HEAT TRANSPORT EXPERIMENTS IN JET: STIFFNESS AND NON-LOCALITY

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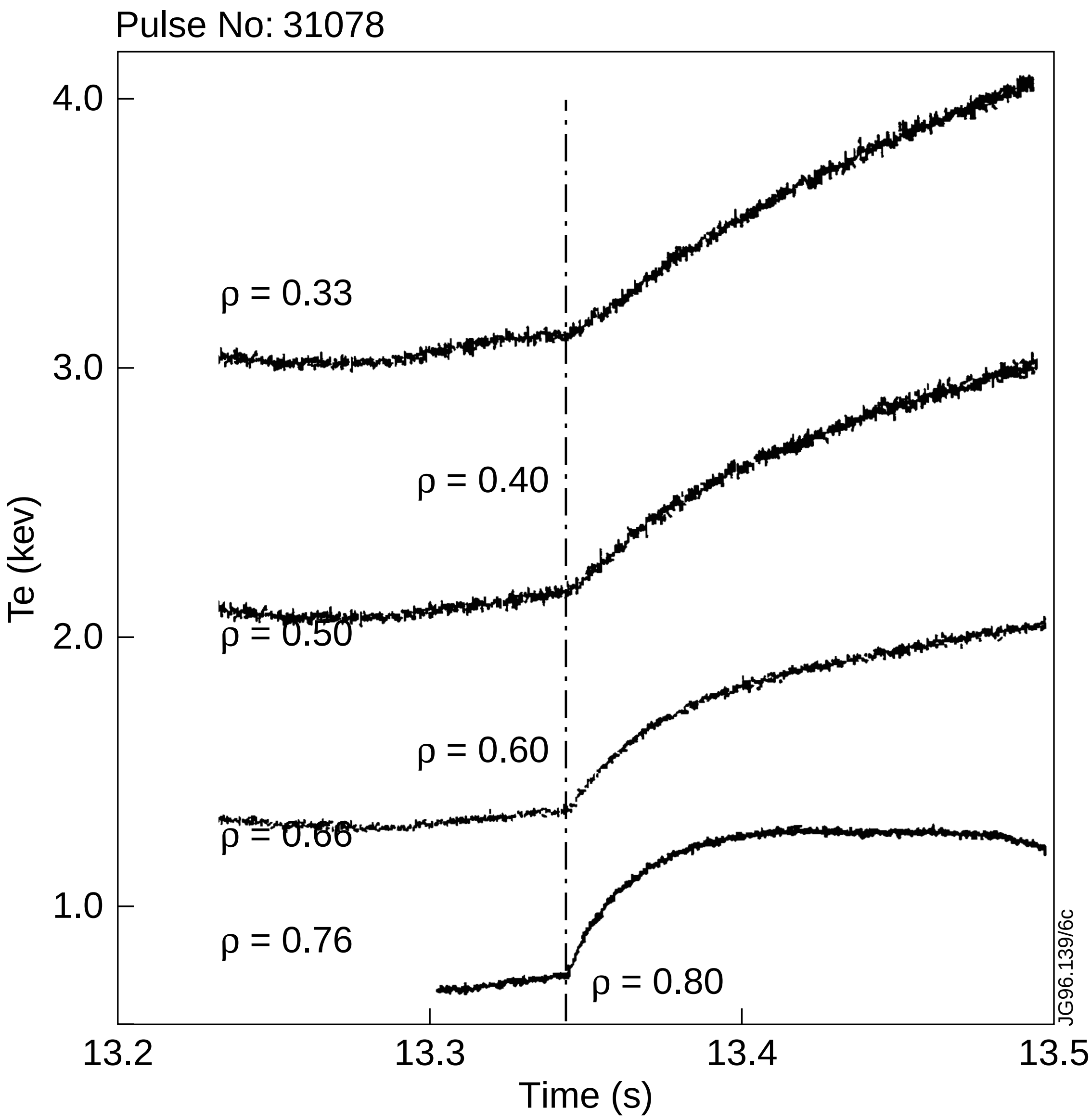
Outline

- Fast transient phenomena in JET-experimental observations;
- Concept of turbulence non-locality;
- Profile stiffness as an alternative approach to fast transient phenomena;
- Conclusions

I. Fast Transient Phenomena on JET- Experimental Observations

- An unusually fast heat pulse, generated by L-H transition, has been first reported in 1993 (*S. Neudachin et al., 20th EPS Conference, Lisbon, 1993*)



- Two unusual features of this heat pulse:

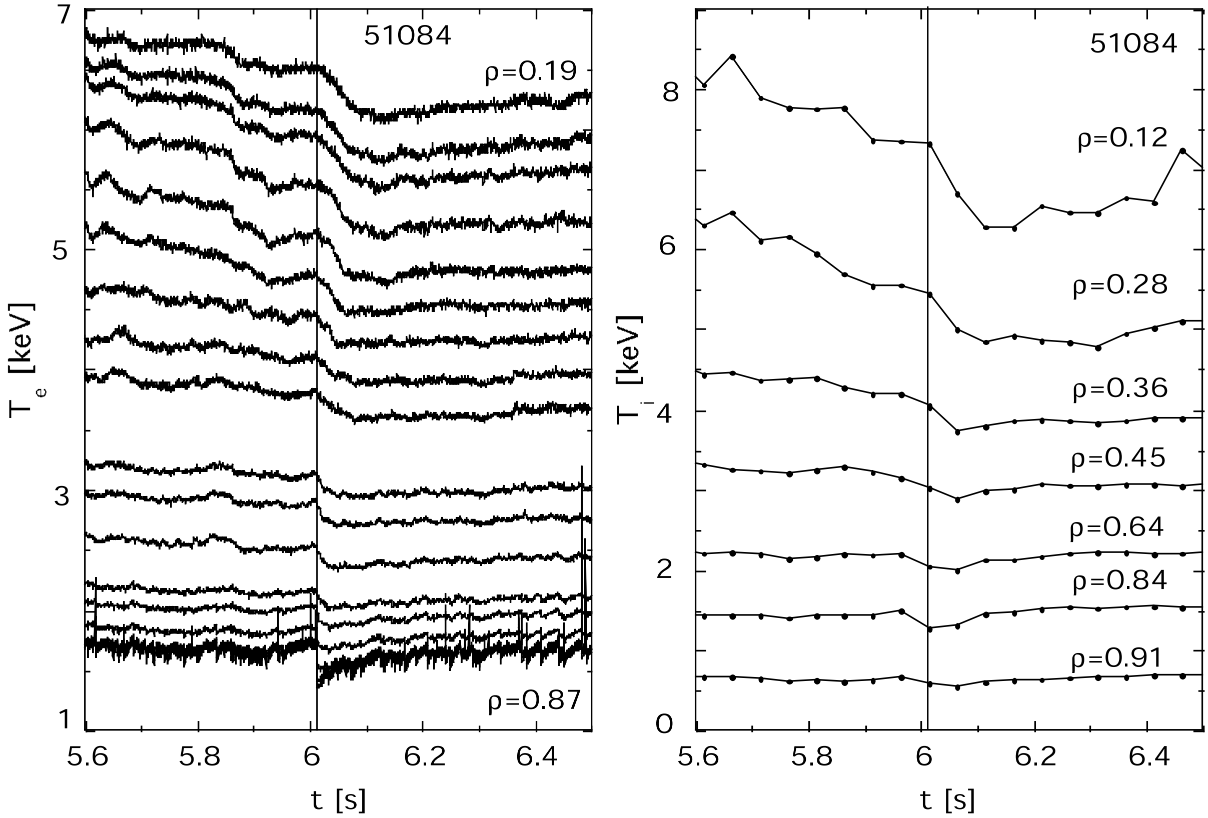
  I. A very fast (sometimes beyond experimental resolution) propagation of the temperature rise;

