# CP1.72: Large Spatial Scale Avalanche Phenomena in DIII-D

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**Large Spatial Scale Avalanche Processes in DIII-D**[1]

P.A. POLITZER, General Atomics, M.E. AUSTIN, U. Texas, E.J. DOYLE, C.L. RETTIG, T.L. RHODES, UCLA, G.R. MCKEE, U. Wisconsin, R.A. MOYER, UCSD, J.G. WATKINS, Sandia National Laboratories — One possible mechanism for transport of heat and particles in plasmas is the avalanche process associated with self-organized criticality. We have found evidence for avalanches in edge and core measurements.[2,3] Recent experiments with low power, essentially stationary L–mode plasmas have allowed collection of simultaneous core plasma data on electron temperature and density fluctuations using the ECE, BES, and reflectometer diagnostics, and edge data using Langmuir probes. These measurements are examined for evidence of SOC-like behavior. The anticipated characteristics include Fourier spectra (1/f), power-law PDF for events, and extended space-time cross-correlations with power-law tails. Cross-correlations between temperature and density fluctuations should give some indication of the energy transport.

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[2]T L. Rhodes *et al.*, Phys. Lett. A **253**, 181 (1999).

[3]P.A. Politzer, Bull. Amer. Phys. Soc. **43**, 1760 (1998).

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☐ Prefer Oral Session
☒ Prefer Poster Session

Special instructions: DIII-D Poster Session 1, immediately following CL Rettig

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## Addendum to abstract:

The abstract for this paper notes that “Recent experiments with low power, essentially stationary L-mode plasmas have allowed collection of simultaneous core plasma data on electron temperature and density fluctuations using the ECE, BES, and reflectometer diagnostics, and edge data using Langmuir probes.” The abstract points out the importance of looking for cross-correlations between these observations in evaluating the energy transport associated with avalanches.

Unfortunately, the data collected in this piggy-back experiment indicated the presence of either very small sawteeth or small n/m = 1/1 modes, which would interfere with the attempt at a cross-comparison between measurements of temperature and density fluctuations.  This important analysis will have to wait until we obtain dedicated time, perhaps in the coming year, so that suitable plasma conditions can be provided.

Meanwhile, the electron temperature data from the spring of 1998 has been further examined. This poster presents some of the observations of intermittent transport events (avalanches) as seen in the data obtained by the Electron Cyclotron Emission (ECE) diagnostic instrument. This analysis looks specifically at the "effective" radial speed.

I hope that presentation of these observations will encourage further theoretical work, particularly with an eye toward prediction of measurable quantities. I am also soliciting suggestions of additional analysis techniques that might be productively applied to these observations.

## Plasma Equilibrium Conditions

A database of 23 discharges suitable for study of intermittent avalanche events in Te has been accumulated. These plasmas were produced in experiments principally dedicated to ECCD studies.

The periods of interest typically have one neutral beam source for heating (~2.5 MW), with 0, 1, or 2 110 GHz gyrotrons for ECH and ECCD (0-1.2 MW). These plasmas have an upper single null divertor shape with high triangularity, and show L-mode confinement.

For each discharge, during the interval selected for analysis q is monotonic, with q(0) > 1 and with negligible MHD activity. For most studies, an interval of 500 ms is used.

The data set is a time series of $T_e$ measurements on 32 channels. The sampling interval is 20 μs, giving a Nyquist frequency of 25 kHz. The sample volumes are at the midplane, at one toroidal location, covering most of the radial extent of the plasma. The channels have a fixed 1GHz frequency separation, which translates into between 1.5 cm and 6 cm separation in $\rho = (\Phi/\pi B_0)^{1/2}$.

At these low frequencies, the equilibration of $T_e$ within a flux surface by parallel electron heat conduction is fast enough that the local $T_e$ measurement provides a representative sampling of the entire magnetic surface. Note that, for $T_e = 1$ keV and $n_e = 3 \times 10^{19}$ $m^{-3}$, $\chi_{||} \approx 5 \times 10^9$ $m^2/s$; so that the characteristic time for 30 toroidal transits (~300 m) is about 20 μs.

To obtain the fluctuating temperature, $\delta T_e(r_i, t_j)$, the mean value ($\overline{T}_e(r_i)$) and any linear trend are subtracted from the ECE value.

Because this is a 2-D data set ($T_e(\rho,t)$), the spatial extent and speed characteristics of the avalanches can be examined. The primary technique used here is the calculation of the cross-correlation matrix for all channels.

The quantity calculated is

$$R_{ijk} = C_{ij}(\tau_k) = \frac{\sum_{s=1}^{N-k} f_i(t_s + \tau_k) f_j(t_s)}{\sqrt{\left[\sum_{s=1}^{N} \left(f_i(t_s)\right)^2\right]\left[\sum_{s=1}^{N} \left(f_j(t_s)\right)^2\right]}}$$

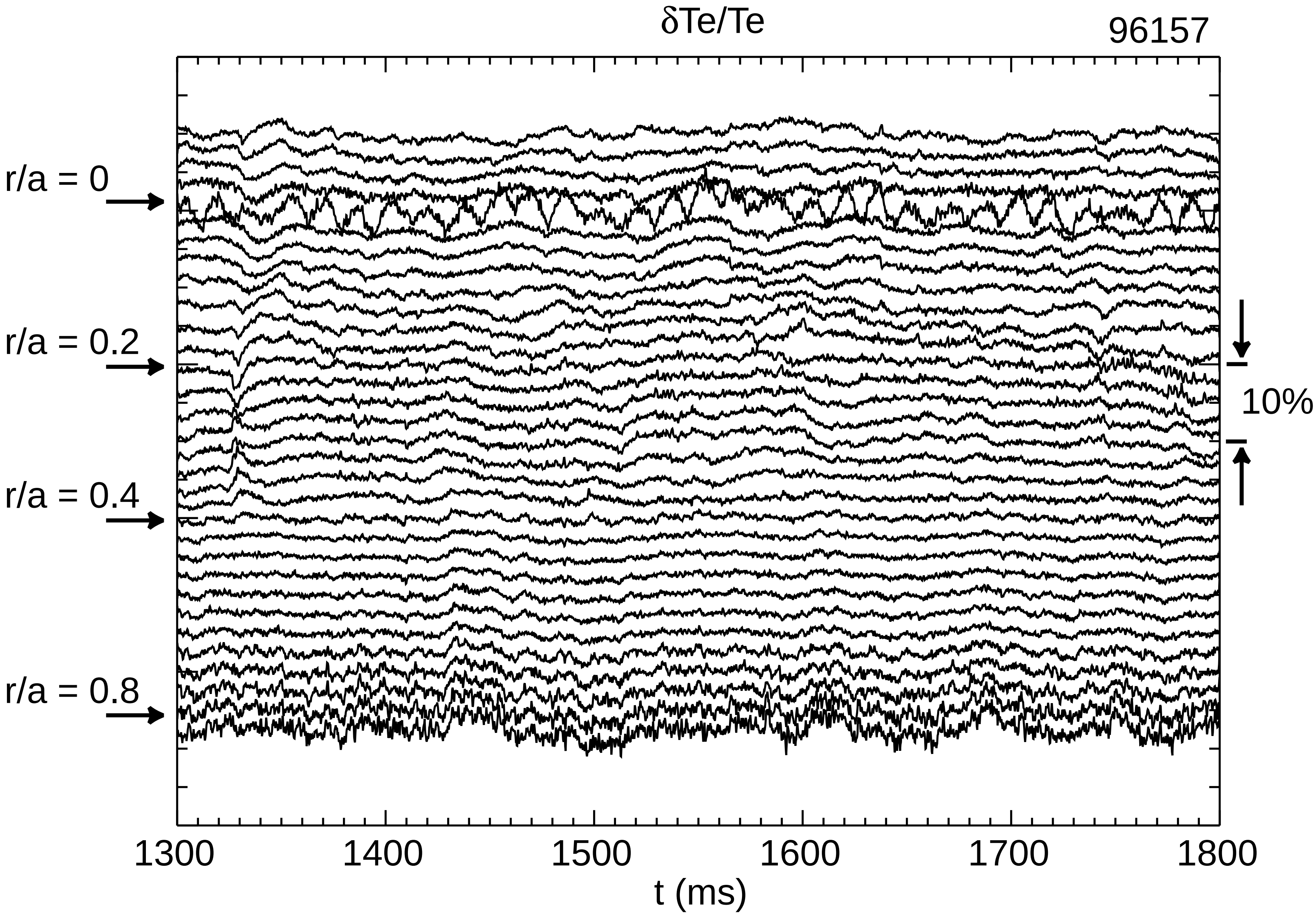
where $f_i$ and $f_j$ can be either the absolute ($\delta T_e$) or the relative ($\delta T_e/T_e$) temperature fluctuation.

