Improving the stability of UTC(NIST) by using the data from the NIST cesium fountains

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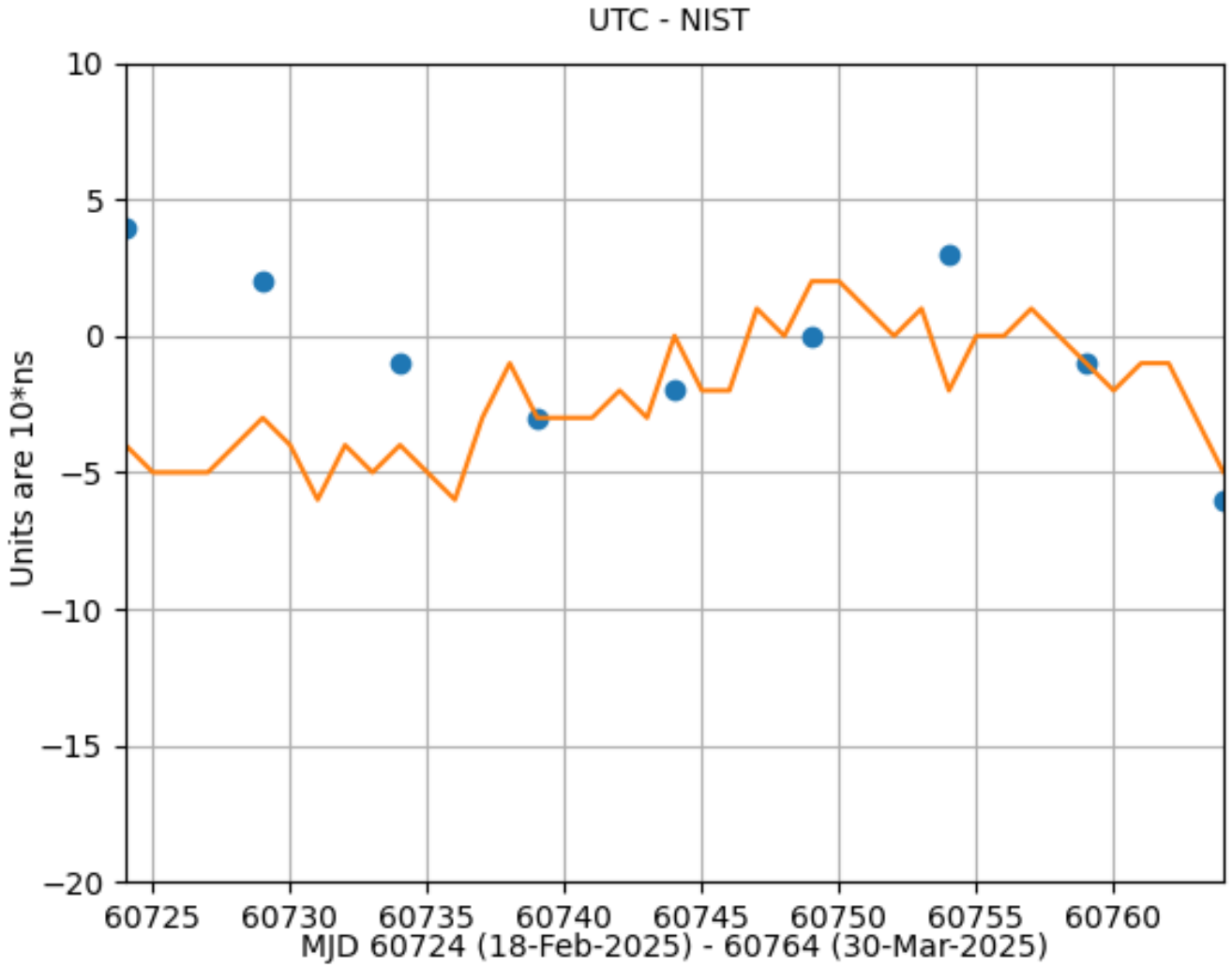
AT1 and UTC(NIST)

