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Assessment of HPAC Urban Modelling Capabilities using Joint Urban 2003 Field Trial Data

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Sponsor:

U.S. Defense Threat Reduction Agency /
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Introduction

- **HPAC: Hazard Prediction and Assessment Capability modelling suite, a product of the U.S. Defense Threat Reduction Agency (DTRA)**

- **IDA is studying the performance of urban models within HPAC**

- **We are evaluating the urban performance by comparing HPAC predictions to data from the Joint Urban 2003 (JU03) field experiment in Oklahoma City**
  - Past IDA studies have examined HPAC performance using data from the Urban 2000 (Salt Lake City) and MUST experiments

- **A wealth of meteorological data recorded during JU03 was used to drive the HPAC predictions**

- **A large number of metrics were employed to assess model performance**

Overview of HPAC

- **Non-Urban HPAC**:
  - Includes two models – SWIFT (default/recommended) and MC-SCIPUFF -- that process meteorological inputs into mass-consistent, gridded wind fields
  - Uses SCIPUFF for transport and dispersion (T&D) in open terrain
  - Not optimized for calculating wind fields or T&D within the urban canopy

- **Urban HPAC:**
  - Includes specialized models to calculate transport and dispersion and/or wind fields within the urban canopy
  - Most of these models use SWIFT or MC-SCIPUFF to pre-process the meteorological input
  - Most of these models hand off to SCIPUFF for transport and dispersion in open (non-urban) terrain

Overview of HPAC Urban Models

- **Urban Canopy (UC),** (our "baseline" model), uses vertical wind and turbulence profiles empirically adjusted to be suitable for urban canopies

- **Urban Dispersion Model (UDM),** uses a dispersion methodology where Gaussian puffs interact with urban obstacles (parameterized by wind tunnel experiments)

- **Urban Windfield Module (UWM),** uses reduced computational fluid dynamics (CFD)-type techniques to generate wind fields suitable for urban environments (meant to be an improvement over SWIFT)

- **Micro-SWIFT/SPRAY (MSS),** uses Micro-SWIFT (Röckle-based empirical model) to generate urban wind fields that drive Micro-SPRAY, a Lagrangian particle dispersion model

- We also considered a combined **UWM + UDM** configuration

Overview of Joint Urban 2003 (JU03)

- **JU03 was a multi-agency field experiment conducted in Oklahoma City, U.S.A. (OKC) during the summer of 2003**
- **Our study considers the 29 thirty-minute continuous releases of SF_6 tracer gas during JU03**
- **SF_6 concentrations were sampled during 2-hour observation periods following the start of each release**
- **We considered arrays of static surface samplers within the OKC Central Business District (CBD) and on 1 km, 2 km, and 4 km radius sampler arcs downwind of the downtown release sites**
- **We used 16 different meteorological inputs to HPAC using data from the JU03 experiment, including:**
  - Single-altitude wind measurements
  - Vertical profile wind measurements from SODARs and radiosondes
  - Wind measurements at sites upwind or downwind of the release sites, and within the CBD near the release sites
  - Data produced by numerical weather assimilation techniques
  - etc.

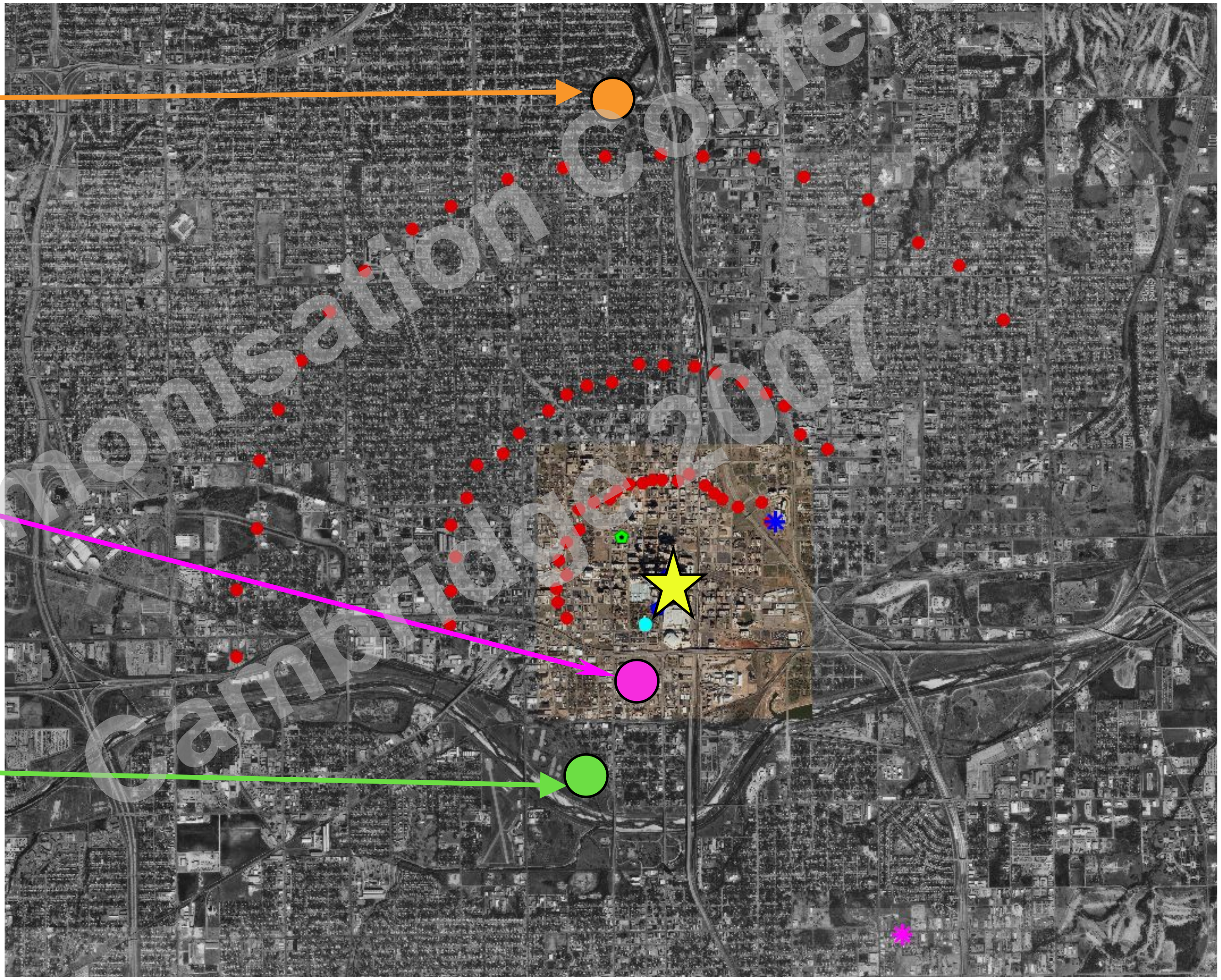
NOAA ARL FRD Samplers (CBD, Arcs)

JU03 MET Stations: PNNL, ANL Clusters, Post Office Rooftop

ANL (CC)
Radiosonde
Profiler/RASS
Mini-Sodar

Post Office Rooftop

PNNL
Radiosonde
Profiler/RASS
Sodar



Baseline MET

Within 30km of Releases

- **Surface**
  - Source: University of Utah Mesonet (MesoWest)
    - » Stations: KOUN, KOKC, KPWA, KTIK
- **Upper Air**
  - Source: University of Wyoming
  - Station: KOUN

