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Update on Divertor Plasma Solutions

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Topics covered in this presentation

- Overview of UEDGE modeling for ACT - I
- Effect of particle pumping on divertor plasma
- Upstream plasma profiles for attached and detached plasma
- Particle throughput
- Effect of tilted plates on divertor plasma
- From yesterday: Radiation heat load on outer and private-flux walls

Main input parameters for modeling divertor plasmas in ARIES ACT-I

- tilt angle of the target plates

  θ_{inner}, θ_{outer}

- impurity radiation in the divertor

  f_{imp}, species, ...

- core plasma boundary conditions

  P_{SOL}, n_{ped}

- particle pumping

  R_p, A_{pf}

Some factors that make it difficult to find solutions:

- multiple solutions are possible for some sets of parameters.
- oscillatory behavior is observed during time evolution.
- adequate mesh resolution continues to be a challenge.

We currently have a database of over 200 UEDGE runs for ACT- I.

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UEDGE runs are catalogued in a spreadsheet format for convenient comparison

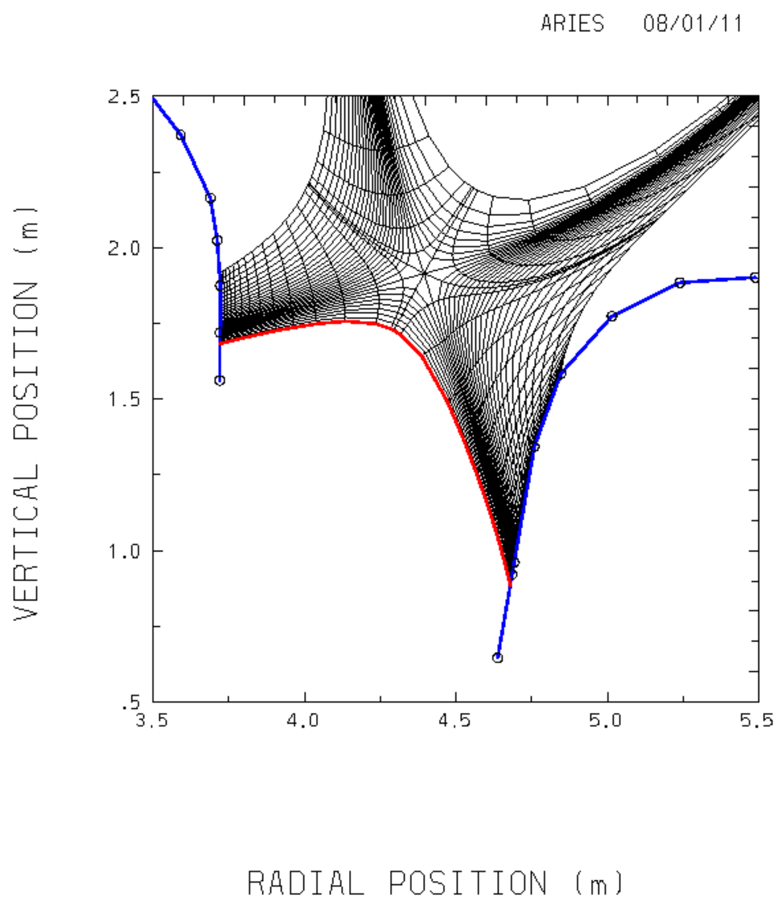
1														
2	**Input File Name**	**sequence #**				plate tilt		DT pumping		radial mesh limits			RESULTS	
3			ncore(1)	pcoree+pcorei	afracs	anfgx(0,iysptrx+1)	angfx(nx,iysptrx+1)	albdsi(1)	recycp(1)	psi0min2	psi0max	psi0max_inner	p_hat_inner	p_hat_outer
4			10^{20} m^{-3}	MW		degrees	degrees						MW/m^2	MW/m^2
5														
6	restart_act1_ne_71x32.8ff6Pc	001	1.0	160	0.0035	0	0	0.9999	1.0000	0.97	1.15	1.15	3.1	4.4
7	restart_act1_ne_71x32.8ff6Pc_nog1	002	1.0	160	0.0035	0	0	0.9999	1.0000	0.97	1.15	1.15	3.2	4.5
8	restart_act1_ne_71x32.8ff6Pc_nog2	003	1.0	160	0.0035	-13	-1	0.9999	1.0000	0.97	1.15	1.15	3.2	8.2
9	restart_act1_ne_71x32.8ff6Pc_nog3	004	1.0	160	0.0035	2	-1	0.9999	1.0000	0.97	1.15	1.15	3.1	4.3
10	restart_act1_ne_71x32_nog.4	005	1.0	160	N/A	47	-61	1.0000	0.9900	0.97	1.07	1.05	52.2	70.3
11														
12	restart_act1_ne_71x32_nog.4.old	006	1.0	160	N/A	46	-62	1.0000	0.9900	0.97	1.07	1.06	62.3	77.6
13	restart_act1_ne_71x32_nog.5	007	1.0	160	N/A	17	-66	0.9995	1.0000	0.99	1.07	1.05	not converged	not converged
14	restart_act1_ne_71x32_nog.5.001	008	1.0	160	0.0010	47	-61	1.0000	0.9900	0.97	1.07	1.05	41.6	68.0
15	restart_act1_ne_71x32_nog.5.0015e	009	1.0	160	0.0015	57	-66	1.0000	0.9900	0.98	1.05	1.03	24.7	57.0
16	restart_act1_ne_71x32_nog.5.001e	010	1.0	160	0.0010	57	-66	1.0000	0.9900	0.98	1.05	1.03	30.2	58.2
17														
18	restart_act1_ne_71x32_nog.5.001o5	011	1.0	160	0.0010	57	-66	0.9995	1.0000	0.99	1.05	1.03	23.2	54.5
19	restart_act1_ne_71x32_nog.5.001o6	012	1.0	160	0.0010	17	-66	0.9995	1.0000	0.99	1.05	1.03	47.6	50.9