  II. Heat pulse amplitude does not decay (sometimes even rise) in the core

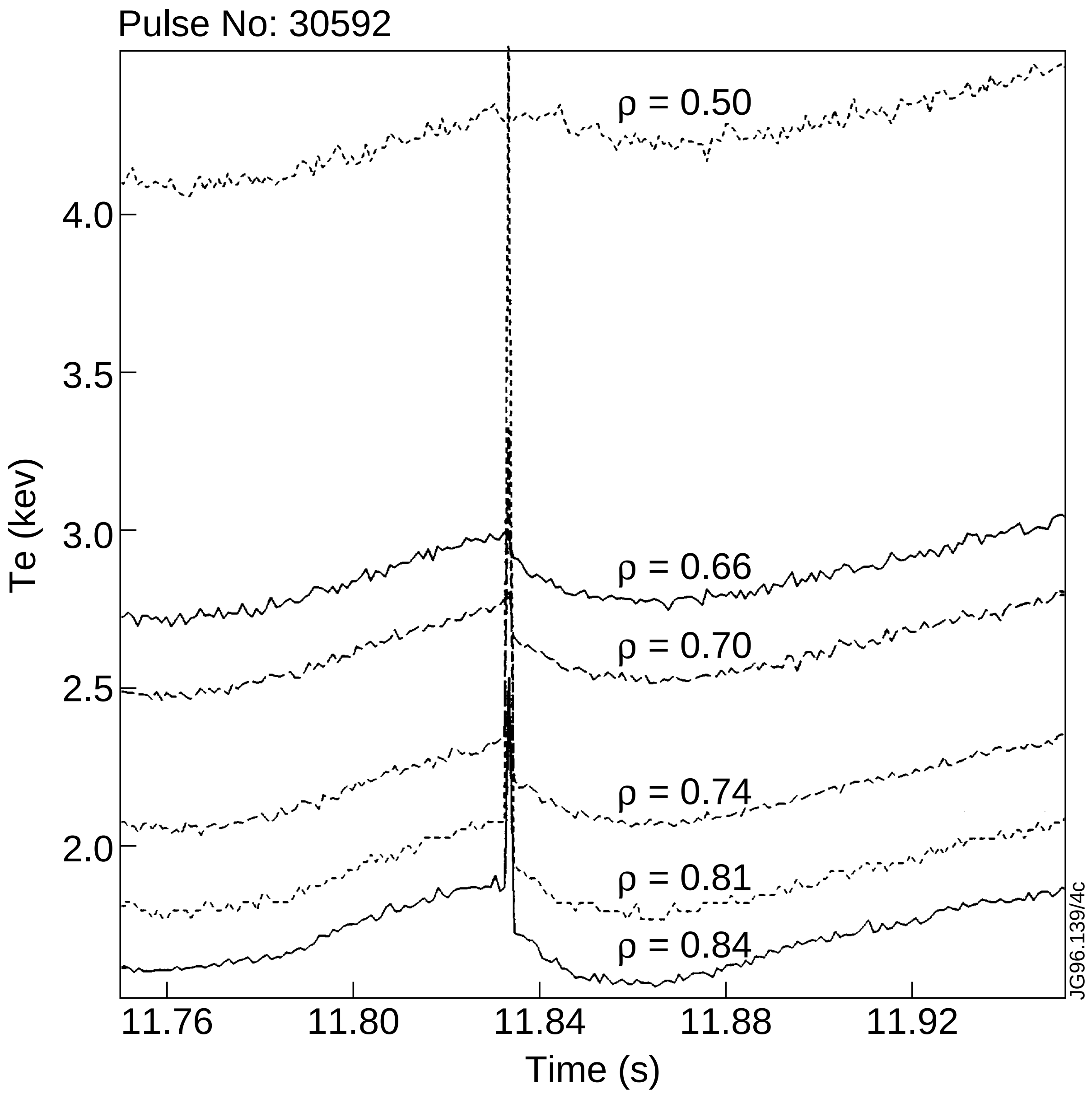
quickly attracted attention of theoreticians and modellers.

- Since then JET and many other tokamaks have reported a number of heat and cold pulses with the similar features;
- Some tokamaks (starting from TEXT, *K. Gentle,1993*) reported cold pulses which change polarity in the core;

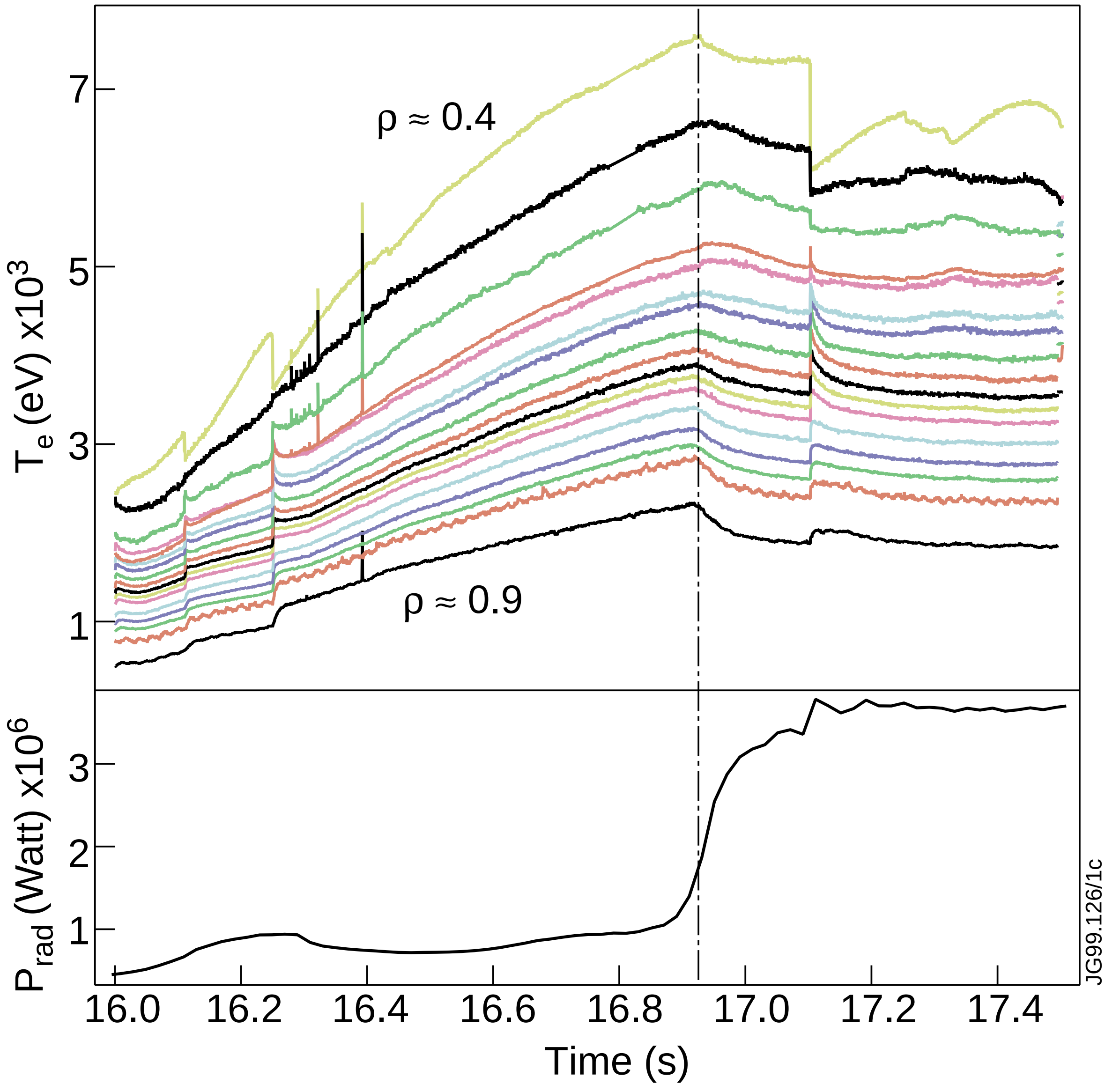
Cold pulse triggered by a shallow pellet injection



