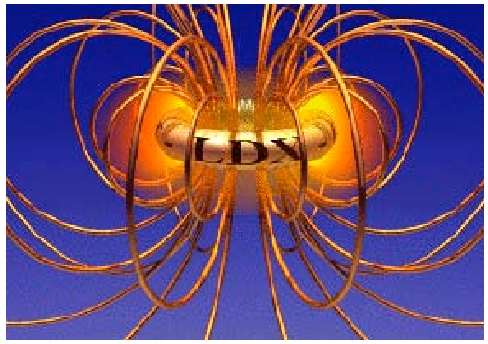
Photo Diode Array Measurements in LDX



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Abstract

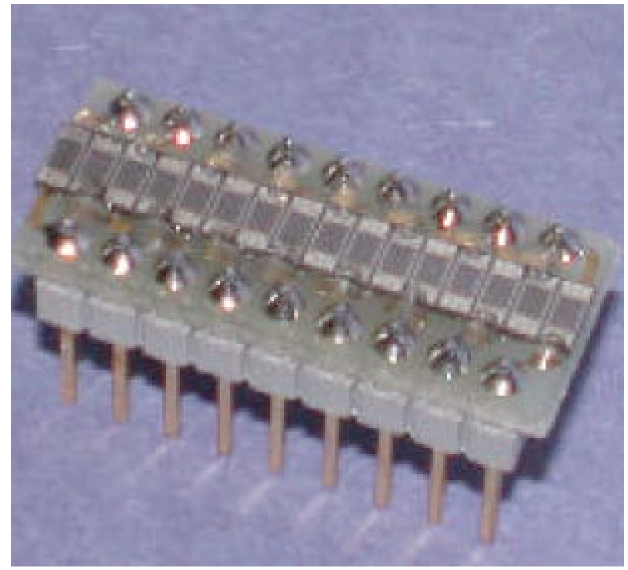
- In a plasma, atoms are ionized, emitting light in the visible range
- Analyzing this light can give information on where the neutral atoms are ionized, and what is the movement inside the plasma
- A photodiode can give much faster information than a regular digital video camera, allowing to see faster changes in the visible light intensity such as a turbulent behavior
- Several photodiodes (16 in that case) forming an array gives spatial resolution, allowing to observe a circulation of plasma such as convective cells

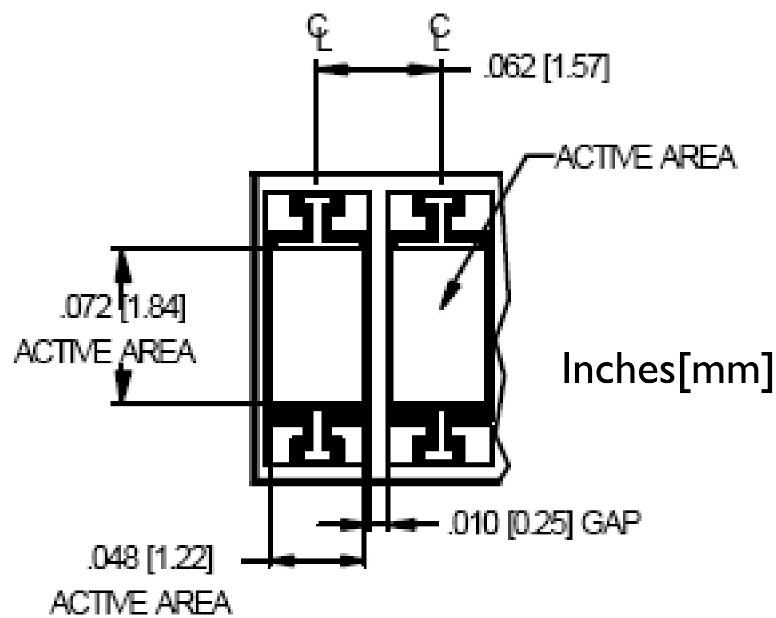
Abstract

In a plasma with closed field lines such as LDX, large scale convective motions are possible due to a charging up of magnetic field lines. This convection can play an important role in transporting plasma, including local micro turbulence, from the plasma core to the edge region. In LDX the plasma density is sufficiently low that neutral atoms can penetrate deeply into the plasma. When these atoms are excited by plasma they emit light in the visible range. Analyzing this light gives information about the convective motions within the plasma. A photodiode gives much faster information than a regular digital video camera and the observation of fast changes in the visible light intensity caused by plasma turbulence can be observed. To obtain spatial resolution we have installed an array of 16 photodiodes in LDX. Using correlation techniques we observe a circulation of plasma such as would be caused by convective cells.

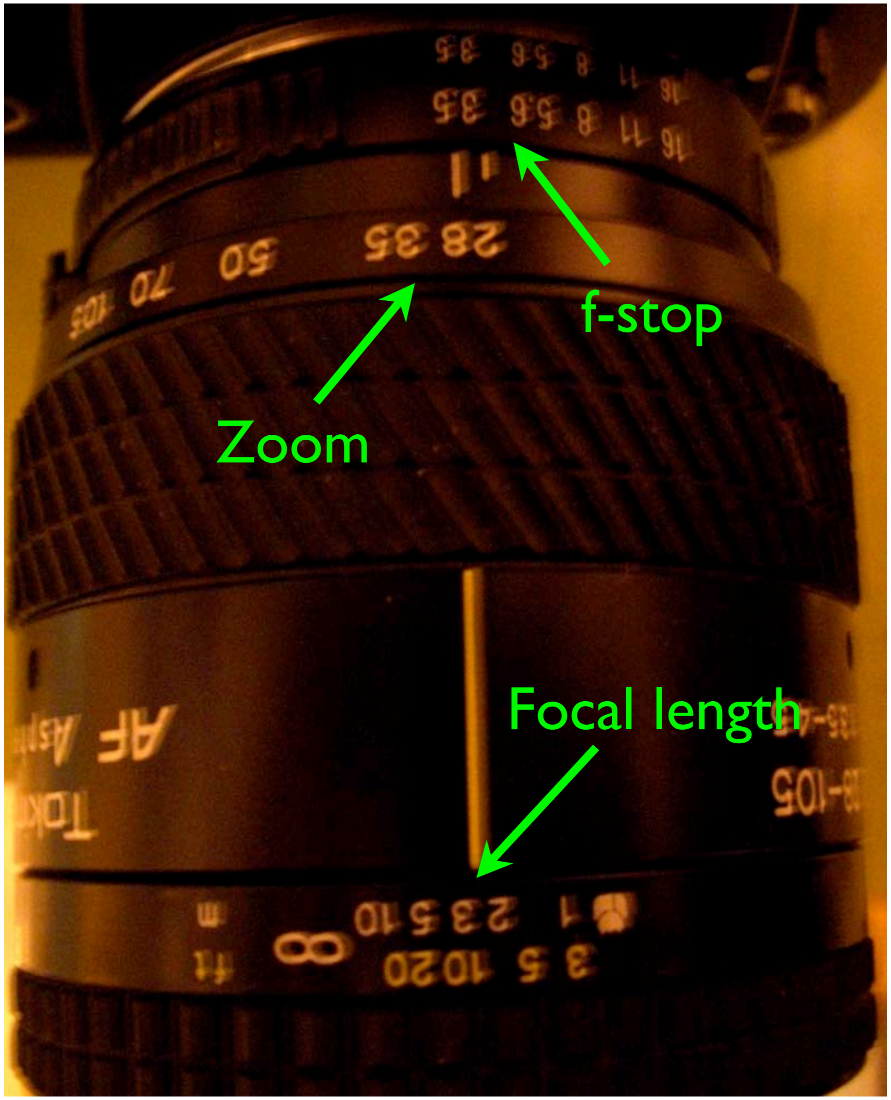
The detector

- The sixteen channels have a common cathode
- When the photodiode are biased, they can achieve a 15 ns time response⇒ can observe very high frequencies
- How to collect light and send it on the detector?





