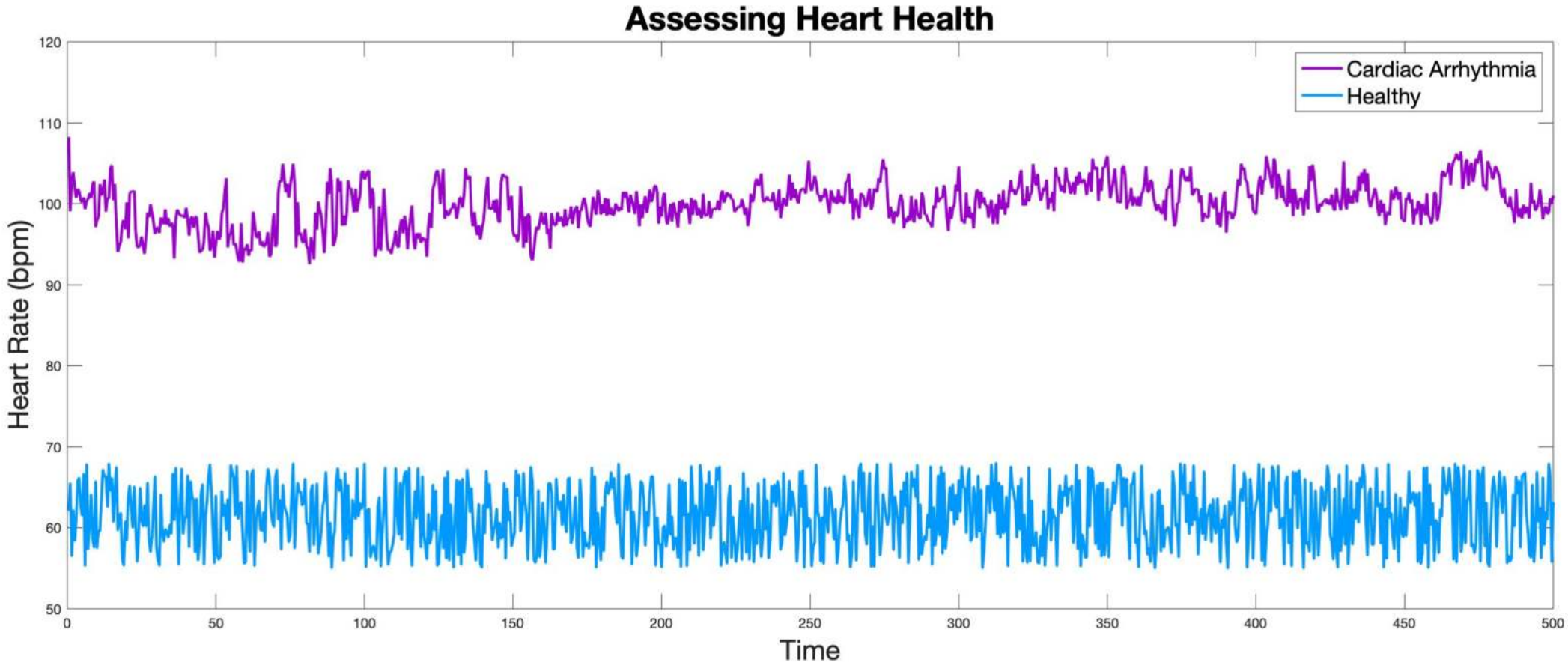
Monitoring Human Performance in Real-Time for NAS Safety Prognostics

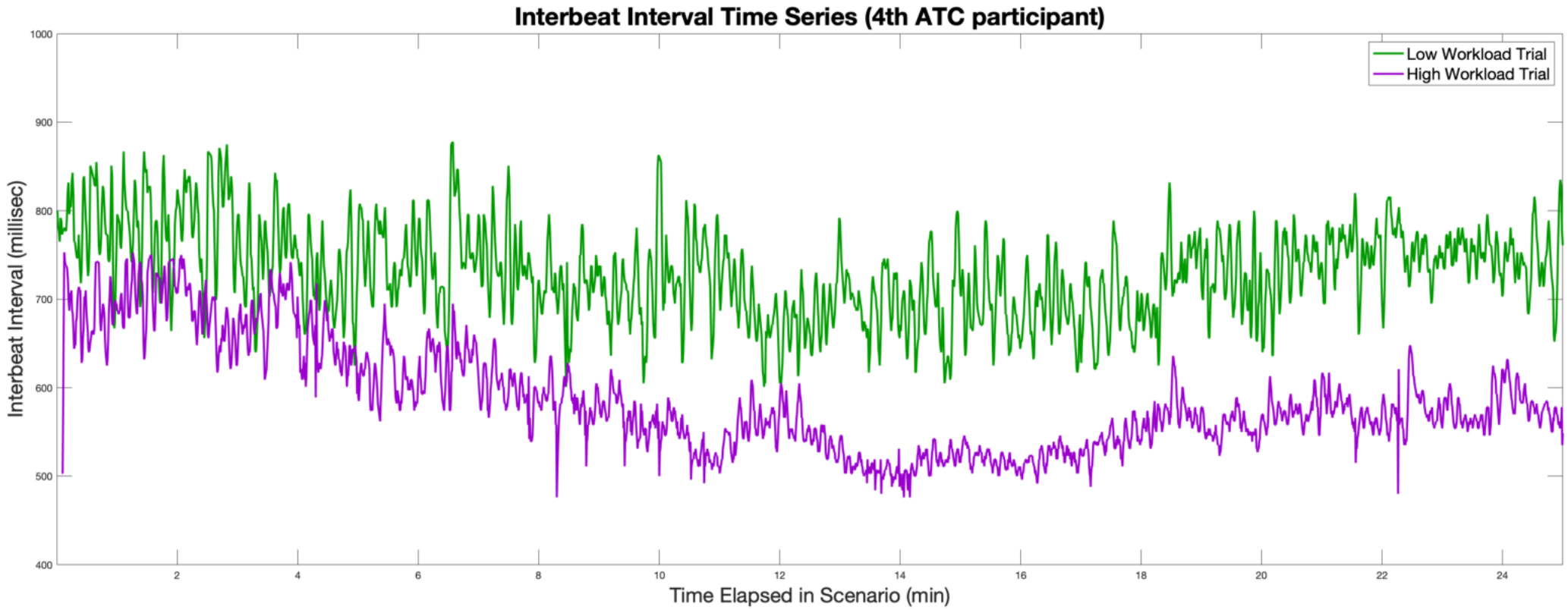
Air Traffic Conflicts & Interbeat Interval Dynamics

