Targeting Inaccurate Atomic Data In Warm Ejecta

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This is work performed in team including:

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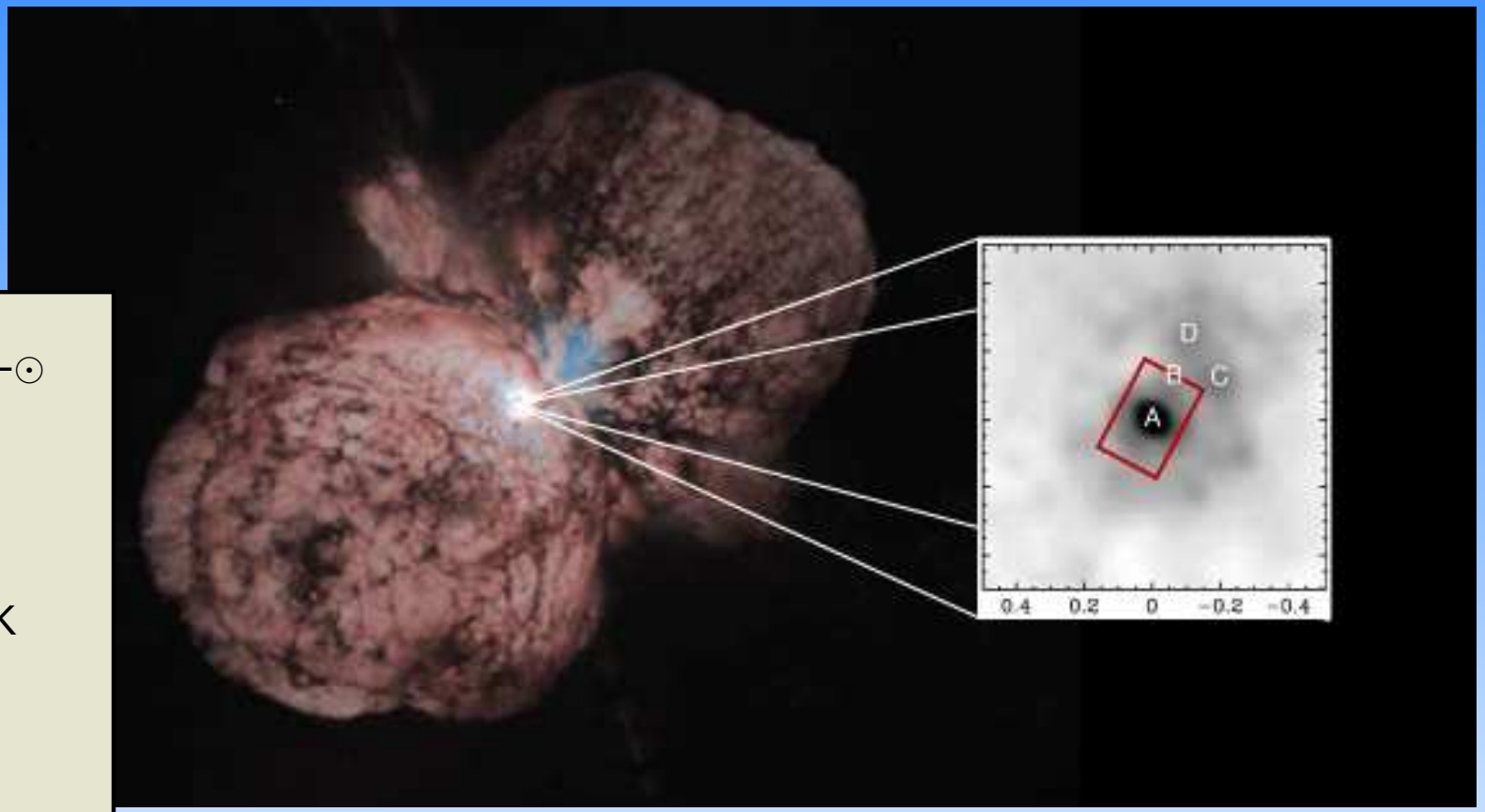
R. Blackwell-Whitehead	**Imperial Collage, UK**

1 – Why bother about η Car?

- A star in its late evolutionary state. Feedback of processed material to the ISM.
- Clues about other extreme objects such as Supernovae Impostors, Hypernovaes or Gamma Ray Bursters. The η Car ejecta is similar to local ejecta of GRB progenitors.
- Massive ($\sim$100 $M_\odot$) and Luminous ($\sim 5\times10^6$ $L_\odot$). Close to/exceeding the Eddington limit.
- An astrophysical laboratory. Possible to target where new accurate atomic data is needed.

