Forward modeling of galaxy kinematics in slitless spectroscopy

Credits:
M. Outini's PhD, 2019
Outini & Copin, A&A (accepted), arxiv:1910.07803

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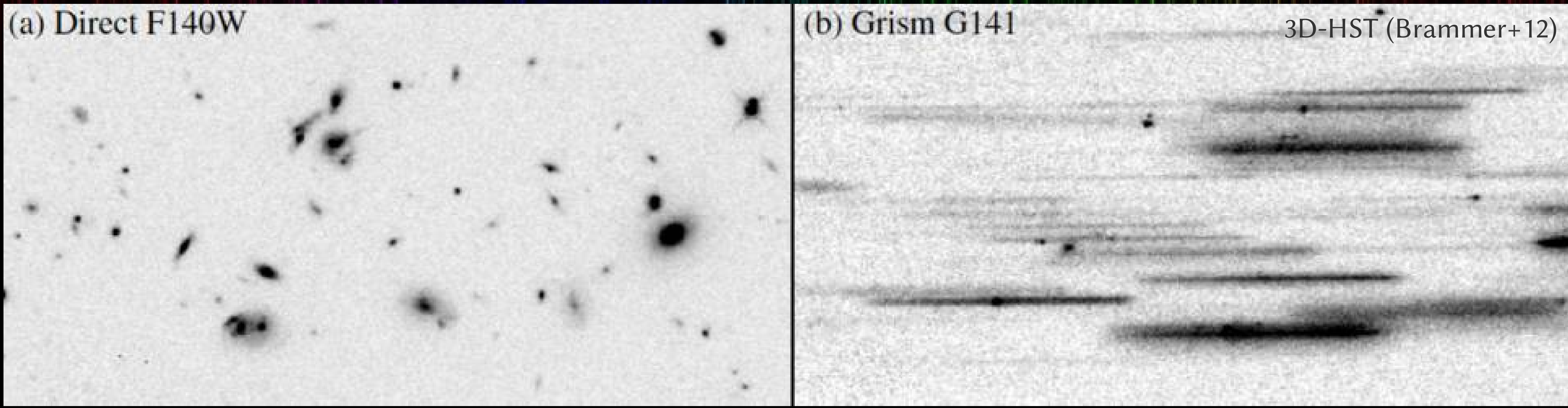
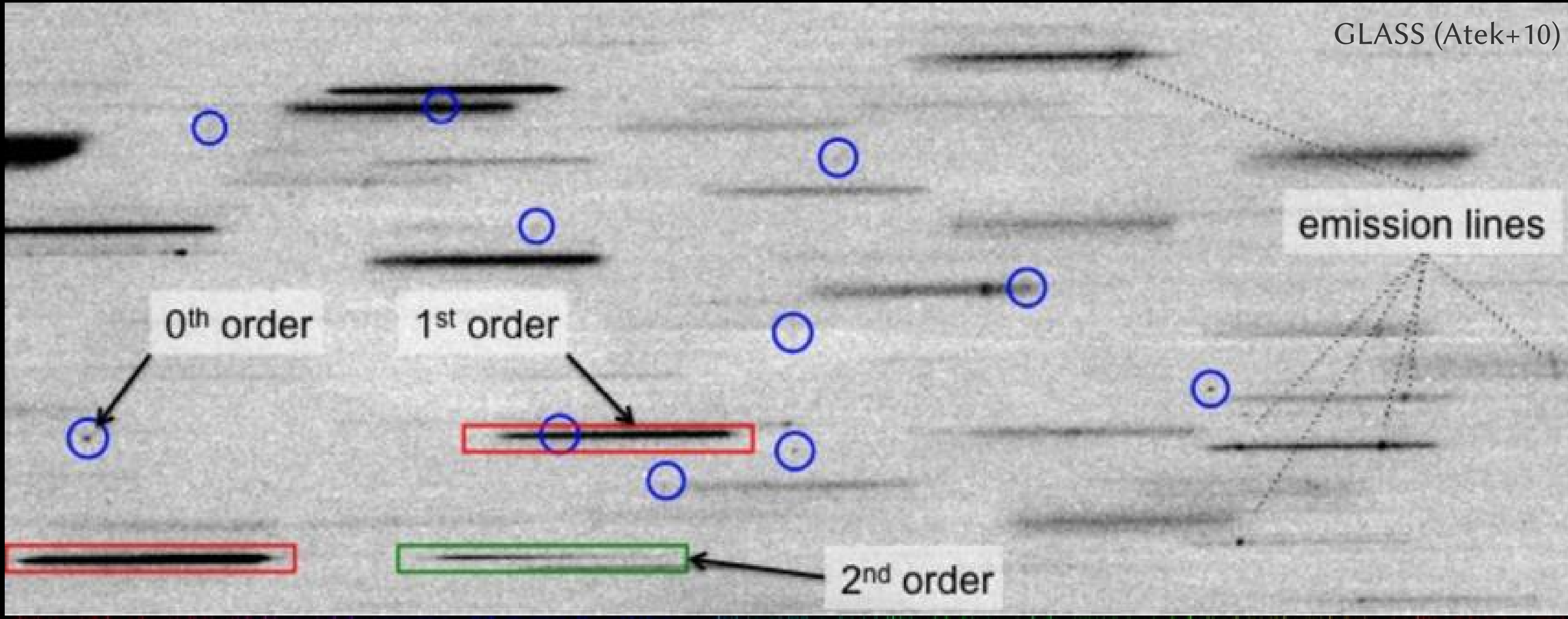
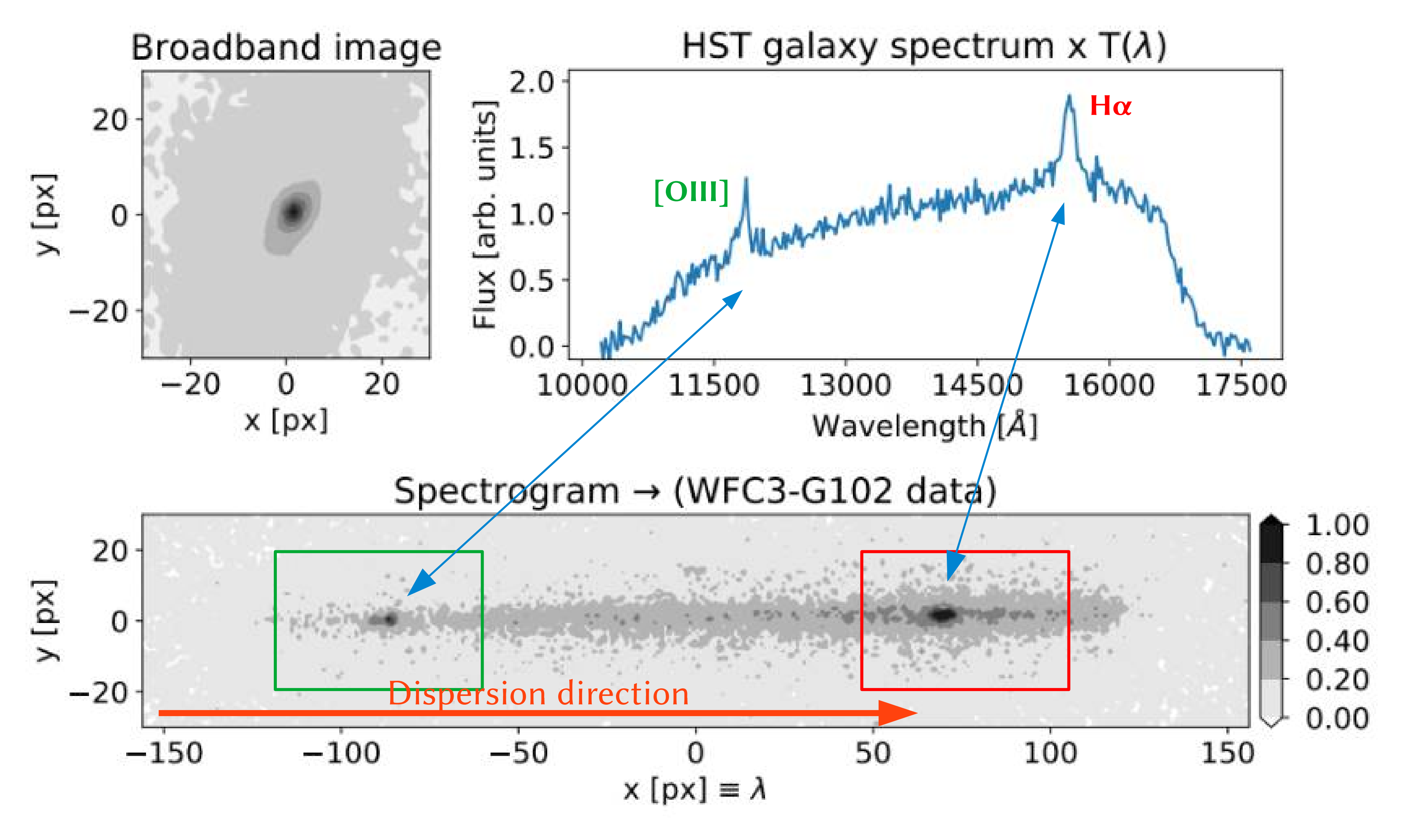
Slitless spectroscopy 101





