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Fourier Transform Infrared Emission Spectroscopy of Si II

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INTRODUCTION & AIM

Significance: Silicon (Si), the 8th most abundant and astrophysically important element, plays a critical role in stellar evolution, nucleosynthesis, and plasma diagnostics.

Precise atomic data, especially for IR transitions of singly ionised silicon (Si II) is essential for:

- Modelling in stellar atmospheres [1].
- High-redshift galaxy studies with JWST NIRSpec [2].

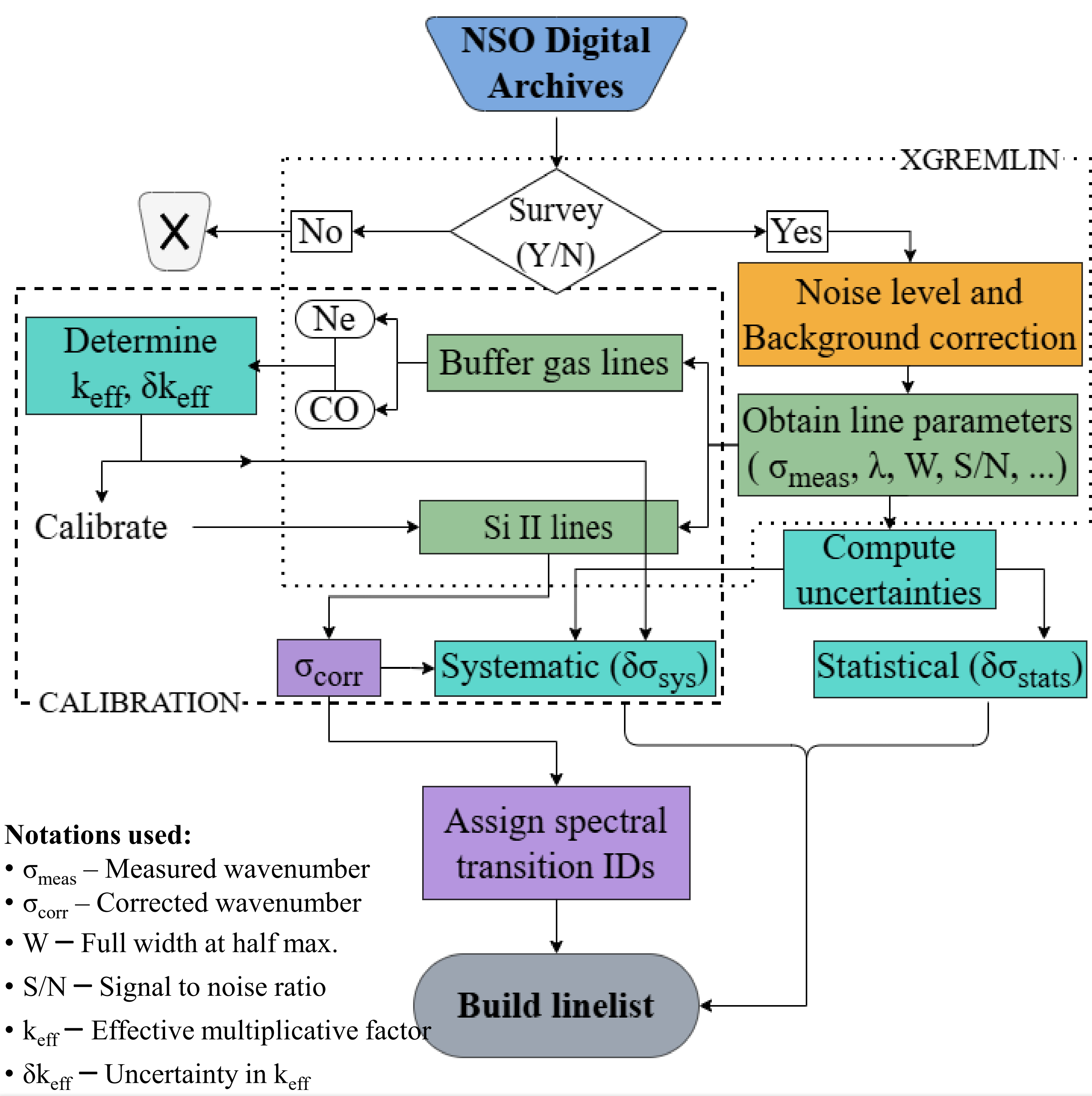
Research gap: Existing Si II data in the NIST atomic spectra database (ASD) lacks sufficient experimental accuracy and precision [3].

Nearly all IR lines are theoretical, except for just three measurements made by Shenstone in 1961, using a 21 ft. grating spectrograph but, without reporting any uncertainties [4].

Aim/objective: To get a precise Si II atomic data, along with uncertainties in the near- and mid-IR regions, by using high-resolution FT spectra recorded by 1-m (f/55 IR-visible-UV) FT spectrometer at KP National Observatory, AZ, USA.

