Electronic Market and High-Frequency Trading[1]

Jing Guo

Strats Associate, Goldman Sachs

PhD in Financial Engineering, Columbia University

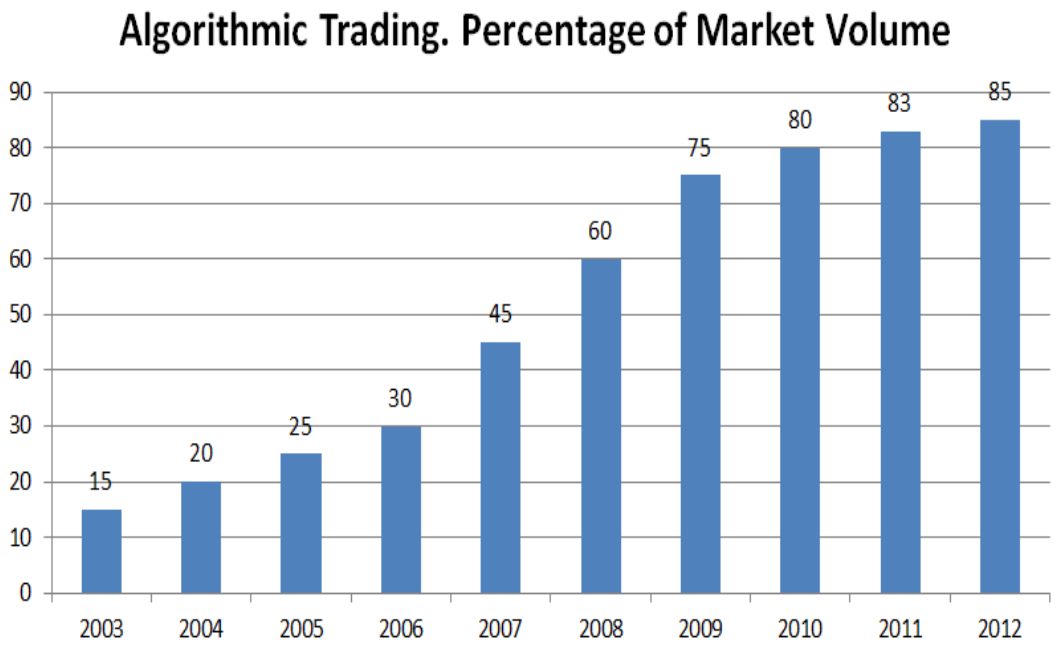
November 2, 2017

[1] Reference: Avellaneda (2011), Maglaras (2015)

Outline

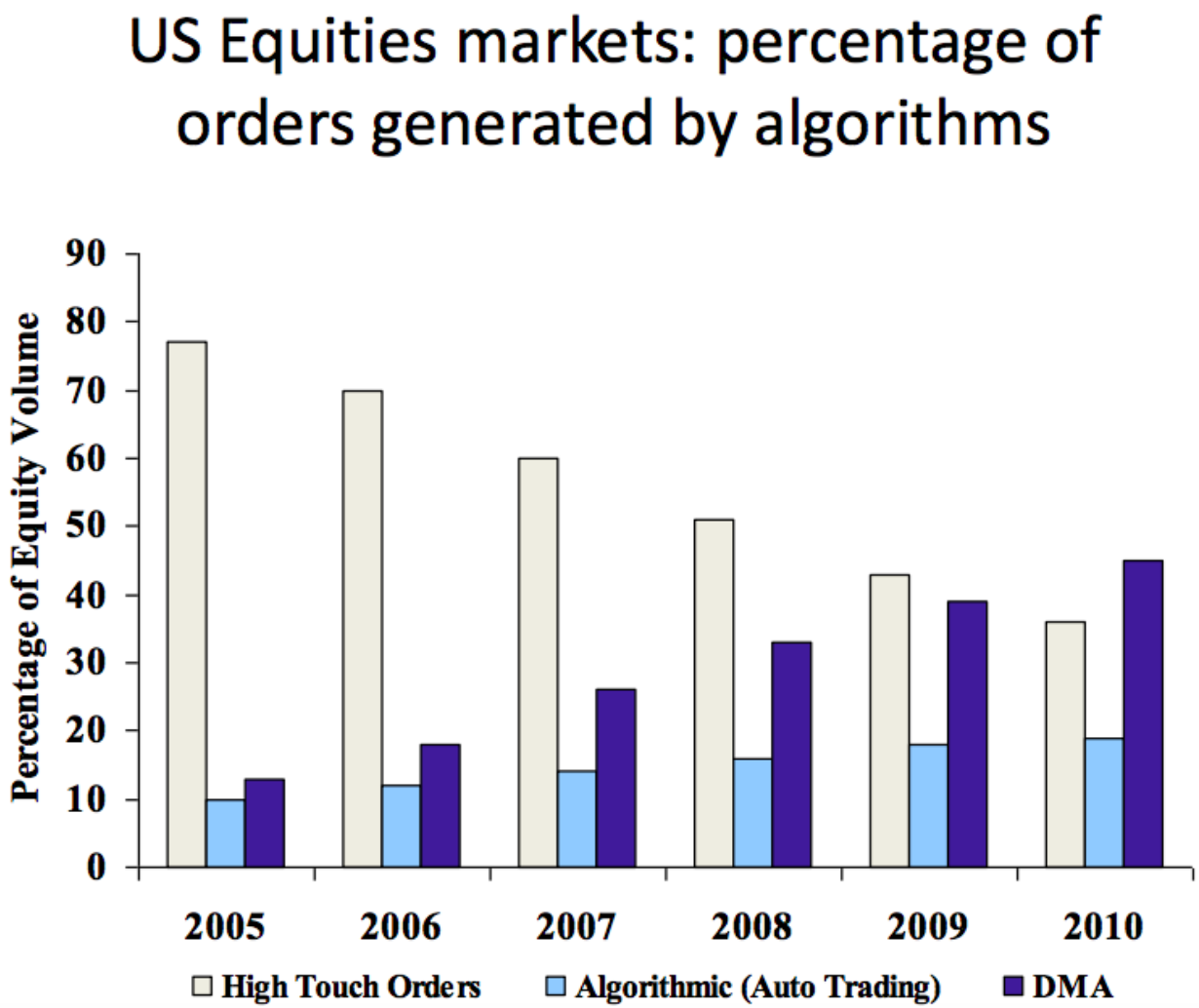
1. Overview of Electronic Trading
2. Algorithmic Trading Strategies
3. Limit Order Book

Increasing Percentage of Algo Trading

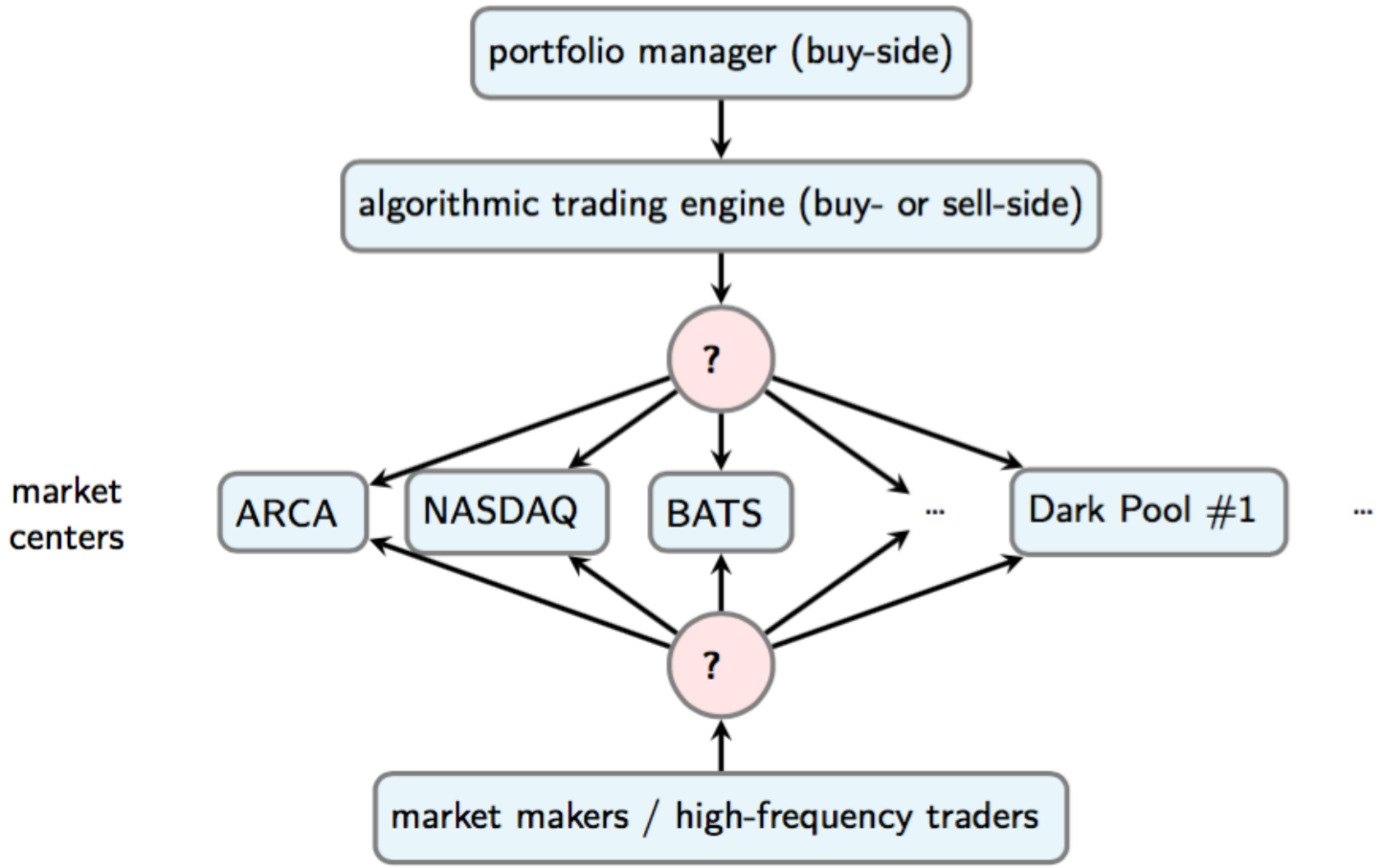


- A third of all European Union and United States stock trades in 2006 were driven by automatic programs, or algorithms.
- As of 2009, studies suggested HFT firms accounted for 60-73% of all US equity trading volume, with that number falling to $\sim 50\%$ in 2012.
- FX markets also have active algo trading ($\sim 25\%$ in 2006).
- Futures markets are considered fairly easy to integrate into algo trading, with $\sim 20\%$ of options volume by 2010.