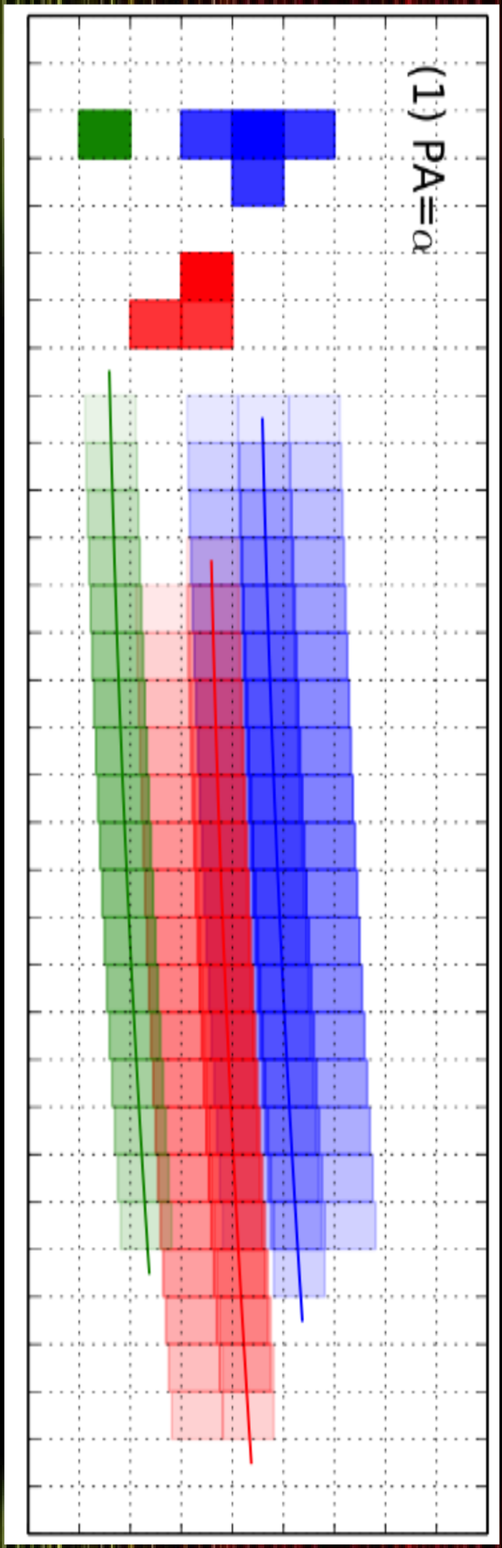
Spectrogram example



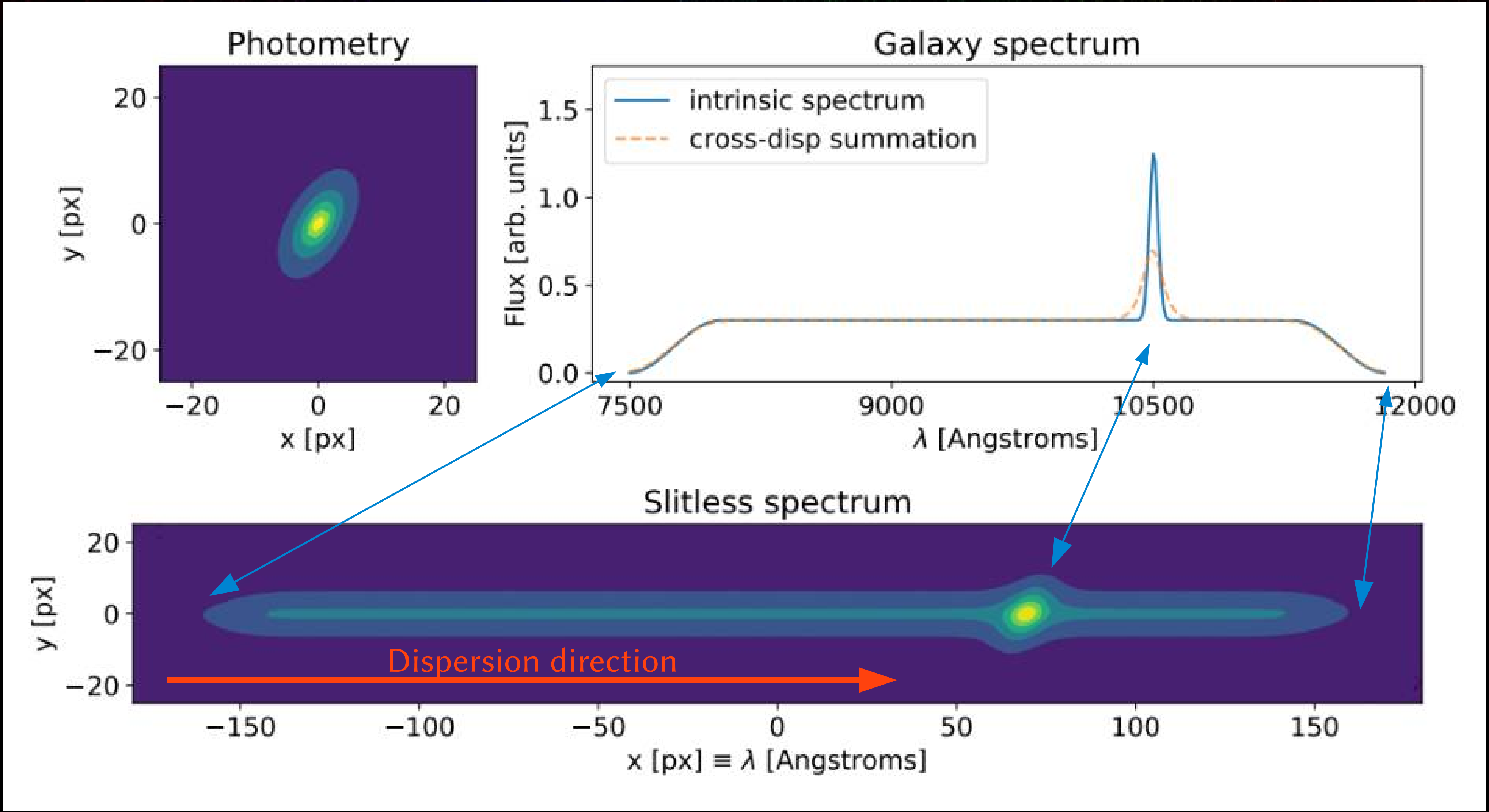
Galaxy 451-MACS2129 @ z=1.36 (HST-GLASS)

