US-EU Collaboration on ITER PFC Materials and Related PMI Studies

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Some highlights from recent PISCES/ UC San Diego experiments :

- Developed liquid lithium limiter and tested on CDX-U Torus at PPPL (UCSD/PPPL collaboration). Lithium pool maintained in molten and high purity state, appears to greatly reduce hydrogen recycling and impurities. In agreement with PISCES-B experiments.
- PISCES-B experiments with ITER materials: beryllium seeding of hydrogen plasmas on carbon target shows reduction in carbon chemical erosion when concentration of beryllium impurities present in plasma increases.
- Disruption Mitigation in DIII-D (UCSD/GA/ORNL collaboration): High pressure gas jet found to rapidly radiate the plasma energy: vertical instability avoided, runaway generation suppressed, halo current effects reduced. (Implications for ITER/BPX)
- PISCES-B experiments identify temperature dependence in physical erosion over a range of materials. Surface ad-atom evaporation model fits data well (submitted to PRL).
- Plasma potential modification experiment on PISCES-A begun, some indications of potential and rotation modification.
- Ballistic blobs (avaloids) identified in SOL of Torre Supra, PISCES-A, MAST, DIIID (e.g. G. Antar et al. PRL 2001). New type of plasma flux to chamber wall.

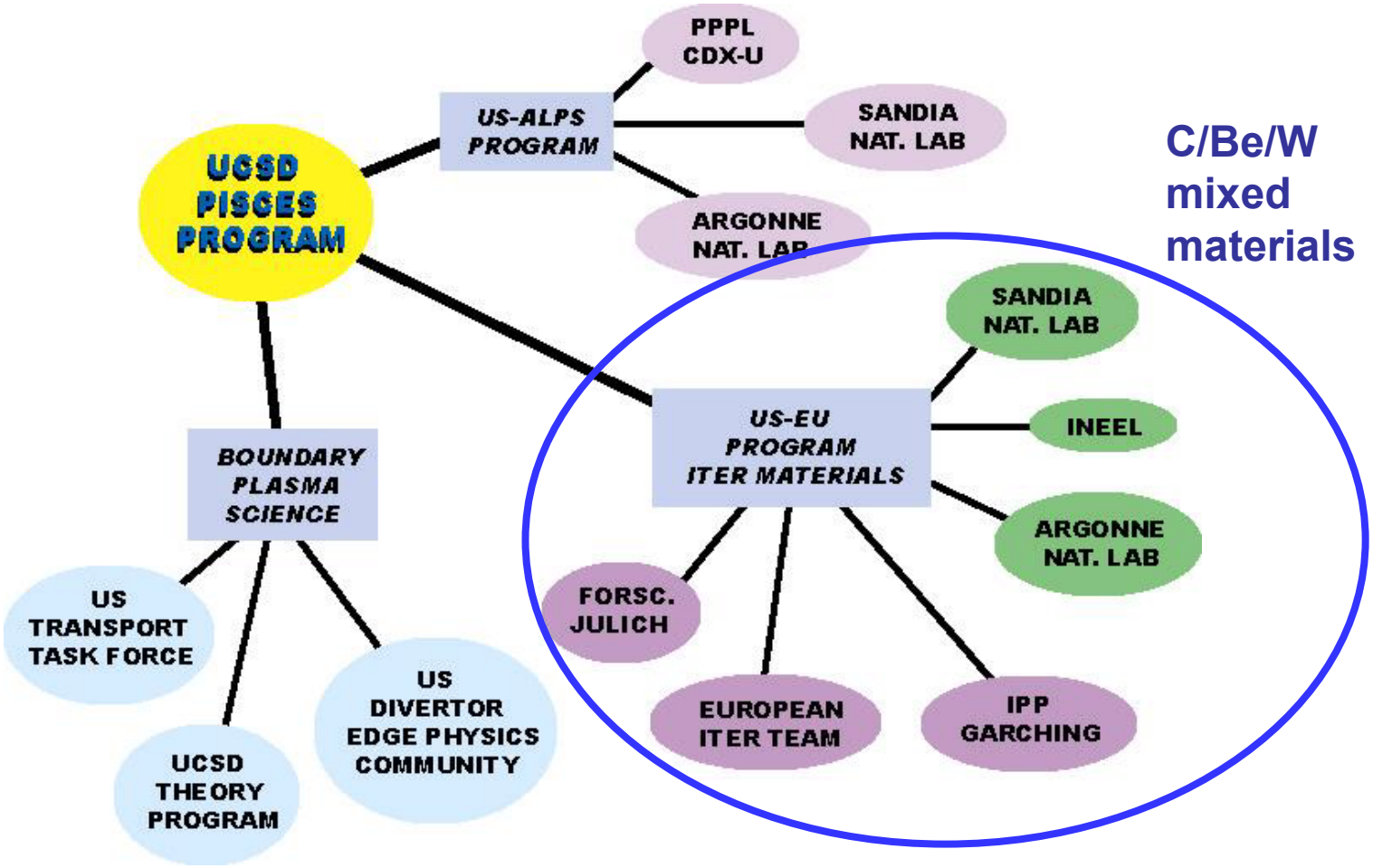
New Program of US/EU collaborative experiments on ITER materials started in mid-2002.

