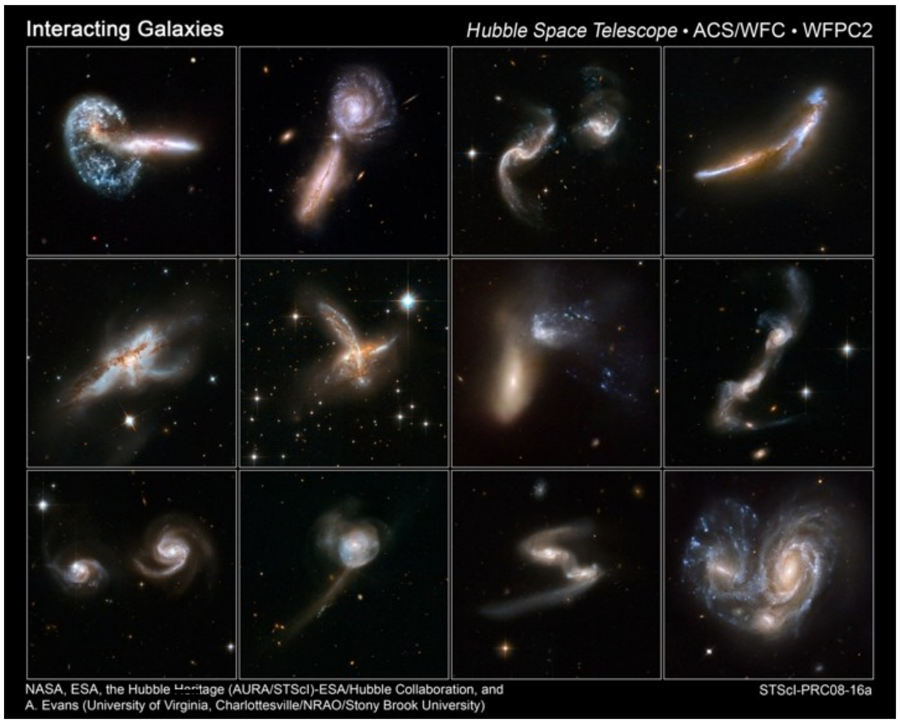
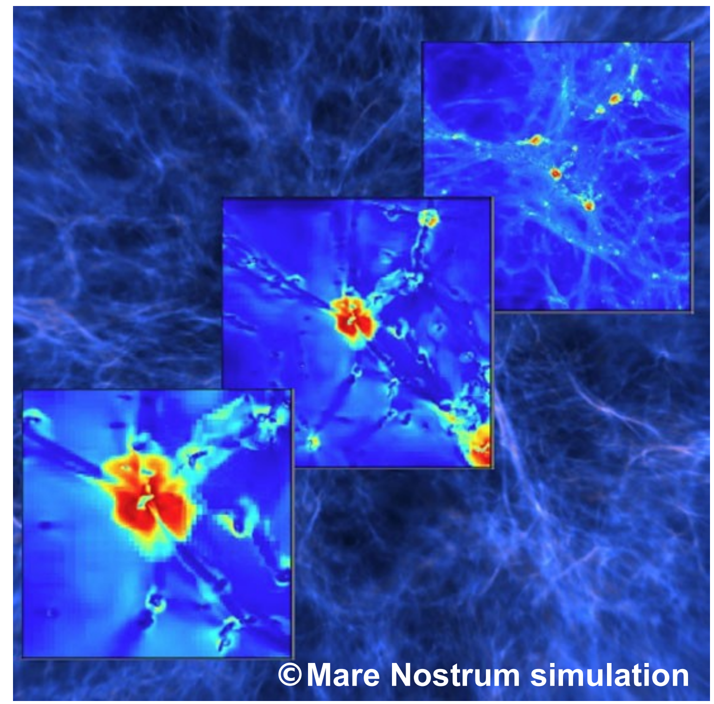
Gas Kinematics of Intermediate - Redshift Galaxies

B. Epinat
LAM

Open issues on galaxy evolution

- Processes of galaxy mass assembly
  - Mergers vs. Smooth gas accretion?

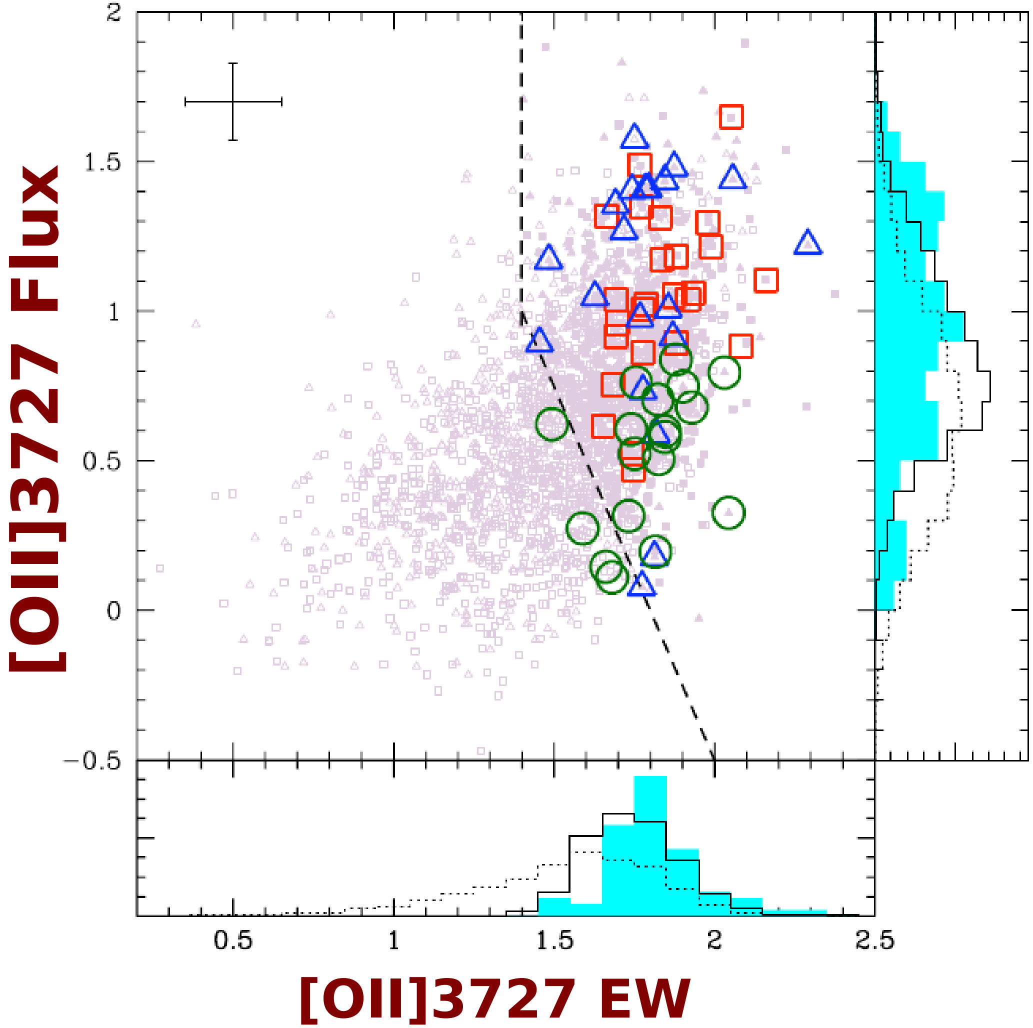




- Construction of Hubble Sequence
- Impact of environment

Mass Assembly Survey with Sinfoni In VVDS

Contini et al. 2012



Selection Criteria:

83 star-forming galaxies

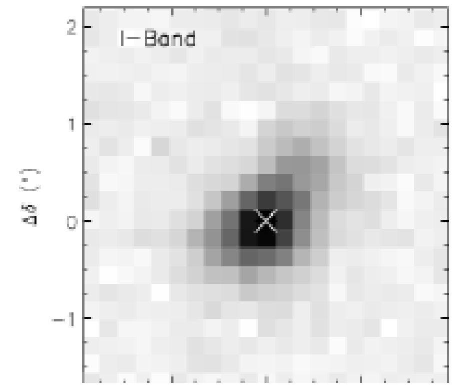
- *z < 1.46*: [OII]3727 strength
- *z > 1.46*: UV slope + abs. lines

+

- SNR>5 in VIMOS spectra
- Ha free of bright OH lines
- Bright star close enough for **AO/LGS** observations

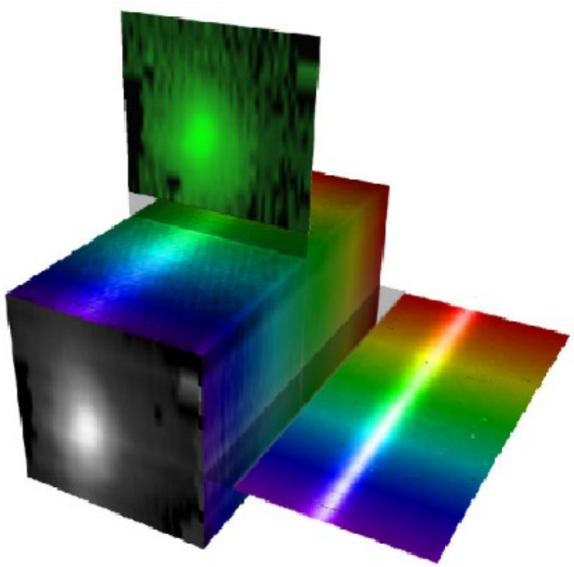
Mass assembly survey with SINFONI in VVDS

Spatially resolved data



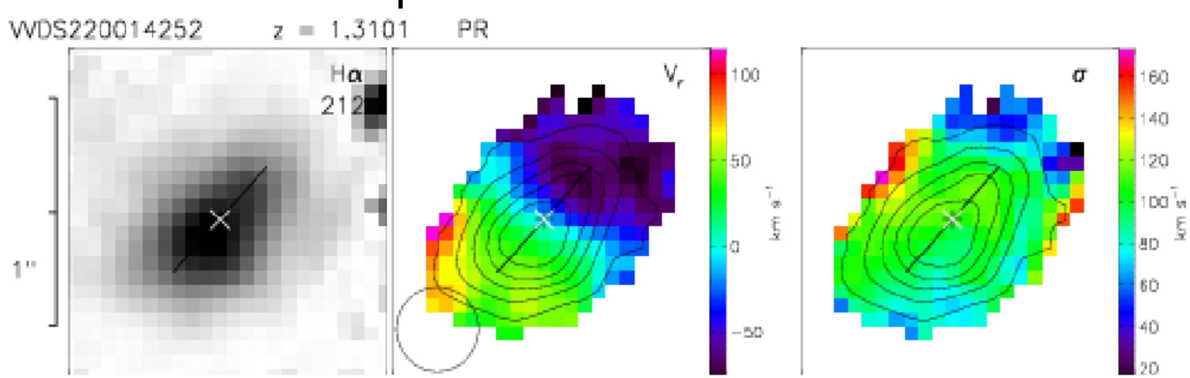
I-band CFHT imaging :

- 0.65'' seeing
- Morphology analysis using GALFIT
- Position angle, center, inclination, size



SINFONI data cubes :

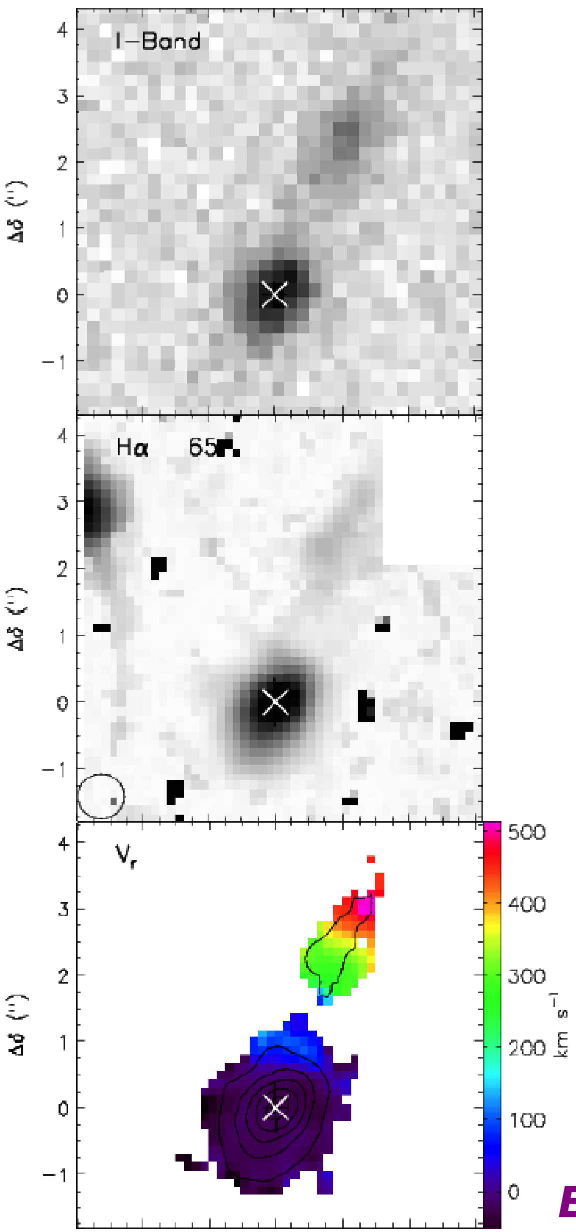
- 0.6'' – 1'' seeing + some AO (~0.25'')
- R~2000 in J or H bands
- ~12' FoV
- Ha moment maps :