Red – Surface
Blue – Profile
Black - Releases

Prevailing wind speed is from South

Notation for Meteorological ("MET") Inputs

- **<u>ACA</u> [MC-SCIPUFF]: ANL (downwind) SODAR + Profiler**
- **<u>PNA</u> [MC-SCIPUFF]: PNNL (upwind) SODAR + Profiler**
- **<u>PO7</u> [SWIFT]: Post Office rooftop station (40 m single-altitude)**
- **<u>BAS</u> [SWIFT]: "Baseline" (airport) Surface + Profiler**
- **<u>GCT</u> [SWIFT]: Global Climatology Analysis Tool (GCAT) output, based on MM5-FFDA numerical weather assimilation**

- **11 other meteorological input options were considered (not presented here)**

Overview of Methodology

- **Use displays / graphics**
  - observations vs. predictions
  - contour plots

- **Calculate Measures of Effectiveness (MOEs) and Statistics**
  - Calculate 2D MOEs and 13 statistics for large number of different regimes, and various quantities of interest
    - » All surface, CBD, 1 km arc, 2 km arc, 4 km arc, all arcs
    - » Averaged Concentration over 2 hr, 1 hr, 30 m, & each separate time increment (15 min, 30 min, 1 hour)
    - » For MOE
      - "Summed" averaged concentration
      - Threshold Exceedance (25, 250, 2500 ppt)

- **Non-parametric tests ("2-dimensional sign" & general permutation) to check for significant statistical differences**

Standard Statistics: Normalized Absolute Difference and Fractional Bias

- **Calculated stats for 30-min average concentrations for all available NOAA ARL FRD surface samplers (CBD + Arcs)**
- **Considered 29 releases**
- **Stats calculated for each 2-hr observation period, then averaged over releases**
  - Separate averages for day and night releases

$$NAD = \frac{\sum_i \left| C_p^{(i)} - C_o^{(i)} \right|}{\sum_i \left(C_p^{(i)} + C_o^{(i)} \right)}$$ (measure of scatter)

$$FB = \frac{\sum_i \left(C_p^{(i)} - C_o^{(i)} \right)}{0.5 \sum_i \left(C_p^{(i)} + C_o^{(i)} \right)}$$ (measure of bias)

Results

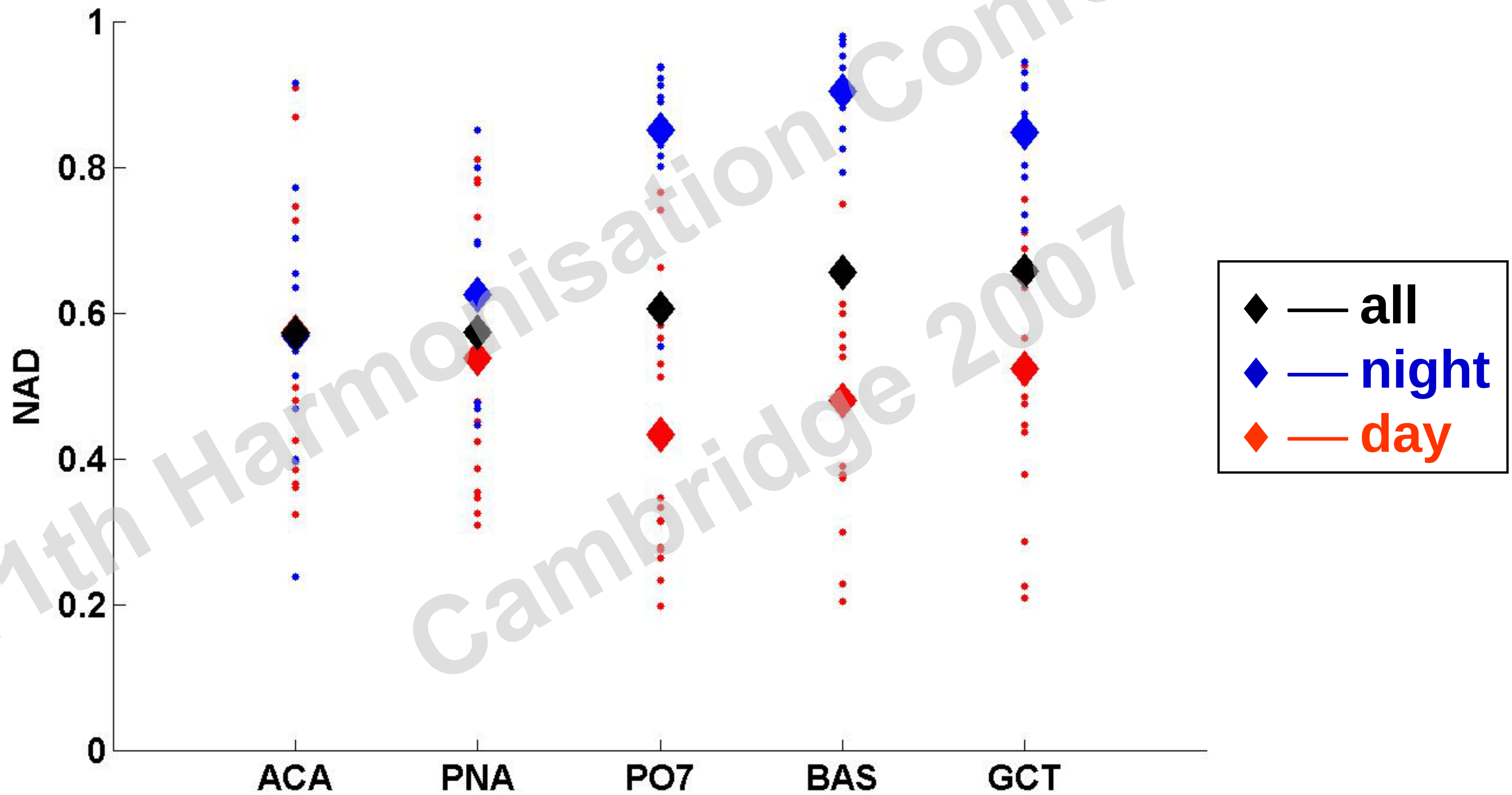
- **Night vs. Day discrepancy**
  - Significant differences in model performance depending on time of day
    - May be related to atmospheric stability category
  - All urban model configurations tend to overpredict concentrations at night
  - All model configurations except MSS tend to underpredict during the day
  - The SWIFT-based MET options tended to perform significantly worse at night than at day, as measured by scatter metrics
    - MC-SCIPUFF-based MET options tended to yield similar day/night performance

- **Model performance – Night**
  - MSS, UDM, and UDW represent improvements over UC for SWIFT-based MET
  - Adding UDW to UDM does not represent a substantial or consistent improvement

