# Interlayer Excitons in BN-Separated $WSe_2/MoSe_2$ Heterobilayers

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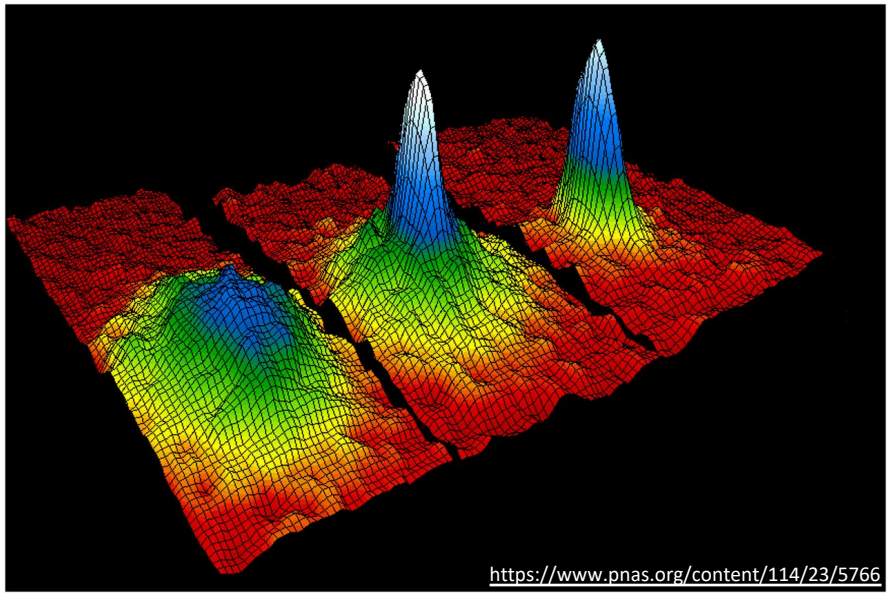
# Outline

- Motivation
  - BECs
  - Exciton condensation
- Background
- Experiment
  - Device Fabrication
  - Optical setup
- Results
  - Photoluminescence measurements
- Next Steps

# Cool Condensates




- What can you do with BECs?
  - Make accurate accelerometers, gyroscopes, clocks, etc.
  - Study GR through an analogue gravity system
  - Investigate fascinating quantum physics!

- What could you do with an exciton condensate?
  - All of the above, but on a smaller, more versatile scale!
  - The (relatively) low mass of the exciton and the possibility of greater spatial confinement raise the critical temperature for condensation ($T_C$)
  - Exciton traps can be created much more compactly using 2D materials (send exciton condensates to space!!)

$$T_C = \left(\frac{n}{\zeta(3/2)}\right)^{2/3} \frac{2\pi\hbar^2}{mk_B}$$

*Gerstner, Nature Physics (2005)*
*Calman et al., CLEO (2019)*

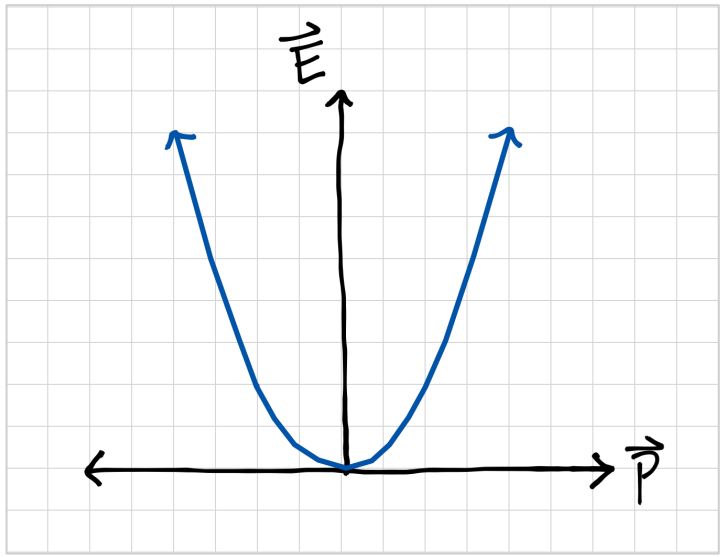
# How might we get there?

- In order to realize exciton condensation, must first be able to:
    1. Keep excitons from recombining for long enough to condense them.
    2. Spatially confine them to increase the density.

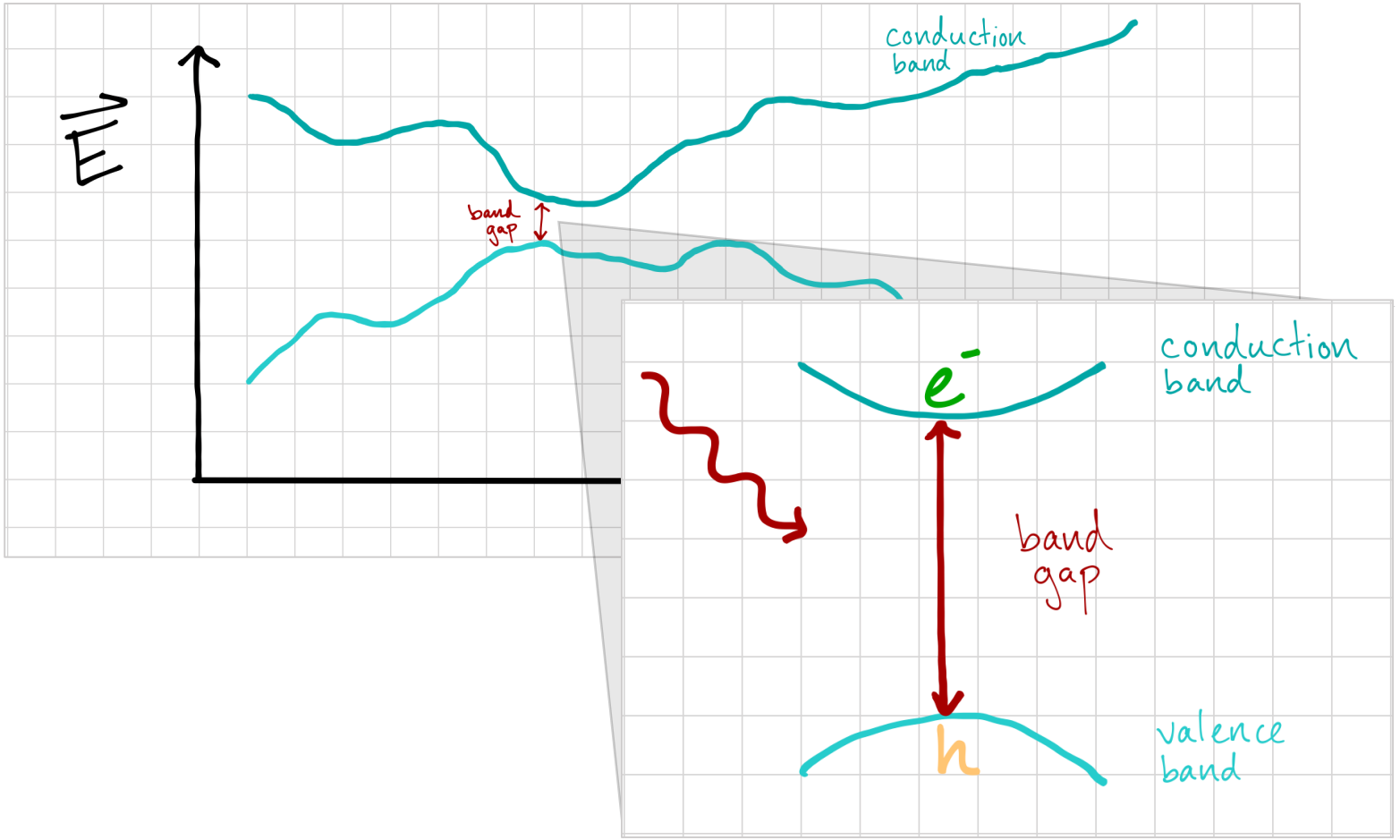
*Calman et al., CLEO (2019)*
*Scheibner et al., Nature Physics 3 (2007)*

