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ABSTRACT

A strong light emission of the C_2 Swan band and the CD Gerö band has been observed during strike point sweeps in the corner region of the inner MKII SRP divertor of JET. The light emission could be correlated to the decomposition of a probably soft hydrocarbon layers at the corner entrance. The ratio of the C_2 and CD photon flux indicates a preferred emission of C_2 and thus of C_2H_y particles. The layer has been removed within one H-mode discharge, where the strike point was fixed at the corner. In the consecutive discharges no enhanced light emission from C_2 and CD could be observed and the C_2/CD ratio drops significantly. The spectroscopic observations are in line with measurements on the quartz microbalance located near the louvre. A similar layer could not be identified in the lines of sight of the spectroscopic systems in the outer divertor.

1. INTRODUCTION

The first wall of JET is made of graphite composites and the impact of deuterium on these plasma-facing areas can cause chemical erosion [1]. The deposition of eroded material finally takes place in the form of hydrocarbon layers in the divertor. The analysis of tiles installed in the MKII GB configuration has shown that the major part of the layers is finally deposited on the horizontal target plate in the corner region of the inner divertor [2]. In contrast to the deposition-dominated inner divertor, the outer divertor is nearly balanced in erosion and deposition. The hydrocarbon layers can be identified as an intermediate storage of carbon and fuel and can act as secondary erosion sources, while the primary erosion sources are not located in the divertor itself but rather in the main chamber [3]. The transport of eroded carbon from the main chamber into the divertor takes place in several steps and, thus, in several deposition and re-erosion processes.

Emission spectroscopy provides access to several species (CD; C_2; C...) of the dissociation chain of the methane and ethane family which are both usually observed in tokamaks with graphite inventory. The observation of the CD Gerö band and of the C_2 Swan band gives useful information about the sources, their location and quantity and about the dissociation process itself [4-6]. A set of spectroscopic systems at JET allows the simultaneous observation of these species in the divertor.

We present spectroscopic measurements from the inner and outer MKII SRP divertor where the intensity of different hydrocarbon break-up products and their variation as functions of the strike-point position and the plasma parameters have been investigated.

2. SPECTROSCOPIC SET-UP

The measurements were performed by means of two sets of spectrometer systems observing two toroidally adjacent sectors [6,7]. The first system is equipped with a manifold of fibre optics which cover both the inner and outer divertor. The second system uses a direct image, which has a better effciency, but covers only the outer divertor.

Two survey spectrometers, in the following labelled as KS3A [6] and KME (Echelle arrangement in cross-dispersion, $\Delta\lambda/\lambda \simeq 21000$, = 375nm...675 nm), are used with the fibre-optics system and allow the simultaneous detection of the C_2 Swan band, the CD Gerö band as well as different CII, CIII and D transitions. The standard system KS3A simultaneously observes the whole inner (ch1) and outer divertor (ch2) by means of two wide-angle fibres (Fig.1(a)), and, additionally, the region along the vertical target (vt) plates down to the corner of the inner (ch3) and outer divertor (ch4) by means of two narrow fibres. From shot to shot, one single fibre (I3...I7) from a set was used for KME. However, as Fig.1 shows, the lines of sight are restricted at two locations in each divertor leg: a) between the two vt plates and b) in the corner.

Information about the released species in the outer divertor has been obtained by the second system which consists of two spectrometers labelled KT3A/B. They are in a direct line of sight and provide a good spectral resolution [7]. KT3A/B have been used for the detection of CD, C2, CII and D. The observed range of 150mm is separated in 12 channels (Fig.1(b)), and thus, a spatial resolution of about 12.5mm on plates 4 and 5 follows. However, the view of the system is restricted at the corner entrance.

3. EXPERIMENTAL RESULTS AND ANALYSIS

Plasma discharges with a sweep of the Strike-Point (SP) have been performed to get local information about the carbon sources in the divertor. The SP and thus the point of highest ion flux is used as a tool to scan along the target plates and to analyse areas with different surface and impurity release properties like freshly deposited amorphous hydrocarbon (a-C:H) layers. The spectroscopic analysis of several discharges shows that the erosion and deposition of a-C:H layers in the corner region of the inner divertor seem to play a crucial role in the carbon transport towards the louvre. There is no indication from the spectroscopic analysis for the presence of similar types of layers in the corner region of the outer divertor.

