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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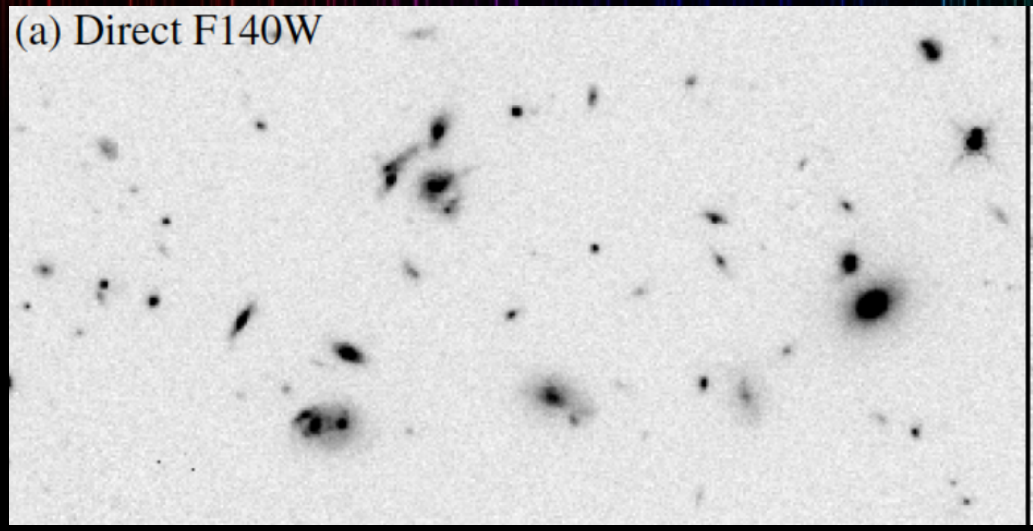
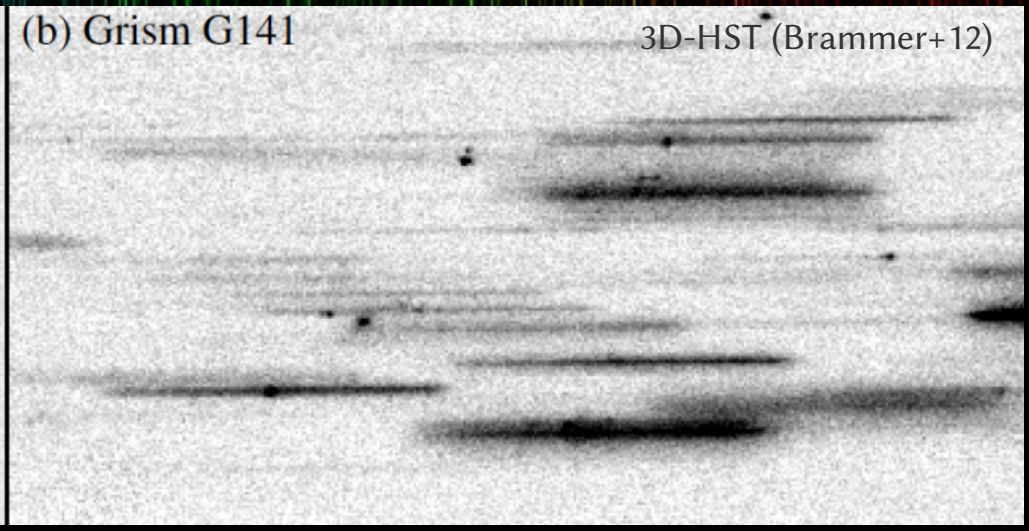
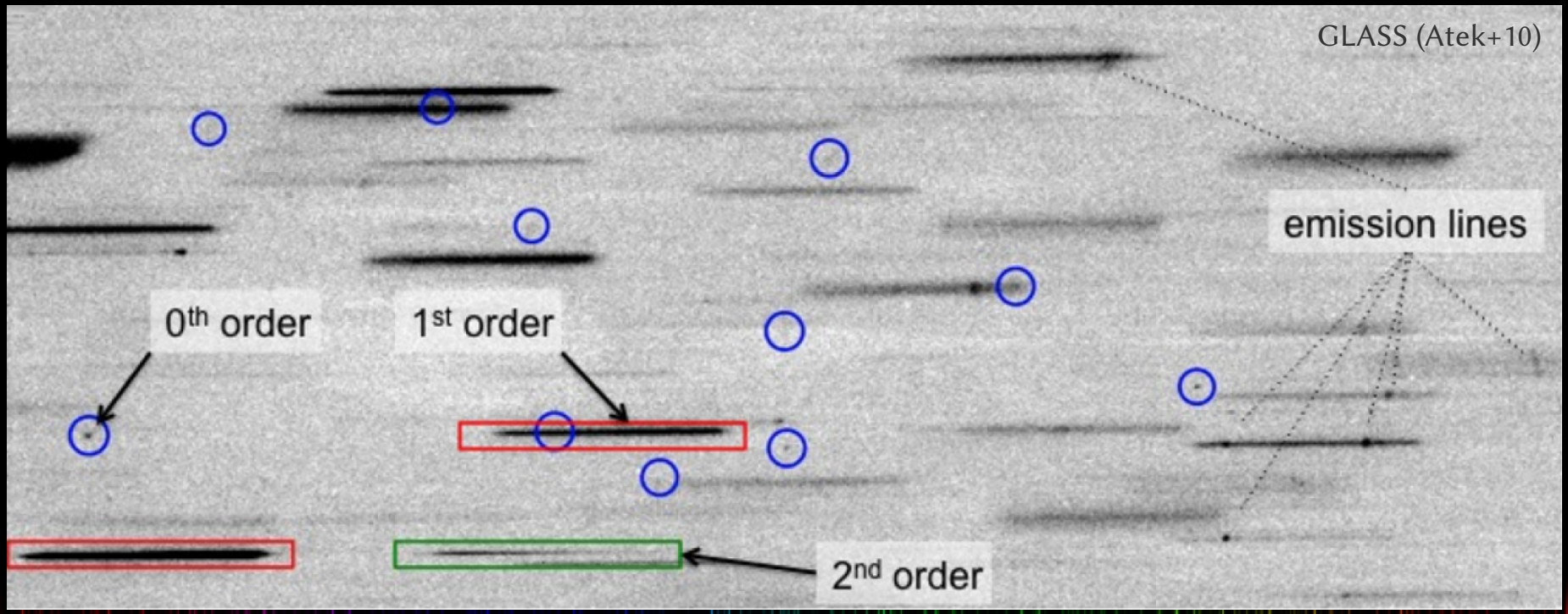
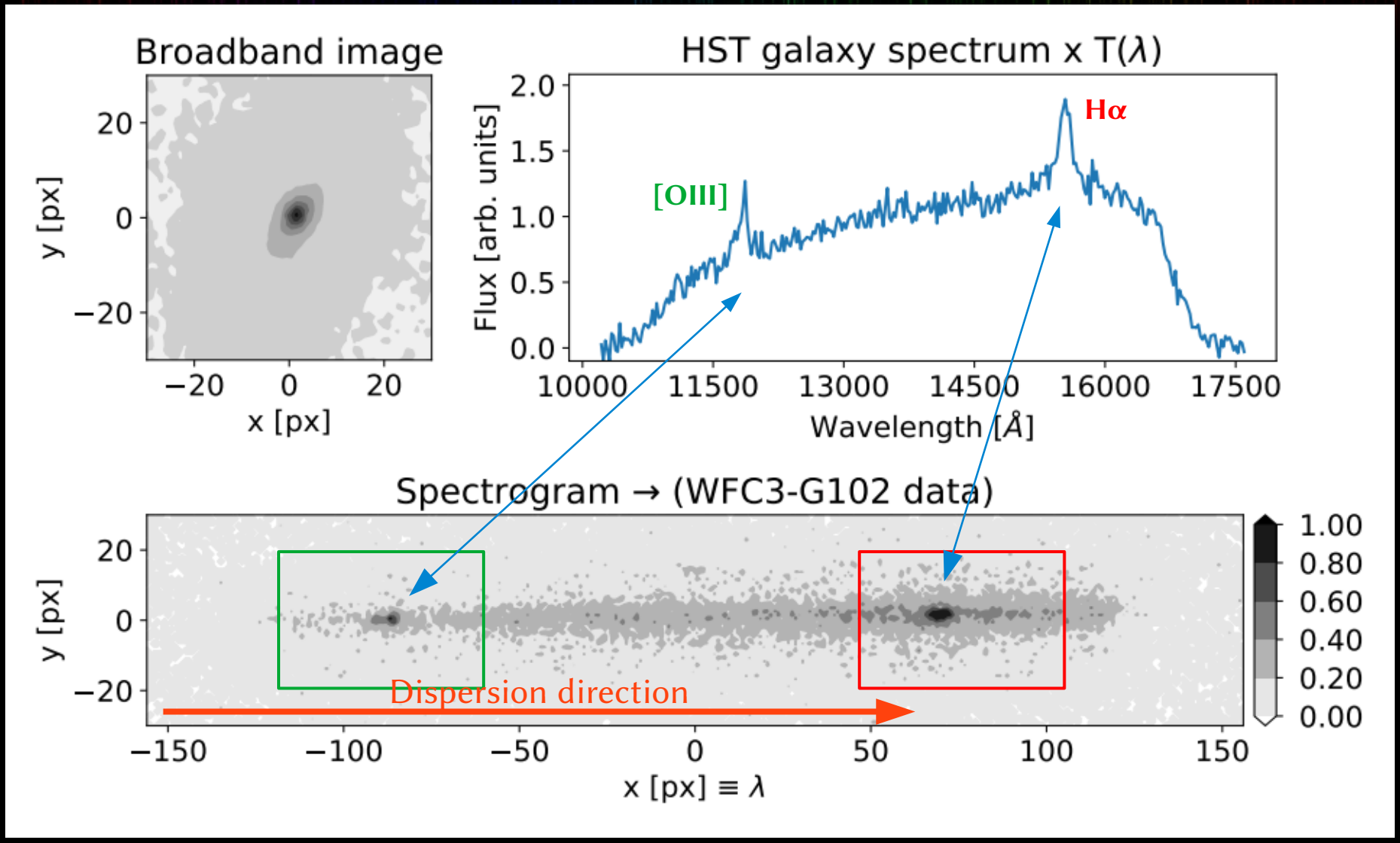
Slitless spectroscopy 101







