Fast time-scale radiometry of DIII-D disruptions

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Outline

Introduction

- Need more wide-bandwidth diagnostics to understand disruptions better.
- AXUV photodiodes allow fast measurement of radiated power
  → DISRAD disruption radiometer diagnostic.

Experimental setup

- Results from single-chord diagnostic aid design of diag. with full poloidal view.
- Optical filtering provides info to account for detector response curve.

Analysis

- Tangential VUV survey spectrometer (SPRED) also provides needed info.
- DISRAD and SPRED data together are enough to assess importance of spectrum.

Results

- Current quench (CQ): Constant effective responsivity can be used.
- Thermal quench (TQ): Time scale of radiation is similar to time for energy loss.
- Quasi-steady: Effective responsivity less stable than CQ due to emission spectrum.
- Quasi-steady: DISRAD agrees quantitatively with bolometer.

Why DISRAD?

- Disruptions need to be understood/controlled for viability of tokamak reactor concept
- Few high-speed diagnostics are available for study of disruptions (thermal quench time $\sim 10^{-4}$ s)
- AXUV photodiodes have been used in tokamaks for radiometric measurements radiometric measurements (bolometry), e.g. TEXT, C—MOD
- Photodiodes offer sufficient bandwidth to time-resolve disruptions (metal foil bolometers limited to $\sim 10^{-2}$ s time scales)

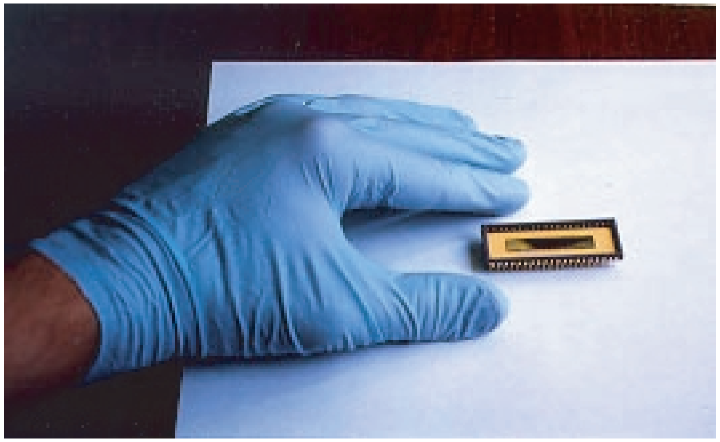
AXUV Photodiode

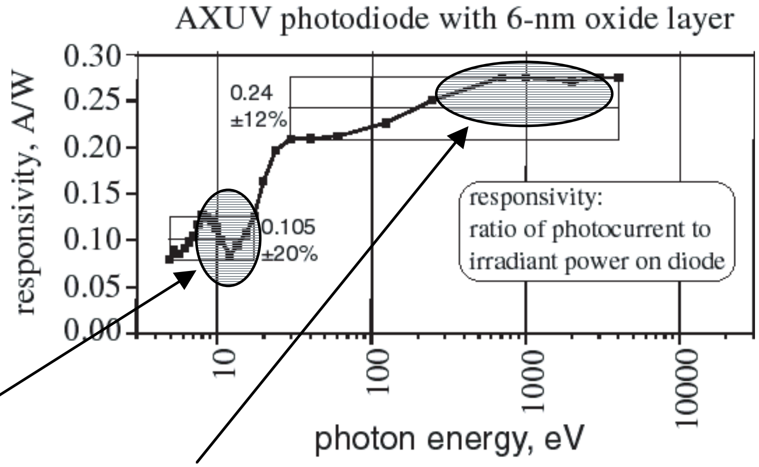
To measure radiant power, ideally want a sensor whose **responsivity** is wavelength-independent over the emitted spectrum.

Absolutely calibrated soft-x-ray/VUV (AXUV) photodiodes[1] are commercially available.[2]

- Vacuum compatible.
- Have been used for radiometry in other fusion devices.[3,4]

- Advantage: wide bandwidth achievable.
- Problem: significant responsivity variation over emitted spectrum in DIII–D.



