The effect of gas mixing on the afterglow transient of beams extracted from an electron cyclotron resonance ion source

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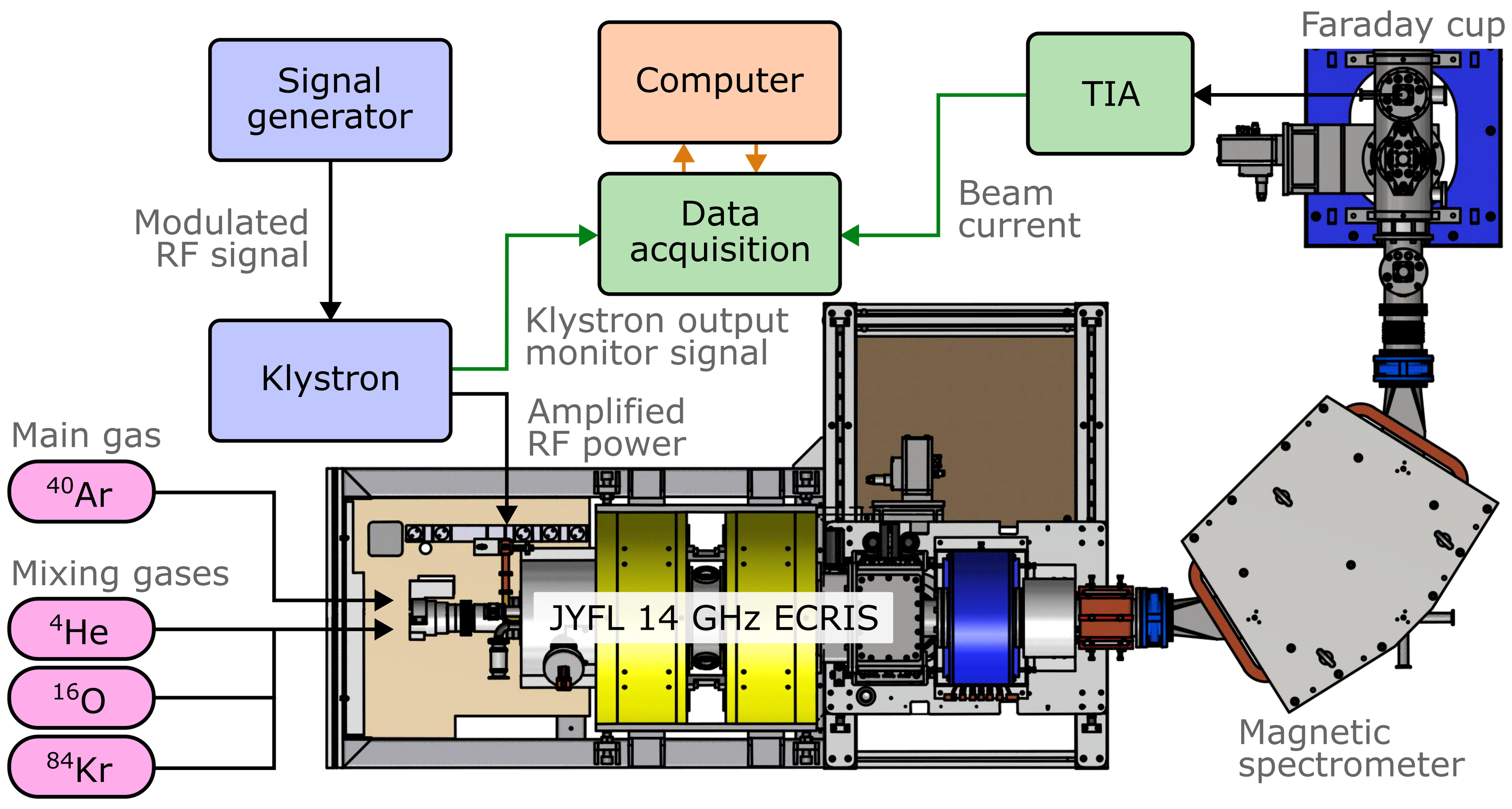
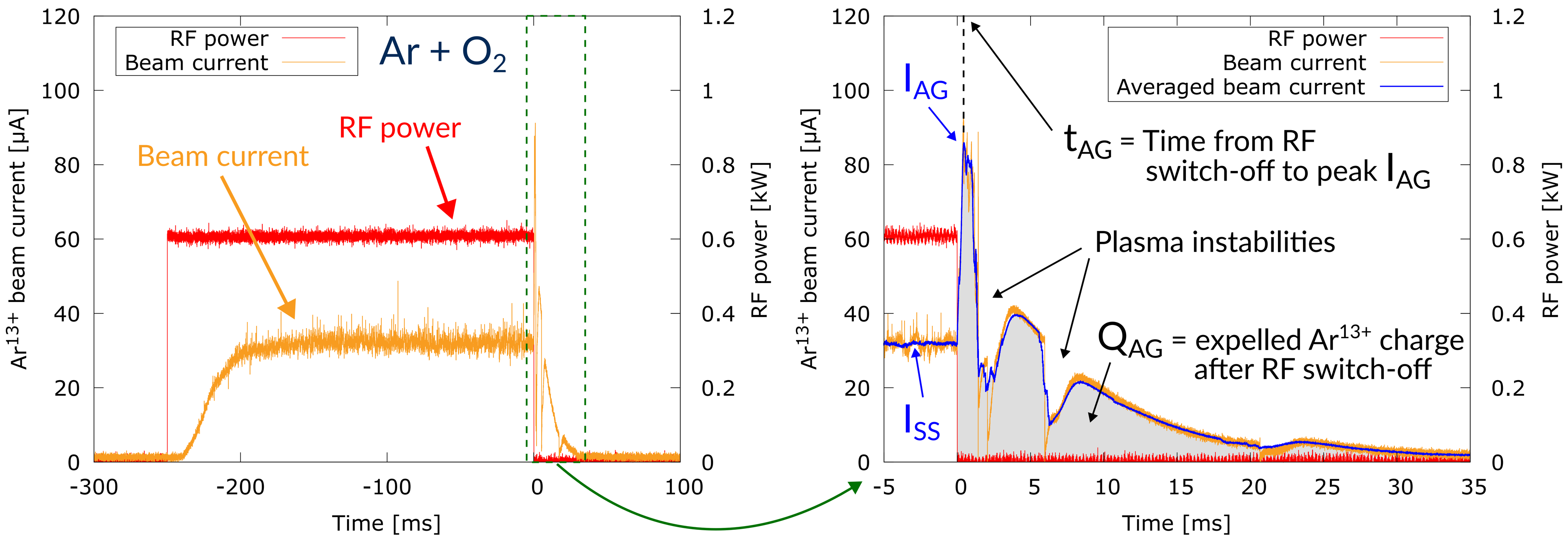
INTRODUCTION