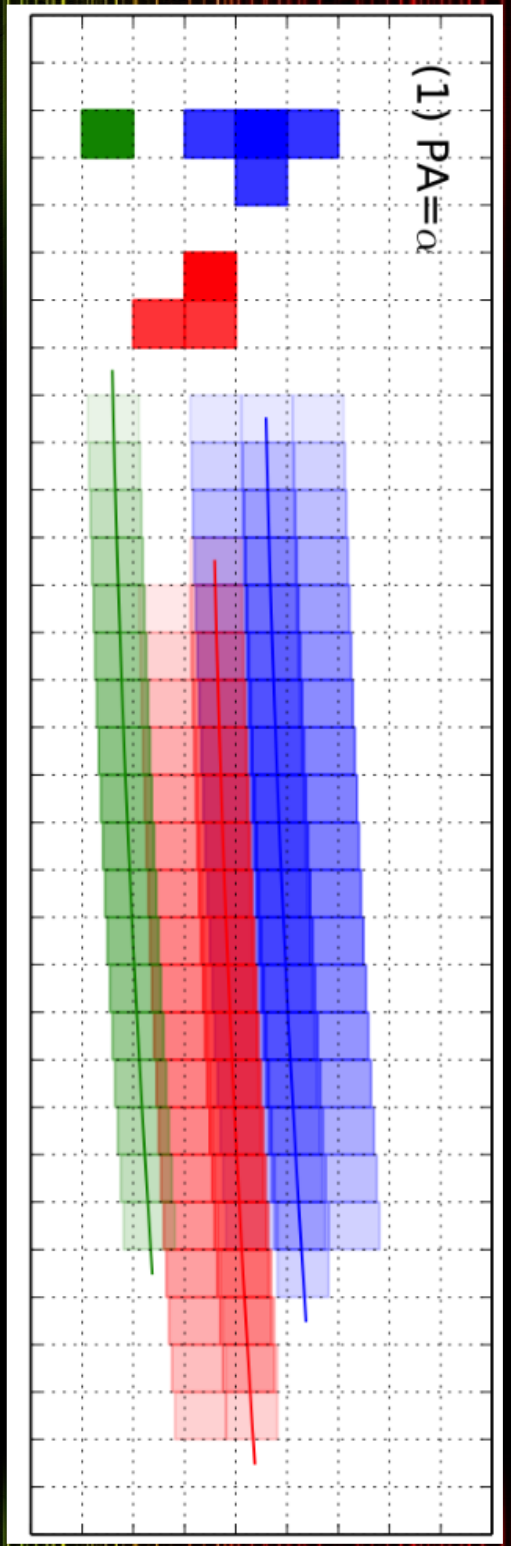
Spectrogram example



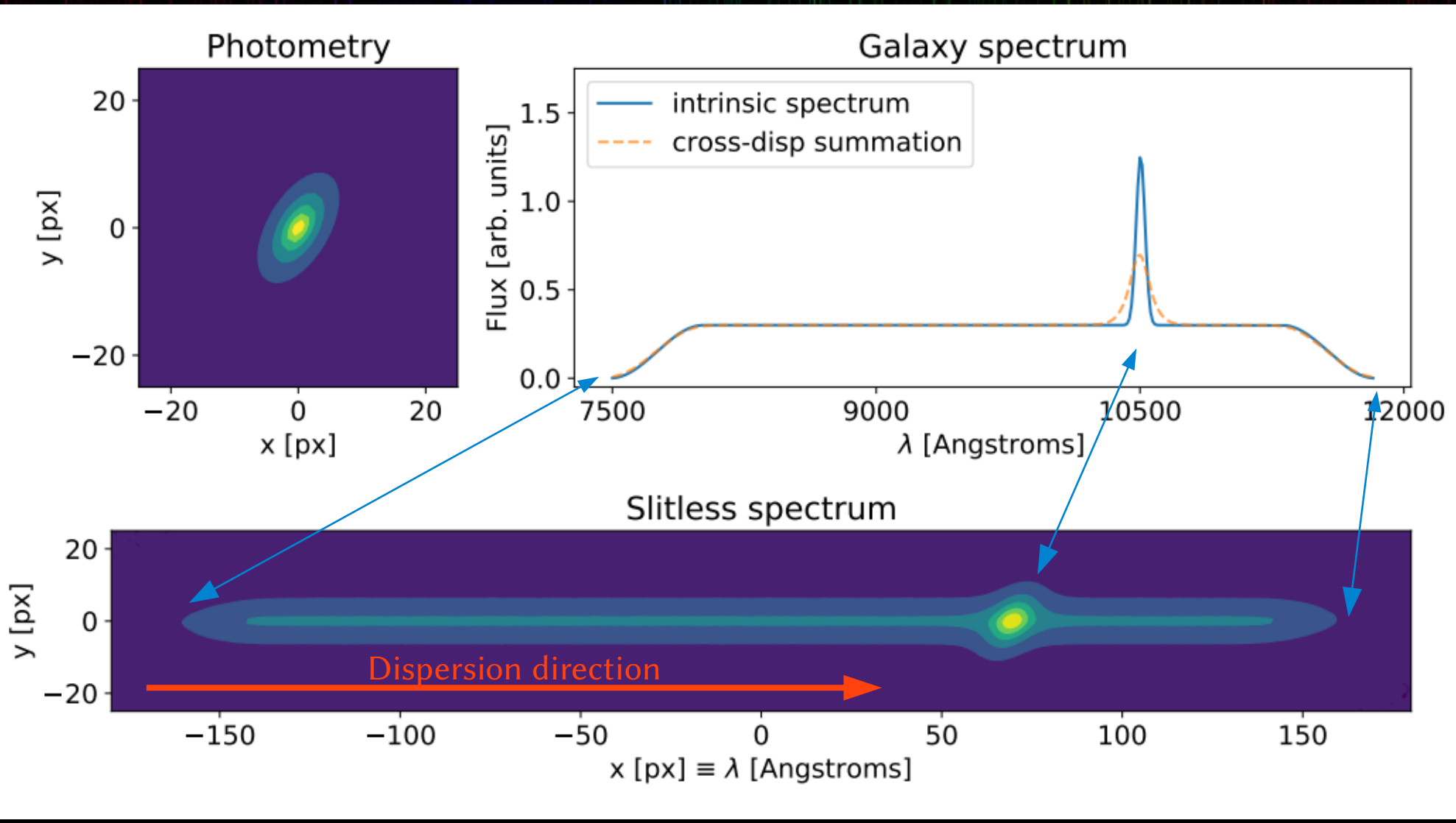
Galaxy 451-MACS2129 @ z=1.36 (HST-GLASS)

Slitless spectroscopy

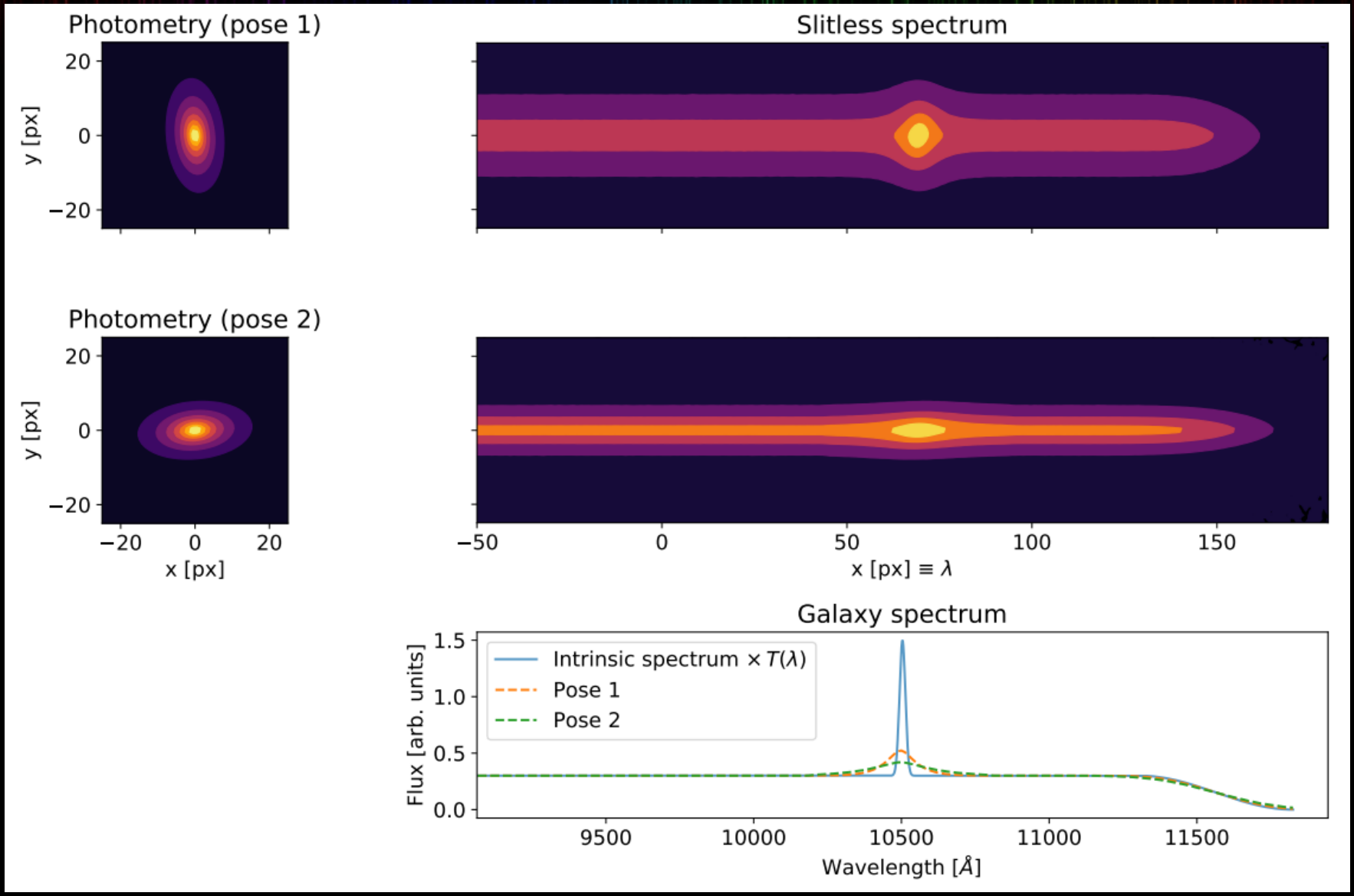
- Advantages
  - Large FoV and high multiplexing
  - Simple to build and to operate
- Drawbacks
  - (High background level ⟶ space)
  - **Cross-contamination**: overlap of different objects (potentially at different orders)
    - Mitigation: multi-roll observations & decont. model
  - **Self-contamination**: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