20	restart_act1_ne_71x32_nog.5.001o7	013	1.0	160	0.0010	17	-66	0.9995	1.0000	0.99	1.05	1.03	45.3	51.1
21	restart_act1_ne_71x32_nog.5.001q1	014	1.0	160	0.0010	17	-66	0.9995	1.0000	0.99	1.07	1.05	not converged	not converged
22	restart_act1_ne_71x32_nog.5.002e	015	1.0	160	0.0020	57	-66	1.0000	0.9900	0.98	1.05	1.03	10.6	50.1
23														
24	restart_act1_ne_71x32_nog.5.002o5	016	1.0	160	0.0020	57	-66	0.9995	1.0000	0.99	1.05	1.03	16.2	53.5
25	restart_act1_ne_71x32_nog.5.002q1	017	1.0	160	0.0020	17	-66	0.9995	1.0000	0.99	1.07	1.05	10.4	54.1
26	restart_act1_ne_71x32_nog.5.003e	018	1.0	160	0.0030	57	-66	1.0000	0.9900	0.98	1.05	1.03	9.0	44.8
27	restart_act1_ne_71x32_nog.5.003eA	019	1.1	160	0.0030	57	-66	1.0000	0.9900	0.98	1.05	1.03	8.8	41.1
28	restart_act1_ne_71x32_nog.5.003eB	020	1.2	160	0.0030	57	-66	1.0000	0.9900	0.98	1.05	1.03	8.7	37.6
29														
30	restart_act1_ne_71x32_nog.5.003eC	021	1.3	160	0.0030	57	-66	1.0000	0.9900	0.98	1.05	1.03	9.1	33.1
31	restart_act1_ne_71x32_nog.5.003eD	022	1.4	160	0.0030	57	-66	1.0000	0.9900	0.98	1.05	1.03	9.4	26.8
32	restart_act1_ne_71x32_nog.5.003o5	023	1.0	160	0.0030	57	-66	0.9995	1.0000	0.99	1.05	1.03	13.2	53.2
33	restart_act1_ne_71x32_nog.5.003q1	024	1.0	160	0.0030	17	-66	0.9995	1.0000	0.99	1.07	1.05	1.2	54.0
34	restart_act1_ne_71x32_nog.5.004	025	1.0	160	0.0040	47	-61	1.0000	0.9900	0.97	1.07	1.05	17.4	62.0
35														
36	restart_act1_ne_71x32_nog.5.004a	026	1.0	160	0.0040	47	-61	1.0000	0.9900	0.97	1.07	1.05	20.4	61.2
37	restart_act1_ne_71x32_nog.5.004a_etb	027	1.0	160	0.0040	47	-61	1.0000	0.9900	0.97	1.07	1.05	15.3	58.1
38	restart_act1_ne_71x32_nog.5.004a_tb	028	1.0	160	0.0040	47	-61	1.0000	0.9900	0.97	1.07	1.05	15.7	60.6
39	restart_act1_ne_71x32_nog.5.004b	029	1.0	160	0.0040	47	-61	1.0000	0.9900	0.98	1.07	1.05	8.4	51.6
40	restart_act1_ne_71x32_nog.5.004c	030	1.0	160	0.0040	47	-61	1.0000	0.9900	0.98	1.06	1.04	8.4	51.6
41														
42	restart_act1_ne_71x32_nog.5.004d	031	1.0	160	0.0040	47	-61	1.0000	0.9900	0.98	1.05	1.03	9.1	52.5
43	restart_act1_ne_71x32_nog.5.004e	032	1.0	160	0.0040	57	-66	1.0000	0.9900	0.98	1.05	1.03	8.4	39.8
44	restart_act1_ne_71x32_nog.5.004e2	033	1.0	160	0.0040	57	-66	1.0000	0.9900	0.99	1.05	1.03	5.2	52.0
45	restart_act1_ne_71x32_nog.5.004eA	034	1.1	160	0.0040	57	-66	1.0000	0.9900	0.98	1.05	1.03	8.4	36.6
46	restart_act1_ne_71x32_nog.5.004eB	035	1.2	160	0.0040	57	-66	1.0000	0.9900	0.98	1.05	1.03	8.6	31.5
47														
48	restart_act1_ne_71x32_nog.5.004eC	036	1.3	160	0.0040	57	-66	1.0000	0.9900	0.98	1.05	1.03	7.6	67.7
49	restart_act1_ne_71x32_nog.5.004f	037	1.0	160	0.0040	57	-66	0.9900	1.0000	0.98	1.05	1.03	37.3	58.3
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Neutral particle removal is controlled by the albedo A_{pf} on the private flux dome