2 – η Car Geometry



Luminosity: 5×10^6 $L_\odot$

Mass: $\sim$100 $M_\odot$

T (η Car): 15 000 K

T (η Car B): 37 000 K

Distance: 2300 pc

Size: $18''$ = 0.2 pc

C and O $\sim$0.01 of Solar

N $\sim$10 of Solar

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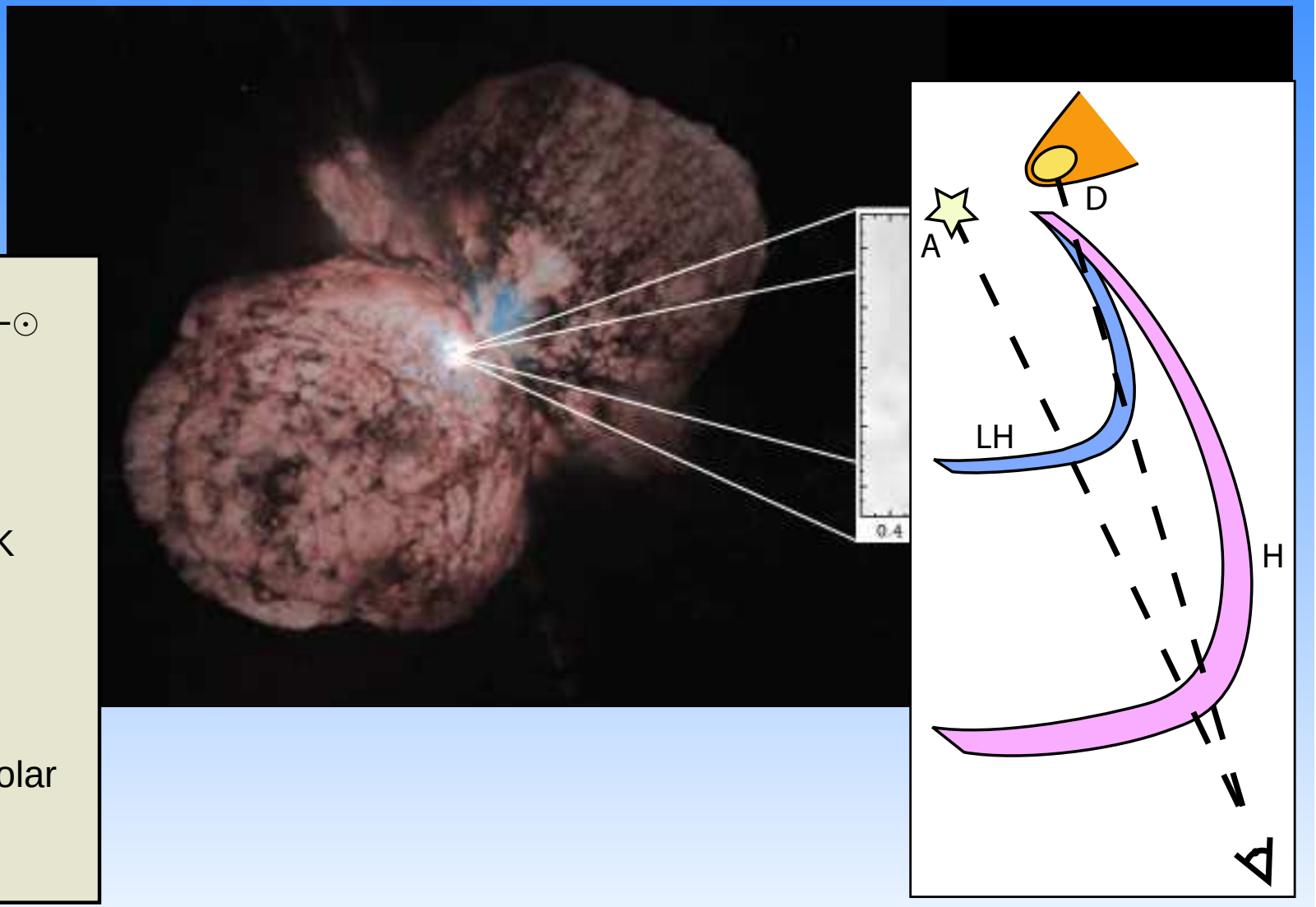
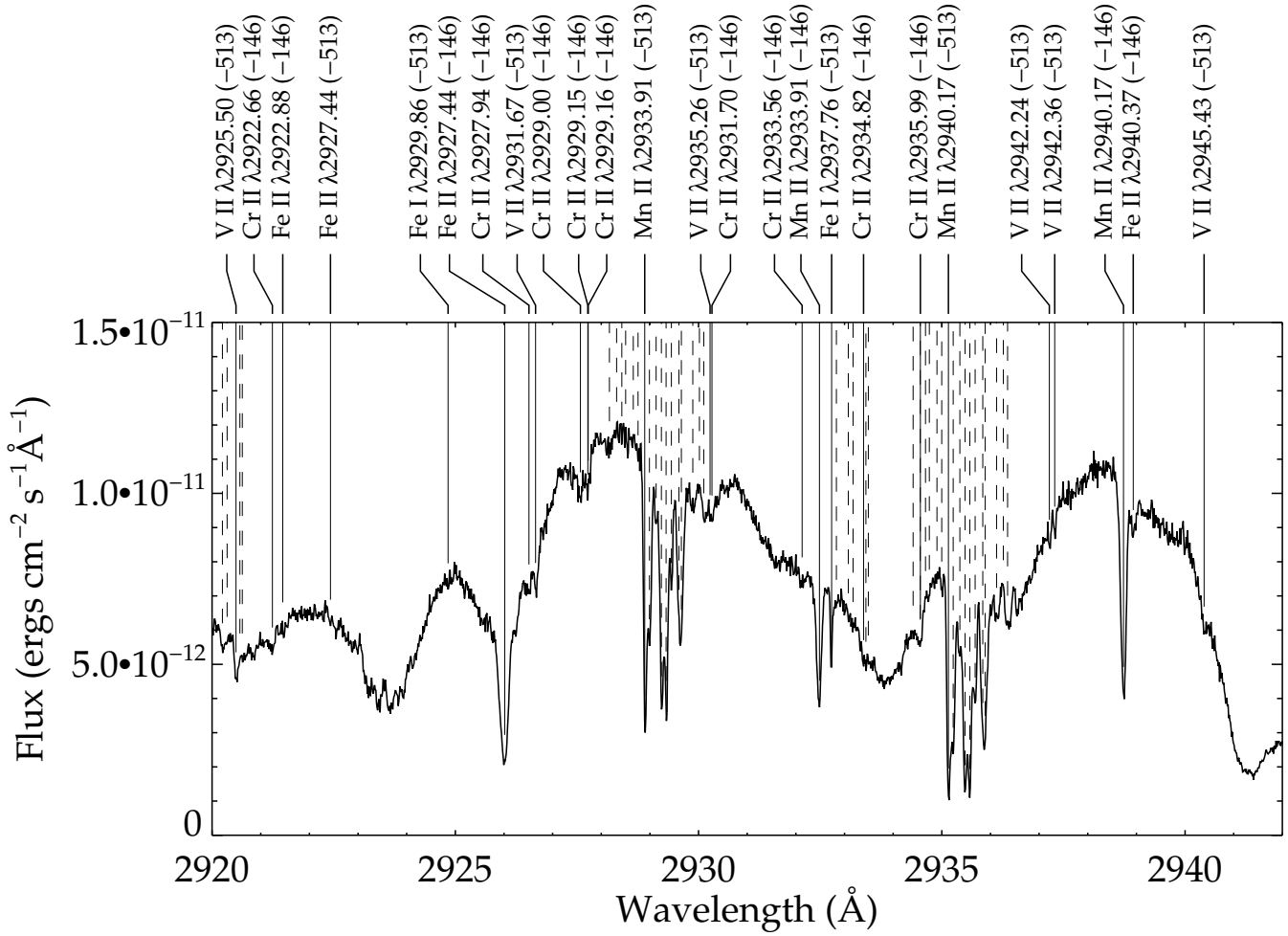
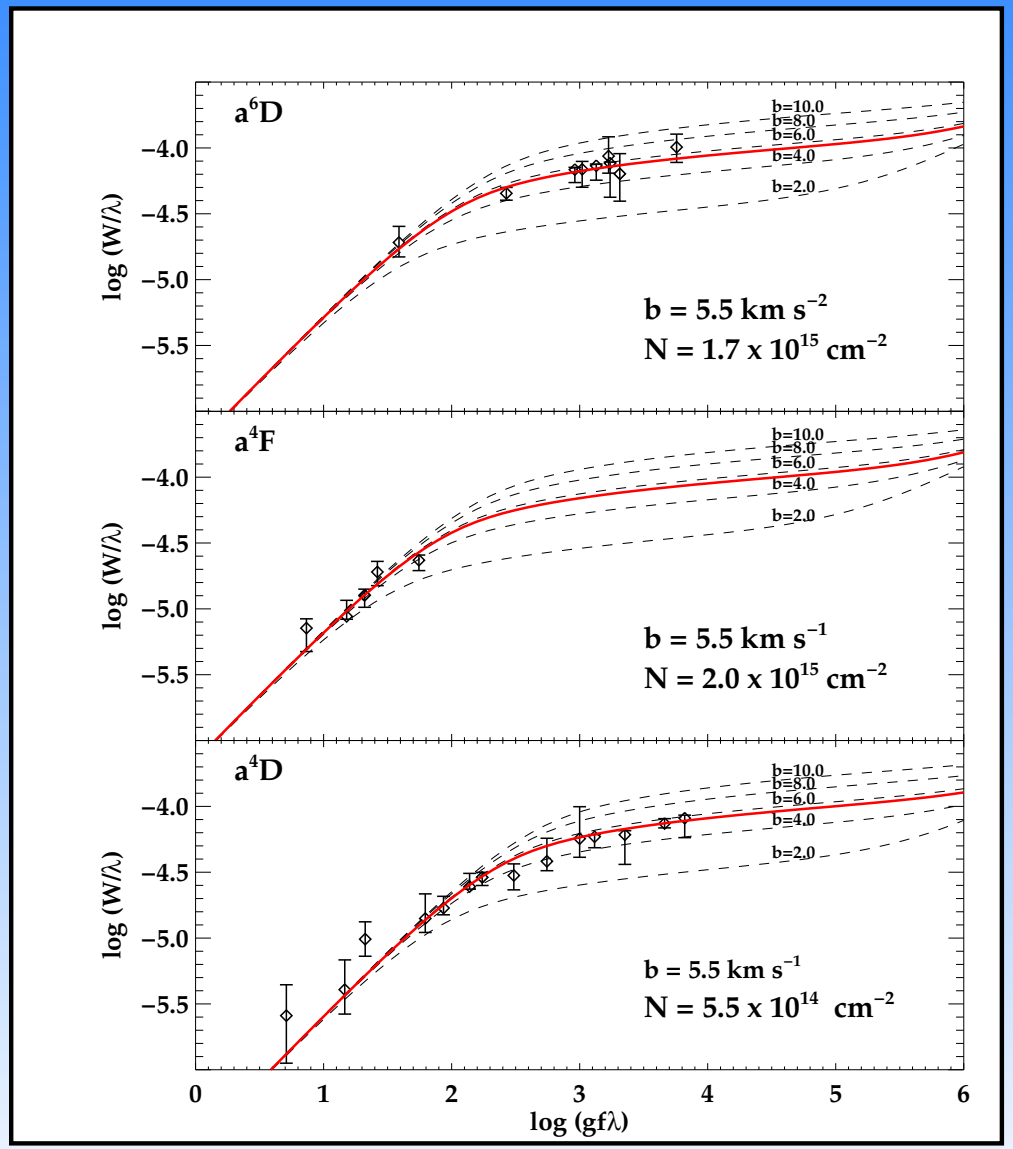