# Physics? Physics!

Energy vs Momentum Graph:
Electron in Free Space



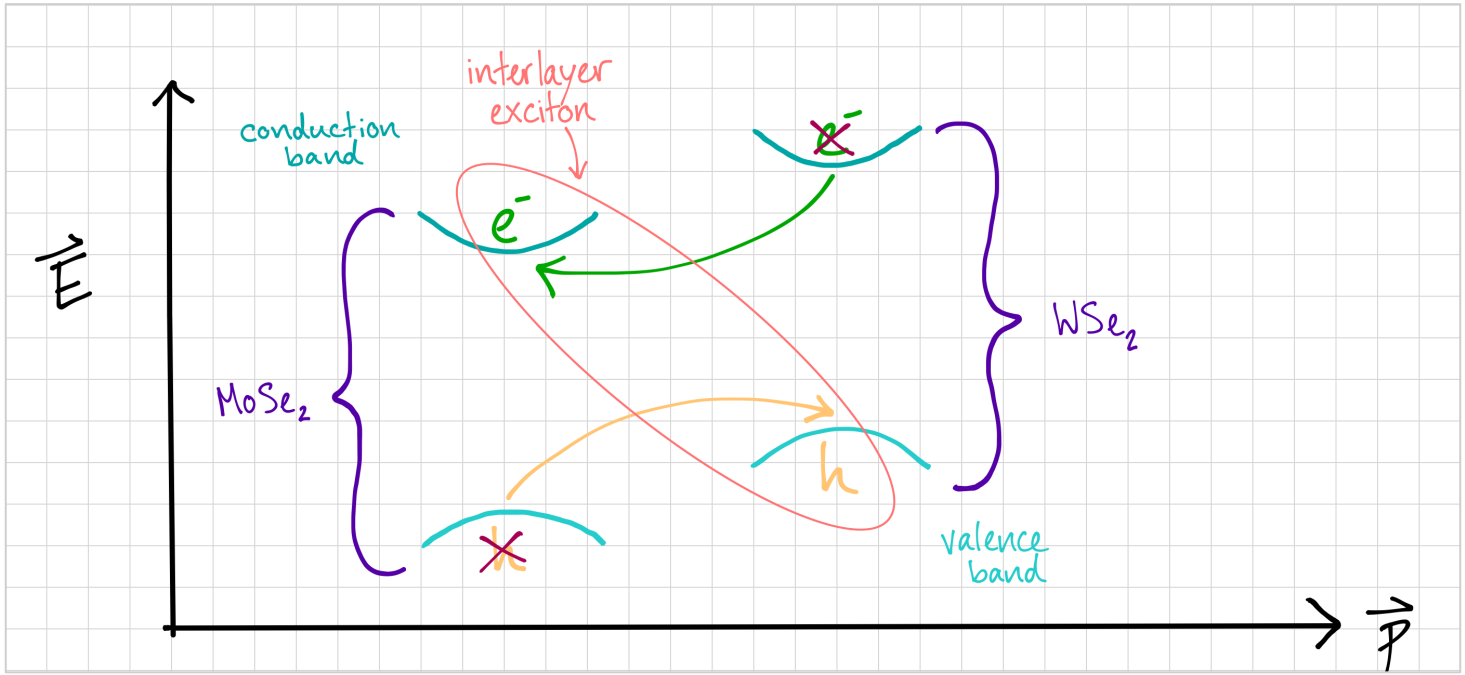

Energy vs Momentum Graph:
Electron in a Crystal Lattice




*Rivera et al., Nature Nanotechnology 13 (2018)*

# TMDCs: $WSe_2$ and $MoSe_2$

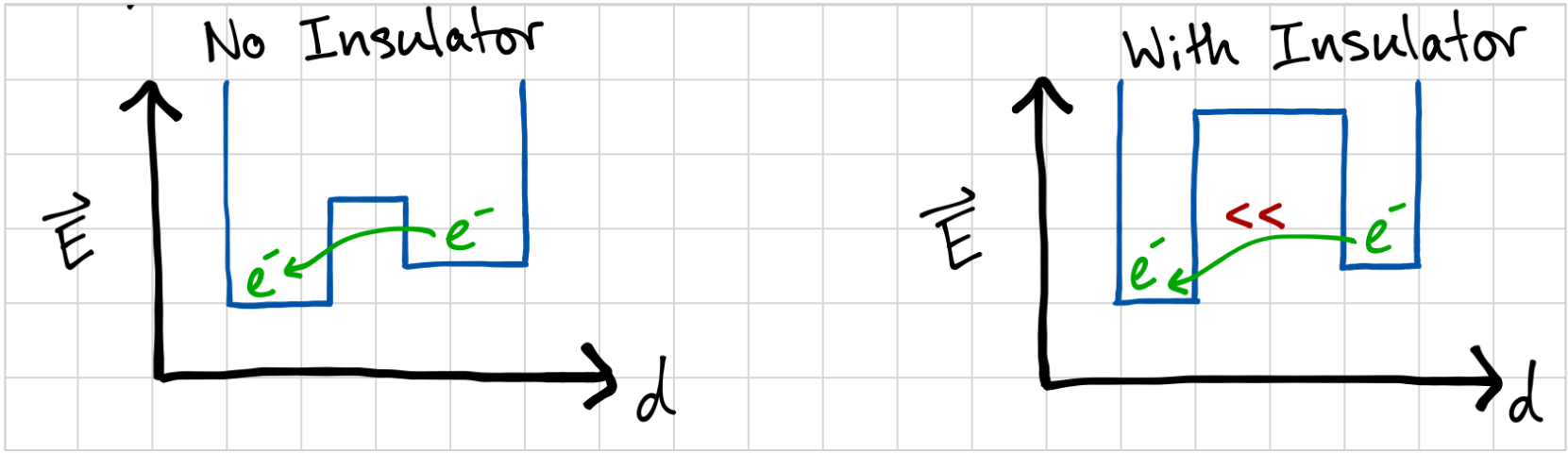
- Use class of materials called transition metal dichalcogenides (TMDCs)
- Type II (staggered) heterojunction between $WSe_2$ and $MoSe_2$




*Rivera et al., Nature Nanotechnology 13 (2018)*

# Long Live the Interlayer Exciton!

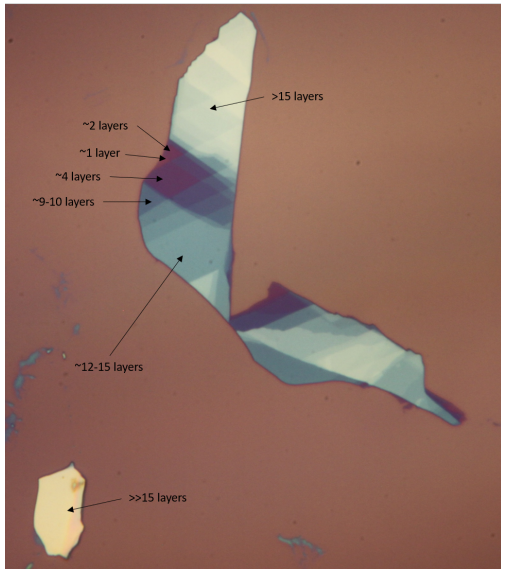
- Further extend lifetimes of interlayer excitons by adding dielectric insulator (hBN) between the TMDC layers.
- Acts as a potential barrier, making it harder for the electron and hole to recombine.

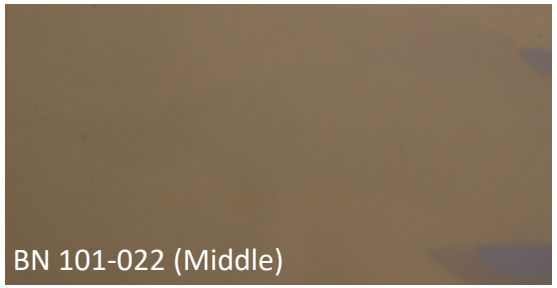



*Rivera et al., Nature Communications 6 (2015)*

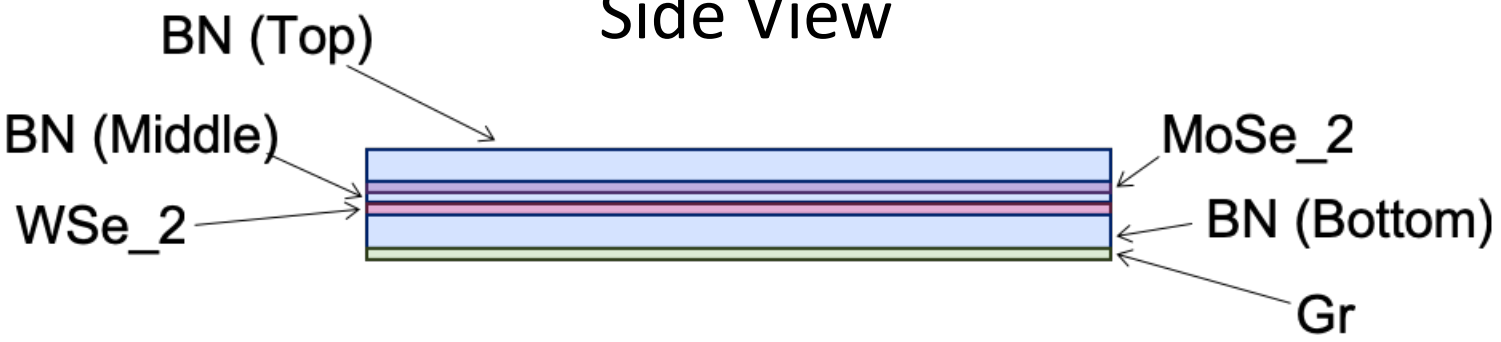
# The Device

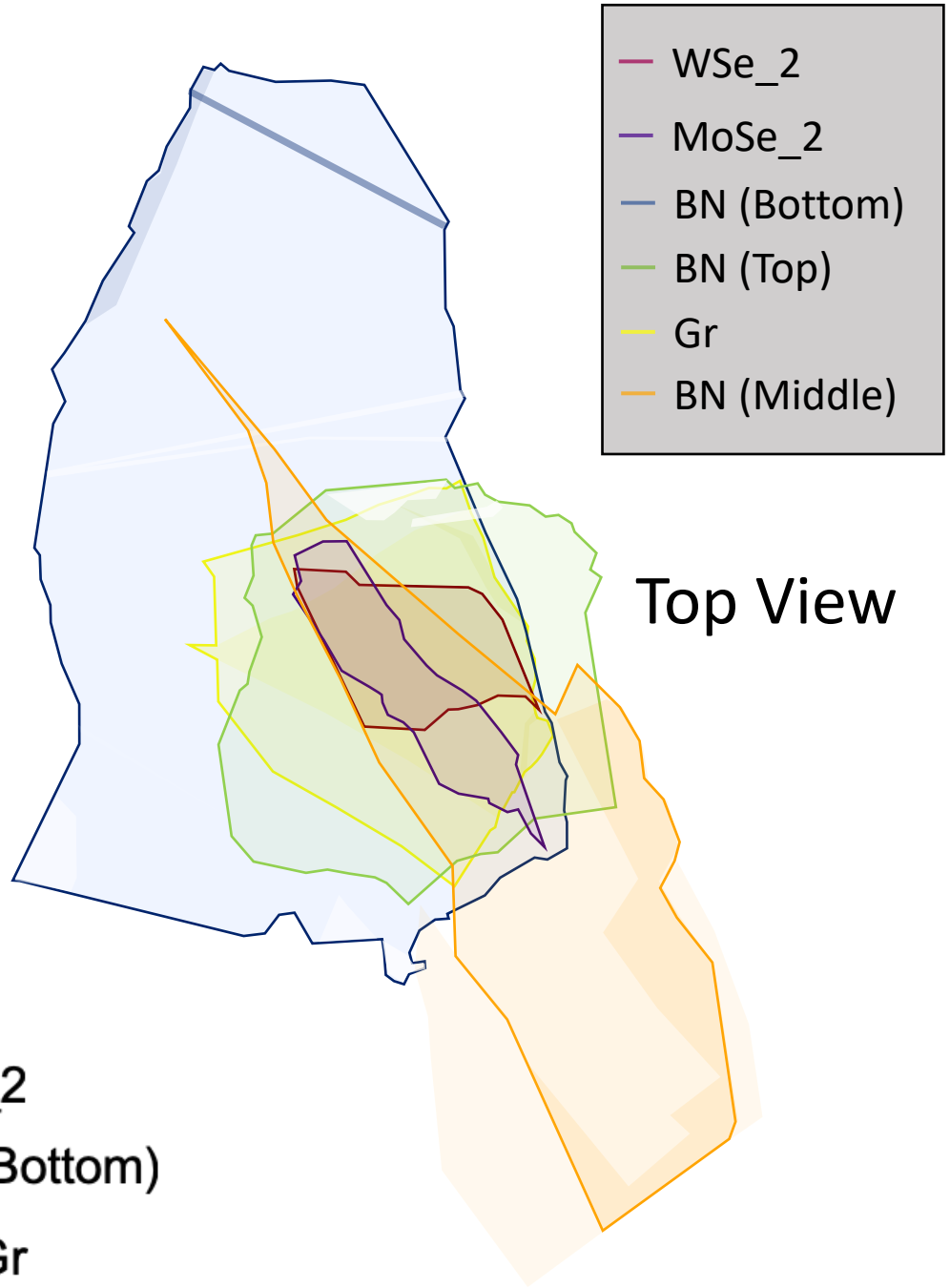
- $WSe_2/MoSe_2$ heterostructure with monolayer BN insulator
- 0° or 60° twist angle (maximize PL)



