

Using GNSS for optical frequency and wavelength measurements

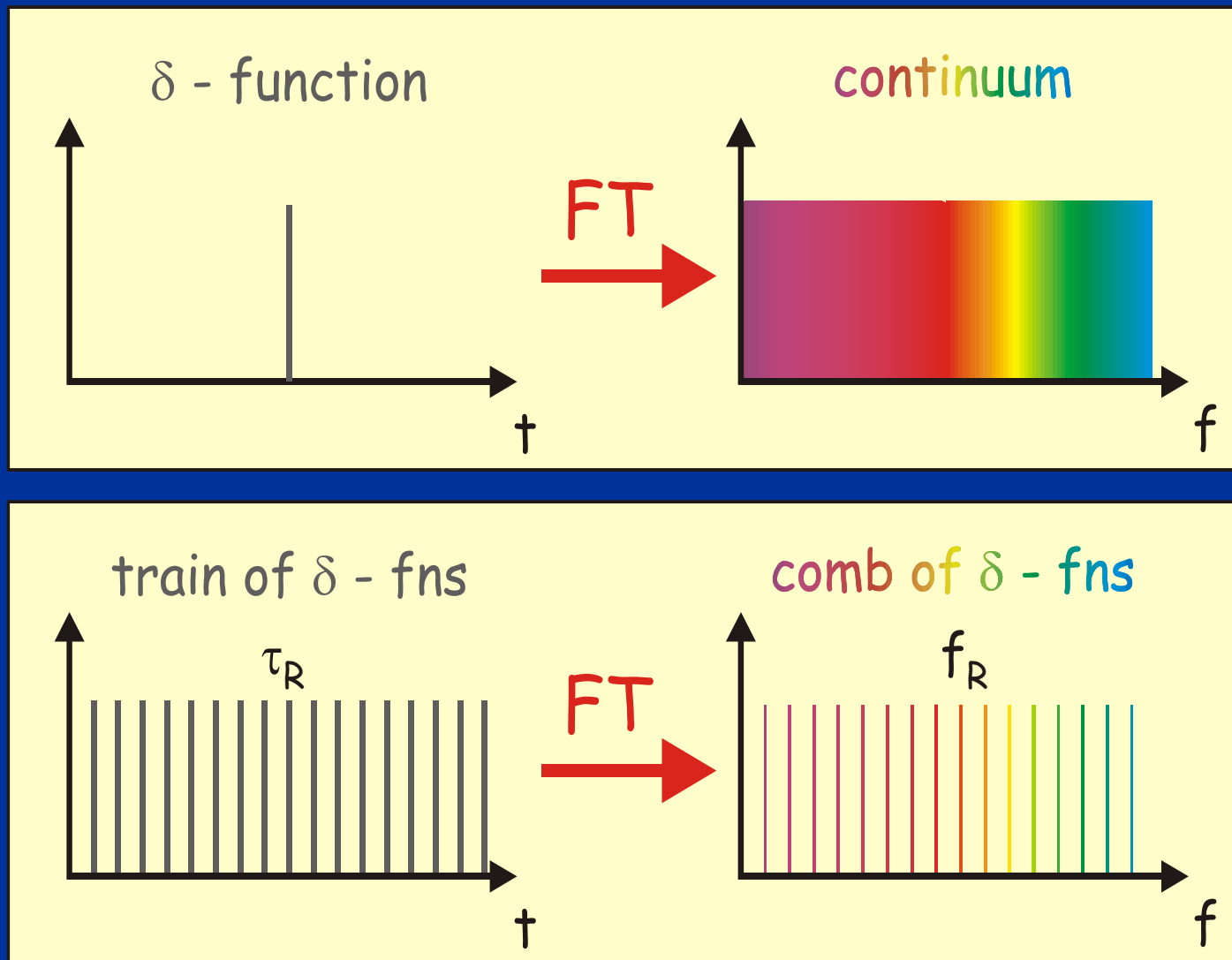
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outline of talk

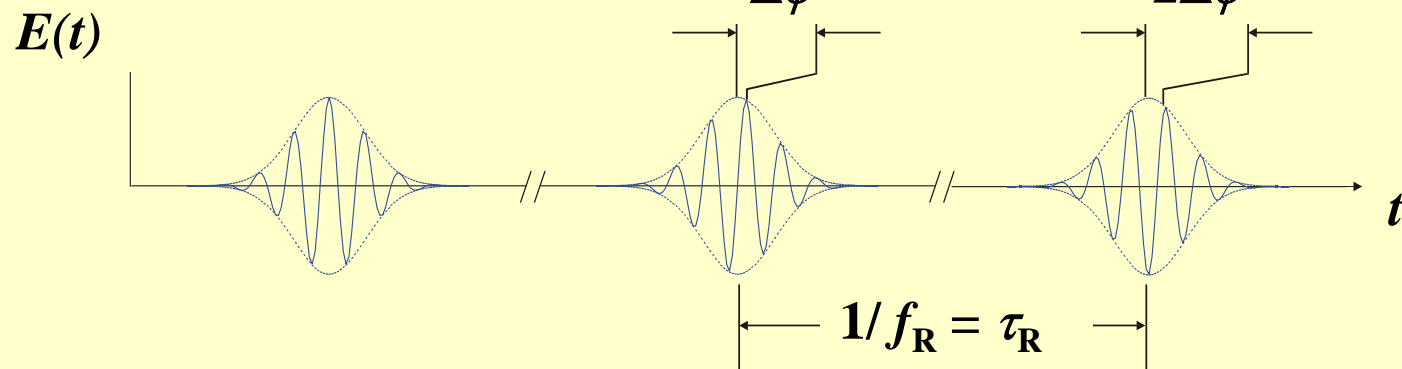
- introduction to femtosecond combs
 - optical frequency metrology revolutionised
 - enabling technology for optical clocks
- brief summary of work at NPL
 - wide variety of optical standards measured
 - H-maser/caesium fountain reference
 - world-leading optical frequency measurement
- GPS referenced transportable comb
 - compact femtosecond laser
 - reference frequency from GPS-disciplined LO

