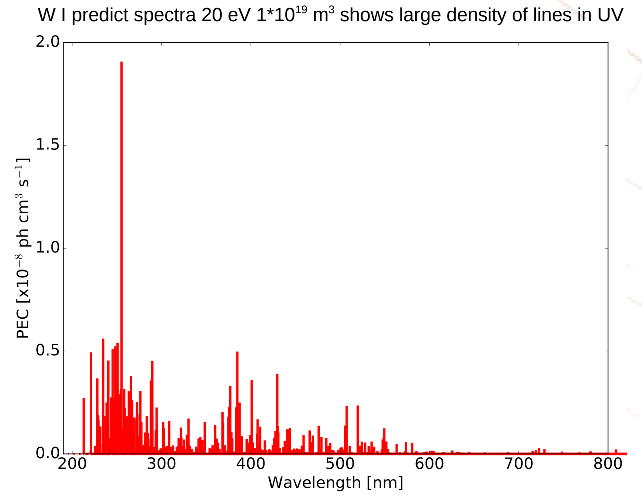
Abstract

- **Erosion of plasma facing components can significantly impact performance**
  - Erosion can be diagnosed from spectral line emission and the (S/XB) coefficient 'ionizations per photon'
- **Emission from W I is most intense in the UV region**
- **Nineteen W I emission lines in the UV from W I are identified**
- **W I spectra are compared to synthetic spectra for vary plasma conditions**
- **A new collisional radiative has been developed to deal with challenges of W I spectral line modeling**

Motivation

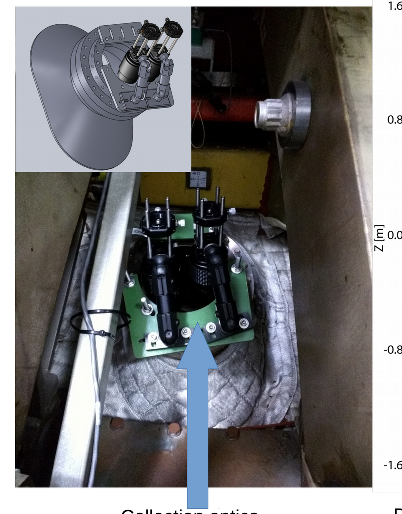
- **High-Z materials are leading candidates for future first wall**
- **Currently, erosion measurements are predominately made with the W I 400.87 nm line**
- **Measurement of multiple large lines allows more accurate erosion measurement**
  - Atomic calculations multiple strong W I lines in the UV

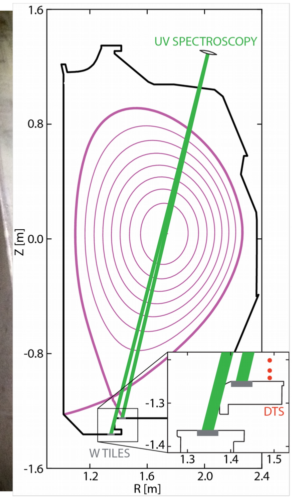


$$\Gamma = \int_0^\infty N_e N^z S^{z\to z+1} dx = \int_0^\infty N_e \frac{S^{z\to z+1}}{A_{j\to i}\frac{N_j}{N^z}} \left(A_{j\to i}\frac{N_j}{N^z}\right) N^z dx$$
$$= \int_0^\infty N_e S/XB^z_{j\to i}\left(A_{j\to i}\frac{N_j}{N^z}\right) N^z dx$$

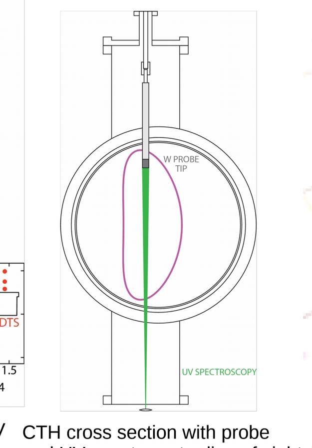
Spectrometer Hardware

- **Three StellarNet survey spectrometers were installed on both DIII-D and CTH**
  - Spectrometers with 200-300, 300-400 and 200-400 nm ranges
  - 2400 grooves/mm ruled plane graing, entrance slit of 7 um, resolution of 0.1 nm
  - Integration times of 30 to 2000 ms utilized
- **Two viewing chords were used on DIII-D**
  - Lenses were located at 75R+2
  - Spectrometers measured W tiles emission from divertor floor & shelf simultaneously
  - 5 m fused silica fibers used to minimize UV attenuation
- **Single viewing chord on CTH that opposite to probe location**
  - Tungsten introduced into CTH with a W tipped probe
  - Probe data also taken with Mo, SS, and SiC probe tips
  - Probe depth scans in CTH help to identify W lines