3 – *HST*/STIS High-Resolution Spectrum



4 – Deriving Ejecta Parameters: Standard Curve-of-Growth



5 – Photo-Ionizing Modeling: CLOUDY

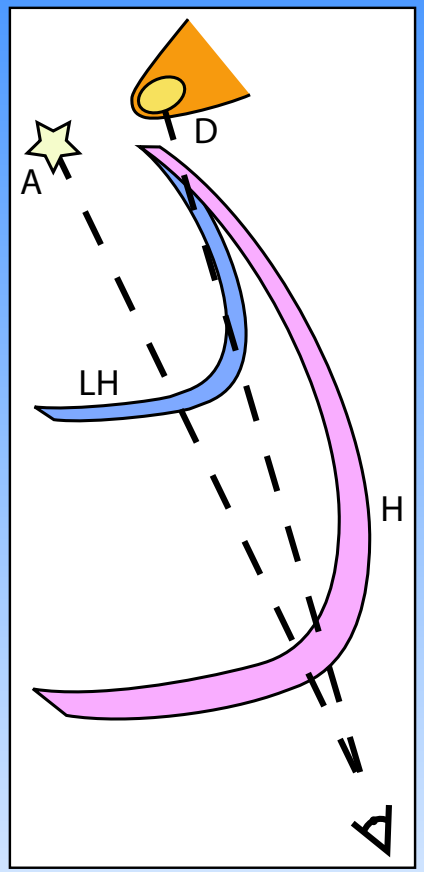
Input Parameters:

Radiation field – Kurucz 15 000 K

Luminosity – 10^{40} erg s^{-1}

C and O $\sim$0.01 of Solar

N $\sim$10 of Solar

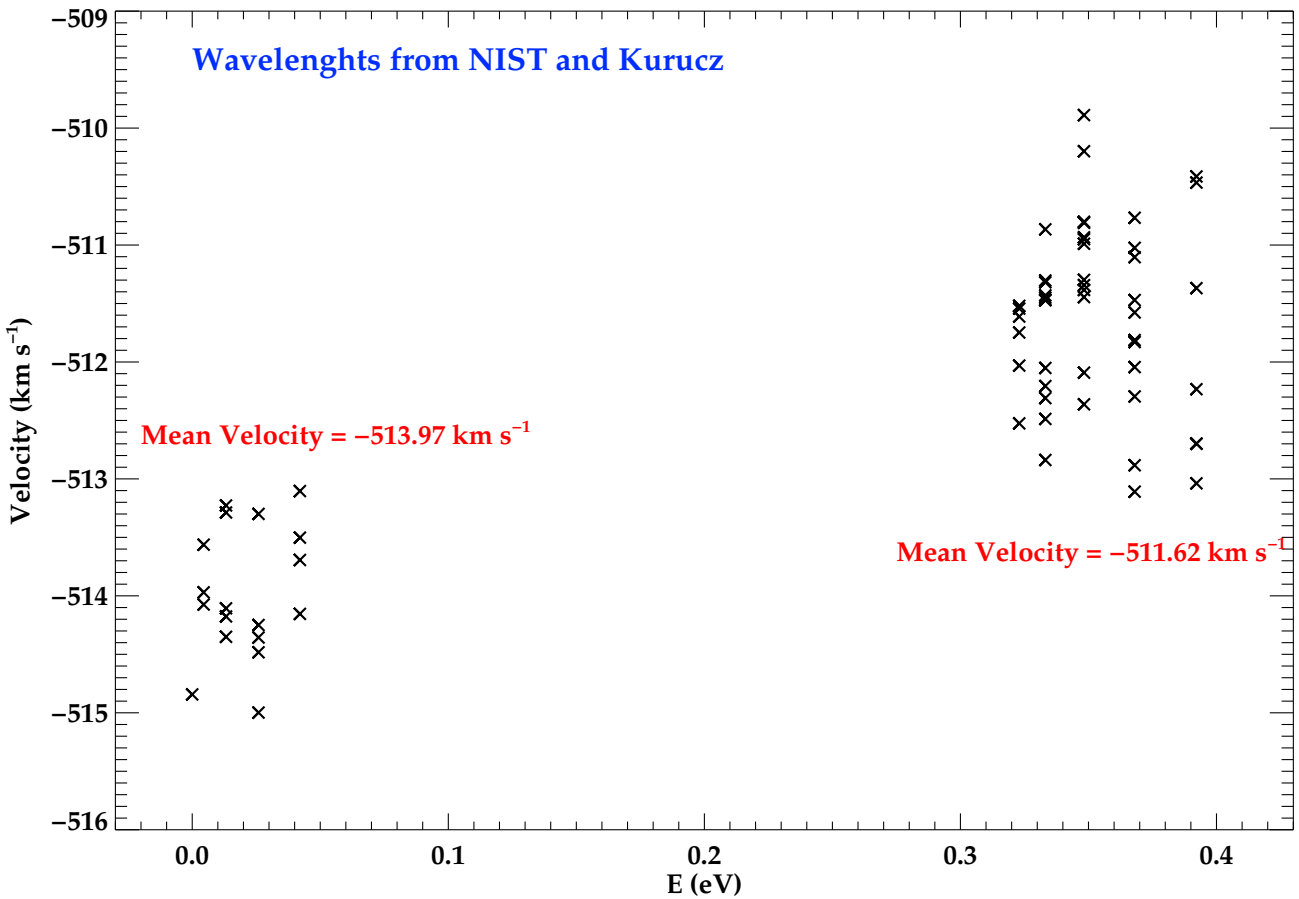


Results:

	-146 km s^{-1}	-513 km s^{-1}
T_{kin}	5000$-$6400 K	760 K
Electron Density (n_e)	10^7 cm^{-3}	10^{7-8} cm^{-3}
Turb. Vel. (v_ξ)	5.5 km s^{-1}	2.2 km s^{-1}
Distance	$\sim$1300 AU	$\sim$10 000 AU

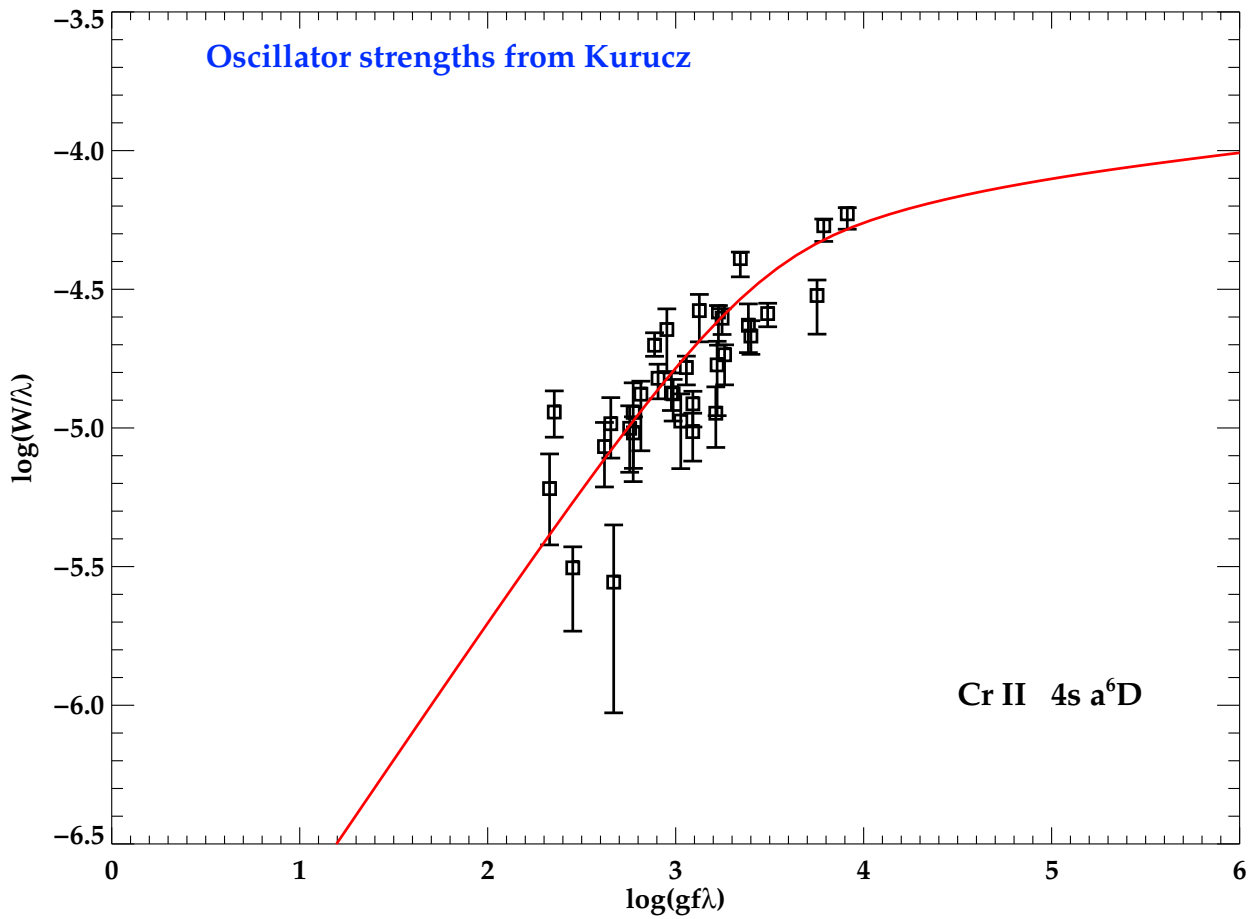
6 – Inaccurate Wavelengths

Velocity Measurement Using the V II Spectrum



7 – Inaccurate Oscillator Strengths

Column Density Measurements Using the Cr II Spectrum

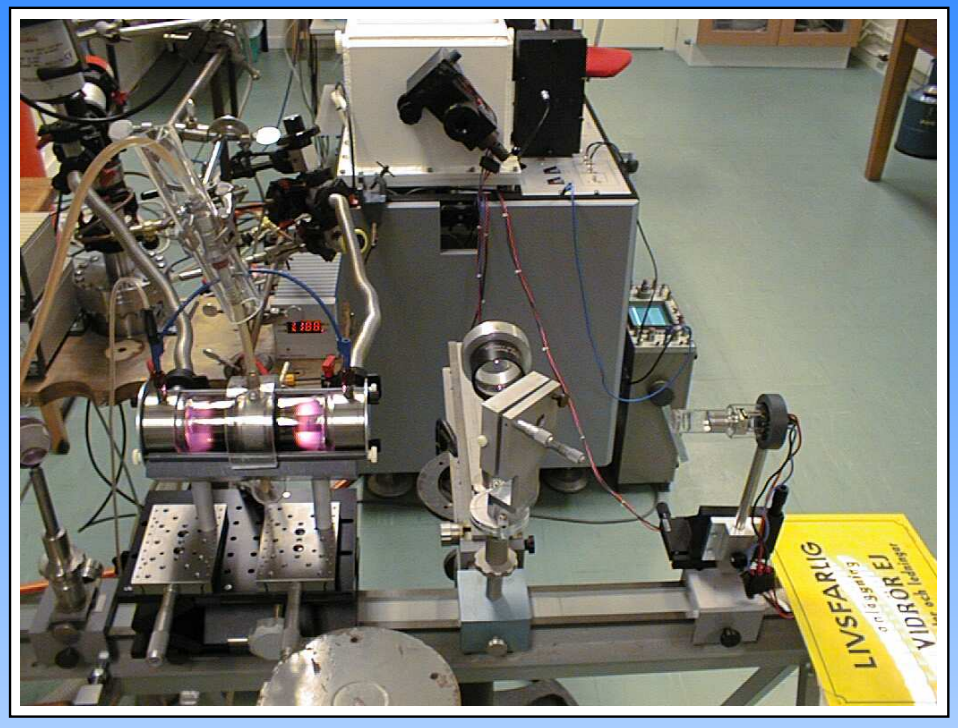


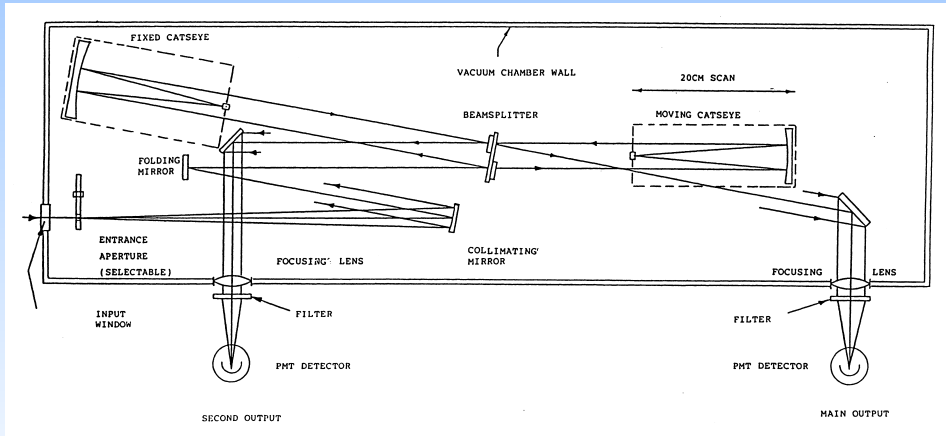
8 – Improving Atomic Data ⇒ Laboratory Spectroscopy

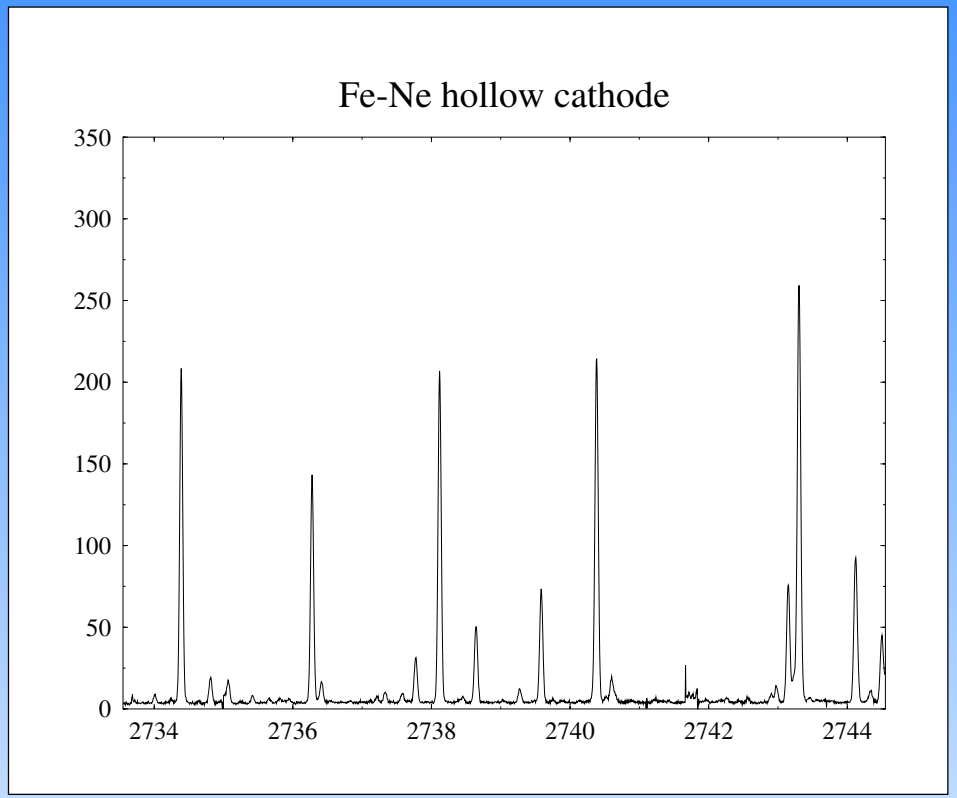
- Accurate Wavelengths from high-resolution Fourier Transform (FT) spectra. Internal wavelength calibration using carrier gas transitions, with well known wavelengths. The wavenumber uncertainty in the FT spectrum is between 0.003 – 0.030 cm^{-1}

- Oscillator strength measurements - combining Branching Fractions from FT spectra with results from Laser Induced Fluorescent (LIF) lifetime measurements.

