Ultrafast laser filament-induced fluorescence of *Chlamydomonas reinhardtii* to identify uranium exposure

MTV Workshop, 2022

March 22, 2022

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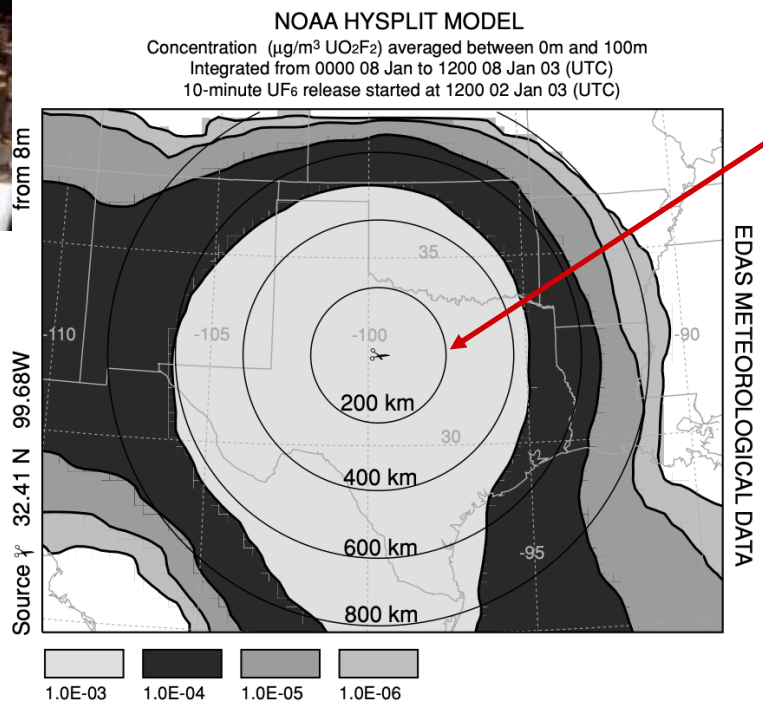
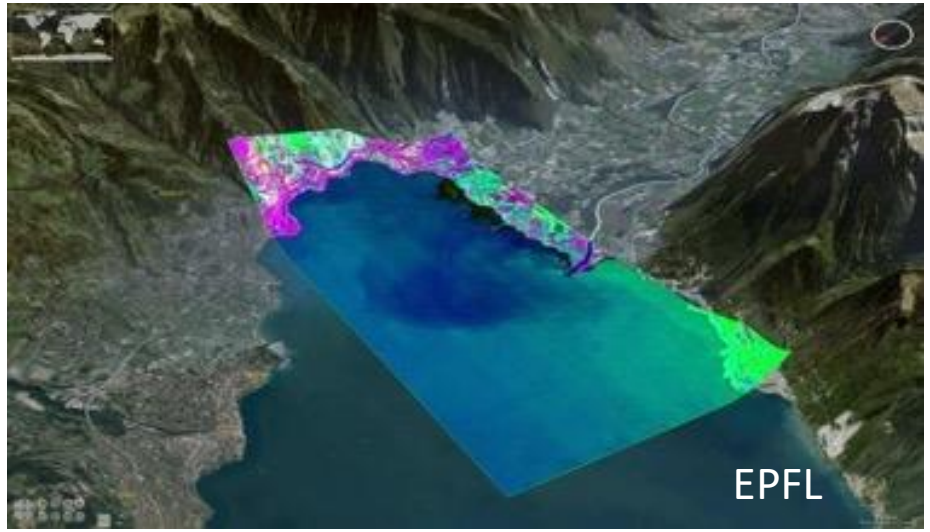
Motivation: Remote detection and monitoring for nuclear nonproliferation

Cylindrical volume of 1 km height and 2 km radius contains enough UO_2F_2 to deposit 50 µM U.



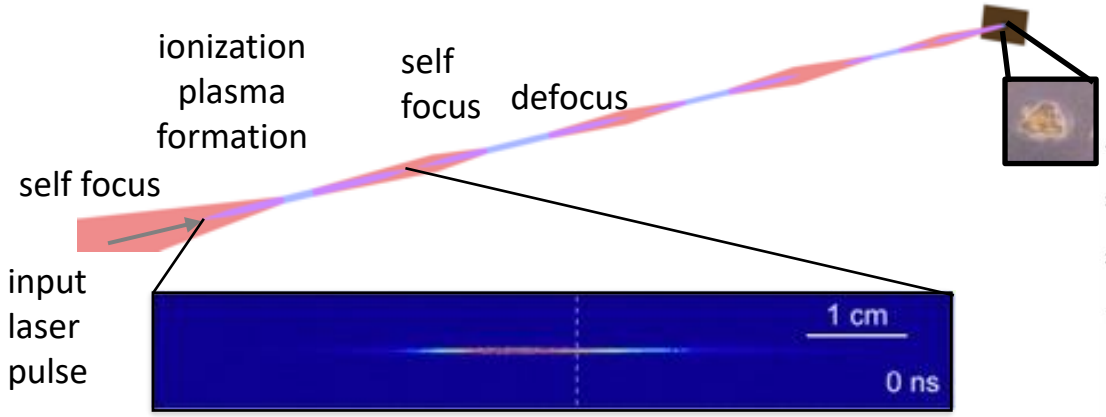


Centrifuge enrichment facilities may emit UF_6, which reacts and deposits as UO_2F_2 in the surrounding environment.

Laser-based methods may be beneficial to detect low concentrations of nonproliferation relevant materials, like UO_2F_2, is necessary for monitoring enrichment activities.

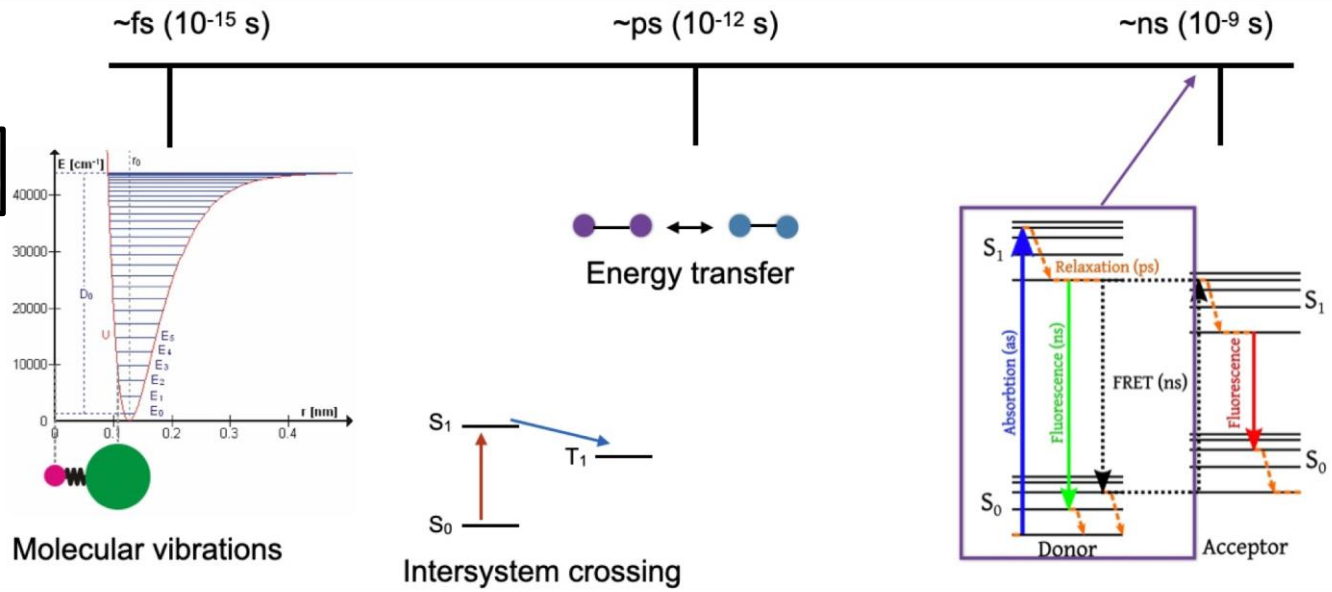
Mission Relevance: Developing remote, high sensitivity methods for in-field monitoring

