The E-ELT Design Reference Mission: Following the galaxy mass assembly with 3D spectroscopy

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Design Reference Mission

- **Set of observing programs which together provide a tool to assist with trade-off decisions in the design of the ELT**
- **Science programs chosen to encompass a wide range of science goals and capabilities: among the highlights of the current ELT science case**
- **DRM is NOT:**
  - **pre-selecting science**
  - **pre-selecting instruments (end of phase-B in around 2009).**

DRM - Proposal

EUROPEAN SOUTHERN OBSERVATORY

Organisation Européenne pour des Recherches Astronomiques dans l'Hémisphère Austral
Europäische Organisation für astronomische Forschung in der südlichen Hemisphäre

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APPLICATION FOR OBSERVING TIME — PERIOD: **78A**

Important Notice:

By submitting this proposal, the PI takes full responsibility for the content of the proposal, in particular with regard to the names of COIs and the agreement to act according to the ESO policy and regulations, should observing time be granted

1. Title — Category: **A–1**

The Physics and Mass Assembly of Galaxies out to $z \sim 6$

2. Abstract

We propose to obtain ELT spatially resolved spectroscopy of a sample of a thousand massive galaxies at $2 < z < 6$, selected from future large area optical-nearIR surveys. These observations will yield direct kinematics of stars and gas in the first generation of massive galaxies (in the range $0.1 < M < 5 \times 10^{11} M_{\odot}$), as well as their stellar population properties. One will able to derive dynamical masses, ages, metallicities, star-formation rates, dust exinction maps, to investigate the presence of disk and spheroidal components and the importance of dynamical processes (e.g. merging, in/outflows) which govern galaxy evolution. These data will also allow one to study the onset of well known scaling relations at low redshifts, and to witness the gradual shift of star formation from the most massive galaxies in the highest density regions to less massive galaxies in the field. The whole program is designed to provide the ultimate test of galaxy formation theories.

3.

Run	Period	Instrument	Time	Month	Moon	Seeing	Sky Trans.	Obs.Mode
A	79	FORS2	100h	any	d	$\leq 0.4''$	PHO	v

The Physics and mass assembly of galaxies out to z~6

Ultimate test of galaxy formation theories: epoch and mode of baryonic mass build-up

➔ Spatially resolved spectroscopy of a sample of ~1000 massive galaxies at $2<z<\sim5$

- ✓ **direct kinematics of stars and gas in the first generation of massive galaxies in the range $0.1<M_{star}<5\times10^{11}$ M**
- ✓ **dynamical masses, ages, metallicities**
- ✓ **differential evolution of disk and spheroidal components as a funct. of z**
- ✓ **physical channels of mass assembly since z~5**

Incremental goals for the DRM

Kinematics is the most demanding analysis in terms of SNR:
enough SNR for kinematics => enough SNR for flux ratio maps (e.g., SFR or metallicity maps)

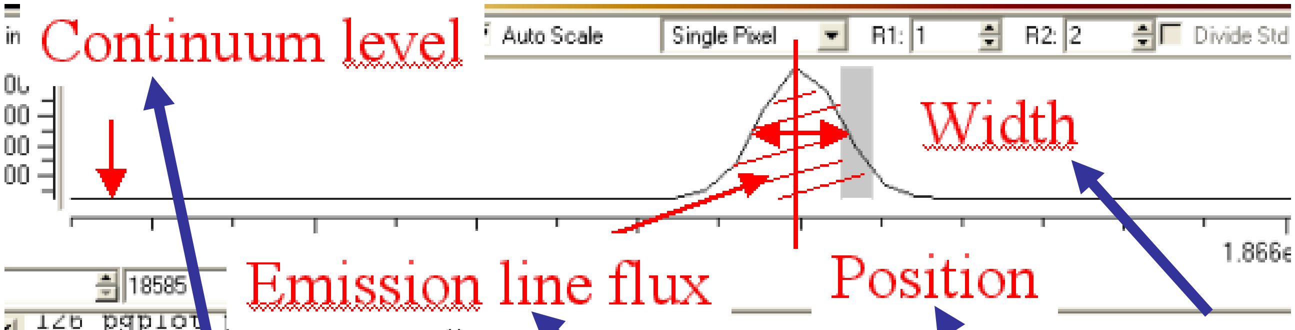
- **STEP 1: 3D detection of emission line galaxies: what mass can we reach with a minimal (emission line spatially integrated) SNR=5?**

