



**COLORADO SCHOOL OF
MINES**

Introduction to Distributed Strain Sensing

Ge Jin, Colorado School of Mines

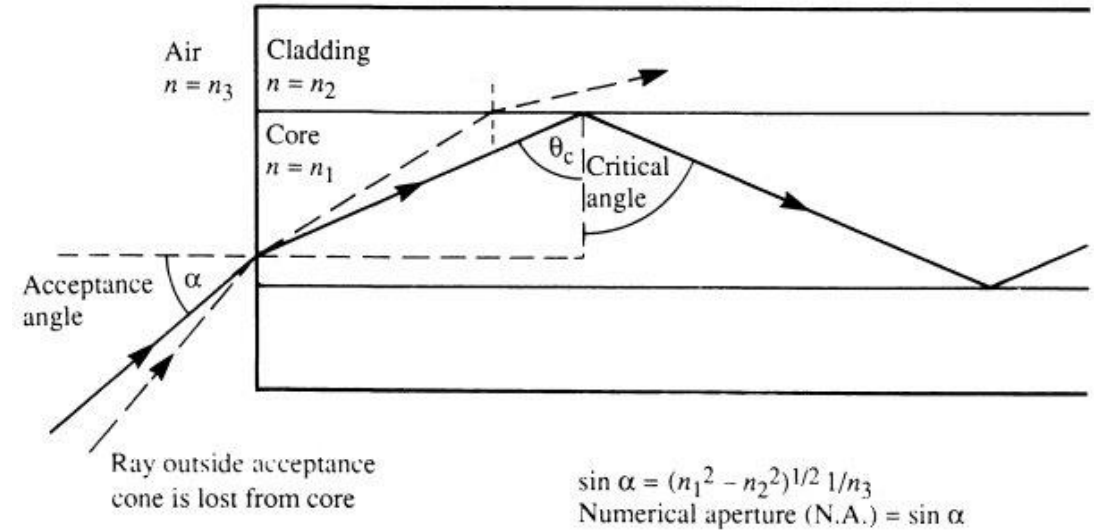
Outline

- Fundamentals of Distributed Fiber Optic Sensing
- DSS Measurements
- Live Demo



**COLORADO SCHOOL OF
MINES**

