

The Wisconsin Atomic Transition Probability (*WATP*) Program

Develop and apply new methods for measuring $\log(gf)$ s:

(1) with well understood & controlled systematic uncertainties.

(2) & high efficiency, e.g. accurate $\log(gf)$ s for many lines of neutral & ionized elements.

Wavelengths were known well enough in most cases.

Key advantages:

- All $\log(gf)$ s are normalized with radiative lifetimes from our Laser Induced Fluorescence (LIF) expt. & are both accurate and precise to $\leq \pm 5\%$.
- The *WATP* program developed a great atom/ion beam source for LIF. (The word “great” is not an exaggeration.)
- The (now defunct) SRC gave the *WATP* program its own synchrotron radiation beamline for 25 yrs.
- Working with Chris Sneden & John Cowan was a boost.

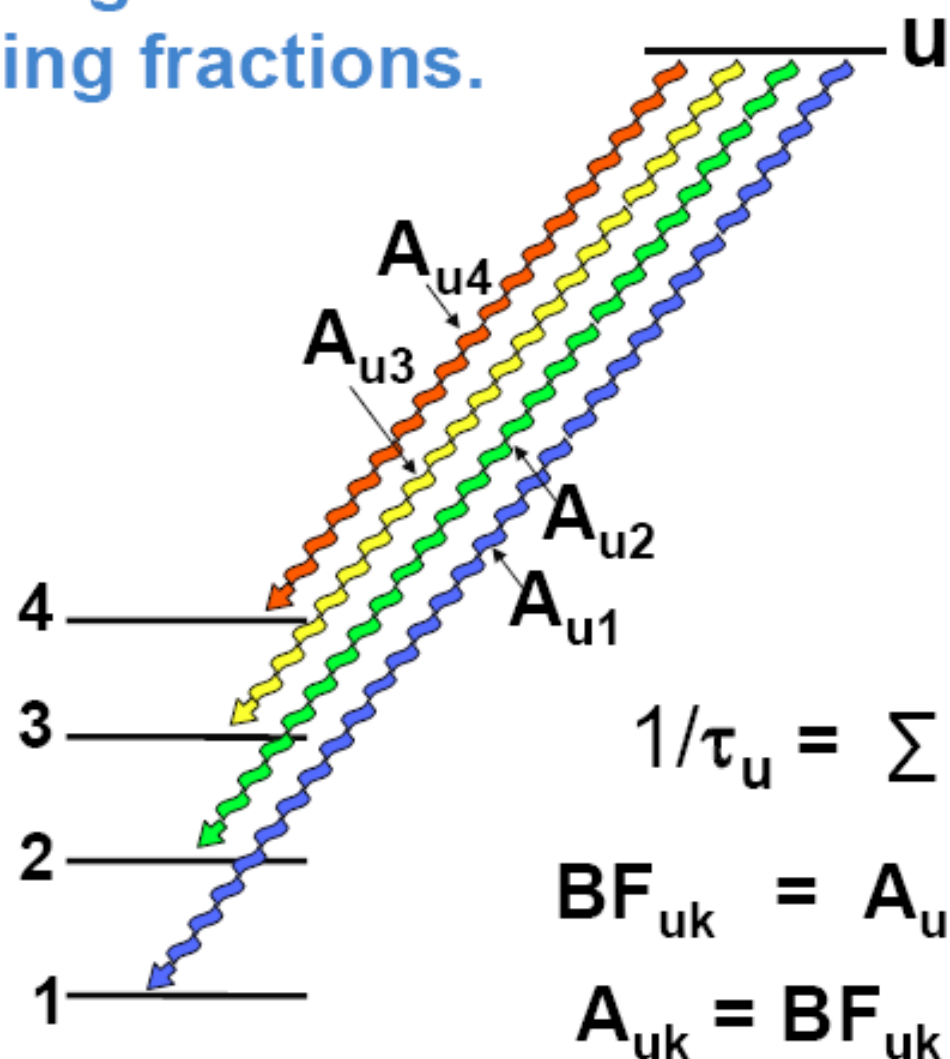
Key advantages:

- Chris & John gave us an edge because they suggested the most important atoms and ions & because they taught us some astrophysics.
- Rare earths are accessible to grnd based observations
- Eu is primarily an *r*-process element & was priority 1.
- La is primarily an *s*-process element & was priority 2.
- Weak, unblended UV ion lines with low E.P. for the Fe-group are important.

Key Challenges:

- Mapping the Galactic Chemical Evolution
- Understanding the limits of 1D/LTE photospheric models (NLTE models require a huge number of accurate and precise rate constants & few are available) What is a Highly Reliable Line (*HRL*)?
- Is there more than one *r*-process site? There is no doubt that a-LIGO/VIRGO has a site.