Hα flux map Hα velocity field Hα velocity dispersion

Close environment classification

Interacting systems



- **Companion detected** both
  - in the Ha map and
  - in the continuum I-band image
- **Gravitationaly bounded**
  - with d < 50kpc
  - and ΔV < 1000 km/s
- 21/74 interacting systems found

Epinat et al. 2012

The major merger rate @ 0.9<z<1.7 from close pairs

Lopez-Sanjuan et al. 2012

<u>Close pairs in projection:</u>

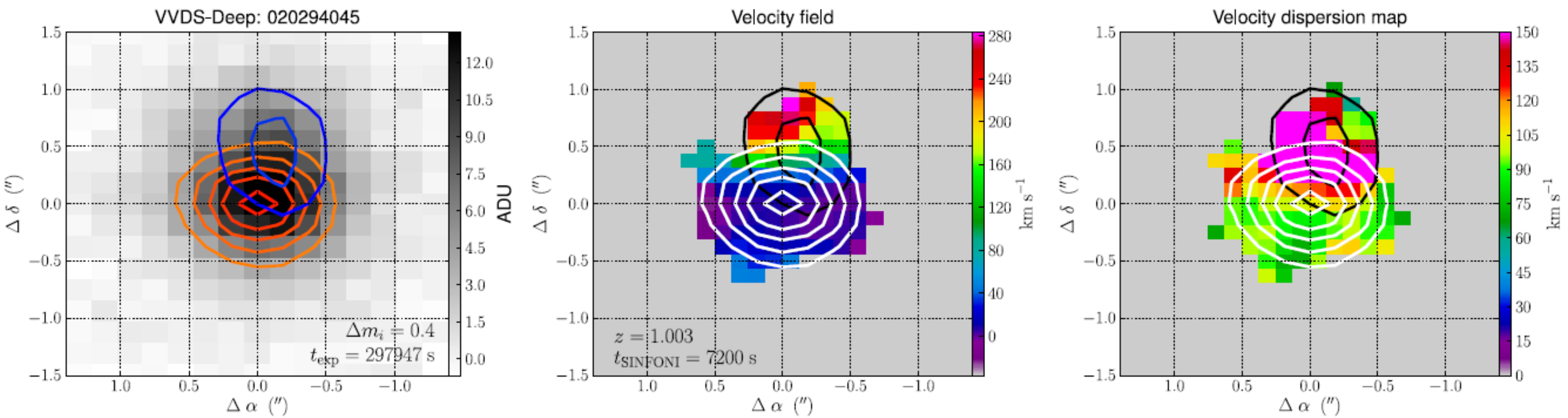
$0 < r_p < 20\ h^{-1}$kpc

$\Delta v < 500$ km/s

N_P major close pairs : $L_2/L_1 > 1/4$

minor close pairs : $L_2/L_1 < 1/4$

$f_{Major\ Merger} = N_P/N$ + corrections for completeness



Example of a major merger

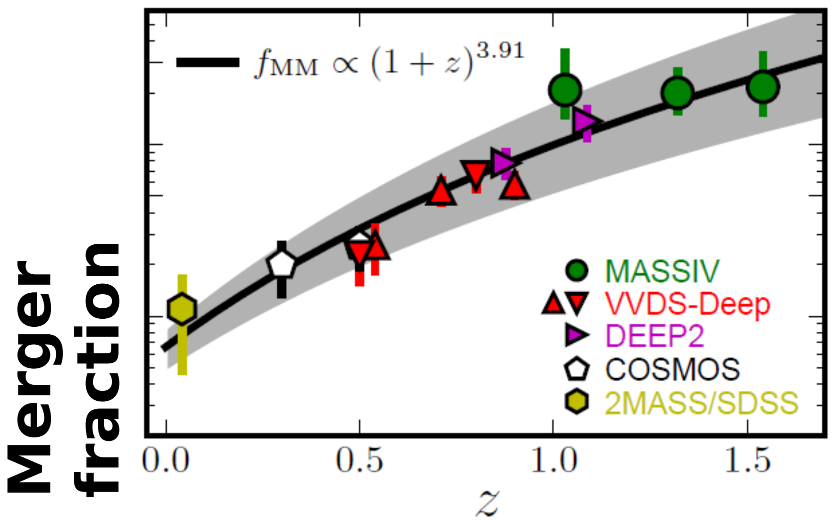
The merger fraction f_{MM} @ z>1 is higher by an order of magnitude than in the local universe

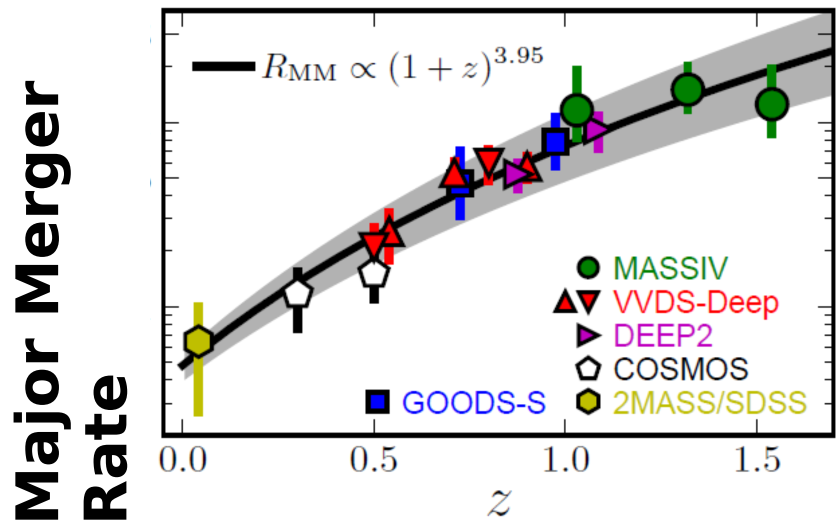
The major merger rate

R_{MM} α f_{MM} /T_{MM}

T_{MM} : Merger time scale from the Millennium simulation

T_{MM} = 1.80 Gyr (0.94 < z < 1.06)
T_{MM} = 1.37 Gyr (1.20 < z < 1.50)
T_{MM} = 2.54 Gyr (1.50 < z < 1.80)





Lopez-Sanjuan et al. 2012

$$N_{MM}(z_1, z_2) = \int_{z_1}^{z_2} \frac{R_{MM}\, dz}{(1+z) H_0 E(z)}$$

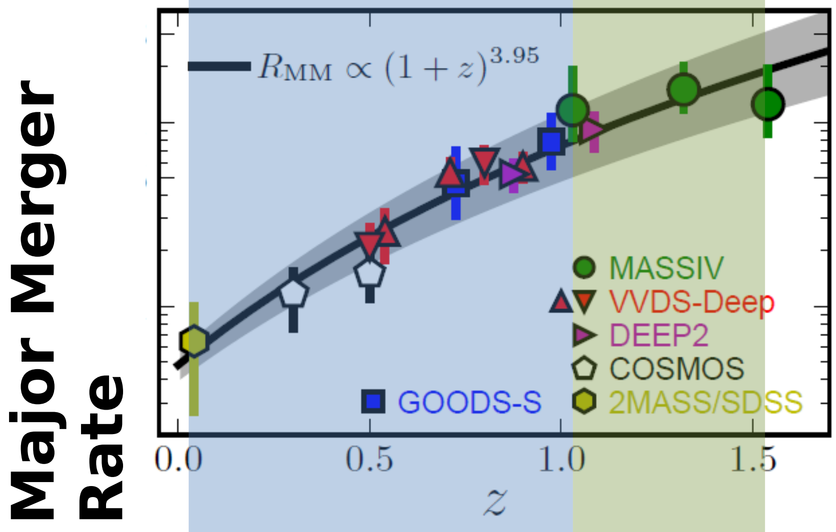
The average number of major gas-rich mergers per star-forming galaxy between z2 and z1

$M^* = 10^{10}$-10^{11} Mo
star forming galaxies
underwent
~0.4 major mergers
since z~1.5