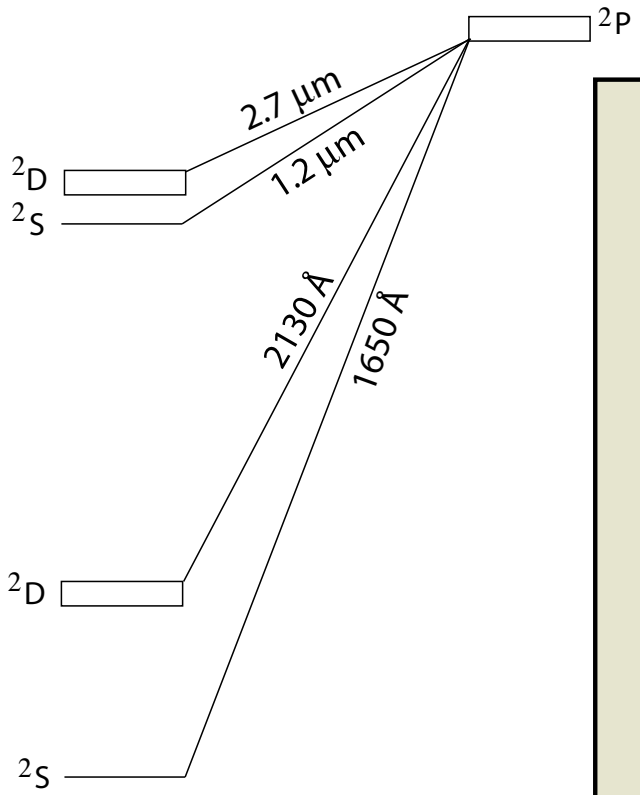
9 – The Chelsea Instrument FT500







10 – Branching Fractions



$$f = 1.499 \times 10^{-16} \frac{g_i}{g_k} \lambda^2 A_{ik}$$

$$A_{ik} = \frac{(BF)_{ik}}{\tau_i}$$

$$(BF)_{ik} = \frac{A_{ik}}{\sum_k A_{ik}}$$

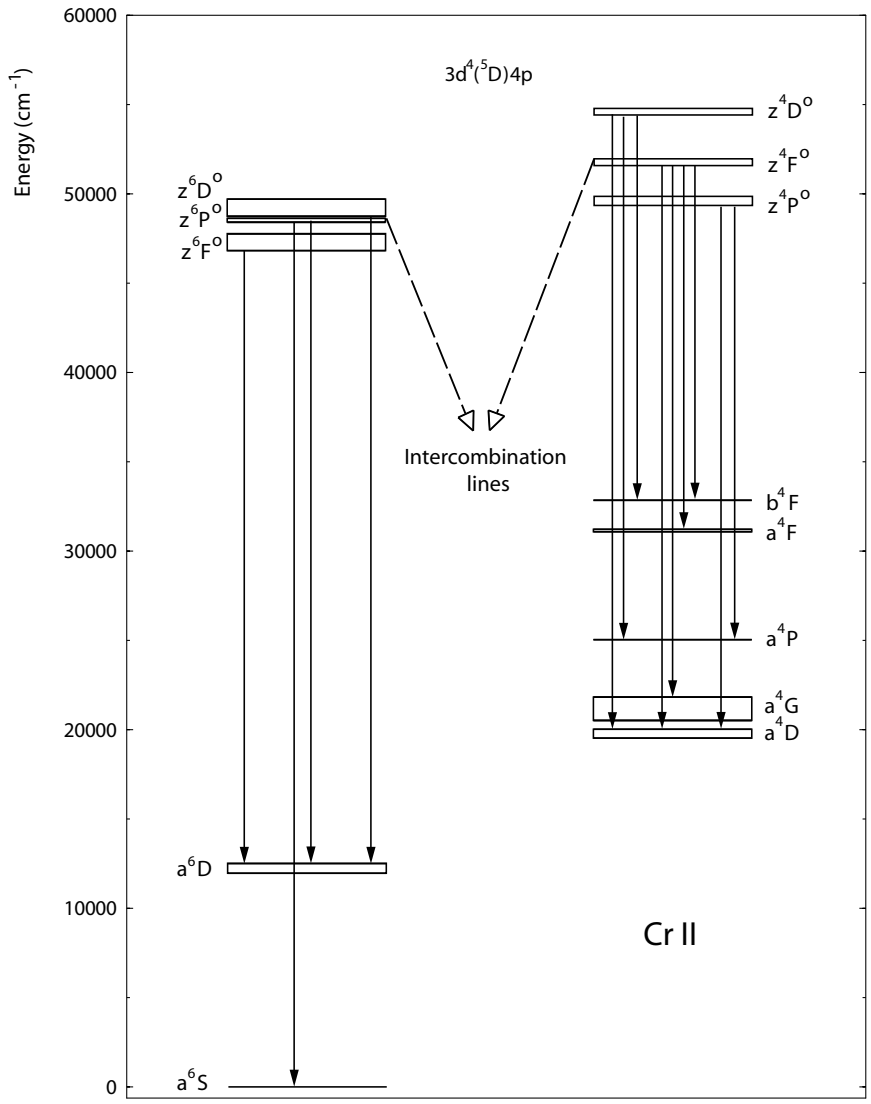
But since $I_{ik} \propto N_i g_i A_{ik}$ then

$$(BF)_{ik} = \frac{I_{ik}}{\sum_k I_{ik}}$$

1) **Measure spectral line intensities in FT spectra**

2) **Correct for the instrumental response.**

11 – The Cr II Energy Level Diagram

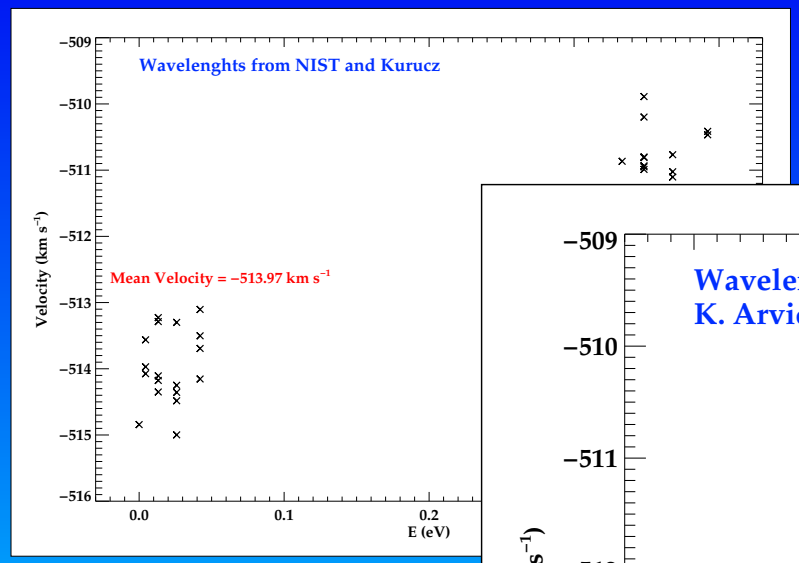


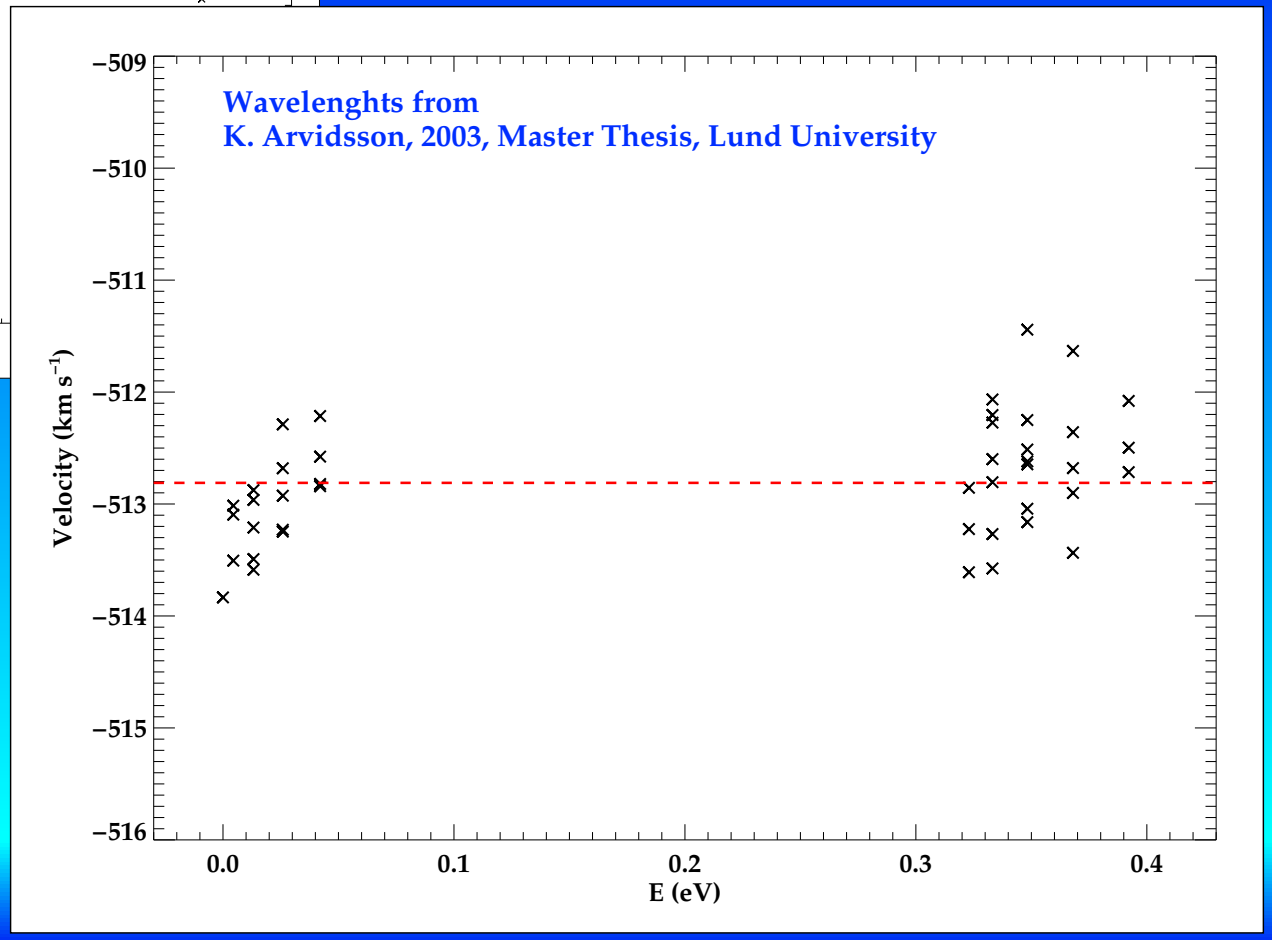
12 – Lifetime Measurements with LIF (short-version)