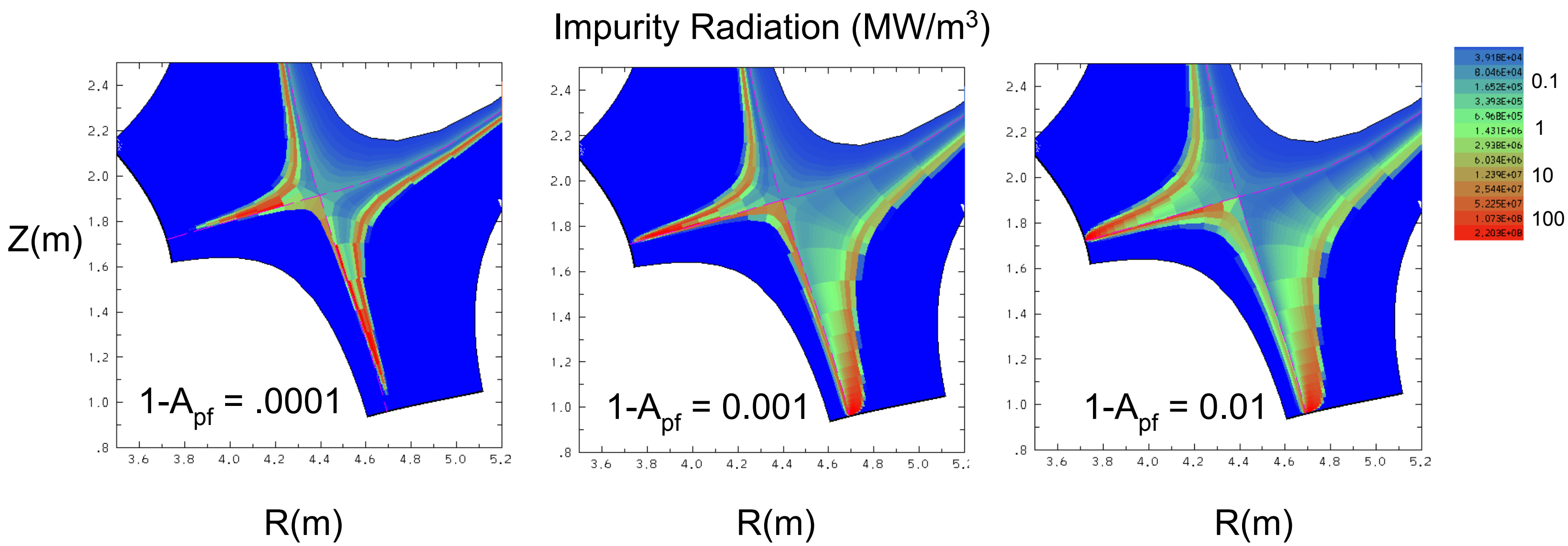
- pumped flux = $(1 - A_{pf})$ * incident neutral-flux where A_{pf} is a constant value on the red highlighted surface shown here

