

Hierarchy of Knowledge: SEL Edition

Ray Ladbury

Radiation Effects and Analysis Group

NASA Goddard Space Flight Center

Knowledge Hierarchies: The Structure or What We Know

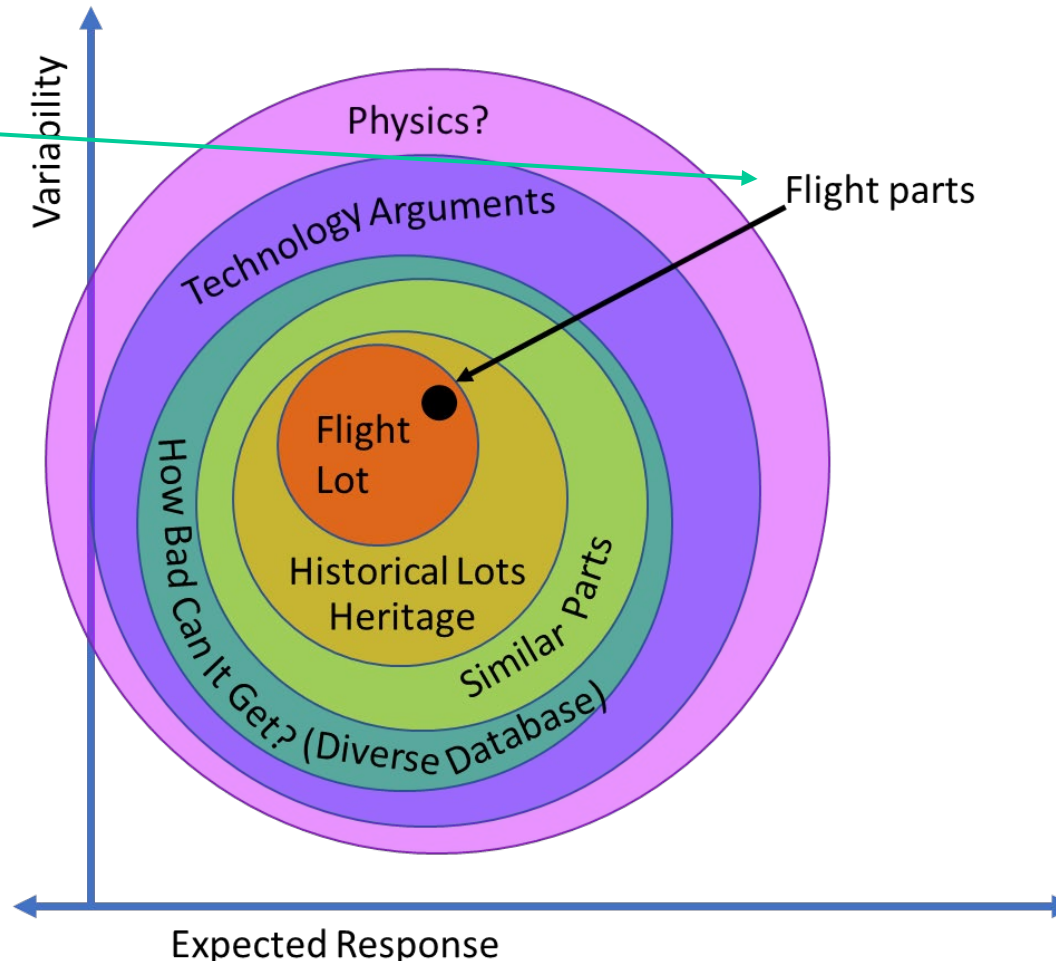
In knowledge hierarchies, knowledge is structured

Most Fundamental level—the thing we want to know (e.g. flight-part performance)

Hierarchies go from most representative outward to greater abstraction

More representative levels are subsets of higher levels, and so must present a consistent picture.

Usually, (not always) more representative levels provide tighter constraints



SEL provides an example of a knowledge hierarchy with an interesting structure

Most useful constraints enter at highest and lowest levels of abstraction

Different levels produce different kinds of constraints—on both consequences and rate.