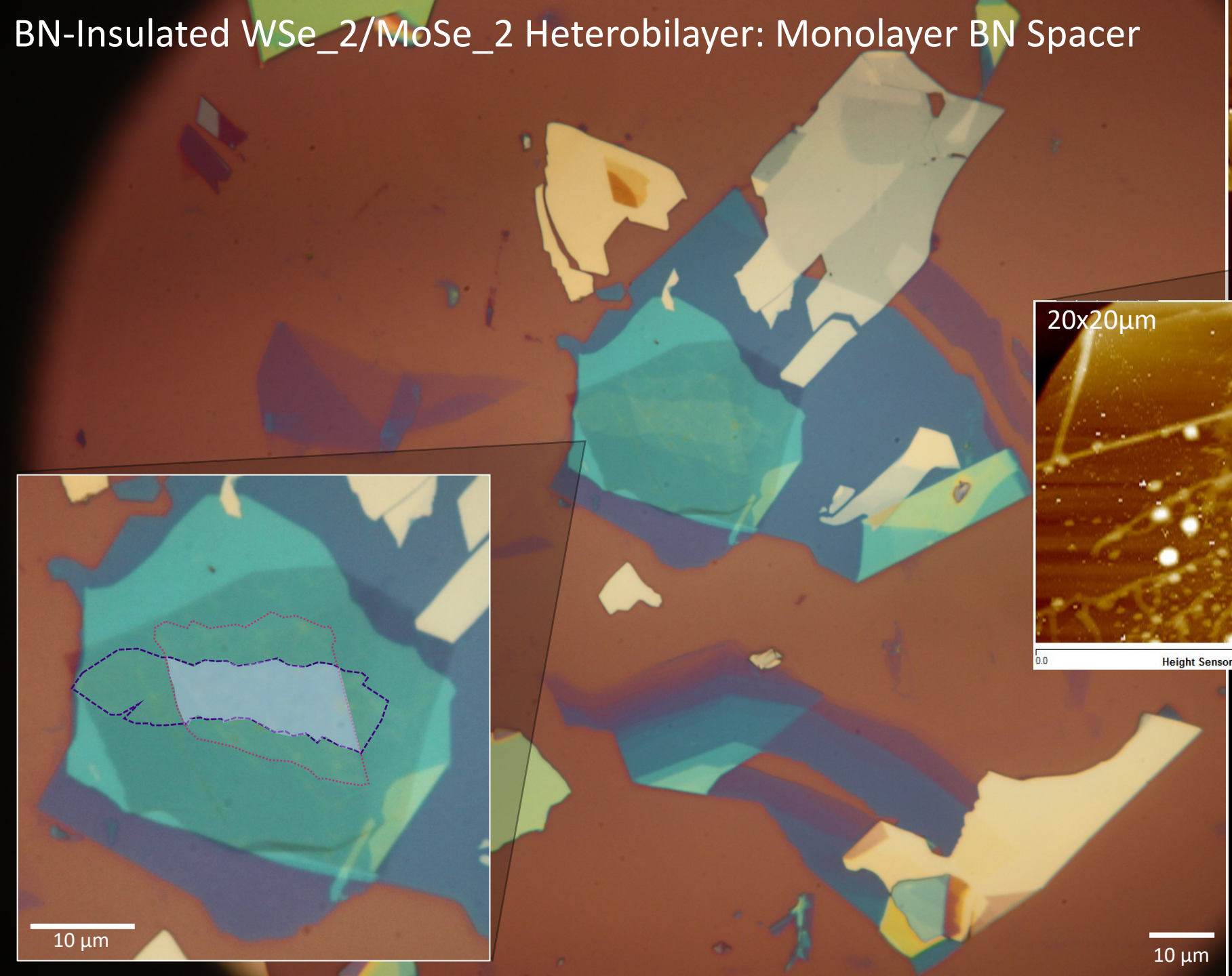

Side View

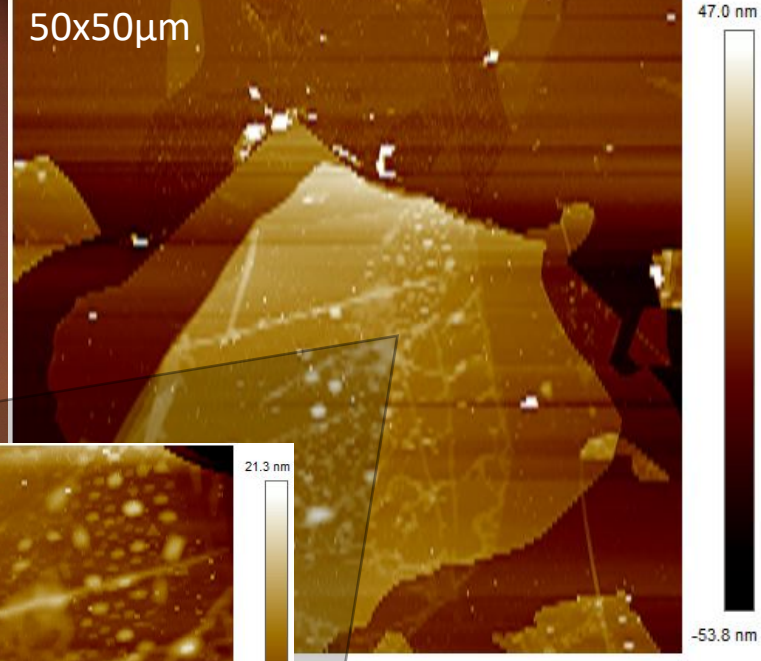



Top View

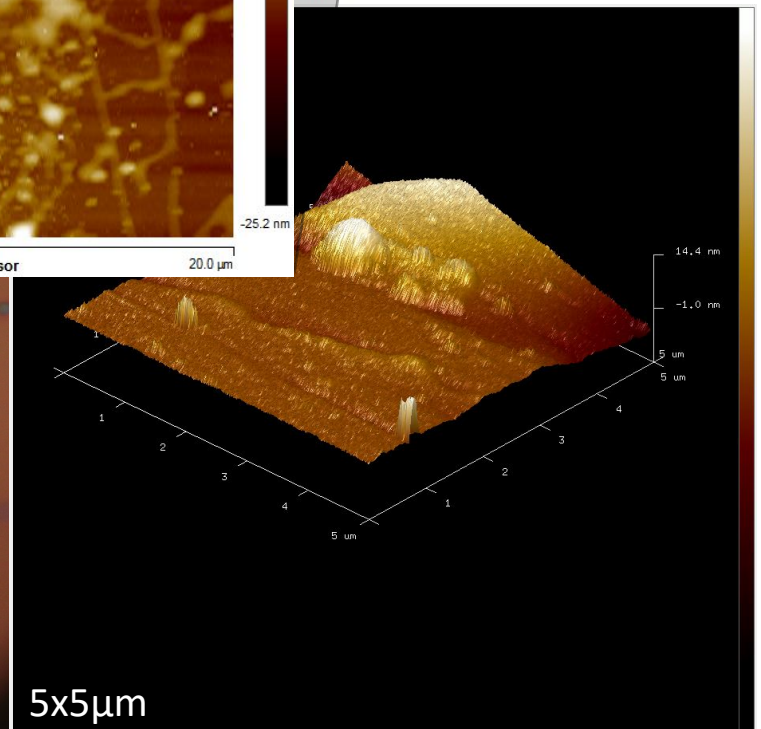
# BN-Insulated WSe_2/MoSe_2 Heterobilayer: Monolayer BN Spacer