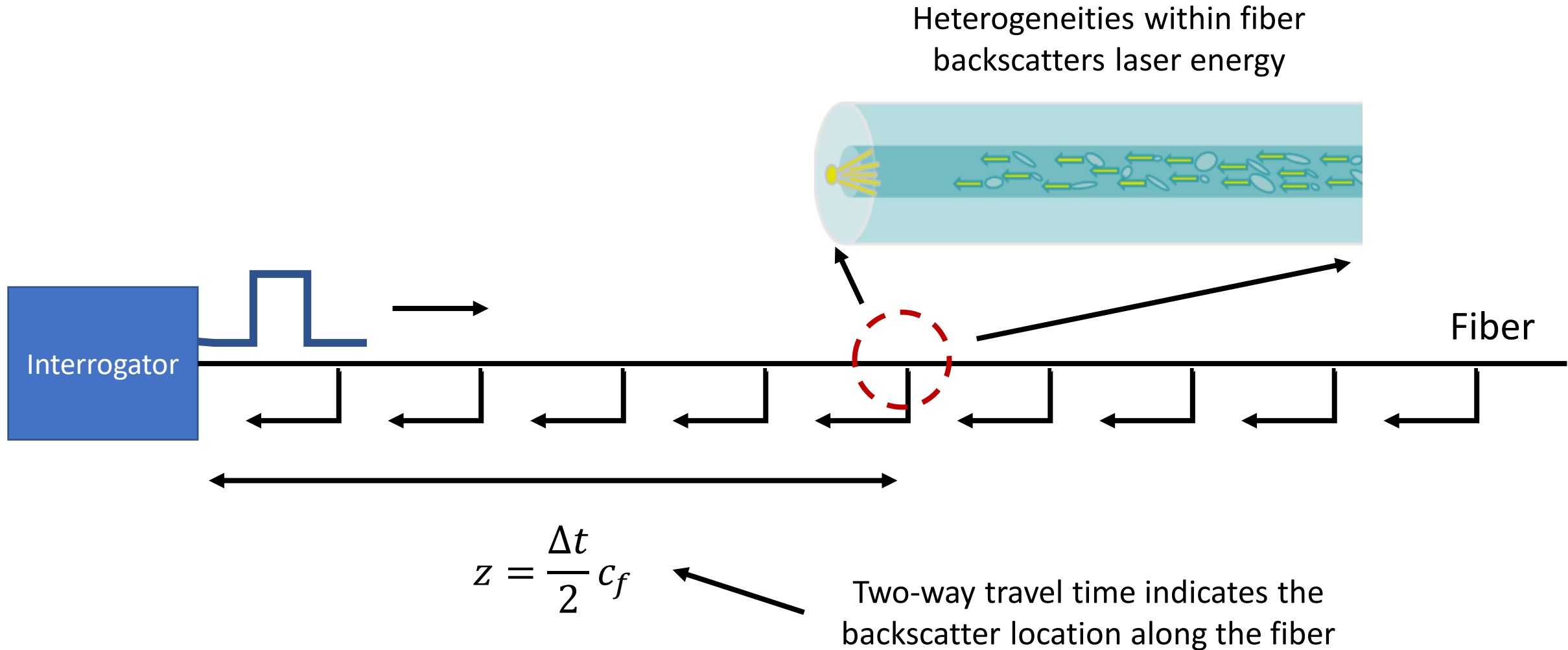
Optical Fiber

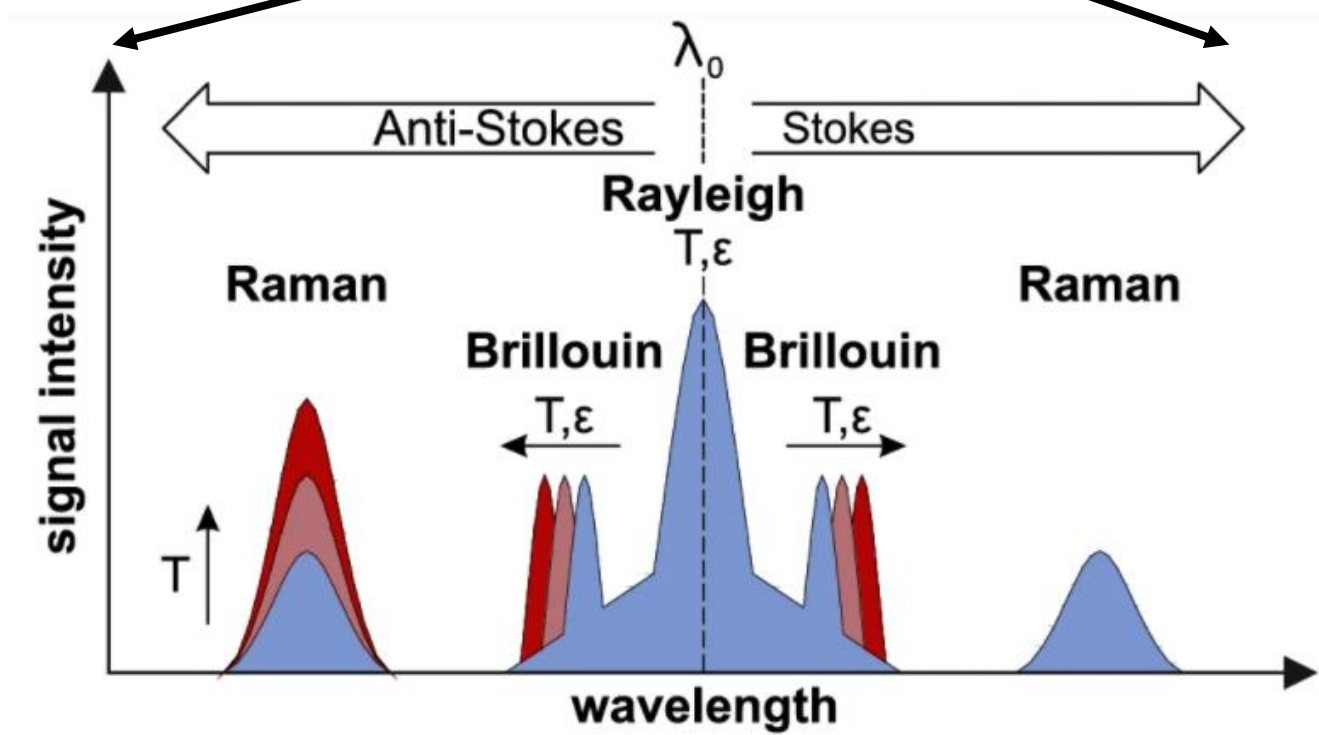
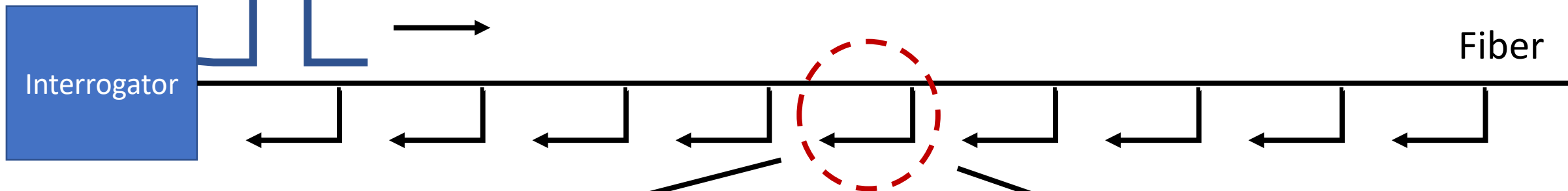


Optical fiber serves as a waveguide that can propagate laser pulses over kilometers with minimum energy loss.