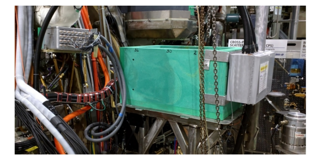

Collection optics

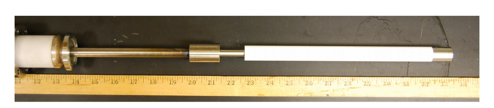


DIII-D cross section with UV spectrometer lines of sight



CTH cross section with probe and UV spectrometer line of sight

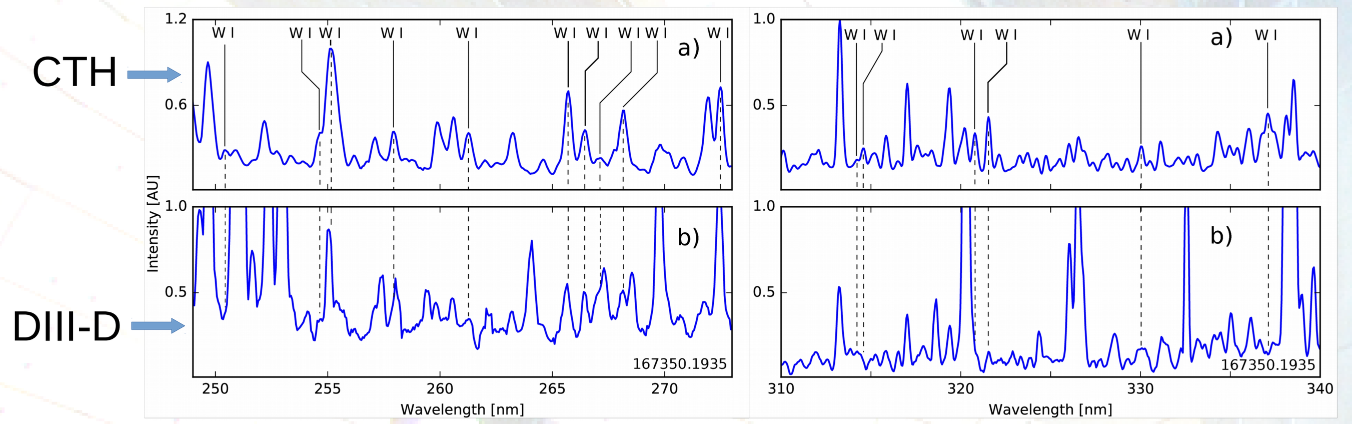



CTH probe with BN sleave


Spectrometers installed on DIII-D

W I UV Line Identification

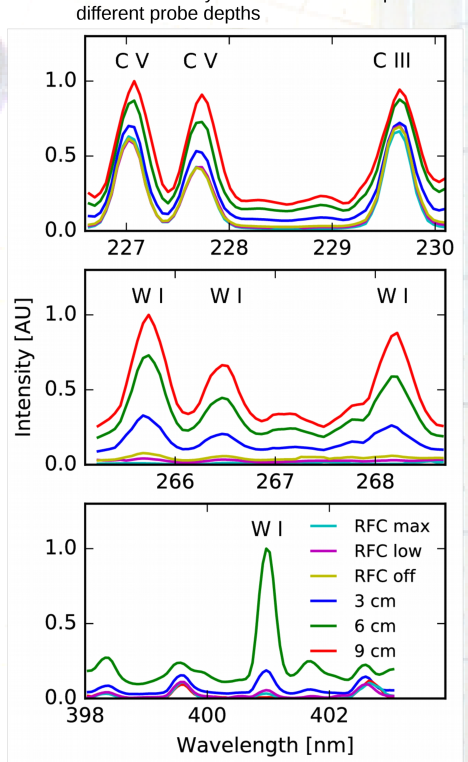
- **27 total W I lines are identified between the CTH and DIII-D experiments**
  - **19 previously unreported/identified in a fusion relevant plasma**
  - Large W I lines observed in DIII-D confirmed in CTH
- **Probe scan in CTH distinguishes between W and other base impurities**
  - W I intensities increased dramatically with probe depth
  - W I lines in CTH can be eliminated when the probe is retracted from the plasma
- **Nineteen new W I lines identified between DIII-D and CTH**
  - Intense W I lines transition down to the six lowest metastable states
- **Regions of high density W I emission in seen in both devices motivates high resolution spectrometer**



Observed W I lines in DIII-D and CTH, with new upper level identifications for most lines