The best way found to display this array is to select one channel as the reference channel ($i = i_{ref}$), and to make a contour plot of $C_{ij}(\tau_k)$ as a function of channel number $j$ and lag $\tau_k$. The qualitative behavior of the cross-correlation can be understood from the contour plots for a sampling of reference channels.

## Observations on the effective avalanche speed:

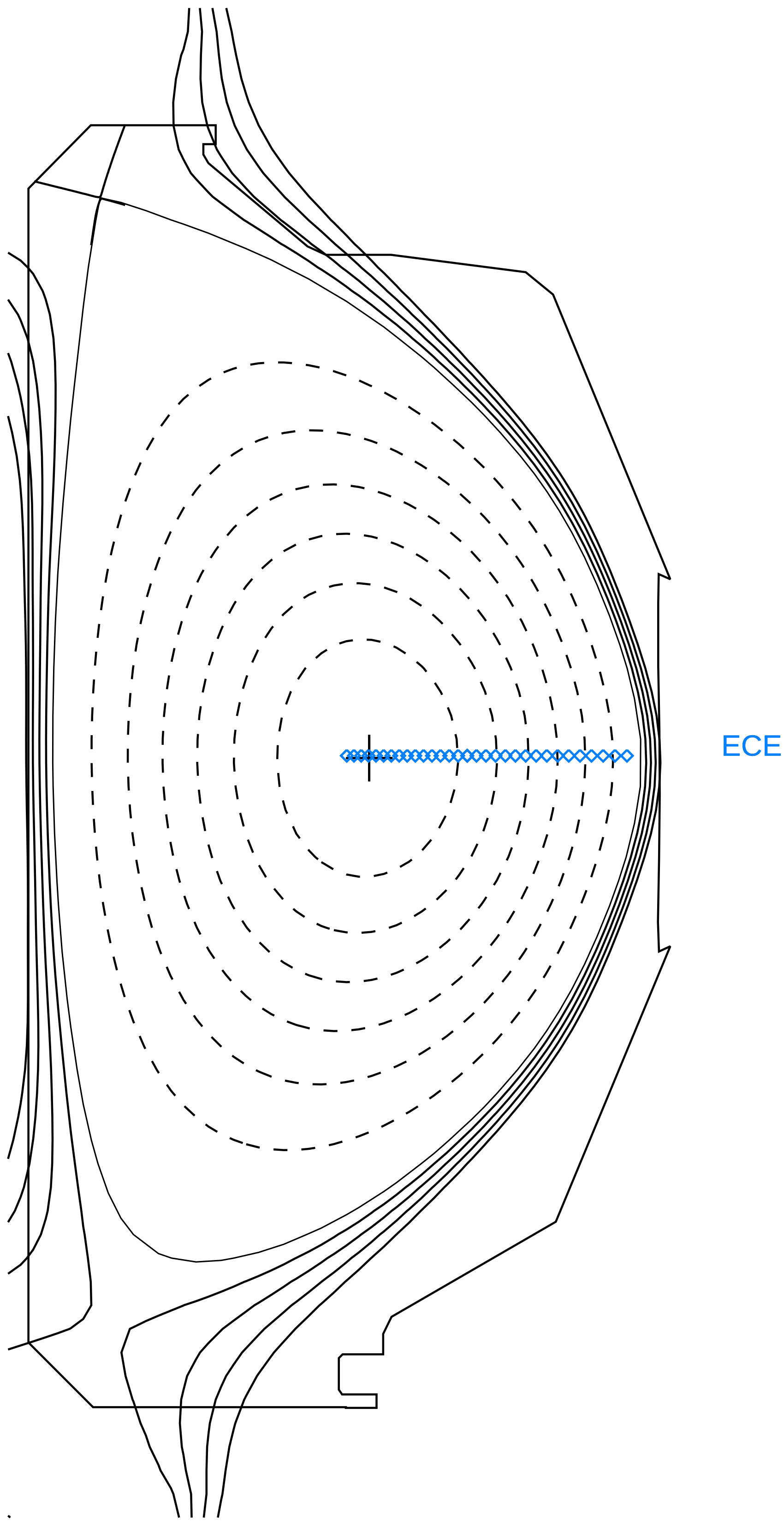
- There is an outer region ($r/a \geq 0.5$) where the effective speed is ~400±200 m/s.
- In an intermediate region ($0.2 \leq r/a \leq 0.4$), the effective speed is ~10±10 m/s.
- Near the axis ($r/a \leq 0.1$), the effective speed is ~10 m/s <u>inward</u>.

- These zones remain in the same places when B is raised or lowered (shifting the ECE channel locations).
- These zones appear to correlate with regions of different behavior of $\nabla Te$.
- There is not enough data to relate the effective speed to the magnitude or location of ECH power deposition.

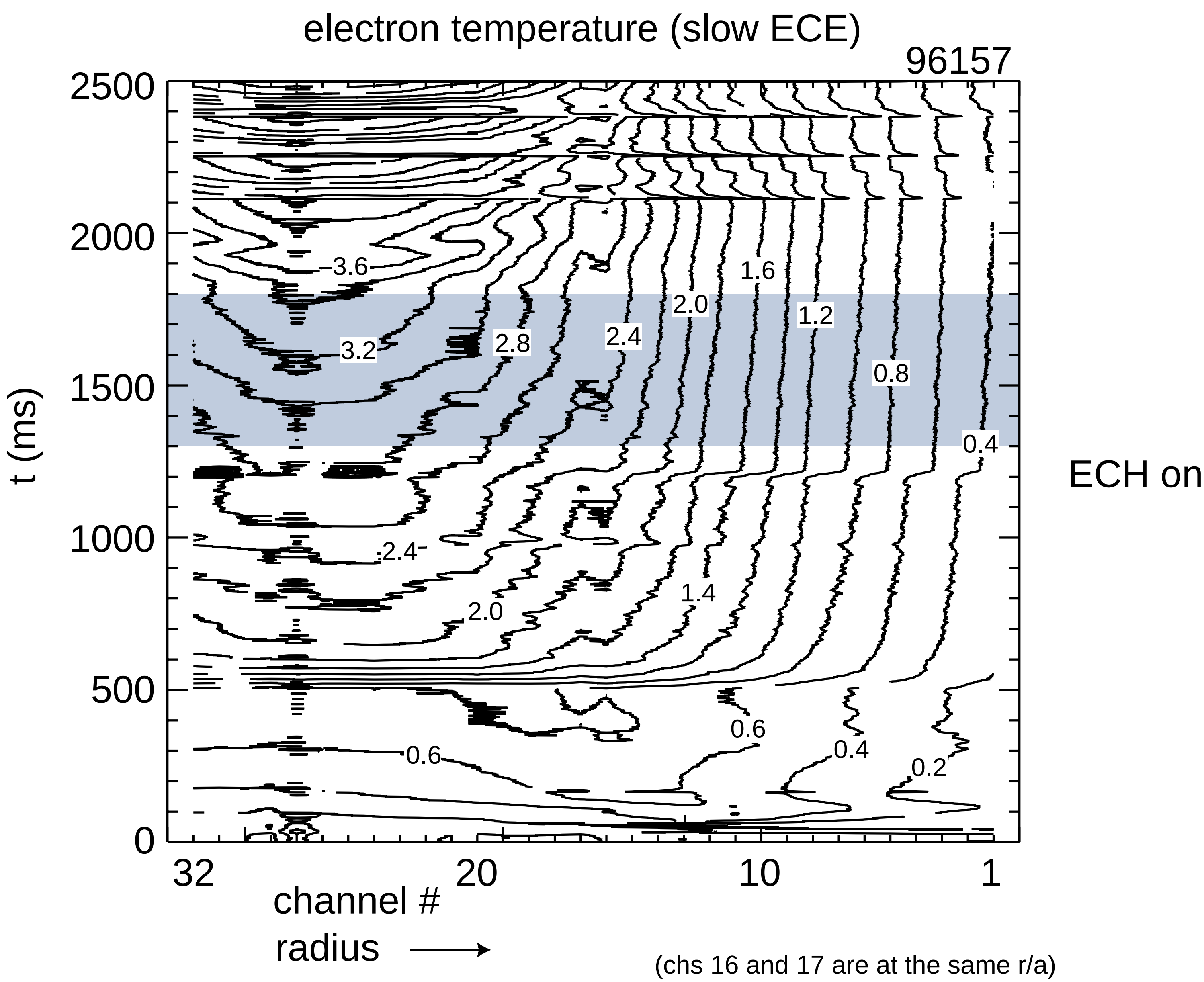


δTe/Te
96157
r/a = 0
r/a = 0.2
r/a = 0.4
r/a = 0.8
10%
1300
1400
1500
1600
1700
1800
t (ms)