Algo Trading in US Equity Market



Simplified View of Trading



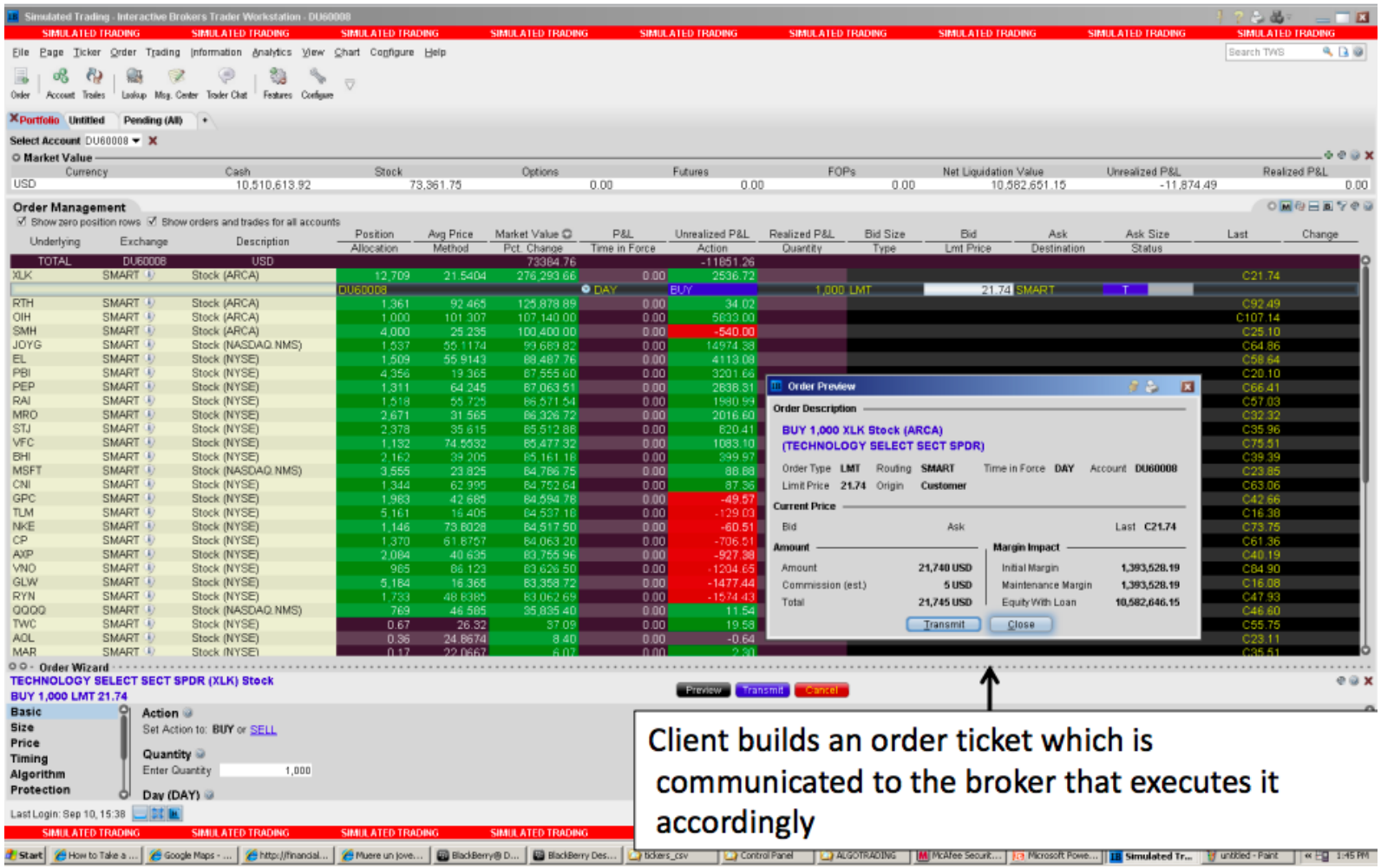
A few trading venues for US equity markets[2]

- ARCA-NYSE: electronic platform of NYSE (ex- Archipelago)
- BATS: (Kansas)
- BEX: Boston Equity Exchange
- CBSX: CBOE Stock Exchange
- CSXZ: Chicago Stock Exchange
- DRCTEDGE: Direct Edge (Jersey City, NJ)
- ISE: International Securities Exchange
- ISLAND: Acquired by Nasdaq in 2003
- LAVA: belongs to Citigroup
- NSX: National Stock Exchange (Chicago)
- NYSE: New York Stock Exchange
- TRACKECN: Track ECN

[2] Avellaneda (2011)

Electronic order-management and execution system (client-broker)

- [3]



[3] Avellaneda (2011)

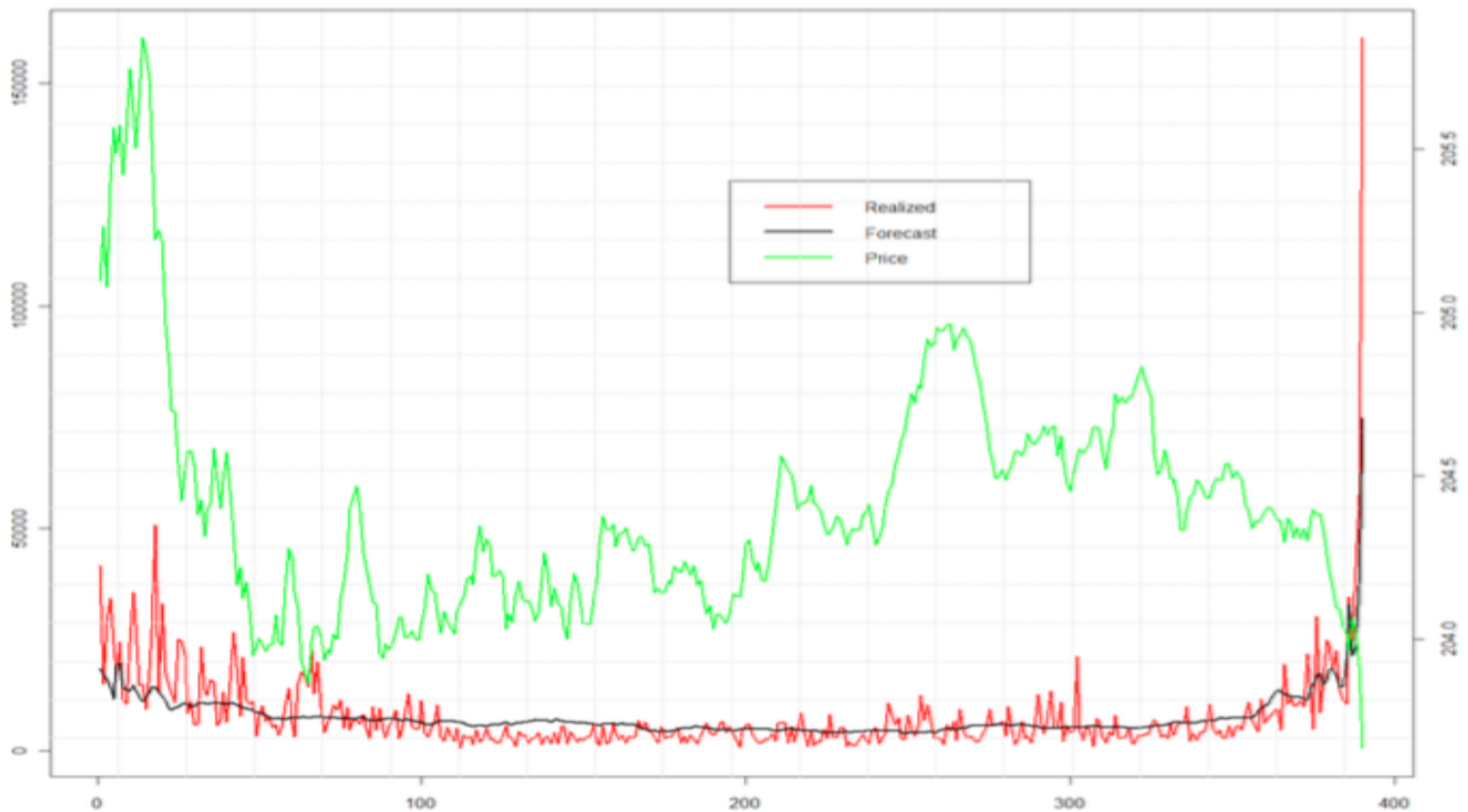
Modern US Equity Markets

- Electronic order-management and execution
- Decentralized/Fragmented
  - NYSE, NASDAQ, ARCA, BATS, Direct Edge, ...
- Exchanges ($\sim$70%)
  - electronic limit order books (LOBs)
- Alternative venues ($\sim$30%)
  - ECNs, dark pools, internalization, OTC market makers, etc.
- Participants increasingly automated
  - institutional investors: algorithmic trading
  - market makers: high-frequency trading ($\sim$60% average daily volume(ADV))
  - opportunistic/active (price sensitive) investors: aggressive/electronic
  - retail: manual ($\sim$5% ADV; small order sizes)

An Example

- How should you buy 250,000 shares of IBM stock between 12:30pm and 4:00pm?
  - Is this order "large"?
  - How fast should you trade? When to post orders?
  - How much will it cost you?
  - Who are you trading against?
- How is it done in practice?

Example Cont'd



- Forecasted Volume 12:30-4pm = 1,525,000 shares
- Average spread = \$.04 (1.95bps)
- Expected Market Impact (12:30-4pm) $\approx$ 20bps $\approx$ 40 pennies/share
- Expected Market Impact (12:30-1:30pm) $\approx$ 28bps $\approx$ 56 pennies/share

Institutional Traders (Broad Strokes)

- Institutional traders are usually informed traders.
- Investment decisions & trade execution are often separate processes.
- Institutional order flow typically has "mandate" to execute.
- Traders select broker, algorithms, block venue, ...
  - (algorithm $\approx$ optimization under trading constraints)
- Main considerations:
  - Best execution
  - Access to liquidity (larger orders)
  - Short-term alpha (discretionary investors)
  - Information leakage (large orders the spread over hours, days, weeks)
  - Commissions (soft dollar agreements)
  - Incentives (portfolio manager & trading desk; buy side & sell side)

Institutional Traders (Cont'd)

- Execution costs feedback affects:
  - Portfolio selection decisions
  - Hedge fund performance
- S&P500:
  - ADV $\approx< 1\%$
  - Market capital $\approx .1\% \sim 2\%$
  - **Depth** (displayed, top of book) $\approx$ .1% ADV
  - **Depth** (displayed, top of book) $\approx 10^{-6} \sim 10^{-5}$ of MktCap
- Orders need to be spread out over time.

Market Depth

CLIMBING THE MARKET

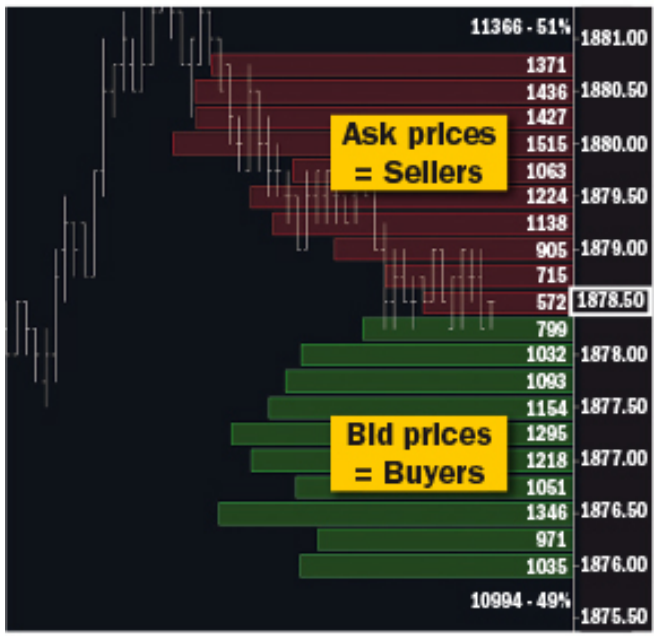
A price ladder or DOM displays market depth data.

Buy	Price	Sell
	1882.00	
	1881.75	
	1881.50	
	1881.25	
	1881.00	
	1880.75	
	1880.50	
	1880.25	1339
	1880.00	1643
	1879.75	1148
	1879.50	876
	1879.25	272
223	(1) 1879.00	
879	1878.75	
1010	1878.50	
1181	1878.25	
1028	1878.00	
	1877.75	
	1877.50	
	1877.25	
	1977.00	
	1876.75	
	1876.50	
Market	PnL	Market
Rev	Flat	Close

Source: NinjaTrader

CHARTING DEPTH

Market depth as an overlay on a price chart. The green bars represent interested buyers; the red bars show interested sellers.