Half of the merger activity occurs between

z=1 and 0 — **~7 Gyr**

z=1.5 and 1 — **~2 Gyr**



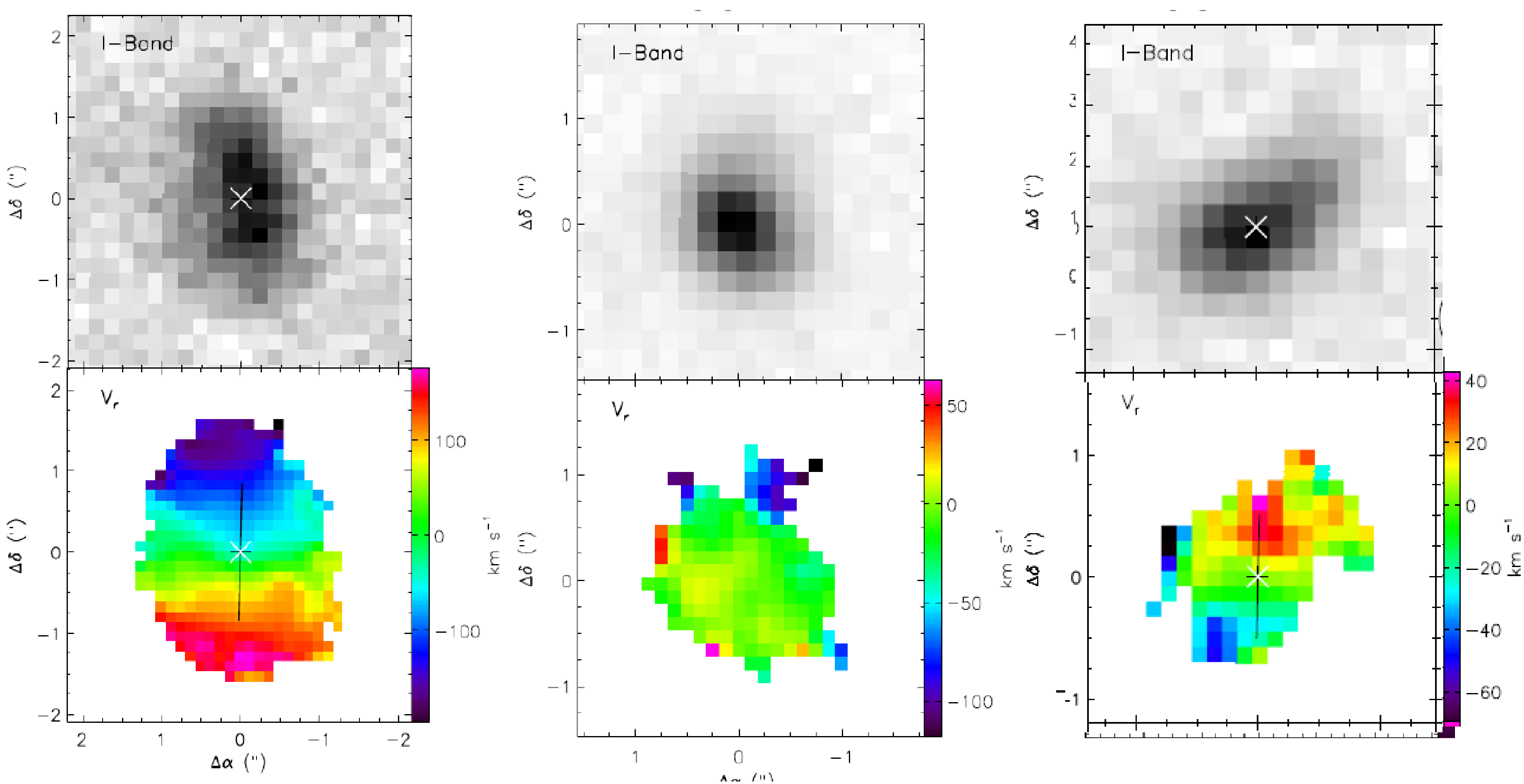
Lopez-Sanjuan et al. 2012

MASSIV Mass assembly survey with SINFONI in VVDS

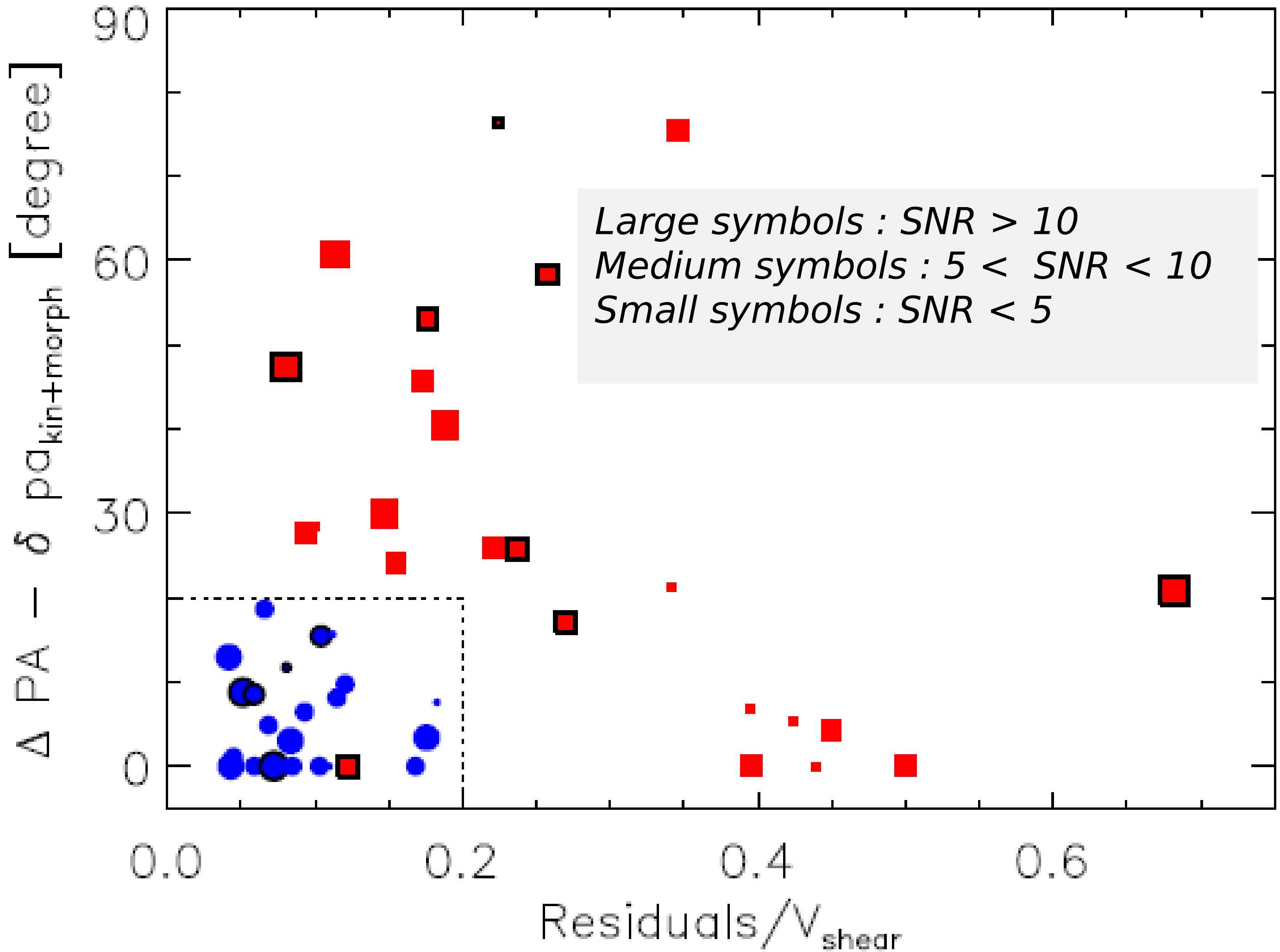
Classification

Based on agreement between morphology and kinematics

Rotator | Slowly-rotating | Non-rotating



Rotators vs slow rotators



Blue circles : fast rotators
Red squares : slow rotators

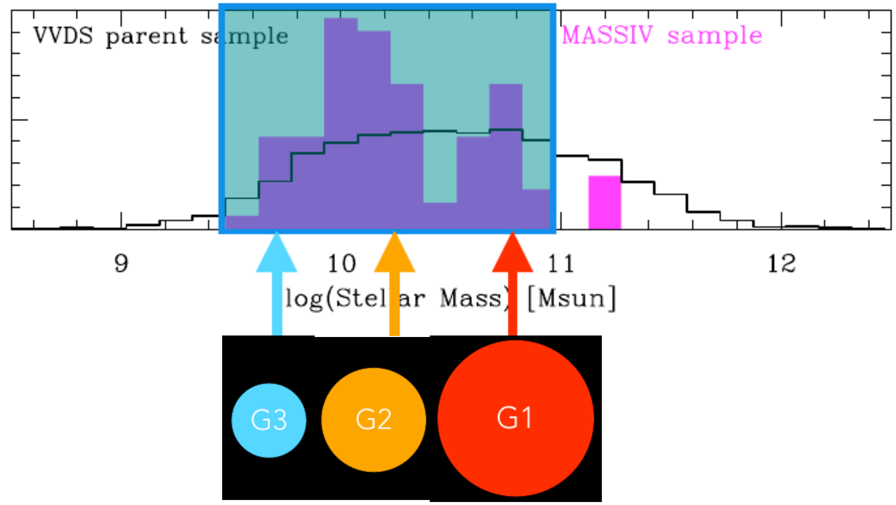
Epinat et al. 2012
From 1st epoch sample

Rotators vs slow rotators

- 29/68 rotating
- 39/68 non-rotating
- 15/83 non classified (9 undetected + low SNR<3)
- Rotators on average are larger and have better SNR
  - Impact of noise?
  - Impact of size vs resolution: clumps impact? Bars?
- Slow rotators: face-on? Megers? In which stage?

The MIRAGE sample *(Perret et al. 2014)*

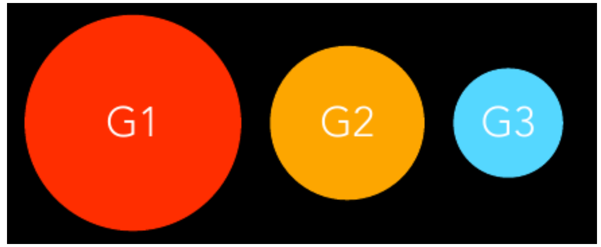
		G1	G2	G3
	Virial quantities			
1	$log(M_\star)$	10.60	10.20	9.80
2	R_{200} [kpc]	99.8	73.4	54.0
3	M_{200} $[10^{10} M_\odot]$	102.4	40.8	16.2
4	V_{200} $[km.s^{-1}]$	210.1	154.6	113.7
	Scalelength			
5	$r_\star$ [kpc]	2.28	1.62	1.15
6	r_{gas} [kpc]	3.71	2.64	1.88
7	$h_\star$ [kpc]	0.46	0.32	0.23
8	h_{gas} [kpc]	0.19	0.13	0.09
9	r_{metal} [kpc]	3.71	2.64	1.88
10	c		5	
	Mass fractions			
11	f_g		0.65	
12	f_b		0.10	
13	m_d		0.10	
	Collisionless particles			
14	N_{disk} $[10^6]$	2.00	0.80	0.32
15	N_{halo} $[10^6]$	2.00	0.80	0.32
16	N_{bulge} $[10^6]$	0.22	0.09	0.04
	Various quantites			
17	Q_{min}		1.5	
18	Z_{core}	0.705	0.599	0.479



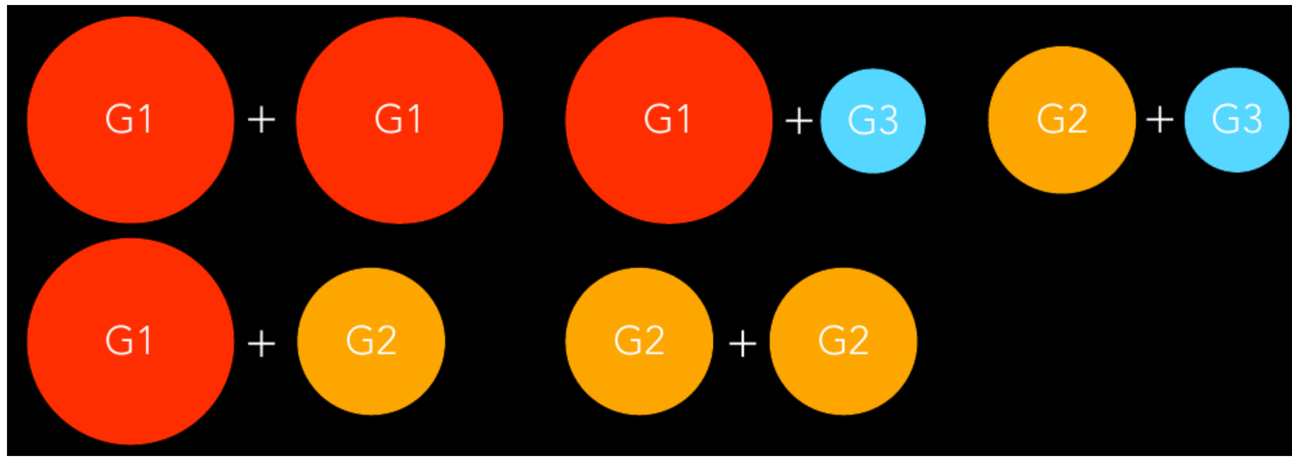
- Match MASSIV mass and size ranges
- High initial gas fraction
- Idealized initial conditions mimicking z~2 galaxies
- RAMSES code (Teyssier 2001)

The MIRAGE sample *(Perret et al. 2014)*

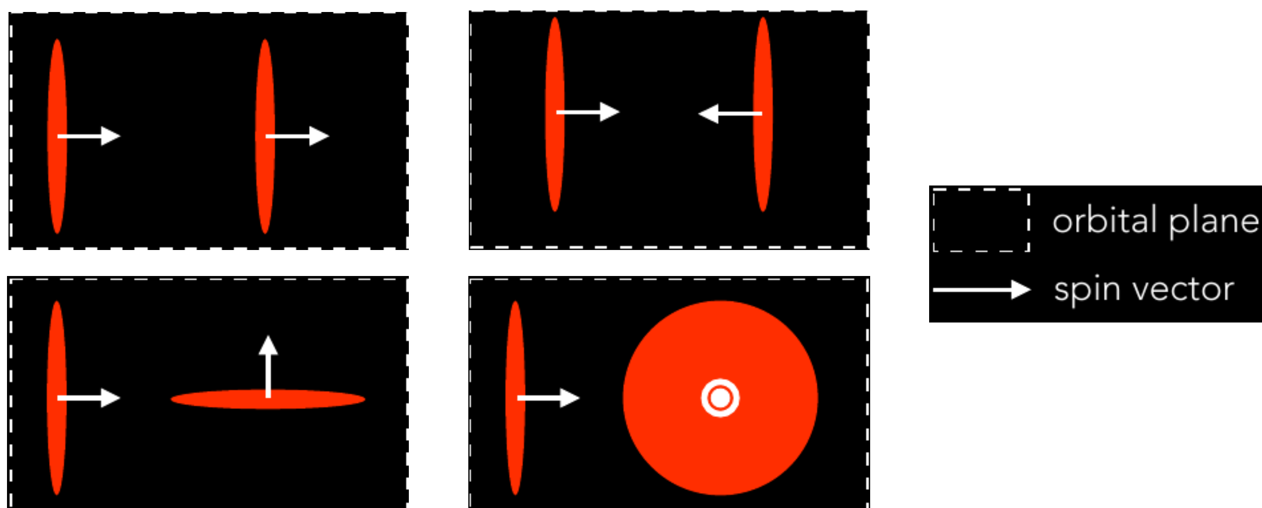
- 3 disk models



- 5 mass configurations for the merger simulations

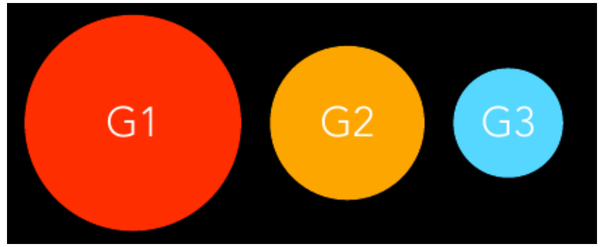


- 4 initial disk conditions



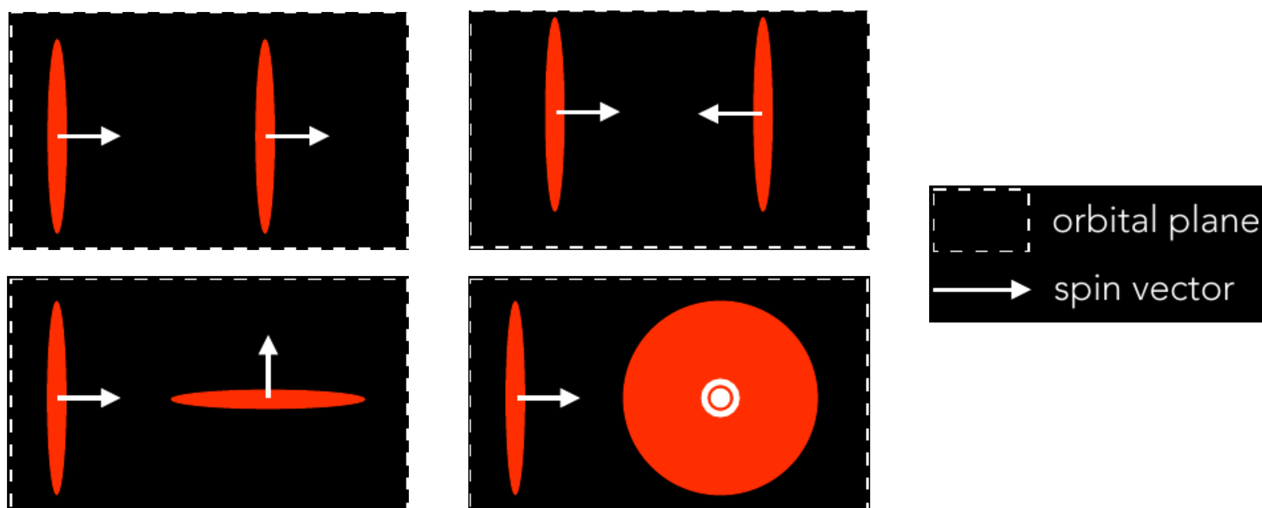
The MIRAGE sample *(Perret et al. 2014)*