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

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

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

DRM – Simulation Pipeline



Continuum map

Emission line Flux map

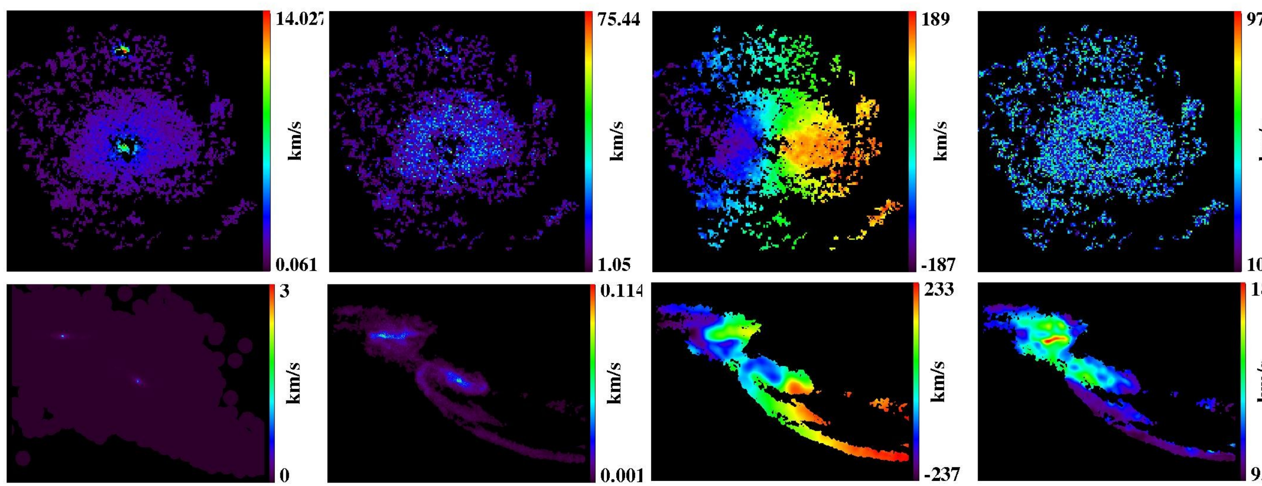
Velocity field

Velocity Dispersion map

Observations

OR

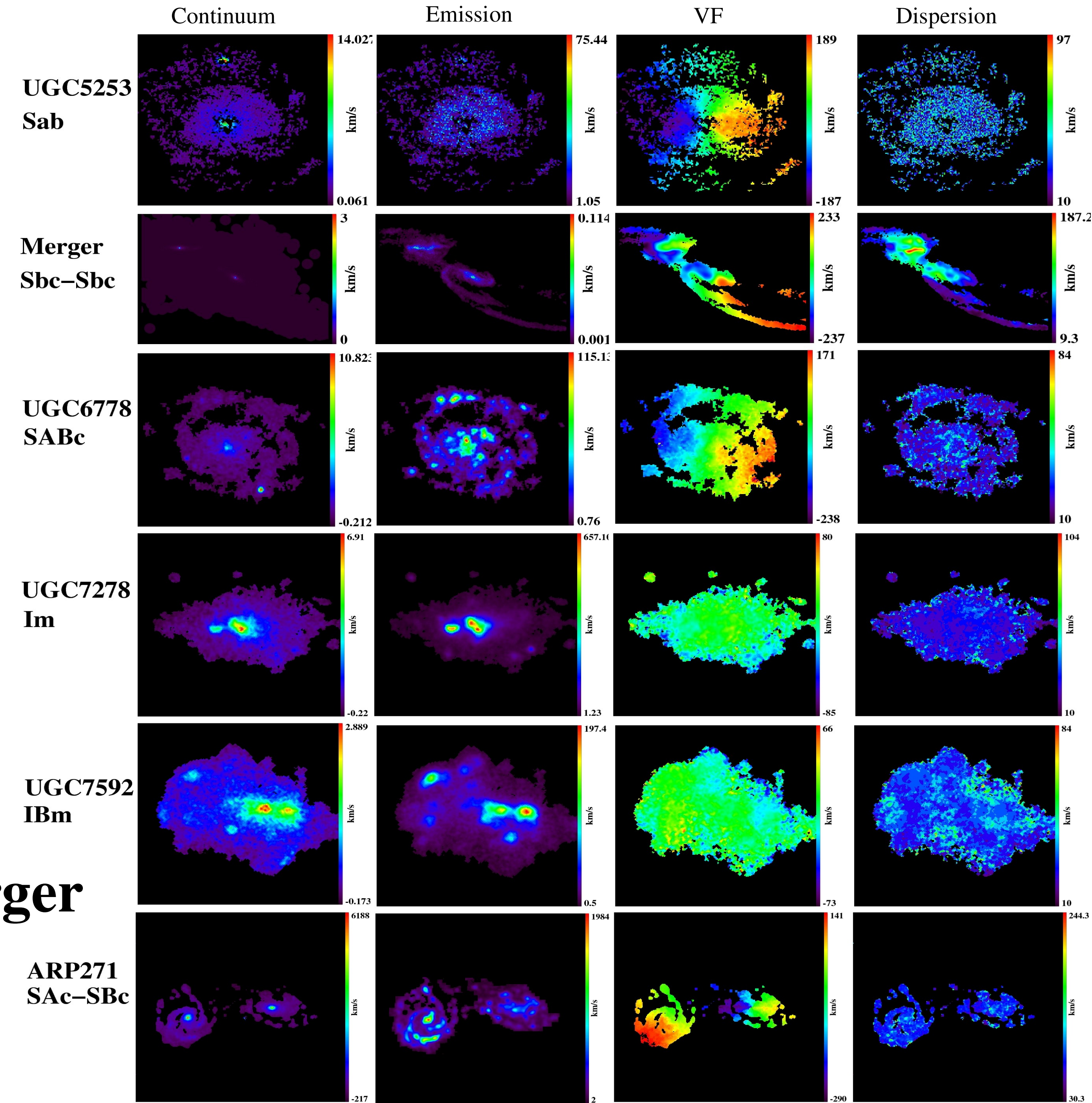
Simulations



Templates

- **Local obs:**
UGC5253
UGC6778
ARP271
UGC7278
UGC7592
From GHASP
Amram+02

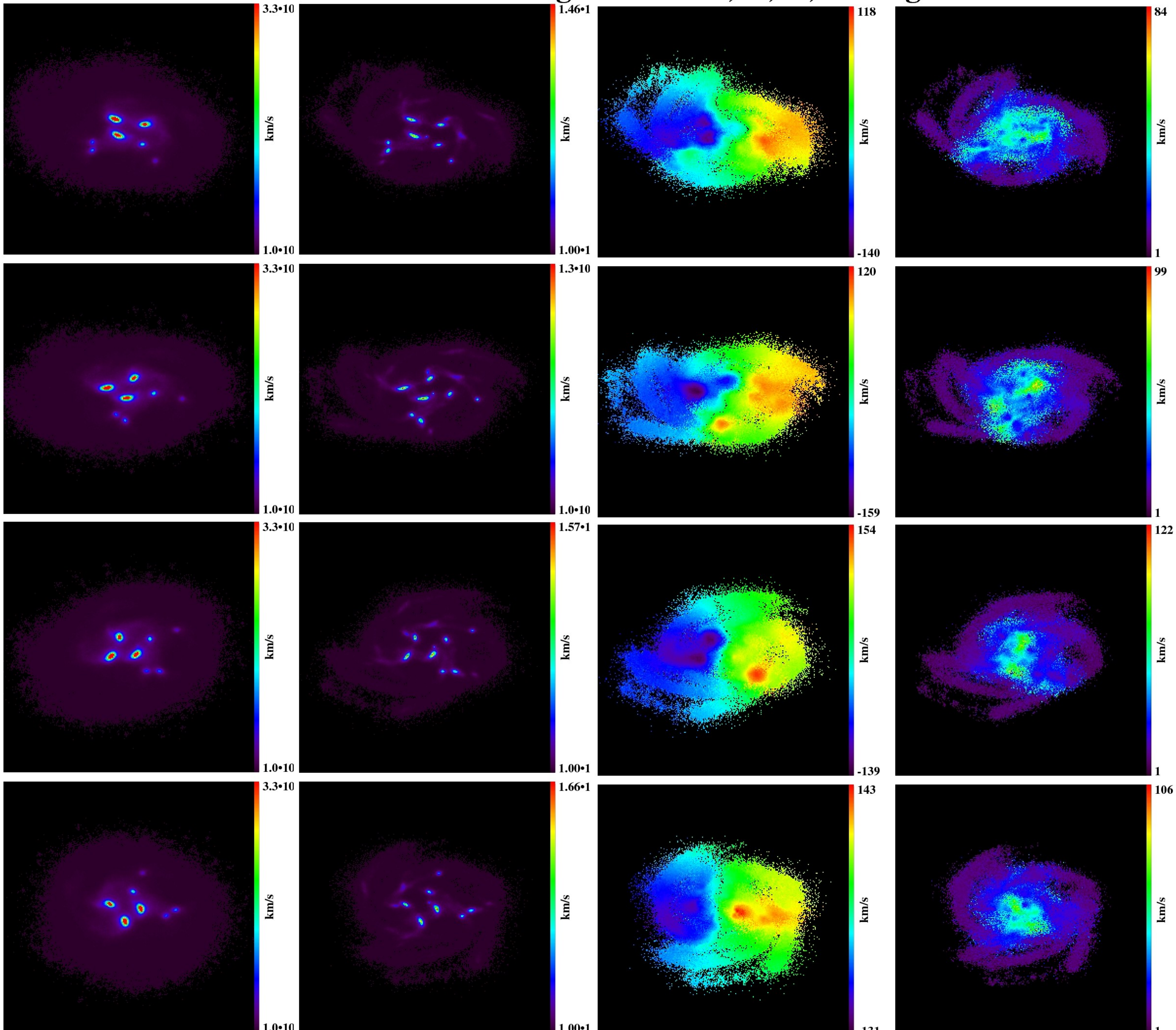
- **Hydro-sims:**
Sbc major merger
Cox+06



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

Bournaud et al. 2007

Hydro-simulations

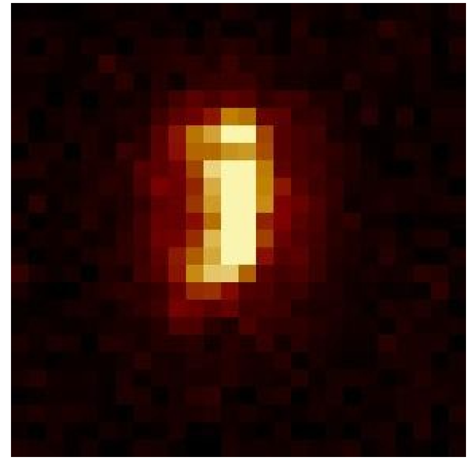


DRM - Simulations

Parameter	Value
$M1$	42 m
$M2$	0 m
R	5000
Δ_{pix}	0.050"
t_{transm}	0.2
CTE	1
p	4000x4000/4
$dark$	0.01 e/sec/pix
ron	2.3 e/pix
dit	3600 s
m_{AB}	24.5 mag
EW	30 Å
λ_{em}	3727 Å
S	0.8"
z	4.0

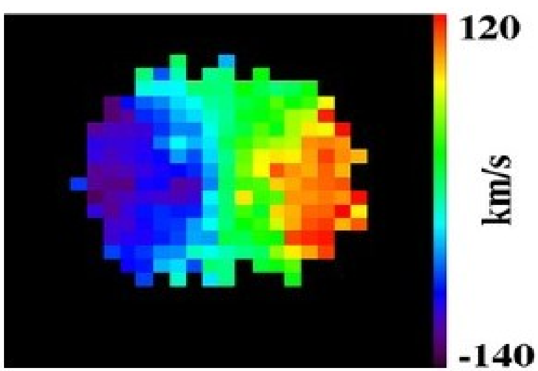
- ✓ Thermal backg.
- ✓ sky (cont.+OH)
- ✓ atm. Abs.

- ✓ Readout noise,dark, etc.

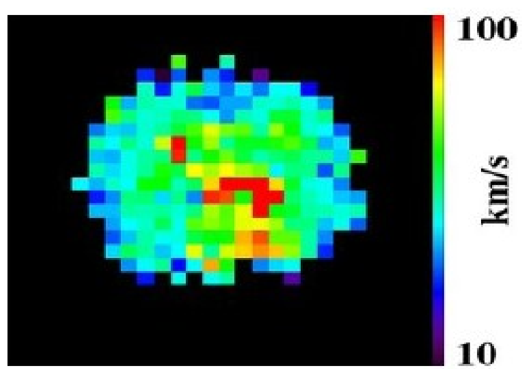


3D datacube
« IFU data »

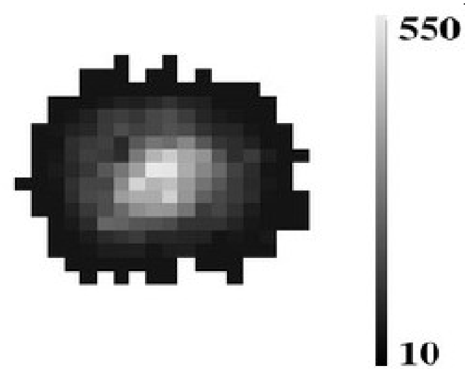
V.F.