Source: www.baranalyzer.com

Market Makers & HFT Participants (Broad Strokes)

- Supply short-term liquidity and capture bid-ask spread
  - Mostly intraday flow
  - Limited overnight exposure
  - Small order sizes & depth
  - Short trade horizons/ holding periods
- Profit $\approx$ (Captured spread) - (Adverse selection) - (Trading cost)
- It is critical to model **adverse selection**.
  - Definition: Short-term price change conditional on a trade.
  - Essentially "uninformedness" premium from information asymmetry.

Market Makers & HFT Participants (Cont'd)

- It is important to model short-term future prices ("alpha")
  - Microstructure signals (limit order book/ instant price impact)
  - Time series modeling of prices (momentum/ reversion)
  - Cross-asset signals (statistical arbitrage, ETF against underlying, ...)
  - News (NLP)
  - Detailed microstructure of market mechanism (human psycho reaction)
  - ...
- Position risks:
  - Adverse price movements
  - Flow toxicity
  - Accumulation of inventory & aggregate market exposure

Toxic Flows

- Types of Toxic Flows [4]
  - Latency arbitrage or "picking-off" the feed
    - Trading on pricing engines of MM's that are slow in updating prices.
    - Slow-price reaction from inefficient technology/ unsophisticated model
  - Market impact of multiple orders
  - News Trading
- VPIN[5]: Volume-Synchronized Probability of Informed Trading, a measure of order toxicity.
  - Higher VPIN indicates that it is more likely that short-term momentum is due to informed trading.

[4] Aratovskaya (2016)
[5] Easley et al. (2012)

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2. Algorithmic Trading Strategies
3. Limit Order Book

Our primary focus is on limit order book dynamics

- Limit order book behavior affects:
  - Algorithmic trade execution systems & performance
  - Trading signals & execution for MMs
  - Regulatory implications

Algorithmic Trading

- algorithmic trading strategies
- typical architecture of algo trading systems
- implementation shortfall
- VWAP

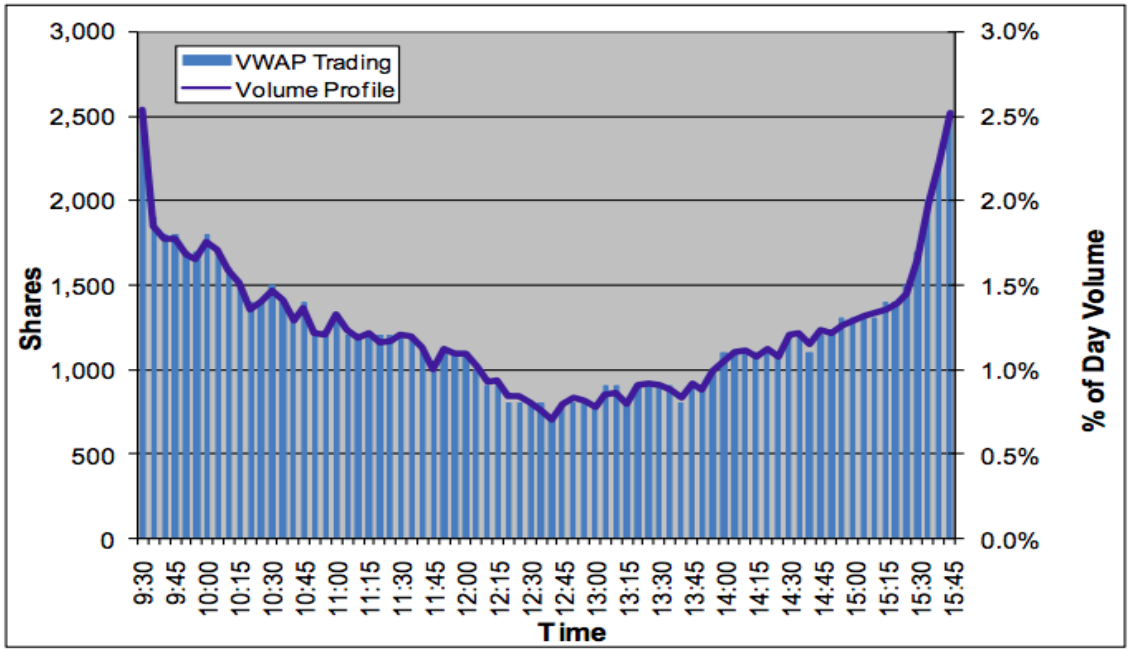
Algo Trading Strategies (90+% of institutional flow)

- **VWAP (Volume-Weighted-Average-Price):** Trades according to forecasted volume profile to achieve (or beat) the market VWAP
  - Passive strategy
  - Subject to significant market risk
  -

$$VWAP(t_1, t_2) = \frac{\sum_{t=t_1}^{t_2} \delta V(t) P(t)}{\sum_{t=t_1}^{t_2} \delta V(t)}$$

- **TWAP (Time-Weighted-Average-Price):** Trades uniformly over time to achieve (or beat) TWAP benchmark
  - Passive strategy
  - Market risk
  - Not very popular in practice

Volume-Weighted Average Price



- Algorithm:
  - Estimate the average volume traded in every 5-min interval.
  - Within interval, execute amount proportional to the normative volume.
- Properties:
  - Trade sizes are known in advance.
  - Volume function is estimated using historical data.

VWAP vs. TWAP

- 6

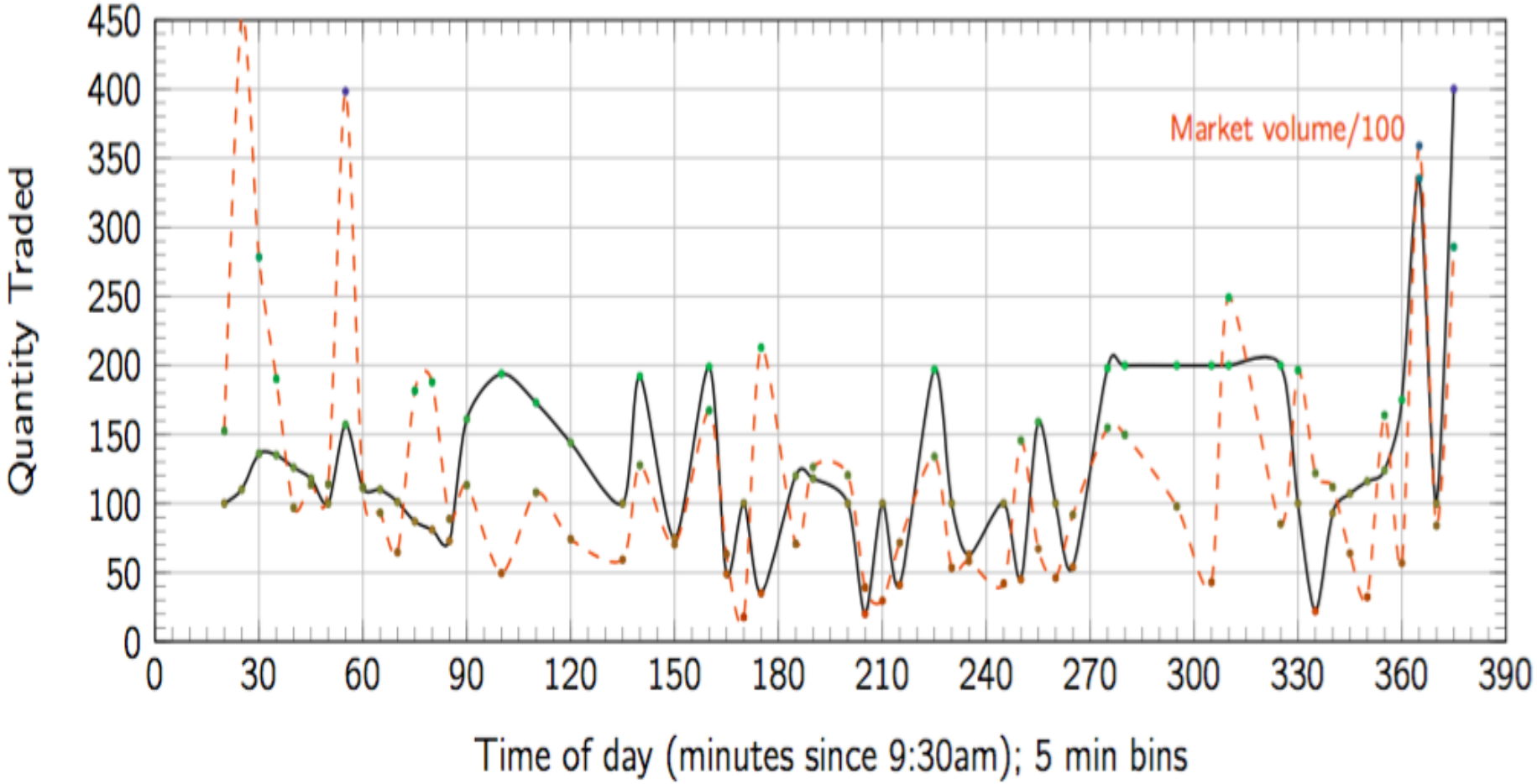
- During a slow trading day, the TWAP may be very similar to the VWAP, even to the penny at times. However, in a volatile session, or when volume is higher than usual, the two indicators may diverge.

[6] Yang (n.d.)

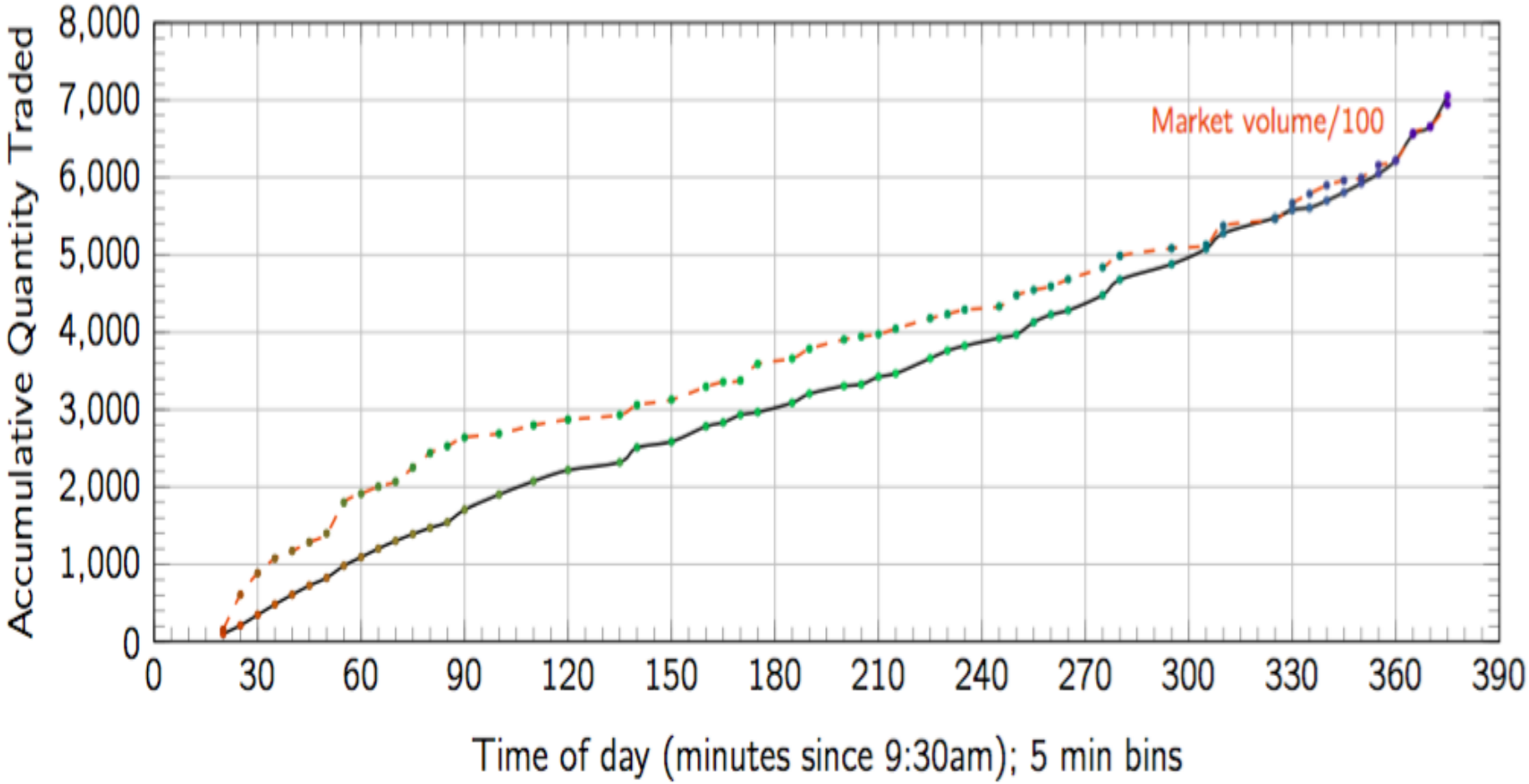
Algo Trading Strategies (Cont'd)

