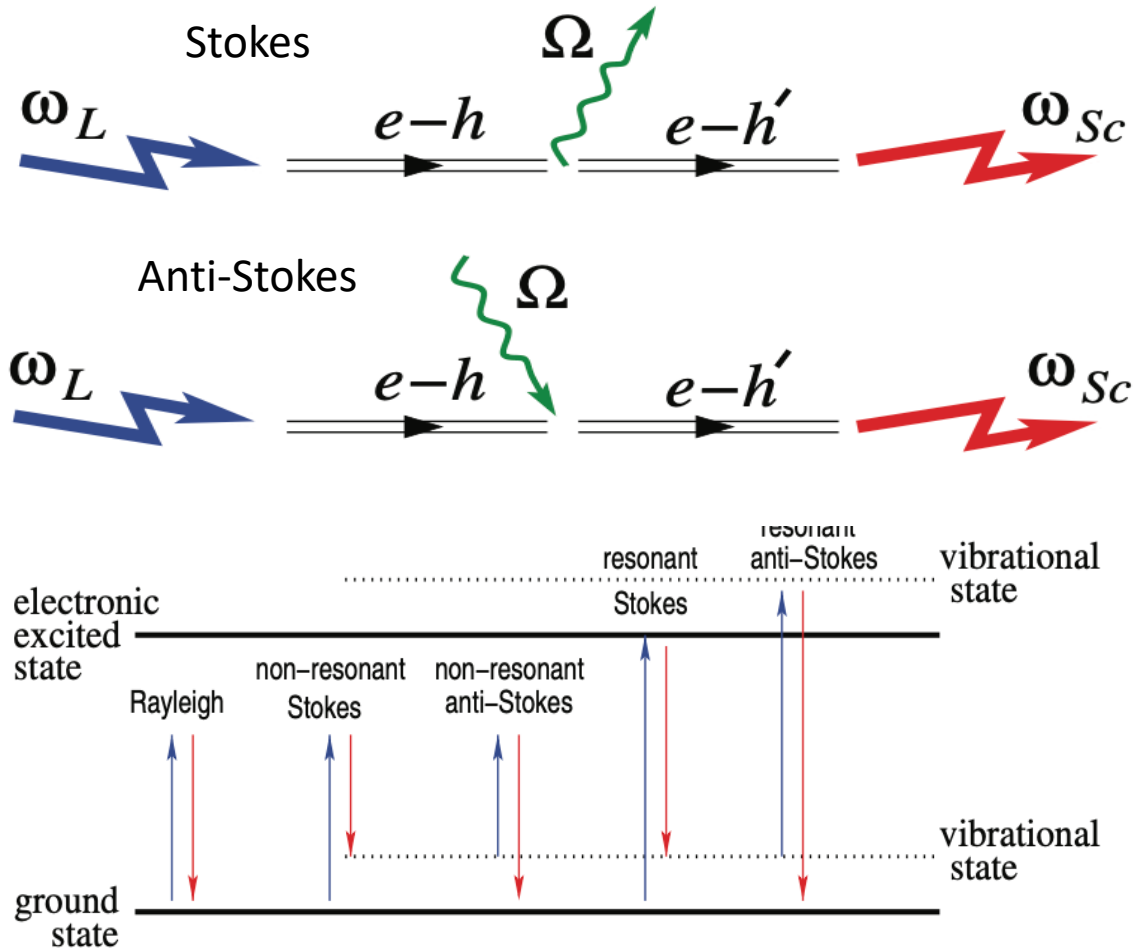# Spectroscopic Techniques and 2D Materials
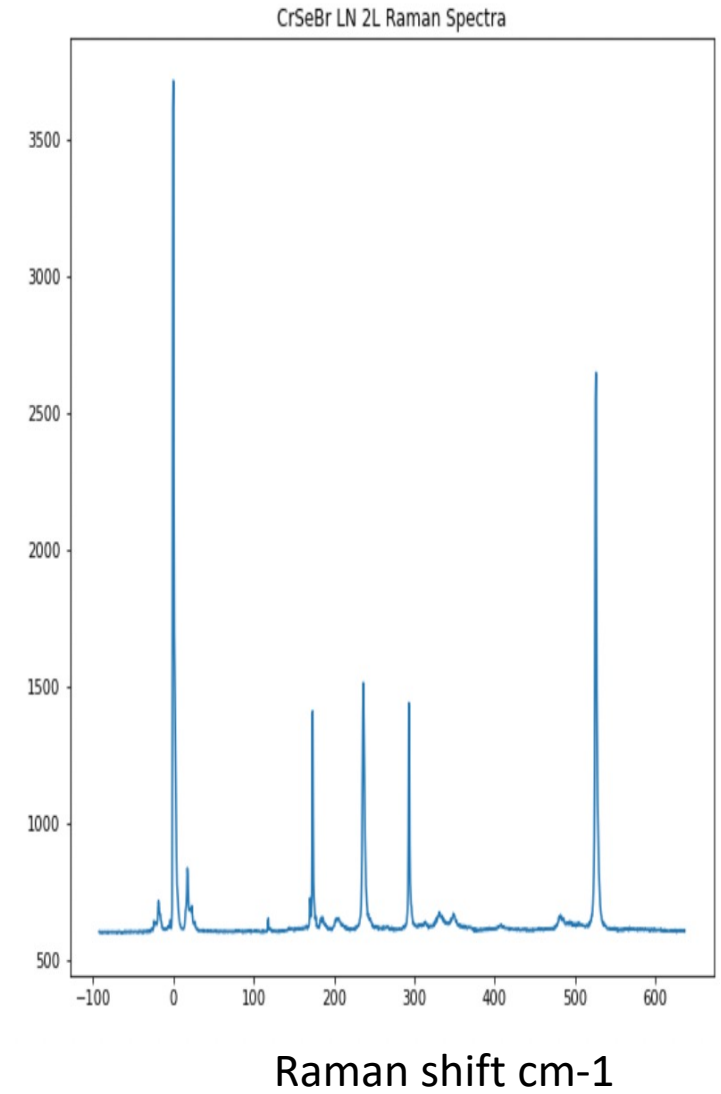