# ALTERNATIVE SPECTRAL WINDOWS FOR PHOTONIC SERVICES DISTRIBUTION

**Josef Vojtěch et al.**

**Optical networks department, CESNET, Czech Republic**

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# Authors

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# This Presentation

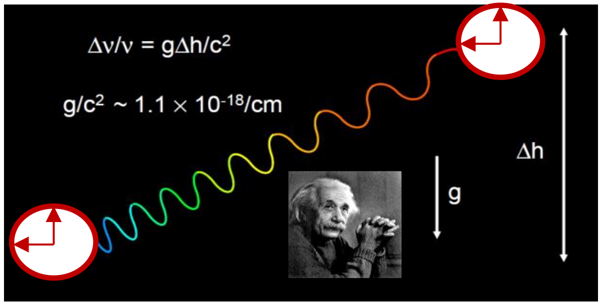
- This presentation deals with delivering of NIR ultra-stable optical frequency / time over telecom fiber or performing NIR distributed sensing using telecom fiber
- Focus on alternatives to 1530-1565 nm band

# Outline

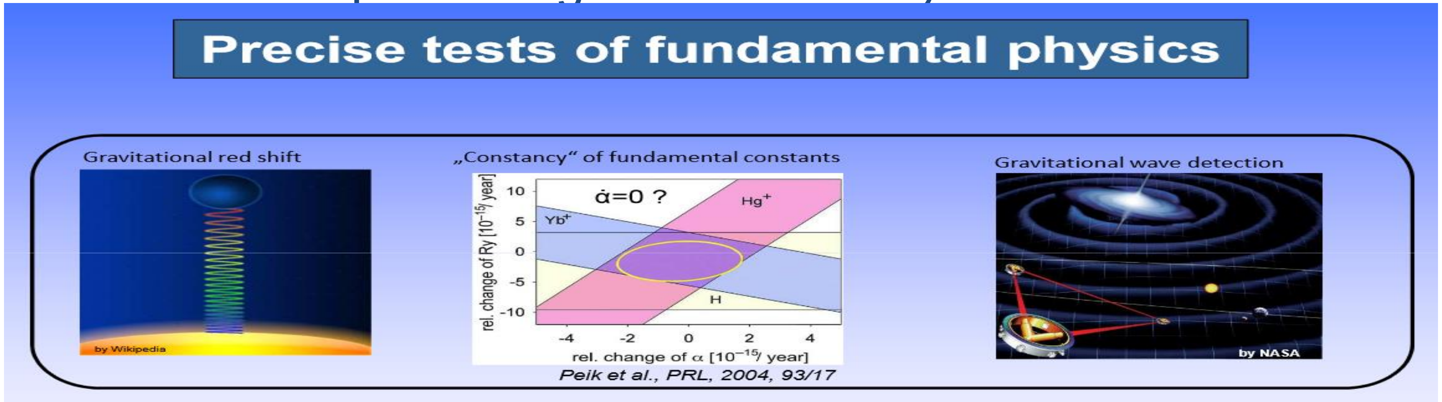
- Motivation for precise time and ultra-stable frequency, fiber sensing using fibers
- Telecom utilization of low loss spectral window in SMF
- Comparison of amplification in: C, L, 1570nm (and S) bands
- Case study of 119 km line in C, L and S bands

# Why Precise Time and Frequency?

- **Time and frequency** = quantities we are able to measure with the highest accuracy
- 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