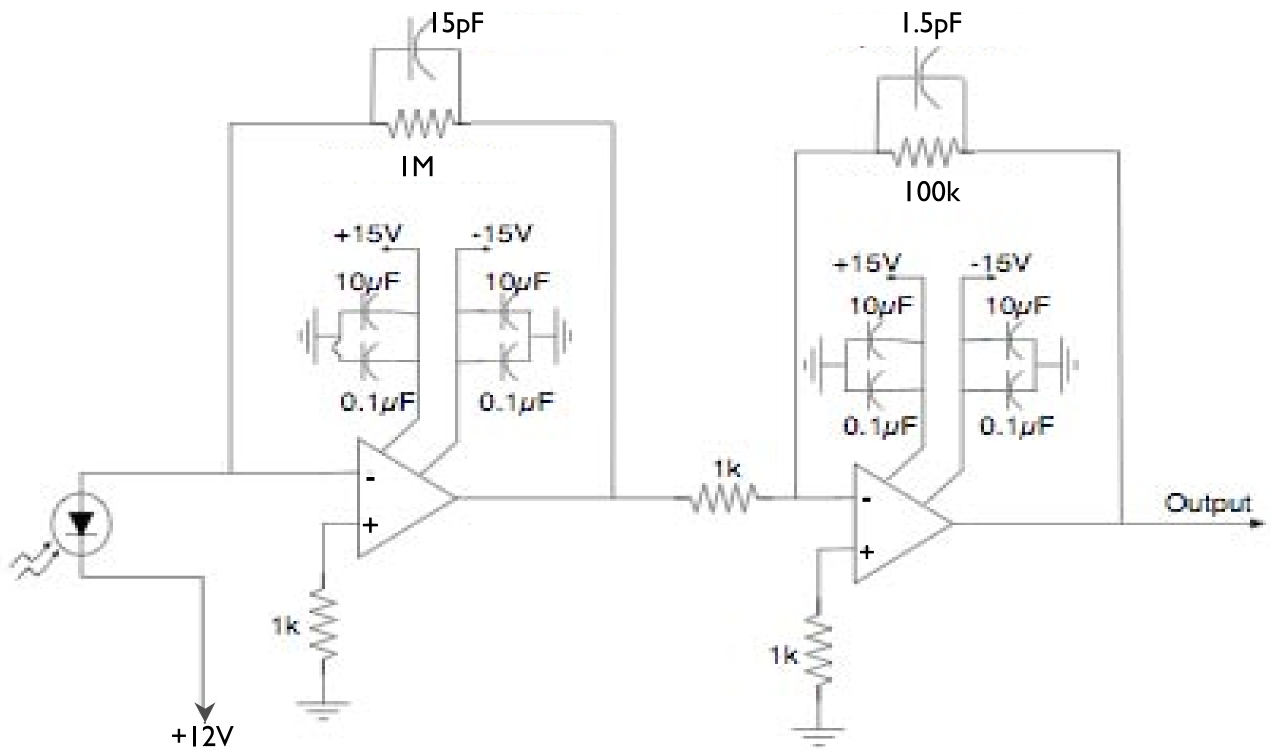
The camera

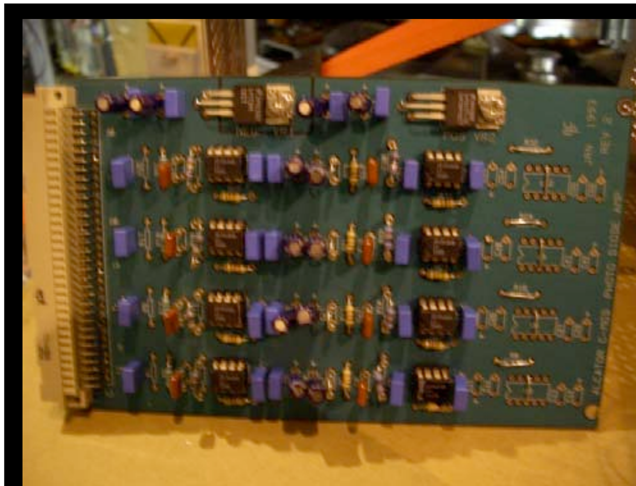


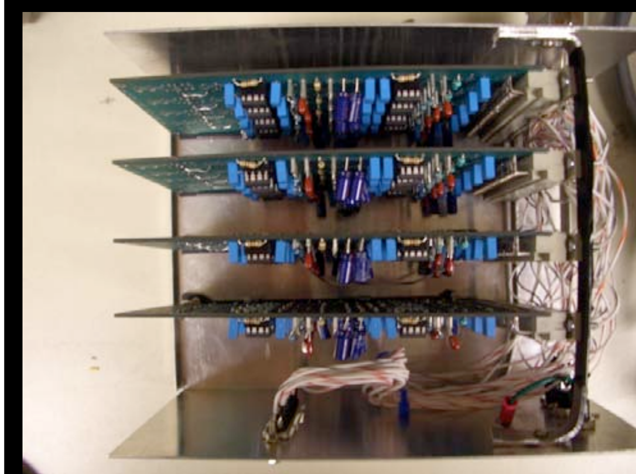
Lens of the camera

- The film has been replaced by the detector in the camera.
- One can use the visor to aim at the right point of the vessel
- We benefit from the capabilities and settings of the SLR lens