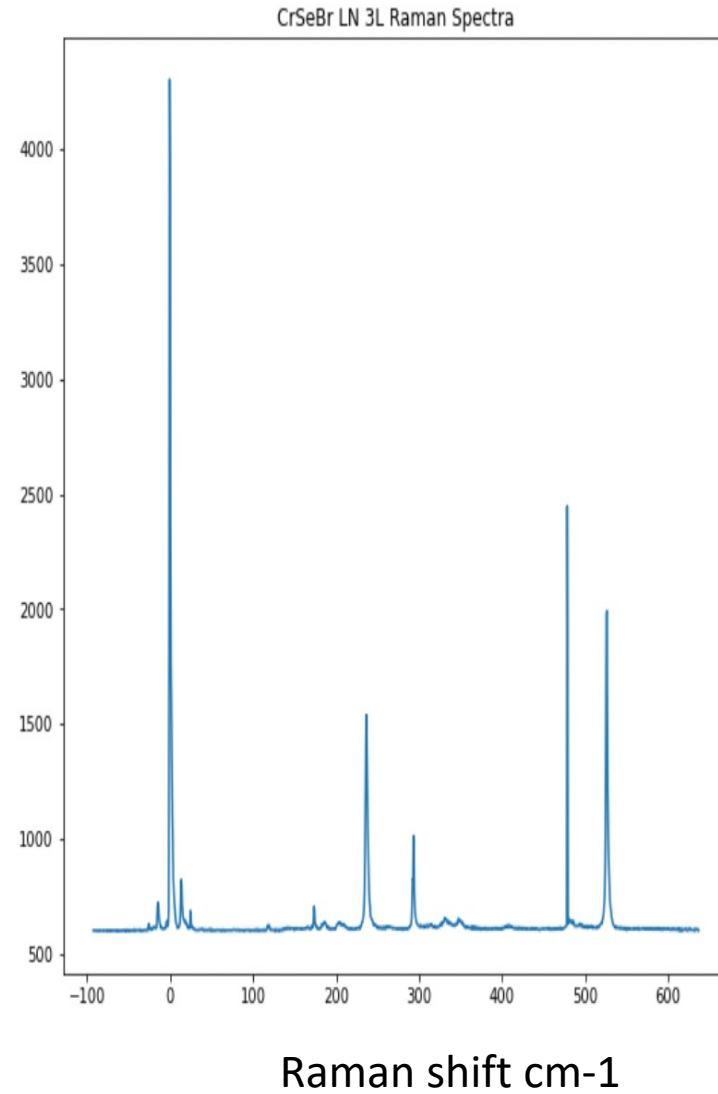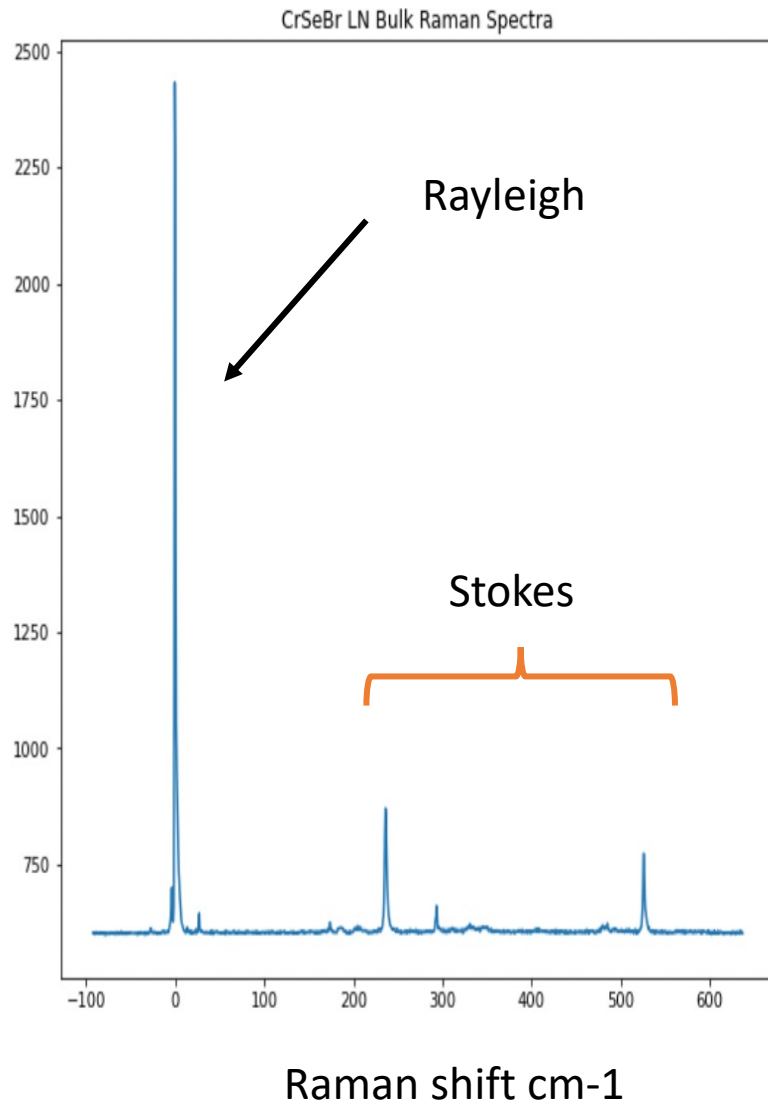
Miles Mackenzie

