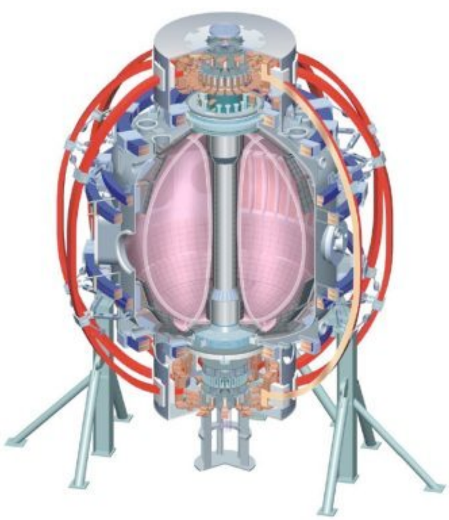
NSTX Supported by U.S. DEPARTMENT OF ENERGY Office of Science

# Thermography analysis of transient events in NSTX


**K.Gan(ASIPP)**

**R.Maingi, J-W.Ahn, T.K.Gray(ORNL), A.G.McLean(LLNL)**



# Outline

- Calculate the 2D heat flux distribution with TACO code
  - How to choose the α parameter
  - Comparison of the Taco and Theodor results
- The characteristics of ELM divertor heat flux
  - Type III ELM
  - Type V ELM
  - Type I ELM
  - Different situation ELM heat flux
- Survery the power load with 2D heat flux distribution
  - Toroidal asymmetry on divertor heat flux
  - Strange edge transport during L-H transition
  - Different 2D heat flux between type V and type III ELM

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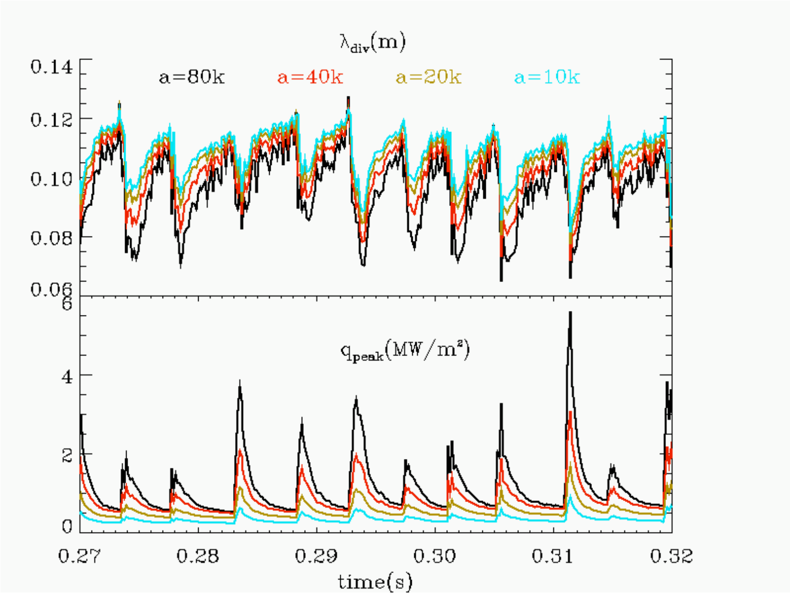
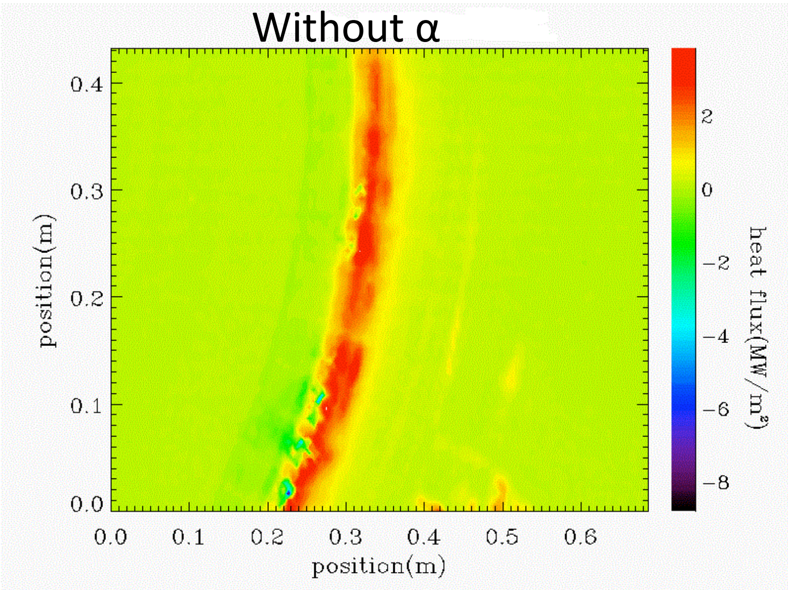
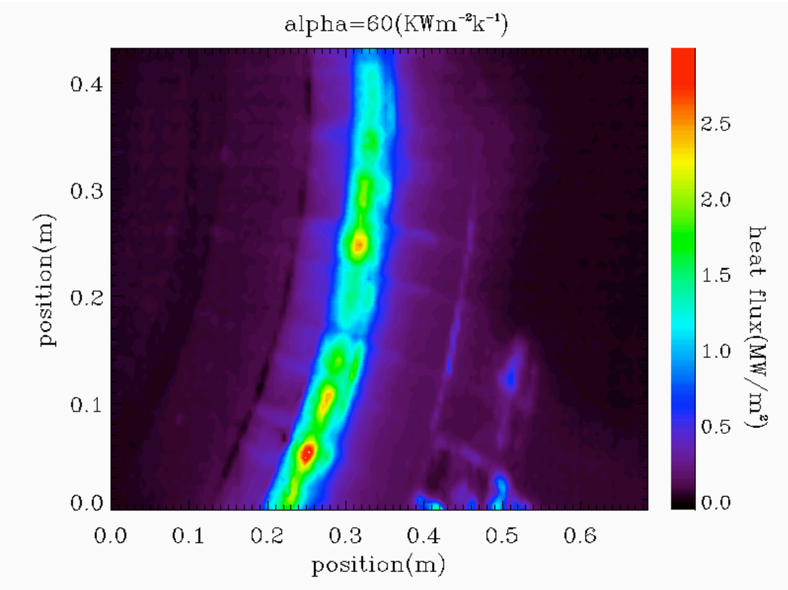
# Taco code

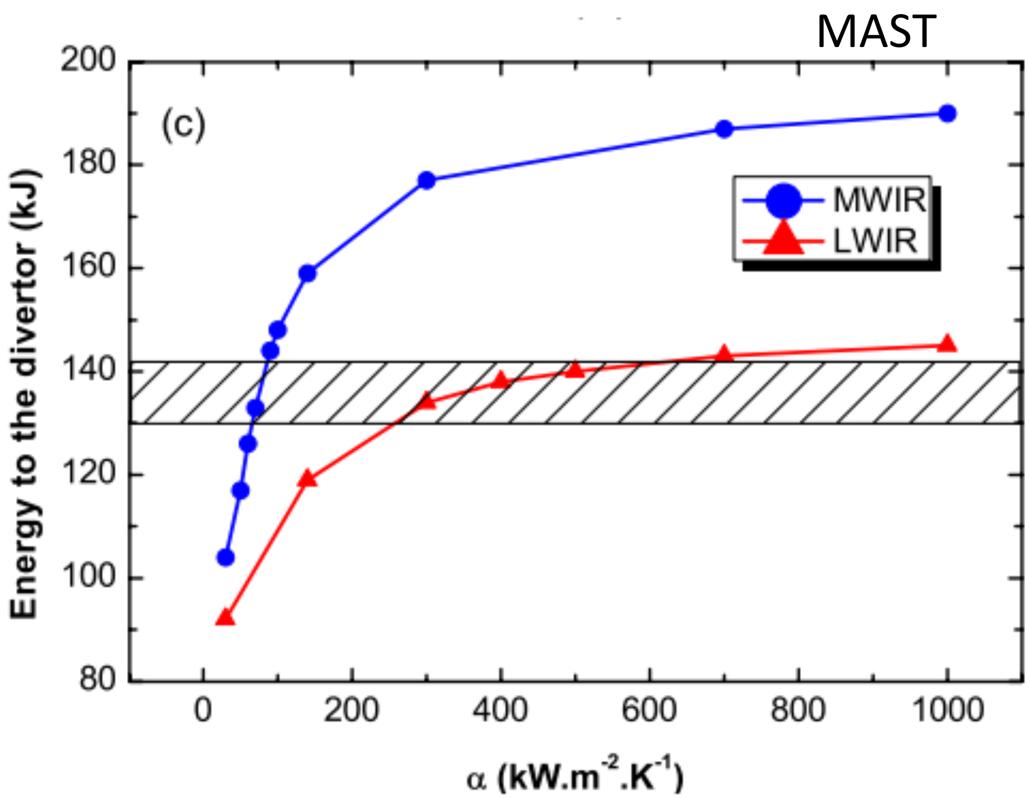
- Taco is a inversion algorithm on a 3D Fourier method which solve the heat transfer equation and get 2D heat flux data.
- previous Taco did not consider the heat transmission coefficient, α parameter (Herrmann)
- Negative heat flux was often calculated after transient event
- Negative heat flux can be removed with α parameter
- α parameter has large impact on the calculation of peak heat fluxes

