Monitoring of Industrial Ale and Lager Brewing Fermentations

Maria Josey, Sarah Bartels, Andrew MacIntosh* and Alex Speers

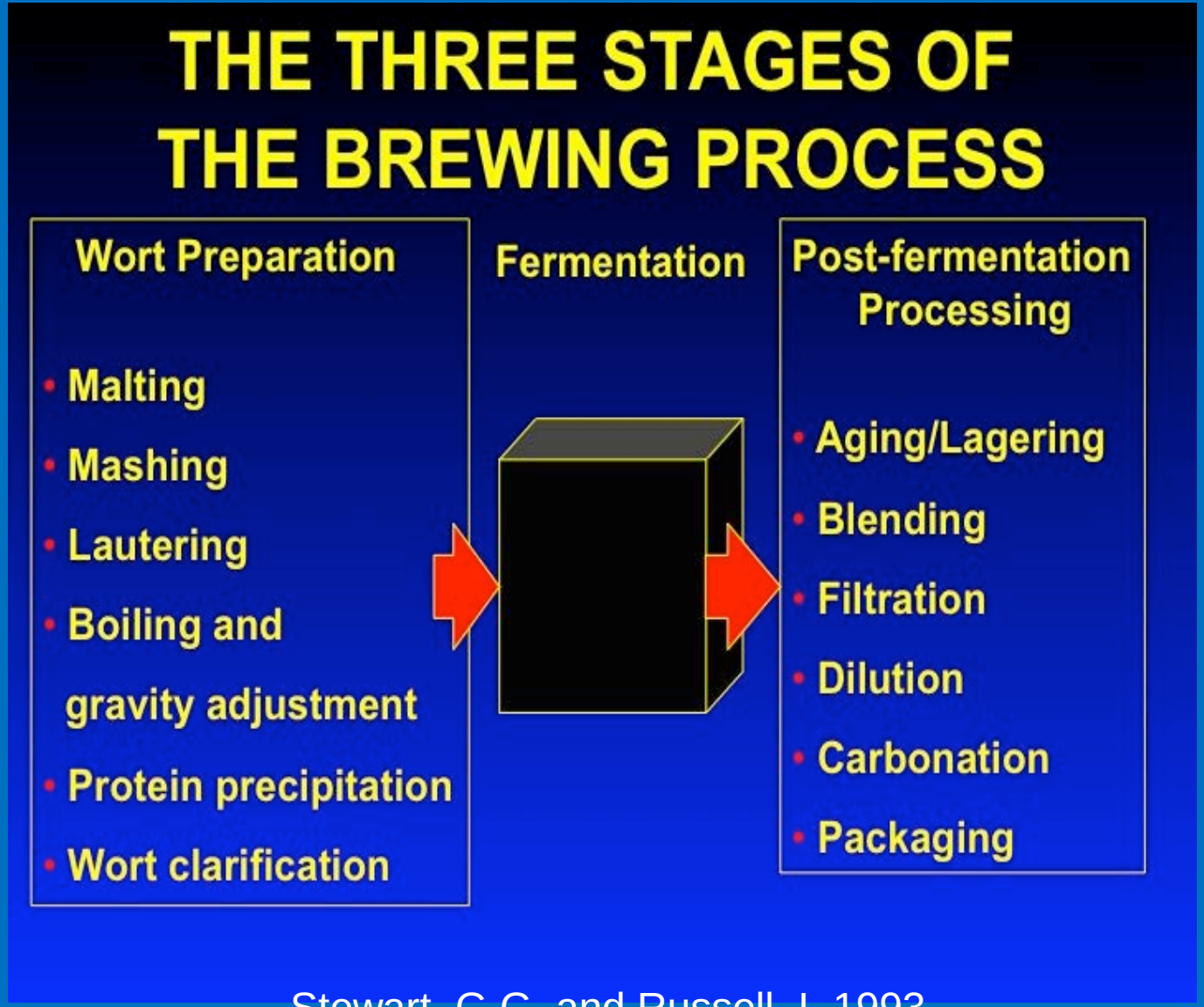
International Centre of Brewing and Distilling
Heriot-Watt University, Edinburgh

*Faculty of Engineering Dalhousie University Halifax

The Science of Beer

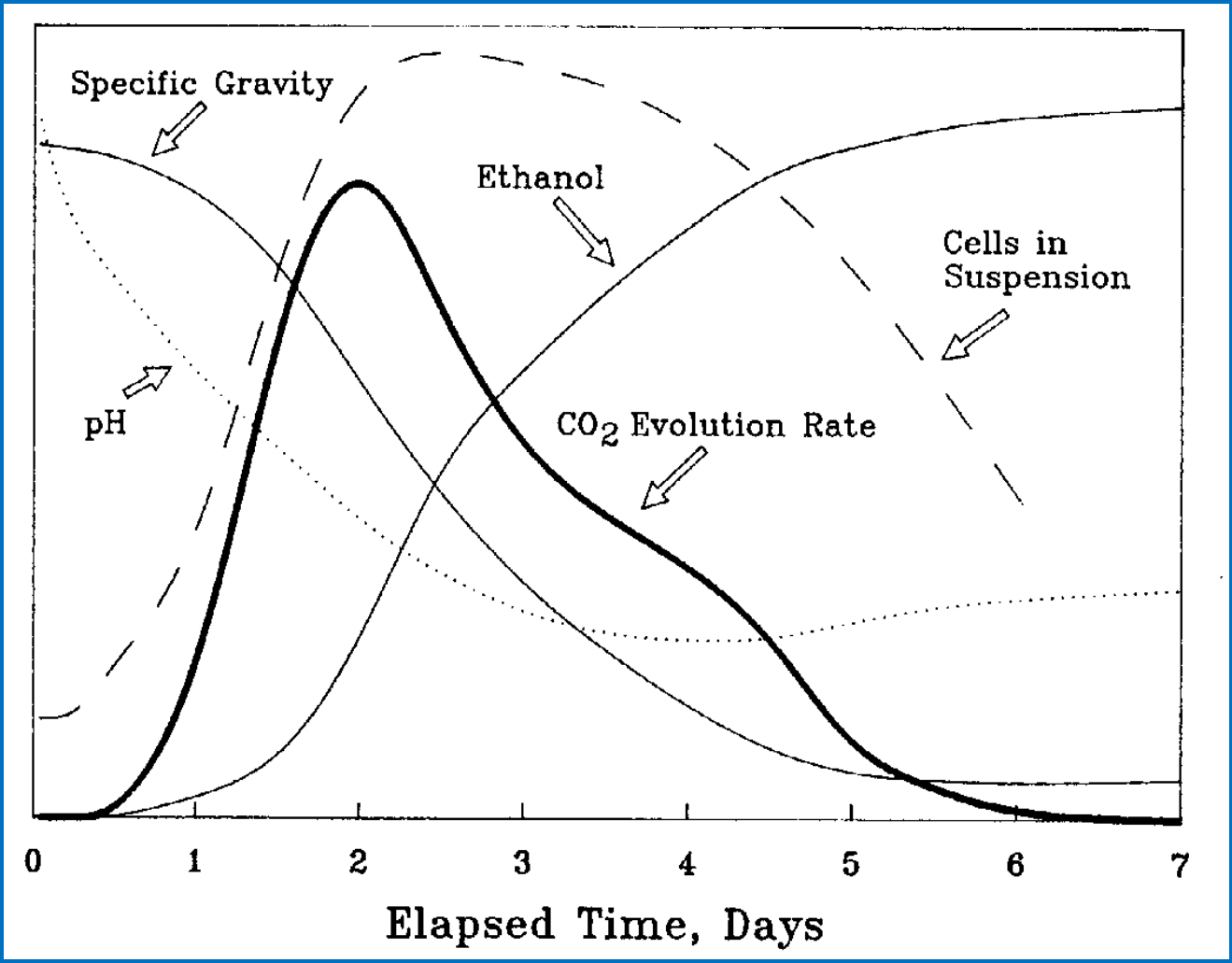
Outline

- Introduction
  - Fermentation Overview
  - Statistics
    - ‘Bell chart’ → Upper and lower control limits
    - Homoscedasticity and Heteroscedasticity
- Fermentation Control Charts
- Applications
- Conclusion



Stewart, G.G. and Russell, I. 1993
Fermentation - the "black box" of the brewing process.
MBAA TQ. 30, 159-168.