- The AT1 time scale is computed as a weighted average of the times of locally maintained commercial cesium standards and hydrogen masers
  - its time and frequency were set equal to UTC in late 1979
  - The frequency has drifted by about 447×10^{-15} (~38.6 ns/day) since then
- UTC(NIST) is the reference time scale for all NIST services
- It is derived from the AT1 time scale by applying offsets in time and in frequency to the time scale AT1 (including the offset above).
  - The adjustments are defined by a piece-wise linear function that adjusts the offset frequency but does not introduce a step in time
  - The parameters of the steering function are adjusted from time to time by using UTC and UTCr data published by the BIPM

UTC and UTCr – UTC(NIST)



Steering is difficult:

UTC data are available only after a significant delay

UTCr noisy relative to UTC

Can we improve the stability of AT1 and UTC(NIST) by using more frequency data from local fountains?

NIST Fountains f3 and f4

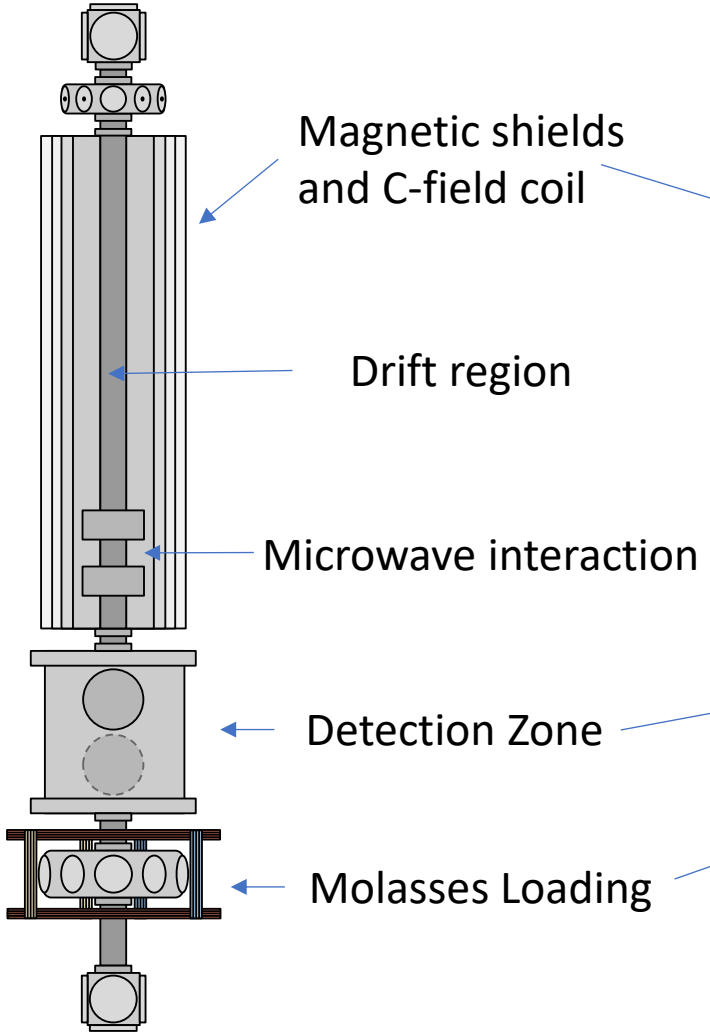
- The F3 fountain is designed for frequency stability
- The F4 fountain is designed as a primary standard with the emphasis on accuracy
- The fountains calibrate the frequency of one of the masers in the time scale every hour
- The frequency of the maser with respect to AT1 is also estimated by the time scale algorithm
- Combining these data estimate the frequency of the time scale with respect to the definition of the second as realized by the fountains

Steering strategy

- Adjust frequency of AT1 based on data from F3 and F4 as available
  - Interval between adjustments derived from stability of fountain with respect to the time scale
- Preserve historic fractional frequency offset of AT1= 447×10^{-15}
- In addition, continue piece-wise linear offset between UTC(NIST) and AT1 to compensate for time offset of UTC(NIST) – UTC from circular T
  - Adjustment uses steps in frequency and is continuous in time
  - Adjustment compensates for historic fractional frequency of 447×10^{-15}
  - These adjustments should become smaller and less frequent