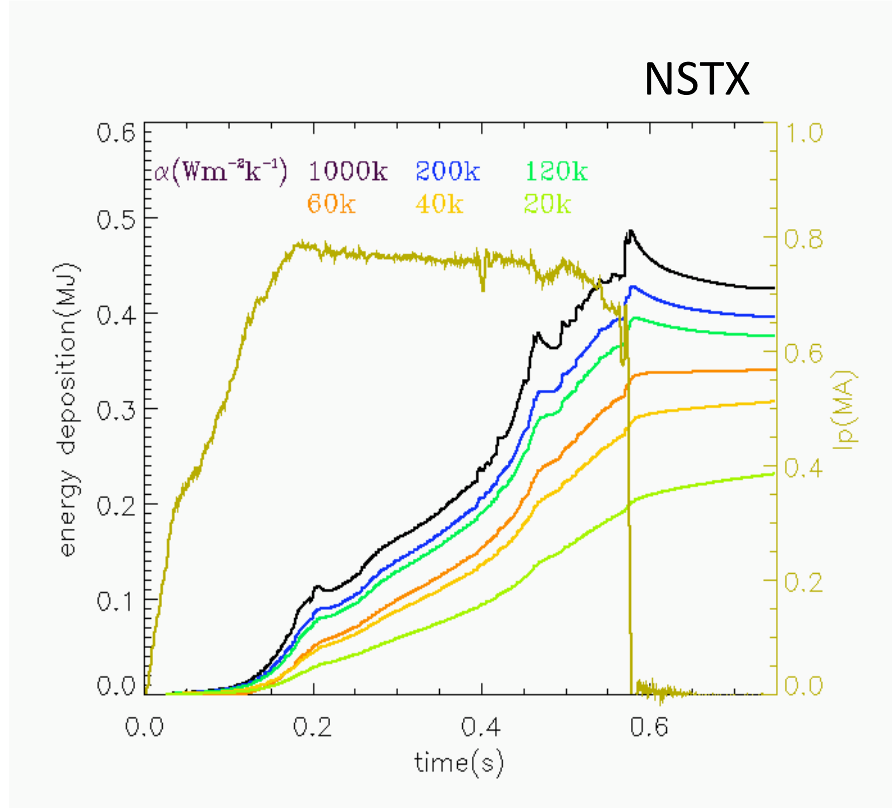


# Choose the α value

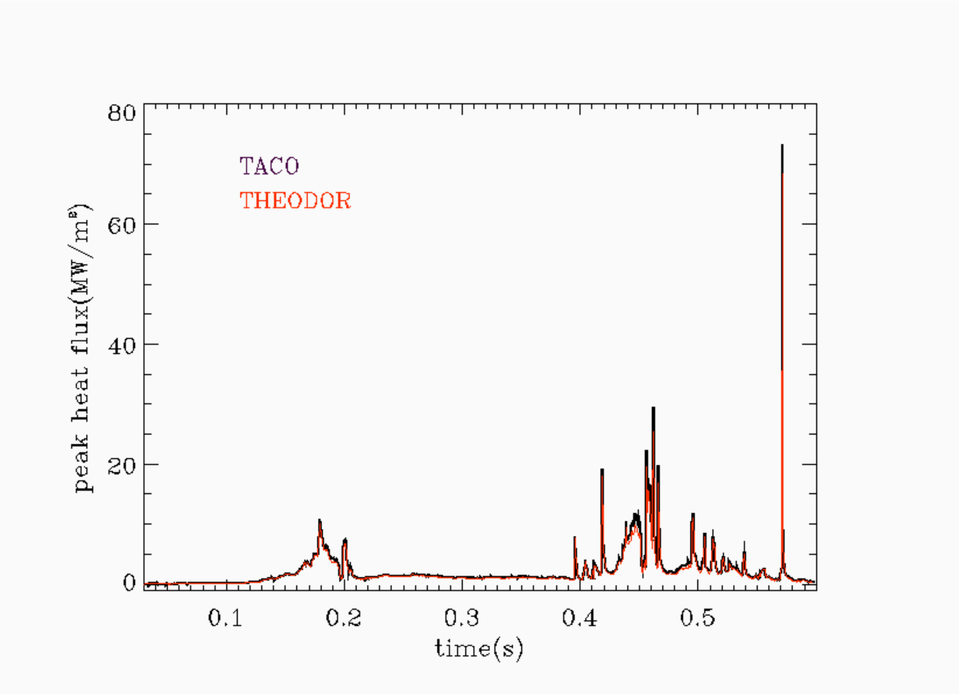


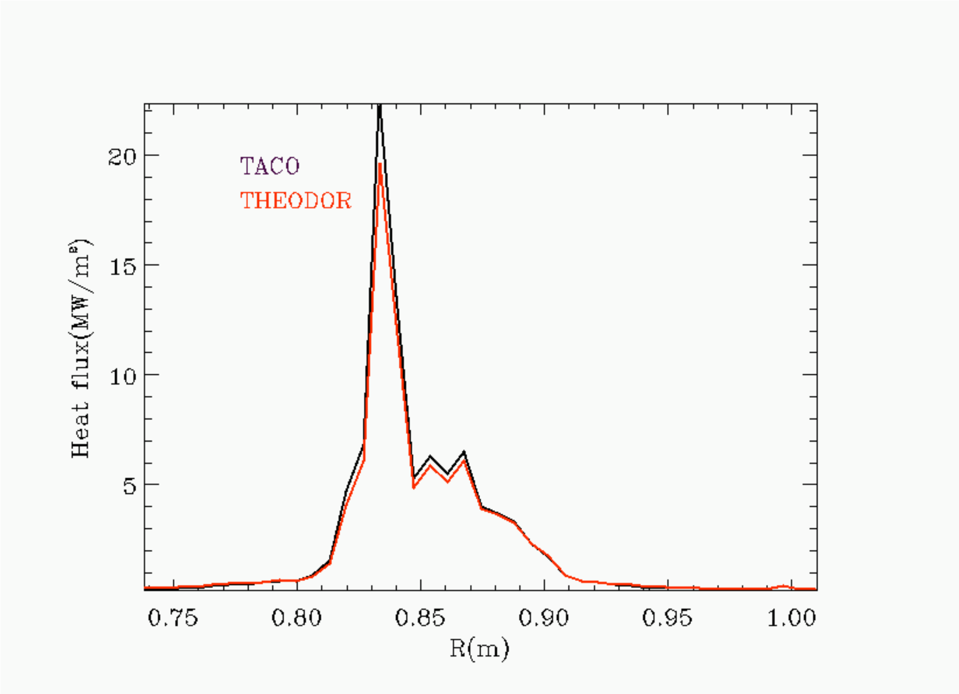




G De Temmerman, PPCF, 52 (2010) 095005 (14pp)

- IN MAST, the optimum value of α for the LWIR case sits at the knee of the curve while in the MWIR case, it sits in the steepest part of the curve
- IN NSTX, Choose the α value to keep the energy deposition constant after discharge

# Comparison of TACO and THEODOR results




- Good consistent q on a single radial line between TACO and THEODOR
- The heat flux distribution almost the same between TACO and THERDOR on a single radial line

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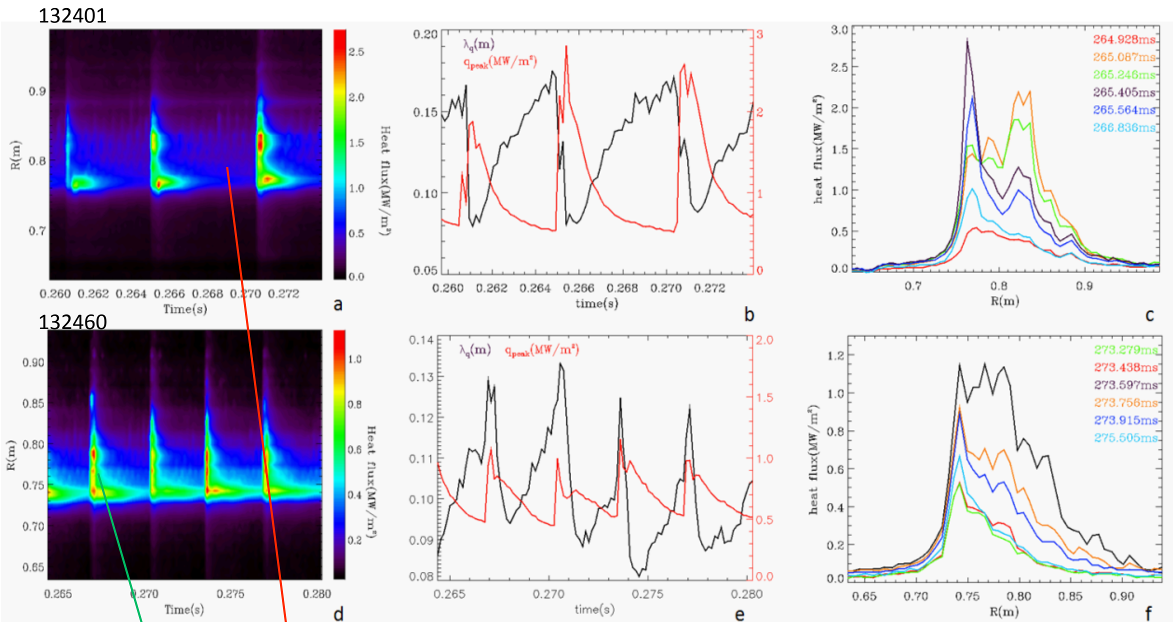
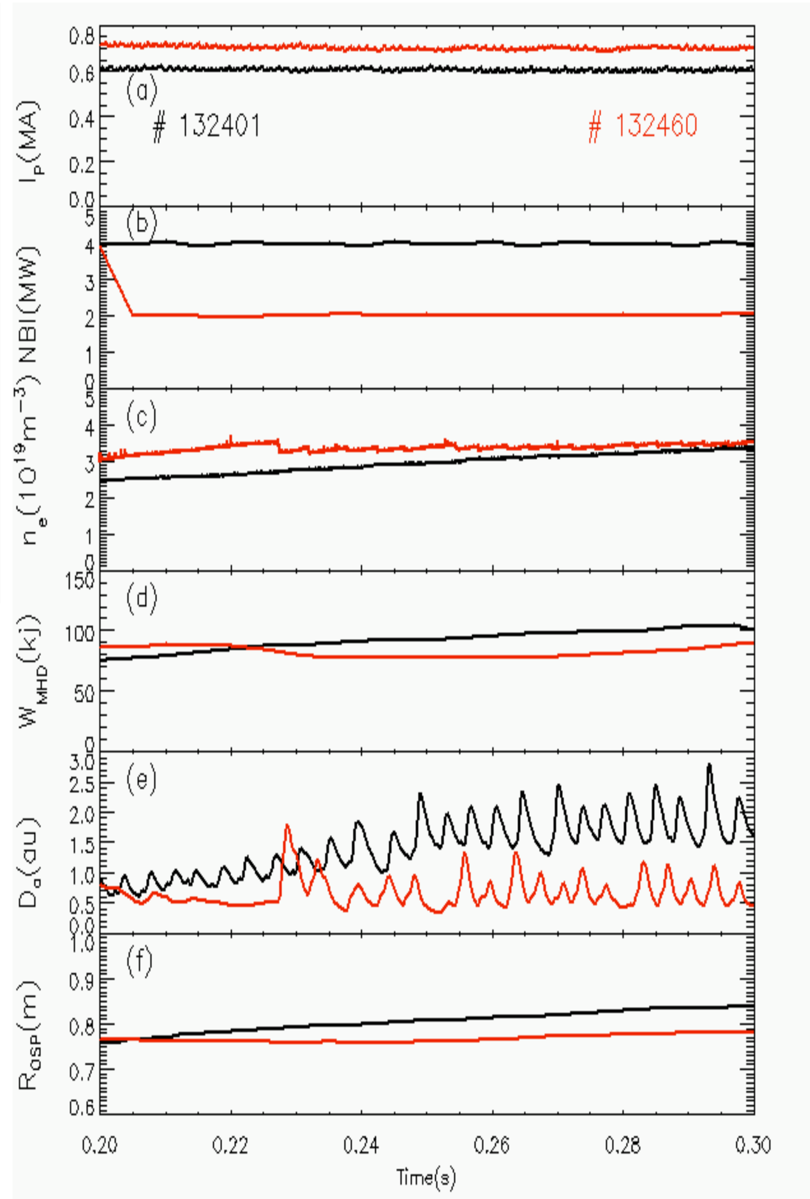
# Divertor heat flux during type III ELM




- Intermittent (2KHZ) type V ELM existed between type III ELM

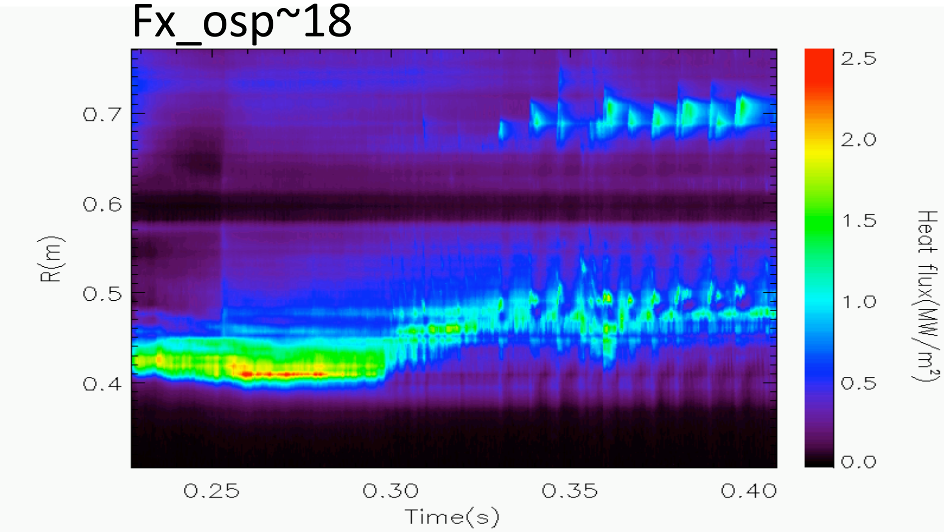
- ELM filament happened during ELM, $\lambda_q$ will be smaller after ELM filament

