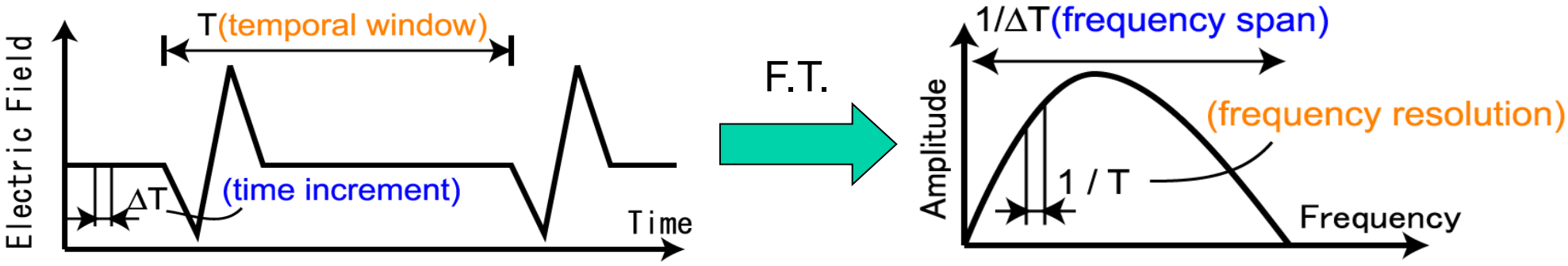
THz time-domain spectroscopy

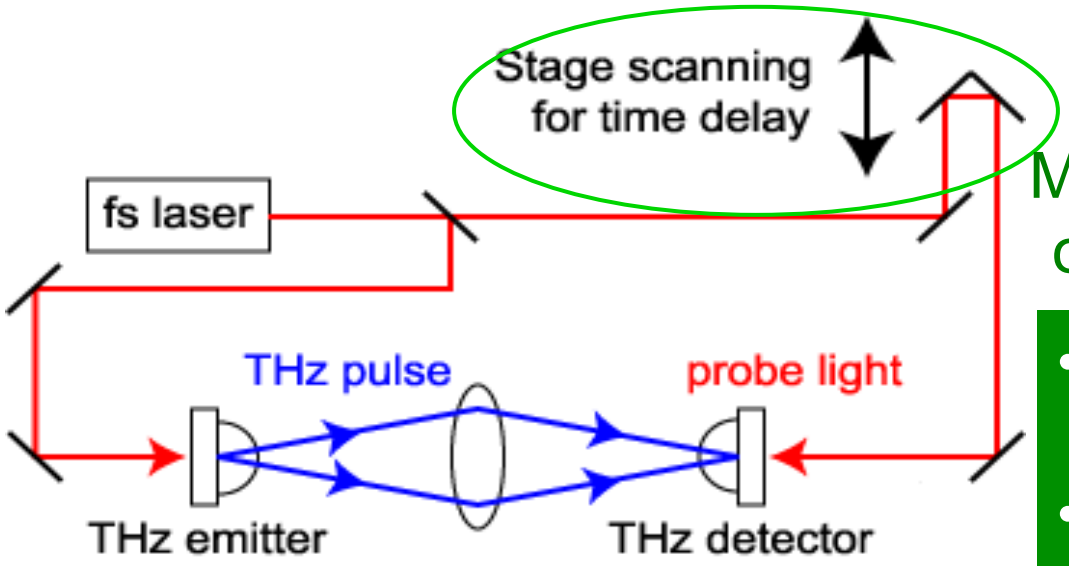


Temporal waveform

Fourier spectra

Spectral resolution
=inverse of time window

Spectral accuracy
= Precision of time delay



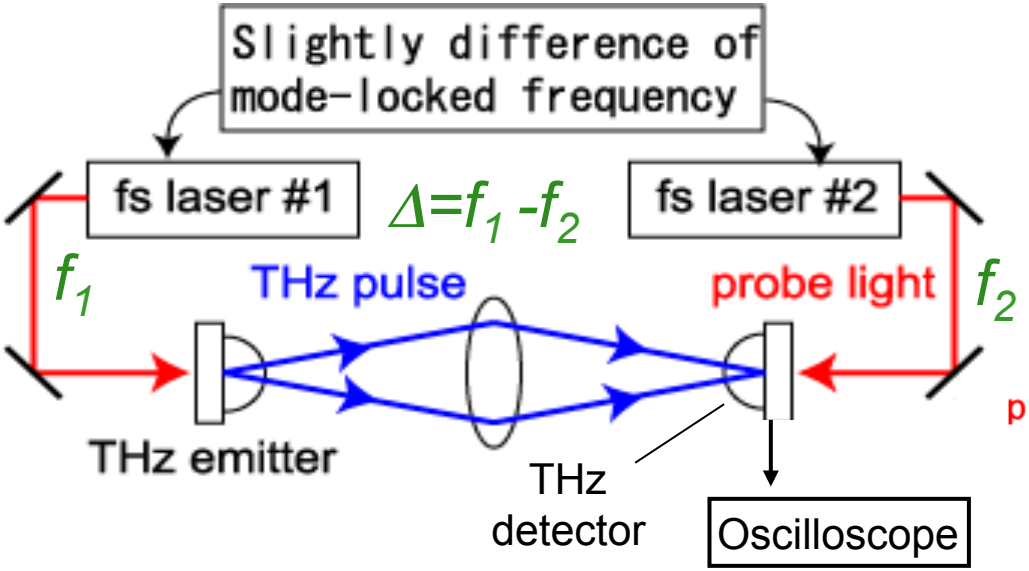
Pump-probe experiment

Marking of frequency scale is based on mechanical movement of stage

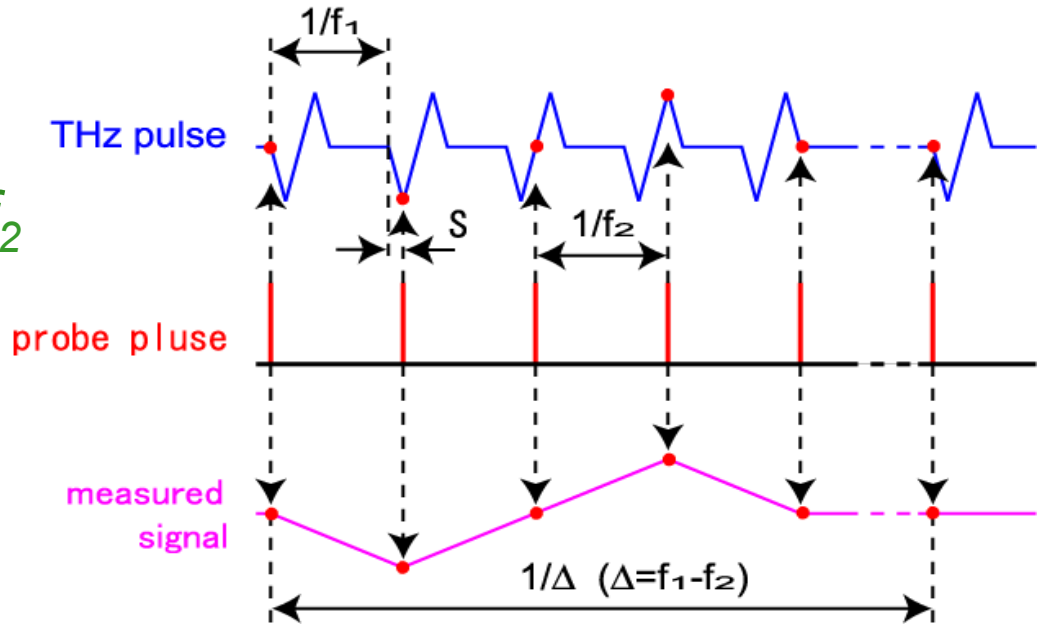
- Trade-off between spectral resolution and measurement time
- Spectral accuracy depends on positioning precision of stage

Asynchronous-optical-sampling THz-TDS (AOS-TH-TDS)

ref) T. Yasui, Appl. Phys. Lett. 87, 061101 (2005).



