Simultaneous observations of meteoric Ca and Ca^+ by employing the Ti: sapphire-laser-based resonance-scattering Ca/Ca^+ lidar

Acknowledgement

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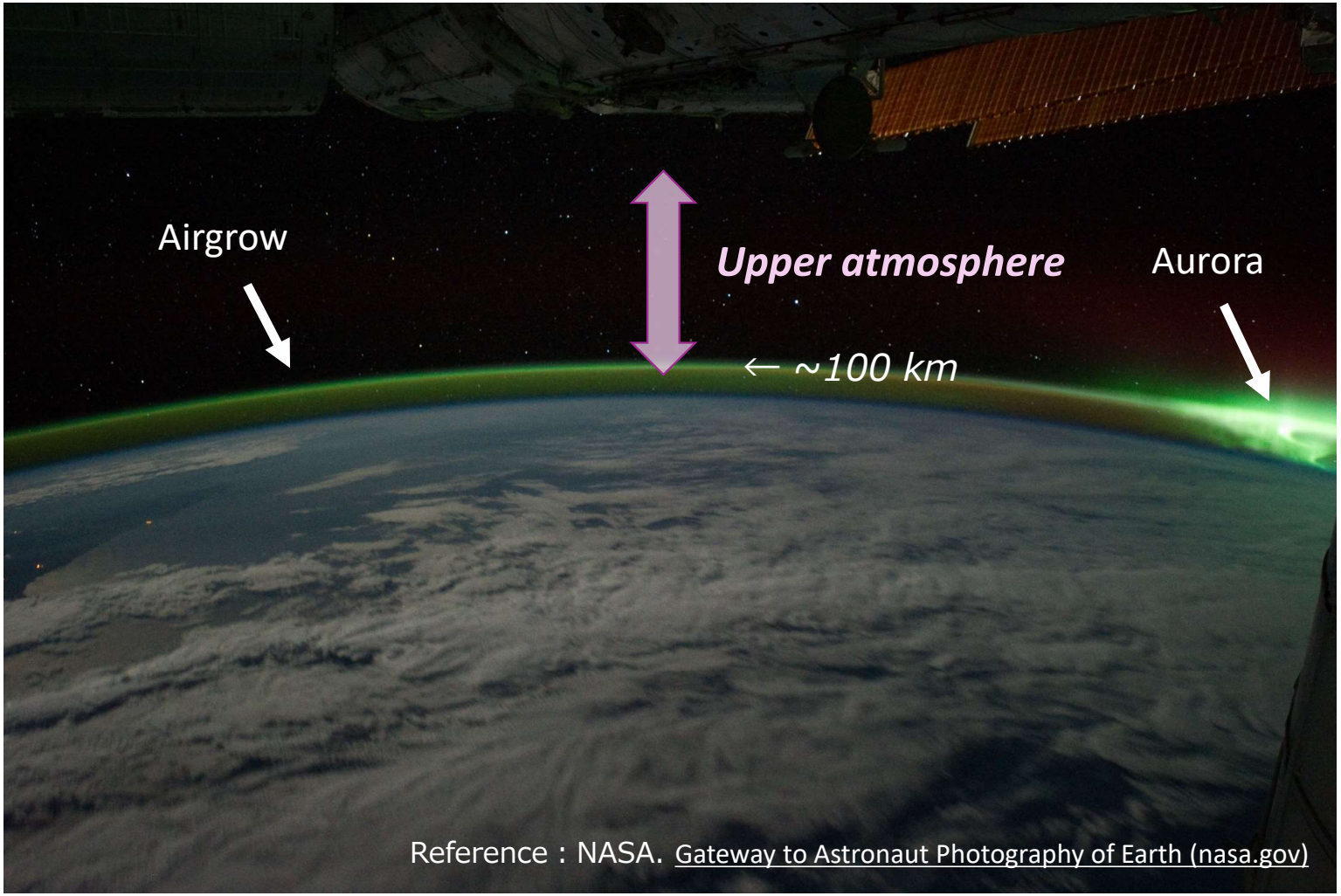
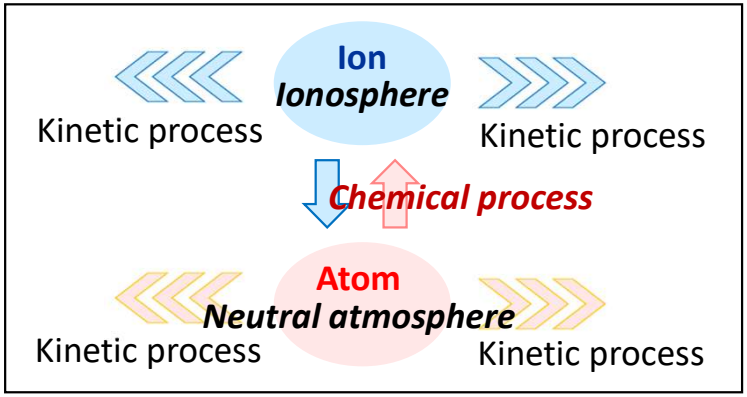
Upper atmosphere

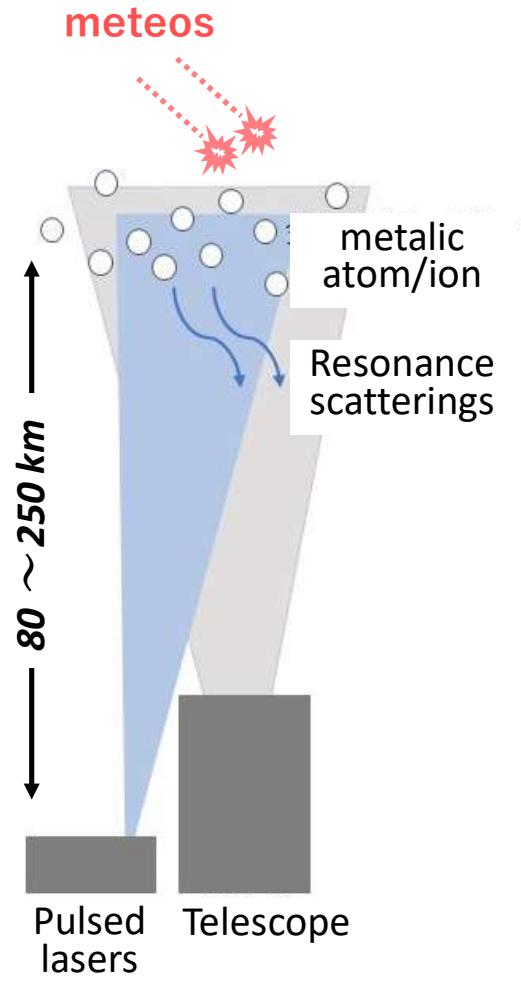


Resonance-scattering Lidar targeting meteoric atoms/ions as tracers in the upper atmosphere

Transition region: meteoric atoms/ions are distributed

	Ca^+	*Ca*	Fe	Na	K
Resonance wavelength (nm)	**393.4770**	**422.7918**	386.1006	589.1583	770.1084

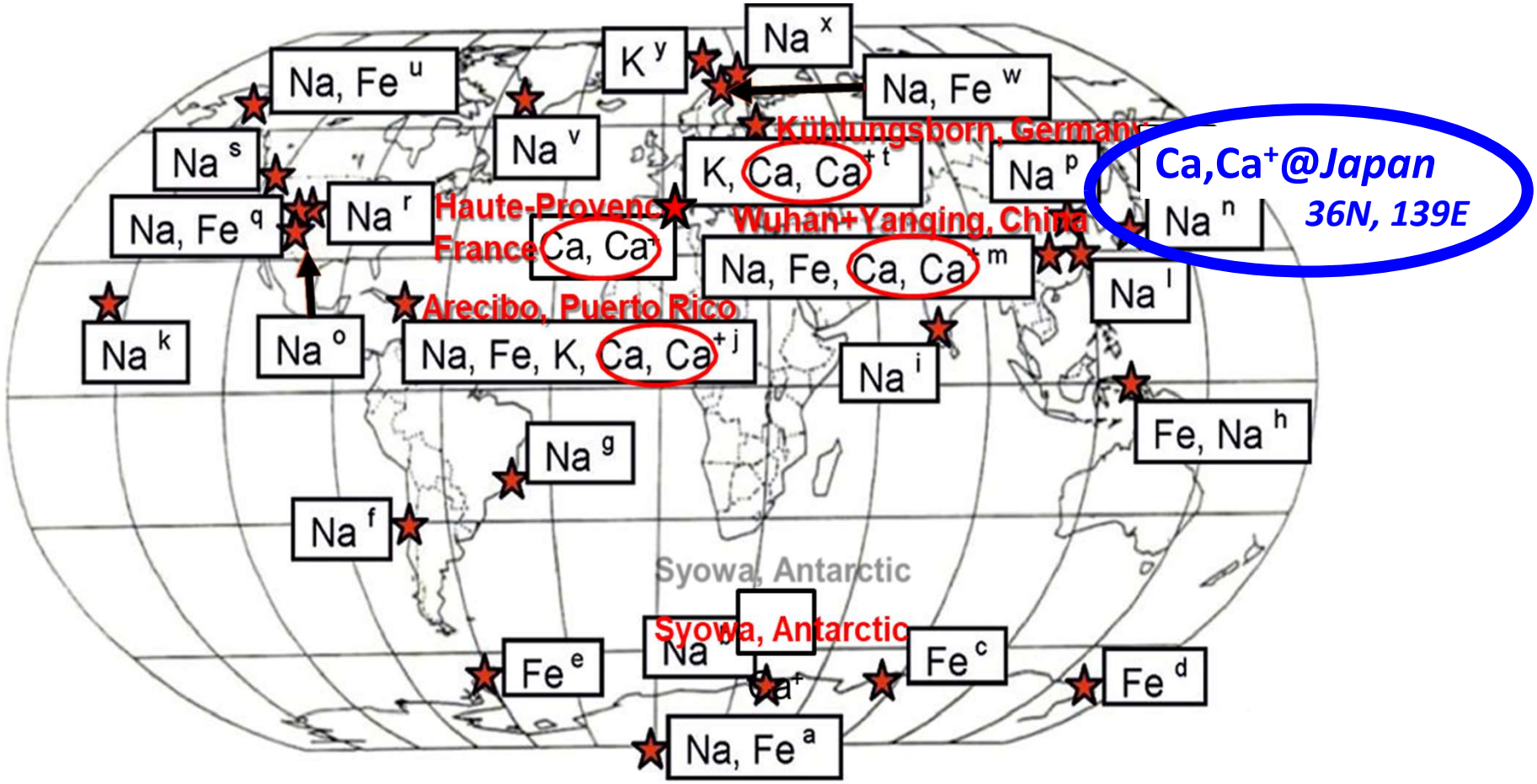




Injection-locked nanosecond pulsed **Ti:sapphire laser**

- ○ **OPO, OPA** ← Chinese Academy of Sciences *et. al.*
- × **Dye laser** ← *difficult to handle over a long term*
- △ **Alexandrite laser** ← *cannot access to neutral Ca*

arranged to Plane+ (2015).