- USDOE and European Fusion Development Agreement (EFDA) laboratories to carry out cooperative experiments on ITER chamber wall and divertor materials.

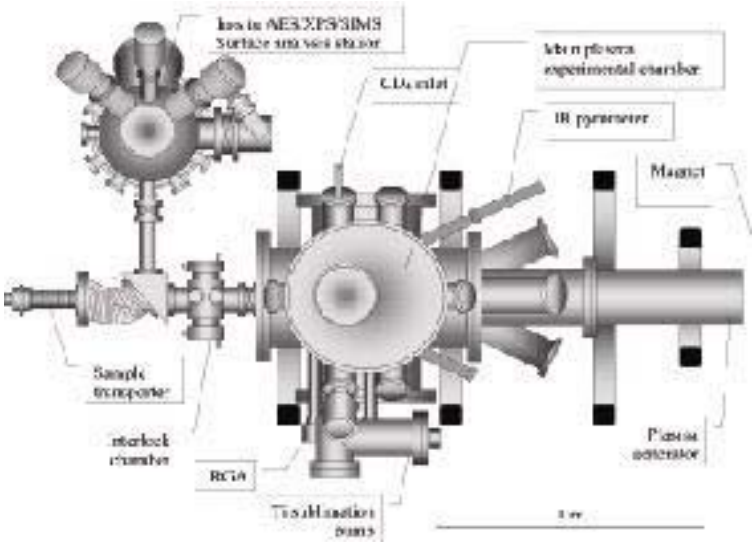
- US Team consists of UCSD PISCES Group, Sandia National Laboratories, and Argonne National Laboratories.
- EU Team consists of IPP Garching, KFA Julich, and others.

- Scope of work: carbon erosion/redeposition, role of beryllium plasma impurities, hydrogen isotope retention, redeposited layers, tungsten materials, and materials mixing effects.

UC San Diego PISCES Program main collaborations



UC San Diego PISCES-B is unique in its ability to safely investigate plasma interactions with ITER beryllium materials in a controlled environment.



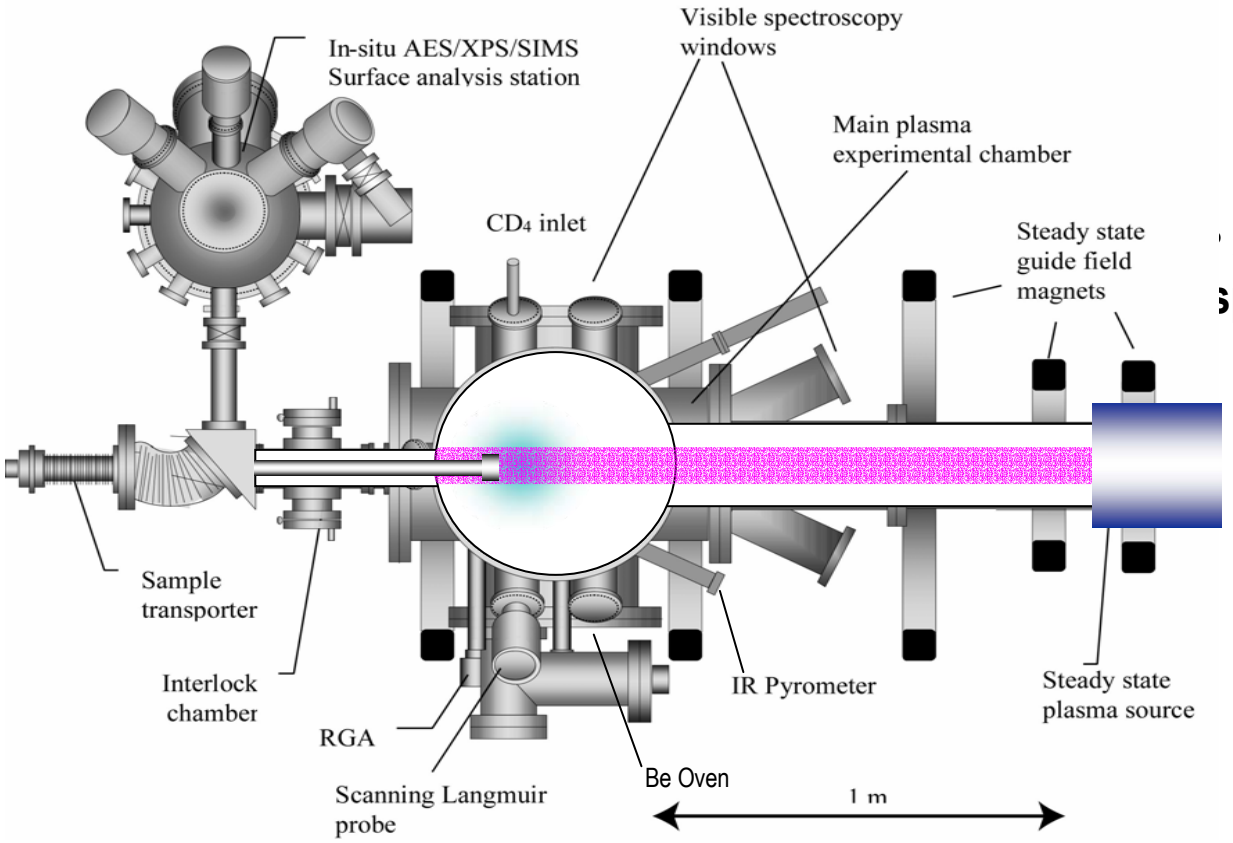
Integrated plasma and surface analysis capability

