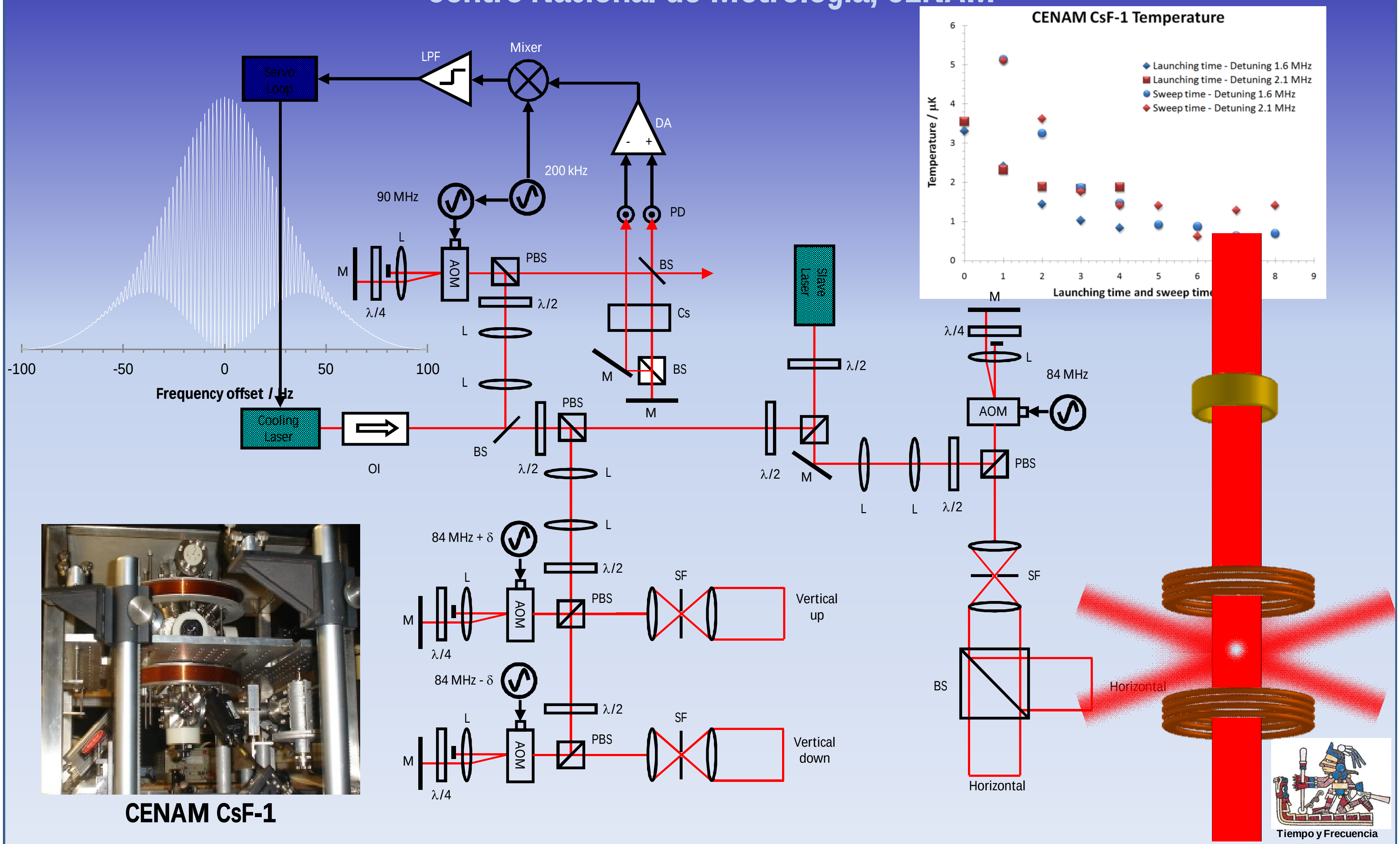
Pasado Presente y Futuro de la Metrología de Tiempo y Frecuencia

J. Mauricio López Romero

División de Metrología de Tiempo y Frecuencia

Centro Nacional de Metrología, CENAM



CENAM CsF-1

Tiempo y Frecuencia

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Contenido

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J. Mauricio López Romero
División de Metrología de Tiempo y Frecuencia
Centro Nacional de Metrología, CENAM

Contenido

TIME

The most measured physical quantity

IOP PUBLISHING METROLOGIA

Metrologia **48** (2011) S132–S144 doi:10.1088/0026-1394/48/4/S03

Evolution of timescales from astronomy to physical metrology

Dennis D McCarthy

US Naval Observatory, 3450 Massachusetts Avenue, NW, Washington, DC 20392, USA

E-mail: dennis.mccarthy@usno.navy.mil

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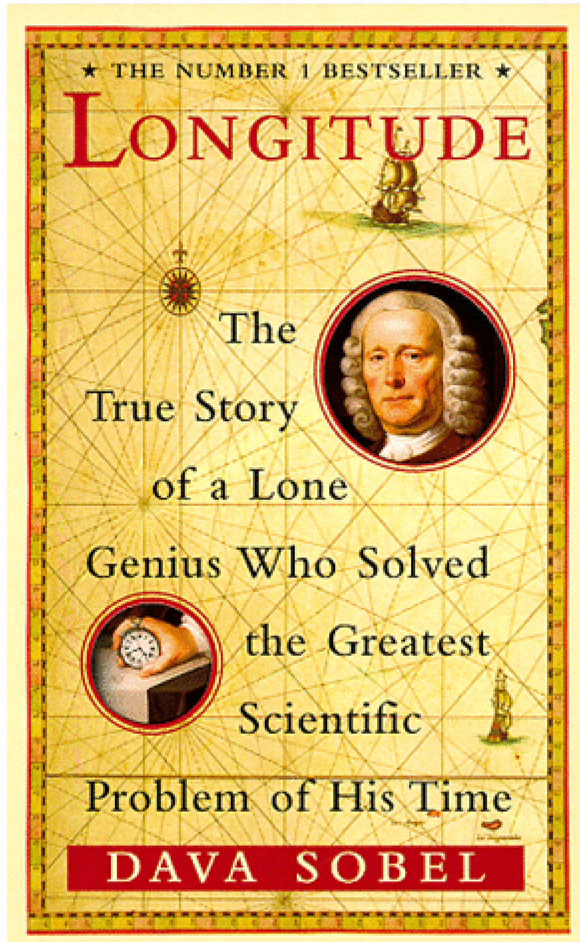
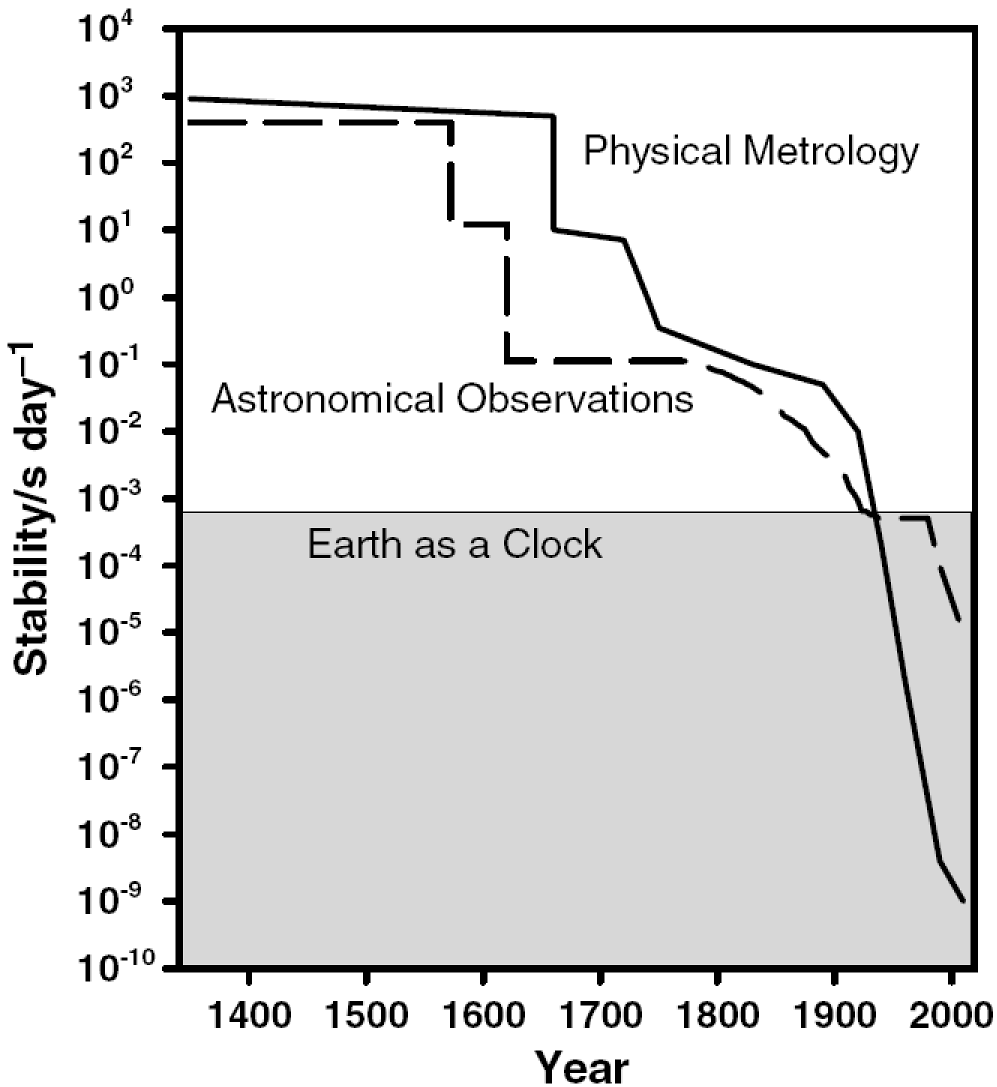
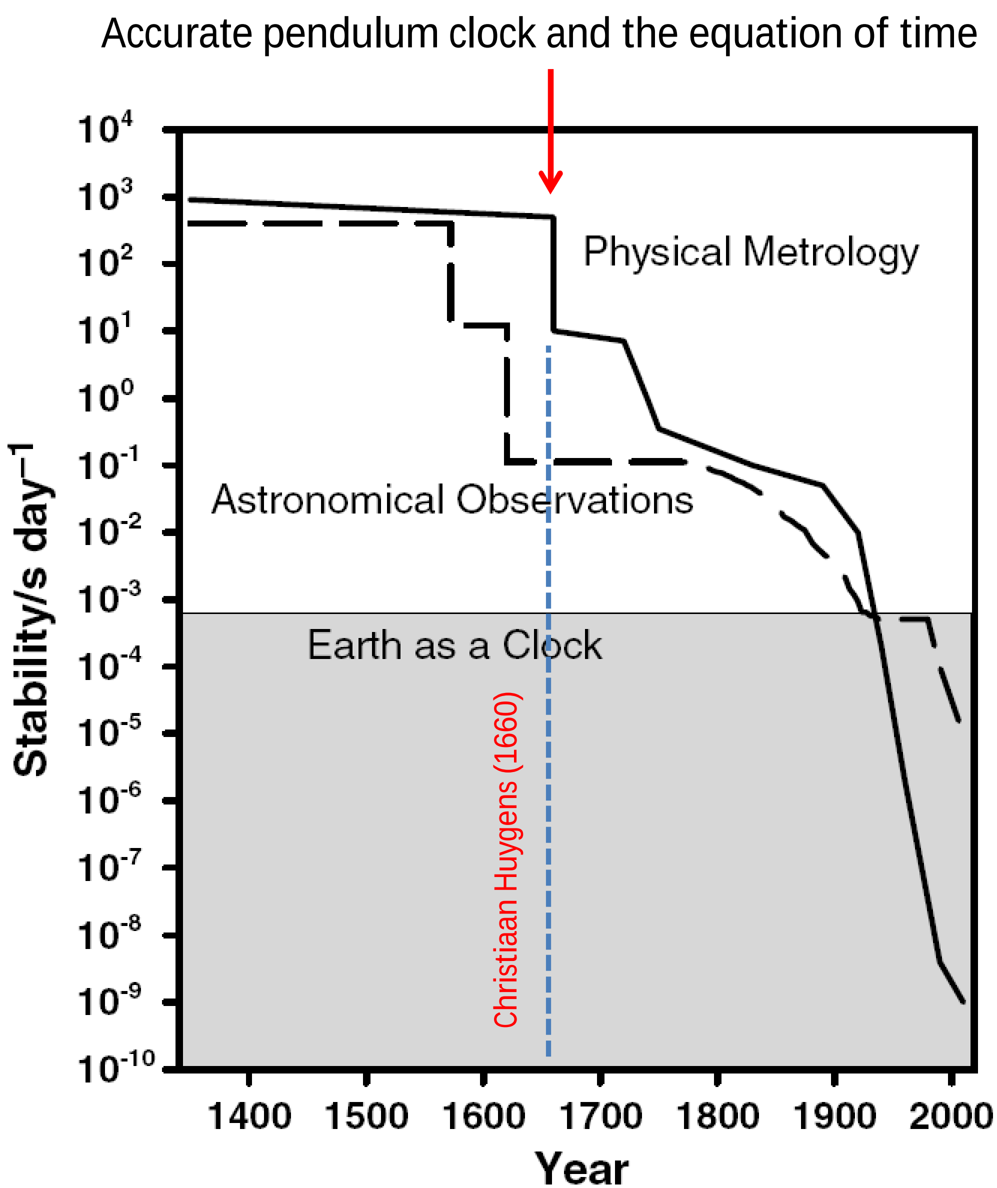
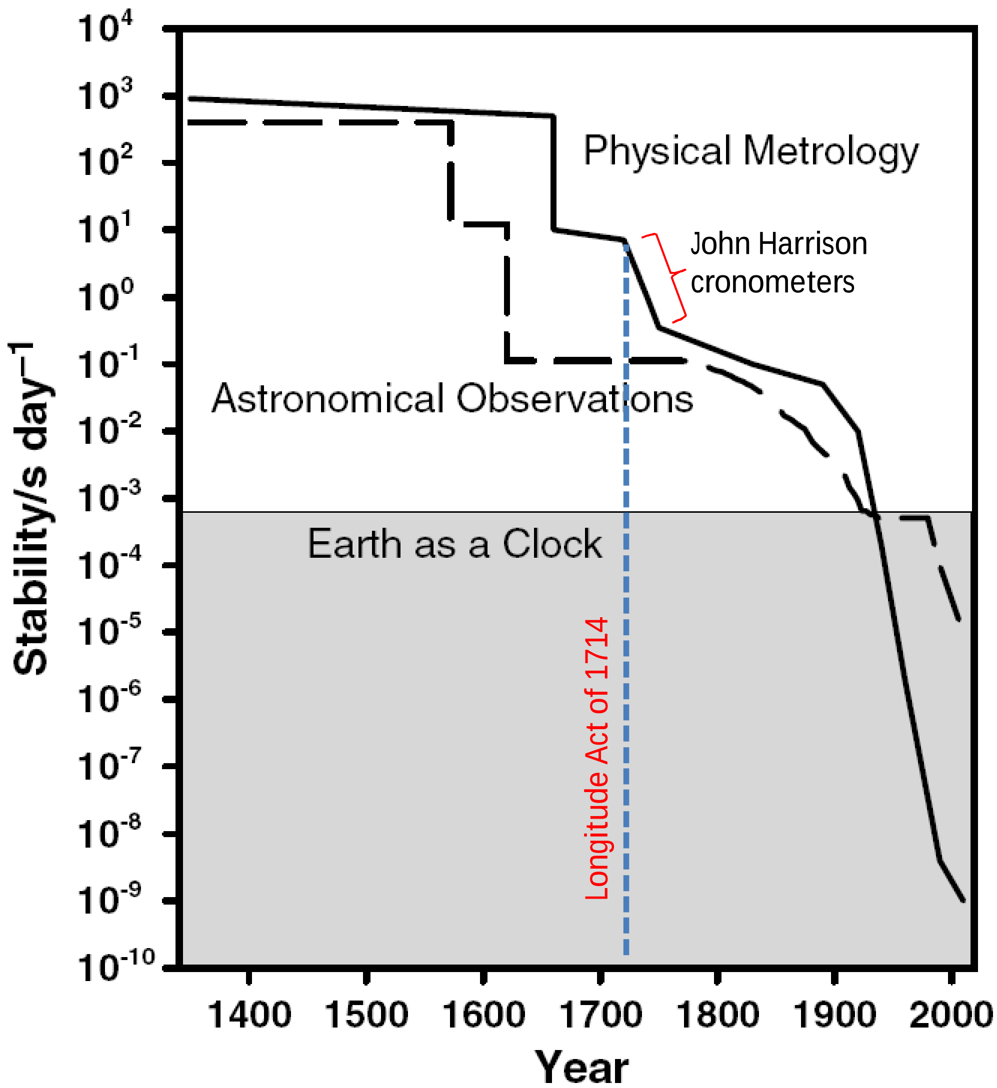
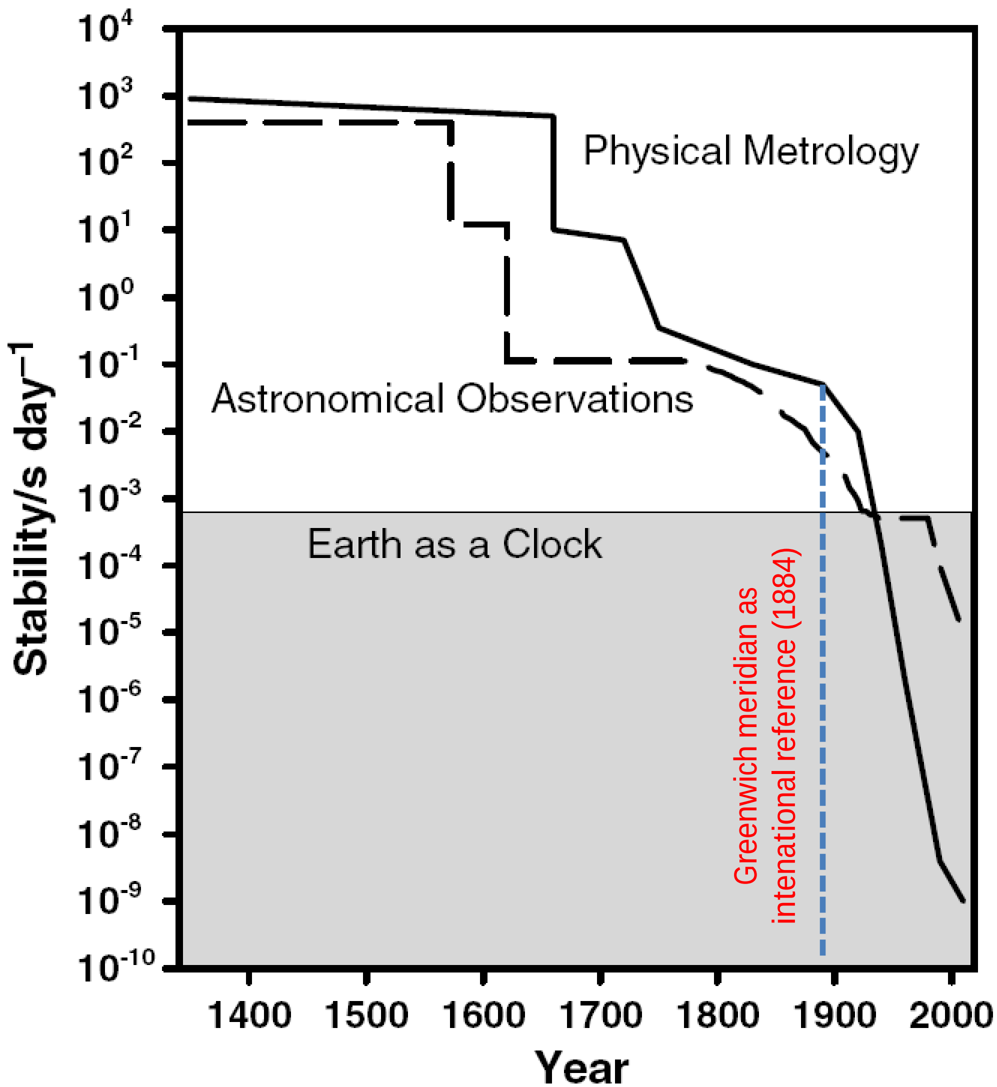

★ THE NUMBER 1 BESTSELLER ★
LONGITUDE
The True Story of a Lone Genius Who Solved the Greatest Scientific Problem of His Time
DAVA SOBEL



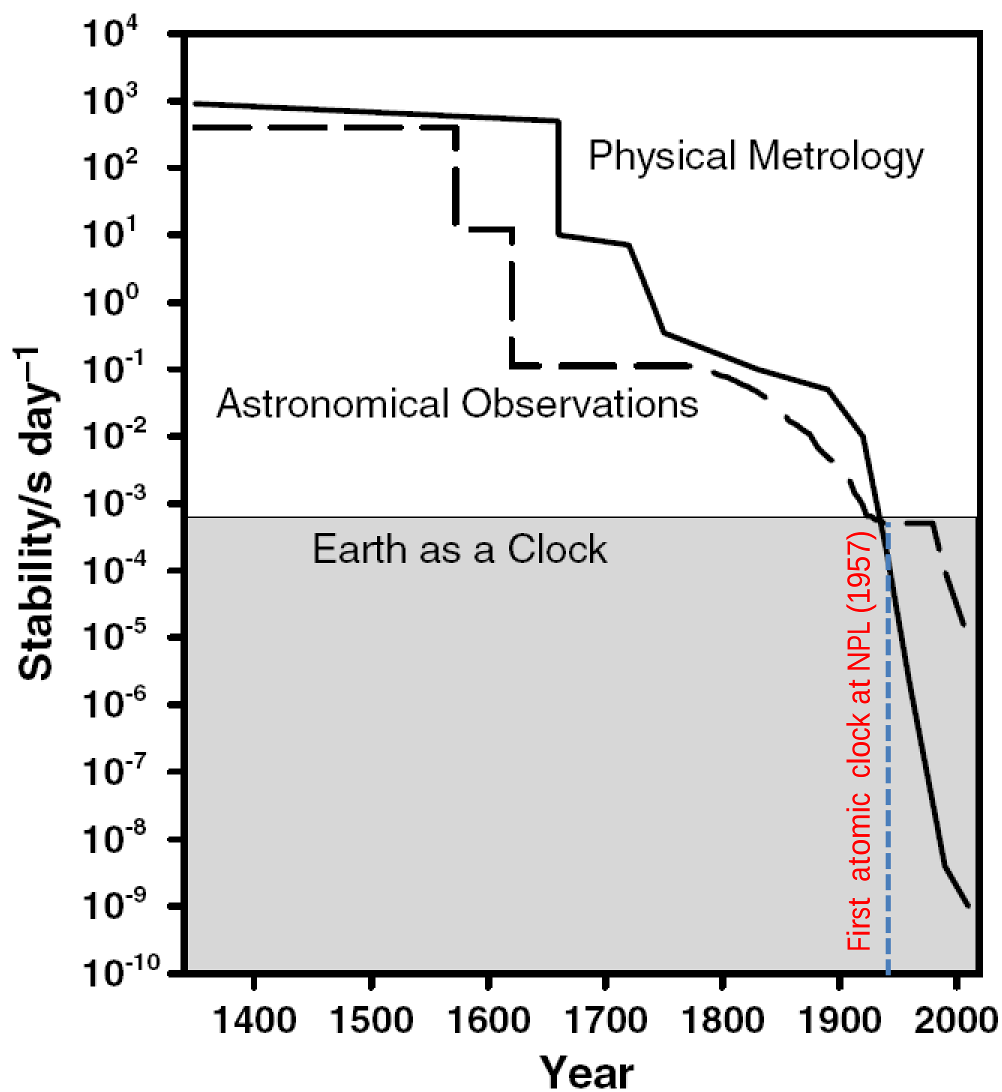
Dennis D. McCarty, *Evolution of Time Scales from astronomy tophysicasl metrology*, Metrologia **48** (2011), S132 – S144.