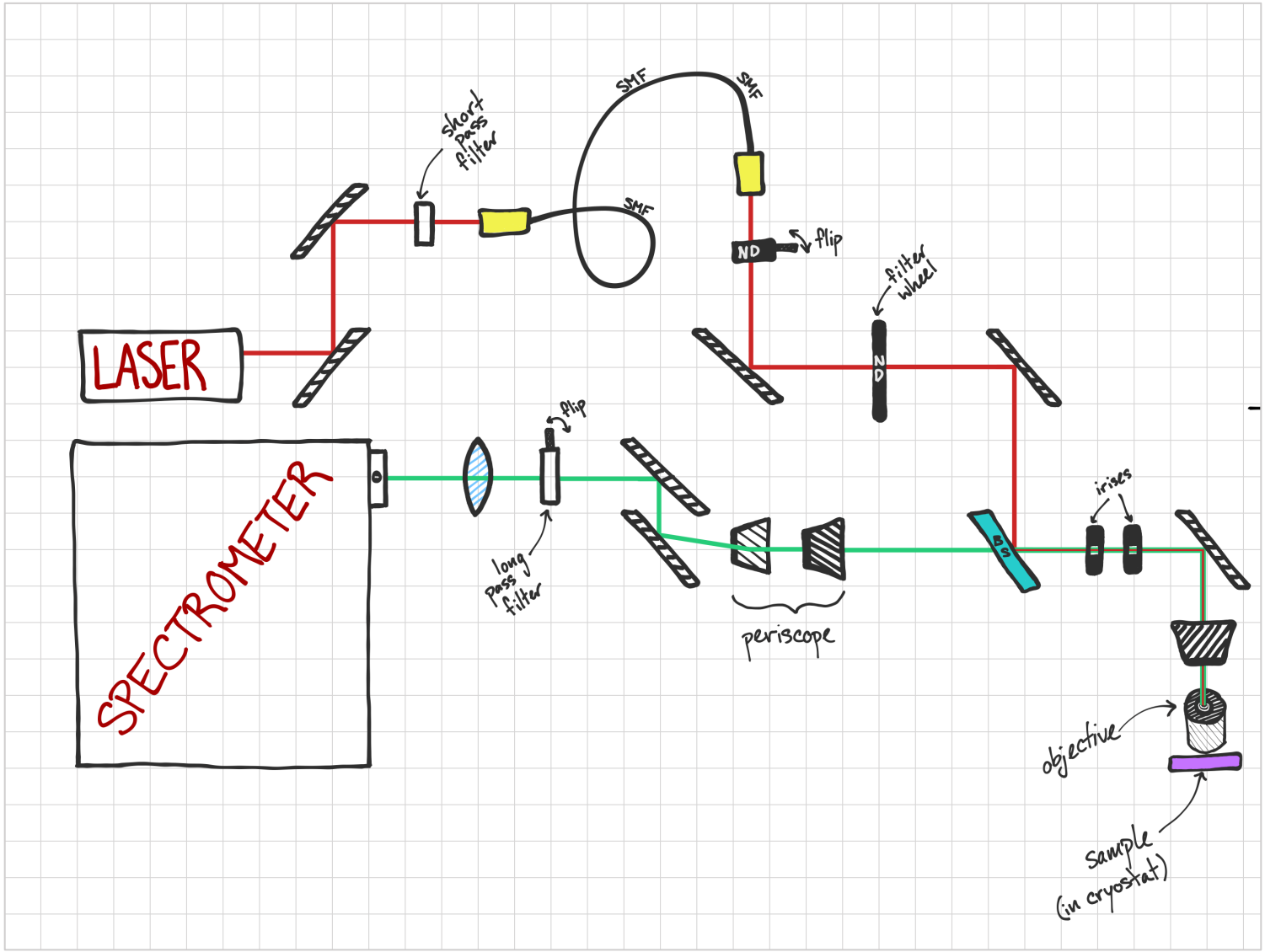






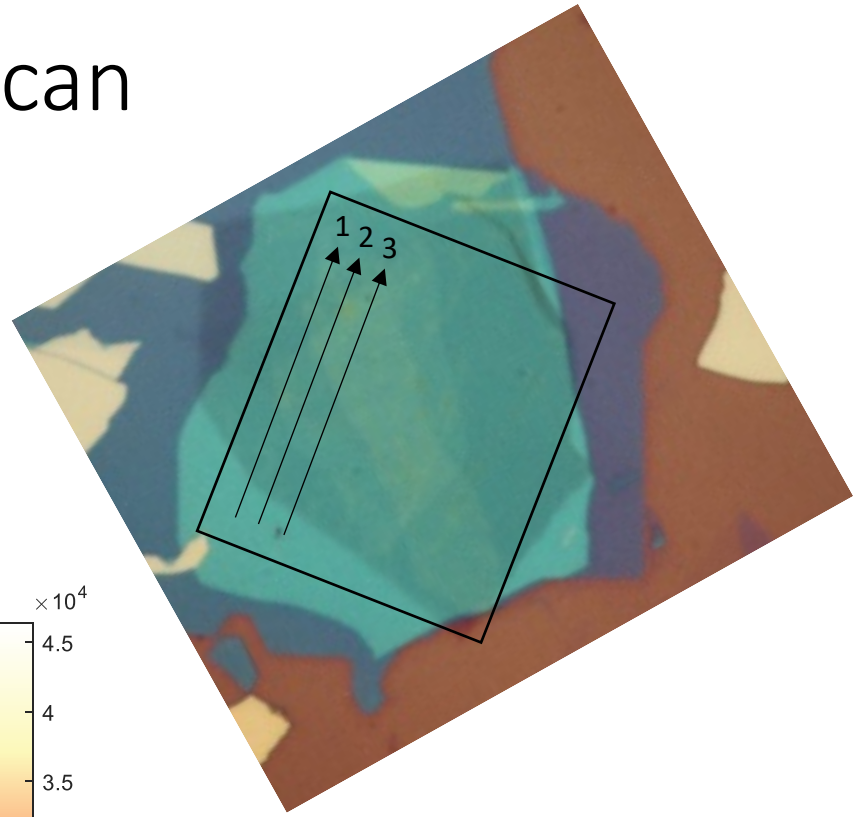

10 µm

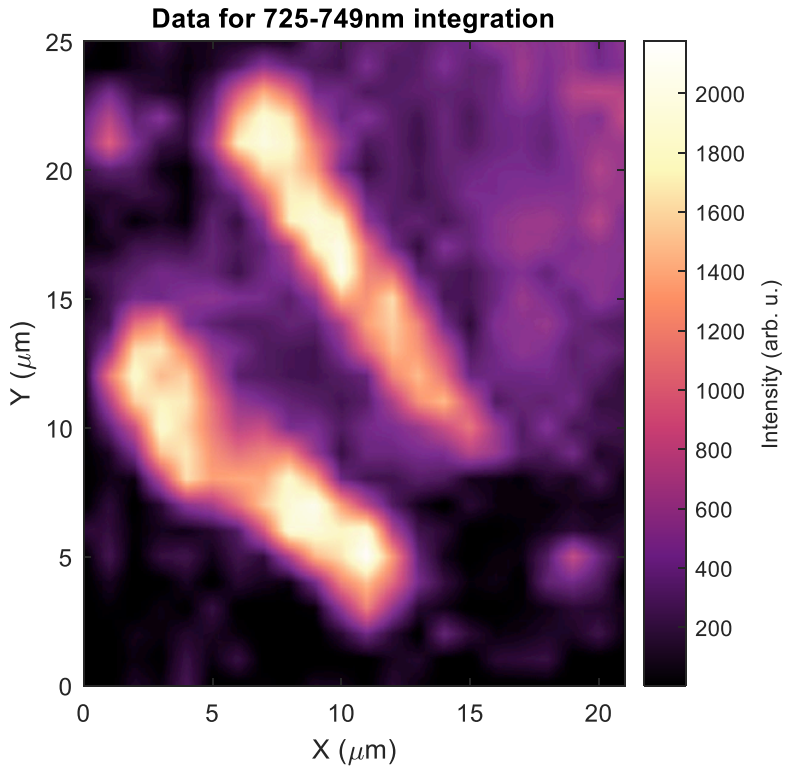
# PL Measurements: Schematics

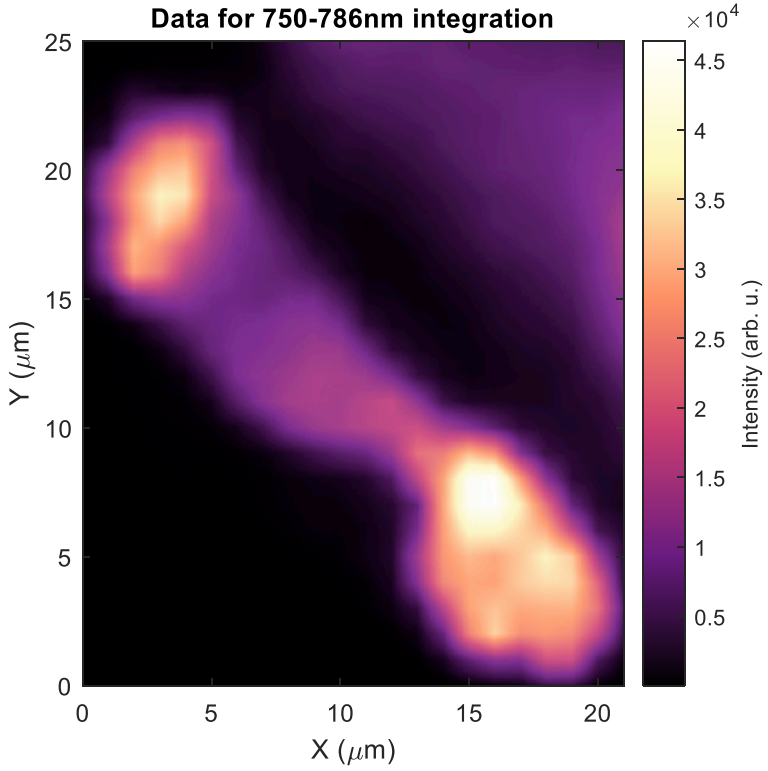


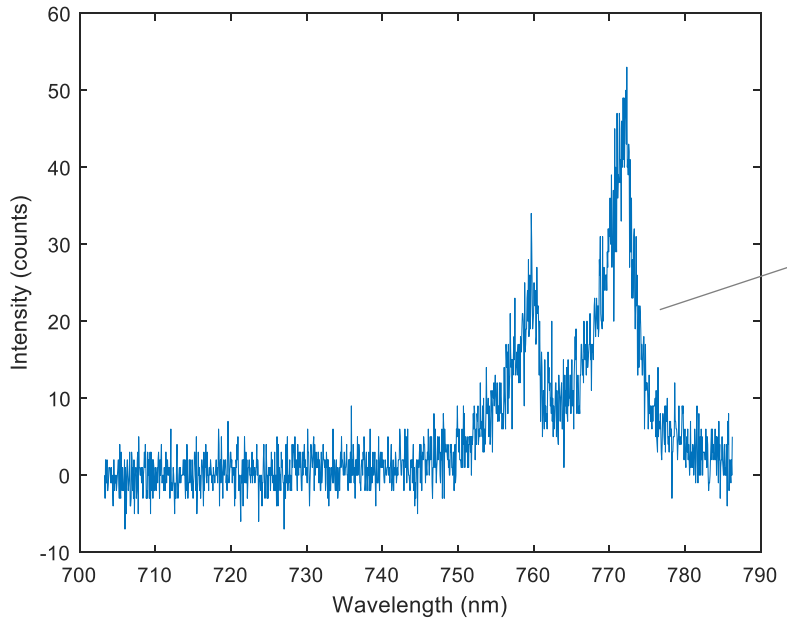
# PL Measurements: Intralayer PL Area Scan