Outline

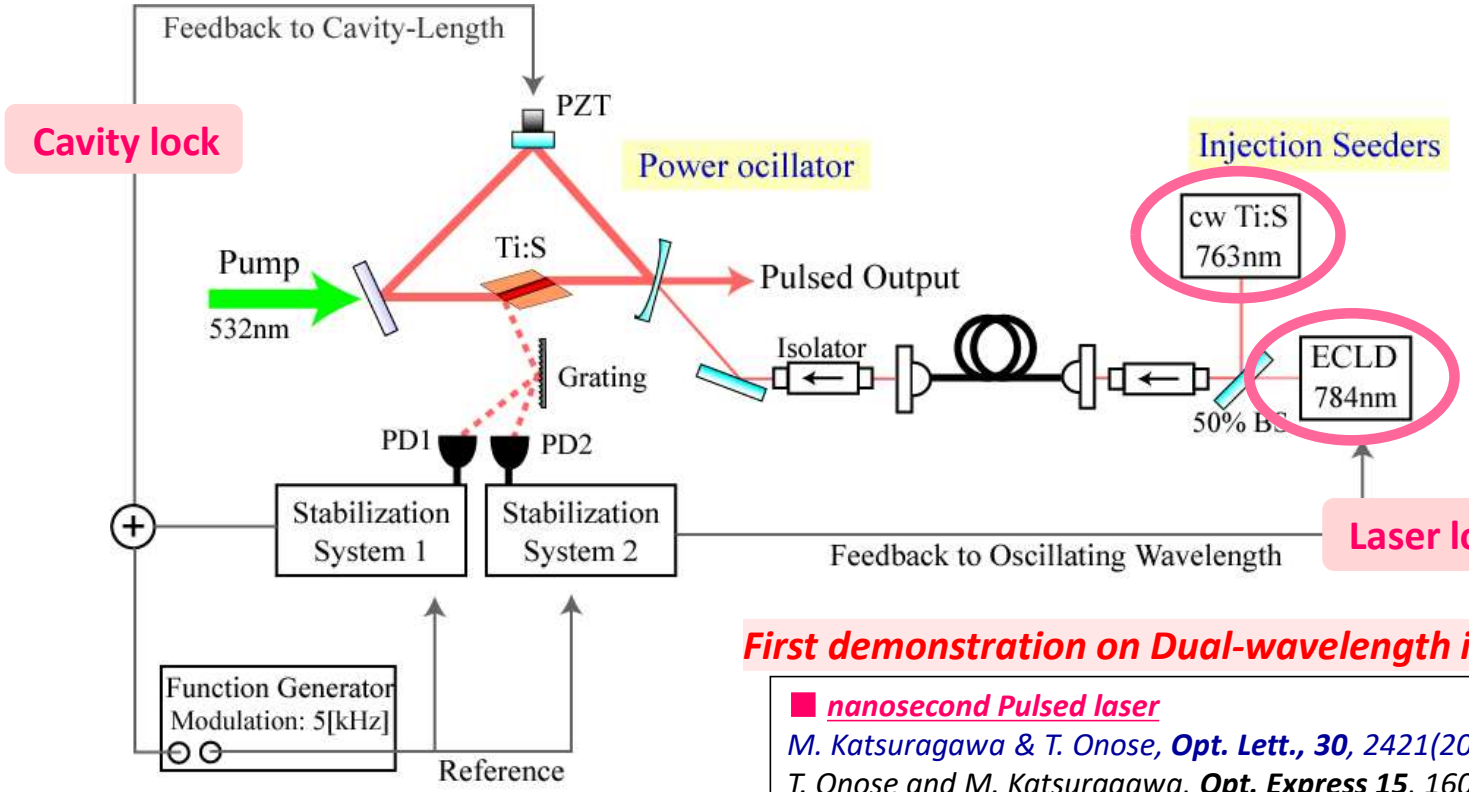
1. Dual-wavelength injection-locked nanosecond pulsed Ti:sapphire laser
   - ➡ Ti:sapphire-laser-based resonance-scattering Ca/Ca^+ Lidar system

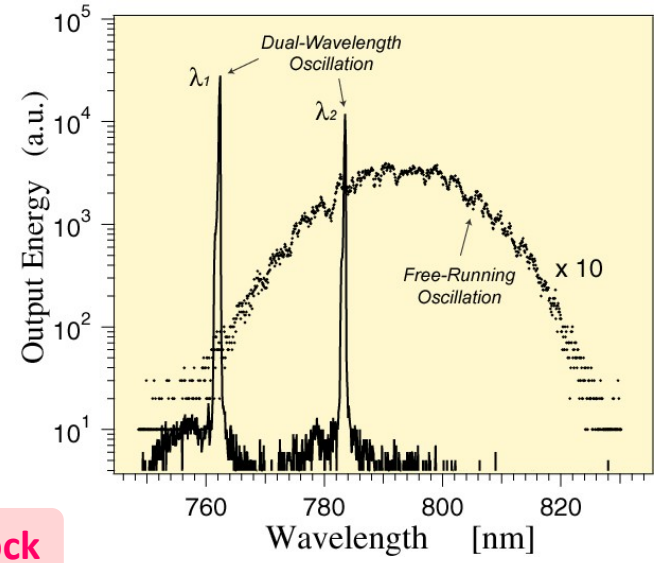
2. Lidar observations
   - 2.1 Benchmark test
   - 2.2 Simultaneous observation of Ca and Ca^+ over an entire night

3. Relationships for other relevant measurement methods
   - 3.1 Ionogram
   - 3.2 HF-Doppler

4. Measurement of Temperature and Velocity of Ca and Ca^+

Dual-wavelength injection-locked nanosecond pulsed **Ti:sapphire laser**





First demonstration on Dual-wavelength injection-locked Pulsed/ CW lasers

■ ***nanosecond Pulsed laser***

M. Katsuragawa & T. Onose, ***Opt. Lett., 30****, 2421(2005).*

T. Onose and M. Katsuragawa, ***Opt. Express 15****, 1600 (2007).*

Y. Fujii and M. Katsuragawa, ***Opt. Lett. 15****, 3065 (2007).*

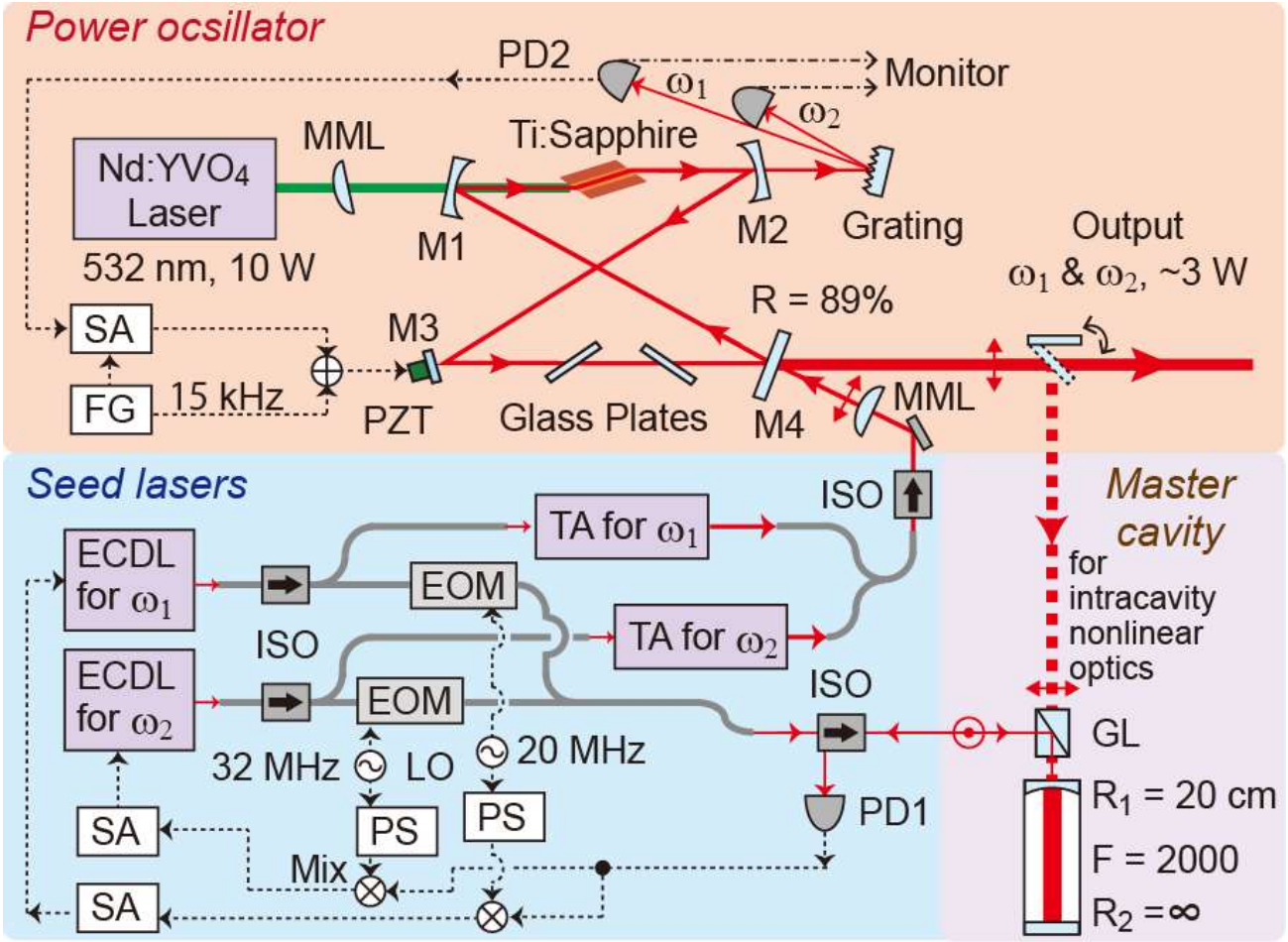
T. Nakano, K. Koizumi, T. Onose, K. Abe, and M. Katsuragawa, ***Opt. Express 18****, 26409 (2010).*

■ ***CW laser***

T. Gavara, T. Ohashi, Y. Sasaki, T. Kawashima, H. Hamano, R. Yoshizaki, Y. Fujimura, K. Yoshii, C. Ohae, and M. Katsuragawa, ***Opt. Lett. 41,*** *2994 (2016).*