- Gas mixing and afterglow (AG) operation are prominent methods with ECR ion sources to optimize extracted beam currents of highly charged ions.
- Gas mixing: a light gas species is introduced to plasma to boost the performance of a heavier main element. Effect is attributed to "cooling" of heavier element ions through collisions, leading to longer ion confinement times and consequently improved high charge state production.
- Afterglow: pulsing of plasma heating RF power leads to an intense short burst of high charge state ions following the RF switch-off. Effect is attributed to change of ion confinement scheme from ambipolar potential dip confinement to diffusive losses.
- Both methods are connected to ion confinement. This work probes this connection by studying the effects of gas mixing on the properties of high charge state ion beams (magnitudes and temporal structure) extracted from an ECRIS operated in afterglow mode.

EXPERIMENTAL SETUP AND PROCEDURE



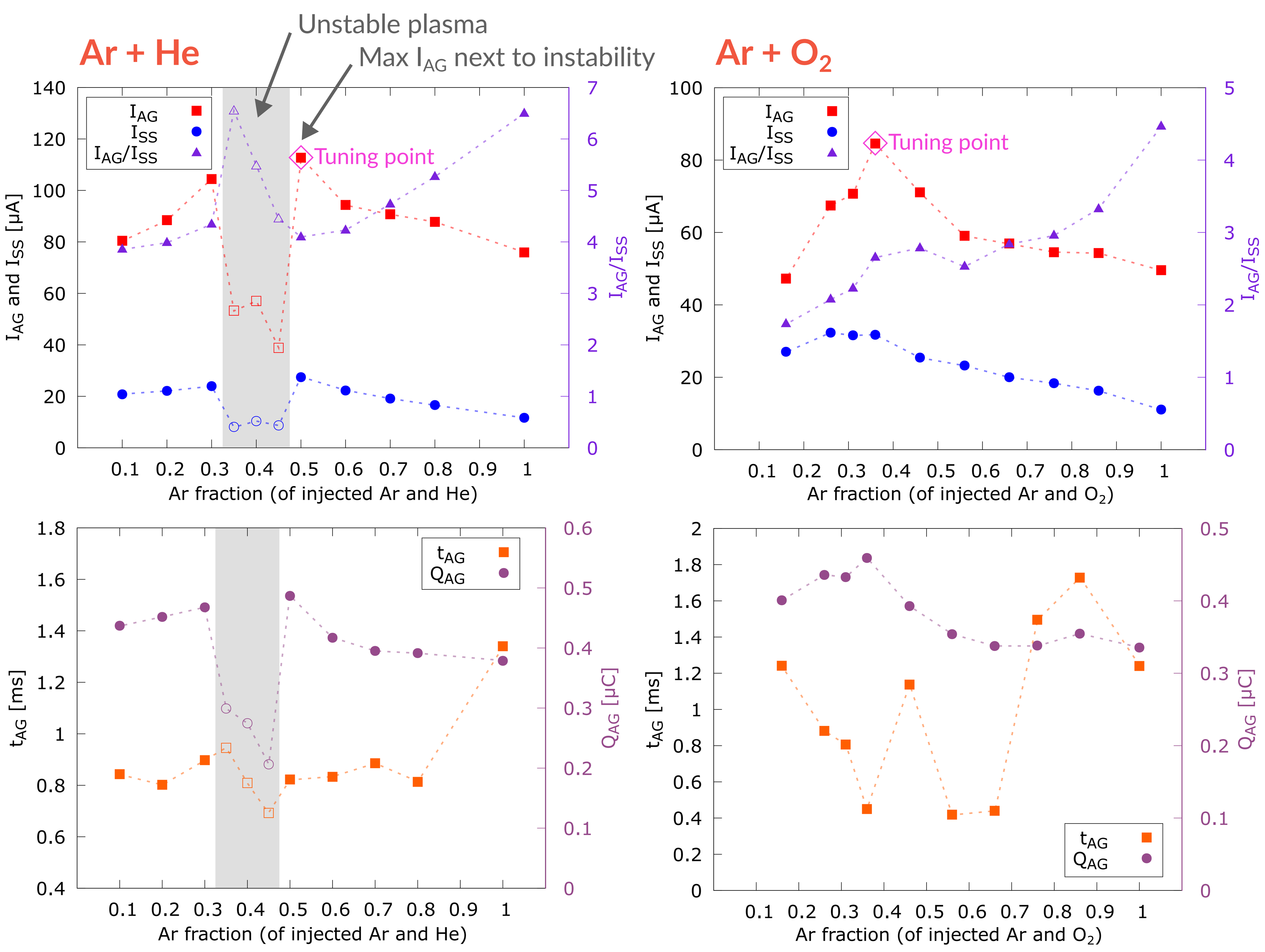


- Ion source optimized for Ar^{13+}, which was used to probe high charge state ion behaviour.
- ^{40}Ar used as main gas, ^{4}He, ^{16}O and ^{84}Kr used as mixing gases.
- RF power pulsed at 2 Hz with 50% duty factor (250 ms ON/OFF).
- To account for pulse-to-pulse variations, up to 20 pulses were measured and averaged to determine beam current behaviour.
- Studies: (1) Effect of gas mixing on afterglow, (2) Effect of tuning; optimized CW beam current vs optimized AG peak current.
- Procedure:
  - (A) Baseline measurement with pure Ar
    - (i) Optimize Ar^{13+} in CW mode, set RF to pulsing → Measure AG properties
    - (ii) Optimize I_{AG} in pulsed mode → Measure AG properties
  - (B) Gas mixing measurements, repeated with Ar+He, Ar+O_2, Ar+Kr
    - (i)-(ii) As above
    - (iii) Vary gas mixing ratio → Measure AG properties