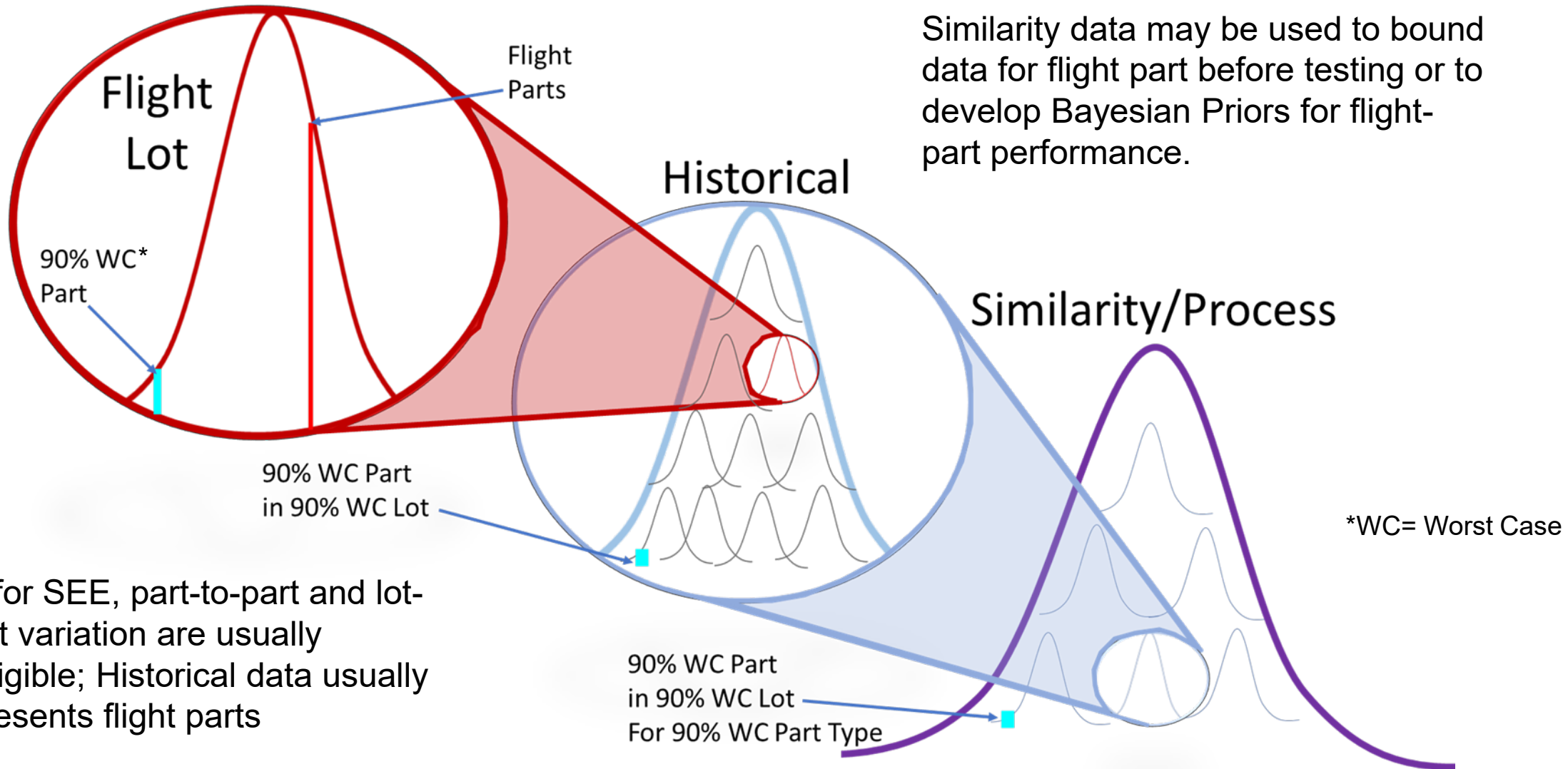


Outline

- Hierarchies of Knowledge
- Single-Event Effect (SEE) Hierarchies in general
- Single-Event Latchup* (SEL) Hierarchy—specificity doesn't help
- Going Waaaaaay out—Physics and SEL
- SEL and Technology
- SEL and a BUNCH of Datasets

*In CMOS=Complementary Metal-Oxide-Semiconductor

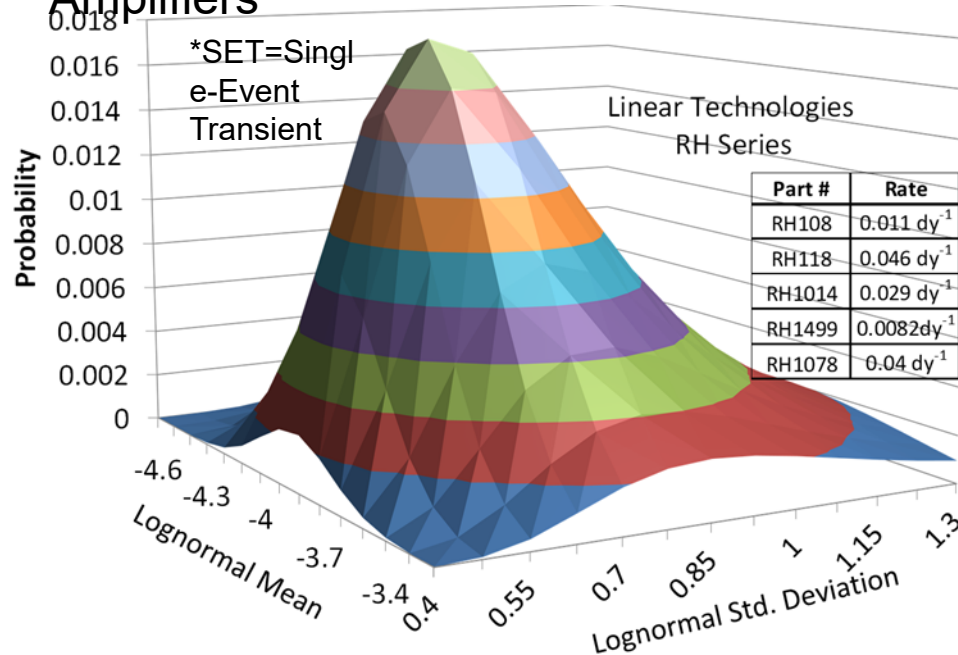
Most Representative Data: If All Levels Mattered Equally



But for SEE, part-to-part and lot-to-lot variation are usually negligible; Historical data usually represents flight parts