The electronics

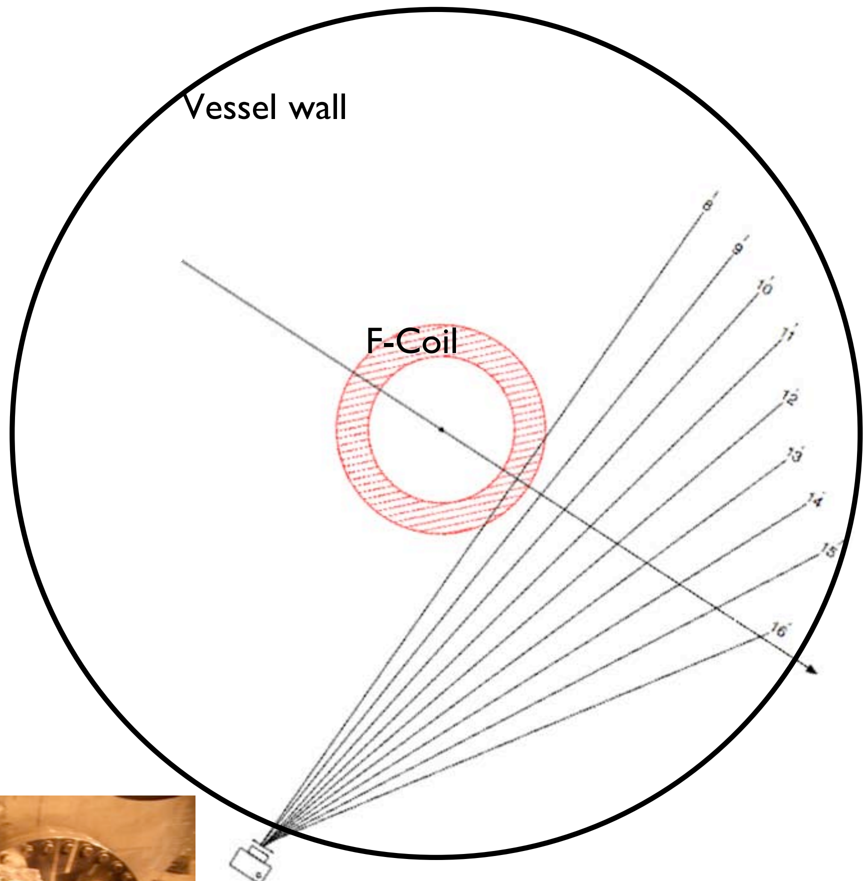




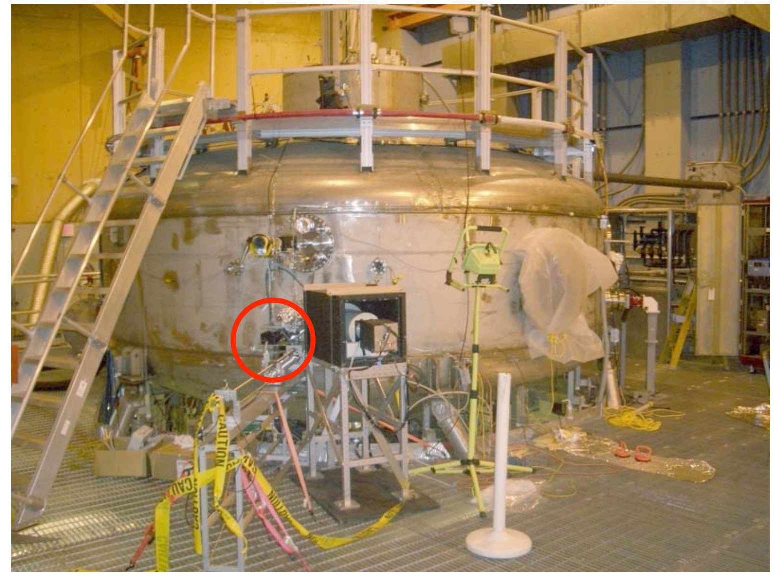


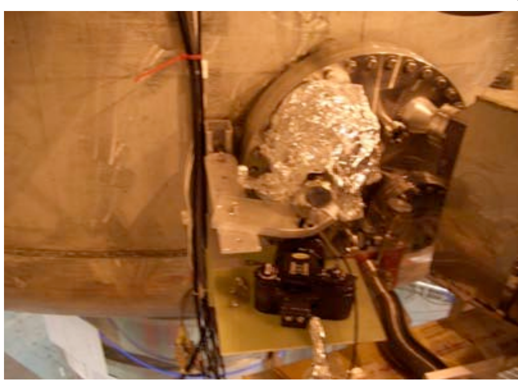
- Trans impedance amplifier : ideal for a photodiode
- Filters necessary to prevent the amplifiers from oscillating

