l'Observatoire de Paris — GEPI
Galaxies Étoiles Physique et Instrumentation

The Physics and mass assembly of distant galaxies with the E-ELT

M. Puech
GEPI – Observatoire de Paris

DRM part: P. Rosati, S. Toft, A. Cimatti, B. Neichel, T. Fusco

EAGLE part: M. Lehnert, J.-G. Cuby, Y. Yang, B. Neichel, T. Fusco, G. Rousset, H. Flores, S. Morris, C. Evans, N. Welikala, and the EAGLE team

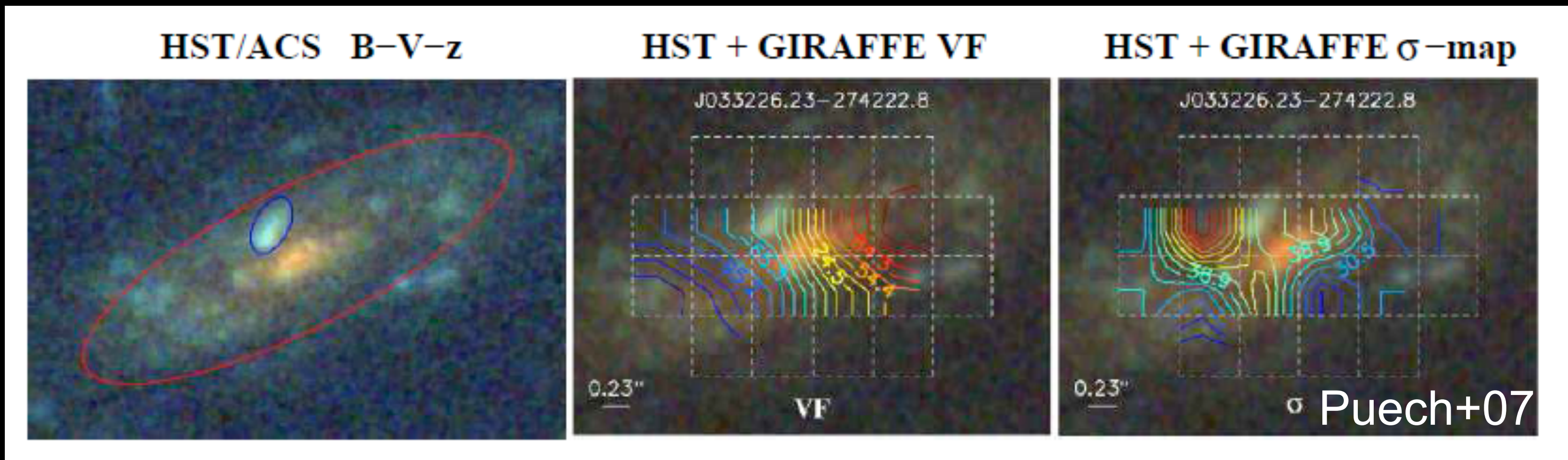
Galaxy Evolution

Q: What is the main channel for mass assembly in galaxies (as a function of cosmic time)?

We don't know… But it should be one of these:

- Cold gas accretion from filaments
- Minor mergers
- Major mergers

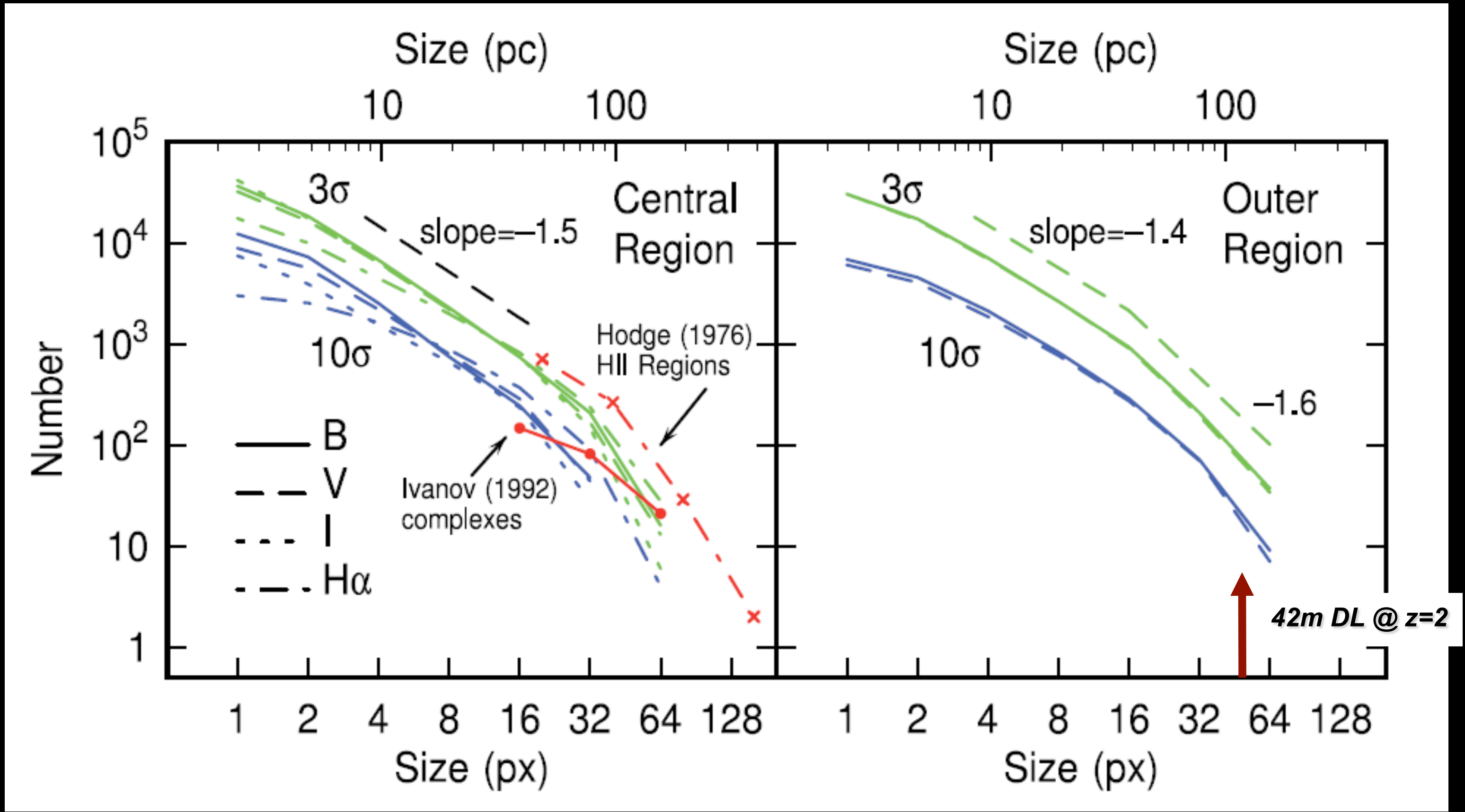
Galaxy evolution processes operate on different spatial scales



We need to map the physical and chemical properties of galaxies… but on which scale?

What is the relevant scale?

