Elisabeth Krause (Arizona)

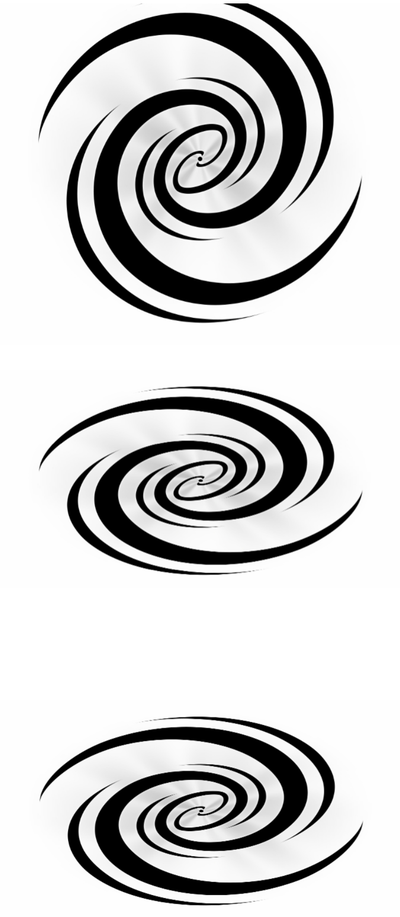
with Jiyun Di, Yu-Hsiu Huang, Pranjal RS, Jiachuan Xu, Tim Eifler & Eric Huff

Weak Lensing Without Shape Noise

Galaxy Weak Lensing Measurements

Weak lensing measurements are challenging:

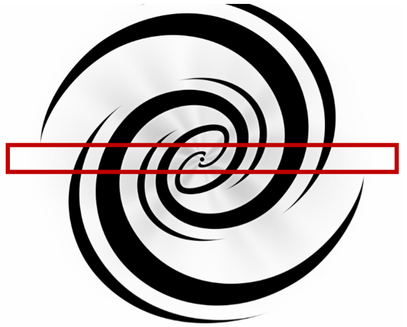
- **intrinsic galaxy shape is unobservable, degenerate with shear (γ ~0.01)**
  - intrinsic ellipticity dispersion σ_ε ~0.25 leads to SNR ~ 0.02 per galaxy,
  - subject to multifarious systematics.

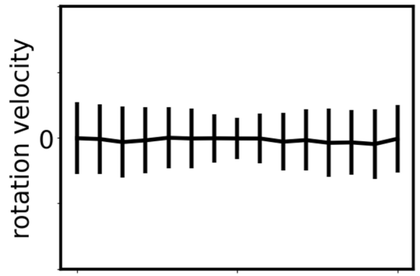


Galaxy Weak Lensing Measurements

Weak lensing measurements are challenging:

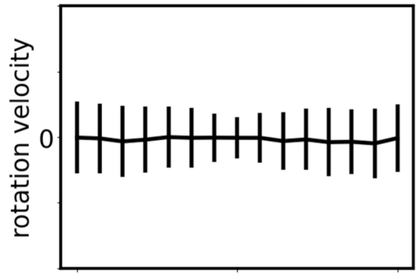
- **intrinsic galaxy shape is unobservable, degenerate with shear (γ ~0.01)**
  - intrinsic ellipticity dispersion σ_ε ~0.25 leads to SNR ~ 0.02 per galaxy,
  - subject to multifarious systematics.
- **Kinematic information can break the degeneracy between shapes and shear** and raise the SNR per galaxy to ~1,
  - also eliminates photo-z and intrinsic alignment systematics.





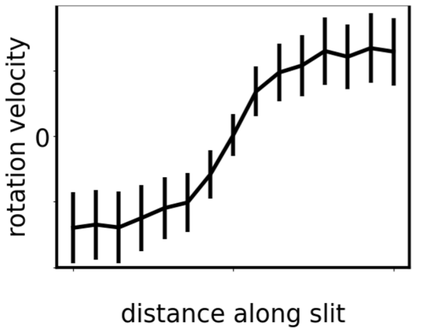
face on





face on, sheared

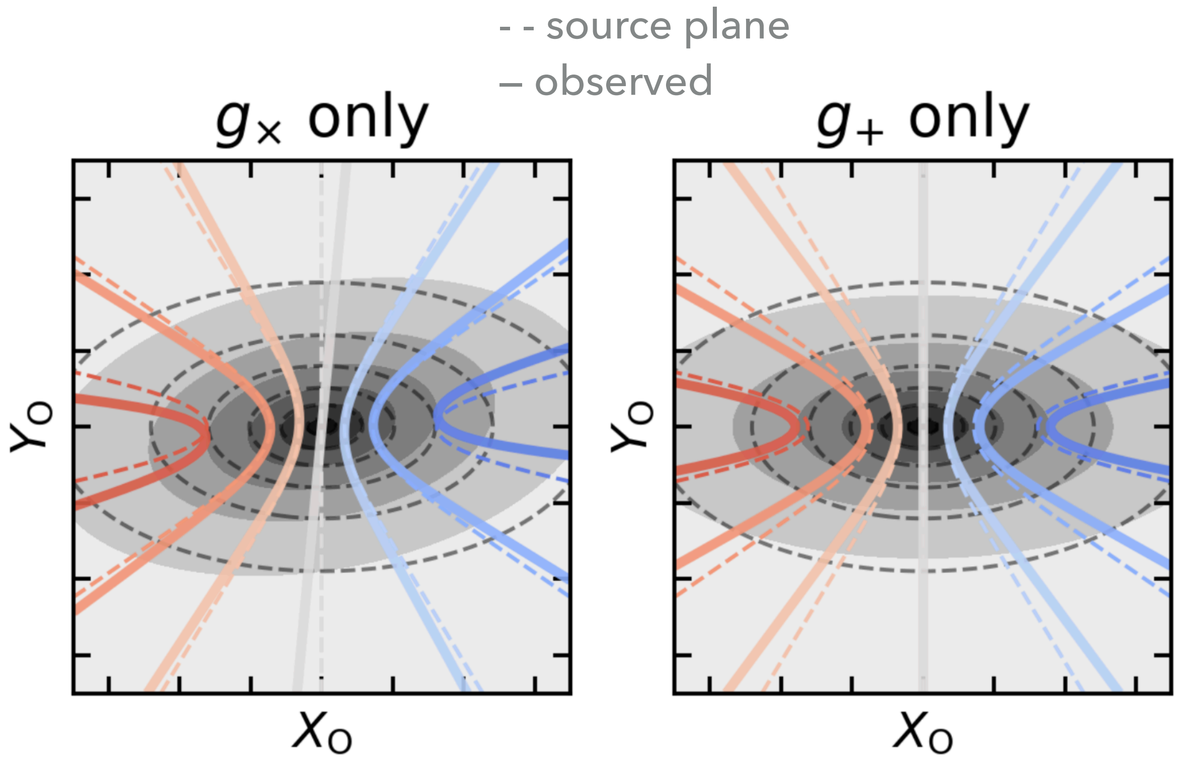




inclined

Weak Lensing & Galaxy Kinematics

- $g_\times$ **causes non-axisymmetric velocity distribution** and offset between photometric/kinematic axes (Blain 2002).
- g_+ **remaps isophotes and kinematics along major axis,** degenerate with change in inclination angle.
  - Additional information required to break degeneracy between g_+ and i.