The view



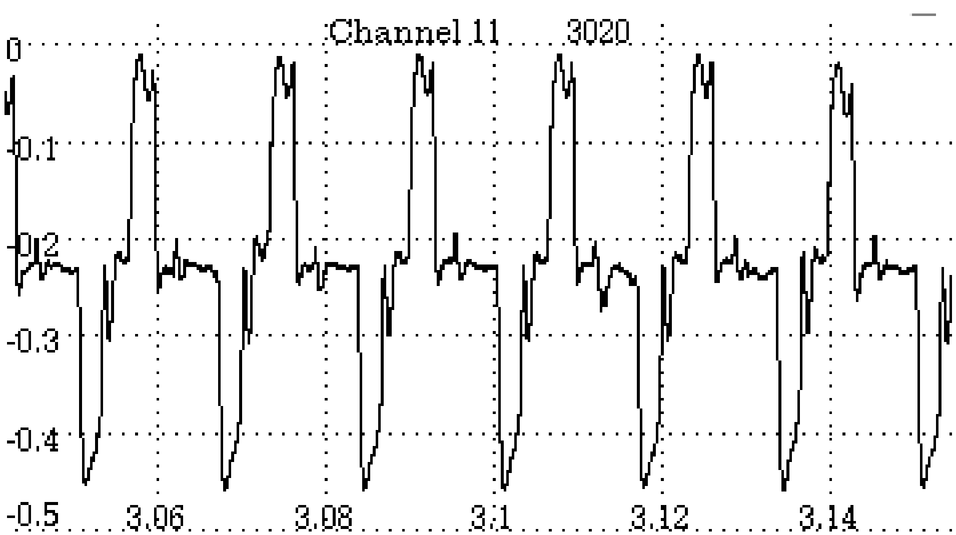
Photodiode
Array

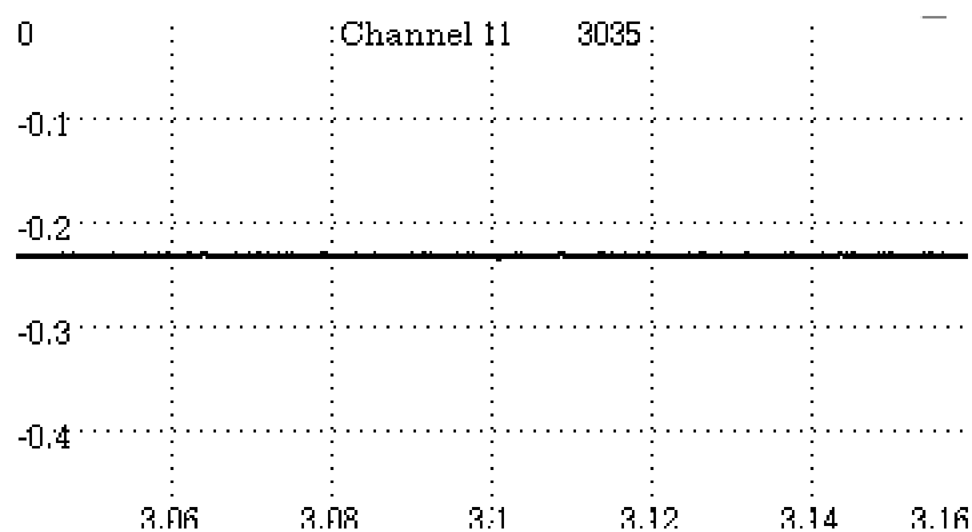




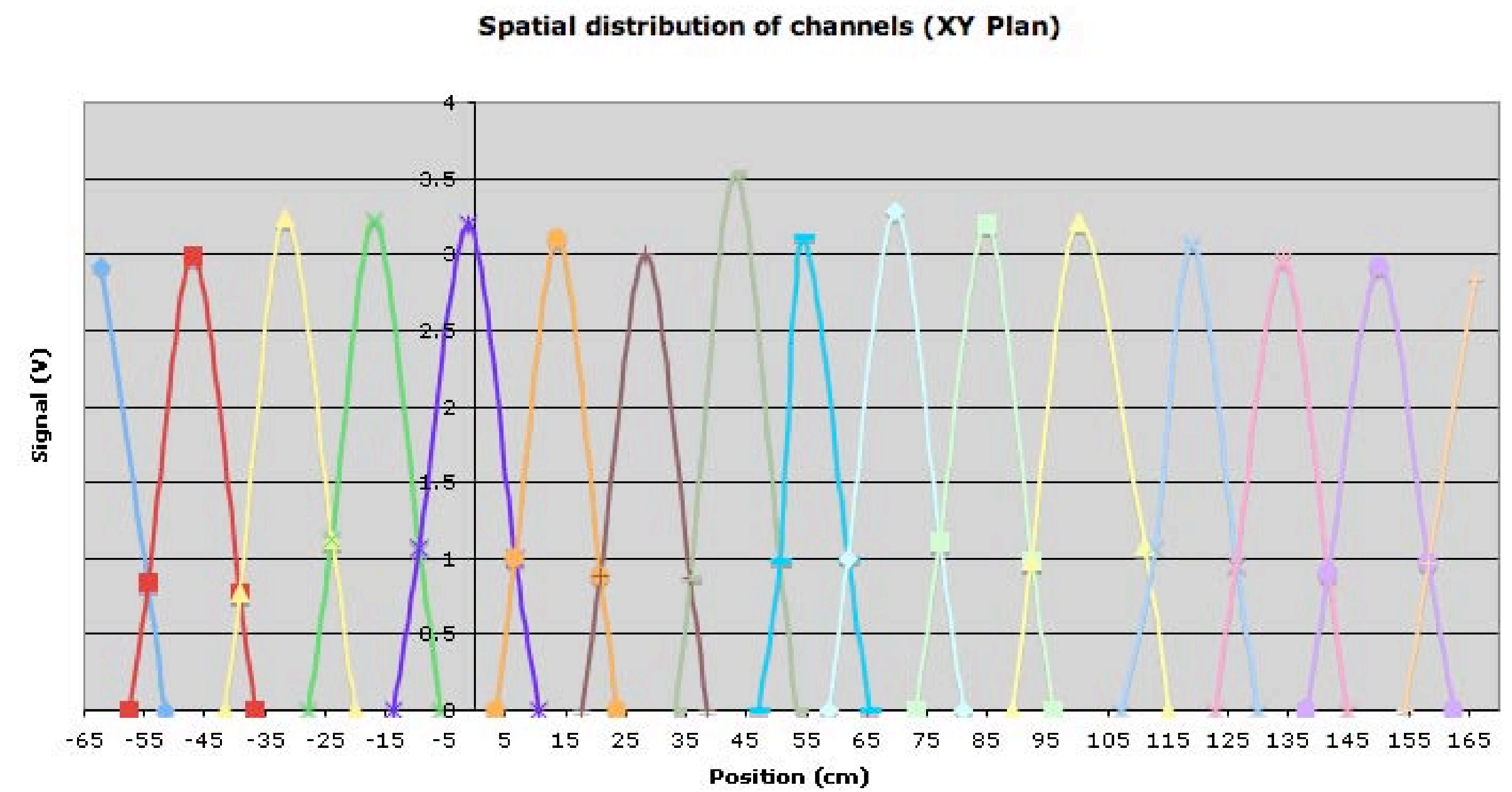
Noise and shielding

- nA intensity before the amplifiers
  ⇒ very sensitive to 60 Hz noise
- Installation of metal braid shielding reduced noise by 50



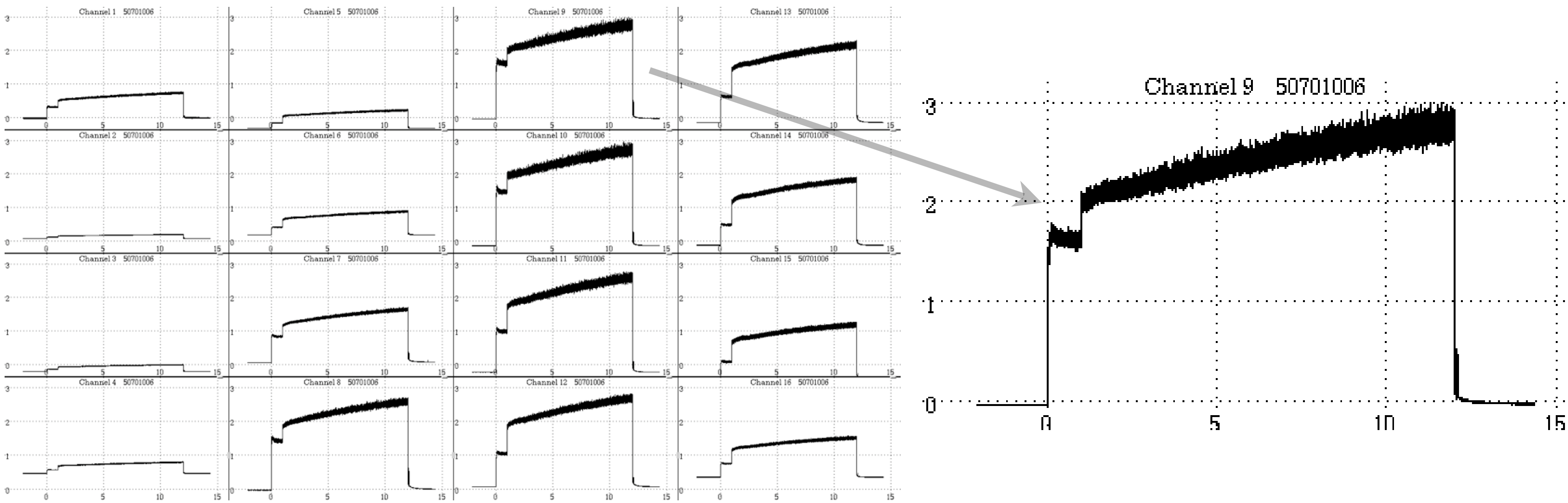


Spatial calibration



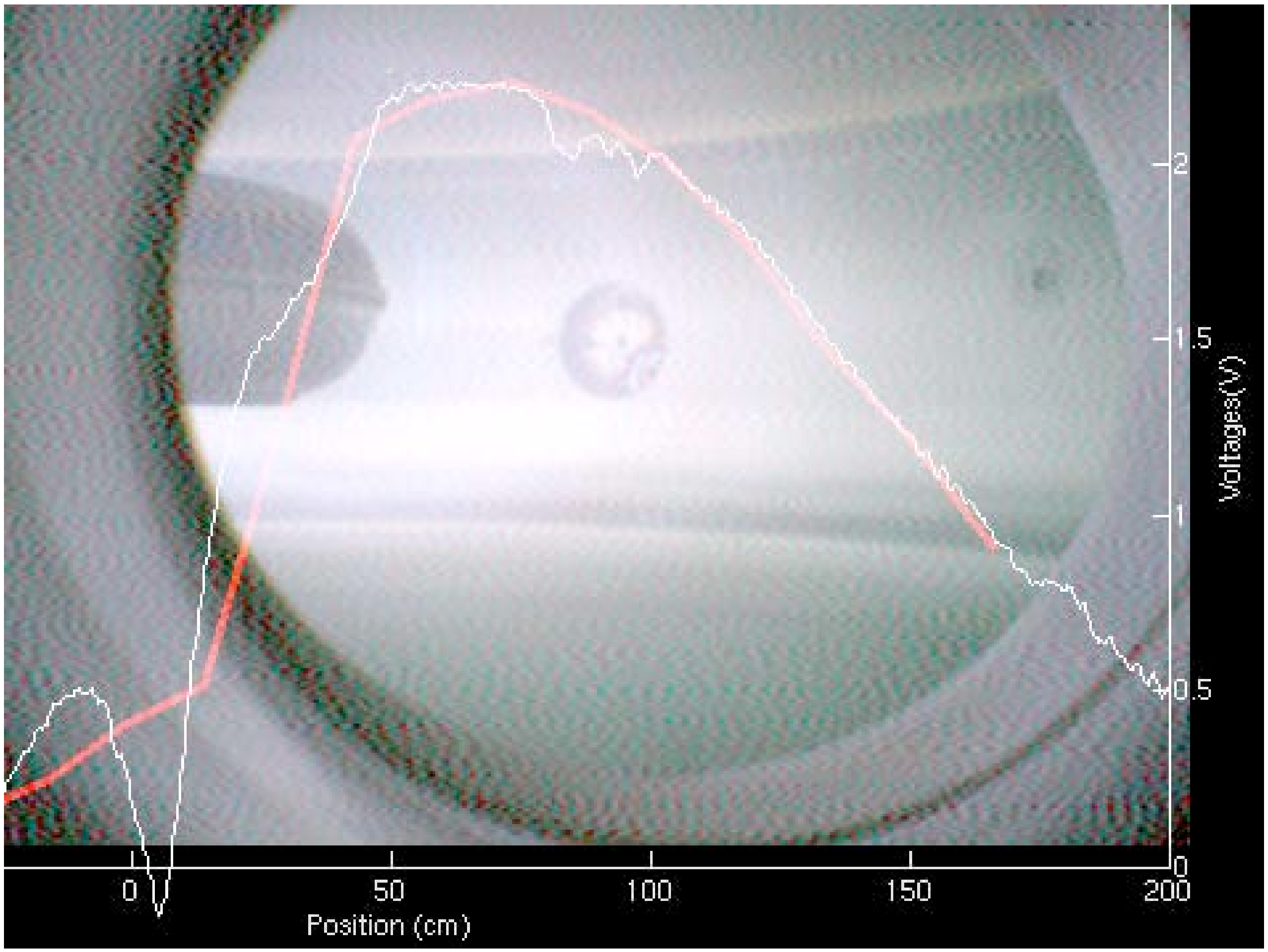
- Calibration achieved by translating a uniform light source in front of the camera.
- The spatial resolution seems approximately homogeneous, and the overlapping is reasonably small.