Raman Spectroscopy

Stokes

ω_L Ω $e-h$ $e-h'$ ω_{Sc}

Anti-Stokes

ω_L Ω $e-h$ $e-h'$ ω_{Sc}

resonant anti–Stokes

resonant Stokes

vibrational state

electronic excited state

non-resonant Stokes

non-resonant anti–Stokes
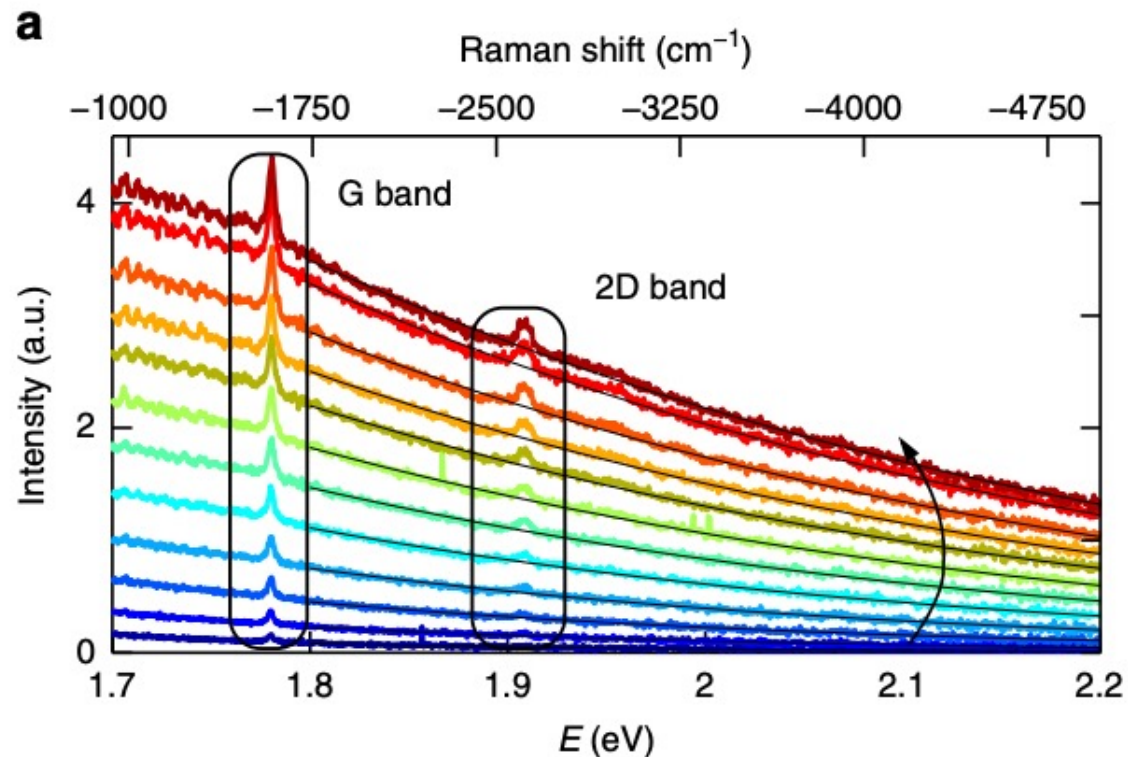
Rayleigh

ground state

vibrational state

- Rayleigh scattering
  - No frequency shift

- Stokes process
  - Scattered photon has less energy
  - Phonon produced

- Anti-Stokes process
  - Scattered photon has more energy
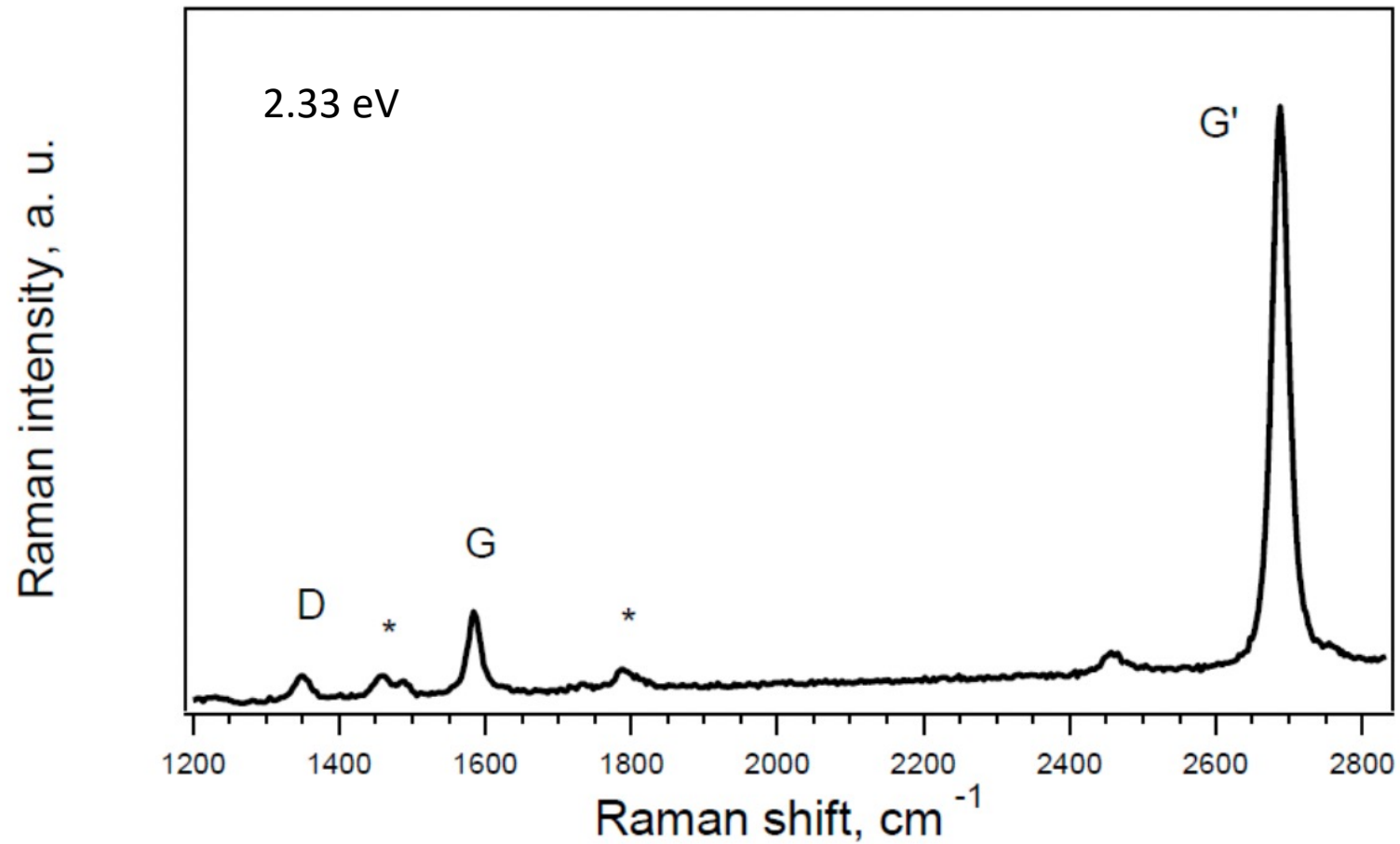 - Phonon absorbed

