



# LABORATORIJ ZA VRIJEME I FREKVENCIJU NA INSTITUTU ZA FIZIKU – PRVI AKREDITIRANI LABORATORIJ S PRIMARNIM VREMENSKIM STANDARDOM U HRVATSKOJ

Institut za fiziku  
Centar za napredne laserske tehnologije  
Laboratorij za vrijeme i frekvenciju

24. travnja, 2026.

11. bionalno savjetovanje Hrvatskog mjeriteljskog društva, 23.-25. travnja 2026.

Neven Šantić, Vjekoslav Vulić Damir Aumiler

[tfl@ifs.hr](mailto:tfl@ifs.hr)

**CALT**  
CENTRE FOR ADVANCED LASER TECHNIQUES

# Grupa za kvantne tehnologije

Institut za fiziku



**Ticijana Ban**  
Senior scientist and team leader



**Damir Aumiler**  
Senior Scientist



**Neven Šantić**  
Research associate

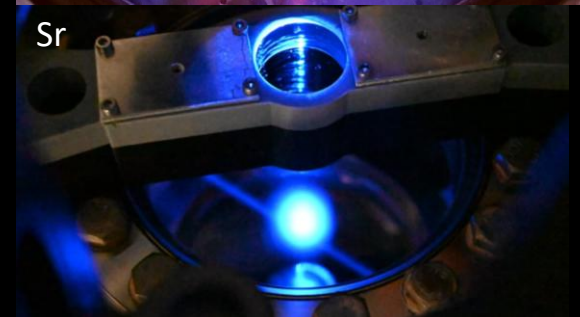


**Ivor Krešić**  
Research associate



**Vjekoslav Vulić**  
Technical advisor

- Prvi hladni atomi u jugoistočnoj Europi u 2011



**Ivana Puljić**  
postdoc



**Johnn Toro**  
PhD student



**Marin Đujić**  
PhD student



**Marko Mandarić**  
PhD student



**Lovre Kardum**  
PhD student



**Tomislav Danielov**  
PhD student



**Juraj Gajović**  
PhD student



INSTITUT ZA  
FIZIKU

**CALIT**

**QUANTIFY**



**QUANTERA**

**EuroQCI**

**HRZZ**  
Croatian Science  
Foundation

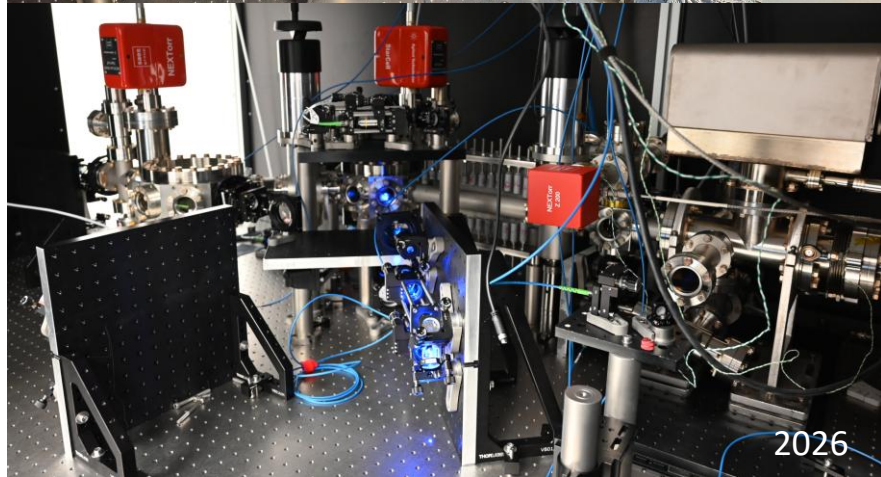
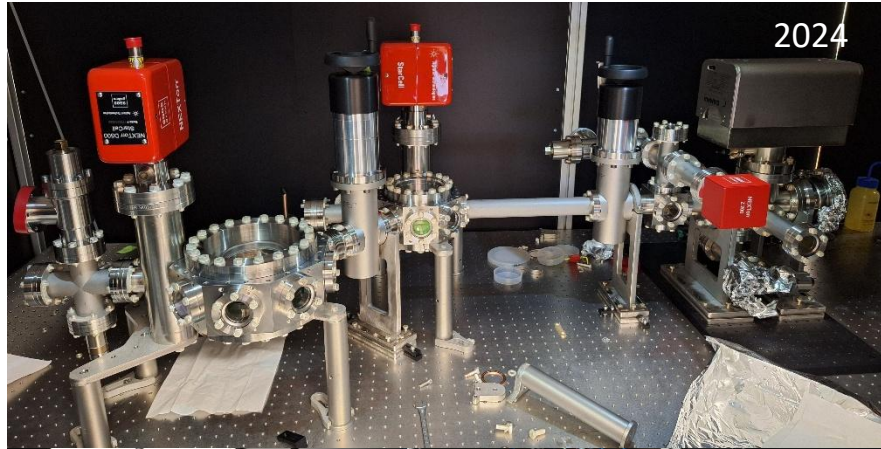


