Atomic clocks

General

- Optical atomic clocks
, N. Poli et al., arXiv:1401.2378v2 (2014)
- Optical atomic clocks
, A.D. Ludlow et al., Reviews of modern physics **87** (2015)
- Fritz Riehle, Frequency Standards, WILEY-VCH Verlag GmbH & Co. KGaA, 2004

Elements

- Best Clock so far (Stand 11/2016)
http://www.nature.com/nature/journal/v506/n7486/pdf/nature12941.pdf
doi:10.1038/nature12941
- Systematic Evaluation for this http://www.nature.com/articles/ncomms7896.pdf
- Best Clock Comparison so far (Stand 11/2016) Comparison of Two Independent Sr Optical Clocks with 1×10−17 Stability at 10^3 s:
physrevlett.109.230801.pdf
- **Mercury:**
  - Comparing a mercury optical lattice clock with microwave and optical frequency standards
, R. Tyumenev et al., arXiv:1603.02026v2 [physics.atom-ph] 13 Nov 2016

Cavities

Summary of the best cavities

- Mercury (Paris) cavity:
  - Ultrastable lasers based on vibration insensitive cavities
, J. Millo et al., PR A **79**, 053829 (2009)
  - Laser locking to the Hg199 □01−□03 clock transition with 5.4×10−15/√□ fractional frequency instability
, J. J. McFerran et al., Optics Letters Vol. **37**, No. 17, 3477-3479 (2012)

General

- Making optical atomic clocks more stable with 10−16-level laser stabilization , V. Jiang et al.,Nature Photonics **5**, 158–161 (2011)

Relevant effects influencing frequency stability

- **Pund-Drever-Hall (PDH):**
  - Laser Phase and Frequency Stabilization Using an Optical Resonator , R. W. P. Drever et al., Appl. Phys. B **31**, 97-105 (1983)
- **Vibration:**
  - Simple vibration-insensitive cavity for laser stabilization at the 10^-16 level , J. Keller et al., Appl. Phys. **B 116**, 203–210 (2014)
- **Thermal-Noise:**
  - Thermal-Noise Limit in the Frequency Stabilization of Lasers with Rigid Cavities , K. Numata et al., PRL **93**, 250602 (2004)
  - Thermal noise in optical cavities revisited , T. Kessler et al., J. Opt. Soc. Am. B Vol. **29**, No. 1 (2012)
- **Residual amplitude modulation:**
  - Reduction of residual amplitude modulation to 1 × 10-6 for frequency modulation and laser stabilization , W. Zhang et al., Optics Letters Vol. **39**, No. 7 (2014)
  - Investigation and cancellation of residual amplitude modulation in fiber electro-optic modulator based frequency modulation gas sensing technique , Z. Li et al., Sensors and Actuators B **196**, 23–30 (2014)
  - Residual amplitude modulation in interferometric gravitational wave detector , K. Kokeyama et al., J. Opt. Soc. Am. A Vol. **31**, No. 1 (2014)
    - Residual Amplitude Modulation in Interferometric Gravitational Wave Detectors , K. Kokeyama et al., aXiv:1309.4522v1 [gr-qc] 18 Sep 2013
- **ULE compensations rings**: http://www.quantummetrology.de/quest/fileadmin/quest/sub_hz_lasers/paper/leg10.pdf

Length

- **7 cm:**
  - Compact, thermal-noise-limited optical cavity for diode laser stabilization at 1×10−15 , A. D. Ludlow et al., Optics Letters Vol. **32**, Issue 6, pp. 641-643 (2007)
- **10 cm:**
  - A compact, robust, and transportable ultra-stable laser with a fractional frequency instability of 1 × 10−15 , Q. F. Chen et al., REVIEW OF SCIENTIFIC INSTRUMENTS 85, 113107 (2014)
- **48 cm:**

- 8 × 10−17 fractional laser frequency instability with a long room-temperature cavity , S. Häfner et al., Optical Letters Vol. **40**, No. 9 (2015)

Mirror layers

- **Crystaline coatings:**
  - Tenfold reduction of Brownian noise in high-reflectivity optical coatings , Garrett D. Cole et al., Nature Photonics **7**, 644–650 (2013)

Other geometries

- **Cubic geometry:**
  - Force-insensitive optical cavity , S. Webster et al., Optics Letters Vol. **36**, Issue 18, pp. 3572-3574 (2011)
    - PTB took the NPL-design and updated it for a better longterm stability (see Häfner PHD-thesis, Chapter 4.2)
- **Cryogenic single-crystal optical cavities:**
  - Ultrastable laser with average fractional frequency drift rate below 5 × 10−19/s , C. Hagemann et al., Optics Letters Vol. **39**, No. 17 (2014)
  - A sub-40-mHz-linewidth laser based on a silicon single-crystal optical cavity , T. Kessler et al., Nature Photonics Vol. **6**, 687-692 (2012)

Applications

- **Transfer of stability:**
  - Providing 10−16 Short-Term Stability of a 1.5-µm Laser to Optical Clocks , C. Hagemann et. al., IEEE Transactions on instrumentation and measurement, VOL. 62, NO. 6 (2013)

Application of Clocks

- Realization of a timescale with an accurate optical lattice clock: optica-3-6-563.pdf