Slitless Spectroscopy in Euclid & beyond

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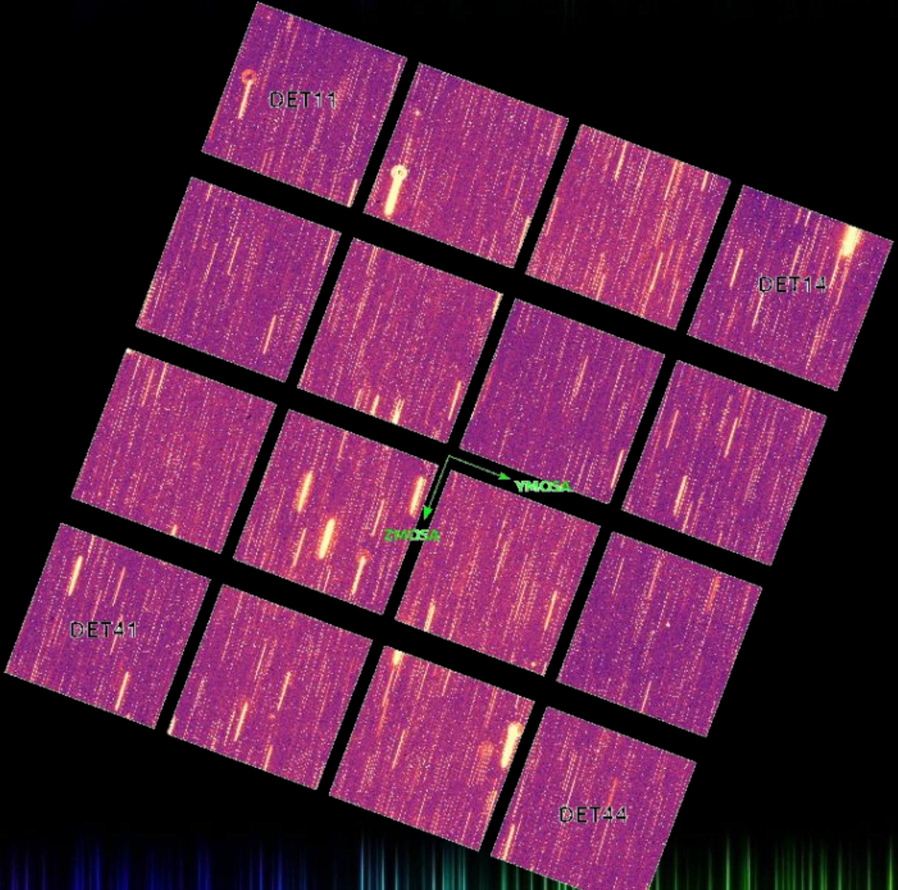


Slitless spectrography 101

Slitless spectroscopy = Dispersed imaging

$C(\mathbf{r}, \lambda)$: intrinsic source 3D flux distribution

P_0 = Point Spread Function

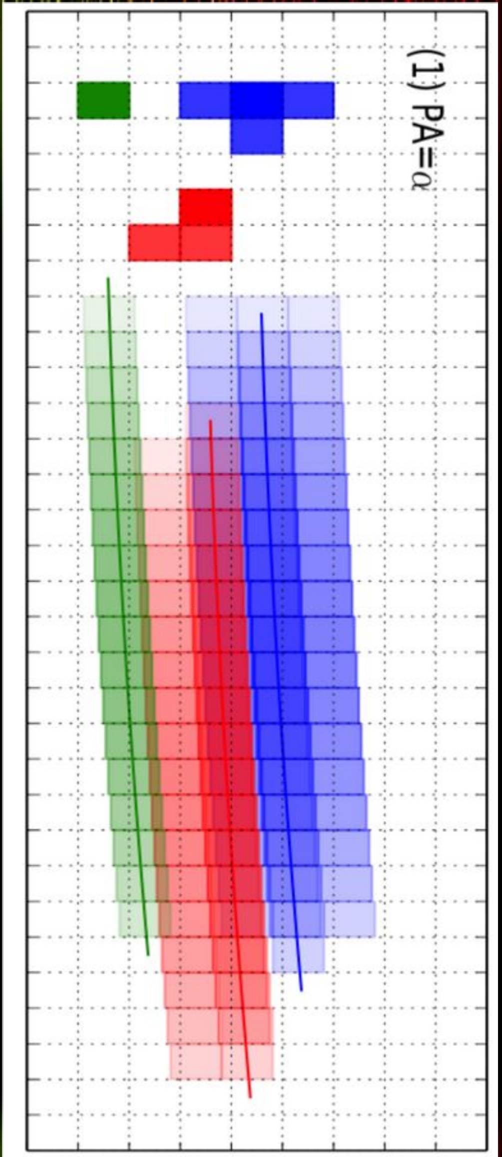
$\boldsymbol{\Delta}(\lambda)$ is the dispersion law

Spectrogram (2D):

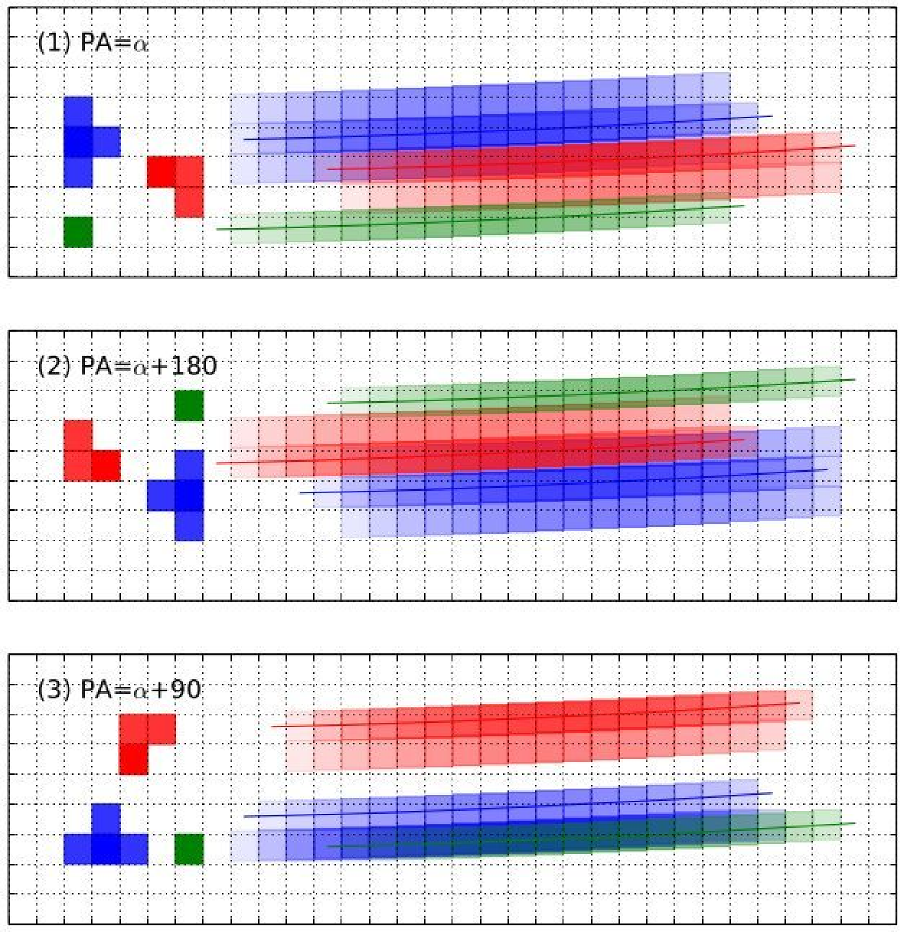
$$\mathbf{I(r) = \int d\lambda\, (C \otimes P_0)(r - \Delta(\lambda), \lambda)}$$

Slitless spectroscopy

- Advantages
  - Large FoV and high multiplexing
  - Simple to build and to operate
- Drawbacks
  - Cross-contamination: overlap of different objects (potentially at *different dispersion orders*)
    - Mitigation: multi-PA observations
  - Self-contamination: mixing of spatial and spectral information
    - Spectral resolution is dependent of source size/seeing conditions
  - High background level (∝ spectral domain)

