Investigation of Self-absorbed Lithium Spectral Line Emissions During Li_2TiO_3 Injection In Aditya-U Tokamak

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Introduction

- When radiation of any emission line source pass through dense plasma medium, the spectra of this emission line get absorbed within the plasma
- This is known as *self-absorprtion* effect in the plasmas. By studying self-absorption one can understand the opacity of the plasma. Opacity of the plasma is measure plasma is how much opaque or transparent to incoming radiation is defined by *opacity τ*.
- Tokamak plasmas are generally less dens to produce any self-absorption in radiations. Its *τ <<1*.
- In Aditya-U tokamak Electromagnetically driven Particle Injector (EPI) has been developed and tested successfully. It can produce sudden energy burst, which disrupts the plasma.
- During these experiments a Li_2TiO_3 Pellets are used.
- Spectroscopic observation is showing for Lithium spectral line emission at 670.8 nm is showing sudden increase in Lithium intensity.
- Further spectroscopic measurements are also indicating the density of Lithium is too high to produce self-absorption in Aditya-U tokamak plasma.

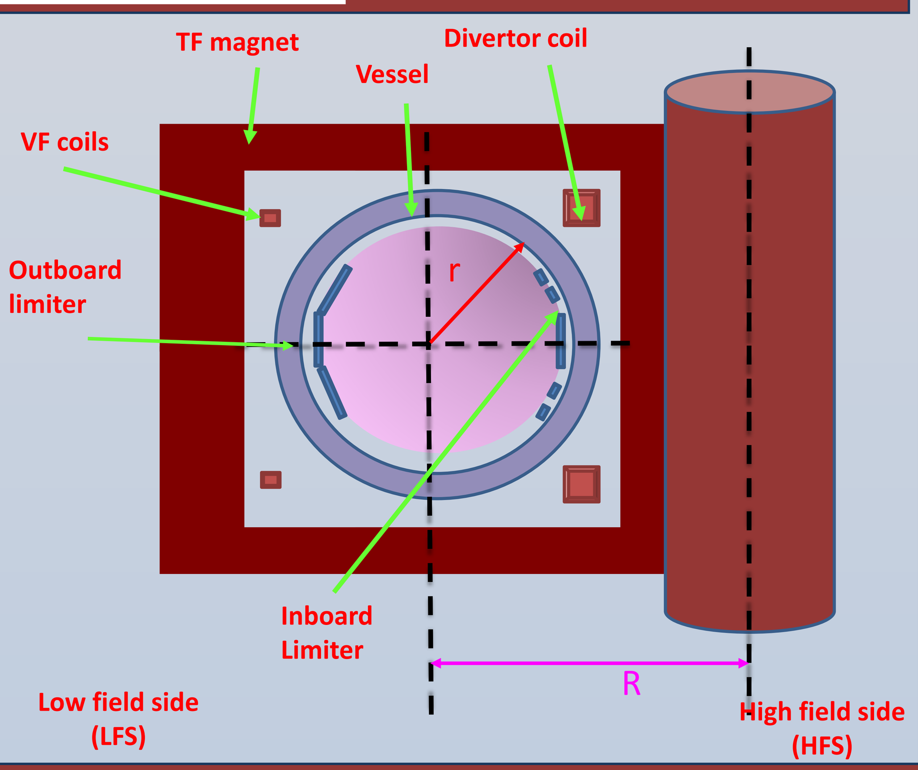
FOR THE FIRST TIME
self-absorption
in Lithium spectral line has been observed with pellet experiment