Overlap timing between THz and probe pulse is automatically shifted every pulse



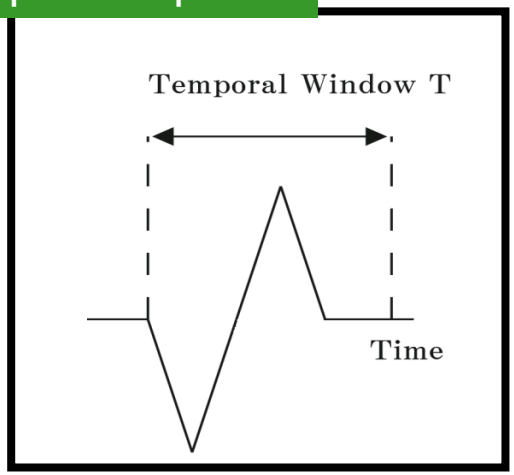
No need for mechanical stage
No limitation for size of time window

Time scale of ps THz pulse is linearly expanded to μs order

High spectral resolution and accuracy can be achieved depending on laser stability

Conversion of frequency scale by ASOPS-THz-TDS

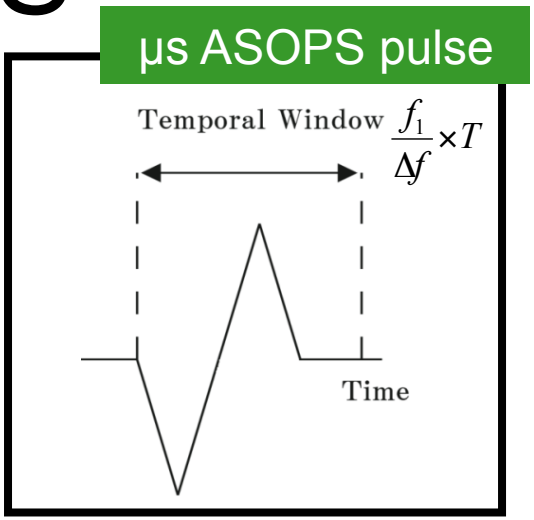
ps THz pulse



ASOPS
(down-scaling)

$\Delta f / f_1$

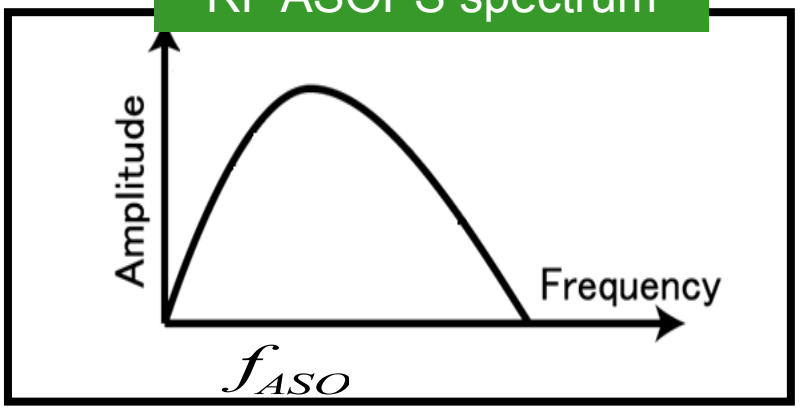
μs ASOPS pulse



This factor is fluctuated by timing jitter of two lasers.

F.T.

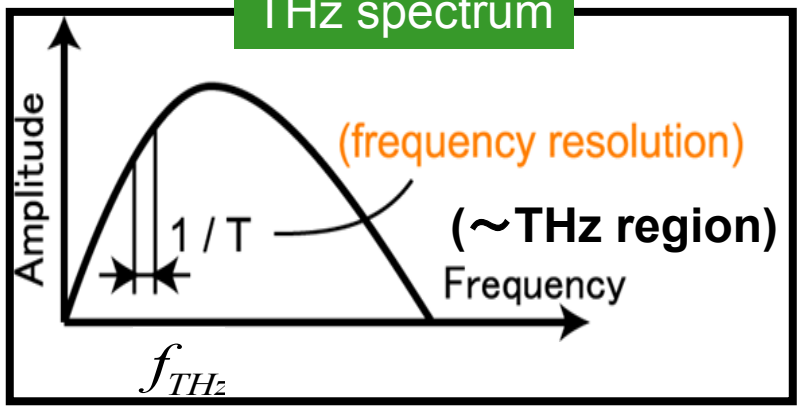
RF ASOPS spectrum



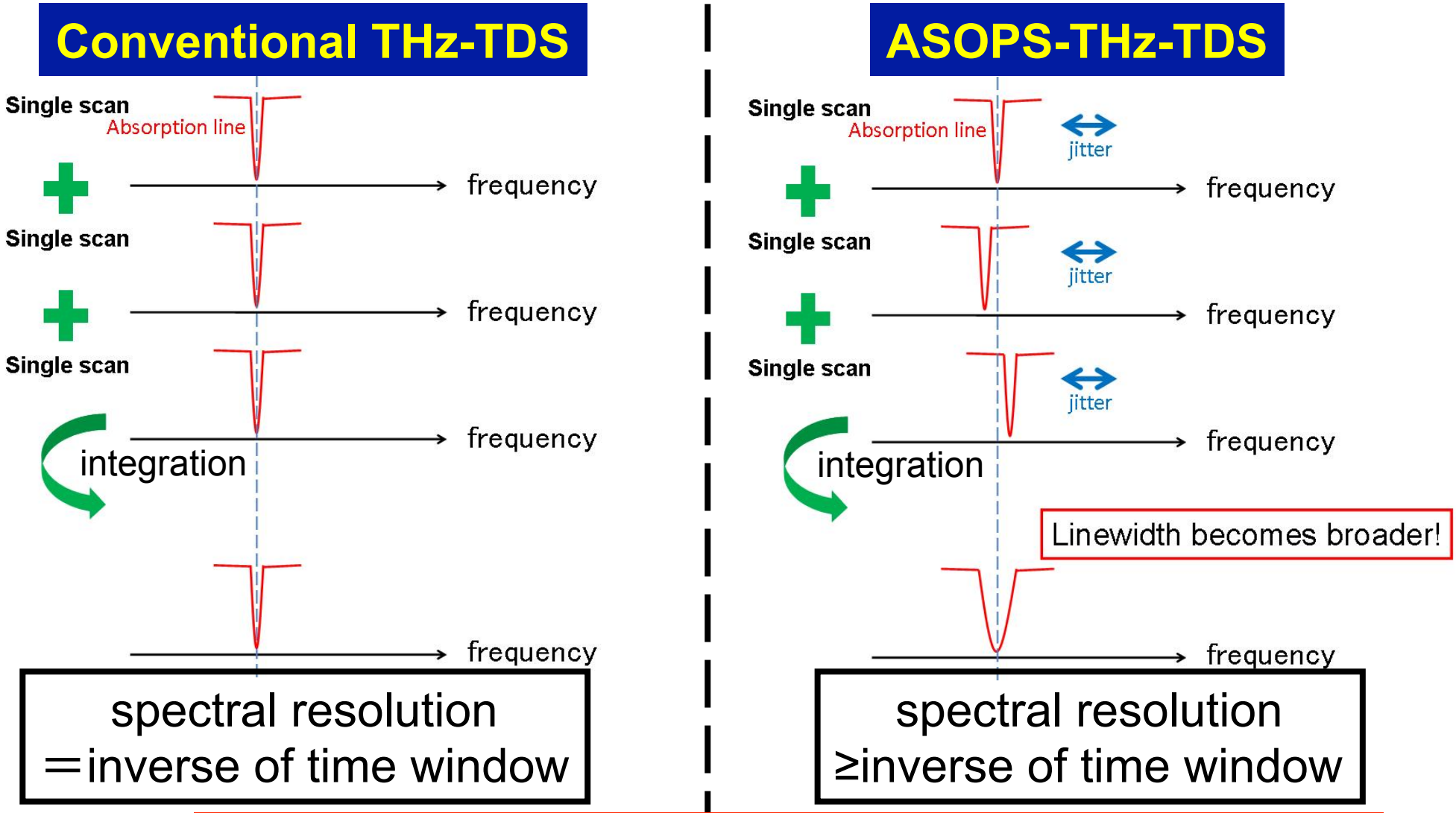
$f_1 / \Delta f$

Calibration
(up-scaling)

