PHOTONIC SERVICES INCREASING UTILISATION OF TELECOM FIBERS

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October 8th 2019
Chicago, IL

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Outline

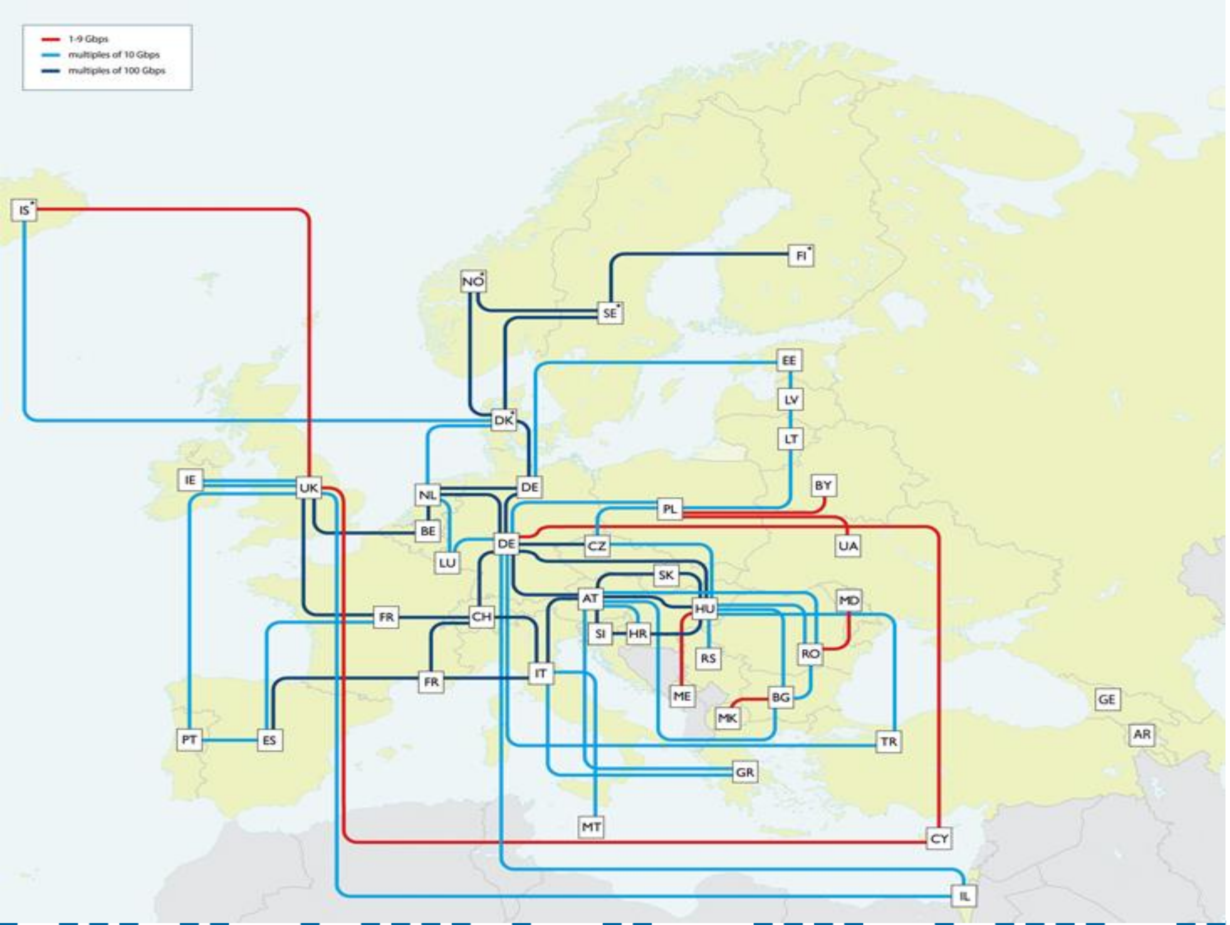
- Background - Introduction of CESNET
- Photonic Services
  - Precise Clocks and Need for Them
- Time and Frequency Transfer
- CESNET Time and Frequency Infrastructure
- Use of Telecom Fibers for Seismic and Vibration Sensing
- Summary & Acknowledgement

CESNET

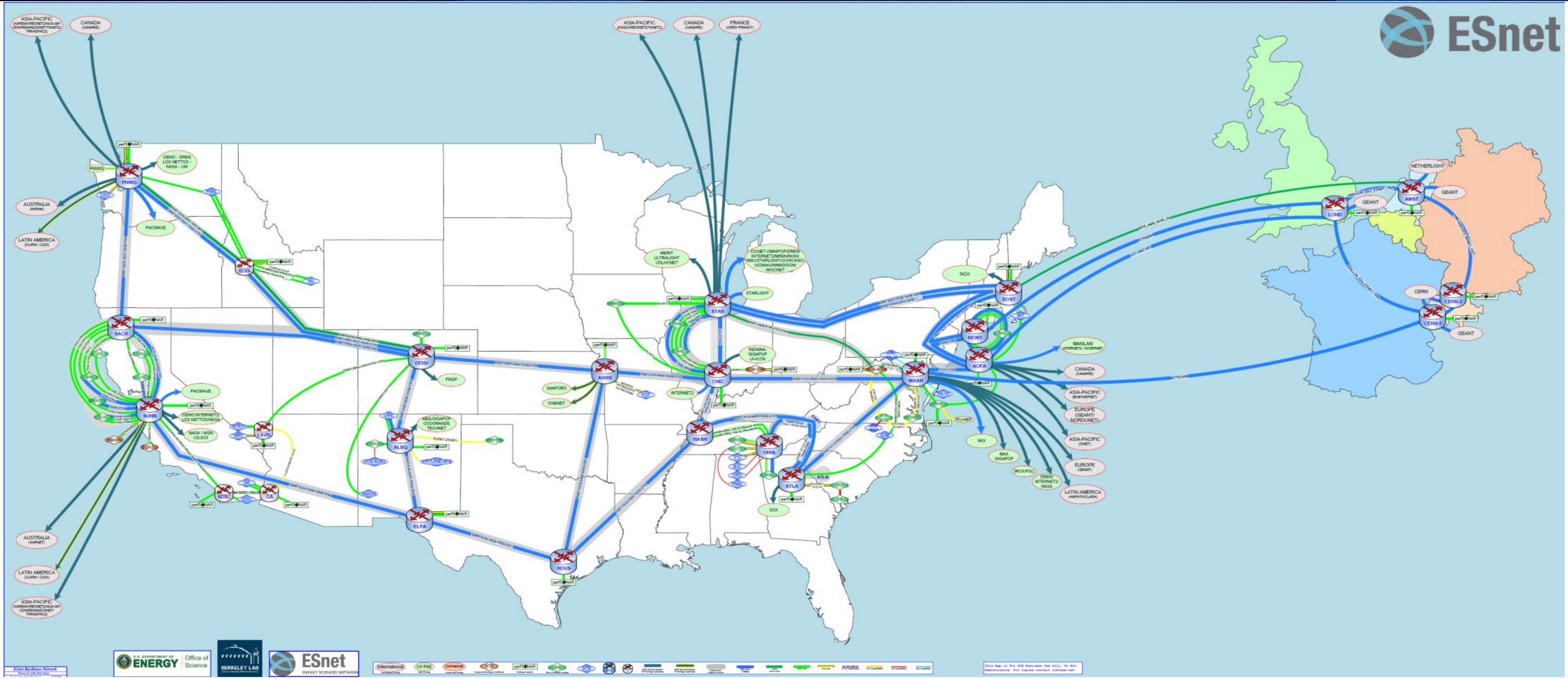
- **E-infrastructure provider in Czechia**
- **Members 26+2 public universities and academy of sciences**
- **Storages, High performance computing, Multimedia**
- **Research and Education Network CESNET2**
- > 5800 km of dark fiber lines
- Two DWDM systems
  - Proprietary 1510 km and Open 3760 km
- Over 1390 km of single fiber lines
- https://cesnet.cz

GÉANT

- **Part of GÉANT project**
- **GN4-2 and GN4-3**
- [*https://www.geant.org*](https://www.geant.org)