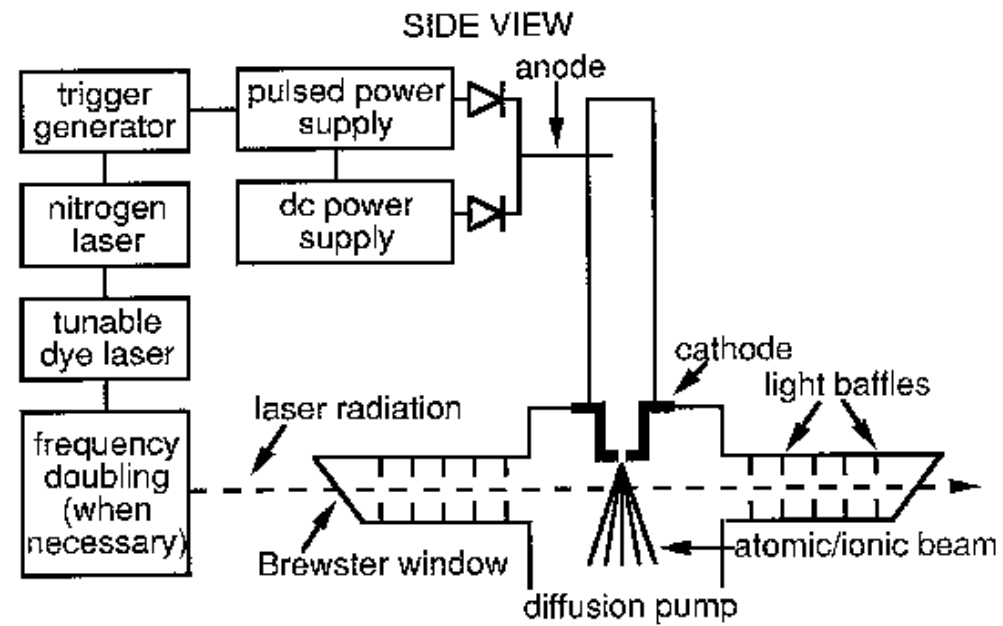
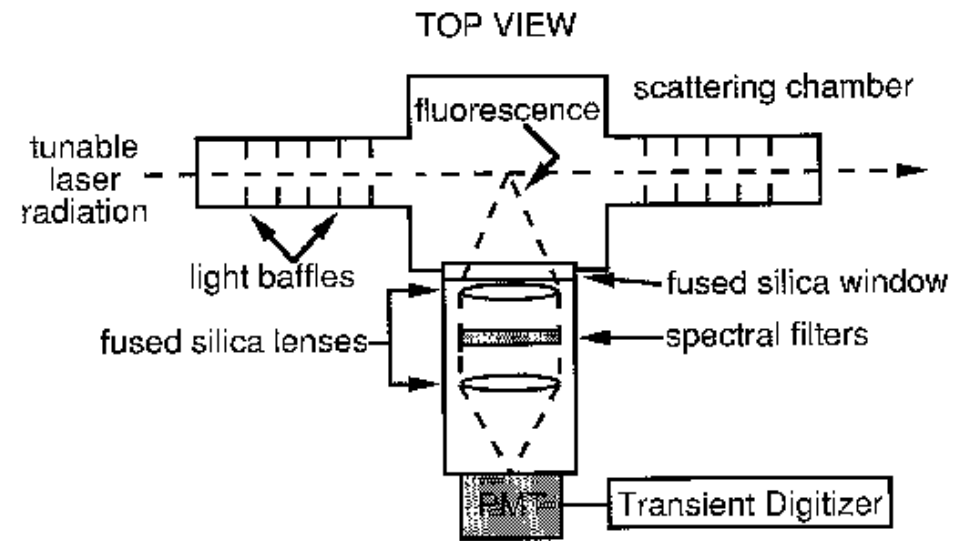
Transition probabilities are determined by combining radiative lifetimes and branching fractions.



$$1/\tau_u = \sum A_{ui}$$

$$BF_{uk} = A_{uk} / \sum A_{ui}$$

$$A_{uk} = BF_{uk} / \tau_u$$



The *WATP* program atom/ion beam source works with all elements. Non-metallic elements, e.g. B, are introduced as alloys.

