Gas Jet Disruption Mitigation Studies on Alcator C-Mod and DIII-D

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Disruption issues and mitigation with high-pressure noble gas jet

Alcator C-Mod

High-pressure noble gas jets can mitigate 3 problems arising from disruptions, without contaminating subsequent discharges.

1) Divertor thermal loading: sudden heat load ablates/melts divertor material
Solution: Deliver large quantities of impurity into core plasma to dissipate high fraction of plasma energy by relatively benign, isotropic radiation

2) Halo currents: large mechanical J×B forces on vessel/first wall components
Solution: Rapid quench, resulting in a plasma that remains centered in vessel during current quench, substantially reducing vessel halo currents

3) Runaway electrons: Relativistic MeV electrons from avalanche amplification during current quench in large-scale tokamaks
Solution: Suppression by large density of electrons in plasma volume.

These issues are particularly important for ITER

Comparison of relevant plasma parameters

	DIII-D	C-Mod	ITER
I (MA)	0.3–1.5	0.5–2.0	15
R (m)	1.70	0.68	6.2
B (T)	0.5–2.1	3.0–8.1	5.3
V (m^3)	20	0.9	830
W_{th} (MJ)	0.05–1.5	0.11–0.25	350
$W_{pol\ mag}$ (MJ)	3.8	0.65–2.6	1460
W_{tot}/V (MJ/m^3)	0.27	0.84–3.2	2.17
P (atm)	0.02–0.5	0.8–1.8	1.75
t_{CQ} (ms)	3.3	1	36
Wall	carbon	molybdenum	Be, W, C

Specific goals of these DIII-D and C-Mod gas jet experiments

- Determine penetration of gas jet/impurities at different plasma pressures, energy densities, and B-field
- Compare gas jet disruptions with NIMROD modeling
- Study disruption mitigation on C-Mod plasmas
- Determine if runaway electron avalanching is an issue
- Determine effectiveness of gas jet mixtures

Lack of deep gas penetration unrelated to plasma pressure

Alcator C-Mod

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

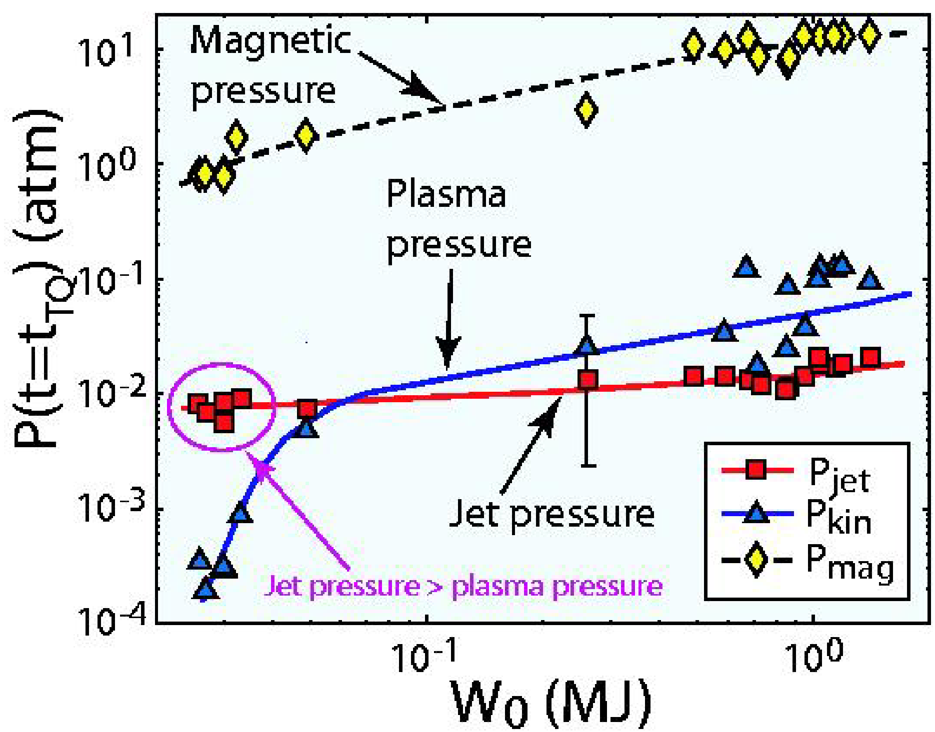
C-Mod always has
plasma pressure > jet

Gas jet does **not** penetrate beyond plasma edge

DIII-D can run with
plasma pressure > jet, or
plasma pressure < jet

In **either** case, the gas jet does **not** penetrate beyond the plasma edge.

