Relation between ionized gas kinematics and Lyα observables in ELARS

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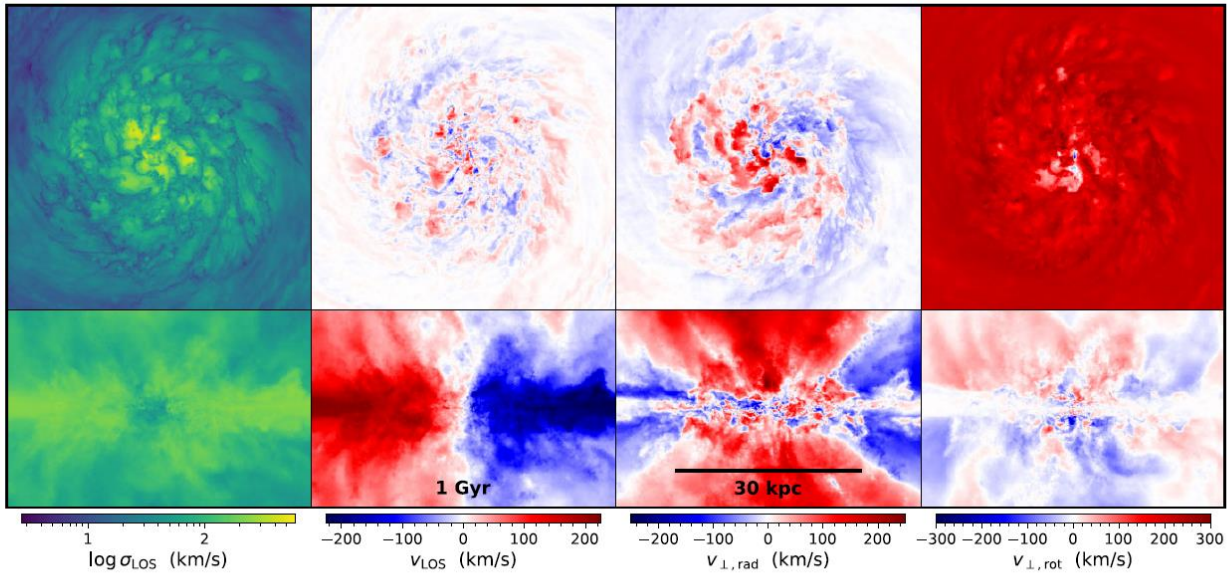
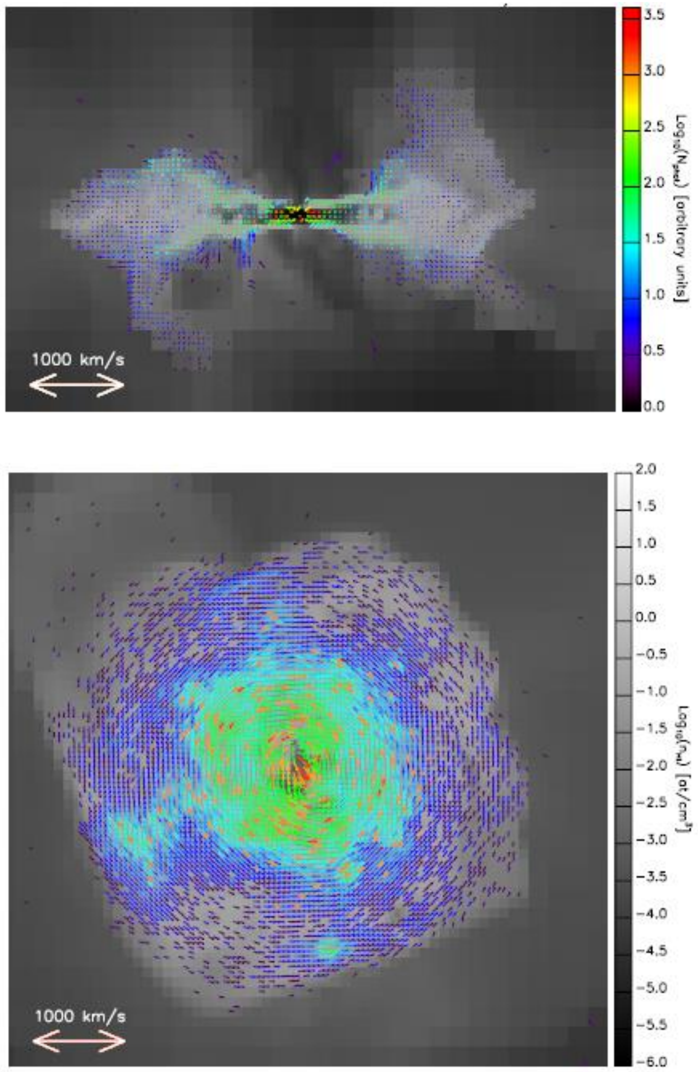
Escape of Lyman radiation from galactic labyrinths
April 18-21, 2023

Motivation

- Simulations study gas kinematics in emission in disk galaxies to understand Lyα escape
- We study observational data to understand the relation between ionized gas kinematics and Lyα observables