# CALT – Strateški istraživački infrastrukturni projekt Republike Hrvatske

- Cilj projekta: Unaprijediti postojeću i razviti novu istraživačku infrastrukturu temeljenu na naprednim laserskim tehnikama
- Proračun: 16 mil. EUR
- Obuhvat projekta: Rekonstrukcija i dogradnja Instituta za fiziku (3200m<sup>2</sup>)  
Znanstvena oprema  
Osnivanje Centra za napredne laserske tehnike (CALT)  
Osnivanje **Nacionalnog umjernog laboratorija za vrijeme i frekvenciju**
- Trajanje: 1.8.2017. – 31.12.2023.

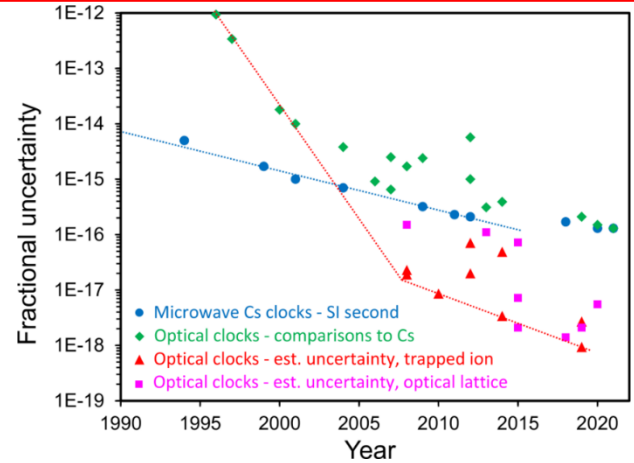


# Sr – optical lattice clock

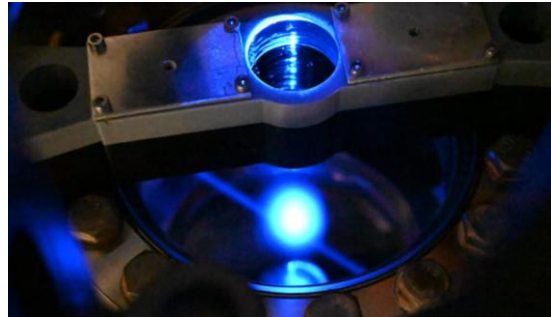


**$^{87}\text{Sr}$  lattice clock, Jun Ye, JILA**

**Preciznost  $\sim 3 \times 10^{-19} \equiv 1 \text{ s}$  in 100 milijardi godina**



Alonso et al., EPJ Quantum Technology 9(1) (2022)