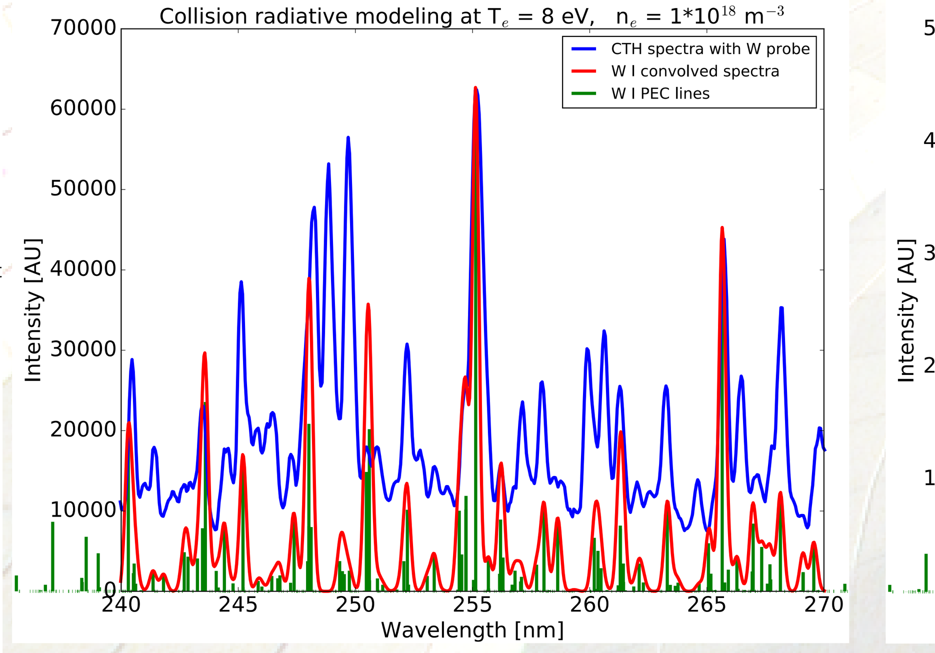
Line Observed [nm]	NIST location [nm]	Upper level	Lower level
233.30	233.28	$5d^4\ 6s\ 6p\ (^3I_5)$	$5d^4\ 6s^2\ (^5D_4)$
	233.29	$5d^4\ 6s\ 6p\ (^5P_3)$	$5d^4\ 6s^2\ (^5D_4)$
246.24	246.28		
243.50	243.60	$5d^4\ 6s\ 6p\ (^5D_4)$	$5d^4\ 6s^2\ (^5D_3)$
247.41	247.42	$5d^4\ 6s\ 6p\ (^5F_4)$	$5d^4\ 6s^2\ (^5D_4)$
250.54	250.47	$5d^4\ 6s\ 6p\ ([]_2)$	$5d^4\ 6s^2\ (^5D_1)$
254.61	254.71	$5d^4\ 6s\ 6p\ (^5F_1)$	$5d^4\ 6s^2\ (^5D_2)$
255.20	255.13	$5d^4\ 6s\ 6p\ (^3P_1)$	$5d^4\ 6s^2\ (^5D_0)$
257.98	258.05	$5d^4\ 6s\ 6p\ (^5P_1)$	$5d^4\ 6s^2\ (^5D_1)$
261.30	261.31	$5d^4\ 6s\ 6p\ (^5F_2)$	$5d^4\ 6s^2\ (^5D_2)$
265.65	265.65	$5d^5\ 6p\ (^7P_4)$	$5d^5\ (^6S)\ 6s\ (^7S_3)$
266.40	266.28	$([]_2)$	$5d^4\ 6s^2\ (^5D_2)$
267.09	267.15	$5d^4\ 6s\ 6p\ (^3F_3)$	$5d^4\ 6s^2\ (^5D_3)$
268.20	268.14	$5d^4\ 6s\ 6p\ (^5G_4)$	$5d^5\ (^6S)\ 6s\ (^7S_3)$
272.50	272.44	$5d^5\ 6p\ (^7P_3)$	$5d^5\ (^6S)\ 6s\ (^7S_3)$
284.82	284.80	$5d^4\ 6s\ 6p\ (^3D_3)$	$5d^5\ (^6S)\ 6s\ (^7S_3)$
	294.44	$5d^5\ 6p\ (^7P_2)$	$5d^5\ (^6S)\ 6s\ (^7S_3)$
294.63	294.70	$5d^4\ 6s\ 6p\ (^5F_3)$	$5d^5\ (^6S)\ 6s\ (^7S_3)$
	294.74	$5d^4\ 6s\ 6p\ (^5I_4)$	$5d^4\ 6s^2\ (^5D_3)$
301.74	301.74	$5d^4\ 6s\ 6p\ (^5D_4)$	$5d^5\ (^6S)\ 6s\ (^7S_3)$
314.20	314.14	$5d^4\ 6s\ 6p\ (^5F_4)$	$5d^4\ 6s^2\ (^3H_4)$
314.57	314.52	$5d^4\ 6s\ 6p\ (^3H_5)$	$5d^4\ 6s^2\ (^3H_5)$
320.79	320.83	$5d^4\ 6s\ 6p\ (^5F_2)$	$5d^4\ 6s^2\ (^5D_2)$
321.53	321.56	$5d^4\ 6s\ 6p\ (^5F_5)$	$5d^4\ 6s^2\ (^5D_4)$
330.03	330.08	$5d^4\ 6s\ 6p\ (^5F_4)$	$5d^4\ 6s^2\ (^5D_3)$
337.09	337.10	$5d^4\ 6s\ 6p\ (^5F_2)$	$5d^4\ 6s^2\ (^5D_3)$
361.80	361.75	$5d^4\ 6s\ (^6D)\ 6p\ (^5P_3)$	$5d^5\ (^6S)\ 6s\ (^7S_3)$
378.08	378.08	$5d^4\ 6s\ (^6D)\ 6p\ (^5P_2)$	$5d^5\ (^6S)\ 6s\ (^7S_3)$
383.54	383.51	$5d^4\ 6s\ (^6D)\ 6p\ (^5P_2)$	$5d^4\ 6s^2\ (^5D_2)$
386.82	386.80	$5d^4\ 6s\ (^6D)\ 6p\ (^7D_4)$	$5d^5\ (^6S)\ 6s\ (^7S_3)$
400.90	400.88	$5d^4\ 6s\ 6p\ (^7P_4)$	$5d^5\ (^6S)\ 6s\ (^7S_3)$