Accurate pendulum clock and the equation of time
Physical Metrology
Astronomical Observations
Earth as a Clock
Christiaan Huygens (1660)
Stability/s day⁻¹
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
1400
1500
1600
1700
1800
1900
2000
Year

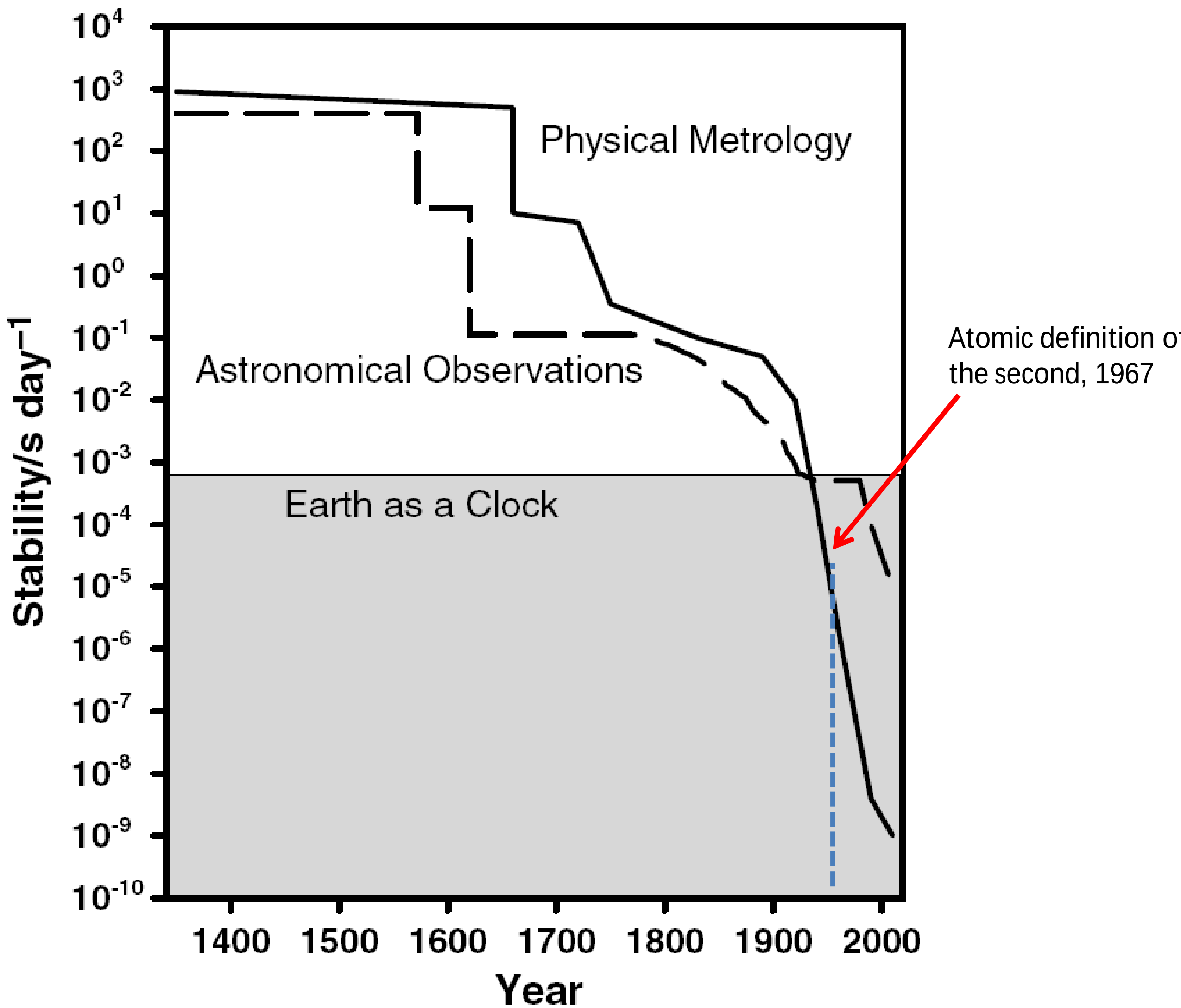

10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
Stability/s day^-1
Physical Metrology
John Harrison
cronometers
Astronomical Observations
Earth as a Clock
Longitude Act of 1714
1400
1500
1600
1700
1800
1900
2000
Year



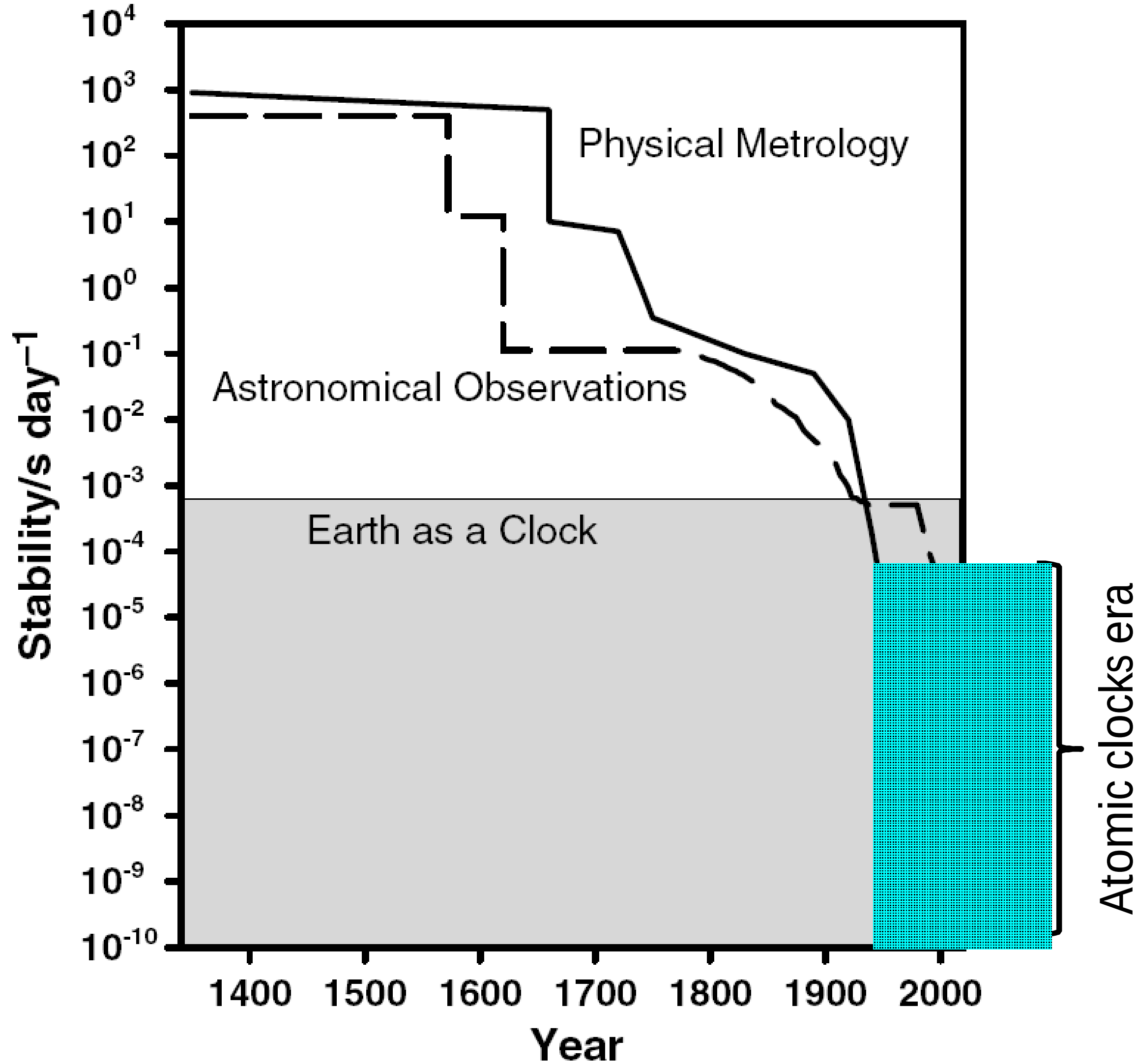
Physical Metrology
Astronomical Observations
Earth as a Clock
Greenwich meridian as
intenational reference (1884)
Stability/s day⁻¹
Year
1400
1500
1600
1700
1800
1900
2000
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}



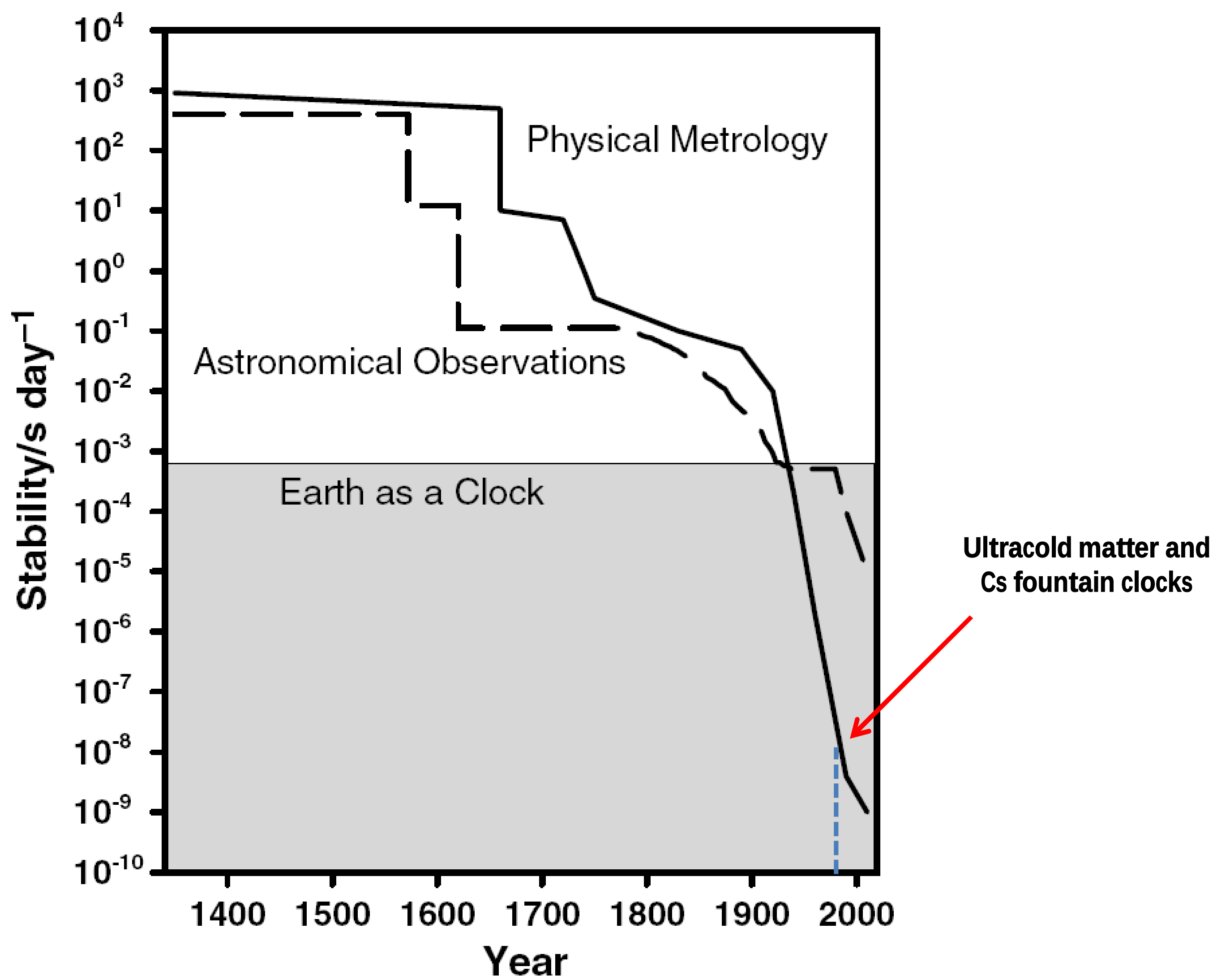
Stability/s day⁻¹
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
Physical Metrology
Astronomical Observations
Earth as a Clock
First atomic clock at NPL (1957)
1400
1500
1600
1700
1800
1900
2000
Year



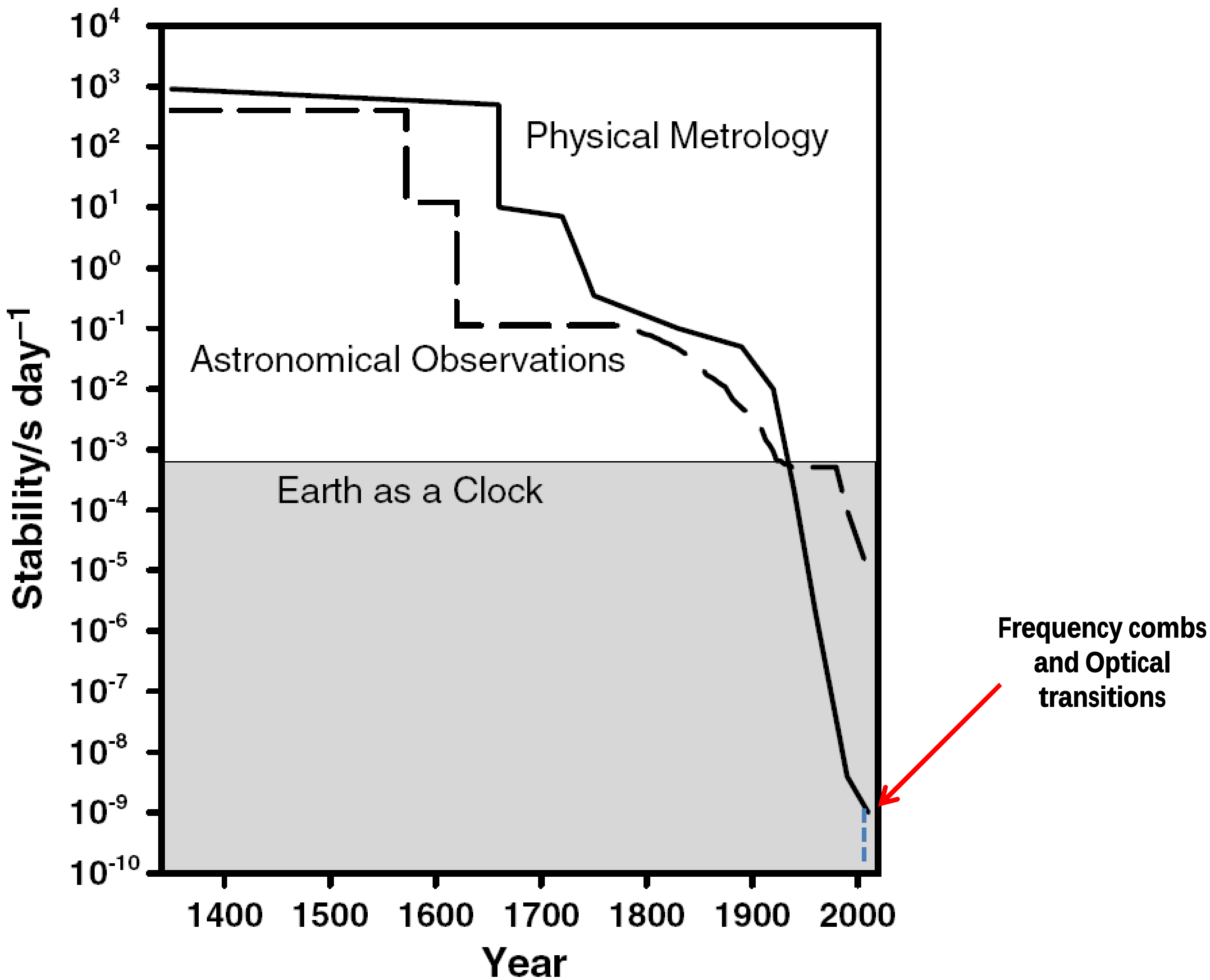
Stability/s day^{-1}
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
Physical Metrology
Astronomical Observations
Earth as a Clock
1400
1500
1600
1700
1800
1900
2000
Year
Atomic definition of the second, 1967



Physical Metrology
Astronomical Observations
Earth as a Clock
Atomic clocks era
Stability/s day⁻¹
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
1400
1500
1600
1700
1800
1900
2000
Year



Physical Metrology
Astronomical Observations
Earth as a Clock
Ultracold matter and
Cs fountain clocks
Stability/s day⁻¹
Year
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
1400
1500
1600
1700
1800
1900
2000

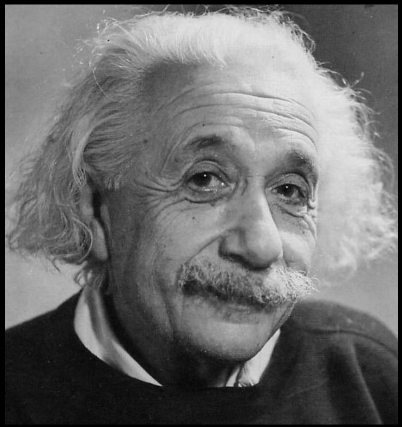


Stability/s day⁻¹
10⁴
10³
10²
10¹
10⁰
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
Physical Metrology
Astronomical Observations
Earth as a Clock
1400
1500
1600
1700
1800
1900
2000
Year
Frequency combs
and Optical
transitions

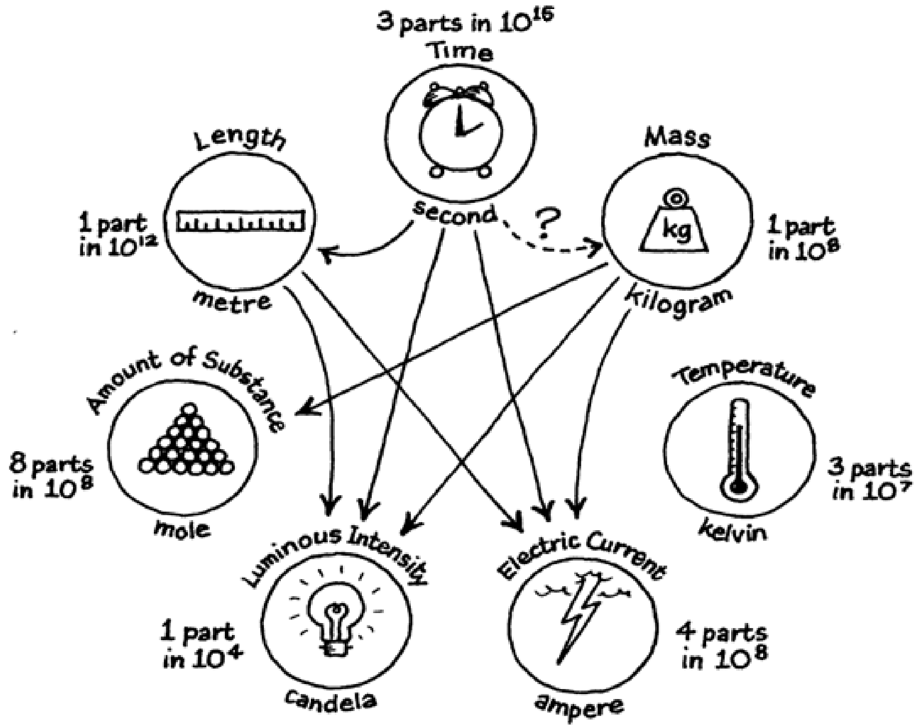
J. Mauricio López Romero
División de Metrología de Tiempo y Frecuencia
Centro Nacional de Metrología, CENAM

Contenido

Time measurement is of great importance for science, technology and commerce. Among physical quantities, time appears as the most measured quantity worldwide and it stands for the highest accuracy measurement made by the human kind.



The base units of the International System of units



CENAM
CENTRO NACIONAL DE METROLOGÍA

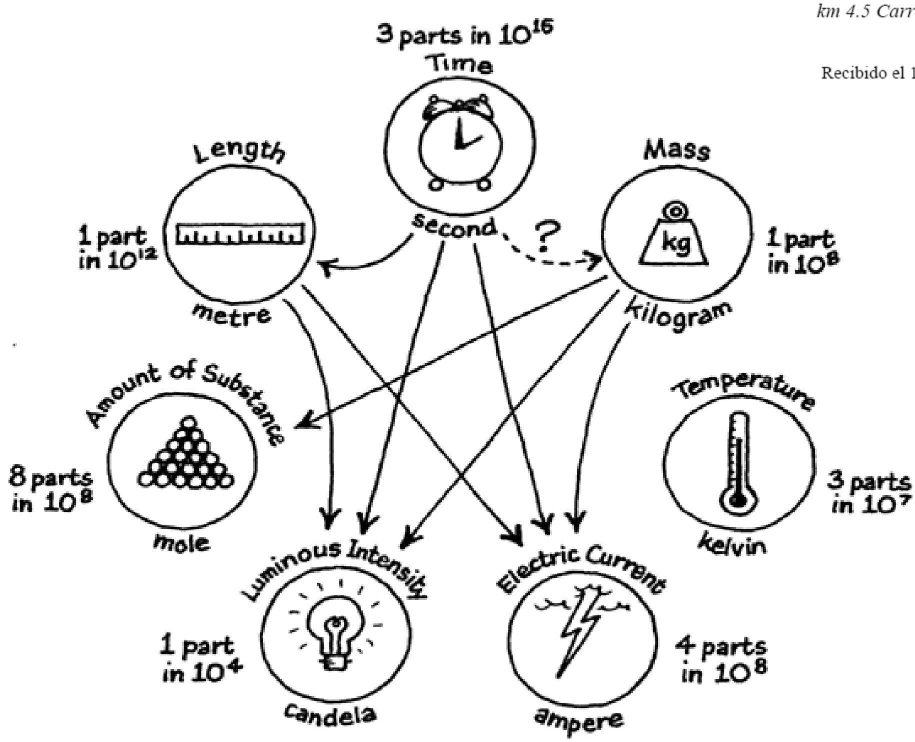
The base units of the International System of units

REVISIÓN — *Revista Mexicana de Física* **57** (2011) 460–469 — OCTUBRE 2011

Constantes fundamentales: la última frontera para el Sistema Internacional de Unidades

J.M. López Romero and R.J. Lazos Martínez
División de Metrología de Tiempo y Frecuencia, Centro Nacional de Metrología,
km 4.5 Carretera a los Cués, El Marqués, 76246, Querétaro, México,
e-mail: mauricio.lopez@cenam.mx

Recibido el 10 de noviembre de 2010; aceptado el 8 de septiembre de 2011

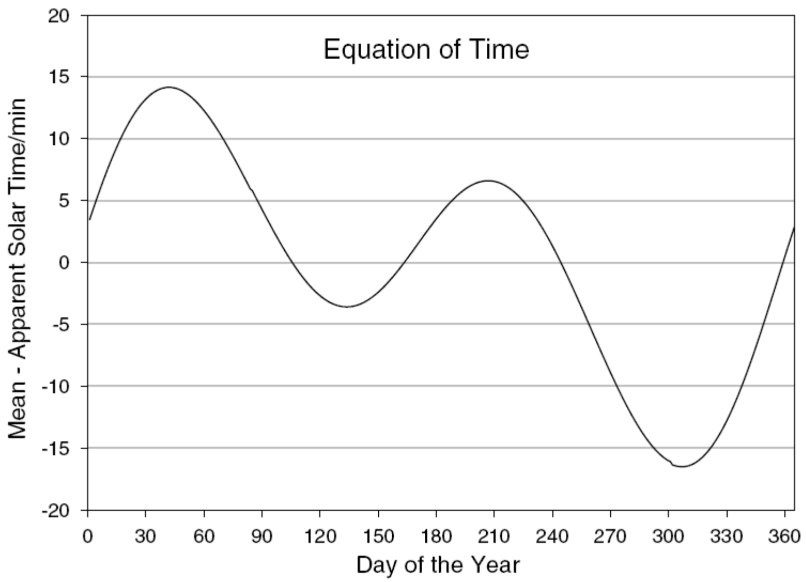


CENTRO NACIONAL DE METROLOGÍA

Time Scales

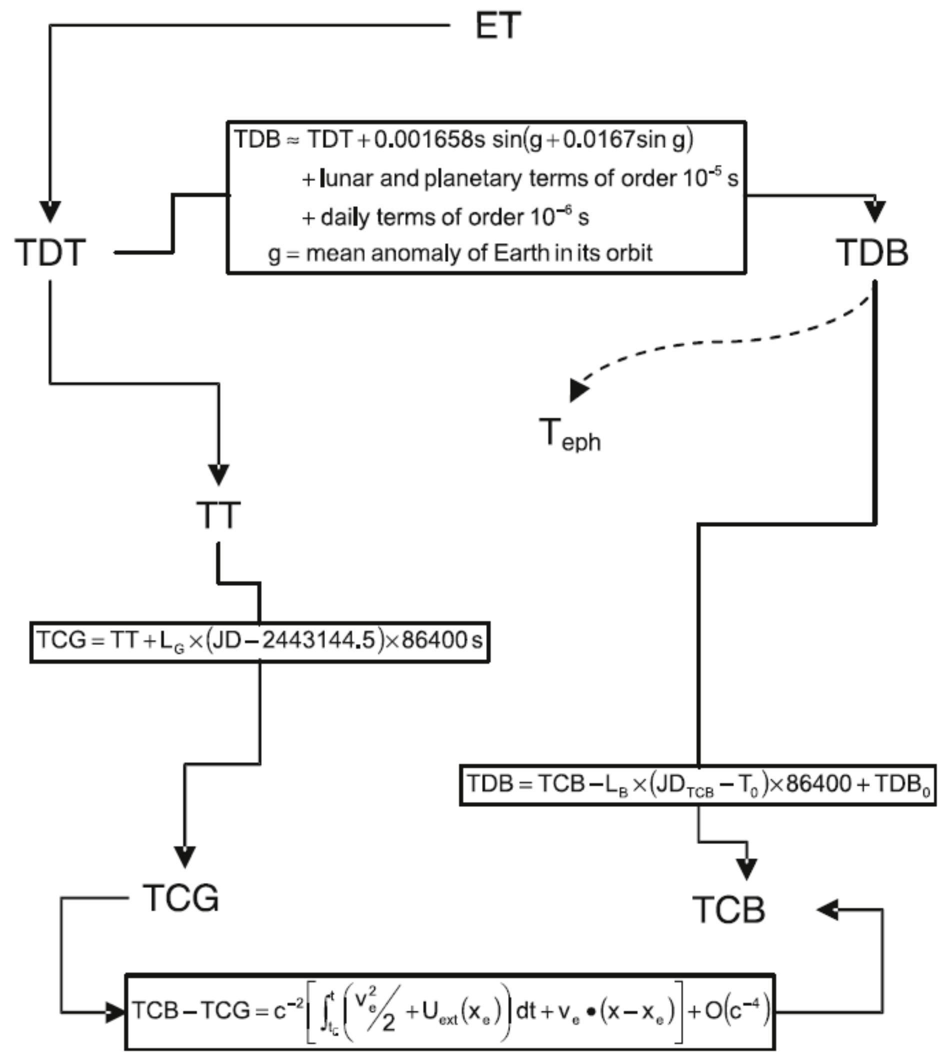
1. Apparent solar time
2. Mean solar time (1660)
3. Sideral time
4. Greenwich Mean time (1766)
5. Universal time (1928)
6. Ephemeris time (1895)
7. Atomic time (1955)
8. Terrestrial Dynamical Time (TDT) and Barysentric Dynamical (TDB) (1976)
9. Terrestrial Time (TT) (1991)
10. Coordinated Universal Time (UTC) (1972)
11. Barysentric and Geocentric Coordinated Times (1980)

Time Scales



Dennis D. McCarty, *Evolution of Time Scales from astronomy to physicasl metrology*, Metrologia **48** (2011), S132 – S144.

