

# Mass assembly and chemical evolution of high-redshift galaxies with SINFONI/VLT

**Thierry Contini**  
*LATT – Toulouse, France*

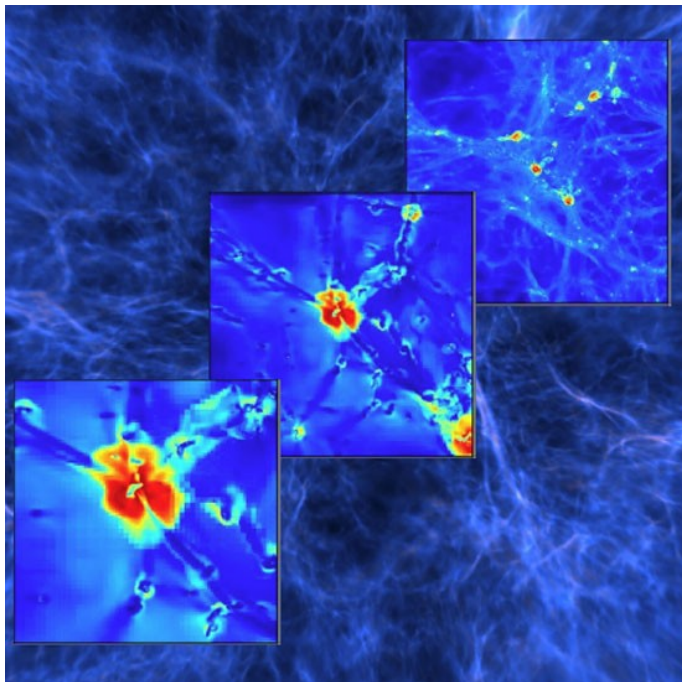
B. Epinat, J. Queyrel, P. Amram,  
B. Garilli, M. Kissler-Patig, O. Le Fèvre,  
E. Perez-Montero, L. Tasca, L. Tresse,  
D. Vergani, & the  collaboration

[www.ast.obs-mip.fr/massiv](http://www.ast.obs-mip.fr/massiv)

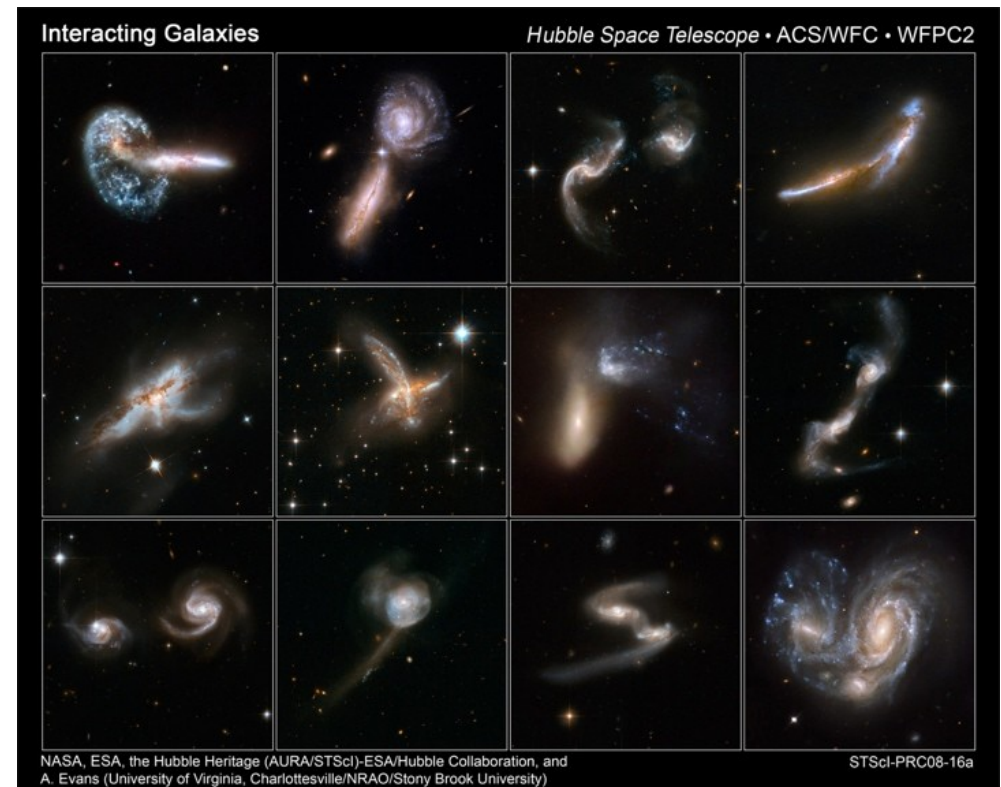


# Open issues in galaxy evolution

- ✓ Process of galaxy **mass assembly** at early epochs?
- ✓ Role of violent **mergers** vs. smooth **gas accretion**?
- ✓ Impact of **feedback** (SNe, AGNs, ...)?
- ✓ Influence of **environment**?



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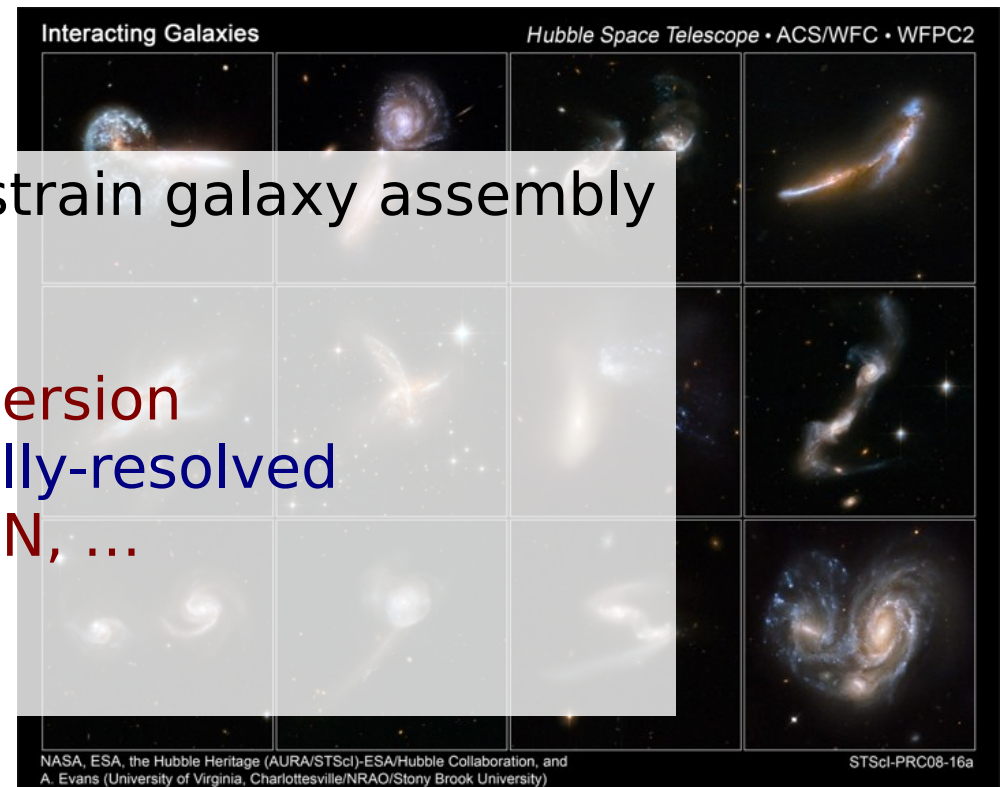
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## Physical parameters to constrain galaxy assembly

- **Mass:** stars + gas + DM
- **Dynamics:** rotation vs. dispersion
- **Metallicity:** global + spatially-resolved
- **Activity:** star formation, AGN, ...
- **Morphology**
- **Density field**

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# Open issues in galaxy evolution


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Interacting Galaxies Hubble Space Telescope • ACS/WFC • WFPC2



**3D spectroscopy**  
is a powerful technique!

GIRAFFE, SINFONI @ VLT, OSIRIS @ Keck, ...

**$z \sim 0.6$ :** Hammer, Flores, et al.  
 **$z \sim 2-3$ :** Genzel, Förster-Schreiber, et al.  
Law, Wright, et al.

NASA, ESA, the Hubble Heritage (AURA/STScI)-ESA/Hubble Collaboration, and A. Evans (University of Virginia, Charlottesville/NRAO/Stony Brook University) STScI-PRC08-16a



# Probing the mass assembly of galaxies at the crucial $1 < z < 2$ epoch

- peak of the cosmic **star formation activity**
- transition between the **morphological diversity** observed @  $z \sim 3-4$  and the modern-day Hubble sequence
- Complete census of the **mix of dynamical types** mergers, disks, perturbed kinematics, etc
- **Dynamical support**, DM halo, and **metallicity**
- Evolution of fundamental **scaling relations**: Tully-Fisher, Mass-Metallicity, Size-Velocity, etc

**ESO "Large Program"**  
started in P79 for **2 years (2007-09)**  
**300 hours in *Service mode***



**Sample: ~ 140 VVDS star-forming galaxies @  $1 < z < 2$**

- **representative** of the galaxy population
- spanning a **wide range of stellar masses**  $\log(M)=[9,12]$

**Strategy: AO-assisted SINFONI observations @ VLT**

- *J* or *H* band to observe redshifted Ha **bright emission line**
- **high spatial resolution** ( $<0.8''$ ) to probe the dynamics Ha velocity fields

## People & Places

About 15 astronomers located in France, Italy, Germany and Spain are involved in the MASSIV project

### **LATT – Toulouse**

T. Contini (PI)  
B. Epinat  
J. Moutaka  
J. Queyrel

### **LAM – Marseille**

P. Amram  
O. Le Fèvre  
L. Tresse

### **INAF – Milano**

B. Garilli  
L. Paoro  
L. Tasca

### **INAF – Bologna**

S. Bardelli  
D. Vergani  
E. Zucca

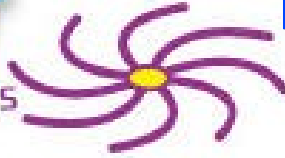
### **ESO – Garching**

M. Kissler-Patig

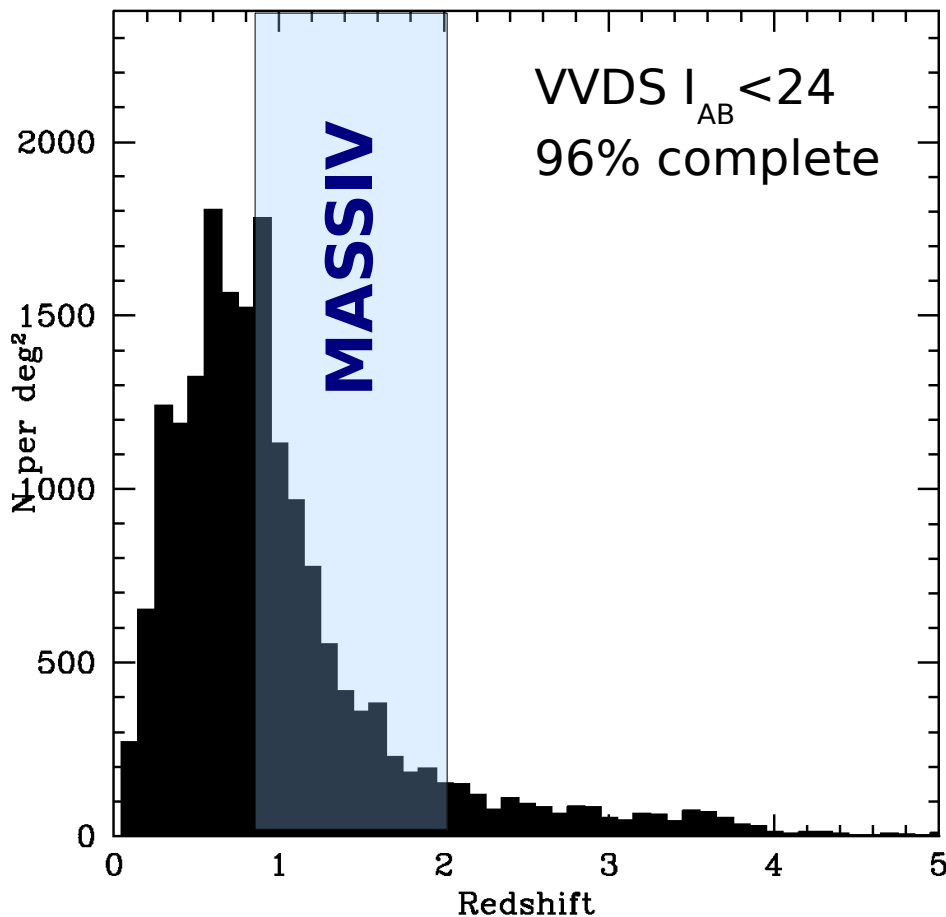
### **IAA - Granada**

E. Perez-Montero

Staff - Postdoc - PhD student - Database manager

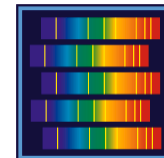


## The parent sample



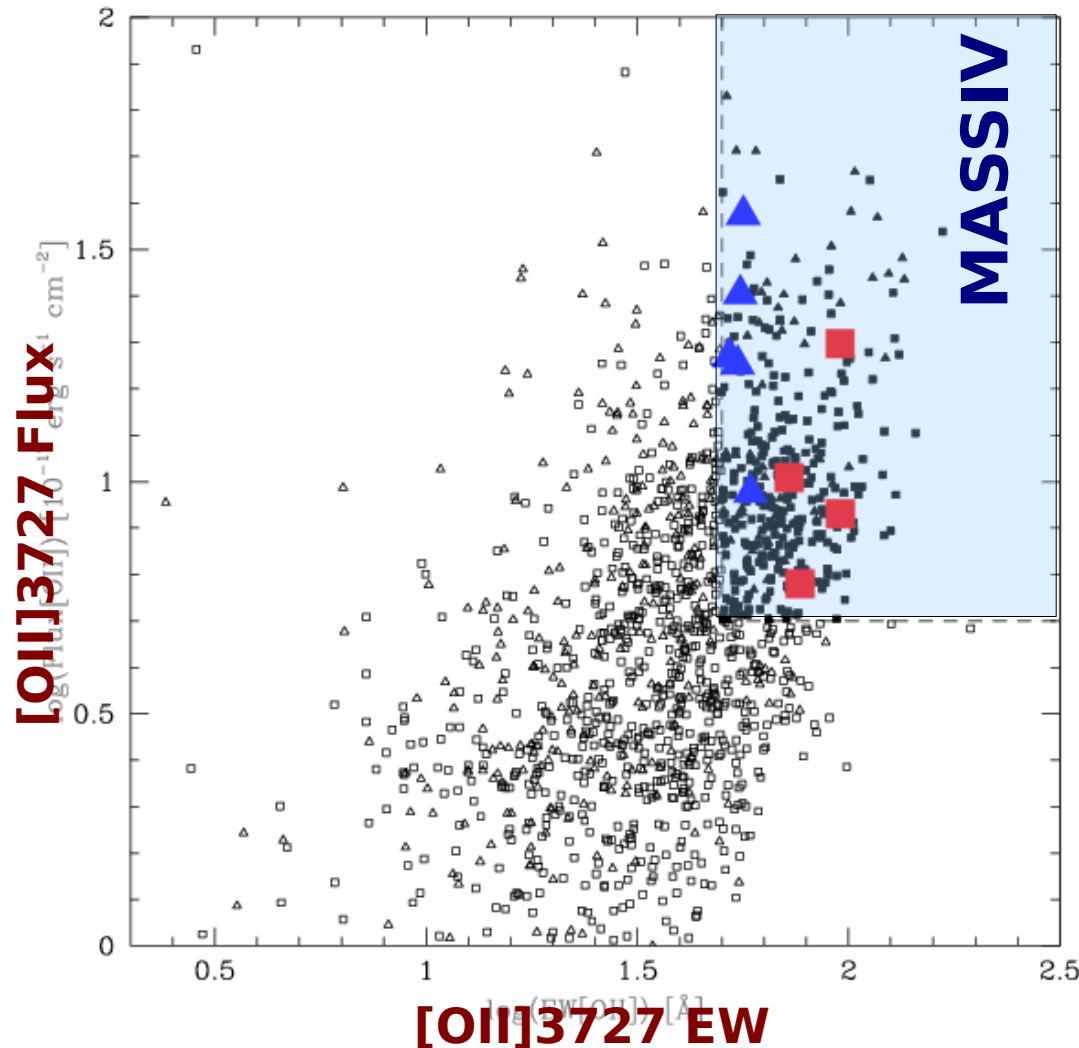
**VVDS offers the best suited parent sample to select high-z galaxies for NIR 3D spectroscopic follow-up**

- Well-defined & **minimal bias**
- Complete & **representative**
- **Accurate spectroscopic redshifts**
- Three fields:
  - F02 **deep** ( $I_{AB} < 24$ ) & **ultra-deep** ( $I_{AB} < 24.75$ )
  - F14 & F22 **wide** ( $I_{AB} < 22.5$ )

