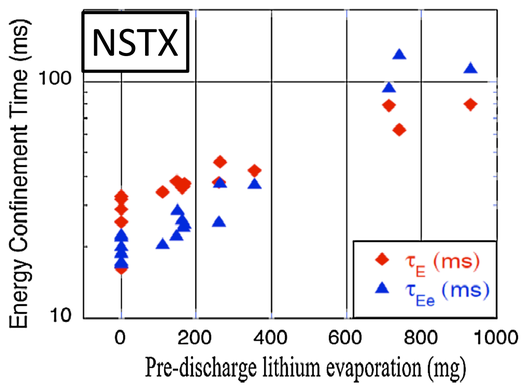
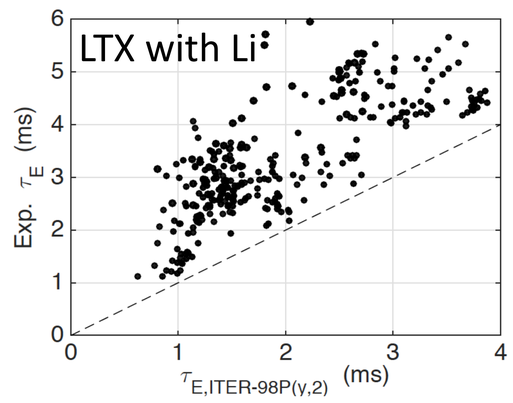
Liquid Lithium for Plasma Exhaust and High Confinement for Compact Fusion Systems

Jonanthan Menard, Rob Goldston, Egemen Kolemen, Rajesh Maingi, Dick Majeski
Princeton Plasma Physics Laboratory

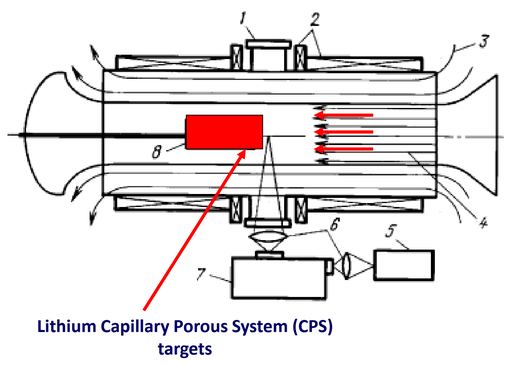
Challenge #1: Compact system designs rely on high energy confinement: how to achieve high τ_E?
Answer: Apply liquid or solid Li to the walls





Issue: How to limit T retention in vessel and extract T & impurities from Li efficiently?

Challenge #2: Compact fusion systems have high power density, which exacerbates plasma exhaust problem: how to exhaust plasma, impurities, and He?
Answer: Liquid Li can withstand higher heat flux than solids, and may be able to entrain He



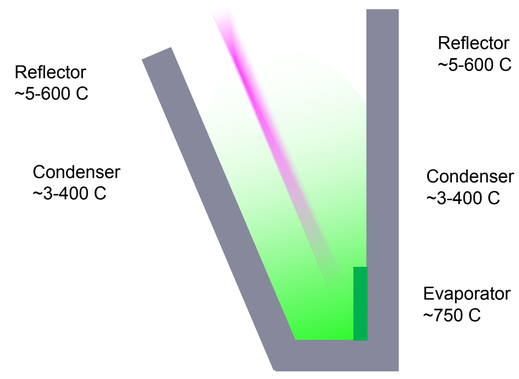
Steady: 1-11 MW/m² for 3 hours

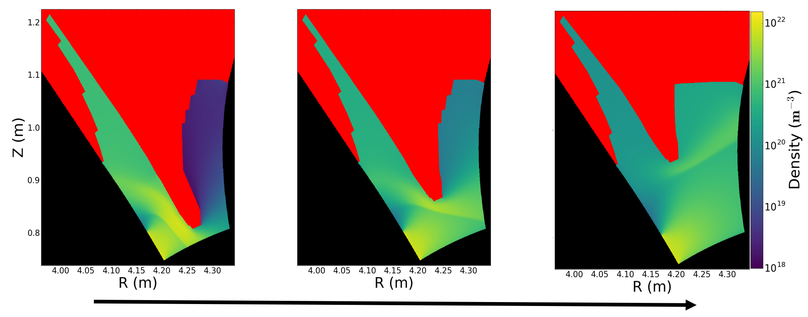
Heat loads ≤ 25 MW/m² withstood with Li targets (5-10 minutes, limited by Li inventory)