- Safety enclosure certified for beryllium, lithium and other materials investigations.
- Dedicated surface analysis lab with SEM, EDX, AES, XPS, SIMS, TDS, and in-situ capability on PISCES-B.
- Extensive and redundant plasma diagnostics: Scanning probe arrays, absolute visible spectroscopy, multiple RGAs, baratrons, omegatron, GEA.
- 4000 sq. ft. laboratory space, 750 gpm, 350 psi closed loop water cooling, 5MVA substation--2.5MW SS.

PISCES-B Upgraded in 2002 for Beryllium/Carbon US/EU collaboration studies

New systems include: Beryllium seeding system, IPP Garching redeposition probe, Absolute visible spectroscopy, new SEM with WDS.

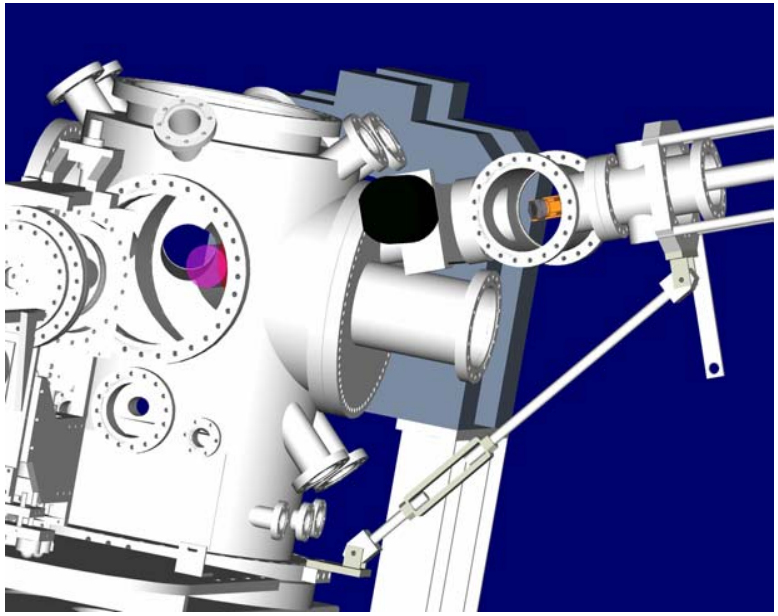
PISCES-B



- **Kerr cells for Be seeding C_{be} ~ 0.1% to 1%**
- **Absolutely calibrated visible spectroscopy**
- **IPP Garching redep probe and manipulator system.**
- **Sample is Plasma heated T_S ~ 60°C to 1000°C**

ITER Beryllium/Carbon mixed materials and hydrogen retention experiments. IPP Garching fabricated witness plate for collection of redeposited carbonaceous layers in PISCES-B (2002-2004).

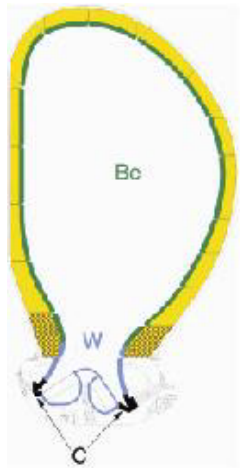
Deposition rates and hydrogen isotope content under study.



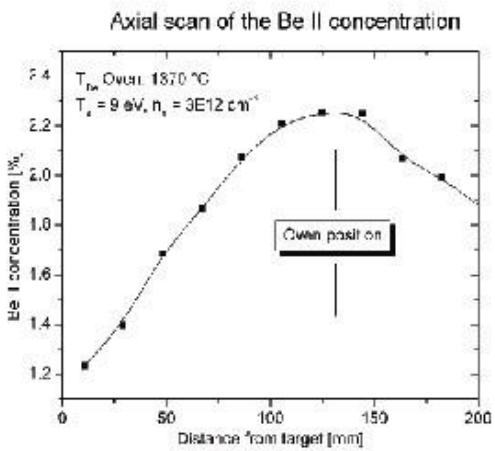
ITER plans call for beryllium chamber wall and carbon divertor plates. Therefore beryllium impurity fraction in divertor plasma may be ~ few percent

The PISCES-B experiments aim to study role of beryllium impurity and mitigate chemical erosion of carbon. One idea is to use the beryllium impurity seed population in divertor plasma to suppress chemical erosion of graphite.