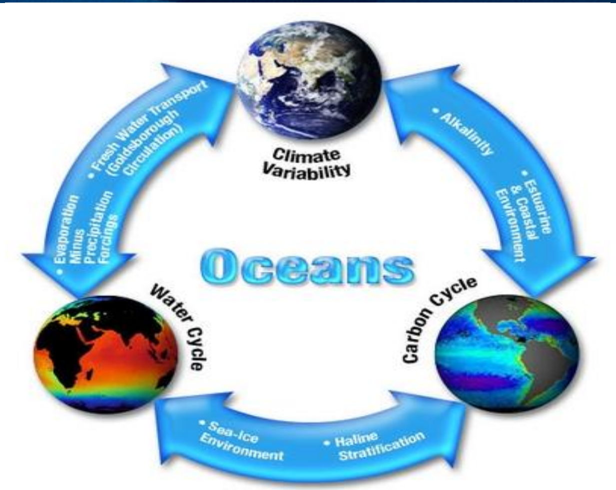


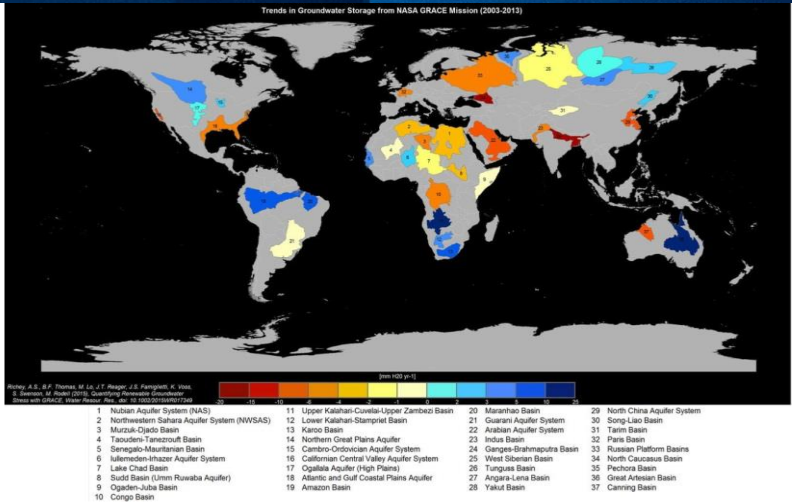

Credit: Schnatz14




Credits: Newbury14, Barr10

# Why Precise Time and Frequency?

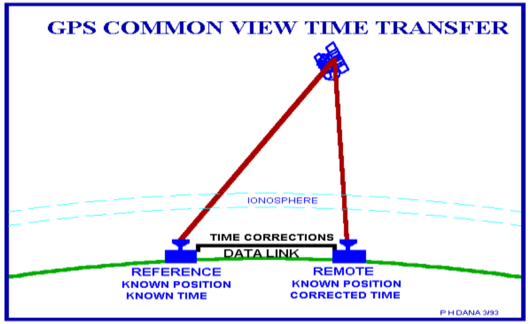


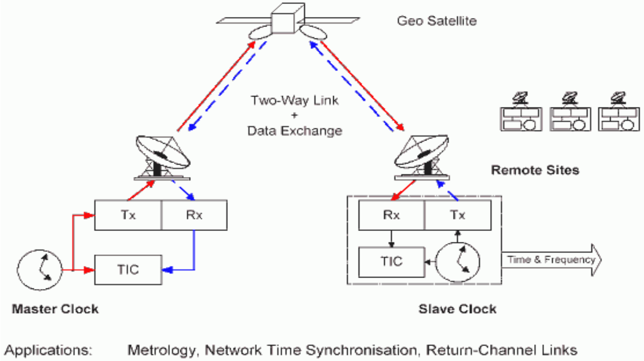




**Earth sciences, remote sensing**

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

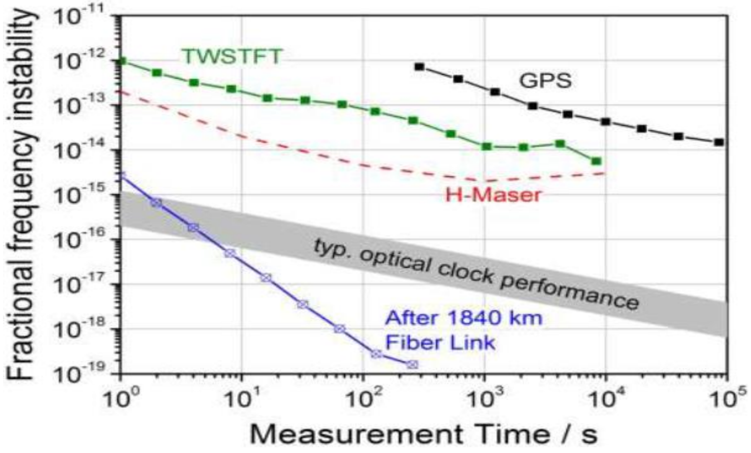
# Satellite RF Based Transfer




- CV GNSS (GPS, GALILEO, GLONASS, …) accuracy 3 – 50 ns
- GNSS PPP (Precise Point Positioning) 0.1 ns
- TWSTF 0.1 ns

Credits: Colorado, Timetech, Droste13



# Ultra-stable Optical F Transfer

- Univ. Paris 13, LNE-SYRTE, RENATER, 150 km
- Lopez et al., Opt. Express 18, 16849 (2010)
- @1542.1 nm

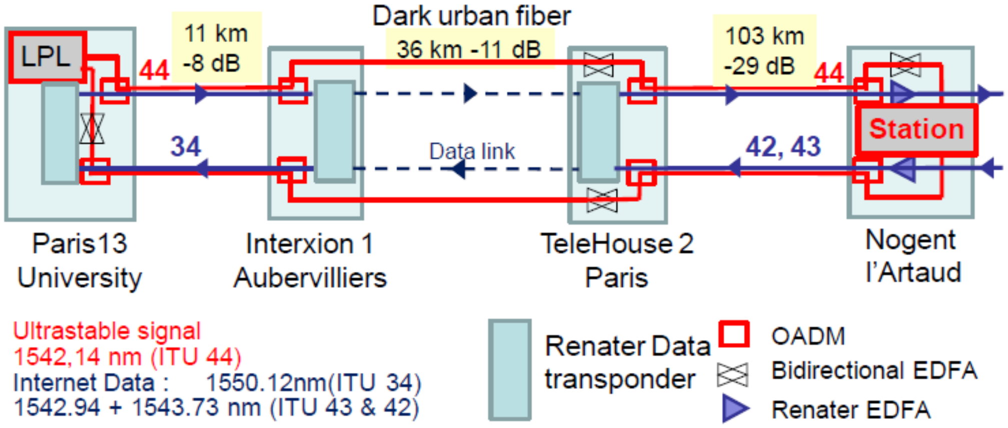
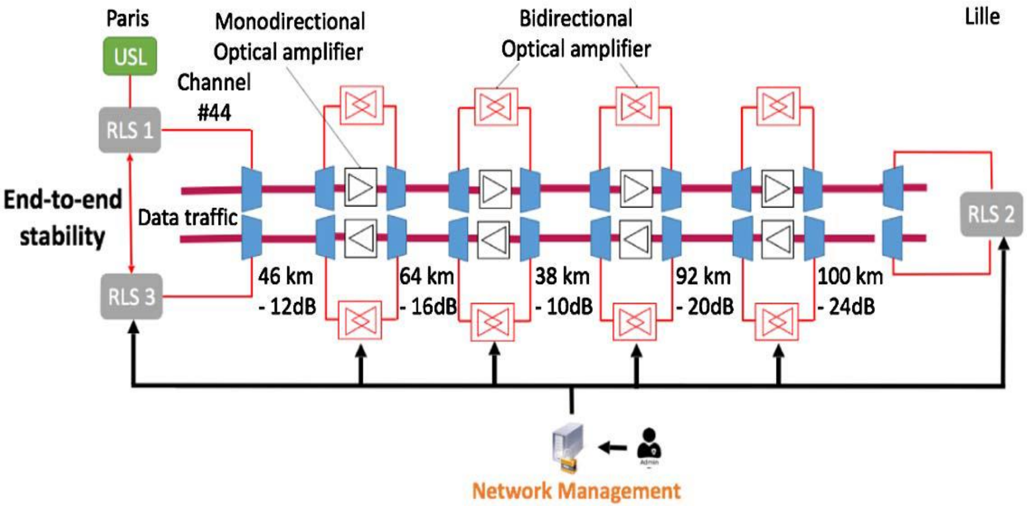
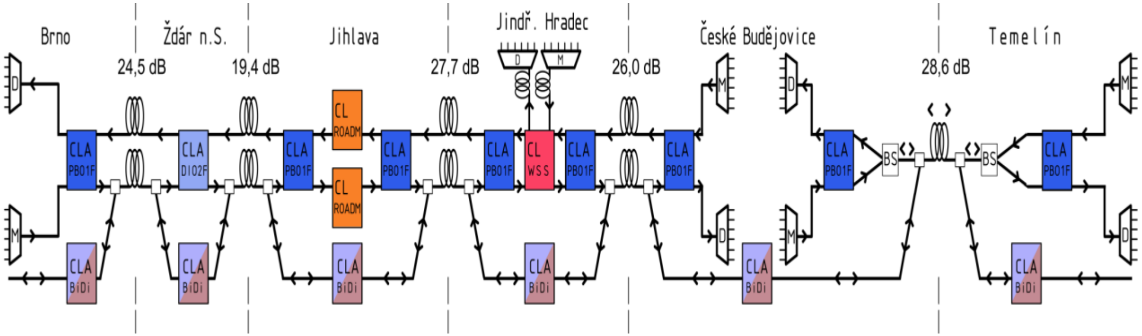


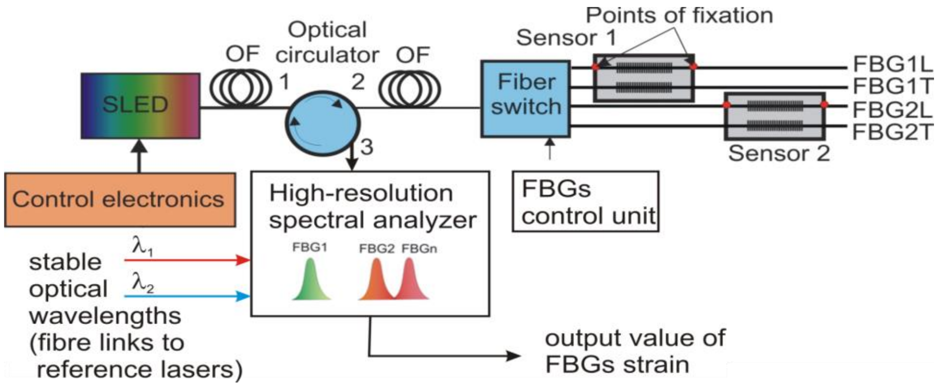

Fig. 3. Scheme of the 2 x 150 km cascaded optical link.