mode-locked laser comb

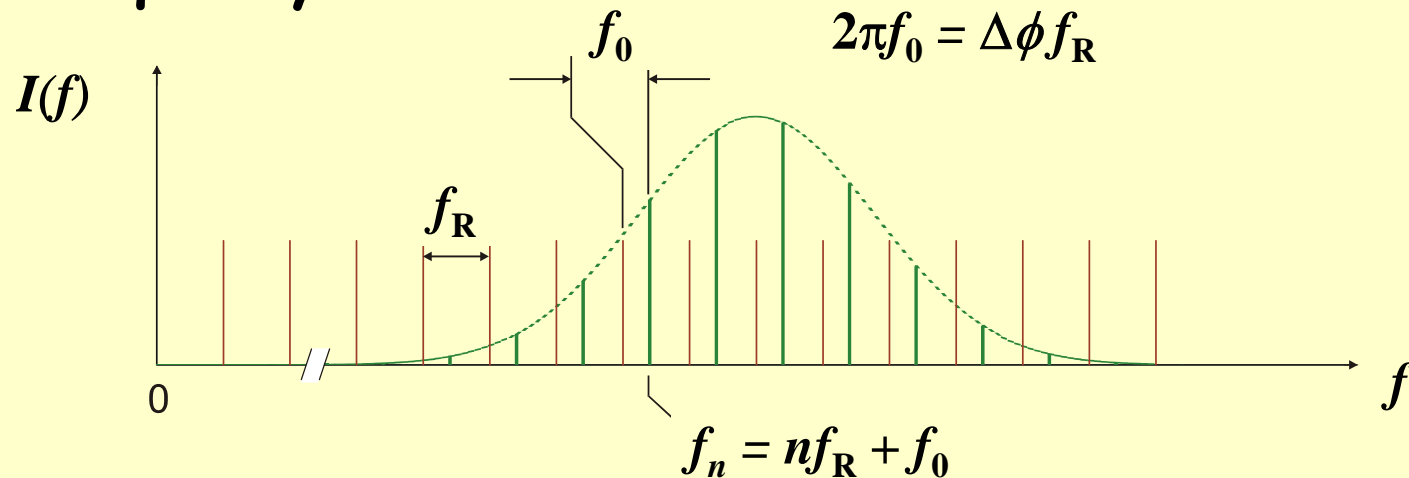


carrier envelope offset frequency

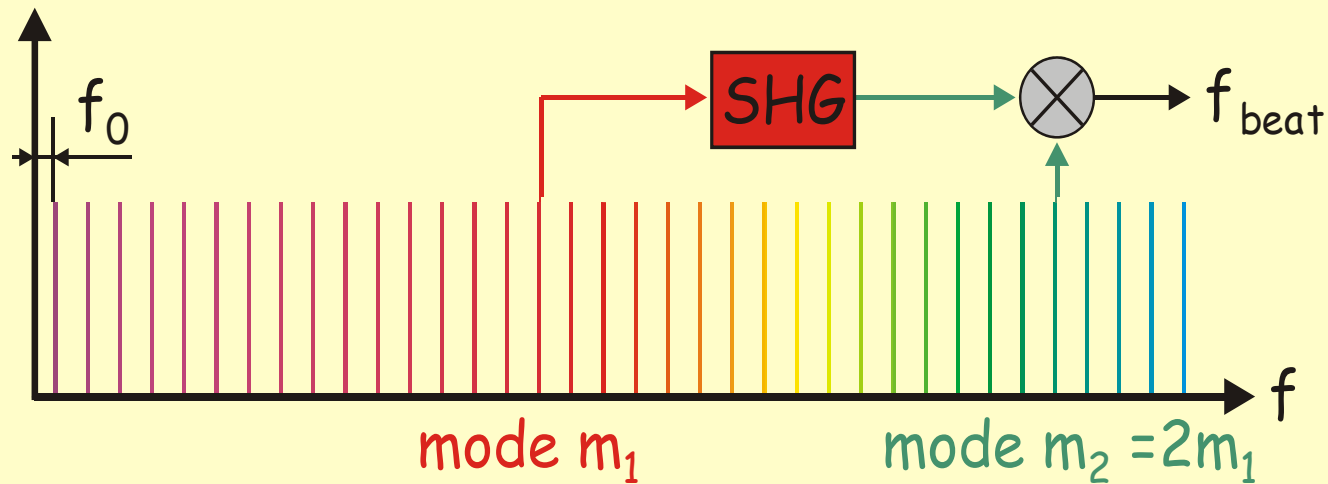
time domain



frequency domain



measuring the offset frequency