# Laboratorij za vrijeme i frekvenciju (TFL)



Damir Aumiler  
Voditelj laboratorija



Neven Šantić  
Voditelj kvalitete



Vjekoslav Vulić

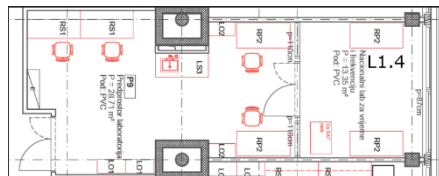


Elinor Trogrlić  
Nije više djelatnik Instituta

## Uvjeti u laboratoriju:

- Temperature:  $(23 \pm 2) \text{ }^\circ\text{C}$
- Relative humidity:  $50 \% \pm 30 \% \text{ RH}$
- Electrical powering:  $230 \text{ V} \pm 5 \%$

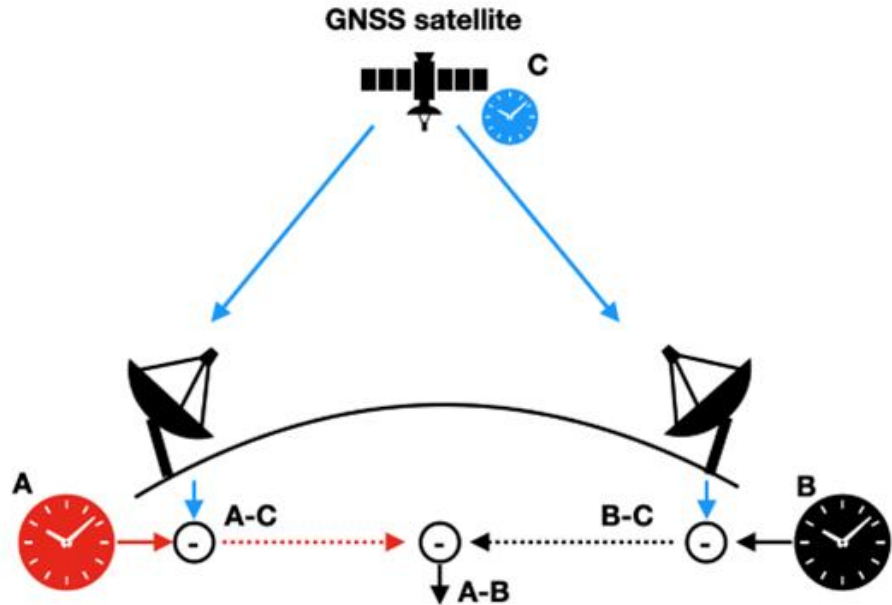
CALT



- 2 x high performance Cs clocks, Mirochip 5071A-C017
- 1 x standard performance Cs clock, Mirochip 5071A-C018
- 2 x GNSS receiver +Choke ring antenna, SEPTENTRIO  
PolaRx5TR + ComNavTechnology SinoGNSS AT600



# GNSS time-transfer



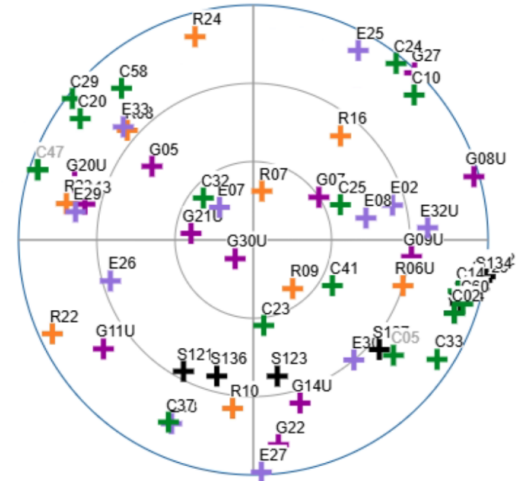
## GNSS



- GPS (Position: 10, Track: 11)
- GLONASS (Position: 7, Track: 10)
- Galileo (Position: 9, Track: 11)
- SBAS (Position: 0, Track: 9)
- BeiDou (Position: 8, Track: 13)
- QZSS (Position: 0, Track: 0)