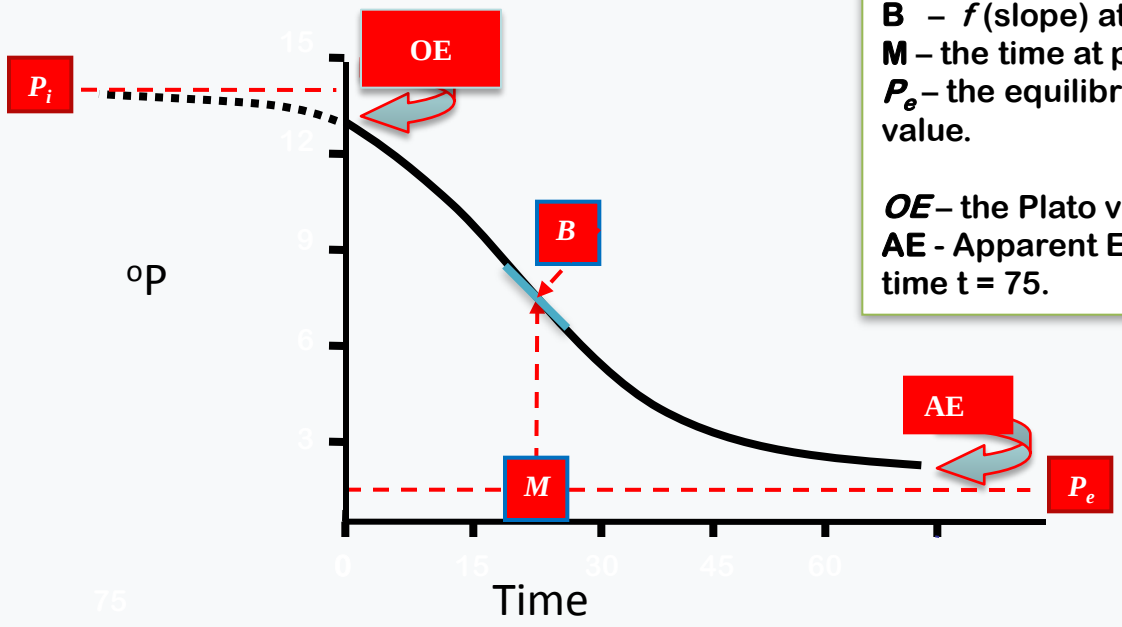
Fermentation



(Munroe, Handbook of Brewing)

Nonlinear Logistic Function Describing Density Attenuation

$$P_t = \{(P_i - P_e)/(1+e^{(-B*(t-M))})\} + P_e$$



P_i – the initial asymptotic Plato value,
B – *f* (slope) at the inflection point,
M – the time at point B,
P_e – the equilibrium asymptotic Plato value.

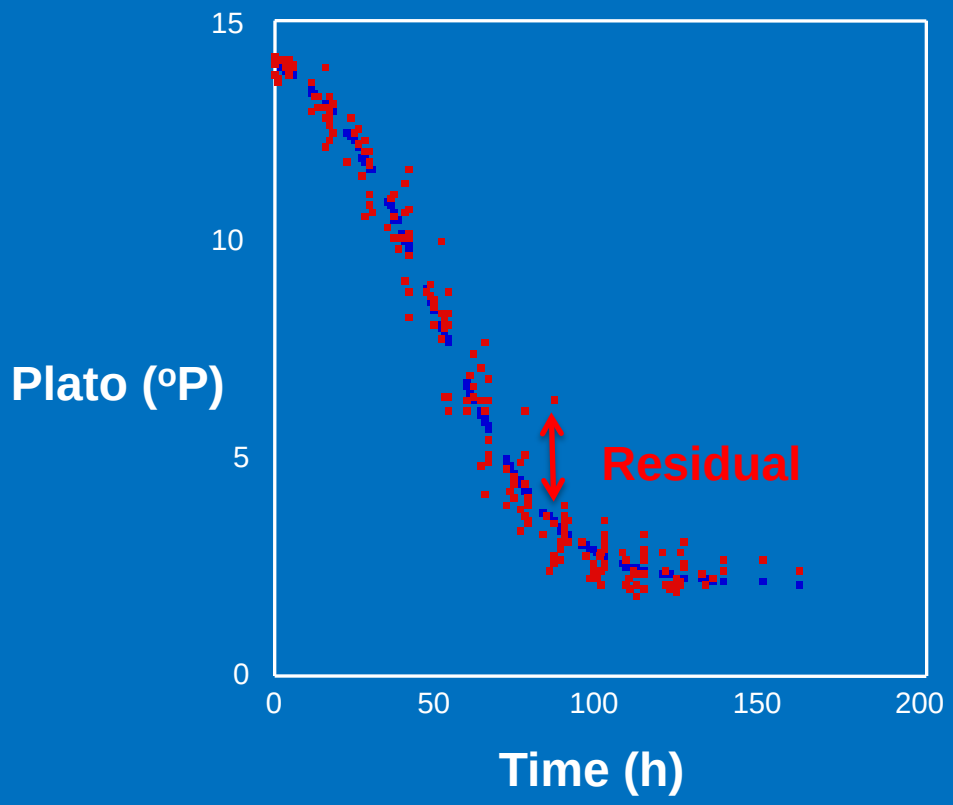
↓

OE – the Plato value at time t = 0,
AE - Apparent Extract-Plato value at time t = 75.