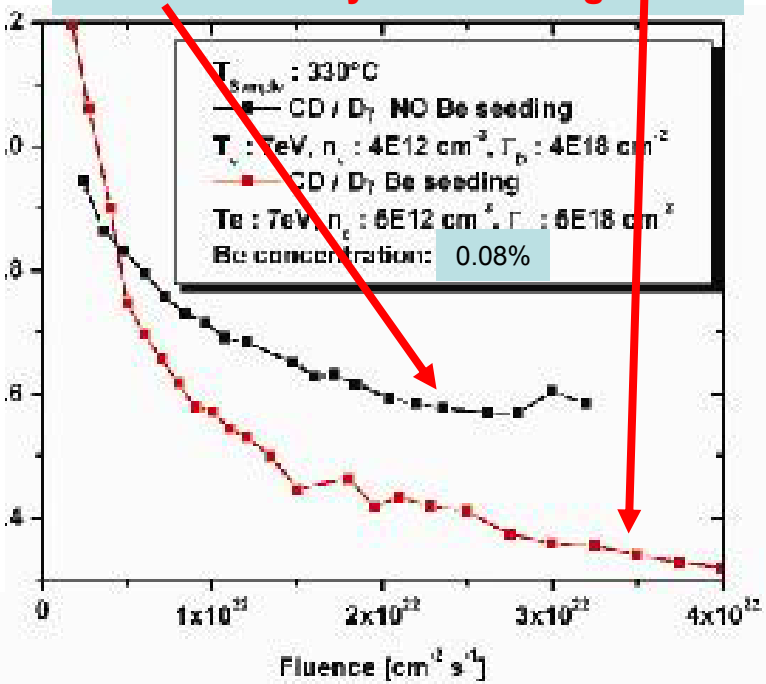
Initial data from PISCES-B shows reduction of chemical erosion by fluence and beryllium seeding.



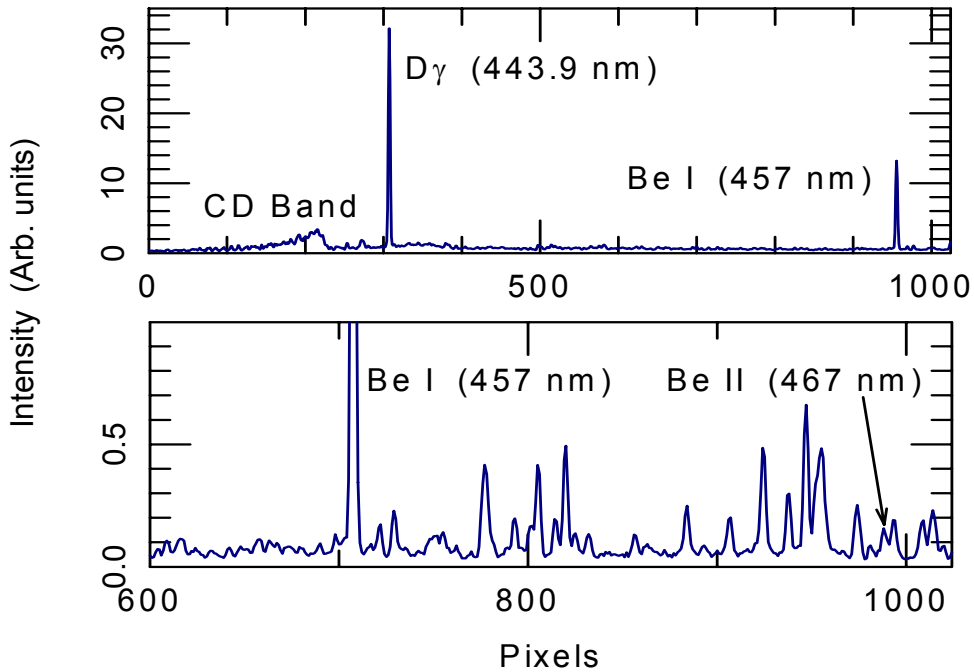
ITER



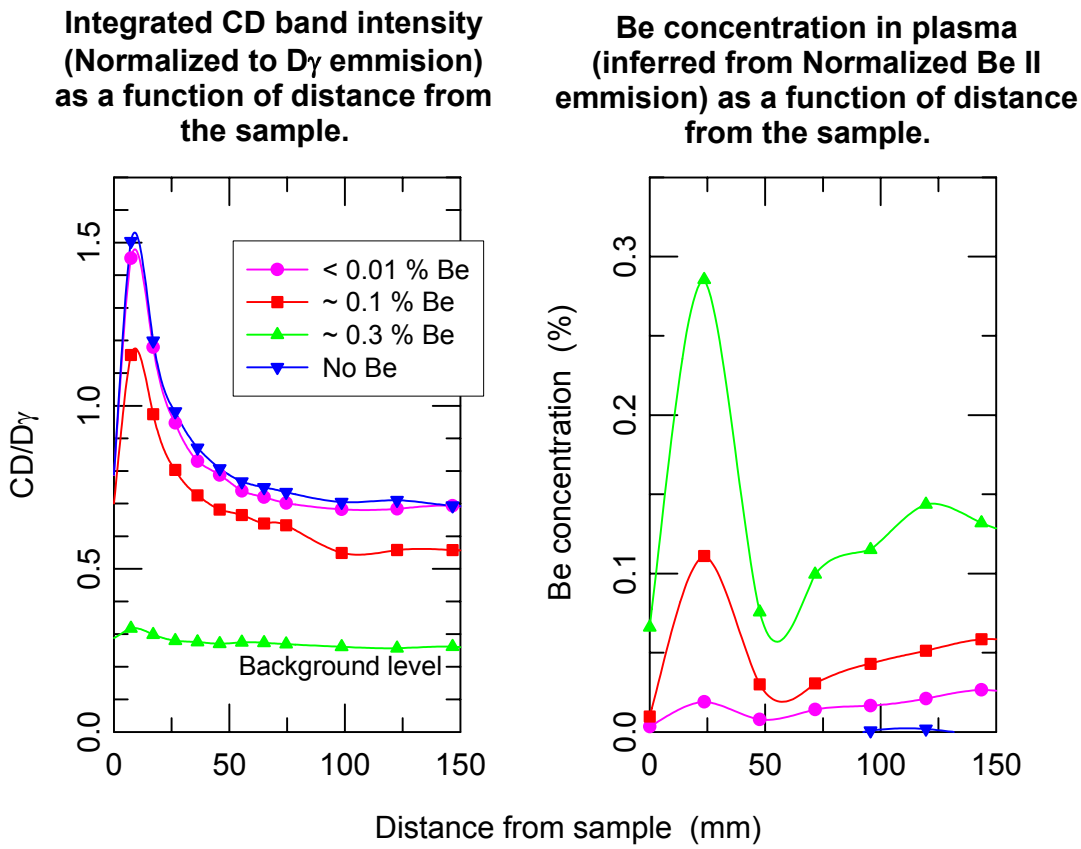
PISCES-B beryllium impurity seed population



