Beyond Sensing: Multi-GHz Realtime Spectrum Analytics

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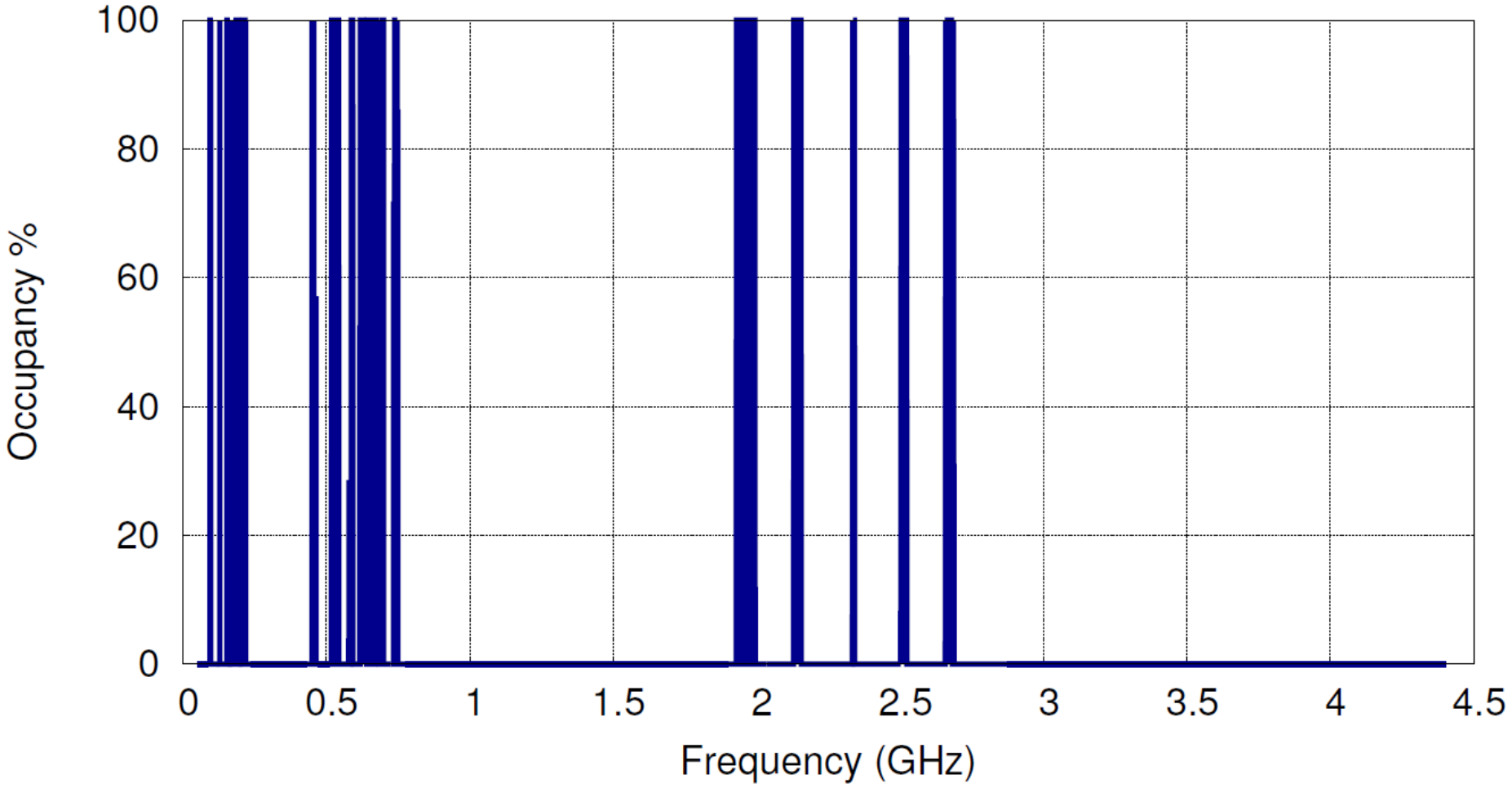
Spectrum Sensing

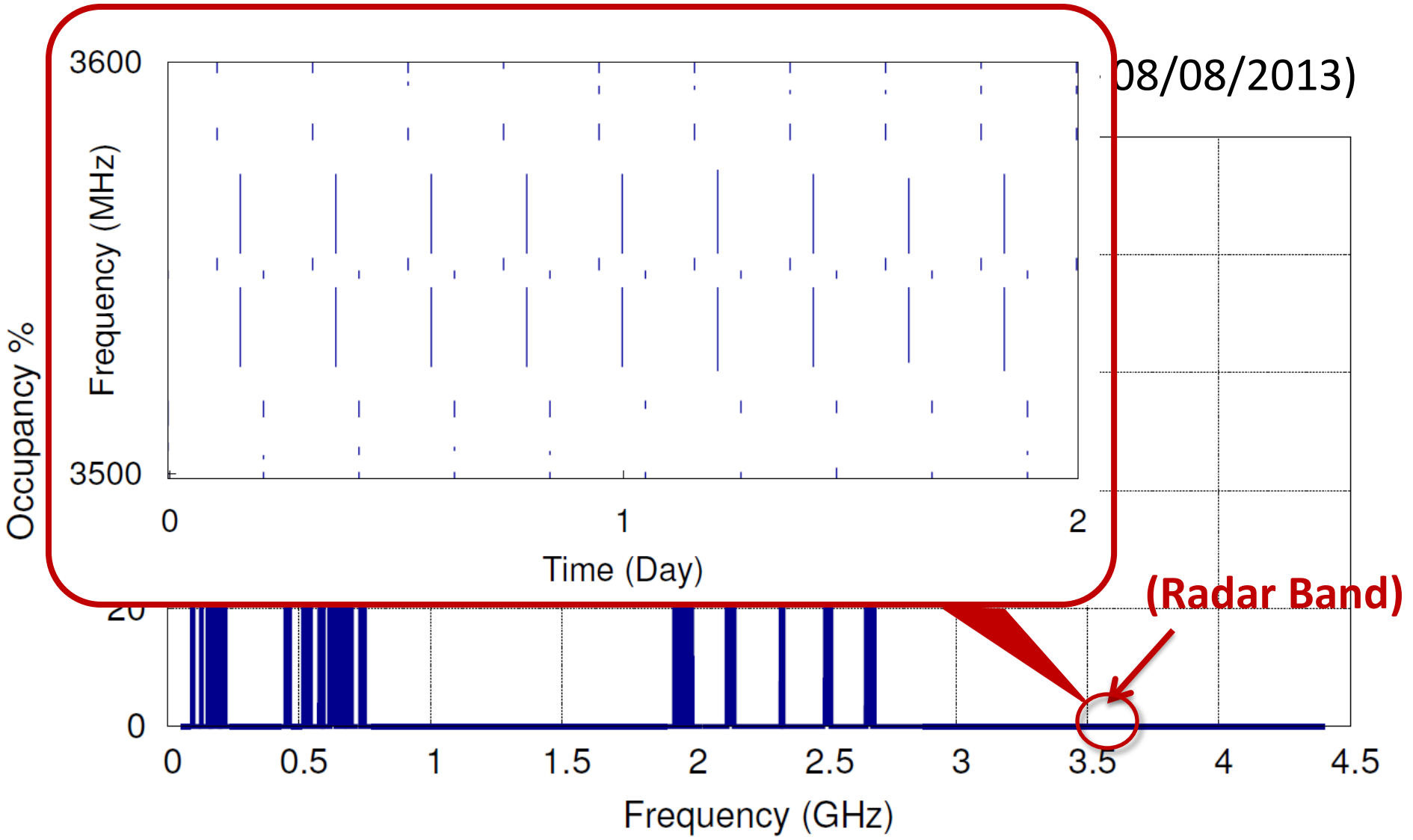
- Measures the usage of each spectrum band
- Important because:
  - Guides the FCC's policies
  - Enables dynamic spectrum access
- Two decades of work on spectrum sensing, but little understanding of how the spectrum is used

Today's Spectrum Sensing Reports

Microsoft Spectrum Observatory (08/03/2013 – 08/08/2013)