Ultrashort, high-intensity pulses enable remote analysis with spatial resolution via filamentation

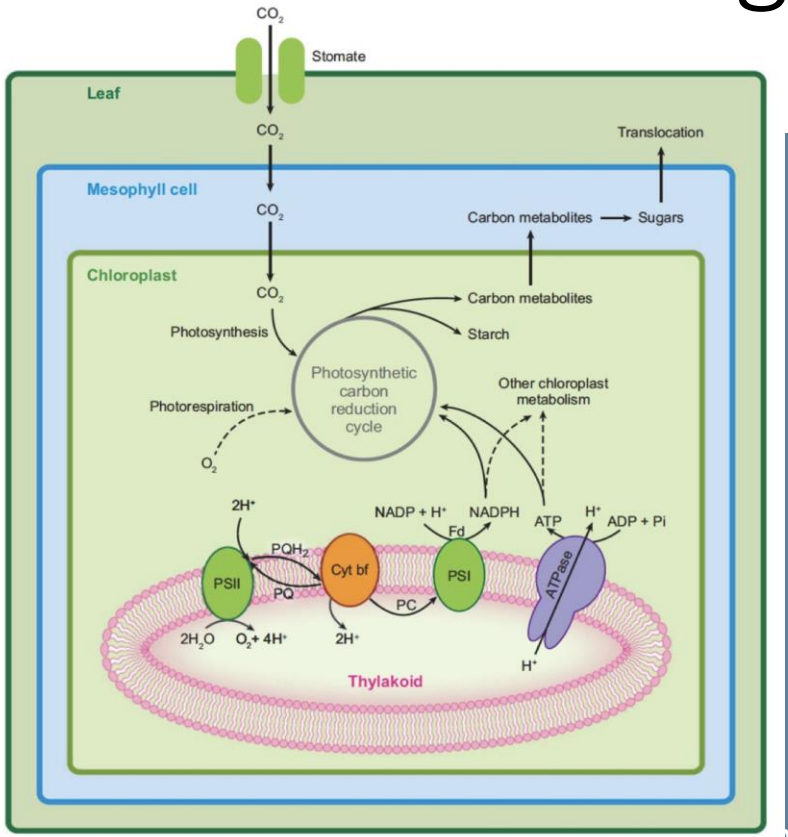


Finney *et al.*, Optics Express **26**, 29110 (2018)

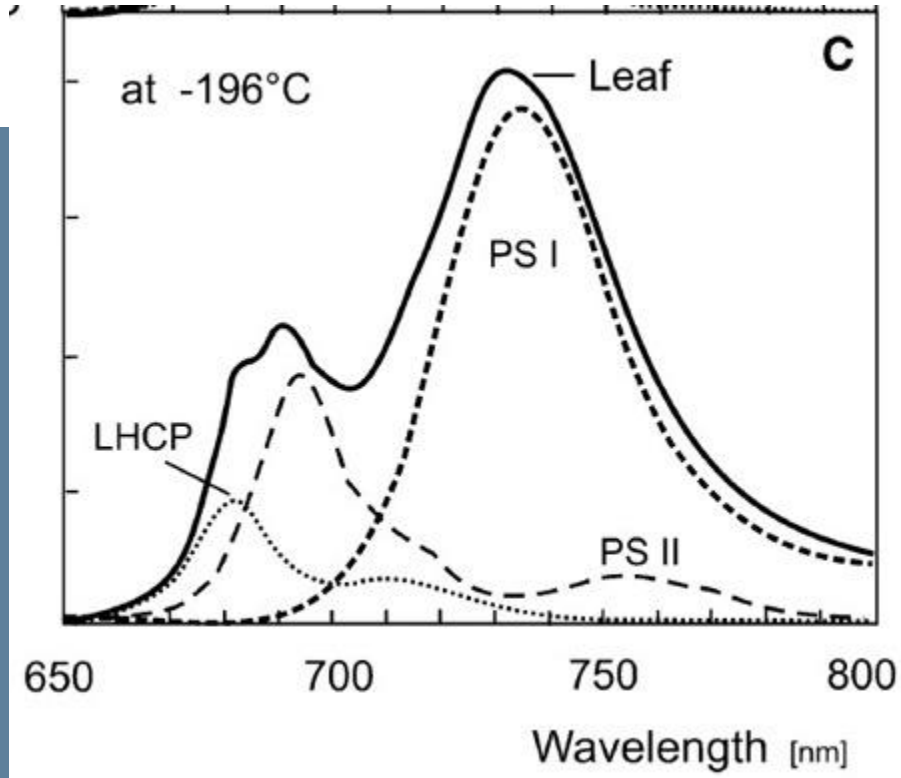
Ultrashort pulsed lasers enable time-resolved molecular dynamics and fluorescence measurements



Technical Background: Chlorophyll fluorescence as an in-field monitoring signature



Baker, Annu. Rev. Plant Biol., **113**, 89 (2008).



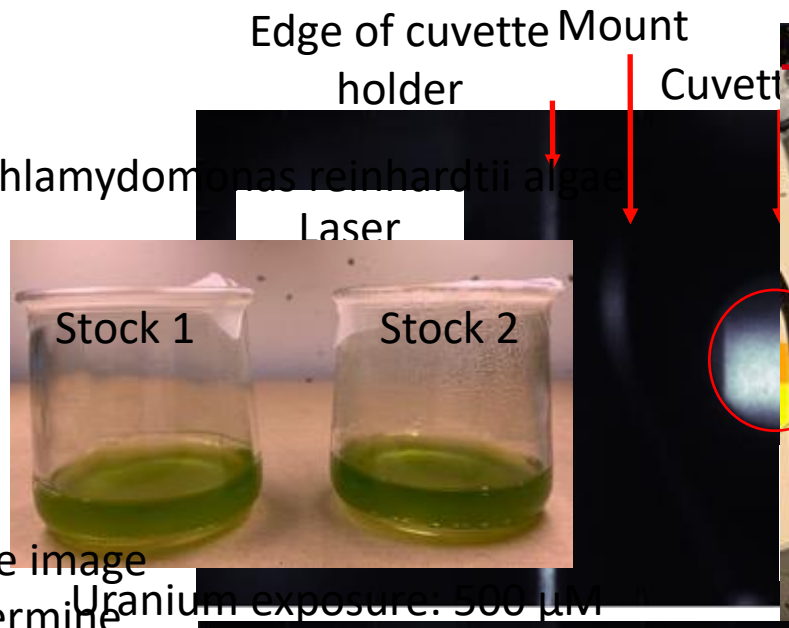
Buschmann, Photosyn. Res., **92**, 261(2007).