Dual-wavelength injection-locked Continuous-Wave Ti:sapphire laser

that allows for oscillations with a variety of two wavelength combinations



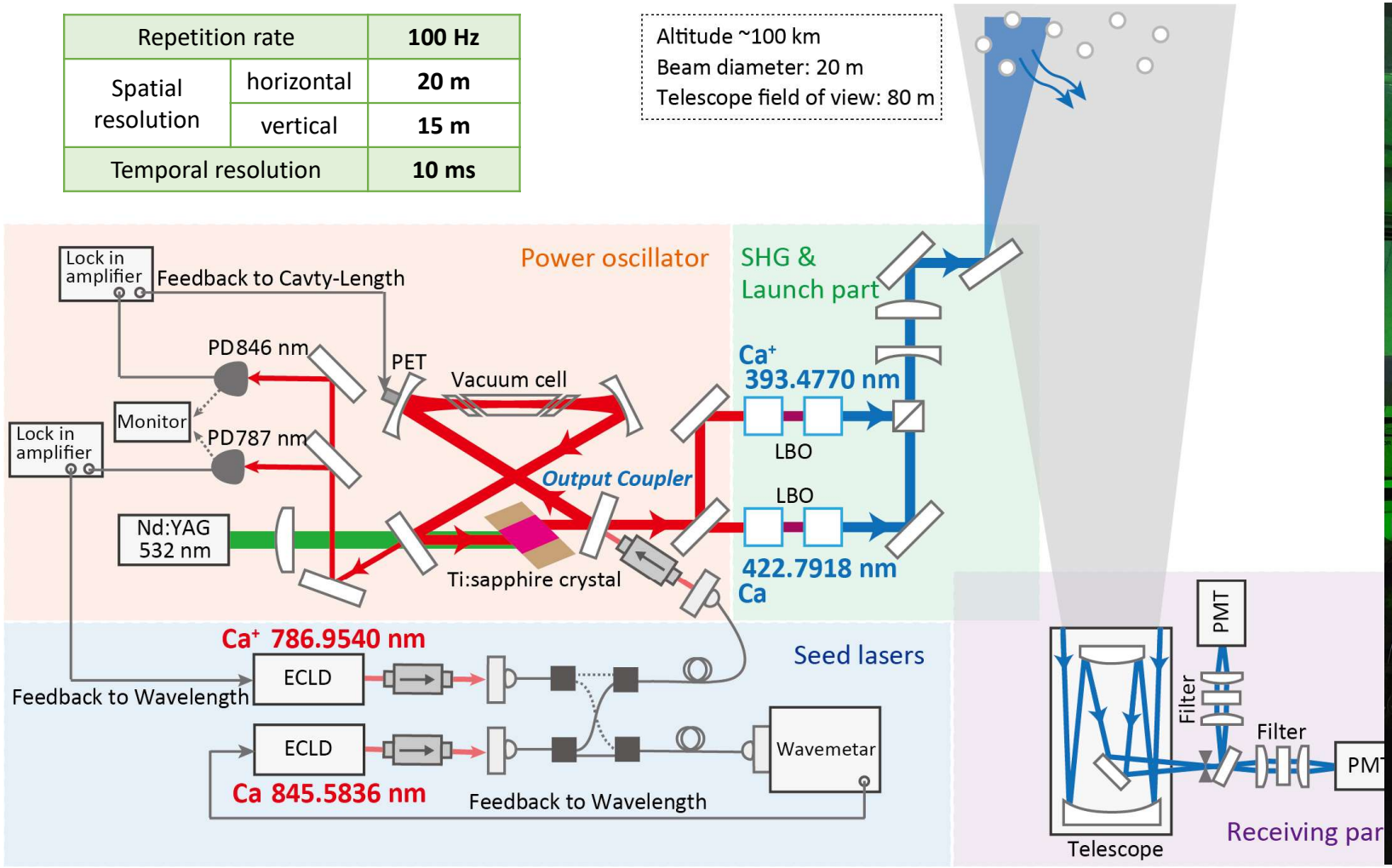
First demonstration on Dual-wavelength injection-locked CW laser

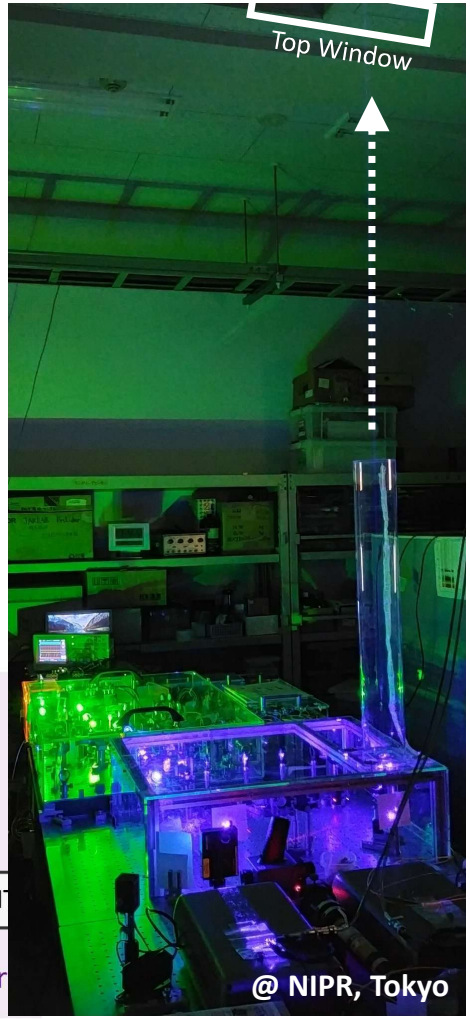
T. Gavara, T. Ohashi, Y. Sasaki, T. Kawashima, H. Hamano, R. Yoshizaki, Y. Fujimura, K. Yoshii, C. Ohae, and M. Katsuragawa, ***Opt. Lett. 41,*** *2994 (2016).*

Ca/Ca^{+} resonance-scattering Lidar system

Repetition rate		100 Hz
Spatial resolution	horizontal	20 m
	vertical	15 m
Temporal resolution		10 ms

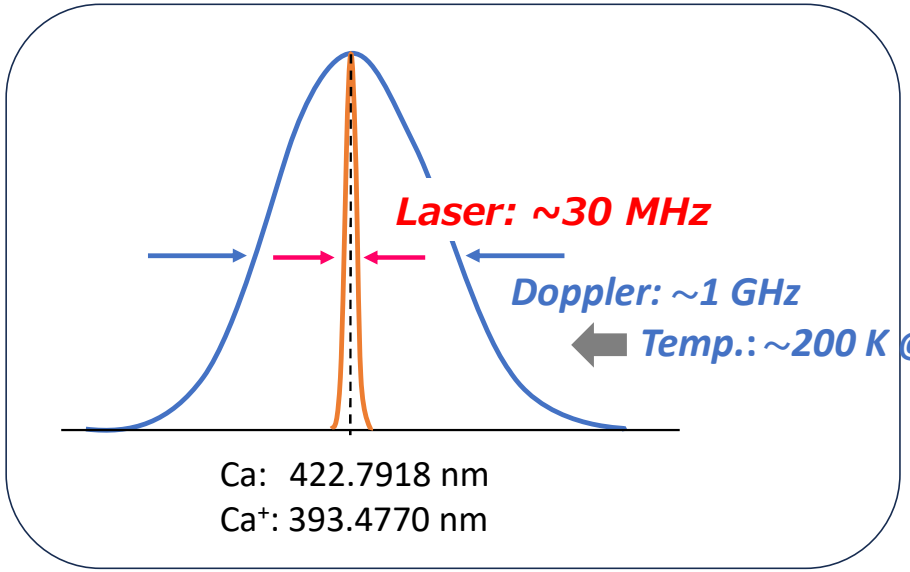
Altitude ~100 km
Beam diameter: 20 m
Telescope field of view: 80 m



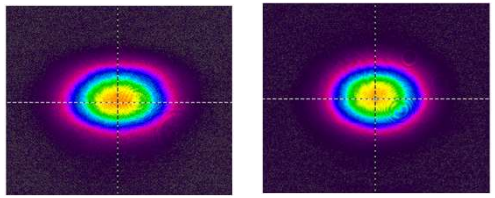


Capability of dual-wavelength Ti:s laser as a Ca/Ca⁺ lidar

	Ca	Ca⁺
Wavelength	422.7918 nm	393.4770 nm
Pulsed energy	5 mJ	4 mJ
Rep. rate	**100 Hz**	
Averaged Power	**0.5 W**	**0.4 W**
Spectral linewidth	**25 MHz**	**35 MHz**