Fractal Dimension Variations

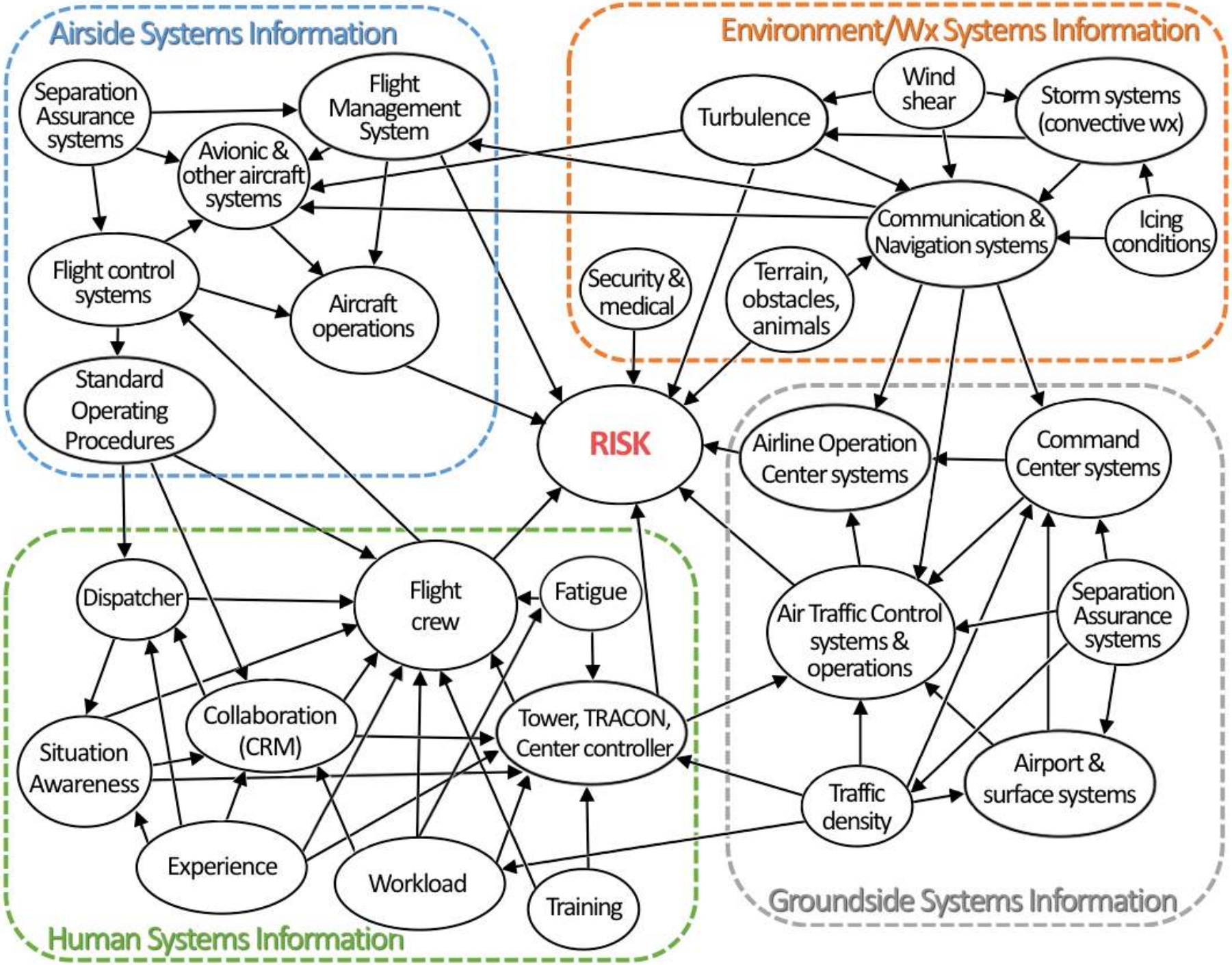


- Diagnose cardiac pathology via dynamical methods

Fractal Dimension Variations

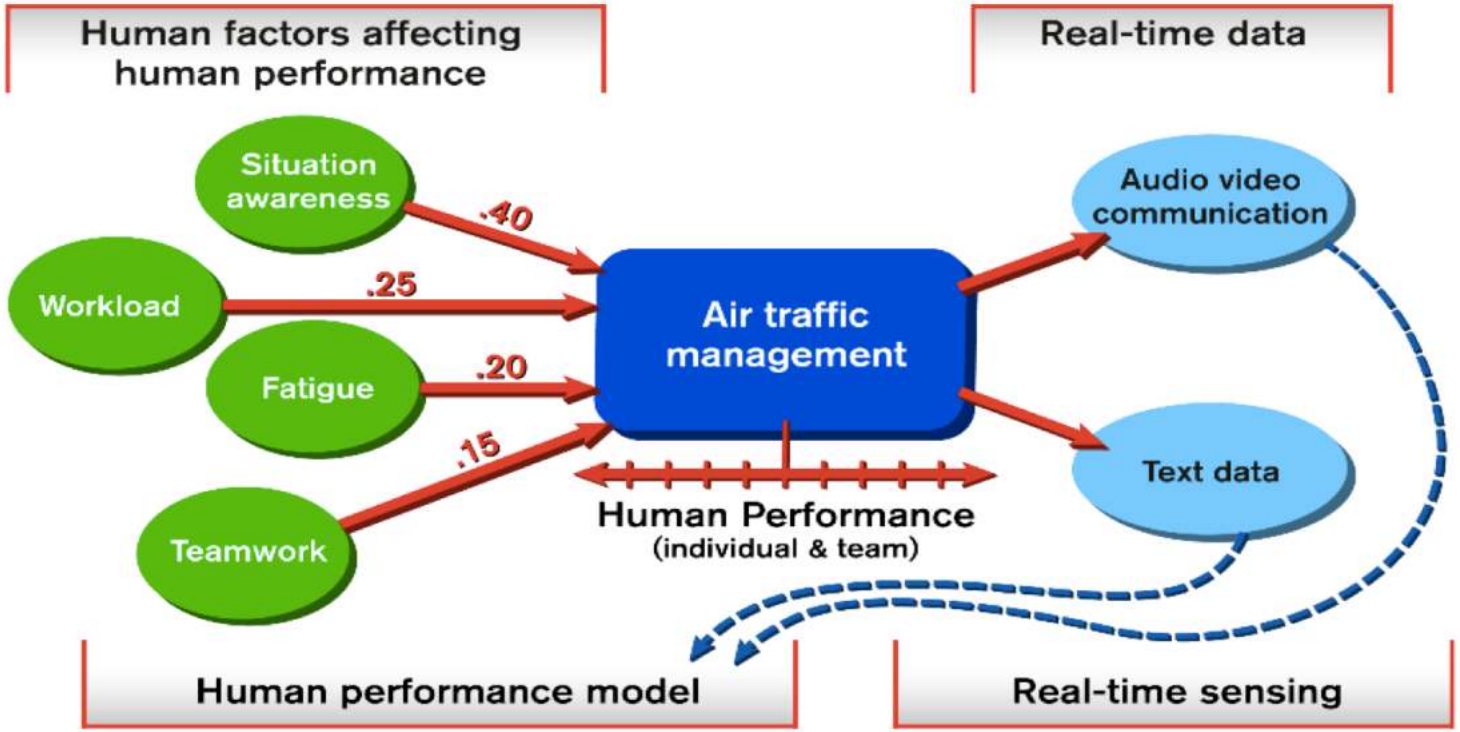


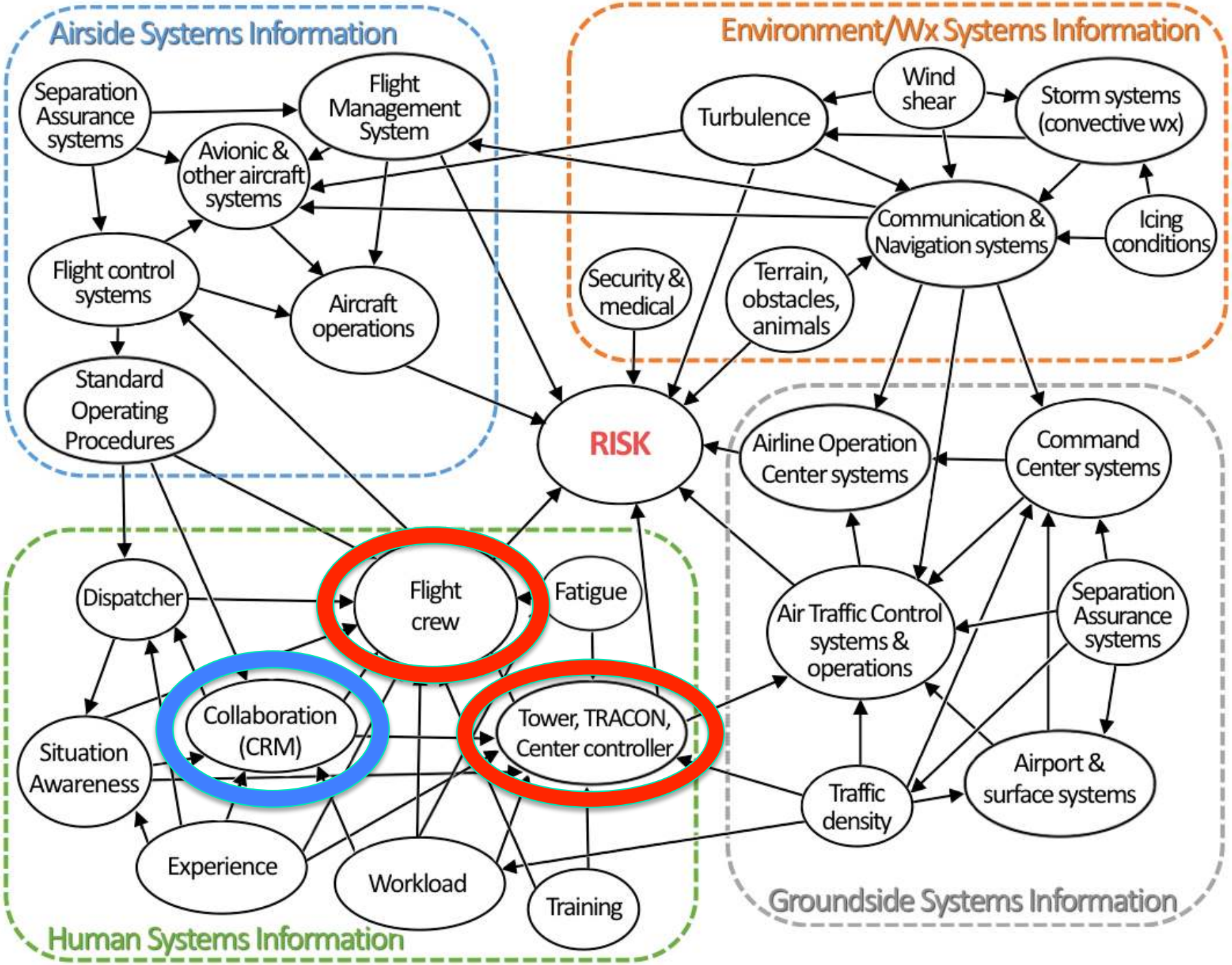
- Also assess physical and mental workload
- Higher workload -> Higher fractal dimension
  - Russell, Funke, Knott, & Middendorf (2011)