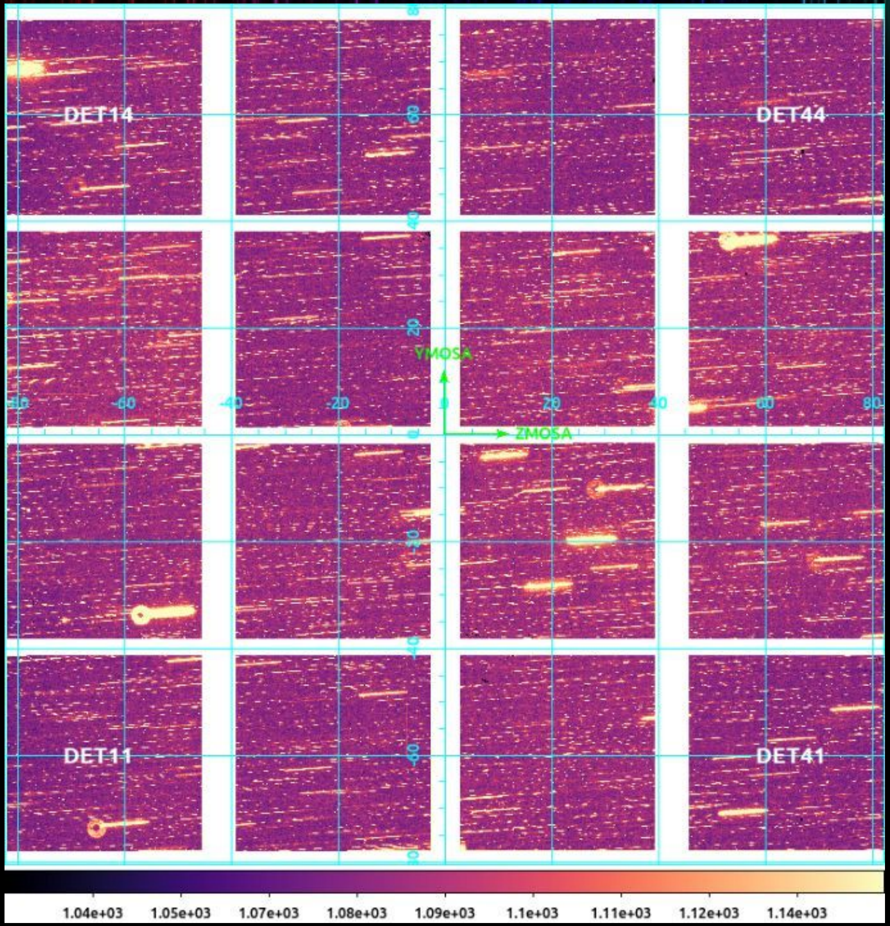


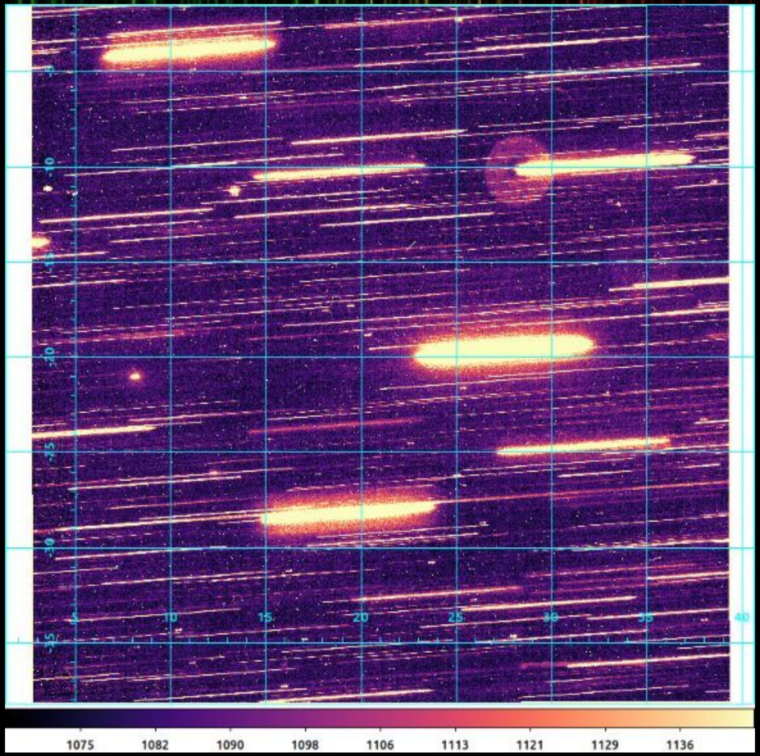
Multi-roll observations

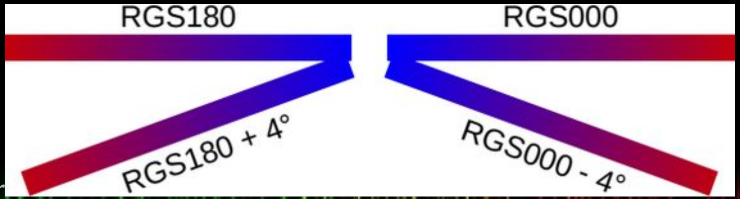


Brammer, Pirzkal & Ryan
TIR WFC3 2014

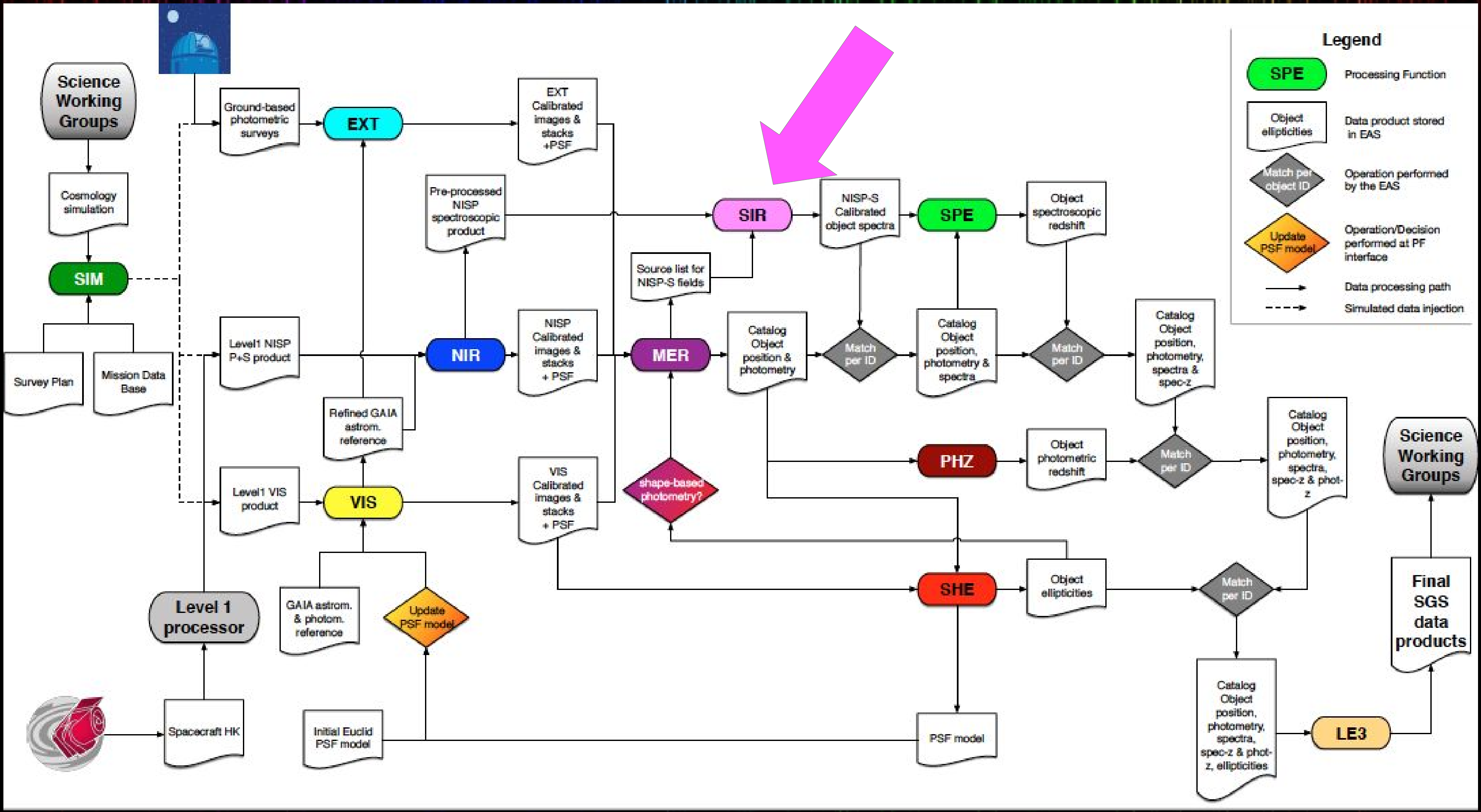
NISP spectroscopic exposure (RGS000-4)





