Quantifying X-ray/Laser Timing Jitter at Interaction Points

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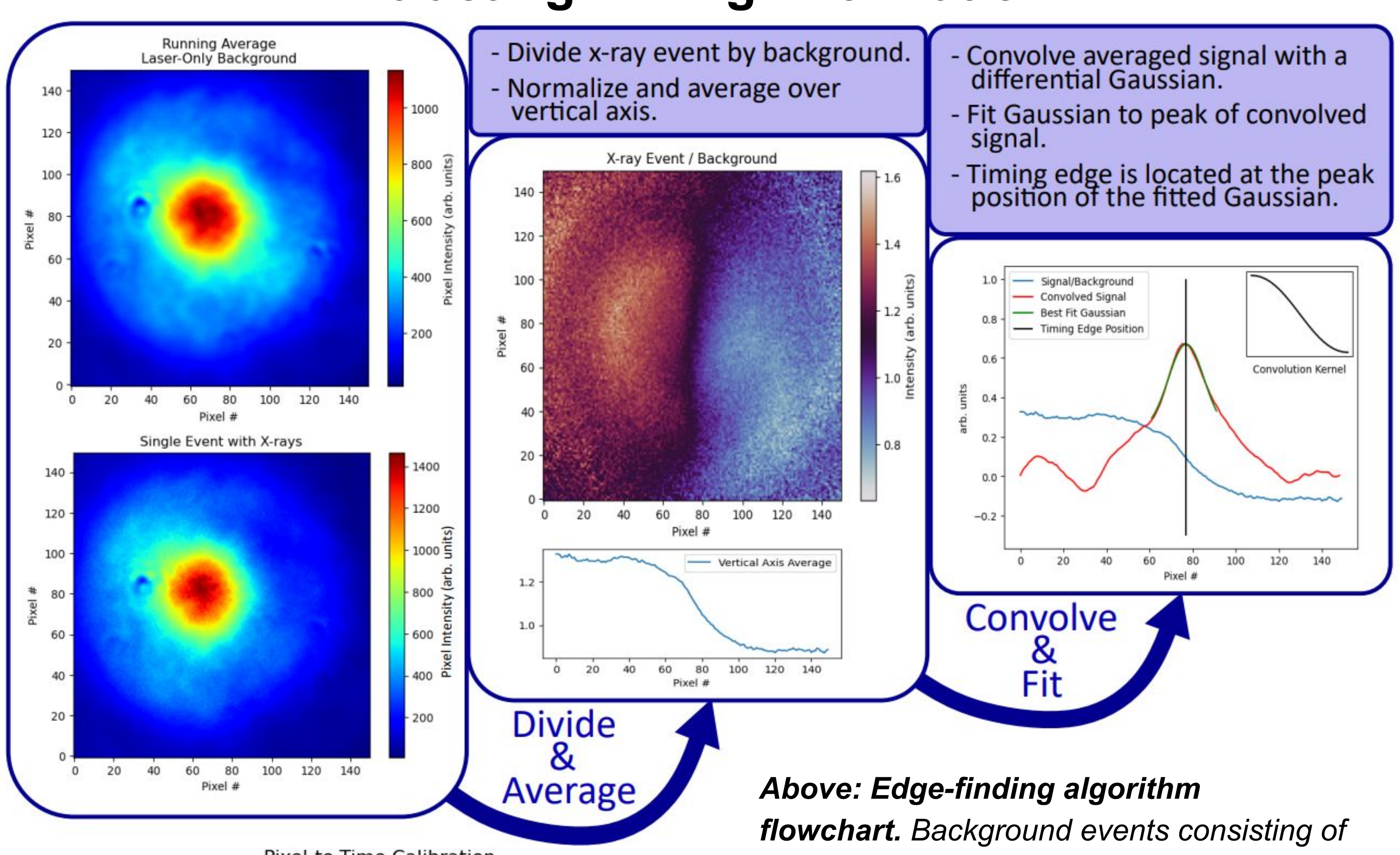
Introduction and Motivation

