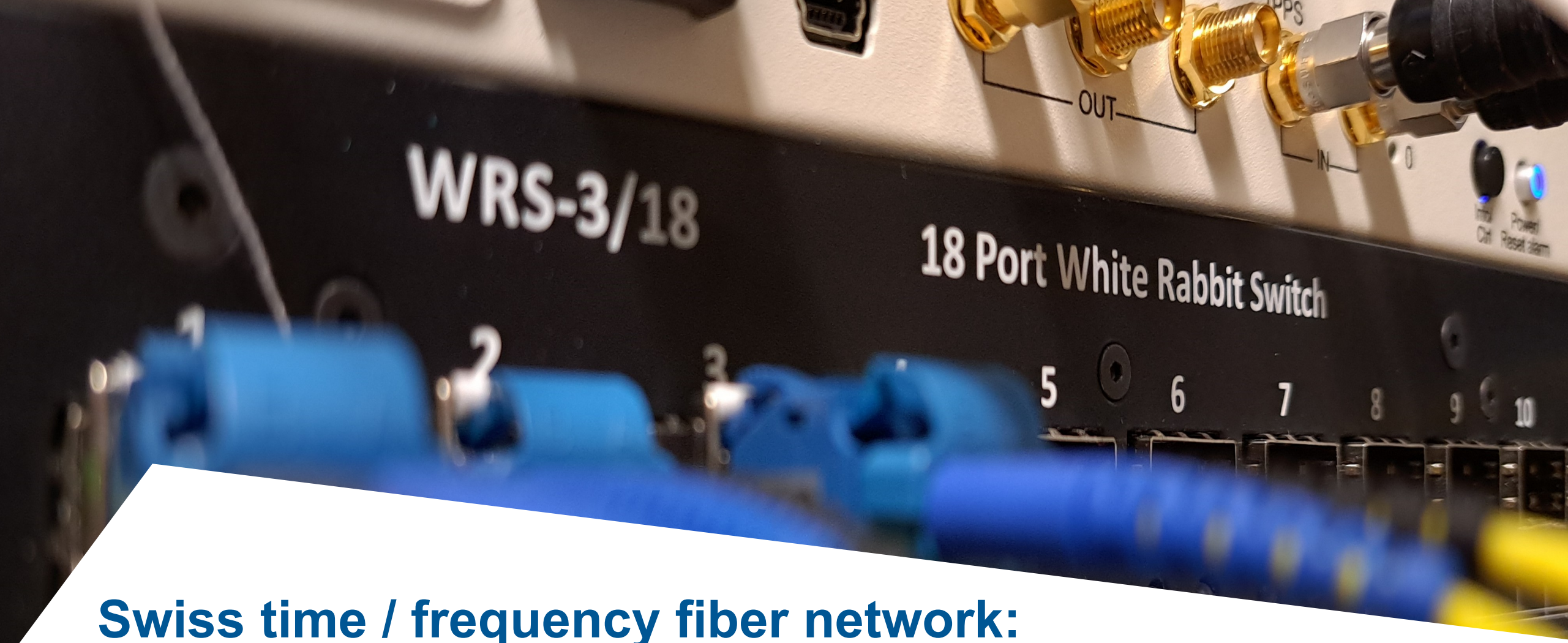


Swiss time / frequency fiber network: Metrology and Sensing

Dominik Husmann

November 19, 2025. Grenoble

Outline

1. Overview: Time and frequency at METAS

2. Time/Frequency dissemination
   - White Rabbit
   - Stabilized optical frequency

3. Fiber sensing

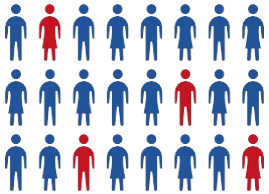
4. Conclusion and Outlook

METAS
METAS is the Swiss Federal Government's competence center for all questions relating to measurement, measuring equipment and measuring methods.

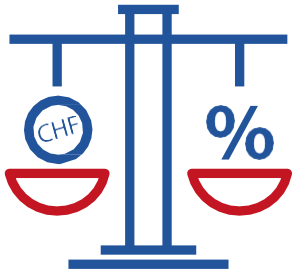
METAS in figures

53,1 MCHF
sales volume

1,2 MCHF
profit



255
employees



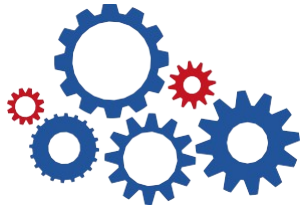
55 %
degree of self-financing

79,7 % German

3 % Italian

17,3 % French

4/5 with a scientific-technical background



20
training places

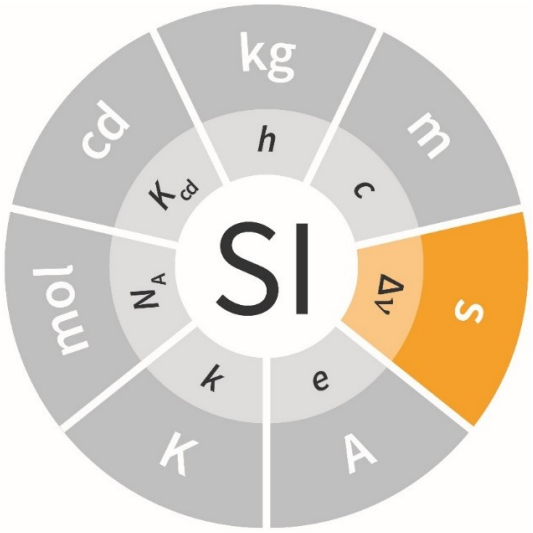
20
apprenticeships

6 internships

2
doctoral students

80,6 %
men

19,4 %
women



Time and frequency at METAS

Legal basis

941.27

Loi
sur l'Institut fédéral de métrologie

(LIFM)

du 17 juin 2011 (Etat le 1er janvier 2013)

L'Assemblée fédérale de la Confédération suisse,

vu l'art. 125 de la Constitution[1],
vu le message du Conseil fédéral du 27 octobre 2010[2],

Section 2 Tâches et collaboration

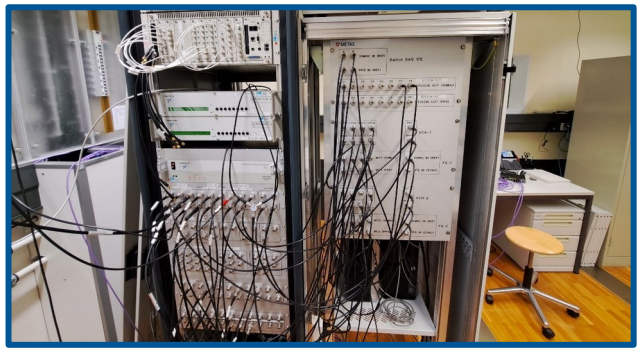
Art. 3 Tâches

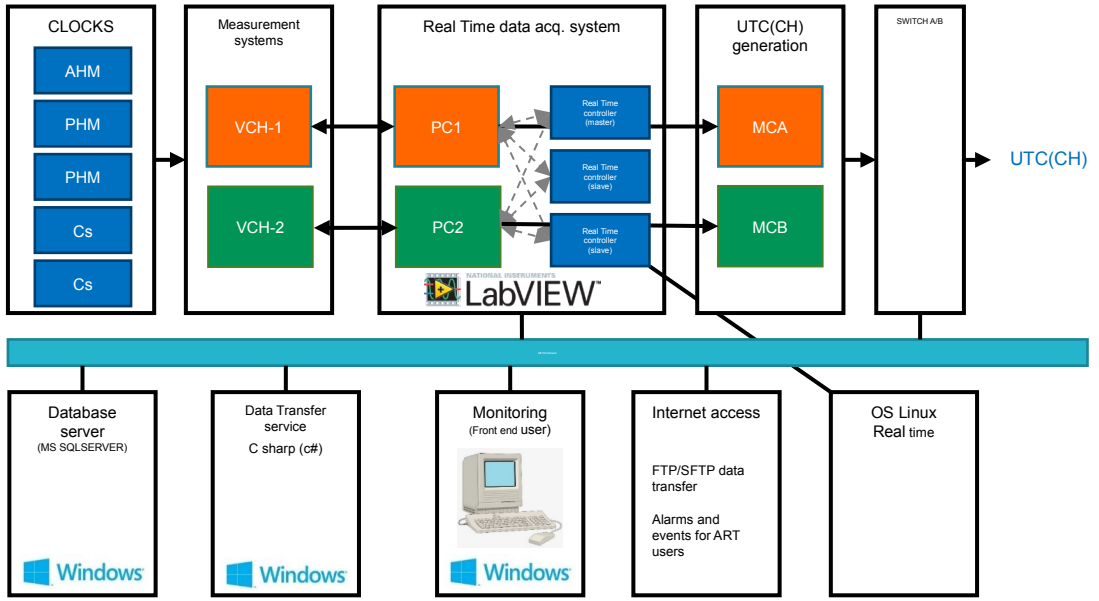
[1] L'Institut est l'institut national de métrologie de la Suisse.

[2] Il a les tâches suivantes:

a. mettre à disposition avec la précision requise des unités de mesure reconnues au niveau international;
b. comparer, à des intervalles appropriés, les étalons à ceux des autres instituts nationaux de métrologie ou des institutions comparables;
c. diffuser l'heure légale suisse;
d. entreprendre les travaux techniques et scientifiques et les travaux de développement nécessaires, analyser, notamment, les conséquences des techniques nouvelles et élaborer des méthodes de mesure ayant une application pratique et répondant à l'état le plus récent des connaissances scientifiques;
e. exercer les tâches qui lui sont conférées par la loi fédérale du 17 juin 2011 sur la métrologie[3];
f. participer à la coopération technique dans le domaine de la métrologie;
g. conseiller les autorités fédérales dans le domaine de la métrologie;
h. assurer la traçabilité des étalons des organes d'exécution cantonaux;
i. diffuser les unités de mesure visées à la let. a par des étalonnages et à l'aide de matériaux de référence.

The Swiss realization of UTC: UTC(CH)

