Oscillator Strength Measurements in Singly-Ionized, Doubly-Ionized and Neutral Lanthanides and Transition Elements (Sm, Nd, Pr, Gd, Cu, and Fe) Using Laser-Induced Breakdown Spectroscopy.

presented at the 2012 CAP Congress
Thursday, June 14th, 2012

Caleb A. Ryder[1] and Steven J. Rehse[2]

[1]Wayne State University, Department of Physics and Astronomy
[2]The University of Windsor, Department of Physics

WAYNE STATE UNIVERSITY

University of Windsor
thinking forward

Laser-induced breakdown spectroscopy
a laser-based atomic spectroscopy
analysis technique

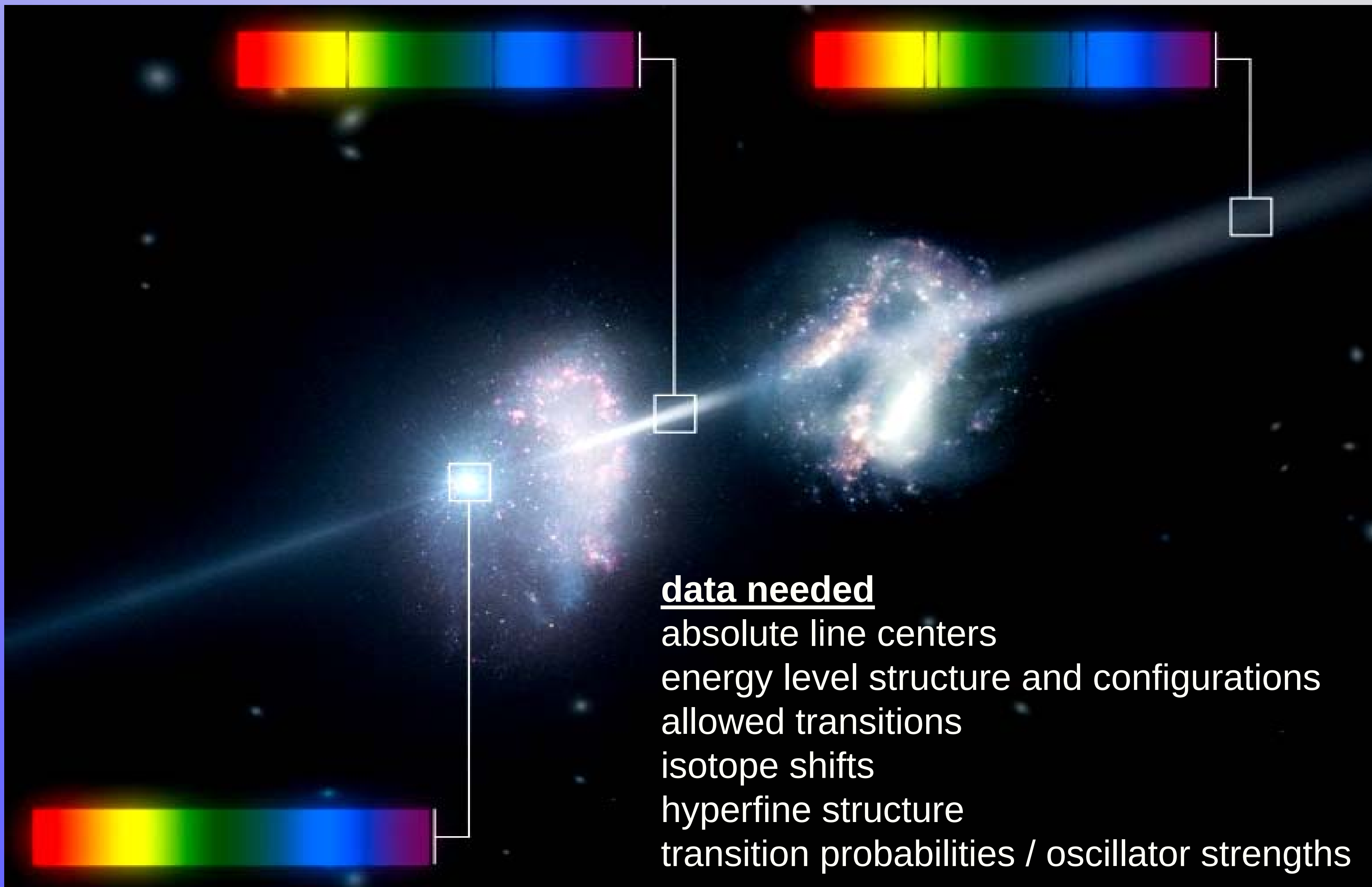
Biomedical Physics
the real-time identification of bacterial pathogens based on rapid atomic/elemental assay

- US Army Research Laboratory
- University of Central Florida (CREOL)
- private industries

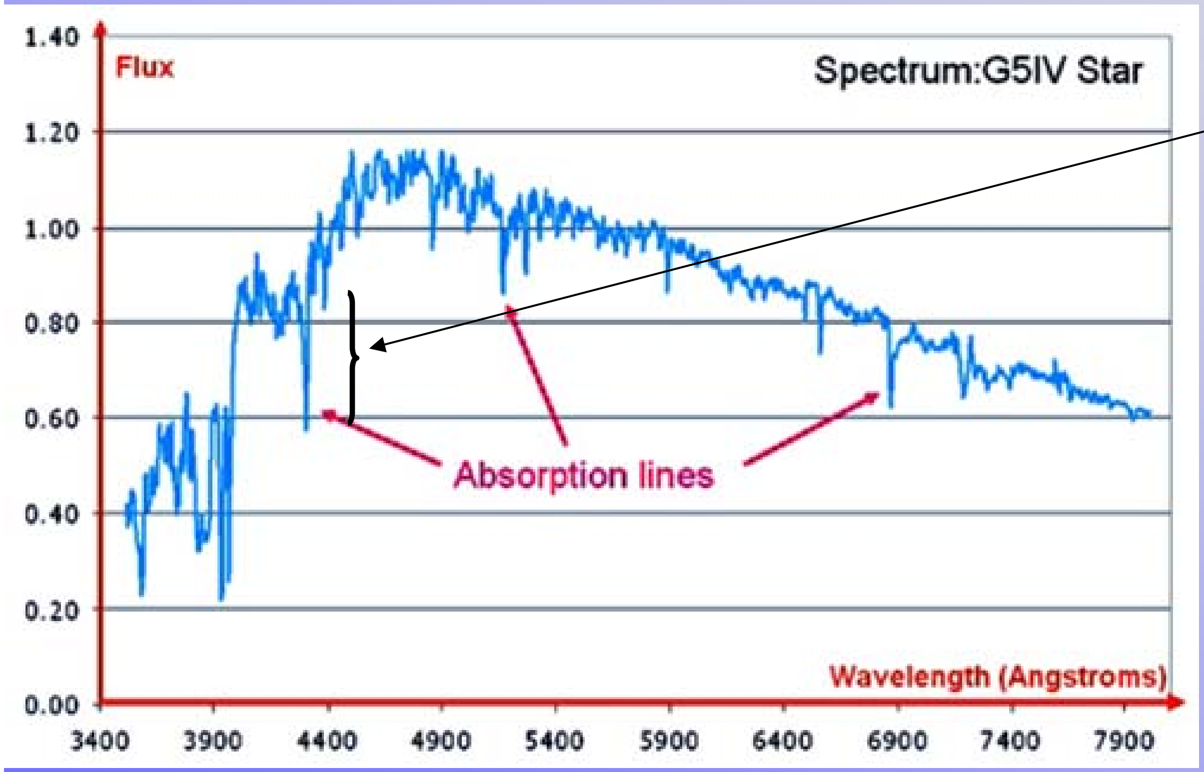
Laboratory Astrophysics
measurement of fundamental atomic properties of atoms/ions of interest to observational astronomers

