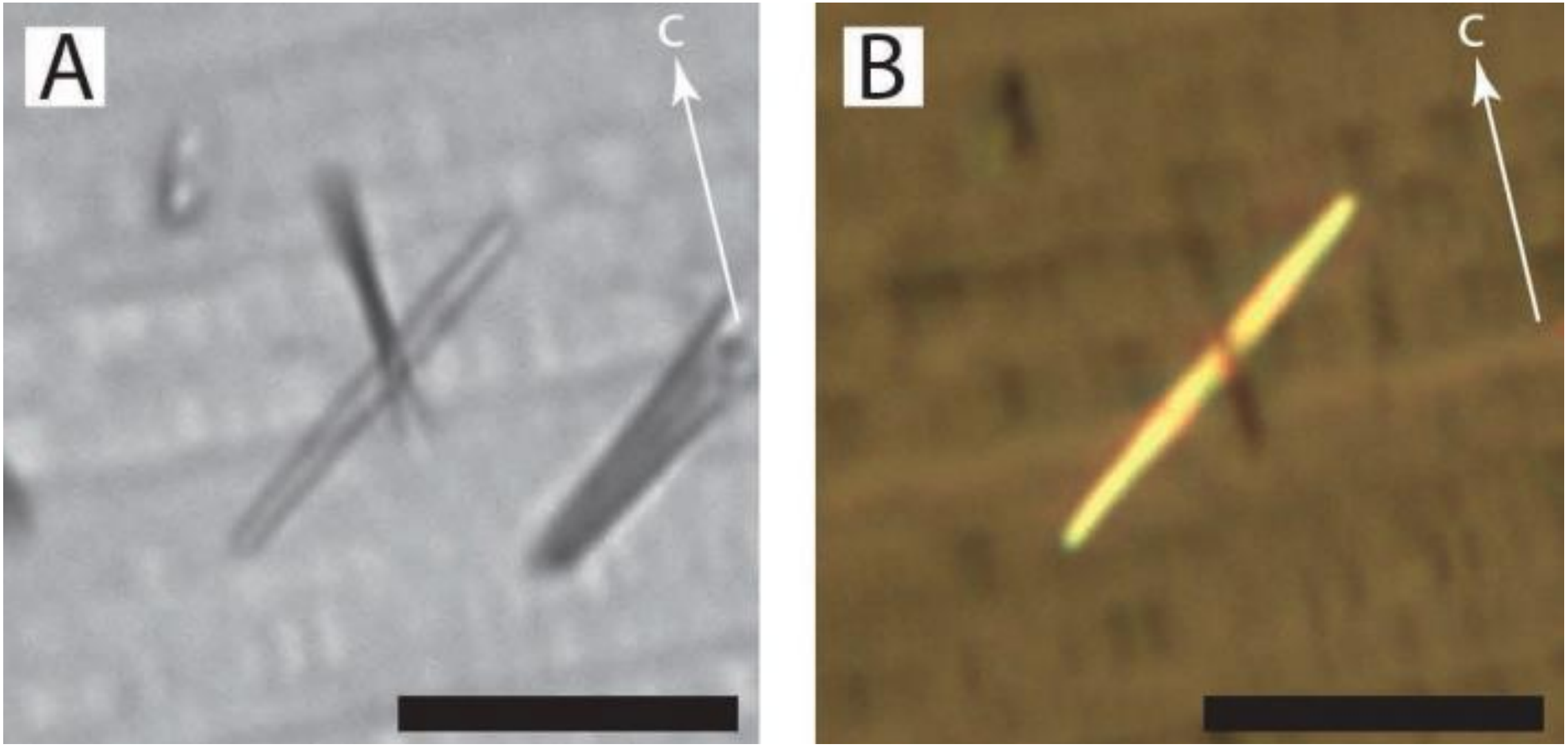
Confined fission track revelation: how it works and why it matters

Richard A. Ketcham and Murat T. Tamer

Department of Geological Sciences, Jackson School of Geosciences

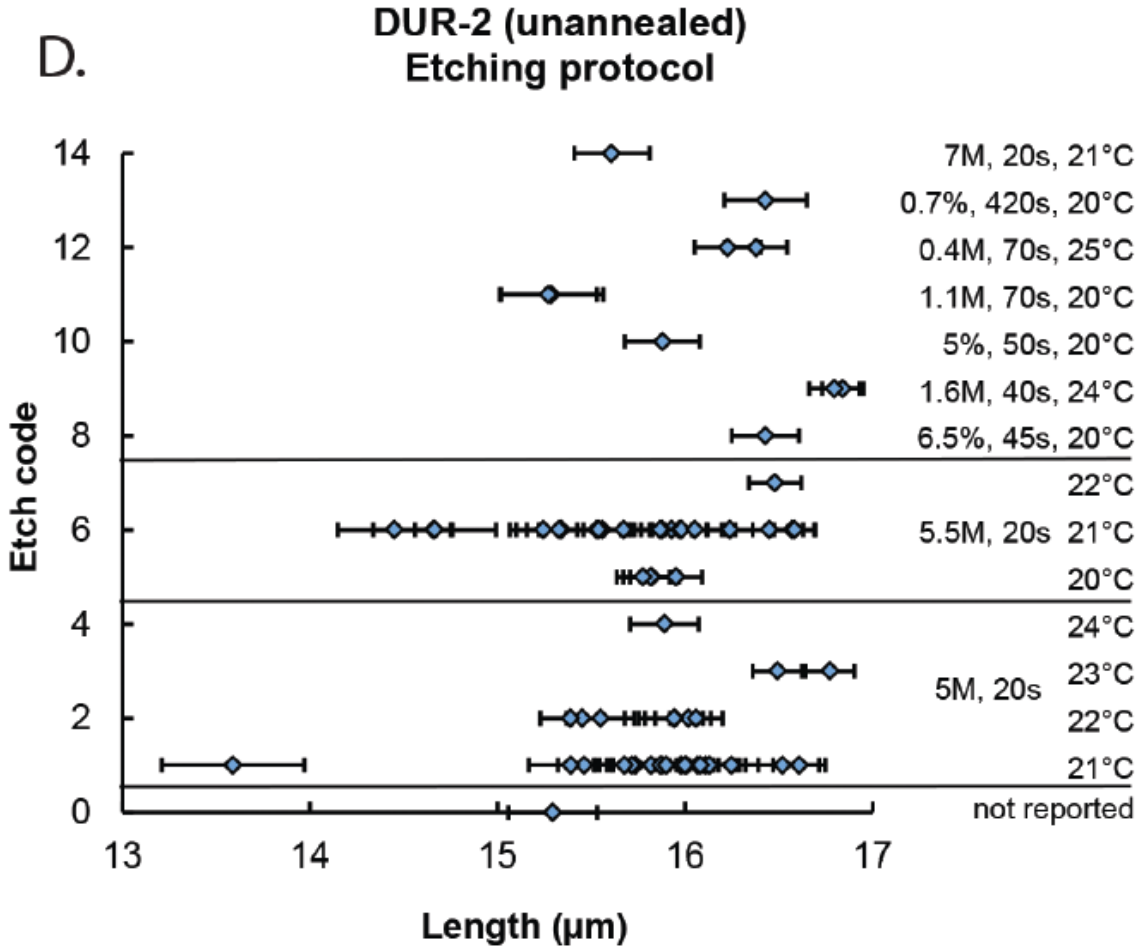
University of Texas at Austin

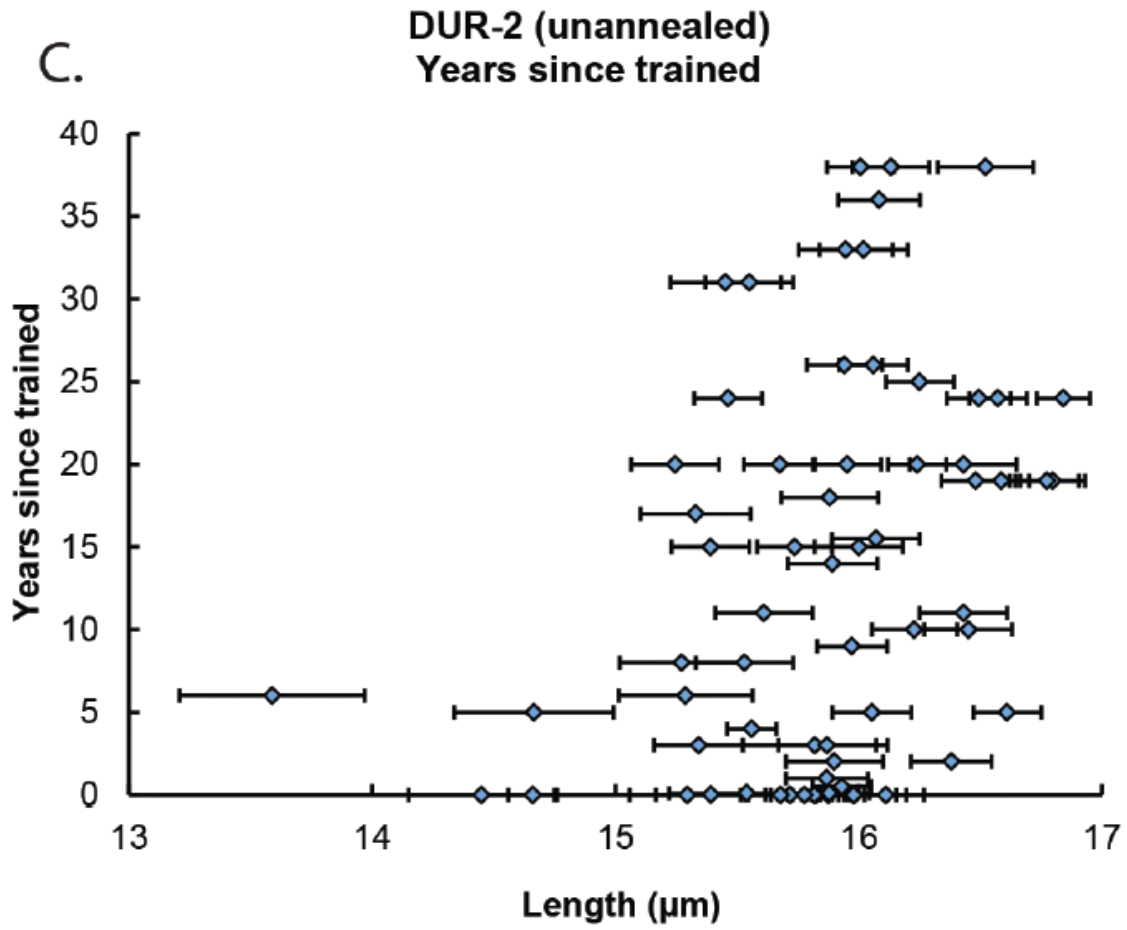
Or, What I did during COVID-19



Ketcham, Carter and Hurford, 2015

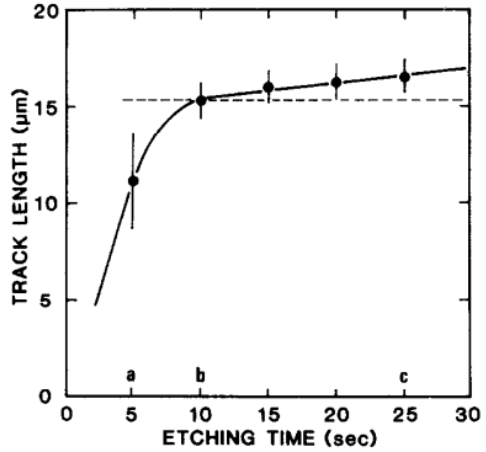
“The easiest length measurement there is”





Ketcham, Carter and Hurford, 2015

What does step etching tell us?