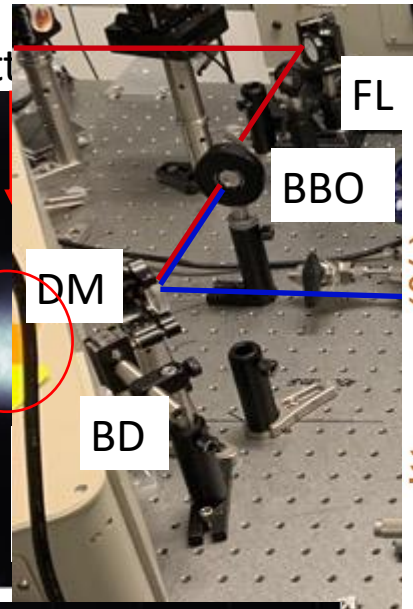
Chlorophyll is the molecule that fluoresces, and is the main molecule involved in light capture for photosynthesis.

PSII reaction center called P680 (primarily fluoresces at 680 nm)

PSI reaction center called P735 (primarily fluoresces at 735 nm)

Experimental set-up for exposure and imaging





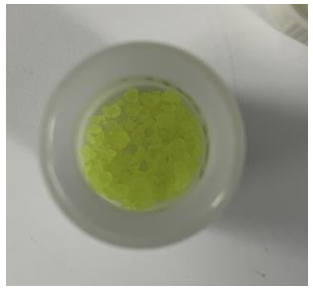
Integrate image to determine fluorescence intensity