Smith et al. 2012

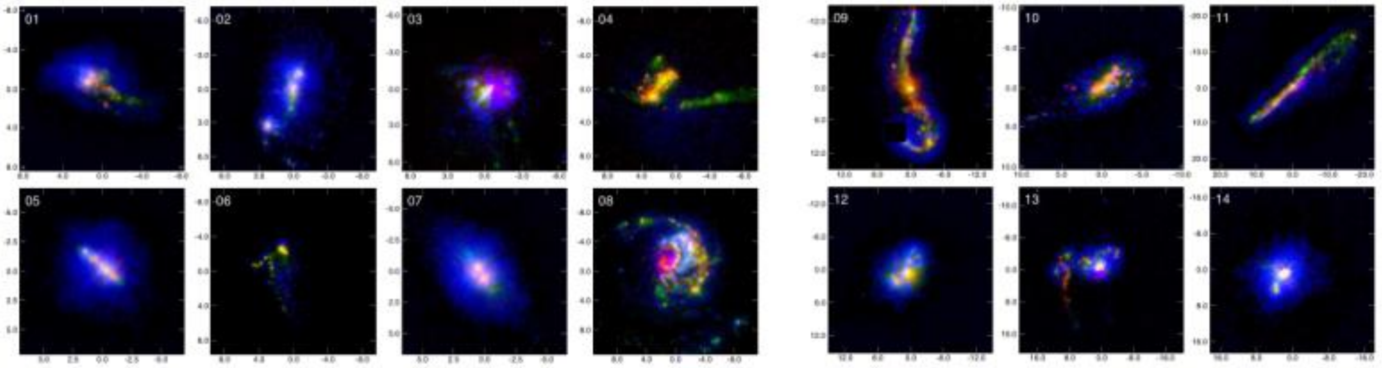


Verhamme et al. 2012

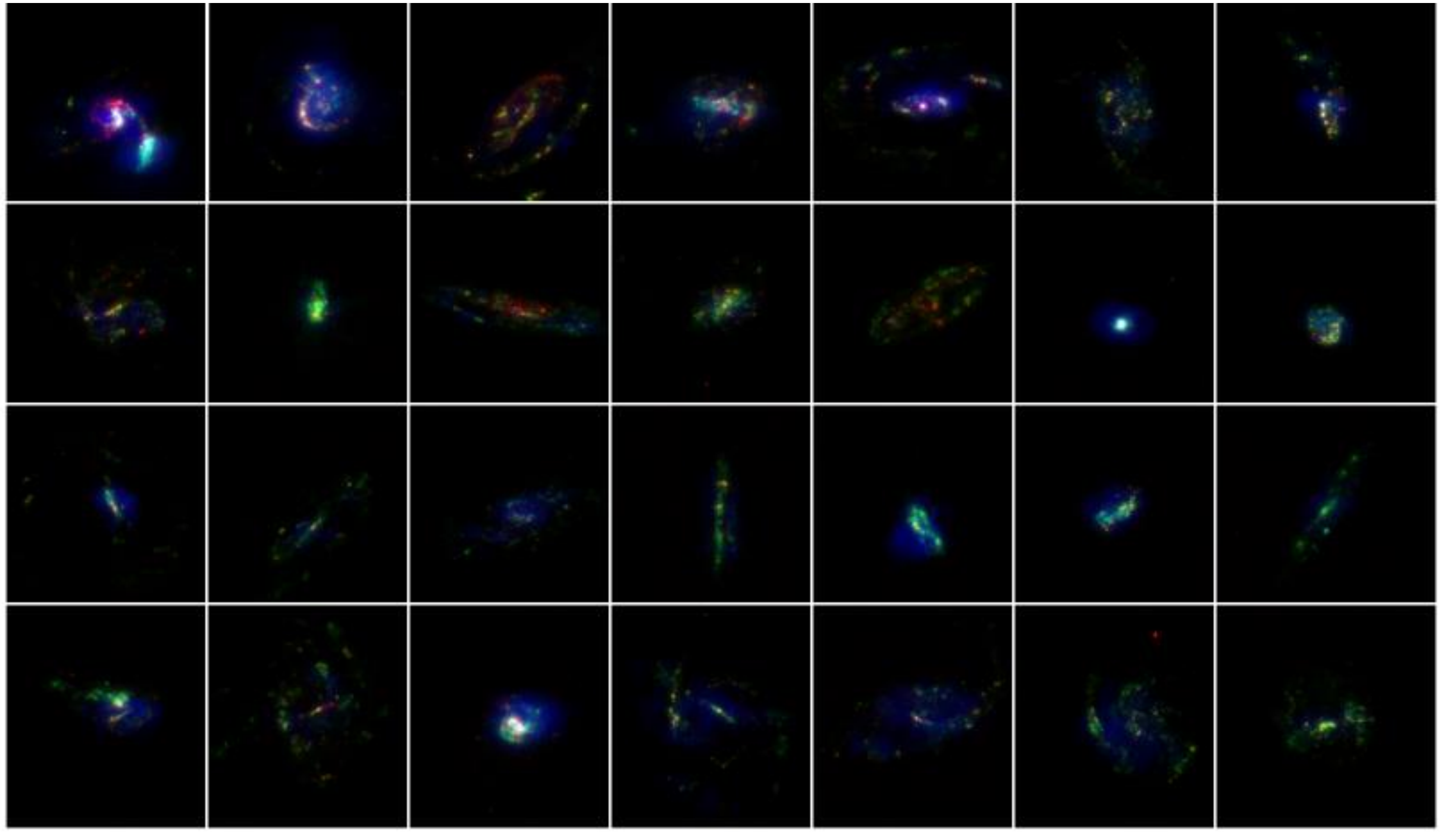
Data

- **E**xtended **L**yman **A**lpha **R**eference **S**ample
  - 42 galaxies
  - High sSFR
- Lyα observables derived from Hubble space telescope data (Melinder et al. 2023)

LARS (14 $W_{H\alpha}$ > 100 Å – Hayes et al. 2014)



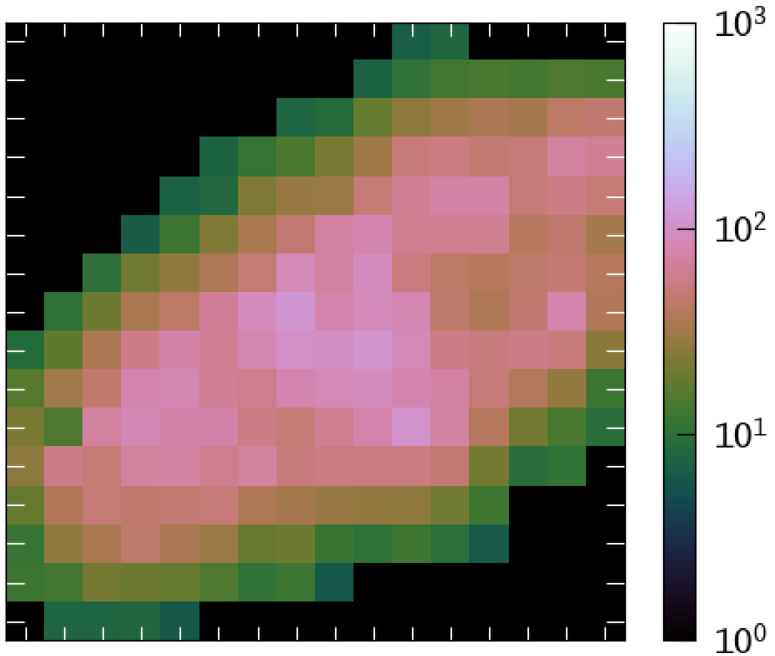
eLARS (28 $W_{H\alpha}$ > 30 Å – Melinder et al. 2023)