W tipped probe scan in CTH allows W lines to be confidently identified. Colors represent different probe depths

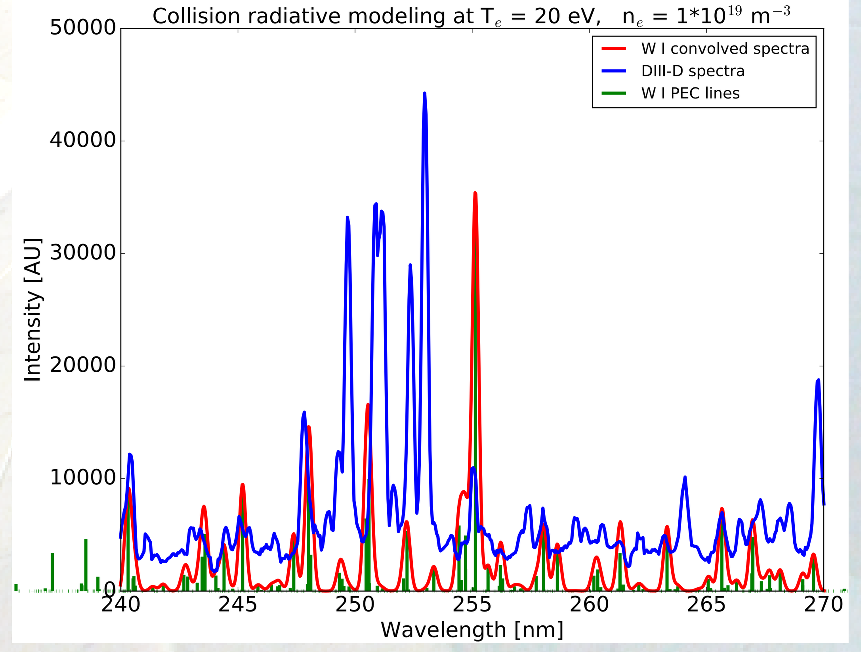


W I spectral modeling

- **New R-Matrix W I excitation calculation completed and being verified see Stuart Loch's poster**
  - Photon emissivity coefficients show good agreement with CTH W I spectra when ionization is included
- **Calculation shows good agreement with CTH spectra**
  - Many large lines in the UV region present great opportunities for simultaneous erosion measurements
  - Line ratios allow measurements of T_e, n_e and metastable fractions
- **Predicted spectra agreement not as good for DIII-D spectra**
  - Line ratio of the 265.65 and 255.13 lines can not be made to agree with DIII-D for Thomson



New PECs for W I emission agrees well with CTH spectra



New PECs line ratios do not match DIII-D spectra

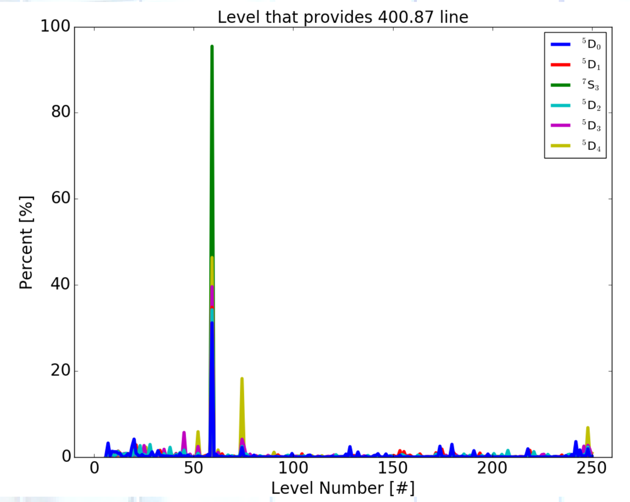
Colradpy: A new python collisional radiative (CR) solver