Today's Spectrum Sensing Reports



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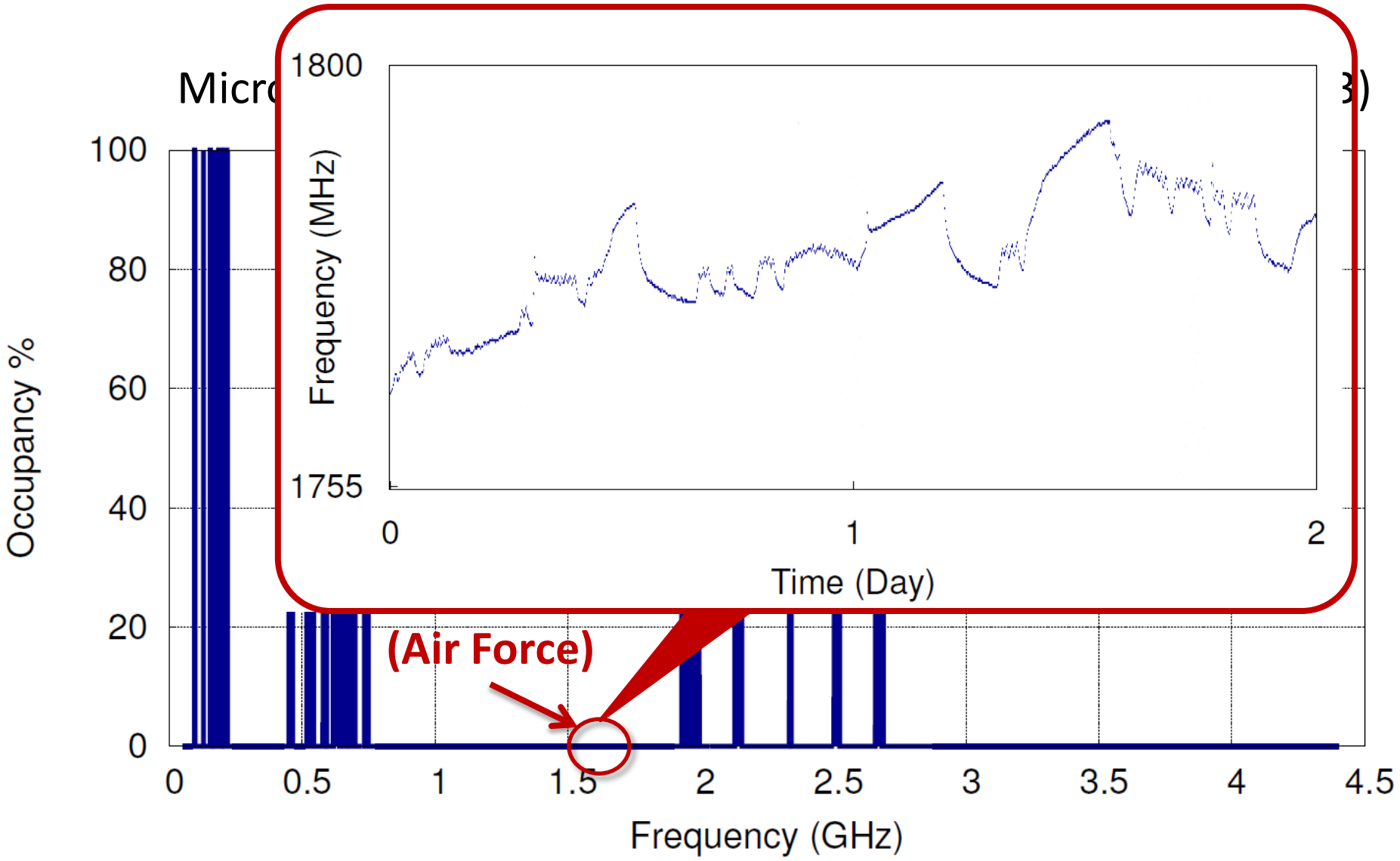
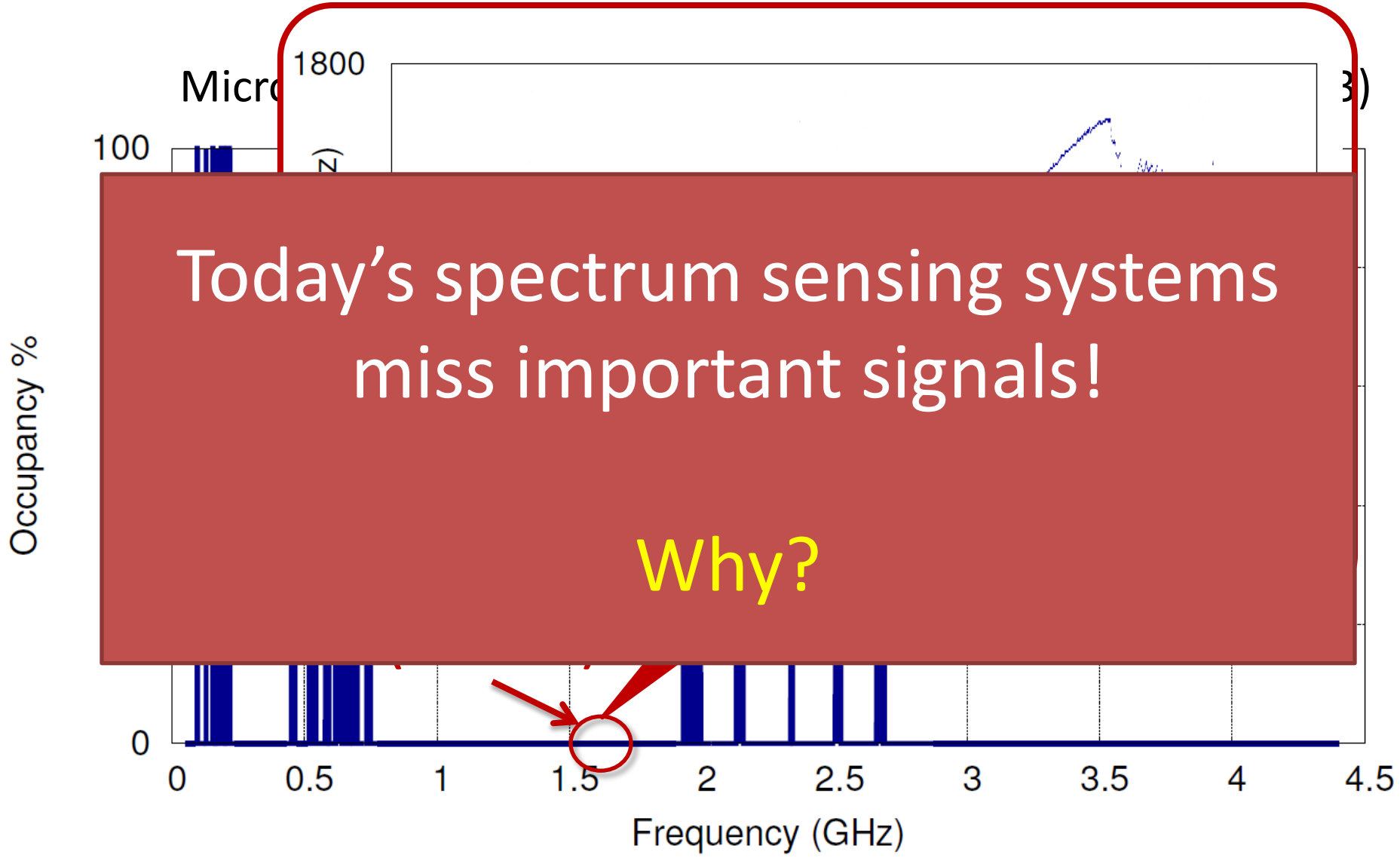


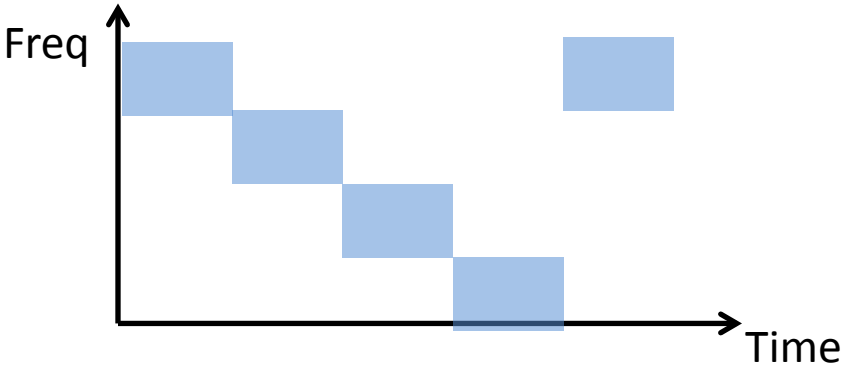
Today's Spectrum Sensing Reports



Today's spectrum sensing systems miss important signals!

Why?

Today: Sequential sensing with MHz BW



- Cheap, practical
- Miss important signals

Ideally: Realtime sensing with GHz BW

- Capture all signals
- Costly, and impractical

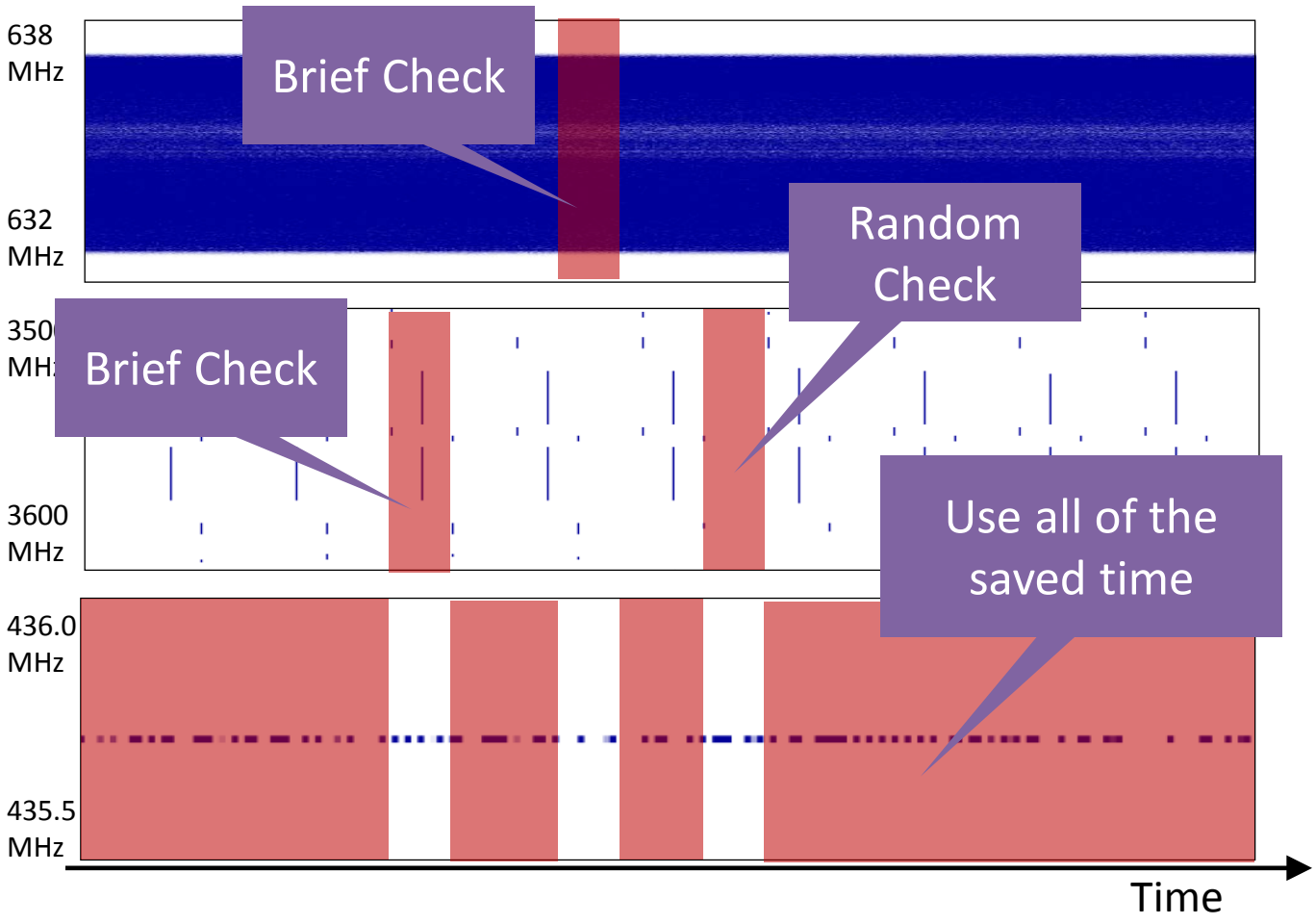
Can we use MHz radios but capture all signals?

SpecInsight

- Uses MHz radios to accurately sense GHz spectrum
- Evaluated in 7 US cities
- Captures very low occupancy signals which are missed by past work

How does it work?

Intuition: Scan Bands to Maximize the Probability of Detecting Signals



Always-on
(TV signal)

Periodic
(Radar Signal)

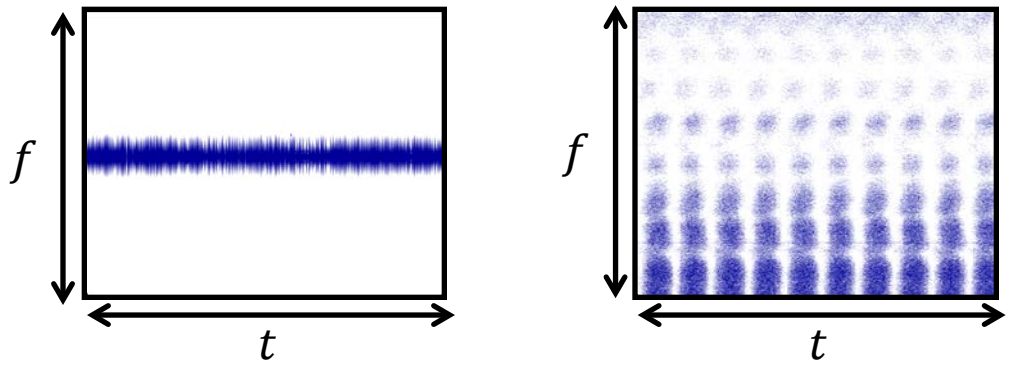
Dynamic
(Amateur Radio)