- University of Western Ontario
- Lund University (Sweden)
- University of Wisconsin-Madison
- University of Oklahoma-Norman
- Universite´ de Liege / Universite´ de Mons-Hainaut (Belgium)

The Need for Laboratory Astrophysics



Abundances in Stellar Atmospheres



the depth of an absorption line depends upon the line **oscillator strength** and the **abundance** in the star

determinations of abundances (required to refine models of nucleosynthesis, stellar evolution, diffusion, etc.) under) therefore require **accurate oscillator strengths** *gf* or log(*gf*).

experimental oscillator strengths require measurement of

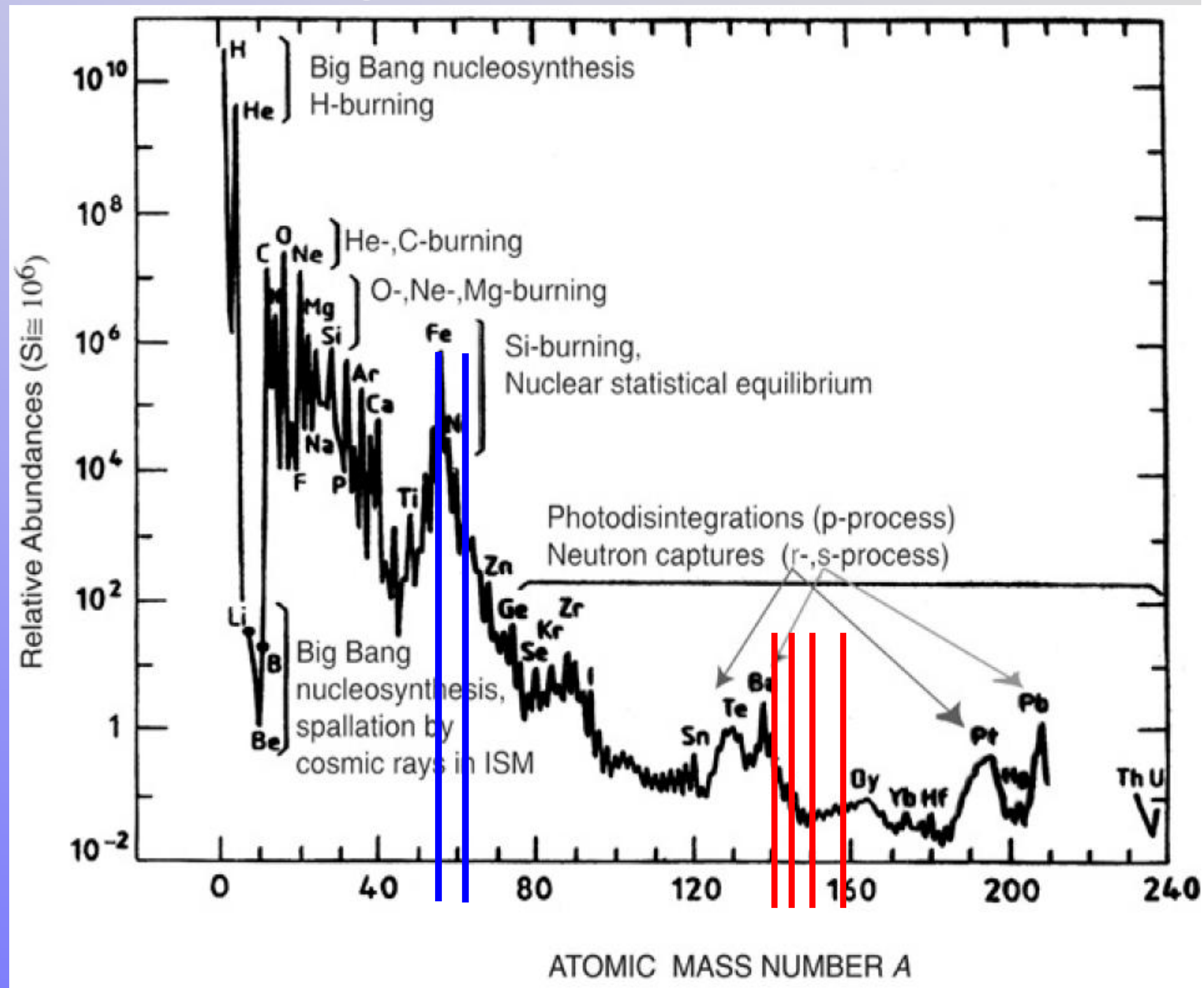
branching ratios

radiative lifetimes

Lanthanides (Rare Earth) & Transition Metals

- Gd, Nd, Pr, Sm are four lanthanide elements (amongst many) found in overabundance in chemically peculiar (CP) stars – requires supernovae nucleosynthesis