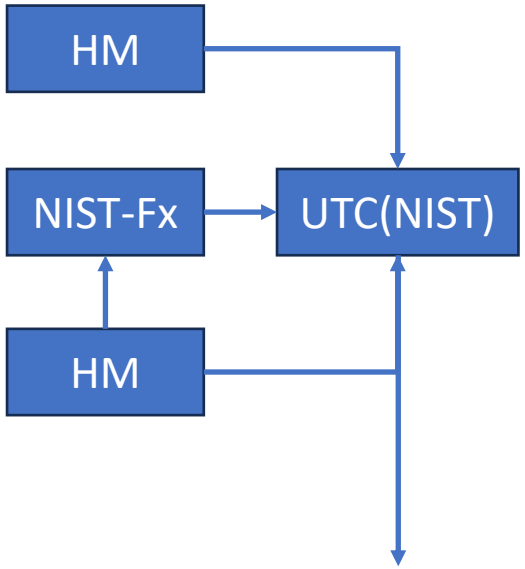
NIST-F3 physics package

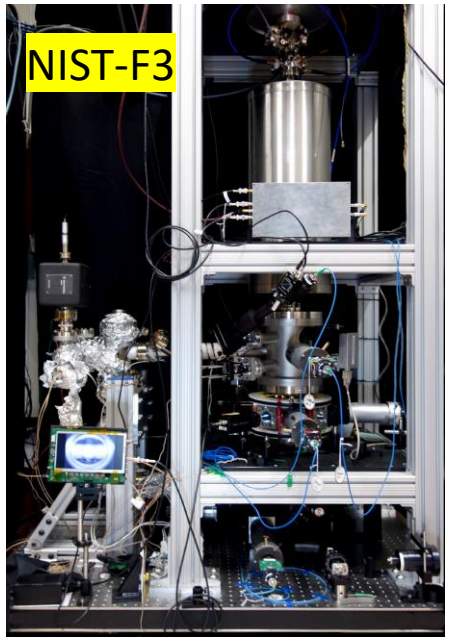
- Molasses loaded fountain.
- For typical sequence, max height of cloud is 0.78 m above the molasses zone.
- Cycle time≈1.4 s (0.5 s molasses load, 0.9 s fountain sequence)