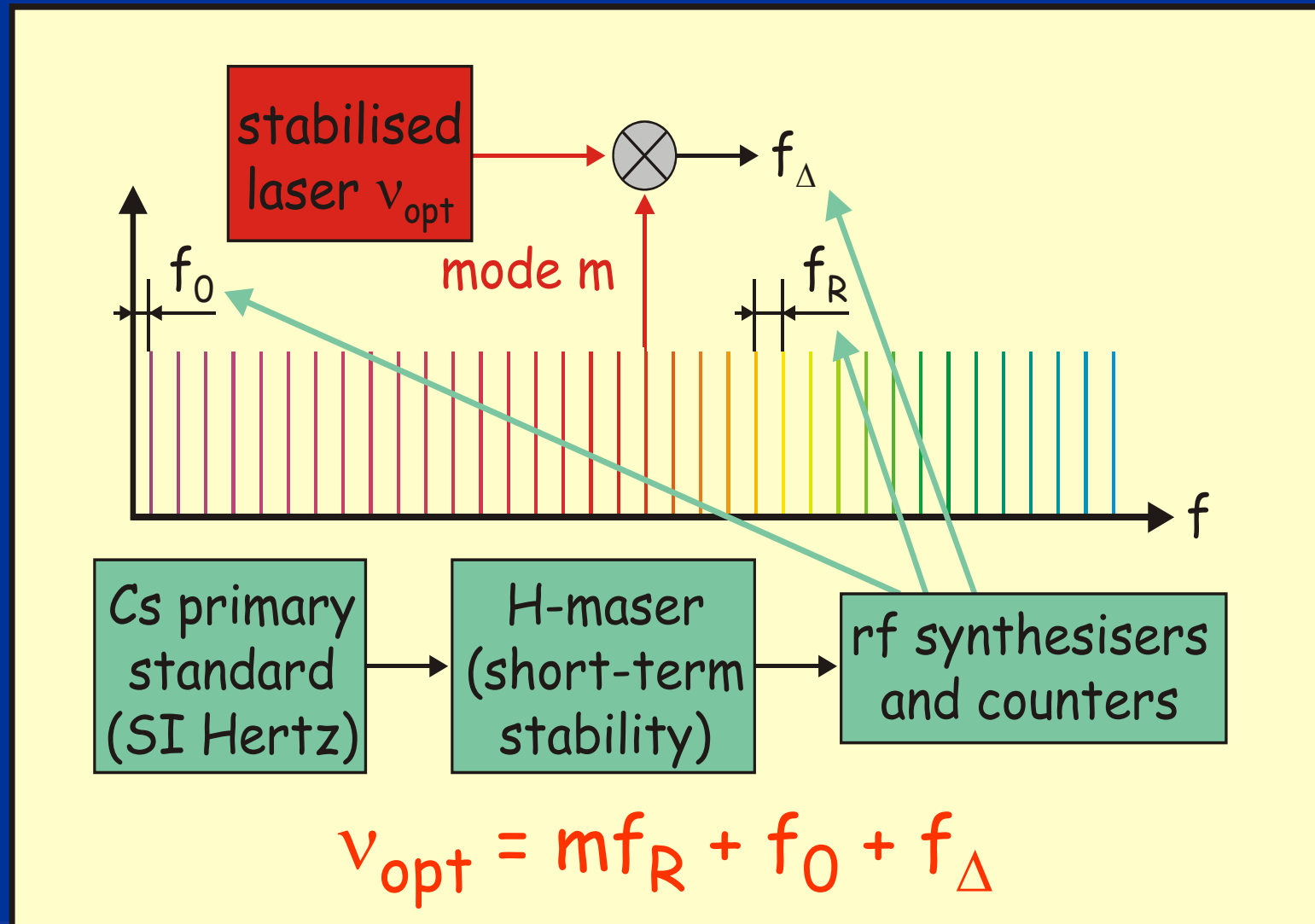
m_1 -th mode: $f_1 = m_1 f_R + f_0$

SHG: $2f_1 = 2m_1 f_R + 2f_0$

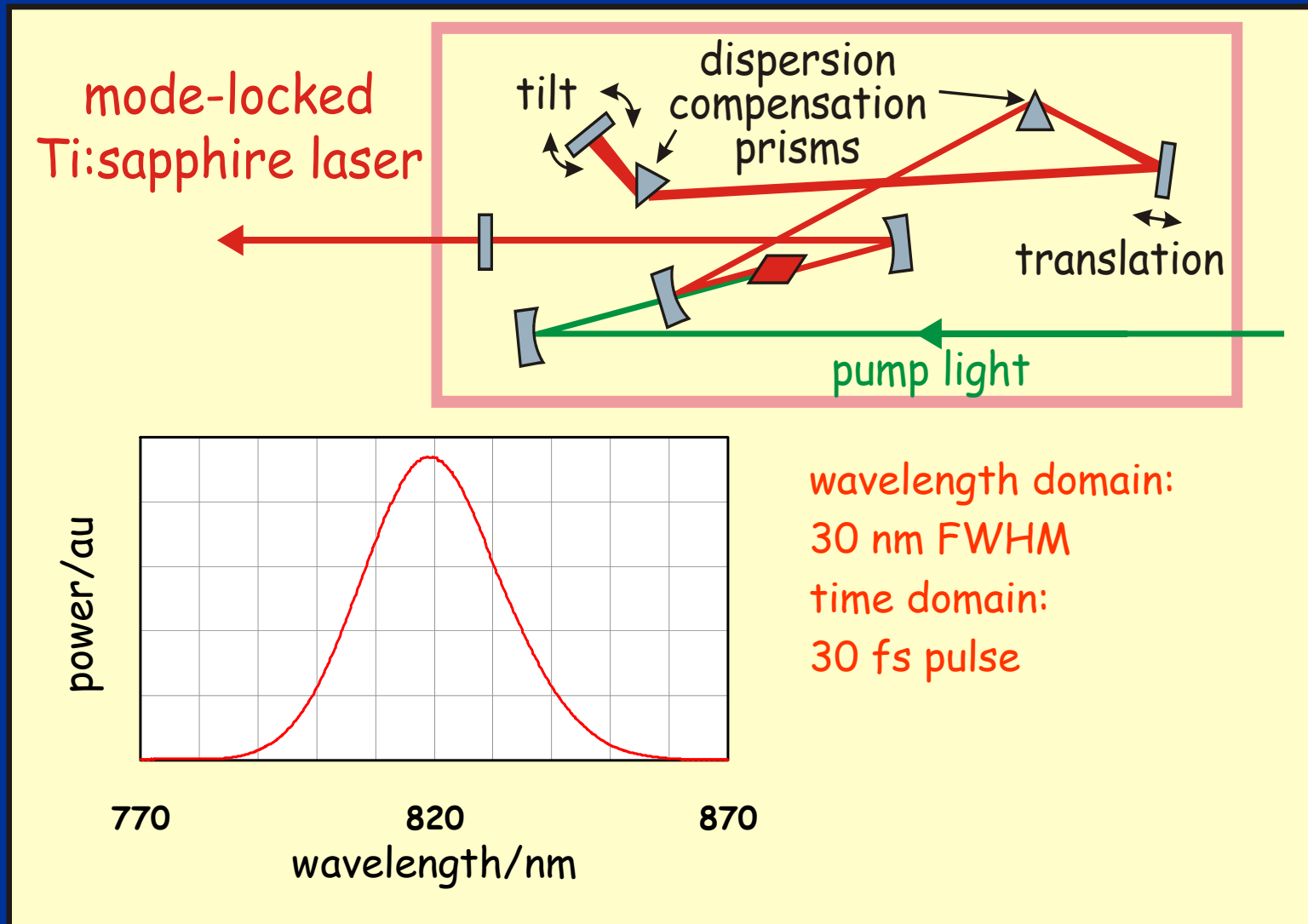
m_2 -th mode: $f_2 = m_2 f_R + f_0$

$m_2 = 2m_1$: $f_{\text{beat}} = f_0$