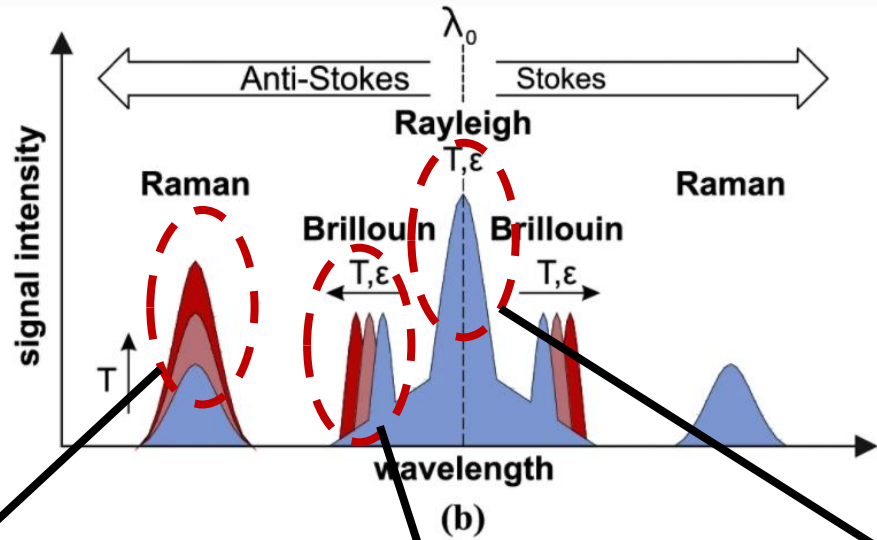
<https://www.cnet.com/home/internet/best-fiber-internet/>

Principles of DFOS





(b)



DAS: Distributed Acoustic Sensing
DTS: Distributed Temperature Sensing
DSS: Distributed Strain Sensing

DTS

DSS

DAS
&
DSS

Four Types of DSS

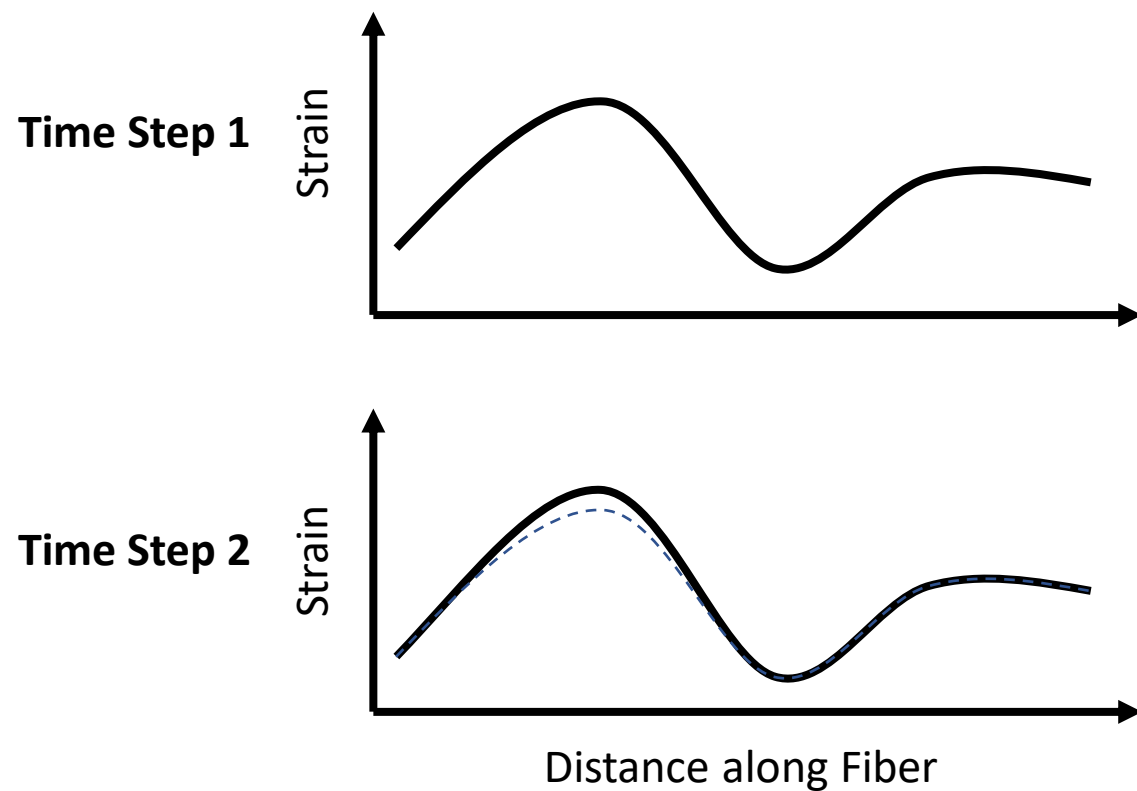


- Rayleigh Intensity Pattern Based DSS (Rayleigh Frequency Shift)
- Low-frequency DAS
- Brillouin-base DSS
- Fiber Bragg Grating based DSS

