Proof of the principle experiment of Machine Learning based online Characterization and Optimisation of a high intensity LAser pulse (ML-COLA)

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Outline

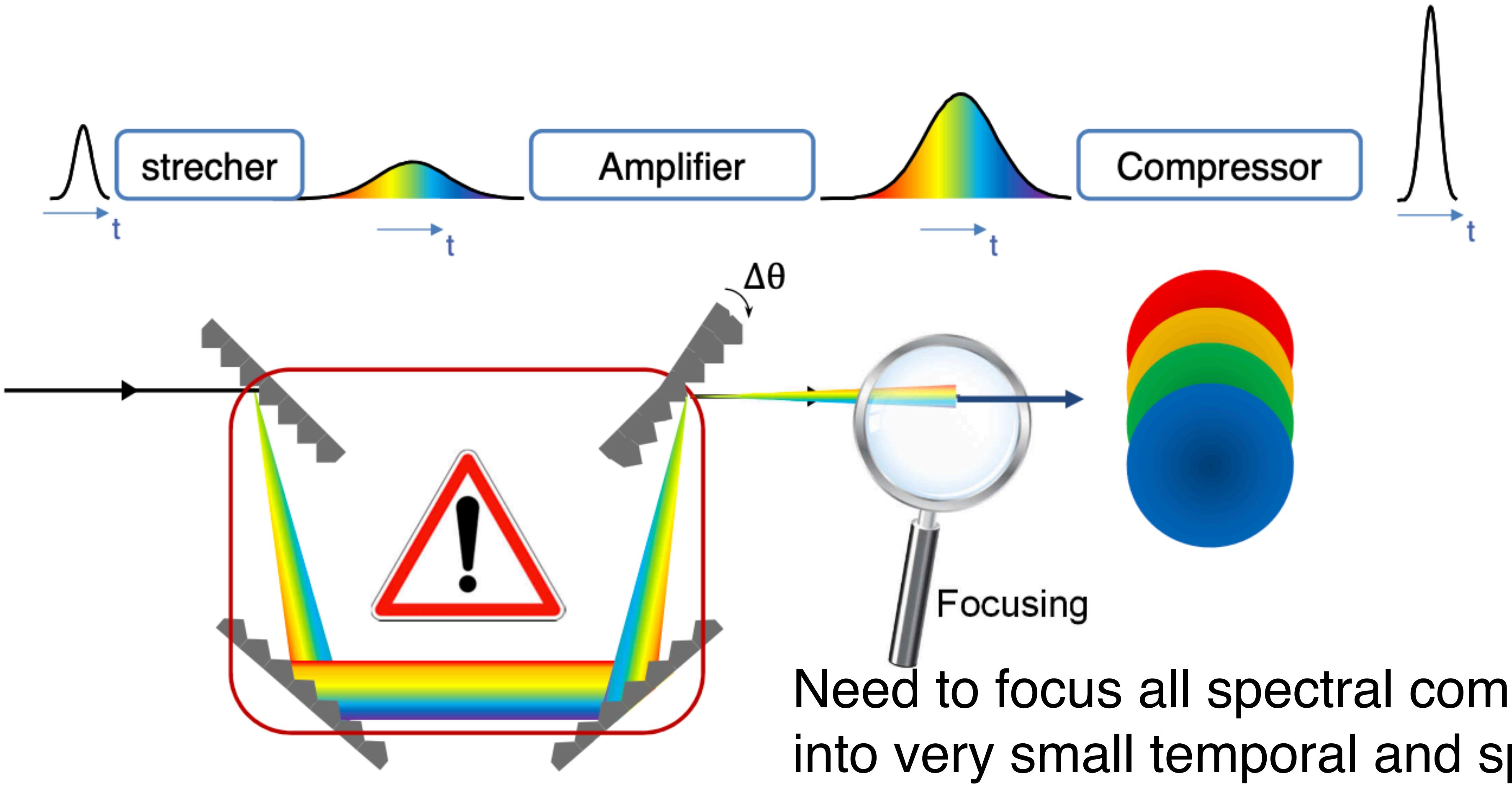
CPA technology

STC problems in the context of PALLAS

Multispectral camera

Next steps

CPA technology



D. Strickland & G. Mourou, *Optics communications*, *56*(3), 219-221 (1985).

Need to focus all spectral components of the pulse into very small temporal and spatial dimensions.

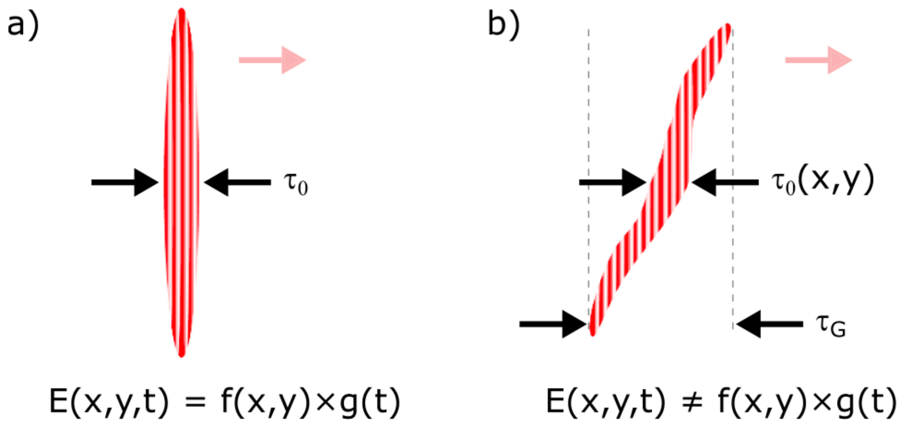
Requires: high level expert, advanced diagnostics and many adjustment iterations.

Source: Fabien Quere. Methods for characterisation of high-power femtosecond lasers

What is STC?

$$E(x,y,t) \neq f(x,y) \times g(t) \quad \forall \quad f(x,y), g(t).$$

One example of STC: pulse-front tilt



$$E_{1a} \propto e^{-r^2/w^2} e^{-t^2/\tau_0^2} e^{i\omega_0 t}.$$

$$E_{1b} \propto e^{-r^2/w^2} e^{-(t-\tau_0(x))^2/\tau(r)^2} e^{i\omega_0 t}.$$

When it is important:

Intensity at the focus is the most critical parameter of a laser pulse.

Misalignment of compressor gratings can lead to STCs such as PFT.

J. Opt. 22 (2020) 103501 (33pp) https://doi.org/10.1088/2040-8986/abad08
Spatio-temporal characterization of ultrashort laser beams: a tutorial
Spencer W Jolly, Olivier Gobert and Fabien Quéré

Is it possible to measure?

With scan-based technique like termites/insight.
Very precise, but slow.
Reconstruction algorithms.

In ML-COLA we proposed to use multispectral camera coupled with ML methods in order to perform **snapshot measurements** for laser characterization.

