LDA mediated Ortholithiation - Implications of Autocatalysis

What seemed so simple … … was certainly not.
First-order / zeroth-order Paradox

Linear decays suggests 0th order in arene. However, the initial rates are linearly dependent on the initial concentration of arene suggesting a 1st order dependence.
The high spectral resolution of $^{19}$F NMR allows the monitoring of all aryllithium aggregates over time.

Structural assignments are based on: $^1$H, $^{13}$C, $^6$Li, $^{15}$N and $^{19}$F NMR.

Second arene injection reveals large acceleration with consumption of aryllithium mixed dimers (green and yellow).
Initiation

\[ \frac{d[\text{ArH}]}{dt} = k[\text{ArH}][\text{LDA}][\text{THF}]^0 \]

At different [LDA] …

\begin{align*}
\text{Absorbance} \\
\text{time (s)}
\end{align*}

\begin{align*}
(\Delta[I]/\Delta t) \times 10^3 \text{ (s}^{-1})
\end{align*}

\begin{align*}
0.00 & \quad 0.05 & \quad 0.10 & \quad 0.15 & \quad 0.20 \\
0 & \quad 2 & \quad 4 & \quad 6 & \quad 8 \quad 10
\end{align*}
Aggregation

\[ f(t) = ae^{-k_{\text{obs}}t} + b \]

\[ \frac{d[\text{ArLi}]}{dt} = k[\text{ArLi}]\text{[LDA]}\text{[THF]}^{-1} \]
Beyond traditional Kinetics

Differential equations describing the model:

\[
\frac{d[ArH]}{dt} = -k_1 [ArH] [A_2] - k_2 [A\cdot ArLi^*] [ArH]
\]

\[
\frac{d[ArLi]}{dt} = -k_3 [ArLi] [A_2] + k_1 [A\cdot ArLi^*] + 2 k_2 [A\cdot ArLi^*] [ArH]
\]

\[
\frac{d[A_2\cdot ArLi]}{dt} = k_1 [ArLi] [A_2] - k_3 [A\cdot ArLi^*] - k_4 [A\cdot ArLi^*] - k_5 [A\cdot ArLi^*] [ArH]
\]

\[
\frac{d[A\cdot ArLi]}{dt} = k_1 [ArH] [A_2] + k_4 [A\cdot ArLi^*] - k_4 [A\cdot ArLi^*] [A_2]^{0.5}
\]

Curve fitting to $^{19}$F NMR derived time-dependent data sets yields values for all six rate constants. More importantly, it supports our model.

Curve fitting involves numerical integration since the above solutions cannot be solved analytically. The fitting was done in *Igor Pro.*
The Connection of Autocatalysis to Linear Decays

The Autocatalysis “Meter”

An increase in the autocatalytic rate $k_{\text{cat}}$ turns exponential decays into linear decays and upon further increase leads to conventional looking sigmoidal decays emblematic of autocatalysis.

Simulation of Chemical Kinetics in *Mathematica*
(see website under group resources)