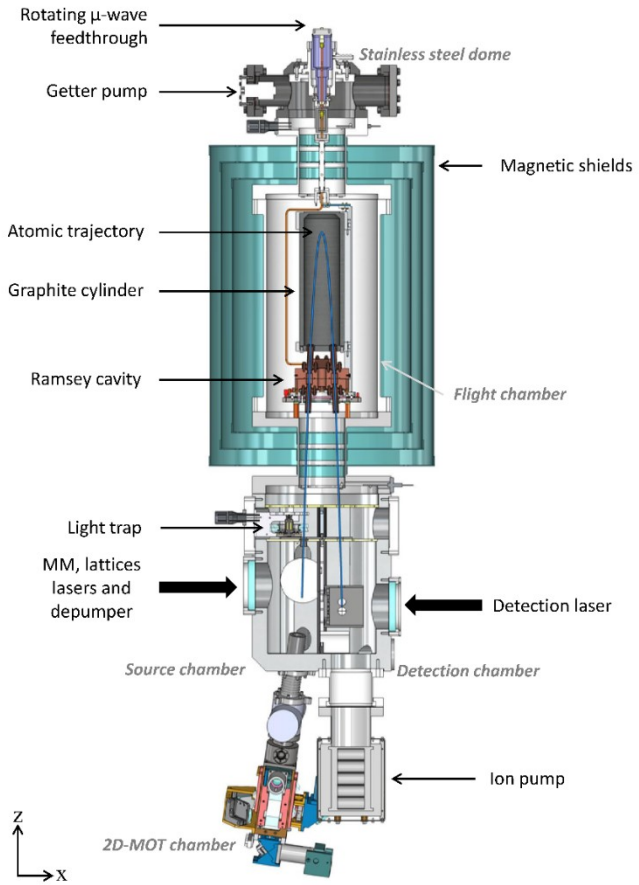


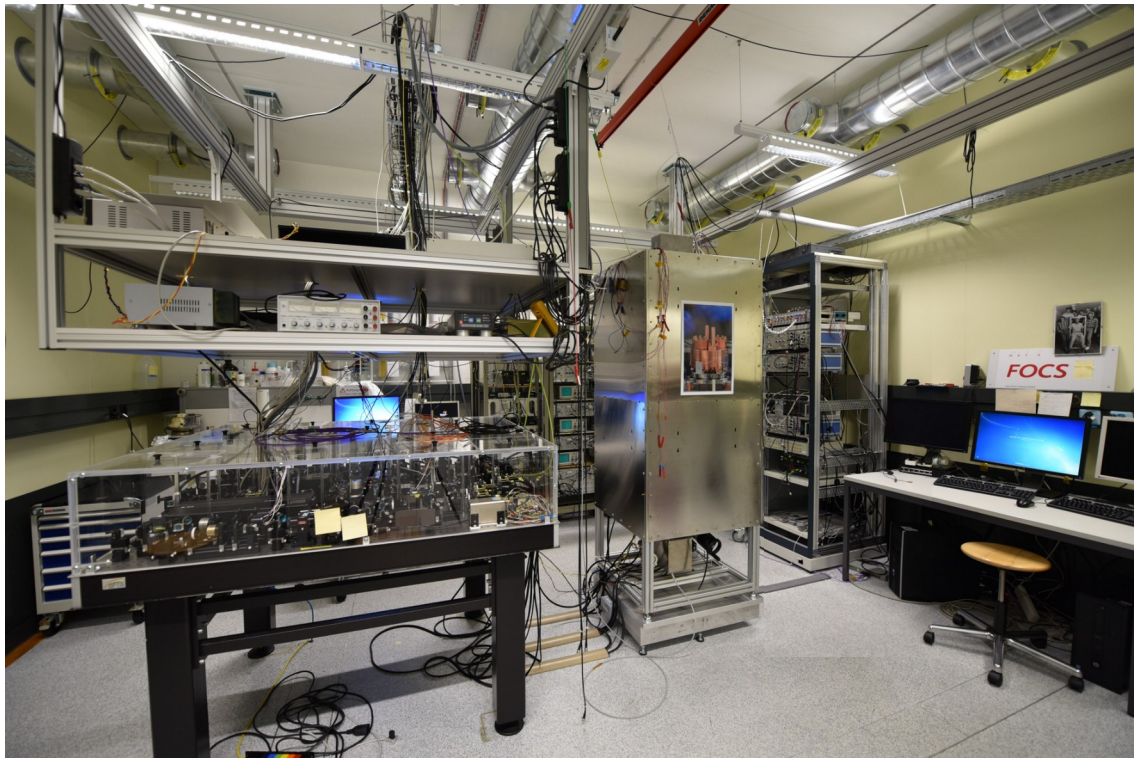


Physical signals:	1-PPS	
	10 MHz	

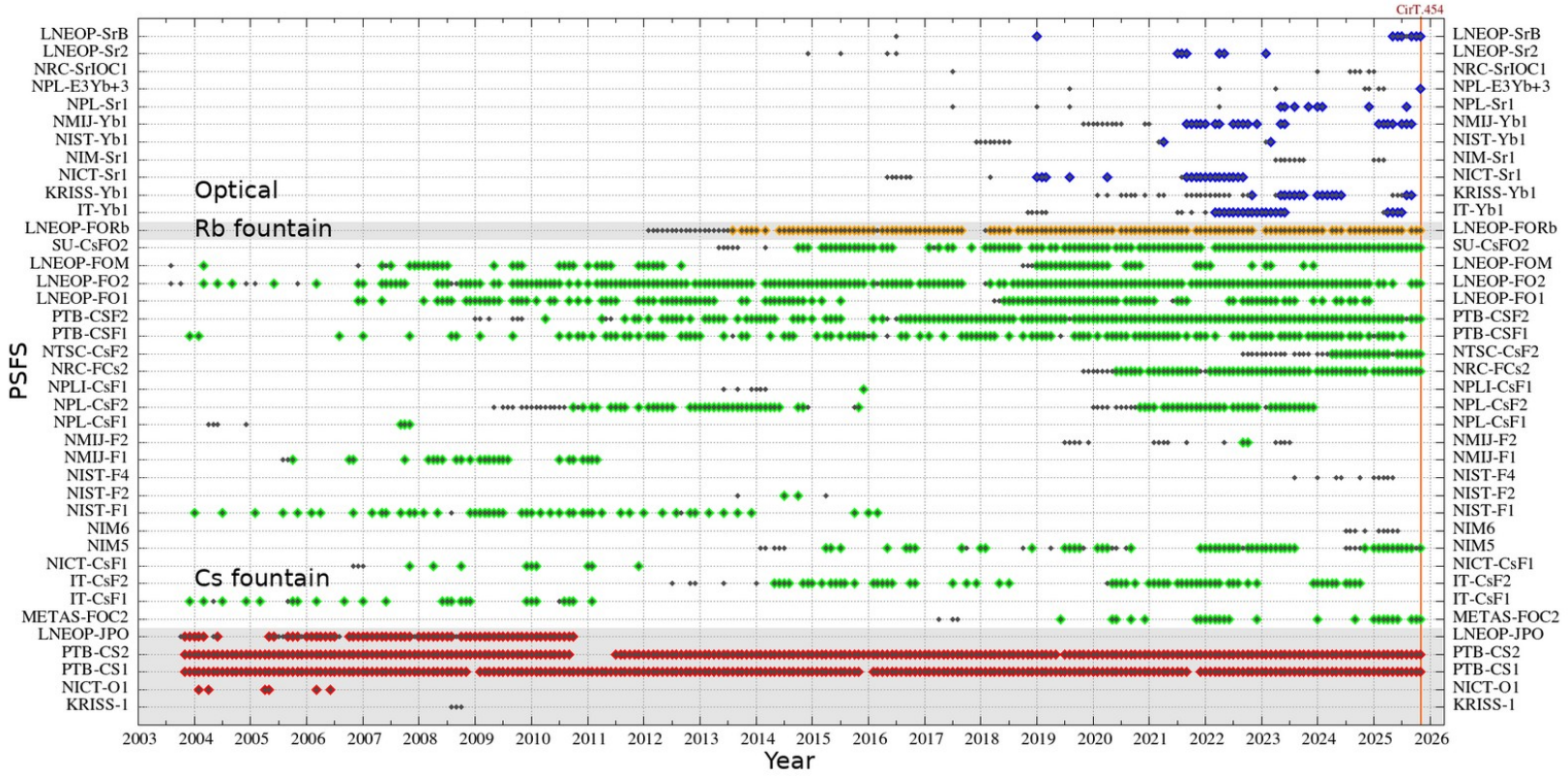
- 5 atomic clocks
- Full redundancy guarantees continuity even in case of critical failures
- GNSS receivers and a TWSTFT station for international time comparison

FoCS-2: Caesium Fountain Clock

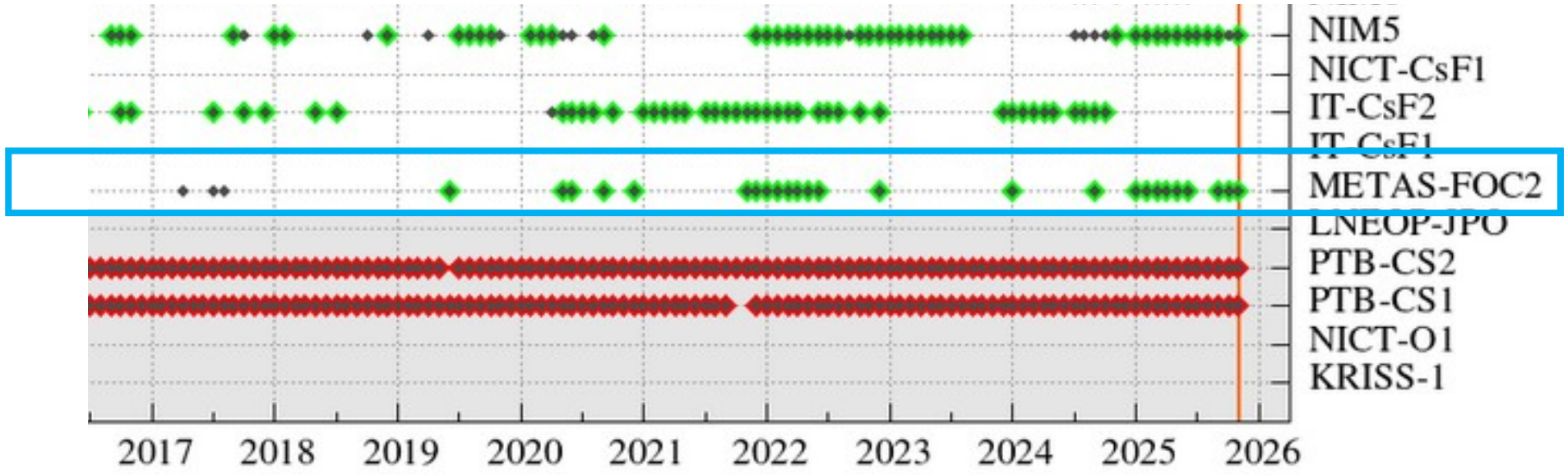




FoCS-2 contribution to TAI



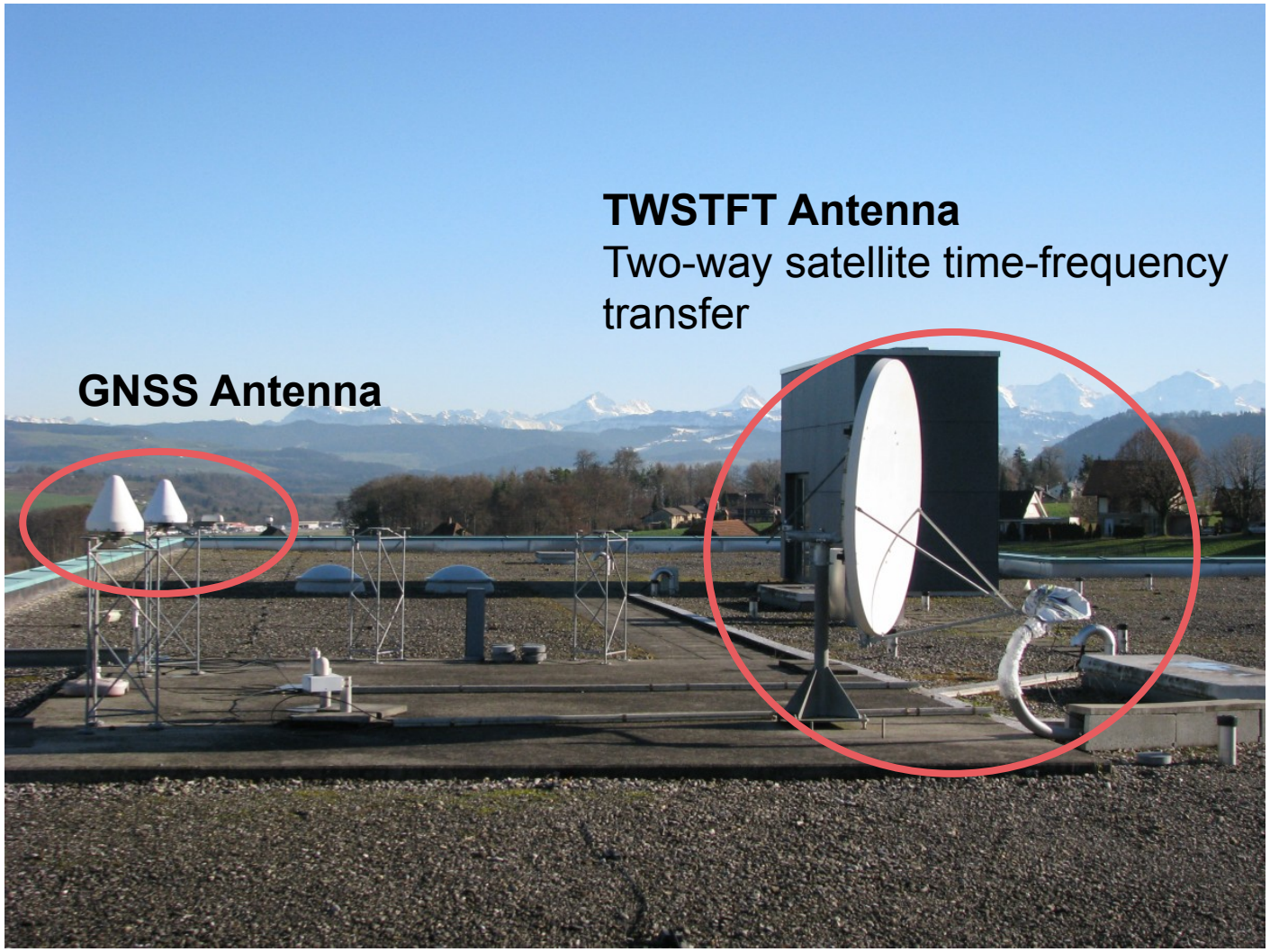
FoCS-2 contribution to TAI



Federal palace

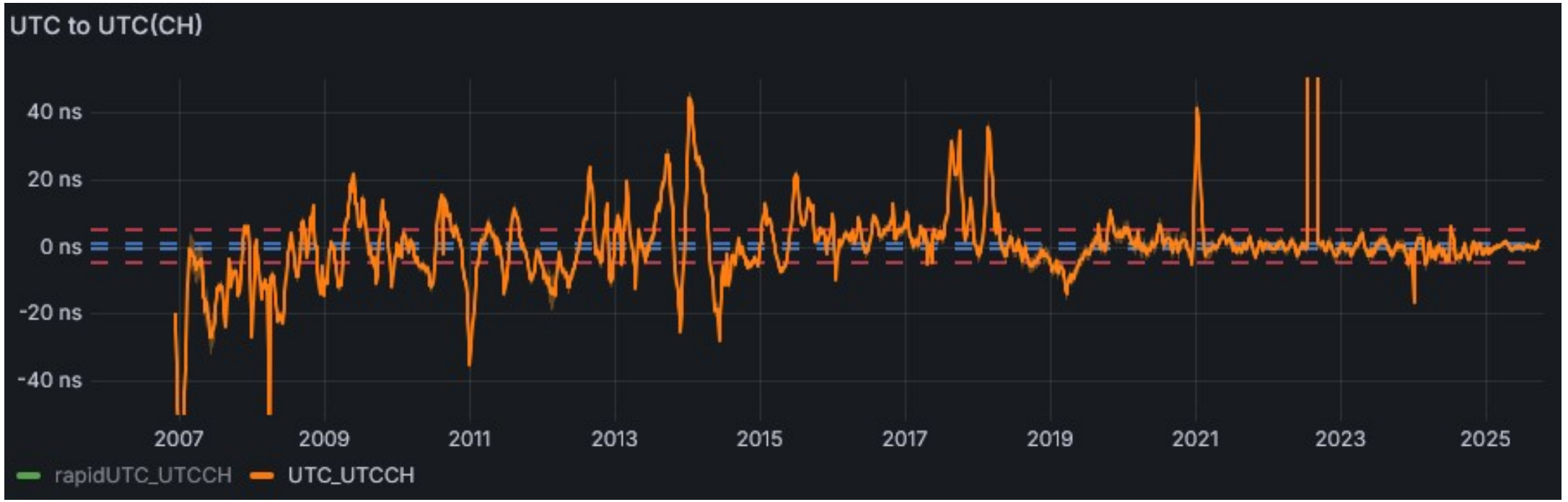
METAS

International UTC comparison via satellite



UTC(CH) over the last 20 years

- Today, UTC(CH) is typically within 1 nanosecond in agreement with UTC



Metrology + Networks

NMIs

- National Metrology Institutes (NMIs) have the **metrological basis** in the form of atomic clocks and international interconnectivity
- They host state-of-the-art time and frequency references
- SI-traceable via international comparisons

NRENs

- National Research and Education Network providers (NRENs) have the **network** know-how, infrastructure and connectivity to the researchers and host institutes
- Provides fiber network access between NMIs and academic institutes

- Since 2019, METAS and Switch are working together to bring accurate, stable and reliable time and frequency references to Swiss research institutes and industry.
- Two key technologies were evaluated and implemented, to be presented in the following.