σ map

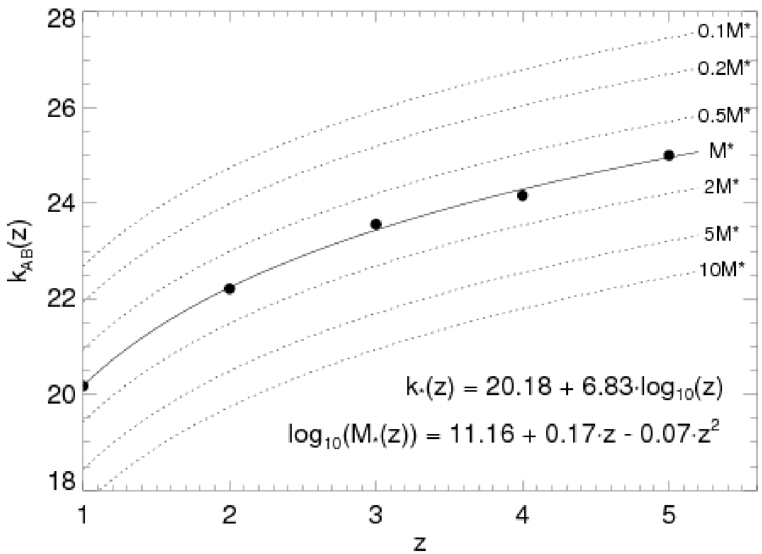


Emission line flux map

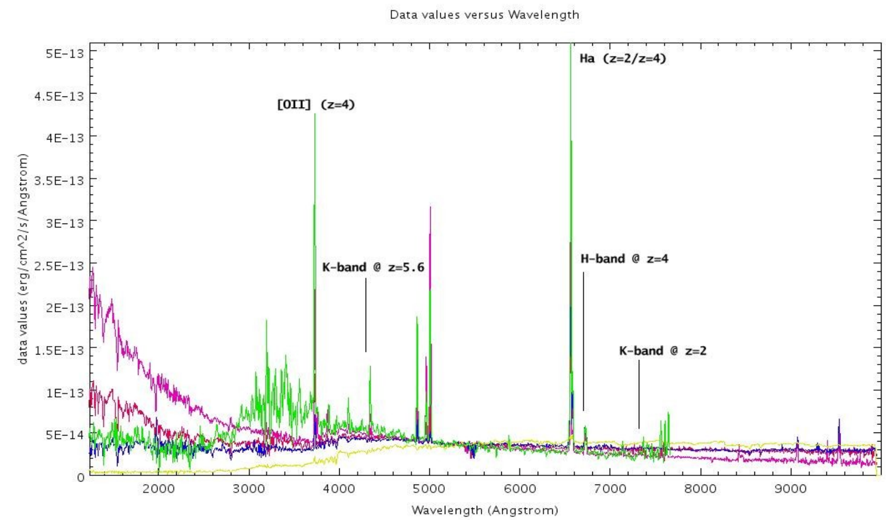


Rescaling: flux and velocity

Z & stellar mass => K-band mag => pseudo-continuum flux



GSMFs from MUSYC survey (S. Toft)



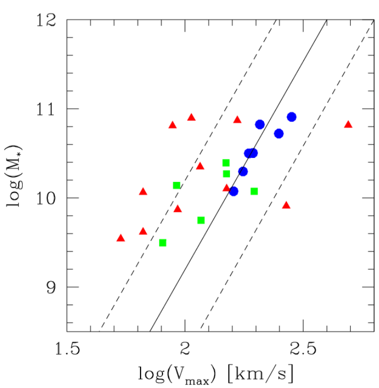
Uncertainties:

$M_{stellar}(z)$~ 0.3 dex

$K_{AB}(z)$ ~ 0.75 mag from GSMFs & LMFs

Continuum Flux(K_{AB}) ~ 2 from SEDs

Assume no evolution of the TFR

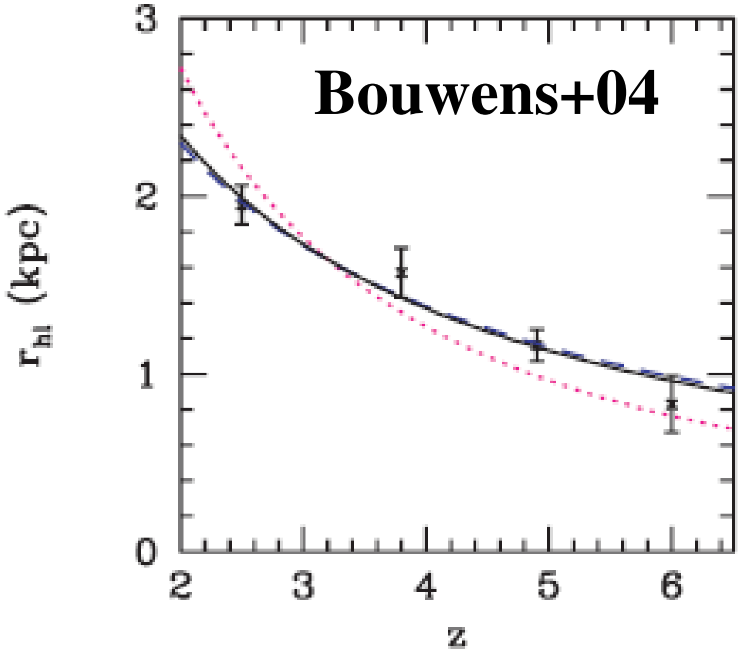


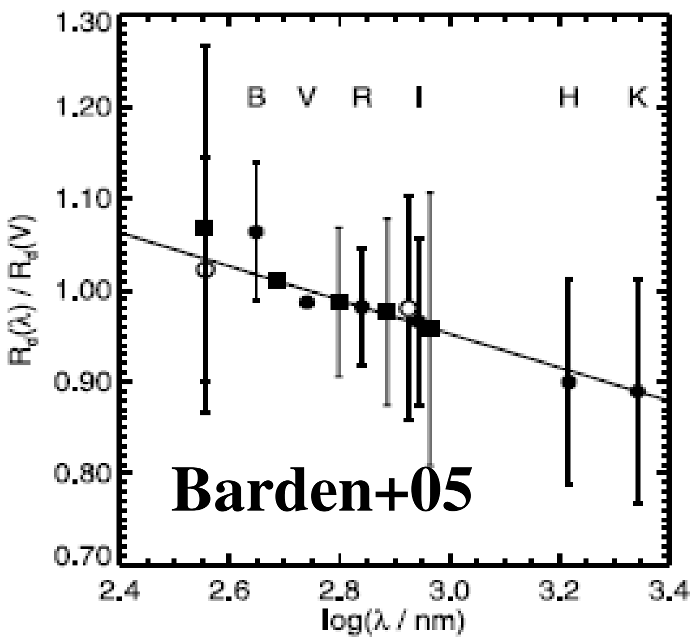
smTFR Flores et al. 06

Rescaling: size

✓ **Redshift: Bouwens+04 Ferguson+04 Dahlen+07**

R_{half} vs. z in the UV



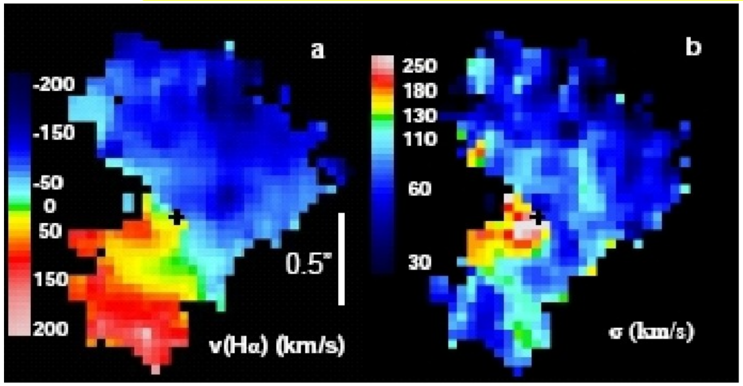


✓ **Size vs. Stellar mass:**

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

Simulating Sinfoni observations of a massive galaxy at z=2.34

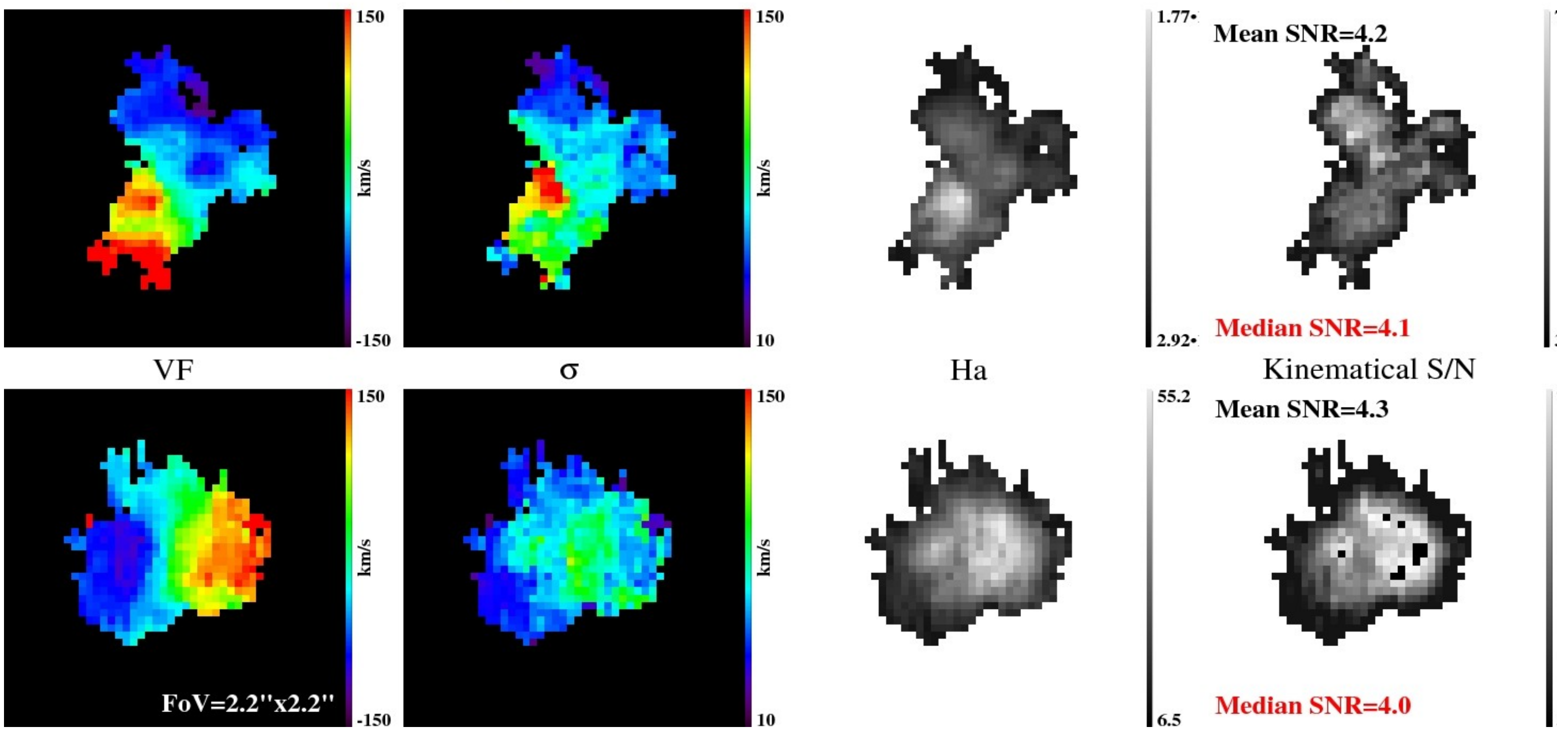
(real life validation of simulations)



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)"



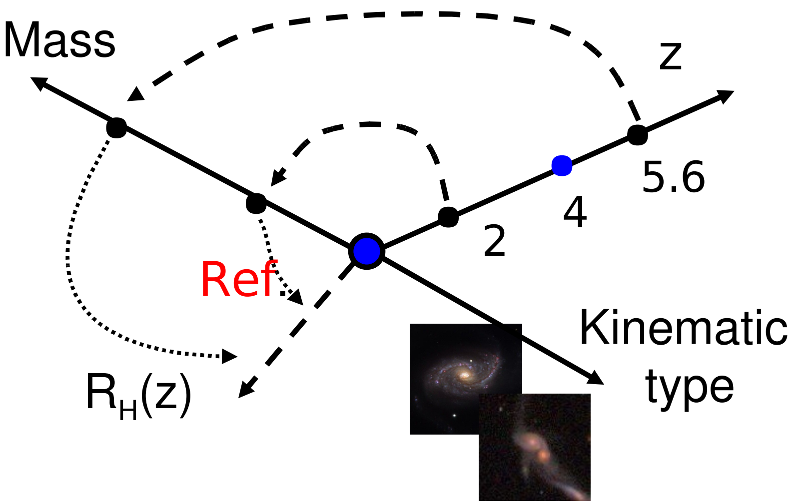
Reference case (z=4, M galaxy)*

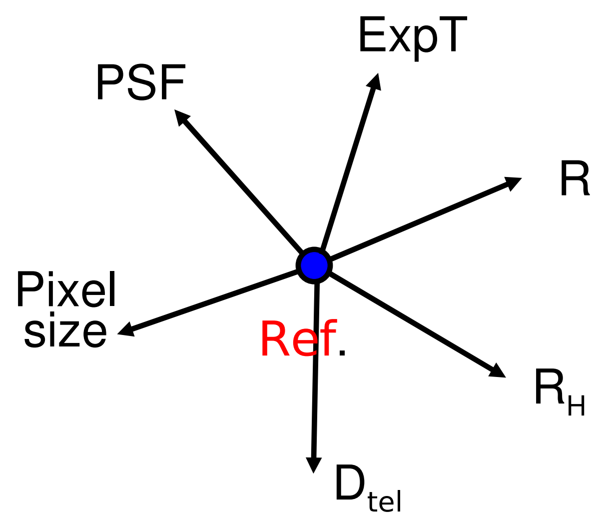
Physical params

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

Instrument params

D=42m   ExpTime=24h
R=5000   Pixel=50 mas





AO Modes

- **AO modes:**

MOAO – GLAO – MCAO – LTAO

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

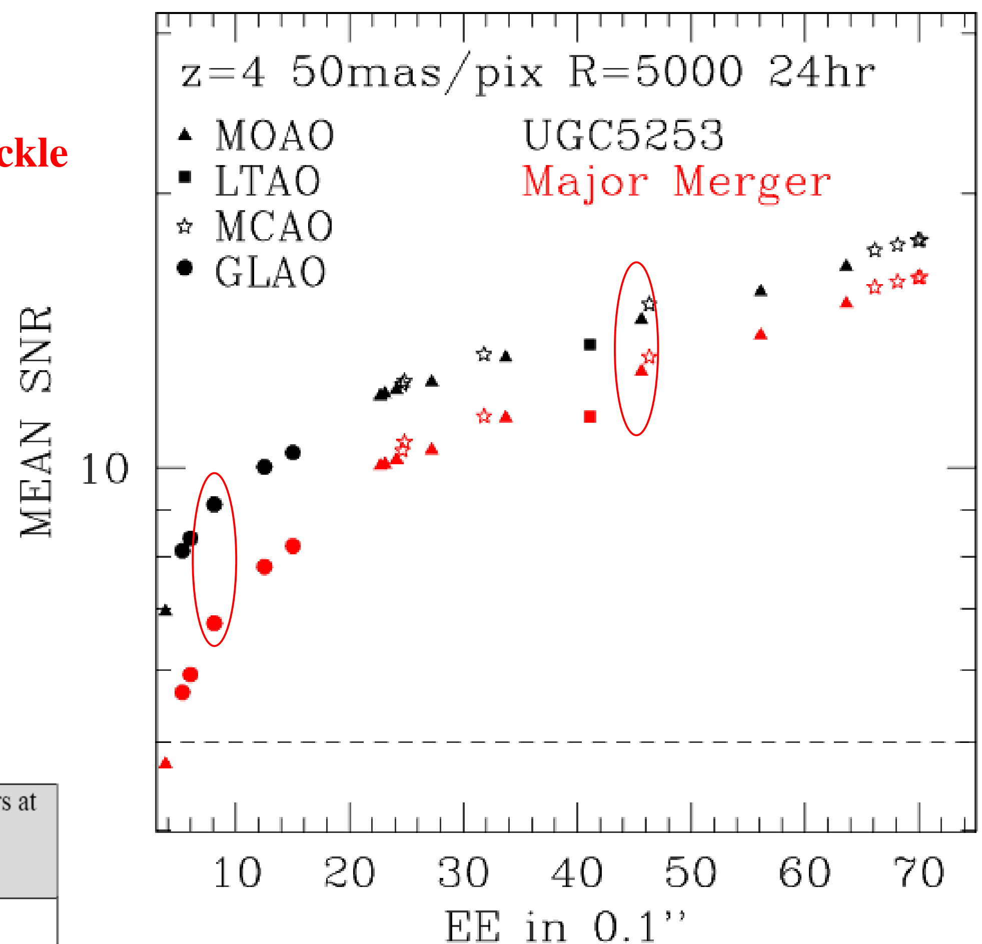
=> From E2E code: GLAO & LTAO
(ESO; M. Le Louarn)