- 3 disk models



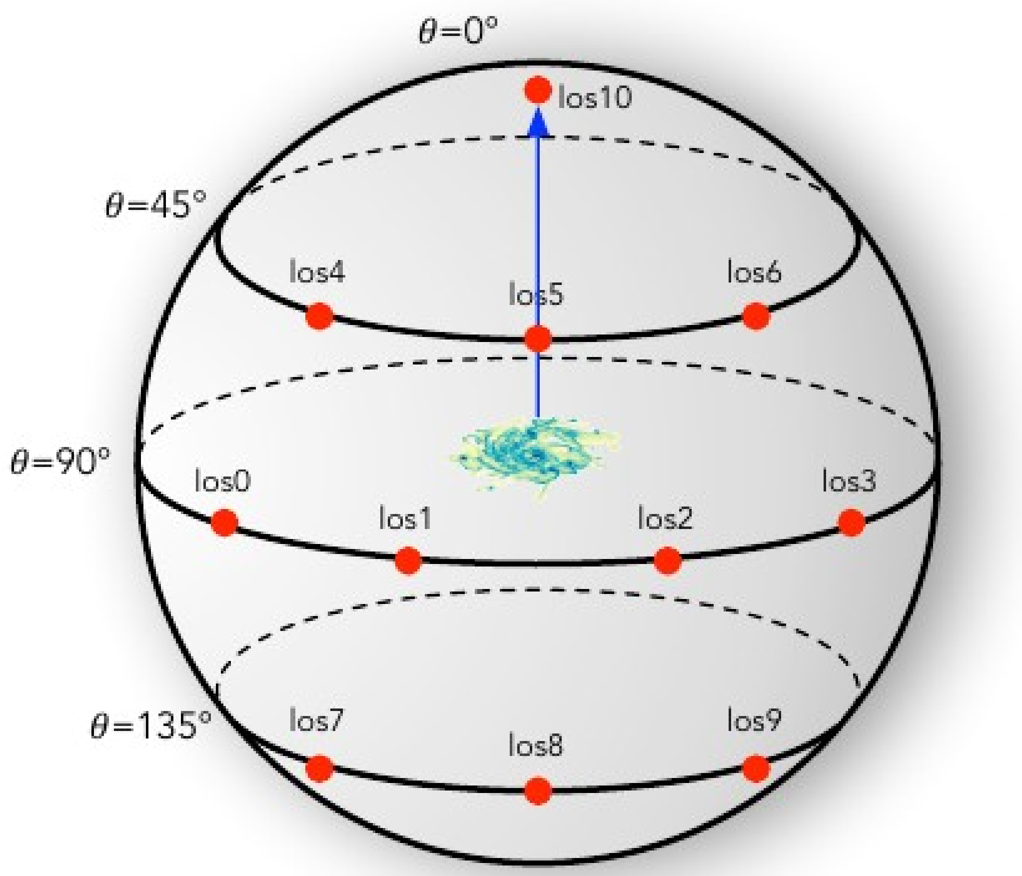
- 5 mass configurations the merger simulations

- 4 initial disk conditions



The MIRAGE sample *(Perret et al. 2014)*

From simulations to observations

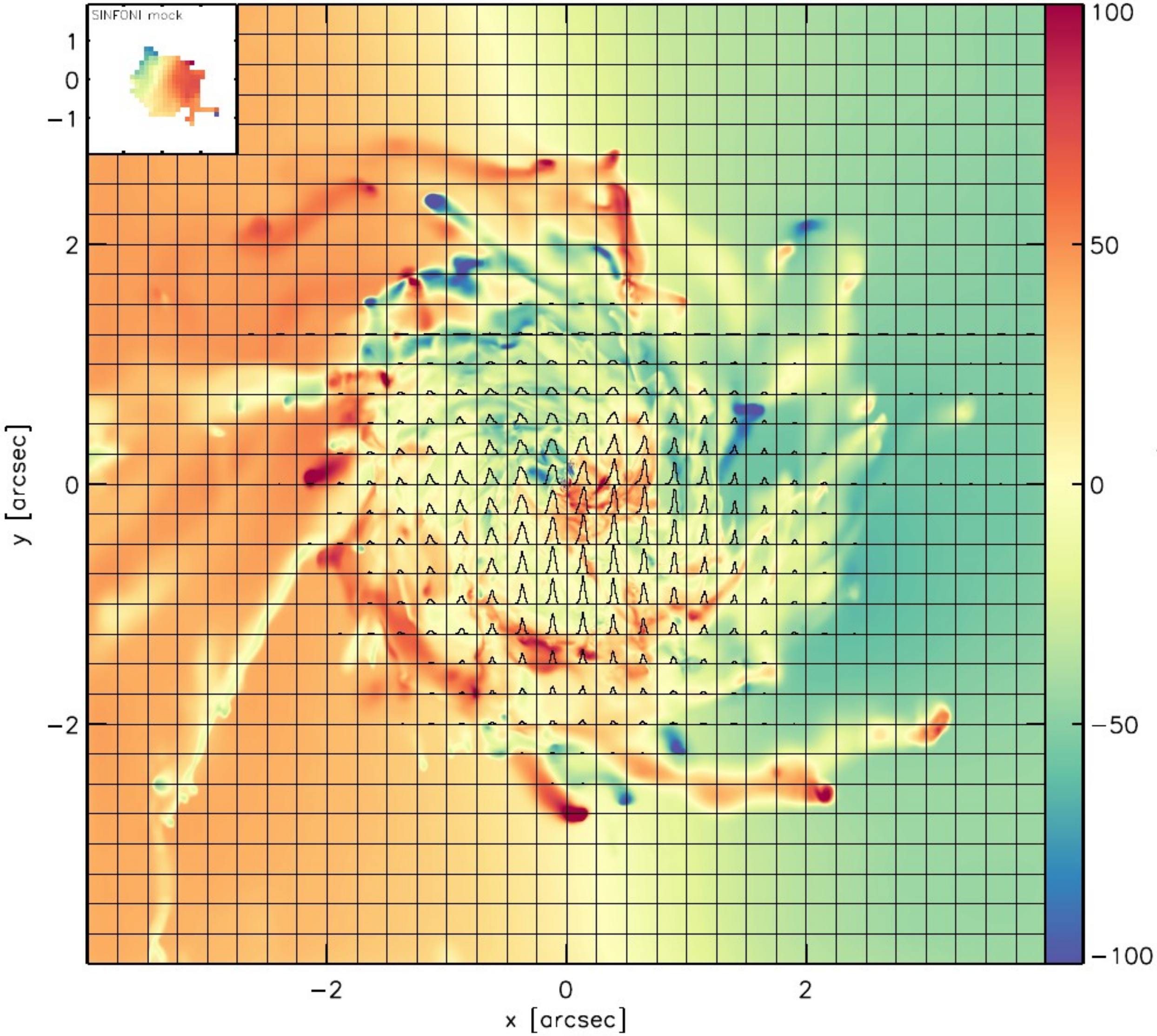


- 23 simulations
- 11 lines of sight
- 1 snapshot every 40 Myr from 200 Myr to 800 Myr

=> 4048 mock datacubes

The MIRAGE sample *(Perret et al. 2014)*

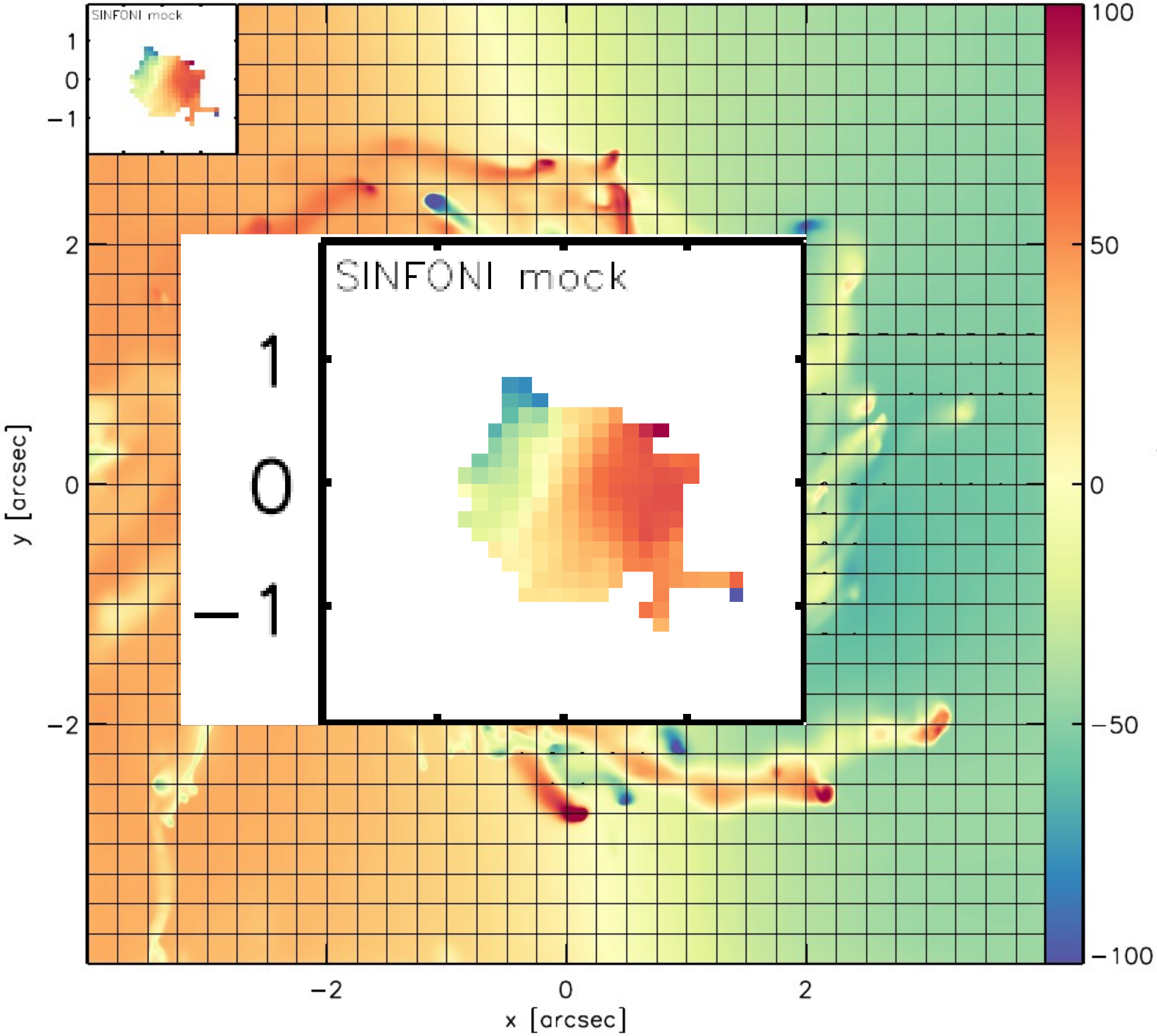
From simulations to observations



- Line flux computed for each hydrodynamical cell
- Line spectrum inserted in mock datacube

The MIRAGE sample *(Perret et al. 2014)*

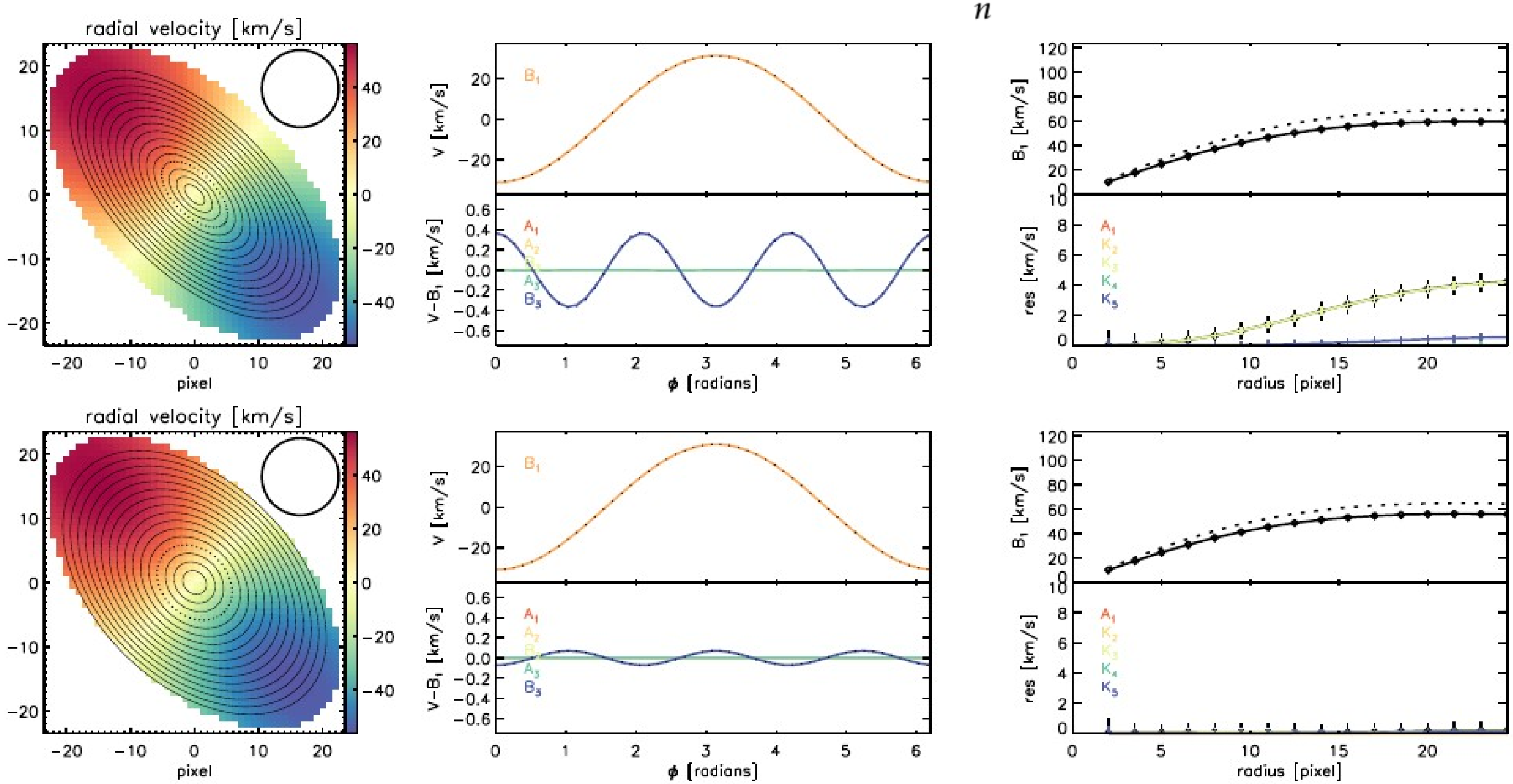
From simulations to observations



- Line flux computed for each hydrodynamical cell
- Line spectrum inserted in mock datacube