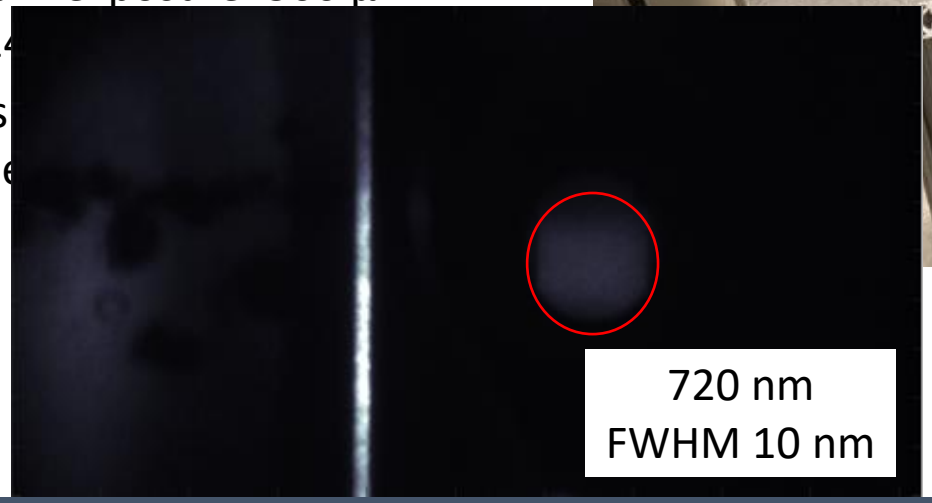
Uranium exposure: 500 µM

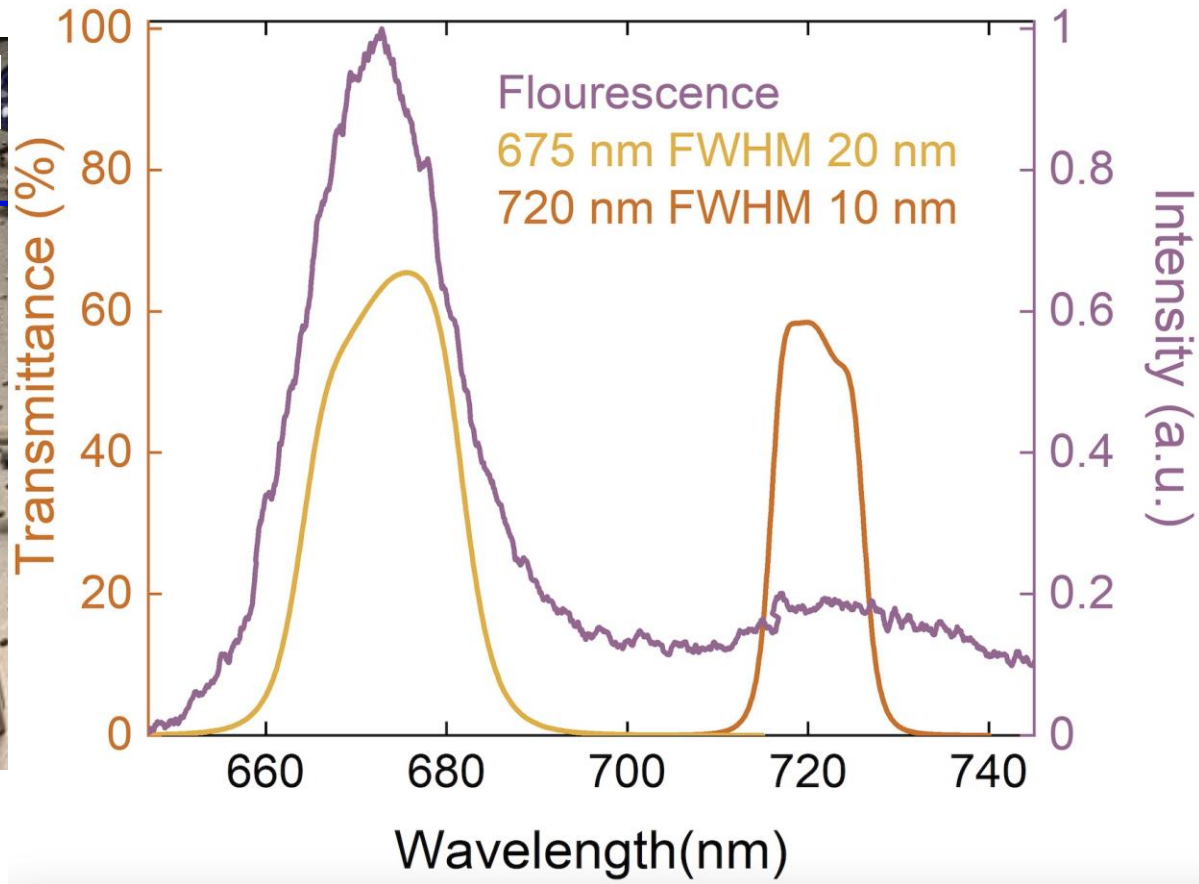
24

2 controls

pe

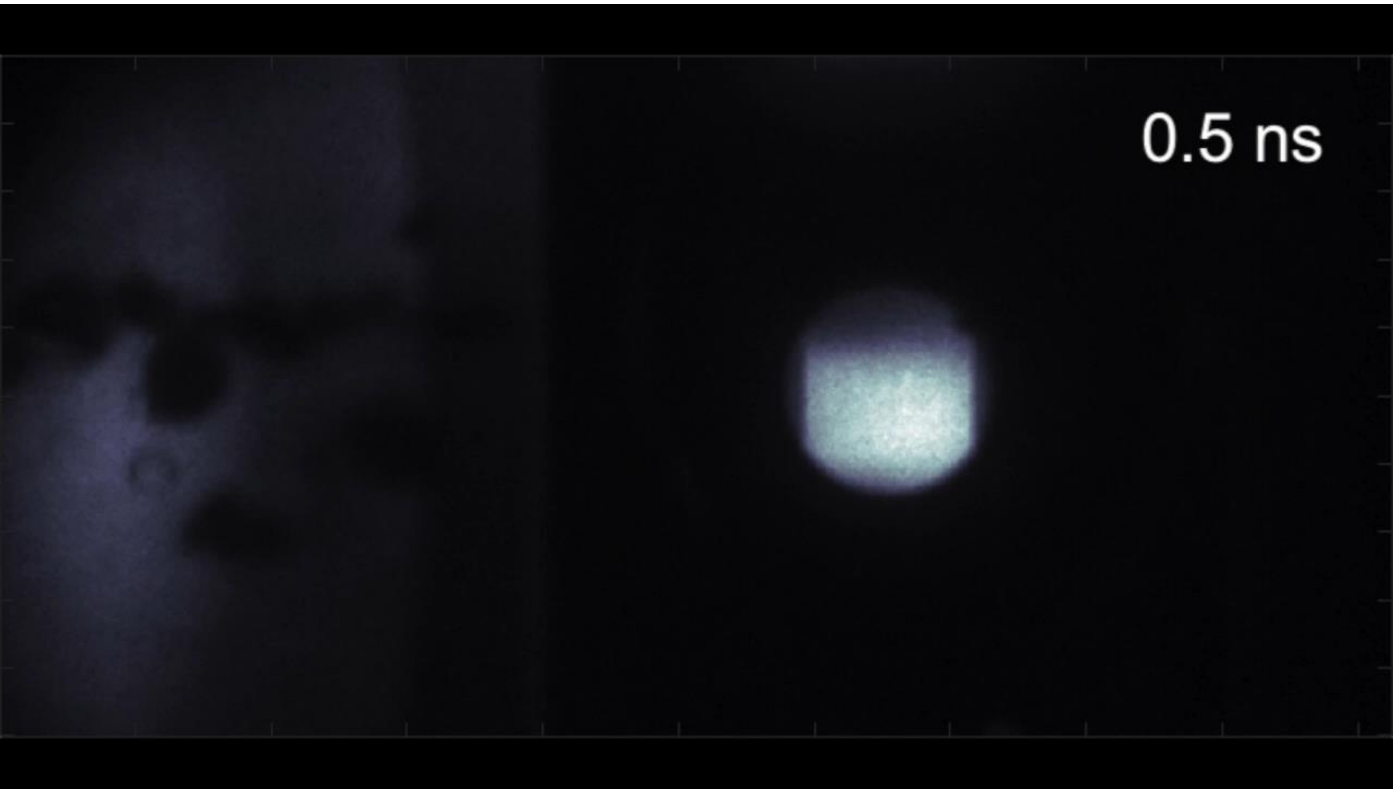


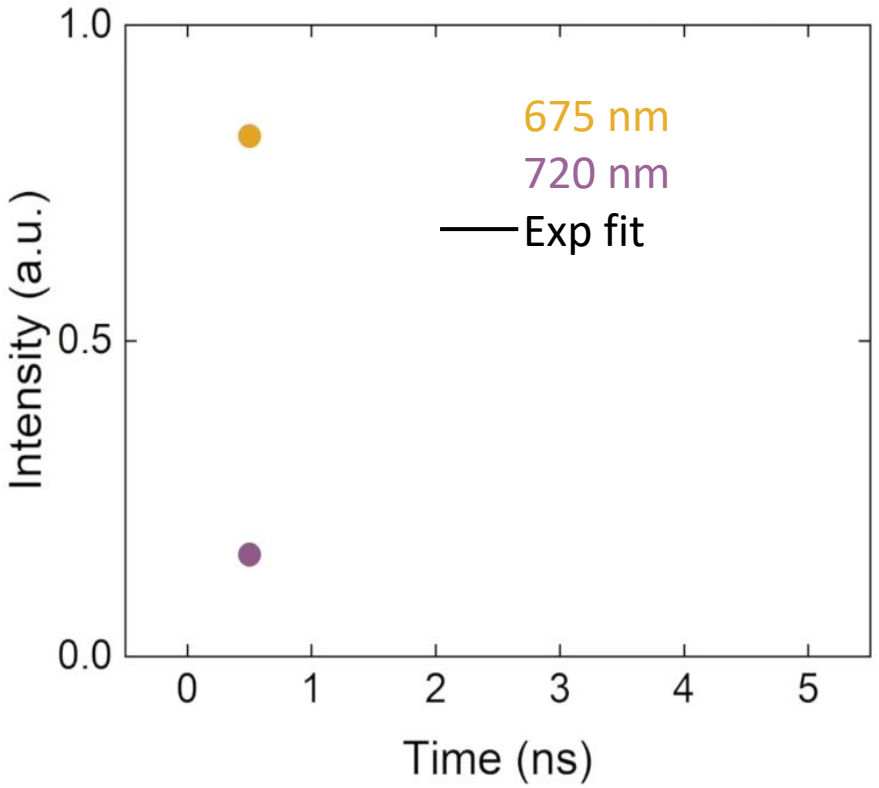




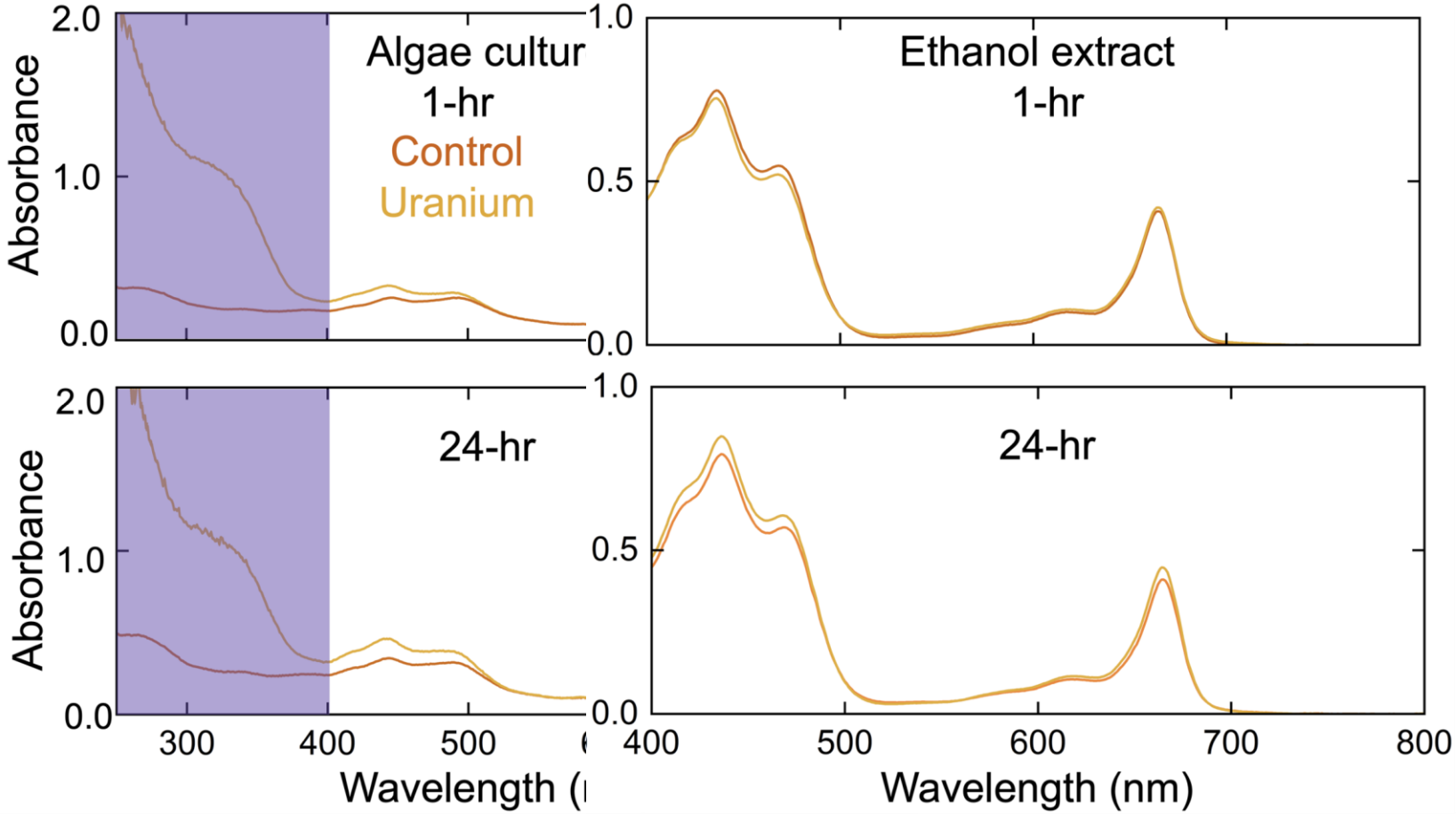
DM: dichroic mirror
FL: focal length

Pulsed laser excitation with gated detectors allows for temporal resolution of the fluorescence