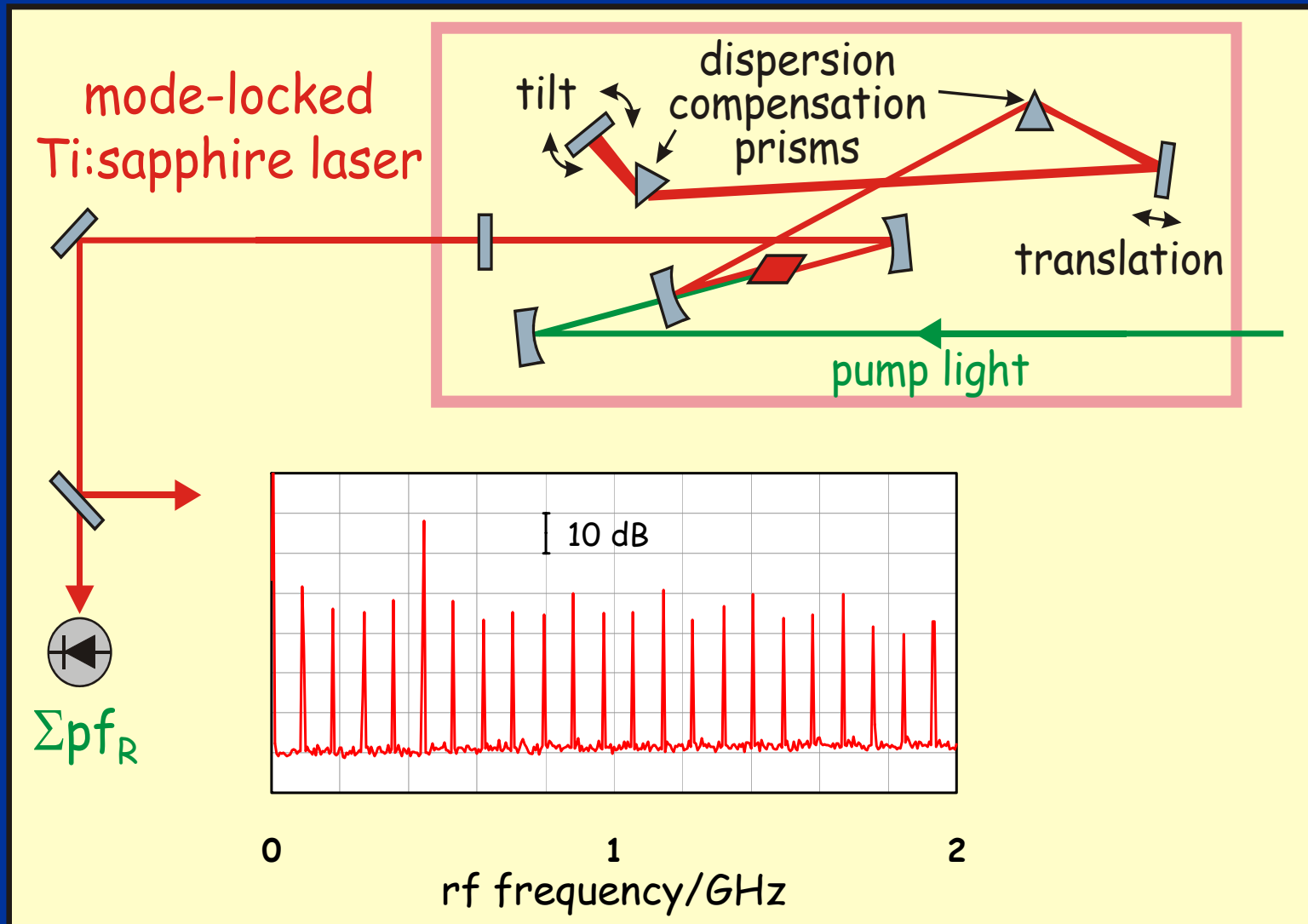
measuring an optical frequency



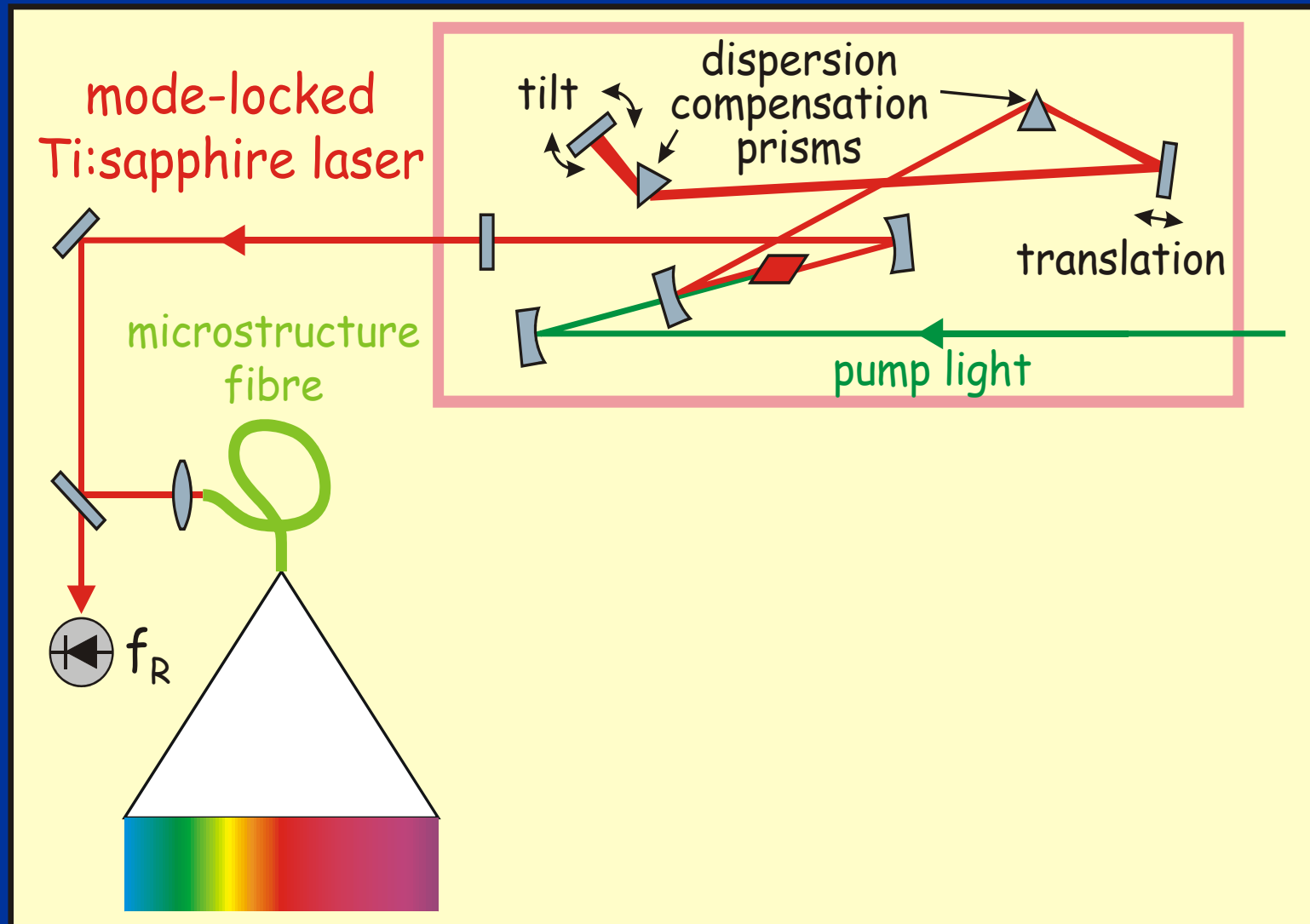
femtosecond laser



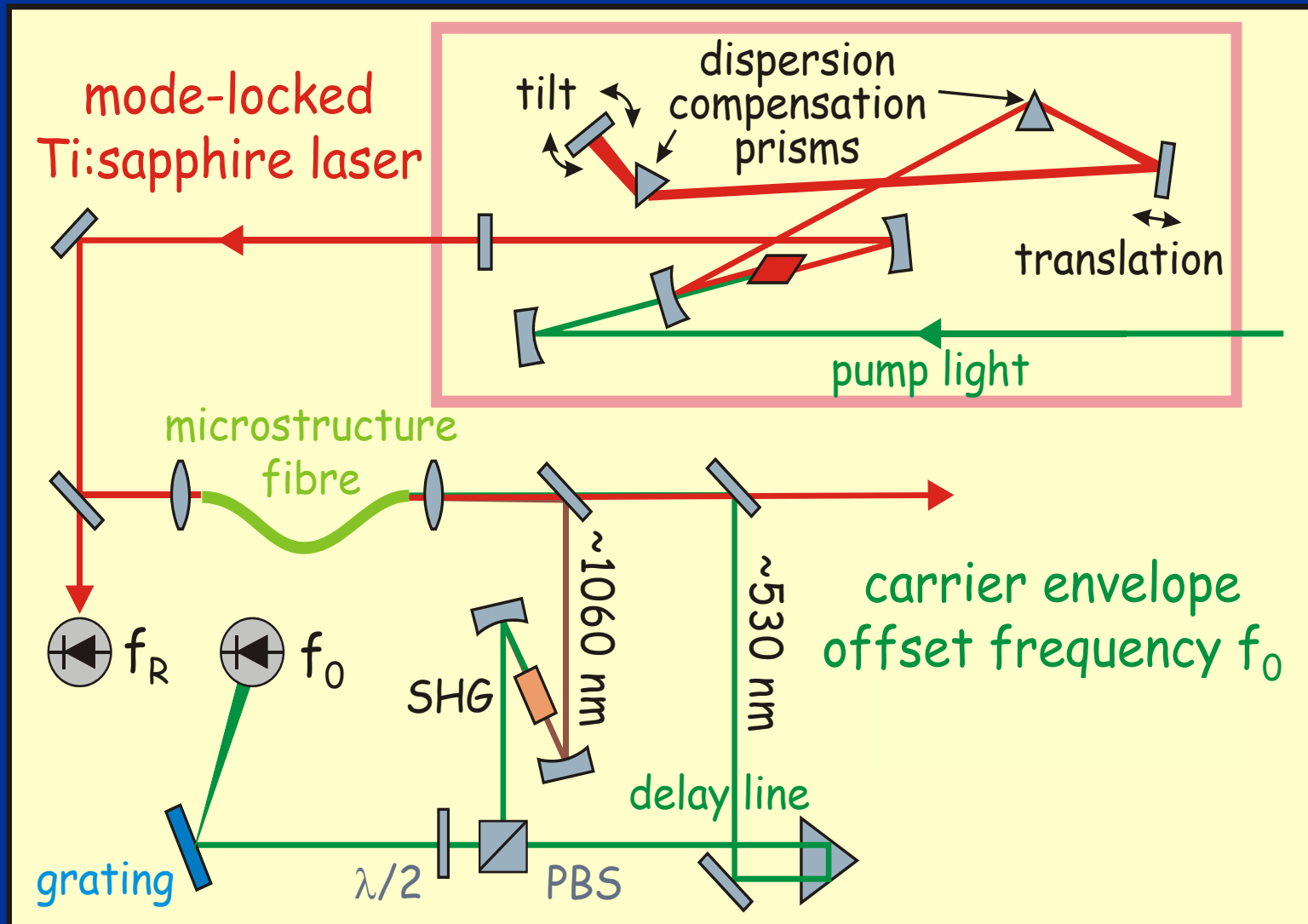
repetition rate stabilisation



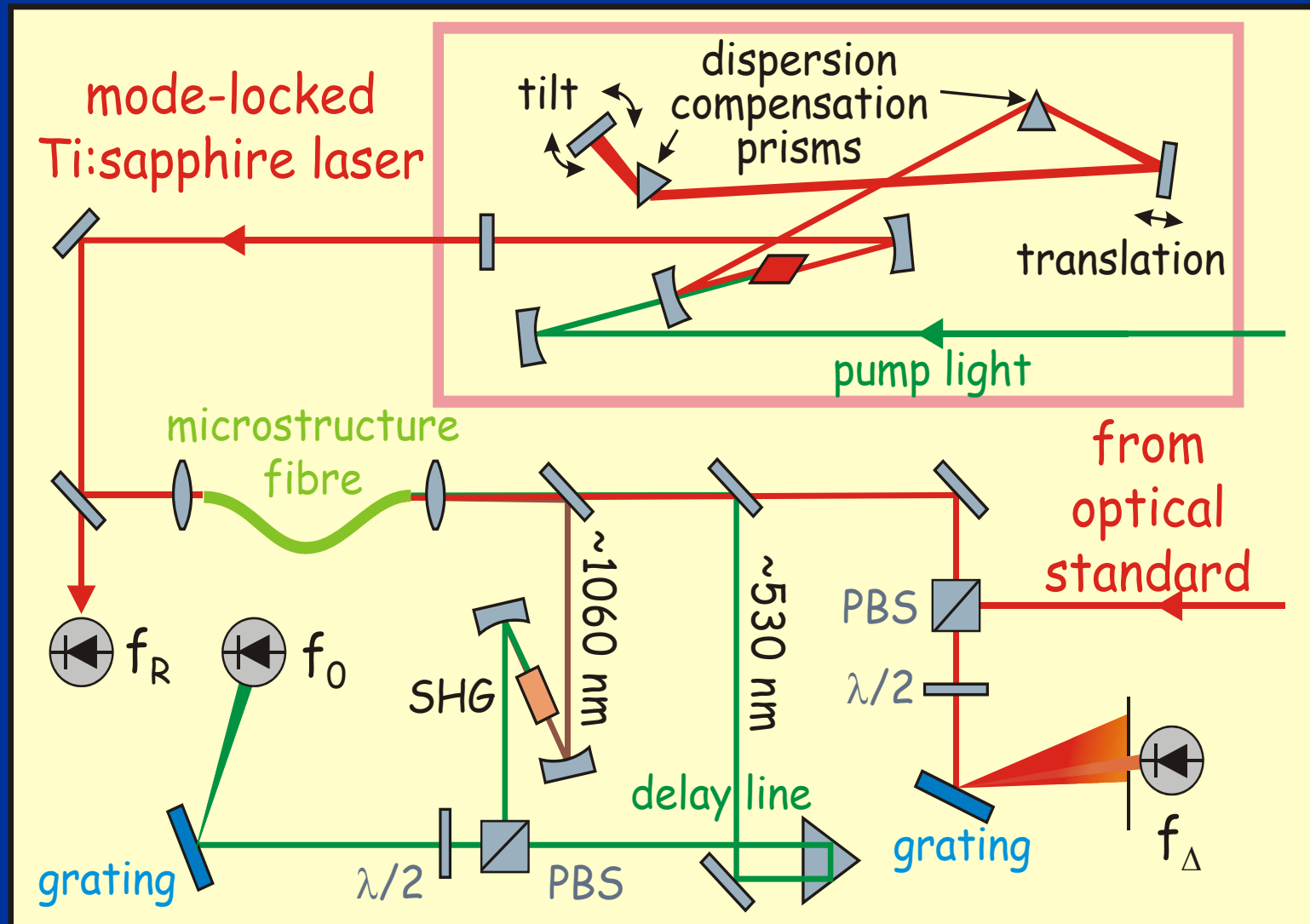