Kinemetry analysis

- Harmonic expansion $V_{kin}(r,\phi) \; = \; A_0(r) + \sum_n \left[A_n(r) \; \sin(n\phi) + B_n(r) \; \cos(n\phi) \right]$

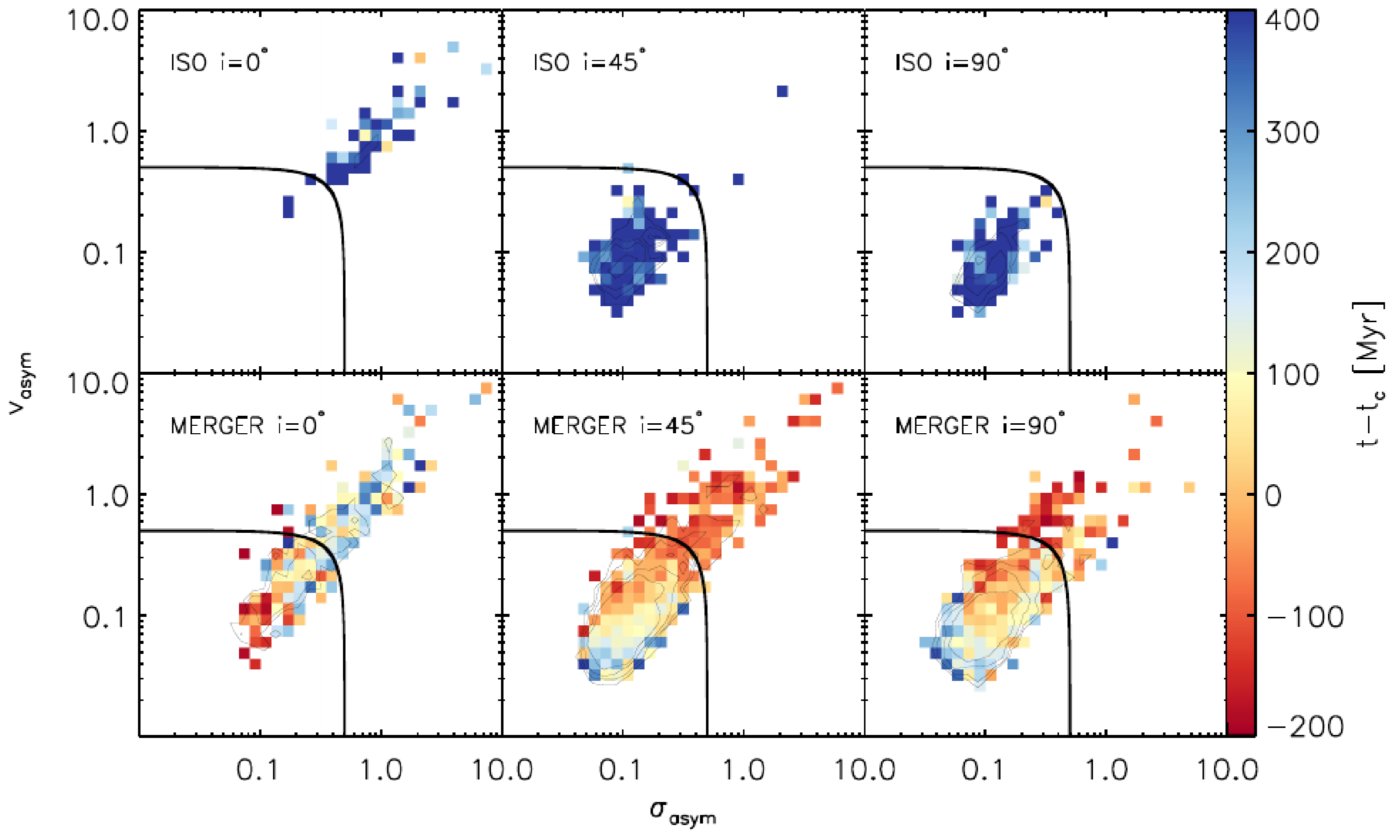


- Asymmetry parameters

$$k_n \; = \; \sqrt{A_n^2 + B_n^2} \qquad v_{asym} = \left\langle \frac{k_{avg,v}}{B_{1,v}} \right\rangle_r \qquad \sigma_{asym} = \left\langle \frac{k_{avg,\sigma}}{B_{1,v}} \right\rangle_r$$

The MIRAGE sample *(Perret et al. 2014)*

- Kinematry analysis



- Not frequent to see no rotation signature in mergers

One MUSE project

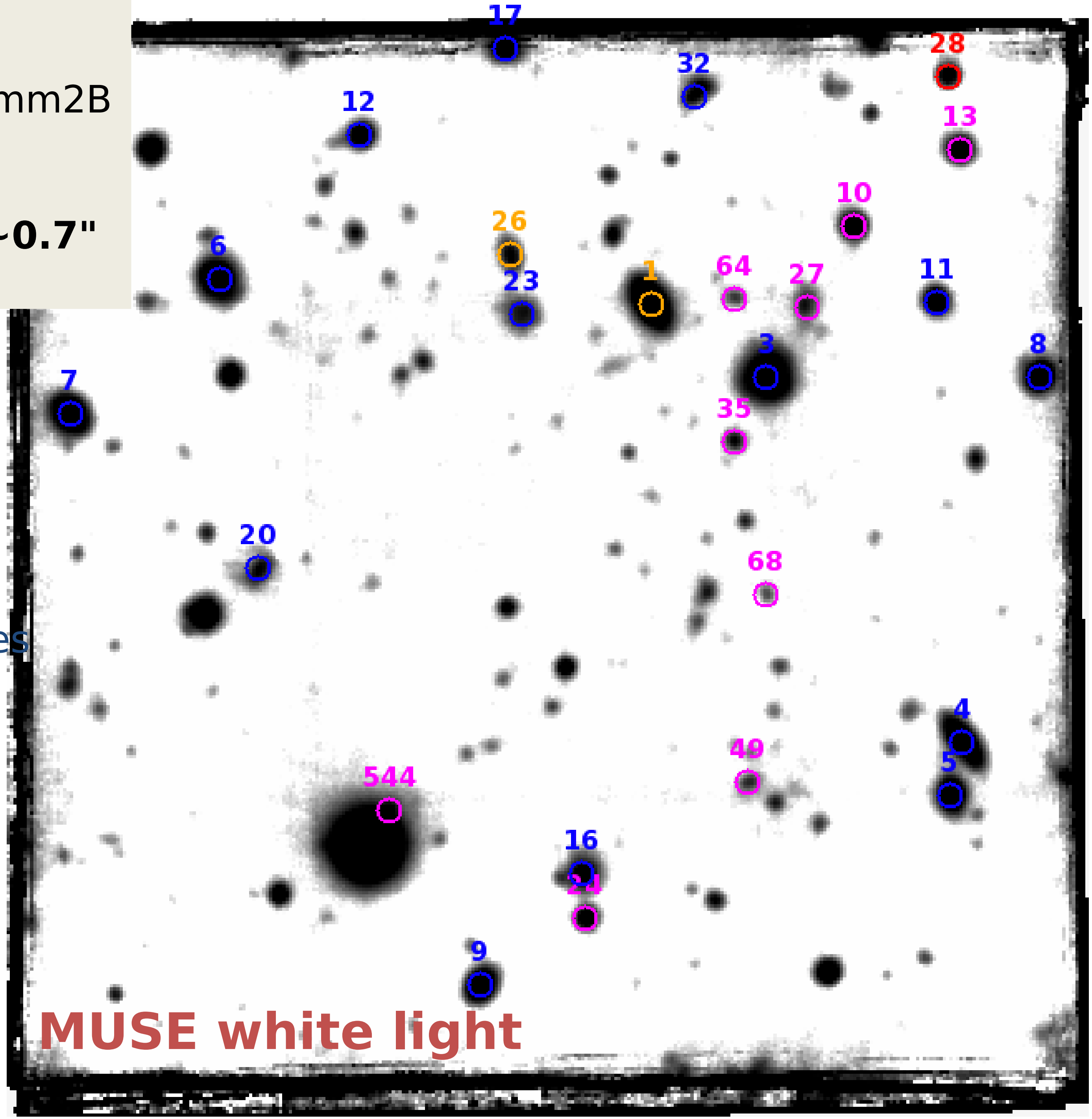
- **MUSE perfectly suited** for $0.2 < z < 1.3$ emission-line galaxies
- Study a sample of ~ 200 'field' galaxies with good data
- Study a sample of ~50 galaxy in groups

➢ Understand role of environment at z~1

HDF-South

Observed during Comm2B

- **Exposure ~ 30h**
- **Median seeing ~0.7"**



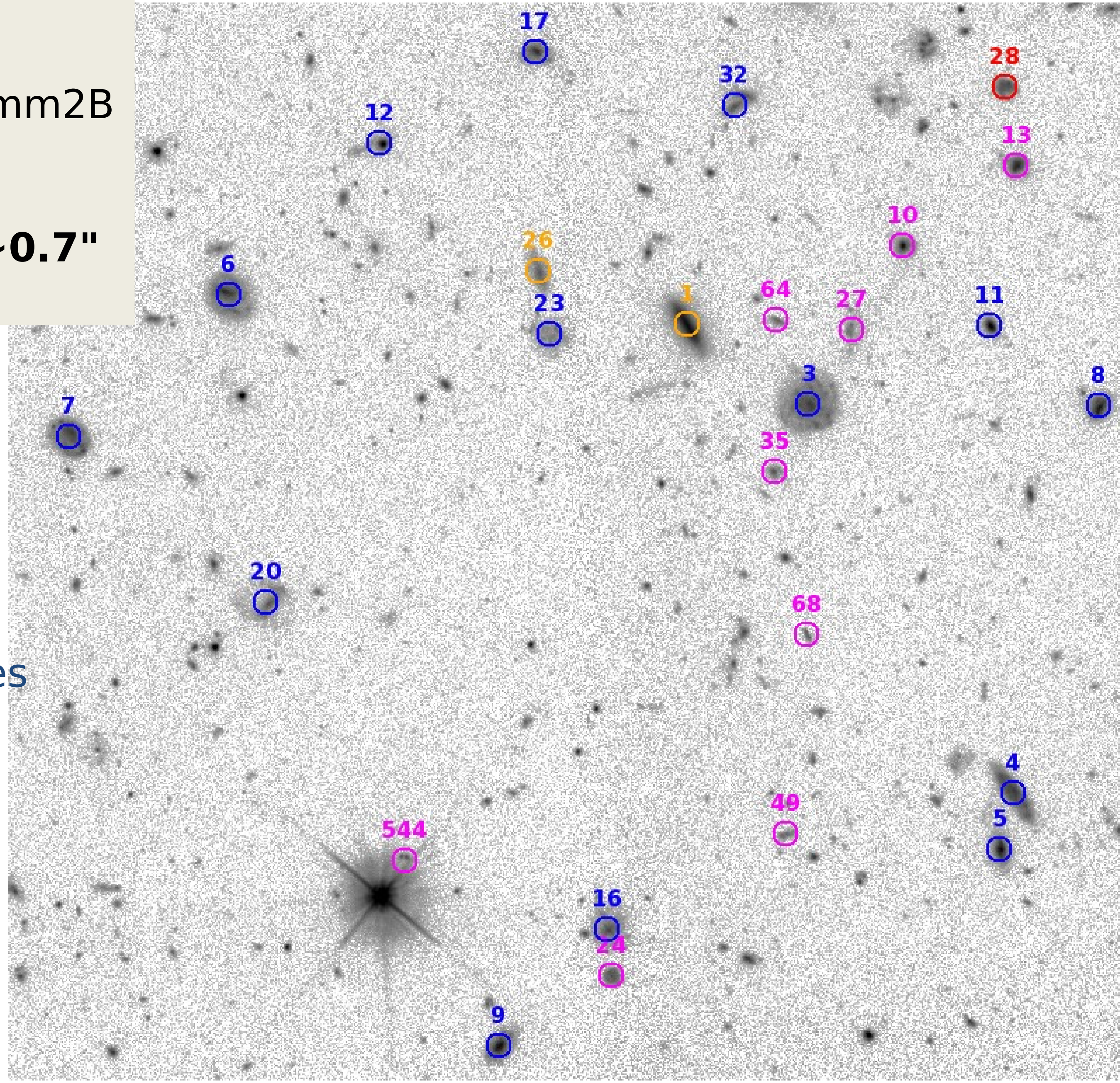
Identification of
spatially-resolved
Emission-line galaxies

