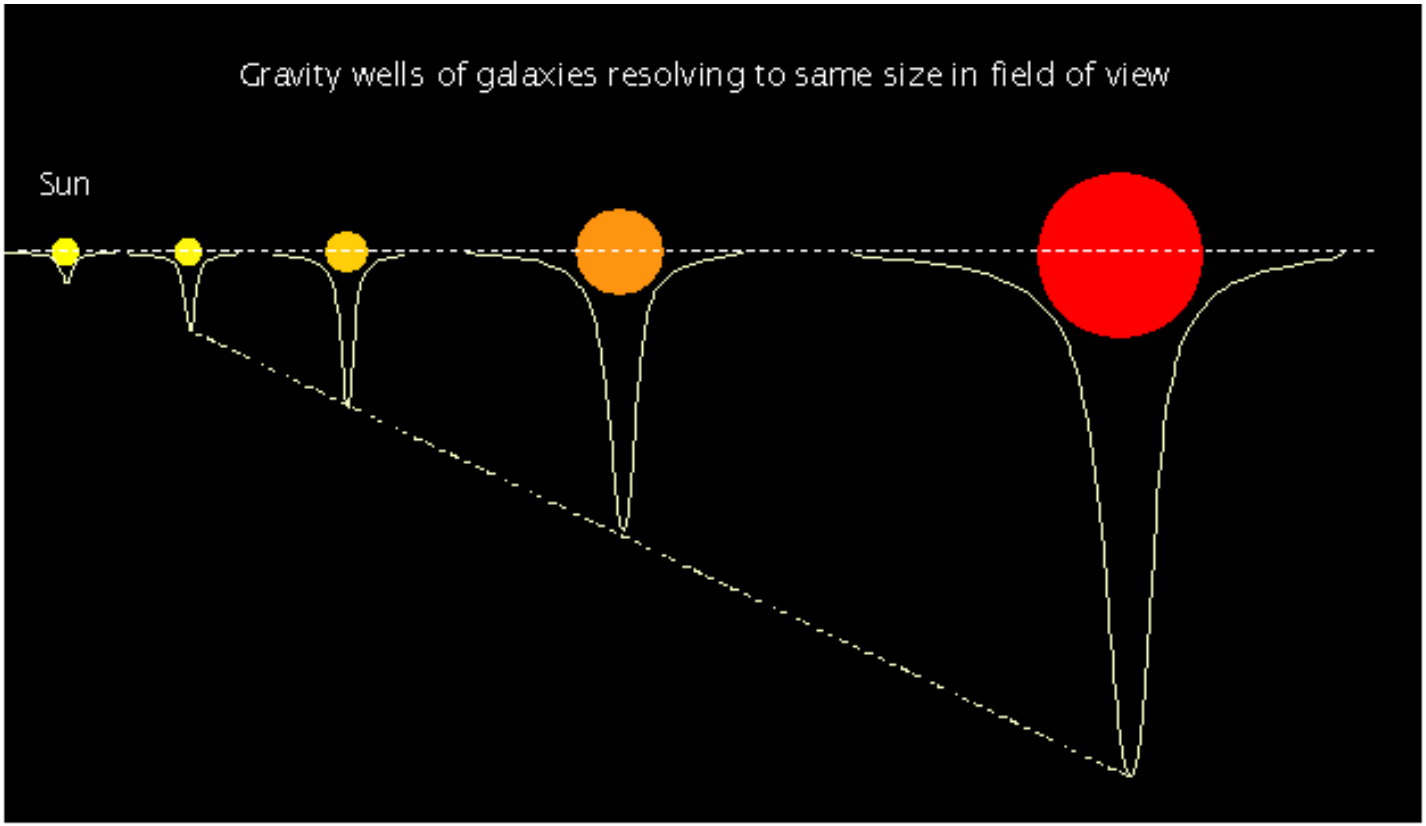
Nikolai Kolachevsky

Lecture 4

- Space and time in Einstein's theory of gravitation, basics of General relativity
- Time transformation in rotating frame, gravitational red shift, time dilation, Sagnac effect.
- Methods of time and frequency transfer, clock synchronization.