1. Apparent solar time
2. Mean solar time (1660)
3. Sideral time
4. Greenwich Mean time (1766)
5. Universal time (1928)
6. Ephemeris time (1895)
7. Atomic time (1955)
8. Terrestrial Dynamical Time (TDT) and Barysentric Dynamical (TDB) (1976)
9. Terrestrial Time (TT) (1991)
10. Coordinated Universal Time (UTC) (1972)
11. Barysentric and Geocentric Coordinated Times (1980)



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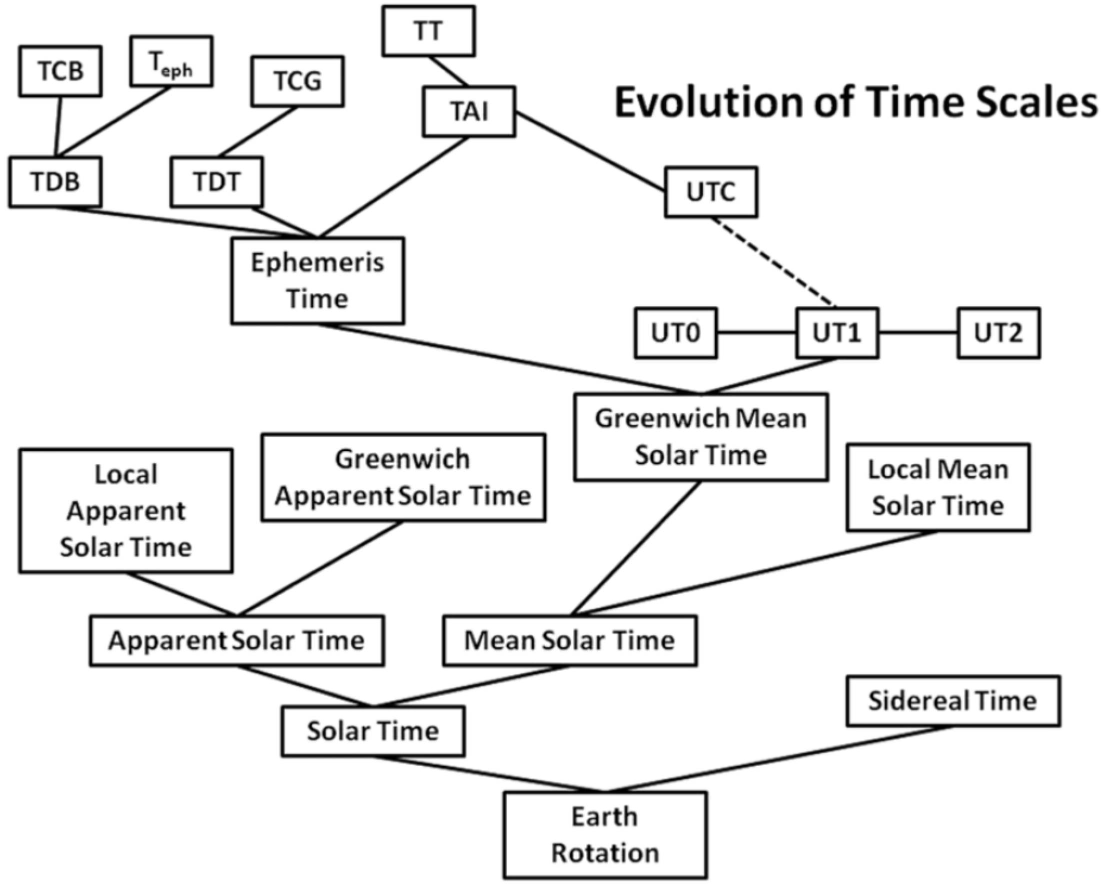
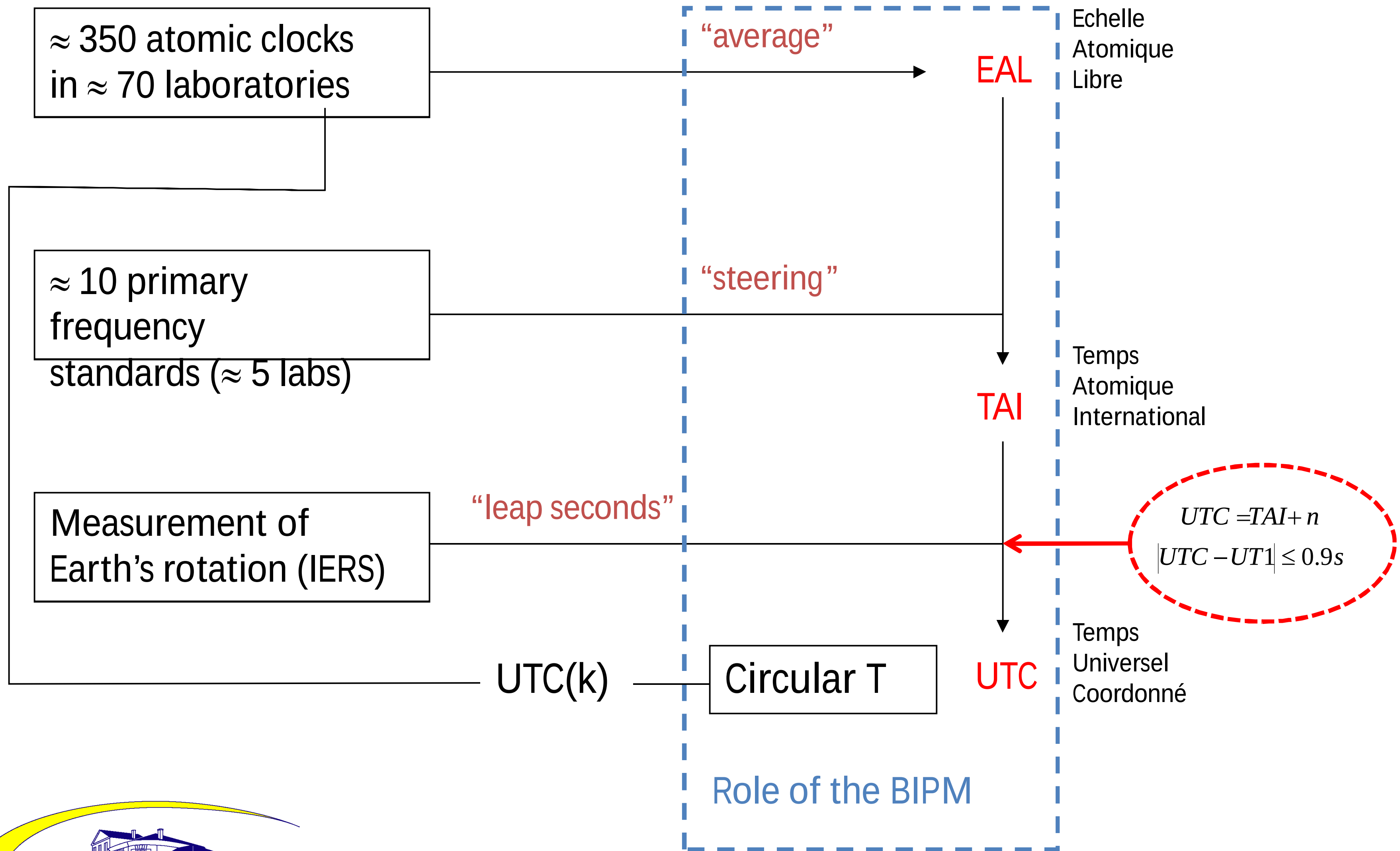
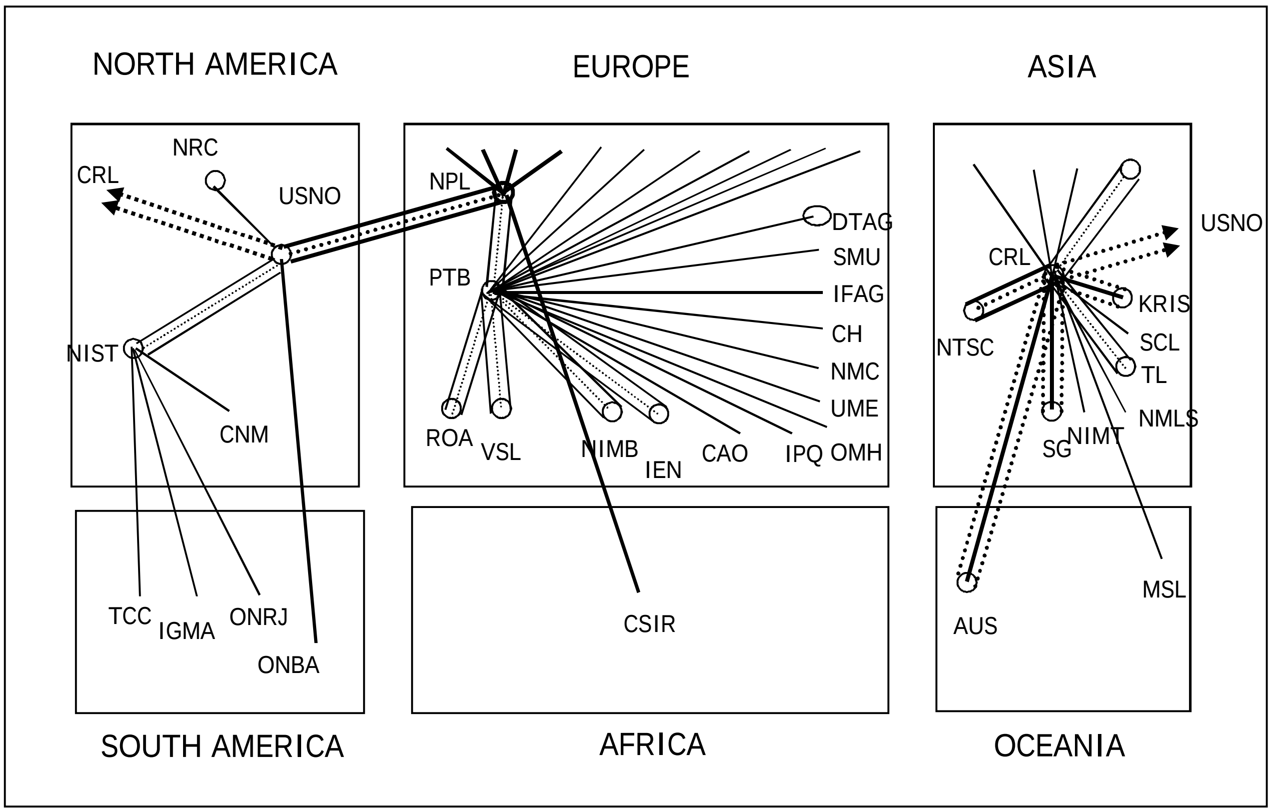


Dennis D. McCarty, *Evolution of Time Scales from astronomy to physicasl metrology*, Metrologia **48** (2011), S132 – S144.

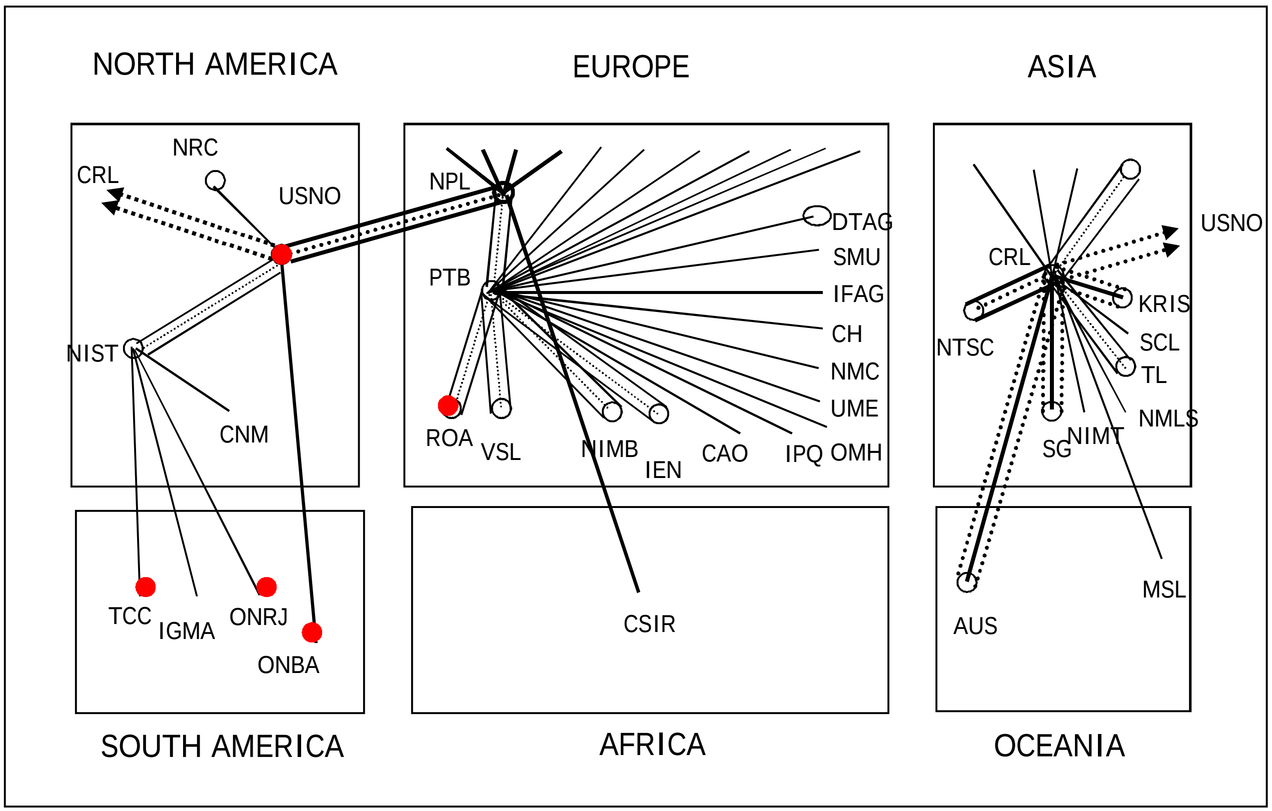
Computation of TAI and UTC



Timing laboratories



Timing laboratories



CIRCULAR T 275 ISSN 1143-1393
2010 DECEMBER 08, 12h UTC

BUREAU INTERNATIONAL DES POIDS ET MESURES
ORGANISATION INTERGOUVERNEMENTALE DE LA CONVENTION DU METRE
PAVILLON DE BRETEUIL F-92312 SEVRES CEDEX TEL. +33 1 45 07 70 70 FAX. +33 1 45 34 20 21 tai@bipm.org

1 - Coordinated Universal Time UTC and its local realizations UTC(k). Computed values of [*UTC-UTC*(*k*)] and uncertainties valid for the period of this Circular. From 2009 January 1, 0h UTC, *TAI-UTC* = 34 s.

Date 2010 0h UTC	OCT 30	NOV 4	NOV 9	NOV 14	NOV 19	NOV 24	NOV 29	Uncertainty/ns		
MJD	55499	55504	55509	55514	55519	55524	55529	u_A	u_B	u
Laboratory *k*	[*UTC-UTC*(*k*)]/ns									
AOS (Borowiec)	-3.8	-2.1	-0.2	2.3	2.2	1.1	-0.6	0.5	5.3	5.3
APL (Laurel)	-2.6	-5.9	-1.0	-1.0	-3.7	-2.5	-4.7	1.5	5.3	5.5
AUS (Sydney)	196.2	208.0	212.6	229.6	233.6	247.2	256.0	0.3	5.2	5.3
BEV (Wien)	-15.1	-23.3	-34.8	-42.1	-45.9	-57.3	-64.0	1.5	3.4	3.7
BIM (Sofiya)	-6474.1	-6456.2	-6436.4	-6418.8	-6405.5	-6403.6	-6401.1	2.0	7.2	7.5
BIRM (Beijing)	-11830.4	-11869.0	-11921.4	-11961.5	-12010.2	-12056.2	-12109.4	2.0	20.1	20.2
BY (Minsk)	13.1	15.6	19.8	27.2	36.0	45.8	57.2	2.0	7.2	7.5
CAO (Cagliari)	-4740.8	-4749.6	-4770.8	-4796.0	-4818.4	-4822.0	-4840.4	1.5	7.1	7.3
CH (Bern)	5.0	4.2	1.7	1.7	0.3	-1.5	-5.9	0.6	1.9	2.0
[redacted]										
CNMP (Panama)	-46.7	-21.2	-25.9	-46.1	-44.3	-71.7	-75.6	3.0	5.3	6.1
DLR (Oberpfaffenhofen)	9.3	1.0	-11.8	-19.0	-0.3	12.8	11.3	0.3	5.3	5.3
DMDM (Belgrade)	-21.3	-8.2	0.5	3.0	3.6	11.8	25.7	2.0	7.2	7.4
DTAG (Frankfurt/M)	-441.5	-429.5	-395.5	-357.9	-351.6	-337.2	-335.6	0.3	10.1	10.1
EIM (Thessaloniki)	6.6	6.4	0.6	6.1	-1.6	-3.7	-3.0	3.5	5.3	6.3
HKO (Hong Kong)	97.7	107.5	114.9	120.3	121.2	125.8	132.5	2.5	5.3	5.8
IFAG (Wettzell)	-36.3	-39.7	-40.9	-39.6	-49.1	-56.7	-58.8	0.3	5.2	5.2
IGNA (Buenos Aires)	-	-	-	-	-	-	-	-	-	-
INPL (Jerusalem)	-	-	-	-	-	-	-	-	-	-
INTI (Buenos Aires)	42.4	7.8	-15.9	-46.7	-60.8	-83.1	-48.4	4.0	20.1	20.5

RevMexAA (Serie de Conferencias), **25**, 21–23 (2006)

THE IBEROAMERICAN CONTRIBUTION TO INTERNATIONAL TIME KEEPING

E. F. Arias[1,2]

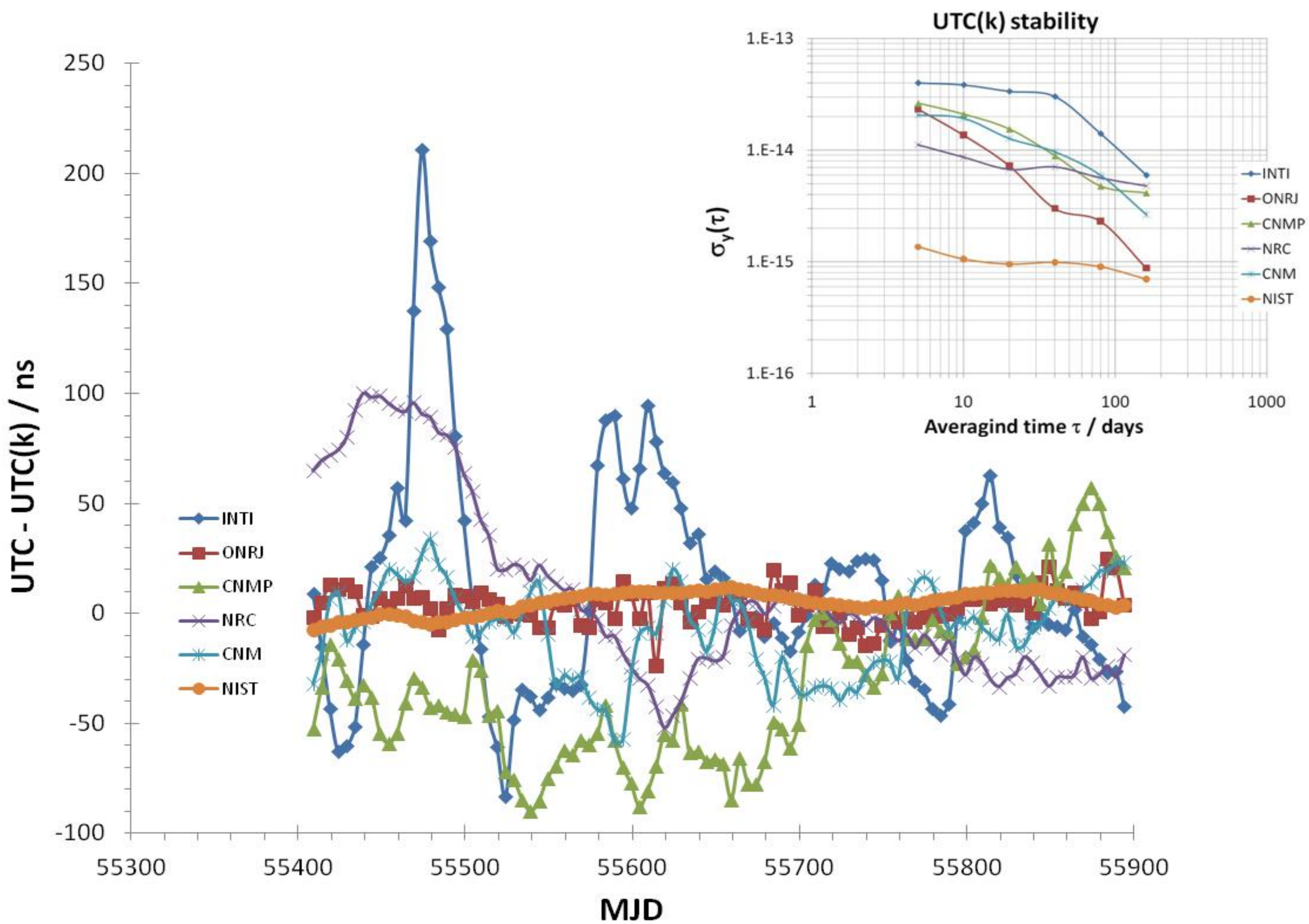
RESUMEN

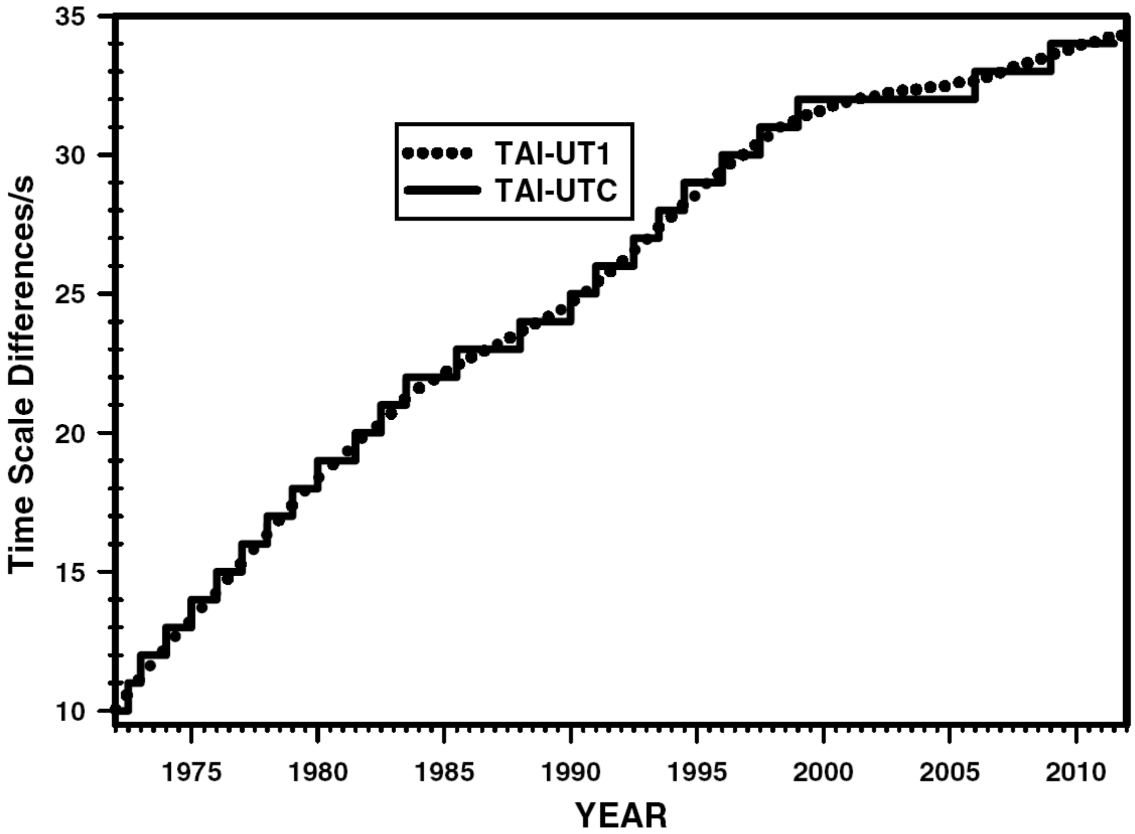
Las escalas internacionales de tiempo, Tiempo Atómico Internacional (TAI) y Tiempo Universal Coordinado (UTC), son elaboradas en el Bureau Internacional des Poids et Mesures (BIPM), gracias a la contribución de 57 laboratorios de tiempo nacionales que mantienen controles locales de UTC. La contribución iberoamericana al cálculo de TAI ha aumentado en los últimos años. Diez laboratorios en las Américas y uno en España contribuyen a la estabilidad de TAI con el aporte de datos de relojes atómicos industriales; una fuente de cesio mantenida en uno de ellos contribuye a mejorar la exactitud de TAI. Este artículo resume las características de las escalas de tiempo de referencia y describe la contribución de los laboratorios iberoamericanos.