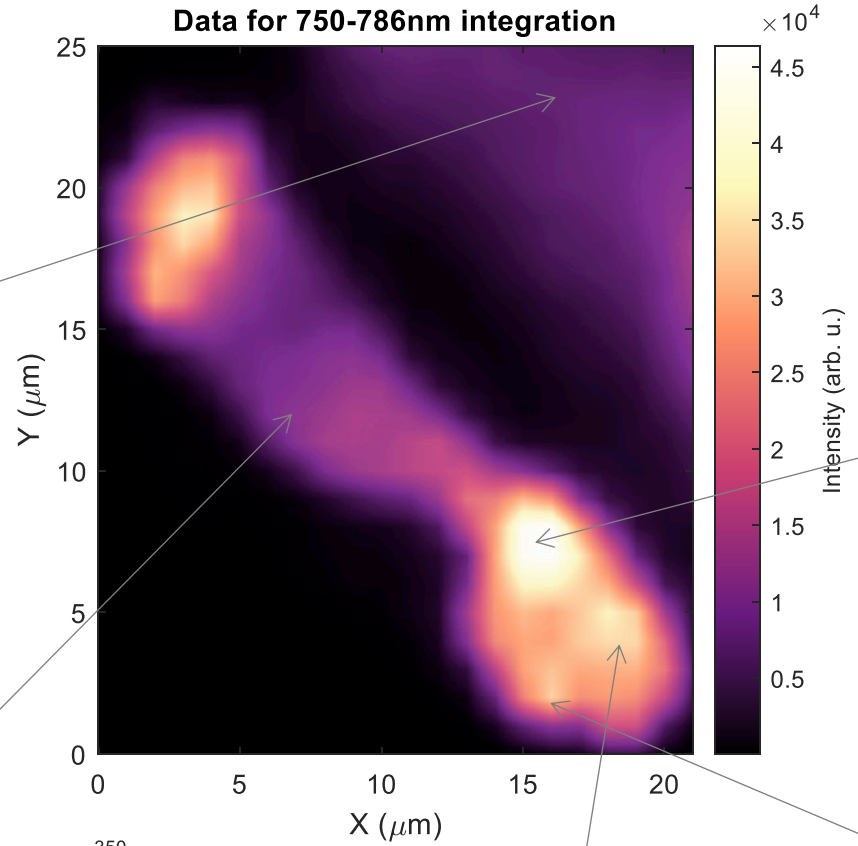
- Laser: 633nm (Supercontinuum: 80MHz, 10μW)
- Scan: (49, 44)-(23,22)
- Int. Time: 5s
- 2 spectra per location (for cosmic ray subtraction later)

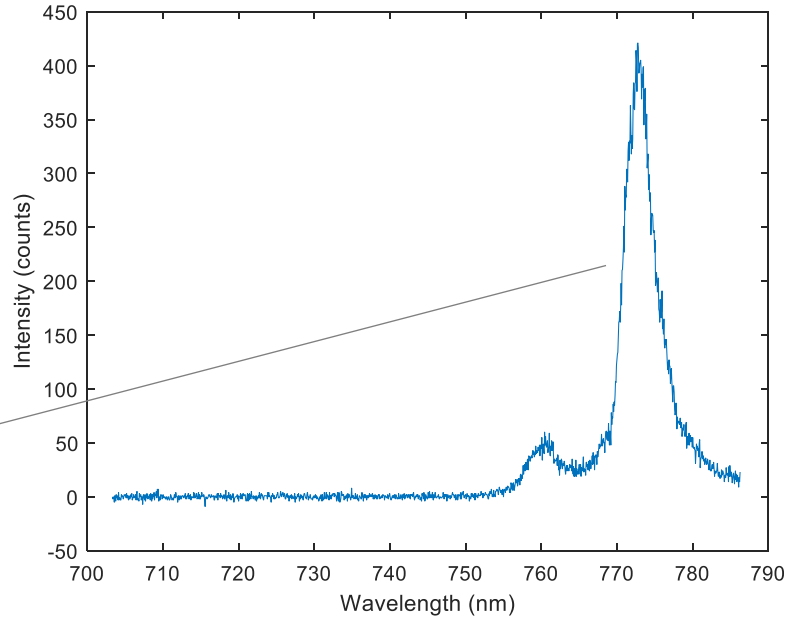


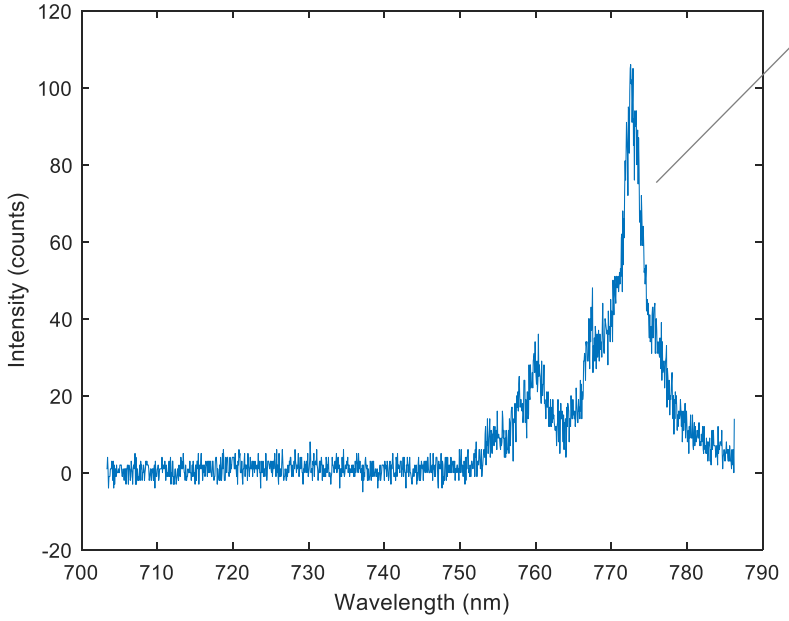



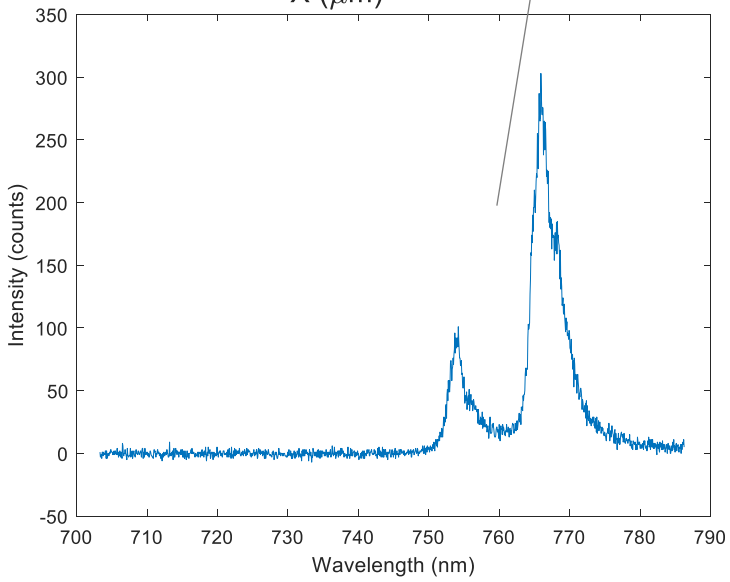



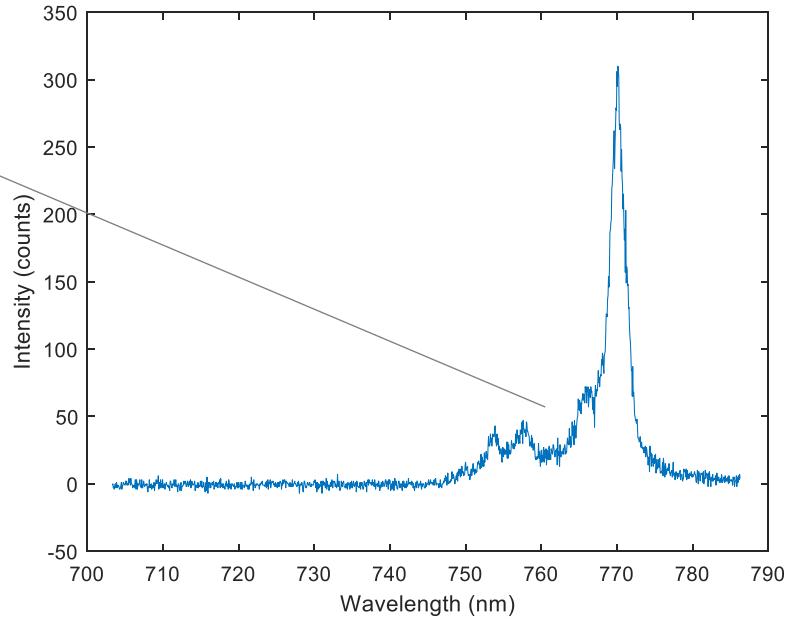

Intensity (counts)
Wavelength (nm)