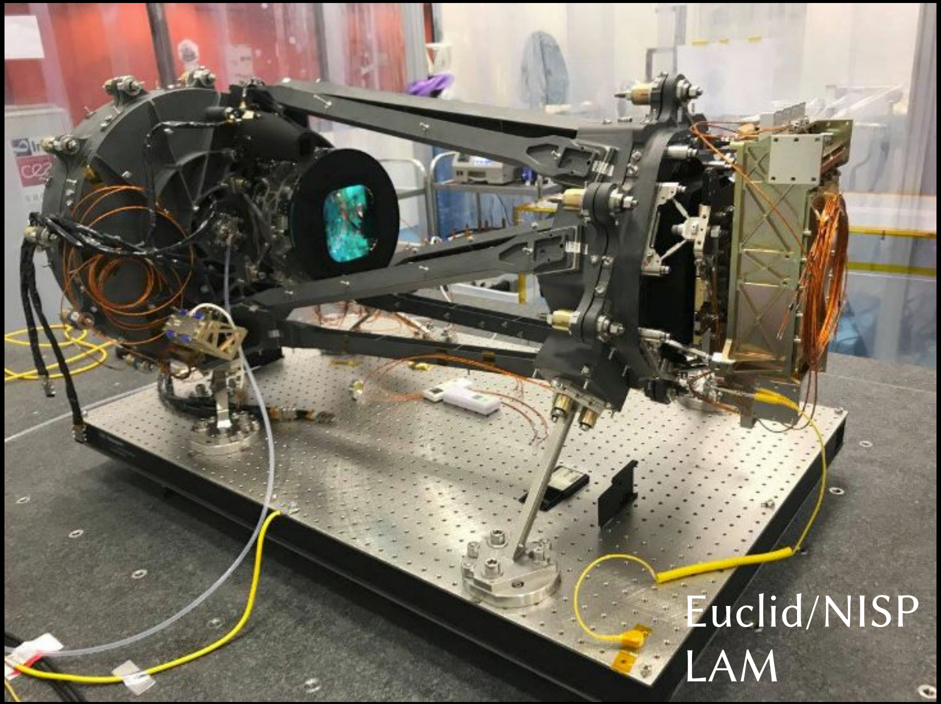


The SIR PF within the Science Ground Segment



SIR interfaces

- **Input**
  - LE1 spectro exposures
    - Signal & 8-bit Quality Factor
  - MER photometric catalog
    - Object IDs, mags and shape params
      - 2MASS for bright (saturated) objects
  - MER thumbnails & segmap
- **Output**
  - Combined calibrated 1D spectra
    - Signal, variance, bitmask, LSF
    - Meta-data (e.g. contaminants)



SIR-PF
Calibration pipelines

The SIR PF – Calibration pipelines

- (detector calibrations handled by NIR: dark, non-linearity, persistence, etc.)
- **Spectrometric pipelines**: describe the spectrogram layout (incl. wavelength sol.)
  - OPT: astrometric solution (incl. fine pointing offset + PA)
  - CRV: distortion model (geometric)
  - IDS: wavelength solution
  - (PSF: spectro-spatial NIS PSF)
- **Photometric pipelines**: provide the flux calibration for the spectra
  - *(Flat-field: detector-level QE flat-field)*
  - RFX: relative flux calibration
  - AFX: absolute flux calibration
- All 5 effective grisms (RGS000, 180+4, 000-4, 180, BGS) are calibrated *independently*

NIS resolving power & wavelength accuracy

- Native spectral sampling:

  s=1.369 ± 0.025 nm/px

- Resolving power (2σ, 0.5'' FWHM source):

  R≈500 to 700

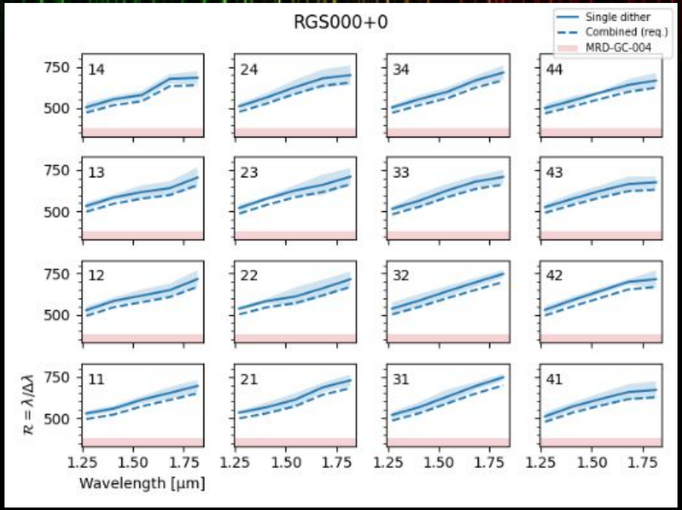
  - Req. MRD-GC-004: >380

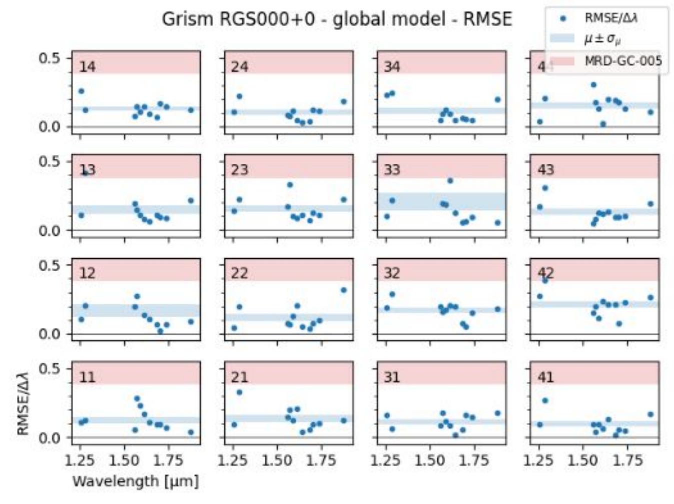
- Wavelength accuracy;