Space-time curvature

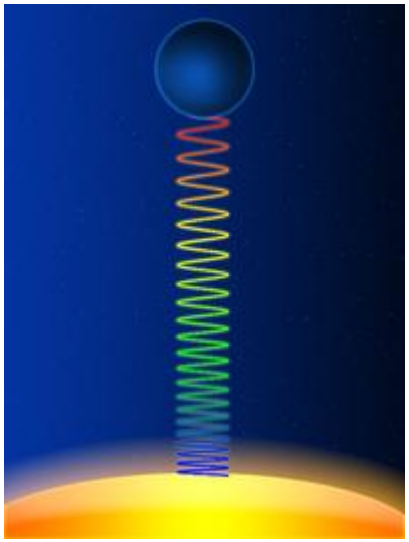


Fractional frequency shift

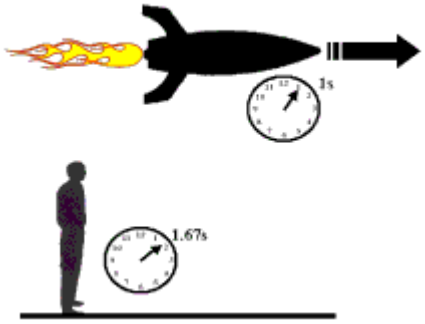
Non-rotating frame

$$h(t) = \frac{U(t)}{c^2} + \frac{v^2}{2c^2} + \mathcal{O}\left(\frac{1}{c^4}\right)$$