Spatio-spectral intensity & Spatio-spectral phase

J. Opt. **22** (2020) 103501 Spencer W Jolly *et al*

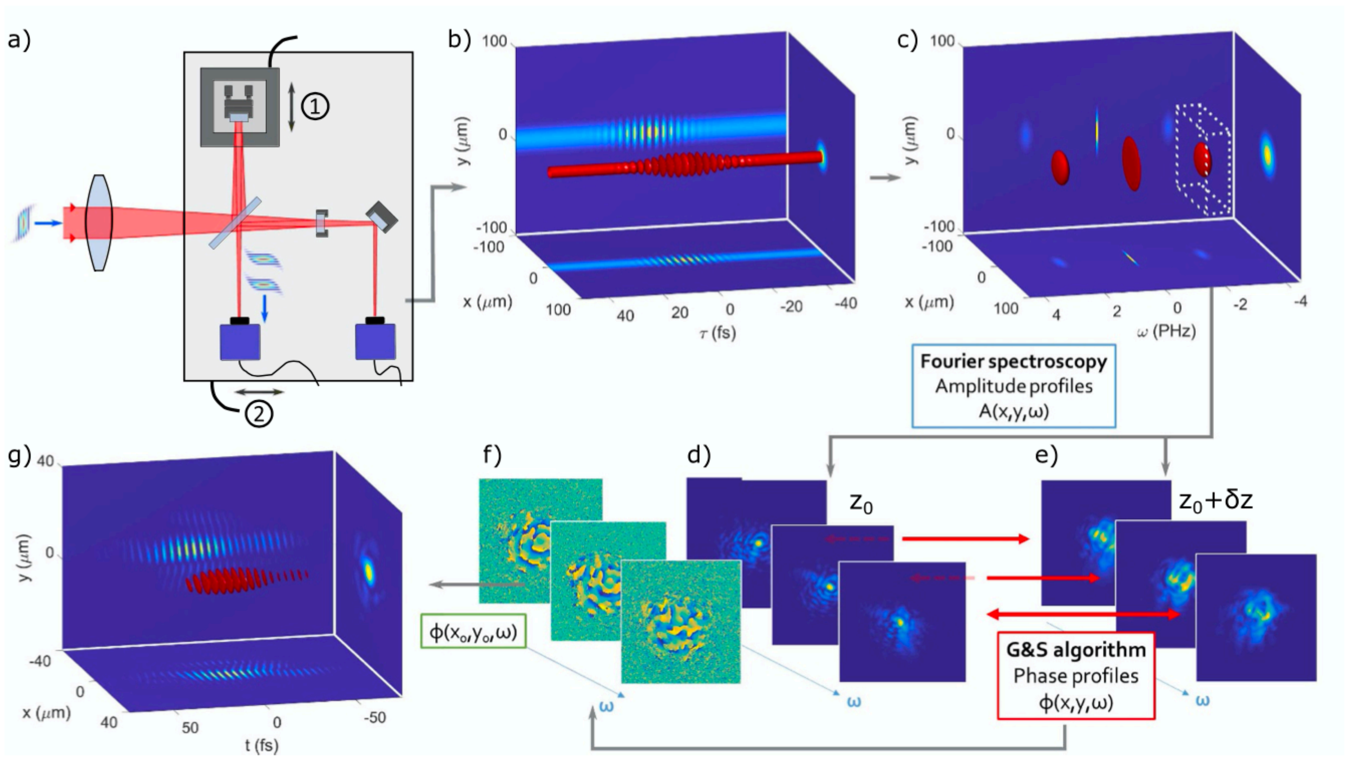
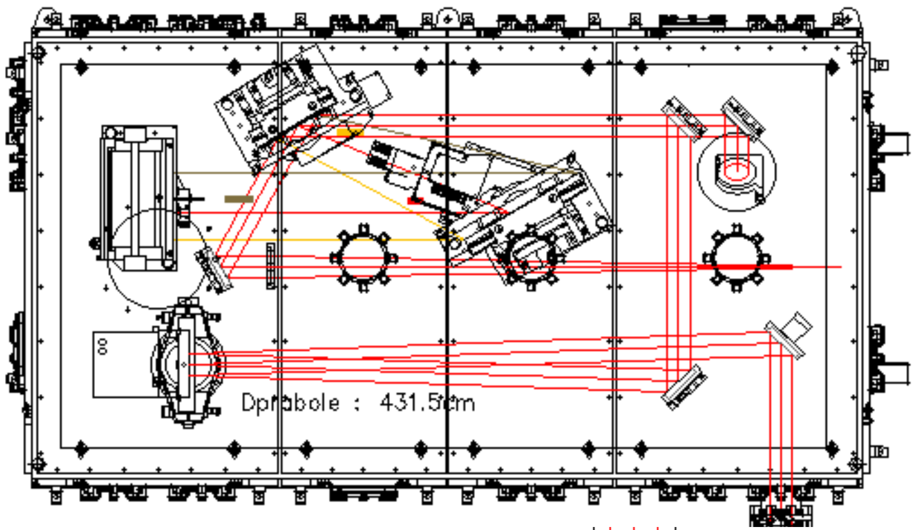


Figure 15. INSIGHT technique. (a) The laser beam to be characterized is focused onto a 2D sensor placed at the output of a simple Michelson or Mach-Zehnder interferometer. A second camera looking at the leakthrough of one end-mirror gives pointing information in order to compensate for any fluctuations during the measurement. A piezoelectric stage in one arm (stage 1 in (a)) is used to scan the delay with sub-optical-period accuracy, and thus measure the spatially-resolved linear autocorrelation of the beam at best focus (longitudinal position z_0), shown in (b). The Fourier transform of this signal with respect to delay (c) is then calculated, in order to filter out (white dashed box) the spatially-resolved spectrum. This 3D dataset provides the amplitude profiles at each frequency, shown in (d). This process is repeated at two other longitudinal positions near focus $z_0 \pm \delta z$ by shifting the interferometer (stage 2 in (a)) in the direction of the incoming beam, thus providing the spectrally-resolved spatial amplitudes at these two other planes (a single panel is displayed in (e)). A Gerchberg Saxton-like phase retrieval algorithm is then applied on these amplitudes at each frequency in order to extract the spatial phase, examples of which are shown in (f). With the addition of an independent measurement of the spectral phase at one position in the beam a Fourier transform with respect to frequency obtains the field in time, the real part of which is shown on (g). Reproduced with permission from [156] © The Optical Society.