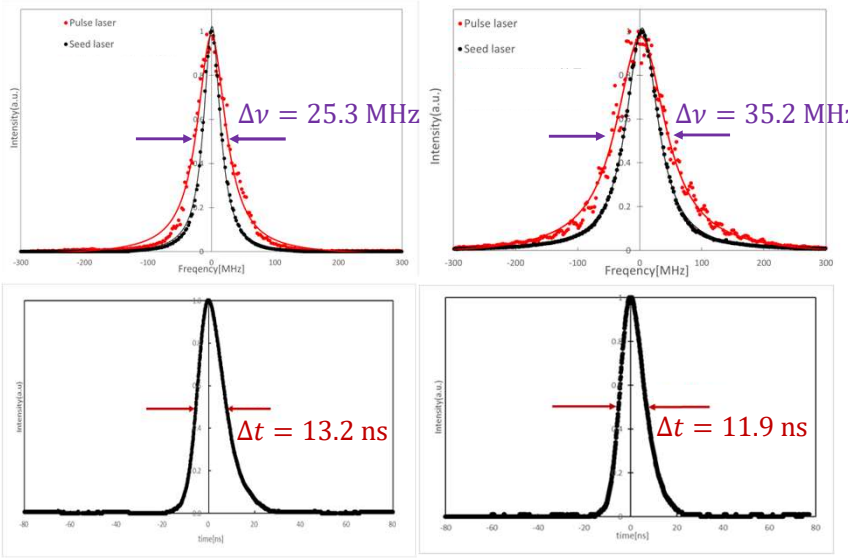


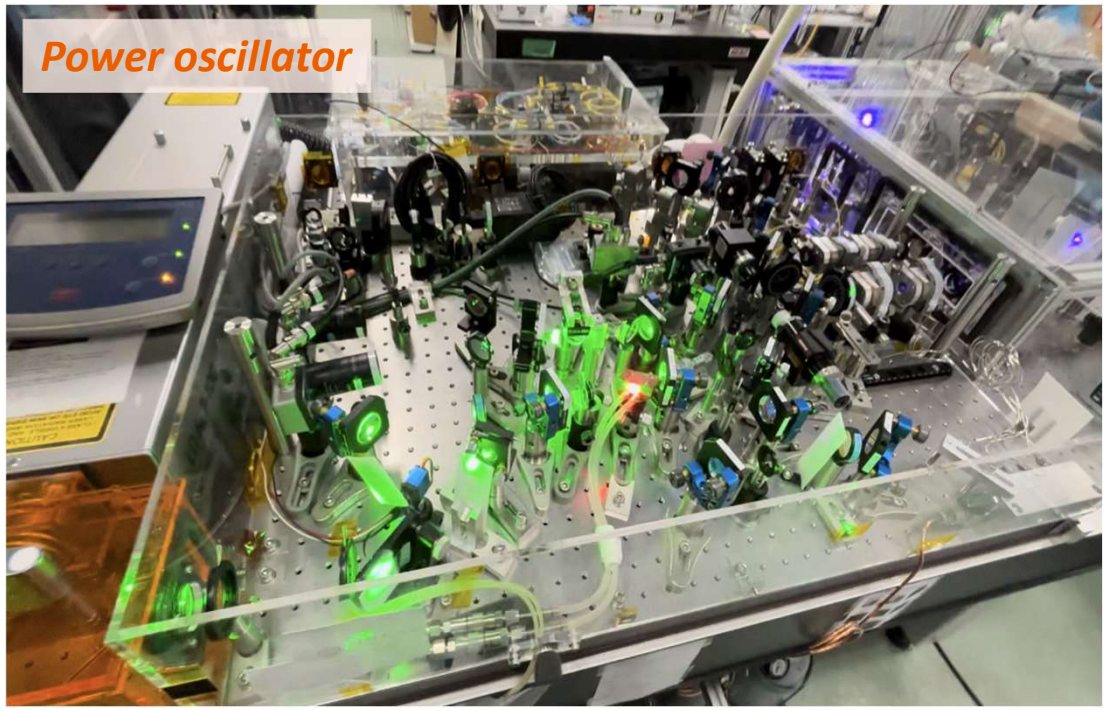
Single transvers mode

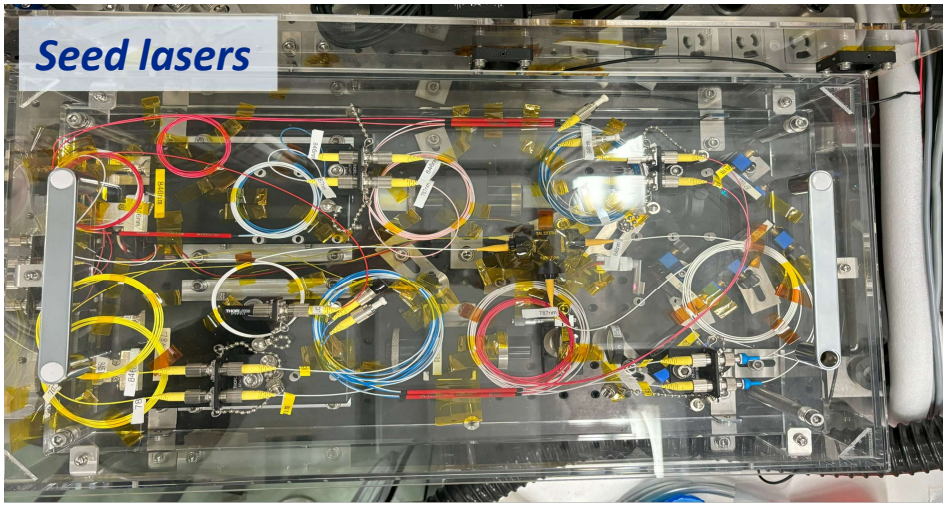


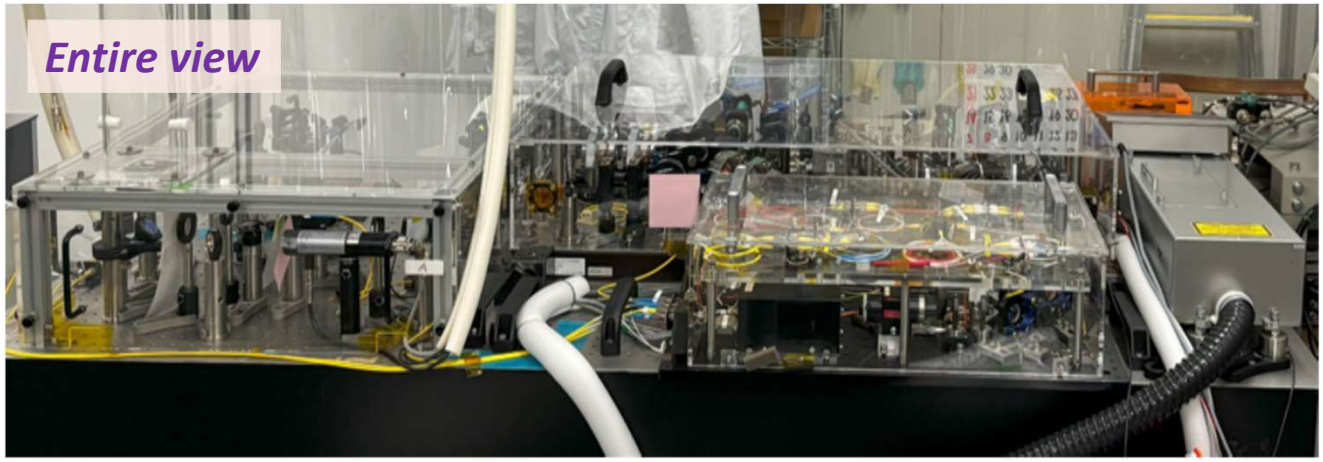
Ca: 846 nm *Ca⁺*: 787 nm

Fourier transform limited linewidth




Power oscillator


Seed lasers


Entire view

Outline

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   - ➡ Ti:sapphire-laser-based resonance-scattering Ca/Ca^+ Lidar system

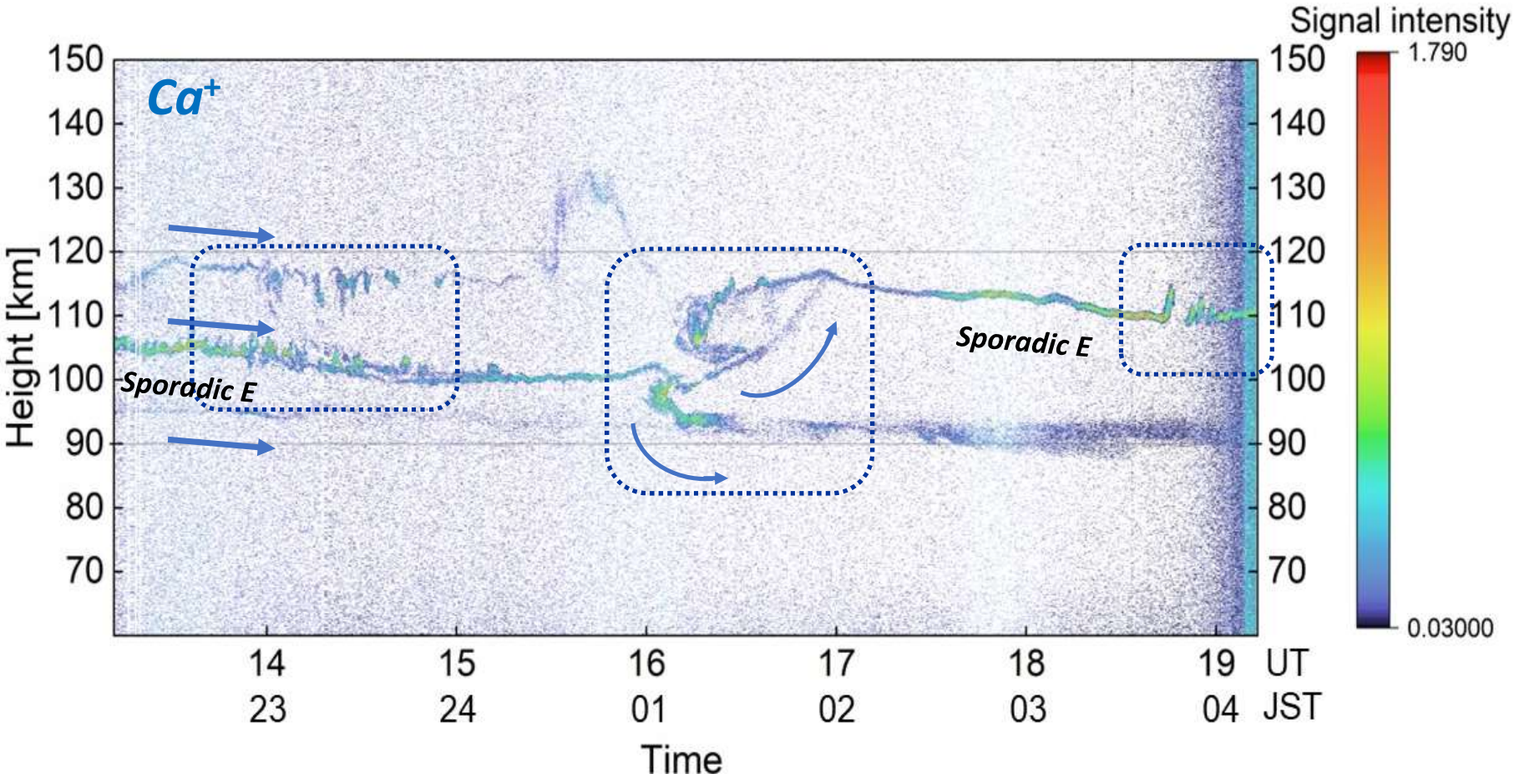
2. **Lidar observations**
   - 2.1 **Benchmark test**
   - 2.2 Simultaneous observation of Ca and Ca^+ over an entire night

3. Relationships for other relevant measurement methods
   - 3.1 Ionogram
   - 3.2 HF-Doppler

4. Measurement of Temperature and Velocity of Ca and Ca^+

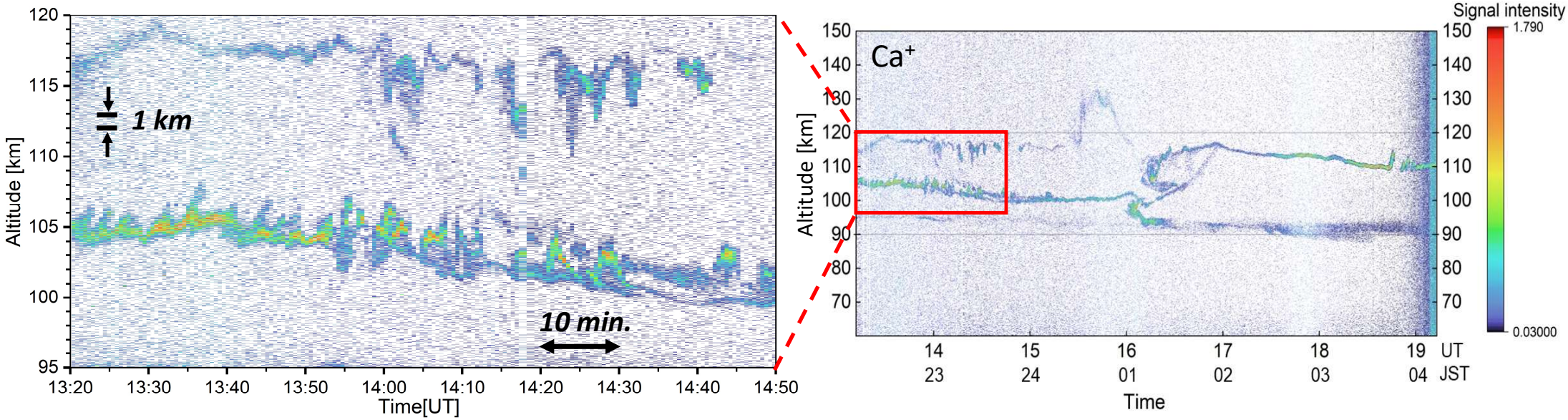
Benchmark test: single freq. operation

Stable operation over an entire night, having a high temporal-spatial resolution



09, Aug., 2022

High temporal-spatial resolution



	Ca⁺
Date	09, Aug., 2022
Ave. power [W]	0.39
Integration time [s]	**30**
Spatial resolution [m]	**15**