ABSTRACT

The international time scales, International Atomic Time (TAI) and Coordinated Universal Time (UTC), are elaborated at the Bureau International des Poids et Mesures (BIPM), thanks to the contribution of 57 national time laboratories that maintain local realizations of UTC. The Iberoamerican contribution to TAI has increased in the last years. Ten laboratories in America and one in Spain participate to the calculation of TAI , increasing its stability with the data of industrial atomic clocks and improving its accuracy with frequency measurements of a caesium source developed and maintained at one laboratory. This paper summarizes the characteristics of the reference time scales and describes the contributions of the Iberoamerican time laboratories to them.

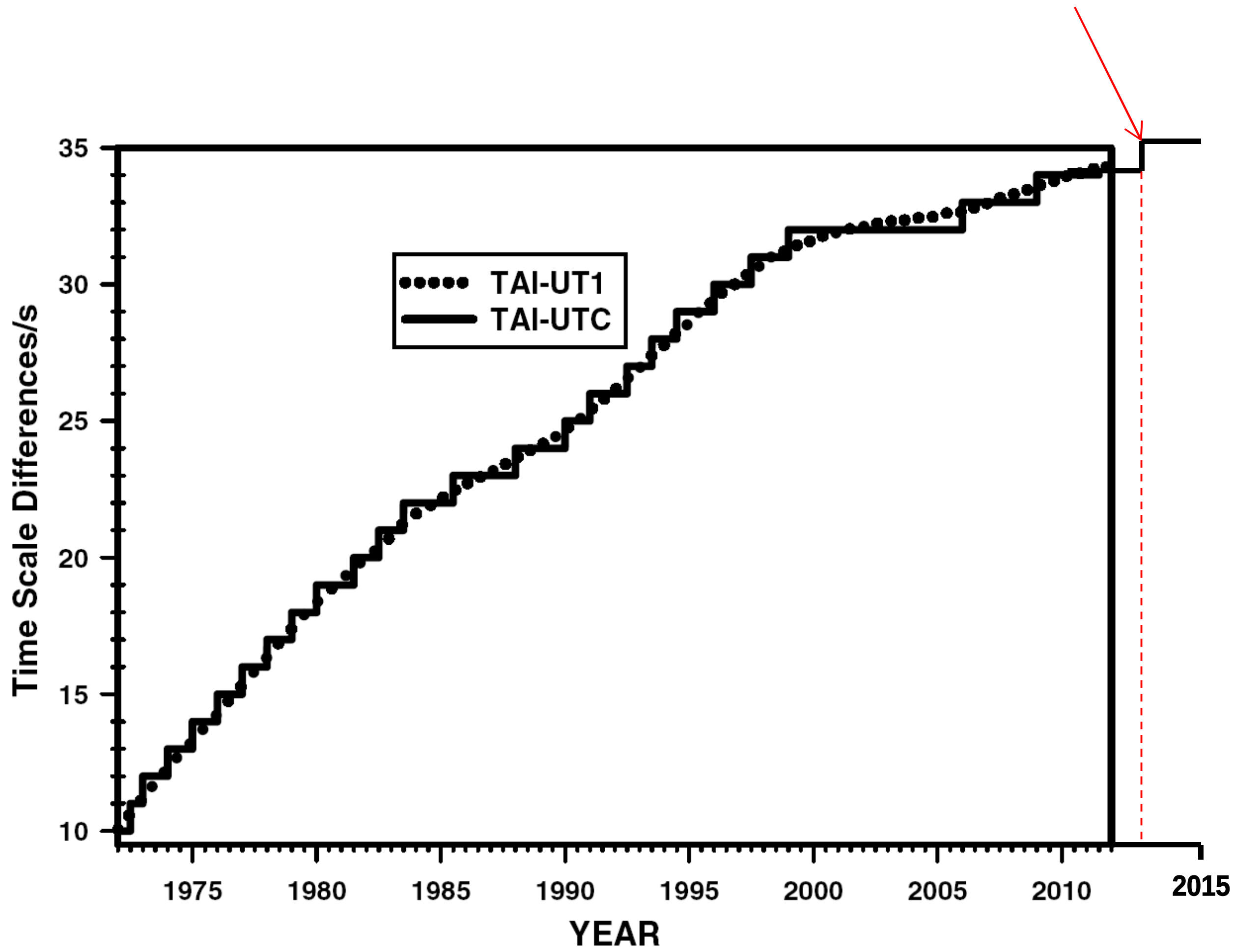
Key Words: **TIME — REFERENCE SYSTEMS**


UTC(k) stability
1.E-13
1.E-14
1.E-15
1.E-16
σy(τ)
1
10
100
1000
Averagind time τ / days
INTI
ONRJ
CNMP
NRC
CNM
NIST
UTC - UTC(k) / ns
250
200
150
100
50
0
-50
-100
55300
55400
55500
55600
55700
55800
55900
MJD
INTI
ONRJ
CNMP
NRC
CNM
NIST

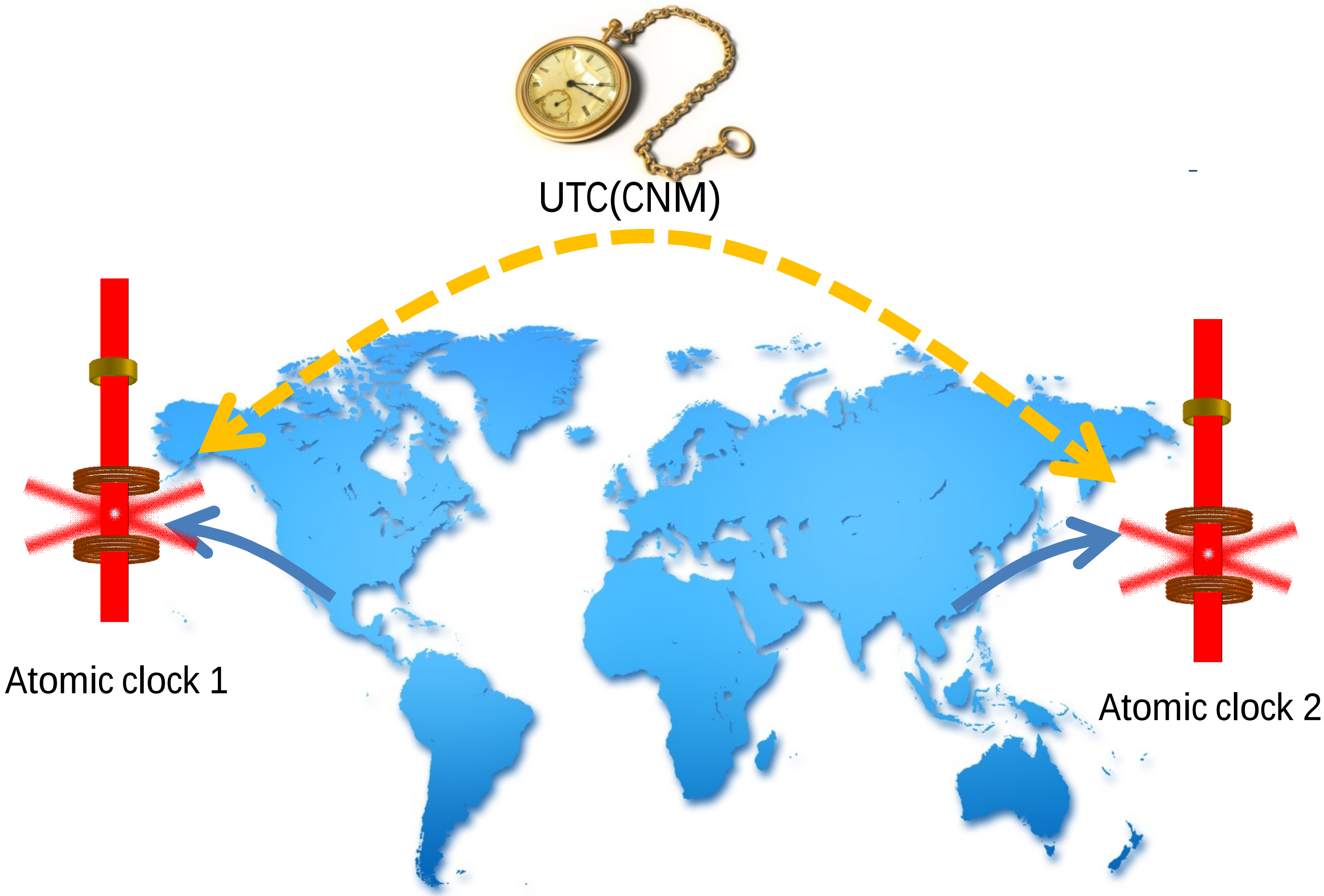


Dennis D. McCarty, *Evolution of Time Scales from astronomy to physicasl metrology*, Metrologia **48** (2011), S132 – S144.

Next June 30, 24h00, UTC, a new leap second will be added to the UTC



National aproximation to the UTC



IOP PUBLISHING METROLOGIA

Metrologia **45** (2008) S59–S65 doi:10.1088/0026-1394/45/6/S10

Progress in the generation of the UTC(CNM) in terms of a virtual clock

J M López-Romero and N Díaz-Muñoz

Time and Frequency Division, Centro Nacional de Metrología, CENAM, km 4.5 carretera a los Cues, El Marqués, 76241, Querétaro, Mexico

E-mail: mauricio.lopez@cenam.mx

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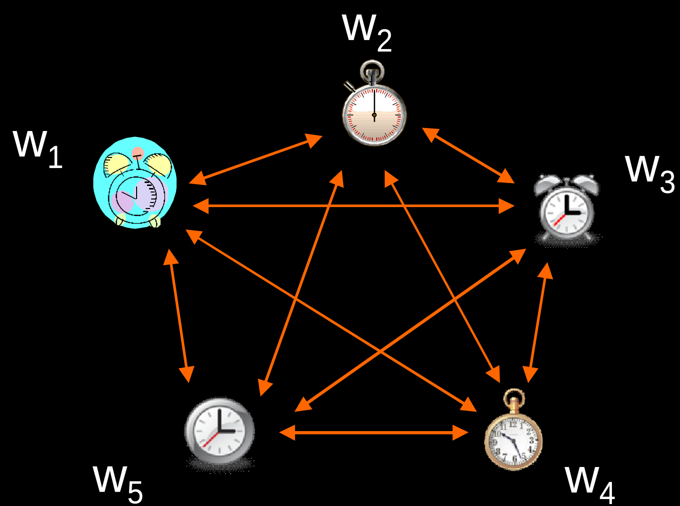
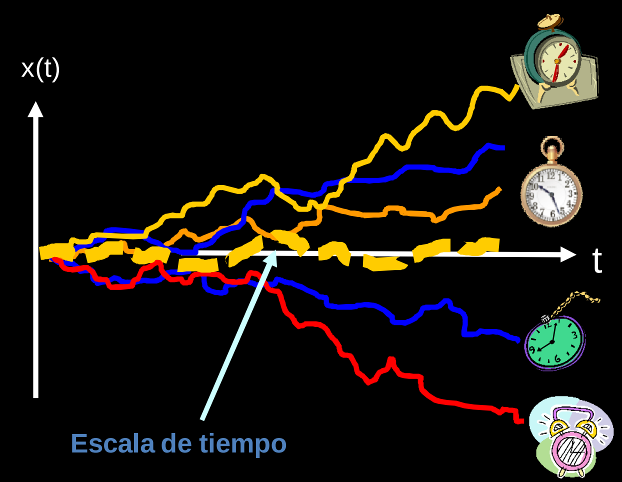
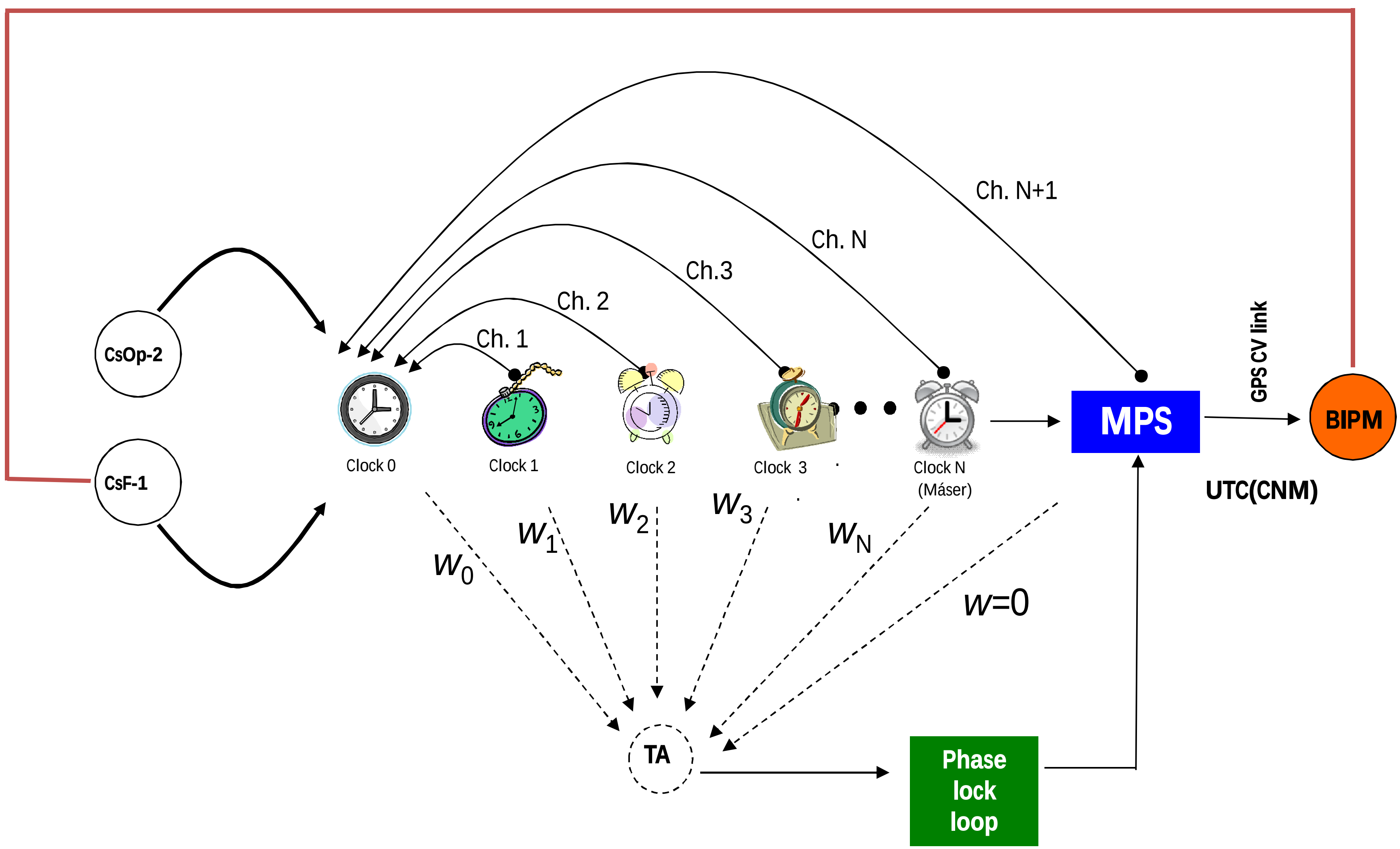


W_2
W_1
W_3
W_5
W_4



x(t)
t
Escala de tiempo

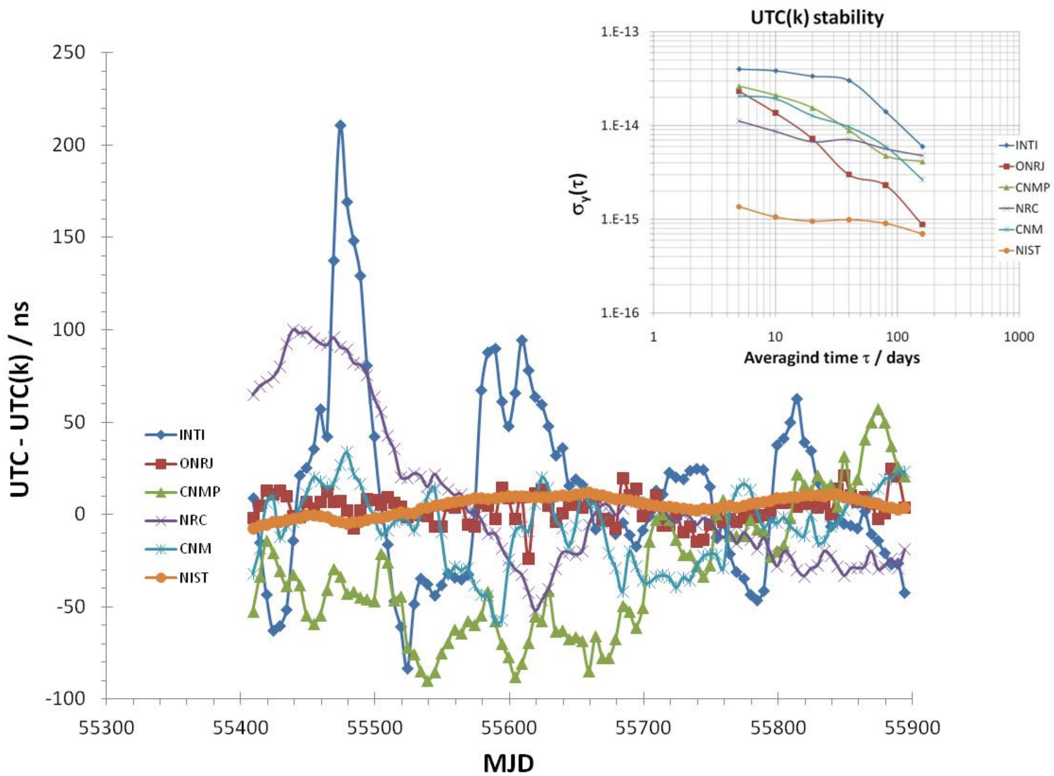
UTC(CNM)



CsOp-2
CsF-1
Ch. N+1
Ch. N
Ch.3
Ch. 2
Ch. 1
Clock 0
Clock 1
Clock 2
Clock 3
Clock N
(Máser)
MPS
GPS CV link
BIPM
UTC(CNM)
w_0
w_1
w_2
w_3
w_N
w=0
TA
Phase
lock
loop

CENAM ensamble of Cs commercial clocks

CENAM Active Hydrogen Maser


UTC - UTC(k) / ns
250
200
150
100
50
0
-50
-100
55300
55400
55500
55600
55700
55800
55900
MJD
INTI
ONRJ
CNMP
NRC
CNM
NIST
UTC(k) stability
1.E-13
1.E-14
1.E-15
1.E-16
σy(τ)
1
10
100
1000
Averagind time τ / days

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Journal of Research of the National Institute of Standards and Technology

[J. Res. Natl. Inst. Stand. Technol. **116**, 557-572 (2011)]

The SIM Time Network

Volume 116 Number 2 March-April 2011

Michael A. Lombardi and Andrew N. Novick

National Institute of Standards and Technology (NIST), Boulder, CO 80305, USA

michael.lombardi@nist.gov
andrew.novick@nist.gov

J. Mauricio Lopez R, Francisco Jimenez, and Eduardo de Carlos Lopez

Centro Nacional de Metrologia (CENAM), Querétaro, Mexico

Jean-Simon Boulanger and Raymond Pelletier

National Research Council (NRC), Ottawa, Canada

Ricardo J. de Carvalho
National Observatory (ONRJ), Rio de Janeiro, Brazil

Gregory Pascoe

Bureau of Standards Jamaica (BSJ), Kingston, Jamaica

Daniel Perez

Instituto Nacional de Tecnologia Industrial (INTI), Buenos Aires, Argentina

Eduardo Bances

Laboratorio Nacional de Metrologia (LNM), Guatemala City, Guatemala

Leonardo Trigo

Administracion Nacional De Usinas Y Trasmisiones Electricas (UTE), Montevideo, Uruguay

Victor Masi

Instituto Nacional de Tecnologia Normalizacion y Metrologia (INTN), Asuncion, Paraguay

The *Sistema Interamericano de Metrologia* (SIM) is a regional metrology organization (RMO) whose members are the national metrology institutes (NMIs) located in the 34 nations of the Organization of American States (OAS). The SIM/OAS region extends throughout North, Central, and South America and the Caribbean Islands. About half of the SIM NMIs maintain national standards of time and frequency and must participate in international comparisons in order to establish metrological traceability to the International System (SI) of units. The SIM time network (SIMTN) was developed as a practical, cost effective, and technically sound way to automate these comparisons.

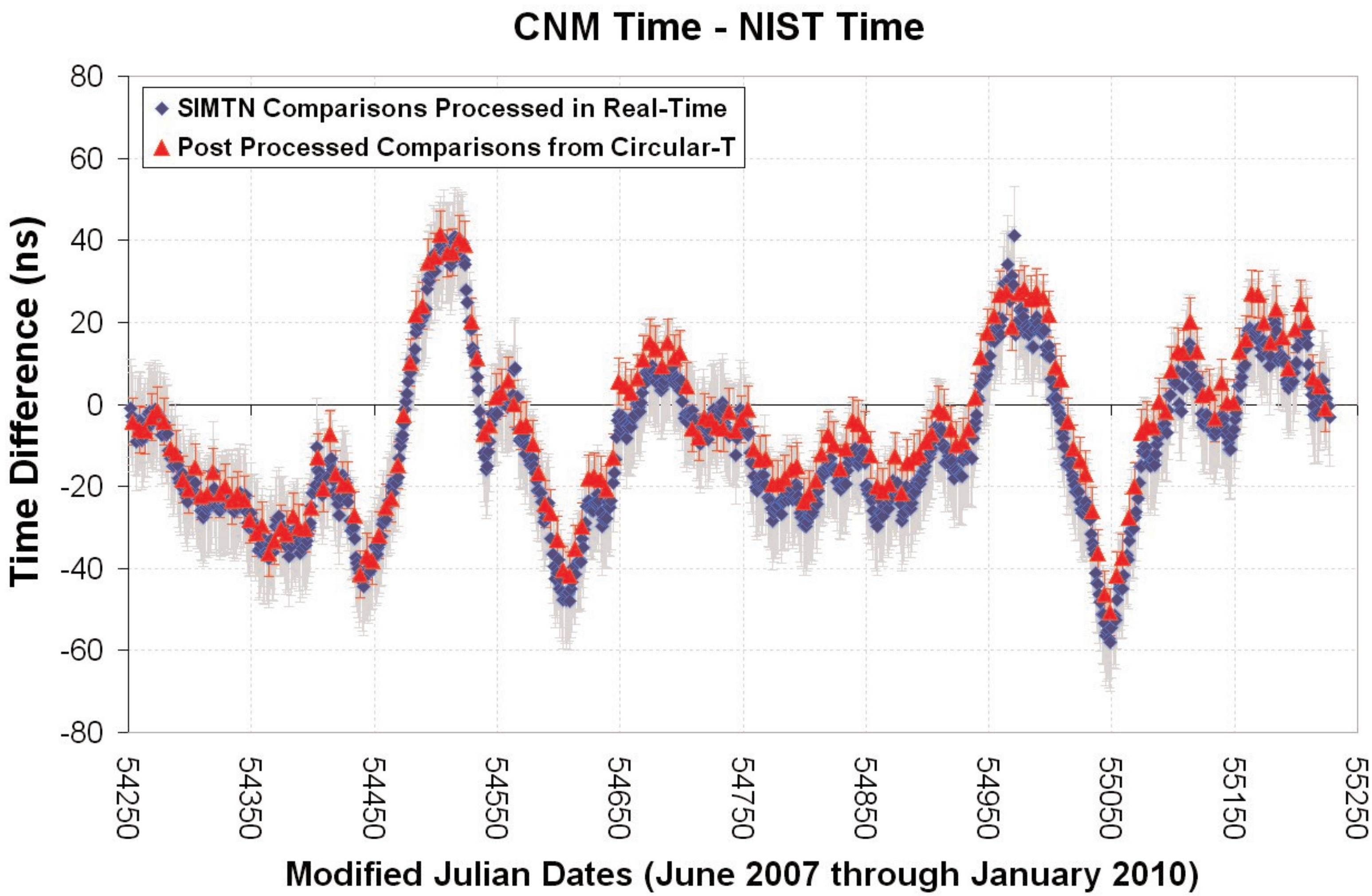
The SIMTN continuously compares the time standards of SIM NMIs and produces measurement results in near real-time by utilizing the Internet and the Global Positioning System (GPS). Fifteen SIM NMIs have joined the network as of December 2010. This paper provides a brief overview of SIM and a technical description of the SIMTN. It presents international comparison results and examines the measurement uncertainties. It also discusses the metrological