OES lines used to characterize Be seeding rate and C chemical erosion



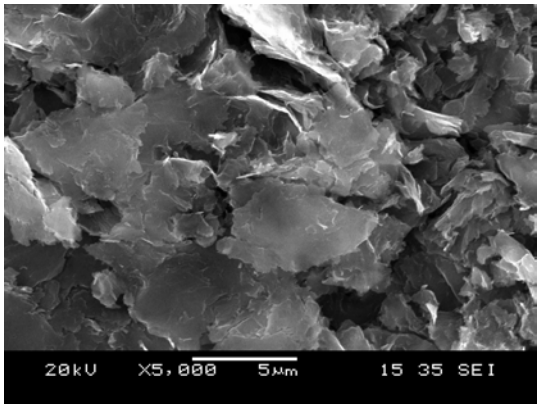
CD band emission data indicates that as beryllium impurity fraction increases above ~0.3% the chemical erosion of graphite is suppressed.



Peak in beryllium ion concentration near the surface is consistent with pre-sheath effects.

PISCES modeling by Kirschner

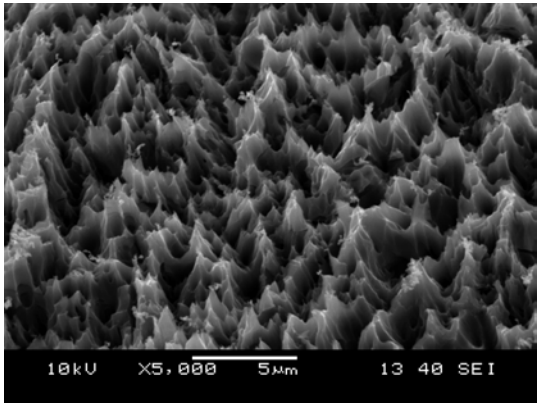
Beryllium surface layer is detected on graphite surface by AES. Surface morphology changes noted as well.



- ATJ - 00
- Not exoposed

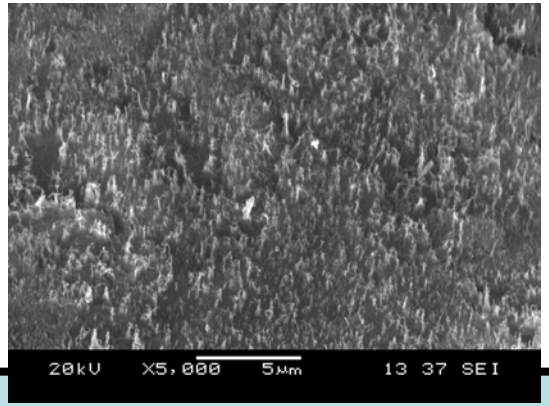
Plasma exposure conditions

Γ_D ~ $3x10^{18}$ cm^{-2} s^{-1}
T_e~ 6eV
n_e~ 10^{12} cm^{-3}
Sample Temp. ~ 500 K
D^+ Ion Fluence ~ $2x10^{22}$ cm^{-2}



- ATJ - 7
- No Be seeding
- Mass loss = 62 mg

- ATJ - 10
- Be concentration in plasma ~ 0.1 %
- AES analysis: 85 % Be, 10% O, 5% C
- Mass loss = 5 mg