Atomic Structure: Si II belongs to the aluminium (Al I) isoelectronic sequence with the ground configuration [Ne]$3s^2 3p$ comprised of two levels, $^2P^o_{1/2,\,3/2}$, the level with J=1/2 being the lowest one. Excitation of the valence electron creates configurations of the type $3s^2 nl$ $(n \geq 3,\ l = s, p, d, f, \ldots)$ with doublet (^2L_J) levels. The $3s3p^2$ configuration containing the ^4P, ^2D, ^2S, and ^2P terms is created from the ground configuration $3s^2 3p$ by excitation of the $3s$ electron. Further excitation from $3s3p^2$ leads to the $3s3p(^3P^o)nl$ $(n \geq 3,\ l = s, p, d, f, \ldots)$ and $3p^3$ configurations.

METHOD



Notations used:

- σ_{meas} – Measured wavenumber
- σ_{corr} – Corrected wavenumber
- W – Full width at half max.
- S/N – Signal to noise ratio
- k_{eff} – Effective multiplicative factor
- δk_{eff} – Uncertainty in k_{eff}

RESULTS & DISCUSSION

Table-1: Summary of spectrograms used and total number of Si II emission lines measured in IR region, from 780 to 5400 nm.

Wavenumber Range (cm^{-1})	Hollow Cathode Lamp		Spectral Resolution (cm^{-1})	Calibration Standards	No. of lines measured
	Type*	Pressure (Torr)			
7664 – 44591	Si–Ne	0.7	0.057	Ne I, Ar I	**3**
1746 – 9937	Al/Si–Ne	1.74	0.013	Ne I	**18**
1746 – 9937	Al/Si–Ne(Ar)	1.8	0.013	Ne I, CO	**18**
1746 – 9937	Cu/Si–Ne(Ar)	2.8–3.8	0.013	Ne I, CO	**25**
1669 – 9937	Al/Si–Ne(He)	2.45–2.8	0.013	Ne I	**23**
1669 – 9937	Al/Si–Ne	2.5	0.013	Ne I, CO	**14**

Table-2: Sample of a few measurements and their comparison.

σ_{corr} (cm^{-1})	S/N	W (mK)	σ_{NIST} (cm^{-1})	$\Delta\sigma_{C\text{-}N}$ (cm^{-1})	Transition	
2531.751(2)	160	18	2531.81	-0.059	4d–4f	$^2D_{5/2}$ to $^2F^o_{5/2}$
–	–	–	2533.11	–		$^2D_{3/2}$ to $^2F^o_{5/2}$
2837.724(2)	17	11	2837.69	0.034	4d–5p	$^2D_{3/2}$ to $^2P^o_{1/2}$
2860.918(2)	48	23	2860.9	0.018		$^2D_{5/2}$ to $^2P^o_{3/2}$
5888.686(2)	123	42	5888.65	0.036	5s–5p	$^2S_{1/2}$ to $^2P^o_{1/2}$
5913.180(2)	299	38	5913.16	0.020		$^2S_{1/2}$ to $^2P^o_{3/2}$
7299.217(2)	70	55	7299.21	0.007	5p–6s	$^2P^o_{3/2}$ to $^2S_{1/2}$
–	–	–	7323.72	–		$^2P^o_{1/2}$ to $^2S_{1/2}$
8509.340(3)	23	59	8509.31	0.030	5p–5d	$^2P^o_{3/2}$ to $^2D_{3/2}$
8509.528(2)	180	53	8509.47	0.058		$^2P^o_{3/2}$ to $^2D_{5/2}$
8533.839(2)	89	54	8533.82	0.019		$^2P^o_{1/2}$ to $^2D_{3/2}$
12735.802(4)	63	91	12735.8	0.002	4d–5f	$^2D_{5/2}$ to $^2F^o_{7/2}$
12737.296(5)	44	92	12737.27	0.026		$^2D_{3/2}$ to $^2F^o_{5/2}$

Notes:

* Type of Hollow cathode lamp, represented as “cathode_material – buffer_gas”.

\# Lines observed by A.G. Shenstone (1961) ref. [4].

CONCLUSION

In this work, we considered 8 different FT spectra and carefully analyzed them with the help of the XGREMLIN package. A comprehensive calibration procedure was followed, involving the use of known low-excitation lines of buffer gas, and an advanced statistical toolbox [5], to determine k_{eff} and δk_{eff}. A total of more than 80 Si II lines were measured, with around 30 unique lines in near– and mid–IR region from 1800 to 12800 cm^{-1} . An immediate comparison of our experimentally measured data with the existing theoretical data in NIST ASD clearly shows that they are at least 10-fold better in accuracy, with the difference not exceeding 0.09 cm^{-1}. Such great precision is extremely important for astrophysicists to accurately determine the composition of stars and galaxies and hence, understand various nucleosynthesis processes and stellar evolution.

FUTURE WORK / REFERENCES

Future Work: Inclusion of lines in visible and UV regions as well as a more in-depth analysis, including the use of Level Optimization (LOPT) procedures to establish the energy levels and hence precisely model the atomic structure of Si II.

References:

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