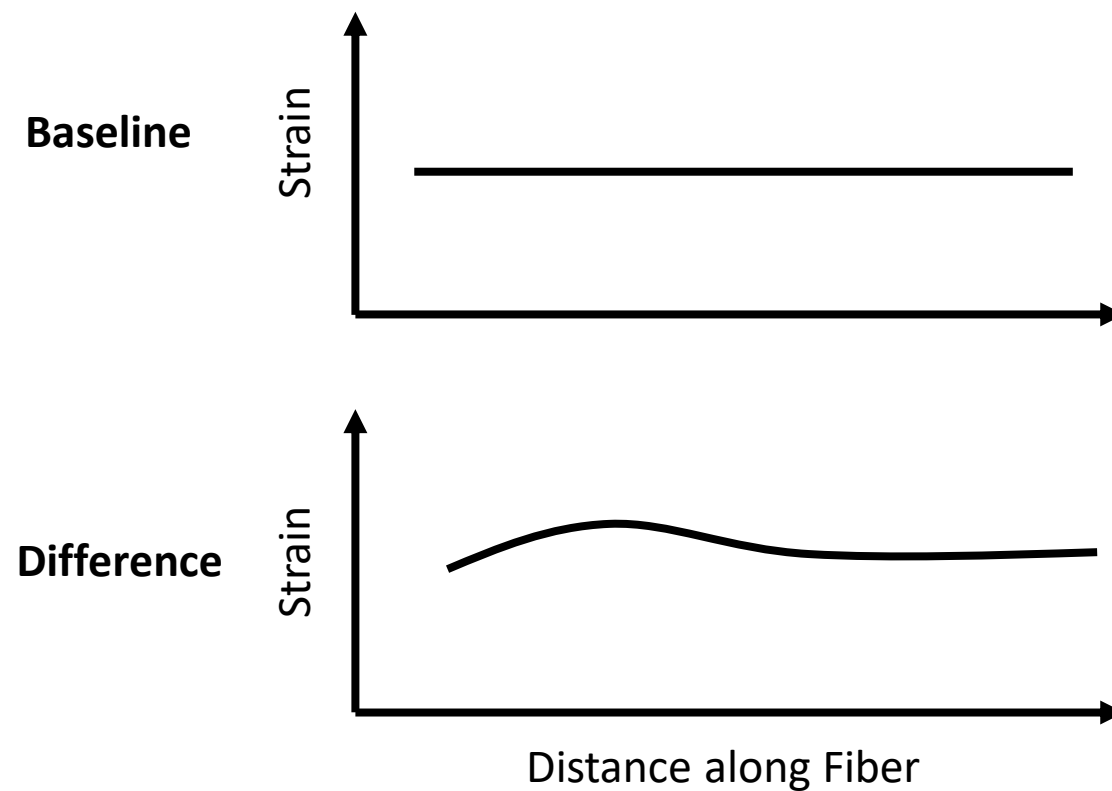
Type	Brillouin	Rayleigh Intensity	Low-frequency DAS	w-FBG
Spatial resolution	0.2 m	0.2 m	1-5 m	0.02 m
Temporal resolution	1-5 mins	6s - 5 mins	< 1 s	Seconds
Strain Sensitivity ($\mu\epsilon$)	25	<1	<1	<1
Environment noise resistant	Fair	Poor	Best	Fair
Measurement Type	Absolute	Change	Rate	Change
Range	~10 km	~10 km	~10 km	200 m
Long-term monitoring	Y	Y	N	Y