ESnet


ESnet
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ATLA
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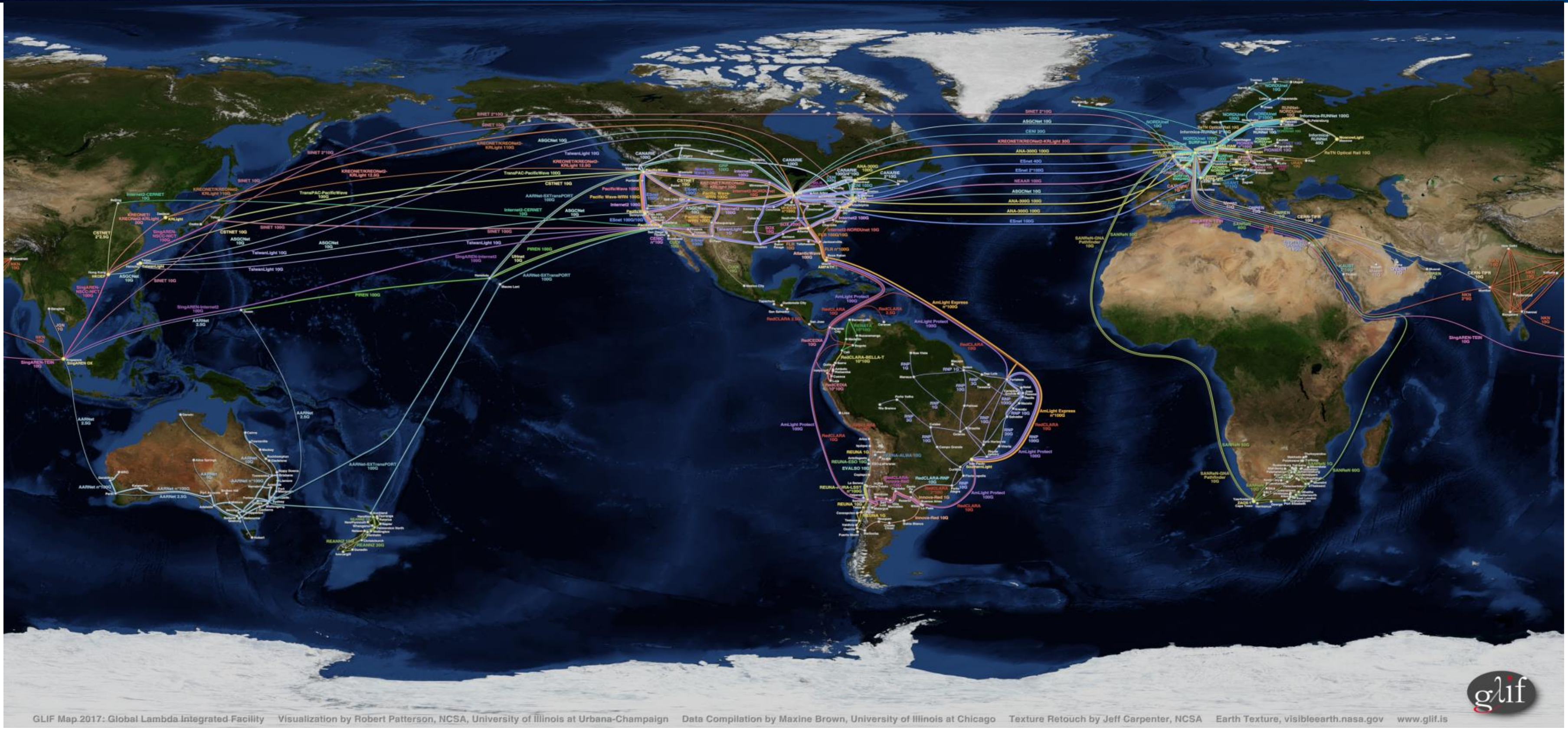


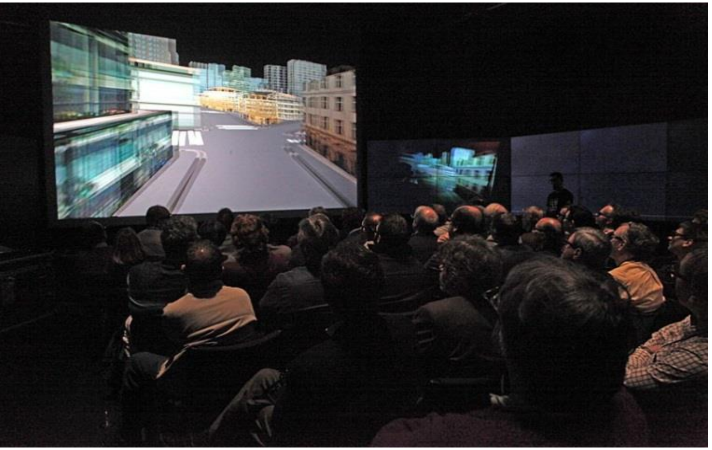
https://www.glif.is/

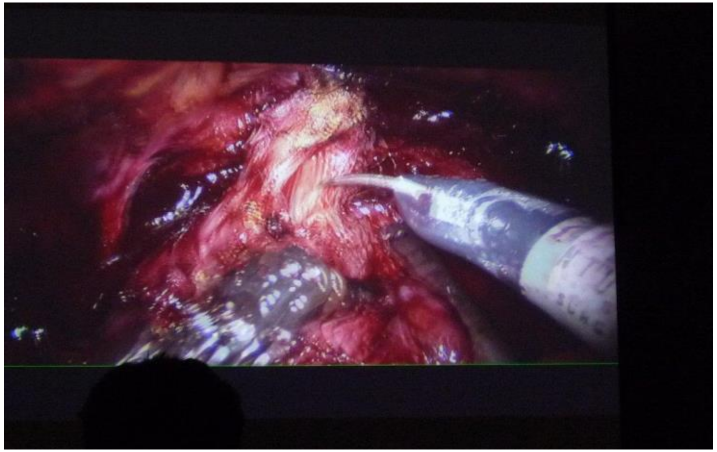
Photonic Service

- End-to-end connection between two or more places in network
- Described by photonic-path and allocated bandwidth
- Photonic-path is a physical route that light travels from the one end point to the other or to multiple other end points respectively
- Allocated bandwidth is a part of system spectrum that is reserved for user of Photonic service all along the Photonic-path.
- Minimal impact of network (no processing) on transmitted data
  - Path all-optical, no OEO except special cases.

Photonic Services

- High speeds (600Gbps) cannot solve all challenges
- Low and stable latency is important
- Remote interactive cooperation (conferences, remote control, art) - 3D, 4K
- Photonic service   Prague Vienna   500 km   3 ms
- IP Service   Prague London   1000 km   30 ms

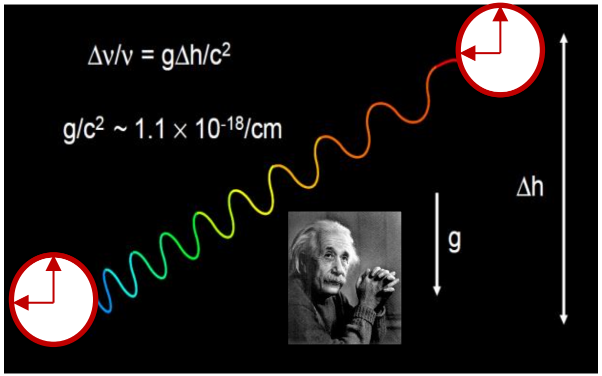




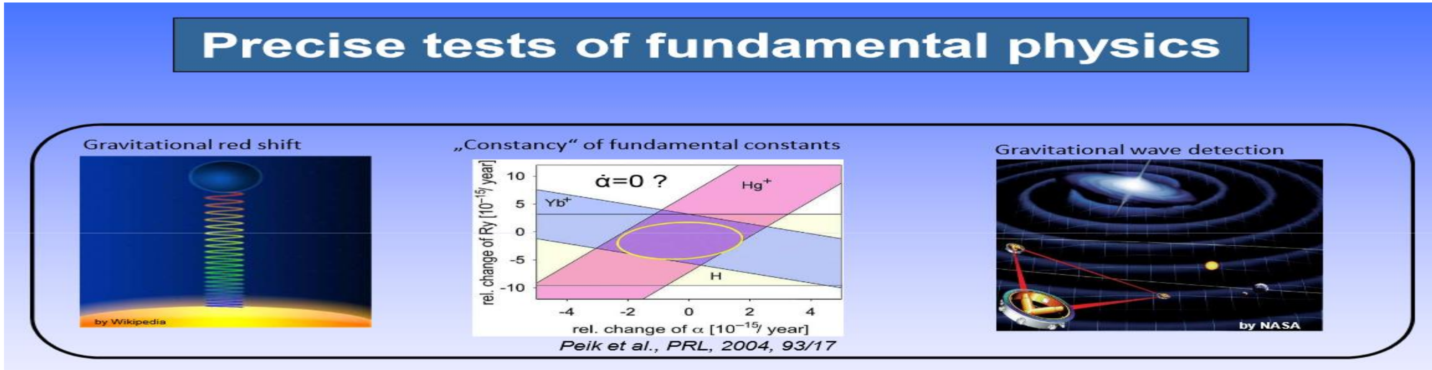
Why More Precise Clocks?

- **Time and frequency** = quantities we are able to measure with the highest precision
- Represent ideal way how to measure tiny effects

- (Radio)astronomy, VLBI, SKA
- Precise tests of fundamental physics:
  - Constancy of fundamental constants
  - Detection of gravitational wave
  - Tests of special & general relativity

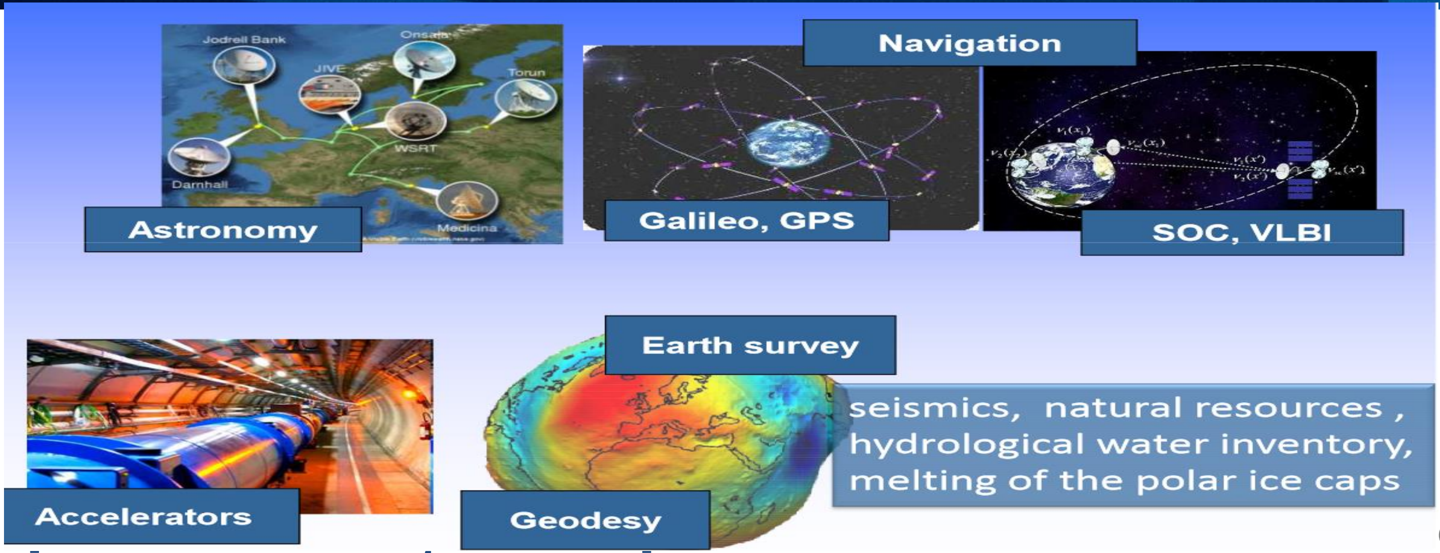


Credits: Newbury14, Barr10



Credit: Schnatz14

Why More Precise Clocks?