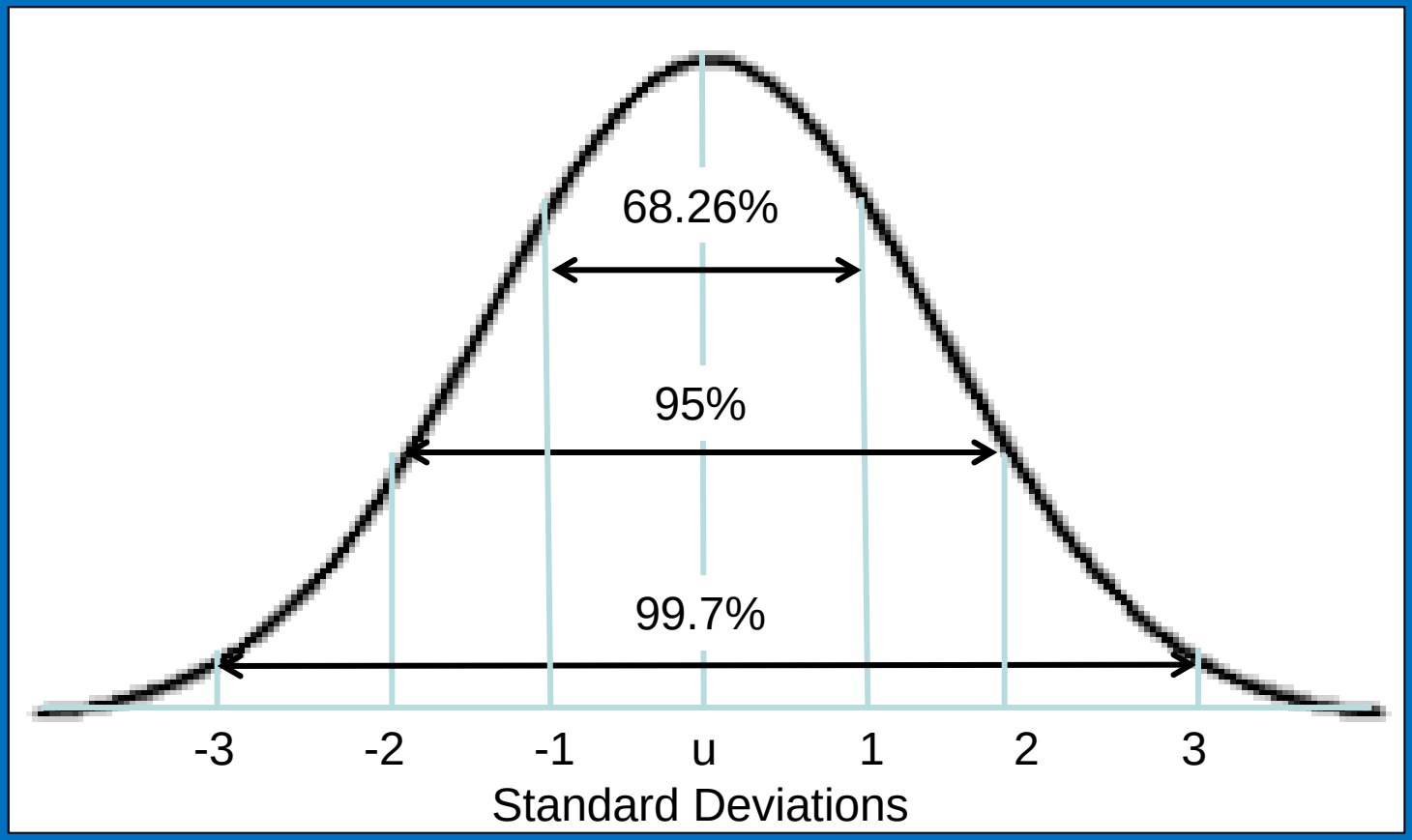
Nonlinear Regression

- To ‘best-fit’ the line through data, computer ‘scores’ fit by summing error (sum of squares).
- Repeatedly ‘guesses’ new line lowering error.

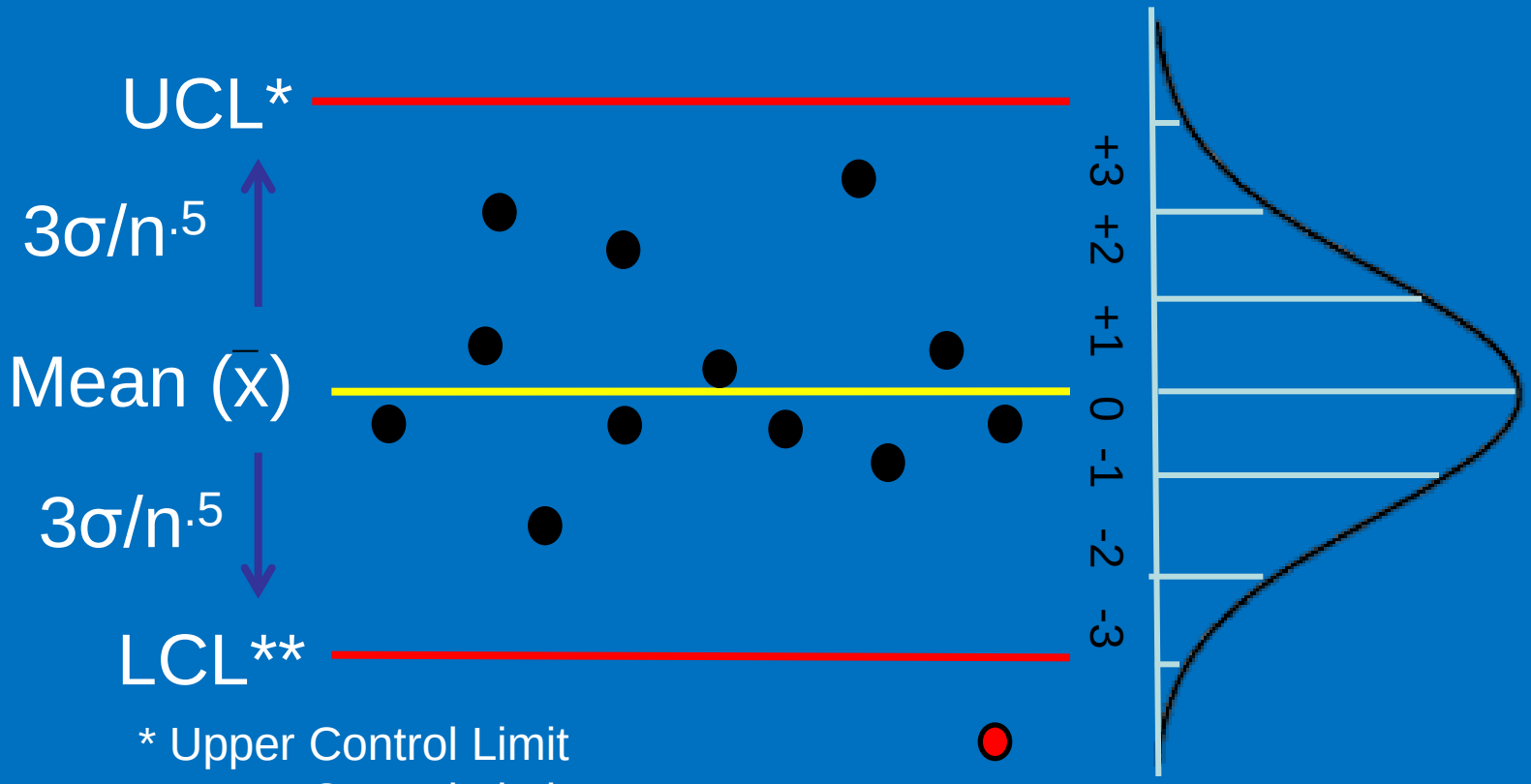
$\Sigma\, Residual^2 = RSS = error$



Statistics - The bell curve: Spread of data about the mean



Statistics
The Bell Curve and Control Charts

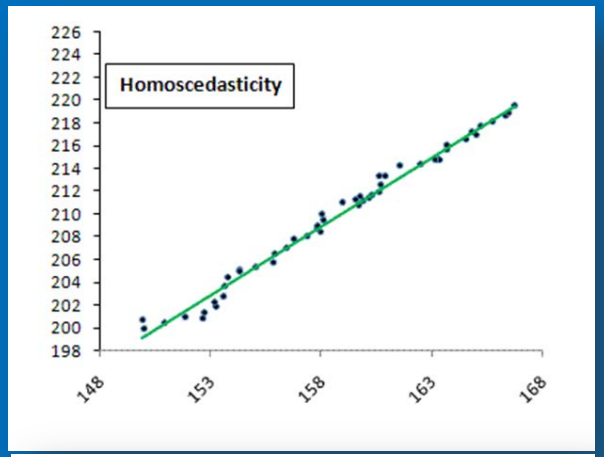


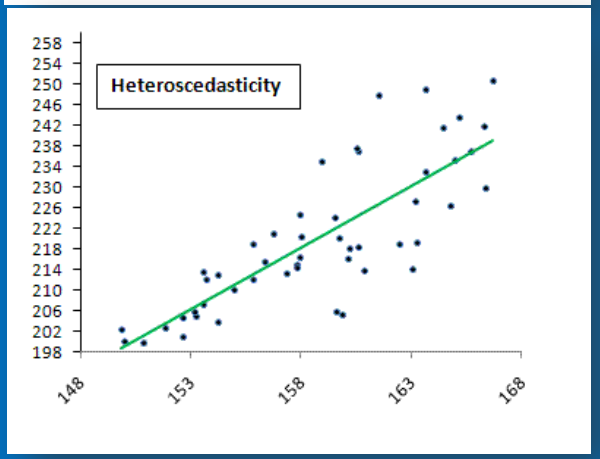
Statistics: Homoscedastic and Heteroscedastic