3.1. INNER DIVERTOR

A SP sweep from target plate 2 to 3 and, thus, over the corner region was performed during the first part of Pulse No: 56976 (L-mode, 1.5MW ICRH). Figure 2(a) shows two spectra which were recorded by means of KS3A (ch3) during the sweep. The first spectrum was measured at t = 14.7s, where the SP was directly positioned in the corner, and the second one at t = 15.0s, where the SP was already set on the Horizontal Target (ht) plate (Fig. 2(b)). The second spectrum is representative of the inner divertor and of SP positions on the ht or vt plate, whereas the first one clearly shows additional features which were identified as the diagonal transitions ($\Delta v = 0;\ \pm1;\ -2$) of the Swan band ($d\ ^3\Pi \rightarrow 3\Pi$) of C_2. The insert in fig.2(a) shows the time evolution of the C_2 photon flux taken from ch3 (narrow view) and from ch2 (wide-angle view) of KS3A. The peak at 14.7s is still visible in ch2, but the absolute value is reduced in comparison to ch3 due to averaging over the whole inner divertor span. The C_2 photon flux was integrated at the band head (515.2nm−516.7nm). The maximum in ch3 is equivalent to a massive local increase of the C_2 photon flux of more than a factor of five. The maximum appears for about 400ms, which corresponds to a radial SP shift of about 27 mm, and, thus, of about

75% of the radial extension of the ch3 view on plate 3 (35mm). A deeper view into the corner is restricted and no information about light emission is available. However, we can conclude that the source is localised at the corner entrance and that the minimum extension is 27mm in radial direction towards the corner.

A comparison between the two spectra also shows a clear increase of the CD Gerö band ($A\ ^2\Delta \rightarrow X\ ^2\Pi$). The increase of the CD photon flux (ch3) amounts to a factor of three in comparison with the reference at t = 15.0s. This is signicantly less than the increase of the C_2 photon flux, but the simultaneous increase of CD and C_2 indicates the strong release of hydrocarbons and the presence of an a-C:H layer. Furthermore, the spectrum at t = 14.7s shows no signicant background from thermal radiation, thus the power density is not sufficient to heat up the layer above the detection limit [8].

Pulse No:56976 is the second one in a series of six consecutive plasma Pulse No's: (56975–56980) which have an identical phase at the beginning. This allows the study of the hydrocarbon release and the properties of the deposited a-C:H layer over several discharges. Figure 2(b) shows the shot-to-shot variation of the peak value of the Swan and Gerö band emission measured at the same time in all discharges. Over the first four discharges, a significant decrease of the C_2 photon flux of more than 50% and of about 30% of the CD photon flux was observed. This is interpreted as a reduction of the hydrocarbon source or as a change of the layer composition. However, for the last two discharges of the series a significant increase of the photon flux of both C_2 and CD occurs. Following the previous argumentation, this might be connected to the deposition of fresh a-C:H layers.

It should be noted that in the later phase of the discharge (15s-24s) different gases (Pulse No's: 56975-77: CD_4, Pulse No: 56978-80: D_2) have been injected into the divertor from different locations, all away from the observation volume of ch3. The amount of injected deuterium in the second phase increases strongly from Pulse No: 56978 on. Obviously, this has an influence on the measurements in the first phase from the fifth discharge on. However, this indicates that, apart from the SP position and the plasma parameters, additional parameters influence the release of hydrocarbons from a-C:H layers. The massive emission of C_2 and CD light described here cannot always be seen with this strength when the SP touches exactly this radial location.

Further studies have been made in a series of identical Pulse No's (61379-61381) with L- (3MW NBI) and H-mode phase (12MW NBI) where the SP was fixed at the expected location of the a-C:H layer. In addition to KS3A (ch2), KME and QMB were deployed in order to obtain information about the release of hydrocarbons in the corner.

A strong light emission of C_2, CD and CII is observed in the first discharge. In the second discharge a strong reduction of the photon fluxes occurs: 35% for C_2, 15% for CD and 45% for CII (H-mode phase). The C_2 and CII photon flux remains constant in the third discharge whereas the CD photon flux increases slightly. This behaviour can be interpreted as the almost complete removal of a (soft) a-C:H layer in therst discharge. The constant photon fluxes of the next two discharges then represent the erosion from the bulk material or from another type of a-C:H layer. The change of the hydrocarbon source is supported by the change in the C_2/CD photon flux ratio, which varies from 0.46 to 0.33

andnally to 0.29. A change in the composition of the released species takes place - C_2H_y becomes less important. Thus, the history of previously performed discharges plays an important role, which is also indicated by deposition measurements with the Quartz MicroBalance (QMB) [9].