ADITYA-U Tokamak

A Medium size Tokamak

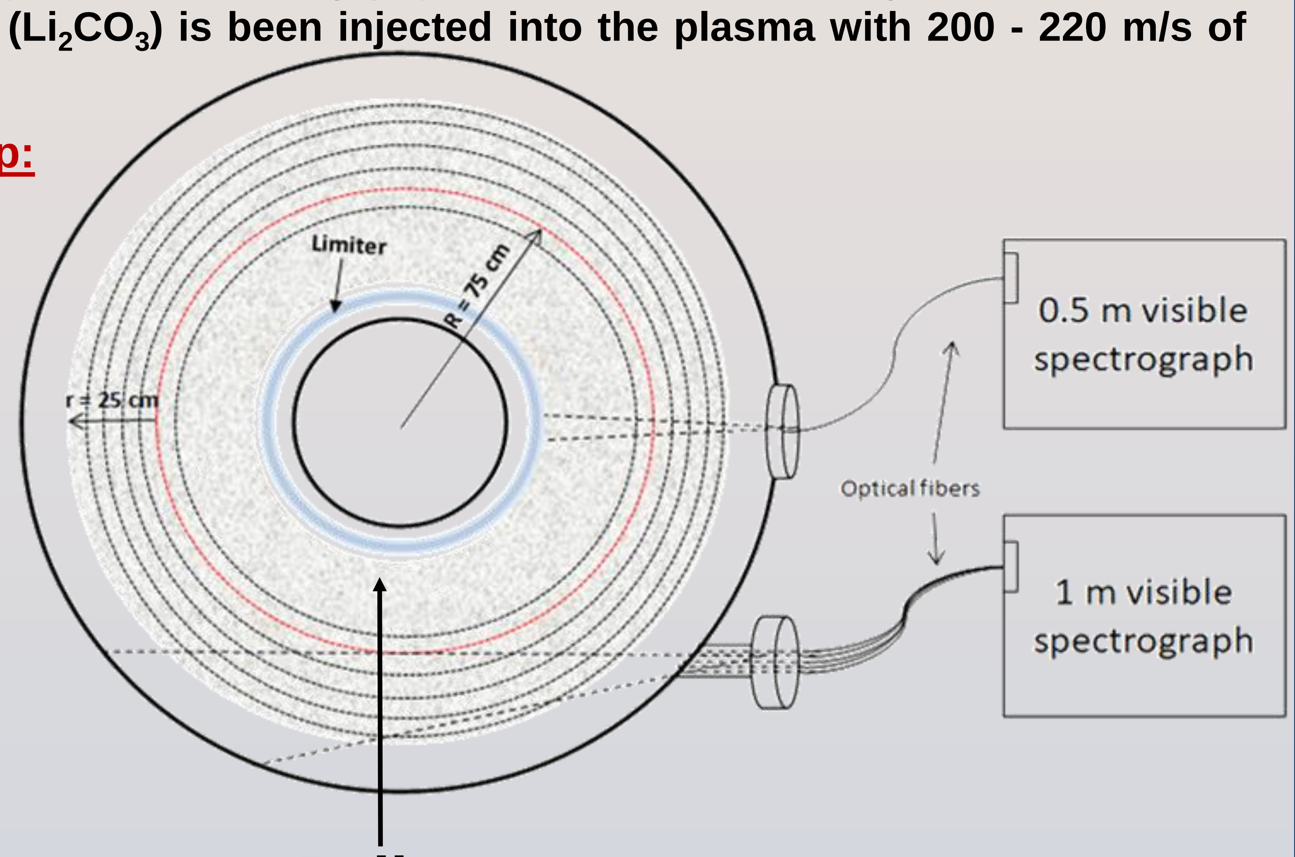
Plasma current Ip: 100 - 160 kA
Plasma duration: 100 - 200 ms
Electron density ne: 1.0 - 3.5x10^13 cm-3
Electron temperature Te: 300 - 650 eV

Major radius (R) = 75 cm
Minor radius (a) = 25 cm
Graphite limiter
Toroidal field B_T: 0.75 -1.2T



Experimental arrangement

- An electromagnetically driven particle injector (EPI) has been developed for the purpose of disruption mitigation experiments.
- The EPI system was installed at the machine's horizontal mid-plane at radial port no 10.
- This pellet is an inductive projectile containing payload of 50 and 200 mg, Lithium titanate (Li_2TiO_3) or Lithium Carbonate (Li_2CO_3) is been injected into the plasma with 200 - 220 m/s of velocity.



Spectroscopic diagnostic setup:

0.5 m visible spectrometer (model: SP-2500i Princeton Instrument)

- Installed to see temporal evolution of plasma
- Looking at limiter surface through radial view-port present at 17 port number
- Grating 1200 grooves/mm
- CCD: Andor 1024 x 248 pixels

1 m multi track spectrometer (model: PI Acton AM-510)

- Installed to see spatial evolution of plasma
- This is high resolution Multi Track Spectrometer.
- It is looking plasma from tangential port number 8
- Grating 1800 grooves/mm
- CCD: Andor 2048 x 512 pixels, 0.023 nm of resolution