CrSeBr Summer Data

CrSeBr LN Bulk Raman Spectra

Rayleigh

Stokes

Raman shift cm-1

CrSeBr LN 3L Raman Spectra

Raman shift cm-1

CrSeBr LN 2L Raman Spectra

Raman shift cm-1

Resonance Raman Scattering

Ferrante, C., Virga, A., Benfatto, L. *et al.* Raman spectroscopy of graphene under ultrafast laser excitation. *Nat Commun* **9**, 308 (2018). https://doi.org/10.1038/s41467-017-02508-x
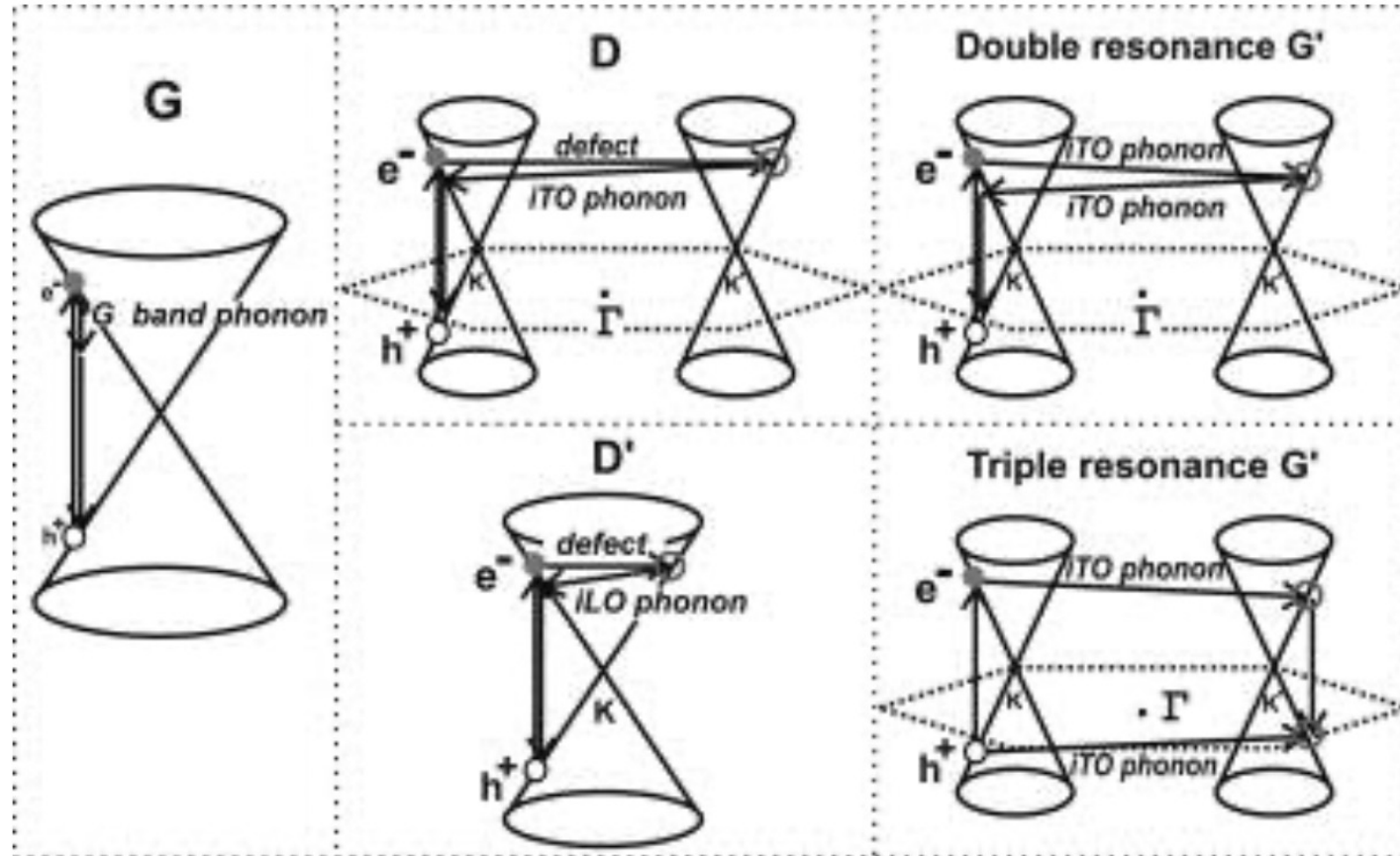
- Excitation energy of photon matches a specific energy level
- Probe sample with different laser energies to create Raman excitation profile
- Intensity increases at van Hove singularity
- Electronic band information

Raman Scattering in Graphene

Different Scattering Processes

D Band in Graphene

(b)

Fermi level (eV): -0.406, 0, 0.406, 0.573, 0.703

$I(D)/I(G)$ vs Charge carriers concentration (cm^{-2})