# Ultra-stable Optical F Transfer

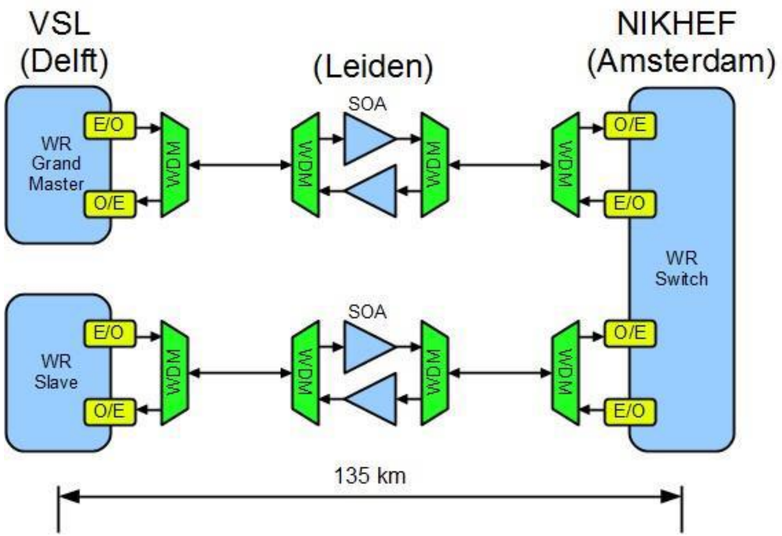
- Long-term measurement of the stability and shape deviation of the containment buildings
- Two PWR reactors, each 1 GWe, protected by its containment building
- Precise measuring methods based on Fiber Bragg Gratings strain gauges
- @1540.5 nm



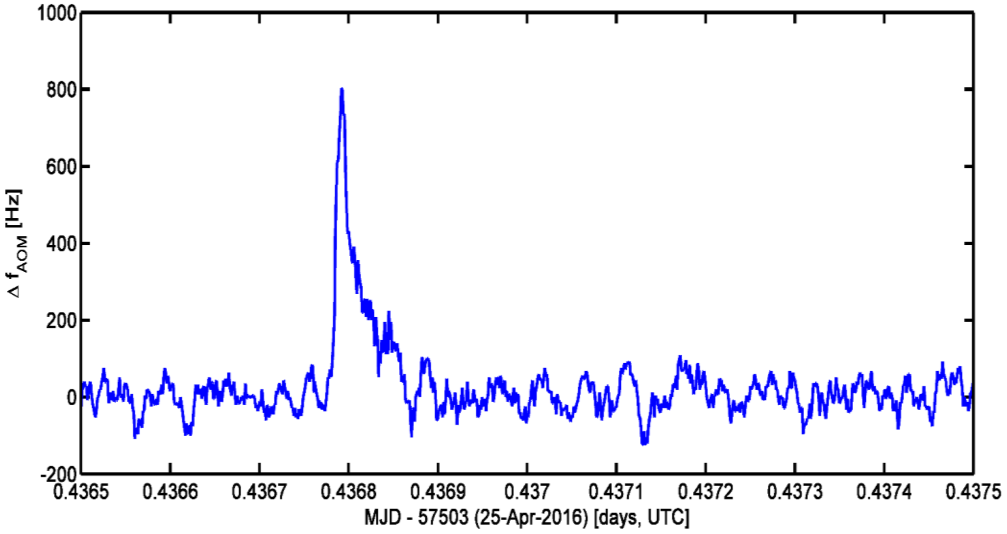



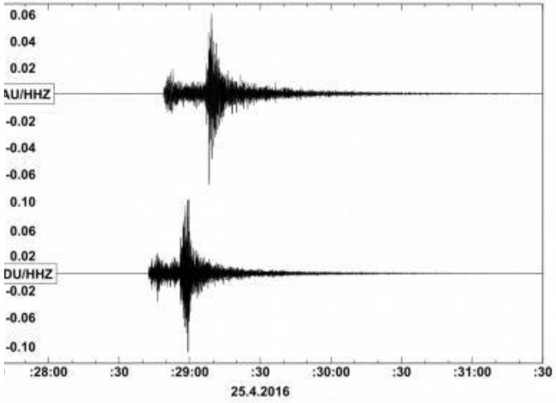
# Optical Time and Frequency Transfer

- Bypassing telco transmission system – within S band
- NIKHEF – VSL 2014, 137 km
- Koelemeij J. et al "Methods for data, time and ultrastable frequency transfer through long-haul fiber-optic links"
- @1470+1490 nm




- **Side product of ultra-stable optical frequency dissemination**
- **25 Apr 2016 – ML 4.1, epicentre located 20 km SW from Vienna**
  - @1540.5 nm

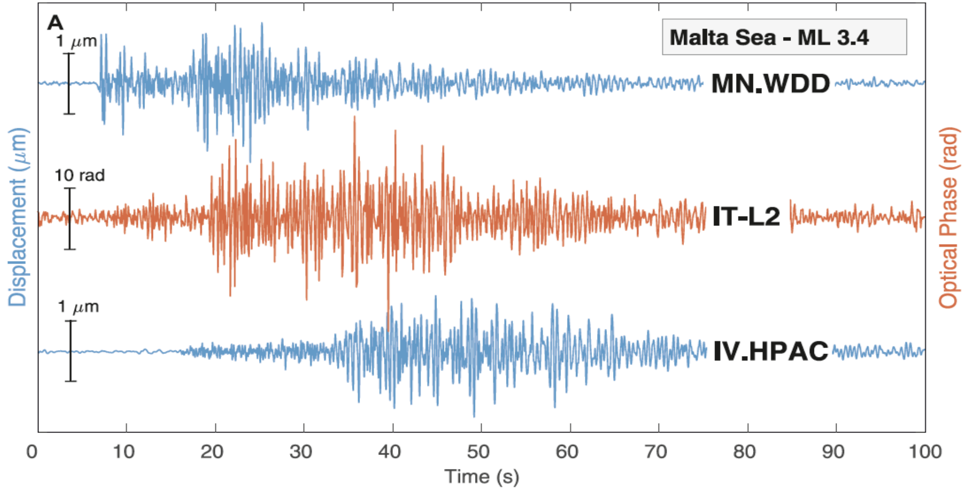


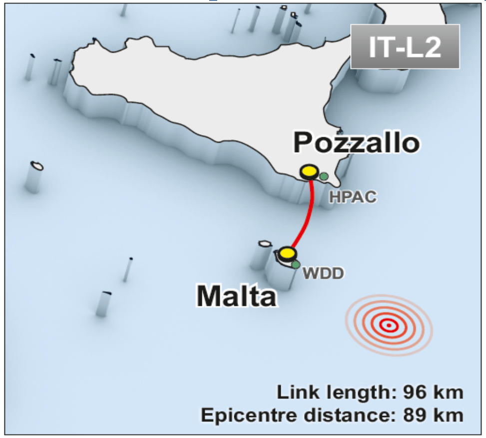





M. Cizek et al., "Transfer of stable optical frequency for sensory networks via 306 km optical fiber link," 2016 European Frequency and Time Forum (EFTF), 2016

