PHYSICS STUDIES OF ADITYA & ADITYA-U TOKAMAKS PLASMAS USING SPECTROSCOPIC DIAGNOSTICS

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Abstract

Radiation emanated from tokamak plasma is an important tool to diagnose it passively without perturbing it. Radiation, especially from X-ray to NIR region can be recorded either in gross or spectrally resolved depending on the parameter need to be obtained. In tokamak, the parameters, such as plasma size and shape, electron temperature $T_e$, ion temperature $T_i$, radiation loss $P_{rad}$ and plasma rotation velocity can be estimated through the recording of emitted radiation. For this purpose, many spectroscopic diagnostics have been developed for ADITYA tokamak having a poloidal ring limiter and now its upgraded version ADITYA-U with toroidal belt limiter. Visible spectroscopy systems consist of PMT (Photomultiplier tube) based system to monitor the Hα, OII, CIII and visible continuum emissions, PMT array based diagnostic to measure the radial profile of Hα emission, a multiple PMT module system to monitor the radial profile of visible continuum, a 3-channel low resolution spectrometer for recording survey spectrum from various lines of sight, a 0.5 m spectrometer for survey, and a high resolution system having a spectrometer with 1 m focal length and equipped with CCD (charge coupled device) camera, capable of multi-track measurement. A VUV survey spectroscopy system (10 – 180 nm), with three gratings is used with the tokamaks to monitor spectral lines from low and highly ionized impurities in VUV range. Along with the measurement of ion temperature and plasma rotation velocity, the impurity behaviour and transport has also been studied in both the tokamaks using visible and VUV spectroscopic diagnostics.

1. INTRODUCTION

Magnetically confined fusion plasmas, the plasmas produced in tokamaks, stellarators, heliotrons, and magnetic mirrors, always contain measurable amount of impurities in addition to the fuel particles. These impurities are introduced into a plasma due to sputtering and desorption processes during interaction of the plasma with vacuum vessel wall and plasma facing components. The presence of impurities leads to enhanced energy loss from the plasma and also reduced the density of bulk plasma ions. Due to these effects the performance of plasma degrades and the fusion reactivity reduces [1]. Thus, in order to understand and minimize the effects of impurities on plasma performance, spectroscopic measurements of the line and continuum radiation emitted by impurities are of utmost importance. Spectroscopy of impurity ions and fuel atoms also enable us to measure plasma parameters such electron and ion temperatures [2] and densities, particle influx rates, particle transport. These measurements play an important role in fusion research [3].

Line and continuum radiation from high temperature, magnetically confined plasmas is emitted over a large wavelength range. This includes the soft X-ray, extreme ultraviolet, vacuum ultraviolet (VUV), ultraviolet, visible, and the near infrared (NIR) regions of the spectrum. Different types of instrumentation are used to make measurements in these regions of the spectrum. On ADITYA [4]/ADITYA-U [5] tokamak, various spectroscopic diagnostics have developed to able to detect emitted radiation from VUV to NIR wavelength range, i.e. from 10 nm to 2200 nm. To carry out measurements in the visible range diagnostics such as PMT (Photomultiplier tube) based system, PMT array based diagnostic [6], a multiple PMT module system, a 3-channel low resolution spectrometer for recording survey spectrum, a 0.5 m spectrometer for survey, and a high resolution system [7] having a spectrometer with 1 m focal length and equipped with CCD (charge coupled device) camera, have been installed and all the diagnostics are operated regularly during the tokamak operation. A VUV survey spectroscopy system [8] (10 – 180 nm), with three gratings is used to monitor spectral lines from low and highly ionized impurities in VUV range. In addition to these diagnostics, a spectroscopic system has been procured to monitor the radiation in the NIR range. The measurement of ion temperature and plasma rotation velocity [9], the impurity behaviour and transport [10, 11] has been studied in both the tokamaks using these spectroscopic systems.