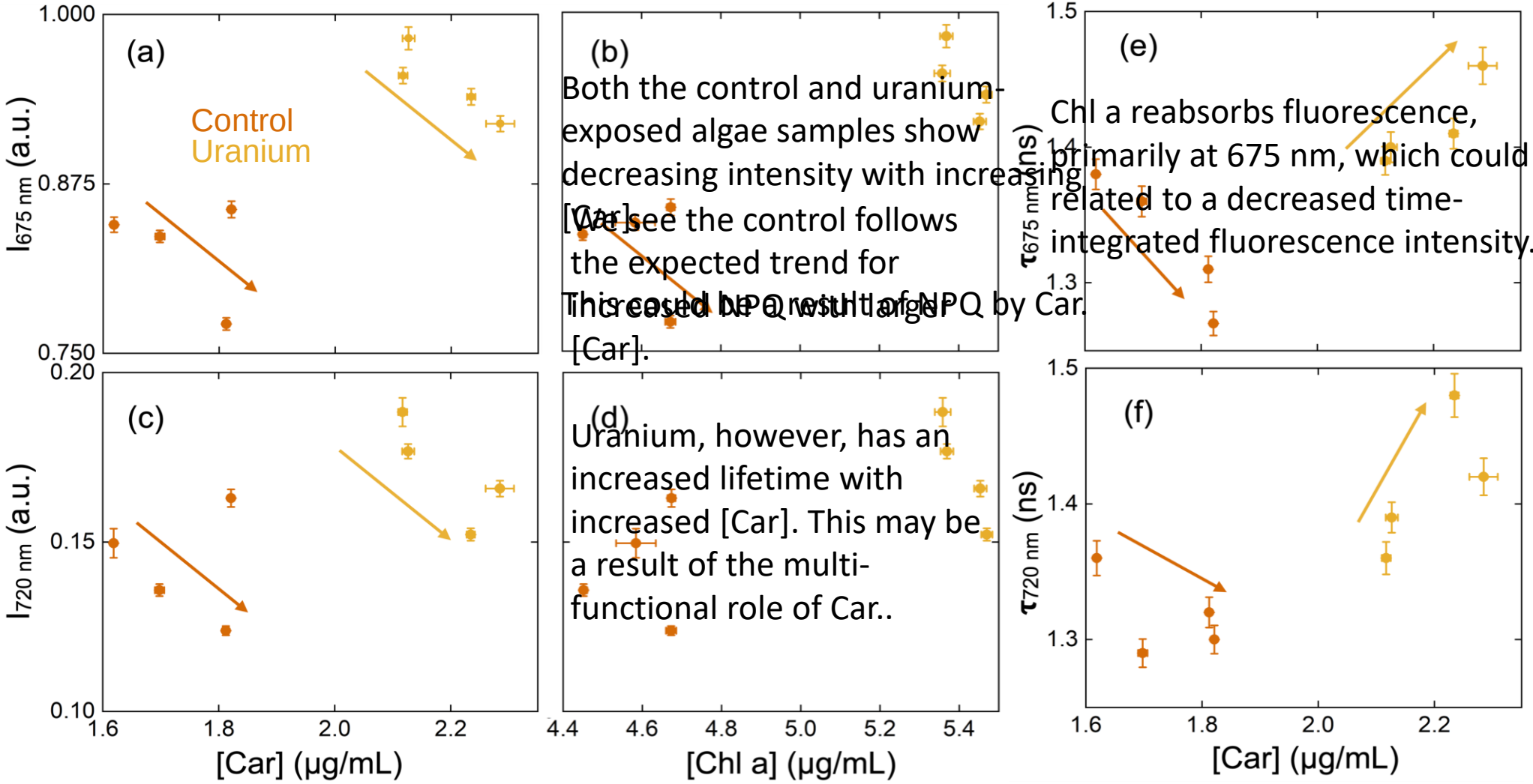
A significant change in the absorption spectrum as early as one hour after exposure to uranium is observed



UV-absorbing compounds in plants are ROS and proteins that act as antioxidants, along with carotenoids to avoid ROS damage. These are prominent as early as 1 hr following the uranium exposure.

