From JWST to Roman: A Physics-Informed AI Super-Resolution Framework for Grism Spectroscopy

Aryana Haghjoo (PhD Student)
Department of Physics and Astronomy, University of California, Riverside
Supervisors: Bahram Mobasher and Shoubaneh Hemmati

Shifting Landscapes in Astrophysics
July 2026

UCR ipac Caltech

Why do we need high-resolution spectroscopy?

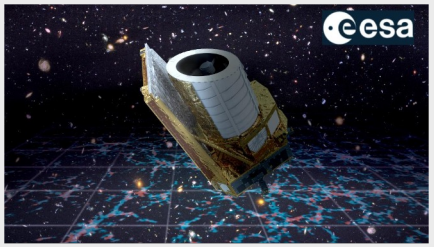
★ The recoverable information content of a galaxy spectrum is set by its resolution.

★ High resolution (R $\gtrsim$ 1000) deblends neighboring emission lines (Hα/[NII]) giving precise redshifts and line fluxes.

★ Line ratios are the diagnostics of galaxy physics: SFR (Hα), dust (Hα/Hβ), metallicity, AGN activity (BPT), electron density.

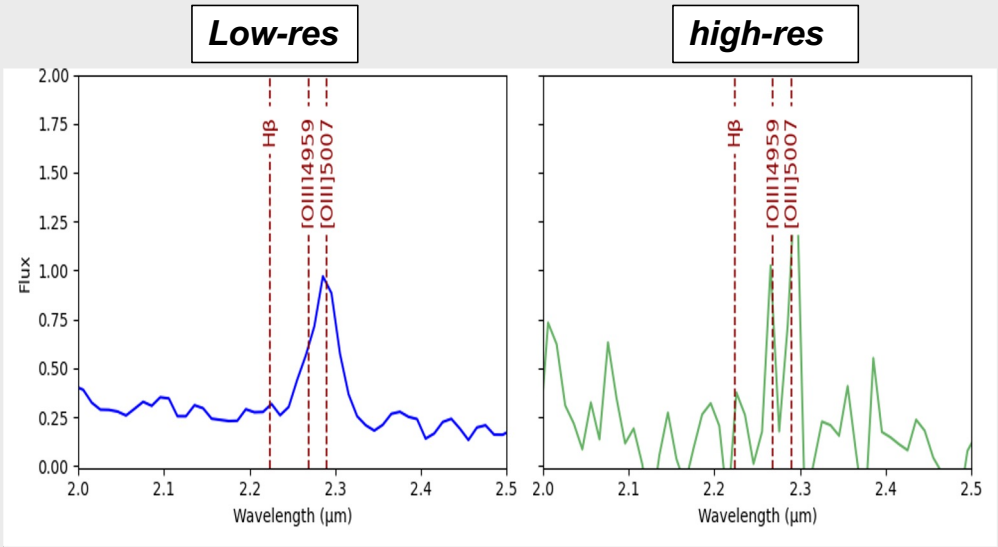
★ Accurate redshifts → cosmology: galaxy clustering and weak lensing.

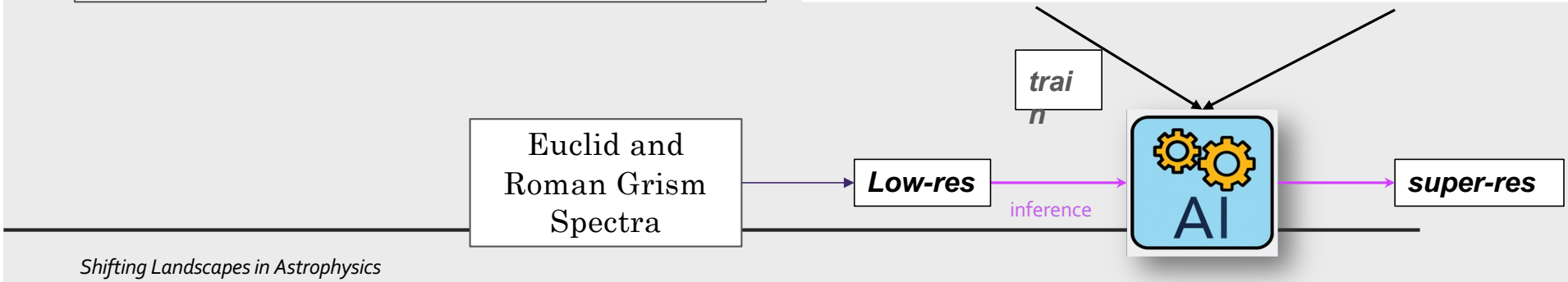
★ *In contrast:* low-resolution surveys (R ~ 100–500) blend the lines, limiting the science