514 nm (green circles), 633 nm (red triangles)
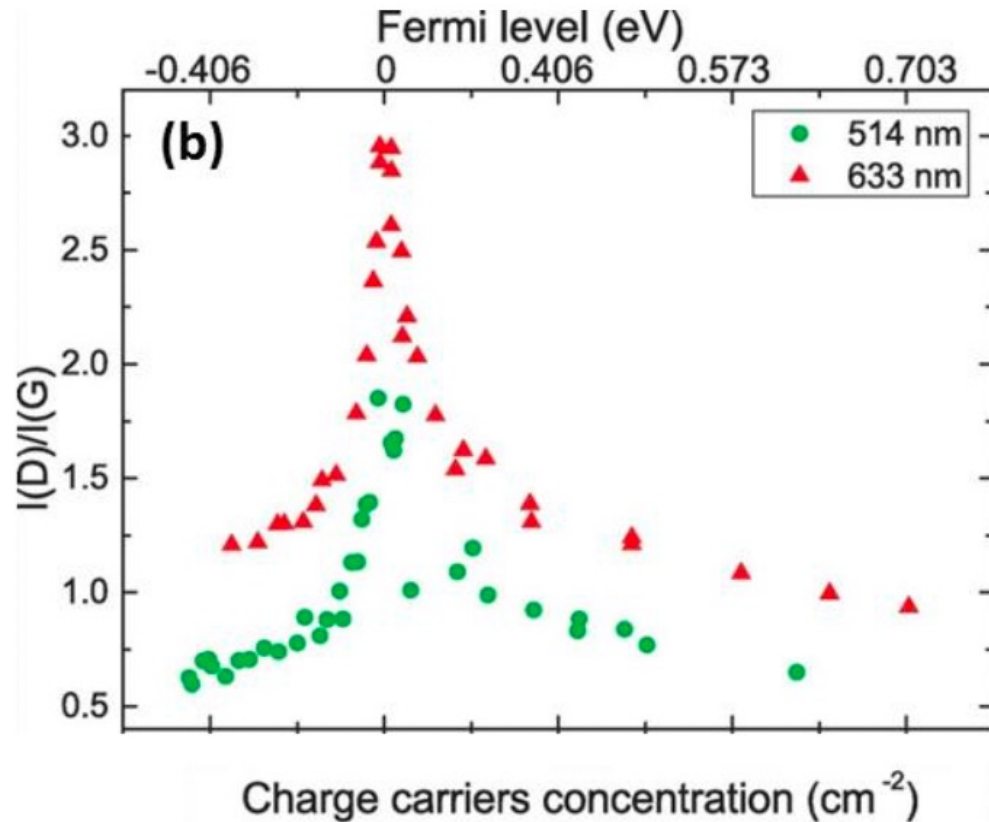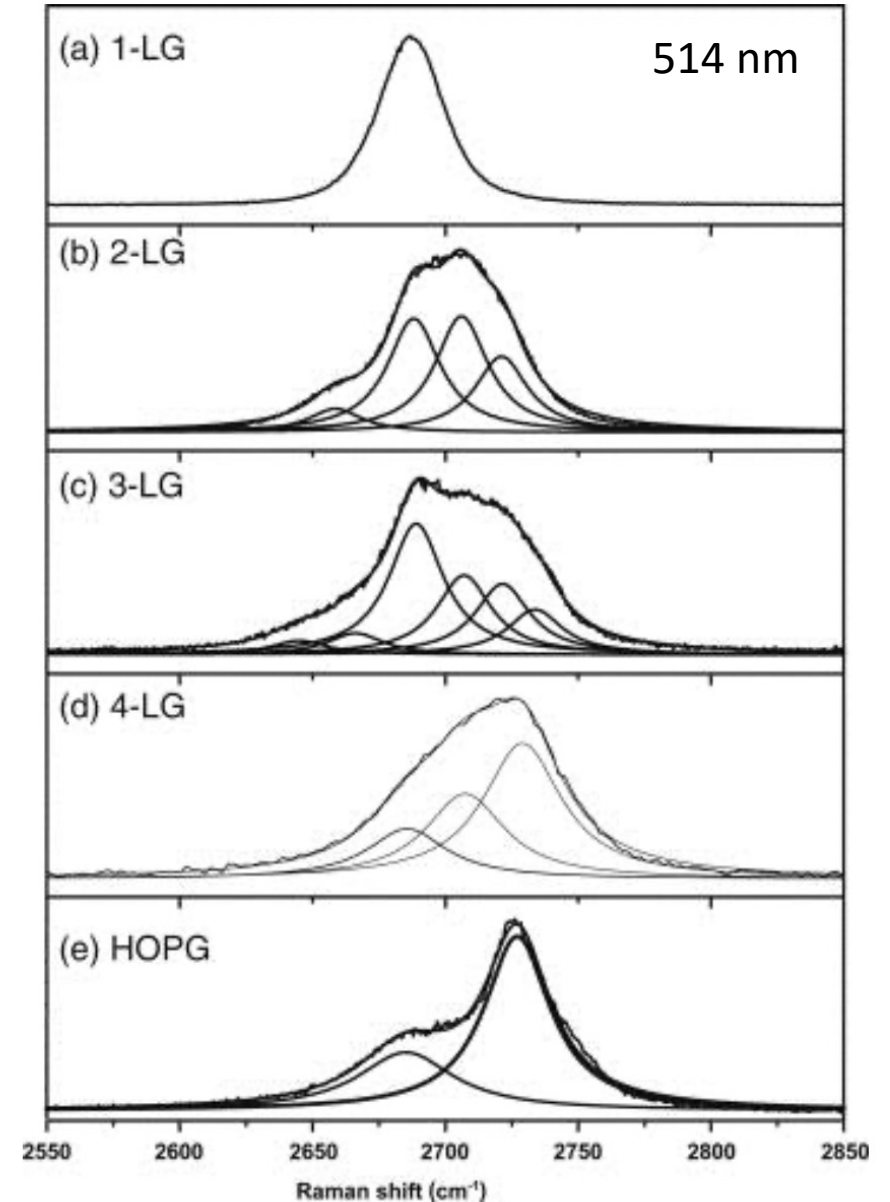
- Symmetry breaking band