- Creating plasma with ions/atoms using a Nd:YAG ablation LASER
- Pump desired energy levels with a second Nd:YAG
- Measure the decay from the pumped states

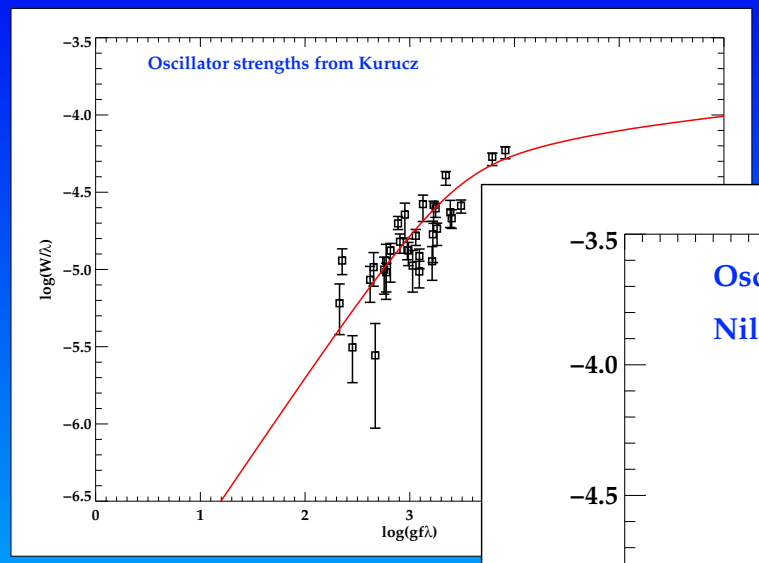
Want to know more? Li et al. 2000, Phys. Rev. A 62, 032505

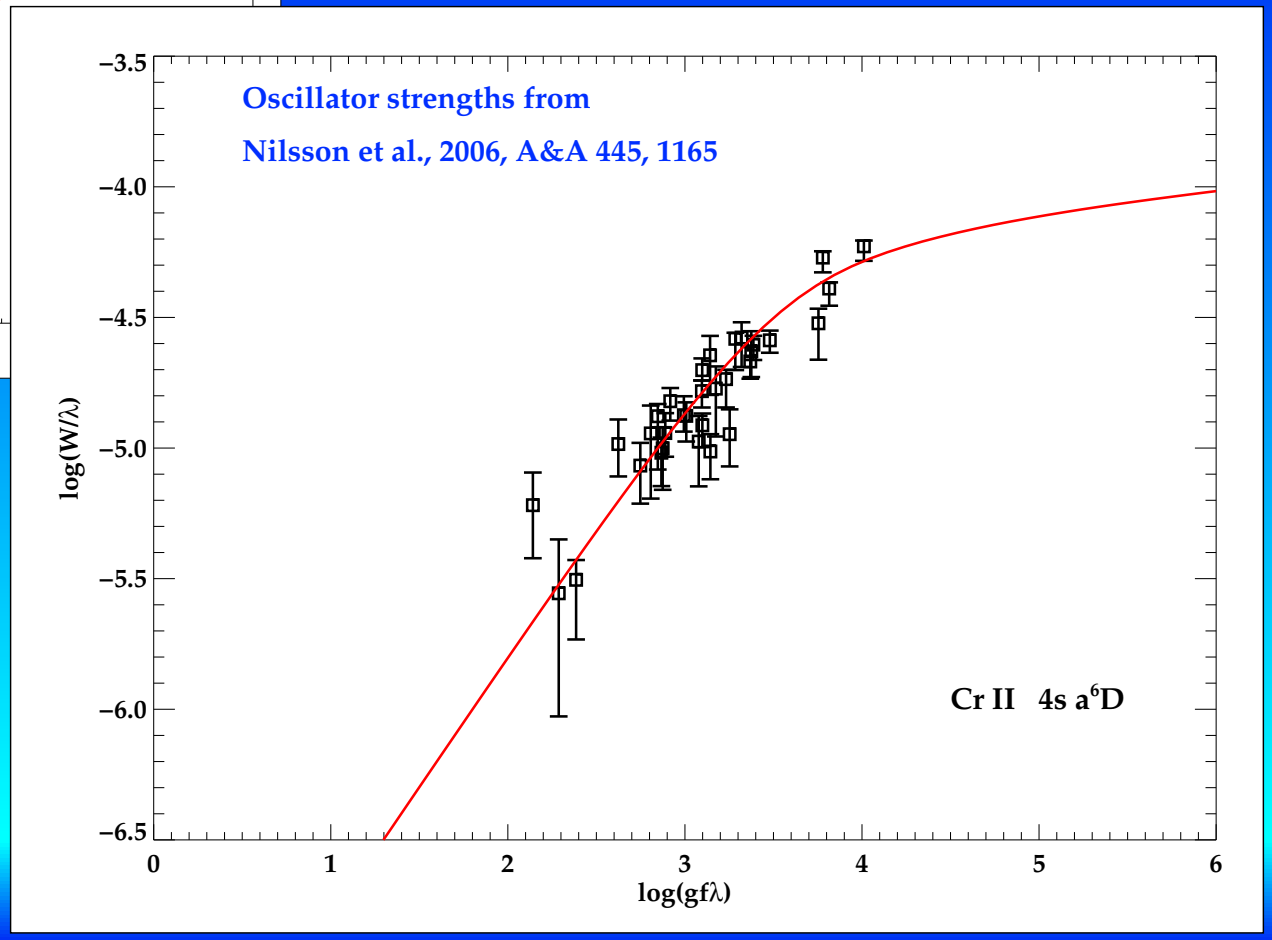
13 – Wavelength Problems in V II : SOLVED