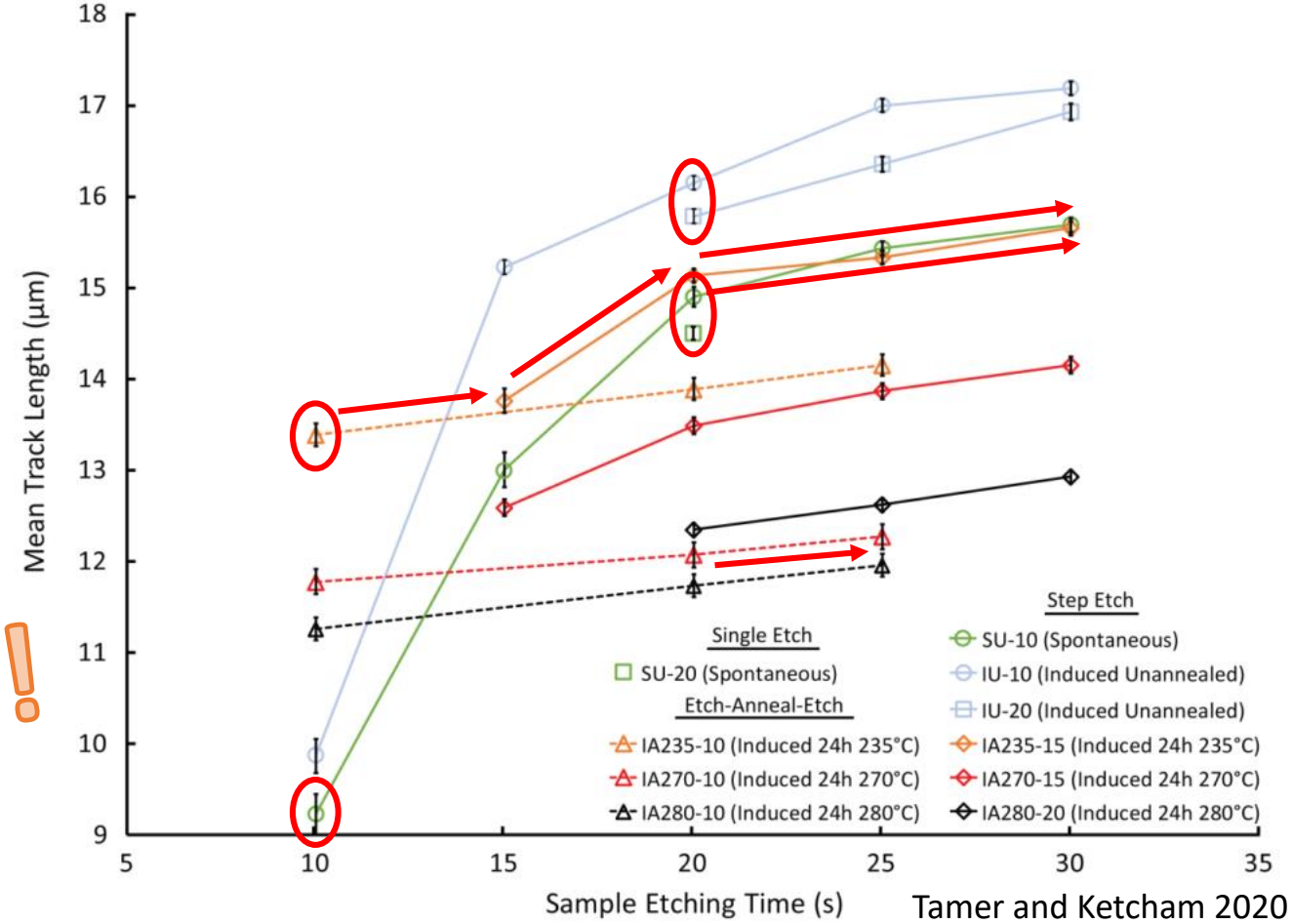


Laslett et al., 1984

Odd results from “follow-each-track” step etching…

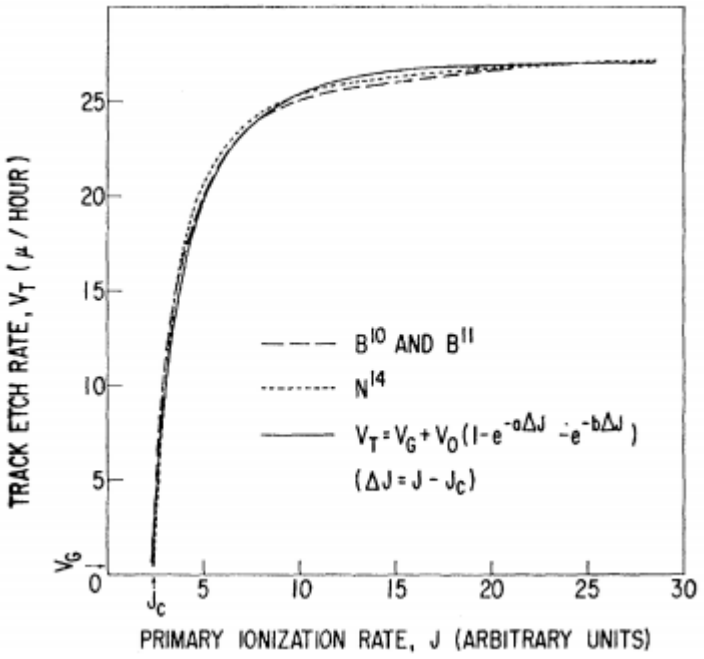
- Bulk etching velocity only reached after 25 seconds(!) in unannealed induced tracks
- Mean lengths 0.4 μm longer if detected after 10 vs. 20 seconds
- Spontaneous and annealed induced tracks very different at 10 s, indistinguishable after 25 s
- Apparent jump in etch rate

All can be explained!



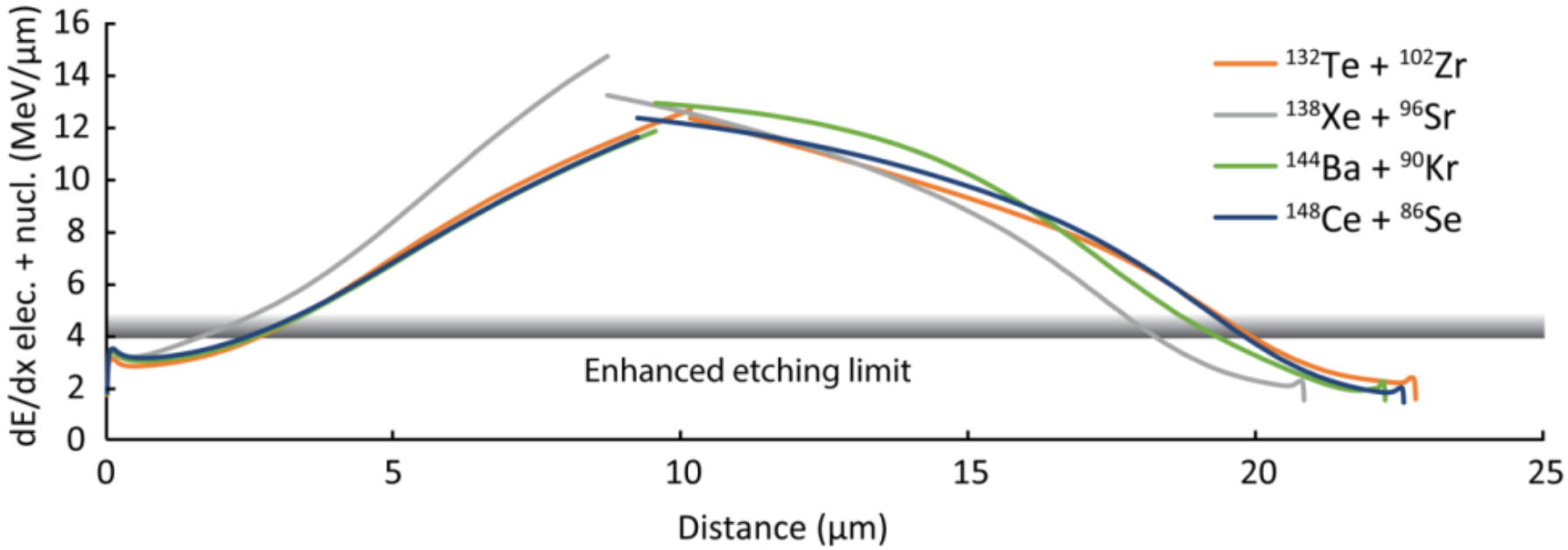
Tamer and Ketcham 2020

Etch rate along track is linked to energy loss rate



Price et al., 1967

Energy loss rates for various possible ^{238}U fission pairs



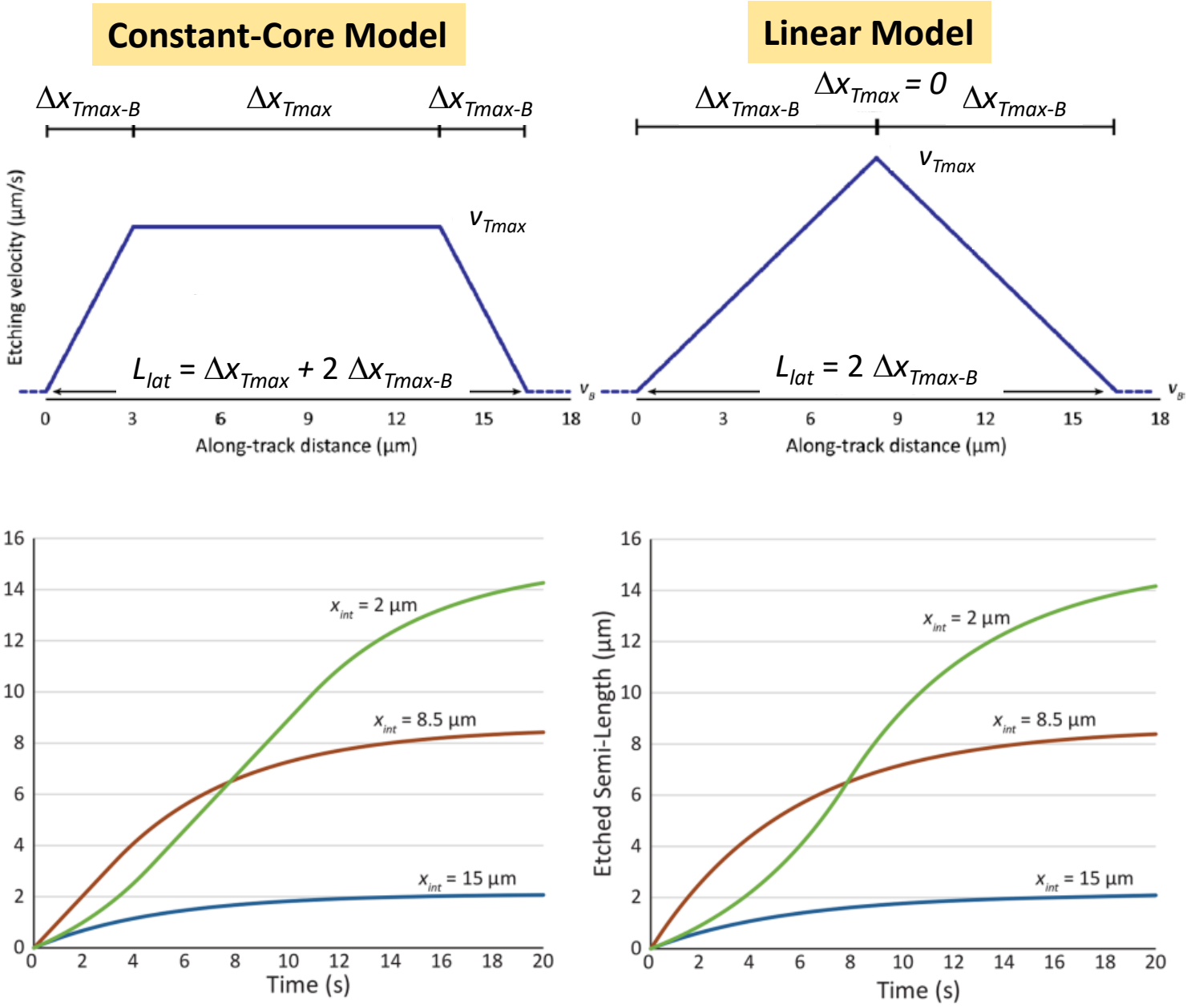
Calculated using SRIM (Ziegler et al. 2013)

Ketcham and Tamer 2021

Can we understand confined track etching better?