Example: Bayesian Priors for SET Rate and Width

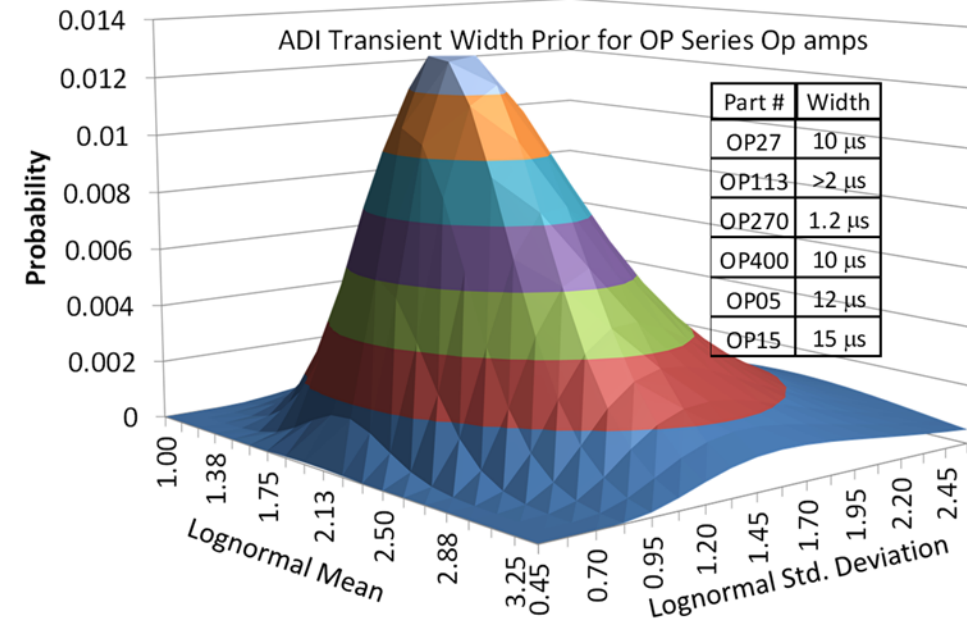
Family Bounding SET* Rate for Operational Amplifiers



Even small datasets 5 parts can bound SET rates

- Only 10% of op amps have >1 SET per week with 90% confidence

Can also serve as Bayesian Prior for Op Amp SET rate in the family (Lognormal Mean & Standard Deviation)

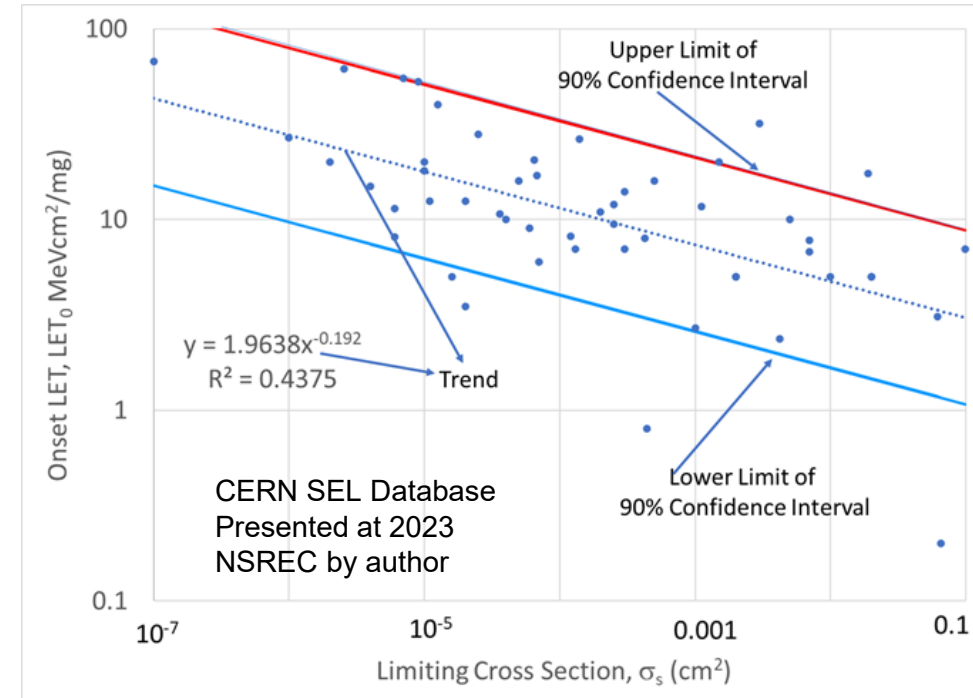
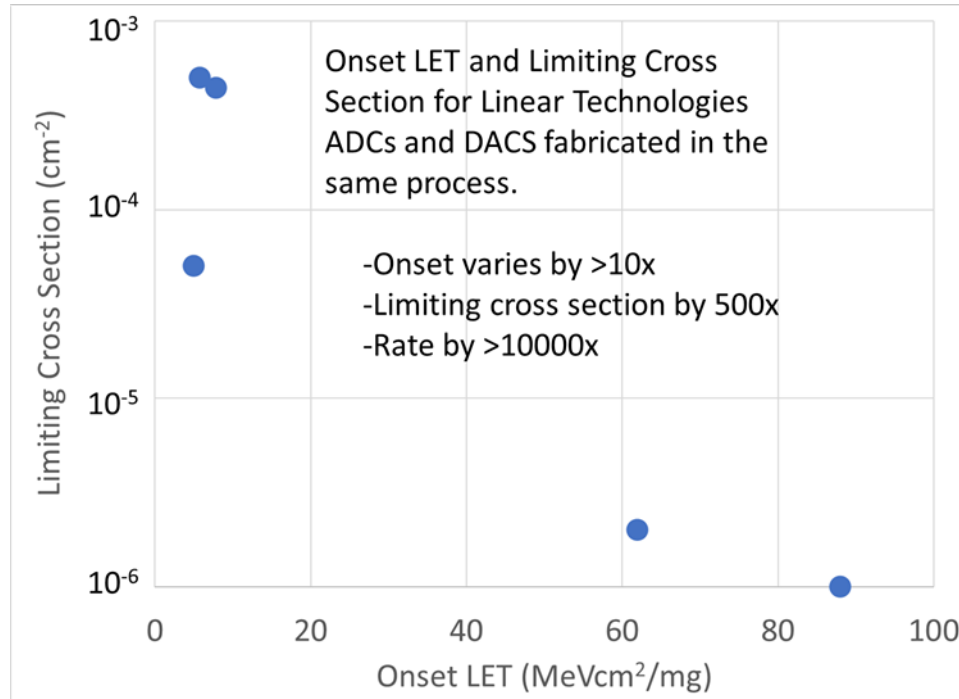