Airside Systems Information
Separation Assurance systems
Flight Management System
Avionic & other aircraft systems
Flight control systems
Aircraft operations
Standard Operating Procedures
Environment/Wx Systems Information
Turbulence
Wind shear
Storm systems (convective wx)
Communication & Navigation systems
Icing conditions
Security & medical
Terrain, obstacles, animals
RISK
Airline Operation Center systems
Command Center systems
Air Traffic Control systems & operations
Separation Assurance systems
Airport & surface systems
Traffic density
Groundside Systems Information
Dispatcher
Flight crew
Fatigue
Collaboration (CRM)
Tower, TRACON, Center controller
Situation Awareness
Experience
Workload
Training
Human Systems Information

Human Systems Integration Objective

- Extract and process real-time NAS data to inform variations in human performance

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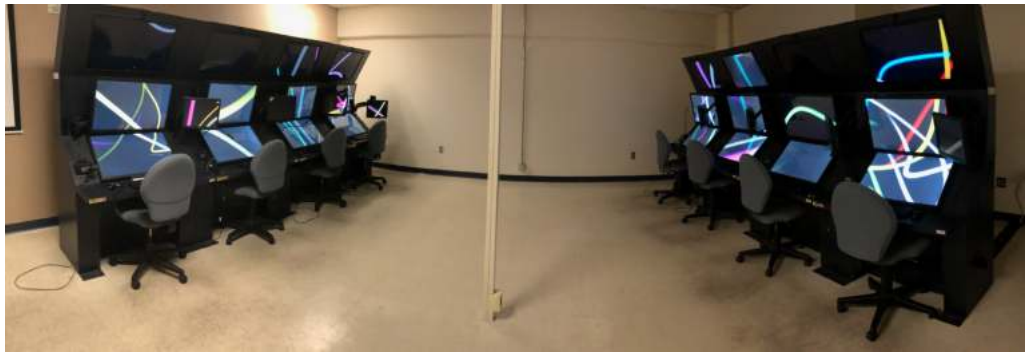
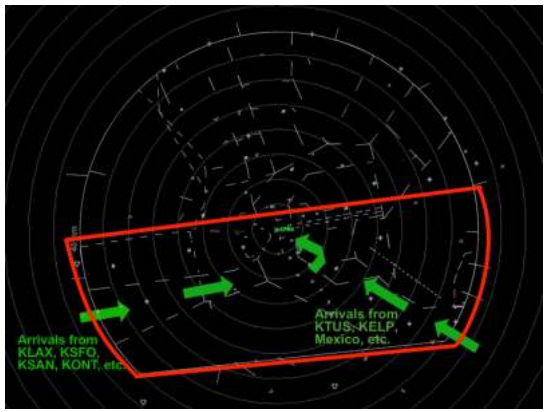
ATC Simulator Experiment

3 Pseudo Pilots
(staff)



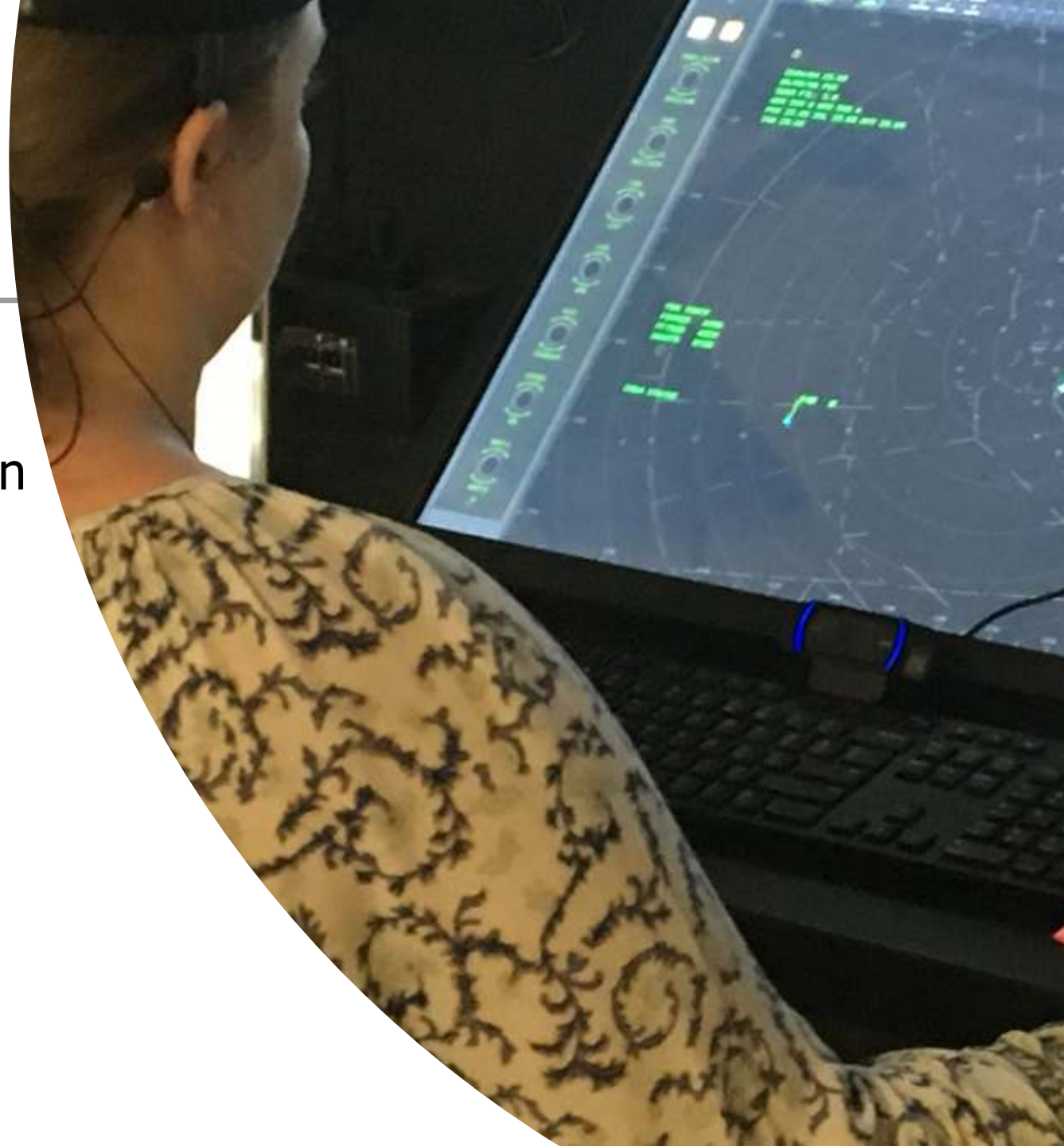
- 5 of 12 experienced FAA controllers
- Three pseudo pilots (students) each controlling 4-8 planes
- Three 25 min simulated approach scenarios (within Ss fixed factor):
  - Baseline: 4-5 aircraft at once, moderate workload (15 aircraft)
  - High Workload Nominal: 2 aircraft, increases to 10-12 at once (30 aircraft total)
  - High Workload Off Nominal: Traffic density same as High Workload Nominal, plus…
    - Pilot deviation
    - Runway switch (runway 25L to 07R)
    - Moderate turbulence in several arrival flows
    - Aircraft reports low fuel

Single Air Traffic Controller
(participant)