octave span comb



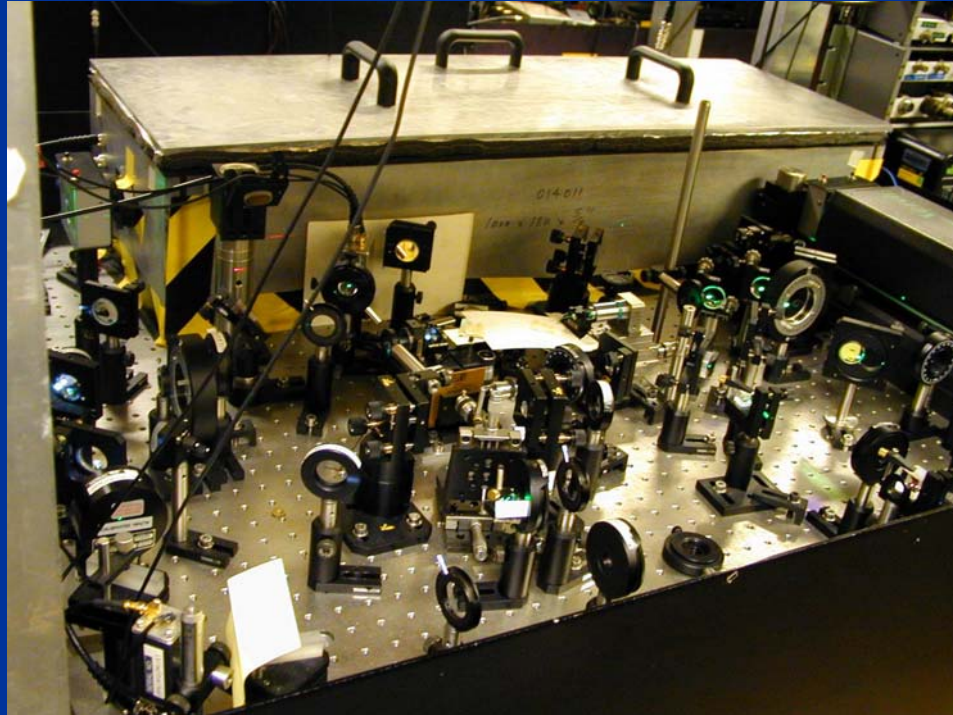
carrier offset frequency stabilisation



optical frequency measurement



Ti:sapphire-based comb



the most intensively used femtosecond comb in the world?