Can similarly bound consequences (SET width)

- <75 μs with 90% confidence for parts in family

Also serves as Bayesian Prior for lognormal distribution of SET widths for family

SEL is Different...



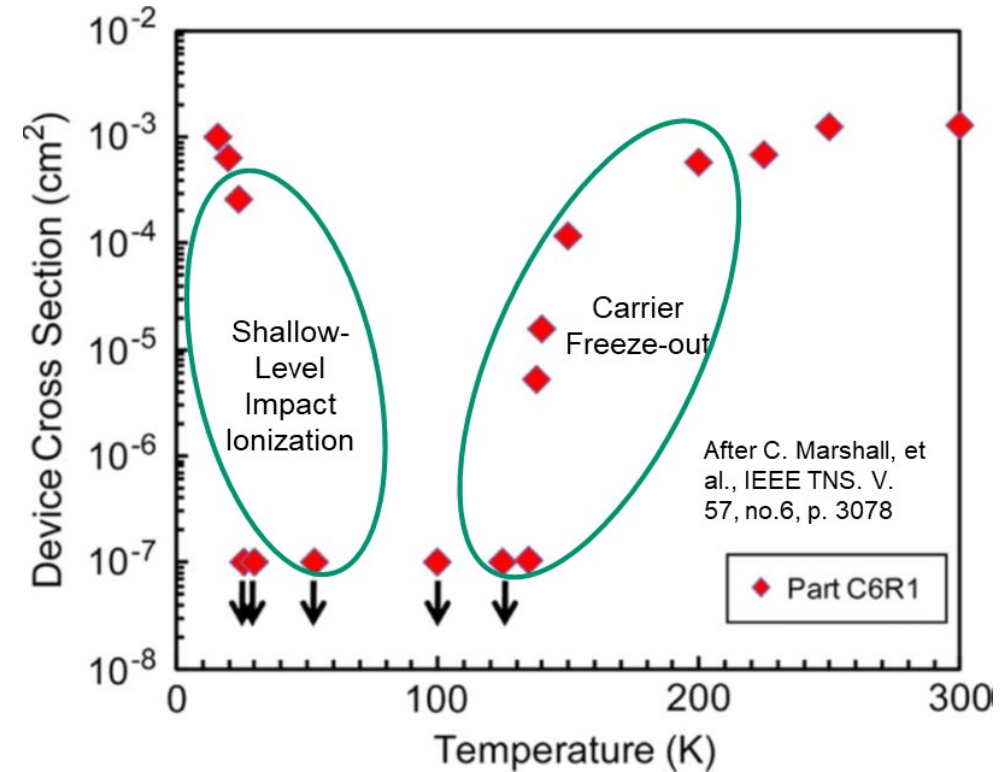
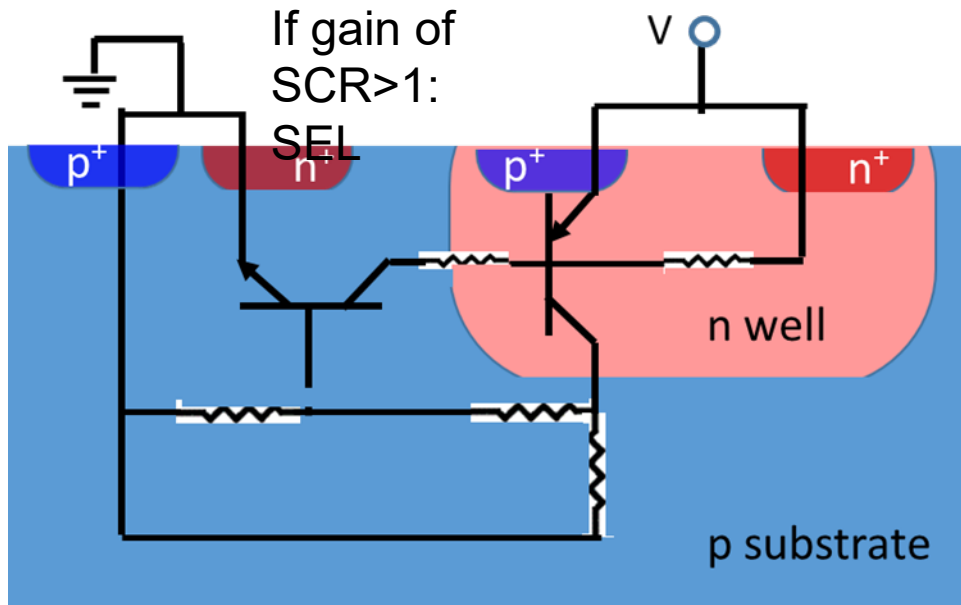
Restricting analysis to “similar” parts does not result in tighter distributions