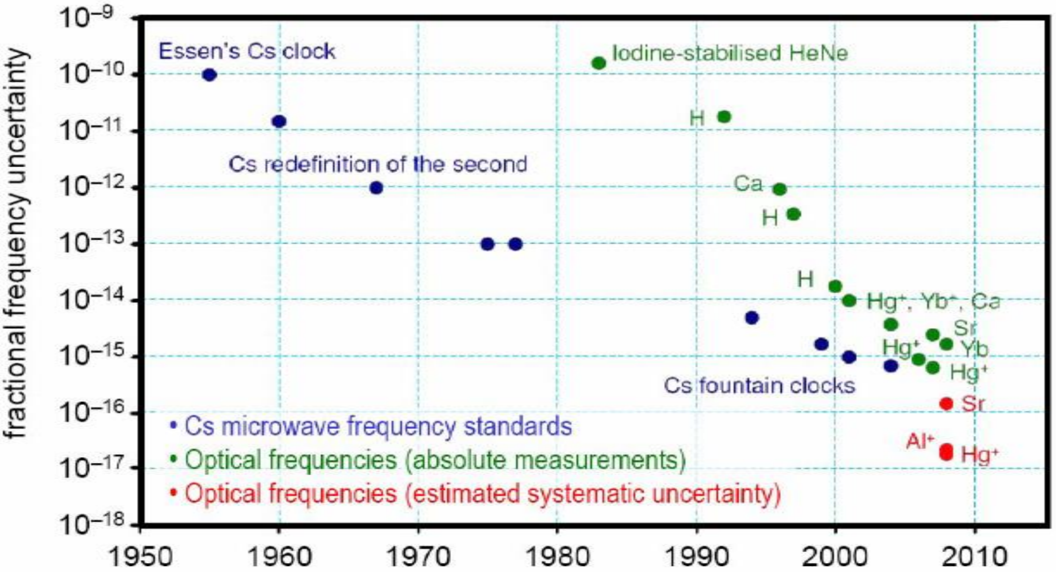


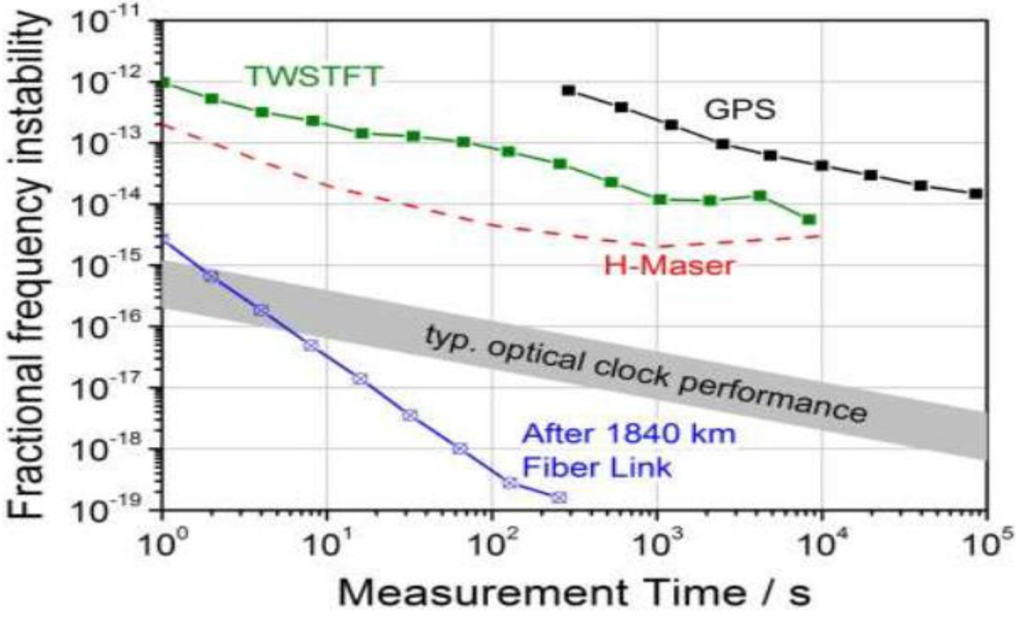
Credit: Schnatz14

Earth sciences, remote sensing

- Land – geodesy, seismology, water resource and other natural resources inventory, etc.
- Atmosphere – climate modelling and changes monitoring, etc.
- Oceans – circulation, geoid monitoring etc.

Clocks Are Improving

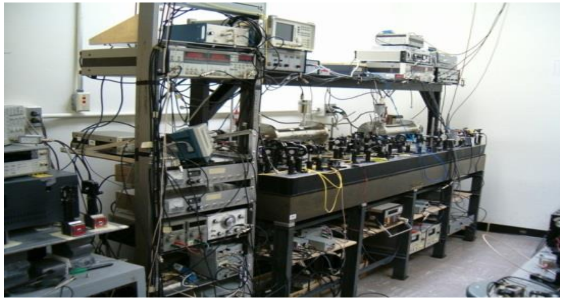




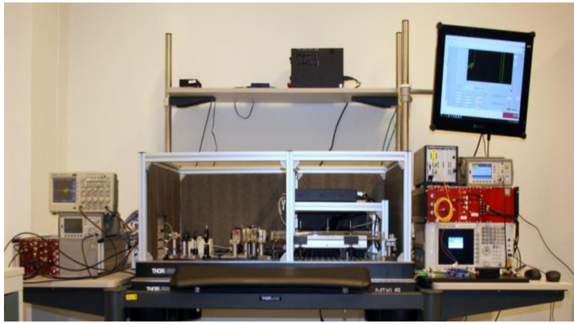
Credit: Droste13

Time and Frequency Transfer

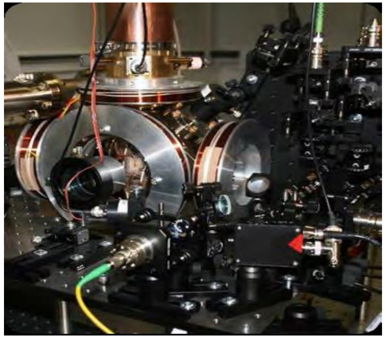
Caesium fountain clock at NPL UK, height of 2.5 m



Acetylene stabilized laser

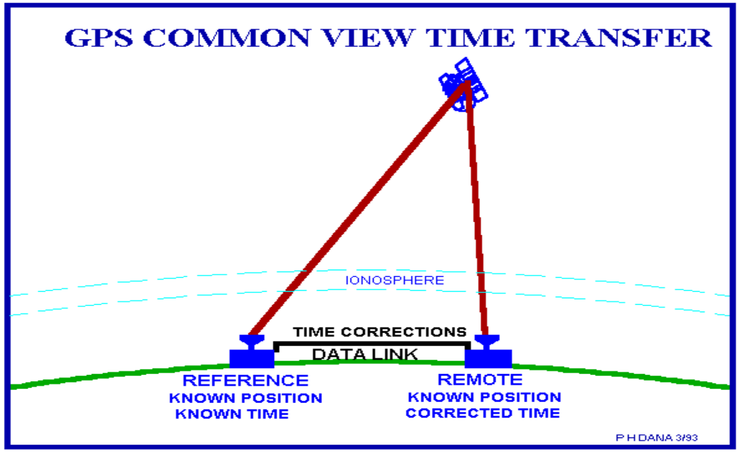


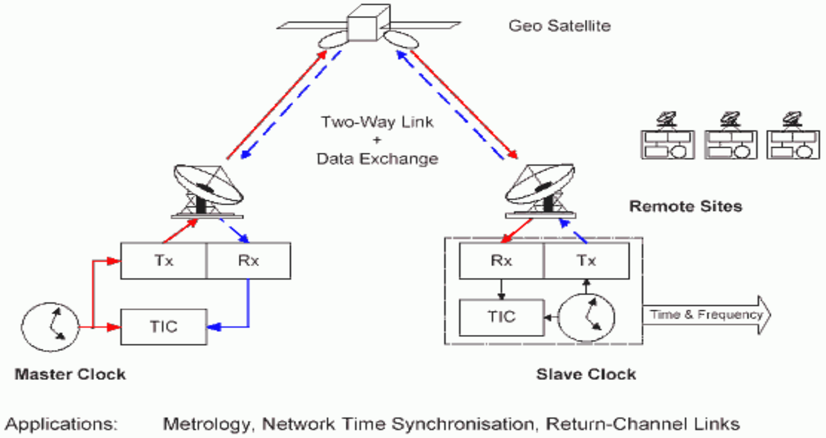
- Cost of ownership
- More interconnected clocks (Cs primary standards and H masers) improve accuracy and stability of the time scale
- “Interconnection” means time transfer
- Hard to transfer some clocks (sensitive + not a small ones)



Optical atomic clock based on trapped single Ca ion

Satellite RF Based Transfer





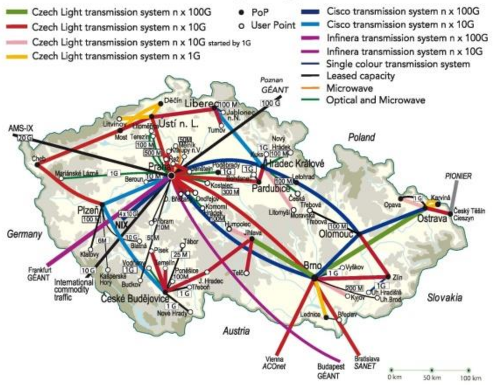
- CV GNSS - 20 000 km:(GPS, GALILEO, GLONASS, …) precision 3 – 50 ns
- GNSS PPP (Precise Point Positioning) 0.1 ns
- TWSTF – 2 x 36 000km: 0.1 ns