## Submarine optical link: Malta Sea earthquake - Sept 2017

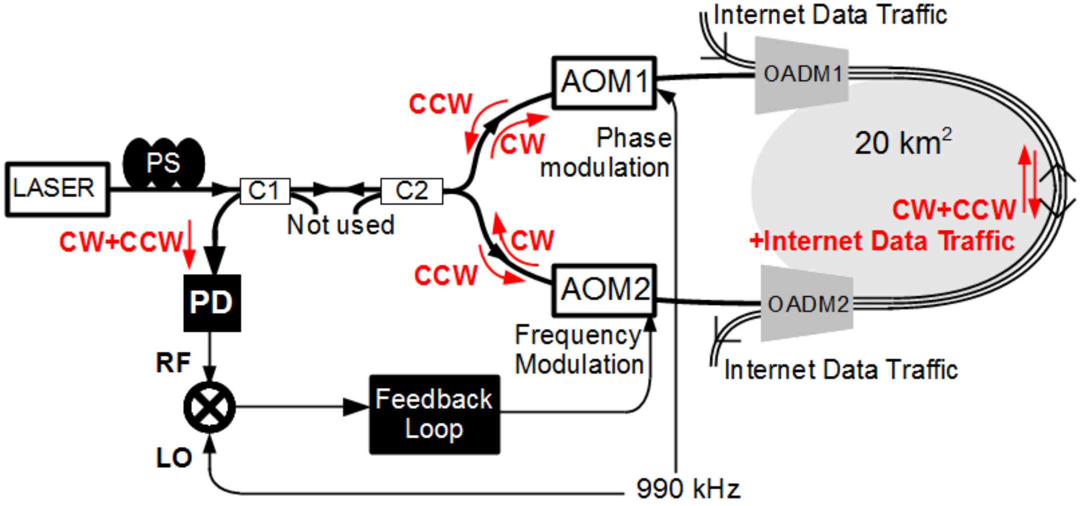



G Marra, C Clivati, R Luckett, A Tampellini, J Kronjäger, L Wright, A Mura, F Levi, S Robinson, A Xuereb, B Baptie, D Calonico „Ultrastable laser interferometry for earthquake detection with terrestrial and submarine cables“, Science, 361, 486-49 (2018)

- **70% of the Earth’s ocean bottom. Submarine lines are far quiet (up to 40 dB) compared to terrestrial ones**
- **Seismometers installation difficult and expensive - over 1 million km of submarine cable already installed**
- **Potential of important application: By detecting underwater earthquakes close to their epicenter, life-saving time could be gained in a tsunami warning**
  - **@1542.1 nm**

# Fiber Optic Gyroscopes

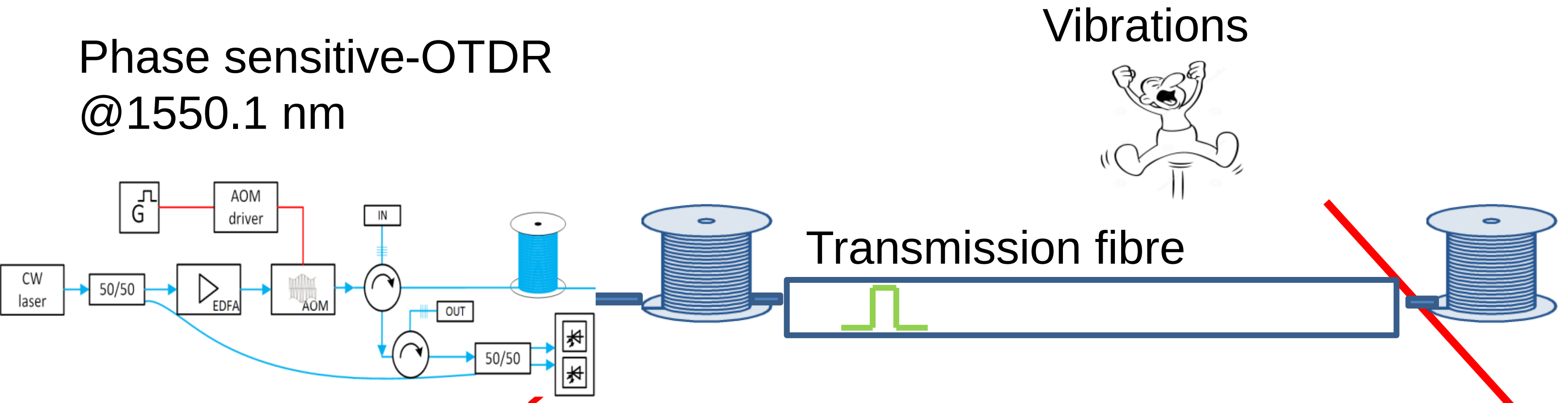


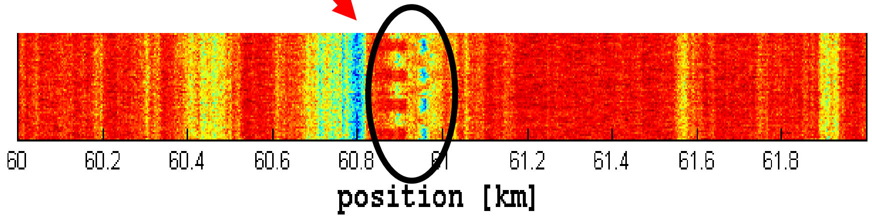

C. Clivati et al „A Large Area Fiber Optic Gyroscope on multiplexed fiber network“, Optics letters. 38. 1092-4. 10.1364/OL.38.001092.