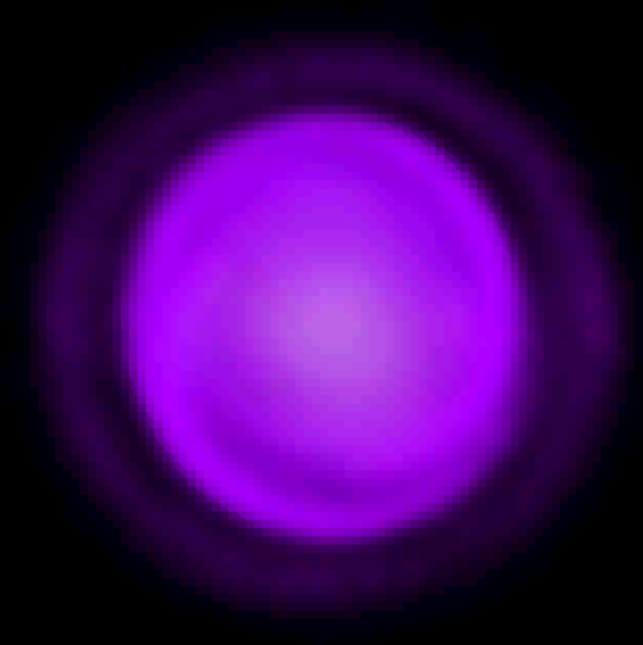
Star formation in galaxies ↔ HII regions



Elmegreen et al. 2006

The E-ELT will allow us to resolve only the largest HII complexes

Clumps



Formation of an exponential spiral disk
and a central bulge

from the evolution of a gas-rich primordial disk

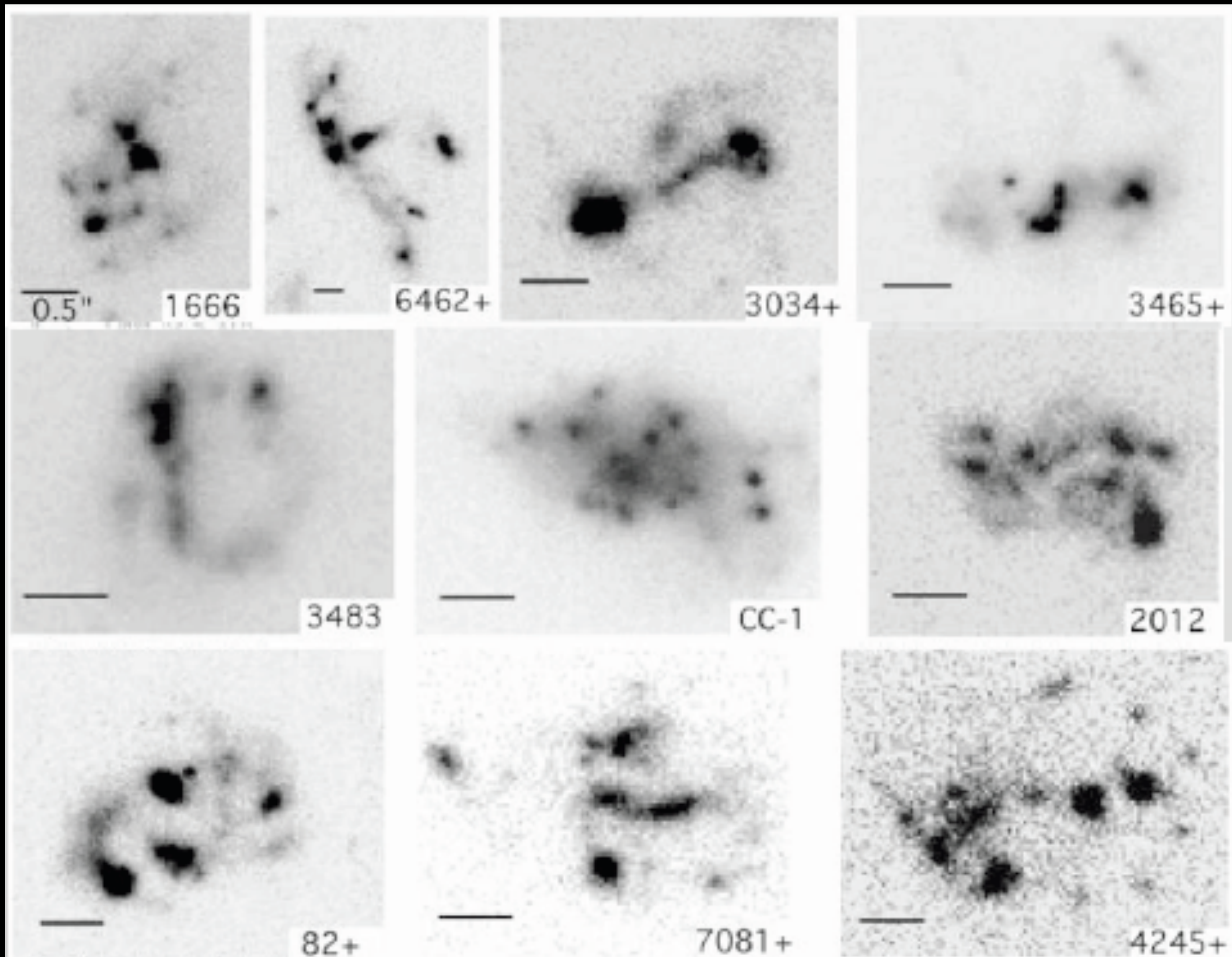
evolving through a clumpy phase

Models from Bournaud, Elmegreen & Elmegreen 2007

Clumps are thought to be resulting from
Jeans-fragmentation in high-z, very gas-rich disks
fed by cold streams (eg, Dekel+09, Puech10)

Clumps

Kpc-sized clumps are ubiquitous in z>1 galaxies:



1 kpc
=
120-160 mas
@ z=1-5

37.5 mas/spaxel

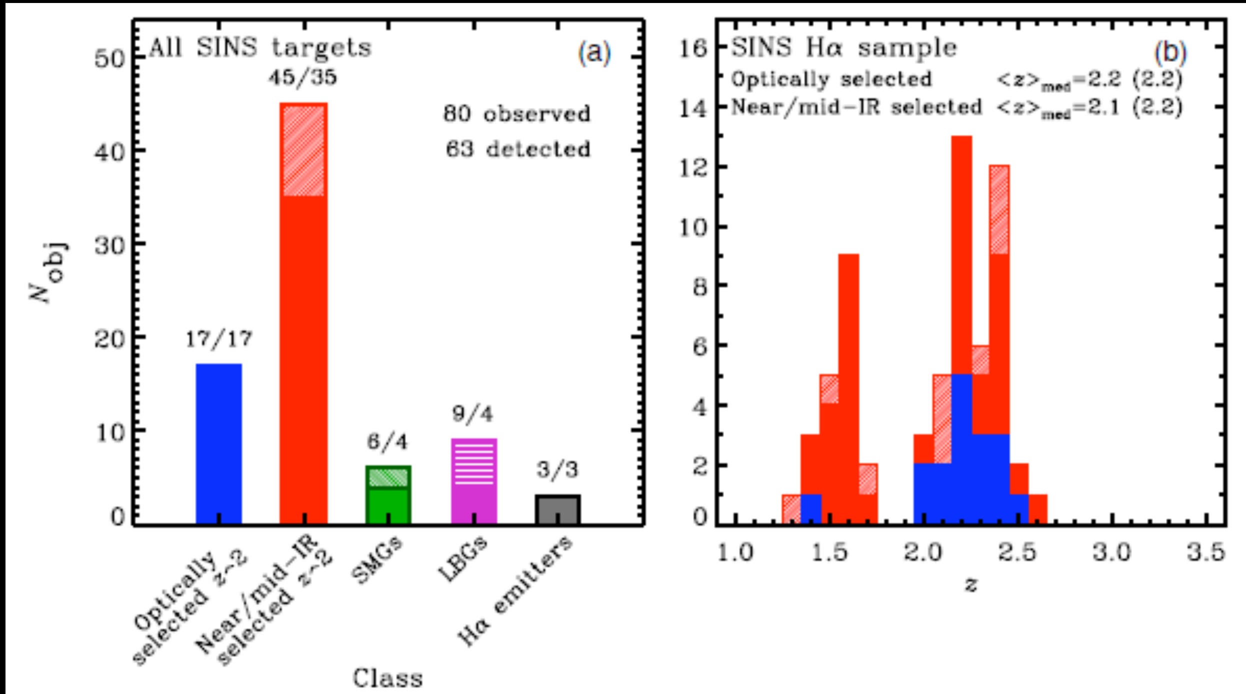
⬍

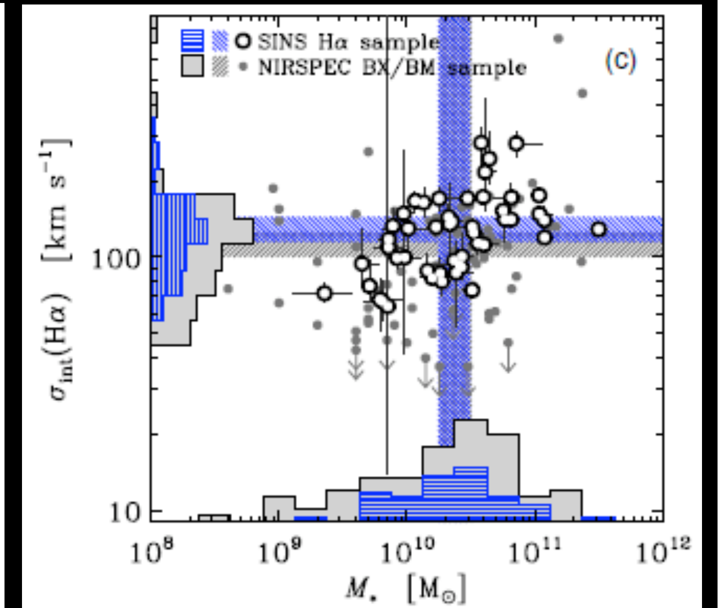
Optimal compromize
Between SB detection
&
Spatial sampling

Elmegreen &
Elmegreen 2005

Galaxy Evolution

Current high-z (z>1.5) 3D samples are drawn using various selection criteria which makes their representativeness more uncertain.





Förster-Schreiber+2009

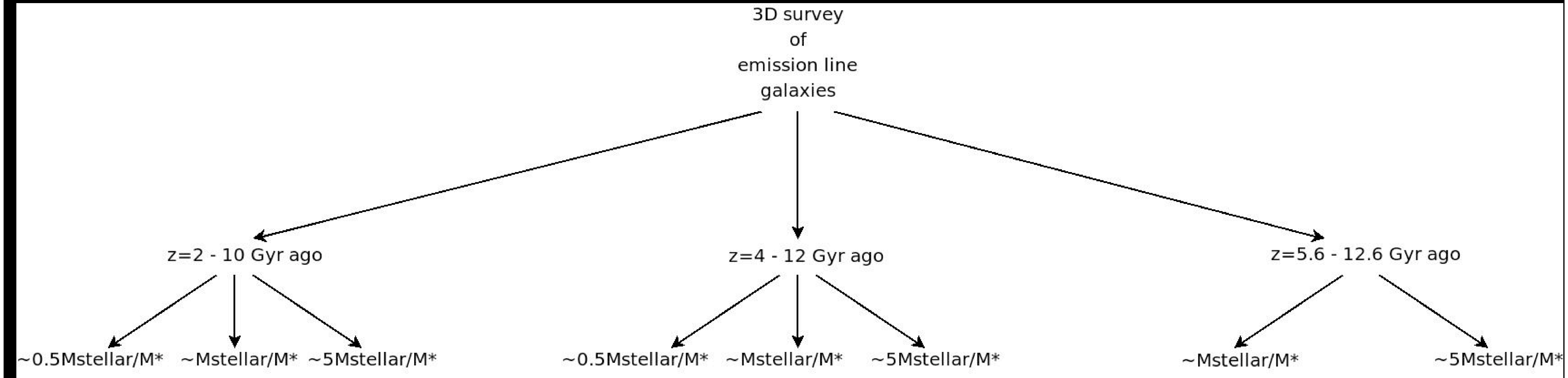
One would like to use the E-ELT collecting power to observe *ALL* galaxies in a given volume, in a mass-limited way and then draw secured representative samples.

Rq: very deep, highly complete, spectroscopic surveys will be needed

DRM Proposal

- **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.**

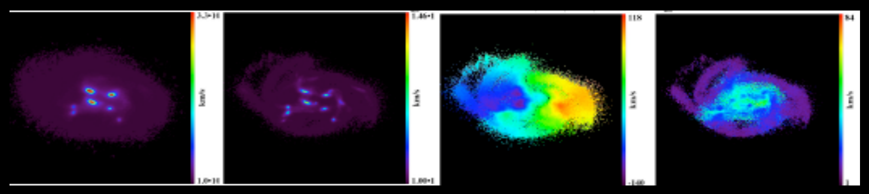
- **Mapping of physical and chemical properties (kinematics, SFR, metallicity, etc.) in a large sample (statistics) of massive, emission line galaxies at $2<z<5.6$ in the range $0.1<M_s<5\times10^{11}\ M_\odot$.**



➡ **Multi-Object Integral Field Spectroscopy is required (EAGLE, see N. Welikala's talk and S. Morris' poster).**

DRM simulations

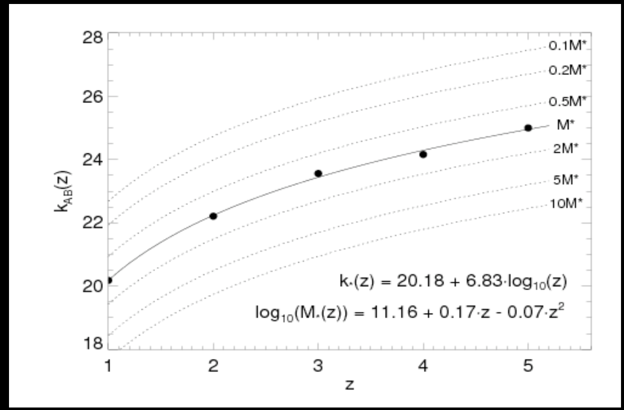
- **Set of ~1000 simulations of IFS of distant galaxies from z=2 to z=5.6**