We expect, along with carotenoids to avoid ROS damage. These are prominent as early as 1 hr following the uranium exposure.

Inverse relationship between carotenoids and fluorescence parameters for uranium than the control is observed



Both the control and uranium-exposed algae samples show decreasing intensity with increasing [Car].

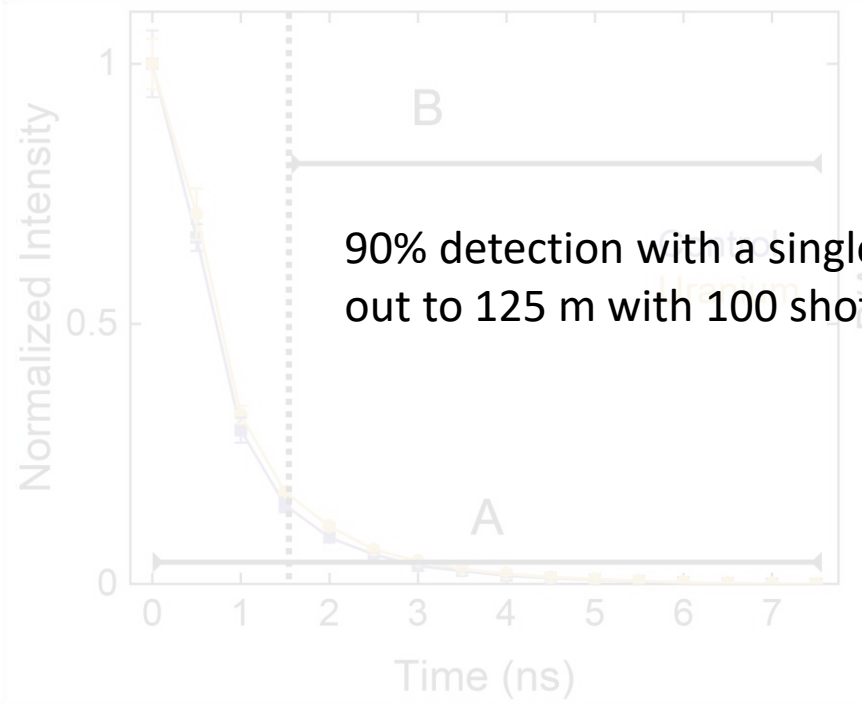
We see the control follows the expected trend for increased NPQ with larger [Car].

This could be a result of NPQ by Car.

Chl a reabsorbs fluorescence, primarily at 675 nm, which could be related to a decreased time-integrated fluorescence intensity.

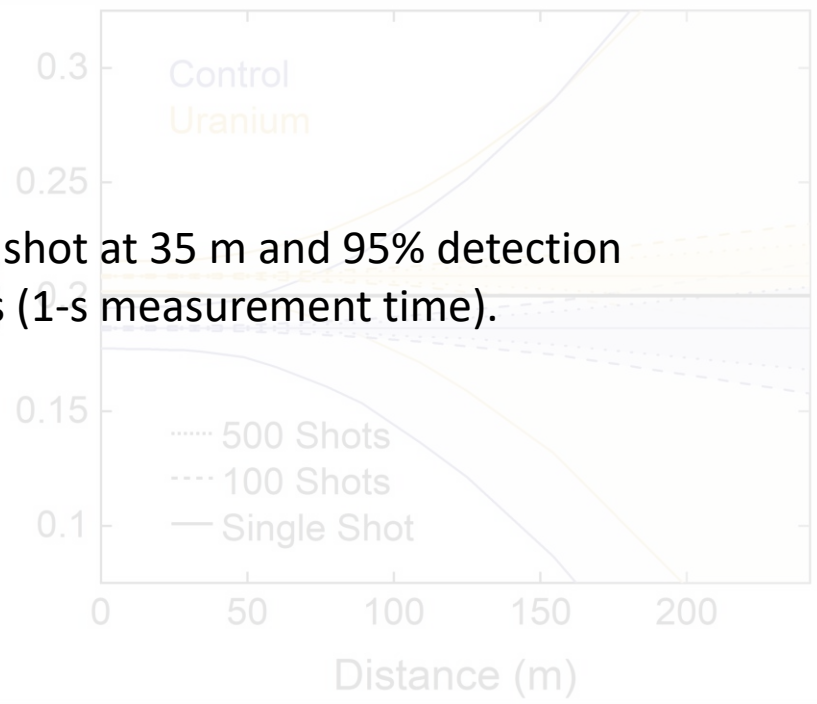
Uranium, however, has an increased lifetime with increased [Car]. This may be a result of the multi-functional role of Car..

The temporal profile for uranium-exposed algae is one discriminating feature with potential remote detection

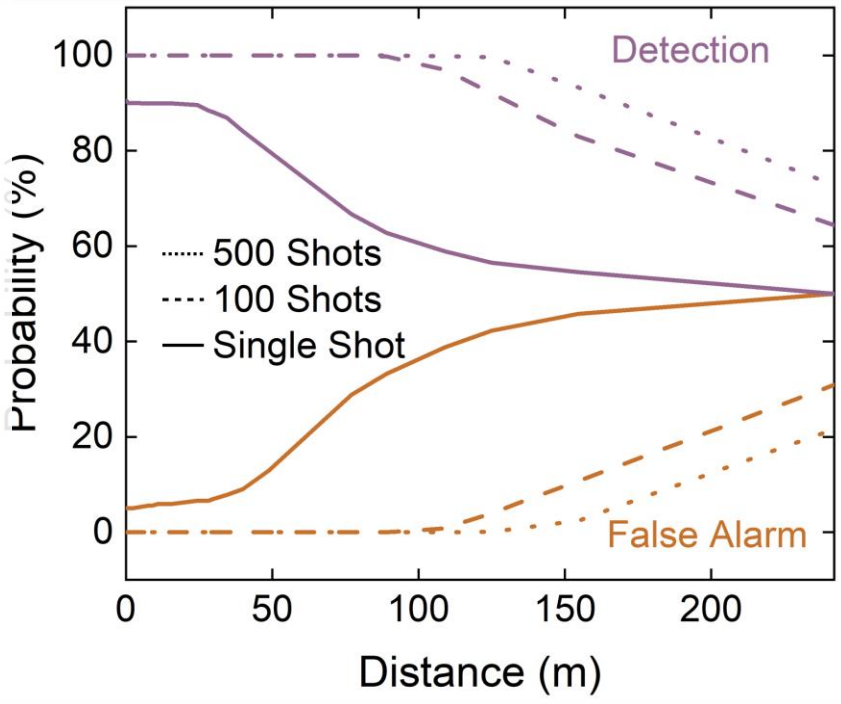


We identify a parameter as B/A to discriminate the two temporal profiles for the mean control and uranium sampless.