The Challenge and the Opportunity

- ★ Population-level studies → large samples of spectra
- ★ high-resolution spectroscopy is *time-consuming* and *expensive*.
- ★ Deep surveys (Euclid, Roman) → collect millions of spectra only at low resolution
- ★ ***a major information bottleneck***
- ★ train an AI model on pairs of low-and high-resolution spectra.

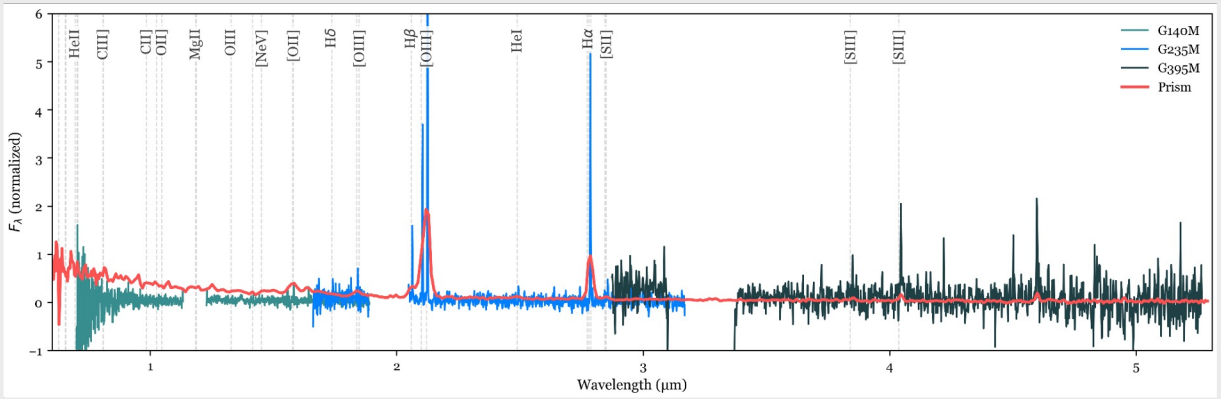




The Pilot: JWST/NIRSpec

- ★ Same galaxies, BOTH resolutions: prism (R~100) and medium gratings (R~1000)
- ★ GOODS-N & GOODS-S
- ★ Preprocessing: merged the 3 gratings, re-grid the prism to the medium-resolution grid
- ★ quality cut (S/N > 3 on Hα, [OII], or [OIII]) → 1,187 pairs
- ★ Augmentation was key: redshift perturbation (σ = 0.3) + noise → ~25,000 training pairs with diverse line positions and S/N.