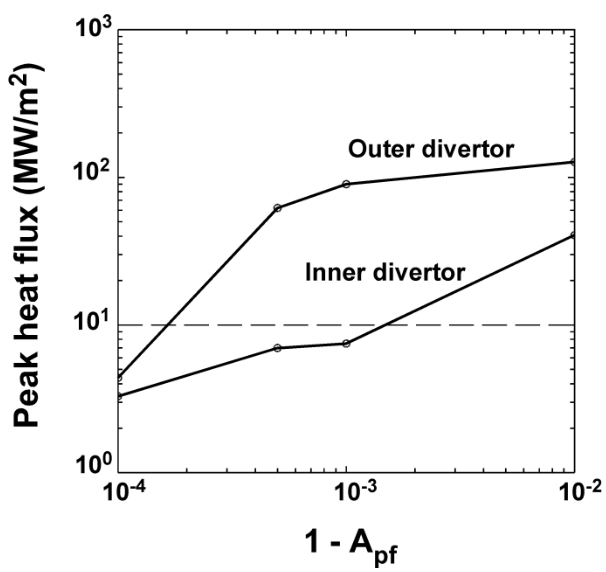
- typical values are $(1 - A_{pf}) = 0.0001$ => 0.01

- stronger pumping reduces the neutral density in the pf region and leads to attached plasmas with high heat flux on the divertor plates

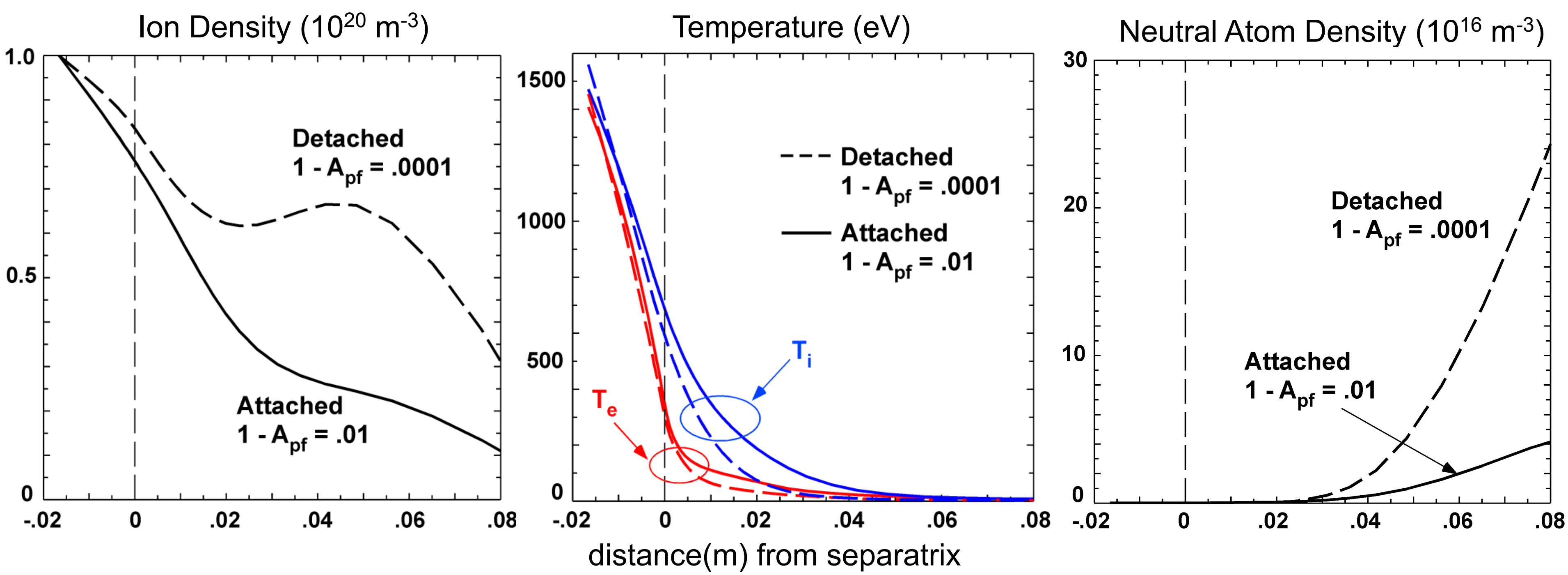


Private-flux pumping can be used to control the transition between attached and detached plasma solutions





Upstream plasma profiles near the wall are very different for attached and detached plasmas



- profiles should match up with core plasma profiles near separatrix
- radial gradient of n_i is related to particle throughput by $I_{part} \approx - D\, \partial n_i/\partial y\, A_{sepx}$

There is significant variation in particle throughput for attached and detached plasmas

- UEDGE simulations (lower half of double-null):