High resolution templates rescaled in size and flux

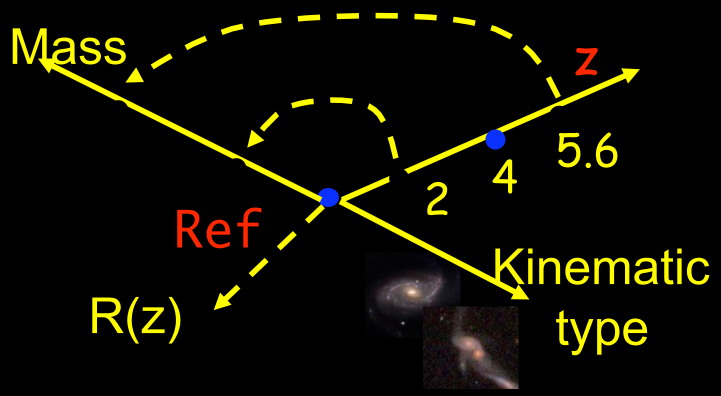
Puech+08,10

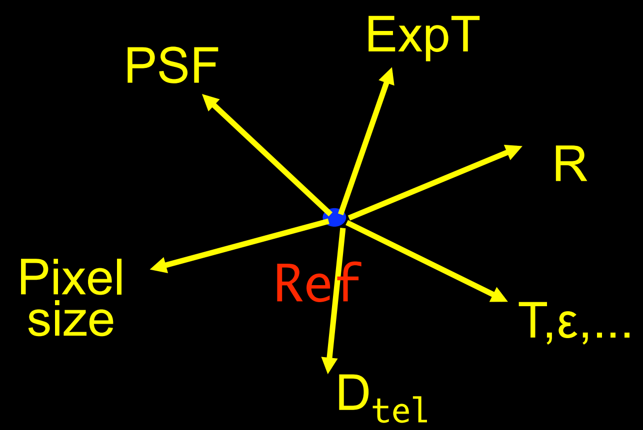
⊕



Empirical relations:
$K_{AB}(M_s,z)$,
$R(z,\lambda,M_s)$, $M_s(z)$, $V(M_s)$

- **Systematic exploration of the science and observational parameter spaces**



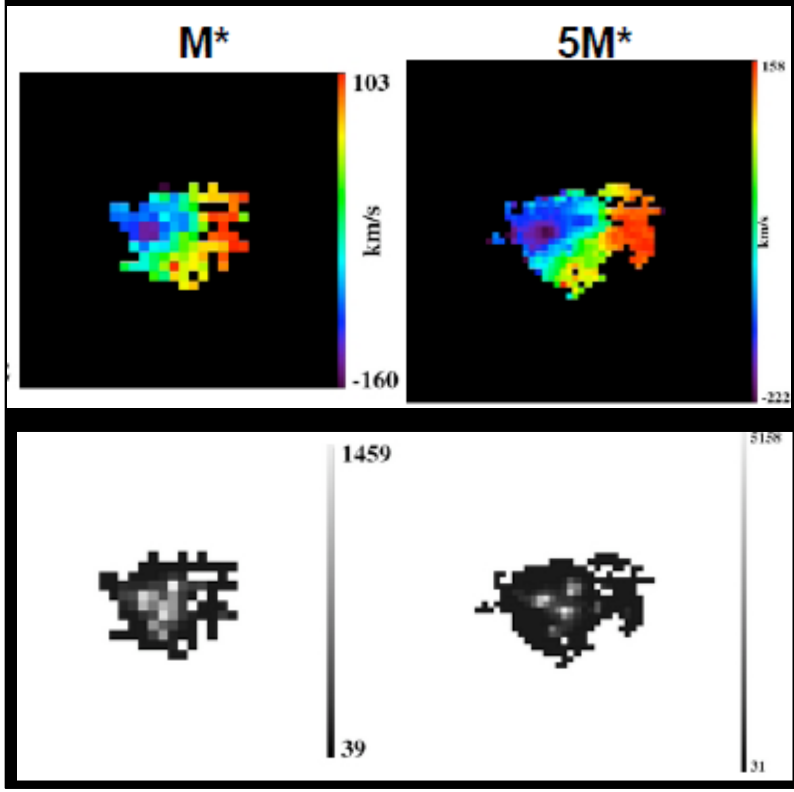


DRM Results: GLAO vs. MOAO

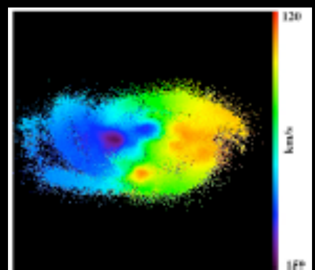
High multiplex required: R_{FoV}>5arcmin ➡ GLAO or MOAO

GLAO leads to smaller S/N compared with MOAO and will limit observations to smaller-mass galaxies. GLAO will impact strongly the recovery of Rotation Curves and detailed kinematics.

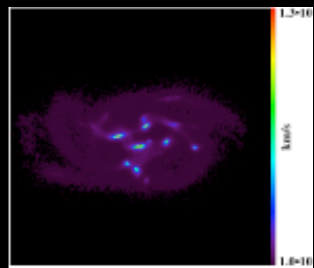
MOAO z=4



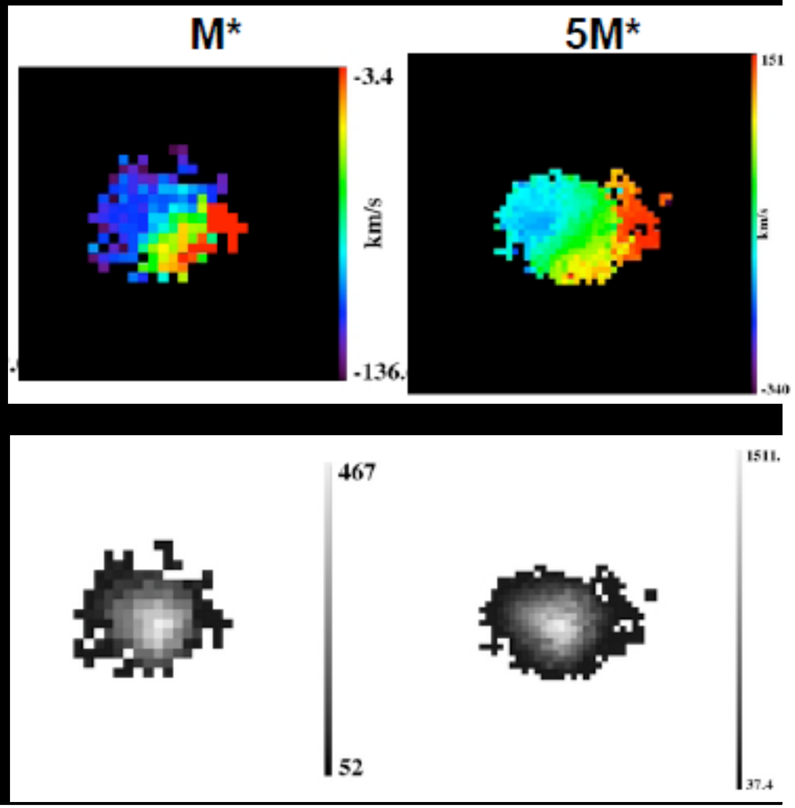
50mas/pix
R=5000



Bournaud+07



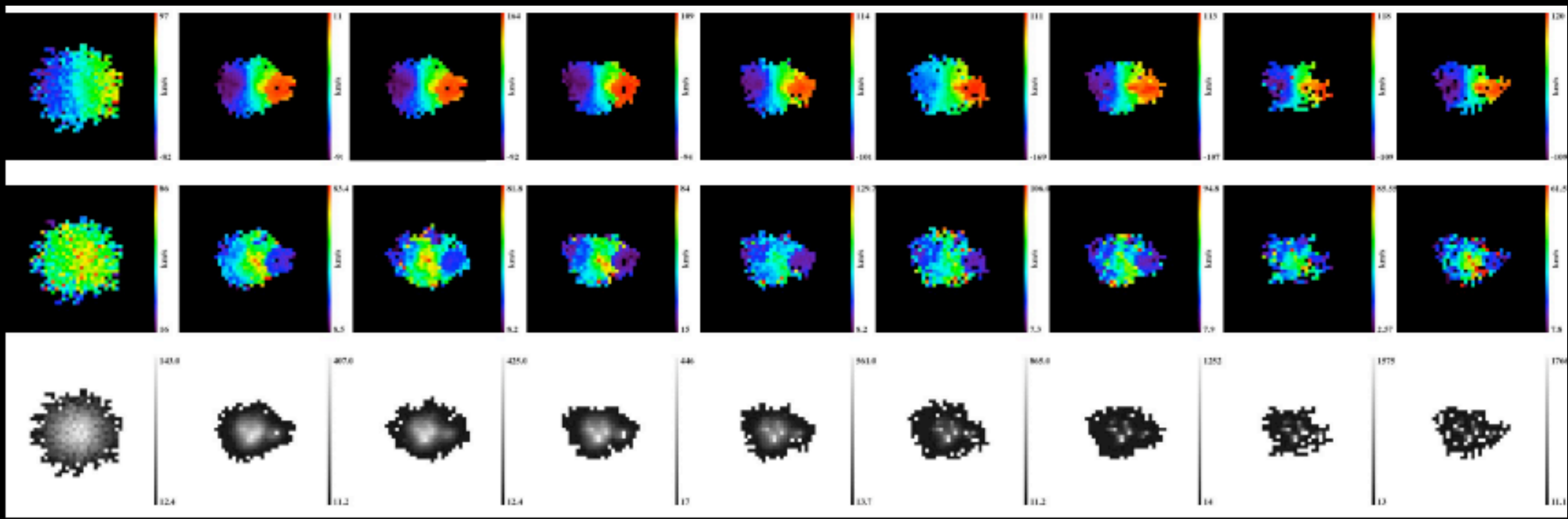
GLAO z=4



Clumpy Disks

Analogs with a range of EEs ... challenging since we consider a very small distant galaxy at z=4 with only 30A EQW (SINFONI data at z~2 show ~100A)