— measurements of over half-a-dozen stabilized laser systems ranging from optical clock transitions in single cold trapped ions Sr^+ and Yb^+ to stabilized yellow HeNe

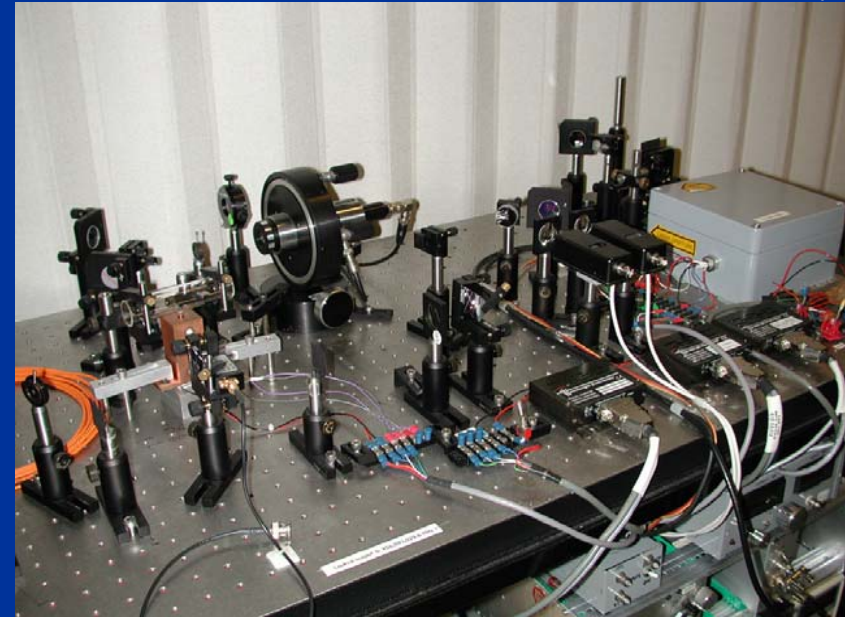
- 88 MHz repetition rate
- comb span $\sim 500 - 1100$ nm
- H-maser/Cs fountain reference
- breadboard system; water cooling

frequency calibrations

in addition to measuring in-house standards, we have calibrated laser systems for users in academia and industry

scientific laser system

iodine-stabilised diode laser at 656 nm from the University of Sussex, for high-precision spectroscopy of He^+



industrial laser

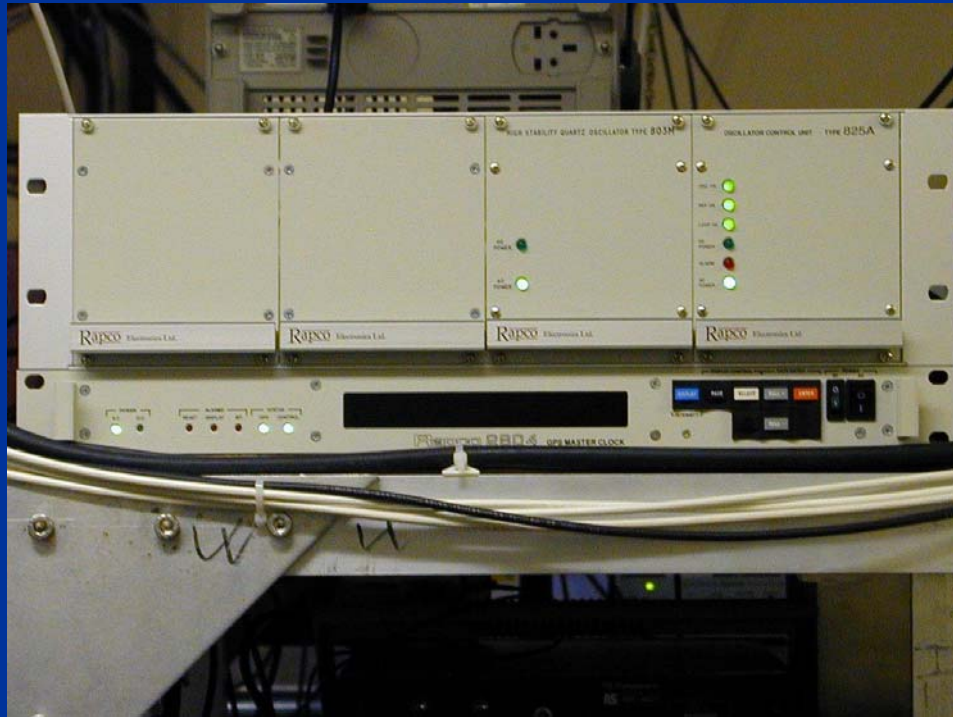
stabilised yellow
HeNe at 594 nm

transportable fs comb

- "off-site" fs comb measurements
 - lower accuracy often adequate (cf. HeNe)
 - possibility of comb comparisons...
- mode-locked Cr:LiSAF laser
 - comb spectrum centred ~ 850 nm
 - diode-pumped at 670 nm, 500 mW
 - compact configuration possible
(laser under development)
- GPS referencing
 - 10 MHz reference frequency from
GPS-disciplined LO in lieu of H-maser

GPS-referenced measurements

tests with Ti:sapphire-based comb referenced to 10 MHz local oscillator (LO) steered by GPS