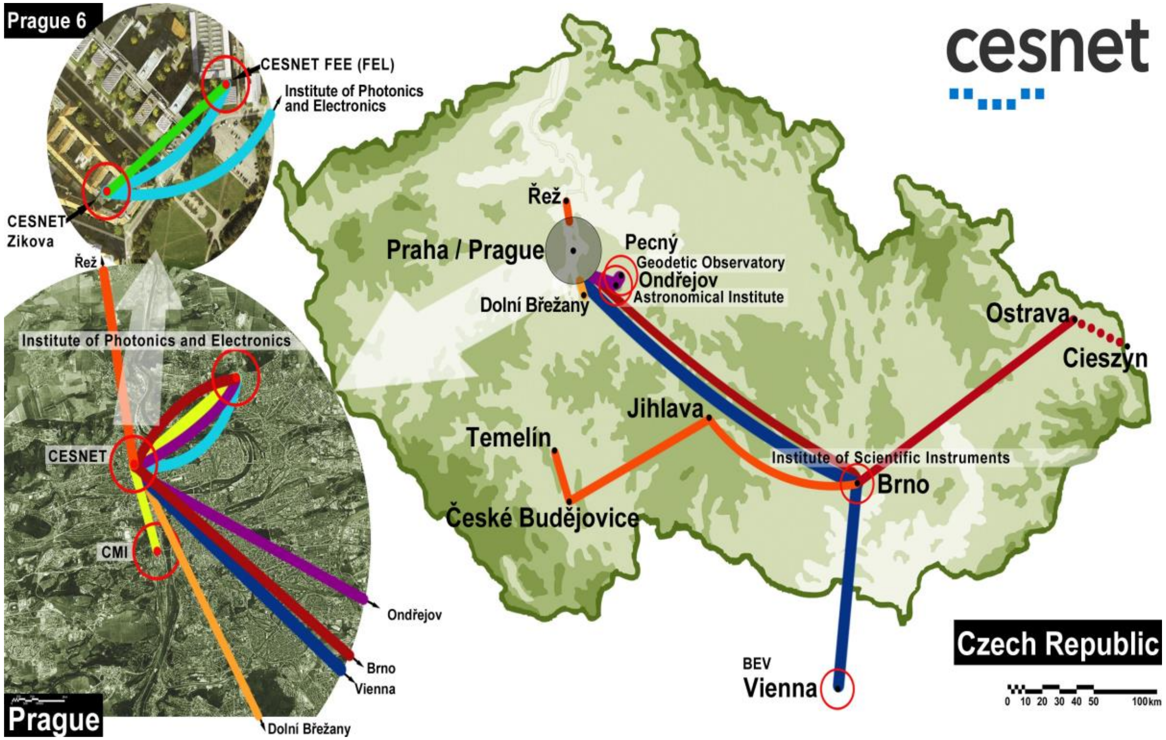
Credits: Colorado, Timetech

Time and Frequency Infrastructure

- T/F transfer + distribution
- Fibers shared with data
- Projected length 2476 km
- Transmission on 1183 km
- Dedicated all-optical channel

CESNET2 Topology (March 2019)



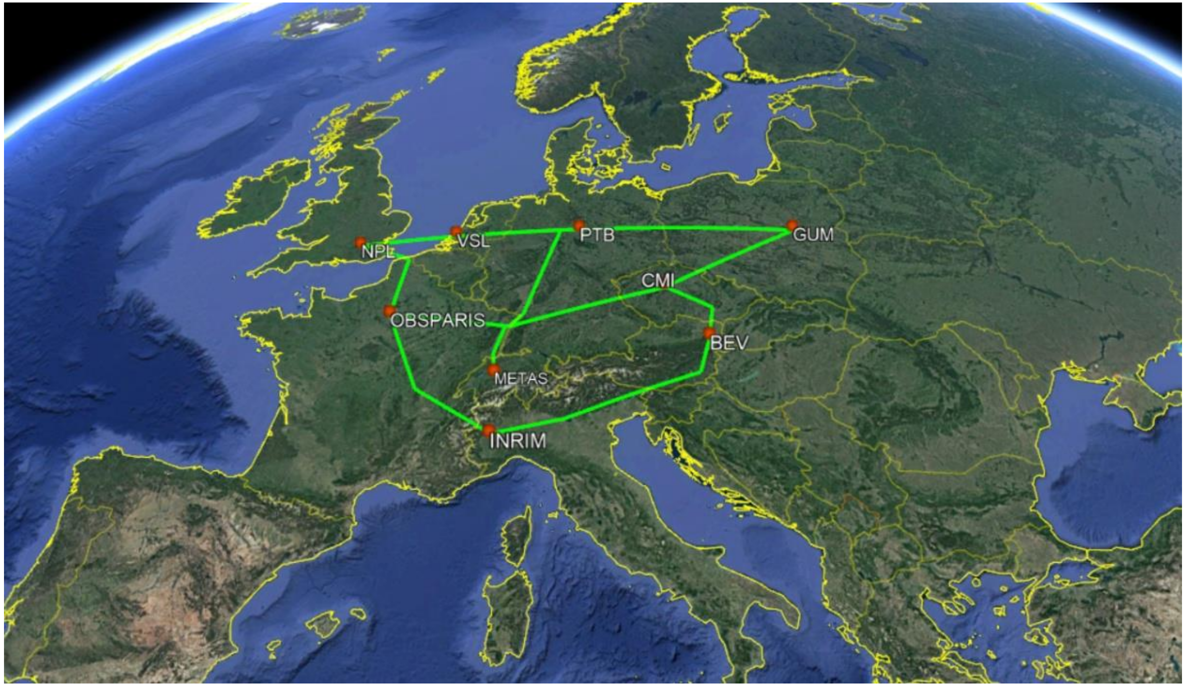


Fibre Sharing

- Total fibre line length 2476 km
- Single fibre transfer is advantage for Time and must for Frequency transfers
- Annual Single Fibre Rental cost EUR 740 000 (based on avg price*)
- Share infrastructure with data

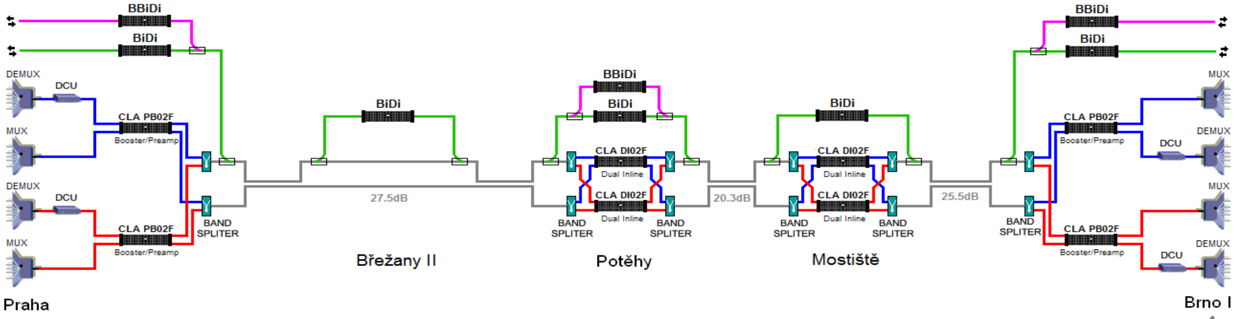
*http://www.porta-optica.org/publications/POS-D3.2_Economical_analysis.pdf

