Potential Titles:
A New Era of Clock Measurements: Statistical Approaches for Addressing Noise and Uncertainty
Future-Proofing Clock Measurements: Addressing Realistic Noise and Analysis Challenges using Evidence-Based Methods
Best Practices and Statistical Framework for Modern Clock Measurements and Frequency Stability Analysis

Abstract: In this work we lay out the best practices for future clock measurements, the potential pitfalls of traditional analysis techniques, and optimal methods for addressing realistic noise types. This work represents a crucial first step toward creating a new and improved handbook of frequency stability analysis, highlighting the challenges of modern clock measurements and presenting a statistical framework, supported by evidence from computer experiments, for meeting these challenges.

I. Introduction

- **Context and Motivation**
  - Advances in atomic clocks (resulting in observations of dark uncertainty), increased downtime, and growing demands for improved statistical tools for frequency stability analysis.
- **Purpose of the Paper**
  - To propose best practices for future clock measurements, identify potential pitfalls in using traditional analysis techniques, and offer optimal statistical methods for addressing noise in modern and future clock data.
- **Significance**
  - A first step toward creating an updated and comprehensive handbook for frequency stability analysis, addressing modern data and challenges.

II. Advances and Challenges in Modern Clock Measurements

- **A. Advances in Modern Clocks**
  - Overview of state-of-the-art clocks
  - Downtime, presence of dark uncertainty
- **B. Types of Noise in Clock Data**
  - Theoretical Noise Models
    - Overview of common noise types in clock measurements (e.g., white noise, flicker noise, mixed noise).
    - No gaps in data (cite Handbook).
  - Realistic Noise in Modern Clocks
    - Real-world examples from recent high-precision clocks
- **C. Aligning Timescales and Frequency Combs**

III. Limitations and Pitfalls of Traditional Analysis Techniques

- **A. Over-reliance on Allan Variance**
    - Assumptions behind traditional techniques (e.g., Gaussian noise).
    - Challenges with short datasets, gappy data, and non-Gaussian noise.
    - Examples of misinterpretations due to outdated methods.
- **C. Lack of Robustness in Uncertainty Quantification**
    - Misestimation of uncertainties in frequency stability due to assumptions of ideal conditions.
- **D. Dealing with Dark Uncertainty**
    - Data from multiple days shows more uncertainty than can be explained by the systematics, no clear method for dealing with this

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IV. Best Practices for Future Clock Measurements

- **A. Discussion of Alternative Metrics**
    - Spectral analysis
        - Can spectrum for exploratory data analysis to examine potential periodic components or combination of noise models present in the data; hypothesis testing for noise models
        - Provides Allan variance estimate for gappy data
    - Lomb-Scargle periodogram?
- **B. Robustness in Experimental Design & Guidelines for experimental protocols.**
    - Blinding data.
    - Best practices for identifying/quantifying systematics
    - Dealing with dark uncertainty.
        - Data from multiple days shows more uncertainty than can be explained by the systematics.
- **C. Best Practices for Aligning Timescales and Frequency Combs**
    - Strategies and considerations for aligning timescales of multiple clocks with a frequency comb, uncertainty propagation, potential missteps

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V. Computer Experiments: Validating the Statistical Framework

- **A. Simulation Setup**
    - Description of simulated clock data with various noise types (e.g., synthetic vs. real-world noise).
- **B. Comparison of Traditional and Proposed Methods**
    - Performance of classical methods (e.g., Allan variance) vs. modern statistical techniques.

    - Metrics of success (improved accuracy, improved uncertainty quantification)

VI. Conclusion

- **Summary of Key Insights**
- **Call to Action**
    - Encouragement for further research and refinement of the presented framework.
    - Commitment to developing the full revised handbook.