- Requires defects or edges
- Used to determined purity of graphene
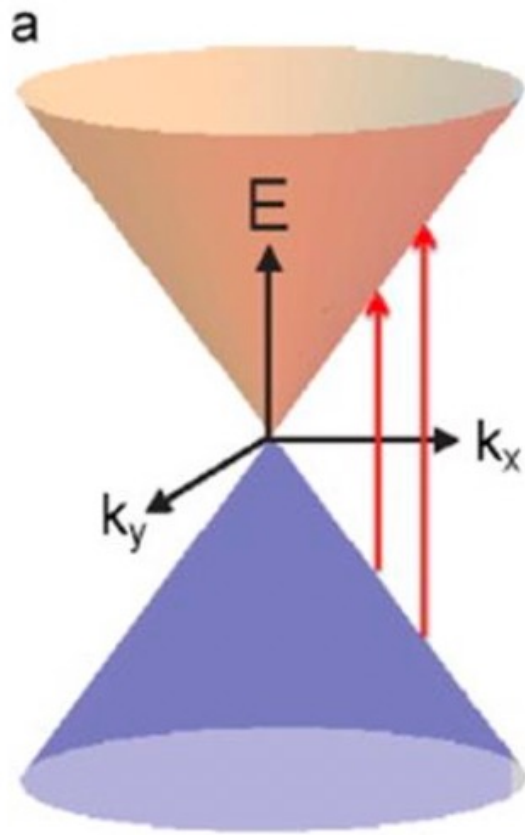- Peak decreases with increasing doping