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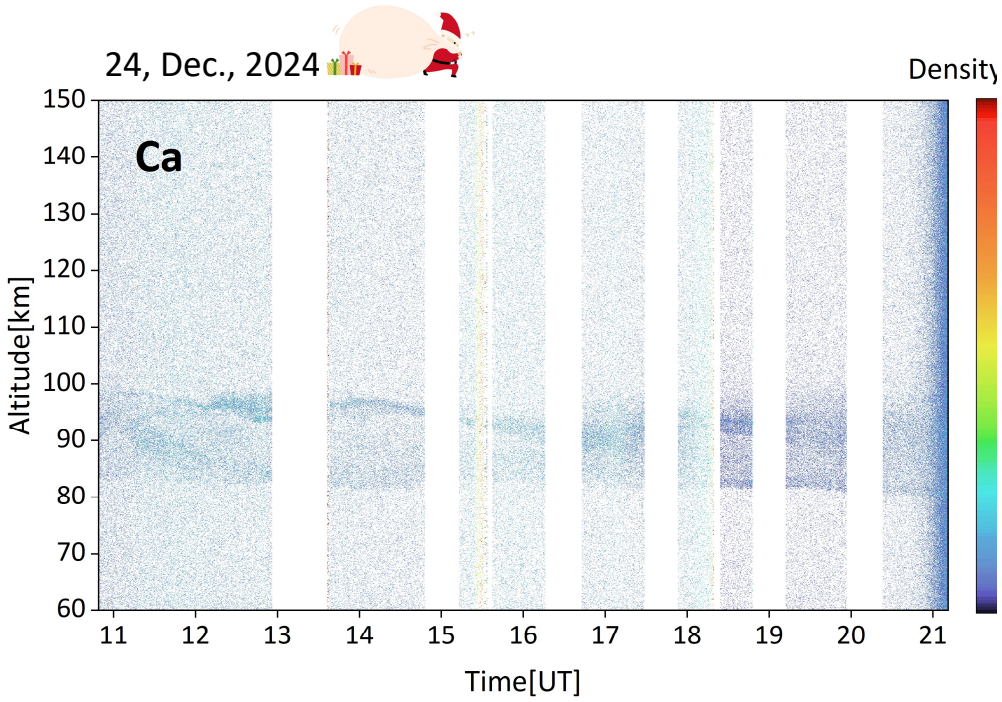
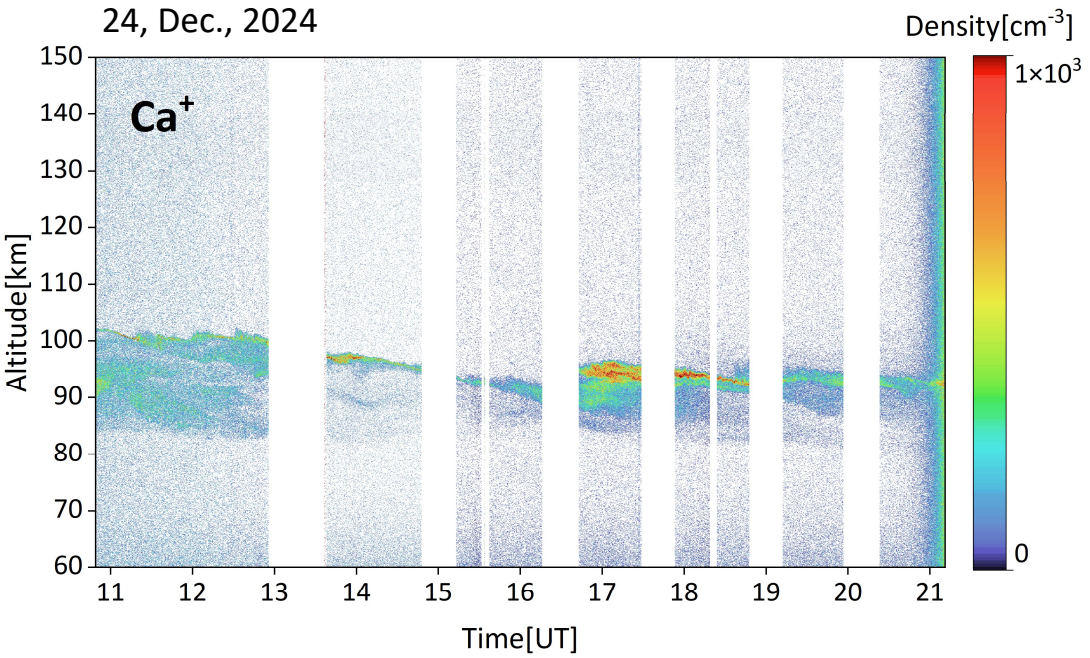
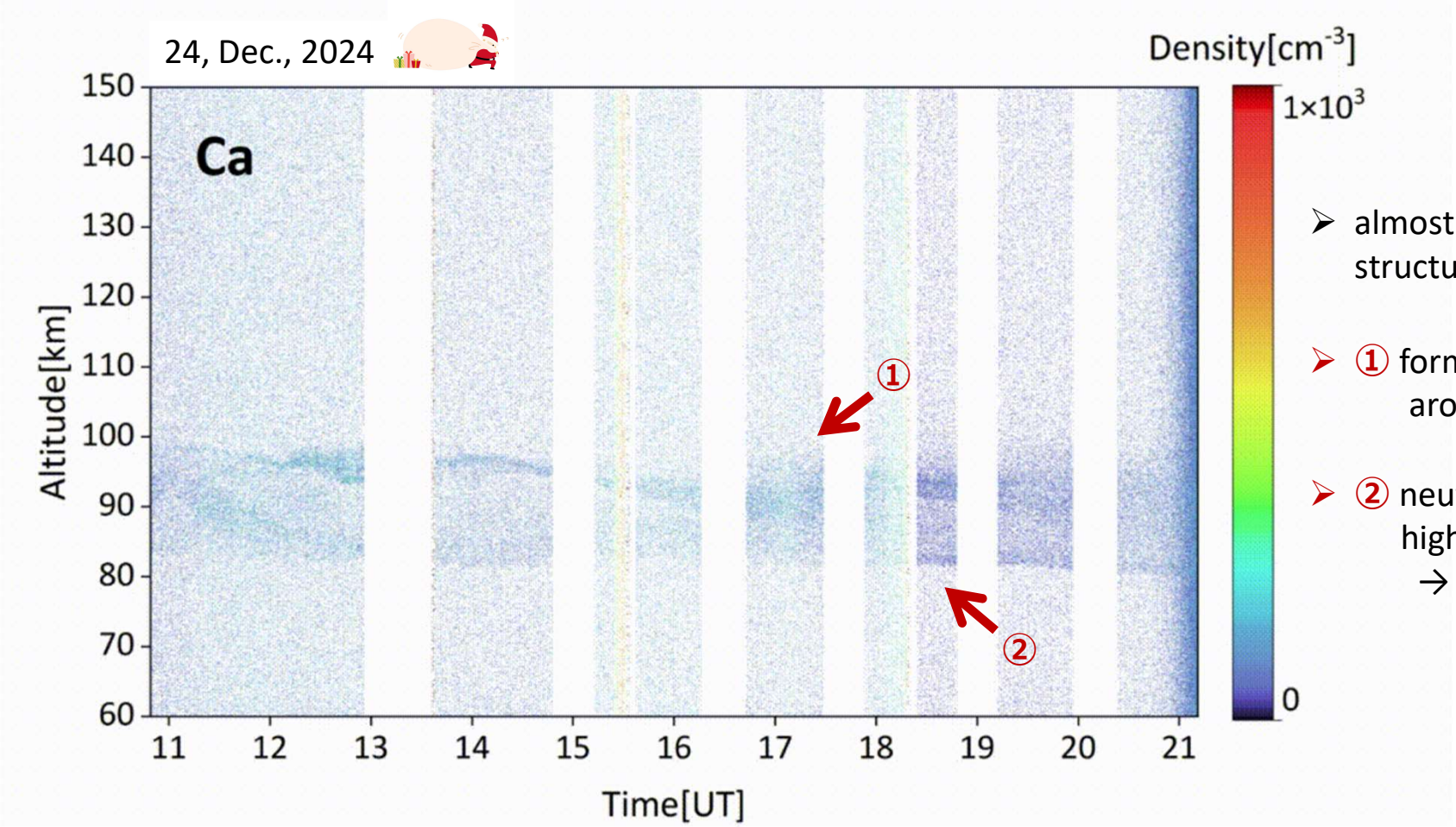
Simultaneous observation of Ca and Ca^+ over an entire night





	Ca	Ca^+
Averaged power [W]	0.2	0.4
Integration time [s]	30	30
Hight resolution [m]	15	30