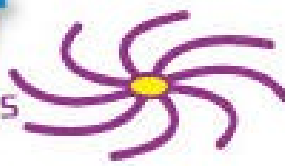




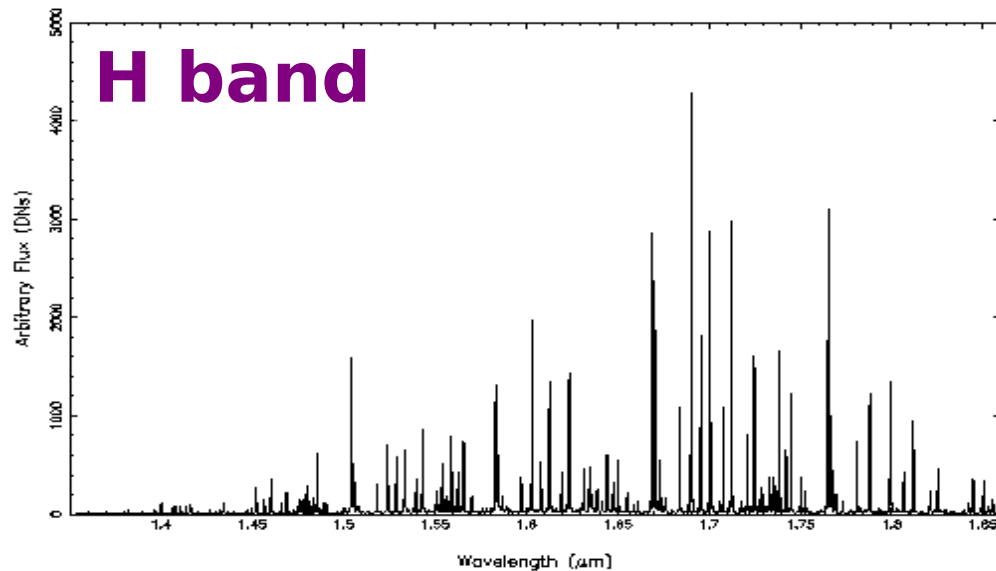
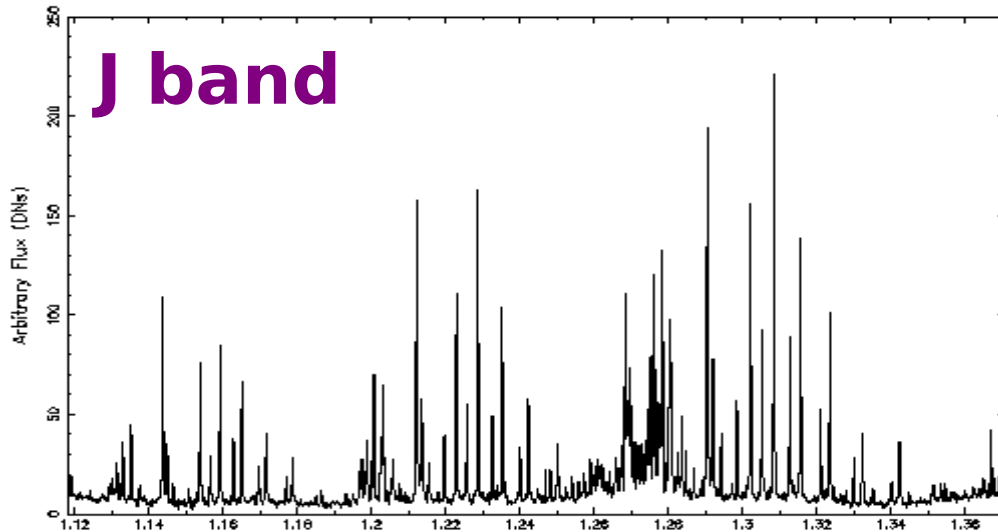
## Selection criteria



- **Star-forming galaxies**
  - $z < 1.4$ :  $[\text{OII}]3727 \text{ EW}$
  - $z > 1.4$ : UV slope

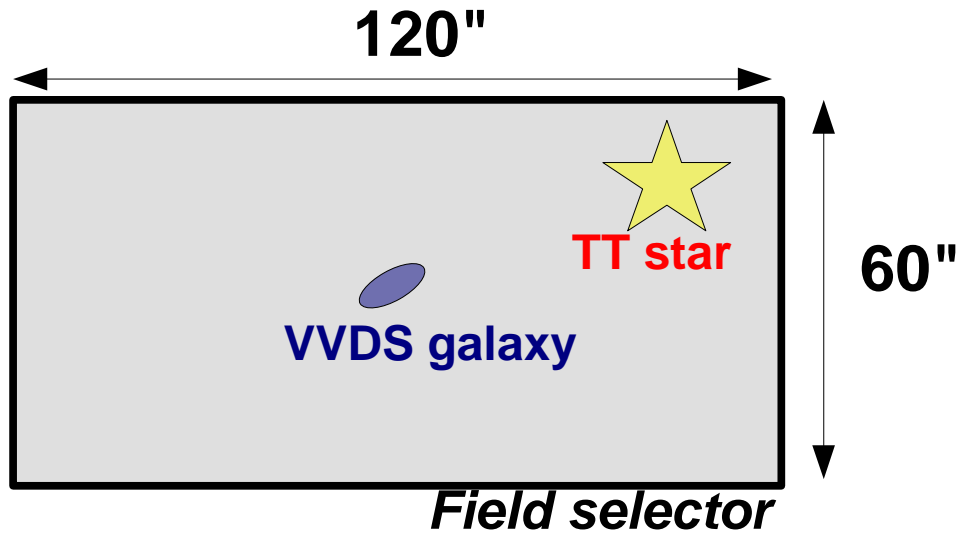


## Selection criteria



- Star-forming galaxies
  - $z < 1.4$ : [OII]3727 EW
  - $z > 1.4$ : UV slope
- **Ha free of bright OH lines**

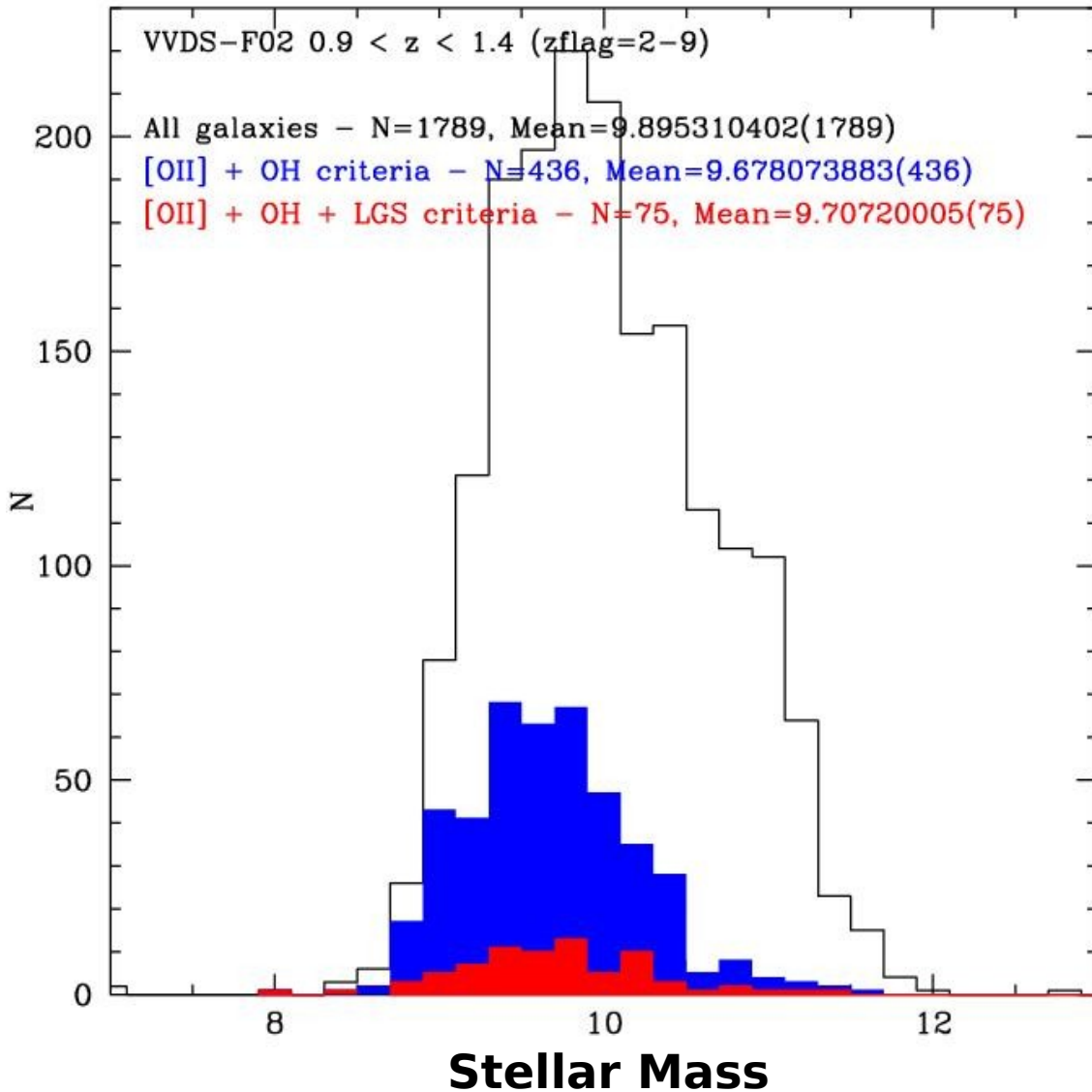
## Selection criteria



- Star-forming galaxies
  - $z < 1.4$ : [OII]3727 EW
  - $z > 1.4$ : UV slope
- Ha free of bright OH lines
- Bright star nearby for AO/LGS observations



## Keeping a representative sample

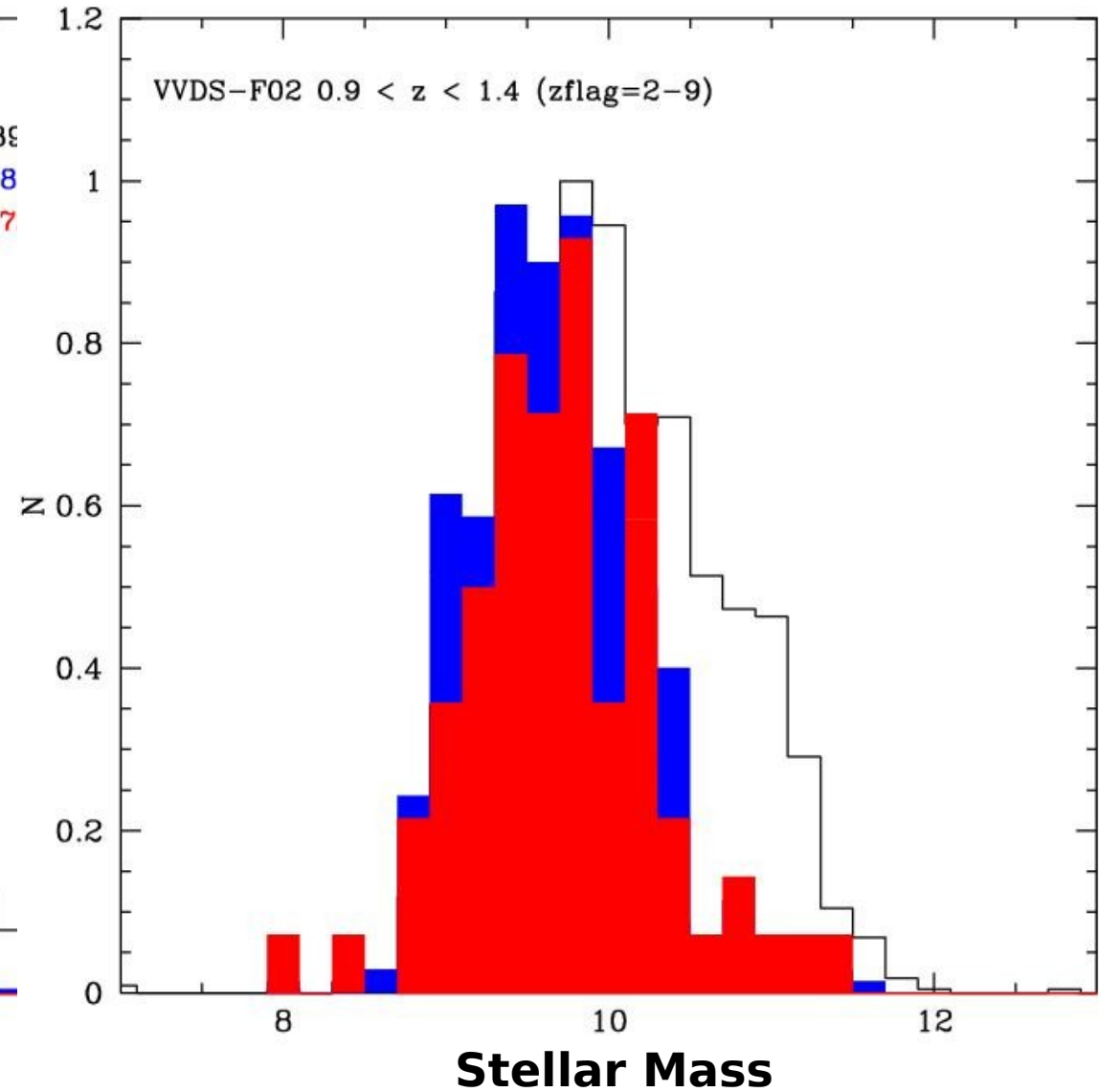
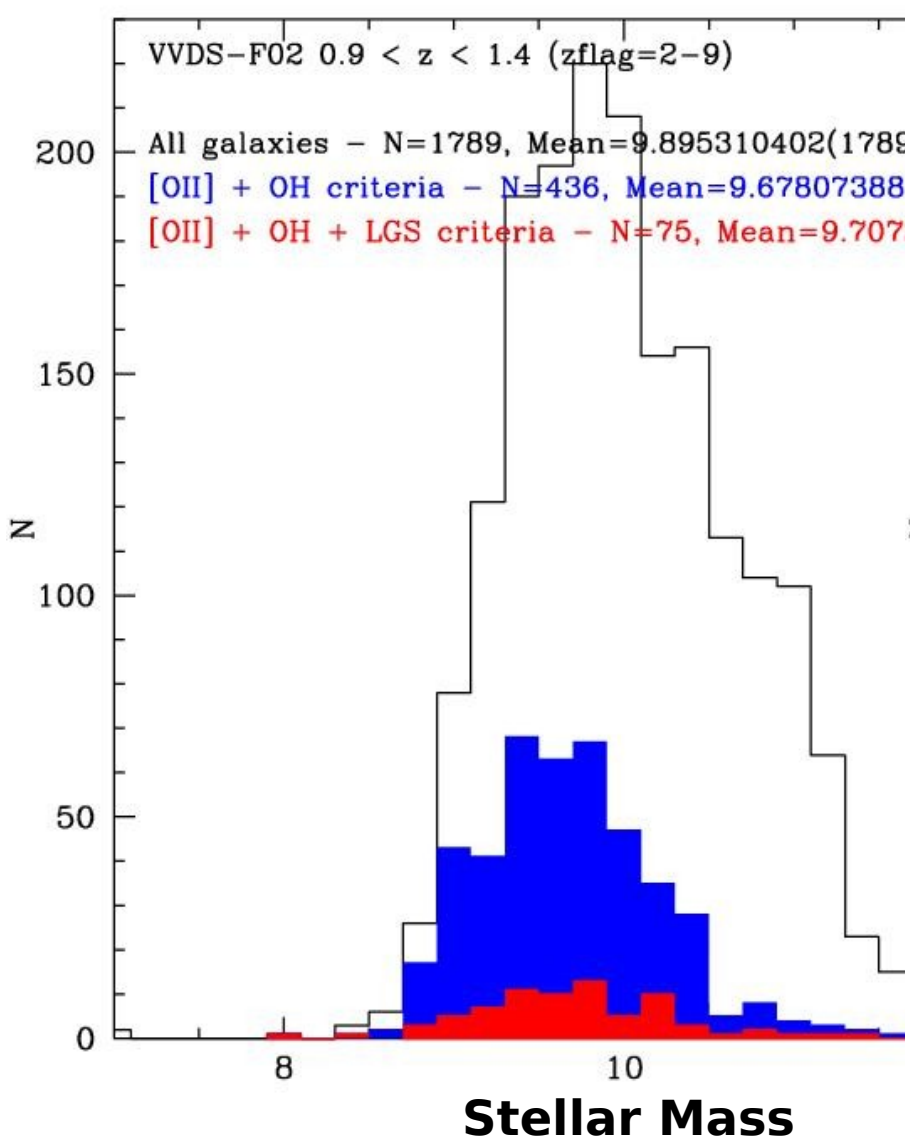