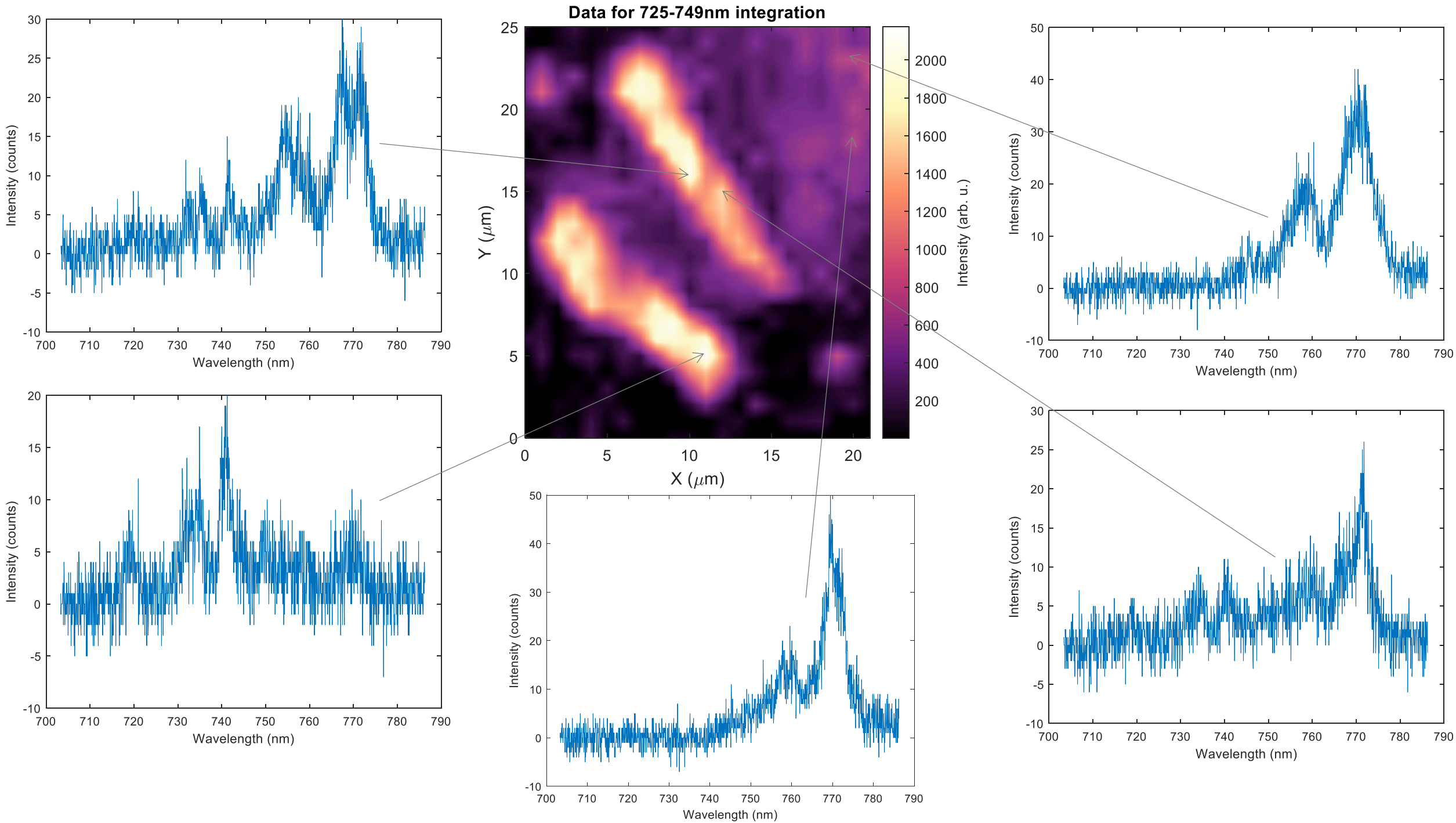

Data for 750-786nm integration
Y (μm)
X (μm)
Intensity (arb. u.)
×10^4


Intensity (counts)
Wavelength (nm)


Intensity (counts)
Wavelength (nm)

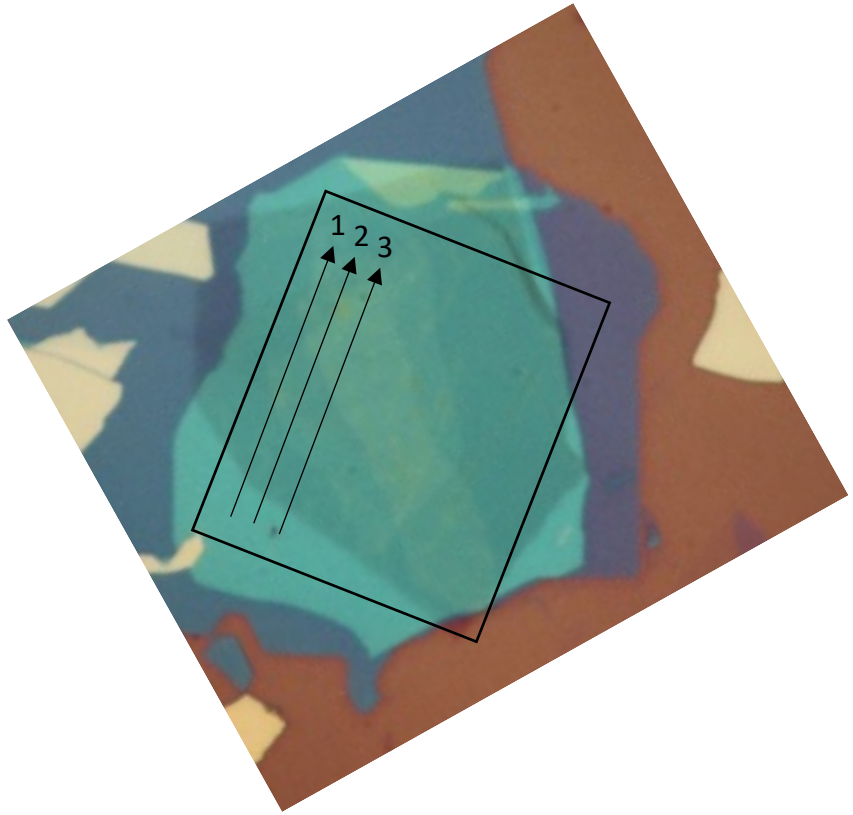

Intensity (counts)
Wavelength (nm)

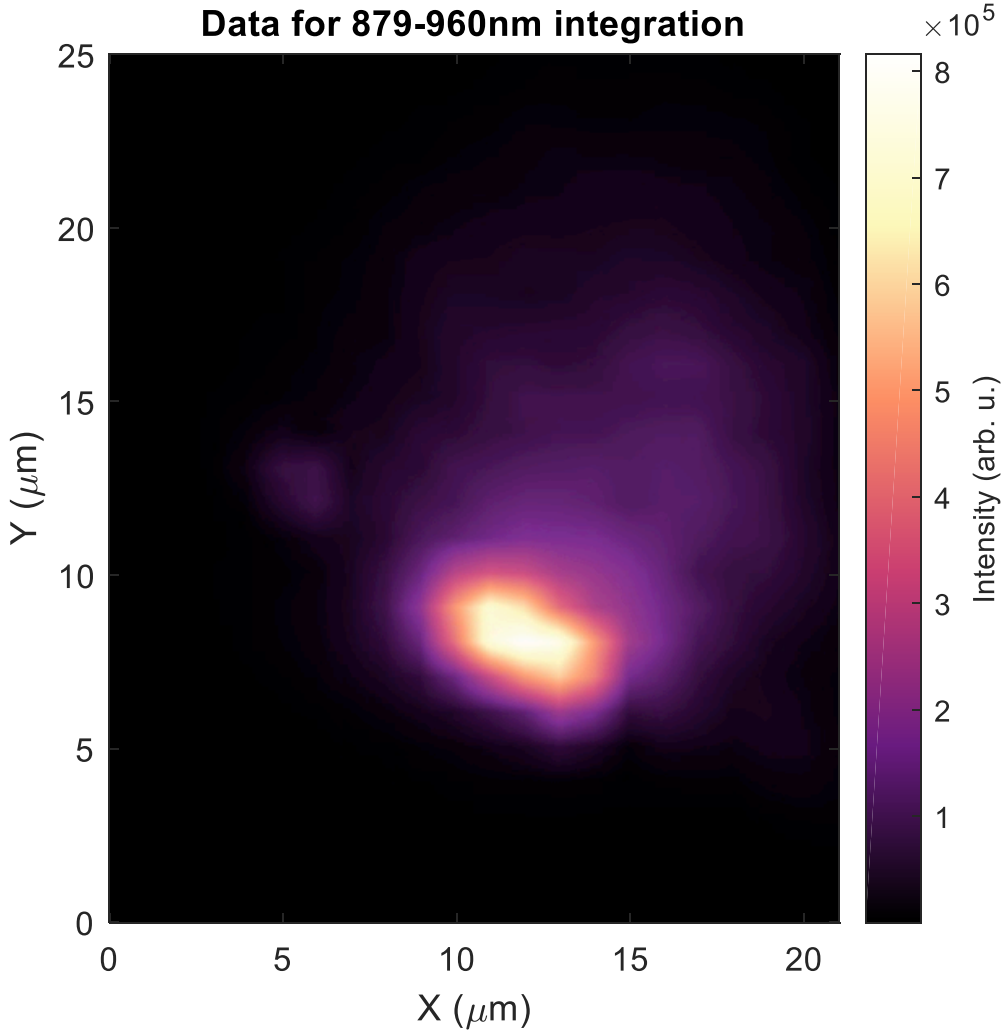

Intensity (counts)
Wavelength (nm)