- SEL response still highly variable
- Lack of statistics makes trends hard to determine

Graph above includes >50 part types—many different functions, vendors, processes

- Distributions no more dispersed
- Added statistics illuminate power-law trend
- Lognormal variation about trend gives good fit

What Physics and Technology Tell Us about SEL



Physics/technology determine technologies and operating conditions that increase risk

SEL occurs in a parasitic *pnpn* structure (Silicon-Controlled Rectifier—SCR) in CMOS if it's gain > 1

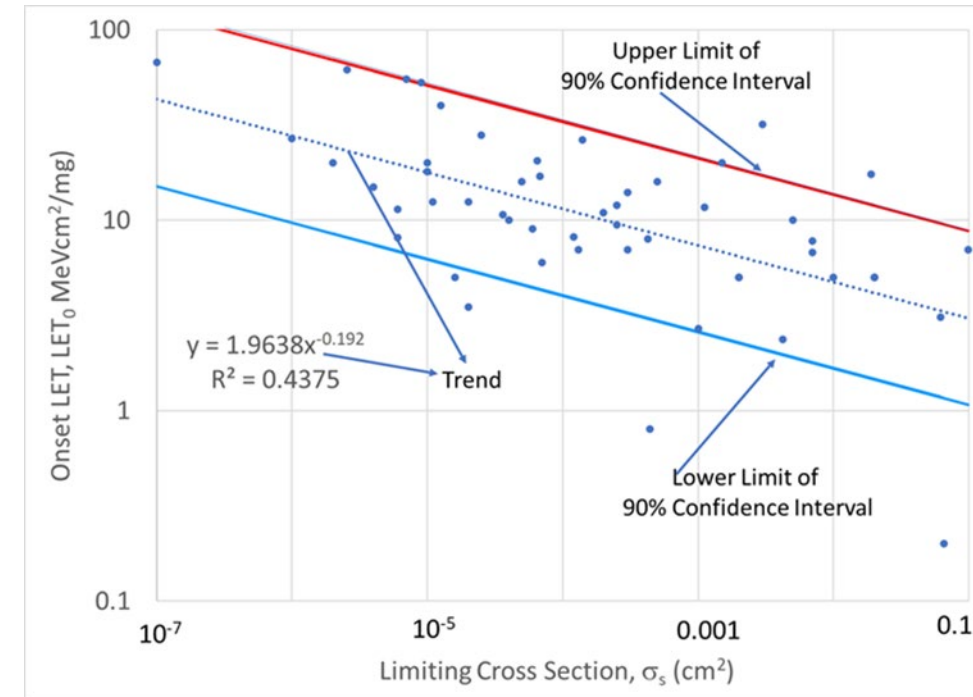
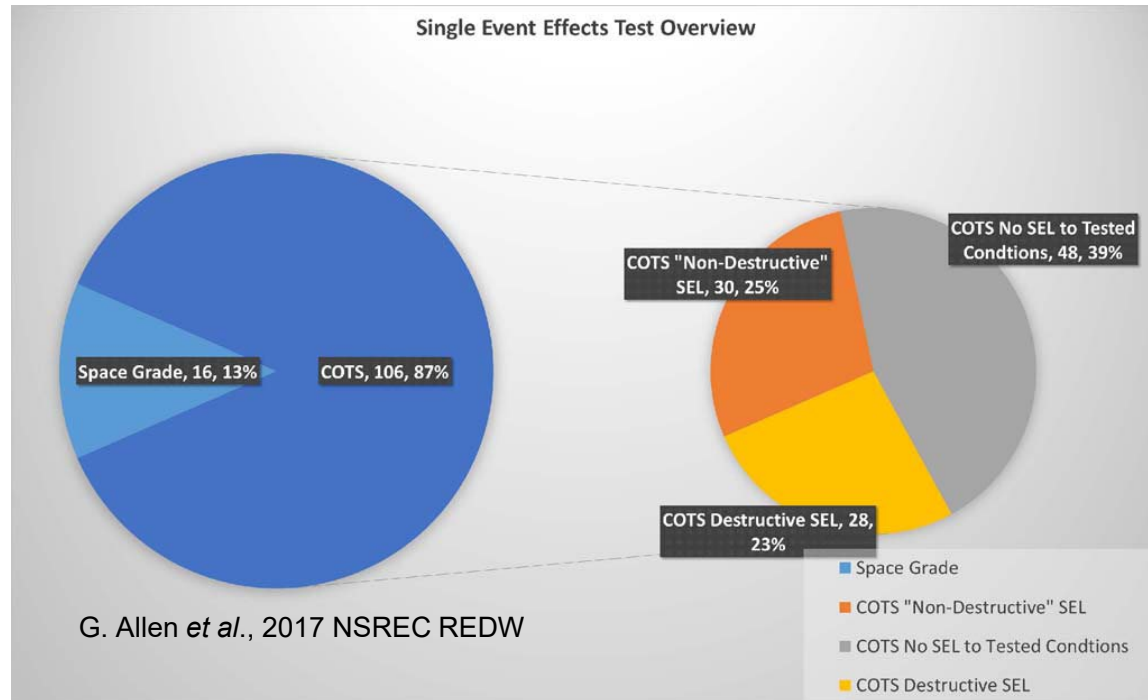
Parasitic nature means SEL is “accidental” effect—unlikely in “designed” bipolar technologies

Higher voltage, high temperature increase SEL risk

Convention: SEL risk decreases at low temperature due to freeze-out of charge carriers (+ lower gain)

However, below ~40K, increased carrier mobility increases # charge carriers due to impact ionization