**Full F02  $0.9 < z < 1.4$  sample**  
 $N=1789$   $\log(M^*)=9.89$

**[OII]+OH criteria**  
 $N=436$  (24%)  $\log(M^*)=9.68$

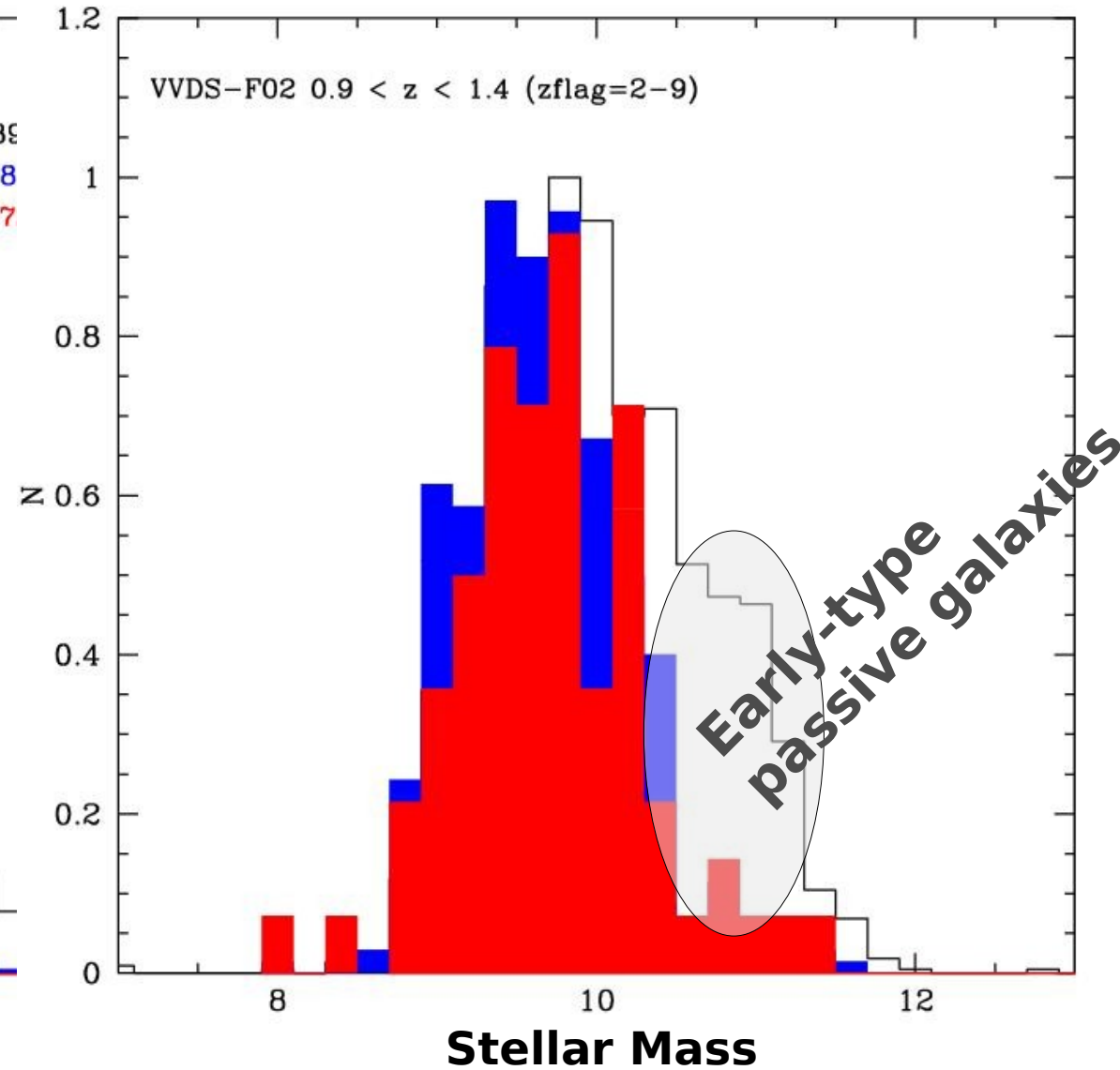
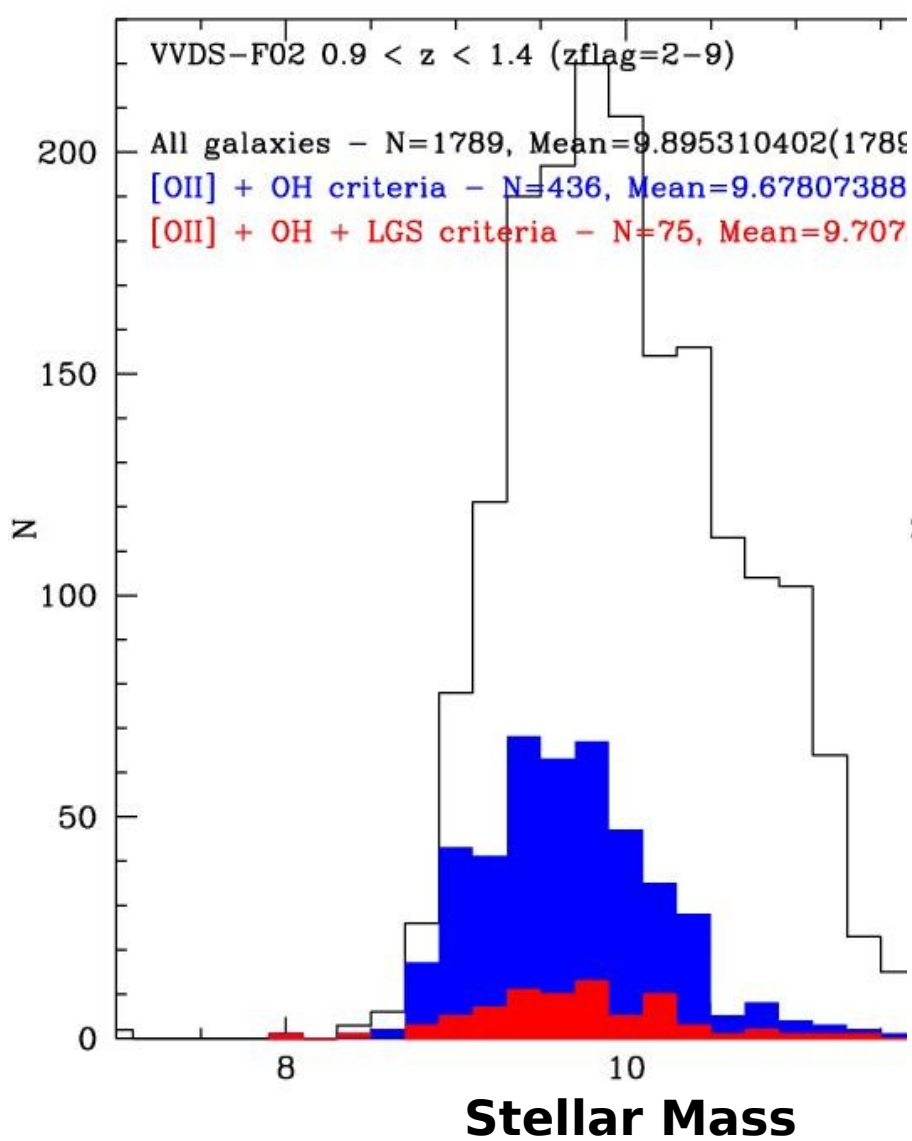
**[OII]+OH+LGS criteria**  
 $N=75$  (4%)  $\log(M^*)=9.71$

## Keeping a representative sample





## Keeping a representative sample



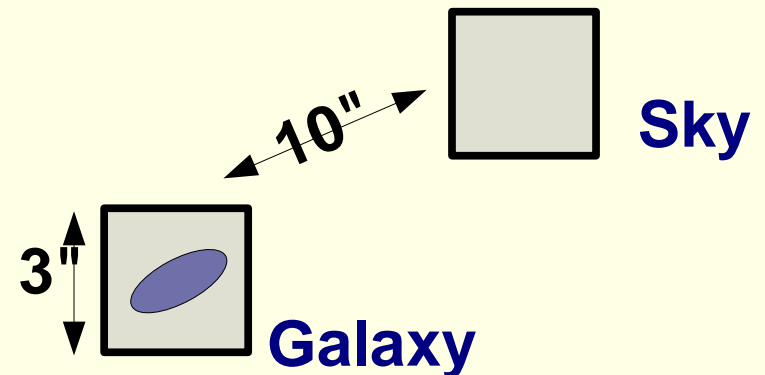
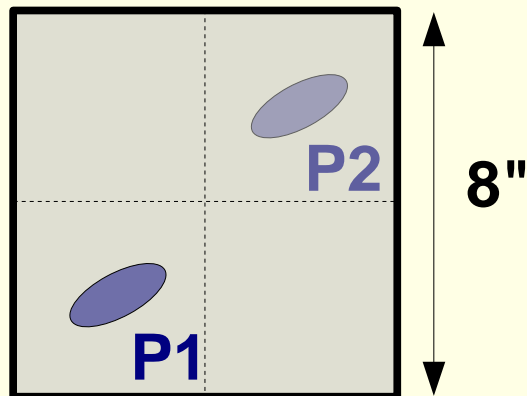
## Observing strategy

**No AO: On-off** sky subtraction

**AO: Offset** for sky subtraction

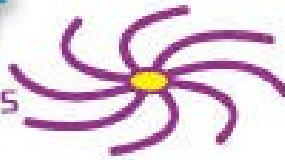
→ **Total** obs. time on source

→ **2/3** obs. time on source



FoV = **8"x8"** @ **0.25"/pixel**

FoV = **3"x3"** @ **0.10"/pixel**



## Project status

**~1/3 observations are completed**

**Important delay** (~ 1.5 year), mainly due to major problems with **Laser Guide Star Facility**

### Data

Already **reduced**, analysis ongoing:

*N* (w/ AO)

**23( 4)**

Data in hand, **to be reduced**

**21( 4)**

Observations **scheduled** (June – Sep 09):

**32(10)**

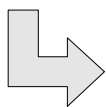
**TOTAL forseen (by October 09):**

**76(18) galaxies**



## *First results from pilot runs*

- 8 nights with SINFONI @ VLT
- 9 VVDS galaxies @  $z \sim 1.2-1.6$
- F02 ( $I_{AB} < 24$ ) and F22 ( $I_{AB} < 22.5$ ) fields
- 1 to 3h exp. time on source
- no AO – FoV =  $8'' \times 8''$  –  $0.25'' \times 0.125''$  spaxel
- mean seeing  $\sim 0.65''$  - phys. scale  $\sim 8.5 \text{ kpc}''$

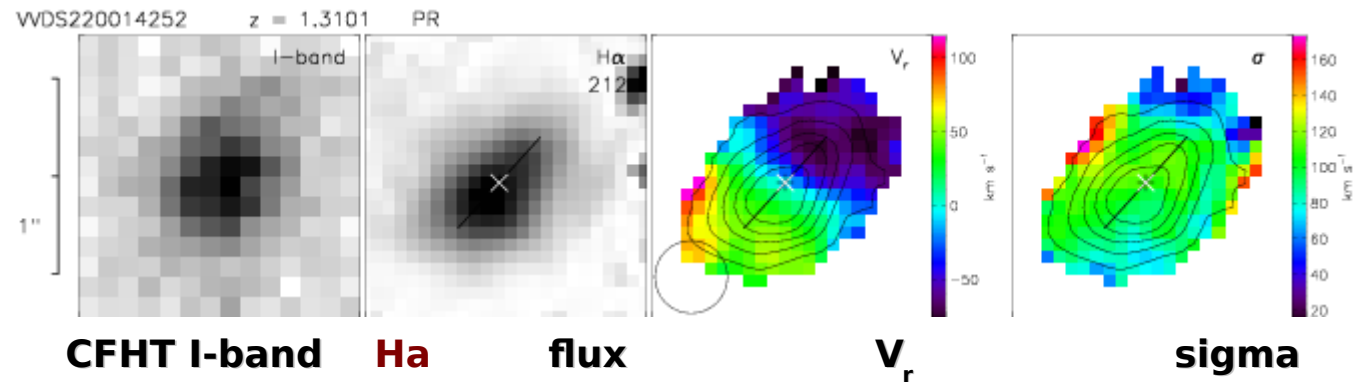


**Kinematics & mass assembly** *Epinat et al. arXiv:0903.1216*

**Mass-Metallicity relation**

*Queyrel et al. arXiv:0903.1211*

- **Ha kinematics**



- **Morphology** from CFHTLS “best-seeing” ( $<0.65''$ ) images using GALFIT  $\rightarrow$  Center position, major axis PA, inclination, ...

- **Stellar mass** from SED fitting



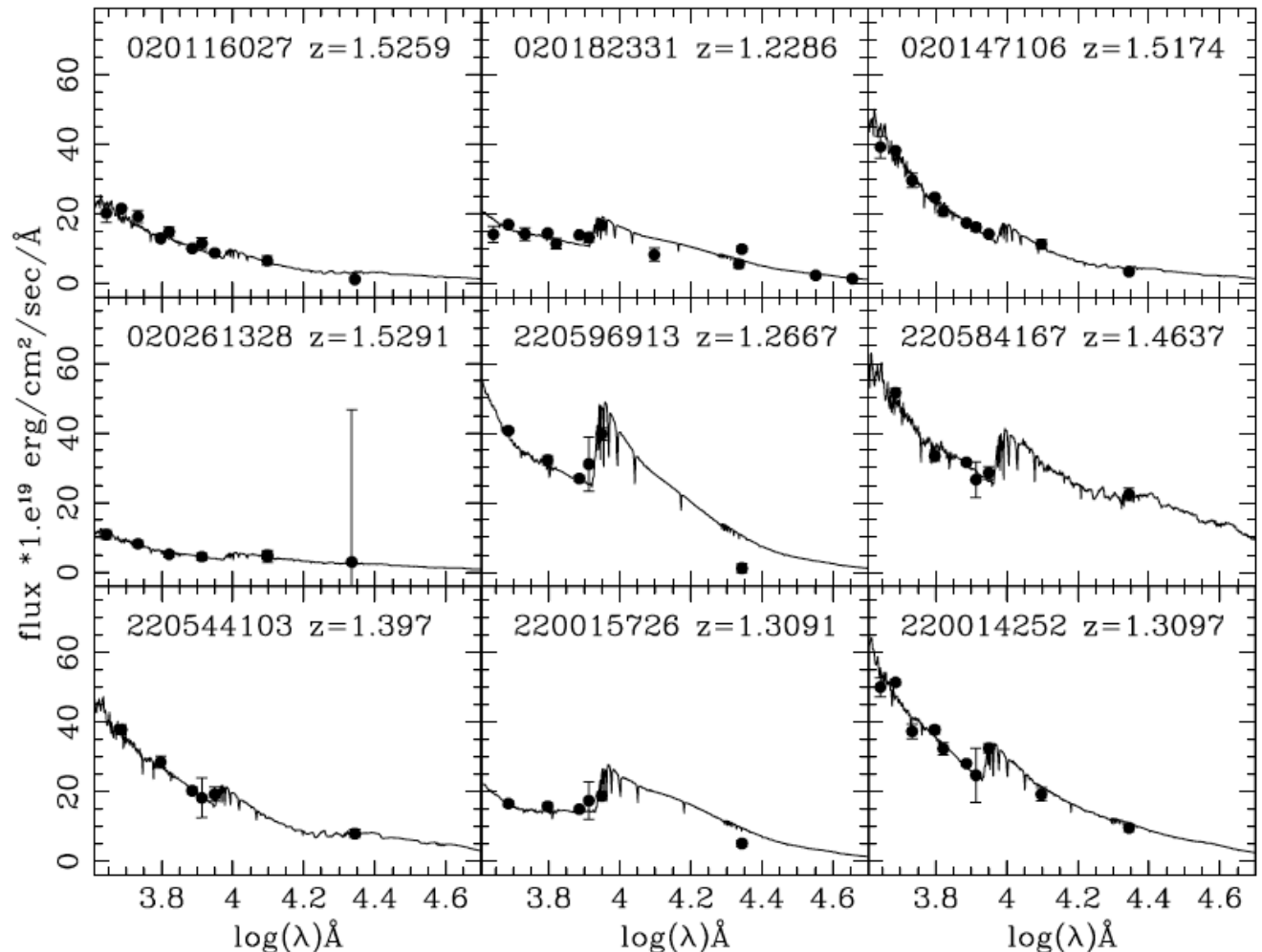
## SED fitting

- **SED from VVDS UV-FIR photometry**

- **GOSSIP software**  
(Franzetti et al. 08)

- ✓ Bruzual & Charlot 03 SSP
- ✓ Delayed SFHs
- ✓ Salpeter IMF (10-100 Msun)
- ✓  $0.02 < Z < 2.5 Z_{\text{sun}}$
- ✓ LMC reddening law
- ✓ Bayesian method

