Uncertainties in common dose reconstruction protocols at low doses

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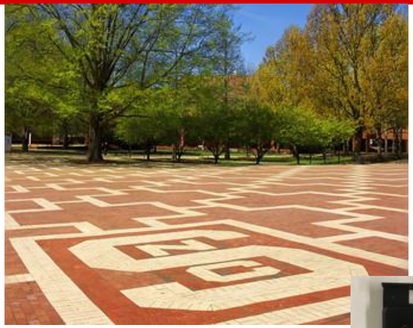
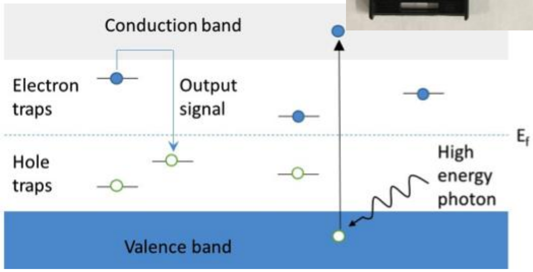
Outline

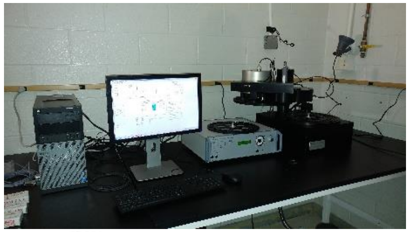
- Luminescence Dosimetry
  - The Band Model
  - The Luminescence Signal
- Dose reconstruction protocols
- Uncertainties in dose estimates
- Monte Carlo dose estimate uncertainties