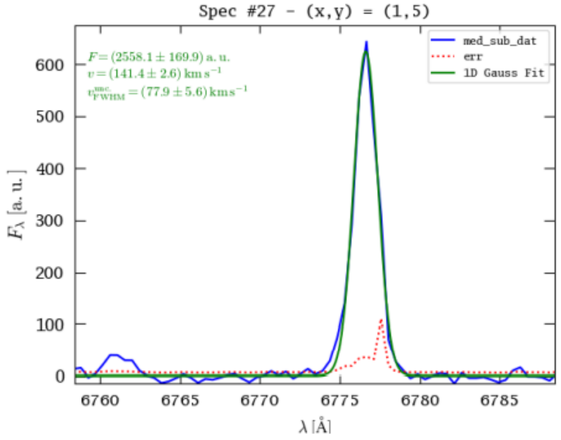
green: FUV continuum
red: continuum-subtracted Halpha emission
blue: continuum-subtracted Lya emission

PMAS data products

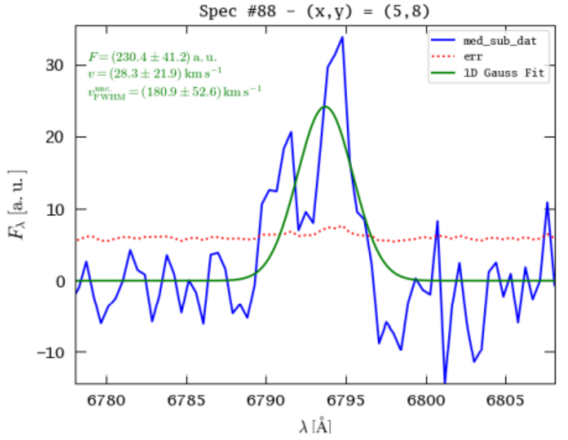
- 16 × 16 spaxel, each 1 × 1 arcsec
- Flux [ADU] & Variance cuboids
- Wavelength range: 6100 - 7400 Å
- Spectral sampling: 0.46 Å
- Spectral resolving power: R ~ 4500
- Seeing: 0.9'' – 2.3''
- Exposure time: 30 – 120 min per galaxy
  - LARS 4 nights in spring 2012
  - eLARS spring 2016/2017
- Backward-blazed R1200 grating



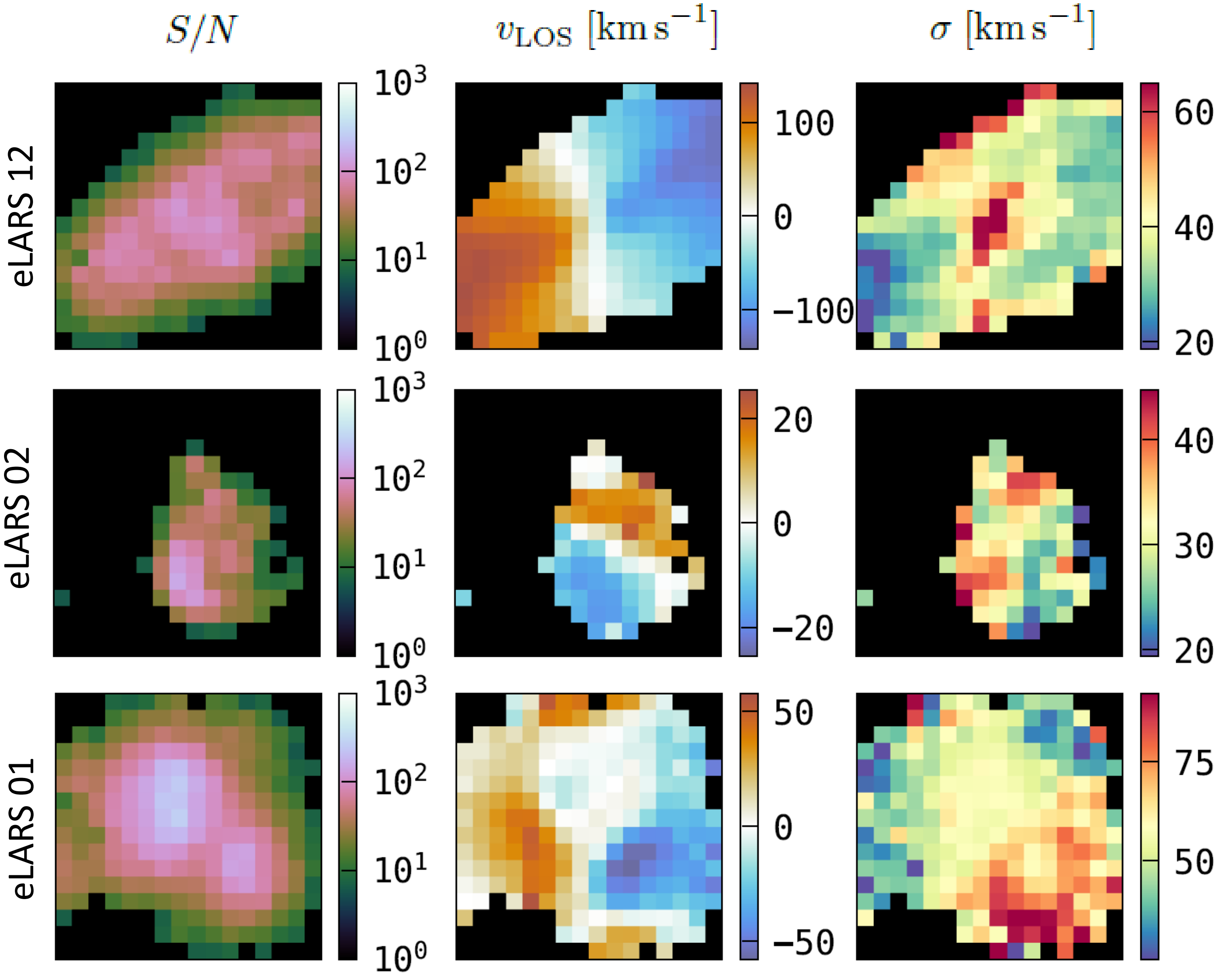
eLARS12



eLARS7



Does visual kinematic classification influence Lyα observabes?



Rotating Discs (RD)

16 eLARS + 2 LARS = 18 RDs

Perturbed Rotators (PR)

9 eLARS + 5 LARS = 14 PRs

Complex Kinematics (CK)

3 eLARS + 7 LARS = 10 CKs

Does visual kinematic classification influence Lyα observabes?