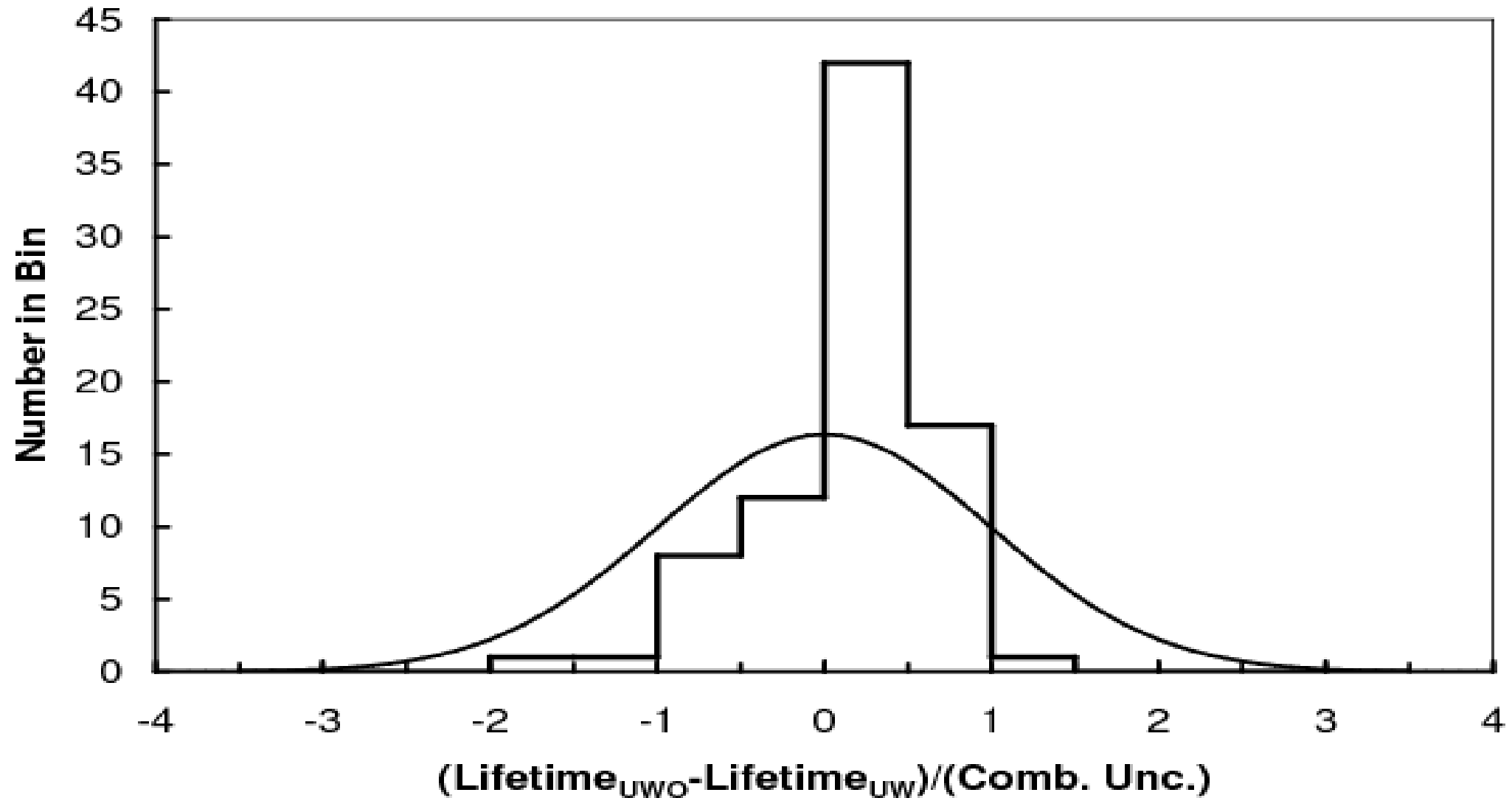
Lifetimes have $\pm 5\%$ quoted uncertainty which is conservative.

Branching fractions are more challenging due to radiometric calibration over large wavelength ranges, due to optical depth of stronger lines, and due to blending, and other effects.

Search for possible systematic errors in *WATP* radiative lifetimes

- Radiation trapping? Vary the beam density
- Collisional quenching? Throttle the pump
- Zeeman quantum beats? $B = 0$ (~ 10 milliGauss) for short lifetimes, $B \sim 25$ Gauss for long lifetimes
- Ultimate end-to-end test: Periodic re-measurement of benchmark lifetimes in He, Be,....

Comparison of Sm II lifetimes UWO vs UW



Clearly, LIF experiments can provide accurate, absolute radiative lifetimes.

Ab-initio theory provide good branching ratios in simple spectra, experiments provide good branching ratios in complex spectra.

