DATA ACQUISITION, SLOW CONTROL SYSTEMS AND IMAGE PROCESSING FOR PHYSICS APPLICATIONS

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SUMMARY

- DAQ system (and Slow Control) are rather large topics...
- I will concentrate on 'simple' systems (and techniques):
  - used by small- and mid-size experiments
  - used for testing setups (rapid development)

  with the aim to demonstrate how your contribution may be crucial
- I will not cover 'big' systems from HEP, supposing you are more acquainted with those, neither very specialized tasks:
  - PVSS / WinCC OA, cutting-edge image analysis for instance
- Main development frameworks: LabView, Qt, ...

SUMMARY

- Practical point of view,
  we will take a look at several experiments/use cases, focussing on their DAQ/CS/Image processing systems:
  - Francium experiment
  - SiPM characterization + ‘PizzaBox’ characterization
  - IFR prototype DAQ
  - Neutron test on SiPM, Radiation Hardness test
  - House heating (?)

USE CASE I: FRANCIUM EXPERIMENT

- GOAL:
  Trapping of Francium atoms in a Magneto–Optical Trap with high efficiency and related spectroscopic measurements
- Several needs for DAQ, CS and Image processing
- Just a brief overview of the experiment

FRANCIUM EXPERIMENT

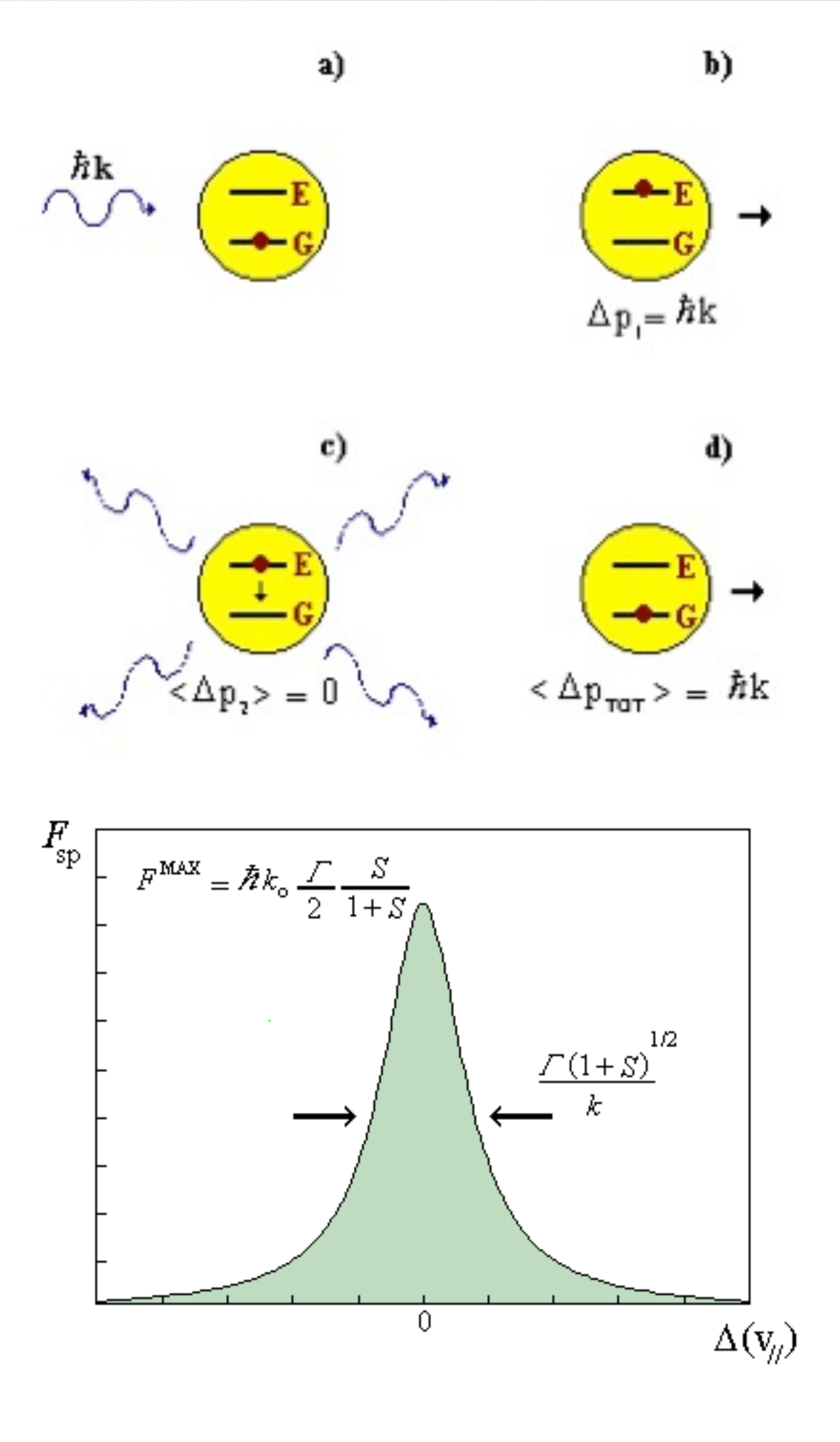
- Development of the first MOT for radioactive atoms in Europe
  - Facility at LNL for the production of Fr atoms
  - Laboratory at LNL for the MOT
  - Fr production, transport, neutralization and trapping
- Development of experimental techniques for the preparation of a parity violation experiment in francium, as a test of Standard Model of electroweak interactions
  - Characterization and optimization of the Fr MOT for different isotopes ⇒ increase the number of atoms trapped
  - High resolution laser spectroscopy, study of the excitation of weak transitions

FRANCIUM EXPERIMENT

- Few concepts to remind:
  - laser cooling
  - magneto–optical trapping
- Some details on the experiment:
  - Fr production/transportation/neutralization
  - Fr spectroscopy

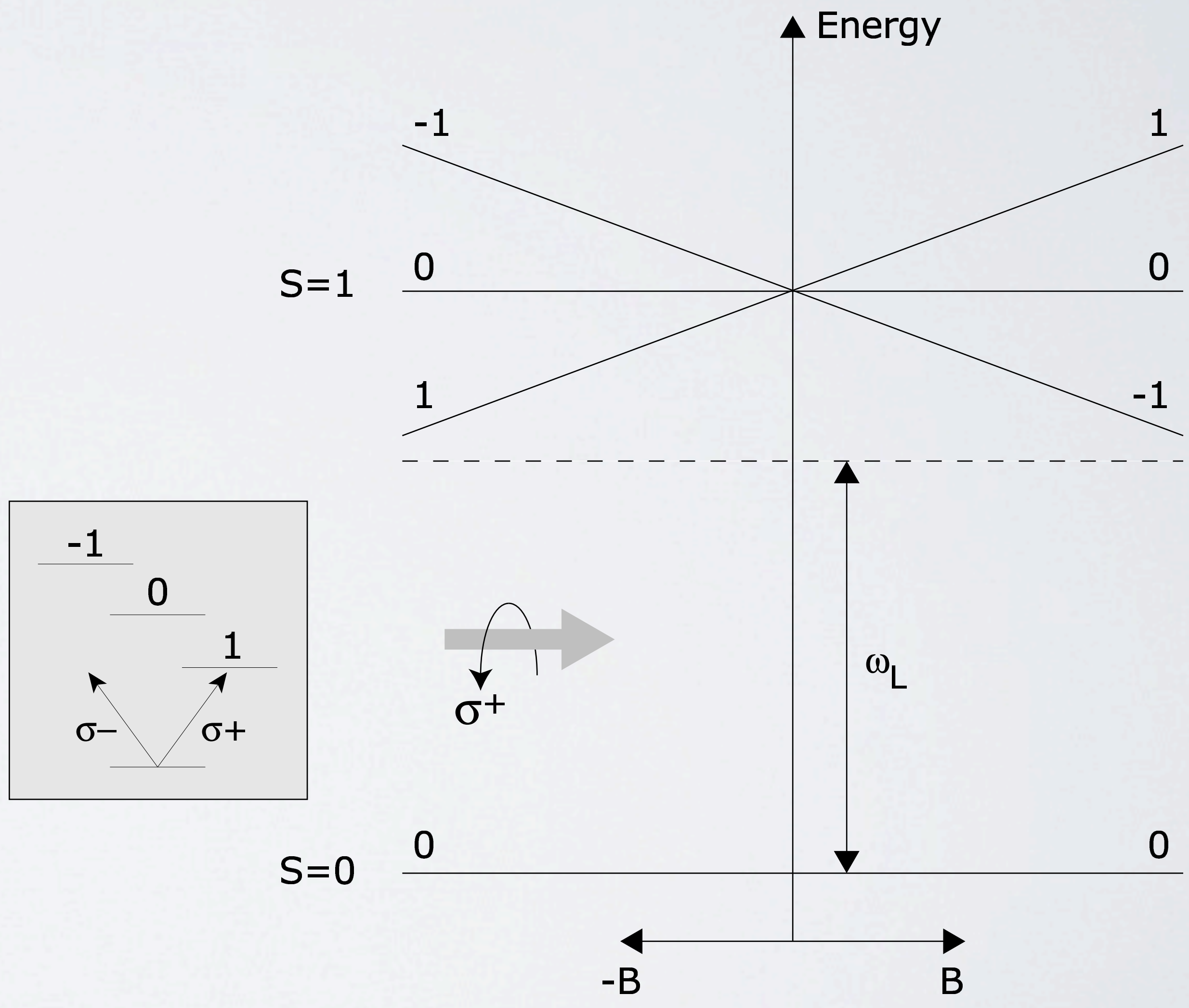
LASER COOLING

- based on spontaneous force:
  - several cycles of absorption and spontaneous emission
  - Doppler effect must be taken into account
  - total p ≠ 0



MAGNETO–OPTICAL TRAPPING

- **1-D model**
- Spatially varying magnetic field
- Quadrupolar magnetic field induces a position dependent Zeeman shift in atomic levels
- Counter-propagating laser beams
- Laser absorption induces a light pressure that slows down atoms
- Light pressure is position dependent



MAGNETO–OPTICAL TRAPPING

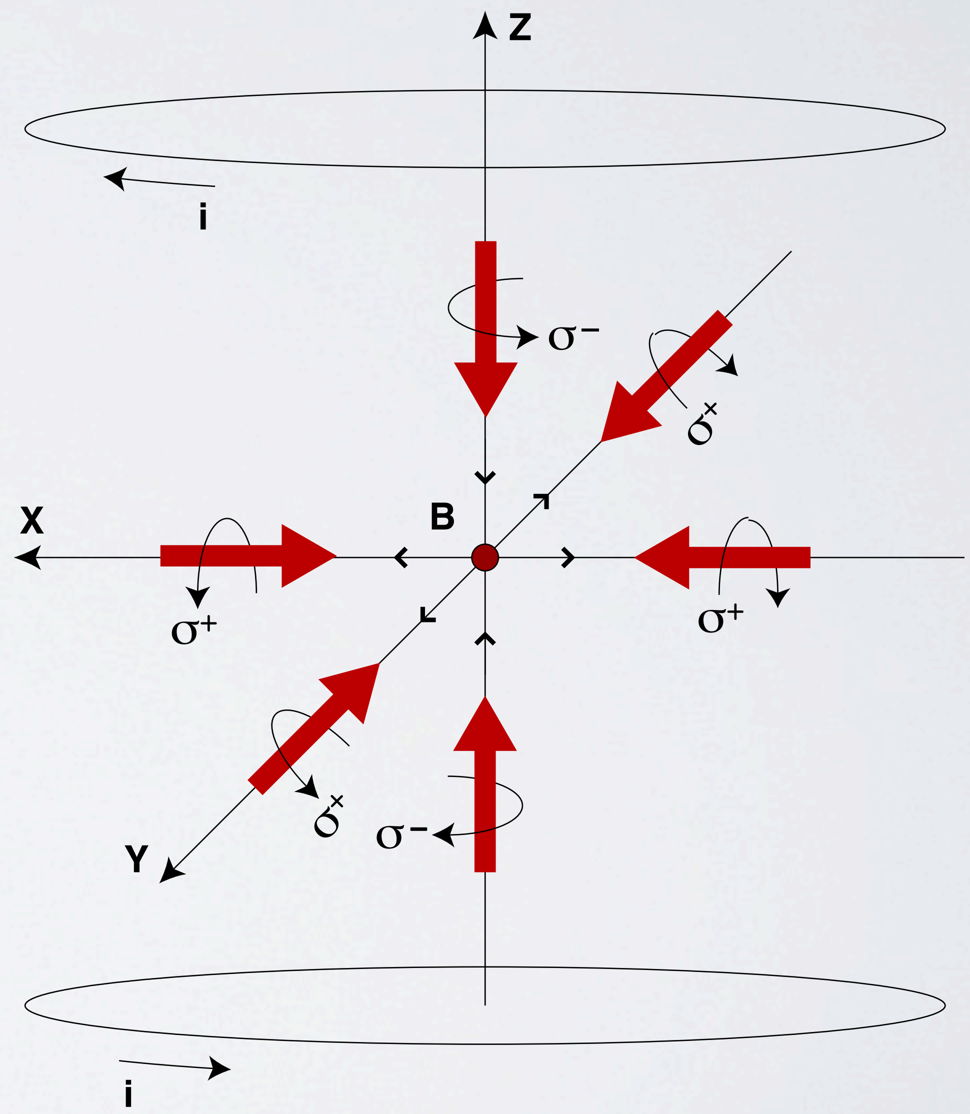
- **3-D scheme**

- Quadrupolar magnetic field can be achieved using two coils in Anti-Helmholz configuration

- Three orthogonal pairs of counterpropagating laser beams

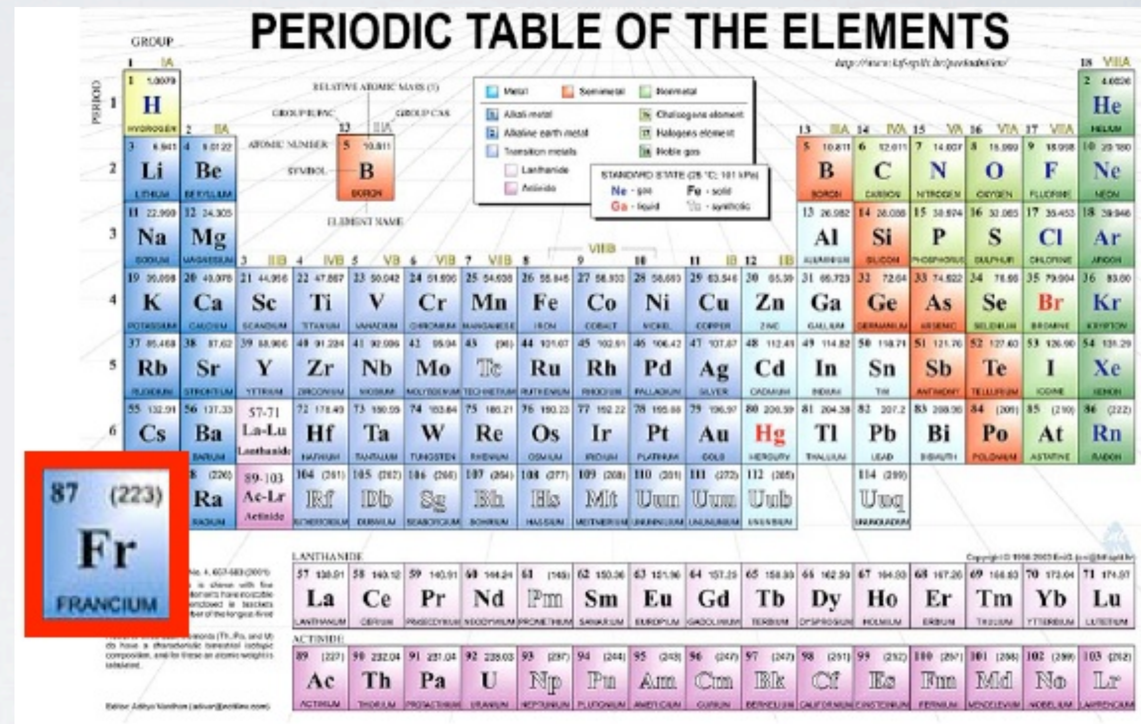
- Red detuning of laser beams to achieve cooling conditions

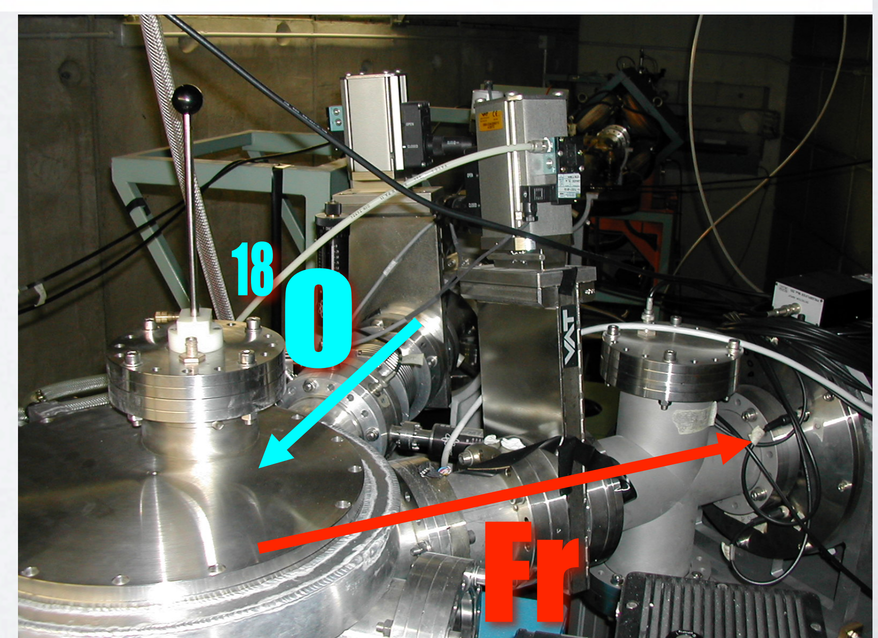
- Resulting force towards B=0



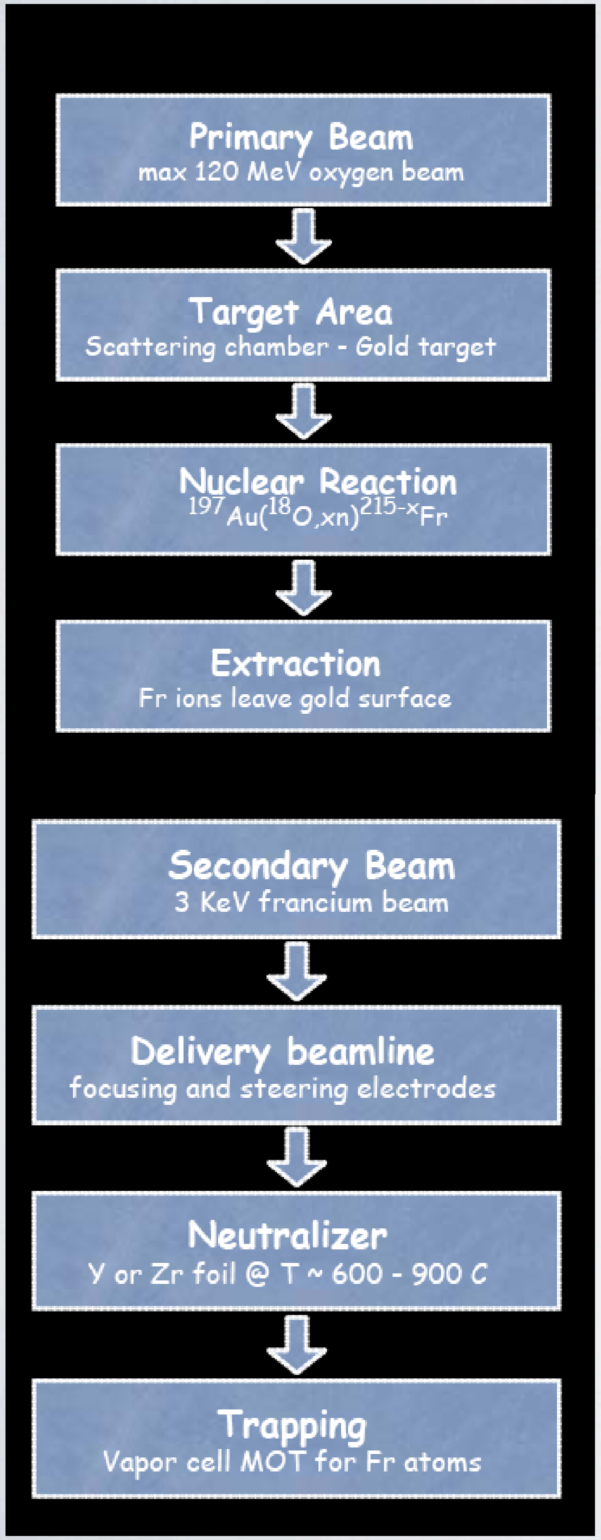
WHY FRANCIUM?

- Heaviest alkali metal (simple atomic structure)
- Enhancement of APV ($\sim Z^3$) and EDM effect
- Several isotopes ($t_{1/2}$ ~ min.)
- No stable isotopes but scarcity compensated by accumulation in MOT
- Needs of accelerator–assisted production





HOW IT WORKS



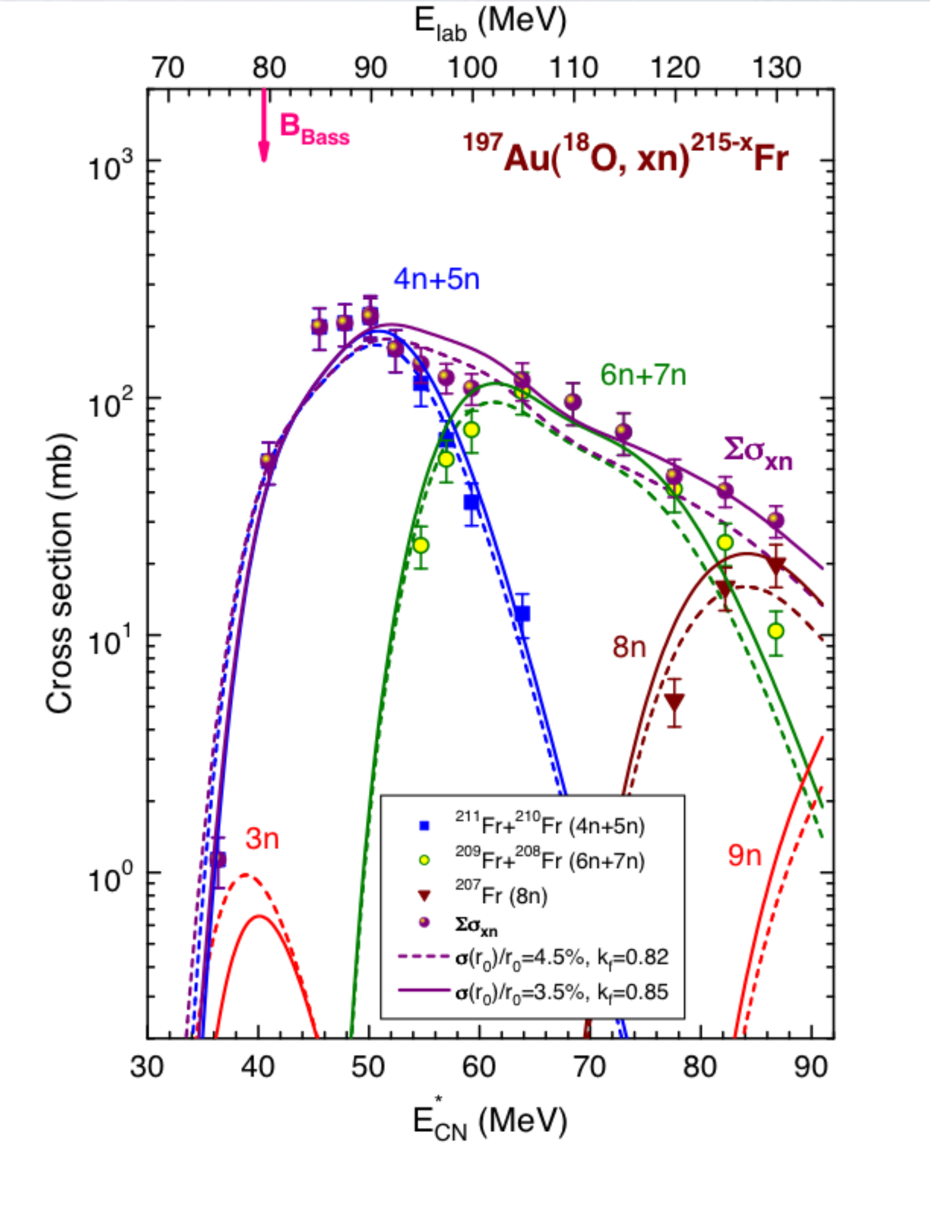
Fr atoms are produced inside a gold target by a fusion-evaporation nuclear reaction

Fr ions are extracted from the target and delivered to the trapping laboratory

Fr ions are focused into the cell where they are neutralized

Y foil at high temperture serves as neutralizer

PDMS or Dryfilm coated cell for trapping



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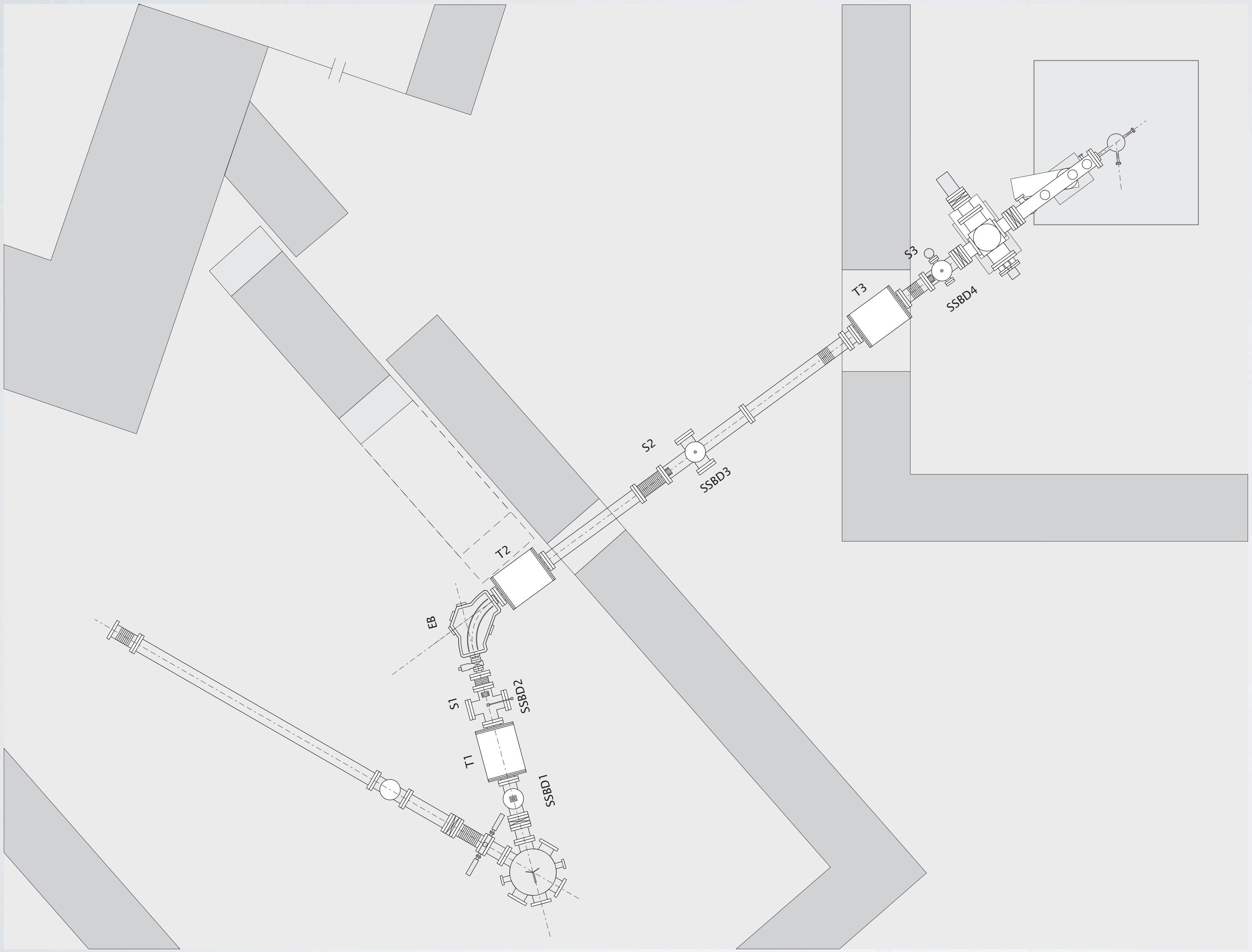
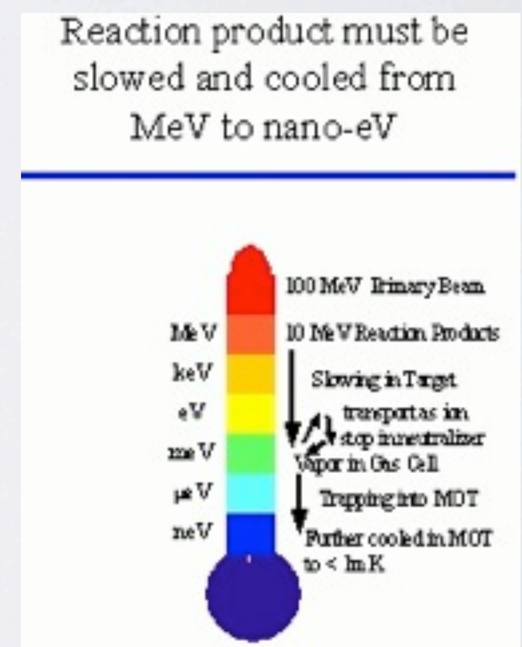
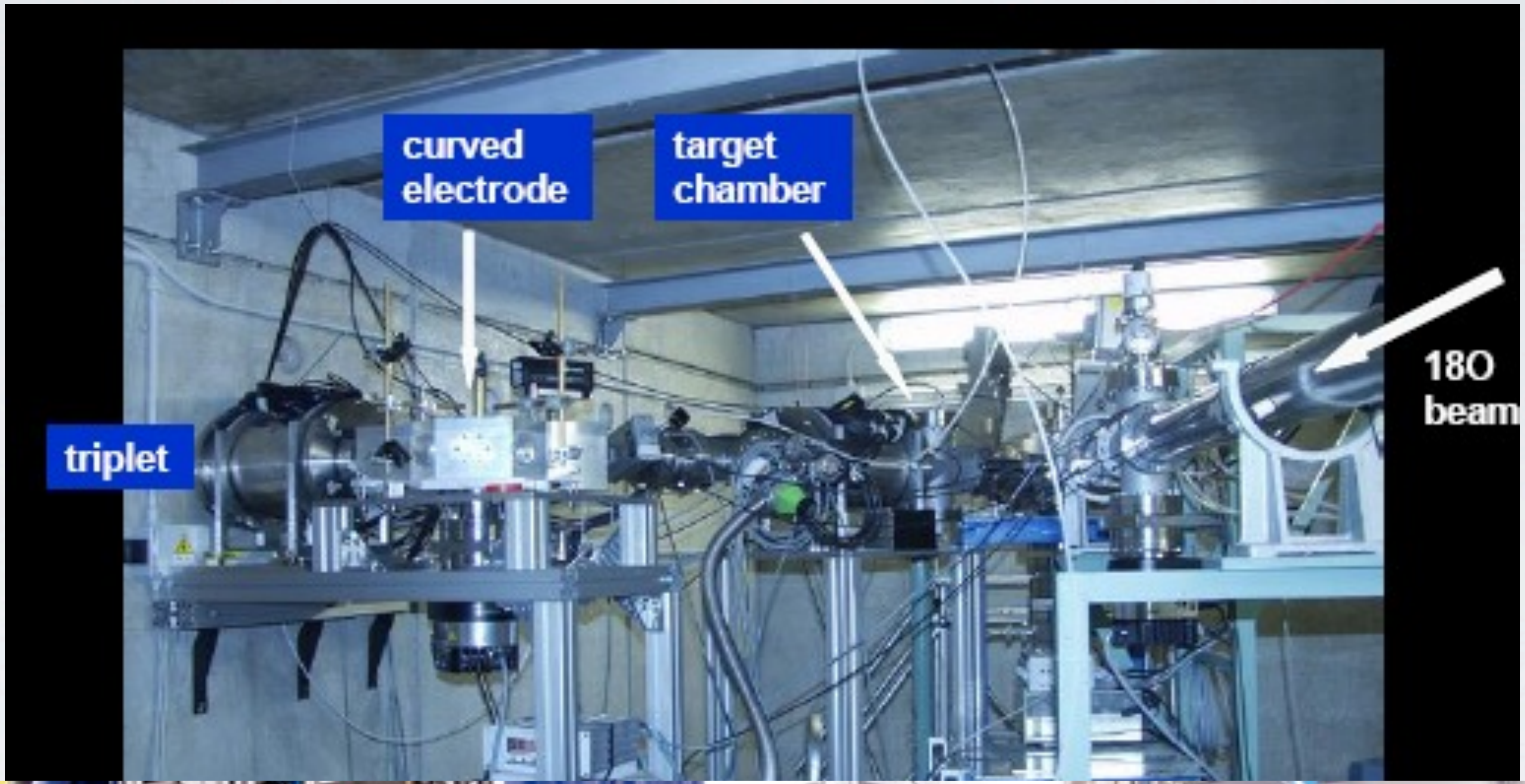
FRANCIUM EXPERIMENT



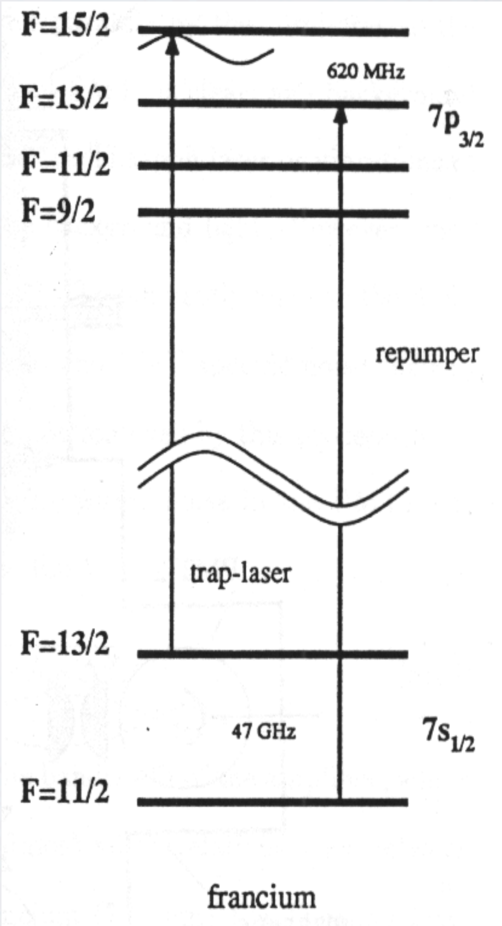


FRANCIUM EXPERIMENT

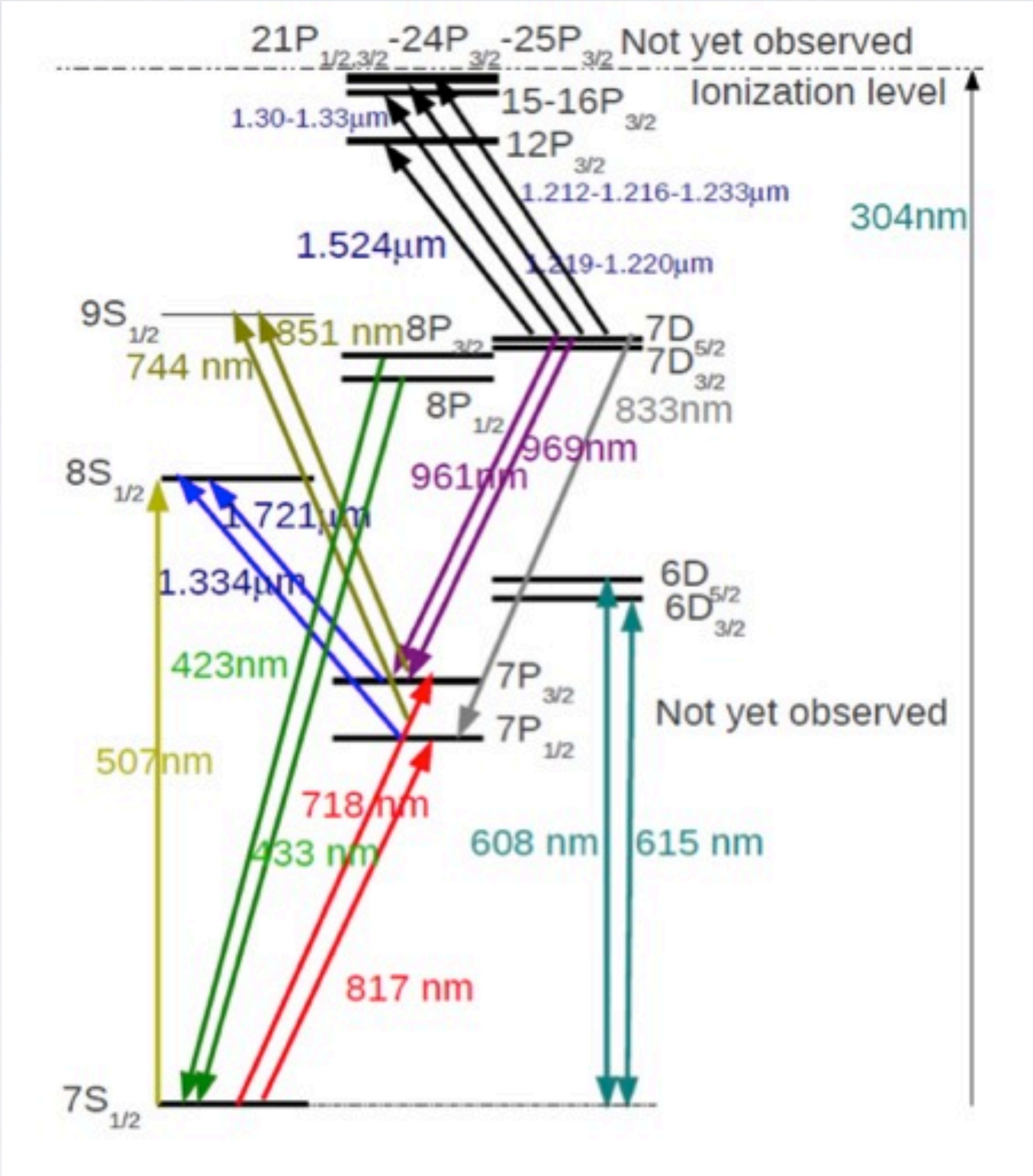


TRAPPING SETUP

- Optical system
  - 12 laser beams: three orthogonal pairs of counterpropagating laser beams
  - Cooling Laser: Ti:Sapphire Laser pumped by Ar^+ laser
  - Repumping Laser: Diode Laser
  - Cell with special coating
  - Six telescopes are used to expand beam diameters (Magnification = 5)
  - Six $\lambda/4$ plates are used to circular polarize the beams
- Magnetic Field
  - Two coils in Anti-Helmholtz configuration
  - d = 8.5 cm, f = 16 cm, IMAX = 4 A, BMAX = 125 Gauss, gradient ~ 10 gauss/cm



FRANCIUM LEVELS



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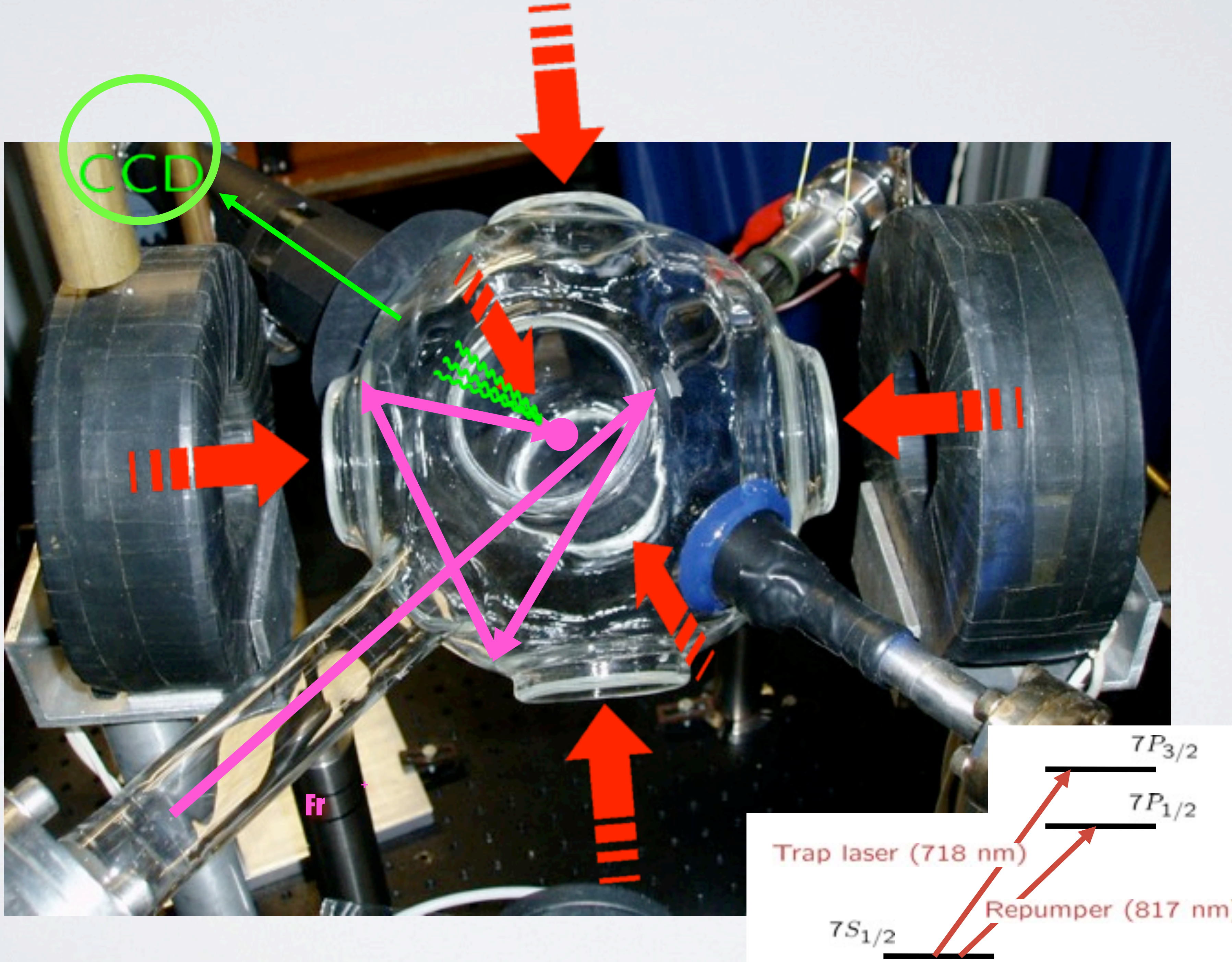
FRANCIUM EXPERIMENT

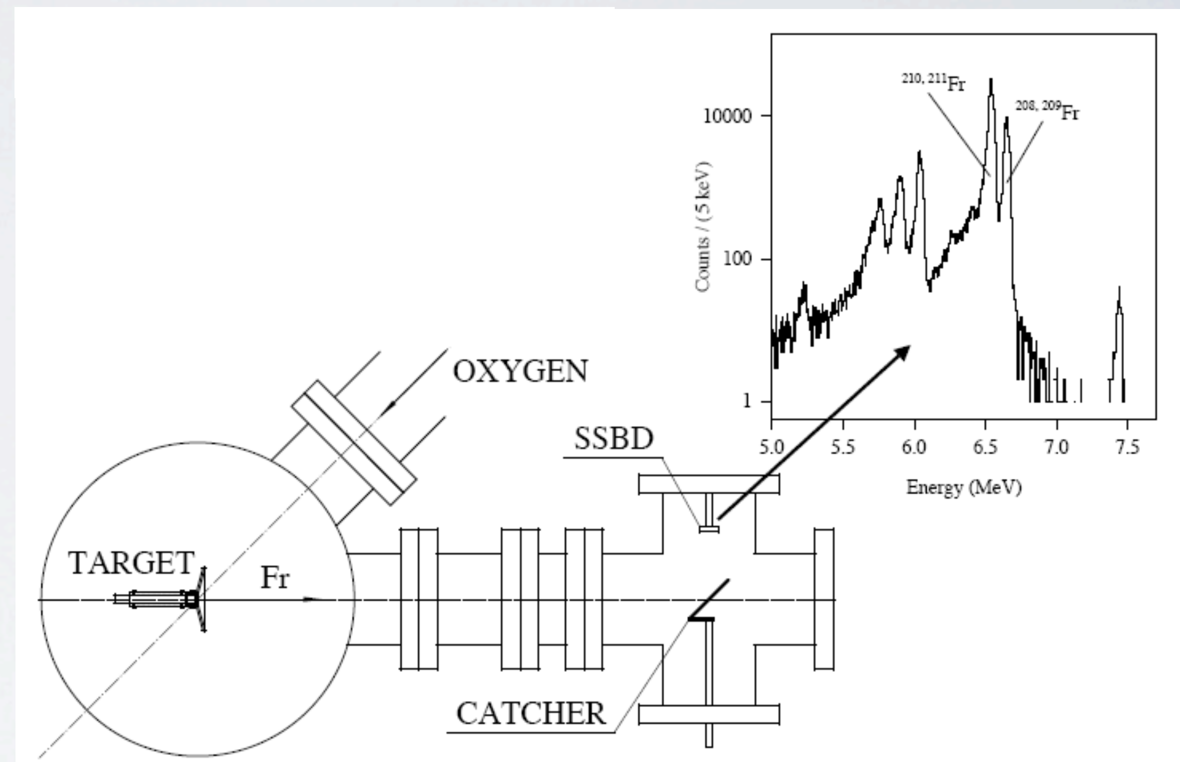


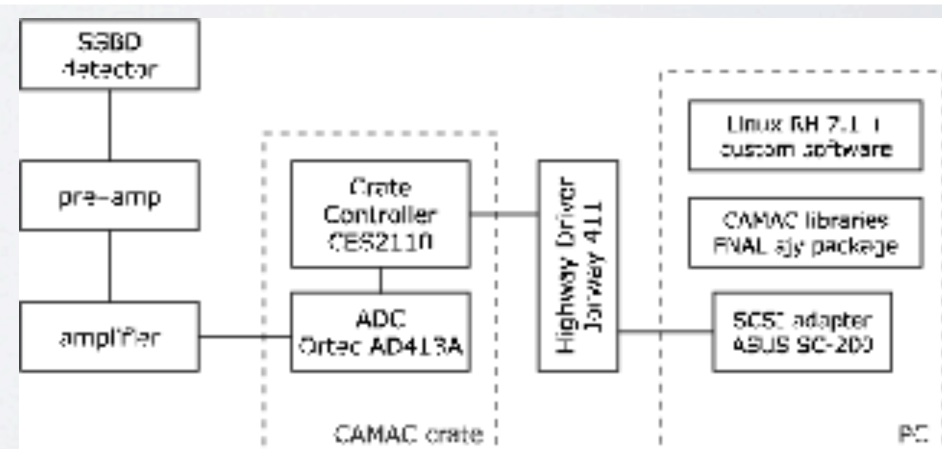
FRANCIUM EXPERIMENT

- Fr production tuning (daq)
- Laser frequency stabilization (daq + cs)
- MOT detection (daq + cs + image processing)
- Target safety (daq + cs)

FRANCIUM PRODUCTION

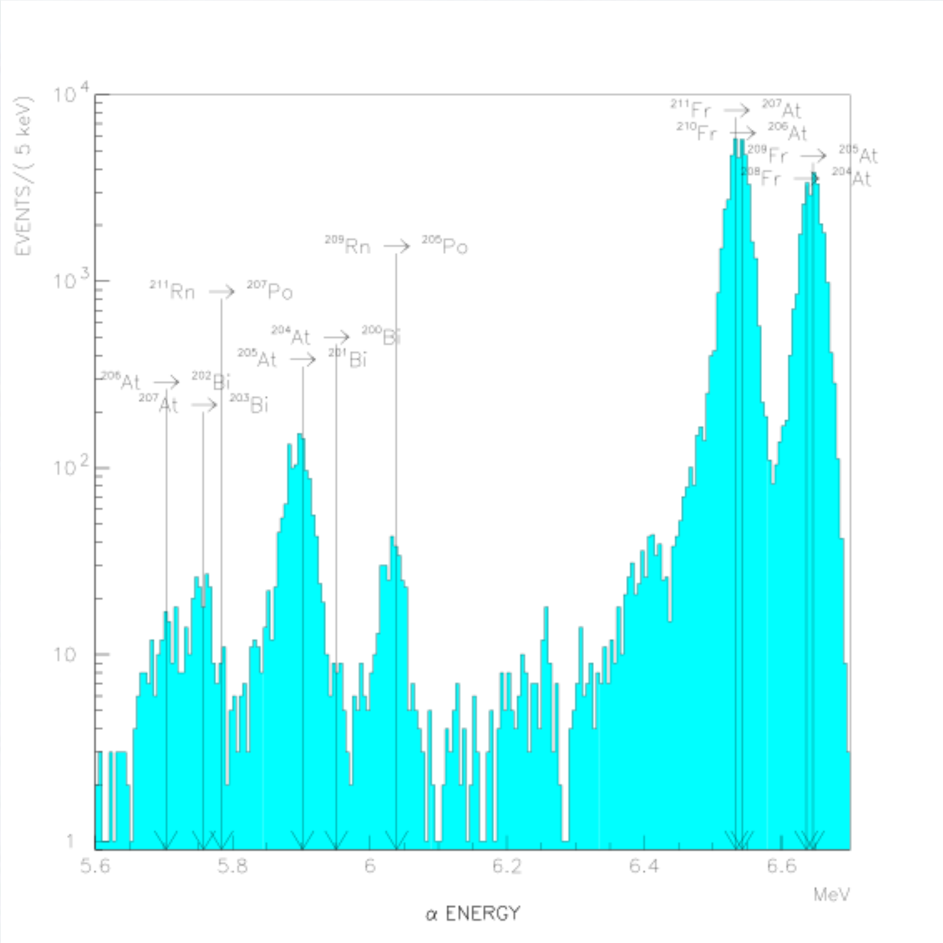
- Fr is detected by counting the α particles emitted during its decay
- DAQ System acquires the signal of a silicon detector
- Spectra are recorded





FRANCIUM PRODUCTION

isotope	half life (s)	α fraction (%)	α energy (keV)
^{208}Fr	59.1(3)	90(4)	6641(3)
^{209}Fr	50.0(3)	89(3)	6646(5)
^{210}Fr	191(4)	60(30)	6543(5)
^{211}Fr	186(1)	> 80	6534(5)



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LASER FREQUENCY STABILIZATION

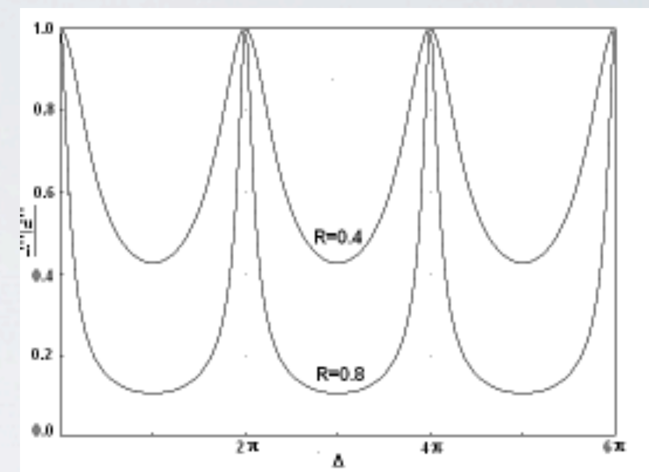
- Laser must have a frequency stability of the order of 10 MHz during the measurement time
  - "Fast" stability provided by laser drivers (jitter, etc…) ≤ 1 MHz
  - "Slow" frequency drift needs another approach to compensate for
- Necessity of long term (slow) stability of the trapping and repumping laser frequencies
- Frequency drift due to:
  - Thermal effects on laser cavity
  - Variations on diode current and temperature
  - Atmospheric pressure variation
  - Noise in the lab (pumps, people, etc…)

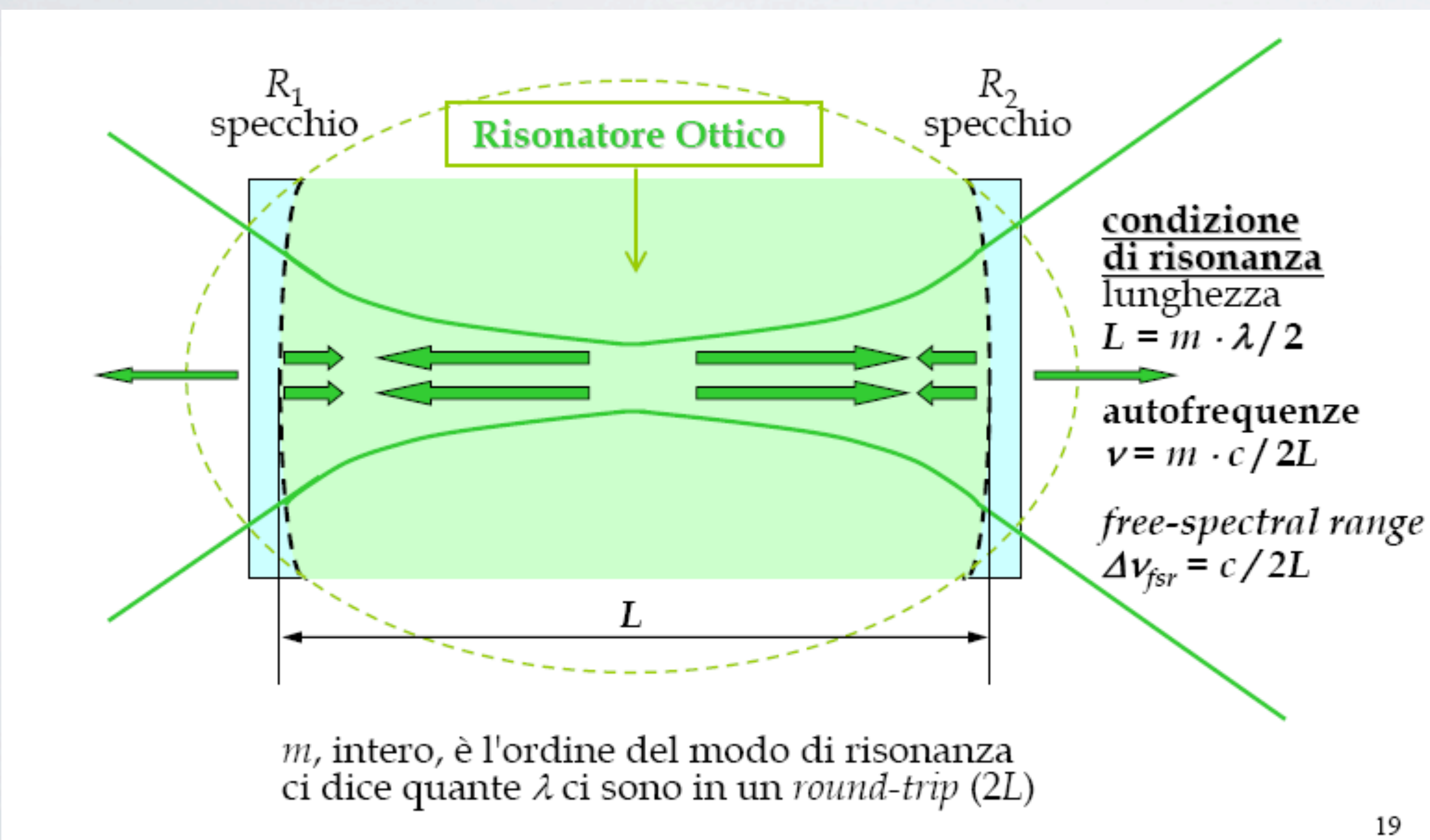
LASER FREQUENCY STABILIZATION

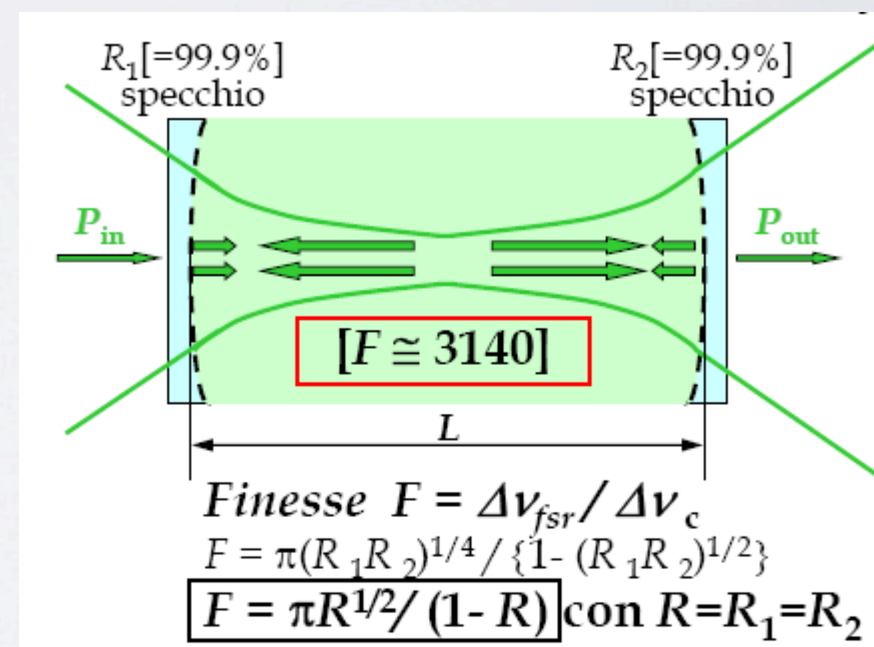
- SOLUTION:
  - Laser frequency monitor
    - Fabry-Perot cavity
  - Identification of the lasers frequency drift
    - Position of the peak of transmission
  - Generation of feedback signal
- WORKING PRINCIPLE:
  - Fabry-Perot cavity locked to a stabilized (2 MHz) He-Ne laser
  - Ti:Sa laser and diode laser locked to the Fabry-Perot cavity

LASER FREQUENCY STABILIZATION

- Fabry-Perot cavity

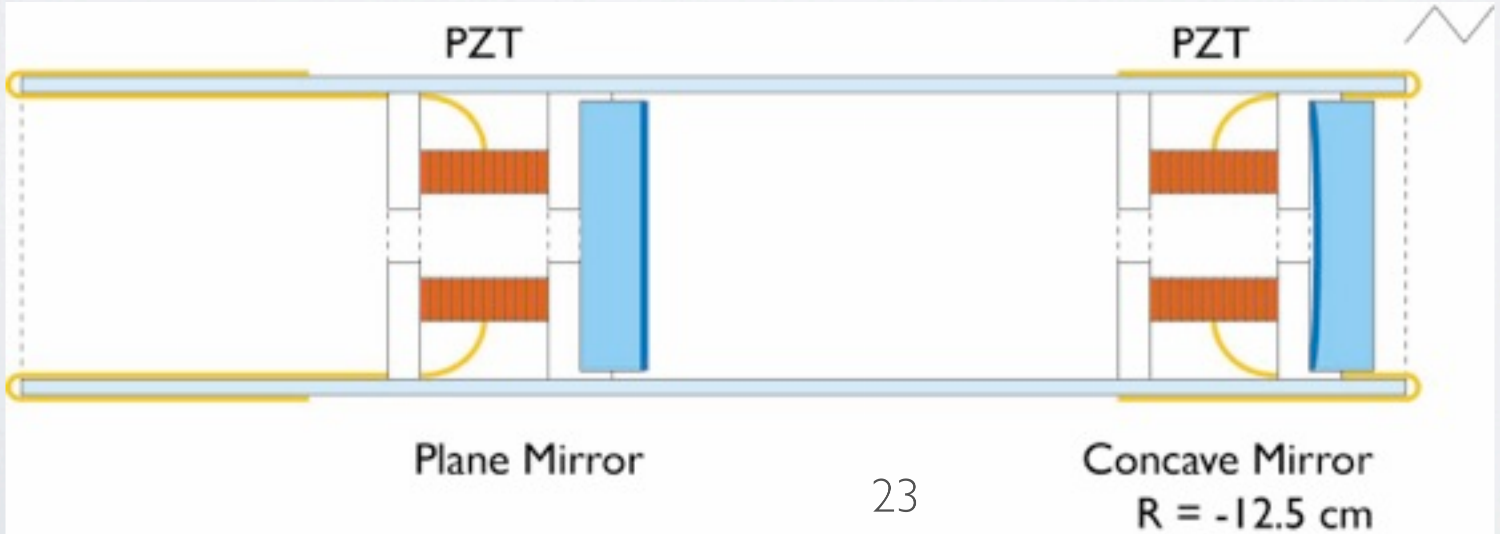


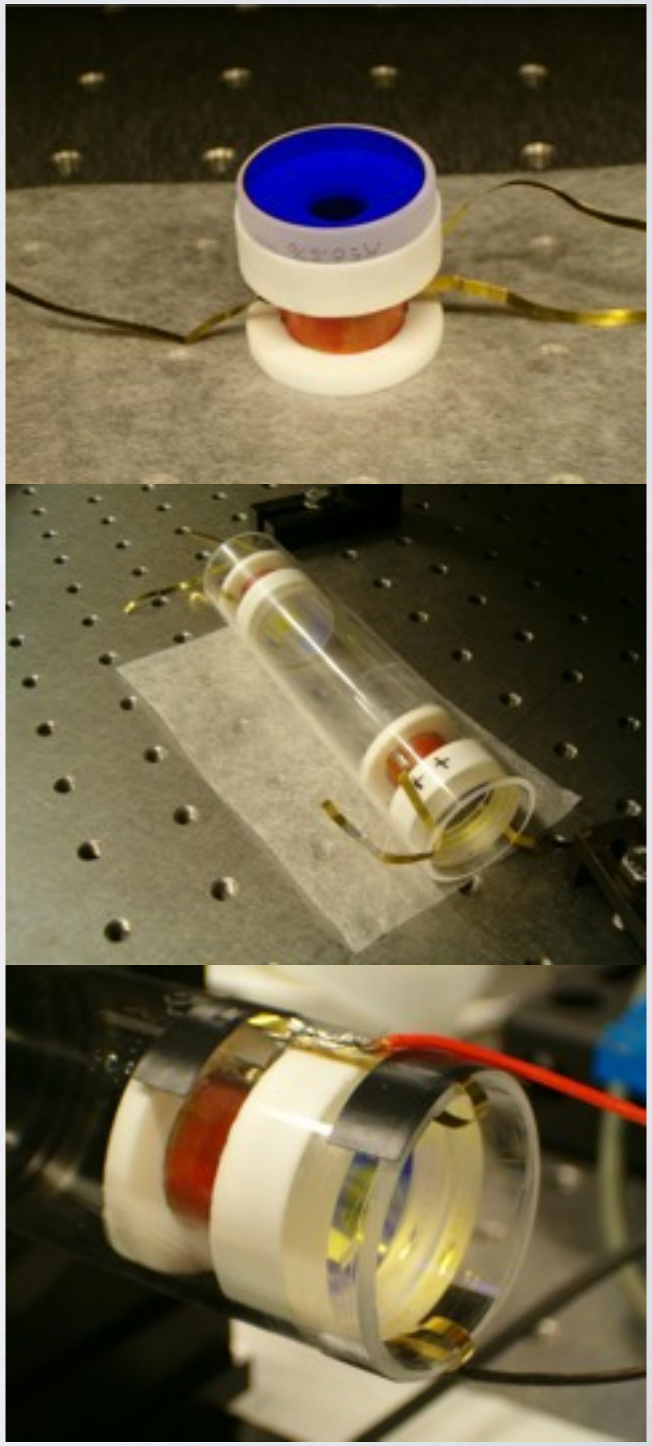




LASER FREQUENCY STABILIZATION

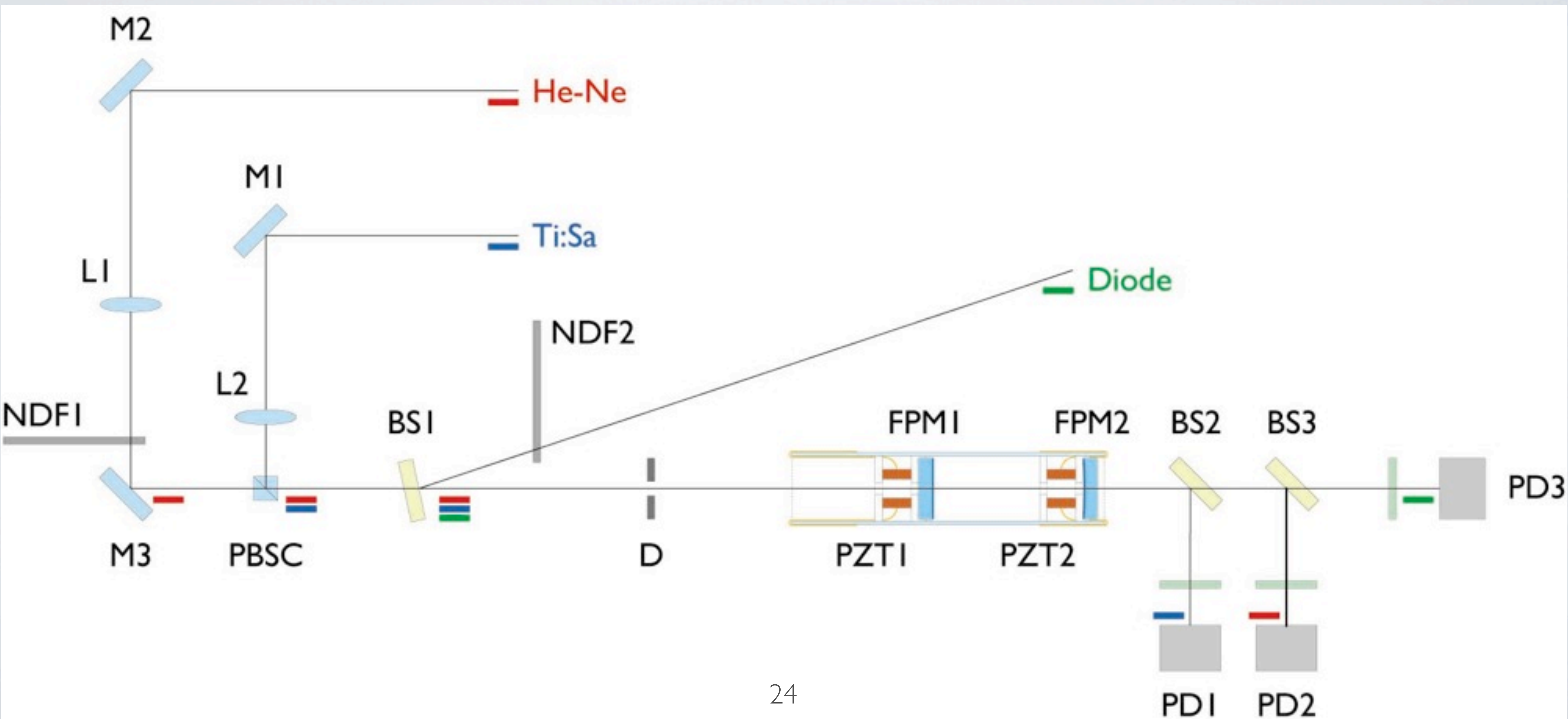
- Mirrors for λ = 633, 718, 780 nm
- FSR = 600 MHz
- Finesse = 209
- PZT: 10 μm @ -1000 V