compare optical frequency measurements using

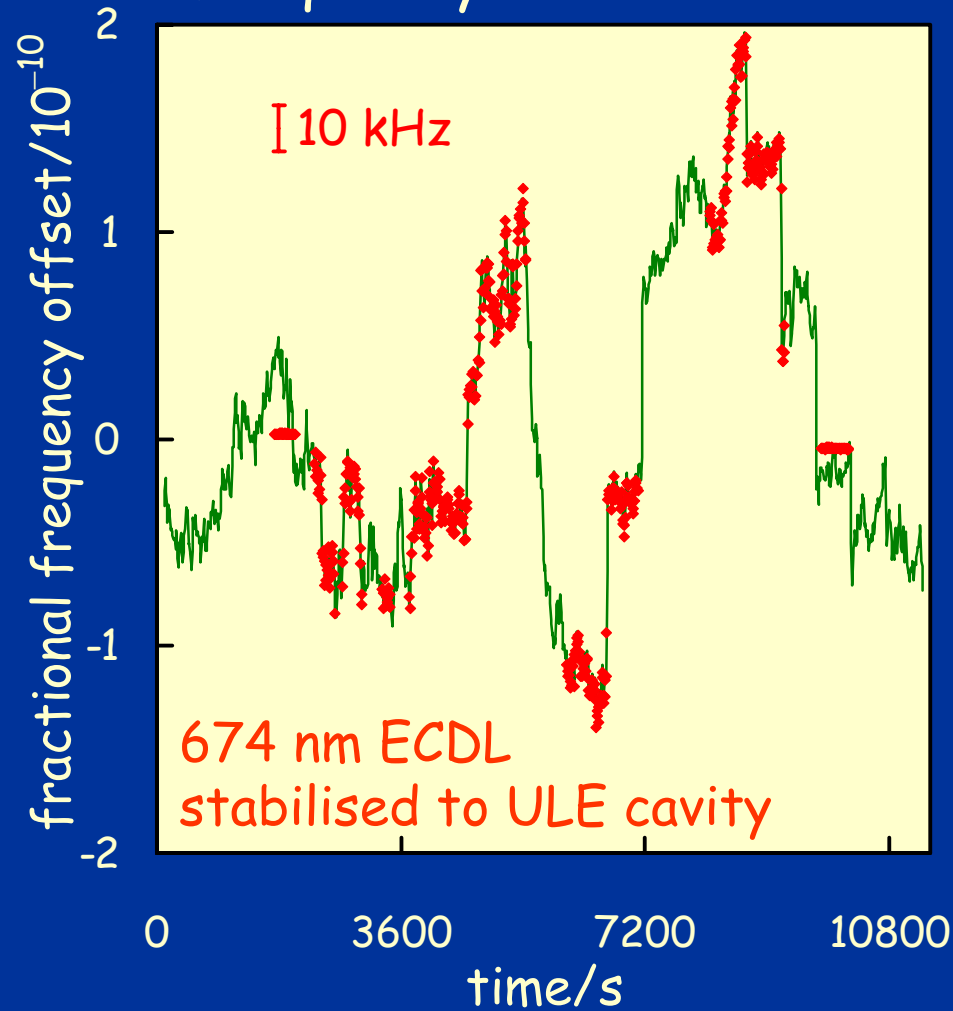
- a GPS-disciplined standard quartz LO

and

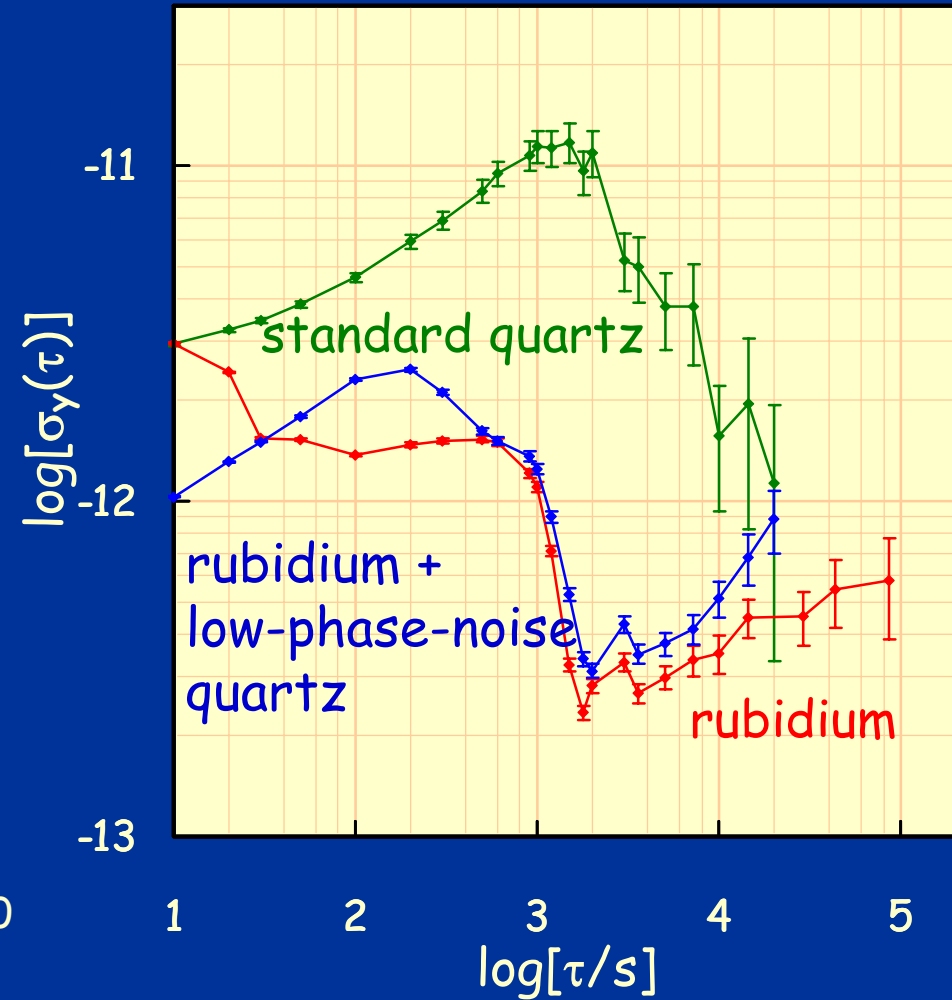
- a GPS-disciplined rubidium oscillator steering a low-phase-noise quartz LO