  I_{part} = 9444 A albdsi=0.99 (both divertors attached – high heat flux)

  I_{part} = 4724 A albdsi=0.9999 (both divertors detached – low heat flux)

- Compare with estimate from systems code for ACT-I:

  $I_{part} = \langle n_i \rangle$ * vol / tau_p

  where

  tau_p = 5 * tau_E = 8 sec

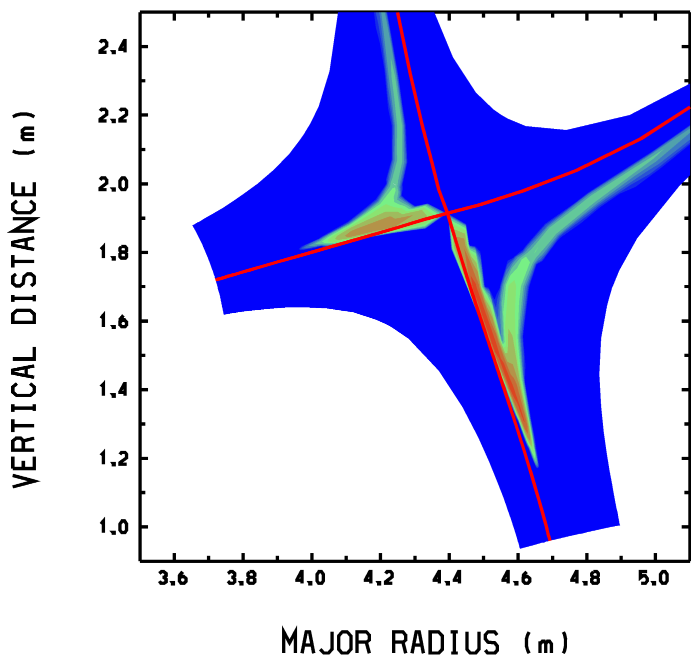
  $\langle n_i \rangle = 1.2e20 / m^3$

  vol = 400 m^3 for full double-null

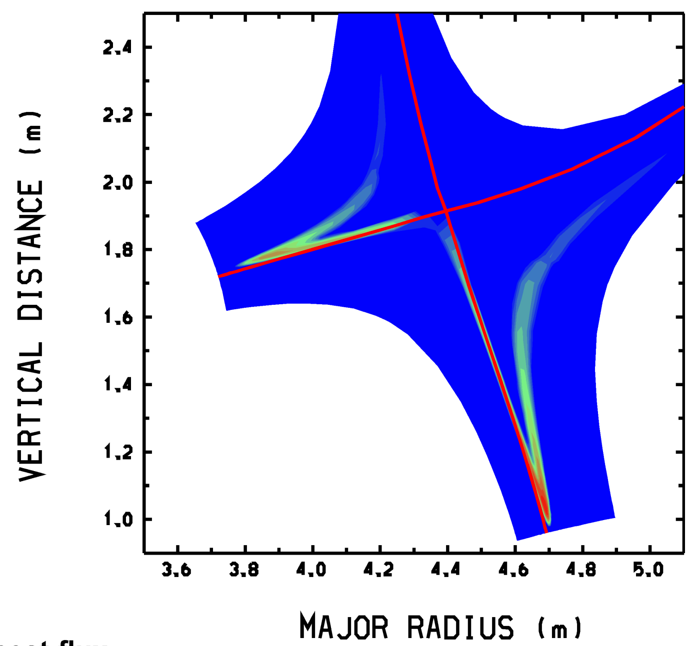
  $I_{part} = 3 \times 10^{21}\ sec^{-1}$ = 50 A for lower half of double-null

Favorable detached divertor-plasma regime occurs only over a limited range of A_{pf}

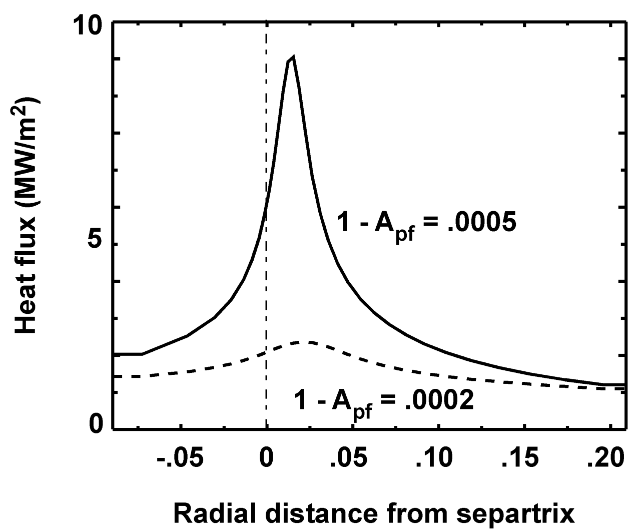
Neon radiation for $1 - A_{pf} = 0.0002$