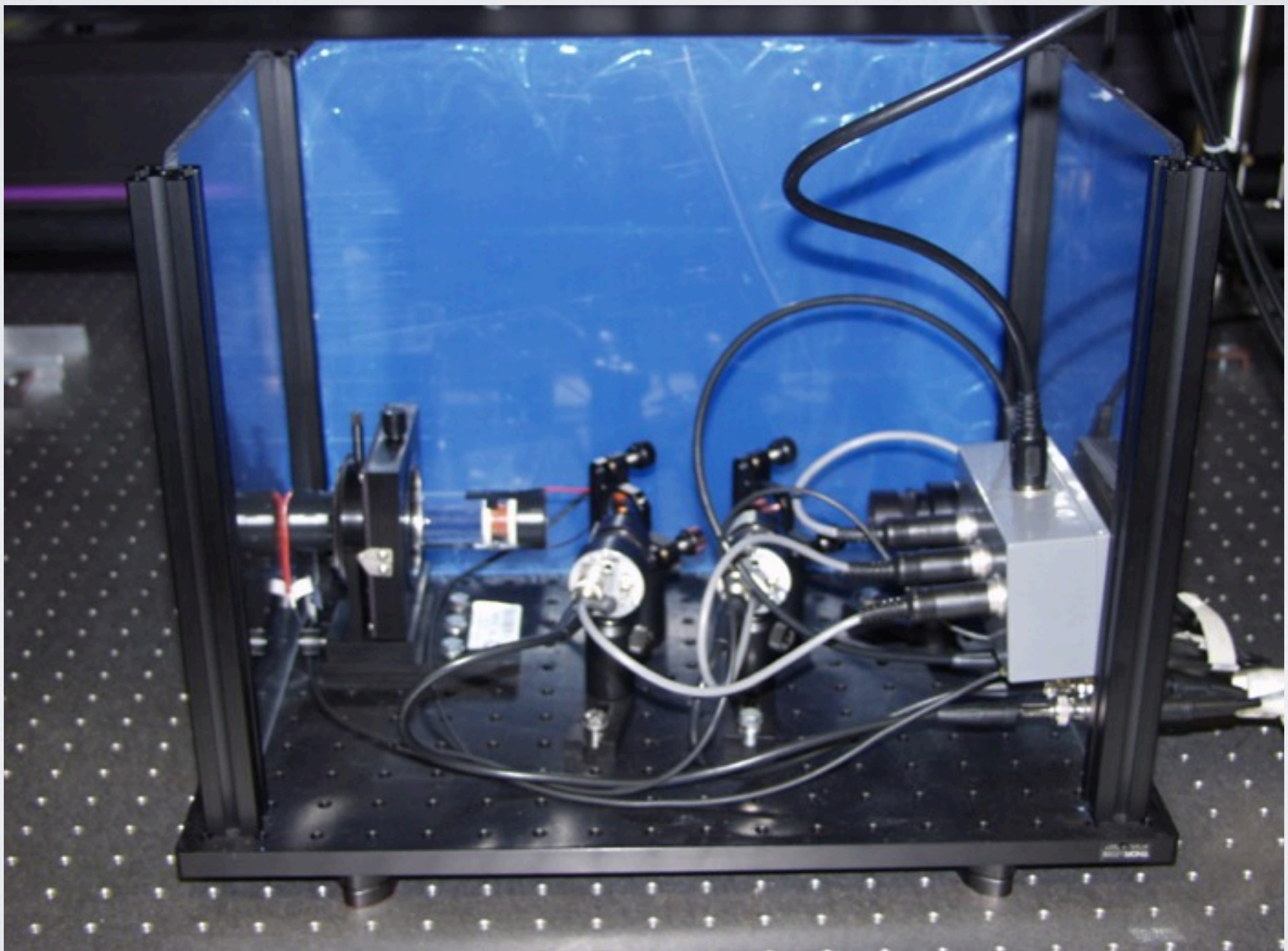


LASER FREQUENCY STABILIZATION

- Optical scheme: reference laser + 2 lasers to stabilize



LASER FREQUENCY STABILIZATION



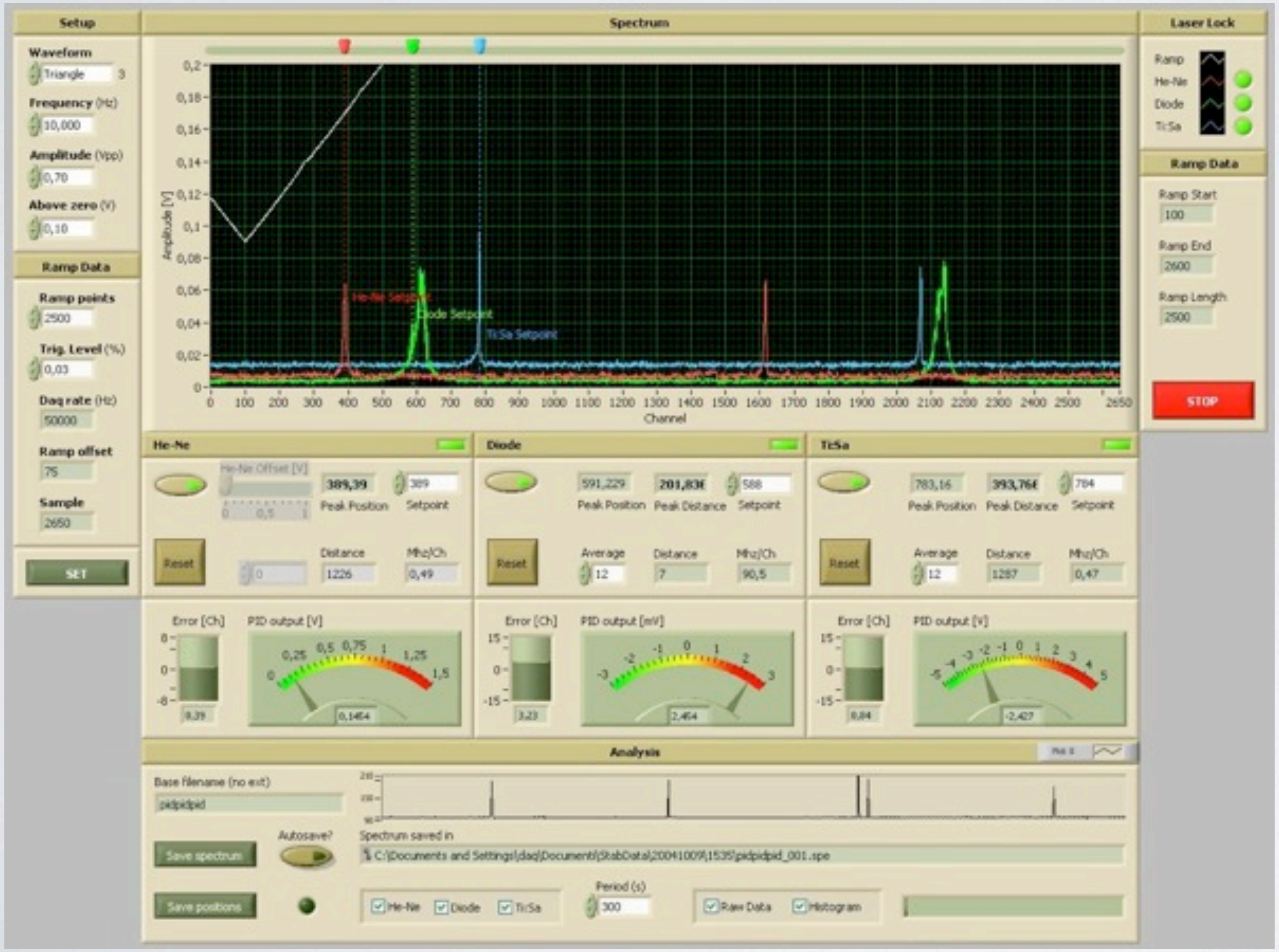
LASER FREQUENCY STABILIZATION

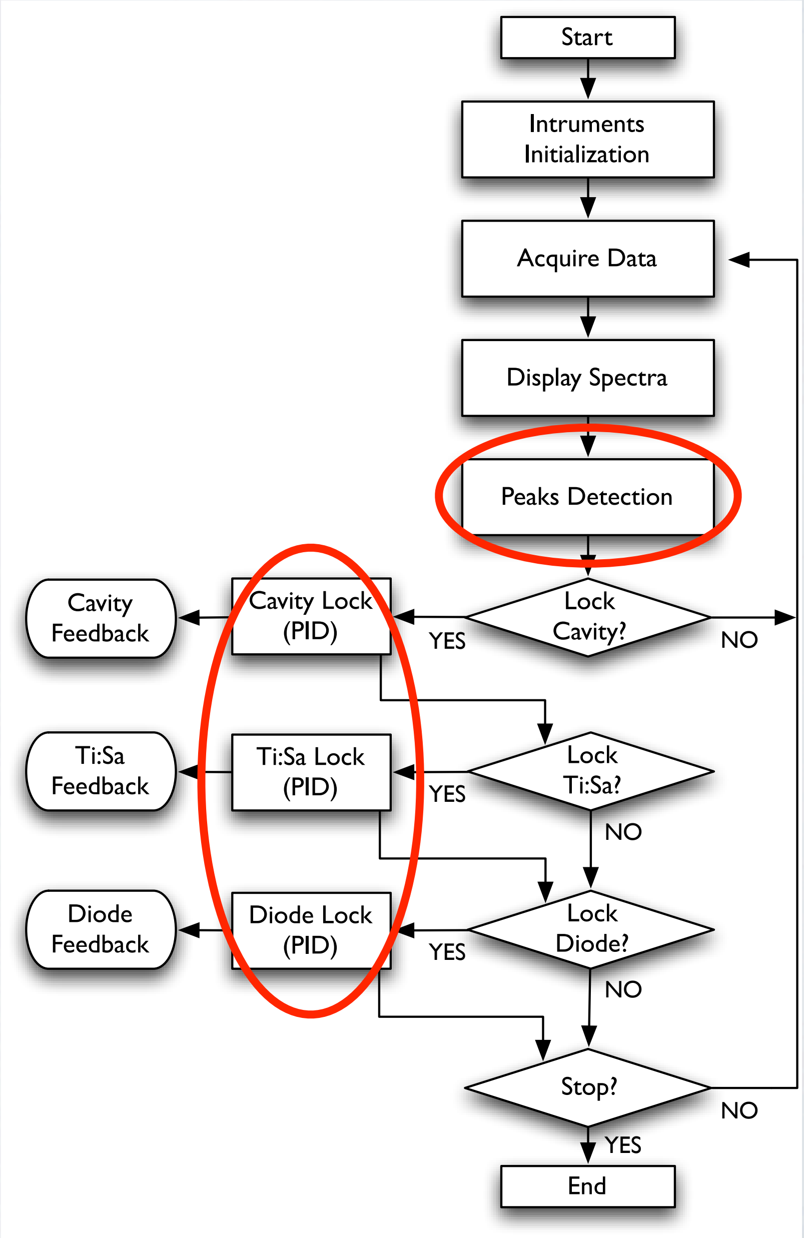
- The principle of working of the stabilization system can be summarized as follows:
- the system has to provide a voltage which keeps the cavity length constant and two voltages that drive each slave-laser frequency.
- These signals are produced according to different philosophies:
  - The cavity length is kept constant by keeping a transmission peak of the master laser locked to a position selected by the user
  - the slave laser peaks are precisely kept at a given distance (selected by the user) from the master laser peak.

LASER FREQUENCY STABILIZATION

- **SOFTWARE & HARDWARE**
- LabView-based
- NI-PCI-6052E card, 16bit, 333 kS/s, 16 analog input, for signal acquisition
- NI-PCI-6704E card, 16bit, 16 analog output for signal generation
- NI-PCI-GPIB, for waveform generator communication
- Agilent 33120A with GPIB connection, for waveform generation
- Physik Instrumente E-507.00, 3 channels HV amplifier, for piezoactuator driving

LASER FREQUENCY STABILIZATION





LASER FREQUENCY STABILIZATION

- **Peak Detection**
  - it calculates the absolute positions of the peaks (in terms of vector indices) in the vector in which the transmission signal of each laser is stored. it requires a threshold level and width as parameters.
  - it performs a quadratic curve fitting to find the peaks.
- For each laser, the peak location function gives at least two peak positions. In the stabilization algorithm we are interested in the position of the first one only.
- Having the position of two consecutive peaks and hence the distance between them, which corresponds to a FSR, allows to easily calibrate the spectrum in frequency. In this way the program calculates the MHz/Sample ratio for each channel (0.5 MHz/Sample typically).

LASER FREQUENCY STABILIZATION

- **PID algorithm**
- PID control is the most common control algorithm used in many fields when closed-loop feedback is needed
- The basic idea is to read a sensor, then compute the desired actuator output by calculating proportional, integral, and derivative responses and summing those three components to compute the output, which affects the next reading of the sensor when applied.
- The calculated feedback signal has the form:

$$m(t) = K_p e(t) + K_i \int_{-\infty}^{t} e(\tau) d\tau + K_d \frac{de}{dt}$$

- where Kp, Ki, and Kd are the proportional, integrative and derivative parameters, respectively, e(t) is the error signal (usually the difference between the read value and a set point), m(t) is the feedback signal.

LASER FREQUENCY STABILIZATION

- The proportional component (Kp) depends only on the error signal and determines the ratio of output response to the error signal. In general, increasing the proportional gain will increase the speed of the control system response. However, if the proportional gain is too large, the error signal will begin to oscillate. If Kp is increased further, the oscillations will become larger and the system will become unstable and may even oscillate out of control.

- The integral component Ki sums the error term over time. The result is that it causes a dumping of the error signal oscillations that allows to reach the set point. Increasing the integral component will reduce the speed of the control system response.

- The derivative component Kd is proportional to the rate of change of the error signal. Increasing the derivative parameter will cause the control system to react more strongly to changes in the error term and will in- crease the speed of the overall control system response. It is common to use very small values, because the derivative response is highly sensitive to noise in the error signal and can make the control system unstable.

$$m(t) = K_p e(t) + K_i \int_{-\infty}^{t} e(\tau) d\tau + K_d \frac{de}{dt}$$

LASER FREQUENCY STABILIZATION

- The stabilization system uses three independent PID functions, one for each laser peak, having as error signals the differences between the first laser-peak positions and the set-points chosen by the user.

	FP	Ti:Sa	Diode
K_p	$8 \cdot 10^{-5}$	$7 \cdot 10^{-4}$	$6 \cdot 10^{-4}$
K_i (min)	$4 \cdot 10^{-3}$	$2 \cdot 10^{-2}$	$1 \cdot 10^{-2}$
K_d (min)	$1 \cdot 10^{-5}$	$1 \cdot 10^{-5}$	$1 \cdot 10^{-5}$
dt (s)	0.5	0.5	0.5

- The ”guess and check” method has been applied to find optimal values

- The implemented PID function requires the PID parameters, the set point, the position of the first laser peak and the range of the output signal. It then evaluates the feedback signal which is sent to the FP cavity or to the laser drivers by means of the DAC card.

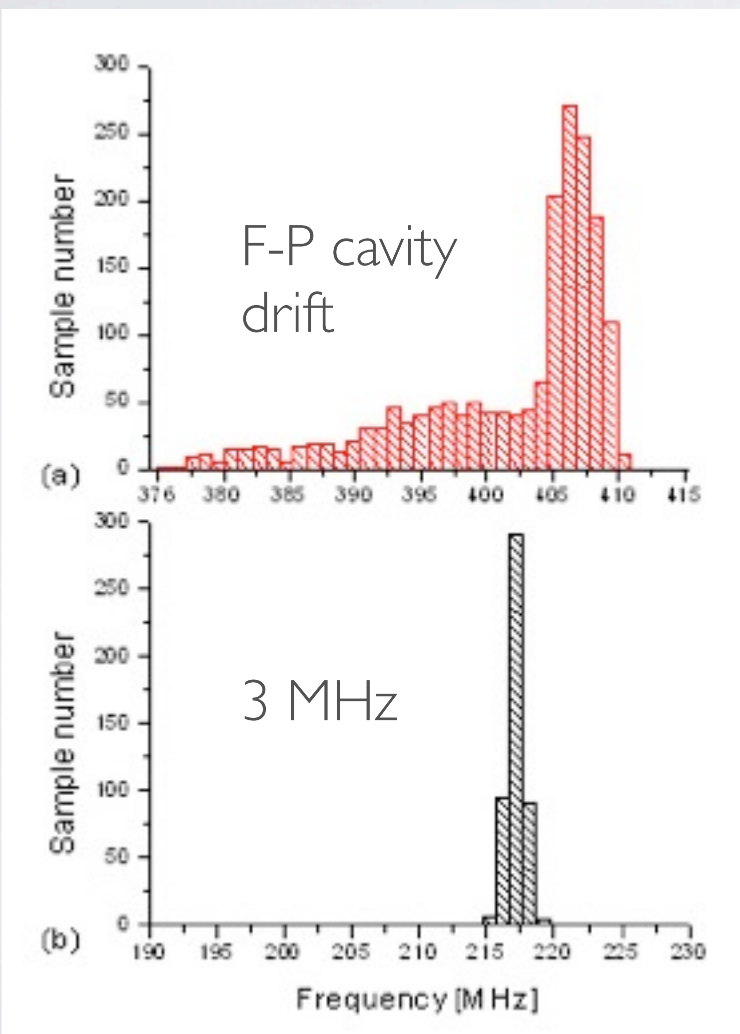
- The signal generation occurs once every iteration of the data acquisition cycle.

LASER FREQUENCY STABILIZATION

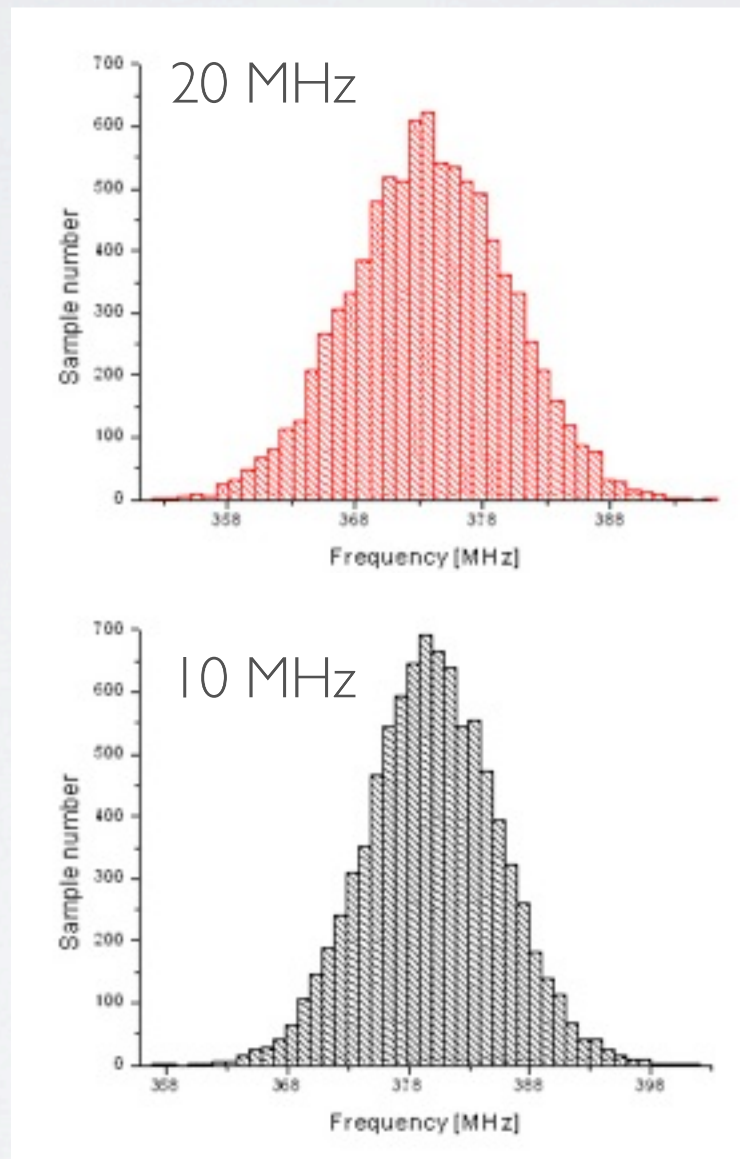
- Results

OFF

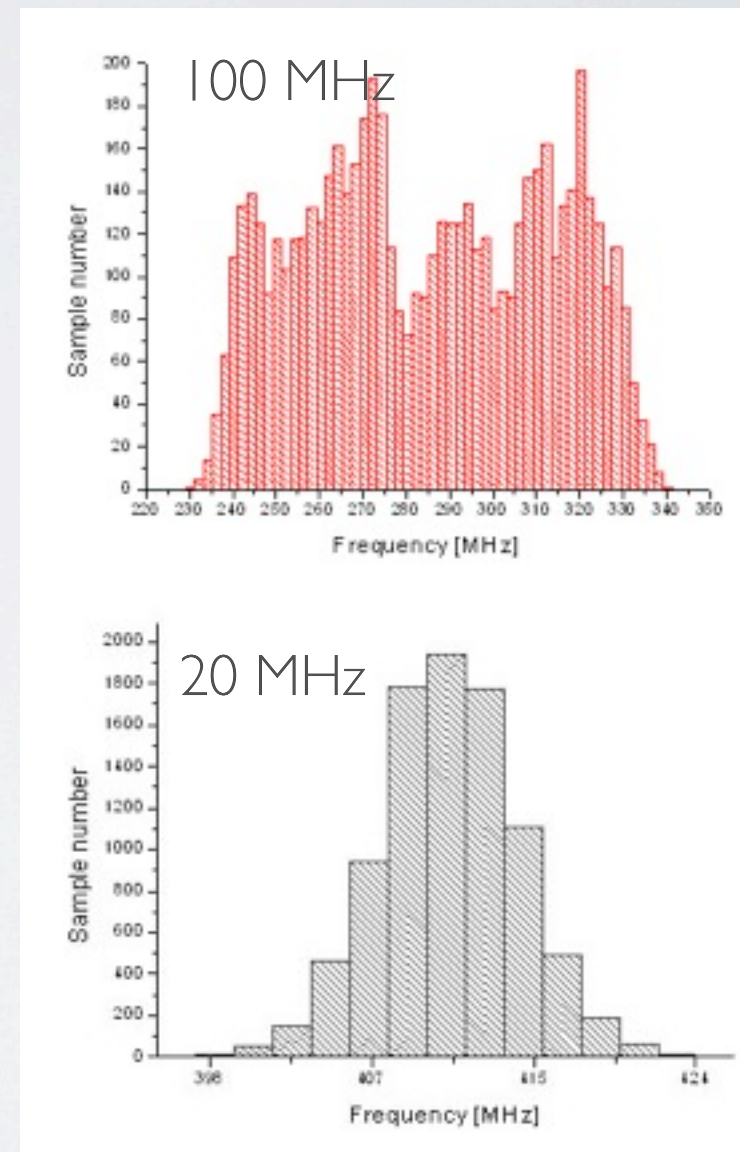
ON



He-Ne ⇒ F-P cavity



Ti:Sa



Diode

TRAP DETECTION

- Hamamatsu ORCA II CCD camera (IEEE1394)
- Short focal length (21mm) objective
- Background subtraction (uniform images)
- Weighted background subtraction (to compensate for laser intensity fluctuations)
- Calibration (number of atoms in the trap)
- Noise < 0.005 pW (50 atoms)
- Labview® based control system for image acquisition and online analysis

Repumping laser:	100 mW Diode, 817 nm. Spectrum enlarged to 100 MHz by current modulation at a rate of 4 kHz. $\nu_{\text{repump}} = 366898751(90)$ MHz.
Trapping laser:	200 mW Ti:sa, 718 nm. Slow scan to find Fr trap. $\nu_{\text{trap}} = 417412461(90)$ MHz.

TRAP DETECTION

- The first important topic is how to deduce from a photogram of a cold cloud of atoms how many atoms are present in the cloud.
  For this we have to set a good definition for the signal S that we have to deduce from the photograms.
  Then we have to establish the proportionality relation between S and the number of atoms.

- Once we have performed this preliminary job, in order to know the sensitivity of the detection system, we have to evaluate the noise.
  The important quantity is not the sensitivity of the CCD with respect to the photon signals, but the signal to noise ratio.
  We will see that we are not limited by the electronic noise of the CCD: the noise comes mainly from the background light present in the cell.

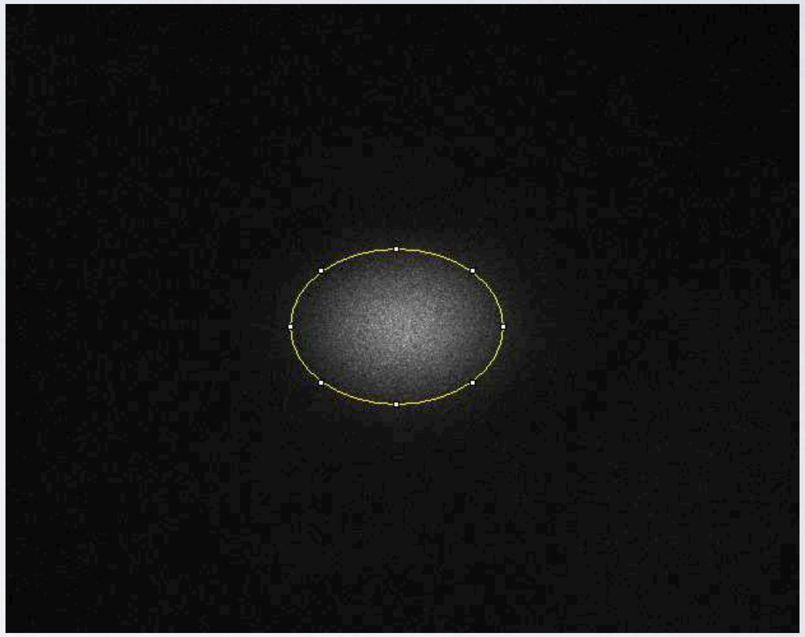
TRAP DETECTION

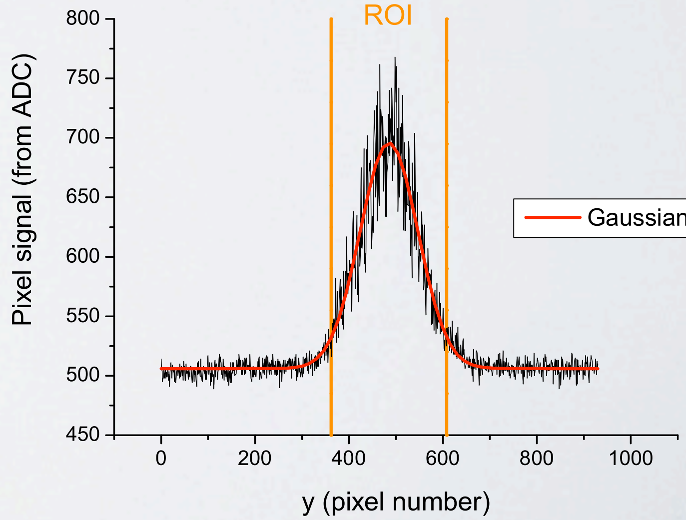
- Photogram of a spot coming from a He-Ne laser, used to simulate the image of a MOT cloud (elliptical shape).

- The logical procedure to know "how much light" has entered the detection system is to sum the digitized signals from each pixel of the photogram.

- Definition of a ROI around the trap by using the profile of the spot along x and y axes.

- The idea is to fit the profiles with gaussian functions $\exp(-2 \cdot ((x-x_c)/w_0)^2$, where x_c is the coordinate of the center of the spot and w_0 the width of the gaussian and take as ROI an ellipse with r_c as center and $2w_0$ (for x and y profiles) as diameters (for the x and y axes of the ellipse).





TRAP DETECTION

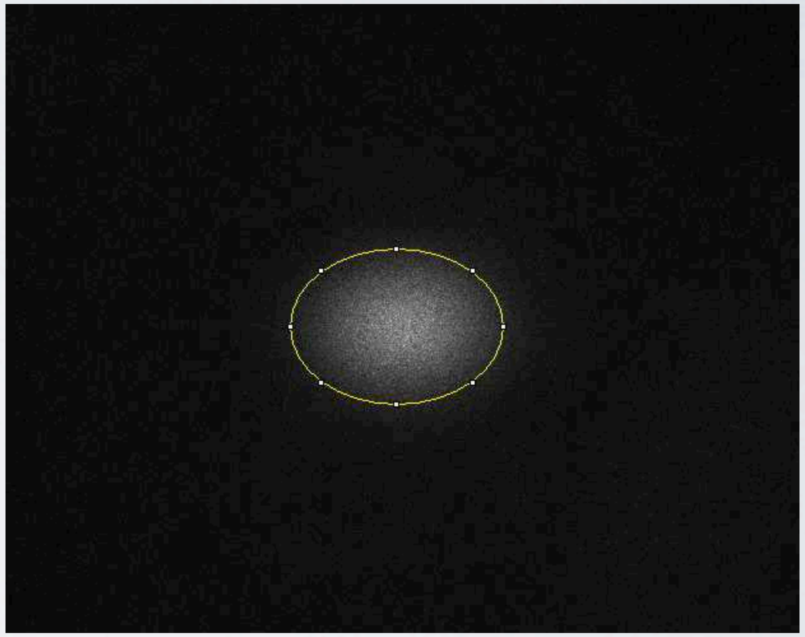
- Raw signal can be defined as:

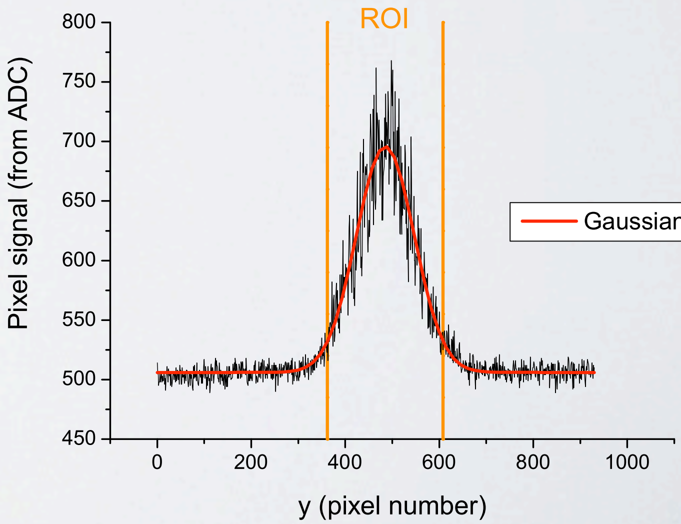
$$S_{\mathrm{raw}} = \sum_{\mathrm{pixels}(i) \in \mathrm{ROI}} S(i).$$

- taking into account background:

$$S = S_{\mathrm{raw}} - S_{\mathrm{background}},$$

- where $S_{\mathrm{background}}$ is the raw signal coming from the detection system when no spot (or trap) is present.





TRAP DETECTION

- **Calibration**
- the signal S must be calibrated with respect to the number of atoms in the MOT cloud.
- This can be performed in two steps:
  - first the calibration of the CCD in terms of the light power entering the zoom lens. (S – power)
  - Then the calculation of how much light is emitted from the single atom and then reaches the zoom lens (i.e. calculations of fluorescence rate and solid angle). (power – atoms)

TRAP DETECTION

- **S – power calibration**

- We choose to calibrate the CCD with a spot obtained from a laser beam (He-Ne or Ti:Sa) incident on a black screen.
  The black screen is tilted with respect to the laser beam, in order to obtain an elliptical shape for the spot.

- Photograms were taken for different powers, at the three wavelengths 633 nm, 721 nm, 779 nm.

- We took photograms for 1 s exposure time, and also 100 ms @ 633 nm in order to check that signals were 10 times less.

	$(S/1000)/P(\mathrm{pW})$
He-Ne, 100 ms	54.5
He-Ne, 1 s	546.2
Rb, 1 s	345.6
Fr, 1 s	461.2

TRAP DETECTION

- **power – atoms calibration**
- Taking into account the rate equations for all possible transitions (fluorescence decay, absorption and stimulated emission induced by trapping and repumping lasers),
  the typical detuning used in the MOT (**Γ**)
  and the solid angle covered by the detection system ($f = 1.5 \cdot 10^{-3}$),
  it is possible to estimate the power emitted by one trapped atom and conversely the number of atoms that emit a certain power

Rubidium

Detuning	-2Γ	0
P_{tot}/atom	1.6 pW	4.7 pW
$P_{det} = 1$ pW $\rightarrow$	400 atoms	140 atoms

Francium

Detuning	-2Γ	0
P_{tot}/atom	2.1 pW	6.2 pW
$P_{det} = 1$ pW $\rightarrow$	300 atoms	107 atoms

TRAP DETECTION

- **Noise evaluation**
- We can distinguish between two kinds of noise:
  - the noise intrinsic to the CCD, measured when no light enters the detection system (in practice camera with the diaphragm completely closed)
  - and the noise coming from the background light (essentially the light from the Ti:Sa laser).
- The simplest way to measure the noise is to take a series of photograms, evaluate the signal S for each photogram and calculate the variance of this quantity for the acquired series.
  By this way we can measure the intrinsic noise (with closed diaphragm) and the background noise (with diaphragm opened and no trap).
- Since the considered quantity (S) is the same we use for the valuation of the trap signal, thanks to our calibrations we can directly express the noise in terms of power (pW) and number of trapped atoms.
- The noise was measured several times: we found that the background noise is always much larger than the intrinsic noise.

TRAP DETECTION

- **Background subtraction**
- In order to improve the quality of the photograms,
  we can subtract from each acquired image a reference background image, pixel by pixel.
- In practice, the background image is obtained from the average of a series of 3–5 photograms taken without trap.
- The resulting images are more uniform, and then a weak trap is more easily detected by eye.
- Note that the noise (the variance of S) does not change, since we only subtract an offset.

TRAP DETECTION

- **Weighted Background subtraction**
- Usually a large part of the background noise is due to power fluctuations of the main laser: in a simplified model, we can say that the background light is directly proportional to the main laser power. It is possible to compensate in part these fluctuations.
- We define a second ROI, named ”background ROI” spatially shifted with respect to the trap ROI and with the same shape and dimension for simplicity.
- Since this ROI is placed in a region where no trapped atoms are present, it directly monitors the background light.
- Let us call S^{bg} and S^{trap} the signals from the background ROI and the trap ROI. S(acq) refers to the acquired raw photograms (usually taken to try to see the trap), whereas S(ref) refers to the reference background image.

TRAP DETECTION

- **Weighted Background subtraction**
- With the simple subtraction, the considered image is obtained from the formula: (acq − ref), giving for the signal the formula $S^{trap}(acq) - S^{trap}(ref)$.
- In order to correct for background fluctuations, we now consider the weighted subtraction:

$$\mathrm{acq} - \frac{S^{\mathrm{bg}}(\mathrm{acq})}{S^{\mathrm{bg}}(\mathrm{ref})} \cdot \mathrm{ref},$$

- which gives the following elaborated signal:

$$S^{\mathrm{w}} = S^{\mathrm{trap}}(\mathrm{acq}) - \frac{S^{\mathrm{bg}}(\mathrm{acq})}{S^{\mathrm{bg}}(\mathrm{ref})} \cdot S^{\mathrm{trap}}(\mathrm{ref}).$$

- Note that electronic offset from raw CCD signals have to be taken into account: instead of the raw photograms acq_{raw} and ref_{raw} we have to use

$$\begin{aligned} \mathrm{acq} &= \mathrm{acq}_{\mathbf{raw}} - \mathrm{offset} \\ \mathrm{ref} &= \mathrm{ref}_{\mathbf{raw}} - \mathrm{offset}. \end{aligned}$$

TRAP DETECTION

- **Software and Hardware**

- The online image-acquisition software has been developed and deployed on a commercial PC using Windows. LabView has been chosen as graphical programming language due to its features in data acquisition and processing, the availability of the driver for the camera and of libraries to manipulate images

- The CCD camera is the model ORCA-ER C4742-80 from Hamamatsu.
  It has 1344 × 1024 pixel^2, low noise and high quantum efficiency at 718 nm (~ 50%).
  Camera parameters, such as exposure time, gain, offset, and syncronization can be set using the provided IEEE1394 interface. Image reading uses the same interface.

TRAP DETECTION

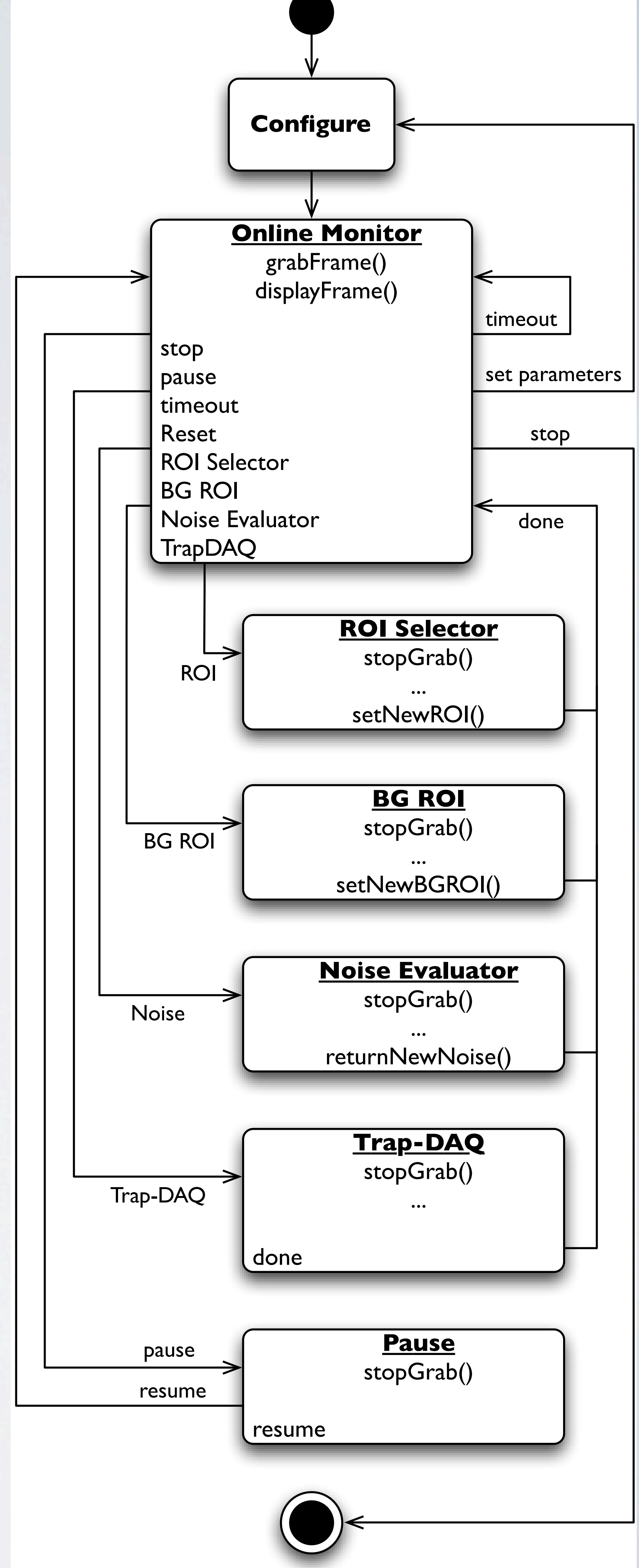
- The main requirements for the application are the following:
- it must be possible to set the exposure time and gain of the camera on-the-fly;
- image-acquisition rate has to be the fastest as possible taking into account the minimum exposure time and the computation time. Typical exposure times are 0.5 s, 1 s or 2 s for francium and of the order of 10–100 ms for rubidium;
- the trap and background ROIs must be selected by the user and then stored;
- the background subtraction and the evaluation of the trap population must be on-line just after each image acquisition and the GUI must show the elaborated image as well as a plot of the calculated trap population as a function of time

TRAP DETECTION

- The software has then to accomplish several different tasks:
  - set the acquisition parameters of the camera,
  - monitor the images,
  - define the trap ROI (signal),
  - define the background ROI,
  - evaluate the background noise,
  - and acquire the photograms implementing the background subtraction algorithm.

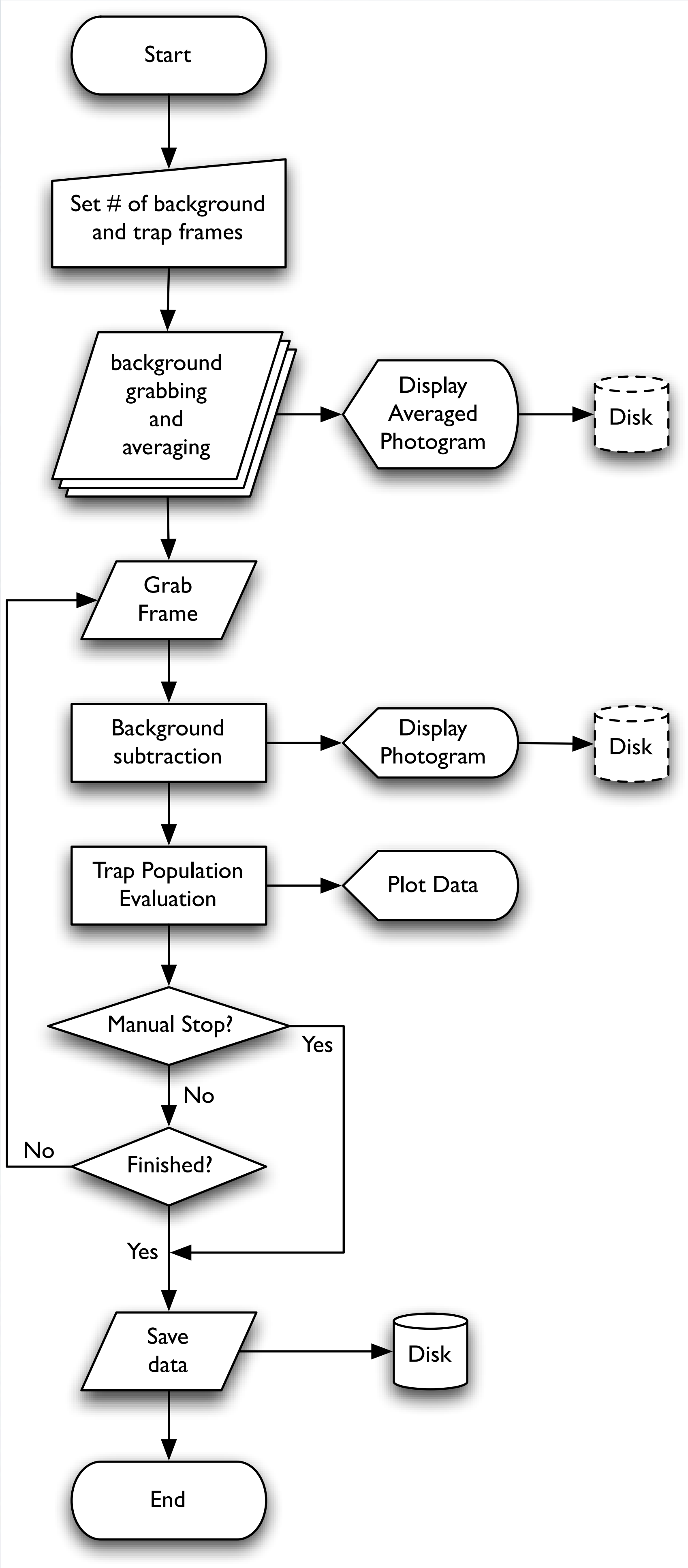
TRAP DETECTION

- It has been built as an event-driven state-machine: the main application cycles waiting for user input and launches the requested task
- It then consists of the following sub-applications:
  - Online Monitor.
    It is the main application, which can be used to set the acquisition parameters, and shows continuously the raw images acquired from the CCD camera.
  - ROI Selector.
    It allows to select the trap ROI using the algorithm presented previously.
  - BG ROI.
    It allows to graphically select the center of the background ROI which will be used for image analysis.
  - Noise Evaluator.
    It allows to evaluate the background level that has to be taken into account in the subtraction algorithm. It also helps in checking the correct alignment of the MOT optics and of the detection system.
  - Trap-DAQ.
    The most important application, which implements the subtraction algorithm. It allows to monitor the trap and to measure its population by on-line processing of the photograms. The acquired photograms are also saved into the file-system for off-line processing.



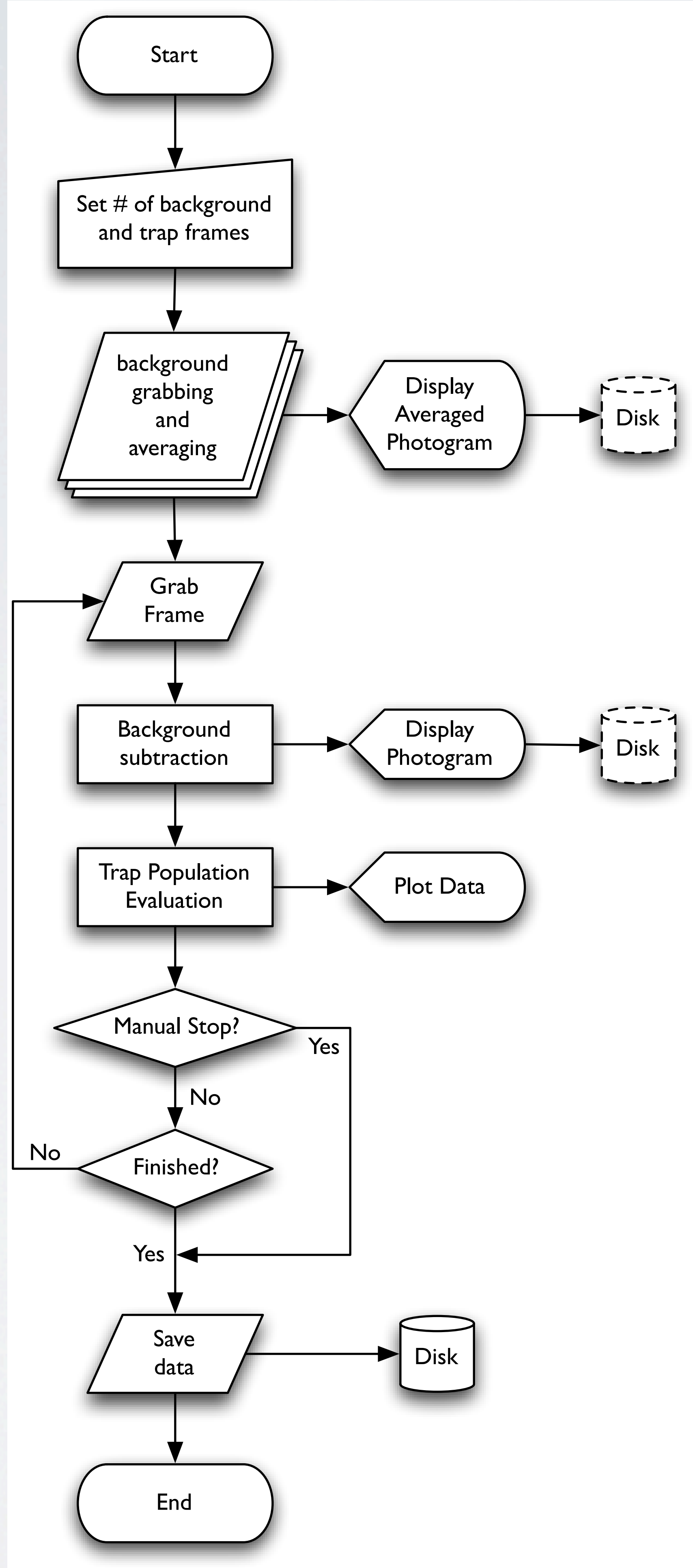
TRAP DETECTION

- The user must then set the number of frames to be used for background averaging and the number of photograms to be acquired and processed (the defaults are 5 and 600, respectively).
- A button starts the frame grabbing for the background. The acquired photograms are then averaged and the resulting image is kept in memory for the next operations and stored on disk. It is important to notice that those images must be taken without trap by keeping magnetic field off. The average is made pixel-by-pixel casting the images into a real-type image. This is the reference background-photogram that will be used in the following elaborations and is shown in the GUI.
- The trap and background ROI coordinates and geometry is read either from file or memory and will be shown on each image. The quantities $S^{trap}(ref)$ and $S^{bg}(ref)$, are calculated from the reference background-image as the sum of pixel values in the trap and background ROI, respectively.
- At this point the magnetic field is switched-on and an acquisition cycle starts grabbing frames of the (eventually) trapped atoms. Each acquired photogram is saved to disk in raw format for off-line processing. Before the program begins, the user can enable or disable this feature.



TRAP DETECTION

- Images are double-buffered into the CCD internal memory in order to guarantee a continuous acquisition while each frame is processed by the program. The relatively slow exposure-time needed by the experiment prevents performance troubles. A sustained rate better than 50 fps is anyway achievable by the system.
- A set of buffers are used to perform the pixel-by-pixel operations on the images. Each frame is type-cast to a real-image to which the electronic offset is subtracted. This image is also displayed in the GUI.
- For each cycle iteration the quantities $S^{trap}(acq)$ and $S^{bg}(acq)$ are calculated from the image and the weight factor $S^{bg}(acq)/S^{bg}(ref)$ is evaluated.
  The value S^{w}, which represents the signal of trapped atoms in terms of pixel values, is then obtained.
- In order to allow the researchers to observe the trap by eye, the background-subtracted image is also generated and displayed into the GUI.
  An image buffer is used for storing the image resulting from the multiplication of the background reference times the weight factor, which finally will be pixel-by-pixel subtracted from the acquired image.
- The LookUp Table (LUT) of these images can be modified during running in order to obtain the best contrast.

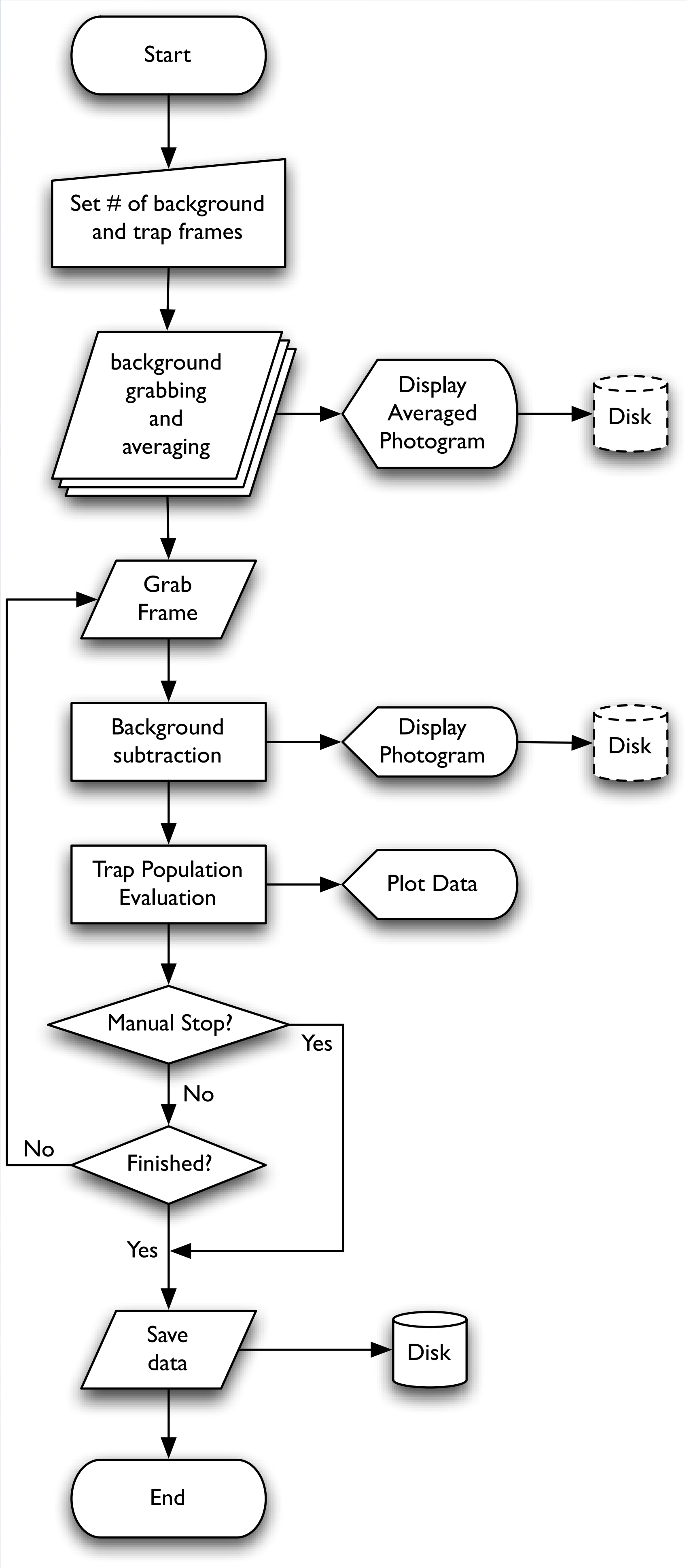


TRAP DETECTION

- At the first iteration of the acquisition cycle, the program read from file the CCD-calibration values and uses them in order to convert the obtained S^w trap-population into power and number of atoms. The latter is then displayed in an indicator of the GUI and stored in a vector.

- A plot of the number of atoms in the trap as a function of the acquired image (i.e. of time, in exposure-time steps) is automatically updated and displayed in the GUI. This plot is necessary when the frequency of the trapping laser is scanned in order to obtain the trap frequency-profile or when the loading or decay curve of the trap must be taken. It also helps during the trap-optimization procedures.

- The program cycles until it reaches the specified number of acquired images or when the user push a stop button.
  The vector containing the number of trapped atoms, the camera parameters, the size of the images and the coordinate of the ROIs are then saved to disk in a text-file for off-line use.

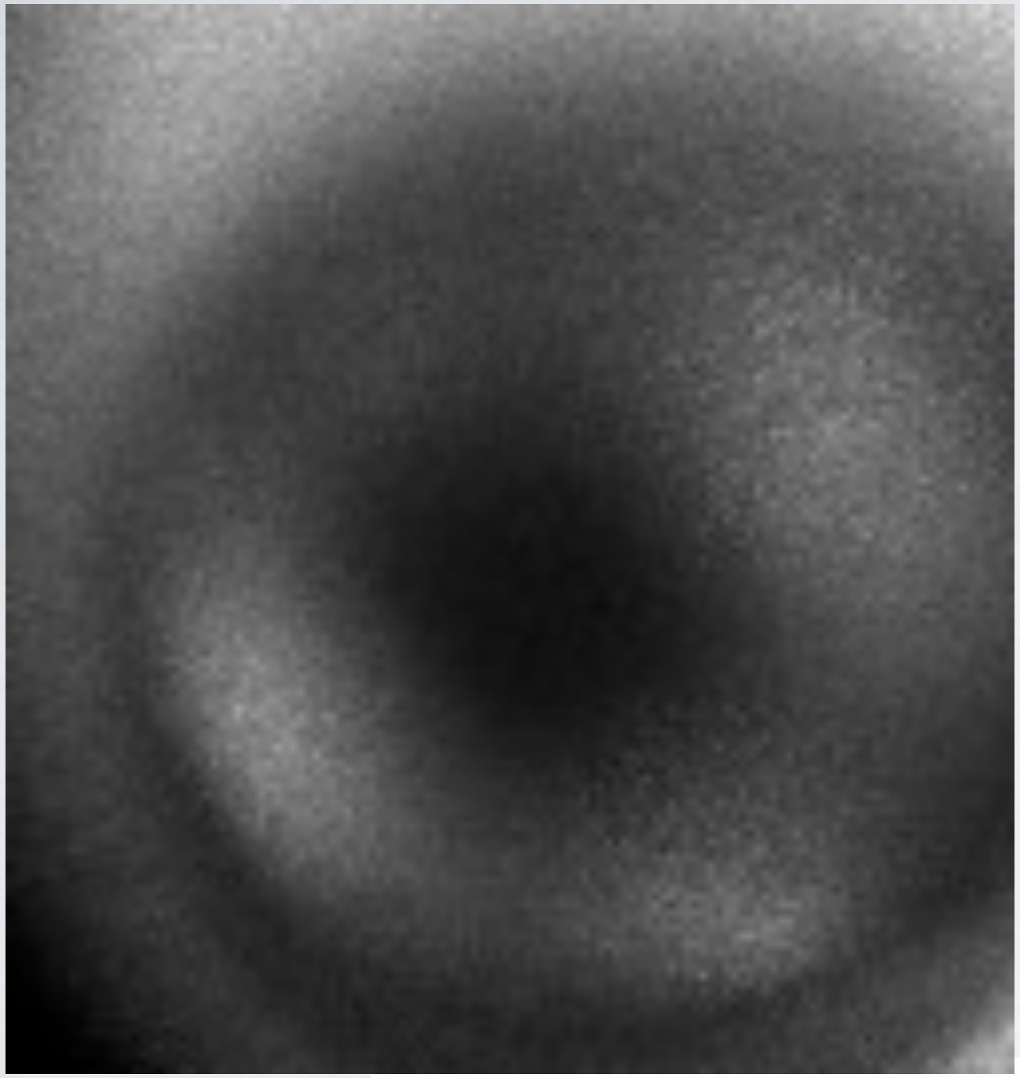


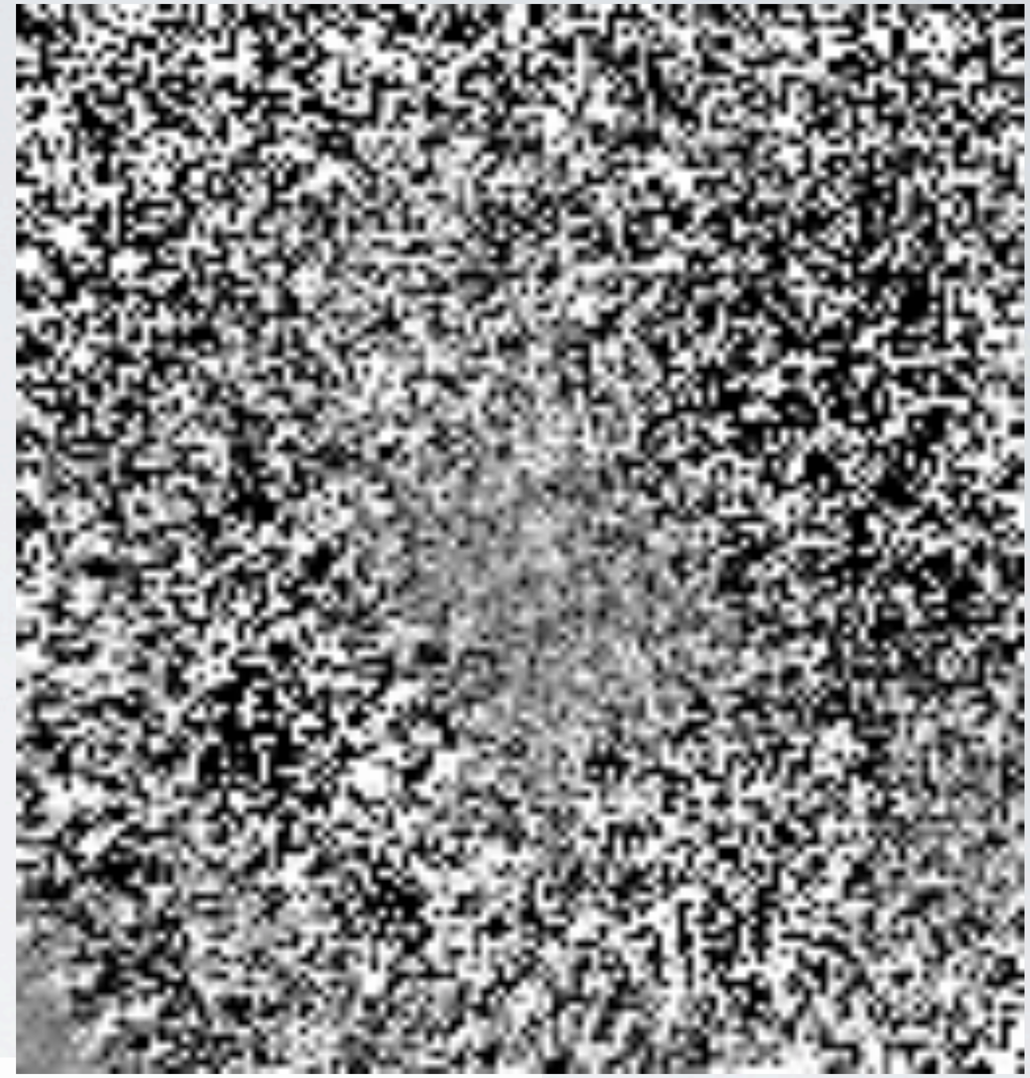
TRAP DETECTION

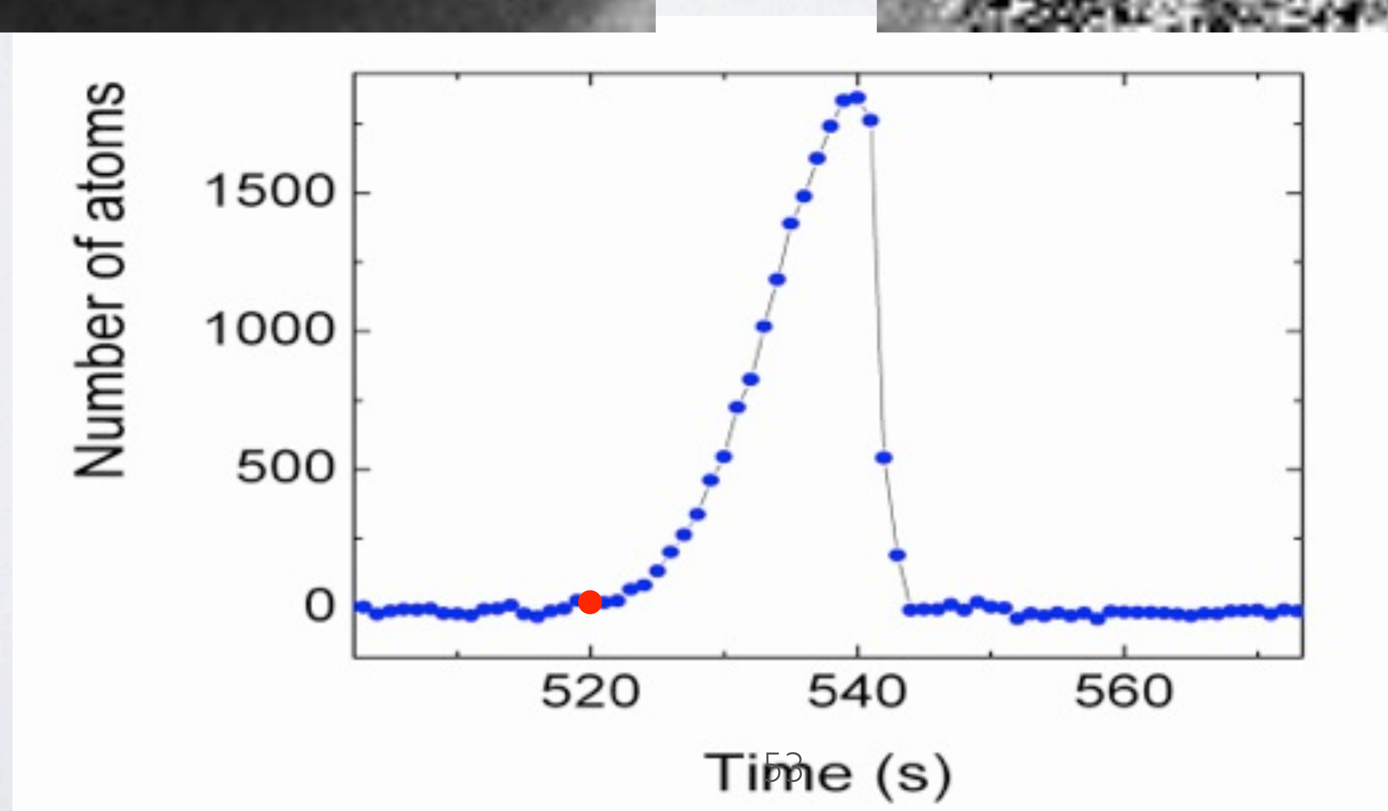
- The developed detection-system has been extensively tested and calibrated at LNL with a rubidium trap. The computer program has demonstrated a great sta- bility and it has been continuously running during several beam-shifts with the francium trap for periods up to 48 hours.