Typical plasma shot



- The voltage on each channel indicates the intensity of the light received, it varies between channels indicating a spatial distribution.
- On each channel, on top of the main profile, one can see a higher frequency signal, that is not noise. What information is it carrying?

Profile comparison



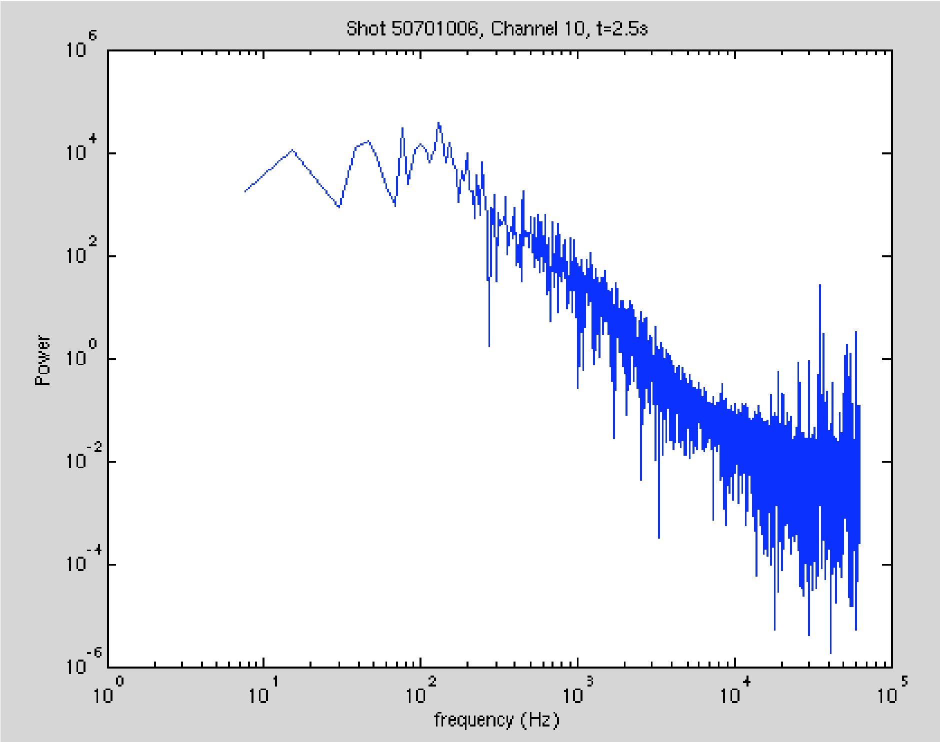
Background: frame taken with a digital video camera looking at the same view

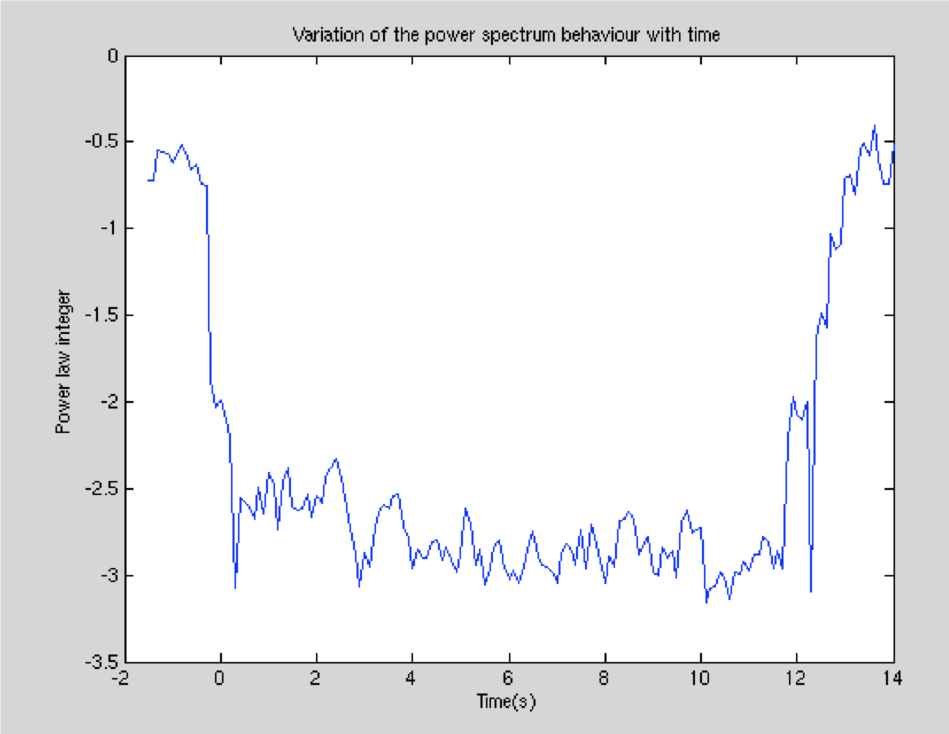
In white : intensity of the light computed from this frame

In red : Profile given by the photodiode array.

The profiles are very similar !

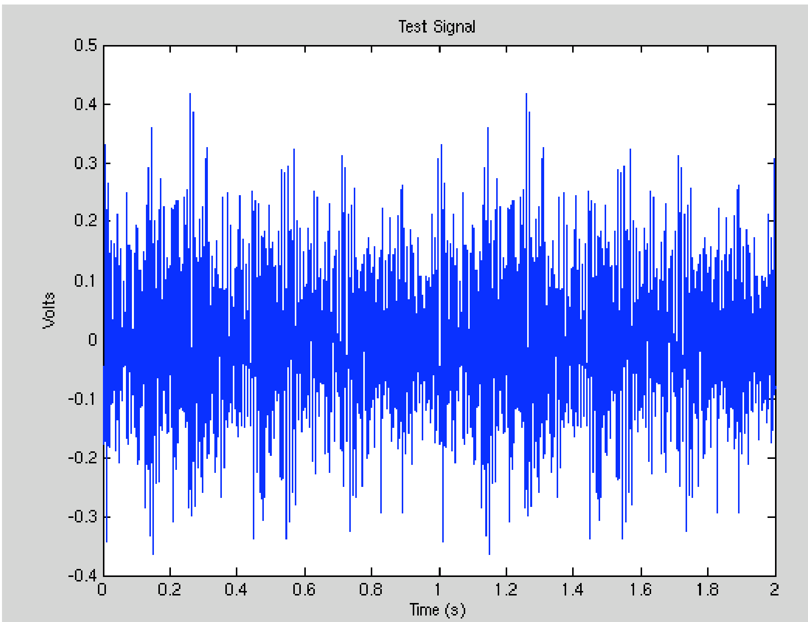
Power spectrum of the light : turbulent behavior?