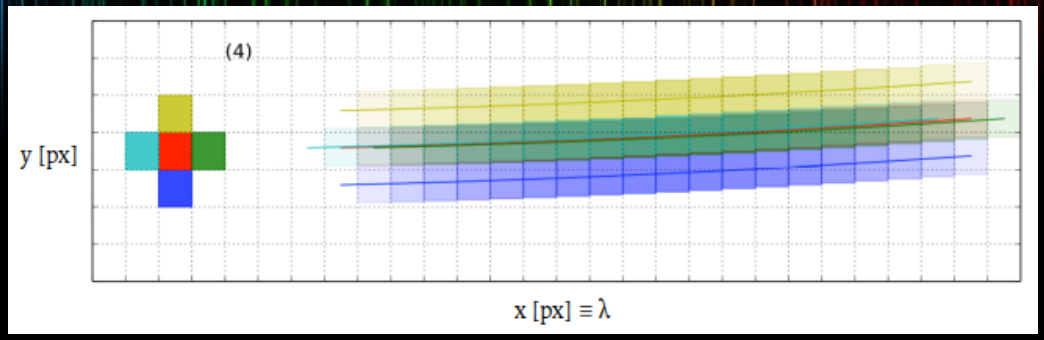
Cross-dispersion spectrum



Multi-roll x-disp. spectra



Spectrogram formation



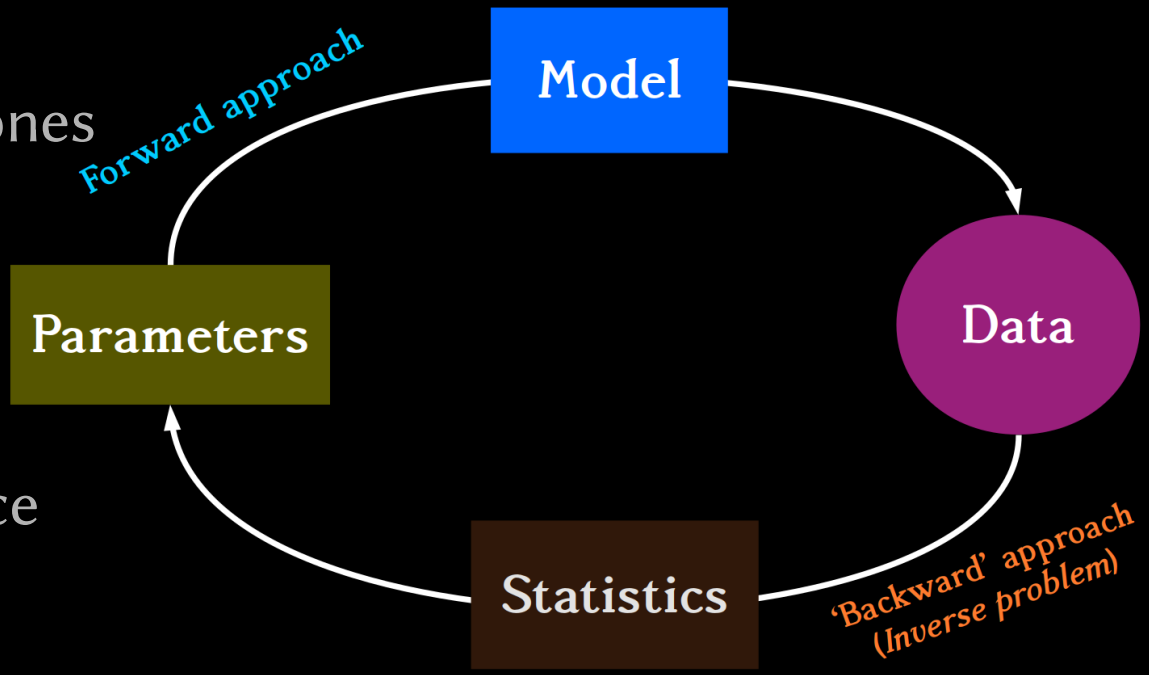
- Dispersed imaging

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

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

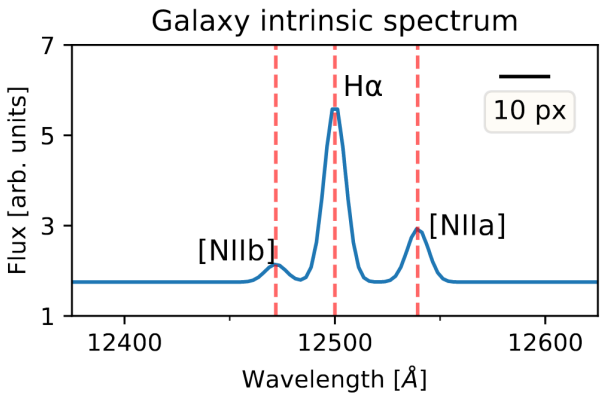
Forward modeling

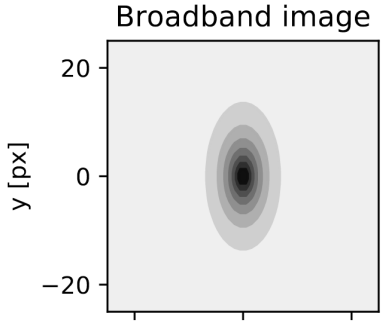
- Forward modeling
  - Build a predictive model
  - Compare predicted spectrograms to observed ones
  - Derive max-likelihood parameters
- Two stages
  - Calibration: reference source (e.g. star) ⟶ instrumental parameters
  - Science: calibrated instrument ⟶ intrinsic source parameters

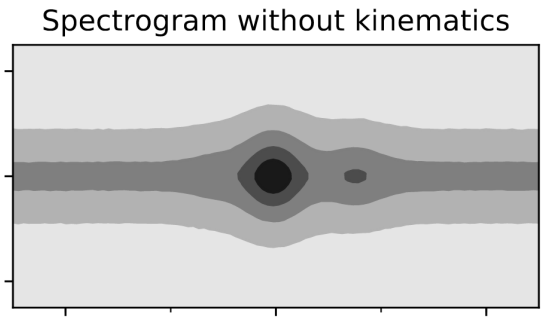


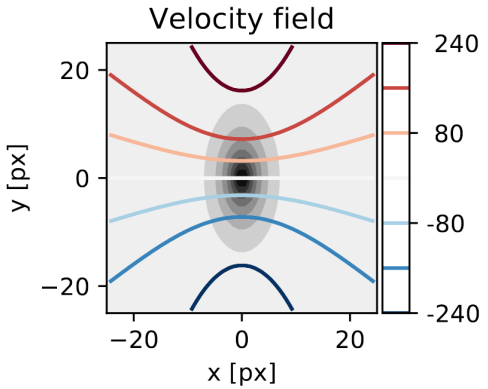
Kinematic signature in slitless

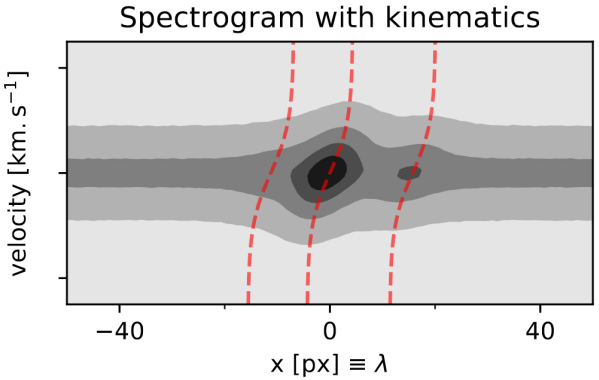
Pedagogic case !
(R ~ 2500)