- Outputs:  
**Stellar mass**, reddening,  
age, SFR .. with realistic errors



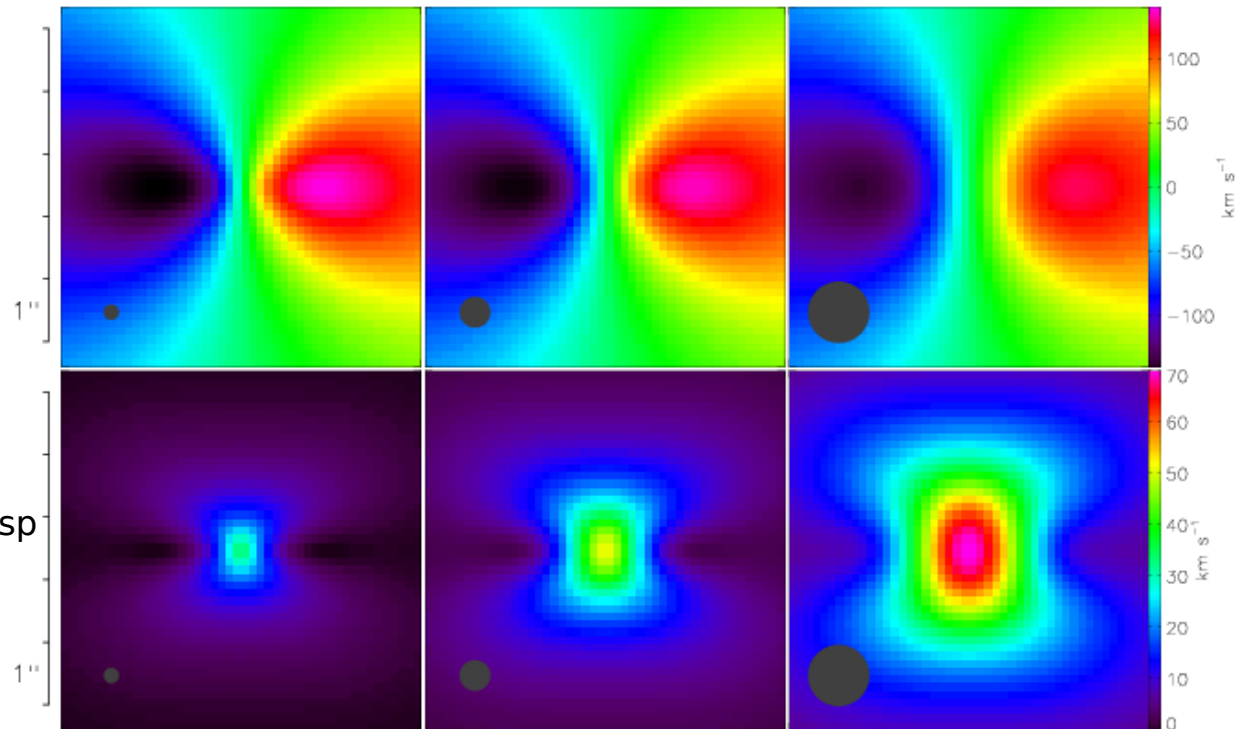
## Exponential disk modeling

Correcting velocity dispersion maps for **beam smearing**

Local velocity dispersion  
+  
Velocity shear

$V_r$

$V_{\text{disp}}$



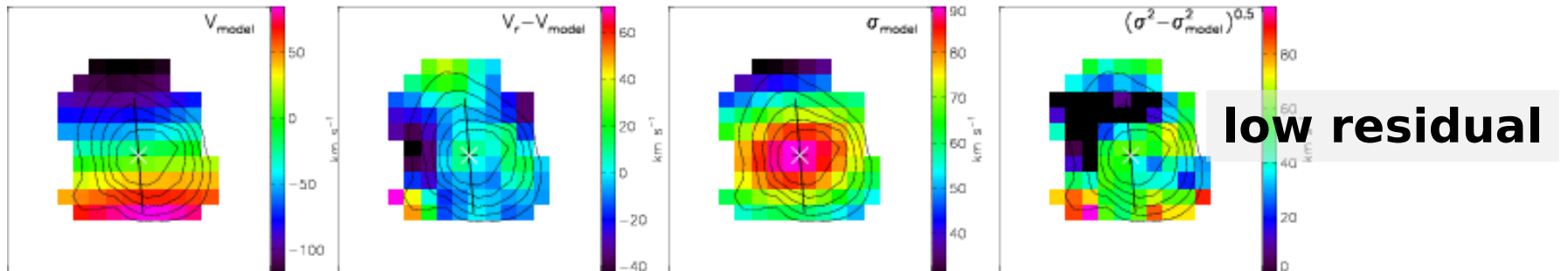
*Epinat et al. 2009, arXiv:0904.3891*

Seeing = 0.125" 0.25" 0.5"