- Homoscedastic : Uniform standard deviation over time

  Heteroscedastic: Changing in standard deviation over time

  www.applyingdata.com/ understanding-linear-regression

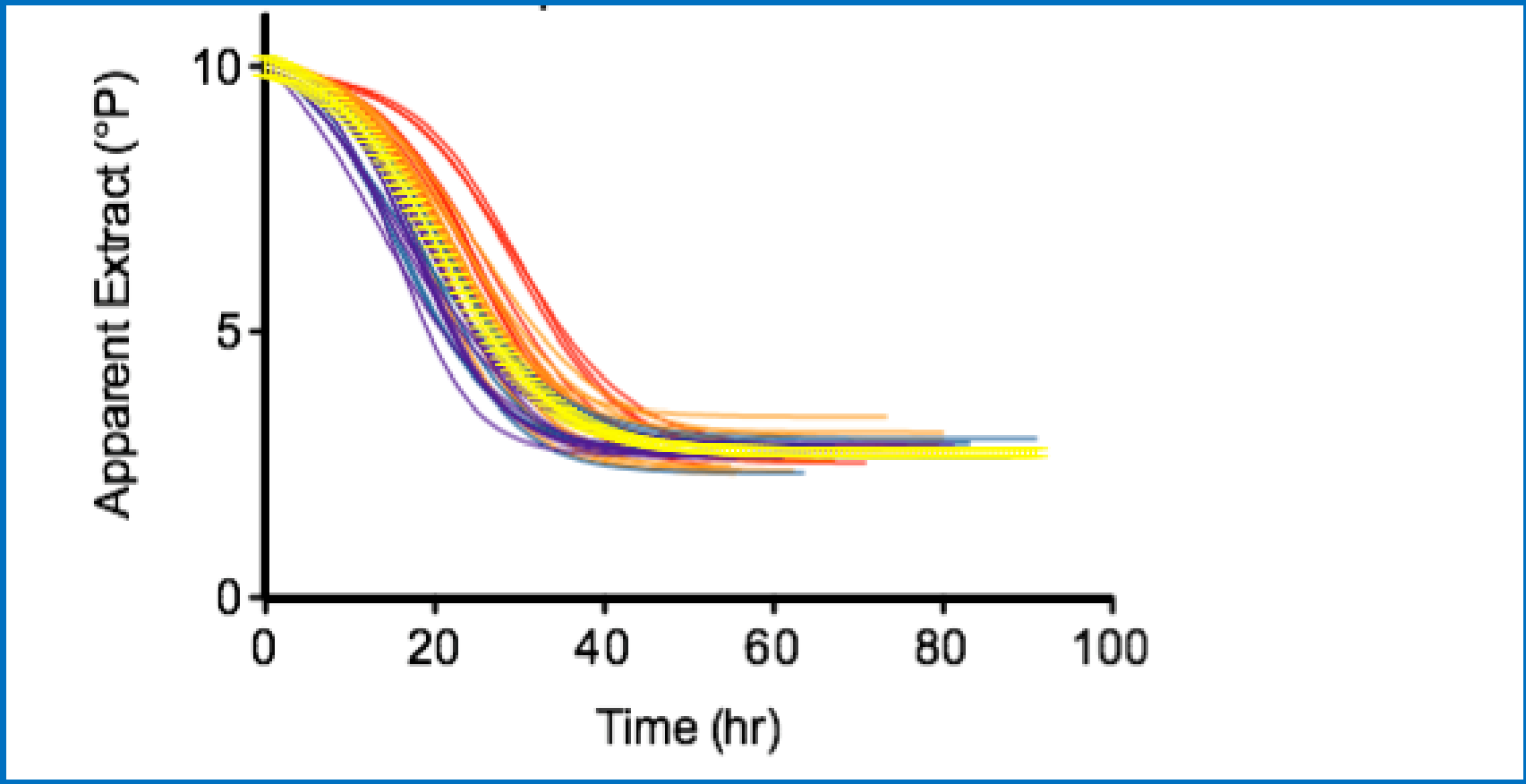




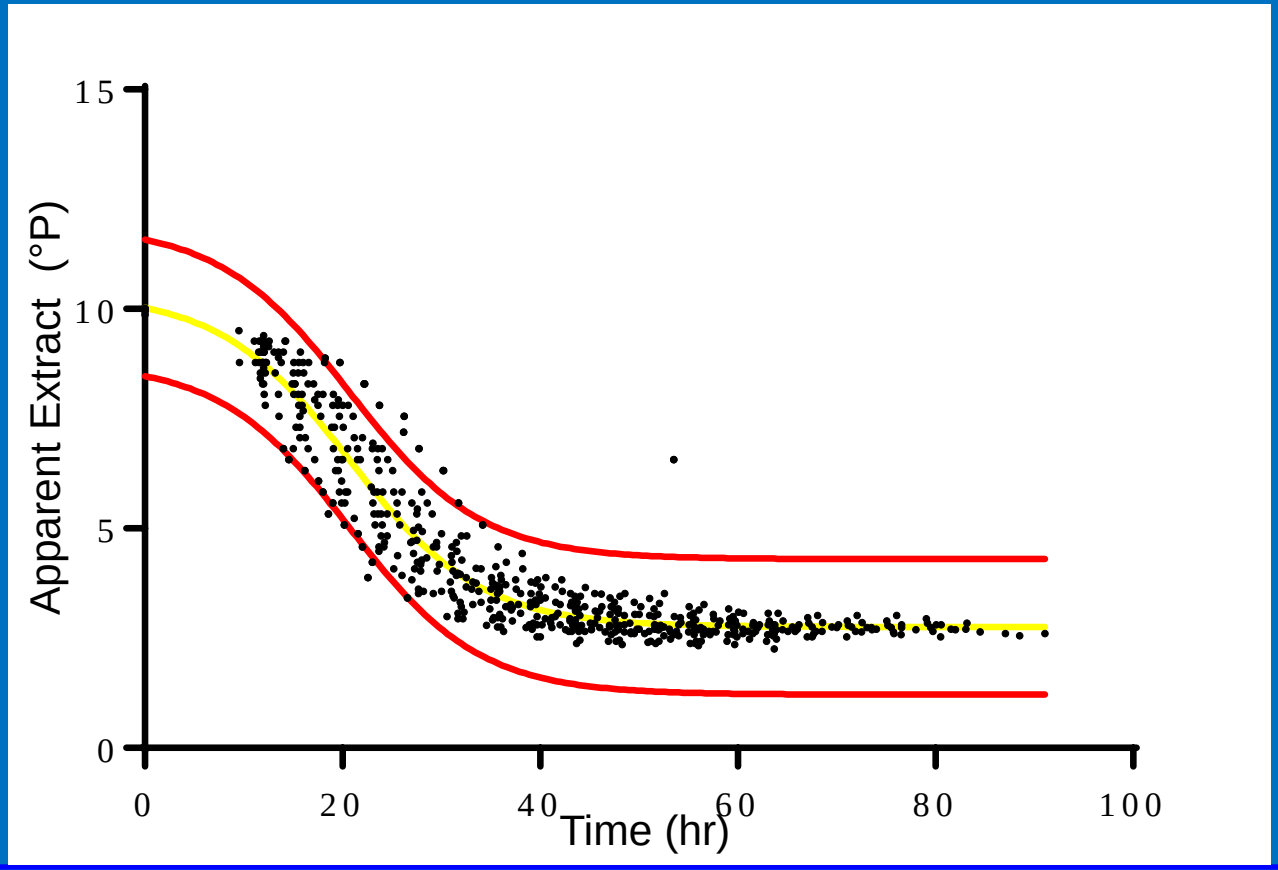
‘Control Charting’ a Fermentation

- **How to ?**
- **Three problems:**
  - **Process average changes with time**
  - **Data points not at set intervals**
  - **Variance heteroscedastic**