- Lyα observables: $\mathrm{EW}_{Ly\alpha}$, $f_{esc}^{Ly\alpha}$, $L_{Ly\alpha}/L_{H\alpha}$
- Classes: Complex and Perturbed (I) vs. Rotators (II)
- KS-Test, single sided p_0 values
- $H_0: F(x) \leq G(x)$
  - With $F(x)$ the Lyα observables for I
  - With $\mathrm{G}(x)$ the Lyα observables for II

	$\mathrm{EW}_{Ly\alpha}$	$f_{esc}^{Ly\alpha}$	$L_{Ly\alpha}/L_{H\alpha}$
D_n	0.25	0.22	0.17
p_0	0.24	0.32	0.52

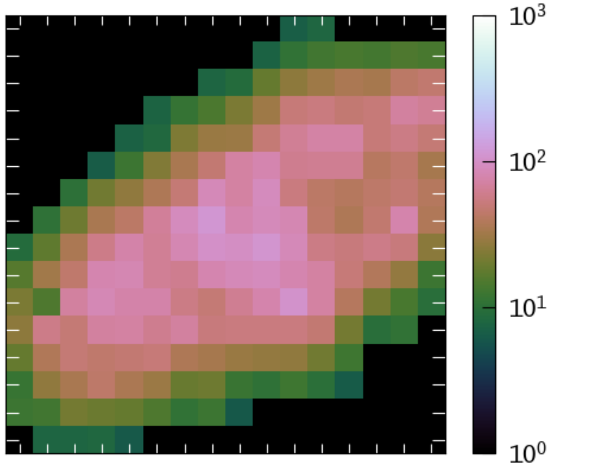
➢ Kinematic classes do not tell anything about Lyα observables

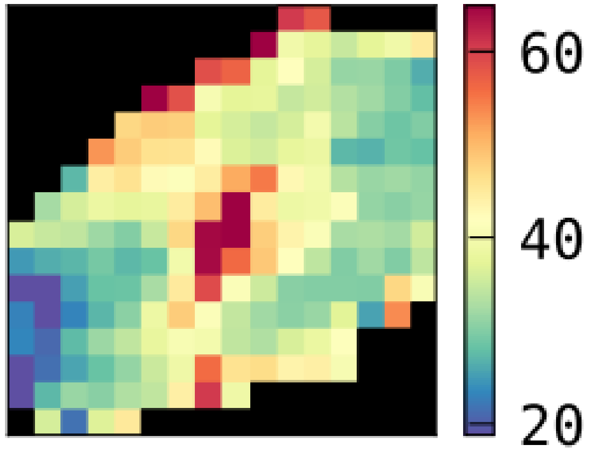
Do quantitatively derived kinematic parameter correlate with Lyα observables?

- Lyα observables derived from HST data
- Ionized gas kinematics via Balmer α line
- Important kinematic parameter
  - Line of sight radial-velocity
  - Velocity dispersion (σ_{emp}) -> problem: PSF smearing
  - v_{shear}/σ_{emp}

Empirical measured velocity dispersion

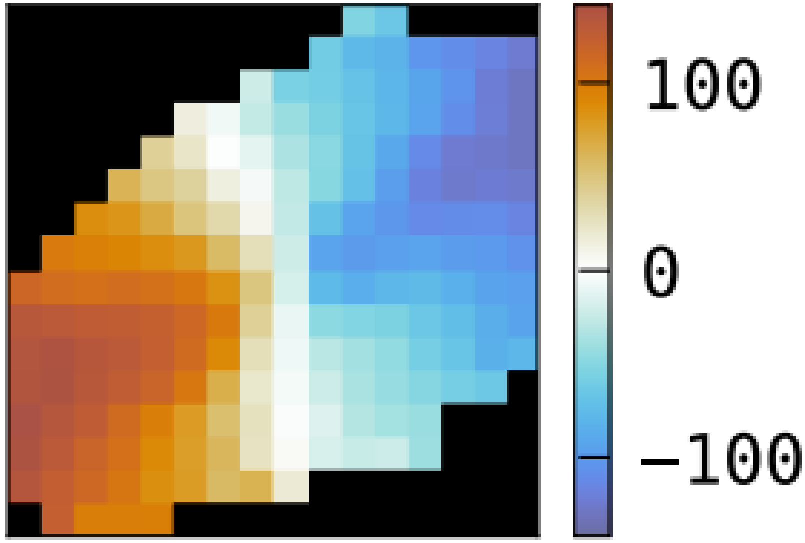
- Measure for random motions of ionized gas in galaxies
- $\sigma_{emp} = \frac{\sum \sigma_{spaxel}}{N}$
- $\sigma_{emp,f} = \frac{\sum F_{spaxel}^{H\alpha} \sigma_{spaxel}}{\sum F_{spaxel}^{H\alpha}}$
- $F_{spaxel}^{H\alpha}$: Hα flux in each spaxel (we use S/N)
- σ_{spaxel}: velocity dispersion in each spaxel
- Problem: PSF smearing (strong velocity gradient broadens Hα line)





Shearing velocity

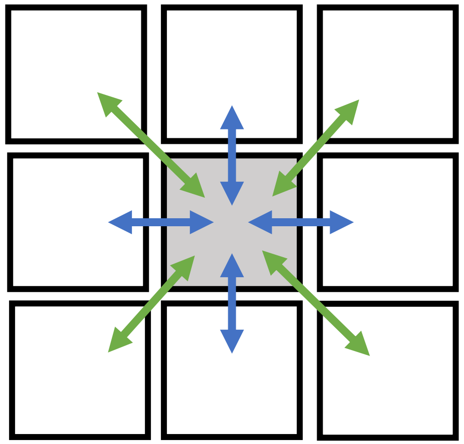
- Large-scale gas bulk motion along the line of sight
- $v_{shear} = \frac{1}{2}(v_{95} - v_5)$
- v_{95}: 95 percentile of the velocity field
- v_5: 5 percentile of the velocity field