**Examples of modeling**

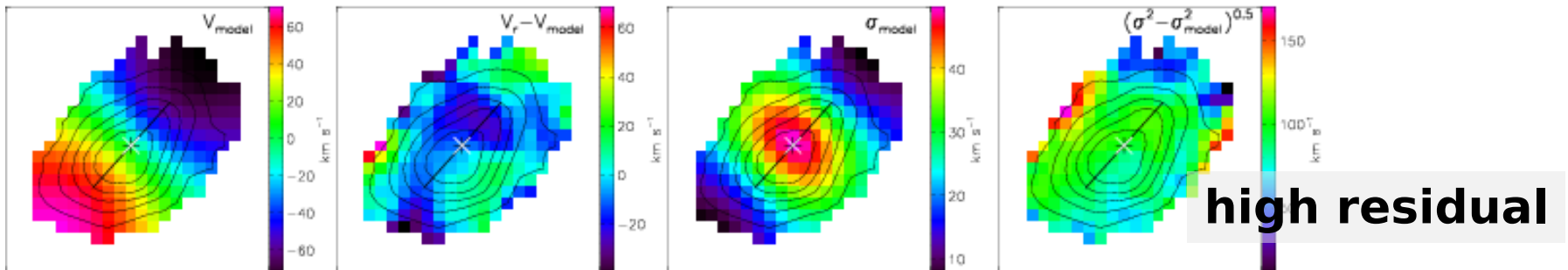
**Rotating disk**

WDS220015726



**Perturbed rotator**

WDS220014252



$V_r$  model

Residual

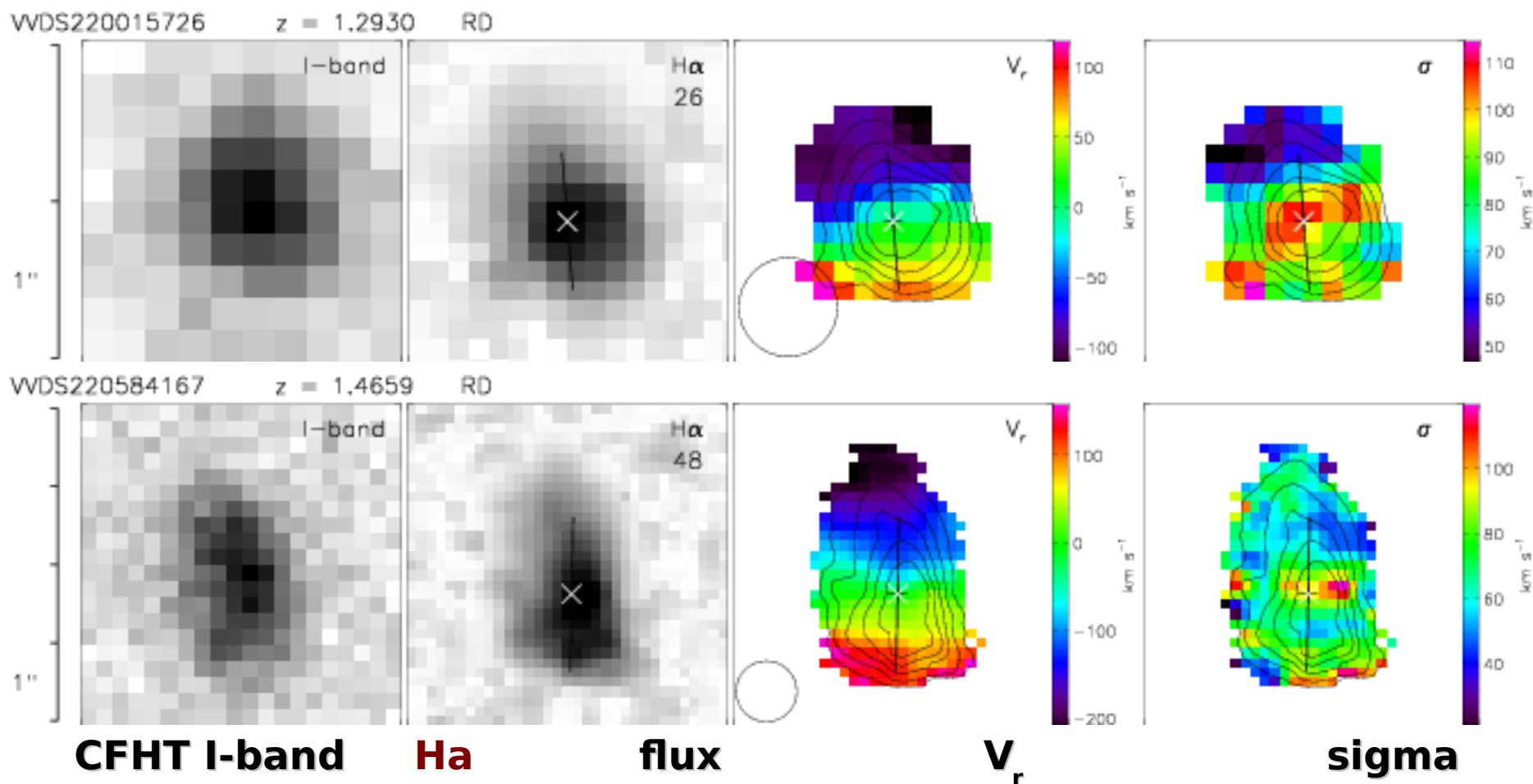
***Sigma*** model

Residual

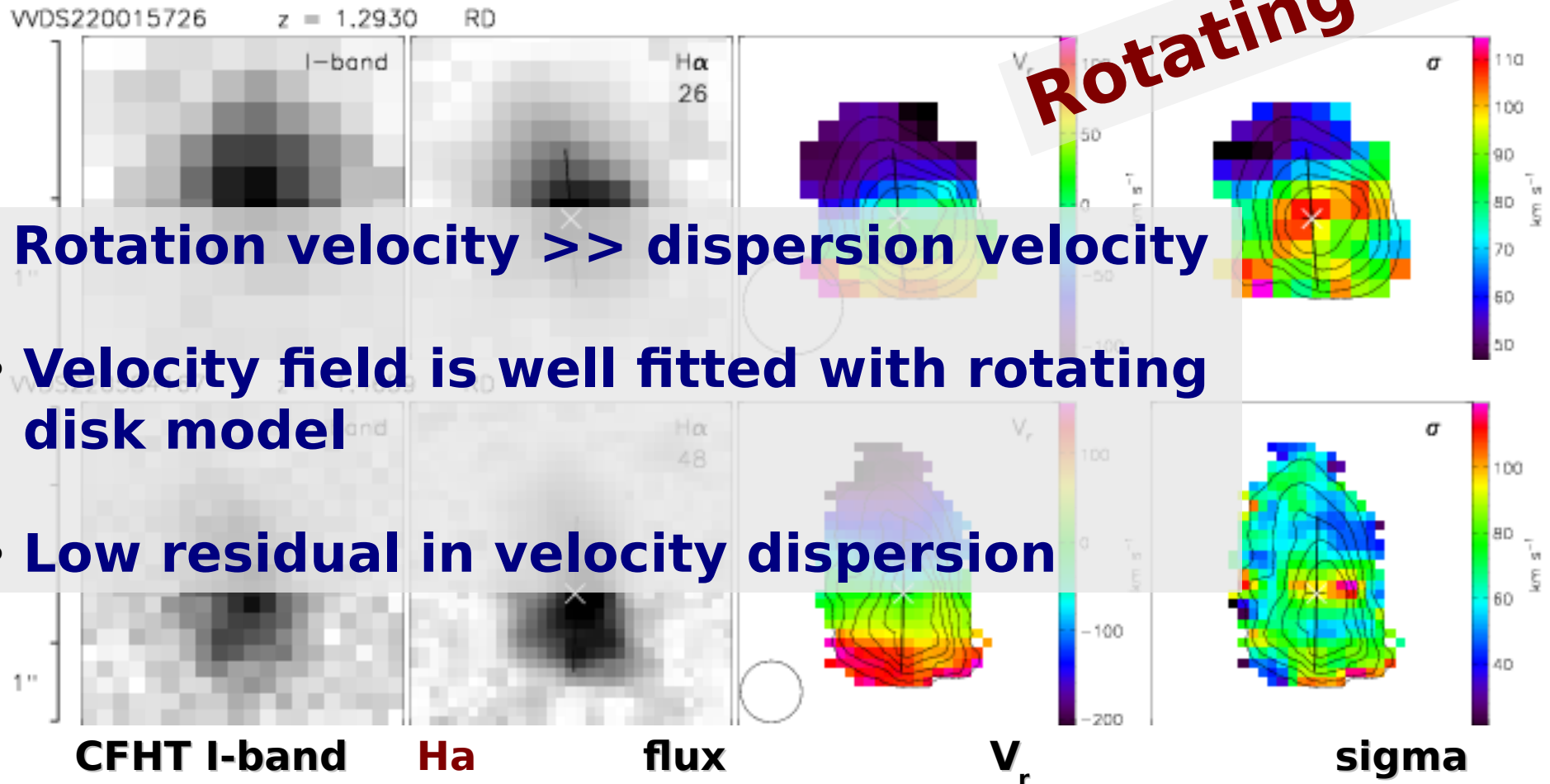
# MASSIV

Mass assembly survey with SINFONI in VVDS

# Mass Assembly Survey with SINFONI in VVDS

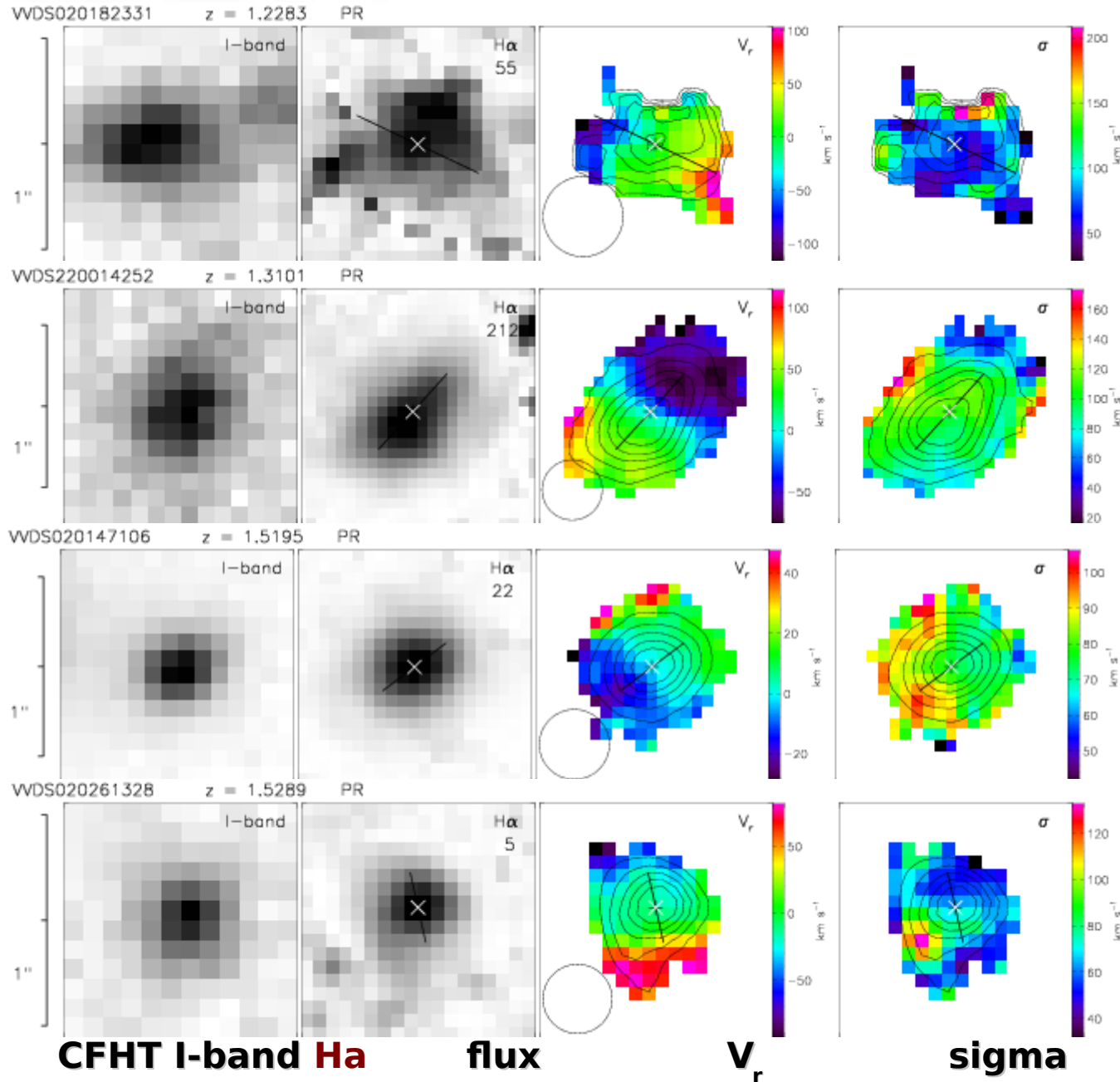


**Rotating disks**

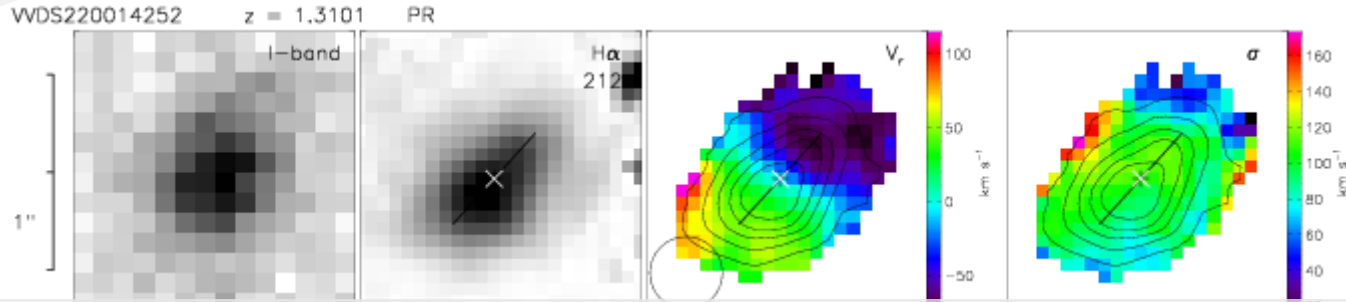
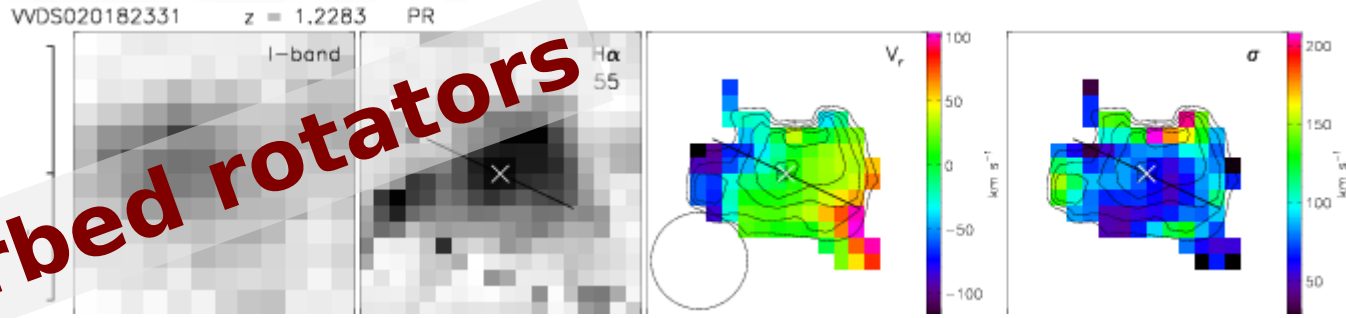


- **Rotation velocity  $\gg$  dispersion velocity**
- **Velocity field is well fitted with rotating disk model**
- **Low residual in velocity dispersion**





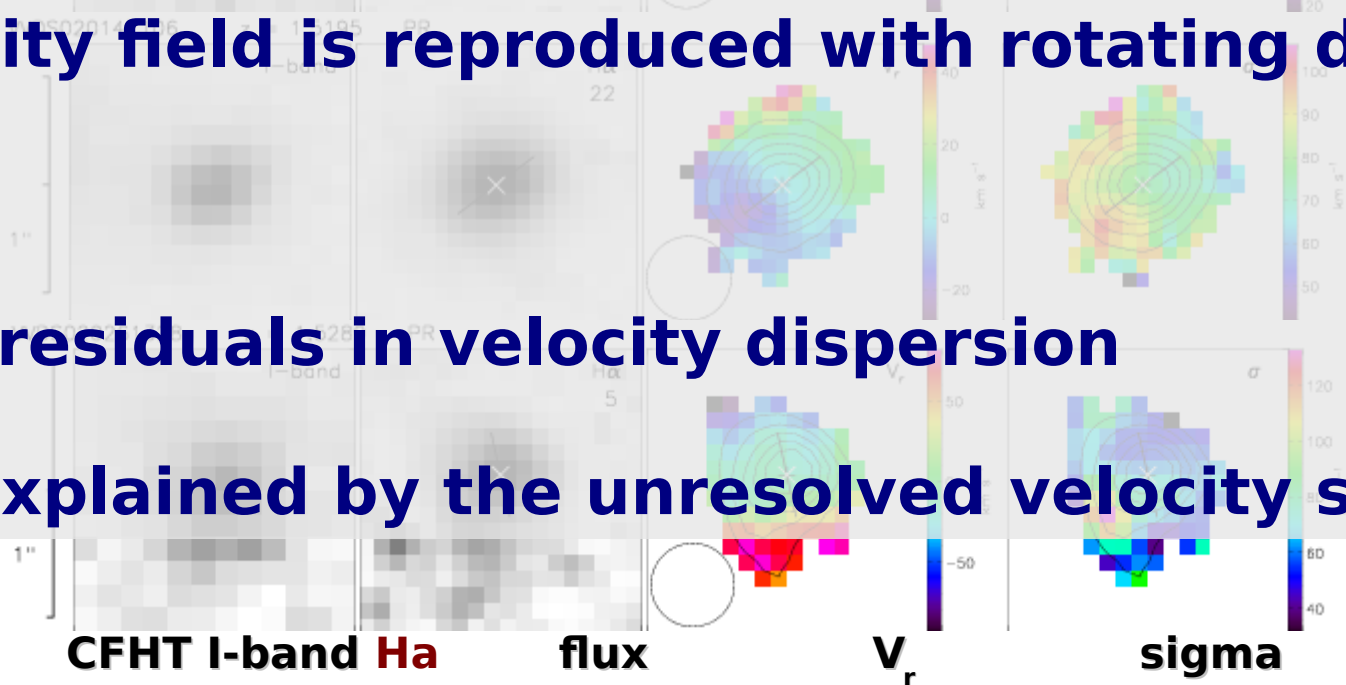
**Perturbed rotators**



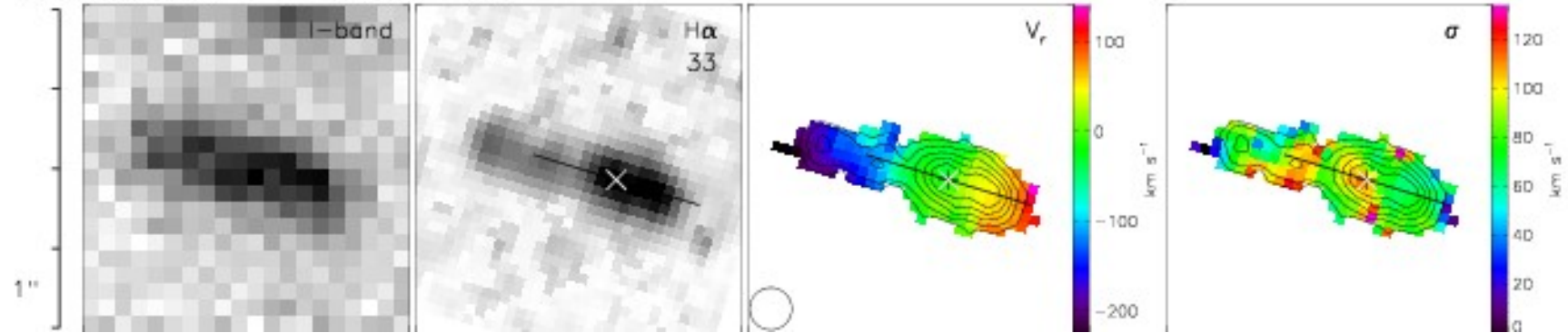
- Velocity field is reproduced with rotating disk model

**BUT**

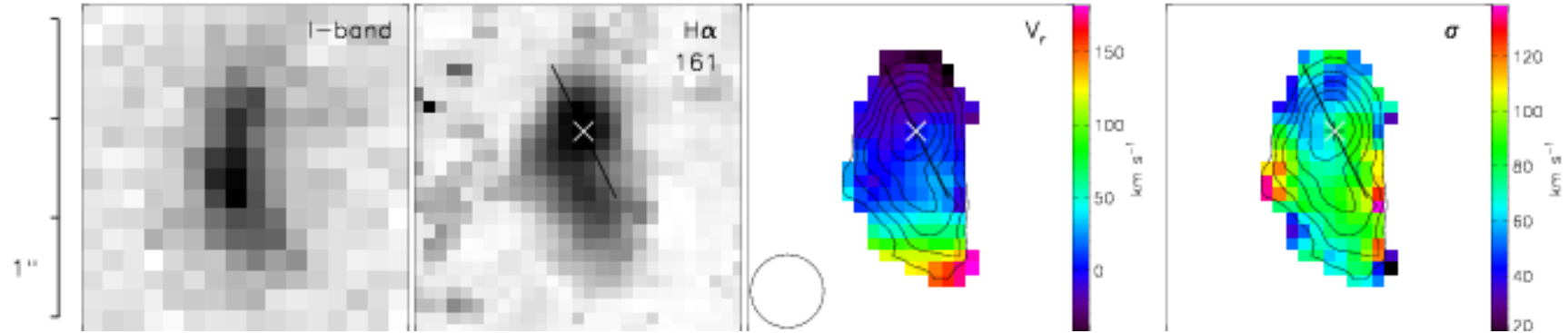
- High residuals in velocity dispersion
- Not explained by the unresolved velocity shear



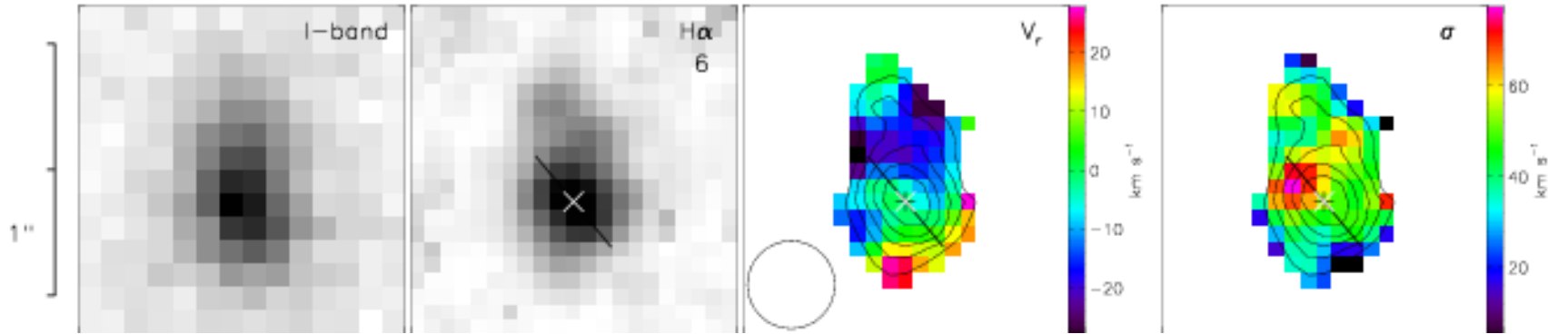
WDS220596913  $z = 1.2662$  MS



WDS220544103  $z = 1.3966$  MS



WDS020116027  $z = 1.5302$  MS



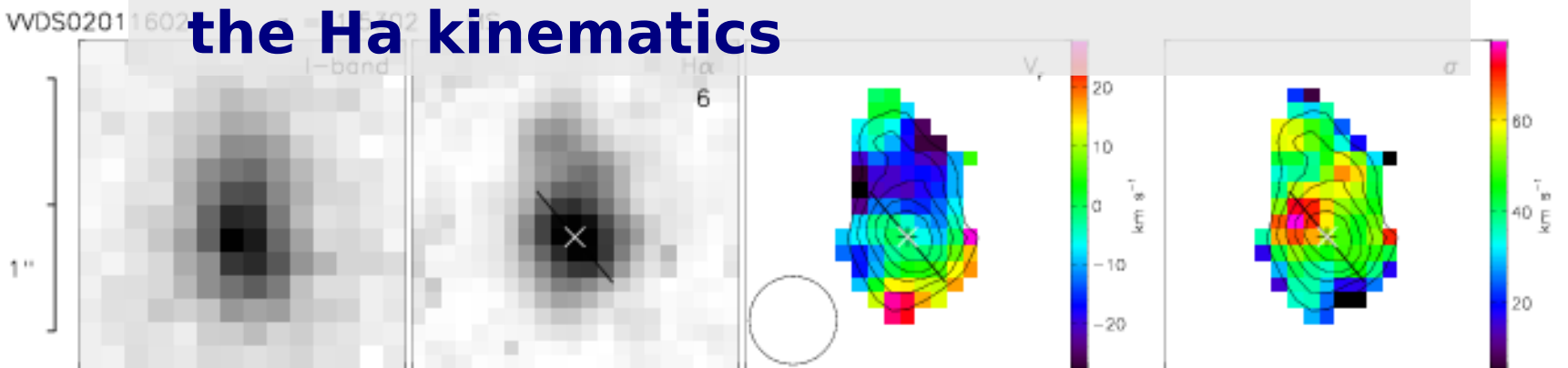
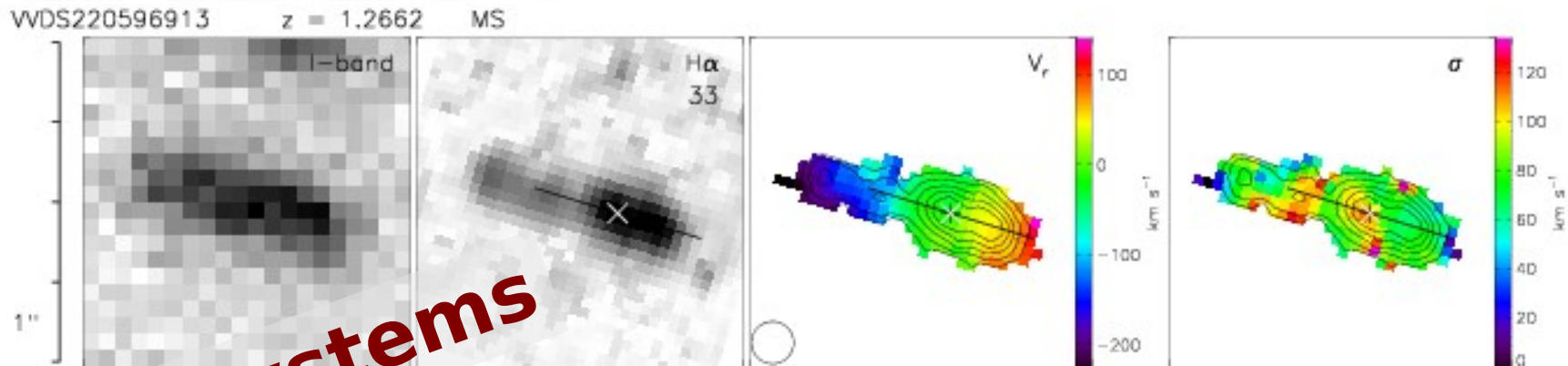
CFHT I-band