The QMB, an independent diagnostic, was activated for the NBI part (Pulse No's: 61379-61381) and supports the spectroscopic results. The QMB measured a massive carbon deposition with a deposition rate of 5.4nm/s in therst discharge. This rate is about 27 times higher than for similar DOC-L discharges and 3.2 times higher than the averaged value for discharges in base-plate conguration. A large part of the released hydrocarbons reaches the area of the QMB, which is located near to the louvre. However, the QMB shows erosion in the two successive discharges whereas the spectroscopy still shows C_2 and CD light emission. One has to taken into account that spectroscopy measures the gross release of particles whereas the QMB measures the net deposition - which is the difference between material deposition and re-erosion - that occurs at the remote location of the QMB mainly by chemical erosion due to atomic hydrogen.

KME (I6) was used to determine the rovibrational population of the eroded hydrocarbons. The measured spectrum of the Swan band, recorded during 3.7s of the 5.5s long H-mode phase, is shown in Fig.3(a) as well as a modelled spectrum with an assumed rotational temperature of about 4000K. Both spectra are in a good agreement, and the deduced population is typical of the JET divertor. The corresponding spectrum in the L-mode phase shows no signicant difference in the population, but a factor of two lower C_2 intensity. A reduction of the C_2 intensity of more than 35% in the H-mode phase and of 25% in the L-mode phase were observed in the successive discharge. This underlines the results previously presented, but shows also that the efficiency for the release of hydrocarbons from layers is higher with larger divertor power deposition.

In Figure.3(b) two C2 spectra (KME I5) are depicted, where the SP was fixed on plate 2. The first spectrum, measured in a L-mode discharge, represents a typical rovibrational population of about 4000K, whereas the second one, measured in H-mode, shows a signicantly lower, unusual population of about 2000K. The rovibrational population is determined by the plasma parameters and by the break-up mechanism; further investigations are necessary to determine the origin of the population with low temperature. Figure 3(c) shows the peaked distribution of C_2 and CD light, recorded by KME with fibres I2 to I7, around the SP position. The different intensity ratios of C_2 to CD in the two modes provide additional information about the composition of the released particles [5]. These ratios are a factor of 2.6 lower for H-mode, in comparison with Pulse No: 61379, and 3.8 lower for the L-mode at the location of maximum emission (I5). This underlines the preferred emission of C2 light according to the preferred release of C_2H_y at the corner.

3.2 OUTER DIVERTOR

In general, no strong light emission of C_2 and CD has been observed in the outer divertor in L-mode discharges. Dedicated SP sweeps (Fig.1(a)) through the corner region (Pulse No's: 56975-56980), show no enhanced molecular light emission in ch4 (KS3A), but occasionally thermal radiation [8].

Strong C_2 light emission has been detected in H-mode discharges. In Pulse No: 62564 (H-mode, 17MW NBI) the SP was positioned at the edge of plate 5 (corner entrance). Figure 4(a) shows the spectral range around 386nm, measured by means of KT3A, where the B-X transition of CD and the Deslandres-d'Azambuja transition of C2 were observed. In Fig.4(b), the time evolution of the C2 and CD light are depicted. The CD photon flux is almost constant during the entire discharge whereas the C_2 photon flux varies and has two different phases, although the plasma parameters were nearly constant at the separatrix. C_2 runs through a maximum at the beginning of the discharge (t = 14.3s) and remains nearly constant at about half the maximum value for the later phase. In line with the C_2 increase is the rise of the CII photon flux, which might indicate a direct release of C2. The radial light distribution (Fig.4(c)) shows a maximum for CD and C2 in the outermost non-vignetting channel of KT3A, which almost observes the SP position. The maxima, and especially the C2 one, are more pronounced in the first phase. A quantitative analysis is restricted owing to the vignetting. However, this example shows that at high ion fluxes additional processes and the time evolution of layer properties have to be taken into account.

CONCLUSION

In the present MKII SRP inner divertor a strong C2 and CD light emission in the corner region has been observed depending on the strike point position. A reduction of the light emission for successive, identical plasma discharges in L-mode has been measured. According to the C_2 to CD photon flux ratio, the release takes place mainly in form of C_2H_y. This indicates that the properties of deposited carbon layers change by the plasma impact, most probably by thermally and ion induced release of loosely bound hydrocarbons (soft layer). A release of carbon clusters can be excluded, according to the high rovibrational population temperature of 4000K for the C2 Swan band.