Effect of self-absorption on line shape profile

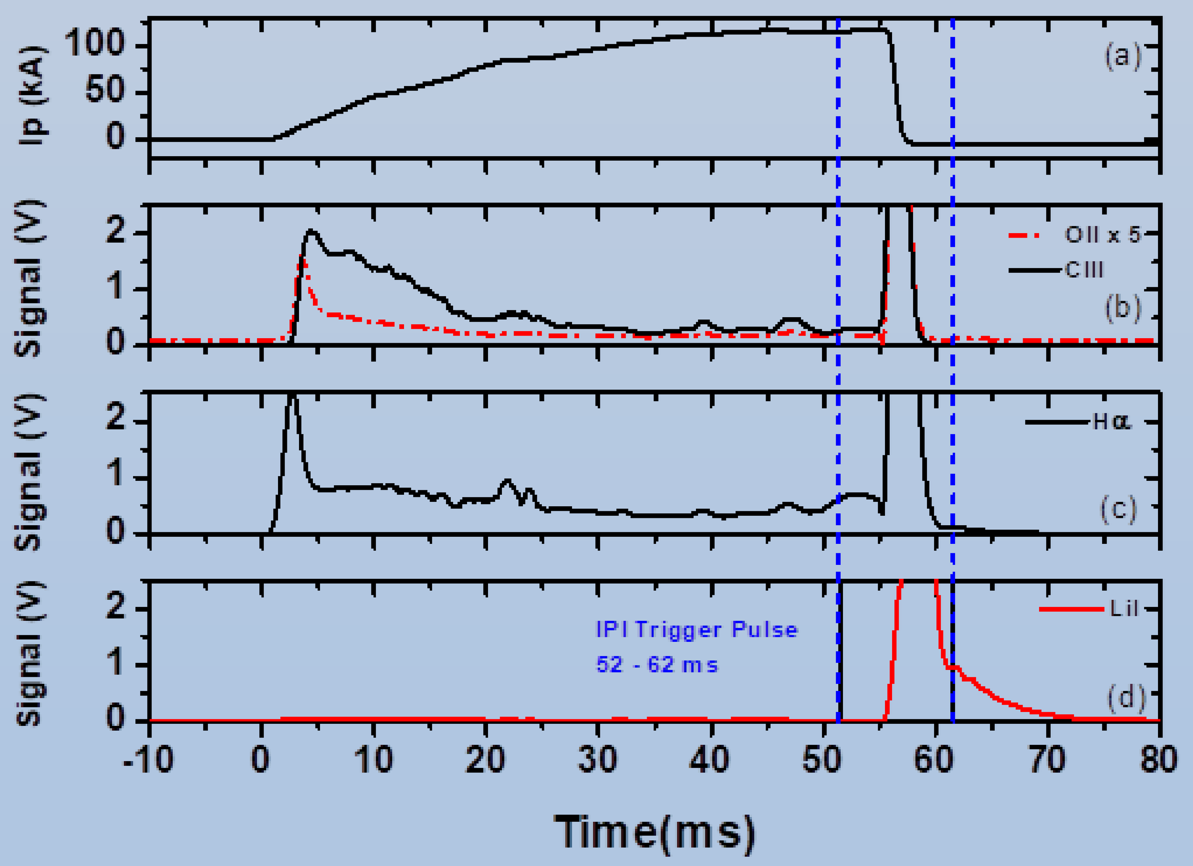
- The spectral line profile of radiation propagating to optical depth τ over certain wavelength range defined as: $T(\tau_0) = \int f(\lambda)\, e^{-\tau}\, d\lambda$
- Here, *f(λ)* denotes different line shape profile functions, i.e., Gaussian, Lorentzian and Voigt. In this paper measured spectra are fitted to the experimental using Gaussian line Profile given by following formula. (Notations has their usual meaning in the calculation)

$$f(\lambda) = \sqrt{\frac{4\ln 2}{\pi}}\,\frac{1}{\Delta\lambda_{FWHM}}\, e^{\left[-4\ln 2\left(\frac{\lambda-\lambda_0}{\Delta\lambda_{FWHM}}\right)^2\right]}$$

- Using above two formulas one can get the measurement of opacity value *opacity τ*, which is nothing but product of absorption coefficient and optical depth of the plasma