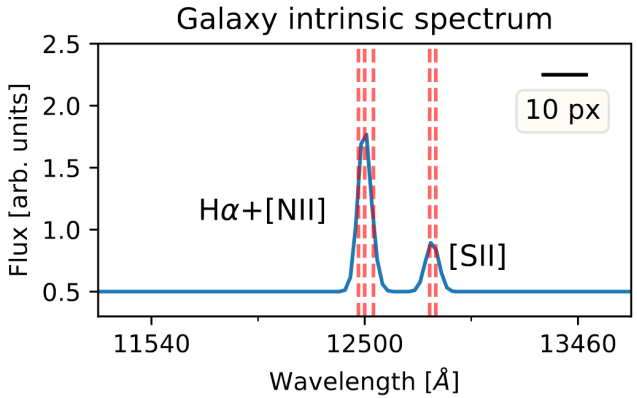


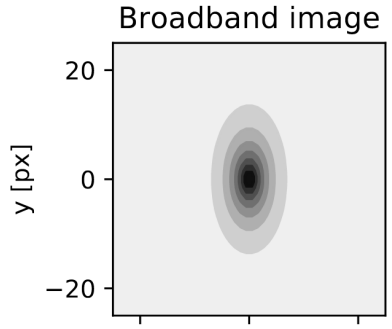
No kinematics

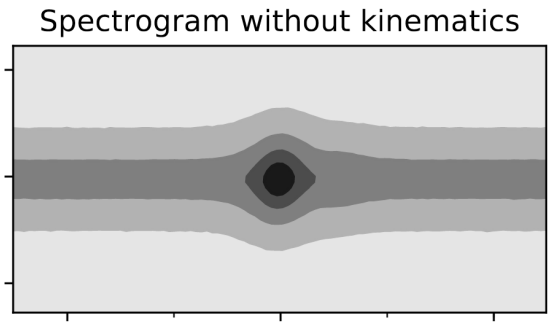
With kinematics
- Velocity curve signature
- Degeneracy between PA and velocity gradient (single roll)
- Competition between disk length and velocity radius

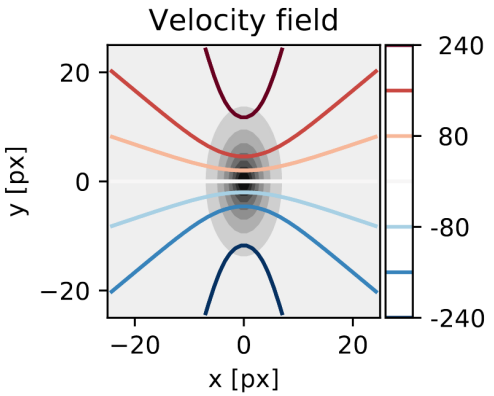
Kinematic signature in slitless

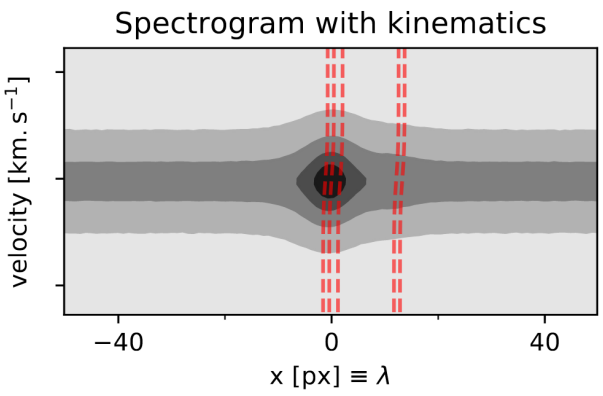
Realistic case (HST-WFC3/G141, R~150)









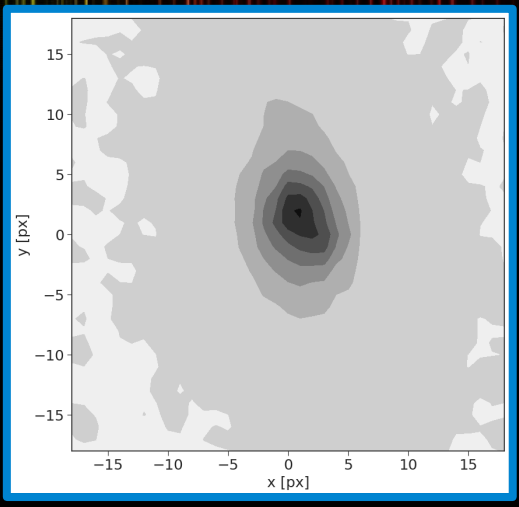


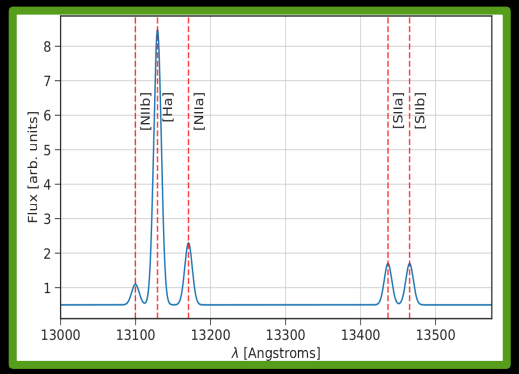
No kinematics
Hα & [NII] fully blended

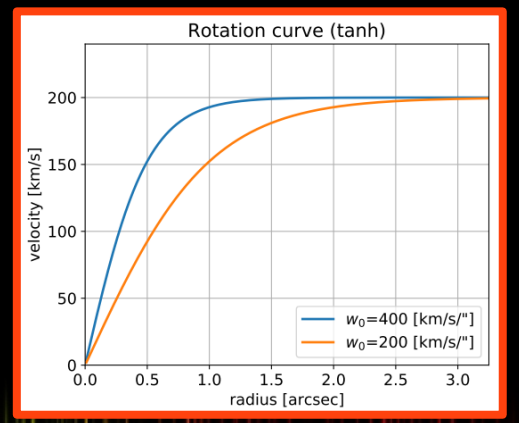
With kinematics
- sub-px kinematic signature