Cold pulse triggered by type-I ELM

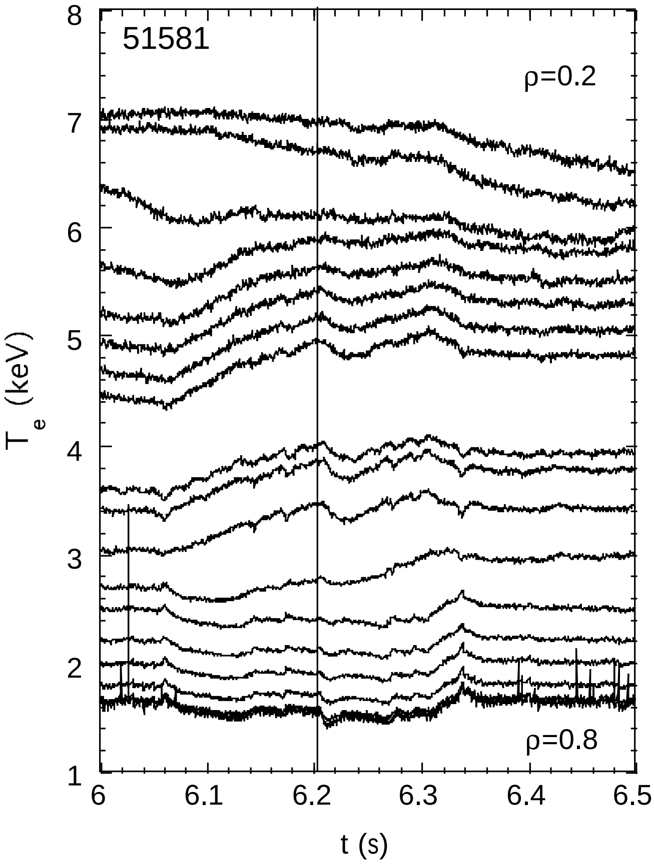


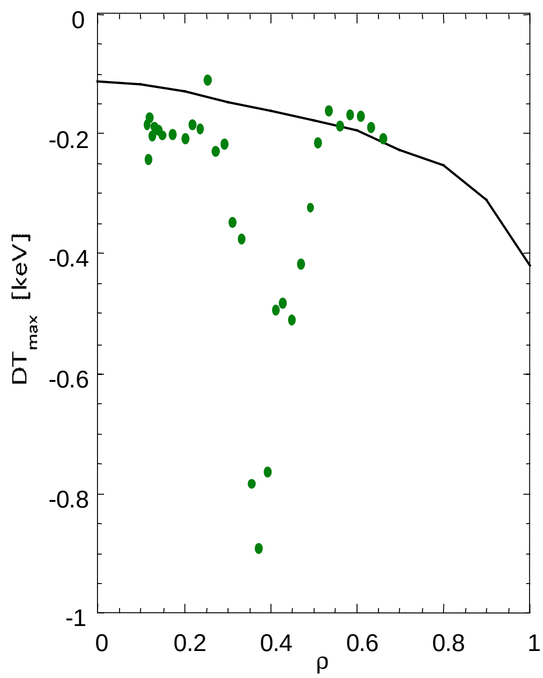
Cold pulse caused by noble gas puffing into ELM-free H-mode



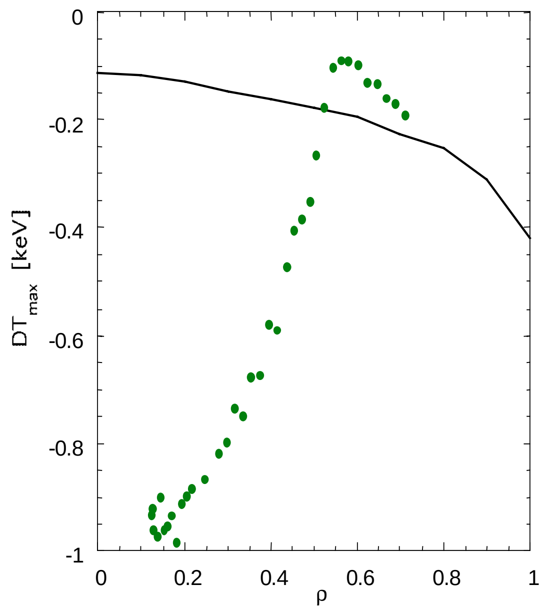
Cold pulse in plasma with ITB

A very recent example shows that cold pulse leads to erosion of the ITB (P.Mantica, EPS 2001)





Weak ITB can be completely destroyed by the cold pulse



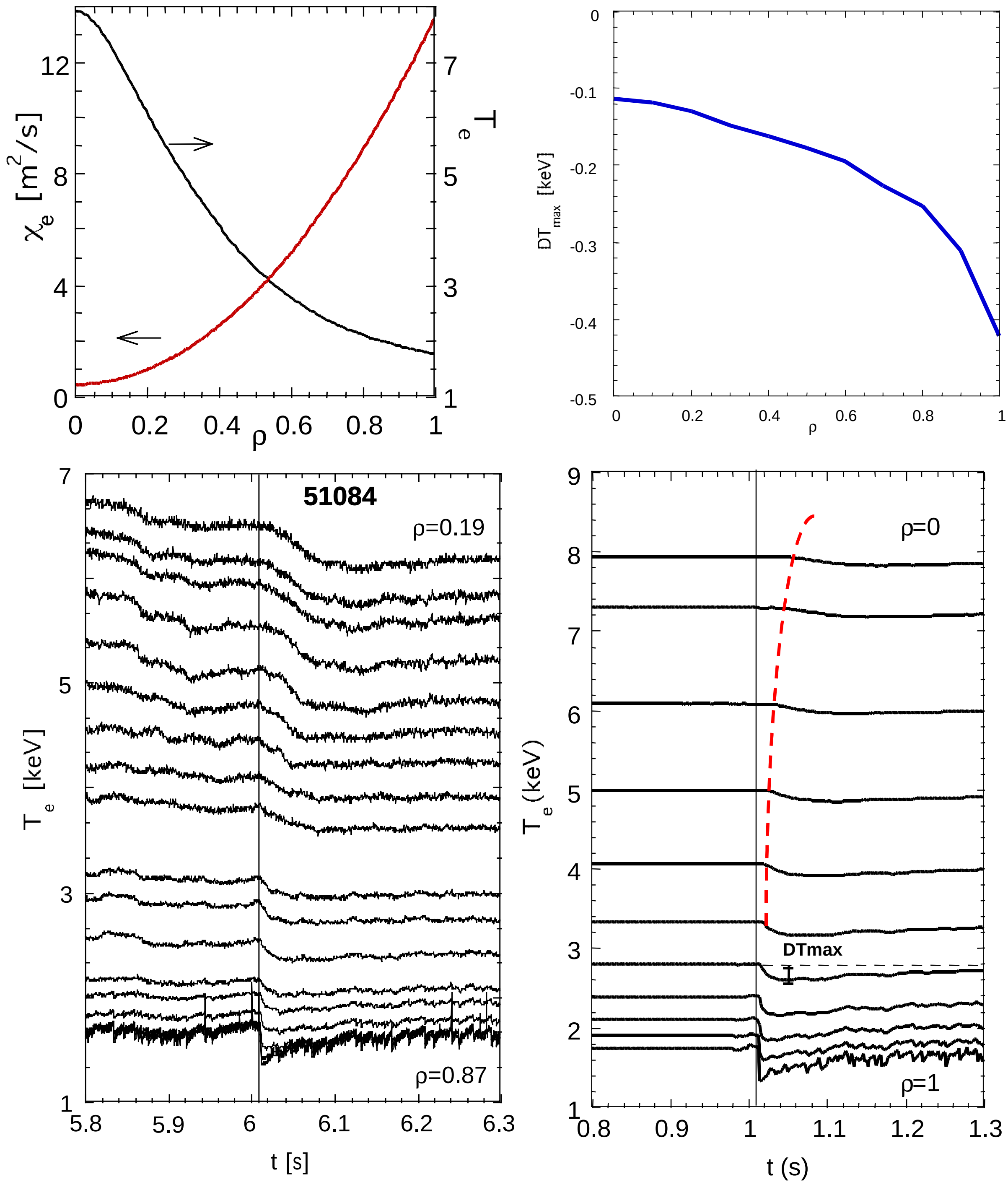
- **Two unusual features of these heat pulses:**

  I. A very fast (sometimes beyond experimental resolution) propagation of the onset of the temperature rise;

  II. Heat pulse amplitude does not decay (sometimes even rise) in the core

quickly attracted attention of theoreticians and modellers.

