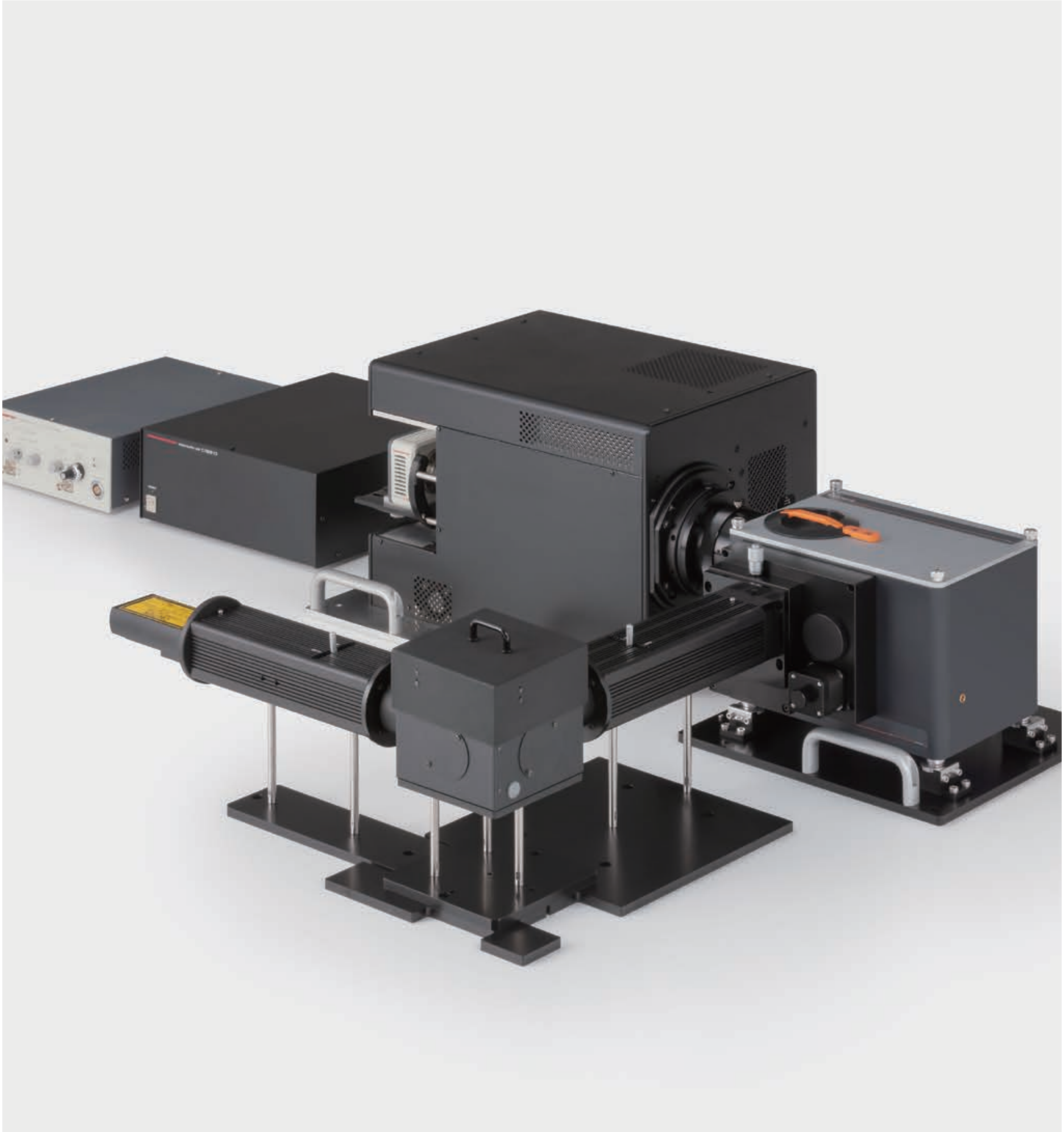
Picosecond fluorescence lifetime measurement streak camera

Captures fluorescence phenomena with 800 fs temporal resolution using 2D photon counting method.
Enables simultaneous fluorescence lifetime analysis and time-resolved spectrophotometry.



HAMAMATSU

PHOTON IS OUR BUSINESS

Directly captures temporal variations of laser-excited fluorescence with 800 fs resolution.

Photoluminescence which is represented by fluorescence, phosphorescence, or delayed fluorescence is one of the energy release processes to be observed when molecules return from the excited state to the ground state.
Measurement of photoluminescence decay with an ultra-fast pulsed excitation light is generally called as fluorescence lifetime measurement and studied to reveal various dynamics of excited molecules.
Recently, development of various kinds of materials such as organic/inorganic phosphors, compound semiconductors, and quantum dots are getting more prosperous and are put into practical uses in the fields of the most advanced technologies such as OLED, LED, solar cell, and applied biology. The photoluminescence lifetime measurement is very important technique to improve the performance or efficiency of these materials.

The Hamamatsu Picosecond fluorescence lifetime measurement system has been developed in response to the requirements from researchers studying such materials. The streak camera, an optical time recorder with picosecond time response, makes it possible to study ultra-fast time-resolved spectrophotometry. The streak camera technology allows detection sensitivities in the photon counting region. For simultaneous measurement of time and wavelength, a spectrometer can be added to the system. The streak camera system is controlled by a designated software with high operation performance.

Applications

- **Study of initial stages of photophysics and photochemistry**
- **Study of microscopic environments and dynamic structures of surfaces and interfaces**
- **Study of dynamic structures of 2D molecular aggregates such as macromolecule film, LB film, liquid crystal, and deposition film**
- **Study of exciton dynamics and quantum size effect**
  (for example, semiconductor doped glass and quantum wire)
- **Time-resolved fluorescence and phosphorescence spectrum evaluation of organic LED materials**
- **Study of photonic crystals**
- **Study, evaluation, and inspection related to fluorescence lifetime measurements in various other fields**

Fluorescence phenomena at multiple wavelengths can be measured simultaneously.

Features

• 800 fs temporal resolution

The system uses a streak camera that can achieve a temporal resolution of 800 fs.