Two possible simplified etching structures

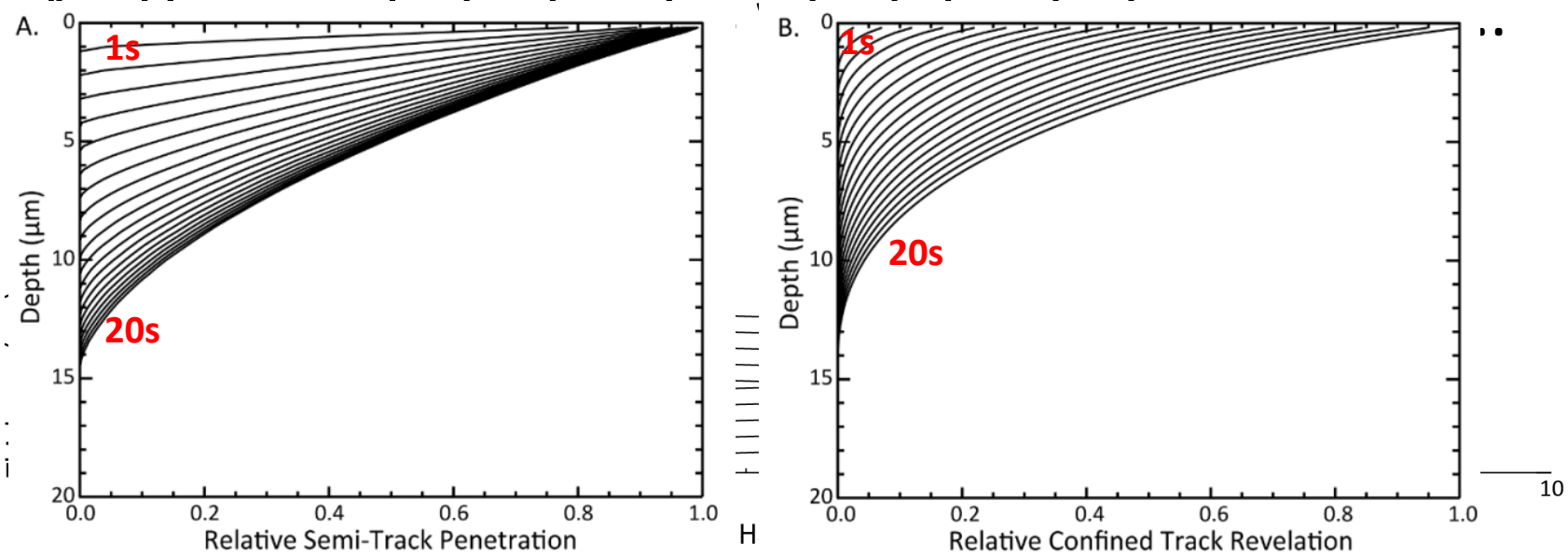
Half-track lengthening curves, depending on impingement point



From Ketcham and Tamer 2021

To figure out etching rates of TINT confined tracks, we need to model:

1. Penetration and then widening of semi-tracks
2. Intersection/revelation of confined latent tracks
3. Etching out of latent tracks



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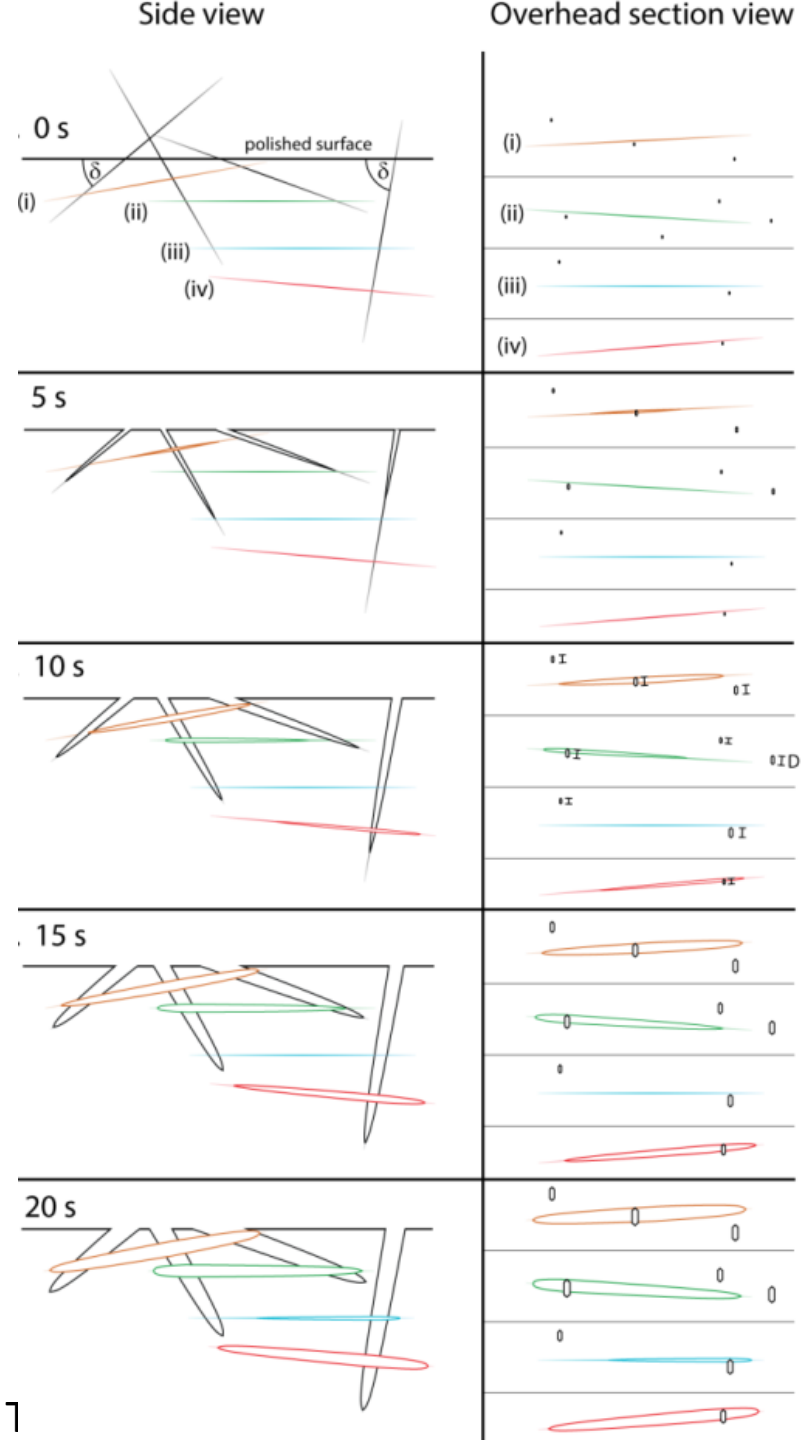

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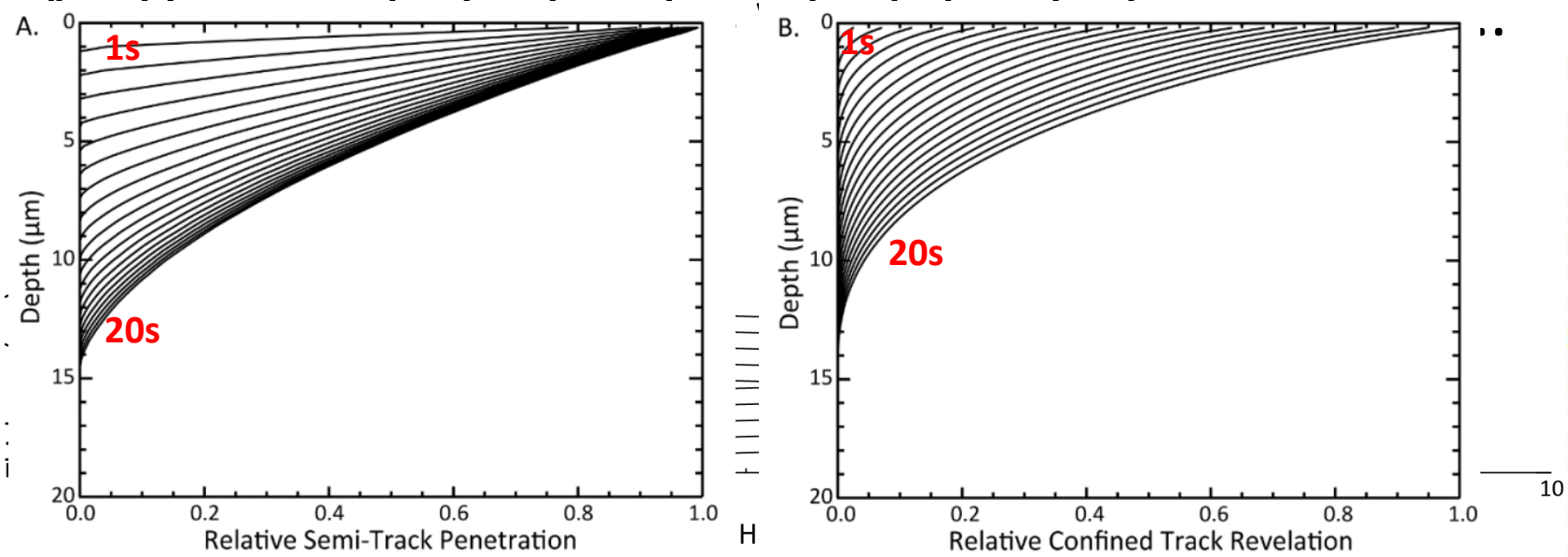