G' Band in Graphene

- Dependent on number of layers and layer orientation
- Drastic change in shape
- Shape fitted with multiple Lorentzian functions
- Created from second-order two phonon intervalley scattering

G Band in Graphene

- Due to optical phonons
- Excitation of electron from valence to conduction band
- Electron-hole pair created
- Recombination generates a phonon and re-emitted electron
- Bandwidth associated with lifetime
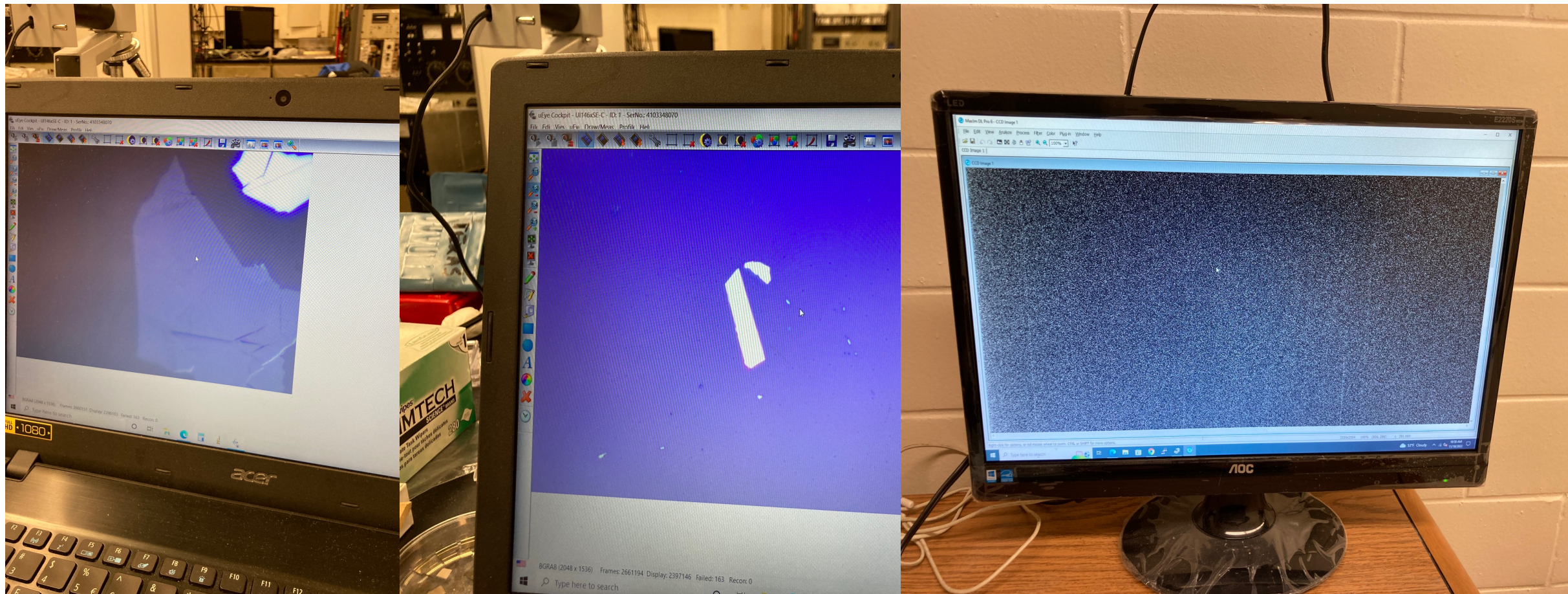- Shifts equally for positive and negative doping

