“Kinematical characterization of a local sample of (U)LIRGs observed with VLT-VIMOS IFS”

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Main goals:

- 2-D kinematic characterization of local (U)LIRGs sample; look for correlations wrt fundamental properties like Dynamical Status, L_ir, Ionization type, etc.; comparison with local and high-z samples

  (Bellocchi et al. in prep.)

- Find out kinematic criteria able to distinguish between "disk" or "merger" systems (e.g., Shapiro et al. 2008). This is relevant to constrain different galaxy evolutionary scenarios. *(Bellocchi et al. 2012)*

Outline of this talk:

Part 1: The sample, Data analysis (Line fitting & Creating maps)

Part 2: PAPER I (**Bellocchi et al. 2012**; sub-sample 4 objects):

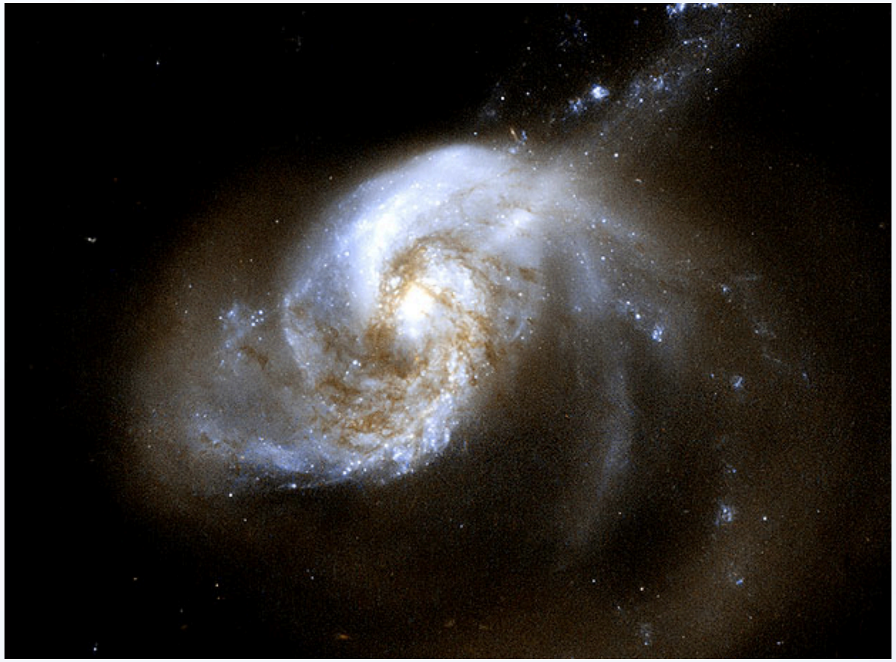
Define kinematic criteria to distinguish “disk/merger” (e.g., Shapiro+08)

locally & at high-z (simulations using NIRSpec resolution) & Results

Part 3: PAPER II: (**Bellocchi et al. in prep**.; the whole sample)

- Kinematical characterization of the whole sample (i.e., narrow + broad comps): v, s, v/s ratio, M_{dyn} (M*)
- Comparison with local and high-z works & Results

Part 1: The sample→ (Ultra) Luminous InfraRed Galaxies



- Important population to study galaxy evolution → they are systems of intense star formation (SF)
- Local ULIRGs have SFRs as high as those @ high-z: rare locally and more numerous at high z (contribute significantly to the past star formation z > 1)
- High SF generates high IR Luminosity:

→L_{IR} (LIRG)= 10^{11}-10^{12} $L_{\odot}$; L_{IR} (ULIRG)> 10^{12} $L_{\odot}$

- The high L_{IR} is produced by UV photons coming from young massive stars and/or active galactic nucleus (AGN), absorbed by the dust and re-emitted at longer wavelength (i.e., IR)
- Analogy local - high-z (U)LIRGs under discussion. So far, comparison through the study of their **SEDs**…→ kinematical properties not studied in detail so far…

- Thanks to IFS, **we can kinematically characterize our sample and compare it with local and high-z populations**

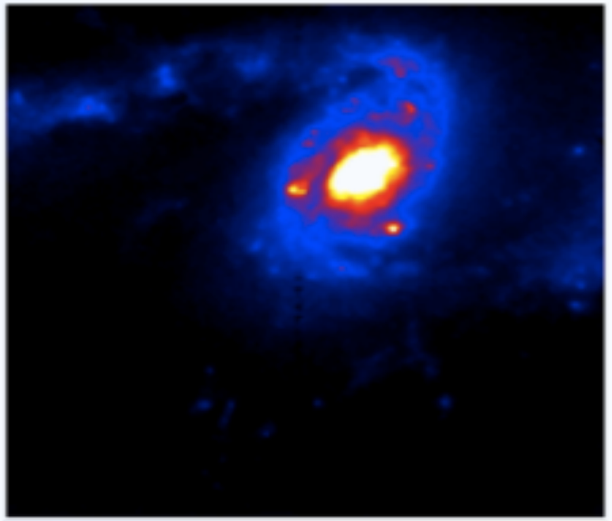
Part 1: The sample & VLT/VIMOS IFU observations (contd)

- From **RBGS** (Sanders +03): 38 (Ultra) Luminous InfraRed Galaxies systems (i.e., 51 galaxies, 7 ULIRGs) observed with VIMOS @ VLT
- <z> ~ 0.022
- Log $L_{IR}/L_{\odot}$ = 11-12.4
- Different morphological types

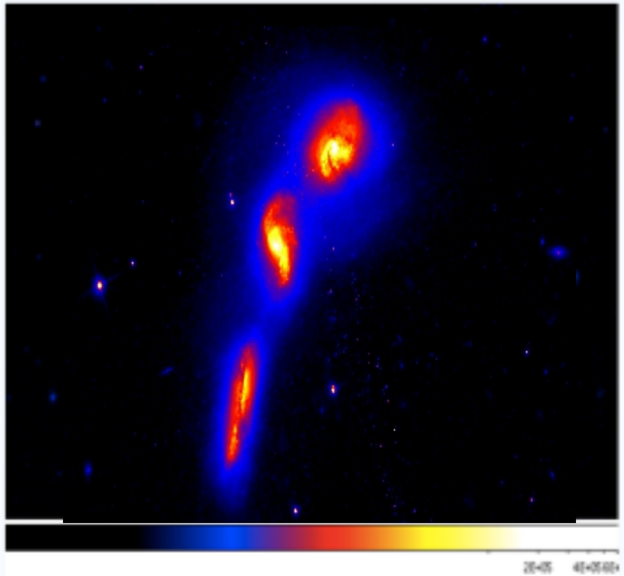
(& different ionization types: LINERs, Seyfert, HII…)

Our observing mode:

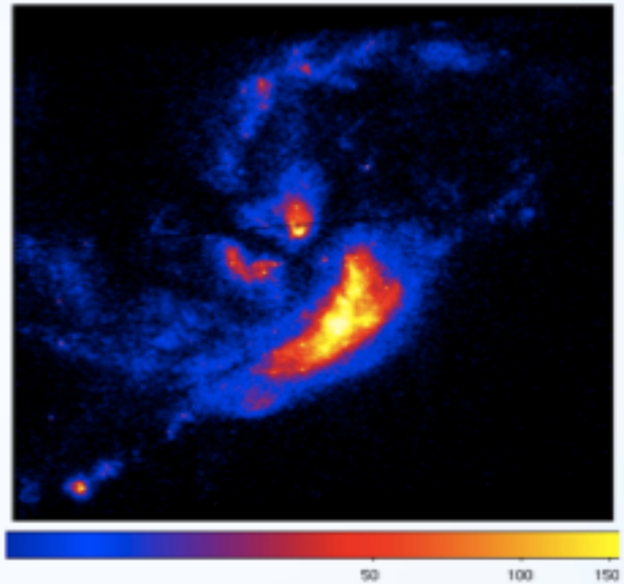
- ✓ FOV = **27x27** $arcsec^2$(@ **0.67”**/fiber)
- ✓ Wavelength range: **5250÷7400** Å
- ✓ **1936** spectra/object
- ✓ High resolution: **R ~ 3470**



Isolated disk (0)



Interacting (1)



Merger (2)

ii. Data analysis:

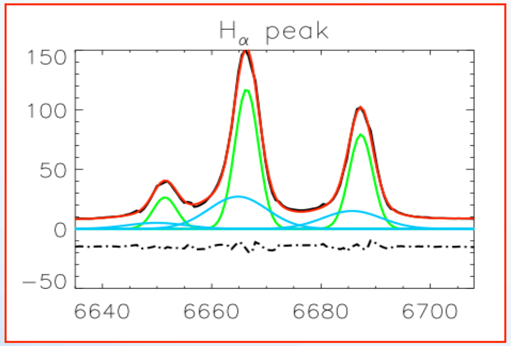
Line fitting (i.e., 1 or 2 comps) and relative maps:

Line profiles fitted with GAUSSIAN model obtaining

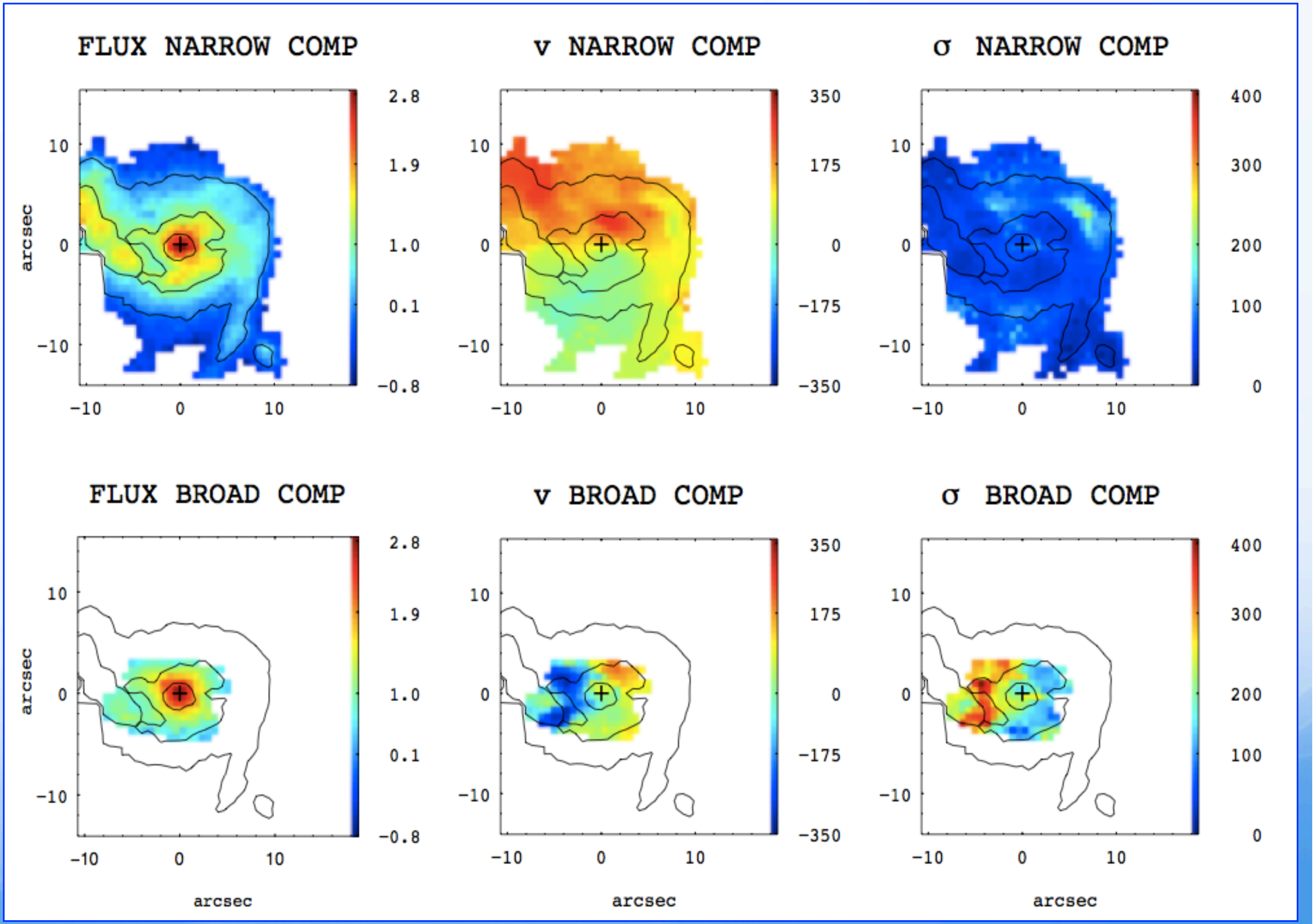
FLUX INTENSITY, FWHM (s) & CENTRAL WAVELENGTH (l_c)

NGC 1614

1° NARROW component



2° BROAD component

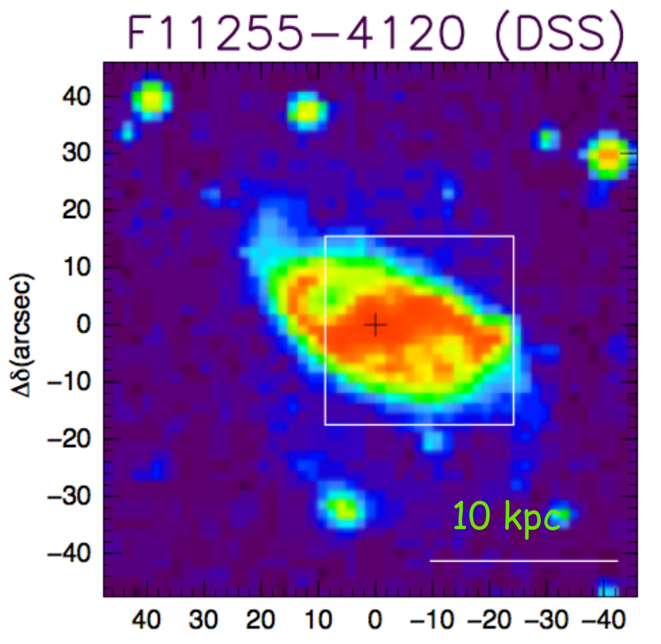


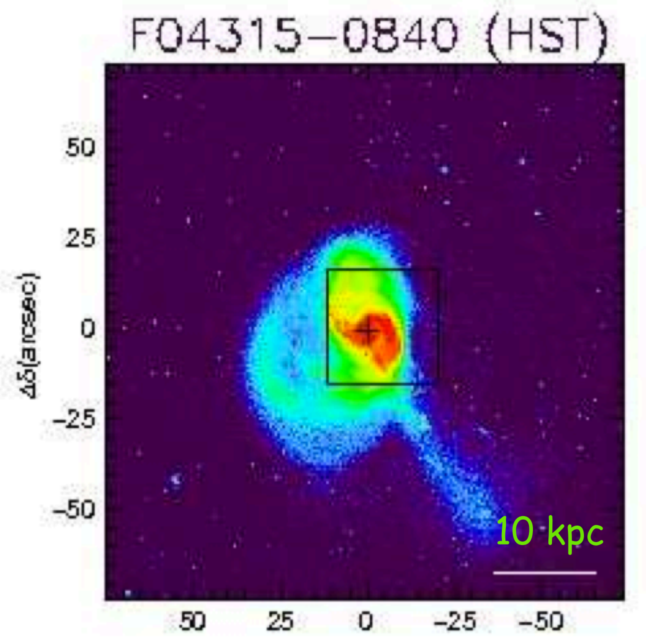
Part 2: Find out kinematic criteria to distinguish between "disks" or "mergers"→ **Sub-sample 4 LIRGs @ 70 Mpc** (Bellocchi +12)

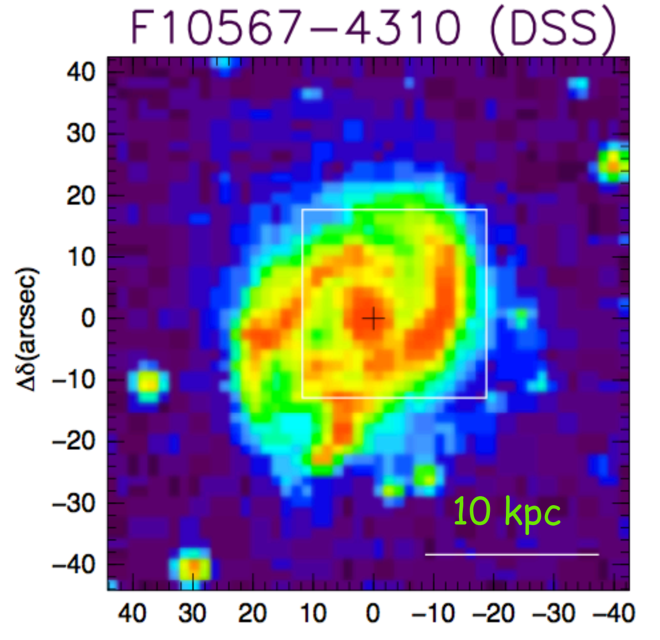
Morphological classification

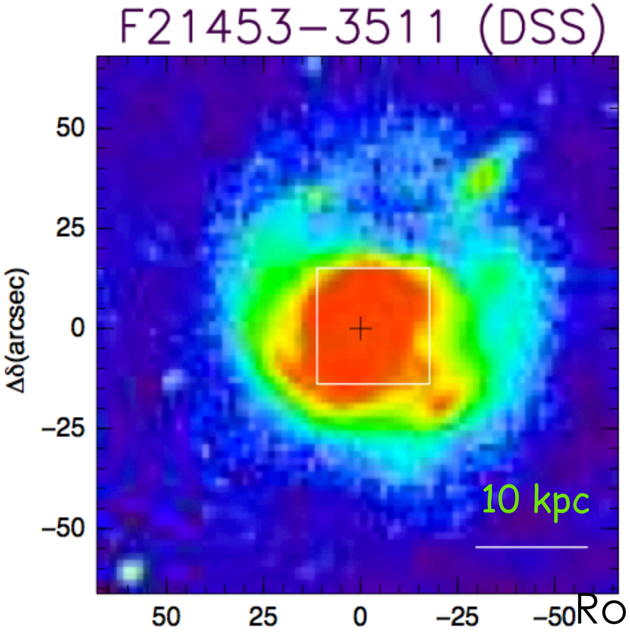
"Disks"