SpecInsight Architecture

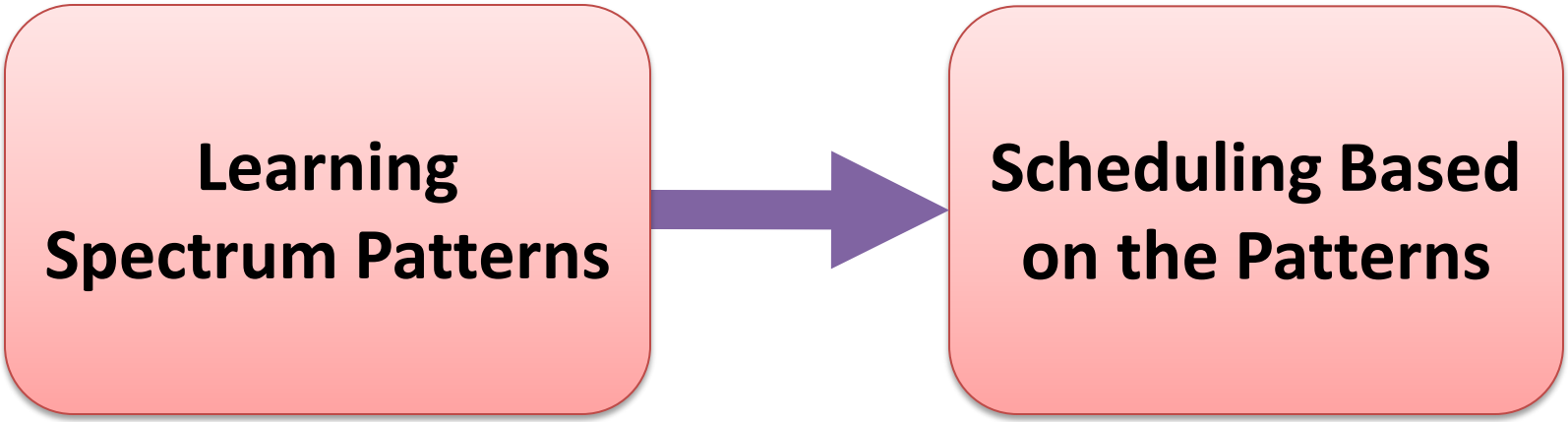
Learning Spectrum Patterns

Scheduling Based on the Patterns

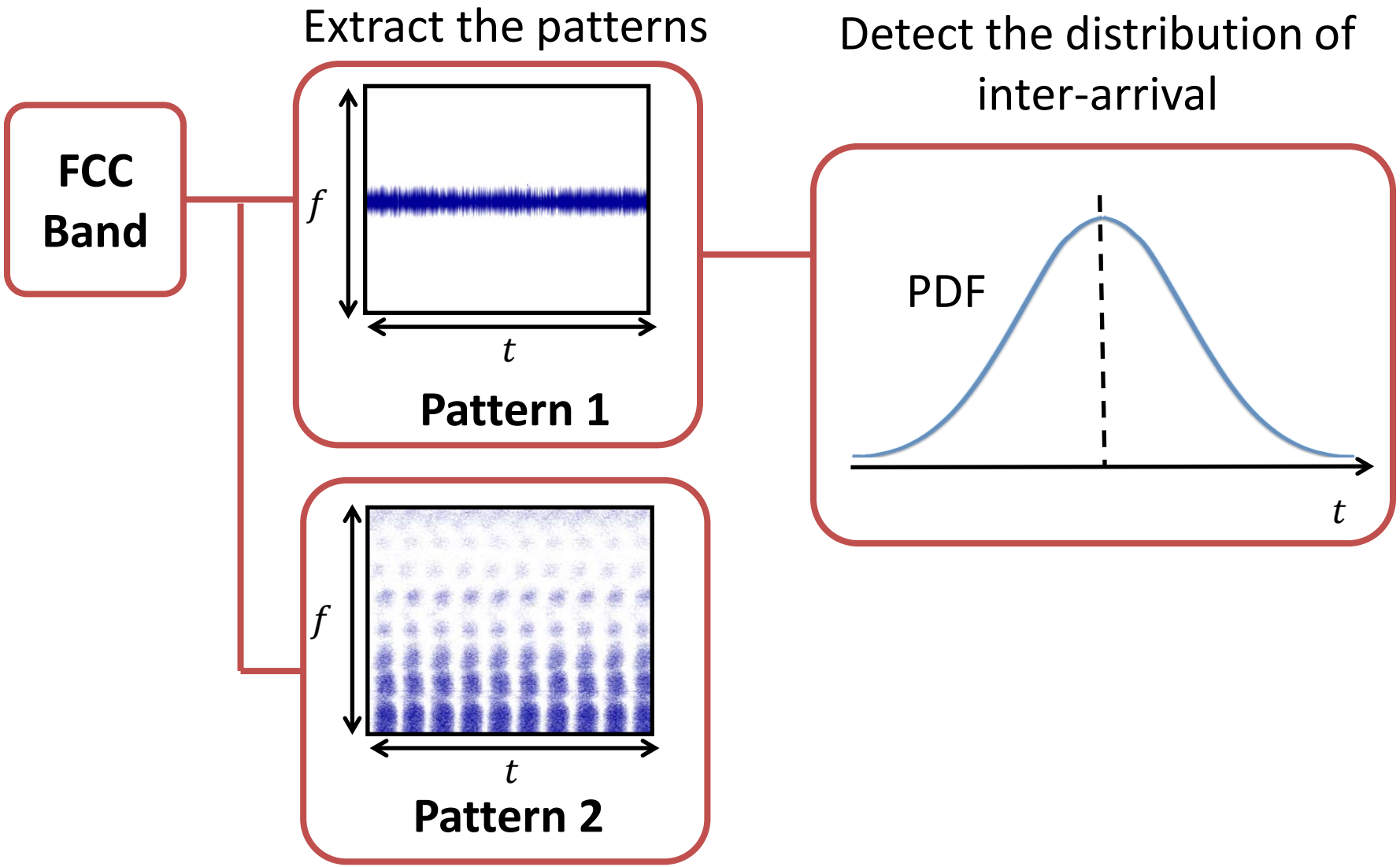
Pattern is a representative time-frequency chunk