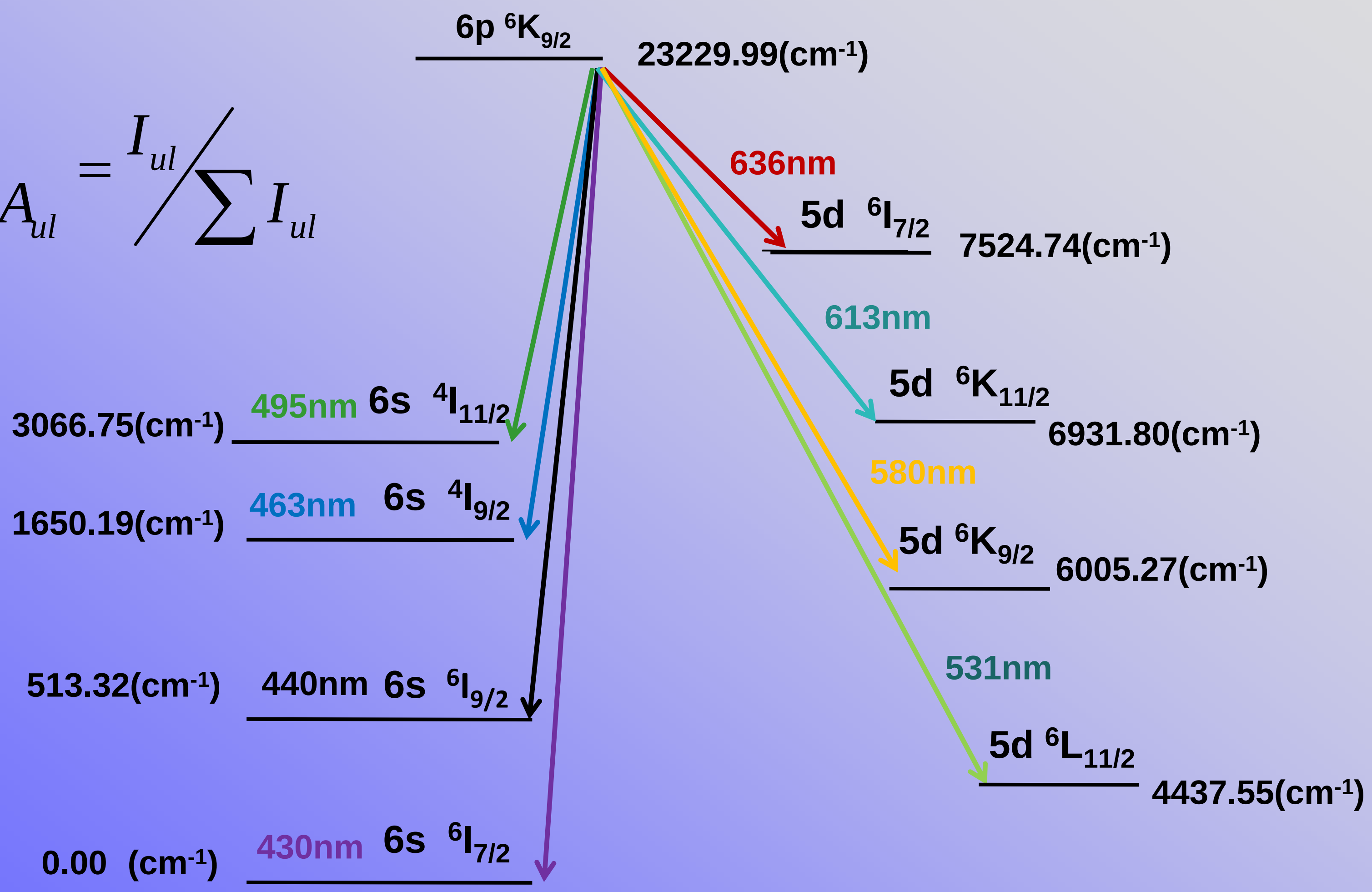
- Cu and Fe are two transition metals studied extensively in stellar spectra.



Metal-poor stars located in the galactic-halo region of our solar system show over-abundances of lanthanides relative to their iron abundances