HDF-South

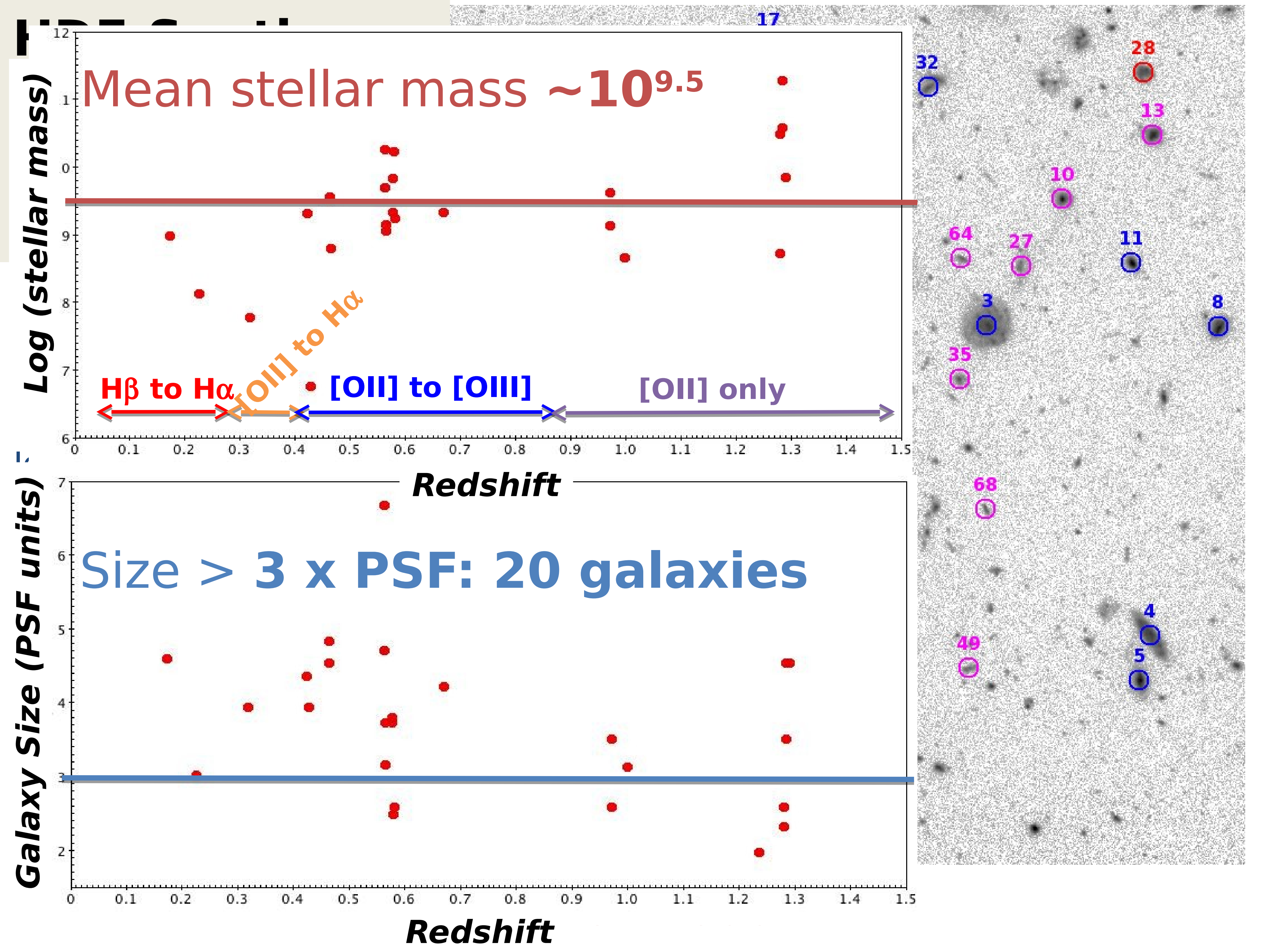
Observed during Comm2B

- **Exposure ~ 30h**
- **Median seeing ~0.7"**

Identification of
spatially-resolved
Emission-line galaxies

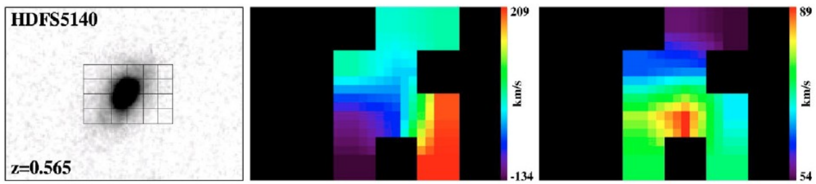


HST WFPC2-F606

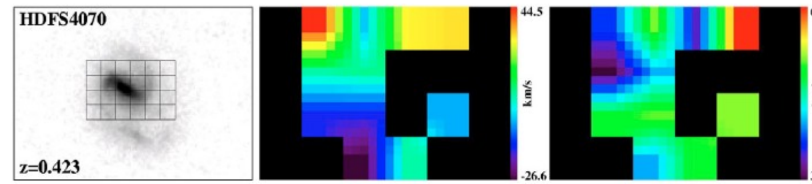

Mean stellar mass ~10^9.5
Log (stellar mass)
Hβ to Hα
[OII] to Hα
[OII] to [OIII]
[OII] only
Redshift
Size > 3 x PSF: 20 galaxies
Galaxy Size (PSF units)
Redshift
17
32
28
13
10
64
27
11
3
8
35
68
4
49
5

Comparison with previous data

- FLAMES/GIRAFFE data (IMAGES survey)

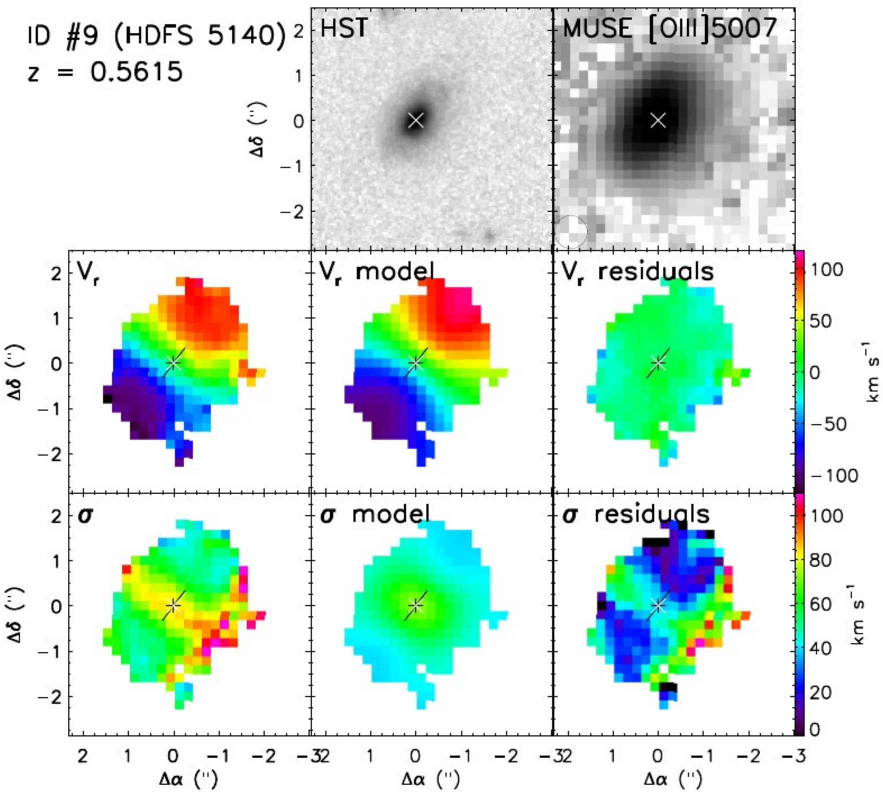


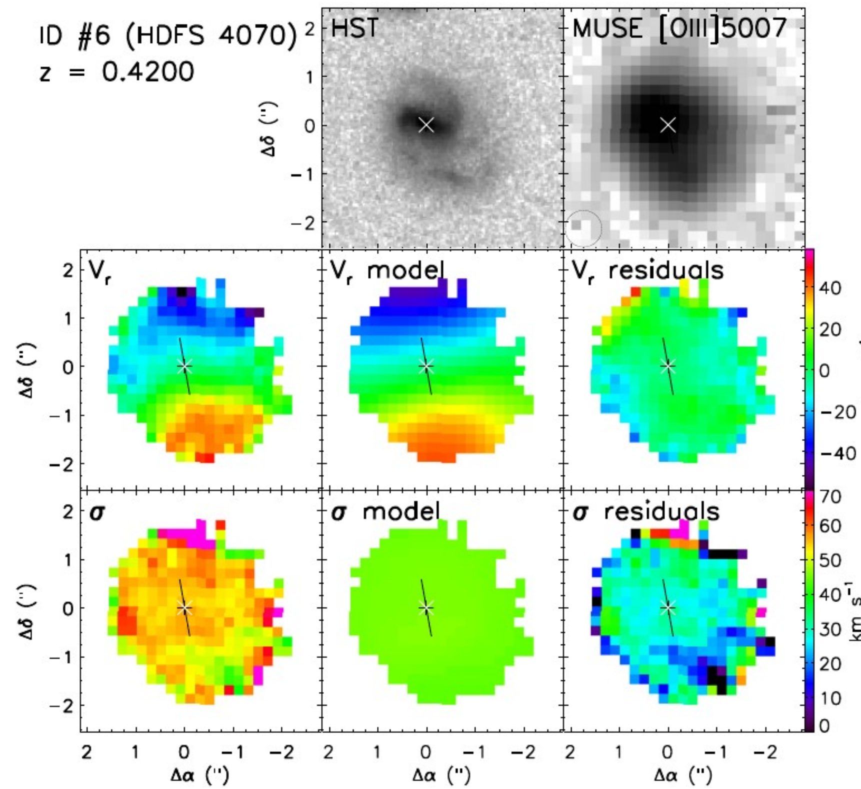
Puech et al. (2006)



Flores et al. (2006)

- MUSE data (HDFS)

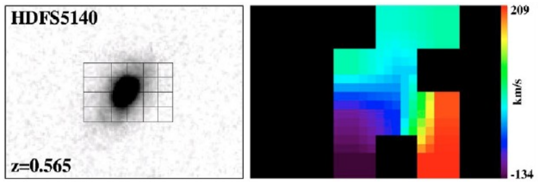




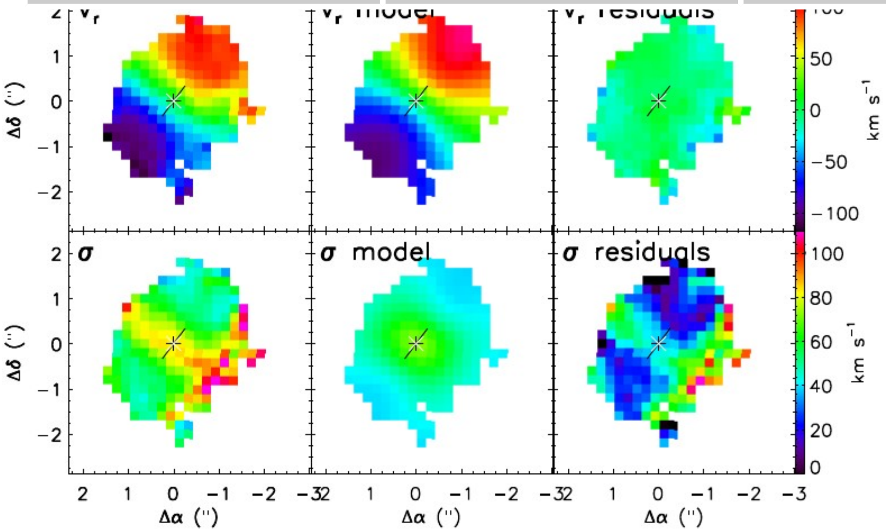
Bacon et al. (in prep)

