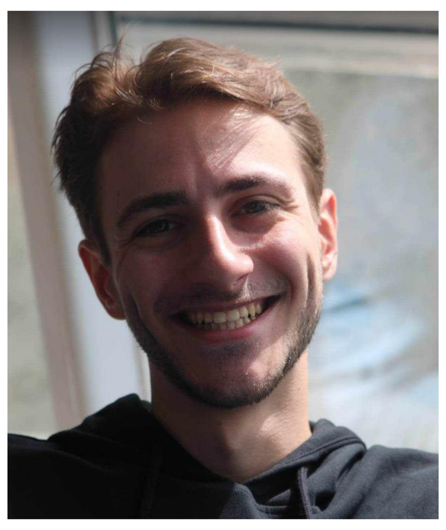


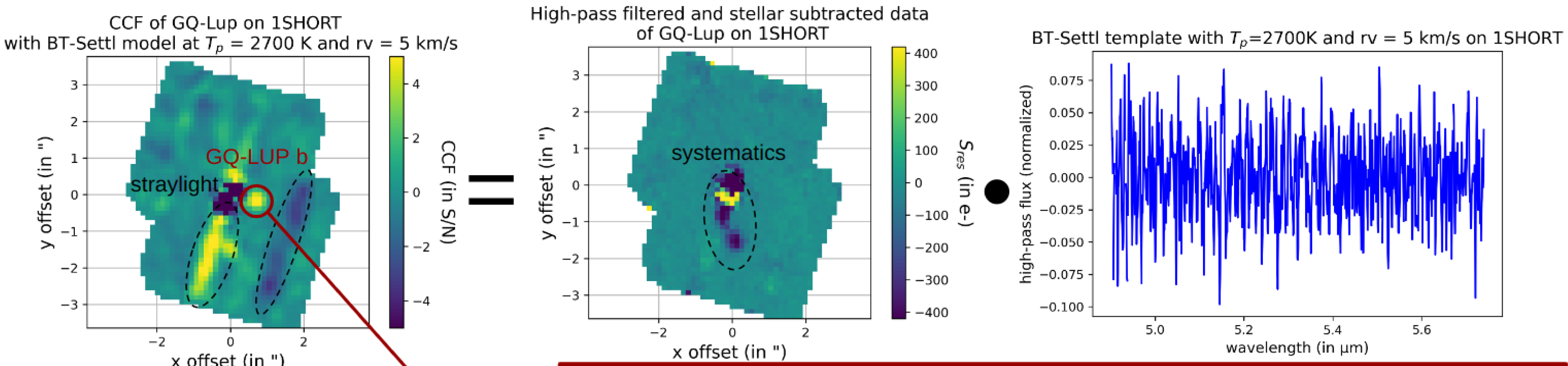
Combining **High-Contrast Imaging** and **High-Resolution Spectroscopy**: MIRI/MRS On-Sky Results vs. Expectations

S. Martos[1] , A. Carlotti[1], A. Bidot[2] and D. Mouillet[1]

1: Institute of Planetology and Astrophysics of Grenoble, University Grenoble Alpes, CNRS, France
2 : Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA
Corresponding author email: steven.martos@univ-grenoble-alpes.fr

Abstract: Combining high-resolution spectroscopy with high-contrast imaging is a powerful approach for detecting and characterizing faint exoplanets. Presently, **speckle noise sets detection limits at short separations**. While **molecular mapping can mitigate speckle noise** with sufficient resolution, **another type of systematic error will limit detections** while using this method. The goal is to elucidate **how systematic effects influence both noise and signal,** manage observations under such conditions, and comprehend their origins (**Martos et al. In prep.**). JWST/MIRI/MRS on-sky data provide a quantitative **comparison against the expected standard signal and noise**, using the recently developed semi-analytical and numerical tool **FastCurves.**