DIII-D



Magnetic pressure ($B^2/2\mu_0$) may be the operative effect

– P. Parks and E. Hollmann, submitted to Phys. Plasmas

Sequence of observed events is the same on both DIII-D and C-Mod

Edge T_e collapse

↓

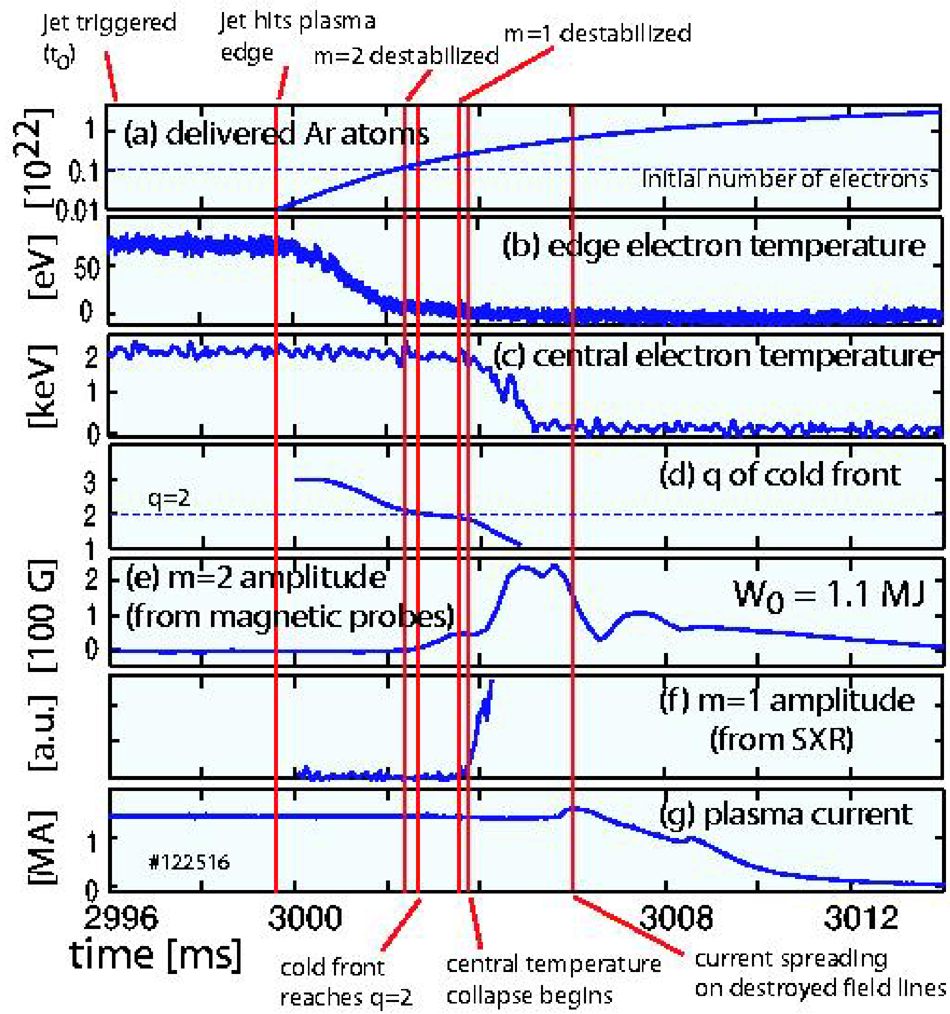
2/1 mode grows

↓

1/1 mode grows

↓

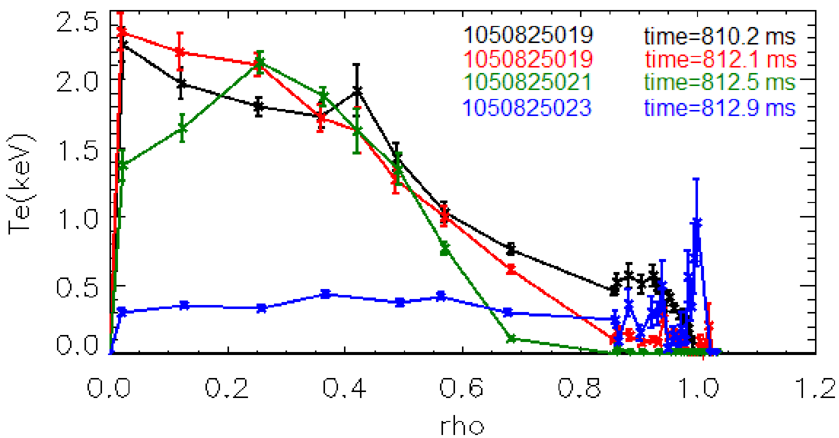
Core T_e collapse