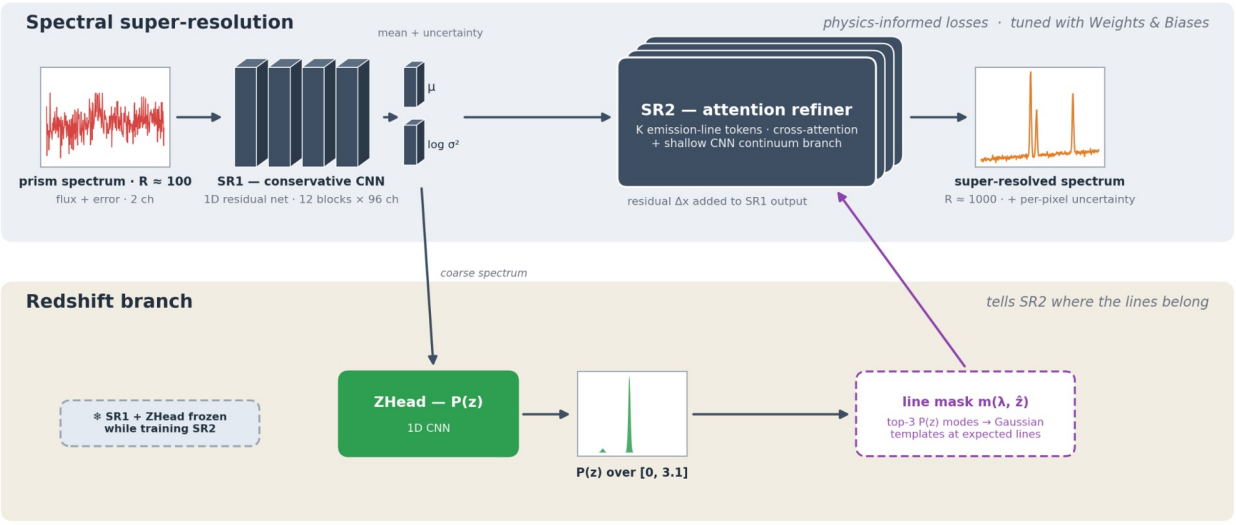
JWST Advanced Deep Extragalactic Survey (JADES)



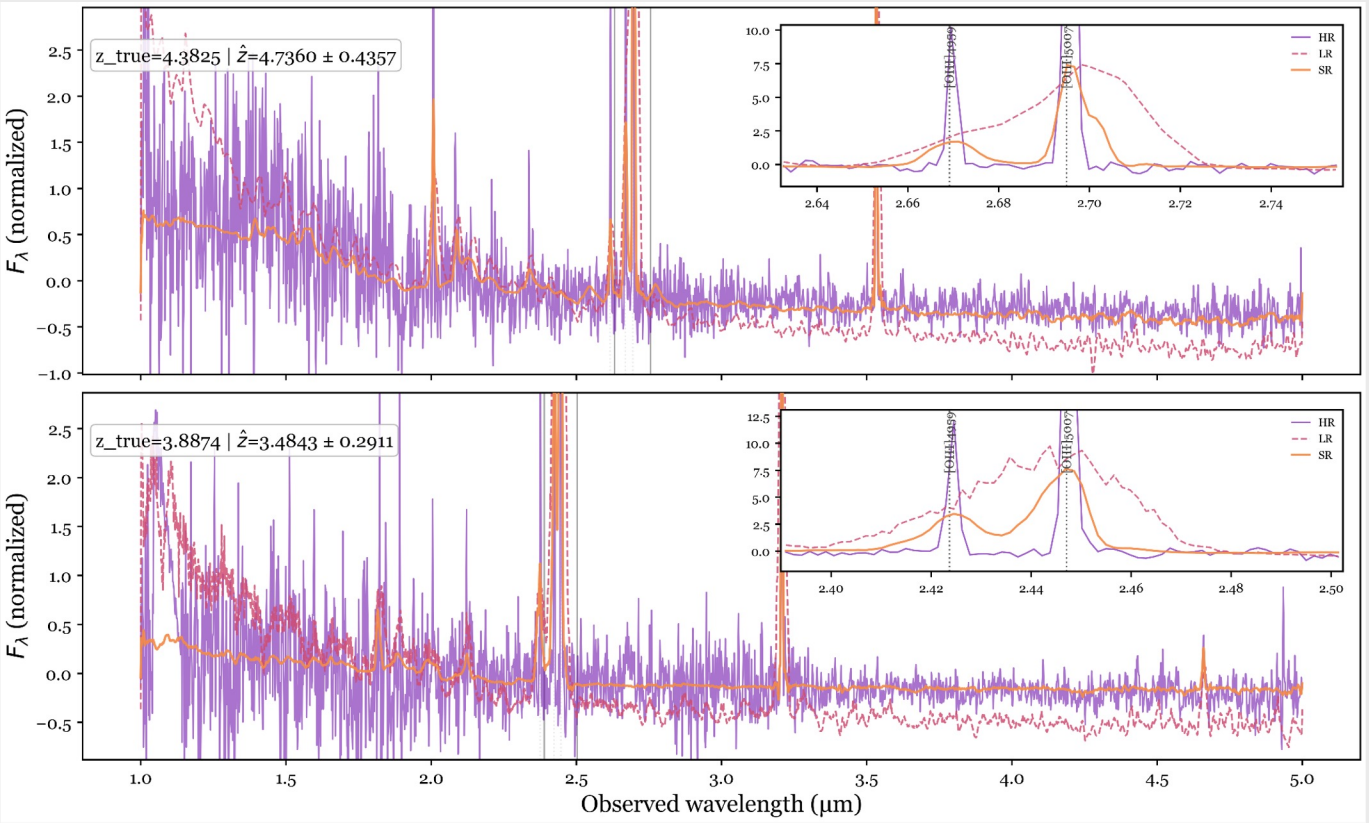
JADES JWST ADVANCED DEEP EXTRAGALACTIC SURVEY