THz spectrum



Influence of timing jitter in absorption spectroscopy

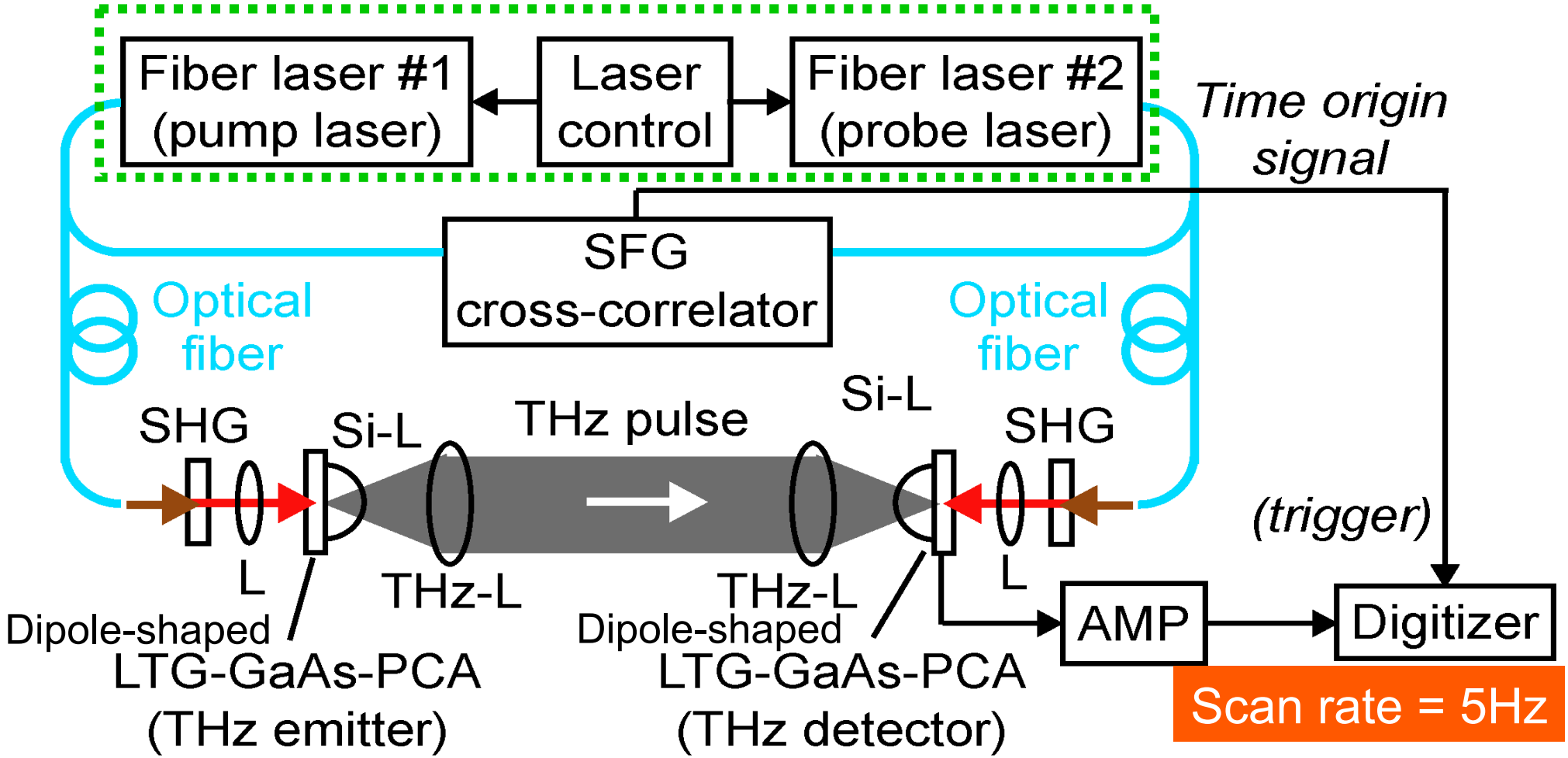


Present talk

Evaluate actual resolution and accuracy in ASOPS-THz-TDS using low-pressure gas spectroscopy

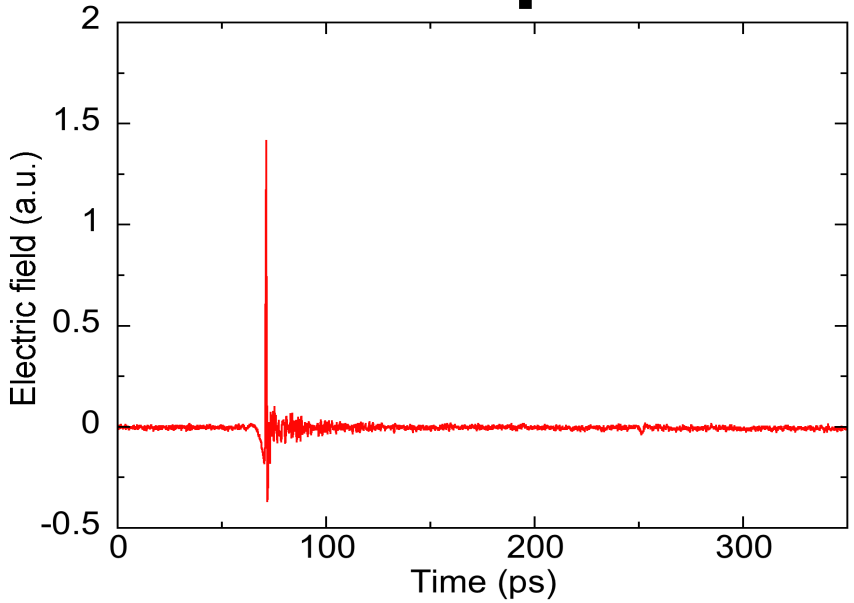
Experimental setup

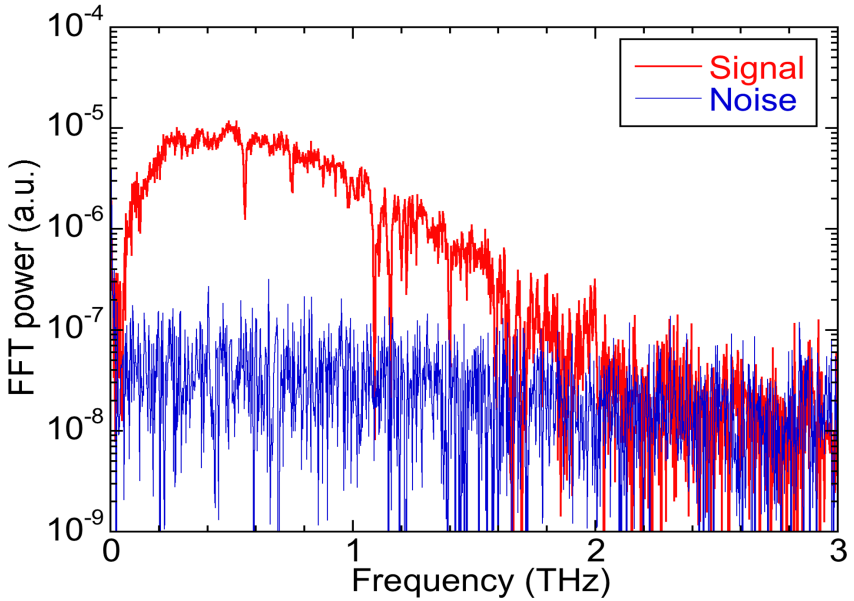
λ_c=1550nm, $\Delta\tau$=50fs, P_{avg} =100mW,
f_1=56.124MHz, f_2= 56.124MHz+5Hz, Δ= f_2-f_1= 5Hz, Timing jitter<300fs