- **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

3D Detection

- SNR=SNR(SB,z,EE,D,EW_0,T_{exp},R,Δpix,…) ➔ $M_{lim=}M_{lim}$(SB,z,EE,D,EW_0,T_{exp},R,Δpix)
- We define $M_{lim} = M_{stellar}$ @ SNR=5 (spatial mean in the [OII] emission line)

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

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

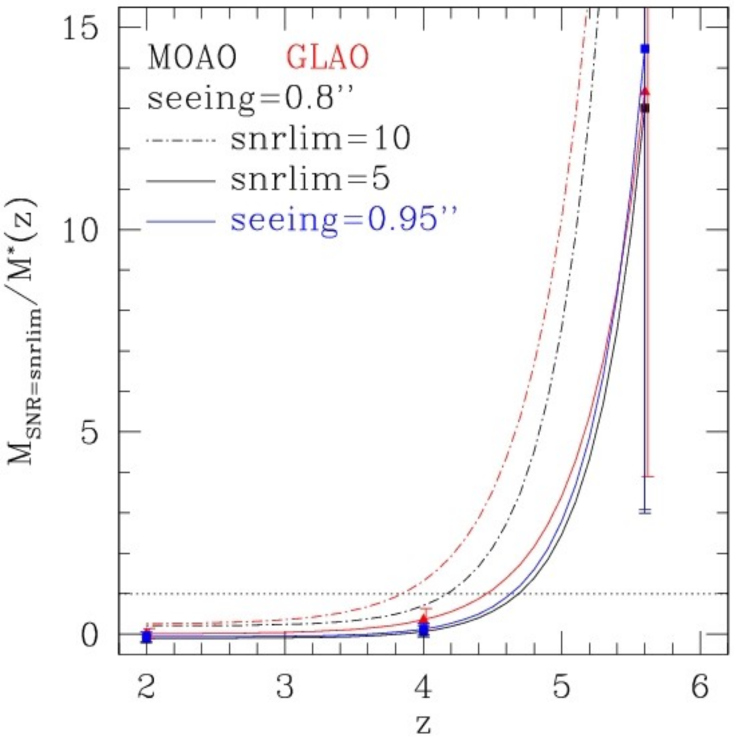
- with MOAO: z~4.7

- with GLAO: z~4.4

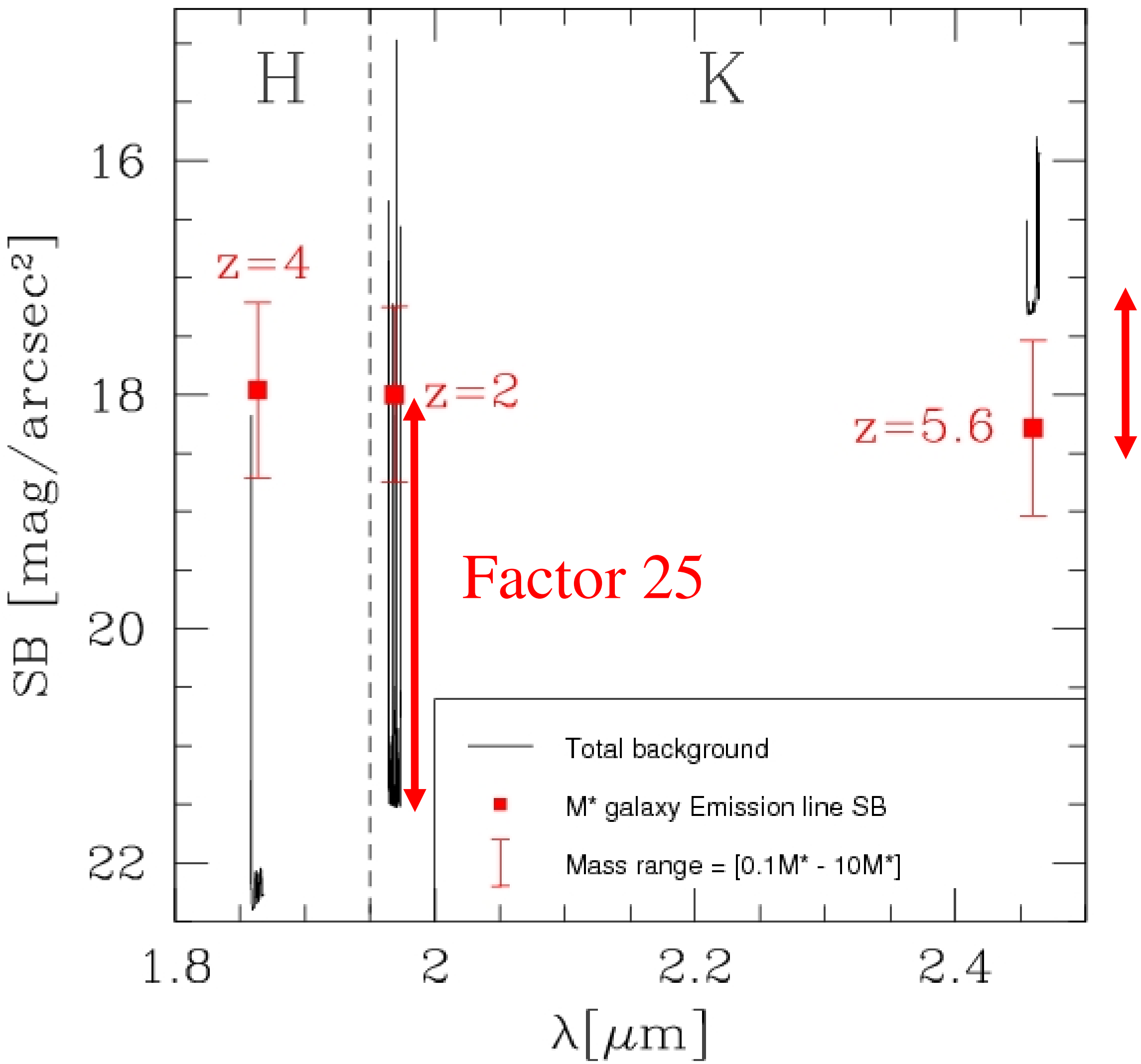
Flat curve below z~4.5: no strong sensitivity to variations

in, eg, seeing, AO mode, SNR limit,...