Luminescence Dosimetry

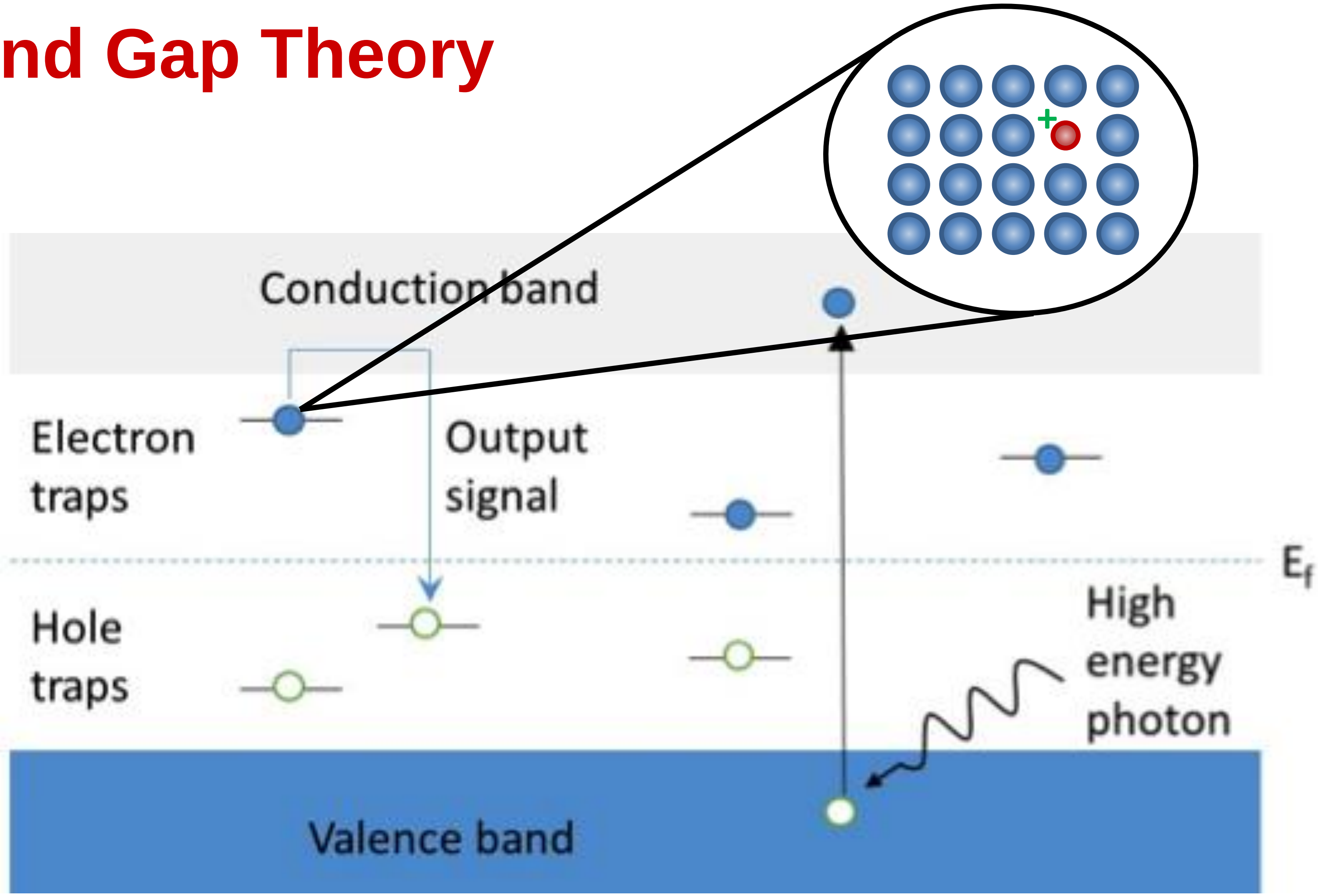


- Patient dosimetry
- Accident dosimetry
- Personnel dosimetry
  - Optically stimulated luminescence dosimeters (OSLDs)
  - Thermal luminescence dosimeters (TLDs)
- Archeological dating





Band Gap Theory

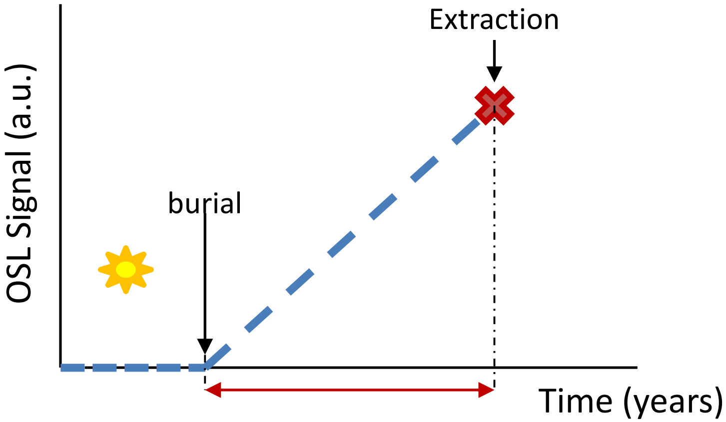


OSL Dating

- Applications: sediments, archeological artifacts

$$\text{Age(yr)} = \frac{\text{Absorbed Dose (Gy)}}{\text{Environmental Dose Rate}\left(\frac{\text{Gy}}{\text{yr}}\right)}$$

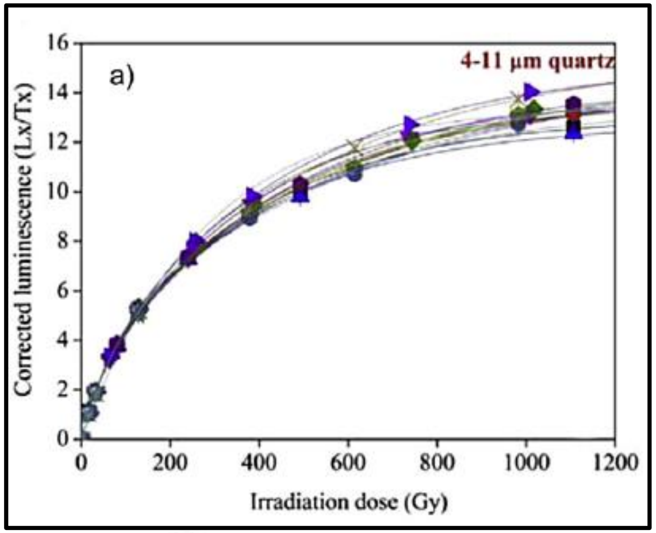
- Assumes OSL signal is zeroed from environmental stimulation
- OSL dosimetry and measured environmental dose rate allows estimation of age