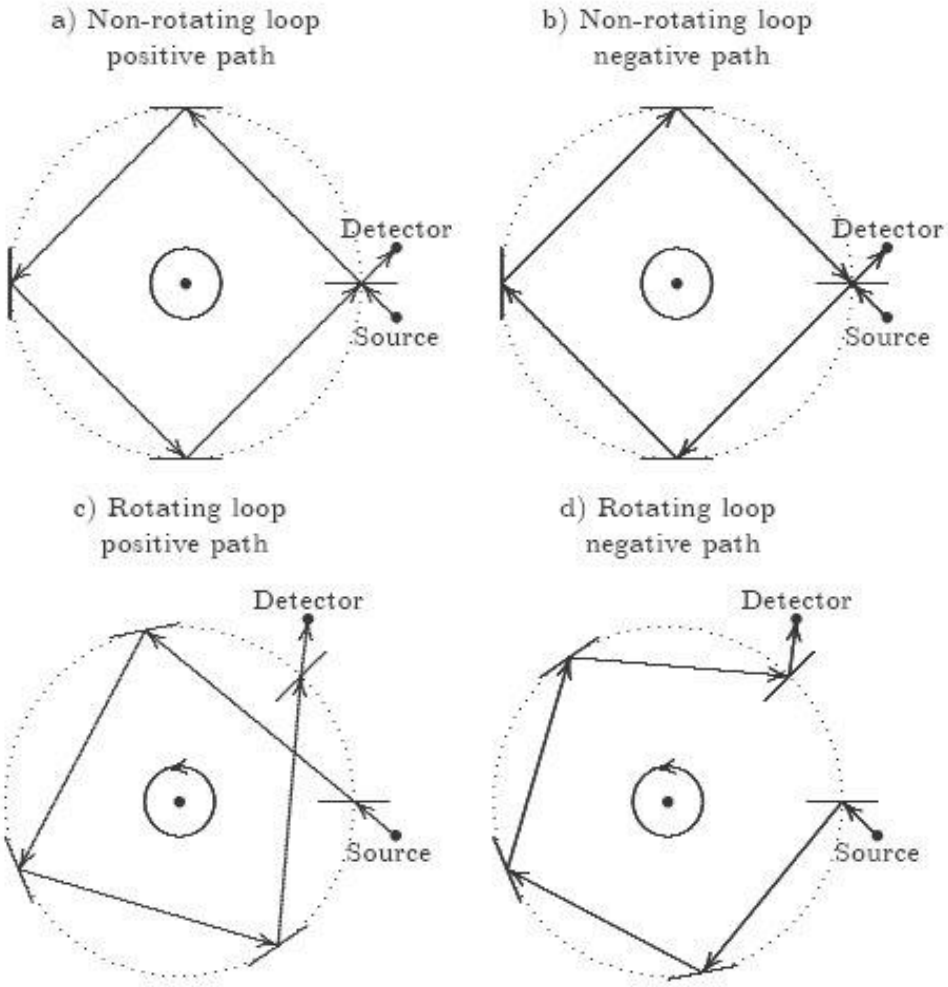
Gravitational red shift



Time dilation

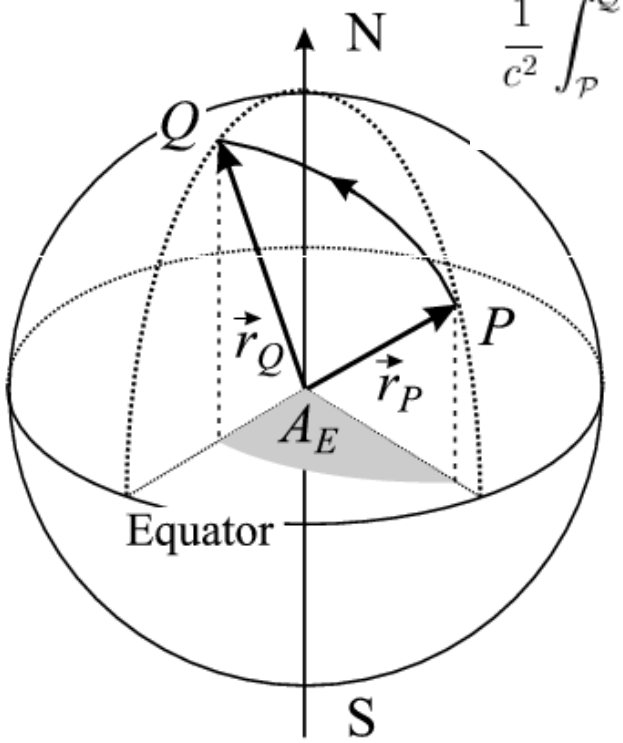


The Sagnac effect



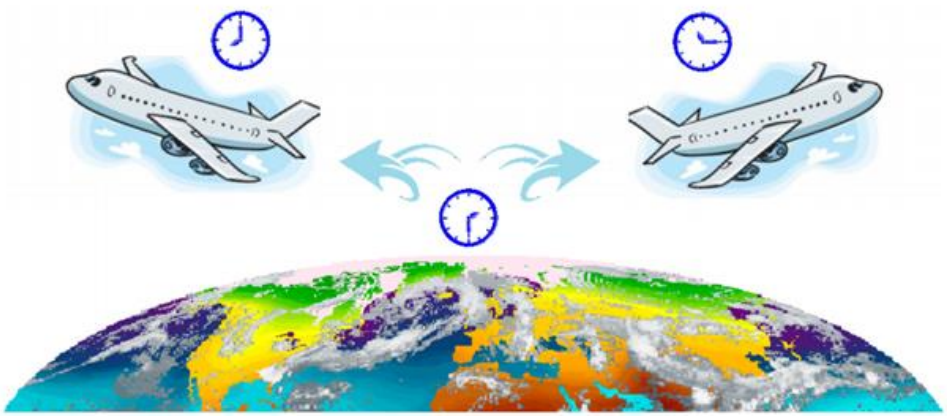
Rotating frame: the Sagnac effect

$$h(t) = \frac{1}{c^2}\left[U_g + \Delta U(t) + \frac{V(t)^2}{2}\right] + \frac{2\omega}{c^2}\frac{dA_E}{dt}$$