High energy pulse compressor

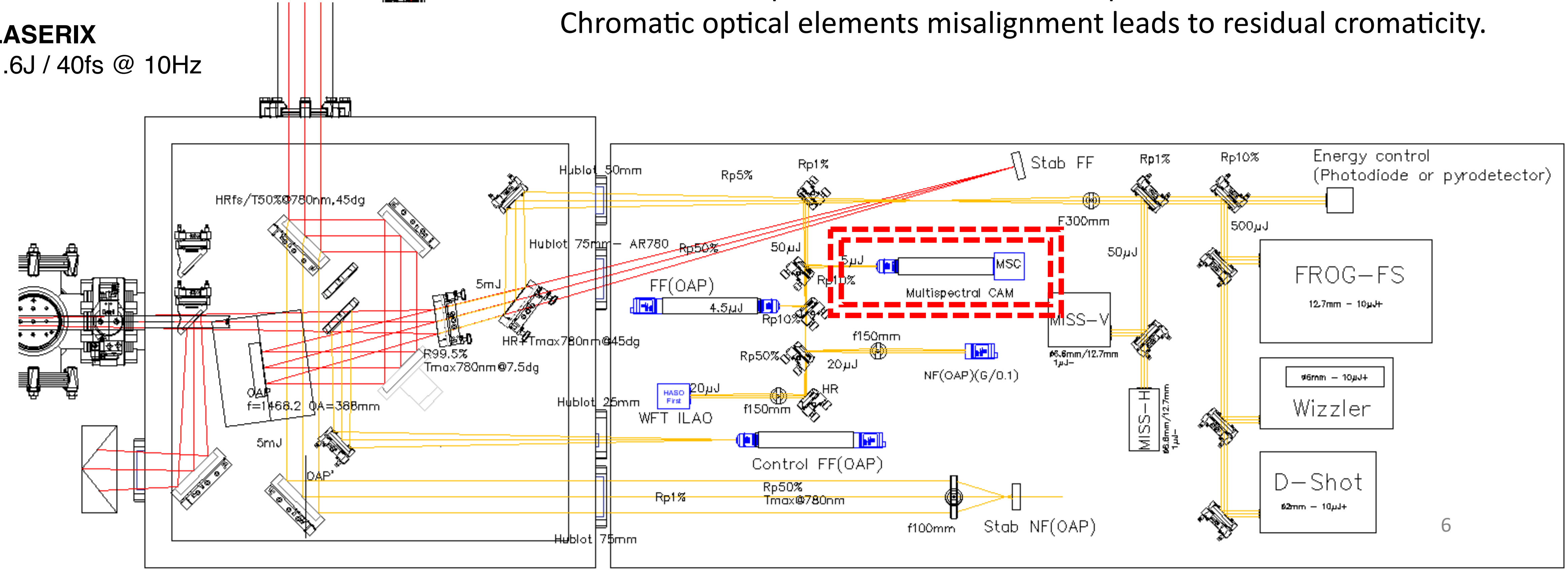


Laser control and beam quality in a context of laser plasma experiment PALLAS

- Laser control. Real time & integrated
- Plasma cell
- Diagnostics and transport

Ultrashort laser pulse needs to be broad spectra.
Chromatic optical elements misalignment leads to residual cromaticity.

UHI CPA LASERIX
40TW 1.6J / 40fs @ 10Hz

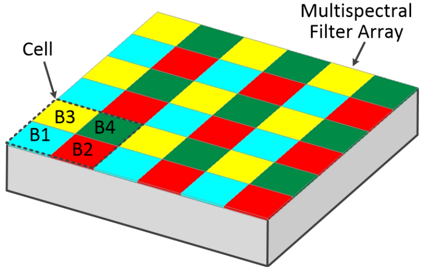


Multispectral camera

Spectral Devices Inc. sensors utilize a multispectral filter array (MFA) that incorporates proprietary pixelated bandpass filters whose transmission **characteristics can be precisely tuned during manufacturing.**

The MFA works by breaking down the image sensor into cells, where each cell contains between 2 and 16 microscale optical bandpass filters (e.g. B1, B2, B3, and B4; Figure 1) to separate colors in the image by wavelength.
The cells are distributed in a 2-dimensional array to form the MFA, which is aligned and integrated onto the image sensor.

Multispectral Sensor

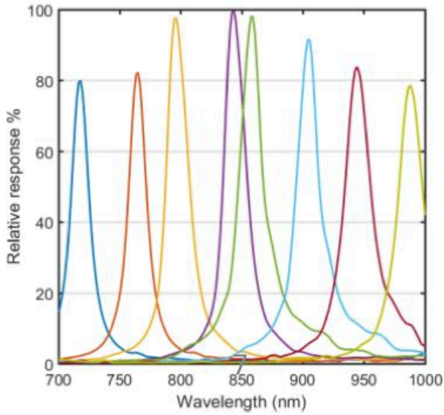


FEATURES:

- Snapshot Operation
- Capture Bands Simultaneously
- 720, 760, 800, 840, 860, 900, 940, 980 nm
- High Frame Rate
- High Performance CMOS Sensor
- USB3 Vision & GenICam Compliant
- Compact and Lightweight
- Low Power Requirement
- 28 mounting points

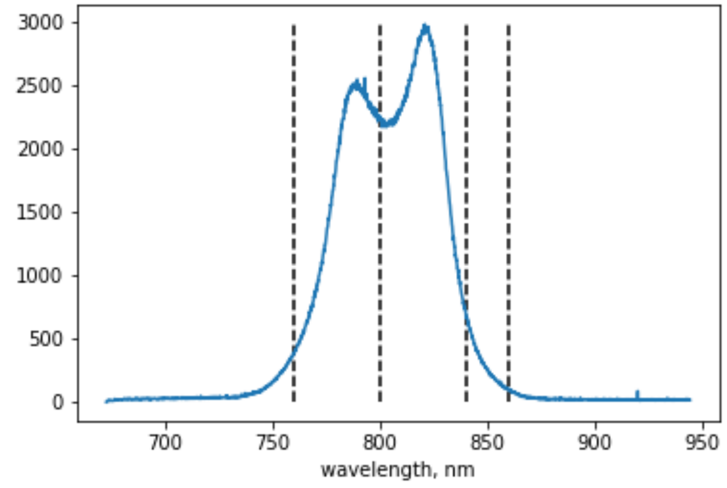
SPECIFICATIONS:

- Lens Mount: C-mount
- Interface: USB3 Vision
- Maximum Bit Depth: 12 bit
- Shutter: Global Shutter
- Sensor Type: CMOS
- Capture Method: Area
- Sensor Model: CMV4000
- Sensor Format: 1-inch
- Number of Channels: 8 bands
- Pixels Per Channel: 256 x 256
- Pixel Size (H x V): 5.5 x 16.5 (µm)
- Dynamic Range: 60 dB
- Dark Noise: 13 e- (RMS)
- Dark Current: 125 e-/s (25 ° C)
- Power Requirement: USB 3.0 interface
- Size: 56 mm x 50 mm x 52 mm (WxHxD)
- Weight: 200 g
- Case: 6061 Aluminium
- 12 x ¼-20 mounting points
- 12 x M3 mounting points
- 4 x 4-40 mounting points
- Compatible with 30 mm cage optics



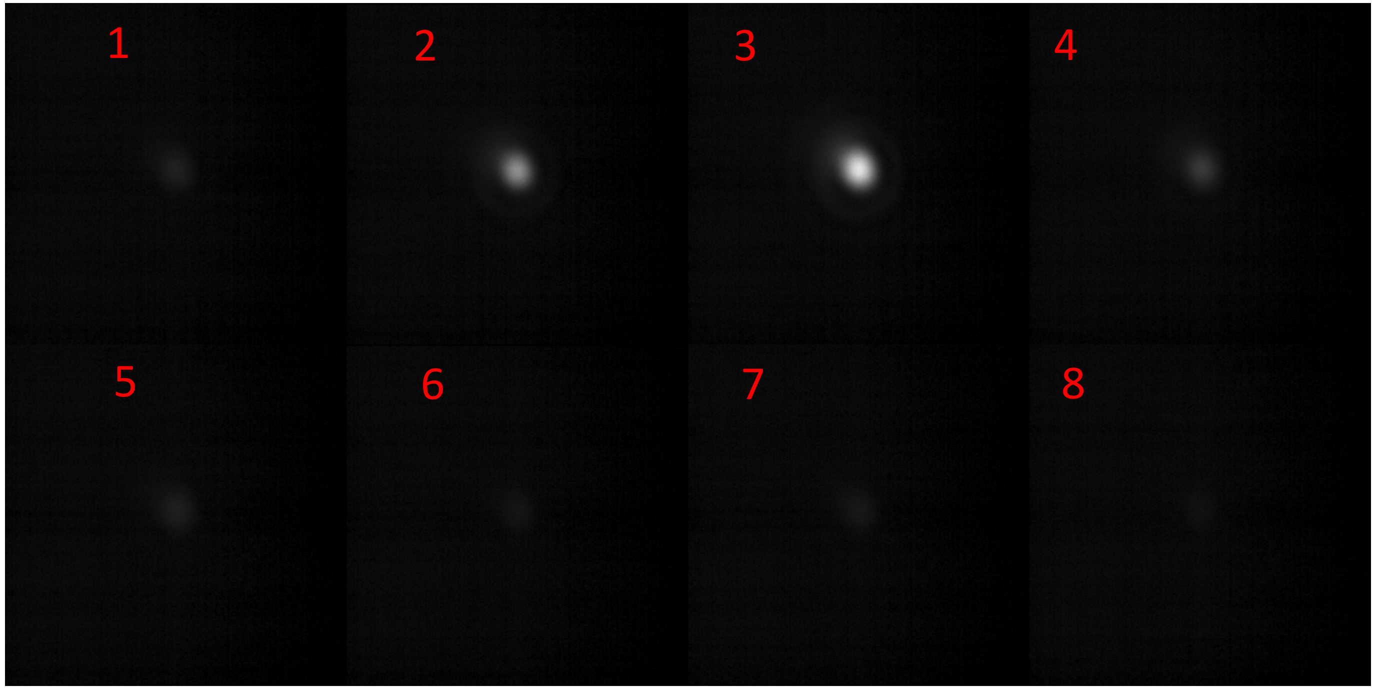
Companies:
need to find a good compromise :
spatial and spectral resolution, integration to the optical setup, interfaces, 10Hz, etc.