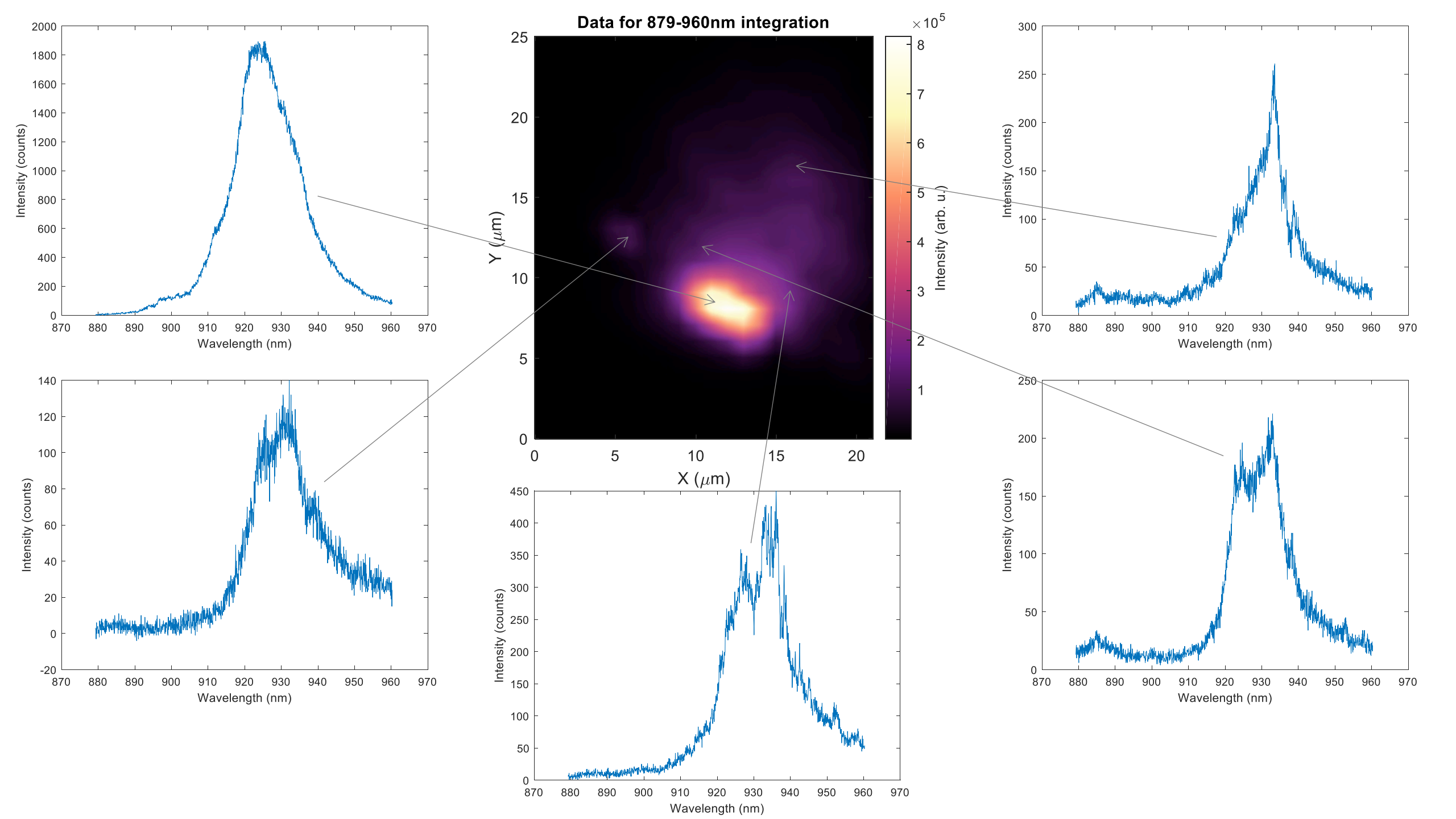

Data for 725-749nm integration
Y (μm)
X (μm)
Intensity (arb. u.)
Intensity (counts)
Wavelength (nm)

# PL Measurements: Interlayer PL Area Scan

- Laser: 725nm (Supercontinuum: 80MHz, 10μW)
- Scan: (49, 44)-(23,22)
- Int. Time: 5s
- 2 spectra per location



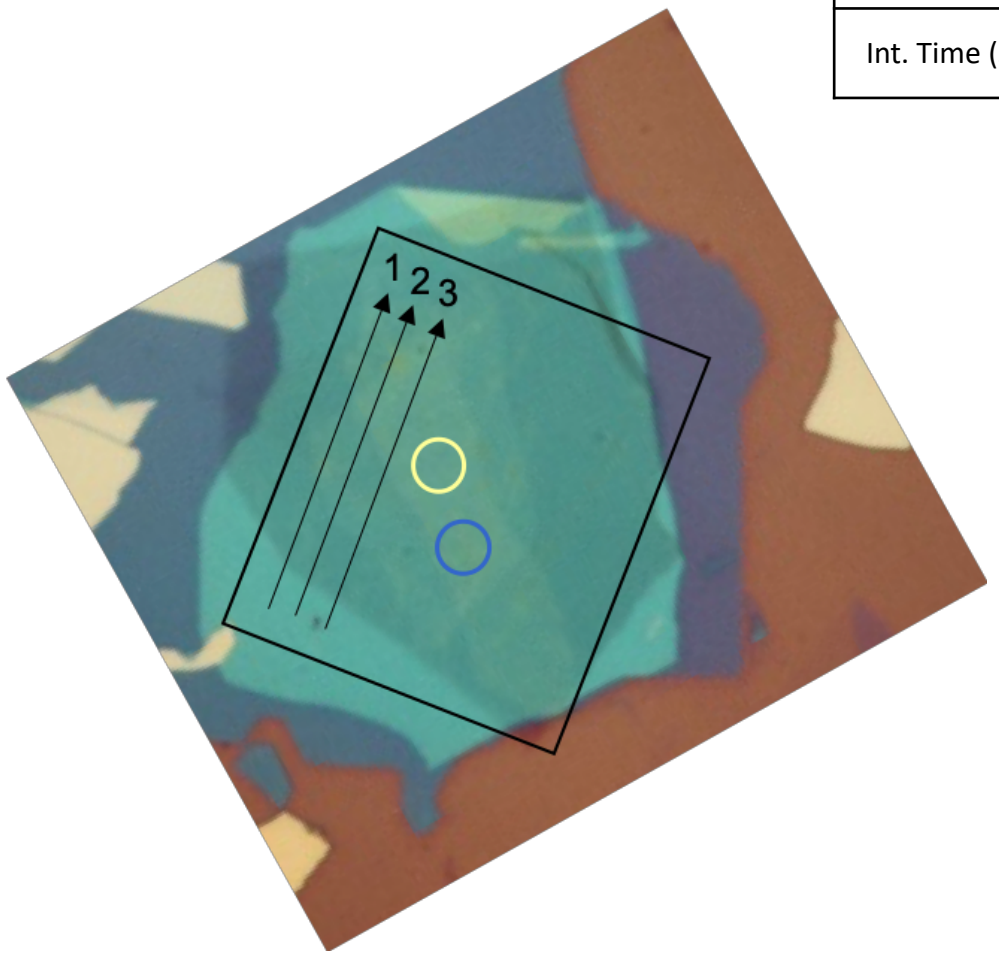



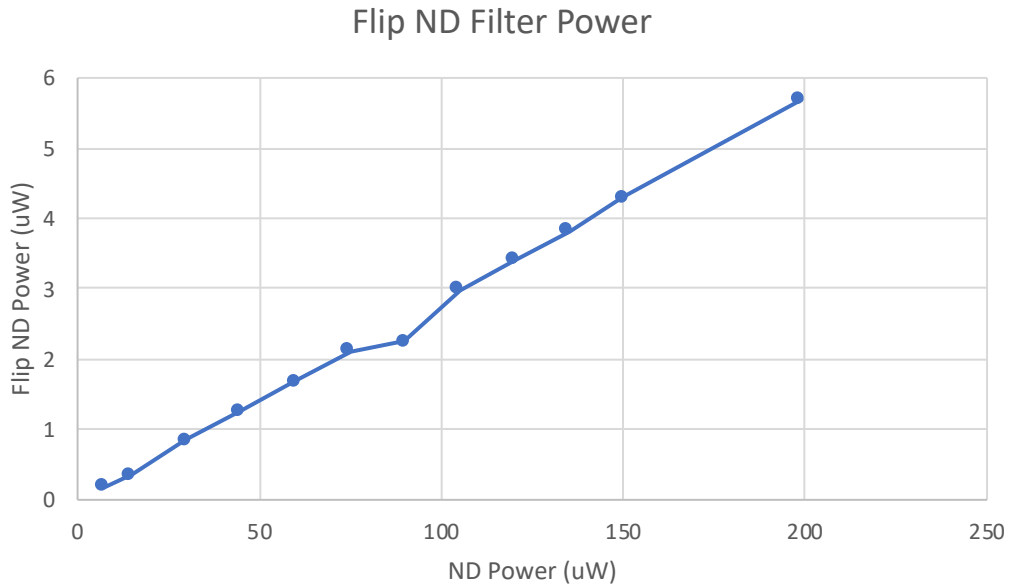

Data for 879-960nm integration
Y (μm)
X (μm)
Intensity (arb. u.)
×10^5
Intensity (counts)
Wavelength (nm)