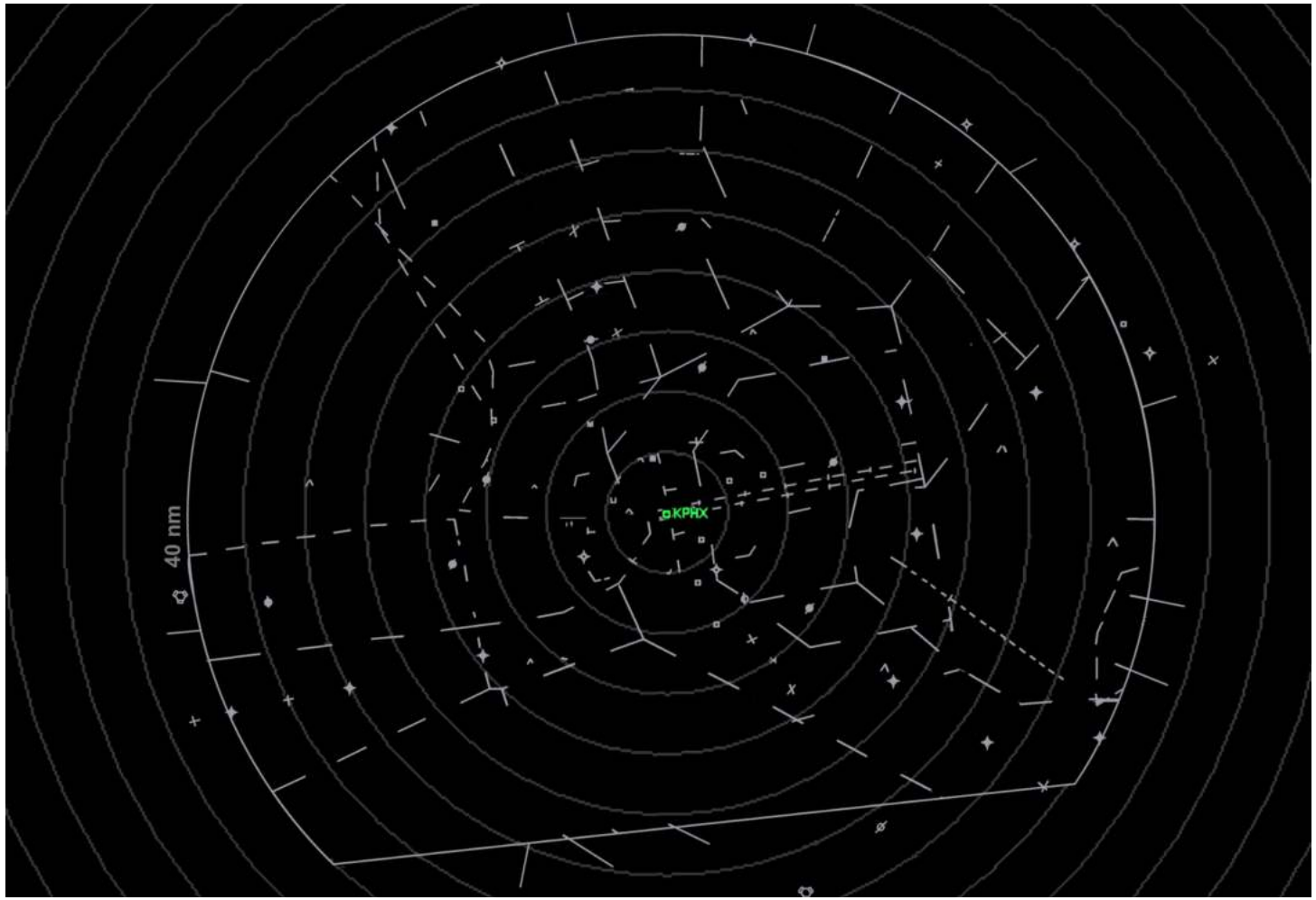
ATC Simulator Experiment

- Criterion measure:
  - ATC performance – Loss of Separation
- Predictors:
  - Biometric heart rate variability (IBI)
    - Equipment: iMotions B-Alert device with clavicle and behind the ear sensors
  - Controller-Pilot radio frequency transmissions
  - Workload & Situation Awareness probes
  - Head pose data
  - Facial expression data

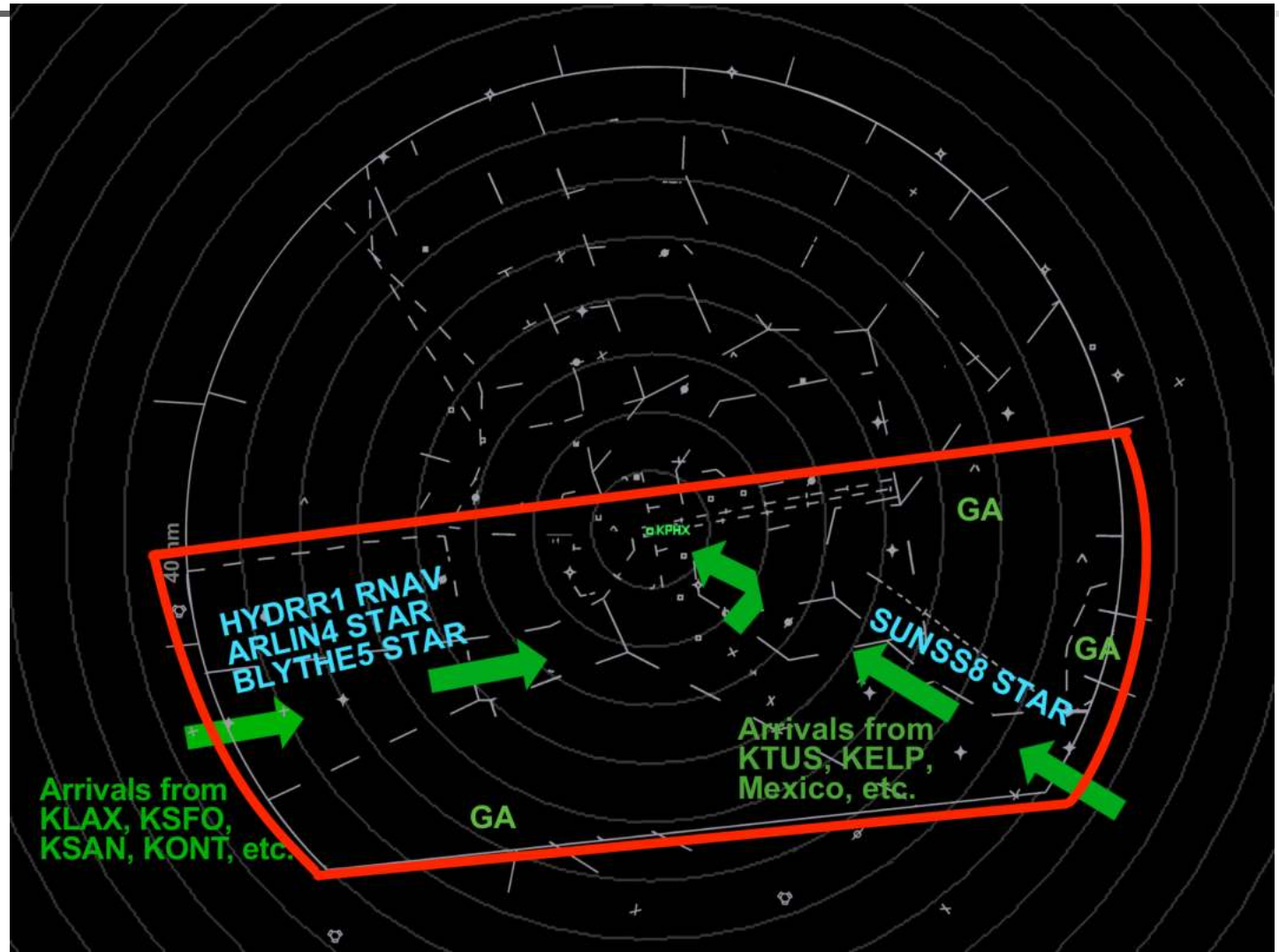


PHX TRACON (P50) on ATC radar scope

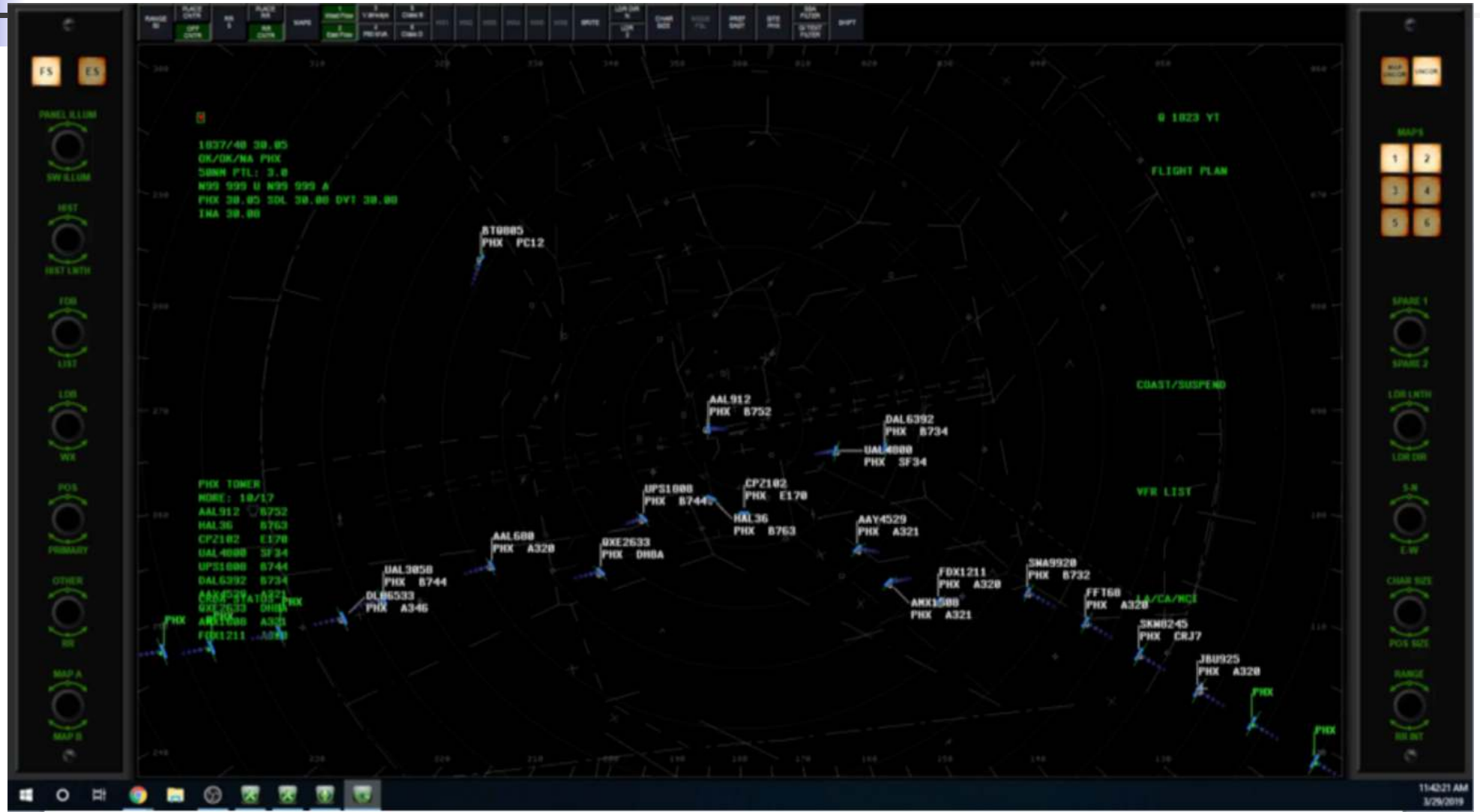
- 3 ATC radar simulation scenarios, 25 min each