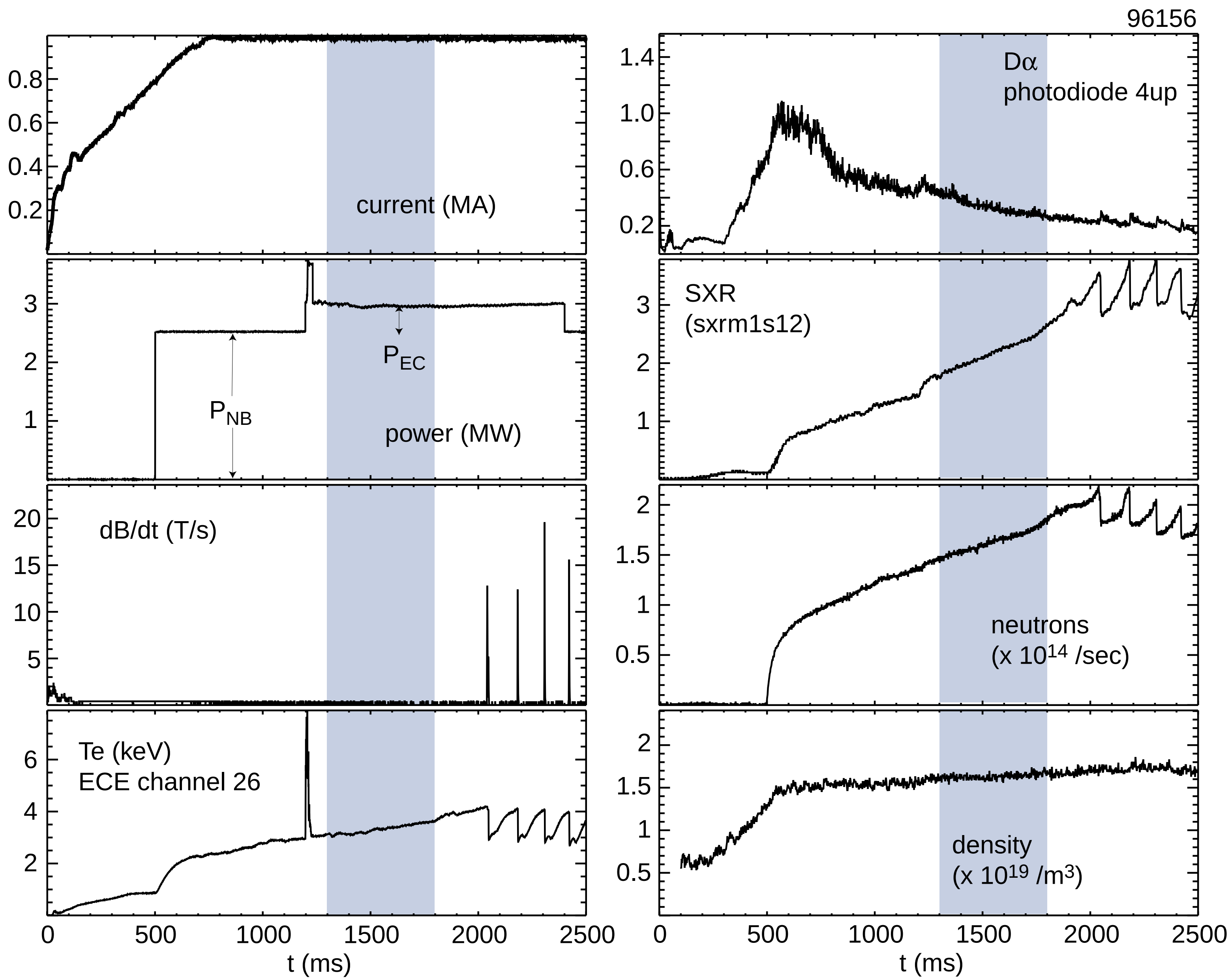
| | |
|---|---|
| shot | 96156 |
| time | 1550.00 |
| chi**2 | 9.737 |
| Rout(m) | 1.691 |
| Zout(m) | 0.070 |
| a(m) | 0.624 |
| elong | 1.807 |
| utri | 0.839 |
| ltri | 0.513 |
| indent | 0.000 |
| V (m**3) | 20.946 |
| A (m**2) | 2.071 |
| W (MJ) | 0.257 |
| betaT(%) | 0.526 |
| betaP | 0.435 |
| betaN | 0.660 |
| In | 0.797 |
| Li | 1.320 |
| error(e-4) | 1.293 |
| q1 | 18.012 |
| q95 | 6.359 |
| dsep(m) | 0.038 |
| Rm(m) | 1.739 |
| Zm(m) | 0.010 |
| Rc(m) | 1.695 |
| Zc(m) | 0.014 |
| betaPd | 0.441 |
| betaTd | 0.533 |
| Wdia(MJ) | 0.261 |
| Ipmeas(MA) | 0.987 |
| BT(0)(T) | -1.974 |
| Ipfit(MA) | 0.984 |
| Rmidin(m) | 1.068 |
| Rmidout(m) | 2.314 |
| gapin(m) | 0.051 |
| gapout(m) | 0.038 |
| gaptop(m) | 0.122 |
| gapbot(m) | 0.260 |
| Zts(m) | 0.779 |
| Rvsin(m) | 1.028 |
| Zvsin(m) | 1.230 |
| Rvsout(m) | 1.221 |
| Zvsout(m) | 1.351 |
| Rsep1(m) | 1.180 |
| Zsep1(m) | -1.195 |
| Rsep2(m) | 1.168 |
| Zsep2(m) | 1.198 |
| psib(Vs/R) | 0.043 |
| elongm | 1.300 |
| qm | 1.167 |
| nev1(e19) | 2.340 |
| nev2(e19) | 1.637 |
| nev3(e19) | -70.851 |
| ner0(e19) | 1.486 |
| n/nc | -0.653 |
| dRsep | 0.010 |
| qmin | 1.167 |
| rhoqmin | 0.000 |