"Mergers"


F11255−4120 (DSS)

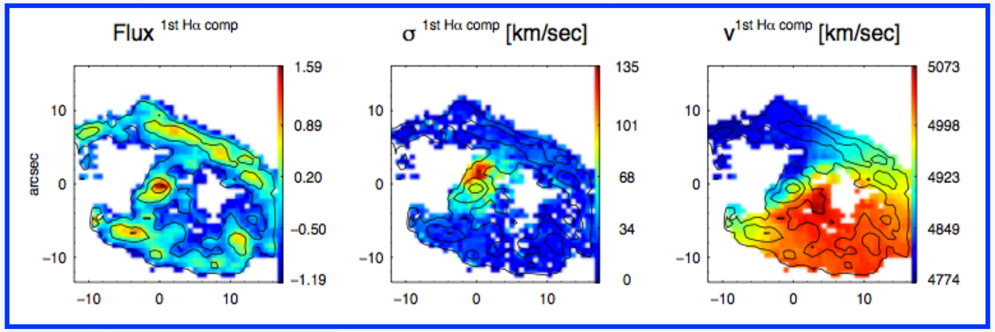

F04315−0840 (HST)

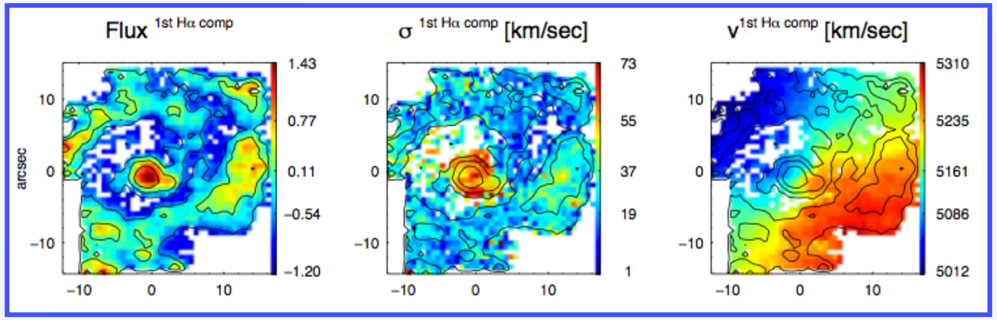

F10567−4310 (DSS)

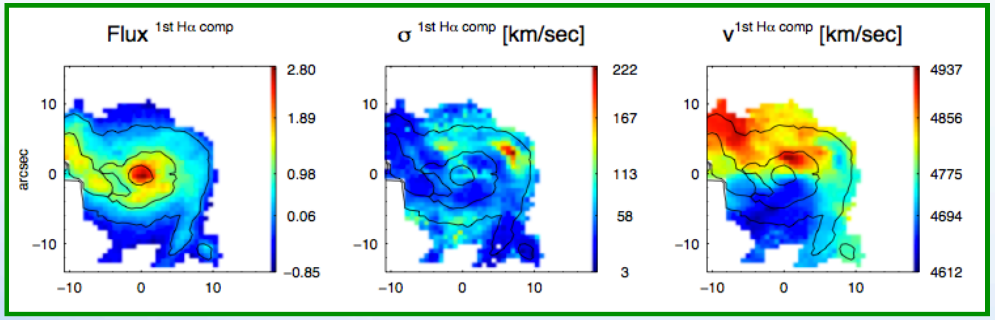

F21453−3511 (DSS)

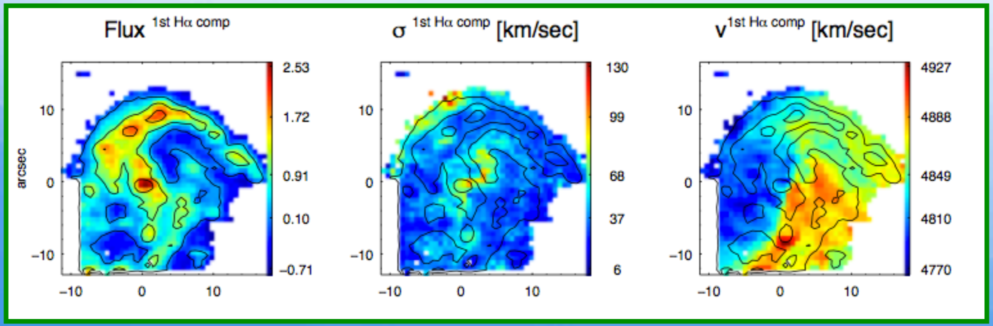
Rodriguez-Zaurin +10

(Local) Observed data

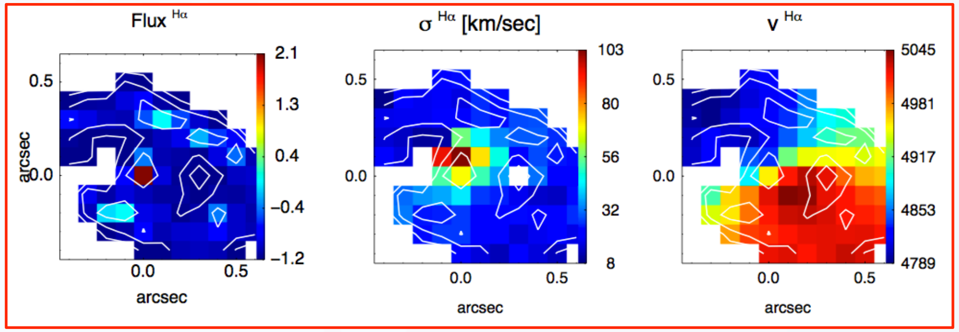


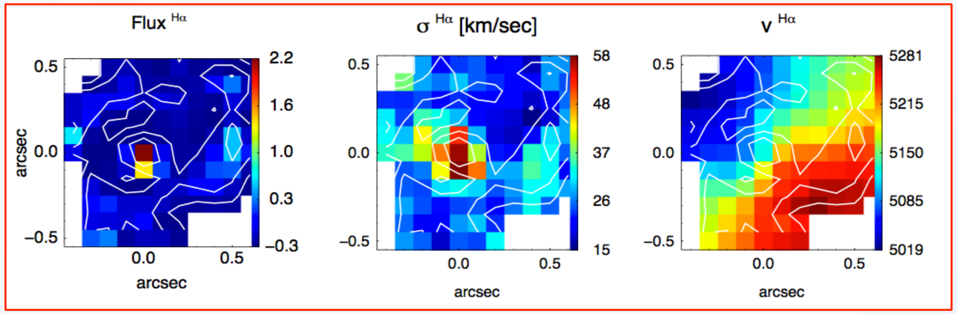


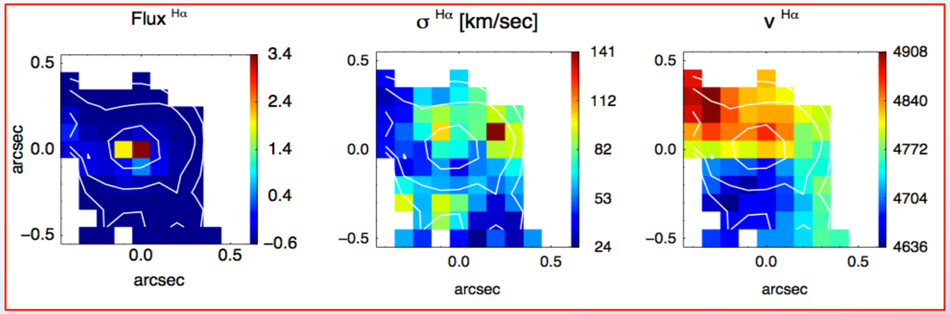


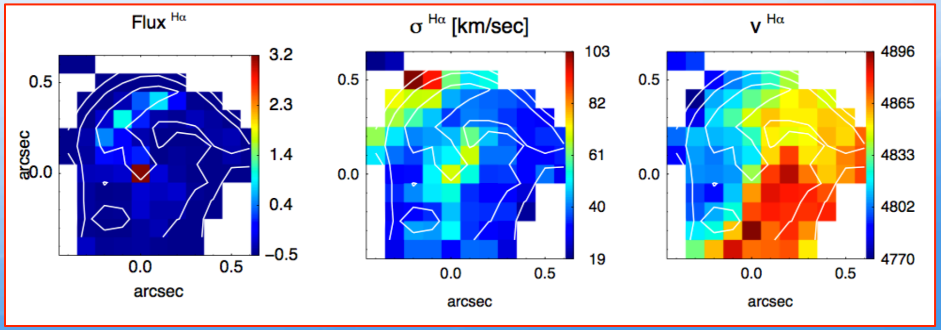


z = 3 Simulated data @ NIRSPEc resolution









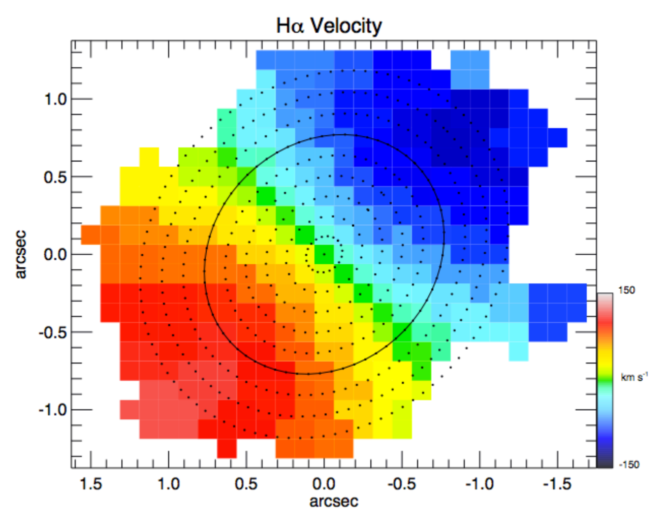
2) The method: "Kinemetry" (Krajnovic +06)