We have evidence that in H-mode discharges, where the strike point was fixed at the a-C:H layer location, a complete removal of the soft layer takes place within one discharge. In the consecutive identical discharges, no enhanced C_2 and CD light could be observed, and further the ratio of C_2 to CD reduces and remains then constant on typical value for the horizontal target plate. This underlines that for the analysis the history of previously performed discharges has to be taken into account.

These observations are in agreement with deposition measurements on the QMB, located near the louvre. The strong C_2 and CD light emission is correlated with the decomposition of soft carbon layers and with the massive transport of particles to the louvre area. However, the strong light emission cannot always be observed when the strike point touches the corner. Apart from the history effect also hidden parameters like the variations of the layer properties may explain this fact.

In contrast to the inner divertor, strike point sweeps through the corner of the outer divertor do not show strong C_2 or CD light emission in L-mode discharges. This indicates that a similar layer is not present in the view of the detection systems.

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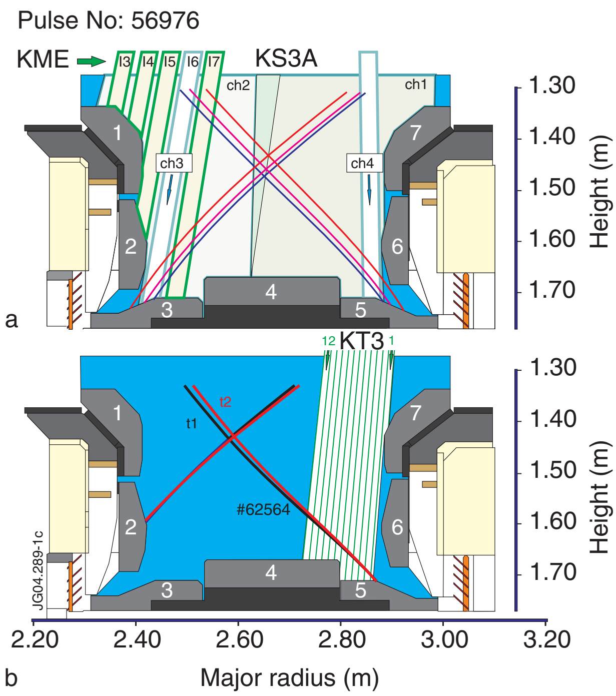


Figure 1: The lines of sight of the spectroscopic systems into the JET divertor.