- **POV (Percent-of-Volume):** Executes while tracking the realized volume profile at a target participation rate, e.g., buy IBM at 15% participation rate
  - Controls behavior during volume spikes to avoid excessive cost
  - Popular in practice $\sim 5\% - 30\%$ participation rates
  - Participation rate is highly related to transaction cost
- **IS (Implementation Shortfall):** Schedules trade so as to optimally tradeoff expected shortfall (cost) against execution risk
  - Variable execution speed; adapts wrt changes in market conditions
  - Popular, especially with portfolios with intricate cost/risk tradeoff

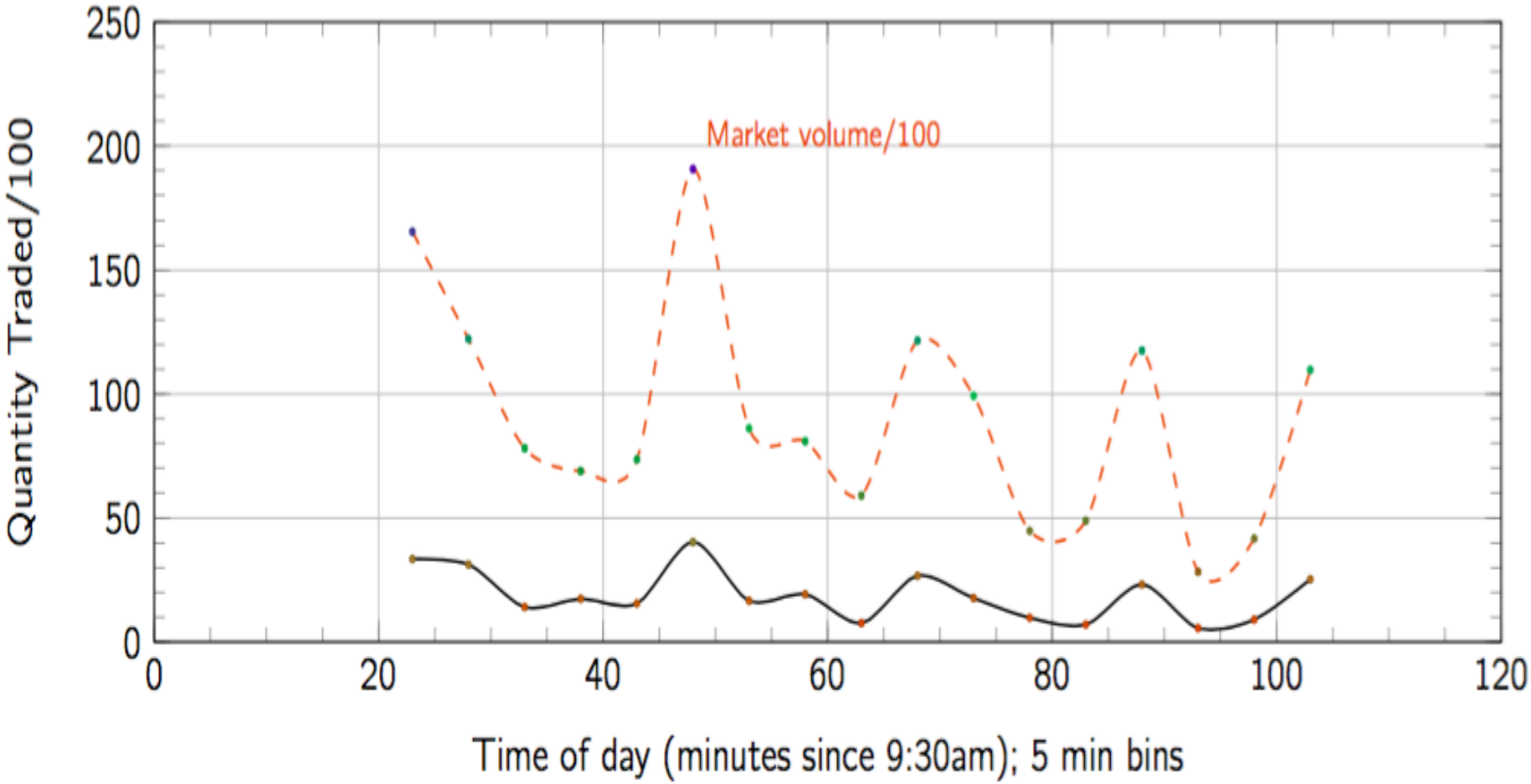
VWAP, XLY, 07/22/2013 (.15%ADV)



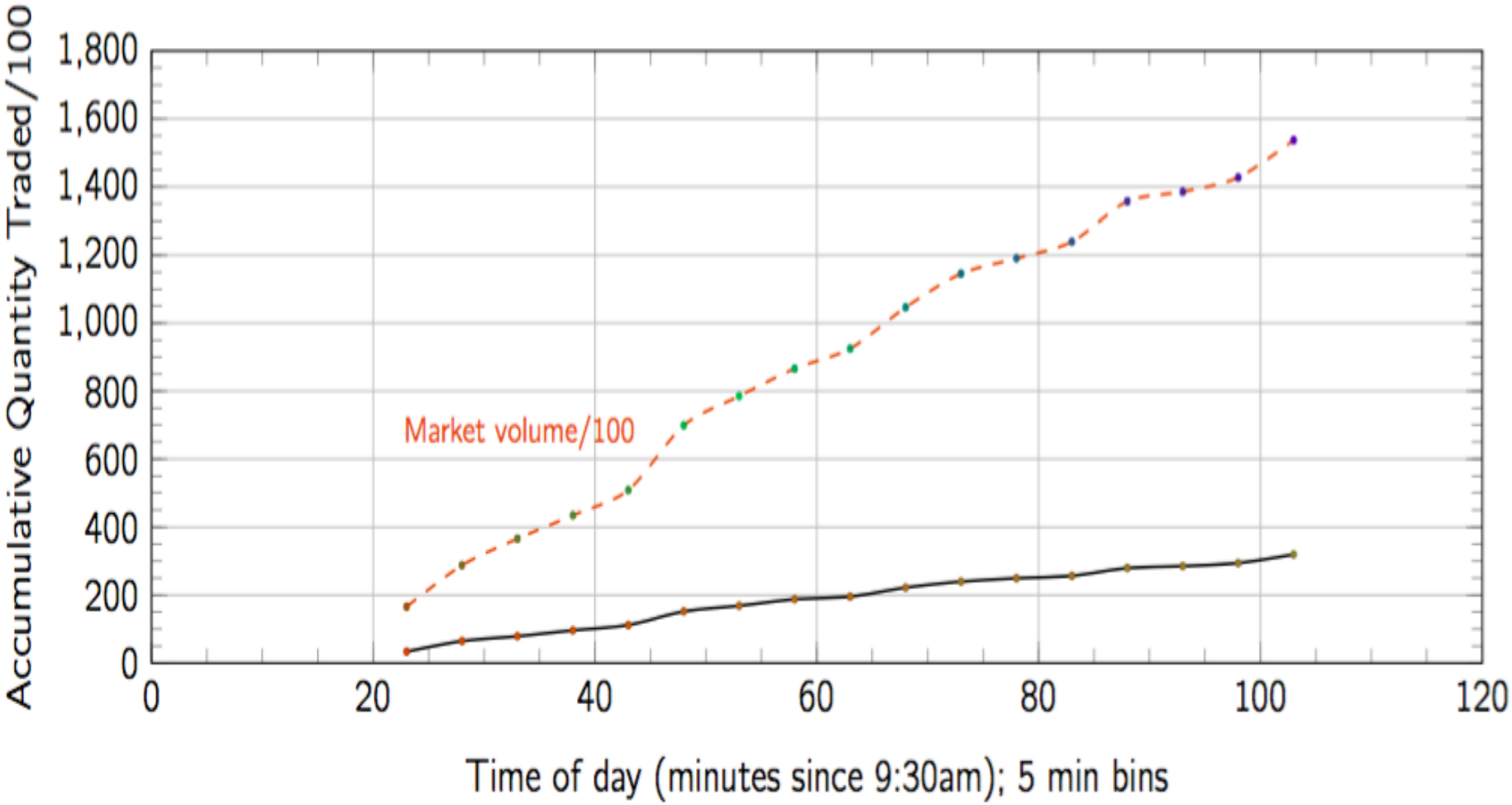
VWAP, XLY, 07/22/2013 (cumulative quantity)