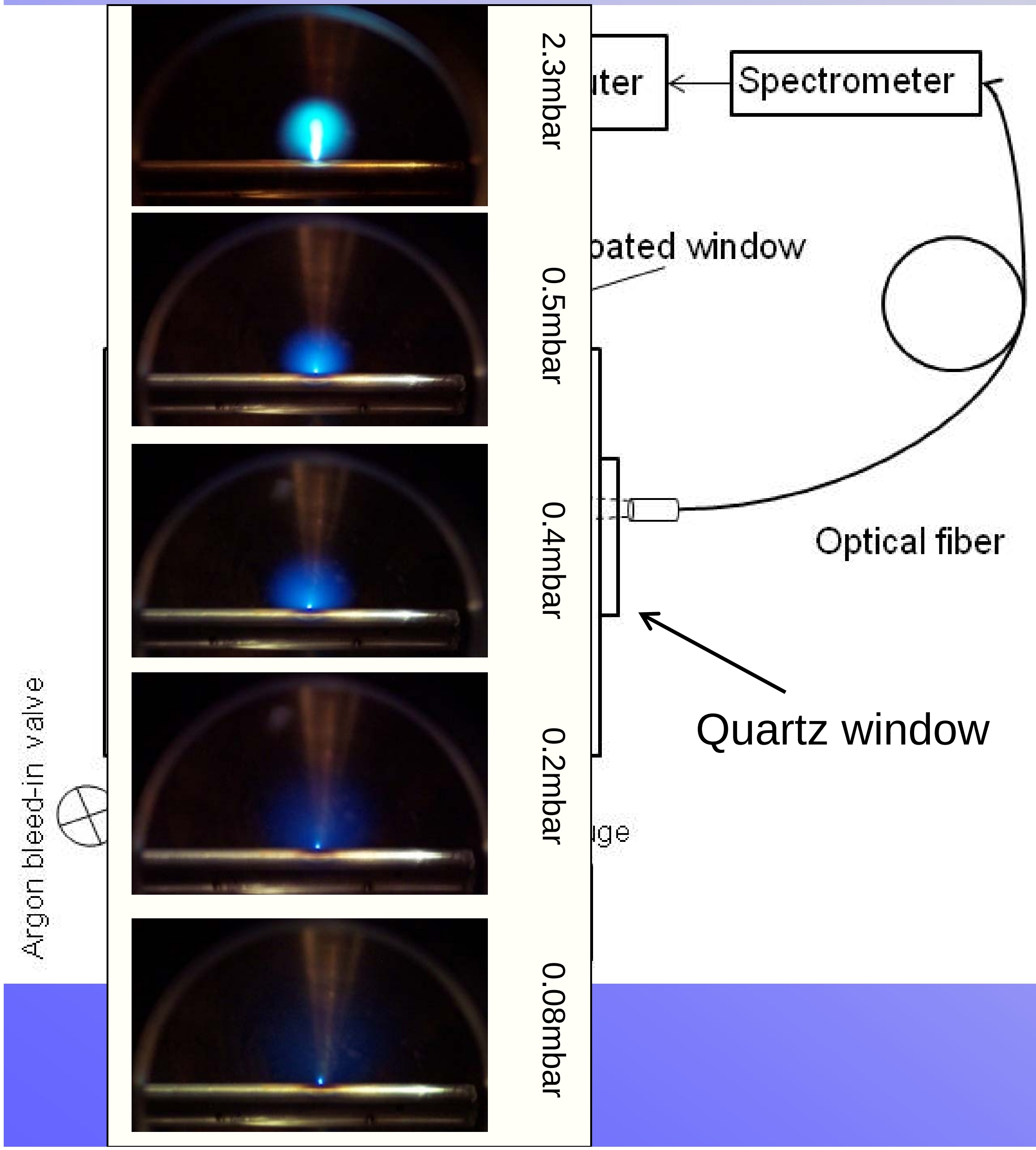
Branching Ratios

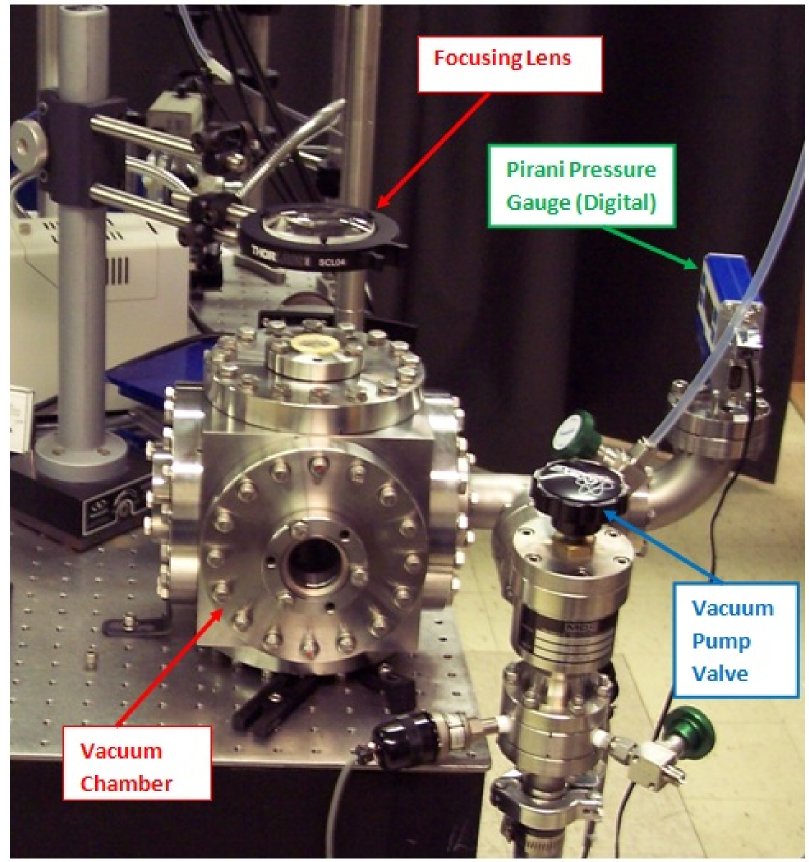
$$\beta_{ul} = A_{ul} \Big/ \sum A_{ul} = I_{ul} \Big/ \sum I_{ul}$$



In order to measure a branching ratio accurately, the relative intensities of all transitions out of a given energy level must be measured.