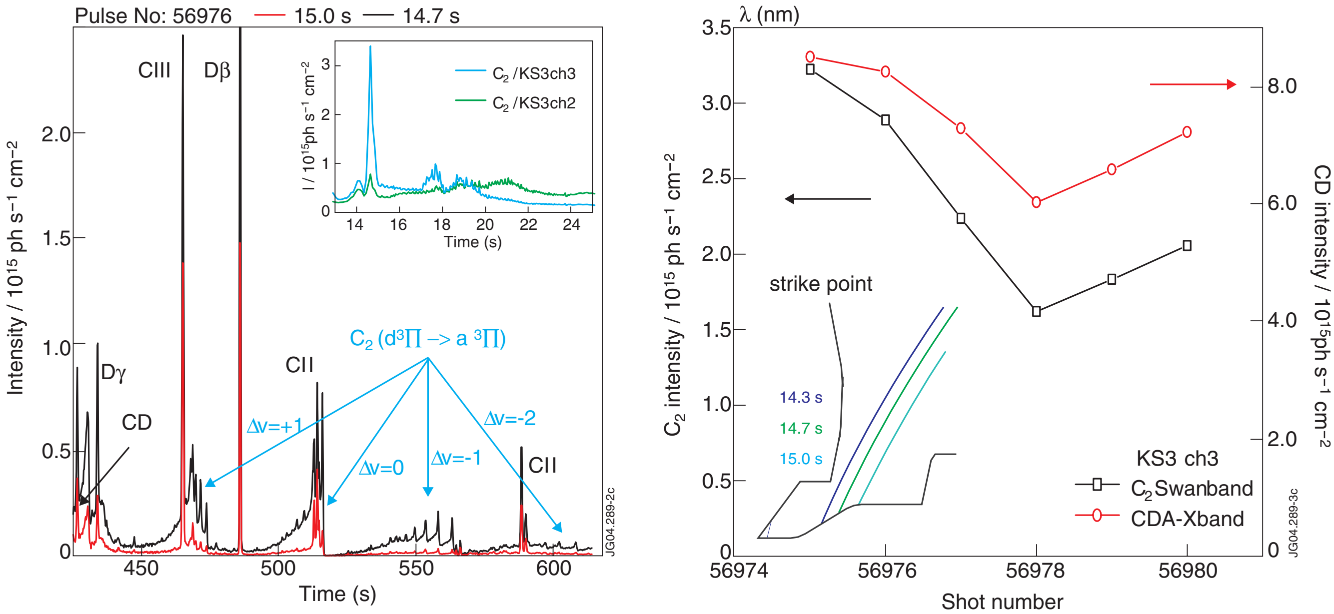


Figure 2: a) Two overview spectra showing strong light emission of the C_2 Swan band and the CD Gerö band when reaching the corner. b) Variation of the C_2 and CD photon flux for the SP position at 14.7s in six discharges.

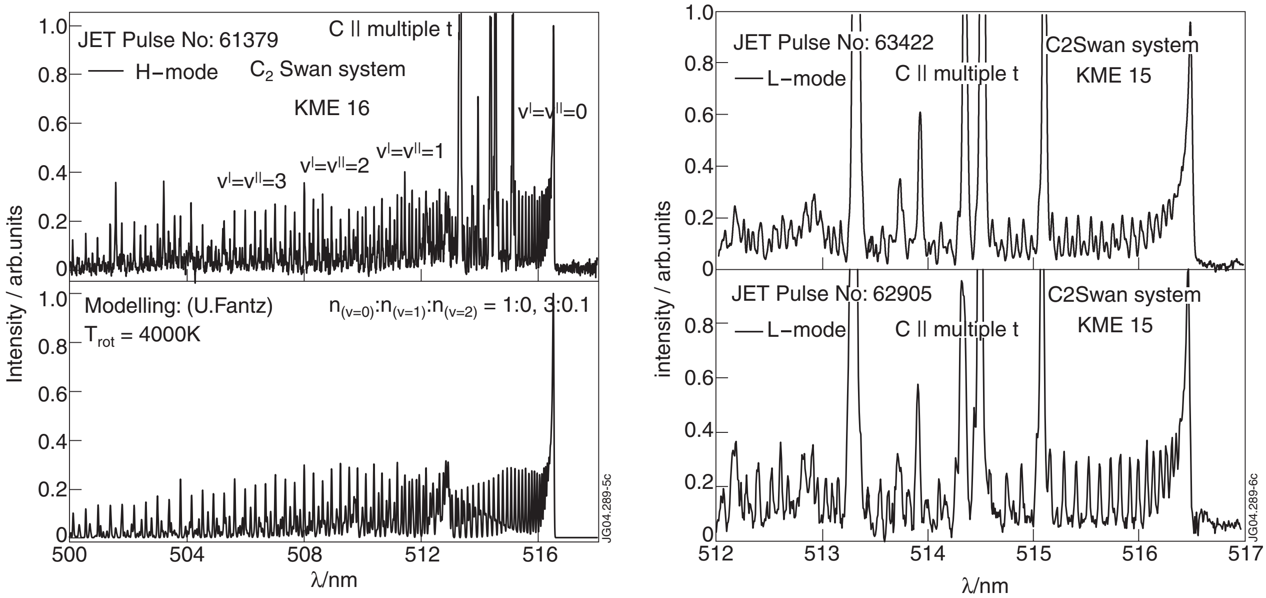
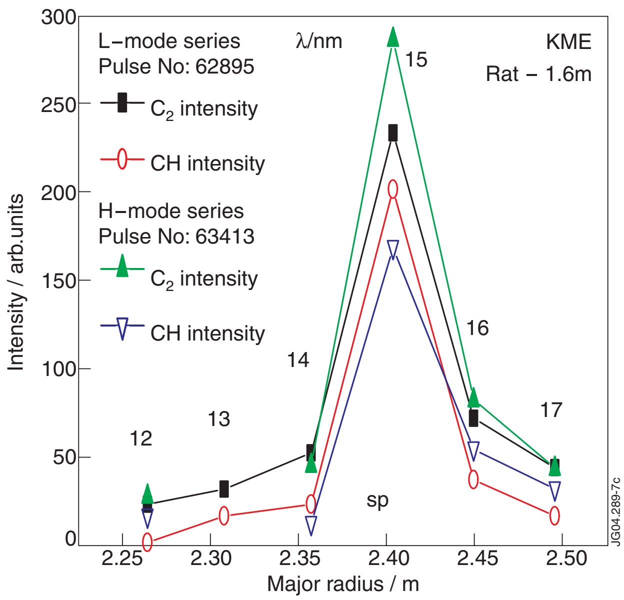
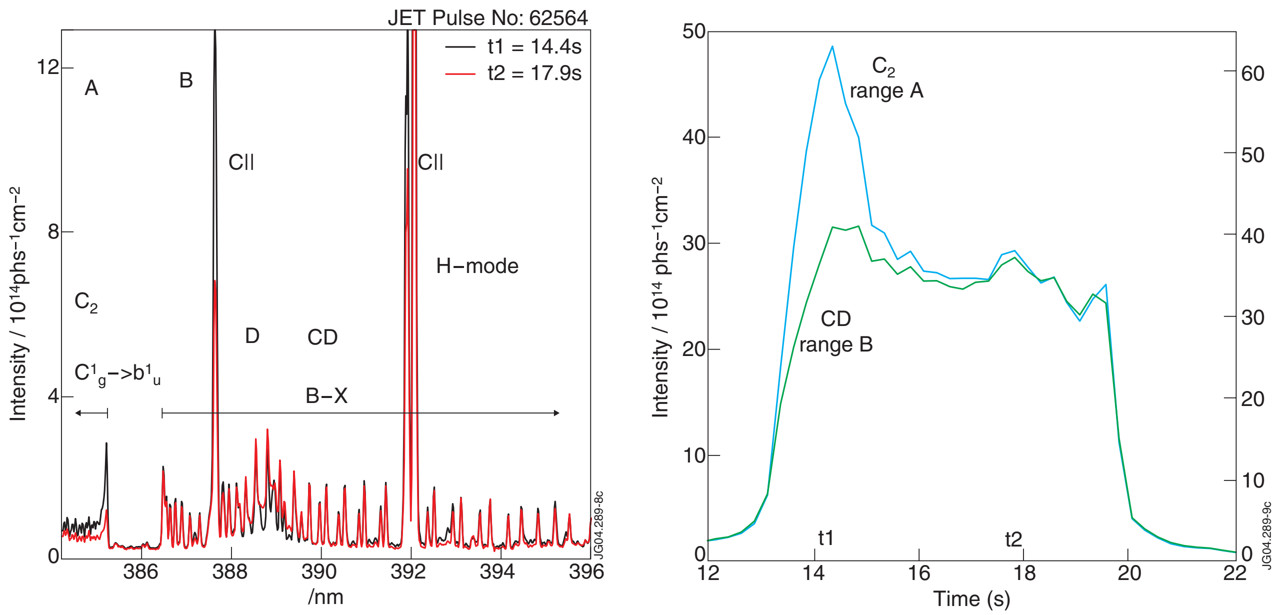