Limitations on OSL Dosimetry

- Sensitivity changes resulting from thermal and optical stimulation
  - Single aliquot regenerative dose (SAR) protocol
- Thermal stability of trapped charge, saturation of traps/recombination centers
- Saturation of the dose response

$$I(D) = I_0 + A\left(1 - e^{-D/D_{01}}\right) + B\left(1 - e^{-D/D_{02}}\right)$$

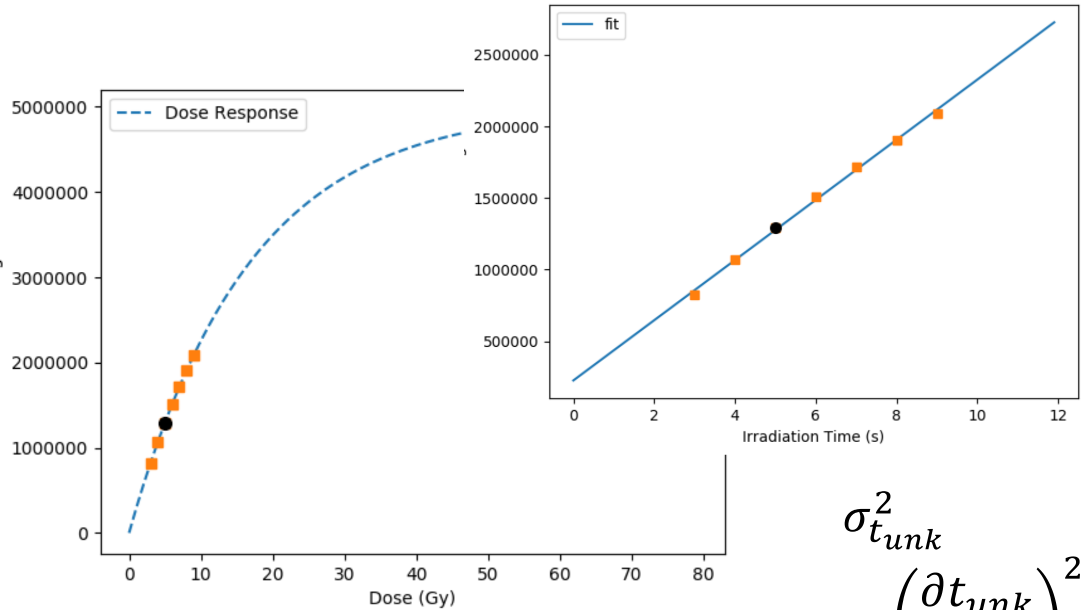


Dose Reconstruction

- luminescence output ∝ dose
- Need to relate measured luminescence output to the dose delivered by a well-known source
  - Measure dose response curve

- Reconstruction protocols
  - Single aliquot regenerative dose (SAR)
  - Additive dose (AD)