- The hardware ROI has been carefully chosen in order to minimize the stray-light present in the frame. The trap and background ROIs have been extensively studied in order to guarantee the best working conditions when changing from rubidium to francium atoms.

- The noise level achievable is of the order of 10 trapped atoms for francium. This means that a trap of 100 francium atoms should be clearly visible by eye.






Number of atoms
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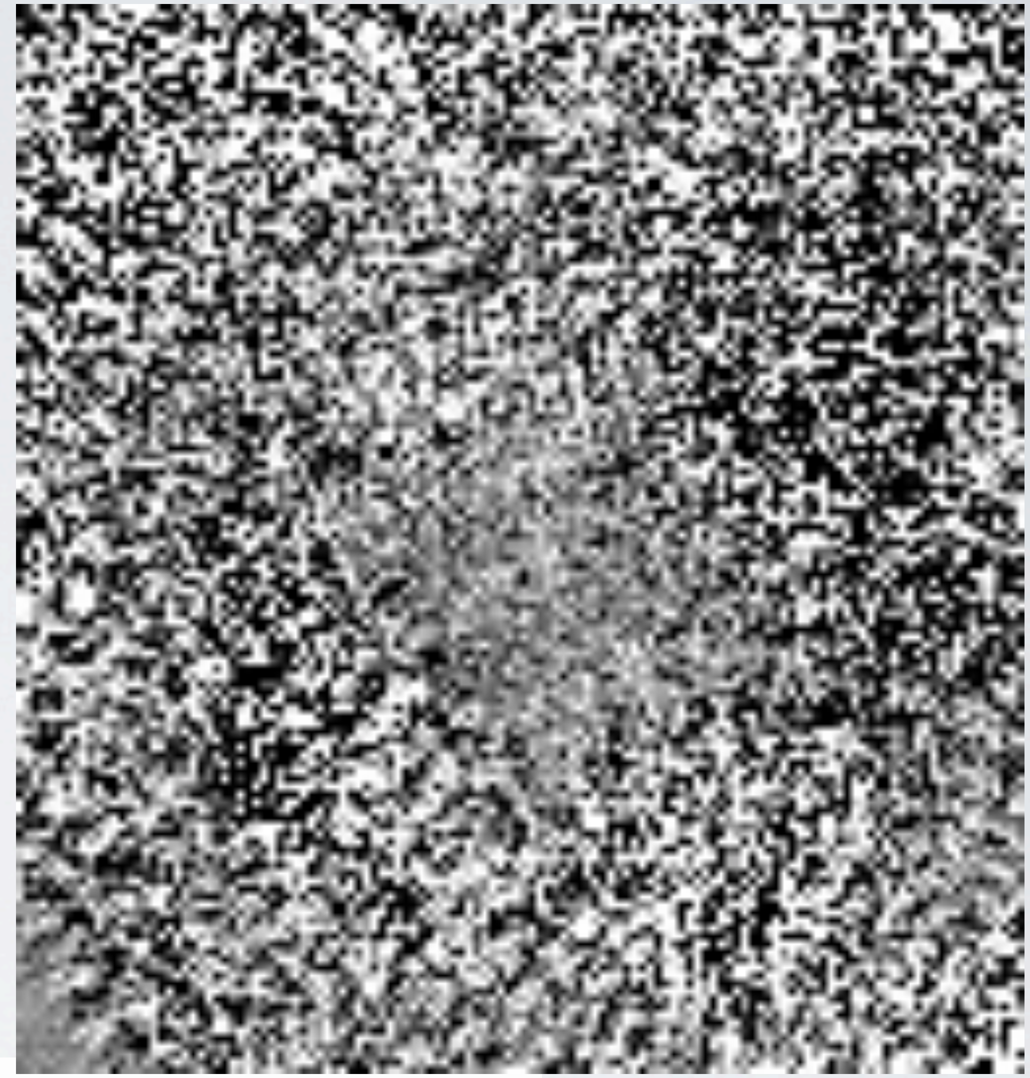
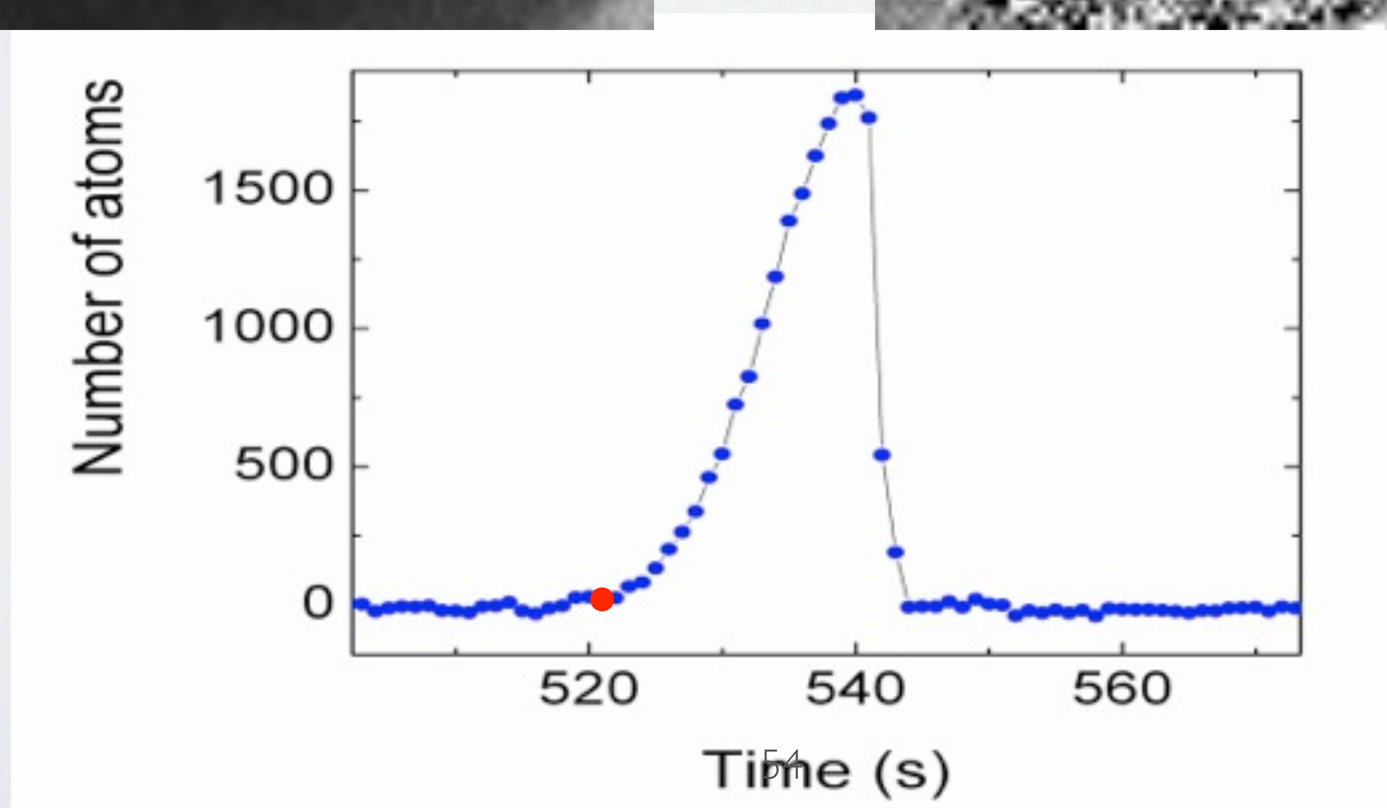
Time (s)

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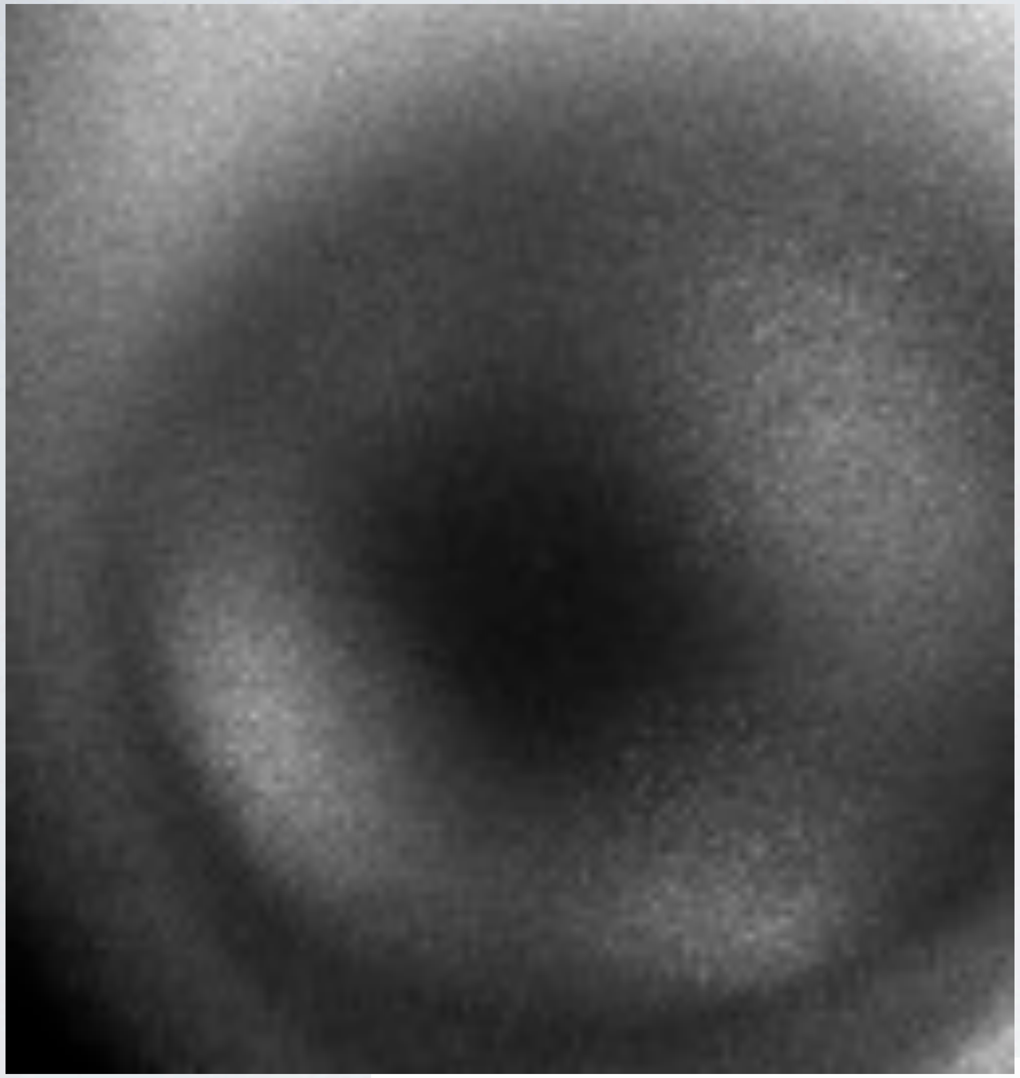
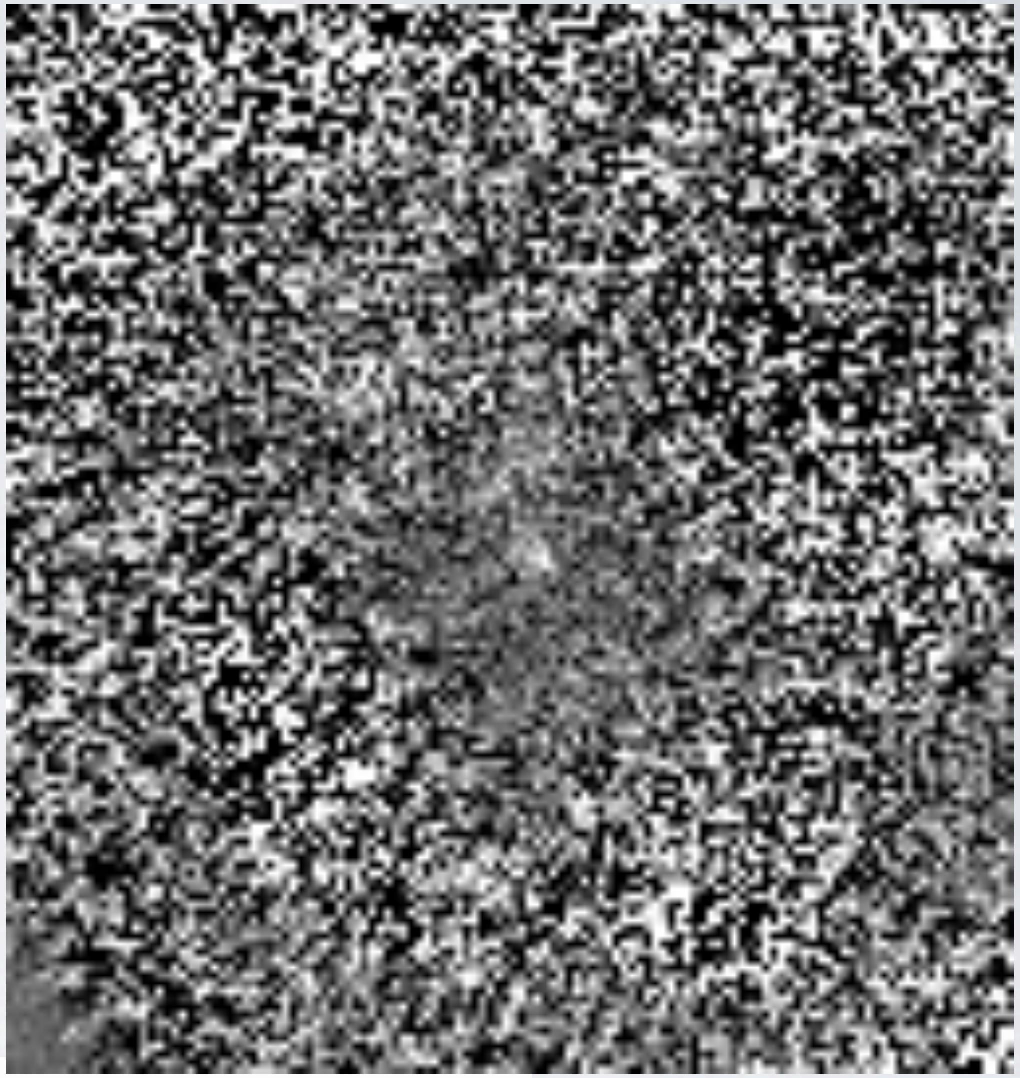
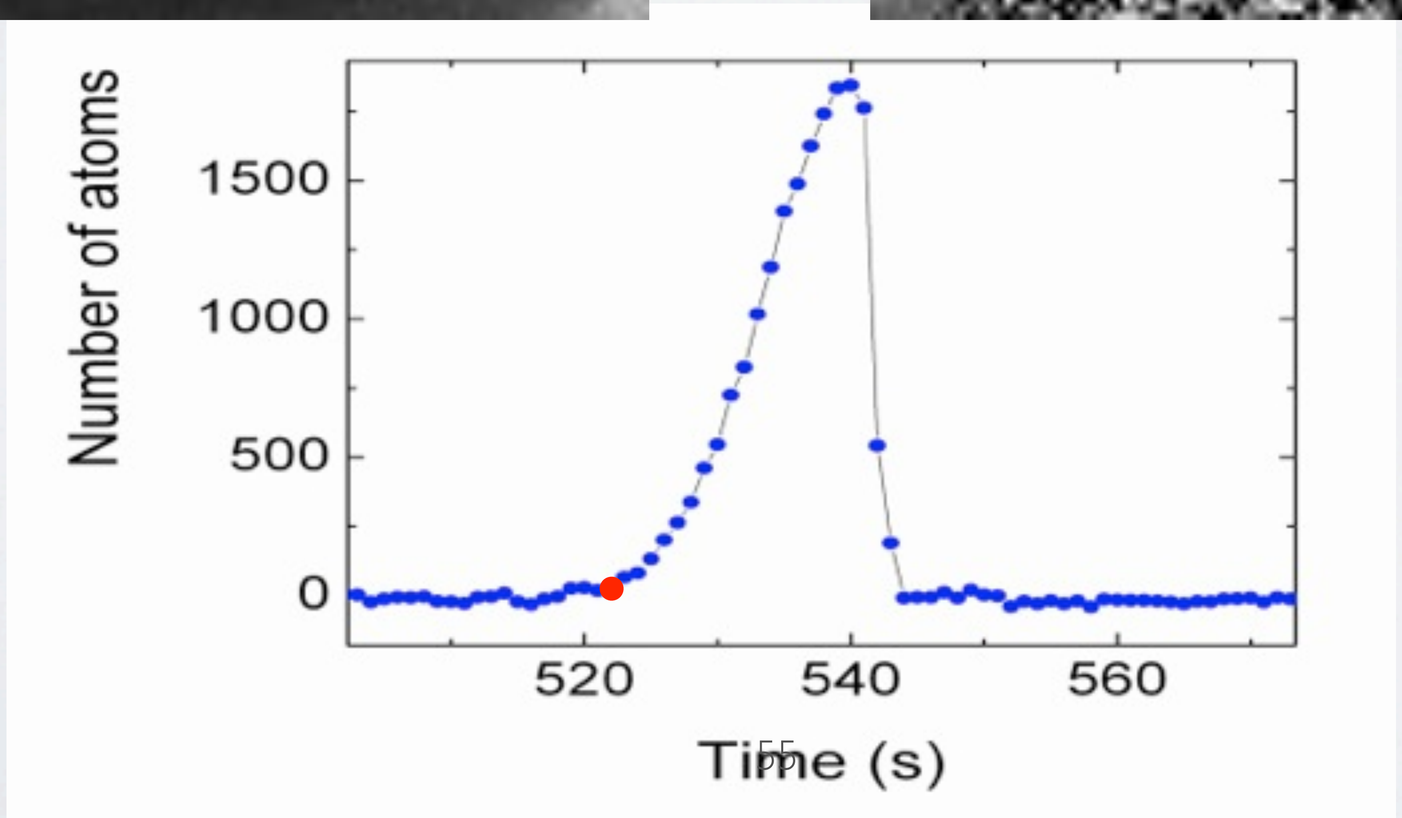
Time (s)



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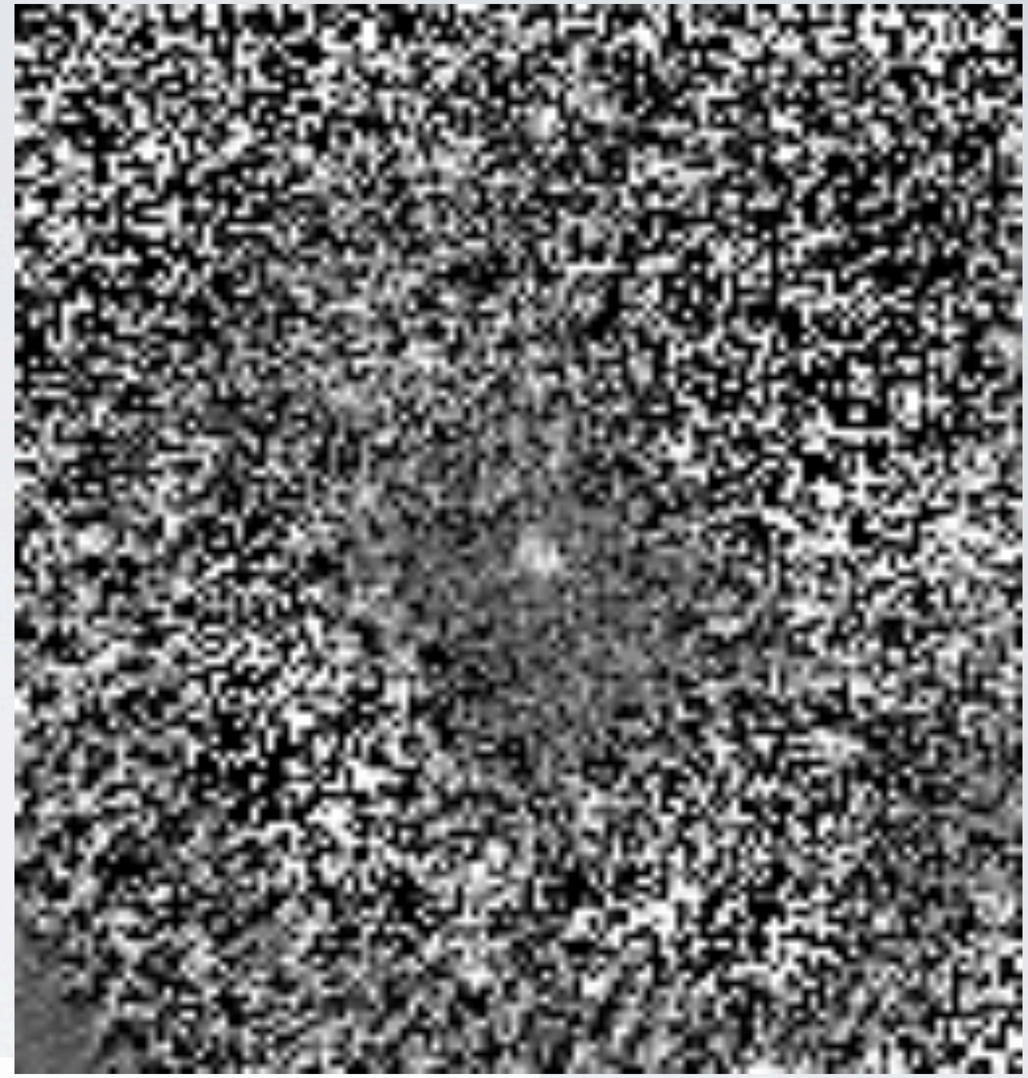

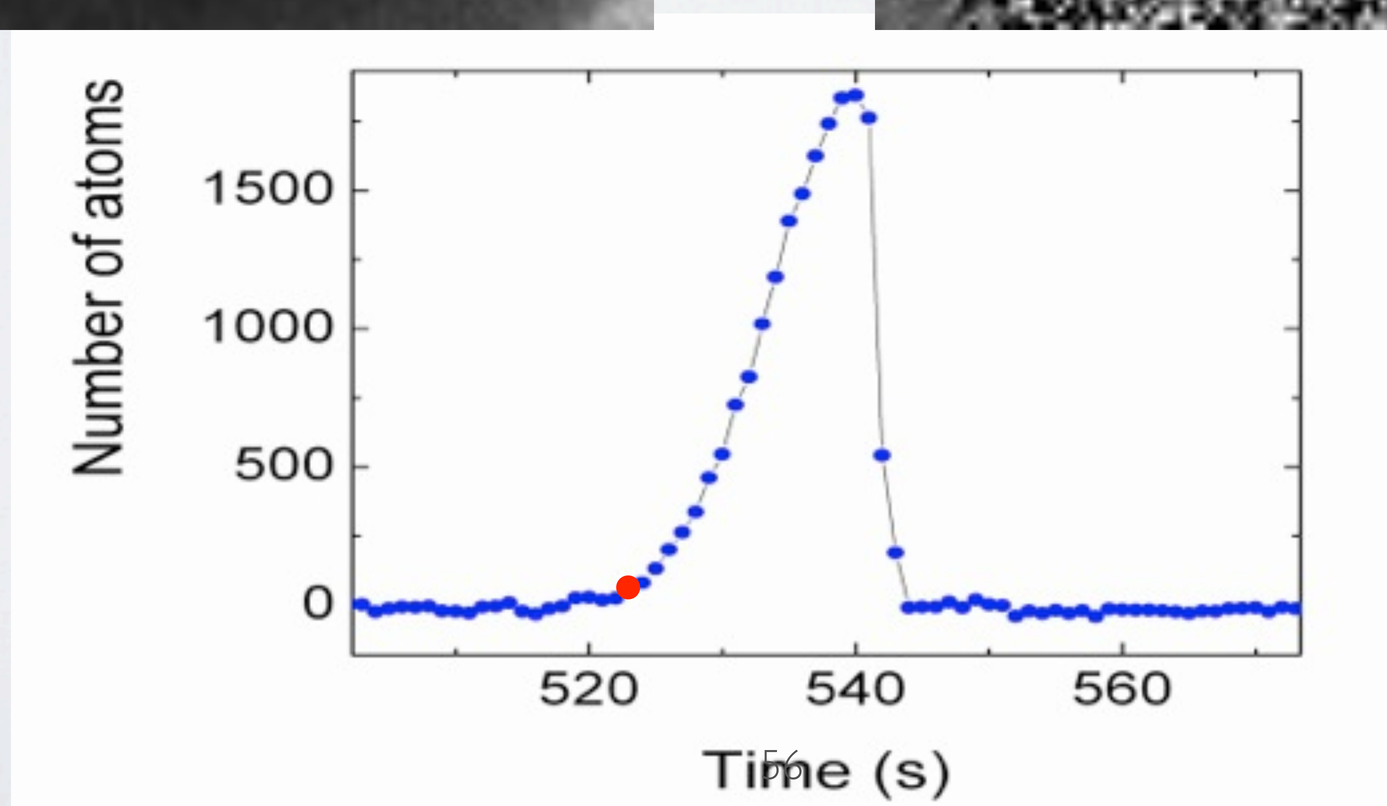
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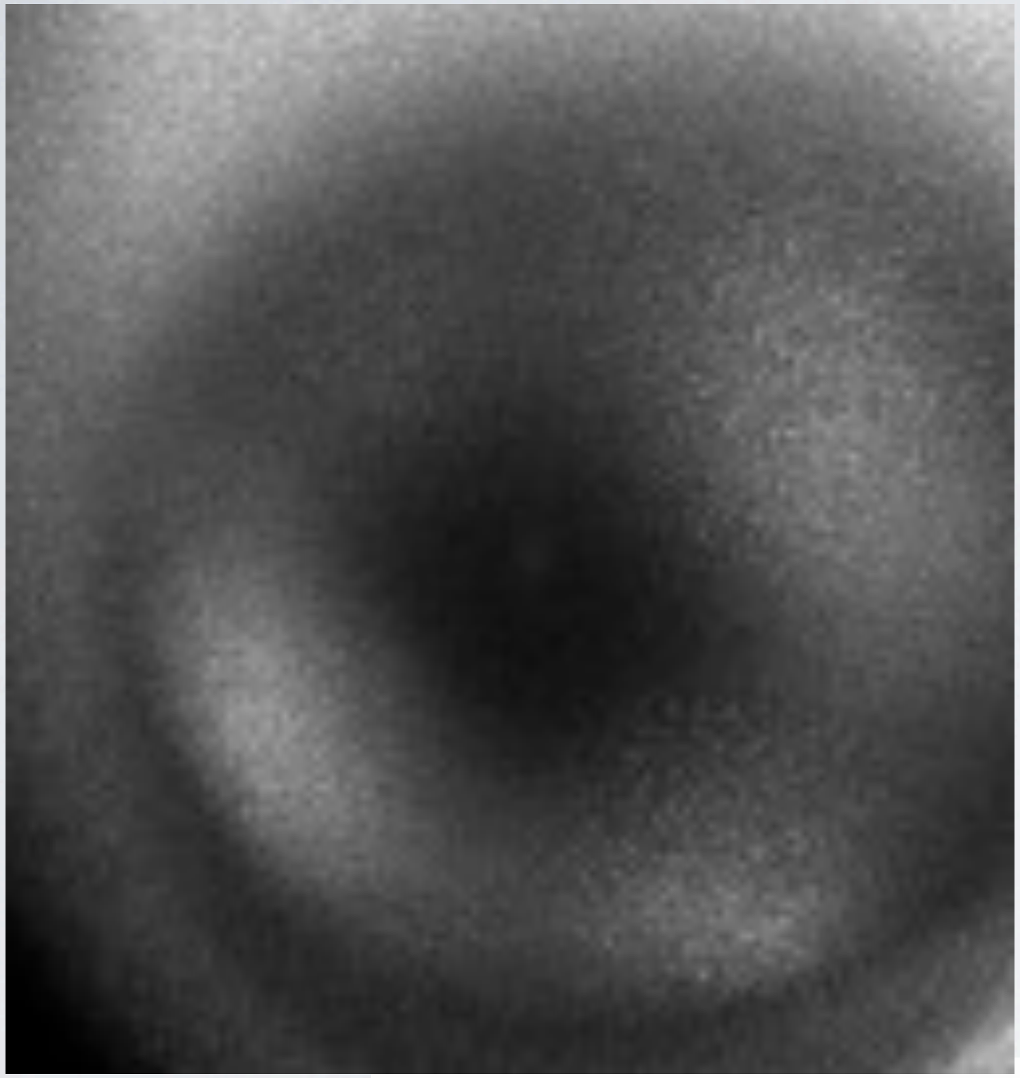

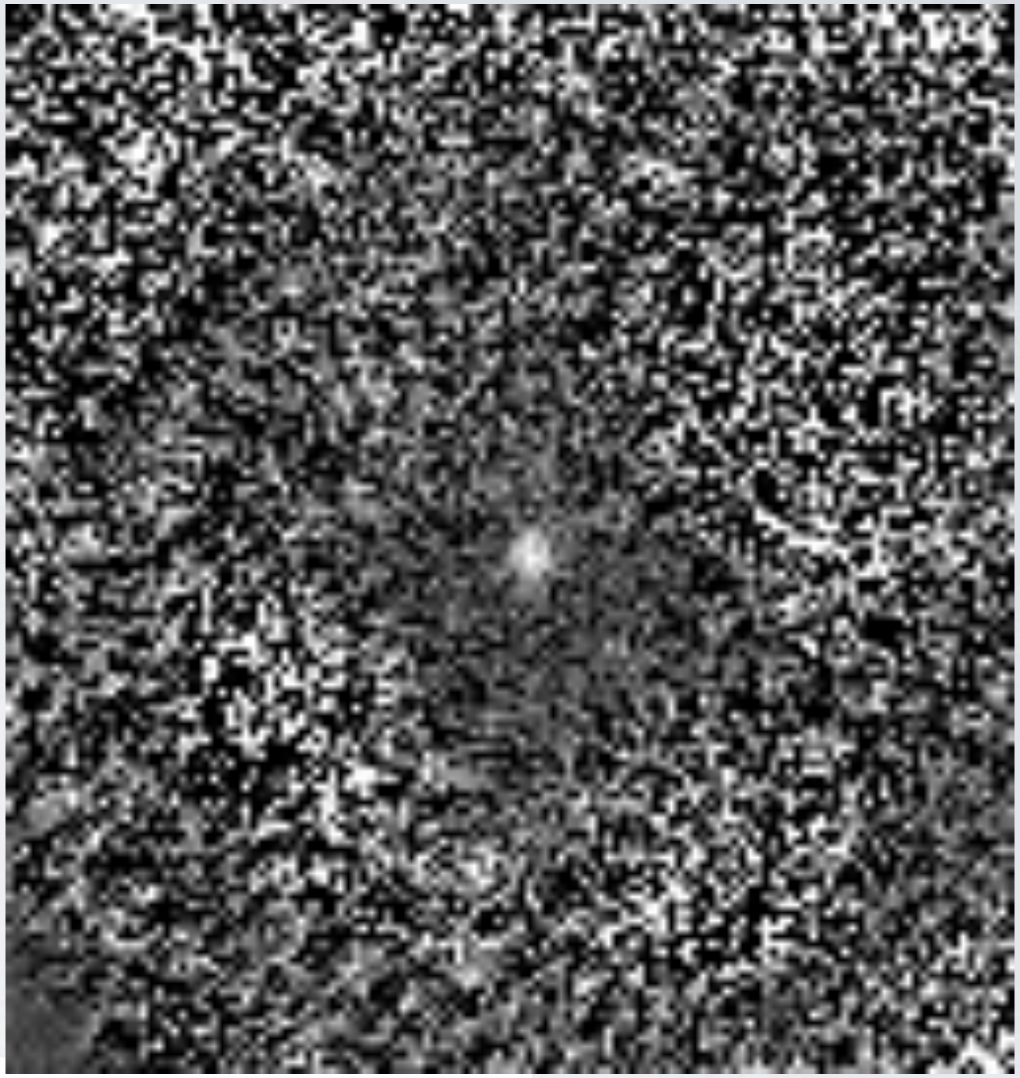

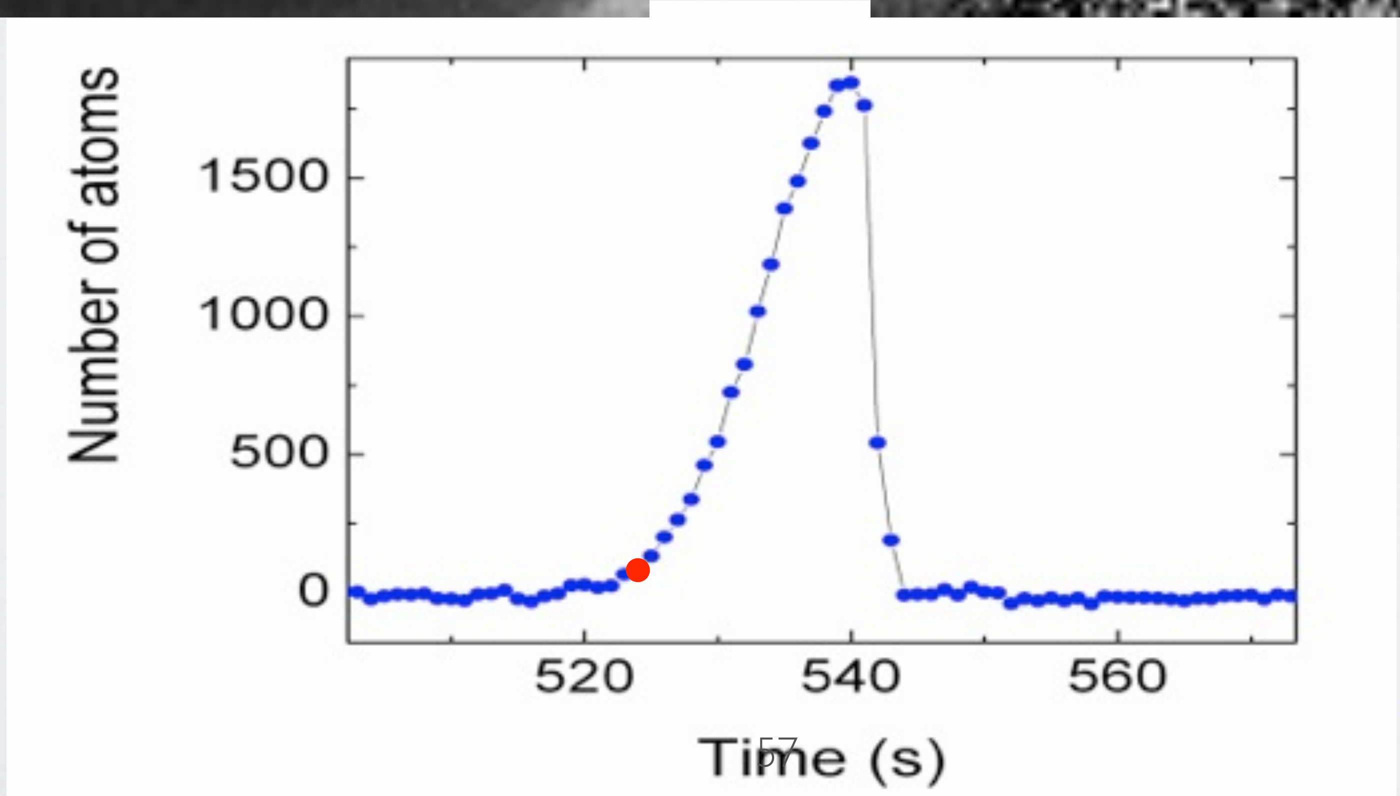
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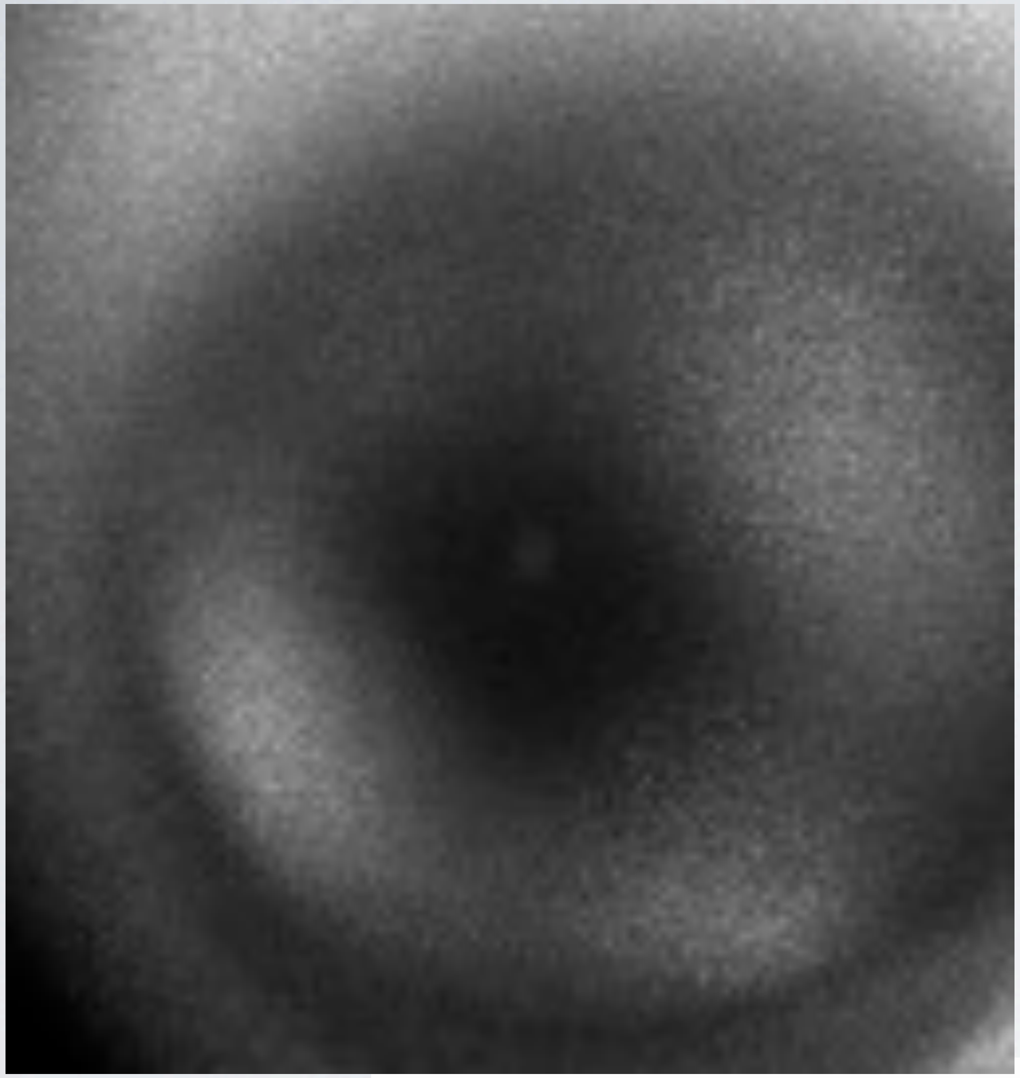

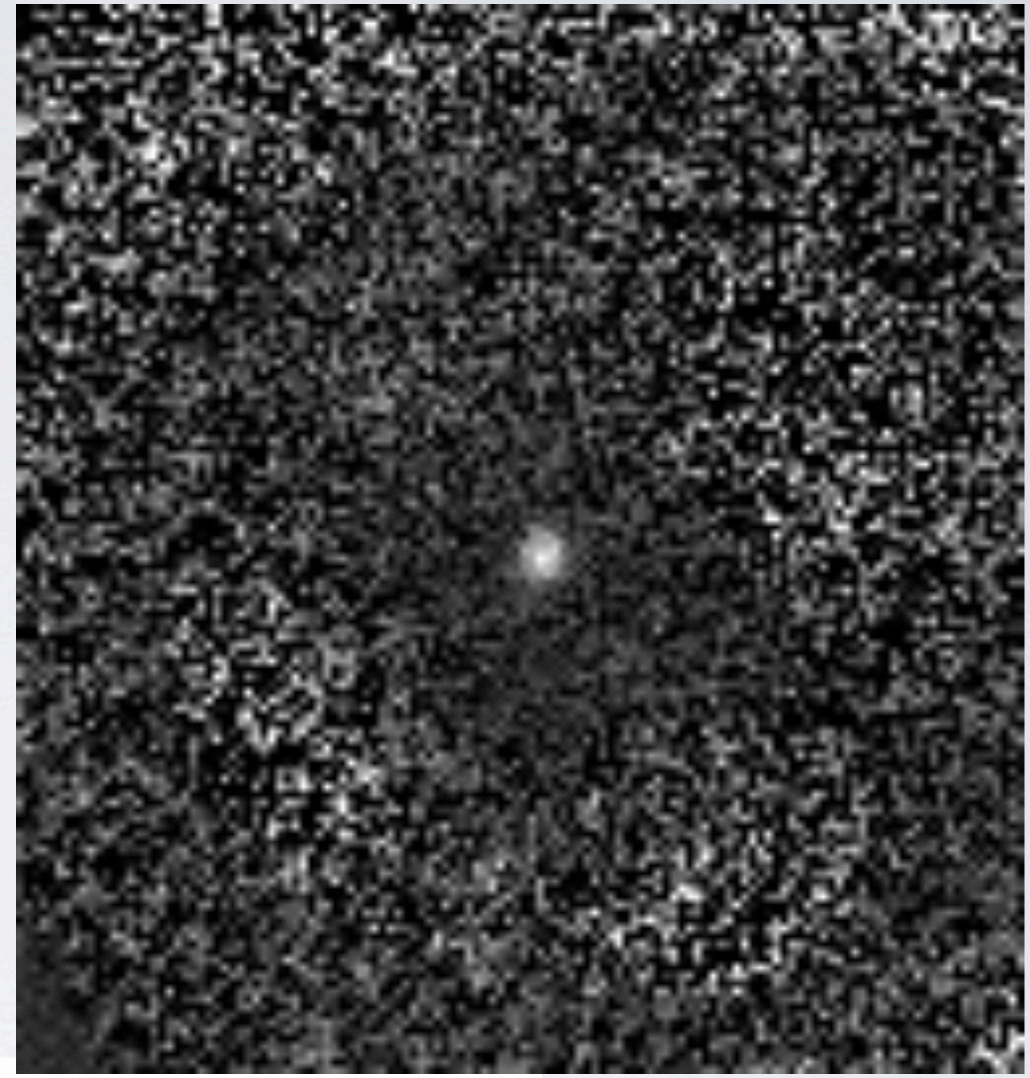

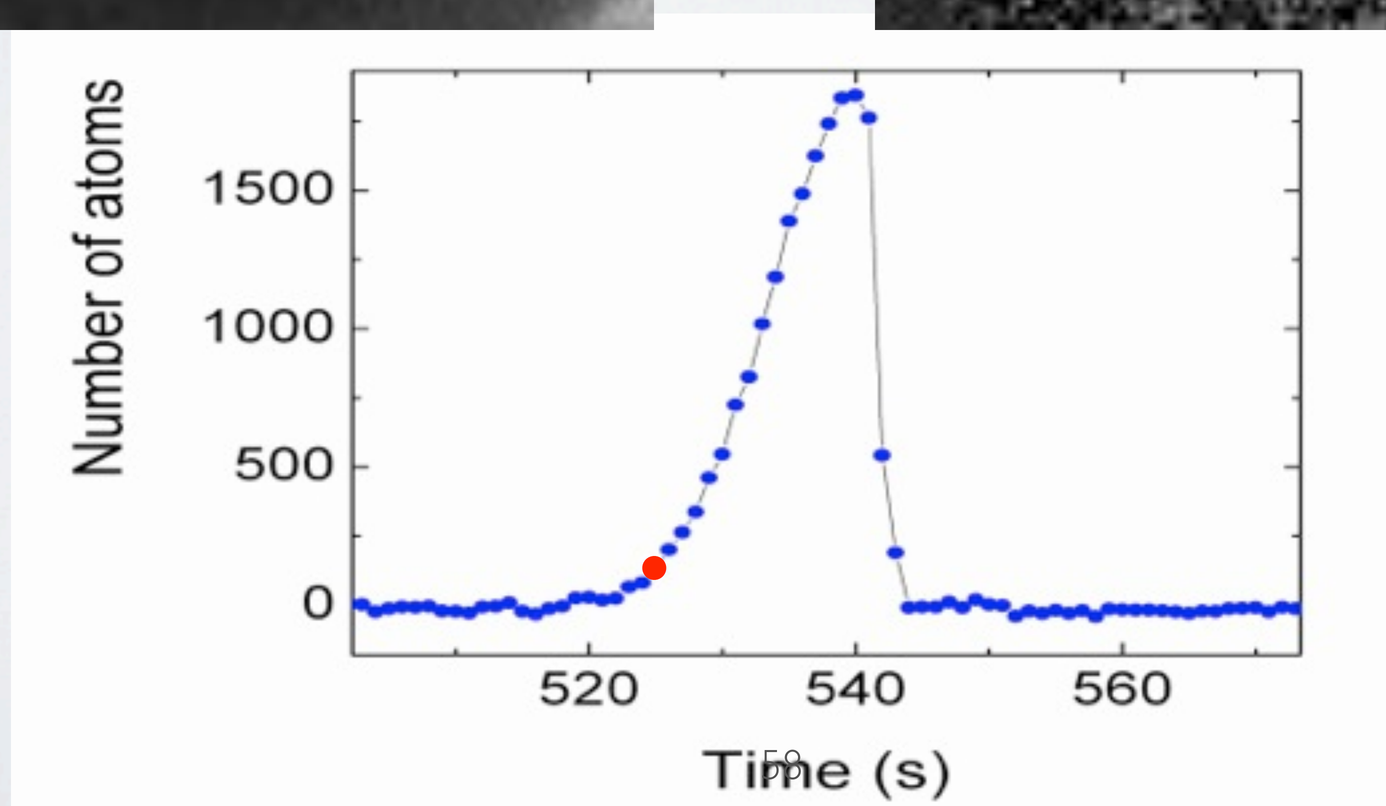
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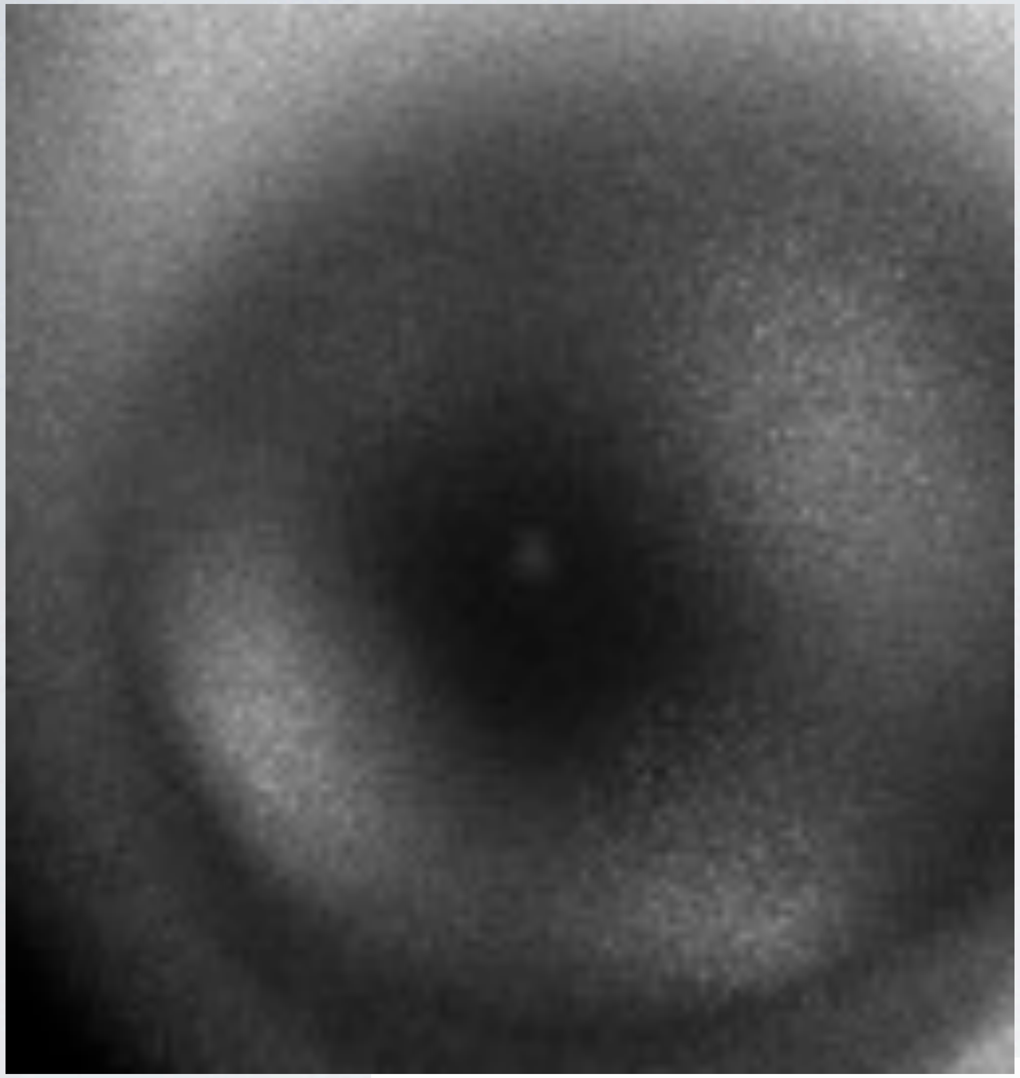

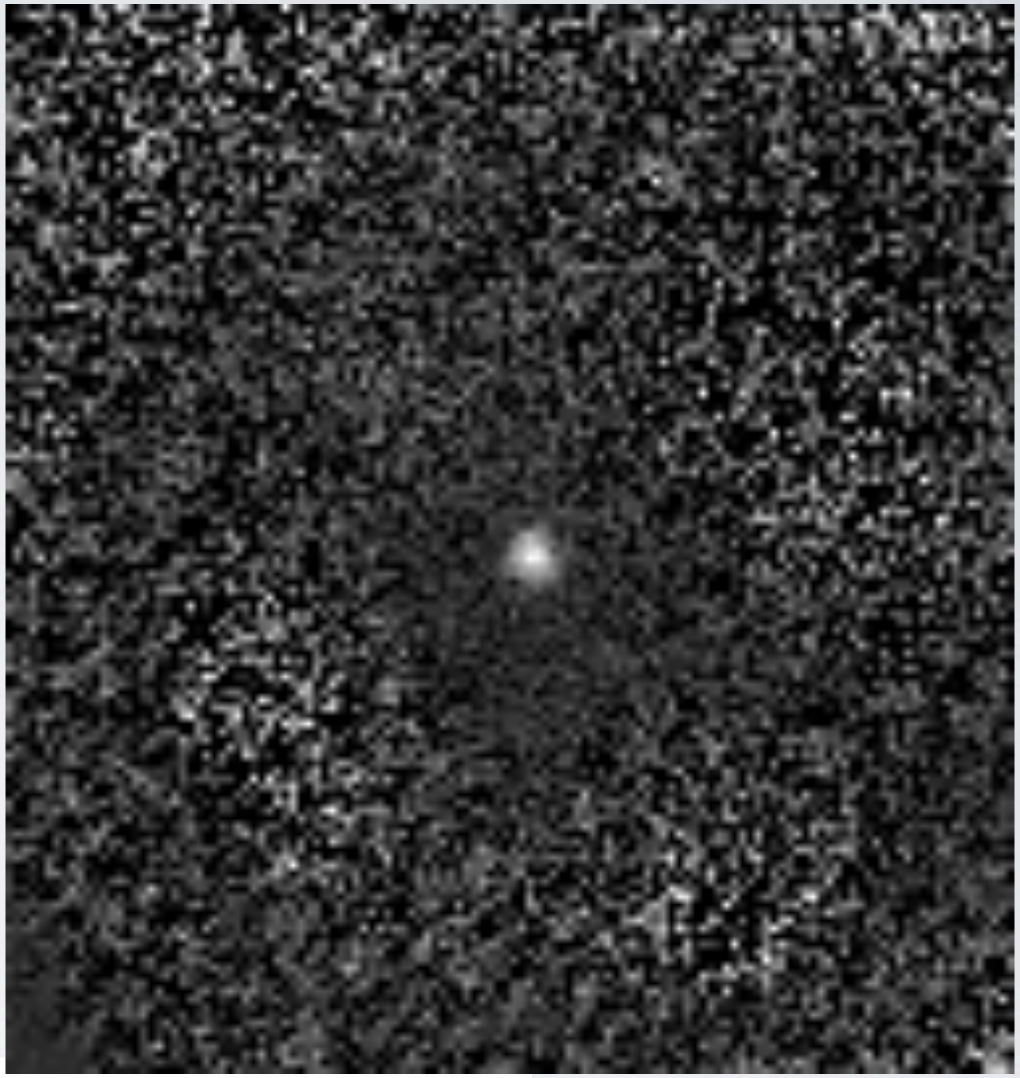

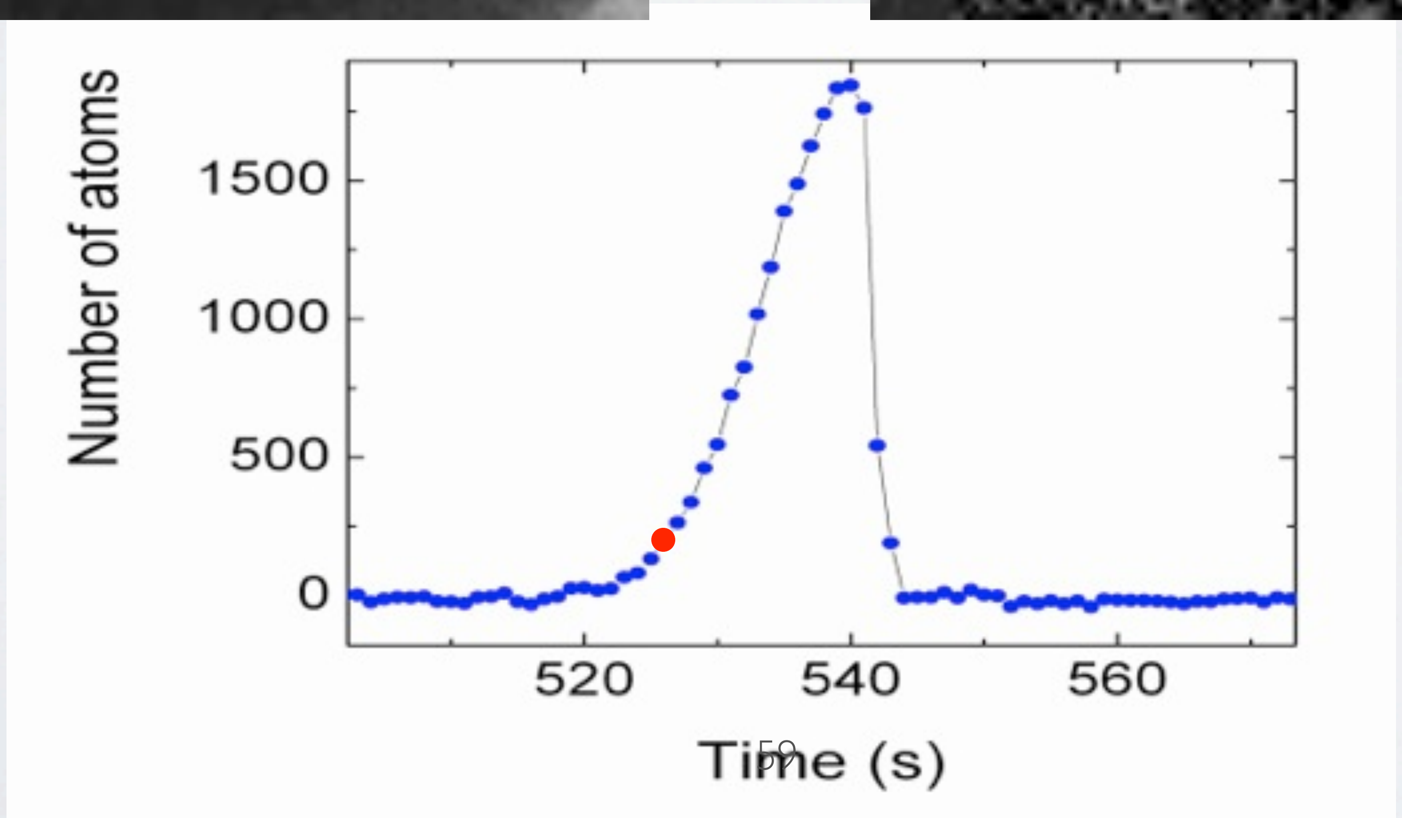
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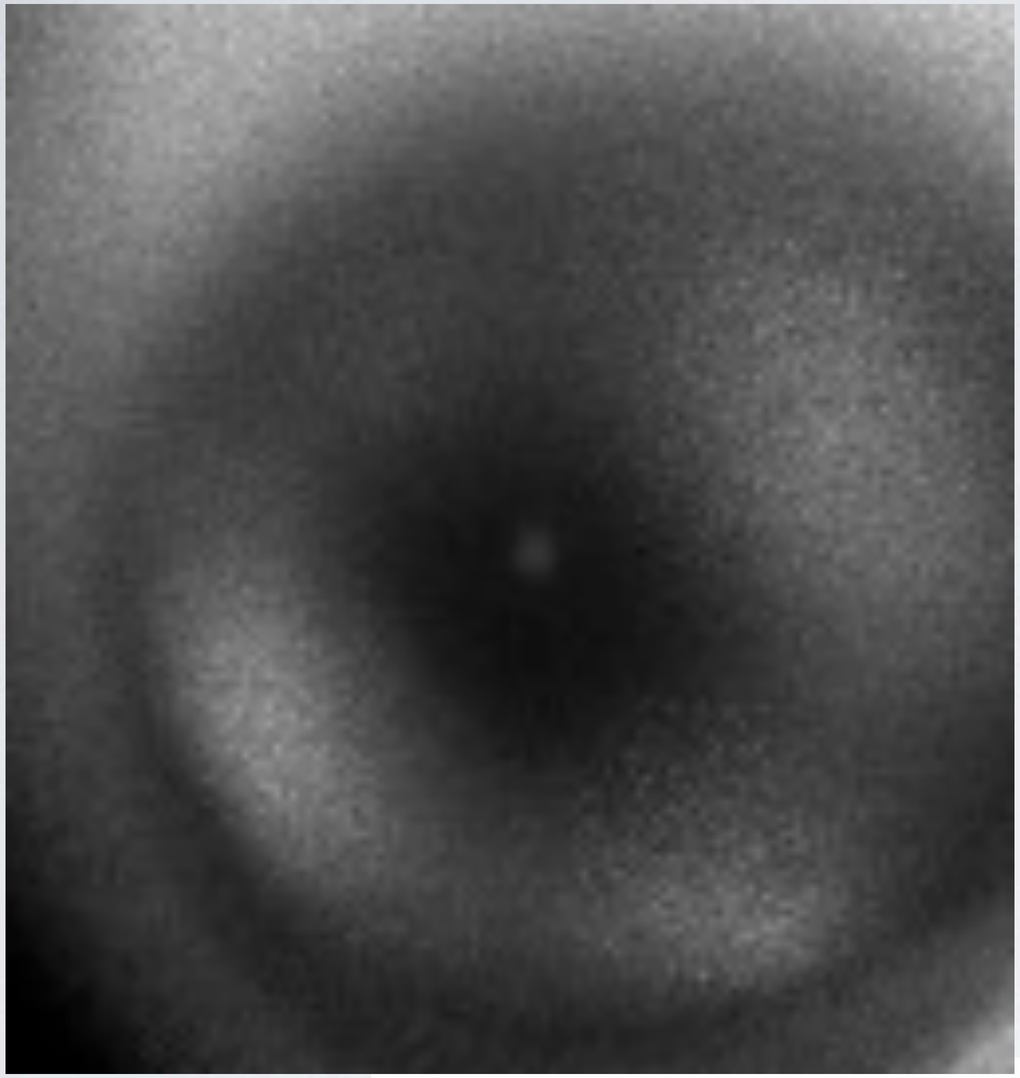