SEL: Different Databases Provide Different Info



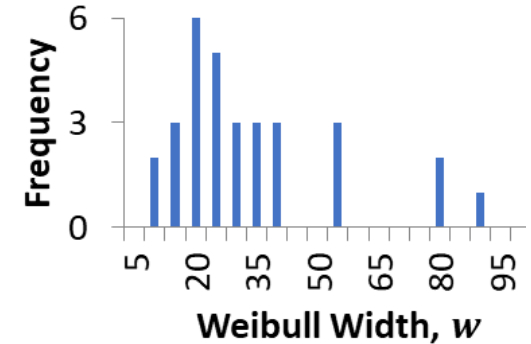
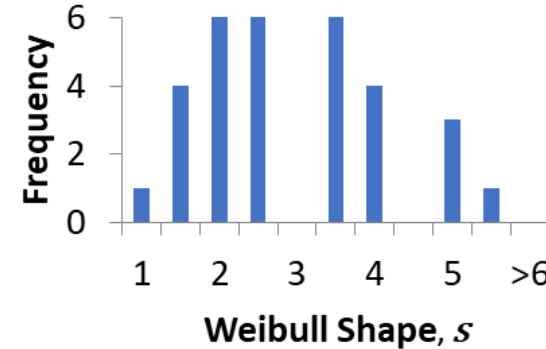
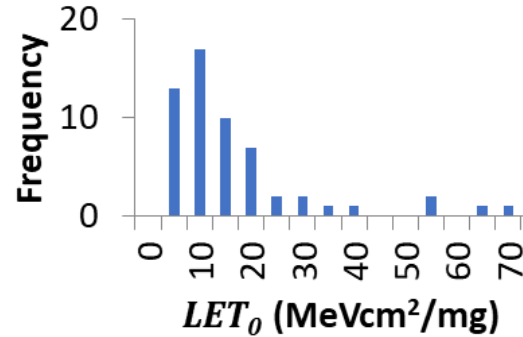
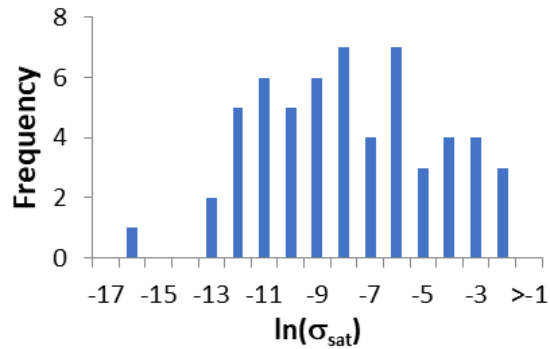
If database has a high percentage of go/no-go SEL test

- Good for determining % parts susceptible, % destructive...
- Good for comparing susceptibilities across part types
- Not good for estimating/constraining SEL rates

If database has Weibull fits to σ vs. LET

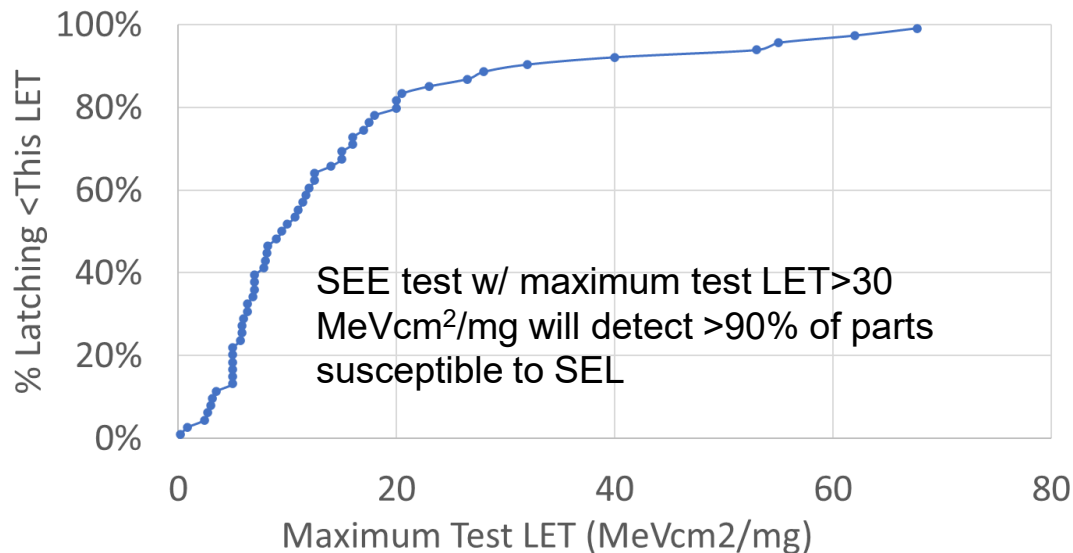
- Can look for trends among fit parameters, rates, etc.
- Onset LET = LET_0 , Saturation = σ_{sat} , width = w , and shape = s .
- Broad database → trends persist across vendor, part type...
- Data can impose constraints influencing rate estimates
- Need to ensure Weibull fit is best fit, not bounding

What Do Parameter Distributions Tell Us



57 of 81 parts in CERN SEL database provide estimates of both onset (LET_0) and saturation (σ_{sat})