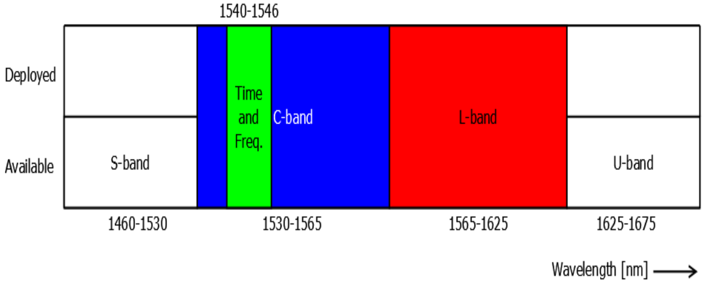
- Project CLONETS – CSA action

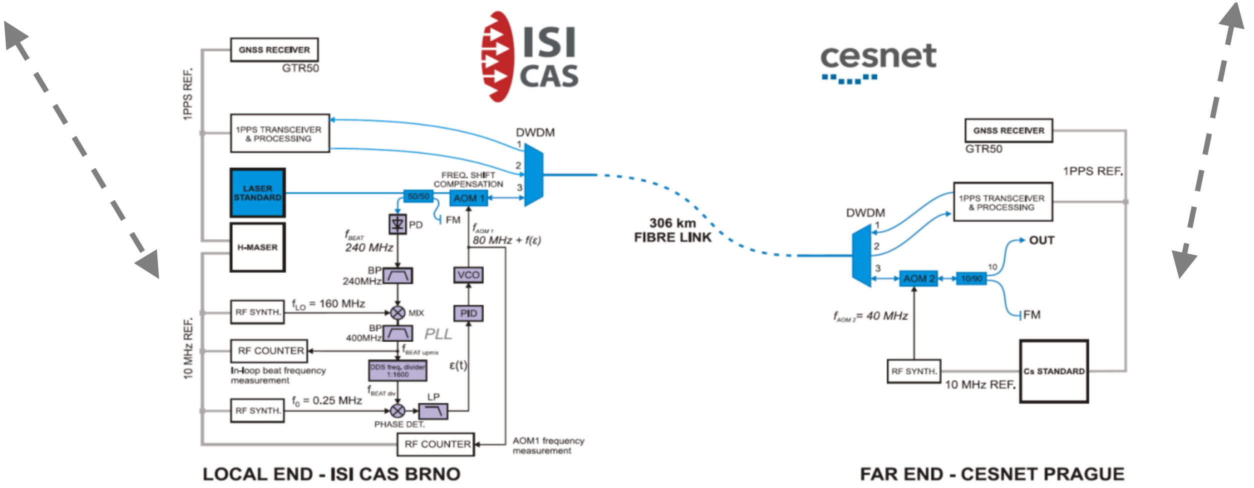


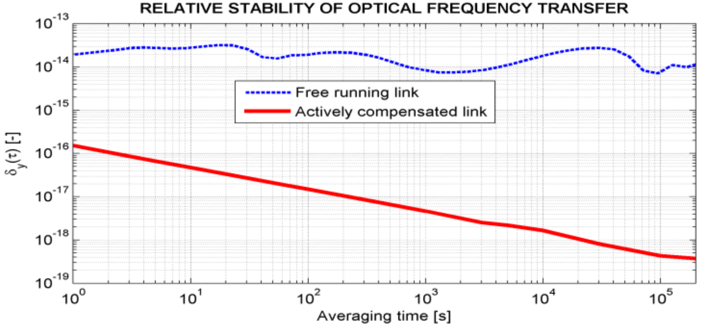
Implementation of Fibre Sharing

- 306 km line, dedicated bandwidth 800 GHz, T+F, since 2014

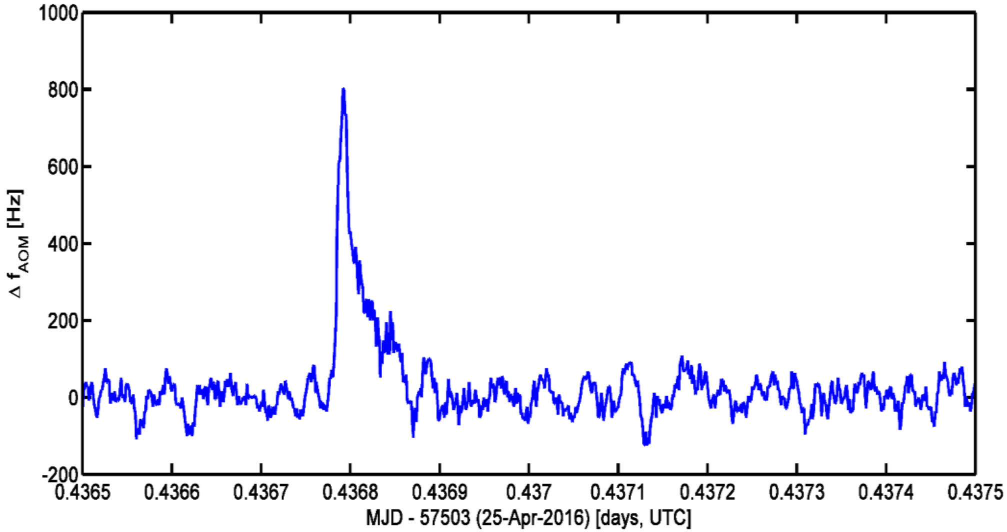


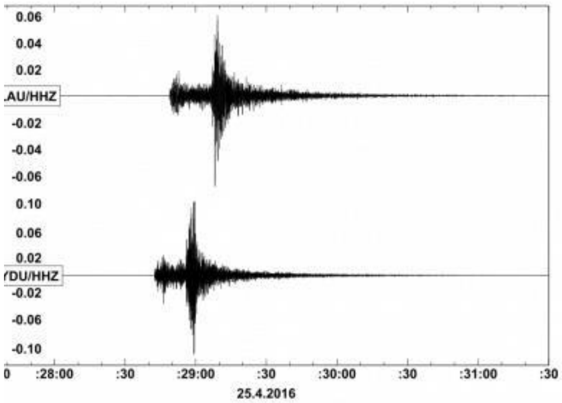






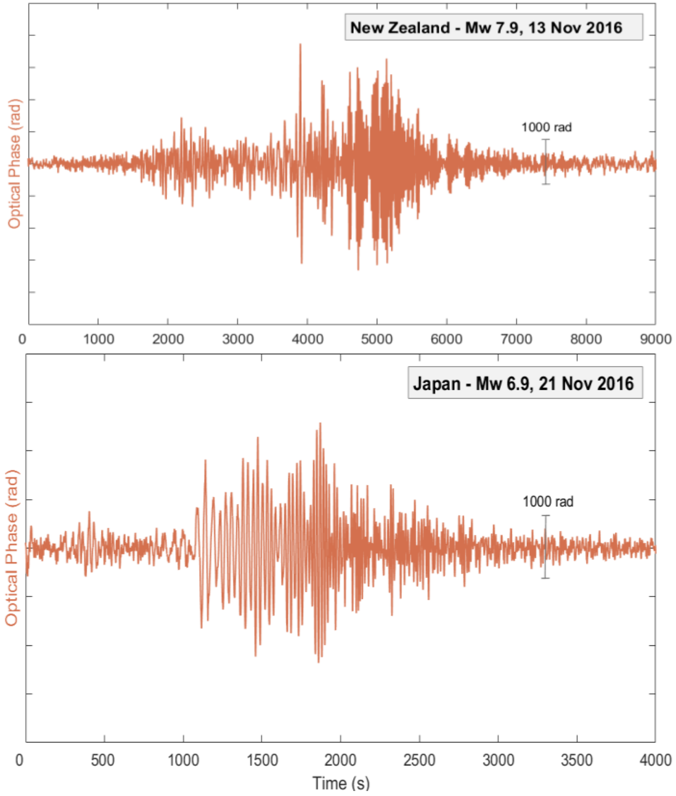
- **Ultra-stable optical frequency dissemination**
- **25 Apr 2016 – ML 4.1, epicentre located 20 km SW from Vienna**

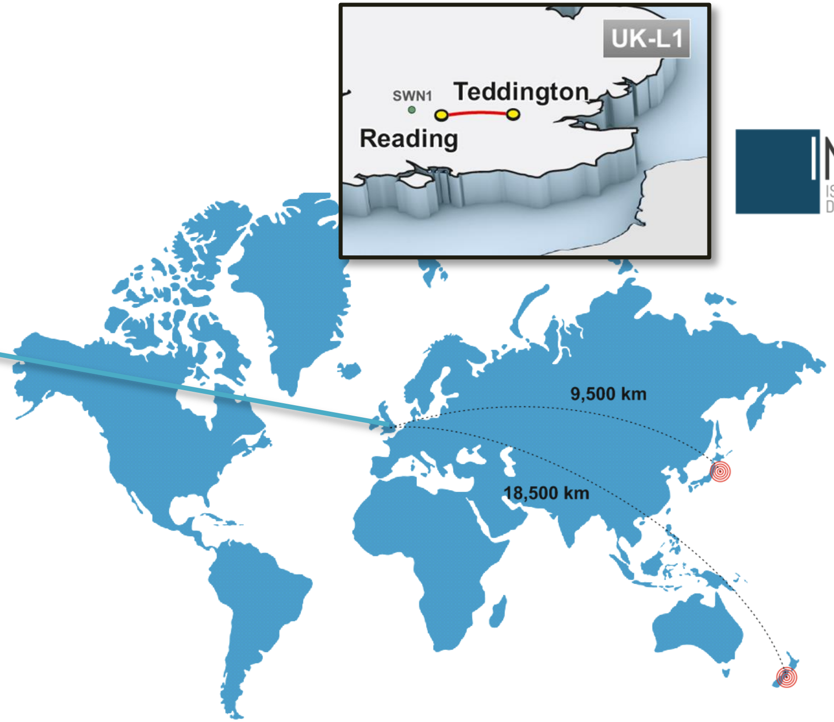




M. Cizek et al., "Transfer of stable optical frequency for sensory networks via 306 km optical fiber link," 2016 European Frequency and Time Forum (EFTF), 2016

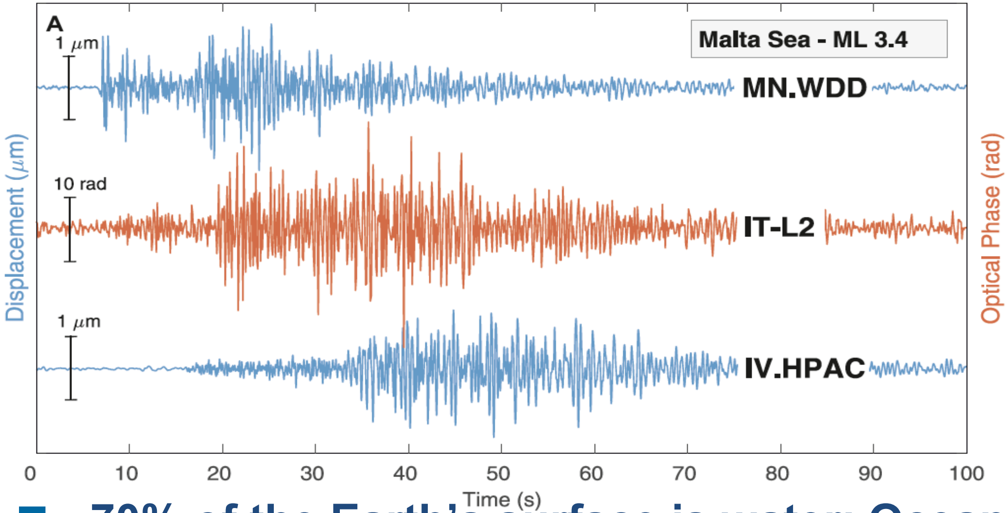
Detection of New Zealand and Japan earthquakes - Nov 2016, 79 km line