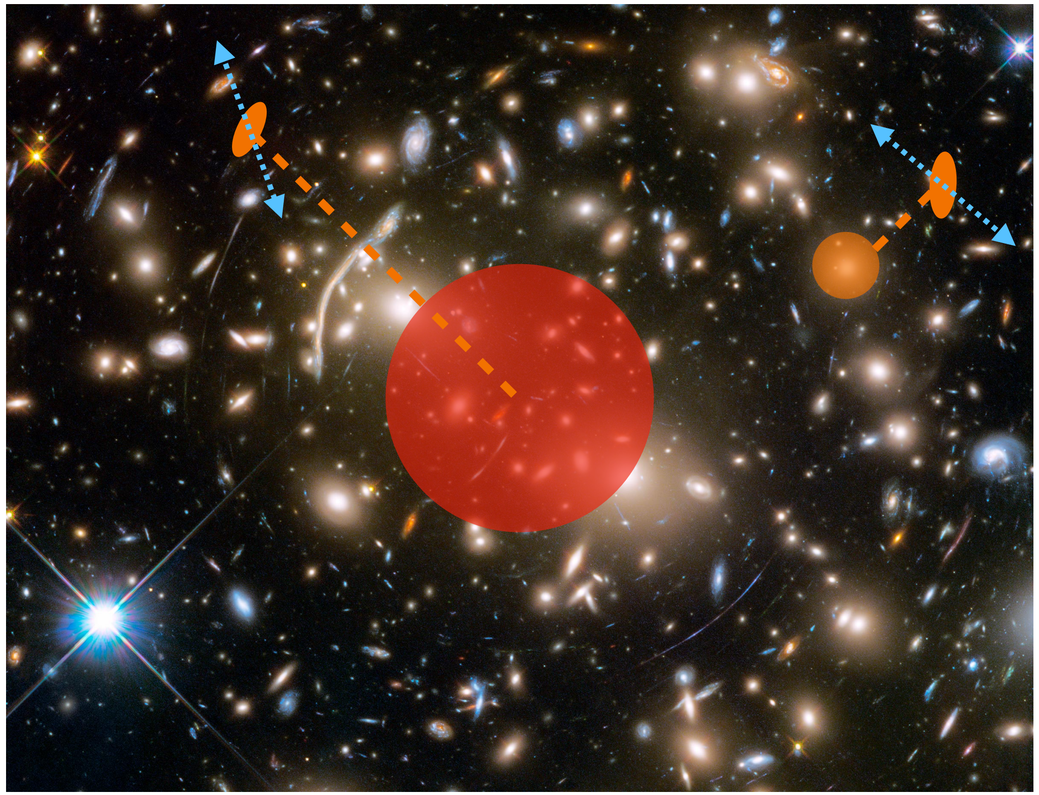


shear components in observed galaxy coordinate system:
g_+ aligned with major axis, $g_\times$ at 45°

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Breaking the g_+ - Inclination Degeneracy

- **Method 1**: cluster lensing / galaxy-galaxy lensing: measure minor axis misalignment, get tangential direction from the closest cluster/galaxy (Morales 06, de Burgh-Day+15, Gurri+20, DiGiorgio+21).

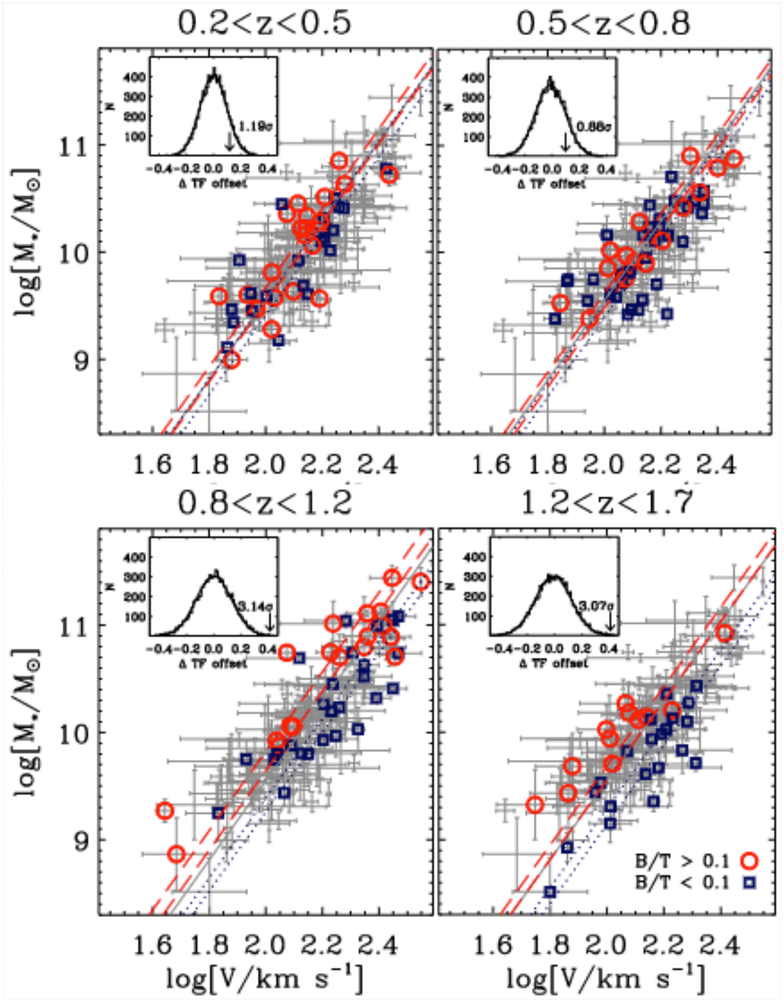


Breaking the g_+ - Inclination Degeneracy

- **Method 1**: cluster lensing / galaxy-galaxy lensing: measure minor axis misalignment, get tangential direction from the closest cluster/galaxy (Morales 06, de Burgh-Day+15, Gurri+20, DiGiorgio+21).
- **Method 2**: Tully-Fisher relation (Huff, EK+13)