Overview: T/F Dissemination

METAS

	White Rabbit	Optical frequency dissemination
Performance	Synchronicity • < 0.1 nanosecond Uncertainty from UTC(CH) • ~ 0.5 nanosecond	Fractional frequency stability • 10^{-13} short term • 10^{-15} long term • 10^{-19} link limit
Network load	CH84+85 (1590 nm +1591 nm)	CH07 (1572.07 nm)
Stakeholders	Industry • Clock/watch industry, fintech, telecom, Defense, PNT, public transport • General: companies that require resilience for GNSS receivers Research • Information technology • Astrophysics • Large-scale facilities	Industry • Atomic clock manufacturers • Laser industry Research • Fundamental physics • Precision spectroscopy • Geophysics
Initial push	Industrial (finance, defense)	Scientific (precision spectroscopy)

White Rabbit network

“TDIS” – Time Dissemination

TDIS collaboration

METAS	Swiss National Institute of Metrology
Switch	Swiss National Research and Education Network (NREN)
Schweizerische Eidgenossenschaft Confédération suisse Confederazione Svizzera Confederaziun svizr armasuisse Office fédéral de l'armement	Swiss Federal Office for Defence Procurement
SIX	Company in the finance sector

White Rabbit for UTC(CH) dissemination

Jallageas et al., JOCN,
Vol. 17, Issue 7, 631-637, 2025
10.1364/JOCN.560593

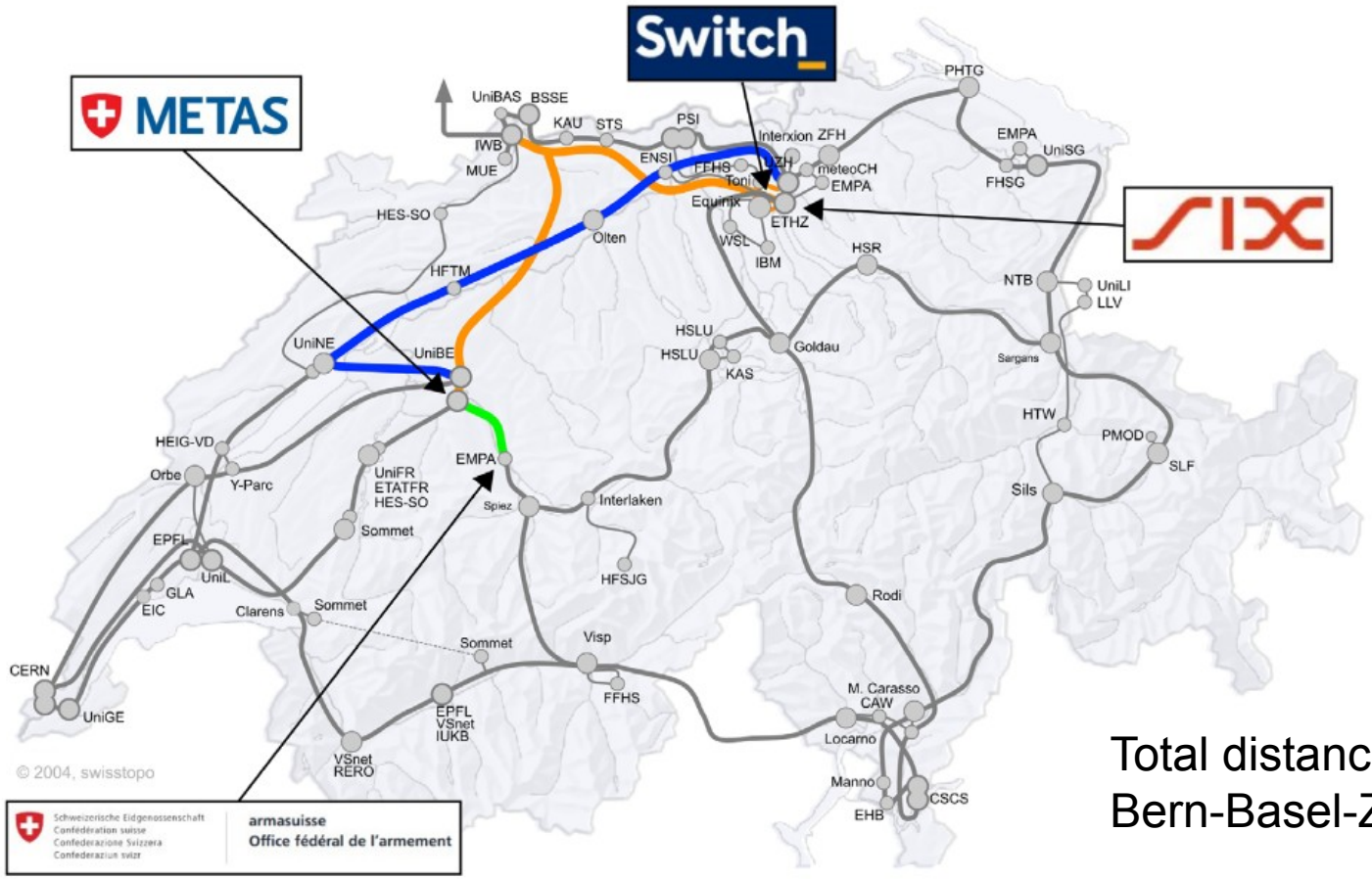
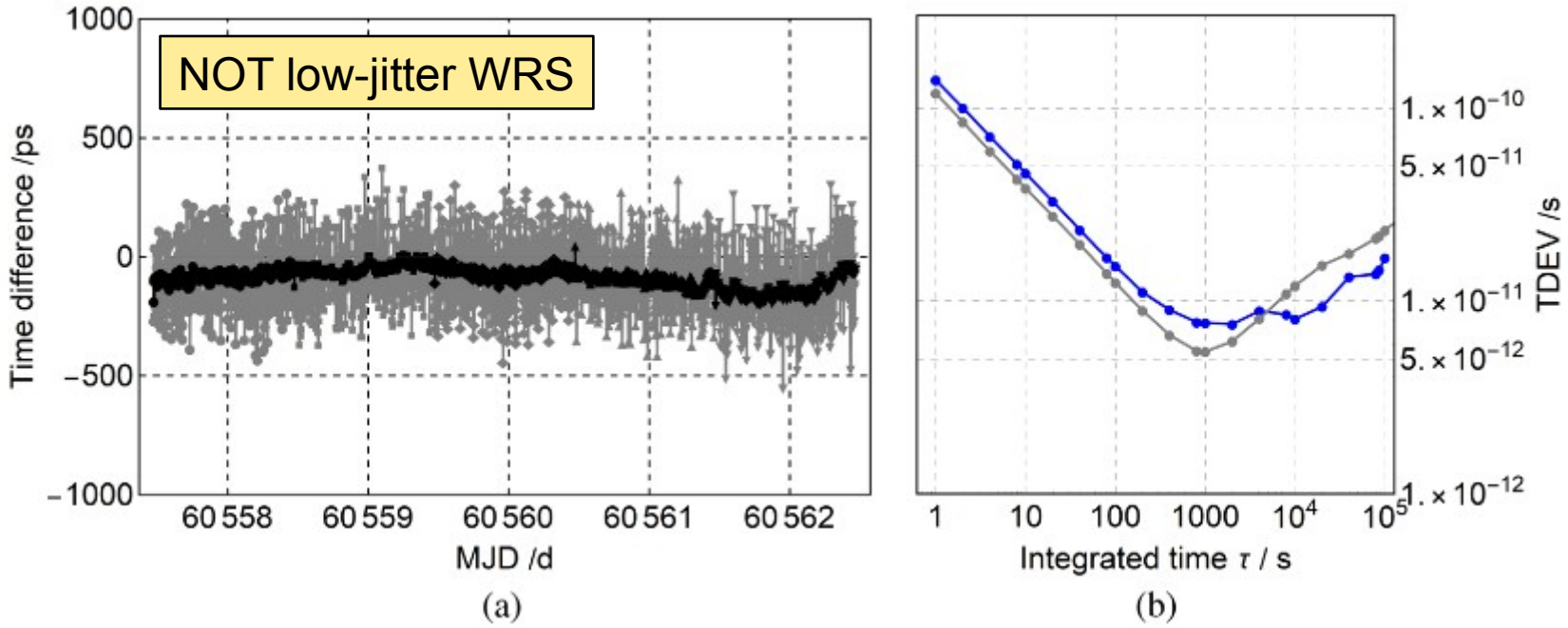


Table 1. Summary of All WR Devices in the Network, with Their Location, Device Type, and Distance Covered by the Network Segment Following the Device[a]

Location	Device	Distance (km)
METAS	WRS	7.5
UniBE	WRS	108.8
Basel	WRS	102
Zurich ETH	WRS	5.5
Zurich SIX	WRS	88
Olten	Repeater	96
Neuchâtel	WRS	83.6
METAS	WRS	—

Total distance: 491 km
Bern-Basel-Zurich-Neuchatel-Bern

Result



- **Total span of 491 km**
- **Multiplexed into Switch telecommunication network**
- **DWDM L-band, spectrally separated from data traffic**
- **Total uncertainty of disseminated UTC(CH): - 84 +/- 415 ps**

Jallageas et al., JOCN,
Vol. 17, Issue 7, 631-637, 2025
10.1364/JOCN.560593

Wrap-up White Rabbit

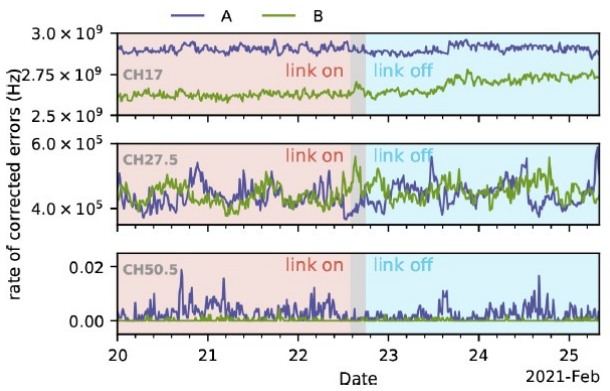
- A core network connecting Bern, Basel, Zurich, Neuchâtel is up and running on the Switch fiber network
- Together with Switch, we are discussing with potential clients and stakeholders in industry, to provide time via White Rabbit as a service
- So far, users are all in industry. However the service being advertised to the academic institutions and their IT/network representatives.

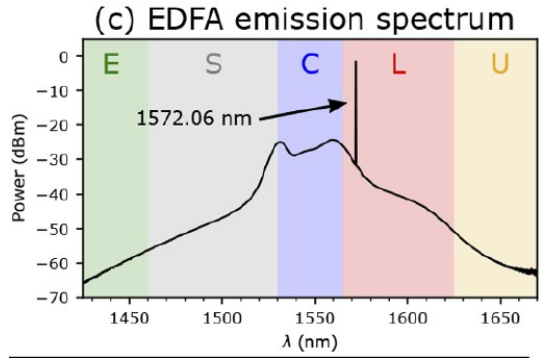
METAS

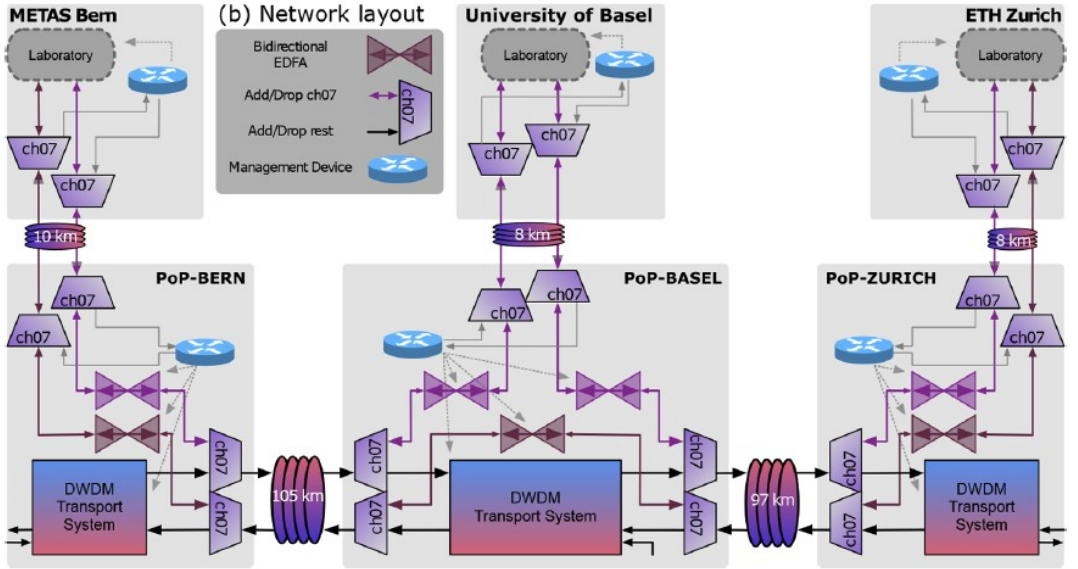
Swiss Frequency Link

Swiss optical frequency metrology network

- Dissemination optical reference frequency to academic institutes via fiber network
  - ETH Zurich
  - University of Basel
- Traceable to SI second
  - optical → maser → UTC(CH) → TAI → TT
- Today's users
  - Prof. Stefan Willitsch (UniBasel)
  - Prof. Frédéric Merkt (ETHZ)
  - Main application: referencing lasers used in precision spectroscopy lasers
- Network implementation:
  - Optical signal in L-band ITU-T Channel 07 (190.7 THz)
  - DWDM network architecture, shared with data traffic
  - Bidir EDFAs optimized for L-band
  - Active noise suppression by phase noise cancellation, provided by INRIM

