# Simulations of IFU spectroscopy of galaxies

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# IFU Simulations

- **Science Case C10: The Physics and Mass Assembly of Galaxies out to z~6 (P.I.: P. Rosati)**

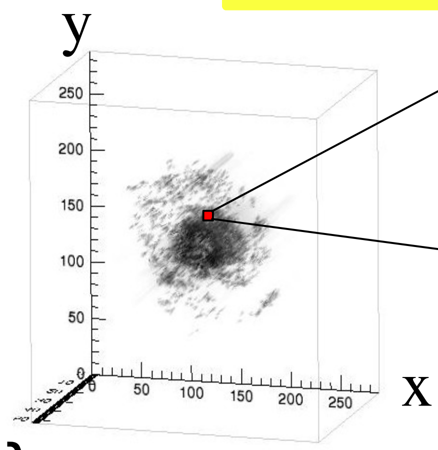
- **Goal is to provide the ultimate test of galaxy formation theories: epoch and physical channels of mass assembly**

- **Mapping of physical and chemical properties (kinematics, SFR, metallicity, etc.) in a sample of ~1000 massive galaxies at $2<z<5.6$ in the range $0.1<M_{star}<5\times10^{11}$ M**

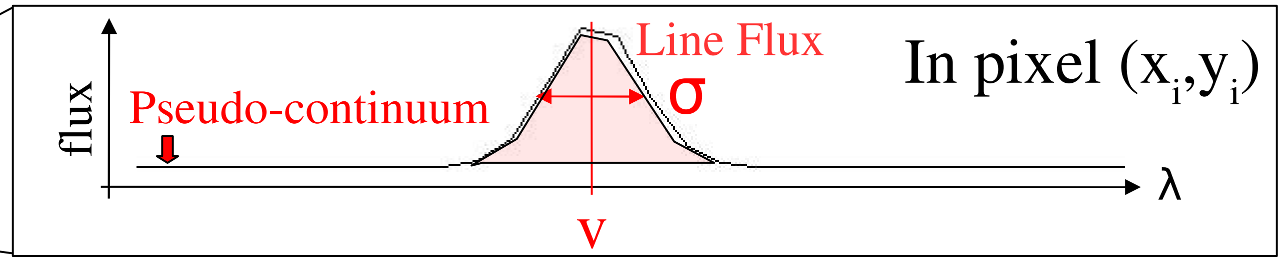
- **Needs Multi-Object Integral Field Spectroscopy (EAGLE)**

- **Most important targets: emission line galaxies → DRM**

# *Simulation Pipeline*



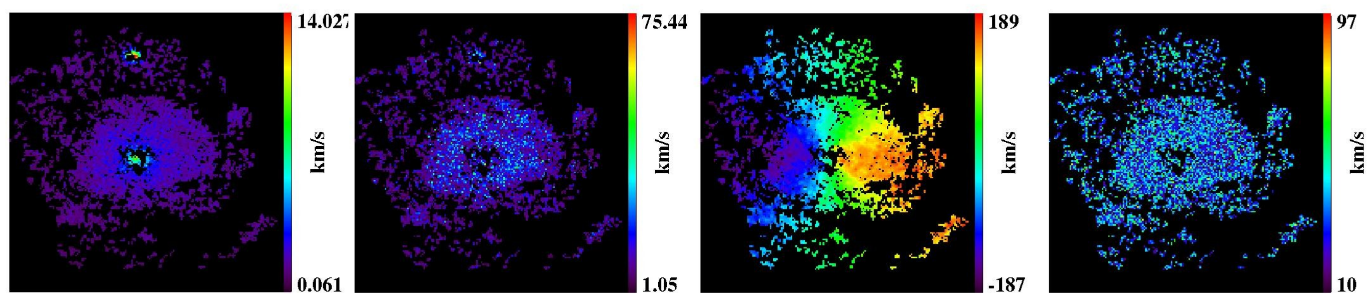

Datacube




Datacube Analysis

"Reverse Analysis" assuming Gaussians
⇒ Datacube simulation

Continuum map | Emission line Flux map | Velocity field | Vel. Dispersion map




<u>Requirement:</u>
High resolution Maps

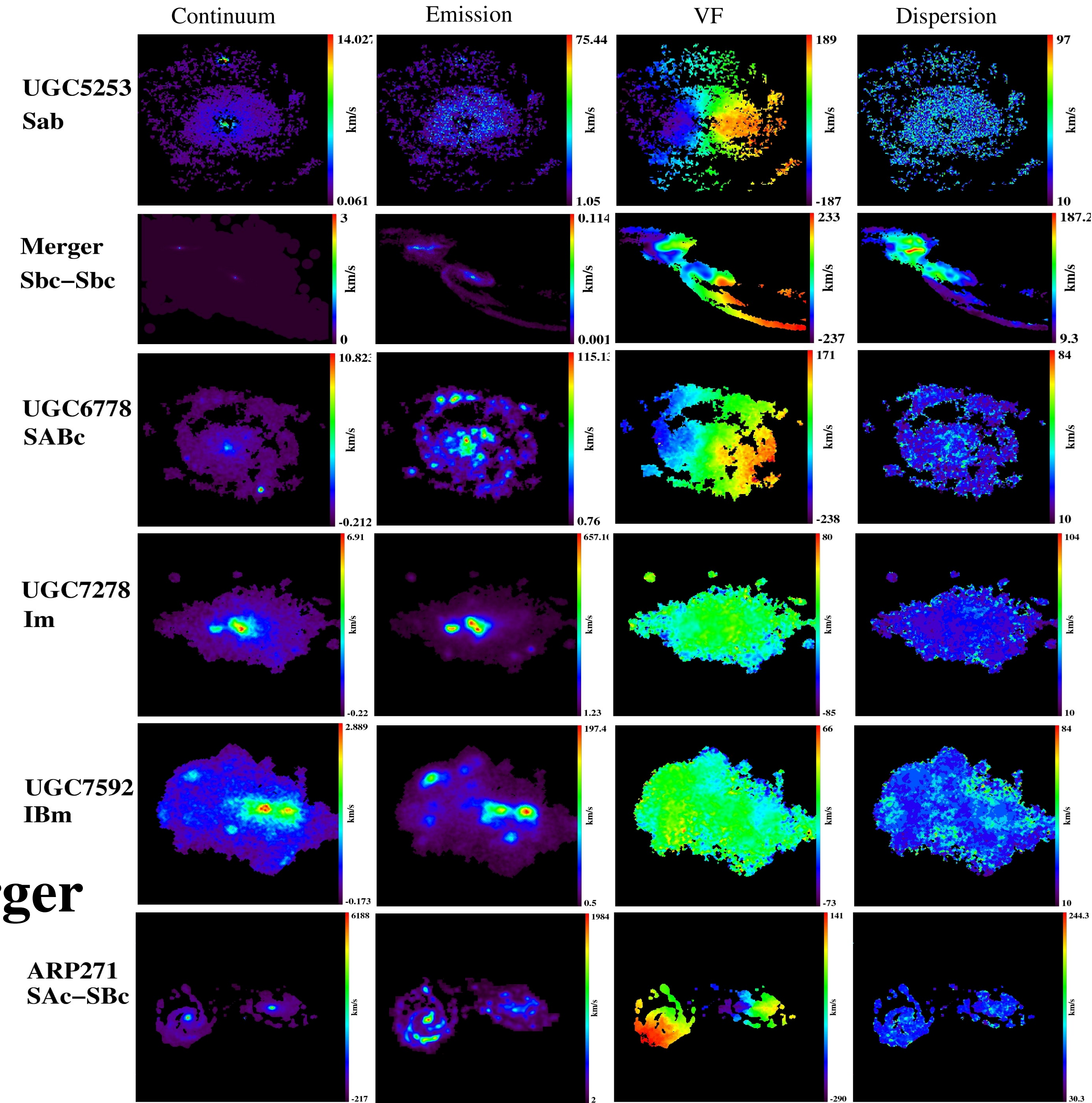
# Templates

- Local obs:

UGC5253
UGC6778
UGC7278
UGC7592
Amram+02
ARP271
Fuentes+04

- Hydro-sims:

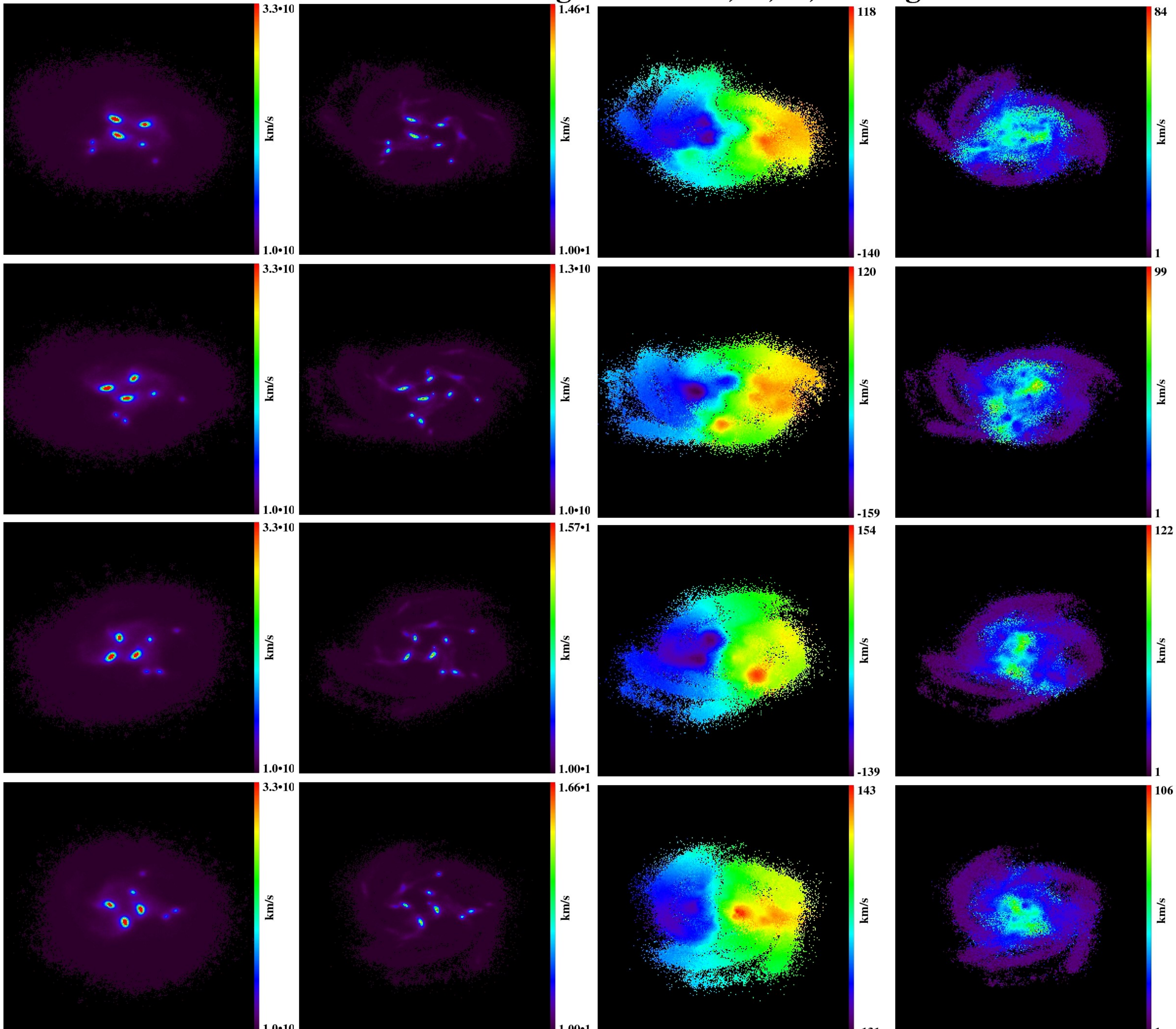
Sbc major merger
Cox+06



# CLUMPY inc=50 deg azimuth=0,45,90,135 deg

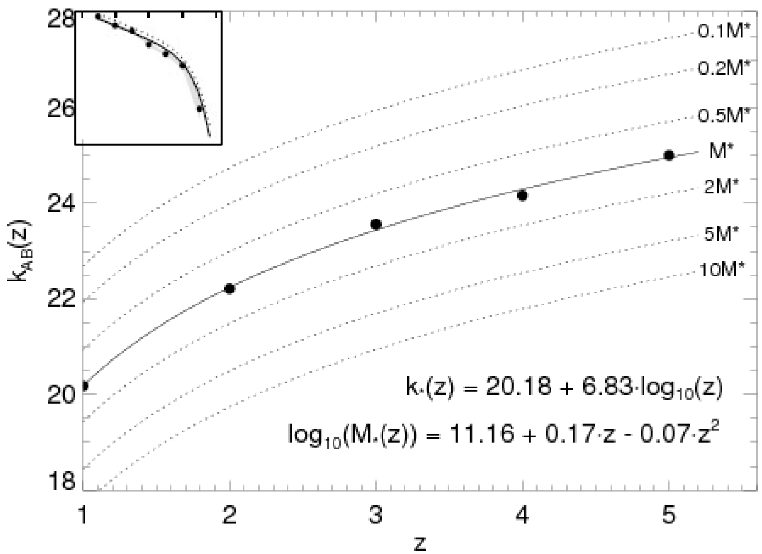
Bournaud et al. 2007

Hydro-simulations

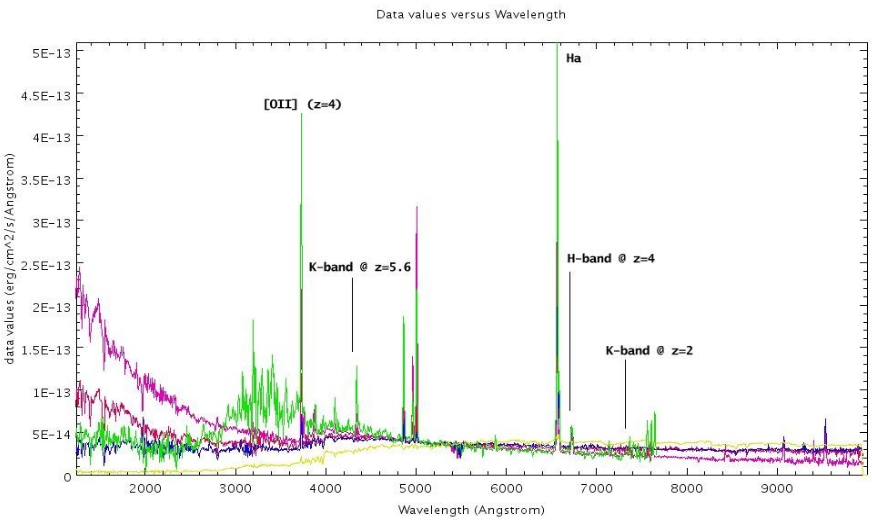


# Rescaling: flux and velocity

- z & stellar mass ⇒ K-band mag ⇒ pseudo-continuum flux




GSMFs from MUSIC survey (S. Toft)



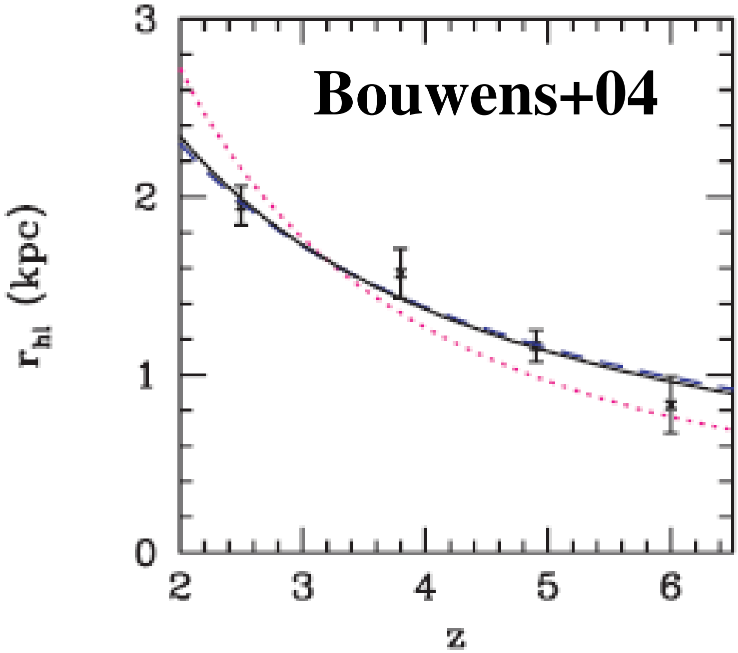

- $EW_0$: rest-frame equivalent width of the emission line, which defines its flux relatively to the continuum

