Introduction
Spinel structures (see Fig.) have been of particular interest because of their geometric frustration. This is especially true of Vanadate spinels (AV$_2$O$_4$), which have orbital degrees of freedom. In these systems the magnetic interactions are incompatible with the lattice geometry, which leads to the material’s inability to choose a single ground state, i.e., the ground state is degenerate. Therefore, external perturbations such as temperature, applied field, doping and strain can be used to alter the ground state of spinels. When the A-site is non-magnetic the V-V distance and their interactions determine the magnetic properties of the system. However, when the A-site is magnetic, both the spin-spin interactions between V-V and A-V are important and cause the crystal to have even more interesting properties. These properties can include several structural transitions and a variety of magnetic orders. Of particular interest is when the A-site is Cobalt. There is some debate as to whether CoV$_2$O$_4$ exhibits any structural transitions down to 10 K, while the magnetic properties, such as a ferrimagnetic transition from paramagnetism around 150 K and a spin canting transition around 90 K, seem well established [1,2]. We investigate these properties by comparing single crystals to thin films so that we can investigate how subtle lattice distortions (i.e., changes to V-V and Co-V distance) imposed by epitaxy (i.e., strain) can be used to tune the magnetic properties of the system.

Growth Methods
Chemical Vapor Transport (CVT) method, with precursors V$_2$O$_5$ and Co$_2$O$_3$ with transport agent TeCl$_2$ , was used to grow the single crystal samples. This method takes advantage of a volatile agent in order to react compounds that would otherwise require extreme temperatures in order to grow crystals. The precursors are heated inside a quartz ampoule. In the charge zone (C) the vapor reacts with the agent and is transported to the growth zone (G), once material is deposited agent will recirculate to transport more precursor material.

In order to grow the thin films and strain the Cobalt Vanadate spinel, a film is grown onto an SrTiO$_3$ (STO) substrate using pulsed laser deposition (PLD). Strain is caused by the lattice mismatch between the film and the substrate. This method involves striking a target composed of precursor material, in this case CoV$_2$O$_4$, with pulses of a high powered laser in order to create a “plume” of the material and deposit it on the substrate.

Structure and Morphology
X-ray diffraction of an epitaxial CoV$_2$O$_4$ thin film on STO (20000 pulses). The spinel structure is confirmed by the peaks present in the XRD data shown. To our knowledge this is the first thin film growth of this material.

Magnetic Properties
We show the magnetic properties of two CoV$_2$O$_4$ thin films (10000 and 20000 pulses). For both films we observe a paramagnetic to ferrimagnetic transition at 150 K (spins on the Co$^{2+}$ and V$^{3+}$ ions align antiparallel but have different moments). Cooling to lower temperature (T = 90 K) the films undergo a second phase transition from the collinear ferrimagnetic state to a non-collinear state showing spin canting, corresponding to the peak in the M vs T curve. It is unclear if the second transition is accompanied by a structural transition[1]; this will be the subject of future research. Here we note that the peak in M vs T at the spin canting transition is not observed by others in bulk crystals[2]. A possible explanation is that by growing a thin film, which results in subtle lattice geometry changes, we have induced a sharper transition compared to bulk. From our M vs H measurements we note that the saturation magnetization scales with the number of pulses (i.e., the film thickness) as expected and that the coercive field (~ 2 T) is large. This indicates strong pinning of the magnetic domain walls.

Conclusions and Future Work
The Cobalt Vanadate spinel was successfully grown in thin film form and its magnetic properties were investigated. Based on our initial growths, the sharpening of the spin canting transition at 90 K could be brought on by epitaxial strain. In the future we will:

• Investigate the thickness dependence of the transitions.
• Test the dependence on strain by using different substrates.
• Probe Co$_2$V$_3$O$_7$ for its own interesting properties, which will be investigated in the future.

Acknowledgements
A portion of this work was performed at the National High Magnetic Field Laboratory, which is supported by National Science Foundation Cooperative Agreement No. DMR-1157490 and the State of Florida. Funds from startup were used that came from the State of Florida.

References

Conclusions and Future Work

The Cobalt Vanadate spinel was successfully grown in thin film form and its magnetic properties were investigated. Based on our initial growths, the sharpening of the spin canting transition at 90 K could be brought on by epitaxial strain. In the future we will:

- Investigate the thickness dependence of the transitions.
- Test the dependence on strain by using different substrates.
- Probe Co$_2$V$_3$O$_7$ for its own properties.
- Grow Co$_2$V$_3$O$_7$ bulk single crystals and compare their magnetic properties to our thin films.