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Xenon plus Additives in the Energetiq EQ-10
Initial Results

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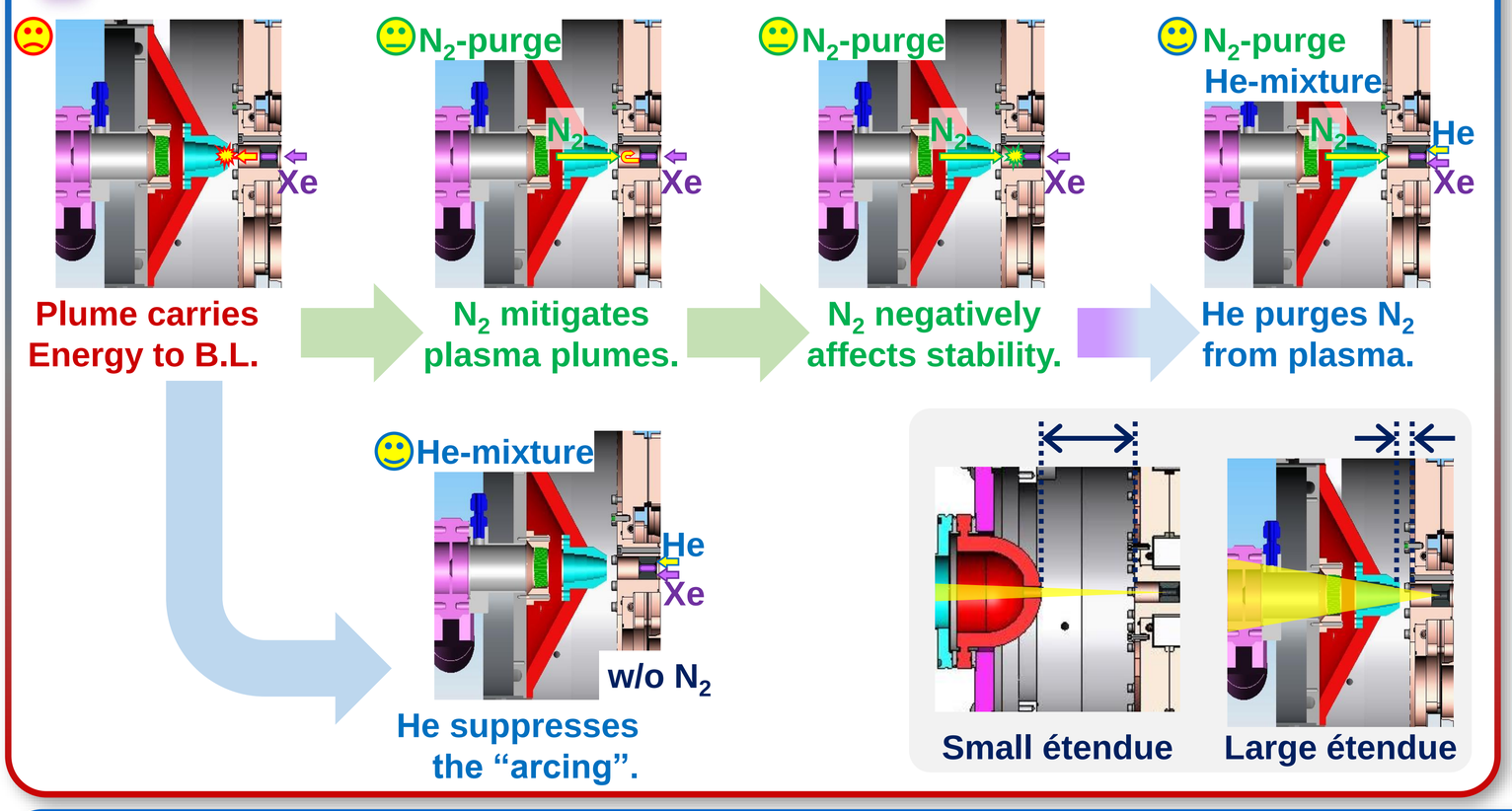
Abstract

When the EQ-10*[1] is used in an application requiring a relatively large source étendue, the nature of the electrode-less discharge causes a plasma plume to exit the source. This plume can carry substantial energy. To dissipate this energy, we rely on nitrogen injection in the beamline. Since nitrogen is molecular (hence radiates efficiently in the IR) and is also electronegative, it removes both energy and electrons from this plume and efficiently shields downstream structures. However nitrogen diffusing upstream into the source discharge can cause the source plasma to become less stable, due to these same characteristics.