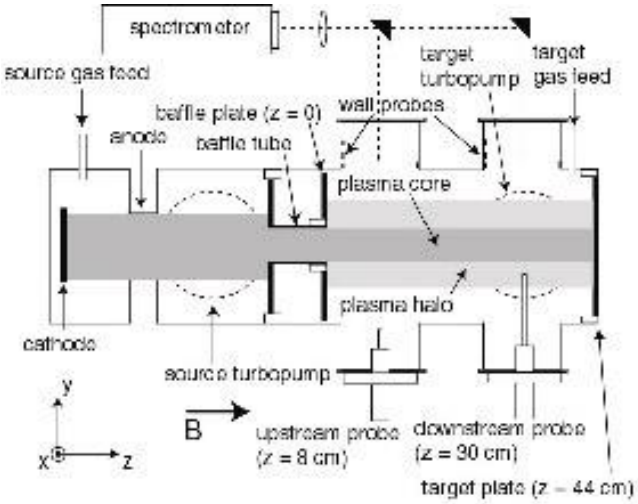


Some preliminary conclusions

- Beryllium impurities in incident deuterium plasma cause the formation of a thin beryllium enriched layer on the surface of carbon at sufficiently high concentration.
- This layer appears to reduce or suppress chemical erosion of graphite. This appears over a range of temperatures so far up to ~750C.
- Divertor/SOL modeling of ITER should include the beryllium impurity to better determine Be concentration at divertor plate.
- Future experiments will extend to higher temperatures, higher beryllium concentrations, and deposition studies using the IPP Garching deposition probe. Are carbonaceous deposits suppressed by Be layers?

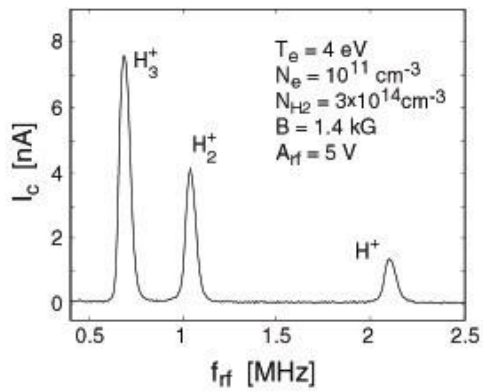
Boundary plasma physics program aims to develop understanding of atomic, molecular, and plasma processes in the plasma boundary.

Gaseous divertor simulation experiments on PISCES-A along with theory lead to good understanding of the H+, H2+, H3+ molecular ion abundances. Hollmann et al. *Controlled Fusion and Plasma Physics*, EPS Conference Proceedings 29 (2002).

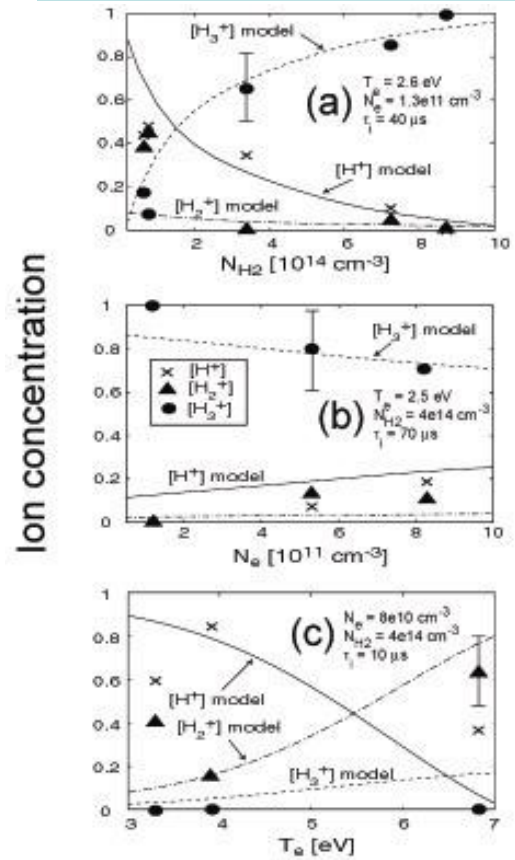


PISCES-A in gaseous divertor configuration.