Result and Discussion

Typical plasma discharge with EPI Pellet Shot #33317



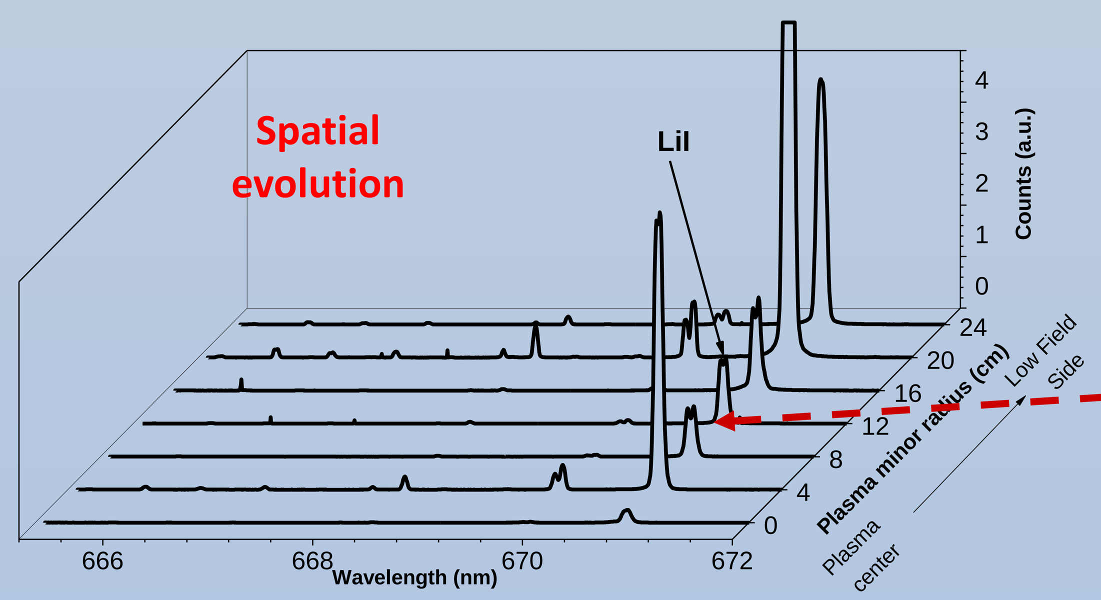
- The temporal evolution of spectroscopic signal
- Measured by Photo-Multiplier Tube (PMT)
- (a) Plasma current profile with EPI trigger pulse
- (b) OII at 441.9 nm and CIII at 464.7 nm
- (c) Hydrogen fuel neutral at 656.28 nm
- (d) Sudden increase in Lithium emission (670.8 nm)

Temporal Evolution of LiI

- 0.5 m Spectrometer
- Slit opening is 100 um with 5 ms exposure
- In all the frames Hα at 656.28 nm, CIII at 658.2 nm and small trace of LiI at 670.8 nm is present
- Lithium in these early to EPI pulse is due to recycling
- In earlier discharges lithium get trapped into PFCs
- EPI fired at ~ 52 ms
- In spectrum: Suddenly around 58.5 ms of discharge duration lithium gets saturates.

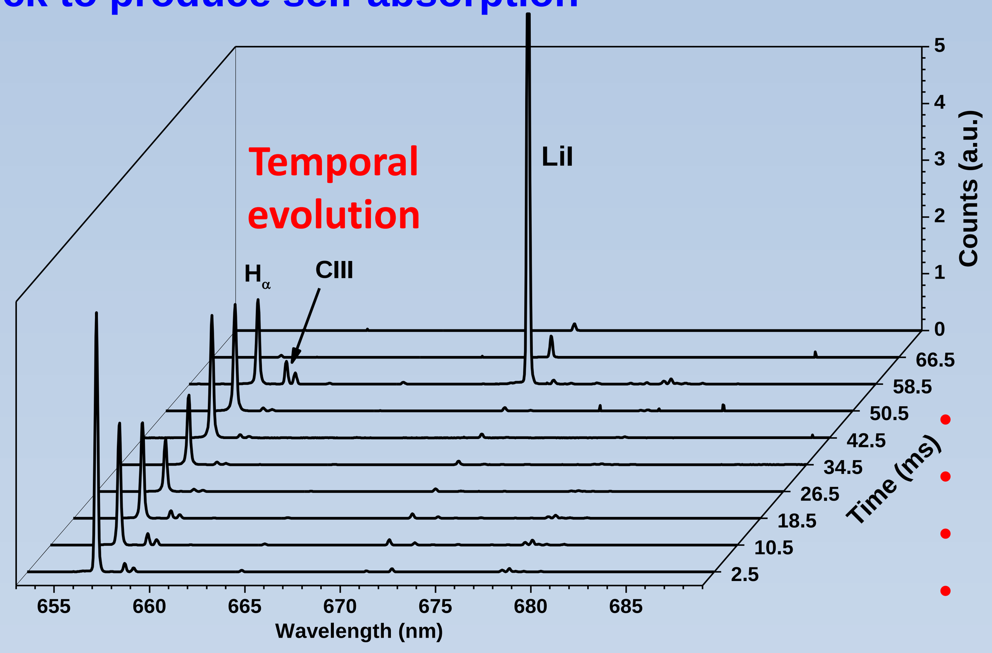
(this frame is seeing radiation between 56-61 ms of total time)