Single Aliquot Regenerative (SAR) Protocol



Interpolation

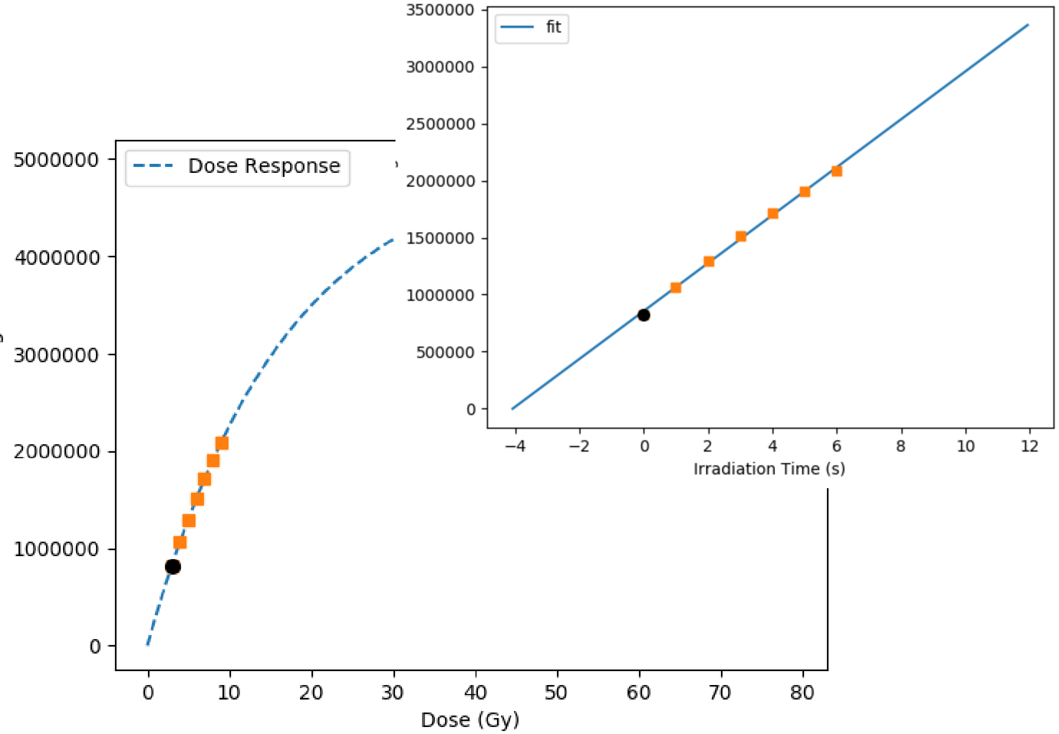
$$I = (m \pm \sigma_m)t + (b \pm \sigma_b)$$

$$t_{unk} = \frac{(I_m \pm \sigma_{I_o}) - (b \pm \sigma_b)}{(m \pm \sigma_m)}$$

$$\sigma_{t_{unk}}^2 = \left(\frac{\partial t_{unk}}{\partial m}\right)^2 \sigma_m^2 + \left(\frac{\partial t_{unk}}{\partial I_m}\right)^2 \sigma_{I_m}^2 + \left(\frac{\partial t_{unk}}{\partial b}\right)^2 \sigma_b^2$$

$$\boxed{\sigma_{t_{unk}}^2 = \left(\frac{(I_m - b)}{m^2}\right)^2 \sigma_m^2 + \left(\frac{1}{m}\right)^2 \sigma_{I_o}^2 + \left(\frac{1}{m}\right)^2 \sigma_b^2}$$