37.5mas/pix (EAGLE baseline)



seeing   15% 61%

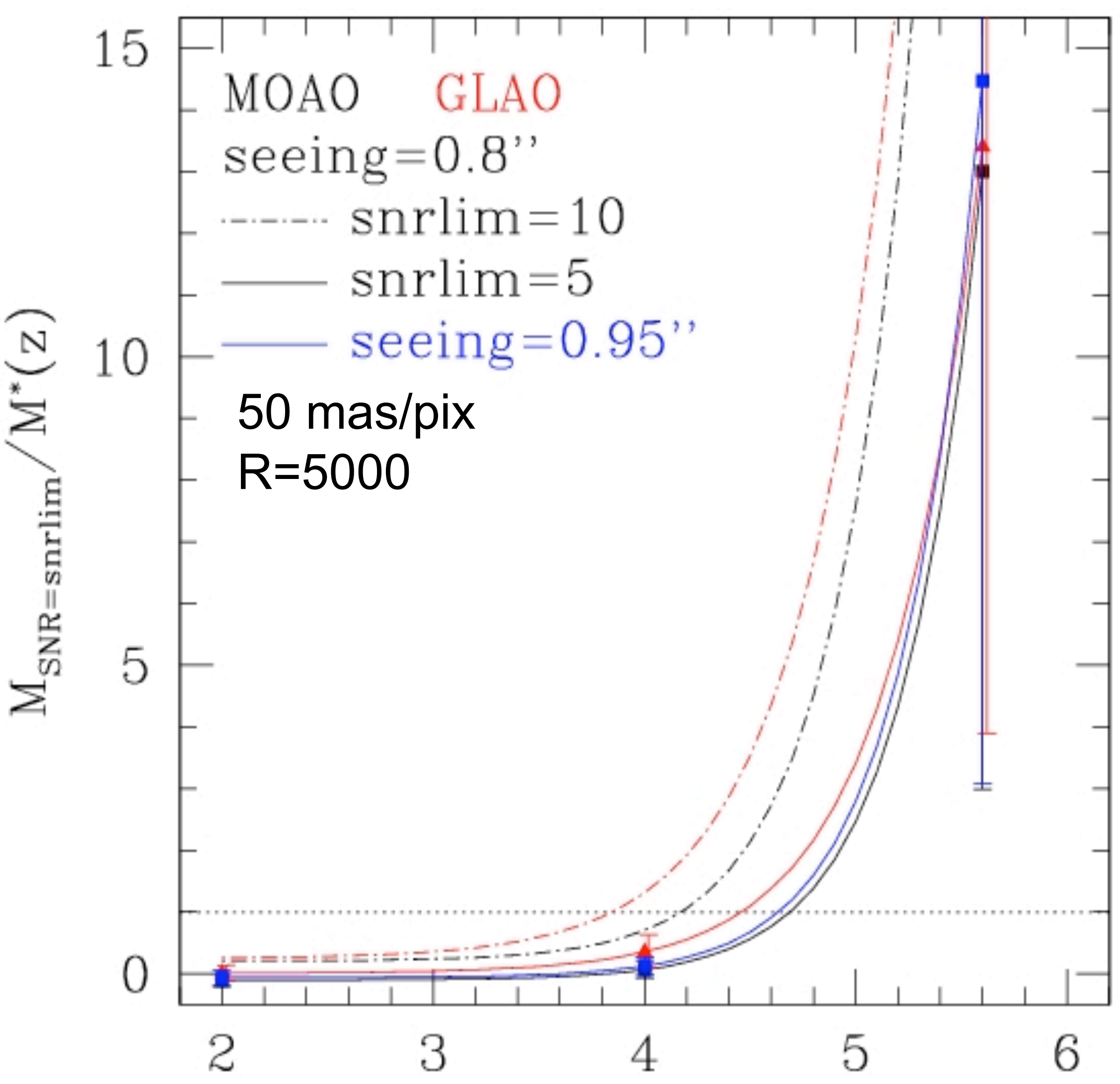
At about 20% can start to see clumpy structure, 30% is more robust

DRM Results: sample selection

The GSMF can be probed down to M* up to z~4.5

Flat curve below z~4: no strong sensitivity to variations in, e.g., seeing, SNR limit,etc.

Above z~5: S/N limited by the thermal background from the telescope



Puech et al. 2010

DRM Results: Optimal IFU survey

DRM Goal: ~ 1000 galaxies at 2<z<5.6 with 0.1 < M_s< 5.10^{11} $M_\odot$ using MOAO

R=5000, 50mas/pix, SNR_{min}=10, Overheads OH= 30 %, 8 bins

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

T_{intg}	$0.5M_*$	M_*	$5M_*$	Total
z=2	1.2	0.8	0.3	2.3
z=4	2.3	1.4	0.6	4.3
z=5.6	—	66.9	16.39	83.2
Total	3.5	69.1	17.2	89.8

In nights (1n = 8 hr)

$$T_{survey}(n) \simeq 90 \left(\frac{125}{M}\right) \left(\frac{SNR_{lim}}{10}\right)^2 \left(\frac{N_{gal}}{1000}\right) \left(\frac{OH}{1.3}\right)$$

Multiplex	Total integration time	Number of galaxies
125	90n	1000
20	90n	160
20	12.5n=100hr (z≤4)	240

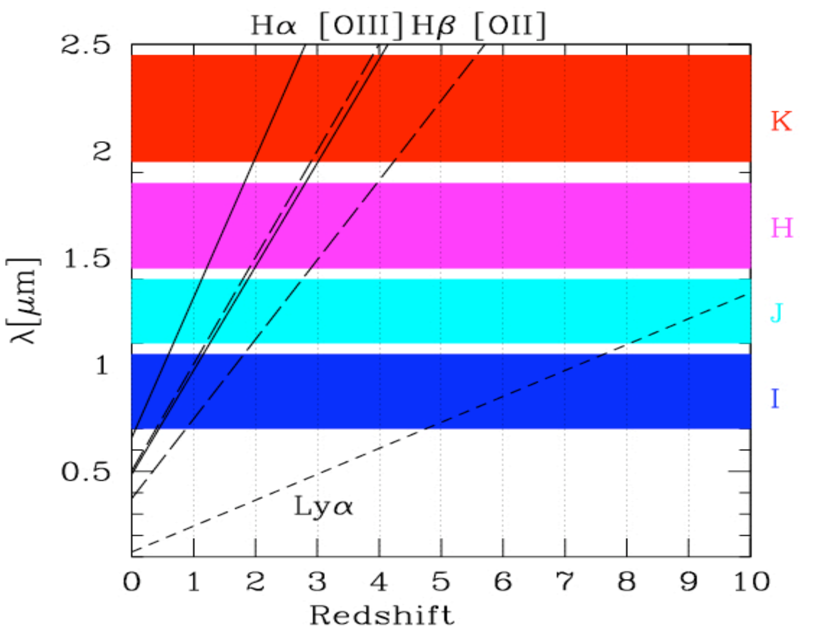
IFU survey (EAGLE DRSP)

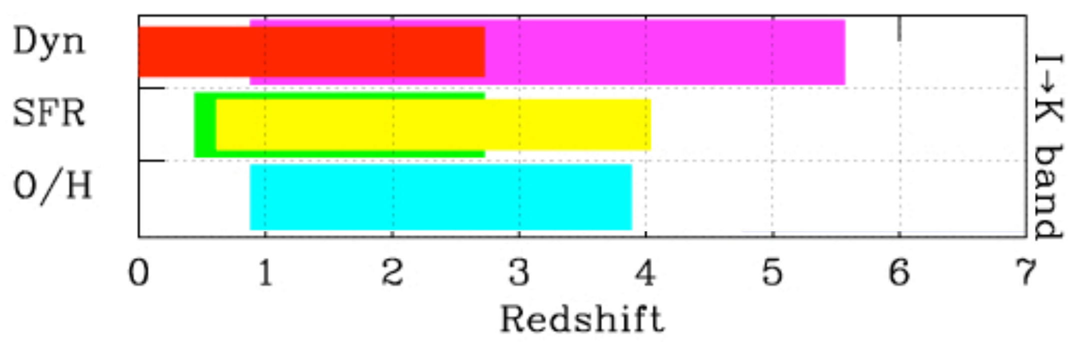
SHALLOW

- Goal = dynamics
- z = 1 to 4
- Switch between lines to avoid the K-band
- Total T_{intg} ~100 hr for several hundreds of gals (M=20)