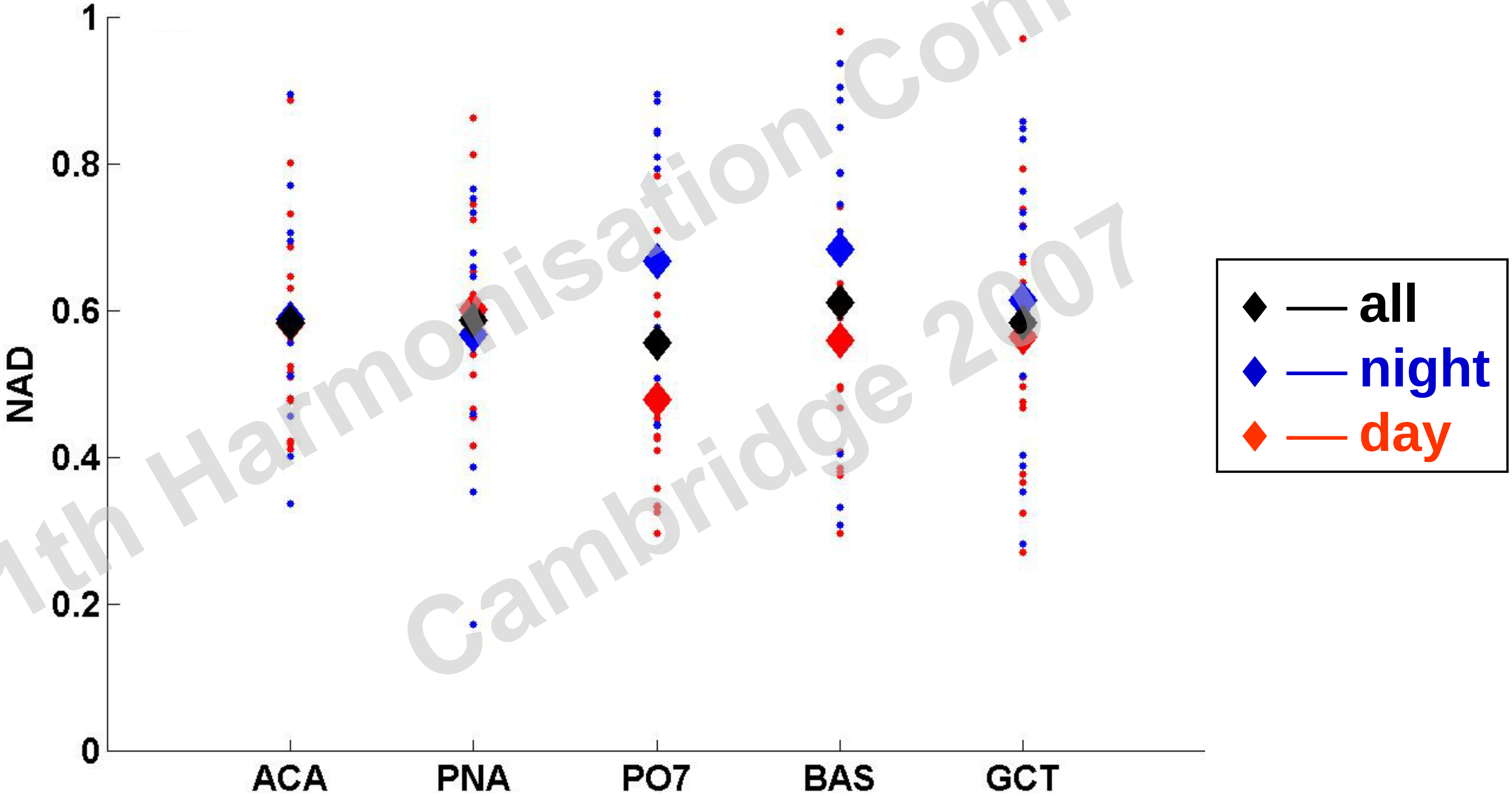
- **Model performance – Day**
  - Relative model performance was mixed and inconsistent

- **Model performance – MSS performance differed from other HPAC urban modes**
  - MSS performance during the day and night was similar
  - MSS generally resulted in less prediction bias than the other urban modes

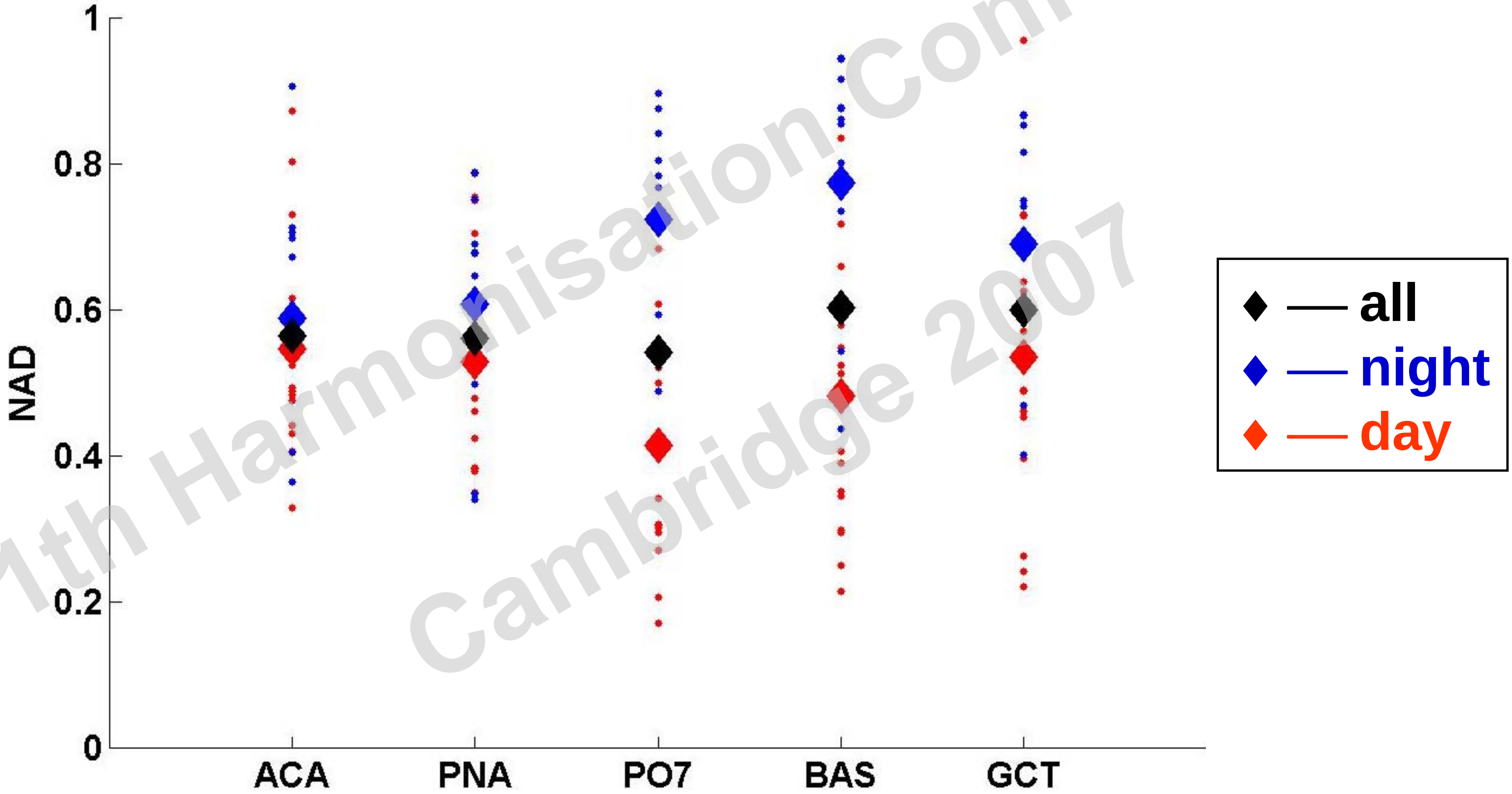
Normalized Absolute Difference for UC Mode