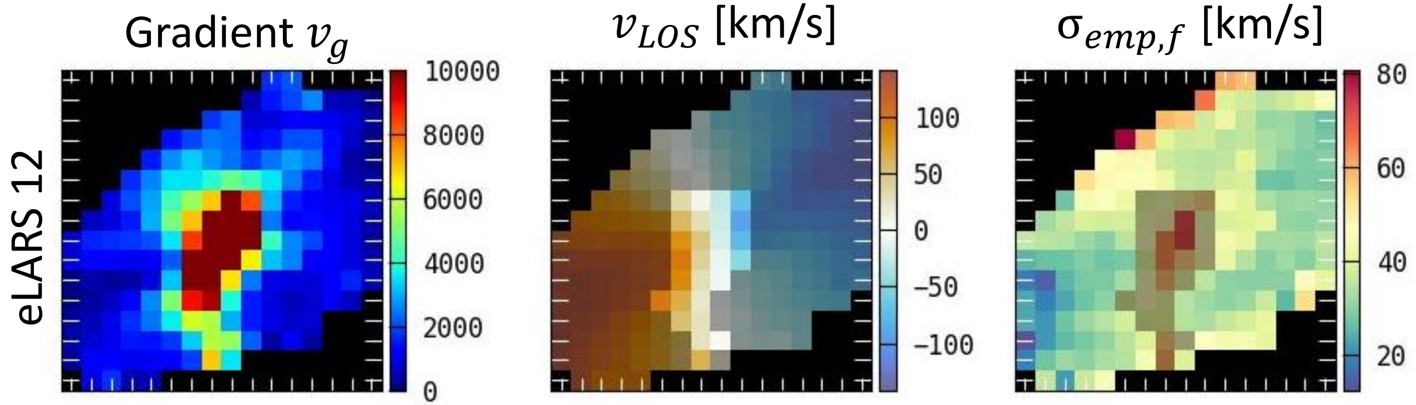
v_{shear}/σ_{emp}

- Gas kinematics dominated by ordered motions (large value) / dispersion dominated motions (small value)

Empirical method



- PSF smearing in regions with high velocity gradient and low spatial resolution
- Automated masking, where σ_{spaxel} is affected by PSF smearing
- $v_g(x,y) = [v(x-1,y)-v(x,y)]^2 + [v(x+1,y)-v(x,y)]^2$
  $+[v(x,y-1)-v(x,y)]^2 + [v(x,y+1)-v(x,y)]^2$
  $+[v(x-1,y-1)-v(x,y)]^2 + [v(x-1,y+1)-v(x,y)]^2$
  $+[v(x+1,y-1)-v(x,y)]^2 + [v(x+1,y+1)-v(x,y)]^2$



- Cut out spaxels with high gradient (>5000)
- Calculate velocity dispersion with remaining spaxels

Varidel gradient method (Varidel et al. 2016)

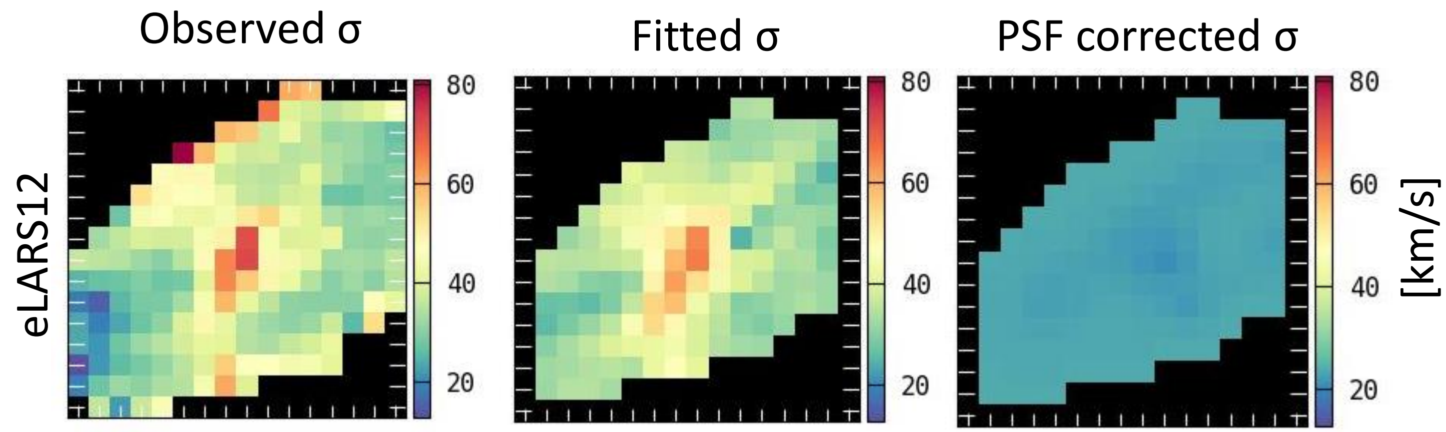
- Local velocity gradient:

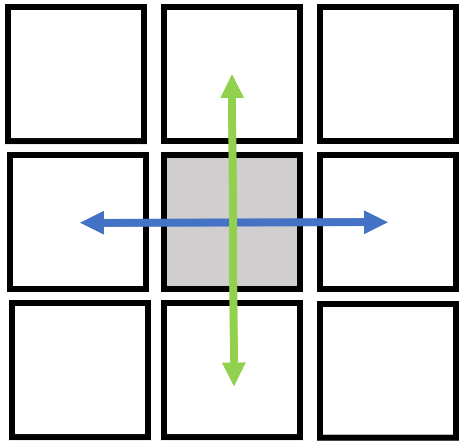
$$v_g(x, y) = \sqrt{[v(x+1, y) - v(x-1, y)]^2 + [v(x, y+1) - v(x, y-1)]^2}$$

- Fit 2D linear model:

$$\sigma_i\left[F(H\alpha_i), v_{g,i}\right] = m_{H\alpha} \log_{10}[F(H\alpha_i)] + m_{v_g}\, v_{g,i} + C$$

- PSF correction: remove $m_{v_g}\, v_{g,i}$





GalPaK3D (3D parametric disk model)