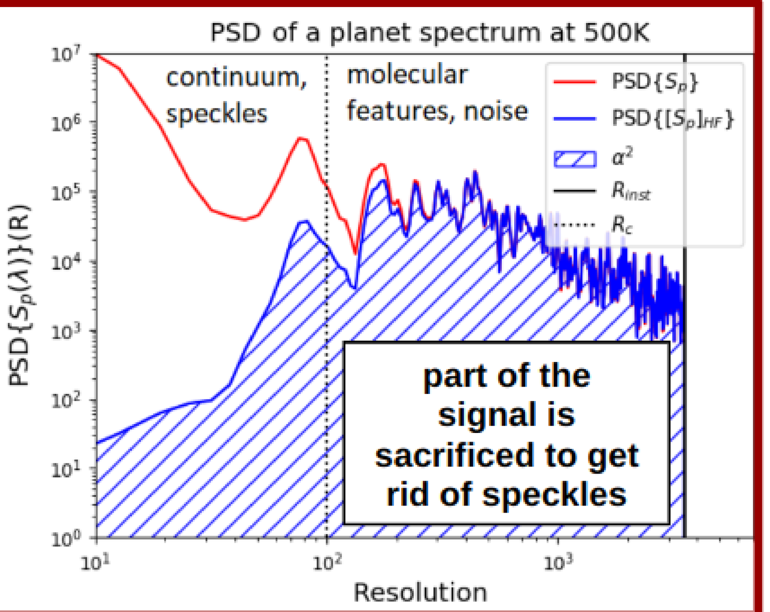
MOLECULAR MAPPING PRINCIPLE: apply **cross-correlations** within the spectral dimension between **high-pass filtered and stellar subtracted data cube** and **planets templates** (BT-Settl, Exo-REM, etc.)



spectral correlation signal = α - β

α = high-frequency spectral content of the planet (based on the planet's properties), proportional to the PSD of the HF spectrum

β = self-subtraction term: similarity degree between the star and the planet that cannot be used to discriminate the planet from the star (minimized if the Doppler shift between planet and star and/or the instrumental resolution is sufficiently important)



LIST OF SYSTEMATICS:

- **STRAYLIGHT [1]:** Scattering within the detector substrate and from light diffraction at the narrow gaps between pixels => broader PSF + detector's diffraction pattern (inducing horizontal band and small spike features).
- **FRINGES [1]:** notable spectral fringing (10 – 30% of the flux) due to Fabry-Perot interference within the detectors.
- **ALIASING ARTIFACTS [2]:** interplay between the cube reconstruction algorithm (re-interpolation of the native detector pixel data into a regular cube grid), spatial undersampling and the curvature of the spectral traces on the detector

FastCurves [3]