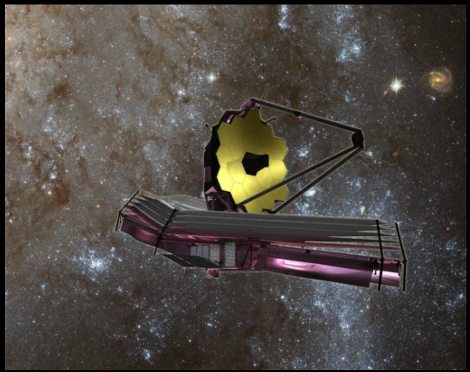
DEEP

- Goal = line ratios
- z range = [1.2-1.7, 2-2.6-3-3.6] to have emission lines available in 2 or 3 bands
- 20 gals / band
- ~30 hr per band
- Total T_{intg} ~270 hr for ~60 gals

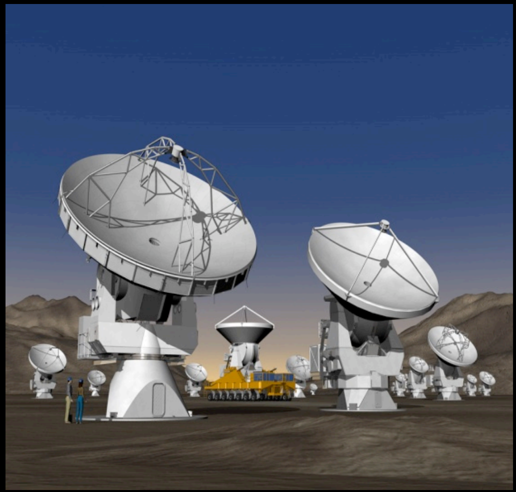




Synergies



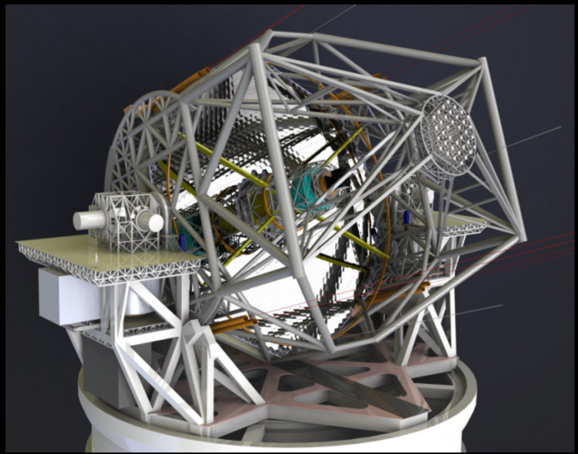
JWST: z, SED



ALMA: molecular gas kin.

Optimized trade-off for studying the internal driver(s) of galaxy mass assembly

Other E-ELT facilities



Spatial Resolution

↕

Surface brightness detection

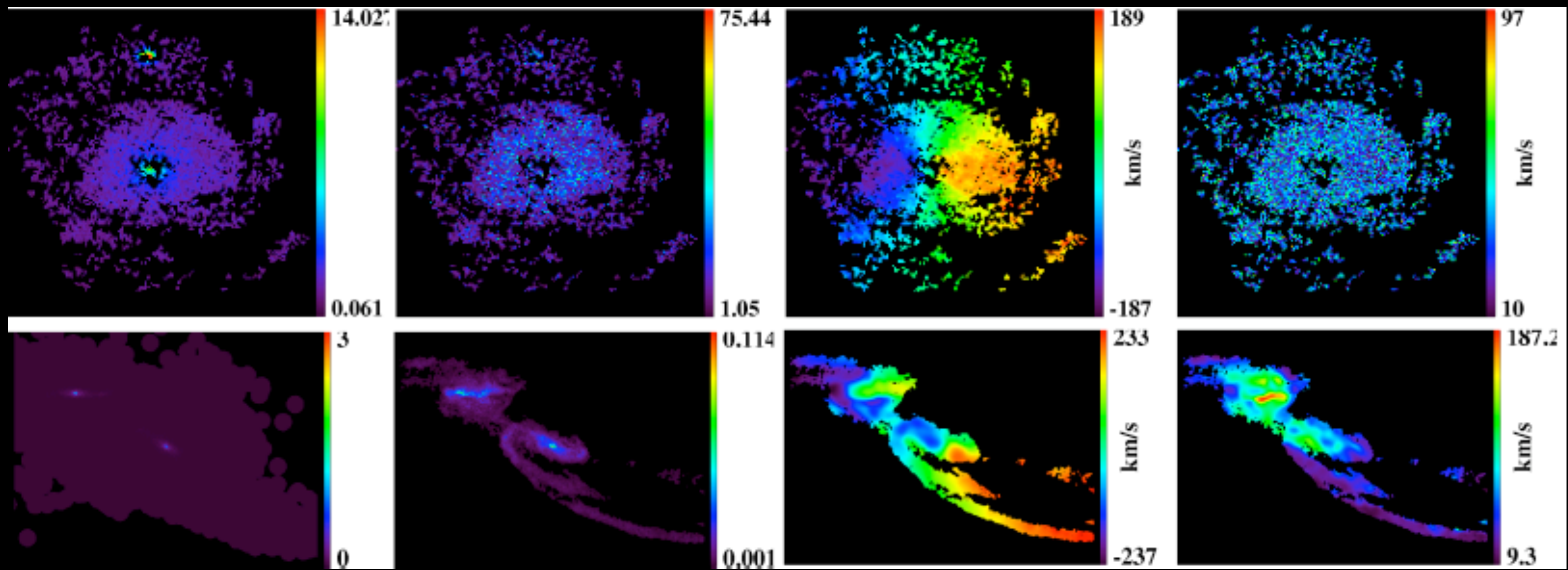
EAGLE will be unrivaled to study statistically the physics of distant galaxies in situ

Extras

Large spatial scales

Test-case II : distinguishing between a grand-design spiral and a merging pair

UGC5253: Fabry-Perot Observations (Garrido et al. 2004)