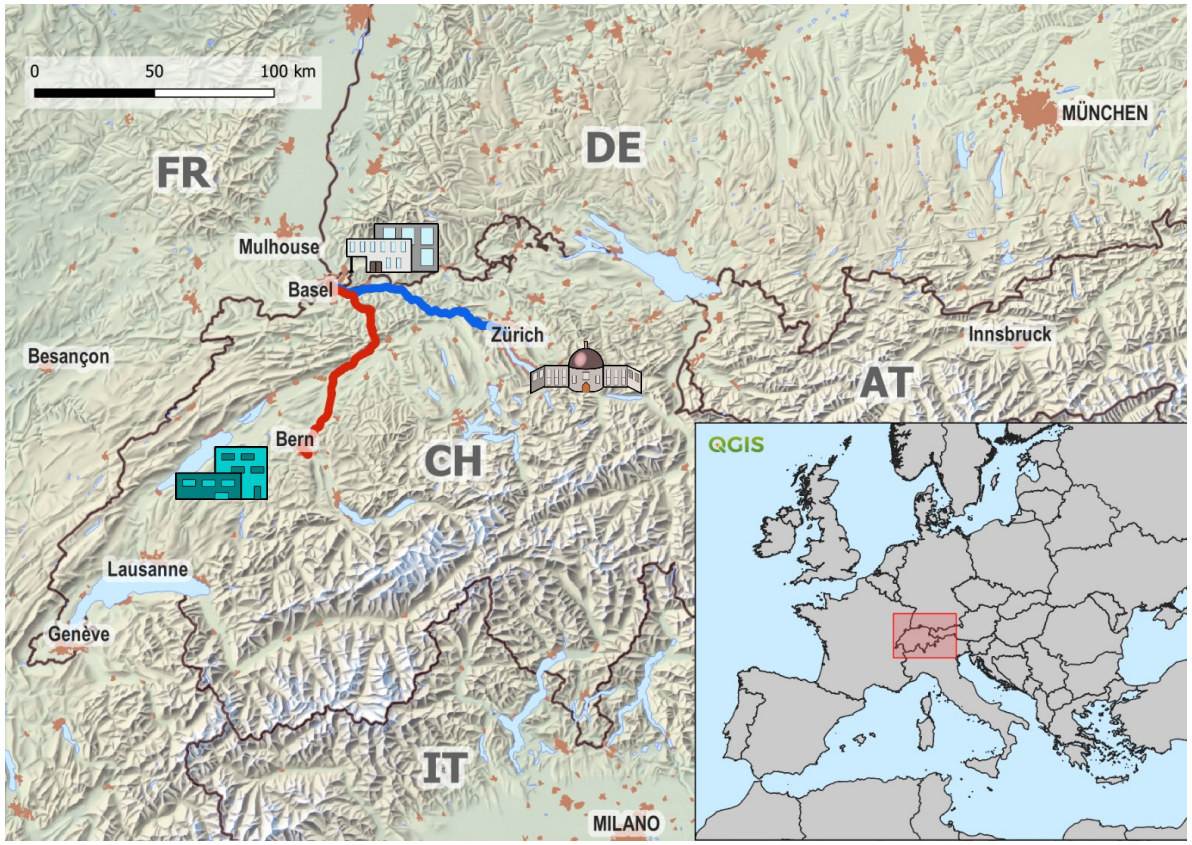




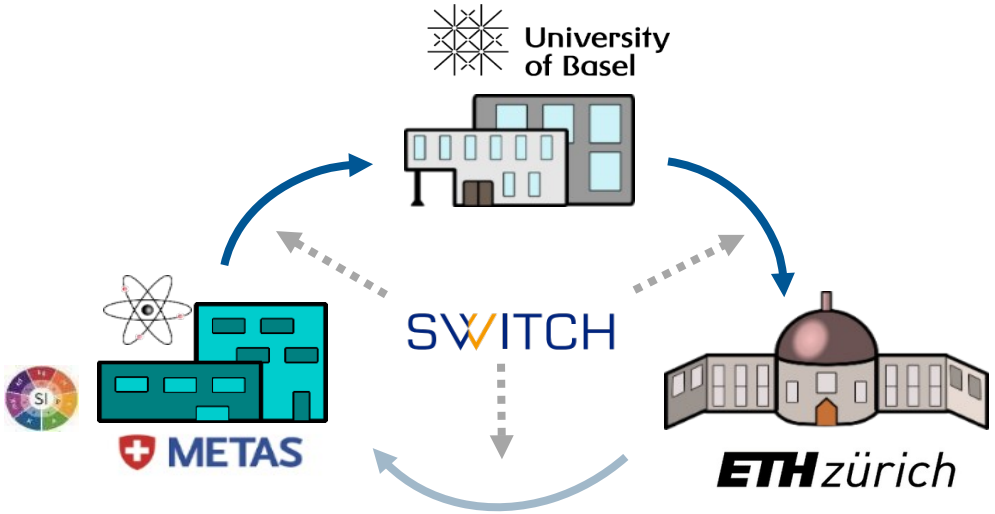


Figures from D. Husmann et al., **Opt. Express 29 (2021) 24592-24605**

Swiss optical frequency metrology network

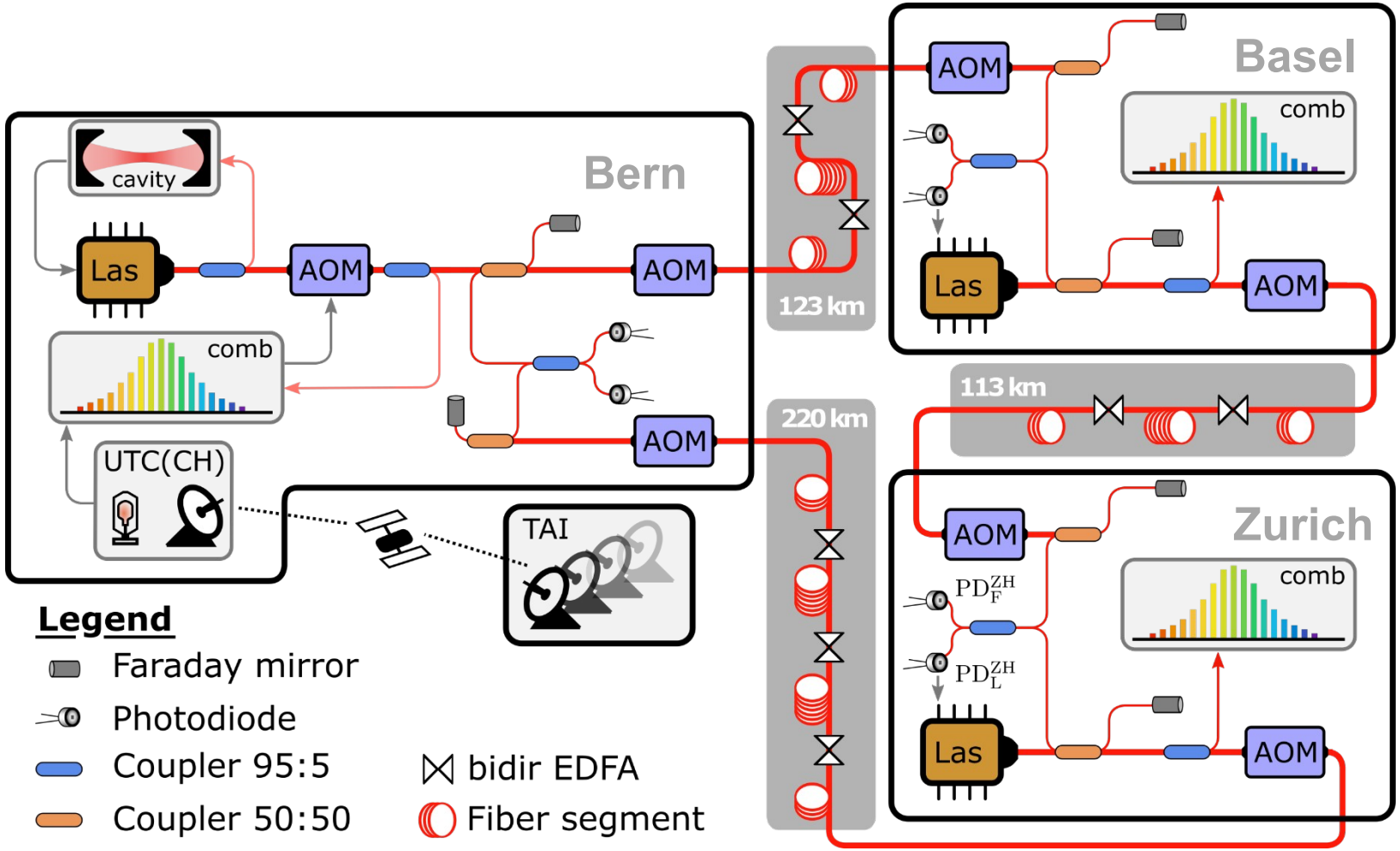


Geodata Source: Bundesamt für Landestopografie
Map created using the Free and Open Source QGIS



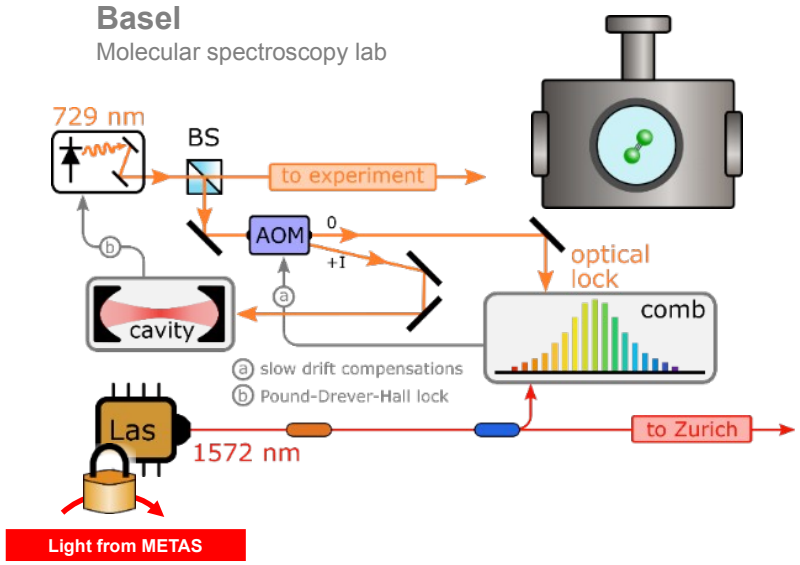
Item	Value
Operating wavelength	1572.06 nm
ITU-T Channel	CH07
Total length	456 km
# Segments	3
# Bidir EDFA	2 / 2 / 3
# Regeneration stations	2 (Basel, Zurich)

Implementation and traceability

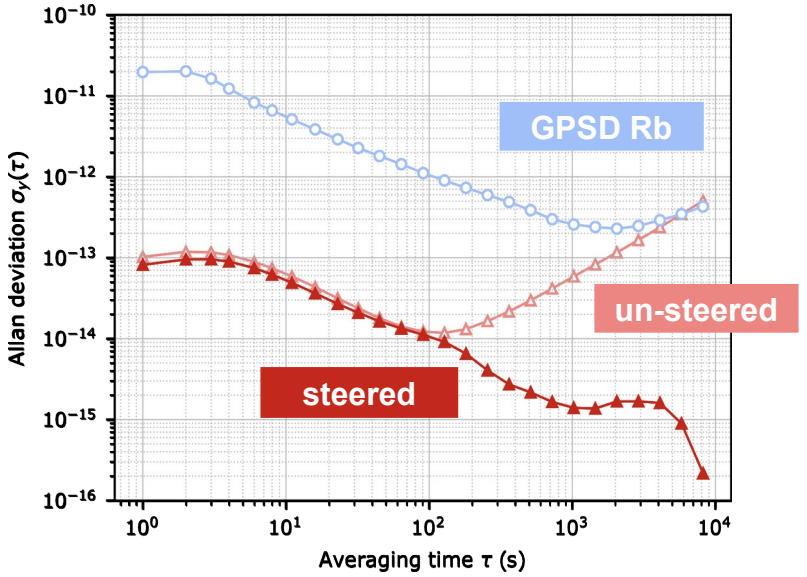


DH et al., Optics Express
Vol. 29, Issue 16, 24592-24605, 2021
10.1364/OE.427921

Applications of the reference frequency



Measured frequency uncertainty of a spectroscopy laser in Basel



Precision-Spectroscopic Determination of the Binding Energy of a Two-Body Quantum System: The Hydrogen Atom and the Proton-Size Puzzle

Simon Scheidegger and Frédéric Merkt
Phys. Rev. Lett. **132**, 113001 – Published 11 March 2024

FEATURED IN PHYSICS | EDITORS' SUGGESTION

Ionization Energy of Metastable ^{3}He ($2\,^3S_1$) and the Alpha- and Helion-Particle Charge-Radius Difference from Precision Spectroscopy of the np Rydberg Series

Gloria Clausen[1] and Frédéric Merkt[1,2,3]

Frequency stabilisation and SI tracing of mid-infrared quantum-cascade lasers for precision molecular spectroscopy

Mudit Sinhal, Anatoly Johnson & Stefan Willitsch

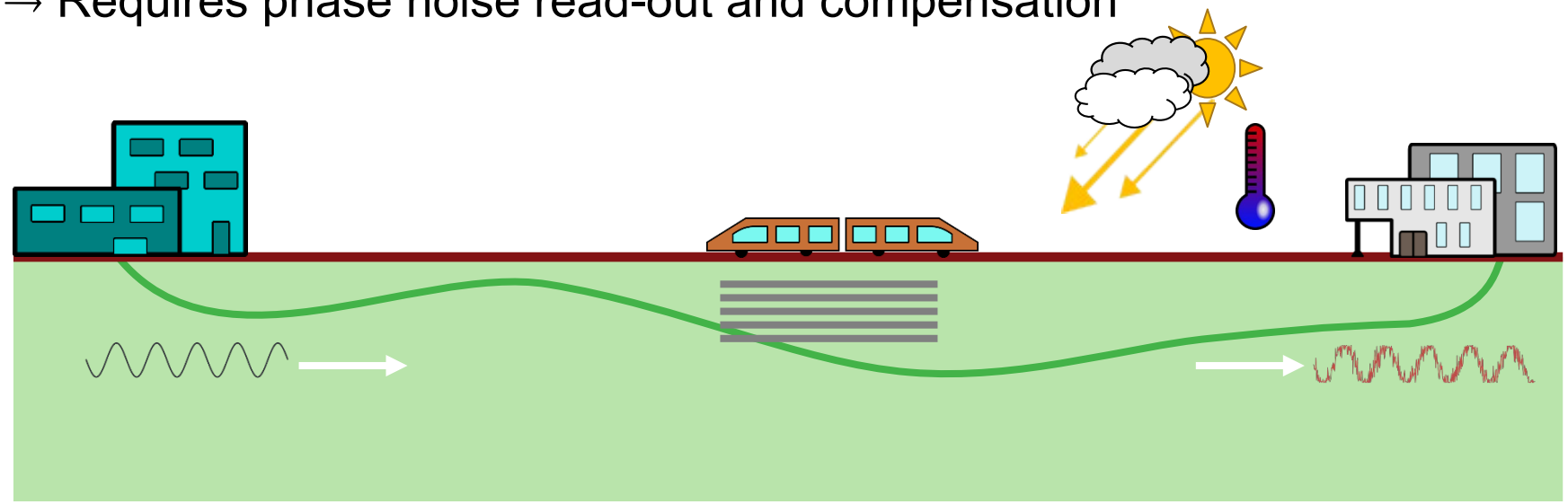
Article: e2144519 | Received 14 Sep 2022, Accepted 27 Oct 2022, Published online: 14 Nov 2022

Monitoring remote cavity drifts

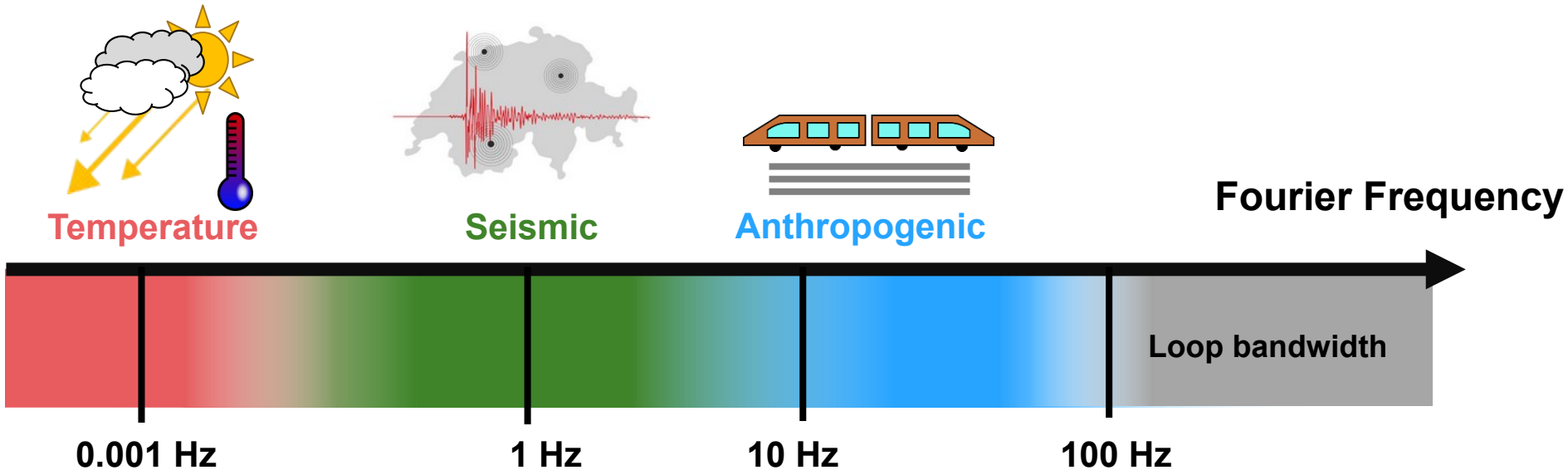
Fiber sensing

Phase noise cancellation

- Fibers act as microphones …
- … picking up noise from environment (temperature, acoustic vibrations)
- Causes variation of optical path length and thus phase
- Distorts the stable frequency at the recipient end
- → Requires phase noise read-out and compensation