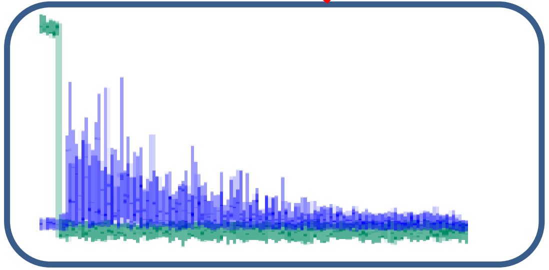
- **20 km$^2$, sensitivity about ($10^{-8}$ rad/s)**
- **Fiber shared with data transmissions**
- **@1542.1 nm**

# Distributed Fibre Acoustic Sensing

Phase sensitive-OTDR
@1550.1 nm



Backscatter is measured while pulse propagates

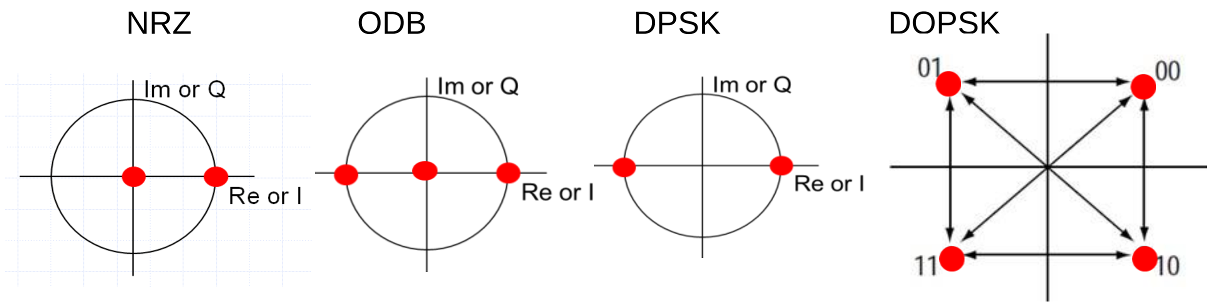
Based on signal intensity change localisation of event is possible in order of tens of meters

# Satisfying Telco Bandwidth Demand

- Bandwidth demand satisfied by serial speed of single channel growth
- 0.155-> 0.622->2.5->10->40Gbps?
- On-off keying (intensity modulation - direct detection)
- 50 GHz channel grid
- 10->40G transition (bit interval 100 -> 25 ps)

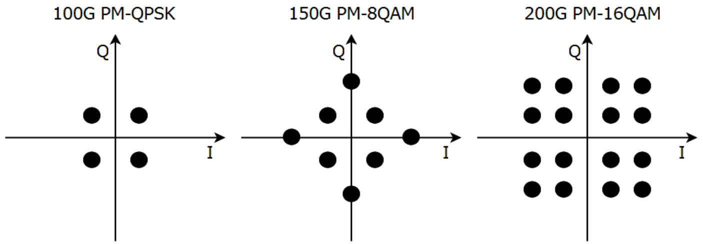
40G NRZ tolerance very weak CD 50ps/nm (equals to 3km of G.652 fibre), PMD 2.5 ps

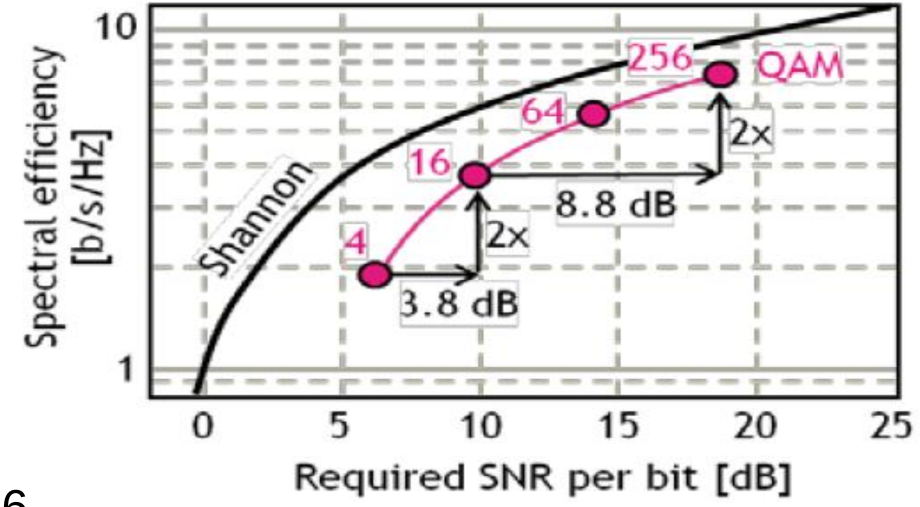
ODB, DPSK proposed, but more strict design rules compared to 10G, DQPSK (20Gbaud)

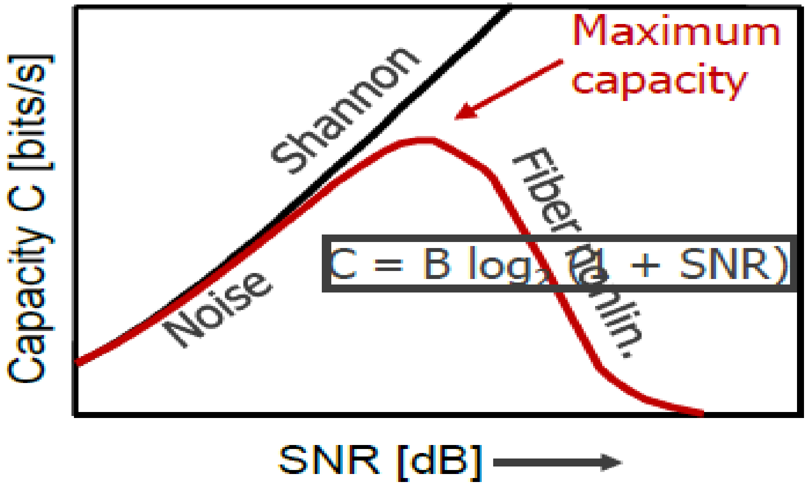


# Satisfying Telco Bandwidth Demand

- 0.155-> 0.622->2.5->10->40->100G->200G->400Gbps
- 100Gbps - Polarization multiplexed DQPSK
- 28 GBaud, 50 GHz grid
- Shannon's law $C = B \cdot \log_2 (1+SNR)$
- C/B (capacity per unit bandwidth) is limited by noise

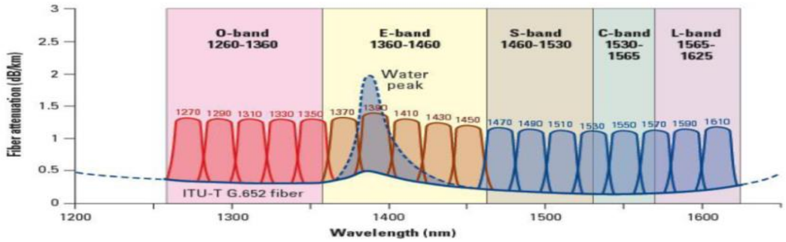


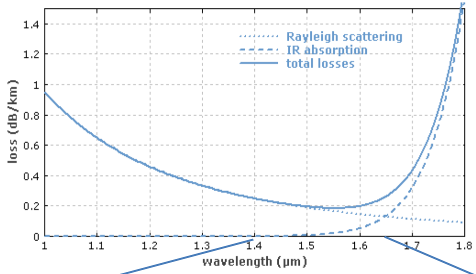



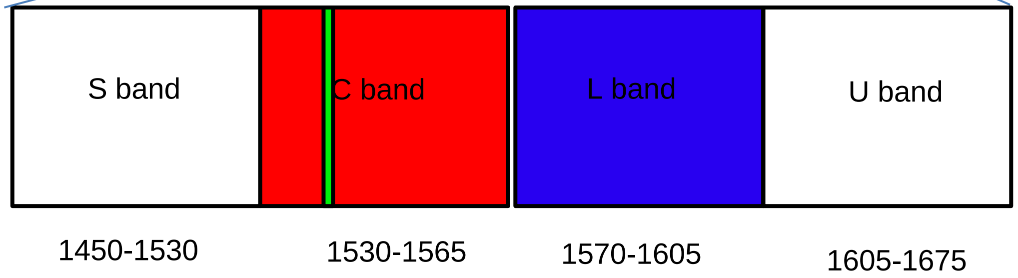



# Low Loss Spectral Window in SMF

- Telecom - C band
  - 40@100 GHz, 80@50, 96@50 GHz
- Metrology
  - C band prevails
    - Telecom grade affordable passive components
    - Amplification
  - Comps + Amps?: Apply also for L?
  - Comps + Amps?: Apply also for 1570 nm?