## Status Settings

### Sky Plot



- GPS
  - GLONASS
  - Galileo
  - SBAS
  - BeiDou
  - QZSS
- Search 18 Tracking 55 Sync 0 Position 34

# Sudjelovanje u UTC-u (koordinirano svjetsko vrijeme)

## Key Comparison: CCTF-K001.UTC

### Circular T, no. 436-April2024

CIRCULAR T 436  
2024 MAY 14, 11h UTC

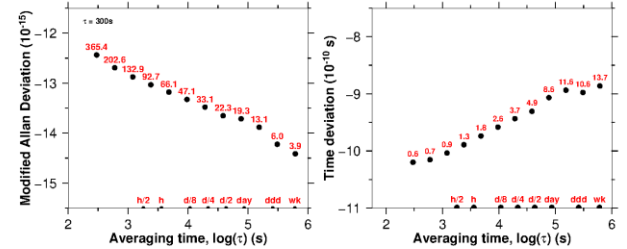
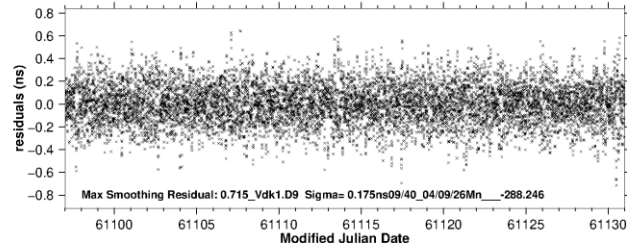
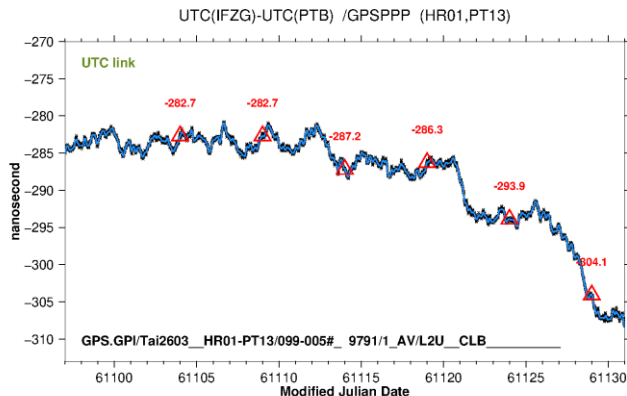
ISSN 1143-1393

BUREAU INTERNATIONAL DES POIDS ET MESURES  
THE INTERGOVERNMENTAL ORGANIZATION ESTABLISHED BY THE METRE CONVENTION  
PAVILLON DE BRETEUIL F-92312 SEVRES CEDEX TEL. +33 1 45 07 70 70 tai@bipm.org

The contents of the sections of BIPM Circular T are fully described in the document "Explanatory supplement to BIPM Circular T" available at [https://webtai.bipm.org/ftp/pub/tai/other-products/notes/explanatory\\_supplement\\_v0.6.pdf](https://webtai.bipm.org/ftp/pub/tai/other-products/notes/explanatory_supplement_v0.6.pdf)

1 - Difference between UTC and its local realizations UTC(k) and corresponding uncertainties.  
From 2017 January 1, 0h UTC, TAI-UTC = 37 s.