SpecInsight Architecture



Learning Patterns



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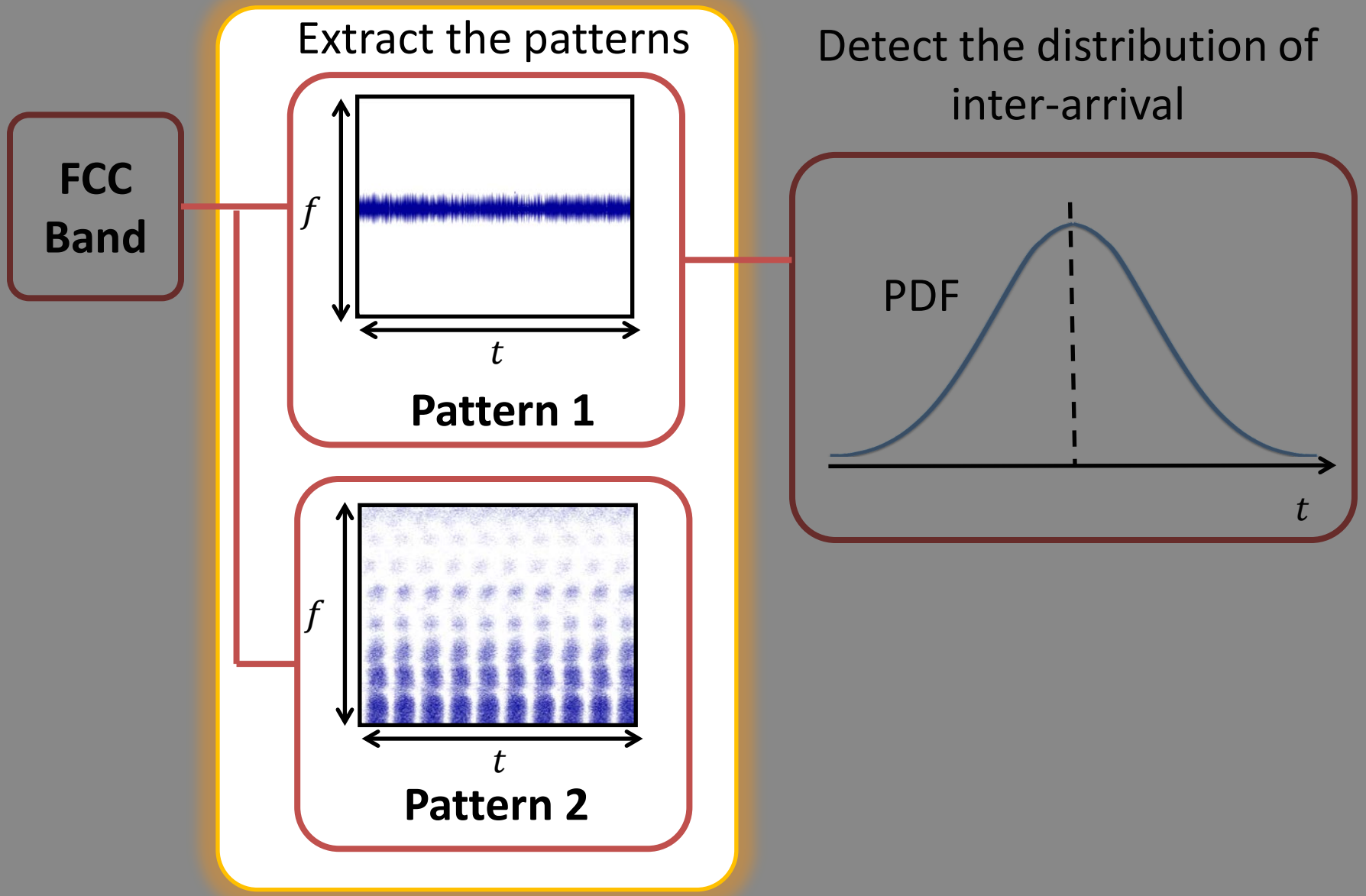
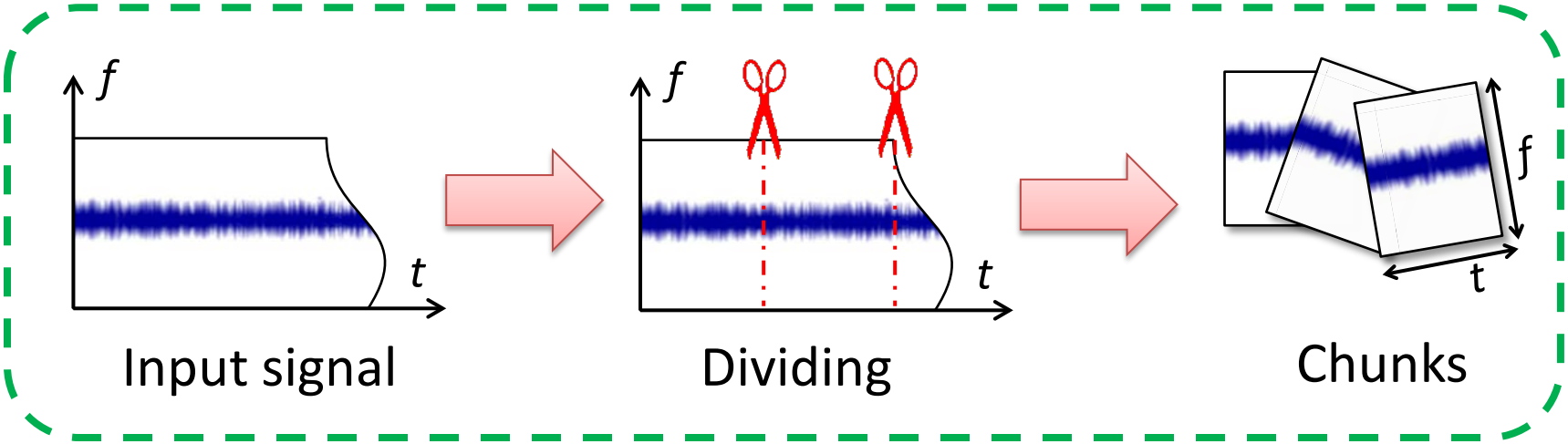
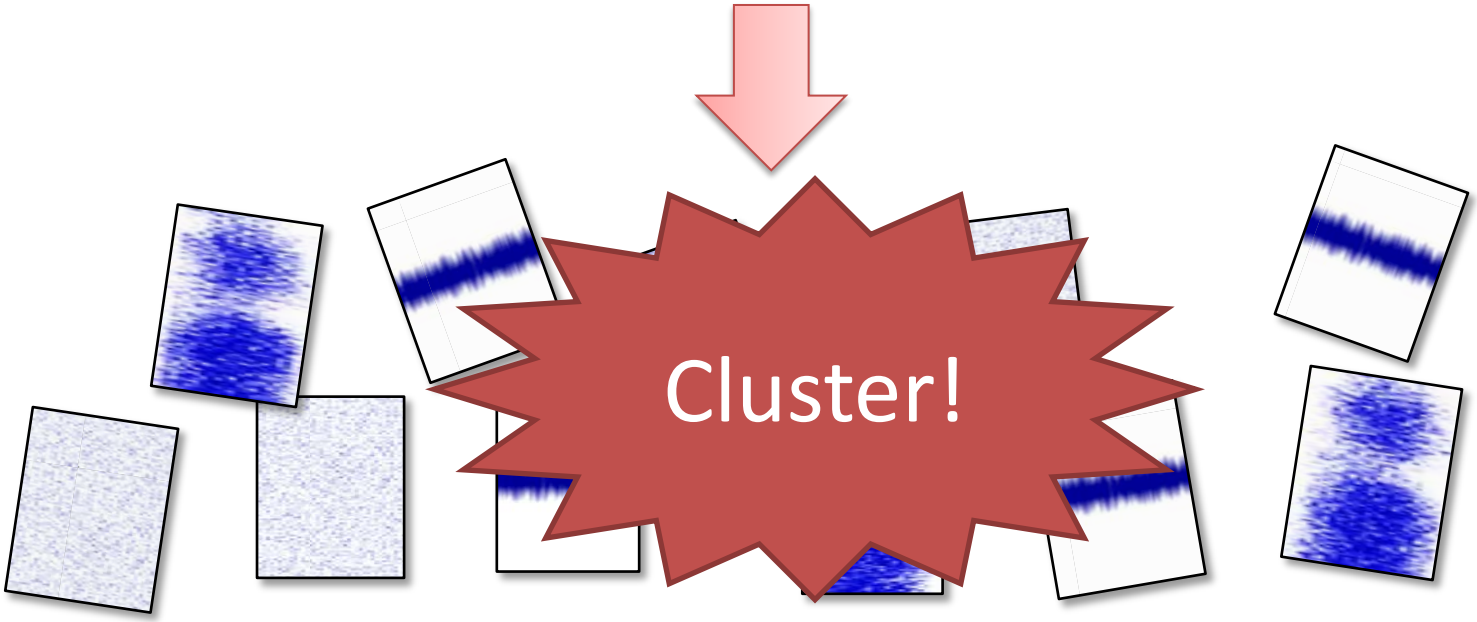
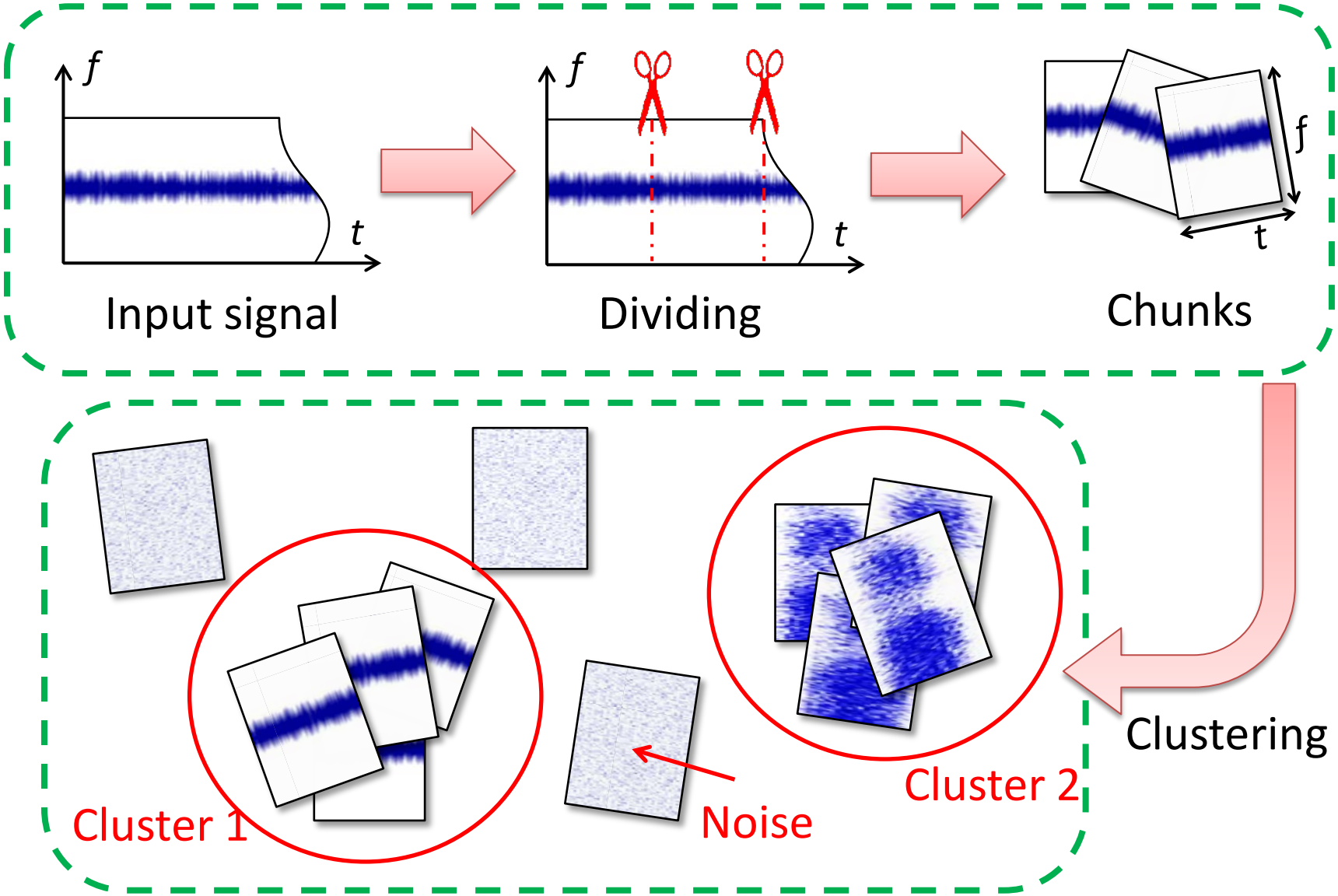