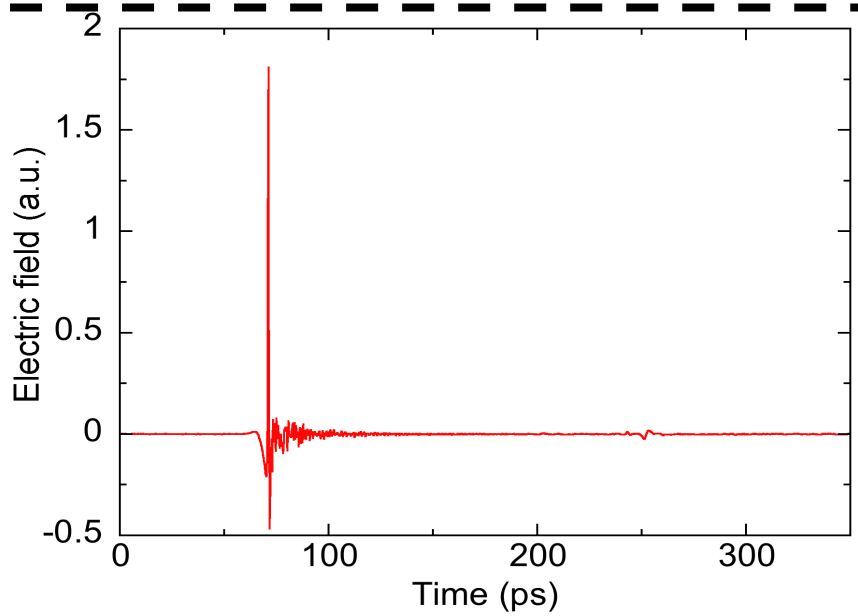
Basic performance

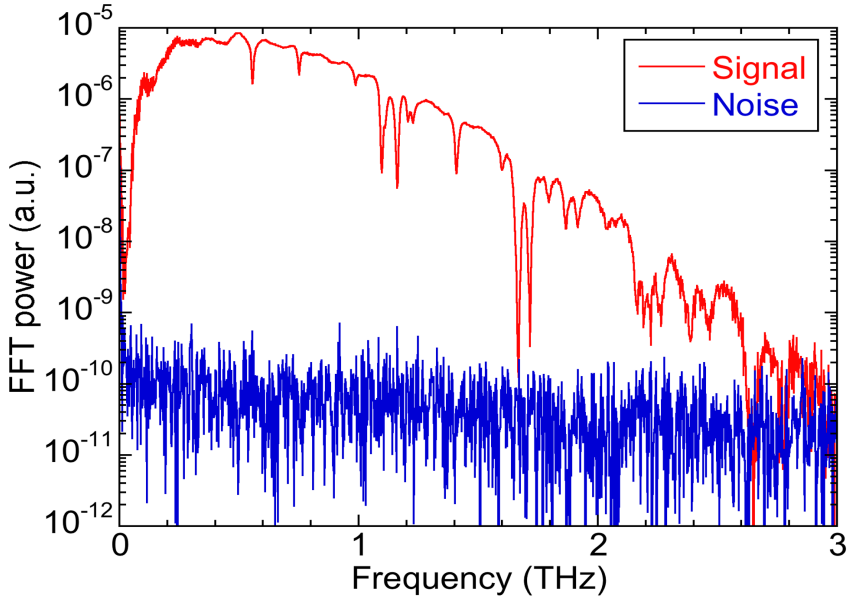
Single sweep (200ms)