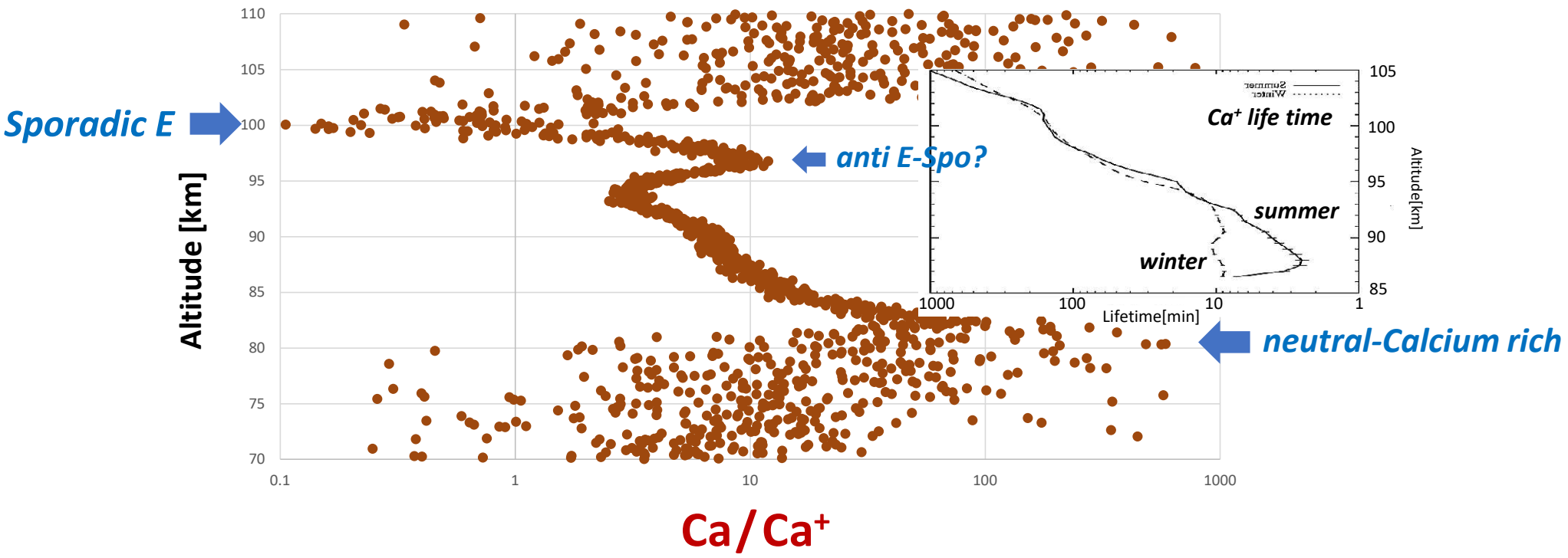
Simultaneous observation of Ca and Ca^+ over an entire night



- almost identical temporal-spatial structures for both of Ca and Ca^+
- ① formation of sporadic-E Ca^+ layer around the highest altitude
- ② neutral Ca density was relatively higher as the altitude was lower
  → showing the chemical reaction of Ca^+ to Ca was faster as the altitude was lower

High capability to simultaneously detect the detailed temporal-spatial structures of Ca and Ca^+

Characteristic behavior of dependence of the ratio: Ca/Ca^+ on altitude



Summer to winter variability in mesospheric calcium ion distribution and its dependence on Sporadic E at Arecibo
Journal of Geophysical Research: Space Physics, Volume: 117, Issue: A2, First published: 07 February 2012, DOI: (10.1029/2011JA016953)

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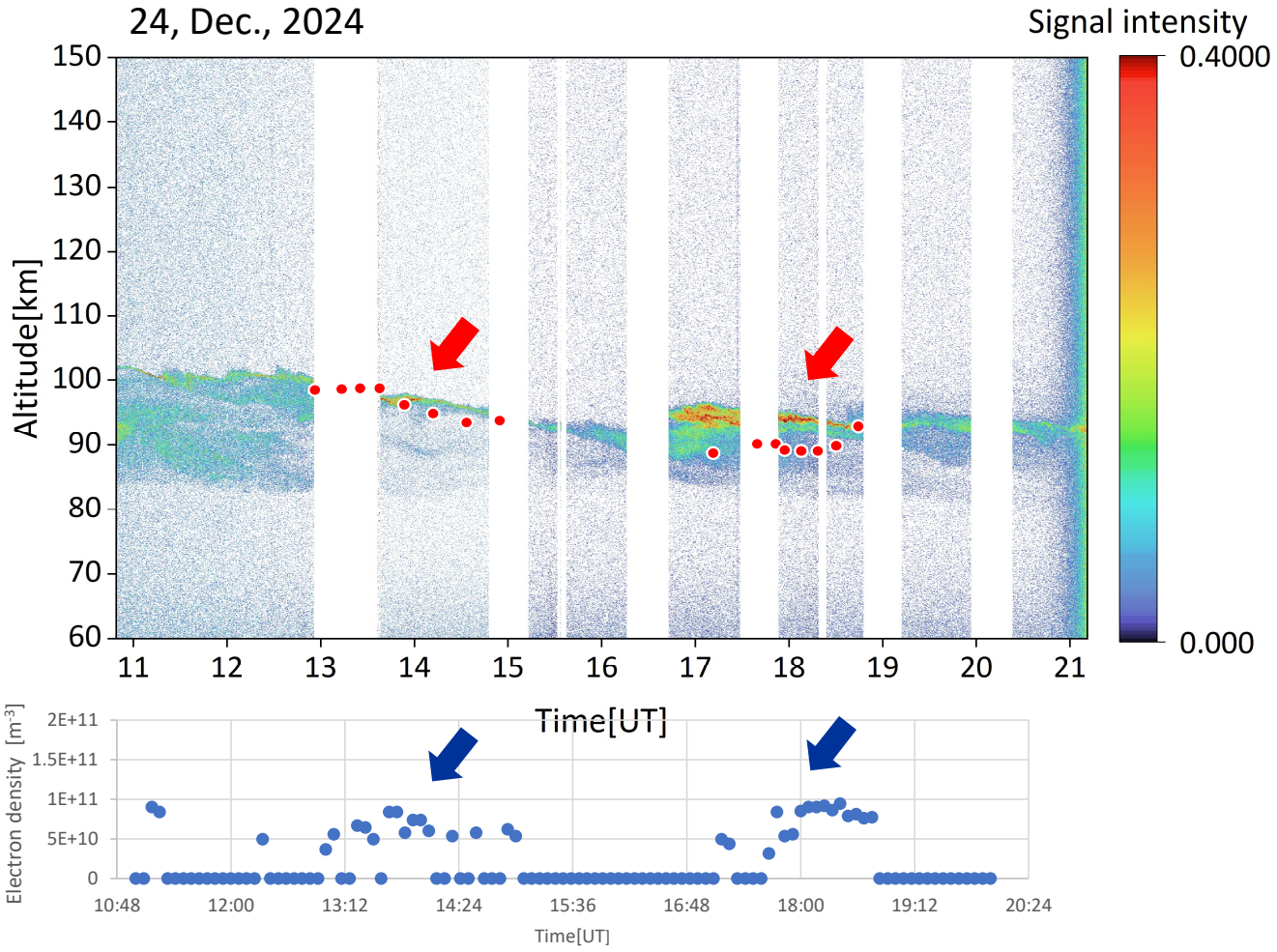
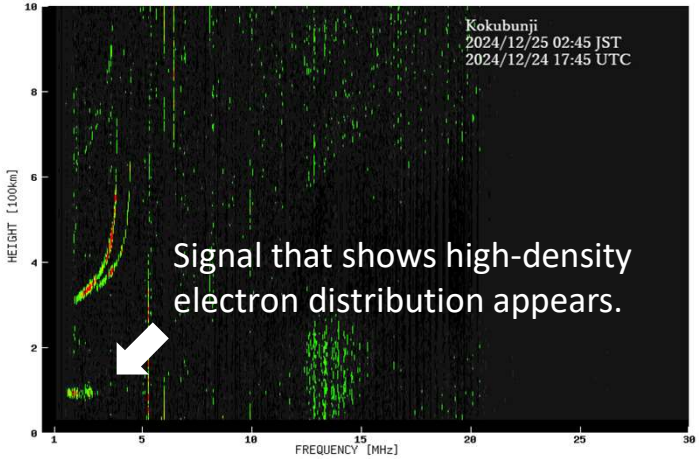
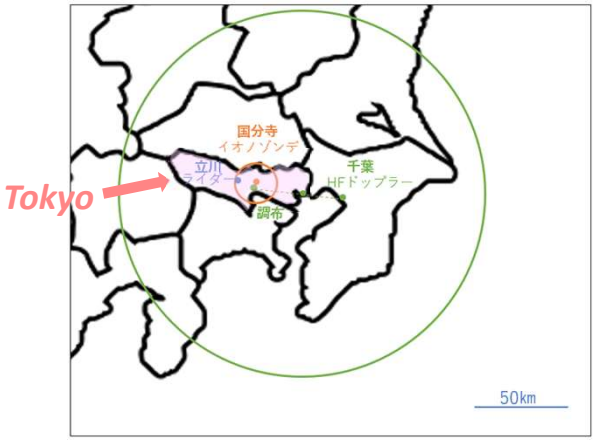
Relationships for other relevant measurements: ① *Iongram*

