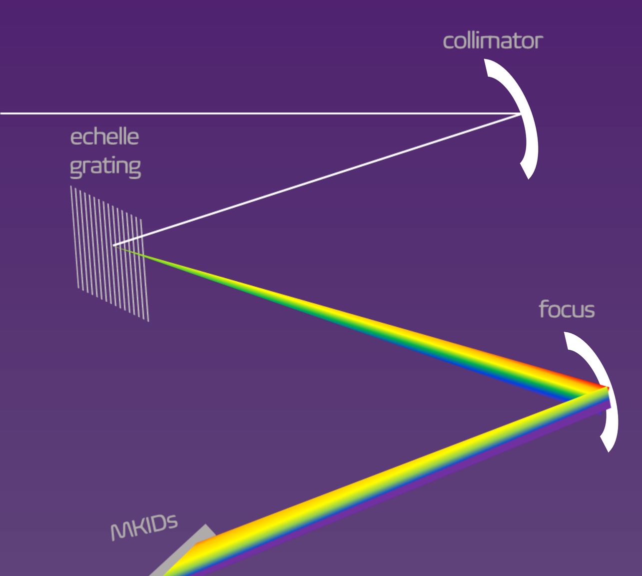

M-Echelle: The MKID Echelle Spectrograph

A novel instrument design using energy-resolving, superconducting detectors

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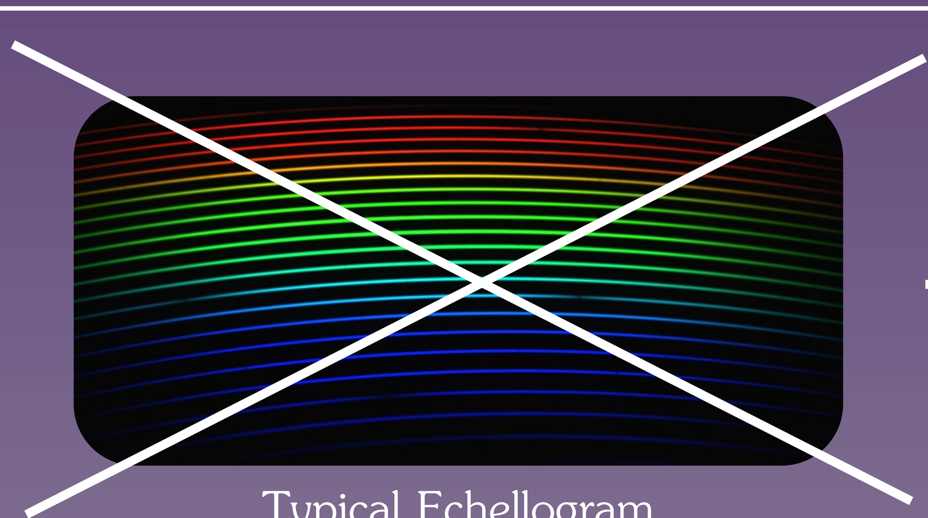
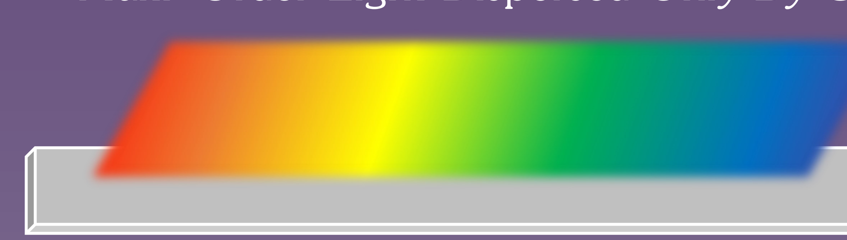
M-Echelle is a proposed visible range spectrograph based on Microwave Kinetic Inductance Detectors (MKIDs) with an initial resolving power of 3500. With their modest wavelength-resolving abilities, MKIDs take the place of both the cross disperser and detector in the spectrograph. MKIDs lack read noise and dark current enabling noiseless post-observation rebinning and characterization of faint objects. This work presents an M-Echelle simulator customizable for different M-Echelle configurations. Treating simulator products as inputs, an algorithm was developed and implemented in the M-Echelle data reduction package to calibrate and extract spectra.