TIME AND FREQUENCY METROLOGY WORKING GROUP

Working to support time and frequency metrology throughout the Americas

SIM
SISTEMA INTERAMERICANO DE METROLOGÍA

1. United States, 2005
2. Mexico, 2005
3. Canada, 2005
4. Panama, 2005
5. Brazil, 2006
6. Costa Rica, 2007
7. Colombia, 2007
8. Argentina, 2007
9. Guatemala, 2007
10. Jamaica, 2007
11. Uruguay, 2008
12. Paraguay, 2008
13. Peru, 2009
14. Trinidad & Tobago, 2009
15. Chile, 2010
16. Saint Lucia, 2010


CNM Time - NIST Time
SIMTN Comparisons Processed in Real-Time
Post Processed Comparisons from Circular-T
Time Difference (ns)
80
60
40
20
0
-20
-40
-60
-80
54250
54350
54450
54550
54650
54750
54850
54950
55050
55150
55250
Modified Julian Dates (June 2007 through January 2010)

SIM Time Network

(real-time measurement results for the 10-minute period ending on 05-23-2011 at 1720 UTC)

	United States SIMT(NIST)	Mexico SIMT(CNM)	Canada SIMT(NRC)	Panama SIMT(CNMP)	Brazil SIMT(ONRJ)	Costa Rica SIMT(ICE)	Colombia SIMT(SIC)	Argentina SIMT(INTI)	Guatemala SIMT(LNM)	Jamaica SIMT(BSJ)	Uruguay SIMT(UTE)	Paraguay SIMT(INTN)	Peru SIMT(INDP)	Trinidad SIMT(TTBS)	St. Lucia SIMT(SLBS)	Chile SIMT(INN)
United States SIMT(NIST)		29.0	18.2	22.6	-10.0	33.5	1.5	-1.6	-8.3		17.8	30.4	-550.3	-314.9	-11168.0	92938830.0
Mexico SIMT(CNM)	-29.0		-12.6	-6.1	-44.7	5.1	-28.6	-34.4	-38.0		-12.7	-5.3	-578.4	-347.4	-11203.9	92938799.5
Canada SIMT(NRC)	-18.2	12.6		7.3	-26.4	16.5	-13.9	-12.2	-24.6		7.1	19.8	-565.3	-329.9	-11183.0	92938819.4
Panama SIMT(CNMP)	-22.6	6.1	-7.3		-40.0	8.1	-24.0	-25.8	-31.8		-5.6	1.3	-572.6	-342.5	-11200.0	92938805.2
Brazil SIMT(ONRJ)	10.0	44.7	26.4	40.0		42.8	15.3	12.2	-0.8		33.5	36.0	-536.2	-313.8	-11170.6	92938847.1
Costa Rica SIMT(ICE)	-33.5	-5.1	-16.5	-8.1	-42.8		-31.4	-30.4	-38.9		-10.2	-3.4	-580.2	-349.2	-11206.7	92939587.9
Colombia SIMT(SIC)	-1.5	28.6	13.9	24.0	-15.3	31.4		2.5	-11.2		17.7	22.2	-550.8	-320.6	-11291.5	92939040.6
Argentina SIMT(INTI)	0.8	32.3	17.2	25.8	-12.0	29.4	3.5		-4.0		21.4	24.2	-544.5	-313.4	-11292.7	92939043.6
Guatemala SIMT(LNM)	9.6	37.5	26.3	31.2	-9.2	40.6	7.1	4.8			25.0	32.0	-541.0	-309.4	-11280.3	92939046.9
Jamaica SIMT(BSJ)																
Uruguay SIMT(UTE)	-15.1	13.3	1.3	7.7	-31.3	13.2	-17.7	-21.4	-25.0			2.5	-566.3	-339.9	-11317.5	92939021.8
Paraguay SIMT(INTN)	-31.1	3.1	-14.7	-2.2	-37.1	0.7	-22.2	-24.2	-32.0		-2.5		-569.1	-340.1	-11319.4	92939018.5
Peru SIMT(INDP)	549.3	575.9	565.4	571.7	528.7	580.9	550.8	544.5	541.0		566.3	569.1		230.5	-10742.7	92939587.9
Trinidad SIMT(TTBS)	318.1	346.1	333.4	341.8	302.4	350.8	320.6	313.4	309.4		339.9	340.1	-230.5		-10975.2	92939360.2
St. Lucia SIMT(SLBS)	11053.4	11087.9	11068.8	11084.8	11051.9	11088.9	11291.5	11292.7	11280.3		11317.5	11319.4	10742.7	10975.2		92950337.8
Chile SIMT(INN)	-92938619.9	-92938592.9	-92938603.5	-92938595.4	-92938637.0	-92938587.6	-92939040.6	-92939043.6	-92939046.9		-92939021.8	-92939018.5	-92939587.9	-92939360.2	-92950337.8	
Last Update (HHMM)	1720	1720	1720	1720	1720	1720	1740	1740	1740		1740	1740	1740	1740	1740	1740

This table was created at 05-23-2011 (MJD 55704) 17:26:43 UTC and will refresh every five minutes. Values are in units of nanoseconds.

Click on a time scale or country name to view a **one-way** GPS graph for the current day (GPS-NMI). Click on a number to view a **common-view** graph between two laboratories for the current day.

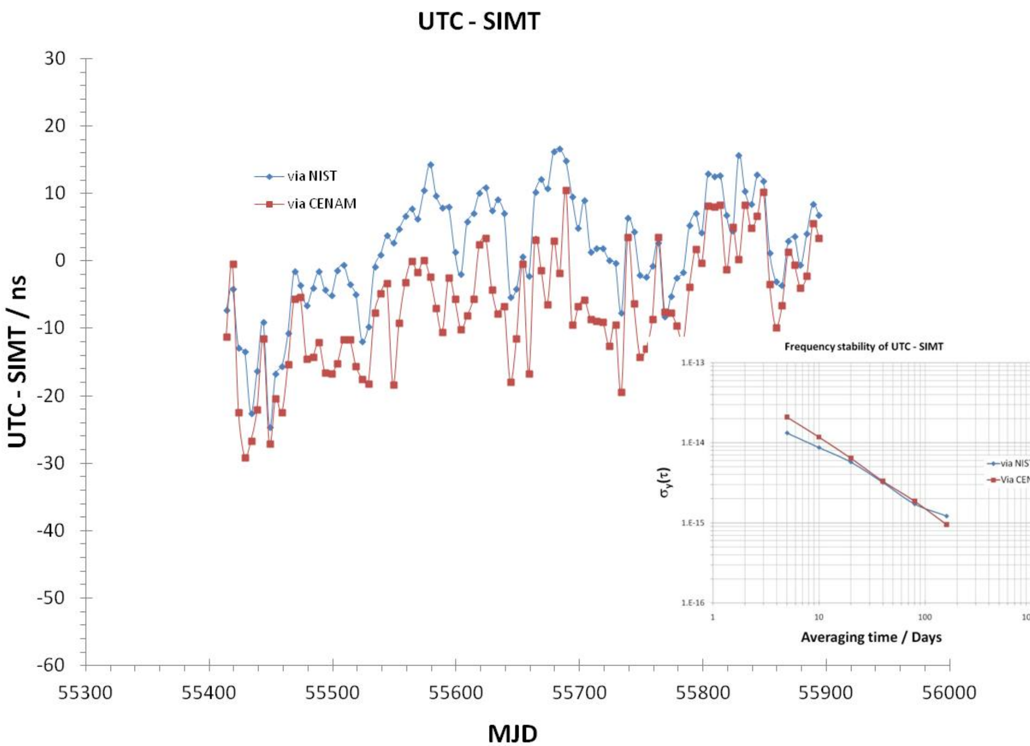
SIM Time Scale

(SIMT - SIMT(*k*) for the 1-hour period ending on 2012-02-20 at 17:20:00 UTC)

National Standard	National Flag	SIMT - SIMT(*k*), ns	SIMT Contribution	National Standard	National Flag	SIMT - SIMT(*k*), ns	SIMT Contribution
United States SIMT(NIST)		3.46	38.67 %	Paraguay SIMT(INTN)		—	0.00 %
Canada SIMT(NRC)		-17.84	11.89 %	Guatemala SIMT(LNM)		-3.52	0.00 %
Mexico SIMT(CNM)		2.56	11.69 %	Jamaica SIMT(BSJ)		—	0.00 %
Brazil SIMT(ONRJ)		34.10	10.79 %	Peru SIMT(SNM)		-15808.13	0.00 %
Panama SIMT(CNMP)		42.55	7.97 %	Trinidad SIMT(TTBS)		262.78	0.00 %
Argentina SIMT(INTI)		24.72	7.19 %	St. Lucia SIMT(SLBS)		-1038.32	0.00 %
Costa Rica SIMT(ICE)		635.50	6.80 %	Chile SIMT(INN)		-584514.48	0.00 %
Colombia SIMT(SIC)		-63.64	5.00 %	Antigua SIMT(ABBS)		-83781.86	0.00 %
Uruguay SIMT(UTE)		—	0.00 %	Ecuador SIMT(CMEE)		—	0.00 %

Click on a SIMT - SIMT(*k*) value to view today's graph. New values are computed at 30 minutes after the hour. This table was updated at 17:37:31 UTC and refreshes every 30 minutes.

J.M. López-Romero, M. Lombardi, N. Diaz and E. de Carlos, "The SIM time scale", to be submited to Metrologia

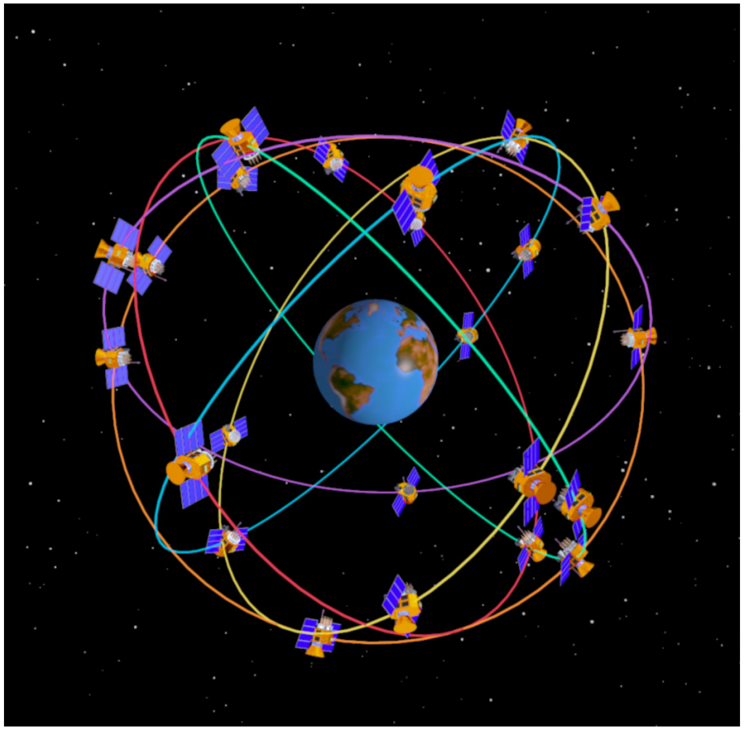


UTC - SIMT
UTC - SIMT / ns
MJD
via NIST
via CENAM
Frequency stability of UTC - SIMT
Averaging time / Days
Via CENAM

GPS Satellite Constellation

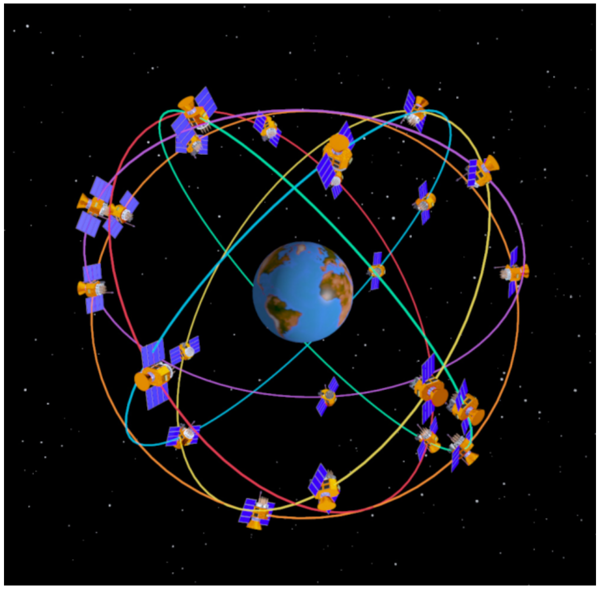
24 satellite constellation

- Semi-synchronous, circular orbits (~20,200 km/10,900 nautical miles altitude)
- Six orbital planes, inclined at 55 degrees, four vehicles per plane
- Orbital period is 11 hours, 58 minutes
- Spares can bring number of satellites up to 32 – new satellites are launched as necessary, lately 2 or 3 per year
  - *Designed to cover entire earth, with at least four satellites always in view*



Cesium and/or rubidium oscillators are on board each satellite

GPS Signal Structure



Two L-band carrier frequencies

L_1 = 1575.42 MHz L_2 = 1227.60 MHz

Two PRN Codes

- P(Y): Military Code
  - 267 day repeat interval
  - Encrypted – code sequence not published
  - Available on L1 and L2
- C/A: Coarse Acquisition (Civilian) Code
  - 1 millisecond repeat interval
  - Available to all users, but only on L1

Code modulated with Navigation Message Data

- Provides ephemeris data and clock corrections for the GPS satellites
- Low data rate (50 bps)

The GPS common view technique

The common-view method involves a GPS satellite (S), and two receiving sites (A and B). Each site has a GPS receiver, a local time standard, and a time interval counter.

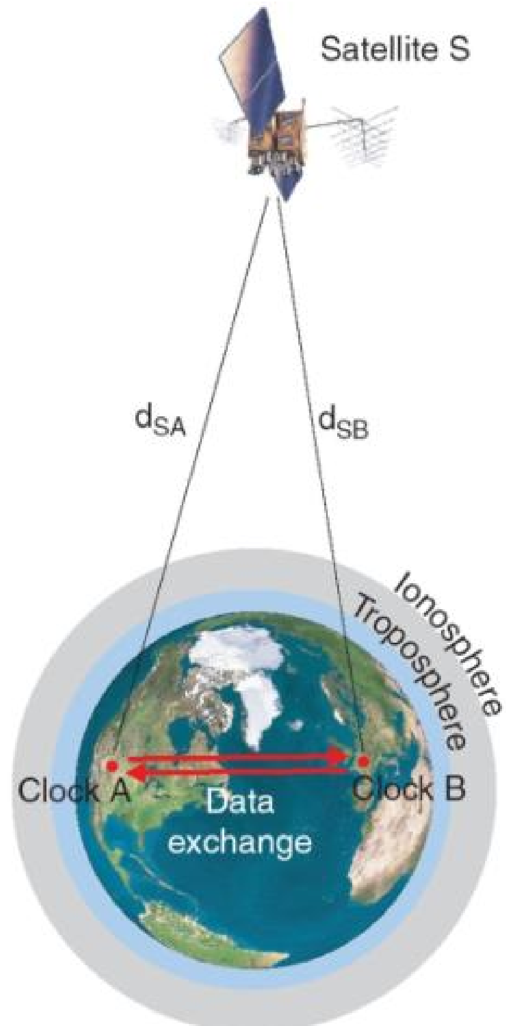
Measurements are made at sites A and B to compare the received GPS signal to the local time standard.

Two data sets are recorded (one at each site):

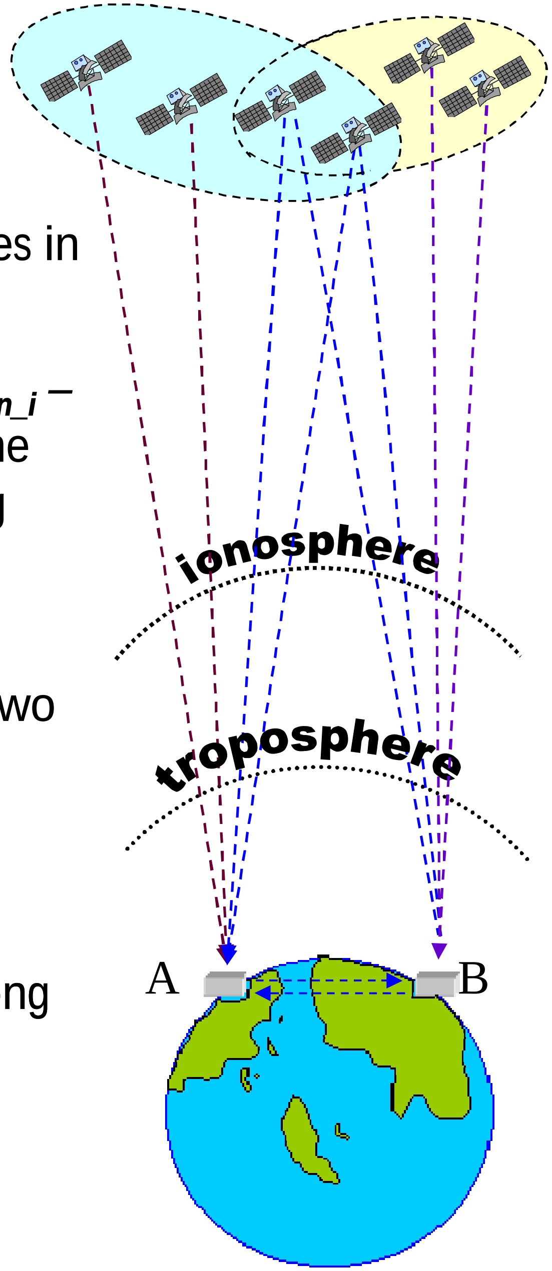
- ◆ Clock A - S
- ◆ Clock B - S

The two data sets are then exchanged and subtracted from each other to find the difference between Clocks A and B. Delays that are common to both paths (d_{SA} and d_{SB}) cancel, but delays that are not common to both paths contribute uncertainty to the measurement. The equation for the measurement is:

(Clock A – S) – (Clock B – S) =
(Clock A – Clock B) + (d_{SA} – d_{SB})



All-in-view GPS



Receivers at remote stationary locations track all the satellites in view

Each receiver makes the *all-in-view measurements, (REF$_{station_i}$ – GPS)*: time difference between a local reference clock and the received composite timing signal from all the satellites being tracked

The all-in-view measurements from two receivers are differenced to obtain the time and frequency difference of two remote clocks

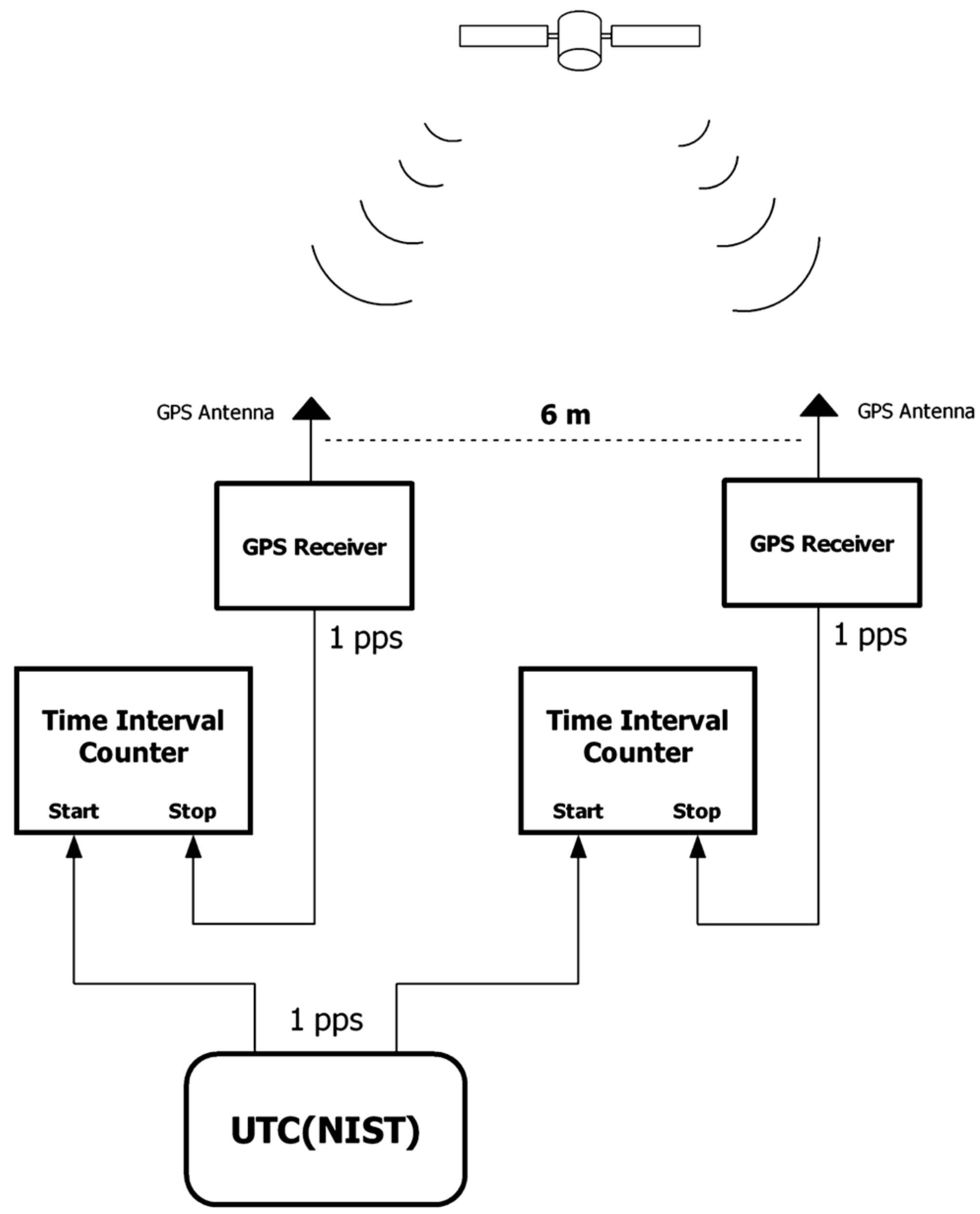
Works when no satellites are in common-view

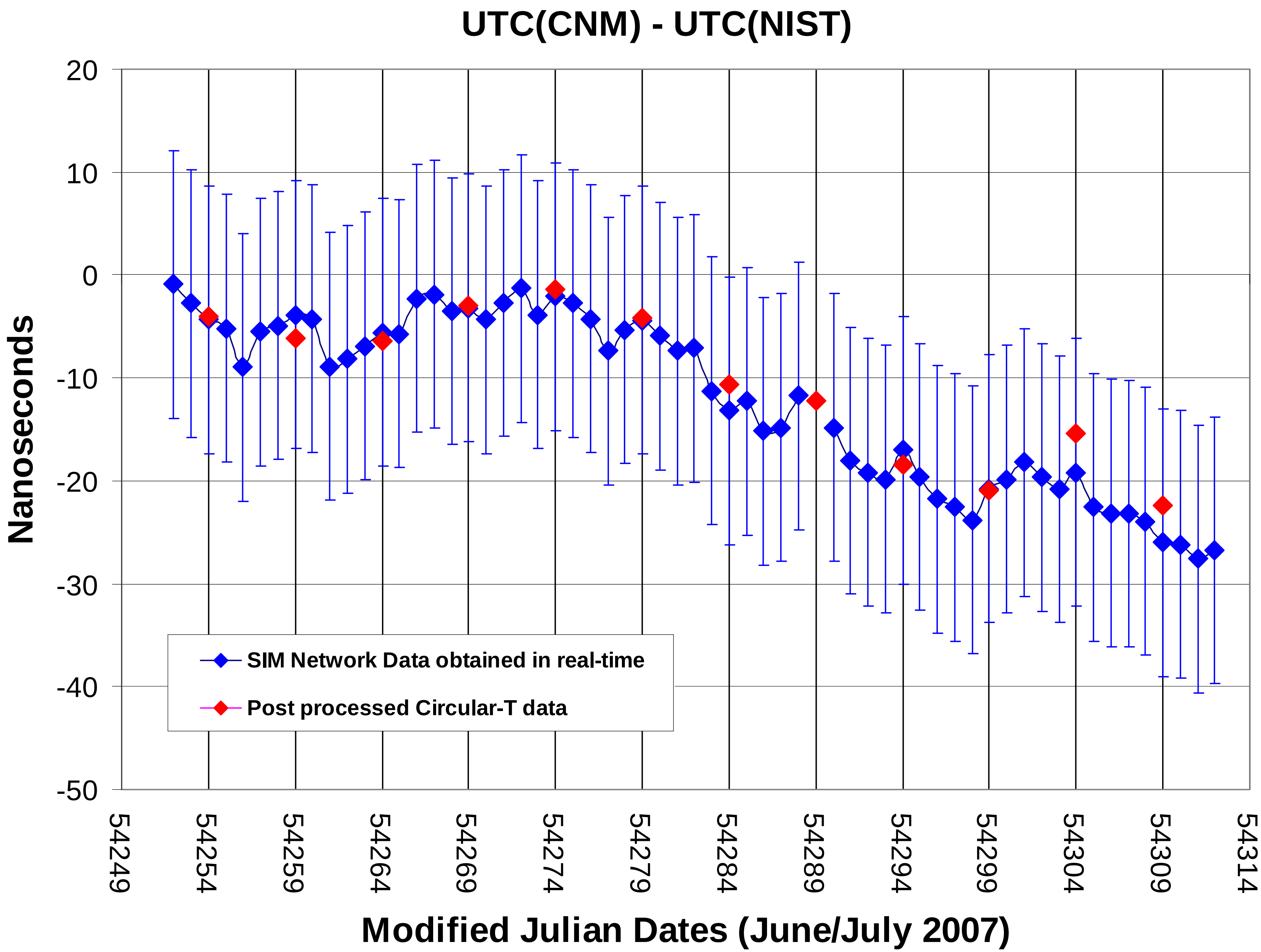
Performance is about the same as common-view for short baselines (2500 km or less), better than common-view for long baselines (5000 km or longer)

SIM Receiver Calibrations

SIM systems are calibrated at NIST prior to shipment. Calibrations are performed using the common-view, common-clock method. The SIM laboratory installs the same antenna cable and antenna that were used during the calibration.