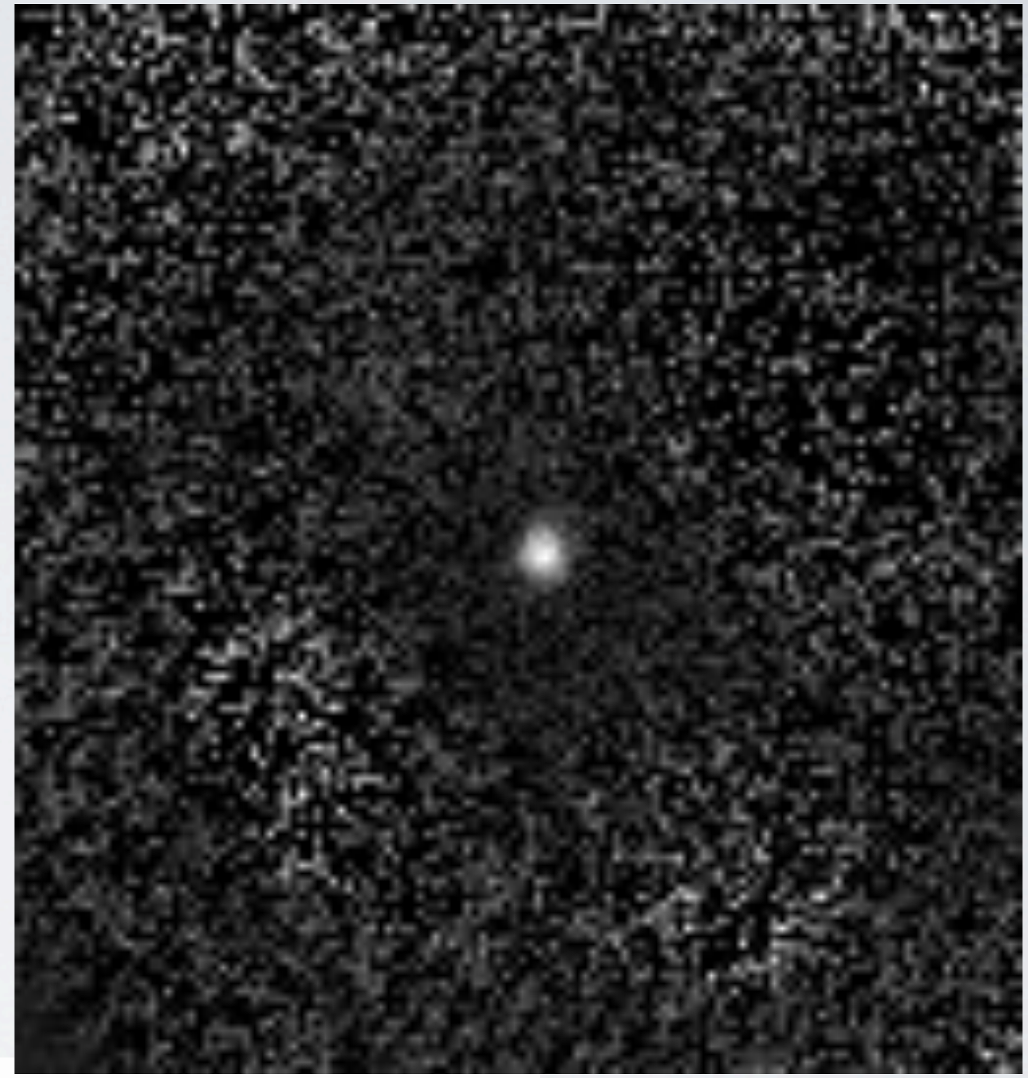

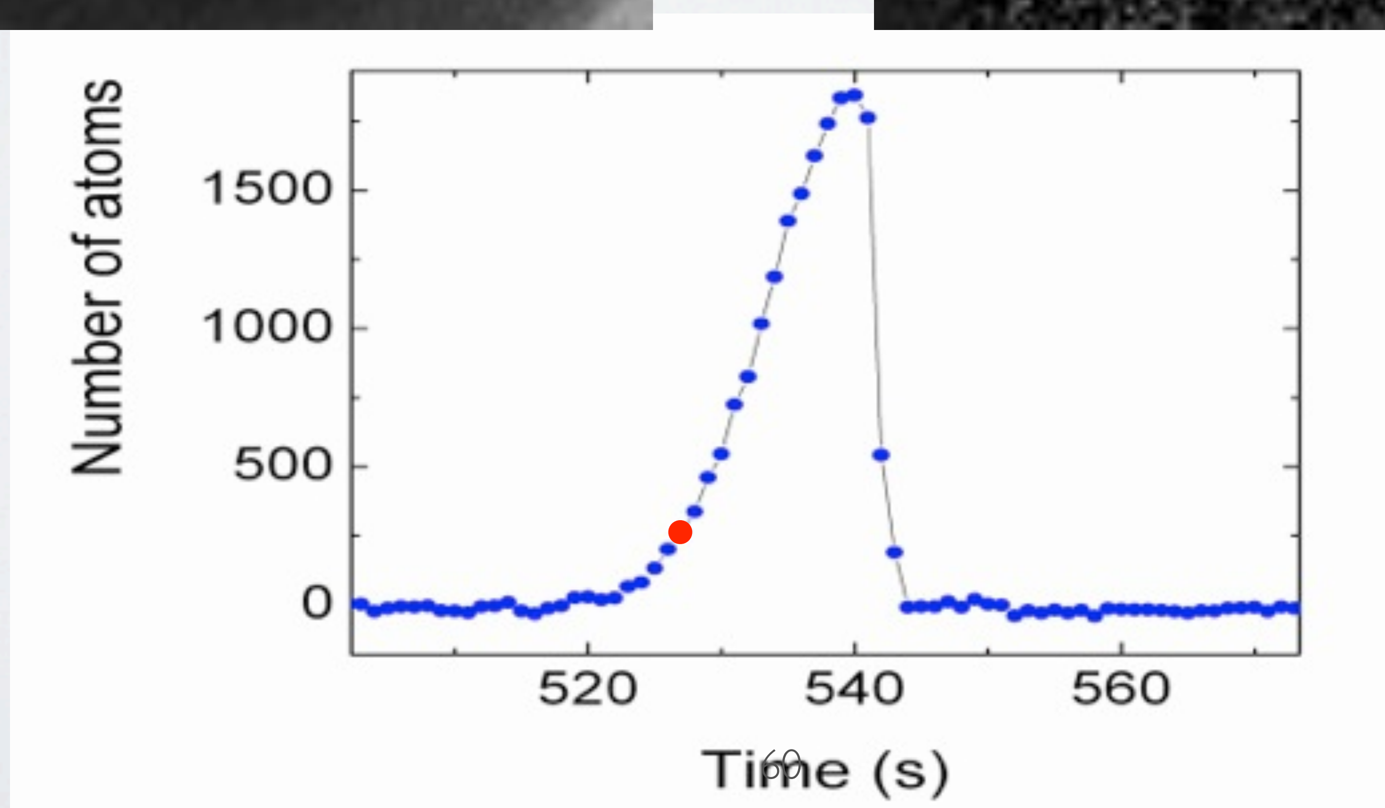
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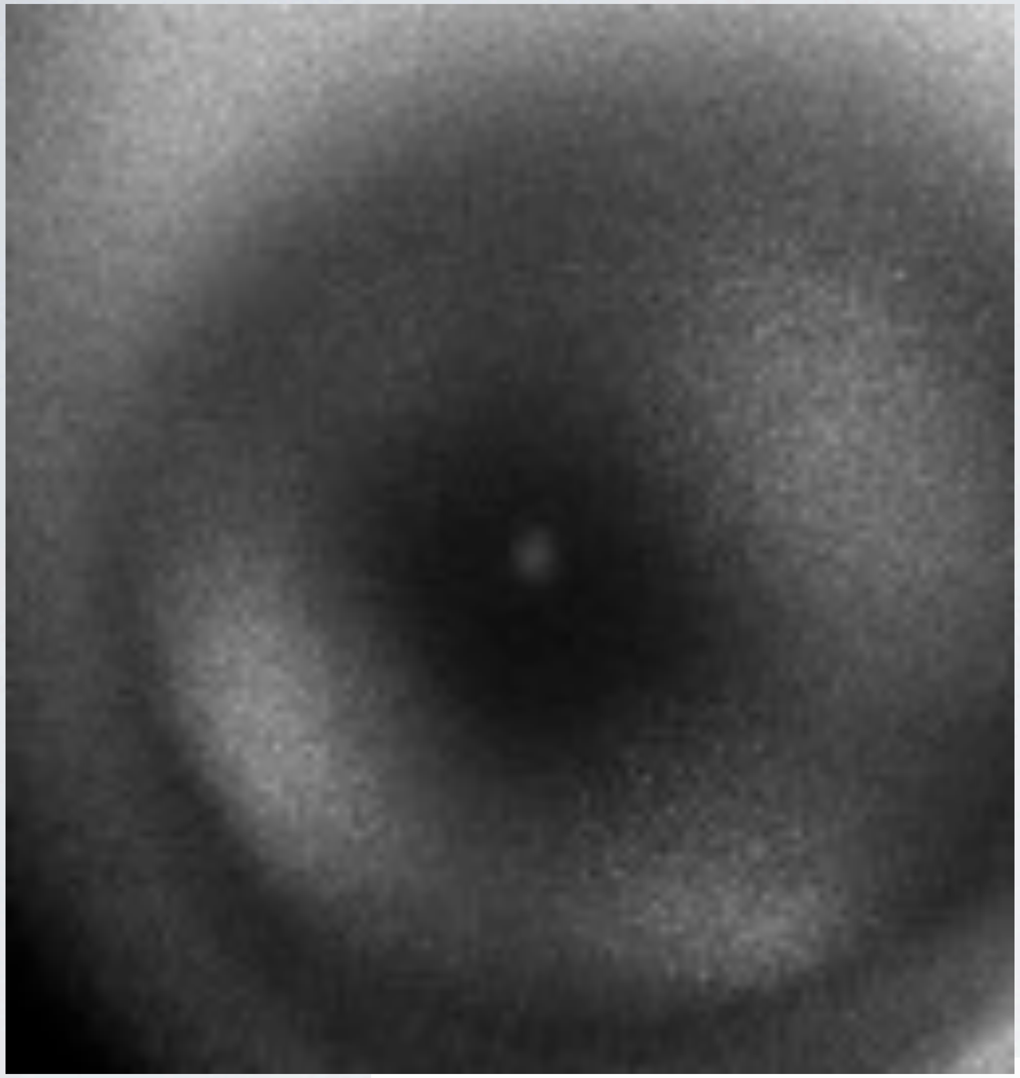

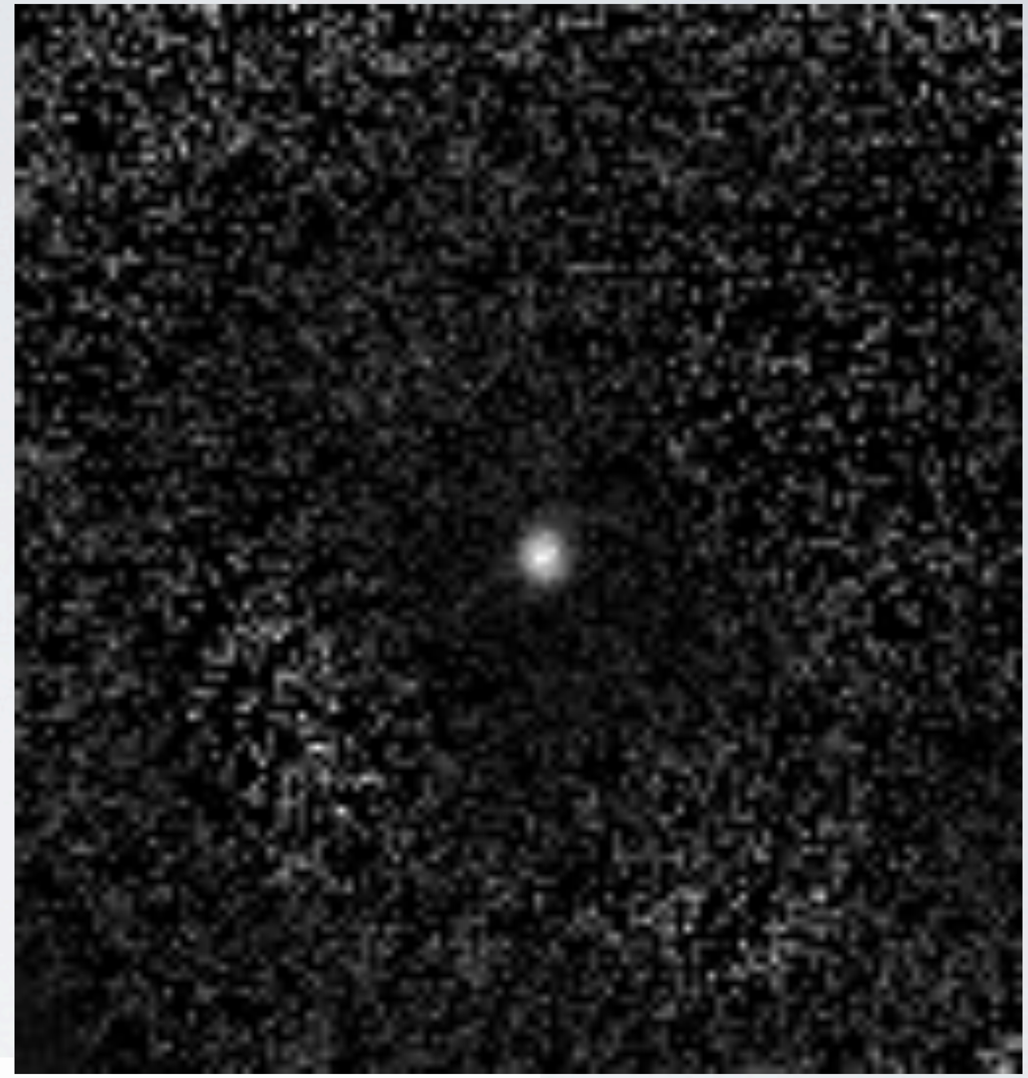

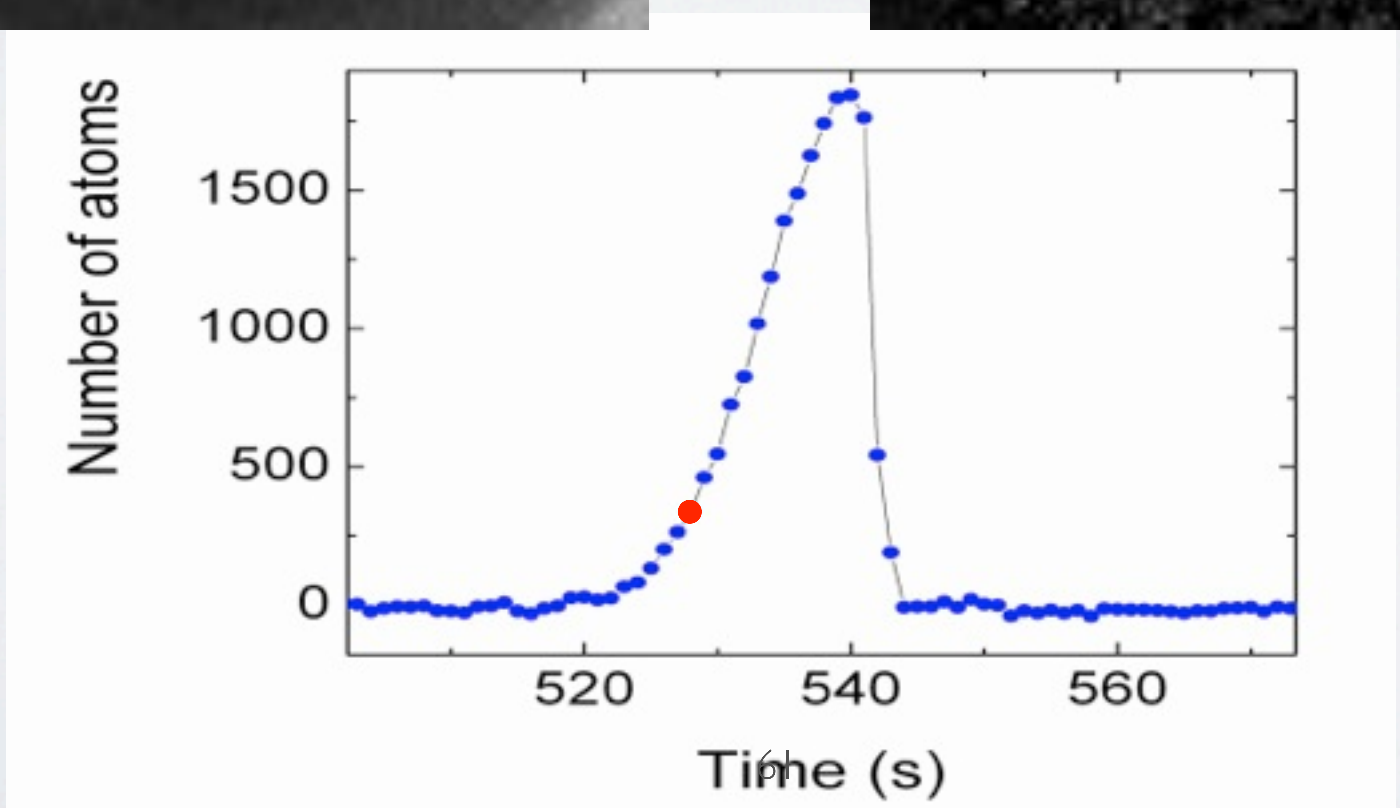
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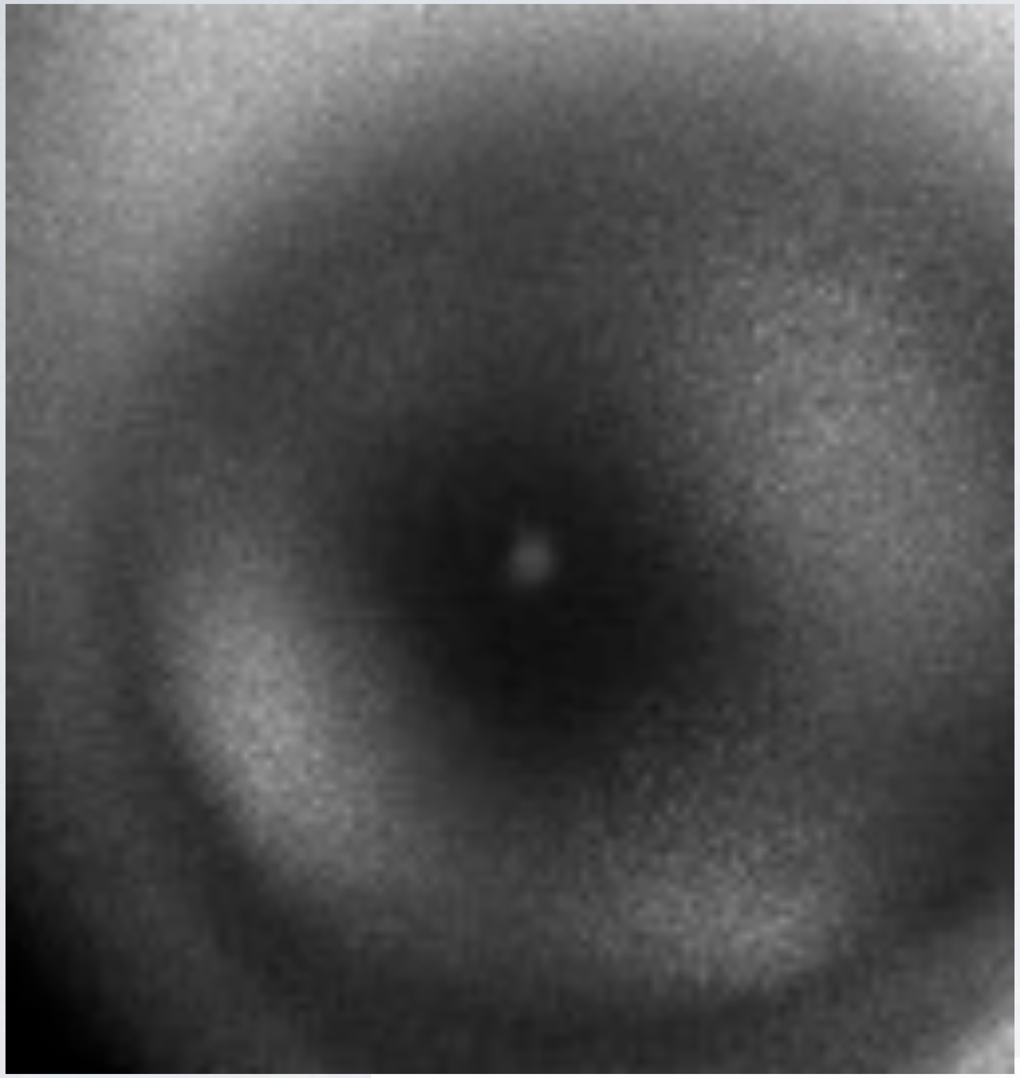

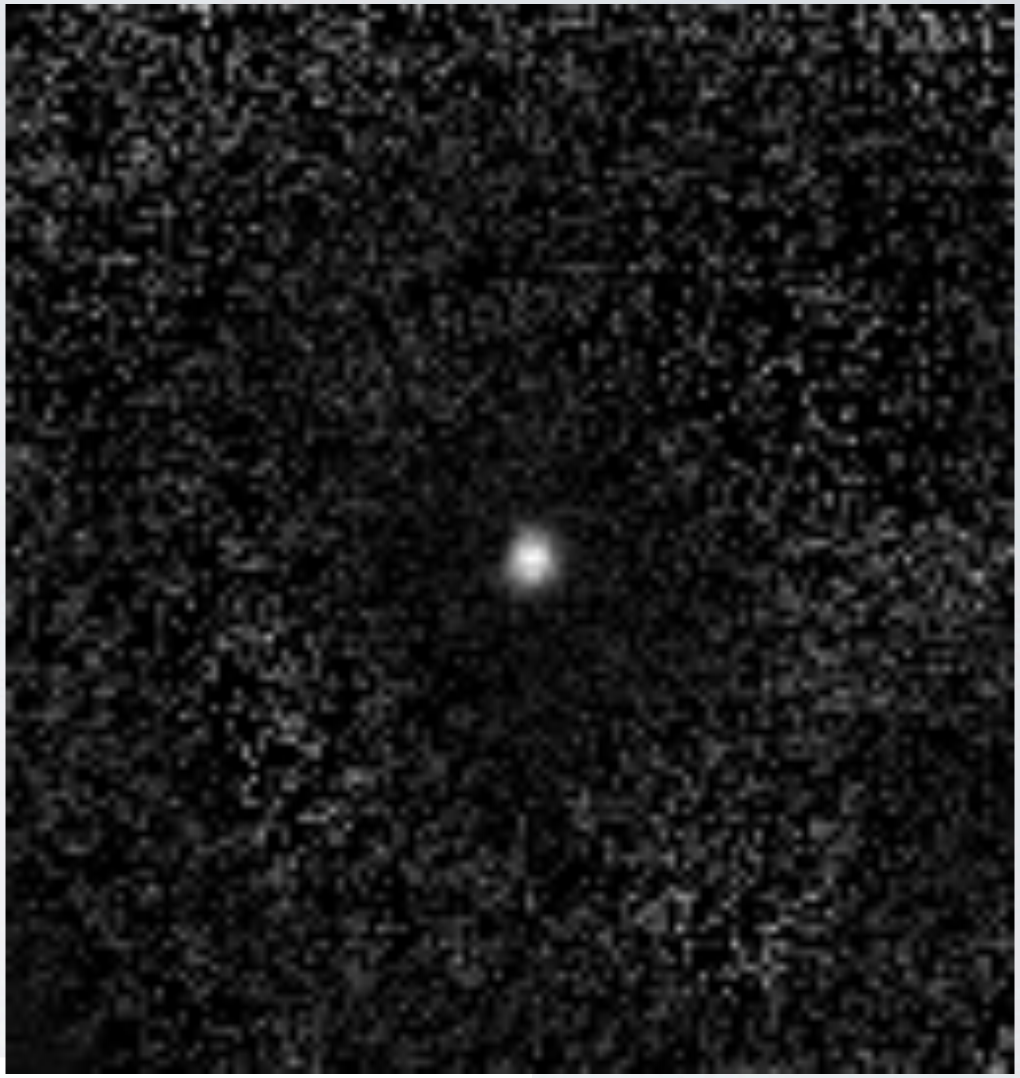

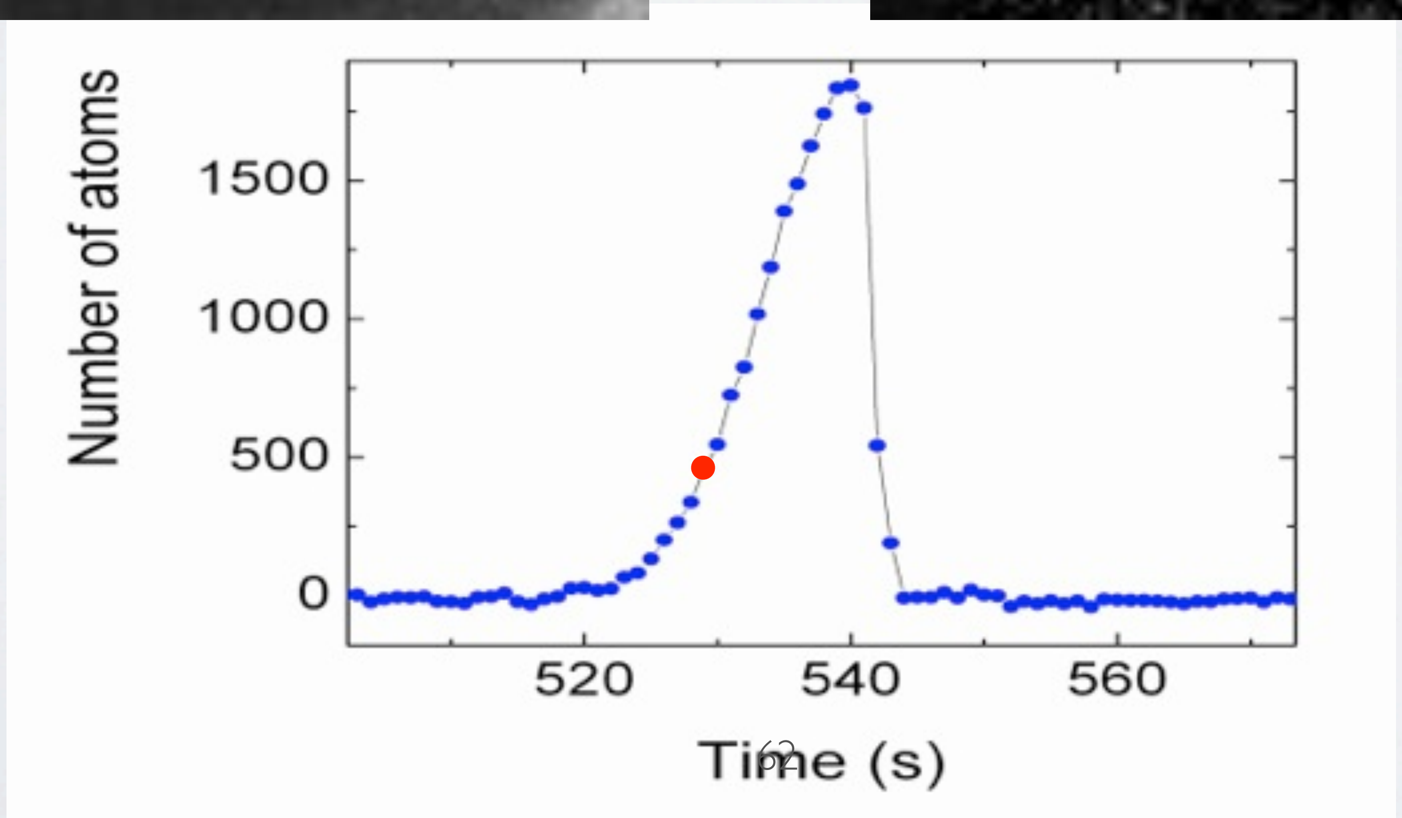
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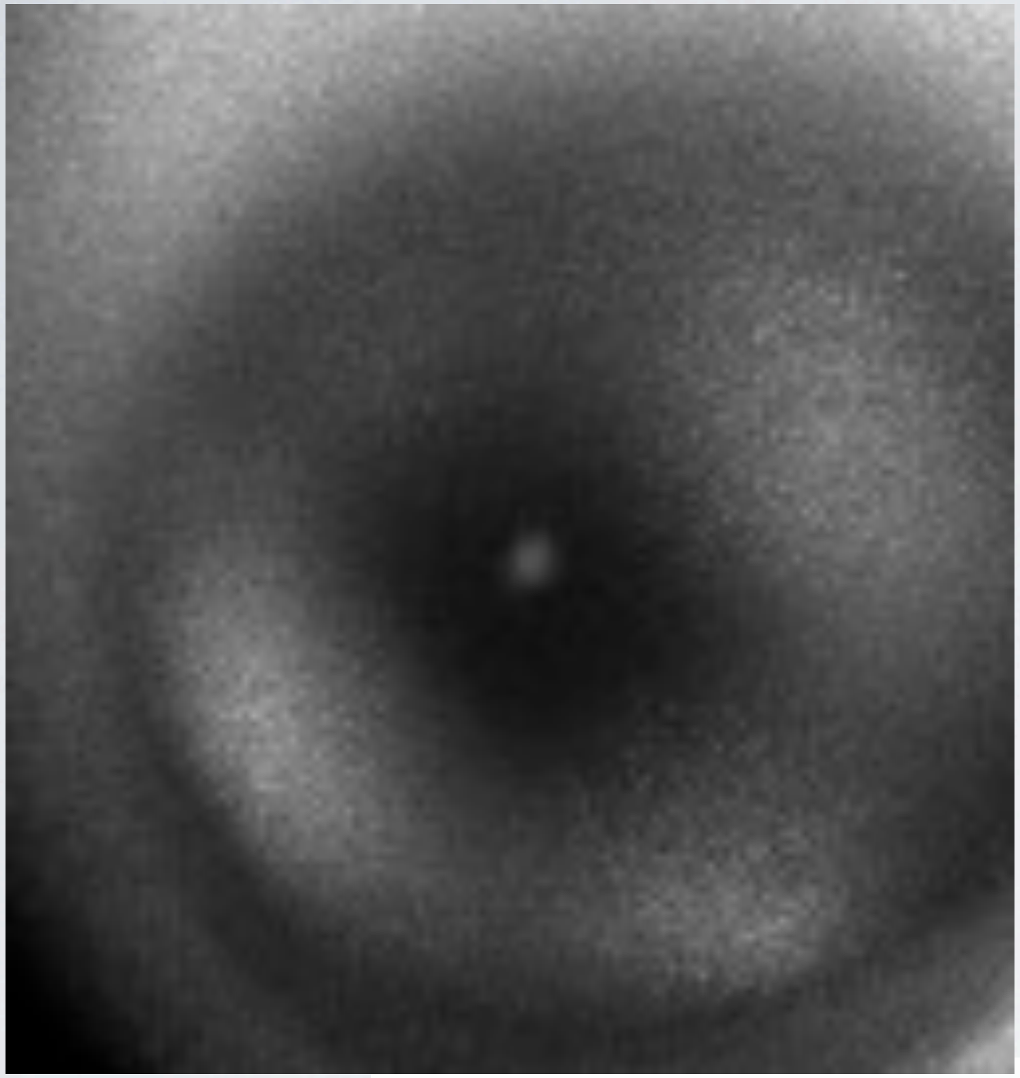

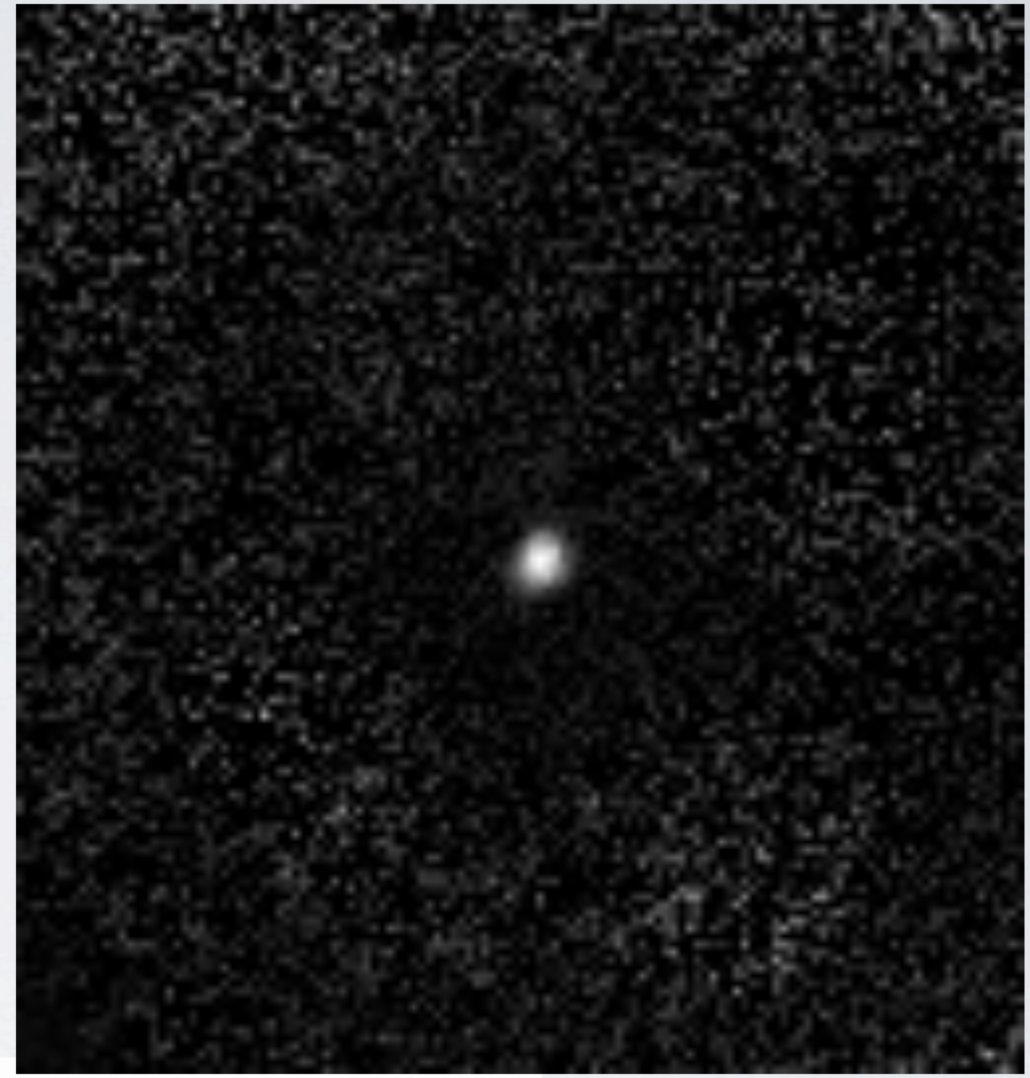

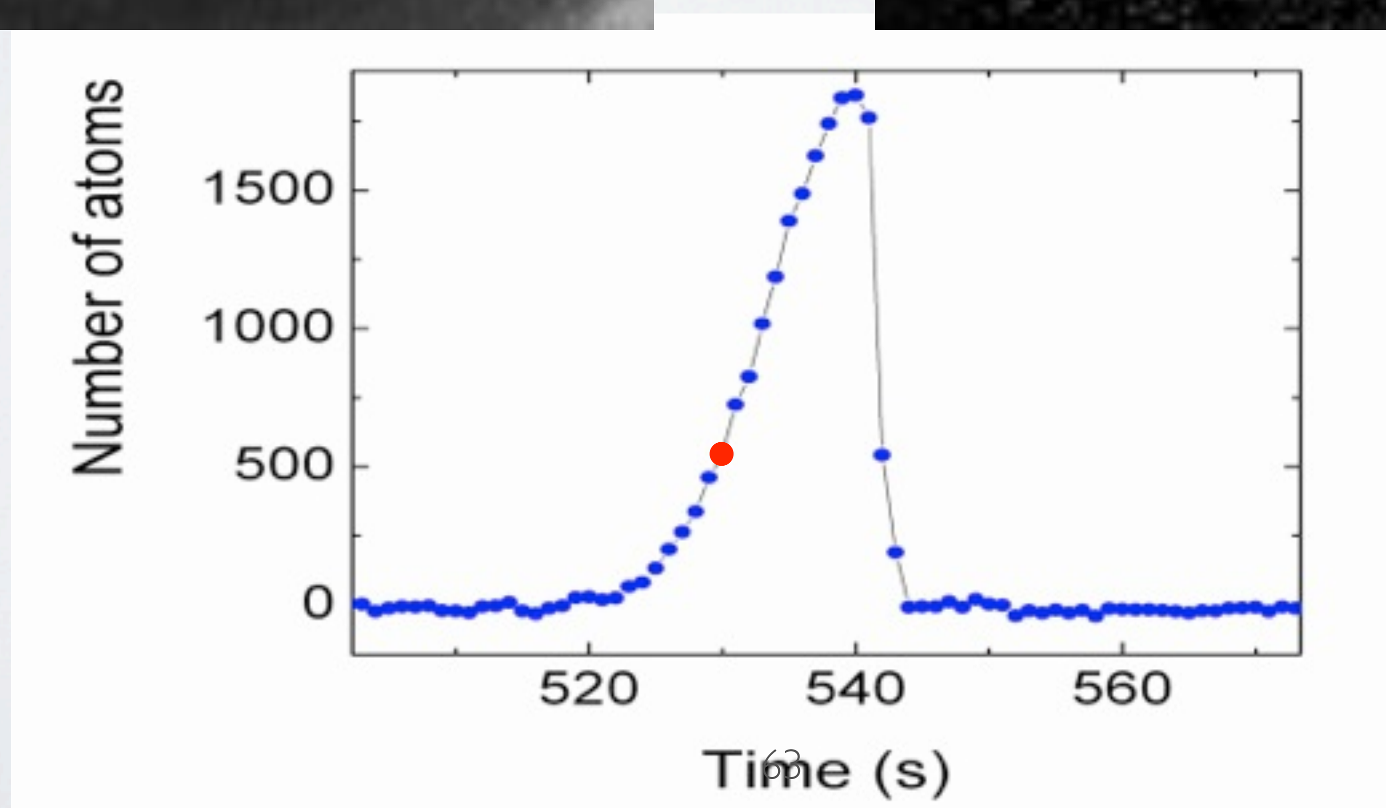
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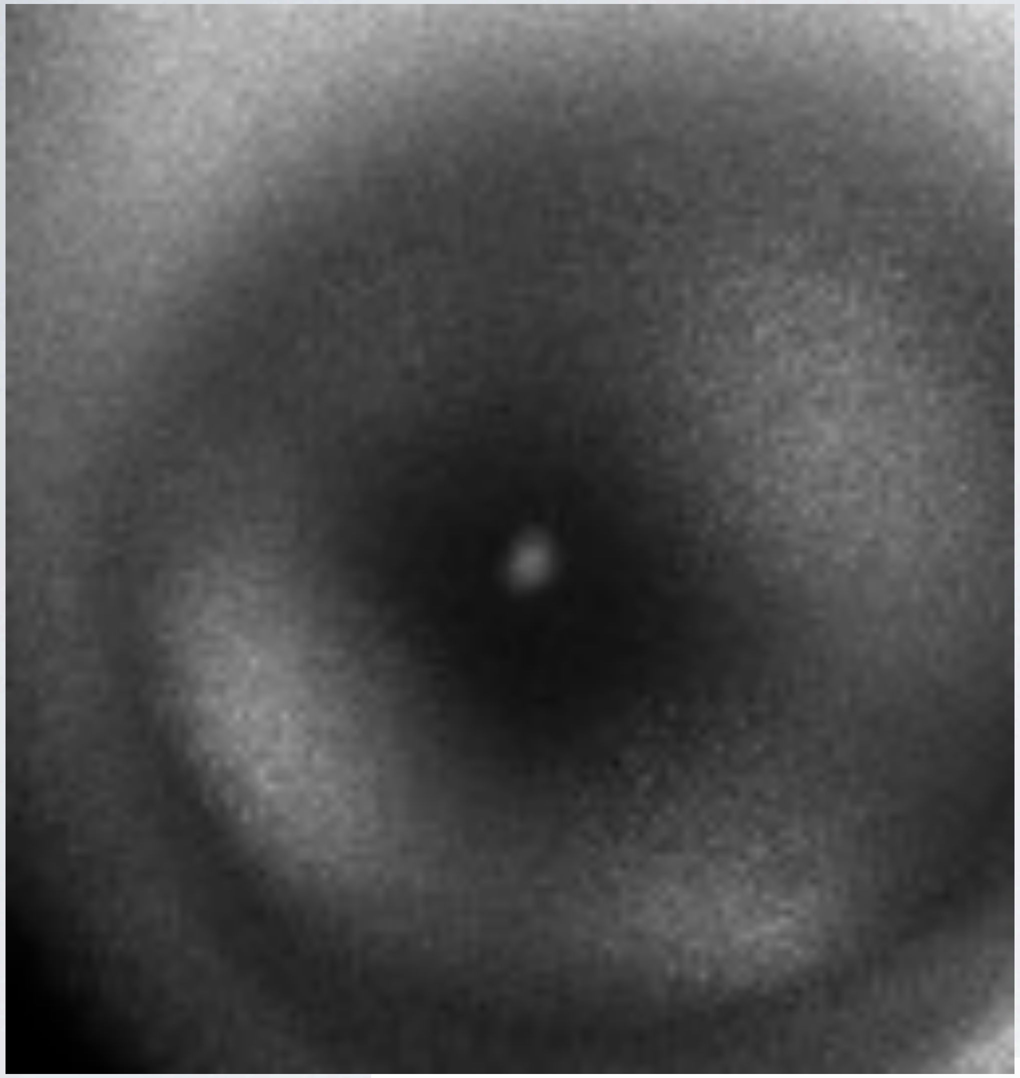

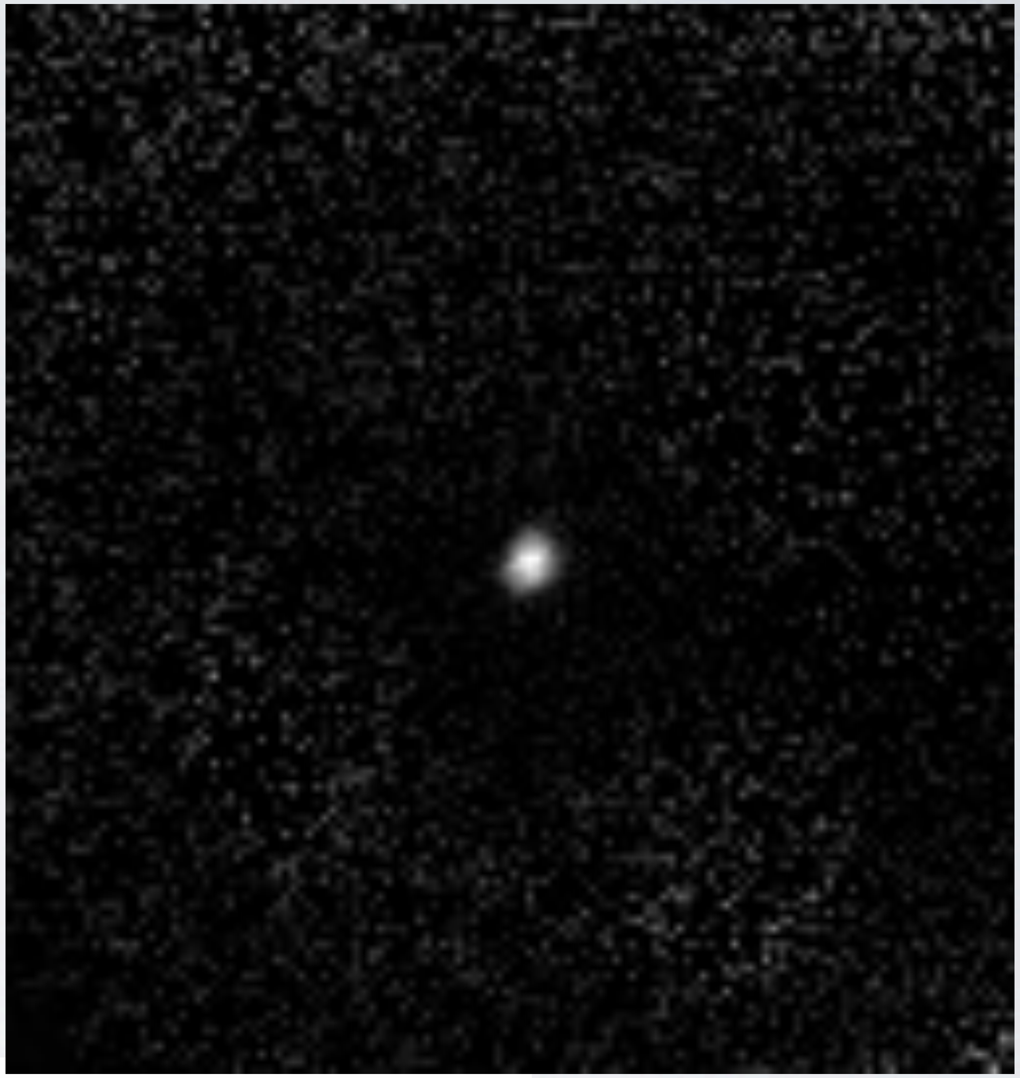

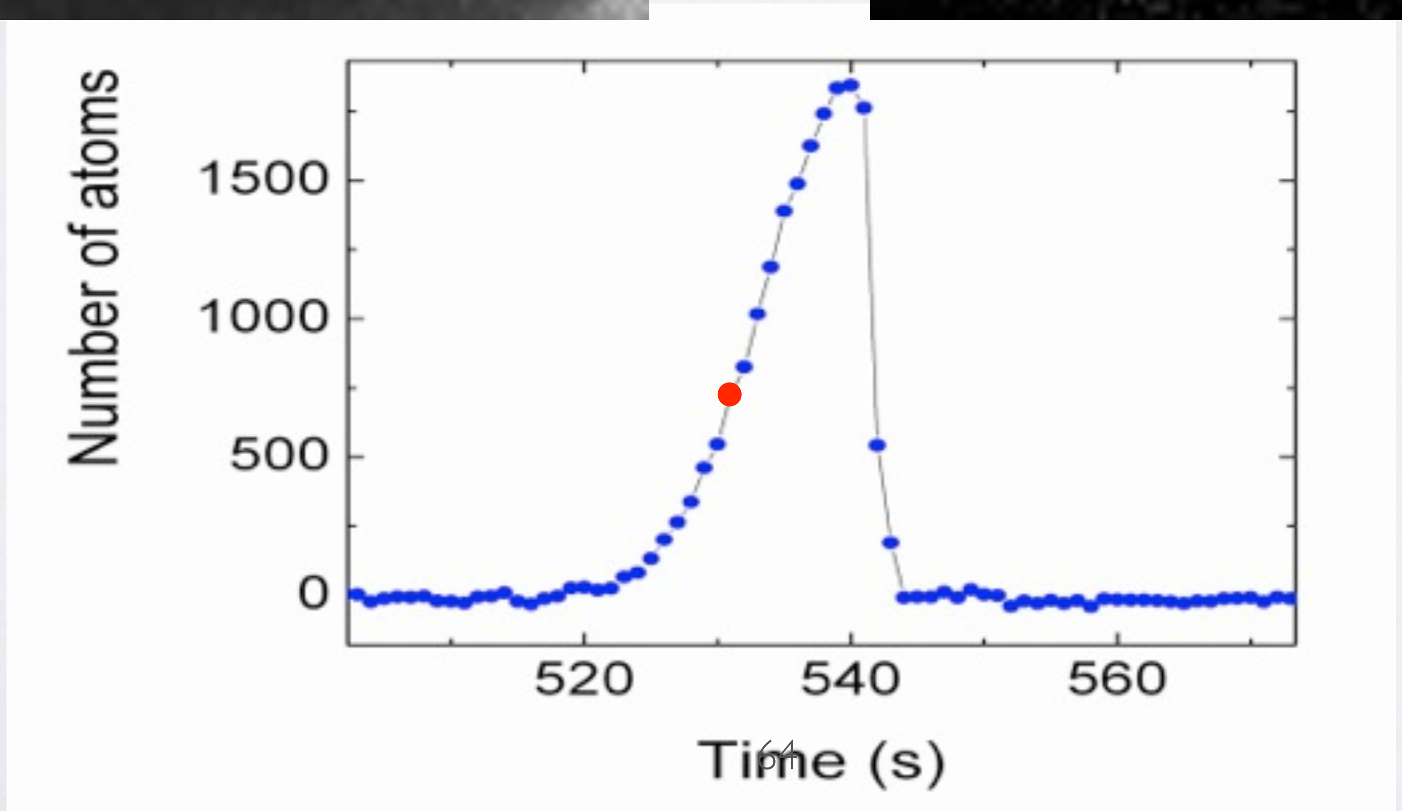
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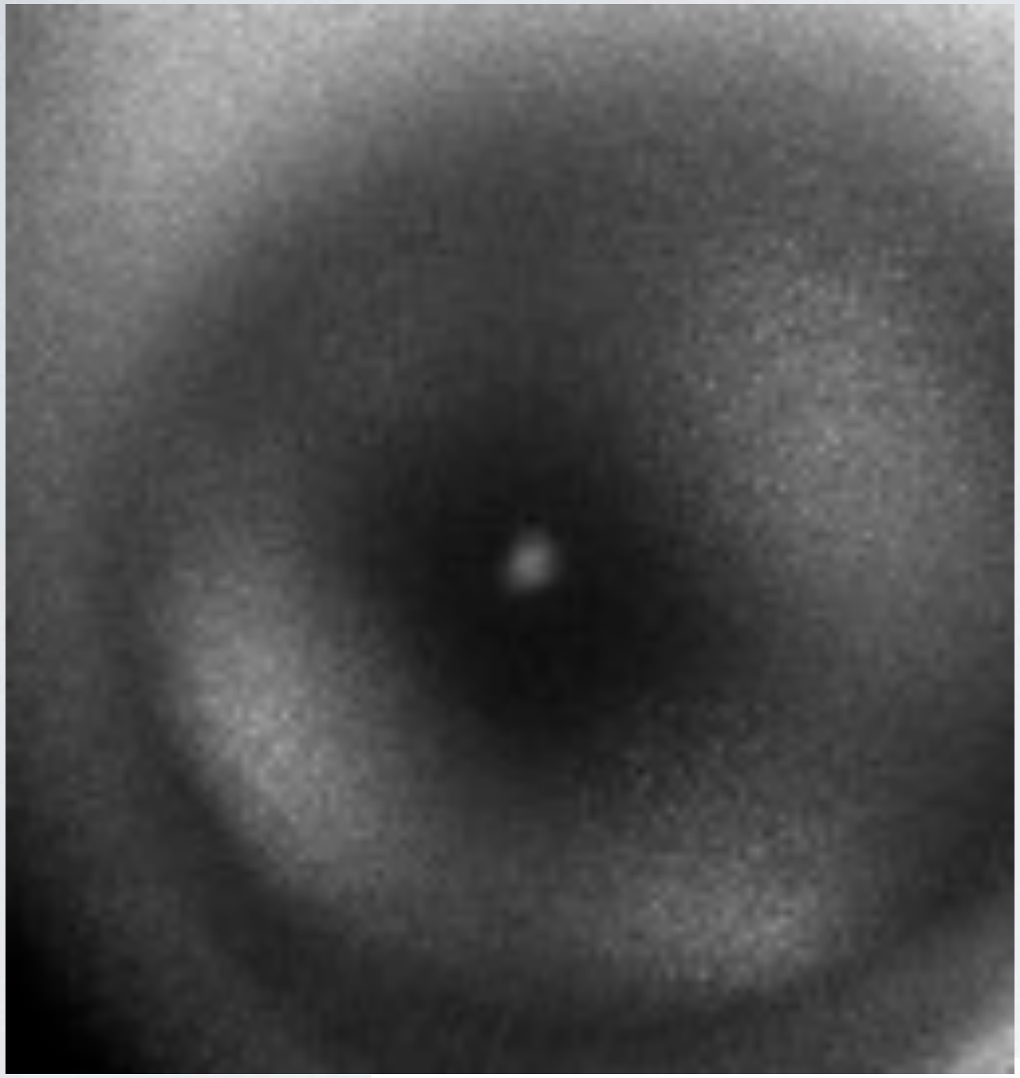

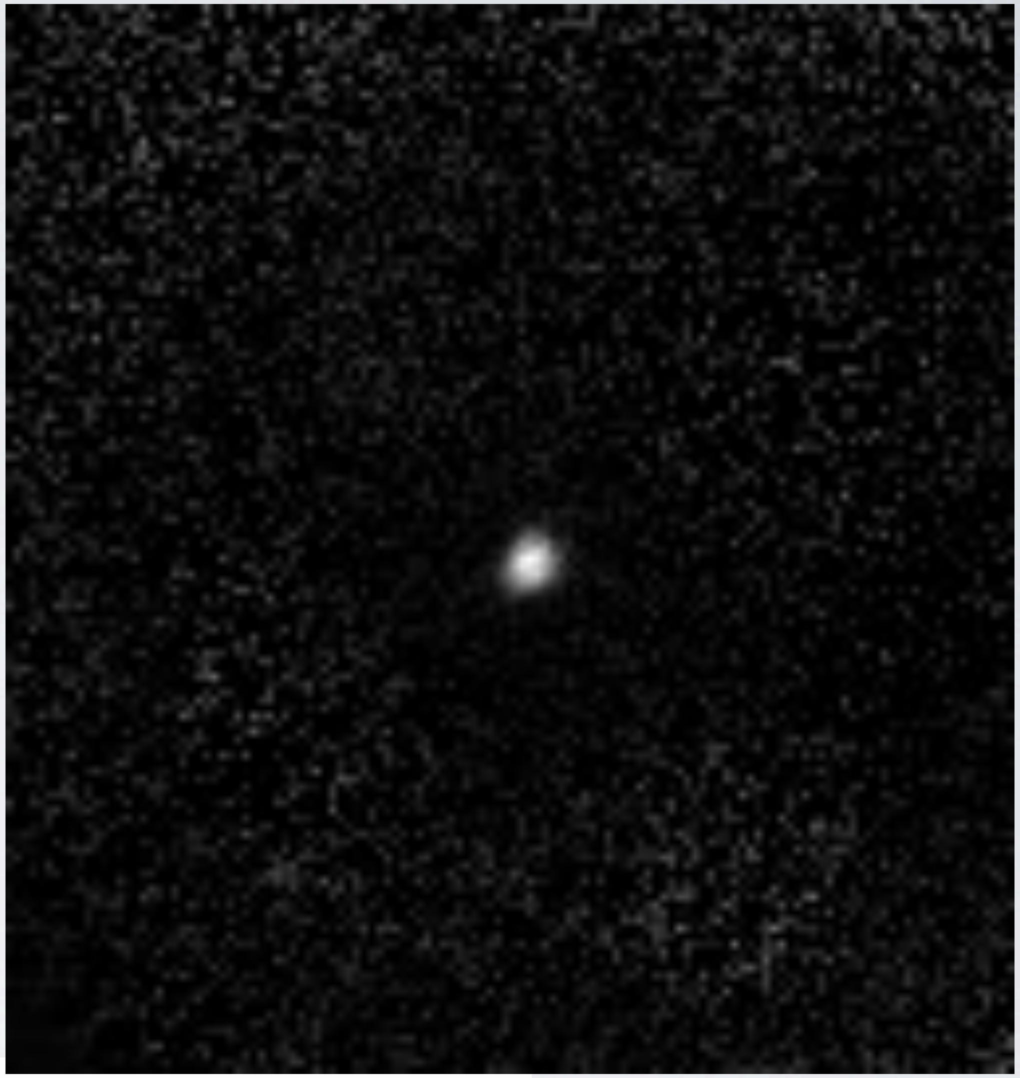

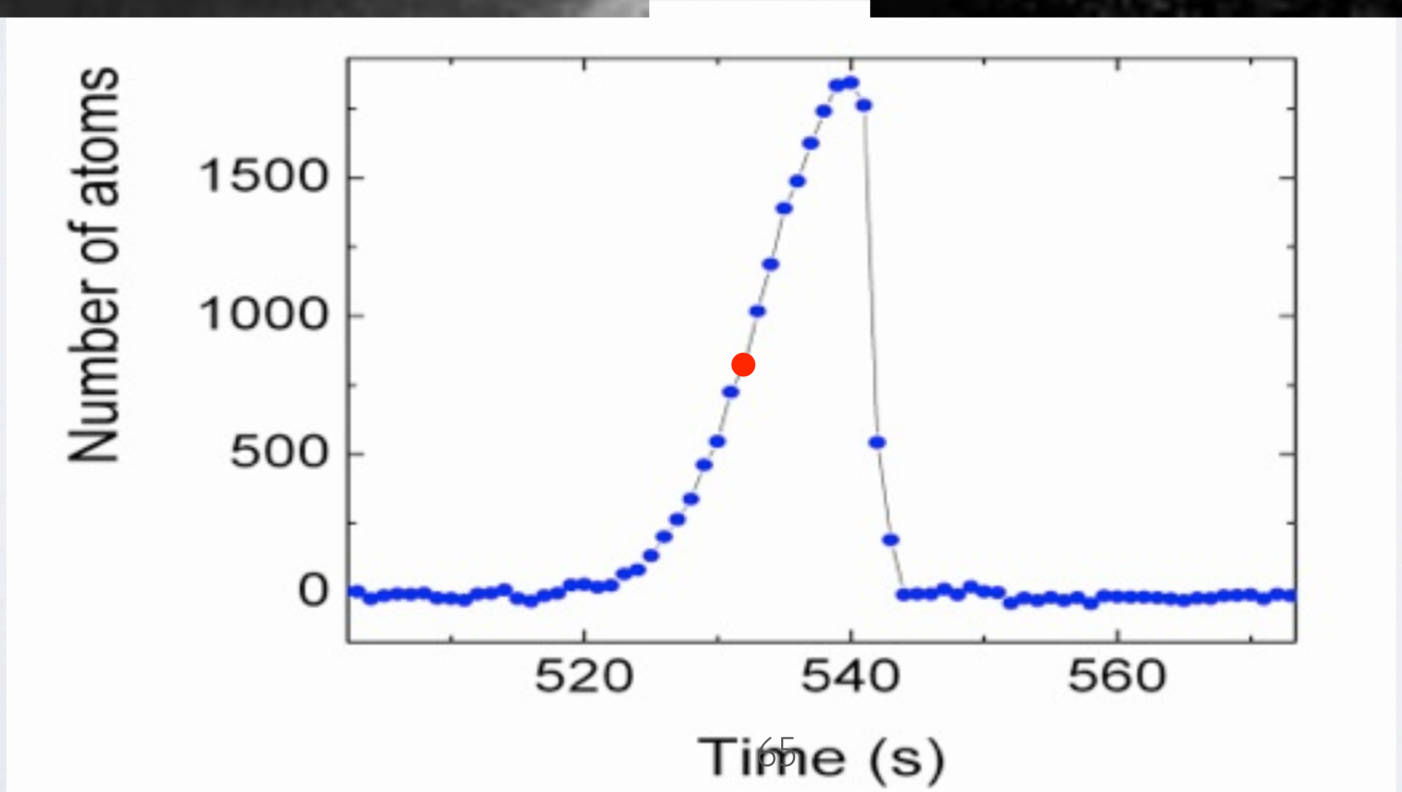
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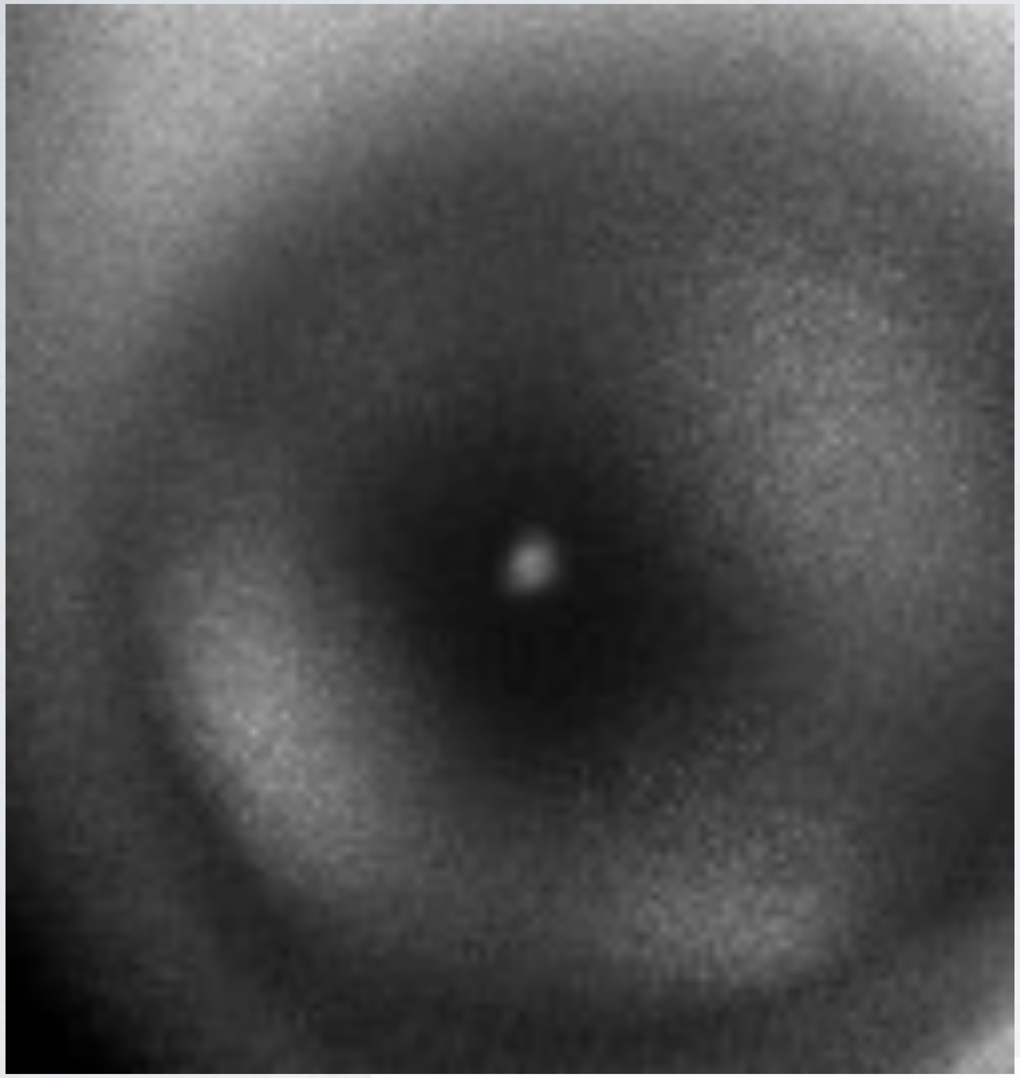