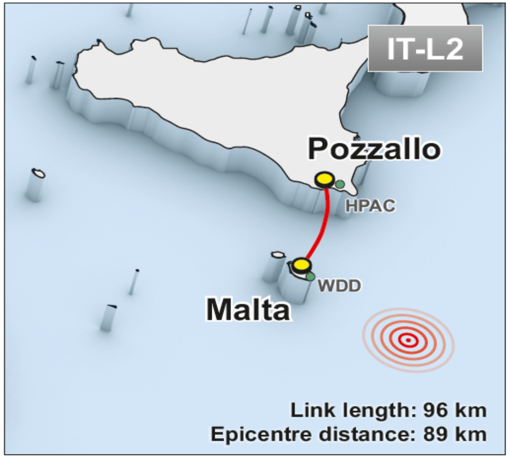




English E.: NPL's Time and Frequency Laboratory Activities, PTTI 2019

Submarine optical link: Malta Sea earthquake - Sept 2017





G Marra, C Clivati, R Luckett, A Tampellini, J Kronjäger, L Wright, A Mura, F Levi, S Robinson, A Xuereb, B Baptie, D Calonico „Ultrastable laser interferometry for earthquake detection with terrestrial and submarine cables“, Science, 361, 486-49 (2018)

- **70% of the Earth’s surface is water; Ocean Bottom**
- Seismometers installation difficult and expensive - Over 1 million km of submarine cable already installed
- **Submarine fibre links are far quiet (up to 40 dB) compared terrestrial links**
- Potential of important application: By detecting underwater earthquakes close to their epicentre, precious life-saving time could be gained in a tsunami warning

Fibre Protection

CESNET
12 fibre cut based outages last year
2.04 /Mm/y

CDT
19 fibre cut outages per 3500 km last year
5.4/Mm/y

Metro networks experience 13 cuts annually for every 1000 miles of fibre [1]
8.08/Mm/y

The most common causes of fibre cuts – digging activities (58%) [2]

[1] W. D. Grover, "Mesh-Based Survivable Networks: Options and Strategies for Optical, MPLS, SONET and ATM Networking", PrenticeHall PTR, Upper Saddle River, 2004.
[2] Orange (France Telecom) in France (January 2010-March 2011).

- **How can that be done?**
- **Most fibre cuts: machinery within constructions/thefts.**
- **Heavy machines digging near a fibre shakes a cable before breaking it.**
- **Active monitoring of vibrations near a fibre cable.**
- **Mostly based on evaluation of phase/polarization/backscatter of light.**
- **In combination with SDN and NetOS allows to reduce outage times.**

Multiple works put vibrations as predecessor of breakage, e.g.:

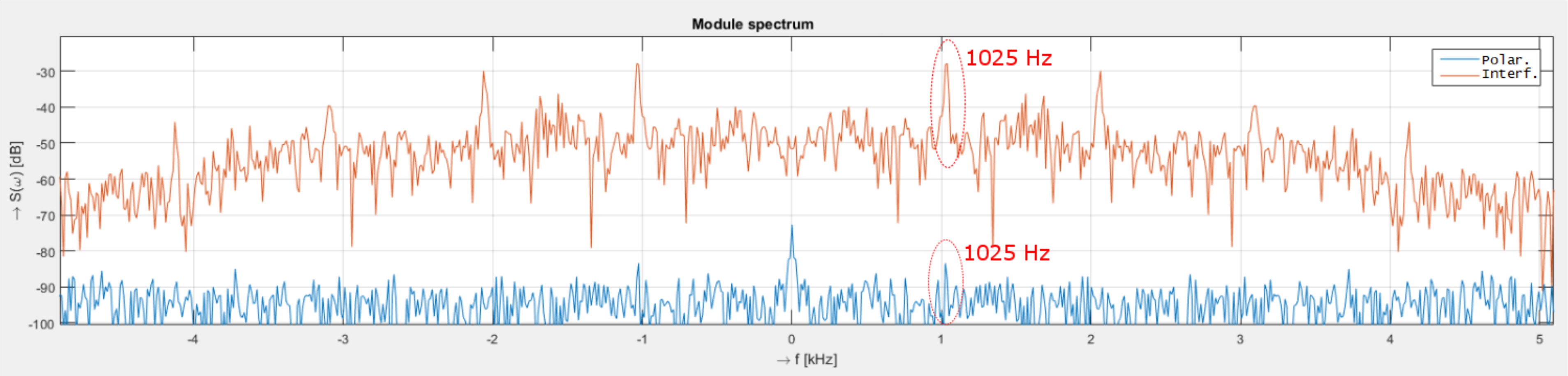
J. E. Simsarian and P. J. Winzer, "Shake before break: Per-span fibre sensing with in-line polarization monitoring," 2017 Optical fibre Communications Conference and Exhibition (OFC), Los Angeles, CA, 2017, pp. 1-3

Vibration sensing methods using fibre/fibres, basic setups

Requirement: Without installation works along fibres

	Phase sensitive OTDR	Polarization based sensing	Interferometers
Sensitivity	++	+	+++
Number of required fibers	1	1	2
Single-ended measurement	Yes	No (passive mirror at least)	No (passive mirrors at least)
Measurement range	Tens of kilometers	Tens of kilometers	Tens of kilometers
Localization of event	Yes	No (in basic configuration)	No (in basec configuration)
Price	High	Low	Moderate
Special requirements	Elimination of reflections in optical route, channel spacing >200 GHz away from data.		

Lab comparison of polarisation and interferometric methods (Michelson)

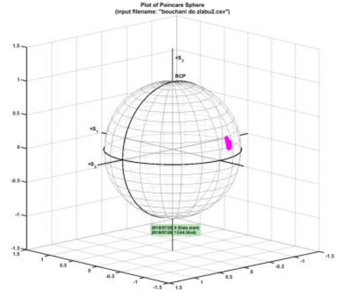


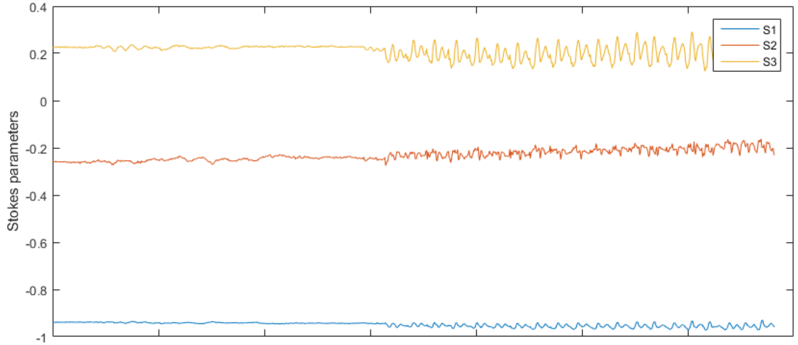
10km of G652.D fibre on spool
Artificial vibrations generated by speakerphone

[1] P. Munster, T. Horvath, P. Sysel, J. Vojtech and R. Velc, "Comparison of interferometry based and polarization based sensing systems for use in fiber infrastructure protection," 2017 International Workshop on Fiber Optics in Access Network (FOAN), Munich, 2017

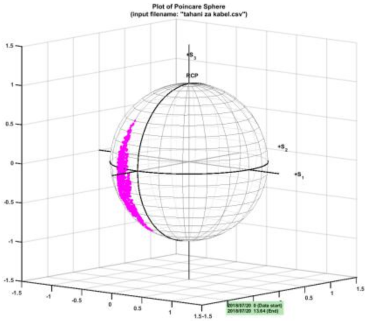
Polarisation method in the field

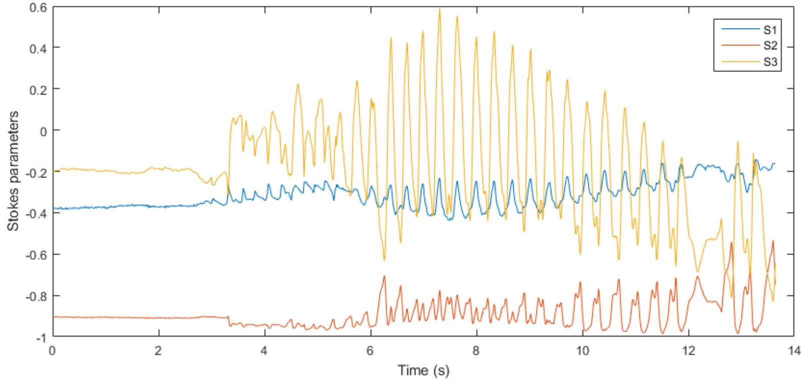
City line 13km of G652 fibre



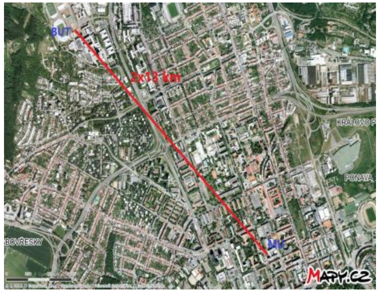


SOP change caused by mechanical vibration near the cable. L: the Poincare sphere, R: Stokes parameters.