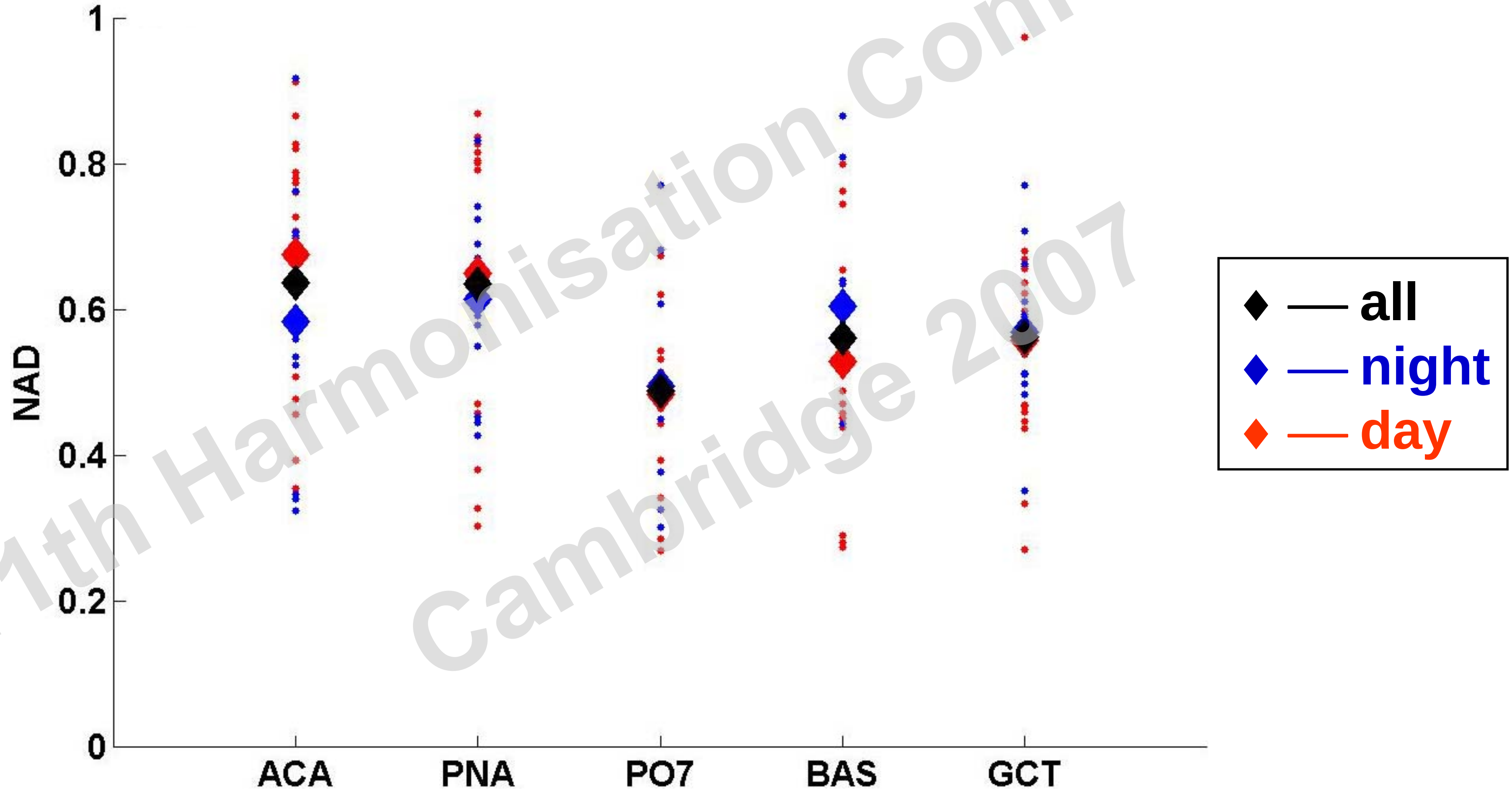
Normalized Absolute Difference for UDM Mode



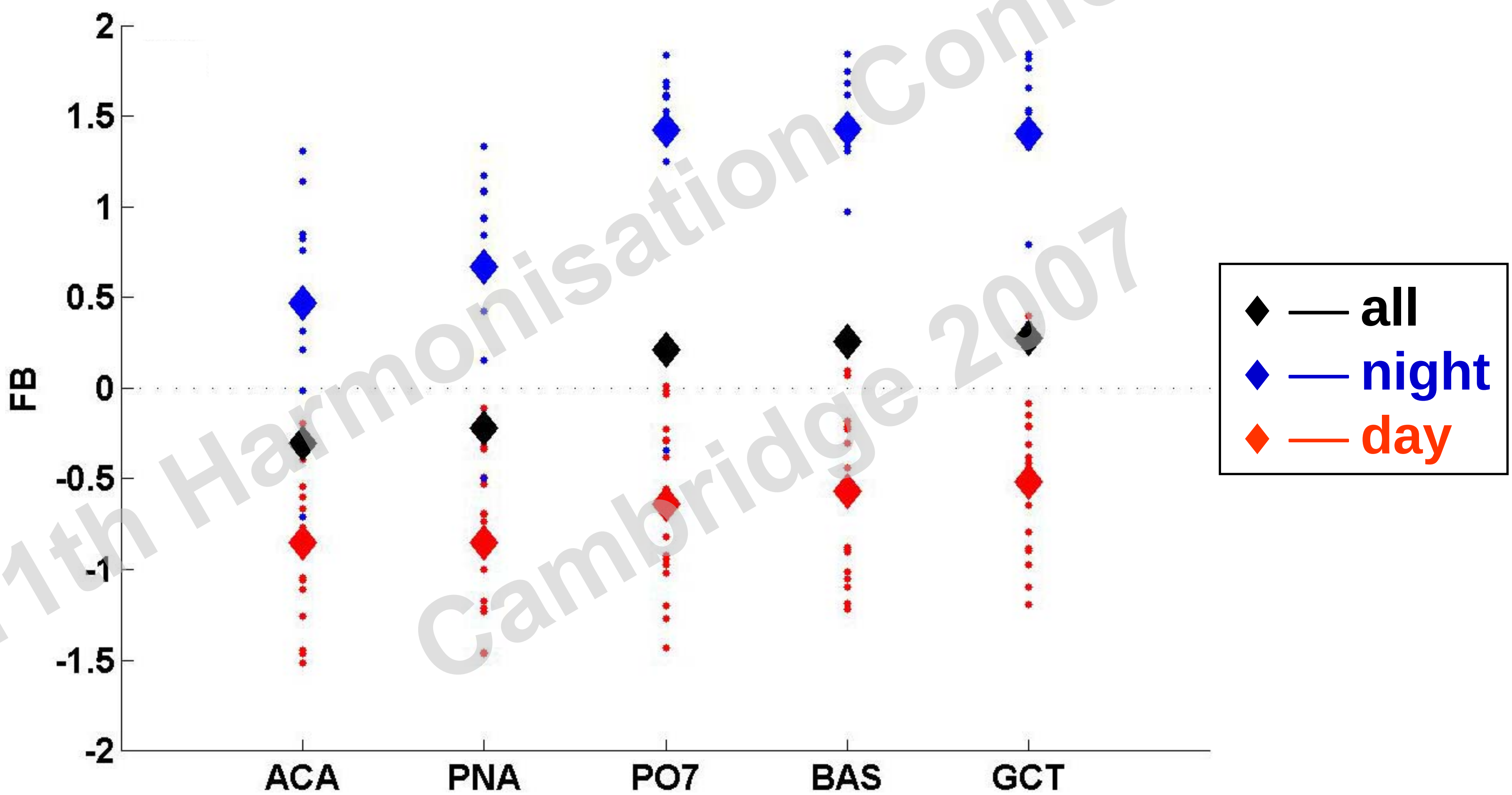
Normalized Absolute Difference for UWM + UDM Mode