Extracting Patterns

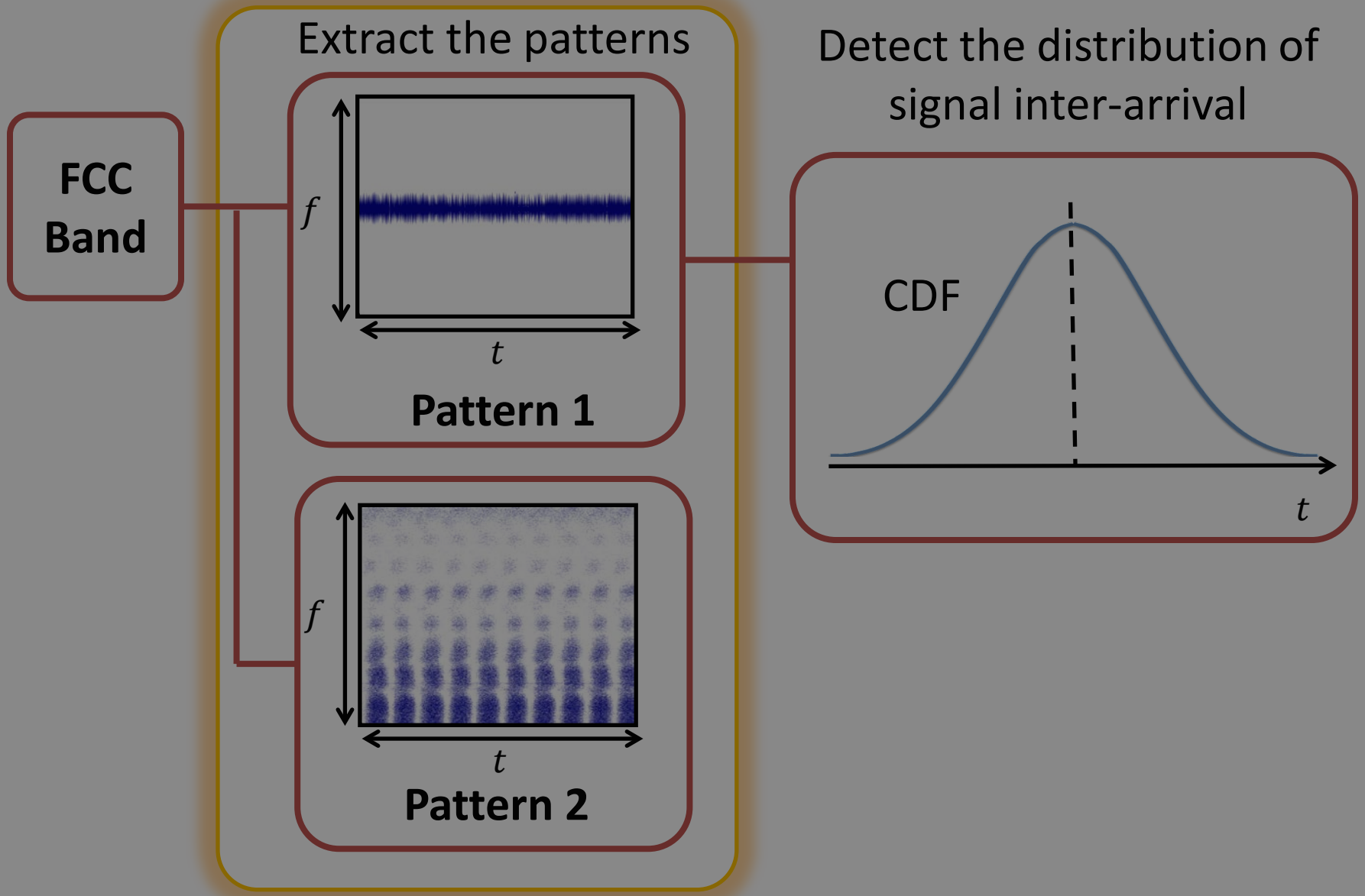




Identifying Patterns



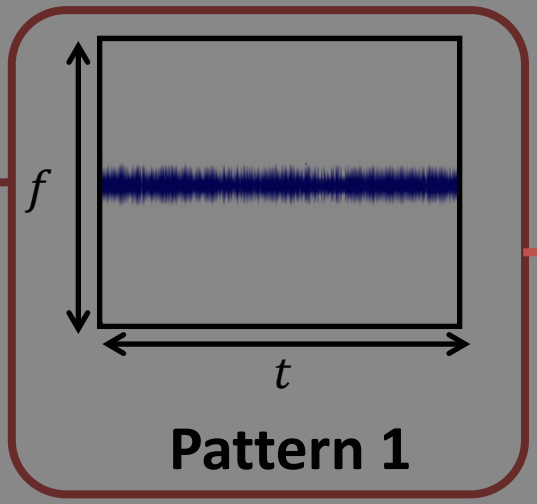
Learning Patterns



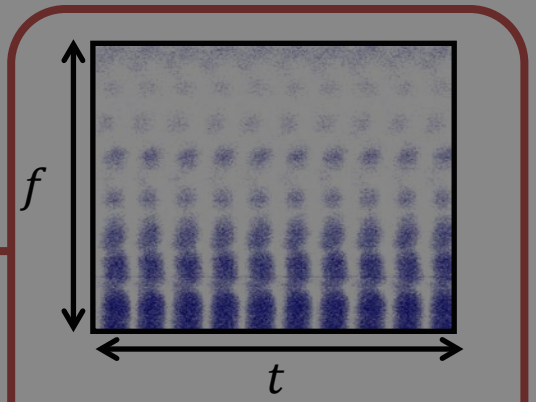
Learning Patterns

FCC Band

Extract the patterns

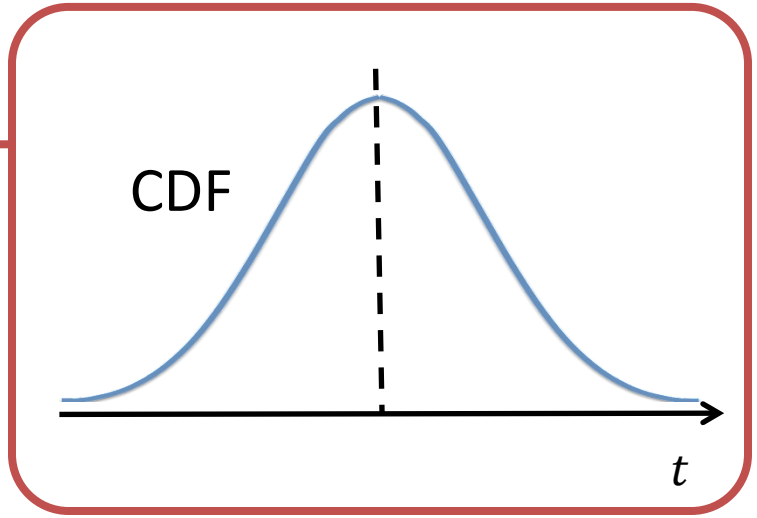


Pattern 1

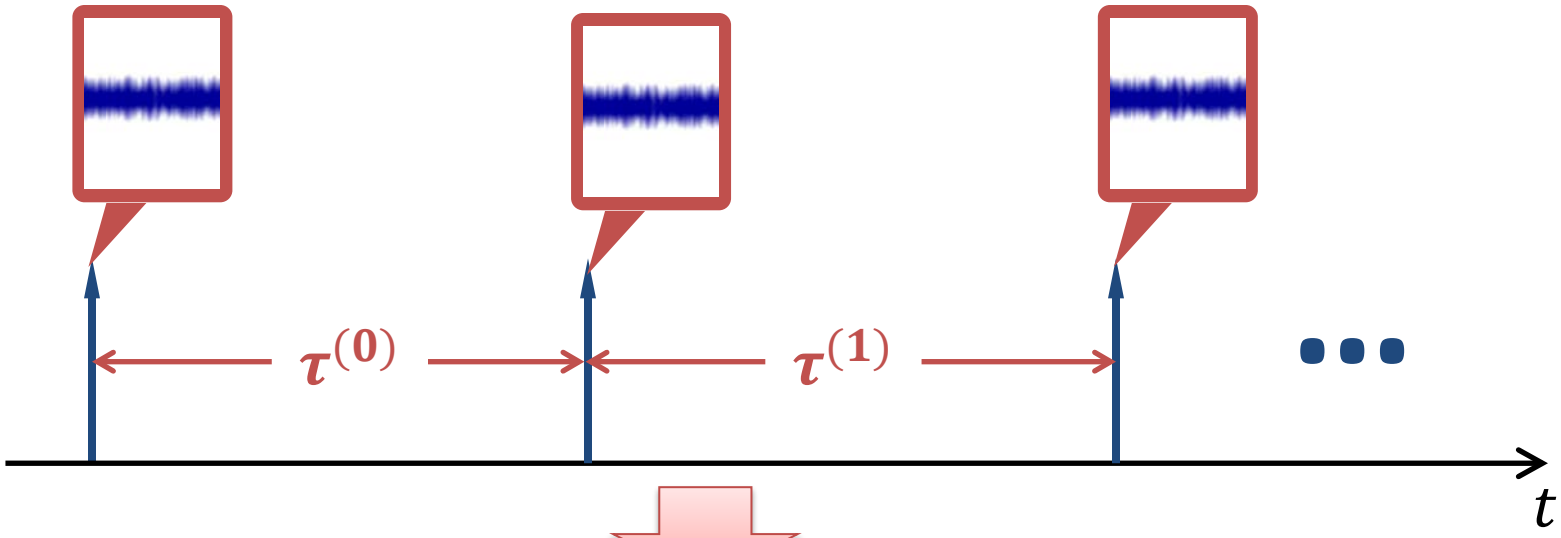


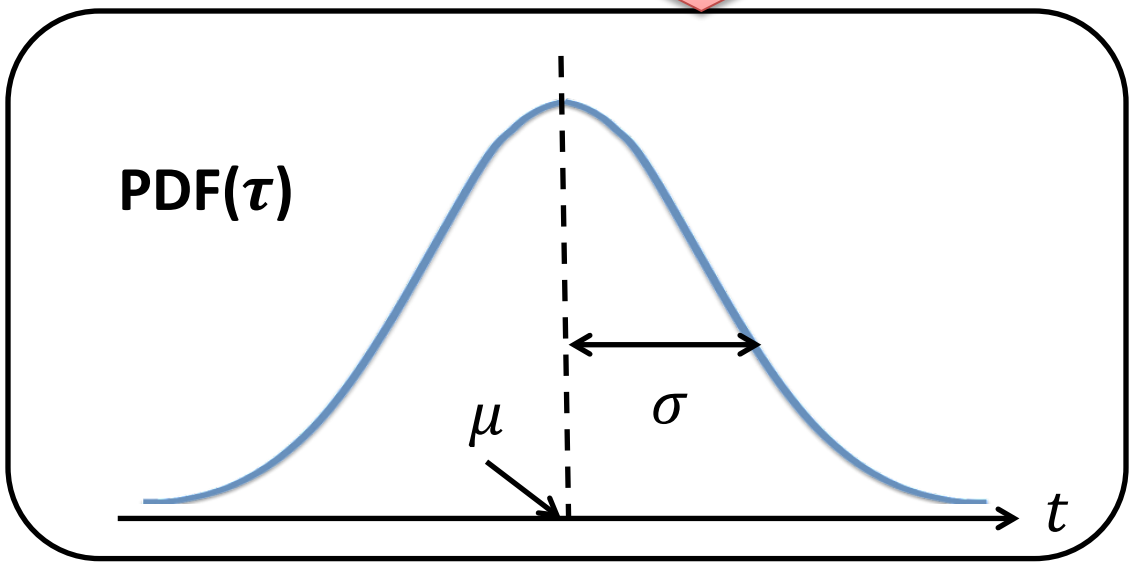
Pattern 2

Detect the distribution of signal inter-arrival



Pattern Inter-Arrival Distribution

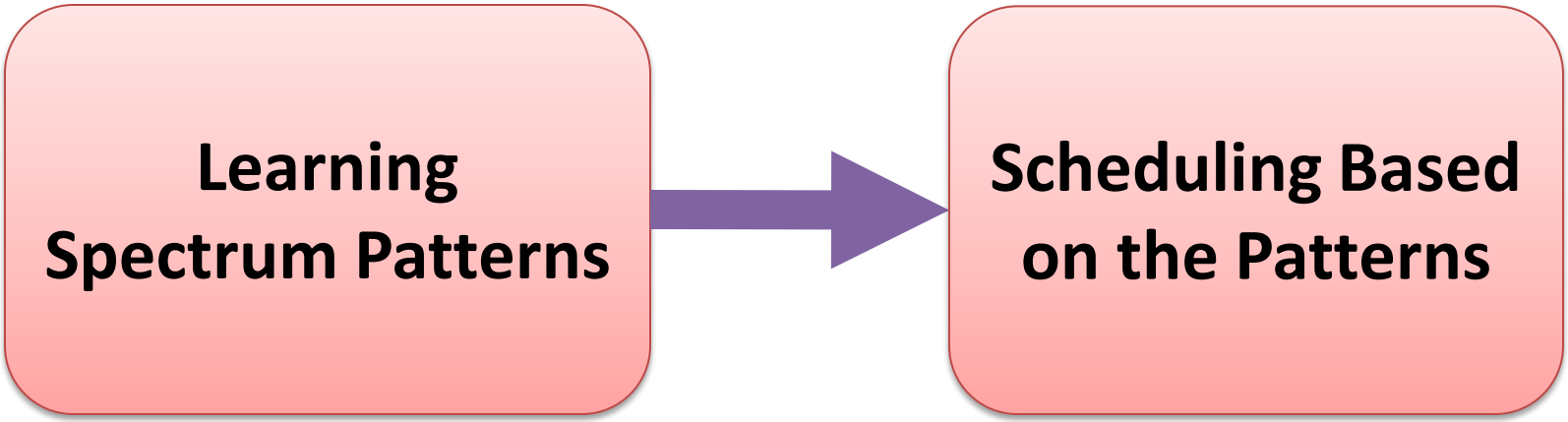




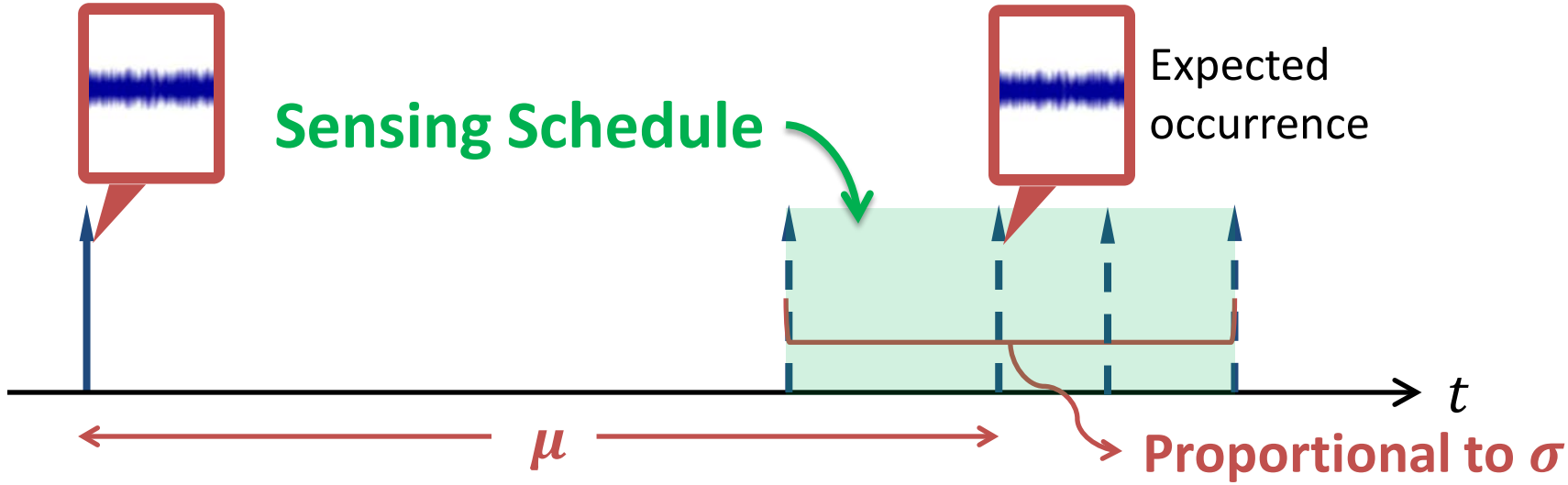
Distribution Parameters:

- μ → Period
- σ → Dynamism

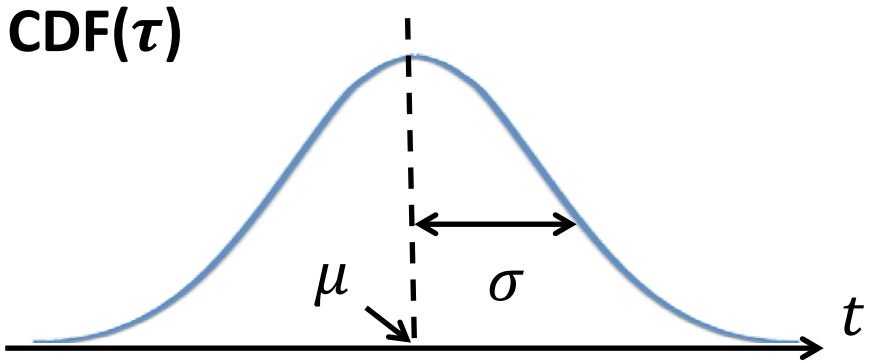
SpecInsight Architecture

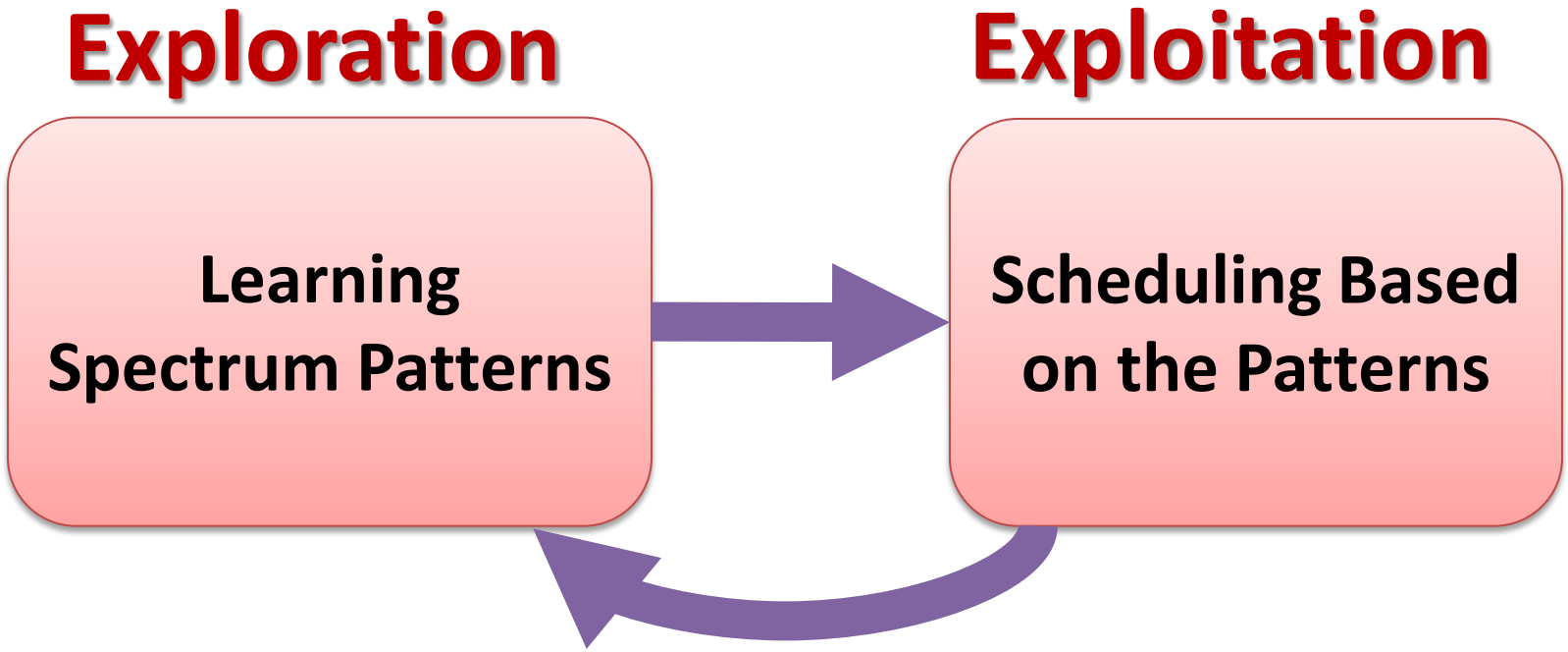


Scheduling Sensing Based on Patterns



When should we schedule the next sensing?





We map the problem to the known multi-armed bandit game to find the optimal tradeoff