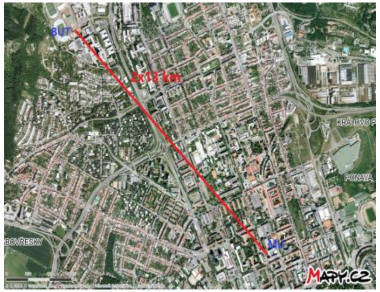


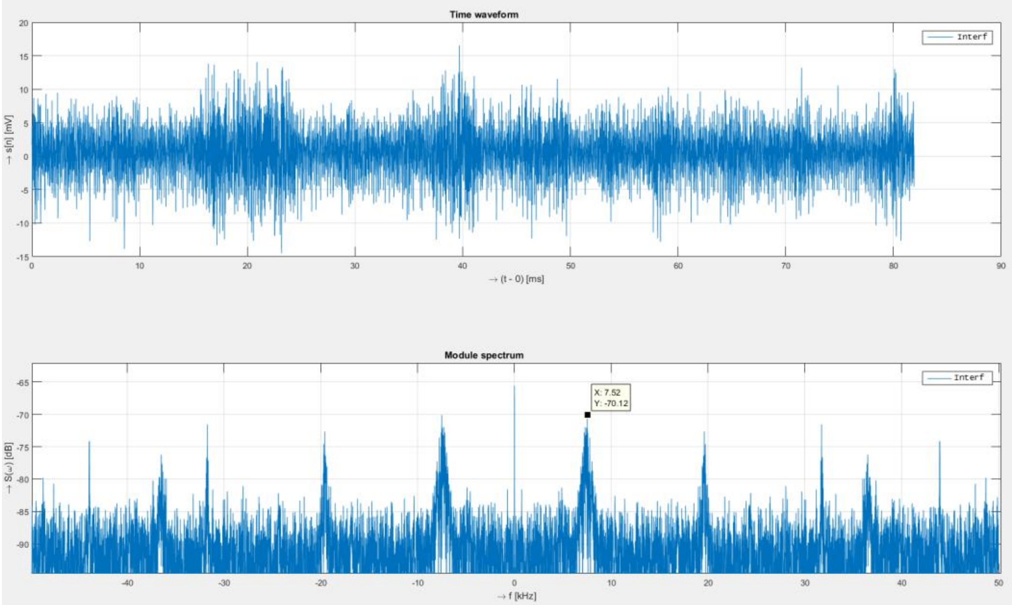
SOP change caused by shaking the cable. L: the Poincare sphere, R: Stokes parameters.



Interferometric method in the field

City line 13km of G652 fibre





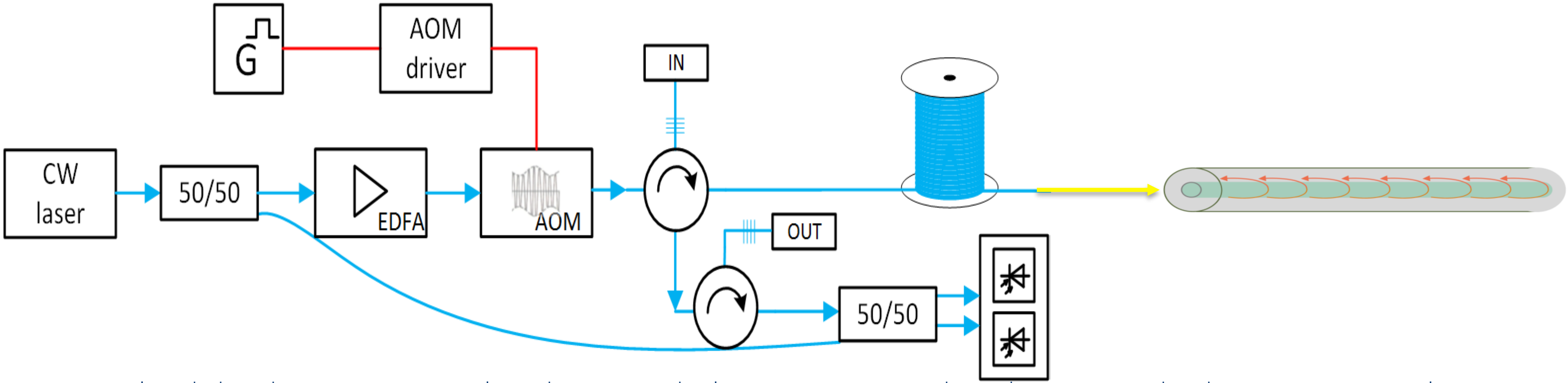
Michelson interferometer, knocking on duct Response in time and corresponding spectra (below).

- Sensitivity of interferometric method

- Polarisation and interferometric method comparison
- Interferometric system has great sensitivity, however in the real network the received signal is very noisy, and it requires a lot of effort to extract useful information.
- Polarisation system sensitivity is lower and detects only mechanical vibrations of the fibre however the signal is not so noisy and hence the post-processing is easier.

Phase sensitive OTDR

- For acoustic/mechanical vibrations detection own back-scatter based fibre-optic sensors based on the Rayleigh scattering
- Ultra narrow spectral width stable laser source and high-power signal

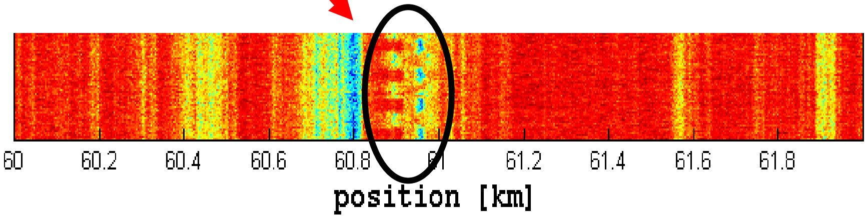


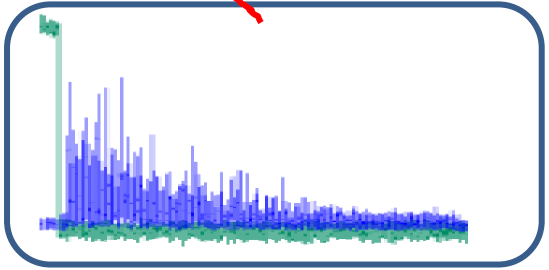
- Rayleigh back-scatter signal is about 60 dB lower compared to the input – high-power optical input signal is necessary.

Vibration Sensing Using Fibre

Vibrations

Phase sensitive-OTDR



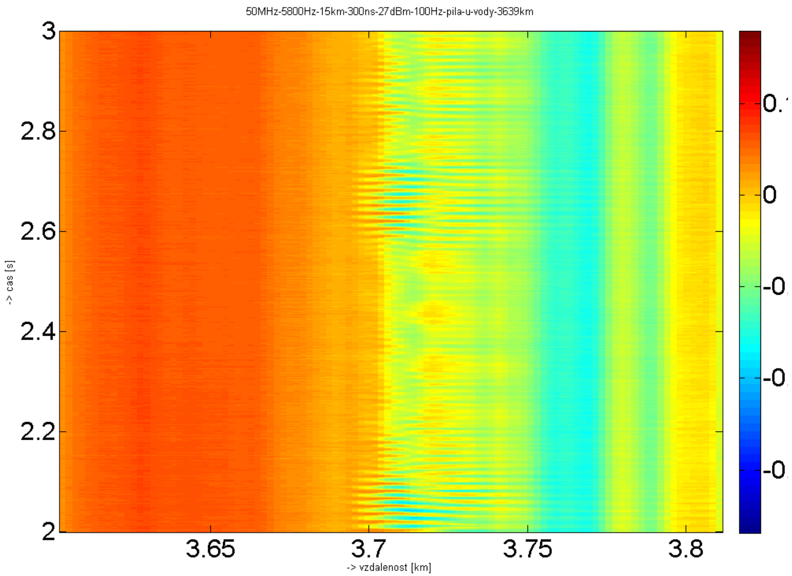


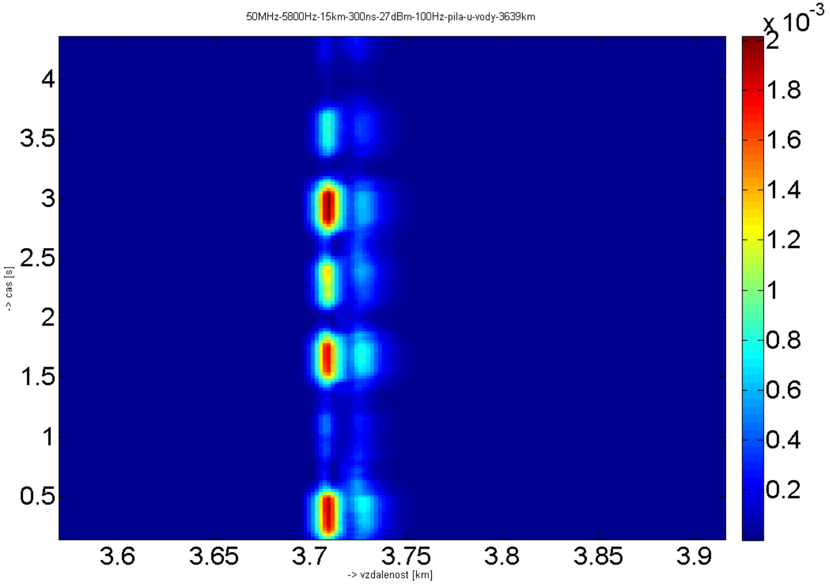
Backscatter is measured while pulse propagates

Based on signal intensity change localisation of event is possible in order of tens of meters

Phase sensitive OTDR

Sawing

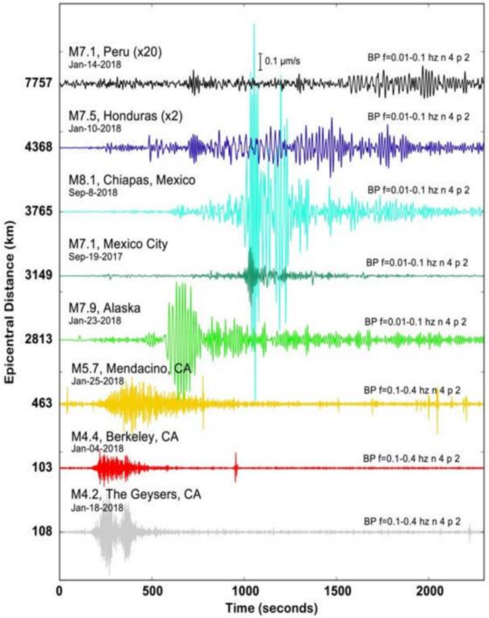


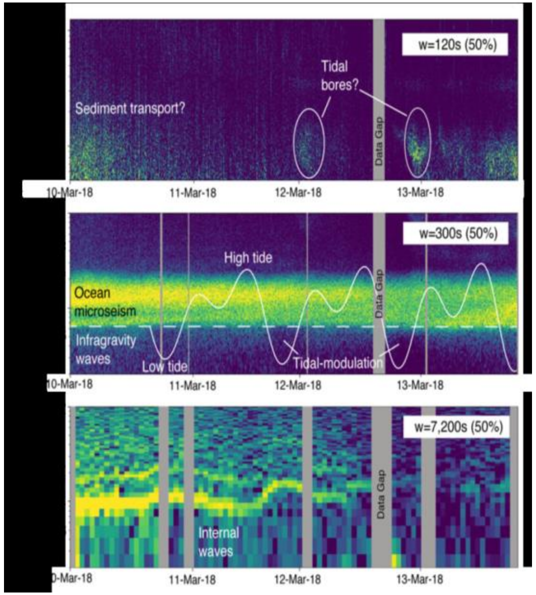


Hammer strokes in distance of about 12 km

Distributed Acoustic Sensing

- Vibration sensing (25 km West Sacramento)
- Hydrogeology
- Oceanographic Measurements (samples from 20 km offshore cable)