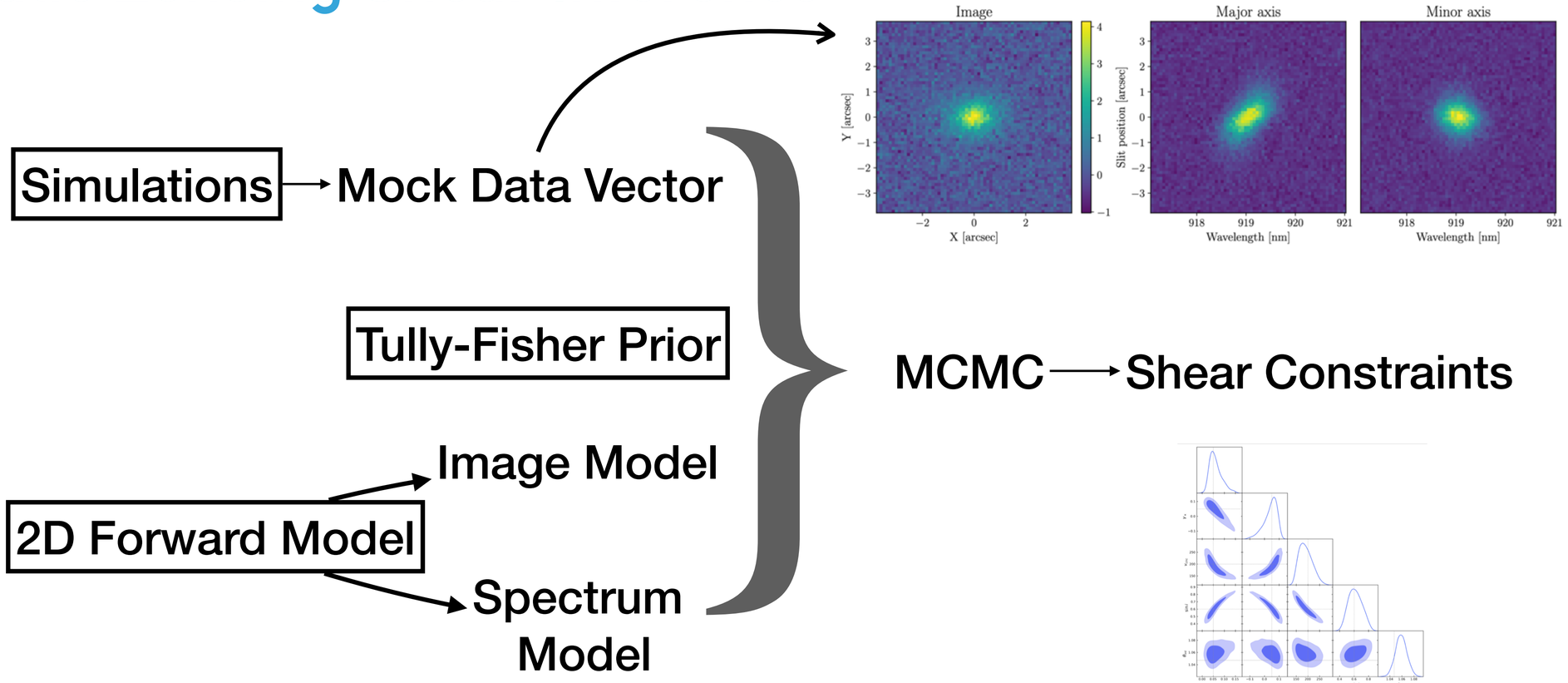
$$\log_{10}(v_{\rm circ}) = a + b(M_B - M_p) + \tilde{\epsilon}$$

$\tilde{\epsilon}$ intrinsic scatter of the TF relation, $\tilde{\epsilon} \sim 0.05\, dex$ (Reyes+11)



Miller+13

Kinematic Lensing Shear Inference



Demonstration of unbiased shear inference on simulated galaxies,

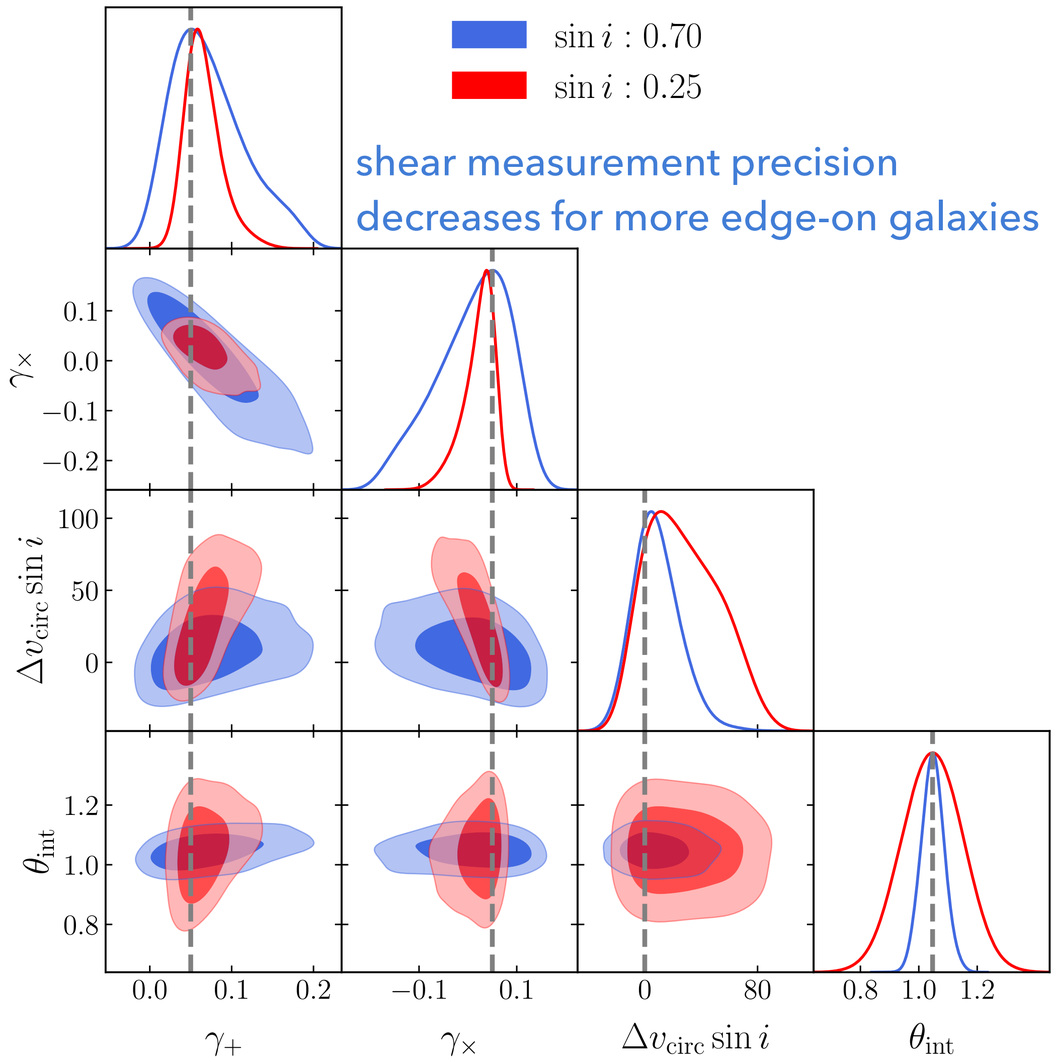
σ_ϵ ~10 smaller than for traditional lensing!

Pranjal RS+23

Kinematic Lensing Shear Inference

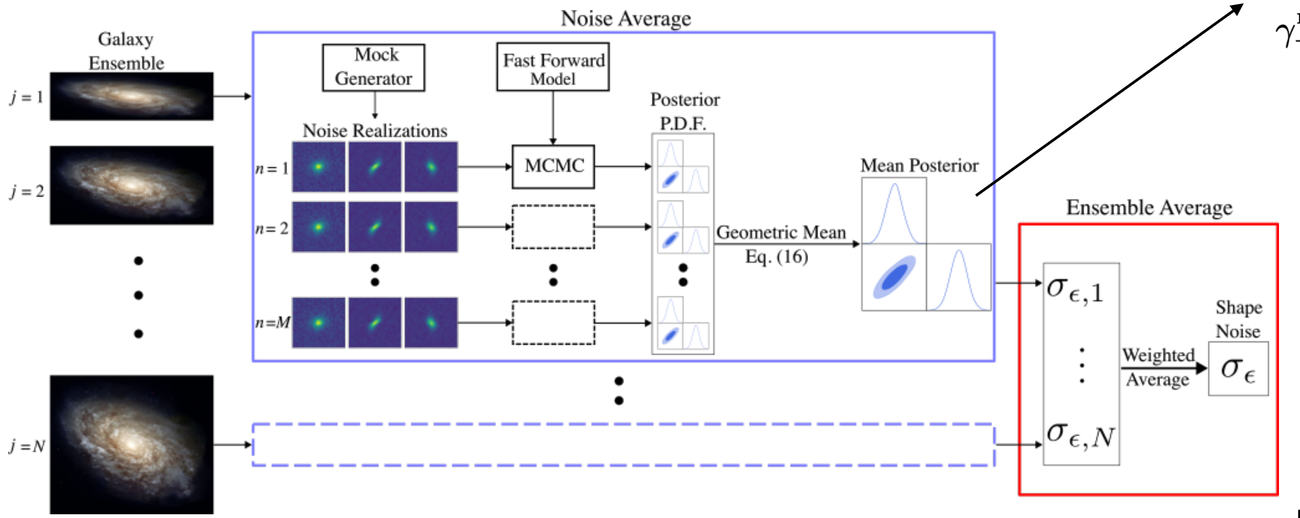
- Analyzed synthetic DEEP2-like spectra (noiseless realization, SNR~30) with fast forward model.
- **Unbiased shear posteriors on noiseless data**
  - fitting 13 parameters to each galaxy is not hopeless.