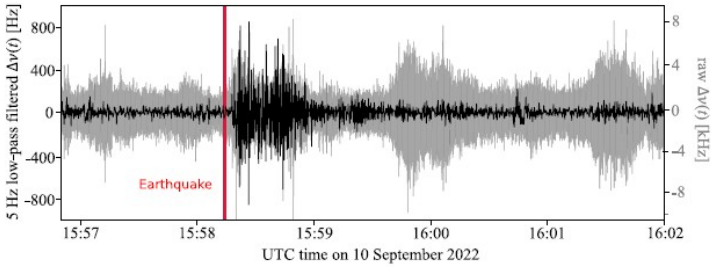


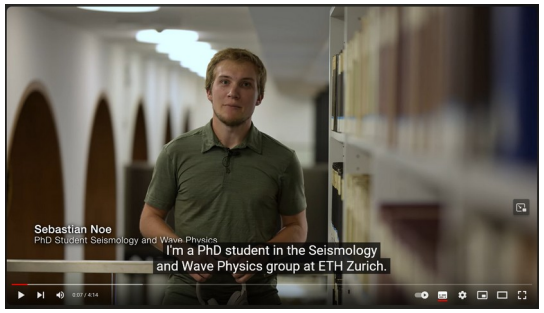
Time scales of observed processes



Signals on the fiber: seismic

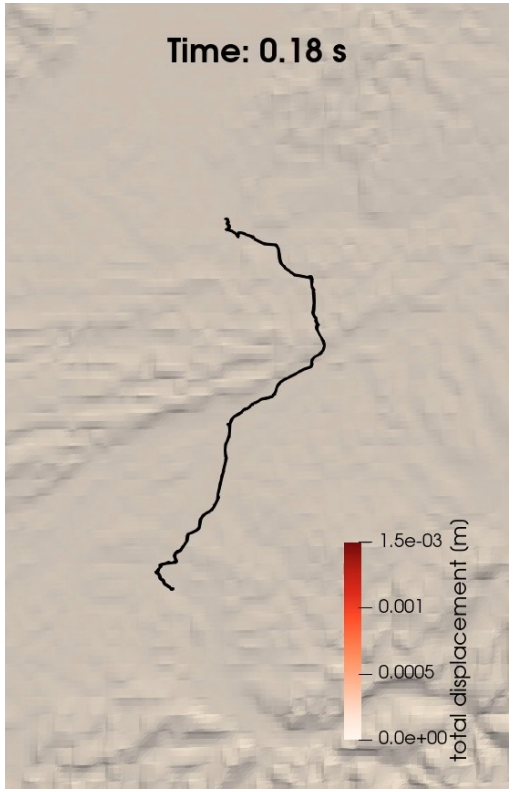
Seismic signals
Sept 10, 2022: Mulhouse Earthquake Mag 3.9



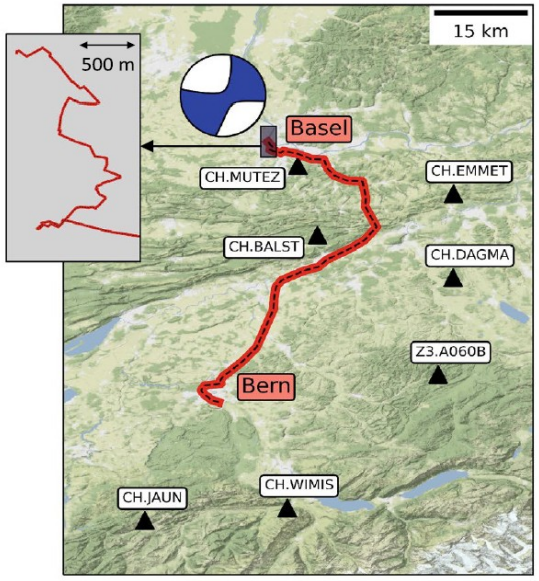


Sebastian Noe (check out youtube movie!)

Prof. Andreas Fichtner



- Simulate impact on fiber, based on 1-D seismic velocity model
- Quantitative agreement between model and data



Article | Open access | Published: 26 August 2023

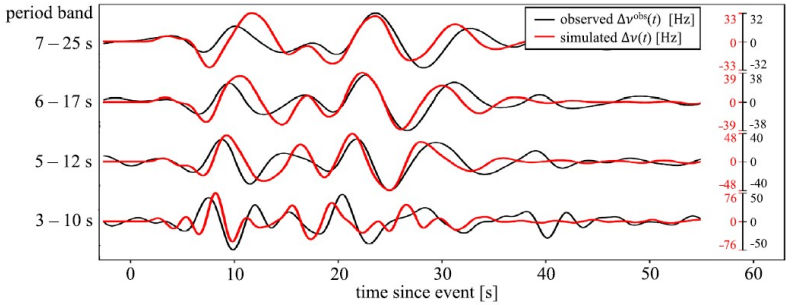
Long-range fiber-optic earthquake sensing by active phase noise cancellation

Sebastian Noe, Dominik Husmann, Nils Müller, Jacques Morel & Andreas Fichtner

Earthquake source inversion by integrated fiber-optic sensing

Nils Mueller [1], Sebastian Noe [1], Dominik Husmann [2], Jacques Morel [2], Andreas Fichtner [*1]

[1]Department of Earth Sciences, ETH Zurich, Zurich, Switzerland, [2]Swiss Federal Institute of Metrology, METAS, Bern, Switzerland