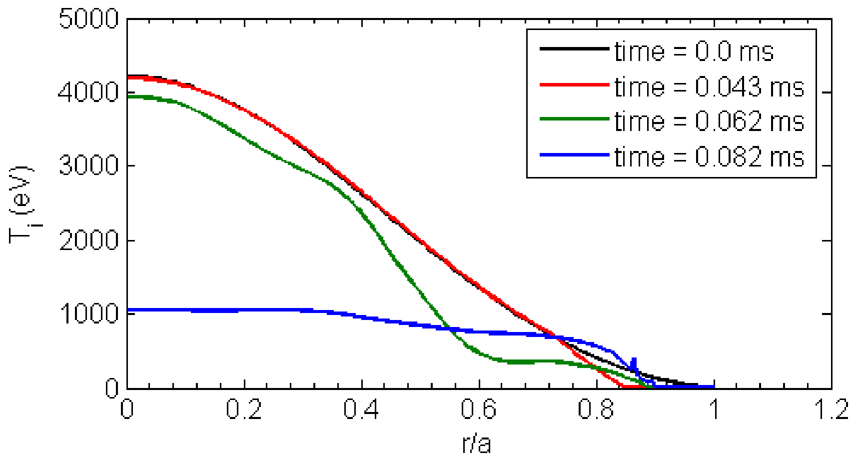
Note: C-Mod and DIII-D have very similar *q*-profiles and shapes for these gas jet experiments

NIMROD modeling of gas jet experiments

Edge T_e collapse in C-Mod



NIMROD T_i profiles



(NIMROD timebase is 20× shorter due to low *S* value used)

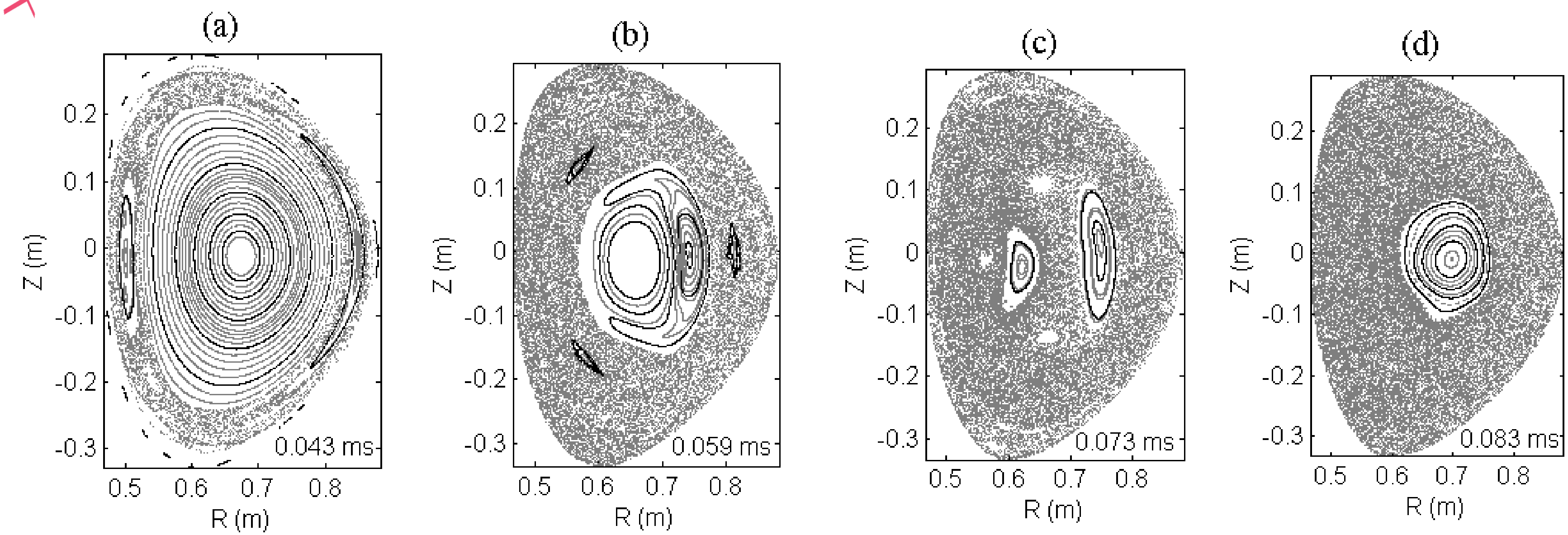
NIMROD modeling uses C-Mod equilibrium from a gas jet shot