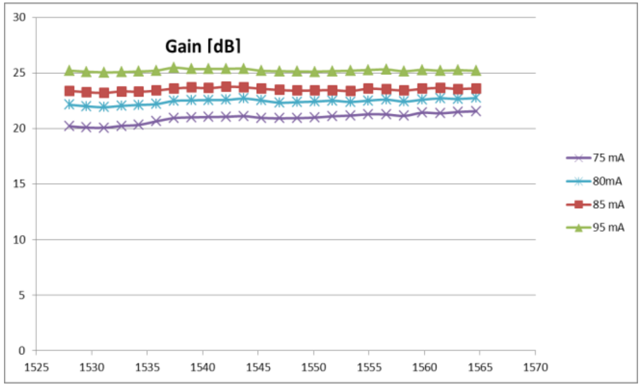


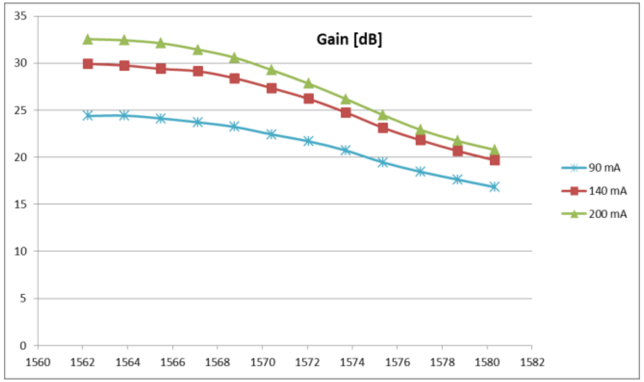



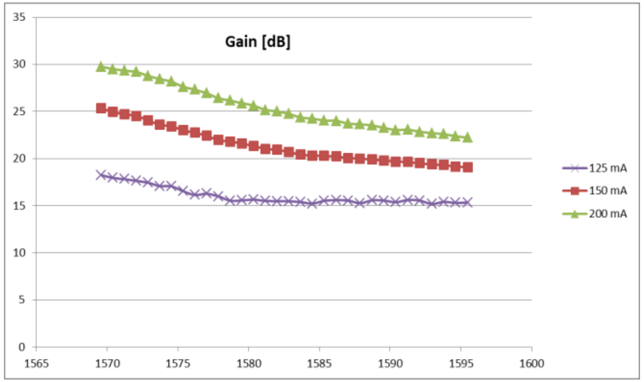



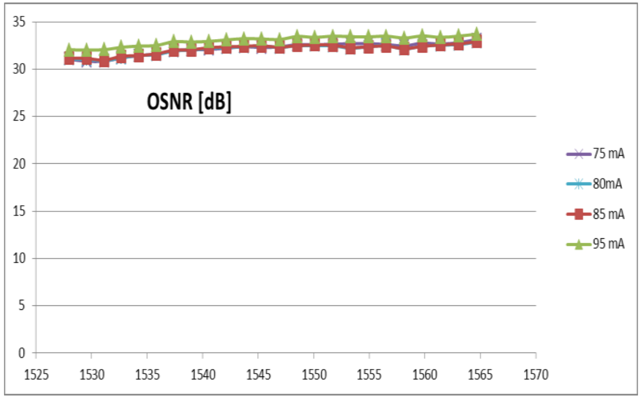
# Bidirectional EDF Amplifiers

C | 1570 nm | L

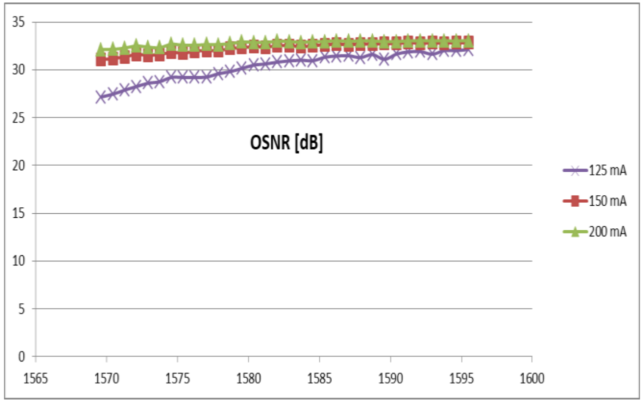


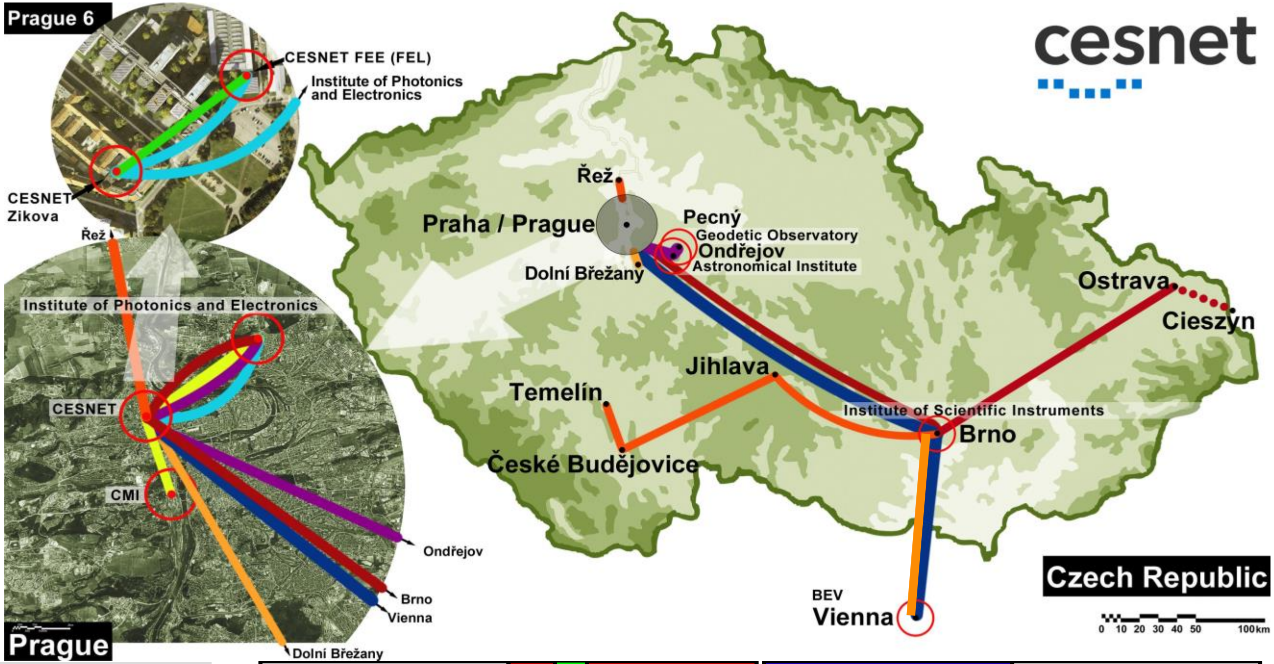



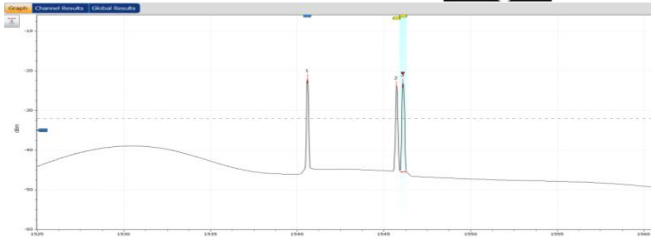


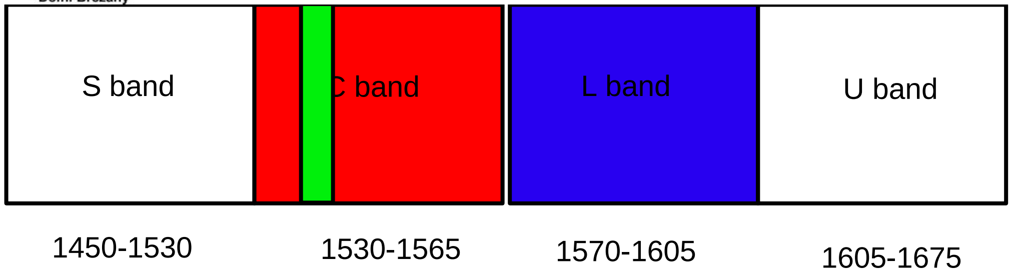