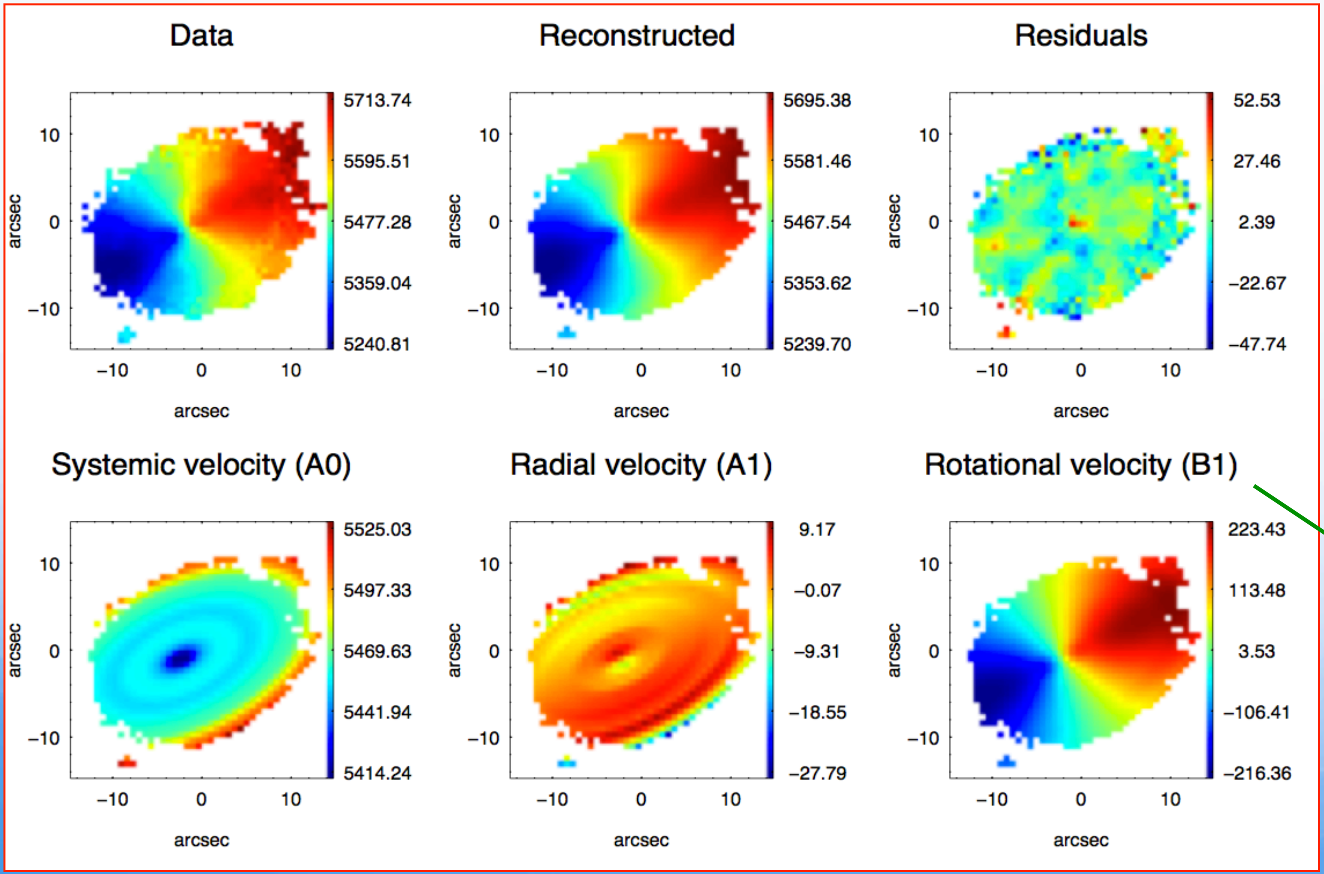
- Harmonic expansion of 2D maps of observed moment along the best fitting ellipses: along each ellipse the moment as a function of angle is extracted and decomposed into the Fourier series

$$K\ (\psi, r) = A_0(r) + \Sigma\ A_i(r)\ \sin\ (i \cdot \psi) + B_i(r)\ \cos(i \cdot \psi)$$

where Ψ is the azimuthal angle in the plane of the galaxy

→ The results are the Fourier coefficients (A_i, B_i) and reconstructed kinematic moment maps !





Rotational Curve !

3) Kinematic criteria

a) Shapiro et al. 2008

To quantify asymmetries of a system (e.g., v_{asym}, σ_{asym}) wrt an *ideal rotating disk*, to differenciate it between "disk" or "merger"

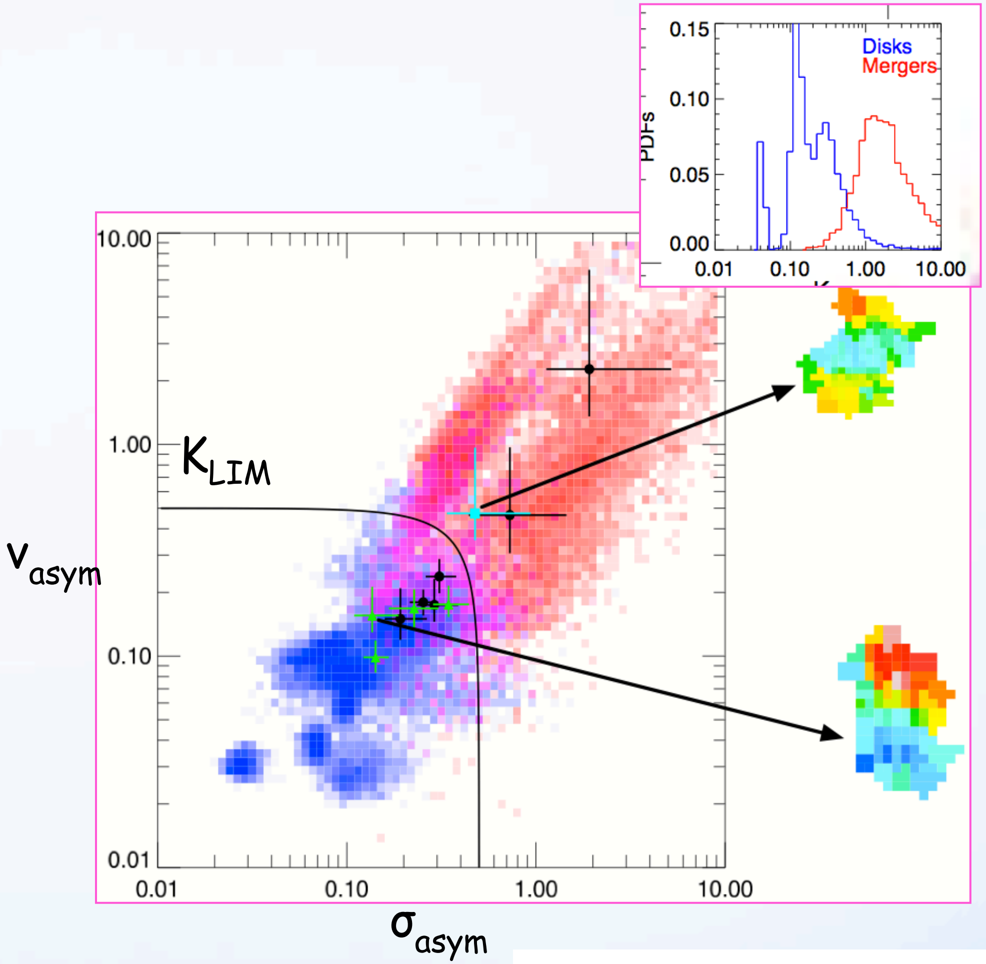
$$\sigma_{asym} = \left\langle \frac{k_{avg,\sigma}}{B_{1,v}} \right\rangle_r$$

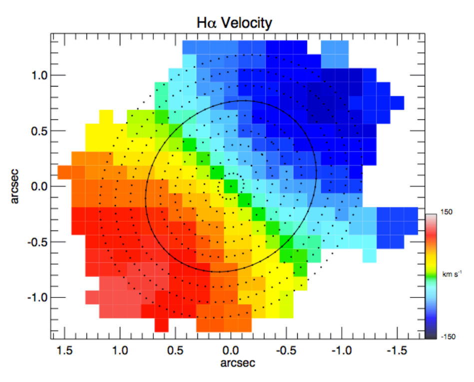
$$v_{asym} = \left\langle \frac{k_{avg,v}}{B_{1,v}} \right\rangle_r$$

$$\boxed{K_{asym} = \sqrt{v_{asym}^2 + \sigma_{asym}^2} = 0.5}$$

→ k_{avg} = high-order deviations (i.e., A_i, B_i)