GalPaK galaxy parameters and kinematics

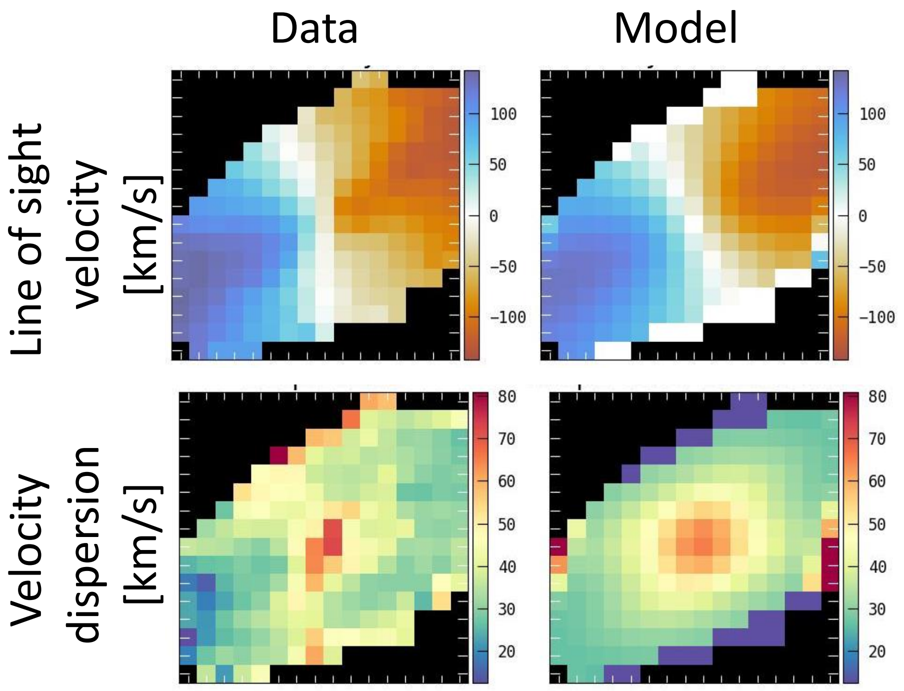
Bouché et al. 2015

- Tool to extract intrinsic Galaxy Parameters and Kinematics from any 3D cubes
- Disk parametric model
  - Flux: Sersic profile
  - Velocity: tanh-profile → use rotating disks
  - LSF: Gaussian
  - PSF: Gaussian
- Input: Cube flux and variance (range of H α line), Seeing (PSF), LSF
- Models on a 3D data cube
- Output: 3D datacube, kernel, from cube extracted maps, …

Parametric intrinsic velocity dispersion

Total line-of-sight velocity dispersion σ_{spaxel} consist of three terms added in quadrature:

- Local velocity dispersion σ_d
  - Driven by self-gravity
  - $\frac{\sigma_d(r)}{h_z} = \frac{V(r)}{r}$ for compact thick or large thin disk
- Mixing term σ_m
  - Mixing velocities along line of sight for a geometrical thick disk
- Intrinsic dispersion σ_0
  - Isotropic and constant spatially
  - Dominates the other two terms often



What we have to compare:

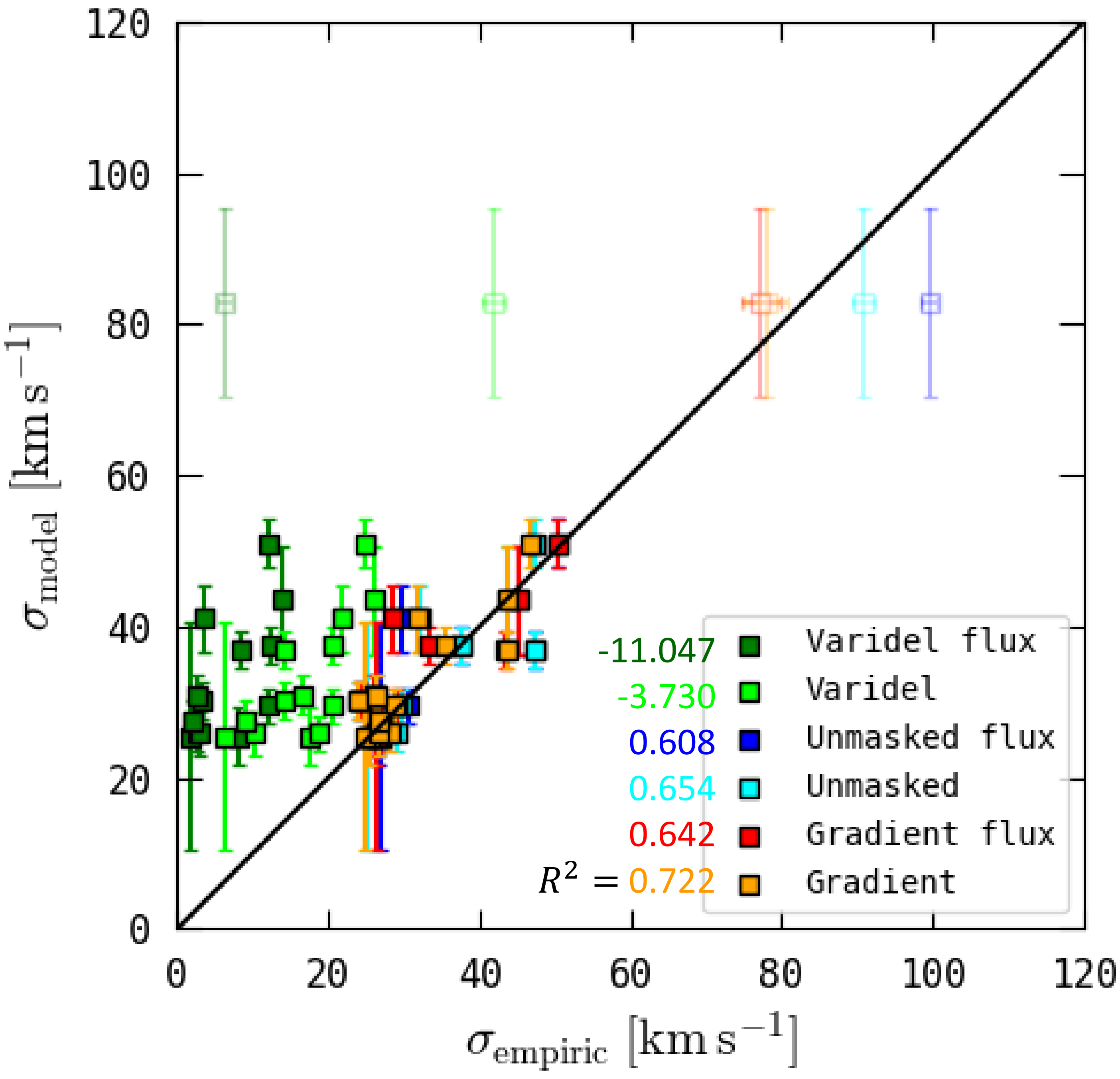
Velocity dispersions:

- Value modelled by GalPaK3D
- Unmasked mean
- Unmasked flux-weighted mean
- Gradient mean
- Gardient flux-weighted mean
- Varidel gradient mean
- Varidel gradient flux-weighted mean