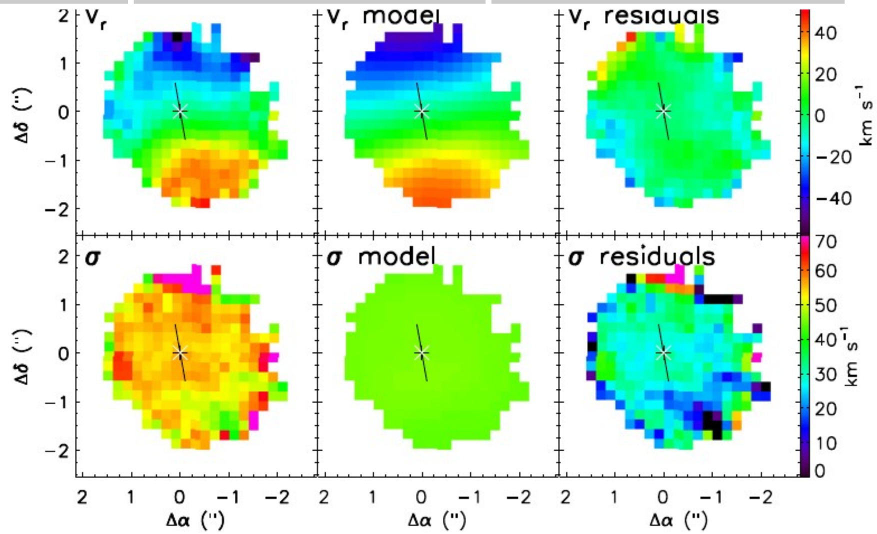
Comparison with previous data

- FLAMES/GIRAFFE data (IMAGES survey)



Parameter	HDFS 5140		HDFS 4070	
	IMAGES	**MUSE**	**IMAGES**	**MUSE**
Vmax [km/s]	220 +- 21	142 +- 5	70 +- 21	66 +- 5
Class	Complex	Rotating	Complex	Perturbed





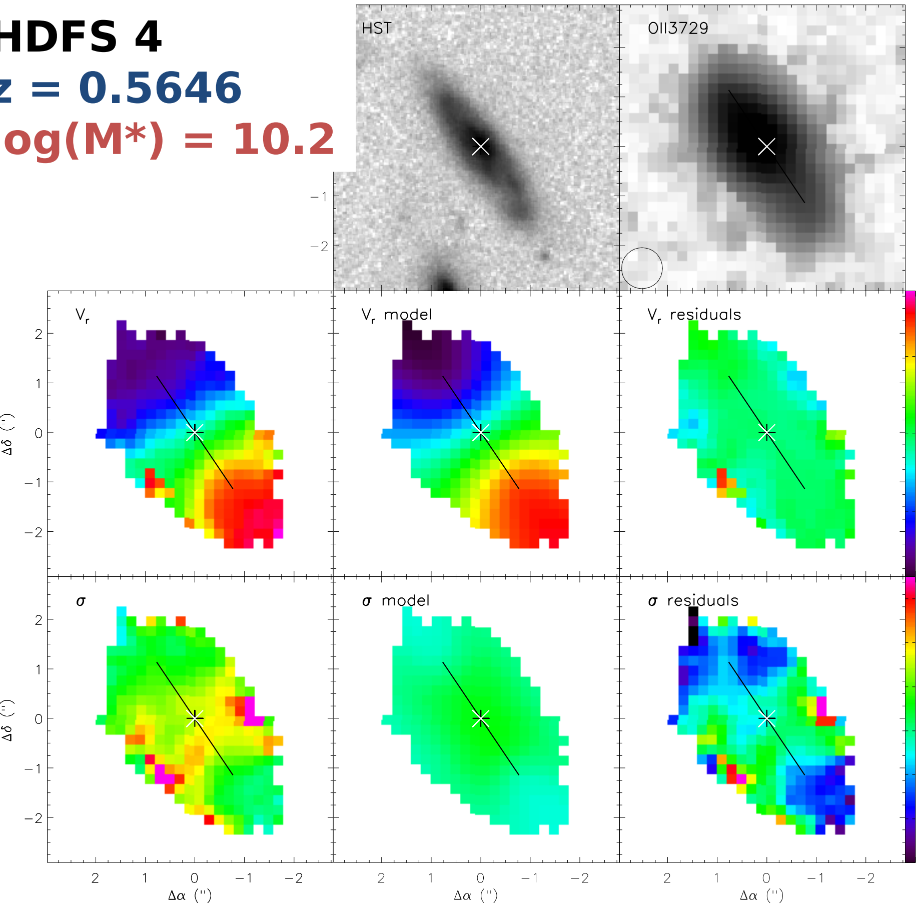
Bacon et al. (in prep)

Conclusions

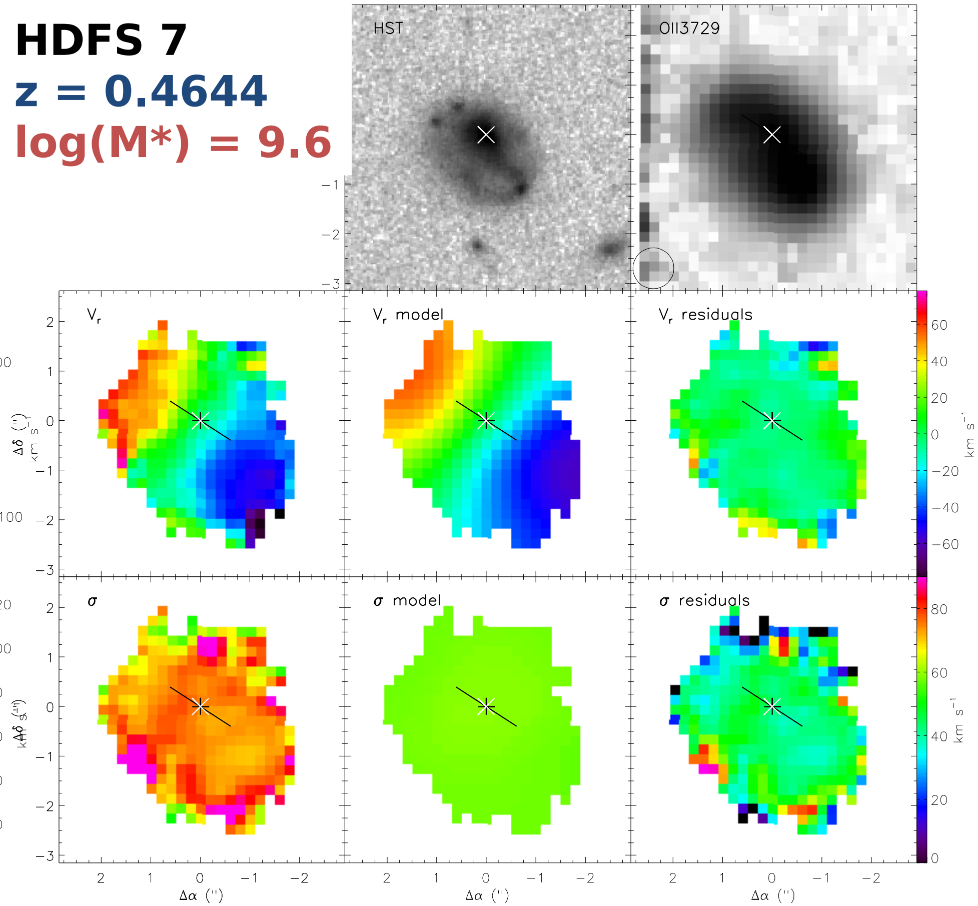
- Ability to track evolution with redshift
- Evolution with small scale and large scale environment
- Comparison with numerical simulations
- Combined analysis morpho/kinematics
- Scaling relations evolution (e.g. Tully-Fisher)
- Search for non circular motions (e.g. bars, outflow/inflow)