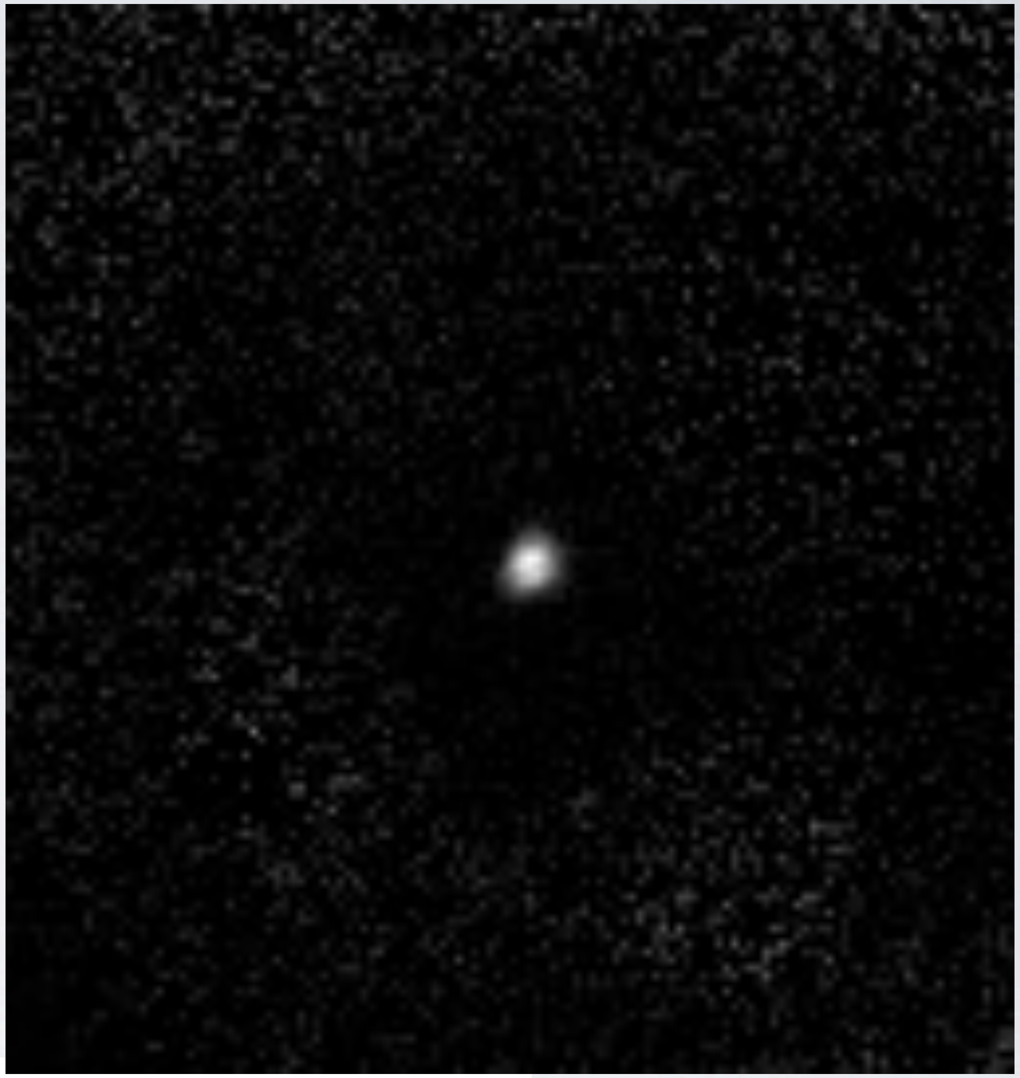

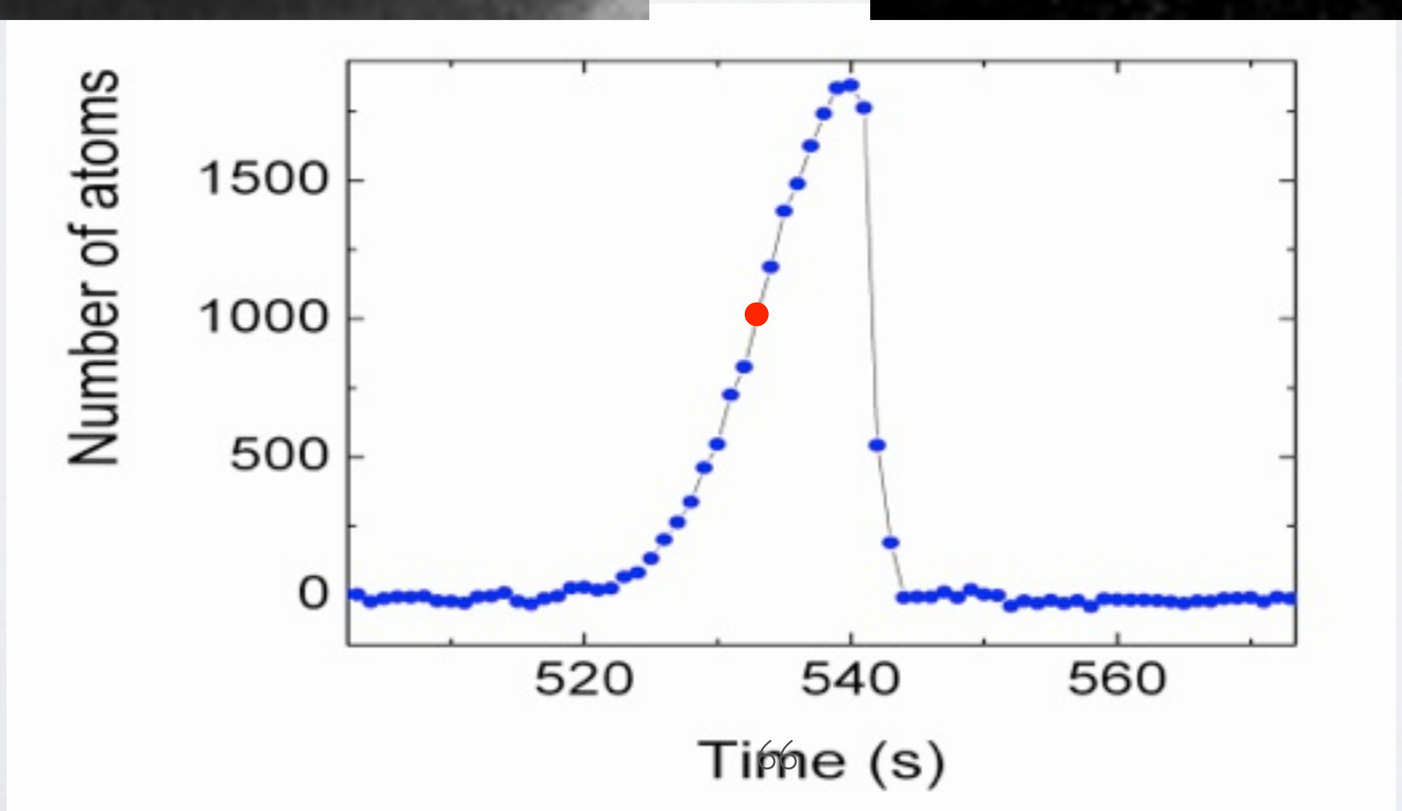
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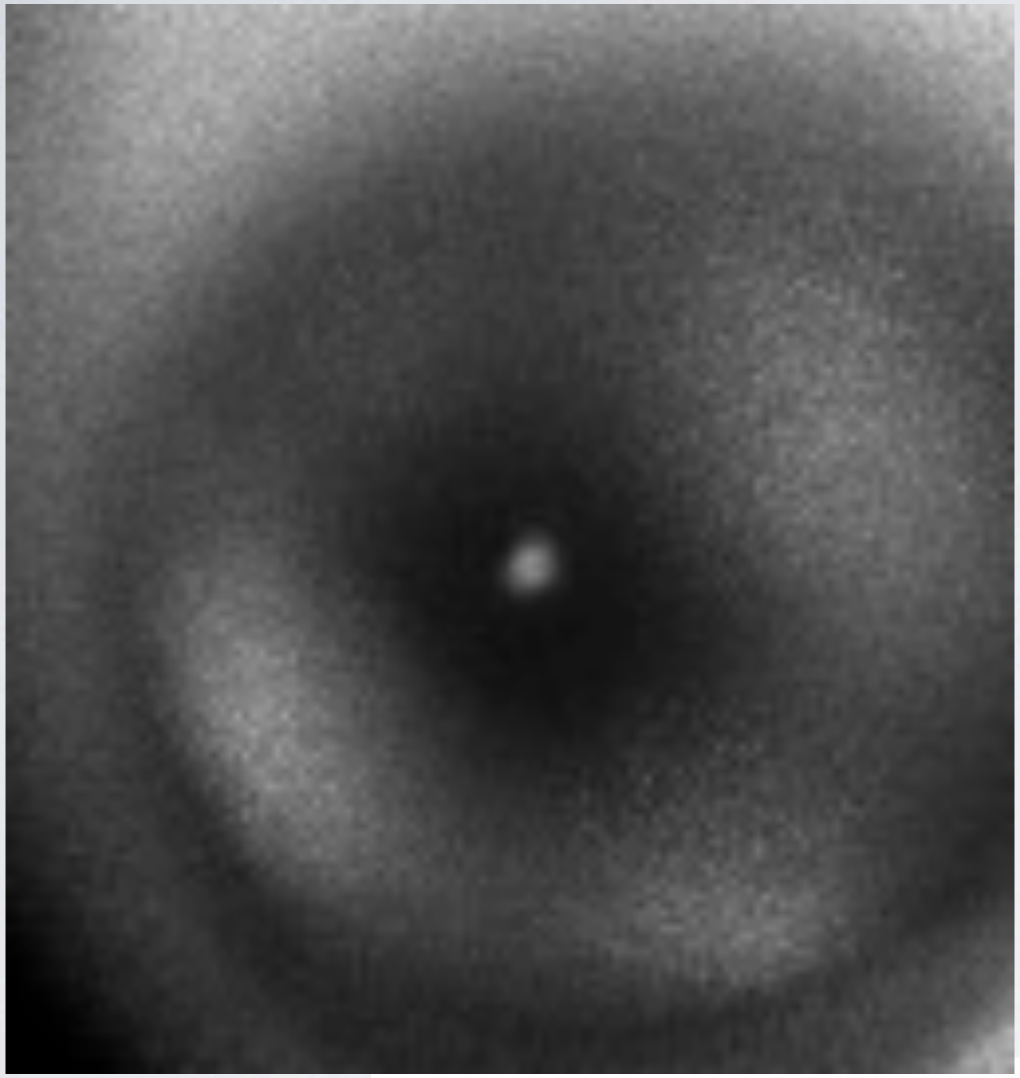

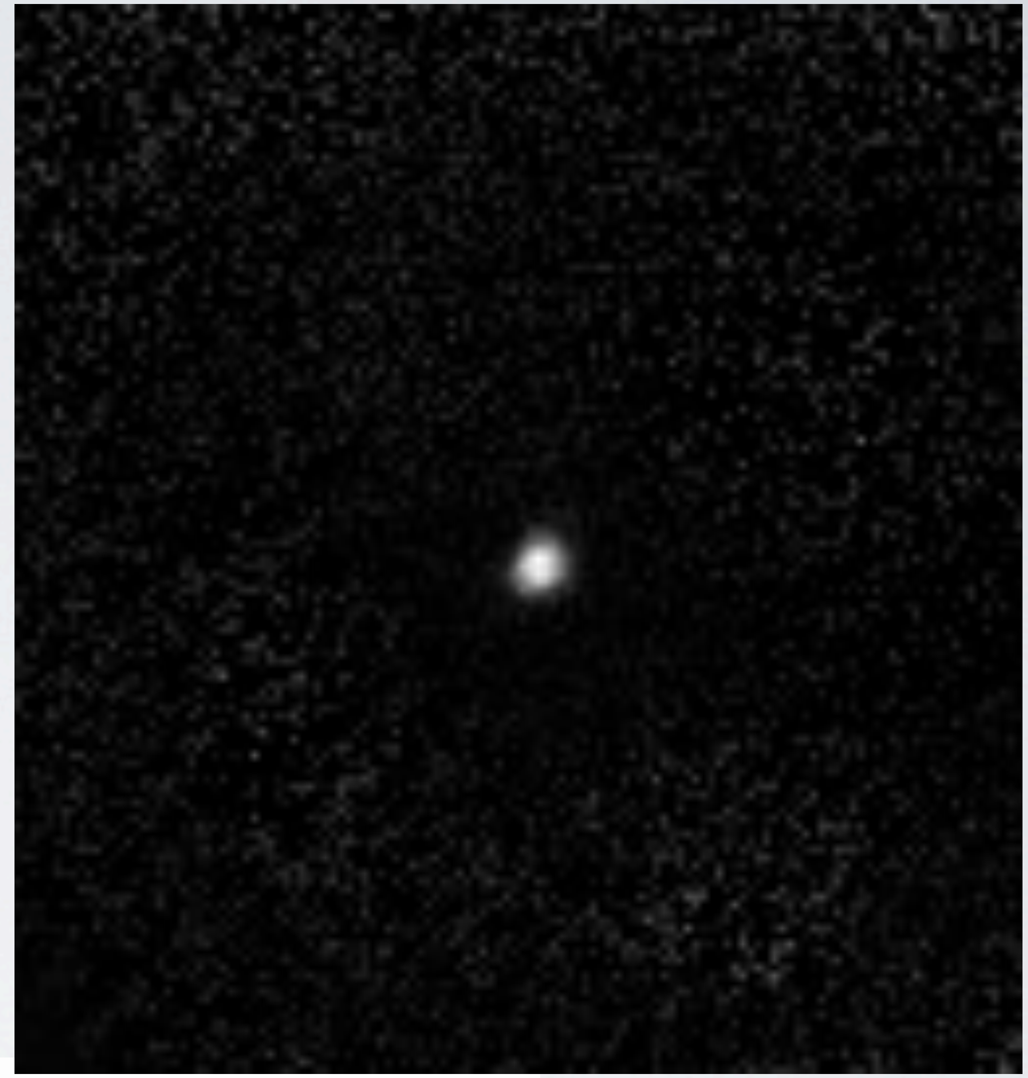

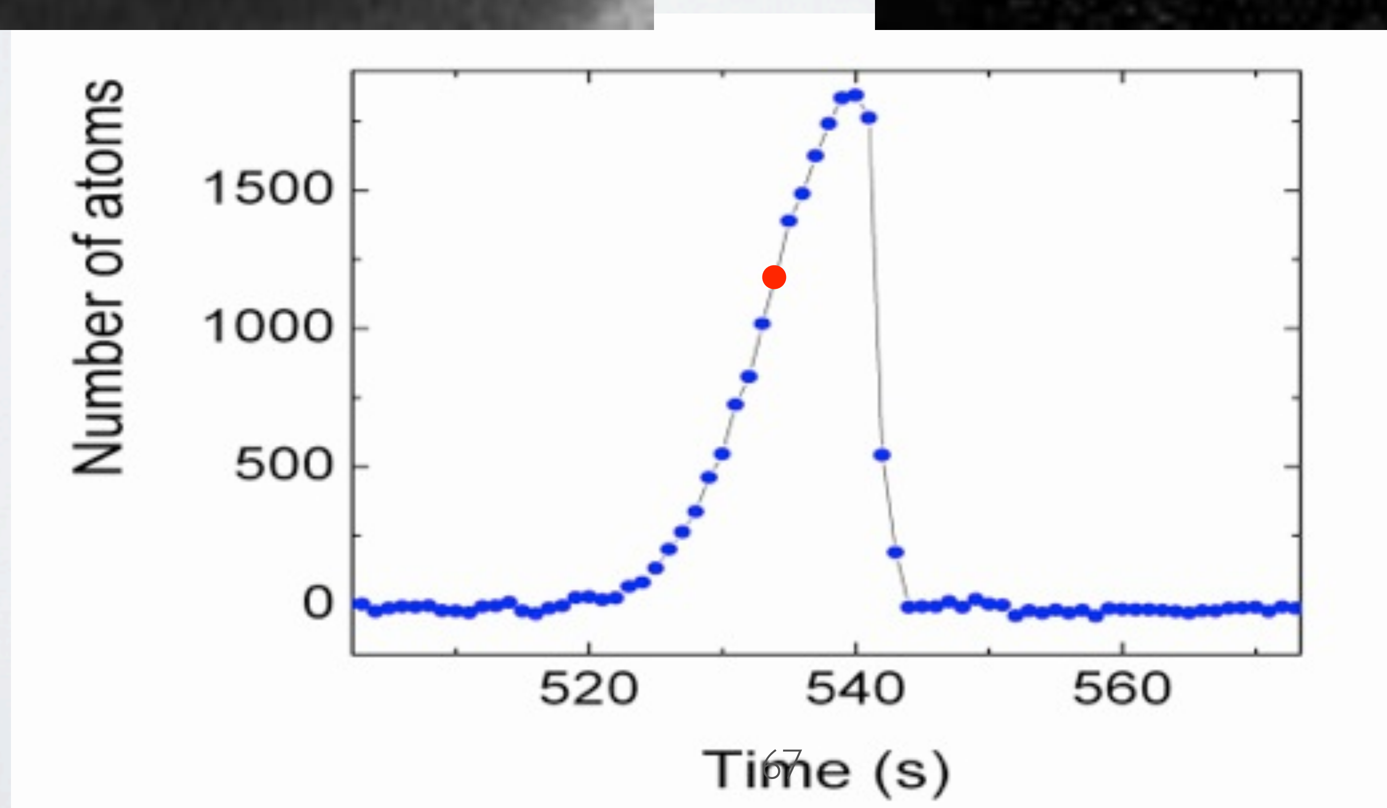
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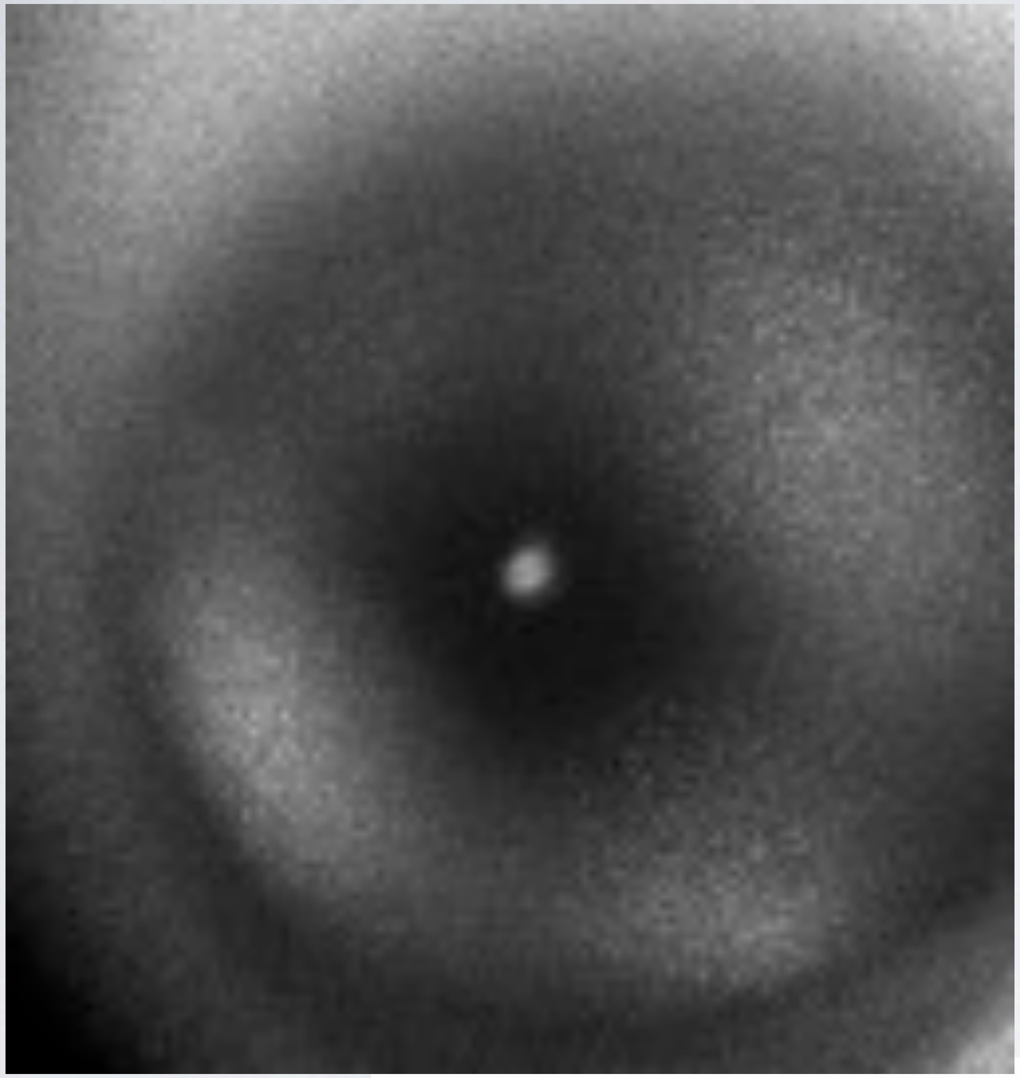
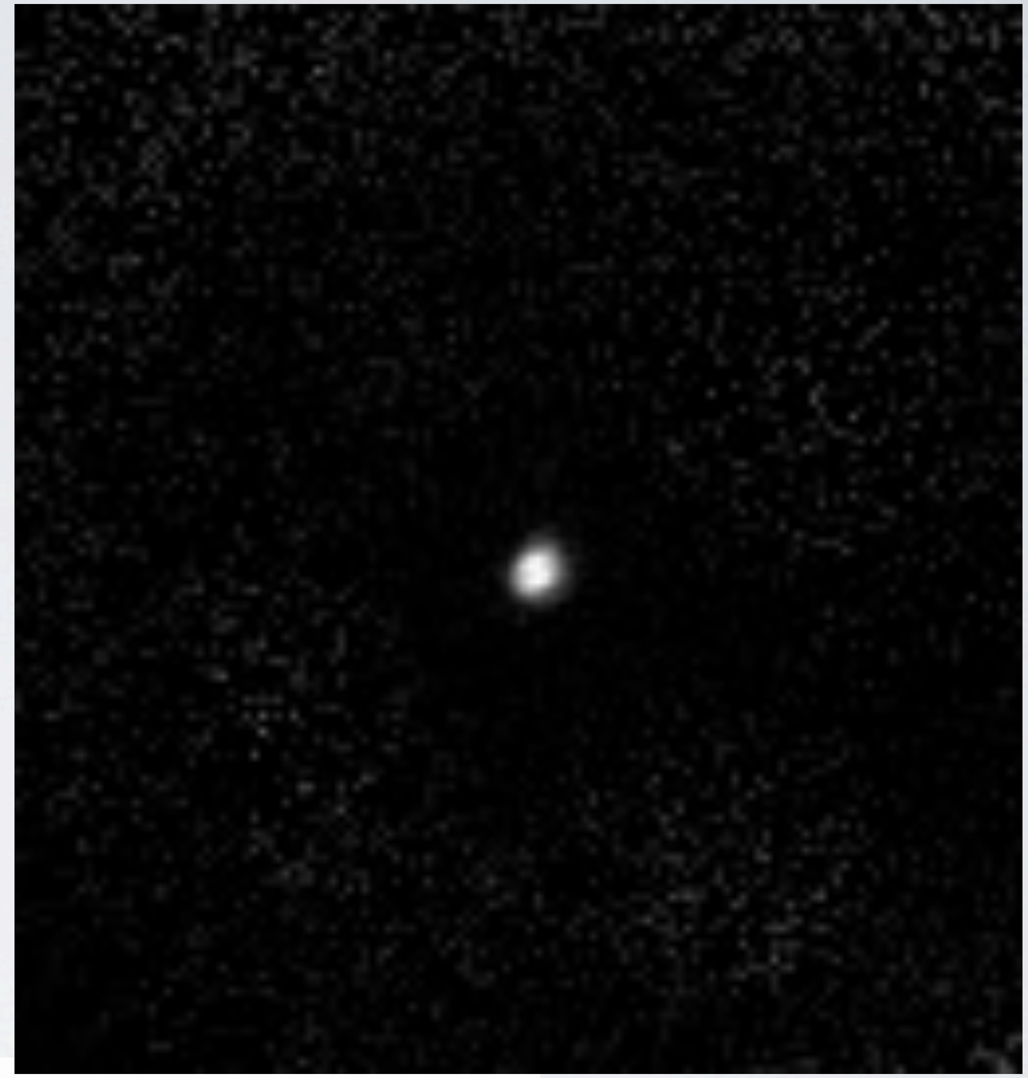
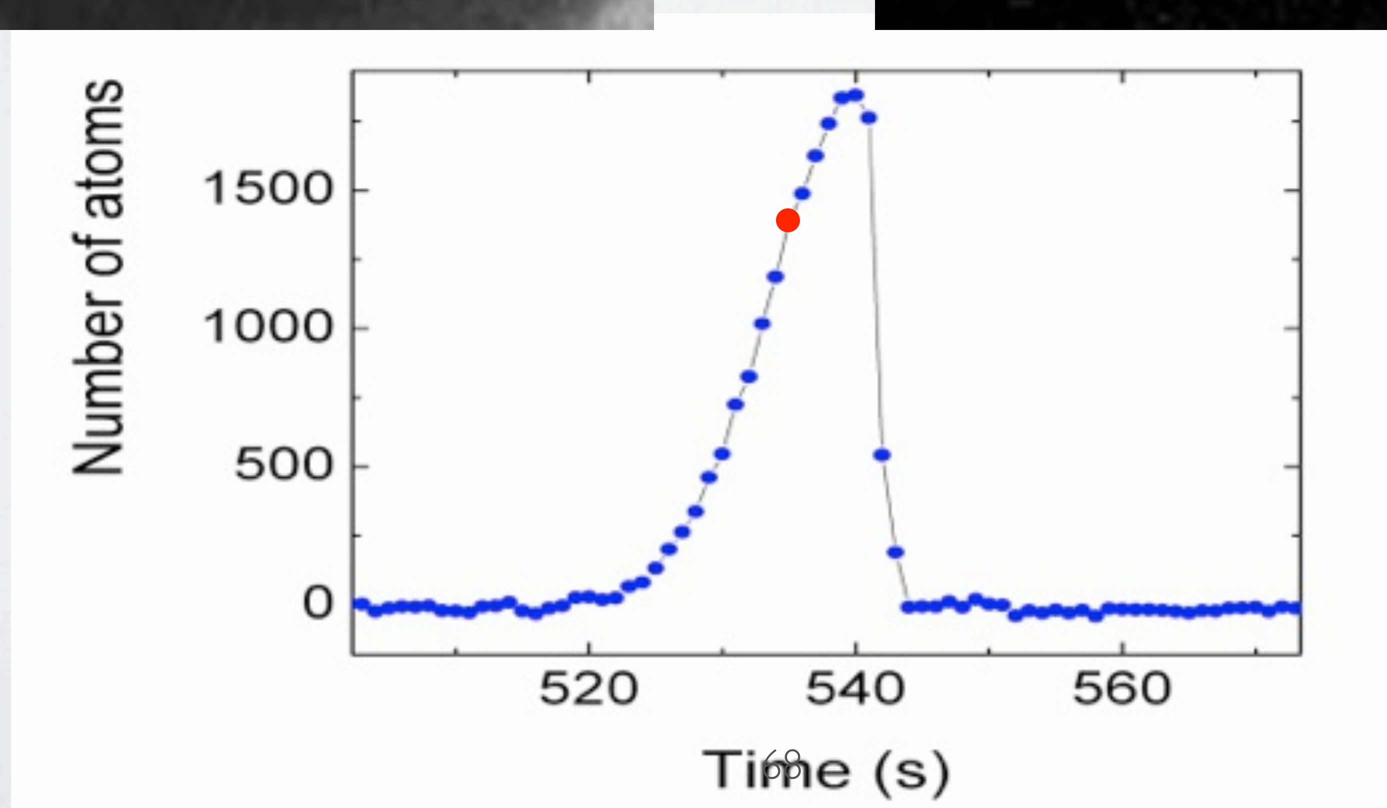
Time (s)



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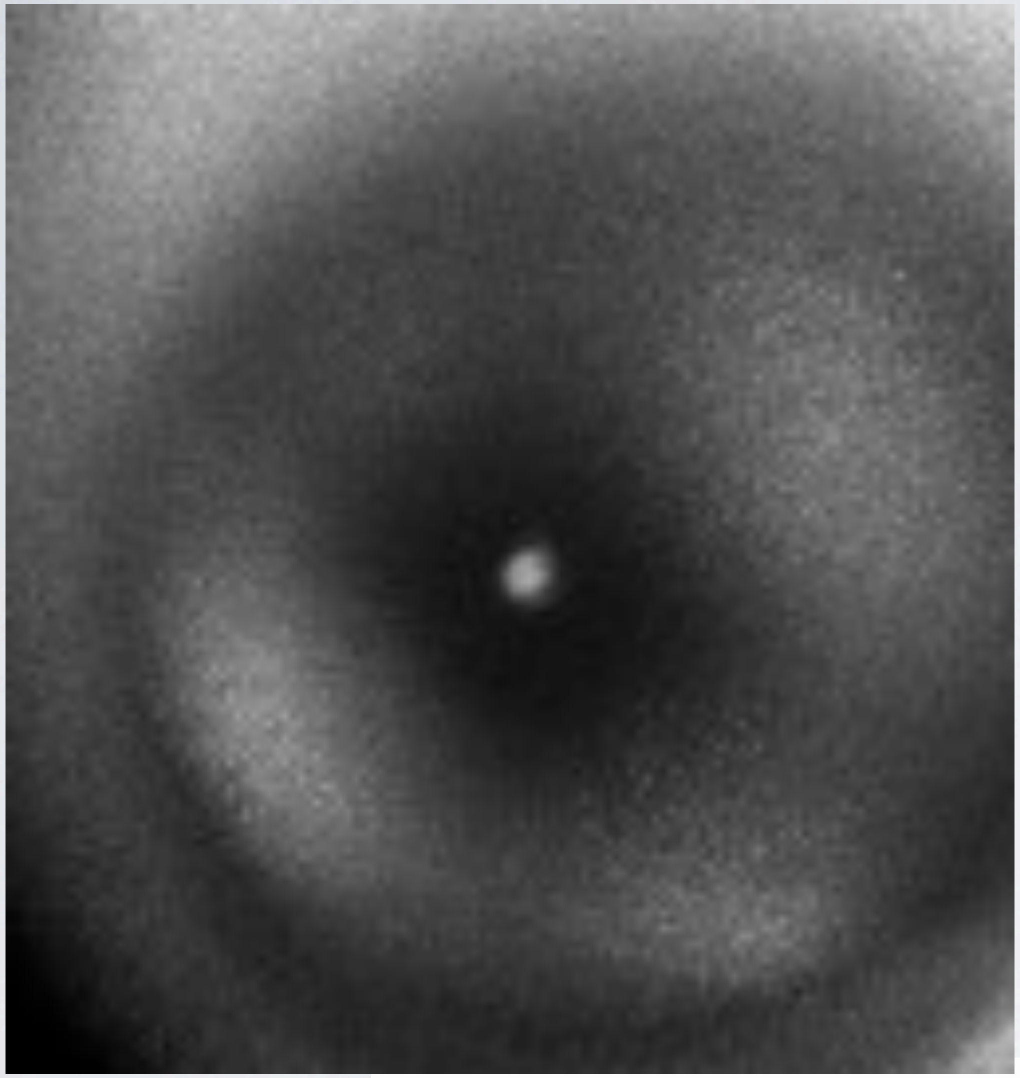
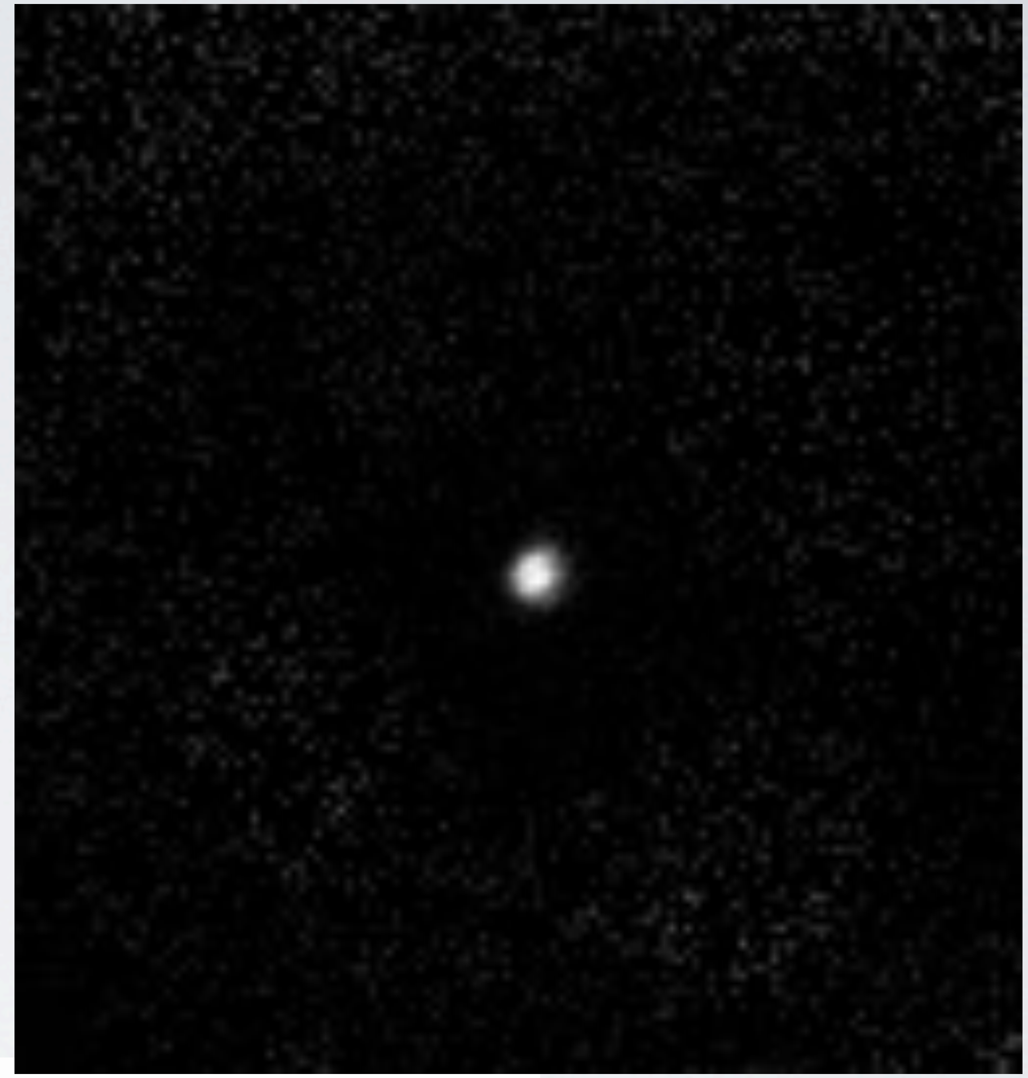
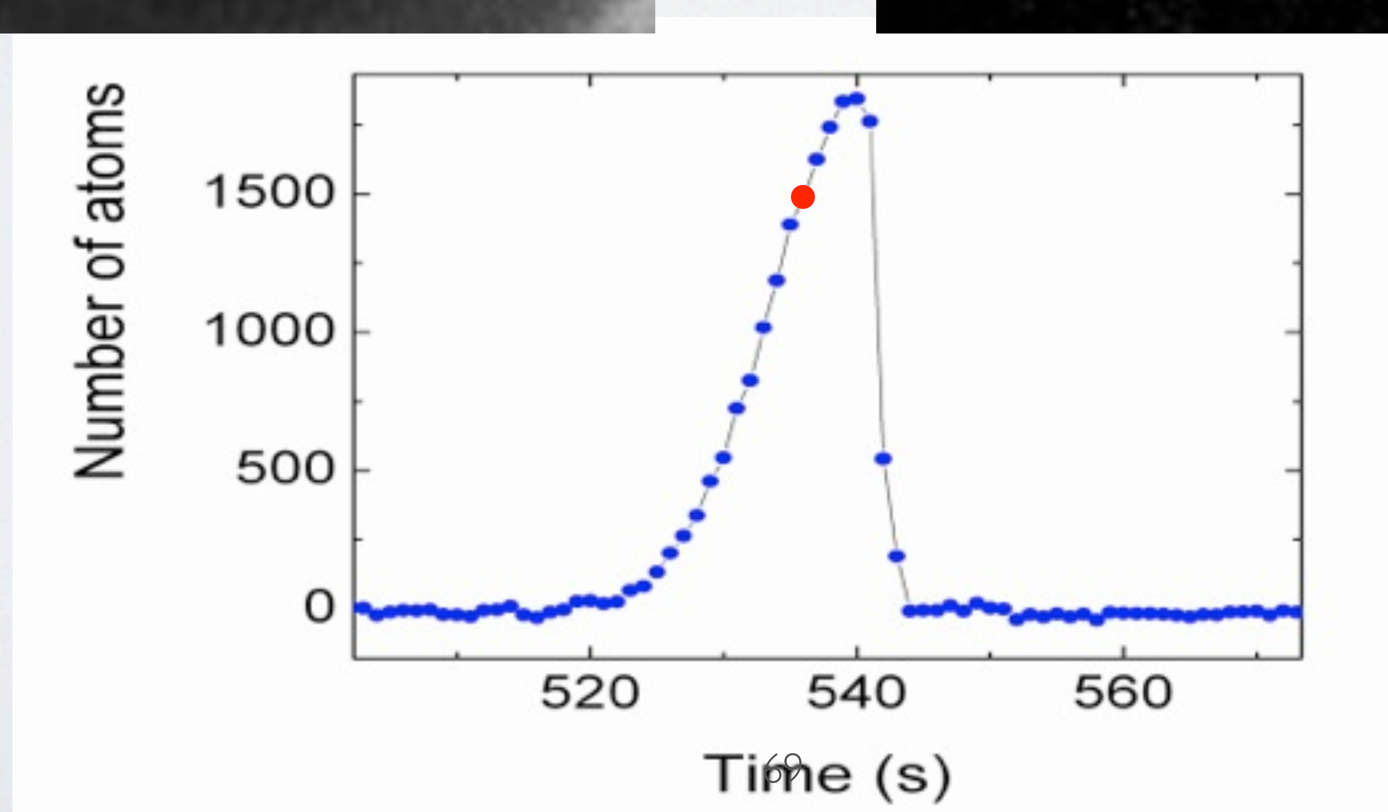
Time (s)



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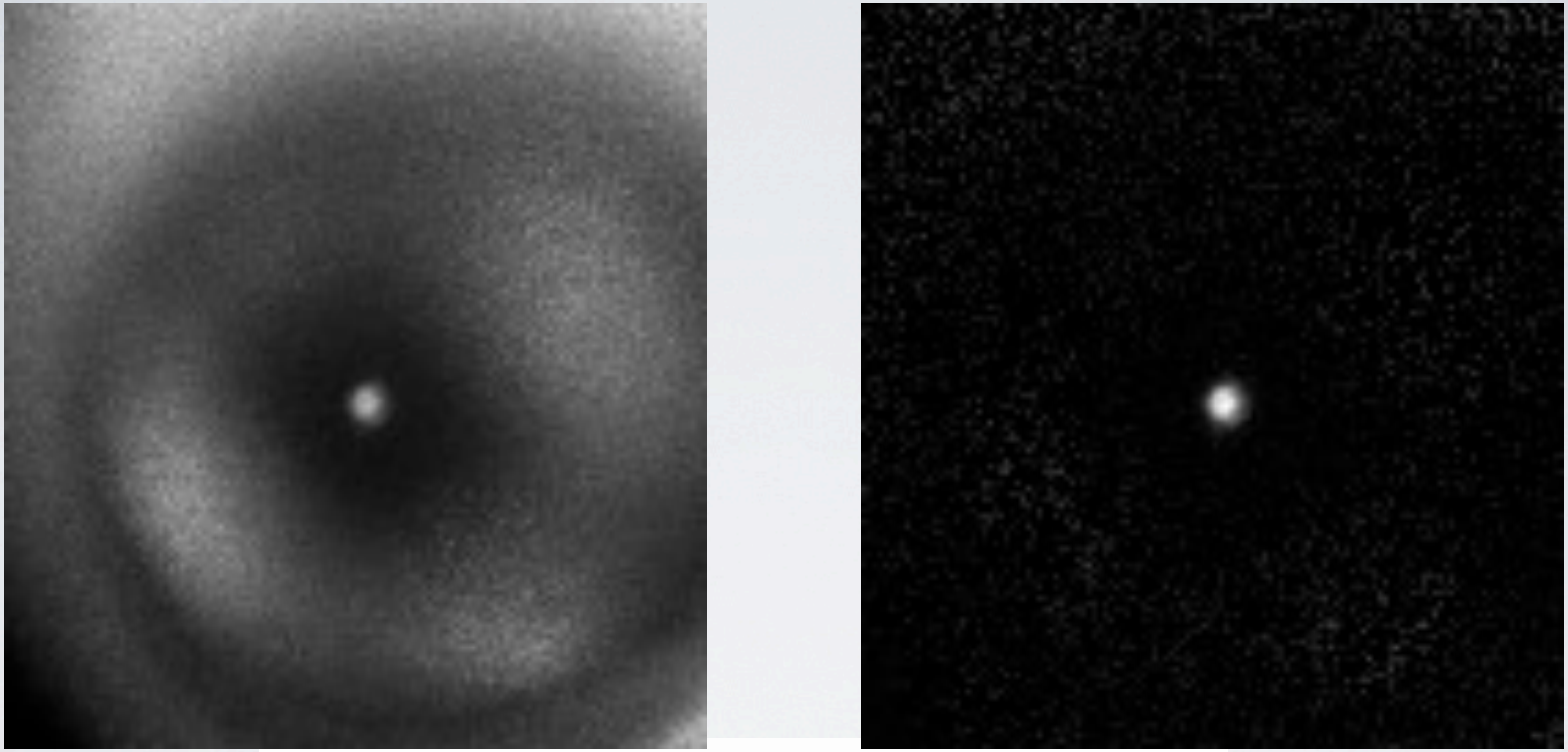
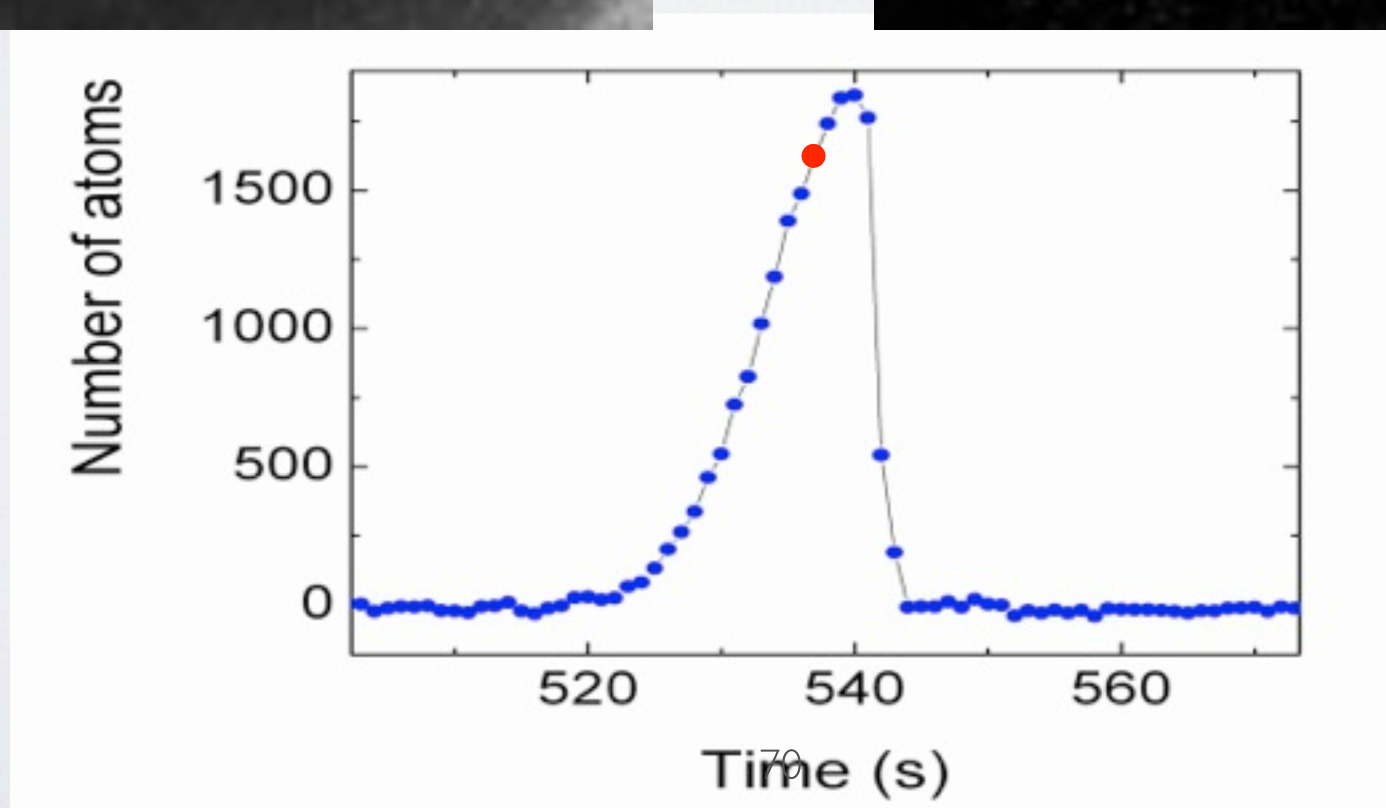
Time (s)

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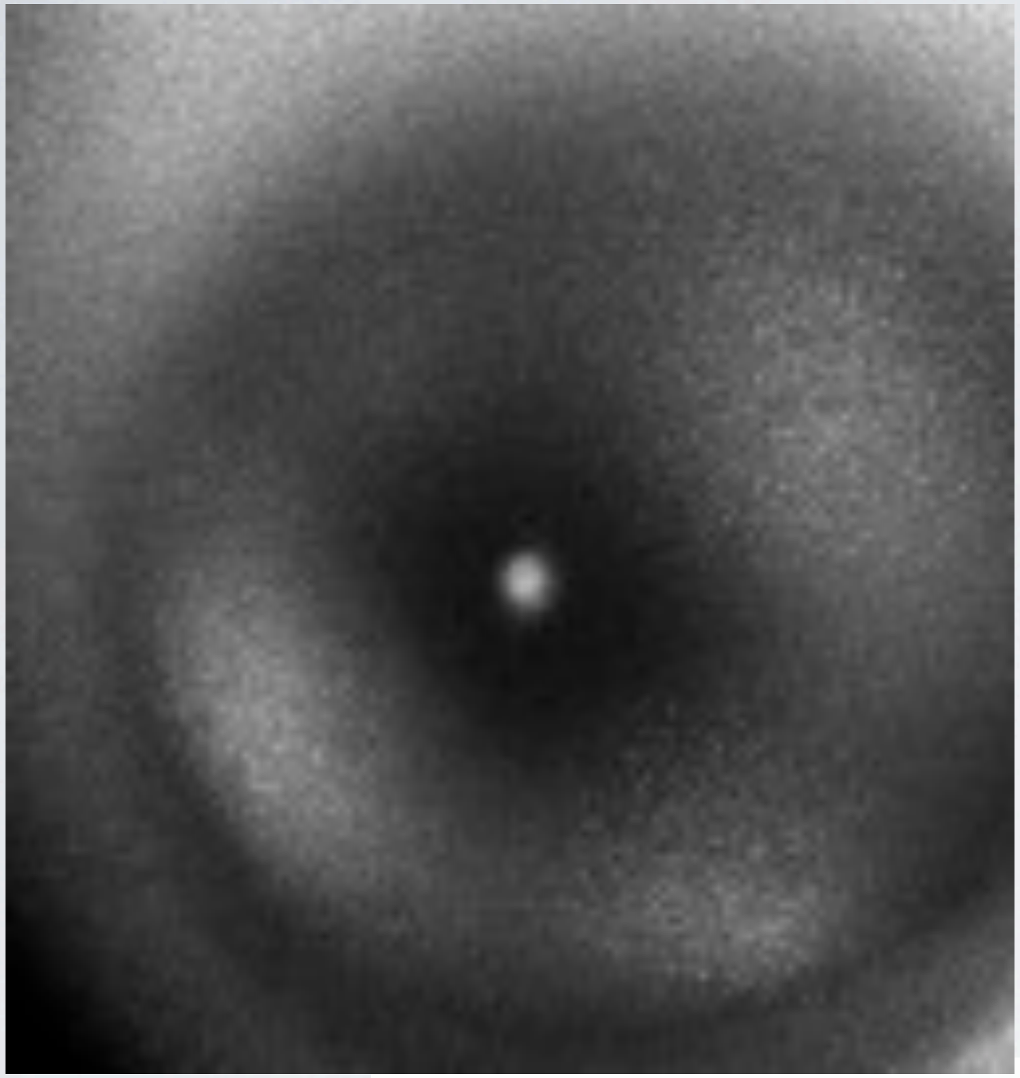
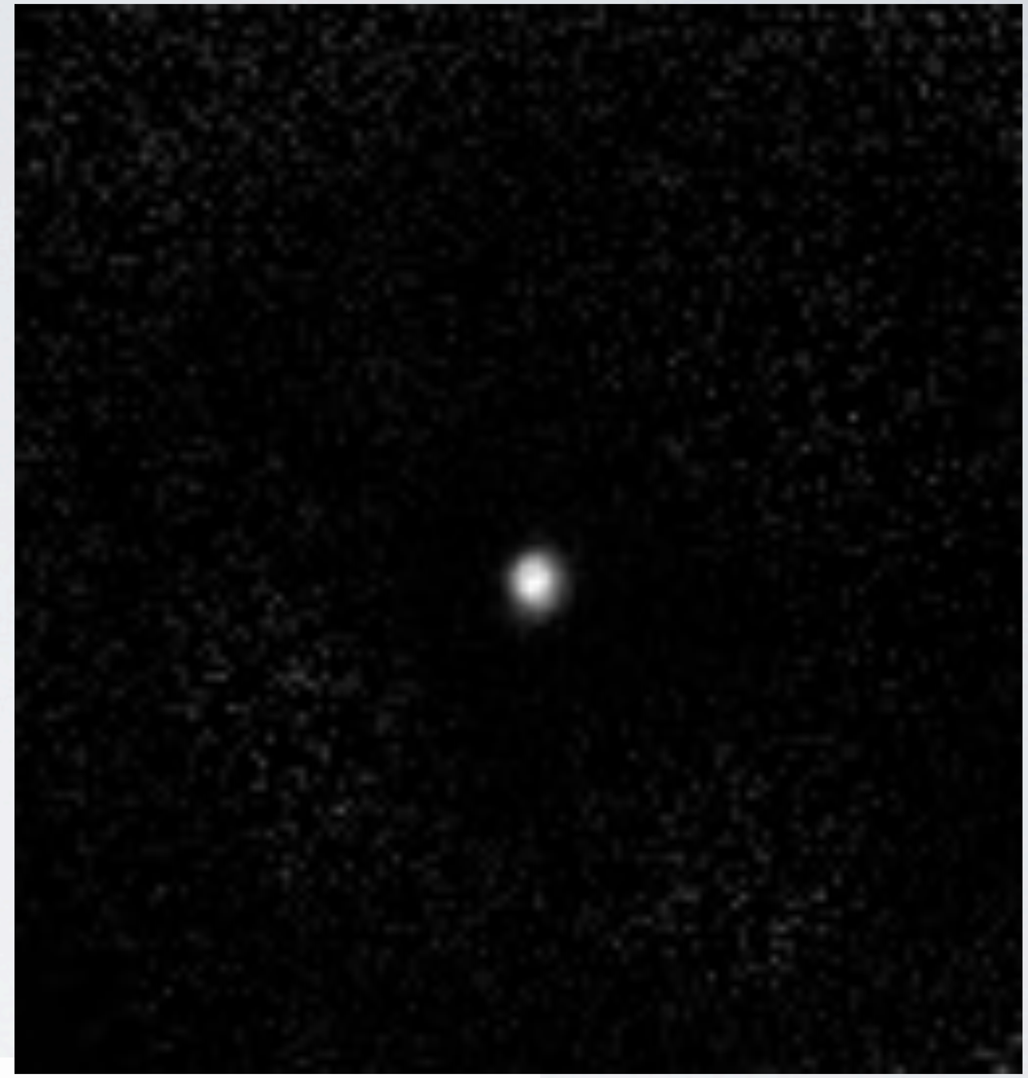
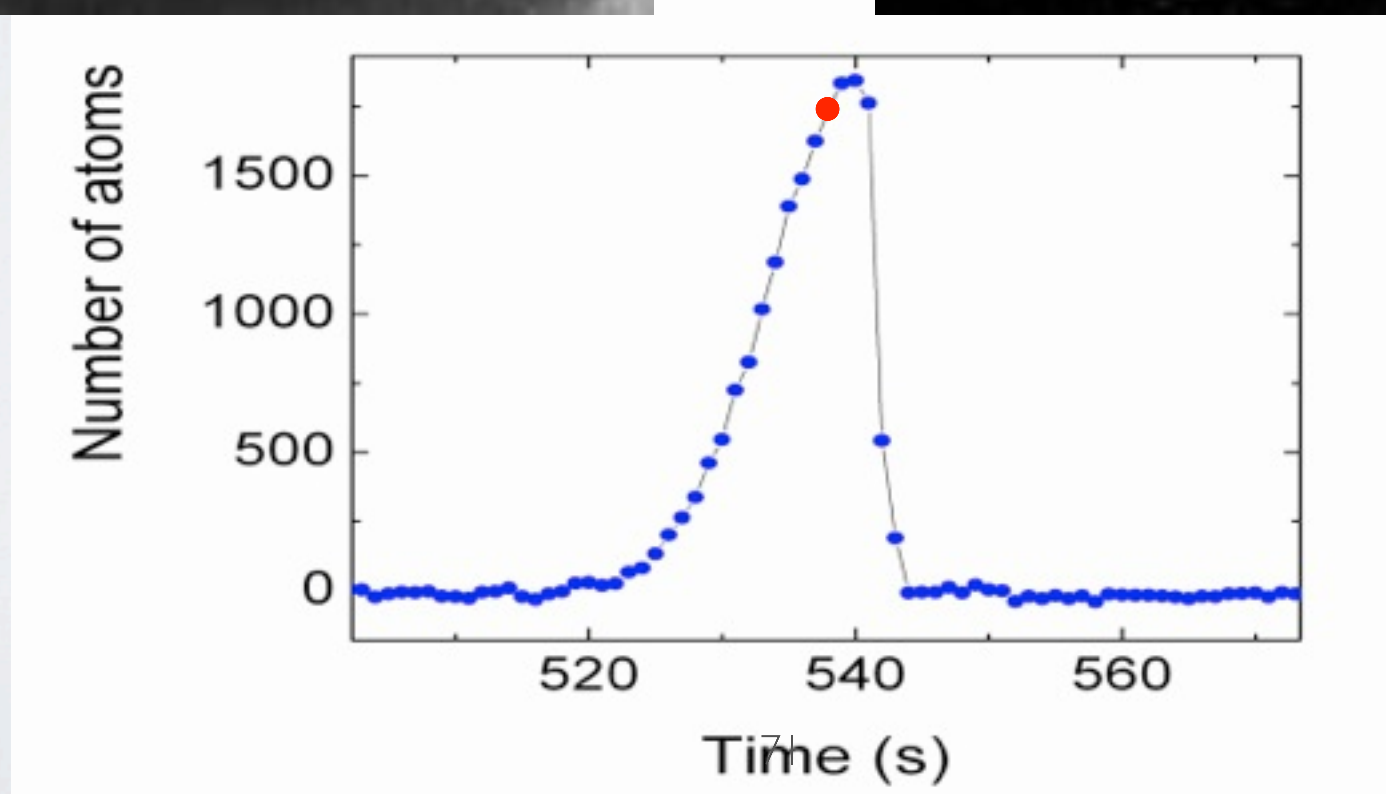
Time (s)



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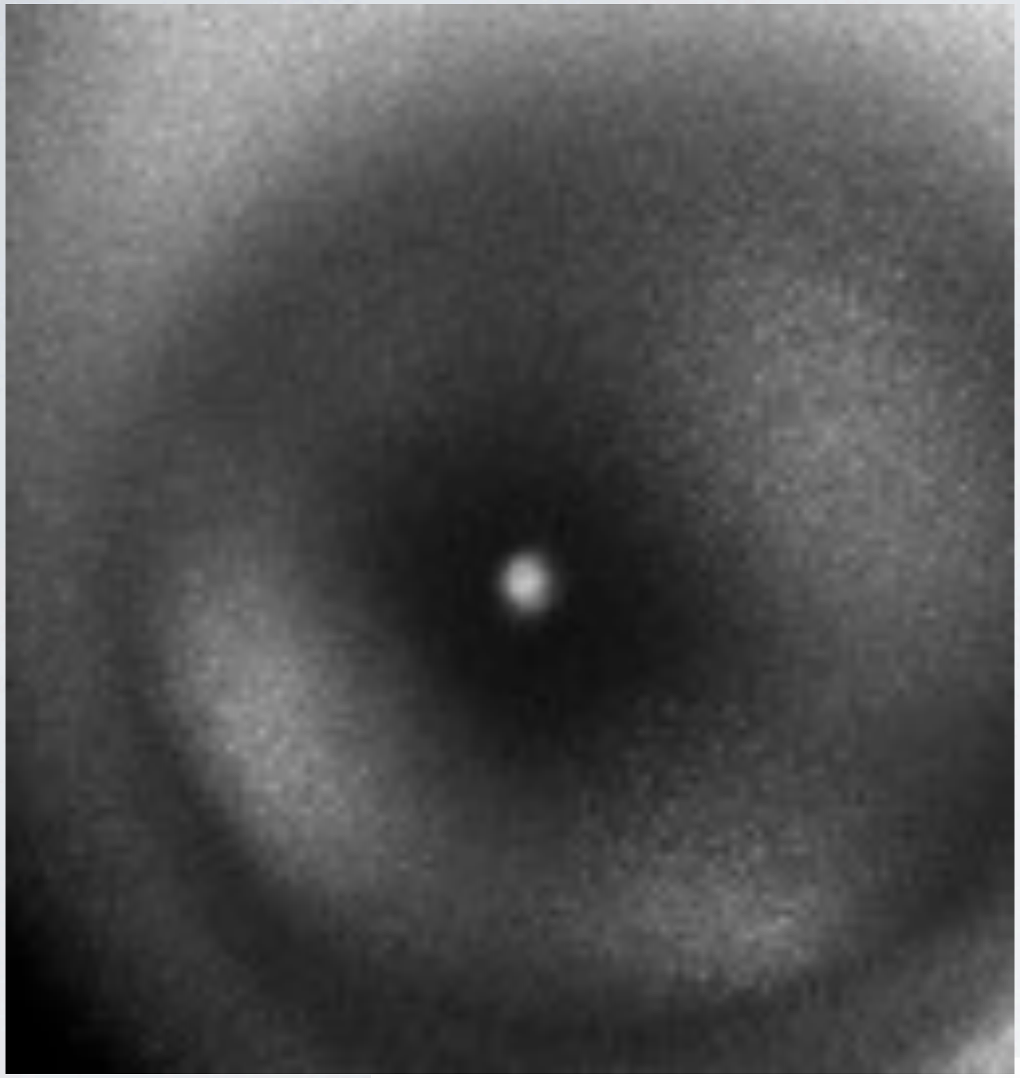
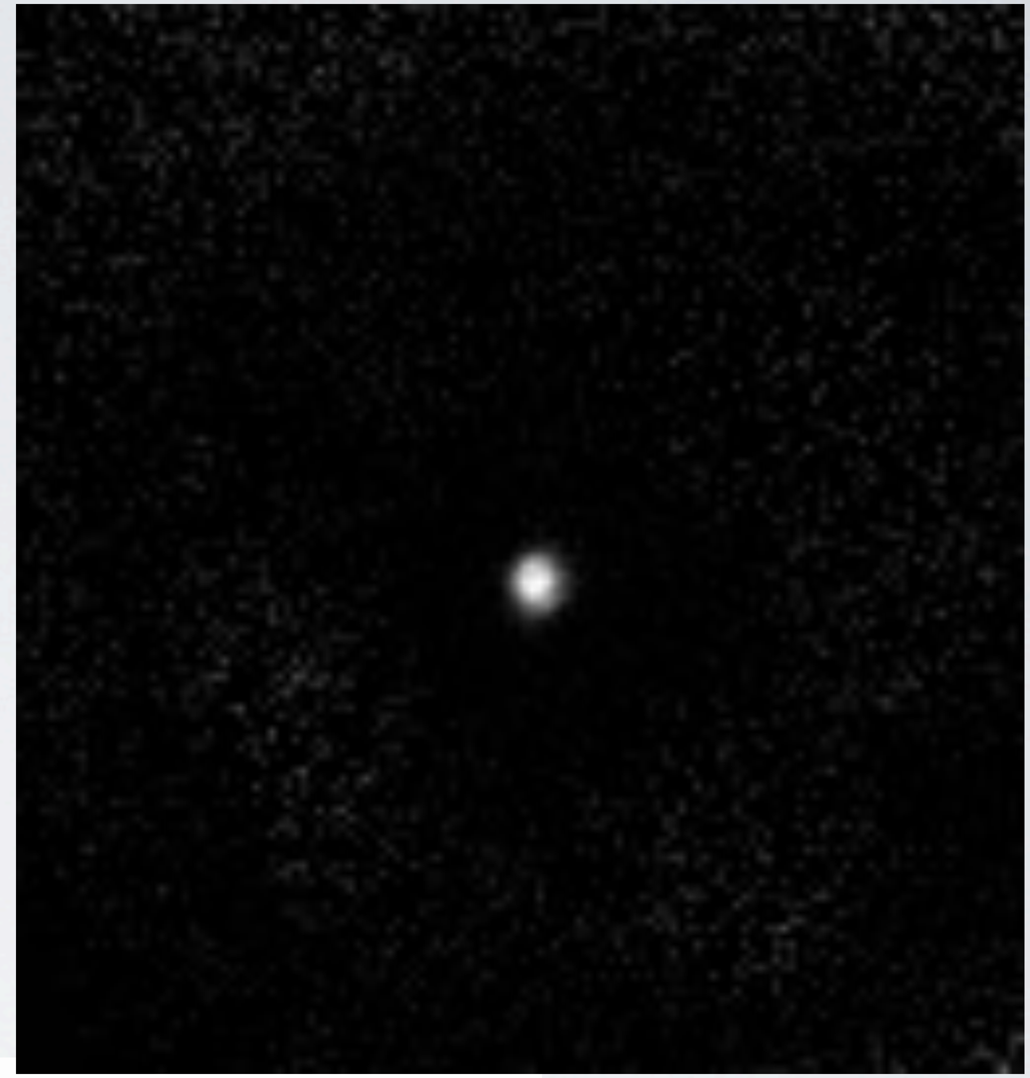
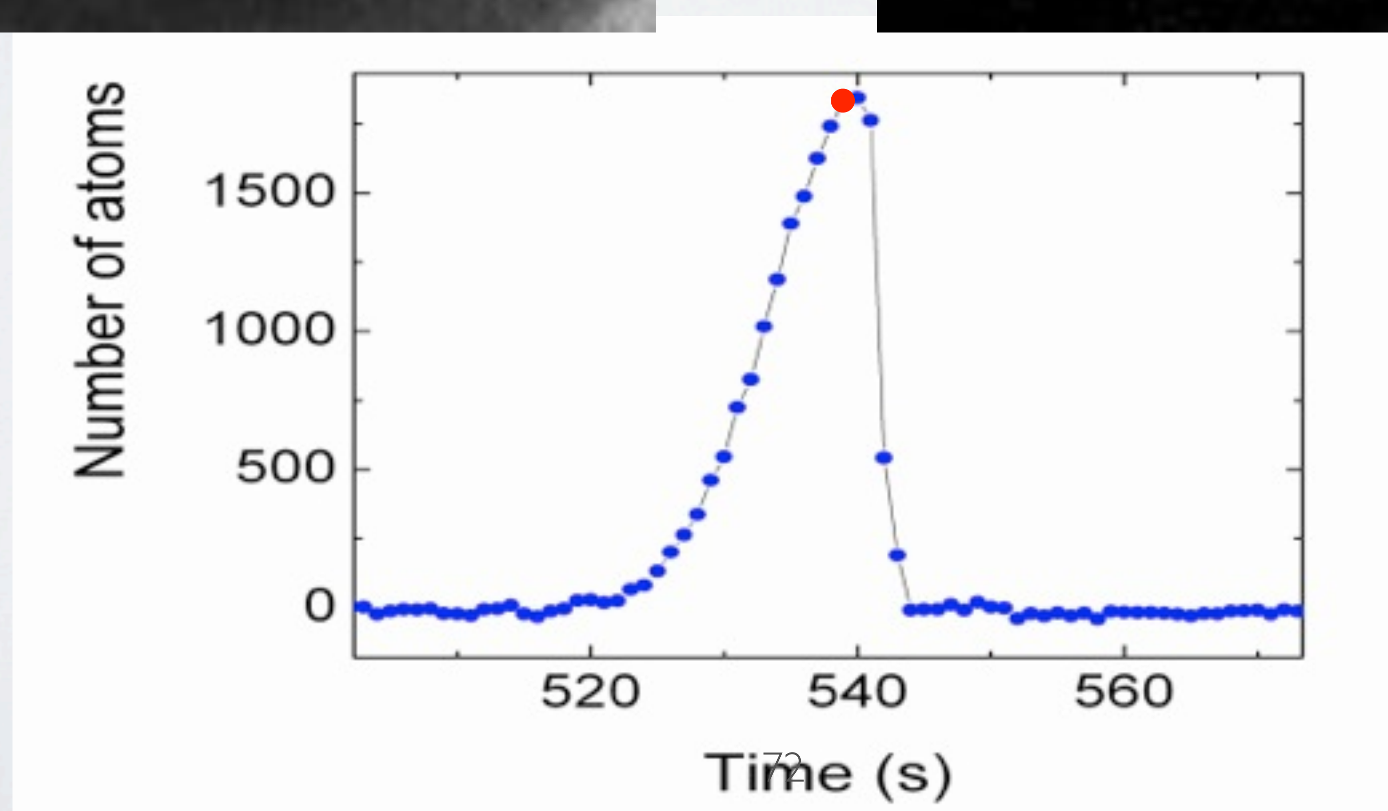
Time (s)