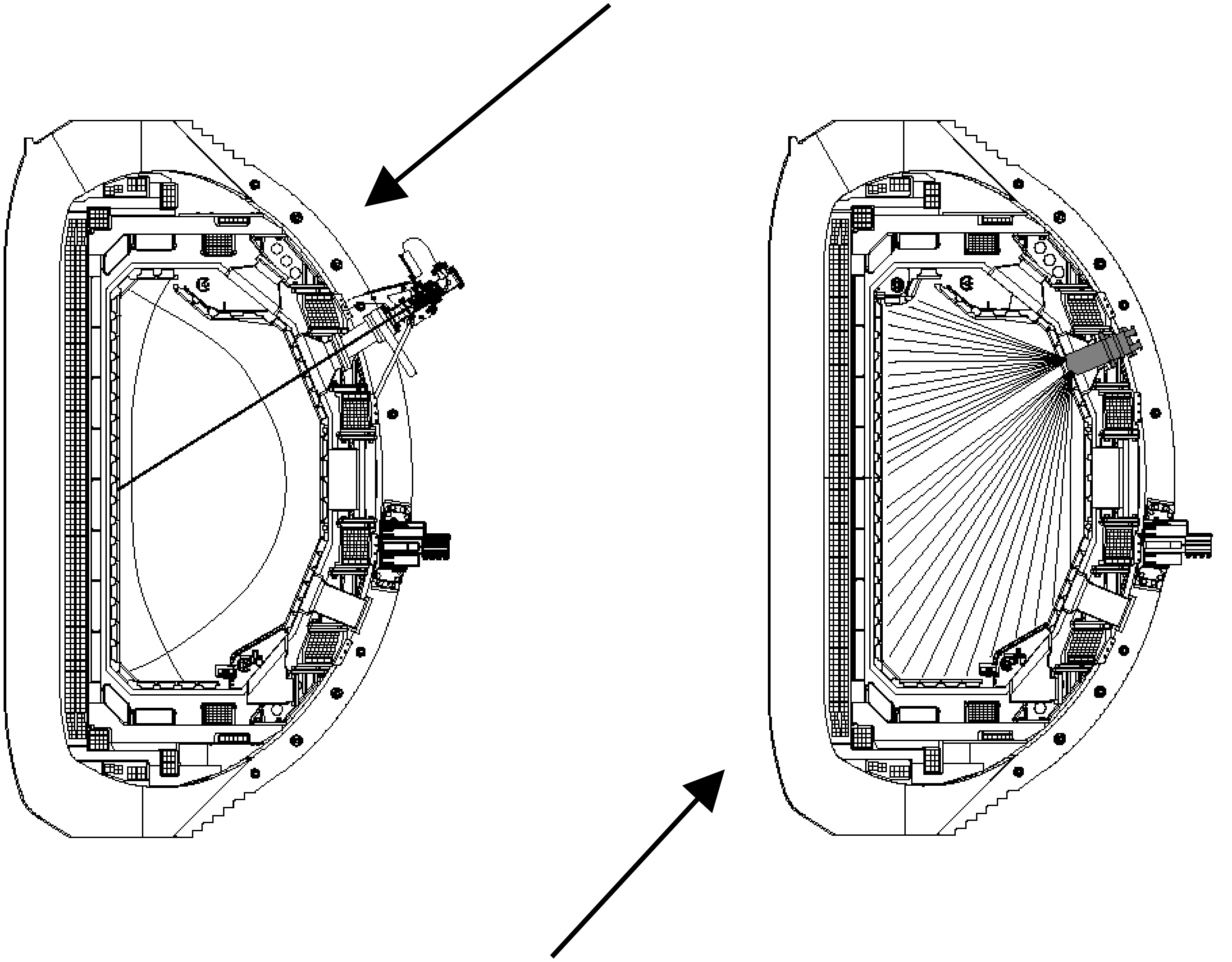


responsivity:
ratio of photocurrent to irradiant power on diode