Next: *check that noise causes only scatter, not biases.*



Pranjal RS+23

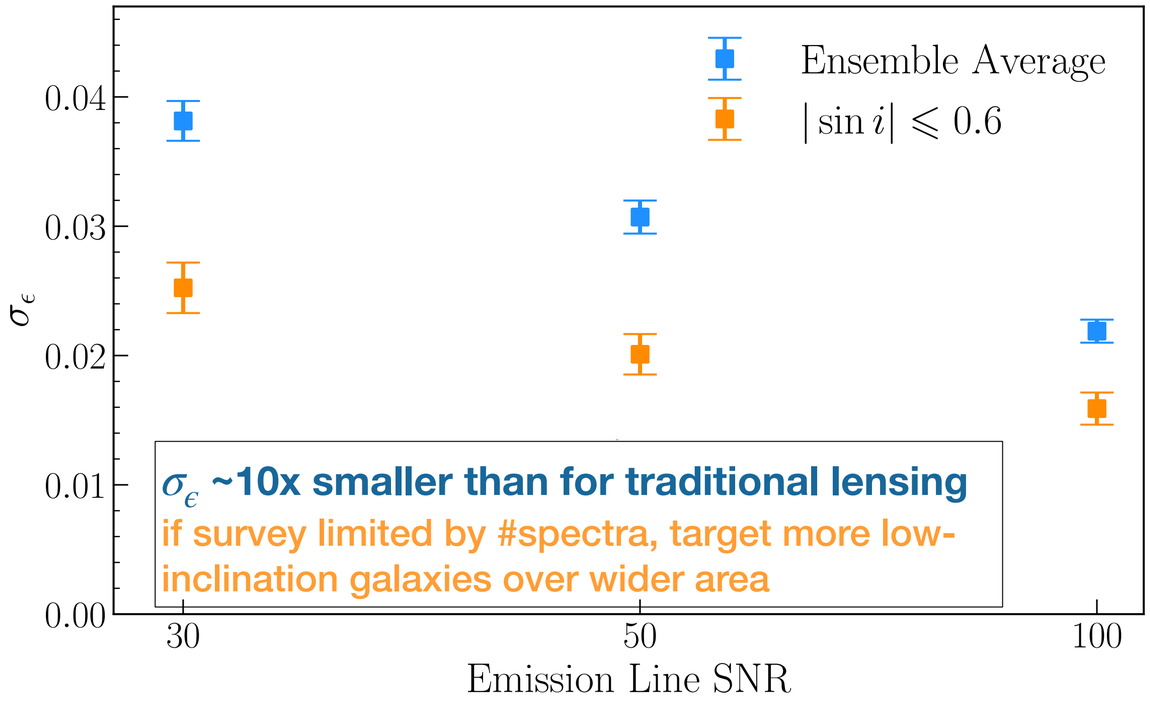
Kinematic Lensing Shear Inference



$$\gamma_{+,\times}^{\text{measured}} = (1+m_1)\gamma_{+,\times}^{\text{input}}$$

$$\gamma_{+,\times}^{\text{measured}} = m_2\gamma_{\times,+}^{\text{input}}$$

Unbiased shear inference: shear calibration biases m_1, m_2 consistent with zero.



σ_ϵ ~10x smaller than for traditional lensing
if survey limited by #spectra, target more low-inclination galaxies over wider area

Pranjal RS+23

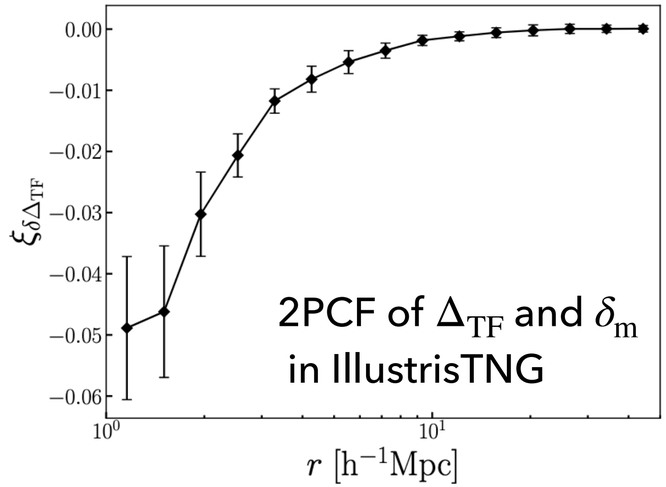
Kinematic Lensing vs. Weak Lensing Systematics

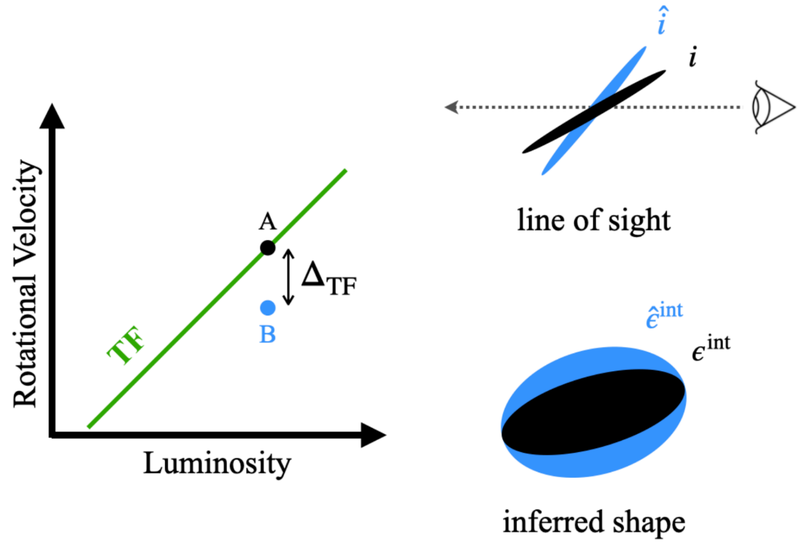
- **Photometric redshifts** → spectroscopic redshifts
- **Shape measurements** more robust for high-S/N galaxies
- Kinematic Lensing is immune to **intrinsic alignments**