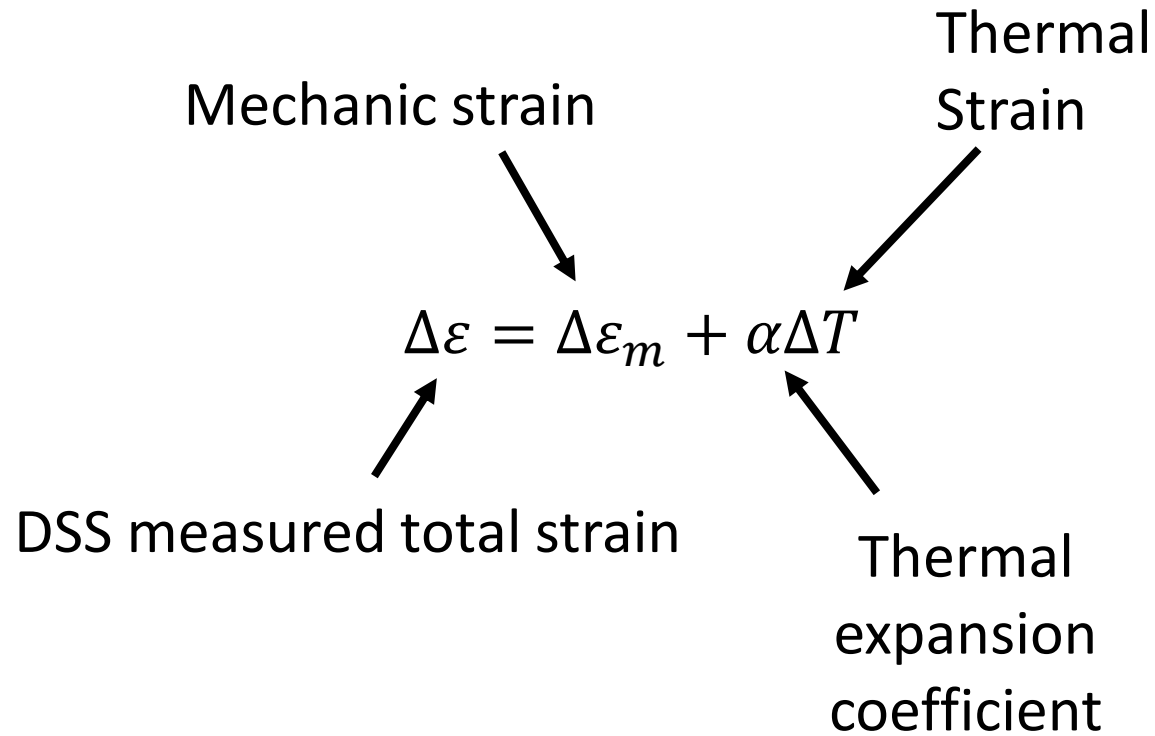
Absolute Measurements



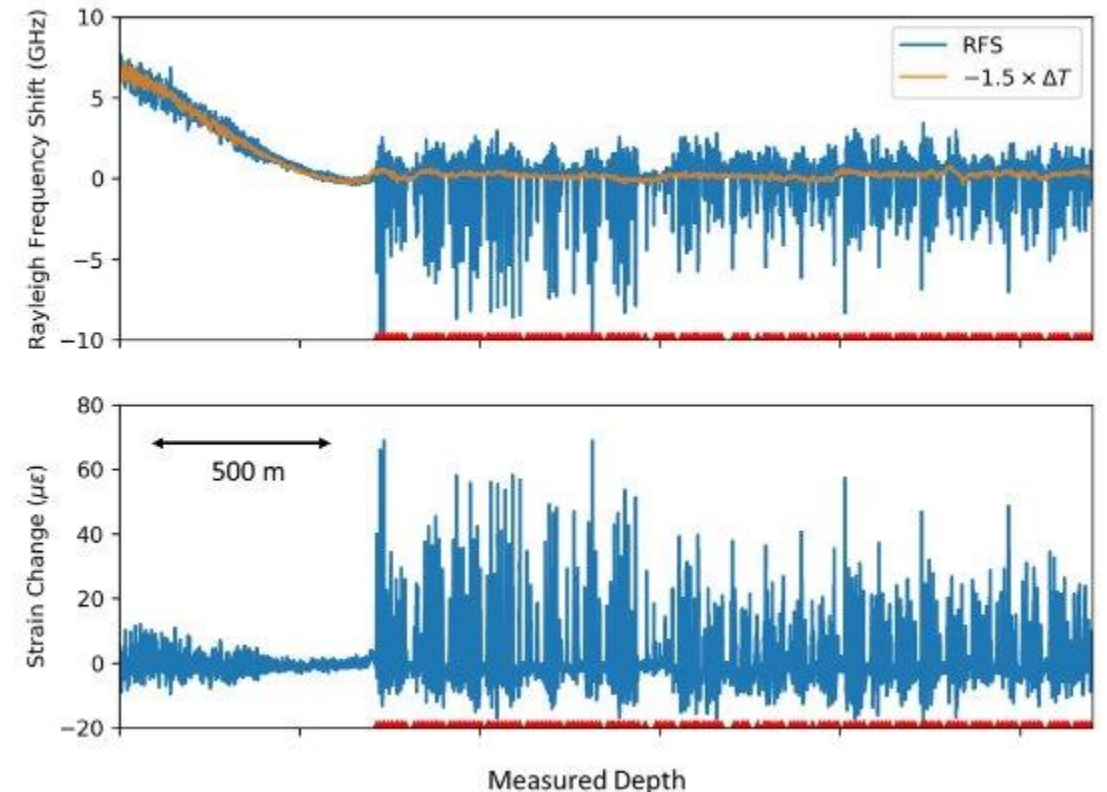
Change Measurements



Temperature and strain sensitivity



ΔT can be measured independently using DTS



DFOS Data Format



Temporal interval



Spatial interval



Distance Along Fiber (m)	06/23/2024 00:00:01.000	06/23/2024 00:01:00.000	06/23/2024 00:01:59.000	06/23/2024 00:02:58.000	06/23/2024 00:03:57.000	06/23/2024 00:04:56.000	06/23/2024 00:05:55.000	06/23/2024 00:06:54.000	06/23/2024 00:07:53.000
0.5	-1.218	2.673	-2.636	-0.084	3.521	3.182	-0.092	-3.575	-2.706
1	3.831	-3.332	-4.796	1.748	3.028	3.194	-3.753	-0.057	3.376
1.5	-4.979	-3.468	1.180	4.650	0.894	-1.039	-3.851	-2.812	0.089
2	-2.389	-0.187	-2.782	-1.545	2.749	-4.299	-2.389	-0.374	-3.634
2.5	-1.395	-2.267	-4.881	1.580	-4.728	-3.616	-0.268	-0.002	-0.633
3	0.205	3.124	-4.803	2.163	-2.012	3.243	-0.271	-4.267	-2.403
3.5	-2.690	-0.622	-0.027	-4.146	-4.903	-2.720	-3.780	-4.334	1.499
...
6732.5	2.159	2.385	-0.232	4.496	0.927	3.256	-3.675	-2.962	-0.891