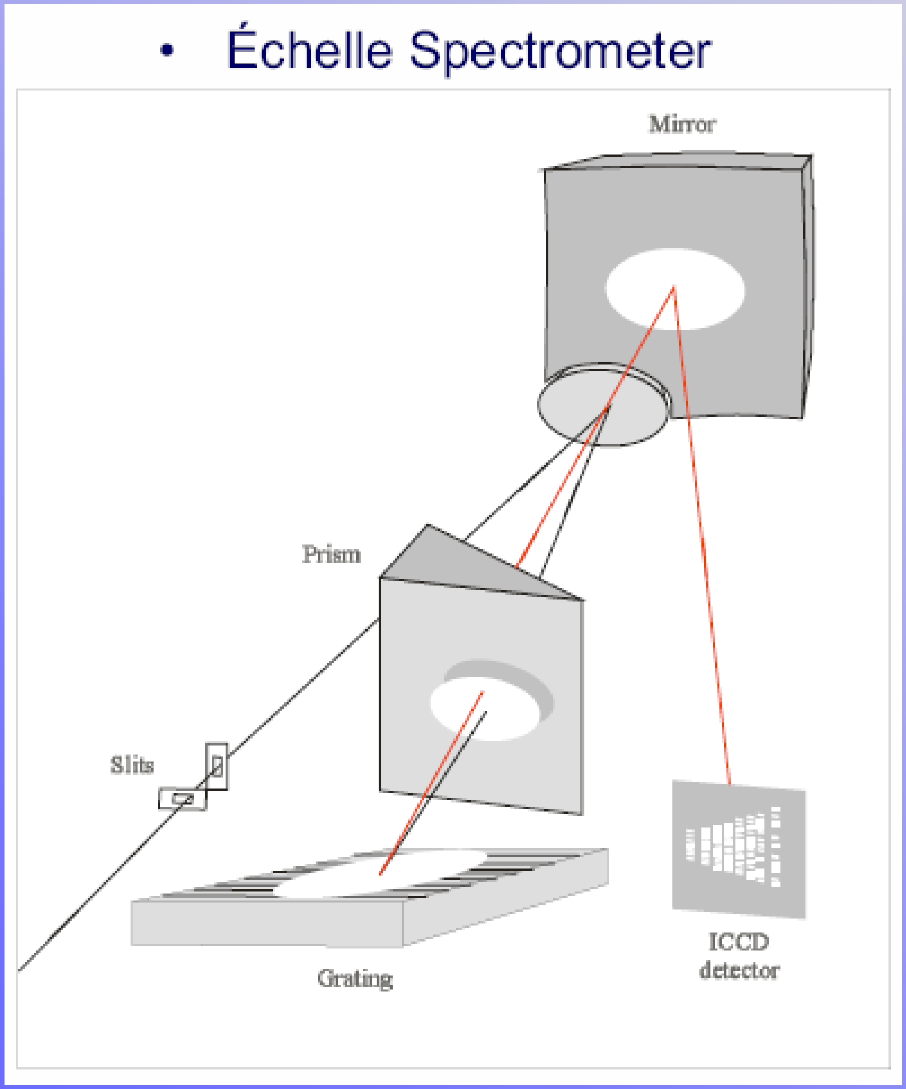
Branching Ratio Experimental Setup

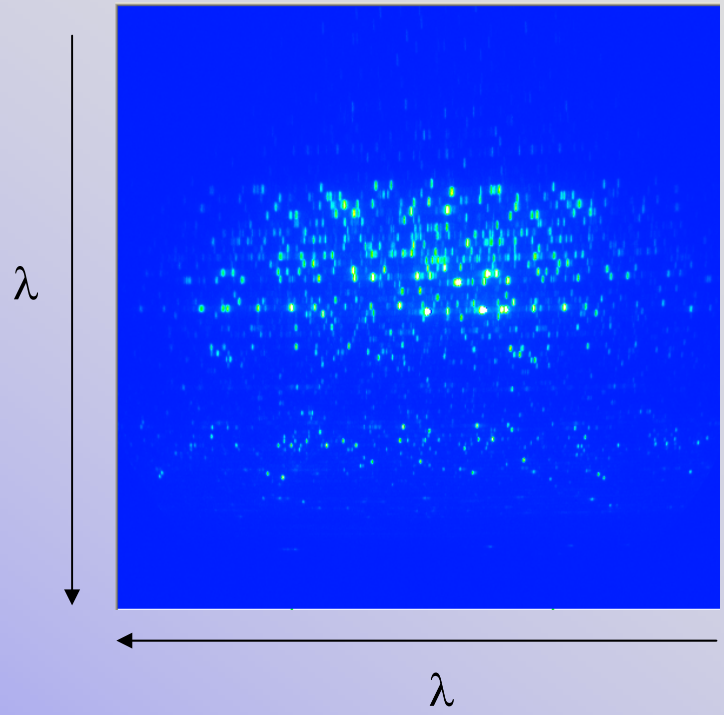




- 10 laser-induced plasmas are collected on the ICCD
- Then these 10 are averaged with another 10 to make 100 shots / spectrum

Èchelle Spectrometer





the entire spectrum obtained with one laser shot!

impervious to drift, shot-to-shot variations, other factors which may degrade relative measurements

Other Experimental Methods

<u>LIBS is more similar to the HCD method</u>

- but due to the use of the Echelle, is VERY fast (insensitive to variations in signal intensity)
- because the pulse laser source is so easy, any element can be studied easily
- multiple ionization states and neutrals produced
- environment of discharge (gas, pressure, etc.) easily controlled

Disadvantages

- overlap of lines
- no selective excitation

HCD lamp method

<u>levels excited in thermal discharge, FTS typically used to observe emission</u>

Advantages:

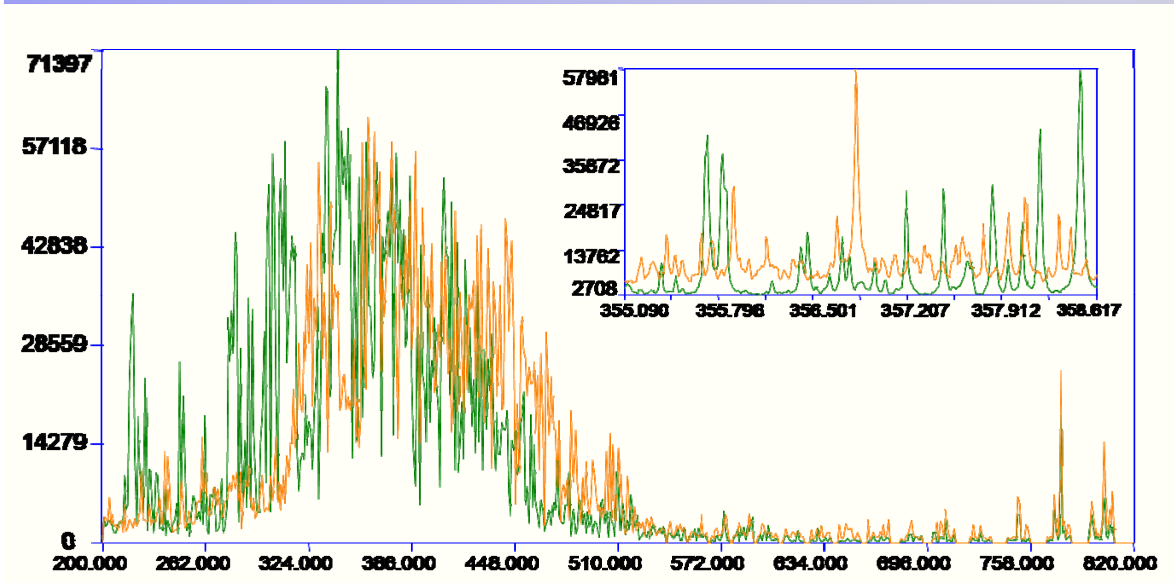
- all lines excited at once
- good signal to noise

Disadvantages

- slow (due to FTS)
- lamps must be specially made
- overlap of lines
- no selective excitation

Spectra

gadolinium (green) & samarium (orange)