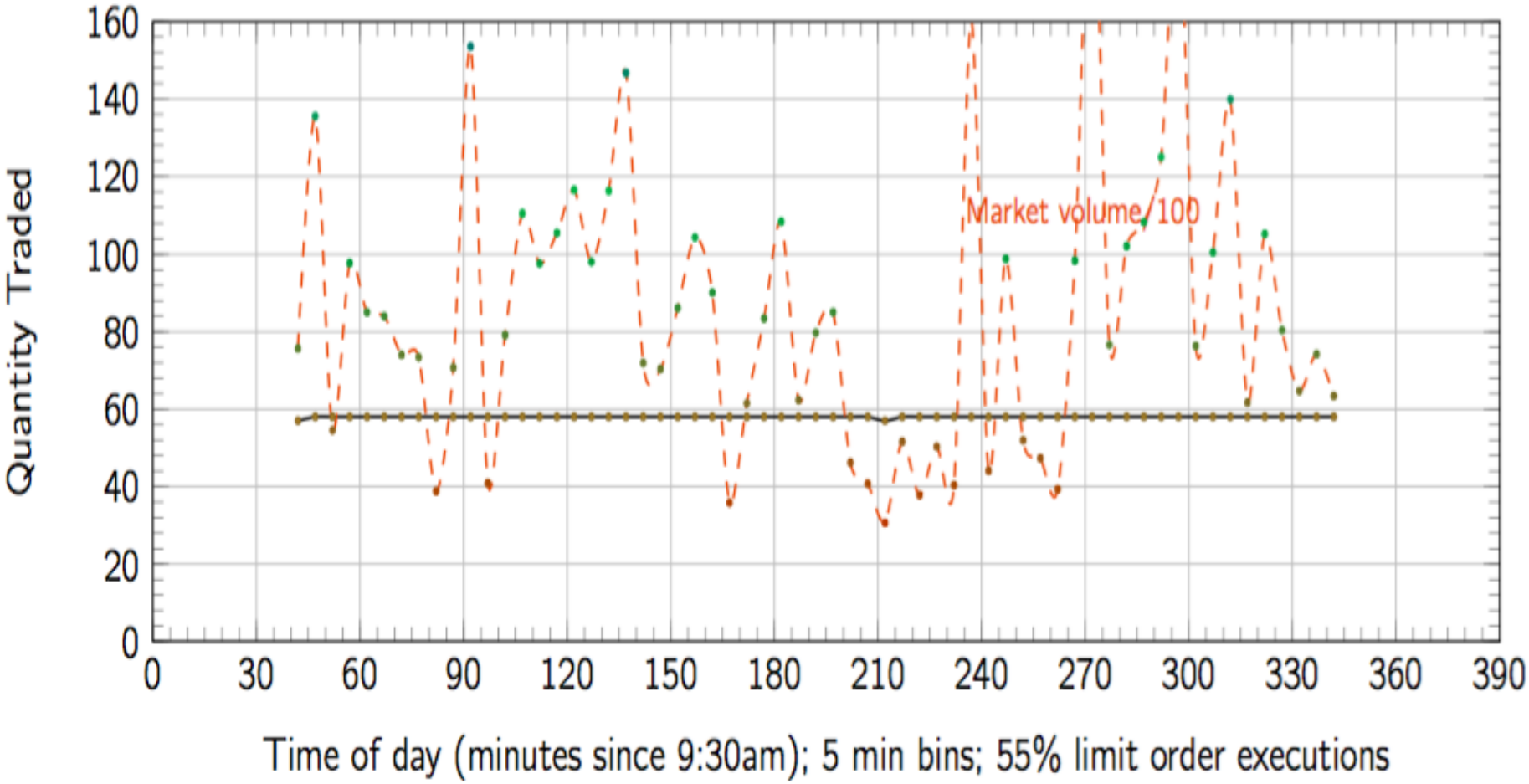
POV 20% ACT, 07/08/2013



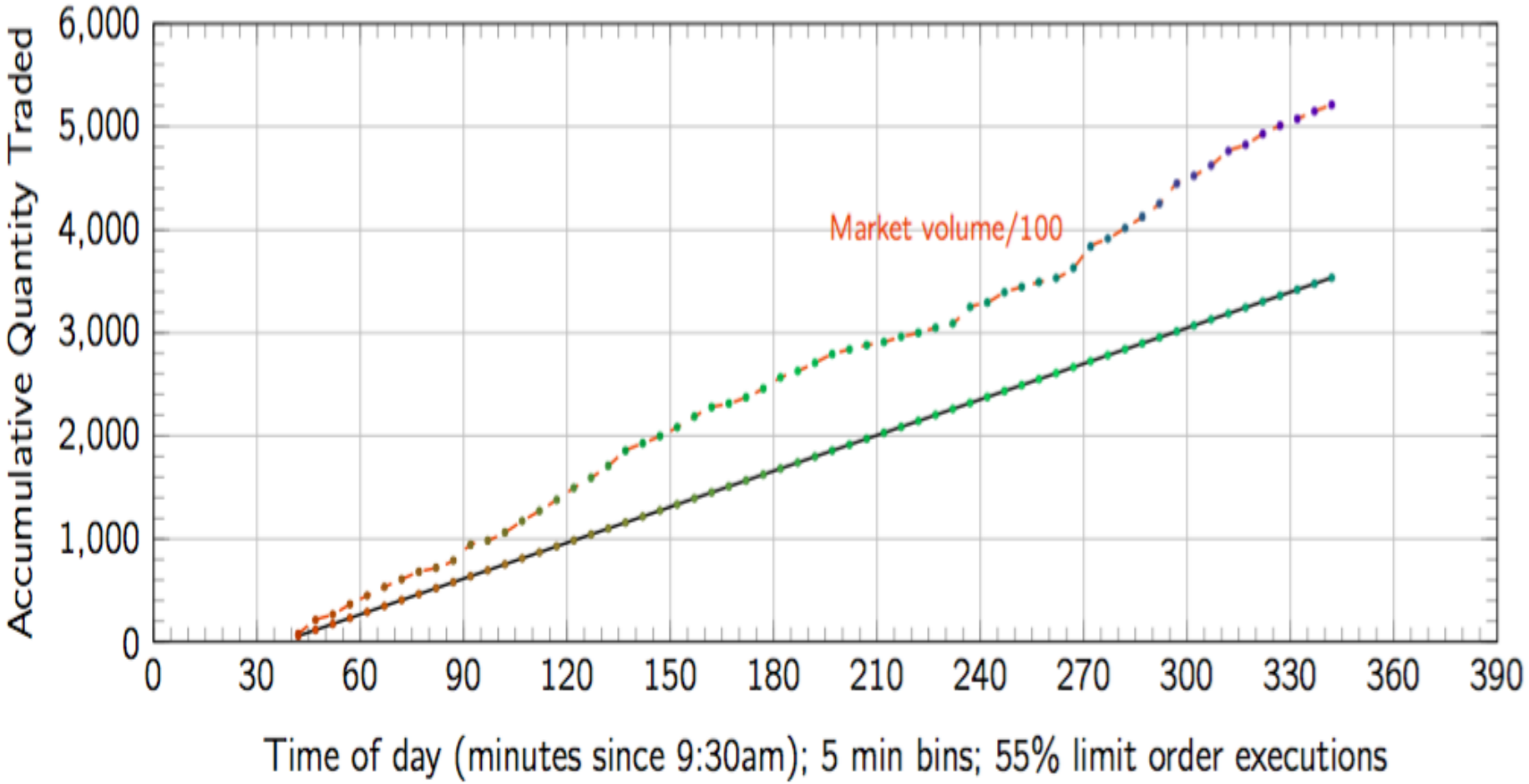
POV, ACT, 07/08/2013 (cumulative quantity)



Schematic of execution profiles: TWAP, XLY, 07/02/2013



TWAP, XLY, 07/02/2013 (cumulative quantity)



Algo Trading Systems: Typically Decomposed into 3 Steps

- **Trade scheduling (macro-trader):** splits parent order into $\sim$ 5 min slices
  - Relevant time-scale: minutes-hours
  - Schedule follows user selected strategy (VWAP, POV, IS, ...)
  - Reflects urgency, alpha, risk/return tradeoff
  - Schedule updated during execution to reflect price/liquidity/...
- **Optimal execution of a slice (micro-trader):** further divides slice into child orders
  - Relevant time-scale: secondsminutes
  - Strategy optimizes pricing and placing of orders in the LOB
  - Execution adjusts to speed of LOB dynamics, price momentum, ...
- **Order routing:** decides where to send each child order
  - Relevant time-scale: $\sim 1 - 50$ ms
  - Optimizes fee/rebate tradeoff, liquidity/price, latency, etc

Algorithmic Trading Systems: basic building blocks

- forecasts for intra-day trading patterns
  – volume
  – volatility
  – bid-ask spread
  – ...
- real-time market data analytics
- market impact model
- risk model
  – of the shelf risk models calibrated using EOD closing price data do not incorporate intra-day correlation structure
  – intra-day data? (tractable for liquid securities, e.g., S&P500 universe)
  – cross-asset liquidity model & market impact model

Essential building block: market impact model

- Optimizing the trade schedule, i.e., how to split a large trade over smaller waves to be executed over time, requires a cost function for:
  - immediate costs due to current trading decisions (e.g., next 3 min)
  - impact of current decisions on future prices (and future trades)
- Key considerations:
  - transient costs: impact of current trading decisions on price
  - decay of transient costs: instantaneous? impact decays over time?
  - permanent costs: is there a permanent cost (information content)?
  - time-scales: interpretation of transient, decay, permanent
- Calibration
  - how to model? functional forms? (depends on relevant time-scale)
  - what data is needed
  - stock segmentation

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Simple Limit Order Book

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ID	Bid Size	Bid Price	Ask Price	Ask Size	ID
Bid1	55	100.00	100.01	2,000	Offer1
Bid2	1,000	100.00	100.02	2950	Offer2
Bid3	3,100	99.99	100.02	600	Offer3
Bid4	200	99.99	100.03	300	Offer4
Bid5	5,000	99.98	100.04	1,000	Offer5

Table 1: Mockup of an Order Book for a Fictitious Ticker

$$\text{Last Trade Price} = ? \quad \text{Last Trade Size} = ?$$
$$\text{Best Bid Price} = 100.00 \quad \text{Best Bid Size} = 1{,}055$$
$$\text{Best Offer Price} = 100.01 \quad \text{Best Offer Size} = 2{,}000$$

[7] Narang (2014)

Simple Limit Order Book (Cont'd)

ID	Bid Size	Bid Price	Ask Price	Ask Size	ID
Bid1	55	100.00	100.02	1,950	Offer2
Bid2	1,000	100.00	100.02	600	Offer3
Bid3	3,100	99.99	100.03	300	Offer4
Bid4	200	99.99	100.04	1,000	Offer5
Bid5	5,000	99.98			

Table 2: Mockup of an Order Book for a Fictitious Ticker after a 3,000-share Market Share to Buy

$$\text{Last Trade Price} = 100.01 \quad \text{Last Trade Size} = 3000$$
$$\text{Best Bid Price} = 100.00 \quad \text{Best Bid Size} = 55$$
$$\text{Best Offer Price} = 100.02 \quad \text{Best Offer Size} = 1{,}950$$

Simple Limit Order Book (Cont'd)

ID	Bid Size	Bid Price	Ask Price	Ask Size	ID
Bid2	55	100.00	100.02	1,950	Offer2
Bid3	1,000	100.00	100.02	600	Offer3
Bid4	3,100	99.99	100.03	300	Offer4
Bid5	200	99.99	100.04	1,000	Offer5

Table 3: Mockup of an Order Book for a Fictitious Ticker after a 1,000-share Limit Order to Sell at $100.00

$$\text{Last Trade Price} = 100.00 \quad \text{Last Trade Size} = 1000$$
$$\text{Best Bid Price} = 100.00 \quad \text{Best Bid Size} = 55$$
$$\text{Best Offer Price} = 100.02 \quad \text{Best Offer Size} = 1{,}950$$

Simple Limit Order Book (Cont'd)

ID	Bid Size	Bid Price	Ask Price	Ask Size	ID
Bid2	55	100.00	100.02	1,950	Offer2
Bid3	1,000	100.00	100.02	600	Offer3
Bid4	3,100	99.99	100.02	1,000	Offer6
Bid5	200	99.99	100.03	300	Offer4
			100.04	1,000	Offer5

Table 4: Mockup of an Order Book for a Fictitious Ticker after a 1,000-share Limit Order Joins the Best Offer $100.02

$$\text{Last Trade Price} = 100.00 \quad \text{Last Trade Size} = 1000$$
$$\text{Best Bid Price} = 100.00 \quad \text{Best Bid Size} = 55$$
$$\text{Best Offer Price} = 100.02 \quad \text{Best Offer Size} = 1{,}950$$