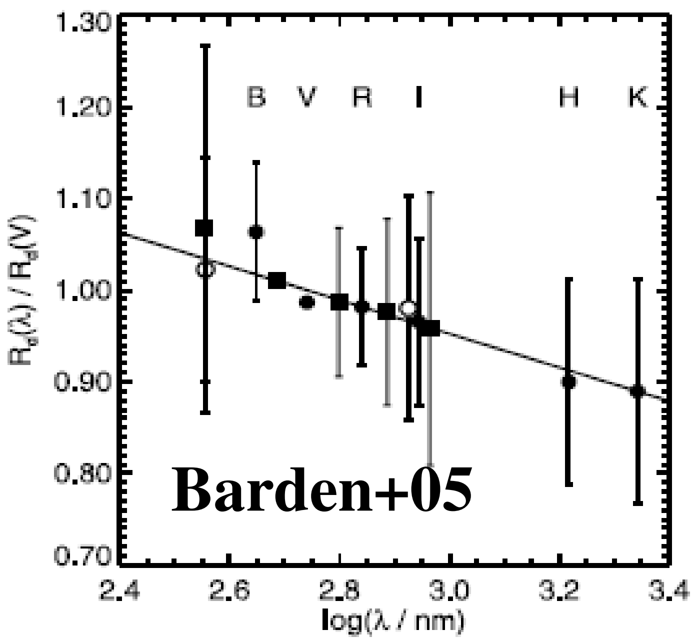
- Rotation Velocity: VF gradient rescaled using the local Tully-Fisher relation assuming no evolution with z

# *Rescaling: size*

✓ **Size vs. z : Bouwens+04 Ferguson+04 Dahlen+07**

**$R_{half}$ (M*) vs. z in the UV: needs k-correction**

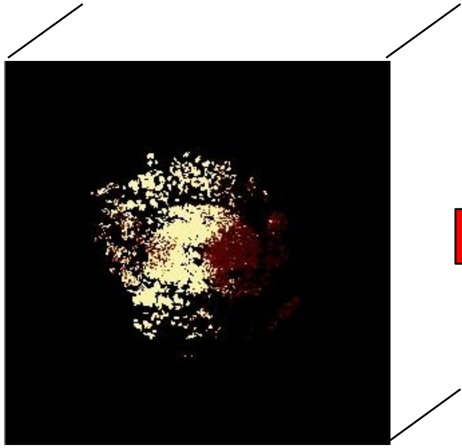



✓ **Size vs. Stellar mass:**

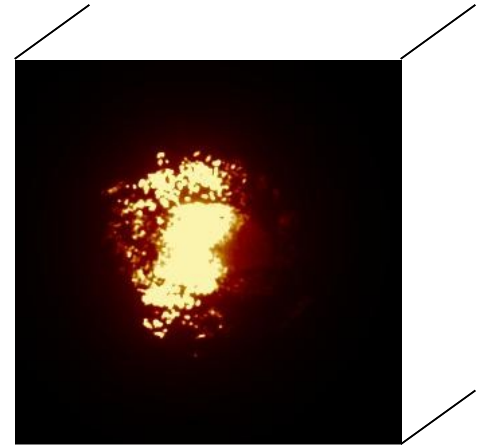
**Courteau+07: $R_{half}(K) \propto L_K^{0.35}$ => $R_{half} \propto M_{stellar}^{0.35}$**

# Simulation pipeline



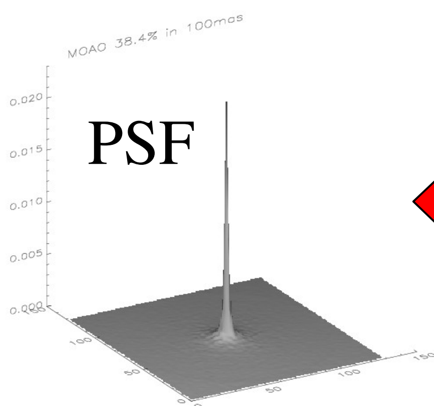
Datacube
- ✓ High resolution
- ✓ High sampling

⊗



Datacube
- ✓ Degraded resolution
- ✓ High sampling

"Rescaled" local data or simulations




AO mode

Telescope pupil

# AO Modes

- **AO modes:**

**MOAO – GLAO – MCAO – LTAO**

**=> From Analytical code: MOAO & MCAO**
**(ONERA; B. Neichel & T. Fusco)** **No Speckle noise - No central obscuration**

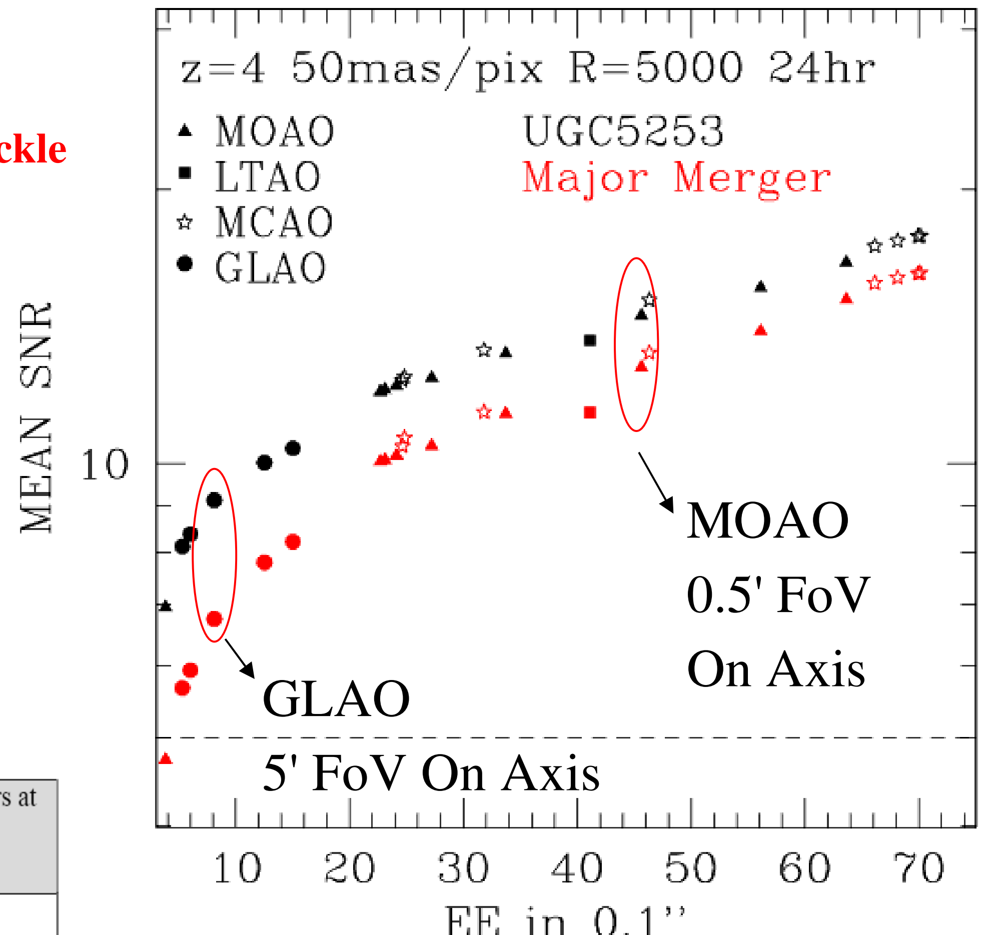
**=> From E2E code: GLAO & LTAO**
**(ESO; M. Le Louarn)**

- **Turbulence model: seeing=0.8'' same turbulence profile & L0**
  **same DM pitch (~ 0.5 m)**

- **Multiplex => MOAO or GLAO**

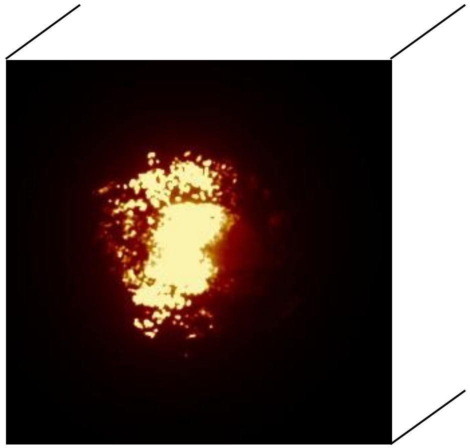
Down to $I_{AB}$=25 :

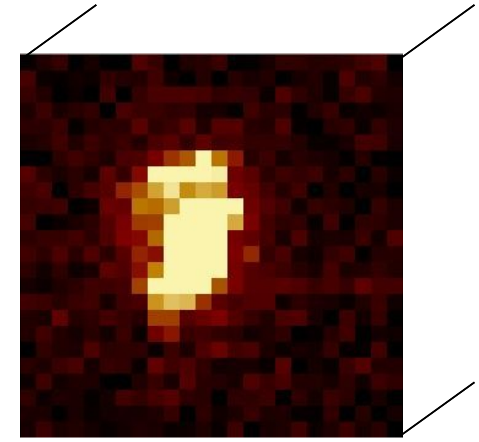
| FoV size (arcmin x arcmin) | Expected numbers at 1.4< z < 2.5 | Expected numbers at 2.7< z < 3.4 | Expected numbers at 3.5 < z < 4.5 | Expected numbers at 4.8 < z < 5.8 |
|---|---|---|---|---|
| 0.5 x 0.5 | 2.25 | 0.45 | 0.2 | ~0.01 |
| 1 x 1 | 9 | 1.8 | 0.8 | ~0.1 |
| 5 x 5 (JWST) | 225 | 45 | 20 | ~1 |
| 10 x 10 | 900 | 180 | 80 | ~6 |