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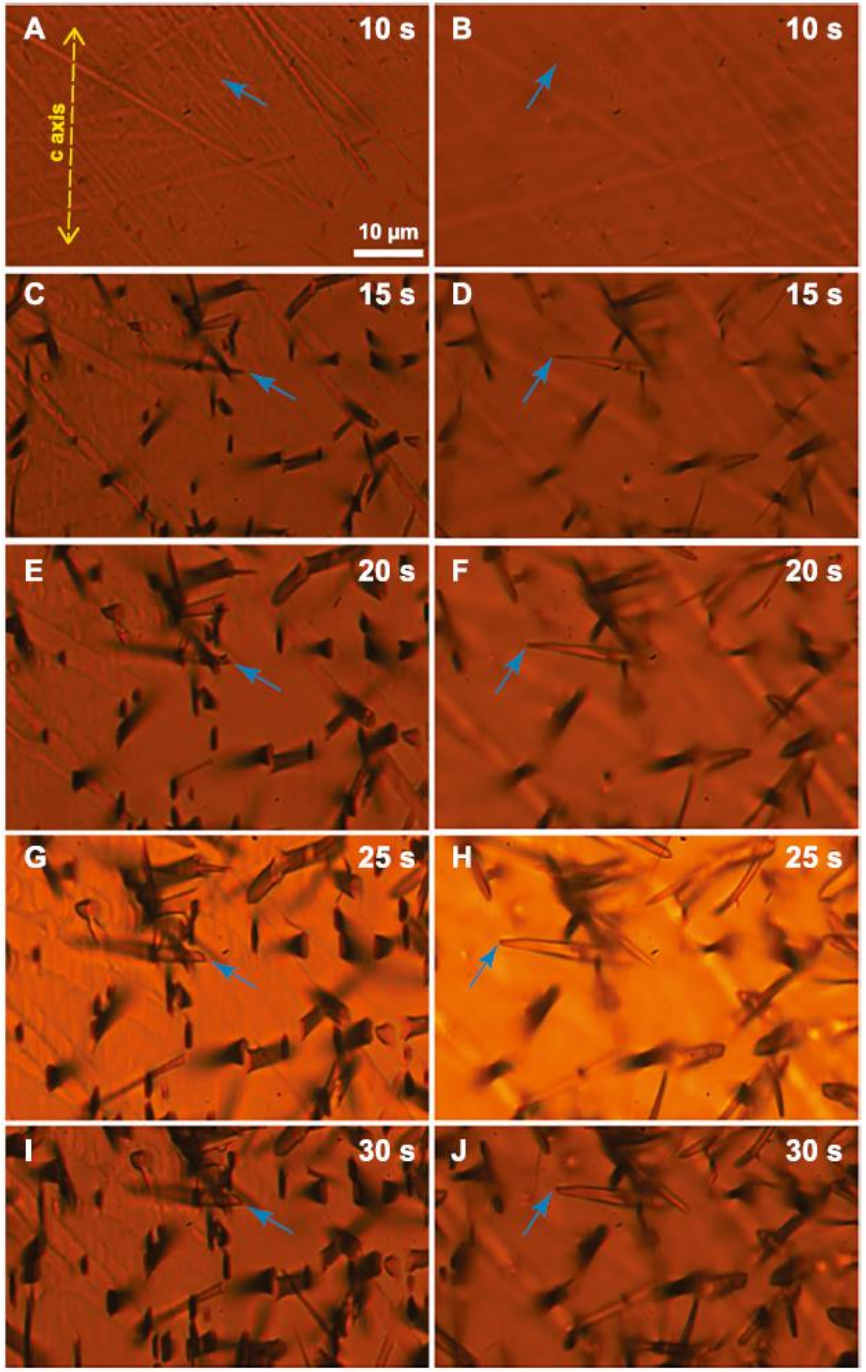
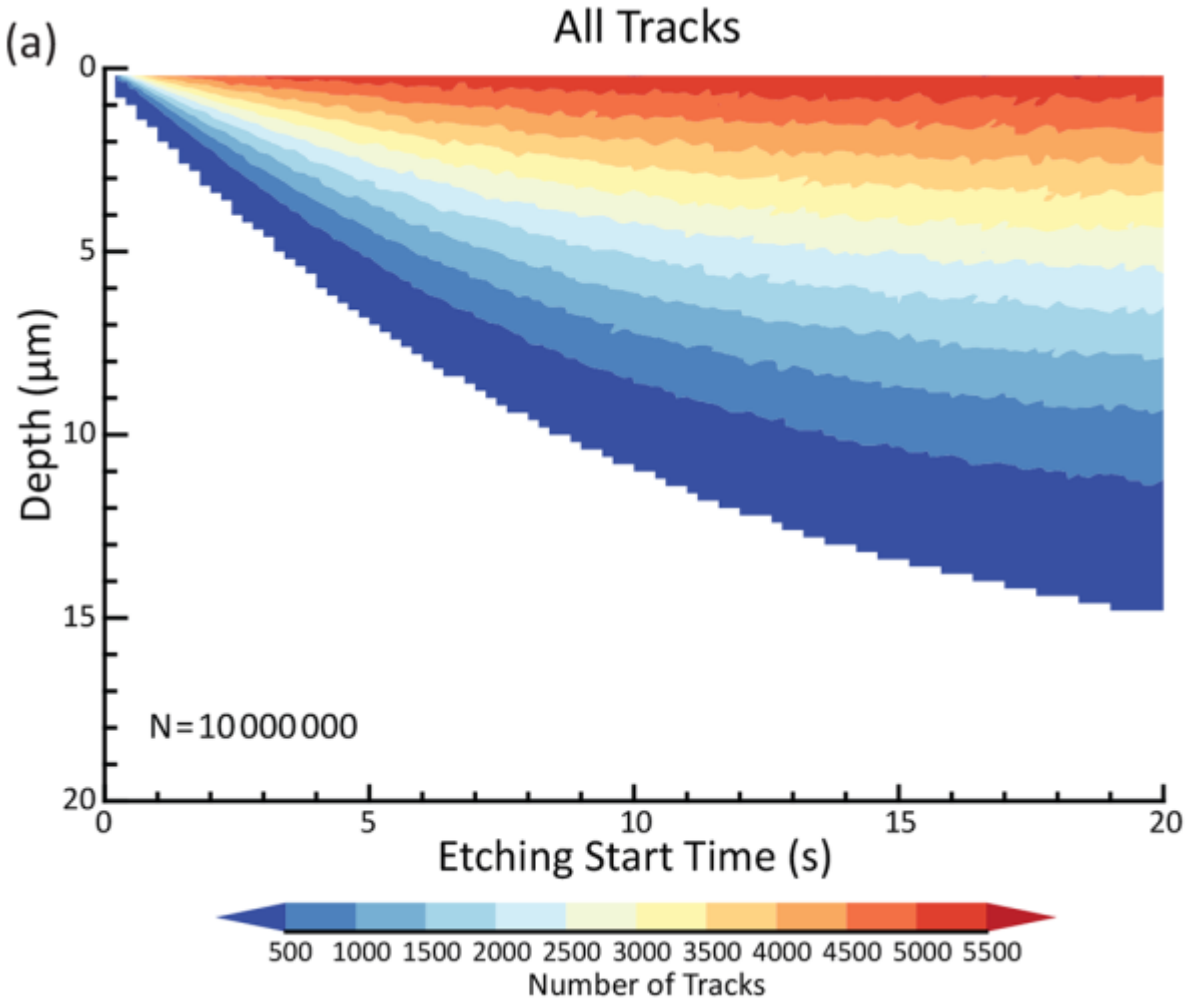
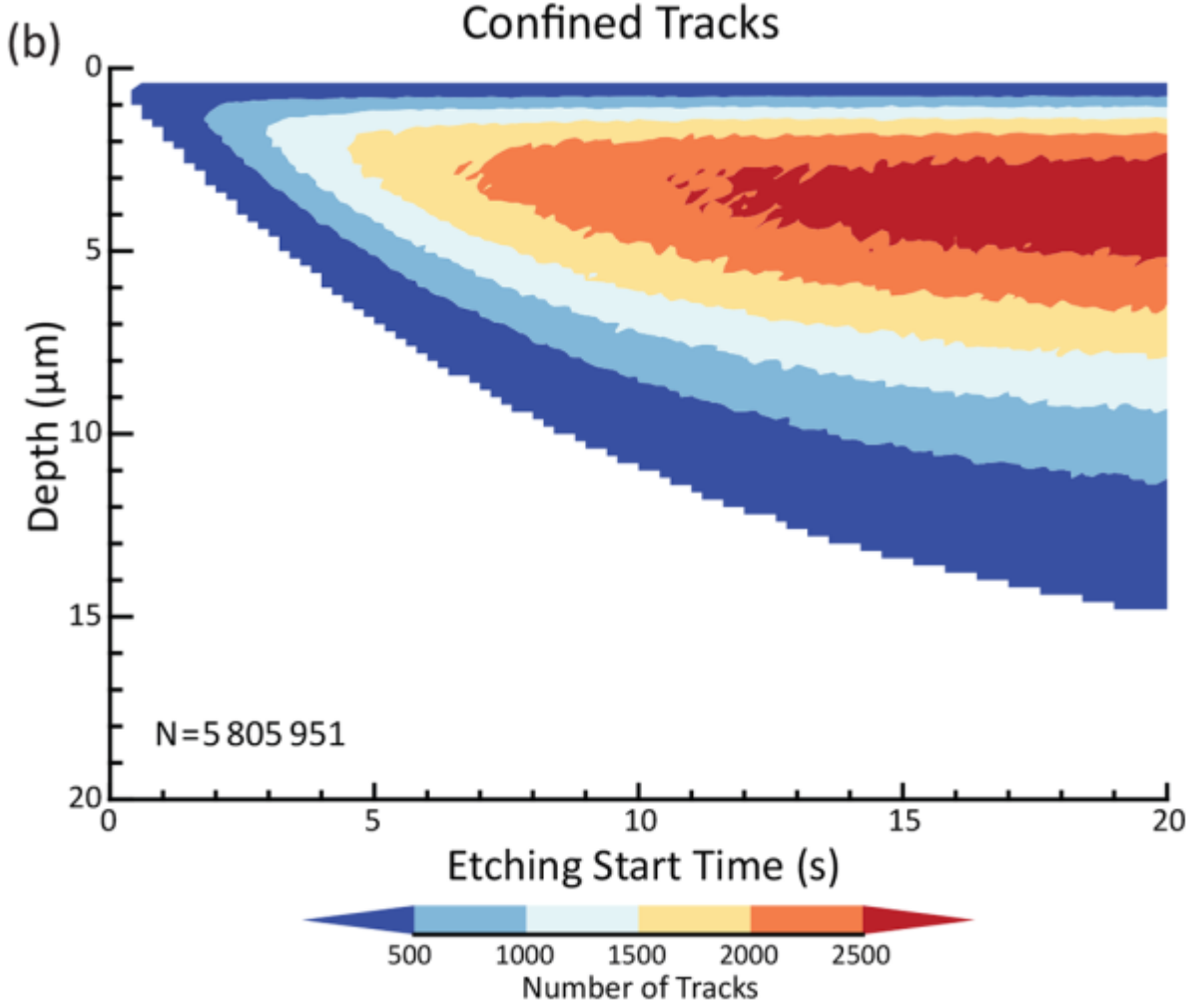


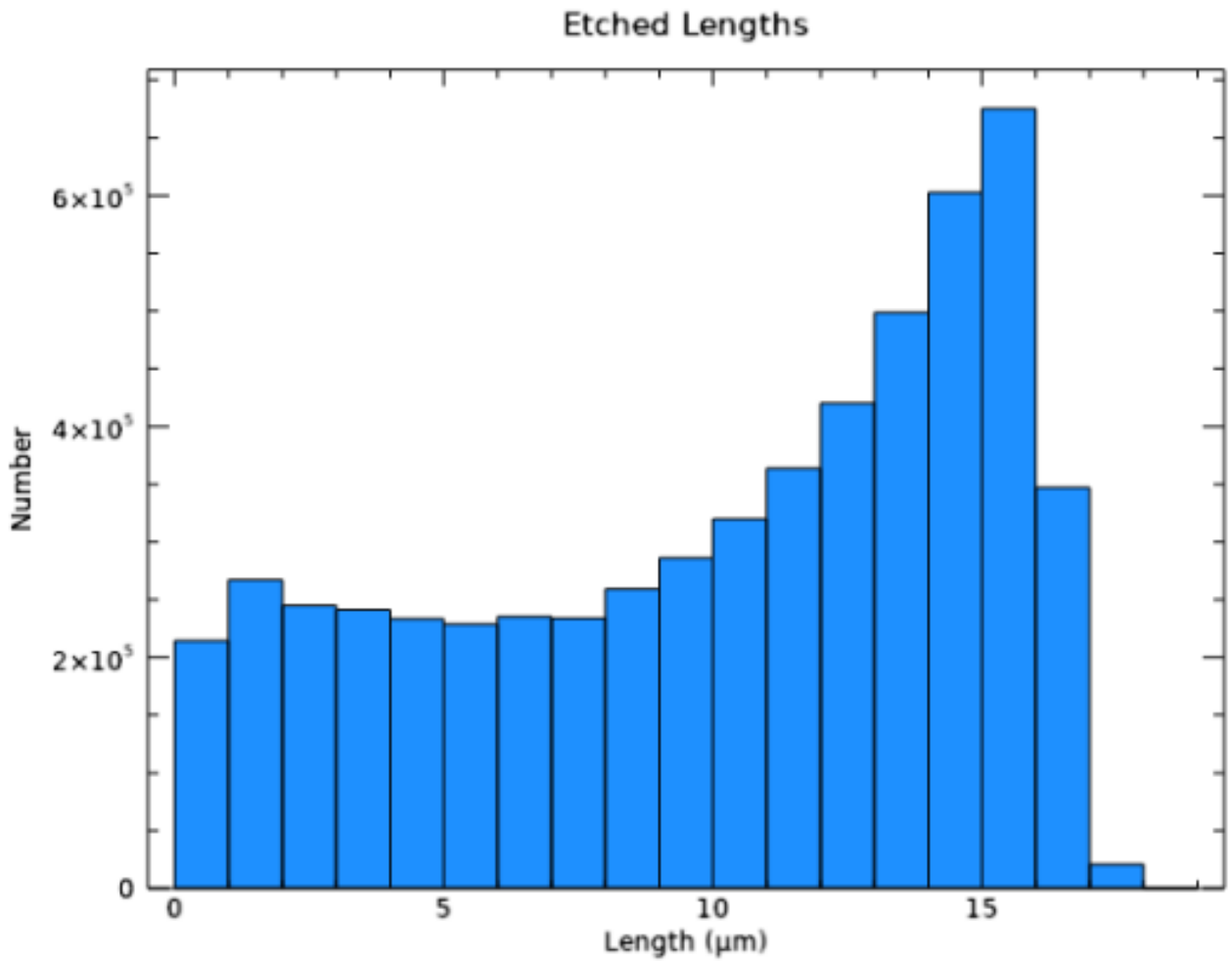
Tamer and Ketcham (2020, Chem Geol)