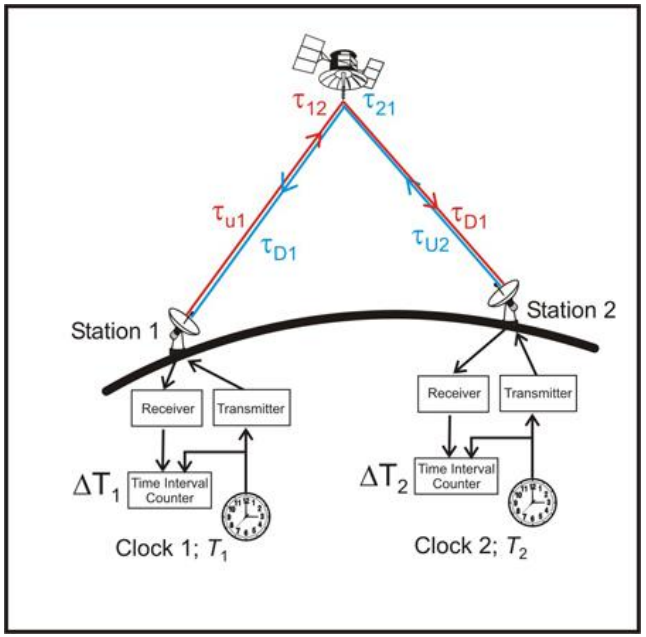


$$\frac{1}{c^2}\int_{\mathcal{P}}^{\mathcal{Q}} (\vec{\omega}\times\vec{r})\cdot d\vec{r} = \frac{1}{c^2}\int_{\mathcal{P}}^{\mathcal{Q}} \vec{\omega}\cdot(\vec{r}\times d\vec{r}) = 2\frac{1}{c^2}\int_{\mathcal{P}}^{\mathcal{Q}} \vec{\omega}\cdot d\vec{A}_E = \frac{2\omega A_E}{c^2}$$