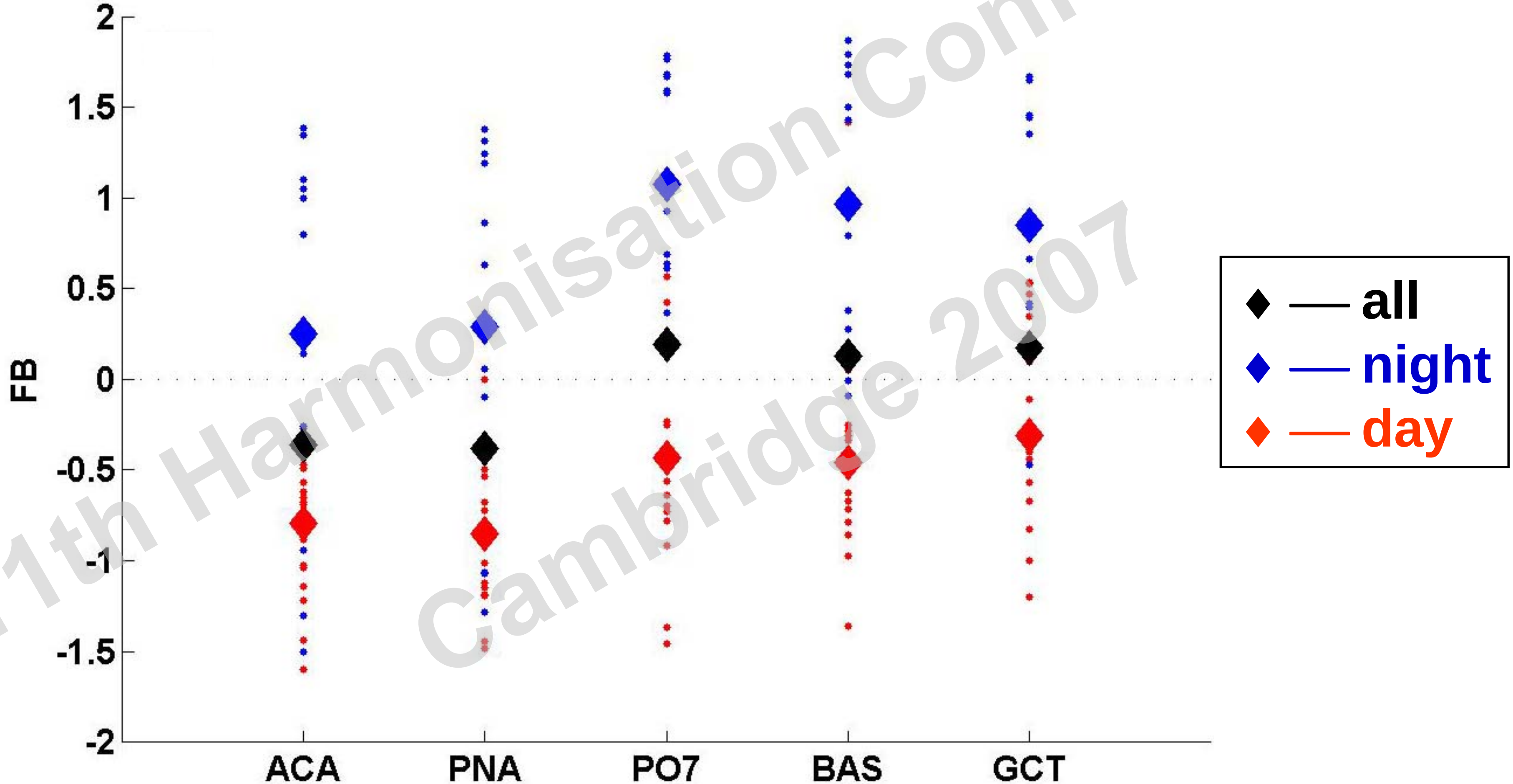
Normalized Absolute Difference for MSS Mode