Date 2024	0h UTC	MJD	MAR 30	APR 4	APR 9	APR 14	APR 19	APR 24	APR 29	Uncertainty/ns	Notes	
Laboratory k			[UTC-UTC(k)]/ns							uA	uB	u
AGGO (La Plata)			729.2	717.6	712.6	705.5	701.2	680.1	693.8	0.7	3.0	3.1
AOS (Borowiec)			-13.4	-14.0	-15.0	-16.4	-17.3	-18.9	-20.0	0.3	3.5	3.5
APL (Laurel)			-0.4	0.0	0.0	0.0	0.0	-1.1	-0.4	0.3	19.7	19.7
AUS (Sydney)			-331.7	-316.3	-305.9	-277.2	-257.8	-263.9	-243.6	0.3	3.0	3.0
BEV (Wien)			-6.6	0.9	-5.9	-10.8	-16.5	-11.6	-20.6	0.3	3.0	3.0
BFKH (Budapest)			10367.3	10414.3	10466.3	10508.5	10552.4	10600.6	10647.2	0.7	7.1	7.2
BJM (Sofiya)			99.1	146.8	198.9	248.5	295.7	345.5	404.0	0.3	3.0	3.0
BIRM (Beijing)			-1.7	-1.8	-2.4	-2.6	-2.1	-0.4	-1.6	0.3	3.4	3.4
BY (Minsk)			-2.8	-1.1	-2.2	-2.4	-1.6	-1.4	-2.0	1.5	3.1	3.5
CAO (Cagliari)			-11982.7	-	-12203.4	-12326.8	-12445.3	-12561.3	-12679.6	0.7	20.0	20.0
CH (Bern-Mabern)			-0.8	-3.3	-1.9	-1.2	-2.5	-4.1	-1.8	0.3	1.9	1.9
CNES (Toulouse)			-0.9	2.1	-2.6	-5.3	-5.5	2.0	2.3	0.3	3.0	3.0
CNM (Queretaro)			2.2	2.4	3.0	3.2	3.2	4.0	0.4	2.0	4.3	4.7
CNMP (Panama)			6.6	0.6	10.1	6.2	-4.5	-1.8	-10.4	0.3	5.5	5.5
DFM (Horsholm)			-5.4	-5.2	-5.7	-5.7	-2.1	3.8	4.7	0.3	3.0	3.0
DFNT (Tunis)			-1886.0	-1996.4	-2095.7	-2202.2	-2299.6	-2401.0	-2488.4	0.7	20.0	20.0
DLR (Oberpfaffenhofen)			-	-	-	-	-	-	-	-	-	-
DMDH (Belgrade)			-15.0	-5.5	-10.7	2.5	-0.1	-7.0	1.1	0.3	3.9	3.9
DTAG (Frankfurt/H)			47.1	52.2	56.4	66.3	64.7	57.3	48.0	0.3	3.4	3.4
ESA (Noordwijk)			-2.6	-2.3	-3.0	-3.0	-2.4	-1.7	-1.3	0.3	3.0	3.0
HKO (Hong Kong)			81.3	99.7	118.1	123.8	135.6	141.9	149.7	0.7	3.6	3.7
IBM (La Paz)			322.0	328.9	338.4	-	345.5	357.5	359.1	4.0	7.5	8.5
ICE (San Jose)			70.2	70.8	70.6	73.8	70.2	82.5	80.8	0.3	7.1	7.2
IDN (Serpong-Tangerang)			1732.0	34.6	32.3	9.2	7.5	2.2	-8.9	0.7	20.0	20.0
ITAG (Nietzki)			-756.1	-750.7	-747.1	-743.6	-737.4	-732.7	-725.1	0.3	3.1	3.1
IFZG (Zagreb)			-	-17.0	-17.3	-17.2	-17.0	-16.6	-8.8	0.3	3.0	3.0
IGRA (Buenos Aires)			-	-57.7	-460.3	-754.3	-689.3	-746.3	-746.3	0.3	20.0	20.0
IMBH (Sarajevo)			-1.1	-0.8	-0.3	0.3	0.9	1.4	1.4	0.3	3.0	3.0
INCP (Lima)			-14.8	-10.9	0.3	-	-90.3	-75.6	-76.7	5.0	20.0	20.6
INM (Bogota D.C.)			-115.8	-114.3	-107.0	-	-111.3	-110.9	-98.8	4.0	20.0	20.4





## Potvrda o akreditaciji Accreditation Certificate

Ovime se utvrđuje da je  
This is to recognize that

Institut za fiziku  
Centar za napredne laserske tehnike  
Laboratorij za vrijeme i frekvenciju  
Bijenička cesta 46, HR-10000 Zagreb

osposobljen prema zahtjevima norme  
is competent according to  
**HRN EN ISO/IEC 17025:2017**  
(ISO/IEC 17025:2017;  
EN ISO/IEC 17025:2017)  
za/to carry out

Umjeravanje mjerila vremena i frekvencije  
Calibration of time and frequency gougues

u području opisanom u prilogu koji je sastavni dio ove potvrde o akreditaciji.  
for the scope described in the annex which is the constituent part of this accreditation certificate.