Performance

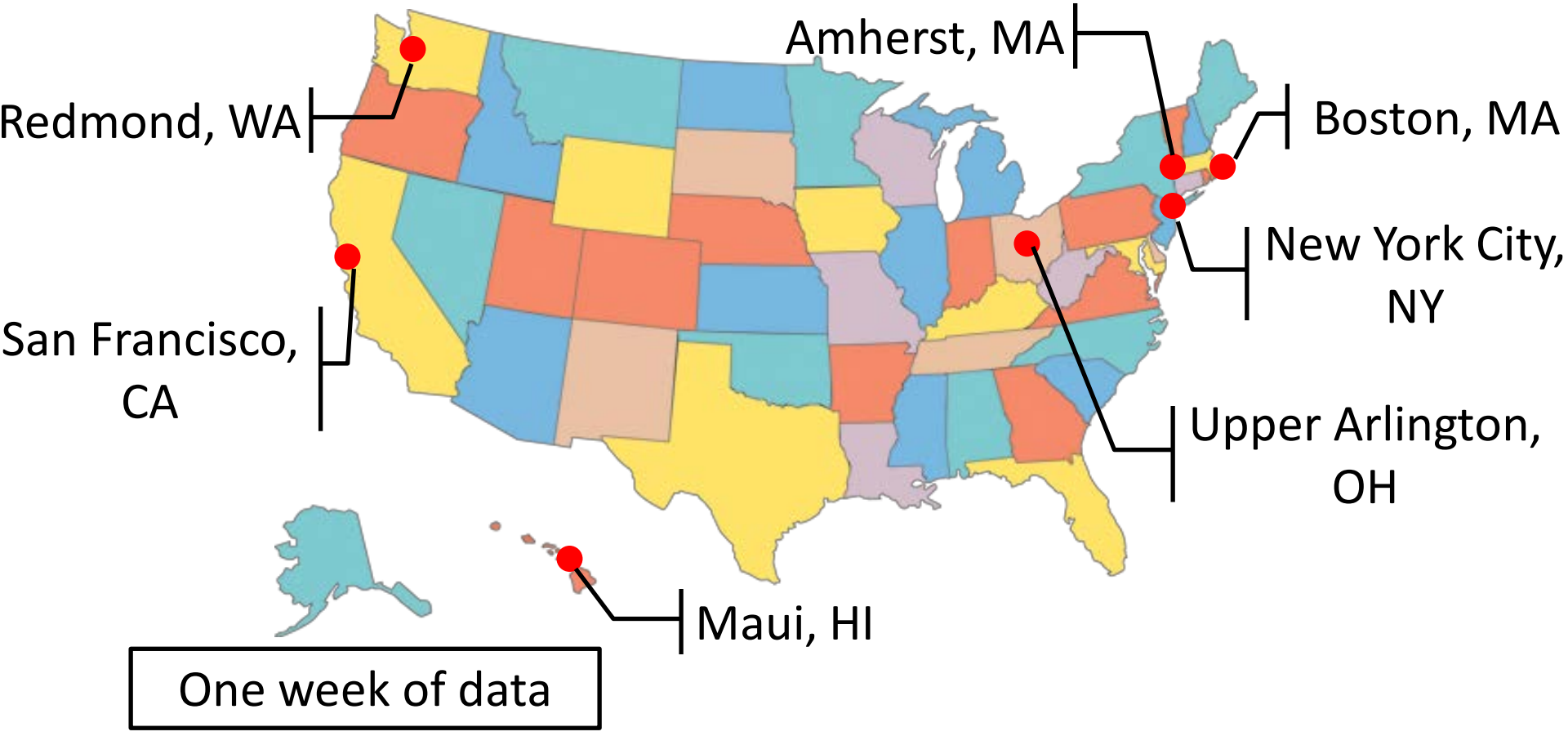
SpecInsight's Implementation

Outdoor Antenna

Indoor USRPs

Frequency Range: 50MHz-4.4GHz
Instant BW: 40MHz

Evaluated in Seven Locations



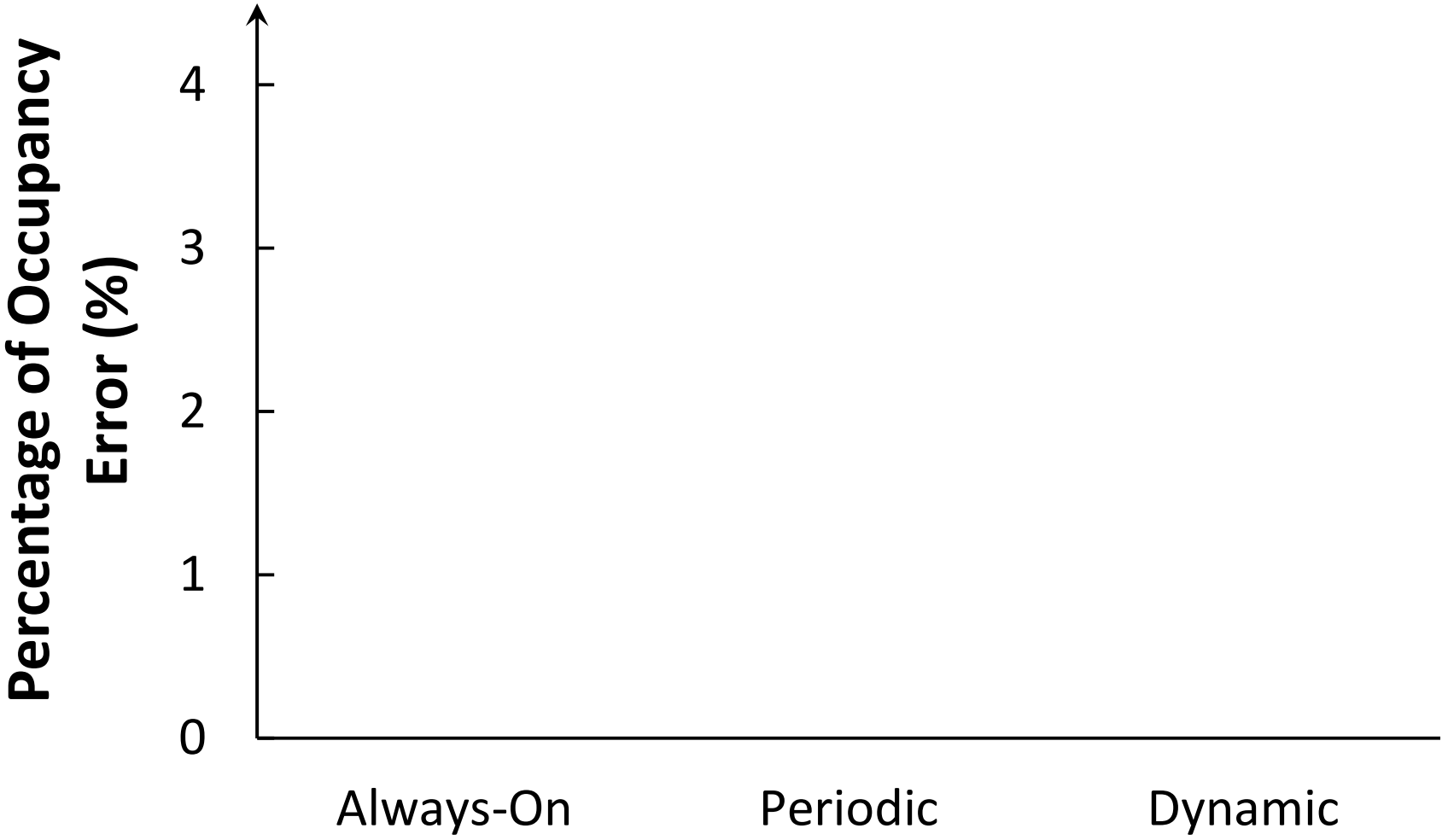
Compared algorithms

- SpecInsight
- Sequential Scanning

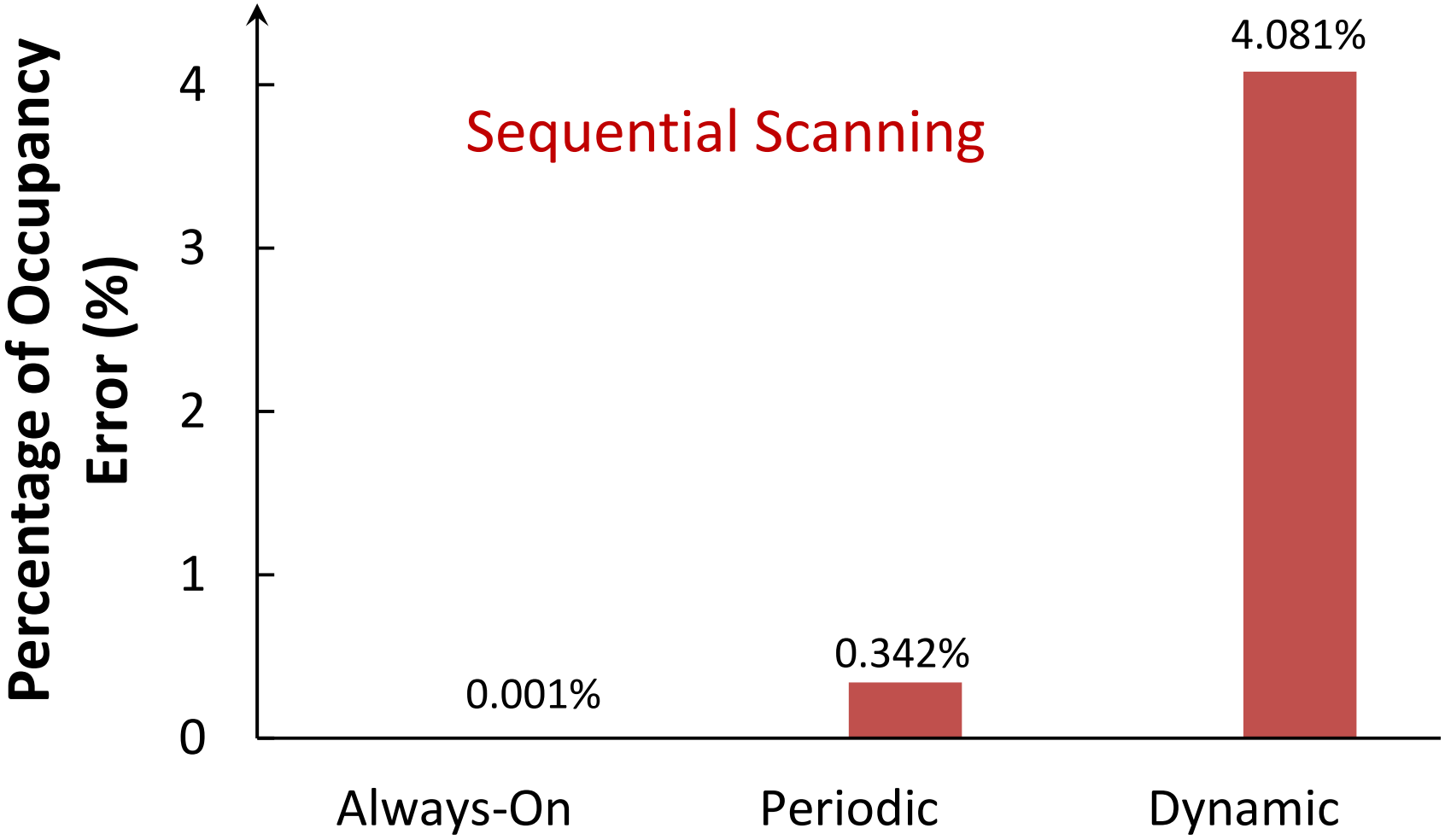
Ground Truth

- 10 USRPs to continuously monitor a subset of the bands; and repeat for different subsets of bands