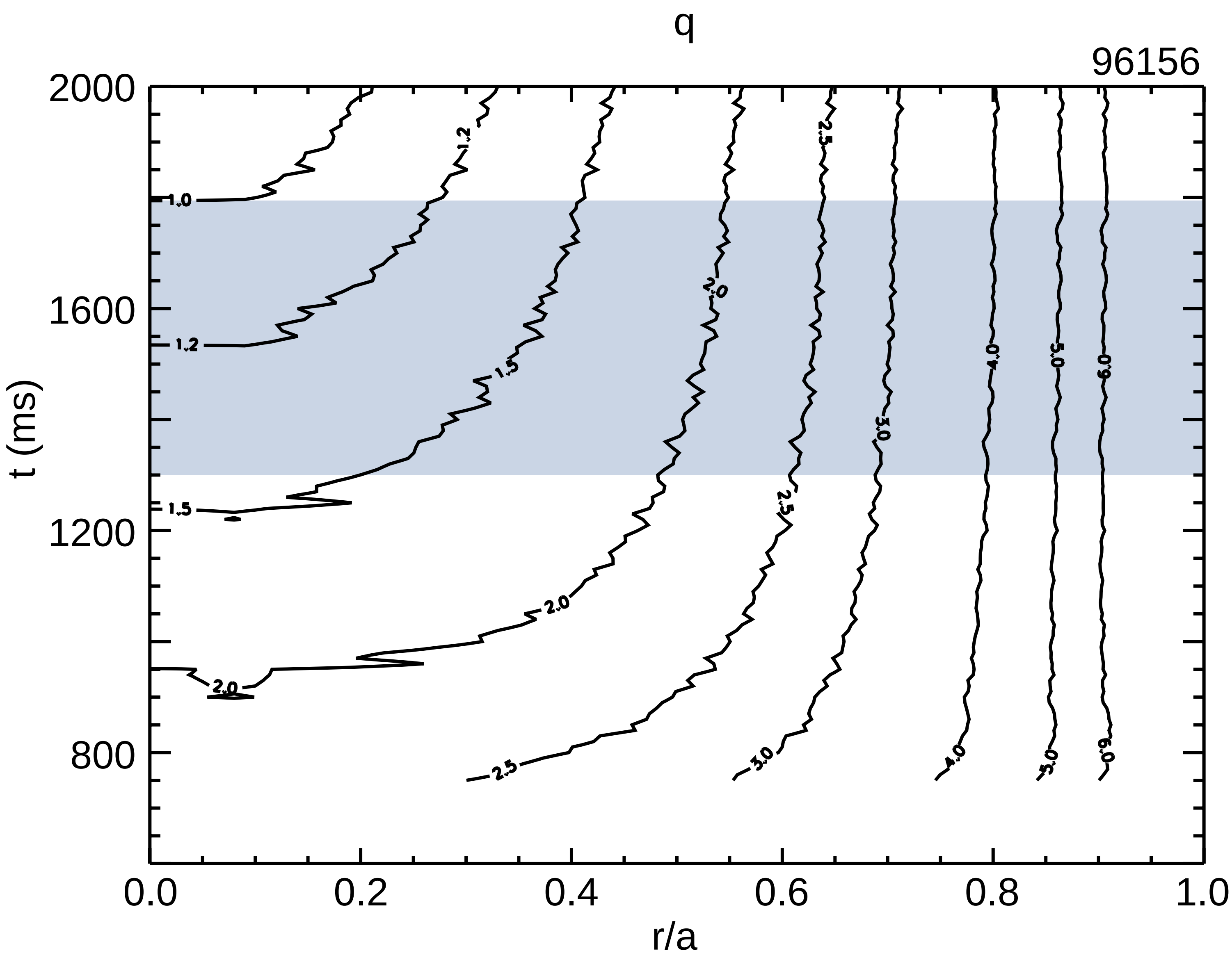

96156 1550.0000



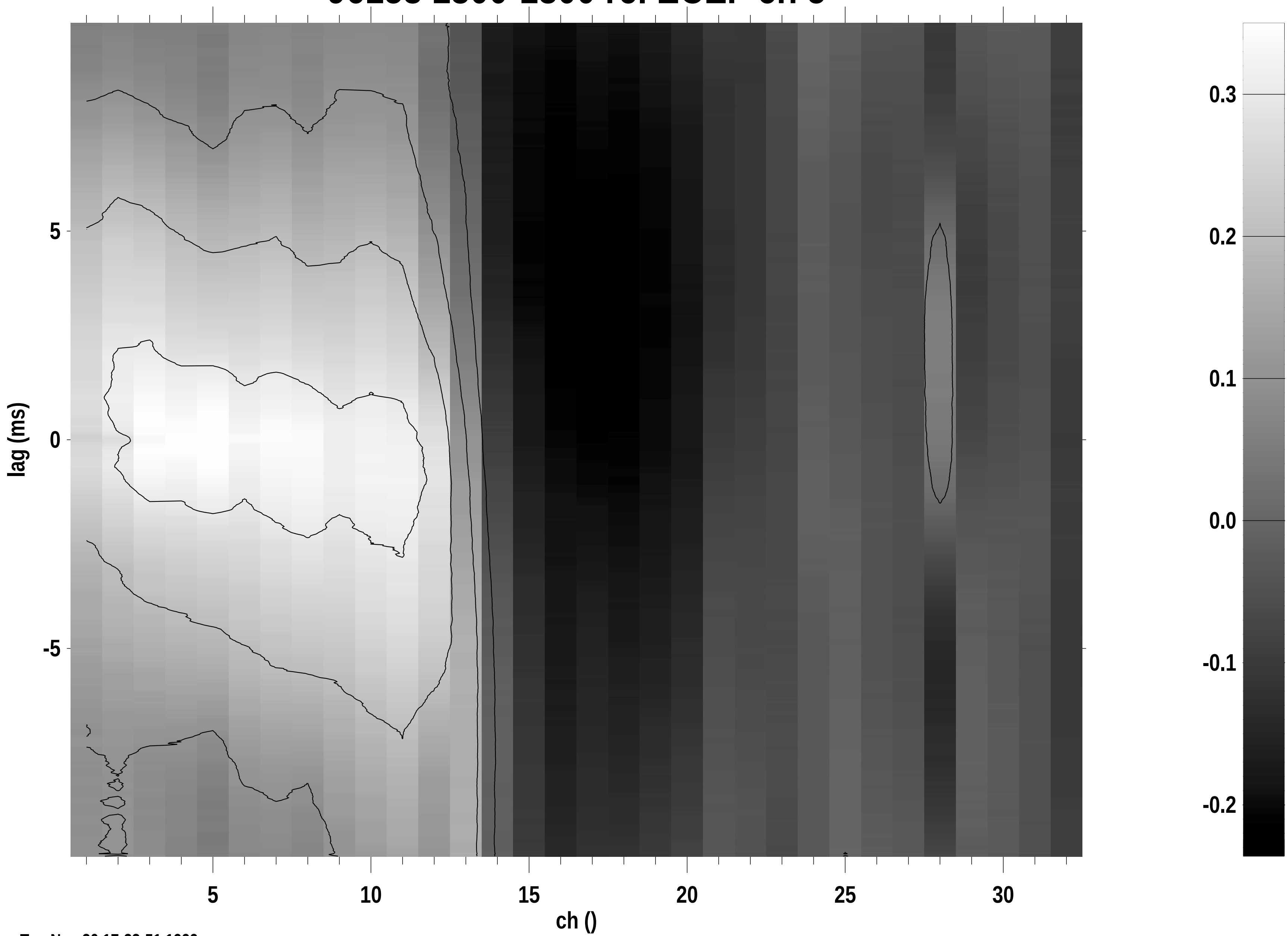
electron temperature (slow ECE)
96157
2500
2000
1500
1000
500
0
t (ms)
3.6
1.6
2.0
1.2
3.2
2.8
2.4
0.8
0.4
ECH on
2.4
1.4
2.0
0.6
0.4
0.2
0.6
32
20
10
1
channel #
radius
(chs 16 and 17 are at the same r/a)



96156
current (MA)
0.2
0.4
0.6
0.8
Dα
photodiode 4up
0.2
0.6
1.0
1.4
$P_{NB}$
$P_{EC}$
power (MW)
1
2
3
SXR
(sxrm1s12)
1
2
3
dB/dt (T/s)
5
10
15
20
neutrons
(x $10^{14}$ /sec)
0.5
1
1.5
2
Te (keV)
ECE channel 26
2
4
6
density
(x $10^{19}$ /m$^3$)
0.5
1
1.5
2
0
500
1000
1500
2000
2500
t (ms)
0
500
1000
1500
2000
2500
t (ms)


q
96156
2000
1600
1200
800
t (ms)
0.0
0.2
0.4
0.6
0.8
1.0
r/a
1.0
1.2
1.5
2.0
2.5
3.0
4.0
5.0
6.0