LTAO FoV=45'' on axis
MCAO Fov=0.5' or 5', Dir=0,0.5,2,2.5' 3DMs
GLAO FoV=1,2,5,10,15' on axis
MOAO FoV=0,0.25,0.5,1,2,3,4,5' on axis

# *Simulation pipeline*





Datacube

✓ Degraded resolution

✓ High sampling

« IFU data »

✓ Degraded resolution

✓ Rebinned pixels

Telescope + IFS Models : transmission, spectral & spatial resolutions

Detector Model : RON, dark, CTE (optical)

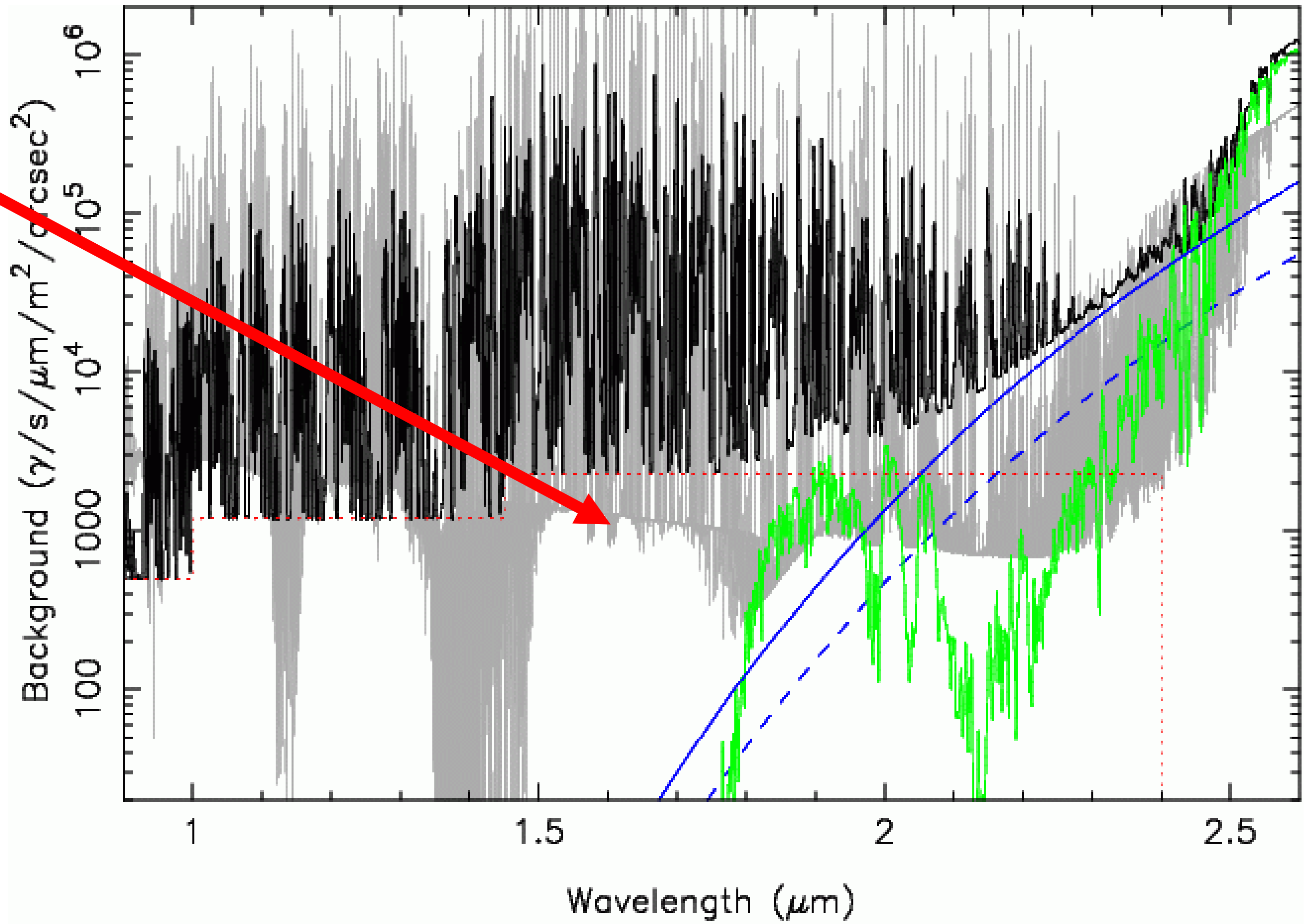
Sky Model : continuum emission + OH lines + atm. transmission

Thermal backgrounds & Photon noise

# Sky Model

Mauna Kea Model:

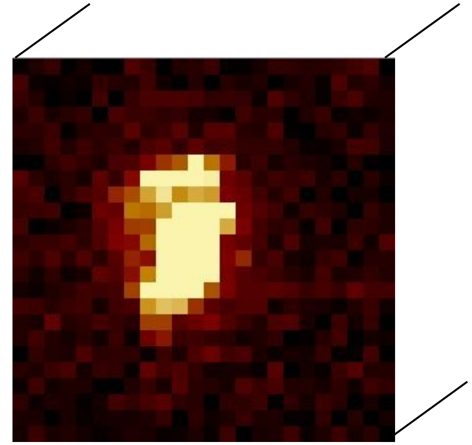
- fainter than Paranal
- higher R
- Includes moonlight, zodial emission, atm. thermal emission




+ Atmospheric transmission curve from Paranal

# *Analysis pipeline*

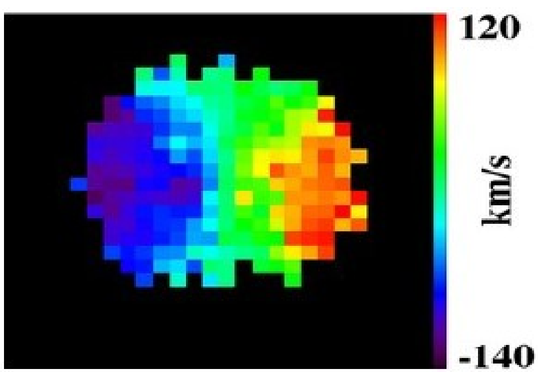
Spatial-Mean SNR
over the galaxy
(in the emission line)



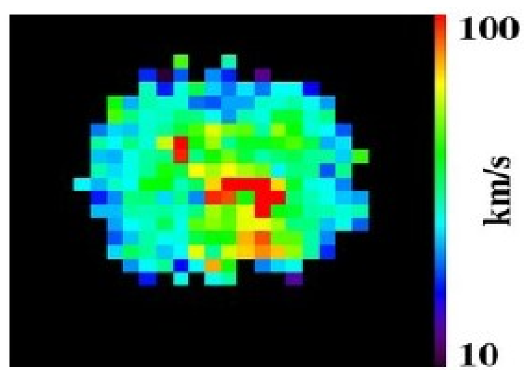
« IFU data »

*Automatic pipeline (line fitting)*

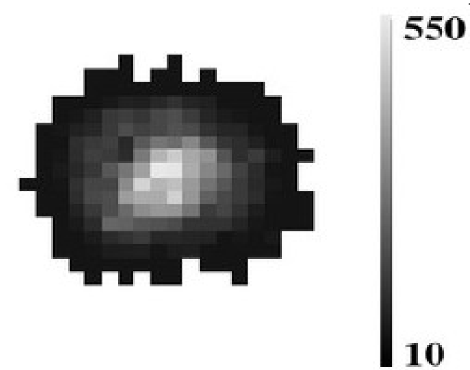
V.F.