Most radiation here during disruption

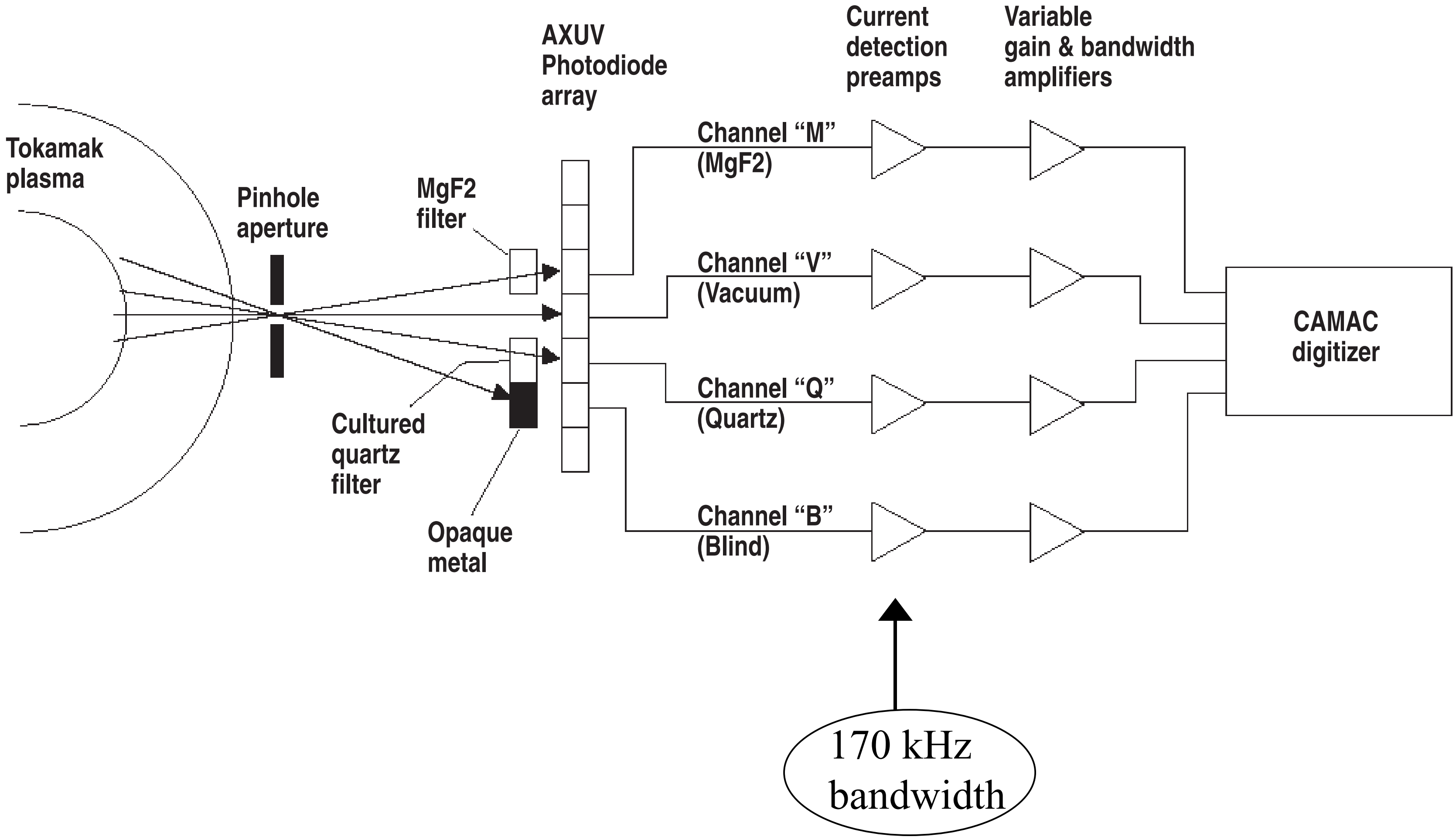
Significant radiation here from quasi-steady plasma