→ $\mathbf{B_{1,v}}$ = Rotational Curve



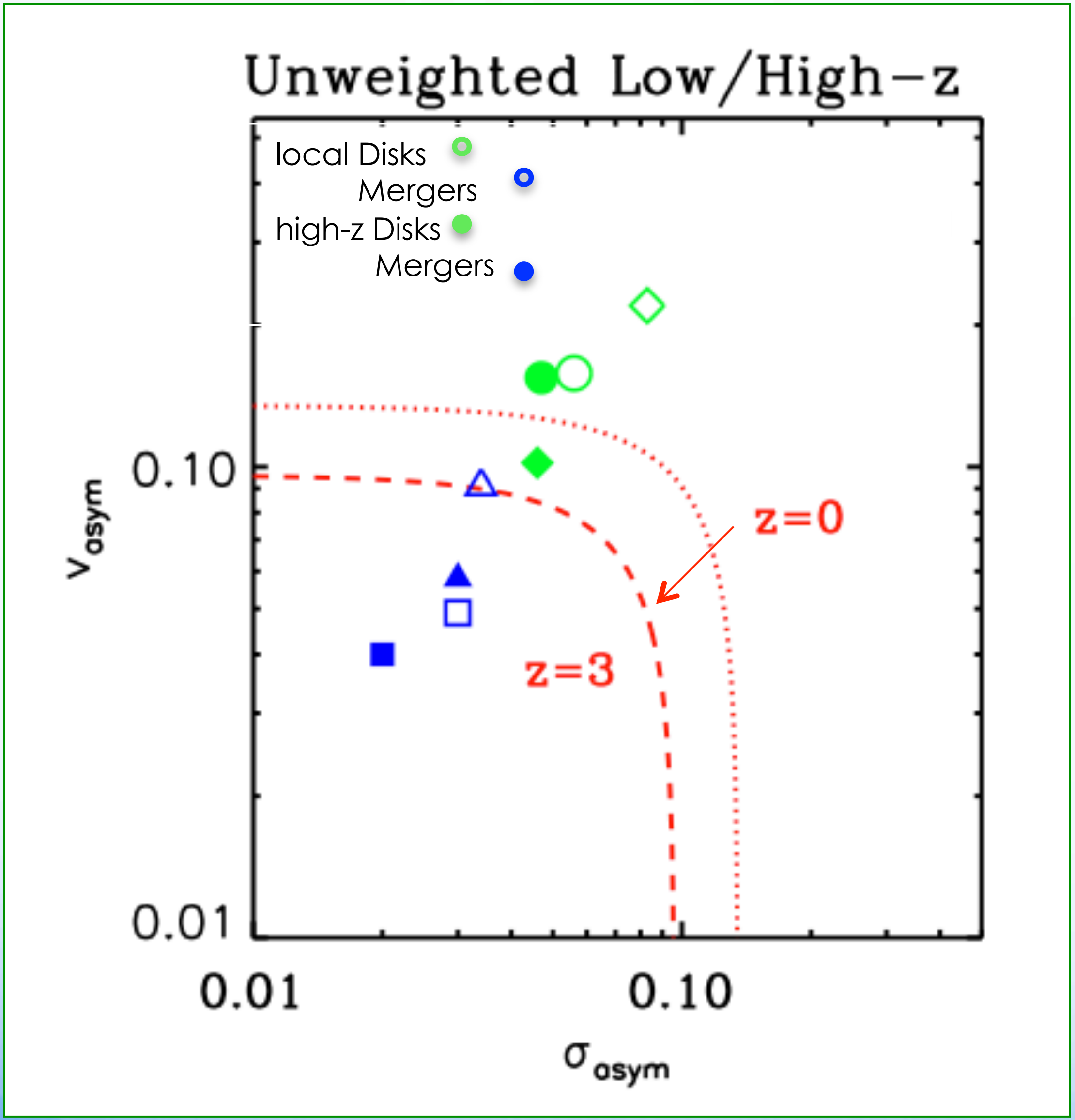


-"Disks" → low values of v_{asym} & σ_{asym}

(i.e., centrally peaked σ & "spider diagram" structure for v.f.)

- "Mergers" → high values of v_{asym} & σ_{asym} (complex and irregular v.f. & σ)

Our results (S08 method) @ low and high–z



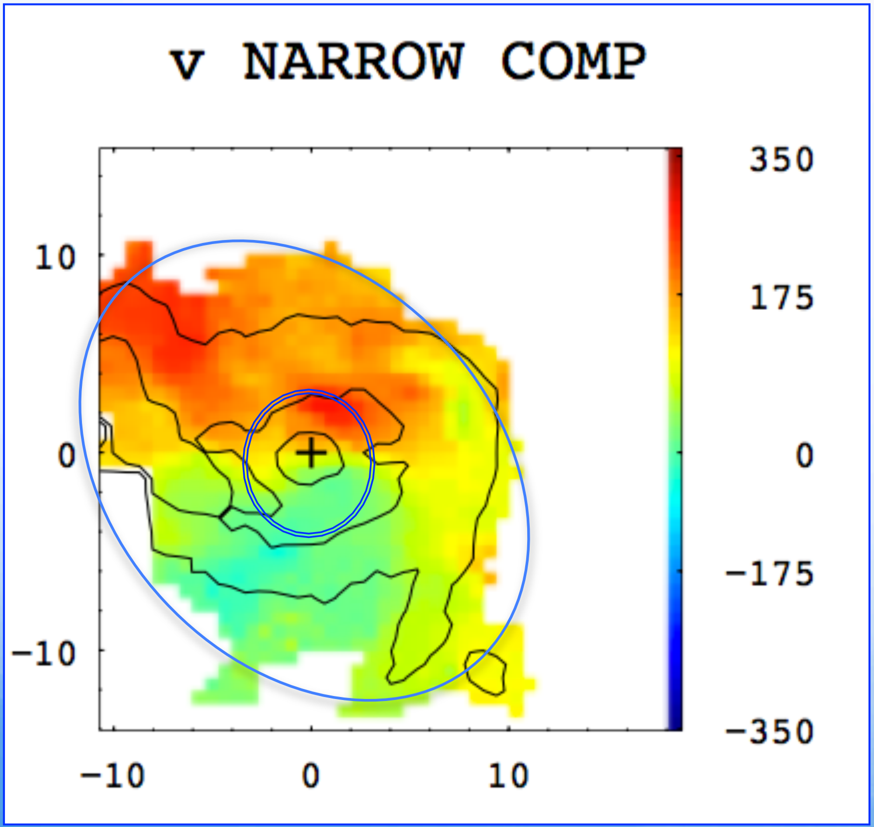
@low-z:
Consistency between morphology & kinematics (higher deviations for mergers) $<K_{LIM}> = 0.135$

@ high-z:
Distorsions are smeared out → objects appear more symmetric than they are! $<K_{LIM}> = 0.096$
(→ 30 % lower than locally)

NEW CRITERIA: “Weighted-plane” (Bellocchi et al. 2012)

In Post-coalescence systems, the inner regions rapidly relax into a rotating disk, while the outer parts remain out of equilibrium
→ large kinematic asymmetries in the outer parts.