GPS-referenced measurements

frequency measurement

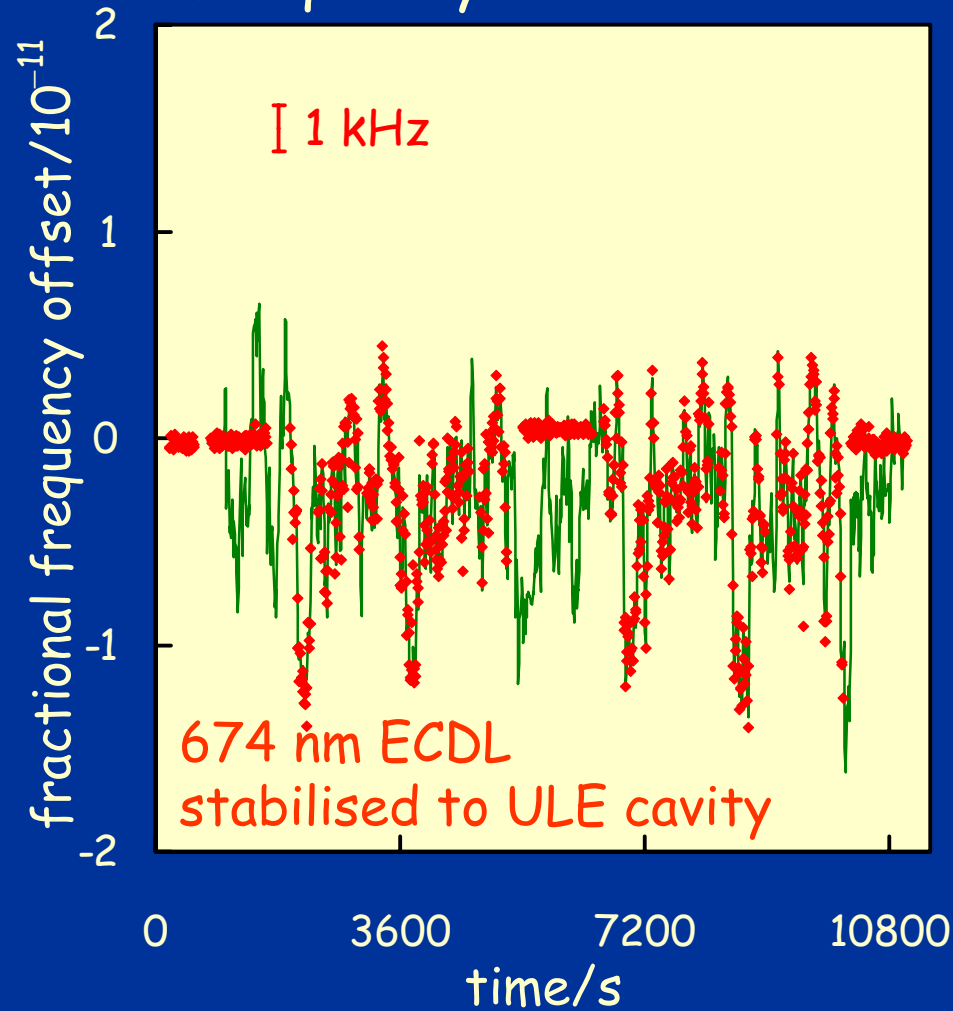


Allan deviation

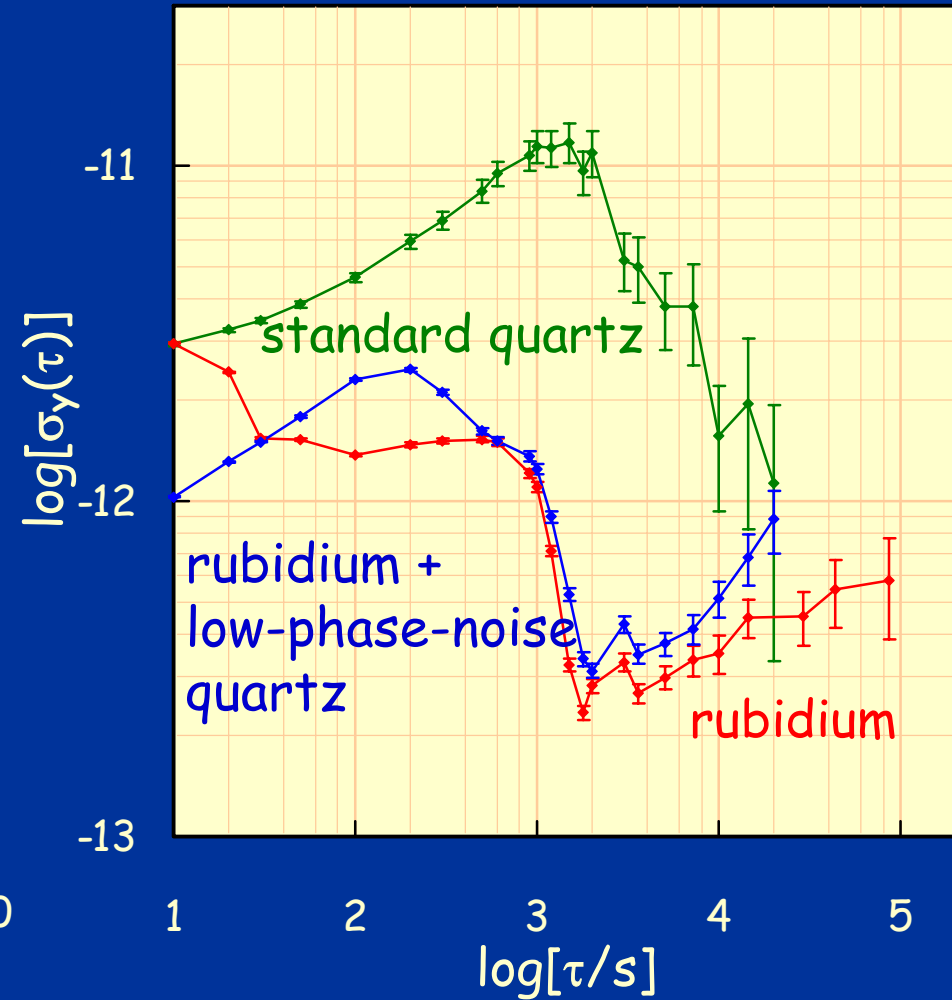


GPS-referenced measurements

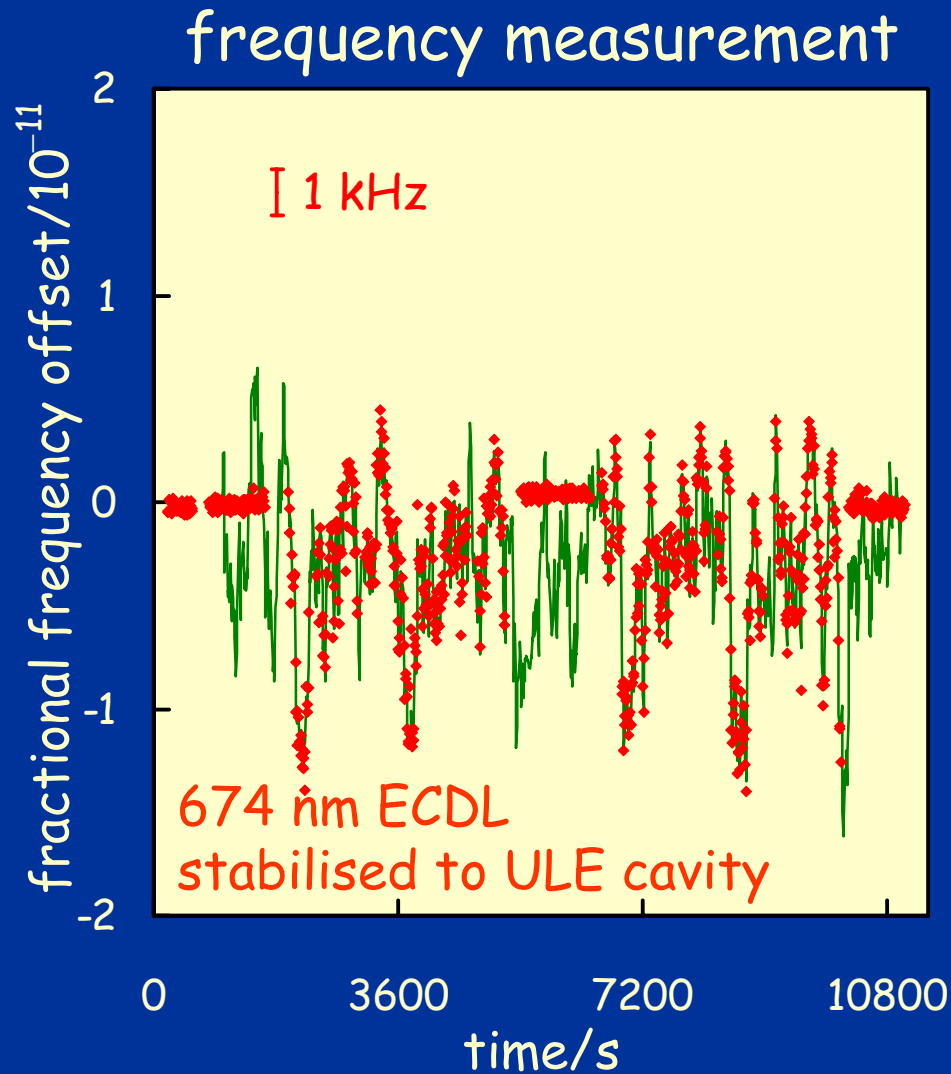
frequency measurement



Allan deviation



GPS-referenced measurements



- low-phase-noise quartz LO gives adequate short-term stability for comb measurements
- 1×10^{-12} stability @ 1000 s
- offset [GPS - H-maser] $< 5 \times 10^{-12}$ over 1 hour averaging time
- compare 1×10^{-10} (50 kHz) limit of interferometric measurements

Summary

- H-maser/Cs referenced comb
 - optical frequency measurement revolutionized
 - enabling technology for representation of the SI second using optical frequency standards
 - future redefinition of the second?
- GPS referenced transportable comb
 - demonstrated: μ ~ few kHz with GPS referenced comb
 - outlook: compact, diode-pumped Cr:LiSAF fs laser

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