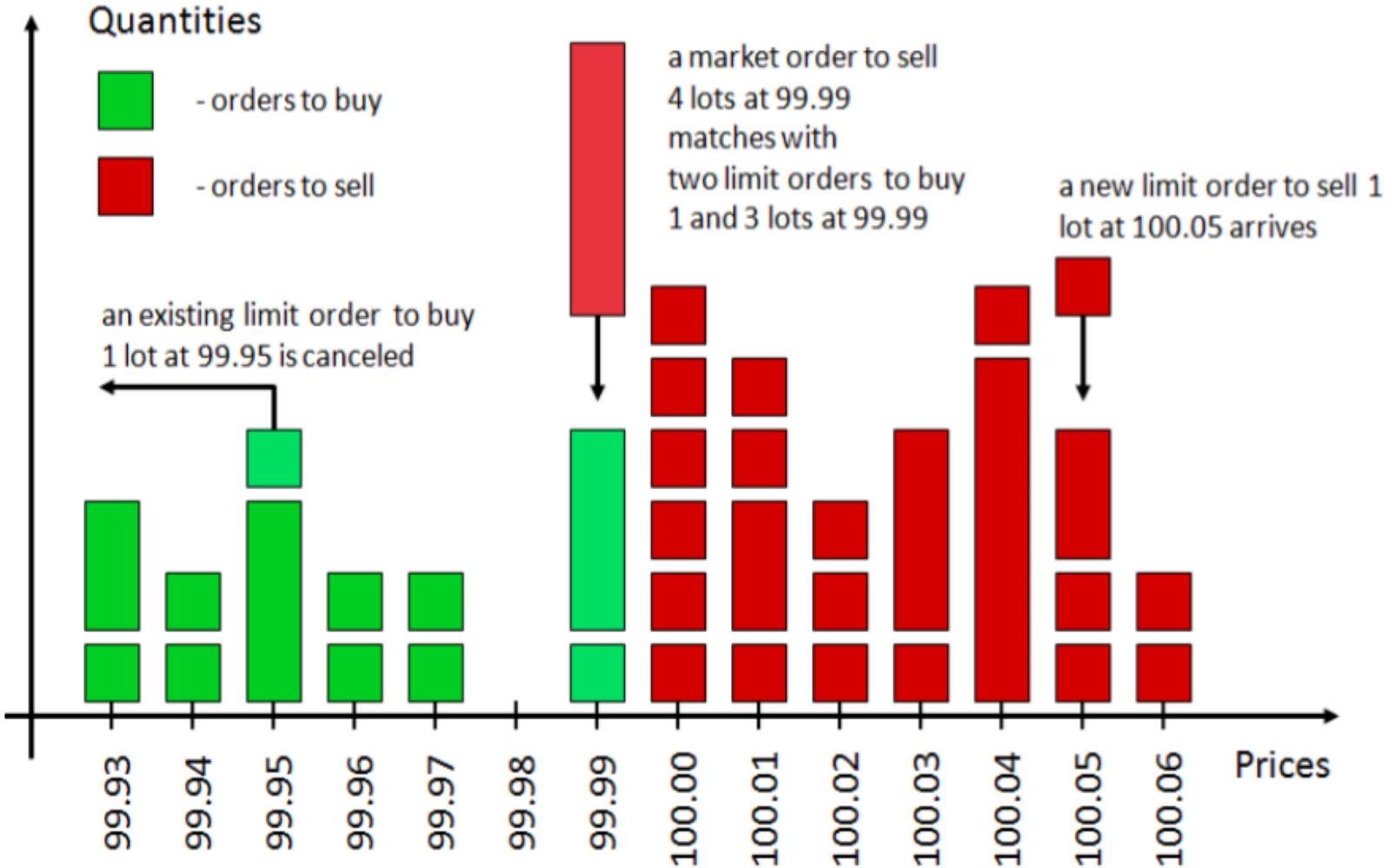
Simple Limit Order Book (Cont'd)

ID	Bid Size	Bid Price	Ask Price	Ask Size	ID
Bid2	55	100.00	100.01	2,000	Offer7
Bid3	1,000	100.00	100.02	1,950	Offer2
Bid4	3,100	99.99	100.02	600	Offer3
Bid5	200	99.99	100.02	1,000	Offer6
			100.03	300	Offer4
			100.04	1,000	Offer5

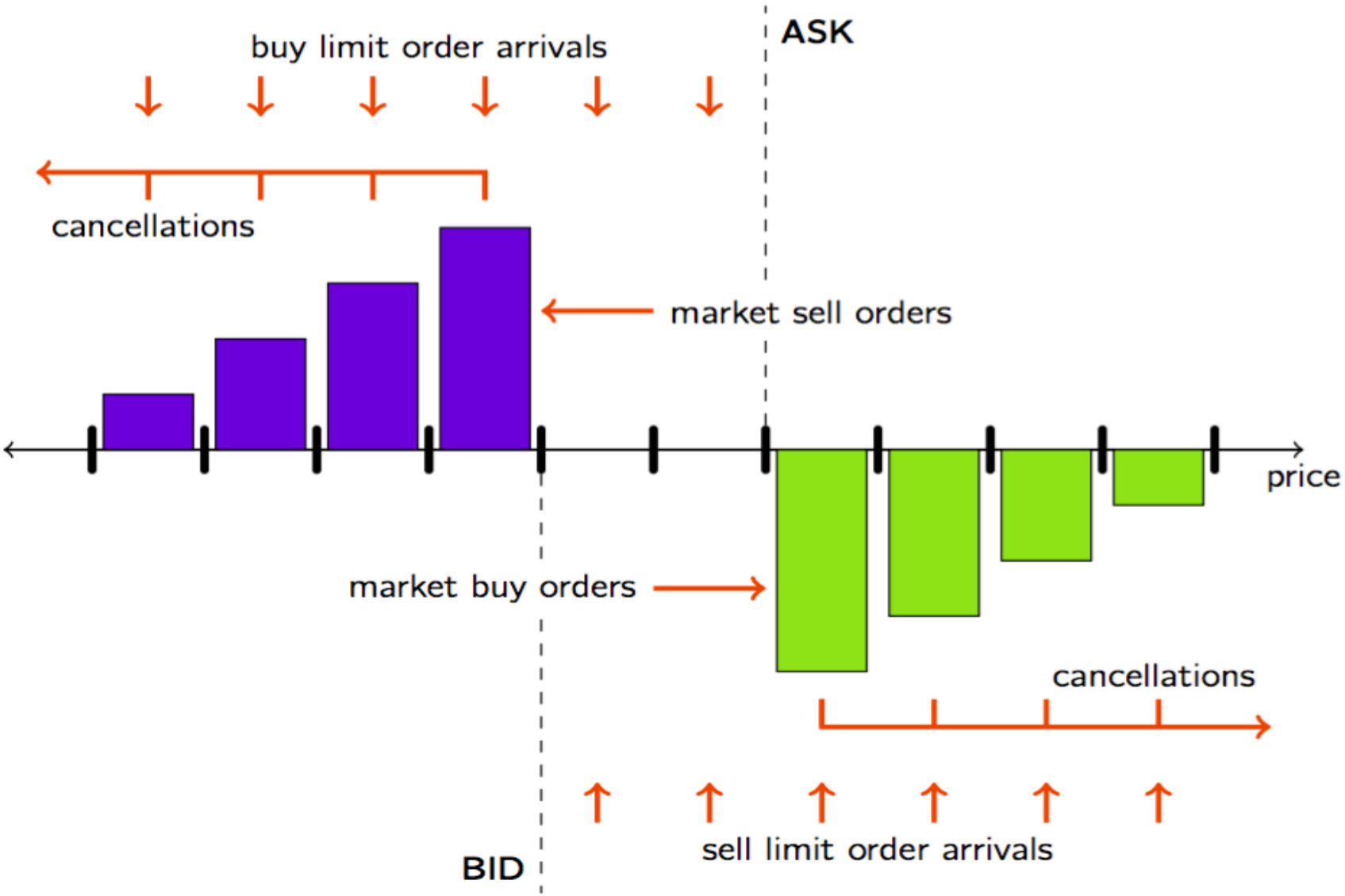
Table 5: Mockup of an Order Book for a Fictitious Ticker after a 2,000-share Limit Order Improves the Best Offer $100.01

$$\text{Last Trade Price} = 100.00 \quad \text{Last Trade Size} = 1000$$
$$\text{Best Bid Price} = 100.00 \quad \text{Best Bid Size} = 55$$
$$\text{Best Offer Price} = 100.01 \quad \text{Best Offer Size} = 2{,}000$$

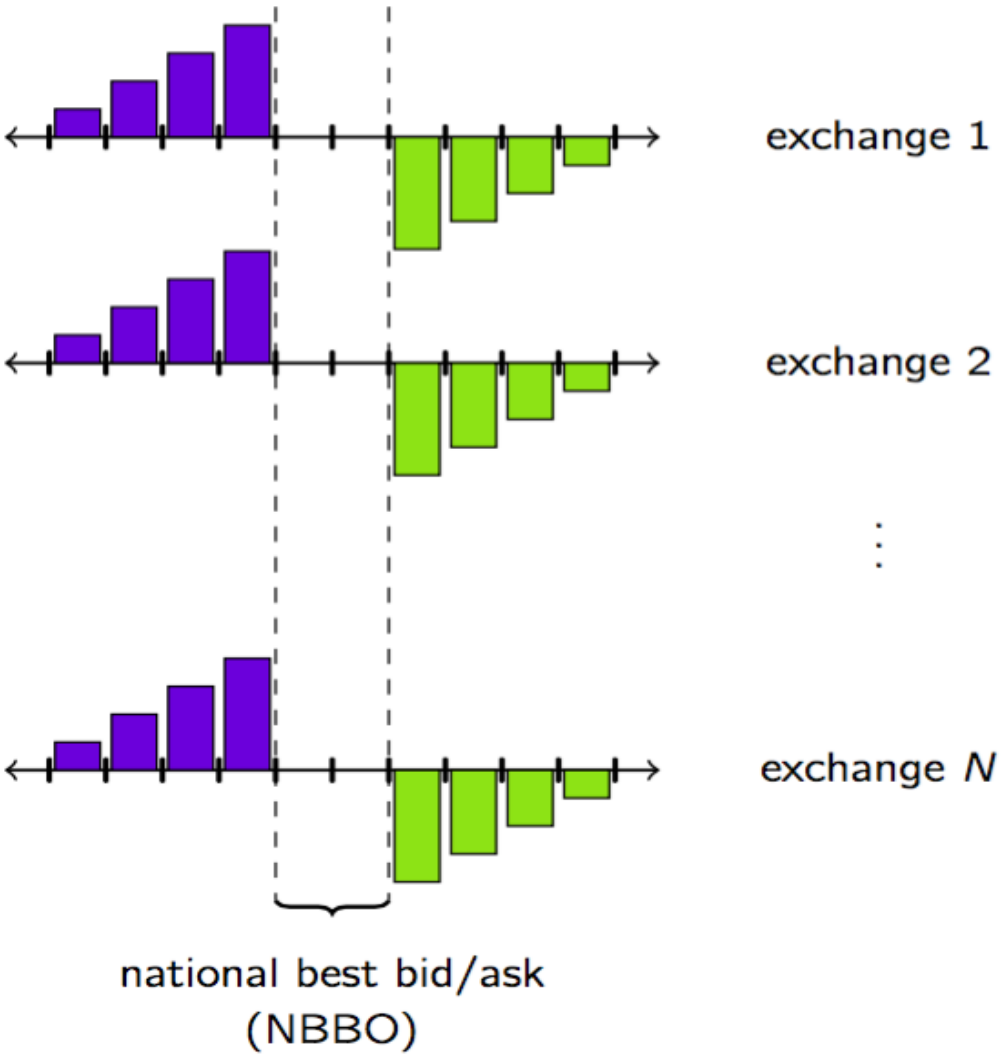
LOB Schematic



The Limit Order Book (LOB)

