
Galaxies Under the Cosmic Microscope:
High-z Galaxies — ELT science questions
SPACE
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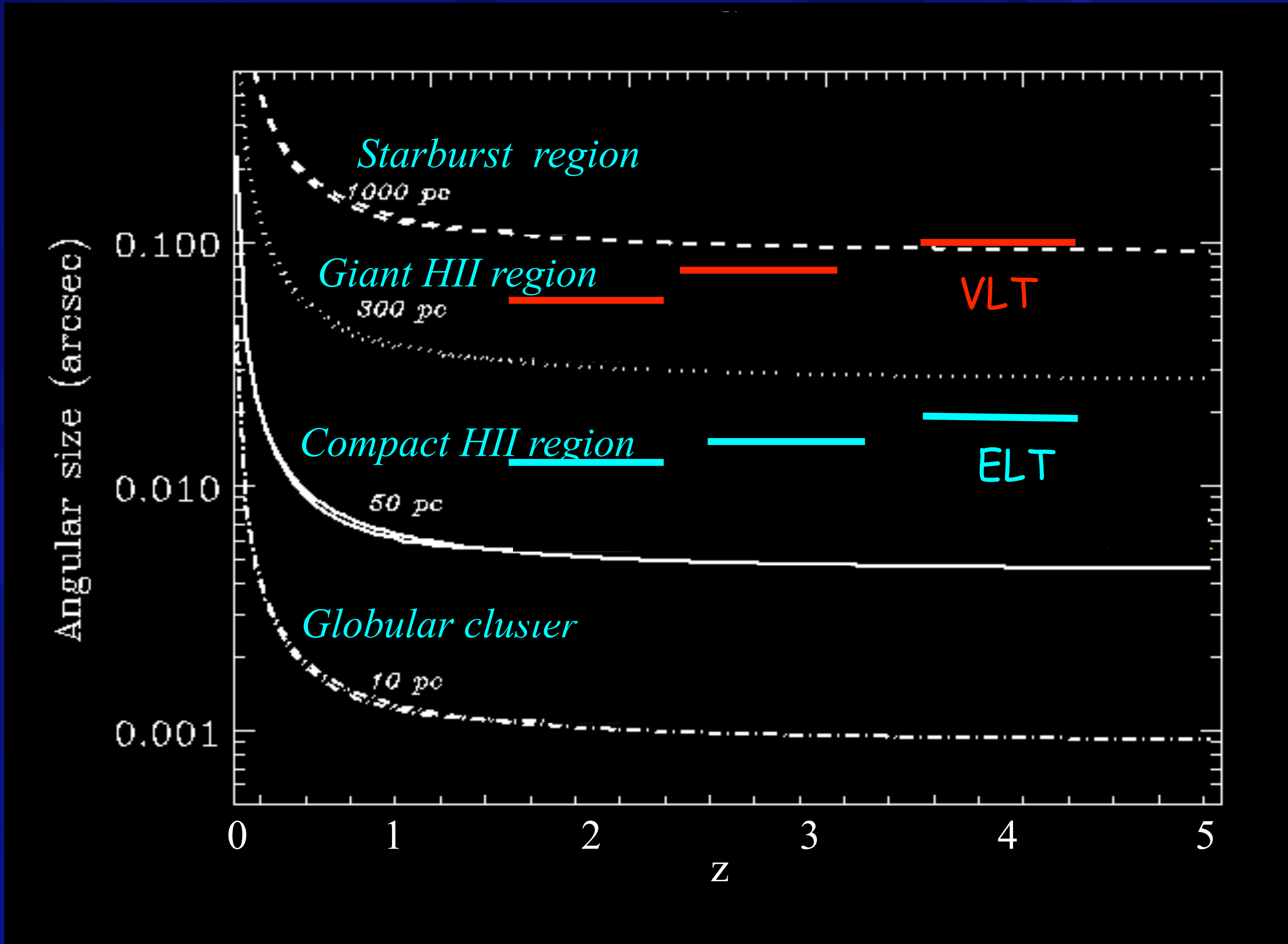
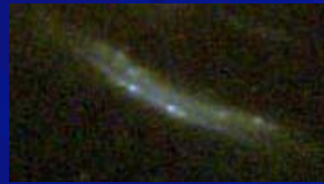
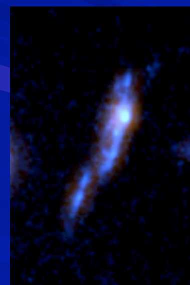
z~1
z~2-3
z~5
Abell 1689b
z = 3.04
MACS J0744
z = 1.28
MACS J1149
z = 1.49