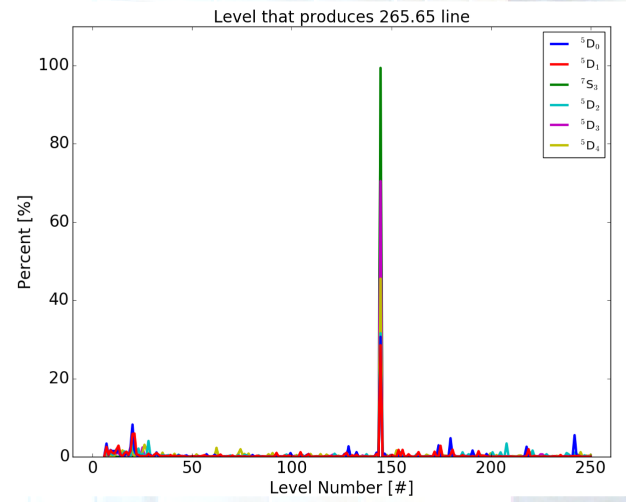
- **Eventually code can be released to other collaborators**
- **Pure python collisional radiative solver**
  - Solves the collisional radiative set of equations
  - Solves the metstable resolved time dependent ionization balance
- **Functionality of colradpy similar to ADAS 208, 405 and 406**
- **Can solve CR equations with an arbitrary number of metastable states, ADAS is currently limited to three**
- **Executes 6-12 times faster than ADAS depending on CR matrix shape and size**
- **Every part of CR matrix readily available for post processing analysis e.g.**
  - How do levels get populated?
  - Which levels ionize?

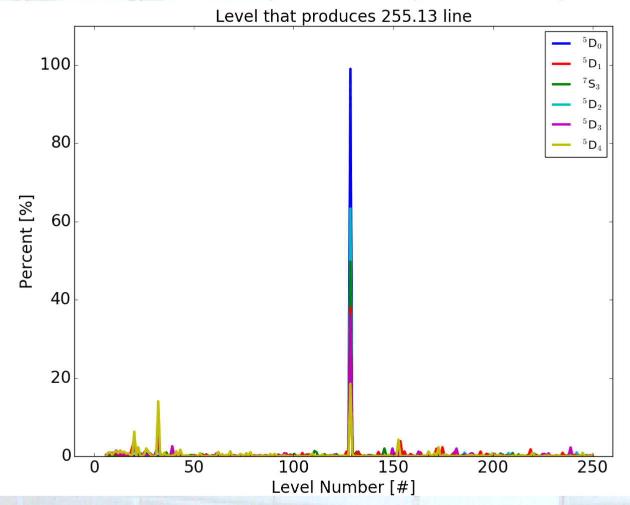
Metastable fractions can be determined from line ratios

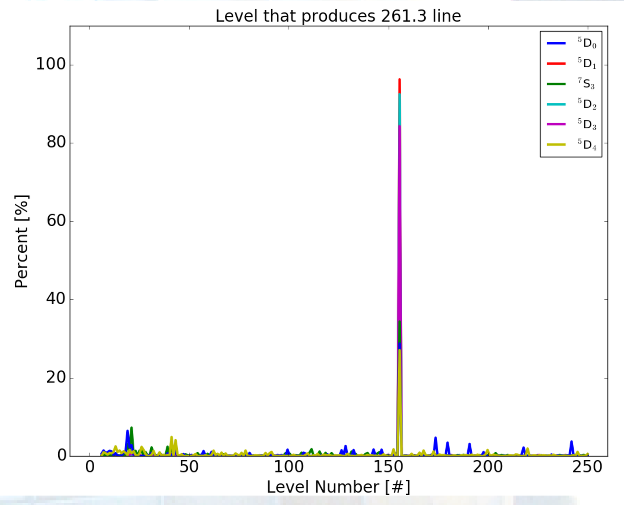
- **Metastable populations can greatly impact spectral lines (see Stuart Loch's poster)**
- **From collision radiative theory the level populating mechanisms can be determined**
  - The method of populating can determine what physical processes are import in atomic modeling
- **Latest calculations show that lines strong lines that radiate down to metastable are fairly pure (they are populated directly from the metastable states)**