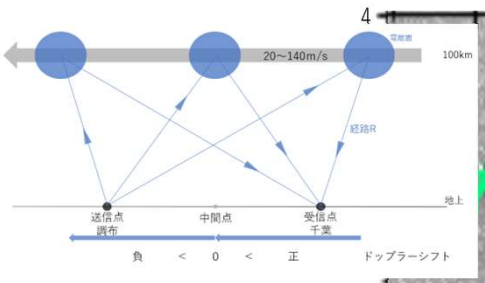


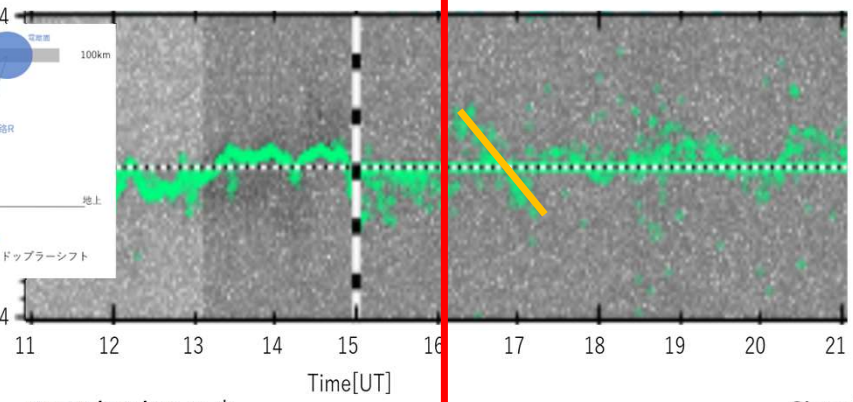
Ionosonde

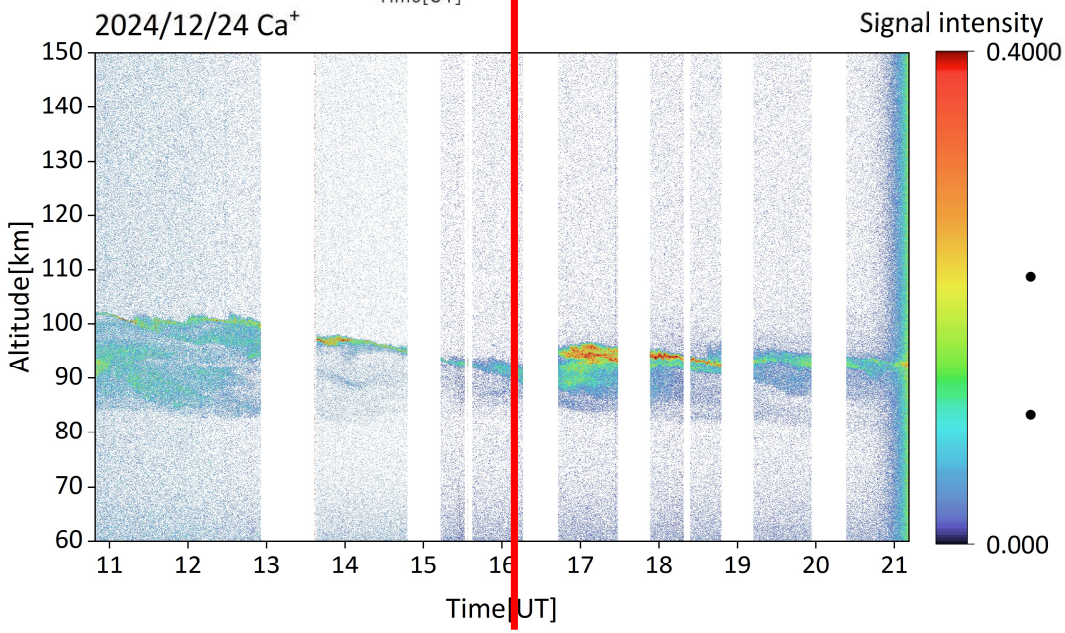


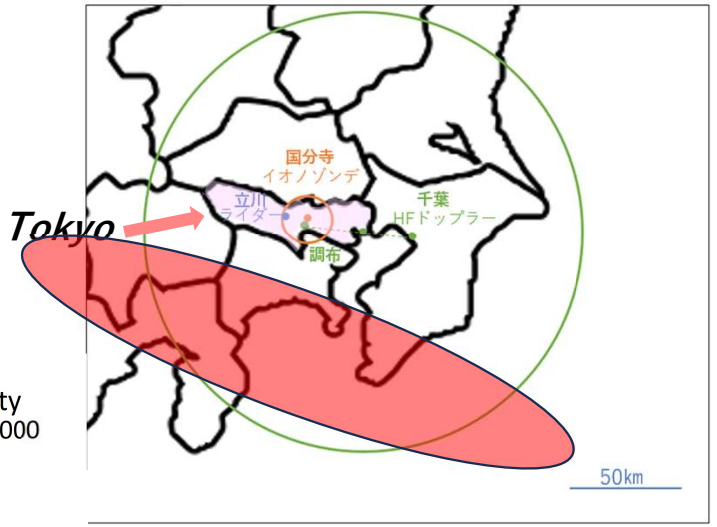


Relationships for other relevant measurements: ② *HF Doppler*









- The Line-crossing structure around 16 – 17 (UT), corresponding to the appearance of Sporadic-E layer
- Estimated velocity: 90 m/s by a Doppler freq. shift of 1.5 Hz at a radio wave of 5 MHz
  → implying 270 km travel in 50 min. (toward south-west to north-east (suggested by TEC)).

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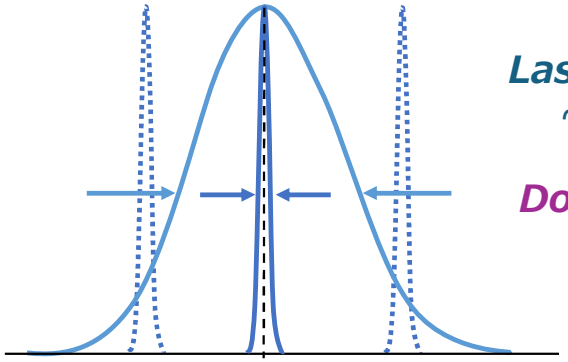
4. **Measurement of Temperature and Velocity of Ca and Ca^+**

Temperature and Velocity of Ca and Ca⁺

2.5-GHz *freq. sweeping*



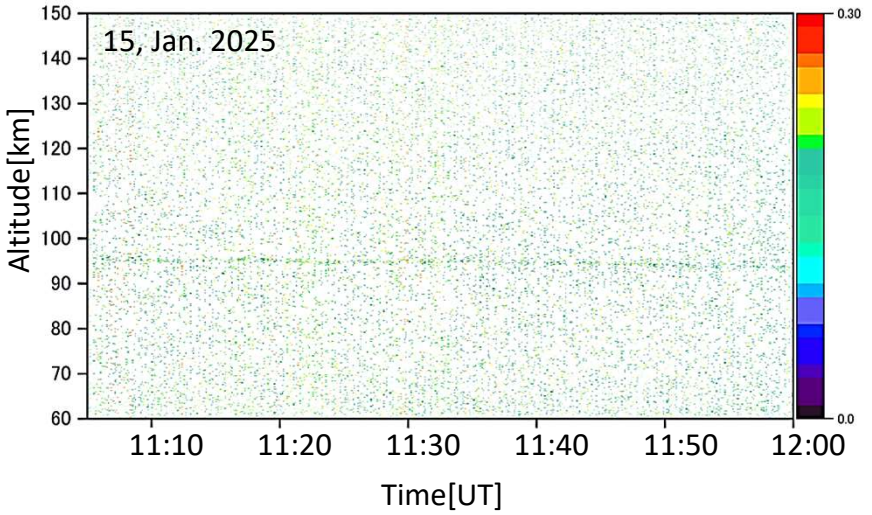
Laser linewidth
~30 MHz

Doppler width
~1 GHz

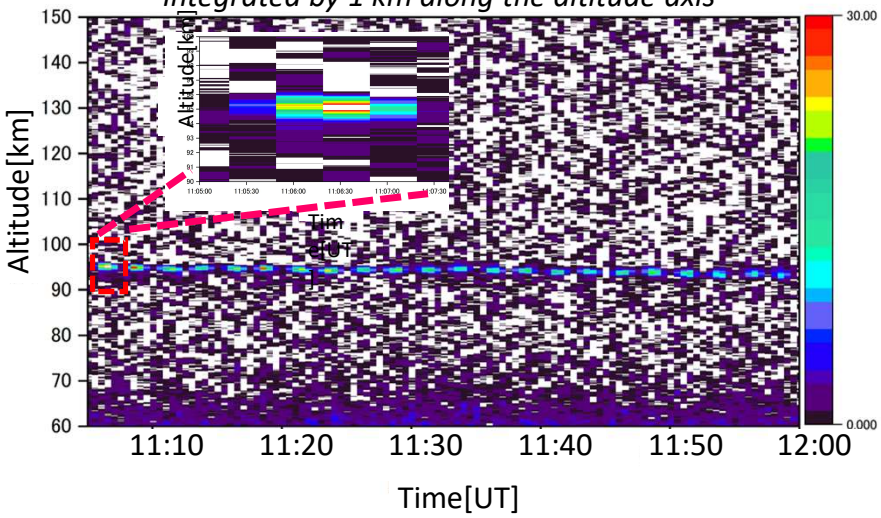
Ca^+ : 761.9059 GHz
(393.4770 nm)

	Ca^+
Ave. power[W]	0.6
Integ. time [s]	20
Hight resol. [m]	15

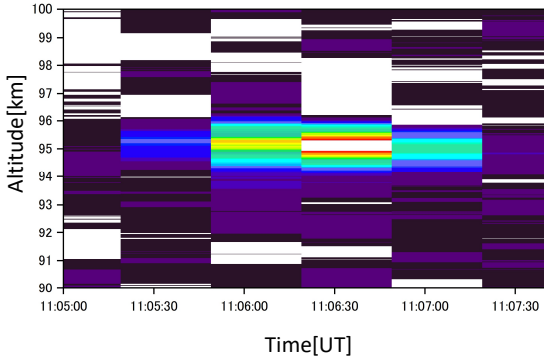
Time [UT]	Freq. [THz]
11:05:04	761.9069
11:05:34	761.9064
11:06:04	761.9059
11:06:34	761.9054
11:07:04	761.9050
11:07:34	761.9045

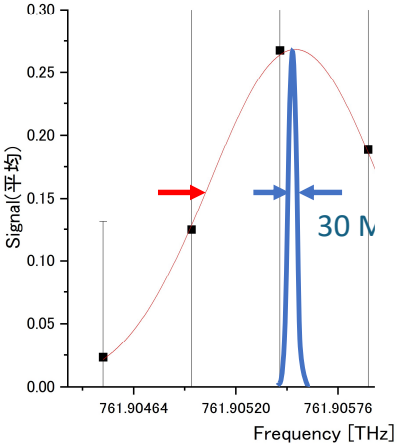


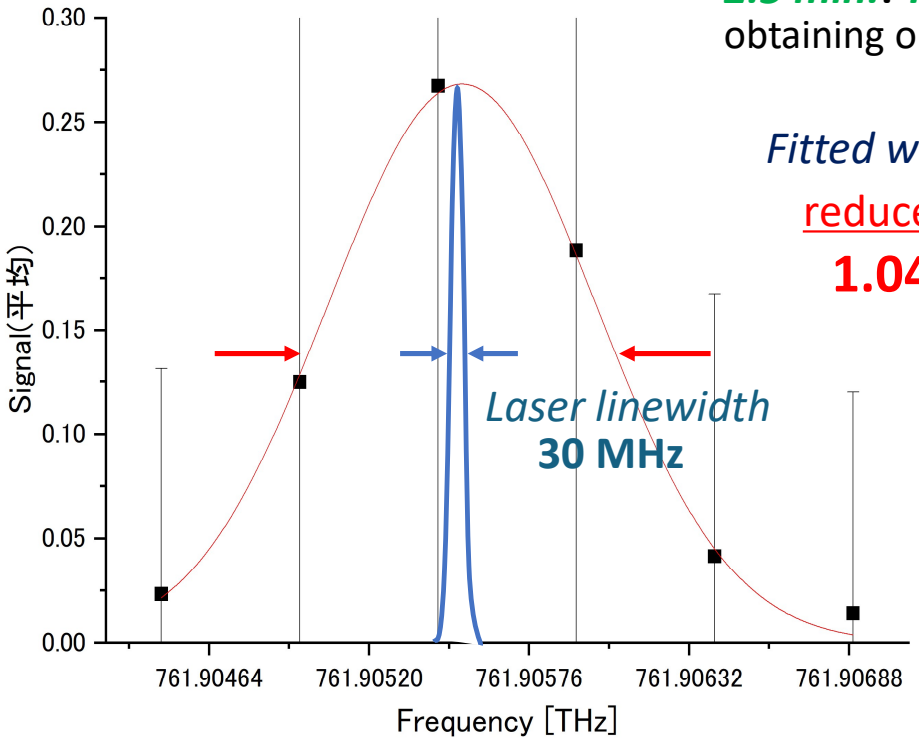
Integrated by 1 km along the altitude axis