Neon radiation for $1 - A_{pf} = 0.0005$



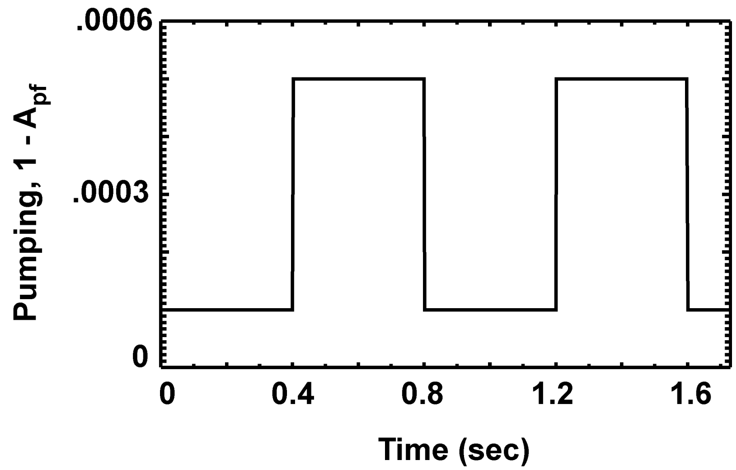
Outer divertor heat-flux



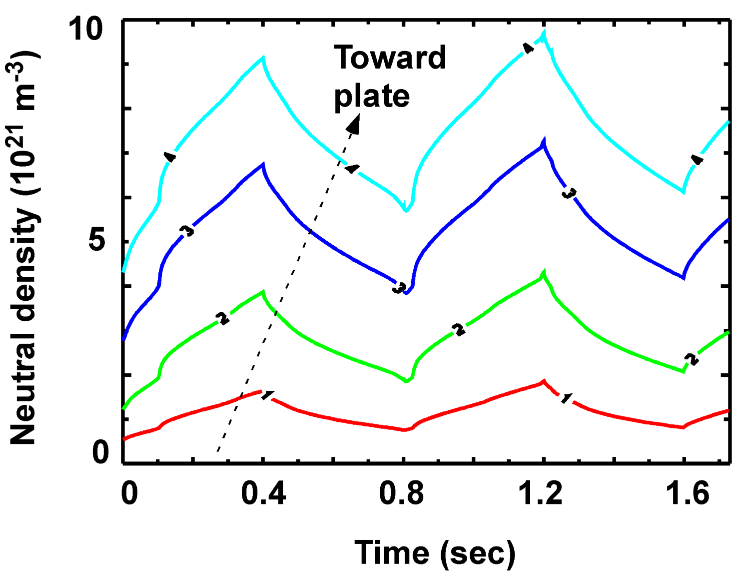
Time-scale of divertor plasma evolution is slow, ~0.5 sec, suggesting control by pumping/gas-puffing

Temporal modulation of A_{pf} shows timescale – set by SOL particle confinement

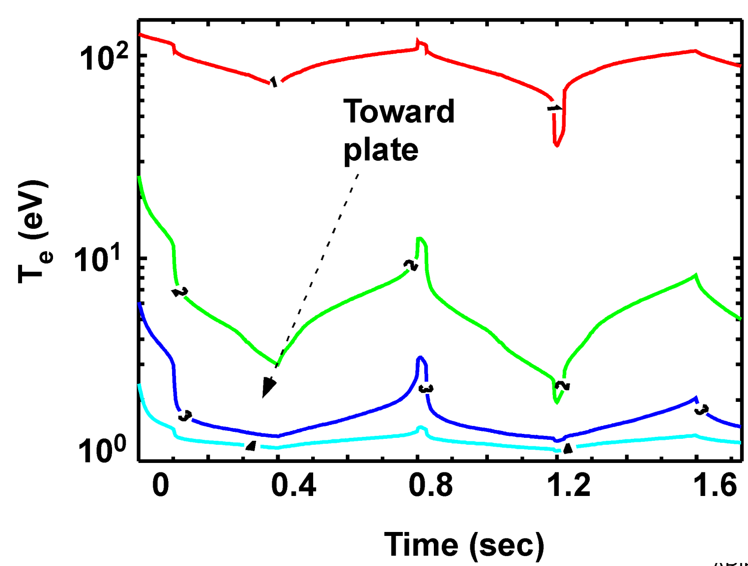
Pumping imposed vs. time



Private flux gas density at various locations



Electron temperature at various locations



Tilting the divertor plates produces competing effects

(1) **It increases the wetted area of the plate, leading to lower heat flux**

(2) **It causes inward radial transport of particles at the target plate, leading to higher temperatures in the SOL and higher heat flux**