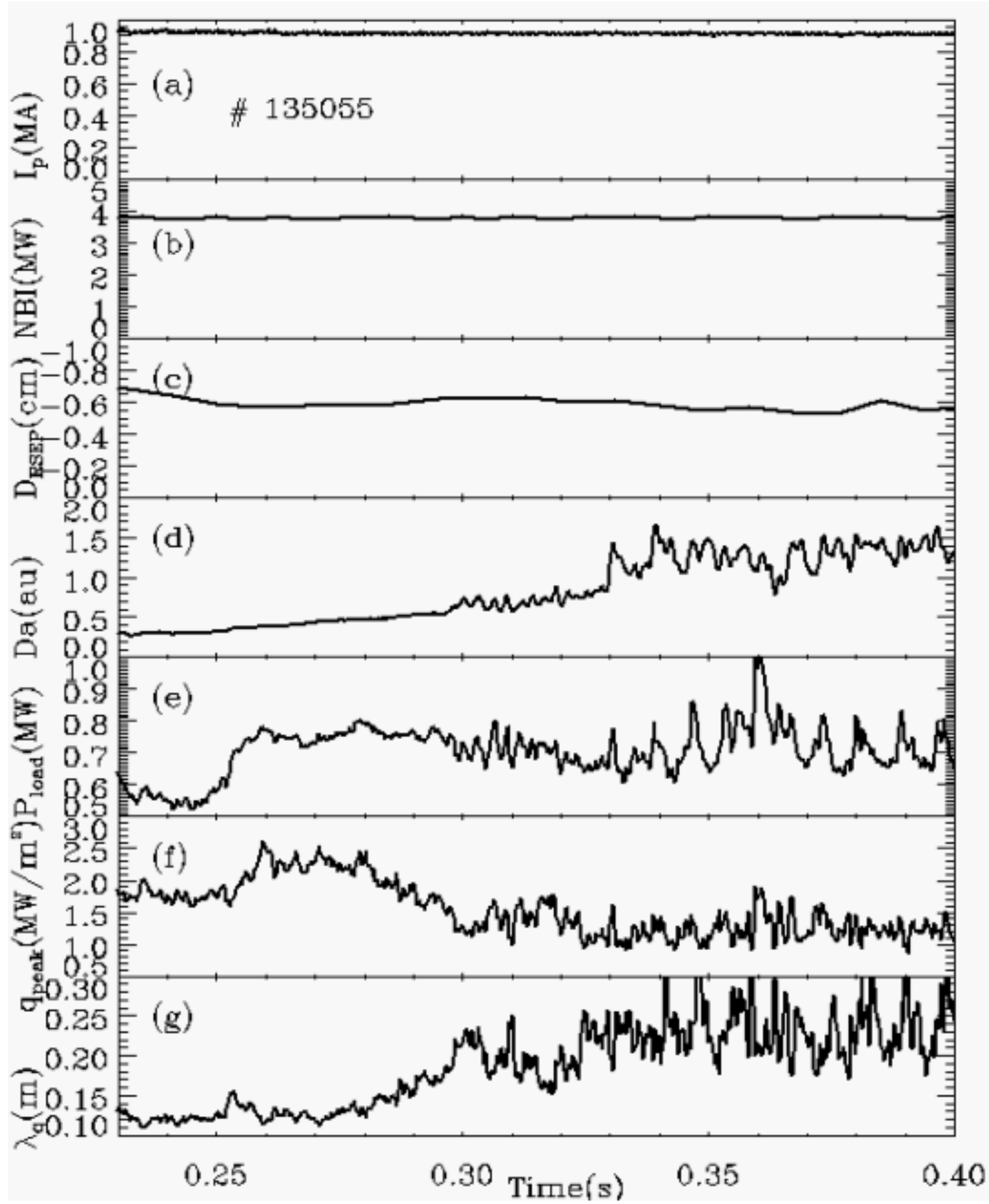
- $\lambda_q$ increase (decrease) with ELM for shot 132460 (132401).

# Divertor heat flux during type V ELM with high δ

- Type V ELM will Increase the transport and reduce the peak heat flux with large $\lambda_q$

- A strange heat flux region existed between 0.25-0.30s

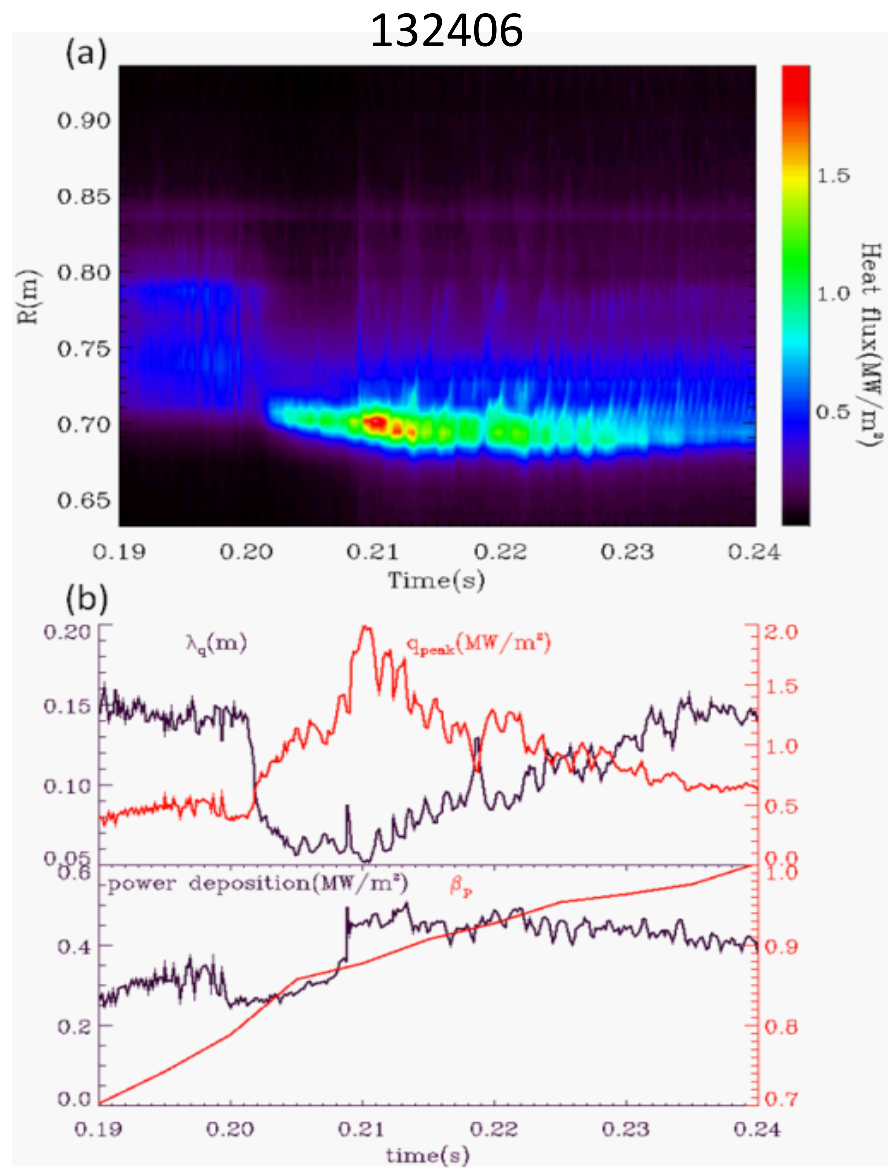


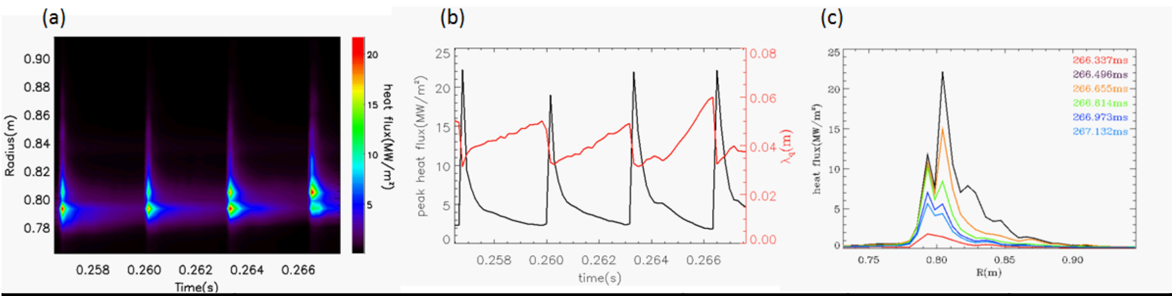
# Divertor heat flux during type V ELM with low δ

- During 0.201-0.208s, the $q_{peak}$ increased and $\lambda_q$ decreased and power deposition seems constant
- the $q_{peak}$ is 0.62MW/m$^2$ at 0.24s, 1.93MW/m$^2$ at 0.21s. It almost decreased 70% $q_{peak}$

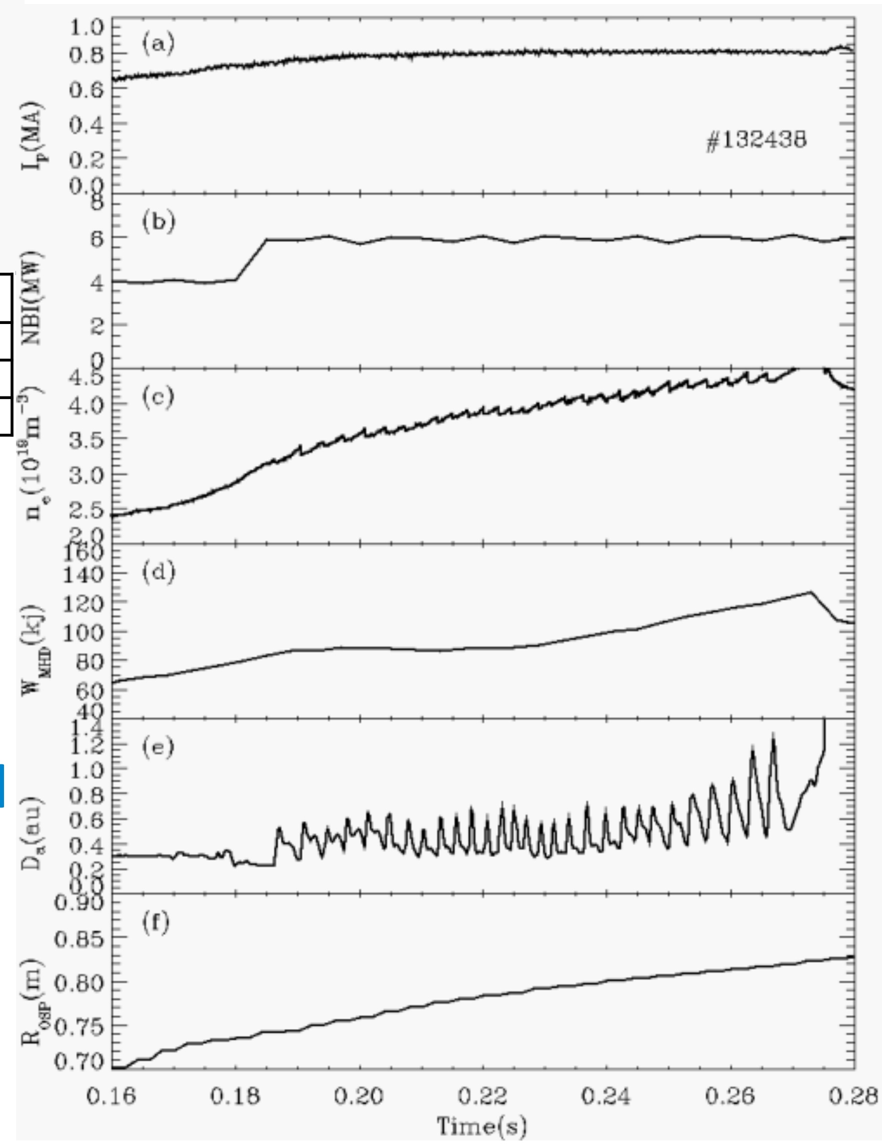
- During type V ELM, the $q_{peak}$ decreased and increased with almost constant power deposition
- Type v ELMs(0.24s) reduced the 40% $q_{peak}$ compare to ELM free phase



# Divertor heat flux during type I ELM




| Shot # | Time (s) | $\lambda_q$ (m) | fx_osp | $\lambda_{qn}$ (m) |
|---|---|---|---|---|
| 132403 | 264.928ms, type v ELM | 0.175m | 5.3 | 0.033 |
| 132406 | 204.809ms,ELM-free phase | 0.056m | 5.4 | 0.01 |
| 132438 | 266.337ms, inter-type I ELM | 0.06m | 1.85 | 0.032 |




- $\lambda_q$ decrease ~40% during type I ELM filament
- 6KHZ energy transport between type I ELM (GPI)
- $\lambda_{qn}$ is similar between type v ELM (# 132403) and inter type I ELM.