# 96158 1300-1800 rel ECEF ch 5




politzer Tue Nov 30 17:33:51 1999

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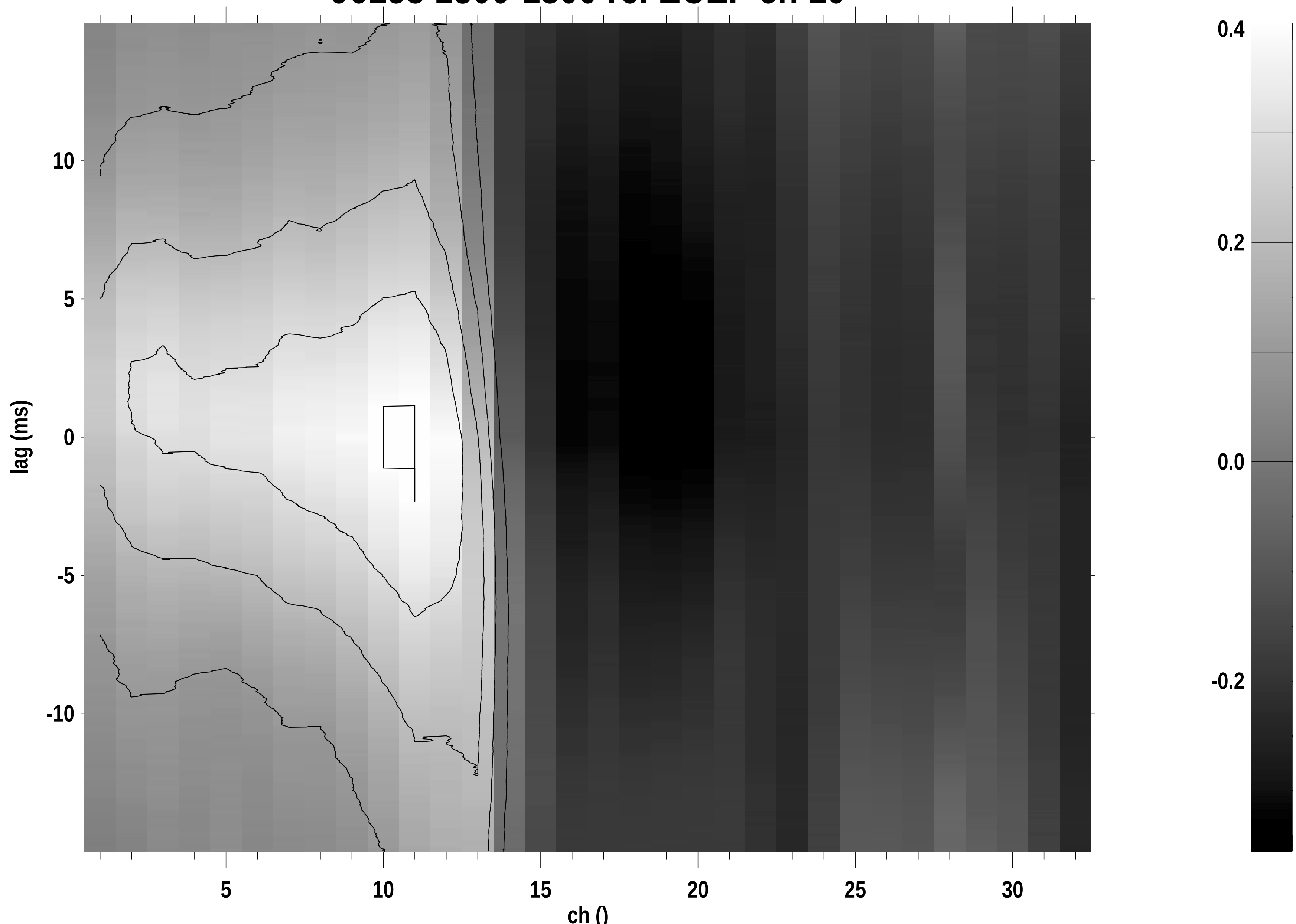


politzer Tue Nov 30 17:35:42 1999

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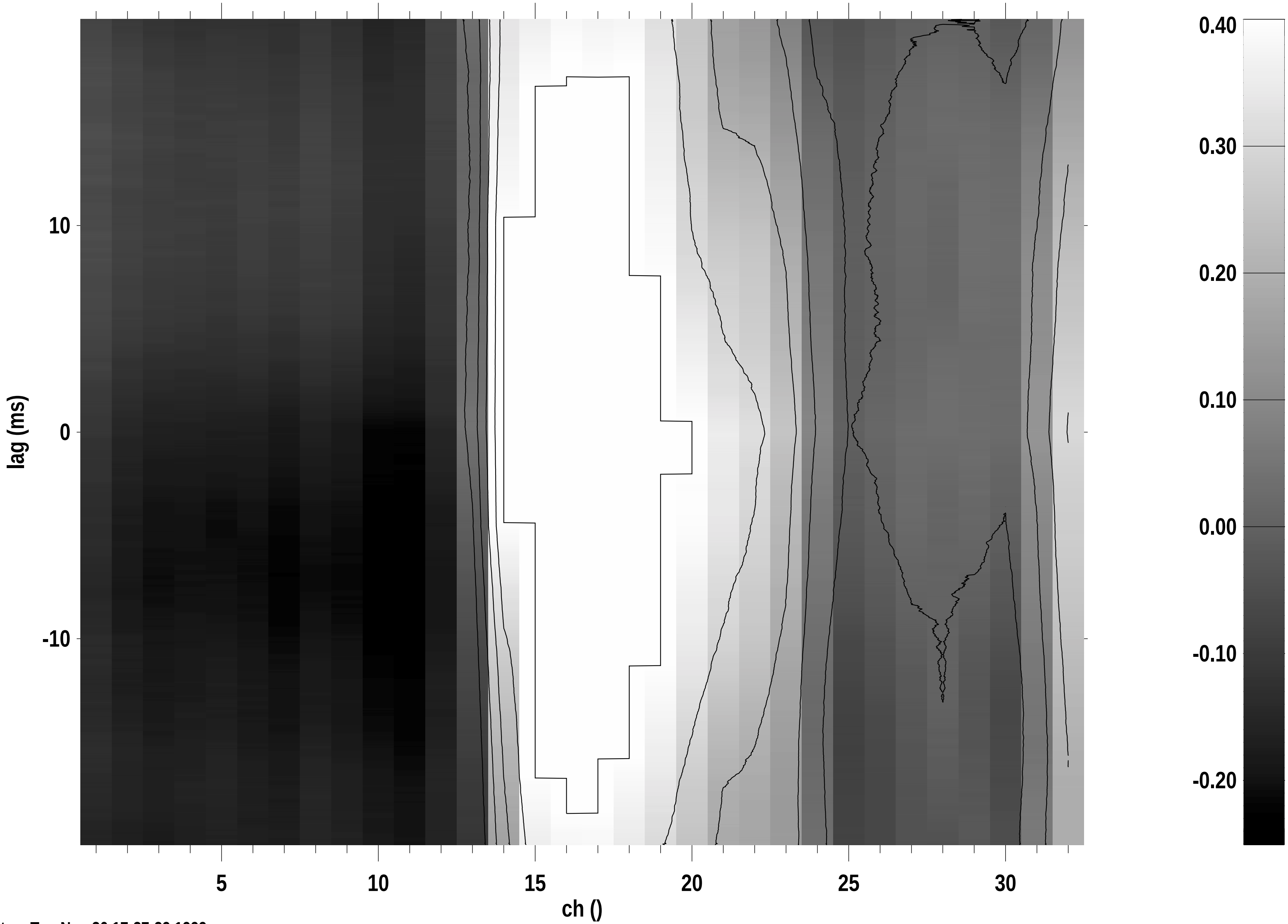
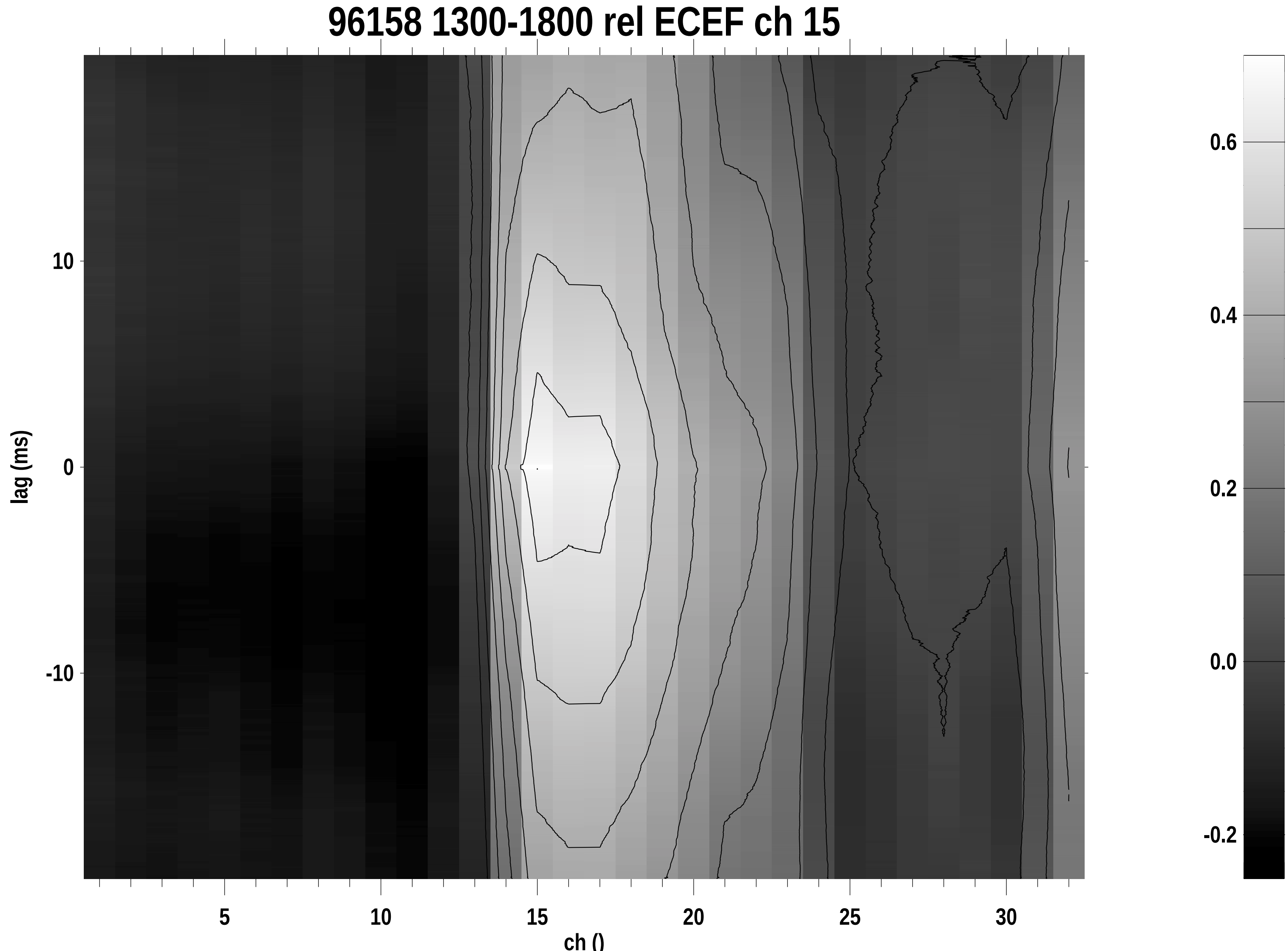