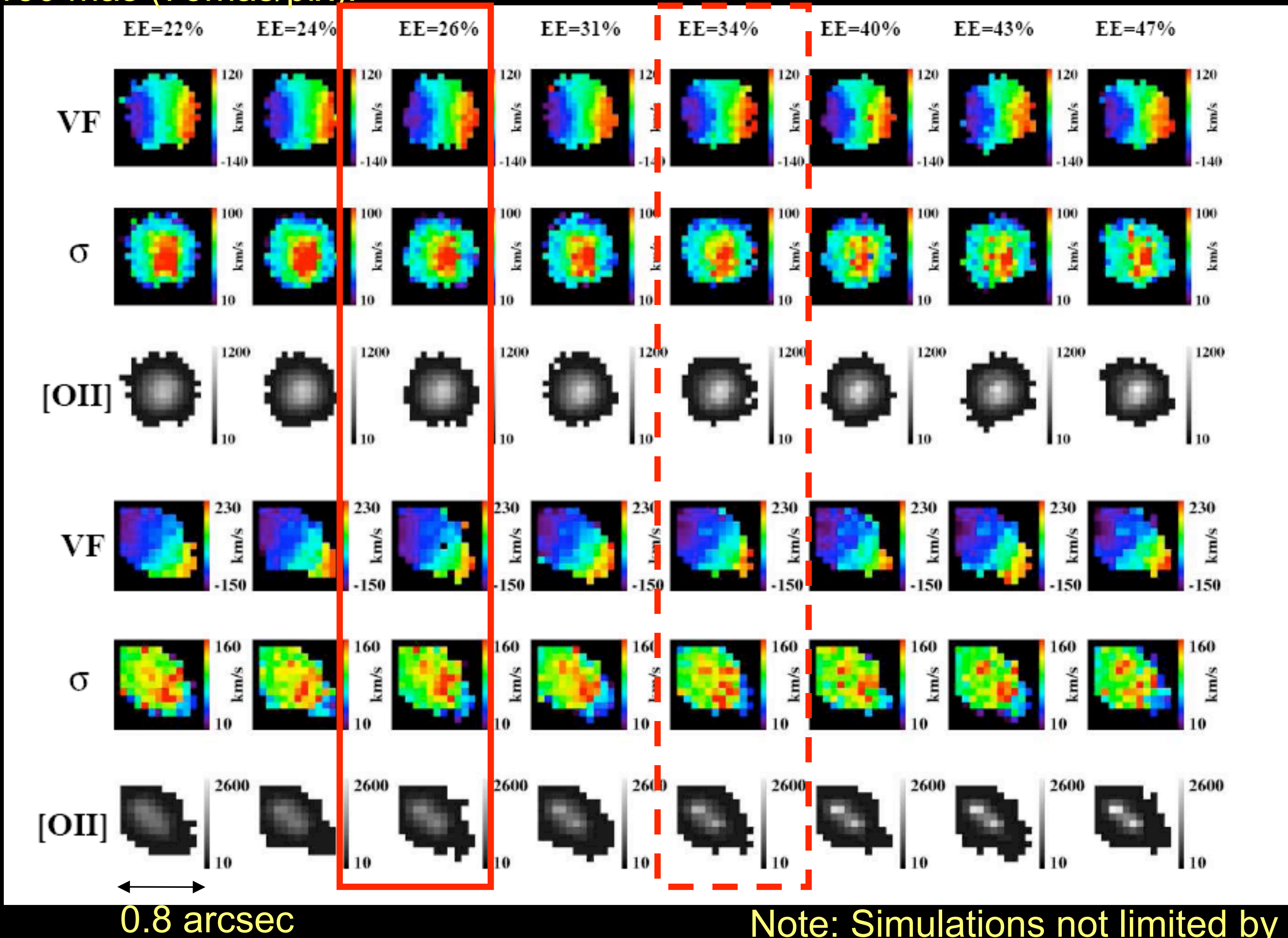


Sbc-Sbc Major Merger SPH Simulation (Cox et al. 2006)

What is the required scale-coupling & contrast to distinguish between them?

Mergers vs. Disks @ z=4

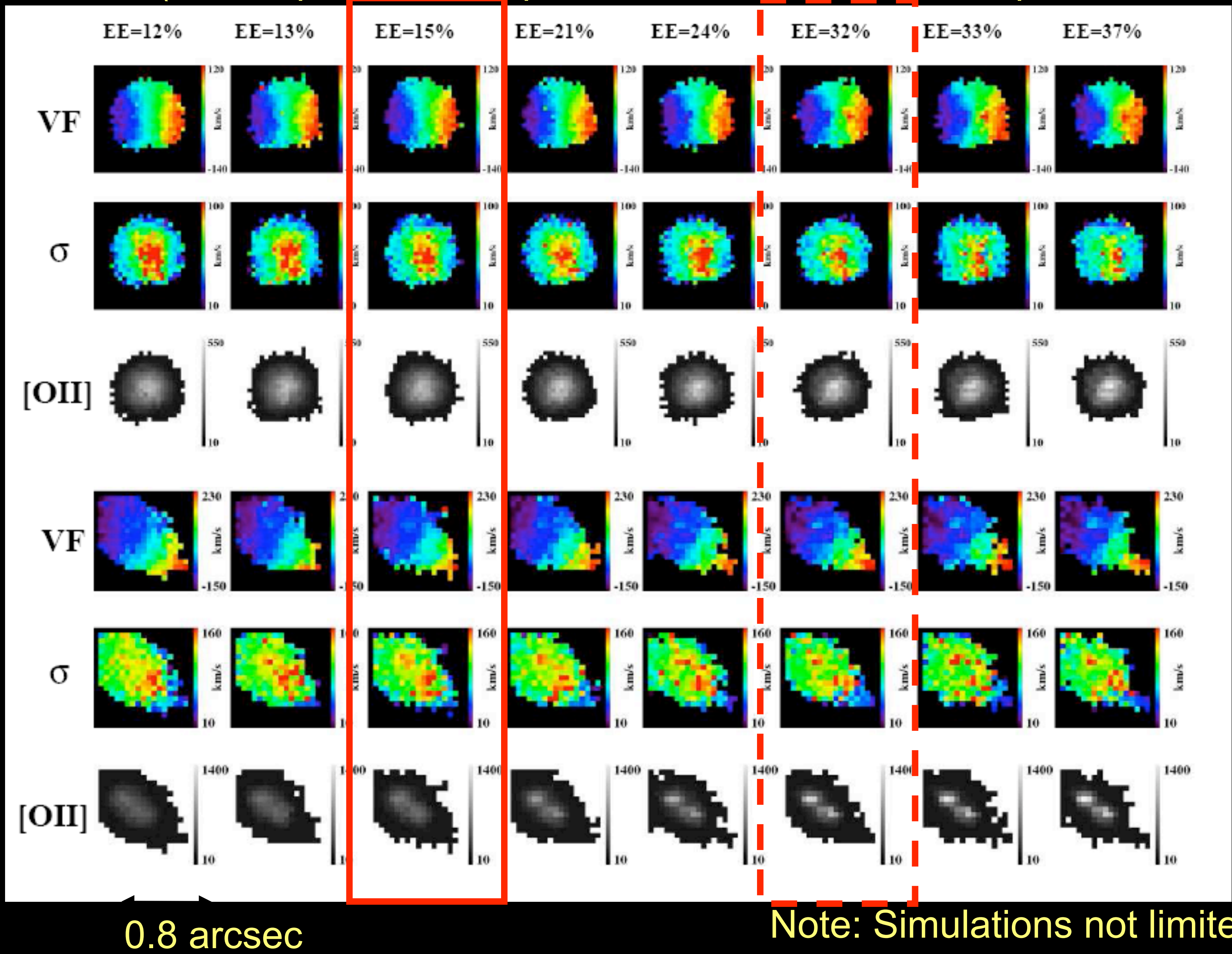
EE in 150 mas (75mas/pix):



Note: Simulations not limited by S/N

Mergers vs. Disks @ z=4

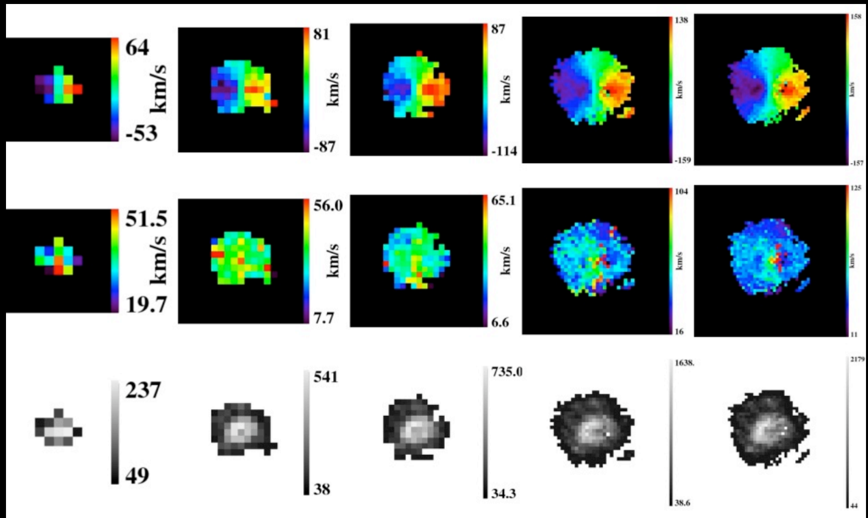
EE in 100 mas (50mas/pix): Smaller pixels ➔ smaller contrast required