=> 3D spectroscopy of z<4 galaxies secure



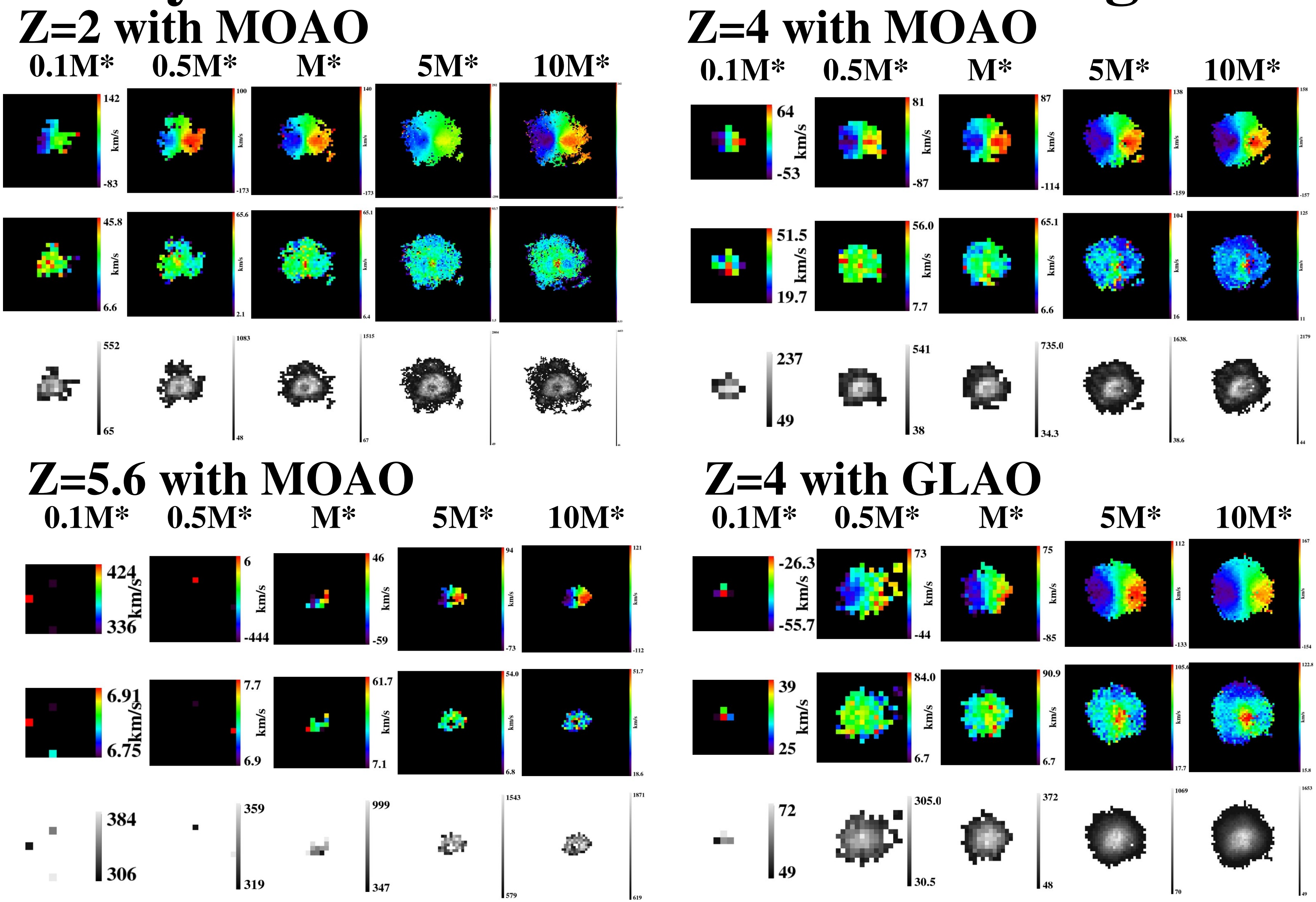
3D Detection



Exponential tail in M_{lim} vs z plot

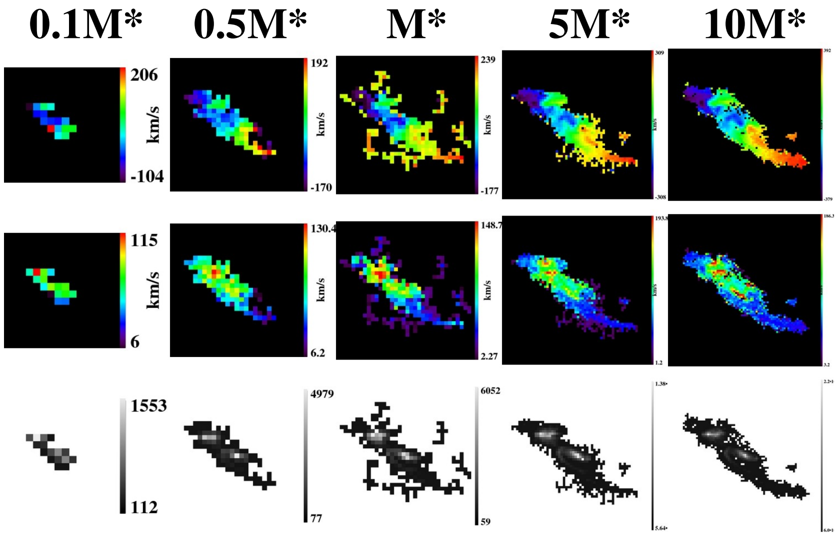
Site sky background: significant impact only above z>5