Ha

flux

$V_r$

sigma



CFHT I-band Ha flux  $V_r$  sigma

**Merger systems**

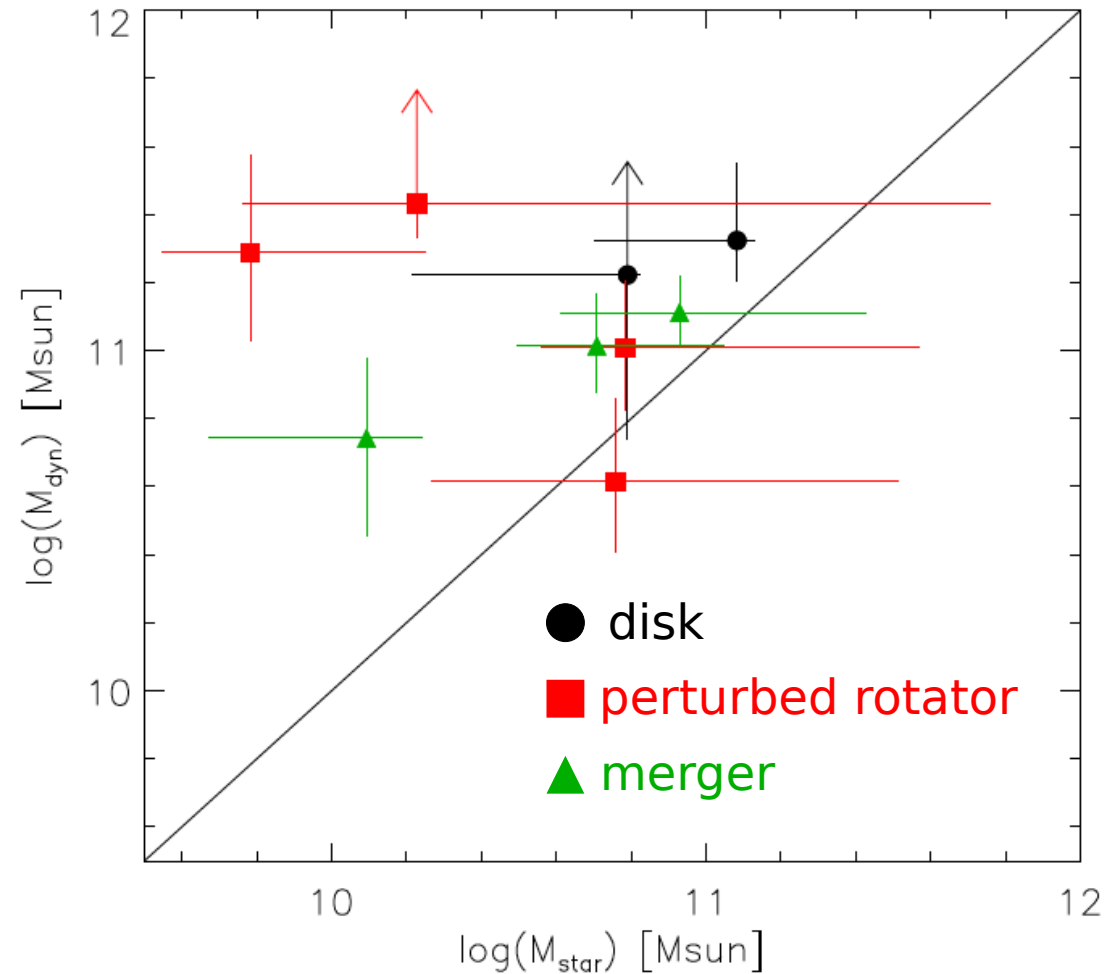
- Several spatially-resolved components
- Rotating disk models do not describe the Ha kinematics

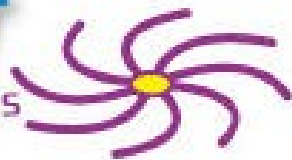


### Dynamical support

$$M_{dyn} = M_{\theta} + M_{\sigma} = \frac{V^2 R}{G} + \frac{\sigma^2 R^3}{G h^2}$$

#### Rotation

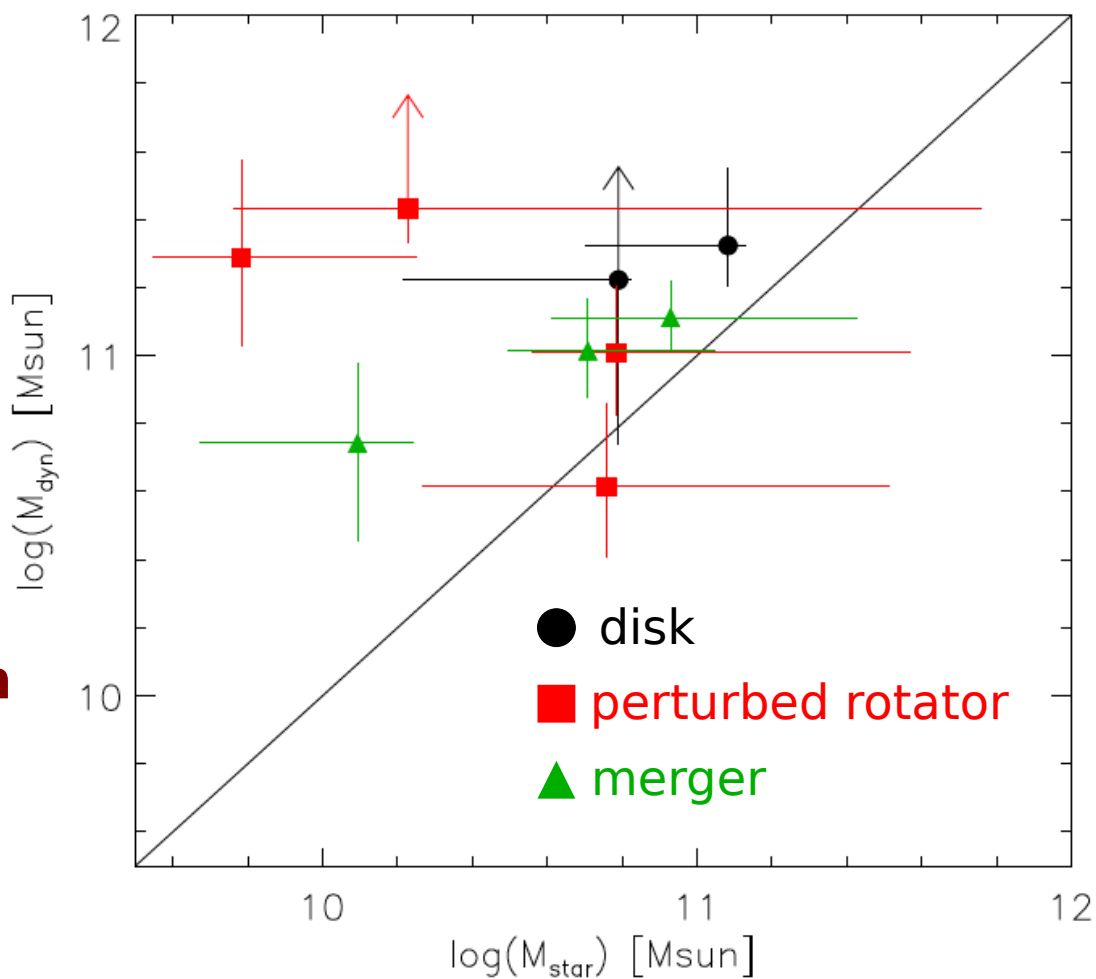




## Dynamical support

$$M_{dyn} = M_{\theta} + M_{\sigma} = \frac{V^2 R}{G} + \frac{\sigma^2 R^3}{G h^2}$$

**Rotation** + **Dispersion**

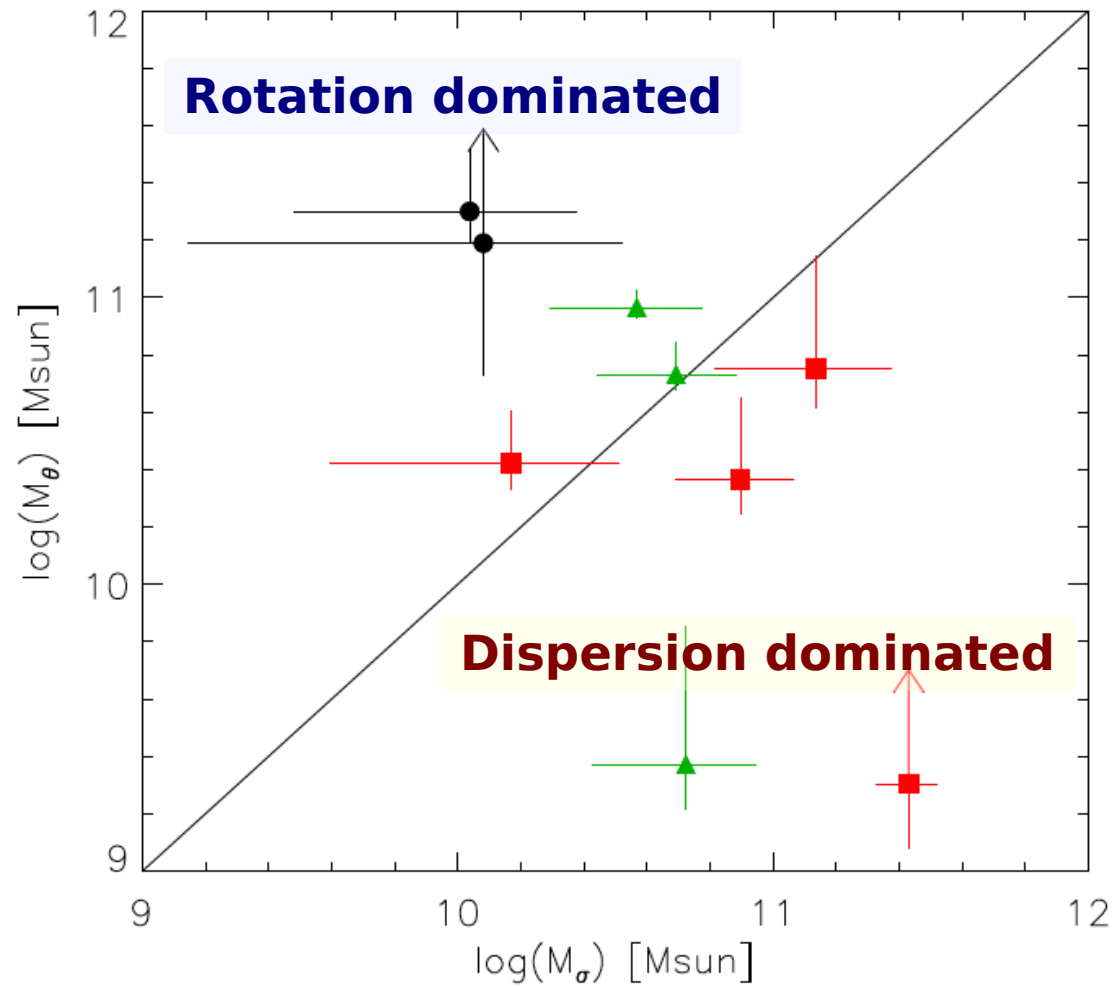




## Dynamical support

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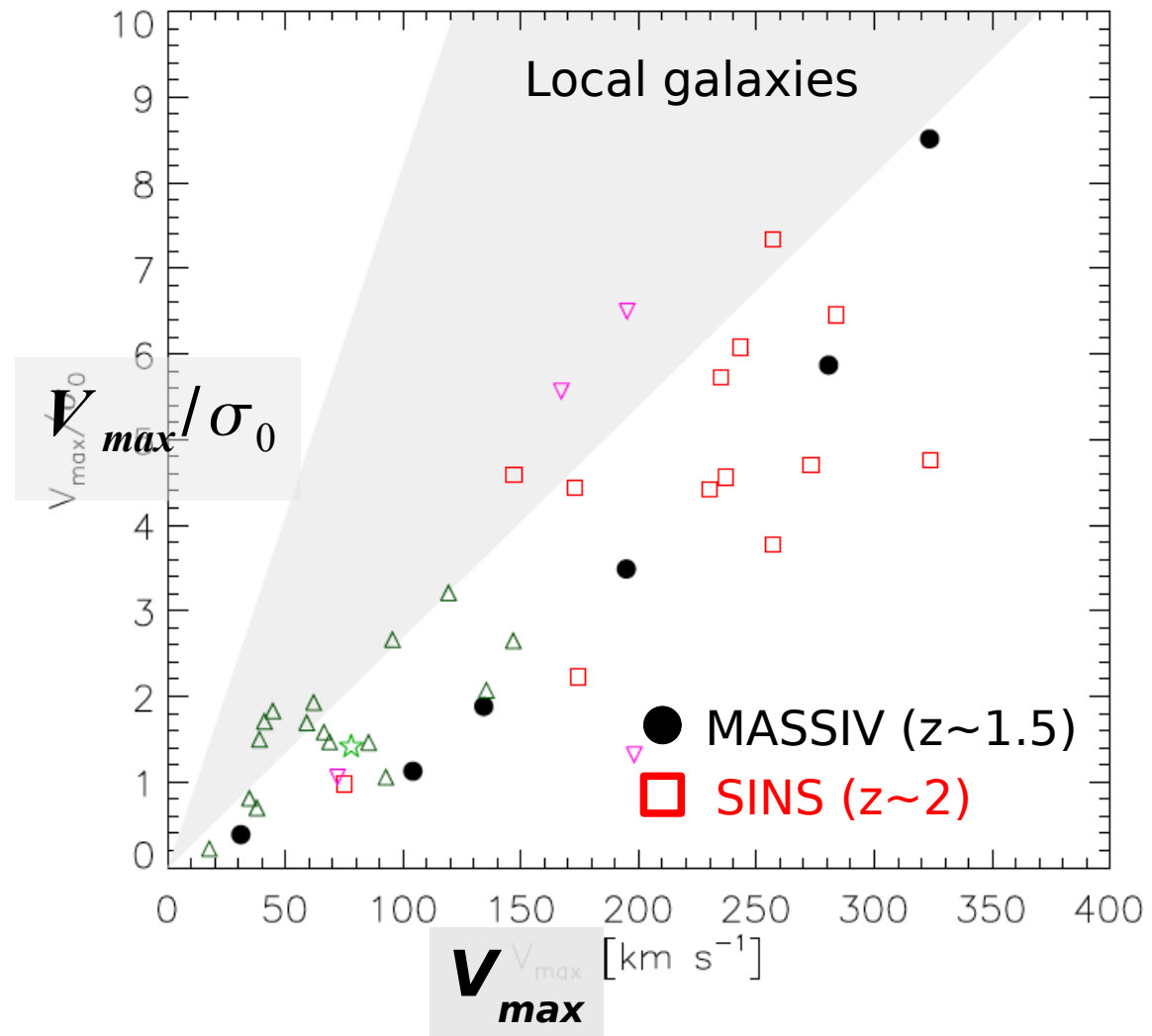
●  $M_{\theta}$  vs.  $M_{\sigma}$

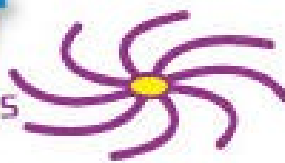


## Dynamical support

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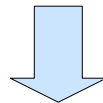
●  $V_{max}/\sigma$  vs.  $V_{max}$





**Preliminary conclusions from first data**

- 1/3 are **major merger** systems
- Two **massive** ( $> 10^{11} M_{\text{sun}}$ ) rotating **disks**
- **High gaseous velocity dispersion** in perturbed rotators

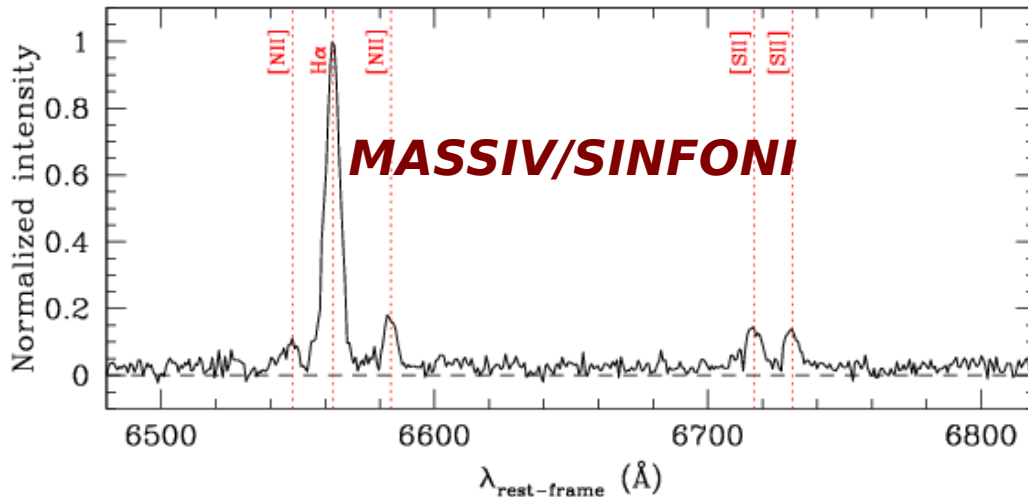
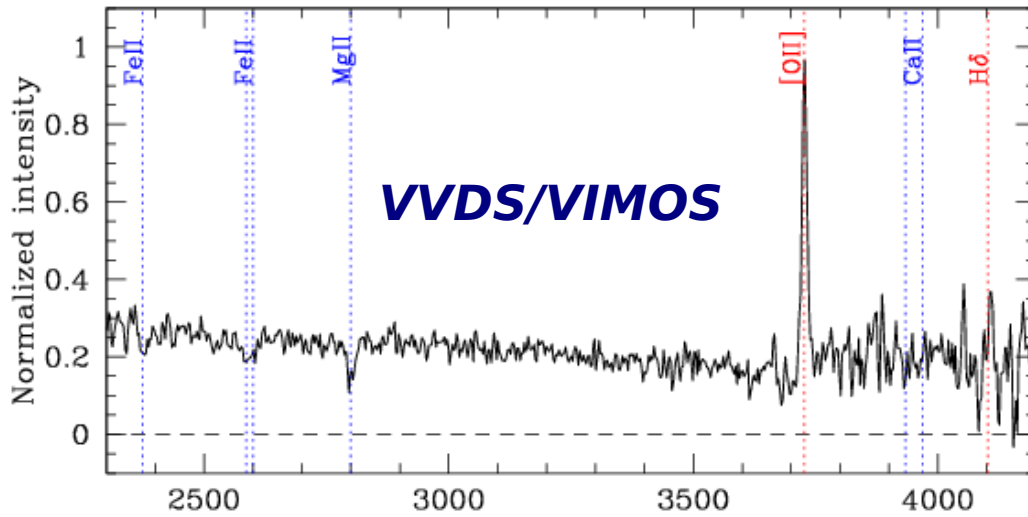