OVERVIEW



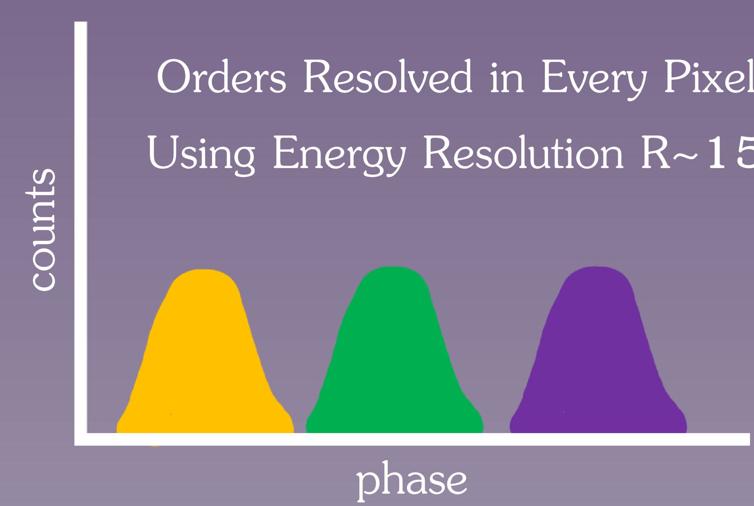
Typical Echellogram

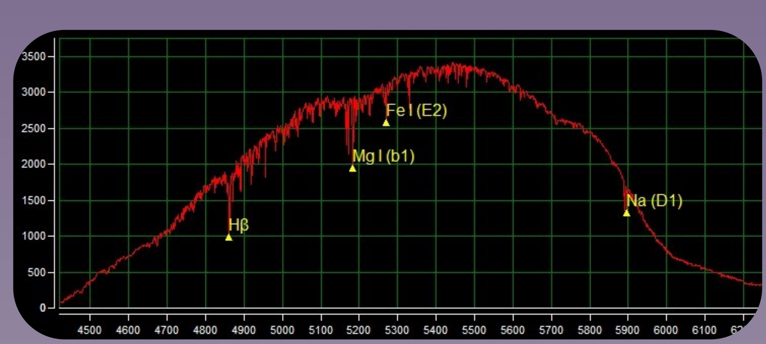
Multi-Order Light Dispersed Only By Grating