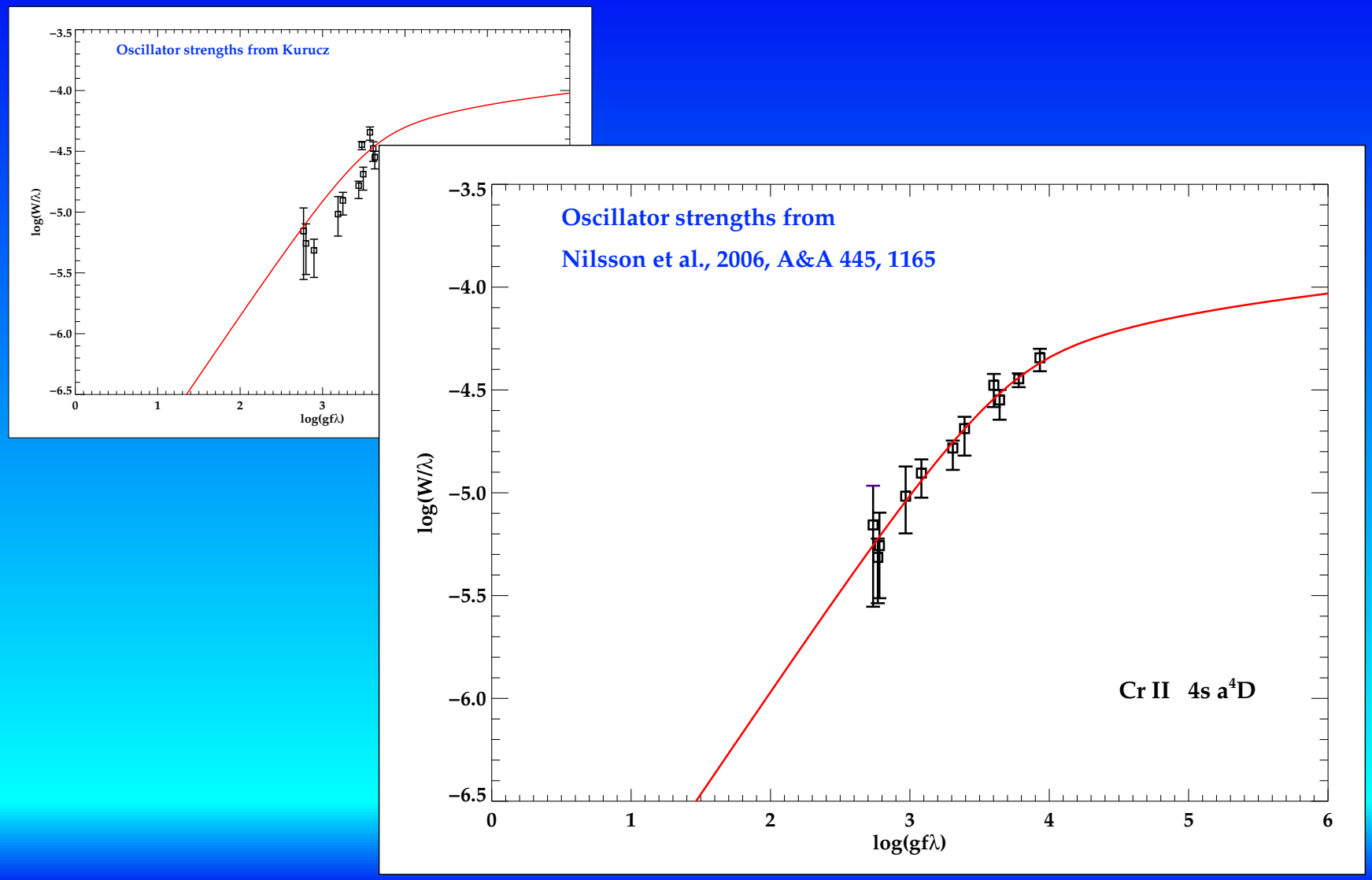


14 – Oscillator Strength Problems in Cr II: SOLVED

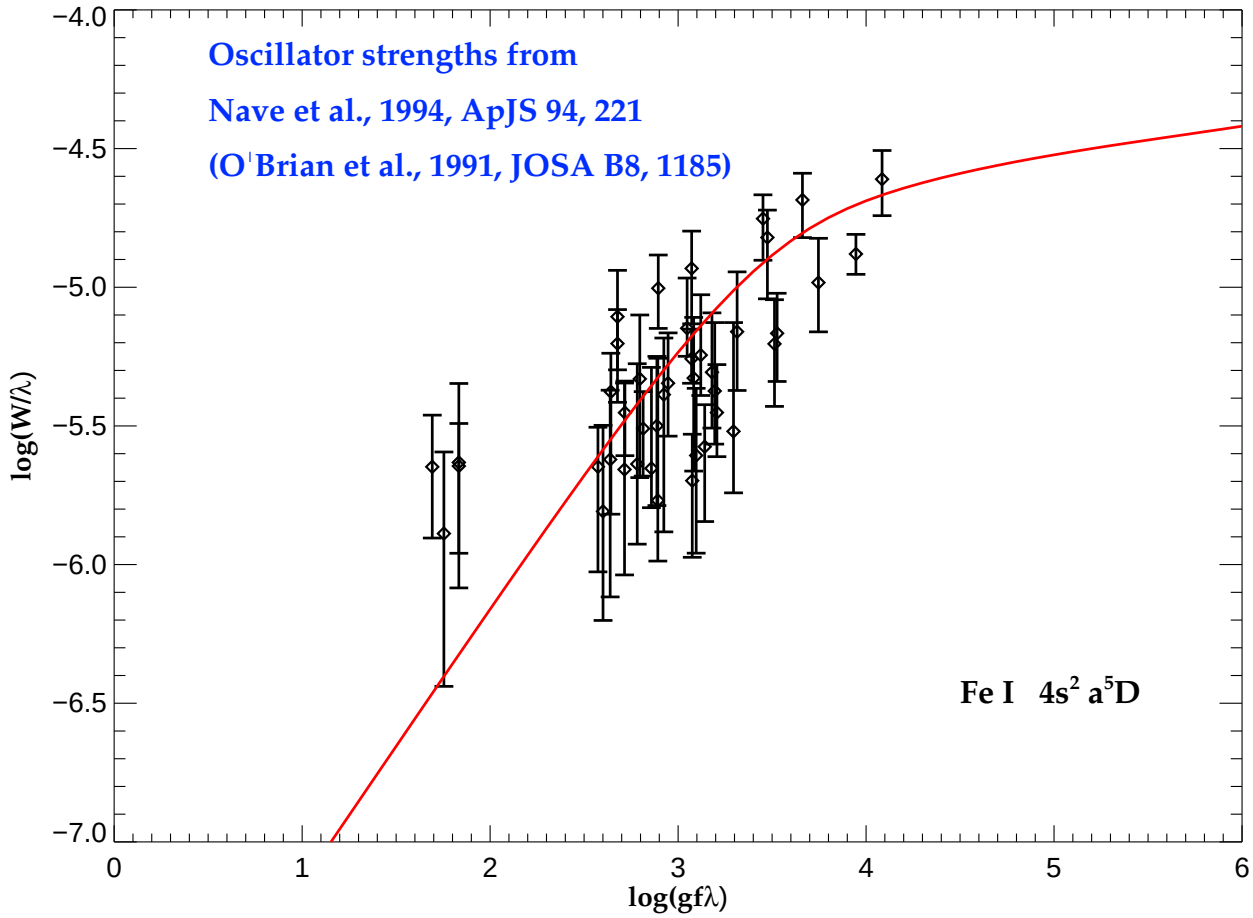




15 – Oscillator Strength Problems: Cr II: SOLVED



Large scatter $\Rightarrow$ not necessarily bad f-values



16 – The Last Slide

- η Car is an excellent astrophysical laboratory and the variety of spectral features has made it possible to target where new accurate atomic data is needed.
- We have improved our spectral analysis by interacting with the laboratory spectroscopist community. More work is, however, still needed.
- But,
  - Often difficult to find existing accurate atomic and molecular data
  - When you find it, reference it properly. Reference the original work not only the compilation where you found it.