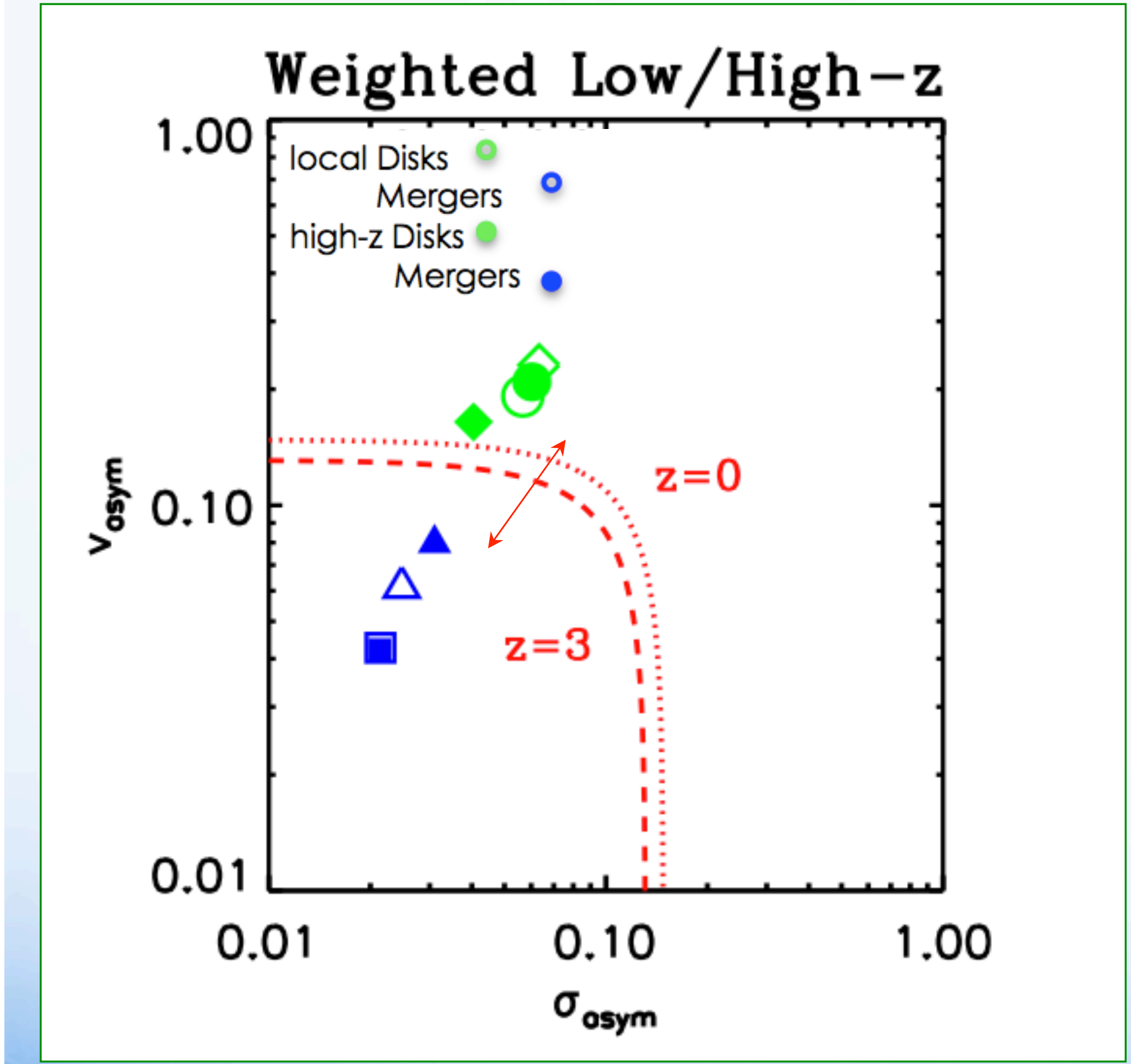
Instead of simply averaging the asymmetries over all radii (as in S08), we then weight these according to the galactocentric distance



$$v_{asym} = \sum_{n=1}^{N} \left(\frac{k^{v}_{avg,n}}{B^{v}_{1,n}} \cdot P_n \right) \cdot \frac{1}{\sum_{n=1}^{N} P_n}$$

$$\sigma_{asym} = \sum_{n=1}^{N} \left(\frac{k^{\sigma}_{avg,n}}{B^{v}_{1,n}} \cdot P_n \right) \cdot \frac{1}{\sum_{n=1}^{N} P_n}$$

Results (Bellocchi +12)



WEIGHTED plane:

→ differenciates better than S08 between DISKS and MERGERS (separation 3 times larger)

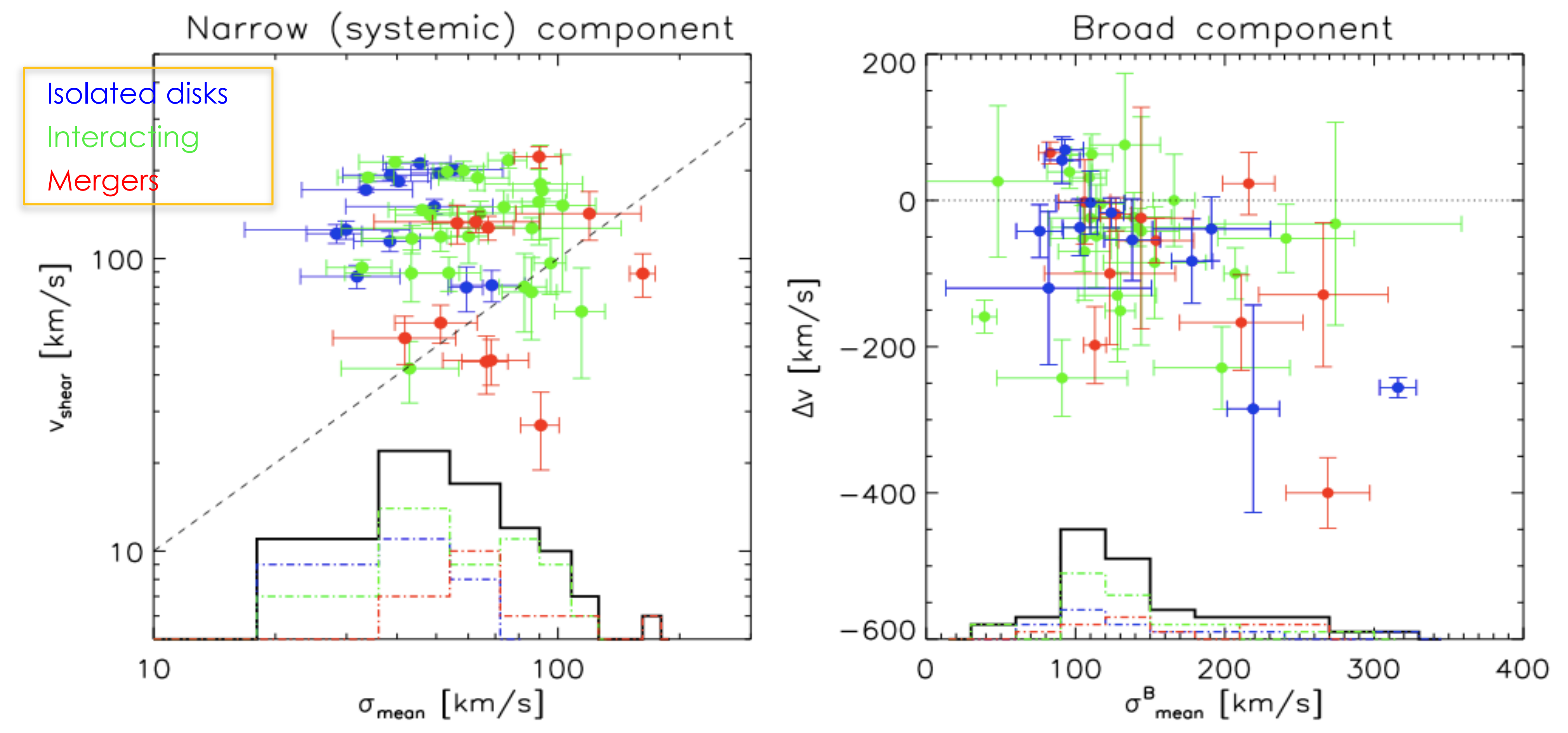
→@high-z: LESS dependent than S08 from RESOLUTION effects (11%)

→ different frontier wrt S08: maybe depending on the kind of systems considered

→this would imply a **different fraction disks/mergers** (larger and more complete sample to confirm this)

Part 3: Kinematical characterization of the whole sample (work in progress)

- Kinematical characterization of the NARROW and BROAD comps (wrt morph. class.)



Ranges of values: N: $30 < v_{shear} < 220$ km/s and $30 < \sigma < 160$ km/s → $v_{shear} > \sigma$

B: Δv up to -400 km/s; $90 < \sigma < 150$ km/s →# 37/46 BLUE-shifted

Comparison with other local samples

→ Dynamical ratio **v/σ:**

Useful to distinguish between Rotation dominated (i.e., >1) and Dispersion dominated (i.e., <1) systems