• Simultaneous multi-wavelength measurement

Time-resolved spectrum is acquired in a very short time since fluorescence lifetimes are measured over multiple wavelengths without scanning.

• Two-dimensional photon counting

Ultra-high sensitivity and simultaneous multiple-wavelength measurement capabilities are realized by the combination of photon counting and streak camera techniques. Since fluorescence phenomena at multiple wavelengths can be measured simultaneously, even very-low fluorescence can be detected and measured with high efficiency, which is not available with previous methods.

• A wide dynamic range better than 100 000:1

Measures very-low fluorescence with a dynamic range better than 100 000:1. This allows an analysis of multi-component fluorescence lifetime with high accuracy.

• Measures fluorescence lifetime with good S/N ratio with short integration time

The streak sweep can be synchronized with Mode lock laser in sweep range of 75 MHz to 165 MHz. Through integration of this high-speed repetitive sweep, measurement with a high S/N ratio can be carried out quickly.

• Covers fluorescence phenomena from picoseconds to milliseconds

Since the sweep time can be varied from 60 ps to 1 ms, a wide range of fluorescence lifetime measurements from picoseconds to milliseconds is possible. For higher temporal resolution, an universal streak camera is an option.

• Covers a wide wavelength range from UV to NIR

The streak cameras are available, with sensitive regions of 115 nm to 850 nm, 200 nm to 850 nm, 200 nm to 900 nm, 280 nm to 920 nm and 300 nm to 1600 nm.

• High-precision measurement due to a temperature controlled picosecond laser diode

As an excitation light source, picosecond laser diodes are available. Other types of lasers can also be used.

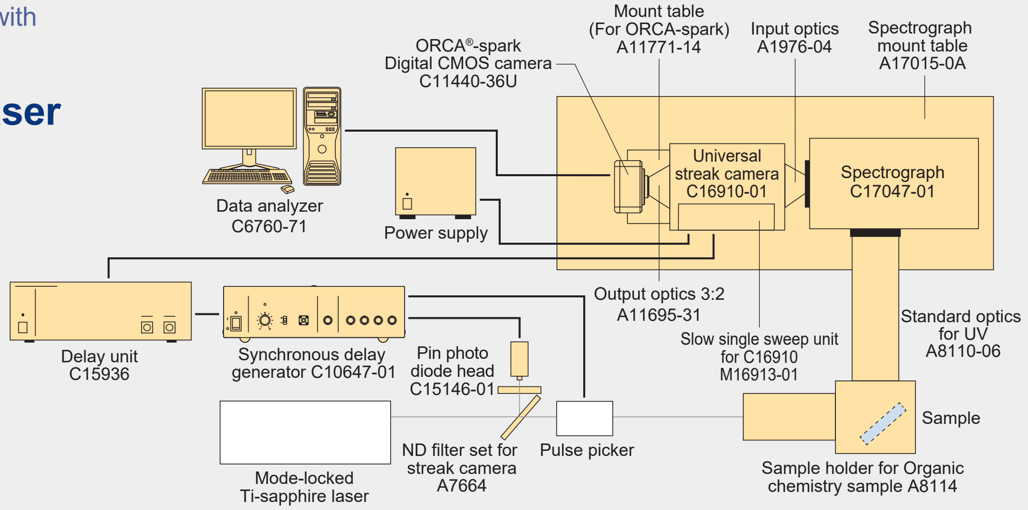
• Standard optical system allows easy optical alignment