- σ_{sat} spans >6 orders of magnitude, LET_0 2 orders



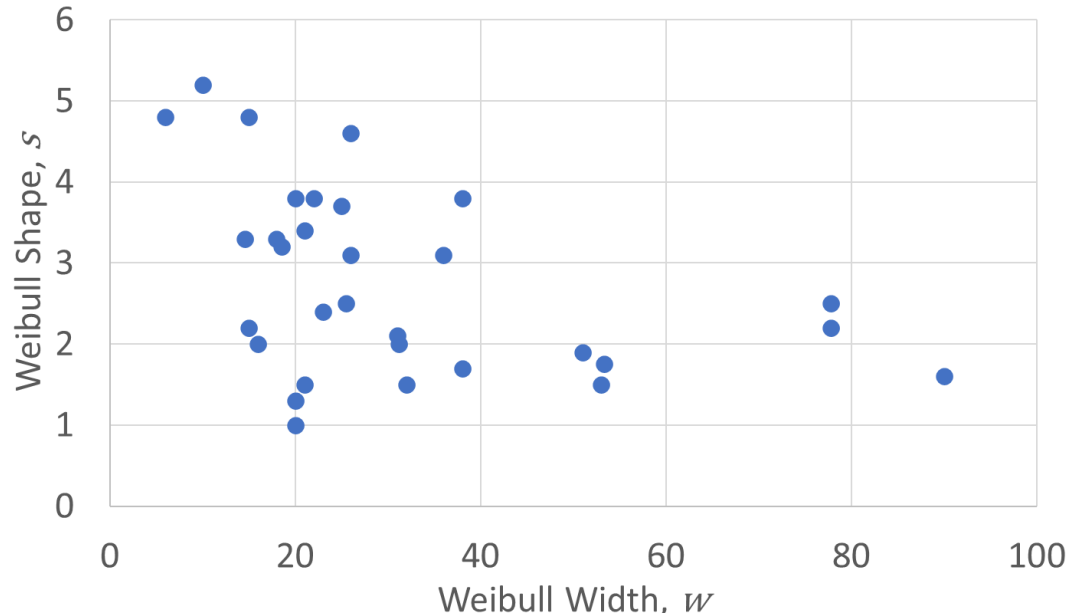
31 of 81 parts in CERN SEL database provide estimates of all Weibull fit parameters

- ~80% of parts have $s \geq 2$; ~80% have $w < 40$

Weibull (4 parameter) → 6 correlation coefficients

- Only 2 are significant
 - $\text{Correl}(\sigma_{sat}, LET_0) = -0.27$
 - $\text{Correl}(w, s) = -0.43$
- Correlations have important implications for how data can be used to model a priori SEL susceptibility

Two Types of Correlation: Bothersome and Useful

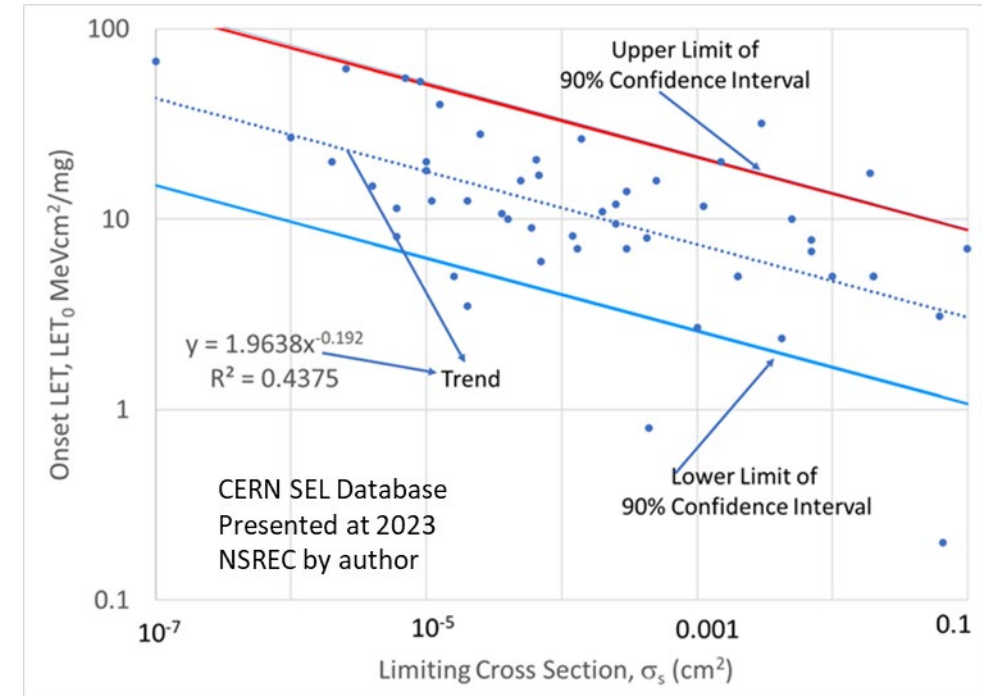


Although correlation of s with w clear at extremes

- Not clear it persists for all parts over full range
- Could be driven by “outliers”
- No clear model for describing either trend or variation

It does mean one cannot treat w and s as independent

- Suggest nonparametric treatment with w - s pairs taken from 31 parts in database for which they are defined