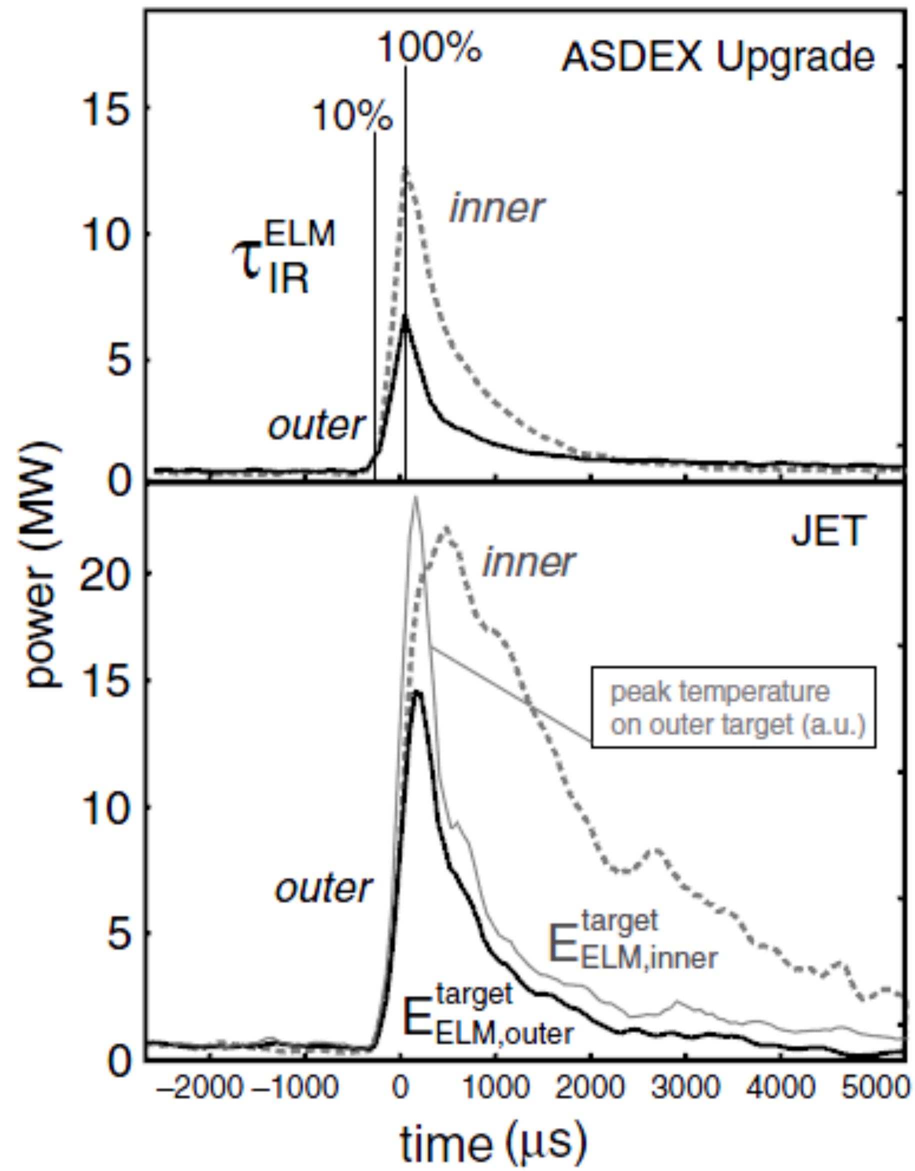
# Heat flux research in JET and ASDEX

- $\tau_{IR}^{ELM}$ was defined as ELM rise time

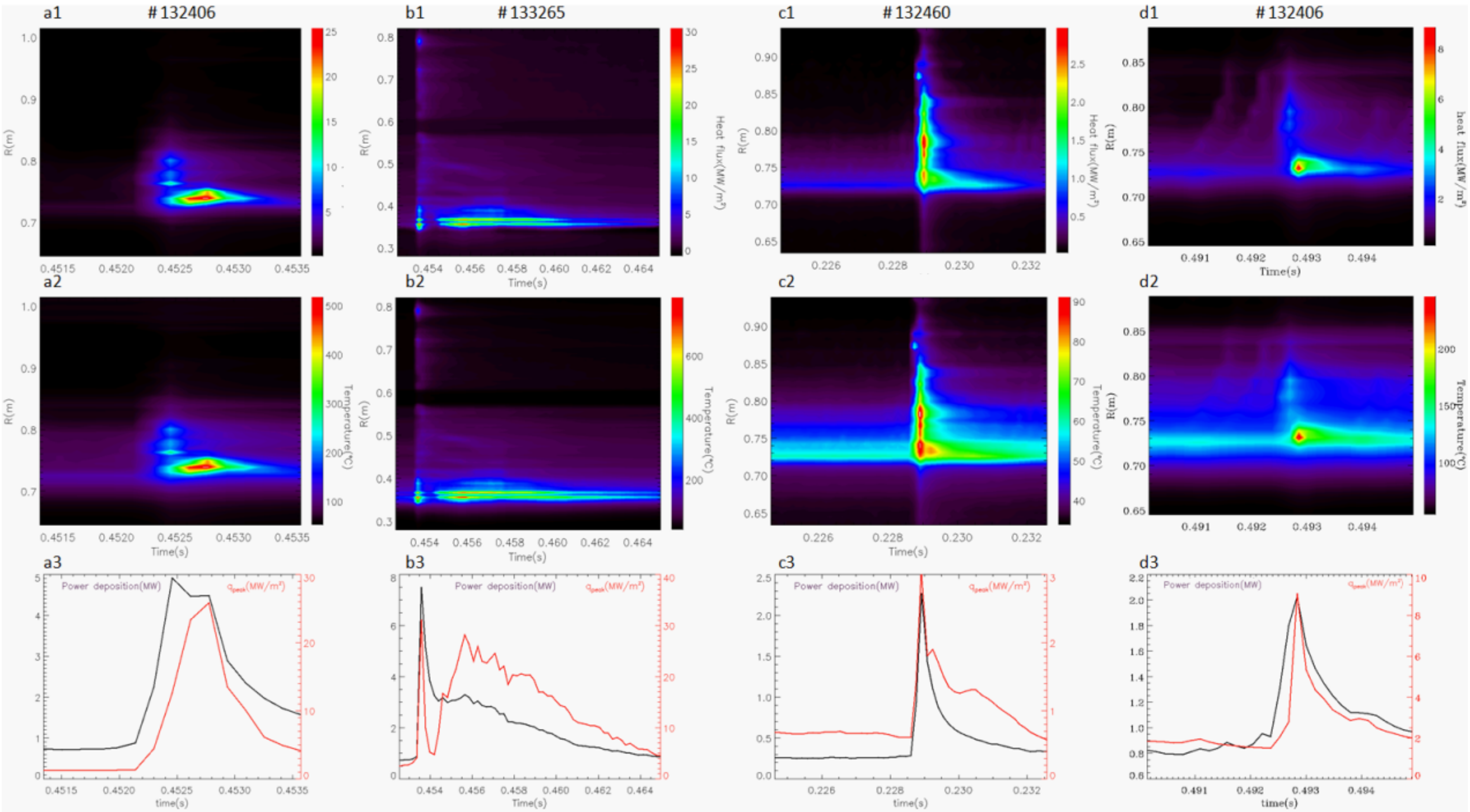
•In the first phase,( $t \le \tau_{IR}^{ELM}$ )the target temperature and the power increase up to a peak value

•In the second phase,( $t > \tau_{IR}^{ELM}$ )the target temperature decays back to the Inter-ELM value

T. Eich, JNM, 337–339 (2005) 669–676



# Different situation ELM heat flux




•Maximum power load in ELM filament, Maximum $q_{peak}$ after ELM filament (situation II ELM)

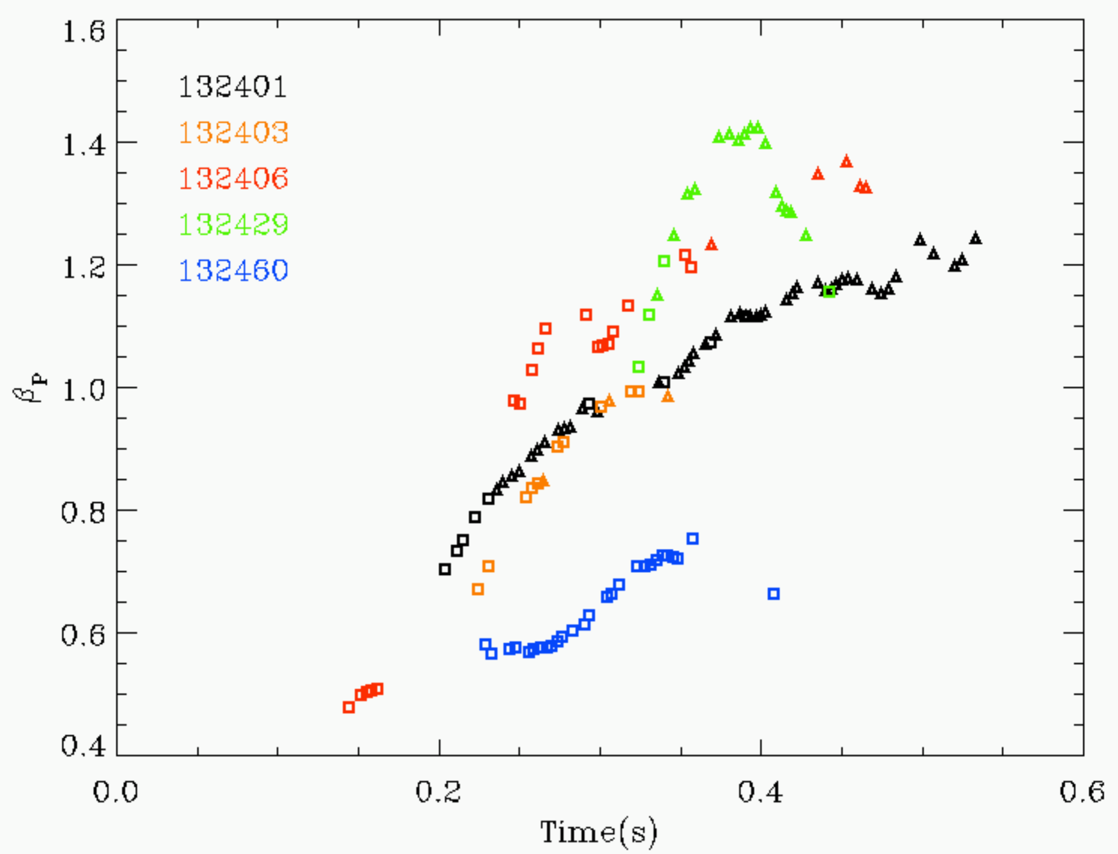
•Triggered ELM

•Maximum power load and $q_{peak}$ appeared at ELM filament (situation I ELM)