Training and Architecture

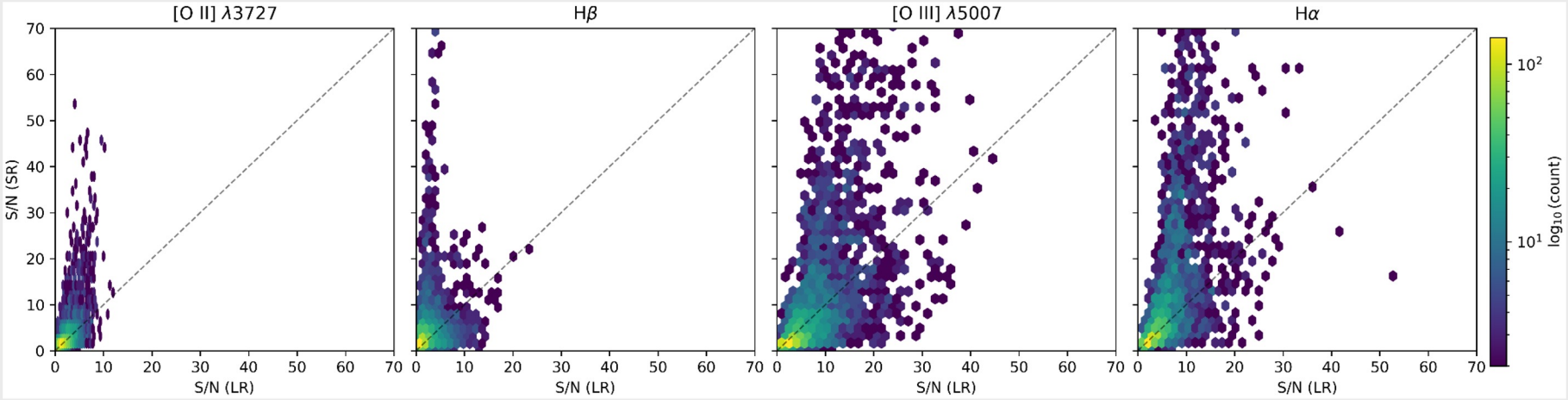
- ★ Three-stage model:
  - *1. Conservative super-resolution (CNN)*
  - *2. Redshift prediction*
  - *3. Second super-resolution (transformer/attention; emission lines)*
- ★ Hyperparameters tuned with Weights & Biases.