Calibrations last for 10 days. The time deviation (Type A uncertainty) of the calibration is less than 0.2 ns after one day of averaging. The combined uncertainty is estimated at 4 ns, because a variety of factors can introduce a systematic offset.

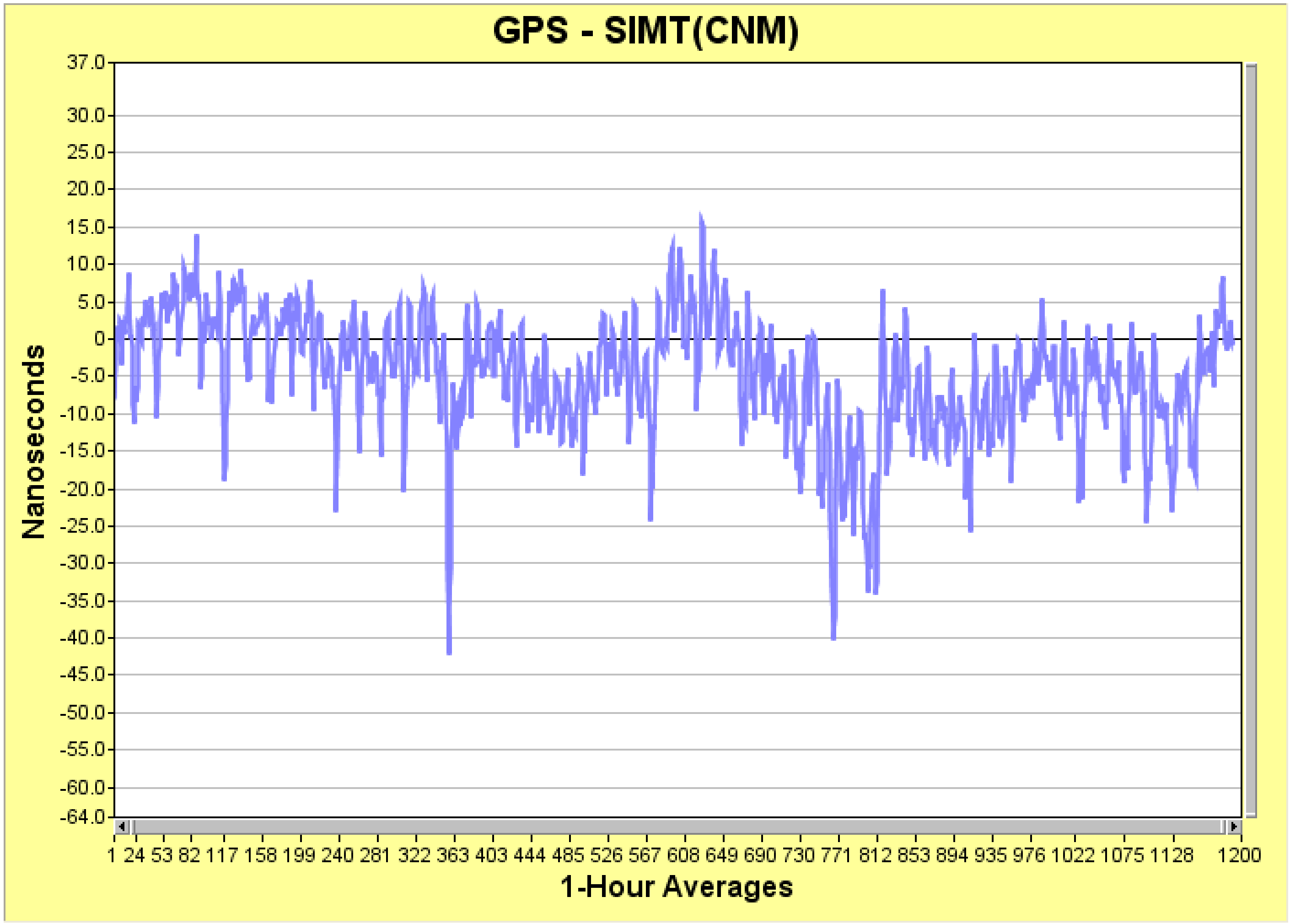




UTC(CNM) - UTC(NIST)
Nanoseconds
20
10
0
-10
-20
-30
-40
-50
SIM Network Data obtained in real-time
Post processed Circular-T data
54249
54254
54259
54264
54269
54274
54279
54284
54289
54294
54299
54304
54309
54314
Modified Julian Dates (June/July 2007)

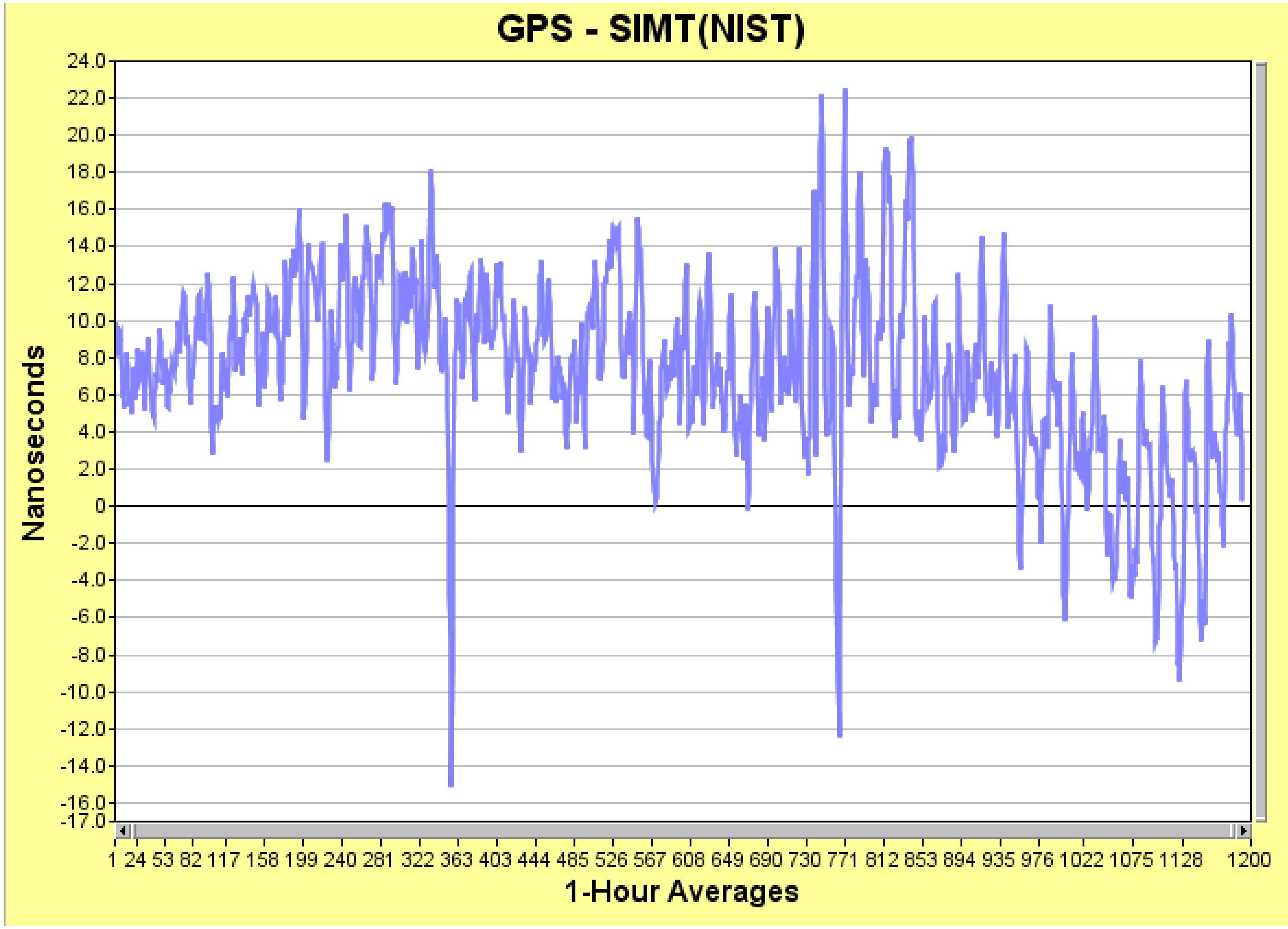
Monitor of the GPS Signal at CENAM

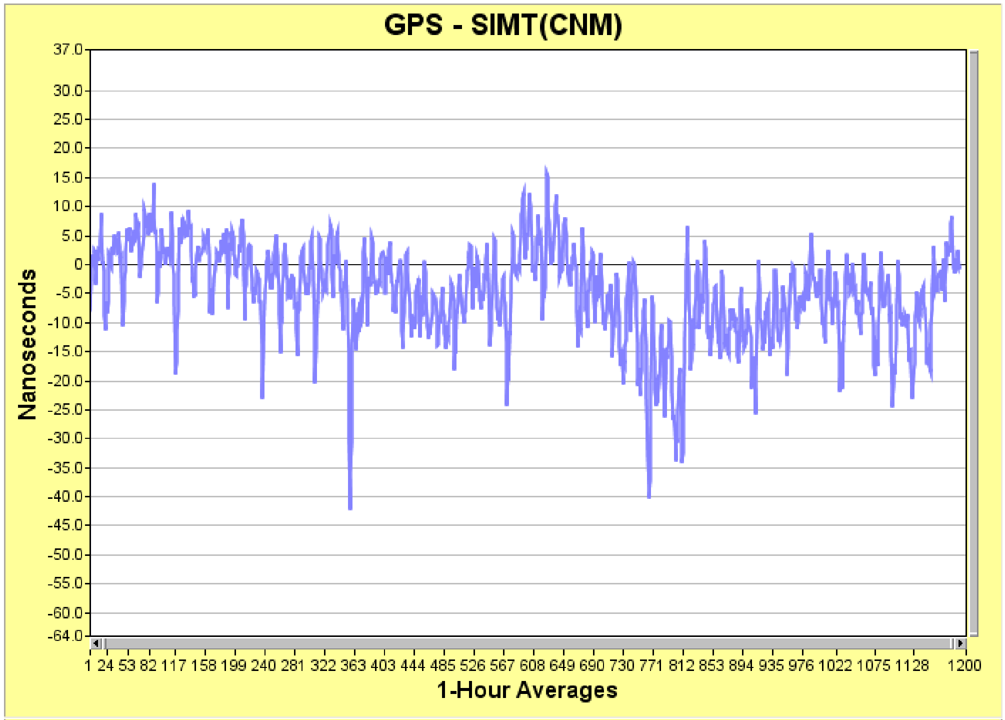
50 days time interval ending at October 14, 2011

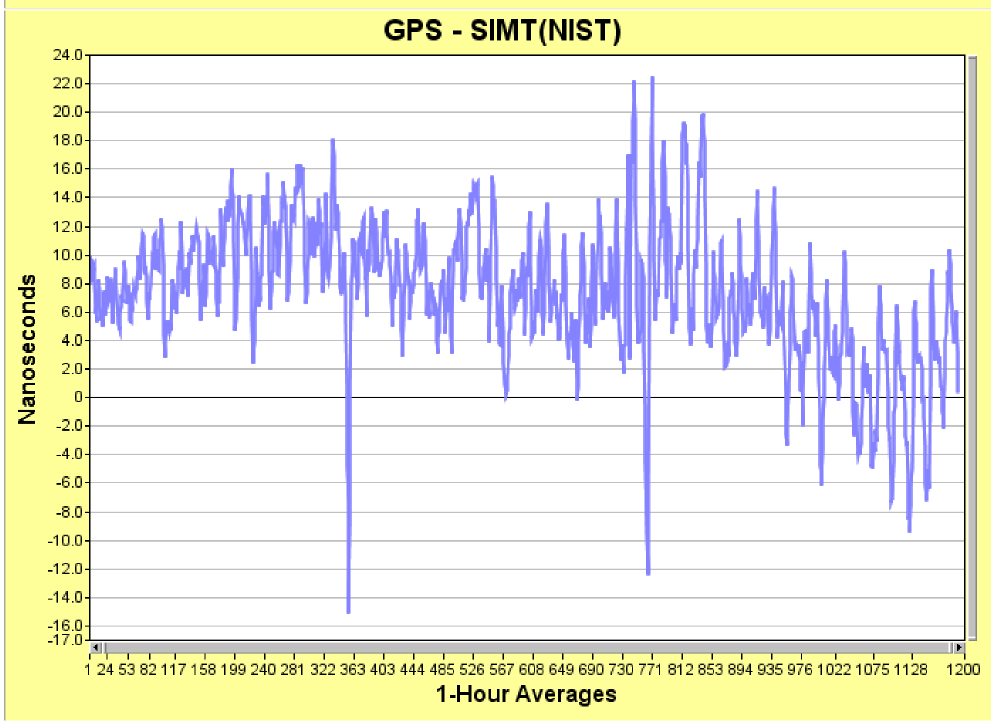


Monitor of the GPS Signal at NIST

50 days time interval ending at October 14, 2011




GPS - SIMT(CNM)
Nanoseconds
37.0
30.0
25.0
20.0
15.0
10.0
5.0
0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
-50.0
-55.0
-60.0
-64.0
1 24 53 82 117 158 199 240 281 322 363 403 444 485 526 567 608 649 690 730 771 812 853 894 935 976 1022 1075 1128 1200
1-Hour Averages

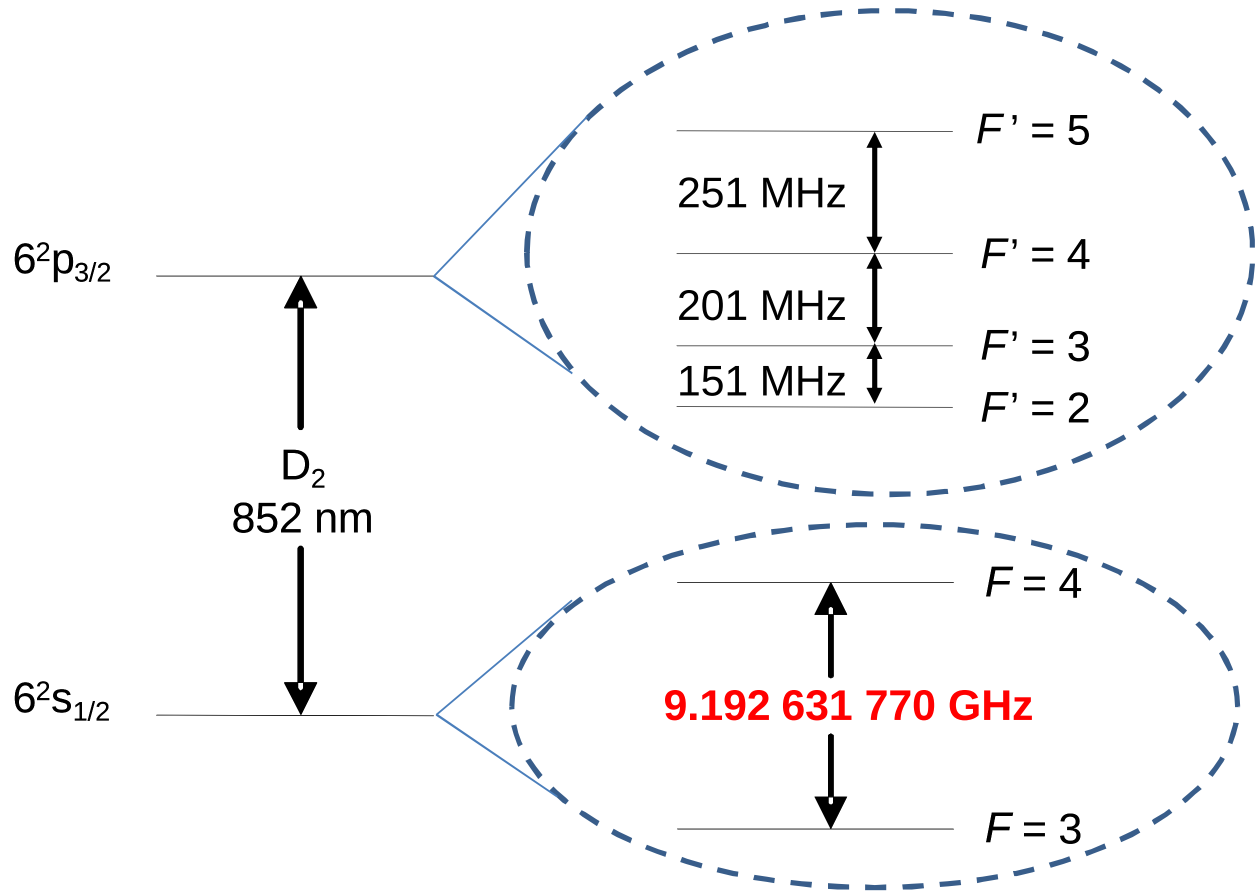

GPS - SIMT(NIST)
Nanoseconds
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
-14.0
-16.0
-17.0
1 24 53 82 117 158 199 240 281 322 363 403 444 485 526 567 608 649 690 730 771 812 853 894 935 976 1022 1075 1128 1200
1-Hour Averages

Pasado Presente y Futuro de la Metrología de Tiempo y Frecuencia

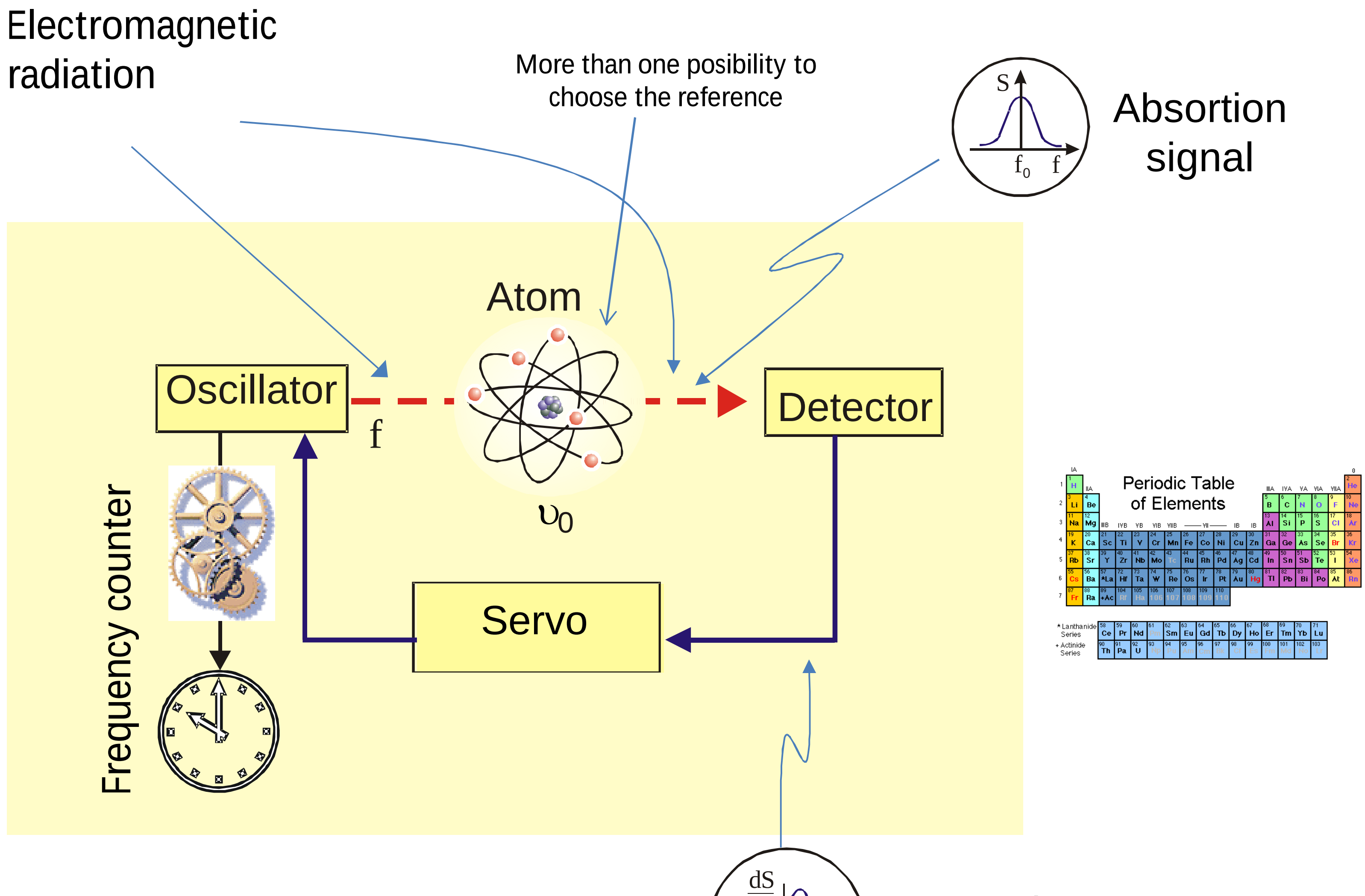
J. Mauricio López Romero
División de Metrología de Tiempo y Frecuencia
Centro Nacional de Metrología, CENAM

Contenido

The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium 133 atom.