In the paper, details of the visible and VUV spectroscopic diagnostic systems on ADITYA/ADITYA-U tokamaks have been presented and the studies carried out using these systems have also been discussed.
2. VISIBLE SPECTROSCOPIC DIAGNOSTICS ON ADITYA AND ADITYA-U TOKAMAKS

Visible spectroscopic diagnostics on ADITYA/ADITYA-U tokamak includes PMT based system to monitor the \( \text{H}_\alpha \), OII, CIII and visible continuum emissions, PMT array based diagnostic to measure the radial profile of \( \text{H}_\alpha \) emission [6], a multiple PMT module system to monitor the radial profile of visible continuum, a 3-channel low resolution spectrometer for recording survey spectrum from various lines of sight, a 0.5 m spectrometer for survey, and a high-resolution system having a spectrometer with 1 m focal length and equipped with CCD (charge coupled device) camera, capable of multi-track measurement. The details of these diagnostics are given in following sections.

2.1 A high-resolution multi-track spectrometer based diagnostic system

A high-resolution spectroscopic diagnostic system [7] is coupled with the Aditya-U tokamak to monitor spatial evolution of different spectral lines. The system consists of 1 m, \( f/8.7 \) Czerny Turner spectrometer (model no. AM510, Acton, USA). A CCD with model no. DV-420 (Andor, UK) detector is coupled at the exit port of the spectrometer. The CCD is having \( 1024 \times 256 \) pixels and size of each pixel is \( 26 \times 26 \) µm\(^2\). The spectral resolution of the system is measured to be 0.023 nm at 650.024 nm with 50 µm slit width and grating of 1800 grooves/mm blazed at 518 nm. A vertical array of nine optical fibers (400 µm core diameter) is coupled at the entrance slit of the spectrometer to be able to carry out the multi-track measurements. Nine tracks have been defined with binning of 16 pixels high rows (tracks); each track is separated with 10-pixel gap to avoid the ‘cross-talk’.

Due to the long focal length of 1.0 m, this spectrometer has been very useful to obtain high resolution measurements of spectral lines coming from the plasma. Various studies have been performed using this spectrometer and details of the studies are given in following subsections.

2.1.1 Measurement of poloidal rotation and edge ion temperature in ADITYA-U tokamak plasma

Plasma rotation study is of utmost importance in understanding the momentum transport and its influence on plasma confinement. In ADITYA-U tokamak, measurements of the impurity poloidal rotation velocity and the edge ion temperature have been carried out [9] using Doppler shift and Doppler broadening of \( \text{C}^{2+} \) visible spectral line at 464.7 nm, respectively. A high-resolution spectroscopic diagnostic system has been used for these measurements.

Optical fibers having a length of 13.0 m have been utilized to transport the light emission from the plasma to the multi-track spectrometer. Each fiber collects light from plasma using collimating beam probes having lens of diameter 11 mm and focal length of 19 mm. These beam probes are mounted on a rectangular viewport at top side of the tokamak. The viewport is made of UV grade fused silica glass. The arrangement of fiber with beam probe provides 2.5 cm spatial resolution at the horizontal mid plane of the plasma. In the present experiment, the fibers have been arranged such that they can cover the region from centre to outboard side of the plasma from the top as shown in Fig. 1.

![FIG. 1. Lines of sight for poloidal rotation measurements on ADITYA-U tokamak with an image](image)

The radial profile of poloidal rotation velocities has been obtained from the line integrated spatial measurements by applying the Abel-like matrix inversion technique. The line integrated and Abel-inverted rotation velocity profile for shot number 33507, which is an ohmically heated plasma discharge of ADITYA-U tokamak, is shown in Fig. 2 [9]. Spectral line emissions monitored using four lines of sight covering the plasma minor radius from \( r \)
= 11.55 cm to r = 21.55 cm viewing from the top port have been used to obtain radial profiles. The maximum poloidal rotation with value \(~4.5 \text{ km/s}\) has been observed at the radial location of \(~21.55 \text{ cm}\).