•Maximum power and $q_{peak}$ Appeared after ELM filament (situation III ELM)

# The relationship between situation I,II ELM and $\beta_p$

- The maximum $q_{peak}$ will appeared at ELM filament with a low β
- With $\beta_p$ increase, the number of situation I ELM begun to decrease, and the situation II ELM appeared.
- The real physical mechanism is still unknown




square represent the situation I ELM heat flux, triangle represent the situation II ELM heat flux

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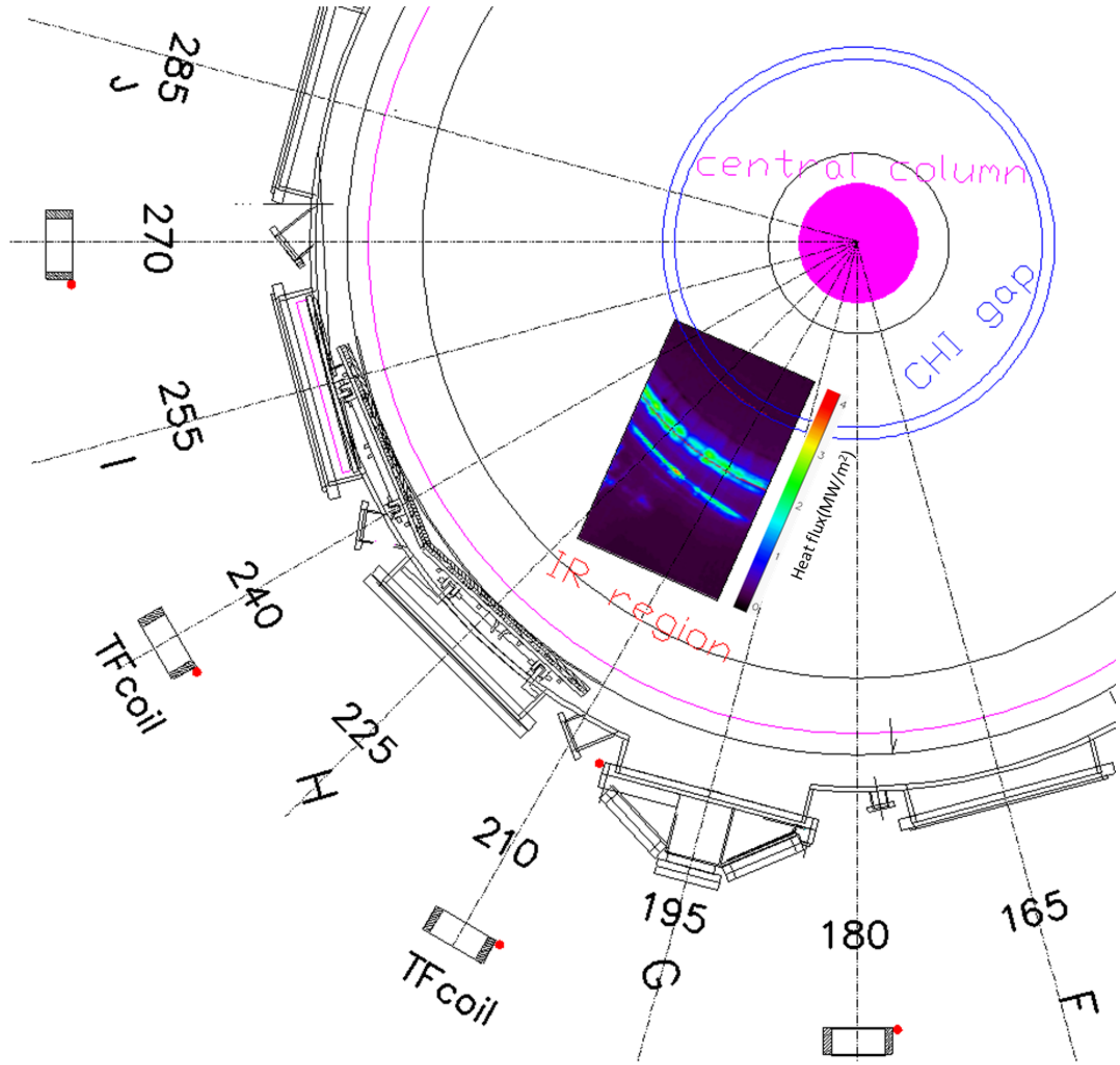
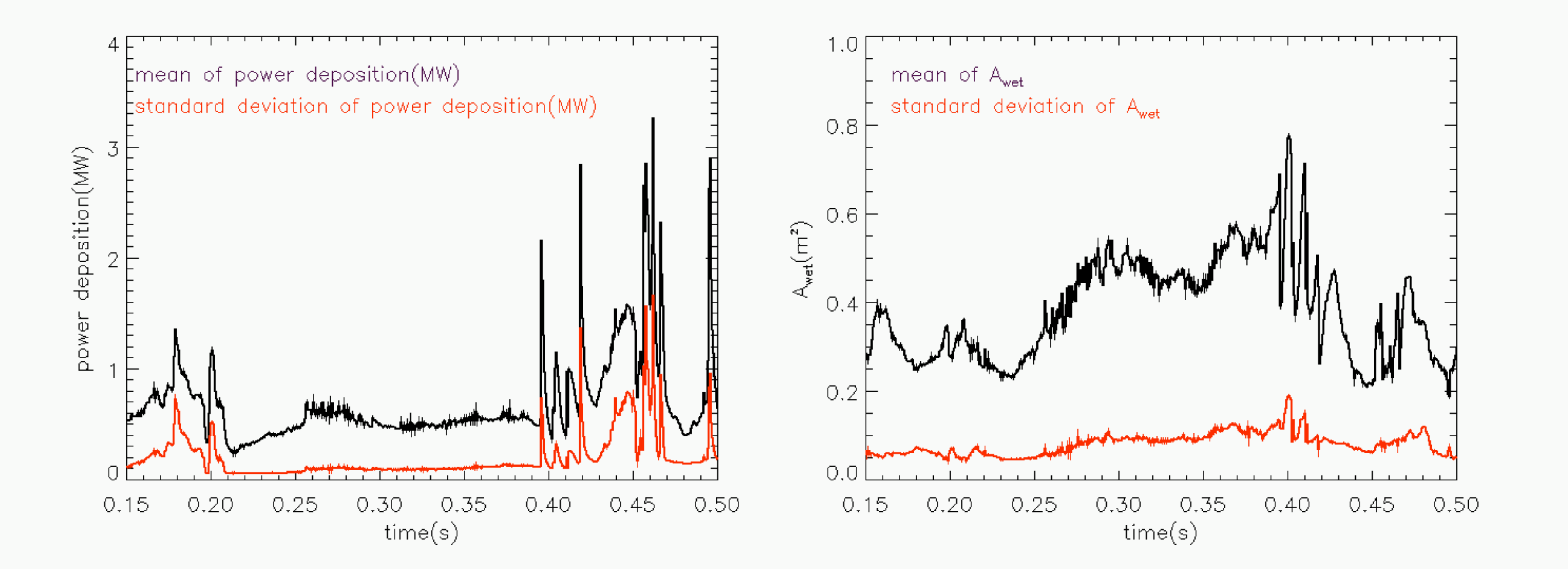
# 2D divertor heat flux distribution on NSTX



# Toroidal asymmtry on divertor heat flux



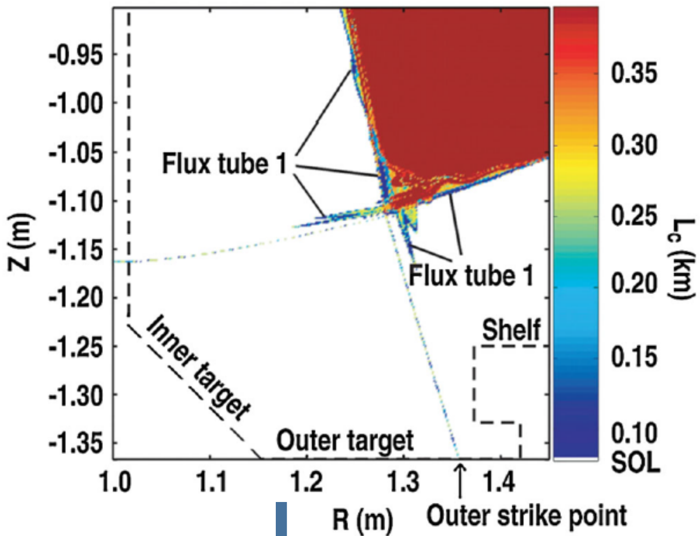

According to the toroidal asymmetry

$$P_{load} = \sum_{\phi_1}^{\phi_2} \sum_{R_1}^{R_2} q(x,y) \cdot (\delta x)^2 \cdot (\phi_2 - \phi_1)/360$$

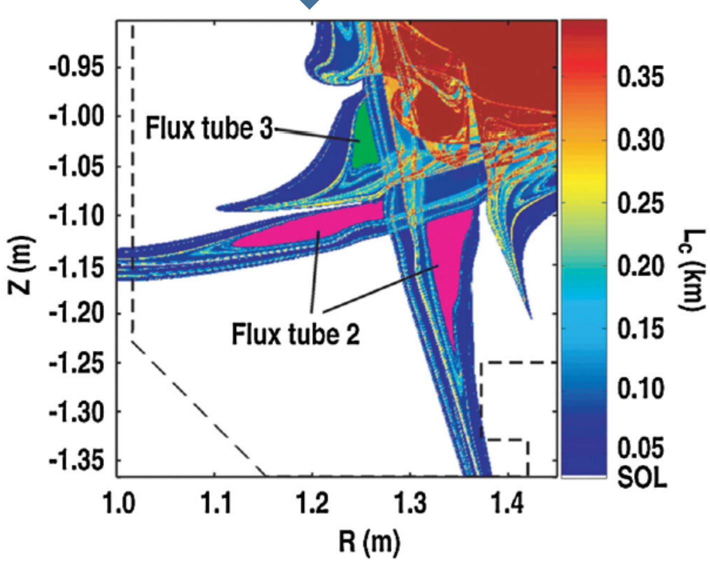
$$A_{wet} = P_{load} / q_{peak}^{mean}$$

The reason of toroidal asymmetry is still unclear, toroidal ripple, 3D structure of filaments, misalign divertor tile or inconsistent surface property (α value)