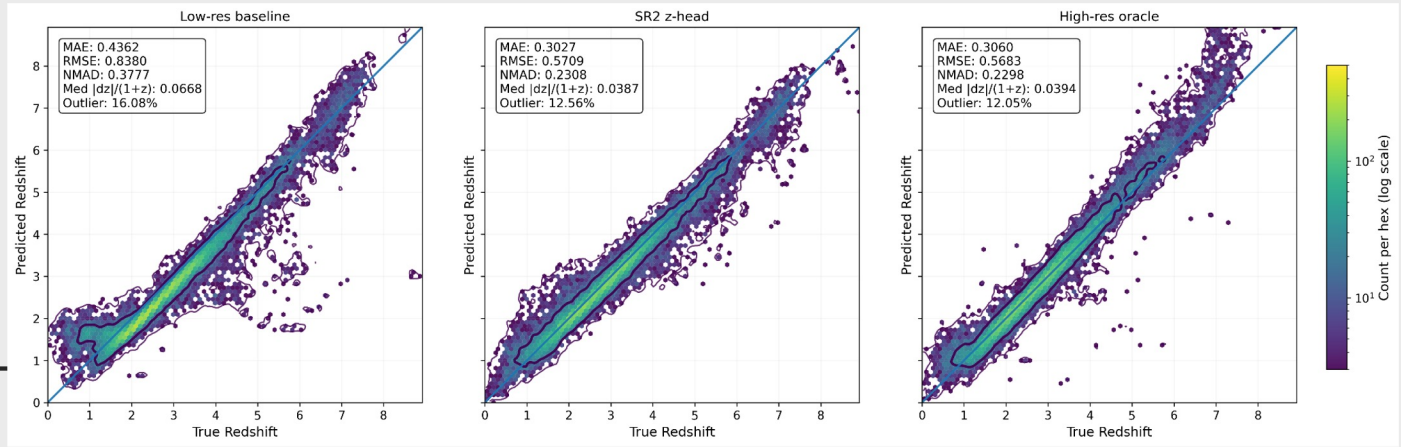


Learning to see sharper!