- Measured edge T_e collapse (red profile) is imposed

Code then calculates growth of MHD instabilities, formation of ergodic regions, and thermal transport self-consistently

Results qualitatively explain sequence of events seen in ***both*** C-Mod and DIII-D

NIMROD modeling reproduces observed sequence of MHD events

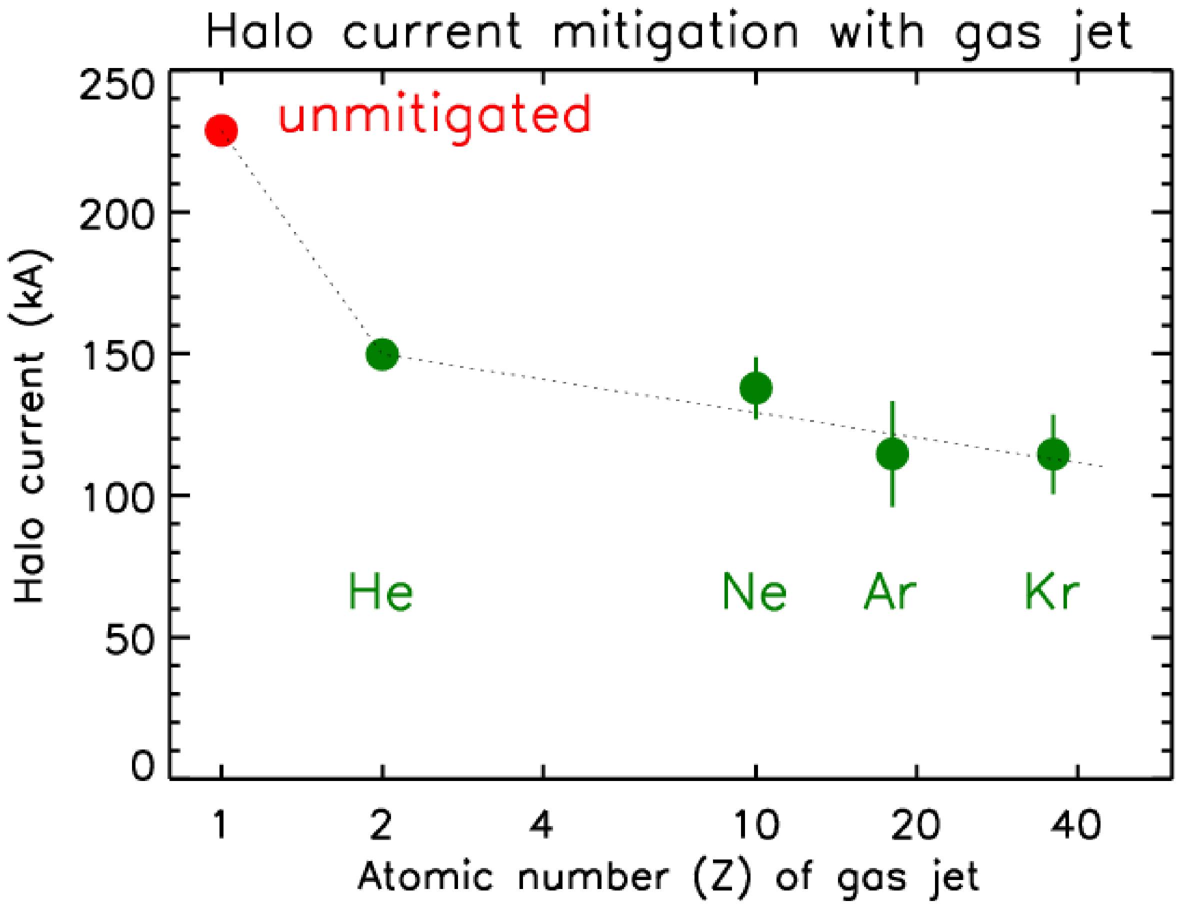


(a) Growth of 2/1 mode; T_e collapse continues moving inward

(b) Growth of 1/1 mode, along with many other smaller modes

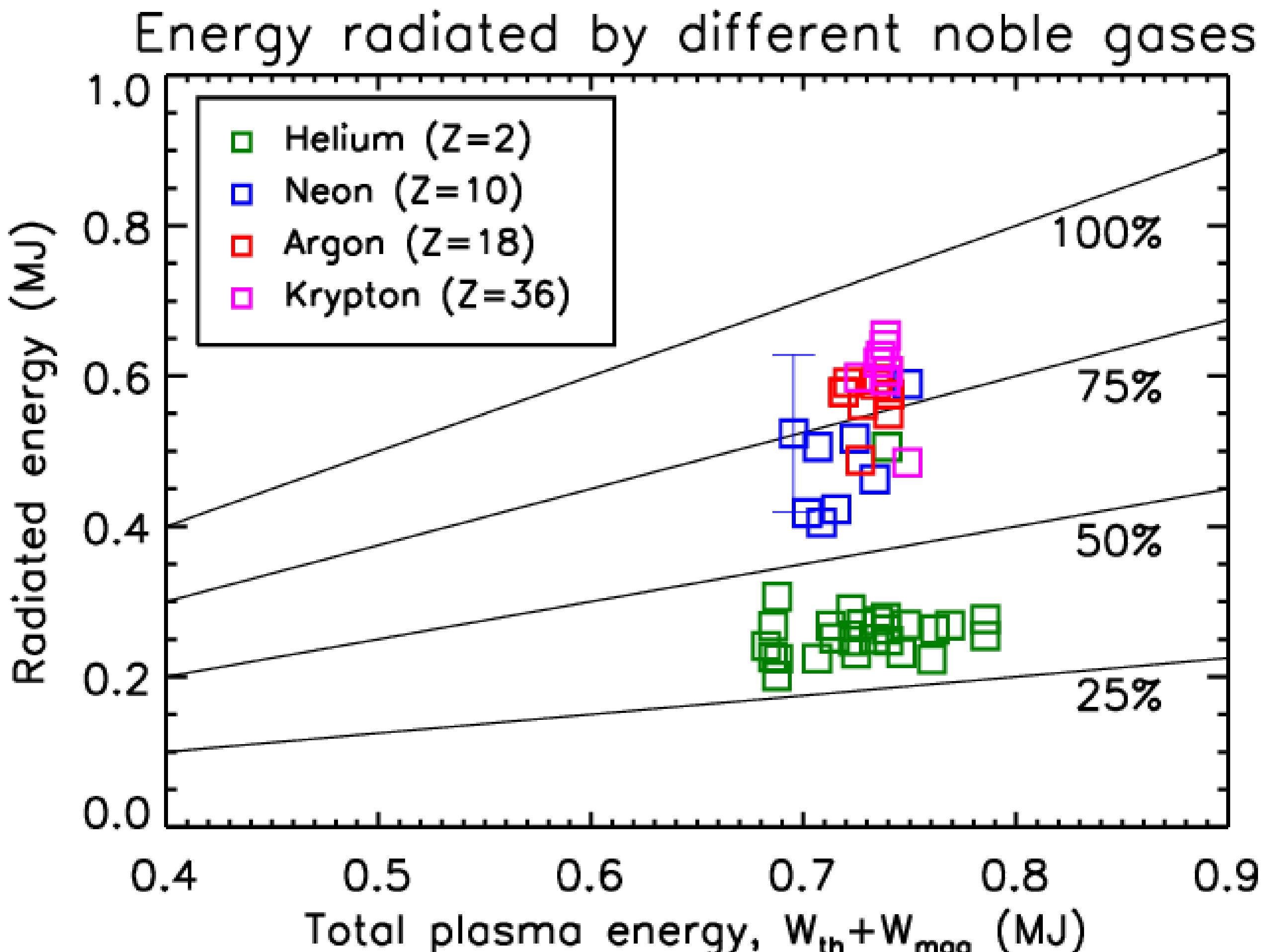
(c, d) Large ergodic region forms, leading to rapid loss of core energy to the radiating edge