Our spectrogram model

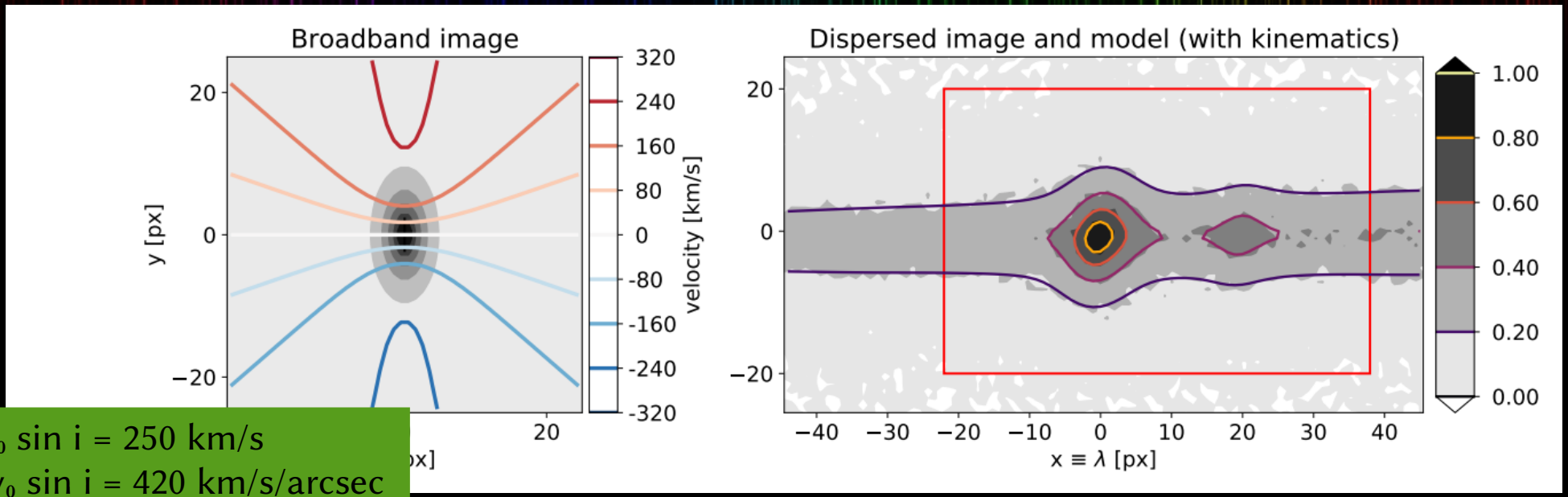
- Assumptions
  - $C(\mathbf{r}, \lambda) = F(\mathbf{r}) \times S(\lambda)$: separability (= uniformity)
  - $\int d\lambda\, F \otimes P \approx B(\mathbf{r})$ broadband image
- Spectrum: continuum + emission lines
  - Hα+[NII], [SII], [OIII], etc.
  - Parameters: redshift, amplitude, cont. level, 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