# Time and Frequency Infrastructure

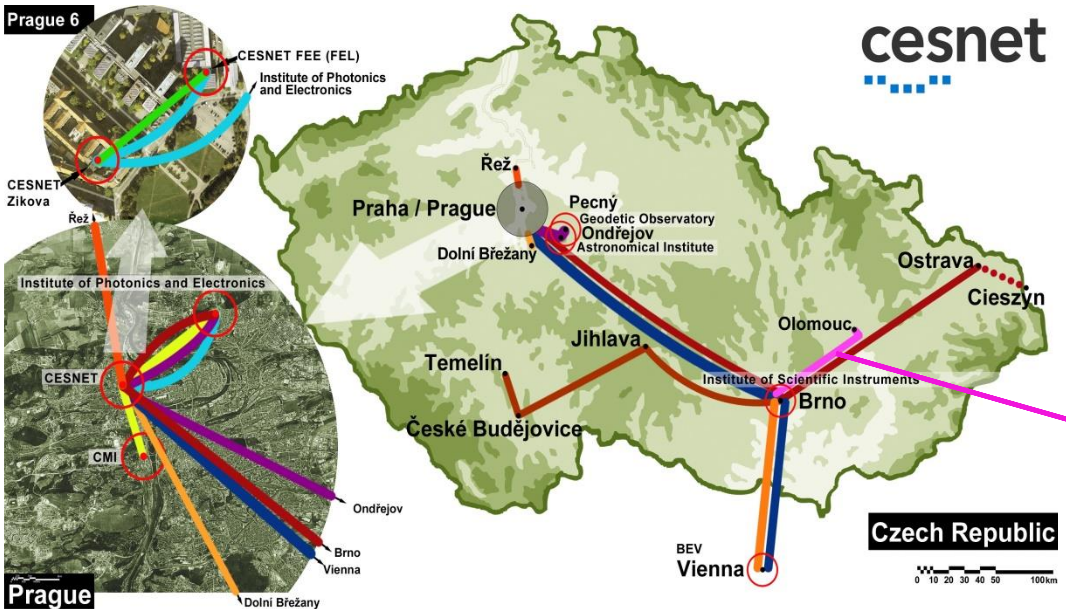
- T/F transfer + distribution
- Fibers shared with data
- Projected length 2500 km, transmission 1340 km
- Dedicated all-optical sub band 800/400 GHz (includes 1540.5 and 1542.1 nm)





# Optical Clock Interconnection

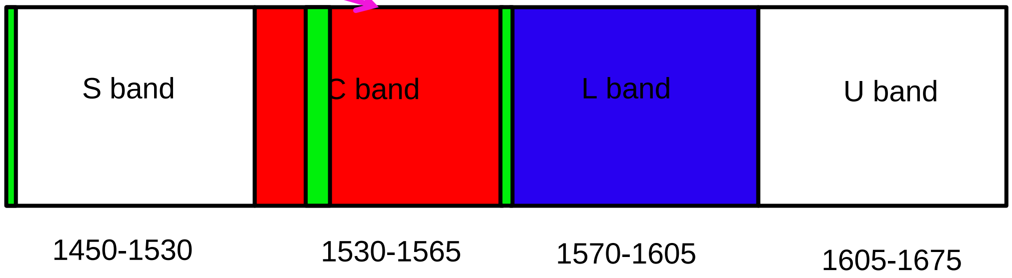



Optical clock based on trapped and cooled single ion $^{40}Ca^{+}$ under development