All results shown here are from single-chord **DISRAD-I**

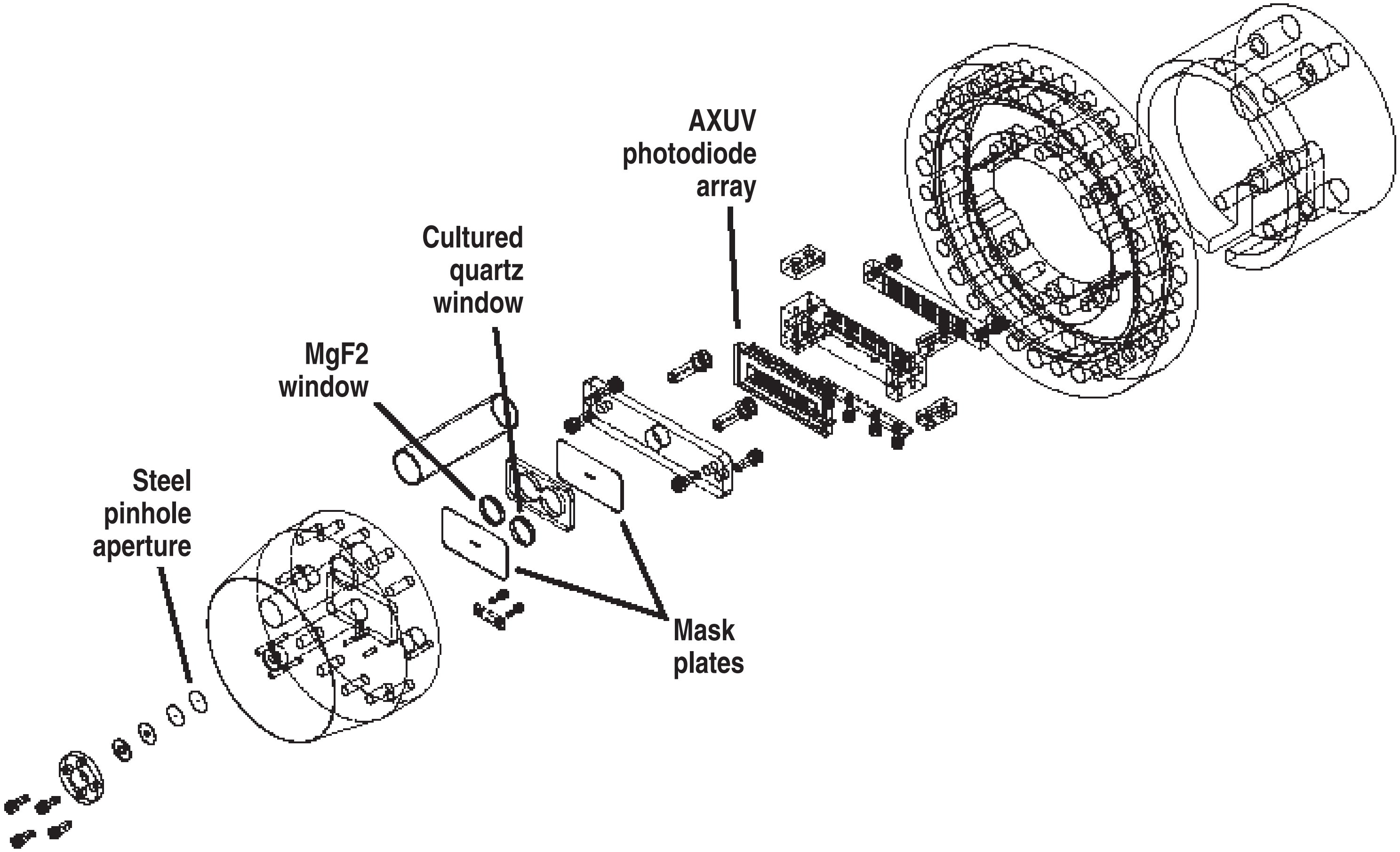


DISRAD-I aids design of multi-chord **DISRAD-II**

Optical filtering provides spectral information to take AXUV diode response curve into account

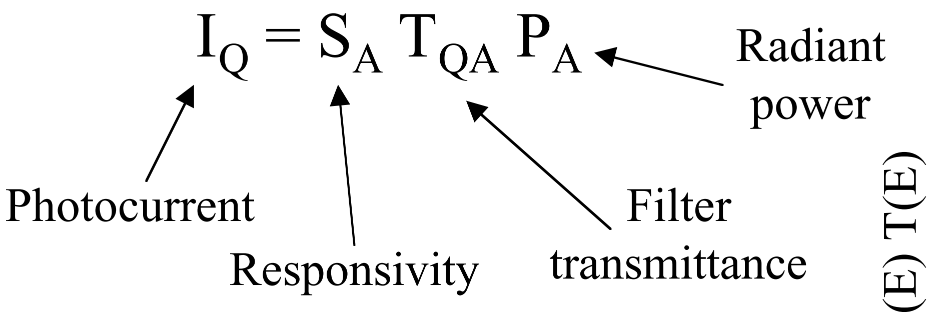


Exploded view of detector flange assembly

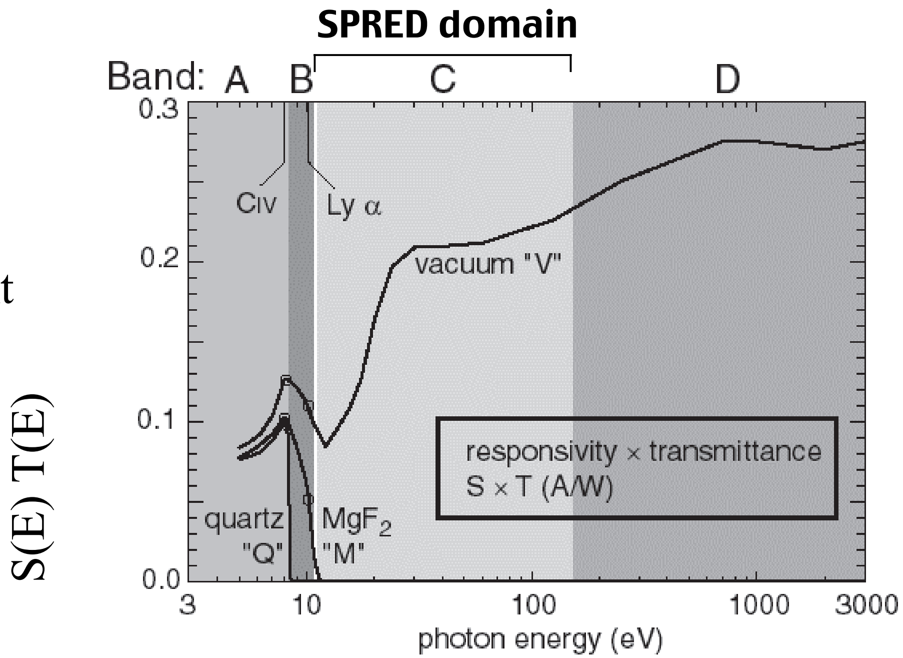


Analysis: Four energy bands are identified (A, B, C, D)