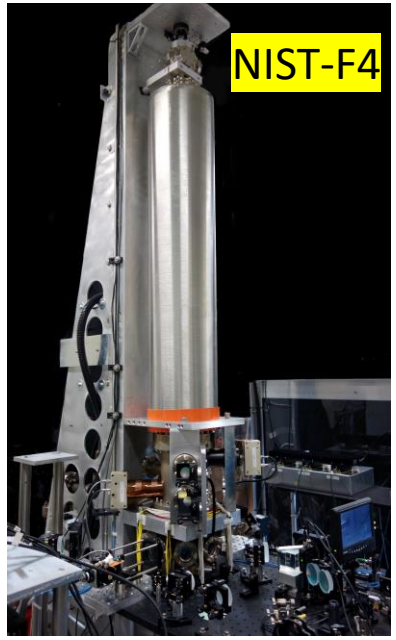


Drawing of NIST-F3 by Peter Mitchell

NIST Cs fountain clocks







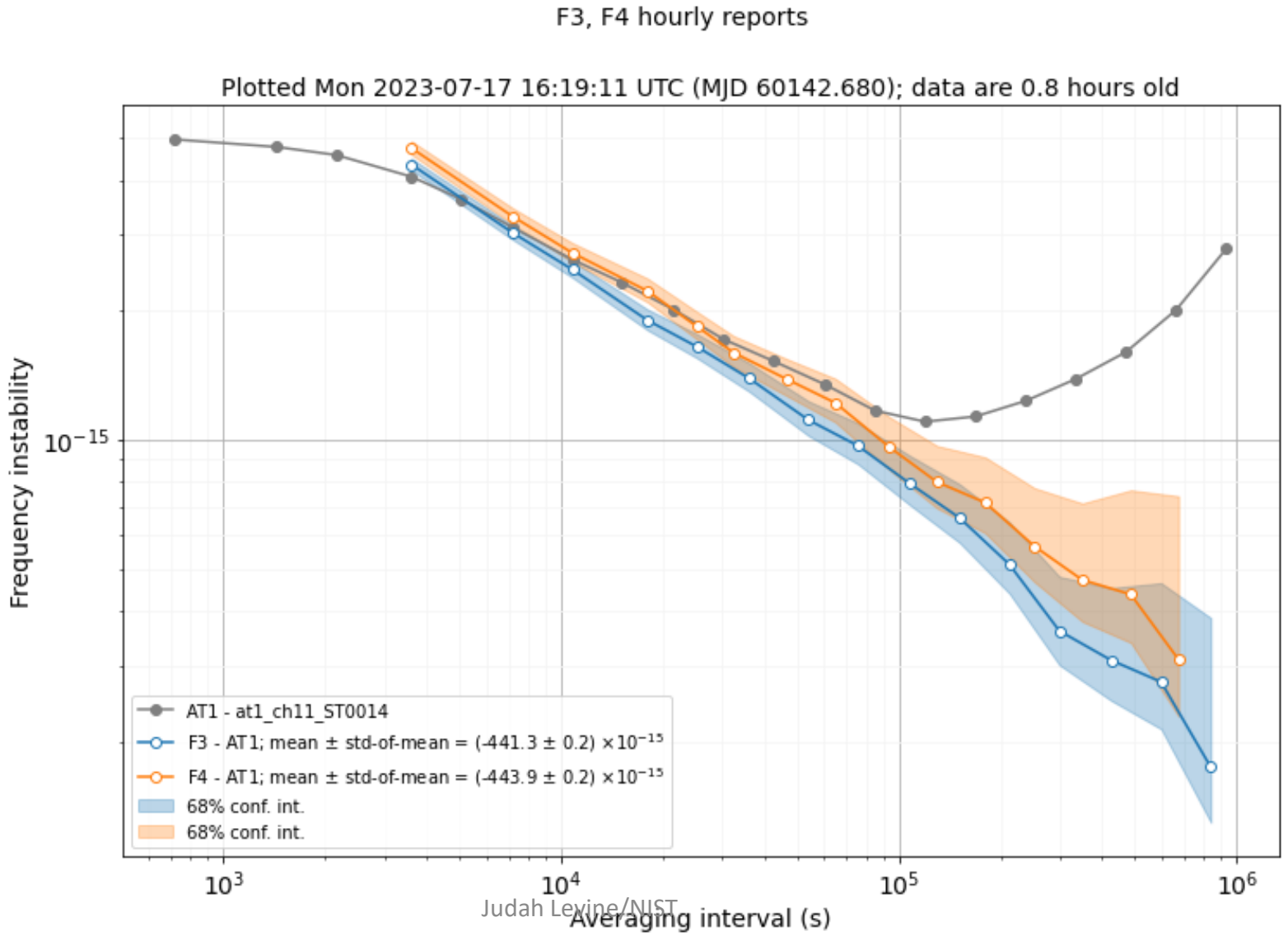
Leading corrections (typical) and type B uncertainties (preliminary) for NIST-F4

Shift	Typical Value ($\times 10^{-15}$)	Uncertainty ($\times 10^{-15}$)
Gravitational Redshift	180.959	0.001
Quadratic Zeeman	126.94	0.02
Black Body Radiation	-17.04	0.06
Cold Collisions	1	0.1