Flexible system configuration supports various types of fluorescence phenomena

System configuration

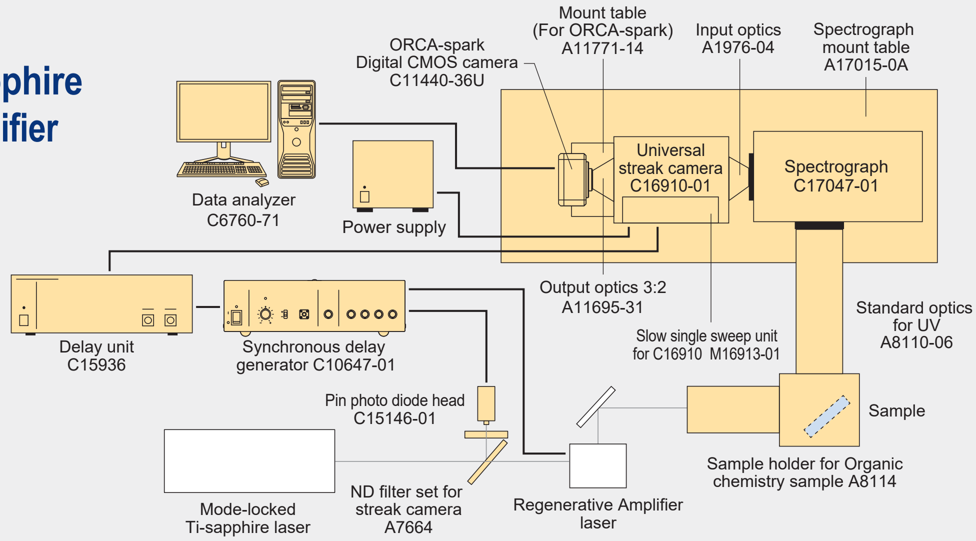
Example when used with

Mode-locked Ti-sapphire laser



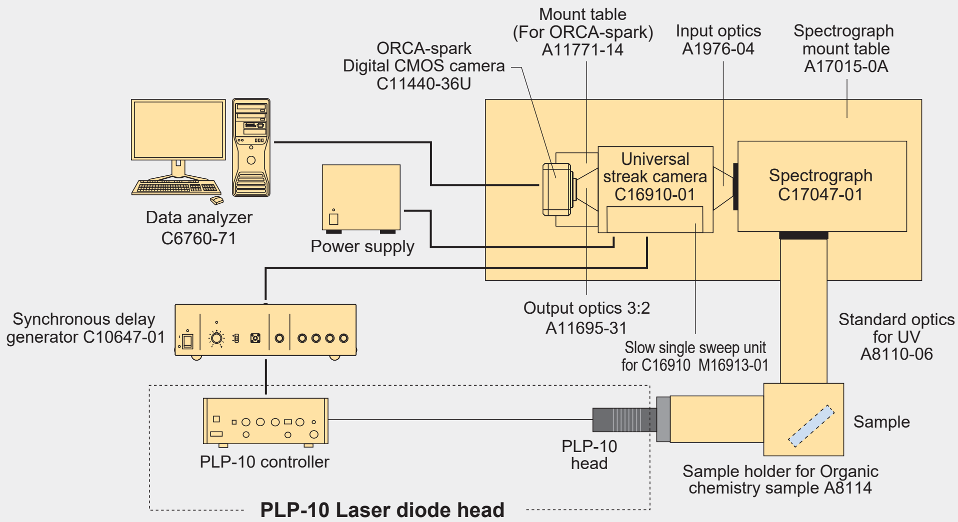
Example when used with

Mode-locked Ti-sapphire + Regenerative Amplifier laser



Example when used with

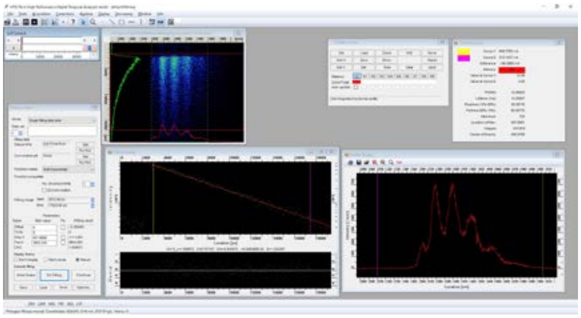
PLP-10 Laser diode head



Fluorescence lifetime measurement software with enhanced functions

Fluorescence lifetime measurement software

Measurement screen



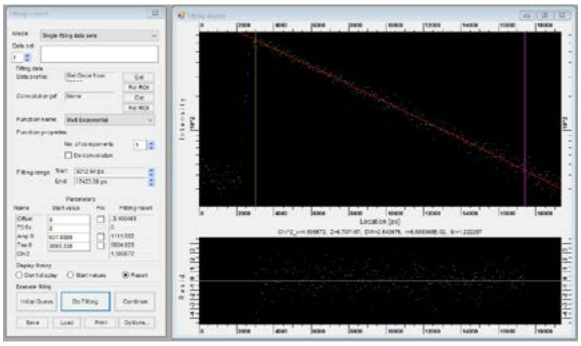
- **Controls a streak camera, a spectrograph, and a delay generator from a PC**

  The streak camera, spectrograph, and delay generator control windows are displayed on the PC monitor, which make it easy to change measurement parameters such as time scales and monitor wavelength selection. The “Auto delay” function eliminates the need to adjust the timing for each time scale for each scale change.

- **Real-time display of time profiles and spectrum**

  Time profiles or spectrum are displayed on the monitor screen in real-time. This is a useful function for selecting the time scale during measurement or determining the analysis data range.

Lifetime analysis



- **Multi-component analysis**

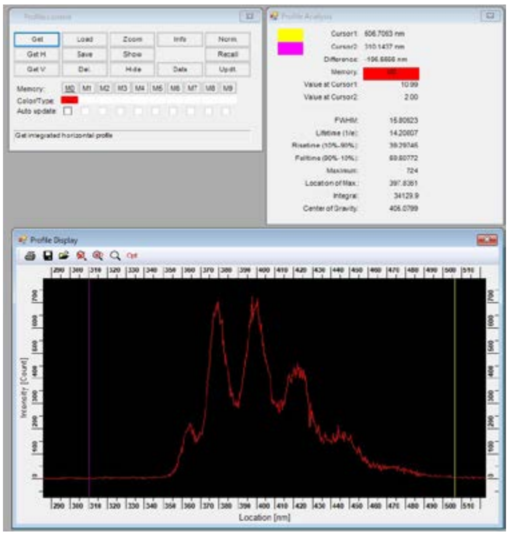
- **Multiple data analysis on the same screen**

  Calculated fluorescence lifetime values are also displayed on the same screen for easy comparison analysis.

- **Highly accurate analysis by deconvolution**

  Deconvolution processing enables fluorescence lifetime analysis with high accuracy. When analyzing longer lifetime components such as phosphorescence, the “Tail Fit” function can be used instead of deconvolution processing.

Profile analysis



- **Time-resolved spectrum display**

  Allows time-resolved spectrum display the greatest feature offered by streak camera systems.

- **Spectrum and fluorescence decay curve display**

  Displays the full width at half maximum (FWHM), peak position and peak intensity for each profile.

- **Multiple data loading and comparison on the same screen**

  Normalized processing allows for easy comparison of multiple data.

The streak camera enables time-resolved photon counting at multiple wavelengths in a single measurement.