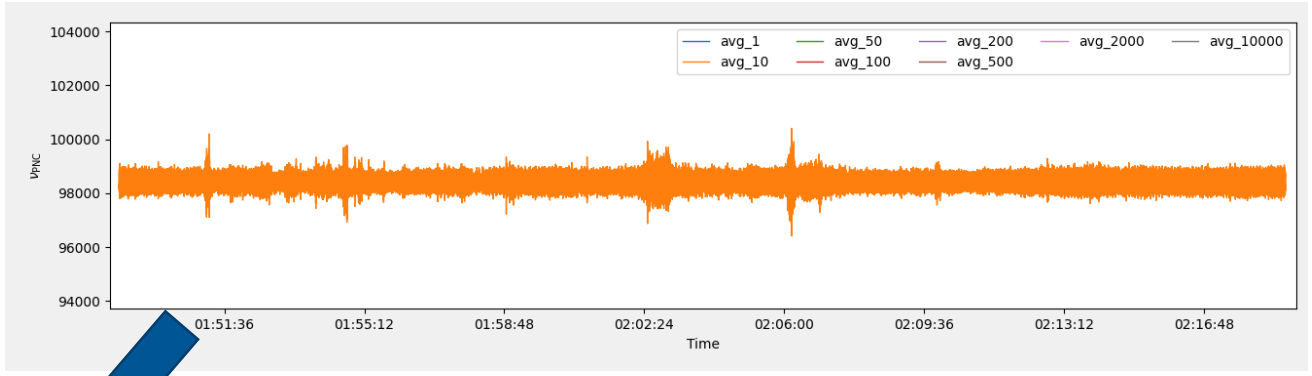


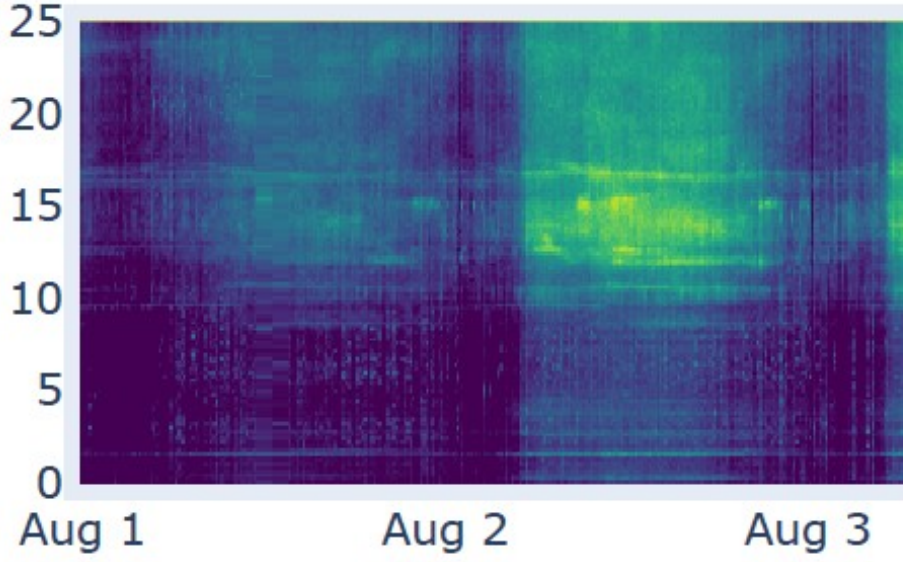
Anthropogenic noise

Frequency correction: time resolved spectrum

Frequency correction time traces

- 500 sps -> 50 sps
- Short time Fourier transfrom: 22 min window



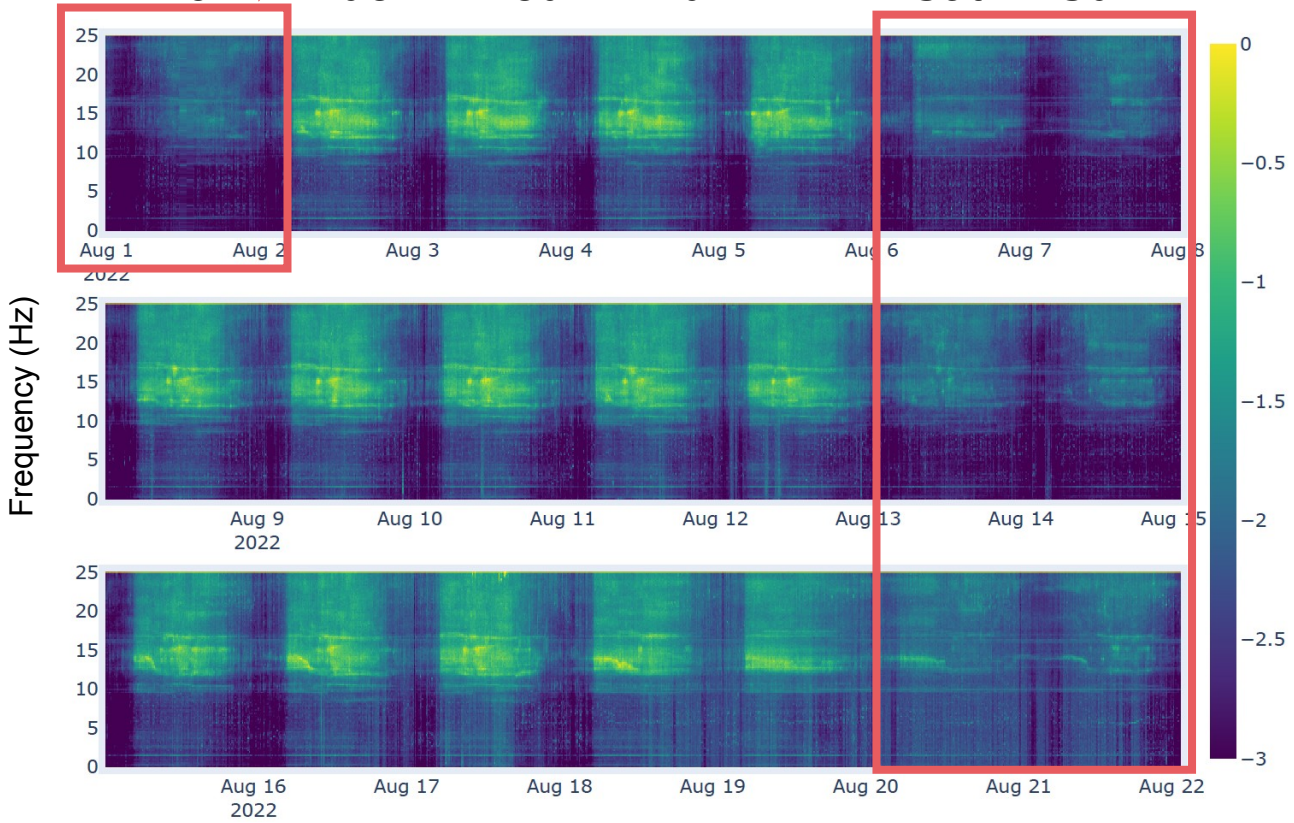


Frequency correction: time resolved spectrum

August 1, Swiss national holiday

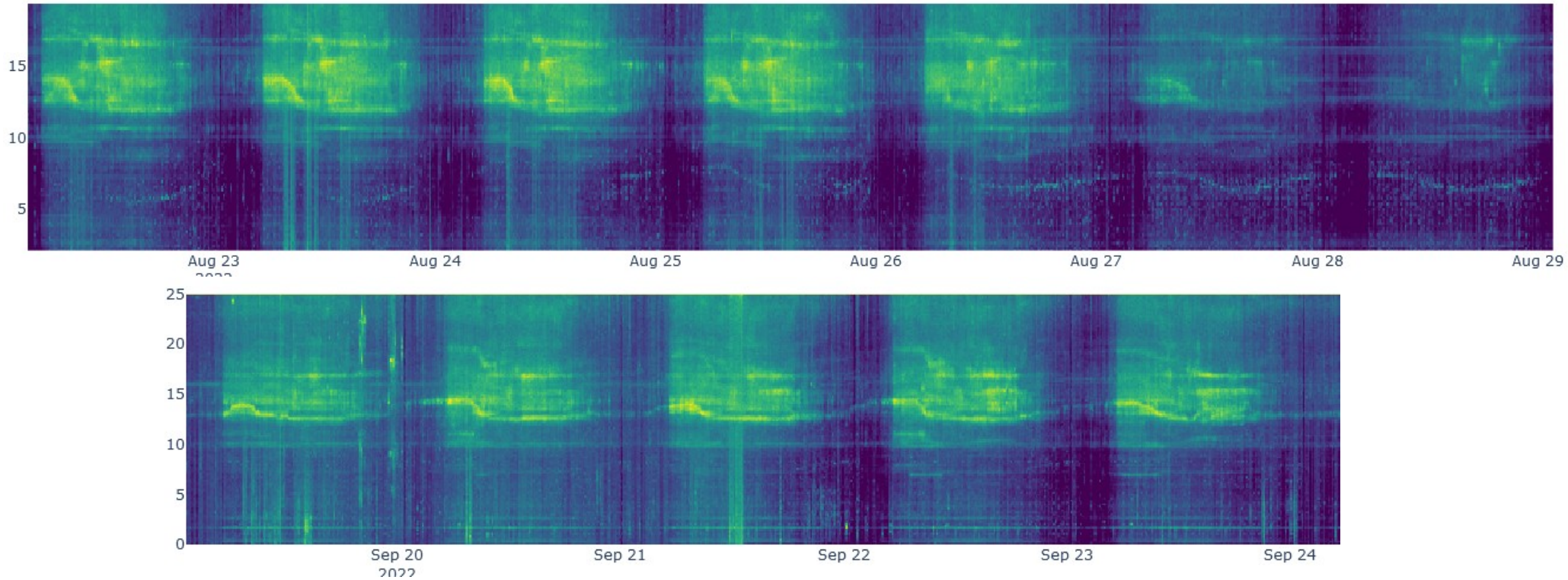
Noise spectrogram over 3 weeks

Reduced noise on weekends



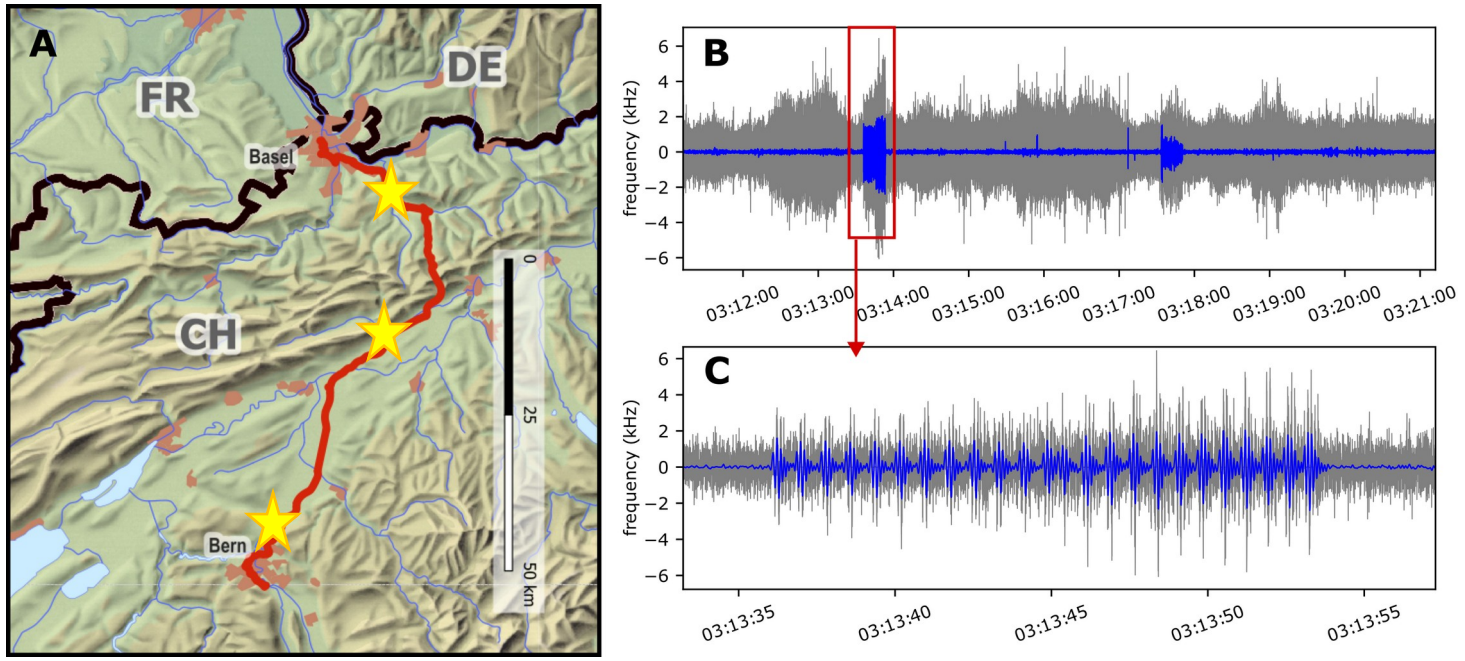
- Frequency correction time traces
- 500 sps -> 50 sps
- Short time Fourier transfrom: 22 min window

Frequency correction: time resolved spectrum



- Frequency correction – the ‘anti-noise’ – is extremely rich in features
- Interpretation is difficult, as noise is integrated along the full extent of the fiber
- Spatial resolution is not given (as opposed to e.g. distributed acoustic sensing systems)

Frequency correction: transient signals



- Generally, spatial resolution of noise signals is not available
- However, signals with sharp start and end indicate localization in space
- Few points high coupling to the fiber could explain the transients
- Objective: automatic detection and classification of these signals

Data processing

Procedure designed and exectued by Serge Zaugg, METAS

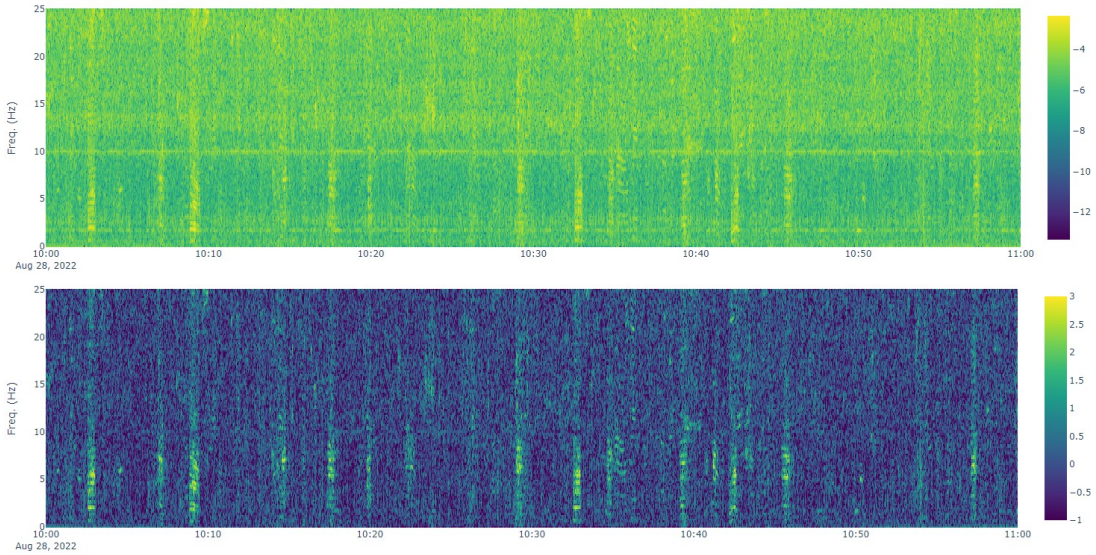
8 months of data
July 2022 to
March 2023
500 samples per second

1 h time series

Short time Fourier transform STFT
Hann window: 5.12 s
Step size 1.28 s

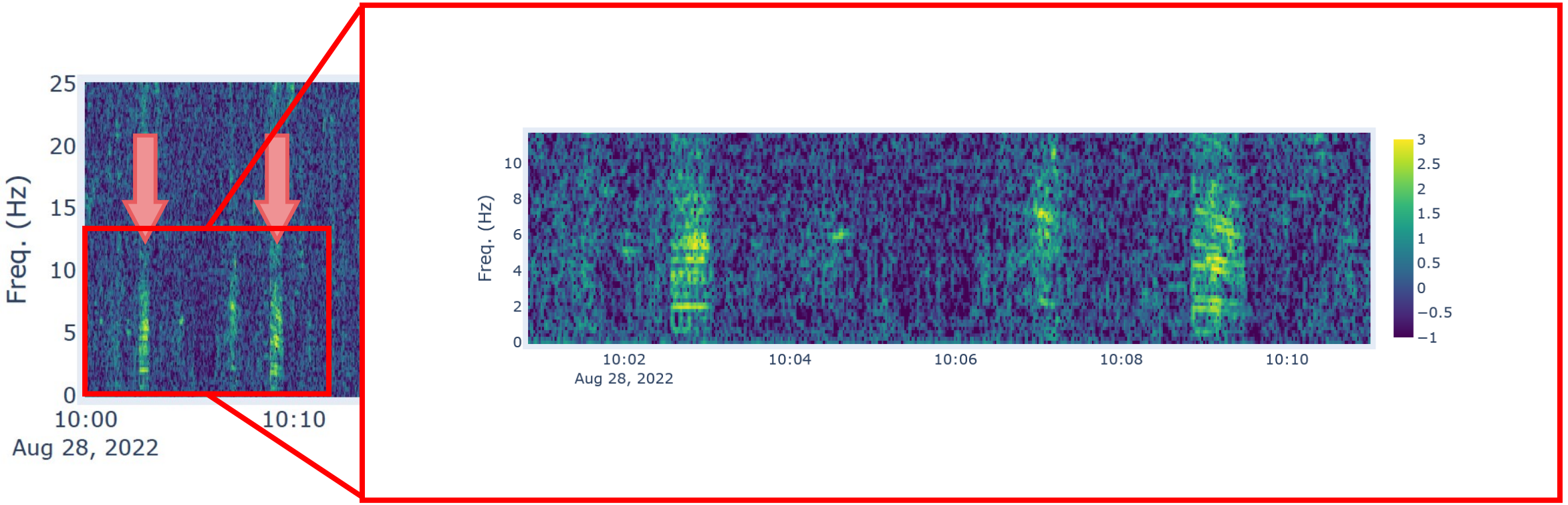
129x2813
Time-frequency bins

Normalize, logarithmize and cap limits



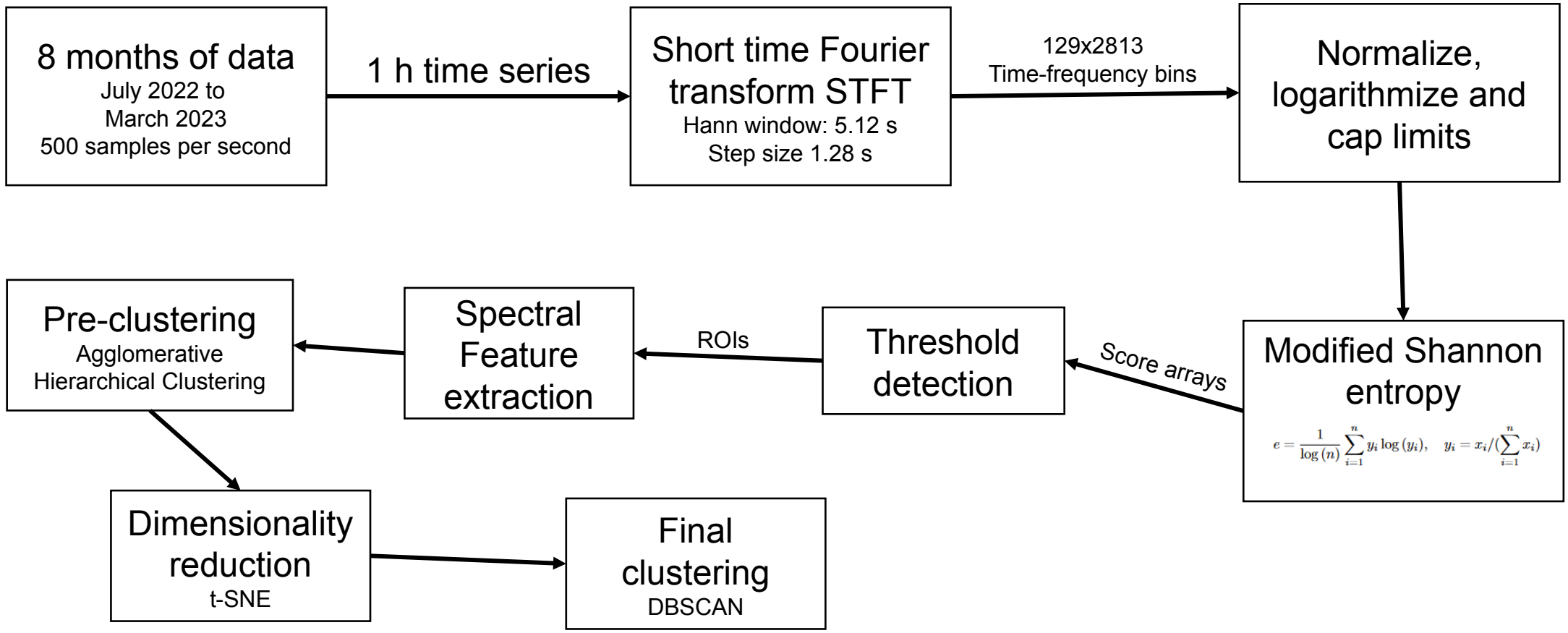
Top: unprocessed spectrogram obtained from STFT
Bottom: Spectrogram after equalizing with median spectrum over 1 hour.