The high ionization energy of helium, and the low mass of the helium ion (both compared to xenon) imply that when mixed with the source xenon it should not participate (to zero order) in the z-pinch electrodynamics. Therefore by injecting helium into the source, the total flow rate might be increased (compared to pure xenon operation) to assist in flushing nitrogen from the source – thus improving source stability.

We will present preliminary data that supports these ideas.

Summary -- He improves the source stability --



Motivations -- Why N_2? , Why He? --

Nitrogen (N_2)

Electronegative (N : 3.04 / Xe : 2.60)
… has tendency to attract electrons to itself.

Molecular
… can absorb plasma energy and radiate it as visible-IR.

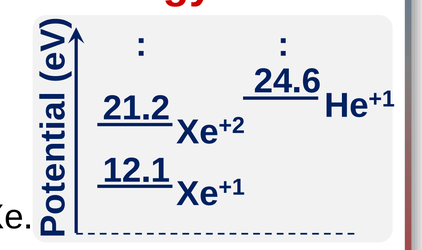
→ **N_2 can remove electrons and energy from plasma plume.**

Helium (He)

Smaller Mass (m_{He}/m_{Xe} = 0.03)
… doesn’t affect pinching physics of Xe.

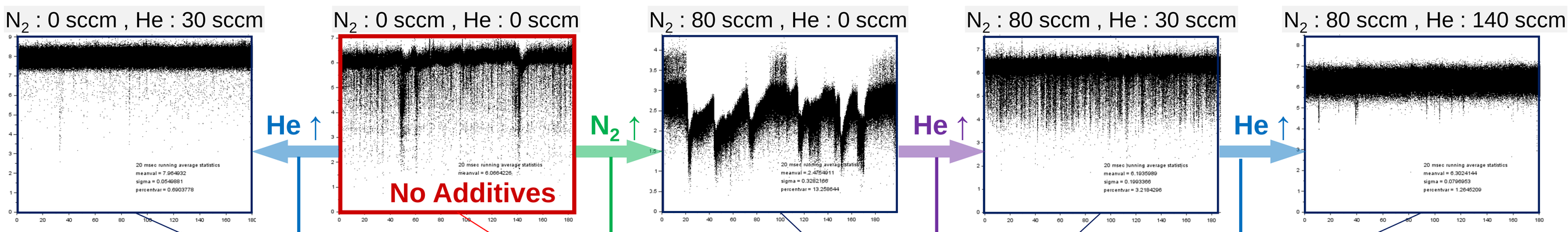
Higher Ionization Potential
(He : 24.6[1st] / Xe : 12.1[1st] , 21.2[2nd])
… remains as neutral in the bulk plasma (before pinch).

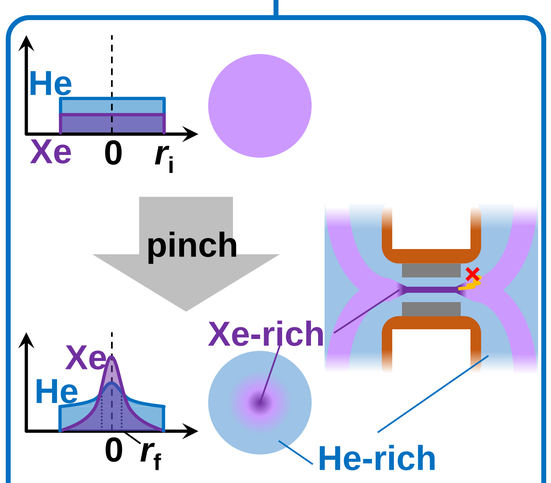
→ **Flow rate can be increased without negative effect to the pinch.**