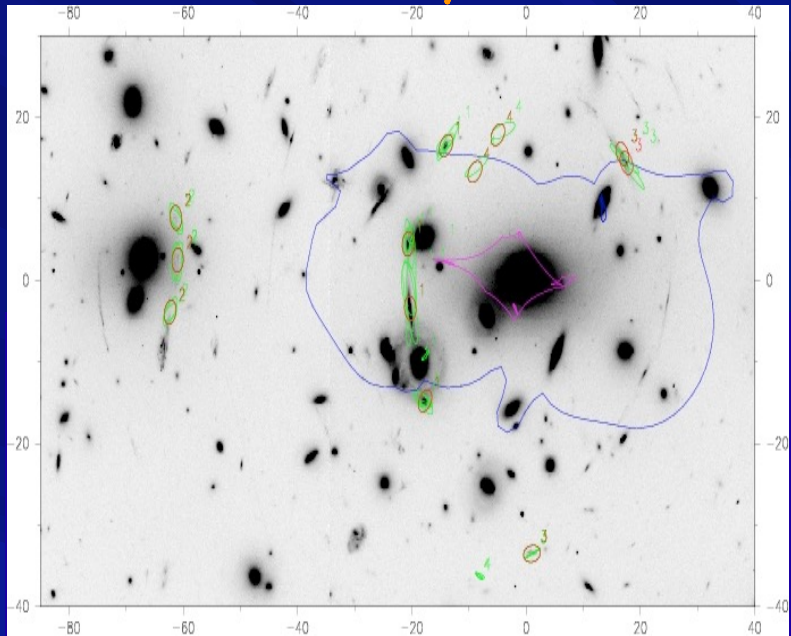


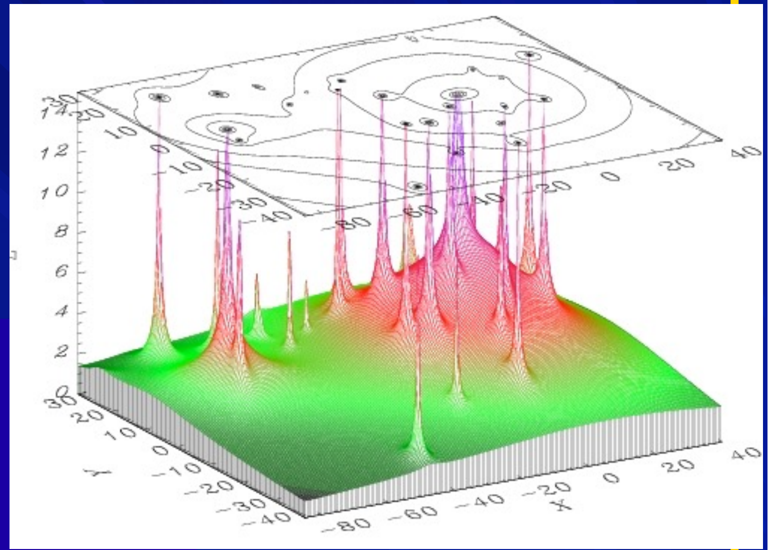
higher resolution (~100-300pc)
lower luminosity
higher-z

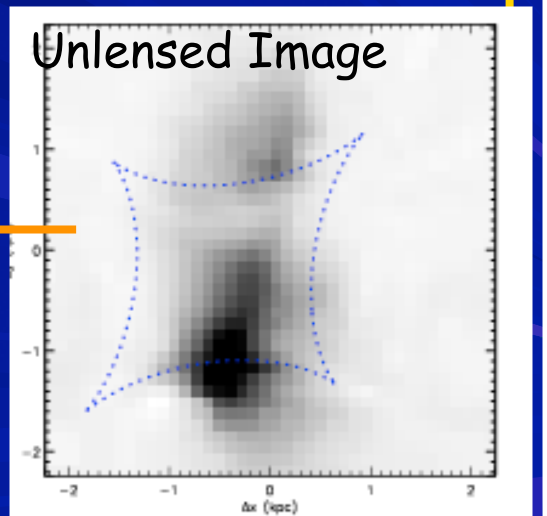


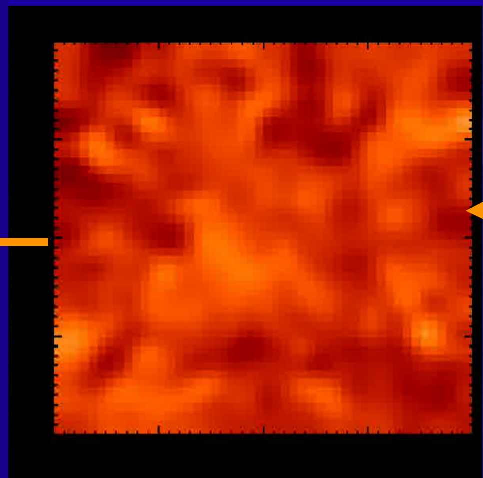
Example: Mass modelling + source plane reconstruction of z=3 galaxy