$$\gamma = \epsilon^{\mathrm{obs}} - \hat{\epsilon}^{\mathrm{int}}$$

Kinematic Lensing vs. Weak Lensing Systematics

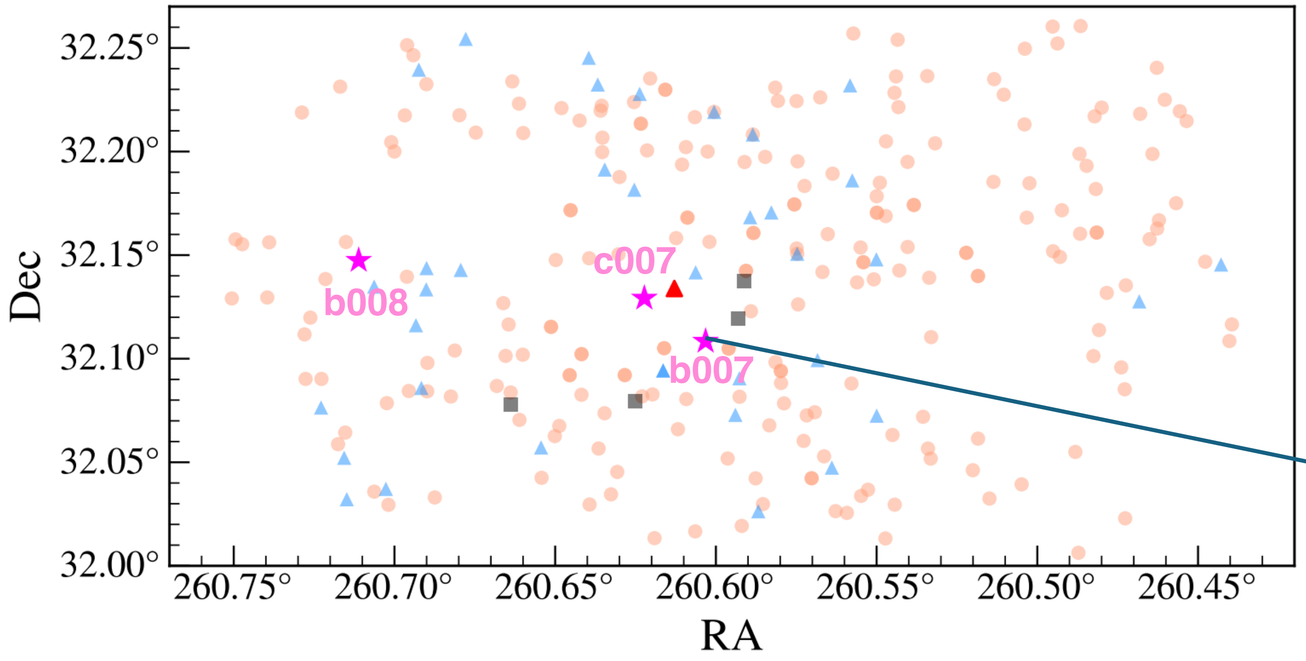
- **Photometric redshifts** → spectroscopic redshifts
- **Shape measurements** more robust for high-S/N galaxies
- Kinematic Lensing is immune to **intrinsic alignments**
  $\gamma = \epsilon^{\rm obs} - \hat{\epsilon}^{\rm int}$
- Intrinsic alignment analogues?
  - (Some) observations suggest environment dependence of Tully-Fisher relation (Pelliccia+19, Mercier+22)
  - No systematic effect on Kinematic Lensing 2PCF, unless source galaxies (disk galaxies) are intrinsically aligned
    - higher-order effect than (undetected) disk galaxy alignments