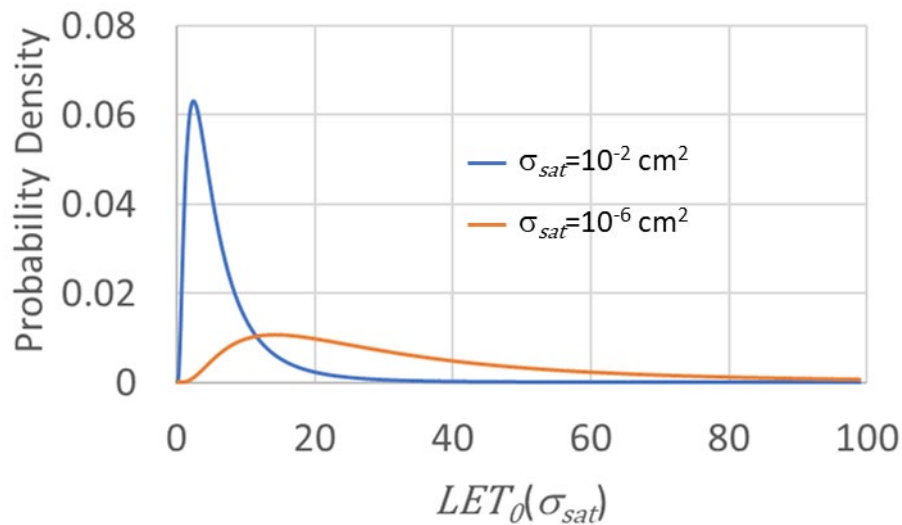
In contrast, power-law trend between LET_0 and σ_{sat} is clear, and variation about trend follows a lognormal with constant standard deviation s_{ln} fairly well

- 90% Confidence Interval contains nearly 90% of the 57 parts with well determined LET_0 and σ_{sat} .

Model useful for supplementing limited flight part data

SEL Rate Bound w/ One (Very High) Test LET

Validating the Model



Can express LET_0 as function of σ_{sat} or vice versa

- Best fit to CERN data yields $m_{ln} = 1.96 * (\sigma_{sat})^{-0.192}$, $s_{ln} = 0.82$

$$R_{FOM} = C_{ENV} * \sigma_{sat} / (LET_{0.25})^2 = C_{ENV} * \sigma_{sat} / (LET_0 + w * 0.288^{1/s})^2$$

$$R_{FOM} < C_{ENV} * \sigma_{sat} / (LET_0(CL))^2 \quad (CL = \text{Confidence Level})$$

$$= C_{ENV} * \sigma_{sat} / (\exp(\text{NORMINV}(1-CL, m_{ln}, s_{ln})))^2$$

Should bound rate conservatively at >CL confidence

- Valid for both measured and upper limit σ_{sat}
- Remember: What we predict here is really LET_0

	σ_{obs}	Mfg.*	Func.	Obs. LET_0	Med. LET_0	90%WC LET_0	P($LET_0 \leq$ Obs.)
AD9283	5.0E-07	ADI	ADC	>29.8	31.70	11.10	47%
Blackjack	1.0E-02	LSI	ASIC	>5	4.47	1.66	53%
NB3N2304NZ	2.5E-04	ON Sem	Buffer	8	15.10	5.20	22%
AD7760	5.0E-04	ADI	ADC	8	8.43	2.95	47%
LTC1864	8.0E-05	LTC	ADC	8.5	11.99	4.19	34%
LMG1210	5.0E-05	TI	Driver	12	13.12	4.59	45%
ADP195	8.0E-07	ADI	Switch	>20.3	29.03	10.15	>33%
CC1200	5.0E-04	TI	XCVR	2.7	8.43	2.95	8%
Snapdragon LPDDR5	1.0E-03	QCOM	DDR	<14.3	7.38	2.58	<79%
MAX2982	9.0E-03	Maxim	XCVR	5	4.84	1.69	49%
MAX2981	1.0E-05	Maxim	FE Line Drvr.	16	17.88	6.25	45%

Look at parts tested by JPL with sufficient data to estimate both LET_0 and σ_{sat} over past ~5 yrs

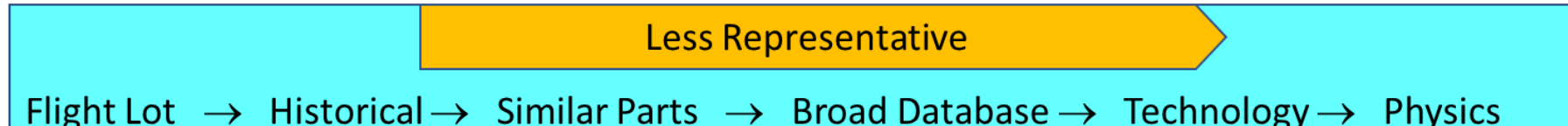
- Use only parts not already in CERN SEL database
- 90% WC bounds all but 1 of the parts
 - Expected for 90% CL given 11 parts

Median predicted LET_0 comes close for most parts!

*See Abbreviations page for Vendors

Conclusion

- Understanding of radiation response derives from many different levels of information
 - Levels form Hierarchy: Usually, the closer to the flight part, the more pertinent the knowledge added



- SEL Hierarchy is different
 - Physics and technology reveal which parts are susceptible and under what conditions
 - Data for same part type (historical or flight) reveal rate and consequences of SEL for that part
 - But...focusing on data for SIMILAR parts does not add more understanding than that from a broad database
 - Focusing only on similar parts decreases statistics and may obscure trends that are clear in broader databases
- Lognormal model for $P(LET_0 | \sigma_{sat})$ is a powerful predictive tool for assessing SEL susceptibility



- Assuming step function σ vs. LET ($w=0$) can bound SEL rate with single σ_{sat} measurement or even upper bound
- See "Under-Constrained SEE Data: Implications for Estimating and Bounding SEE Rates," in IEEE TNS for method using this model for Bayesian SEE analysis and to bound system SEL rates prior to testing (*a priori*)