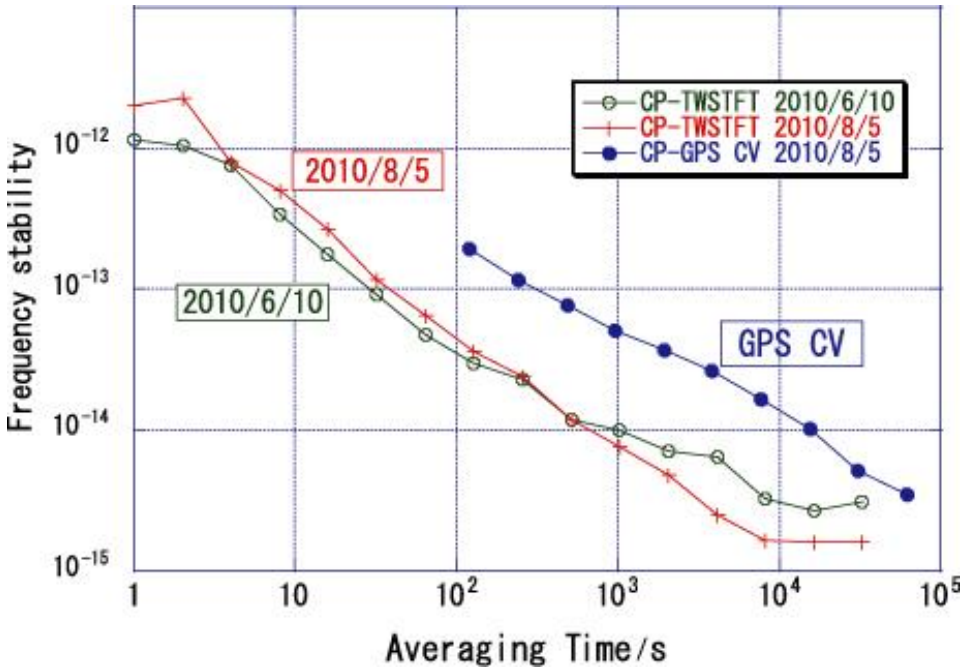
Hafele and Keating Experiment



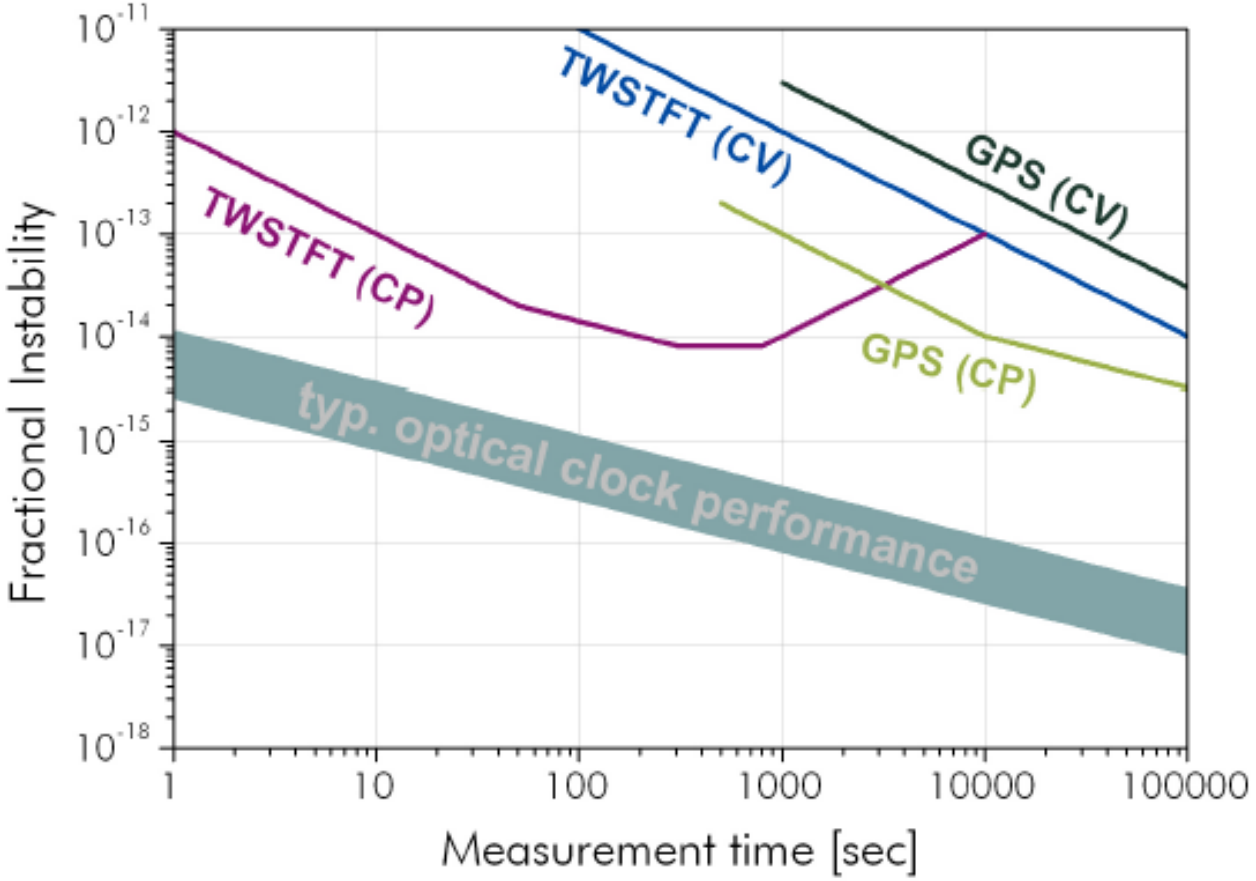
Two-way time and frequency transfer