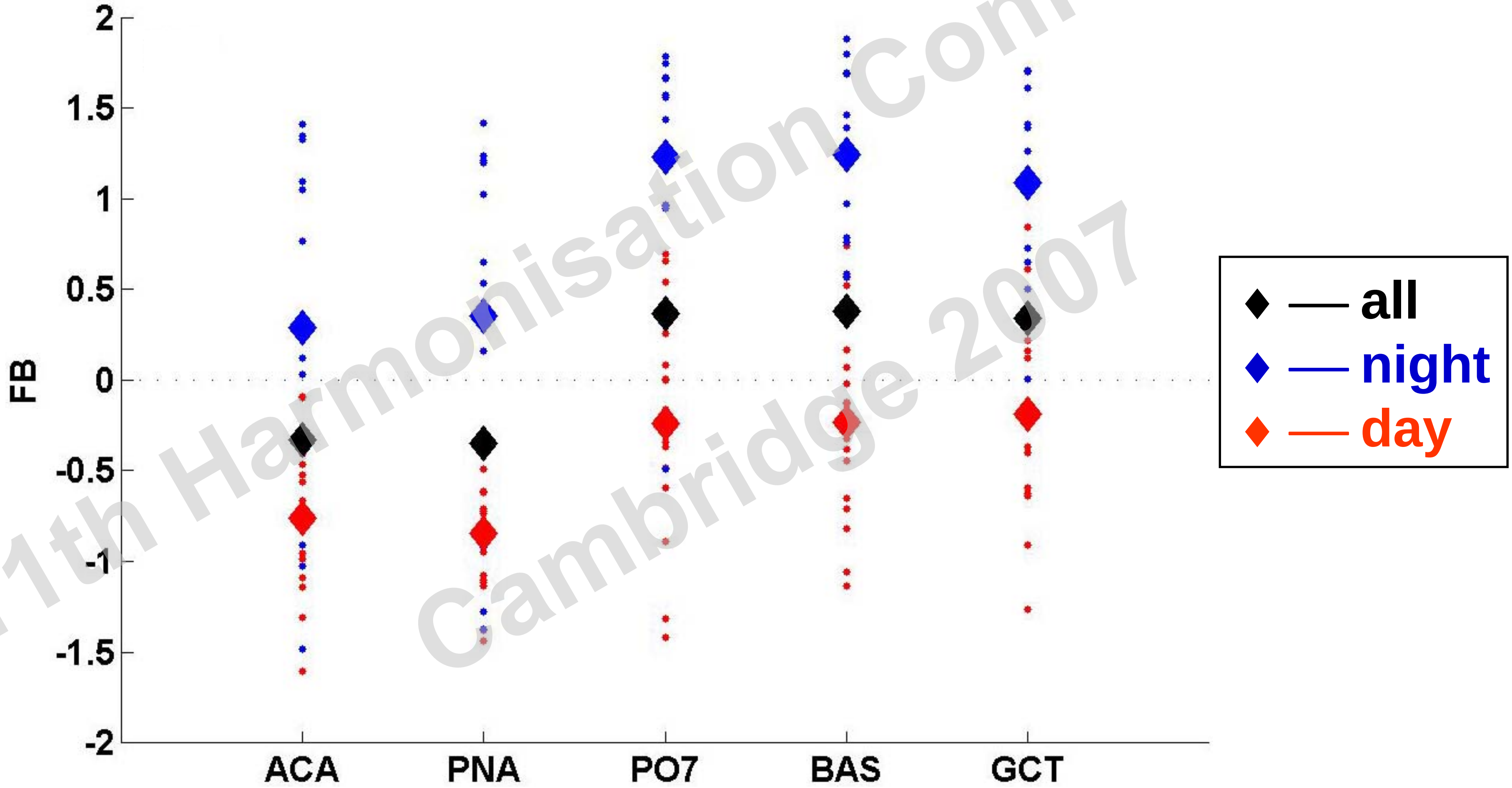
Fractional Bias for UC Mode



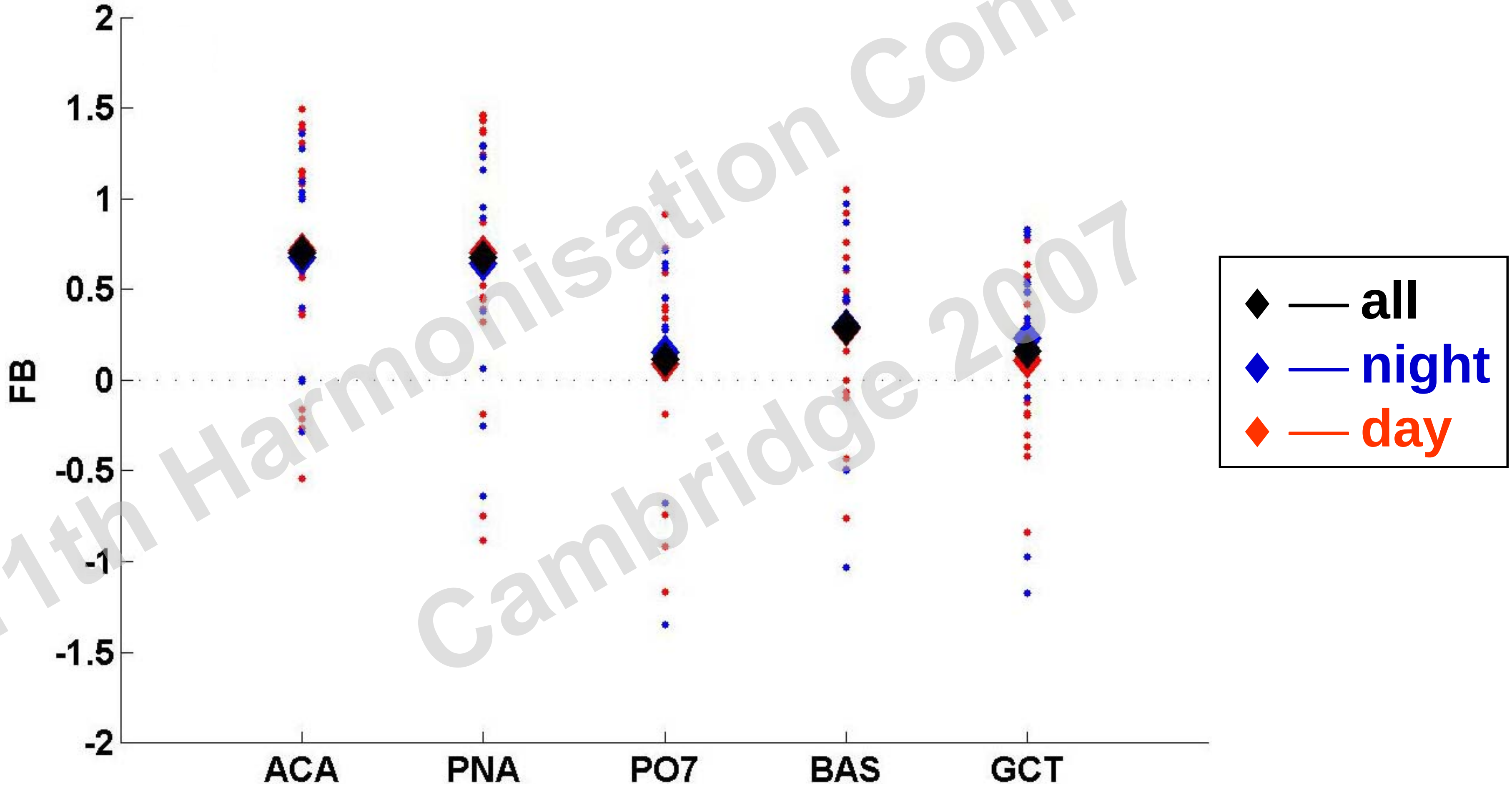
Fractional Bias for UDM Mode



Fractional Bias for UWM + UDM Mode



Fractional Bias for MSS Mode



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Near-Term Plan for Urban T&D Evaluation
Using Data from the JU03 Field Experiment

- **Urban HPAC Configurations**
  - Urban Canopy (UC)
  - Urban Dispersion Model (UDM)
  - Micro-SWIFT/SPRAY (MSS)
  - Most likely will re-run using JU2003 met to account for minor updates to met that were suggested for other models
    - Include sensible heat flux values when possible
- **QUIC-URB/QUIC-PLUME (Los Alamos National Laboratory)**
  - QUIC-URB is an urban wind field model
    - Uses a modified Röckle approach for urban terrain
  - QUIC-PLUME is the associated urban Lagrangian particle dispersion model
  - Prediction runs for JU03 are underway
- **MESO/RUSTIC (ITT Industries)**
  - RUSTIC is an urban wind field model
    - Uses modified Reynolds-Averaged Navier-Stokes equations and a k-ω turbulence model
  - Urban MESO is the associated urban Lagrangian particle dispersion model
  - A set of MESO-RUSTIC predictions for JU03 have just been generated using PNNL SODAR (PNS) and Post Office (PO7) MET