1 RNAV and 3 STARS arrival routes

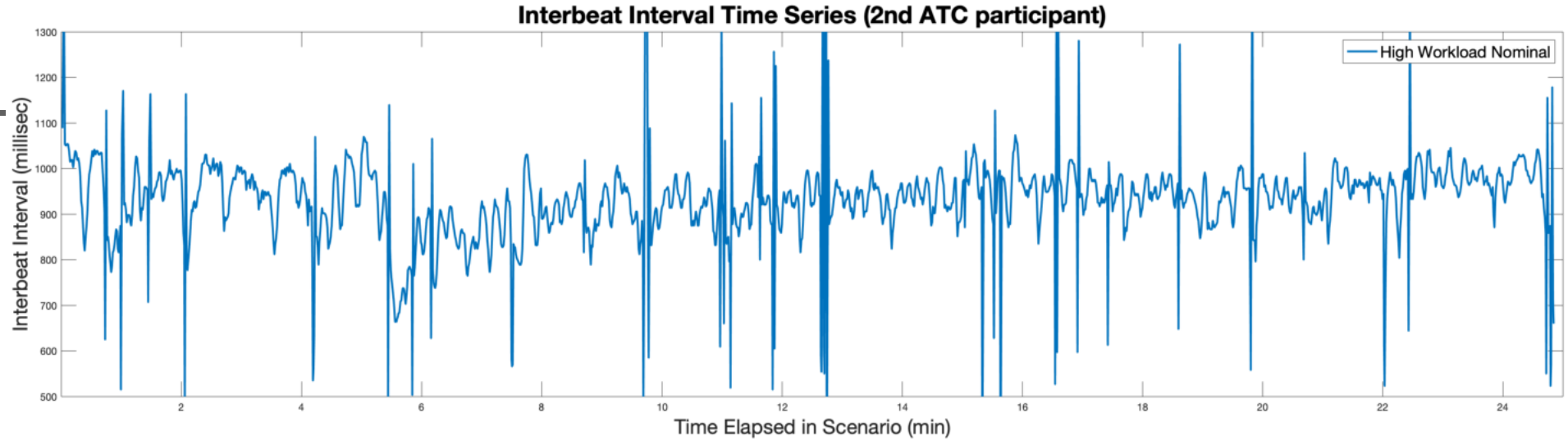


Hypothesis: As workload increases in trial, fractal dimension will increase in ATC Interbeat Interval time series data



Trimming Criteria: 1) Remove Null Values

	Elapsed Time	Beat Quality	Inter-Beat In	Heart Rate
	00:05:48:520	1	781	76
	00:05:49:297	1	777	77
	00:05:50:063	1	765	78
X	00:05:50:566	0	503	119
X	00:05:51:578	0	1011	59
	00:05:52:344	1	765	78
	00:05:53:129	1	785	76
	00:05:53:949	1	820	73



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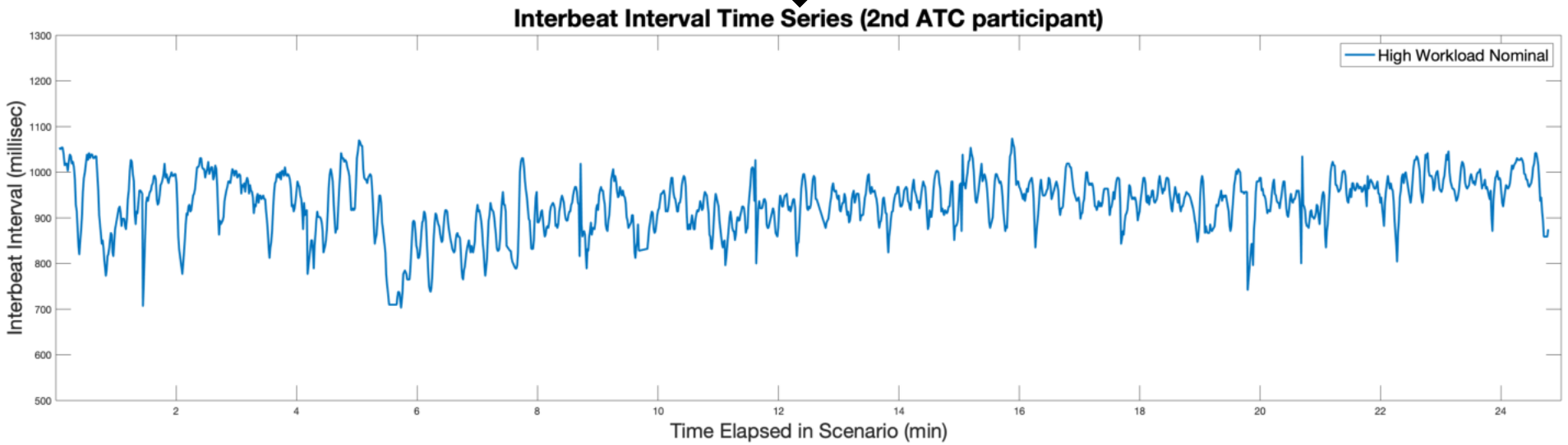
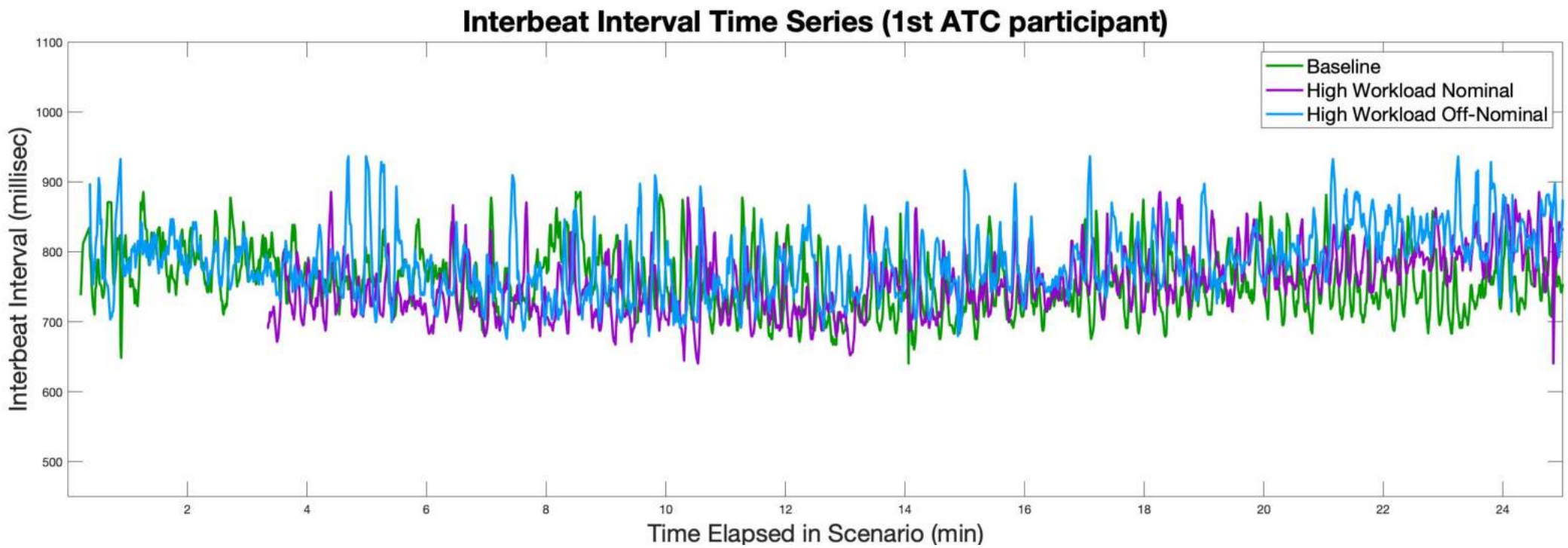