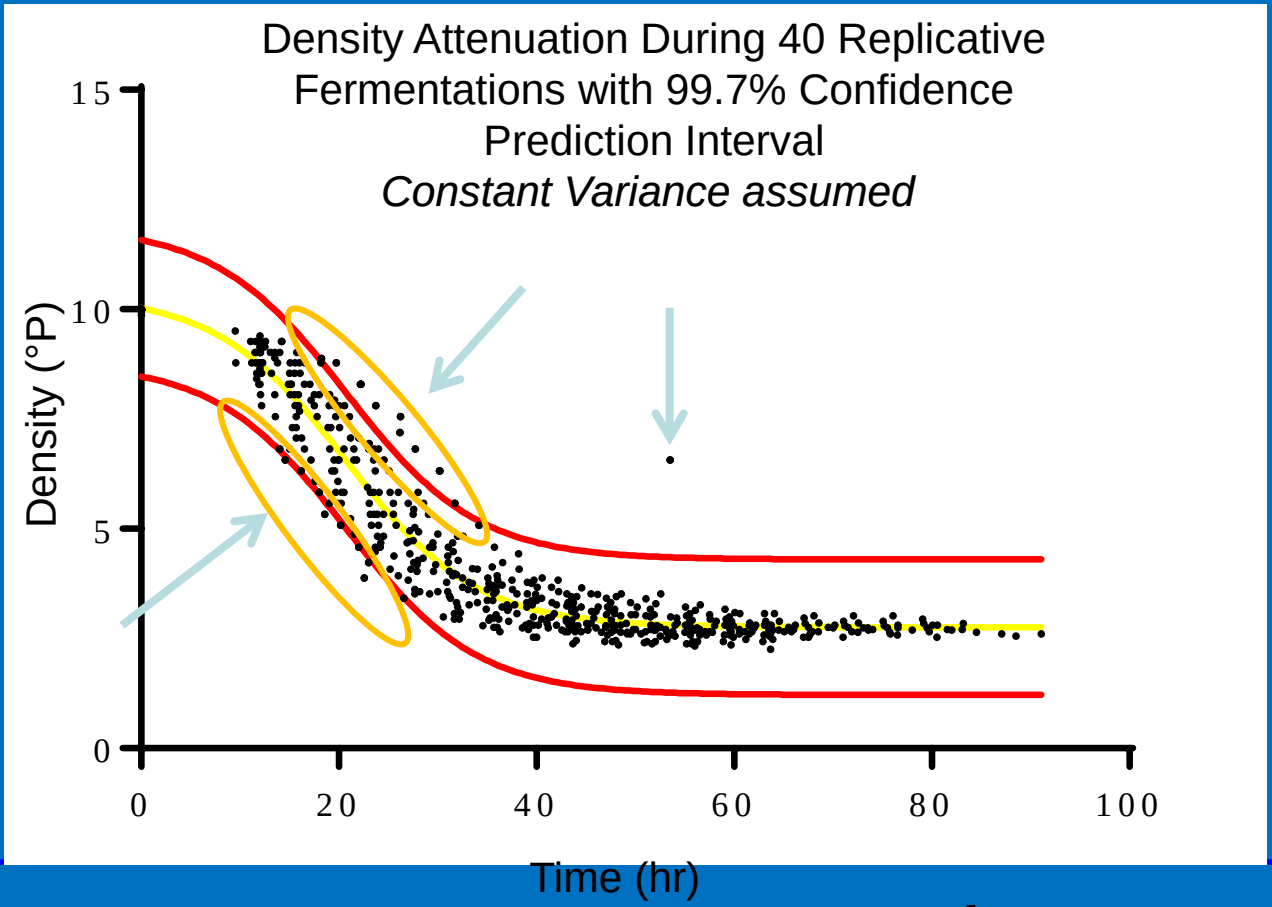
Noisy fermentations



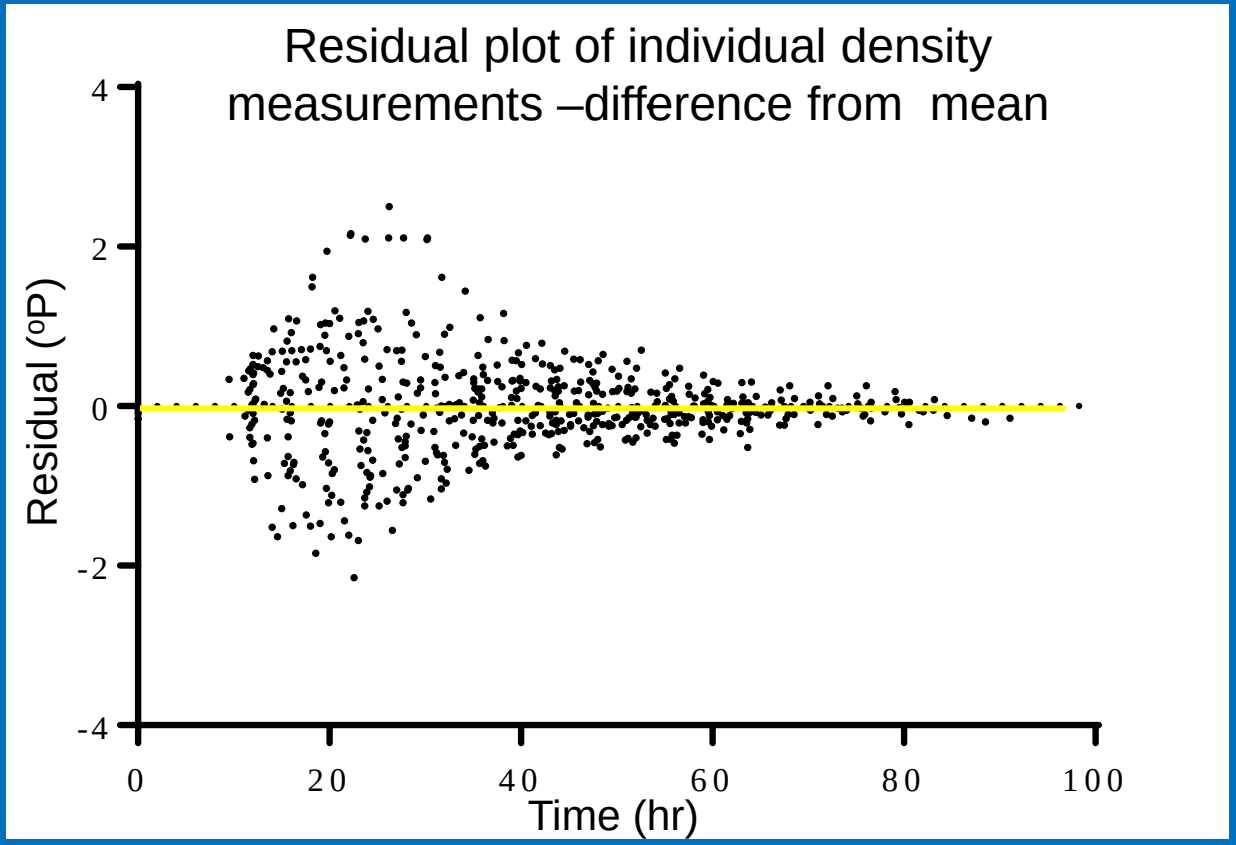
Fermentation Control Chart- Assumes Homoscedasticity



Fermentation Control Charts

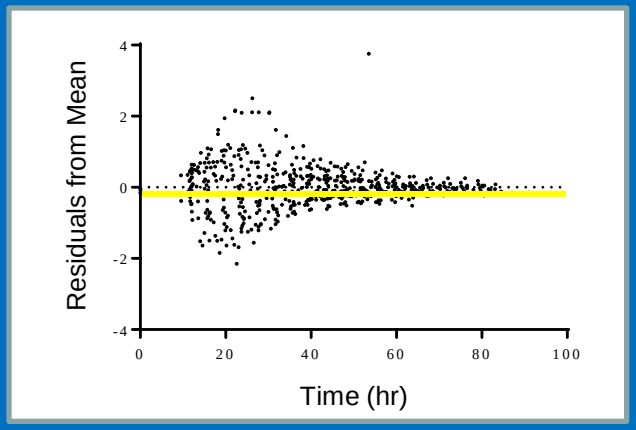


Fermentation Control Charts- Fermentations are Heteroscedastic



Fermentation Control Chart- Heteroscedasticity

- How do we adjust for it?