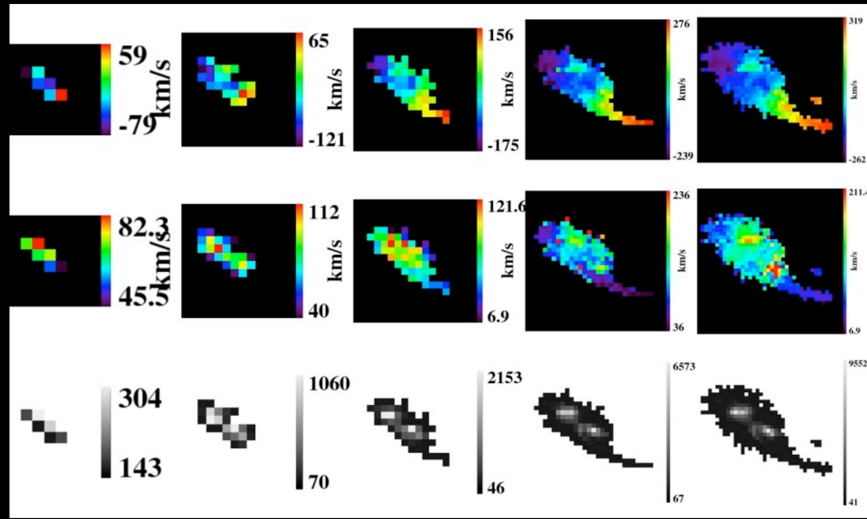
Note: Simulations not limited by S/N

Large scale motions

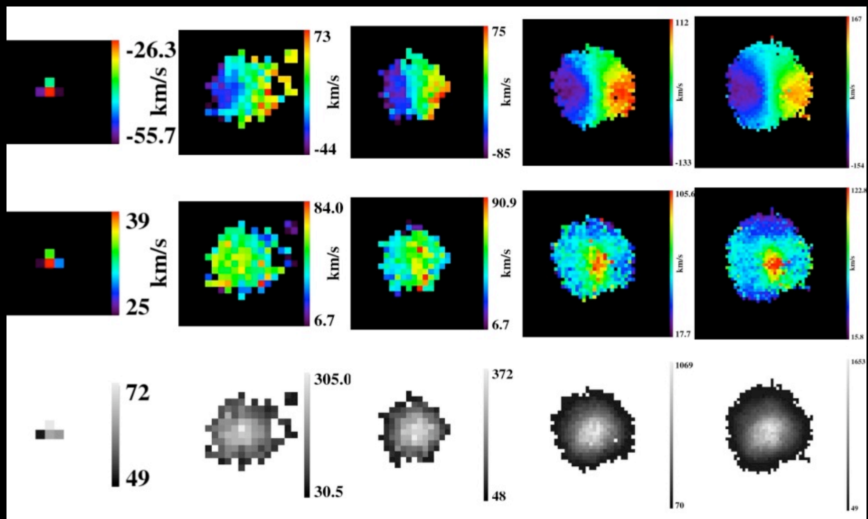
Z=4 with MOAO



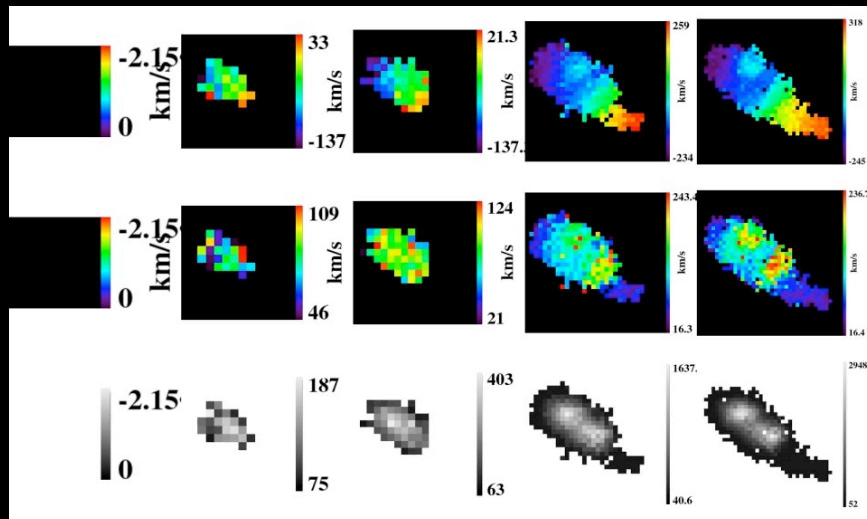
Z=4 with MOAO



Z=4 with GLAO



Z=4 with GLAO



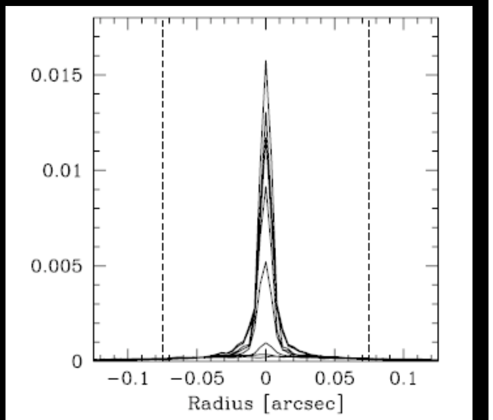
Needs at least SNR~5

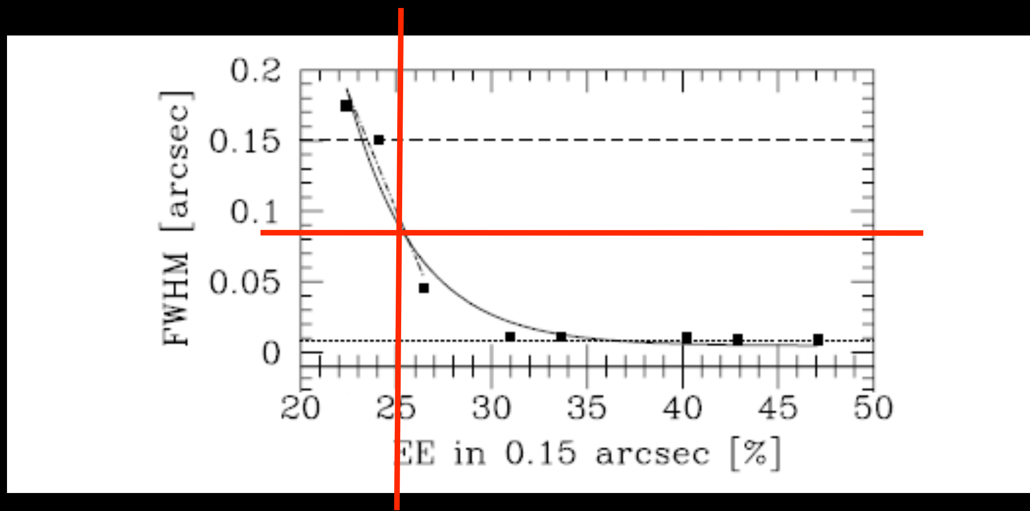
DRM Results: spatial resolution

Pixel scale: depends on the scale-coupling needed (ratio between the spatial feature to be recovered by the IFU and the number of spatial element of resolution). SC=3 is a min. for large-scale kinematics (ie, detection of large-scale rotation; Puech+08; Epinat+2010)

➡ Trade-off between resolution vs. surface brightness detection limit

MOAO PSFs
From ONERA
(Neichel & Fusco)





Above EE ~25%, s.e.r. = 2 spaxels = 75 mas

MOAO correction ⟶

Puech et al. 2008