# Numerical Modeling of ELM Filaments on Divertor Plates



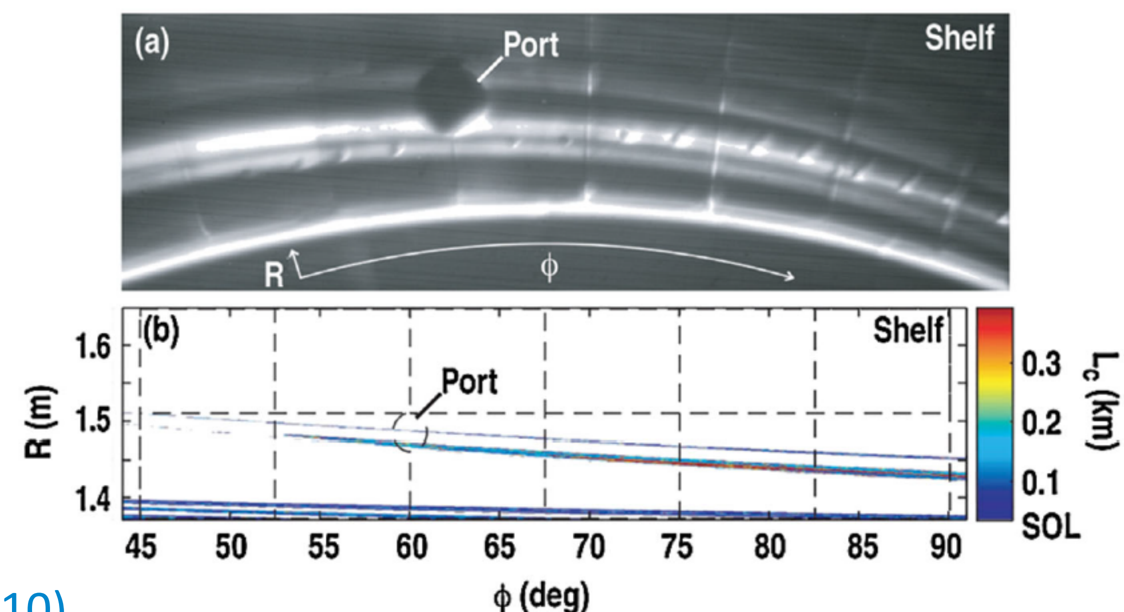

Add 300A on Flux tube 1



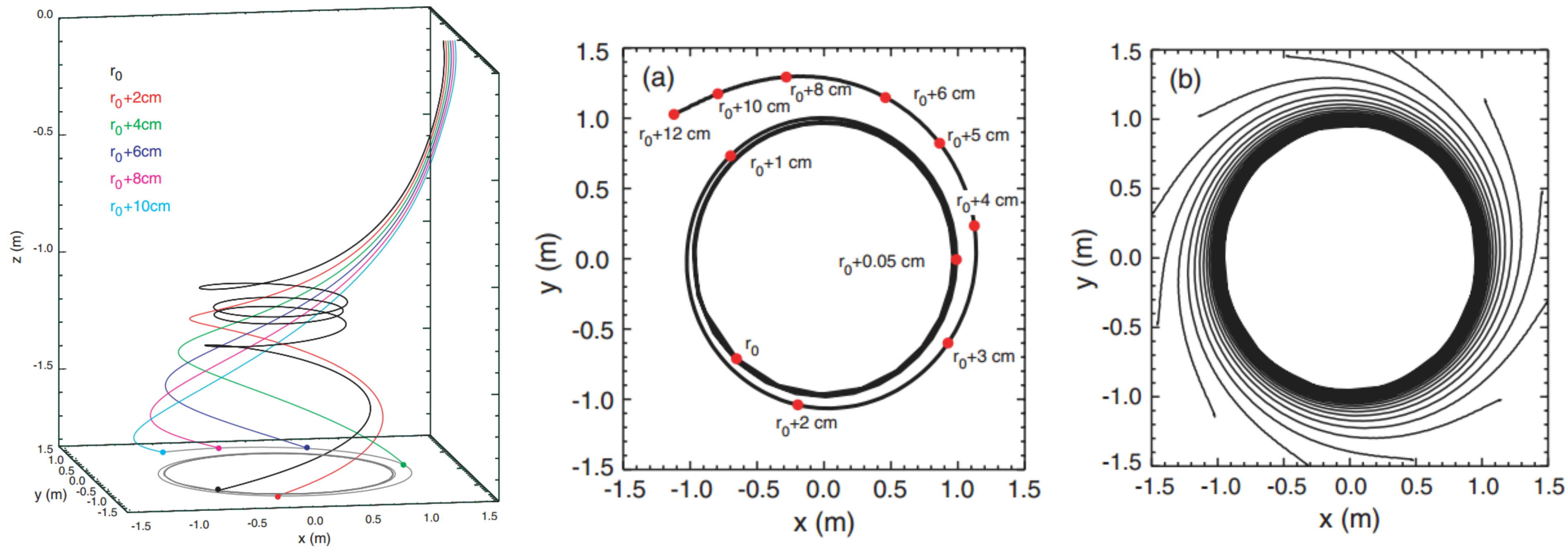

A. Wingen, PRL, 104, 175001 (2010)

- The initial heat pulse during an ELM generate thermoelectric current between two divertor plate

- typical ELM stripe structures can be correctly modeled



# **ELM power load** in MAST




**A Kirk, PPCF, 49 (2007) 1259–1275**

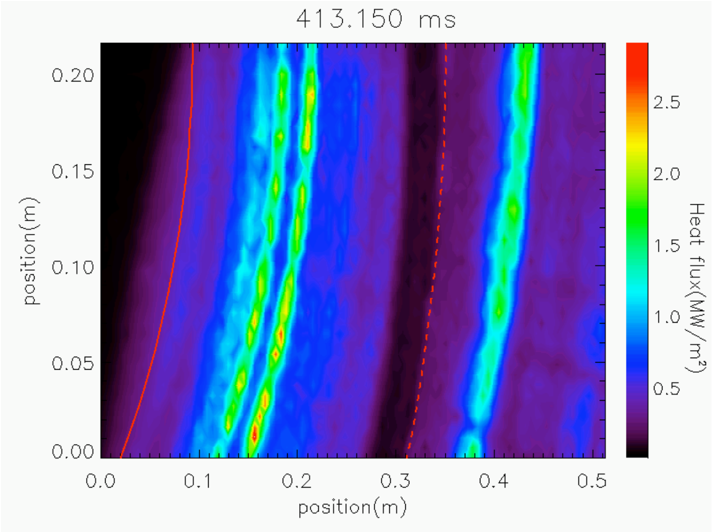
Filament at different radial position and different toroidal angle generate the striated divertor heat flux

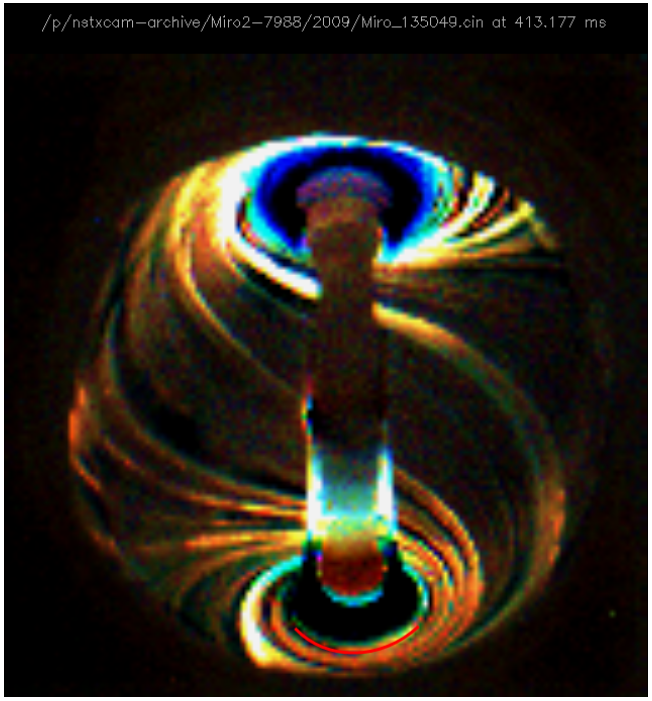
# Striated heat flux in NSTX

• The striated heat flux (R>0.61m) was generated by filaments

•It's unclear the reason which cause the striated divertor heat flux (R<0.57m)

Question: Did the filaments and magnetic topology generate the striated divertor heat fluxes together?



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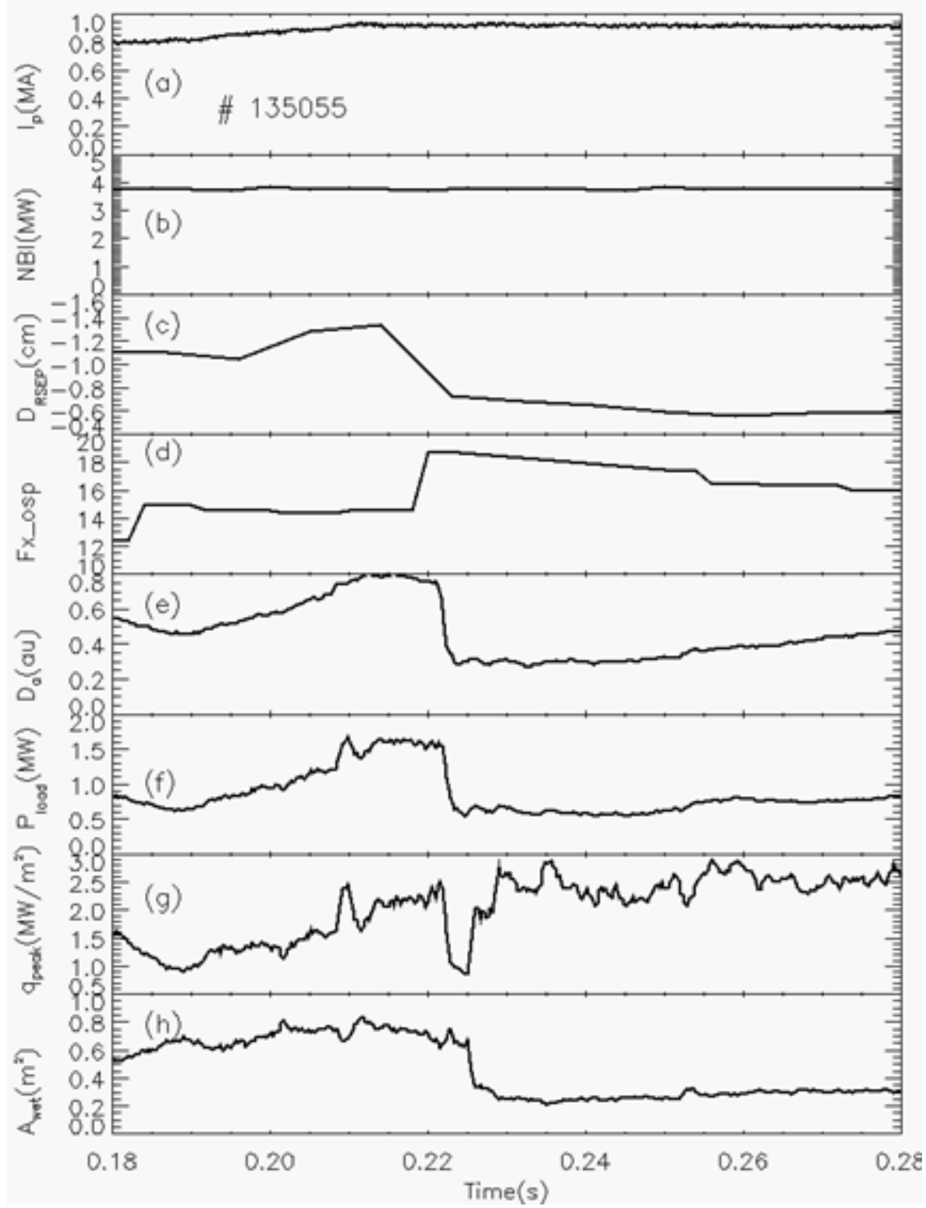
# Strange edge transport during L-H transition