Slitless spectroscopy

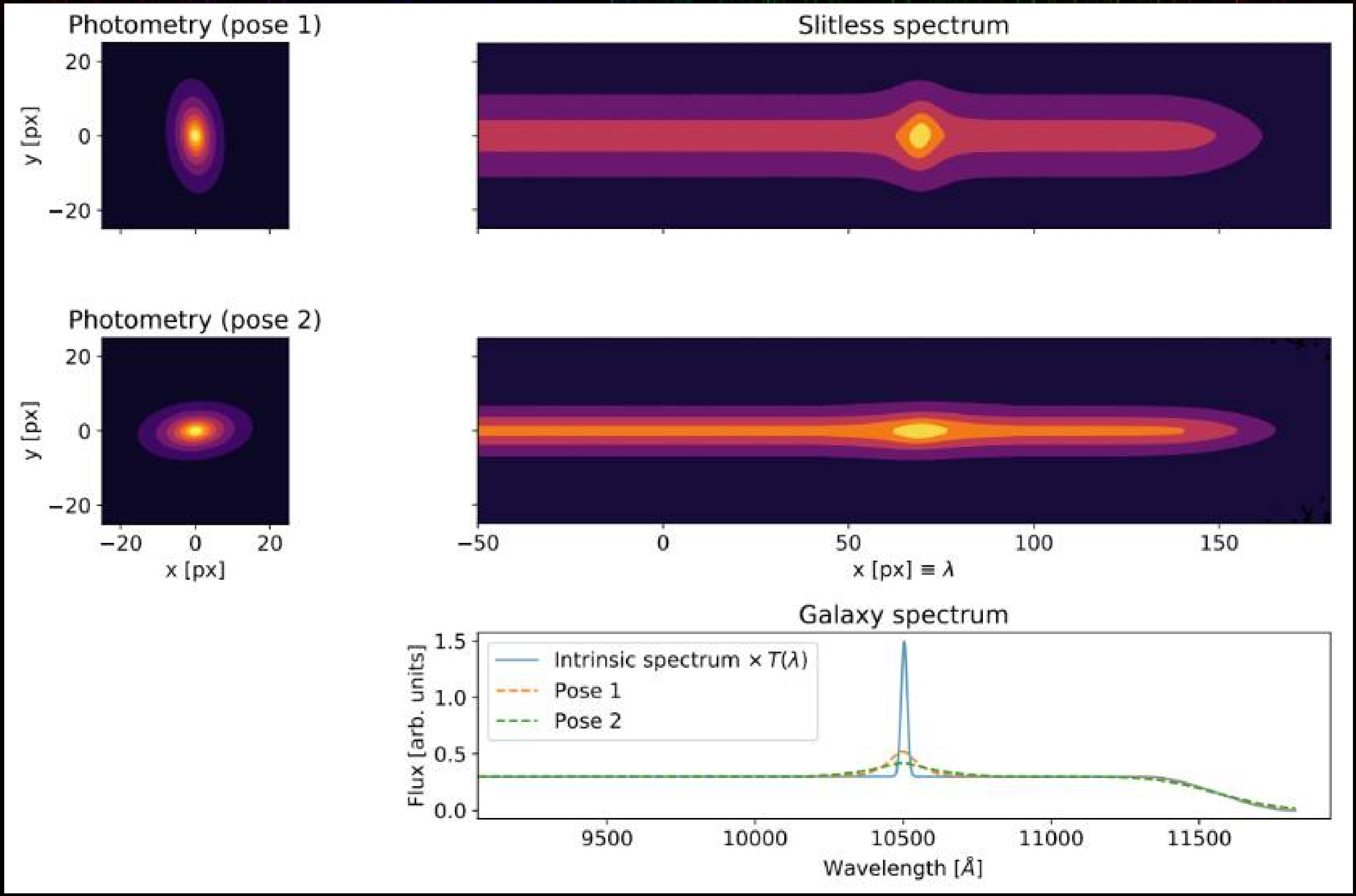
- Advantages
  - Large FoV and high multiplexing
  - Simple to build and to operate
- Drawbacks
  - (High background level ⟶ space)
  - **Cross-contamination**: overlap of different objects (potentially at different orders)
    - Mitigation: multi-roll observations & decont. model
  - **Self-contamination**: mixing of spatial and spectral information
    - Effective spectral resolution is dependent of source size and relative orientation