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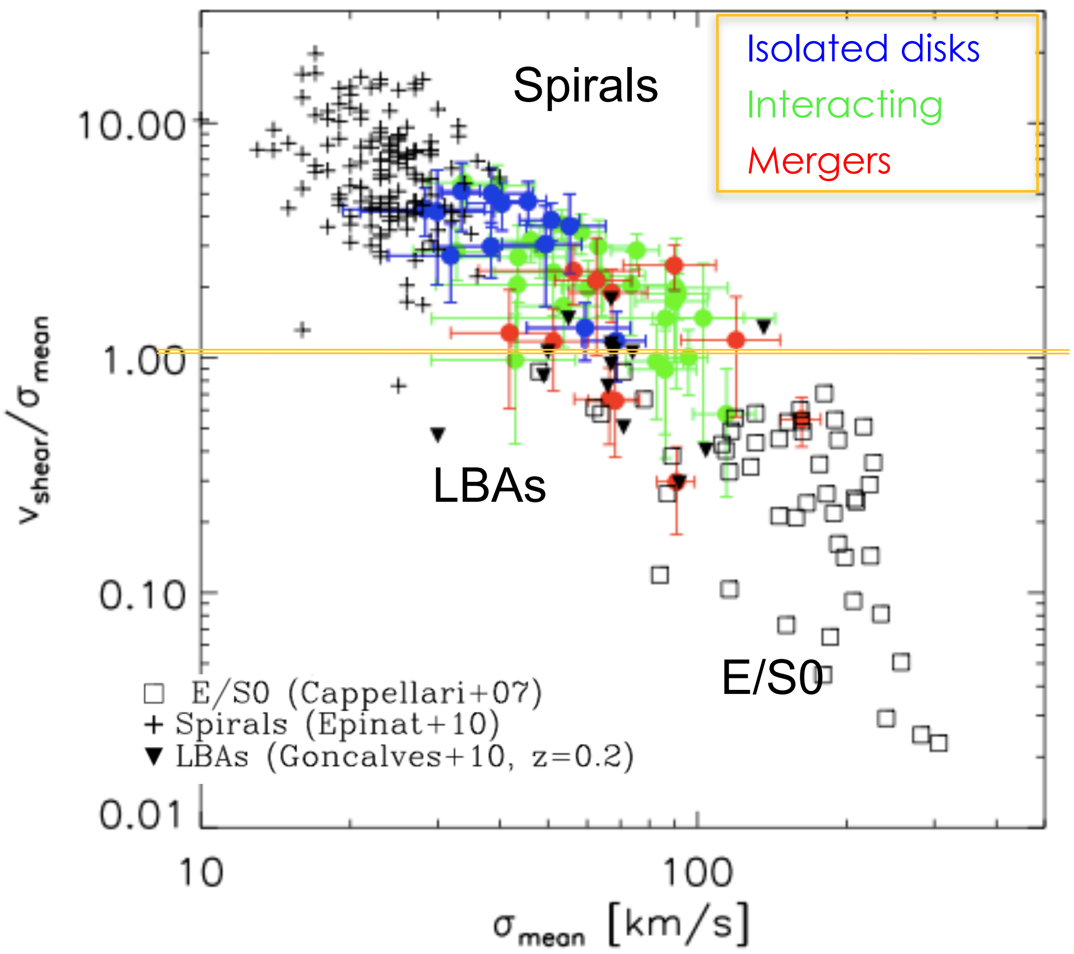
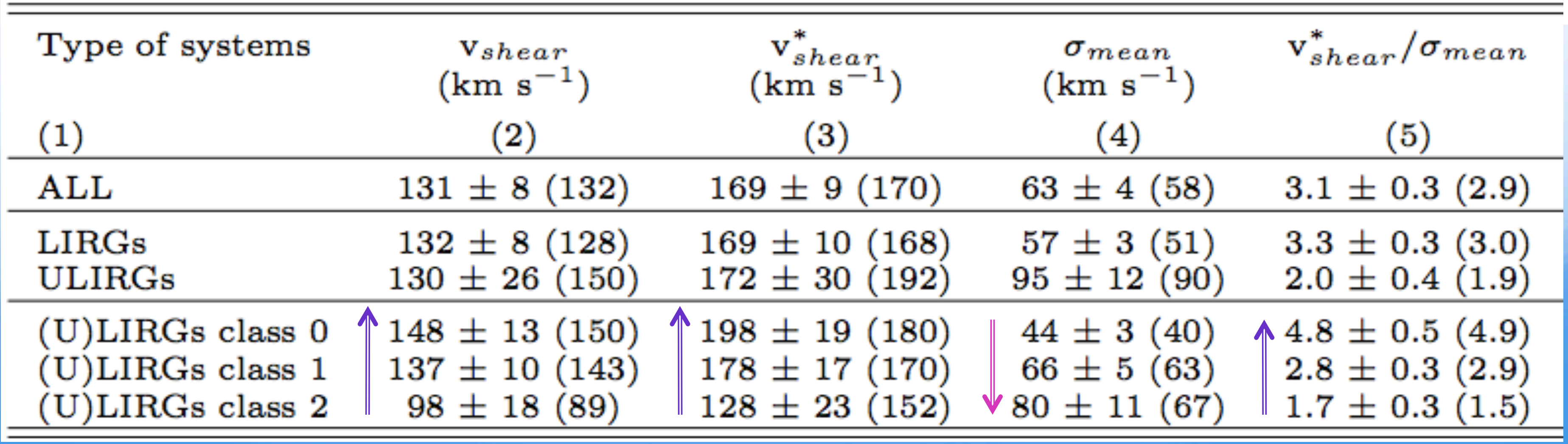
… it has to be used with caution since a high v_{shear} can be generated not only by rotational motions (e.g., merger events)

→ Consistent with the scenario where the merging of 2 SPIRALS can generate an ELLIPTICAL

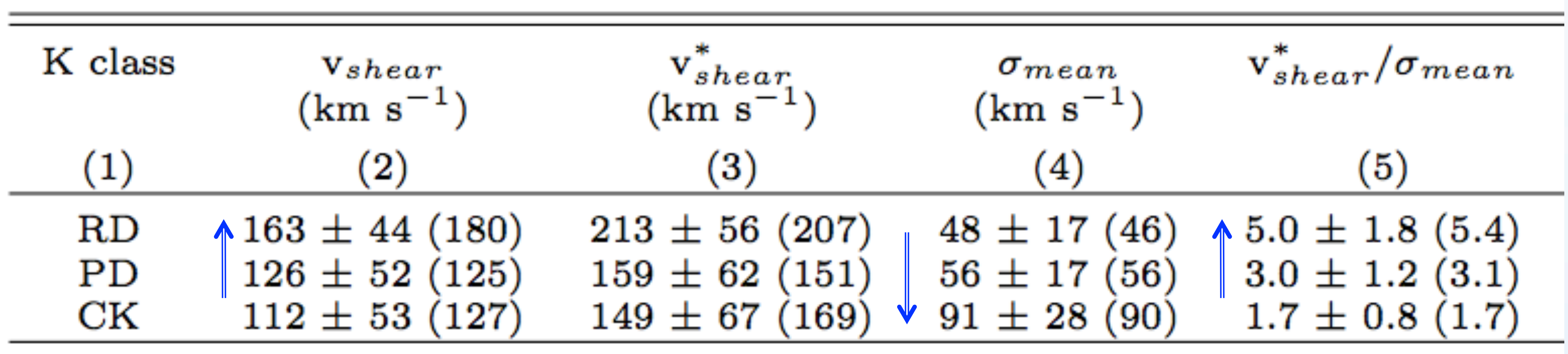




Type of systems (1)	v_{shear} (km s^{-1}) (2)	v^*_{shear} (km s^{-1}) (3)	σ_{mean} (km s^{-1}) (4)	$v^*_{shear}/\sigma_{mean}$ (5)
ALL	131 ± 8 (132)	169 ± 9 (170)	63 ± 4 (58)	3.1 ± 0.3 (2.9)
LIRGs	132 ± 8 (128)	169 ± 10 (168)	57 ± 3 (51)	3.3 ± 0.3 (3.0)
ULIRGs	130 ± 26 (150)	172 ± 30 (192)	95 ± 12 (90)	2.0 ± 0.4 (1.9)
(U)LIRGs class 0	148 ± 13 (150)	198 ± 19 (180)	44 ± 3 (40)	4.8 ± 0.5 (4.9)
(U)LIRGs class 1	137 ± 10 (143)	178 ± 17 (170)	66 ± 5 (63)	2.8 ± 0.3 (2.9)
(U)LIRGs class 2	98 ± 18 (89)	128 ± 23 (152)	80 ± 11 (67)	1.7 ± 0.3 (1.5)

KINEMATICAL classification
(based on the morphology of their kinematic maps, e.g., Flores+06):

- Rotation Dominated (RD)
- Perturbed Disk (PD)
- Complex Kinematics (CK)