- (Common statistical software cannot)

Fermentation Control Chart: *First Approximation*

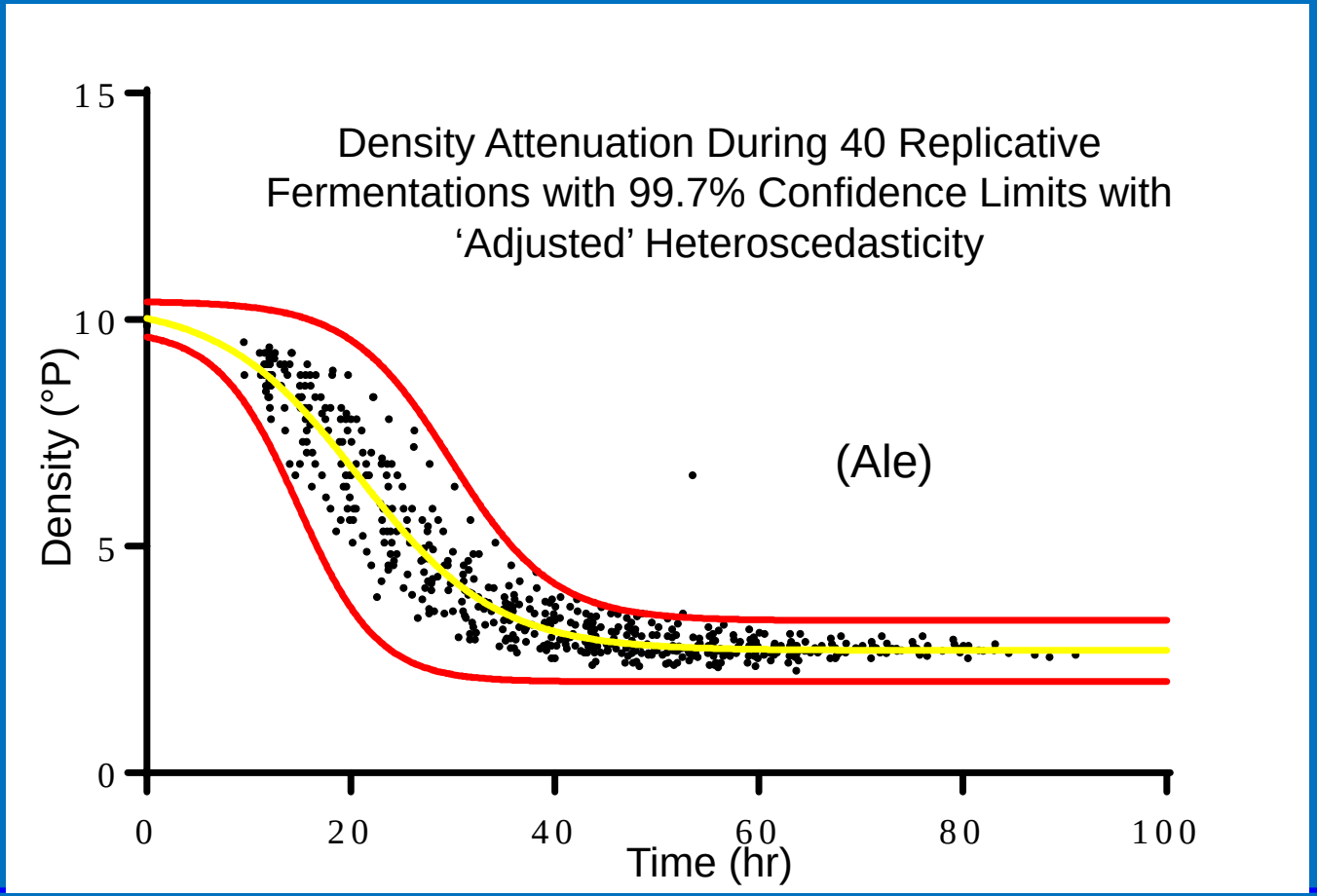
- Predict values from individual fermentations at fixed times,

  (get value from each ferm curve fit)

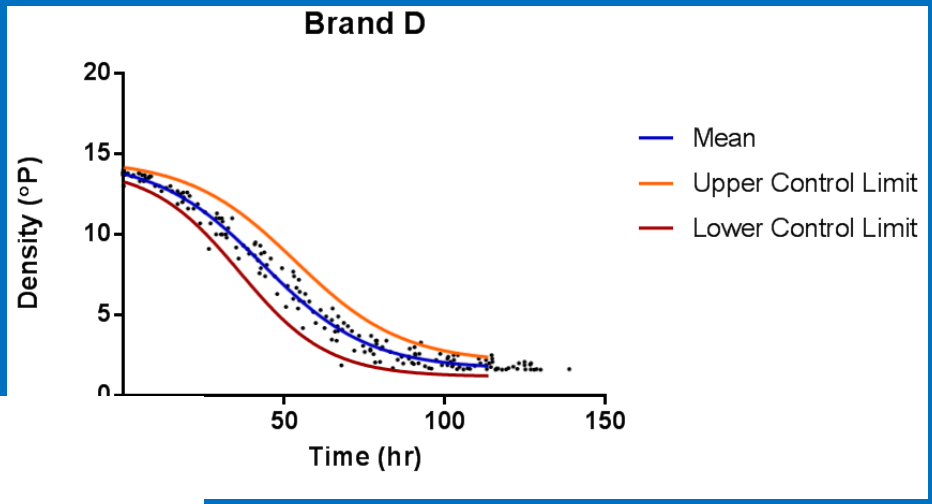
- 2) Use values to calculate +/- 3'σ'/$n^{.5}$

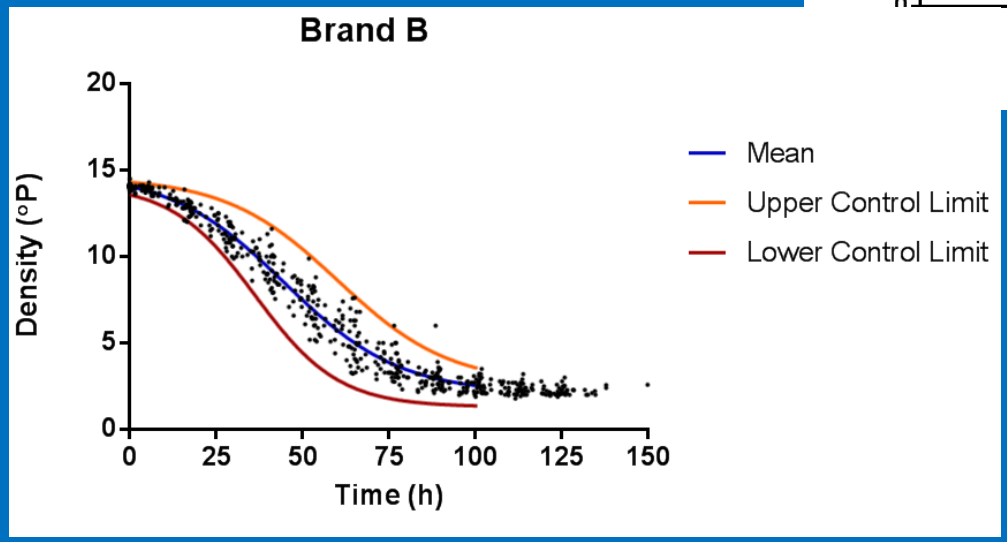
- This method removes variance and thus may bias UCL and LCL (too tight!)