Quartz channel sees A only:



$$I_Q = S_A \; T_{QA} \; P_A$$



MgF_2 channel sees A & B only:

$$I_M = S_A T_{MA} P_A + S_B T_{MB} P_B$$

Unfiltered channel sees A, B, C, D:

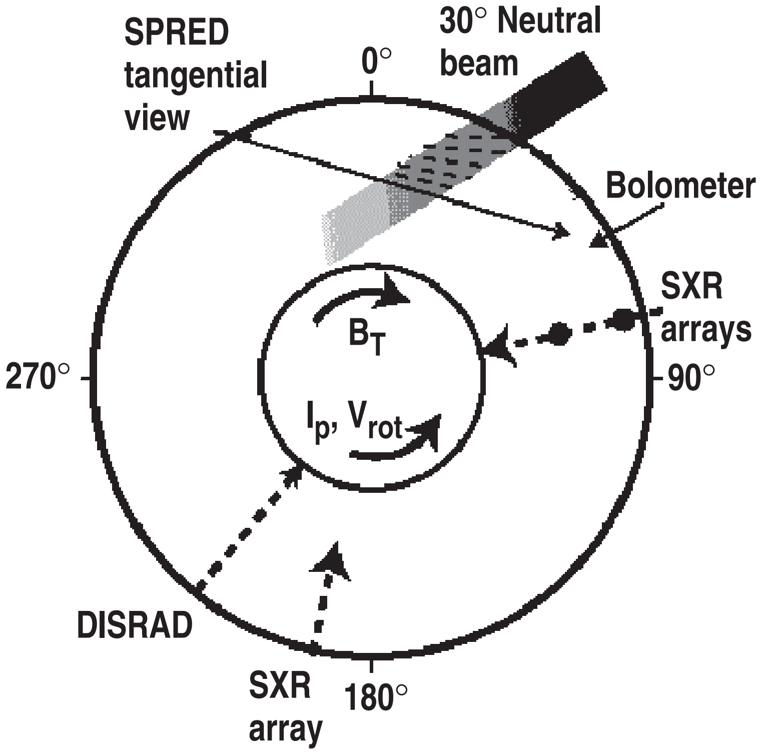
$$I_V = S_A P_A + S_B P_B + S_C P_C + S_D P_D$$

Note only 3 eqs for 4 powers!
Assumptions to close system discussed below.

Assumptions:

- in band A, C_{IV} (8.0 eV) is dominant
- in band B, L_α (10.2 eV) is dominant

Core SPRED VUV spectrometer aids interpretation



- Spectrum used as weighting function for averaging response curve in C band:

$$S_C = \frac{\int_C I(E)S(E)dE}{\int_C I(E)dE}$$

- SPRED has tangential view, different from DISRAD.
- Like DISRAD, SPRED chord passes through core plasma.
- SPRED photon energy domain is from 11 eV to 150 eV.
- Integration time is typically 1 ms or 5 ms (provides a few spectra in a disruption).

Assumptions for spectral decomposition depend on case

CURRENT QUENCH CASE

No D-band radiation (plasma too cold):