Generate lots of track intersections…





… and calculate the track length distribution…



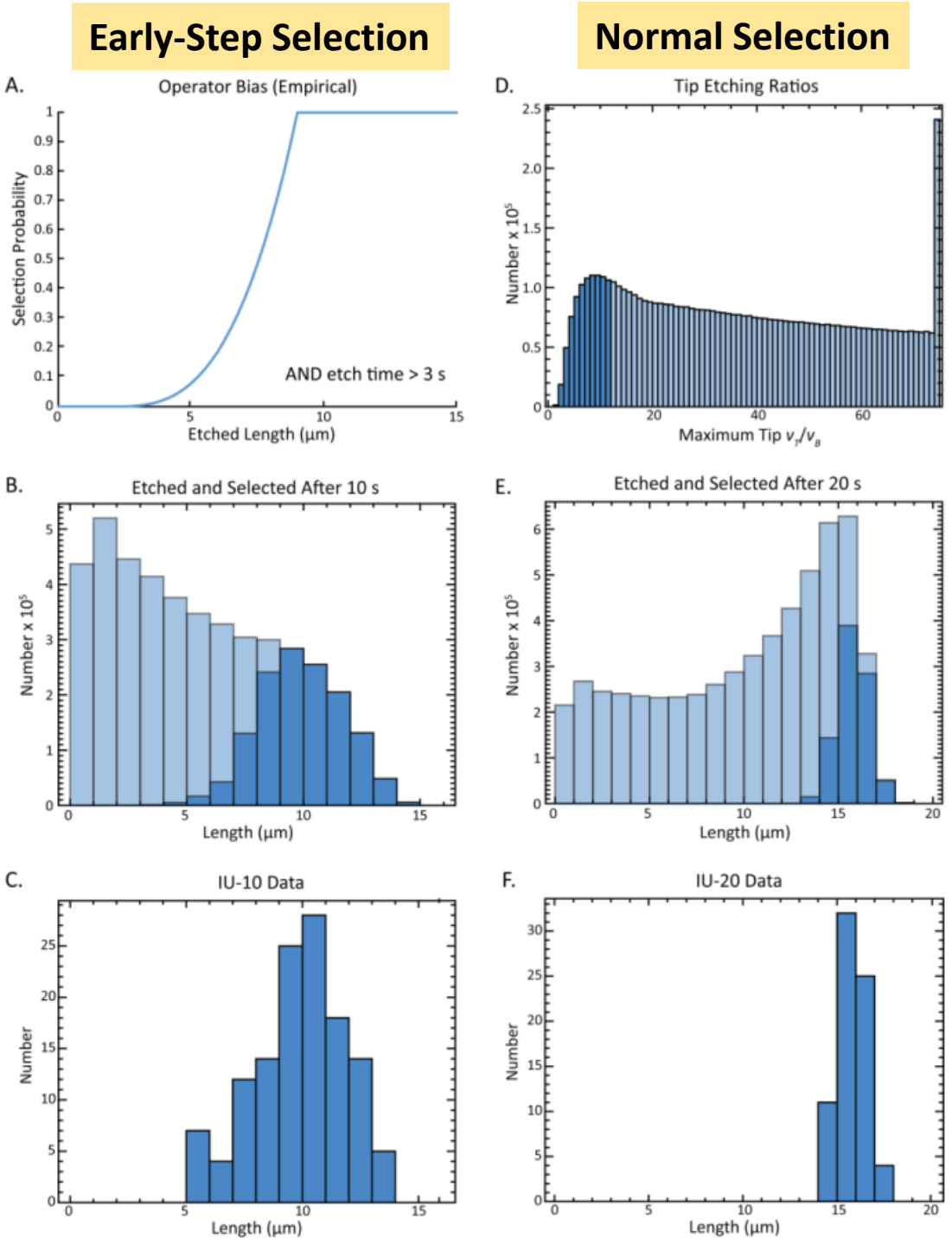
What measured length distributions really are

- Right side of length distributions: longest etched lengths
- Left side: which tracks analyst picks
  - 10-15 sec: visibility
  - 20 sec: shape, tips, etc.
- Grayed bars: tracks intersected but not selected.

Bias functions

Which are taken, which are not?

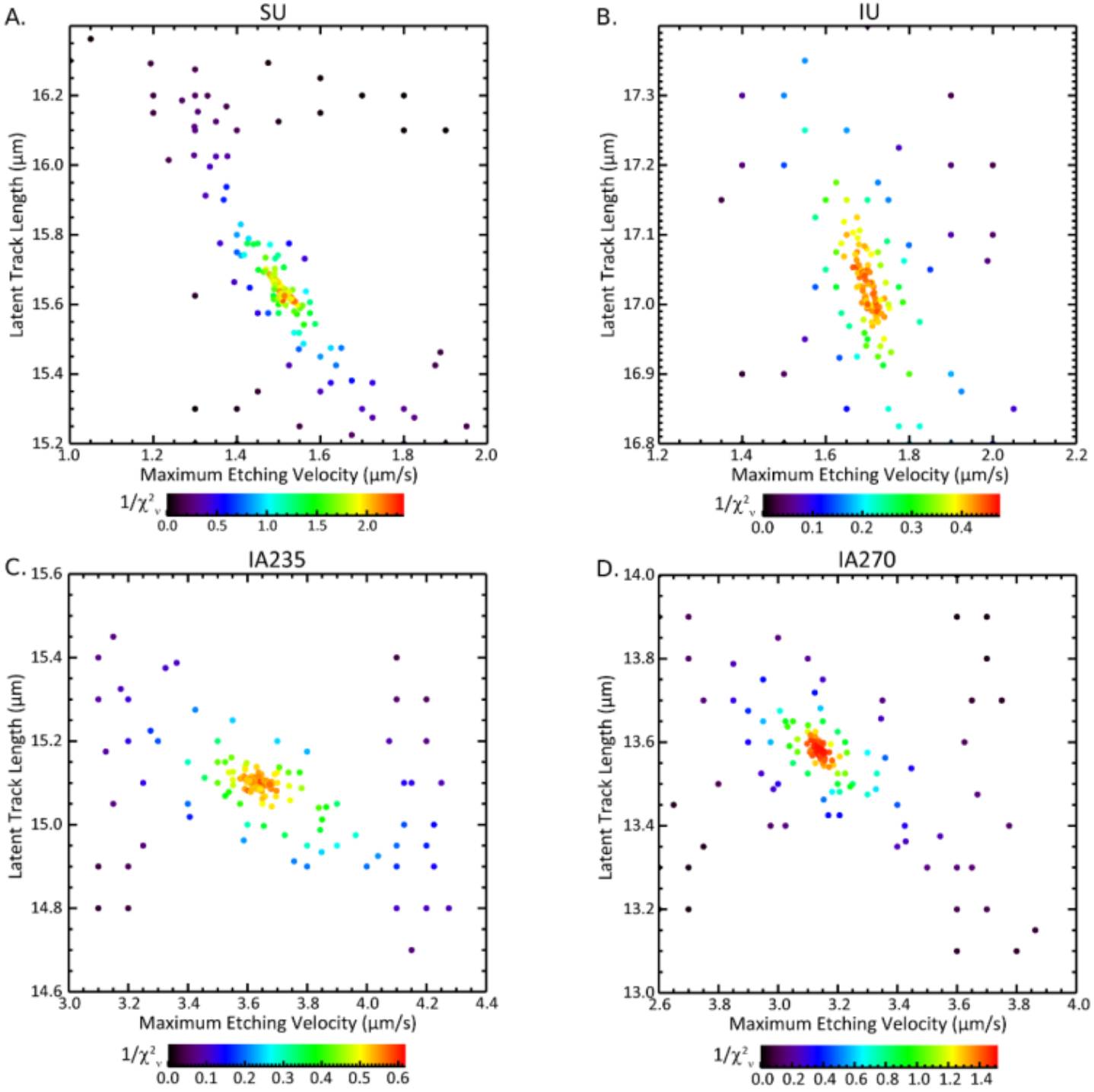
Measurements for these time steps



From Ketcham and Tamer, 2021

Fitting the models to the data

- Tricky, as much is randomized
  - Semi- and latent track L, ϕ, δ
  - Intersection time and depth
  - Impinged point along latent track
  - Leads to transitory minima
- Method: simplex, minimize χ_ν^2
  - Randomize 10^5-10^7 tracks
  - Use many starting points
- Fitted parameters:
  - Latent length
  - v_{Tmax}
  - Core length