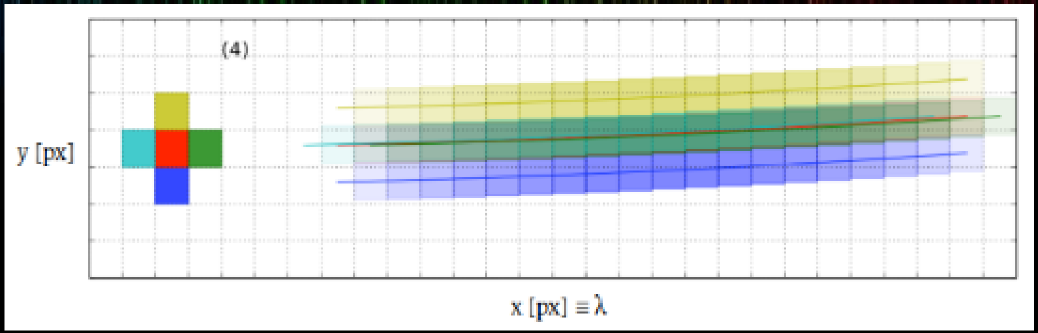
Cross-dispersion spectrum



Multi-roll x-disp. spectra



Spectrogram modeling

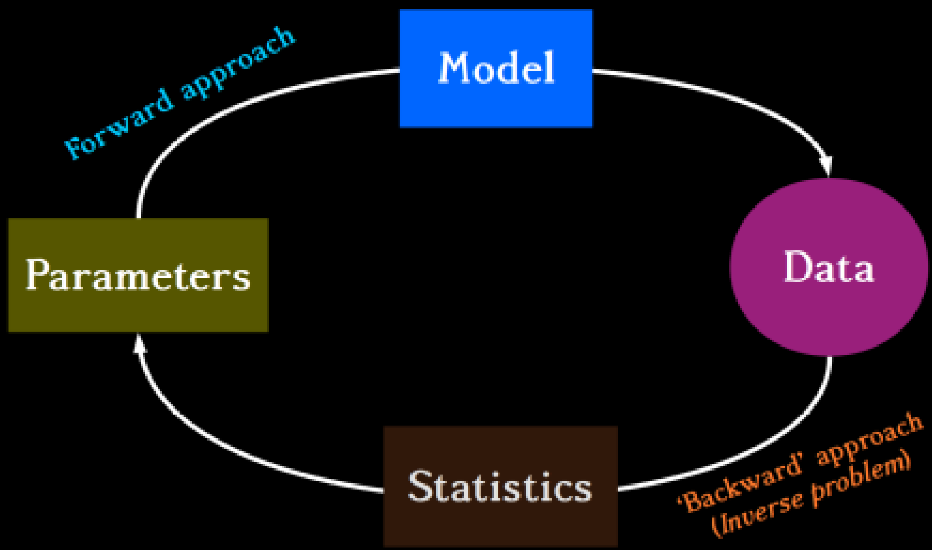


- Dispersed image

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

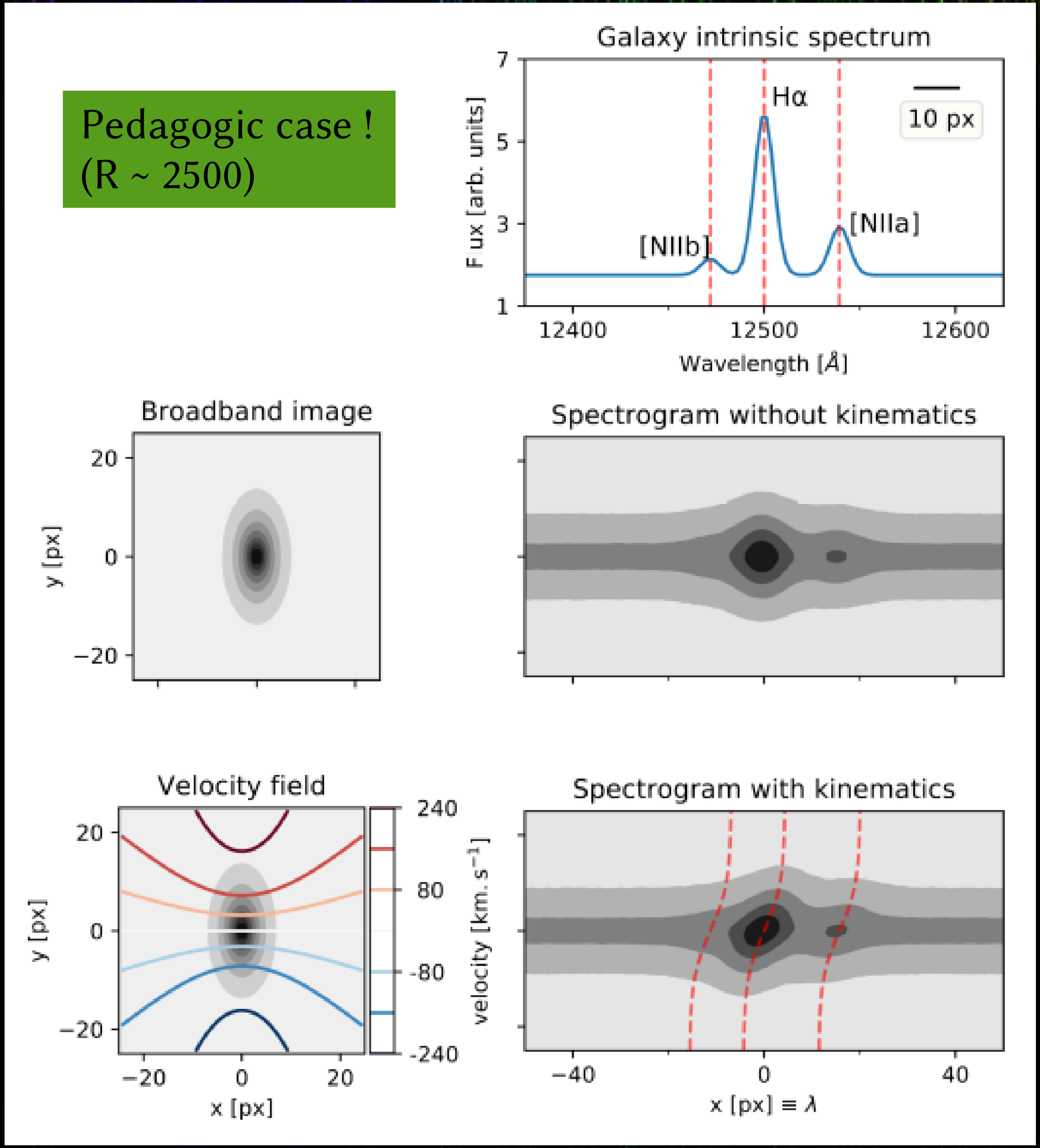
- Observation $I(\mathbf{r})$: 2D spectrogram
- Source $C(\mathbf{r}, \lambda)$: intrinsic spectro-spatial flux distribution ("cube")
- Instrumental signature
  - $P(\lambda)$: Impulse Response Function ("PSF")
  - $\boldsymbol{\Delta}(\lambda)$: dispersion law
  - $T(\lambda)$: transmission

Forward modeling



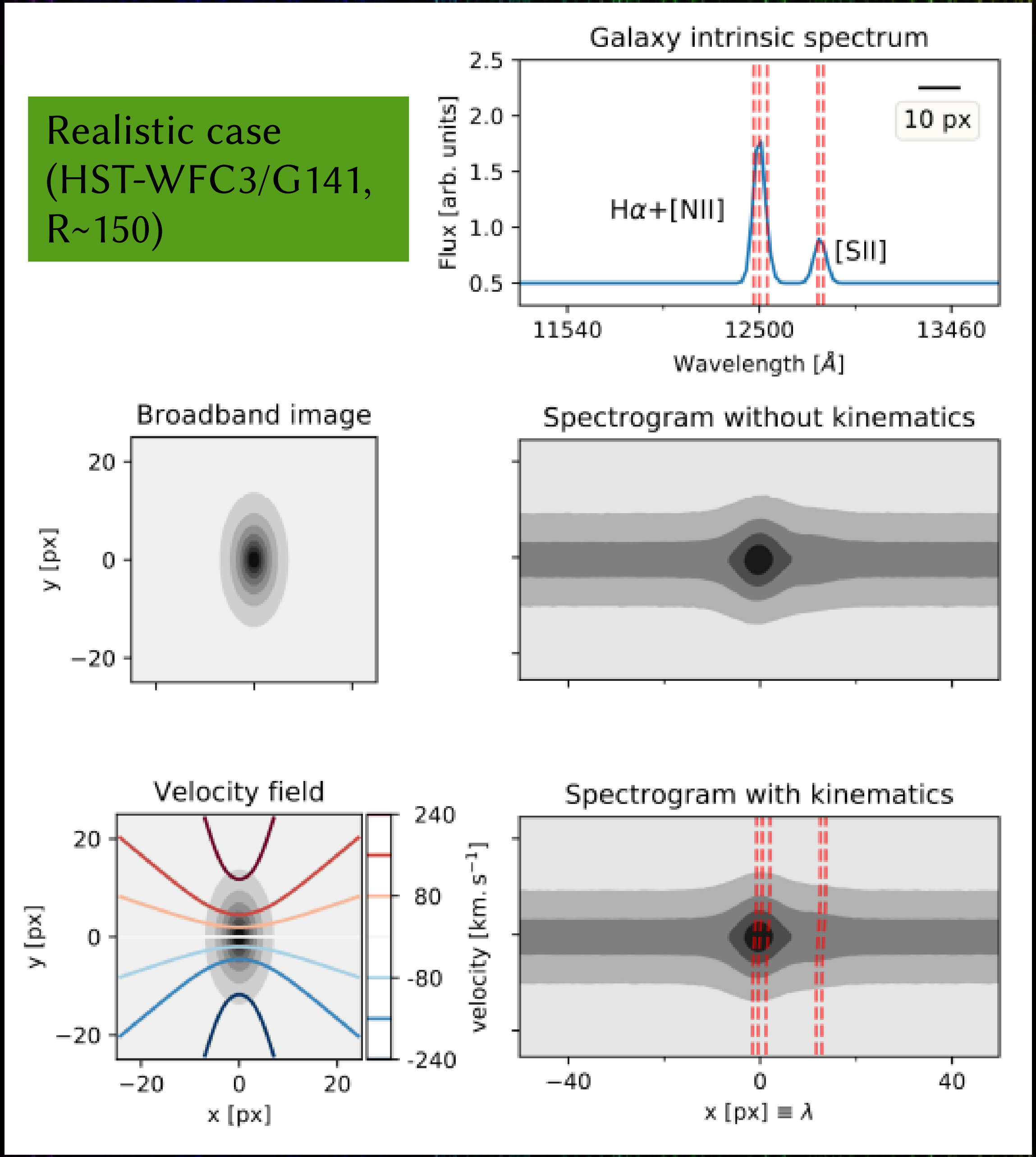
- Forward modeling
  - Build a predictive model
  - Compare predicted spectrograms to observed ones
  - Derive max-likelihood parameters
- Two stages
  - Calibration: reference source (e.g. star) ⟶ instrumental parameters
  - Science: calibrated instrument ⟶ intrinsic source parameters