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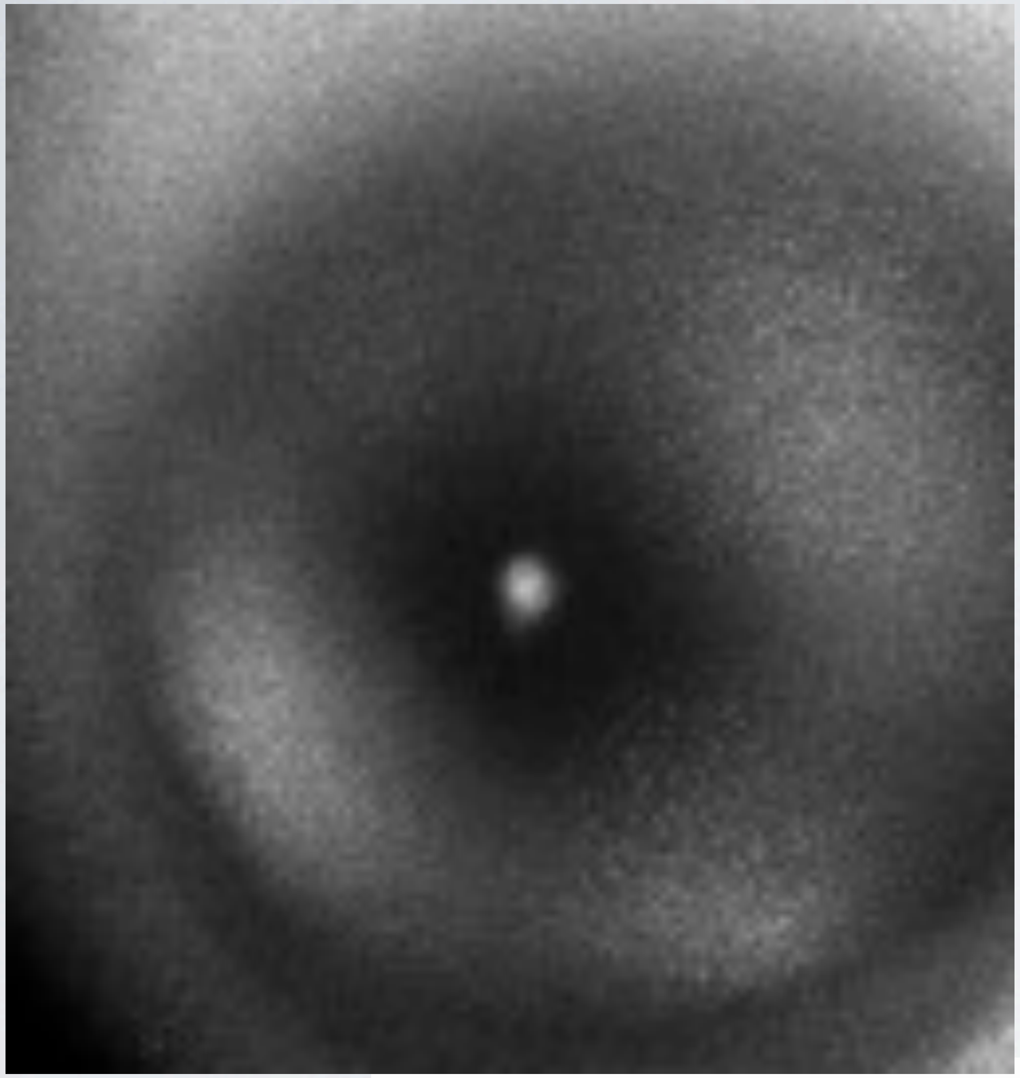
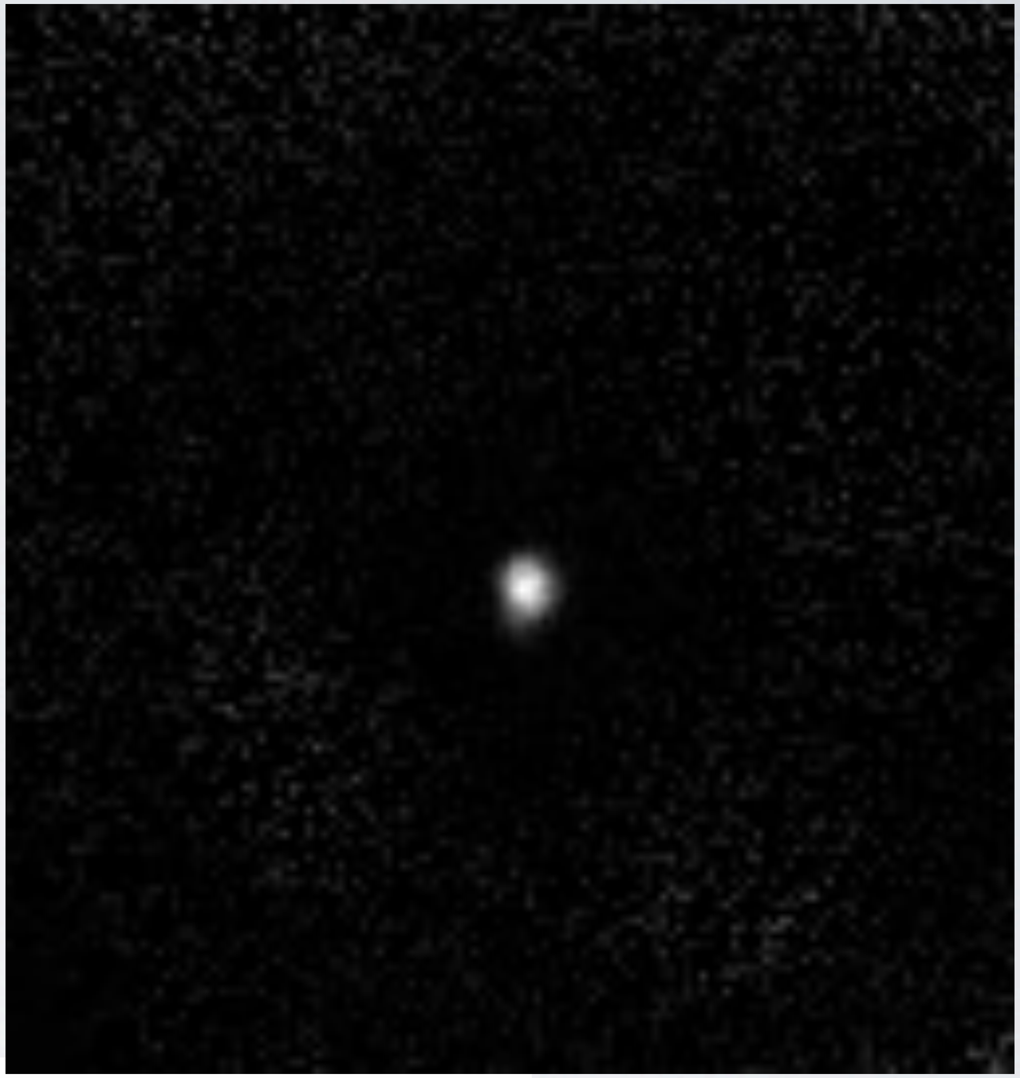
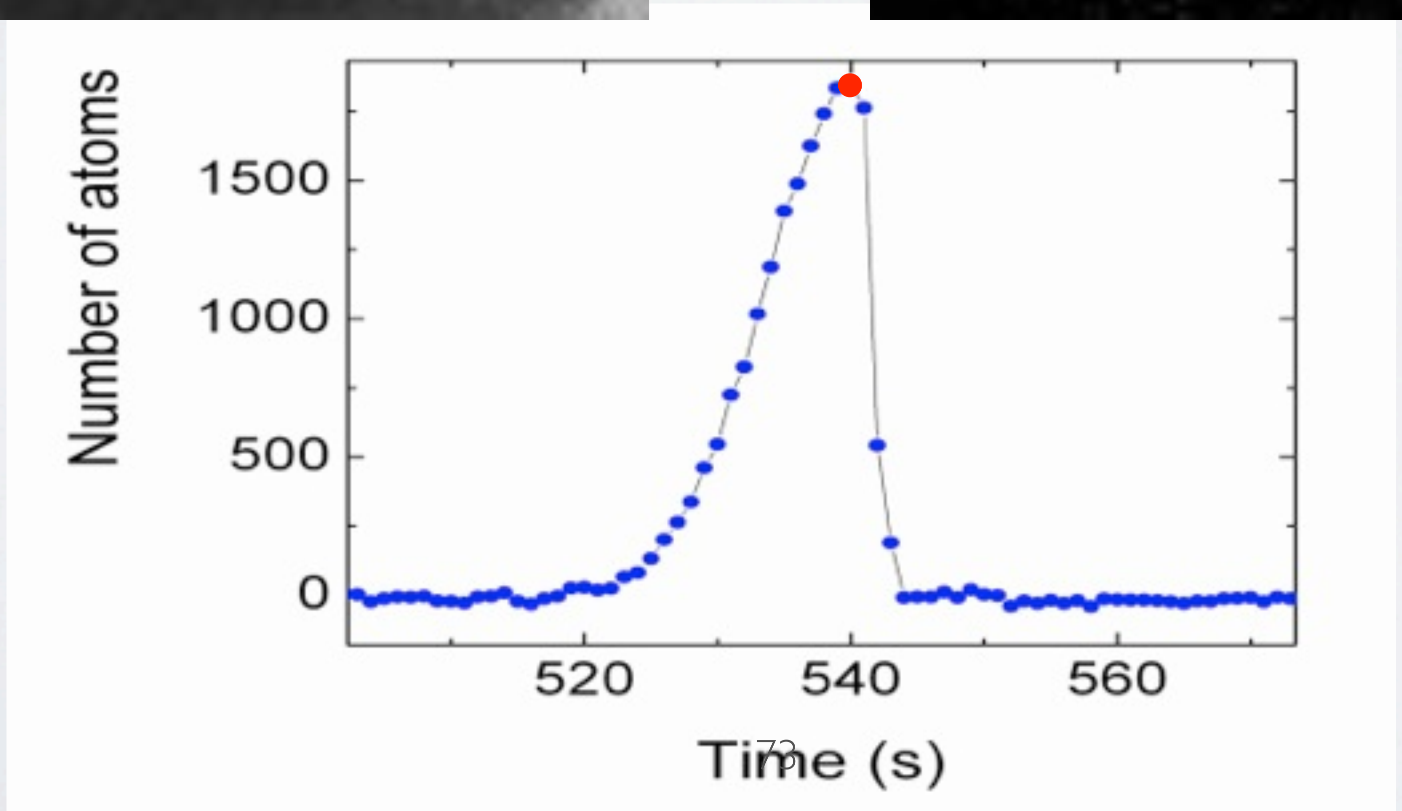
Time (s)






Number of atoms
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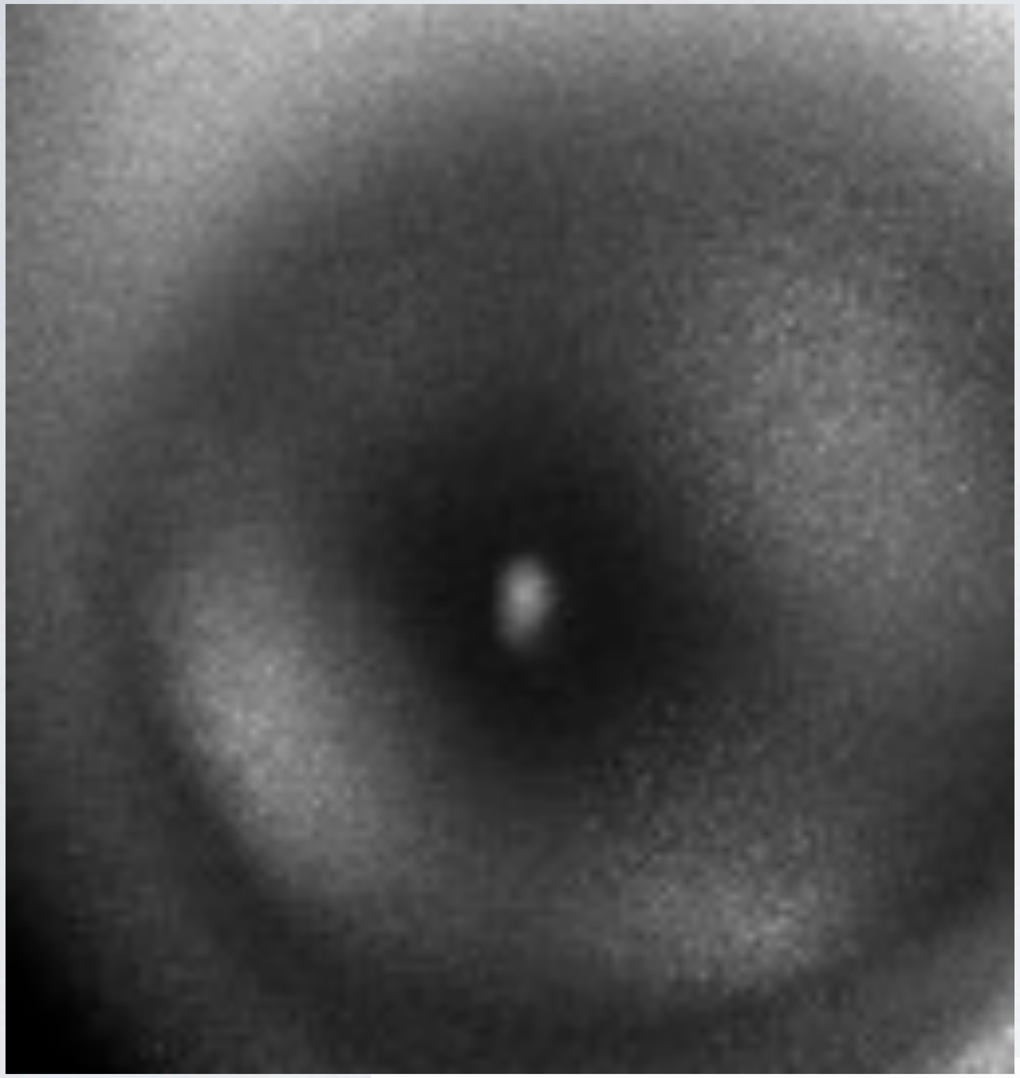
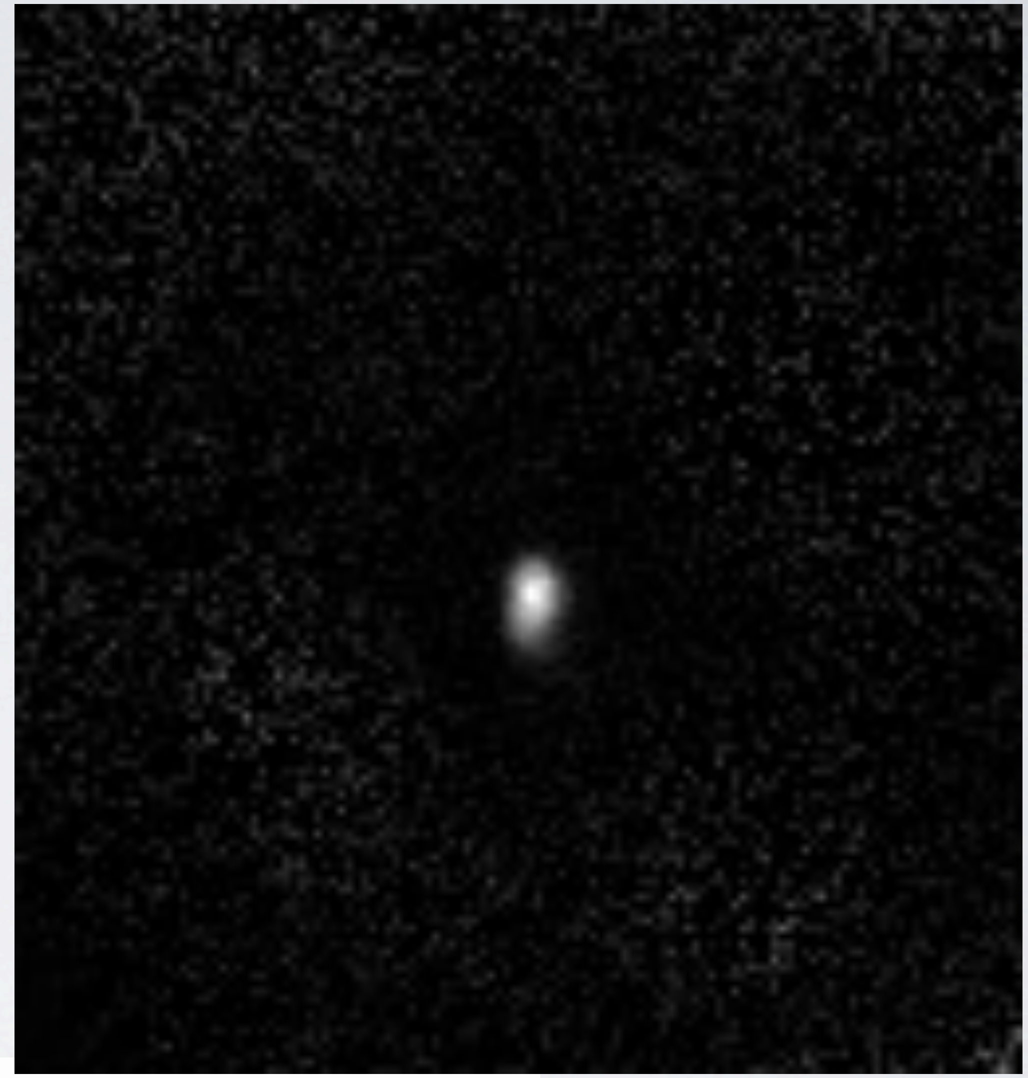
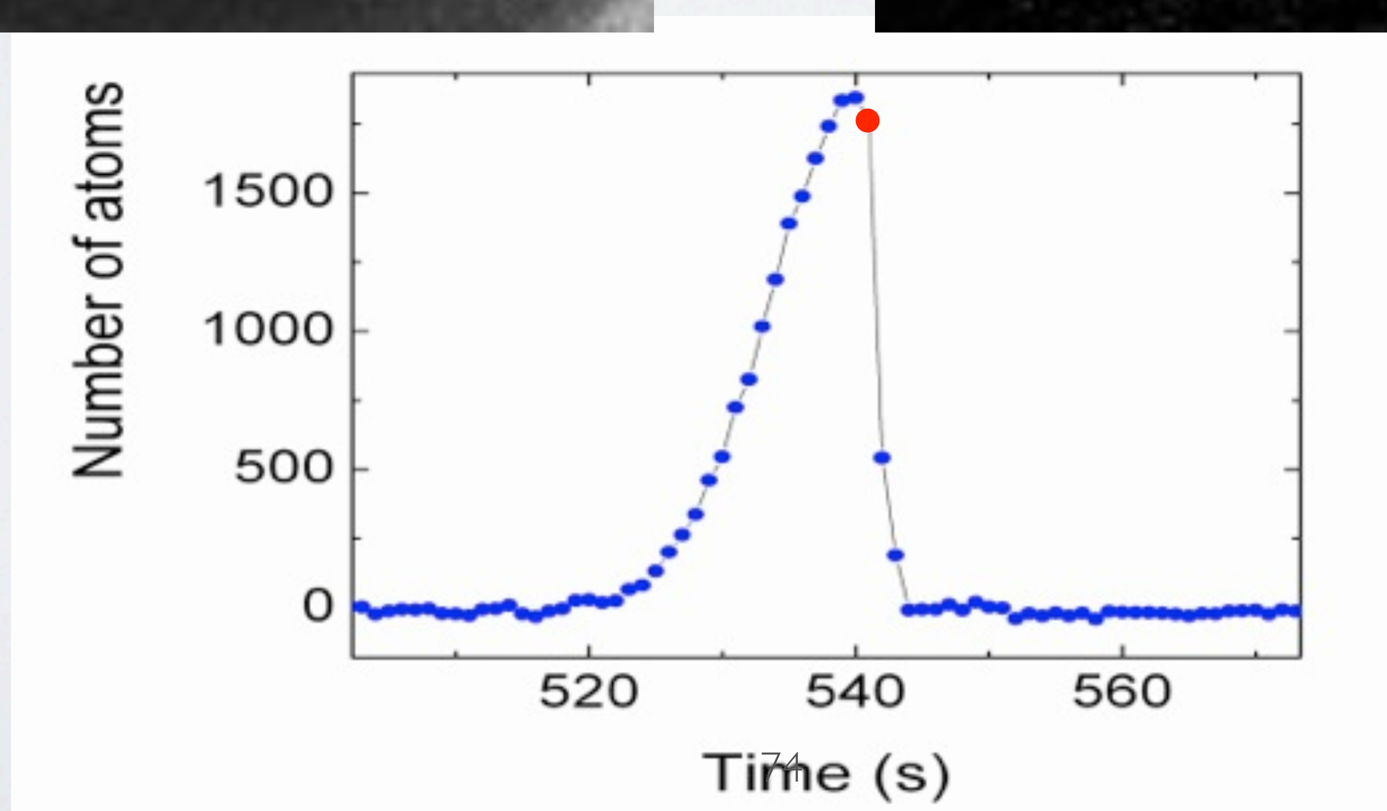
Time (s)






Number of atoms
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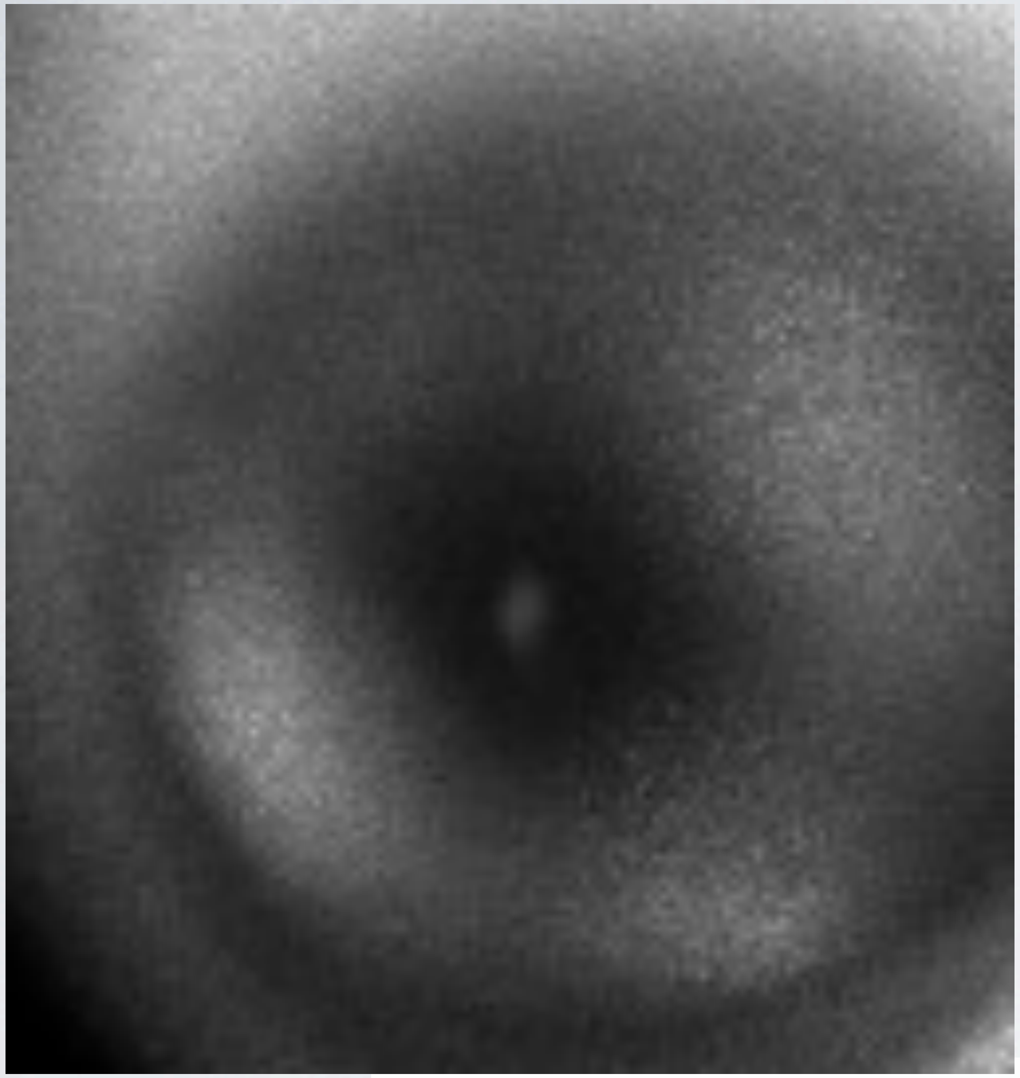
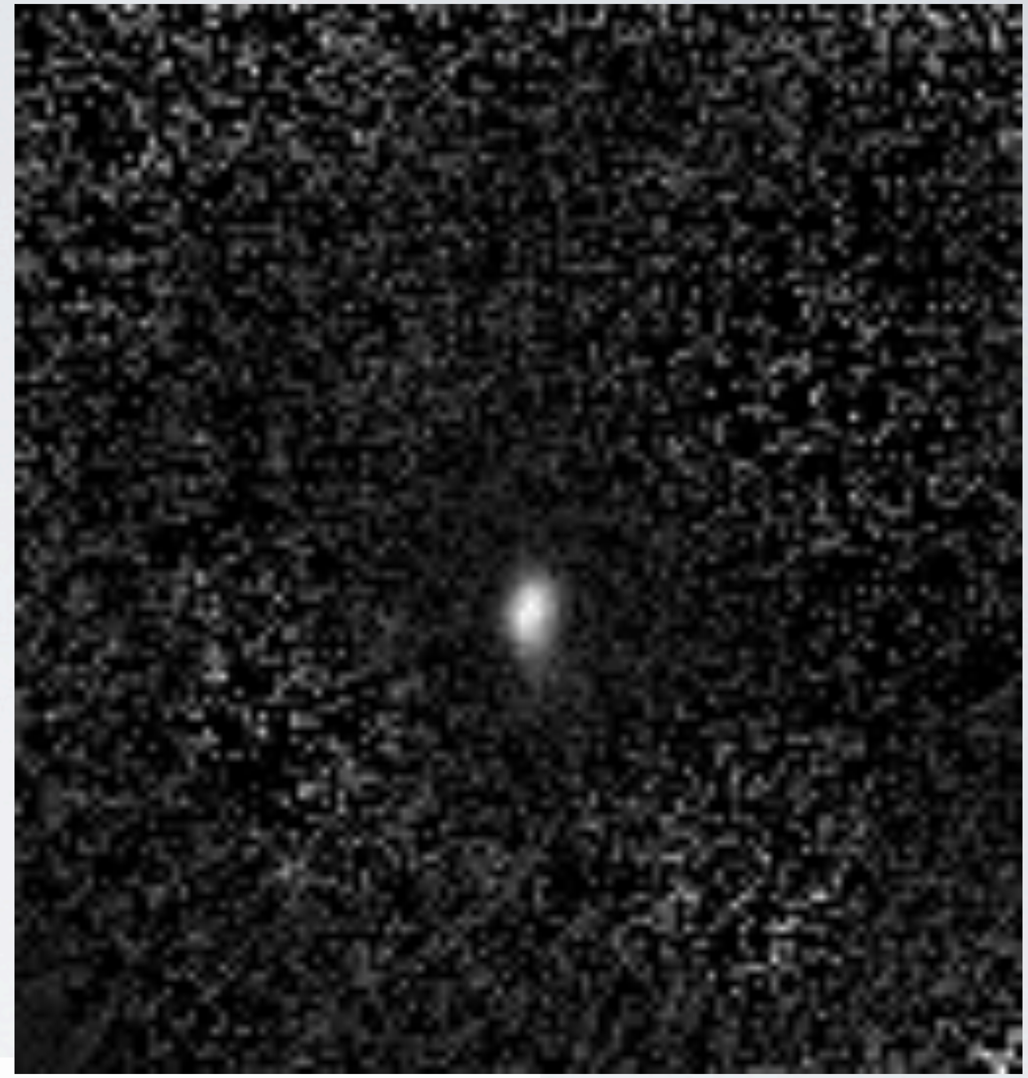
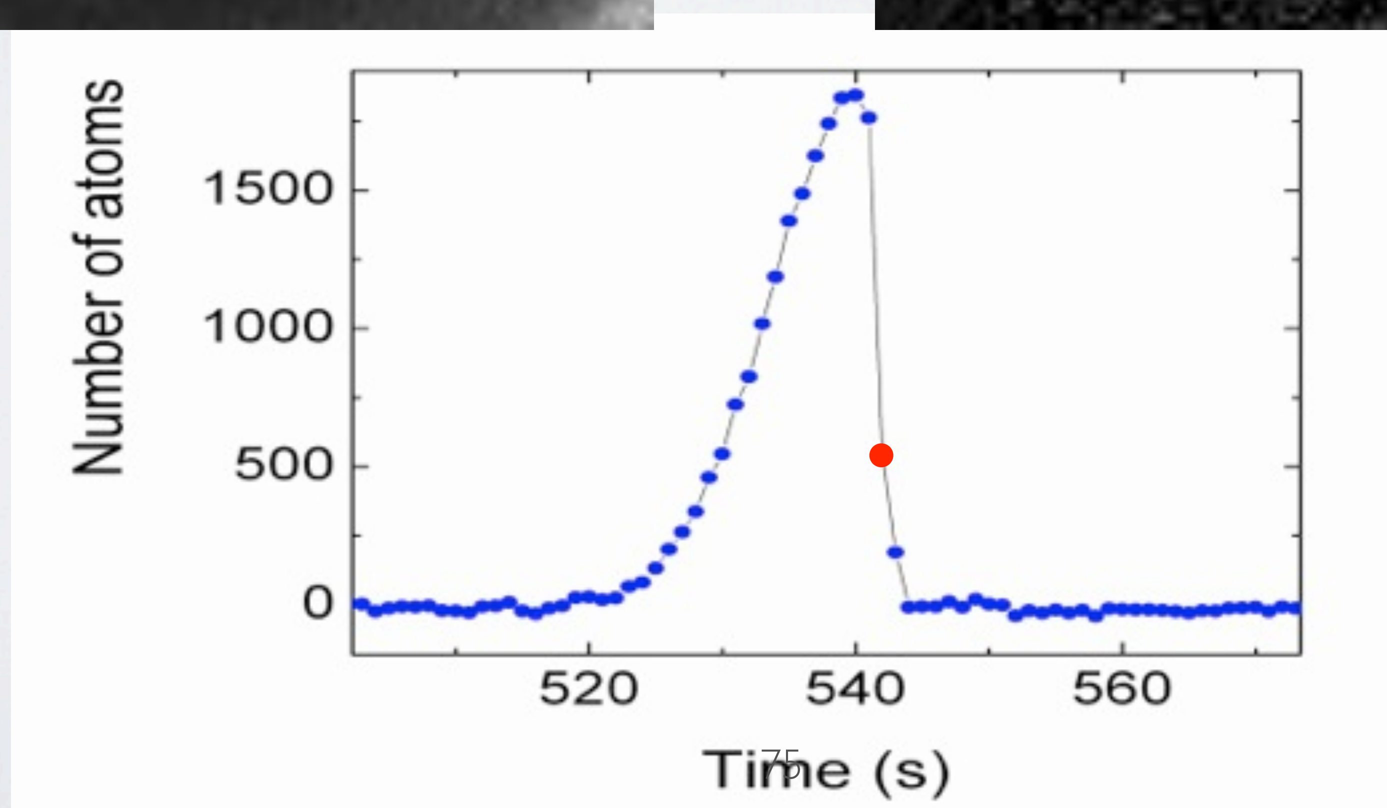
Time (s)






Number of atoms
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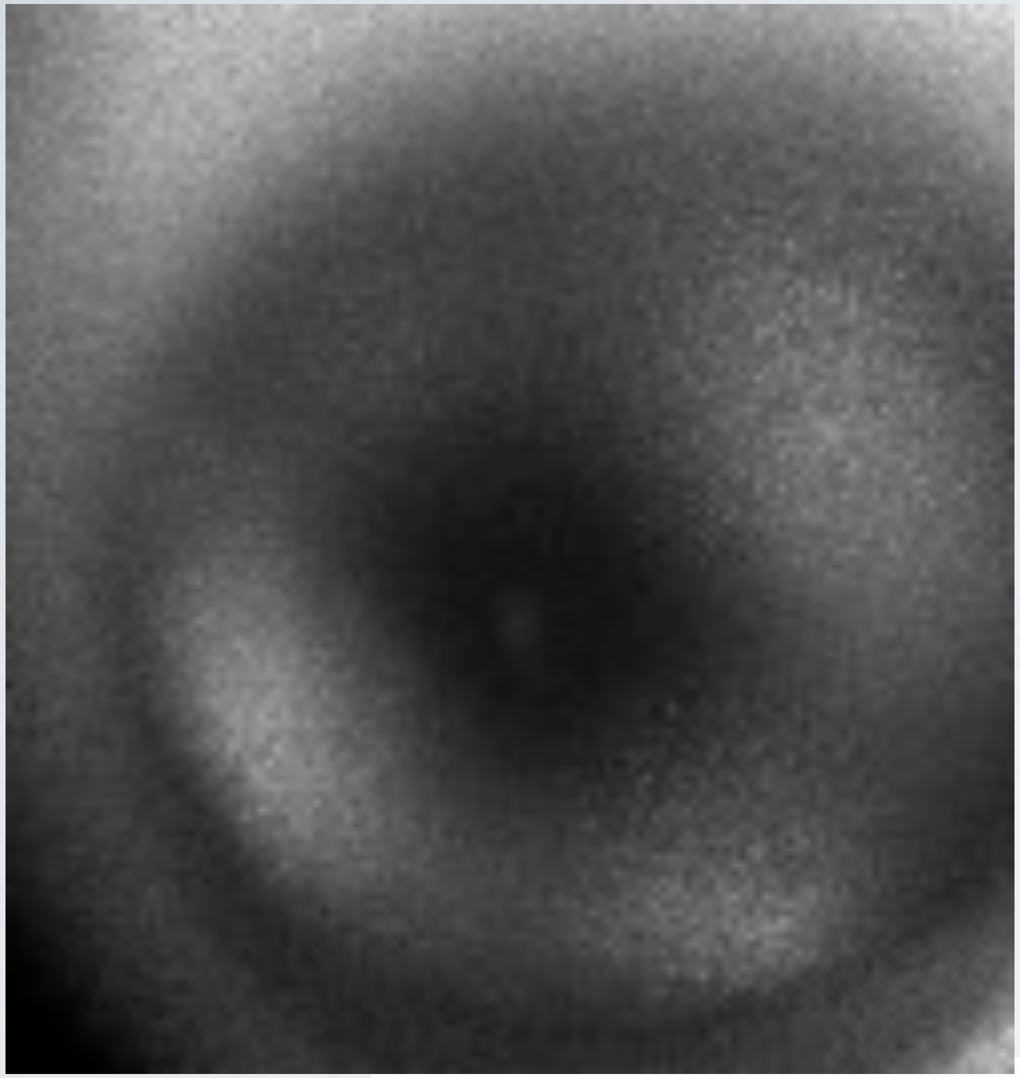
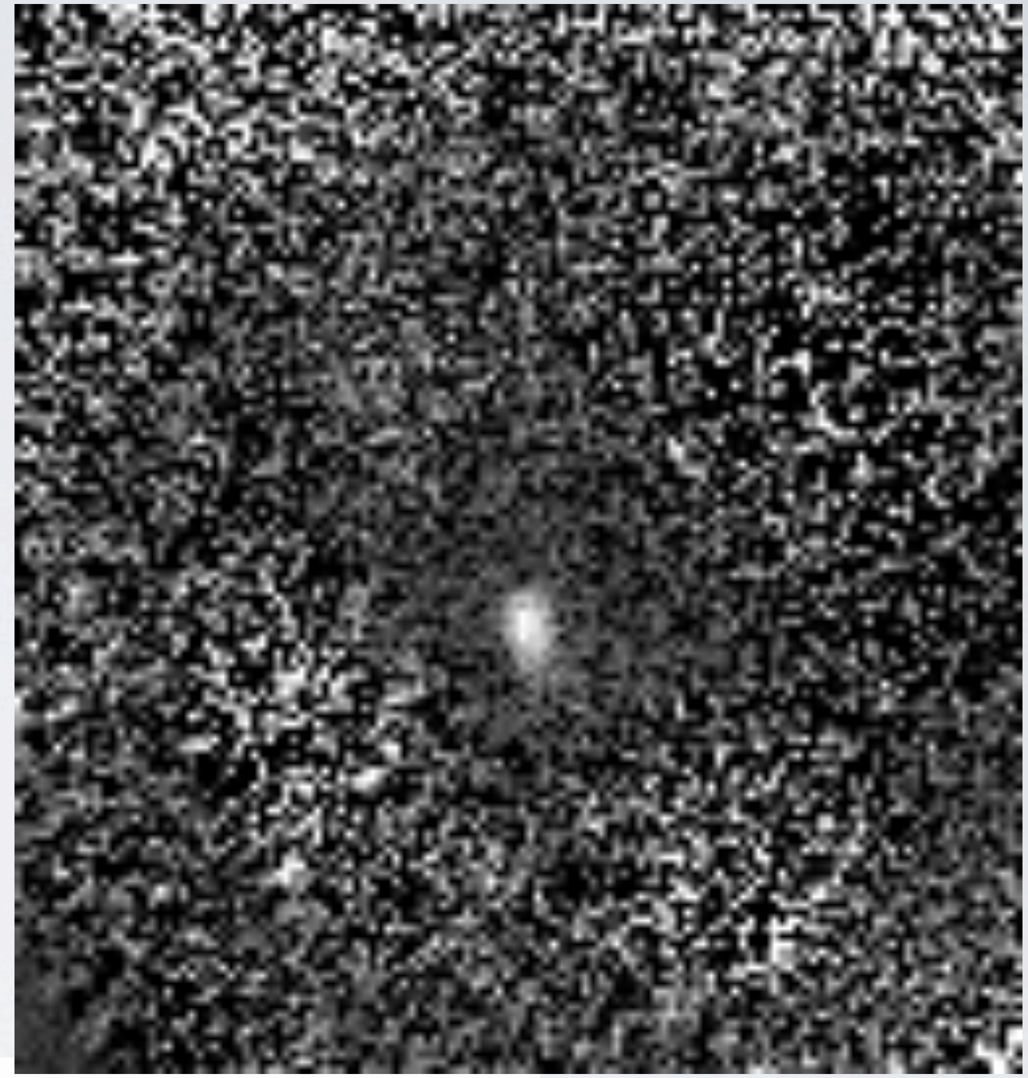
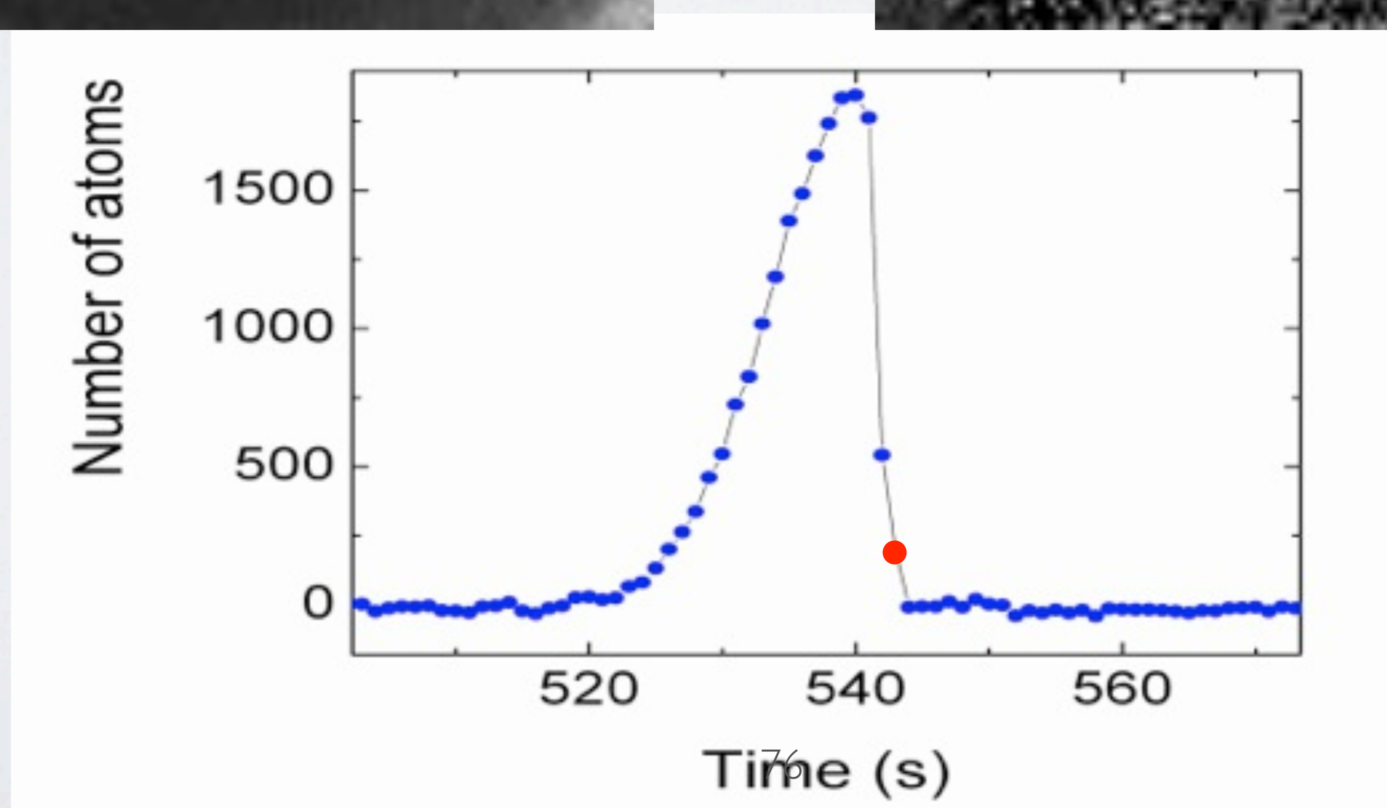
Time (s)






Number of atoms
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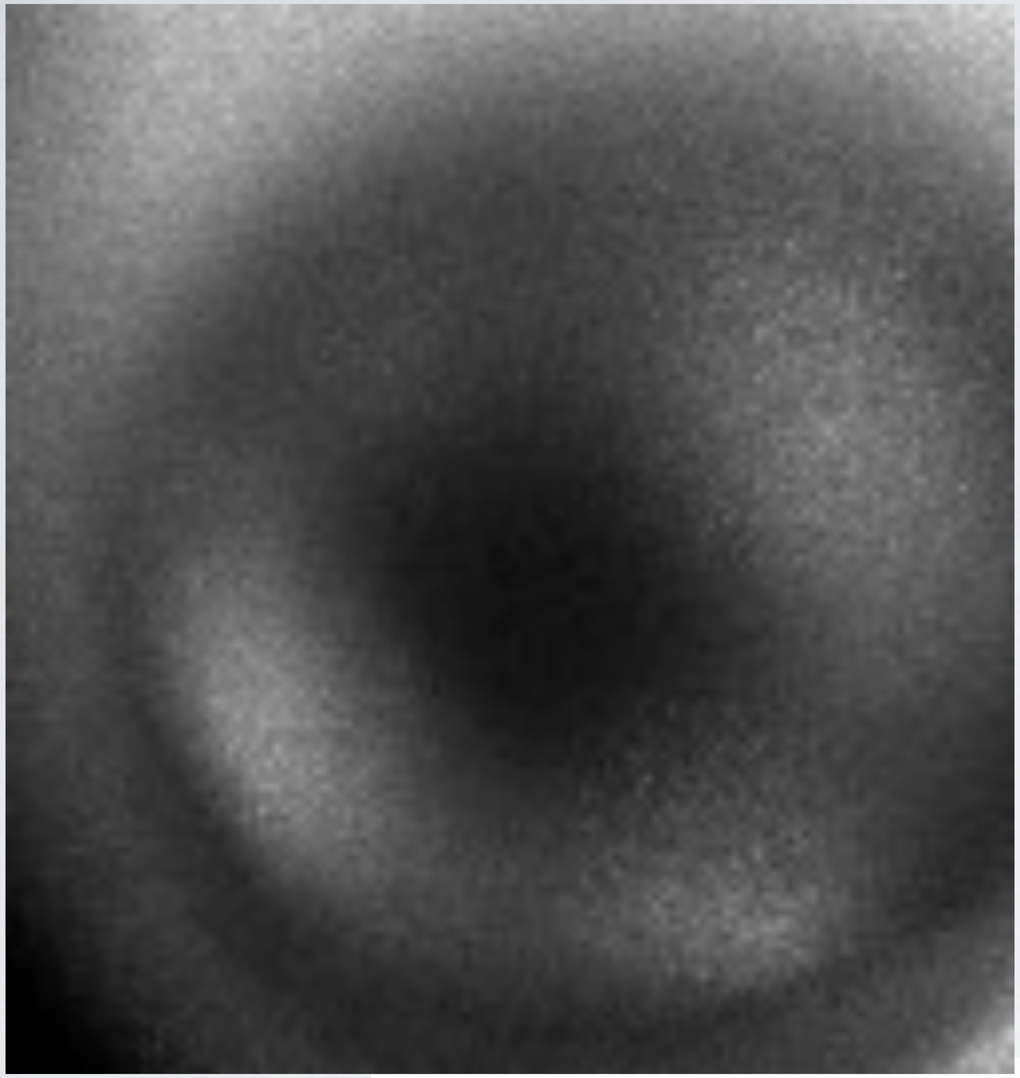
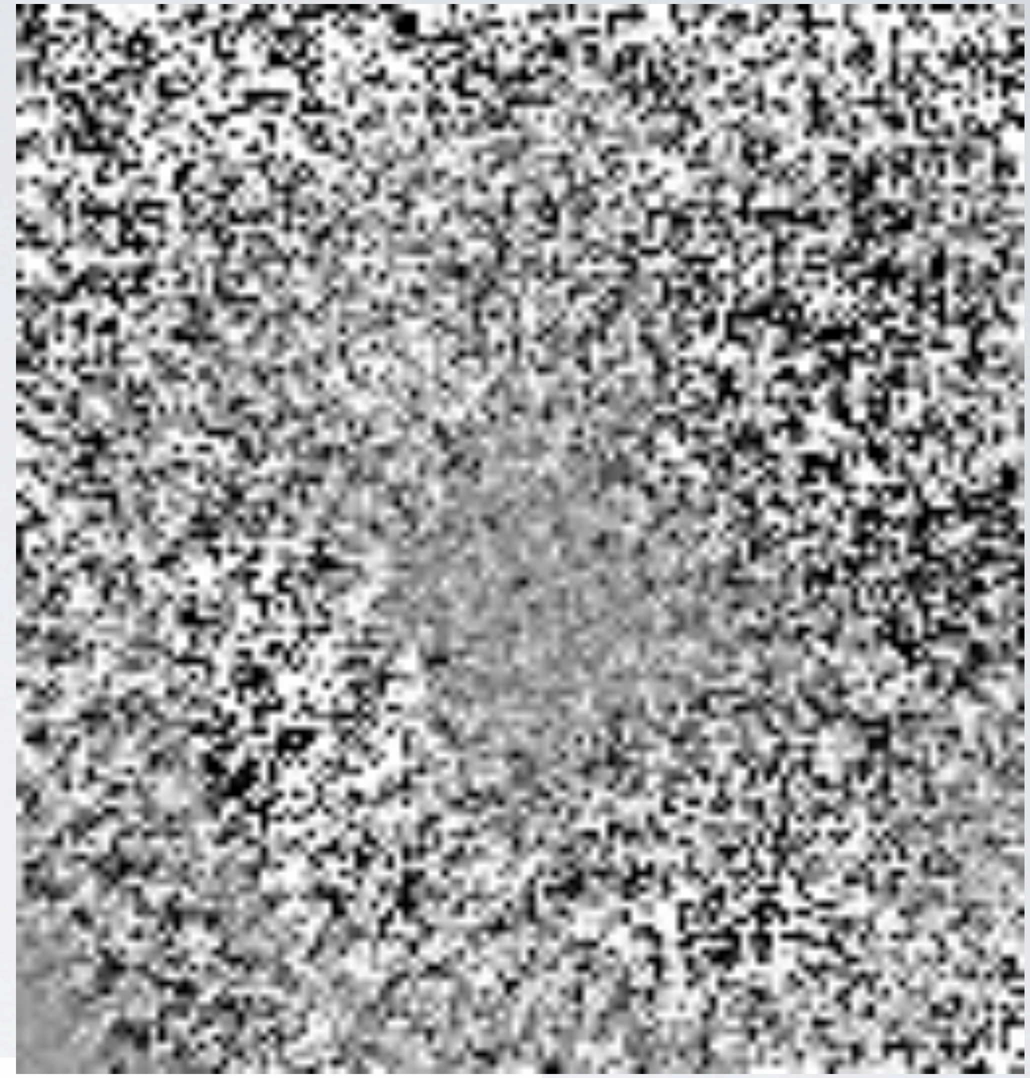
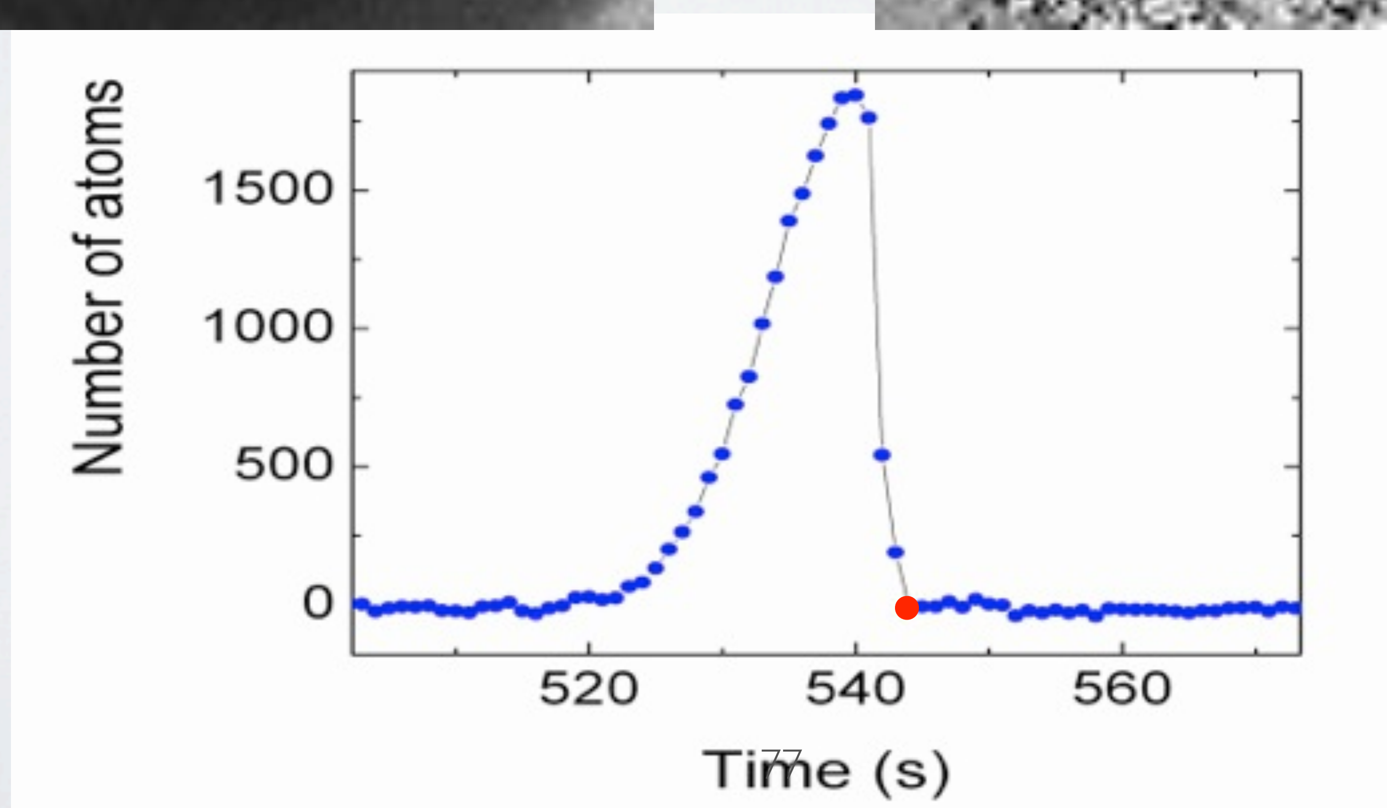
Time (s)







Number of atoms
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520
540
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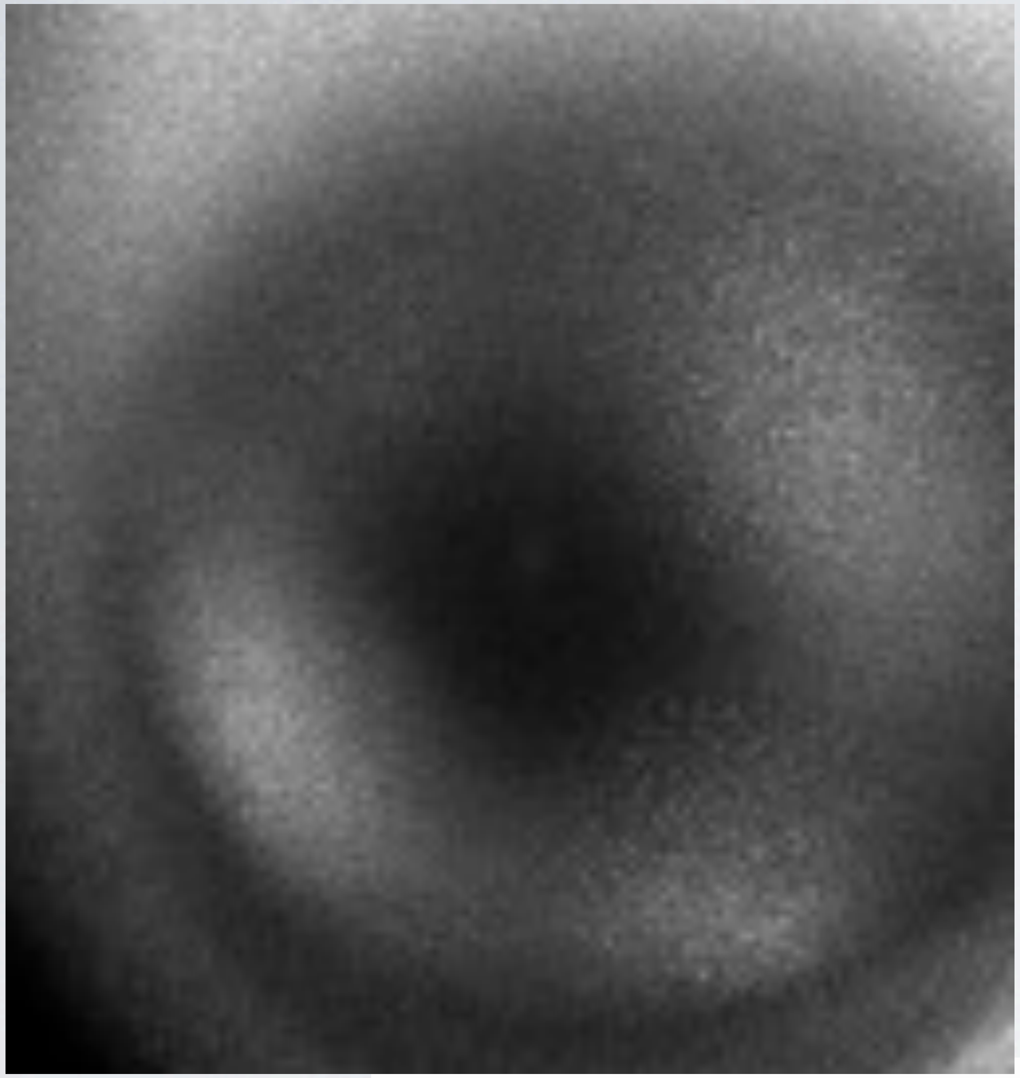
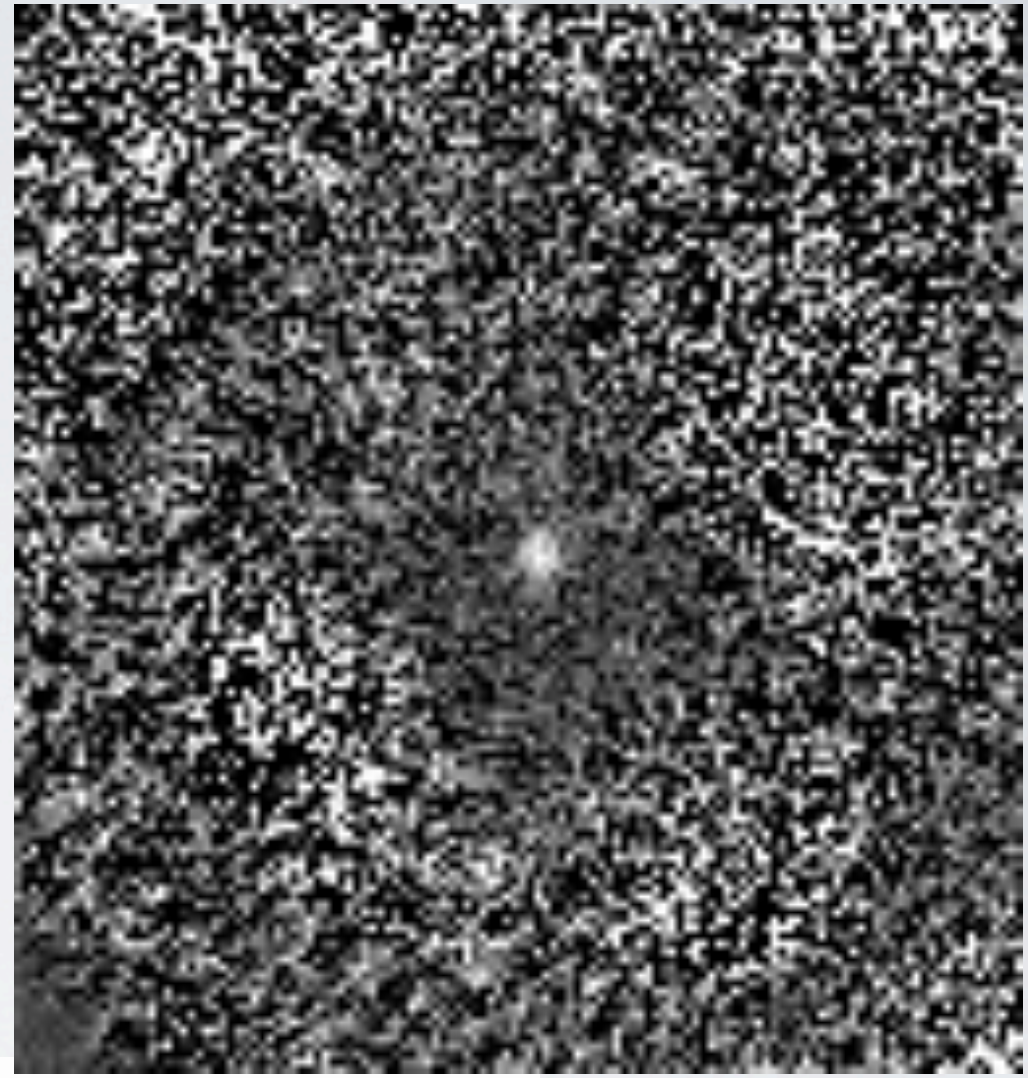
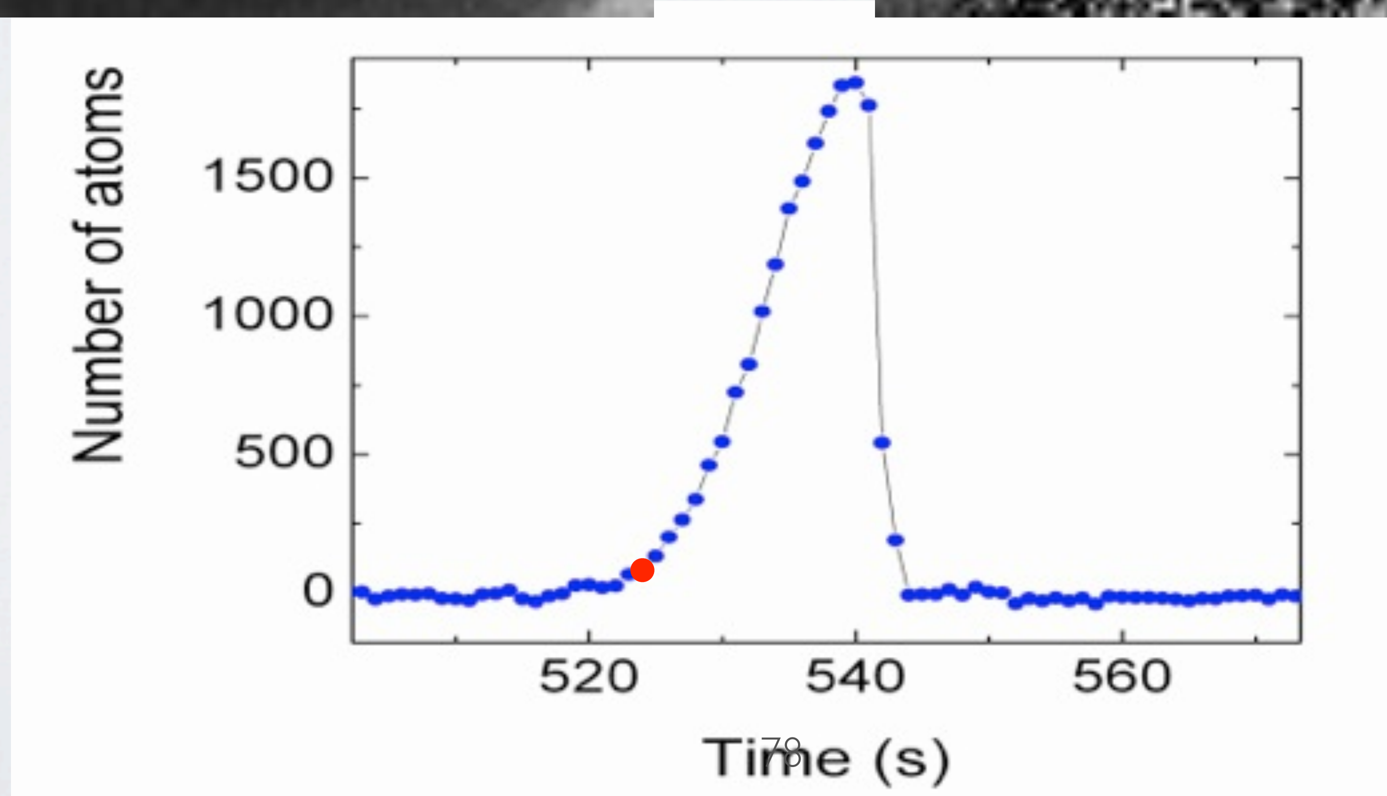
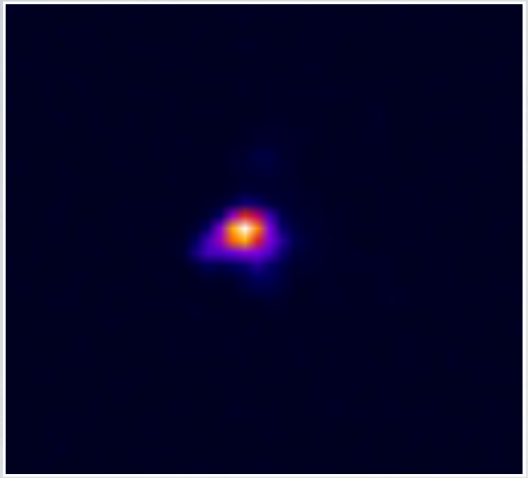
Time (s)



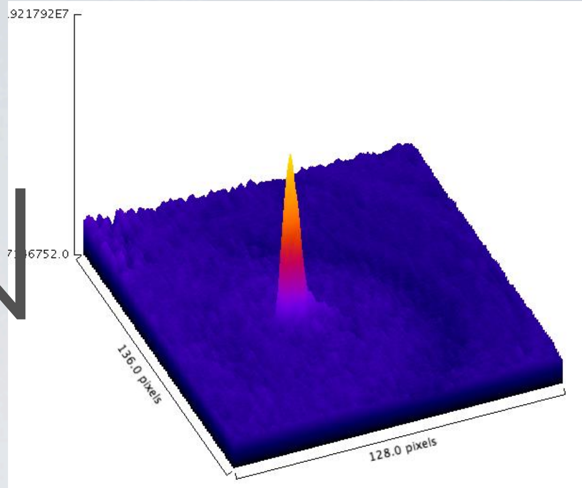




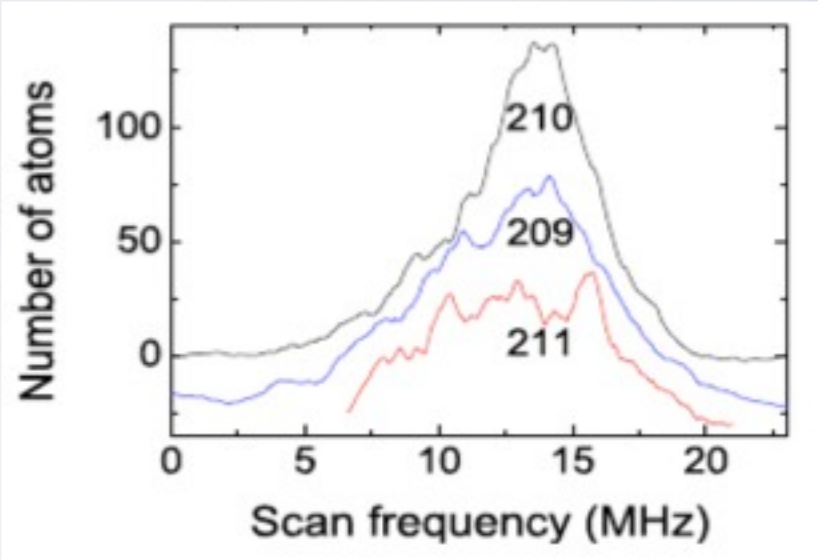
~50 atoms



TRAP DETECTION

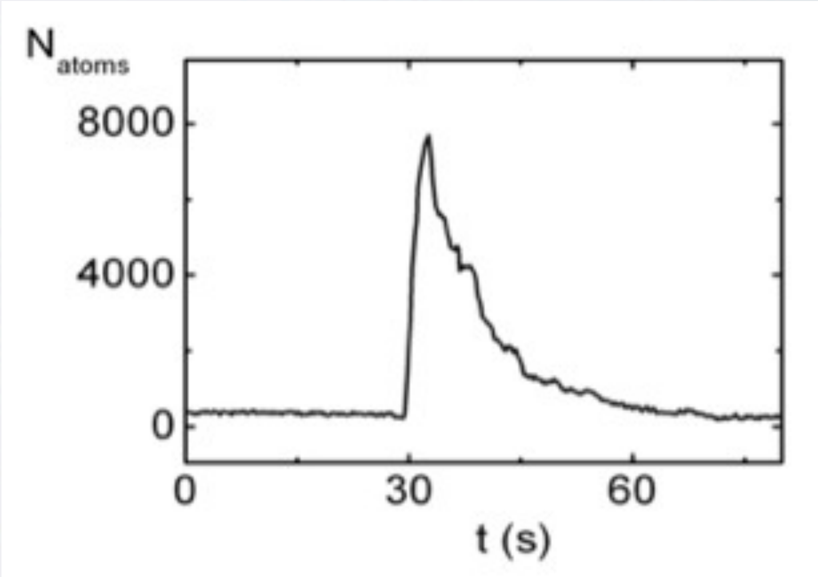


- Trapped Fr isotopes:
  - ^{210}Fr 1100 atoms
  - ^{209}Fr 270 atoms
  - ^{211}Fr 180 atoms