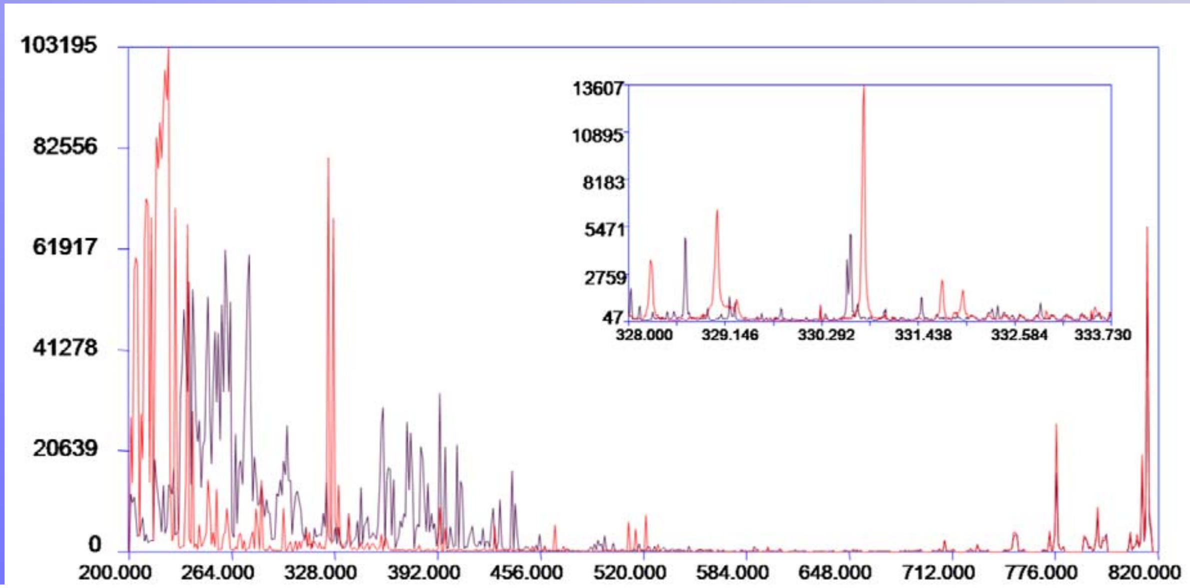


<u>thousands</u> of transitions (lines) measured simultaneously

(measure BG-subtracted integrated AUC)

iron (purple) and copper (red)

<u>hundreds</u> of upper energy states in neutral, singly-, and doubly-ionized species

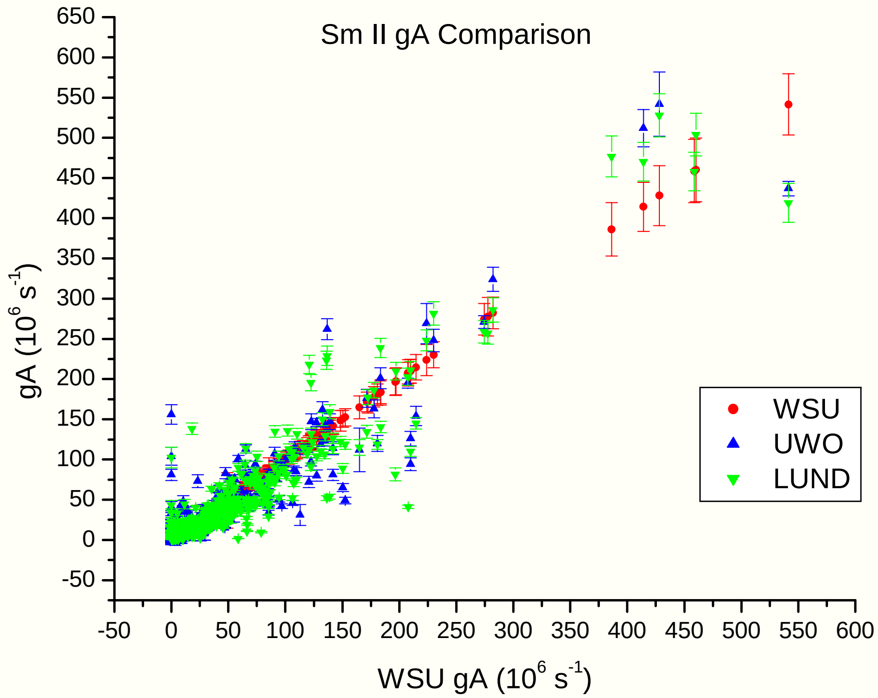


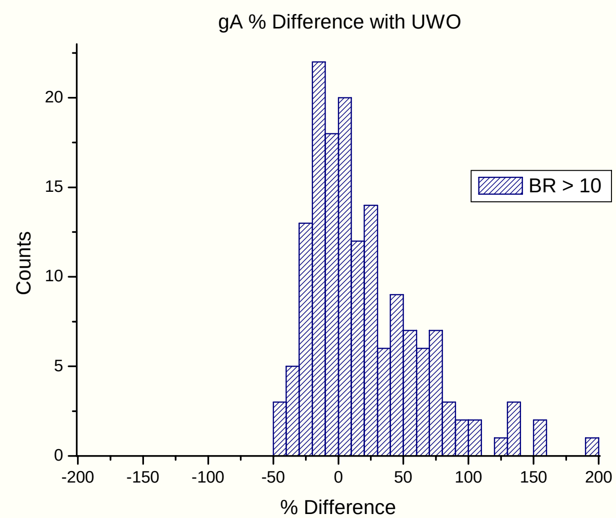
Uncertainties

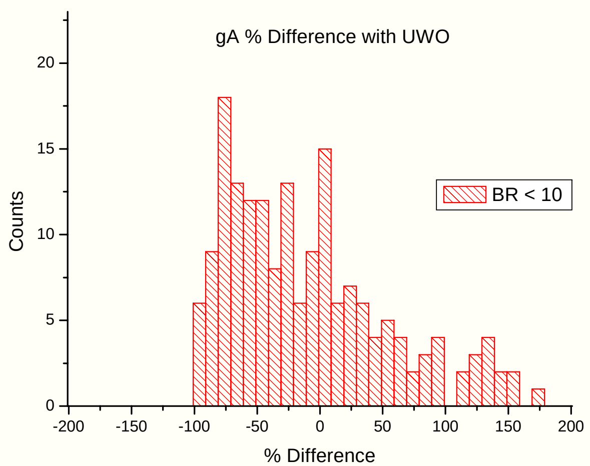
Source of Uncertainty	Uncertainty (%)		
	Branch Strength		
	Strong (>30%)	Moderate (10-30%)	Weak (<10%)
Systematic Uncertainty			
SCF – Deviation Between Fit and Data	3	3	3
SCF – Multiple Day Scatter	4.4	4.4	4.4
Systematic Total (added in quadrature)	5.3	5.3	5.3
Statistical Uncertainty			
Branch Uncertainty (combined)	4	5	18
Total Uncertainty (added in quadrature)	6.6	7.3	19