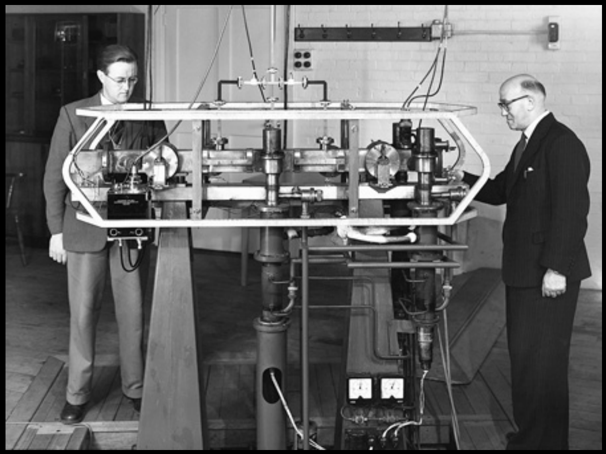


The concept of an atomic clock

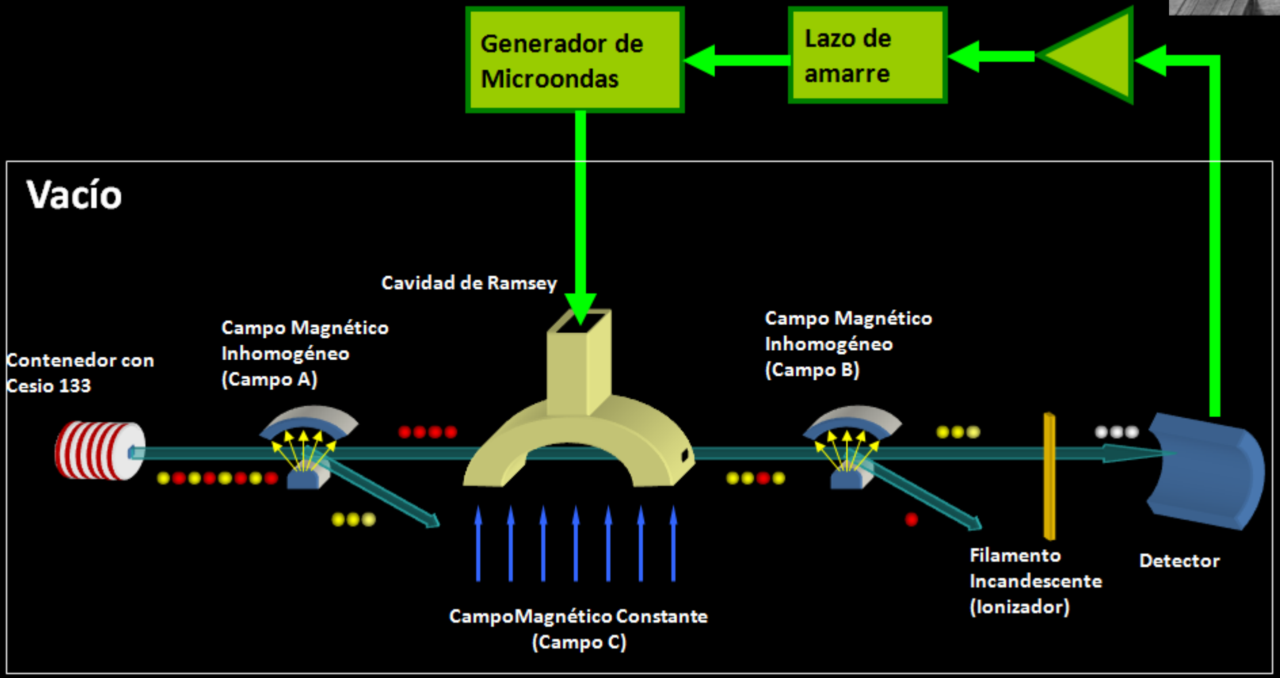


CENAM
CENTRO NACIONAL DE METROLOGÍA

First atomic clocks (1957)



Ramsey Method



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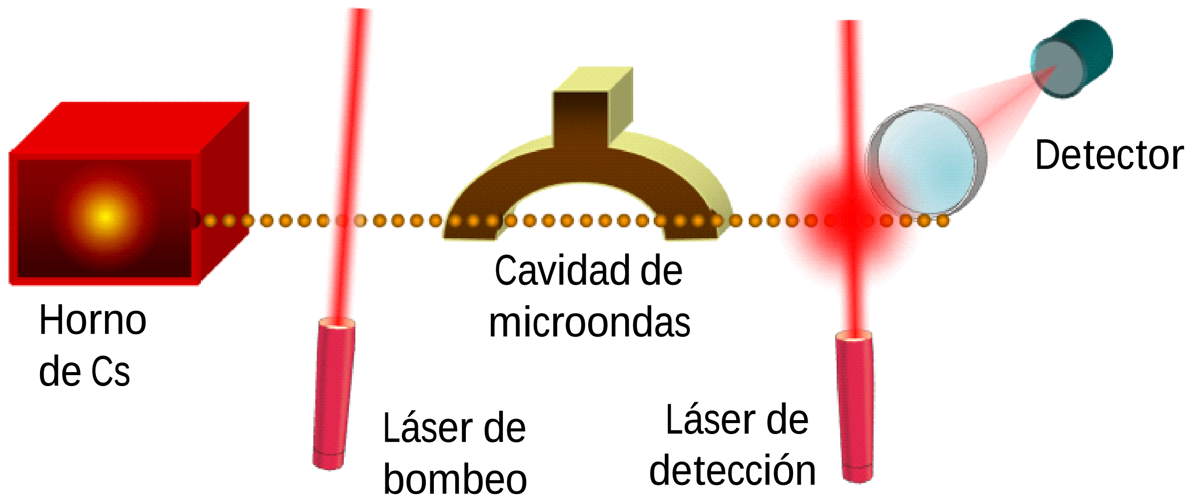
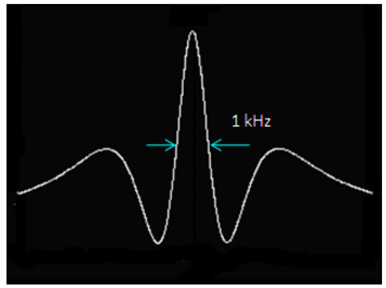
Commercial availabe Cs atomic clock using the magnetic selection of N. Ramsey

Ramsey method with optical pumping (1985)

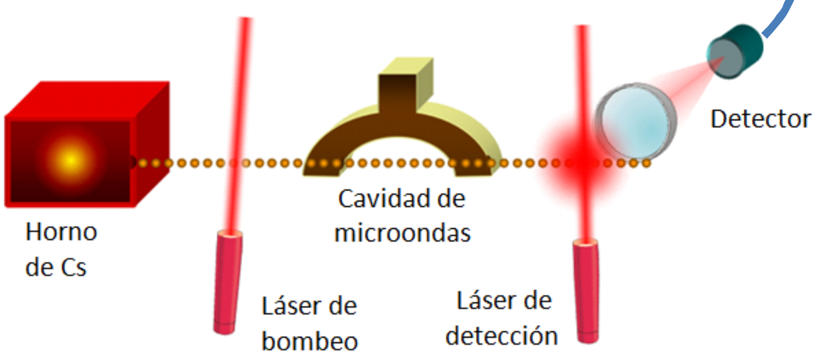


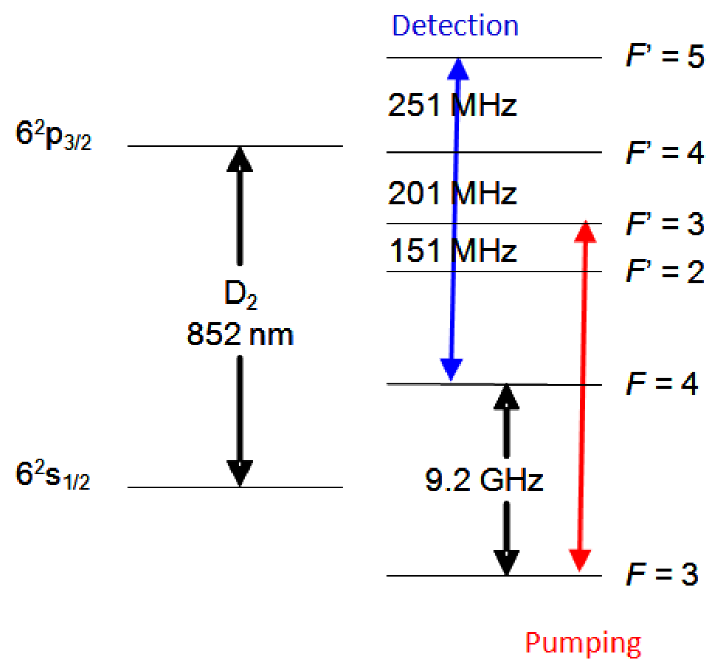


$$\Delta E \times \Delta t = h$$
$$E = h\upsilon \Rightarrow \Delta E = h\Delta\upsilon$$
$$\Delta\nu \times \Delta t = 1$$

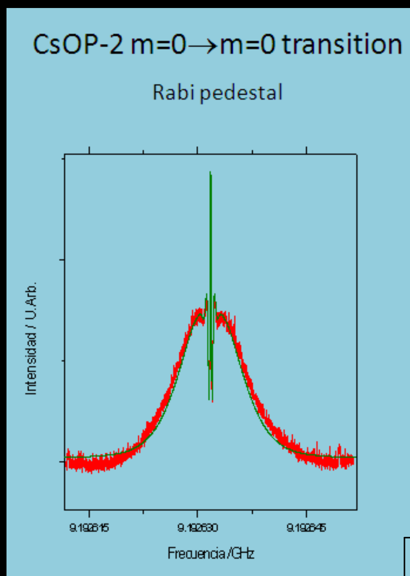
Ideal case: $\Delta\nu \rightarrow 0 \quad \Delta t \rightarrow \infty$

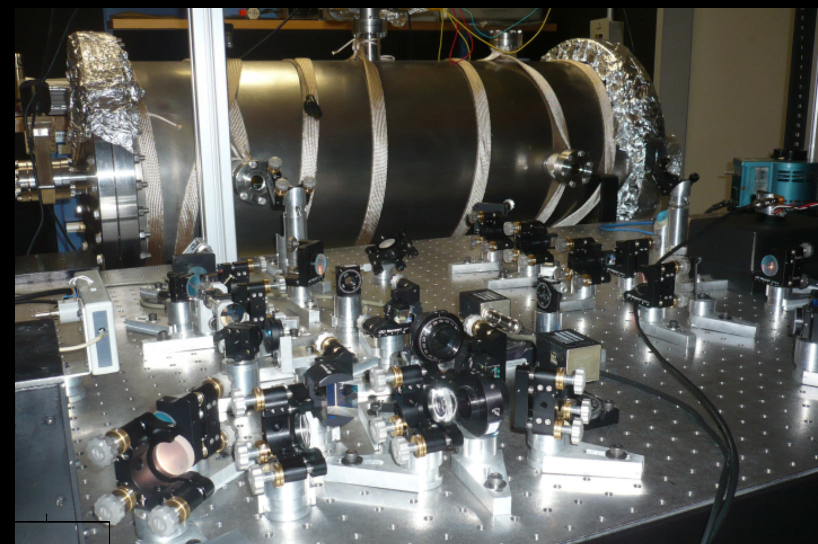
Ramsey method with optical pumping

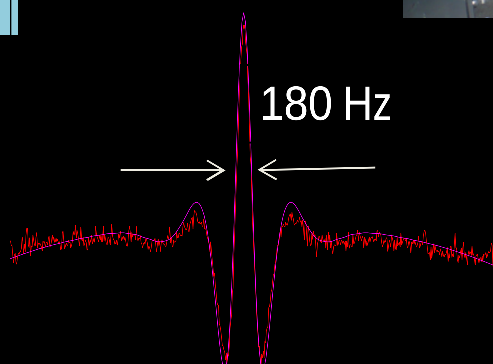




Optically pumped thermal Cs beam clock
CENAM CsOp-2







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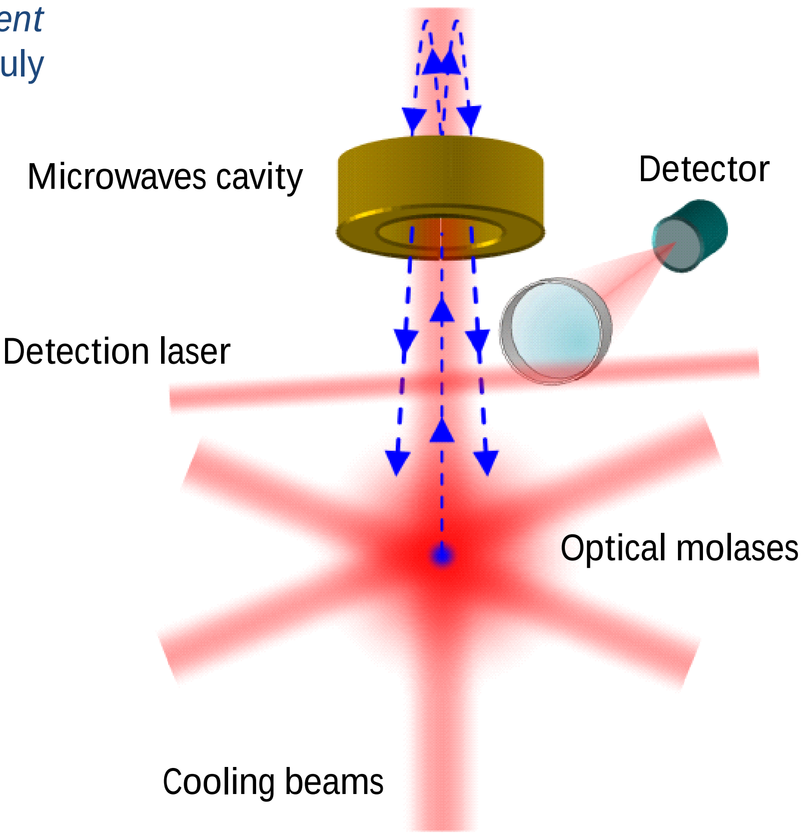
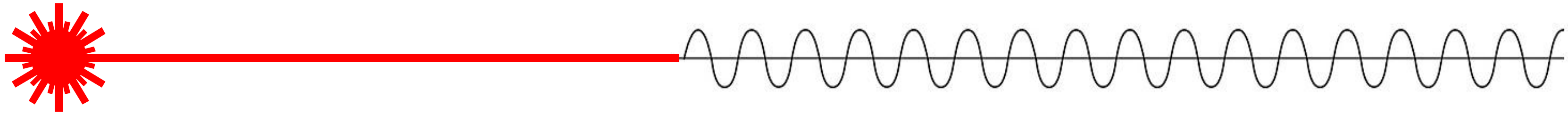
CENTRO NACIONAL DE METROLOGÍA

Cs Fountain Clock
(1990)

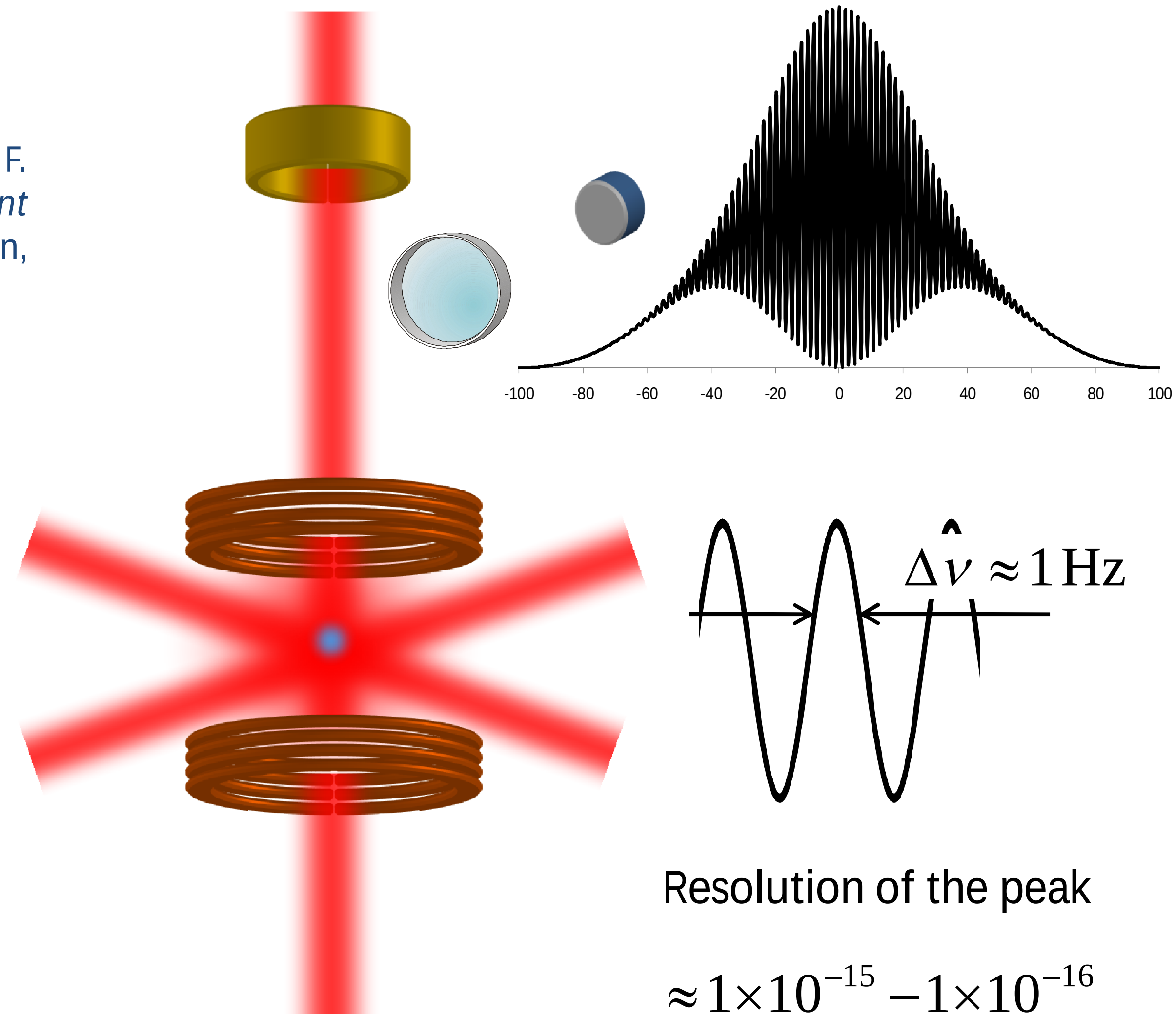
Wayne M. Itano, Norman F. Ramsey, *Accurate Measurement of Time*, Scientific American, July 1993.





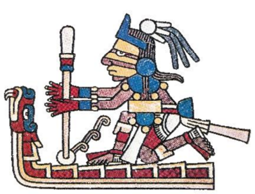
Clock transition

Wayne M. Itano, Norman F. Ramsey, *Accurate Measurement of Time*, Scientific American, 1993.

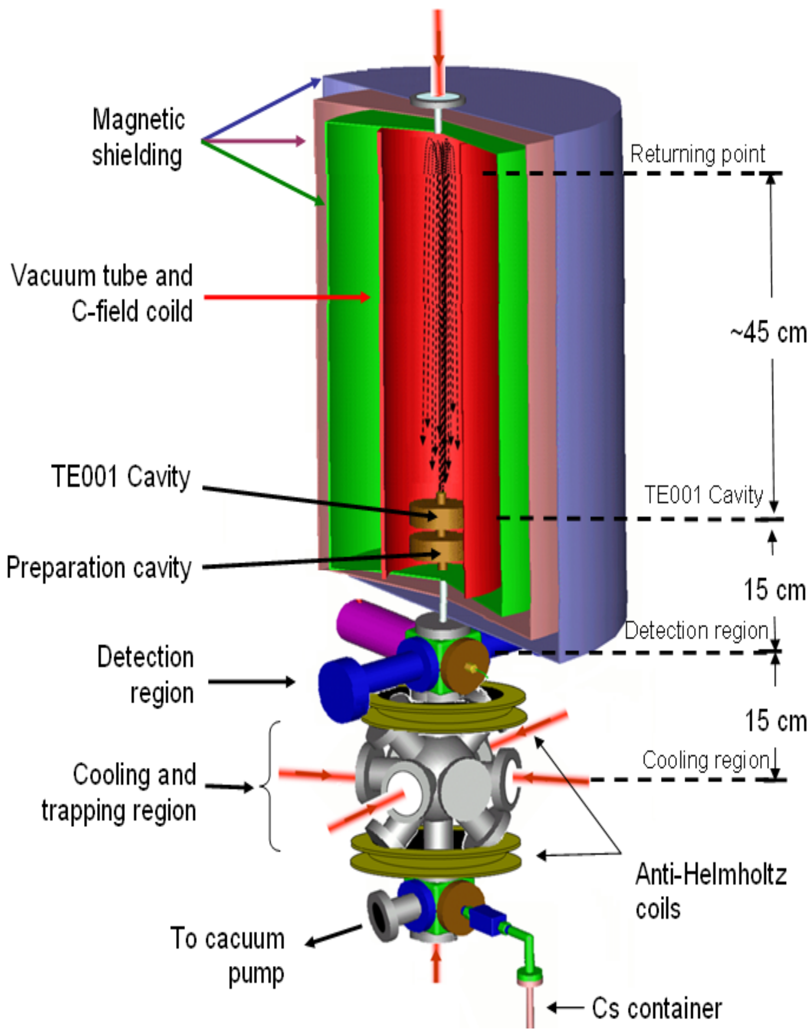


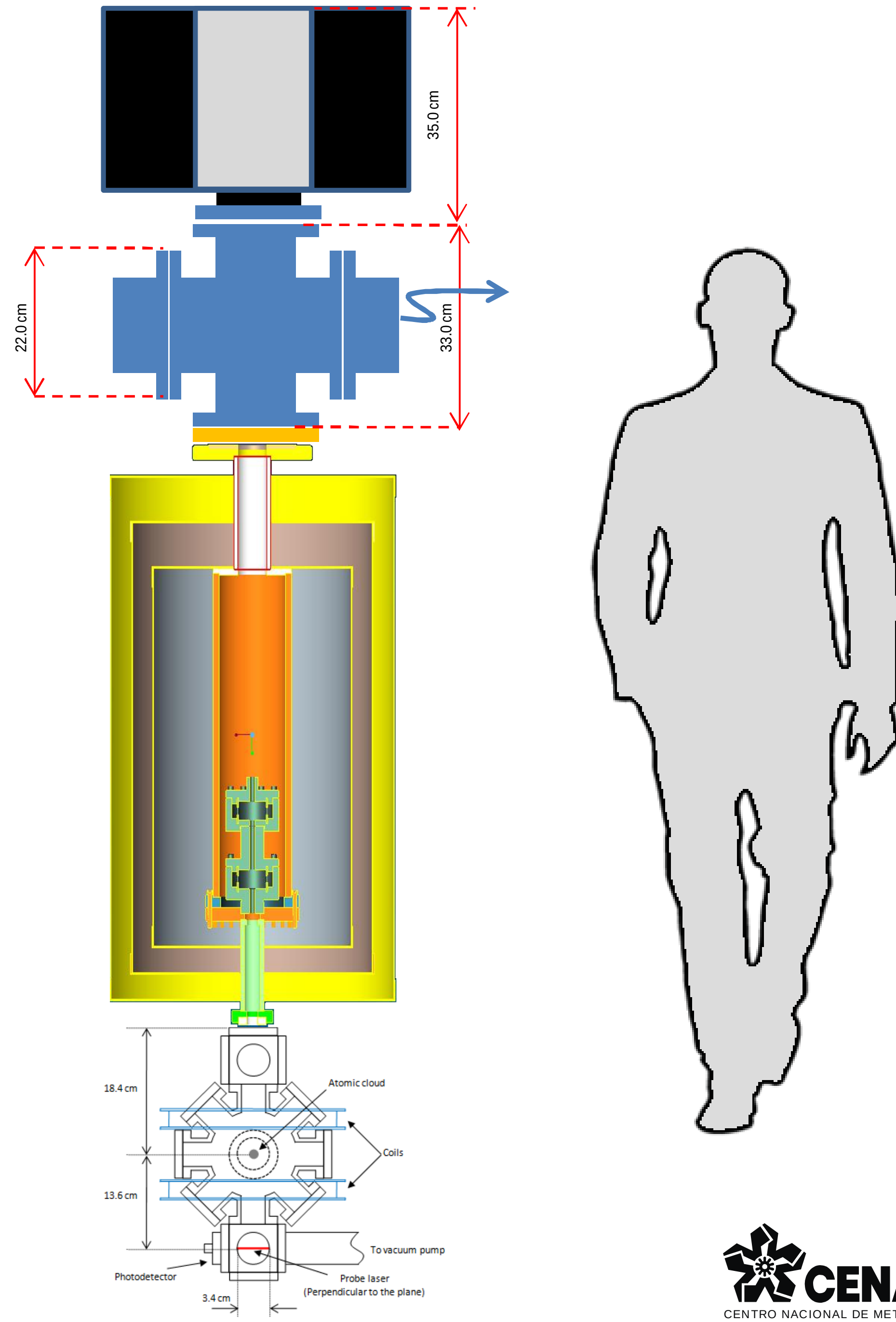
Resolution of the peak

$$\approx 1\times10^{-15} - 1\times10^{-16}$$



CENAM CsF-1 physical package





CENAM
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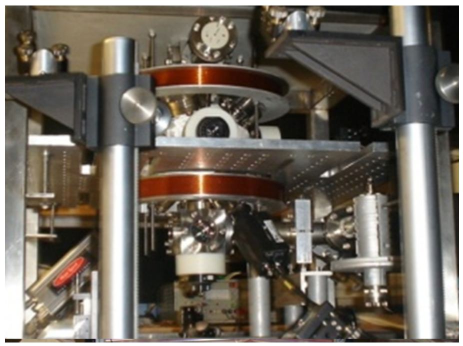
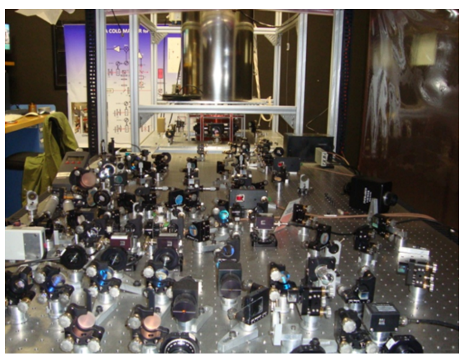
Cesium fountain clock