1x2048 MKID Pixel Array

Orders Resolved in Every Pixel Using Energy Resolution R~15





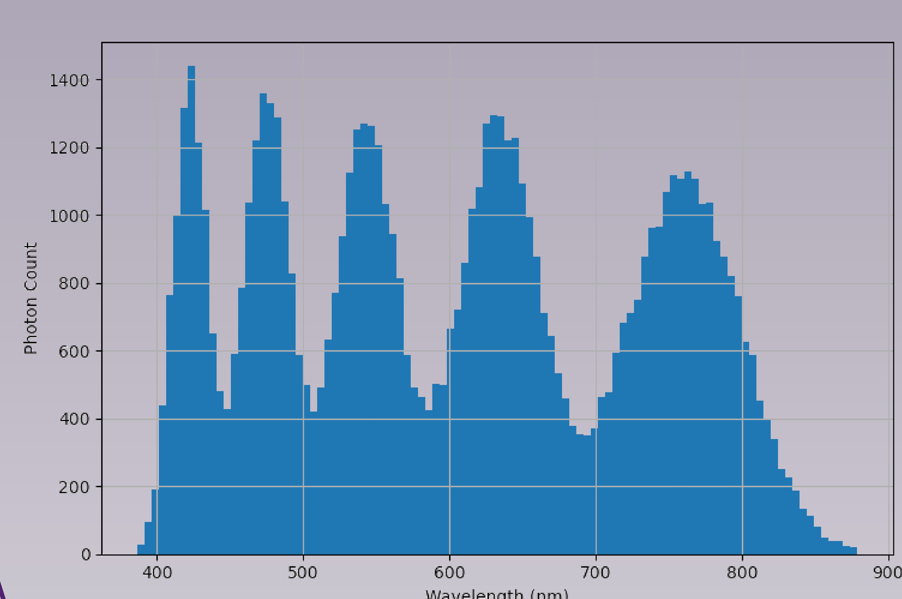
Extracted Spectrum

- photon counting
- no cross-disperser
- overall R~3500
- visible wavelength range
- multi-object potential
- cryogenic operation

SIMULATION

For every pixel i and order m, the blazed[1] model spectrum is convolved with the MKID response Gaussian approximation M with parameters determined by input arguments.

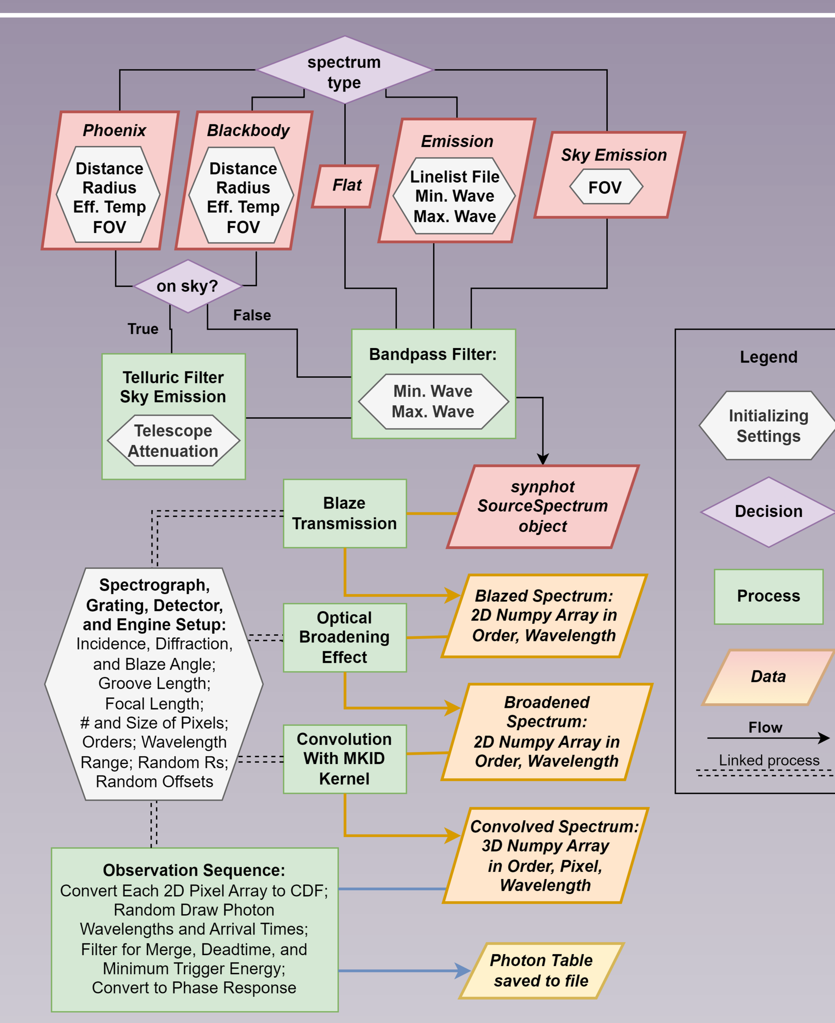
$$M_{im}(\lambda) = \frac{1}{\sigma_{im}\sqrt{2\pi}} \exp\left(-\frac{(\lambda-\lambda_{im})^2}{2\sigma_{im}^2}\right)$$