Additive Dose (AD) Protocol



Extrapolation

$$I = (m \pm \sigma_m)(t_o) + (b \pm \sigma_b)$$

$$t_o = \frac{(b \pm \sigma_b)}{(m \pm \sigma_m)}$$

$$\boxed{\sigma_{t_o}^2 = \frac{\sigma_b^2}{m^2} + \frac{b^2\sigma_m^2}{m^4}}$$

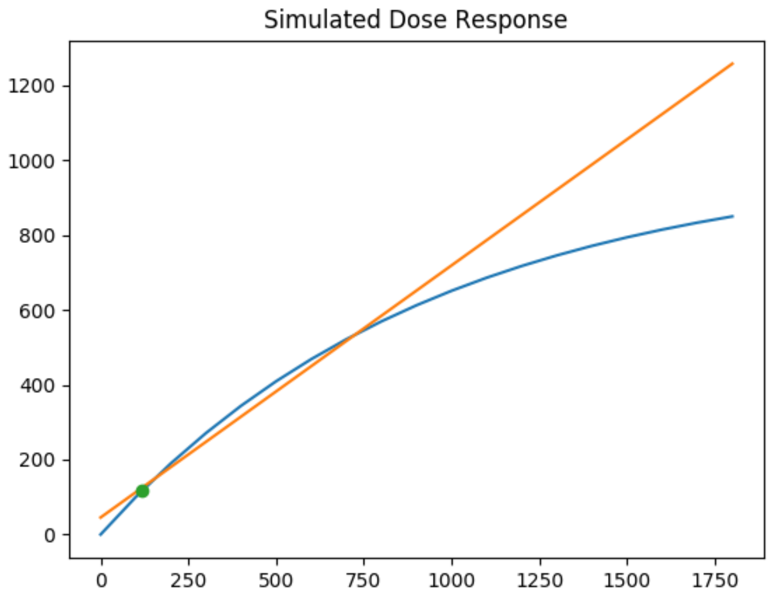
SAR versus AD Uncertainties

$$\boxed{\sigma_{t_{unk}}^2 = \frac{(I_m - b)^2}{m^4}\sigma_m^2 + \frac{\sigma_{I_m}^2}{m^2} + \frac{\sigma_b^2}{m^2}}$$ SAR

$$\boxed{\sigma_{t_o}^2 = \frac{\sigma_b^2}{m^2} + \frac{b^2\sigma_m^2}{m^4}}$$ AD

$\sigma_{I_m}^2 \propto I_m$ and $I_m > b$

Monte Carlo Dose Estimate Uncertainties



Simulated dose response:

$$I(t) = 1000\left(1 - e^{-t/950}\right)$$

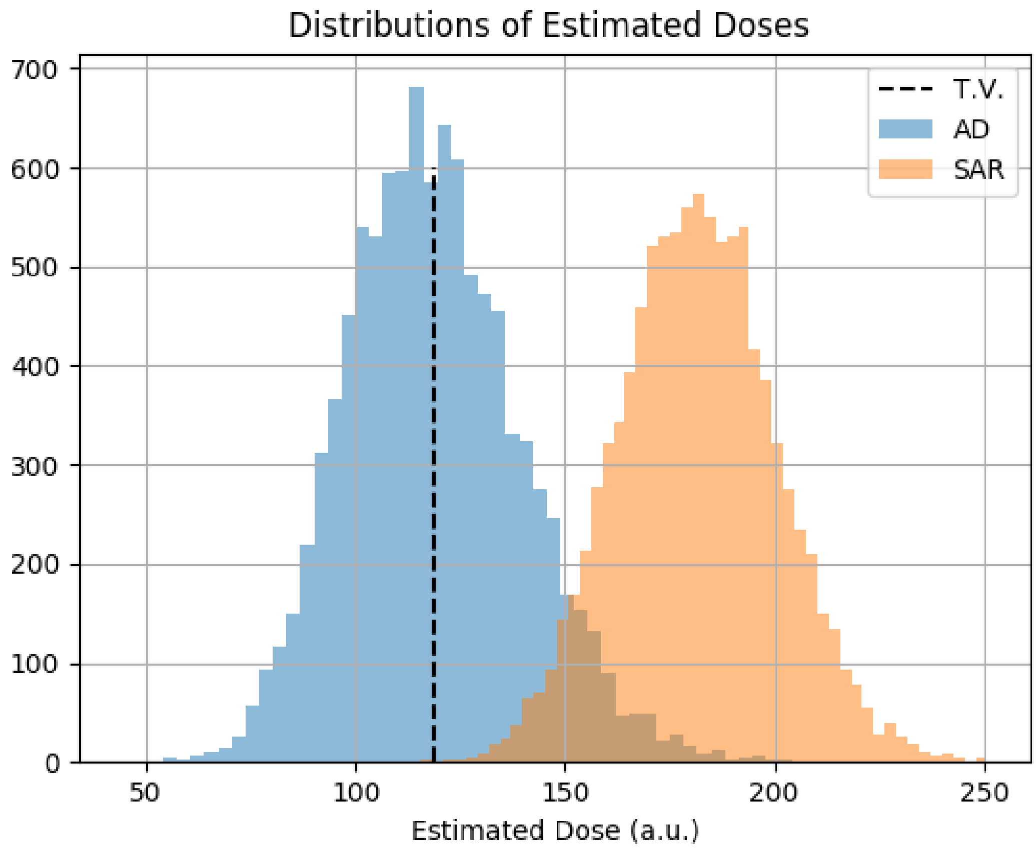
t_{dose} = 118 a.u.
(12% D_o)