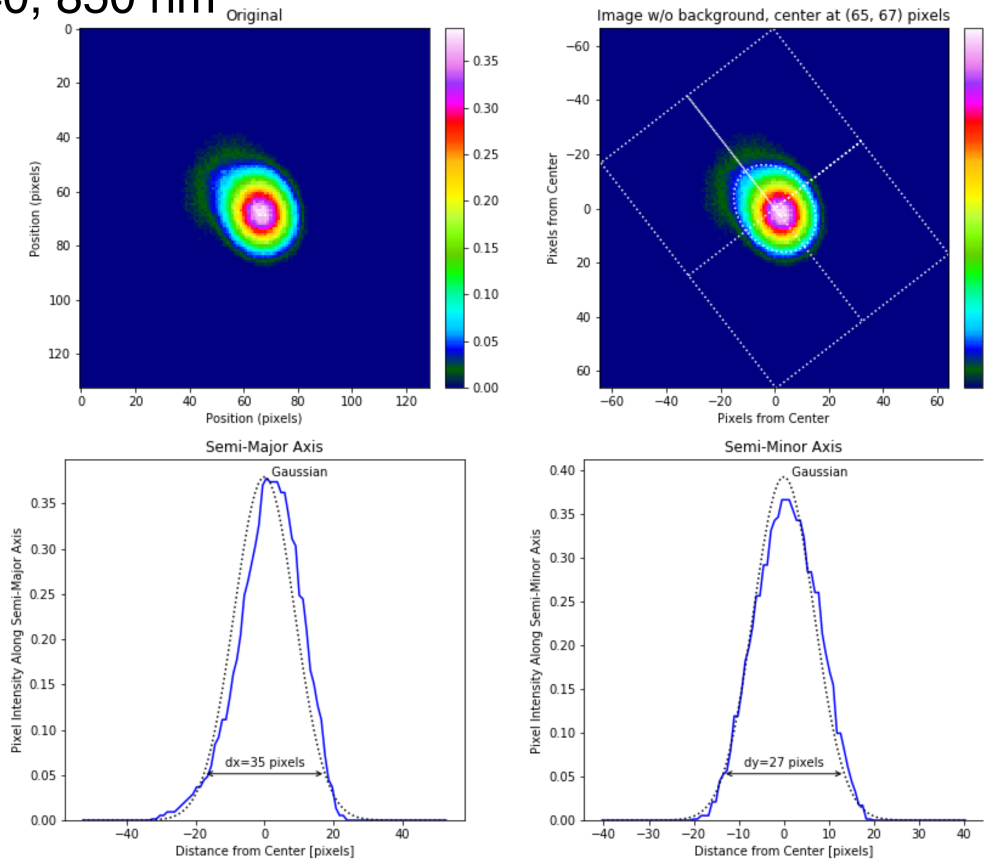
First tests of the camera. Results and analysis



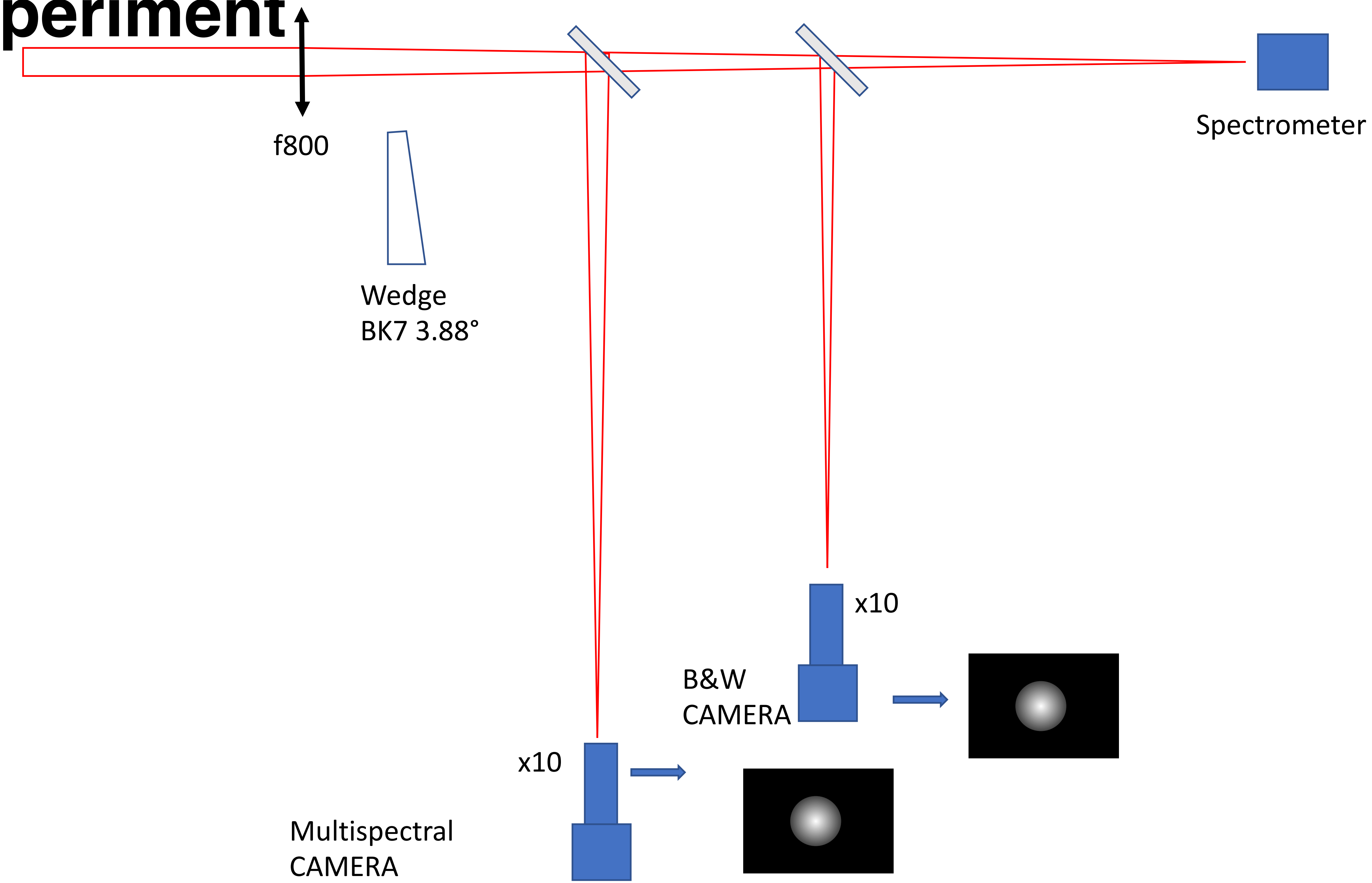
Standard 8 band camera is not really compatible with LASERIX spectrum.
720, **760, 800, 840, 860,** 900, 940, 980 nm.