politzer Tue Nov 30 17:37:29 1999




politzer Tue Nov 30 17:37:35 1999

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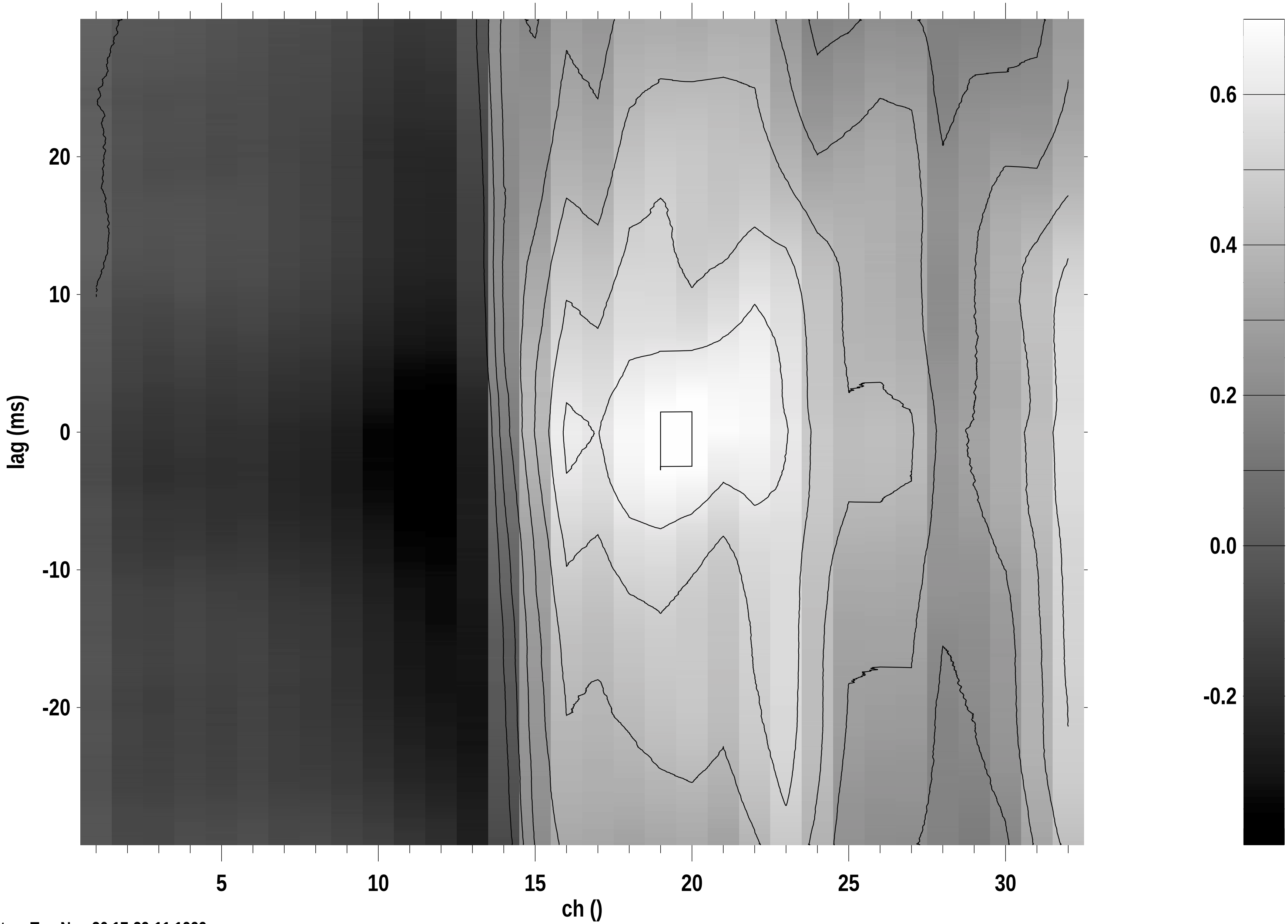
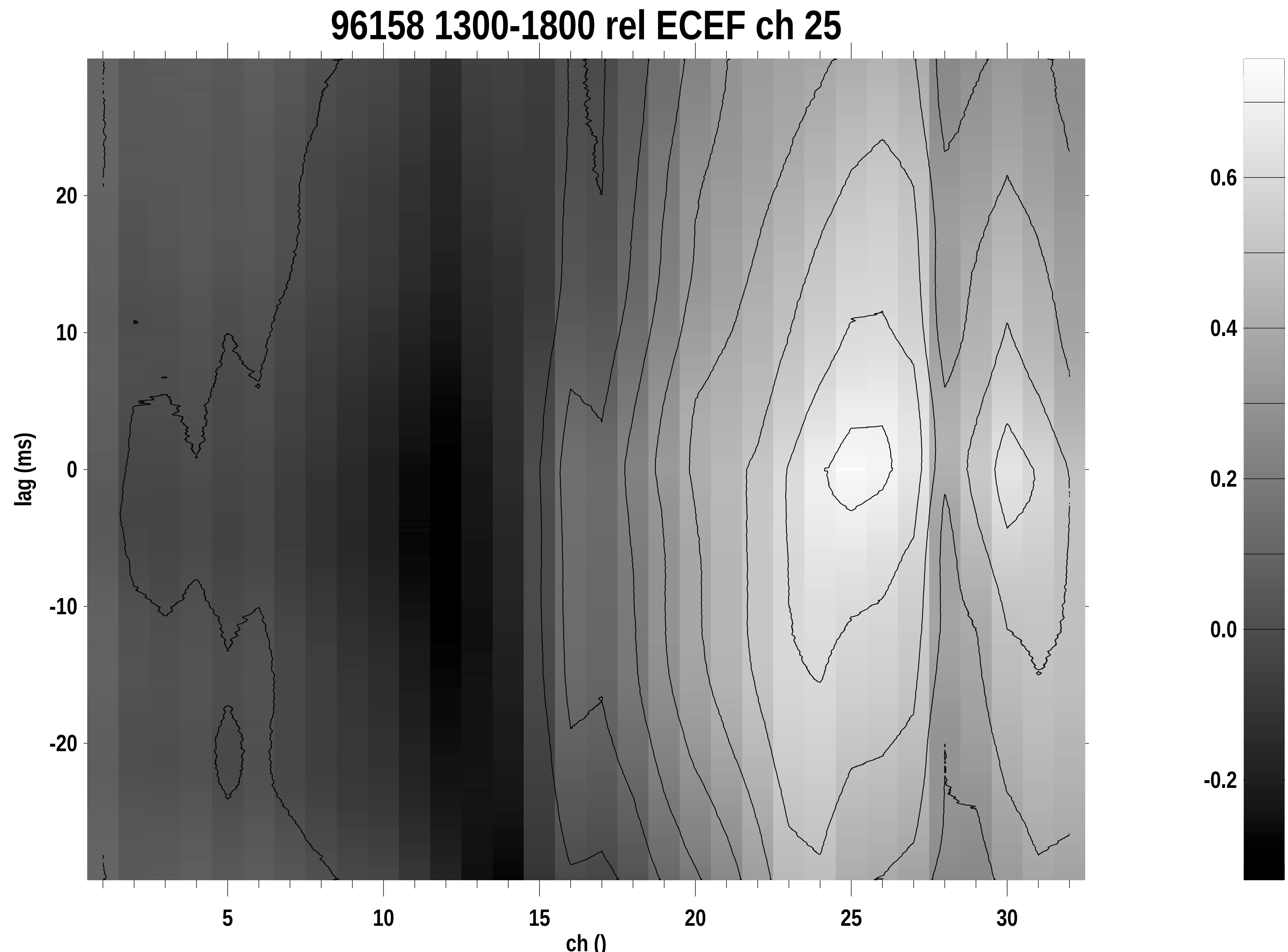
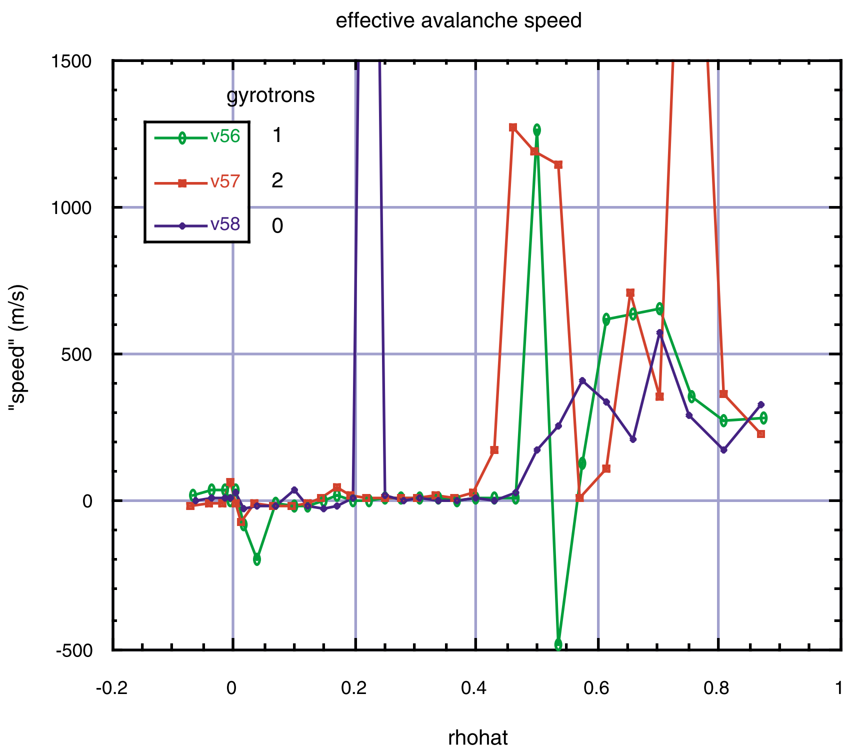