**Massive stable disks are in place @  $z \sim 1.5$**

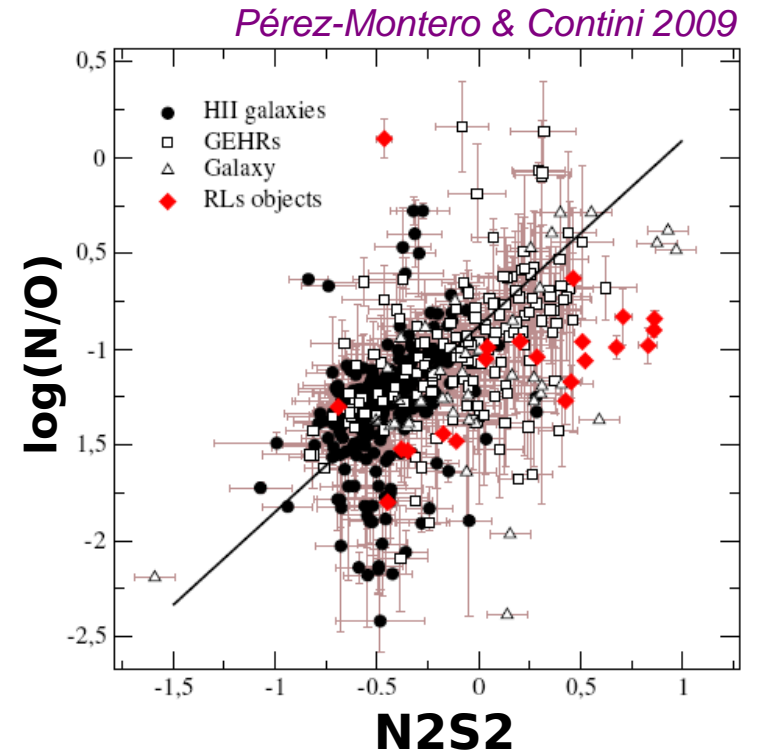
**Major mergers play an important role in mass assembly**

**Difficult to disentangle between minor mergers and continuous gas accretion in disk formation processes**

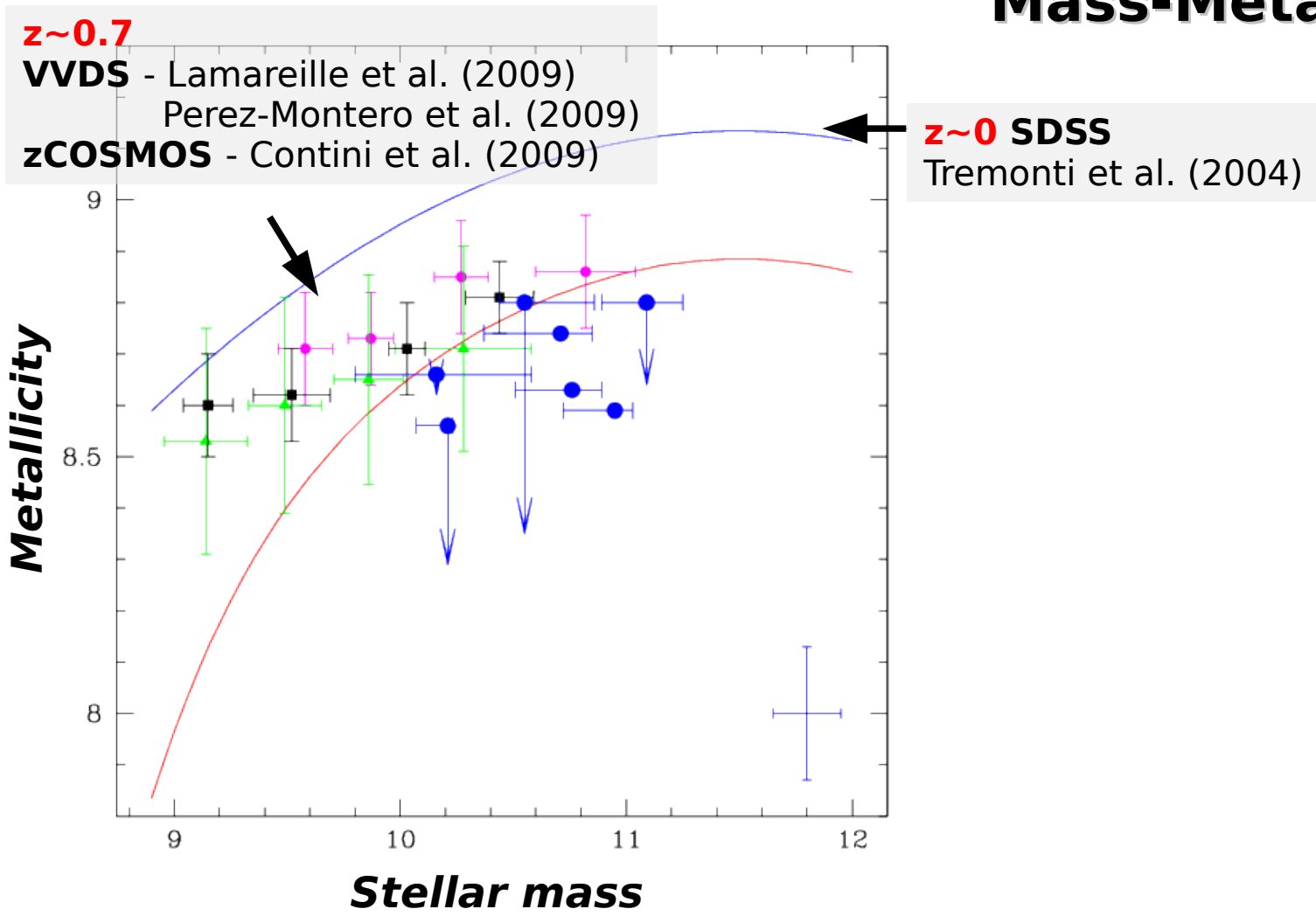
## Metals @ $z \sim 1.5$



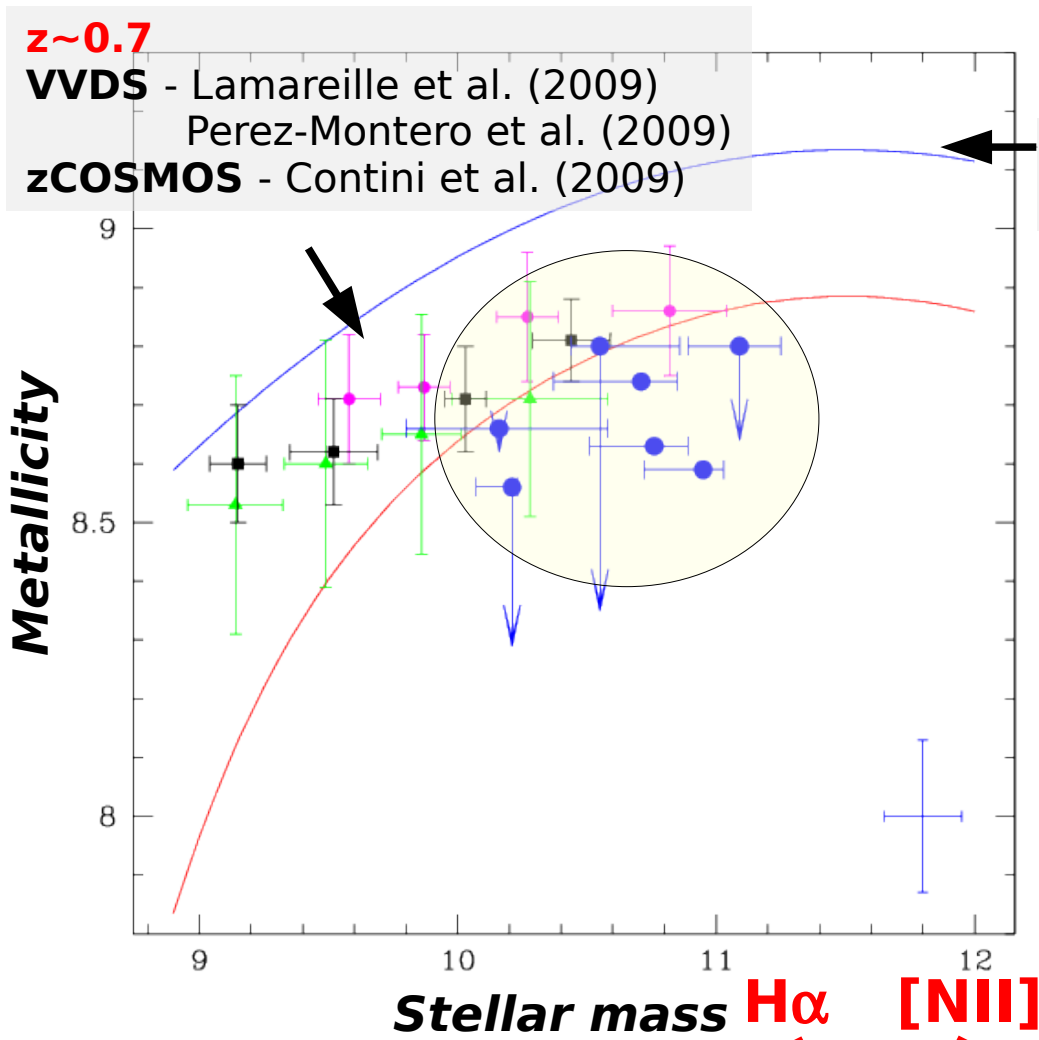
- **O/H from [NII]/H $\alpha$**
- **N/O from [NII]/[SII]**



## Mass-Metallicity relation

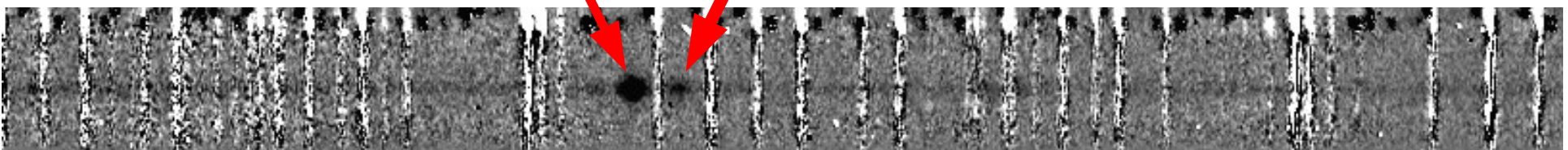


## Mass-Metallicity relation



**MASSIV z ~ 1.2-1.6 galaxies**  
 Queyrel et al. (2009)  
*O/H from [NII]/H $\alpha$  ratio*

- metal-poor (0.2-0.4dex)
- High SSFR
- 1/3 are merging systems
- Lower Z if N/O taken into account

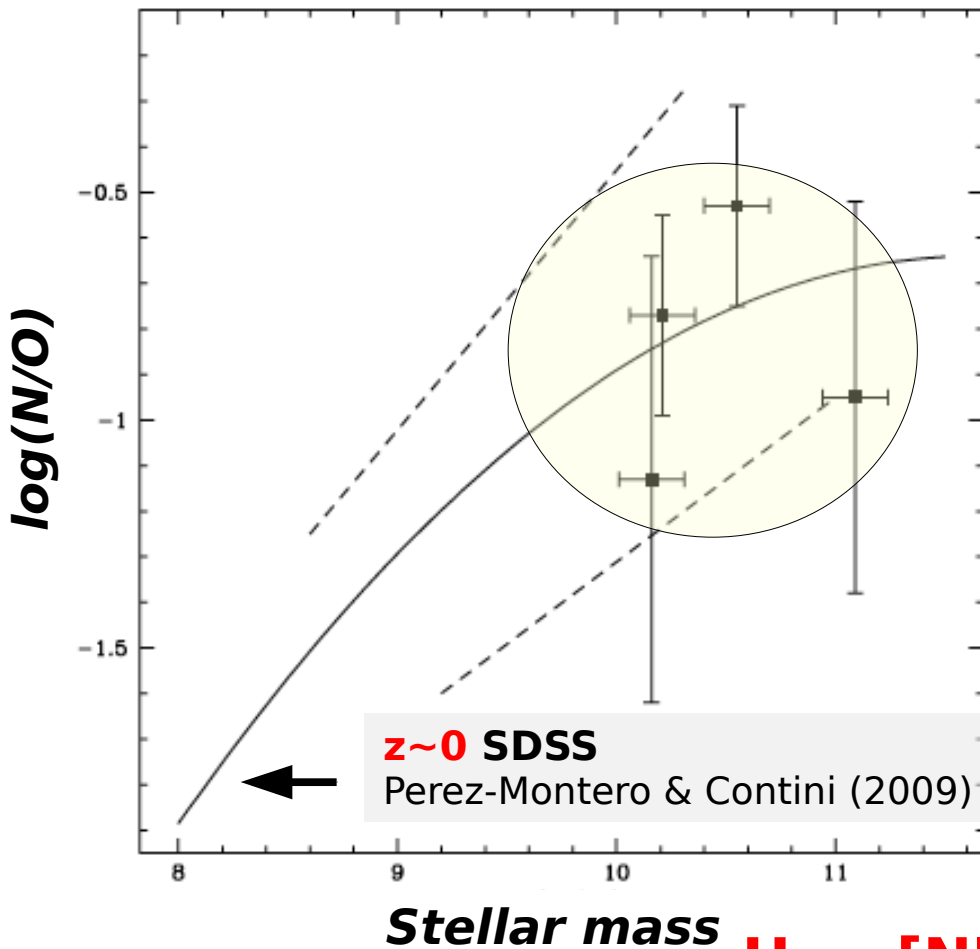


## Nitrogen-to-oxygen abundance ratio

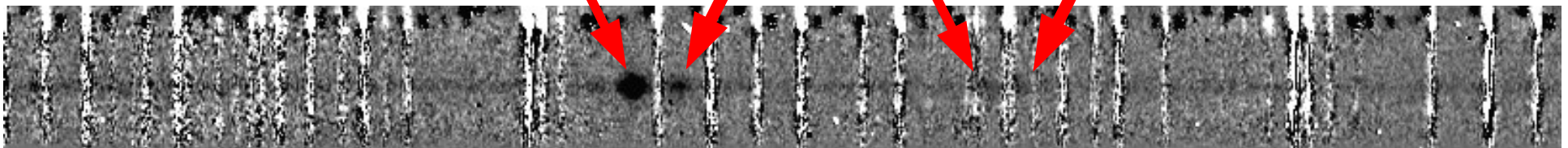
### MASSIV $z \sim 1.2-1.6$ galaxies

Queyrel et al. (2009)  
*N/O from [NII]/[SII] ratio*

- N/O typical of  $z \sim 0$  galaxies
- High uncertainties



$H\alpha$  [NII] [SII] [SII]