# PL Measurements: IX PL Spots

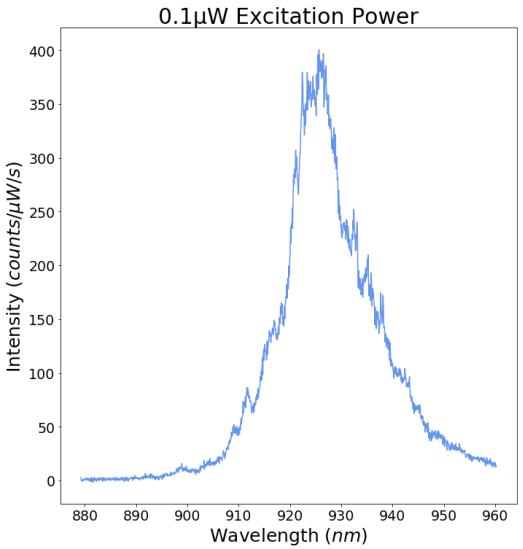
- Laser: 725nm (Solstis)
- Point 1 IX PL: (40.446, 31.673)
- Point 2 IX PL: (36.4, 32.4)

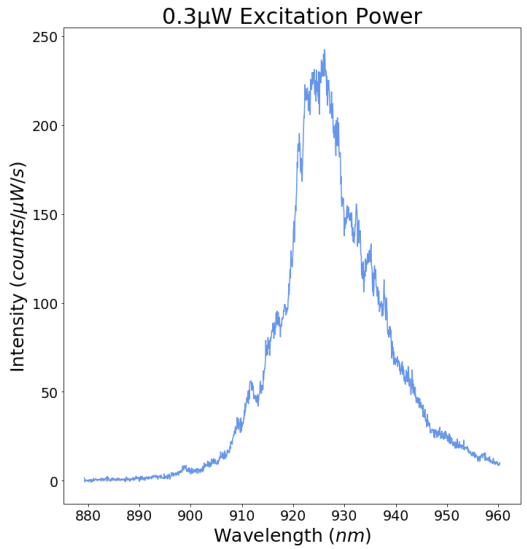
| Power | 30uW | 10uW | 3uW | 1uW | 0.3uW | 0.1uW | 30nW | 10nW | 3nW |
|---|---|---|---|---|---|---|---|---|---|
| Int. Time (s) | 1 | 1.5 | 3.5 | 9 | 19 | 35 | 350 | 390 | 500 |

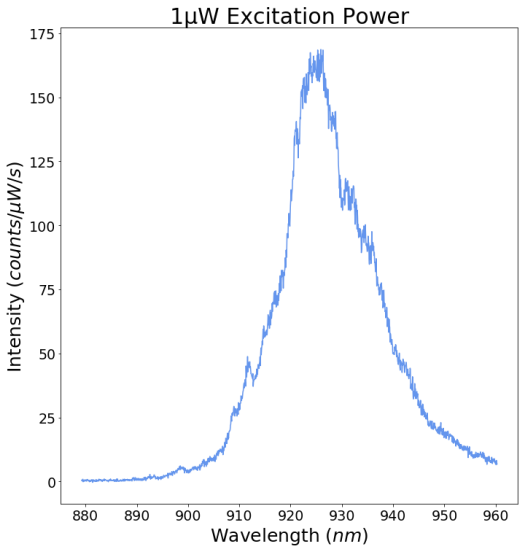


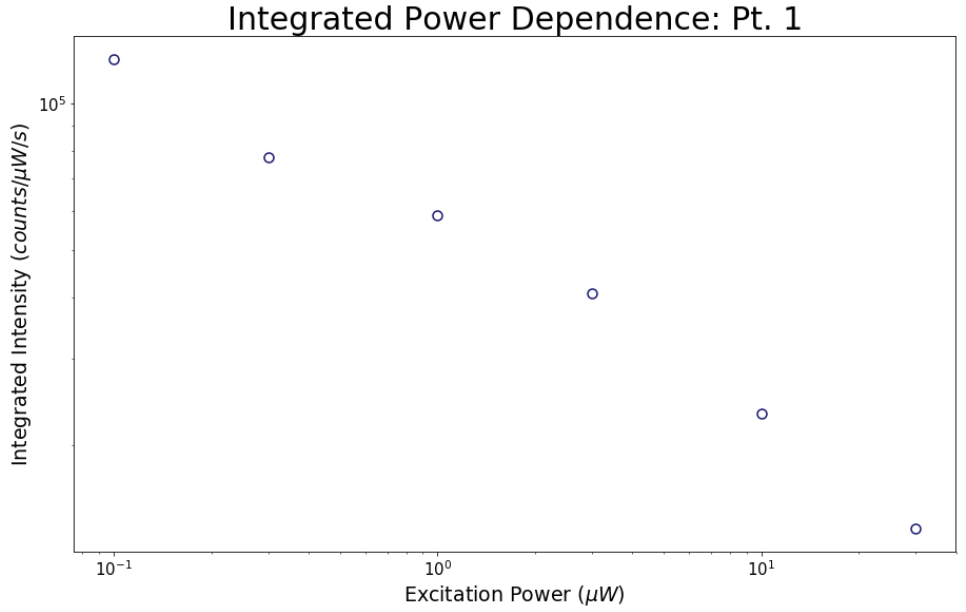



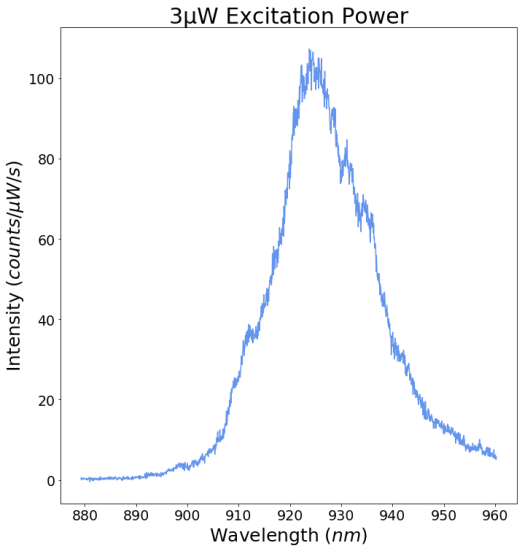
# Point 1 Power Dependence

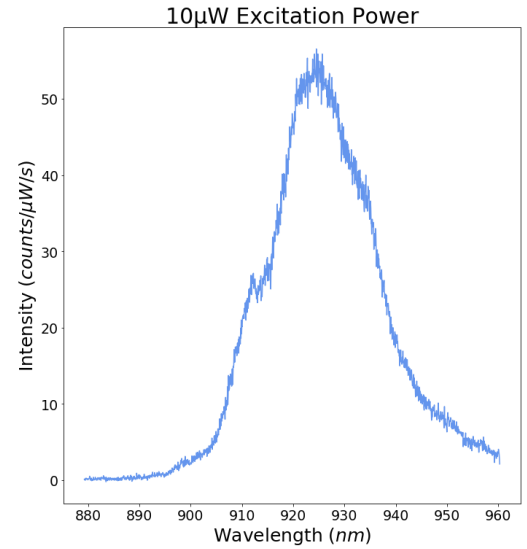


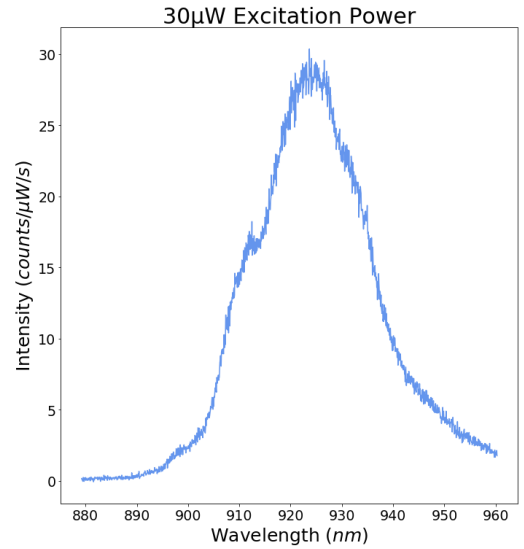



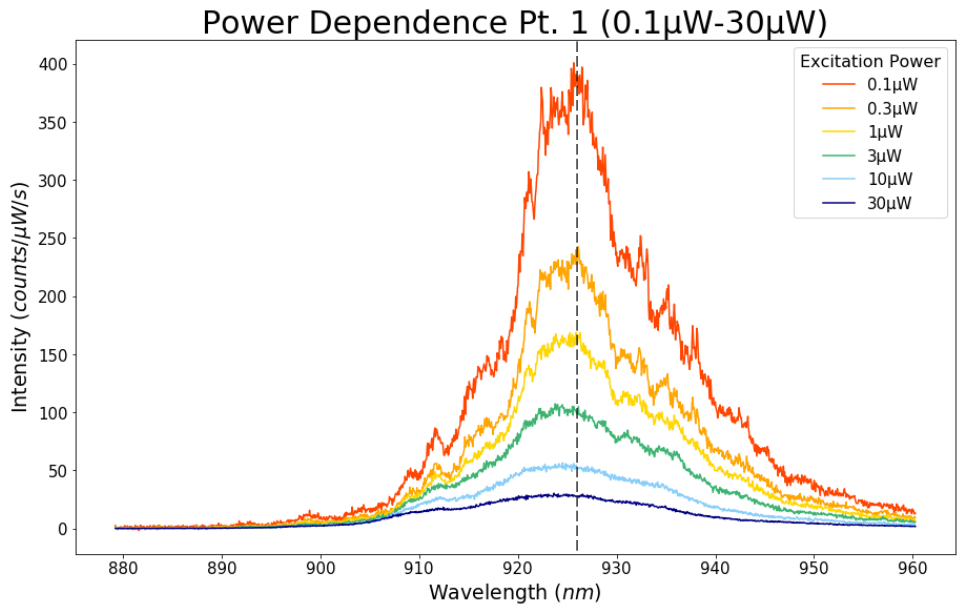



# Next Steps

- Photon counting
  - Time-dependent measurement to study IX dynamics
- Layer dependence
  - Fabricate samples with 2- and 3-layer BN spacers
- Traps
  - Heterobilayer devices w/ small overlap region
  - Boring and filling BN
  - Punctured BN spacers

# Thank you!!

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- Xu Lab @ University of Washington
  - Nathan Wilson
- NSF UW Physics REU

# References

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