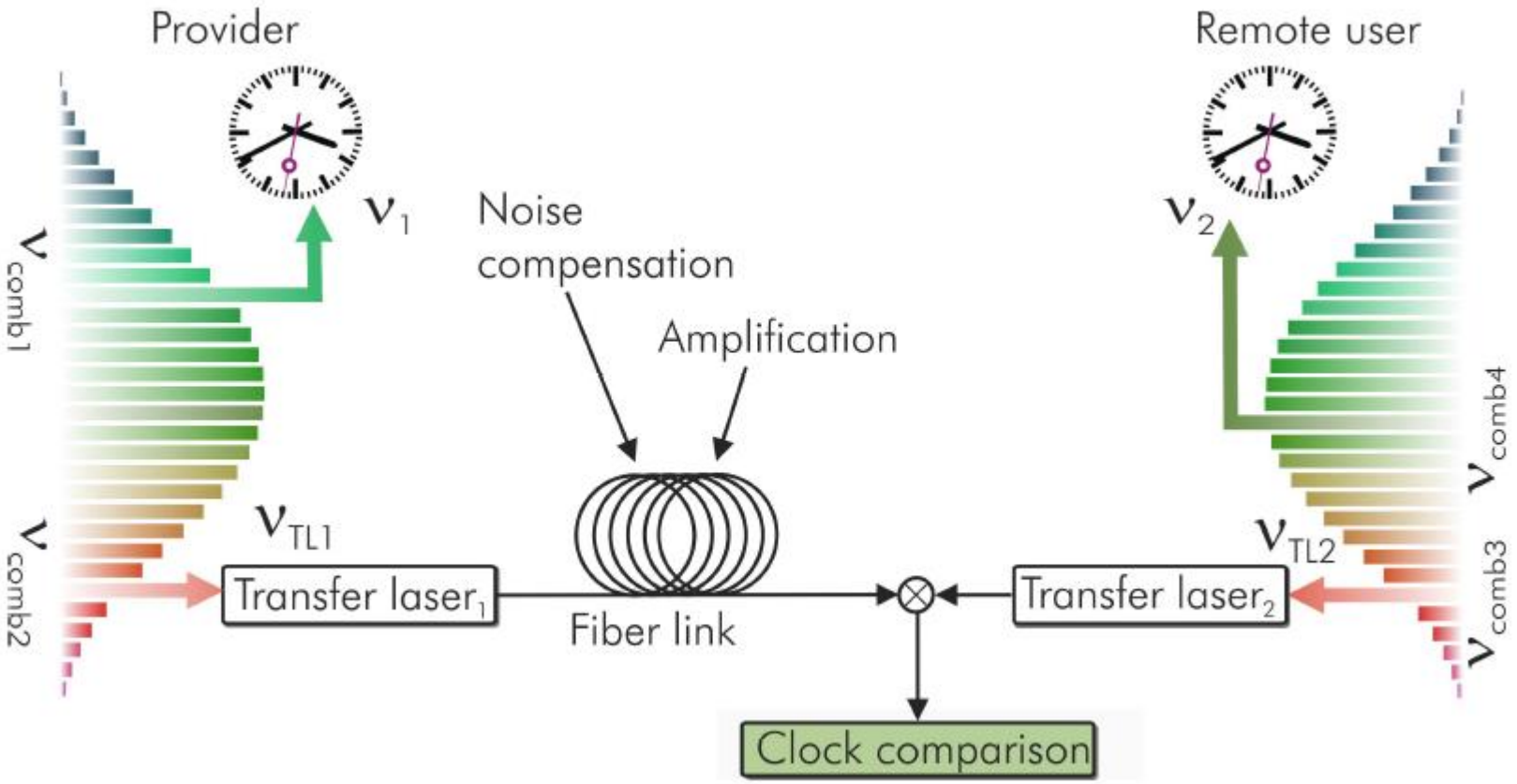
$$\Delta t_A = t_A - t_B + \delta_{B\to A}$$
$$\Delta t_B = t_B - t_A + \delta_{A\to B}\,.$$