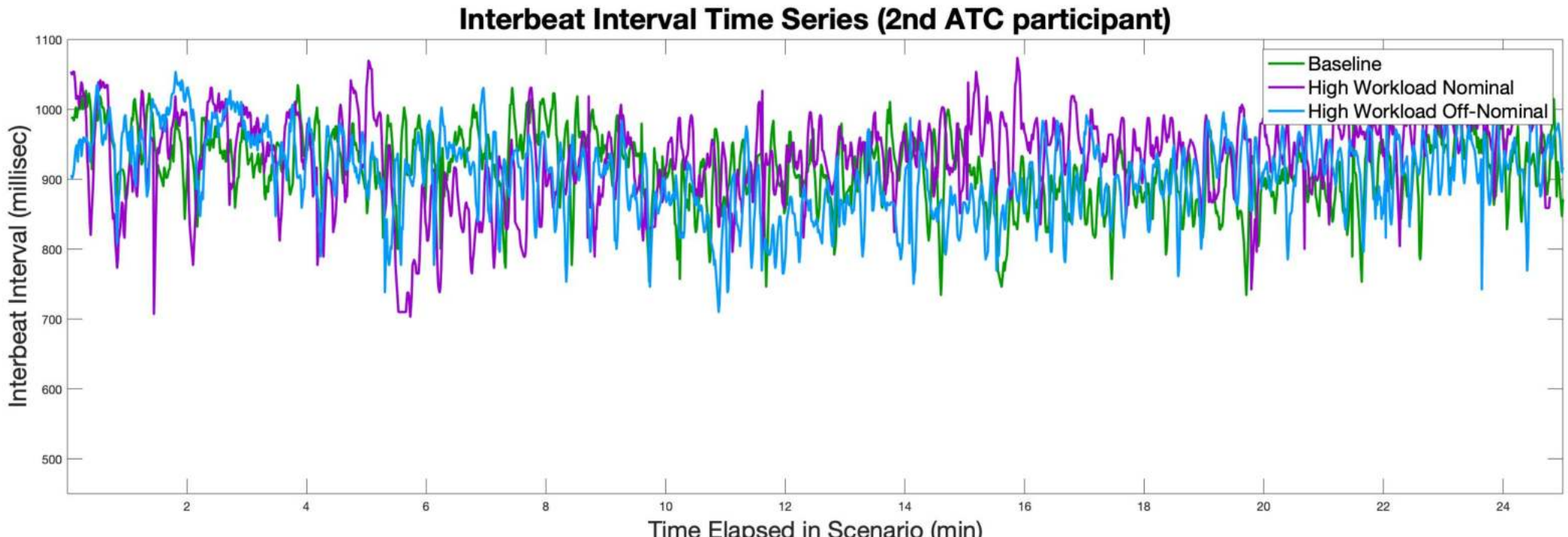
Trimming Criteria:
2) Eliminate outliers >3 SD from means

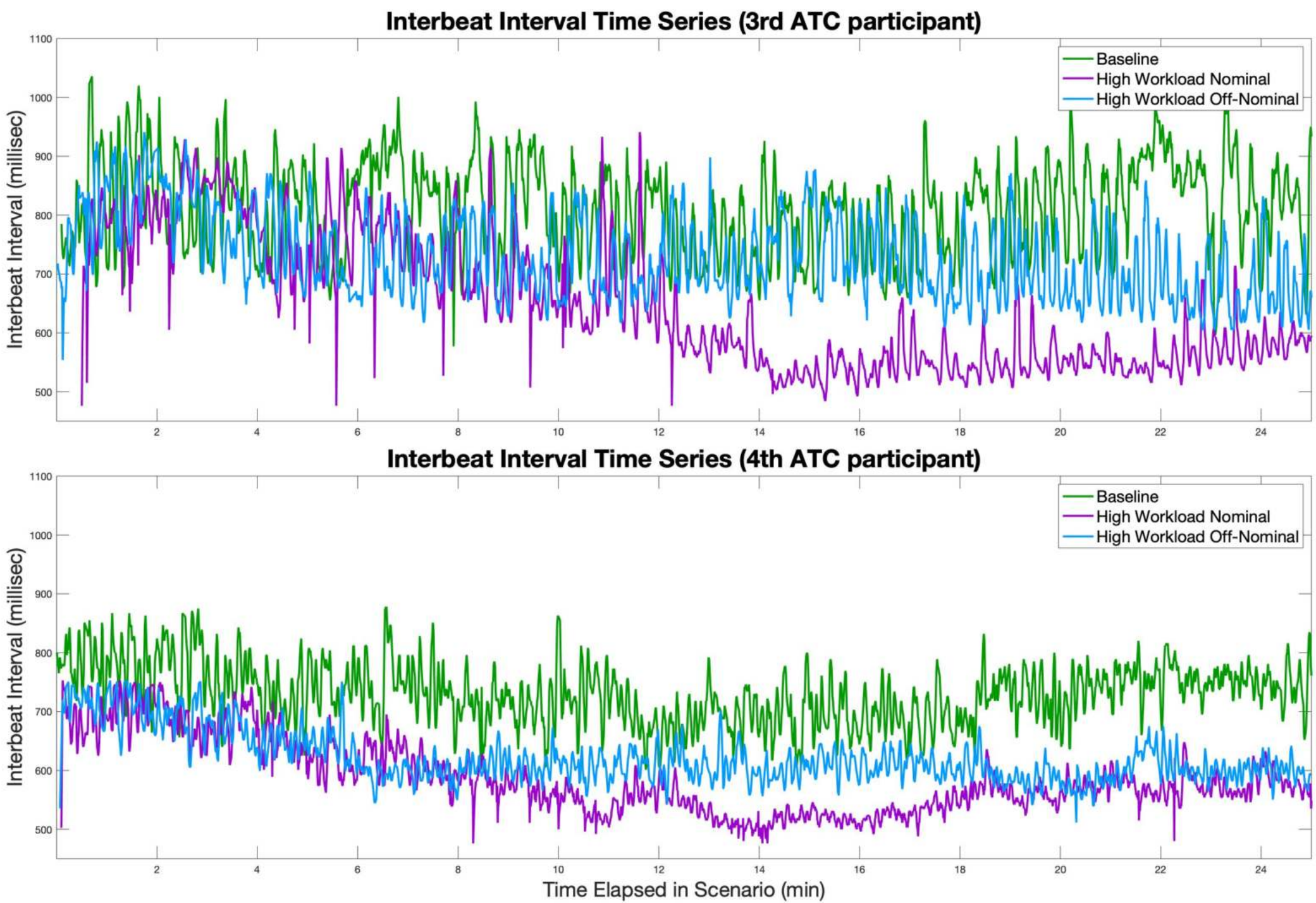
Eliminated 163 of 25,619 values (0.64%) that fell beyond three standard deviations from each trial's IBI mean

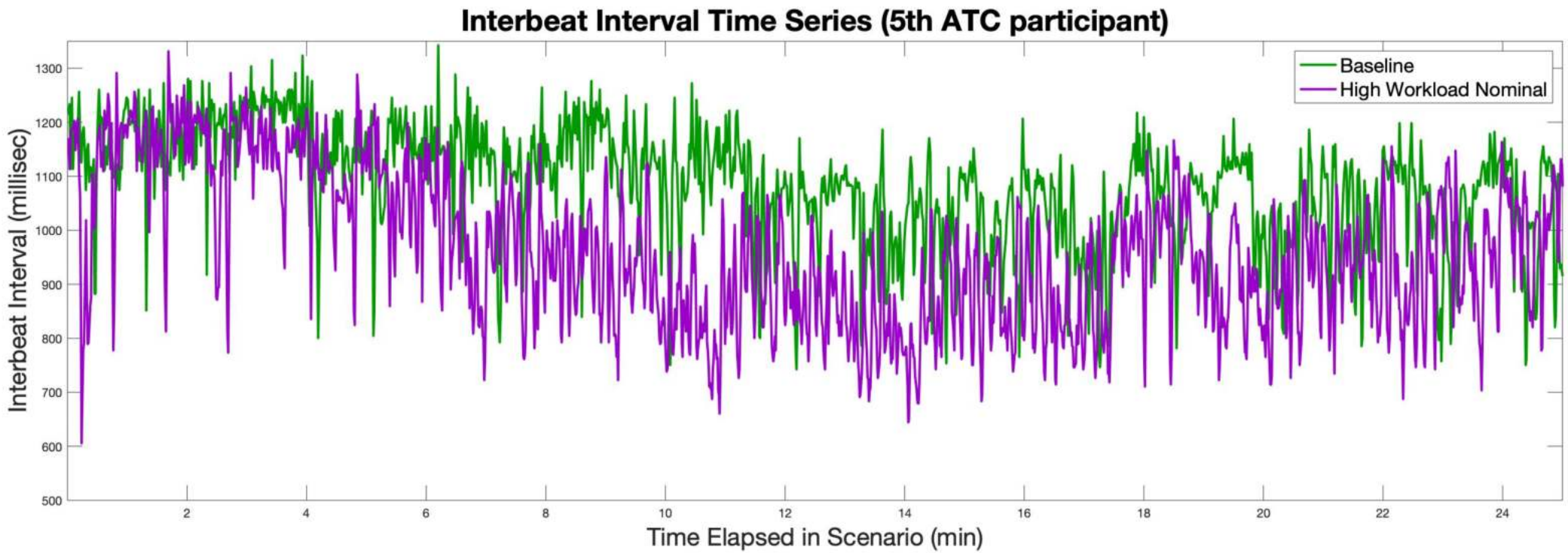
- after removing total of 275 "Beat Quality" null instances from raw data