The estimation of the temporal evolution of the measured poloidal rotation velocity of C\(^{2+}\) ion at the plasma edge at a radial location of 21.55 cm for two plasma discharges, shot no. 33507 and 33081, has been measured and it is shown in Fig. 3(a) [9]. Figure 3(b) [9] shows the impurity ion temperature from the same radial location for the two discharges. The maximum edge ion temperature is measured to be \(~40 \text{ eV}\) [9].

2.1.2 Measurement of neutral temperature in ADITYA-U tokamak plasma

The detailed understanding and characterization of neutrals present in plasma is necessary, as they directly interact with plasma facing components, through particle recycling, different atomic processes and energy transport. The hydrogen particles are continuously generated by different atomic and molecular processes in the edge, the occurrence of the processes dominated defines temperature of neutral hydrogen. In ADITYA-U tokamak, operated at magnetic field of 1.5 Tesla, these hydrogen atoms are also influenced by high magnetic field and produce Zeeman effect in atoms. The detailed study of hydrogen neutrals [12] has been performed to measure neutral temperature by monitoring spectral line emission at 656.28 nm. The neutral temperature estimation from Doppler broadened spectral line has carried out after considering the Zeeman effect. To get the accurate temperature of the neutral hydrogen, multi temperature components (warm and hot) have been considered. This study has been performed using the same arrangement of optical fibers as shown in Fig. 1 with the multi-track spectrometer. It is observed that the line profile fits well when two temperature, warm and hot components are fitted over experimental spectra. Warm component represents temperature less than 10 eV while hot components are for temperature more than 10 eV. Temperature for two shots is analysed and given in Fig. 4 [12].
The warm component is having temperature in the range of ~ 3 - 5 eV. The temperature of this component shows slightly higher value in the core than the plasma edge. This indicates different molecular dissociation processes involve in the production of the warm component. Another temperature component, hot atomic hydrogen has the temperature variation between ~ 15 - 30 eV. This study may lead to the understanding of how the neutral having different temperature effect the particle distribution in the Aditya-U tokamak plasma.

2.1.3 Numerical estimation of oxygen impurity transport in ADITYA tokamak

The oxygen impurity transport [10] studies have been carried out through the indigenous development of impurity transport code using semi-implicit numerical method [11].

The multi-track spectrometer has been used for this study with the optical arrangement of fibers as shown in Fig. 5. The plasma has been viewed from total eight lines of sight, four at the inboard side and four at the outboard side. Figure 6 [11] show a comparison between the experimental emissivity data and the radial emissivity profiles calculated using the O^+ number densities form the semi-implicit method and the STRAHL code in the outboard region of the ADITYA plasma.

2.2 PMT based diagnostic system

PMT based spectroscopic systems are being used during routine operation of tokamak to monitor temporal evolution of Hα, OII, CIII and visible continuum emissions from the tokamak plasma. In such systems a
collimating beam probe having lens of focal length of 19 mm and diameter of 11 mm collects light from the plasma and an optical fiber, 1 mm core diameter and 0.22 NA, is connected with the beam probe to transport light from the plasma to PMT. The light from plasma enters into PMT after passing through an interference filter of a desired wavelength. The current output of PMT is converted into voltage using I/V converter having gain of $10^5$. The voltage output is then sent to ADITYA data acquisition system for digitization and storing. In addition to Hα, OII, CIII and visible continuum emissions, depending on the requirements the emissions from Li I and He I lines have also been monitored.

By using PMT based system recycling and impurity influxes have been investigated and the also the behavior of effective charge of ADITYA/ADITYA-U plasma has been studies. The details of these investigations are given in following sub-sections.

### 2.2.1 Investigation of recycling and impurities influxes in ADITYA-U tokamak plasmas

Fuel particles entering into a plasma affect the global particle balance and play a key role in achieving better plasma confinement in a magnetically confined fusion device. Fuel particles enters into a plasma through several methods, such as gas puff, molecular beam injection, pellet injection etc. They also enter the plasma through recycling, a process in which particles leave from the plasma and re-enter into the plasma multiple time during a plasma discharge.