$P_D = 0$ so find P_A, P_B, P_C

QUASI-STEADY CASE

Can use C-band power from SPRED

P_C given so find P_A, P_B, P_D

THERMAL-QUENCH CASE

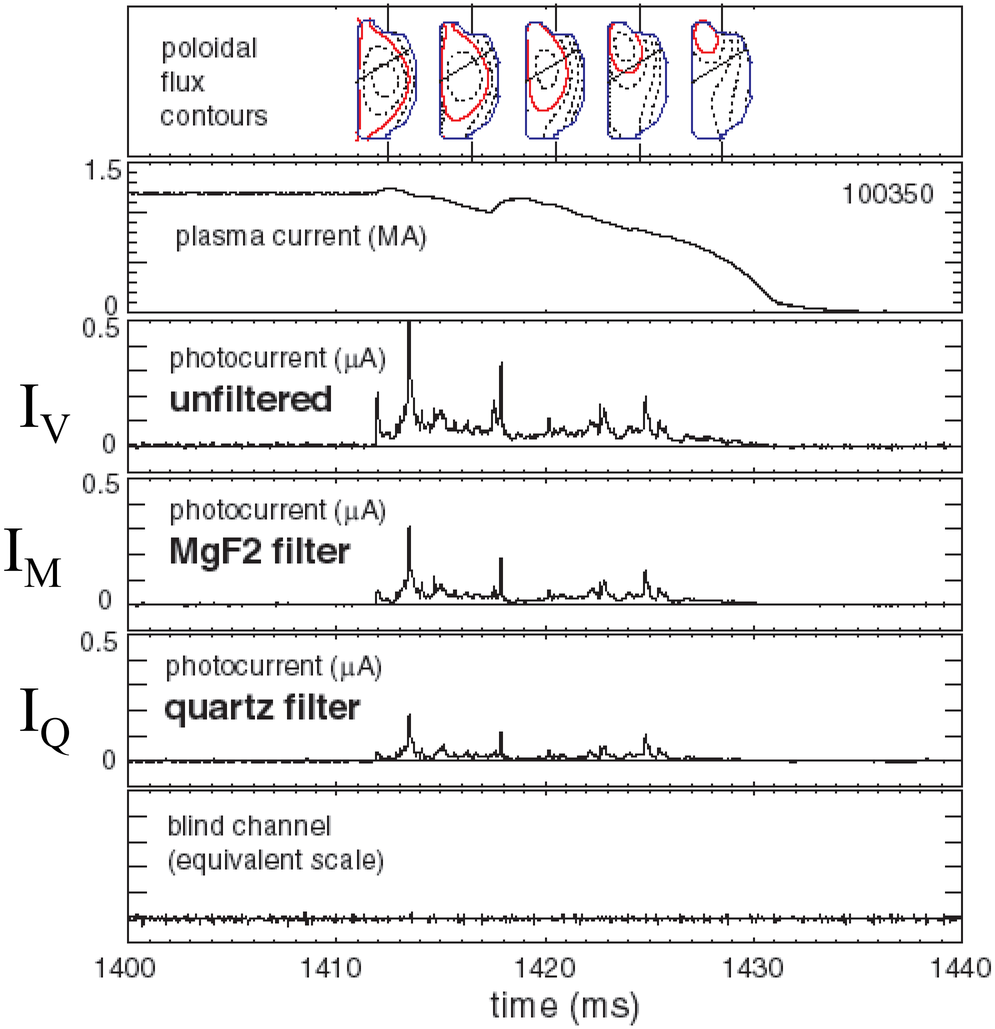
Transition from hot to cool plasma.

Too fast for spectral decomposition.

Deduce brightness by assuming value

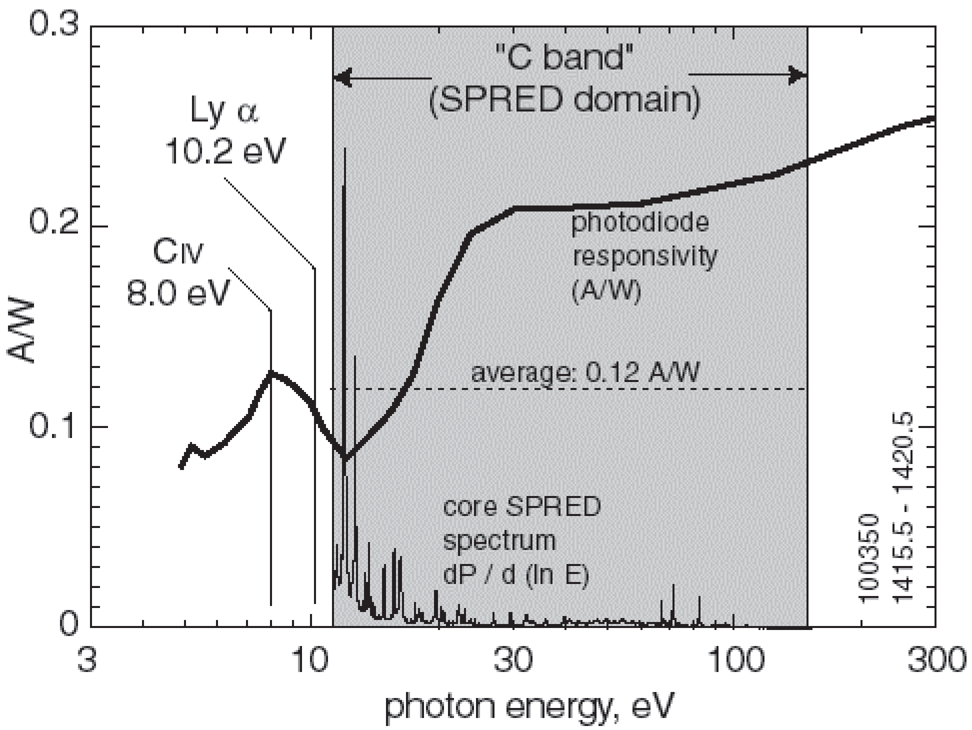
of $S_{eff} = I_V / P_{total}$

Disruption Current Quench phase (CQ):
Bands A and B account for large fraction of radiation



- No deflection on blind channel
  ⇒ signals due to optical radiation only.
- Peak photocurrents correspond to ~10^6 photons/µs
  ⇒ no statistics concerns
- Channels M and Q comparable to channel V
  ⇒ large fraction of radiation is in A and B