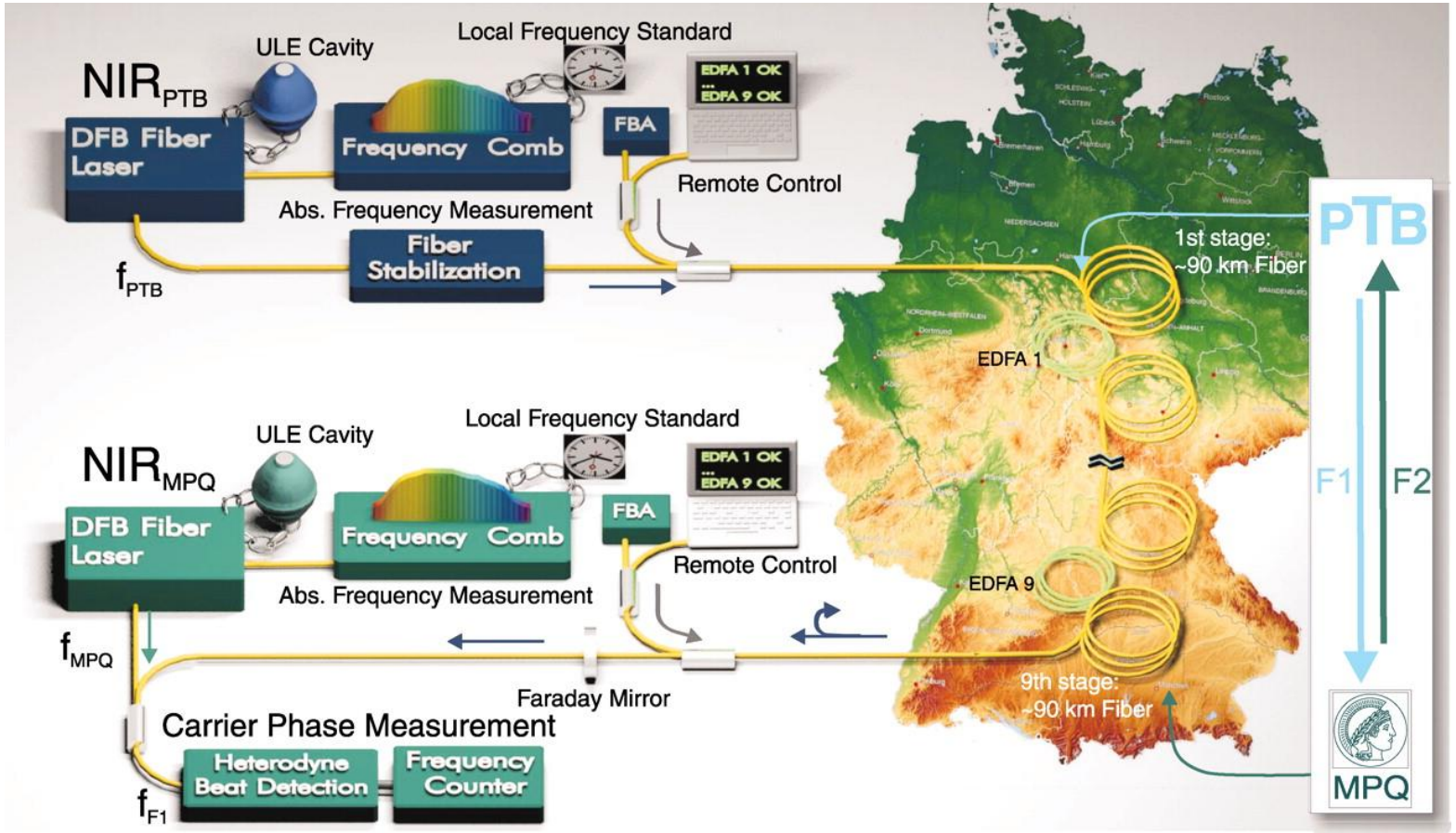
Today's demands for frequency transfer



Optical frequency transfer

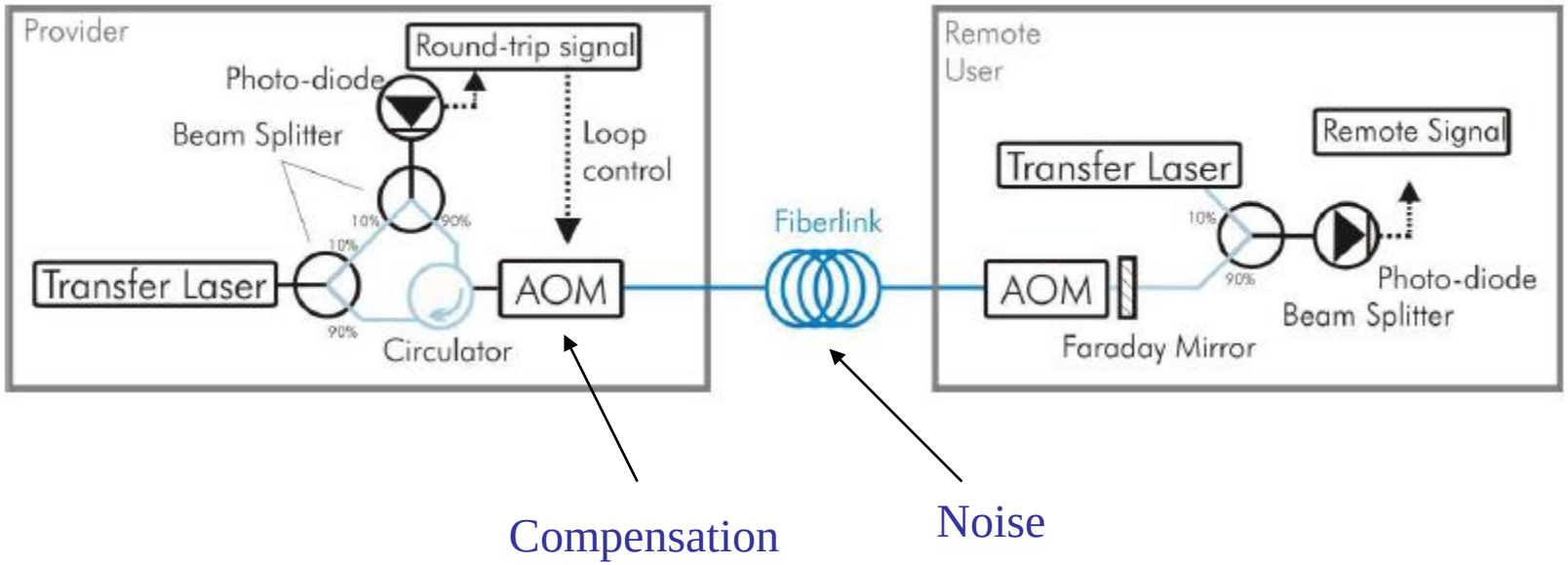


The 920-km fiber link