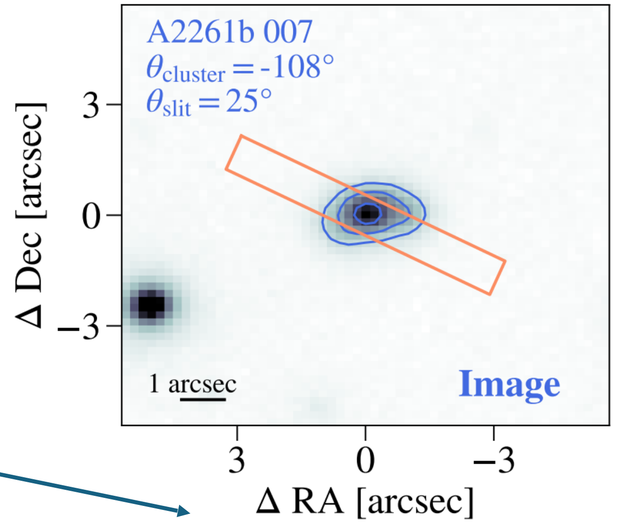


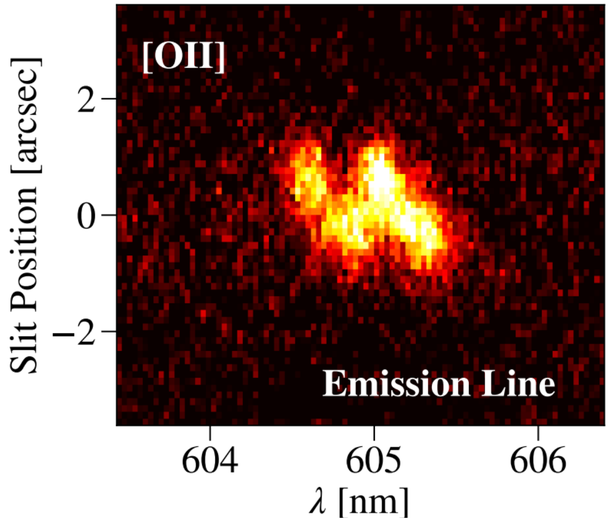


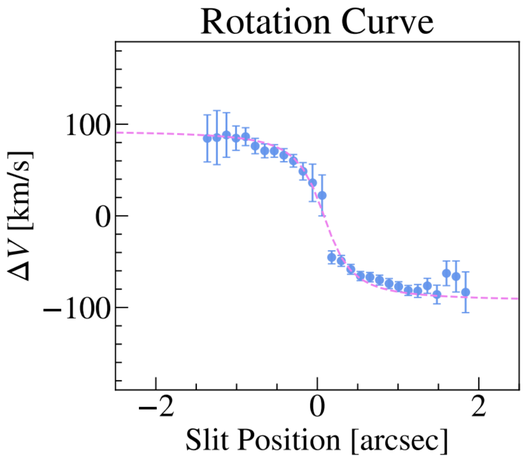
Y-H. Huang+24

A2261 Cluster Kinematic Lensing Observations With DEIMOS





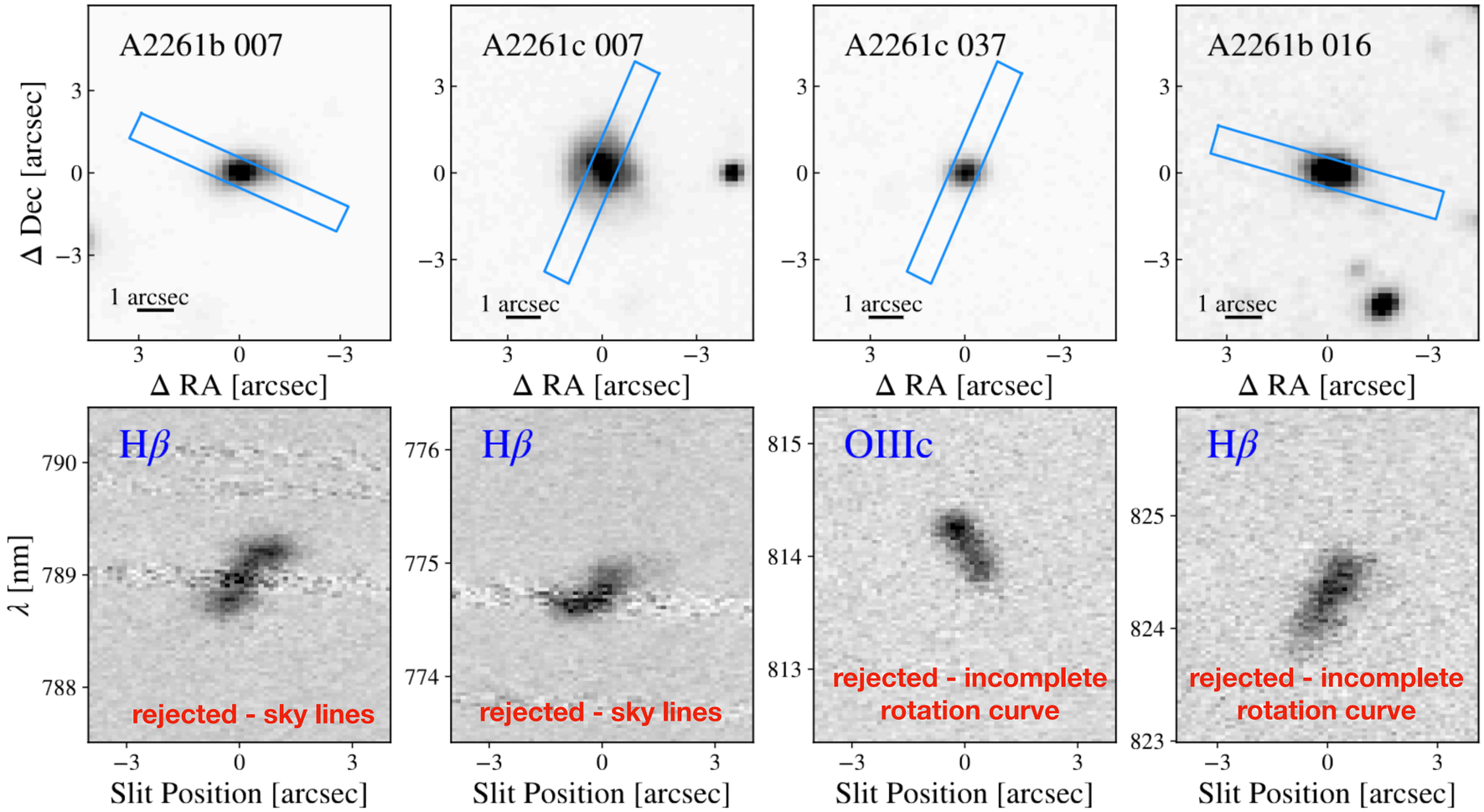




Joint image + spectrum forward model described by 15-18 model parameters

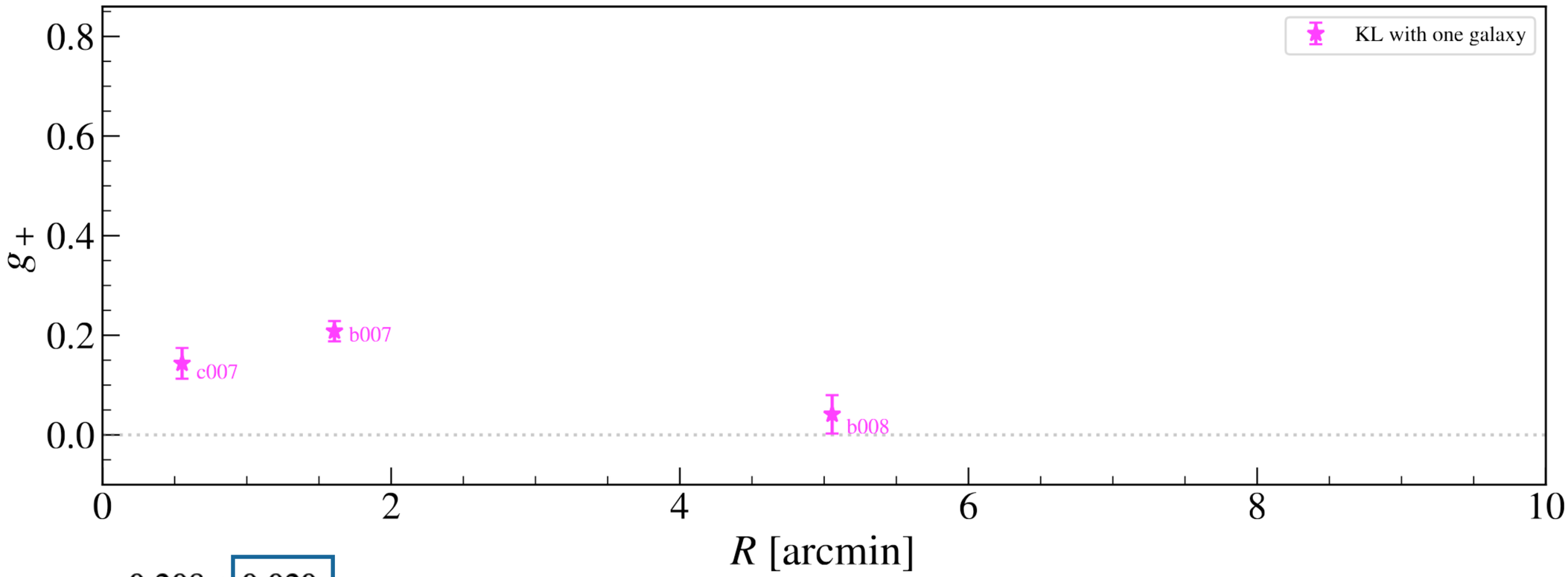