σ map

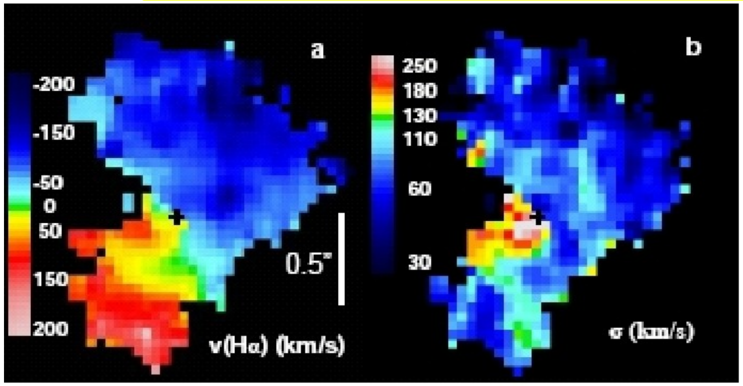



Emission line flux map



# Simulating Sinfoni observations of a massive galaxy at z=2.34

(real life validation of simulations)

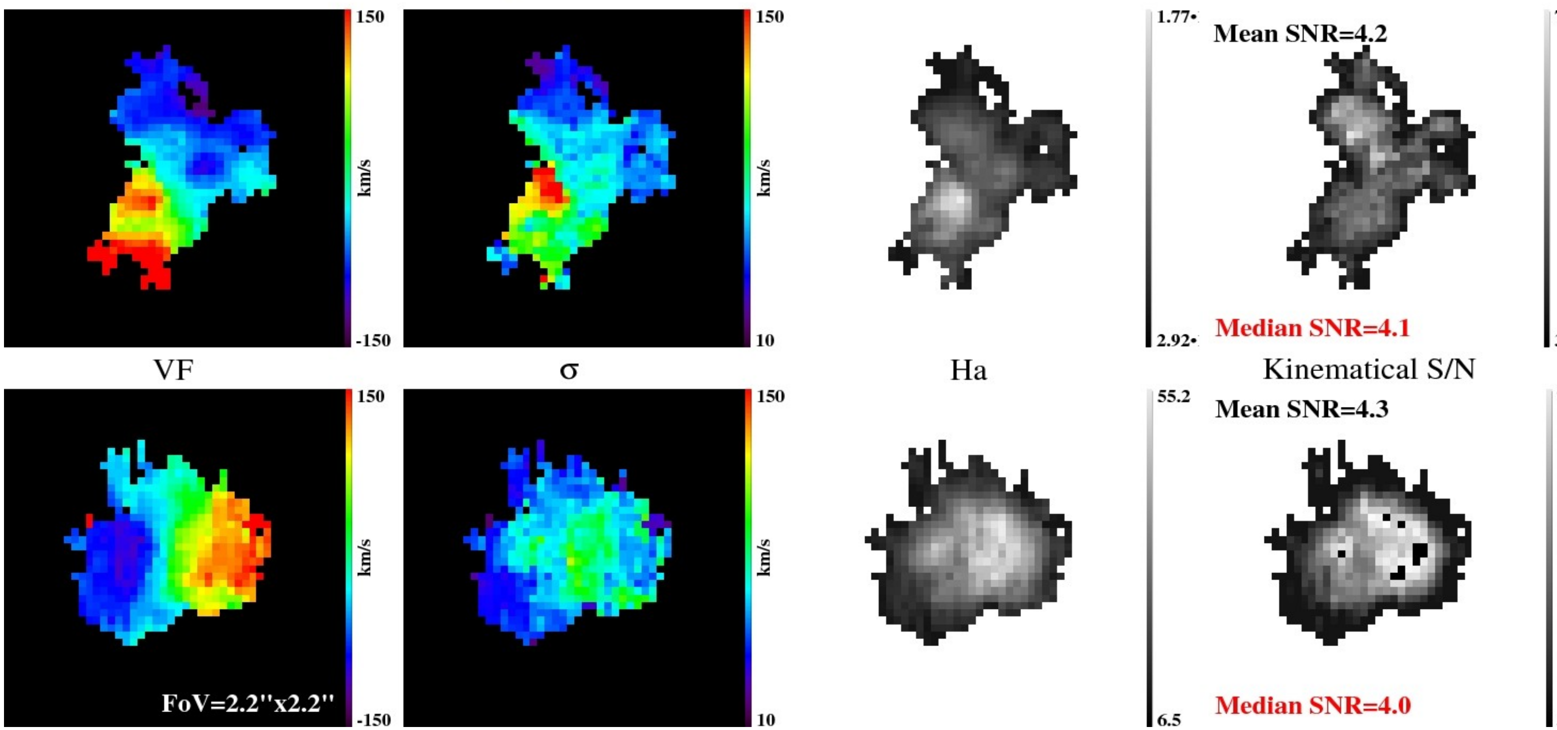



**Genzel et al. (2006)**
**SINFONI data**

Data courtesy of N. Forster-Schreiber

| | |
|---|---|
| **z=2.3834** | **Rgal~0.8"** |
| **K=21.47** | **EWo(Ha)=140A** |
| **Tintg=6hr** | |

**50x100mas FWHM=150" (smoothed to 190)"**



# Incremental goals for the DRM

**Increasing "complexity":**

- **STEP 1.** **3D detection of emission line galaxies: what mass can we reach with a minimal (emission line spatial-mean) SNR=5?**

- **STEP 2.** **Dynamical state of distant galaxies: can we recover large scale motions? Major mergers vs. Rotation disk.**

- **STEP 3.** **Rotation Curves: can we recover $V_{rot}$ (eg, Dynamical masses, Tully-Fisher)? Shape of the RC (mass profiles and decomposition)?**

- **STEP 4.** **Detailed kinematics: detection of, e.g., clumps in disks?**

# Reference case (z=4, M* galaxy)

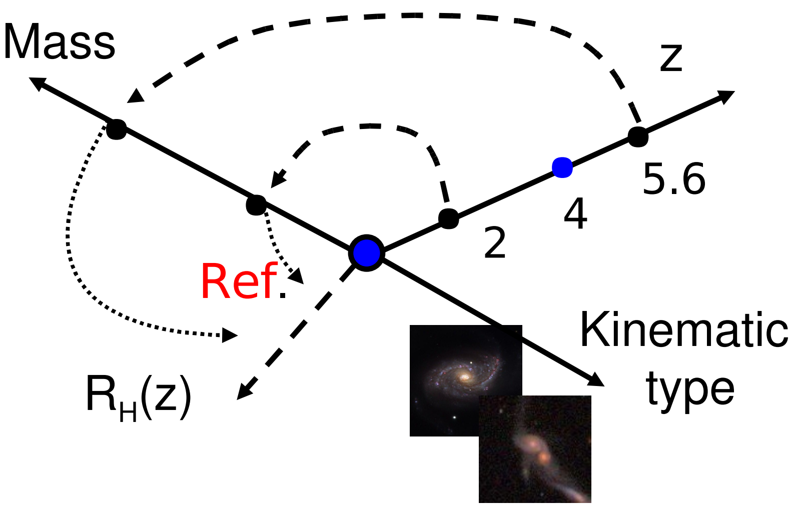
$$SNR=SNR(SB,z,AO,D,EW_0,T_{exp},R,\Delta pix,\ldots)$$

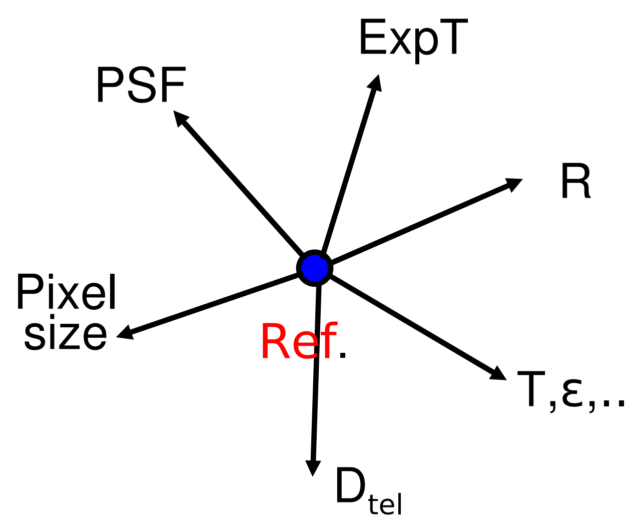
## Physical params

z=4, $H_{AB}$=24.3 (M* @ z=4)
Spiral Rotating Disk $V_{max} \approx$ 230 km/s
Log(M*/ $M_{\odot}$)=10.7
EW=30A (rest frame, [OII] in H band)
$R_{gal}$= 4$R_H$=0.75”(5.2 kpc)

## Instrument params

| | |
|---|---|
| D=42m | ExpTime=24h |
| R=5000 | Pixel=50 mas |
| RON=2.3 e/pix | Dark=0.01 e/s |
| Global transmission = 20 % | |
| $T_{tel}$=280 K | $\varepsilon_{tel}$=5 % |
| $T_{instr}$=[240,150] K | $\varepsilon_{instr}$=[15,69] % |



# STEP 1 - 3D Detection

**We define $M_{lim}$ = $M_{stellar}$ @ SNR=5 (spatial mean in the [OII] emission line)**

$$< S/N >_{min} = 5 \left(\frac{T}{24h}\right)^{0.5} \left(\frac{D}{42\,m}\right) \left(\frac{EW}{30Å}\right) \left(\frac{R}{5000}\right)^{-0.5} \left(\frac{\Delta pix}{50\,mas}\right)$$