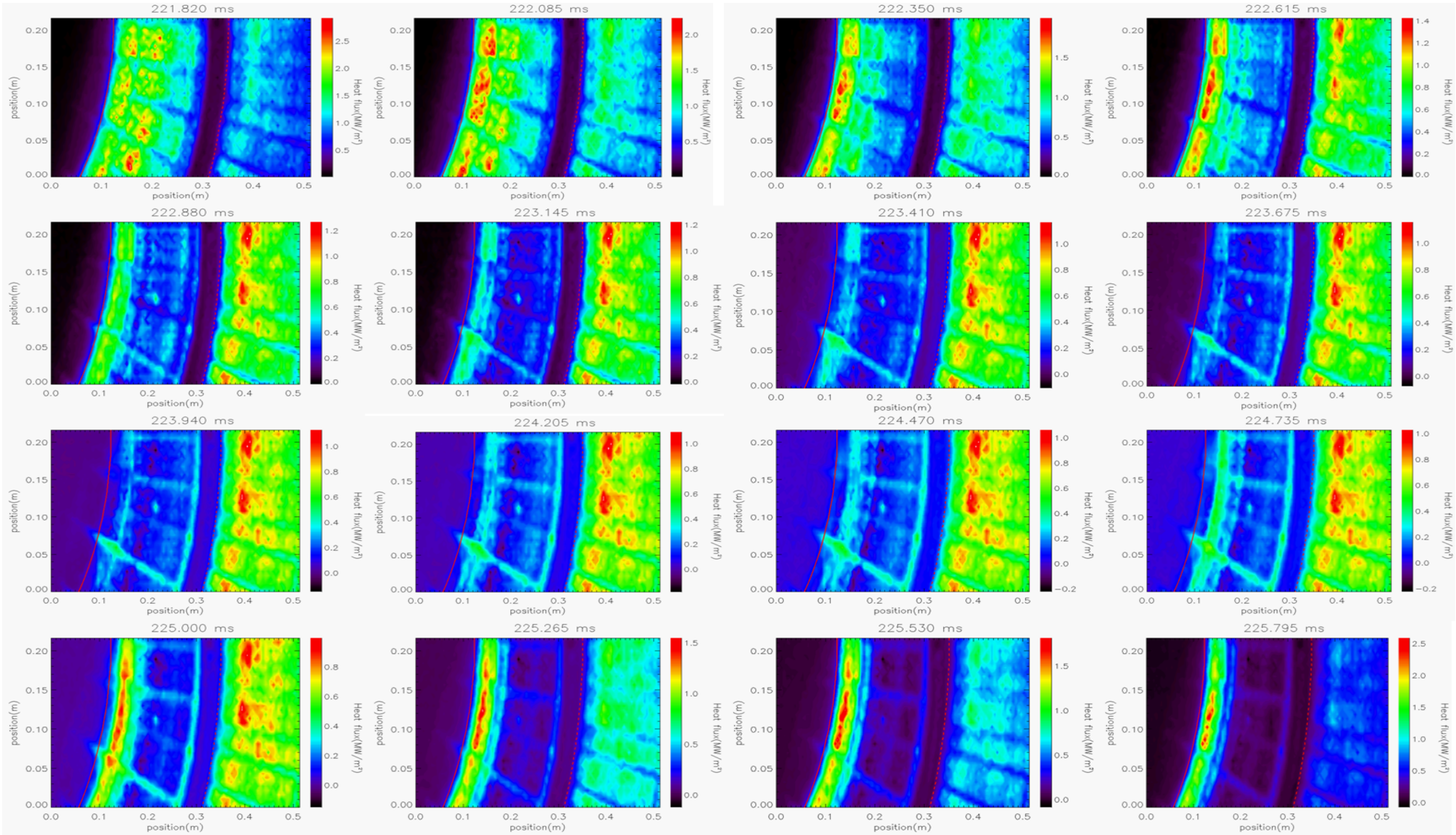
- Increasing $P_{load}$ before L-H transition was caused by decreased Drsep

- During L-H transition , the $q_{peak}$ first decrease then increase

- A delayed time existed between $q_{peak}$ and $A_{wet}$ during L-H transition



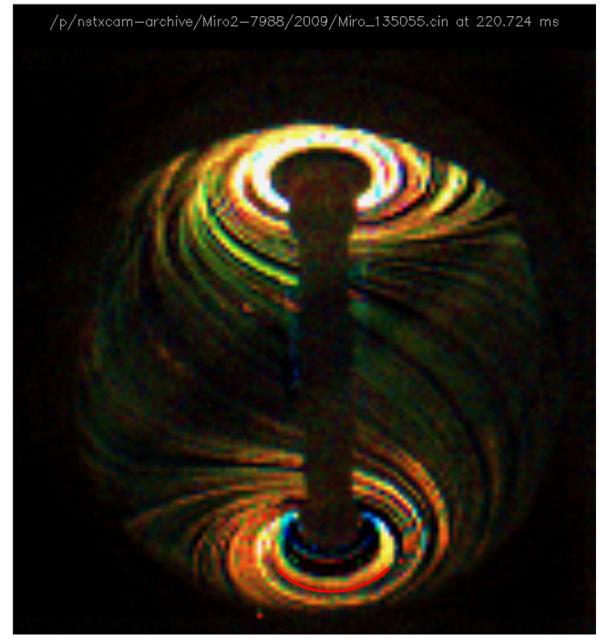
# 2D heat flux distribution during L-H transition




During L-H transition, the heat flux around the out strike point first become very small, then increase to ELM-free phase

# Filaments during L-H transition

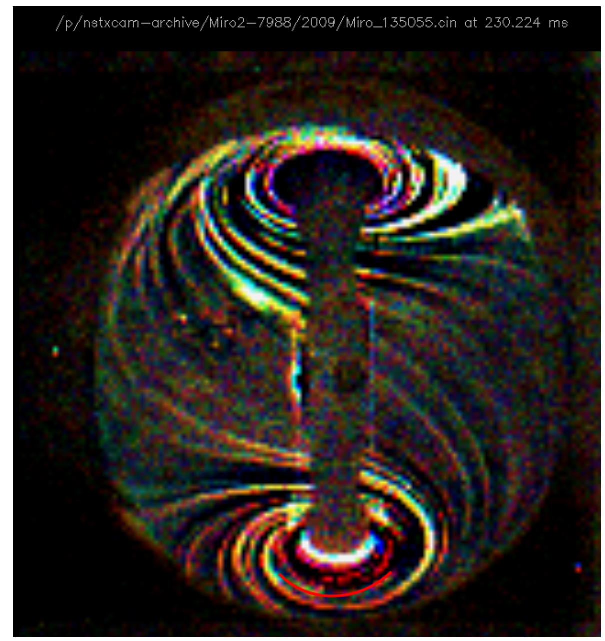
Filaments generated the striated heat flux(R>0/61m)



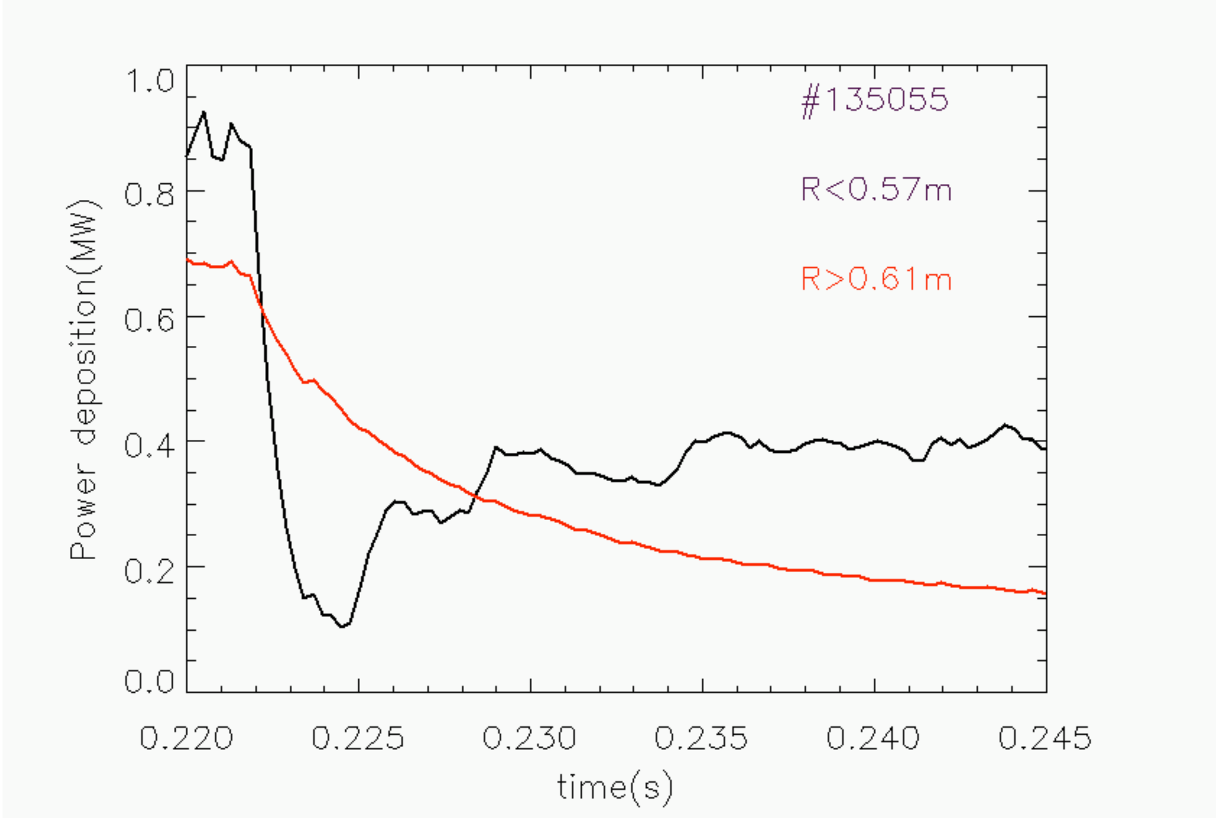

Separate the power deposition with two parts:

$$P_{in} = \sum_{\phi_1}^{\phi_2} \sum_{R<0.57m} q(x,y) \cdot (\delta x)^2 \cdot 360/(\phi_2 - \phi_1)$$

$$P_{out} = \sum_{\phi_1}^{\phi_2} \sum_{R>0.61m} q(x,y) \cdot (\delta x)^2 \cdot 360/(\phi_2 - \phi_1)$$ (filaments)



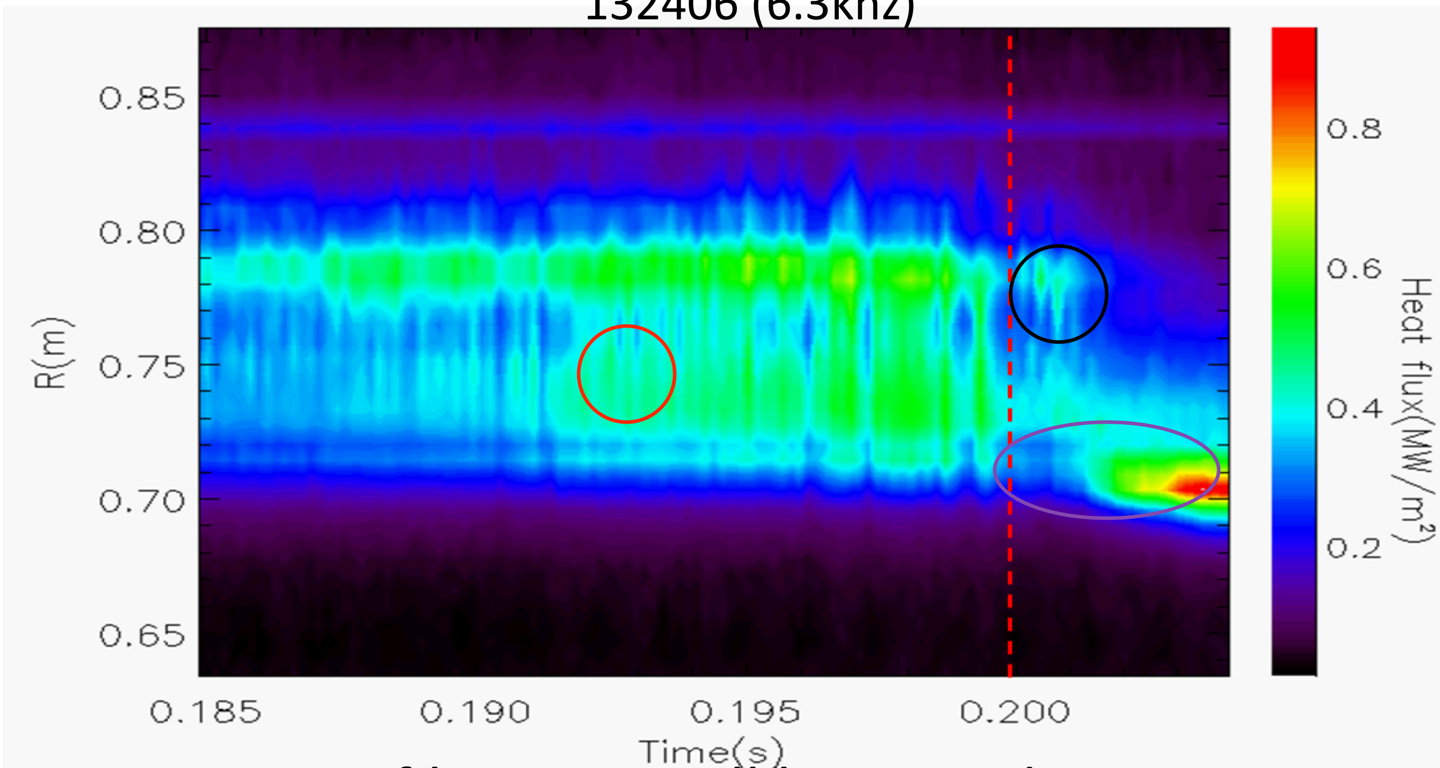
# The power load during L-H transition




## During L-H transition

- $P_{in}$ decrease fast to a low value then increase
- $P_{out}$ decrease slower than $P_{in}$
- $P_{out}$ can be several times bigger than $P_{in}$