For attached plasmas, effect # 1 dominates:

increased tilt => decreased Q_{peak}

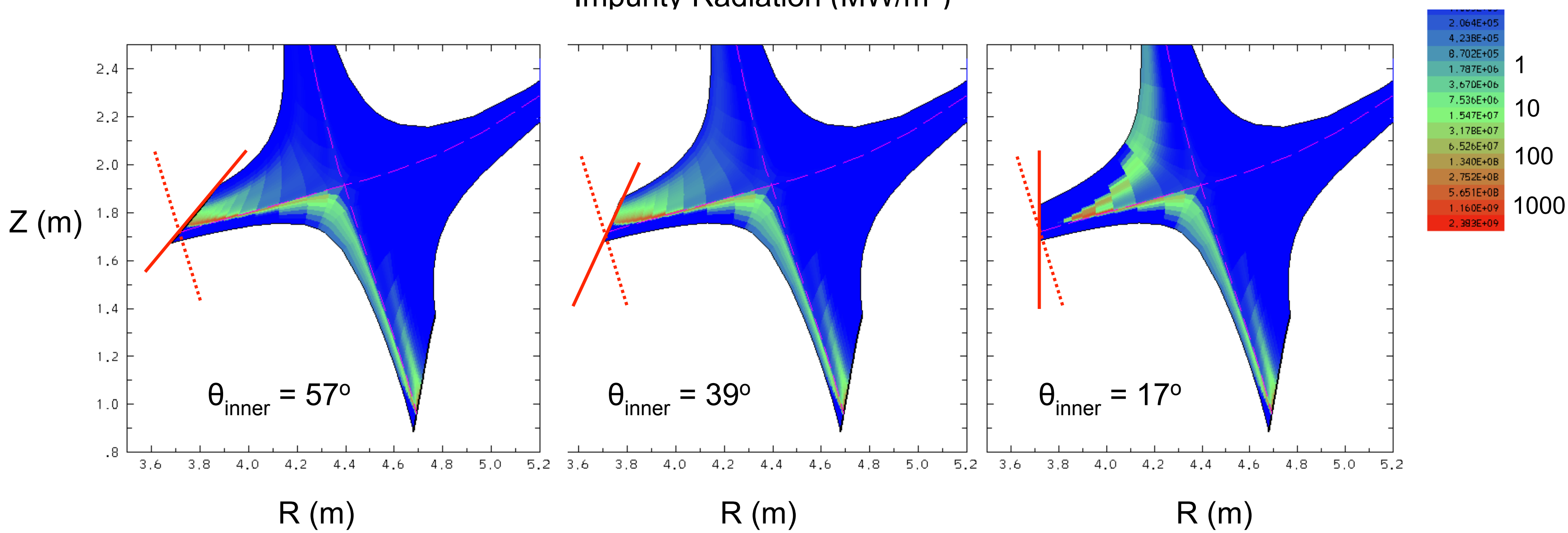
For detached plasmas, effect # 2 dominates:

increased tilt => re-attachment and increased Q_{peak}

Tilted divertor plates can be used to control a transition between attached and detached plasma solutions

- Only the inner plate is varied; outer plate remains fixed

Impurity Radiation (MW/m^3)



$Q_{peak,inner}$ = 11.1 MW/m^2 $Q_{peak,inner}$ = 8.9 MW/m^2 $Q_{peak,inner}$ = 3.0 MW/m^2

Summary

- Attached plasmas have unacceptably high heat flux on the divertor plates

- Detached plasmas have peak heat flux less that 10 MW/m^2

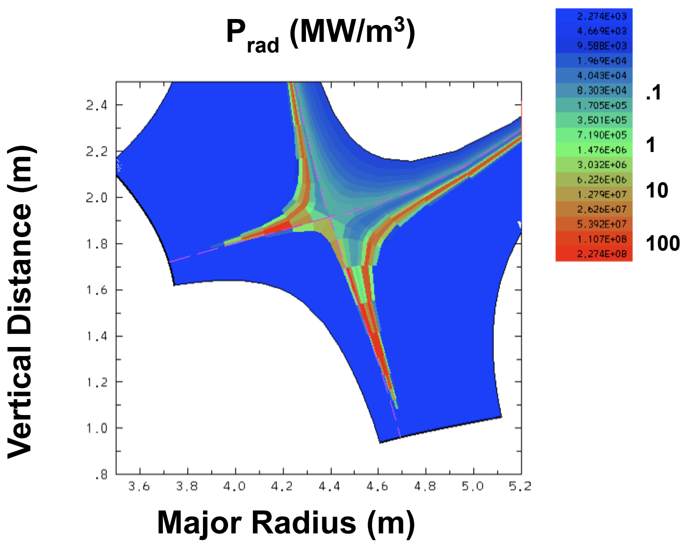
- Several key parameters determine the divertor plasma state:

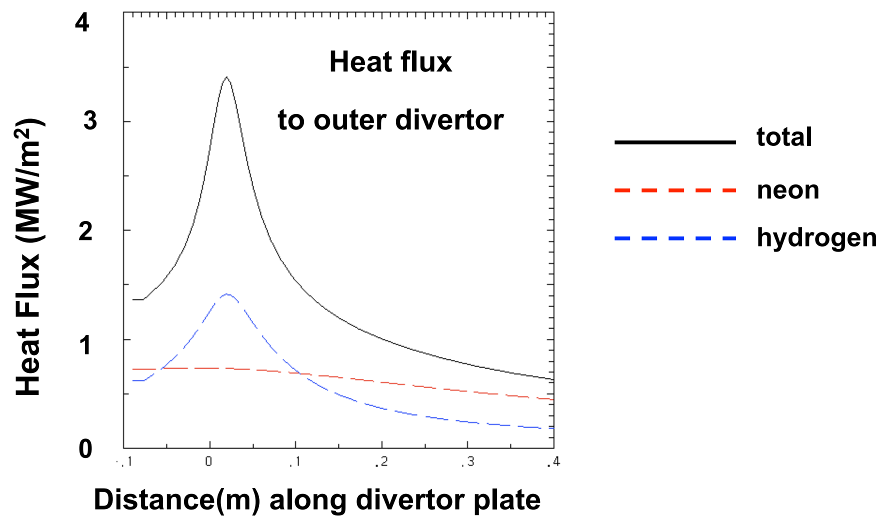
  θ_{inner}, θ_{outer}, A_{pf}, f_{imp}, n_{ped}, P_{SOL}

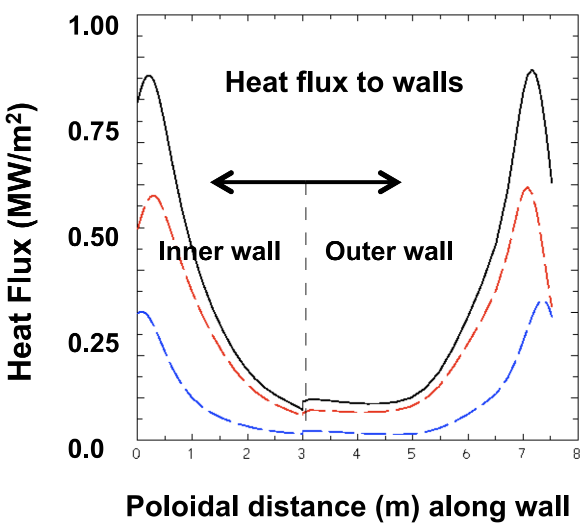
- Particle pumping and plate tilting can be used to control the transition between attached and detached plasmas
  - Pumping/gas-puffing may offer dynamic detached-plasma control

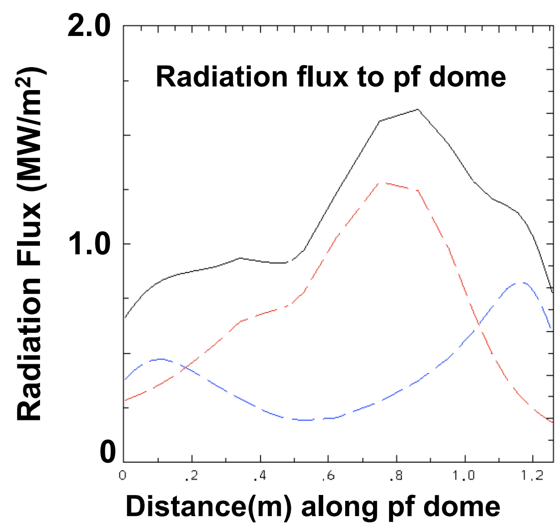
Follow-on to yesterday's discussion: particle and radiation heat loads to side walls and target plates

Heat flux to divertor and side wall: orthogonal plates, detached plasma









Heat flux to divertor and side wall: strongly tilted plates, attached plasma