Current quench: little radiation above 20 eV

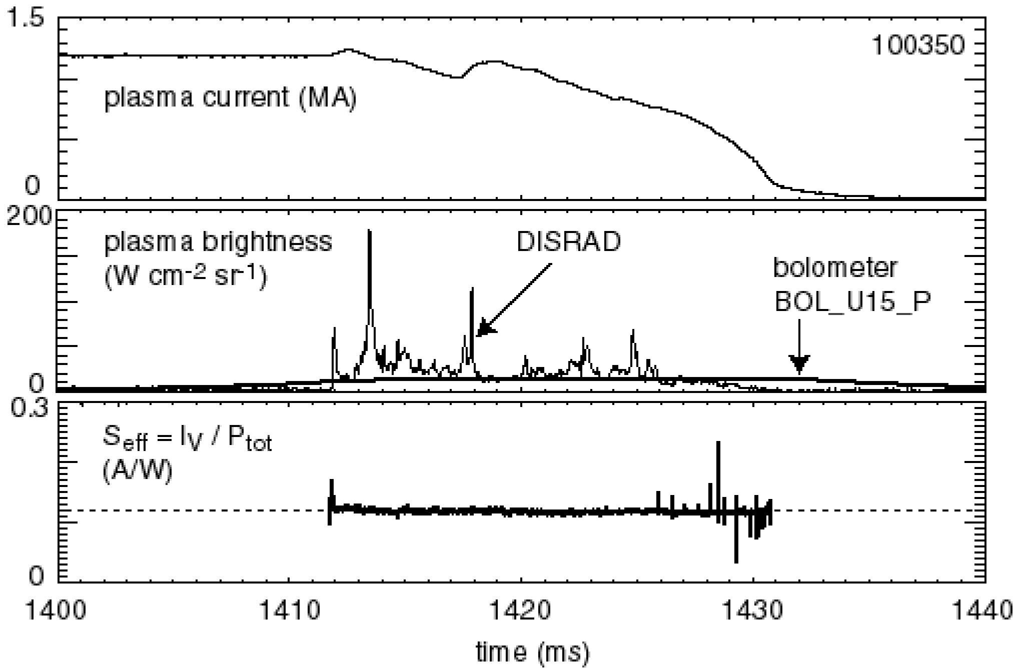


Spectrum is used as a weighting function to average the responsivity in the C band:

$$S_C = \frac{{}_C I(E)S(E)dE}{{}_C I(E)dE}$$

In current quench, S_C is generally close to 0.12 A/W.

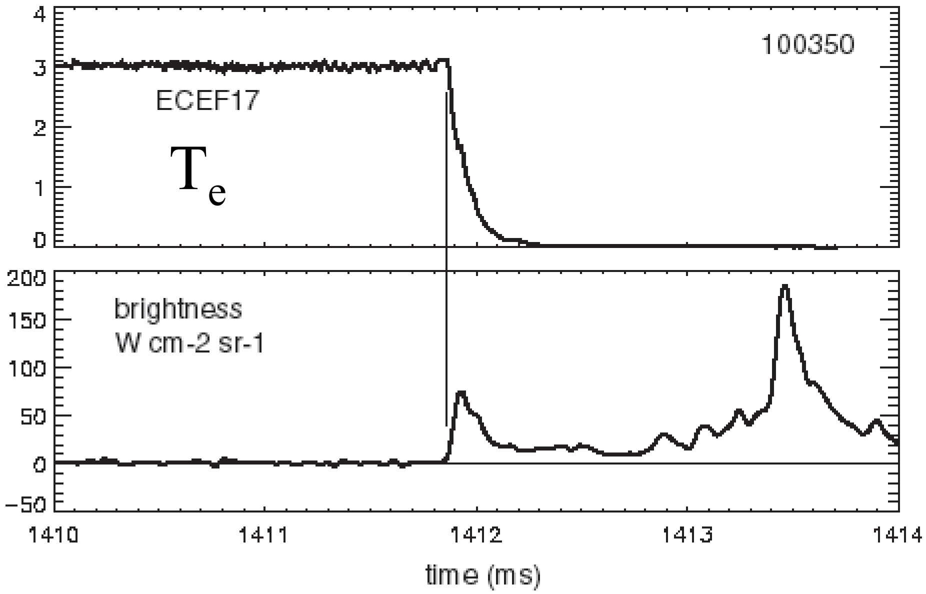
Current quench: S_{eff} is ~constant



Areas under DISRAD and bolometer curves agree well.

Effective responsivity is stable throughout CQ: $S_{eff} = 0.12$ A/W.