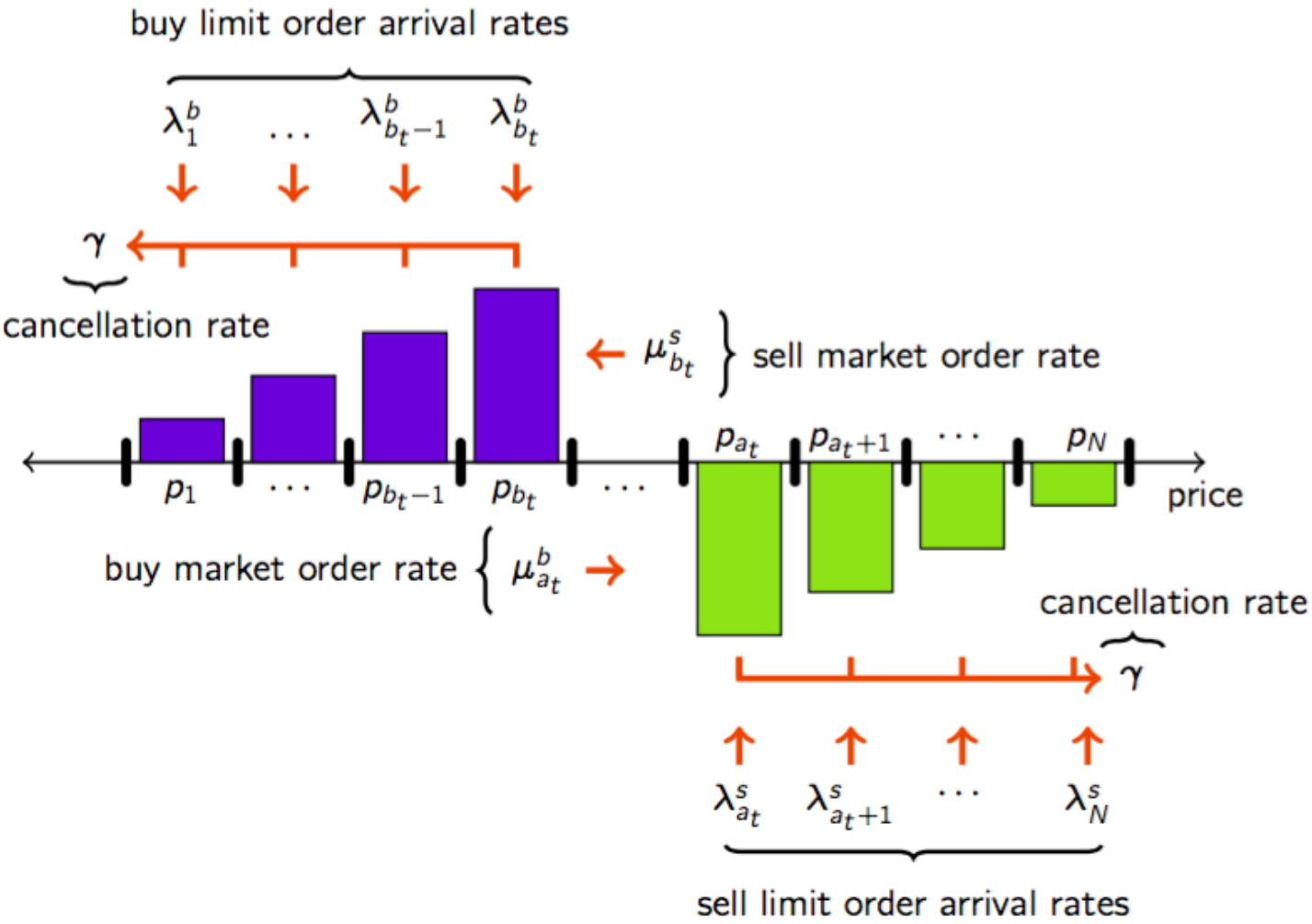


Multiple Limit Order Books

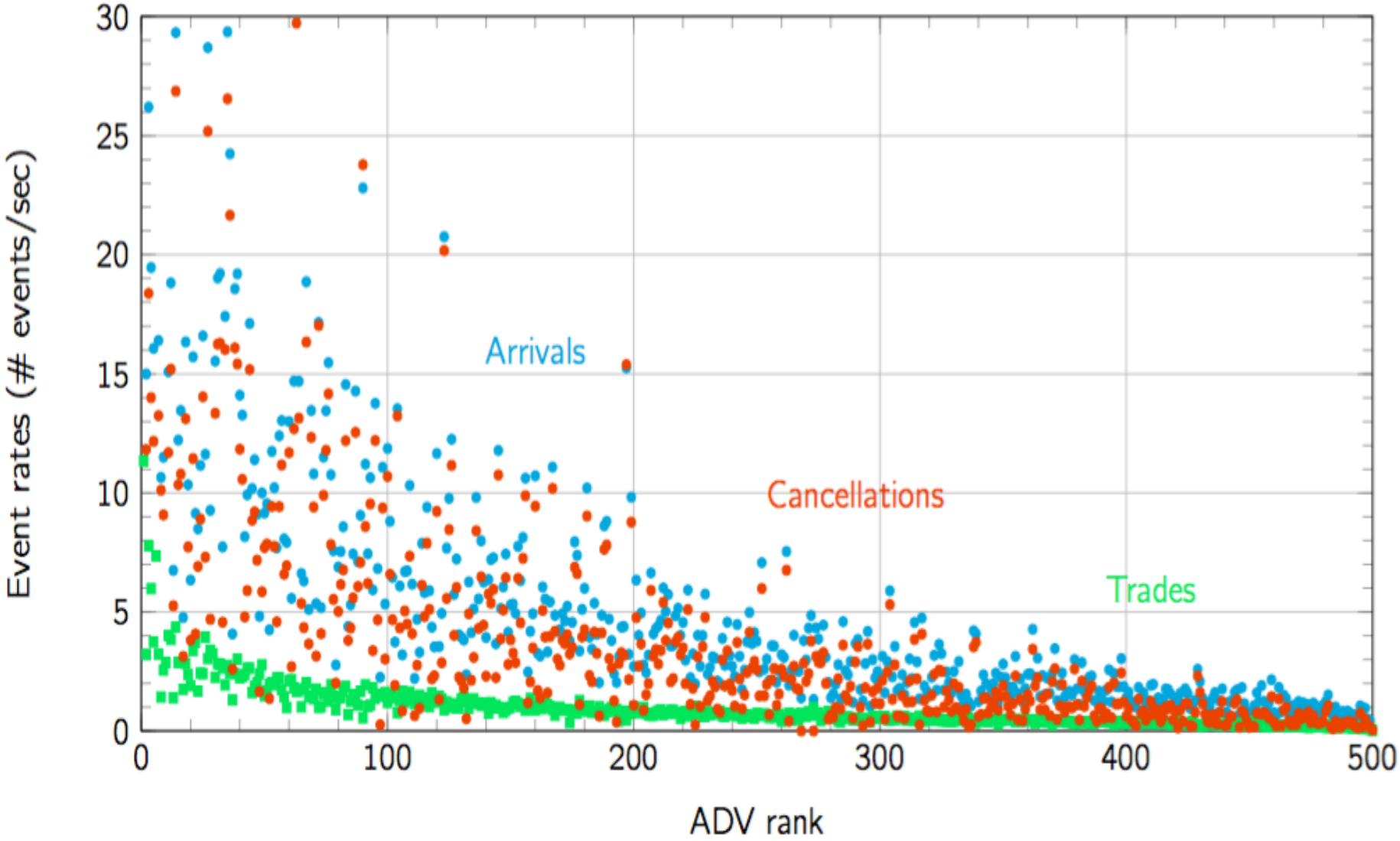


Price levels are coupled through protection mechanisms (Reg NMS)

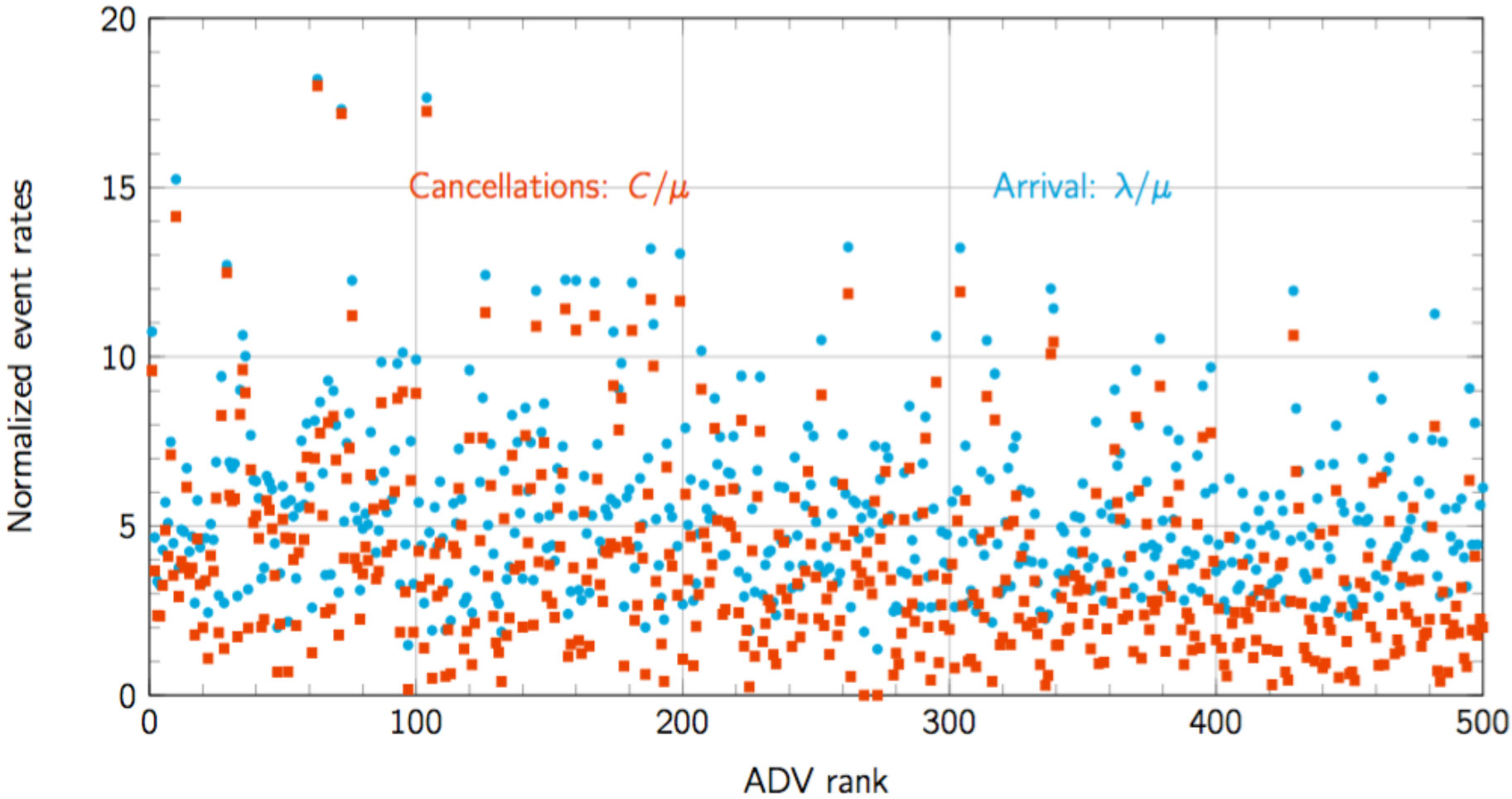
LOB: event driven (short-term) view



Event rates (top of book)