Spectrogram over 1 hour



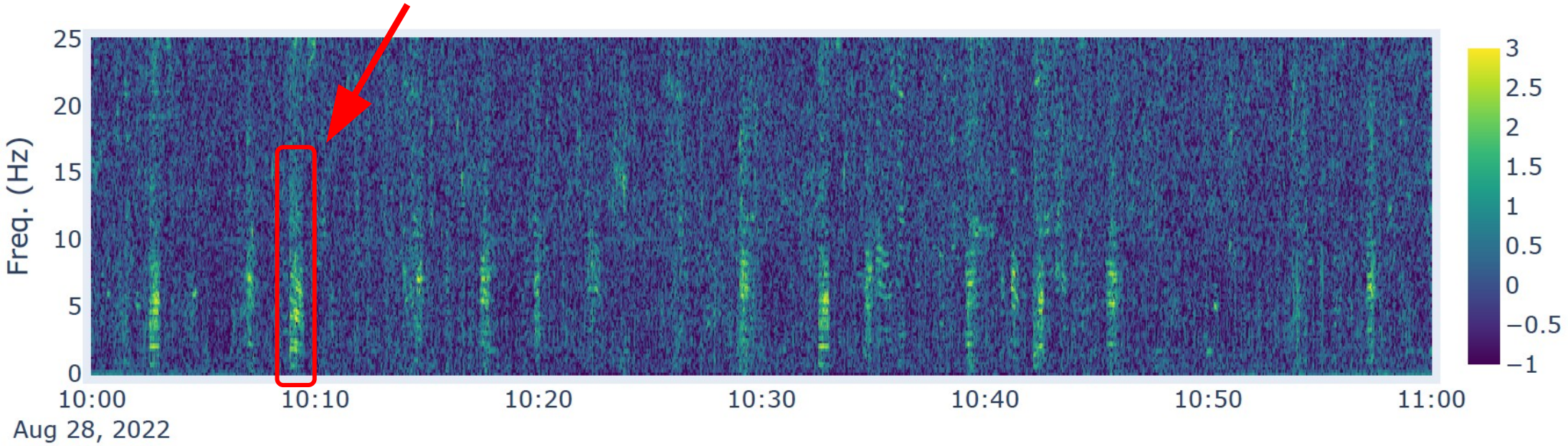
Data processing

Procedure designed and exectued by Serge Zaugg, METAS



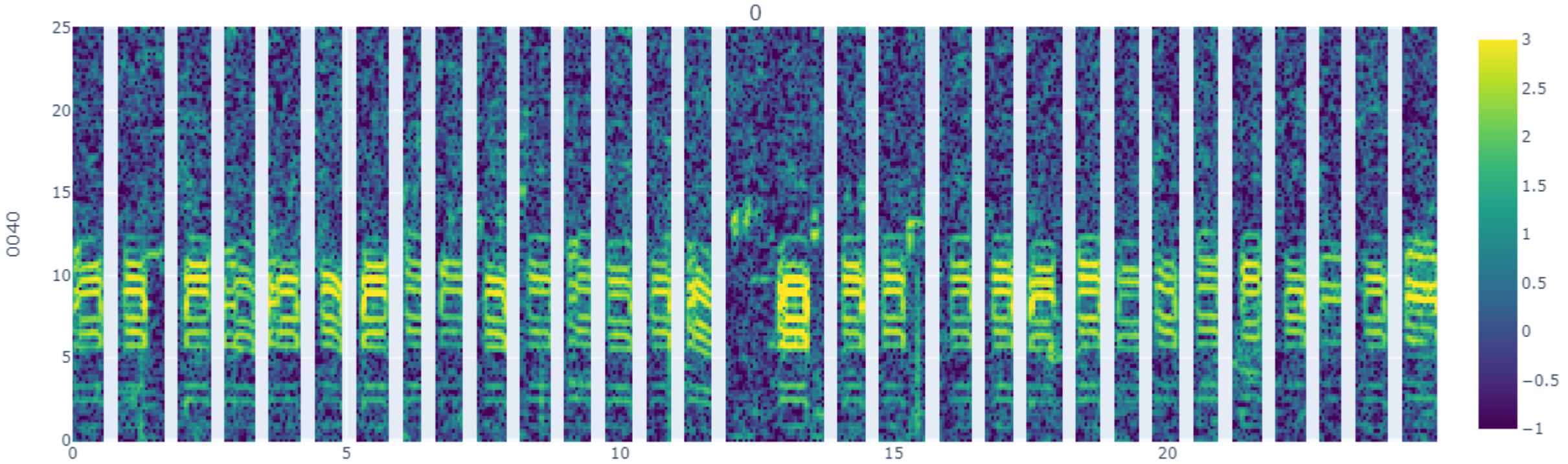
Spectrogram over 1 hour

Extract all ROIs and cluster according to their spectral fingerprint



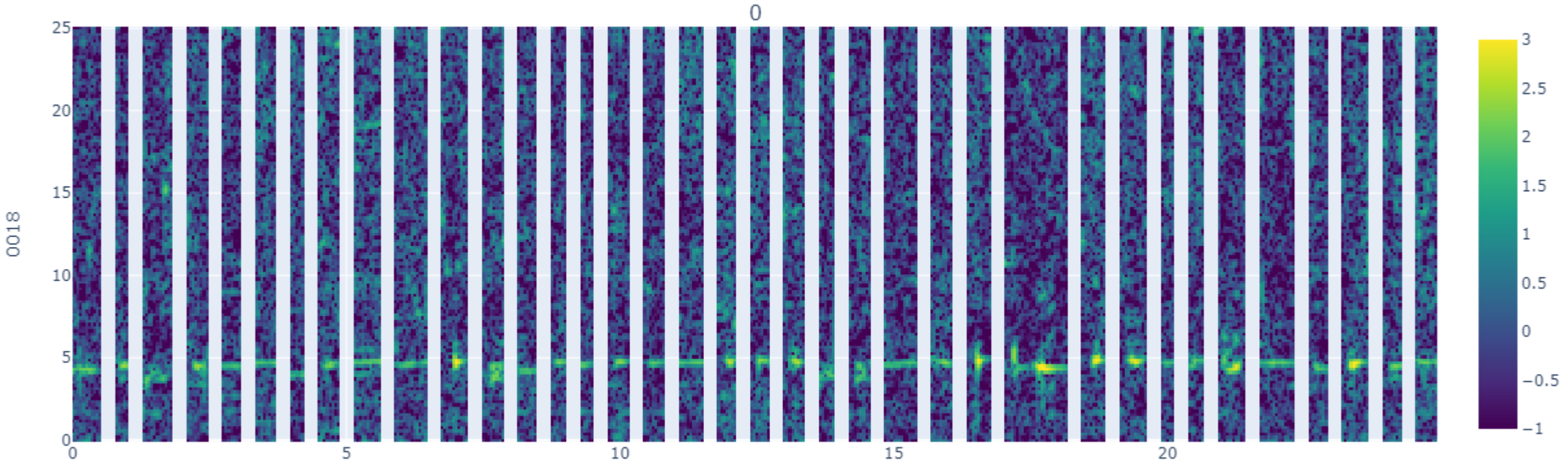
Selected clusters

Cluster are defined purely by spectral features (not e.g. absolute time, duration ...)



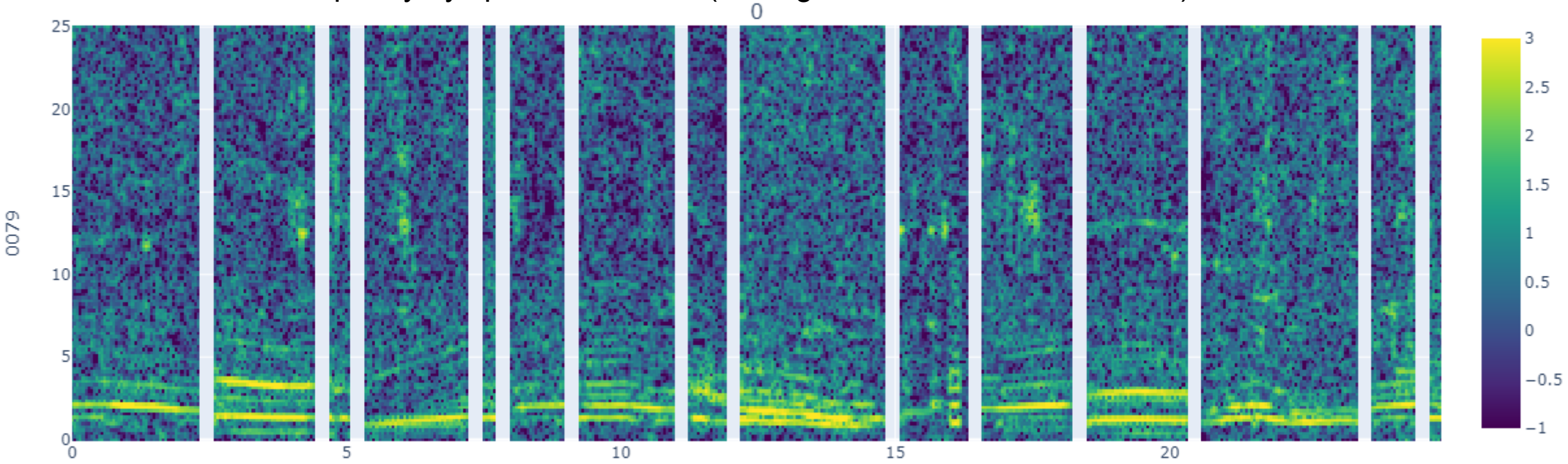
Selected clusters

Cluster are defined purely by spectral features (not e.g. absolute time, duration ...)

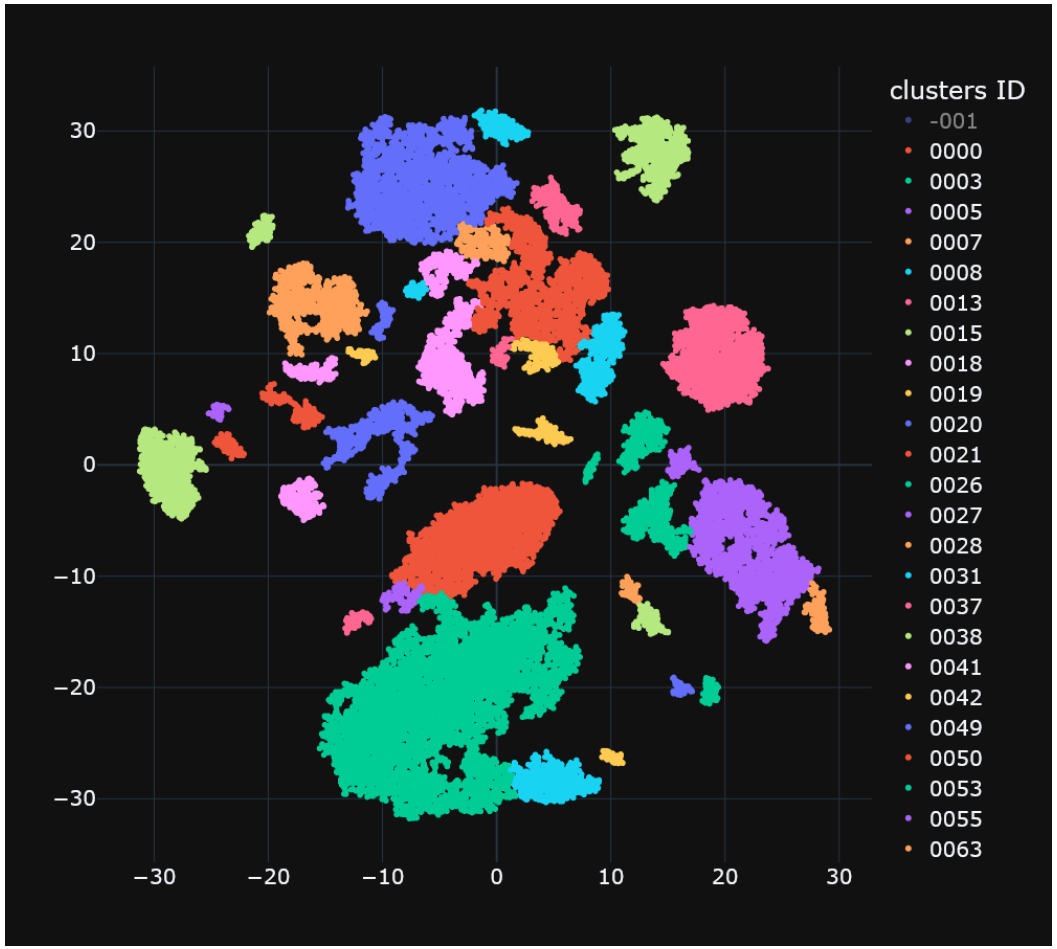


Selected clusters

Cluster are defined purely by spectral features (not e.g. absolute time, duration ...)



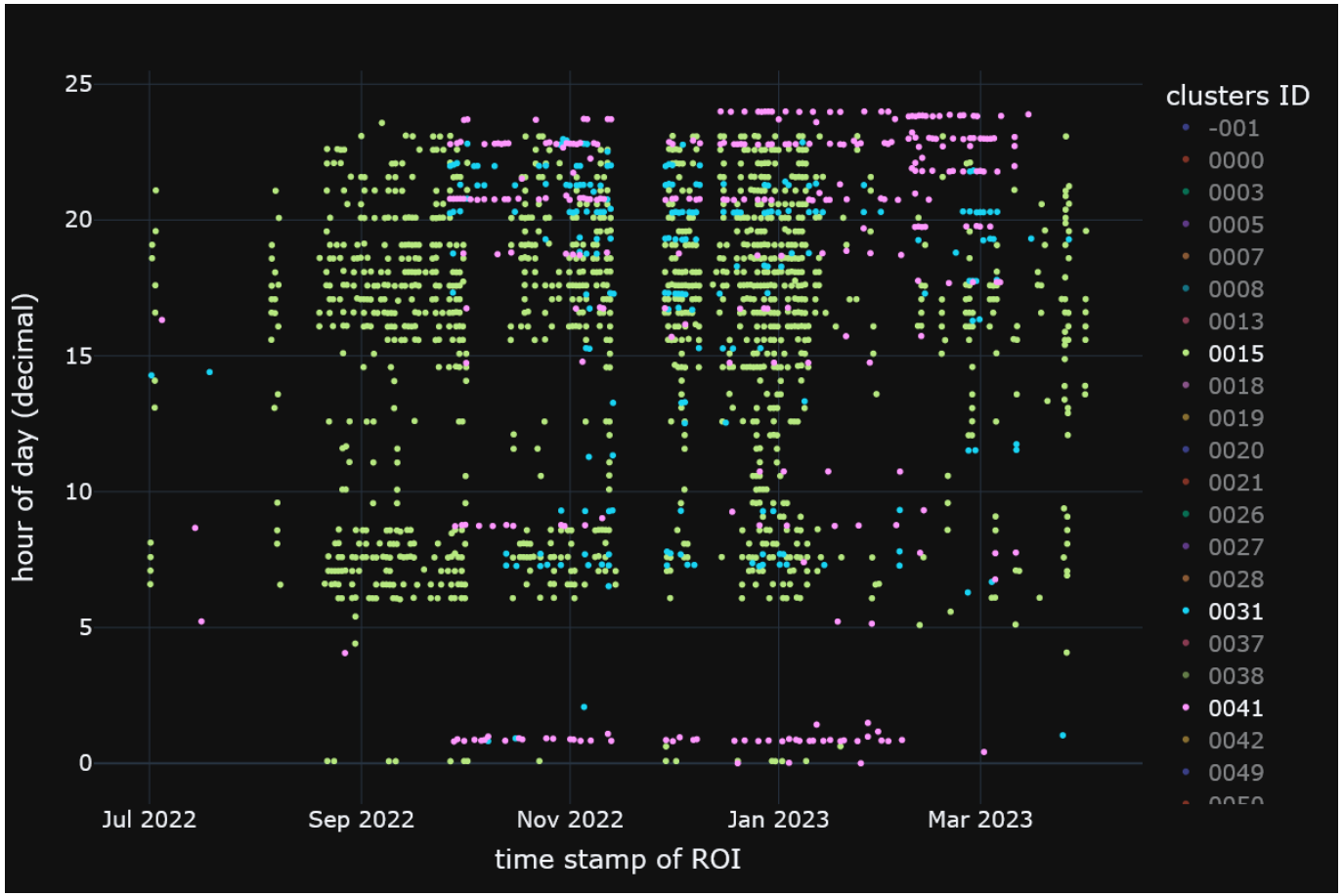
Final clusters in 2D feature space



- The 129 spectral features (representing the 129 frequency bins) are mapped to 2D space using t-SNE
- T-SNE: t-disctributed Stochastic Neighbor Embedding
- Clustering: DBSCAN: A density-based algorithm for discovering clusters in large spatial databases with noise