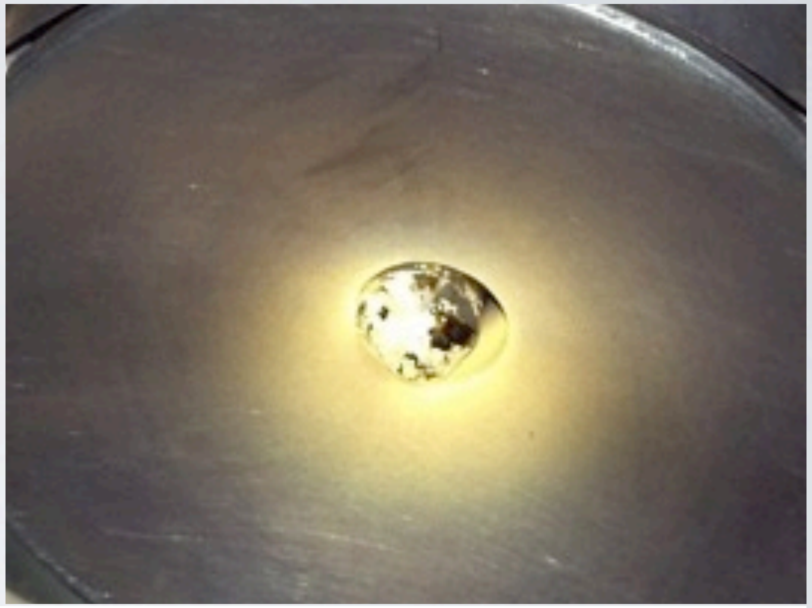
- Efficiency:
  200 ^{210}Fr trapped atoms for 10^5 Fr^+/s

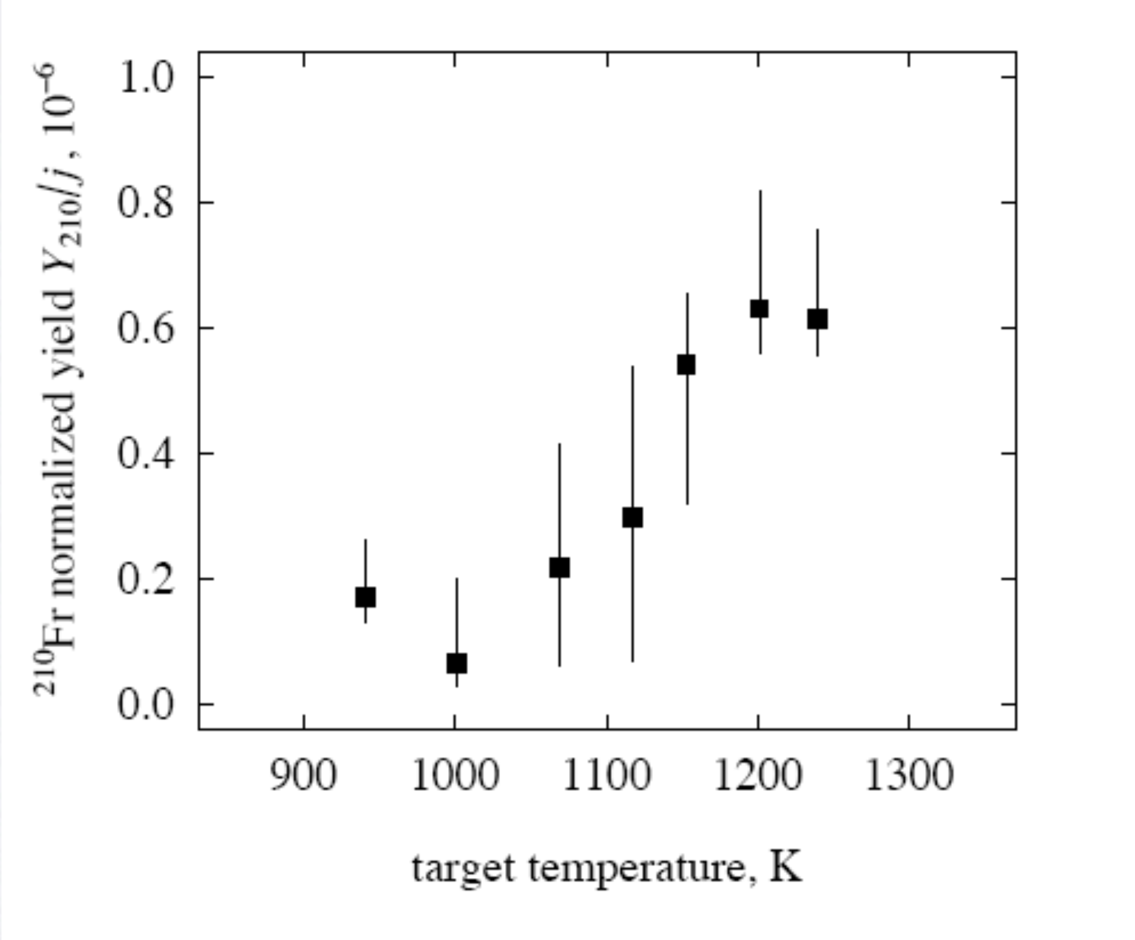
- Pulsed mode:
  8000 ^{210}Fr atoms trapped



TARGET SAFETY

- Fr yield depends on target temperature
- Working point: as close as possible to Gold melting point
- Gold is heated by:
    - external heater (tungsten wire)
    - oxygen beam (~120deg / 1μA)
- Avoid melting! It takes weeks to replace (activation)





TARGET SAFETY

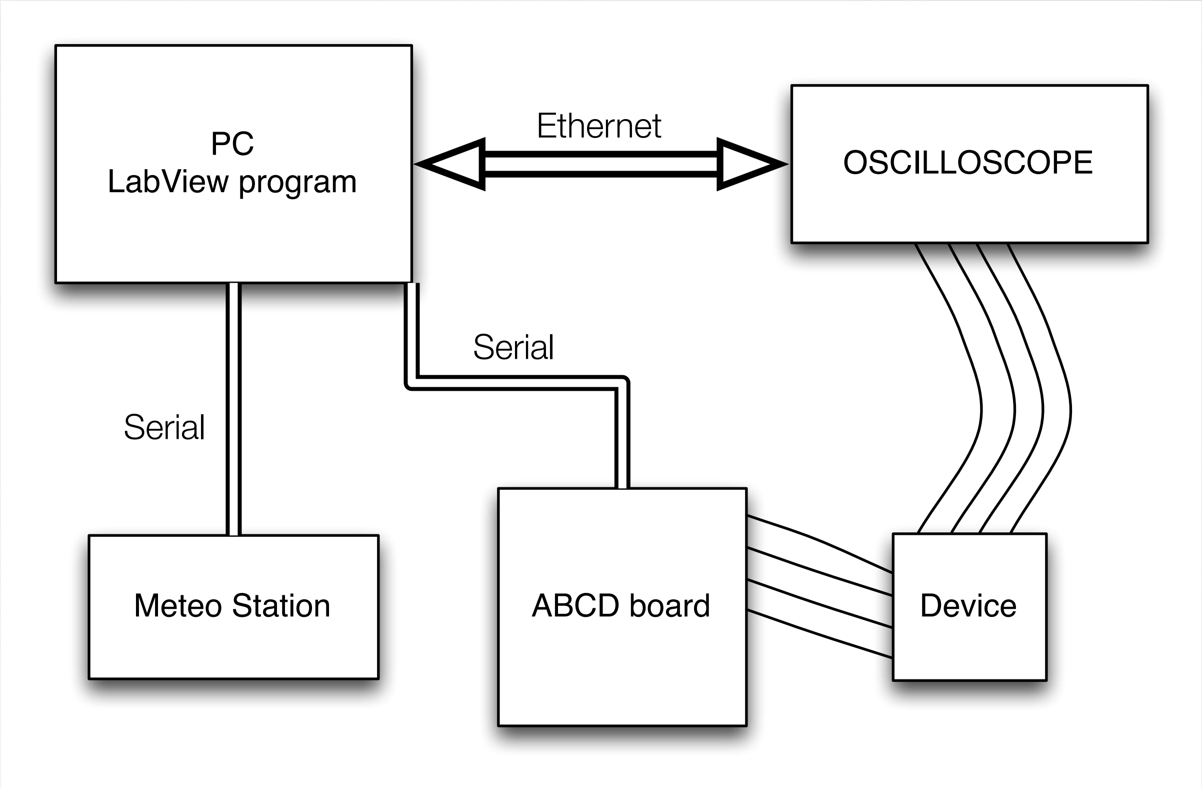
- Target temperature is continuously monitored by a pyrometer
- Its analog signal is acquired @ 1 Hz rate by a low-cost daq card, a Labview software plots the temperature values.
- If temperature is above a threshold, a signal is generated: it closes the valve in front of target blocking the Oxygen beam
- Arduino-based solution is under deployment. More robust, lacks plotting

USE CASE II
SIPM CHARACTERIZATION

- Objective:
  - determine the Gain of SiPM photosensors as a function of power voltage (Vbias)
  - measure the Dark Count above 0.5, 1.5, 2.5 pe thresholds (at fixed Vbias voltage)
- Although SiPM are built with the same technique, they may present different performances
- Characterization needed to equalize. SiPM were supposed to be used at first in IFR prototype, then in the SuperB IFR detector

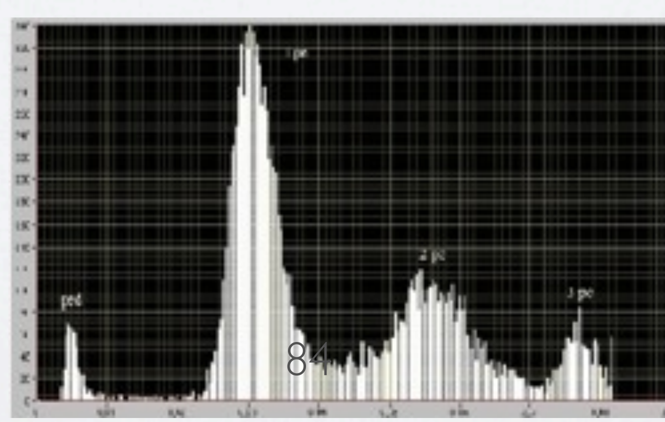
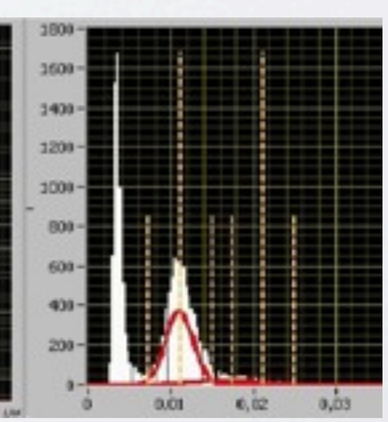
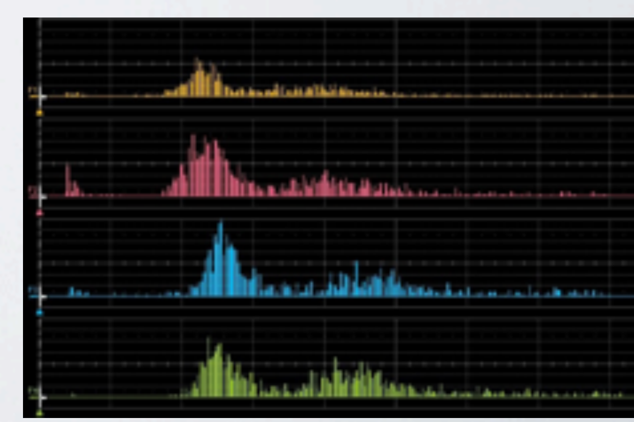
SIPM CHARACTERIZATION

- DAQ based on LabView
- 4 SiPM are analyzed in parallel
- A custom made 'ABCD' board set Vbias, Thresholds and reads rates
- DAQ communicates with ABCD board via serial link
- Analog signals from ABCD are sent to a LeCroy WR204xi-A oscilloscope
- DAQ communicates with oscilloscope via Ethernet (vxi11 protocol)



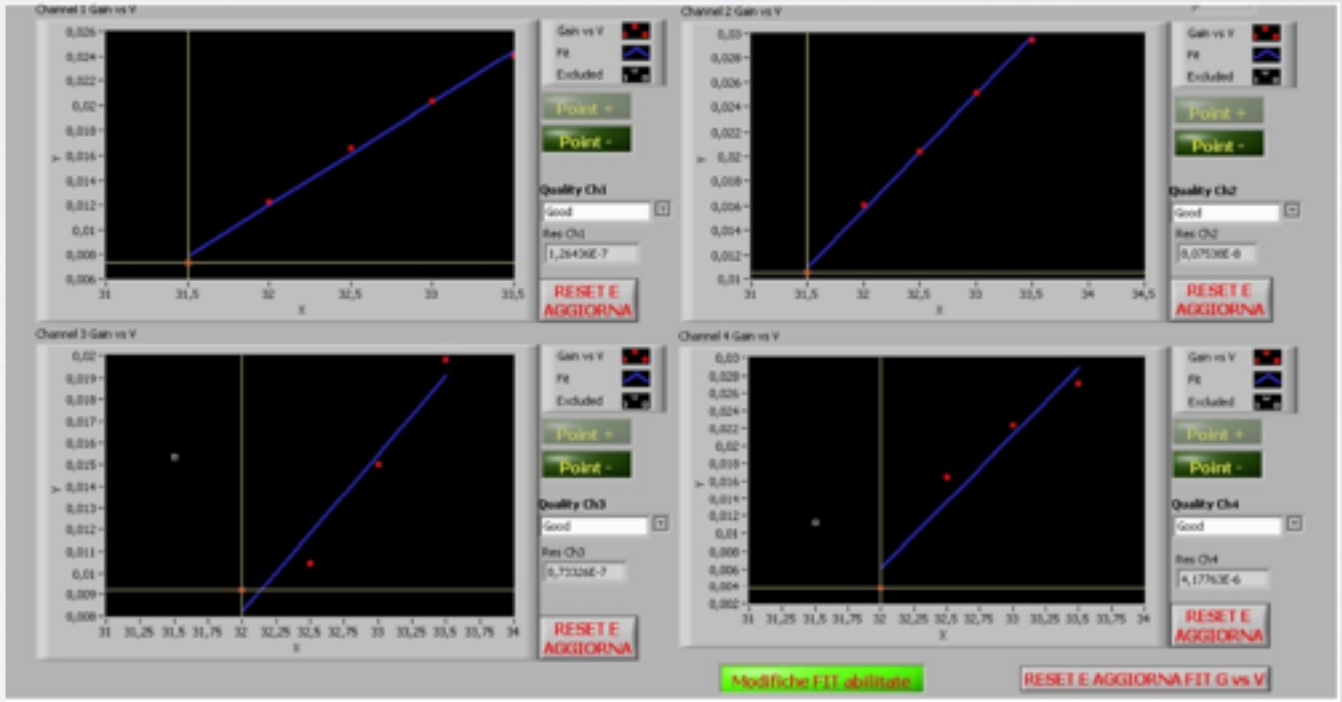
SIPM CHARACTERIZATION

- Gain as a function of Vbias, calculated as the distance between the 1pe and the 2pe gaussian peaks in the amplitude spectrum.
- Spectrum is generated on the oscilloscope (upon DAQ request)
- DAQ acquires the spectrum and performs the following steps:
  - rebinning
  - determination of raw limits in the spectrum (that contain the two gaussians peaks)
  - determination of fit parameters.
  - fitting of the two gaussians
  - Gain measurement

SIPM CHARACTERIZATION

- DAQ automatically varies the Vbias (according to the user-defined range and steps) and repeats the measurements
    - Vbias scan and Gain as a function of Vbias



- The user can operate on the Gain vs Vbias curve, repeating measurements, including other Vbias points, excluding points.

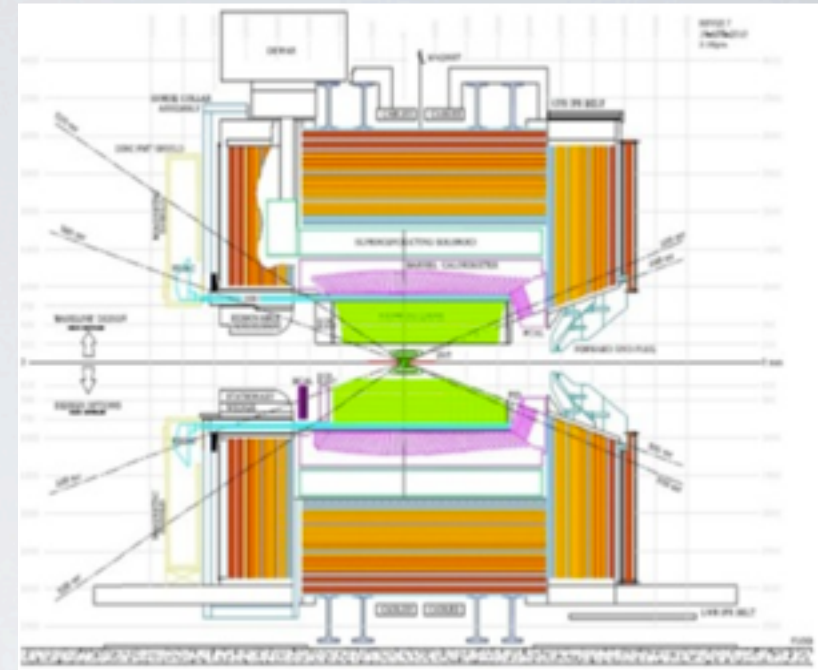
- the procedure finish storing the parameters for the 4 tested SiPM, (+ temperature and atmospheric pressure)

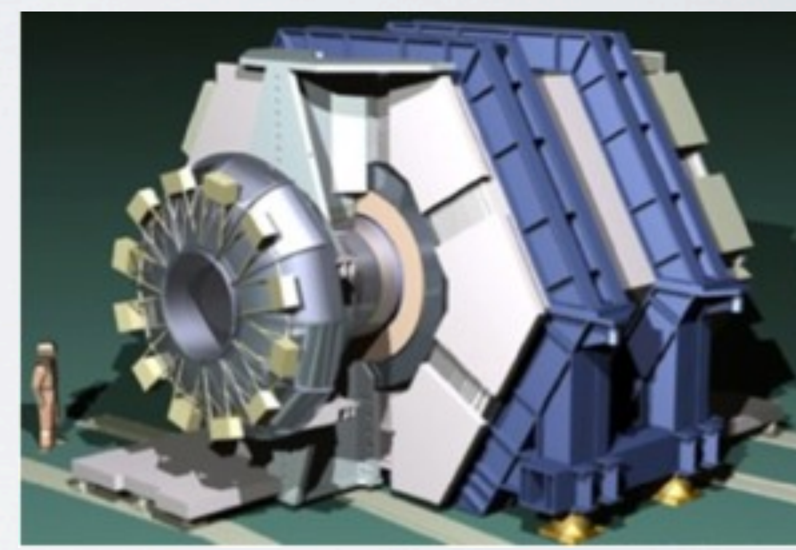
PIZZABOX

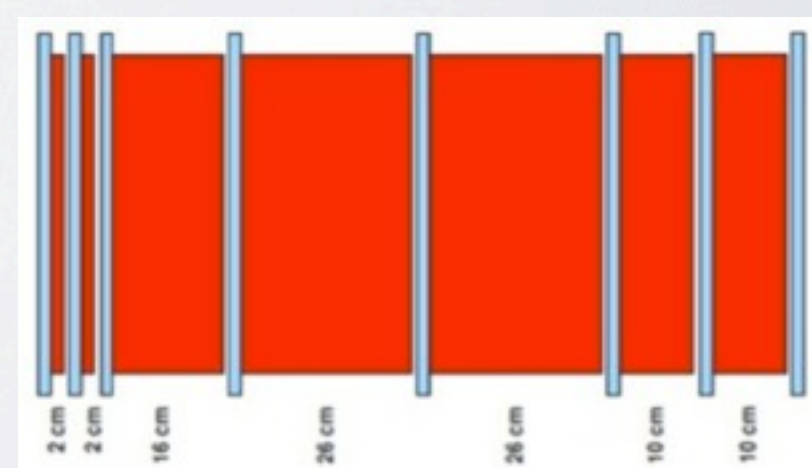
- The characterization DAQ has been ‘upgraded’ in order to operate on a ‘PizzaBox’ at once
- The PizzaBox is a sort of module for IFR detector

SUPERB IFR

- For muon identification (outer detector)
- Made of a barrel (exagonal geometry around the innermost detectors) and two end-caps
- Layers of iron of variable thickness
- 8/9 active layers
- Plastic scintillators (high rate, ~ KHz/cm^2)

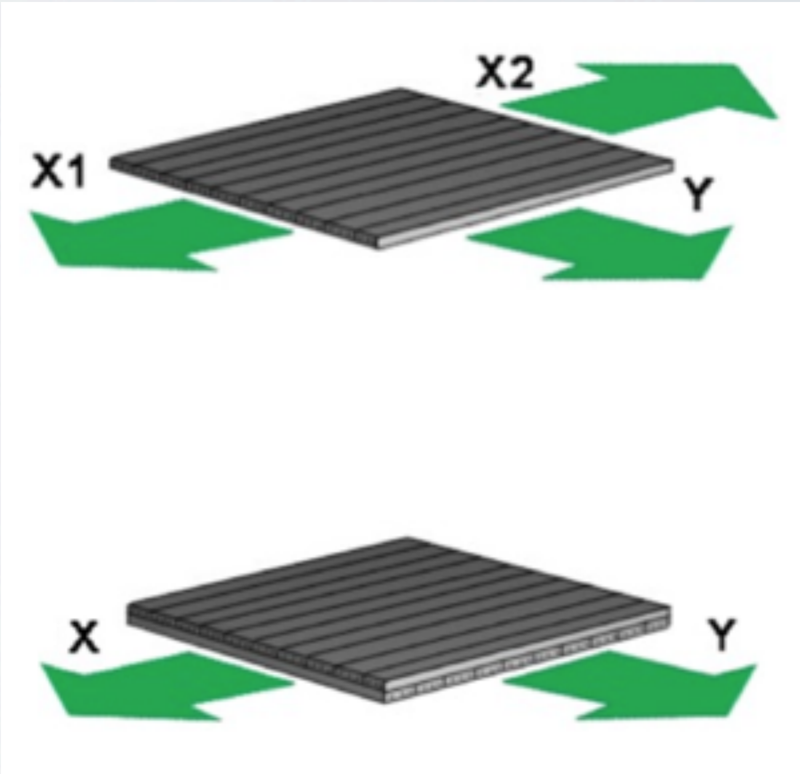






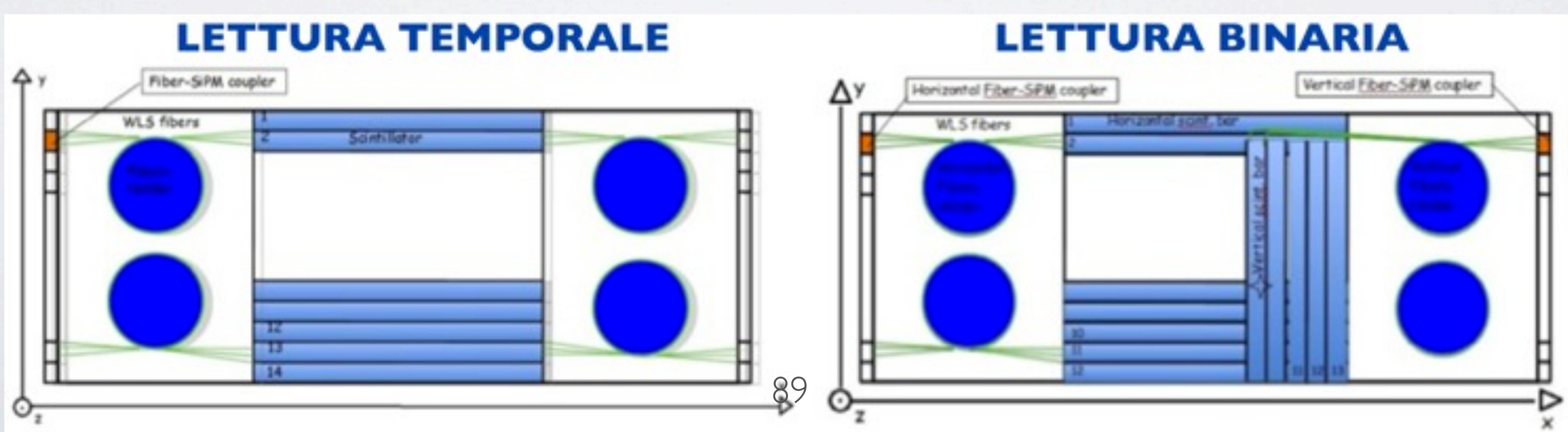
IFR

- Scintillators length up to 4 m, width 4 cm
- Temporal reading (barrel):
  - layer of 2 cm
  - X position calculated through arrival time
  - spatial resolution of 20 cm
- Binary reading (end-caps):
  - Two orthogonal layers of 1 cm
  - X position given by the hit scintillator
  - spatial resolution depends on scintillator width
- Every scintillator is provided with 3 optical fibers
- SiPM for each scintillator



IFR PROTOTYPE

- Iron support
- dimension: 60x60x100 cm^3
  1:1 scale portion of IFR
- Can accomodate up to 9 layers
  Each layer is inside an aluminum box ⇒ PizzaBox!
- Two types of PizzaBox, depending on reading technique



ELECTRONICS

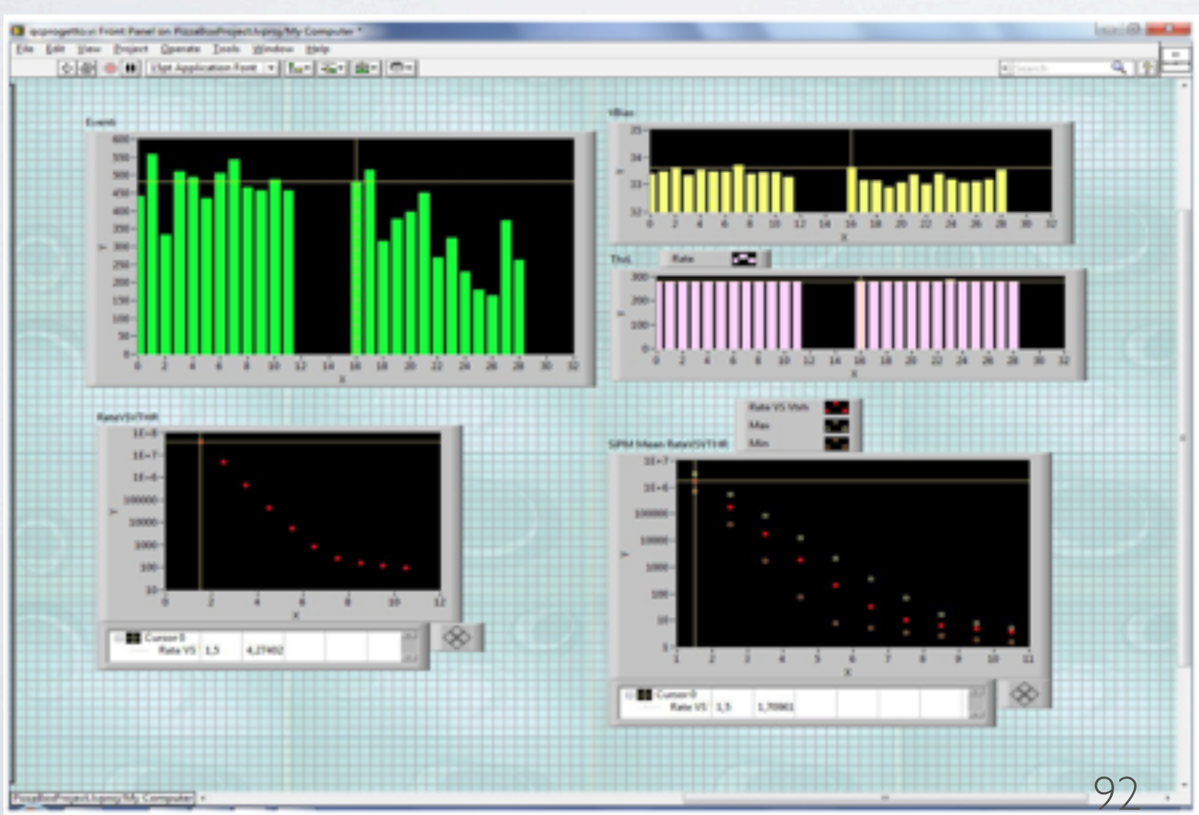
- For each PizzaBox, a 32ch ABCD board gives power supply and reads the SiPM signals
- ABCD boards on a custom VME crate
- ABCD signal for temporal reading PizzaBox are sent to TDC system:
    - 3 TDC boards on a VME crate
    - 1 PC controls the TDC boards / crate
- ABCD signal for binary read-out PizzaBox are sent to BiRO system:
    - 1 board equipped with a FPGA + adaptor for ABCD reading
    - FPGA controls the ABCD boards

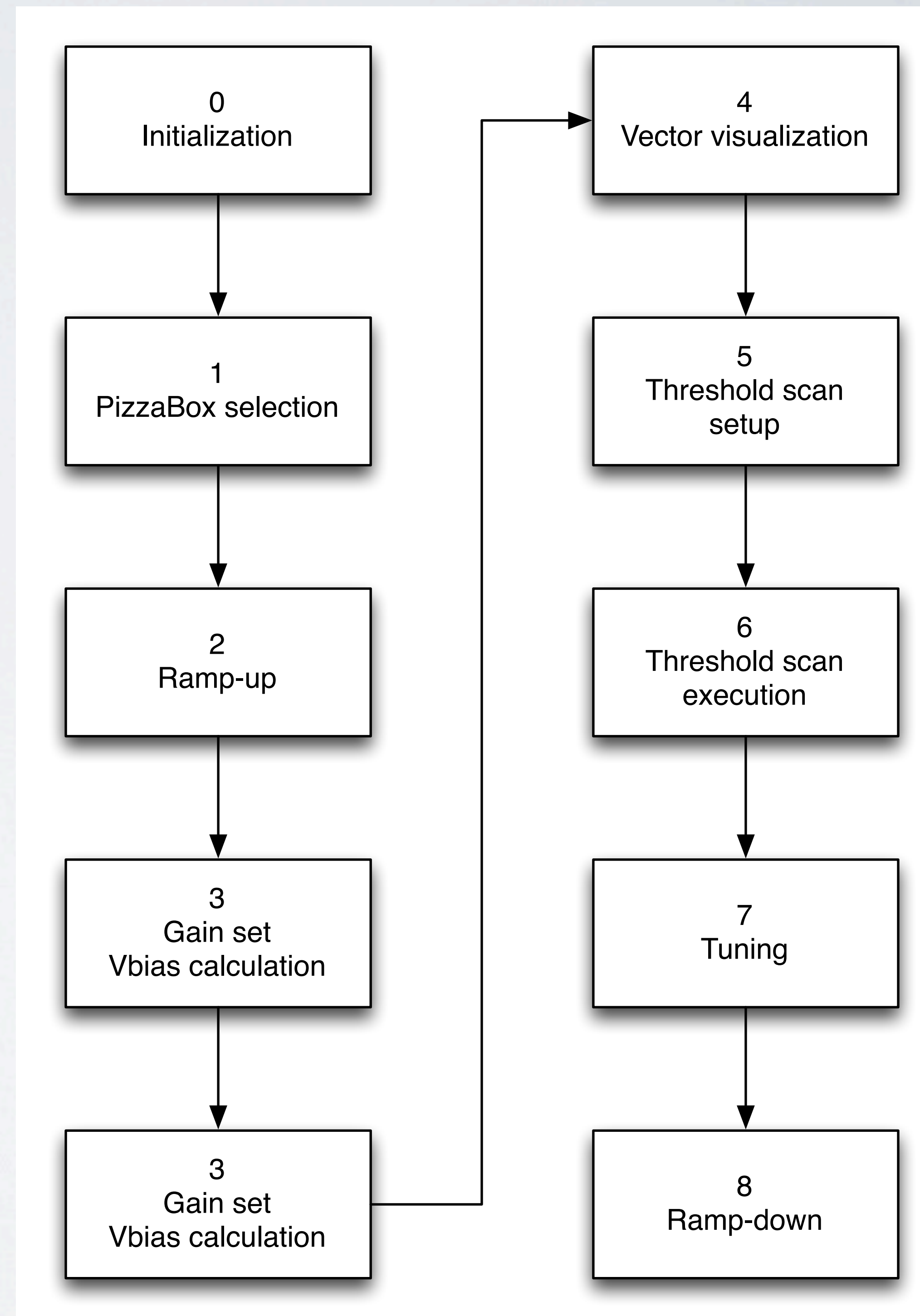
PIZZABOX CHARACTERIZATION

- It uses Gain vs Vbias parameters obtained with SiPM characterization
- depending on desired Gain, the system set a proper Vbias
- a threshold scan is performed (1.5, 2.5, 3.5, 4.5, ... pe). The PizzaBox rate is measured from this scan
- working point (in threshold) is defined: when rate doesn't change as threshold increases
- fine-tuning: desired threshold is set.
  Rates are measured channel by channel.
  If channels have large variations with respect to average, Vbias are modified, new thresholds are computed.
  Procedure is repeated until all channels are equilized
- the new parameters (Gain vs Vbias + Thresholds) are saved and will be used by other systems

PIZZABOX CHARACTERIZATION

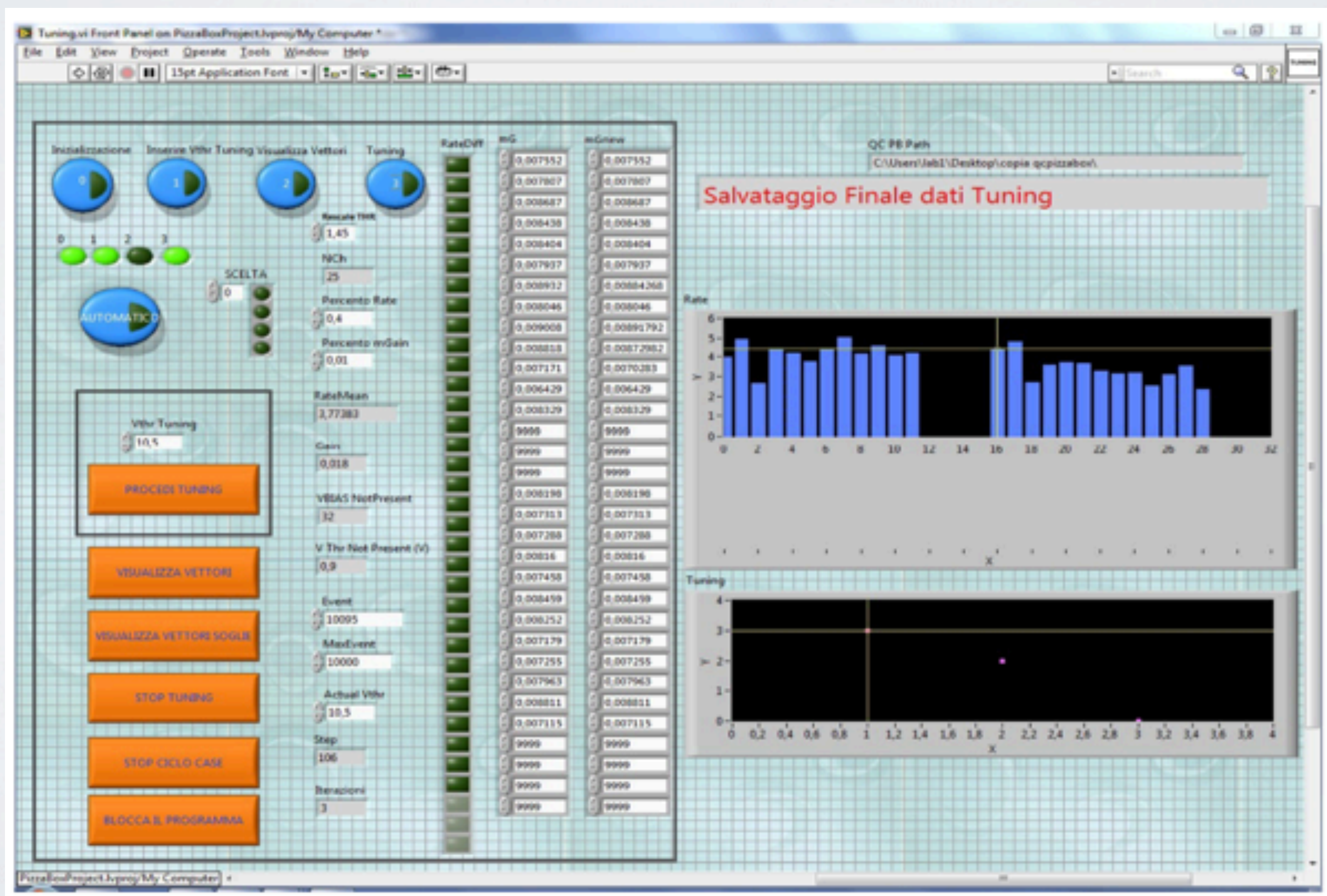
- Implemented as a state machine operating in automatic or manual mode





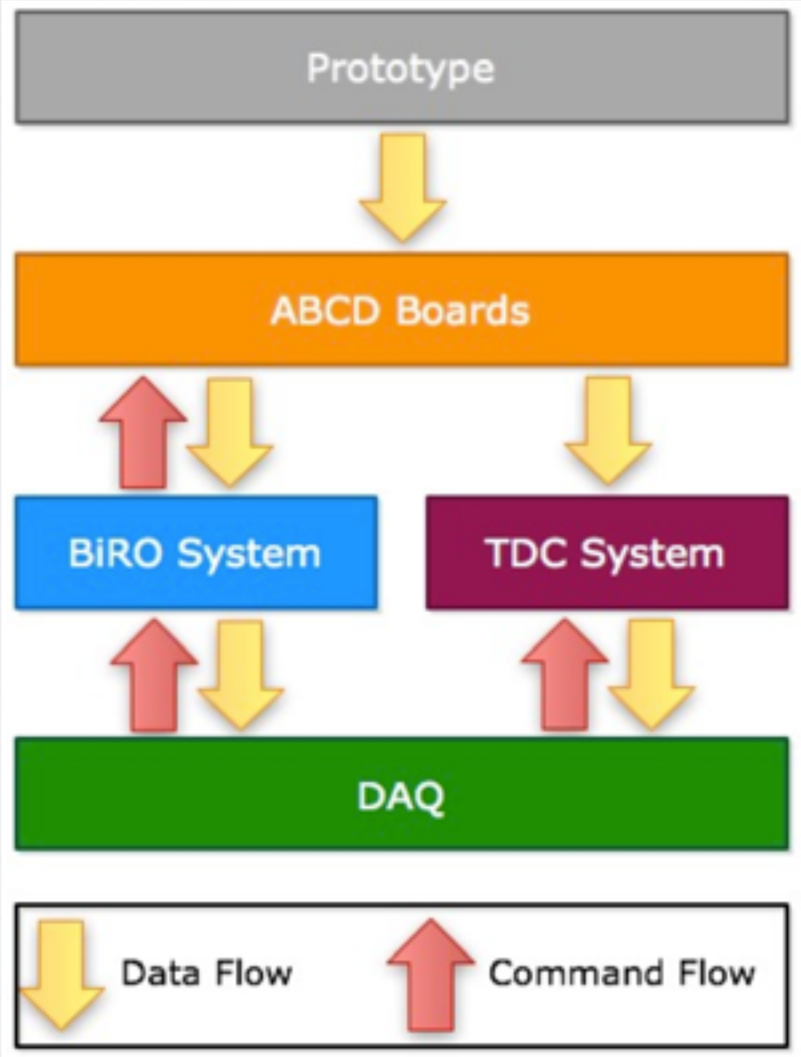
PIZZABOX CHARACTERIZATION

- Tuning window



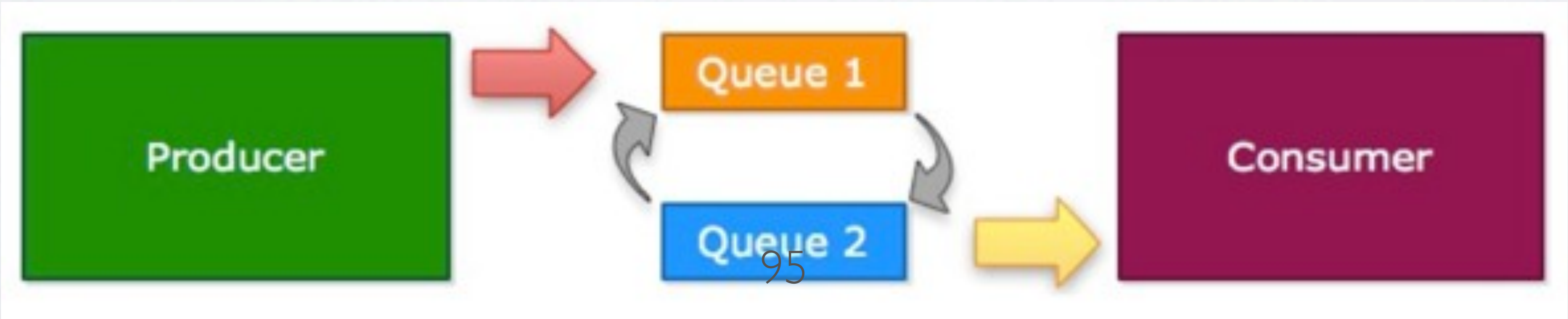
USE CASE III
IFR DAQ

- **Requirements**:
- Must connect to BiRO and TDC systems electronics
- Must implement electronics configuration commands
- Must implement DAQ commands
  (connect, start/stop, disconnect)
- Must acquire data from electronics and process them
- Must store acquired data and processed data
- GUI



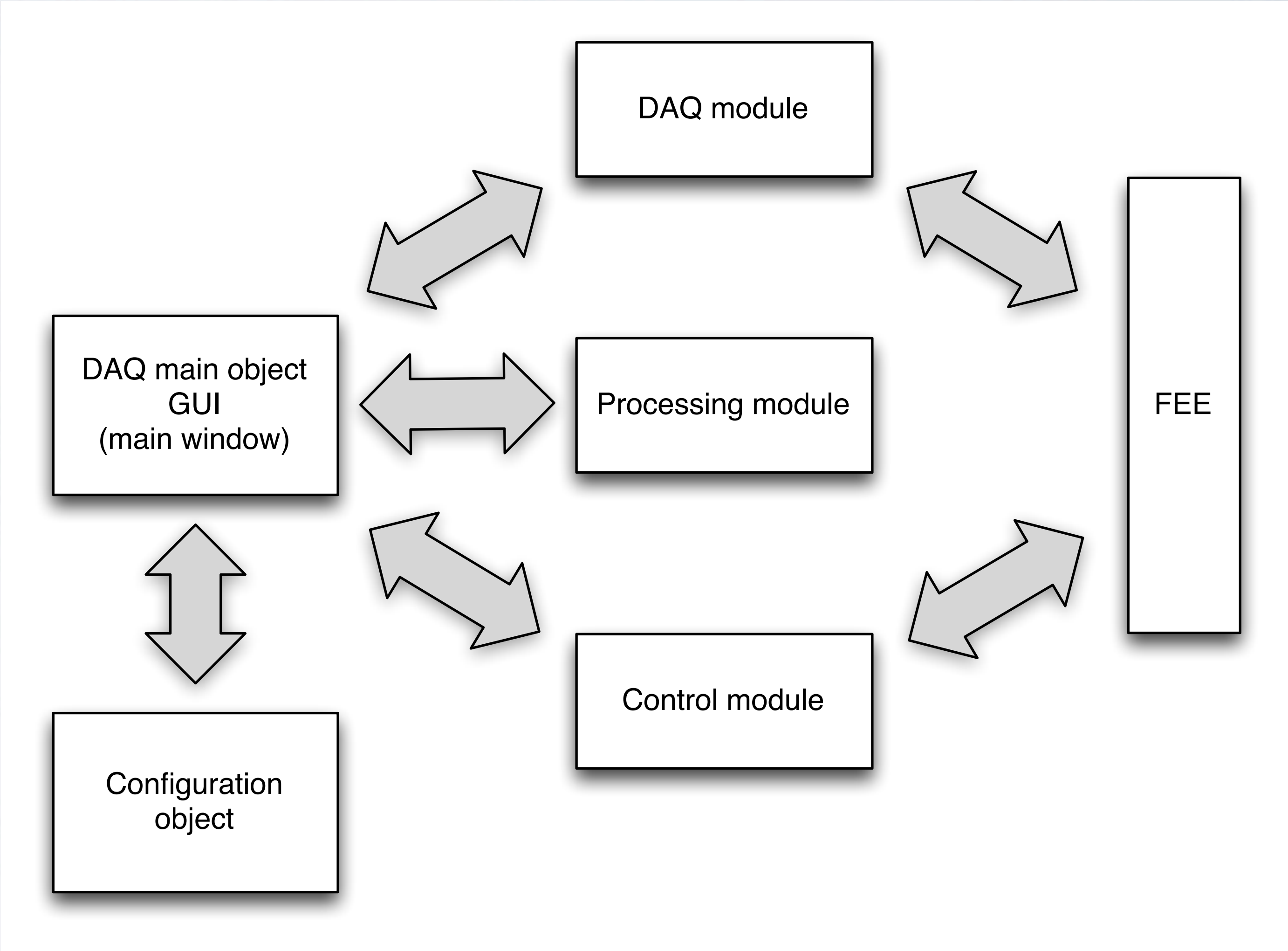
IFR DAQ

- Development environment: Qt Creator
  (programming language: Qt, based on C++)
- Client/server architecture between DAQ and Front-End Electronics (FEE):
  - Data exchange ➞ DAQ server / FEE client
  - Control Command ➞ DAQ client / FEE server
- Objects controlling electronics and acquiring and processing data are implemented with threads
- Buffer with two queues (using semaphores) is used to pass data between data acquisition and data processing threads
- Queues are flipped when the 'consumer' empties its queue and/or the 'producer' inserts elements

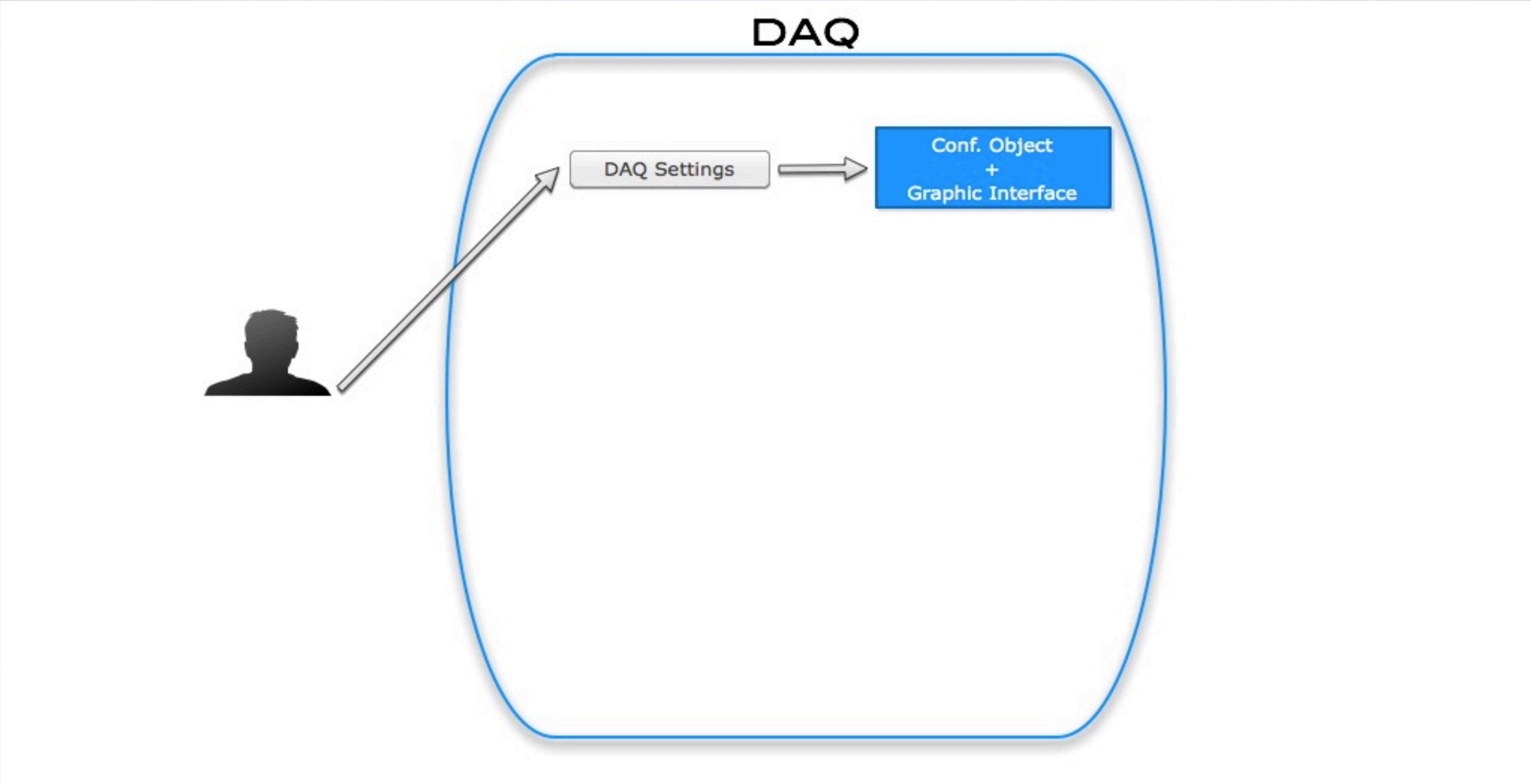


IFR DAQ COMPONENTS

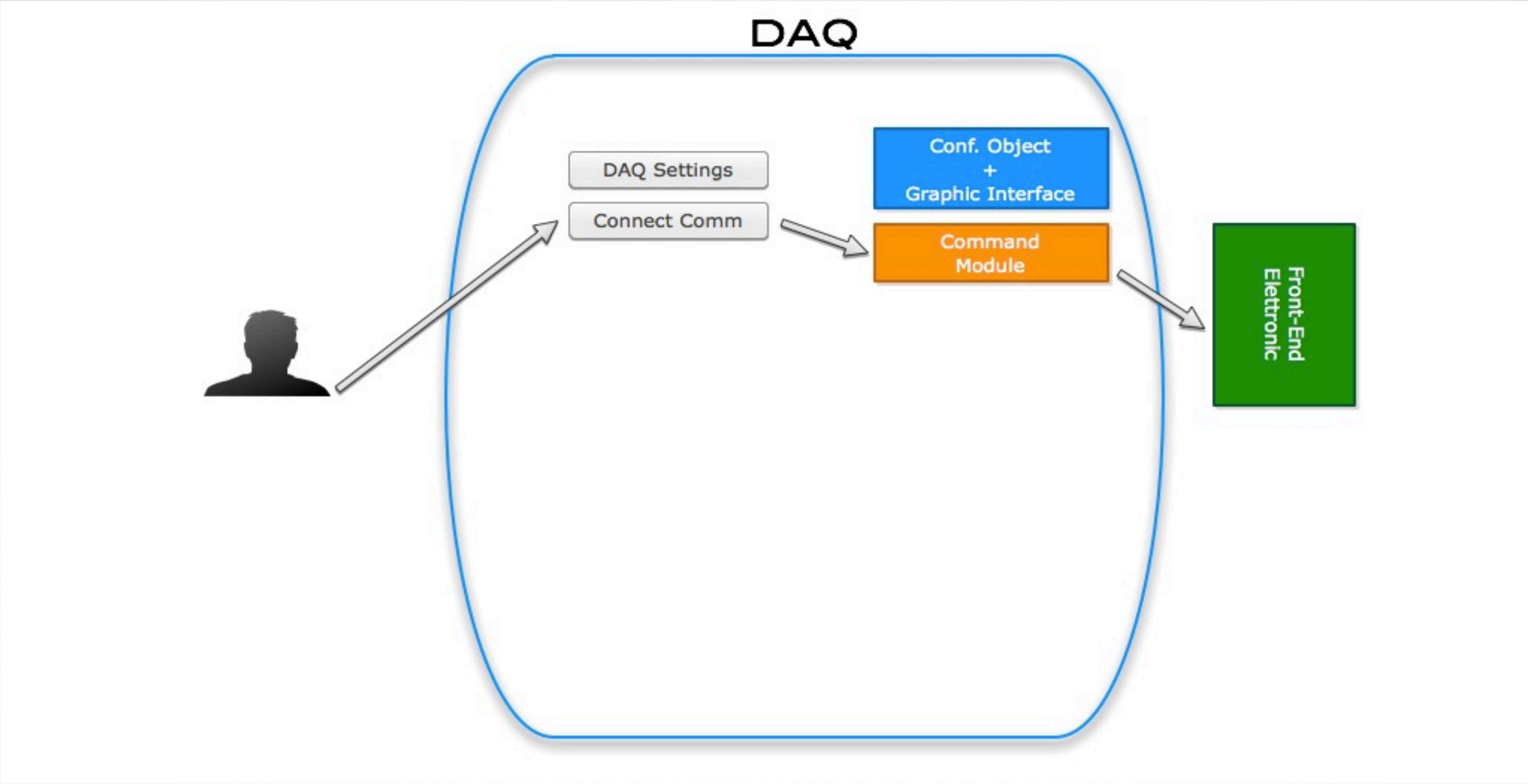
- Control module: controls the FEE
- DAQ module: acquires data from FEE
- Processing module: processes acquired data, verifies data integrity and formats data for output to disk
- Main window: user interface using the three modules
- Configuration window



IFR DAQ

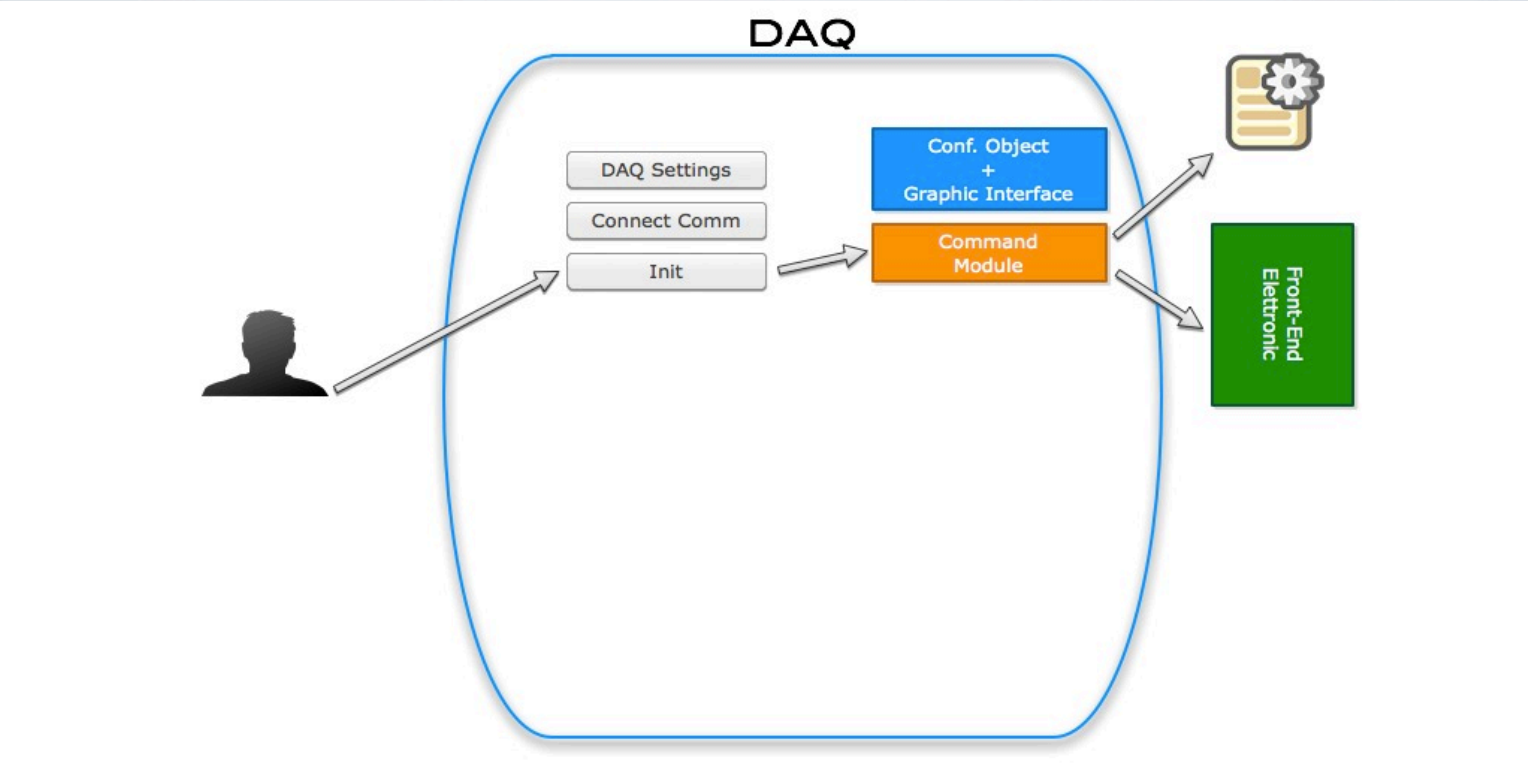


IFR DAQ



DAQ
DAQ Settings
Connect Comm
Conf. Object
+
Graphic Interface
Command
Module
Front-End
Elettronic

IFR DAQ



DAQ
DAQ Settings
Connect Comm
Init
Conf. Object
+
Graphic Interface
Command
Module
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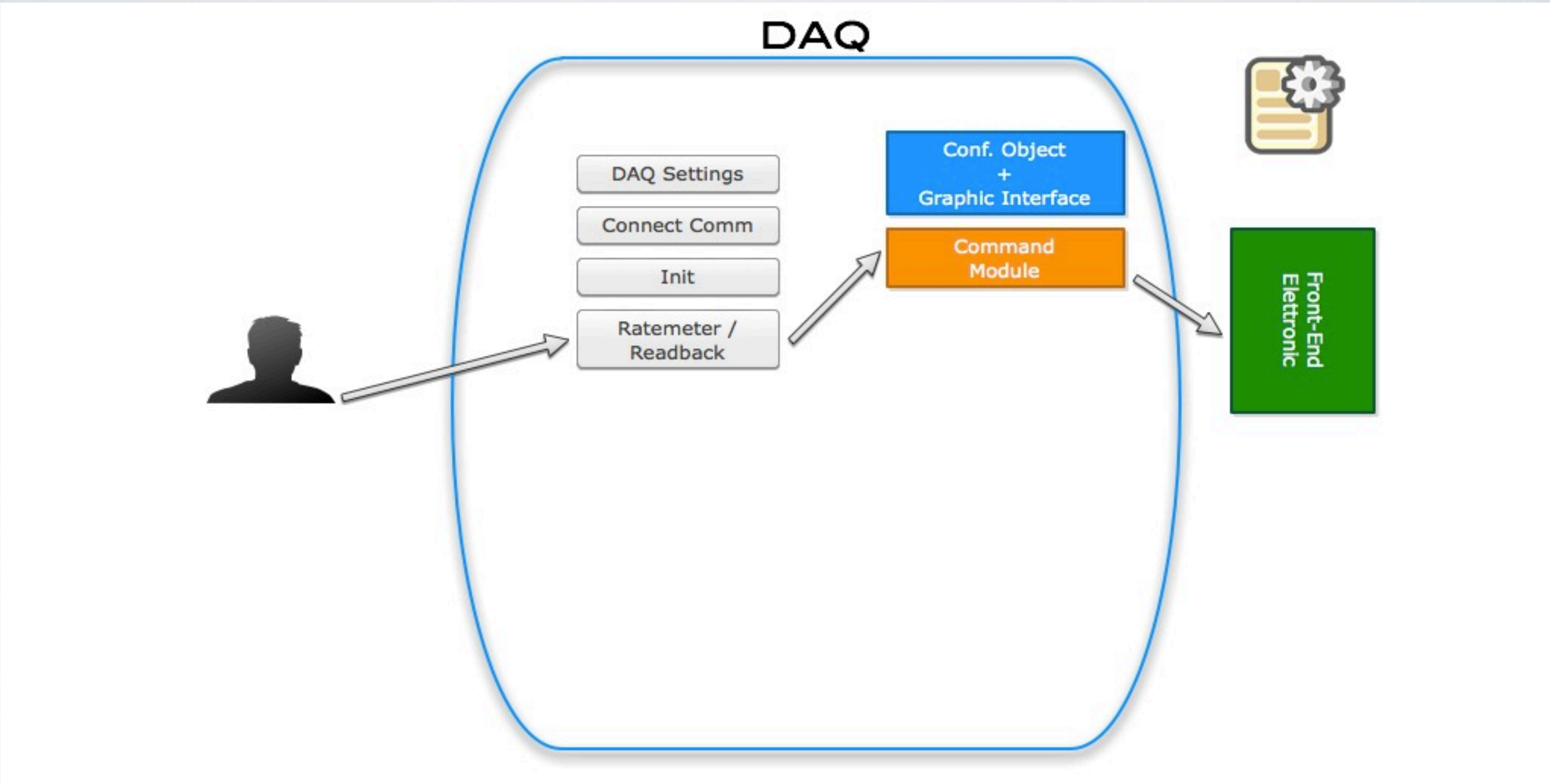
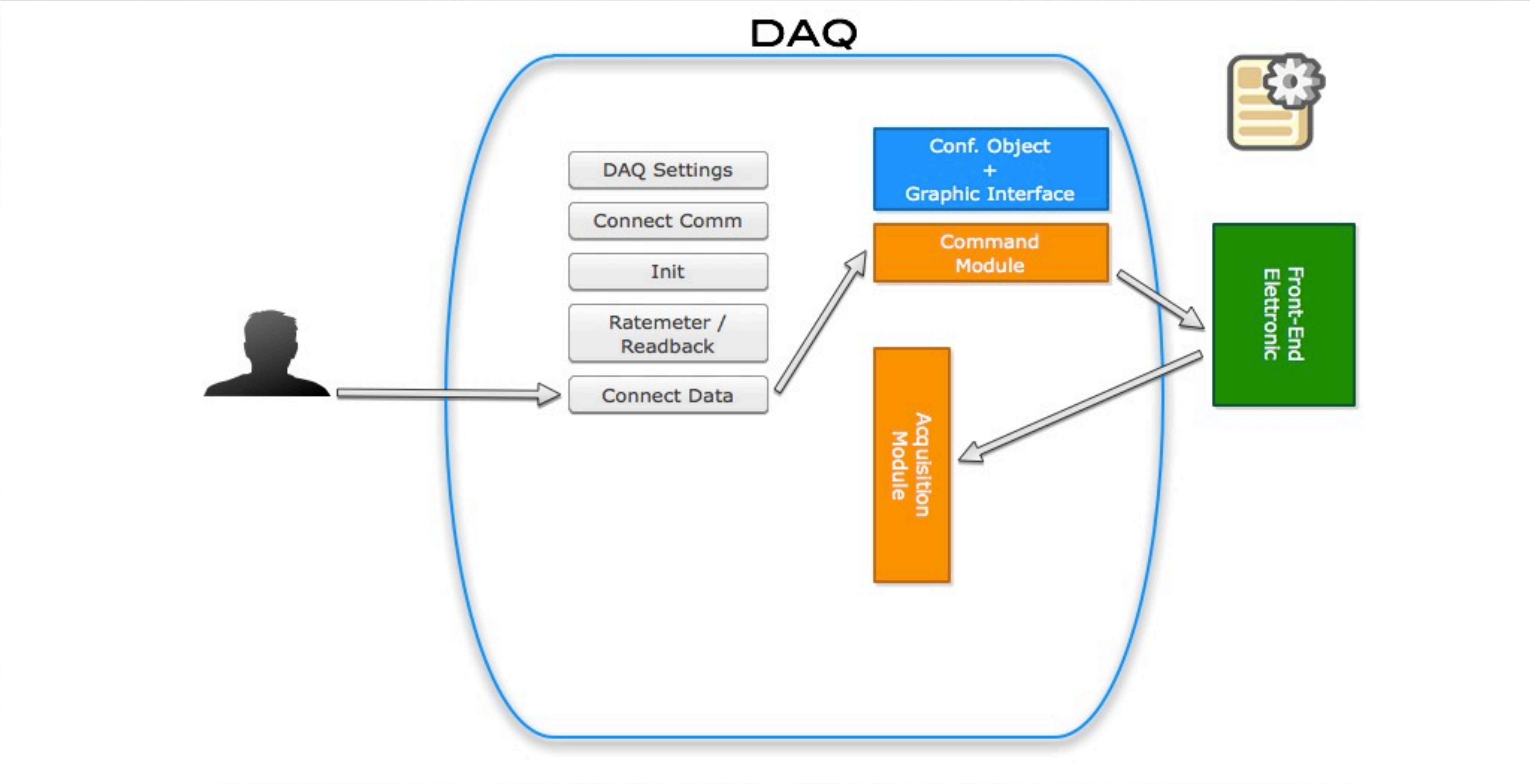
Elettronic