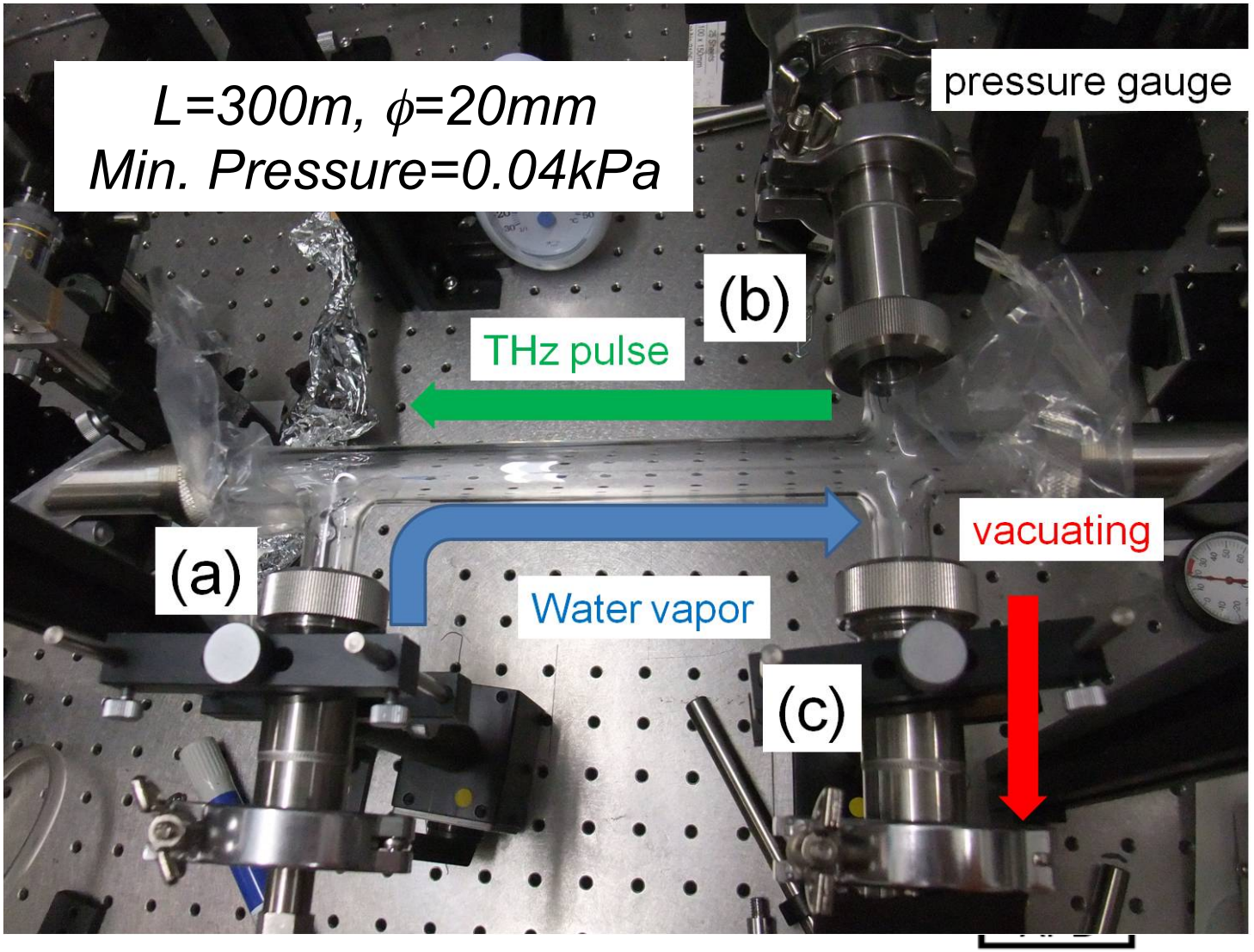


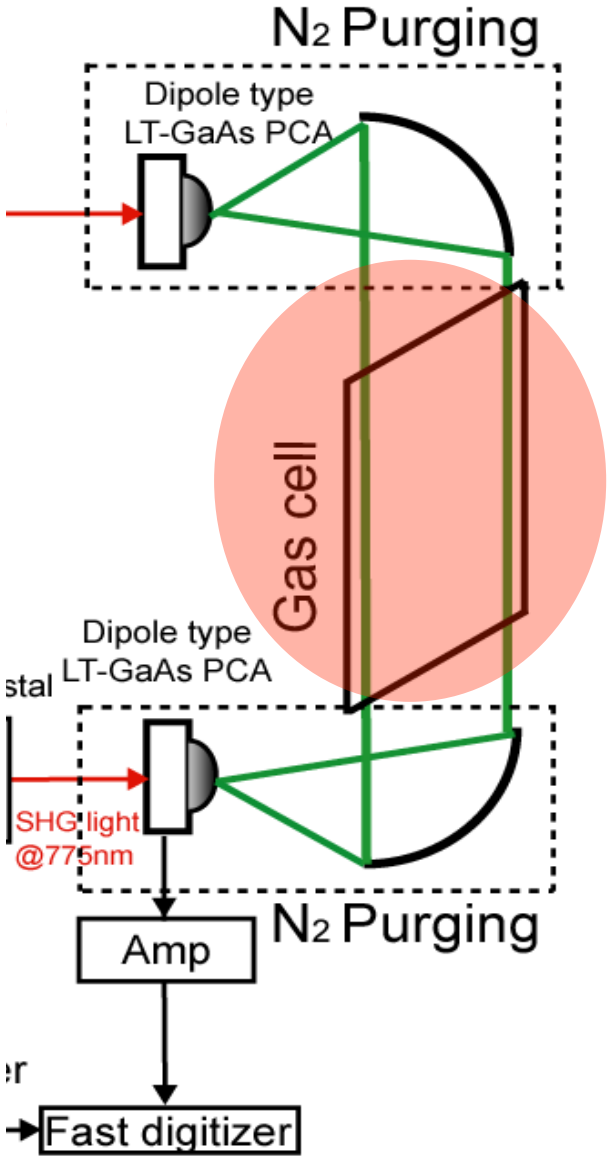
200 sweeps (100s)