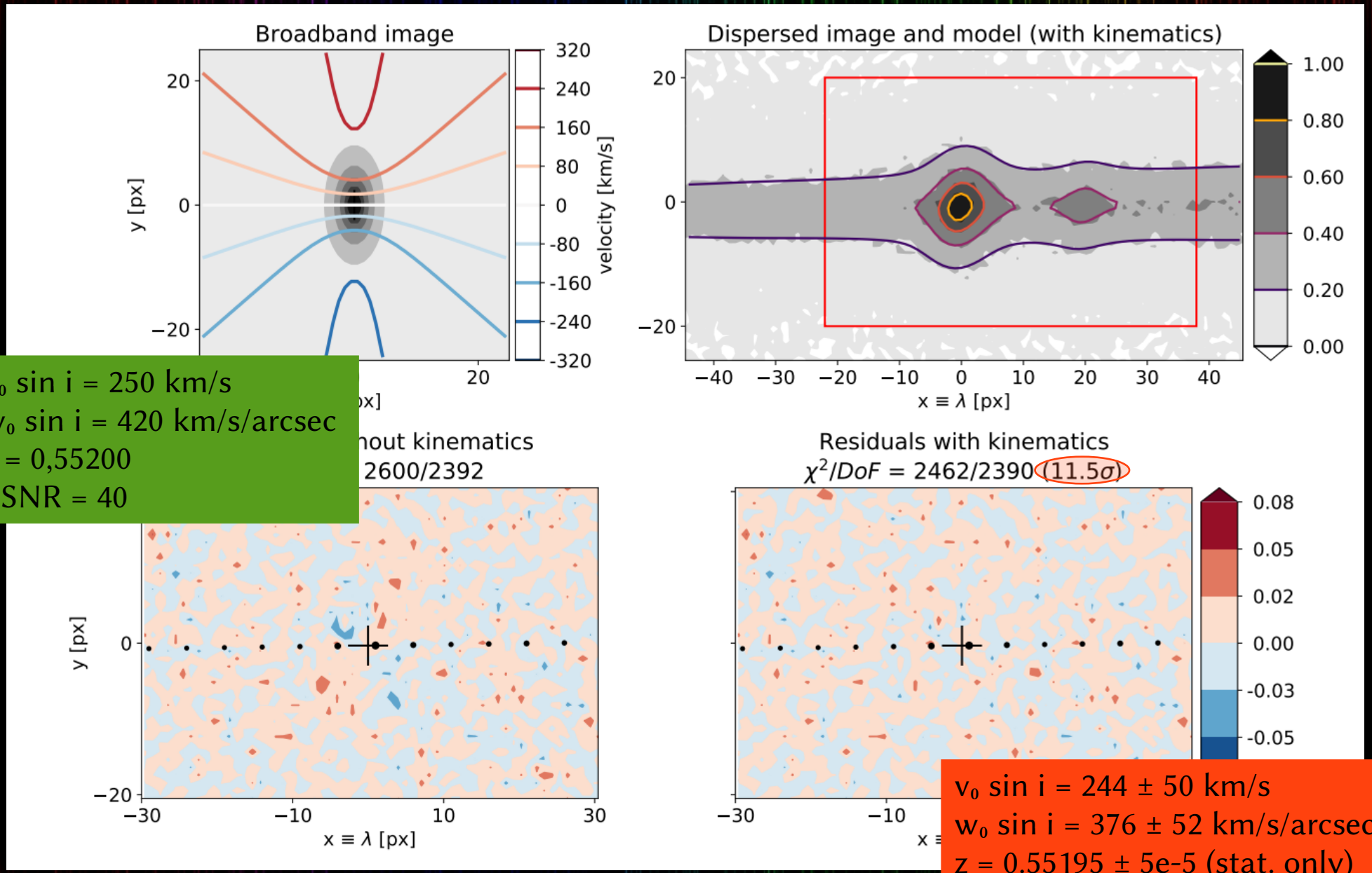


Simulations - HST-WFC3/G102



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

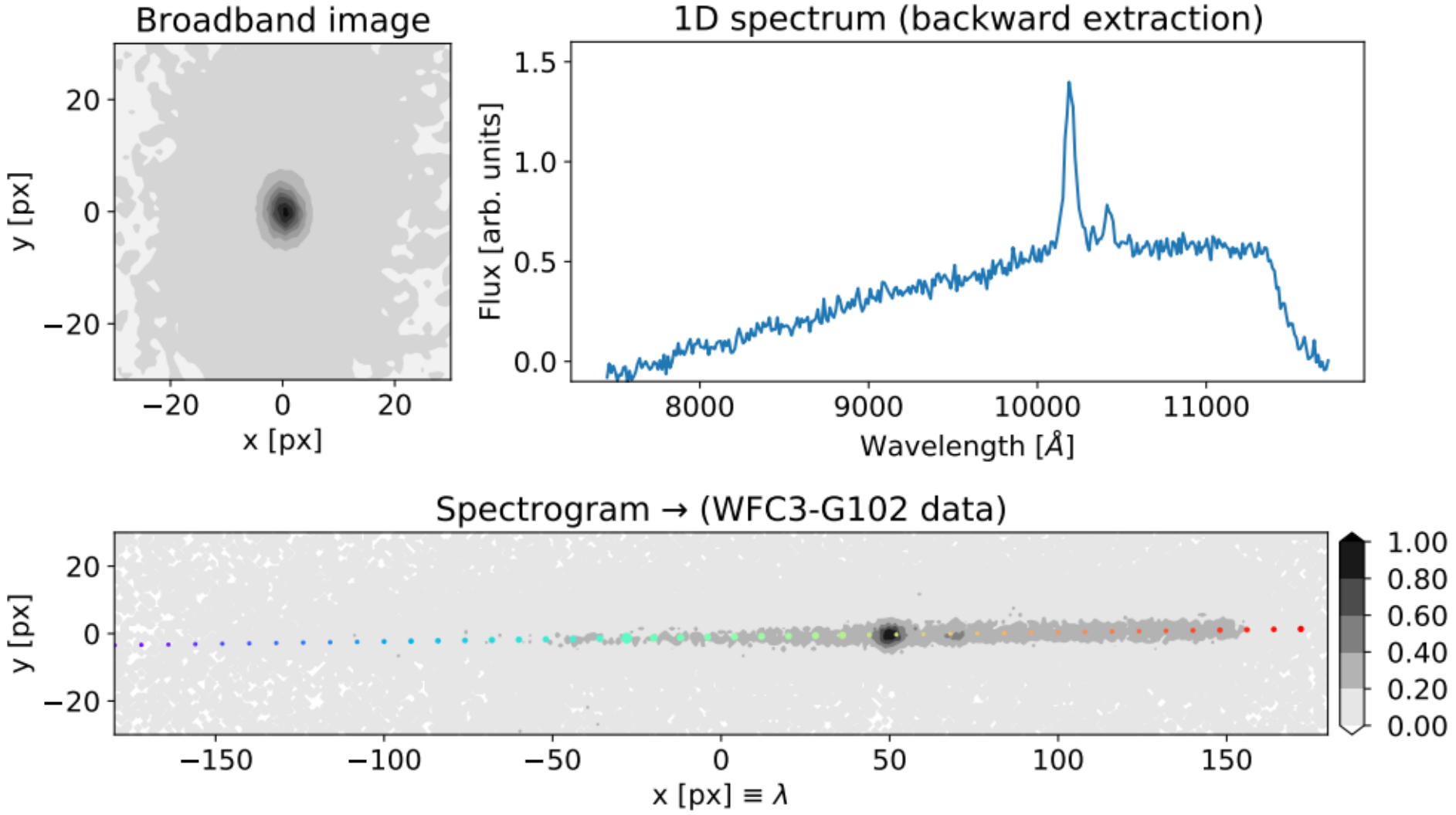
Simulations - HST-WFC3/G102



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