IFR DAQ

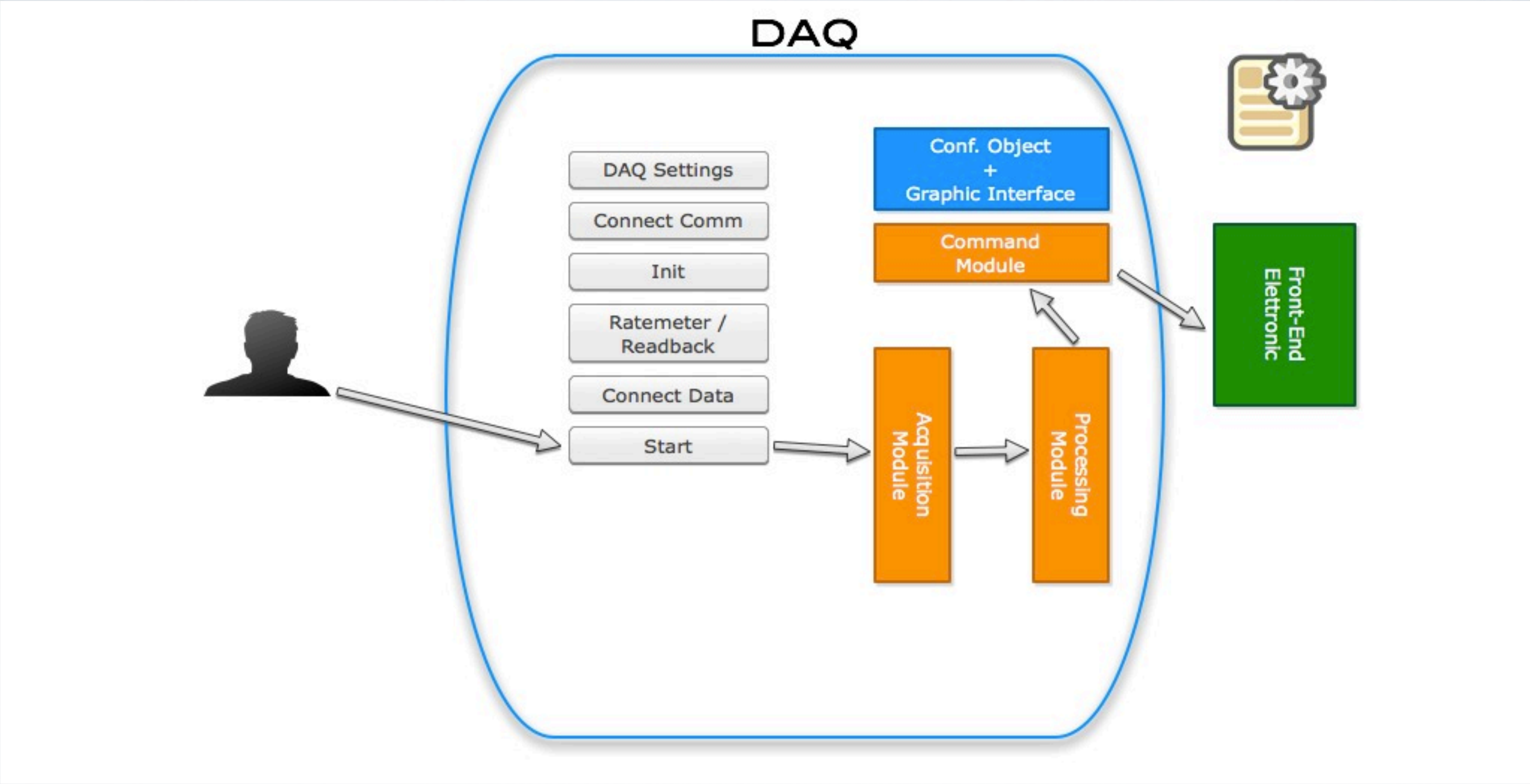

DAQ
DAQ Settings
Connect Comm
Init
Ratemeter / Readback
Conf. Object + Graphic Interface
Command Module
Front-End Elettronic

IFR DAQ

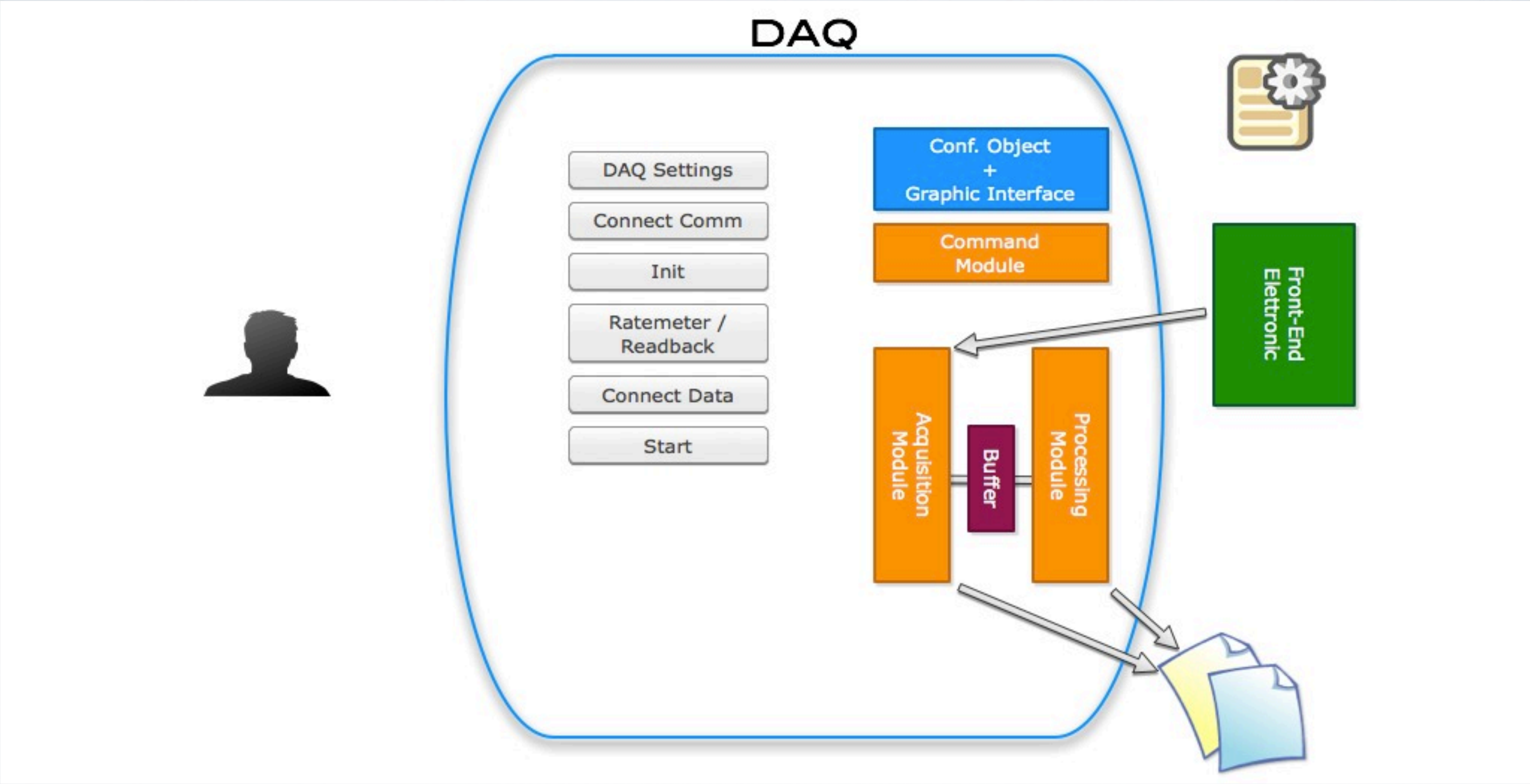


DAQ
DAQ Settings
Connect Comm
Init
Ratemeter / Readback
Connect Data
Conf. Object + Graphic Interface
Command Module
Acquisition Module
Front-End Elettronic

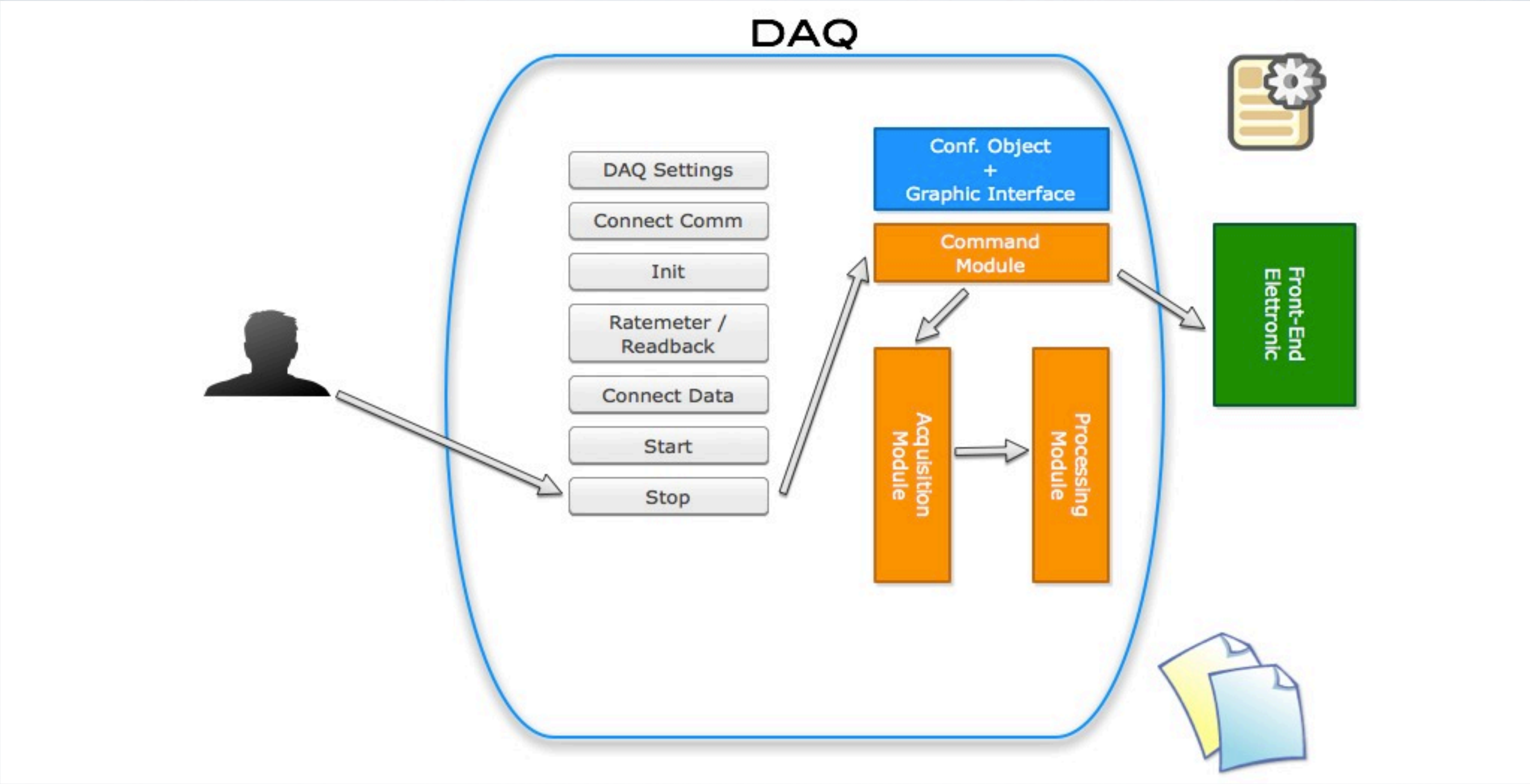
IFR DAQ


DAQ
DAQ Settings
Connect Comm
Init
Ratemeter / Readback
Connect Data
Start
Conf. Object
+
Graphic Interface
Command Module
Acquisition Module
Processing Module
Front-End Elettronic

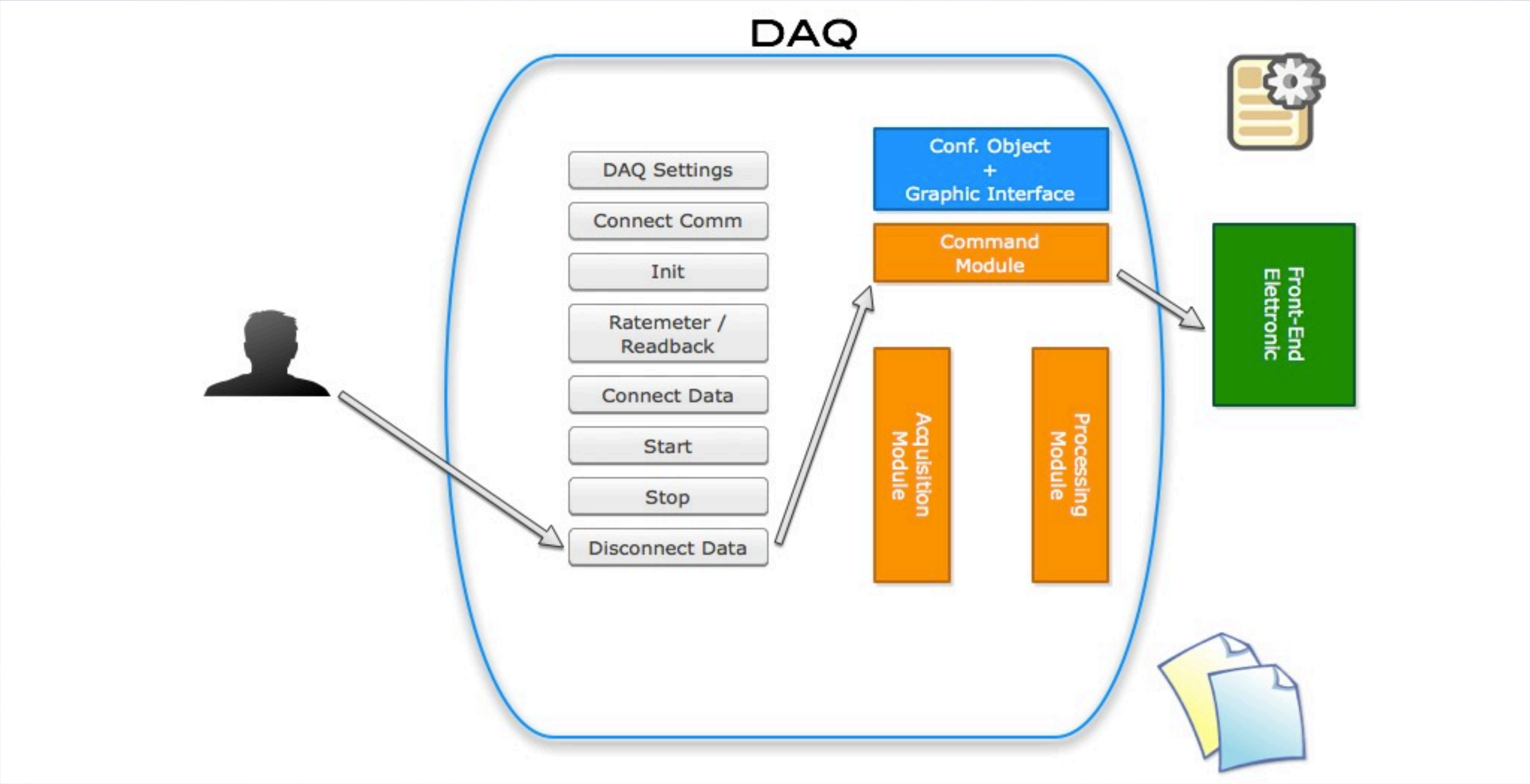
IFR DAQ


DAQ
DAQ Settings
Connect Comm
Init
Ratemeter / Readback
Connect Data
Start
Conf. Object
+
Graphic Interface
Command Module
Front-End Elettronic
Acquisition Module
Buffer
Processing Module

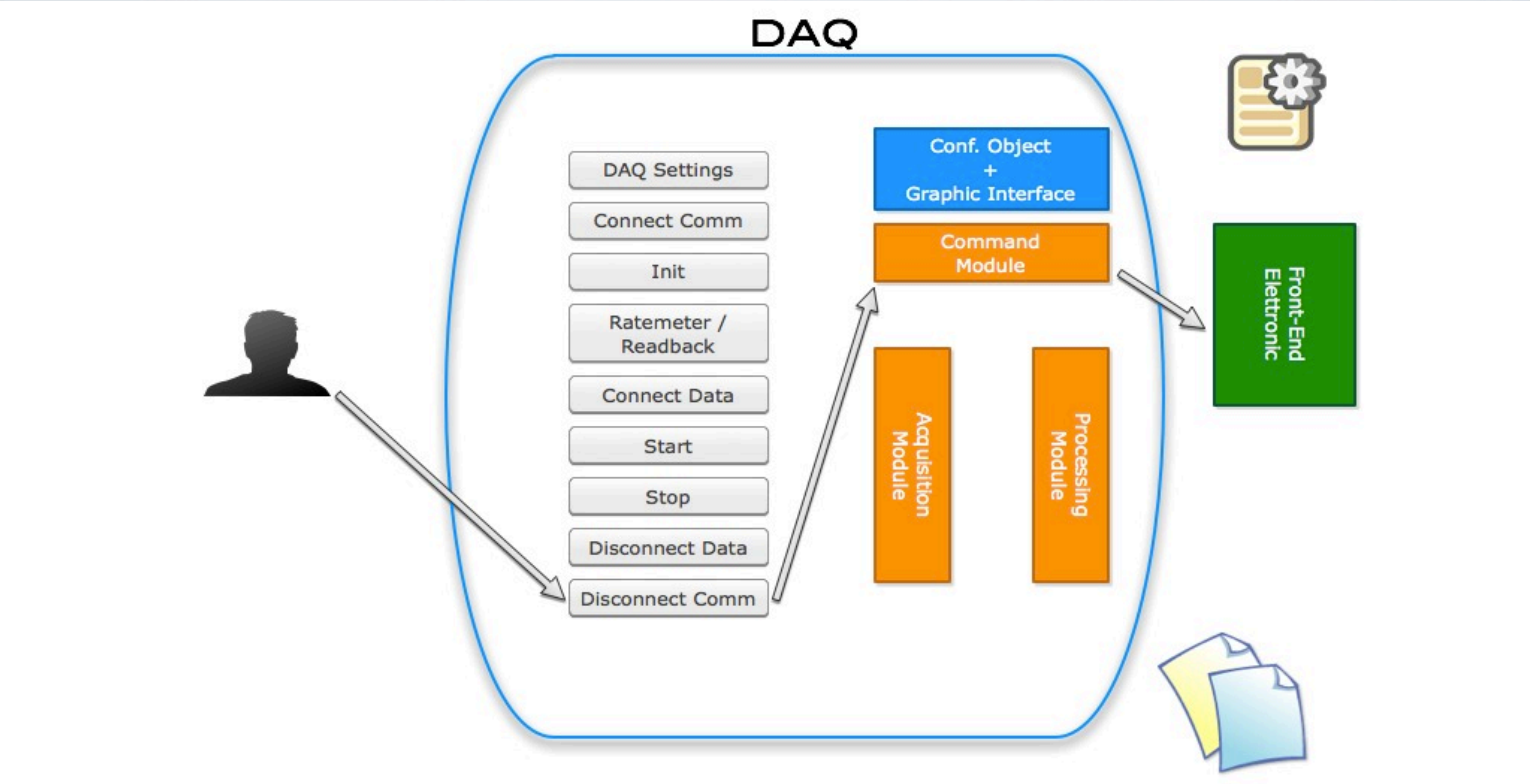
IFR DAQ


DAQ
DAQ Settings
Connect Comm
Init
Ratemeter / Readback
Connect Data
Start
Stop
Conf. Object + Graphic Interface
Command Module
Acquisition Module
Processing Module
Front-End Elettronic

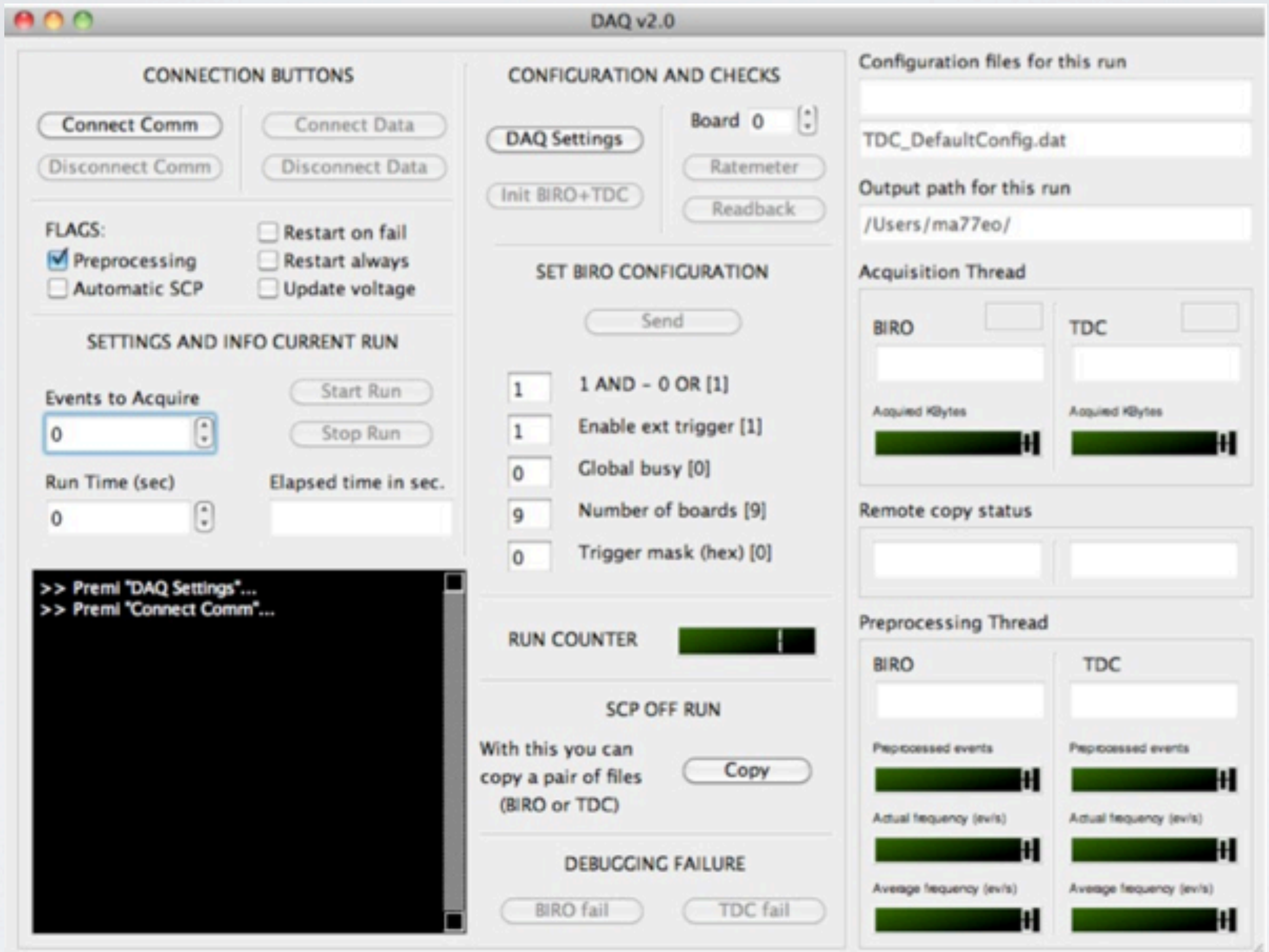
IFR DAQ


DAQ
DAQ Settings
Connect Comm
Init
Ratemeter / Readback
Connect Data
Start
Stop
Disconnect Data
Conf. Object + Graphic Interface
Command Module
Acquisition Module
Processing Module
Front-End Elettronic

IFR DAQ


DAQ
DAQ Settings
Connect Comm
Init
Ratemeter / Readback
Connect Data
Start
Stop
Disconnect Data
Disconnect Comm
Conf. Object + Graphic Interface
Command Module
Acquisition Module
Processing Module
Front-End Elettronic

IFR DAQ



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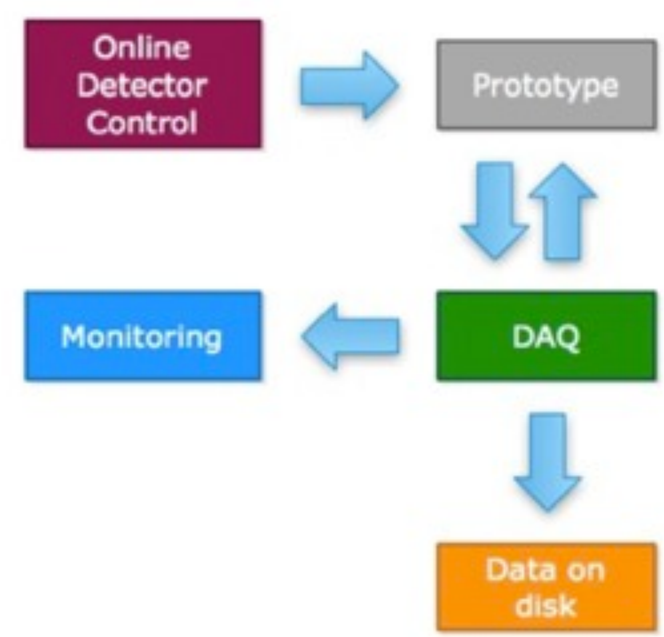
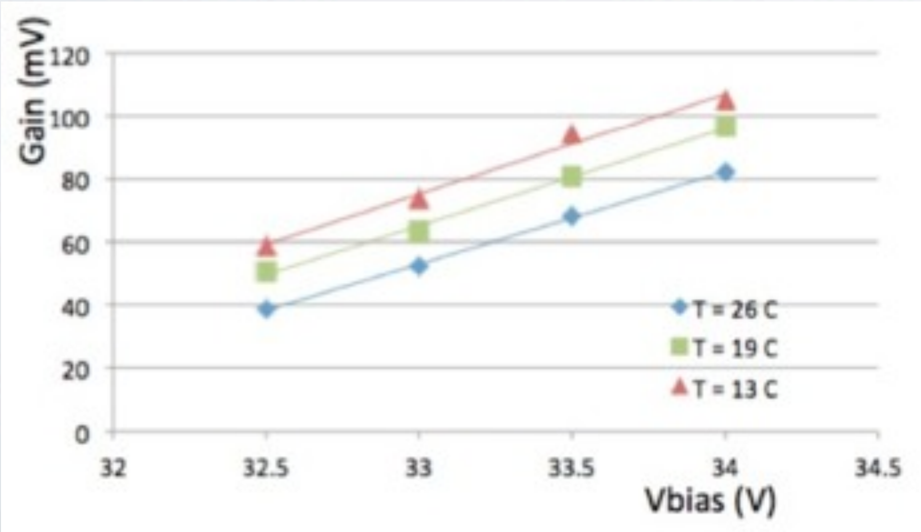
TEST BEAM

- IFR DAQ used during tests @Fermilab Meson Test Beam Facility
- Two more software modules: ODC and Monitor
  - Online Detector Control (ODC) used in offline mode for configuration files creation or in online mode to directly configure ABCD boards
  - Monitor application used to perform a online analysis on acquired data



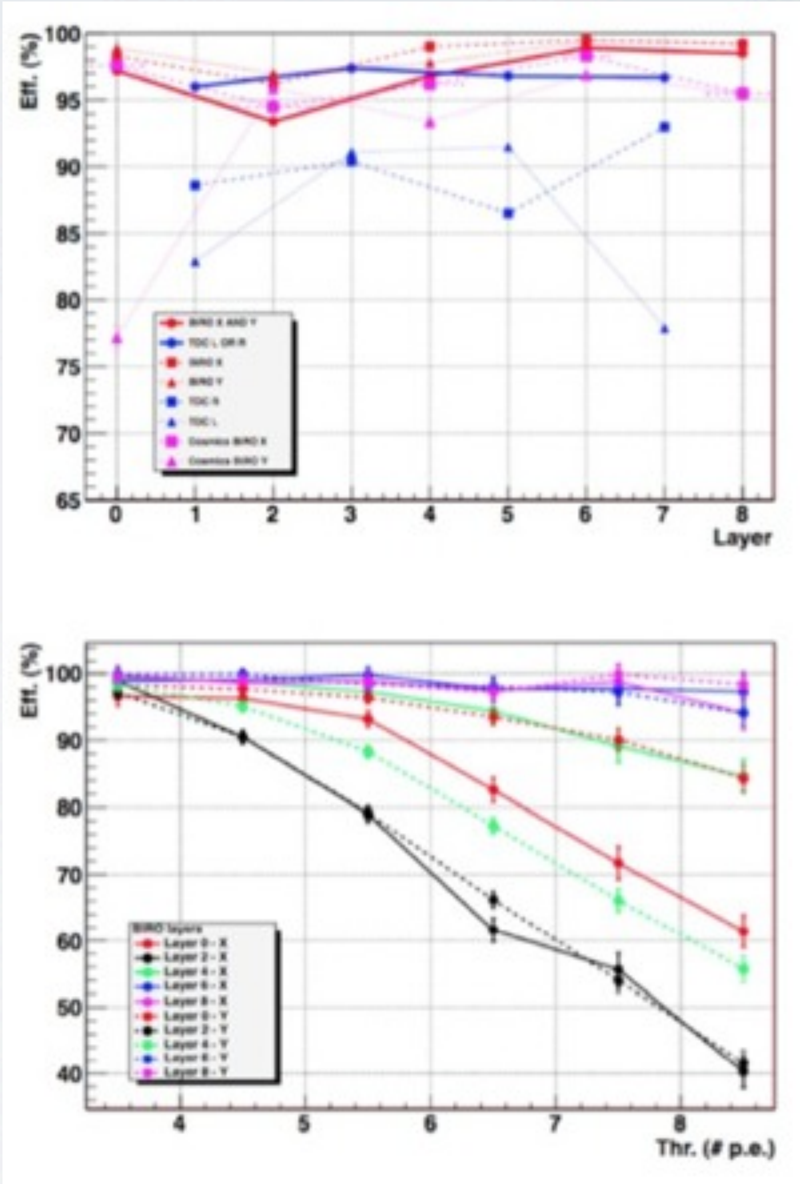
TEST BEAM

- SiPM gain depends on environment temperature
  - Tested using cosmics with runs at different hours (winter)
  - NI cRIO controller continuously monitors prototype temperature (up to 4 zones), reading through http interface
  - DAQ can read temperatures and apply a Vbias correction automatically
  - "Cooling" system for the prototype



TEST BEAM

- DAQ has been developed in a couple of months by physicists and CS students
- Very effective during tests
- Results
    - efficiency of 95%, confirming MC simulations (FullSim, GEANT4 based)
    - studies on detector parameters needed to define the geometry (layers, thickness, etc...)

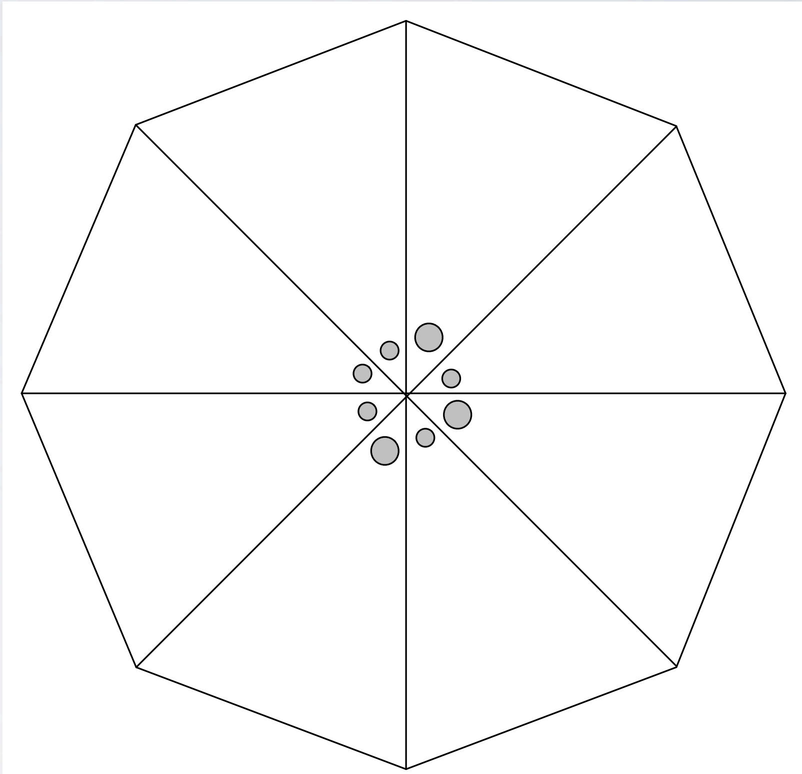


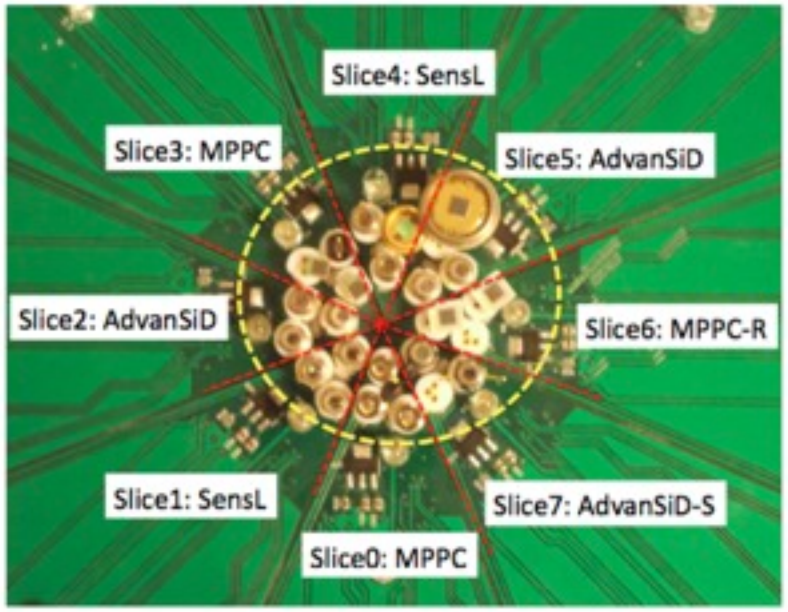
USE CASE IV
NEUTRON TESTS

- Radiation Hardness test with neutrons on SiPM + read-out electronics
- **Gelina** and Leuven facilities
- Understanding the sensitivity of SiPM to the radiation damage is crucial in the High Energy Physics field where a high irradiation exposure is common. Hadrons and high energy leptons are able to produce in the active volume of the photodetector point defects and cluster-related defects.
- In particular neutrons traveling within the silicon lattice induce displacements of many silicon atoms forming disordered agglomeration, called cluster. From the macroscopic point of view these defects produce an increase of dark events, producing a partial blindness in the photodetector.
- In High Energy Physics experiments neutrons are often produced by photo-nuclear reactions of X and Gamma rays with the surrounding matter.
  The emitted neutrons spectrum is broadened in energy. For this reason we have studied the SiPMs radiation damage induced by an approximately white neutron spectrum.

NEUTRON TEST

- Experimental setup
- 8 different SiPM in octagonal mount

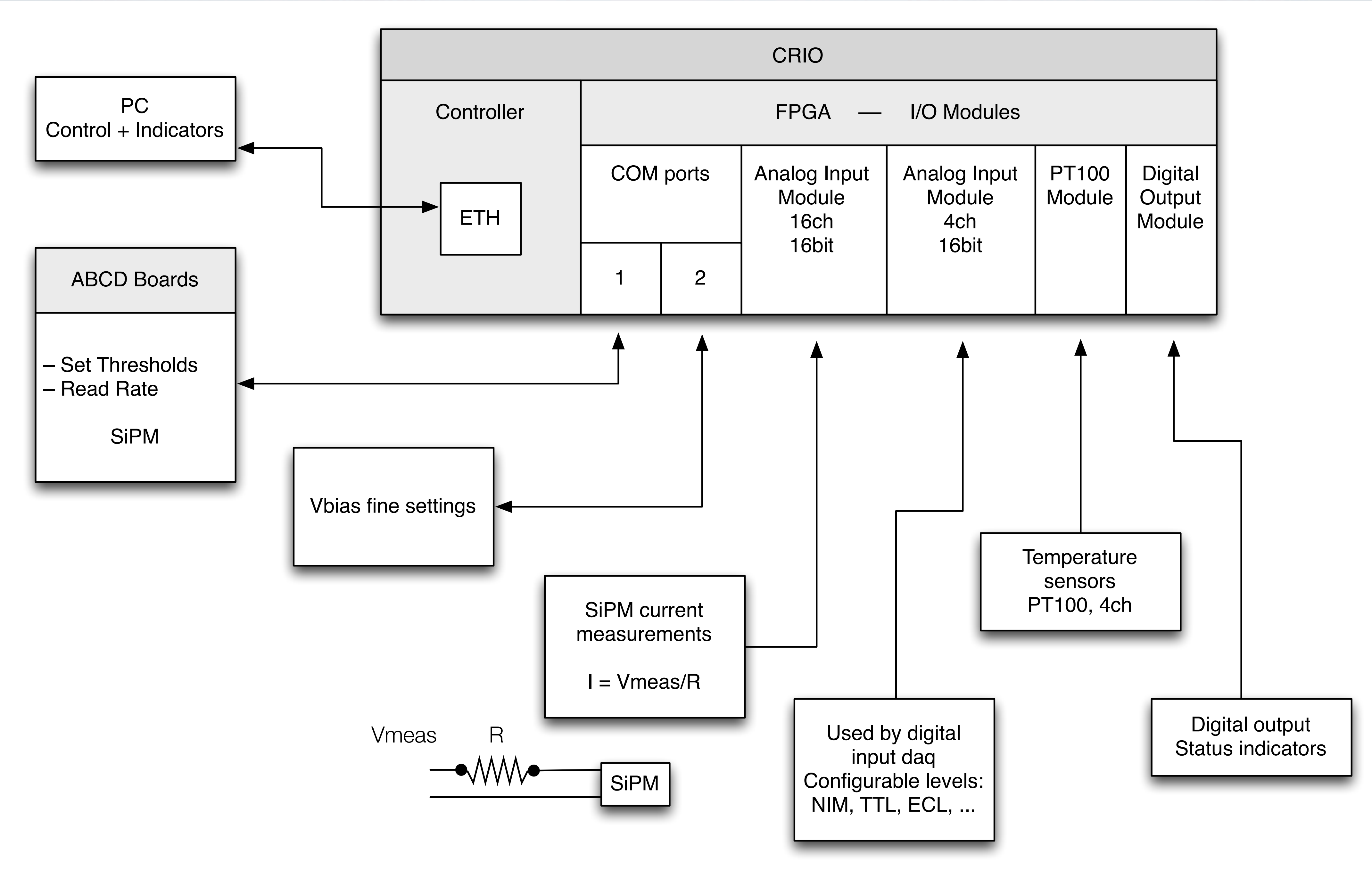




USE CASE IV
NEUTRON TESTS

- Needs for robust DAQ and CS system capable to operate without direct supervision
  - NI cRIO FPGA-based Realtime controller + PC for control and visualization System is standalone, PC can be disconnected while DAQ continues. In case of power outage, cRIO resumes operations automatically
- Developed the following functions:
  - serial communication protocols to interface with ABCD boards
  - Temperature reading from PT100 raw data
  - Rate of analog signals

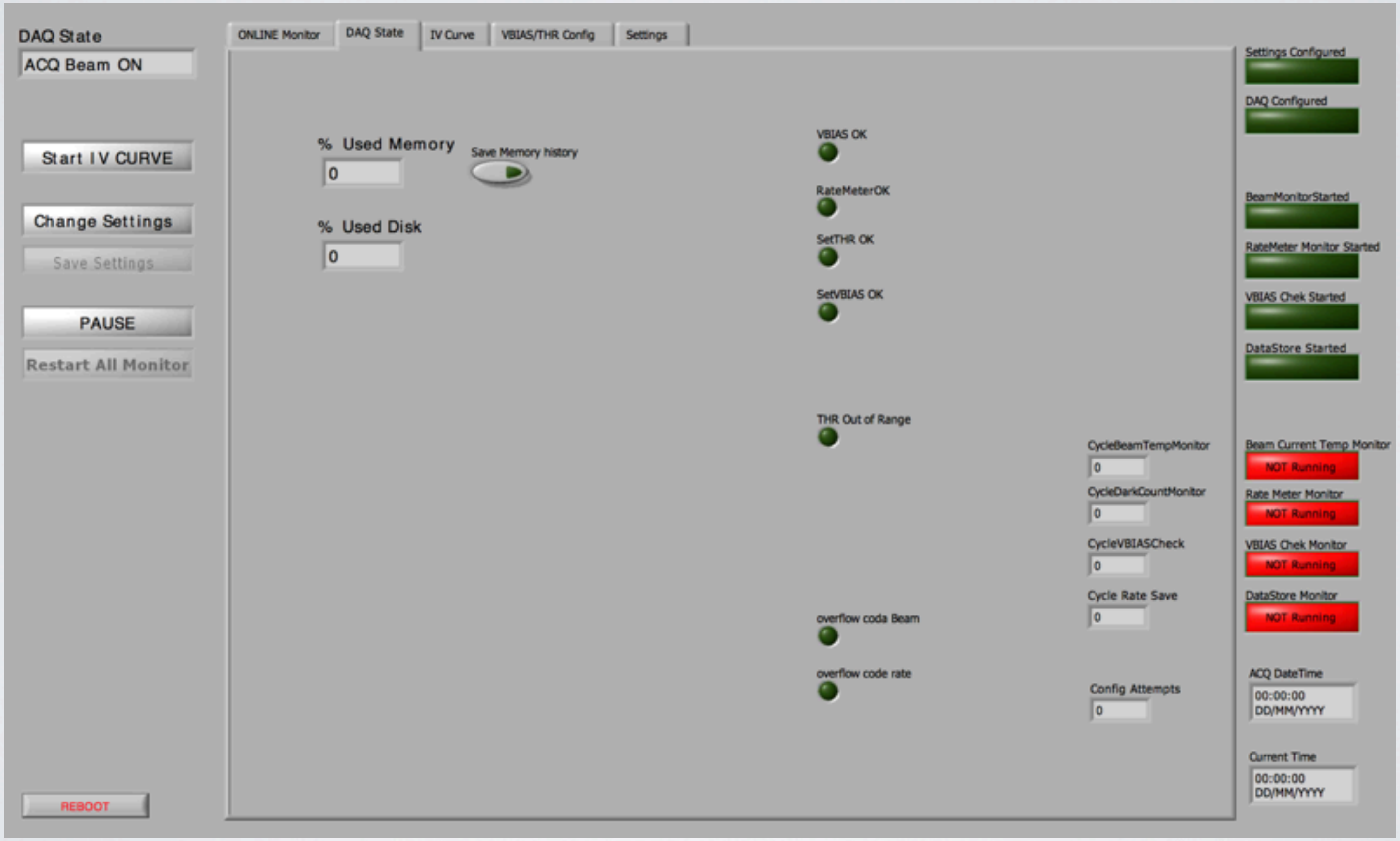
NEUTRON TEST



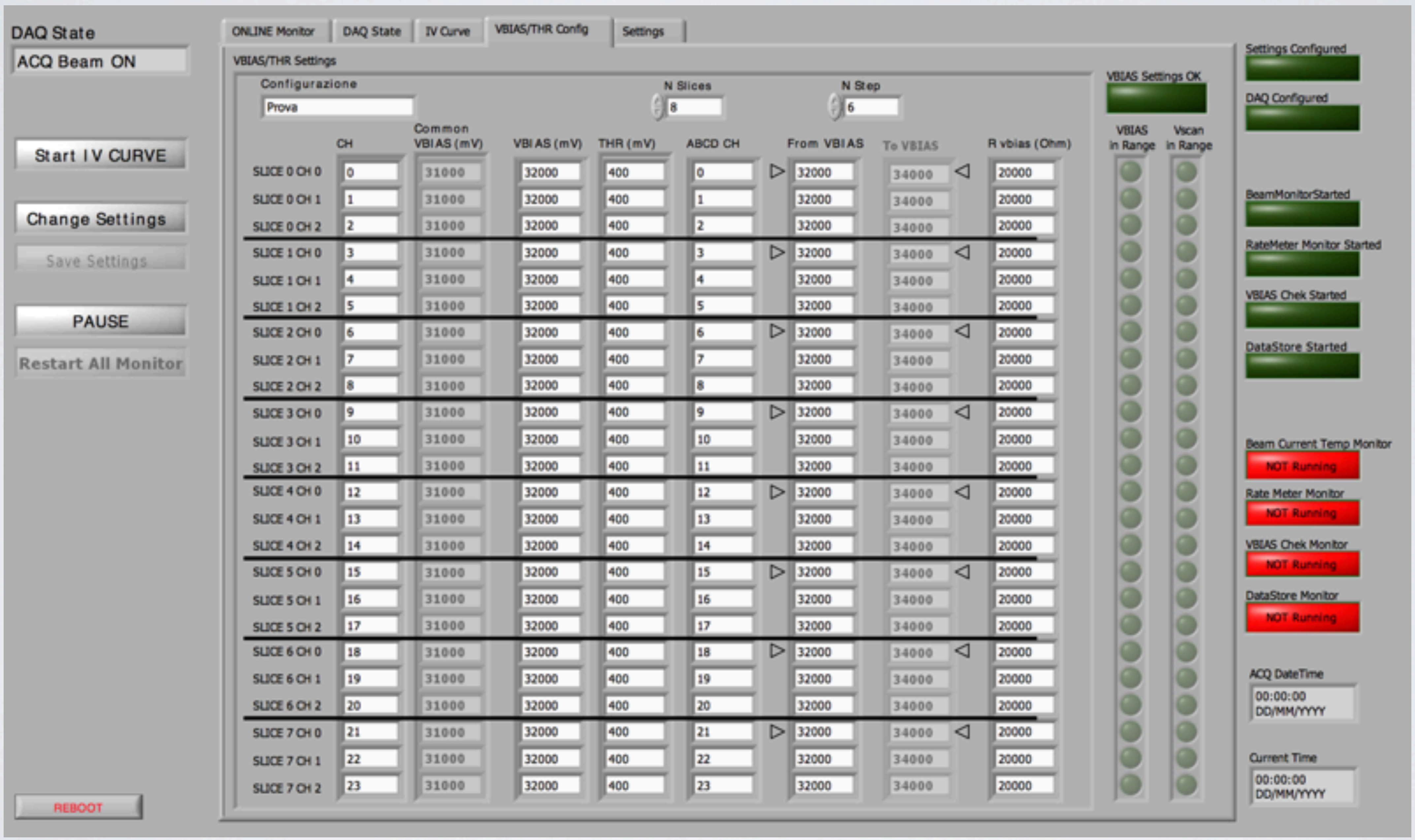
NEUTRON TESTS

- Scan frequency on FPGA is higher than cRIO controller one
  - Needs for measurements every minute: average on the previous 10 s (user selectable)
- Automatic measurements of SiPM I-V curve. At regular interval is possible to vary the Vbias, measuring the absorbed current

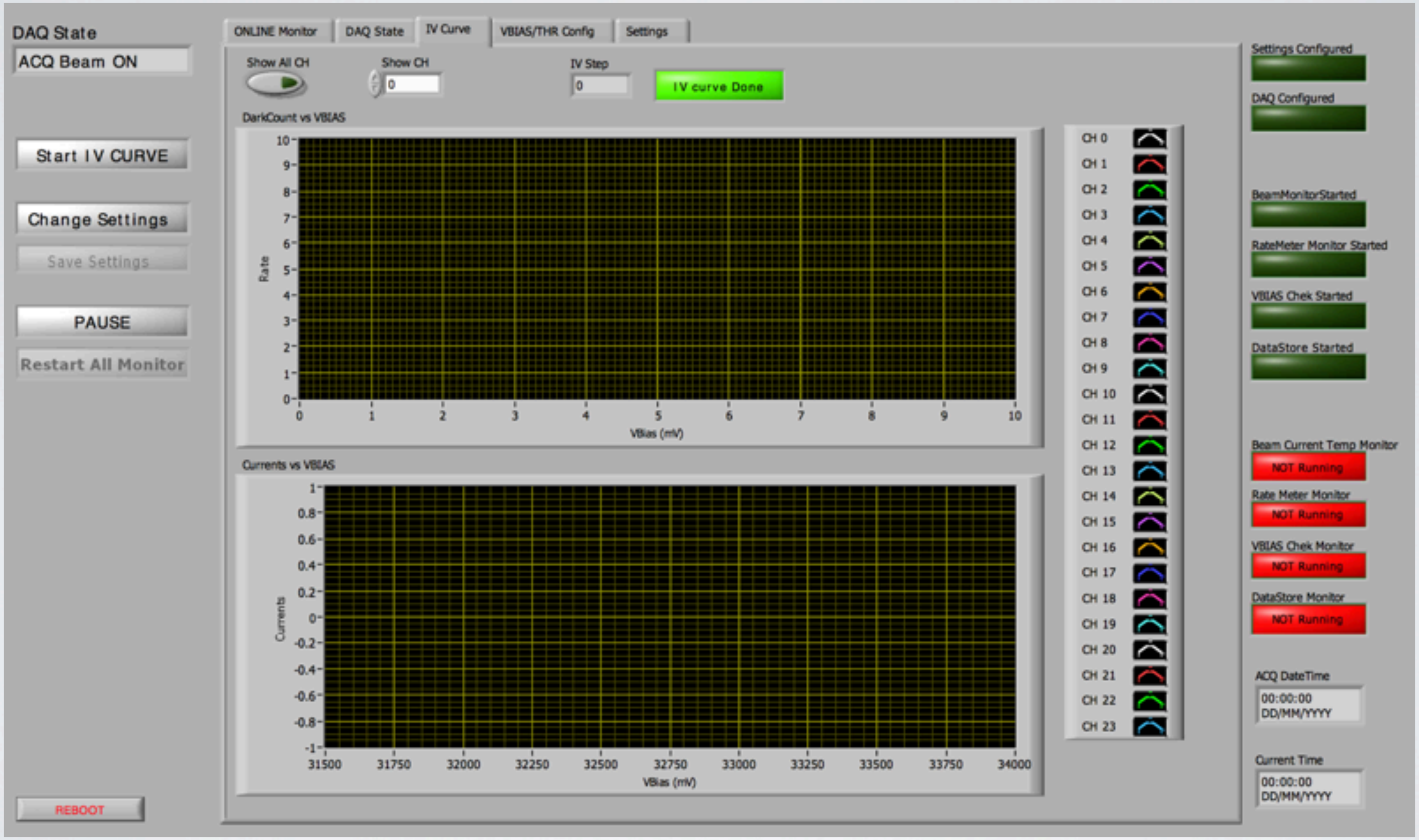
NEUTRON TEST



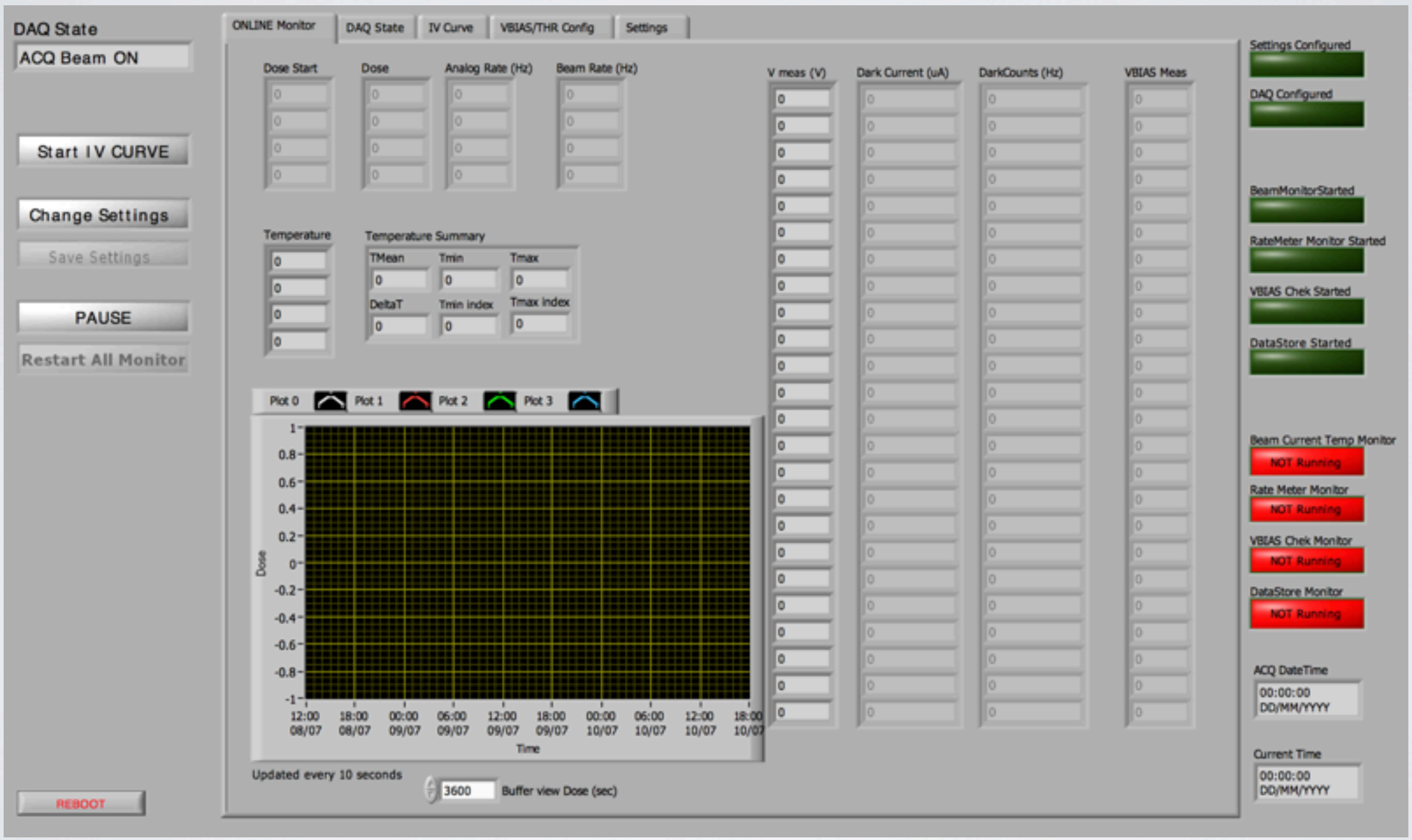
NEUTRON TEST



NEUTRON TEST

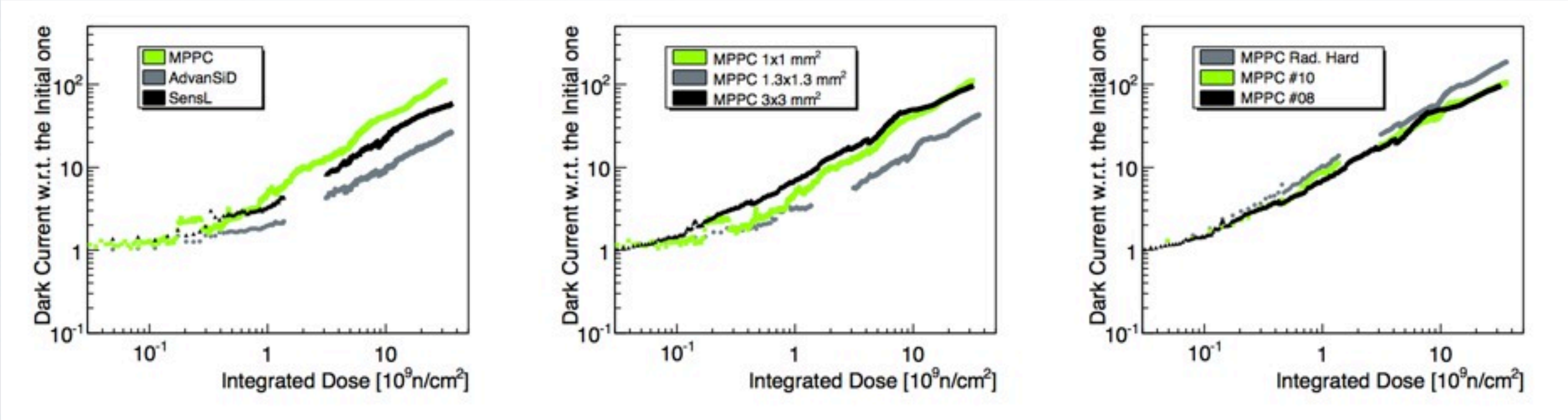


NEUTRON TEST



NEUTRON TEST

NEUTRON TEST



1mm 50µm 50µm

USE CASE V
DRHOUSE

- DRHousE:
  Diagnosis of a Real House Envelope

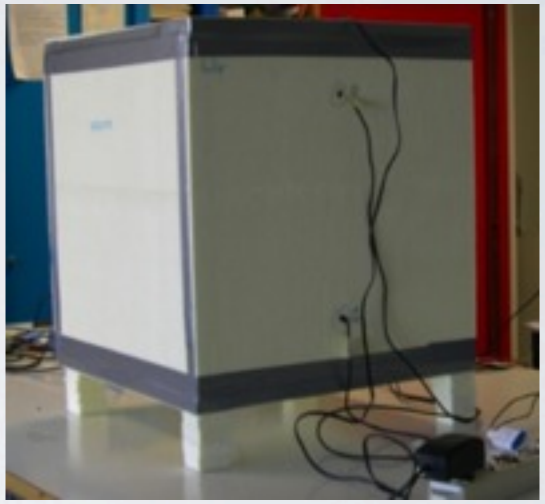
- Development of a Test System to study heat exchanges with the aim of derive the heat exchange coefficient of Historical buildings by measuring temperatures during a heating curve

- Topic of a Ph. D. Thesis in Architecture
  Some of the Physicists/INFN expertise needed

  ... just for fun ... !

DRHOUSE

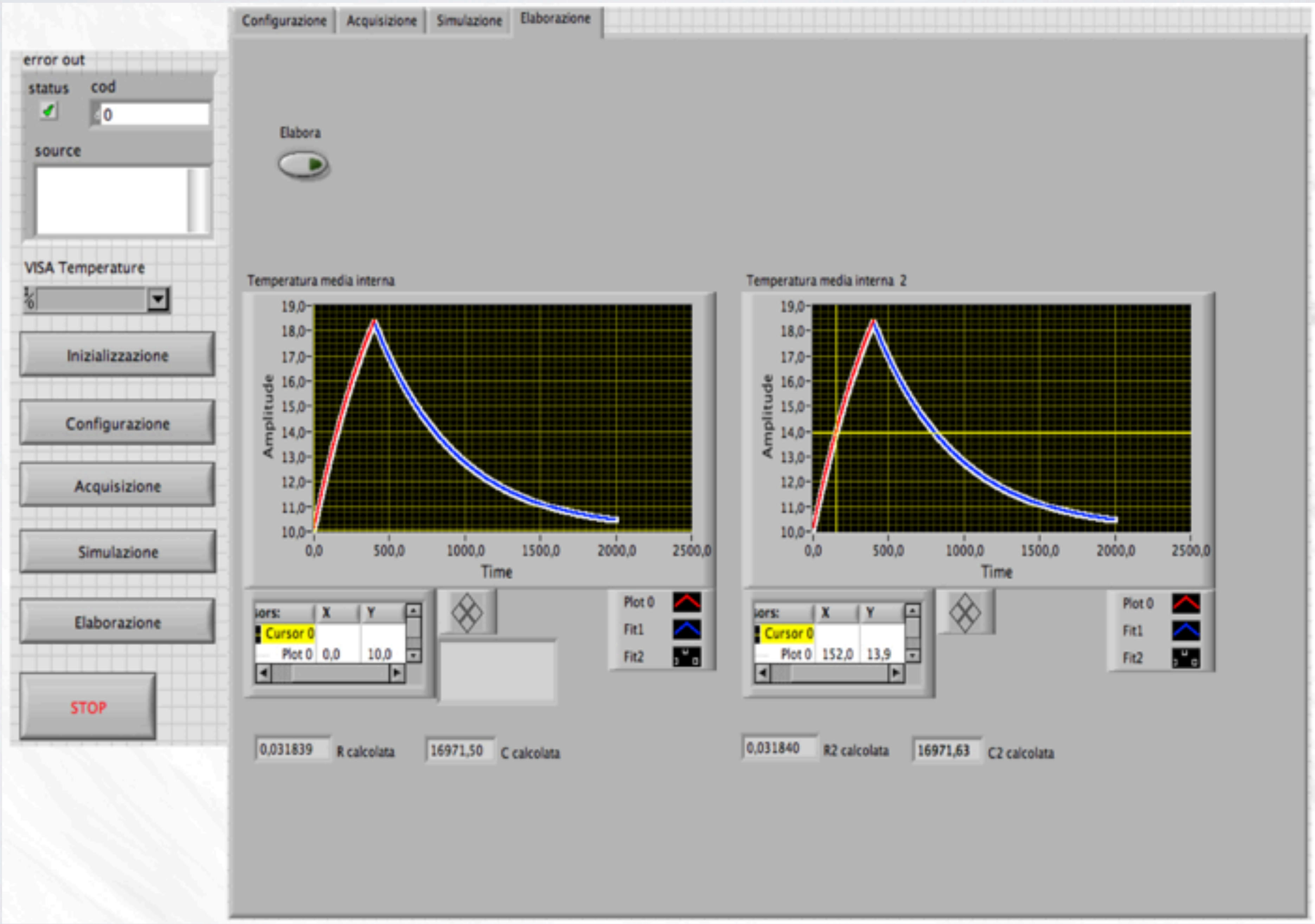
- LabView interface (state machine)
- Arduino + ICPcon + NI cDAQ
- PT100 + Dht22 sensors
- Several 'house models' for testing



DRHOUSE

- Heater is a resistor
- Several test have been performed (with a proper DAQ system)
  - heating curve test: to measure the exponential heating curve, its thermic constant and the heat exchange coefficient
    (Labview + ICPcom via serial + PT100 readings)
  - constant-T test: by using a rele to keep temperature constant inside
    (Labview + arduino via serial + thermistors + rele)
  - ‘following test’: heater always on at constant power, measuring internal and external temperature (there is summer and winter!)
    (Labview + arduino via serial + thermistors)

DRHOUSE



Configurazione
Acquisizione
Simulazione
Elaborazione
error out
status
cod
0
source
VISA Temperature
Inizializzazione
Configurazione
Acquisizione
Simulazione
Elaborazione
STOP
Elabora
Temperatura media interna
Amplitude
Time
Plot 0
Fit1
Fit2
Cursor 0
0,031839
R calcolata
16971,50
C calcolata
Temperatura media interna 2
152,0
13,9
0,031840
R2 calcolata
16971,63
C2 calcolata

CONCLUSIONS

- DAQ is never ending in Physics!
- You must be versatile to cope with different requirements and constraints
- Sometimes you need to be quick-and-dirty
- Working in collaboration with computer science researchers and/or electronics engineers may greatly enhance your expertise
- Your contribution in development of DAQ systems is always fundamental for the success of the experiment

ACKNOWLEDGMENTS

- Francium experiment collaboration
- Former SuperB IFR collaboration
- M. Andreotti (FE) and M. Manzali (FE + CNAF)
- The organizers!