Due to the interaction of outgoing fuel particles with plasma facing components and vacuum vessel wall, various impurities introduce into a plasma. These impurities dilute the fuel and they also cause radiation losses. Major factors on which impurity influxes and recycling depend are the wall conditioning and the particle outflux from the plasma. Therefore, investigation of particle sources and their control is quite necessary in a fusion plasma.

In ADITYA-U tokamak, the neutral particles and impurities influx has been investigated [13] using a photomultiplier tube (PMT) based spectroscopic system. Figure 7 illustrate the experimental setup of the diagnostics system. In present study two different lines of sight have been used as shown in Fig. 7. One set of lines of sight views the plasma from the top and terminates on the bottom wall of the stainless steel vacuum vessel, whereas the other set views the plasma from a radial port of the tokamak and terminates on the toroidal belt limiter placed at the inboard side wall. In Fig. 7 PMT-1 and PMT-2 represents two sets of PMT, one set with line of sight from top to bottom and the other with line of sight from radial port. Each set consists of three PMT systems and using these PMTs the temporal profiles of Hα (656.3 nm), OI+ (441.6 nm), and CII+ (464.7 nm) have been recorded.

### Table 1. Summary of Measured Influxes and Integrated Influxes from Different Lines of Sight

<table>
<thead>
<tr>
<th>Species</th>
<th>Measured Influx</th>
<th>Integrated Influx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hα</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OI+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CII+</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The measured influx of neutral hydrogen, OI+, and CII+ are summarized in table 1 [13].
Many discharges of the tokamak with toroidal magnetic field of 1.1 T at machine center, more than 100 ms duration and plasma current 78 – 87 kA have been analysed to carry out the statistical analysis of particle influxes and the results are shown in Fig. 8 [13]. The influxes of neutral hydrogen, O\textsuperscript{1+}, and C\textsuperscript{2+} are shown in Fig. 8(a), Fig. 8(b) and Fig. 8(c), respectively.

The results clearly indicate that the influxes of hydrogen and O\textsuperscript{1+} are higher from limiter compared to influxes from the wall, while the influx of C\textsuperscript{2+} from limiter and wall are nearly the same [13]. The limiter is a big source of oxygen impurities and hydrogen neutrals.

<table>
<thead>
<tr>
<th>Species</th>
<th>Particle influx when line of sight terminating on limiter (particle cm\textsuperscript{-2} sec\textsuperscript{-1})</th>
<th>Particle influx when line of sight terminating on bottom wall (particle cm\textsuperscript{-2} sec\textsuperscript{-1})</th>
<th>Integrated influx when line of sight terminating on limiter (particle sec\textsuperscript{-1})</th>
<th>Integrated influx when line of sight terminating on bottom wall (particle sec\textsuperscript{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>9.0 × 10\textsuperscript{16}</td>
<td>2.6 × 10\textsuperscript{16}</td>
<td>1.8 × 10\textsuperscript{21}</td>
<td>1.4 × 10\textsuperscript{21}</td>
</tr>
<tr>
<td>O\textsuperscript{1+}</td>
<td>2.5 × 10\textsuperscript{15}</td>
<td>6.0 × 10\textsuperscript{14}</td>
<td>5.0 × 10\textsuperscript{19}</td>
<td>3.2 × 10\textsuperscript{19}</td>
</tr>
<tr>
<td>C\textsuperscript{2+}</td>
<td>1.9 × 10\textsuperscript{15}</td>
<td>1.7 × 10\textsuperscript{15}</td>
<td>3.8 × 10\textsuperscript{19}</td>
<td>9.2 × 10\textsuperscript{19}</td>
</tr>
</tbody>
</table>

2.2.2 Investigation of the effective charge of ADITYA plasma

The effective charge, denoted as \(Z_{\text{eff}}\), of a plasma is one of the key parameters of the plasma, which indicates the plasma purity. The estimation of \(Z_{\text{eff}}\) is very important to obtain information about the concentration of impurities.