Thermal quench: DISRAD provides appropriate time resolution

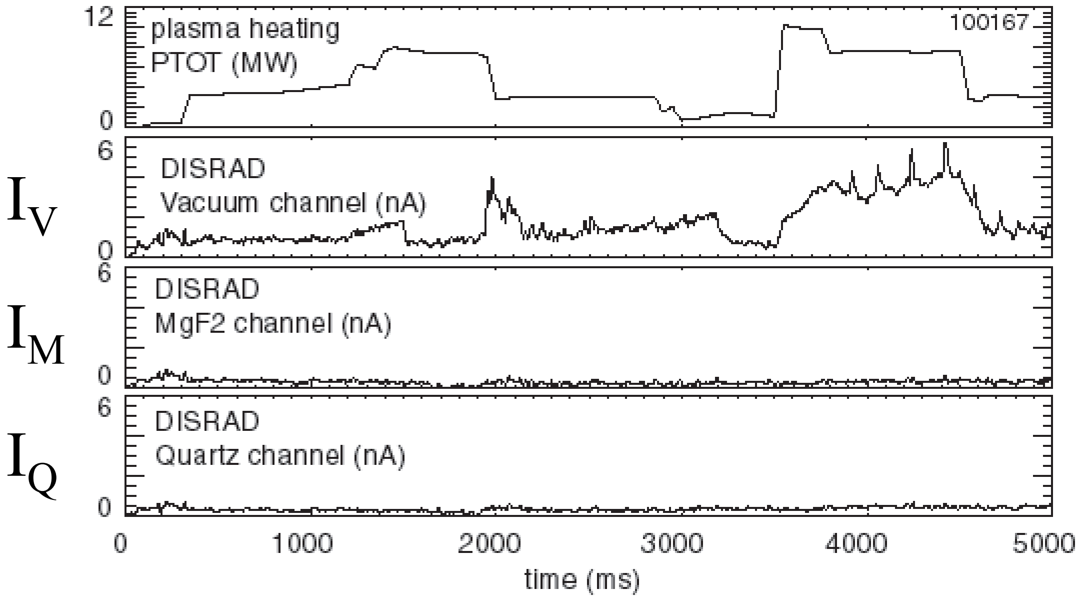


Results above are from same shot as CQ results.

Decay time of 0.13 ms observed in both:

- Brightness measured by DISRAD
- Electron temperature (ECE)

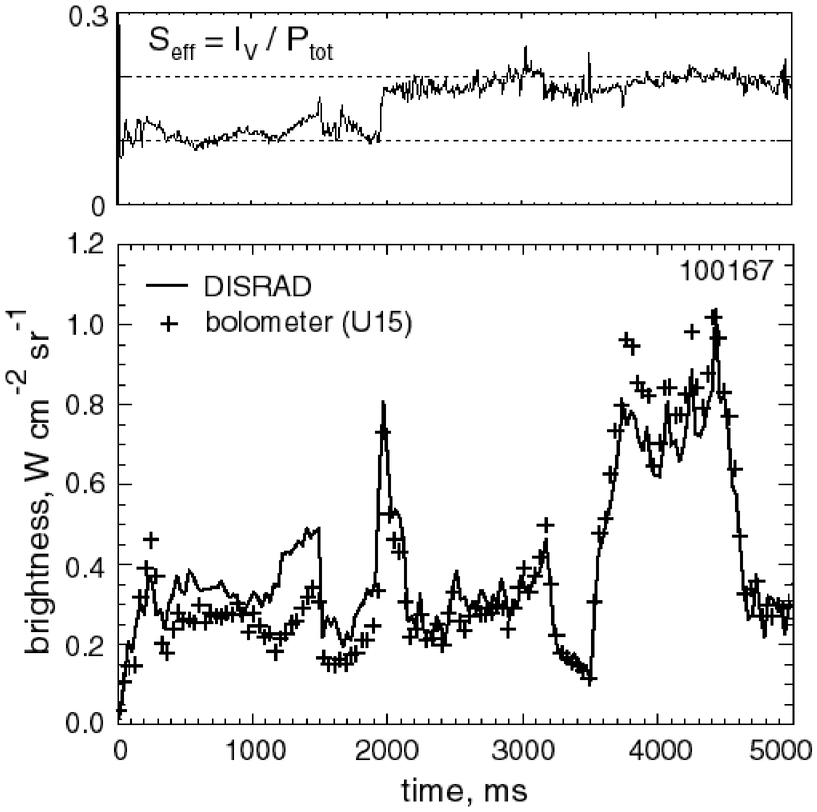
Quasi-steady plasma: A and B bands less important than in CQ



- M and Q signals weak compared to V channel (most radiation in C and D band).

Quasi-steady plasma: DISRAD in agreement with bolometer

S_{eff} less stable than in CQ because much radiation is in C band, where responsivity curve varies strongly.



Quasi-steady plasmas are only ~10^{-2} as bright as disruptions.

Agreement with equivalent bolometer channel is within ~10% over much of the discharge, with $S_{eff} \approx 0.18$ A/W (S_{eff} determined independent of bolometer).

Discrepancy early in discharge is attributed to noise in photocurrent signals. Techniques to improve signal-to-noise in these (relatively) dim plasmas are being developed.

Conclusions

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