  ~0.23 pix = 17% resolution element

  - Req. MRD-GC-005: <38%

- Caveat: computed from PN itself

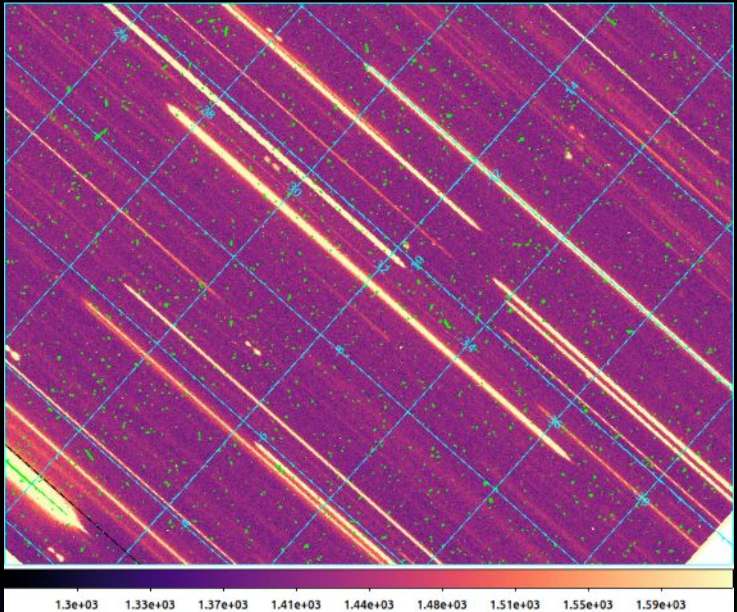


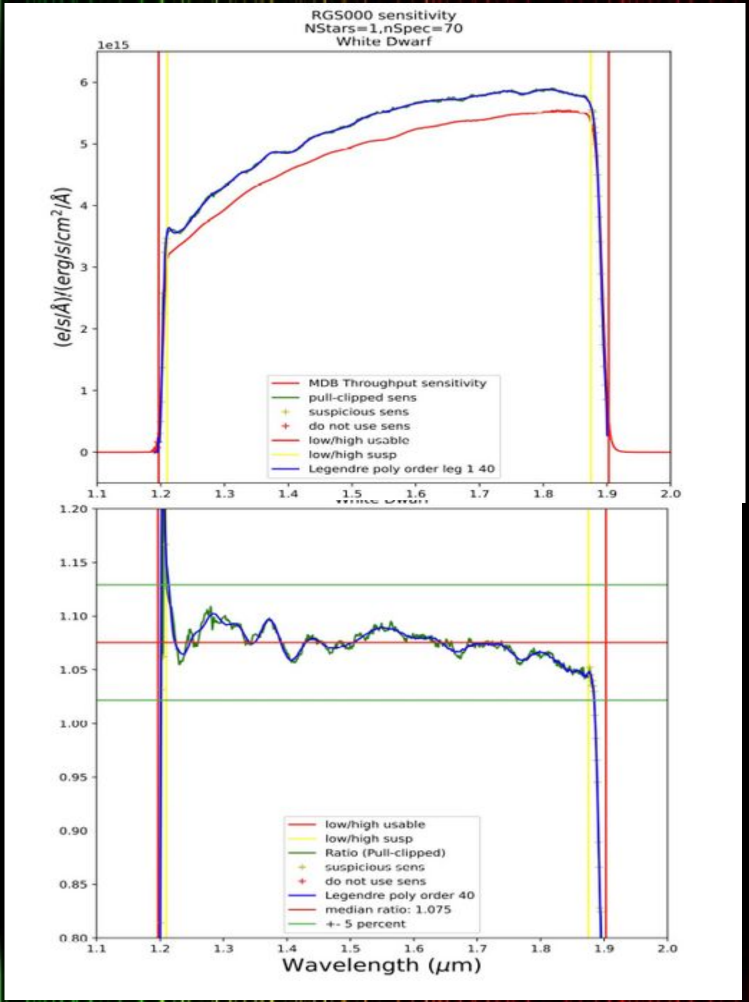


SIR calibration – Absolute Flux

- Procedure (PV-003)
  - 16×5 observations of WD GRW+70 per grism
  - Derive sensitivity per grism from ref. flux

- Sensitivity slightly better than expectation
- Need to account for proper motion (400 mas/yr)
- Requires optimized obs. sequence





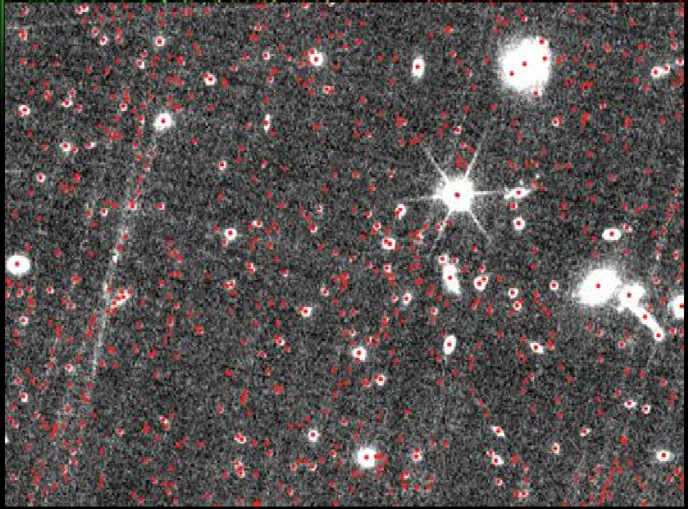
SIR-PF
Science pipeline

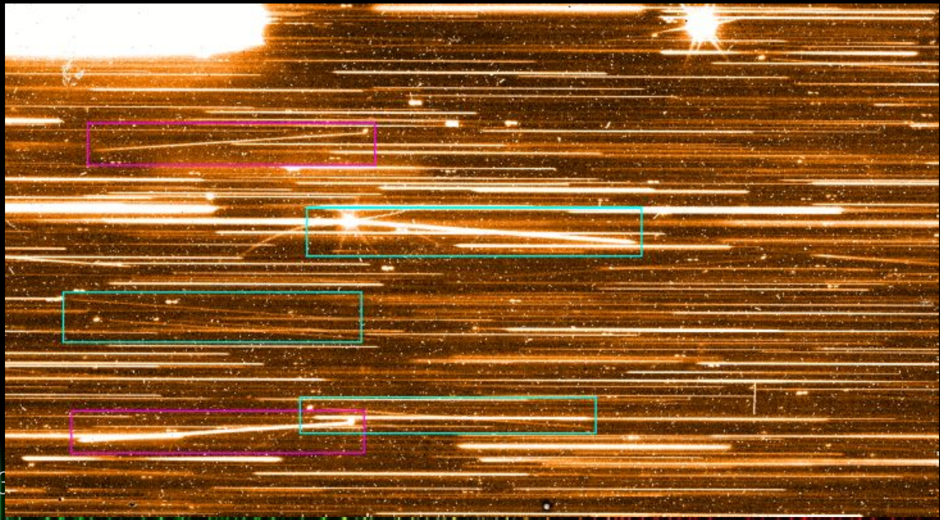
The SIR PF – Science pipeline

- Main steps:
  - pre-processing: detector effects (⟶NIR PF) + cosmic rays
  - spectra location: mapping (det, i, j) ↔ (α, δ, λ) + background
  - spectra extraction: 2D spectrogram ⟶ 1D calibrated spectrum
    - incl. detector flat-field, decontamination, relative and absolute flux scalings
  - spectra combination: N_{dith} spectra ⟶ combined spectrum
- Two separate temporal triggers: per pointing or per tile (combination)

NISP detector persistence

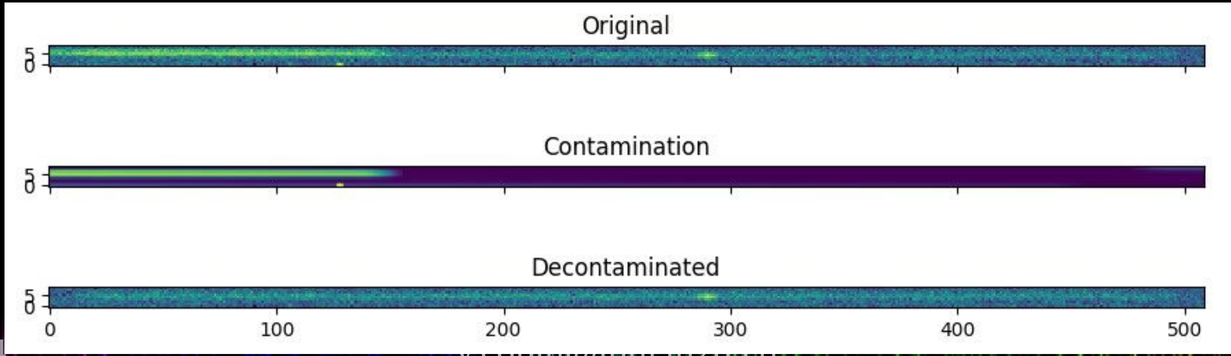
- Persistence in NIR results in large numbers of spurious sources (×2-3) in MER catalog
  - Algo flooding & memory crash
  - Temporary fix: H<22.5 mag
- Persistence in NIS exposures is not addressed yet
  - P⟶S: spurious emission-like features in spectra
  - extra ghost-like features





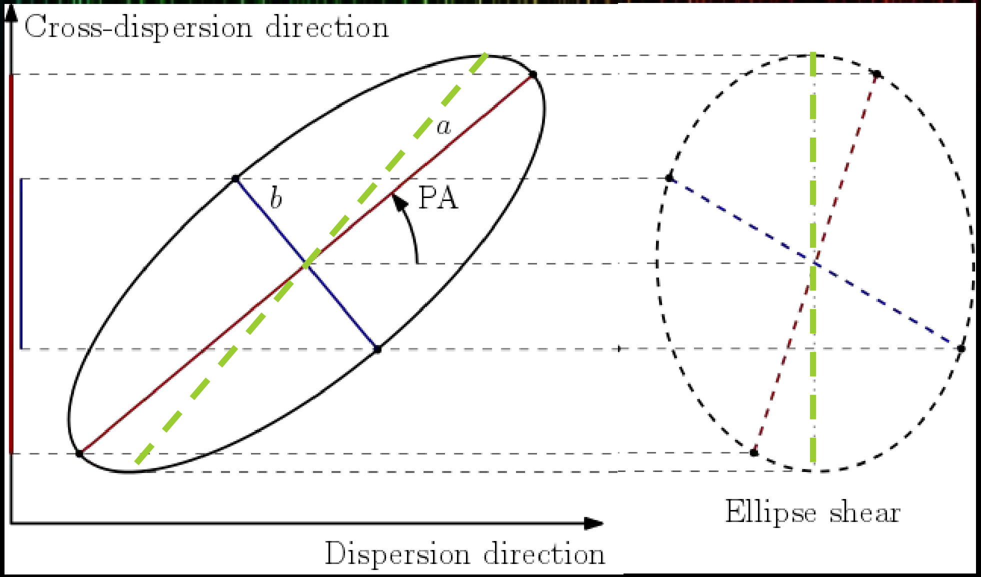
SIR science pipeline – Spectra Decontamination(s)