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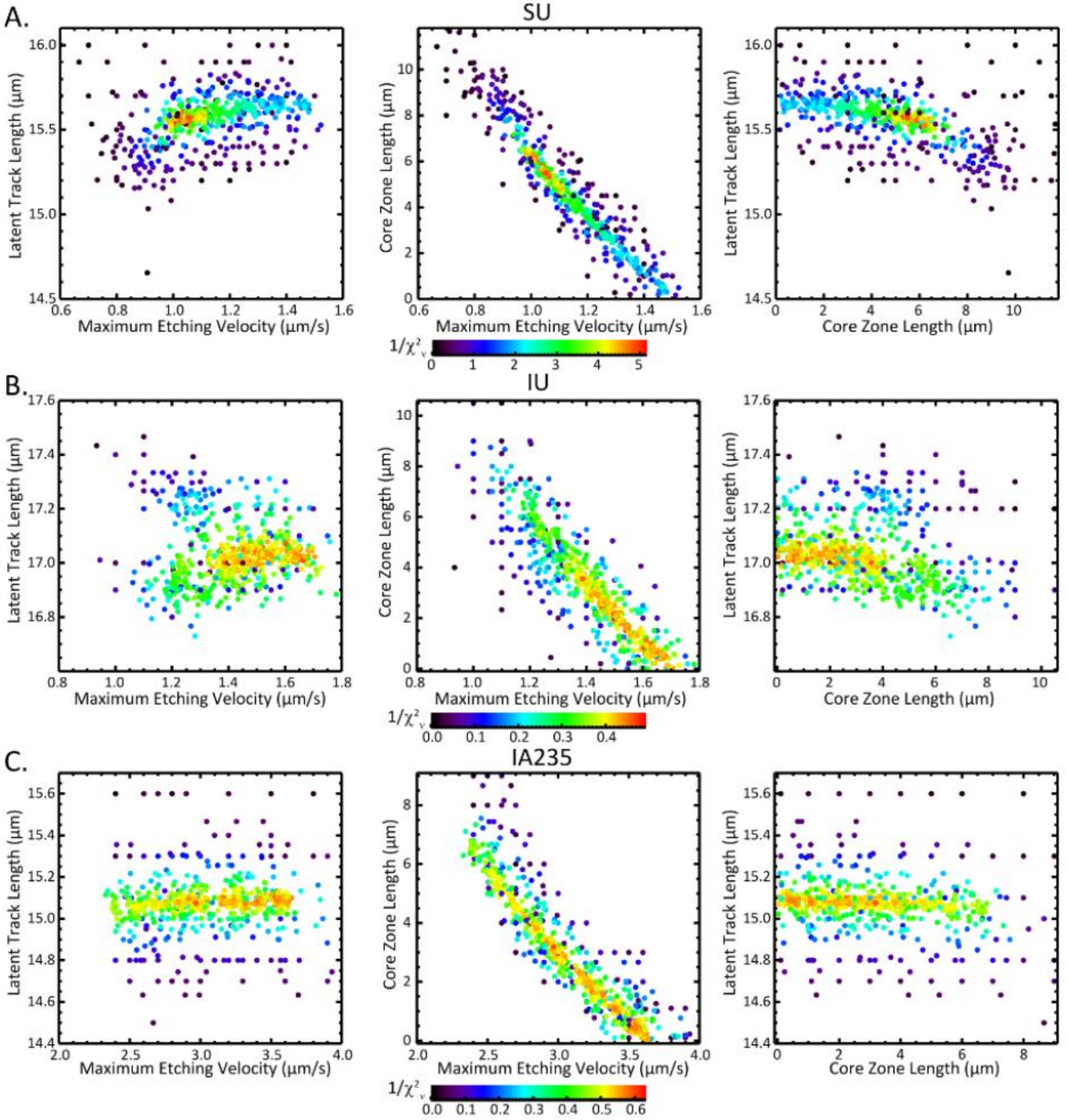

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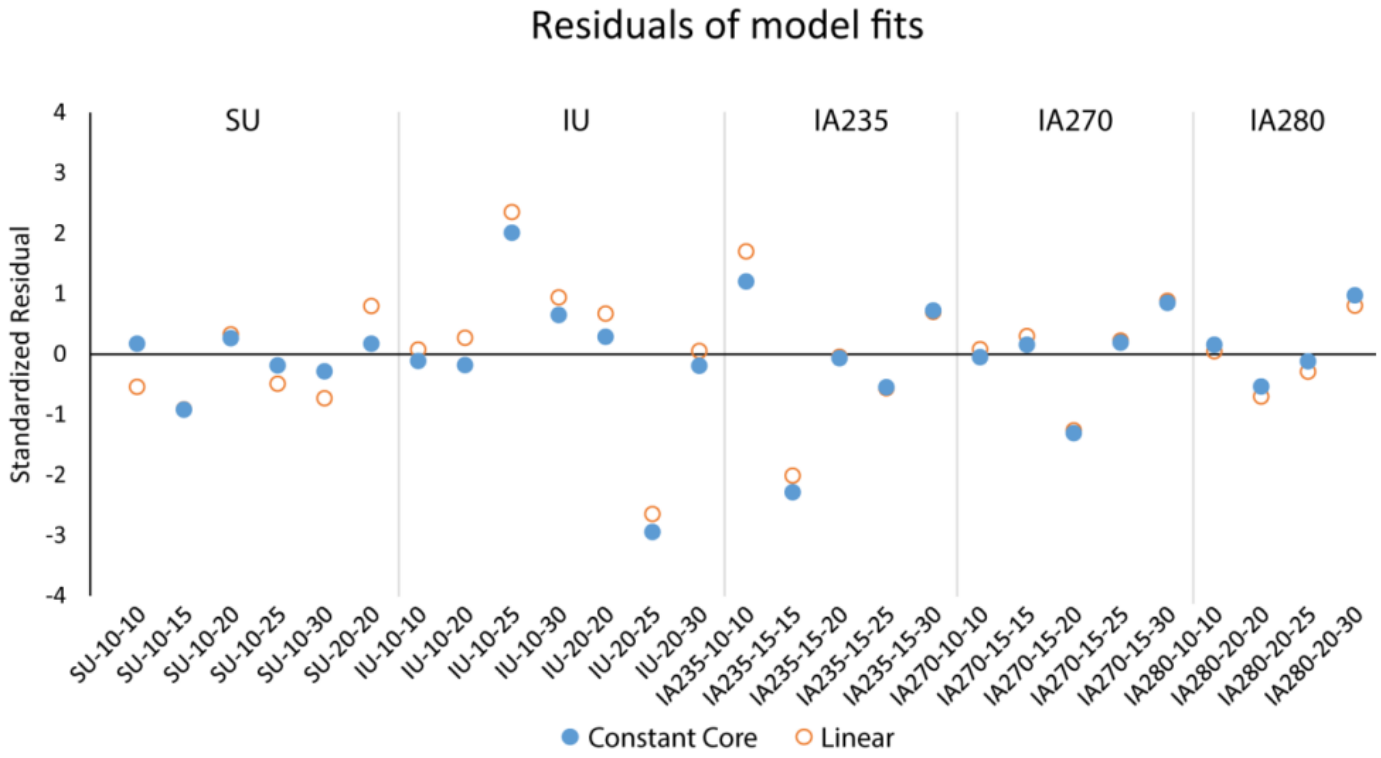
- Models fit pretty well



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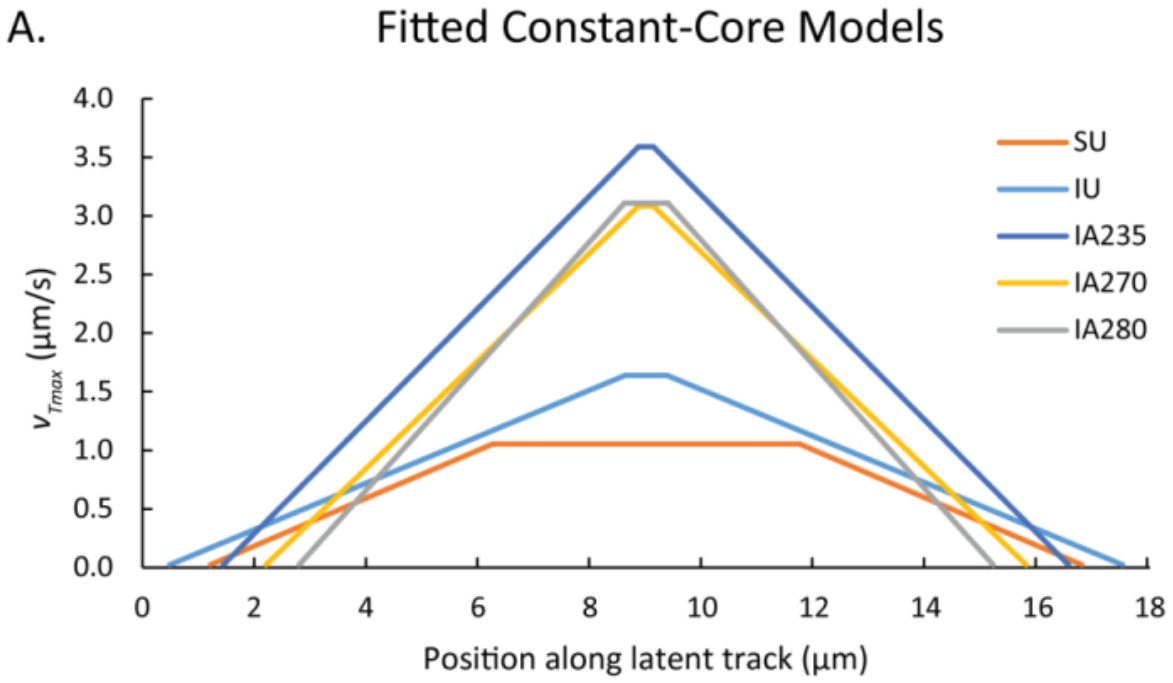
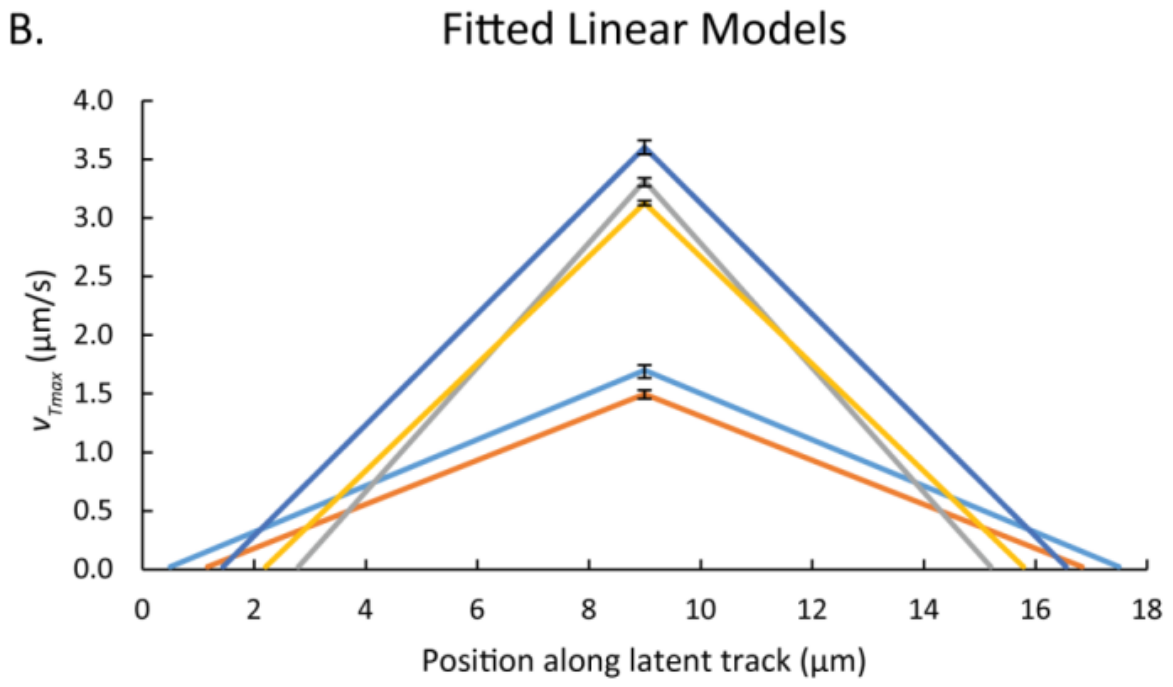
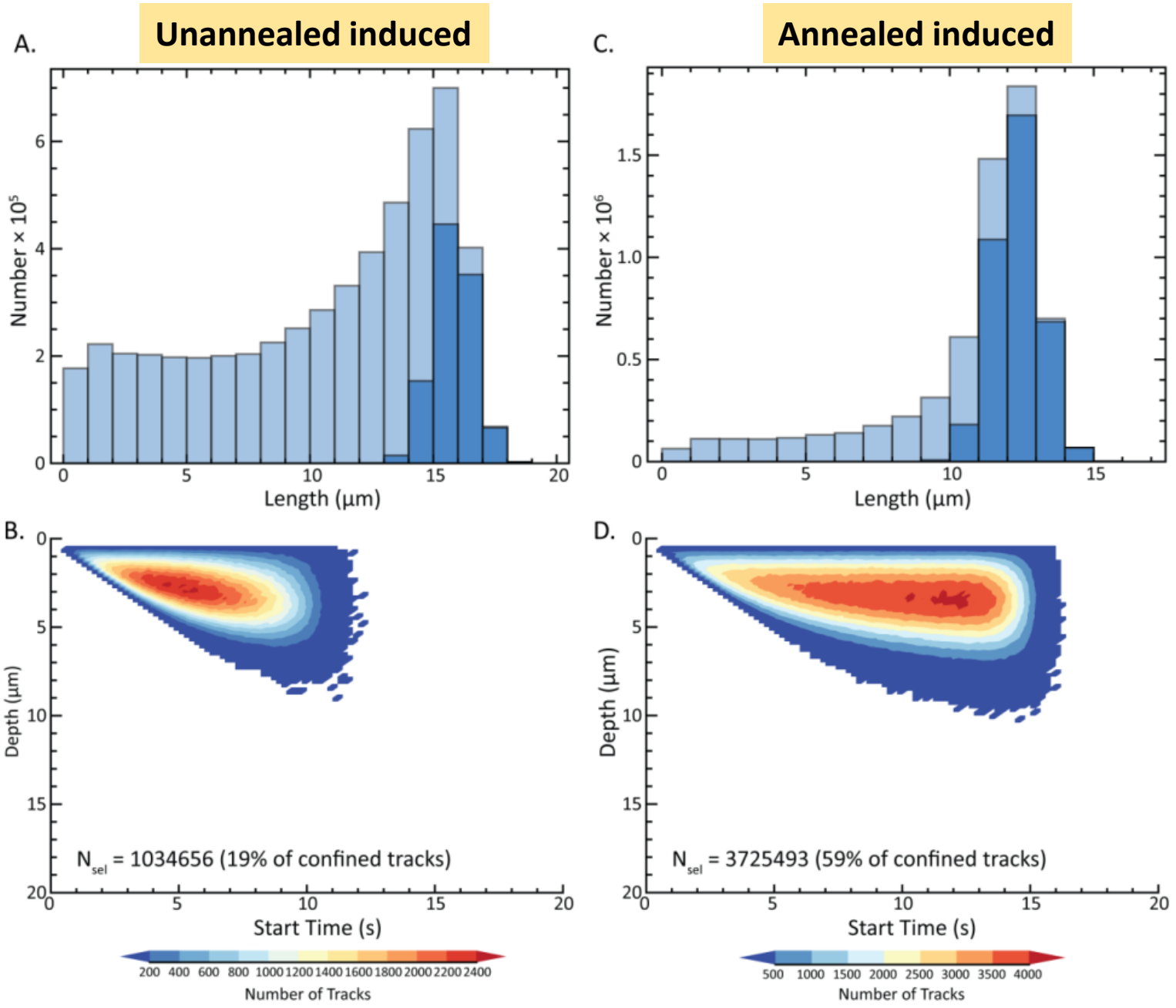
- Models fit pretty well
- Unannealed look different than annealed…