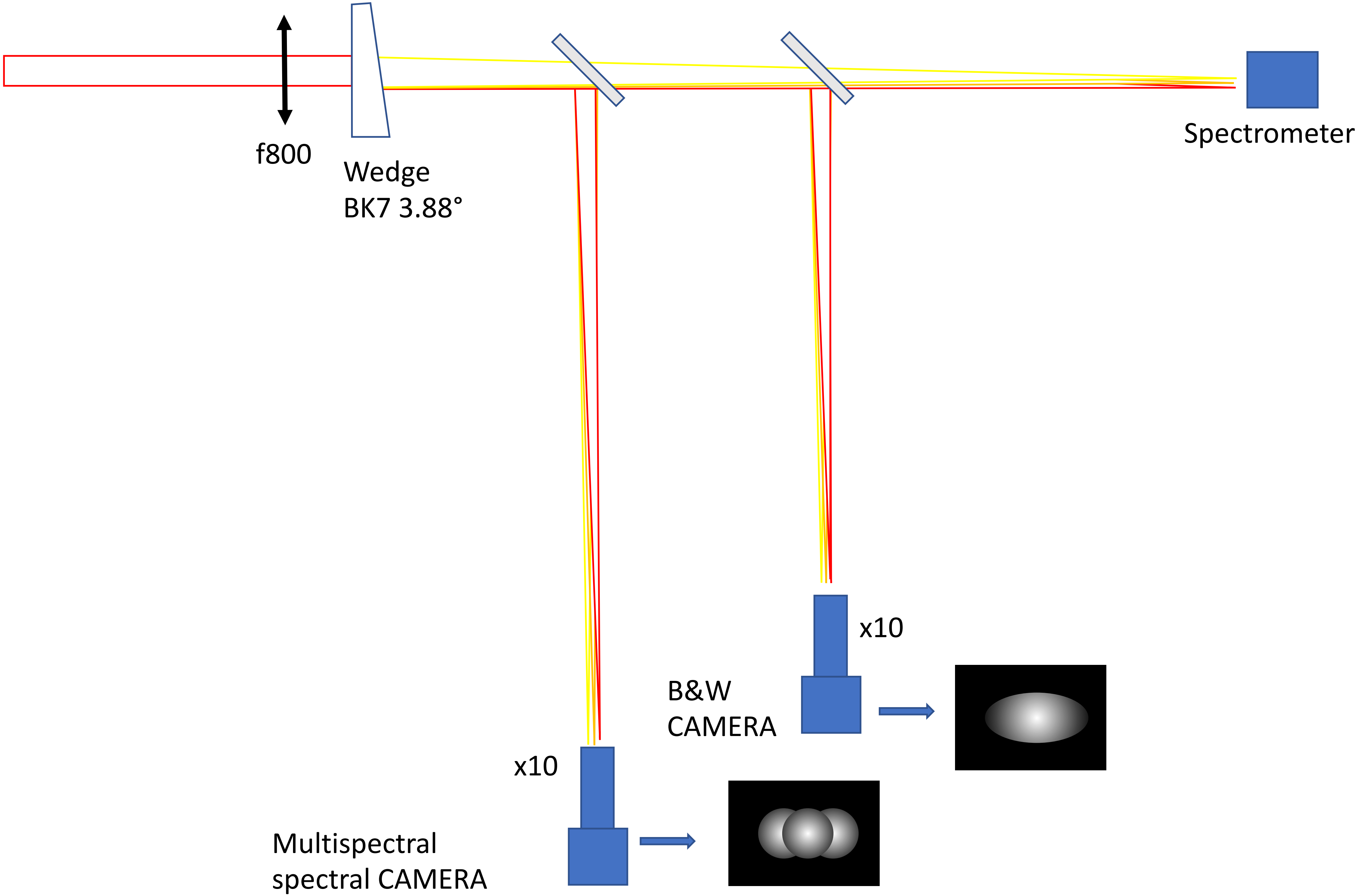
Custom filters, more narrow-band:
780, 790, 800, 810, 820, 830, 840, 850 nm