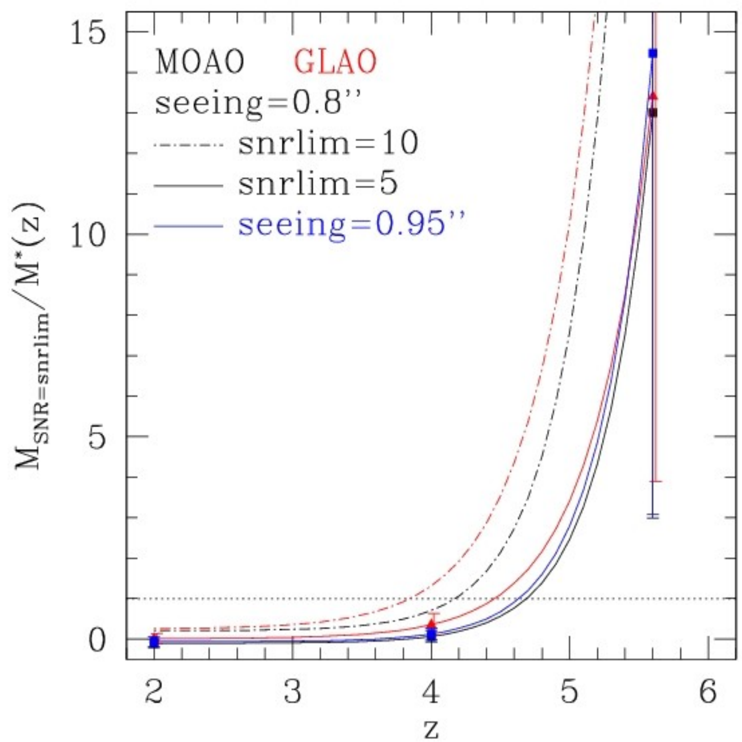
The GSMF can be probed down to M* up to a redshift of:

- with MOAO: z~4.7

- with GLAO: z~4.4

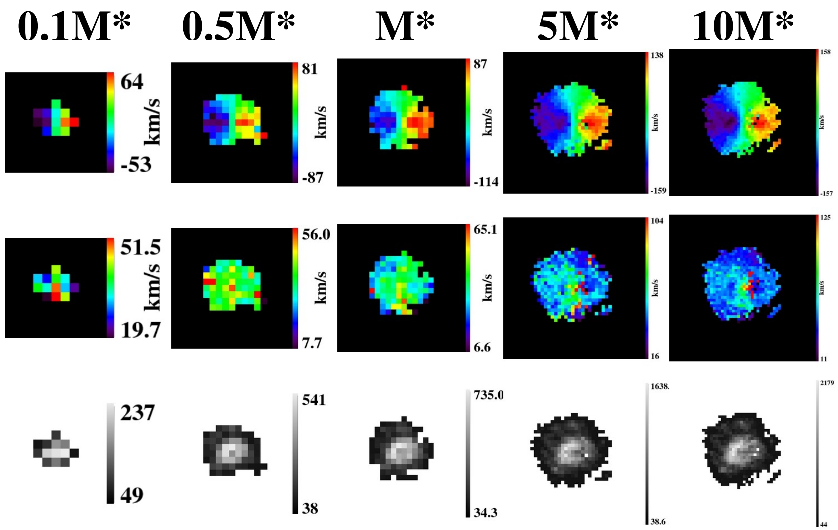
Flat curve below z~4: no strong sensitivity to variations in, eg, seeing, AO mode, SNR limit,...

=> 3D spectroscopy of z<4 galaxies "secure"