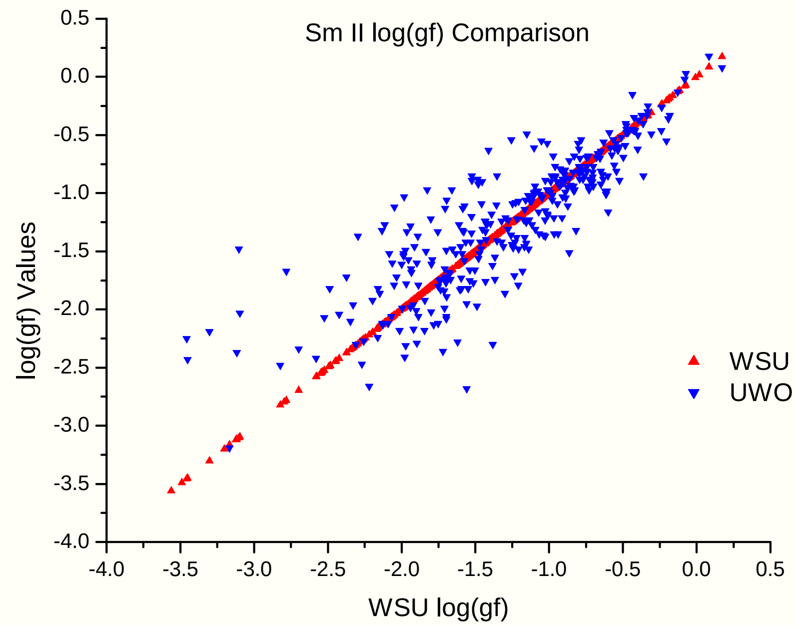
SCF = "spectral correction factor" the relative wavelength calibration of instrument

Sm II Results

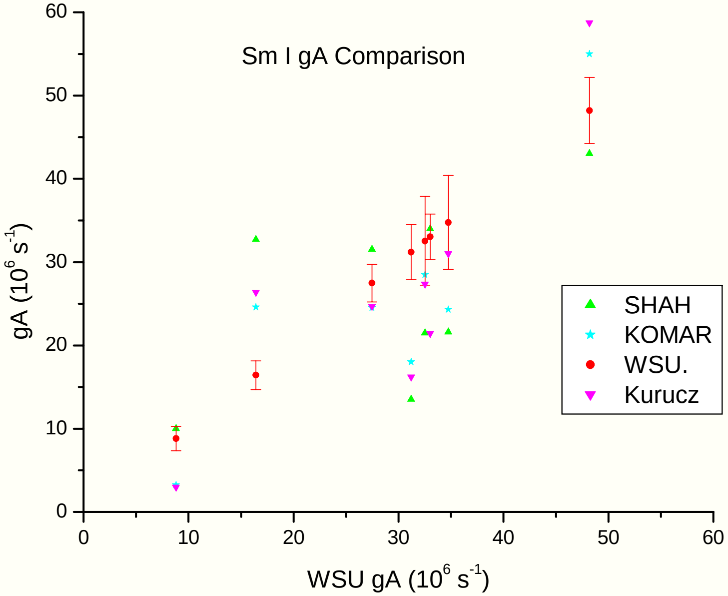


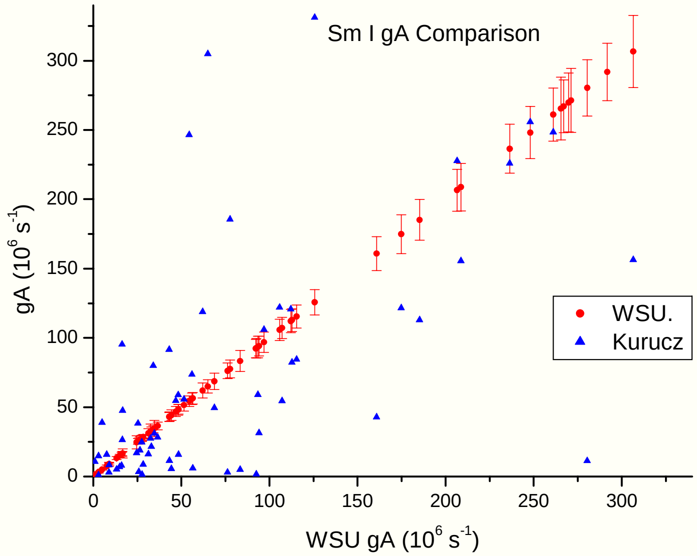




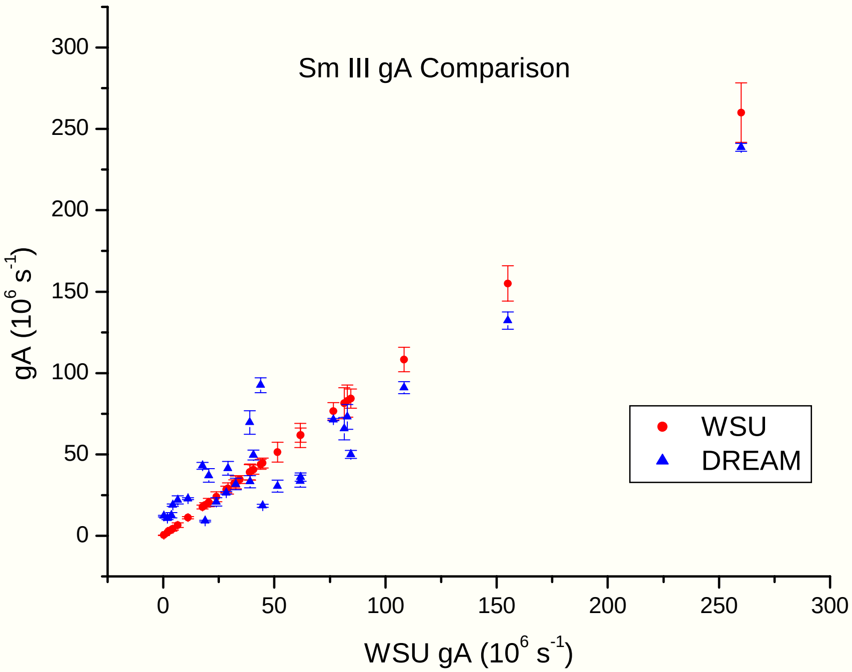


Sm I Results





Sm III Results



Conclusions

	# of Log(gf)s	# of Upper Energies
Cu I	192	68
Cu II	79	27
Fe I	776	108
Fe II	1,453	108
Gd I	587	113
Gd II	480	164
Gd III	40	3
Nd I	121	93
Nd II	460	46
Nd III	19	1
Pr I	19	19
Pr II	551	87
Pr III	7,200	392
Sm I	137	70
Sm II	713	115
Sm III	49	17
Total	12,876	1,431