Br. No.	Mjerna veličina/ Mjerilo <i>Measurand/ Calibration item</i>	Mjerno područje <i>Measurand range</i>	Uvjeti mjerenja <i>Measurement Conditions</i>	Proširena mjerna nesigurnost <i>Expanded Uncertainty</i>
1.	Frekvencija/ <i>Frequency</i>	3 mHz do/to <1 Hz	generiranje/generating sinusni signal/sine wave gate time = 1000 s	1·10 <sup>-6</sup> Hz
		1 Hz do/to <10 kHz		1·10 <sup>-7</sup> · f
		10 kHz do/to <100 kHz	generiranje/generating sinusni signal/sine wave gate time = 100 s	1·10 <sup>-10</sup> · f
		100 kHz do/to <1 MHz		1·10 <sup>-11</sup> · f
		1 MHz do/to 500 MHz		2·10 <sup>-12</sup> · f
		3 mHz do/to 1 kHz	generiranje/generating pulsni signal/pulse wave gate time = 1000 s	1·10 <sup>-7</sup> · f
2.	Frekvencija/ <i>Frequency</i>	1 Hz, 10 MHz	generiranje/generating 1 PPS pulсни signal ili 10 MHz sinusni signal/ 1 PPS pulse wave or 10 MHz sine wave vrijeme usrednjavanja/ averaging time ≥ 24 h	5,5·10 <sup>-13</sup> Hz/Hz
		1 kHz do/to 40 MHz	generiranje/generating pulsni signal/pulse wave gate time = 100 s	1·10 <sup>-7</sup> · f
3.	Vremenski interval/ <i>Time interval</i>	1 ns do/to 100 s	generiranje/generating	0,6 ns
4.	Porast/pad signala <i>Signal rise/fall</i>	5 ns do/to 10 ns	generiranje/generating	0,4 ns
10 ns do/to 25 ns		0,25 ns + 0,015 · t		
25 ns do/to 10000 ns		0,025 · t		
7.	Razlika vremenskih skala <i>I Time scale difference</i> Lokalni sat prema UTC(IFZG)/Local clock vs. UTC(IFZG)	-1 s do/to 1 s	Pulse amplitude > 1 V	2 ns
8.	Razlika vremenskih skala <i>I Time scale difference</i> Lokalni sat prema UTC/Local clock vs. UTC	-1 s do/to 1 s	Prediction time < 45 days Pulse amplitude > 1 V	40 ns
9.	Razlika vremenskih skala <i>I Time scale difference</i> Lokalni sat prema UTC/Local clock vs. UTC	-1 s do/to 1 s	Pulse amplitude > 1 V	20 ns

# Važnost mjerenja vremena?



Električna mreža



GPS, Galileo



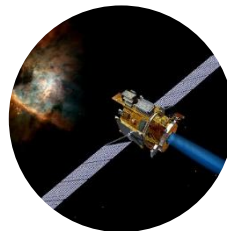
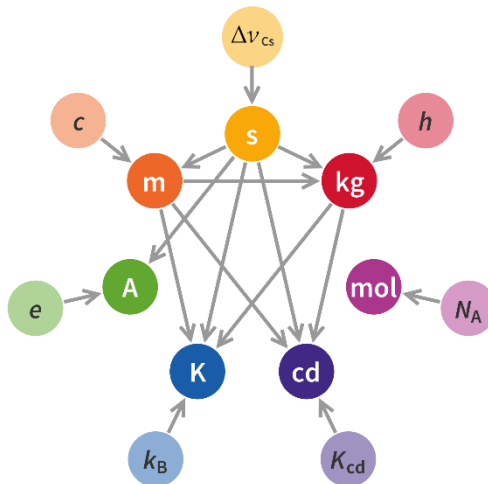
Transakcije