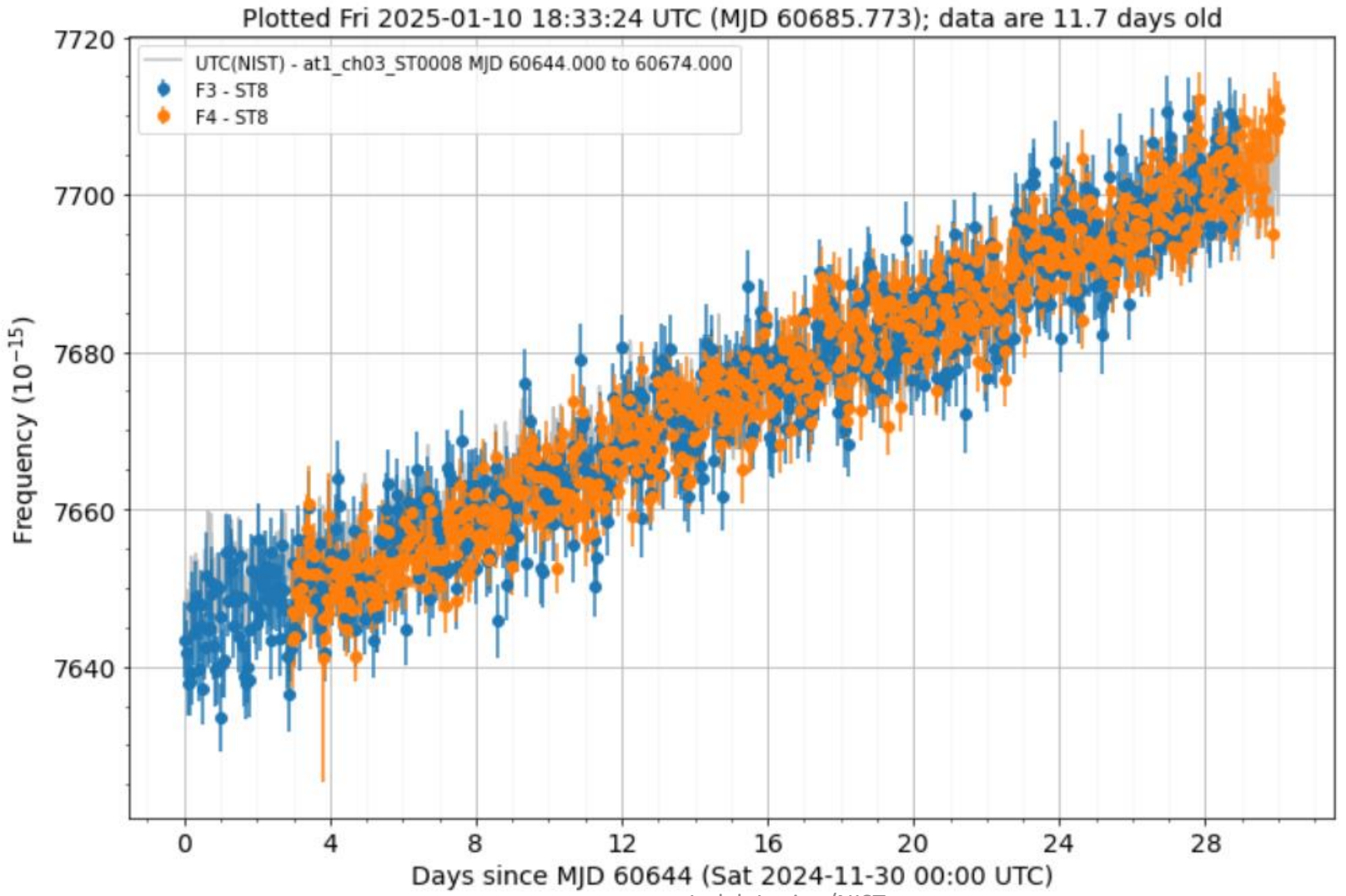
- NIST-F3 [1] is a frequency reference, $\sigma_y(\tau) \approx 2 \times 10^{-13}/\sqrt{\tau(s)}$.
- NIST-F4 [2] is currently being evaluated as a primary standard, $\sigma_y(\tau) \approx 1.5 \times 10^{-13}/\sqrt{\tau(s)}$.
- Both fountains produce hourly reports of HM frequency for time scale steering [3].

[1] G. W. Hoth et al. "NIST-F3, a cesium fountain frequency reference", Proceedings of PTTI (2023)
[2] V. Gerginov et al. "Accuracy evaluation of primary frequency standard NIST-F4", Submitted to Metrologia (2024)
[3] A. Bauch et al., "Generation of UTC(PTB) as a fountain-clock based time scale", Metrologia **49** (2012)