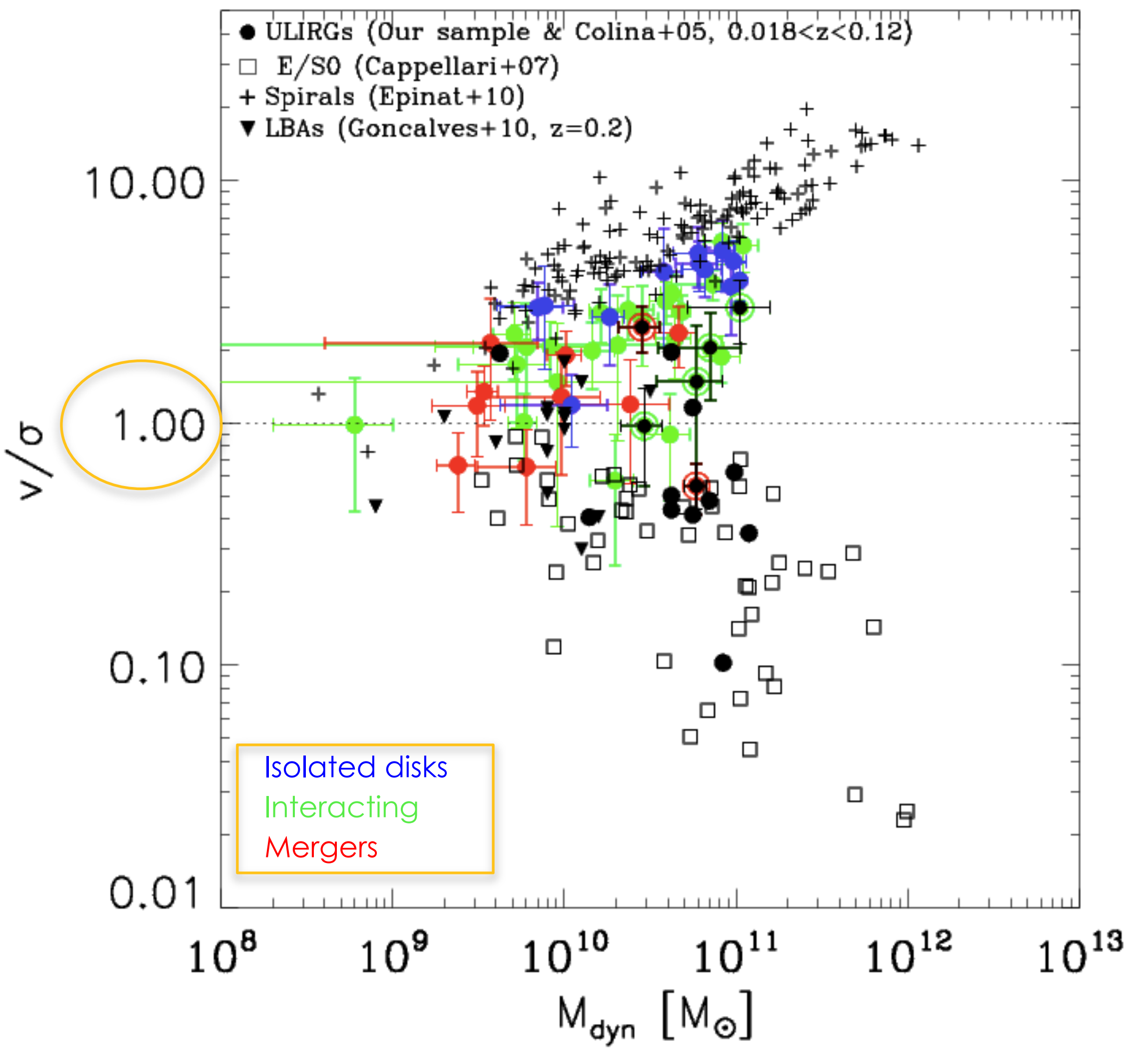


K class (1)	v_{shear} (km s^{-1}) (2)	v^*_{shear} (km s^{-1}) (3)	σ_{mean} (km s^{-1}) (4)	$v^*_{shear}/\sigma_{mean}$ (5)
RD	↑ 163 ± 44 (180)	213 ± 56 (207)	48 ± 17 (46)	↑ 5.0 ± 1.8 (5.4)
PD	126 ± 52 (125)	159 ± 62 (151)	56 ± 17 (56)	3.0 ± 1.2 (3.1)
CK	112 ± 53 (127)	149 ± 67 (169)	↓ 91 ± 28 (90)	1.7 ± 0.8 (1.7)

→ Consistency with morphological classification i.e., RD have higher v_{shear} and lower σ_{mean}, while CK have the opposite trend)

→ but not in ALL cases….

Comparison with other local samples (work in progress…)



M_{dyn} estimation:

1) Using the virial theorem (Cappellari+12, Taylor+10):

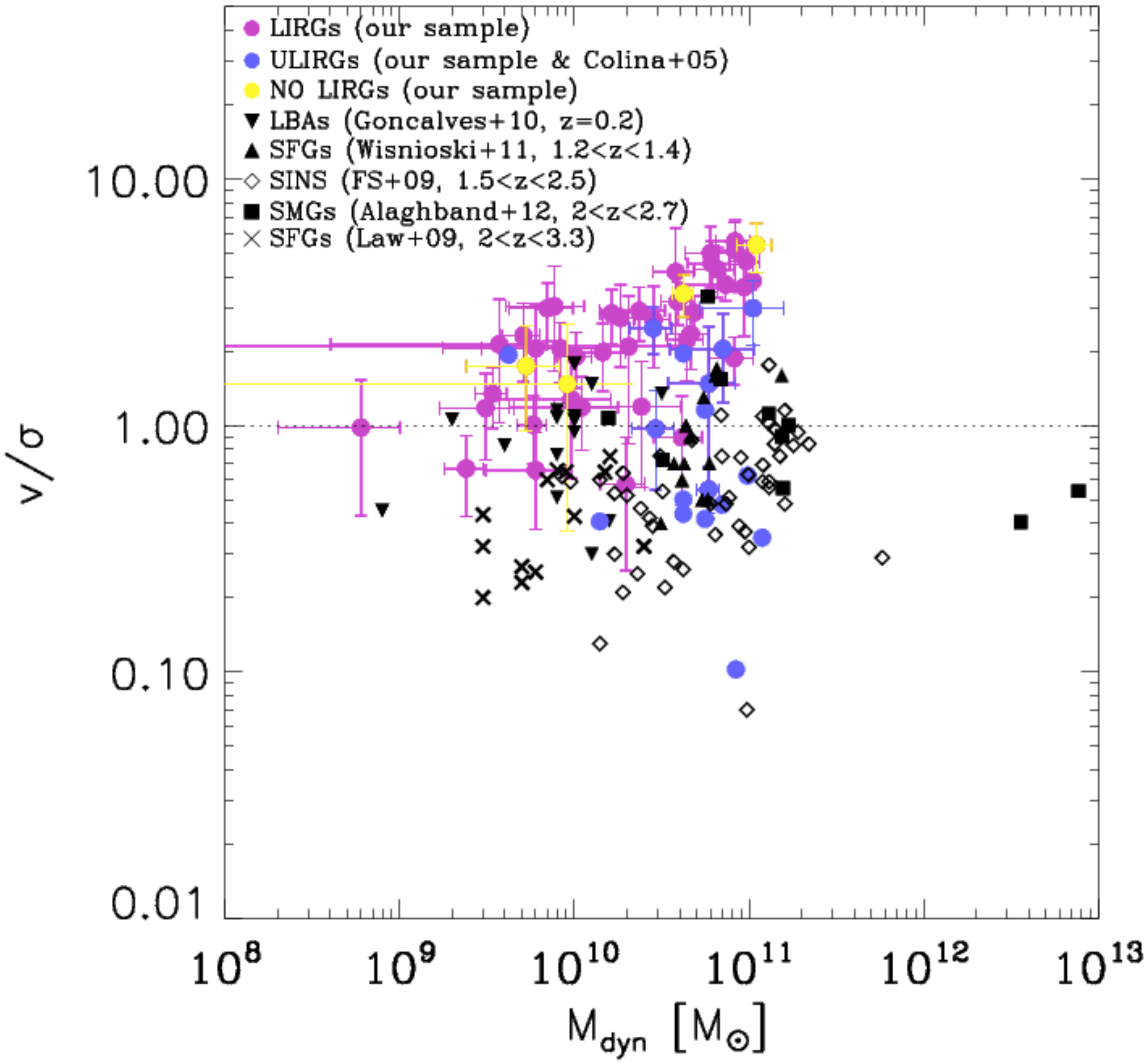
$$M_{dyn} = \frac{K}{G} \, R_{eff} \, \sigma^2$$

2) Rotation + Dispersion motions (Epinat+09, Williams +10):

$$M_{dyn} \approx \frac{2 * R_{eff}}{G} * ({v^*_{shear}}^2 + 1.35\,\sigma^2)$$

- Intermediate mass 10^9-10^{11} $M_\odot$ → $(3.7 \pm 0.5)\mathrm{x}10^{10}$ $M_\odot$
- Less massive than Spirals →$(11.5 \pm 1.5)\mathrm{x}10^{10}$ $M_\odot$
- most of ULIRGs closed to dispersion-dominated populations (≈ E)

Comparison with other high-z samples (work in progress…)



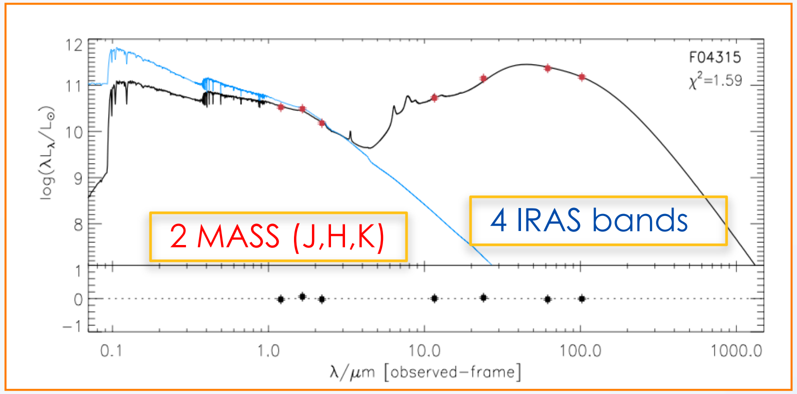
- v/σ ratio → local (U)LIRG systems are **more RD** than **high-z** sources (as expected)

- local *ULIRGs* overlap area covered by high-z galaxies ($v/\sigma < 1$; e.g., FS09 (9.0 ± 1.3) x10^{10} $M_{\odot}$)

Kinematics powerful tool in order to:

1. Define new kinematical criteria (Bellocchi et al. 2012)
2. Kinematically characterize the whole sample (local (U)LIRGs) & compare it with other high-z galaxies & derive the dynamical masses M_{dyn} of the whole sample

Next Future…



3. Complete II paper & Write my thesis (beginning of 2013?)
4. (beyond my thesis…) Check the consistency between our M_{dyn} and the stellar masses M^* derived in collaboration with S. Charlot and C. Pacifici
5. (beyond my thesis…) Apply the "kinemetry" method to the whole sample

Kinemetry outputs (I)