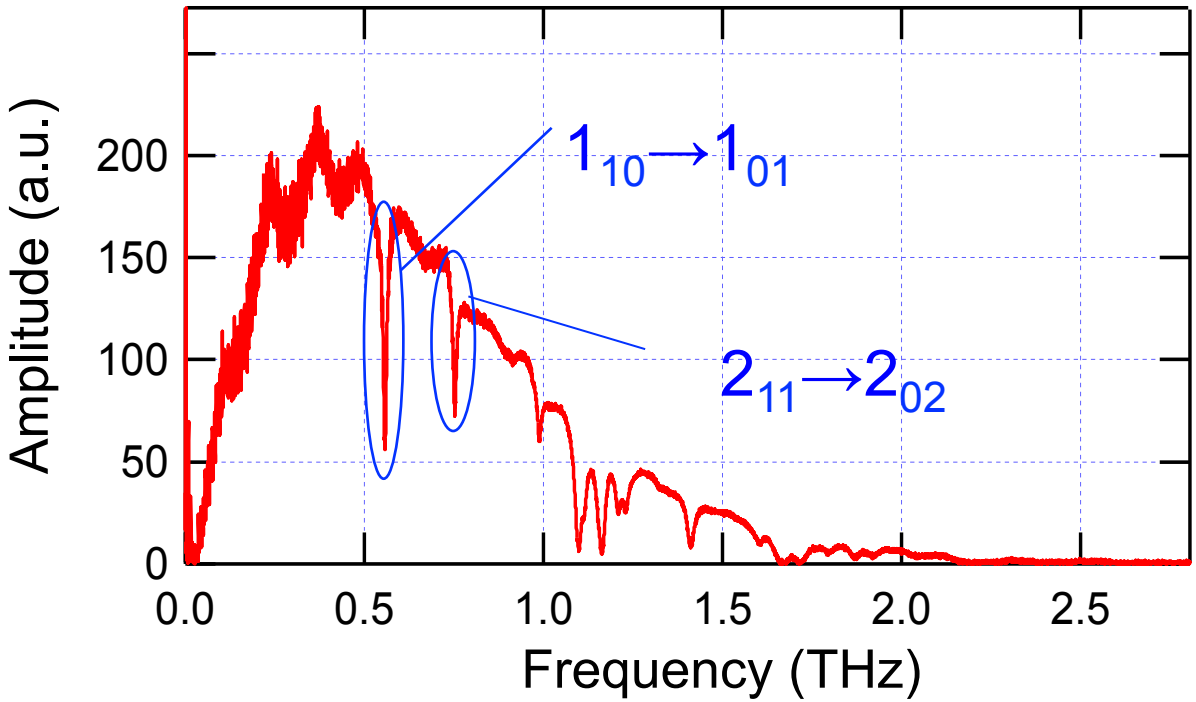


Low-pressure gas cell





Absorption lines of water vapor

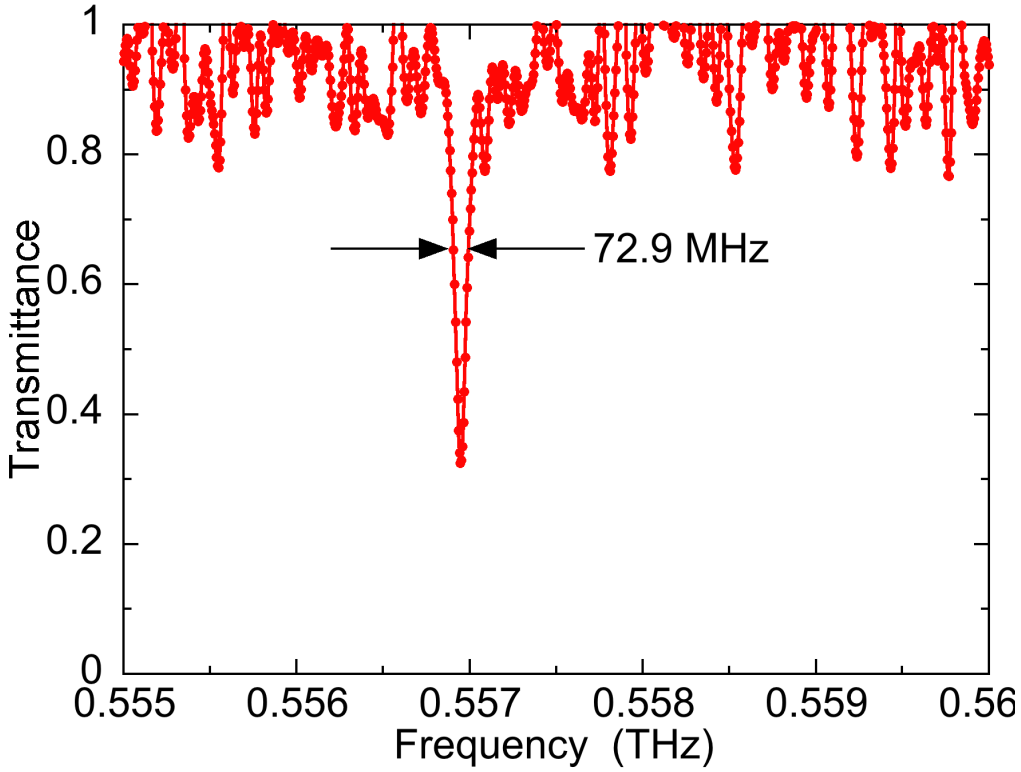


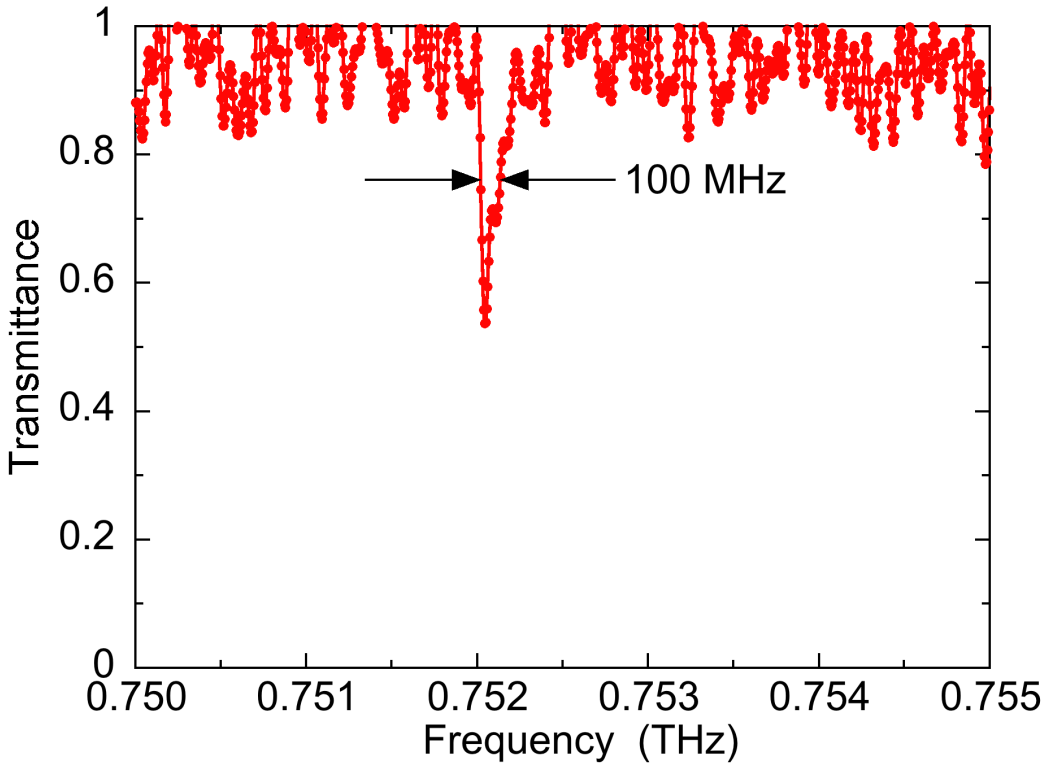
Transition	Absolute frequency (NASA database)	Pressure broadening at 1 kPa[1)]
$1_{10} \rightarrow 1_{01}$	0.556 936 0 THz	30.1 MHz
$2_{11} \rightarrow 2_{02}$	0.752 033 2 THz	29.7 MHz

[1)] *T. Seta, et al., J. Quantitative Spectroscopy & Radiative Transfer* ***109****, 144-150 (2008).*

Evaluation of spectral resolution

Time window =17.9 ns (= one pulse period)
Inverse of time window = 56 MHz

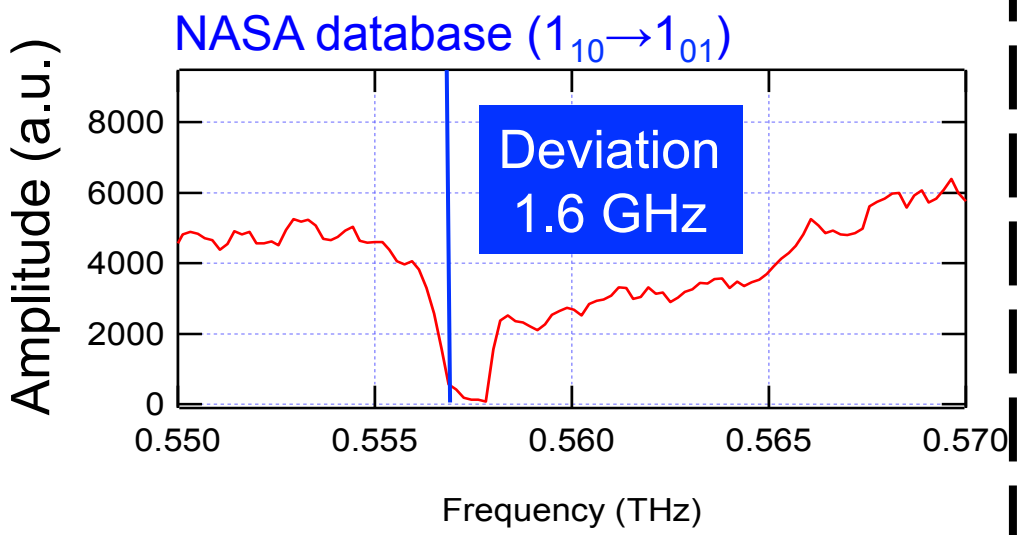


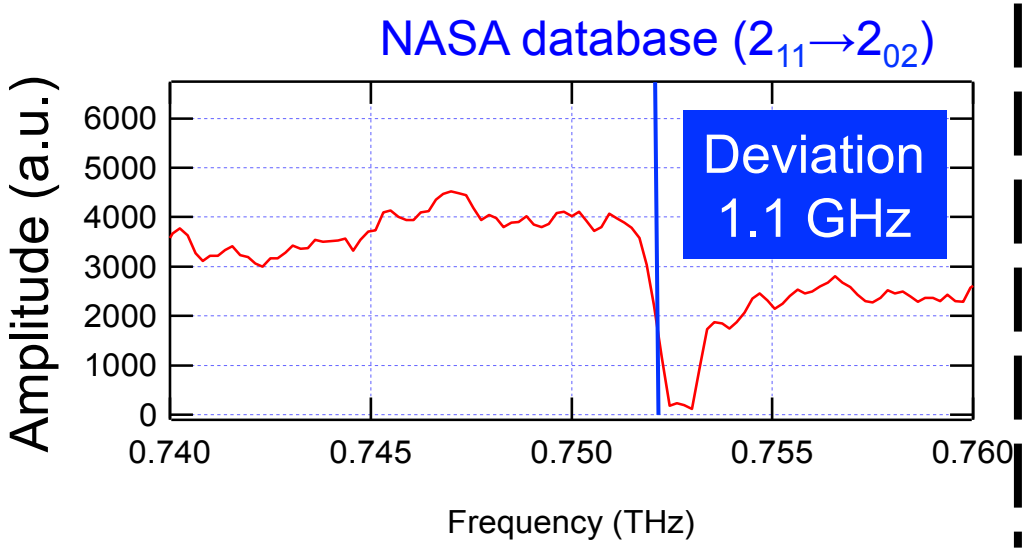


Actual spectral resolution ≥ inverse of time window
Decline of spectral resolution by timing jitter is small