Pranjal RS+24

A2261 Kinematic Lensing Pilot Measurement



Pranjal RS+24

A2261 Kinematic Lensing Pilot Measurement

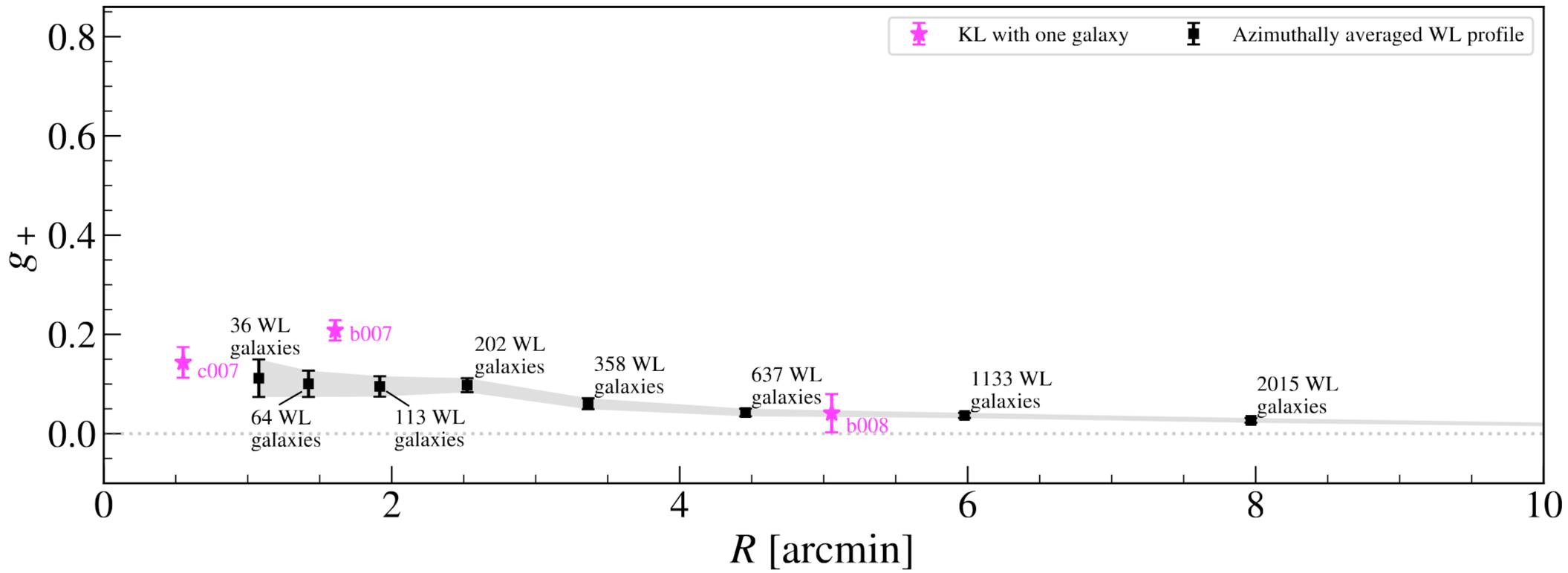


b007: $g_{+,\,\mathrm{KL}} = 0.208 \pm 0.020.$
b008: $g_{+,\,\mathrm{KL}} = 0.041 \pm 0.038.$
c007: $g_{+,\,\mathrm{KL}} = 0.144 \pm 0.030.$

Measured KL shear uncertainty meets expectations!

