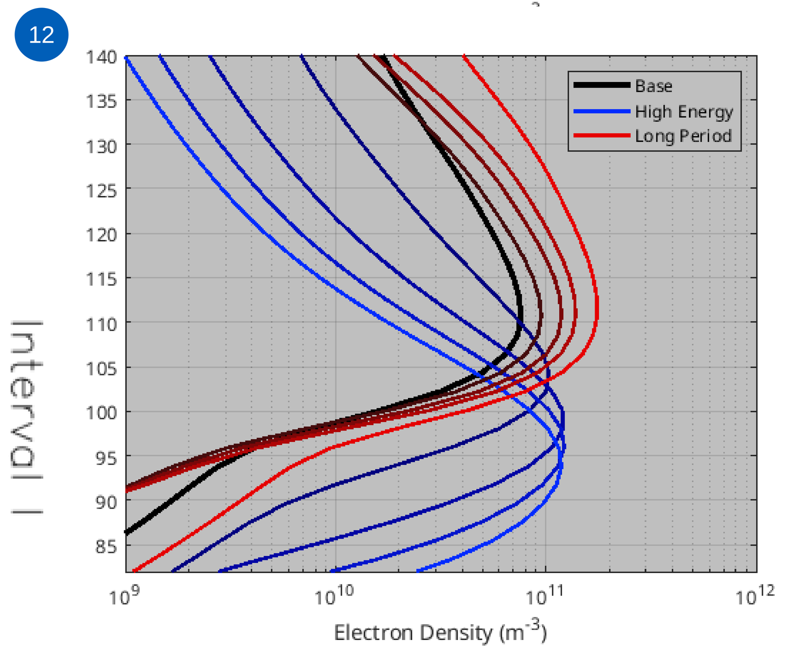

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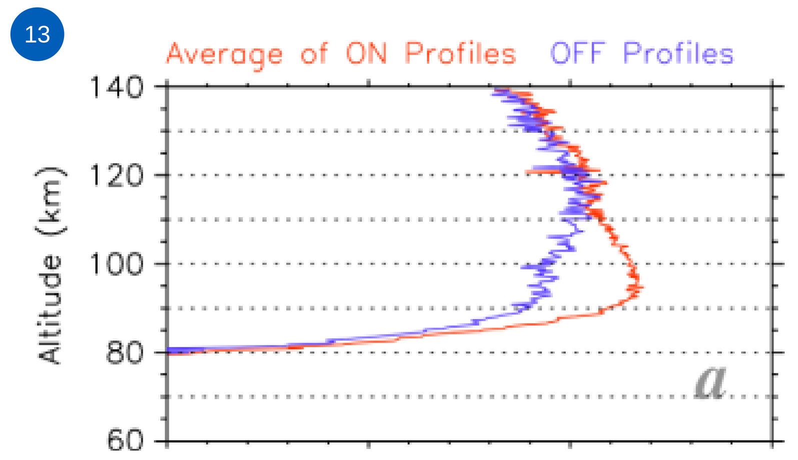

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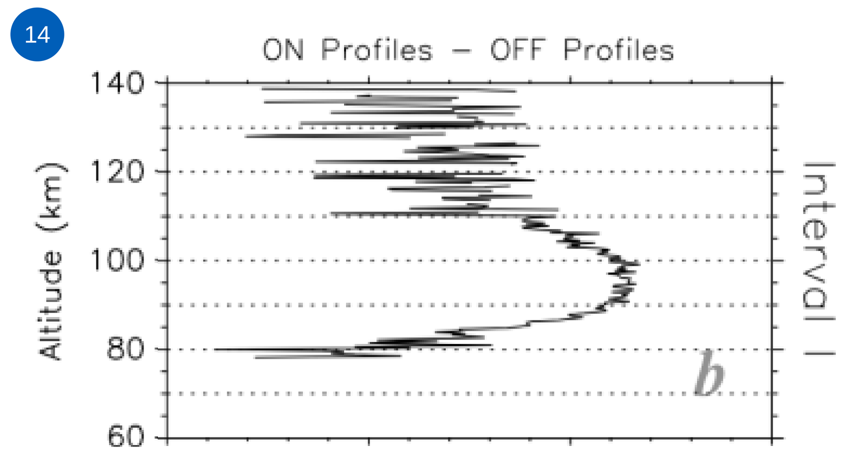

Results and future work

- The simulations produced by GEMINI are in partial agreement with the model proposed by Oguti and Hayashi (1984), producing half of the expected two-mode current structures
- The height and strength of the electron density peak is dependent on the period and energy of the pulsations, with stronger peaks directly correlated with increased period and peak height inversely correlated with characteristic electron energy
- The twin vortex current does not appear in the GEMINI simulation, possibly due to a higher conductivity enhancement in the GEMINI parameters
- Future goals include constraining the field-aligned discharge rate in GEMINI to check for twin-vortex currents, quantifying the changes in electron/ion temperature and drift velocity across various altitudes based on changing particle precipitation characteristics, and isolating the impact of the variation of conductivity by altitude on the current system

References:
- Hosokawa, K. and Y. Ogawa (2015), Ionospheric variation during pulsating aurora, *J. Geophysics Res. Space Physics*, 120, 5943-5957, doi:10.1002/2015JA021401
- Oguti, T. and K. Hayashi (1984), Multiple Correlation Between Auroral and Magnetic Pulsations 2. Determination of Electric Currents and Electric Fields Around a Pulsating Auroral Patch, *J. Geophysics Res.*, 89, 7467-7481,

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