EXPERIMENTAL RESULTS AND DISCUSSION

1 Gas mixing with varied mixing ratio

Ar fraction of injected gases varied while maintaining constant total pressure



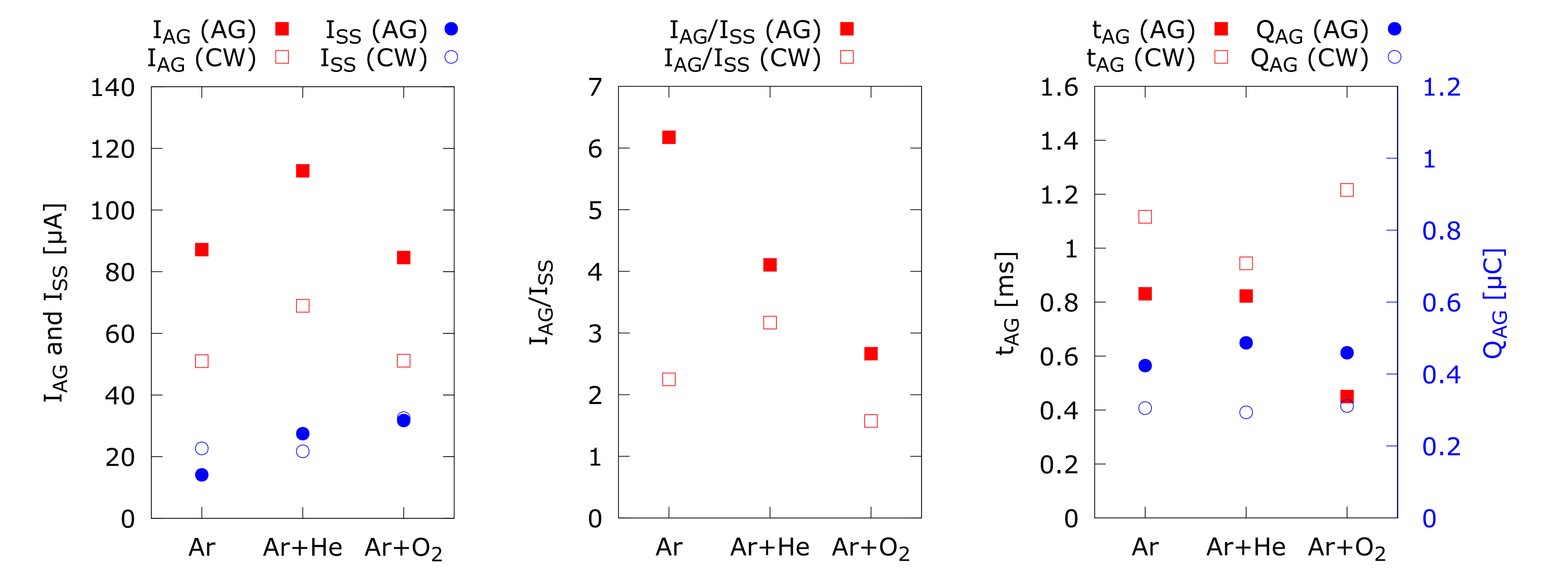
Ar + Kr (inverse gas mixing)

Adding any Kr only degrades performance, resulting to steady decrease of I_{AG}, I_{SS}, I_{AG}/I_{SS} and Q_{AG}, and increase in t_{AG}.

2 CW tune versus AG tune

CW = Tuned for maximum Ar^{13+} current in CW mode
AG = Tuned for maximum Ar^{13+} afterglow current in pulsed mode

Main difference: AG tune has higher *B* fields and lower gas feed



Ar+Kr data omitted, because adding Kr only degrades performance, resulting to same tuning as pure Ar

Conclusions and discussion

Observations:

- Afterglow performance (i.e. I_{AG}, Q_{AG}) can be improved with gas mixing
- Highest I_{AG} with gas mixing, but highest I_{AG}/I_{SS} with pure Ar
- Max I_{AG} coincides with high Q_{AG} and low t_{AG}, i.e. potential dip disappears faster and the dip confined population is larger when optimized for AG

Question: are effects due to changing ion density/production or confinement?

- Extracted current behaviour can be described with the following eqs.:

$$I_i^q \propto \frac{n_i^q}{\tau} \quad \text{and} \quad \frac{I_{AG}}{I_{SS}} = \frac{n_i^q/\tau(\Delta\phi \to 0)}{n_i^q/\tau(\Delta\phi)} = \frac{e^{\frac{q\Delta\phi}{T_i}}}{e^{\frac{q(\Delta\phi\to 0)}{T_i}}} = e^{\frac{q\Delta\phi}{T_i}}$$

- Future: measurement of light emitted by high charge state ions in plasma (intensity, emission line broadening) provides information about n_i and T_i
- When combined with the presented measurements, one can resolve the behaviour of τ and $\Delta\phi$ and determine whether the observed effects are caused by changing ion density/production or ion confinement in plasma

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