6 laboratory irradiations (max 1188)
- AD: half and half distributed
- SAR: linear distribution

Assumed both relative and absolute errors

10,000 MC runs

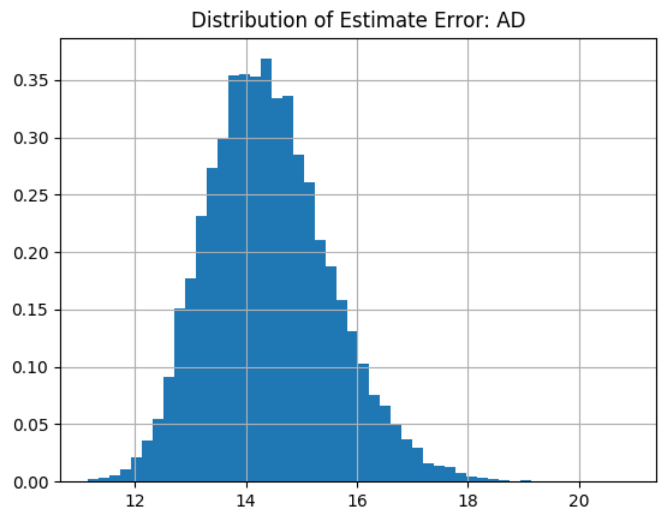
MC Results - Dose Estimations



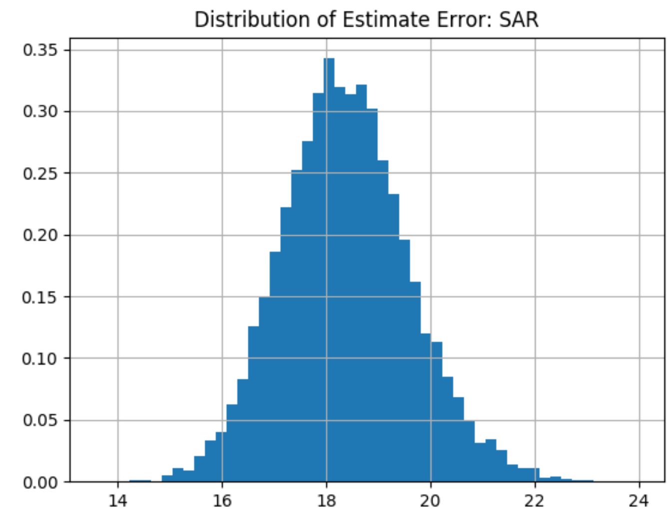
AD:
119 ± 20

SAR:
181 ± 19

MC Results – Distribution of Errors



SAR:
Mean uncertainty: 18.3
Stdev uncertainty: 1.2



AD:
Mean uncertainty: 14.4
Stdev uncertainty: 1.1

Practical Considerations

- SAR dose estimate uncertainties can be significantly reduced using multiple aliquots
- Simple size may constrain the ability to use AD protocol
  - Ex. Environmental swipe analysis
- Analysis here only considered linear approximations of the dose response
  - Linearity breaks down at higher doses
- Further work should be devoted to comparing uncertainties for other dose response functions

Special thanks to…

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Questions?

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