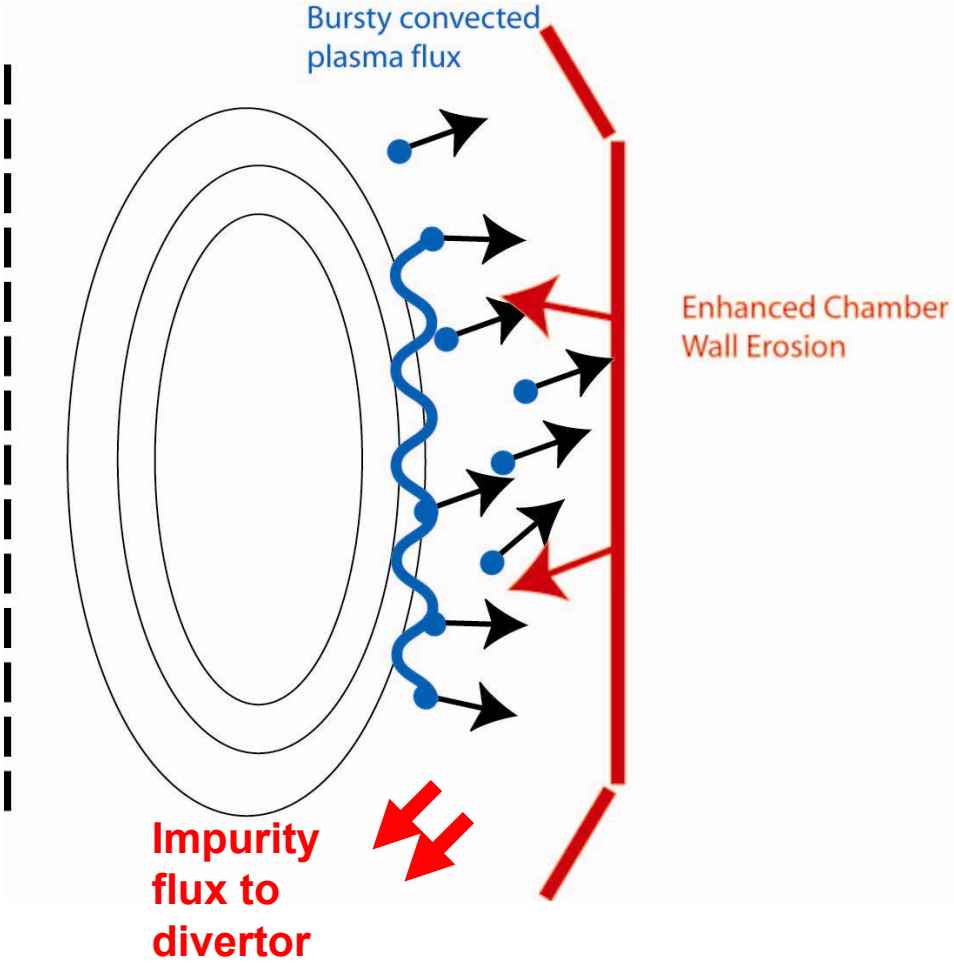
Developed novel molecular ion mass spec. for in-situ monitoring of H+, H2+. H3+



Ion species abundance in agreement with model.



Bursty convected coherent plasma blobs (variously called Avaloids, Blobs, etc.) observed ubiquitously

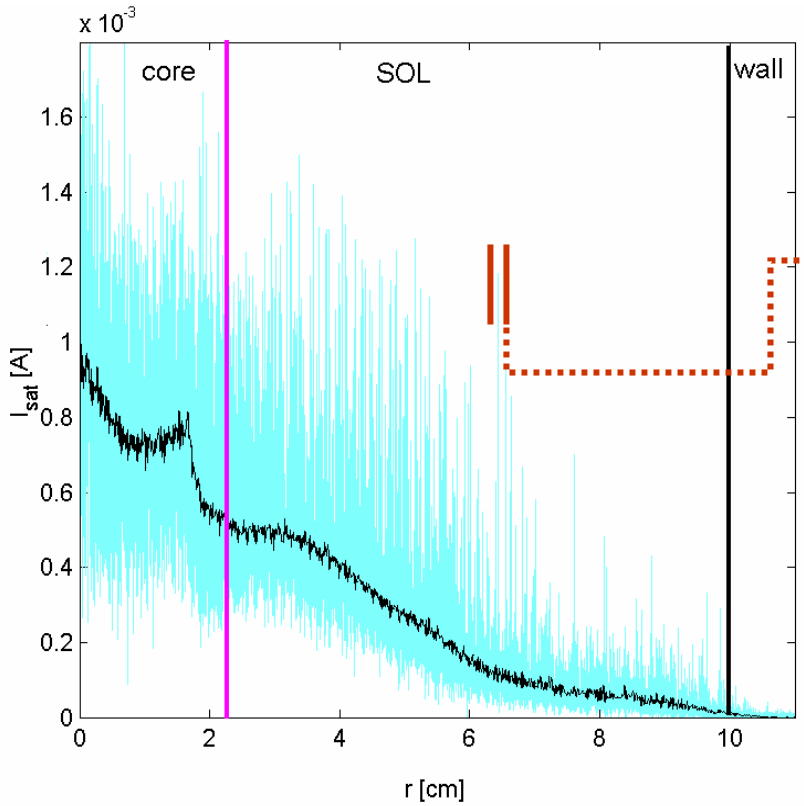


Bursty flux is not well understood and not included in chamber wall flux models.

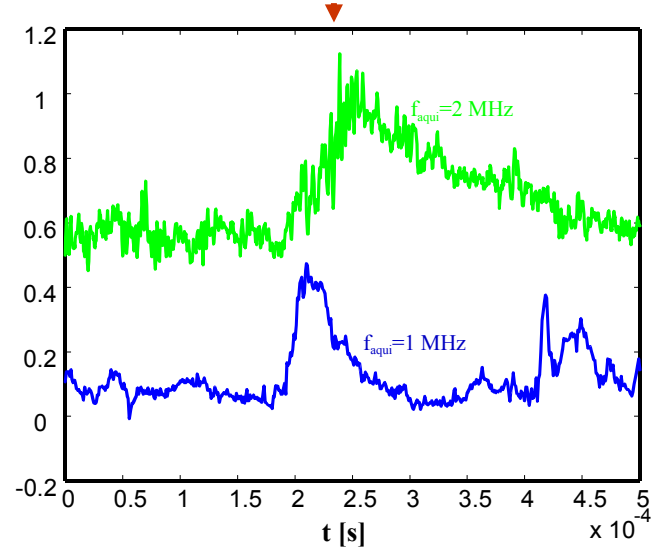
Bursty flux may generate additional influx of wall atoms