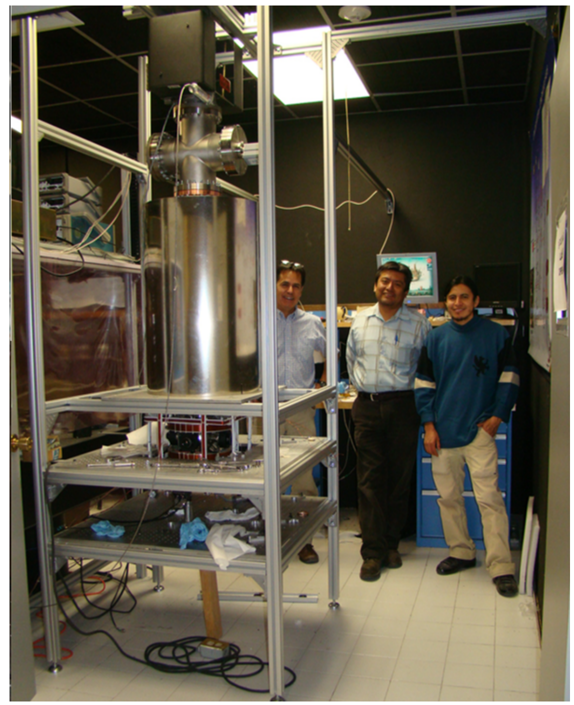
CENAM CsF-1

MOT



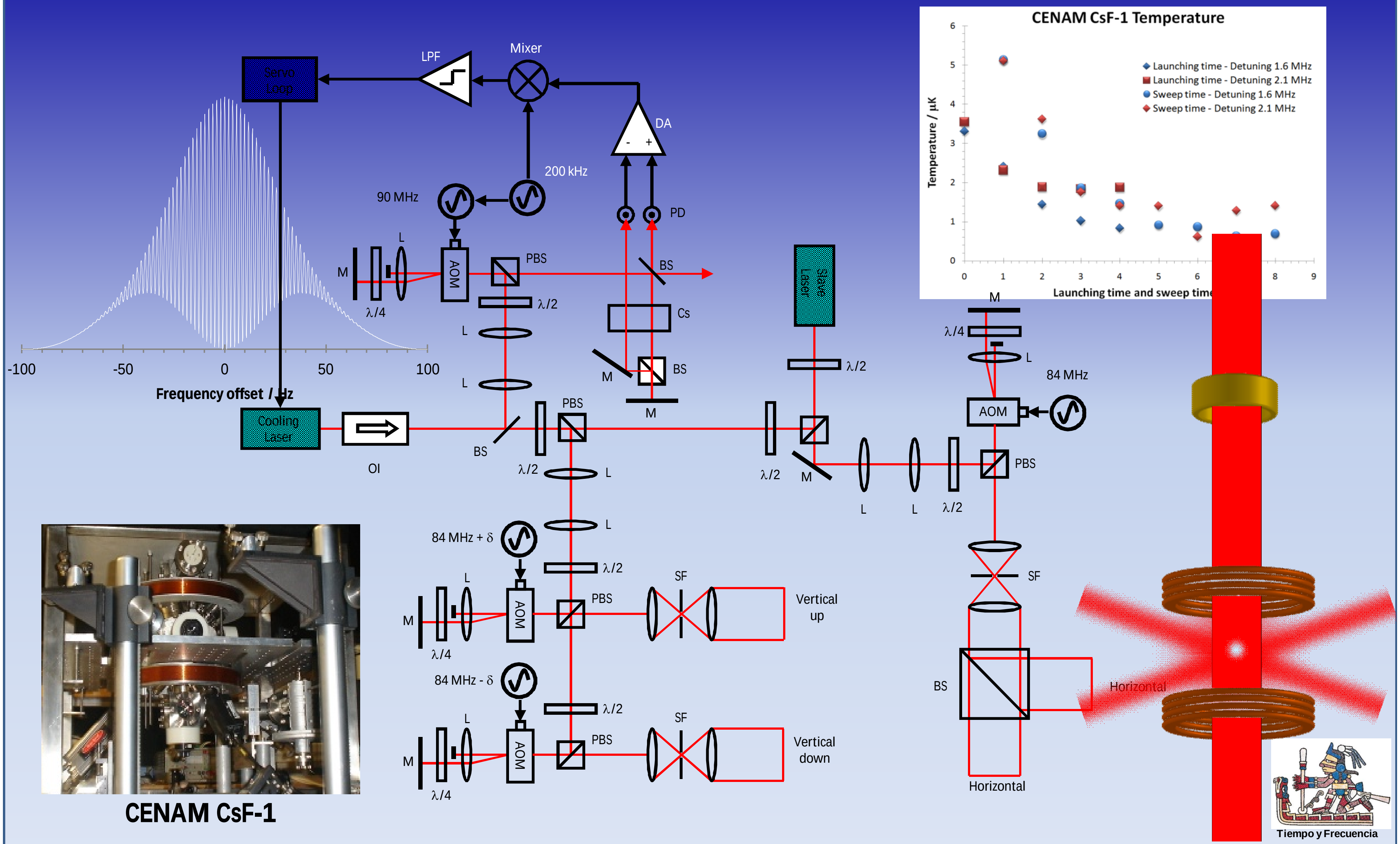


Optical system



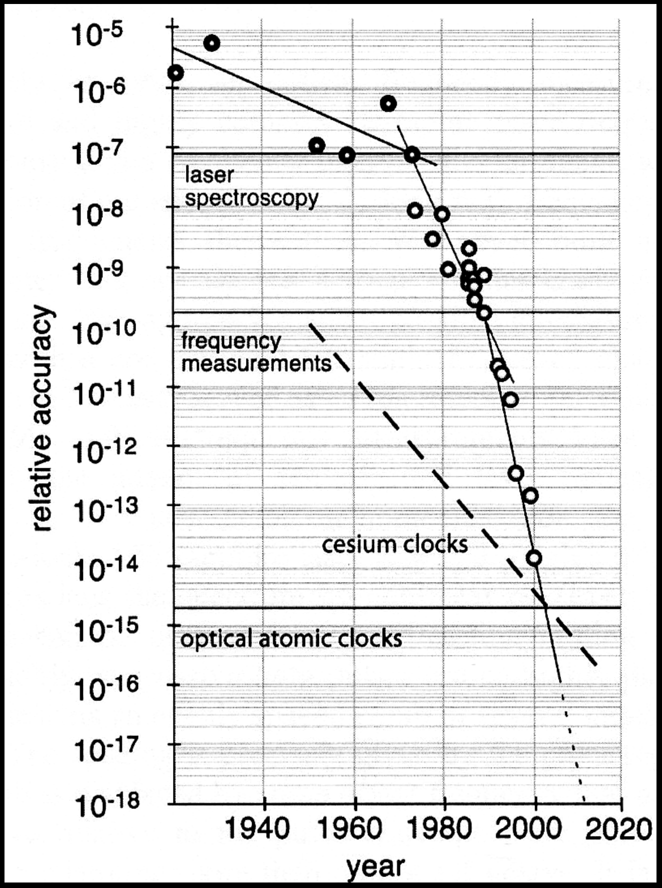
Physics package

ULTRA COLD MATTER for ULTRA PRECISE CLOCKS



CENAM CsF-1

Optical spectroscopy and a new definition of the second



Pasado Presente y Futuro de la Metrología de Tiempo y Frecuencia

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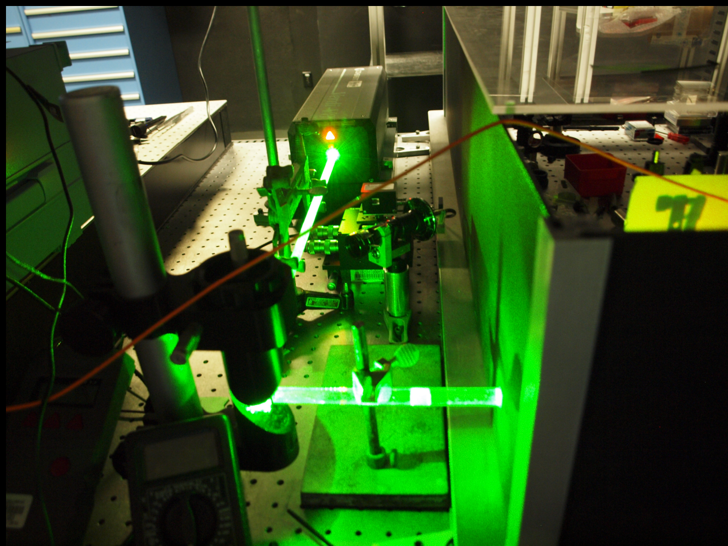
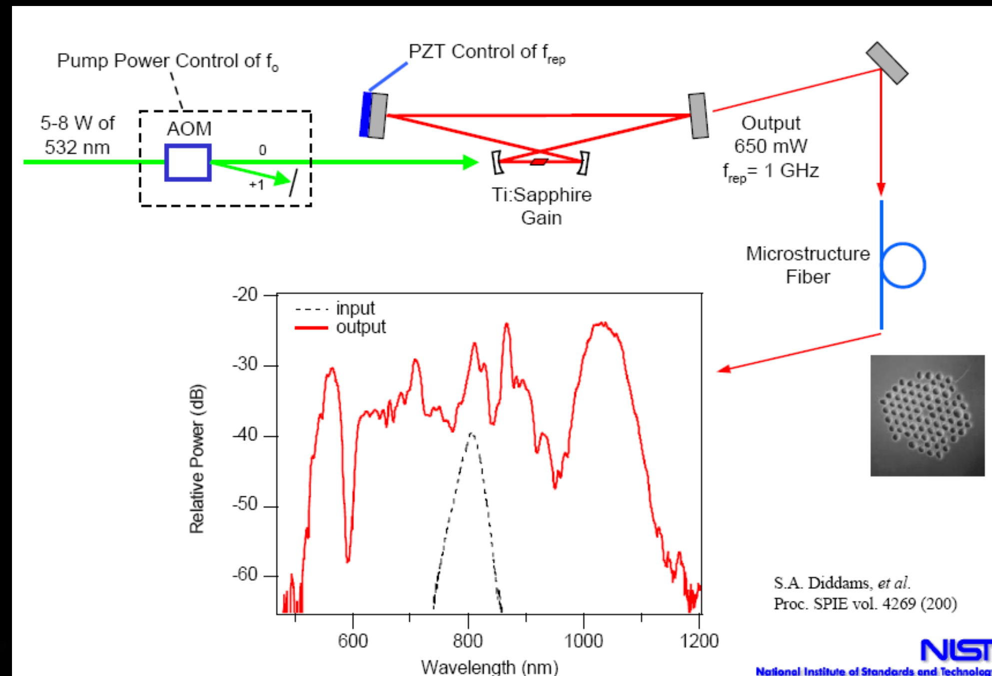
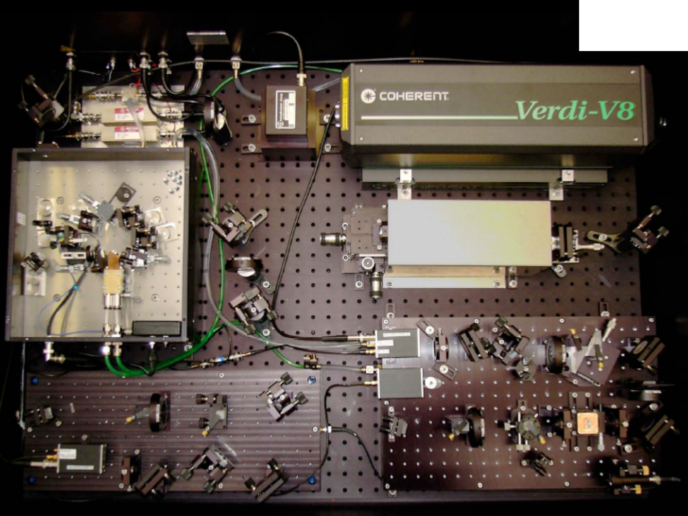
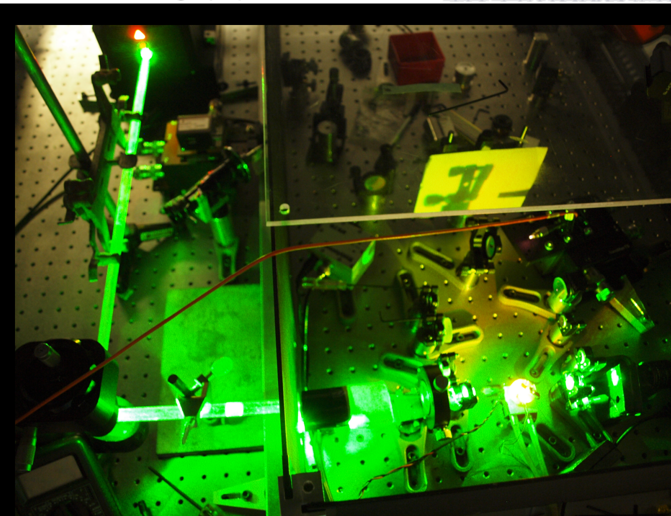
Contenido

Frequency combs



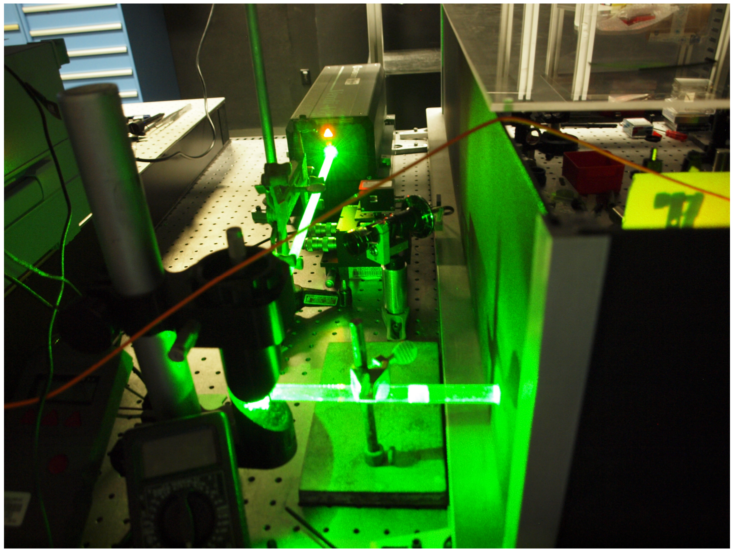


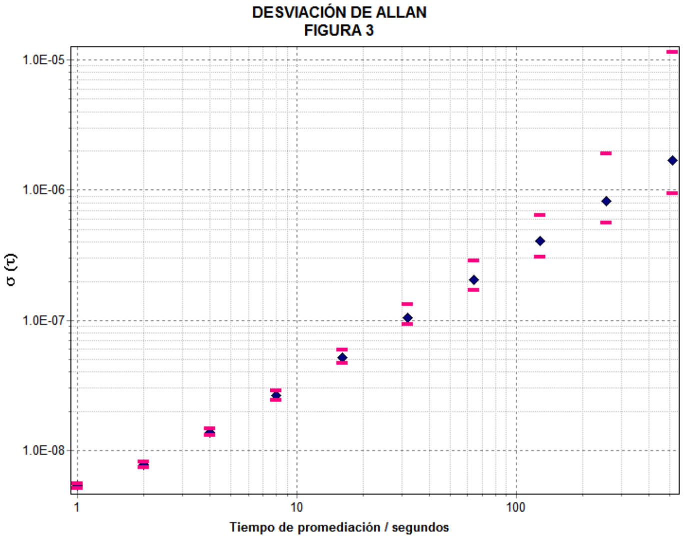


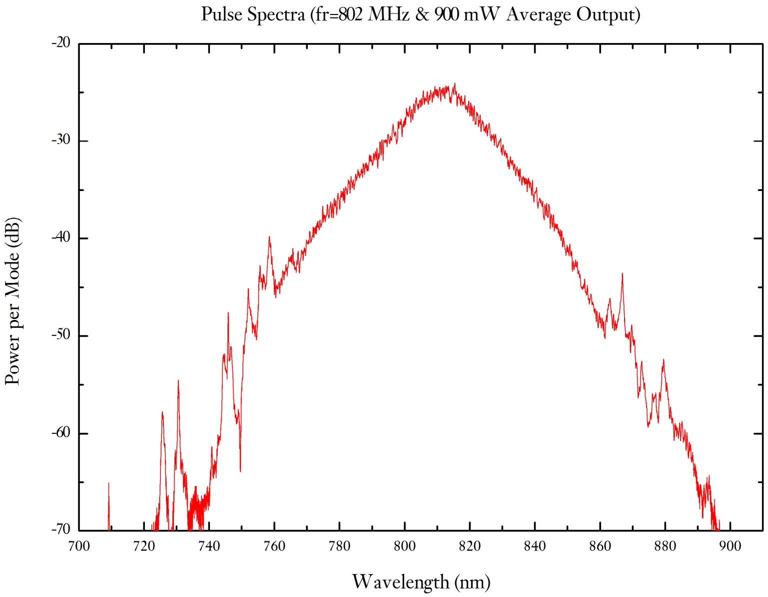


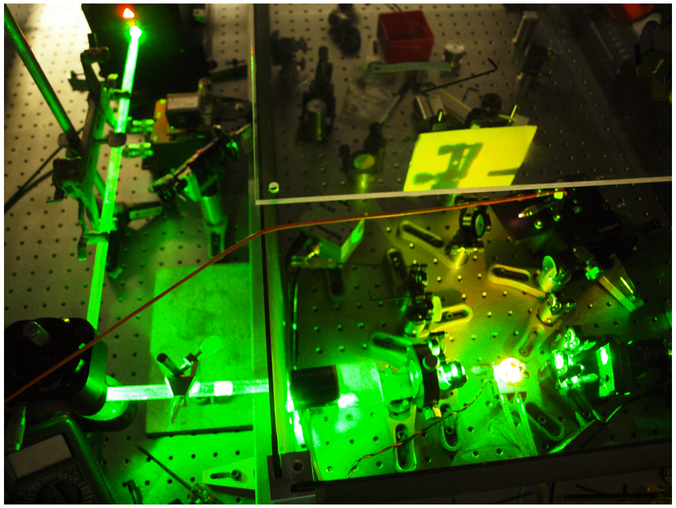
CENAM Ti:Sa Frequency comb

0.8 GHz repetition rate, pulsewidth < 50 fs









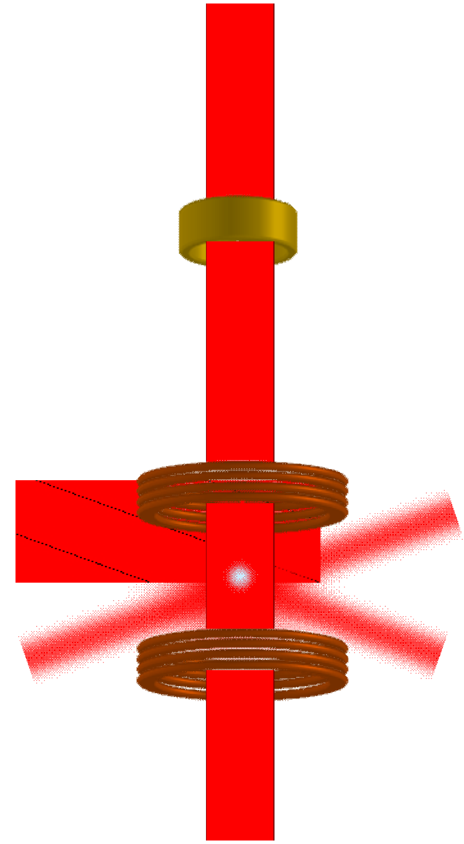
State-of-the-art Time & Frequency Standards

Cesium fountain clocks use a ***large number of atoms*** for a limited period of time:

HIGH stability: 10^{-14} in 1s,

Accuracy: 2×10^{-16}.

(Accuracy limit reached in 10 minutes)

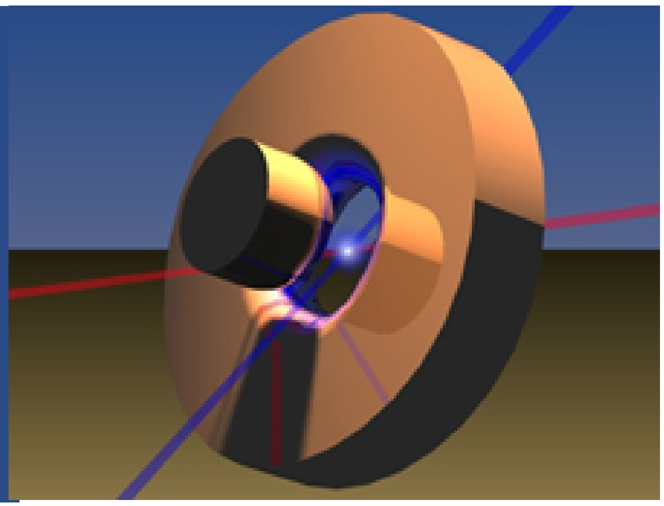


Ion clocks use atoms trapped for ***extended periods of time***:

HIGH accuracy: 10^{-17},

Stability: 5×10^{-15} in 1s.

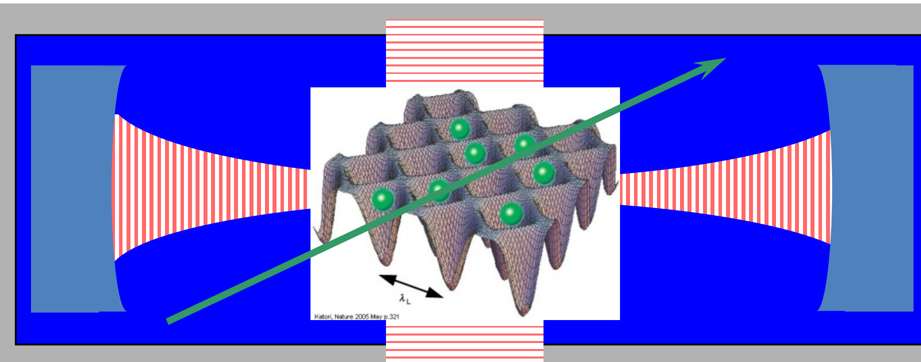
(Accuracy limit reached in one month)



Lattice clocks combine the advantages of trapped ion clocks and cooled neutral atoms clocks: ***large number of atoms*** *for* ***extended periods of time***:

HIGH stability 10^{-17} in 1s

AND HIGH accuracy: 10^{-17}.



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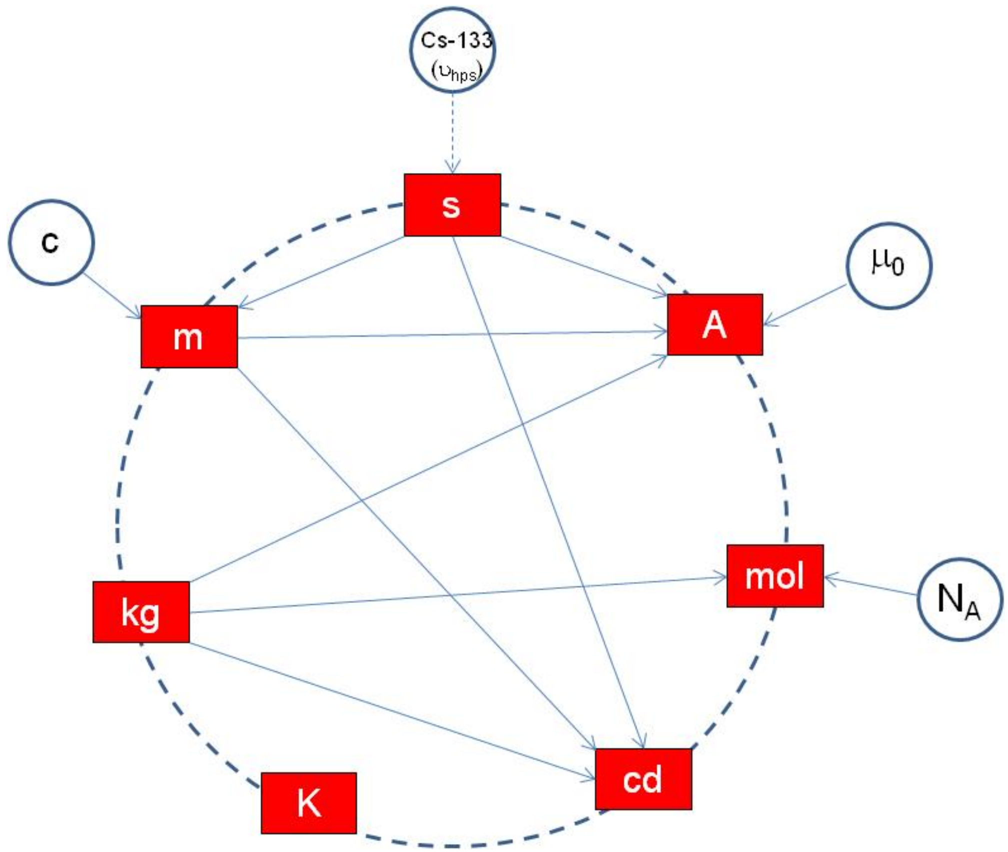
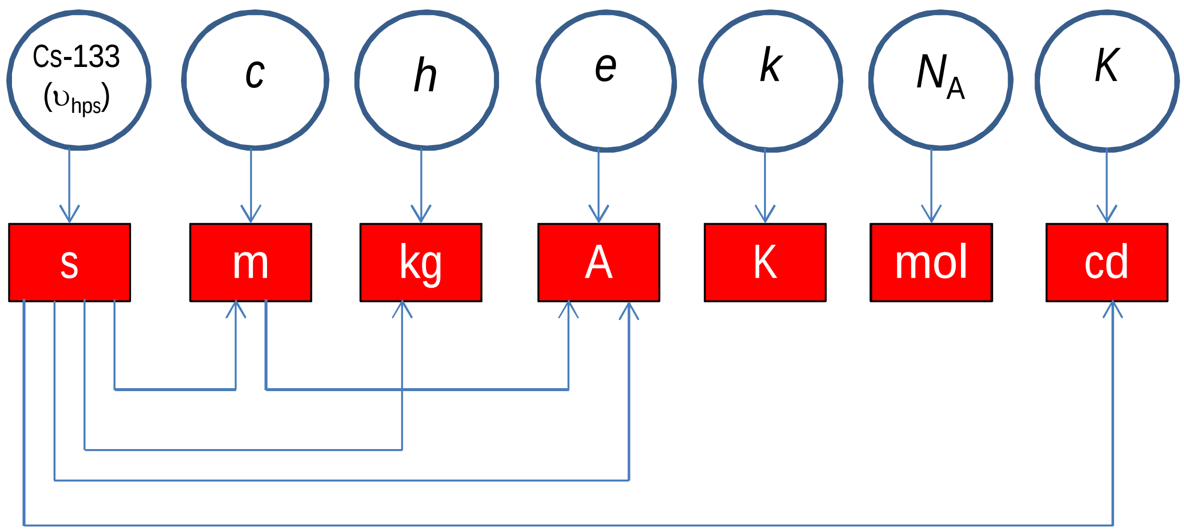
Contenido

El Sistema Internacional actual



El Sistema Internacional en el ¿2014?



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