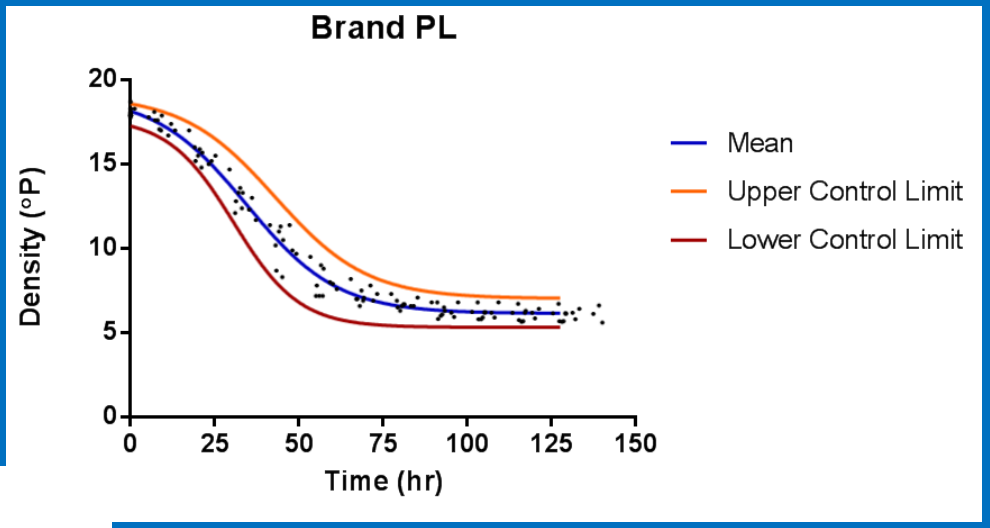
Fermentation Control Chart – Adjusting for Heteroscedasticity

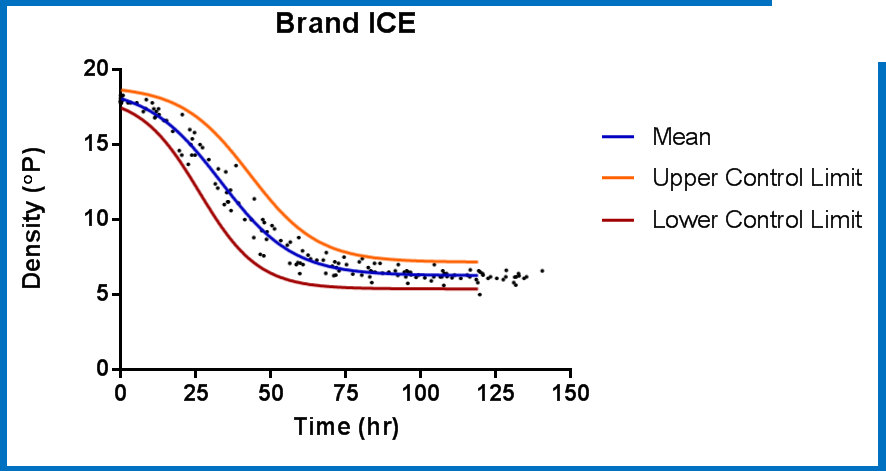


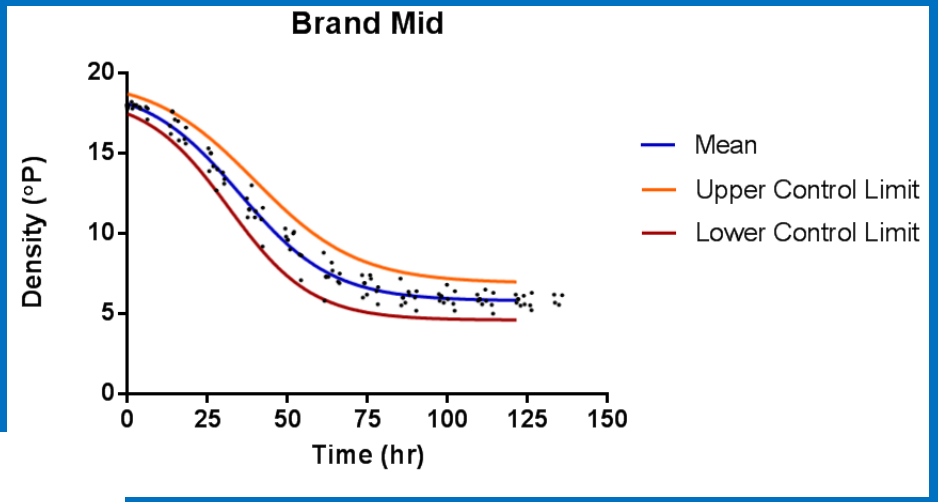
- Following curves are all lager brands

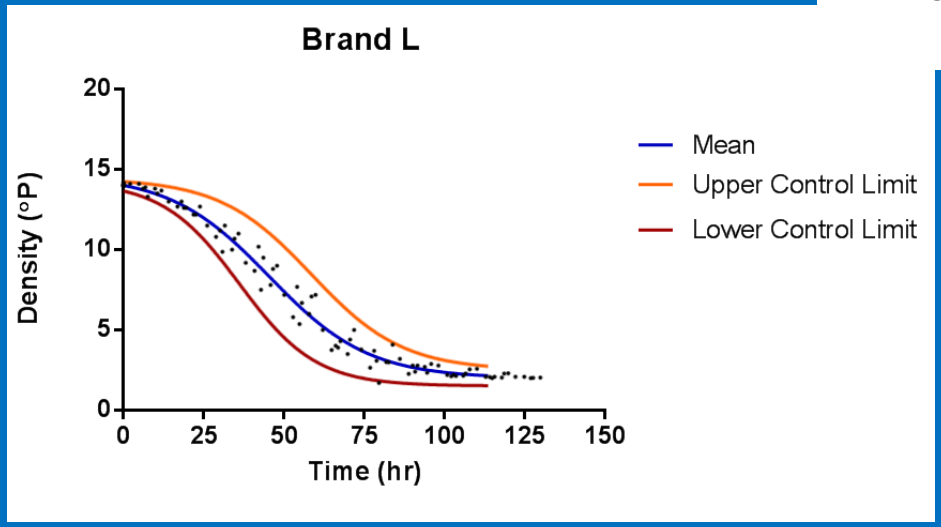


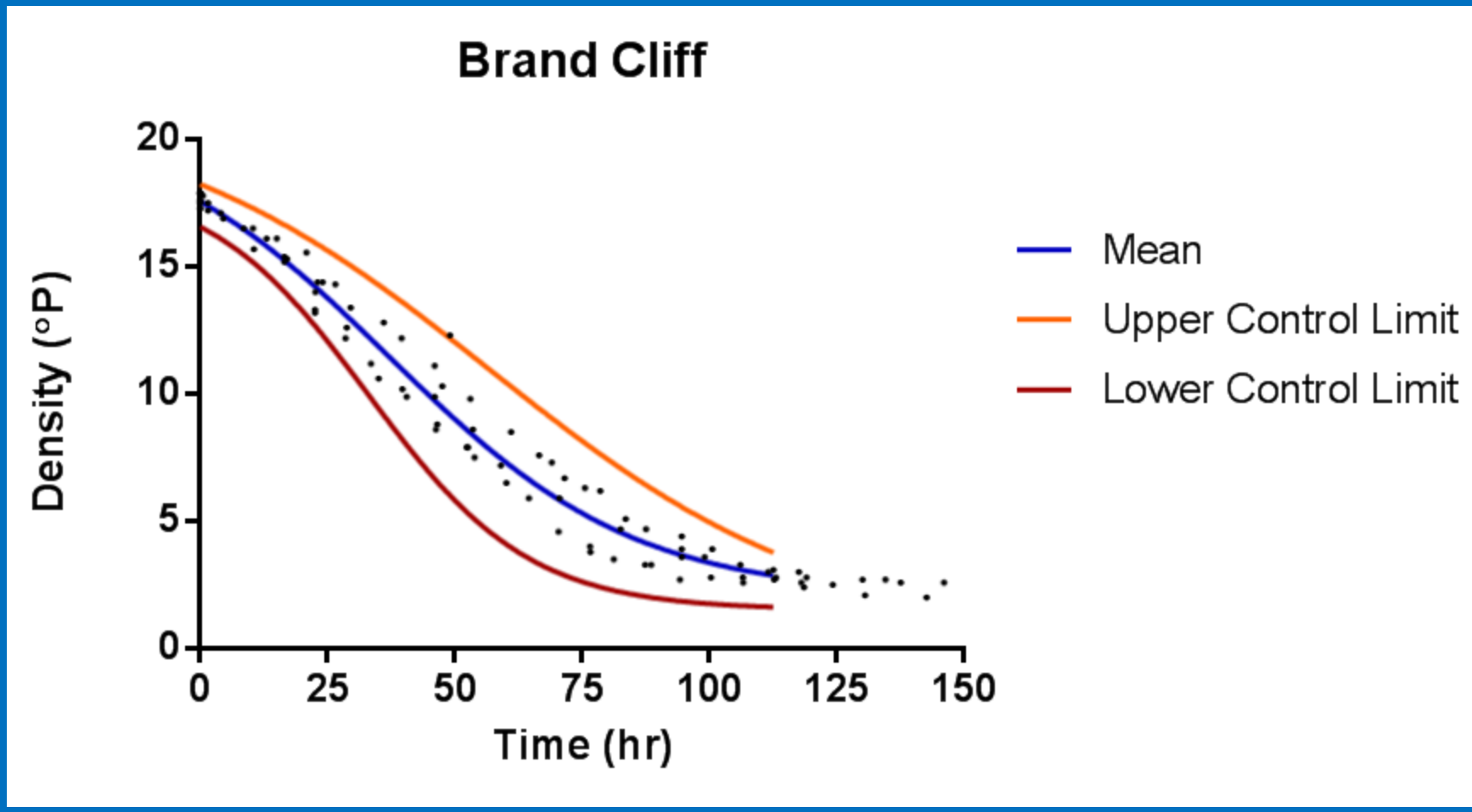



Brand PL
Density (°P)
20
15
10
5
0
0
25
50
75
100
125
150
Time (hr)
Mean
Upper Control Limit
Lower Control Limit