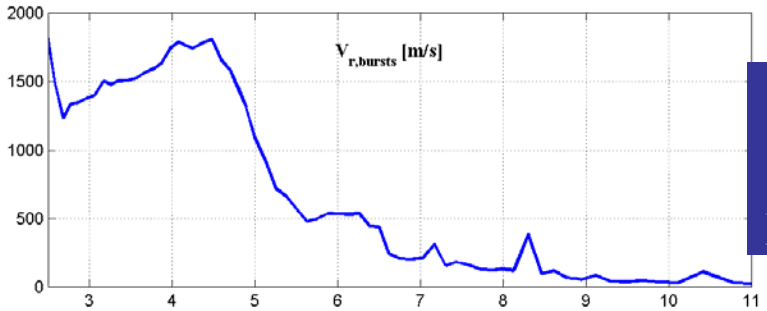
Generating additional impurity flux into divertor

δI_{sat} decreases and changes in nature with increasing r:
In the core fluctuations **about** an average value
In the SOL fluctuations **above** the average value
PISCES A experiments

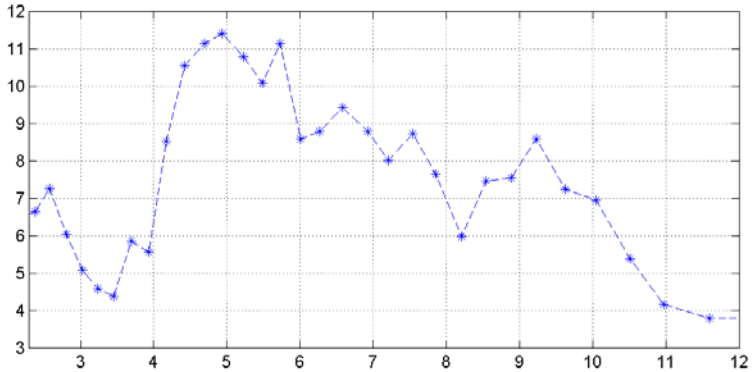


Zoom on one burst in the SOL





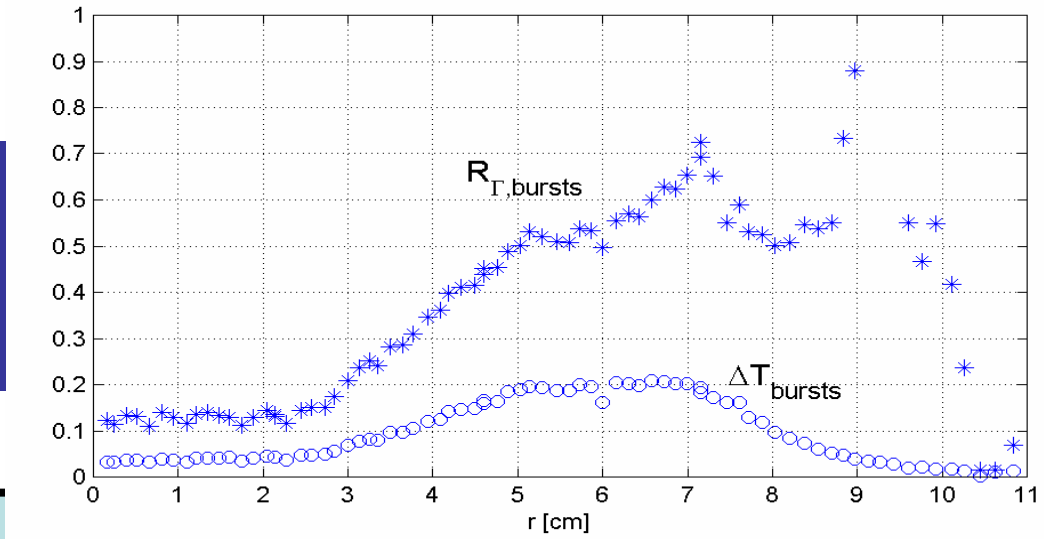
The radial velocity of the bursts as function of distance to the plasma center [m/s]



The spatial scales of the bursts as function of distance to the plasma center [mm]

$R_{\Gamma,bursts}$ id the contribution to the total radial transport

$\Delta_{Tbursts}$ is the time the bursts occupy in a given signal



Conclusions

- Bursty ballistic transport in the SOL is seen ubiquitously in the plasma boundary
- It is a new type of plasma flux to the chamber wall that is not well understood or modeled.
- It may be important as a generator of wall erosion, but this is unknown at the present.
- Further studies both experimental and theoretical are needed to quantify and understand this flux.

PISCES Group Publications on Bursty Ballistic Transport

- G. Y. Antar et al., Turbulence Intermittency and Bursts Properties in the Scrape-off layer of the Tore Supra Tokamak, Phys. Plasmas 8, 1612 (2001).
- G. Y. Antar et al., Experimental Evidence of Convective Transport in Fusion Devices, Phys. Rev. Lett. 87, 065001 (2001).