# Heat flux evolution during L-H transition




- The intermittent filaments still happen during L-H transition

•~3KHZ heat flux oscillation appeared before L-H transition

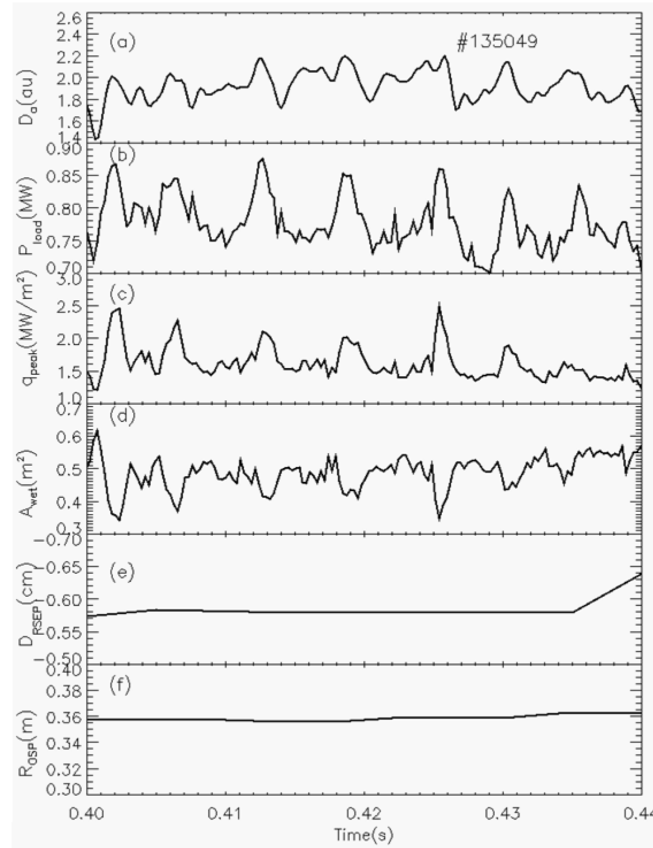
- During L-H transition, the heat flux near the OSP first decrease then increase

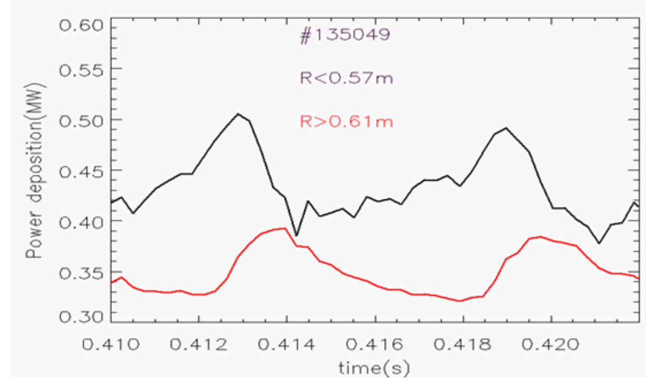
# 2D heat flux distribution during ELM

•The Power deposition seems just increase ~13% during Type V ELM peak than between ELMs

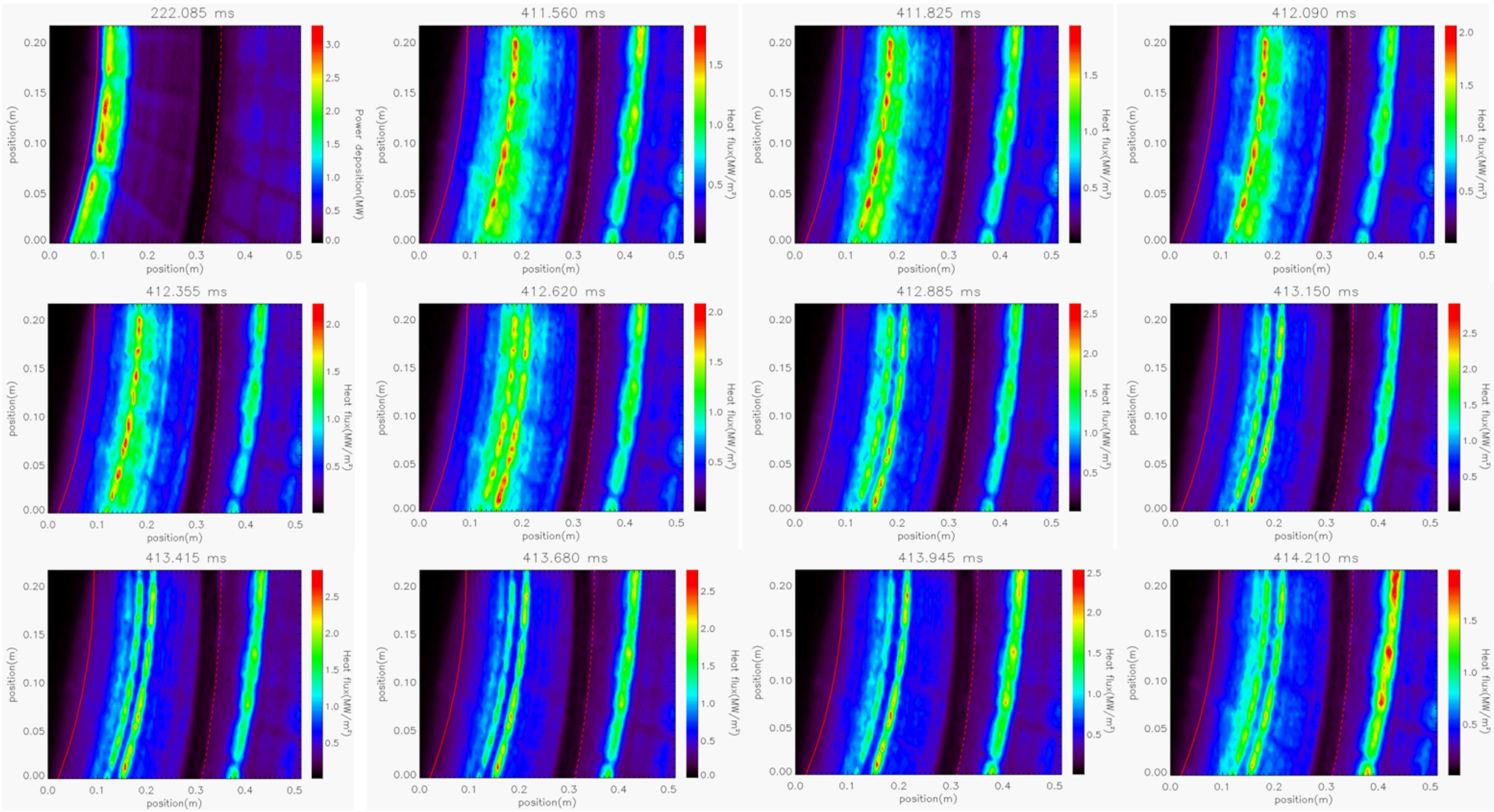
• The plasma wetting area decrease with type v ELM

• There is a delay time between $P_{in}$ and $P_{out}$ during type V ELM



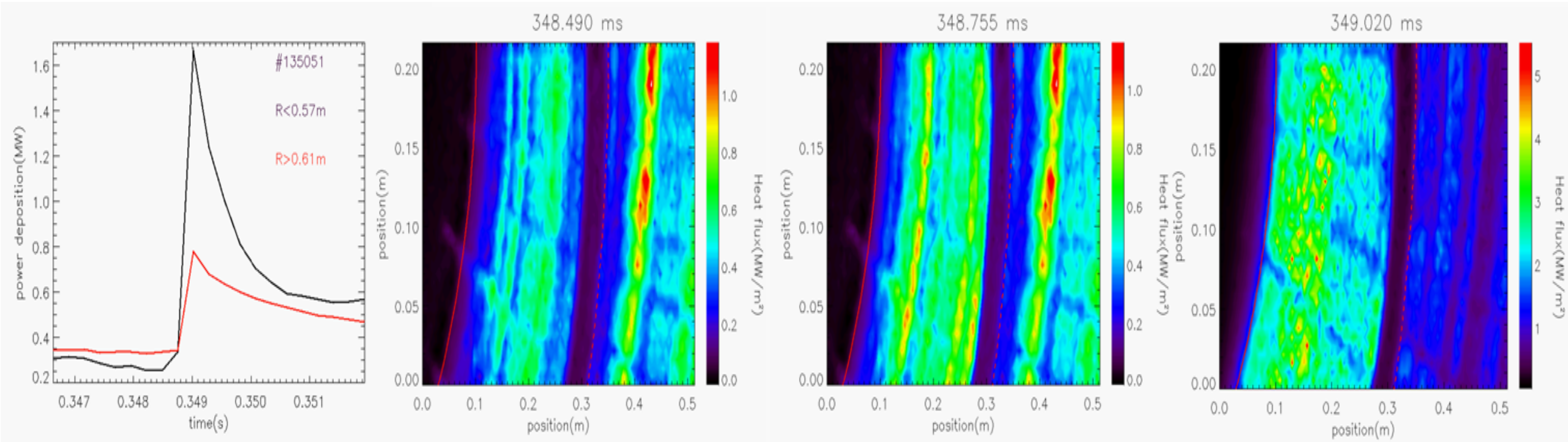



# 2D heat flux distribution during type V ELM




- During ELM-free , the heat flux region is close to the OSP
- During type V ELM, the heat flux region is far from the OSP
- The heat flux inside the CHI gap increase first

# 2D heat flux during type III ELM




- The position of $q_{peak}$ can be 34cm far from the OSP at pre-ELM

- The $P_{in}$ and $P_{out}$ increase together during type III ELM

# Summary

- TACO has been applied successful on heat flux calculation in NSTX
- A criteria to choose the α value: Modify α until the energy deposition is kept constant after discharge
- The width of power deposition on divertor ($\lambda_q$) will decrease with type III ELM due to the obvious type v ELM during inter-type III ELM.
- Type v ELM will increase the transport and decrease the peak heat flux Compare to ELM phase phase
- Situation II ELM will appeared under high $\beta_p$
- It was first time to analyze the power load with 2D heat flux distribution in NSTX
  - Divertor heat flux is toroidal asymmetry
  - Strange edge transport has been reported during L-H transition
  - There is a delay time between Pin and Pout during type V ELM, Pin and Pout increase together during type III ELM