Advantages of an FTS:

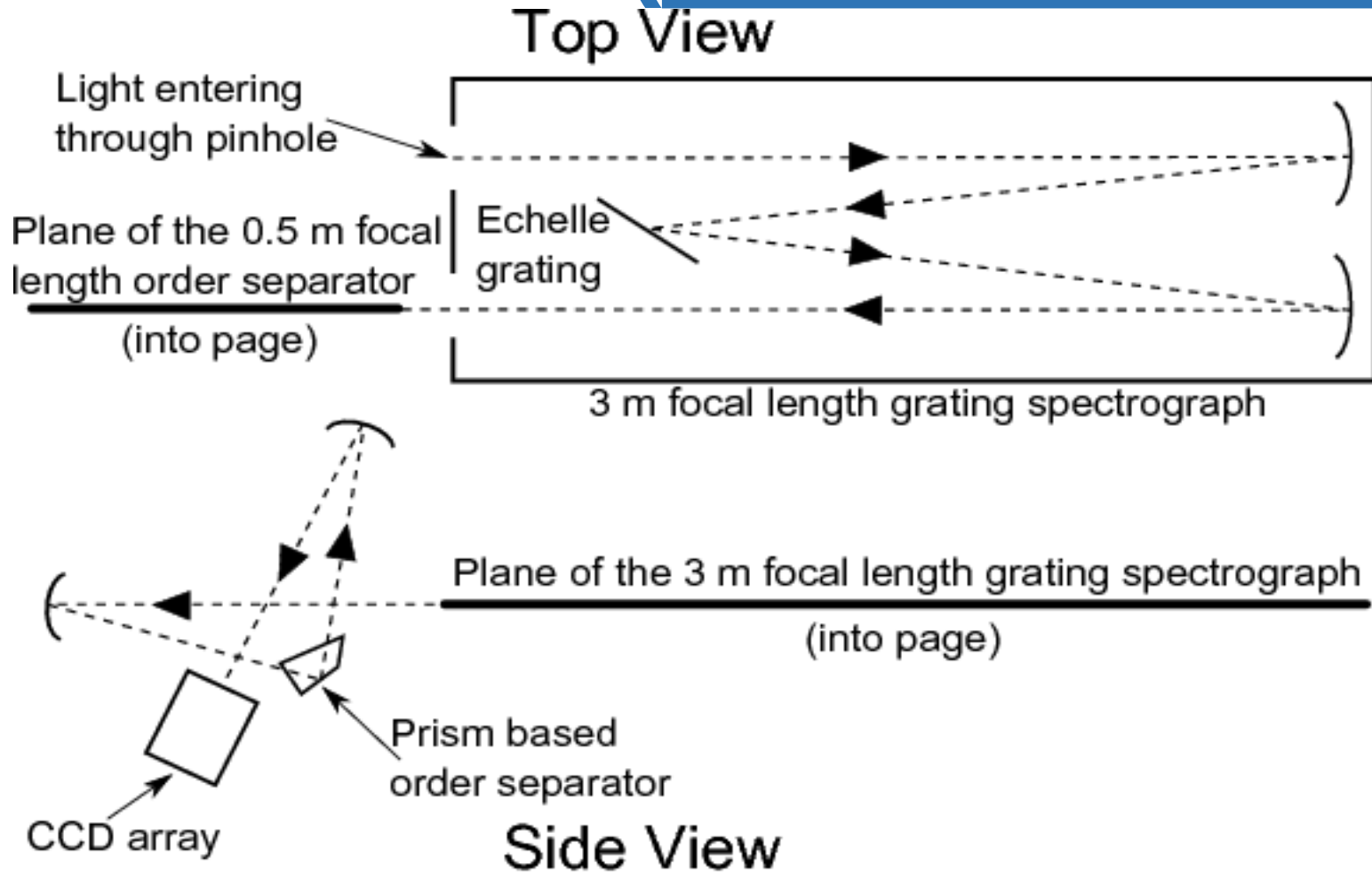
Kitt Peak (James Brault), NIST, Lund

- Very high spectral resolving power
- Excellent absolute wavenumber accuracy
- Extremely broad spectral coverage
- Very high data collection rates
- Insensitive to source intensity drifts
- Large etendue (etendue = solid angle x area = grasp)
- **Ward Whaling (Caltech) relative radiometric calibration of FTS**

Fe-group: *HRL* UV lines to ground & low metastable levels (*HST-STIS* data needed)

- Lightly populate levels of the neutral atom and excited levels of ion can be far from *LTE*
- Primary reservoir levels (low E.P. lines) are in *LTE*
- Multiply ionized Fe-group species cannot persist in a neutral H photosphere due to charge exchange with H
- The primary reservoir levels are the ground & low metastable levels of the ion. Such levels have most of the photospheric Fe-group material.

Fe-group Progress: UV cross dispersed echelle (no multiplex noise)



On to the IR

- HgCdTe detector arrays have opened the IR
- NASA's JWST has HgCdTe arrays but no high resolution spectrometer
- NASA's IRTF on Mauna Kea has HgCdTe arrays & iShell (high resolution spectr.)
- NASA's UVOIR will likely have such arrays
- The IR is important because interstellar dust is more transparent, the Galactic bulge is accessible