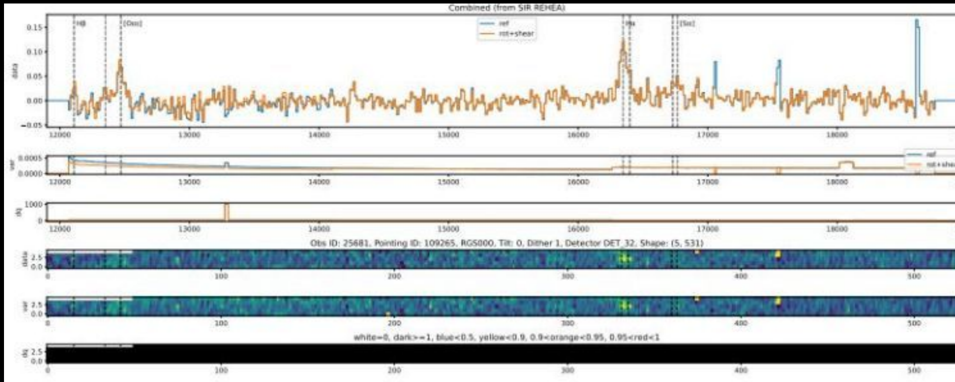
- Standard decontamination
  - Uncontaminated spectral domains or J/H broadband interpolation
    - Segmented NIP cutouts
    - NIP/NIS differential PSF
    - LocationTable (astro-spectrometric model) & Flux solution
- Advanced decontamination
  - Joint regularized MLE of *intrinsic spectrum* from the N dithers
  - Includes extraction and relative flux scaling
- Flagging
  - 0^{th} order, contamination > 10%



SIR science pipeline – Spectra Extraction

- **Spectrogram resampling**
  - Aperture(mag), min 5 px
  - Virtual slit to minimize LSF (shear)
- **Optimal extraction**
  - WLSQ fit of x-disp. profile amplitude
  - X-disp. profile from NIP cutout
    - NIP/NIS differential PSF
    - Cutout rotation and shearing
  - Estimate of effective LSF
  - Implemented but not in production
    - Still using plain summation