Doping Effects on Bands

633 nm
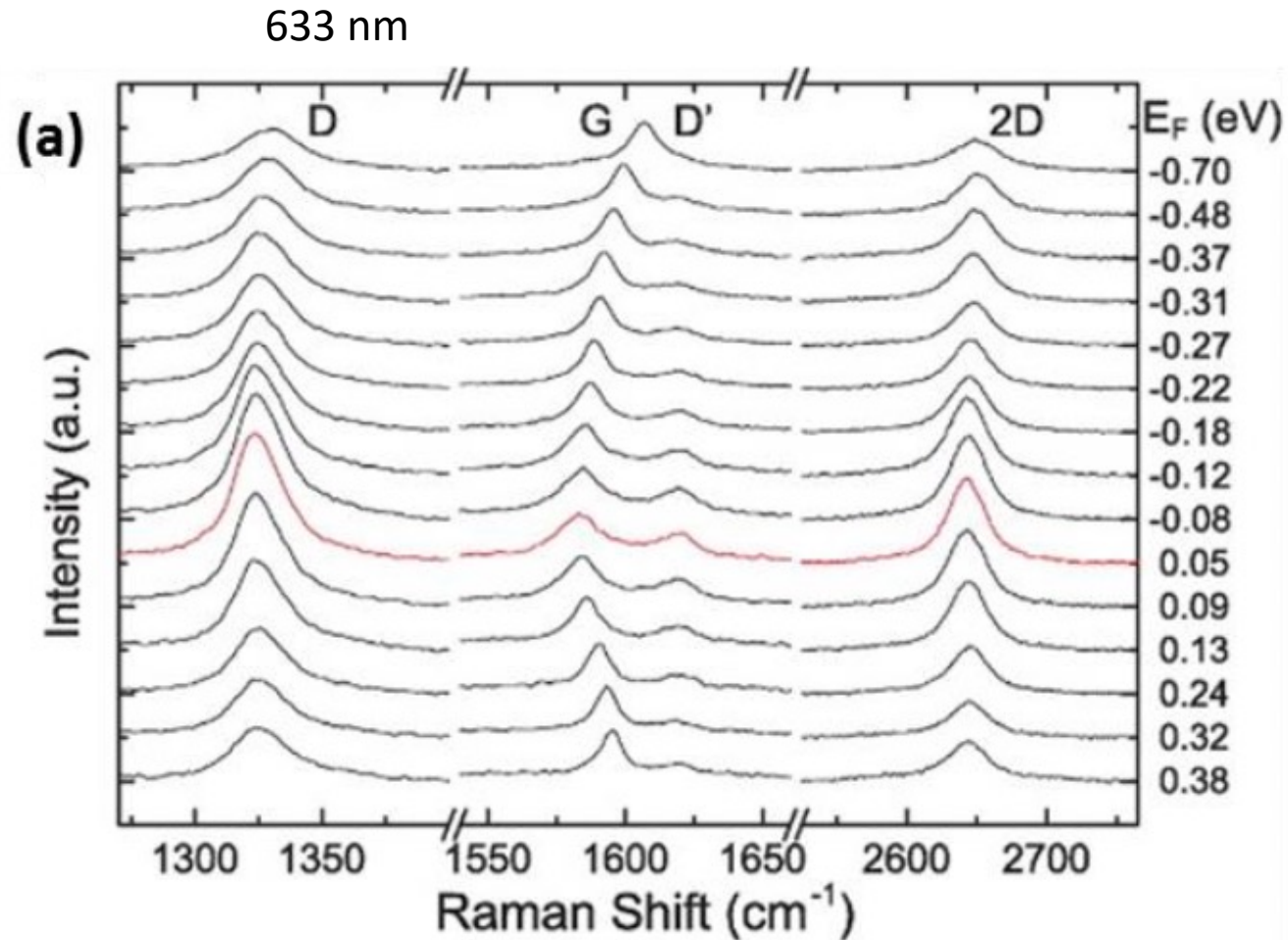
- D band decreases with increased doping
- G band shifts equally for positive and negative doping
- G' (2D) band also decreases with increased doping

My Progress

Things I Need to Do

- Learn to read data from CCD and test it with atomic lamp
- Attach CCD to spectrometer (might need to make a custom fitting)
- Practice transferring materials more
- Learn other optical techniques like PL