Model: σ_{model}

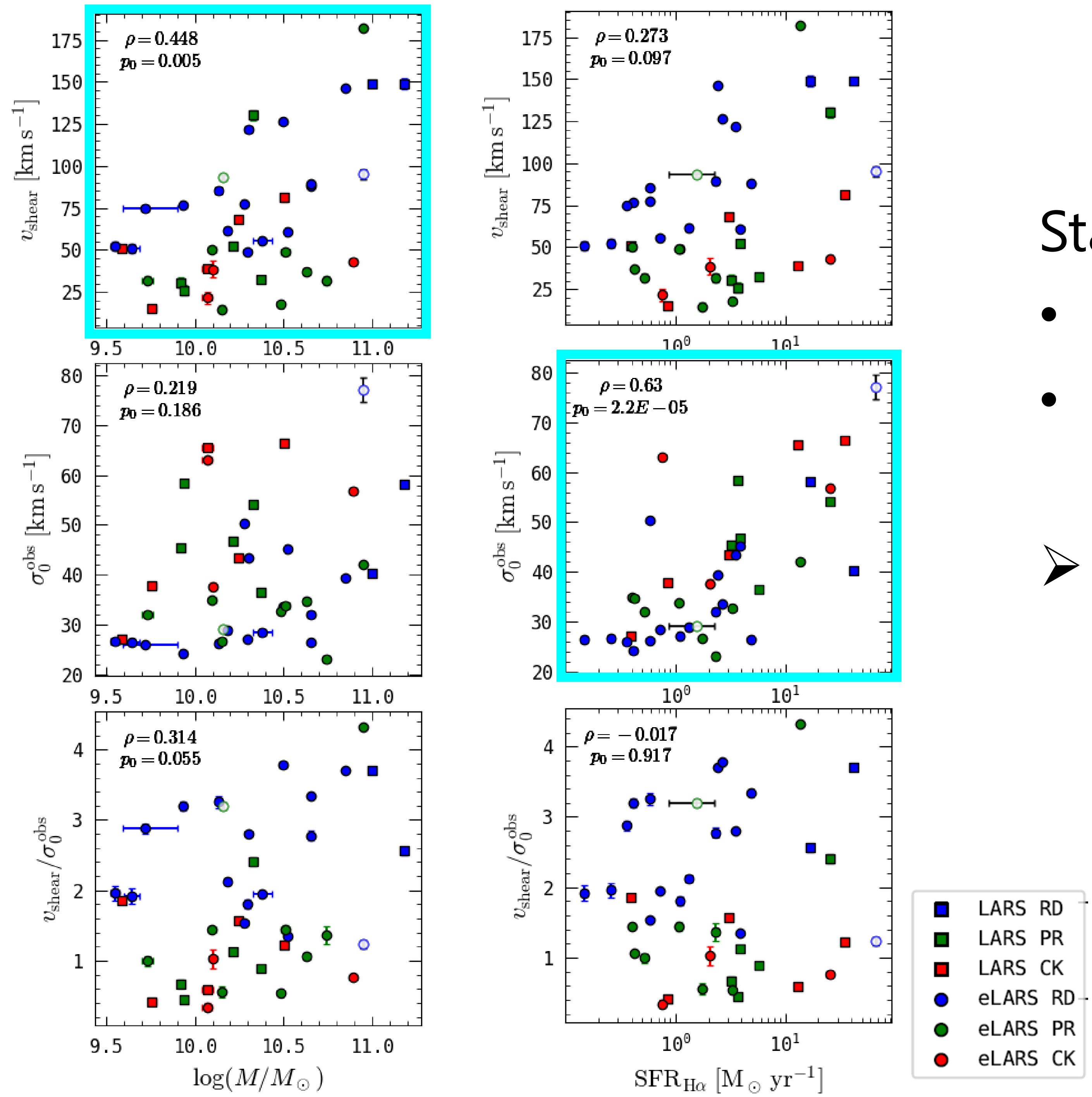
Empiric calculation: $\sigma_{empiric}$

Comparison velocity dispersions



- $R^2 = 1 - \frac{\sum_i (y_i - f_i)^2}{\sum_i (y_i - y_{mean})^2}$
- y_i: measured data points
- y_{mean}: mean of y_i
- f_i: model value

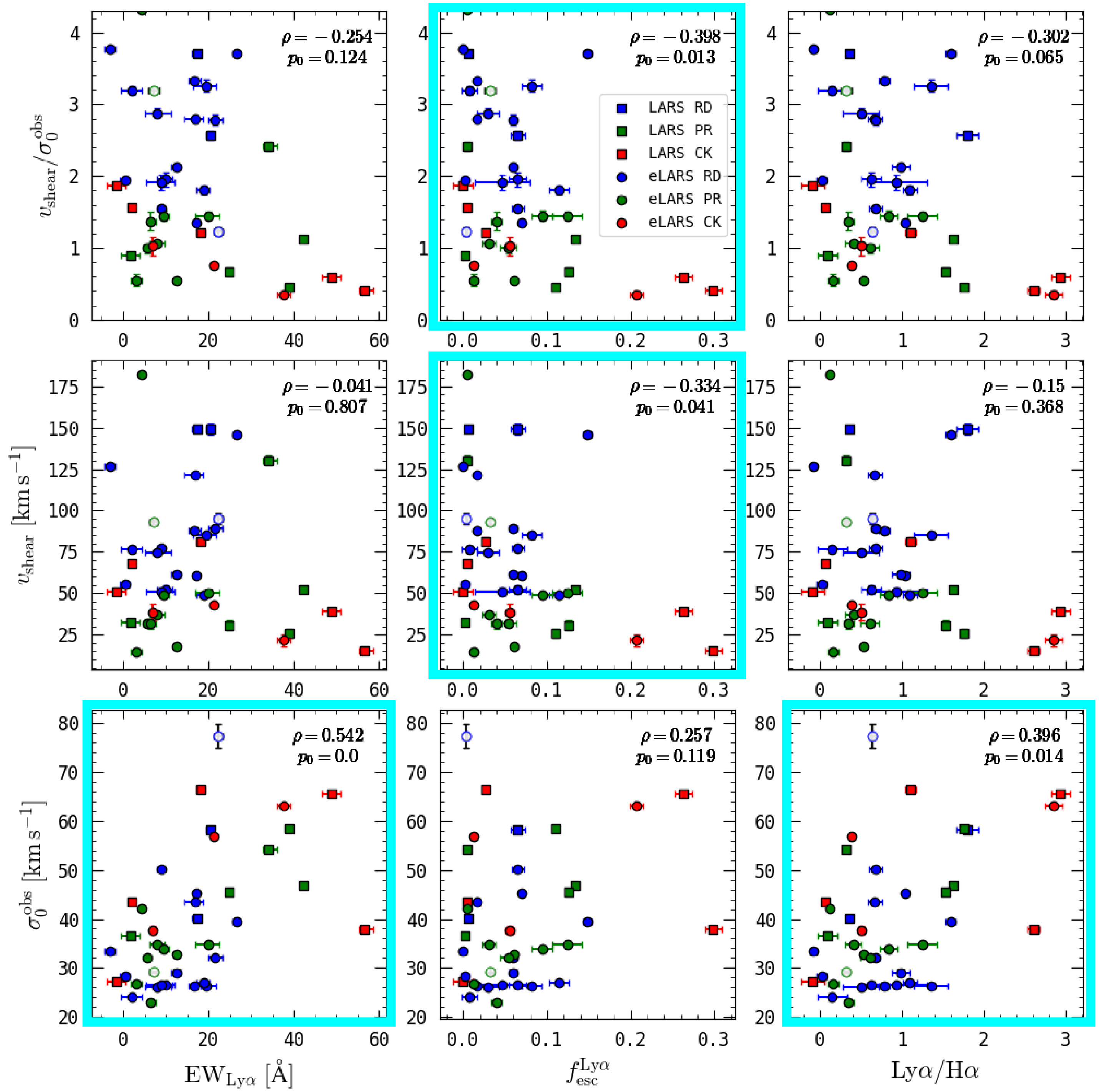
➢ Best: Gradient masked sigma without flux-weighting