Kinematic signature in slitless



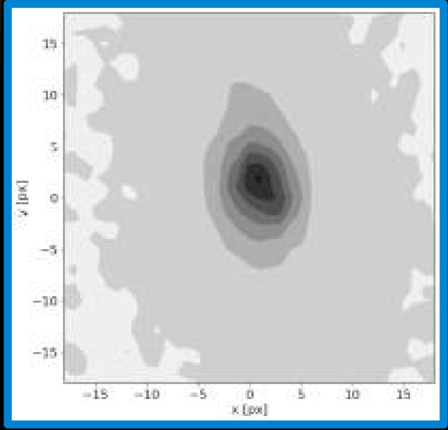
Kinematic signature in slitless

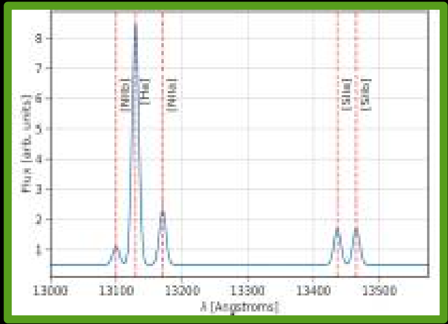
Realistic case (HST-WFC3/G141, R~150)

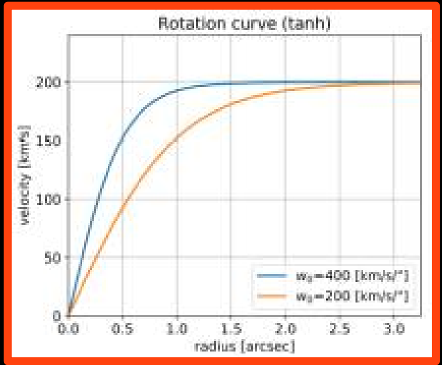


Forward model

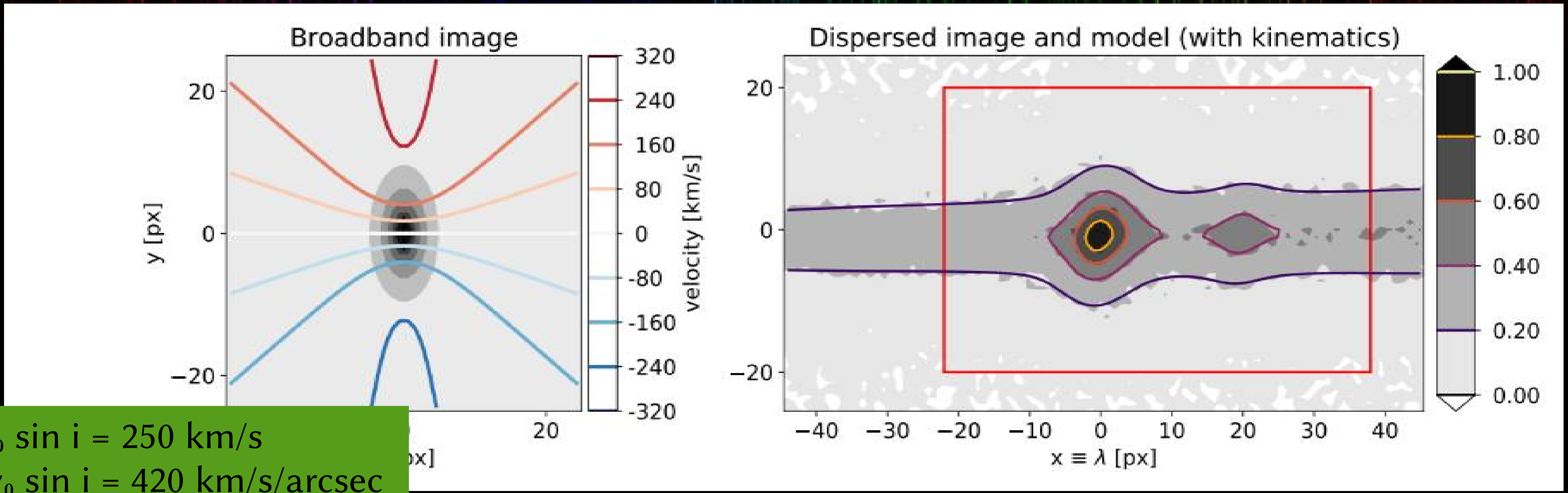
- Assumptions
  - $C(\mathbf{r}, \lambda) = F(\mathbf{r}) \times S(\lambda)$: separability (= uniformity)
  - $\int d\lambda\, F \otimes P \approx B(\mathbf{r})$: broadband image
- Spectrum: continuum + emission lines
  - Hα+[NII], [SII], [OIII], etc.
  - Parameters: redshift, amplitude, cont. level, etc.
- Velocity field: cold thin disk approximation
  - 2-parameter RC: $v(r)/\sin i = v_0 \tanh(w_0\, r \,/\, v_0)$
  - Velocity field impact: $S(\lambda) \longrightarrow S(\lambda \,/\, (1 + v(\mathbf{r})/c))$
- Instrumental parameters: supposedly known
  - Few nuisance parameters