Let us compare experimental results with the prediction from a simple diffusive model with the constant χ:



- The difference in the speed of cold pulse propagation and in the radial profile of the cold pulse amplitude is obvious.
- How can we explain such a fast, non-diffusive kind of cold pulse propagation?
- Two possible explanations are being considered by theoreticians at present:
  - *Non-local turbulence paradigm (streamers),*
  - *Stiff local transport paradigm (avalanches).*

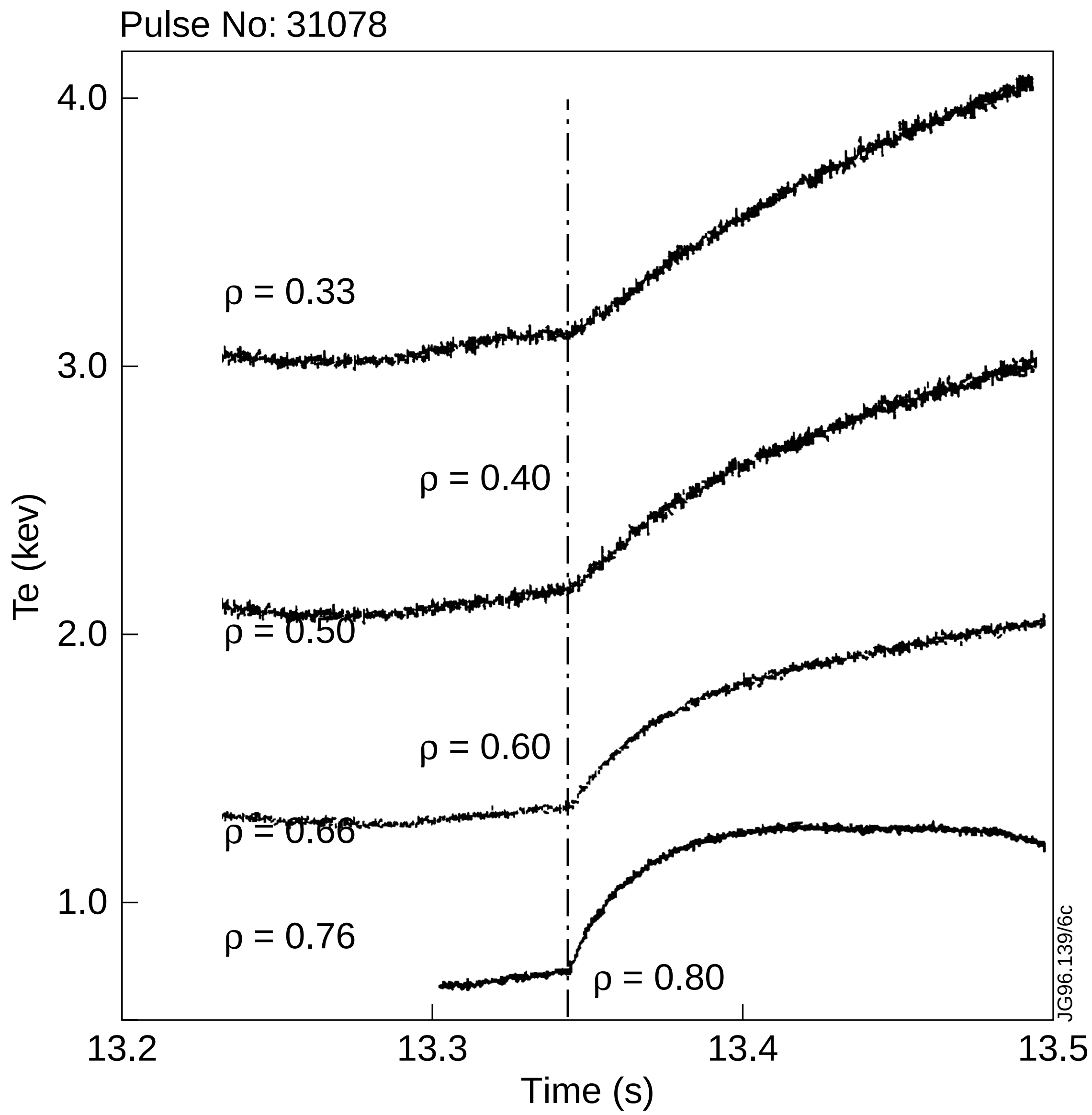
Non-local turbulence.

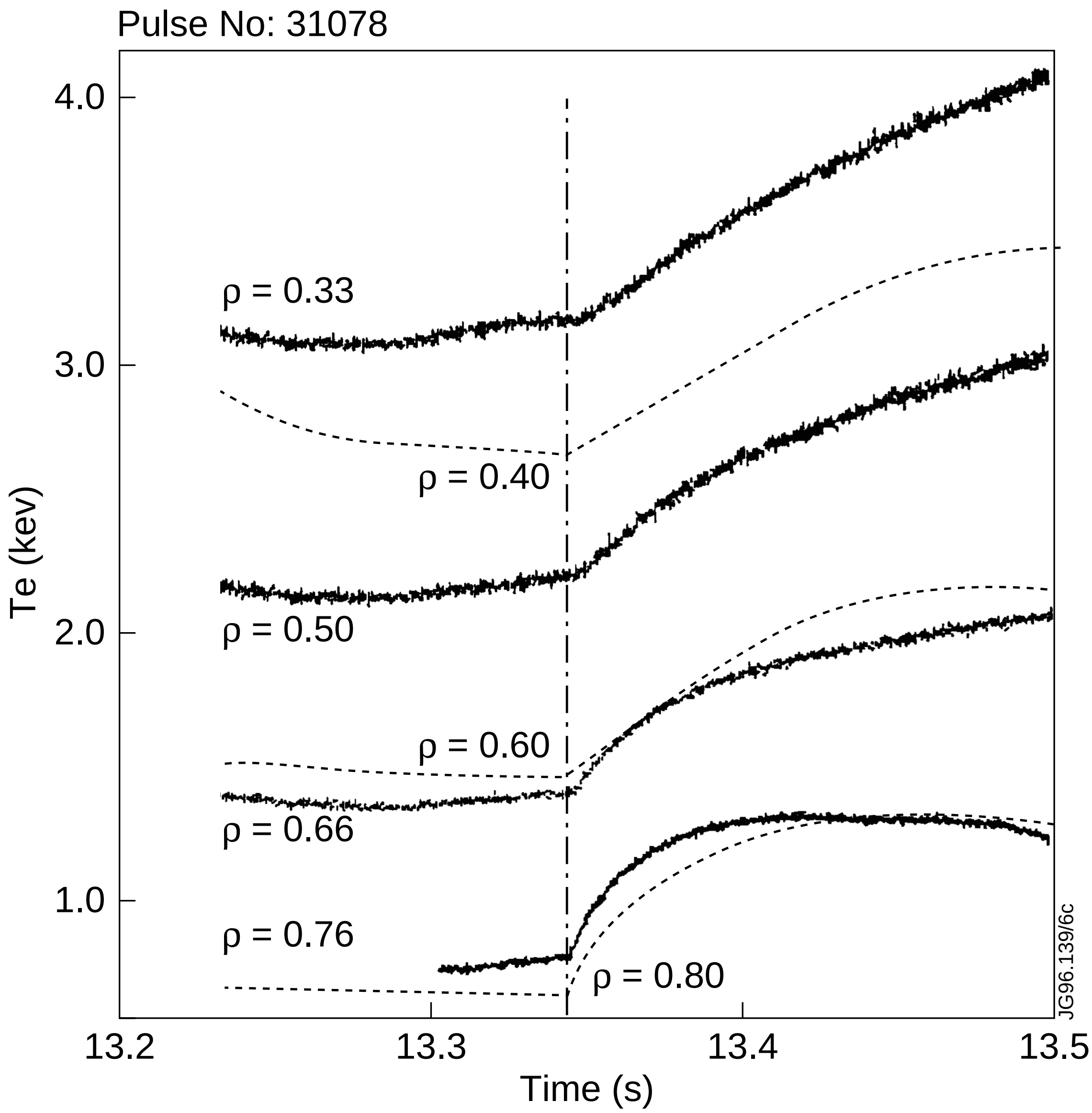
- Non-local turbulence as a mean of a fast L-H transition in JET has been proposed in (*J.G. Cordey et al., NF 1995*) and implemented in an empirical JETTO transport model (*M. Erba et al., PPCF, 1997*);
- Since then the model has been successfully applied to a number of transient phenomena.