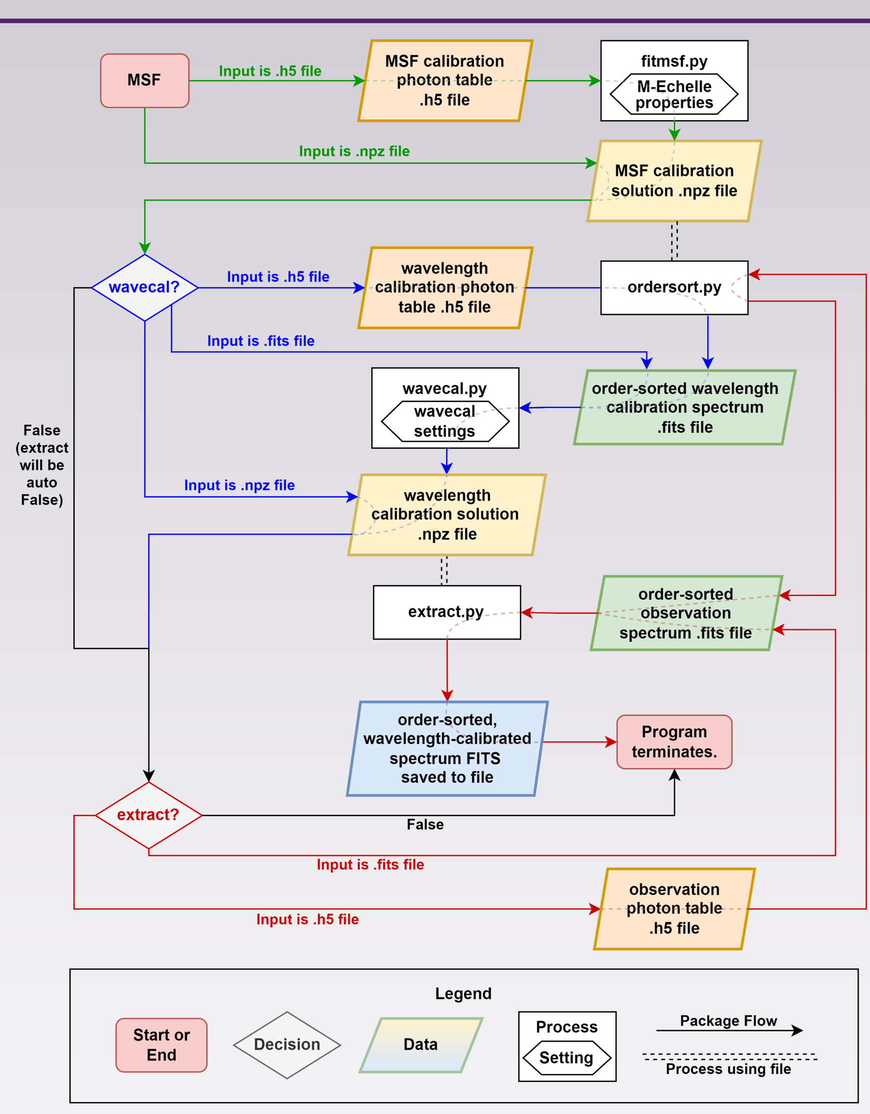
Photon List

#	Phase	Time	Pixel
0	-0.2π	12.4 s	0000
1	-0.3π	0.3 s	0000
2	-0.8π	4.4 s	0000
3	-0.4π	18.2 s	0001
4	-0.6π	97.6 s	0001
⋮	⋮	⋮	⋮