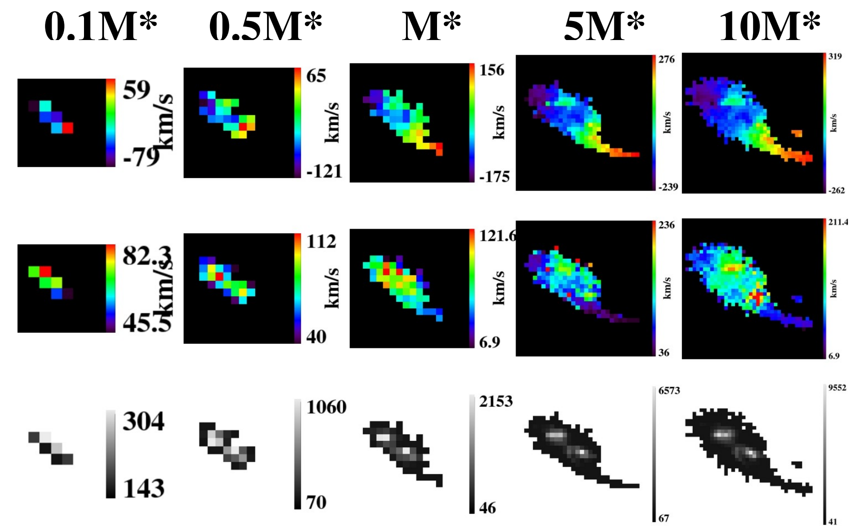


# STEP 2 – Large scale motions

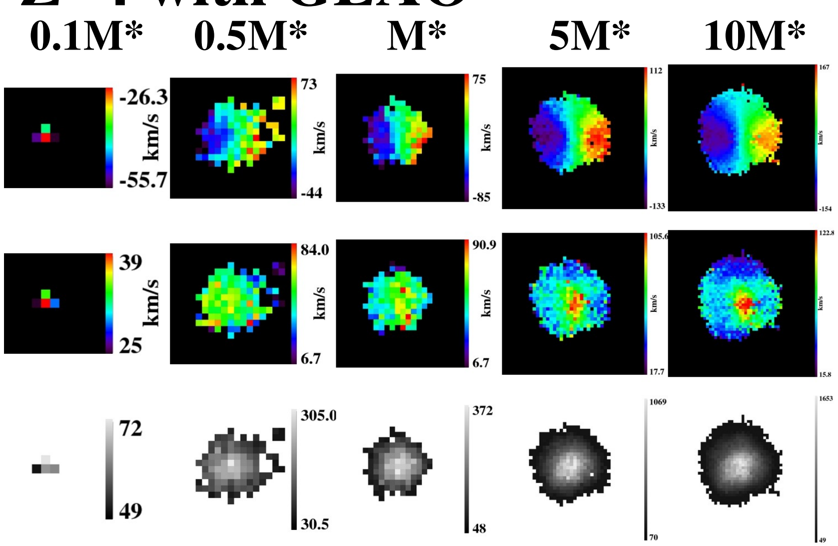
## Z=4 with MOAO



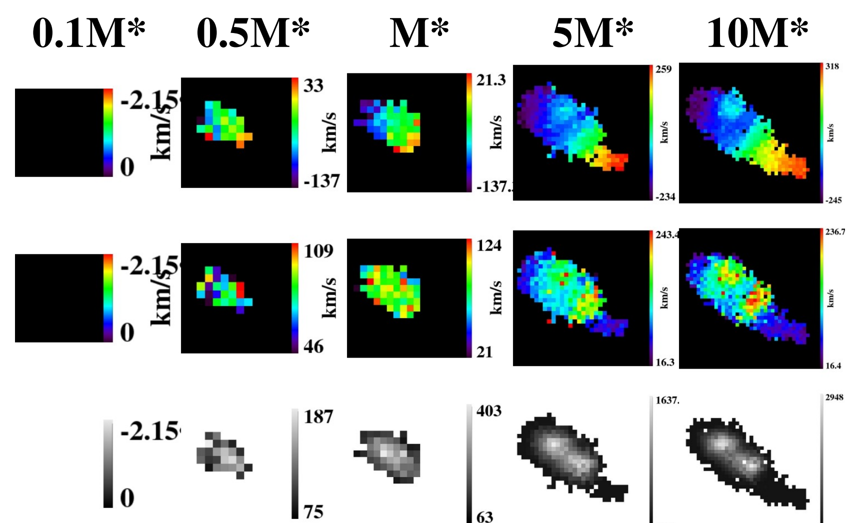

## Z=4 with MOAO




## Z=4 with GLAO




## Z=4 with GLAO

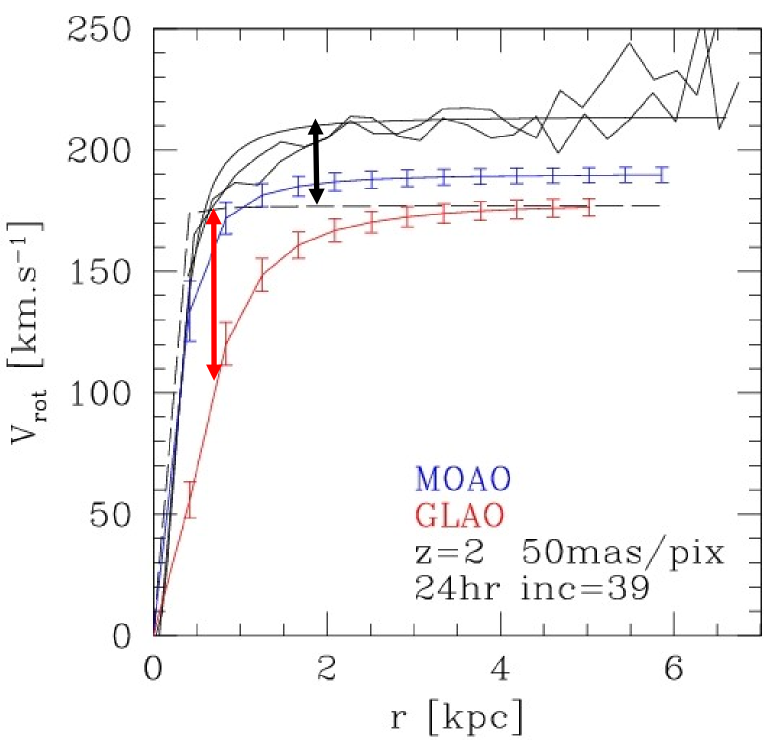



Needs SNR=5-10 depending on redshift

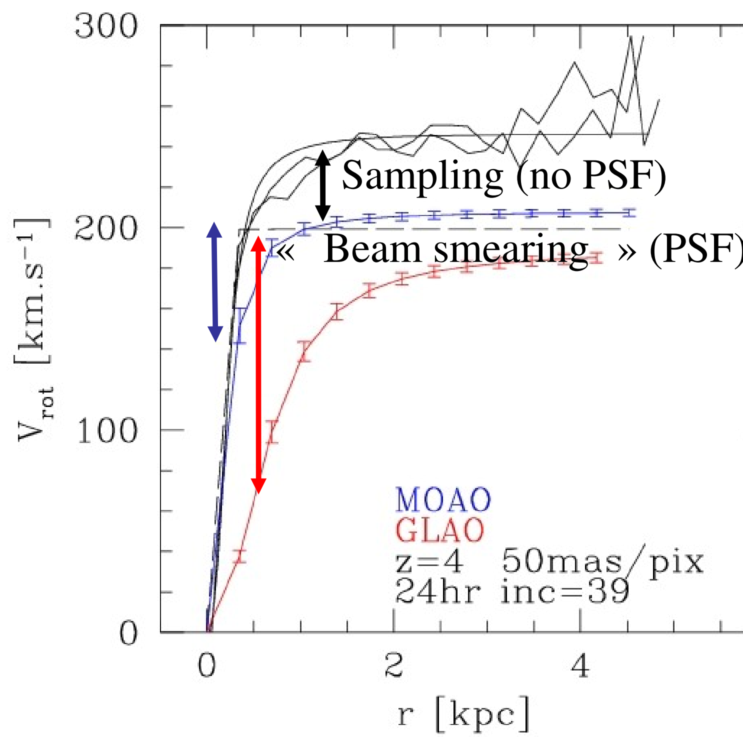
# STEP 3 - Rotation Curves (UGC5253)

- ✓ Accuracy on the RC limited by the spatial resolution and sampling
- ✓ z=2: $M_{stellar}$=M* FWHM$_{MOAO}$~11mas FWHM$_{GLAO}$~161mas $D_{gal}$/2Δpix=15
- ✓ z=4: $M_{stellar}$=5M* FWHM$_{MOAO}$ ~ 8mas FWHM$_{GLAO}$~235mas $D_{gal}$/2Δpix=6