- The physics mechanism of the turbulence non-locality originates from:
  - *Toroidal coupling of unstable vortices,*
  - *Inverse non-linear cascade of unstable modes into long wave length part of the wave spectrum;*
- Both mechanisms lead to a formation of long radially correlated structures (strimmers), which can explain fast non-local change in transport coefficients during transient phenomena (*F. Romanelli, F. Zonca, PF, 1993; V. Parail et al., NF 1997; Y. Kishimoto et. al., IAEA, 1998; K. Itoh, S.-I. Itoh, 2001*);
- JET transport model assumes that the source of the turbulence localised near the separatrix, so that

$$\chi_{Bohm} \approx C \cdot c_s \cdot \rho_i \cdot q^2 \left| \frac{\nabla T_e}{T_e} \right|_{sep}$$

- Next slide shows an example of L-H transition simulation with JET model;


Pulse No: 31078
4.0
3.0
2.0
1.0
Te (kev)
ρ = 0.33
ρ = 0.40
ρ = 0.50
ρ = 0.60
ρ = 0.66
ρ = 0.76
ρ = 0.80
13.2
13.3
13.4
13.5
Time (s)
JG96.139/6c



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13.2
13.3
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13.5
Time (s)
JG96.139/6c

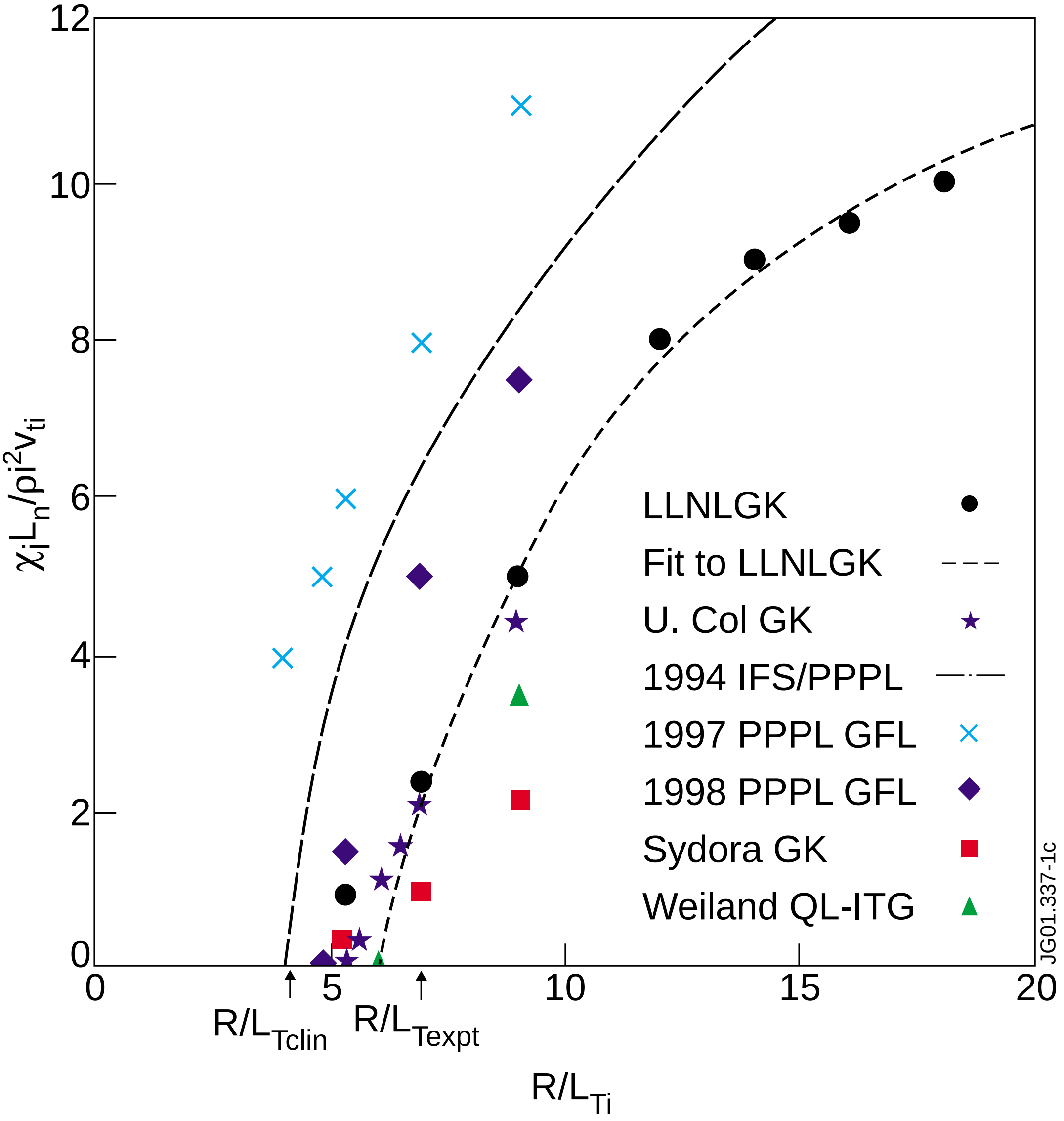
Profile stiffness.

- Profile stiffness is a known concept, based on theoretical finding that both electron and ion anomalous transport increases rapidly when some plasma parameters ($\left|\frac{\nabla T_i}{T_i}\right|$ in case of ITG) exceed certain limit *(F. Romanelli, F. Zonca, PF 1993; A. Dimits et. Al., PP 2000)*;
- Generally, transport coefficient with a profile stiffness has the following form:

$$\chi_i = \chi_i^{res} + C\frac{\rho_i^2 \cdot V_{Ti}}{R} a \cdot \left(\left|\frac{\nabla T_i}{T_i}\right| - \left|\frac{\nabla T_i}{T_i}\right|_{crit} \right) \times H\left(\left|\frac{\nabla T_i}{T_i}\right| - \left|\frac{\nabla T_i}{T_i}\right|_{crit} \right)$$

- Usually $\chi_i^{res} << C\frac{\rho_i^2 \cdot V_{Ti}}{R}$, therefore transport changes rapidly in the region

$$\left|\frac{\nabla T_i}{T_i}\right| \approx \left|\frac{\nabla T_i}{T_i}\right|_{crit} \quad ;$$



A.Dimits et al., Phys. Plas., 2000

The figure allows concluding:

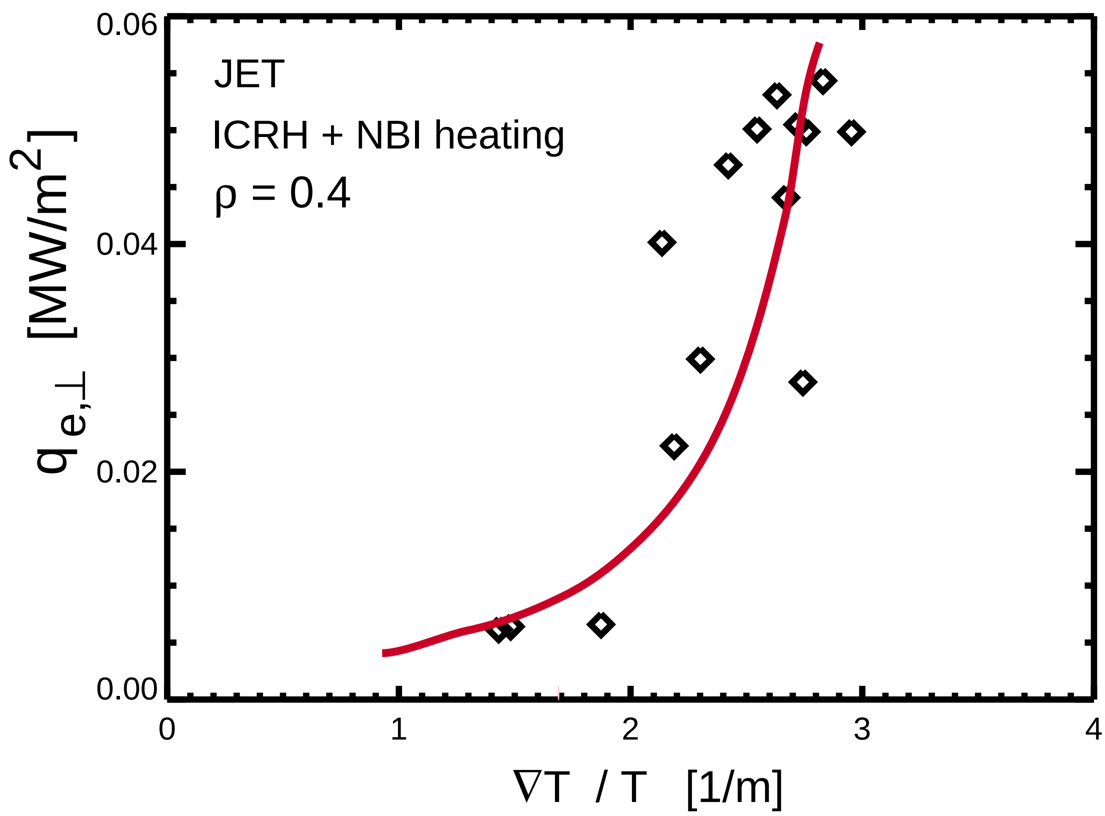
- Temperature profile keeps the same shape in case when heating power exceeds critical level;

- Core temperature depends on the edge temperature rather than on the level of transport;

- Cold pulse can propagate rapidly (like avalanche) with the characteristic χ

$$\chi_i^{HP} \cong C\frac{\rho_i^2 \cdot V_{Ti}}{R} a \cdot \left|\frac{\nabla T_i}{T_i}\right|_{crit} >> \chi_i^{PB}$$

- Profile stiffness is a recognised concept, which has been found in practically every tokamak;

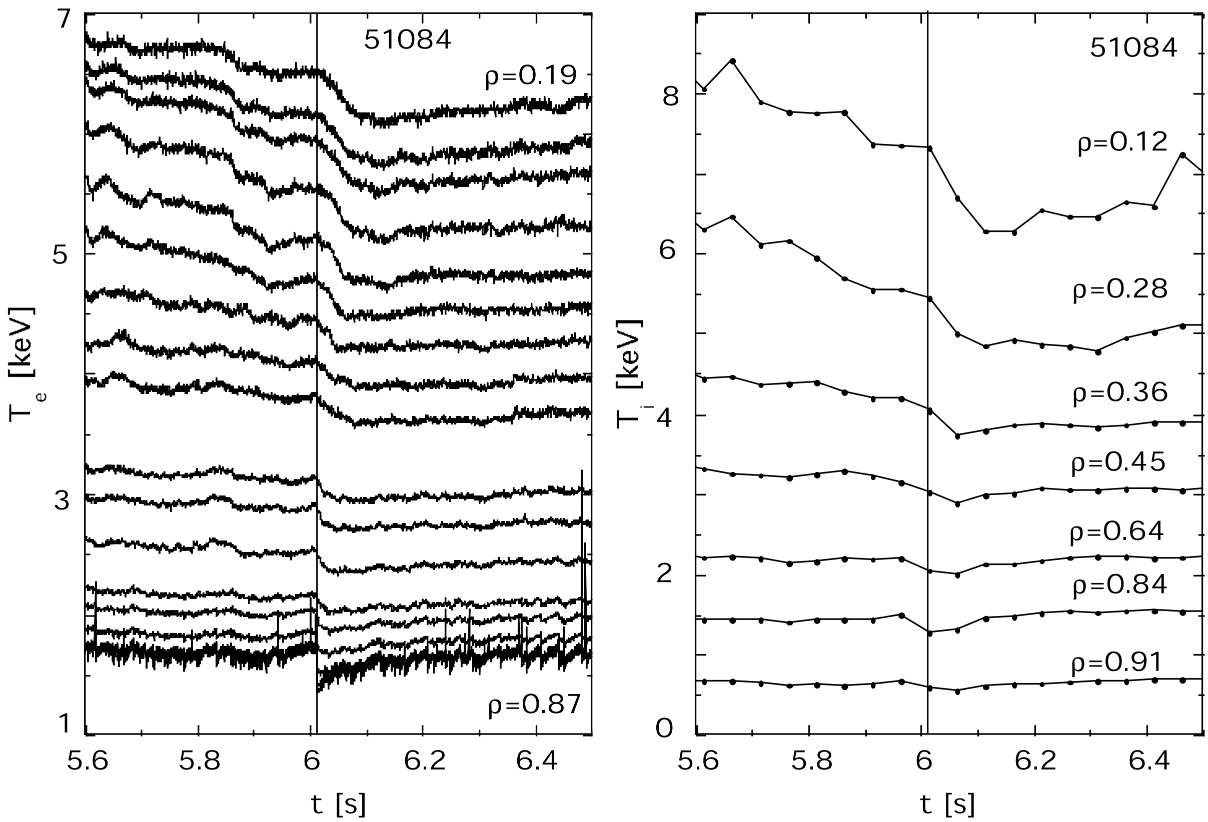


- The question is whether this concept can explain all experimentally observed fast transient phenomena, or we still need a non-local transport on the top;

Profile stiffness vs. non-locality

- Before going to a detailed comparison of two concepts, let us look at some recent result of cold pulse modelling which uses stiff transport models
(*J. Kinsey, 2000-01*)