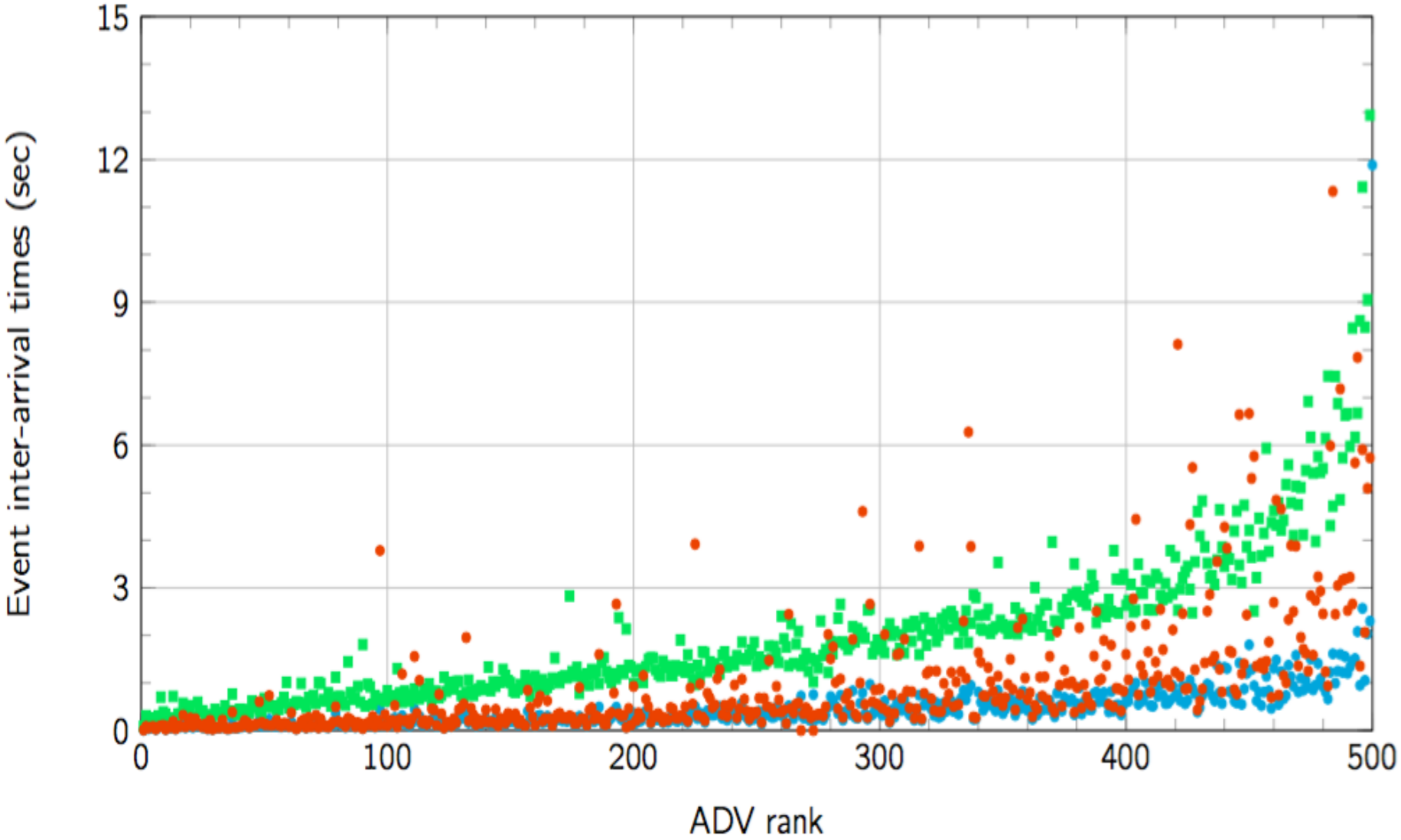


Normalized event rates (top of book)

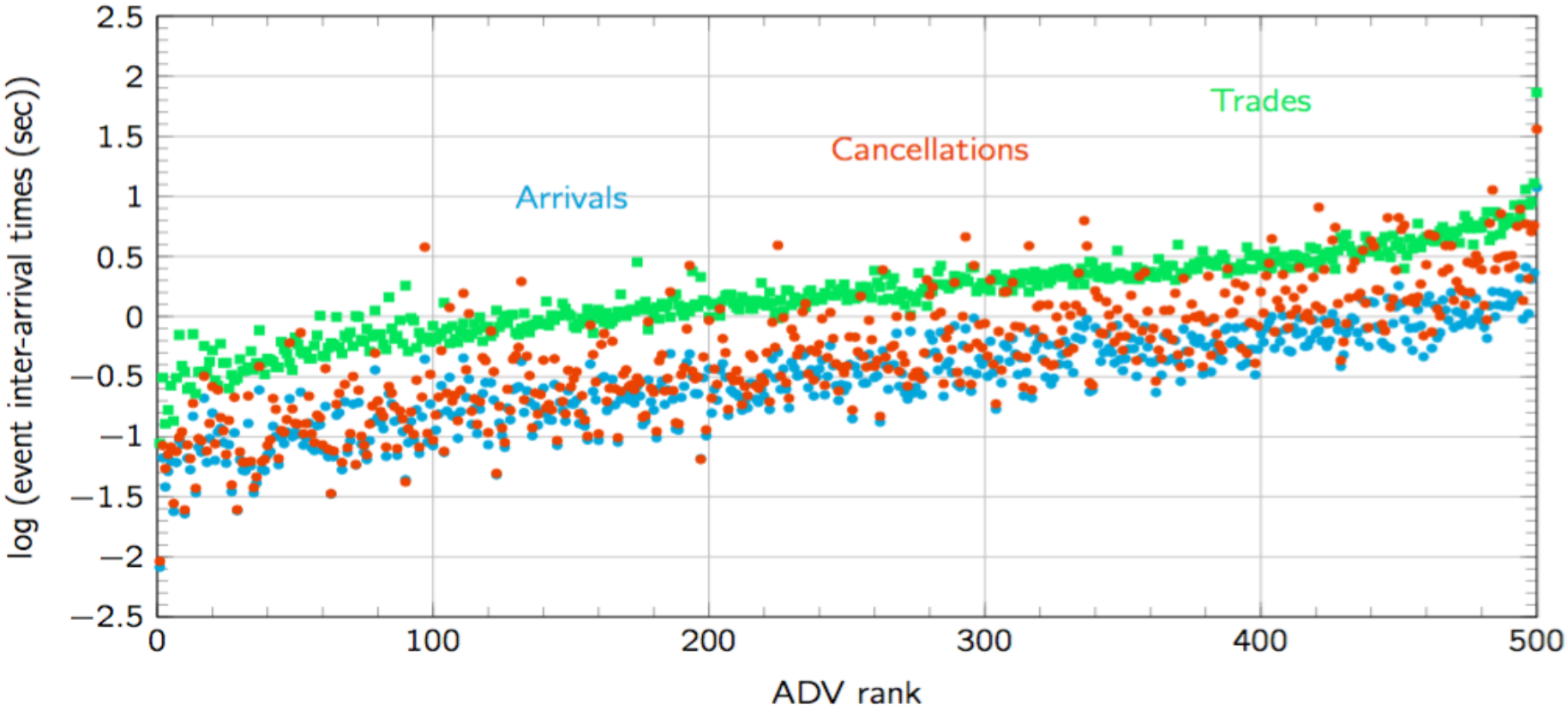


- cancellation volume (at top of book) $\approx$ trade volume
- arrival volume (limit orders at top of book) $\approx$ traded volume

Interarrival times (top of book)



Interarrival times (log scale) (top of book)



- liquid stocks: # trades, # cancellations, # large limit order arrivals
- # trades $\approx$ 1 order of magnitude less frequent than cancels or order arrivals

Interarrival times (log scale) (top of book)

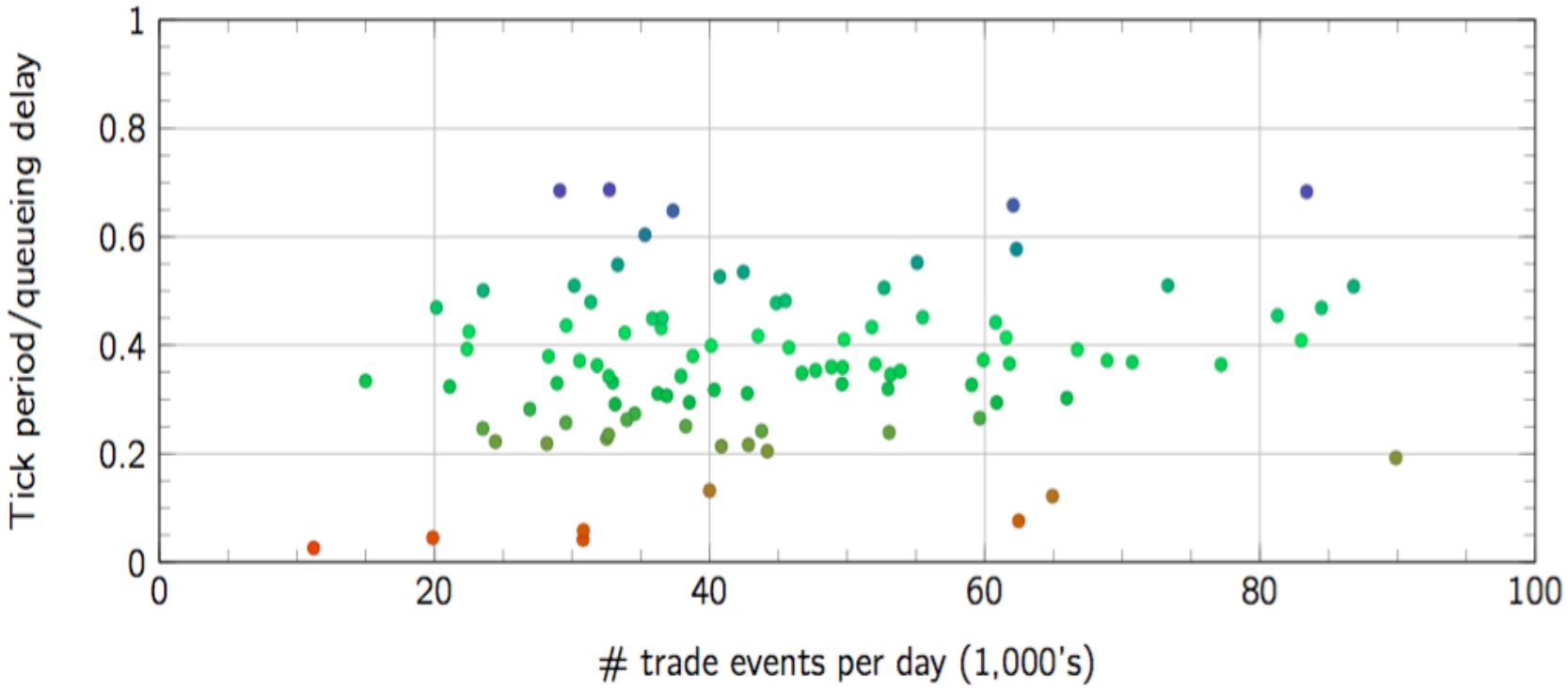


Figure 2: Tick period VS queueing delay: ratio against # trade events. (liquid names)

- tick period = avg time between changes in the mid-price
- tick period is on same (or smaller) order magnitude as queueing delay

Some tactical questions in optimizing trading decisions

- given state of LOB, how long will it take for a limit order to trade?
  – e.g., VWAP schedule wants 1,000 shares over next 3 min, when do we post limit orders?
- which exchange to post limit order taking into account orders already posted there, and the way that market orders will prioritize over different exchanges due to rebate/fee differences
- what is the dependency on event dynamics on the bid-side and ask-side of the book
- how can we keep track of our queue position?
  – how do adverse selection costs depend on queue position:
  – queue ahead of my order
  – queue behind my order
  – queue on opposite side of the book
- market orders, cancellations, etc.,

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