Operating principle, functions, and performance

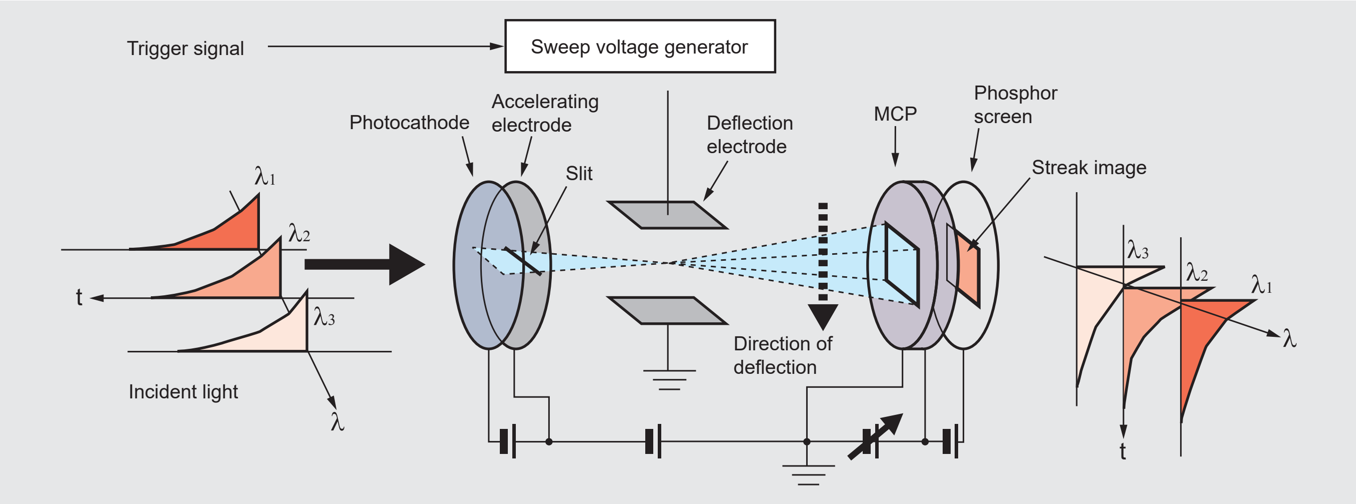


Figure 1: Operating principle of the streak camera

1. Principle of streak method

This section explains the principle and features of fluorescence lifetime measurements using the streak camera. (In the following description, this method is simply called the “streak method”).

The heart of the streak camera is an electron tube called the “streak tube”. Figure 1 shows the operating principle of a streak tube. When fluorescence pulses enter the photocathode, they are converted into photoelectrons in proportion to the number of incident photons. Being accelerated by the accelerating electrode, these photoelectrons pass through a pair of deflection plates. At the instant they pass through the deflection plates, a high-speed sweep voltage is applied to the deflection plates so that the photoelectrons' trajectories are swept from top to bottom.

The swept photoelectrons are then multiplied in the microchannel plate (MCP) by a factor of 10^4, and reconverted into an optical image by the phosphor screen. The optical image produced on the phosphor screen is called the “streak image”. In this way, time is converted into the spatial axis (vertical axis): thus, the time in which the photons reached the photocathode and the intensity can be determined by the position and luminance of the streak image. In addition, because the position information in the horizontal direction on the photocathode is contained in the horizontal direction of the streak image, if a spectrograph is used to focus a spectrum onto the photocathode, a streak image can be obtained in which the vertical axis serves as the time axis and the horizontal axis as the wavelength axis, and in which the luminance is proportional to the intensity on the phosphor screen.

The streak images thus obtained are read out by a CMOS camera coupled to the streak tube. To perform data measurement with a high S/N ratio, the read-out streak images are integrated in a memory of computer. In this case, there are two methods of integration: 1) the analog integration method, in which the output signal from the CMOS camera is directly integrated to create an image, and 2) the photon counting method, in which the signal is separated from noise by setting a threshold level, and only the signal is integrated. (See Section 2.) By using these two methods properly, a wide variety of fluorescence intensity can be measured, ranging from extremely weak fluorescence, for example, in cases where only one photon is detected as a result of hundreds of excitations, to bright fluorescence which is visible to the human eye.

The above figure shows the principle how intensity profiles are extracted from a time-resolved spectrum image. After the full spectrum has been recorded, the fluorescence decay curves can be extracted at arbitrary wavelength bands by just placing vertical sampling windows at the desired positions. Alternatively, by using horizontal windows, it would also be possible to extract spectral profiles at various time positions and “gate” lengths.

2. Principle of photon counting method using streak camera

The photoelectrons emitted from the photocathode of the streak tube are multiplied by the MCP with a high gain. One photoelectron can be observed as one light spot produced on the phosphor screen.

This photoelectron image is read out by a CMOS camera, and then undergoes digitization. Since the noise level of the CMOS camera is exceptionally low, the photoelectron image can be clearly separated from the noise by setting a threshold level. Figure 2 shows this threshold level setting.

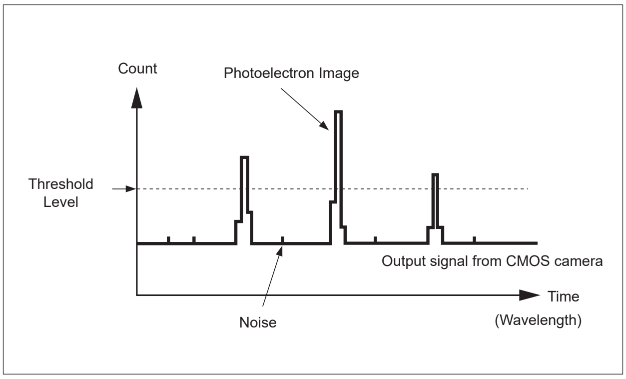


Figure 2: Separating the photoelectron image from noise

With the threshold set at an appropriate level, detecting the position of the photoelectron image and integrating it in the memory allow data measurement with a high S/N ratio, wide dynamic range. Moreover, this photon counting method is carried out over the entire surface of the 2 dimensional streak image, enabling photon counting measurement to be made at simultaneous multiple wavelengths. Also, even if multiple photo-electrons are produced by one excitation, they can be counted. Consequently, in the case of time-resolved spectrophotometry, the streak method offers high-sensitivity measurement which is two orders of magnitude higher than the conventional time-correlated single photon counting method requiring a wavelength scan in a spectrograph for wavelength isolation.

3. Functions of the streak camera

The streak method offers the following features:

- **High temporal resolution**
- **Wide dynamic range and high S/N ratio due to photon counting integration**
- **Simultaneous multiple-wavelength measurement for fluorescence lifetime analysis and time-resolved spectrophotometry**

[High temporal resolution]

Conventional time-correlated single photon counting methods using a photomultiplier tube have proven inadequate in fluorescence lifetime measurement and rise-time analysis in the order of sub-nanoseconds, because temporal resolution is limited to about 1 ns and the signal waveform may be distorted by the TTS (photoelectron transit time spread) of the photomultiplier. The universal streak camera C16910 used with the streak method has a superior temporal resolution of better than 800 fs, and furthermore, it is free of waveform distortion. (Figure 3 shows the device function of the universal streak camera C16910.) As seen from the figure, the device function is negligibly small. Therefore, the streak method is capable of fluorescence lifetime measurement and rise-time analysis from several picoseconds to nanoseconds with high accuracy, both of which have been difficult with conventional methods. The streak sweep time is switchable between 60 ps and 1 ms full scale, allowing a wide range of fluorescence analysis from picoseconds to milliseconds.