	Baseline	High Workload Nominal	High Workload Off-Nominal
ATC #1	- Removed 3 "Beat Quality" nulls - Then 20 of 1969 values beyond 3 SD range of 621.93 - 888.01	- Removed 1 "Beat Quality" nulls - Then 6 of 1726 values beyond 3 SD range of 616.80 - 889.13	- Removed 13 "Beat Quality" nulls - Then 22 of 1891 values beyond 3 SD range of 627.46 – 940.77
ATC #2	- Removed 39 "Beat Quality" nulls - Then 13 of 1610 values beyond 3 SD range of 733.75 - 1086.30	- Removed 67 "Beat Quality" nulls - Then 29 of 1543 values beyond 3 SD range of 698.23 – 1153.40	- Removed 19 "Beat Quality" nulls - Then 4 of 1642 values beyond 3 SD range of 721.50 – 1082.70
ATC #3	- Removed 15 "Beat Quality" nulls - Then 2 of 1849 values beyond 3 SD range of 559.52 – 1042.80	- Removed 24 "Beat Quality" nulls - Then 7 of 2307 values beyond 3 SD range of 313.91 – 942.92	- Removed 10 "Beat Quality" nulls - Then 13 of 2056 values beyond 3 SD range of 505.34 – 942.69
ATC #4	- Removed 15 "Beat Quality" nulls - Then 8 of 2040 values beyond 3 SD range of 570.46 – 884.22	- Removed 9 "Beat Quality" nulls - Then 15 of 2566 values beyond 3 SD range of 403.90 – 755.72	- Removed 19 "Beat Quality" nulls - Then 20 of 1478 values beyond 3 SD range of 486.00 – 756.78
ATC #5	- Removed 15 "Beat Quality" nulls - Then 3 of 1384 values beyond 3 SD range of 738.63 – 1407.10	- Removed 26 "Beat Quality" nulls - Then 1 of 1558 values beyond 3 SD range of 531.19 – 1358.80	-- *data collection failed to record IBI*


Interbeat Interval Time Series (1st ATC participant)
Interbeat Interval (millisec)
Time Elapsed in Scenario (min)
Baseline
High Workload Nominal
High Workload Off-Nominal
1100
1000
900
800
700
600
500
2
4
6
8
10
12
14
16
18
20
22
24


Interbeat Interval Time Series (2nd ATC participant)
Interbeat Interval (millisec)
Time Elapsed in Scenario (min)
Baseline
High Workload Nominal
High Workload Off-Nominal
1100
1000
900
800
700
600
500
2
4
6
8
10
12
14
16
18
20
22
24

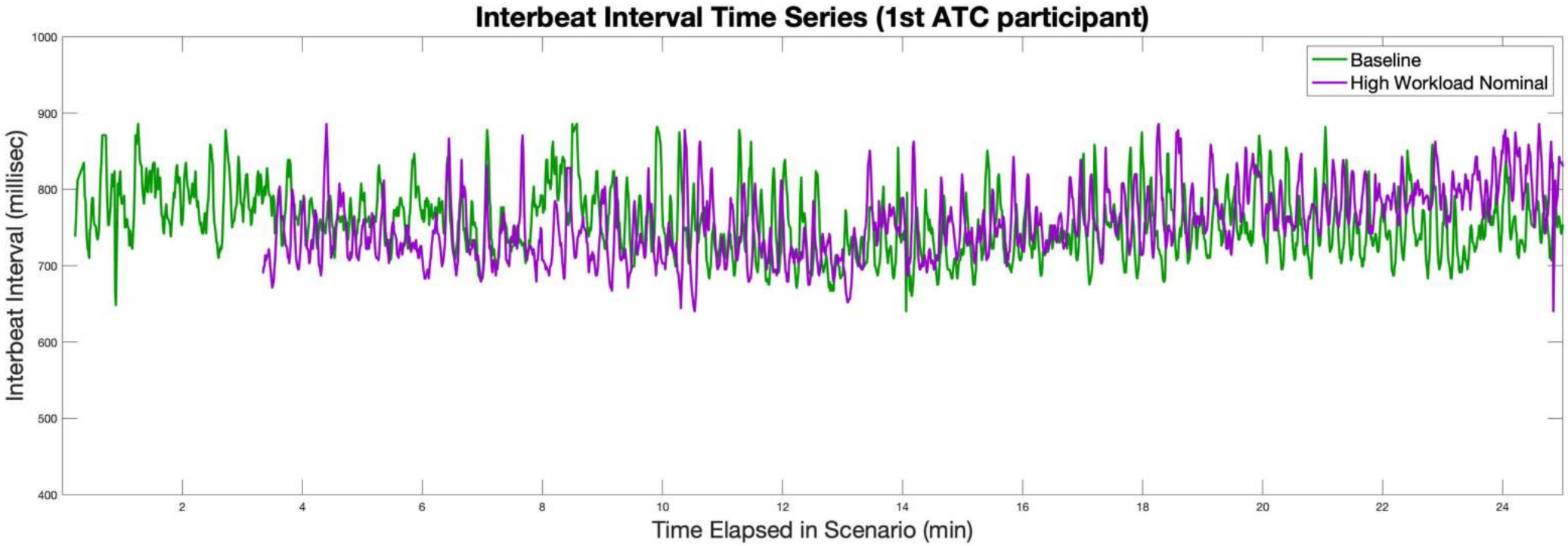

Interbeat Interval Time Series (3rd ATC participant)
Interbeat Interval (millisec)
1100
1000
900
800
700
600
500
2
4
6
8
10
12
14
16
18
20
22
24
Baseline
High Workload Nominal
High Workload Off-Nominal
Interbeat Interval Time Series (4th ATC participant)
Interbeat Interval (millisec)
1100
1000
900
800
700
600
500
2
4
6
8
10
12
14
16
18
20
22
24
Baseline
High Workload Nominal
High Workload Off-Nominal
Time Elapsed in Scenario (min)


Interbeat Interval Time Series (5th ATC participant)
Baseline
High Workload Nominal
Interbeat Interval (millisec)
1300
1200
1100
1000
900
800
700
600
500
2
4
6
8
10
12
14
16
18
20
22
24
Time Elapsed in Scenario (min)

Detrended Fluctuation Analysis

	Baseline	High Workload Nominal	High Workload Off-Nominal
ATC #1	M = 753.42 *(41.80)* Hurst = 0.653	M = 752.40 *(44.80)* Hurst = 0.813	M = 782.55 *(46.98)* Hurst = 0.764
ATC #2	M = 912.46 *(51.57)* Hurst = 0.825	M = 930.61 *(61.70)* Hurst = 0.812	M = 902.50 *(58.17)* Hurst = 0.746
ATC #3	M = 800.87 *(80.07)* Hurst = 0.736	M = 627.36 *(103.22)* alpha = 1.097 (H = 0.097)	M = 722.42 *(70.26)* Hurst = 0.750
ATC #4	M = 726.84 *(51.03)* Hurst = 0.678	M = 578.66 *(56.85)* alpha = 1.194 (H = 0.194)	M = 619.26 *(41.54)* Hurst = 0.802
ATC #5	M = 1073.70 *(109.82)* Hurst = 0.882	M = 944.74 *(137.58)* Hurst = 0.756	--

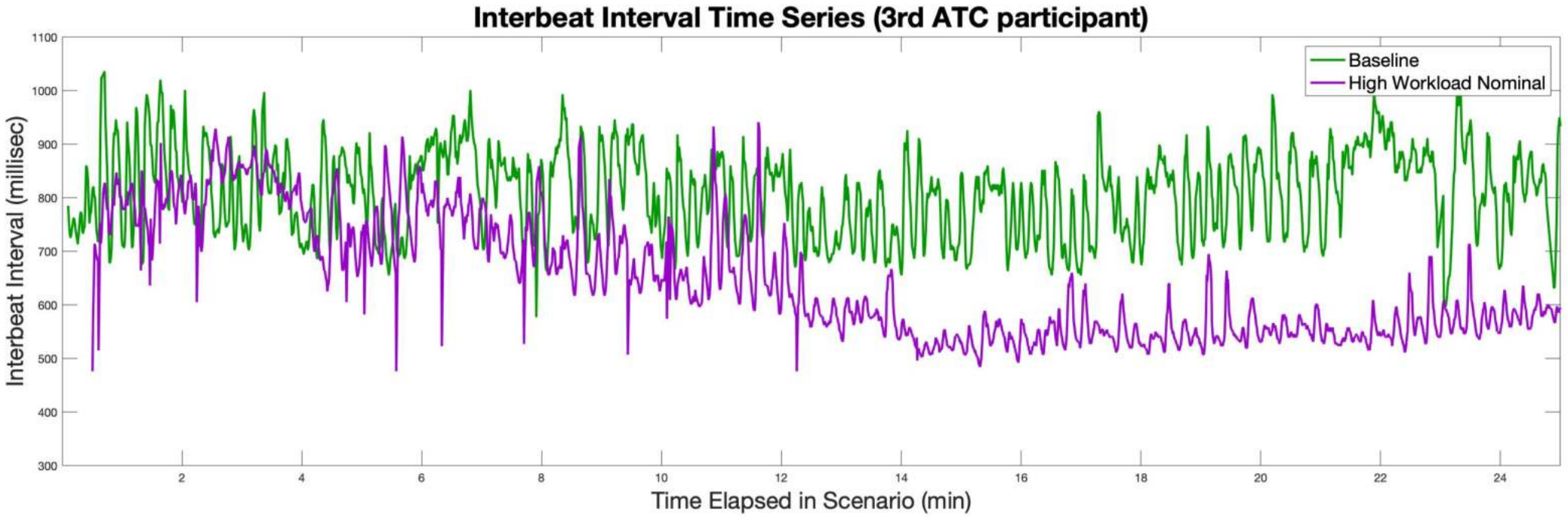
Repeated Measures ANOVA: $F(2,12) = 2.63$, $p = .13$