Telekomunikacije



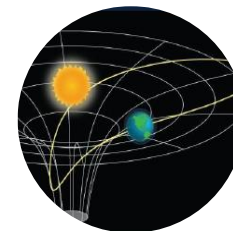
Promet



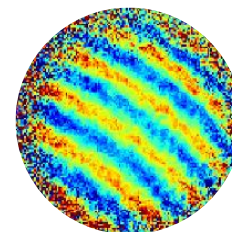
Svemirske misije u dubokom svemiru



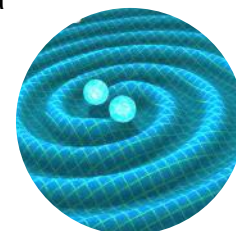
Radio teleskopi



Fizika van stand. modela



Kvantni senzori



Detektori g. v. i tamne materije

- Trenutno se velik dio korisnika oslanja na rubidijevе atomske satove disciplinirane GPS-om

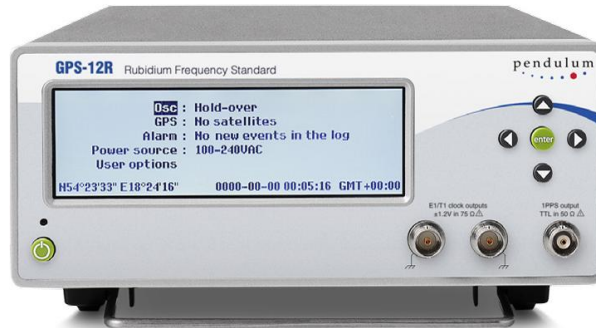
## GPS-12R/HS

GPS-Controlled Frequency Standards

DATA SHEET

pendulum  
.....●

- GPS-controlled Rubidium clock for near-Cesium stability
- Internal battery option for transportation and mains-free field use
- Switchable 1.544 MHz (T1) or 2.048 MHz (E1) front-panel outputs for telecom
- 1 PPS/10 MHz square wave front-panel output
- 3x 10 MHz and 1x 5 MHz sine rear-panel outputs for lab bench and test systems (house standard)
- 1, 5 & 10 MHz optional low-noise sine outputs for general lab use (rear panel)
- GPS-12 Monitor, Control and Monitoring SW