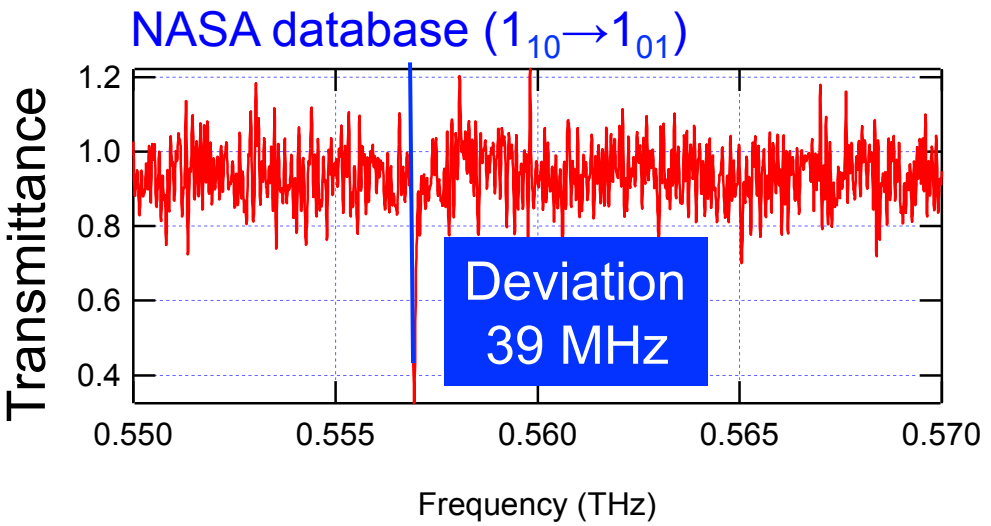
Frequency deviation from NASA database

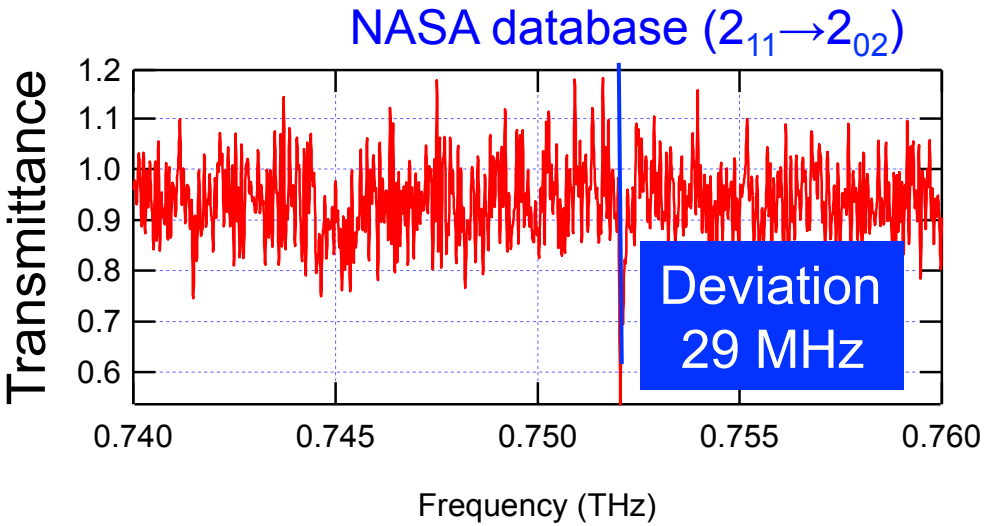
Conventional THz-TDS



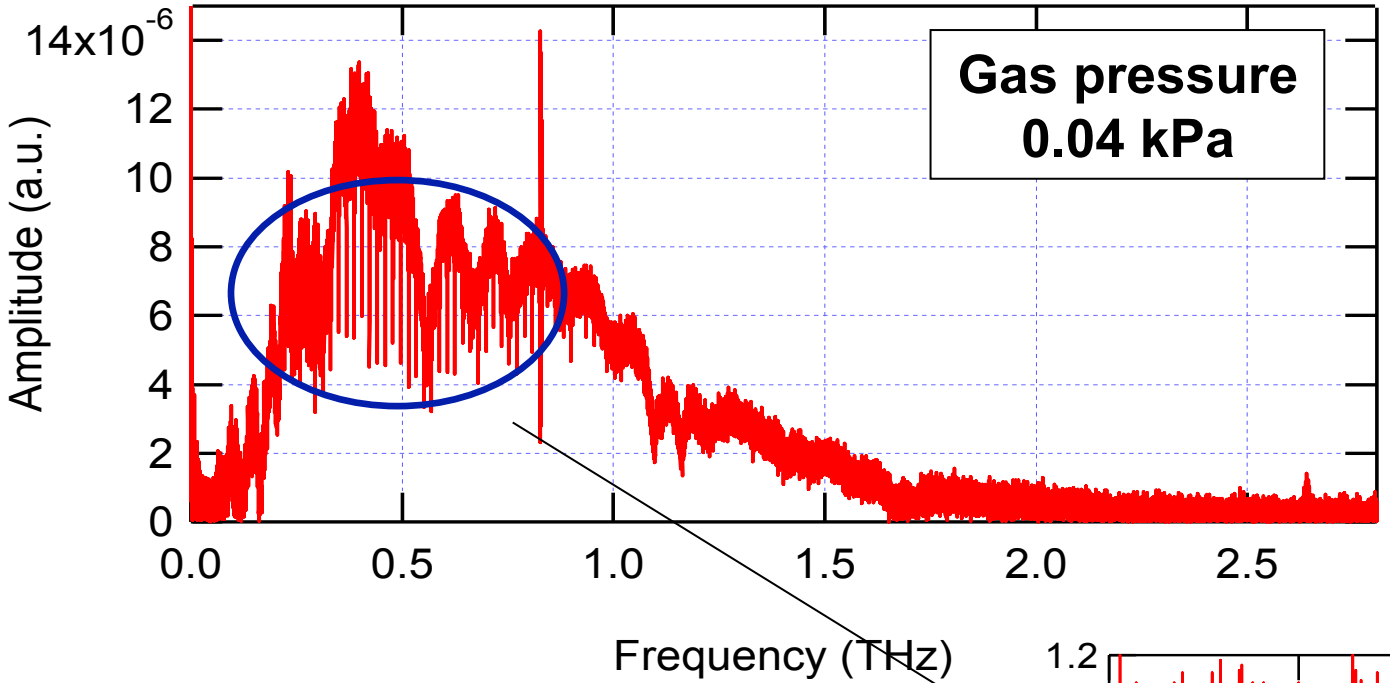


ASOPS-THz-TDS





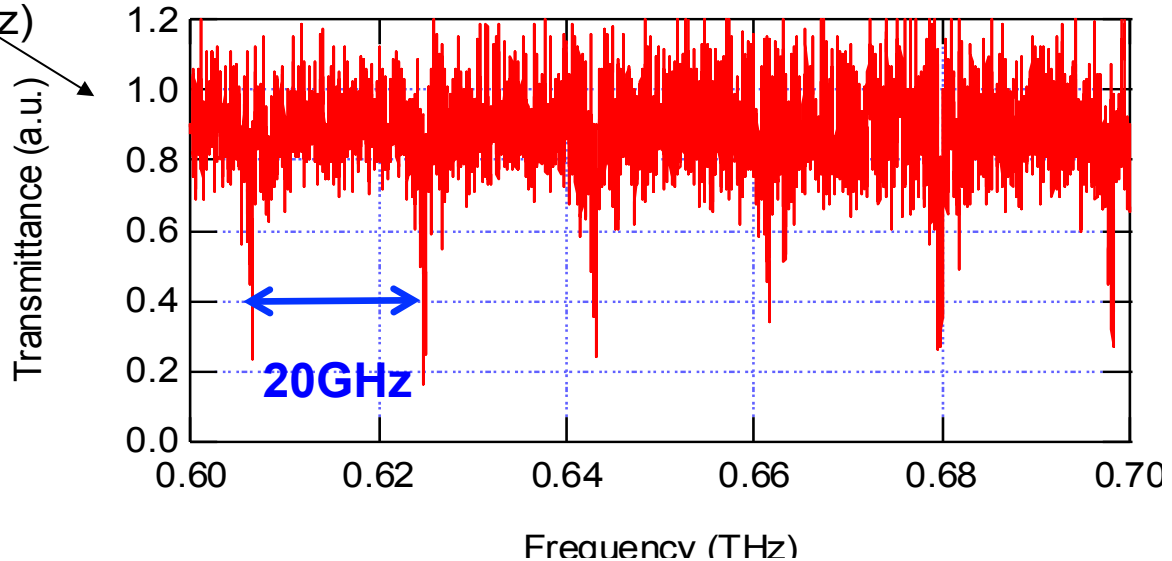
Spectroscopy of acetonitrile gas



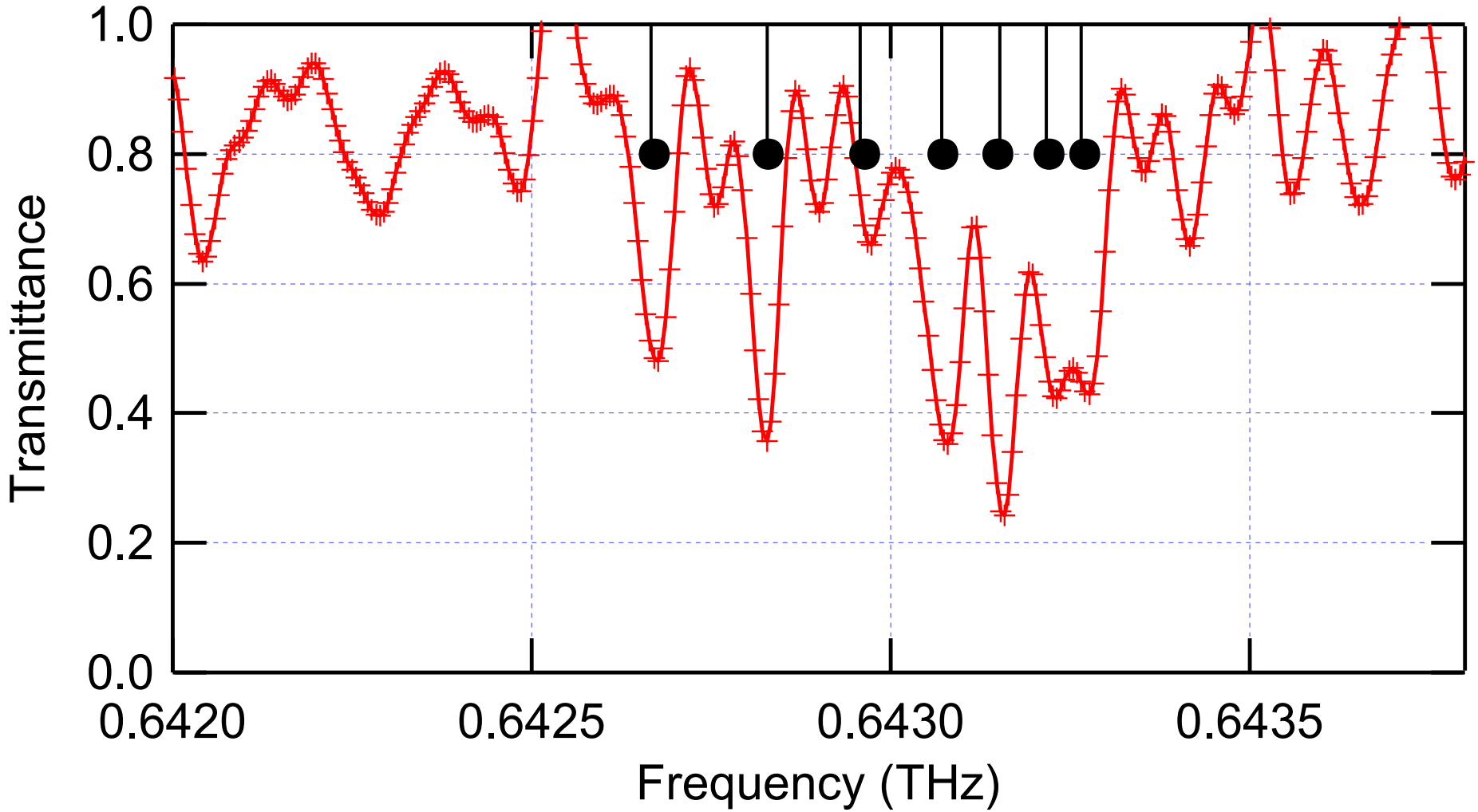
Interstellar molecule

Important in the field of radio astronomy

Groups of absorption lines periodically appeared at an interval of 20 GHz



Hyperfine structure of absorption lines in acetonitrile molecules



Evaluation of spectral accuracy using absorption lines of acetonitrile

Experimental results [THz]	NASA database [THz]	Deviation[MHz]
0.642 675 924 0	0.642 670 849 7	5.0743
0.642 827 458 8	0.642 829 579 3	2.1205
0.642 973 381 2	0.642 963 997 8	9.3834
0.643 080 016 7	0.643 074 051 0	5.9657
0.643 158 590 4	0.643 159 694 2	1.1038
0.643 231 551 6	0.643 220 892 8	10.6588
0.643 276 450 8	0.643 269 866 7	6.5841