$$N_{j,mechism} = C'^{-1}_{ji} C_{i\sigma} N_\sigma$$



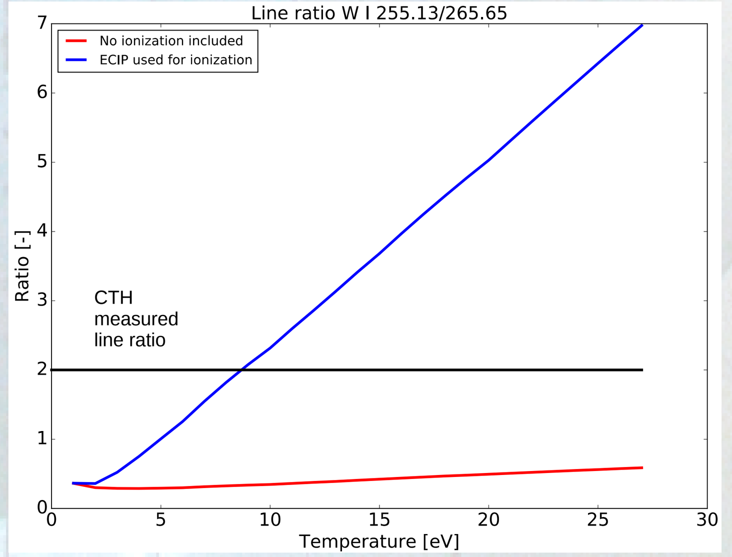






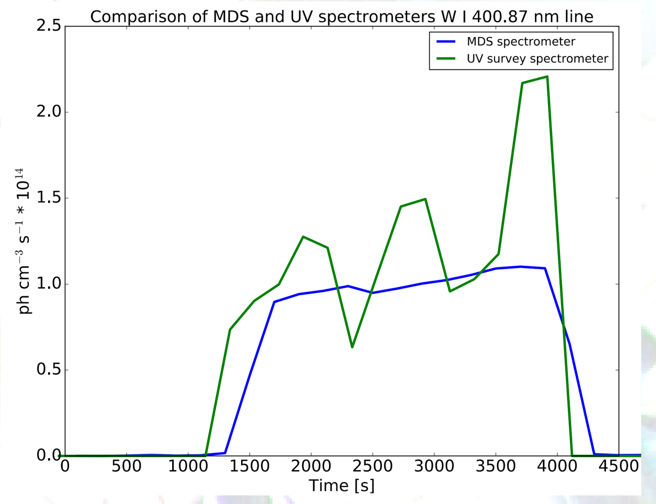
Ionization significantly impacts W I PECs

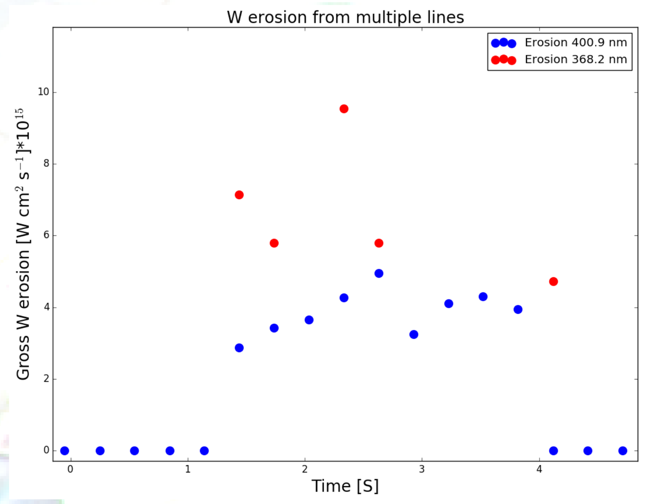
- **In light systems the relative intensities of PECs are not greatly impacted by ionization**
- **Neutral tungsten PECs show a strong dependence on the ionization**
- **S/XB now extremely dependent on ionization also impacts PEC**



Preliminary W I erosion measurement in DIII-D

- **Absolute in vessel calibration completed for UV spectrometers 350-410 nm**
- **Erosion measurements from UV generally in agreement with ersoion from other diagnostics**
- **Erosion made from different spectral lines in relatively good agreement**
  - Erosion could be different do to the poor resolution of the survey spectrometers
  - Difference could also be attributed to atomic data used