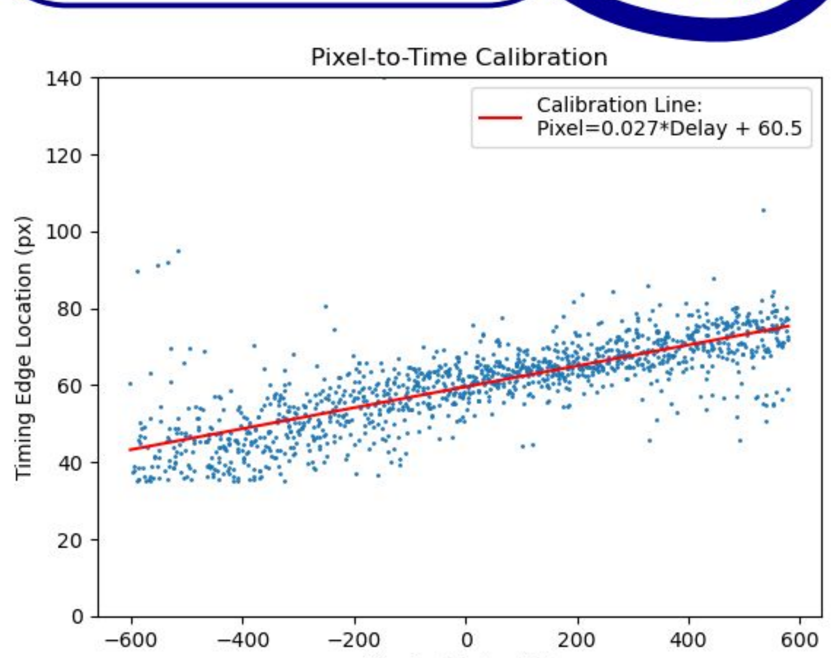
- Many LCLS experiments must know the time delay between x-ray and optical laser pulses to perform pump-probe measurements.
- However, XFELs have significant (>100fs) shot-to-shot timing jitter, preventing the study of ultrafast dynamics unless corrected for.
- The Arrival Time Monitor (ATM) uses x-ray induced reflectance changes in a dielectric thin film sample to measure and correct for timing jitter [1].
- Some hutch ATMs are >1m upstream from the interaction point (IP), but the potential additional timing jitter between the ATM and IP is unknown.
- The additional jitter is not measured by the ATM, so we conducted an experiment to quantify it by placing a second ATM at the interaction point.
- Our results will motivate and inform future timing solutions that take into account the additional jitter introduced between the ATM and IP.

Experimental Method

- To quantify the additional jitter, a second temporary arrival time monitor was constructed at the XCS hutch interaction point as shown below.
- A calibration time scan was performed by repeatedly sweeping the nominal delay between laser and x-ray pulses over a several-picosecond window about zero-delay. Several minutes of events were then recorded at a nominal delay of zero with a repetition rate of 120Hz.