90% detection with a single shot at 35 m and 95% detection out to 125 m with 100 shots (1-s measurement time).

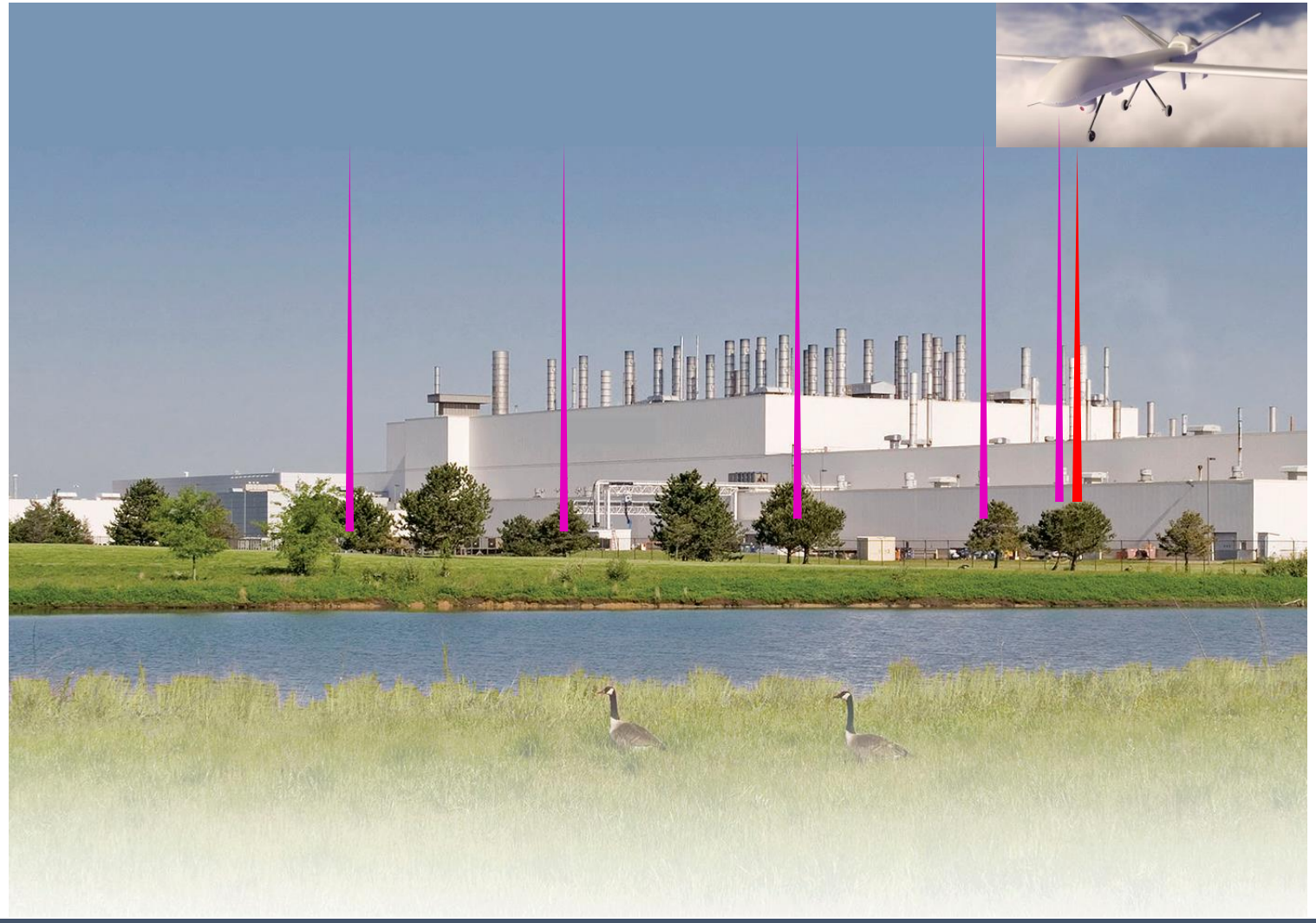


The shaded regions show 1-σ experimental and background uncertainty. These can be reduced by averaging multiple shots together.



Gaussian distributions can be formed from the mean B/A and σ and integrated to determine detection (U-exposed) and false alarm (control) probabilities.

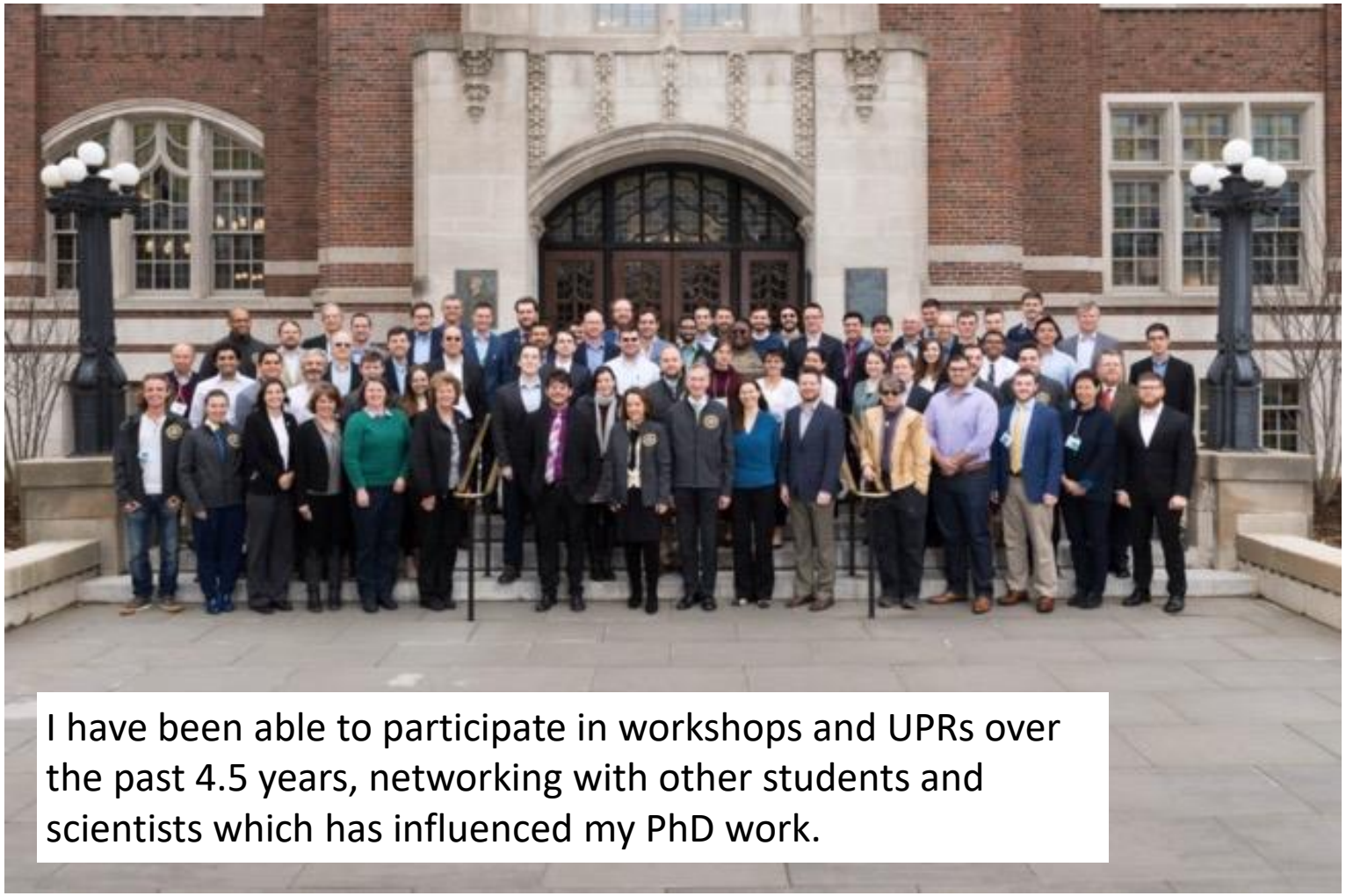
Impact: Development of *in-situ* environmental monitoring for identification of nuclear materials