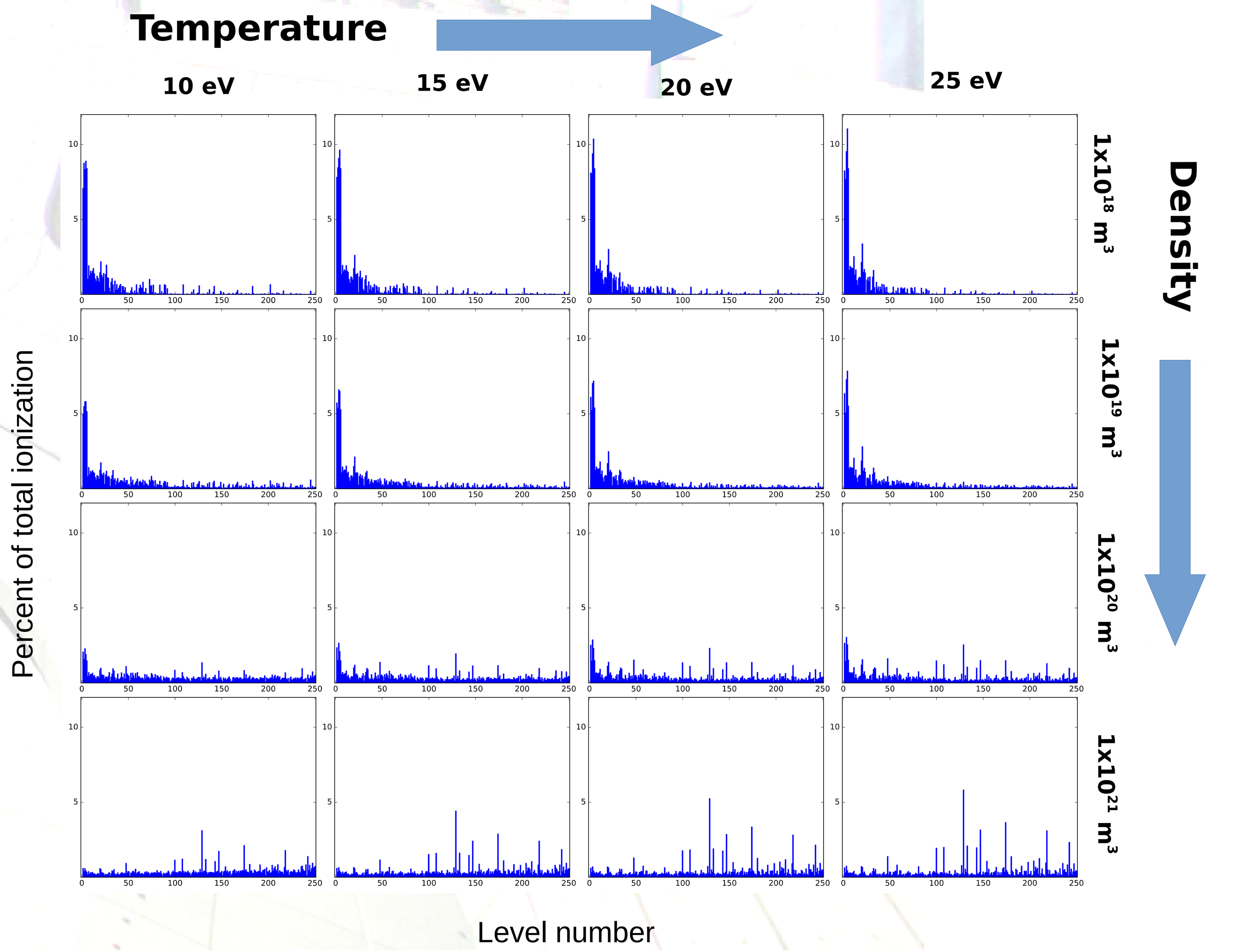




Analysis of which levels get ionized

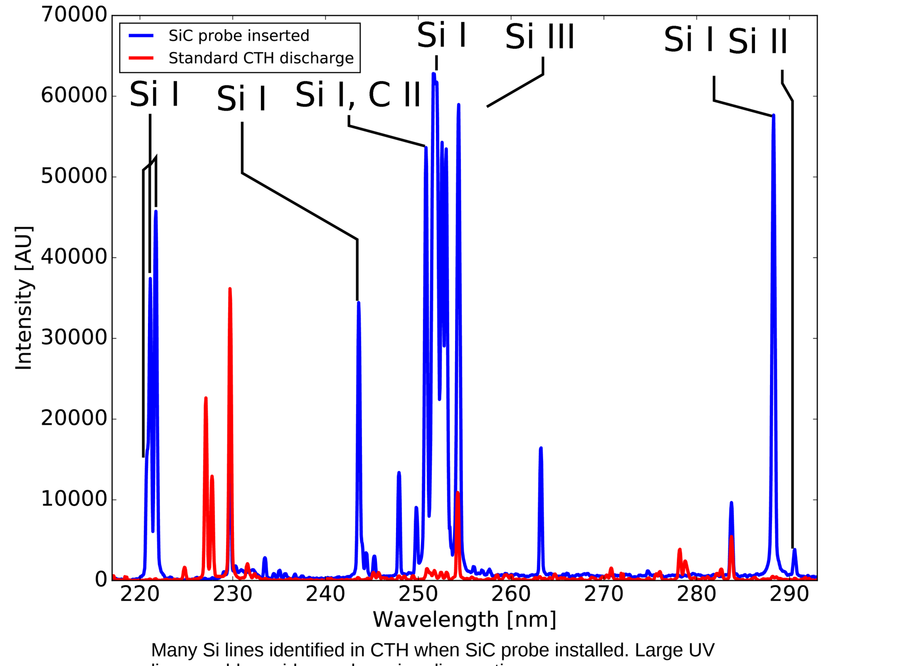
- **At low temperatures ionization is dominated by the low lying levels**
- **At high temperatures ionization comes from many different levels**
- **Ionization balance completed shows the steady state metastable populations**
  - Are DIII-D plasmas in steady state conditions?
  - Collisional radiative assumes that everything is in steady state with the ground state, this could significantly change spectral modeling conclusions
- **At low densities ionization is dominated by the metastables**
- **Electron classical impact factor (ECIP) is the only W I ionization data presently available**
  - **ECIP not ideal for lower levels**
- **High quality ionization calculations in progress will allow greater confidence in ionization**