Extracting Timing Information

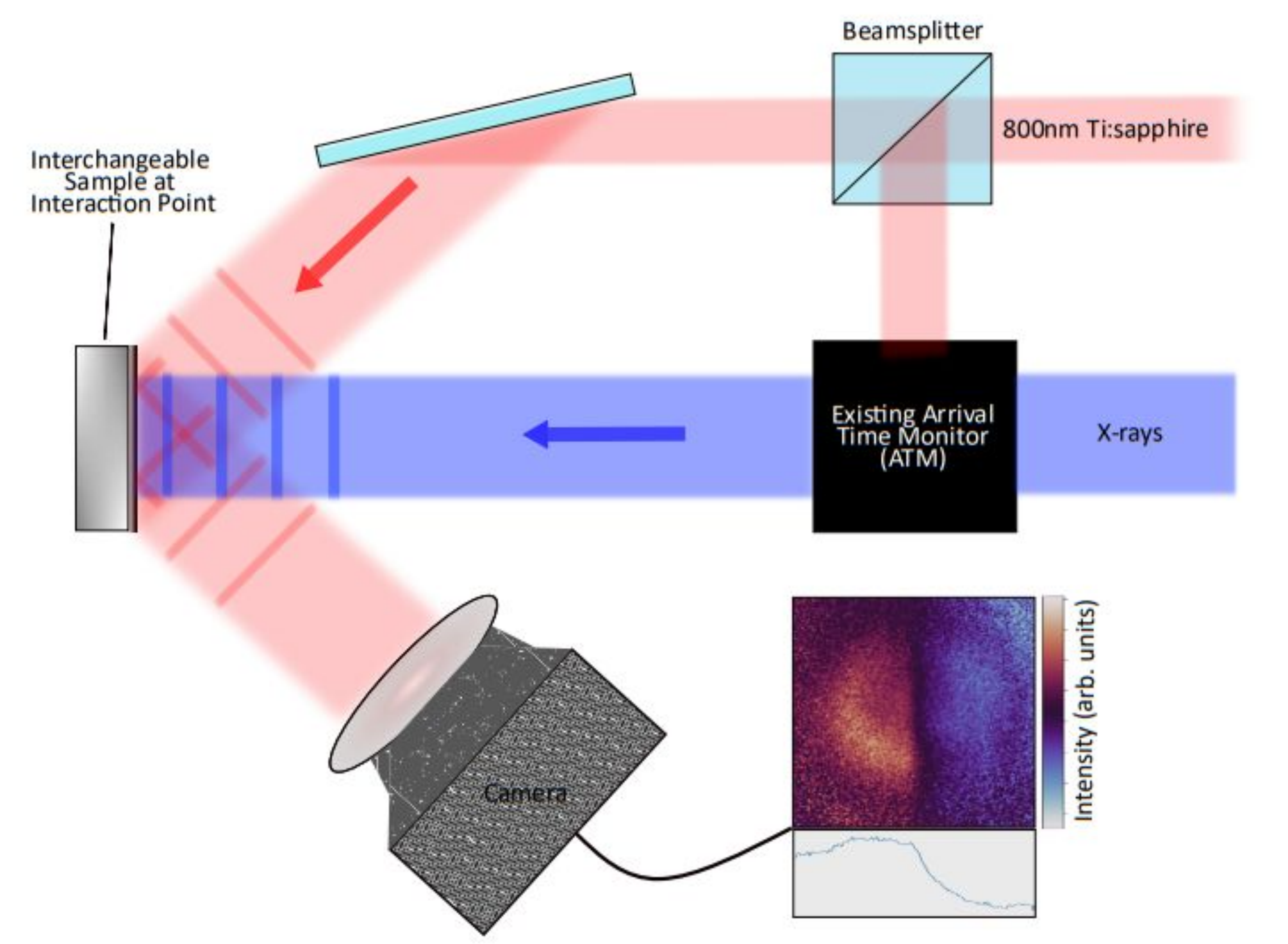




Above: Edge-finding algorithm flowchart. *Background events consisting of only the optical laser spot were used to isolate the x-ray induced reflectivity change and find timing edges through a convolution and fitting process.*

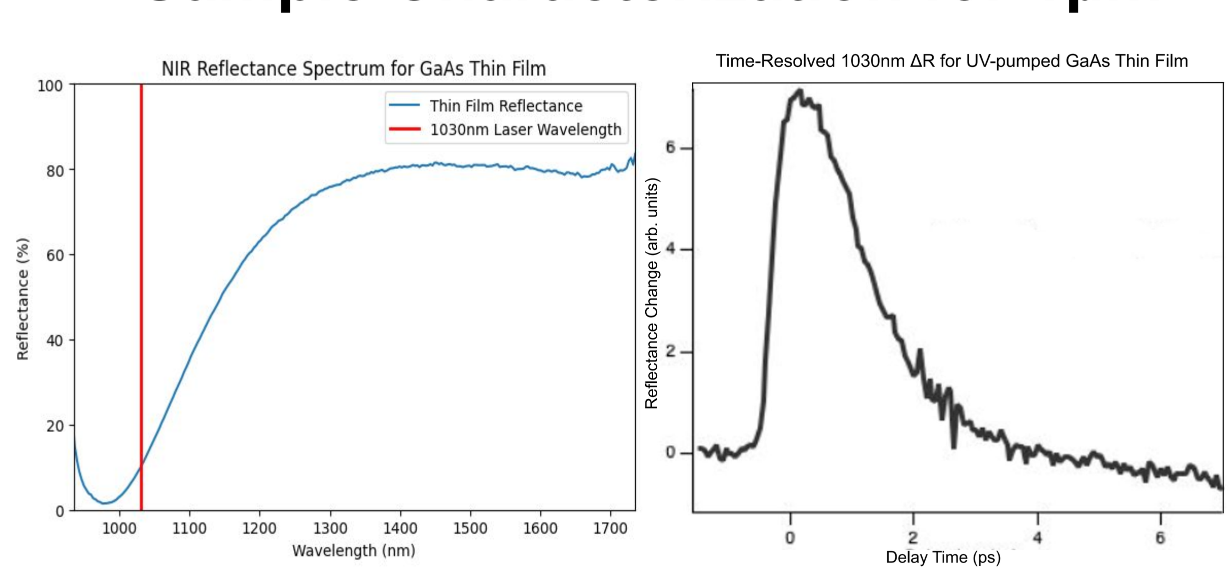
Left: Time-to-space calibration. *A calibration line was fitted to the timing edges located during a time scan which swept over nominal delays. The calibration is used to convert timing edge positions into jitters during runs conducted at a nominal delay of zero.*

Experimental Setup



The double arrival time monitor experimental setup. *The existing spectral ATM was left untouched while a temporary spatial ATM was constructed at the interaction point. The principle of operation for the time-to-pixel position mapping is illustrated with a correlation between spatial and temporal coordinates. The onset of the x-ray induced change in reflectivity manifests as a 'timing edge' between brighter and dimmer regions of the imaged laser spot. The vertically averaged pixel intensity, exhibiting a sharp timing edge, is shown below the raw image. The image shown is of a real timing edge on a YAG sample.*