Brand ICE
Density (°P)
20
15
10
5
0
0
25
50
75
100
125
150
Time (hr)
Mean
Upper Control Limit
Lower Control Limit

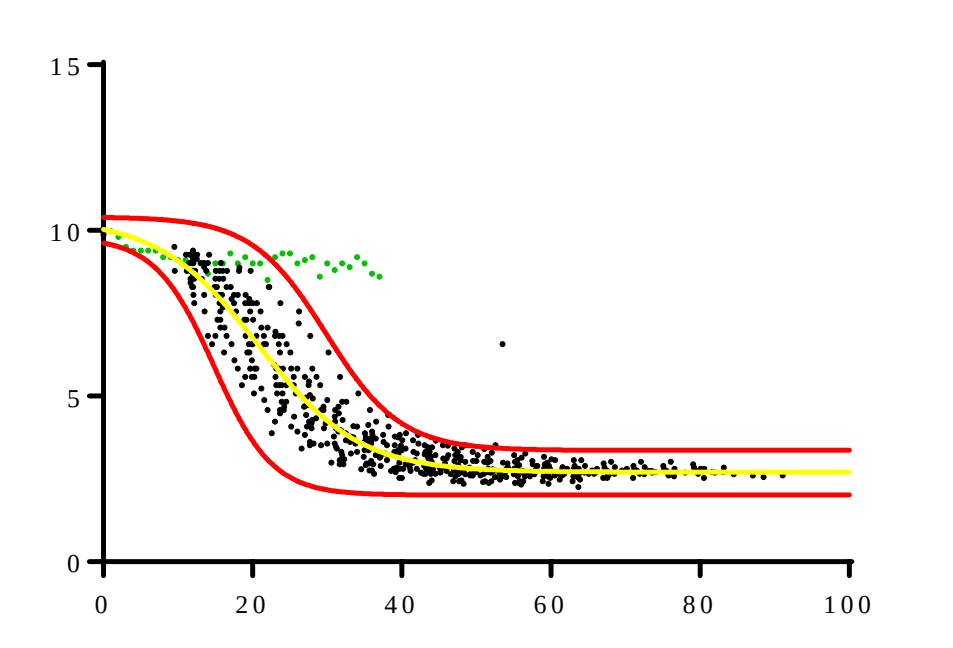

Brand Mid
Density (°P)
20
15
10
5
0
0
25
50
75
100
125
150
Time (hr)
Mean
Upper Control Limit
Lower Control Limit


Brand L
Density (°P)
20
15
10
5
0
0
25
50
75
100
125
150
Time (hr)
Mean
Upper Control Limit
Lower Control Limit


Brand Cliff
Density (°P)
20
15
10
5
0
0
25
50
75
100
125
150
Time (hr)
Mean
Upper Control Limit
Lower Control Limit

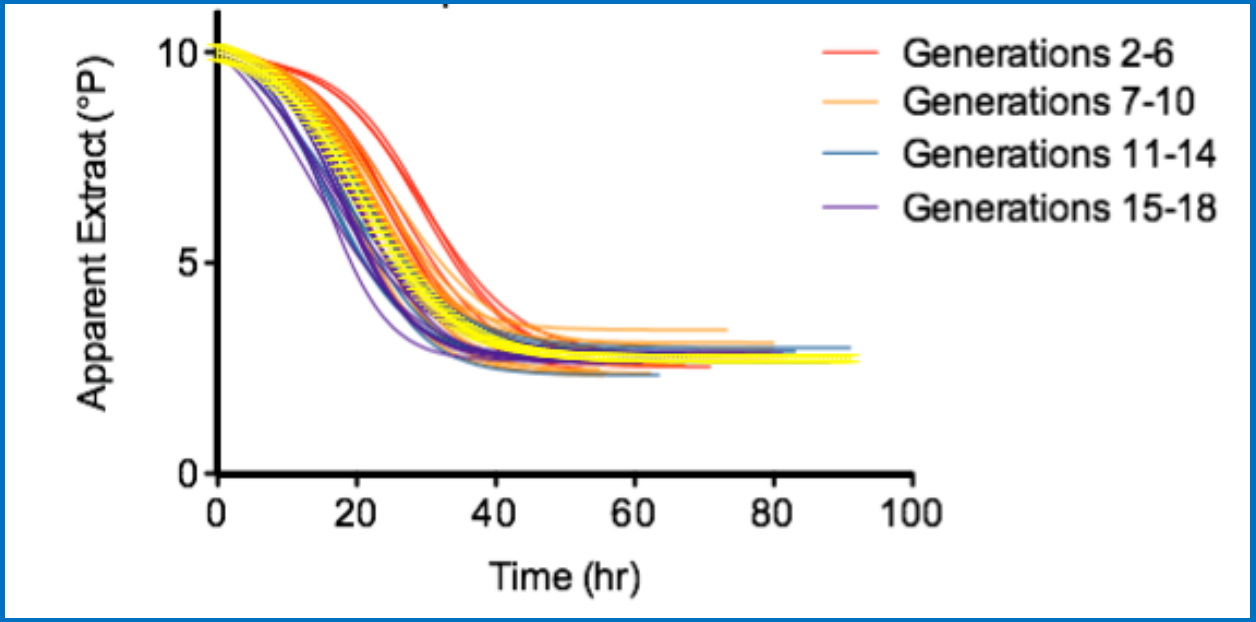
Applications

- *Objectively* determine abnormal fermentations
  - Evidence based decisions
  - Program alert system



Applications

- *Cropping studies*



Conclusion

- Fermentation control charts can be a useful concept applied to any fermentation,
  - Unique to each brand,
  - A useful measure to monitor/reduce variation,
- More work/experience needed,
  - i.e., speed vs flavour
  - Tease out causes of variation effect of boil, PYF
- Money and time saving measure.

Acknowledgements

- ASBC, IBD, ICBD
- Canadian malting companies,
- Australian, Canadian and Scottish brewing companies,
- S. Murray

And the Canadian and Scottish Taxpayers!

Don’t worry it is all written down!

people recognized her

back in our arms," her

Smart, said yesterday. "I ha

Ga-
cided
eived
others
al."
Angola,
and

Chip may one day fix your ailing memory

BY CAROLYN ABRAHAM
MEDICAL REPORTER

gap between mind and machine, could one day be used to boost the damaged brains of people wh suffer strokes

Pa
bro
res
tic

A.Speers@HW.AC.UK>

Questions?

Brand Name	No of Fermentations	Data points (total)	Outliers	%
B	48	537	12	2.2
Scotia	40	454	13	2.86
D	17	200	5	2.5
Ice	13	161	2	1.24
PL	10	125	0	0
Mid	10	124	3	2.42
L	8	93	2	2.15
Cliff	7	91	0	0

Confidence Interval (C.I.) vs. Prediction Interval (P.I.)

95% C.I.

- A range of values estimated to hold a population mean based on a sample mean
- Has a 95% probability that it contains the population mean

95% P.I

- A range of values estimated in which future observation will fall
- Has a 95% probability based on observations already completed