**Z=2**




**Z=4**

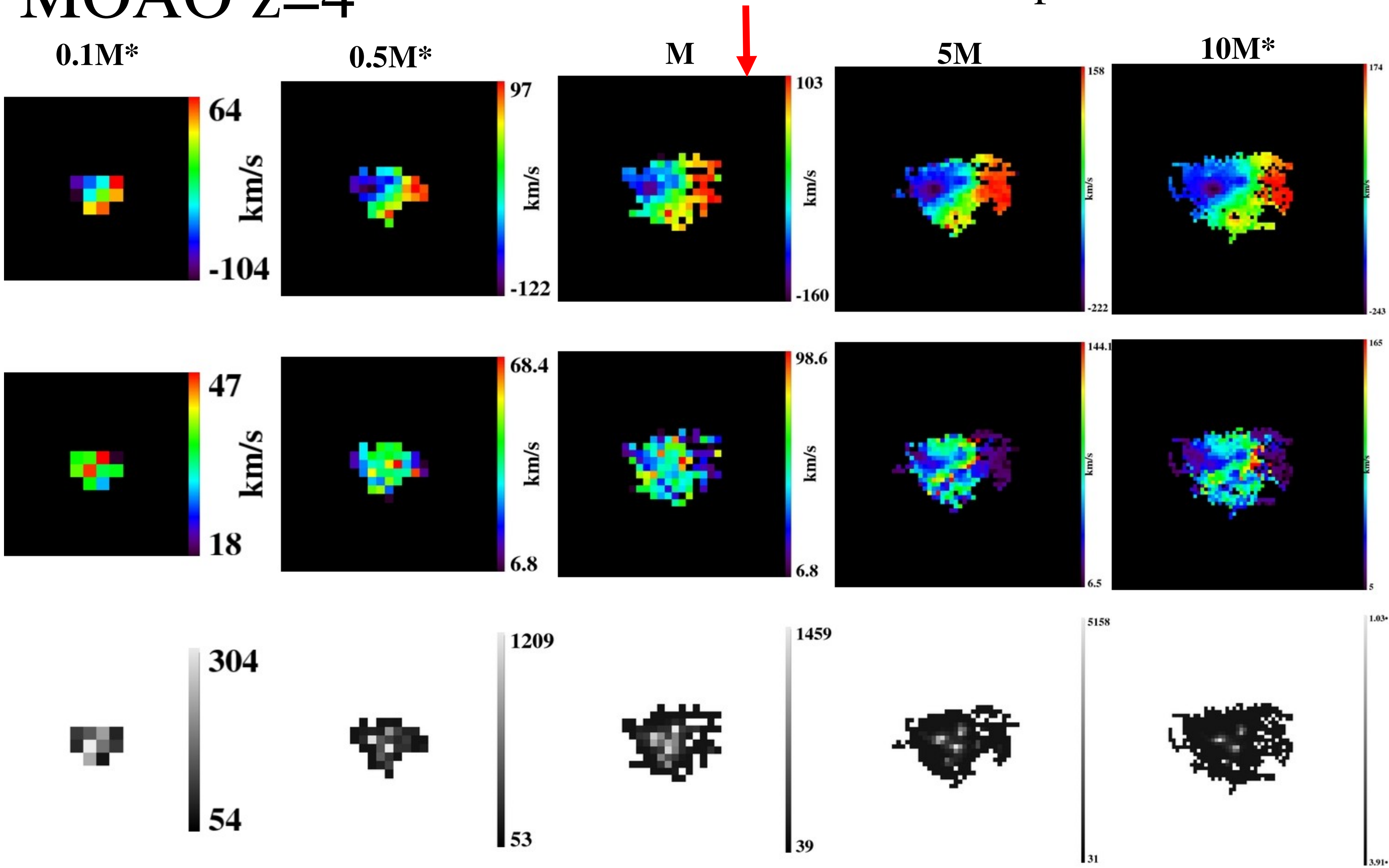



Deconvolution needed

# STEP 4 - Detailed kinematics: clumpy disks

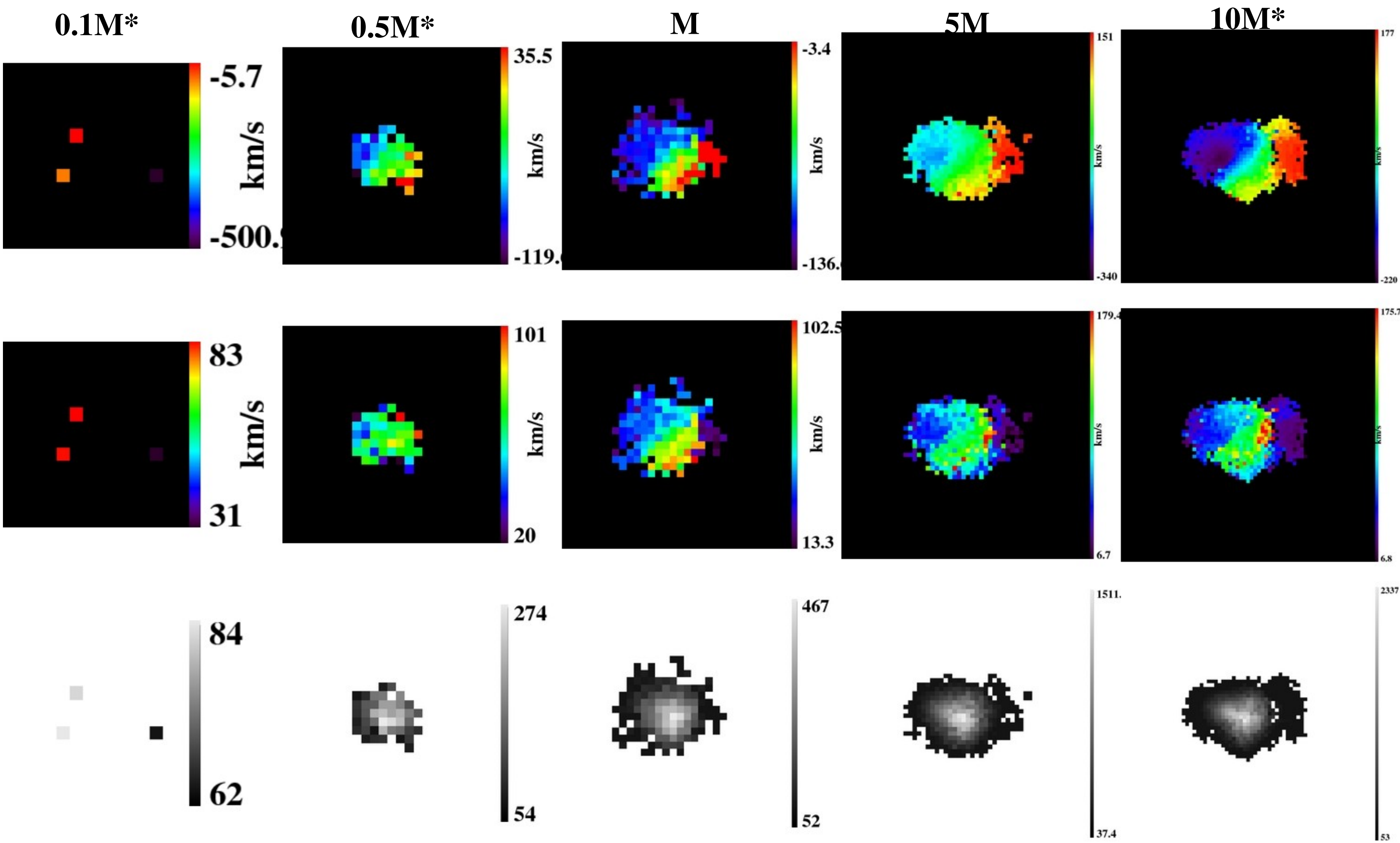
MOAO z=4

Detection of clumps down to M*



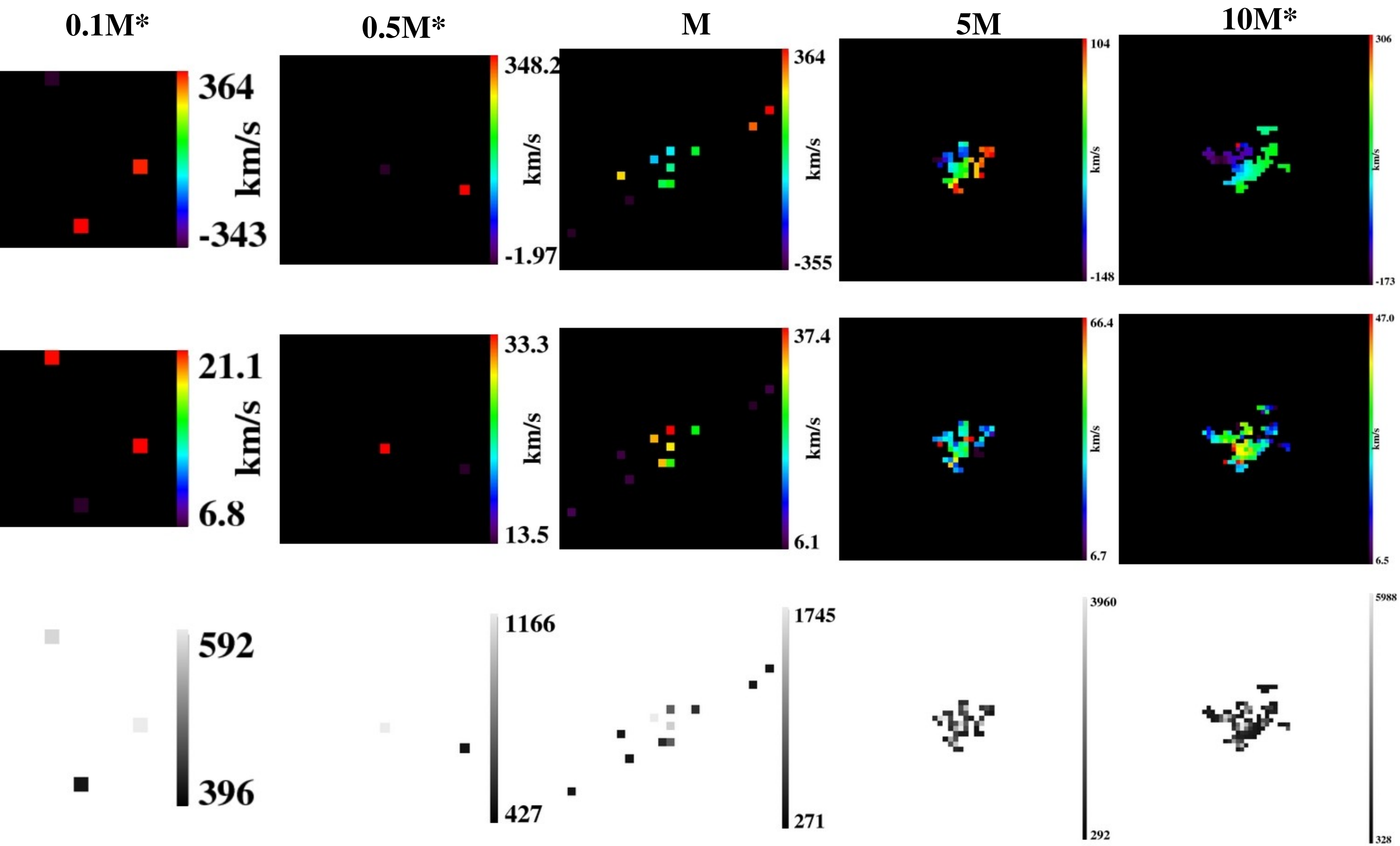
# STEP 4 - Detailed kinematics: clumpy disks

## GLAO z=4



# STEP 4 - Detailed kinematics: clumpy disks

## MOAO z=5.6



# Proposal

Goal: ~ 1000 galaxies at $2<z<5.6$ with $0.1 < M_{stellar} < 5.10^{11}\,M_\odot$

Assumptions:

- MOAO, Mauna Kea-like Background, R=5000, 50mas/pix
- $SNR_{min}$=10, Overheads = 30 %
- 3 redshift bins: z=2 (~10 Gyr ago), z=4 (~12 Gyr ago), z=5.6 (~12.6 Gyr ago)

    ↳3 mass bins per z bin : 0.5 – 1 – 5.0 $M^*(z)/M_\odot$

        ↳3 morphological/kinematical types per z/mass bin

- Multiplex=37 = minimal # of targets per elementary bin => 1000 galaxies

# Proposal

| Texp (hr) | 0.5M* | M* | 5M* | Total |
|---|---|---|---|---|
| Z=2 | 28 | 20 | 8 | 56 |
| Z=4 | 56 | 34 | 13 | 103 |
| Z=5.6 | 3220 | 1605 | 391 | 5215 |
| Total | 3304 | 1658 | 412 | 5373 |

| Texp (n) | 0.5M* | M* | 5M* | Total |
|---|---|---|---|---|
| Z=2 | 4 | 2 | 1 | 7 |
| Z=4 | 7 | 4 | 2 | 13 |
| Z=5.6 | 402 | 201 | 49 | 652 |
| Total | 413 | 207 | 51 | 672 |

(SNR=10)

- Program feasible in ~ 100 nights, selecting galaxies with $M_{stellar}>10^{10} M_{\odot}$ ($M^*(z=5.6)=0.8\ 10^{10} M_{\odot}$)
- Highest-z bin limited by thermal background from the telescope. In simulations, “optimistic” case with T=280K and ε=5% (could be 15% depending on coating).