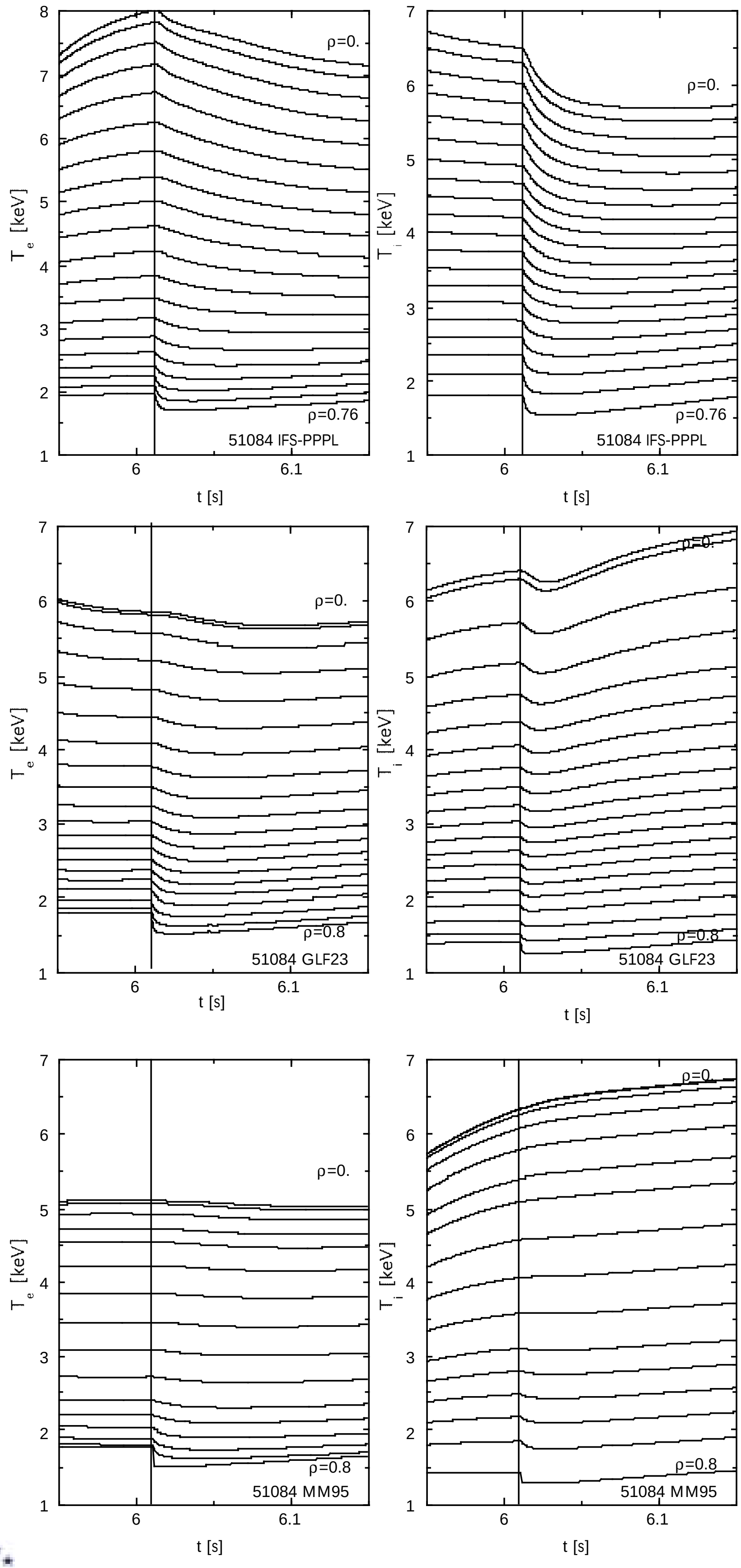
- Three theory based transport models (MMM-95, IFS/PPPL and GLF-23) have been used to simulate the same recent cold pulse from JET;



IFS/PPPL

GLF 23

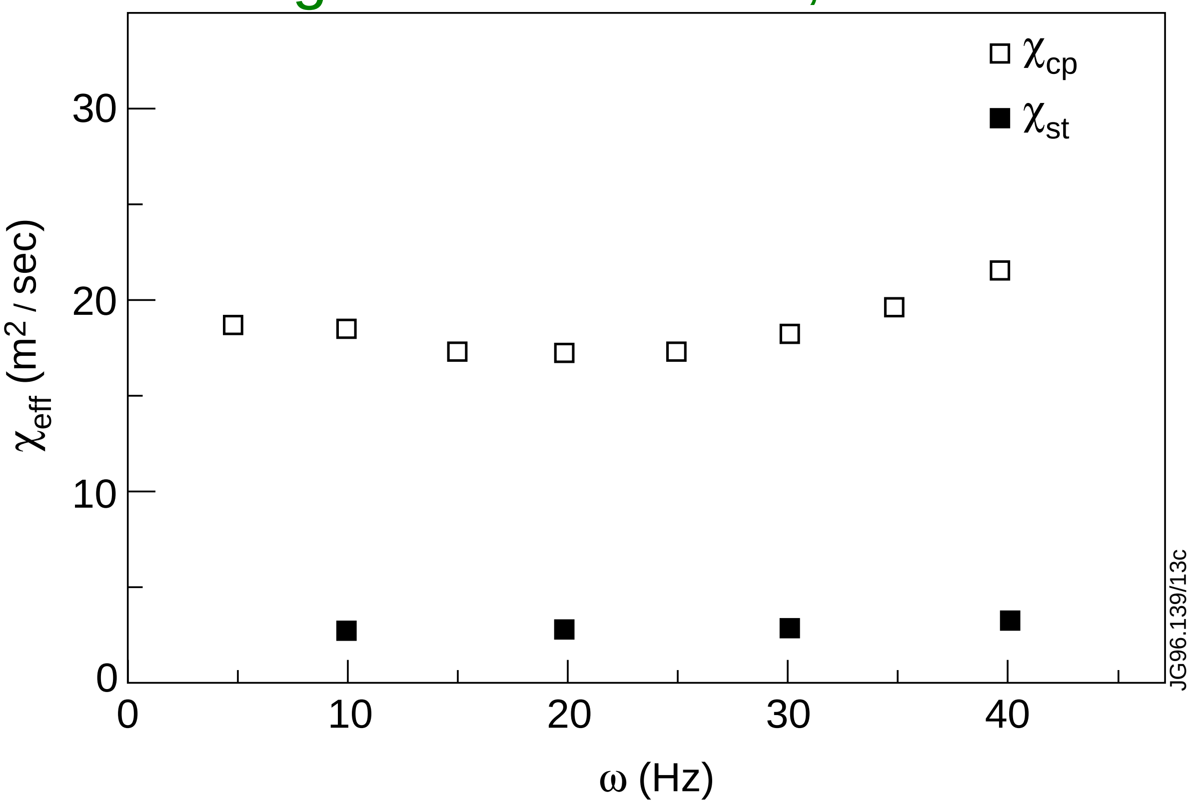
MMM-95



Now we can try to answer the question:

"Can we explain all fast transient phenomena by a stiff local transport or we still need a non-local transport?"

- Stiff models should have a problem reproducing L-H transition (the perturbation should actually reduce transport rather than increase it);
- It will be difficult to reproduce experimentally observed asymmetry in propagation of the cold pulse, triggered at the edge and in the core;