Dynamical state: relaxed rotating disk

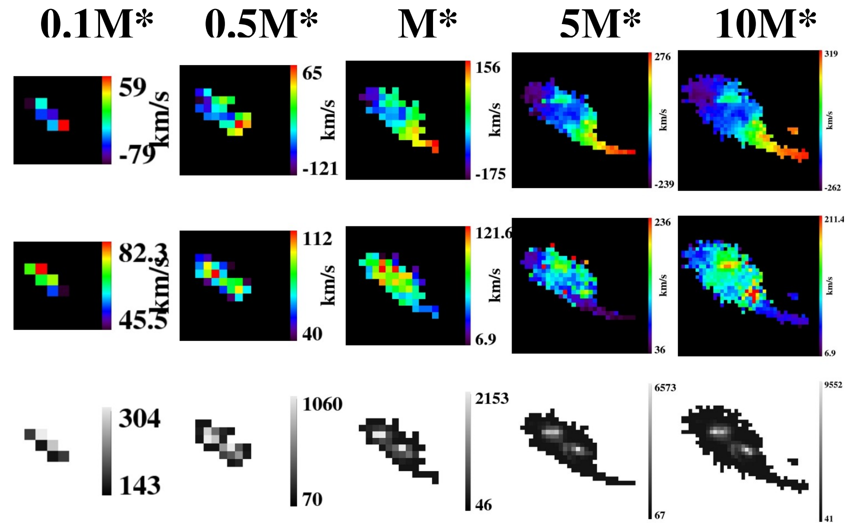


Dynamical state: major merger

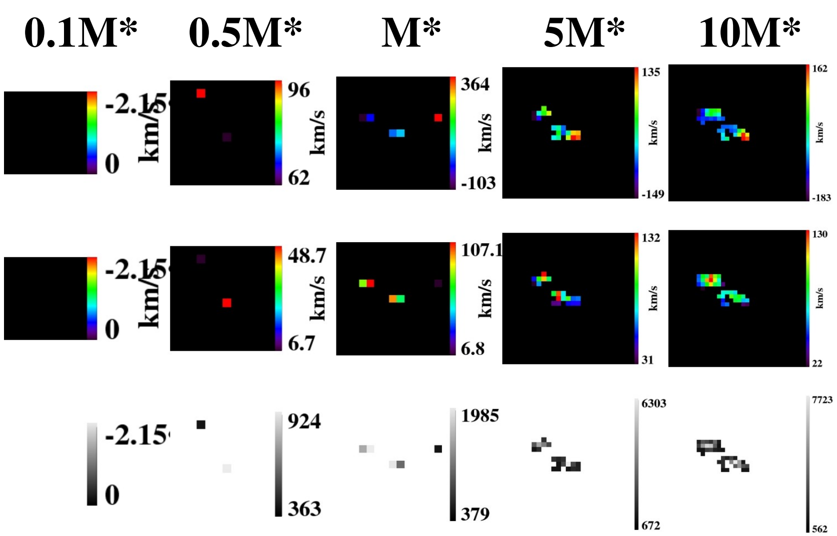
Z=2 with MOAO



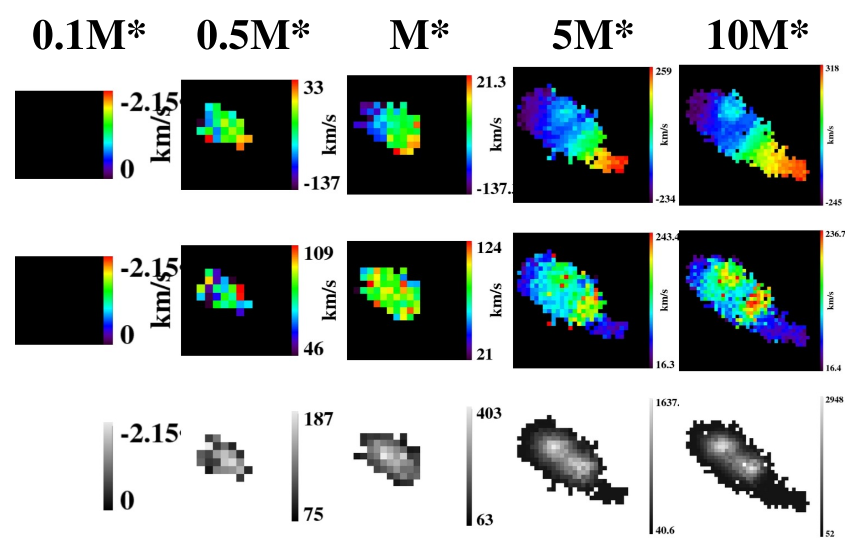
Z=4 with MOAO



Z=5.6 with MOAO



Z=4 with GLAO

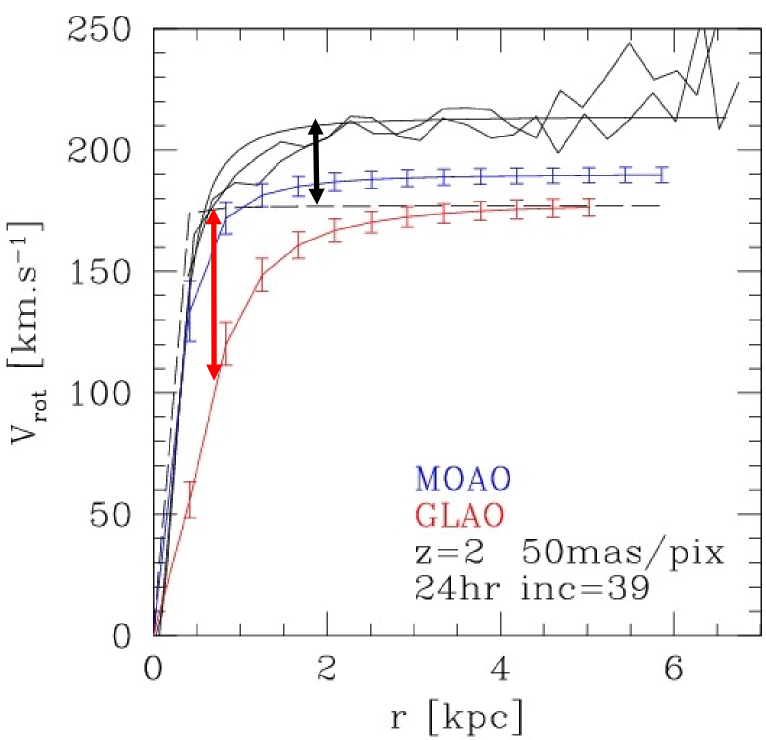


Needs SNR=5-10 depending on redshift

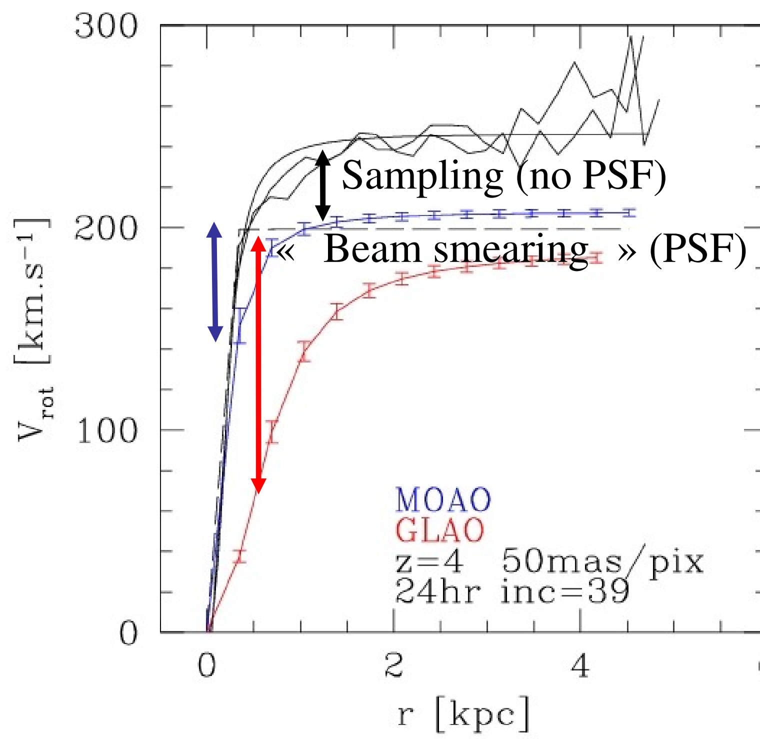
Rotation Curves (UGC5253)