Additional Project: Sample Characterization for 1μm

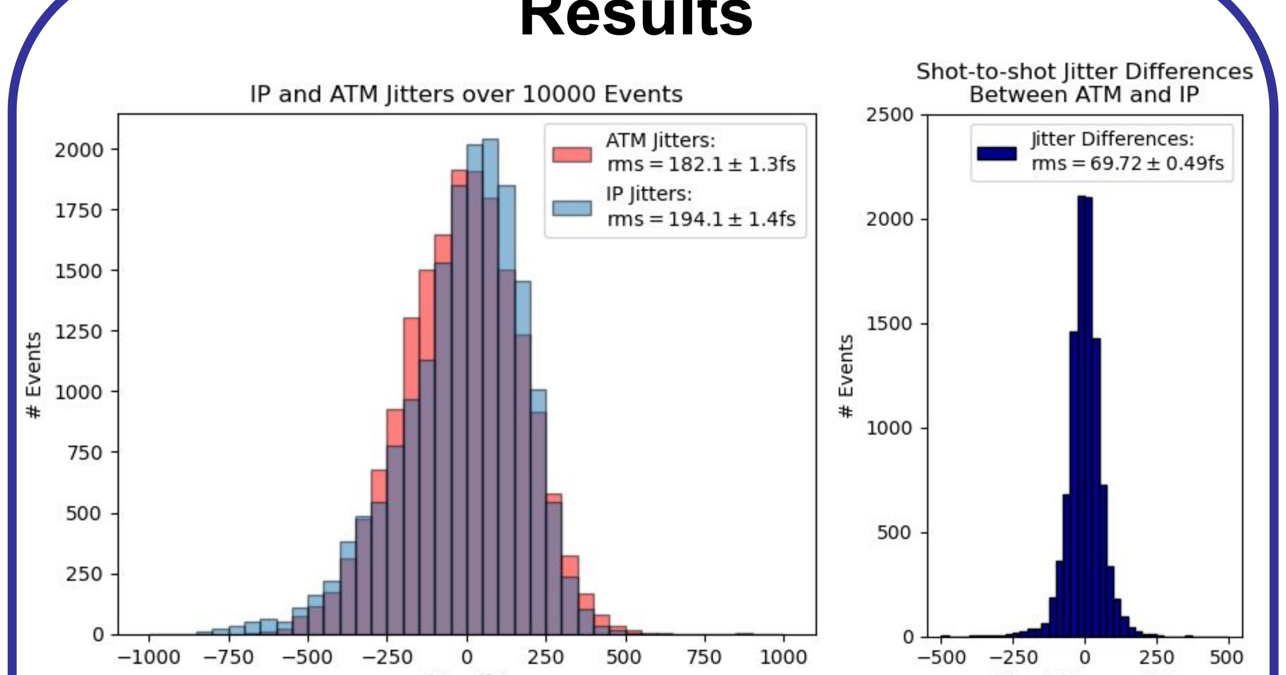


Above Left: Reflectance spectrum of Gallium Arsenide (GaAs) thin film. *A node exists near the 1030nm target wavelength of the new laser system.*

Above Right: Time-resolved relative reflectance change of a 266nm UV-pumped GaAs thin film. *Reflectance was measured with a 1030nm probe. A sharp reflectance increase is present immediately after pumping.*

- All hutches will be upgraded to a ~1μm laser system (1030nm) as part of LCLS-II-HE. Current ATM targets (optimized for 800nm Ti:Sapphire lasers) must therefore be replaced.
- Ideal ATM samples should have a reflectance node near 1030nm, leading to the greatest relative reflectivity change when pumped.

Results



Above Left: Distributions of shot-to-shot timing jitters at the ATM and IP. *Both distributions are approximately normal. See the legend for rms timing jitters with standard uncertainties assuming an underlying Gaussian population distribution [2].*

Above Right: Shot-to-shot timing jitter differences between the ATM and IP. *The rms timing jitter difference for the approximately normal distribution, along with its standard uncertainty, can be seen in the legend.*

- An additional 69.72±0.49fs of timing jitter (rms) is present between the ATM and IP of the XCS hutch.
- We have that $rms^2_{ATM} + rms^2_{Difference} = rms^2_{IP}$ within standard uncertainties. This is consistent with the jitter introduced along the optical laser path from the ATM to the IP being independent of the jitter introduced before the ATM.

Conclusions and Future Work

- It is necessary to account for the ~70fs rms of additional jitter to achieve higher time resolution at the interaction point.
- Motivation has been provided for installing a permanent second ATM near the IP which would also enable the correction of long-term timing drifts introduced along the optical laser path.
- We wish to measure IP jitter at hutches other than XCS (attempts at other hard x-ray hutches need follow up).

Acknowledgements

I want to express my gratitude to the LCLS Internship Program team and to all my colleagues who have been nothing but kind and supportive. A special thanks goes to Mat Britton for his help with the edge-finding algorithm. Finally, a big thank you to my mentor Mina for her guidance and encouragement which has made my time at SLAC a pleasure.

References

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[2] Taylor, J.R. (1997). An Introduction to Error Analysis, 2nd Ed. *University Science Books.* p. 140