$$S_{\nu,mechism} = S_{\nu j} C'^{-1}_{ji} C_{i\sigma} N_\sigma$$

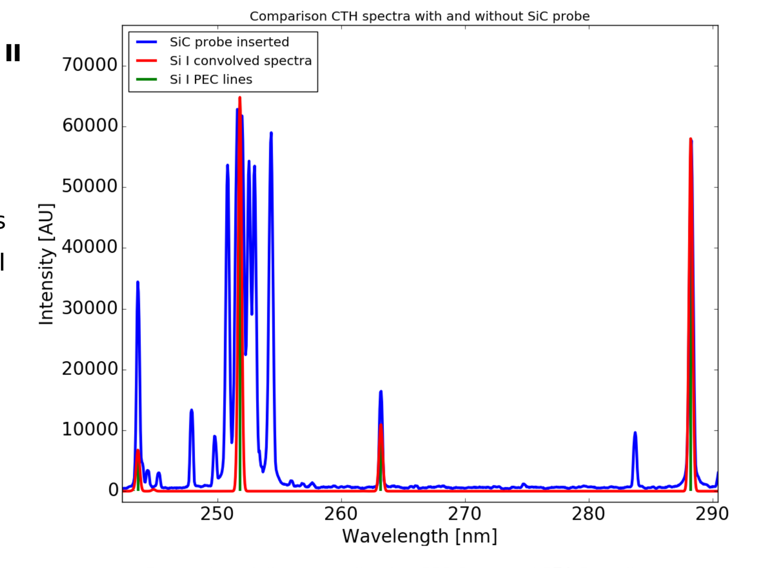


Initial Si experiments and spectral modeling

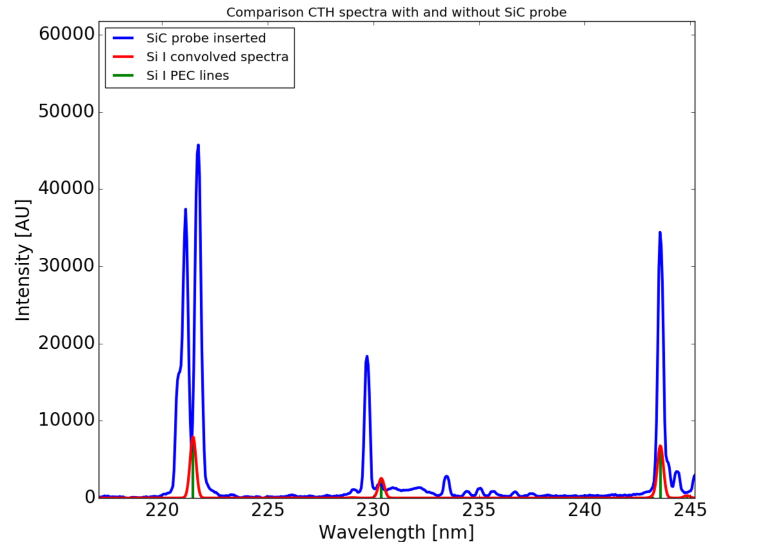
- **SiC probe inserted into CTH to assess SiC as a PFC**
  - Si lines showed the same behavior as W with probe depth
- **Large S I, S III observed within 200-300 nm as well as small Si II lines**
- **Si data currently available does not agree well with CTH measurements**
  - Atomic data generated using method not ideal for neutral systems
  - Spectral modeling requires two metastable states for experimental agreement
  - No current R-Matrix data available for Si I, Si II or Si III better atomic data will be needed to make accurate Si erosion measurements



Many Si lines identified in CTH when SiC probe installed. Large UV lines could provide good erosion diagnostics



Spectral modeling normalized to 288.2 nm and 251.8 nm lines



Summary

- **Erosion of plasma facing components can significantly impact performance**
- **Emission from W I is most intense in the UV region**
- **Nineteen W I emission lines in the UV from W I are identified**
- **W I spectra are compared to synthetic spectra for vary plasma conditions**
- **A new collisional radiative has been developed to deal with challenges of W I spectral line modeling**
- **Initial erosion measurements in DIII-D have been completed and compared to other DIII-D diagnostics**

Future Work

- **Upgrade UV diagnostic to obtain better time and spectral resolution**
- **Compare ionization calculations to determine match to experiment**
- **Investigate W I line ratios for diagnostics**
- **Compare W I S/XB with erosion measured postmortem from DIMES samples**
- **Compare upcoming W II calculations to DIII-D and CTH data**
- **Analysis of gross/net erosion spectroscopically**

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