*FIG. 8. Particle influxes of (a) neutral hydrogen, (b) oxygen impurity ion and (c) carbon impurity ion. The red circle and black square represent the influxes measured along the line of sight terminating on limiter and bottom wall, respectively.*
present in the plasma. The $Z_{\text{eff}}$ of a plasma can be measured using different methods, such as from continuum radiation within infrared, visible, extreme ultra violet and soft x-ray range, through line radiation of impurities in vacuum ultra violet (VUV) range, and from conductivity of plasma. Among these methods, the estimation of $Z_{\text{eff}}$ using bremsstrahlung continuum radiation in the visible region is well known and it is a widely used method.

The main impurities present in Aditya tokamak plasma are oxygen, carbon, and iron. The presence of nitrogen has also been observed after the major opening of the vacuum vessel. To understand the impurity behaviour in Aditya tokamak plasma, $Z_{\text{eff}}$ is estimated by monitoring the continuum emission in the visible range [14].

For the measurement of visible bremsstrahlung emission, the spectral region of about 2 nm near 523.0 nm has been considered. It has been confirmed that the interested region of spectral radiation is free from any line radiation. Figure 9 shows the schematic diagram of the visible bremsstrahlung system on the Aditya tokamak. The emitted continuum radiation in the visible range is very weak. In order to increase the light input, a fiber bundle of six optical fibers has been used to transfer the emission from tokamak plasma to the detector which is kept at a distance of 10 meter. The core diameter and numerical aperture of the fiber are 1.0 mm and 0.47, respectively. A lens having a focal of 40 mm and a diameter of 36 mm is placed at a top port of the tokamak as shown in Fig. 9.

The lens views plasma from the top and its line of sight passes through the plasma center. The diameter of the viewing chord at plasma mid plane is 40 mm and at bottom of the plasma it is 70 mm. With this arrangement the effective area of viewing chord inside the plasma increases. The viewport window is made from BK7 glass and it is having transmittance of more than 90% at the selected wavelength. Similar lens arrangement has been used at the detector end, which collimates the emergent light beam. This beam passes through an interference filter and subsequently it is detected at a PMT (photomultiplier tube). The center wavelength of interference filter is 523.4 nm and having bandwidth of 1.0 nm. The PMT used as a detector is Thorne-EMI PMT with model no. 9884 and has larger cathode area to increase the signal level. The output of PMT is amplified to 0 – 5 volt range. The output is transferred to Aditya tokamak data acquisition system, where it is digitized and stored.

It has been observed that the $Z_{\text{eff}}$ of a plasma is reduced after the Li coating of vacuum vessel wall and plasma facing components. Many experimental studies have been carried out to understand the plasma behavior in high temperature plasma devices due to the Li coating or use of liquid lithium as the plasma facing material. In order to achieve better plasma performance in terms of improved confinement, lower recycling, and reduction in impurity concentration inside the plasma, the Li coating on the first wall components and inner wall of the Aditya tokamak vacuum vessel has been carried out. The Li coating has been done by introducing two Li rods into the hydrogen glow discharge plasma.

The behaviour of $Z_{\text{eff}}$ of a plasma in ADITYA tokamak has been investigated under various plasma conditions and wall conditioning. The values of $Z_{\text{eff}}$ have been observed to be in the range 1.7 – 4.0 for ADITYA tokamak plasma. It has been found that the $Z_{\text{eff}}$ reduced to 1.7 – 2.5 range after the Li coating as shown in Fig.10 [14]. The results indicate the $Z_{\text{eff}}$ reduces due to decrease in oxygen concentration as well as reduction of metallic impurities, such as iron, inside the plasma. From the result shown in Fig. 11 [14] it has been found that $Z_{\text{eff}}$ decreases with decrease in electron density and varies as $1/n_e^2$. 