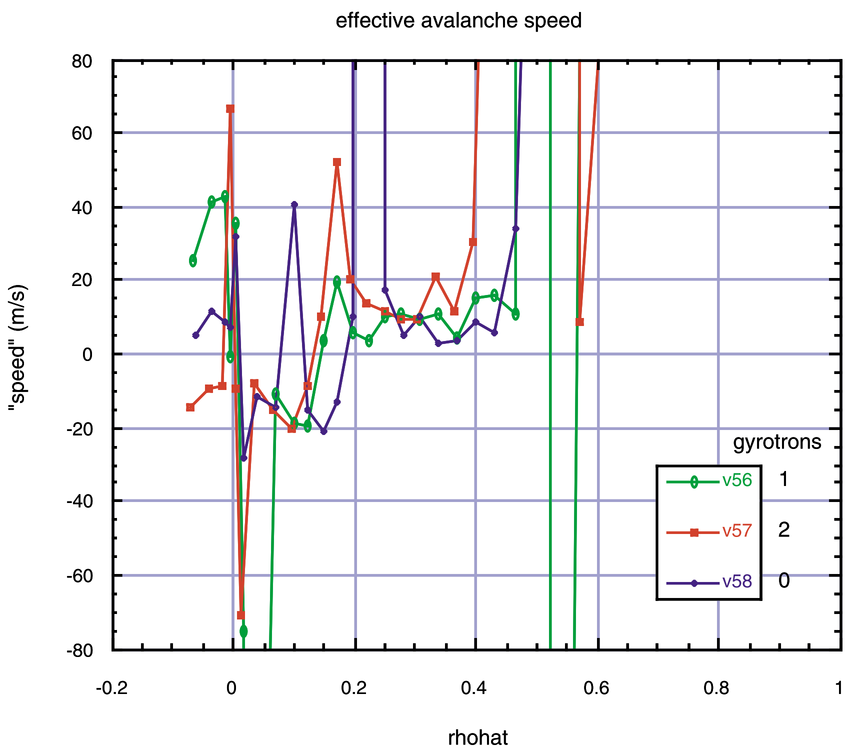

politzer Tue Nov 30 17:39:11 1999

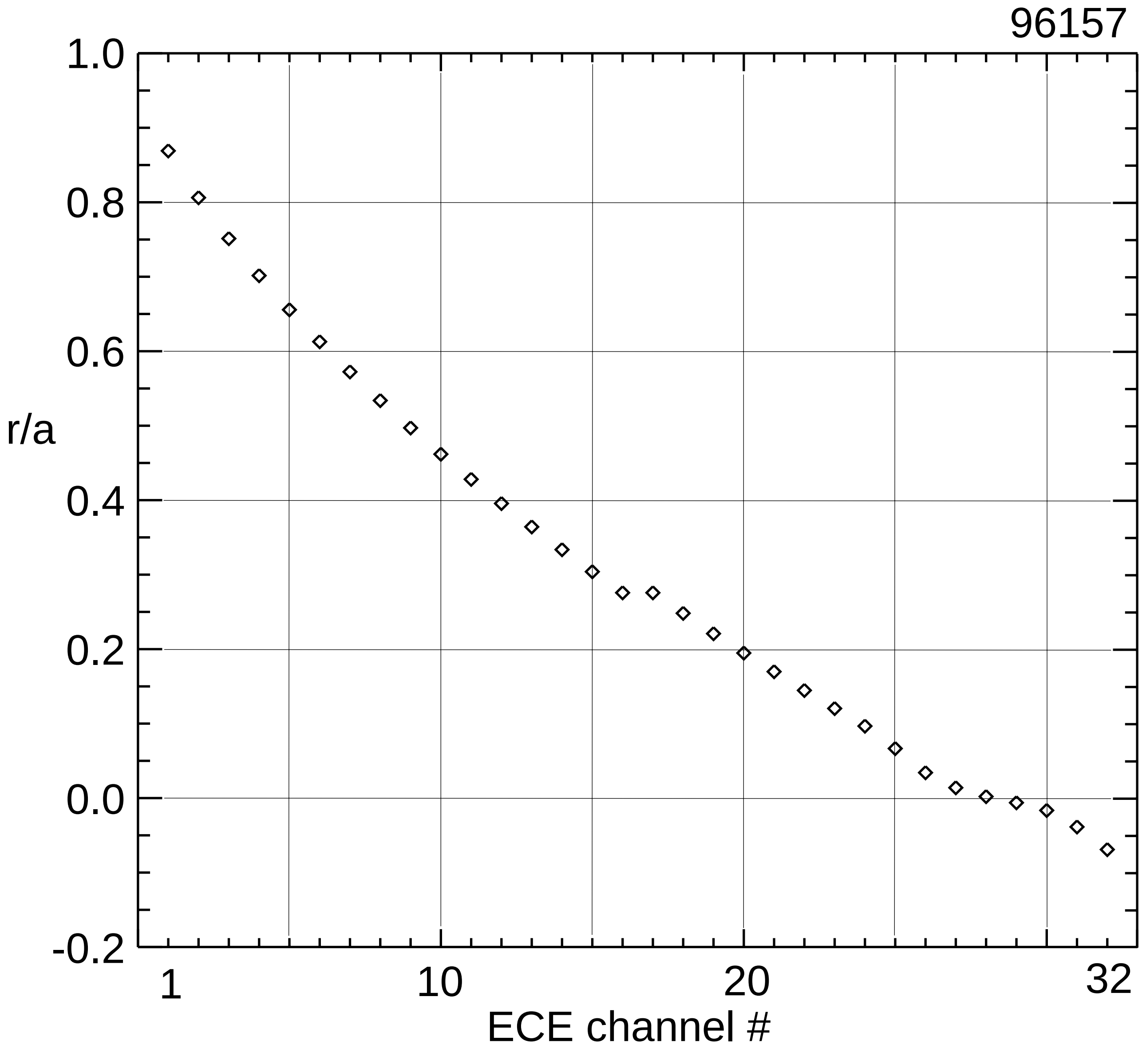


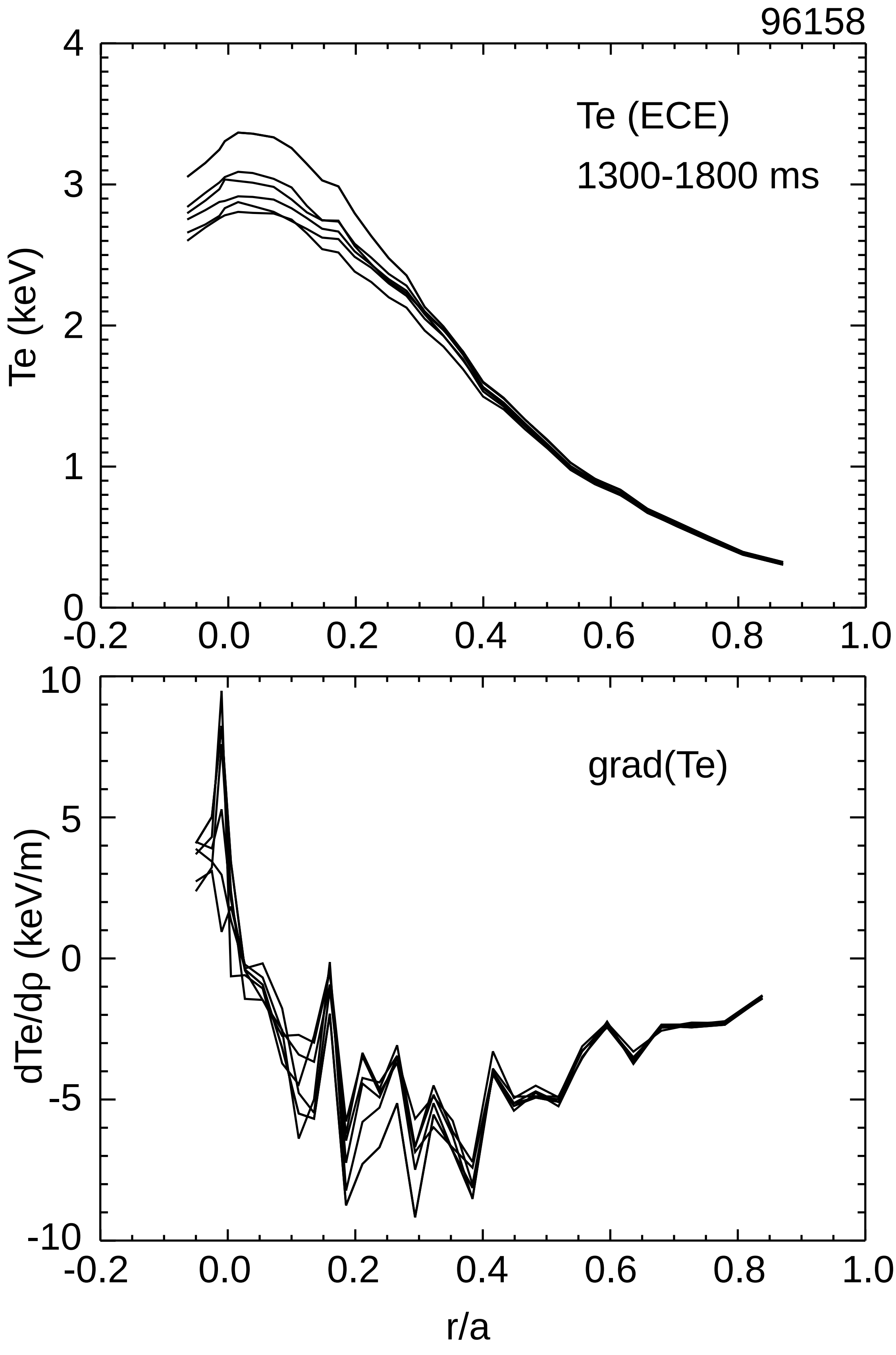

politzer Tue Nov 30 17:40:32 1999



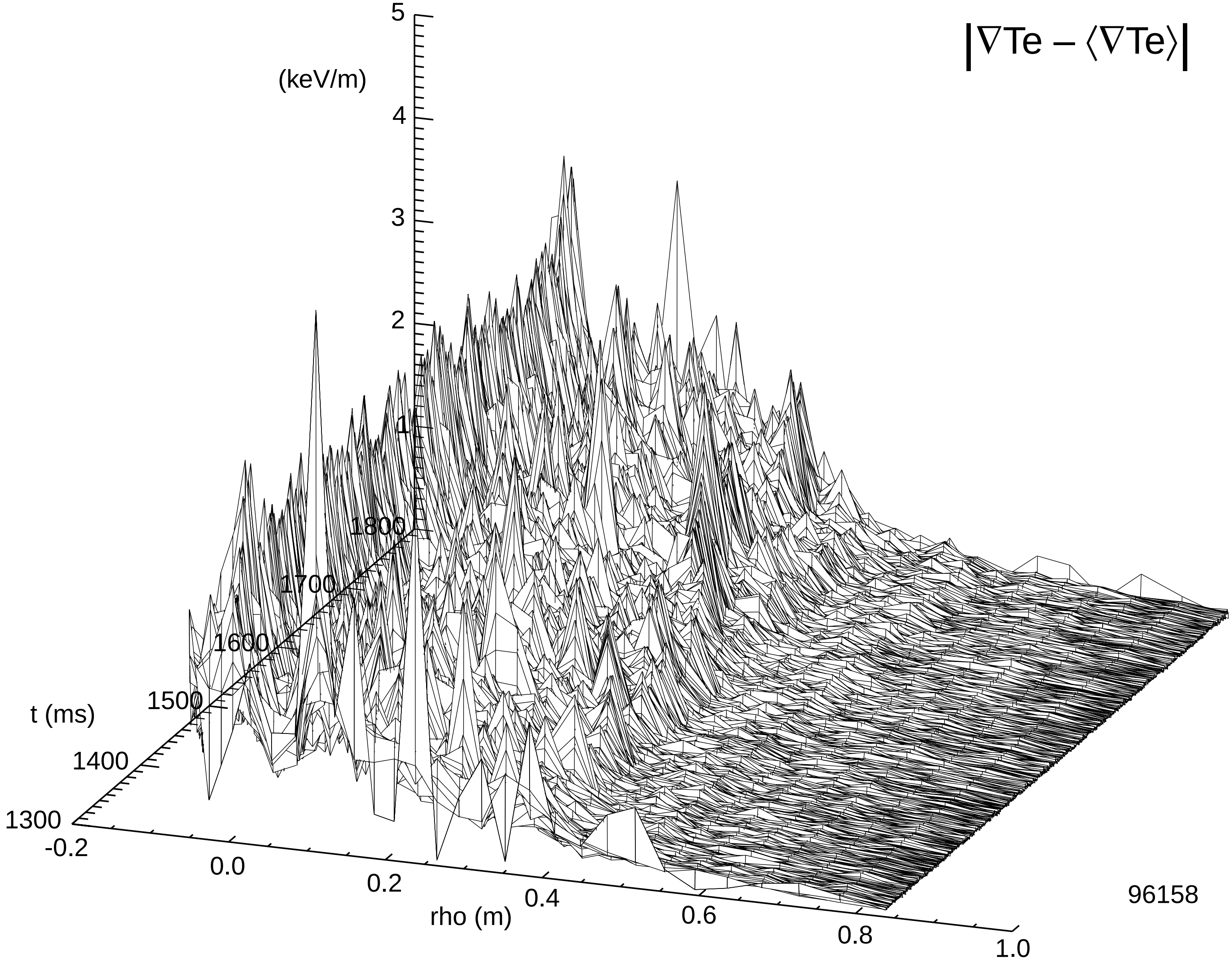
effective avalanche speed
gyrotrons
v56 1
v57 2
v58 0
"speed" (m/s)
1500
1000
500
0
-500
-0.2
0
0.2
0.4
0.6
0.8
1
rhohat


effective avalanche speed
80
60
40
20
0
-20
-40
-60
-80
"speed" (m/s)
-0.2
0
0.2
0.4
0.6
0.8
1
rhohat
gyrotrons
v56 1
v57 2
v58 0


96157
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
r/a
1
10
20
32
ECE channel #



96158
Te (ECE)
1300-1800 ms
Te (keV)
4
3
2
1
0
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
grad(Te)
dTe/dρ (keV/m)
10
5
0
-5
-10
r/a



$|\nabla Te - \langle \nabla Te \rangle|$
(keV/m)
5
4
3
2
1
t (ms)
1300
1400
1500
1600
1700
1800
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
rho (m)
96158