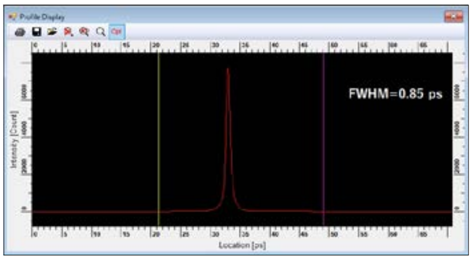


Figure 3: Device function of the universal streak camera C16910

[Wide dynamic range and S/N ratio due to photon counting]

In addition to high temporal resolution, the universal streak camera features high sensitivity and a wide dynamic range.

In photon counting integration, a major factor that determines the detection limit of the light level is the dark current (noise) of the photocathode. The photocathode dark current of the C16910 is smaller than that of the photomultiplier tube used in the conventional time-correlated single photon counting method by 3 orders of magnitude: thus, the streak method offers a high S/N ratio in measuring even very low fluorescence. Also, low dark current assures a low noise level, thereby easily achieving a wide dynamic range better than 100 000:1. This enables multi-component fluorescence lifetime analysis to be made with high accuracy. On the other hand, in cases where fluorescence intensity is so high that it may saturate in the photon counting method, the C16910 can be switched from the photon counting integration method mode to the analog integration mode, making possible highly efficient measurement without reducing the signal light level. Consequently, the C16910 is the most ideal device currently available in optical measurements.

[Simultaneous multiple-wavelength measurement]

As explained in the section on “Principle of streak method”, the combination of the C16910 with a spectrograph enables simultaneous multiple wavelength measurement to be made. In conventional time-correlated single photon counting, because simultaneous multiple-wavelength measurement is not possible, the wavelength range to be observed must be scanned for time-resolved spectrophotometry and multiple-wavelength fluorescence lifetime analysis. These measurements sometimes require several hours. As the universal streak camera C16910 is capable of simultaneous multiple-wavelength measurement without doing the wavelength scan in the spectrograph, it greatly reduces the time needed to obtain a time-resolved spectrum. In particular, this will prove dramatically effective when fluorescence is very low.

Measurement examples

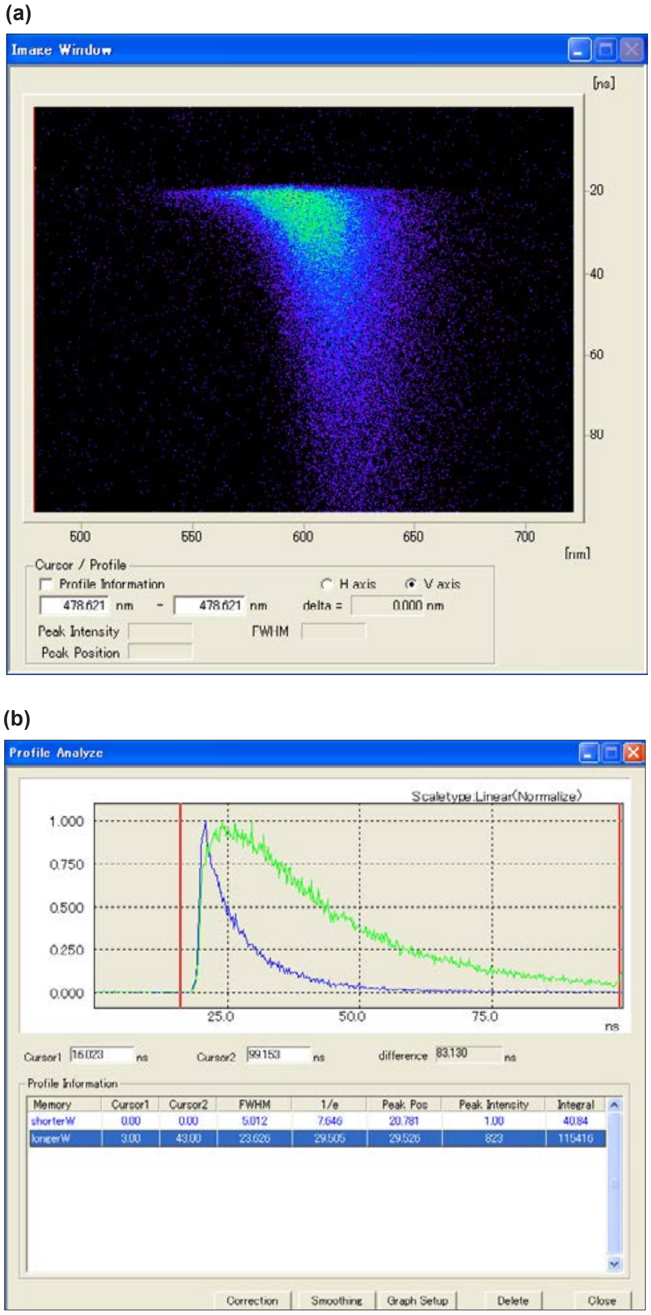


Figure 4: Colloidal quantum dots (CdSe/ZnS Core/Shell structure)
(a) Streak image of time-resolved luminescence spectra.
(b) Decay curves at different wavelength ranges.