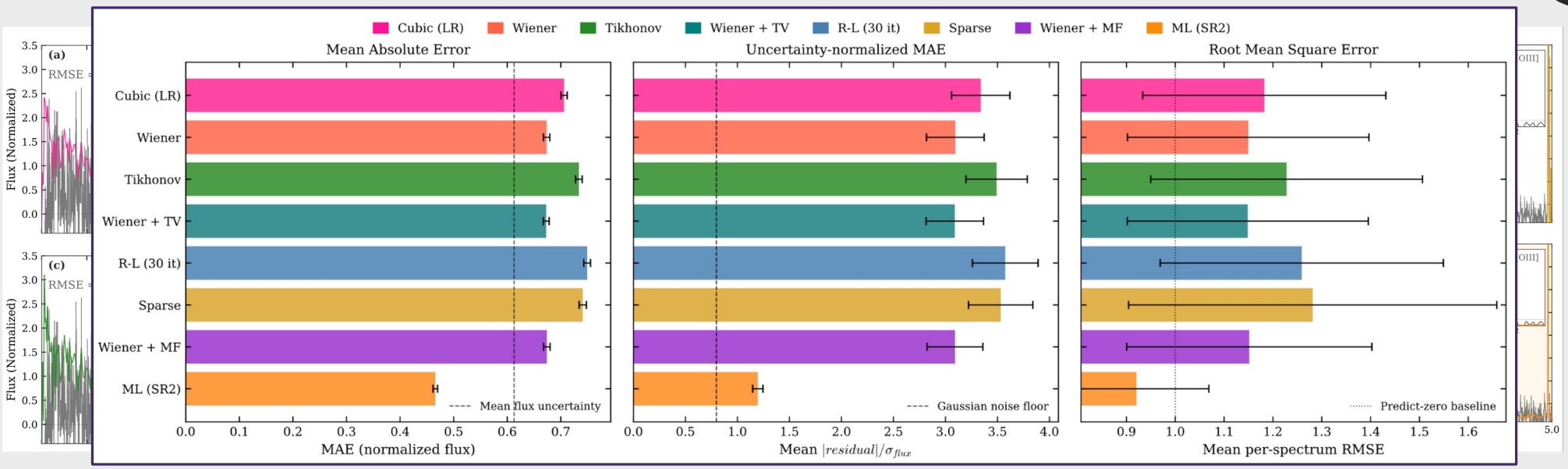
Emission-Line S/N and Redshift

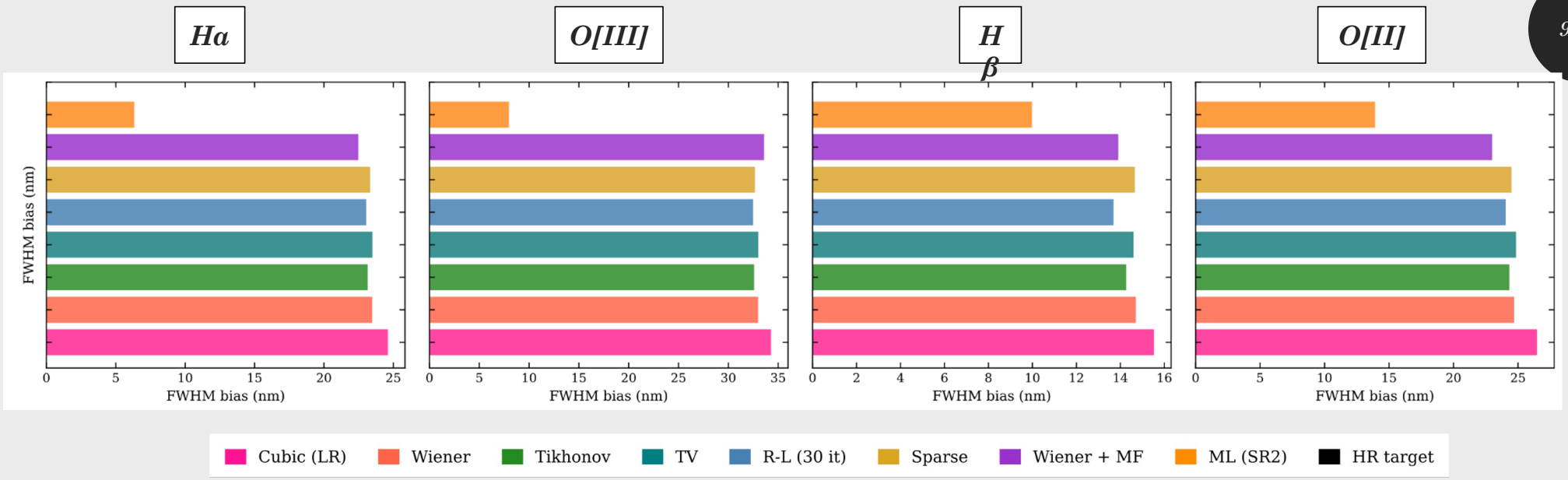




Sharper at What Cost?