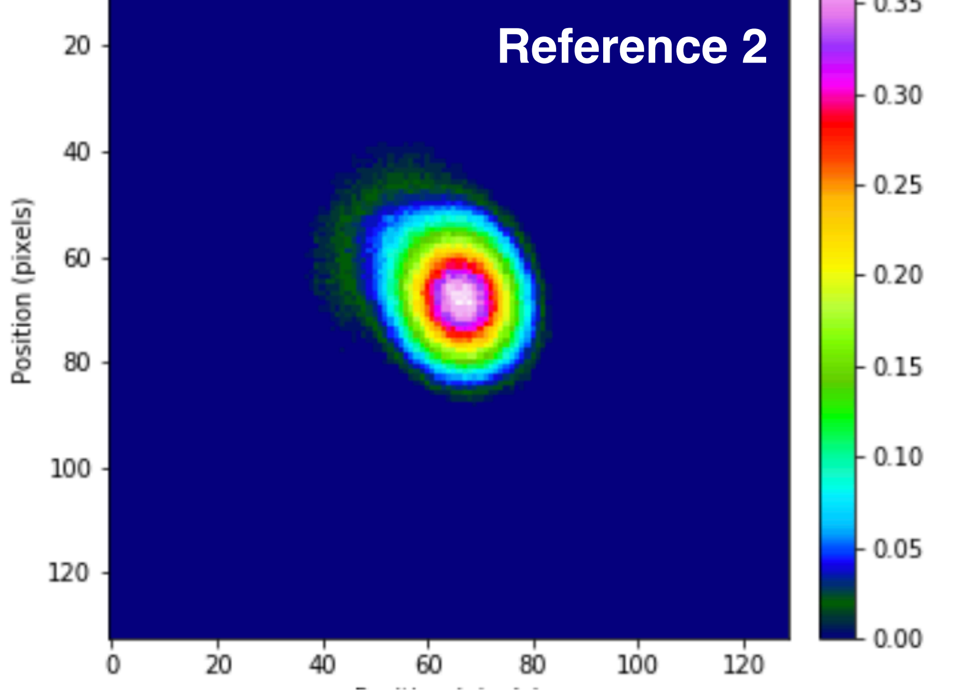


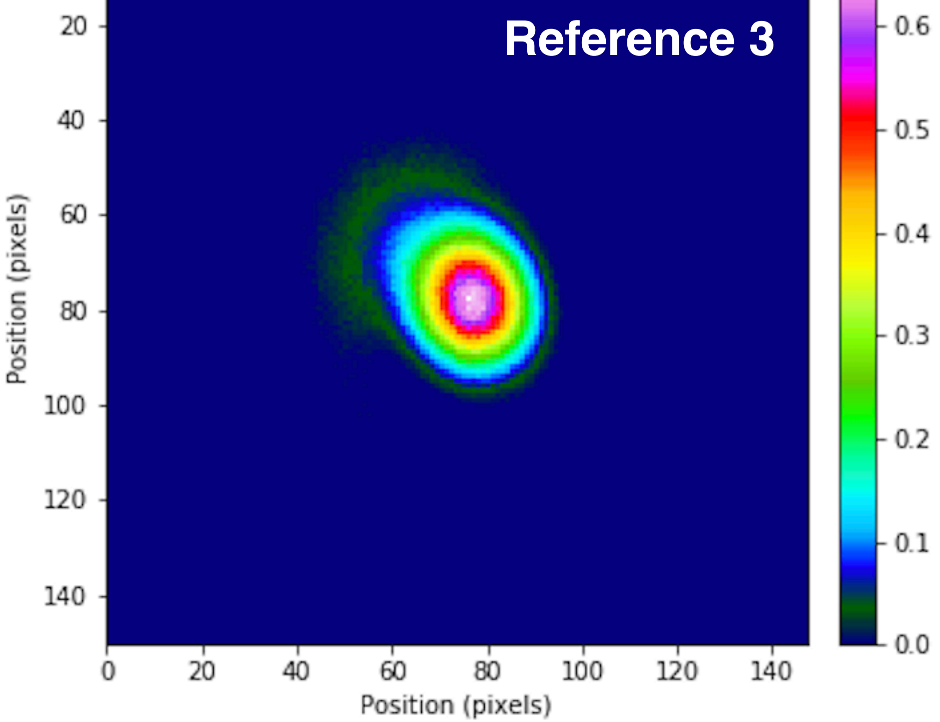


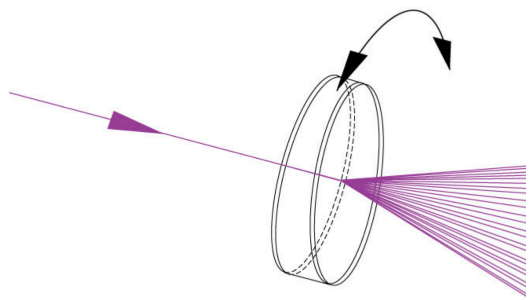
Experiment

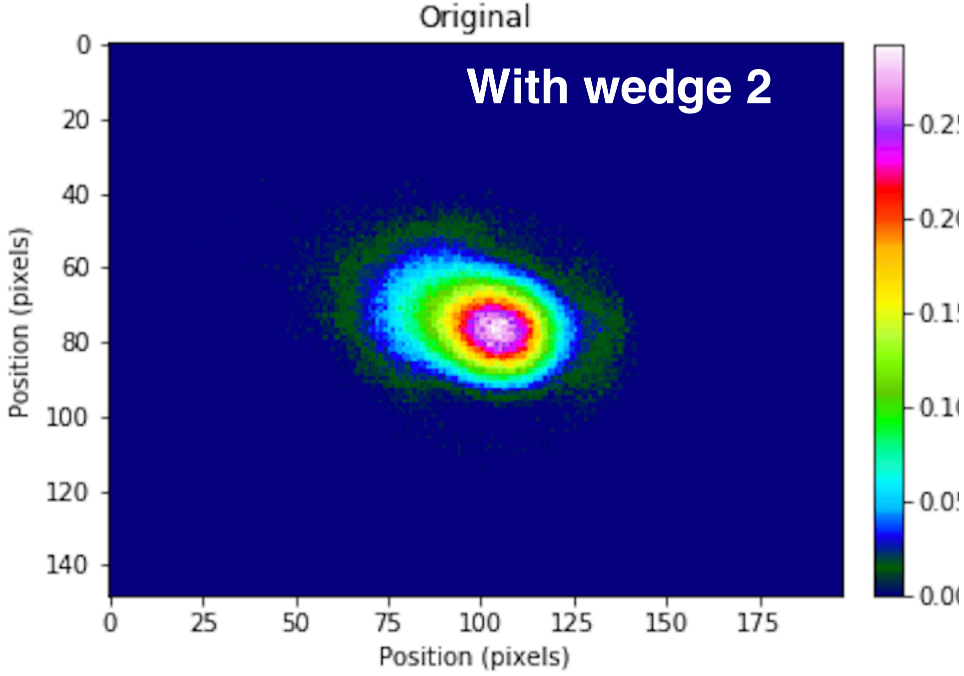

f800
Wedge
BK7 3.88°
Spectrometer
x10
B&W
CAMERA
x10
Multispectral
CAMERA

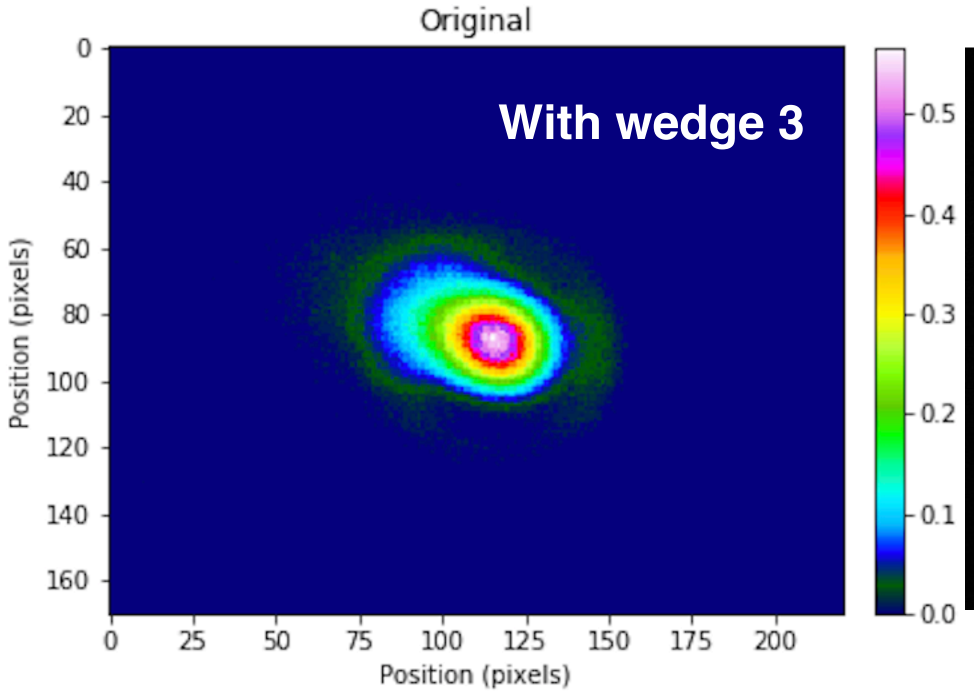

f800
Wedge
BK7 3.88°
Spectrometer
x10
B&W
CAMERA
x10
Multispectral
spectral CAMERA