backups

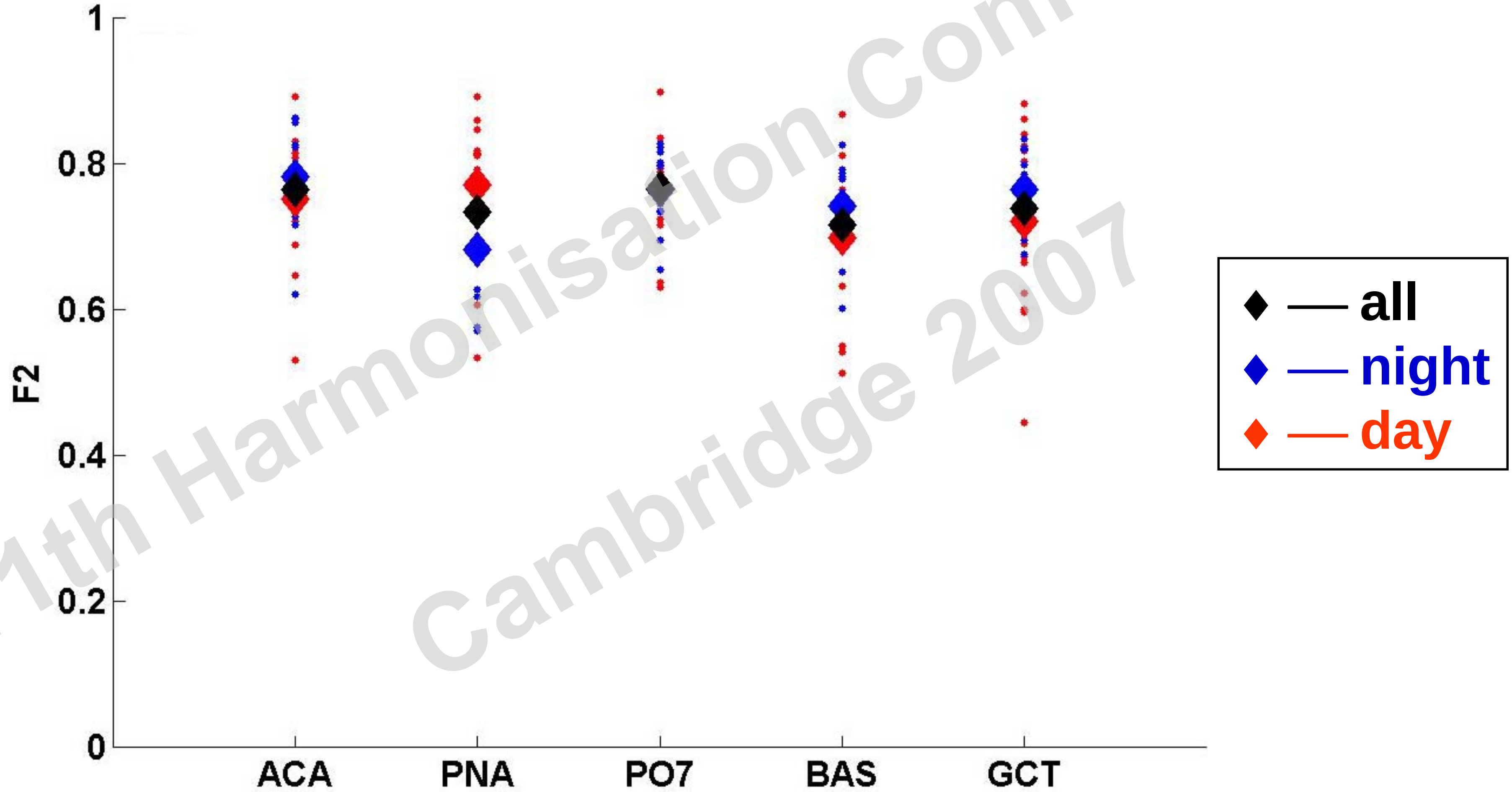
Day Performance Mixed, Night Performance Improved by MS, DM, and DW Relative to UC and WM for SWIFT-Based MET Options

Urban HPAC Modes, for Five MET Input Options, That Led to Improved Predictive Performance of JU03 Releases Based on Measures of Predicted / Observed Scatter (Concentration- Based MOE, NAD, and NMSE)

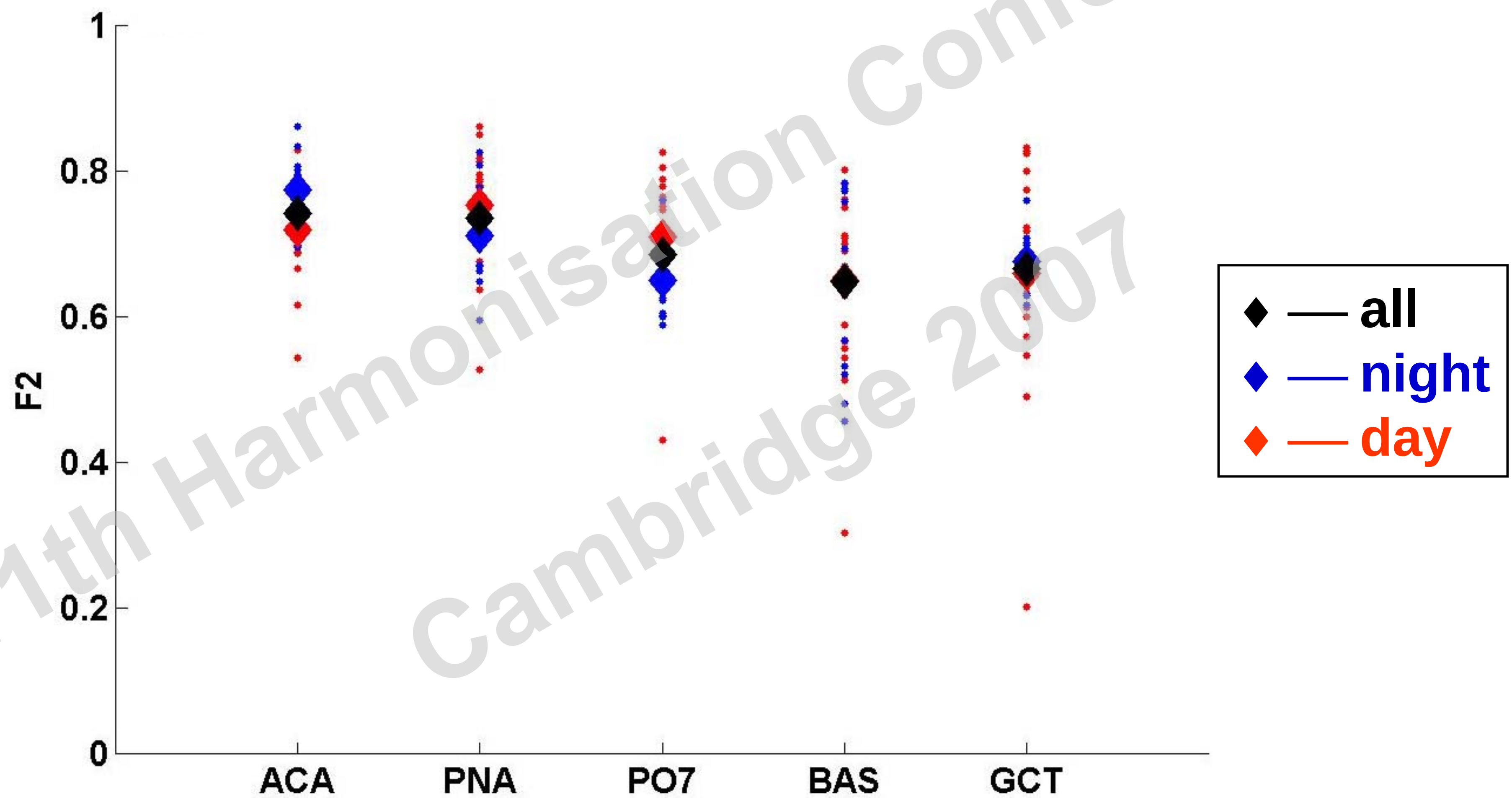
Condition / MET Input Option	BAS (SWIFT)	BRB (SWIFT)	PO7 (SWIFT)	PNA (MC-SCIPUFF)	ACA (MC-SCIPUFF)
Day CBD	DW/DM	mixed	mixed	(UC,WM,DM,DW) /MS and DW/DM	DW/MS
Day Arcs	(MS,DW) /(UC,WM)	mixed	mixed	mixed	no differences
Night CBD	(MS,DM,DW) /(UC,WM)	(MS,DM,DW) /(UC,WM)	(MS,DM,DW) /(UC,WM) and MS / (DM,DW)	mixed	no differences
Night Arcs	(MS,DM,DW) /(UC,WM) and DM/DW	(MS,DM,DW) /(UC,WM)	(MS,DM,DW) /(UC,WM) and MS/ (DM,DW)	mixed	MS / (UC,WM,DM)