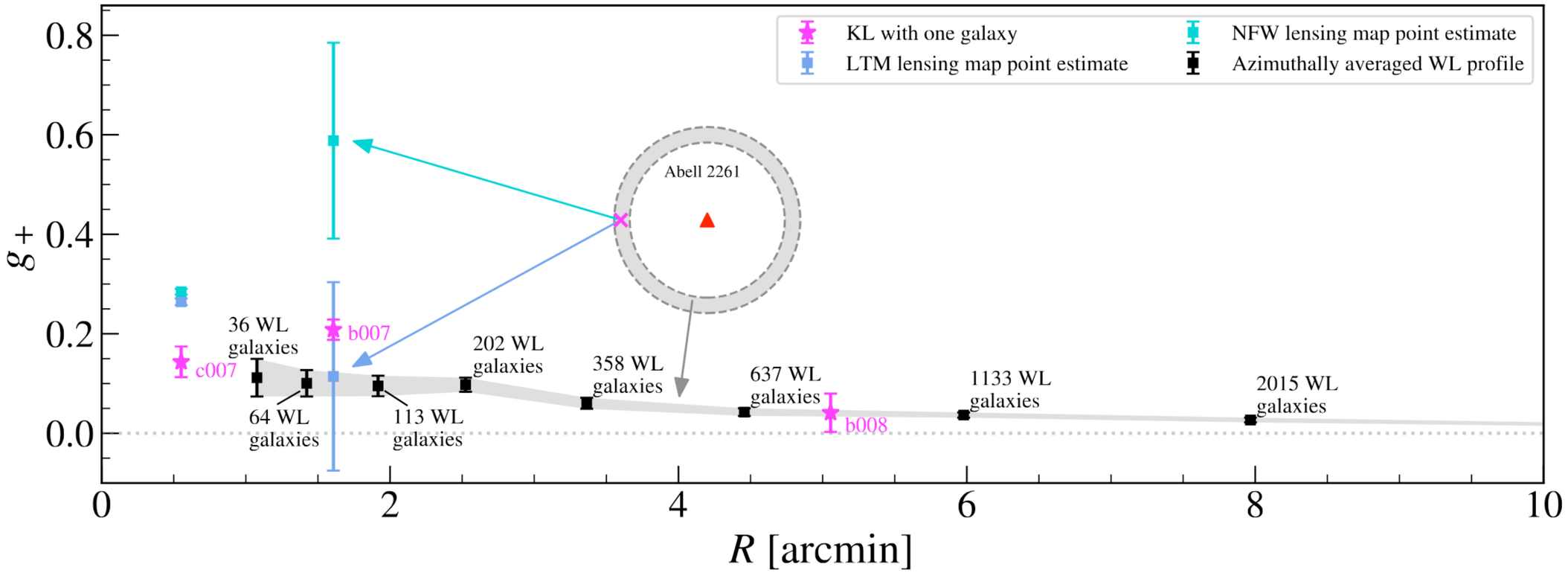
Pranjal RS+24

A2261 Kinematic Lensing Pilot Measurement



Pranjal RS+24

A2261 Kinematic Lensing Pilot Measurement

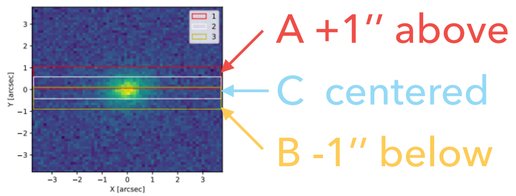


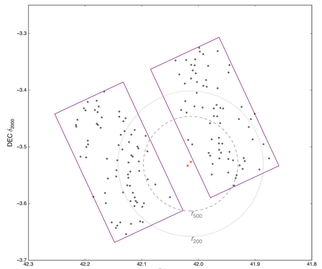
Pranjal RS+24

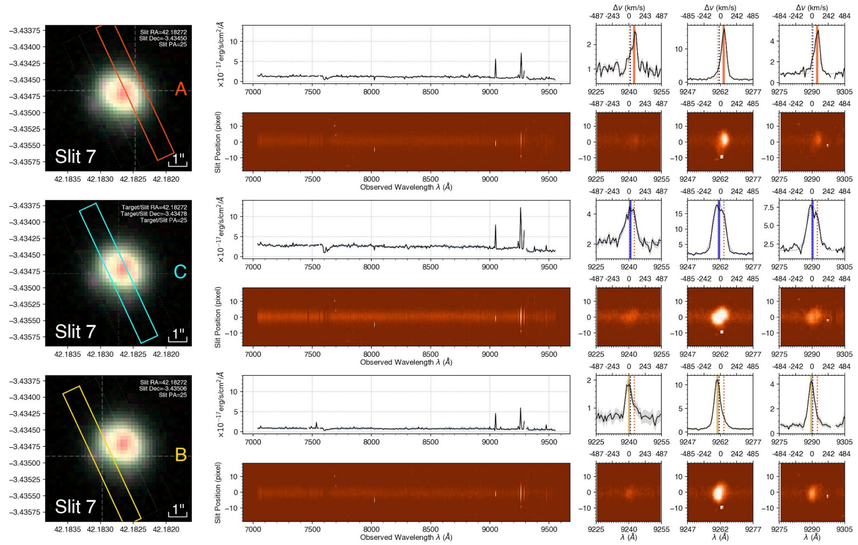
Next Steps

MMT Binospec: pseudo-IFU mode

142 slits in A383 cluster field

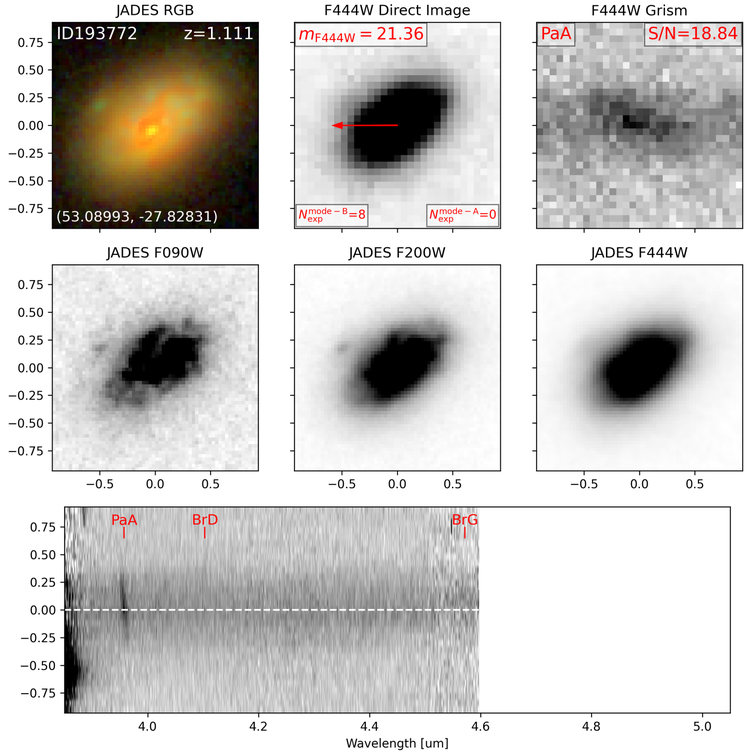






JWST FRESCO: Grism spectra

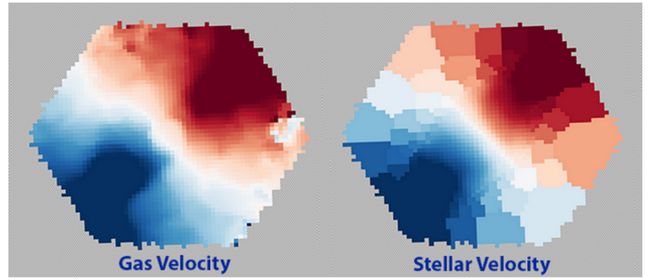
124 arcmin² in GOODS/CANDELS

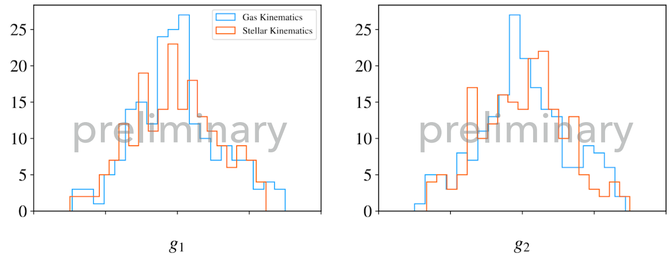


SDSS MaNGA: IFU spectra

879 local galaxies (‘rotator’ sample)

null-test for impact of kinematic substructure on shear inference



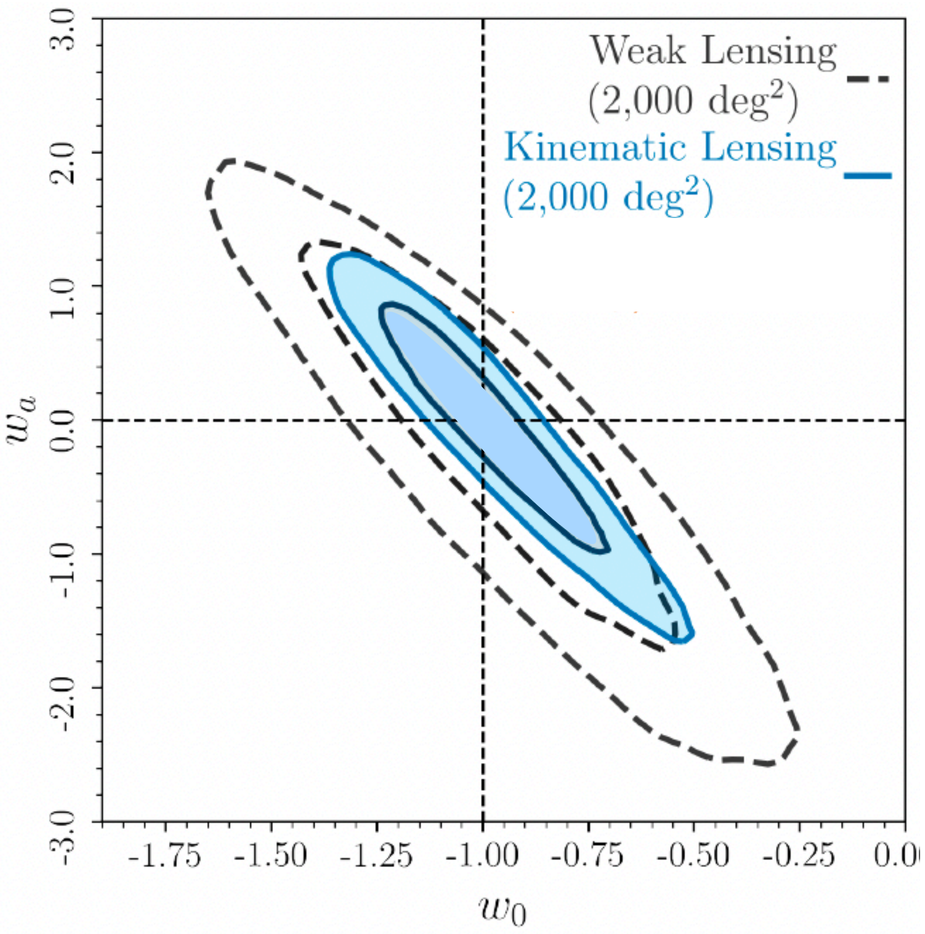


MMT analysis led by Jiyun Di, FRESCO analysis led by Jiachuan Xu, MaNGA analysis led by Pranjal RS

Kinematic Lensing With Roman Space Telescope

- Simulations with Roman's spatial & grism resolution predict shear measurement with $\sigma_\varepsilon \sim 0.03$-$0.04$.
- $n_{eff} \sim 4$ gal/arcmin^2 ELGs with sufficient grism SN for Kinematic Lensing (based on COSMOS+CANDELS)
  - ca. x10 fewer source galaxies than traditional weak lensing, compensated by σ_ε
- **Kinematic Lensing expected to outperform weak lensing analysis (e.g., x3.5 FoM for dark energy)**
  - Novel analysis of data from planned community surveys, no additional observations required!

    Implementation through large Roman Wide Field Science program in progress



J. Xu+22

Summary

- Imaging + galaxy kinematics breaks degeneracy of intrinsic galaxy shape and shear
- 10x reduction in shape noise can compensate for reduced source density
  - Competitive cosmic shear constraints feasible even with Roman grism
- Kinematic lensing inference unbiased on noisy simulations, first cluster lensing measurement confirms predicted shear measurement accuracy
- Several ongoing observing programs and archival analyses to extend sample size and characterize astrophysical uncertainties

Roman Kinematic Lensing Forecast: Jiachuan Xu, Eifler+22 (2201.00739)
Kinematic Lensing Pipeline: Pranjal RS, EK+23 (2209.11811)
Insignificance of IA Analogues: Yu-Hsiu Huang, EK+24 (2404.00197)
Kinematic Lensing Pilot Measurement: Pranjal RS, Huff+24 (2409.08367)