Measurement range (fiber length)

Measurement value

DFOS Four Key Criteria



**COLORADO SCHOOL OF
MINES**

- Measurement resolution
- Spatial resolution
- Measurement range
- Measurement time (temporal resolution)

Measurement range

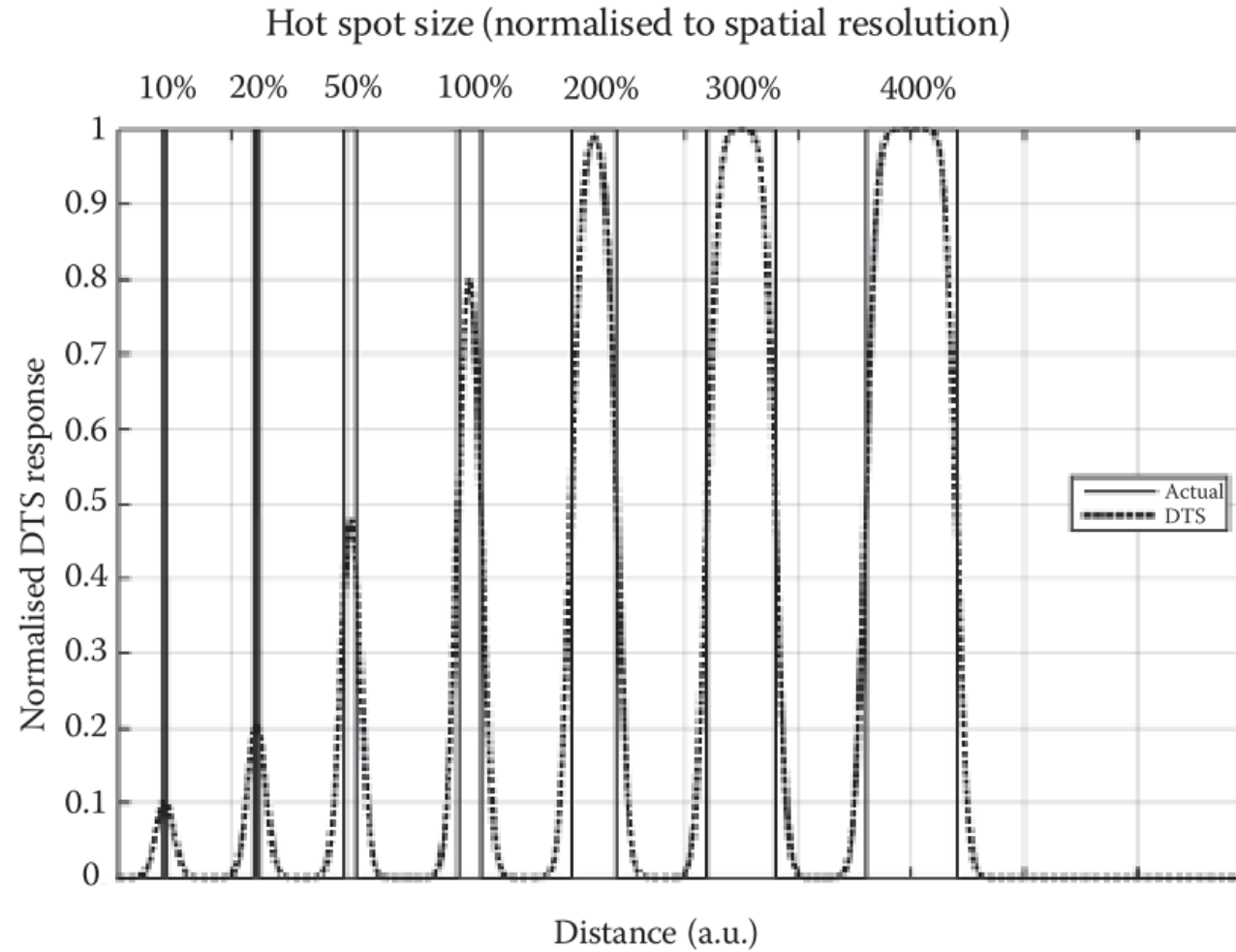


10 km



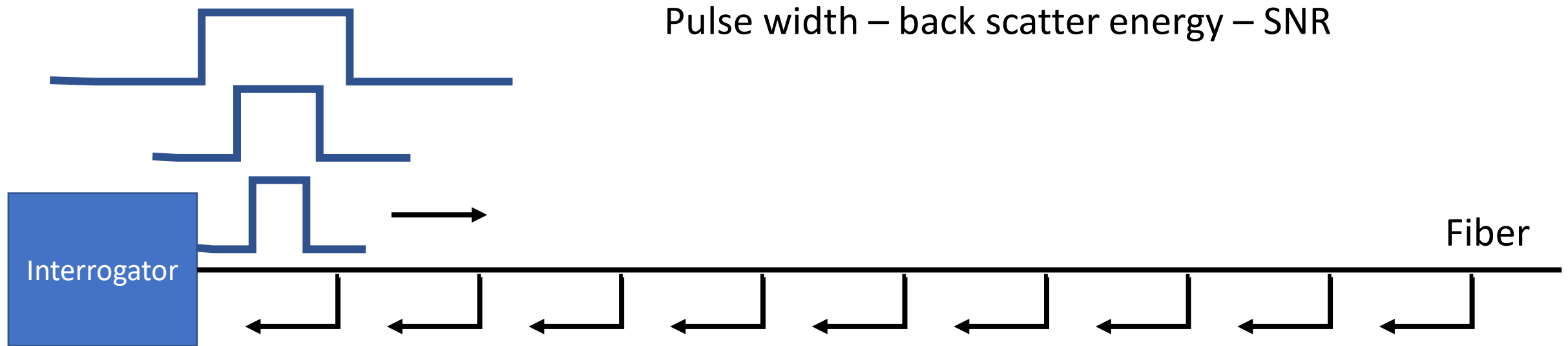
5 km

Spatial resolution



Hartog, 2017

Different pulse width (time)