Transients ≤ 50 MW/m² with Li targets without cooling for ≤15 s

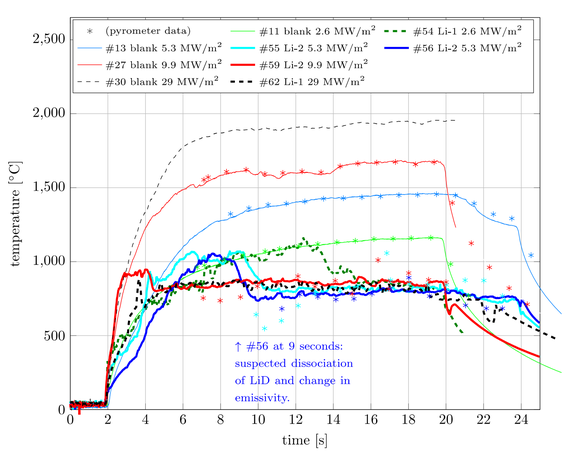
Lithium Vapor Box

- Vapor-shielded/vapor-box "slow-flow" system: Li ionization rate of 1.3 g/s / MW
- Modest flow rate
- Modest lithium processing



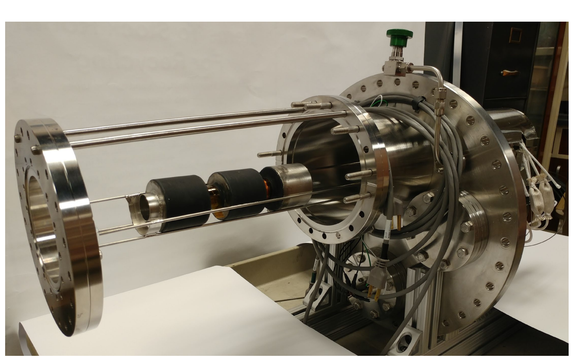


Factor of 6 reduction in lithium ionization as plasma retreats from vapor region ⇒ stable detachment front

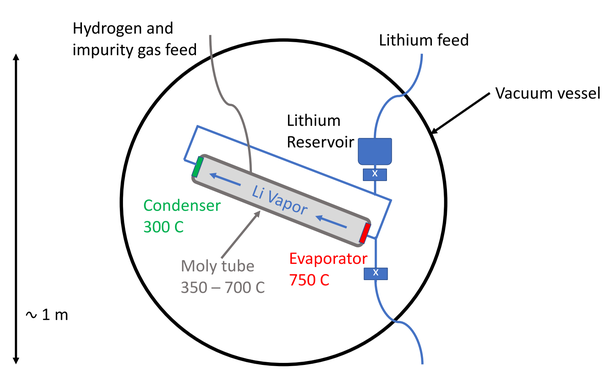


- 3-D printed porous W target
  - Greatly reduces thermal stresses
- Up to 29 MW/m²
  - No damage
- msec transients to 0.5 GW/m²
  - No damage

Potential ARPA-E Projects



- Inject D + impurities into existing small Vapor Box at PPPL, with internally evaporated lithium. 1g Li inventory.
- Add glow probe for ionization.
  - Compare trapping of ions vs. neutrals.
- Measure D, He, impurities and Li wall retention vs. wall temperature, for a range of impurities.
- Tests key issue of tritium retention.
- Notional budget: $300k/year x 3 years



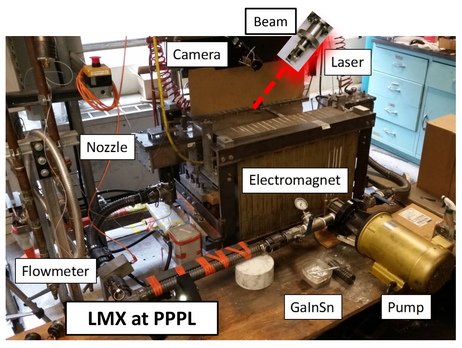
- Same as small Vapor Box, plus …
- Much higher lithium and D/He/impurity throughput for more accurate retention measurements.
- Variable wall temperature, independent of lithium evaporation source temperature.
- Test Li vapor feed and withdrawal mechanism + D, He, impurity extraction.
- Close lithium flow loop. Test-bed for D, He, impurity extraction techniques.
- Notional budget: $1M/year x 3 years