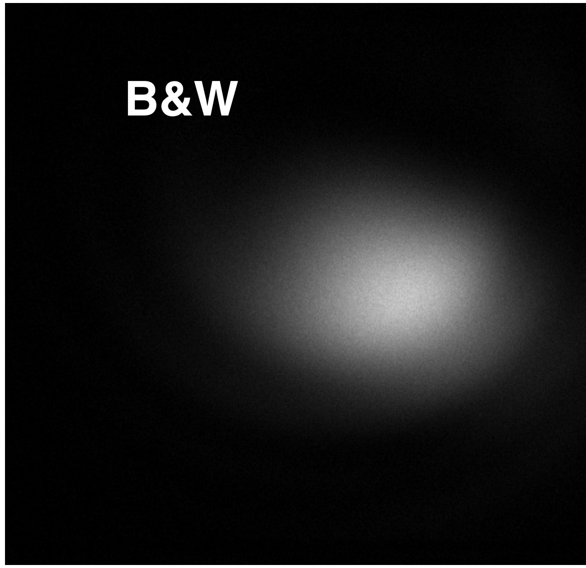

Reference 2
Position (pixels)


Reference 3
Position (pixels)
Position (pixels)

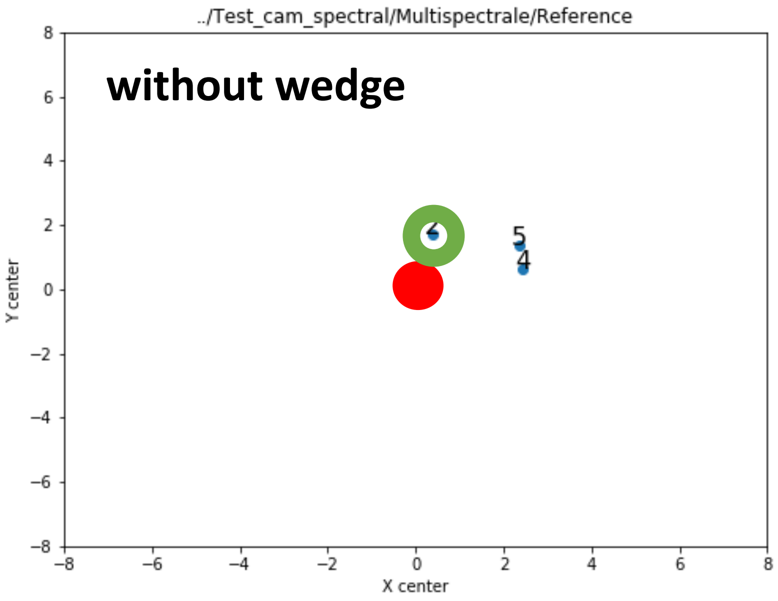


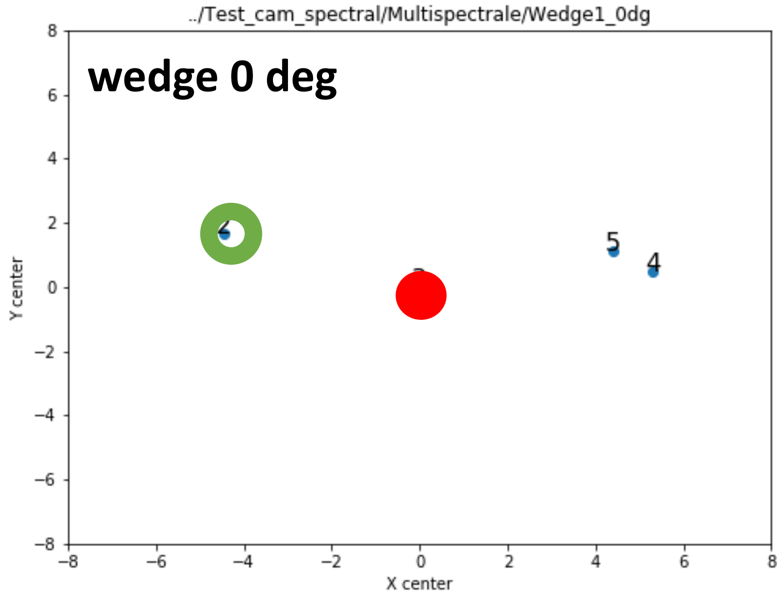

Original
With wedge 2
Position (pixels)
Position (pixels)

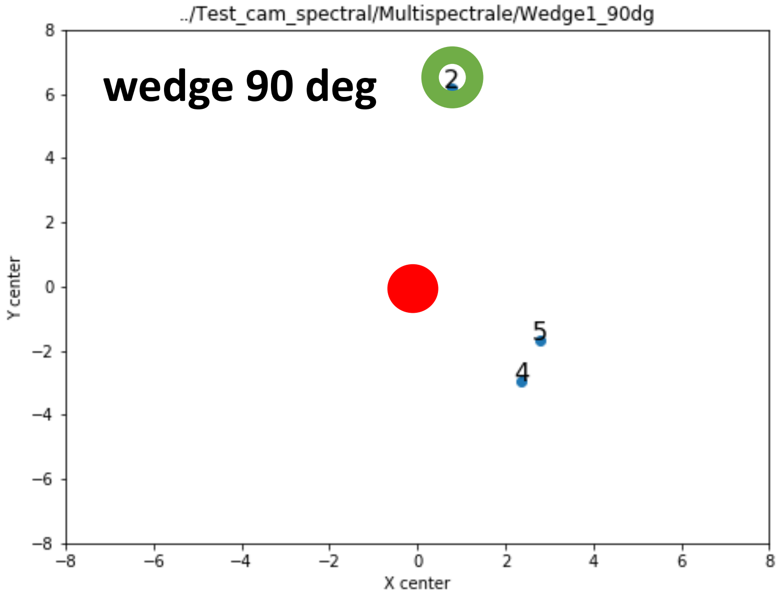

Original
With wedge 3
Position (pixels)
Position (pixels)

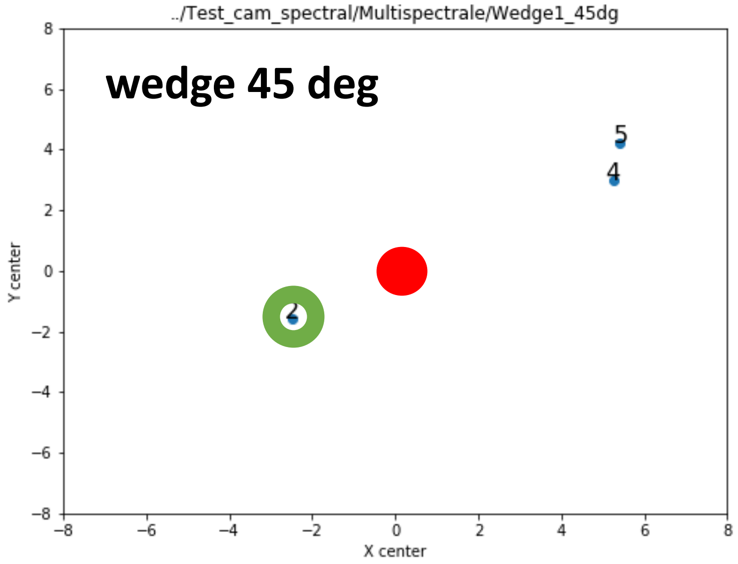

B&W

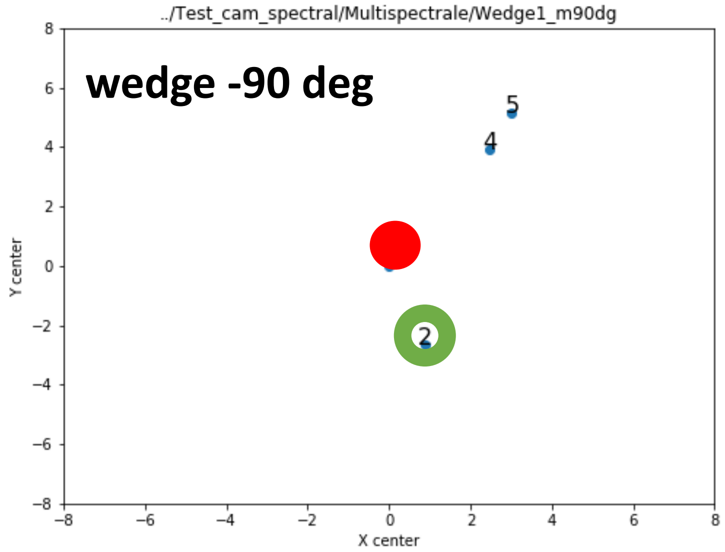
Beam center position for different orientations of wedge











ch2 : 760 nm

ch3 : 800 nm

New camera: more channels!