Figure 3: a) Measured and simulated spectra of the C2 Swan band (H-mode, corner conguration).
b) Typical C2 spectra for a L- and a H-mode discharge with fixed SP on plate 2.
c) C_2 and CD light distribution at the vt plates for two series of identical discharges.





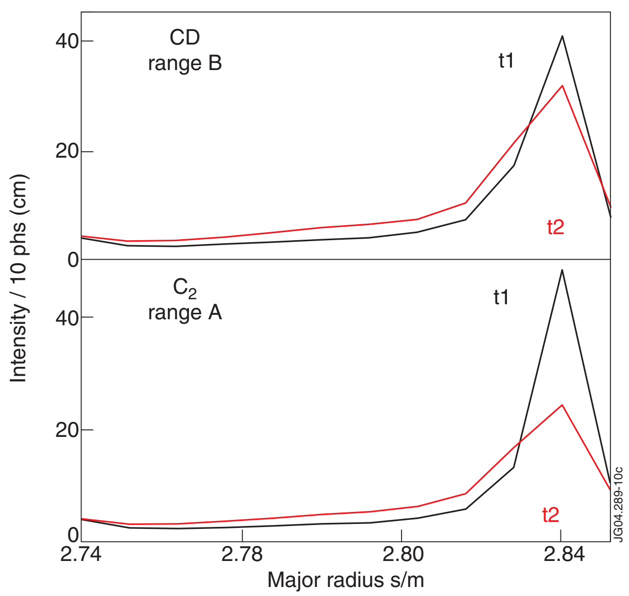


Figure 4: a) The CD B-X and the C2 Deslandres-d'Azambuja band.
b) Time evolution of C_2 (A: 384.4nm-385.4nm) and CD (B: 386.4nm-387.4nm) in a H-mode discharge and SP on plate 5.
c) Radial distribution of the CD and C_2 intensity at two times.