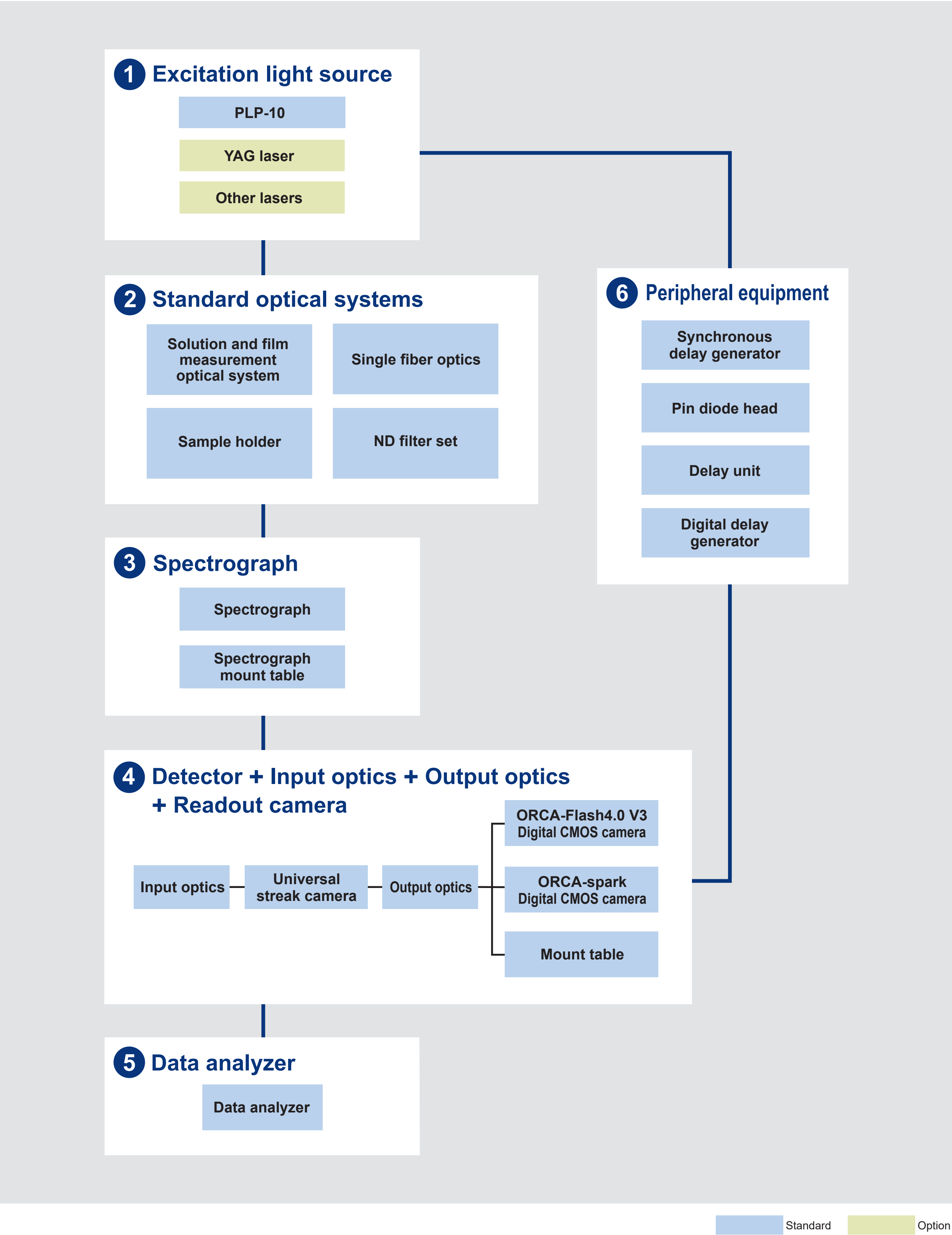
- The lifetime of QDs at different longer wavelength (600 nm to 670 nm) is longer than that of shorter wavelength (540 nm to 600 nm). The lifetime distribution does not correspond to the photoluminescence peak distribution.

  This novel material is expected to be applied for fluorescent material, LED material, single photon source, and bio-labeling. These results open the possibility to experimentally study the behavior of exciton dynamics of colloidal QDs including energy transfer between QDs.

  *Data produced by Professor Yong-Hoon Cho
  Nano-Bio-Photonics Laboratory, Dept. of Physics,
  Korea Advanced Institute of Science and Technology (KAIST), Korea

The optimum system can be tailored to your samples by selecting the excitation light source, optics, spectrograph, etc.

Configuration and specifications



1 Excitation light source

To excite a specimen, various pulsed light sources are provided.

● PLP-10 Laser diode head M10306

The PLP-10 is a picosecond light pulser using a temperature controlled laser diode. It is virtually maintenance-free and generates stable picosecond pulsed light over a long period of time.

Type	Laser diode (temperature-controlled)
Laser wavelength*	375 nm, 405 nm, 445 nm, 465 nm, 483 nm, 510 nm, 655 nm, 785 nm
Output pulse width	50 ps to 130 ps
Repetition rate	max. 100 MHz
Peak power (typ.)	50 mW to 600 mW (It depends on each laser head.)

* Select one wavelength from among these wavelengths.

● Other excitation light sources

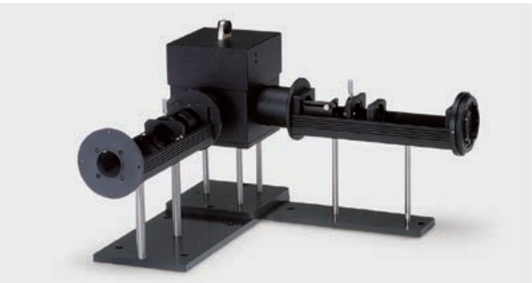
Besides the PLP-10 above, various types of excitation light sources can be used according to the specimens to be measured. These include a nitrogen-laser-pumped dye laser, semiconductor-laser-pumped Q-switched YAG laser, and mode-locked laser.

2 Standard optical systems

Various optical systems are available for solution and solid state specimens. Select from the list below the optical system that best matches the specimen of interest. Fiber optics and excitation light guide adapters for microscopes are also available. Please consult Hamamatsu should the specimen of interest require temperature control.

Type number	Product name
A8110-06	Standard optics for UV
A8112-02	Sample holder for Optistat DN cryostat
A8114	Sample holder for Organic chemistry sample
A7664	ND filter set for streak camera
A17058-01	Fiber adapter

Aside the above optical systems, we also design custom optical systems ideal for the specimens of interest. Your own optical systems can also be used.



▲ Standard optics for UV A8110-06 and Sample holder for Organic chemistry sample A8114

3 Spectrograph

● Spectrograph C17047-01

The C17047-01 is a Czerny-Turner type spectrograph with a focal length of 193 mm and an aperture of F/3.6. Due to the aberration-corrected optics, it is highly efficient in focusing light to the streak camera detector, enabling high-sensitivity measurements. More than twenty optional gratings are available for the C14047-01, and up to three gratings can be installed at one time. Grating and wavelength selection is controlled by the integrated streak camera software, in addition to the entrance slit width, for fine control of incident light.