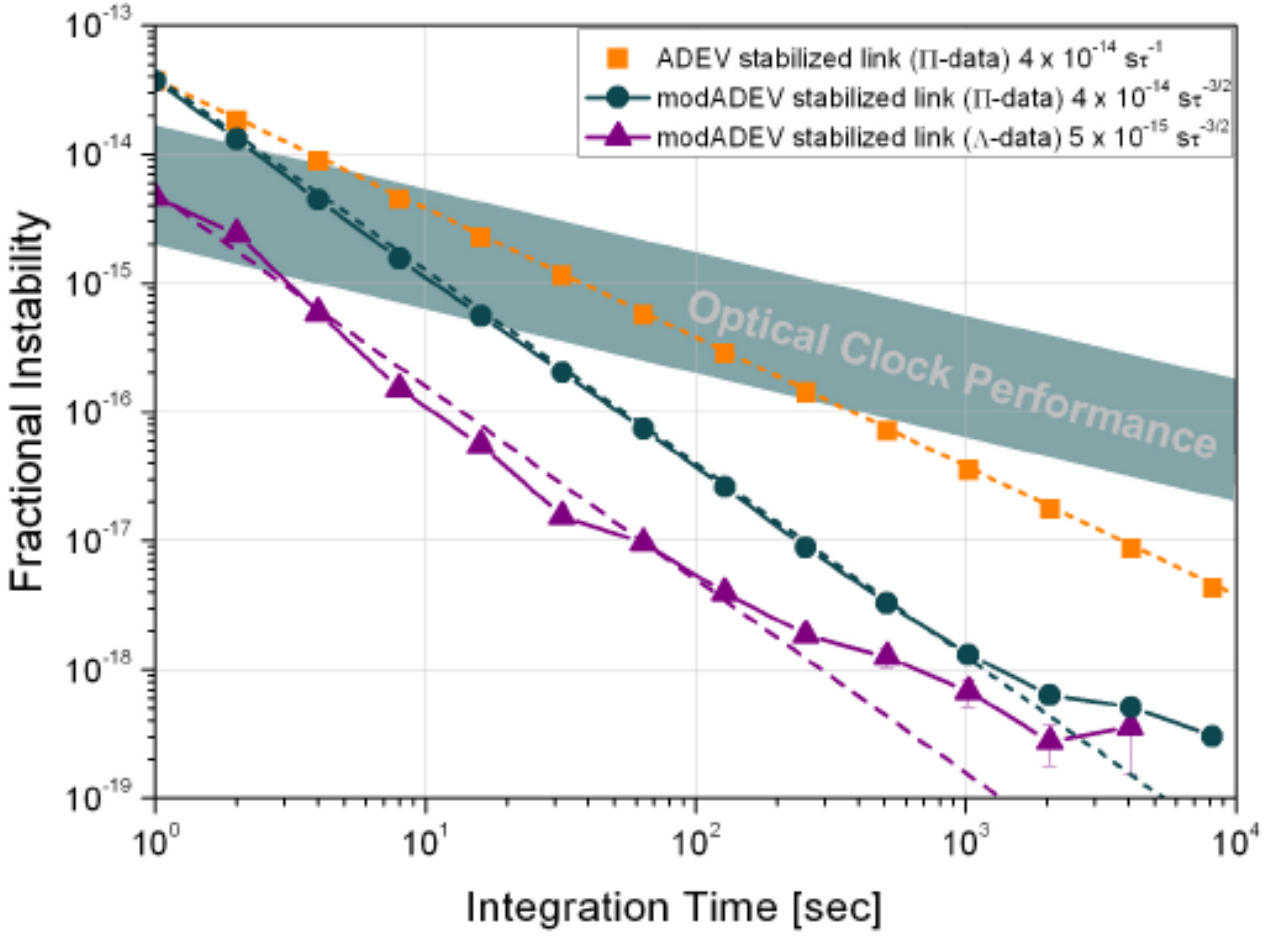


Stabilization loop

Mach-Zender interferometer setup



Stability of the 920-km link



Future prospects: All European optical fiber link network