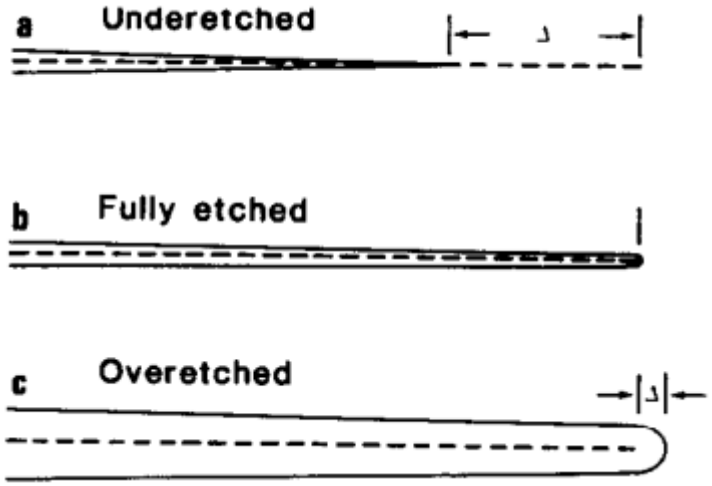


Anti-length biasing

- Shorter tracks are less likely to be intersected (length biasing), but…
- They also take less time to etch, and are more likely to etch completely



This contradicts how we've thought of tracks for >40 years



Laslett et al 1984

The "Fully etched tracks" model

Tamer et al. 2019

LENGTH DISTRIBUTIONS OF FISSION TRACKS IN THICK CRYSTALS

M. DAKOWSKI*
Centre d'Etudes Nucléaires, Saclay, 91190 Gif-sur-Yvette, France

(*Received* 3 *January* 1978; *in revised form* 17 *March* 1978)

BIAS IN MEASUREMENT OF FISSION-TRACK LENGTH DISTRIBUTIONS

G. M. LASLETT
C.S.I.R.O. Division of Mathematics and Statistics, P.O. Box 310, South Melbourne, Victoria 3205, Australia

W. S. KENDALL
Department of Mathematical Statistics, The University, Hull HU6 7RX, U.K.

and

A. J. W. GLEADOW and I. R. DUDDY
Department of Geology, University of Melbourne, Parkville, Victoria 3052, Australia

(*Received* 19 *October* 1981; *in revised form* 21 *April* 1982)

THE RELATIONSHIP BETWEEN FISSION TRACK LENGTH AND TRACK DENSITY IN APATITE

G. M. LASLETT
C.S.I.R.O. Division of Mathematics and Statistics, Private Bag 10, Clayton, Victoria 3168, Australia

and

A. J. W. GLEADOW and I. R. DUDDY
Department of Geology, University of Melbourne, Parkville Victoria 3052, Australia

(*Received* 22 *February* 1983; *in revised form* 3 *January* 1984)

Apatite Fission Track Analysis: Geological Thermal History Analysis Based on a Three-Dimensional Random Process of Linear Radiation Damage

R. F. Galbraith; G. M. Laslett; P. F. Green; I. R. Duddy

Philosophical Transactions: Physical Sciences and Engineering, Vol. 332, Stochastic processes. (Sep. 15, 1990), pp. 419-438.

All assume that tracks are line segments in space, and p(intersection) = p(measurement)

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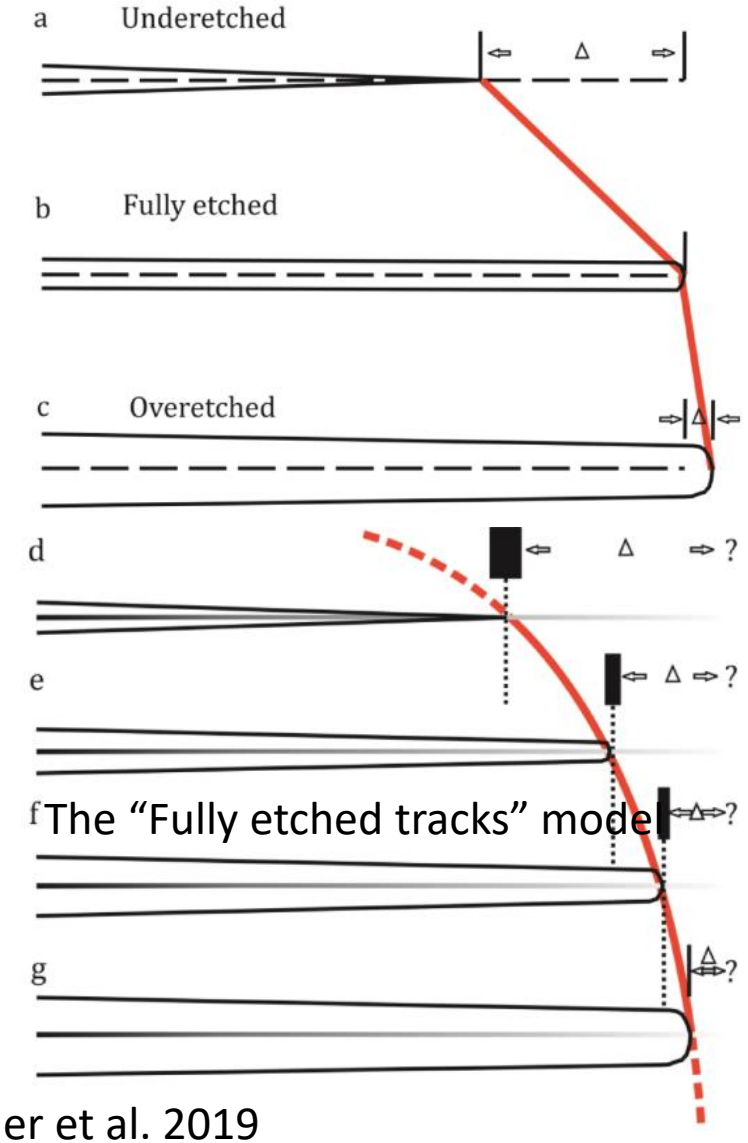

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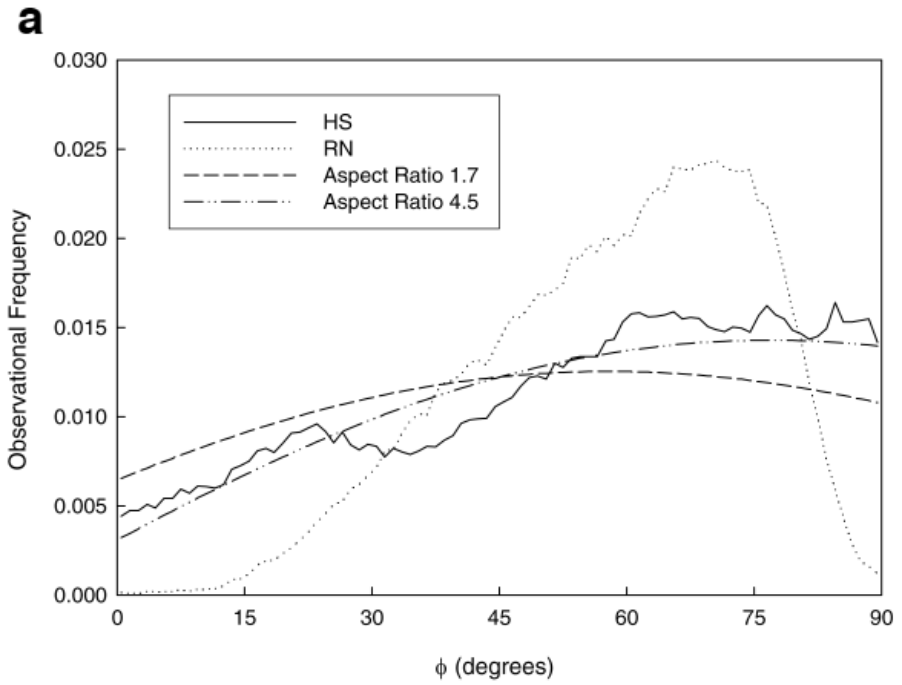


American Mineralogist, Volume 88, pages 817–829, 2003

Observations on the relationship between crystallographic orientation and biasing in apatite fission-track measurements

RICHARD A. KETCHAM[1,*]

[1]Department of Geological Sciences, The University of Texas at Austin, Austin, Texas 78712, U.S.A.