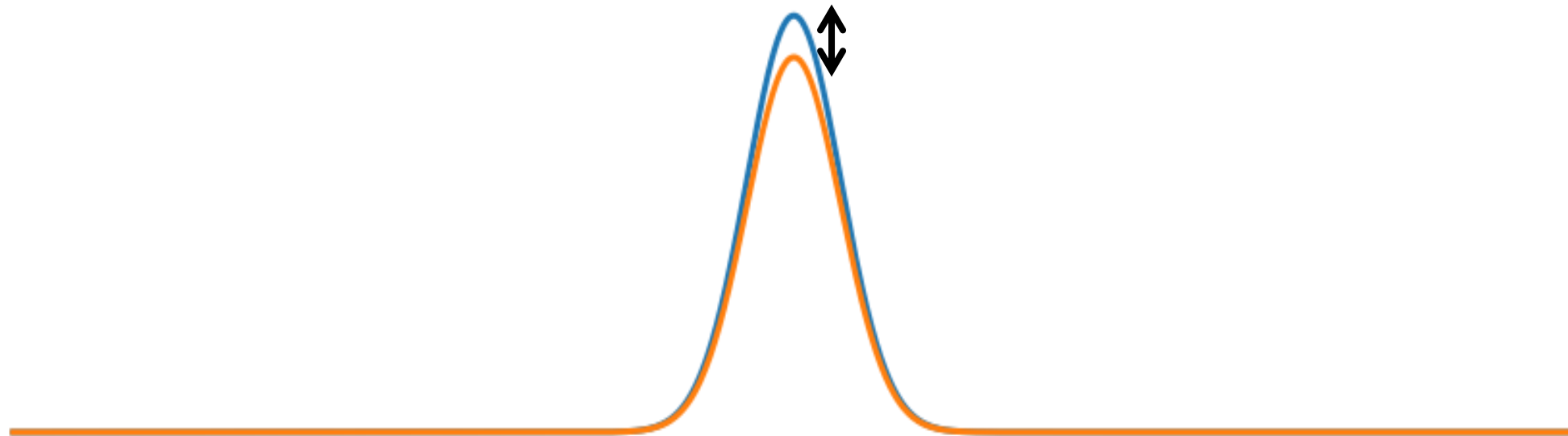


Measurement time

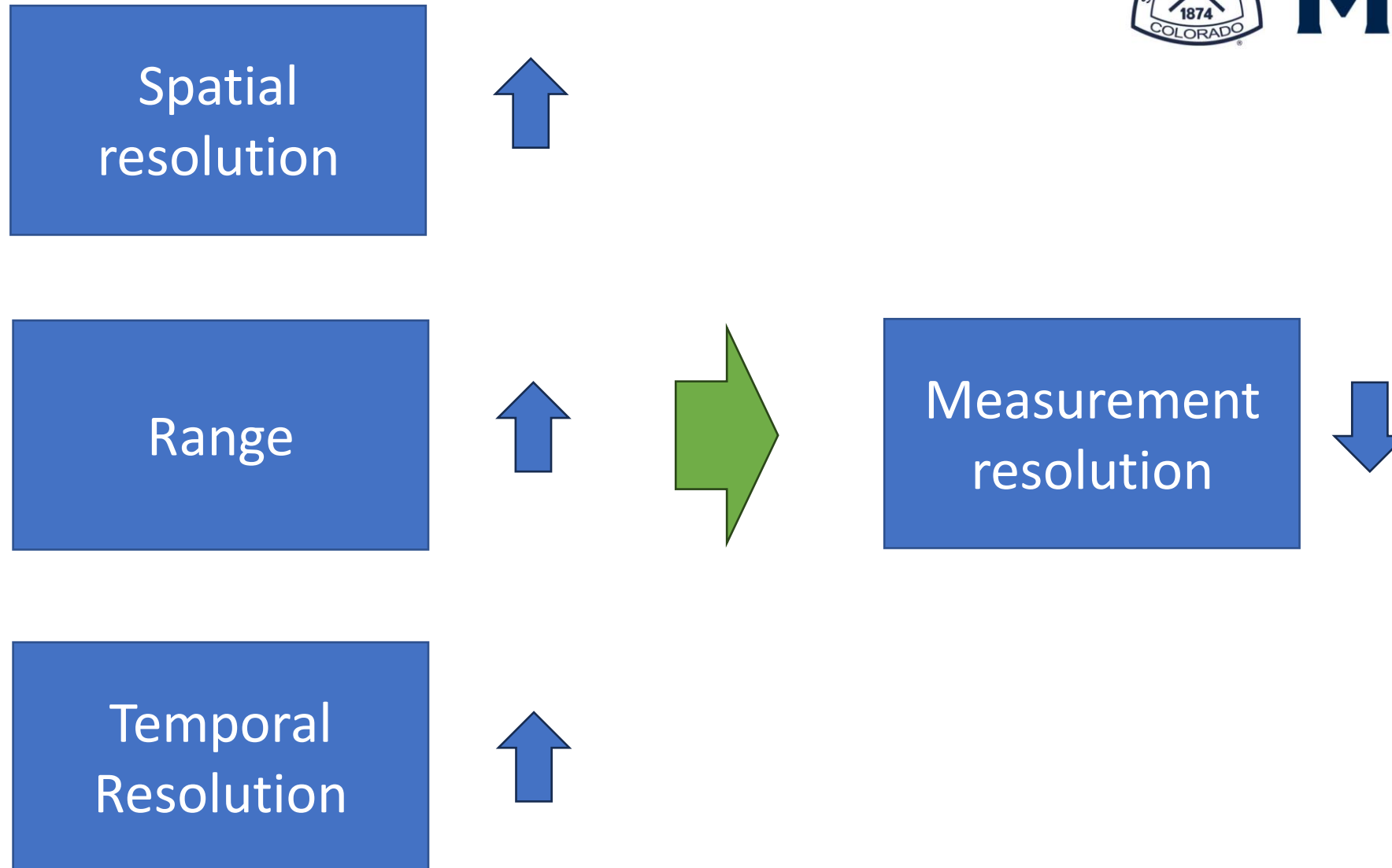


- Some measurements, especially DTS and DSS, requires averaging the results from millions of laser pulses to obtain a reliable results.
- The time taken by the system to acquire the readings for all points in the sensing fiber to the required measurand resolution.
- Temporal resolution = $1/\text{measurement time}$

Measurement Resolution



Resolution \approx Sensitivity \neq Accuracy



ODiSI Short-range DSS System



ODiSI SYSTEM

ODiSI controller with the ODiSI application software (Linux OS)



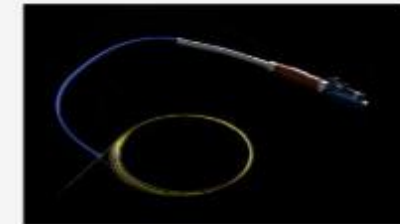
ODiSI mainframe
(1, 2, 4 or 8 channels)



Rugged standoff cables
(for each channel)



Remote modules -
interface to sensor



Fiber optic sensors

- High-definition strain
- High-definition temperature
- Strain-compensated temperature
- Continuous fiber grating (CFG) sensors

Strain Change Measurement



Multichannel sensor plot (strain/temperature versus length) in the ODiSI software.

ODiSI Data Sheet



High-Definition (HD) and Continuous Fiber Grating (CFG) Modes						