Statistic relevant correlations:

- Stellar mass and v_{shear}
- SFR and σ^{obs}

➢ From the kinematical perspective eLARS appears representative for typical star-forming galaxies.



Statistic relevant correlations:

- f_{esc} and v_{shear}
- $\text{EW}_{Ly\alpha}$ and σ^{obs}
- $L_{Ly\alpha}/L_{H\alpha}$ and σ^{obs}
- f_{esc} and $v_{shear}/\ \sigma^{obs}$

Larger statistic sample than in Herenz et al. 2016

➢ Correlations differ to Herenz et al. 2016

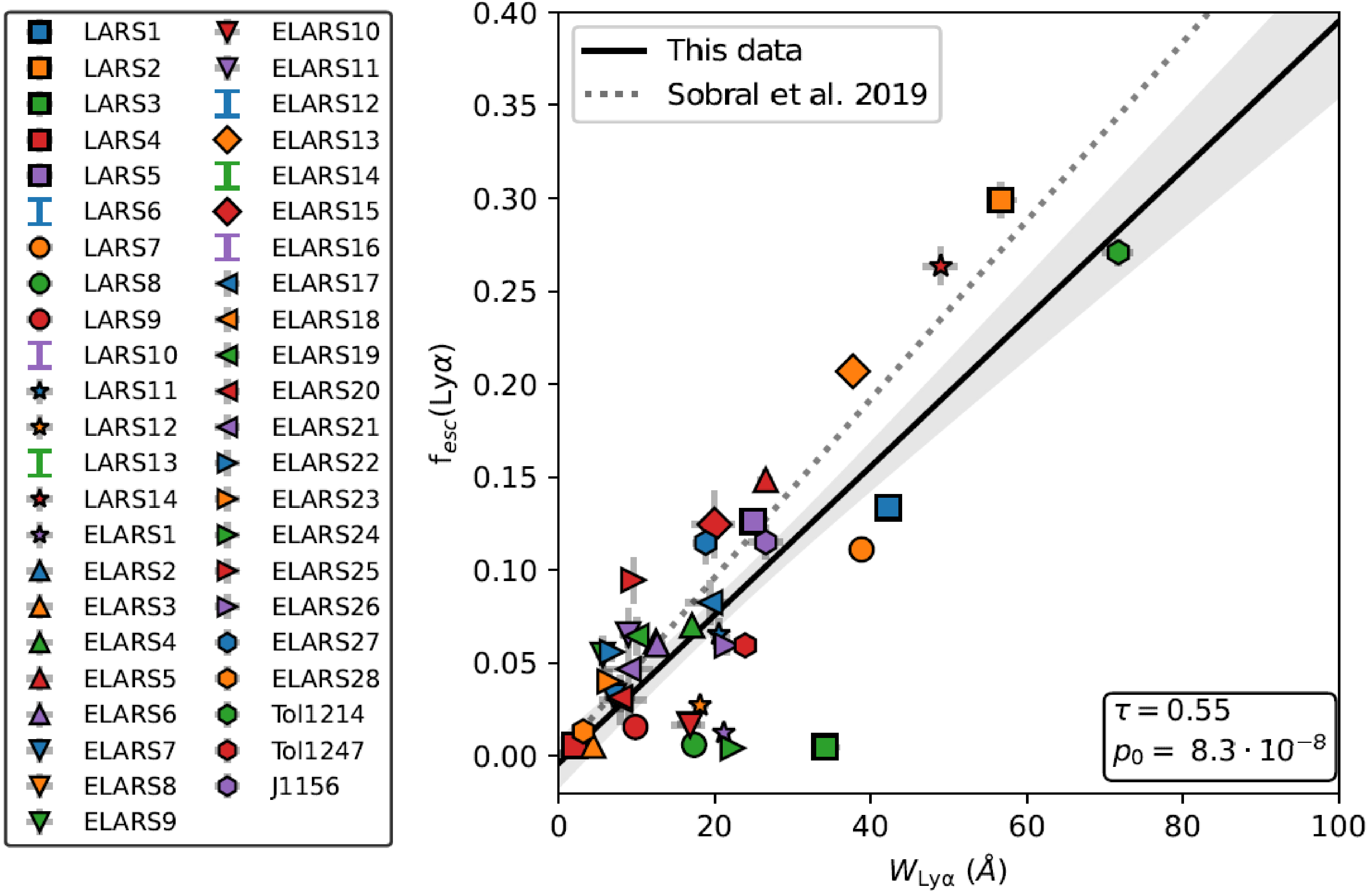
Conclusion

- First time that we have a statistical sample to relate kinematics and Lyα

- Correct velocity dispersion for PSF smearing with different methods
- Best correction: Gradient method without flux-weighting

- Velocity dispersion correlates with Lyα equivalent width and Lyα/Hα
- Shearing velocity anticorrelates with Lyα escape fraction
- Dispersion dominated systems have higher escape fractions

➢ Turbulent kinematics shift enough emitting and absorbing material out of resonance and thereby enhance the probability of Lyα escaping



Melinder et al. 2023