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

Z=2



Z=4

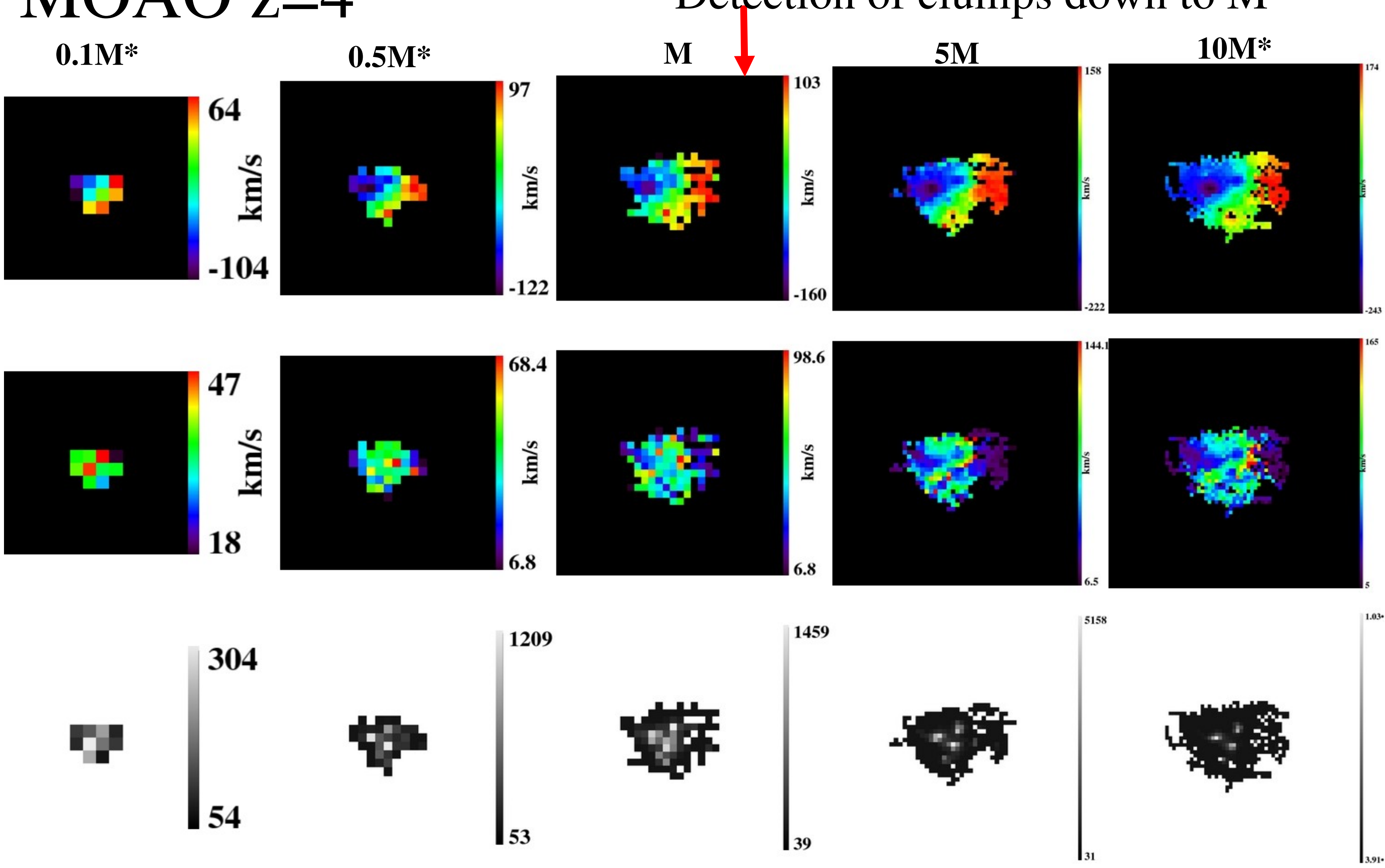


Bosma78's rule of thumb : $D_{gal}/2\Delta pix > 14$

Detailed kinematics: clumpy disks

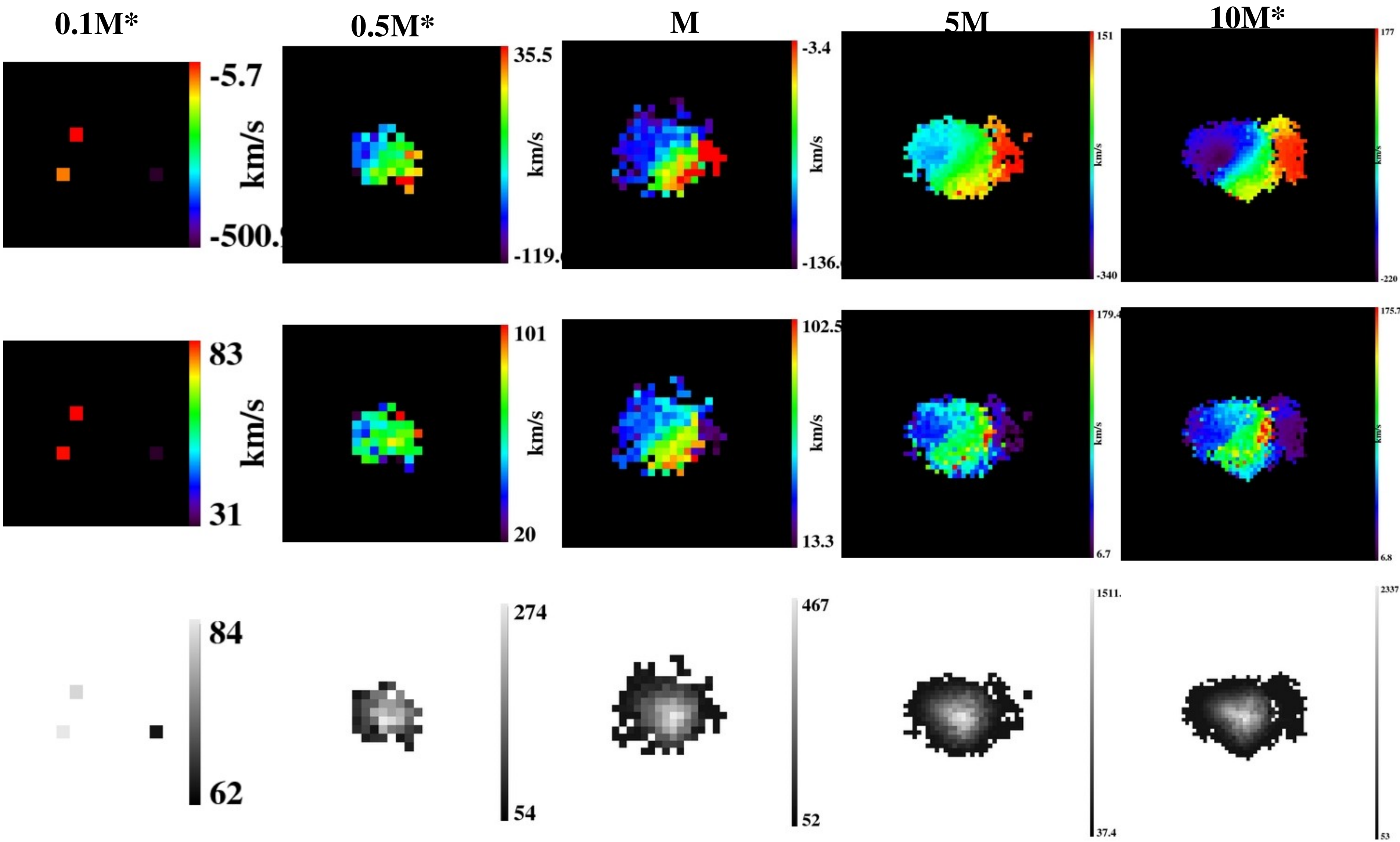
MOAO z=4

Detection of clumps down to M*



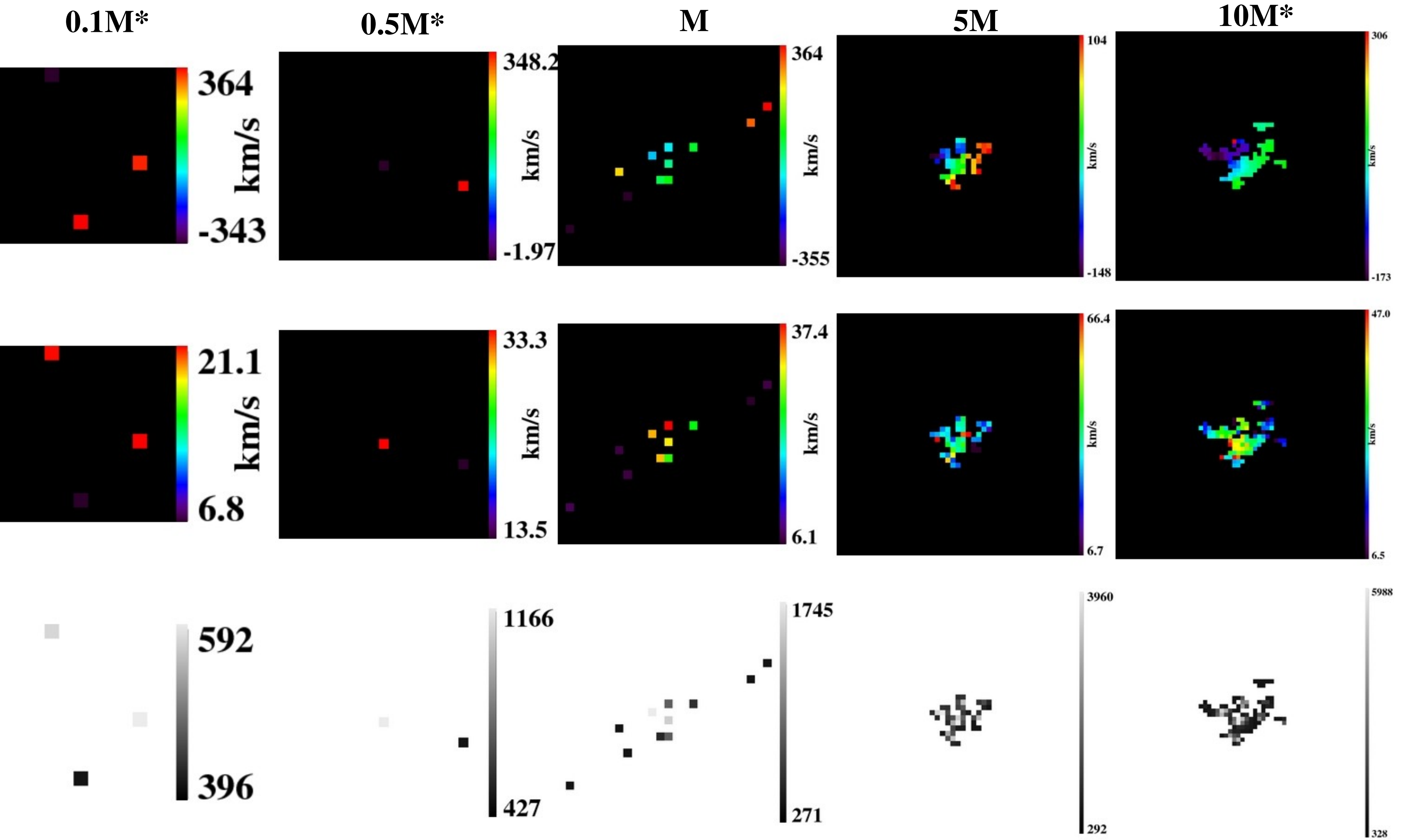
Detailed kinematics: clumpy disks

GLAO z=4



Detailed kinematics: clumpy disks

MOAO z=5.6



Summary - Science

- DRM STEP 1: 3D detection: The Galaxy Mass Function can be sampled down to M* up to z~4.9 (4.2) using MOAO and z~4.4 (3.8) using GLAO with SNR_{lim}=5 (10). At z>5: kinematics of super-M* galaxies possible. 3D kinematics of M* galaxies secured up to z~4.

- DRM STEP 2: Dynamical state of galaxies (large scale motions): SNR_{min}=5-10. No need for very high spatial resolution (GLAO enough) nor sampling (75mas/pix enough).

- DRM STEP 3: Rotation Curves: Bosma's rule of thumb requires D_{gal}/2Dpix > 14. z=2: V_{rot} (MOAO/GLAO) and shape of RC (MOAO) recovered for M* galaxies. z=4: V_{rot} only with MOAO, beam smearing affecting RC shapes. In any case: deconvolution will be needed as it is already the case at at z=0.5-2.5 with GIRAFFE & SINFONI.

- DRM STEP 4: Detailed kinematics: recovery of clumps using MOAO for M* galaxies up to z=4. GLAO does not provide enough spatial resolution.

Summary - Technical

<S/N> vs. phys. parameters, instr. parameters, telescope parameters

Scaling relations compared to and validated by simulations

- Impact of telescope diameter:
  - No impact on spatial resolution (partial AO correction regime)
  - No breaking point in telescope diameter. $SNR \propto D$: reducing the diameter from 42 to 30m would require longer exposures by a factor 2.
- Impact of site:
  - Sky background: background dominated regime above z=4. Then $SNR \propto 1/\sqrt{(background)}$. A 4 times higher background (Paranal vs. Mauna Kea) would require 4 times longer exposures.
  - Seeing: limited impact on (integrated) SNR (loss of ~5-15% from 0.8'' to 0.95''). Strongest seeing conditions will limit ability in recovering Rotation Curves and detailed kinematics.

Proposal

Goal: ~ 1000 galaxies at $2<z<6$ with $0.1 < M_{stellar} < 5.10^{11}\ M_{\odot}$

Assumptions:

- MOAO, Mauna Kea-like Background
- R=5000, 50mas/pix
- $SNR_{min}=10$
- 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
- Overheads = 30 %

Conclusion

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

- Need to optimize the instrument for the highest-z bin: bigger pixels, better transmission, more multiplex, improved AO, ...
- Program feasible in ~ 100 nights, selecting galaxies with $M_{stellar}>10^{10}\,M_{\odot}$ ($M^*(z=5.6)=0.8\ 10^{10}\,M_{\odot}$)