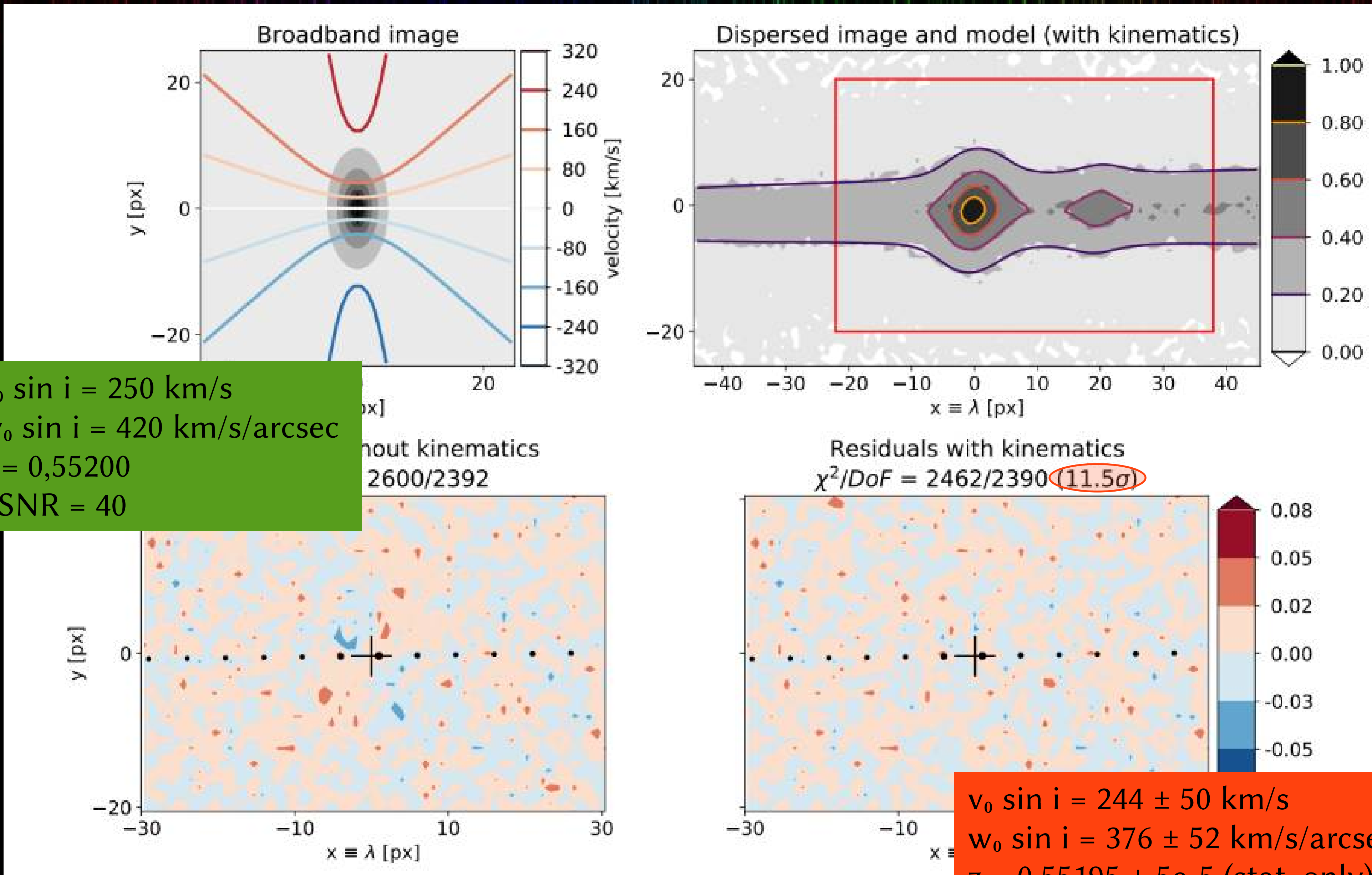


Simulations - HST-WFC3/G102



v_0 sin i = 250 km/s
w_0 sin i = 420 km/s/arcsec
z = 0,55200
PSNR = 40

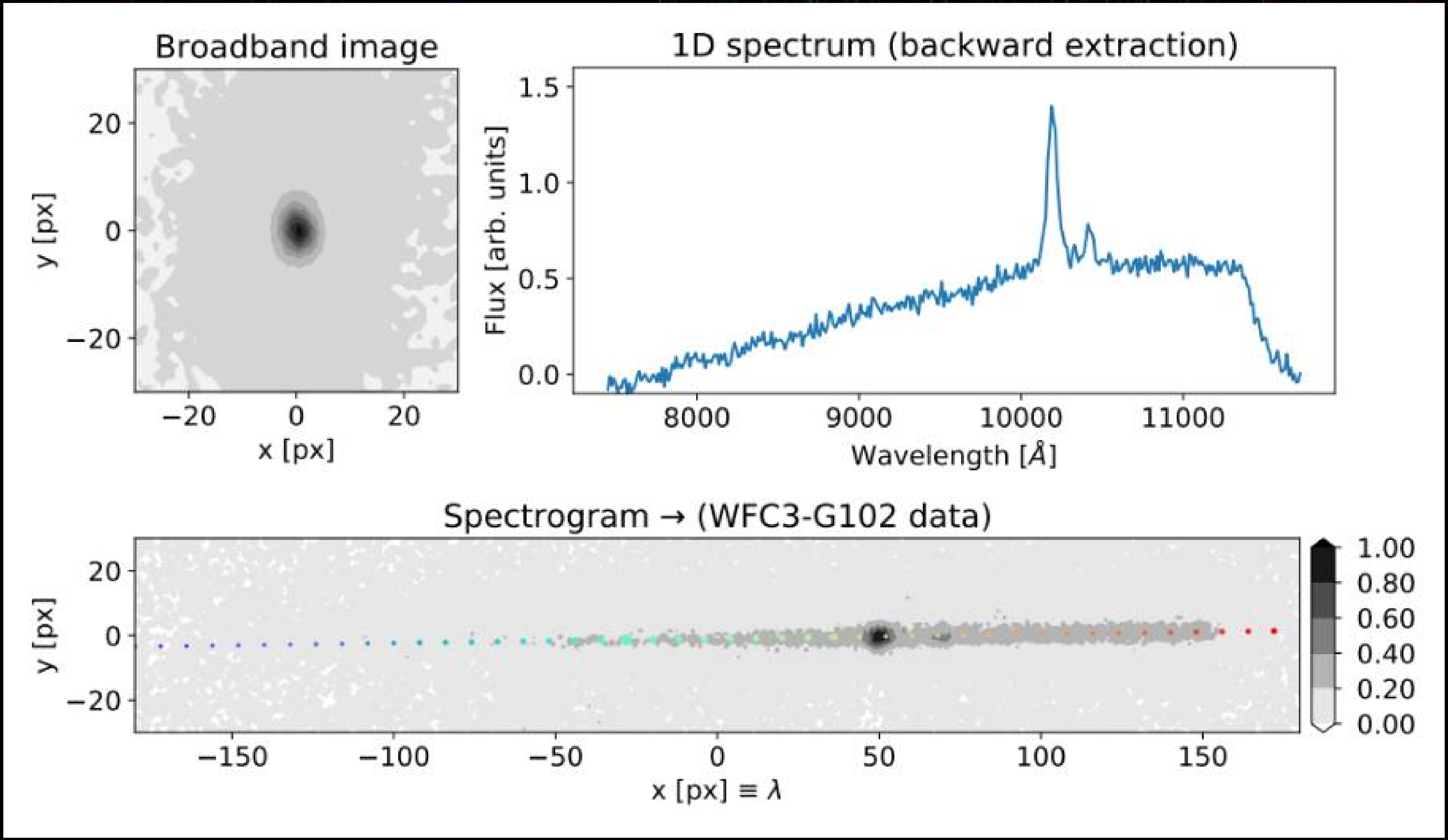
Simulations - HST-WFC3/G102



$v_0 \sin i$ = 250 km/s
$w_0 \sin i$ = 420 km/s/arcsec
z = 0,55200
PSNR = 40