https://www.thinplytechnology.com/markets/uav-drones

J. Walsworth, *U.S. Plant took subaru on new journey*, web (2018).

MTV Impact



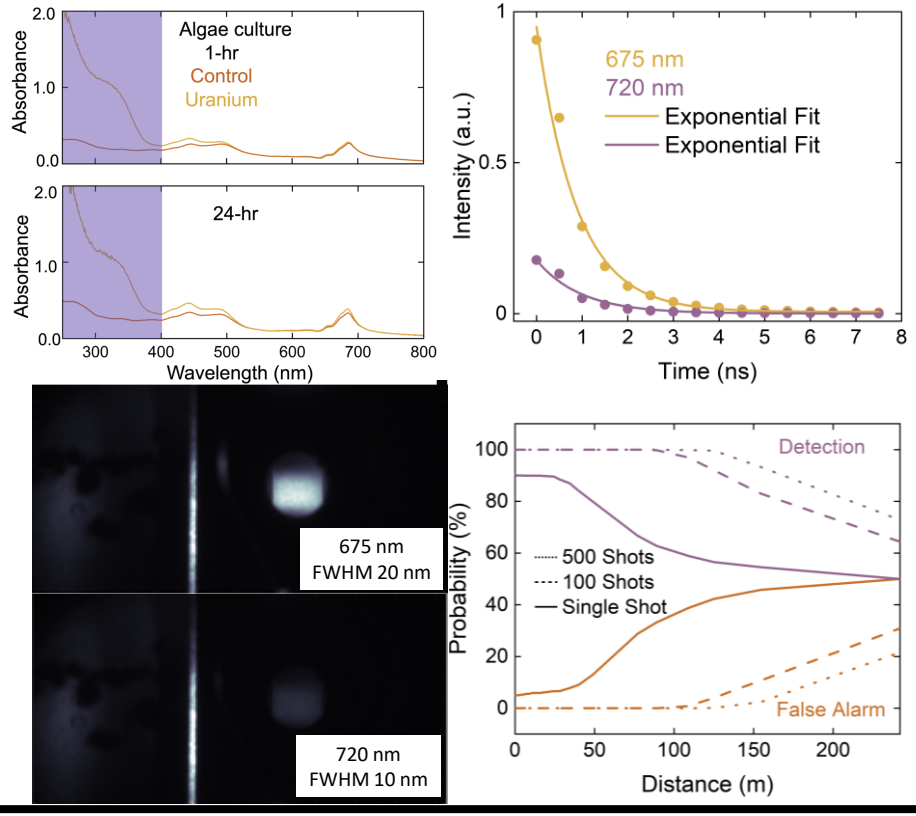
I have been able to participate in workshops and UPRs over the past 4.5 years, networking with other students and scientists which has influenced my PhD work.

I met Dr. Laura Tovo from SRNL at MTV Workshop 2020. She is now a member of my dissertation committee.

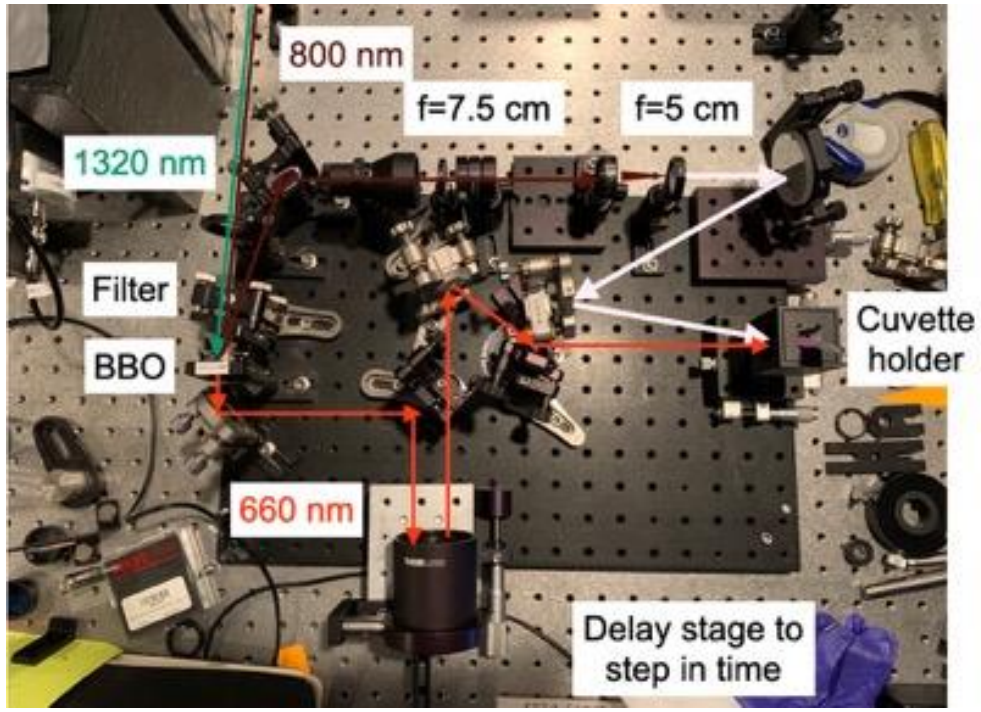
Discussions with SRNL has helped me develop plans for my work and progress.

Conclusion: Filament-induced fluorescence is promising for in-field stress monitoring

Demonstrated non-destructive filament-induced fluorescence of live algae for the first time



Implement higher sensitivity method to understand how stress induces changes in plants' optical properties



Acknowledgements

The Consortium for Monitoring, Technology, and Verification would like to thank the NNSA and DOE for the continued support of these research activities.

This work was funded by the Consortium for Monitoring, Technology, and Verification under Department of Energy National Nuclear Security Administration award number DE-NA0003920; National Science Foundation Graduate Research Fellowship DGE 1256260.