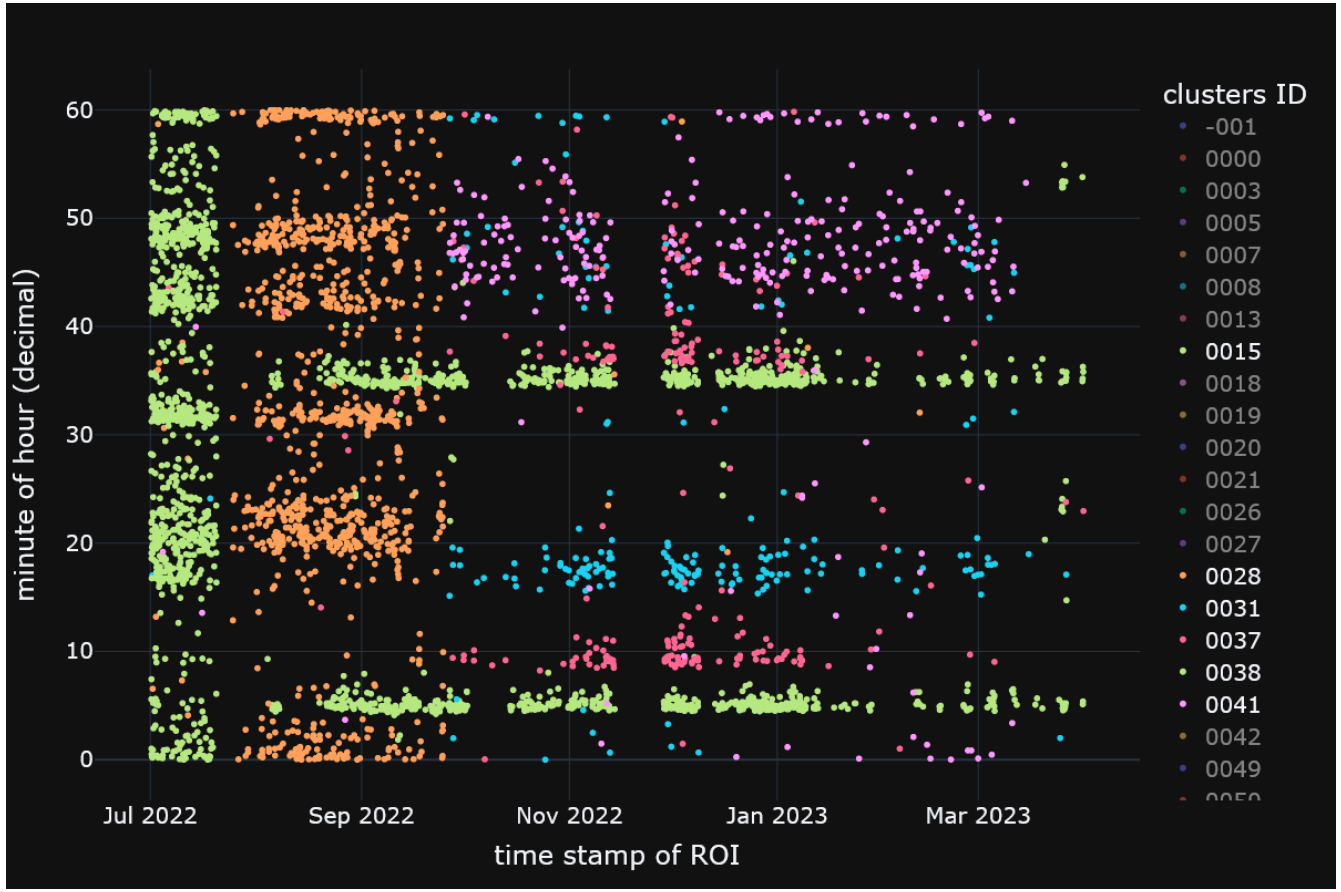
- There are many well defined clusters detected

Time stamps of ROIs: hour of day



- Horizontal lines indicate scheduled events
- High level of scheduling within certain clusters
- Reduced events detected at night and around noon

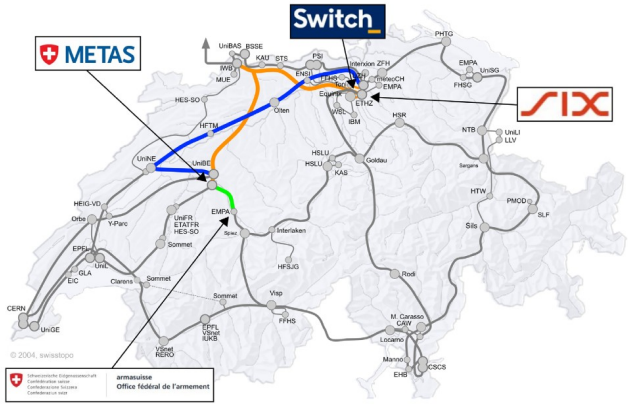
Time stamps of ROIs: minute of hour

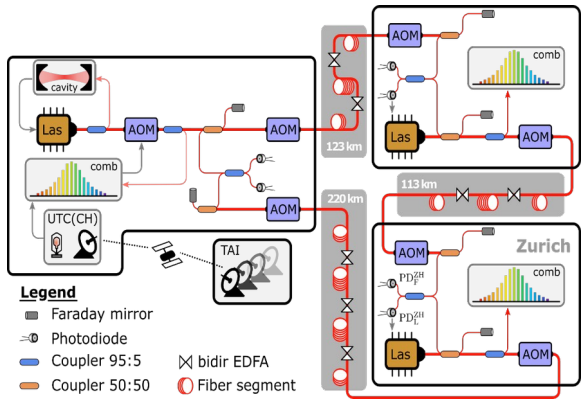


- Horizontal lines indicate scheduled events
- E.g. yellow dots at minute 05 and 35: This is a typical schedule for trains commuting between cities

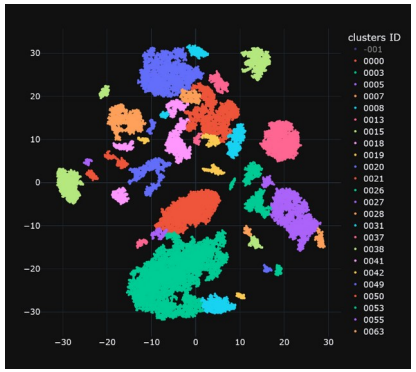
Wrap-up

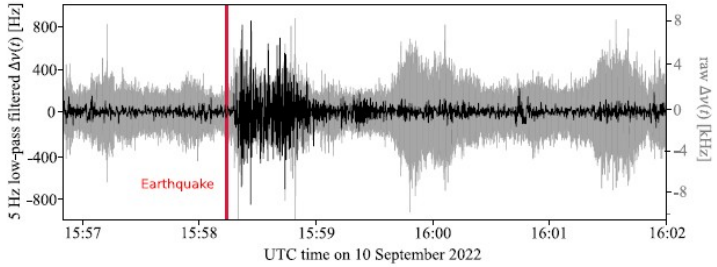
- We have presented ...
  - ... the current setup of UTC(CH) with its dissemination methods
  - ... the TDIS project for White Rabbit based time dissemination toward industry
  - ... phase-stabilized optical frequency dissemination for precision spectroscopy

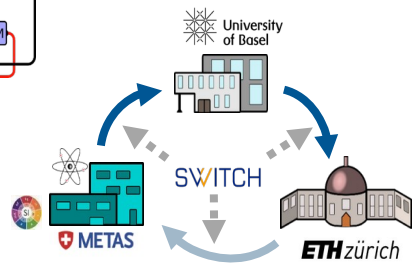




- ... various fiber sensing exploits of the frequency correction signal
  - Temperature
  - Seismic
  - Anthropogenic



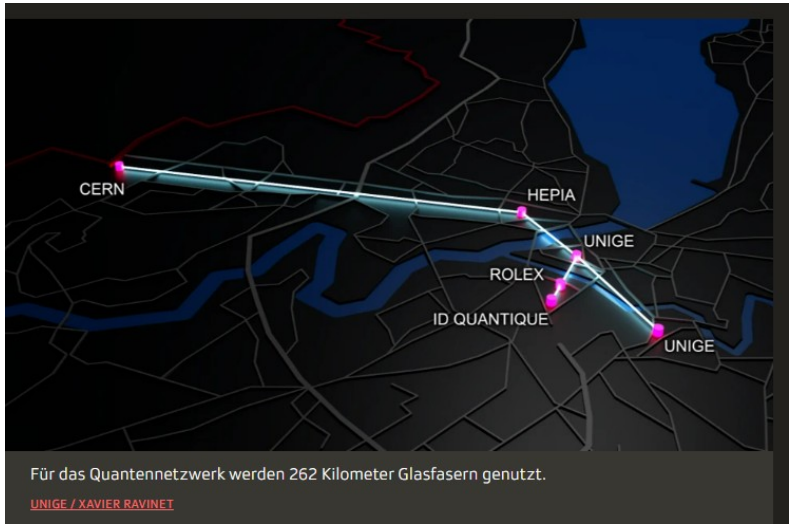




Outlook

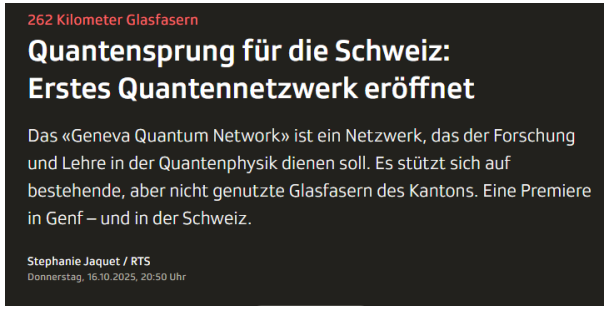
- METAS continues provisioning of time / frequency links to research institutes together with Switch. Established connections are maintained and further developed

- Initiatives for connections to new institutes are highly welcome. Funding is the limiting factor. For bottom-up approach: We need key users to give the critical push for an institute to connect to the network.



- **National Centre of Competence in Research: NCCR Precision (funding under evaluation)**
  - Potential kick-off in spring 2026
  - Goal: push precision measurements in quantum systems, and its enabling technologies
  - Structural aspects
    - Development of an optical clock
    - Extension of frequency dissemination network

- **Geneva Quantum Network**
  - Local urban network for Quantum technology
    - White-Rabbit-based time dissemination
    - QKD / Quantumm communication



Our collaborations

METAS

Jacques Morel
Antoine Jallageas
Dominik Husmann
Etienne Friedrich

Switch

Daniel Bertolo
Ernst Heiri
Konstantinos Chaloulos
Fabian Mauchle
Stéphane Racine

University of Basel

Stefan Willitsch
Ziv Meir
Mudit Sinhal
Anatoly Johnson
Aleksandr Shlykov

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EURAMET. Neither the European Union nor the granting authority can be held responsible for them.

The project has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

METROLOGY PARTNERSHIP

EURAMET

COMOMET
metrology with cold molecules

ETH zürich

Frédéric Merkt
Hansjürg Schmutz
Gloria Clausen
Simon Scheidegger
Urs Hollenstein

ETH zürich

Jérôme Faist
Giacomo Scalari
Mathieu Bertrand

INRiM
ISTITUTO NAZIONALE DI RICERCA METROLOGICA

Davide Calonico
Cecilia Clivati
Alberto Mura

FNSNF
SWISS NATIONAL SCIENCE FOUNDATION

Thank you for your attention

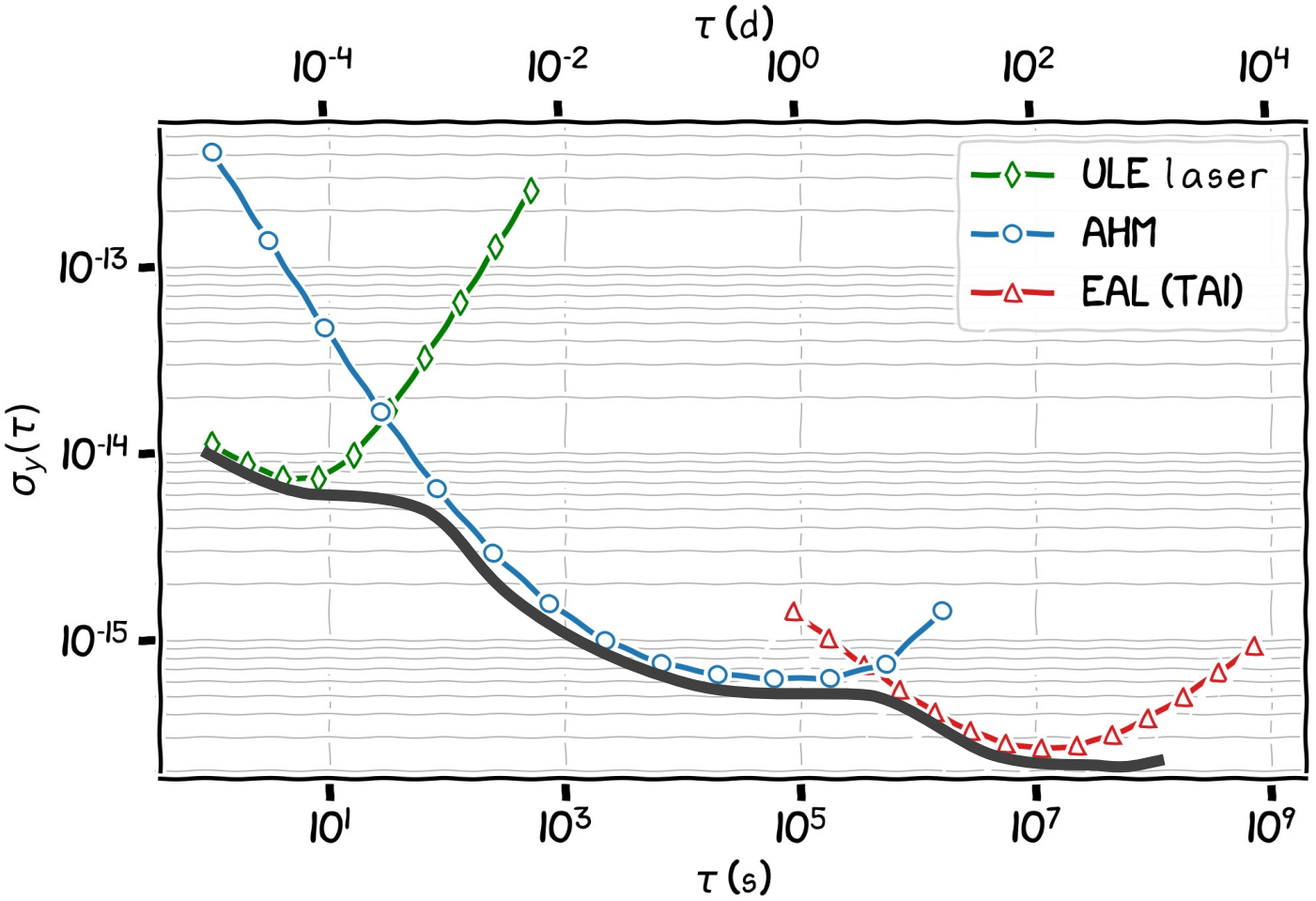
Dominik Husmann
Dominik.husmann@metas.ch

METAS
Ihre Referenz.

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Eidgenössisches Institut für Metrologie METAS

Simplified picture

- Different frequency standards excel in different integration times.
- Design your frequency lock chain in a way that profits from the optimal stability regimes of each stage

	+	-
Cavity-stabilized laser	• Unprecedented short-term stability	• Not an absolute reference • Drifts (0.1 Hz/s)
Active hydrogen maser	• Only small deterministic drifts • Reliable local oscillator	• Not an absolute reference • phase noise inferior to laser
International atomic time	• Unprecedented long-term stability	• Paper clock • Not real-time available