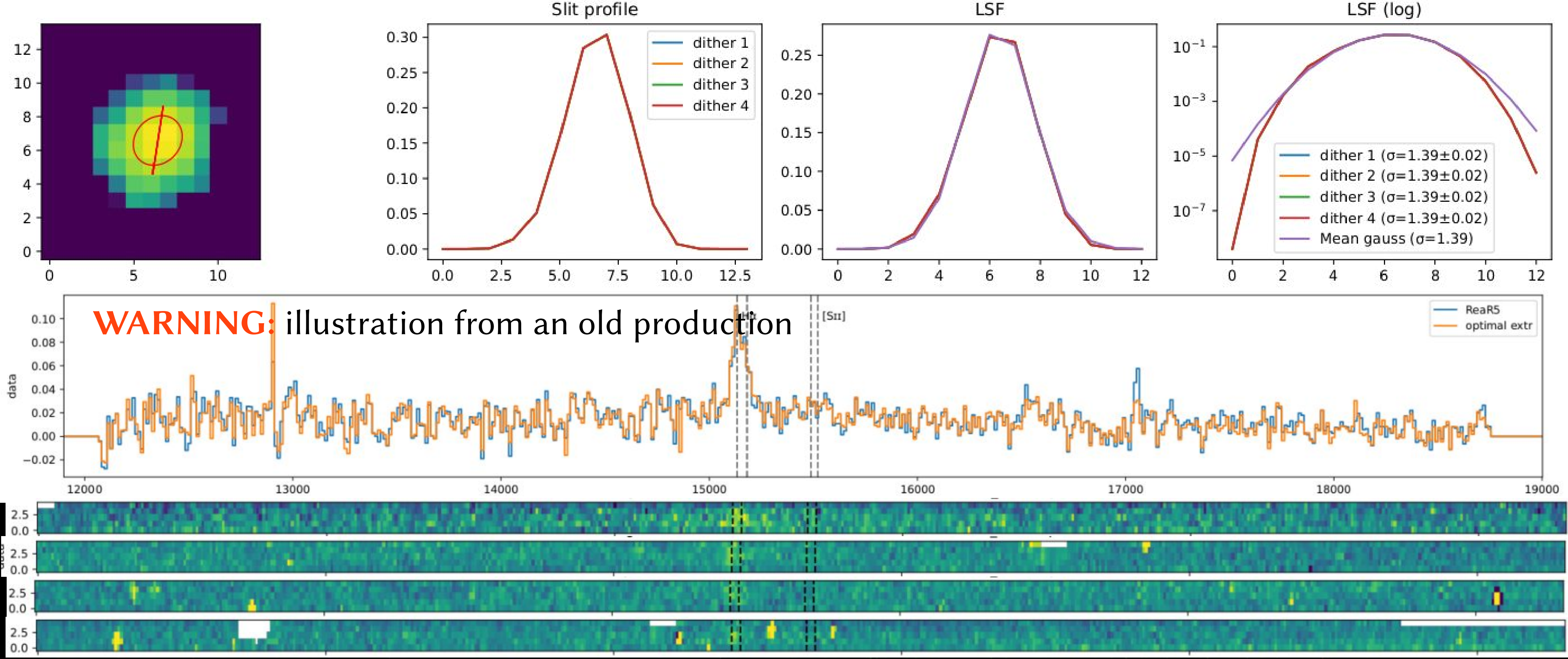




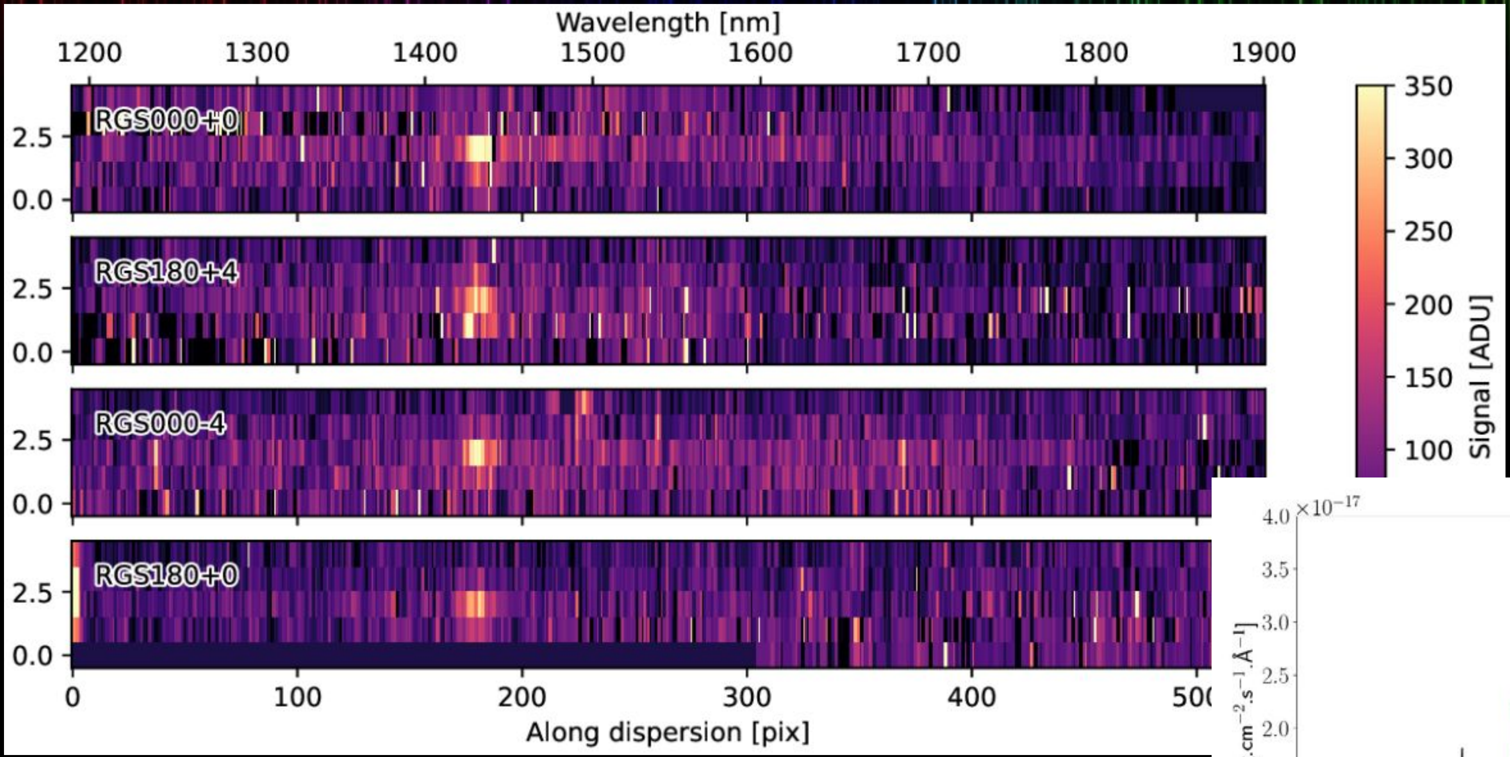
Virtual slit & Optimal extraction

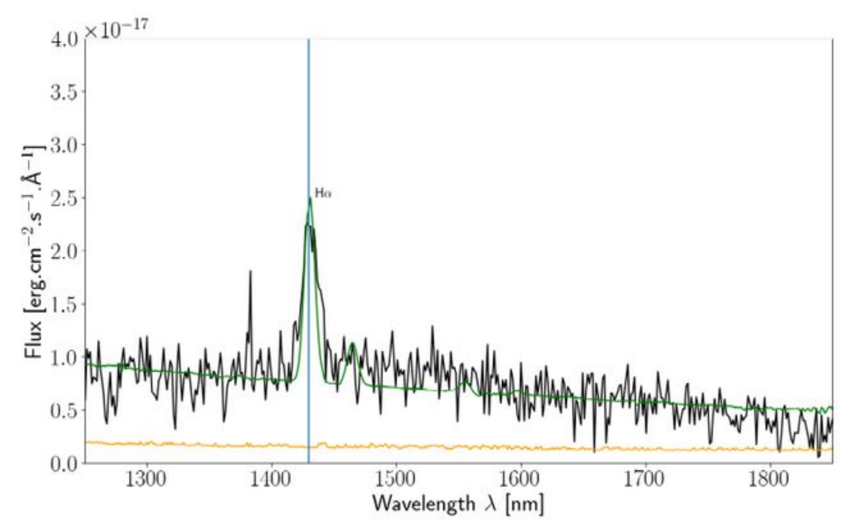
z=1.31 - J=21.61 - F_Hα=-15.20 - F_NII=-15.50 - F_SII=-15.95 - A=3.17, B=2.68, PA=-21.4

WARNING: illustration from an old production



A (bright) galaxy at z=1.1783 ± 0.0005





Galaxy ~ 10× brighter
than estimated Hα limit (~2e-16)

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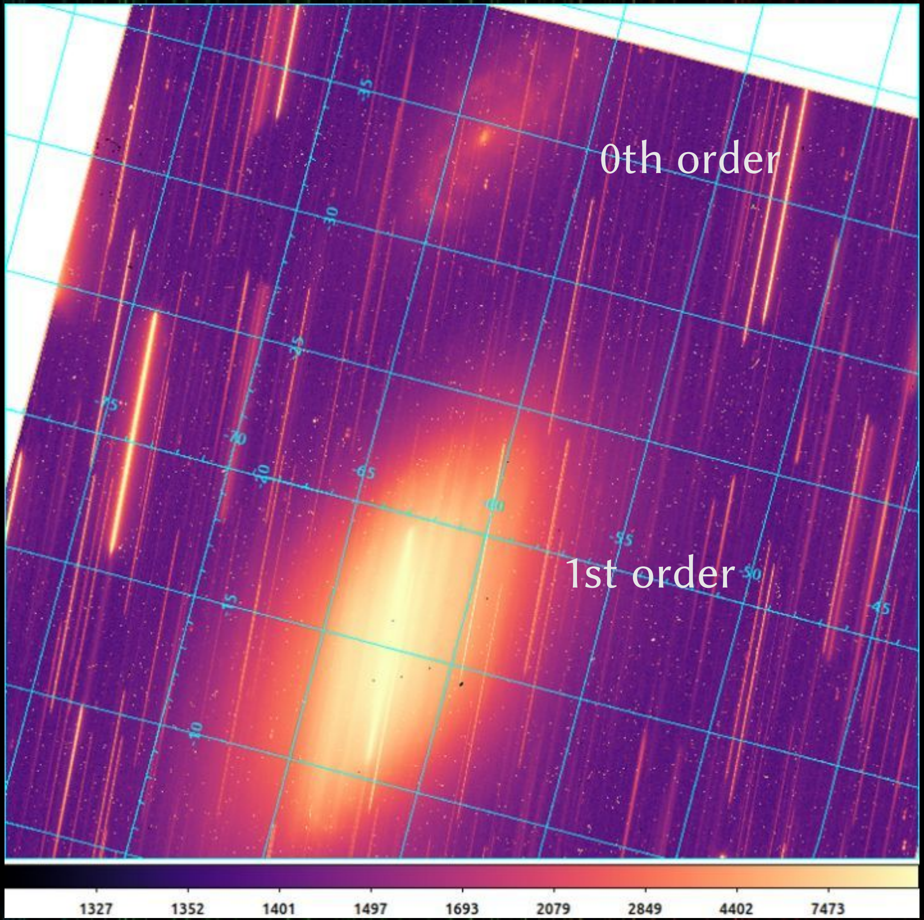
NGC 1792

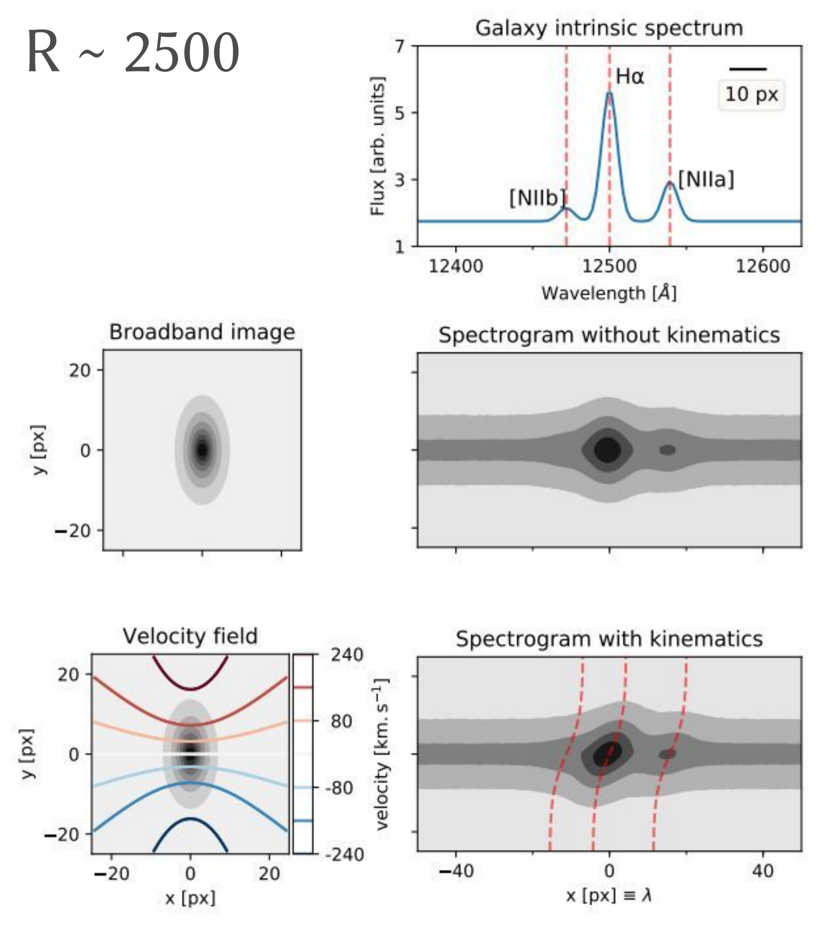
YJH image

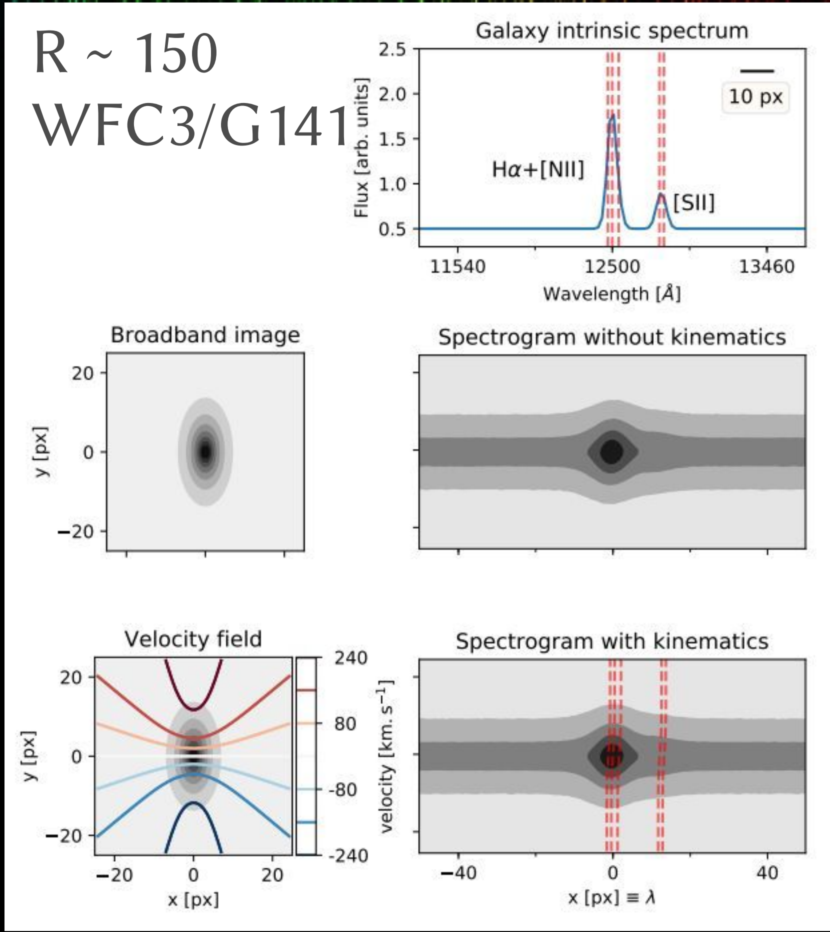


Slitless spectrography beyond Euclid

PhD M. Outini (2019)