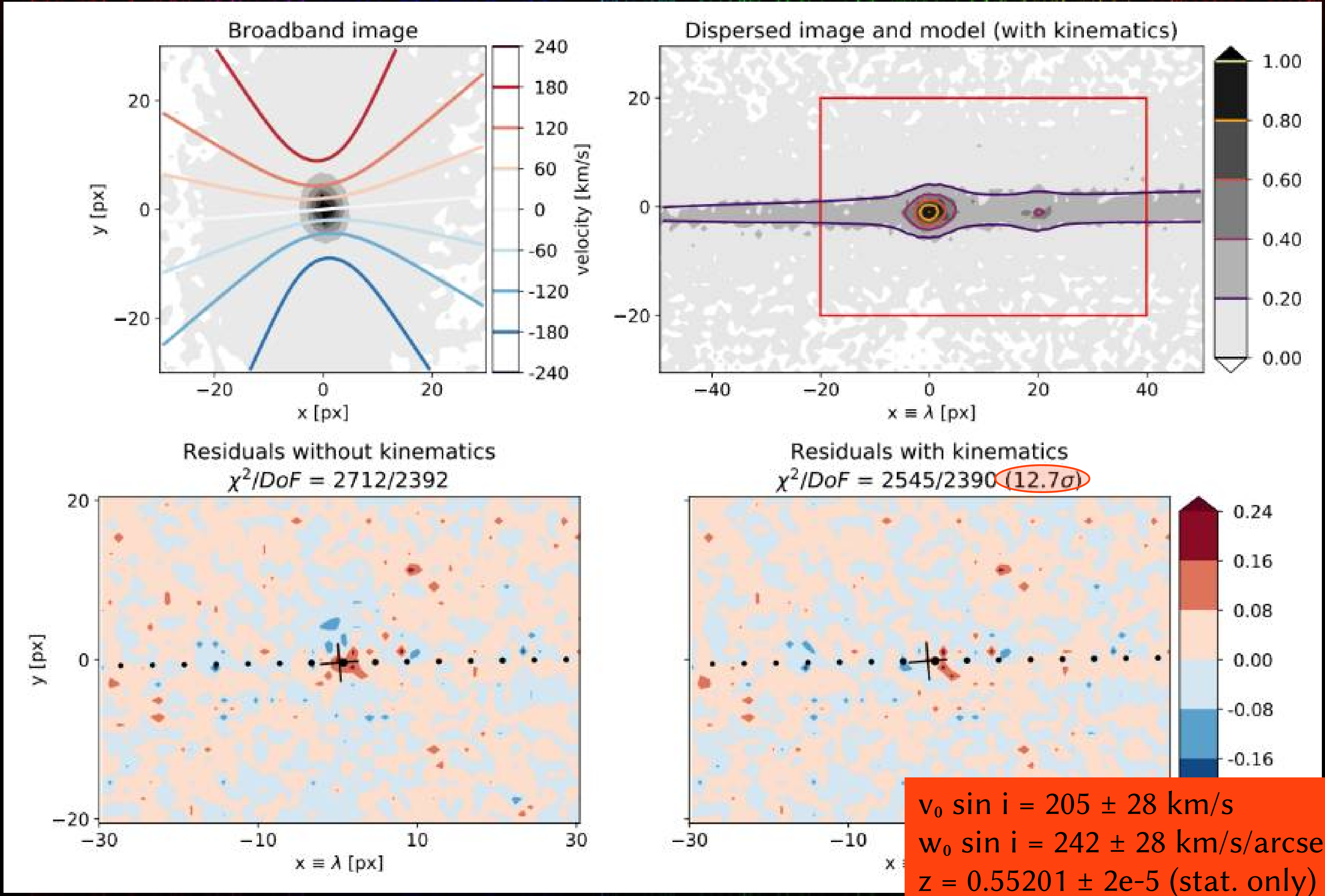
$v_0 \sin i$ = 244 ± 50 km/s
$w_0 \sin i$ = 376 ± 52 km/s/arcsec
z = 0.55195 ± 5e-5 (stat. only)

Observations - HST-WFC3/G102



Galaxy 1134-MACS1423 @ z=0.55 (HST-GLASS)

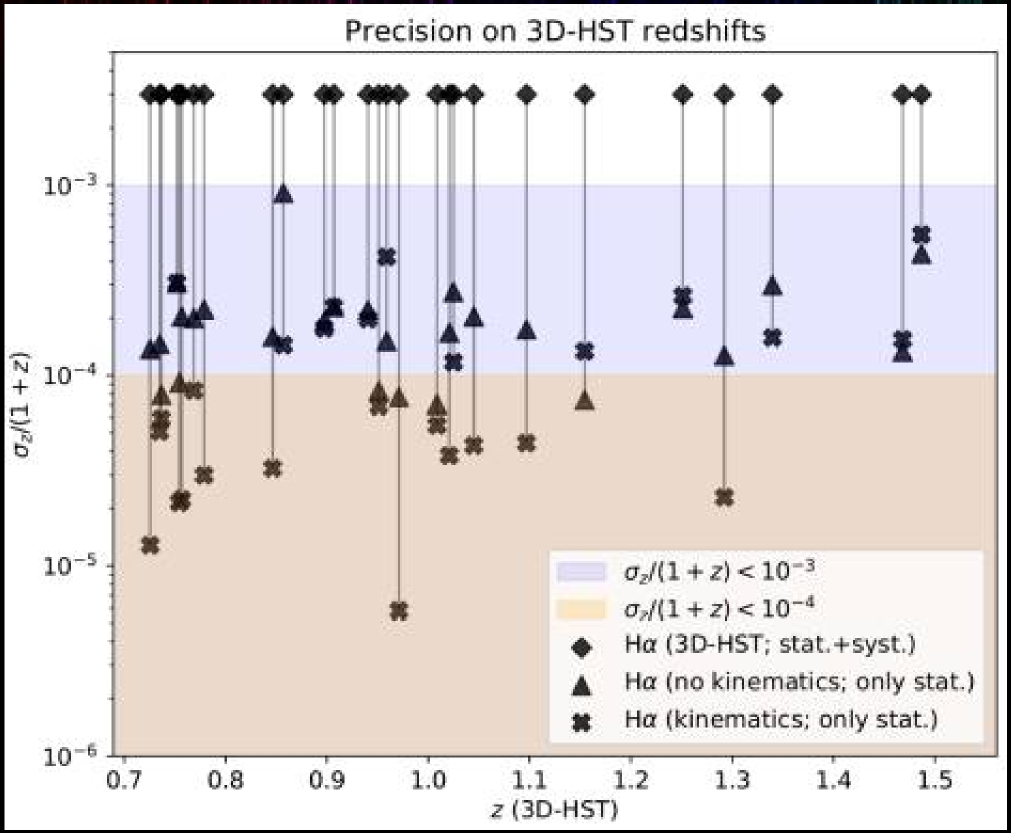
1st kin. detection from slitless spectro.