![FIG. 9. Schematic diagram of visible bremsstrahlung measurement system](image)
2.3 PMT array based diagnostic system

The system consists of light collecting lens, optical fibers to transport light from plasma to detector, interference filters assembly, and a detector housing. The housing contains PMT arrays, Hamamatsu model no. H11451-20, fiber interconnectors, fiber holder, and essential electronics circuits. The input supply of ± 15 V is necessary to operate the array. The output the detector can be obtained at BNC connectors located on back side wall of the housing. The output is sent to ADITYA data acquisition system where it is digitized and stored. The schematic diagrams of PMT array detector with fiber holder and filter holder is shown in Fig. 12 [6]. The viewing geometry of fiber is illustrated in Fig. 13 [6].

2.3.1 Investigation of atomic and molecular processes in $H_\alpha$ emission through modelling of measured $H_\alpha$ emissivity profile using DEGAS2 in ADITYA tokamak
The study of neutral particle dynamics in tokamak plasma is of considerable interest to fusion community. The neutrals play an important role in achieving high-confinement modes and affect the energy and particle fluxes to the vacuum vessel wall, divertor plates and/or limiter tiles which is responsible for wall erosion and production of impurities. Considering the importance of knowing neutral particle dynamics in a high temperature plasma device, the measurement of spatially resolved emission from fuel neutrals and modelling of their transport inside plasma and at the edge is very important.

In Aditya tokamak, the experimental profiles of Hα brightness have been measured using an eight channel PMT array-based system which consist of collimating beam probes, optical fibers with 1.0 mm core diameter, an interference filter, and a PMT array detector. The viewing geometry of fiber is as shown in Fig. 13.

The measured radial profiles of Hα emissions have been employed to study the details of contribution from various atomic and molecular processes in the Hα emission by modelling it using DEGAS2 neutral transport code. The choice of atomic and molecular processes, for example ionization, dissociation, recombination, and charge exchange etc., needs to be given as input to the code. The most relevant processes are considered in the present work [15] and they are listed in Table 2.

**TABLE 2. THE ATOMIC AND MOLECULAR PROCESSES INCLUDED IN THE PRESENT WORK**

<table>
<thead>
<tr>
<th>No</th>
<th>Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>H+e → H^+ +2e</td>
</tr>
<tr>
<td>ii</td>
<td>H^+ +e → H^*</td>
</tr>
<tr>
<td>iii</td>
<td>H₂ + e → H(1s)+H(1s)+e</td>
</tr>
<tr>
<td>iv</td>
<td>H₂+e → H(1s)+H^+ +2e</td>
</tr>
<tr>
<td>v</td>
<td>H₂+e → H^+ +2e</td>
</tr>
<tr>
<td>vi</td>
<td>H₂+e → H(2s)+H(2p)+e</td>
</tr>
<tr>
<td>vii</td>
<td>H₂+e → H(2s)+H(1s)+e</td>
</tr>
<tr>
<td>viii</td>
<td>H₂+e → H(1s)+H(n=3)+e</td>
</tr>
<tr>
<td>ix</td>
<td>H₂+e → H(1s)+H^+ +e</td>
</tr>
<tr>
<td>x</td>
<td>H₂+e → H^+ +H^+ +2e</td>
</tr>
<tr>
<td>xi</td>
<td>H₂+e → H^+ +H(n=2)+e</td>
</tr>
<tr>
<td>xii</td>
<td>H₂+e → H^+ +H(n=3)+e</td>
</tr>
<tr>
<td>xiii</td>
<td>H₂+e → H(1s)+H(n ≥ 2)</td>
</tr>
<tr>
<td>xiv</td>
<td>H₂+e → H(1s)+H(n=3)</td>
</tr>
<tr>
<td>xv</td>
<td>H+H^+ → H^+ +H</td>
</tr>
<tr>
<td>xvi</td>
<td>H₂+H^+ → H^+ +H</td>
</tr>
</tbody>
</table>

Figure 14(a) [15] shows the neutral density profiles for atomic hydrogen, molecular hydrogen and molecular hydrogen ion for shot no. 29029 of Aditya tokamak. The results of this figure indicate that both molecular hydrogen and hydrogen ion densities fall quickly as they enter the inner region of the plasma, whereas the hydrogen atoms significantly penetrate into the plasma inner region. The Hα emission rates as a function of ρ (r/a) are plotted in Fig. 14(b) [15] in which the contributions from atomic and molecular processes have been shown.