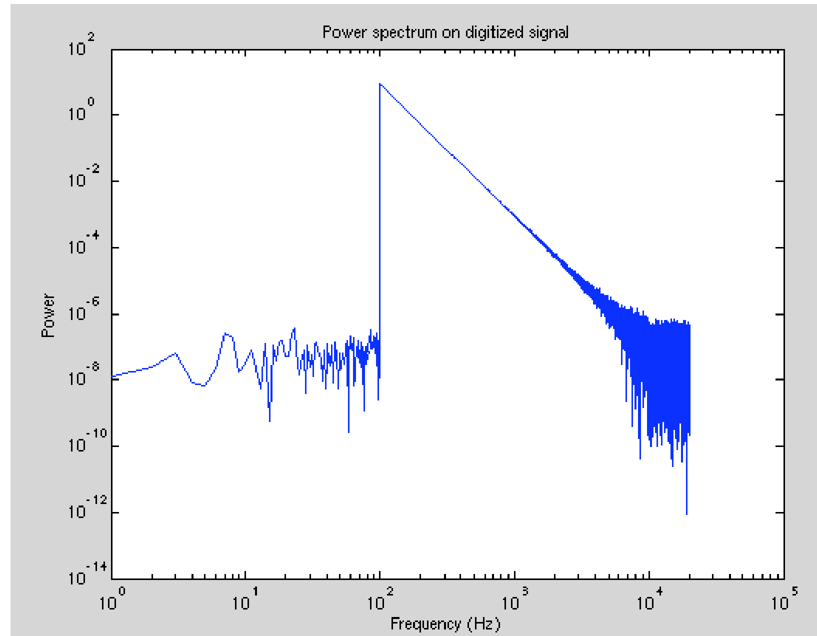


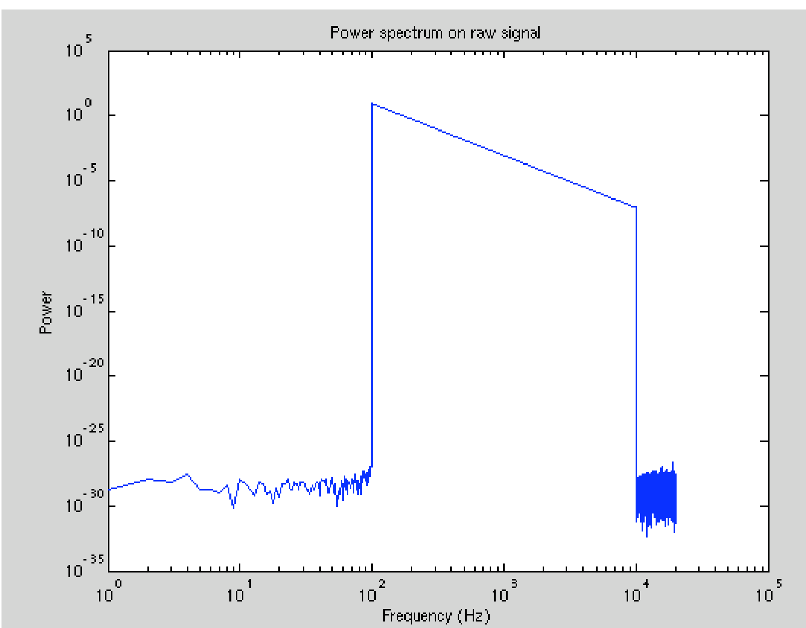


- The power spectrum seems to go like $P_I \propto f^{-a}$ with 2.5≤a≤3
- The intensity of the light emitted being proportional to the neutral density, we obtain $\tilde{n}_e \propto f^{-a}$
- This result is consistent with other plasma turbulence observations (F.F. Chen, PRL **15** (65) 381).

Is this spectrum for real?