$v_0 \sin i = 205 \pm 28$ km/s
$w_0 \sin i = 242 \pm 28$ km/s/arcsec
$z = 0.55201 \pm 2e-5$ (stat. only)

Outini & Copin, A&A (accepted), arxiv:1910.07803

Impact on redshift measurements (HST)



Backward, syst. + stat. : 3e-3

Forward, no kinematics,
stat. only : ~ 2-3e-4

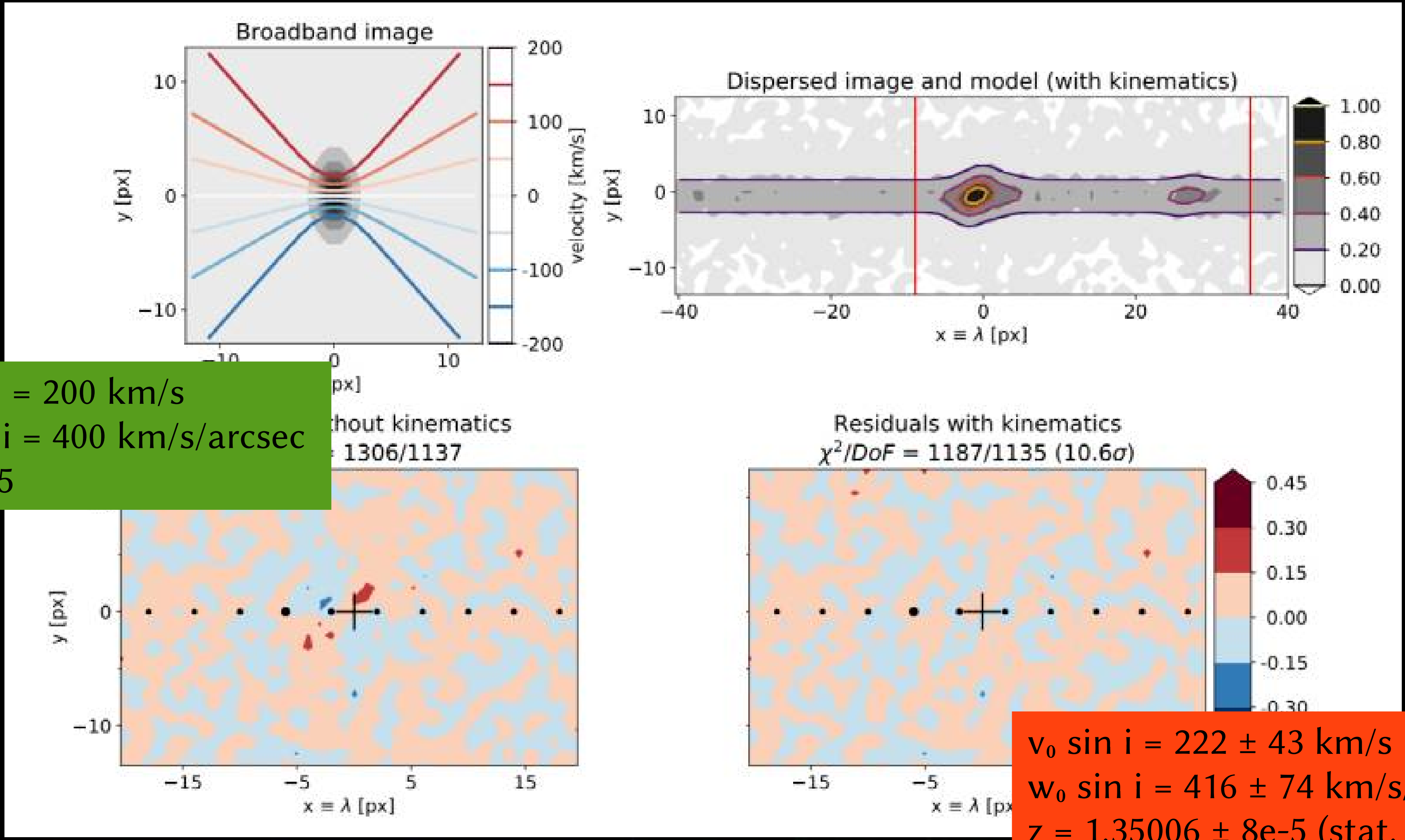
Forward, kinematics,
stat. only : ~1e-4 or better

- Redshift
  - Significant improvement for resolved galaxies, scale with multi-roll observations
  - Could easily be generalized to spectral template fitting (no 2D⟶1D info loss)
- Galaxy kinematics: only for bright, large, massive disk galaxies

Euclid simulations – NISP-R

- Better spectral sampling (~13 A/px)
- Coarser spatial resolution (0.3 ''/px)

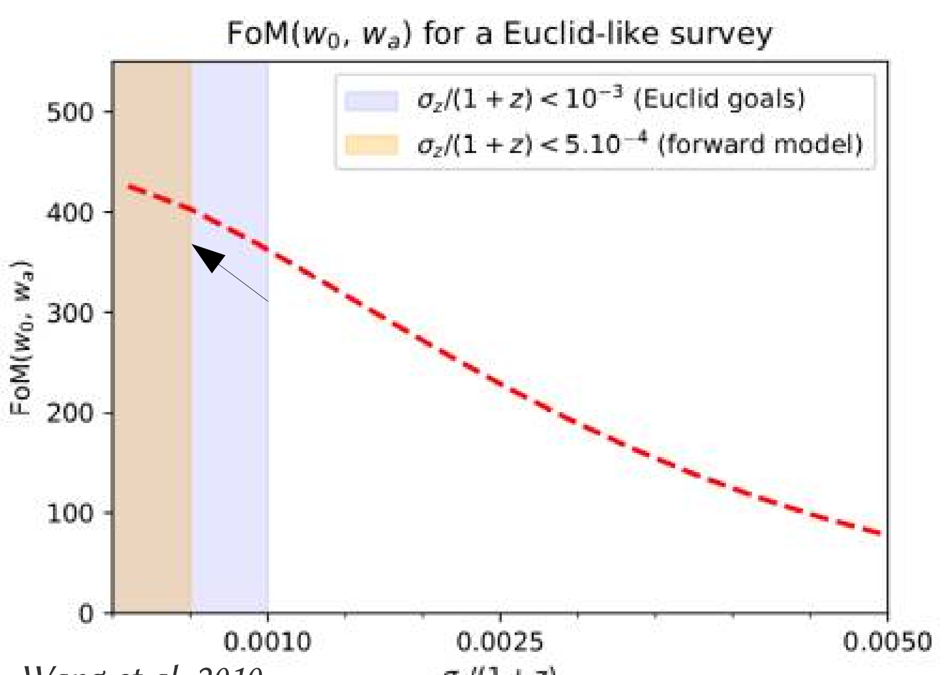
- Exp. disk, r_d ~ 0.5''
- Simulation of a single roll (dither)



v_0 sin i = 200 km/s
w_0 sin i = 400 km/s/arcsec
z = 1.35

v_0 sin i = 222 ± 43 km/s
w_0 sin i = 416 ± 74 km/s/arcsec
z = 1.35006 ± 8e-5 (stat. only)

Impact on FoM



Wang et al. 2010

- Full forward model
  - Both for calibration and science analysis
- Foreseeable redshift precision: $\sigma_z/(1+z) \sim 5e\text{-}4$
  - ×2 better than requirements
- FoM prediction (Wang+10, Red Book)
  - $F_{H\alpha} > 4e\text{-}16$ erg/s/cm², $0.5 < z < 2.1$, 20 000 deg², $e = 0.5$
  - Forward model: FoM + 15%

Conclusions

- Better understanding of slitless spectroscopy
  - Still, fundamental spectro-spatial degeneracy cannot be recovered
- Call for full forward modeling (calibration + analyses)
  - Optimal treatment of available observations
    - Calibration: instrument model ⟶ minimize overhead
  - Major impact on redshift precision for resolved sources
  - Natural method for decontamination
- Galaxy kinematics w/ Euclid
  - Possible for a small fraction (yet to be quantified) of 30M galaxies
    - Definitely easier in the Deep Survey (deeper, ~40 rolls)
  - Open new perspectives: morpho-kinematic classification, distance estimates (e.g. Tully-Fisher), cosmography & cosmology

To be continued…