		High Definition (Rayleigh) Sensors				
Gage pitch ⁵		0.65 mm	1.3 mm	2.6 mm	5.2 mm	
Gages (measurement locations) per meter of sensor		1,538	768	384	192	
ODiSI System Compatibility	ODiSI 610x	√	√	√	√	-
	ODiSI 600x	-	-	-	-	√
Measurement rates for (Rates are aggregate; divide by number of active channels to determine the per-channel rate)	2.5 m mode	62.5 Hz	125 Hz	250 Hz	250 Hz	30 Hz
	5 m mode	40 Hz	80 Hz	160 Hz	160 Hz	20 Hz
	10 m mode	25 Hz	50 Hz	100 Hz	100 Hz	12.5 Hz
	20 m mode	12.5 Hz	25 Hz	50 Hz	50 Hz	6.3 Hz
	50 m mode	-	10 Hz	20 Hz	20 Hz	2.5 Hz
	100 m mode	-	-	10 Hz	10 Hz	1 Hz
Strain measurement range		±15,000 µε				
Resolution		0.1 µε				
Instrument accuracy		±1 µε				
System (instrument and sensor) accuracy ⁶		±25 µε	±30 µε	±30 µε	±30 µε	±30 µε
Measurement uncertainty ⁷		±5 µε	±4 µε	±2 µε	±2 µε	±2 µε
Dynamic loading rate		1 Hz	2.5 Hz	5 Hz	5 Hz	5 Hz
Temperature measurement range ⁸		-40 to 200 °C (with standard Luna senso				
Temperature measurement resolution		0.1 °C				
Temperature measurement uncertainty ⁷		±2.2 °C	±1.6 °C	±0.6 °C	±0.6 °C	±0.6 °C