**FIG. 14(a) Density profiles of atomic hydrogen, hydrogen molecule and molecular hydrogen ion, (b) Hα emission rate from molecular processes and atomic process along with the total emission rate as evaluated from DEGAS2 for the shot no. 29029.**
hydrogen molecules, molecular hydrogen dissociation, dissociation of the hydrogen molecular ions, and molecular ion dissociative recombination processes. These processes control the neutral hydrogen generation and penetration in the Aditya edge plasma.

3. VUV SPECTROSCOPY SYSTEM ON ADITYA AND ADITYA-U TOKAMAKS

A VUV spectroscopic system with a VUV survey spectrometer [8] having a working wavelength range of 10 – 180 nm is coupled to the radial port of the ADITYA/ADITYA-U tokamak at the vertical mid plane of the machine. The spectral line emission from various ionization stages of carbon, oxygen and iron are regularly being monitored using this system. A schematic diagram of the system is illustrated in Fig. 15.

The system is operated in the ultra high vacuum conditions. The spectrometer views ~ 75 mm range along the toroidal direction at the vertical mid-plane of the plasma. The VUV spectrometer (model no. TG-320, JYUV) has a focal length of 0.3 m. The spectrometer is equipped with three toroidal gratings with groove densities 290, 450, and 2105 grooves/mm. The gratings are mounted on a UHV compatible movable translator. The gratings cover the spectral range of 10 – 31 nm, 100 – 120 nm, and 10 – 180 nm depending of the grating selection. The width of entrance slit can be adjusted between 10 – 250 µm. The dispersed VUV light is detected using a combination of a multi-channel plate with model no. 3040FM, Burle, and a visible charge coupled device, having model no. 7343-0001, PI.

3.1 Study of Iron impurity behaviour in Aditya tokamak using VUV spectroscopy system

With the aim of studying impurity behaviour in Aditya tokamak plasma, spectral emissions in the wavelength range of 10 – 120 nm is being monitored regularly using the VUV survey spectroscopy system with 450 grooves/mm grating. Figure 14 [8] shows a typical VUV spectrum recorded during the steady-state phase of a plasma discharge in Aditya tokamak.

For quantitative analysis, spectral emissions from Fe\textsuperscript{14+} and Fe\textsuperscript{15+} impurity ions are modelled with the STRAHL code, which is a one dimensional impurity transport code. In present study spectral line emissions at λ = 28.41 nm and λ = 33.54 nm have been used. The spectral emission ratio of intensities \( I_{28.41} / I_{33.54} \) has been calculated using STRAHL code and matched with the experimentally observed ratio by varying the parameter \( \upsilon/D \) and particle source rate \( i \) in the code [8]. Here \( \upsilon \) is the convective velocity and \( D \) is the diffusion coefficient. \( I_{28.41} \) and \( I_{33.54} \) represent the intensities of lines at 28.41 nm and 33.54 nm, respectively. Figure 17 [8] shows the resultant radial profile of \( \upsilon/D \) obtained for the best-fit of experimentally observed intensity profile.
Although the individual diffusion coefficient and convective velocity profile cannot be obtained exactly, for the sake of completeness, the individual radial profiles of $\nu$ and $D$ are shown in Fig. 18 [8]. The result shown in above figures indicate that the convective velocity is directed towards the plasma core region and this inward nature of the Fe impurity transport is indicated by negative sign of $\nu/D$.

REFERENCES