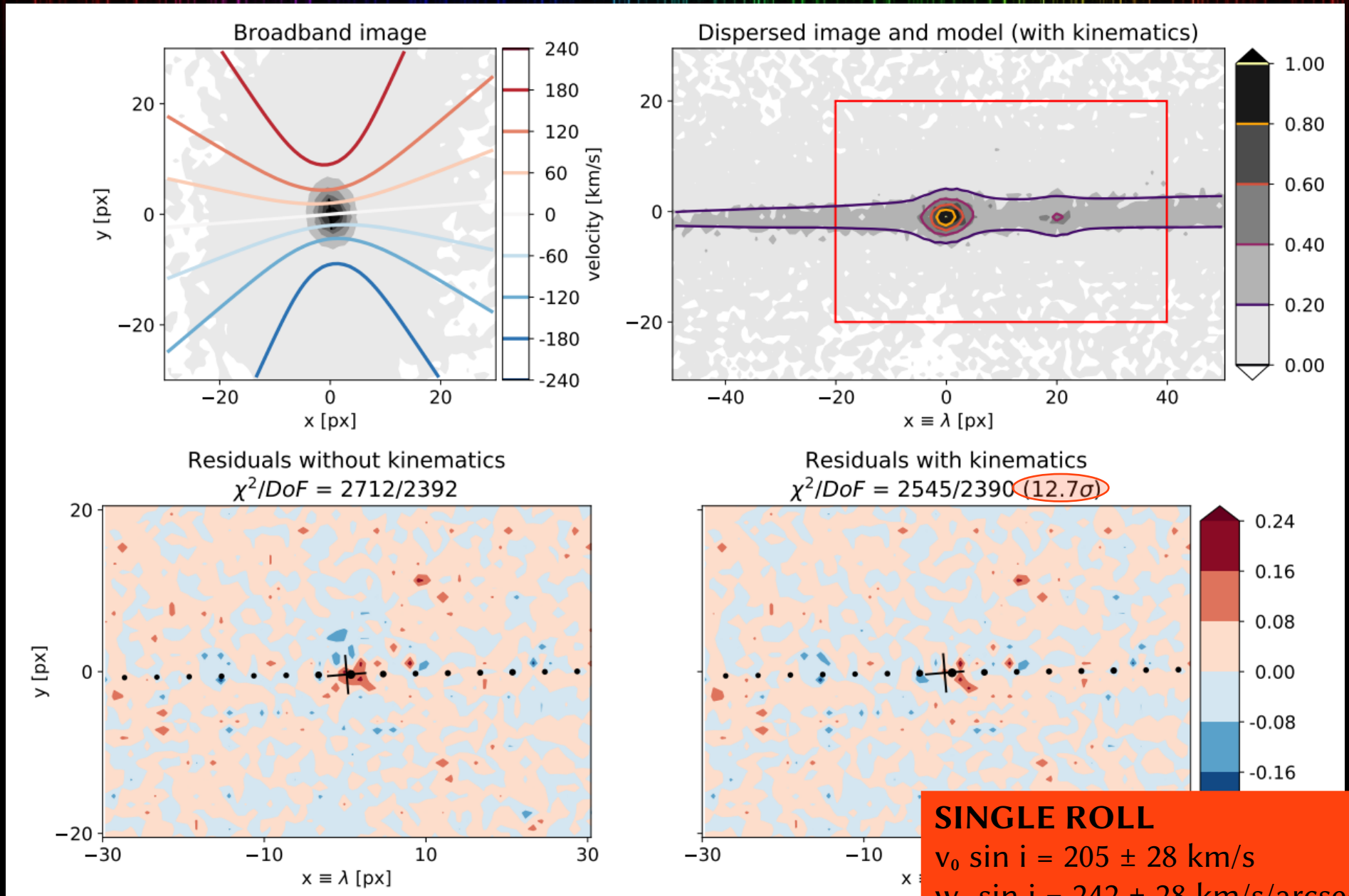
v_0 sin i = 244 ± 50 km/s
w_0 sin i = 376 ± 52 km/s/arcsec
z = 0.55195 ± 5e-5 (stat. only)

Observations - HST-WFC3/G102



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

1st kin. detection from slitless spectro.