Mean accuracy = 10^{-5}

Discussion on spectral accuracy

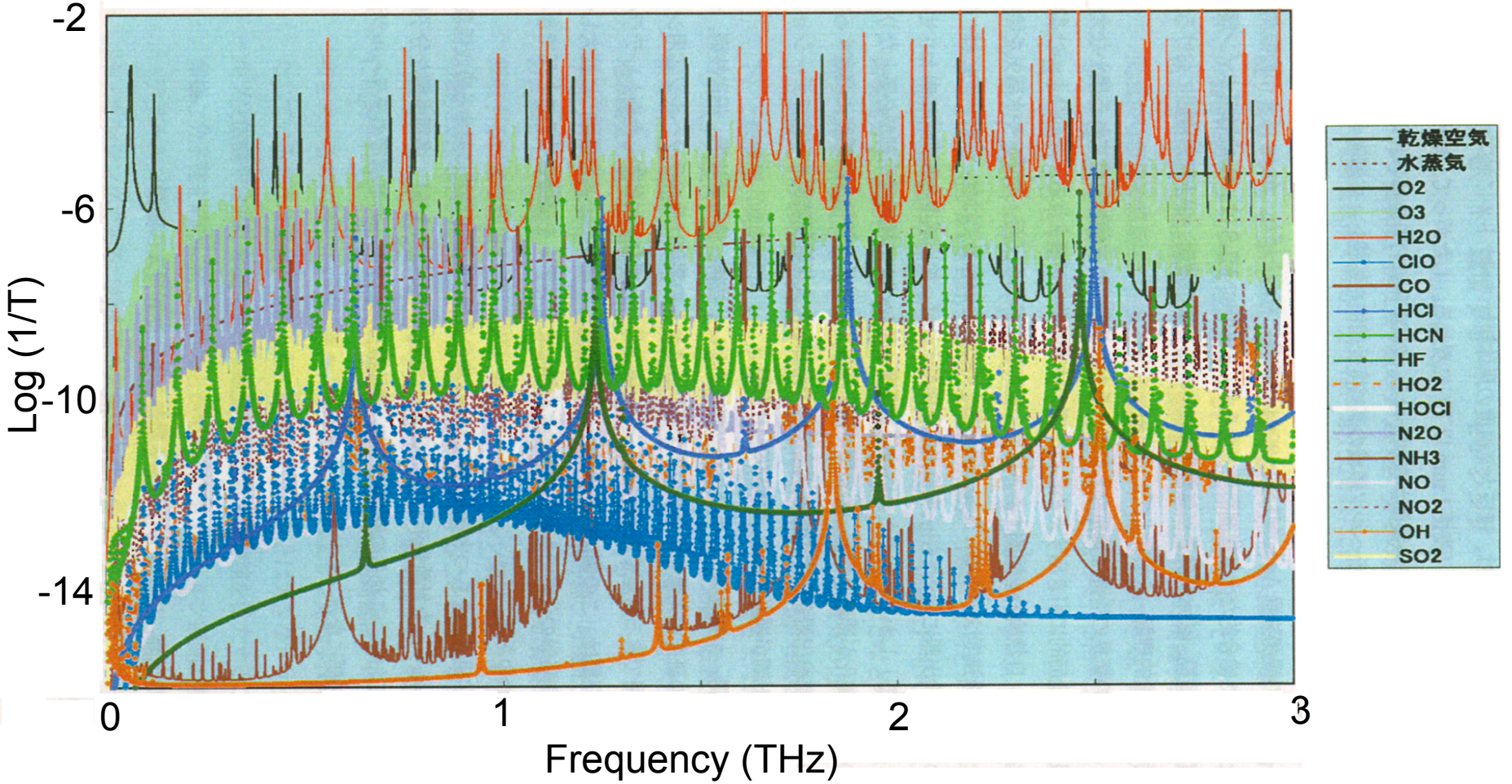
Achieved accuracy=10^{-5} >> Rb atomic clock=10^{-12}

	Frequency fluctuation	Mean frequency	Instability
f_1	several 10s mHz	56 MHz	10^{-12}
Δf		5 Hz	10^{-5}

Limit the spectral accuracy

Future plan: Analysis of atmospheric gas molecules

Many absorption line of molecular gases are concentrated in THz region



To identify each molecular gases correctly,
high accuracy, high resolution, and broadband are required.

Conclusions

(1) Evaluation of actual spectral resolution and accuracy in ASOPS-THz-TDS using low-pressure gas spectroscopy
- resolution = 72.9 MHz, accuracy = 10^{-5}

(2) Decline of spectral resolution caused by timing jitter is small.

(3) Spectroscopy of acetonitrile molecular gas
- periodical groups of absorption lines at every 20 GHz
- hyperfine structure of individual absorption lines