Halo current reduction on C-Mod improves with Z of gas jet

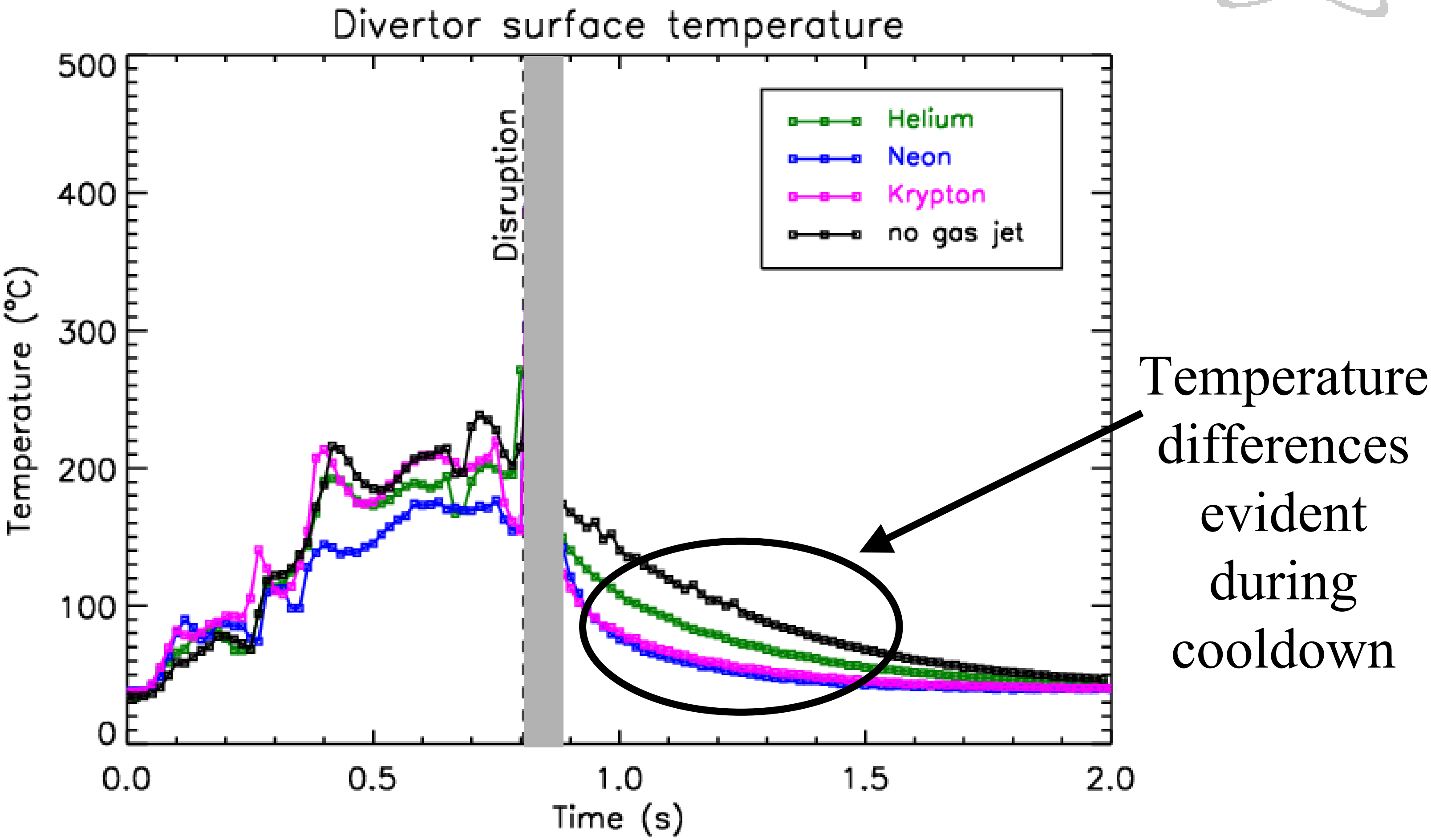


Target plasmas: I_p=1.0 MA, B_T=5.4 T, $\bar{n}_e=1.6\times10^{20}\ m^{-3}$

Fraction of Energy Radiated on C-Mod increases with Z of gas jet



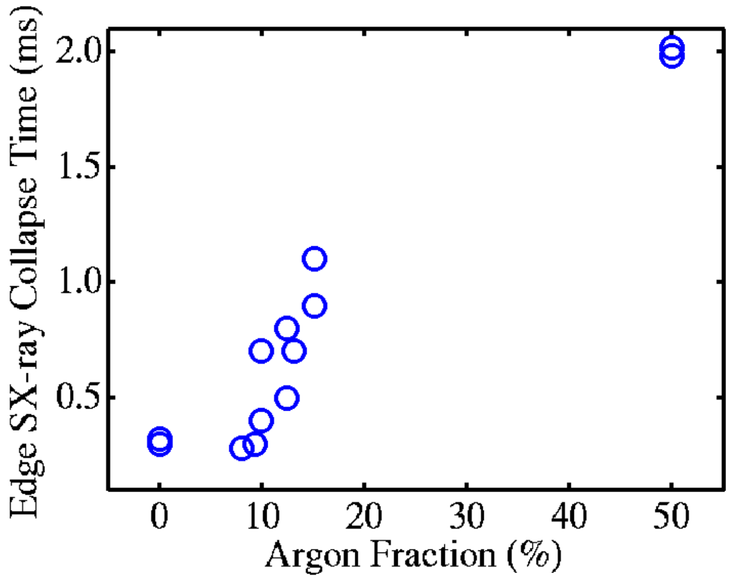
Gas jet reduces energy deposition on C-Mod divertor surface



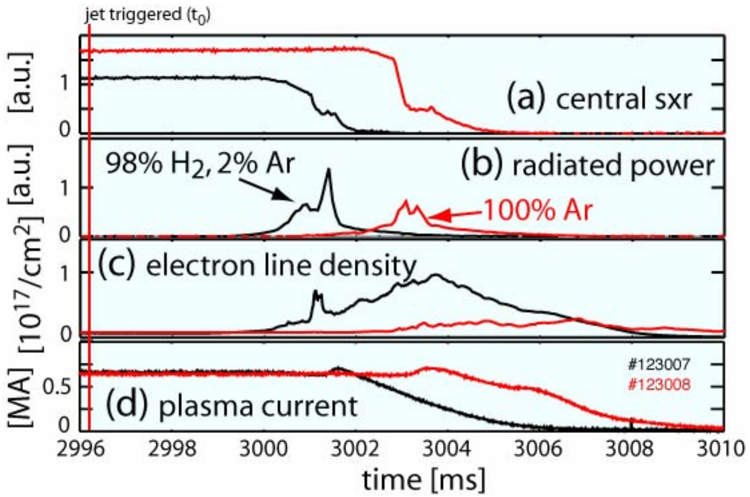