Timeline

Tests: end of April 2021

Negotiated together with Apollon team for two identical cameras

Ordered beginning of September

Expected delivery : December 2021

03/2021-06/2021 : Dataset collection on low-energy laser beamline of compressor tuning with single shot 2D detector and integrated phase measurement + INSIGHT/Termites measurement.

03/2021 - 12/2022: ML model development with LRI expert.

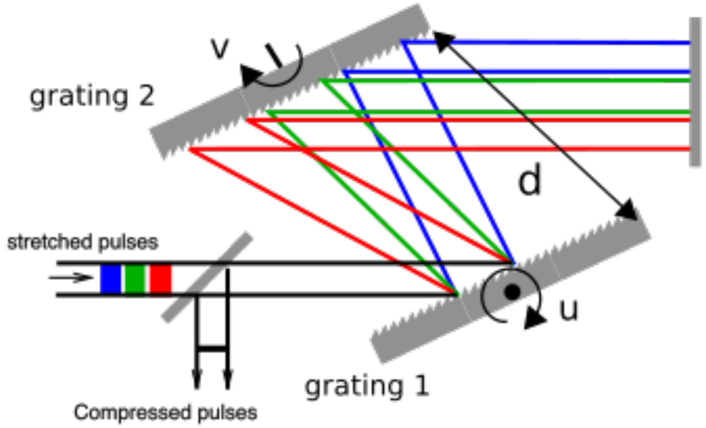
09/2021 – 03/2022: Testing of the prototype on the simple compressor test bench

03/2022 - 12/2022: Installation of the prototype on the high energy laser diags line for laser-plasma accelerator.

Optimisation and ML models.

Tango-based control system. Laser shot timestamp, tagging.

No constraints / Beam line always accessible



DATASET:

1. Amplitude and phase data: images from multispectral camera and INSIGHT/termite measurements
2. Compressor and principal laser parameters: (u, v, d), adaptive mirror configuration, timings, temporal length, energy, pointing stability etc.
3. Categorical labels assigned by the laser expert

Task1 : Optimize compressor parameters , such as angles and positions (u, v, d) of diffraction gratings.

Task 2 : retrieve the stability of the laser parameters and identify the set of most significant parameters

Task 3 Spectral phase retrieval

Summary

Key idea: Snapshot measurement combined/reinforced with ML techniques.

Outcomes:

- Unique diagnostics of ultrashort high intensity laser
- Online control and shot to shot stability.
- Laser characterization for PALLAS.

Backup

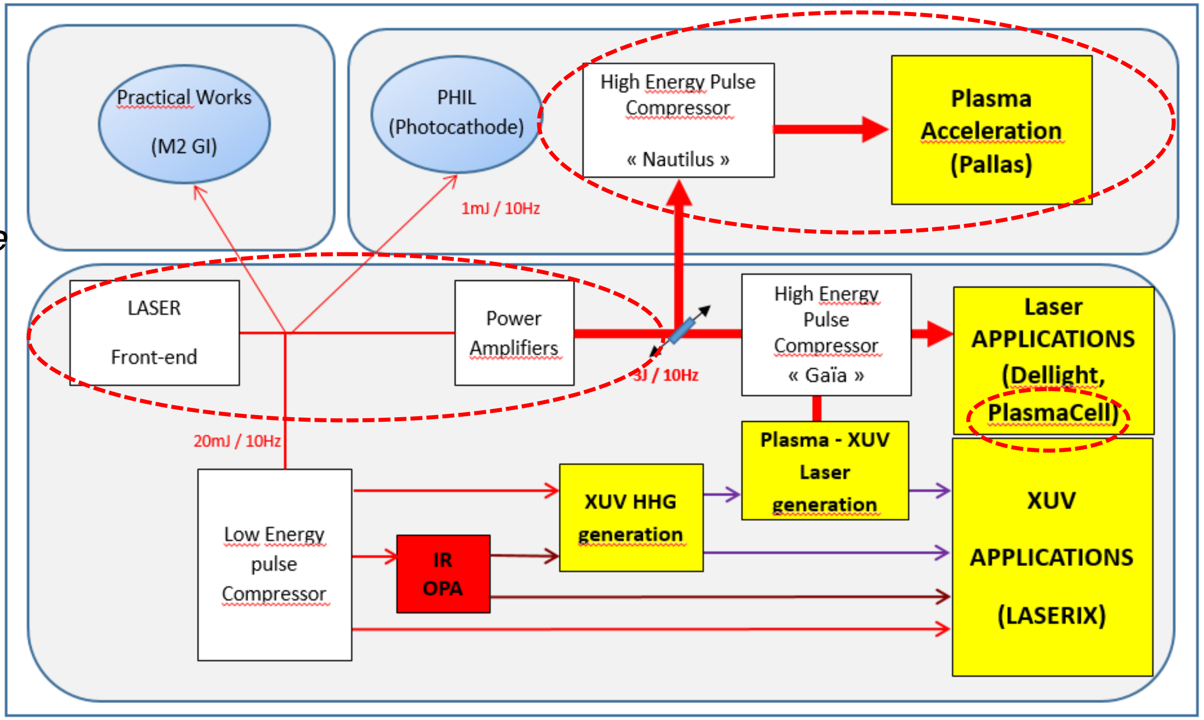
LASERIX platform at IJCLab

Equipements : UHI CPA Laser

- 40TW 1.6J / 40fs @ 10Hz *(37J @ 0.1Hz démontrés en 2007)* (*)
  → *matériels disponibles et « gros » potentiel d'upgrade*

Base Amplitude Laser « customisé » (flexibilité & performances)

Contrôle Commande développé avec Amplitude Laser, évolutif



Activités Scientifiques / Techniques

- R&D sources intenses (laser, XUV) et diagnostics spécifiques
- TP lasers intenses (M2-GI-PLATO, Polytech)
- Applications : Physiques des Plasmas, matériaux, irradiation, expériences résolues en temps (régions XUV - NIR), façonnage de faisceaux XUV, Physique non-linéaire, QED (Dellight) et… accélération par laser : PALLAS

Temps faisceau

- PALLAS 50% (20 semaines)
- Autres 50% (20 semaines)
- Maintenances (7 semaines)
- Arrêt : Août (5 semaines)

(*) F. Ple et al., "Design and demonstration of a high-energy booster amplifier for a high-repetition rate petawatt class laser system," Opt. Lett. 32, 238-240 (2007)