Direct output at: 729 nm

-> doubling to 1458 nm

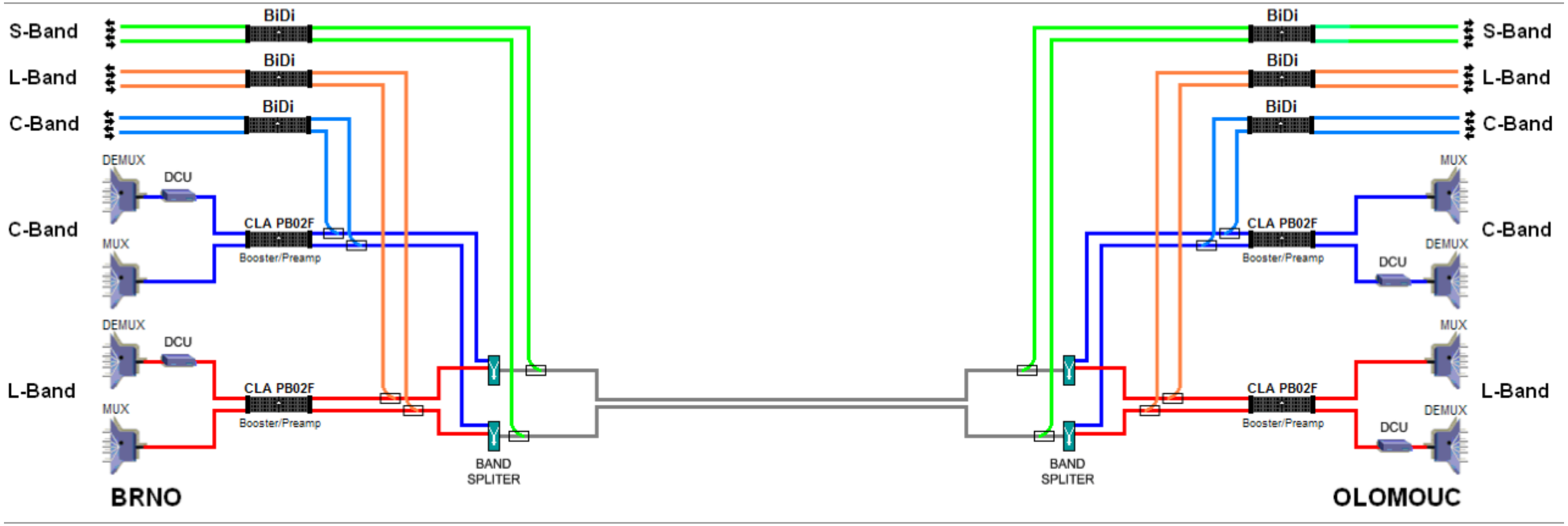
Distance: 119km, 29 dB



# Optical Clock Interconnection

- Propposed design I

7 km



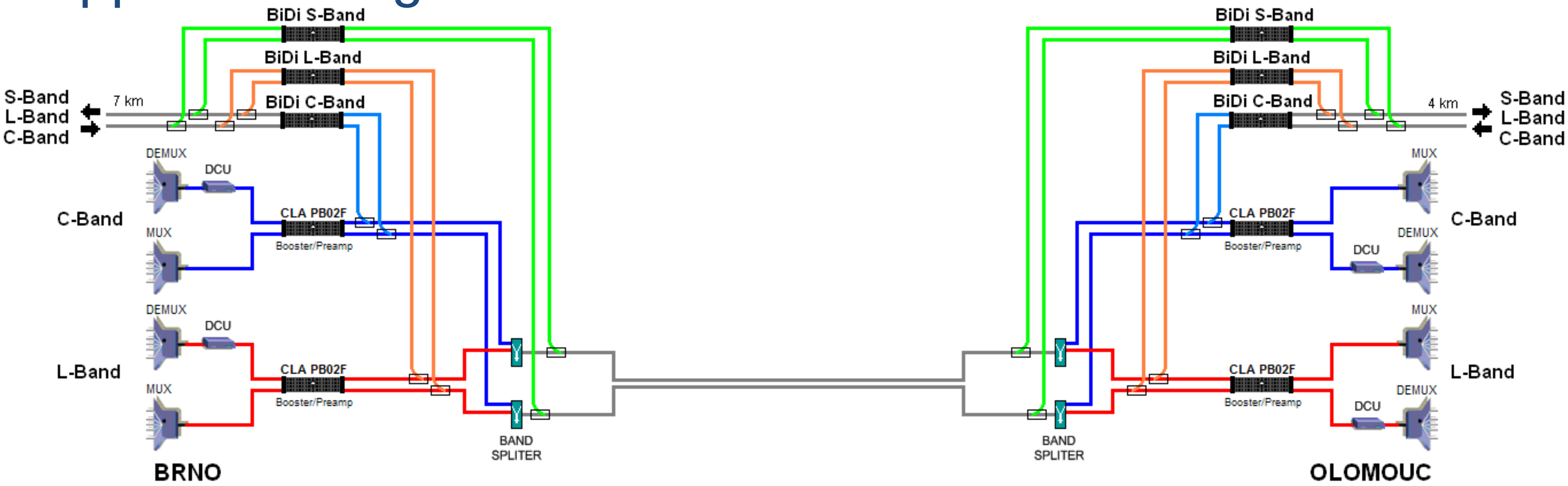

4 km

| System | Attenuation [dB] |
|---|---|
| DWDM data systems | 25 |
| C band bidi | 32.2 |
| L band bidi | 34.6 |
| S band bidi | 39.9 |

- L band penalty max 0.02 dB/km totally 2.4 dB
- S band according G.652D max 0.31 dB/km at 1460 nm, fiber attenuation about 36.9 dB

# Optical Clock Interconnection

- Proposed design II

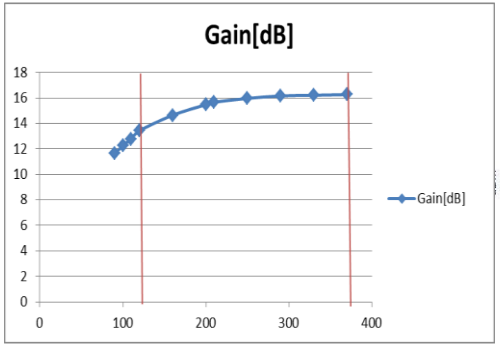


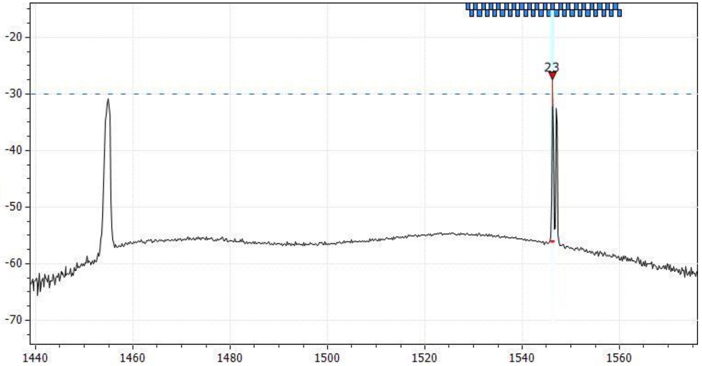

| System | Attenuation [dB] |
|---|---|
| DWDM data systems | 25 |
| C band bidi | 35.2 |
| L band bidi | 37.6 |
| S band bidi | 41.4 |

- L band penalty max 0.02 dB/km totally 2.4 dB
- S band according G.652D max 0.31 dB/km at 1460 nm, fiber attenuation about 36.9 dB

# S Band Amplification

- Raman - quite ineffective (500mW to 8 dB of gain)
- Semiconductor Optical Amplifier
- Will require some gain stabilization e.g.
- holding beam injection
- Estimate max available gain 2 x 16 -18dB




Vojtech, J., Radil, J., Smotlacha, Vl. (2015). Semiconductor Optical Amplifier with Holding Beam Injection for Single Path Accurate Time Transmission. JTh2A.78. 10.1364/CLEO_AT.2015.JTh2A.78.

# Summary

- Low attenuation and minimal reflections
  - Careful selection of passives components, all filters ideally fused together
  - S band SOAs should be fine for CW
  - Backup - Thulium doped fluoride fibre based amplifiers
- Passives partially deployed in the field

# Acknowledgement

Jan Gruntorád, Helmut Sverenyak

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# Thank You Very Much for Kind Attention!

# Questions Please?

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# Transfer stabilisation