Higher Z works better than lower Z

Mixed gases: He or H_2 carrier with Ar seed speeds up delivery of argon

C-Mod
Helium + Argon



DIII-D
Hydrogen + 2% Argon



Thermal quench in both machines starts several ms earlier with He or H_2 + few percent Ar compared to pure argon

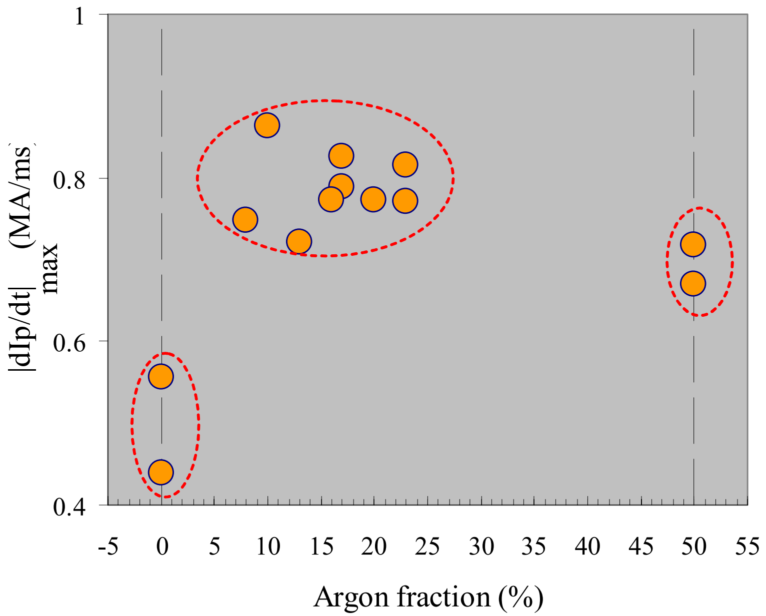
Mixed gases: An optimum argon fraction exists for mitigation effects