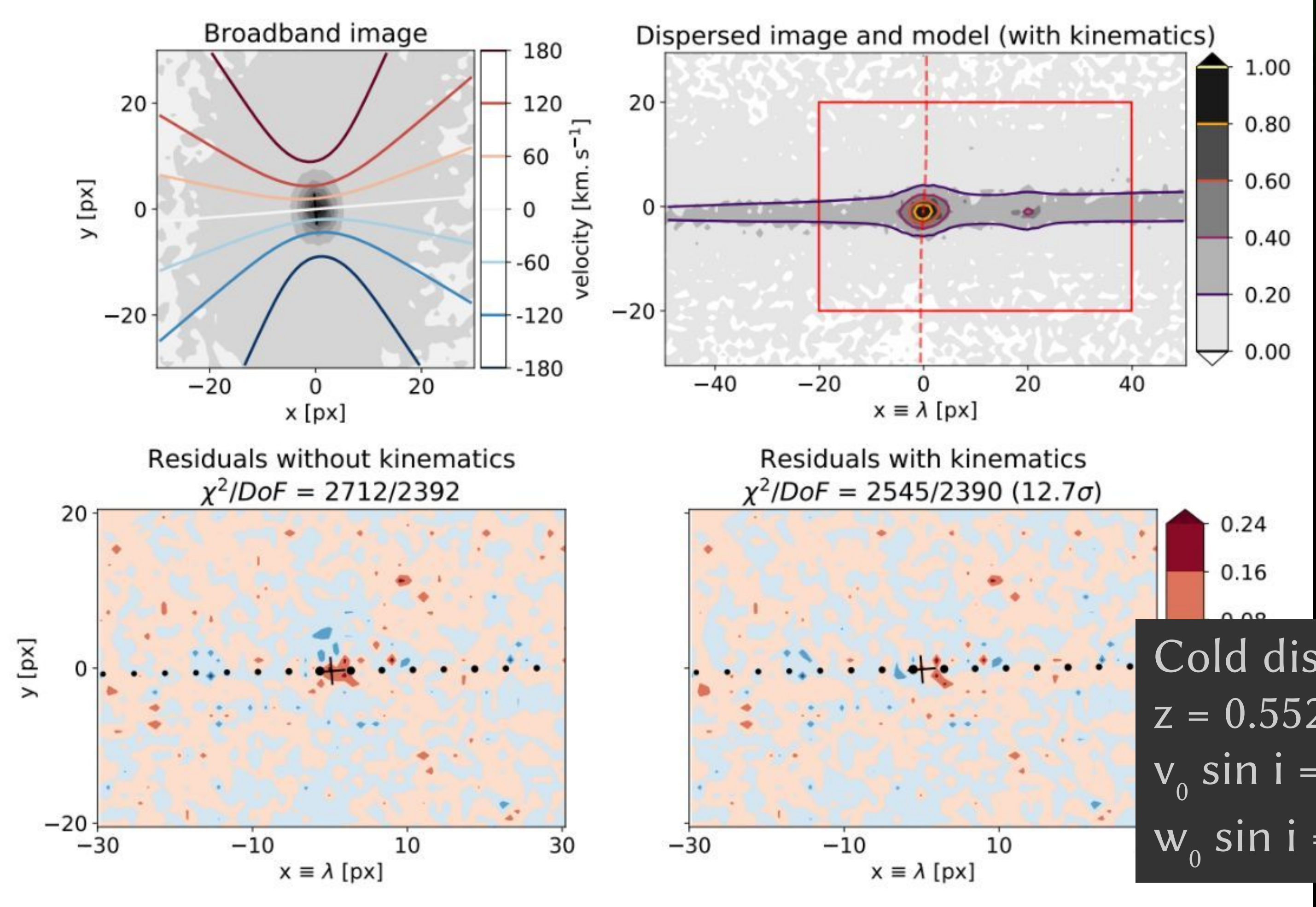
Kinematics in slitless spectroscopy





Outini & Copin 2020A&A...633A..43O

#1134 GLASS – G102 (24 A/px)



Cold disk, velocity curve:

$z = 0.55237 \pm 0.00016$

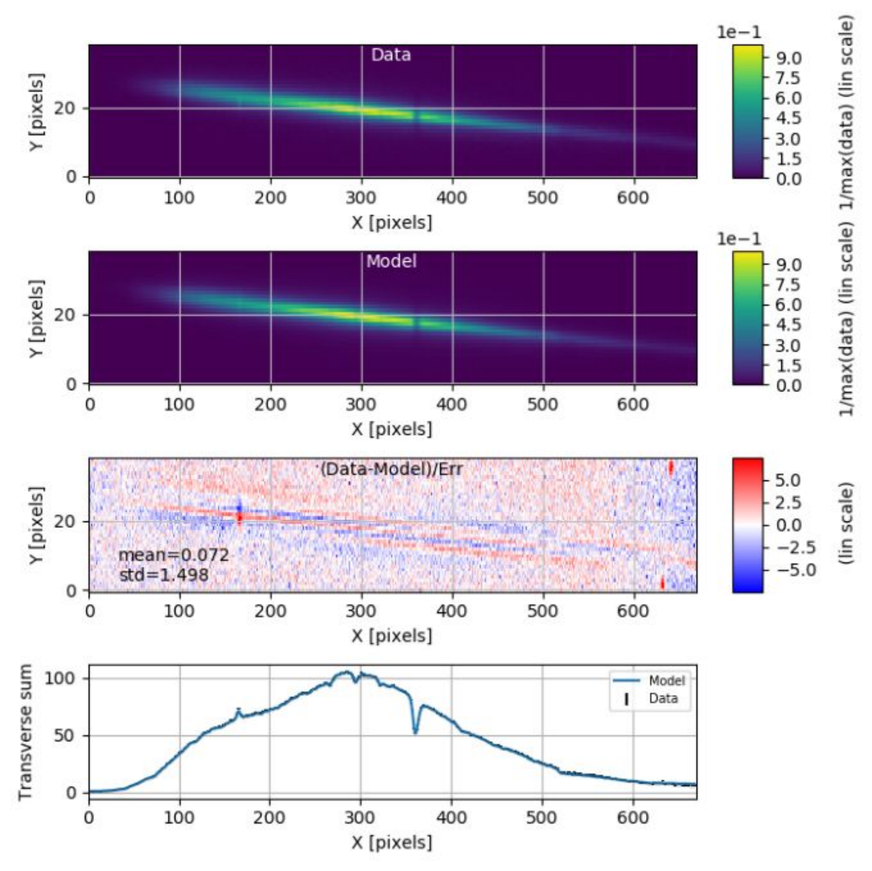
$v_0 \sin i = 205 \pm 28$ km.s^{-1}

$w_0 \sin i = 242 \pm 28$ km.s^{-1}.arcsec^{-1}

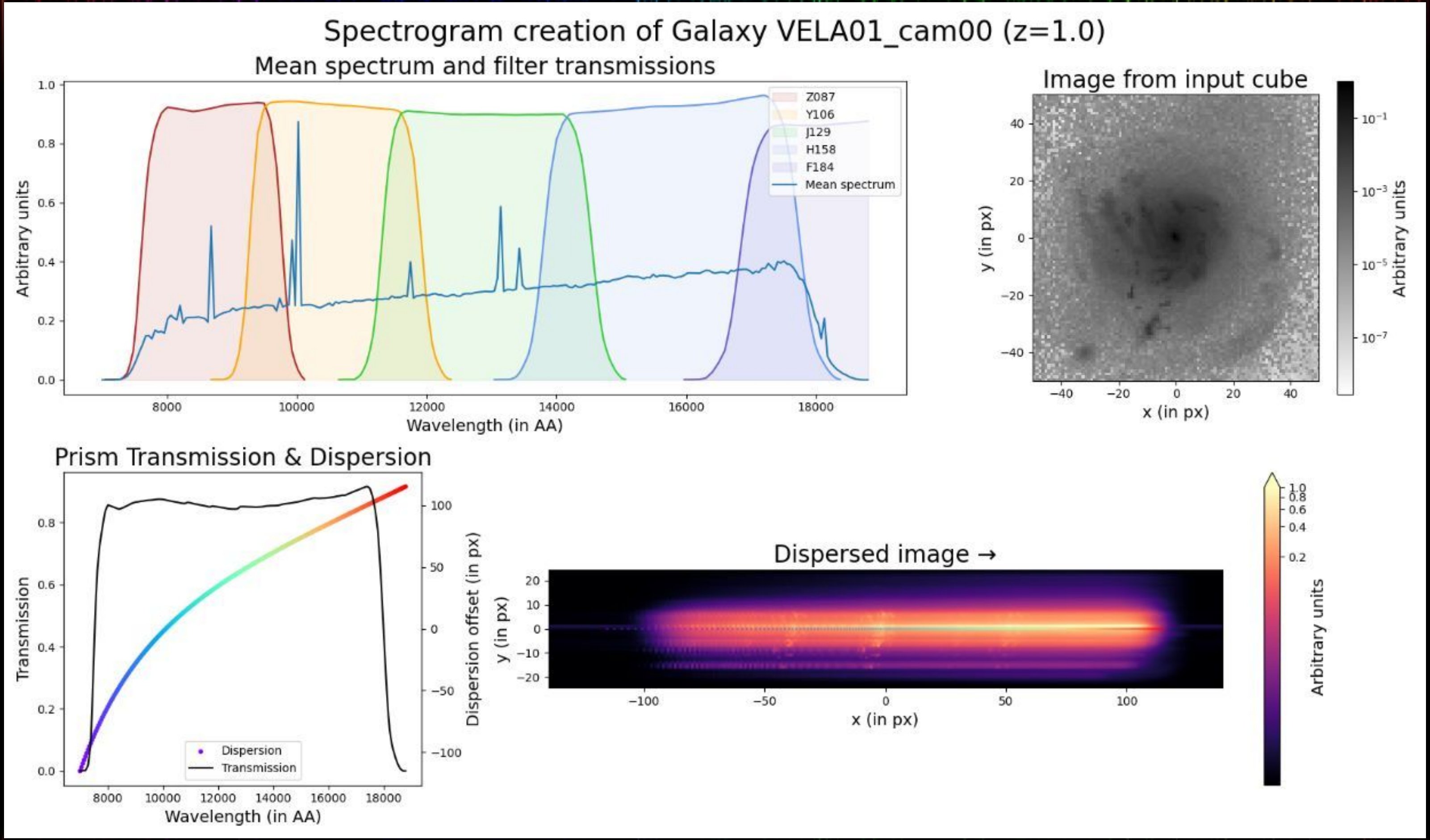
Slitless spectro-photometry

J. Neveu et al. 2024A&A...684A..21N

- AuxTel: real-time atmospheric characterization for LSST
  - Simple slitless spectrograph
- Full forward model of spectrogram to derive atmosph. parameters $\mathbf{p}_{atm}$
  - P_0: seeing × instr. PSF
  - $\Delta(\lambda)$: dispersion law
  - $S(\lambda) = S_{ref}(\lambda) \times T_{inst}(\lambda) \times T_{atm}(\lambda \mid \sec z, \mathbf{p}_{atm})$
  - T_{atm} modeled w/ libRadTran



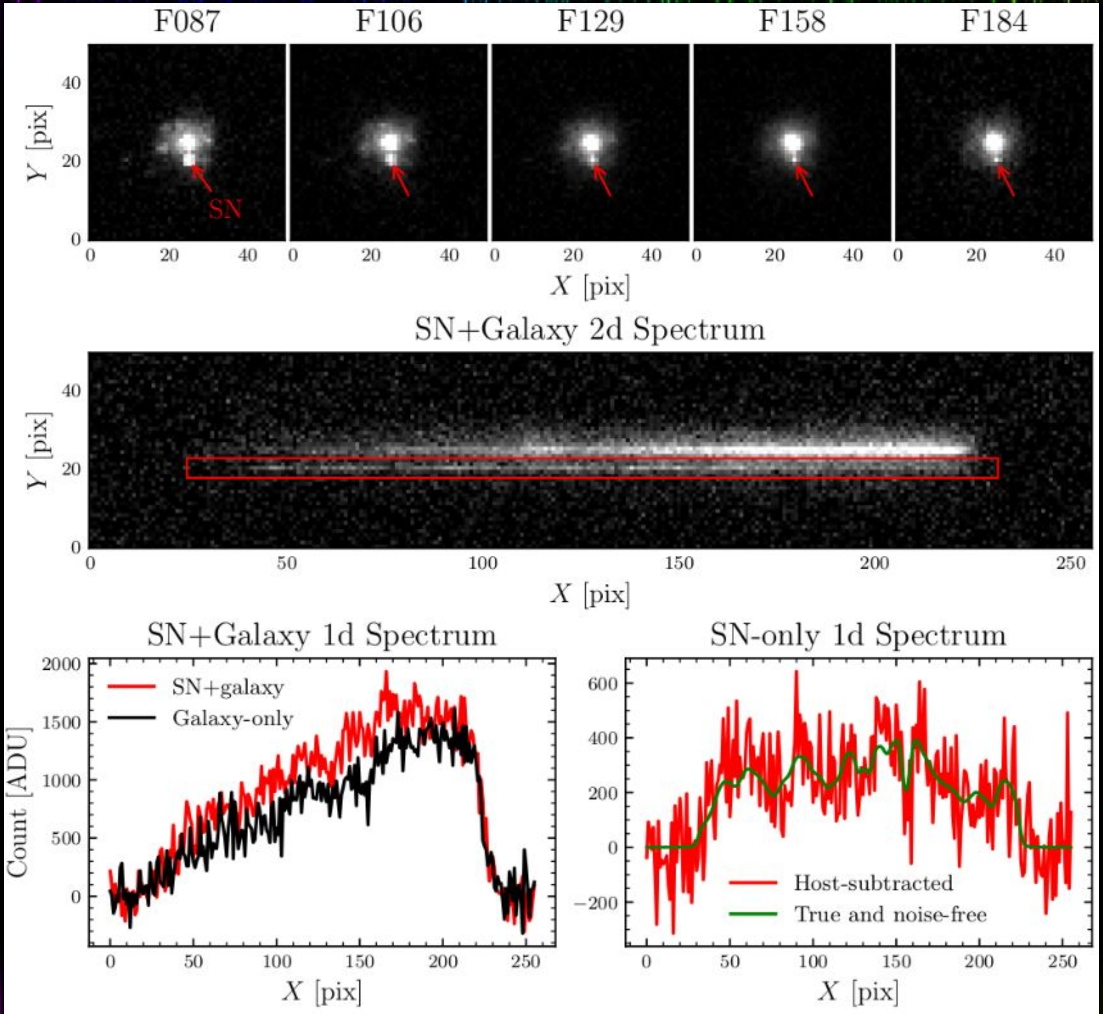
Spectrogram simulation -- Roman Sp. Telescope



3D scene reconstruction -- Roman Sp. Telescope

Simulation of a galaxy + SN at z=1.0

Astraatmadja et al. (in prep.)



Conclusions

- Slitless spectroscopy is an old yet blooming technique
  - JWST, Euclid Roman
- Slitless (“crappy”) spectroscopy = dispersed (“ultimate”) imaging
  - Self-confusion & cross-contamination still require dedicated developments
  - Phase diversity from multi-PA observations
- Adapted to “sparse” sources (spatially *or* spectrally)
  - Euclid: Hα-emitting barely-resolved galaxies
  - Roman: Supernova

BACKUP

SIR-PF roadmap

- Short term (DPRR):
  - Integrate & validate flux calibrations
  - Restore optimal extraction
    - SNR and contamination residuals
  - Include BGS
  - DEEP stacks (on WIDE cats)
  - Improve background estimate
- Longer term (DR):
  - NISP focal plane metrology
  - NIS PSF calibration
  - Higher dispersion order (-1, +2) masking or decontamination
  - 0^{th} order modeling (registration, masking)
  - Persistence masking/subtraction
  - Deep survey optimization
- Further work needed to keep CPU/memory under control