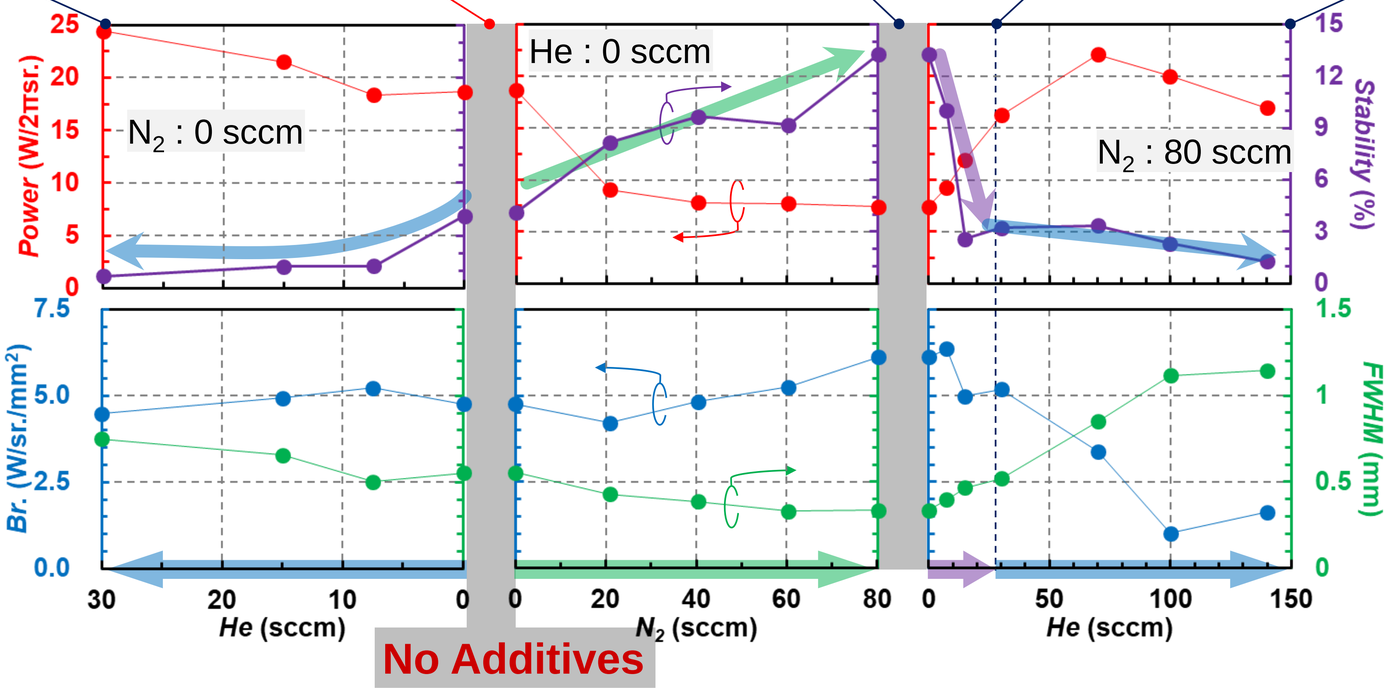
Results & Discussions -- How Do Other Gases Affect the Stability? And Why? --

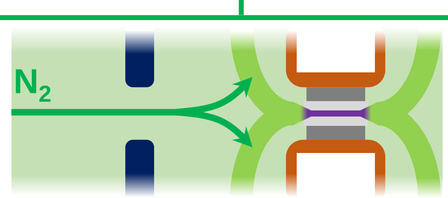
Operating Condition
300 V, 2.5 kHz, Xe: 35 sccm, 70 mT



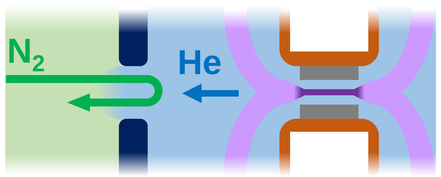


He remains around the pinch.
It suppresses “arcing” between the pinch and plate.





N_2 “mitigates” plasma plume, and also source plasma. Plasma become more resistive, then **“dropout” is caused**.



He purges N_2 from pinch and suppress “dropout”.

- 2-types of instability …
  1) random drop due to “**arcing**”
  2) relatively slow drop due to “**dropout**”

  … can be improved with He-purge.

- “**Arcing**” is caused by high-power operation even without additives.
  … He gas remains around the Xe-pinch, and prevent “arcing”.
- “**Dropout**” is mainly caused by N_2-flow.
  … He purges the N_2 from the plasma, and prevent “dropout”.

*[1] Horne, Stephen F., Matthew M. Besen, Paul Blackborow, Ron Collins, Deborah S. Gustafson, Matthew J. Partlow, and Donald K. Smith. “The EQ-10 Electrodeless Z-Pinch™ Metrology Source” (2018): 193-206. in Vivek Bakshi , “EUV Lithography, Second Edition”

*[2] Muehe, C. E. (1965). “AC breakdown in gases” (No. TR-380). MASSACHUSETTS INST OF TECH LEXINGTON LINCOLN LAB.