Asymmetric galaxies with bright HII regions

HDFS 4
z = 0.5646
log(M*) = 10.2



HDFS 7
z = 0.4644
log(M*) = 9.6

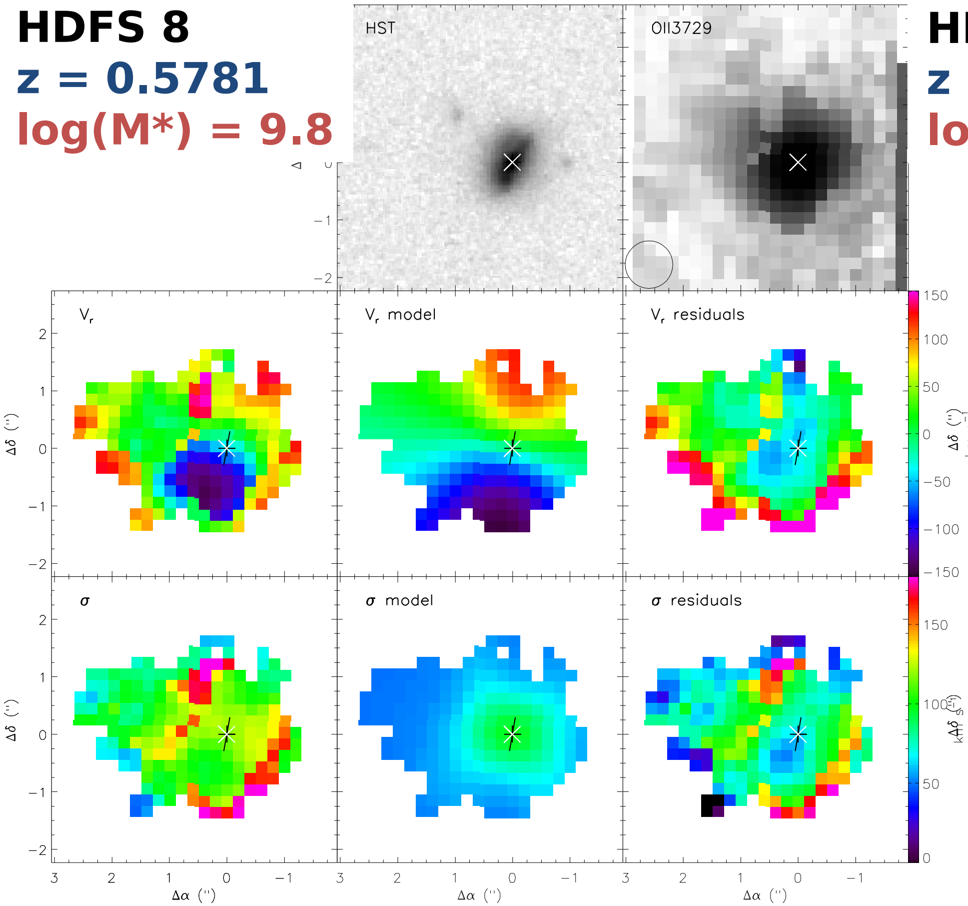


Disturbed/peculiar velocity fields

HDFS 8

z = 0.5781

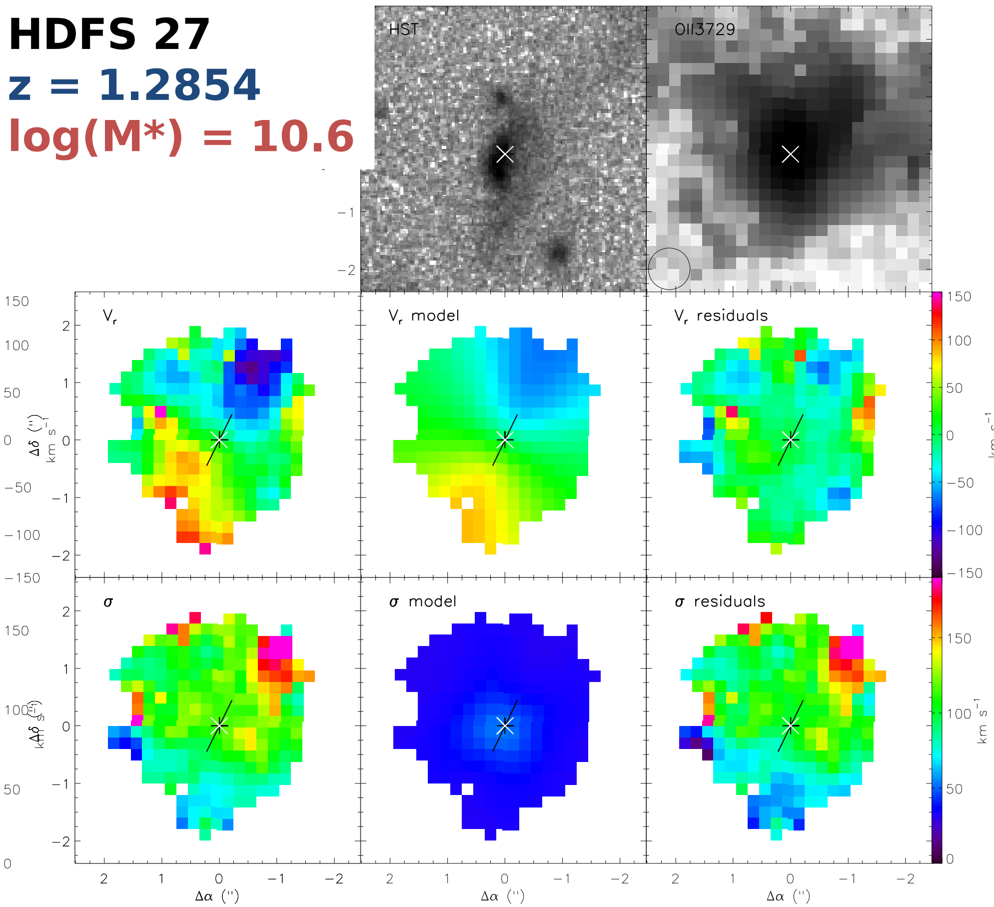
log(M*) = 9.8



HDFS 27

z = 1.2854

log(M*) = 10.6



Beam smearing and kinematics

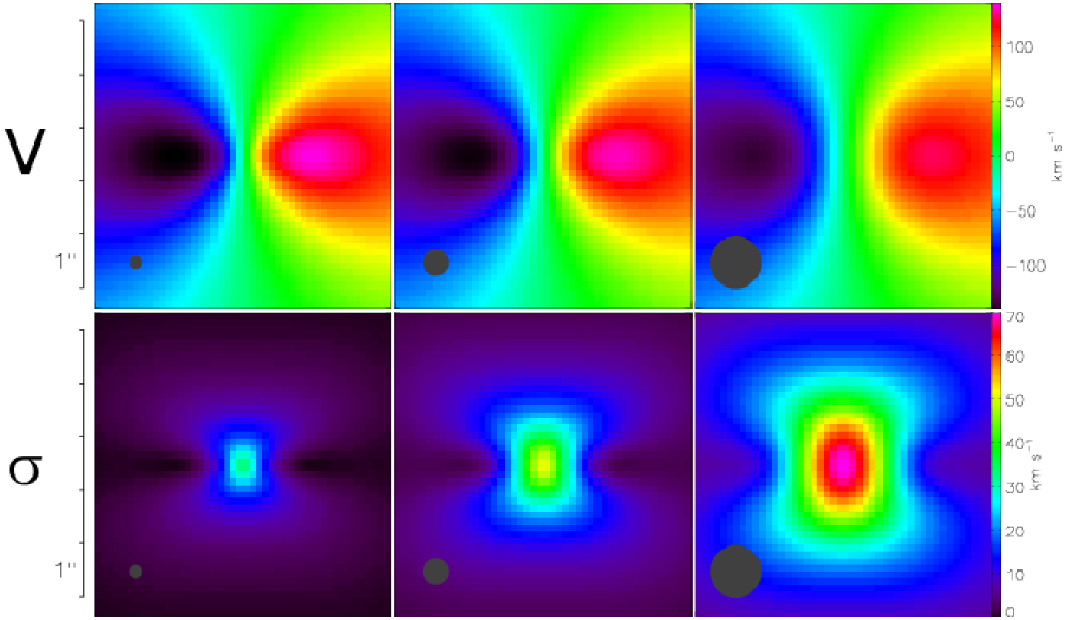
At z~1, seeing is almost as large as Ha extent (1''>8 kpc)

Rotating disk simulation with

- Seeing increases from 0.125'' to 0.5''
- No local velocity dispersion

Effect of beam smearing :

- Inner velocity gradients decrease
- Central velocity dispersion peak

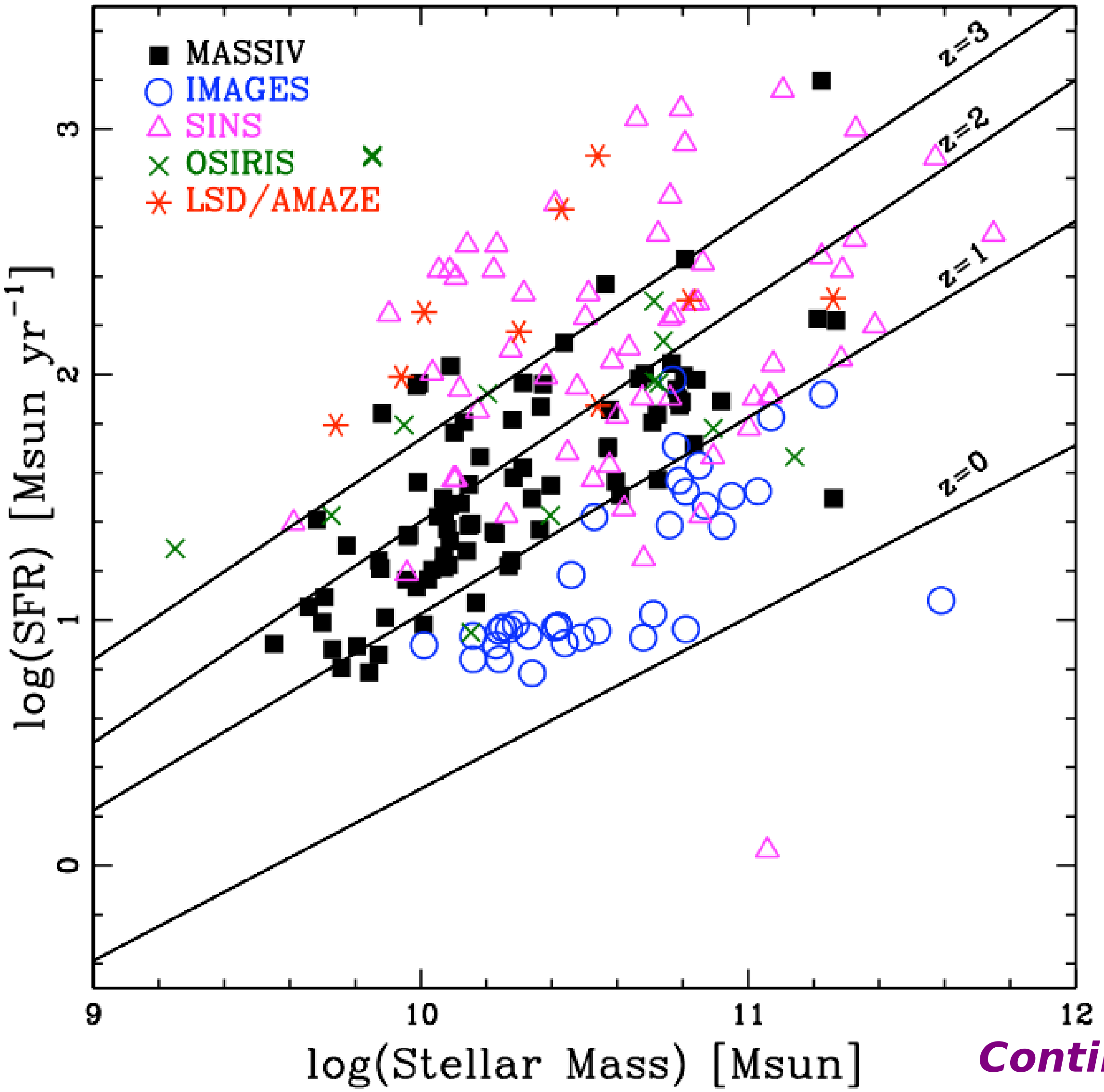


Conclusion

Epinat et al. 2010

- Need to take beam smearing into account to recover the true galaxy parameters (PA, inclination, maximum velocity, velocity dispersion)

Sample properties

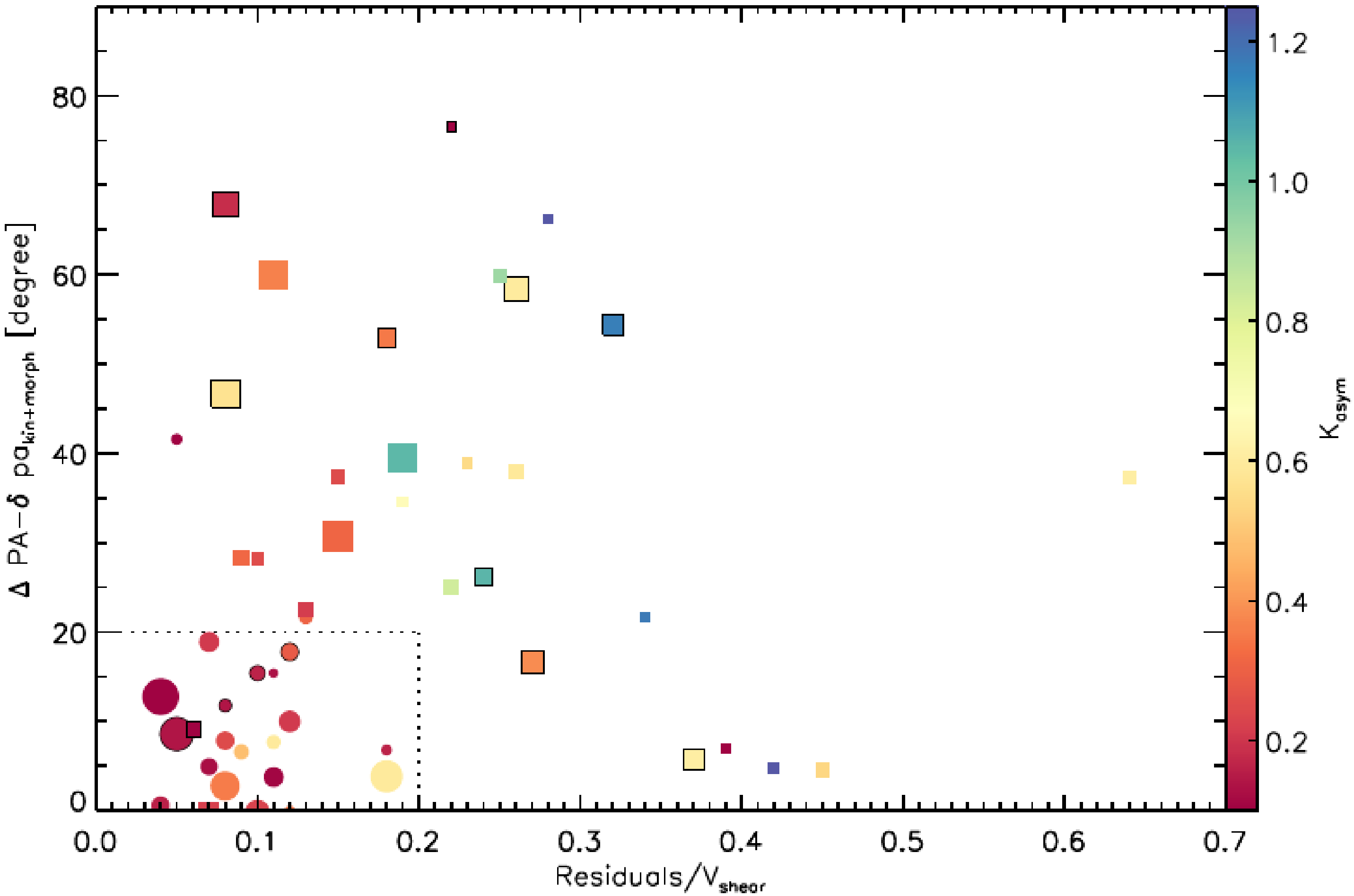


Lines @z=0-3
Empirical relations from Bouché et al.+10

IMAGES	**0.4 < z < 07**
MASSIV	**0.9 < z < 1.8**
SINS	**1.4 < z < 2.6**
OSIRIS	**1.5 < z < 3.3**
LSD/AMAZE	**2.6 < z < 3.8**

Contini et al. 2012

Rotators vs slow rotators



Perret (2014)
Full sample

Observational approach

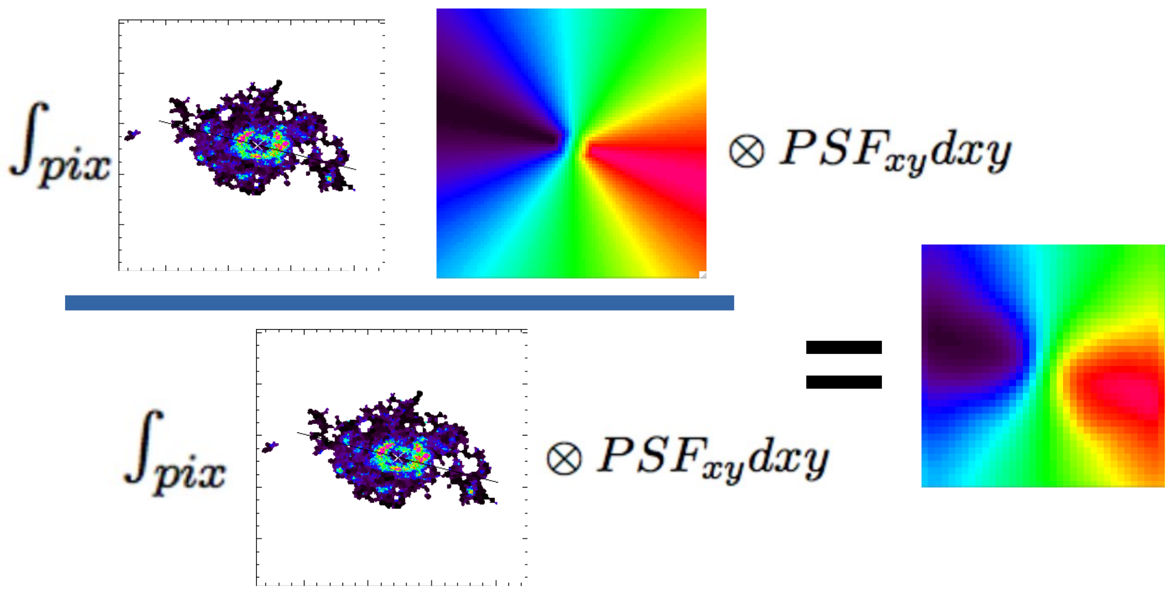
- Integral field spectroscopy
- Spatially resolved properties
  - Kinematics
  - Abundances
- 'Representative' samples at various redshifts
- Comparison with numerical simulations

2D model *(Epinat et al. 2008)*

Map modeling

- ***Inputs:***
  - velocity field
  - flux map
  - PSF
- ***Parameters:***
  - Turn-over radius
  - Vmax
  - Center
  - Inclination
  - Position angle
  - Systemic velocity

- χ_2 minimisation



Unknown high resolution flux map
=> **observed line flux map**