## Nedostaci

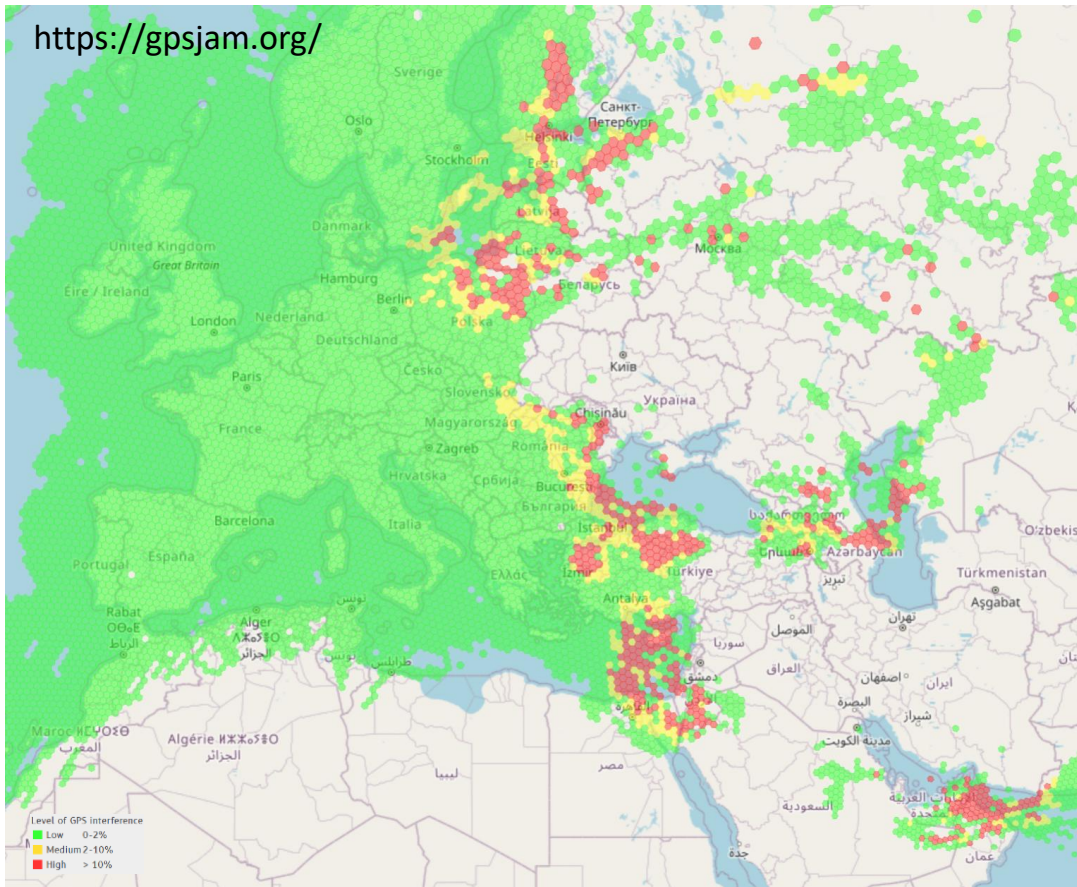
- Većina koristi samo **GPS** (ne i Gallileo)
- Odmak od UTC-a u slučaju nestanka GPS signala (**best case scenario!**):

≈ 1 μs po danu

- Ključna infrastruktura** se oslanja na GPS vrijeme:
  - Energetska mreža
  - Telekomunikacijske mreže
  - Financijske transakcije
  - Promet

# Diseminacija vremenske skale

<https://gpsjam.org/>



## Rusi ometaju GPS signal, Finci pauziraju dio letova prema Estoniji

Index Vjesti  
16.38, 29. travnja 2024.

### ELEKTRONIČKO RATOVANJE

## Misteriozni 'valovi' šire se iz Kalinjingrada, NATO očajan: 'Što se događa? Gubimo GPS signal!'



Incident se dogodio upravo kada na Baltiku započnuju najveće vježbe NATO-a od kraja Hladnog rata

Foto: T.S. | Objavljeno: 23. ožujka 2024. 18:24

LINAD BUGARSKÉ

## Drama na nebu. Ursula von der Leyen prisilno sletjela. Rusi ometali GPS zrakoplova

Foto: Filip Sulmasy, ponedjeljak, 1.9.2025. u 11:25

Čitanje članka: 2 min



10 mW



4 x 300 mW



240 W

GNSS jammeri

# Diseminacija vremenske skale

- Stratum 1 NTP server: **time.ifs.hr**
- Time as a service:  
Putem White Rabbit protokola - baza za novi PTP standard IEEE-1588-2019 High Accuracy Default profile

@ IF



Z16



Stabilnost:  
1  $\mu$ s u > godinu dana

@ korisnici

TP-FL



TP-FL



TP-FL



fiber

fiber

fiber



# LABORATORIJ ZA VRIJEME I FREKVENCIJU NA INSTITUTU ZA FIZIKU – PRVI AKREDITIRANI LABORATORIJ S PRIMARNIM VREMENSKIM STANDARDOM U HRVATSKOJ

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Neven Šantić, Vjekoslav Vulić Damir Aumiler

[tfl@ifs.hr](mailto:tfl@ifs.hr)

**CAL T**  
CENTRE FOR ADVANCED LASER TECHNIQUES

**HVALA!**