Based on hypothesis test results for scatter metrics

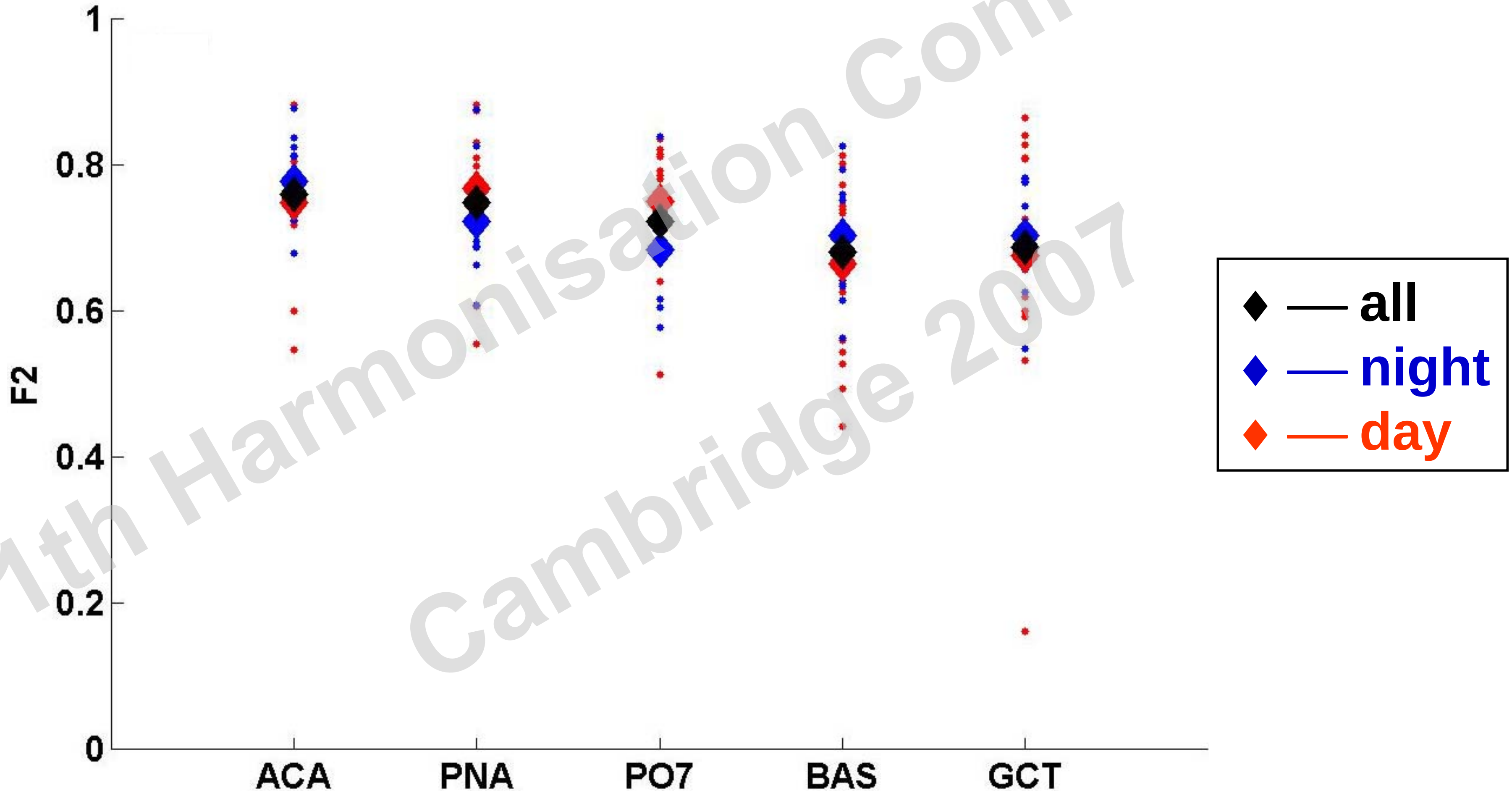
FAC2: UC



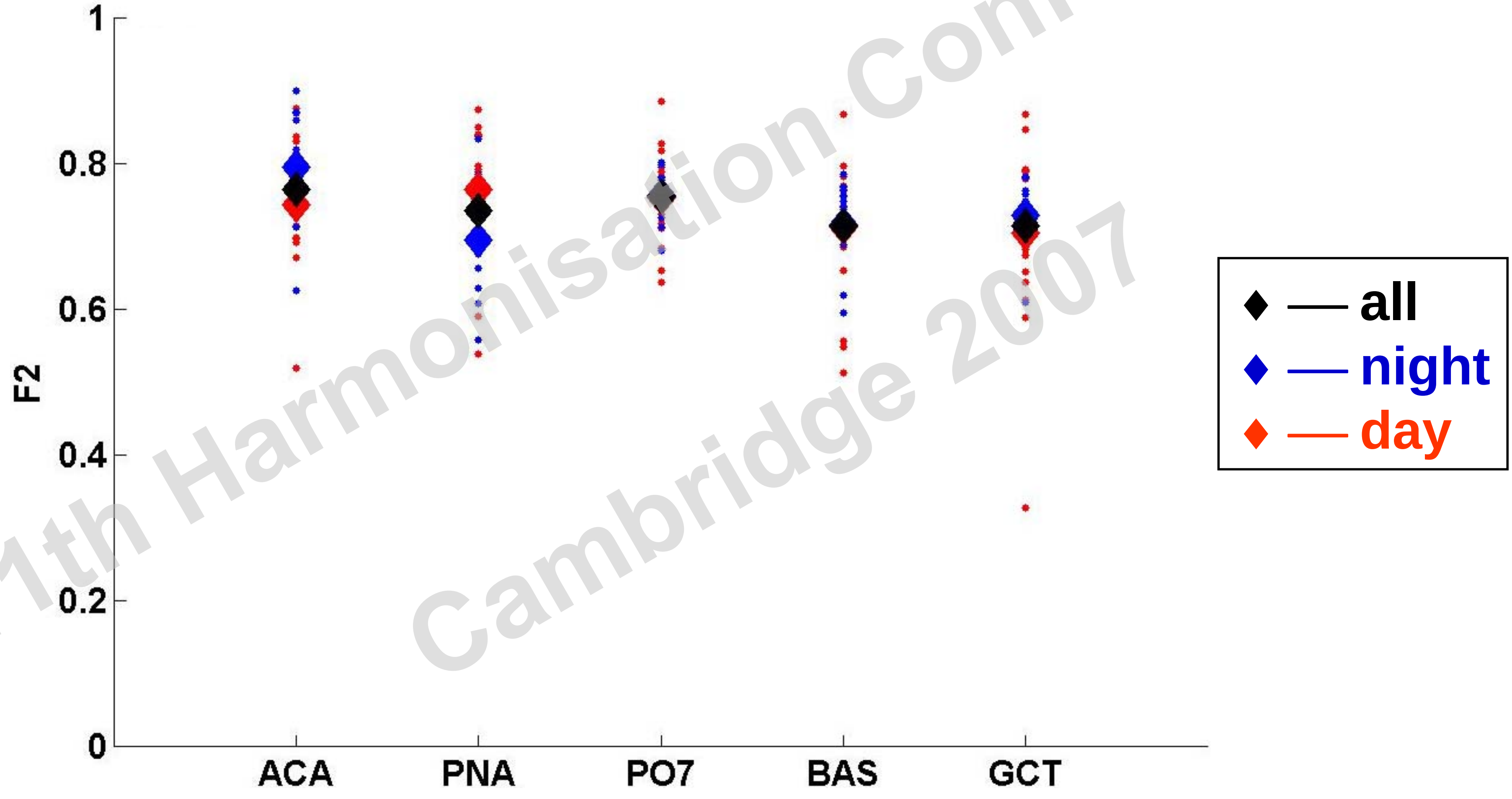
FAC2: UDM



FAC2: UDM + UWM



FAC2: MSS



JU03 Downtown - Releases