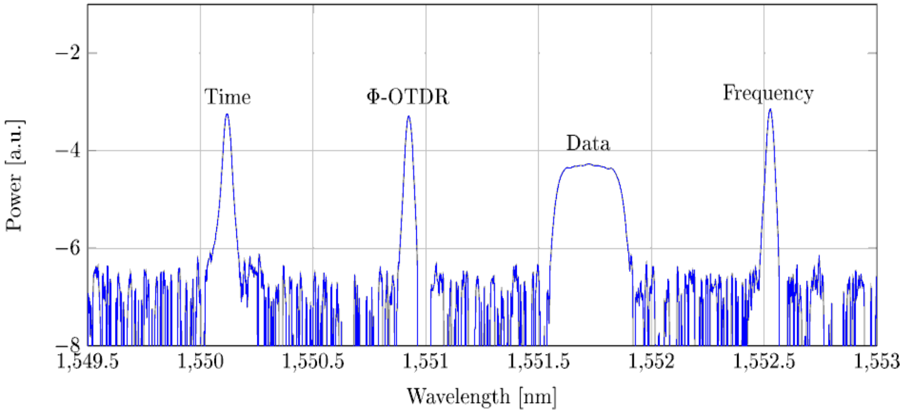


Jonathan B. Ajo-Franklin “Exploring the Subsurface with Distributed Acoustic Sensing & Dark Fiber”
https://www.cesnet.cz/wp-content/uploads/2019/09/ajofranklin_darkfiber_CEF_2019v2shortSmall-1.pdf

Vibration Sensing Using Fibre

- For long distances sharing of fibre is highly desirable (100 km single fibre rental ~ 40 kEUR annually)
- Intensive verification of parallel operation with coherent data and also precise time and ultra stable optical frequency

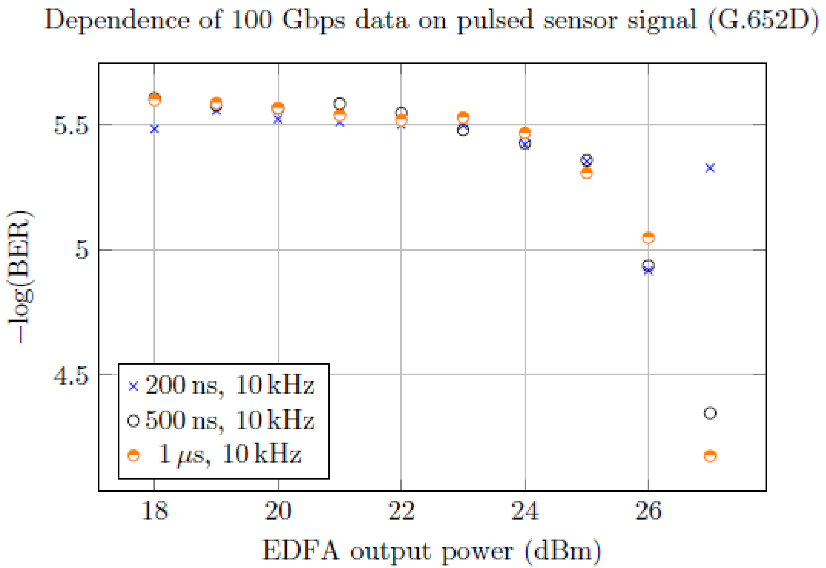
All in one: time, phase sensitive OTDR, 100G DP-QPSK data, optical frequency [1]

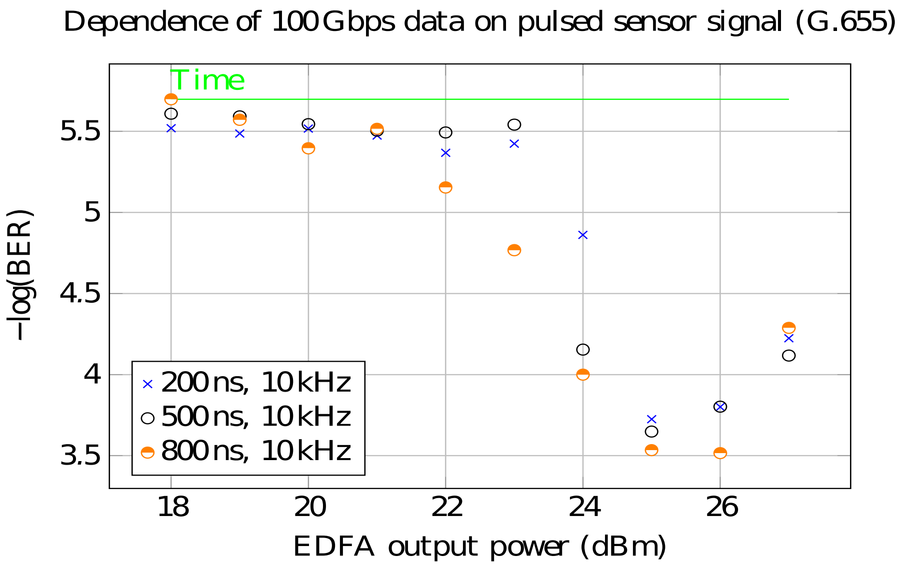


[1] T. Horvath et al.,"Simultaneous transmission of accurate time, stable frequency, data, and sensor system over one fibre with ITU 100GHz grid" Optical Fibre Technology, 2018

Vibration Sensing Using Fibre

- Parallel operation of phase sensitive OTDR with coherent data





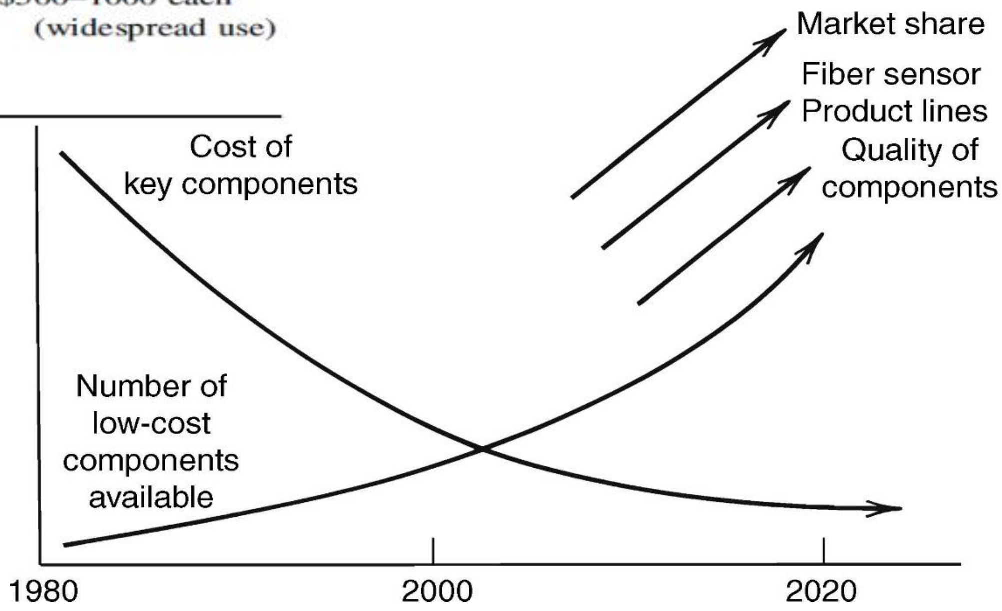
T. Horvath et al.,”Simultaneous transmission of accurate time, stable frequency, data, and sensor system over one fibre with ITU 100GHz grid” Optical Fibre Technology, 2018

Mass Production

	1980	2000	2020
Laser diodes	$3000 each (prototypes)	$3 each (compact disc players)	<$1 each (CD and DVD players)
Single-mode fibers	$5–10 per meter (limited availability)	$0.10 per meter (standard telecom)	<$0.05 per meter (standard telecom)
Integrated optic modulators	Laboratory devices	$500 each	$50 each (fiber optic gyros)
Fiber optic gyros	Laboratory devices	$500–5000 each (low- to medium cost navigation, early use)	$500–1000 each (widespread use)

Techna Vio, Global fiber optic sensors market, London, United Kingdom, 2015.

E. Udd, E. and Wi B. Spillman Jr., Fiber optic sensors: an introduction for engineers and scientists, 2nd Ed., Hoboken, NJ, John Willey 2011



Summary

- Huge overinvestment into fiber infrastructure during dot.com bubble
- Time and frequency are quantities we can measure the most precise, suitable to detect very tiny effects
- Fibres (even telecomm) can provide very stable transfer of time and frequency
- Can be used for seismic, oceanographic…. measurements/ detection
- Down time is expensive - built-in OTDR functionality allows limiting it by remote fault location
- Built-in OTDR is becoming standard part of DWDM transmission systems
- However, much more effective way would be to locate the potential place of future fault in advance, and to try avoiding it
- Telecomm industry benefits from mass production

Acknowledgement

Jan Gruntorád, Helmut Sverenyak

Martin Míchal, Jakub Mer, Josef Verich, Václav Novák

Thank you very much for Kind Attention!

Questions?

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