Alcator C-Mod

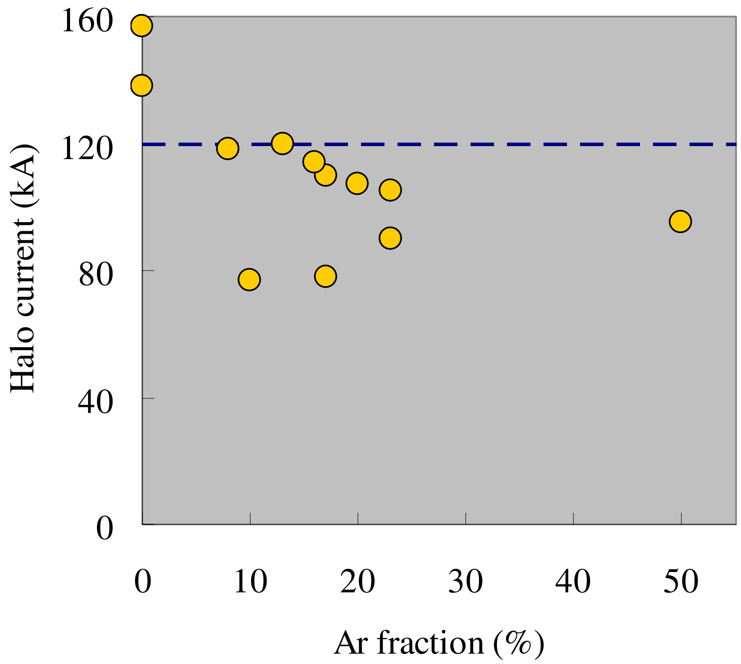
DIII-D NATIONAL FUSION FACILITY SAN DIEGO

C-Mod

Current quench rate



Halo current



He-Ar mixture reduces halo current better than pure helium and is quicker than pure argon

Summary of these DIII-D and C-Mod gas jet experiments

- **Determine penetration of gas jet/impurities at different plasma pressures, energy densities, and B-field**
  - **Gas jet does not penetrate beyond edge under any condition. Deep penetration of neutral gas jet is not necessary for disruption mitigation.**
- **Compare gas jet disruptions with NIMROD MHD modeling**
  - **NIMROD modeling qualitatively reproduces observed sequence of MHD events on DIII-D and C-Mod**
- **Study disruption mitigation on C-Mod plasmas**
  - **Good mitigation, especially with higher Z. Very similar to results from DIII-D.**

Summary of these DIII-D and C-Mod gas jet experiments, cont.

- **Determine if runaway electron avalanching is an issue**
  - **Experiments are continuing; implications for ITER are not yet clear**
- **Determine effectiveness of gas jet mixtures**
  - **Seeding higher Z (Ar) into He or H_2 carrier improves response time while still providing good mitigation.**

Implications for ITER

- Gas jet mitigation can work without deep penetration
- MHD processes in standard operating scenario will probably be similar, since q-profile is similar (q_{95}=3.1, sawtoothing, monotonic)
- Mitigation of halo currents and divertor heat loads should be successful at ITER energy density
- Gas jet mixtures could be used to minimise response time

Related talks and posters at IAEA FEC 2006

MHD Simulations for Studies of Disruption Mitigation by High Pressure Noble Gas Injection, V.A. Izzo, TH/P3-15

Mitigated Plasma Shut-Down with Fast Impurity Puff on ASDEX Upgrade, G. Pautasso, EX/P8-7

Disruption scenarios, their mitigation and operation window in ITER, M. Shimada, IT/P1-19