Optical layout	Czerny-Turner type
Focal distance	193 mm
F value	3.6
Grating	2
Reciprocal dispersion	3.53 nm/mm

● Gratings (typical examples)

Type number	No. of grooves	Blaze wavelength	Measurement wavelength range	Resolution
A17048-005-060	50 L/mm	600 nm	Approx. 440 nm	Approx. 6.6 nm
A17048-010-078	100 L/mm	780 nm	Approx. 220 nm	Approx. 3.3 nm
A17048-015-050	150 L/mm	500 nm	Approx. 140 nm	Approx. 2.1 nm
A17048-030-050	300 L/mm	500 nm	Approx. 72 nm	Approx. 1.1 nm
A17048-060-050	600 L/mm	500 nm	Approx. 35 nm	Approx. 0.52 nm

● Filter wheel M17059-01
(Including 3 types of long pass filters)

● Turret for Andor spectrograph, Kymera-193i-A
A17057-01 (For C17047-01)

● Spectrograph mount table A17015-0A

The A17015-0A is a mount table for coupling the universal streak camera C16910 and the spectrograph f=193 mm C17047-01.

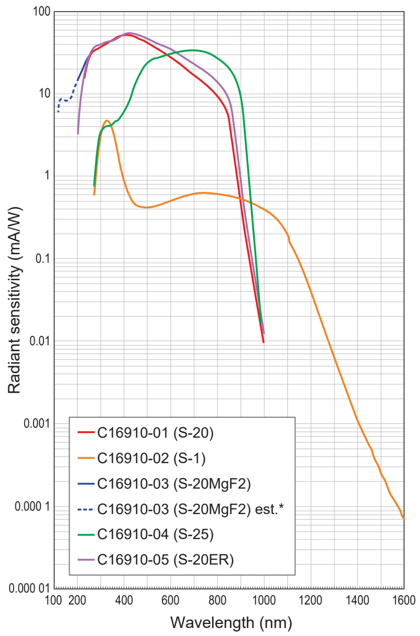
4 Detector, Input optics, Output optics, Readout camera

The system is an ultrafast optical detector - the universal streak camera C16910. It can capture very weak luminescence phenomena, from picoseconds to milliseconds, achieving very high signal-to-noise ratio within short measuring times due to its high repetition rates of up to 165 MHz. The spatial axis of the C16910 allows multichannel spectral measurement, making it the ideal detector for time-resolved spectroscopy. The system is completely remote-controlled from the data analyzer.

● Universal streak camera C16910

Spectral response	C16910-01	200 nm to 850 nm
	C16910-02	300 nm to 1600 nm
	C16910-03	115 nm to 850 nm
	C16910-04	280 nm to 920 nm
	C16910-05	200 nm to 900 nm
Temporal resolution		< 800 fs FWHM (fastest sweep range)
		< 20 ps FWHM (fastest sweep range)
Maximum repetition frequency		165 MHz (with Synchroscan unit)
		4 MHz (fastest sweep range)
Sweep time		60 ps, 200 ps, 600 ps, 1200 ps, 2083 ps (with Synchroscan unit : 80 MHz)
		1.2 ns, 2 ns, 5 ns, 10 ns, 20 ns, 50 ns, 100 ns, 200 ns, 500 ns, 1 μs, 2 μs, 5 μs, 10 μs, 20 μs, 50 μs, 100 μs, 200 μs, 500 μs, 1 ms

< Spectral response of the streak tube (typ.) >



*Estimated values below 200 nm

< A typical example of temporal resolution (FWHM) >

The values were measured at the wavelength of 800 nm and at the center of a photoelectric surface. These do not include jitter of a light source.

Main unit / Sweep unit	C16910-01 S-20	C16910-02 S-1	C16910-03 S-20MgF2	C16910-04 S-25	C16910-05 S-20ER
M16911-01	< 800 fs	< 1.5 ps	< 800 fs	< 4 ps	< 800 fs
M16911-03	< 2 ps			< 4 ps	< 2 ps
M16913-01	< 20 ps				

● ORCA-Flash4.0 V3 Digital CMOS camera C13440-20CU

Standard readout camera for streak camera applications with extremely low readout noise and high frame rate.

Effective number of pixels	2048 (H) × 2048 (V)
Pixel size	6.5 μm (H) × 6.5 μm (V)
Effective area	13.312 mm (H) × 13.312 mm (V)
Number of pixels on working area	1280 (H) × 968 (V)
Working area on phosphor screen	12.48 mm (H) × 9.44 mm (V)
Exposure time	1 ms to 10 s (Standard scan internal trigger mode with full resolution)
Frame rate	100 frames/s, Standard scan (Full resolution, Camera Link)
Digital output	16 bit
Power supply	AC 100 V to AC 240 V, 50 Hz/60 Hz
Power consumption	Approx. 120 VA

● ORCA-spark Digital CMOS camera C11440-36U

Low cost model of readout camera. Balanced performance at readout noise and frame rate.

Effective number of pixels	1920 (H) × 1200 (V)
Pixel size	5.86 μm (H) × 5.86 μm (V)
Effective area	11.25 mm (H) × 7.03 mm (V)
Number of pixels on working area	1408 (H) × 1072 (V)
Working area on phosphor screen	12.39 mm (H) × 9.44 mm (V)
Exposure time	26.17 μs to 10 s (Standard scan internal trigger mode with full resolution)
Frame rate	64.9 frames/s (Full resolution, Camera Link)
Digital output	12 bit
Power supply	DC +12 V
Power consumption	Approx. 20 VA

▲ ORCA-Flash4.0 V3 Digital CMOS camera C13440-20CU

▲ ORCA-spark Digital CMOS camera C11440-36U

● Input optics A1976-04

Spectral transmission	200 nm to 1600 nm
Effective F value	3.5
Slit width	0 mm to 5 mm
Slit width reading precision	5 μm
Overall length (excluding the fitting part)	103.2 mm

● Output optics 3:2 A11695-31

The A11695-31 is lens optics for coupling the universal streak camera C16910 and a readout camera.