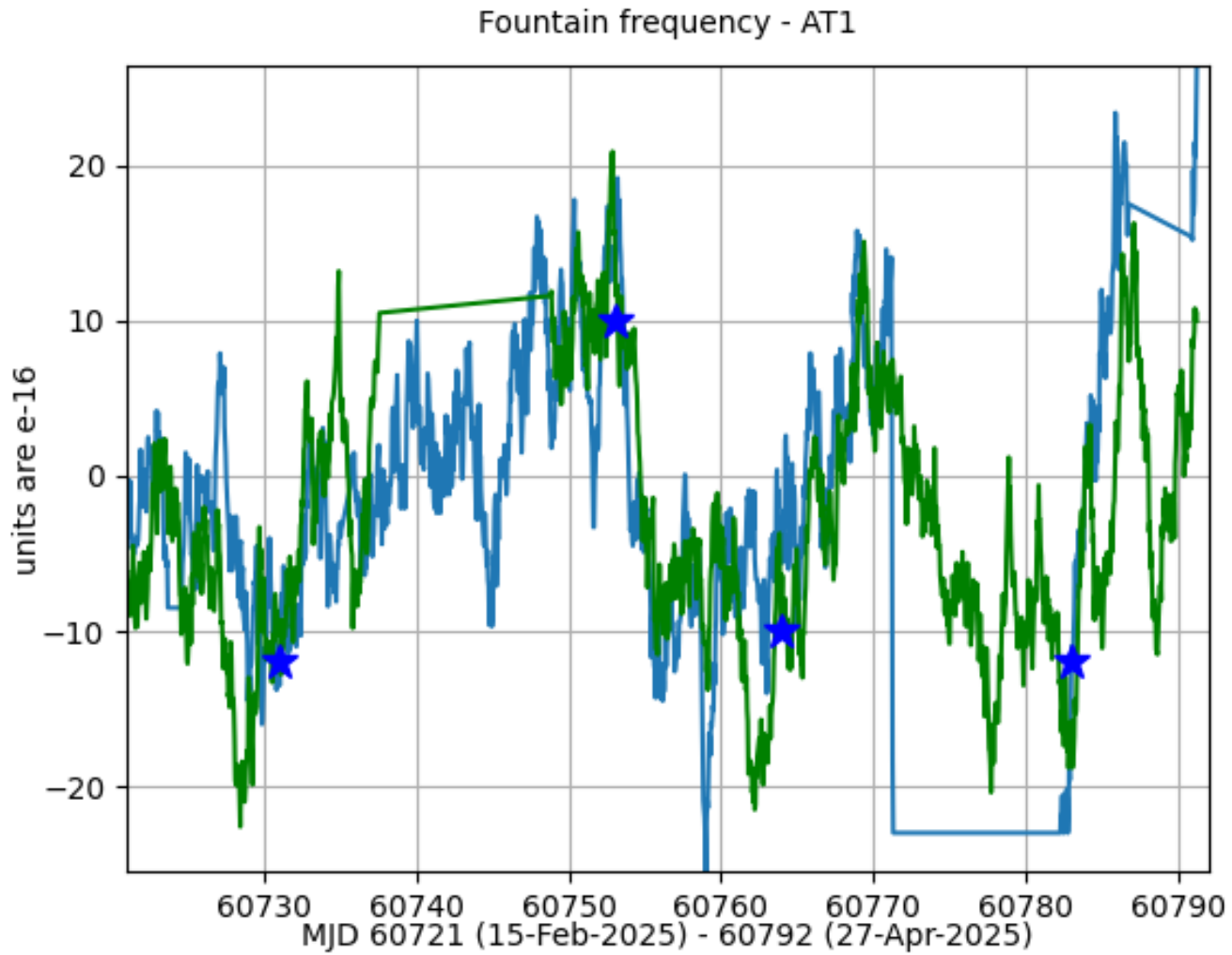
Fountain stability



Hourly fountain data



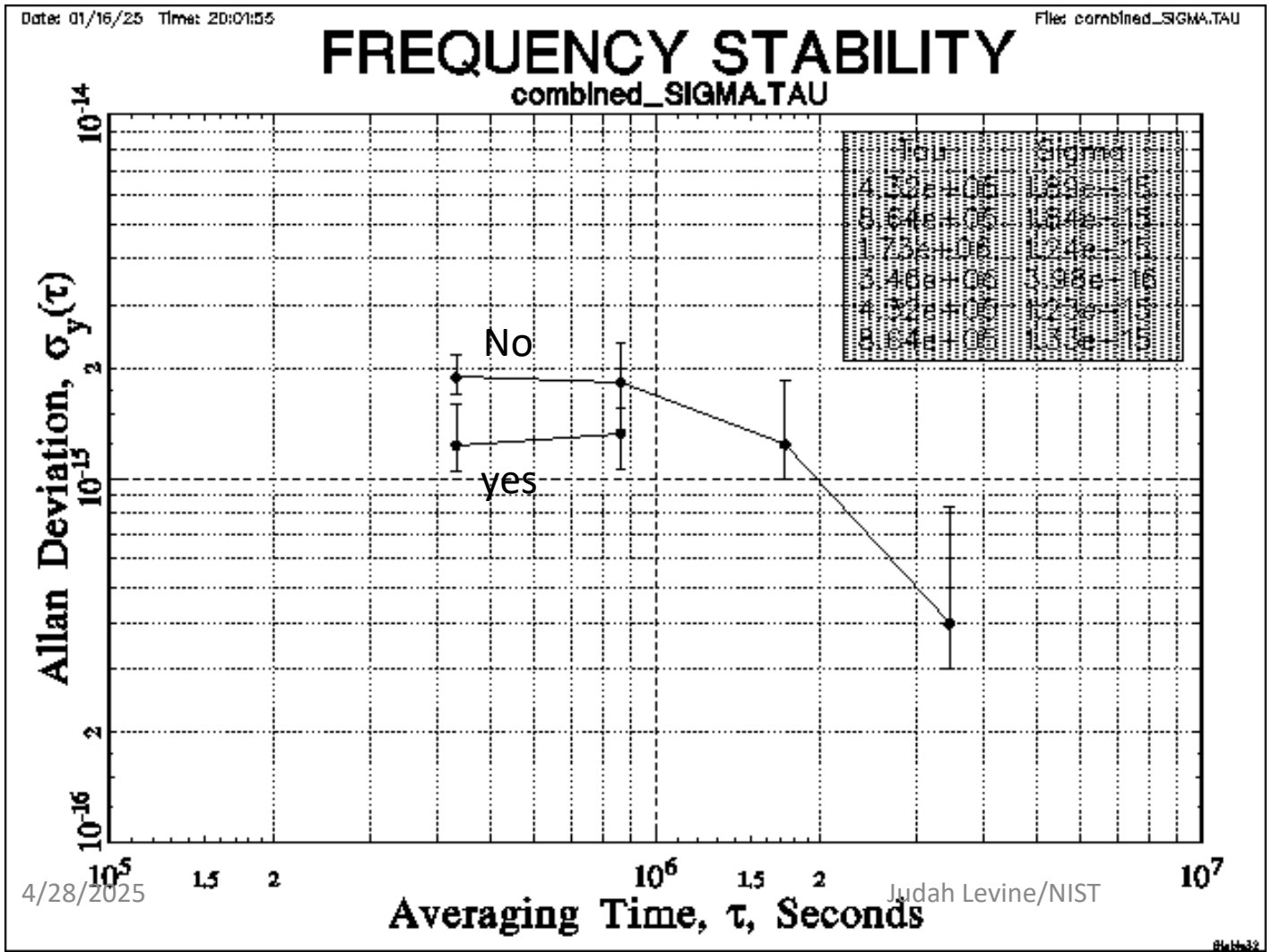
24-hour running avg f3, f4 – AT1 - 447×10^{-15}



F3 in blue, f4 in green
Stars show time and magnitude
of frequency adjustments to AT1

Short-term fountain noise defines
Interval between steering adjusments

AVAR of UTC- UTC(NIST) with/without AT1 steering



No=Allan Variance of
UTC-UTC(NIST) with
No steering of AT1 frequency

Yes= Allan variance of
UTC-UTC(IST) with steering
Adjustments as specified on
Previous slide

Summary and conclusions

- Steering of frequency of AT1 improves stability of UTC(NIST), which is defined by a linear offset from AT1 and has the same stability
  - Improvement is about a factor of 1.4
  - Improvement most significant at periods of a few days
    - Short-term stability limited by stability of fountain data
    - Long-term stability of UTC(NIST) driven by UTC-UTC(NIST) from BIPM Circular T
- Experiment is continuing