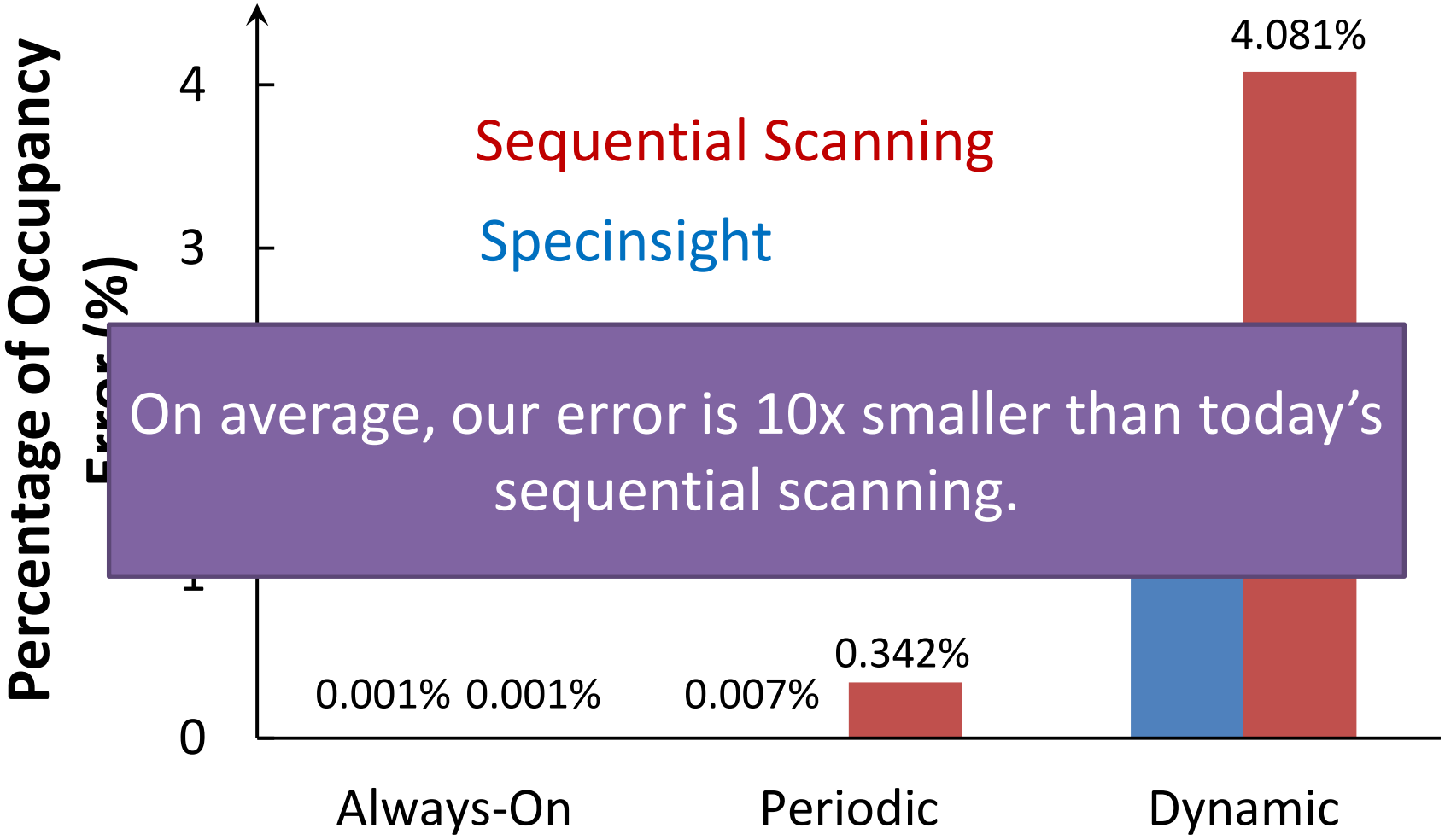
Accuracy


Percentage of Occupancy Error (%)
4
3
2
1
0
Always-On
Periodic
Dynamic

Accuracy

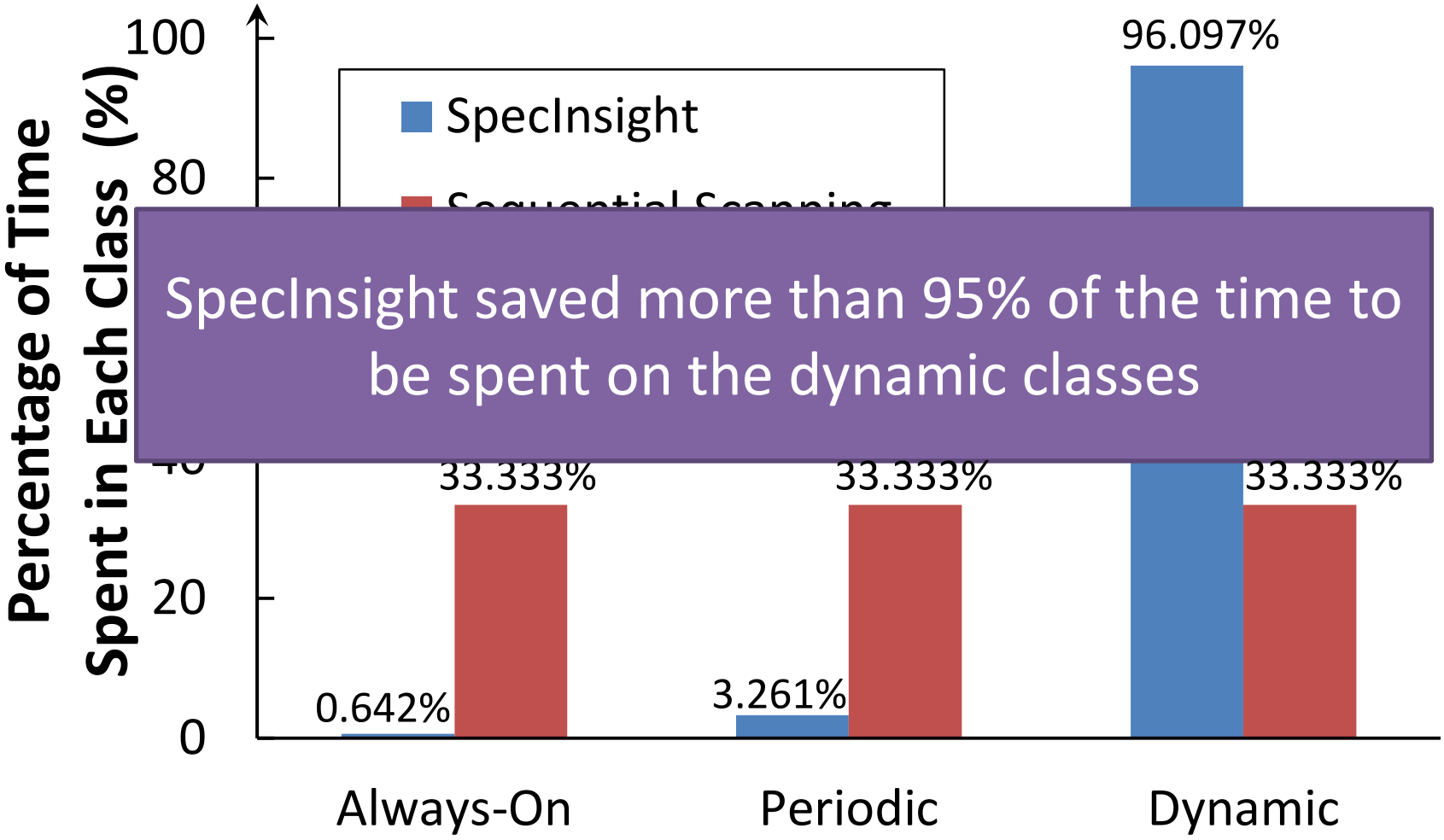

Percentage of Occupancy Error (%)
0
1
2
3
4
Sequential Scanning
0.001%
0.342%
4.081%
Always-On
Periodic
Dynamic

Accuracy



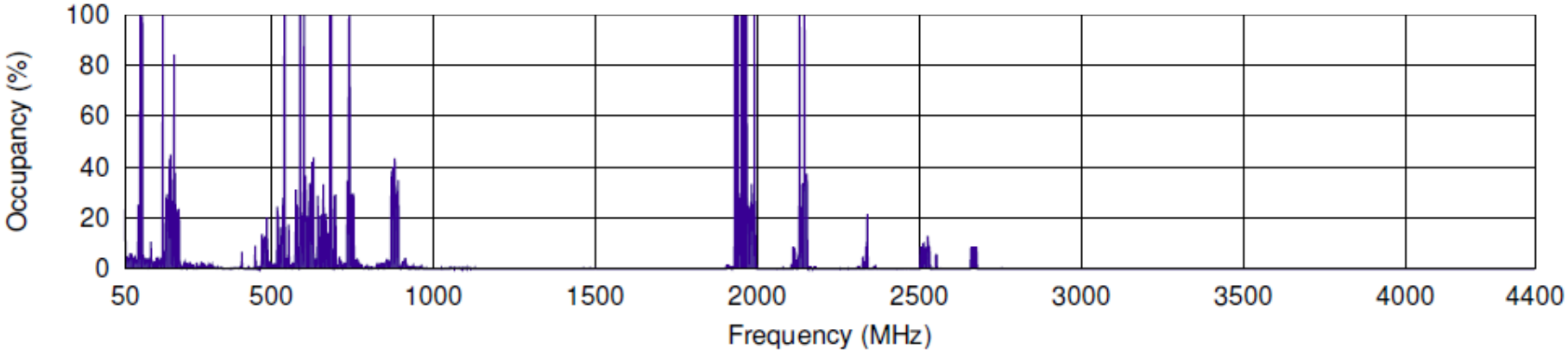
On average, our error is 10x smaller than today's sequential scanning.

Understanding why SpecInsight is more accurate

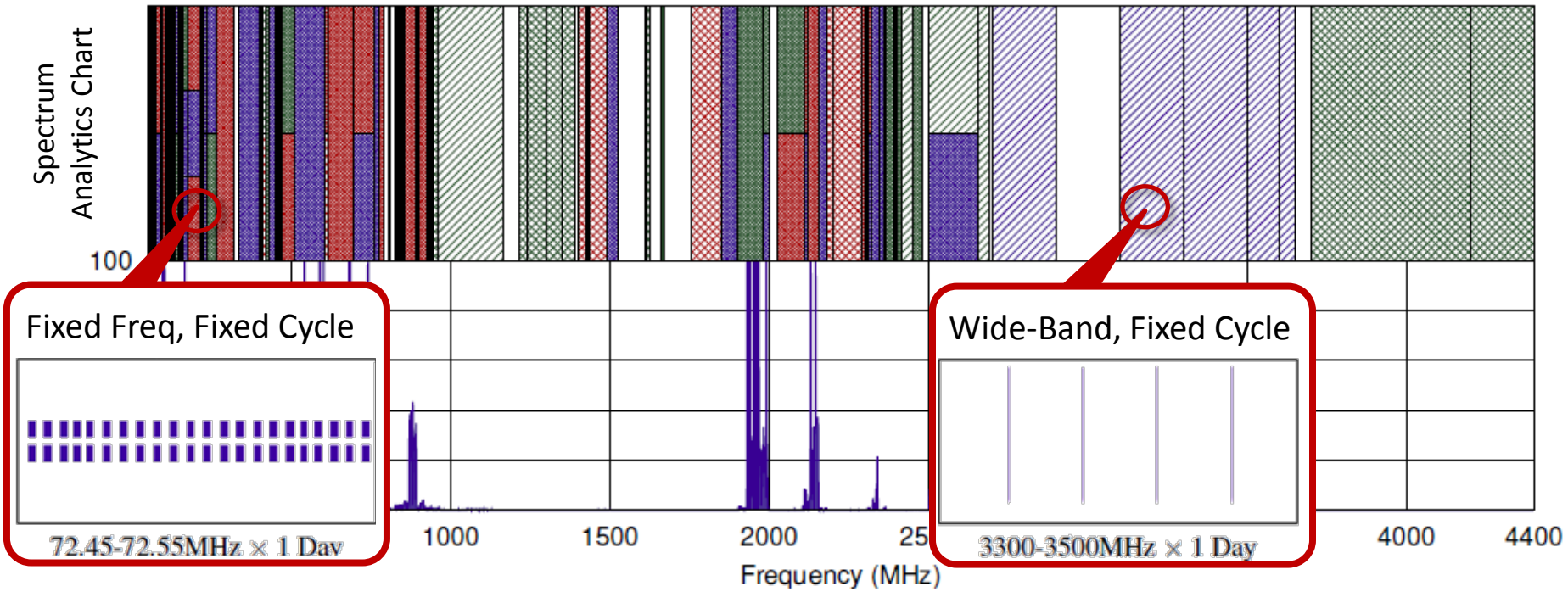


SpecInsight saved more than 95% of the time to be spent on the dynamic classes

Spectrum Report

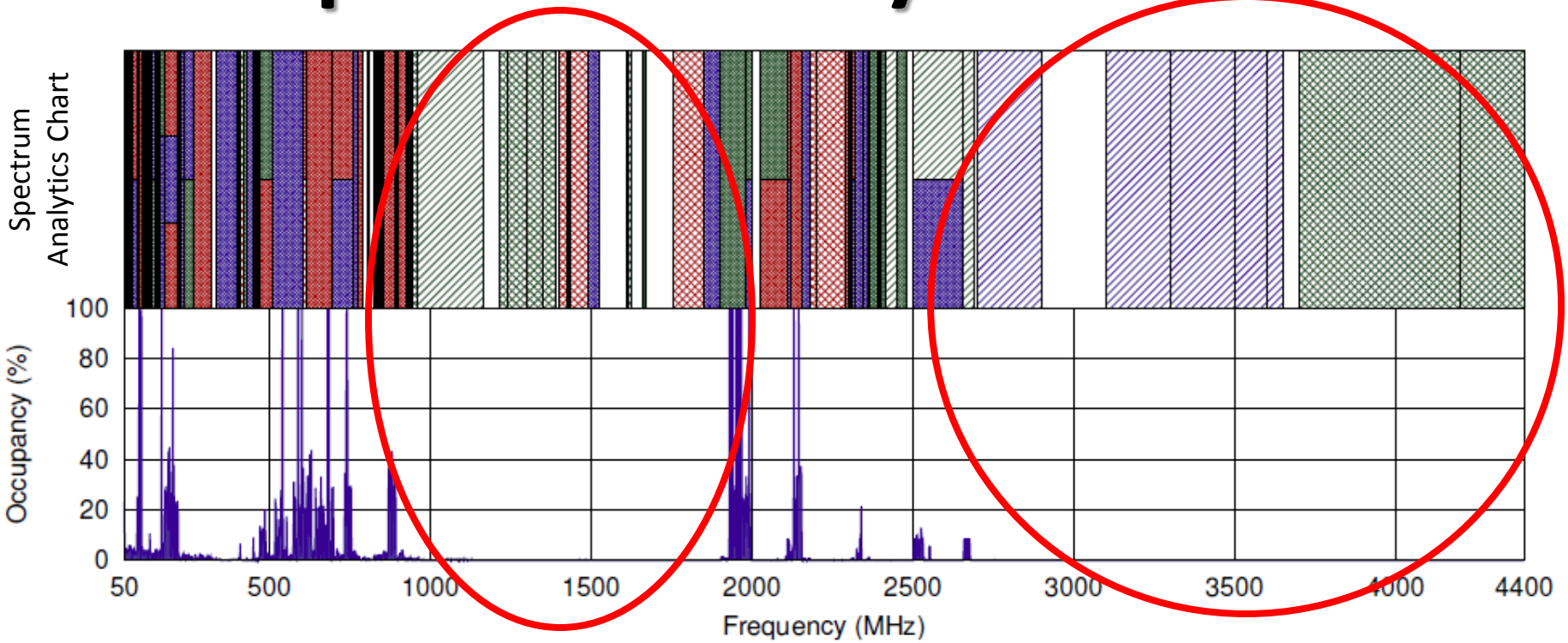


Spectrum Analytics Chart



- Frequency Hopping, Always On
- Fixed Frequency, Always On
- Fixed Frequency, Fixed Cycle
- Wide-Band, Fixed Cycle
- Frequency Hopping, Dynamic
- Fixed Frequency, Dynamic
- Wide-Band, Dynamic

Spectrum Analytics Chart



38% of spectrum is reported empty by past systems while it is actually used

Wide-Band, Fixed Cycle

Conclusion

- SpecInsight can sense multi-GHz spectrum using cheap, MHz radios
- Provides deep understanding of spectrum utilization
- Key primitive for future dynamic usage of the spectrum

Thanks!