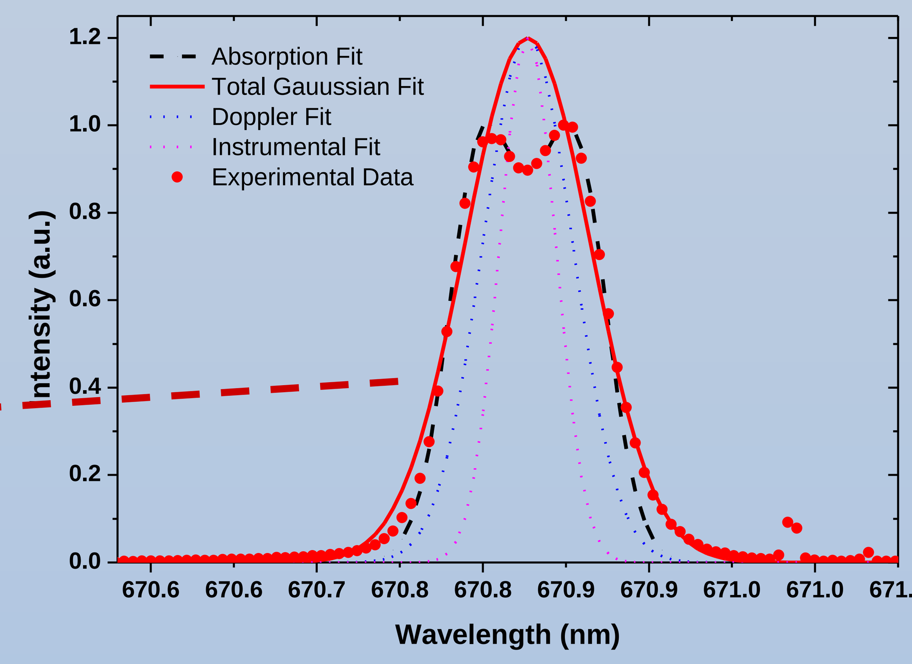
- This is clear indication of sudden increase in lithium density in the plasma. This sudden increase in density is likely producing the self-absorption in plasmas.



Spatial Evolution of LiI

- 1 m high resolution spectrometer is
- shot #33375 (same plasma parameter as shot #33317)
- Slit: 70 um , Expauser: 8 ms exposure Delay: 48 ms
- Space resolved profile 48 – 56 ms of plasma duration
- EPI is triggered at 52 ms.
- X-axis 0 cm is plasma centre,
- X-axis 24 cm is outboard radial location
- Absorption dip present: between 0-20 cm of radial distance
- Within this region plasma is said to be optically thick to produce self-absorption





Line integrated data from LoS representing 12 cm of radial plasma is analysed

The experimental data is fitted

1. Without considering self-absorption

Total measured Gaussian (Red solid line) = Doppler Gaussian profile + Instrumental Gaussian profile

2. With considering self-absorption

Absorption Gaussian fit (black dashed line) = Opacity value + Reduced Gaussian due to Self-absorption

- Opacity is derived and optical depth is known ~ 6 cm
- Measured absorption coefficient = 0.25 cm^{-1}
- Lithium density derived using formula of absorption coefficient n_{Li} ~ 2 ×10^{16} cm^{-3}.
- Calculating radiative power loss, $P_{loss} = n_e n_{Li} L_{LI}$
- Li ~ 0.66 ×10^{-22} erg.cm.sec^{-1} n_e ~ 1.2 ×10^{13} cm^{-3}
- P_{loss} ~ 148 kW, known P_{In} ~ 260 kW
- more than 60% of power is radiated due to the pellet and then it can be said that the sudden plasma disruption has happened due to radiative cooling of the plasma.

Summary

- Lithium self-absorption is observed in Aditya-U tokamak
- Absorption coefficient and Lithium density is derived
- Using derived information radiative power loss is derived
- More than 60% of power is radiated because of radiative cooling caused by pellet, it causes the sudden disruption of plasma