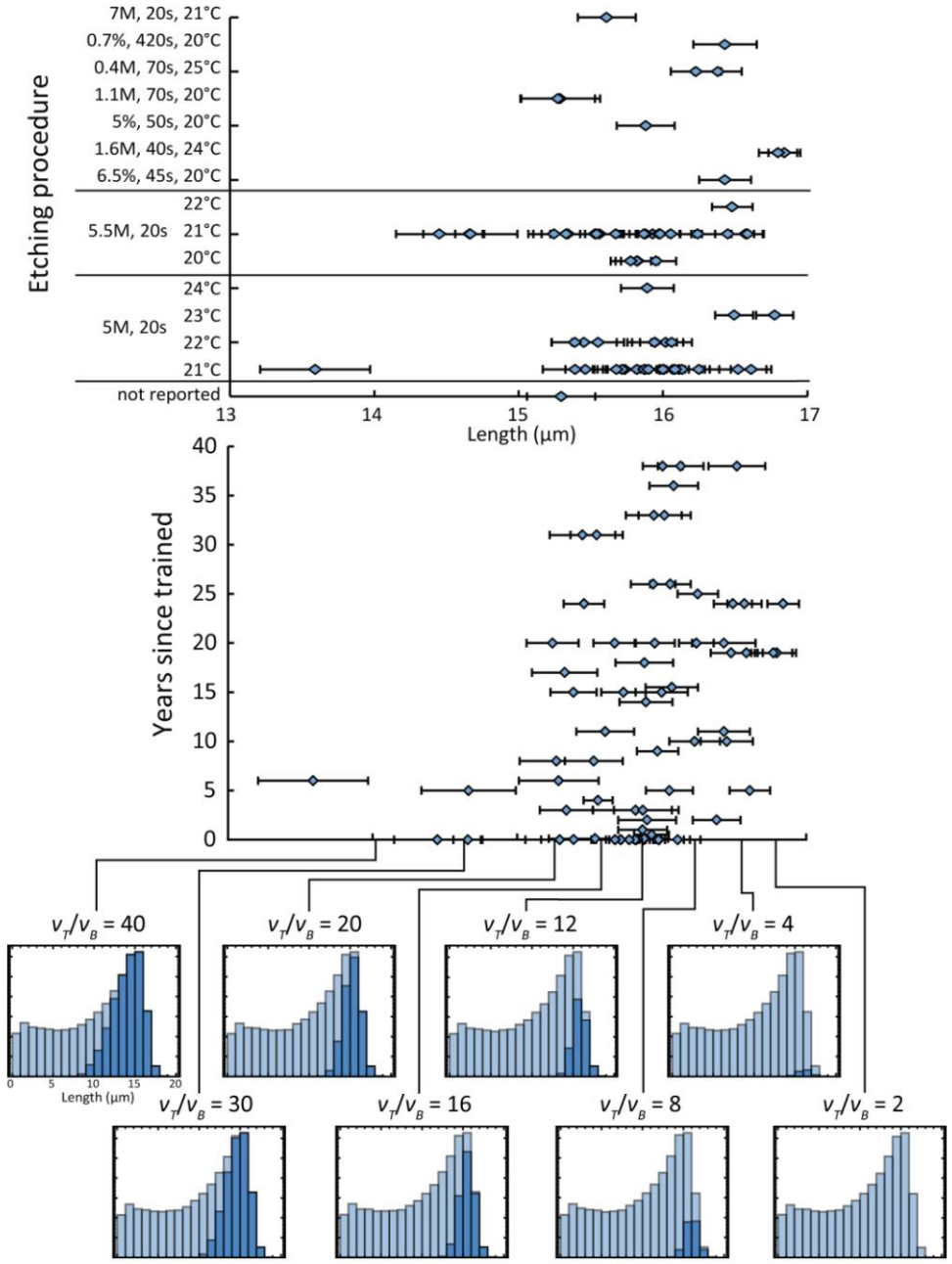
American Mineralogist, Volume 92, pages 789–798, 2007

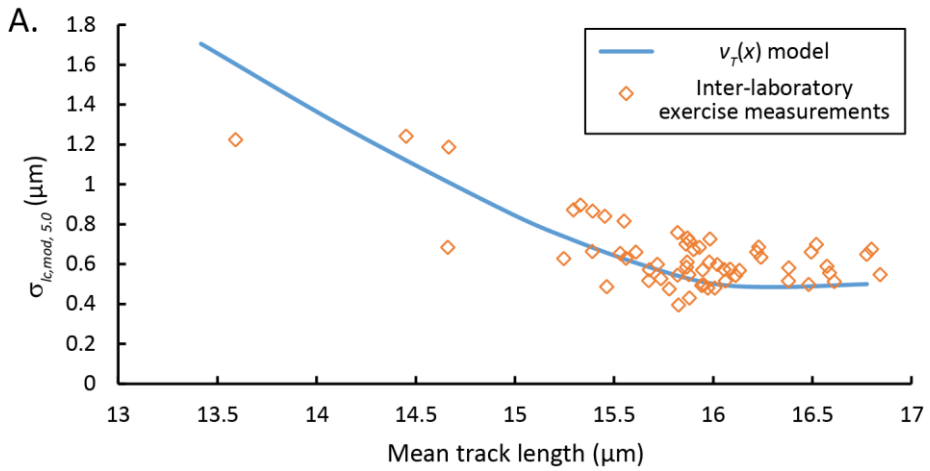
Improved measurement of fission-track annealing in apatite using c-axis projection

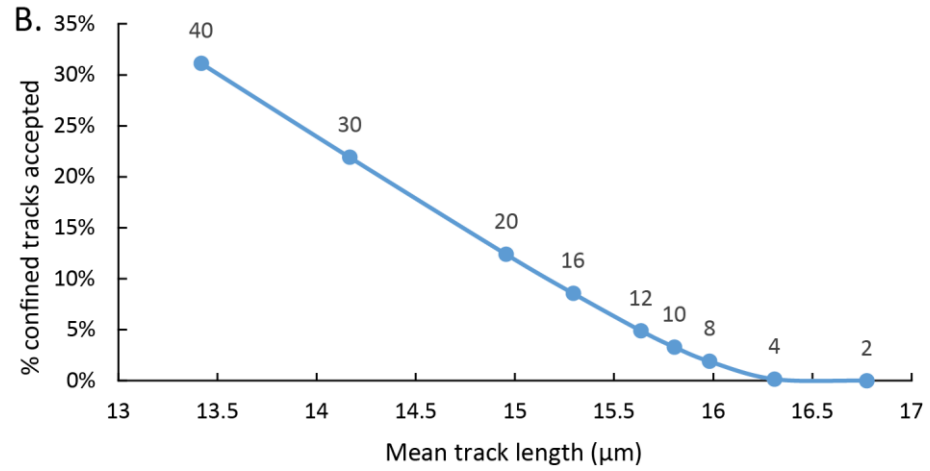
RICHARD A. KETCHAM,[1,*] ANDREW CARTER,[2] RAYMOND A. DONELICK,[3] JOCELYN BARBARAND,[4] AND ANTHONY J. HURFORD[2]

All assume that tracks are line segments in space, and p(intersection) = p(measurement)

Is track selection responsible for variation?



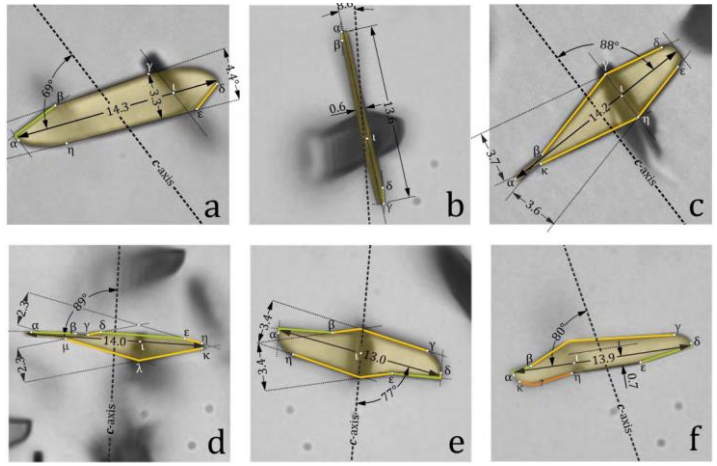




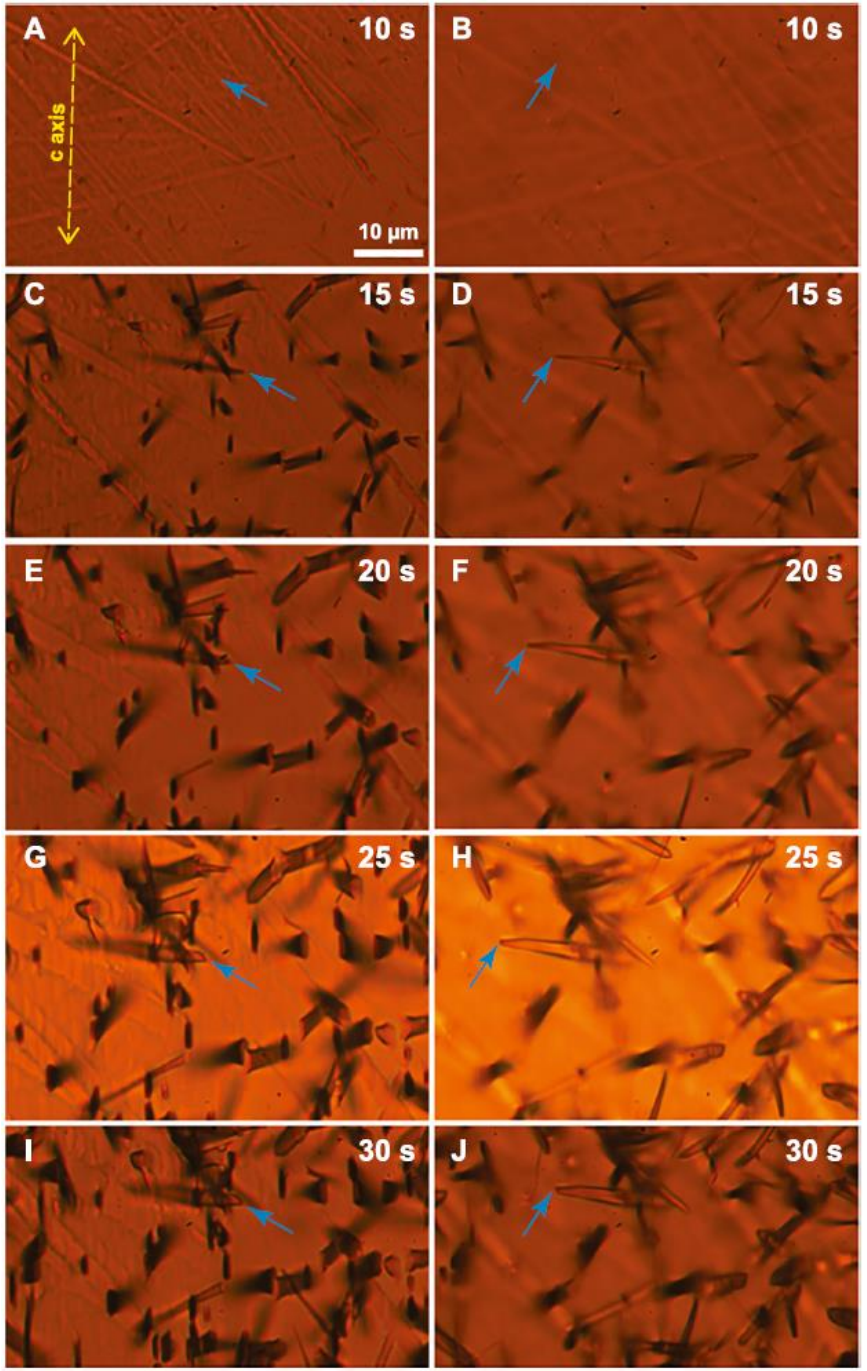
From Ketcham and Tamer, 2021

Why it matters

- Our conception of tracks comes closer to reality
  - Lo, Anti-length biasing, left vs. right
  - Focus on source of reproducibility
- It paves the way for redoing FT based on computer vision



From Jonckheere et al., 2021



Why it matters

- Our conception of tracks comes closer to reality
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  - Focus on source of reproducibility
- It paves the way for redoing FT based on computer vision
- But there's a LOT of work to do
  - More apatites with different etching
  - More levels of annealing
    - Both spontaneous and induced
  - Etching and annealing anisotropy