- **LIBS is capable of exciting transitions in neutral, singly-ionized, and doubly-ionized states in lanthanides and transition metals, and of providing accurate radiative parameters.**
- **Observing hundreds of transitions simultaneously can lead to blended lines which are sometimes unresolvable.**
- **LIBS could be a significant technique for contributing rapid, large scale or single "measurement on demand" radiative parameters of interest in astrophysics, atomic physics and plasma physics.**

All credit goes to ***Dr. Caleb Ryder*** who did this work (his Ph.D. dissertation)

Mr. Russell Putnam who is doing a co-op placement with me this summer analyzing this data

Thanks to ***NSERC*** Discovery grant and ***University of Windsor*** for funding Russell's work and ***Wayne State University*** for funding Caleb's work.

NSERC CRSNG

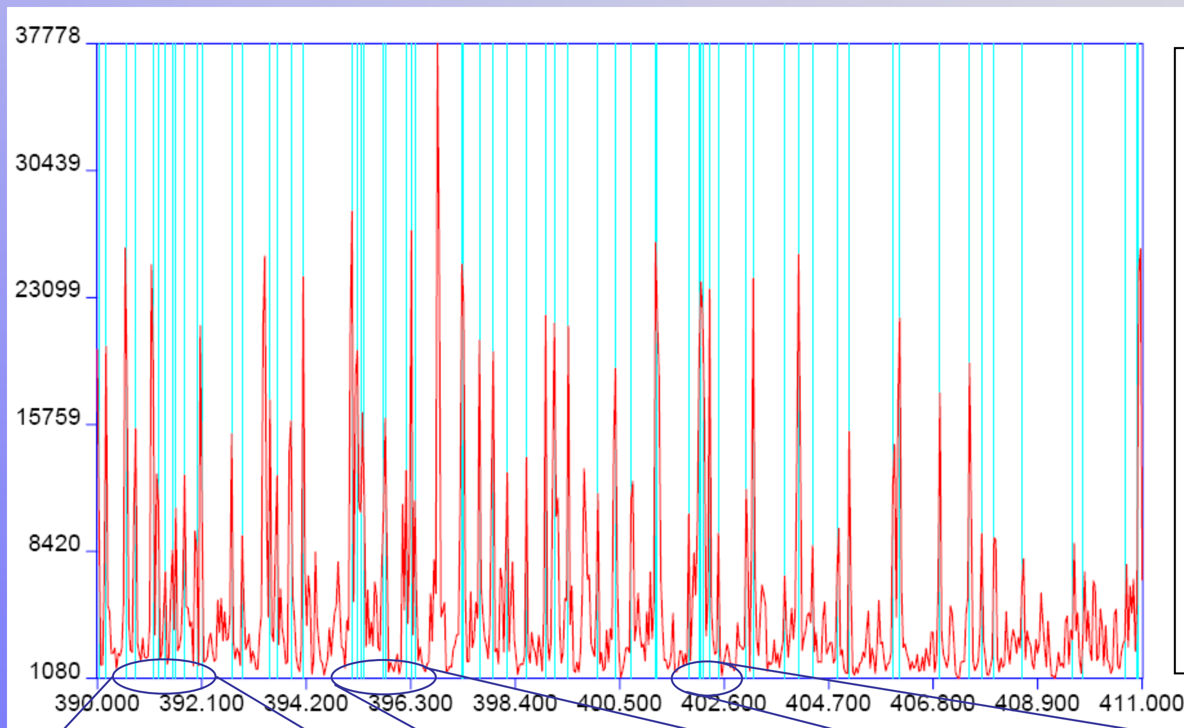
University of Windsor

WAYNE STATE UNIVERSITY

More information can be found at my website:
http://www.uwindsor.ca/rehse/

The Rehse Group
at the University of Windsor
Biomedical Optics, AMO, & Medical Physics

Thank you so much for your attention!



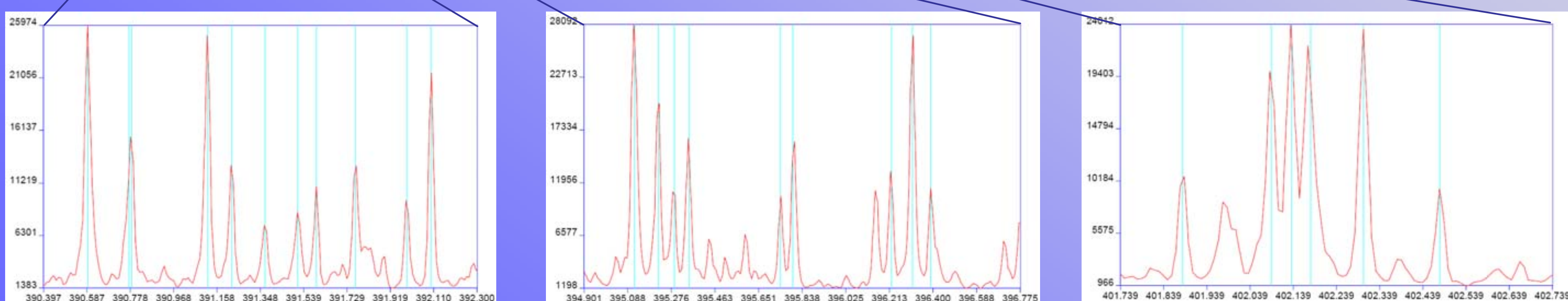


Figure 5: A typical section of a neodymium laser-induced plasma spectrum (390.0 – 411.0 nm). Vertical turquoise lines denote the wavelengths of known Nd I and Nd II lines. Insets: zoomed in regions of the spectrum showing clearly resolved peaks, demonstrating the resolution of the Èchelle spectrometer is sufficient even in spectrally dense regions of the spectrum.