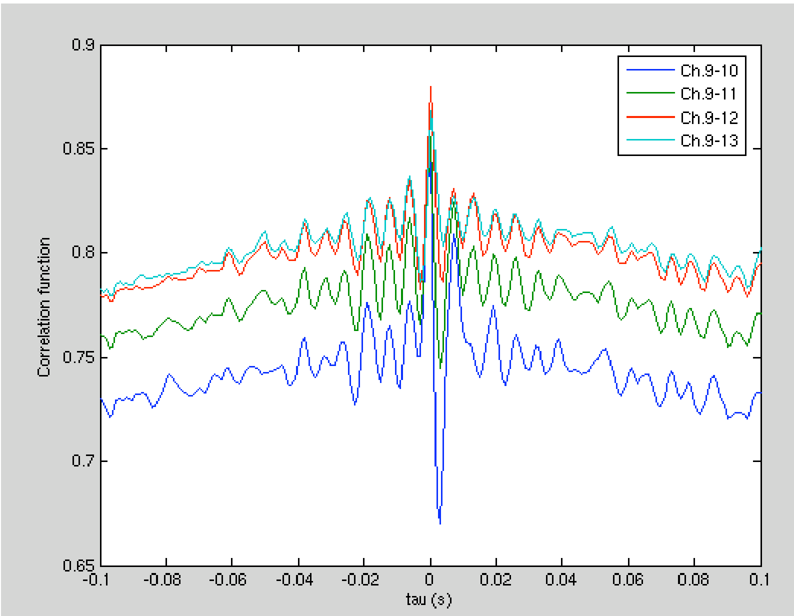


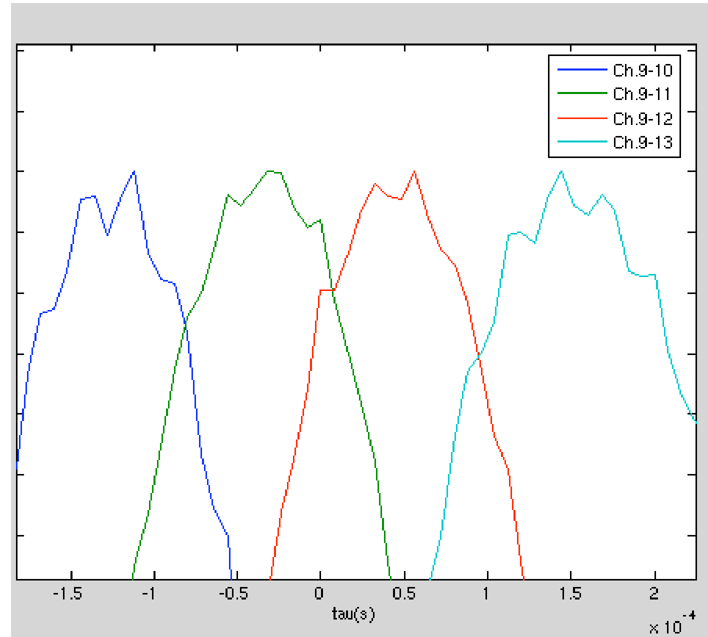


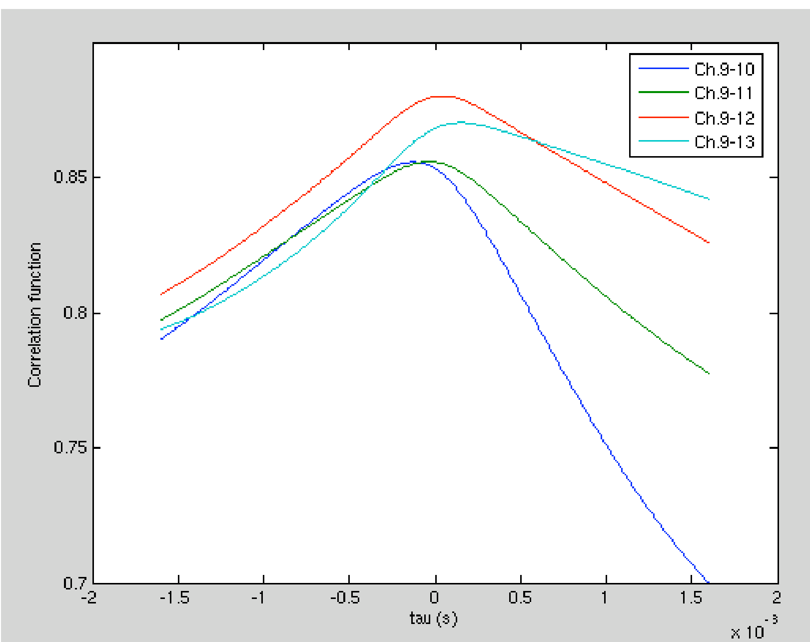
- Computer generated signal (top left)with a $1/f^4$ power spectrum on a 100Hz-10kHz range (below)
- After digitization, the power spectrum is still meaningful (above), not very corrupted by the digitizer:

  The power spectrum we saw is for real!

Spatial correlations ?







$$h(\tau) = \frac{< (f(t) - < f >)(g(t+\tau) - < g >) >}{\sqrt{< (f(t) - < f >)^2 >}\sqrt{< (g(t) - < g >)^2 >}}$$

- Correlations computed between channel 9 and following channels
- High correlations and delayed maximum : propagation at 1.5e03 m.s^{-1}?

Experiment vs. theory

According to Pastukhov's theory the velocity of the convective cells (Eq. 12, Pastukhov and Chudin, 2001) is :

$$v_a \sim \epsilon c_s$$

where C_s is the sound velocity of the ion ($9\ 10^4$ m/s for T_e=100 eV) and

$\epsilon \sim (\chi/ac_s)^{1/3}$, χ the local thermal diffusivity (about $1 m^2.s^{-1}$) and *a* a minor radial scale. This gives $v_a \sim 2e03 m.s^{-1}$,

which is consistent with the value $v_a \sim 1.5e03 m.s^{-1}$ we observe.

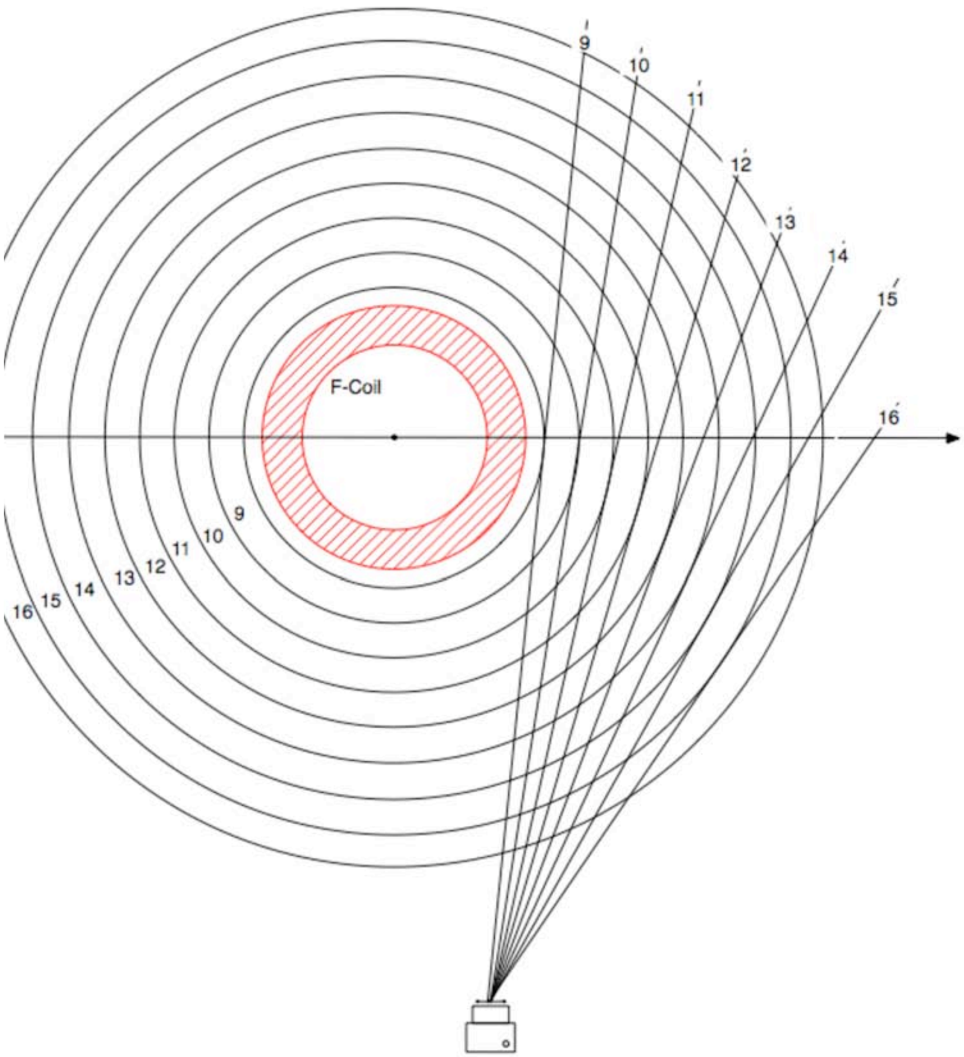
Making several hypothesis on the properties of the convective cell, one can show that the potential fluctuation responsible for it is related to its speed via:

$$\Phi = \frac{\pi}{a} v_a \Delta\Psi$$

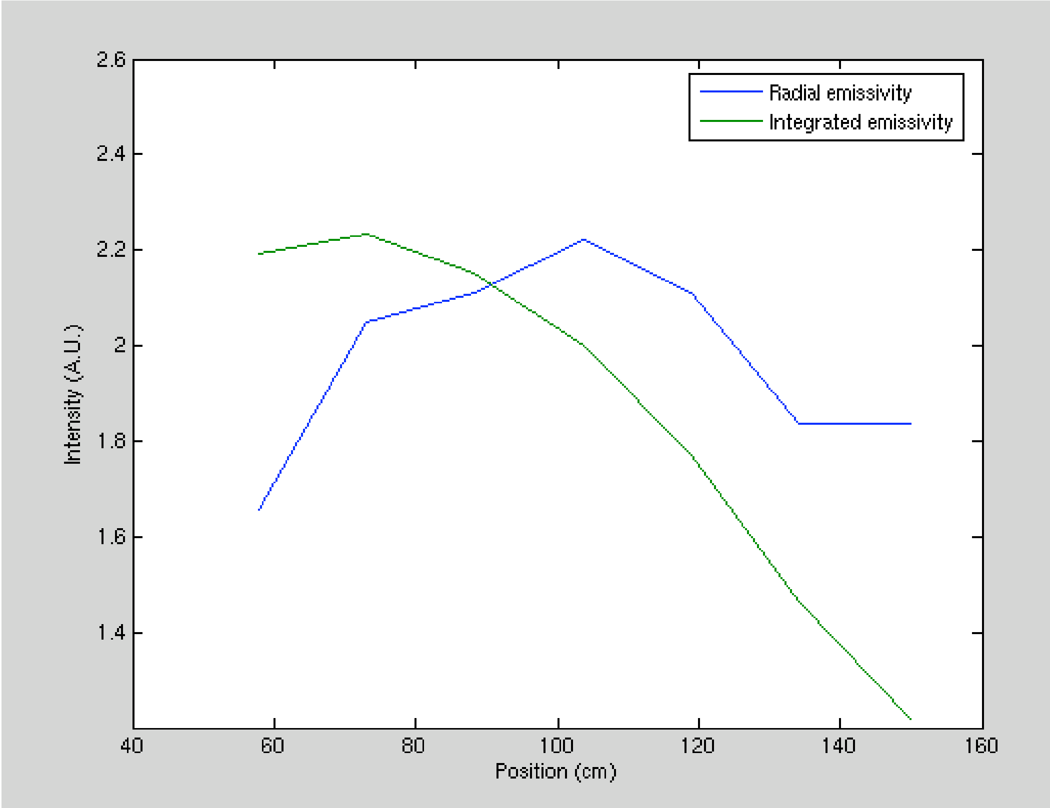
which agrees with the parameters of our plasma and the assumed speed v_a for a potential fluctuation: $\Phi \sim 200V$