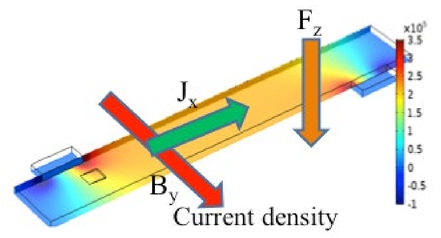
Flowing Lithium Walls/Divertor

- Fast flowing (m/s) liquid Li PFCs
- All in one Cooling + Particle Pumping ➔ Allow smaller/simpler reactor
- Solves material issues: Take plasma heat ➔ Substrate designed for neutrals only which allows currently available ferritic steels
- Acts as a pump: no need for a separate system for D/T and He!
- Issue 1: Fast flow is inhibited by the magnetic field (MHD)
- Issue 2: He/D/T pumping rate/separation in realistic T, dwell times (speed)
- Issue 3: Pumping becomes hard at high B and speed

Potential ARPA-E Projects

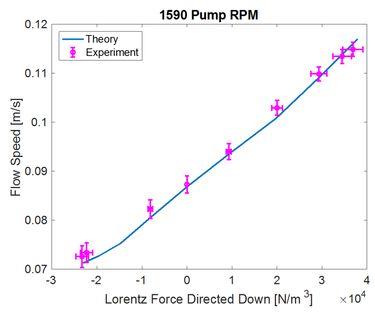
Address 1 & 2: Fast flowing Li He/D pumping and separation under high B



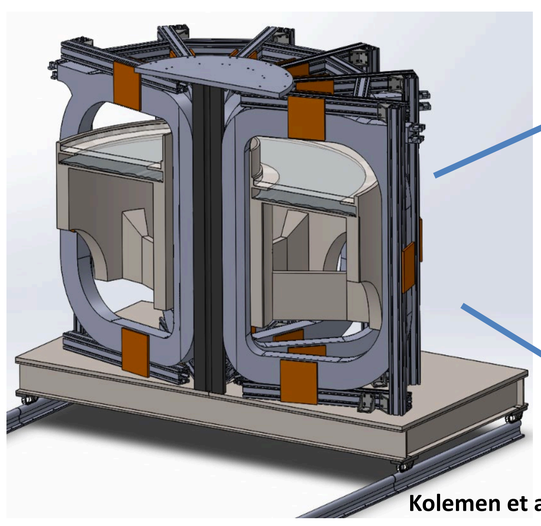


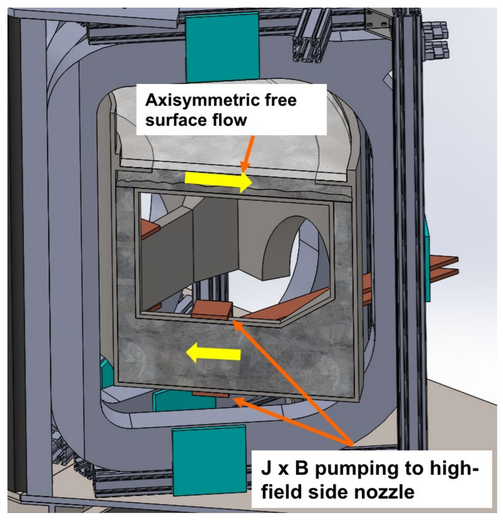
J in LM allow control of u (LMX)

- Liquid Metal eXperiment (LMX) uses Galinstan
- Build *mini-LMX* with Li (no plasma)
- Electron gun heating; Ion gun D, He injection
- Run currents through LM to apply jxB force
- He and D collection and separation
- Notional Budget $3M (3 years)



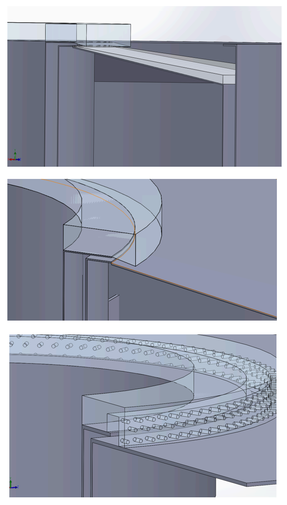
Address 1 & 3: Test fast flowing and recirculation in high magnetic fields





Kolemen et al, NME (2019)

Build Flowing LIquid metal Torus (FLIT)



- High B(1 T) with high heat flux capability (10 MW/m²)
- Axisymmetric ➔ No B_t MHD drag + Magnetic Propulsion
- Adjustable thickness, speed, inclination (vertical wall) and allows jets
- Build full LM system (jxB pumps, nozzles, …)
- *No plasma and use Galinstan to simplify these tests*
- Final Design Review held: $2.2M total cost (3 years)