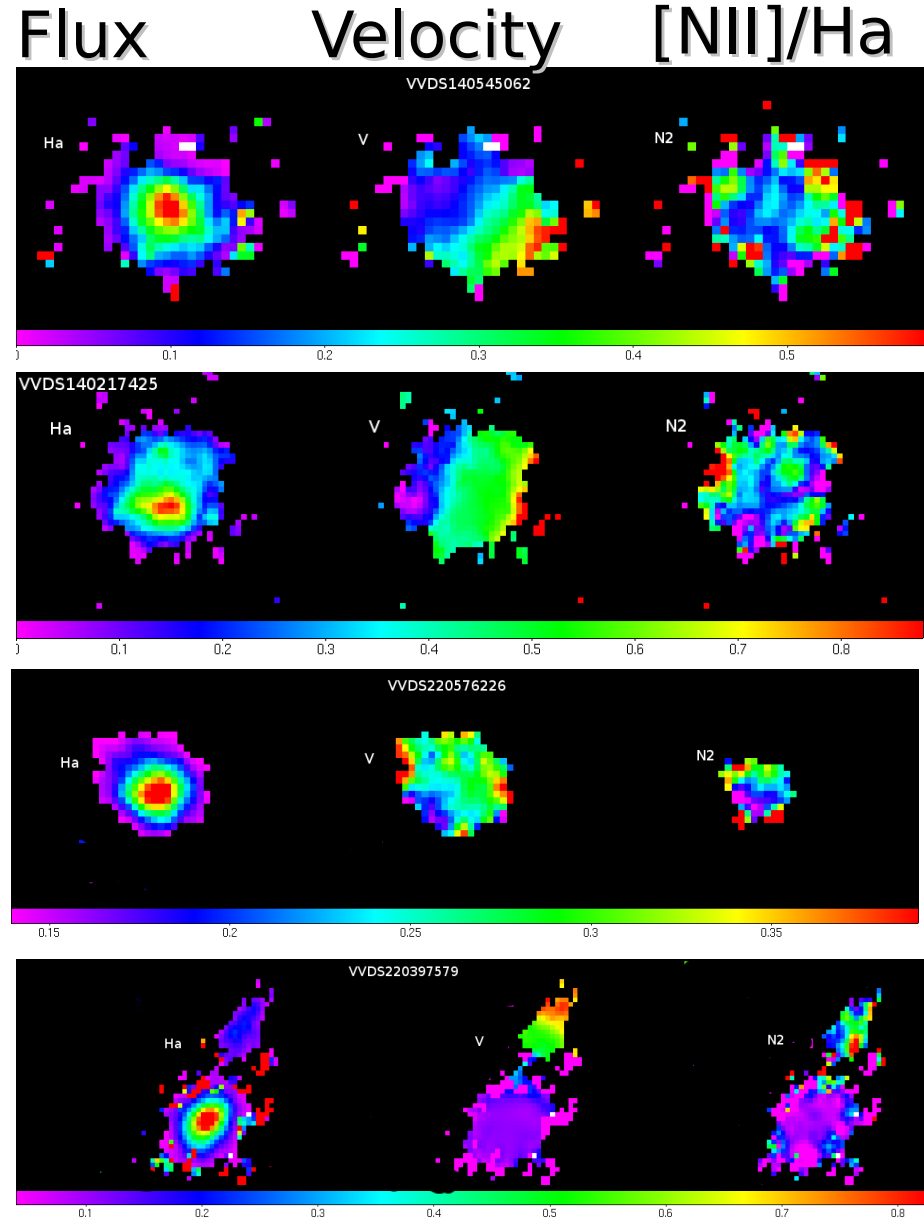
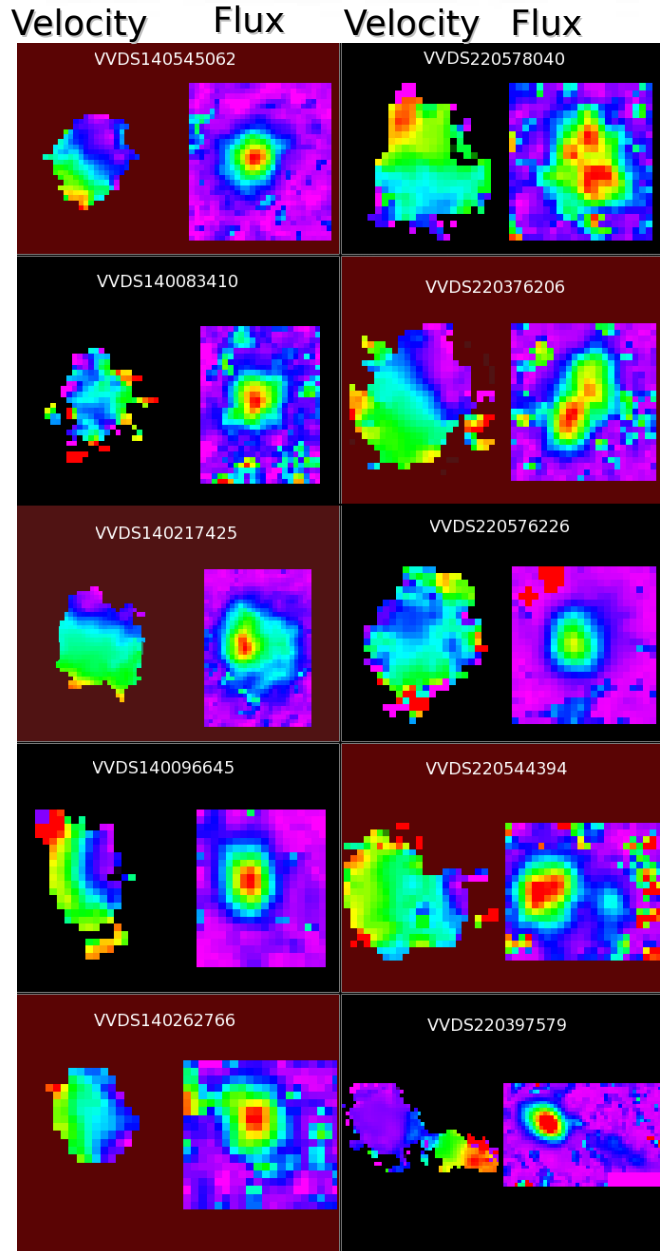


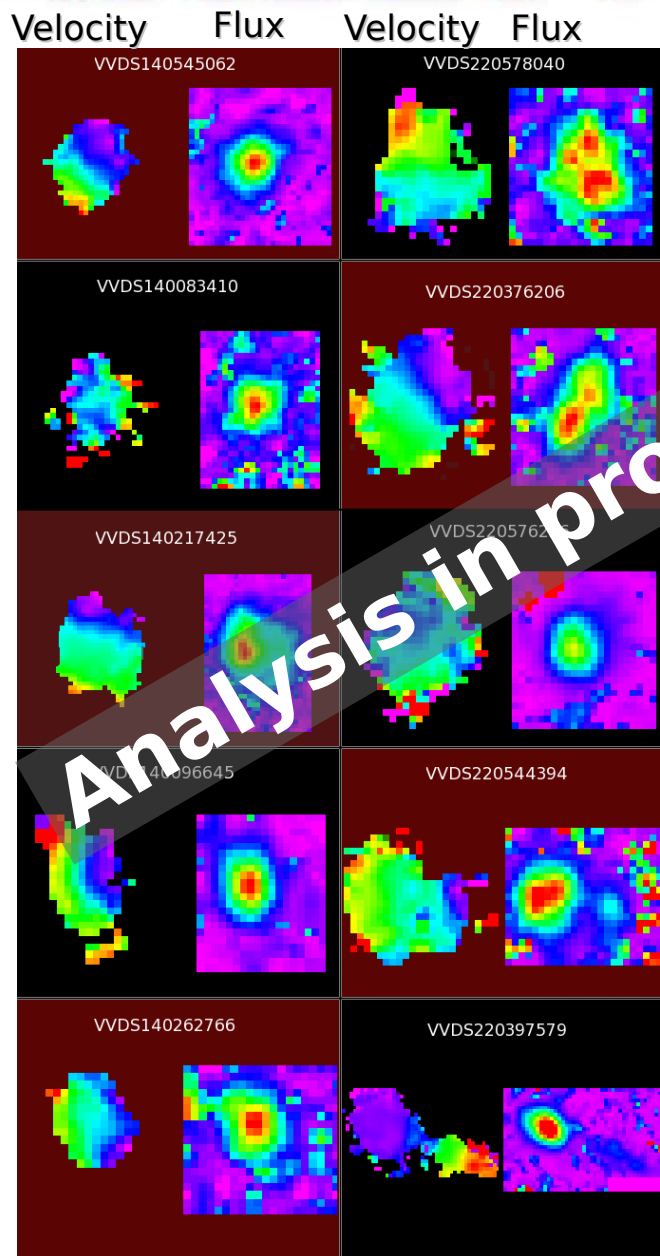


# MASSIV

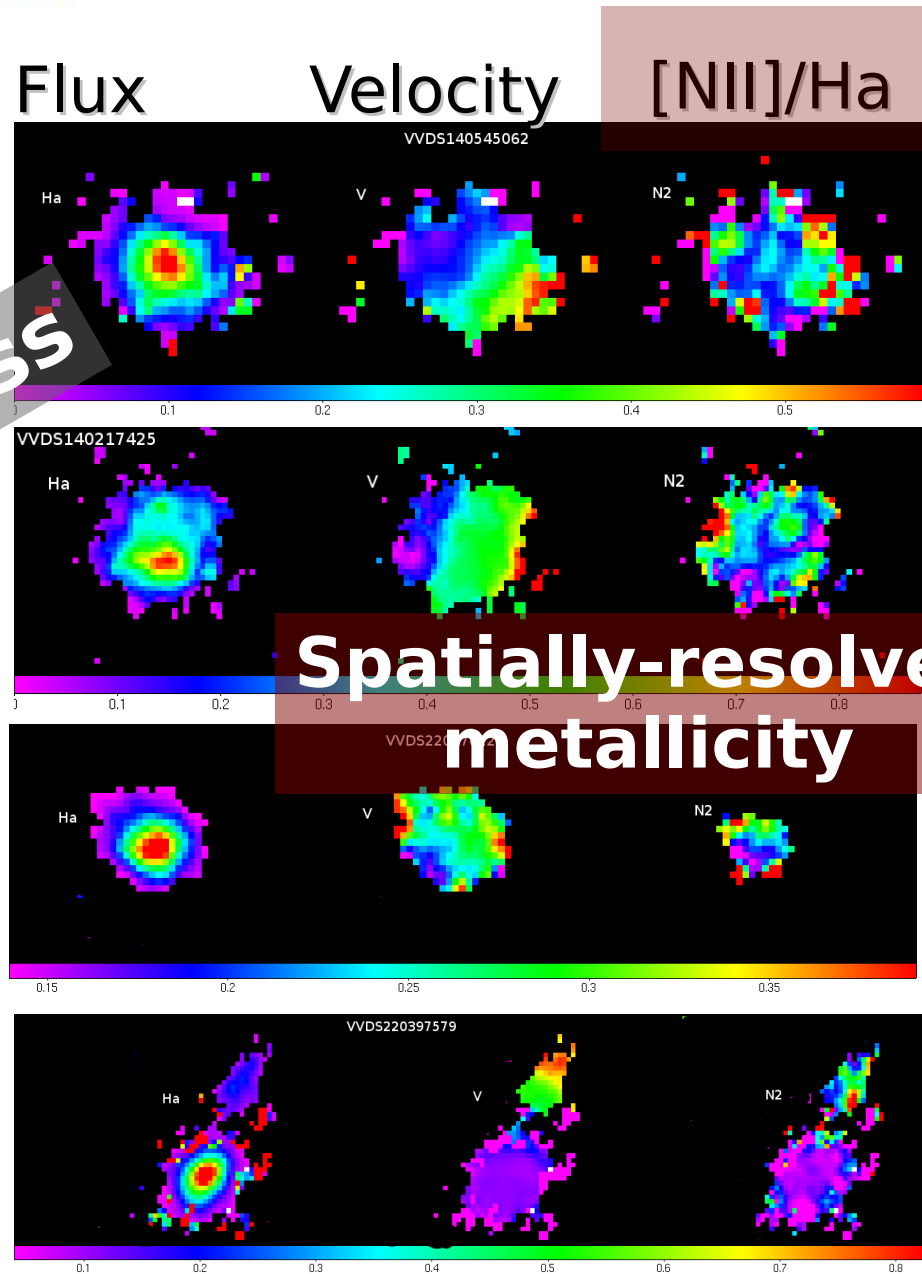
Mass assembly survey with SINFONI in VVDS

# Mass Assembly Survey with SINFONI in VVDS



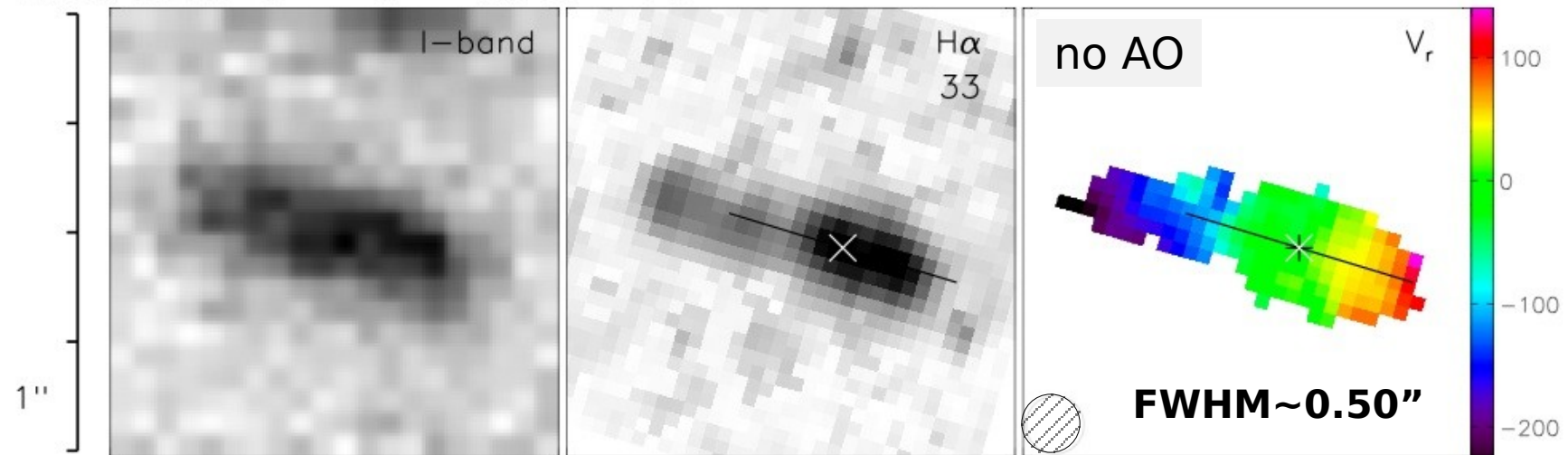


Analysis in progress

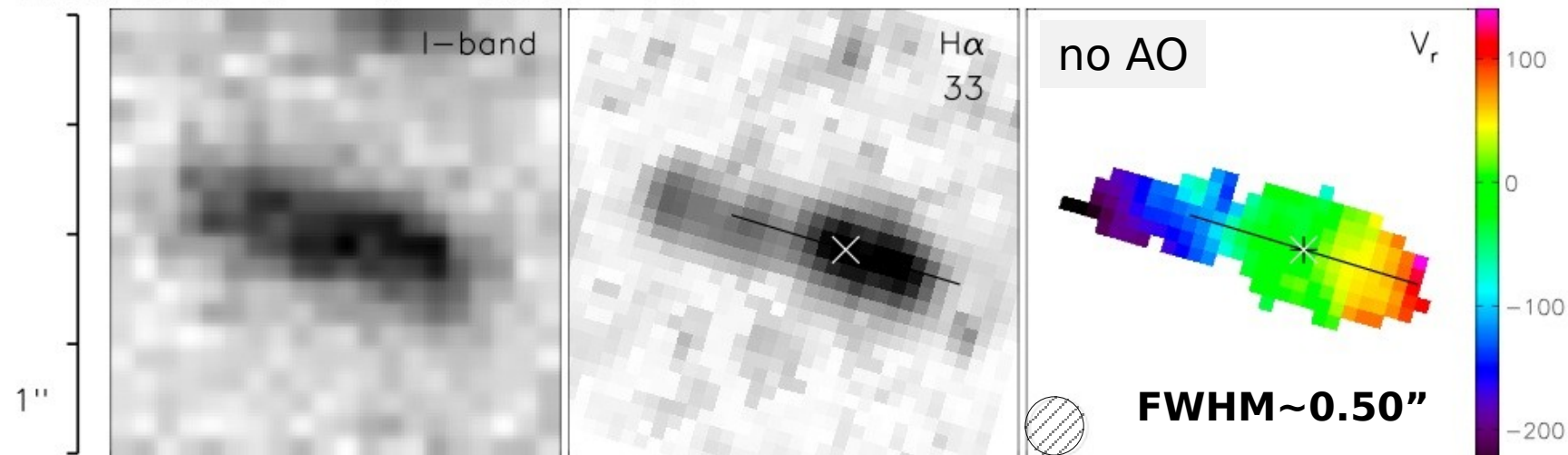


Spatially-resolved  
metallicity

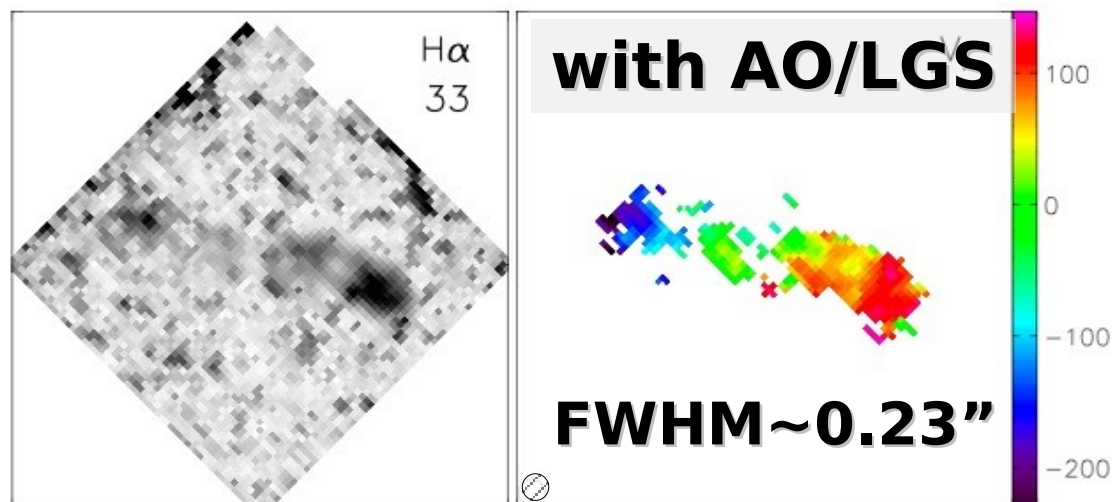
VVDS220596913       $z = 1.2662$       MS



WVDS220596913       $z = 1.2662$       MS



**Resolving  
sub-components**  
with high-spatial  
resolution



**Thank you!**