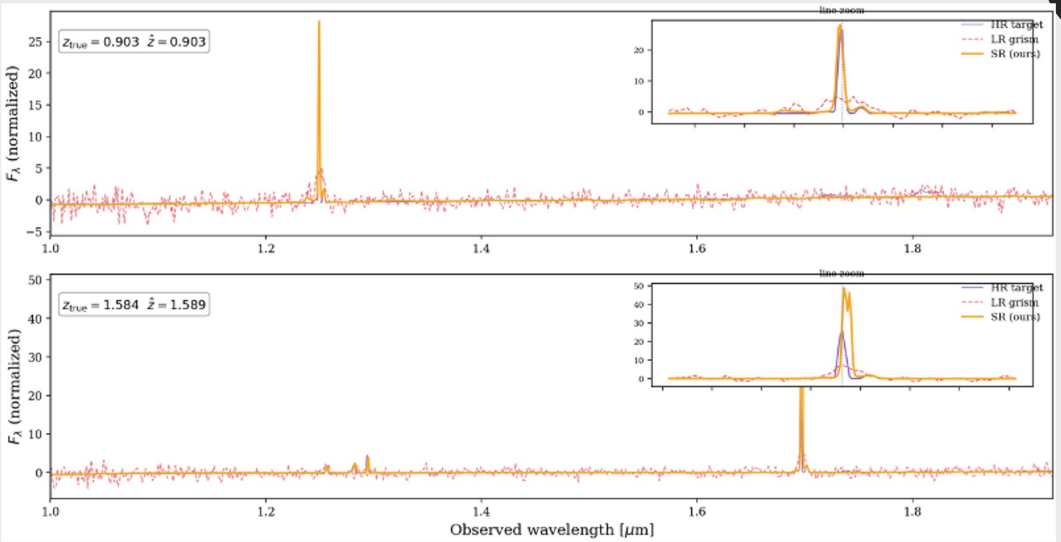
Benchmarking vs. Classical Methods




Hα
O[III]
Hβ
O[II]
FWHM bias (nm)
FWHM bias (nm)
FWHM bias (nm)
FWHM bias (nm)
FWHM bias (nm)
Cubic (LR)
Wiener
Tikhonov
TV
R-L (30 it)
Sparse
Wiener + MF
ML (SR2)
HR target