SINGLE ROLL

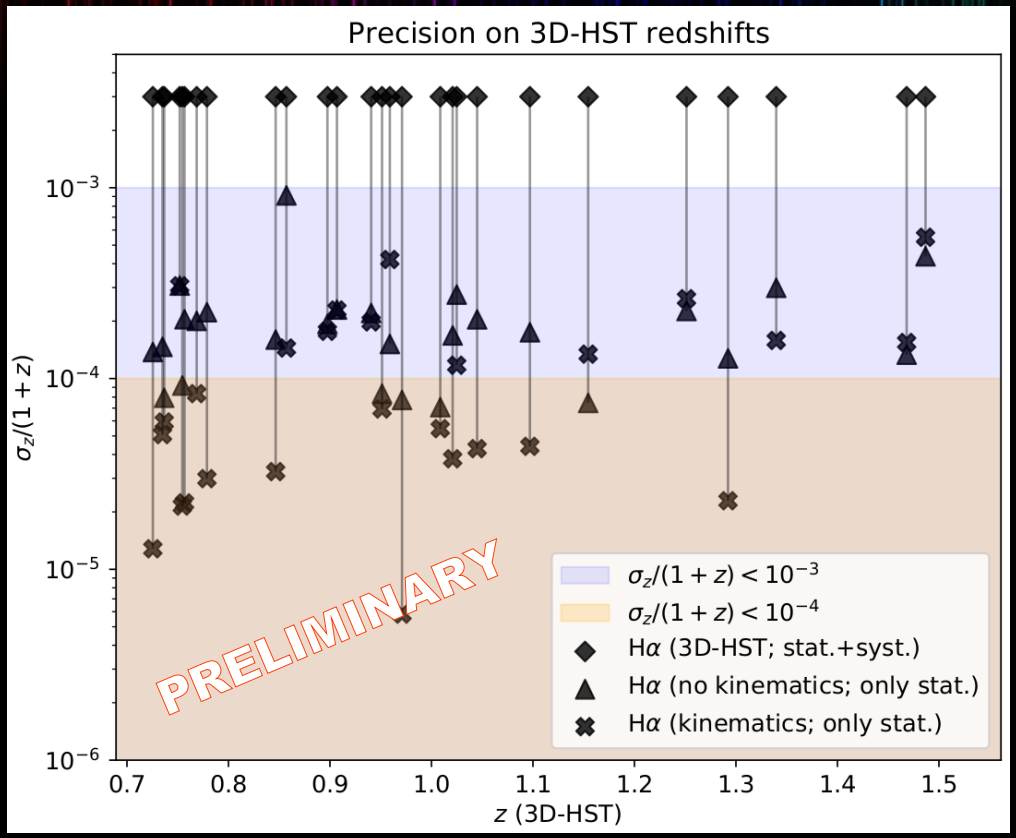
$v_0 \sin i = 205 \pm 28$ km/s

$w_0 \sin i = 242 \pm 28$ km/s/arcsec

$z = 0.55201 \pm 2e\text{-}5$ (stat. only)

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

Impact on redshift measurements (3D-HST)



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

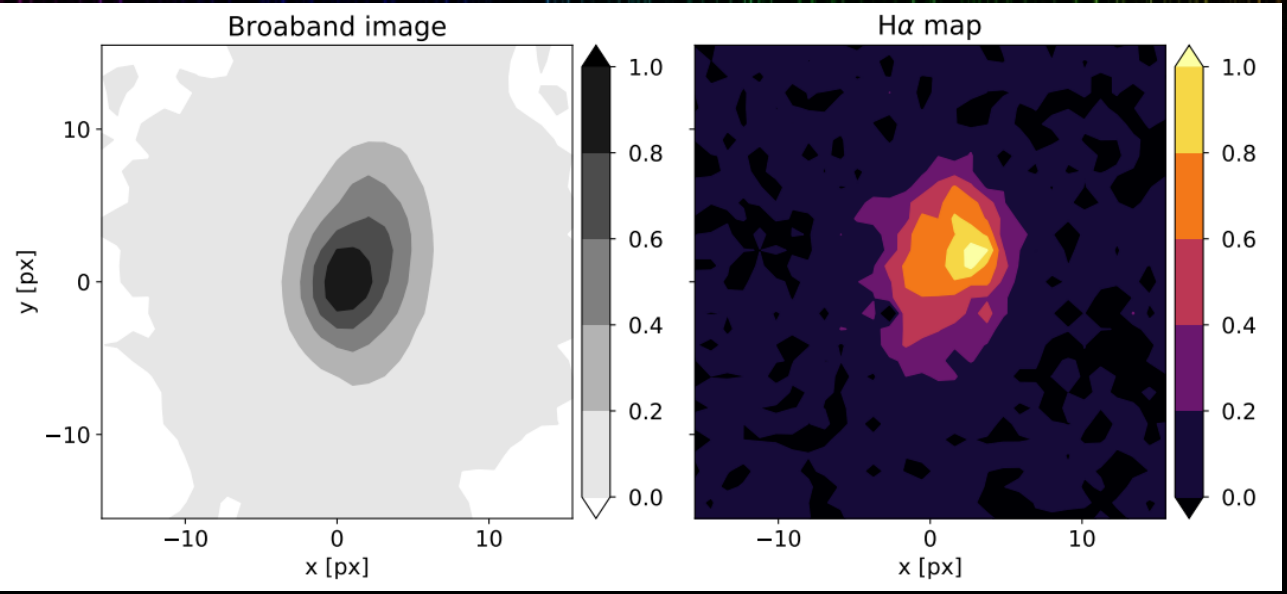
Forward, no kinematics,
stat. only : ~ 2-3e-4

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

Emission line maps

3D-HST 37018-AEGIS



- Hα+[NII] map (single roll)
  - Obtained after continuum subtraction
  - Still include px-level kinematic signature (fundamental degeneracy)
- Degeneracy can be broken from multi-roll observations
  - See N. Pirzkal presentation

Conclusions

- Better understanding of "**dispersed imaging**"
  - Still, fundamental spectro-spatial degeneracy cannot be recovered
  - Development of improved inverse methods ("disp. deconvolution")
- Call for full forward modeling (calibration + analyses)
  - Natural handling of cross-contamination
  - Major impact on redshift precision for resolved sources
  - **Can be adapted to all resolved analyses, e.g. px SED fitting**
- 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, scaling relations (e.g. Tully-Fisher), cosmography & cosmology