Image multiplication ratio	3:2
Effective F value	2.0

● Mount table A11771

The A11771 is a mount table for coupling a readout camera for streak camera.

A11771-13	For C16910 + ORCA-Flash4.0 V3
A11771-14	For C16910 + ORCA-spark

5 Data analyzer C6760-70, -71

The dedicated software (U13313-02) controls the streak camera, spectrograph and peripheral units to perform fluorescence lifetime analysis. The software runs under Windows®. Fitting analysis enables 5 component analysis.

Control functions	● **Universal Streak camera C16910** Time axis setting Gain setting Shutter control ● **Spectrograph C17047-01** Center wavelength setting Grating selection
Data acquisition functions	Photon-counting integration (Peak Detection, Center of gravity)
	Analog integration
Correction and calibration functions	Time axis calibration (Calibrated prior to shipment)
	Wavelength calibration (Requires optional light source for calibration)
	Dark current correction
	Shading correction (Requires optional light source for calibration)
Data analysis functions	5 component exponential function analysis by fitting
	Profile analysis (wavelength axis, time axis)
Interface	Camera Link (C6760-70)
	USB 3.0 (C6760-71)

6 Peripheral equipment

● Synchronous delay generator C10647-01

When using a Ti-Sapphire laser in conjunction with a pulse picker, this unit generates low-jitter trigger signals synchronized with the laser repetition rate. Also, it is generated for to adjust performance timing of PLP-10 and streak camera.

● Trigger mode

INTERNAL mode, EXTERNAL mode, DUMP mode

● Input signal, output signal

Mode-lock IN	Input signal frequency	10 MHz to 200 MHz
	Input signal level	0 dBm to 15 dBm
	Impedance	50 Ω
TRIG.IN	Input signal frequency	0 Hz to 16 MHz
	Input signal level	+0.25 V to +3.3 V
	Impedance	50 Ω/High Z (10 kΩ)
OUTPUT A	Output signal level	2 V
	Impedance	50 Ω
OUTPUT B, C, D	Output signal level	2.5 V
	Impedance	50 Ω
Interface	RS-232C	

● Pin photo diode head C15146-01

The C15146-01 generates a low-jitter trigger signal when coupled with various lasers including passive mode-locked lasers. A specially designed circuit produces a highly stable trigger signal compatible with the universal streak camera C16910.

Optical Input signal frequency	74 MHz to 100 MHz
Recommended optical input level	Around 2.0 mW (averaging power)
Typical output signal level	About 2.0 V (peak to peak) (typ.) (50 Ω, optical input level 2.0 mW)

● Delay unit C15936

The C15936 is a passive delay unit, with zero jitter, used for fine tuning the trigger delay times to match the selected streak time.

Variable delay range	0 ns to 31.96 ns
Delay setting range	30 ps, 60 ps, 120 ps, 250 ps, 500 ps, 1 ns, 2 ns, 4 ns, 8 ns, 16 ns
Interface	USB 3.0

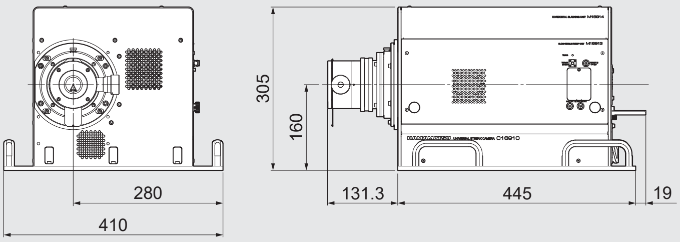
● Digital delay generator DG645 C13430-02

This is a general-purpose delay generator that matches the streak camera timing with the pulsed laser timing, mainly for slower streak times.

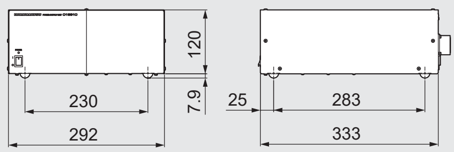
Number of output channels	4 ch (AB, CD, EF, GH output terminal)
Output level	0.5 V to 5.0 V 50 Ω
Variable delay range	0 ps to 2000 s
Delay resolution	5 ps
Internal delay time	85 ns
Repetition rate	Single to 10 MHz
Jitter	< 25 ps rms
Interface	GPIB / RS-232C

Dimensional outlines (Unit: mm)

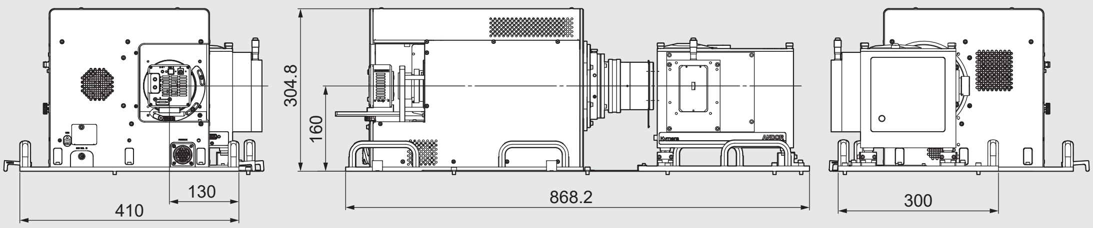
● **Universal streak camera C16910**
+ Input optics + Output optics + Slow single sweep unit + Horizontal blanking unit + Mount table
+ Readout camera ORCA-spark Digital CMOS camera C11440-36U (Approx. 28 kg)



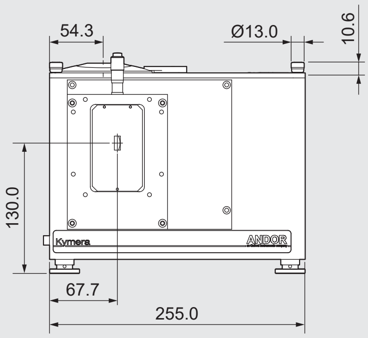
●Power supply (Approx. 6.1 kg)



● **Universal streak camera C16910**
+ Readout camera ORCA-spark Digital CMOS camera C11440-36U + Spectrograph + Spectrograph mount table (Approx. 50 kg)



● **Spectrograph C17047-01** f=193 mm (Approx. 7.5 kg)



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