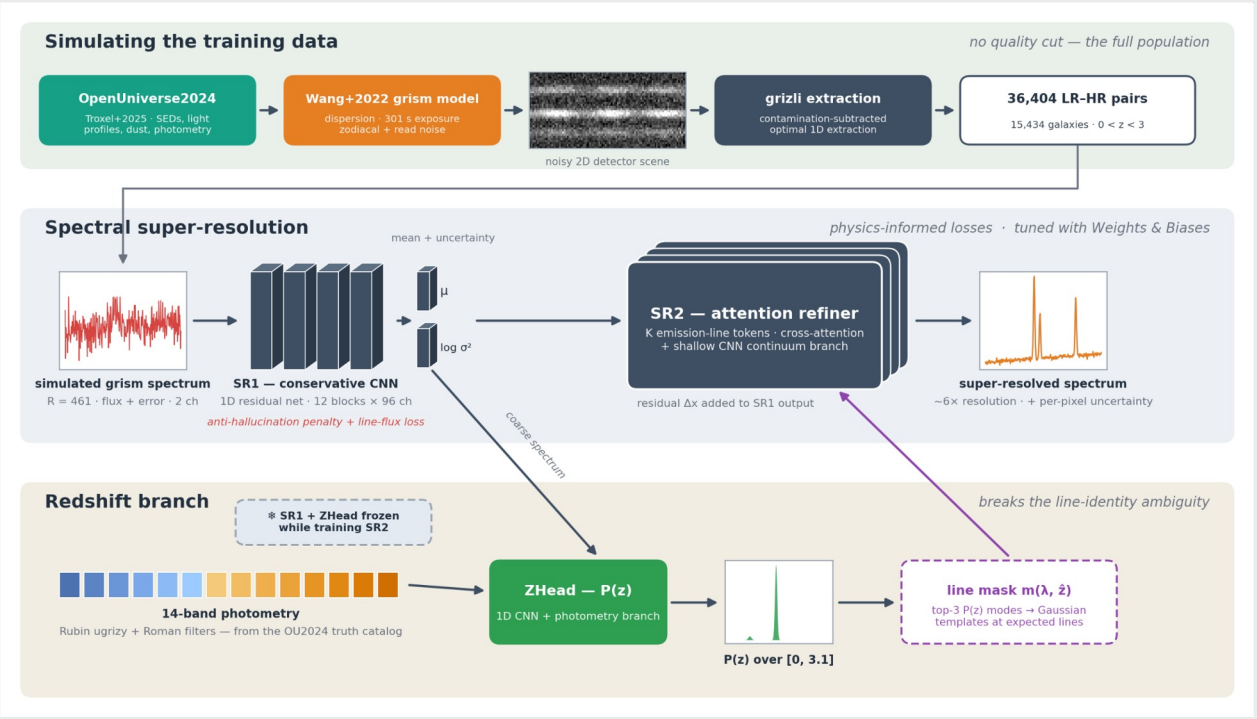
Transferring to Roman

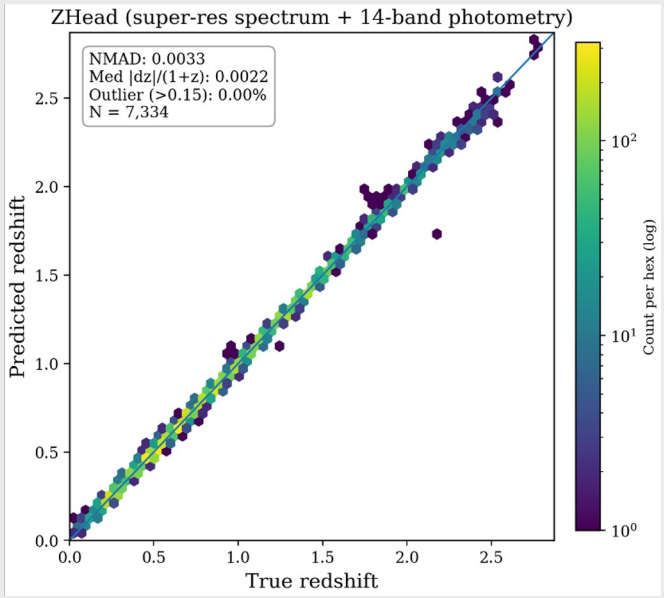
- ★ Roman's tens of millions of grism spectra (R ~461)
- ★ narrow bandpass(1–1.93 μm) → most galaxies show at most *ONE* strong emission line
- ★ the model struggles to find the correct redshift



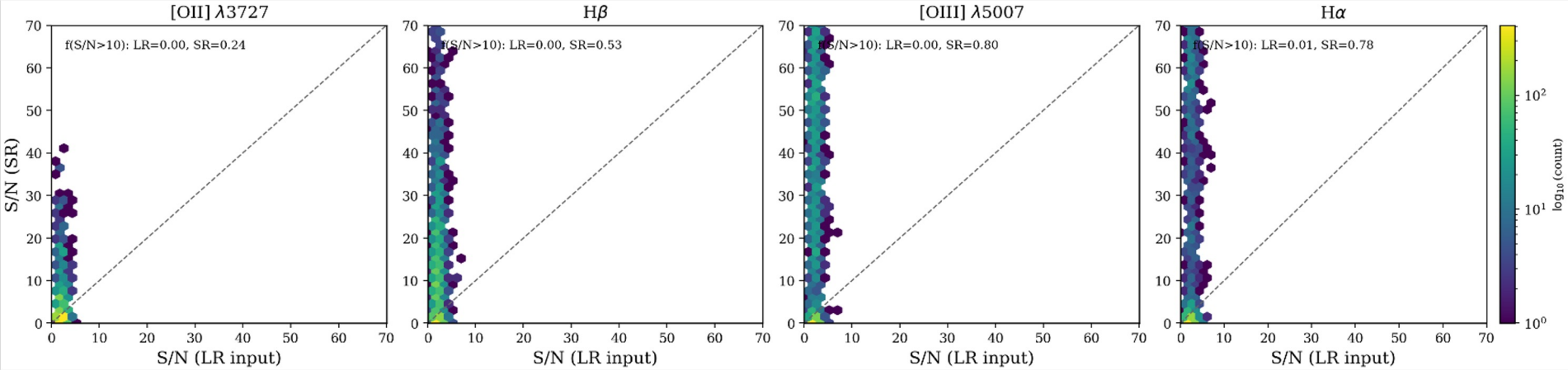
Grism input (red), truth SED (purple), super-resolved (orange)

Photometry Breaks the Degeneracy





Emission Line Recovery



Summary

Arxiv preprint
Learning to See Sharper: A Physics-Informed Artificial Intelligence Framework for Super-Resolving Galaxy Spectra

- ★ High-resolution spectroscopy is critical but costly; deep surveys observe at low resolution.
- ★ We built a physics-informed AI framework that super-resolves galaxy spectra (JWST: R~100 → R~1000), recovering blended lines and improving S/N.
- ★ We transferred it to the Roman grism on end-to-end simulations: ~6× resolution gain,
- ★ redshifts with zero catastrophic outliers when combined with photometry.
- ★ Ready for the next generation of Roman simulations — and, after launch, the real HLSS.