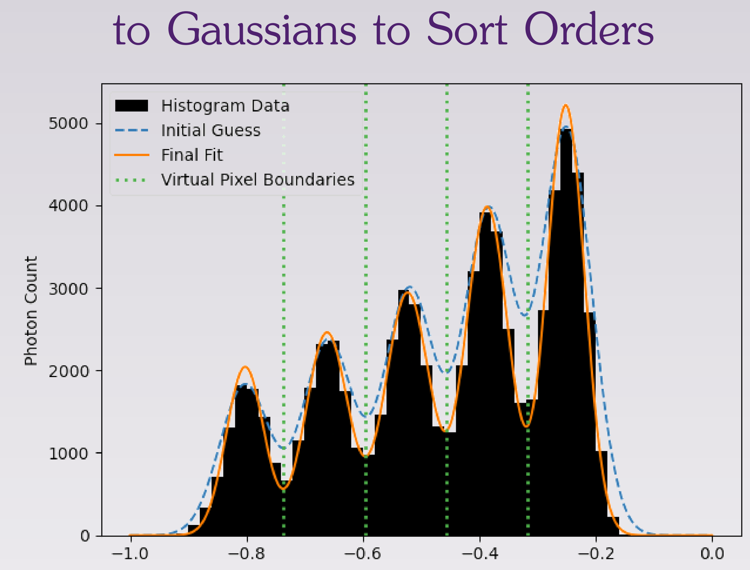
What would happen if we used a different grating? A different number of MKID pixels? A different MKID resolution? A different overall resolution? These questions are answered using the M-Echelle Simulator, which turns a user-specified *synphot* spectral model into the output photon list that describes the **energy** (as linear in phase)[2], **arrival time**, and **pixel number** of every photon. The simulator adds in randomized variations in pixel resolution,[3] which is a result of the manufacturing process, and phase value offsets, which is a result of the readout electronics. The format of the output is compatible with the data reduction pipeline described below. This allowed backwards extraction of the original spectrum to test and finetune the pipeline, which will then be used on real observational data.