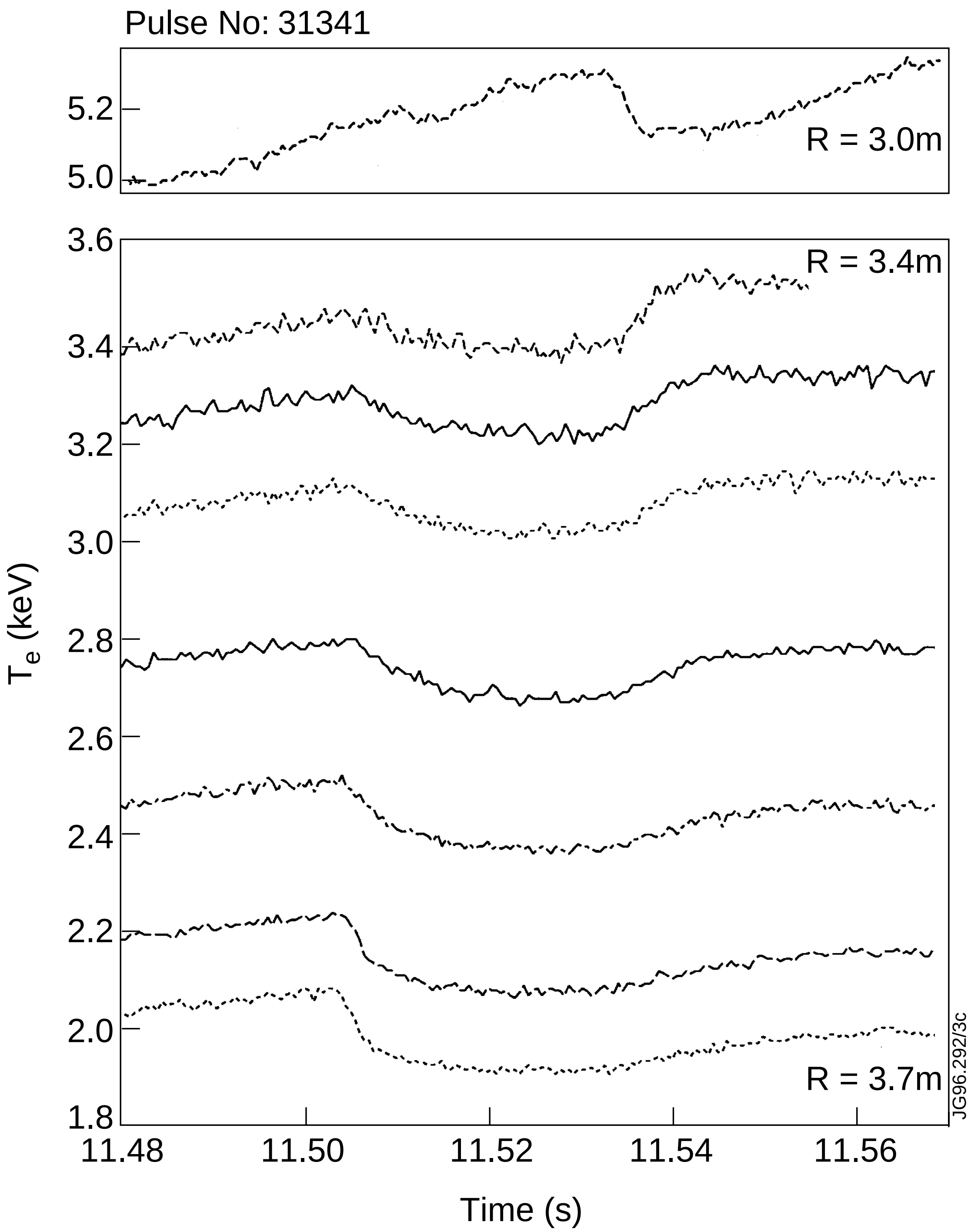


JET, 1994

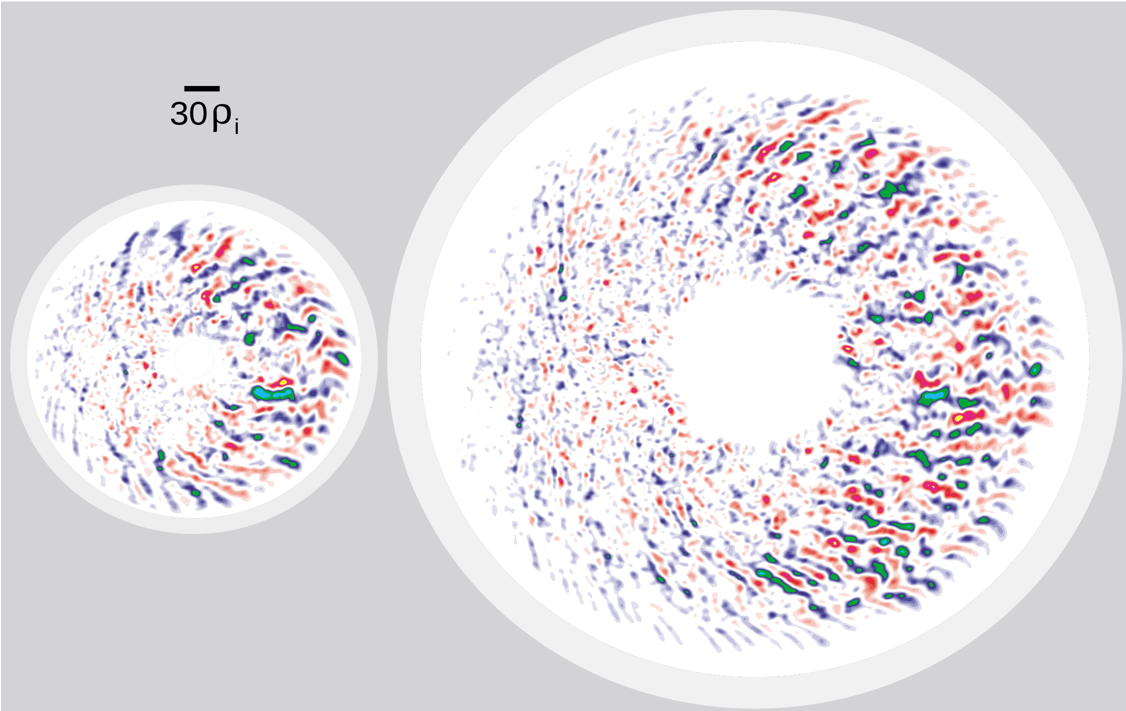
- Very fast cold pulse propagation requires extremely high level of stiffness, which has only a limited support from the theory;

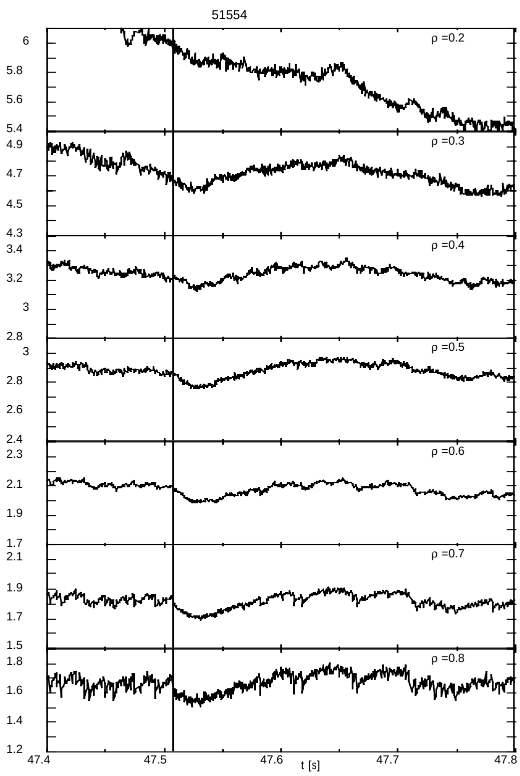
Conclusions

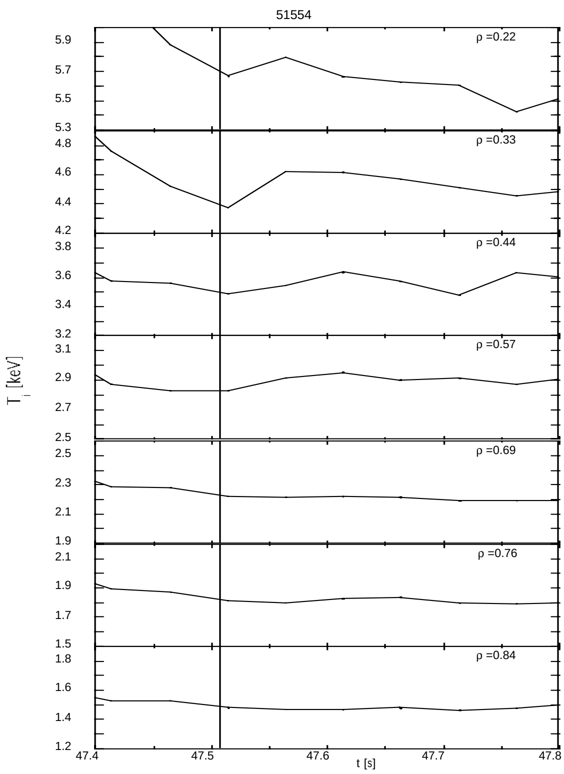
- Fast transient phenomena found on JET and other tokamaks make a big impact on a theory of plasma turbulence.
- It led to a development of a non-local approach to plasma turbulence (streamers) as well as to a development of stiff local transport models (avalanches);
- A single theoretical model able to reproduce all experimentally observed phenomena (both steady state and transient) has yet to be found;
- Most probably such a model will be a combination of stiff transport with elements of non-locality in it.



Pulse No: 31341
5.2
5.0
R = 3.0m
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
R = 3.4m
R = 3.7m
T_e (keV)
11.48
11.50
11.52
11.54
11.56
Time (s)
JG96.292/3c


30ρi


51554
ρ =0.2
ρ =0.3
ρ =0.4
ρ =0.5
ρ =0.6
ρ =0.7
ρ =0.8
t [s]


51554
ρ =0.22
ρ =0.33
ρ =0.44
ρ =0.57
ρ =0.69
ρ =0.76
ρ =0.84
T_i [keV]
t [s]