Benchmark test: *Temperature* and Velocity measurement of Ca and Ca^+







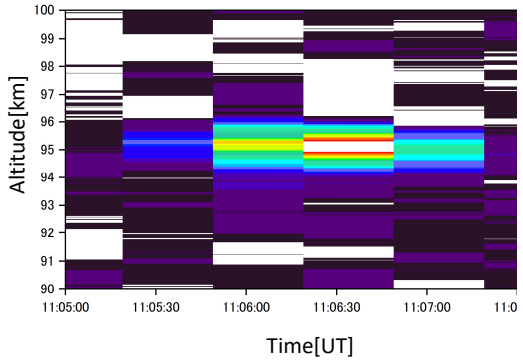
2.5 min.: ***Time*** required for obtaining one Doppler profile

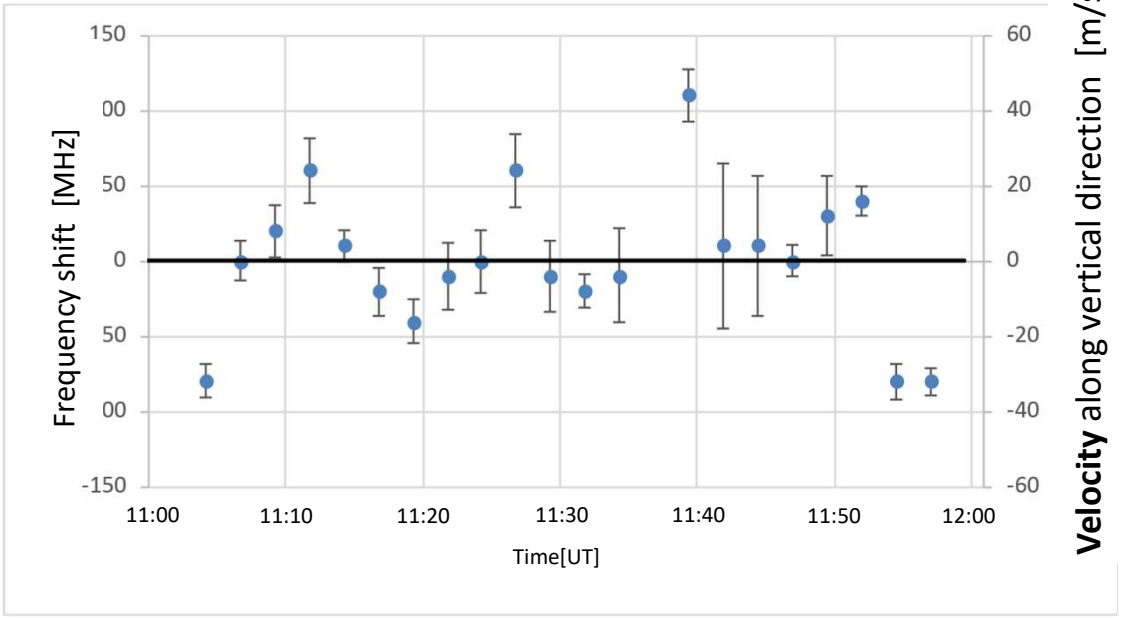
Fitted well by ***Voight*** func.

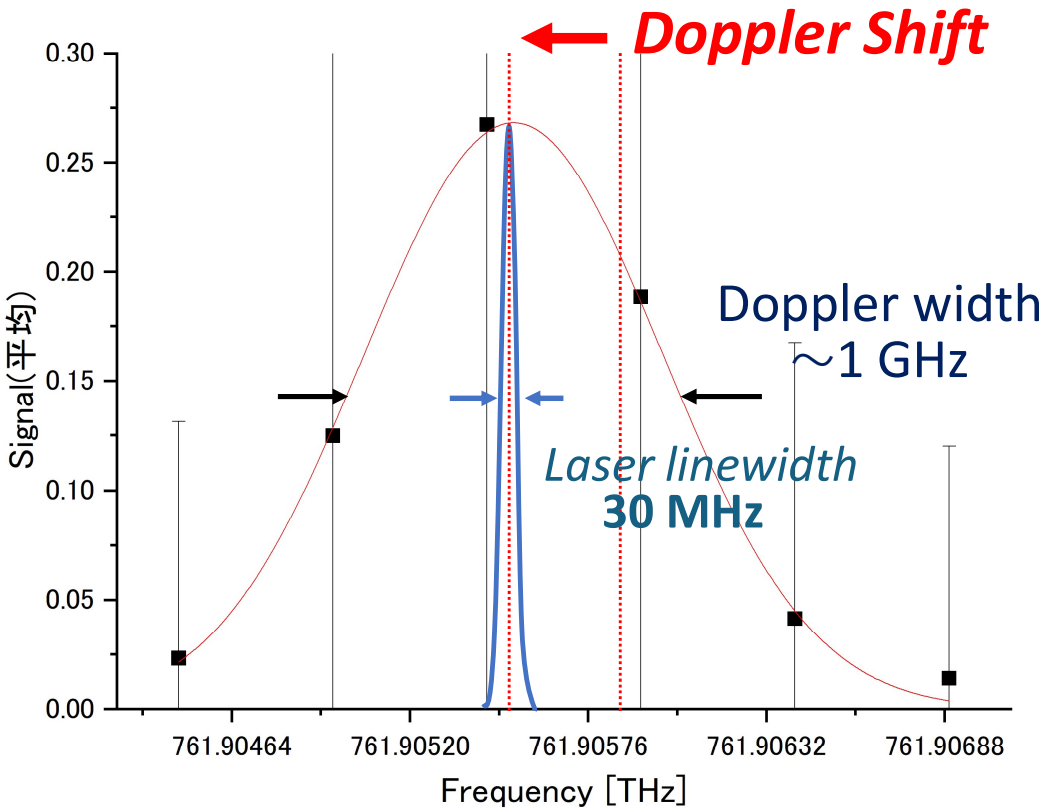
reduced **Doppler width**

1.04 GHz ➡ 145 K

Benchmark test: Temperature and Velocity measurement of Ca and Ca^+





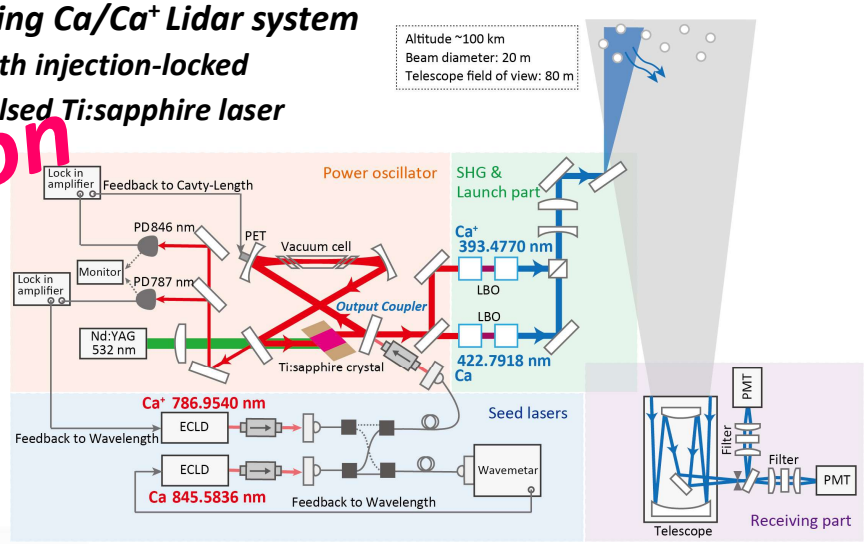


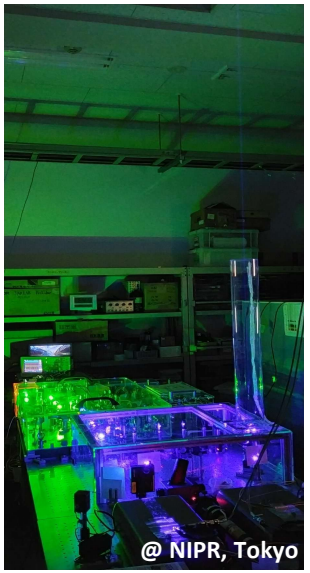
Summary

■ ***Resonance-scattering Ca/Ca⁺ Lidar system***

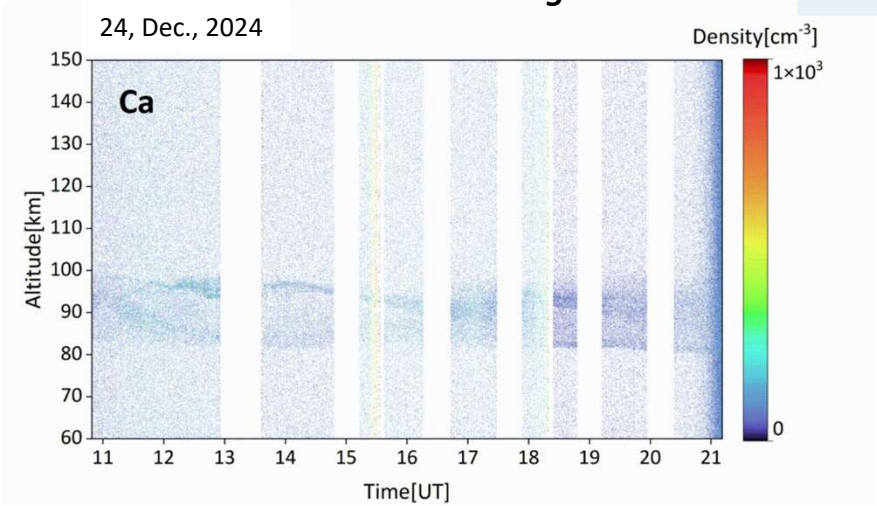
Dual-wavelength injection-locked nanosecond pulsed Ti:sapphire laser

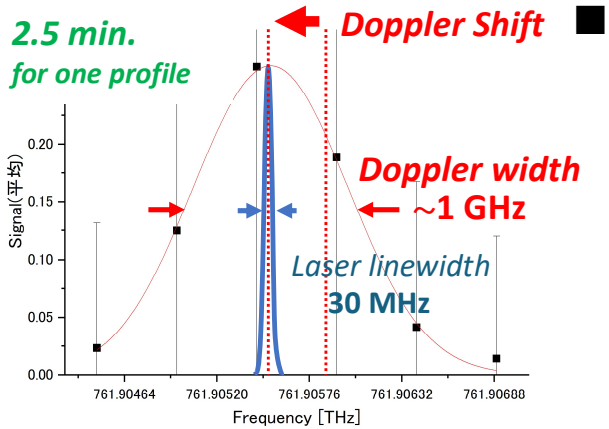
Call for collaboration





■ ***Simultaneous observation of Ca and Ca⁺ over an entire night***





■ ***Temperature and Velocity measurement of Ca and Ca⁺***