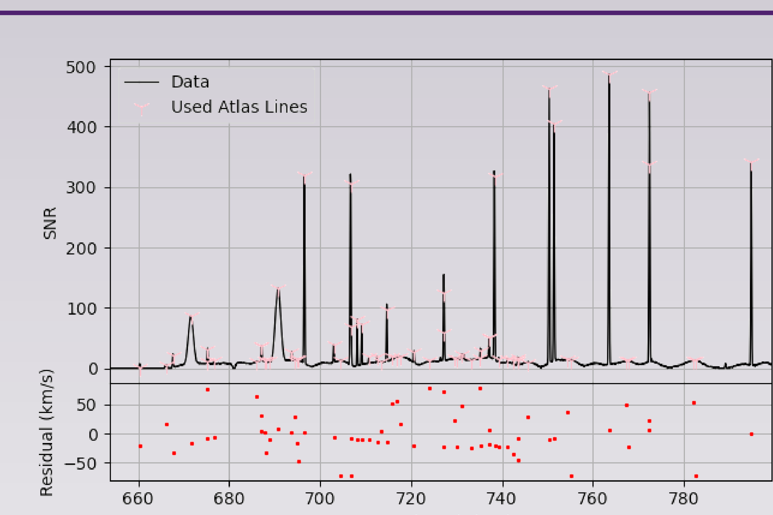
PIPELINE



Photons in Each Pixel Binned & Fit to Gaussians to Sort Orders



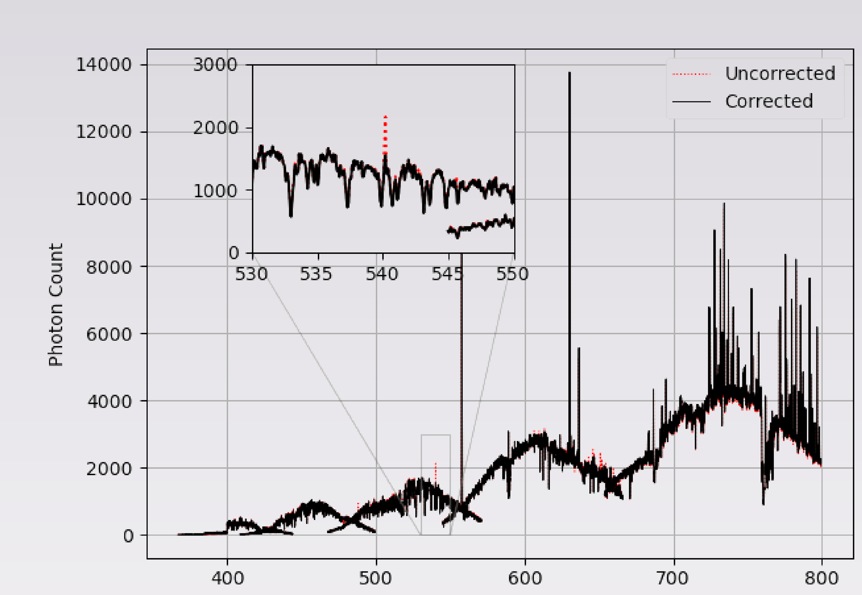
2048 of these plots!



Use Emission Lamp Data for Wavelength Calibration[4]

Pipeline Requires 3 Photon Lists: Continuum, Emission, Observation

Use Gaussian Fits to Correct Counts Bleeding into Other Orders



References:

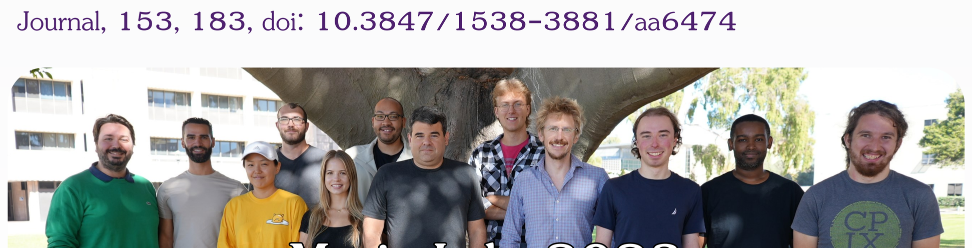
[1] Casini, R., & Nelson, P. G. 2014, Journal of the Optical Society of America A, 31, doi: 10.1364/JOSAA.31.002179

[2] Day, P. K., LeDuc, H. G., Mazin, B. A., Vayonakis, A., & Zmuidzinas, J. 2003, Nature, 425, 817, doi: 10.1038/nature02037

[3] Walter, A. B., Fruitwala, N., Steiger, S., et al. 2020, Publications of the Astronomical Society of the Pacific, 132, doi: 10.1088/1538-3873/abc60f

[4] Piskunov, N., Wehrhahn, A., & Marquart, T. 2021, Astronomy and Astrophysics, 646, doi: 10.1051/0004-6361/202038293

[5] Wang, J., Mawet, D., Ruane, G., Hu, R., & Benneke, B. 2017, The Astronomical Journal, 153, 183, doi: 10.3847/1538-3881/aa6474



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THE FUTURE

- lab and telescope testing
- detector & grating upgrades
- software improvements
- increase to 5 fibers
- propose new instrument
- High Dispersion Coronagraphy[5]

Low noise, photon counting, multi-object spectrographs will be especially advantageous when used with adaptive optics and coronagraphs to push the contrast ratio needed to detect extremely faint companions. While 5 fibers are enough for a few objects and background subtraction, imagine a ~100 fiber MKID-based spectrograph that can carefully probe a region that is suspected of harboring a faint companion. This data could be cross-correlated with atmospheric models to unearth otherwise invisible objects. Though superconducting detector-based spectrographs require cryogenic operation that increases the total instrument footprint, the significant decrease in required detector real estate is a potential argument for reduced size and cost.