Conflicts

BL →
HiNom →

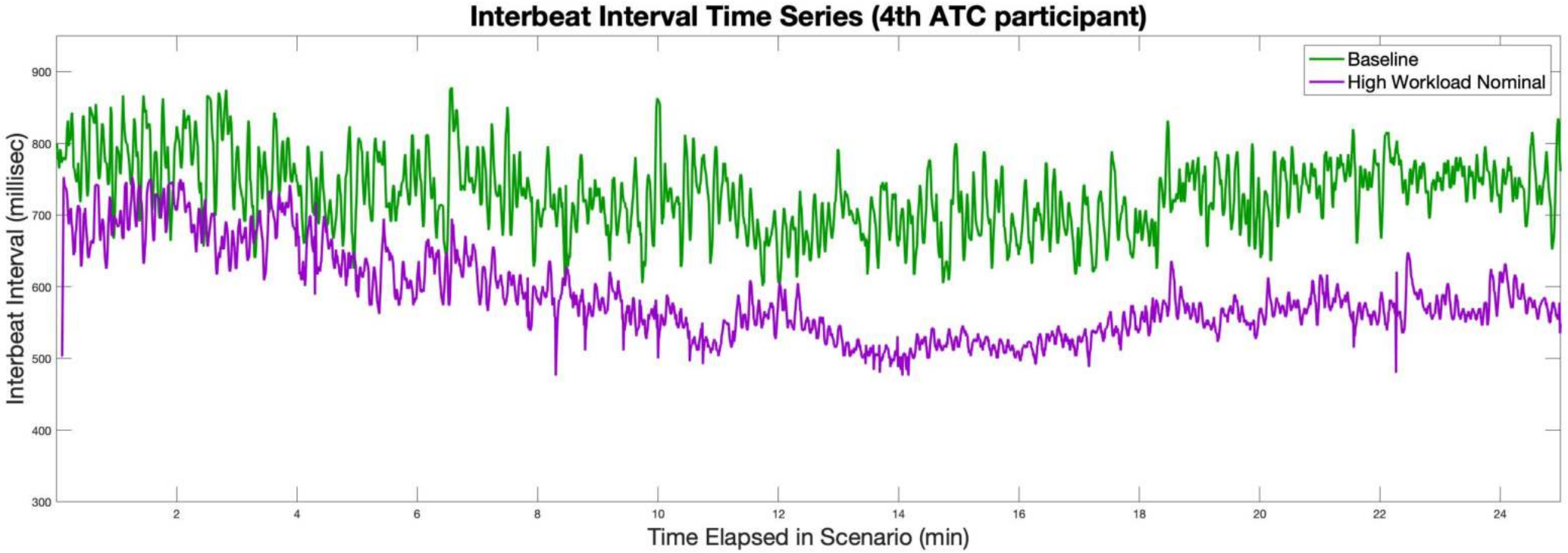
	Baseline	High Workload Nominal
ATC #1	M = 753.42 *(41.80)* Hurst = **0.653**	M = 752.40 *(44.80)* Hurst = **0.813**



Conflicts

BL →
HiNom →

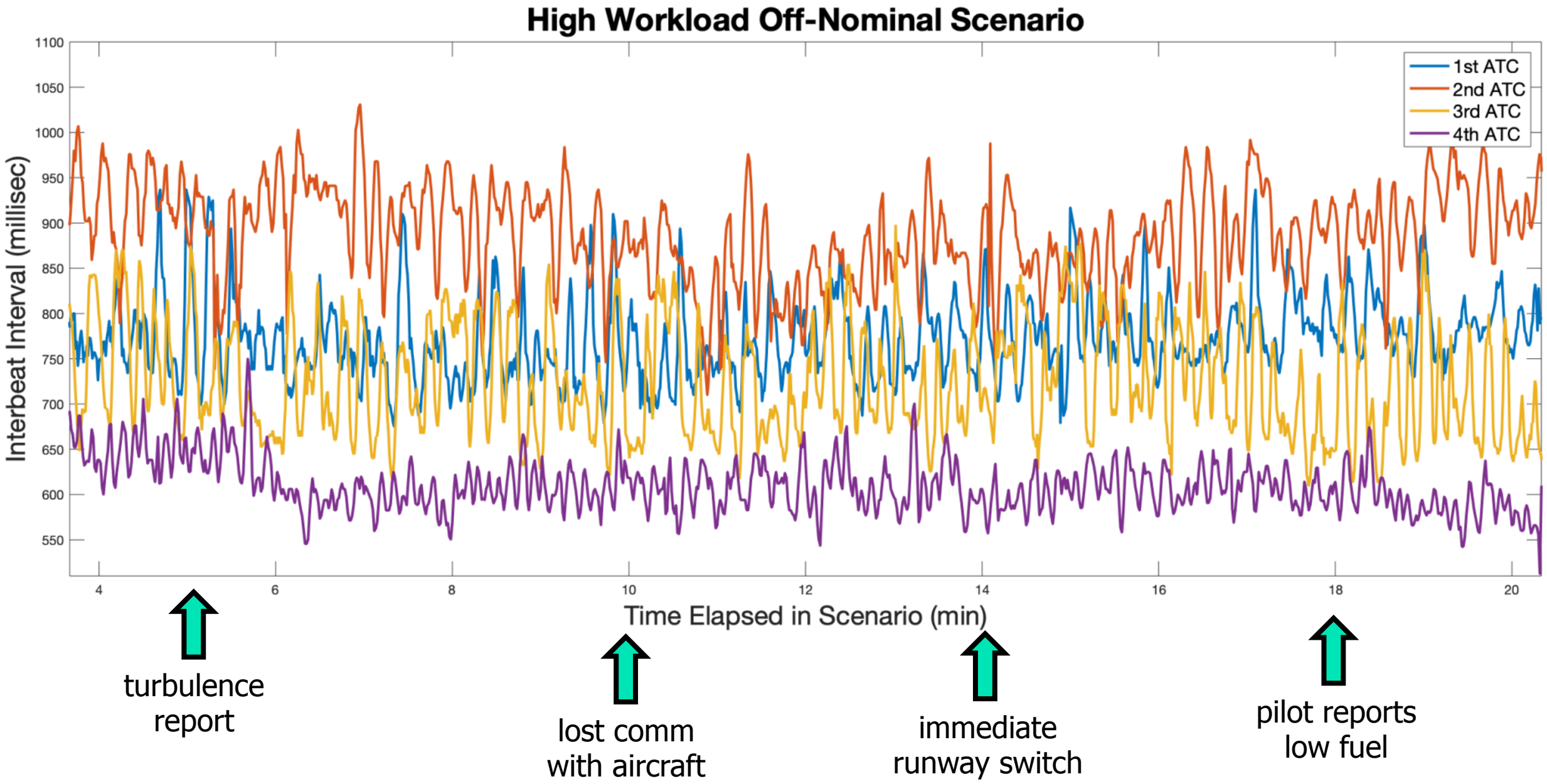
	Baseline	High Workload Nominal
ATC #3	M = 800.87 *(80.07)* Hurst = **0.736**	M = 627.36 *(103.22)* alpha = **1.097**



Conflicts

BL →
HiNom →

	Baseline	High Workload Nominal
ATC #4	M = 726.84 *(51.03)* Hurst = **0.678**	M = 578.66 *(56.85)* alpha = **1.194**



- Off-nominal events – considered perturbation?

Next Steps

- Collect more data
- Shift DFA bins & compare for analysis validity/stability
- Wavelet analysis on IBI and conflicts in BL & HiNom
- Wavelet analysis on IBI and Off-Nom trials
- Explore fractality with other data sets & pair with IBI
  - Communication
  - Facial expression?
- Compare IBI results to other measures of workload
  - Any relationships?

References

- Joint Planning and Development Office. Next Generation Transportation System: Concept of Operation v.3.0. Government Printing Office, Washington D.C. (2010)
- Mansikka, H., Virtanen, K., & Harris, D. (2019). Comparison of NASA-TLX scale, modified Cooper–Harper scale and mean interbeat interval as measures of pilot mental workload during simulated flight tasks. *Ergonomics, 62*(2), 246-254.
- Russell, S. M., Funke, G. J., Knott, B. A., & Middendorf, M. (2011). Fractal Time Series Analysis of Human Heartbeat Intervals for Physical and Mental Workload. *16th International Symposium on Aviation Psychology*, 160-165.
- Wilson, G. F., Caldwell, J. A., & Russell, C. A. (2007). Performance and psychophysiological measures of fatigue effects on aviation related tasks of varying difficulty. *The international journal of aviation psychology,* 17(2), 219-247.