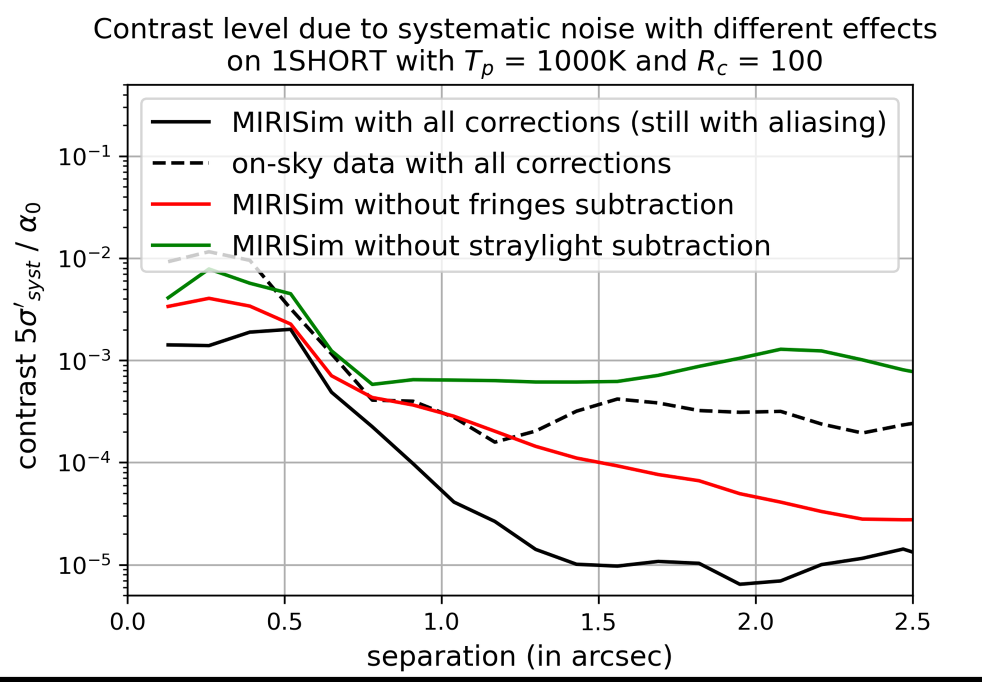
FastCurves shows promise as an **ETC** for **predicting IFS performance** when employing molecular mapping (high-pass filtering) as a post-processing method for speckle removal: it can be used to **estimate the level of fundamental** (non-systematic) noises.

MIRISim [4]

MIRISim is an **end-to-end simulator** specifically crafted to produce realistic MIRI data, incorporating various effects (fringes, distorsion, etc.): it can be used to **estimate the level of systematic noises.**

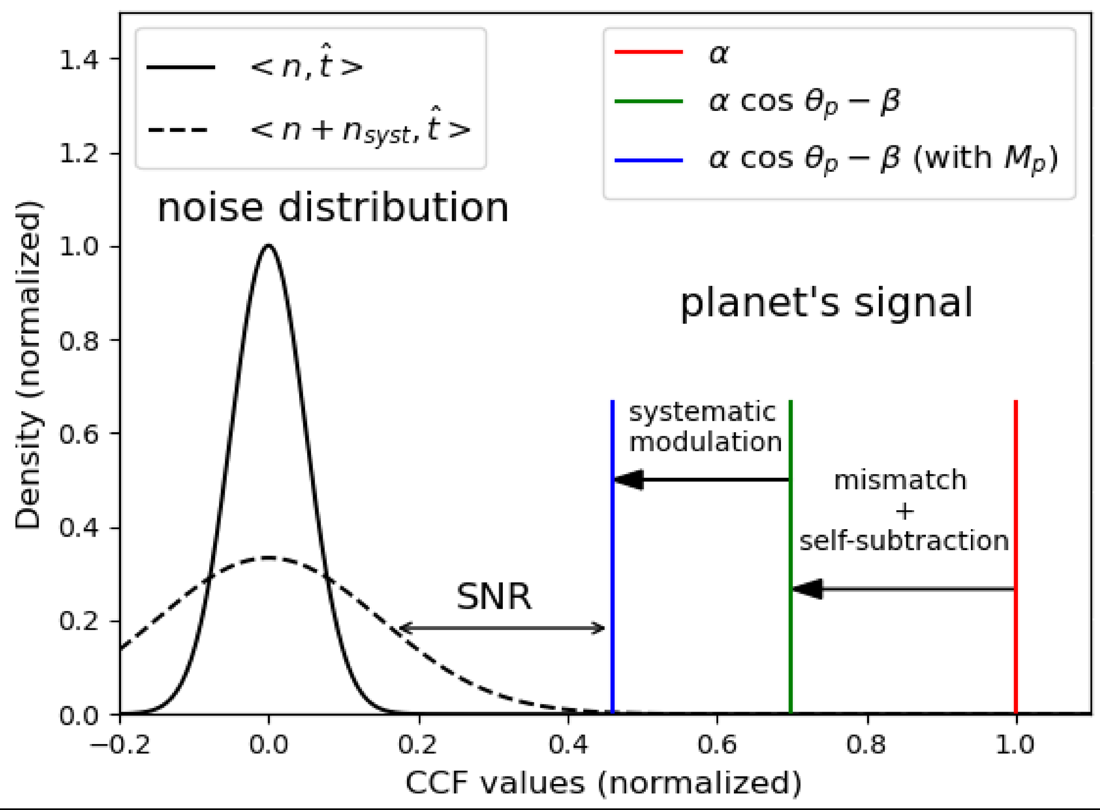
Systematic contributors:

Straylight and **fringes** are the most important systematic effects to correct properly + the level of systematics in on-sky data lies between bad straylight and fringe subtraction:

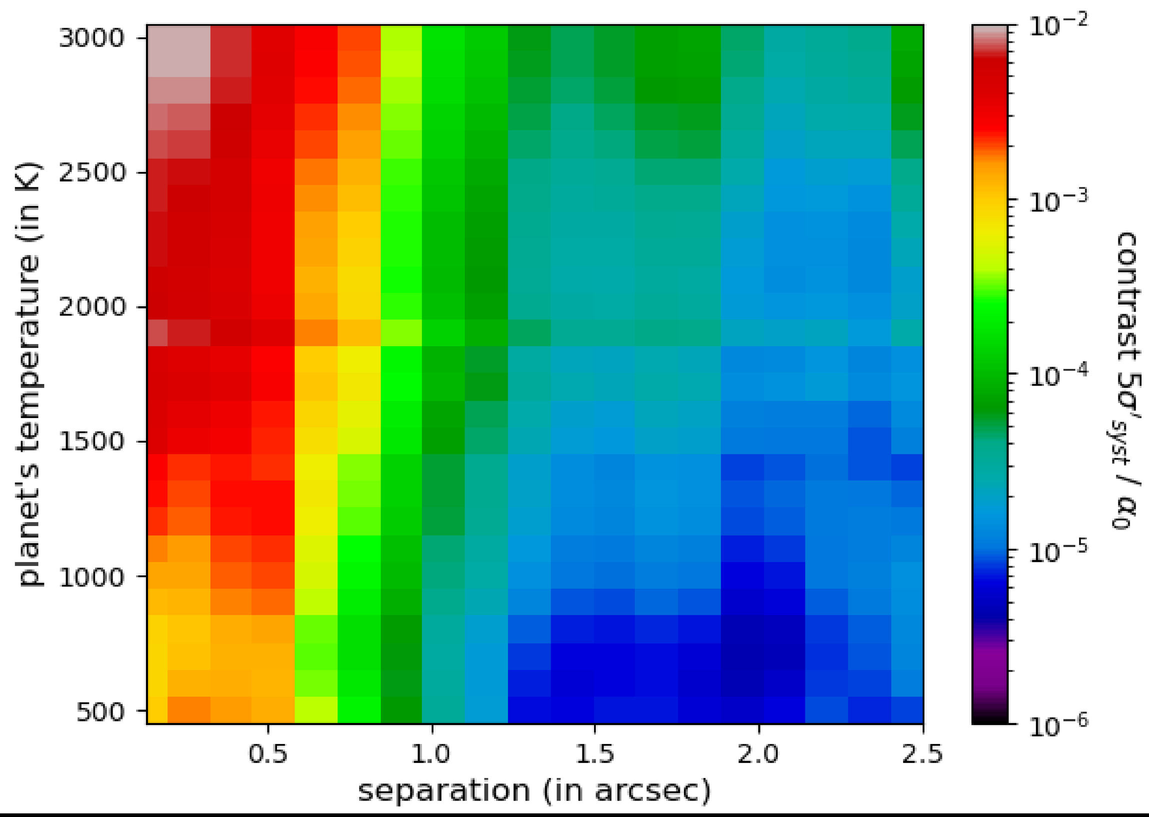


Systematic behaviour:

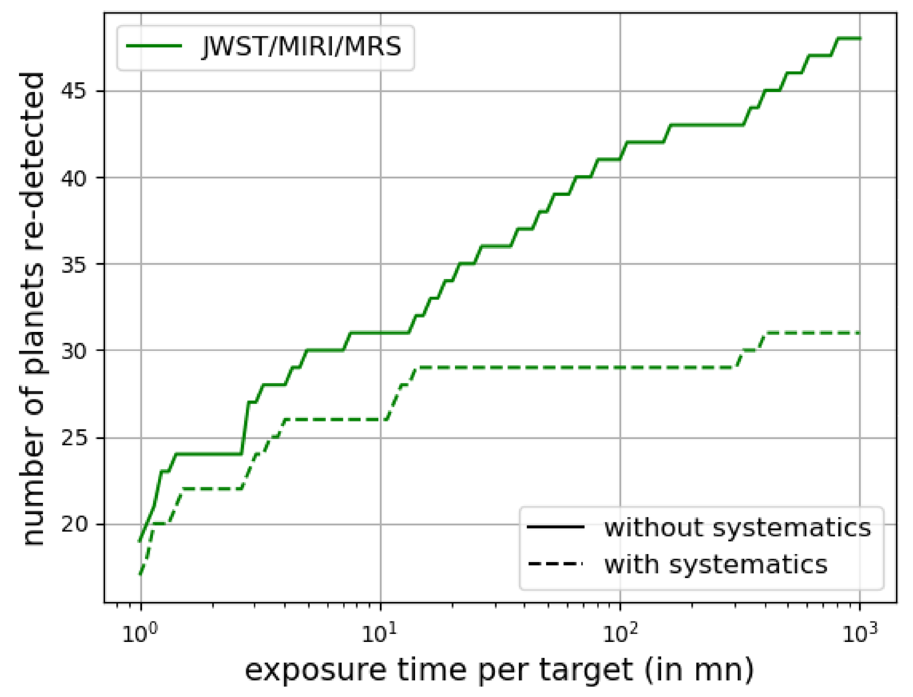
Structure of systematic modulations impacts correlation/signal & spatial variations of systematic modulations impact noise statistics:



Systematic noise is directly proportional to the integrated stellar flux and therefore sets new **detection limits with molecular mapping**:

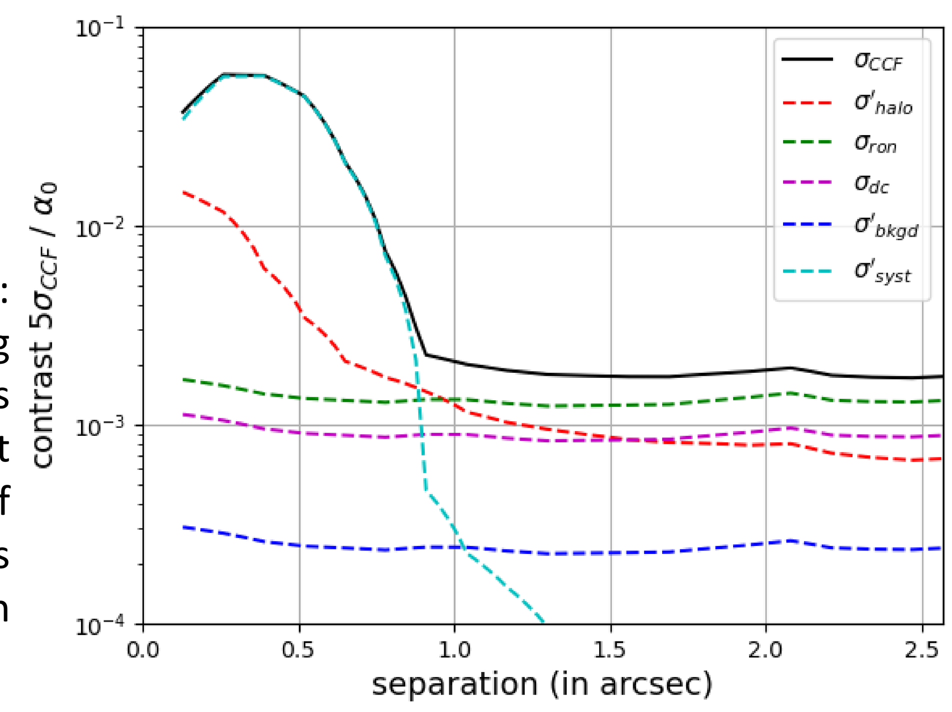


Yield estimations:



FastCurves + MIRISim estimates are valid => working ETC !

The initial challenge persists: while molecular mapping effectively removes speckles that limit detection at short separations, the presence of another type of systematics continues to limit detection in this region.

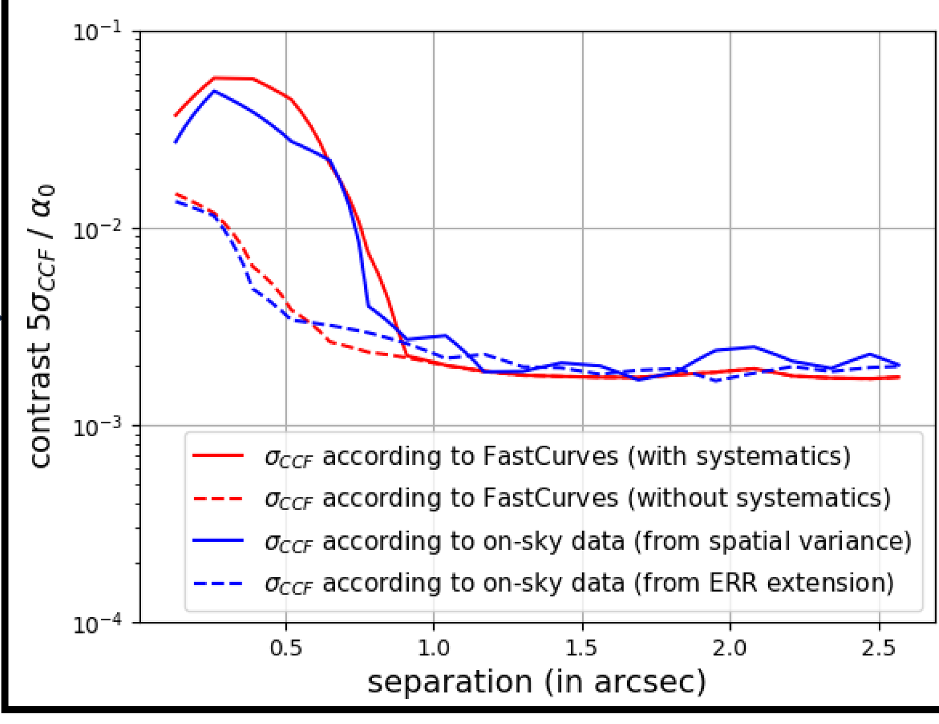


Noise level comparison:

Empirical estimation :

- From ERR extensions (JWST Pipeline estimations): **fundamental noises**
- From spatial variance of the CCF: **fundamental + systematic noises**

Analytical estimation (FastCurves+MIRISim): **fundamental noises with or without systematics**



One potential strategy to mitigate this systematic noise is by opting for a higher cut-off resolution, but a trade-off must be found to avoid filtering out too much signal. Another approach could involve directly utilizing 2D calibrated detector images and implementing an alternative molecular mapping technique [5].

→ See the poster 1541 on yield estimations

→ See the poster 1611 on reflecting planets direct detection

Github :

FastCurves (initial version): https://github.com/ABidot/FastCurves

FastYield (includind updated FastCurves): https://github.com/StevMartos/FastYield

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