possible in our plasma but probably not measurable with the probes we have.

Abel inversion, from side profile to radial profile



Abel inversion diagram



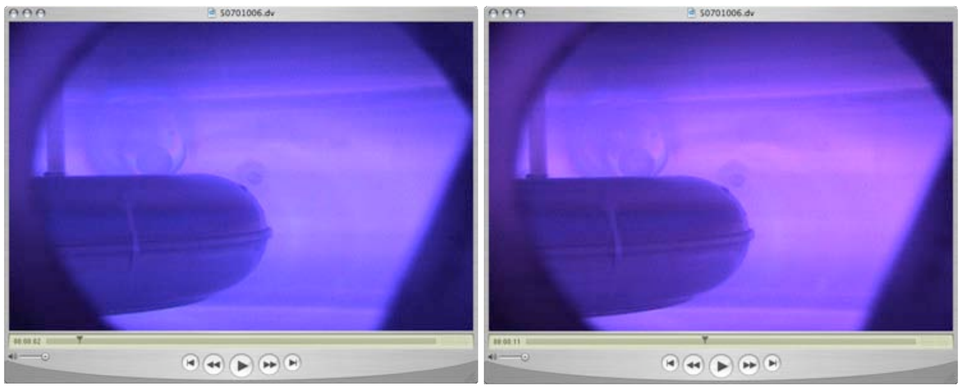
$$E_i = \sum_{j=9}^{16} L_{ij} ej \;\; \Rightarrow e_i = \sum_{j=9}^{16} L_{ij}^{-1} E_j$$

E_i : chord i integrated emissivity

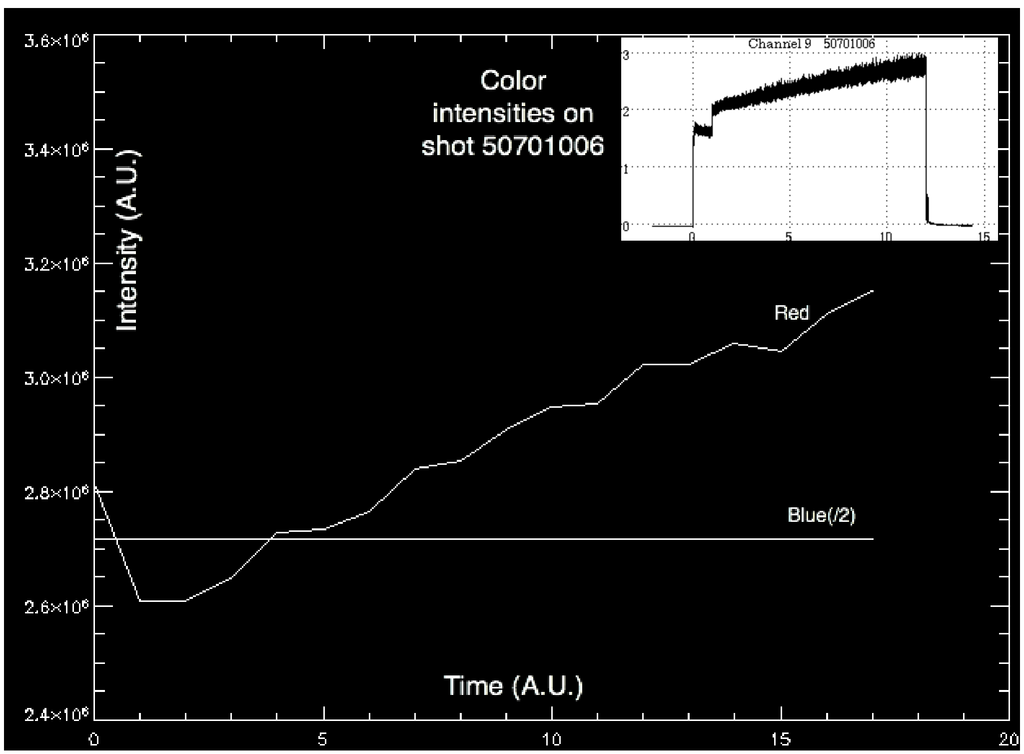
e_i : radial r_i emissivity

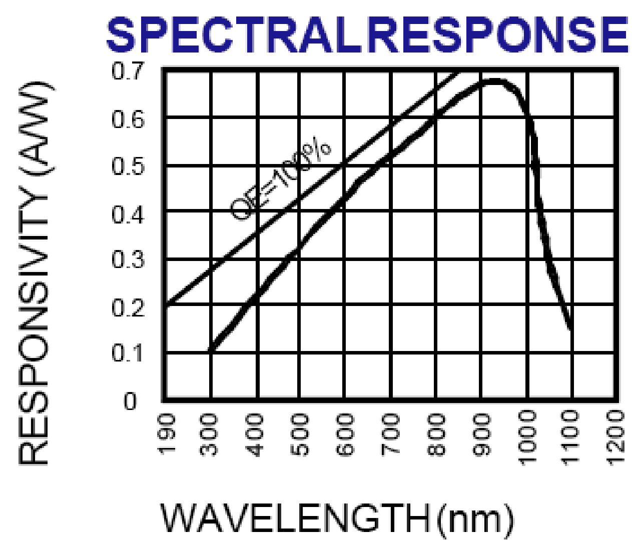
L_{ij} : path length of chord i in shell j

Considerations of the light spectrum



- The red intensity that is causing the increasing of the signal during the shot
- Evident because the photodiodes are more sensitive to red
- In addition to a blue background something is getting ionized during the shot ⇒ a spectrometer could tell us what





Conclusions

- A one dimensional photodiode array for visible light has been built & calibrated. It works as expected
- Simple but robust electronics ensure reliable amplification: shielding allows us to get rid of most of the noise
- Turbulent behavior has been observed on light signal. It is qualitatively and quantitatively reasonable
- Correlations and delay in time between channels could indicate the presence of convective cells at a fairly fast speed (1.5e03 m/s), compatible with theoretical considerations

Possible future improvements

- These convective cells observations should be verified with other diagnostics
- A 2D photodiode array could give better information about the geometry of convective cells and their circulation in the plasma
- A filter could be added to only follow a given line in the visible light spectrum, and therefore only one species of atom (for example the D_ line at 656.3 nm)