Original image → Galaxy Cluster → Lens model

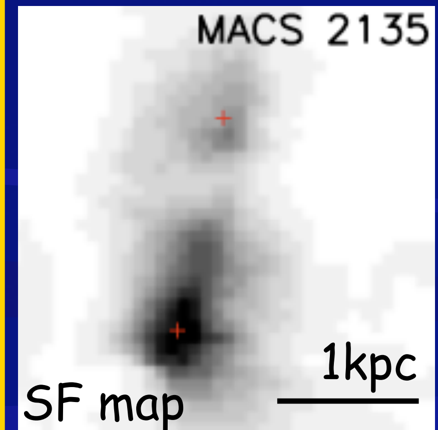




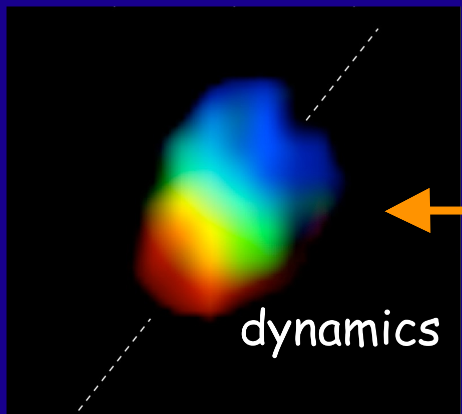




SF and dynamics maps with
spatial scale of 100pc
15mas in non-lensed case!

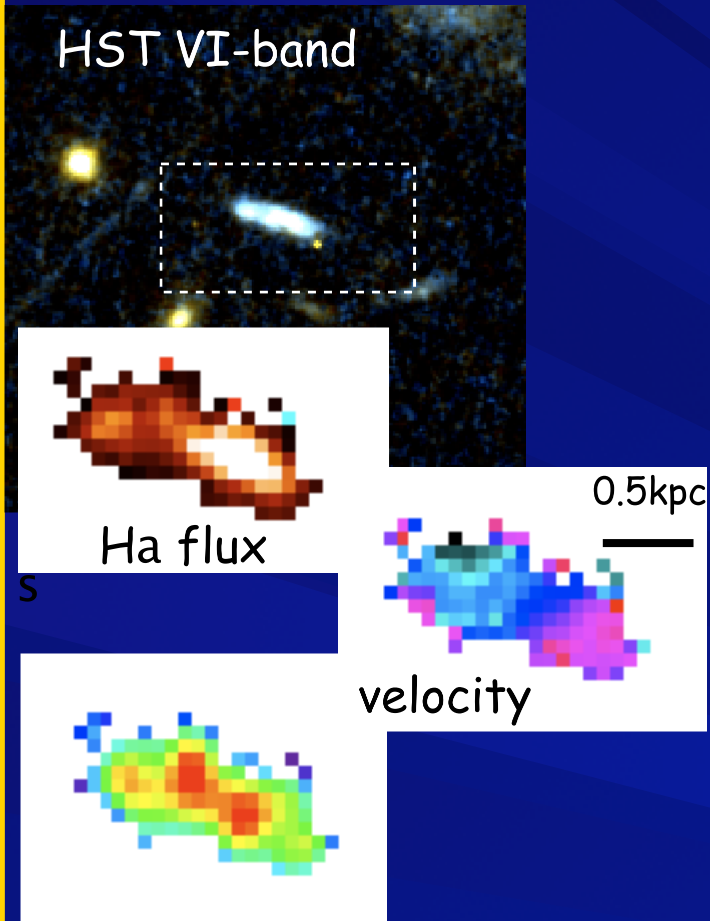


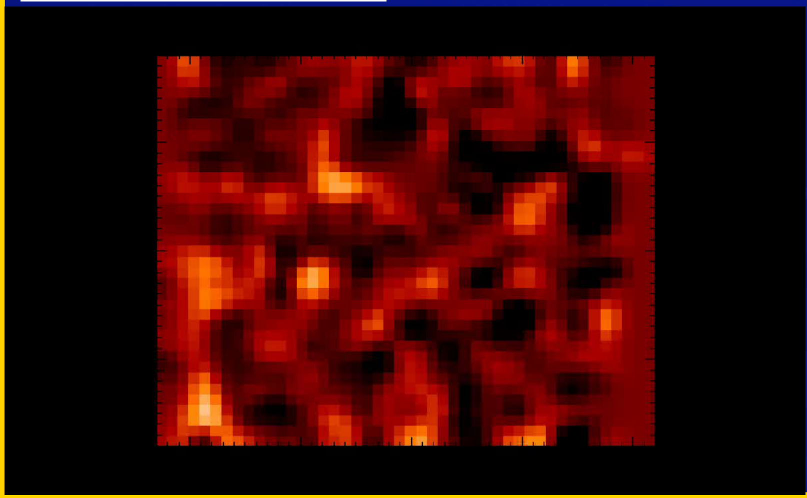
+

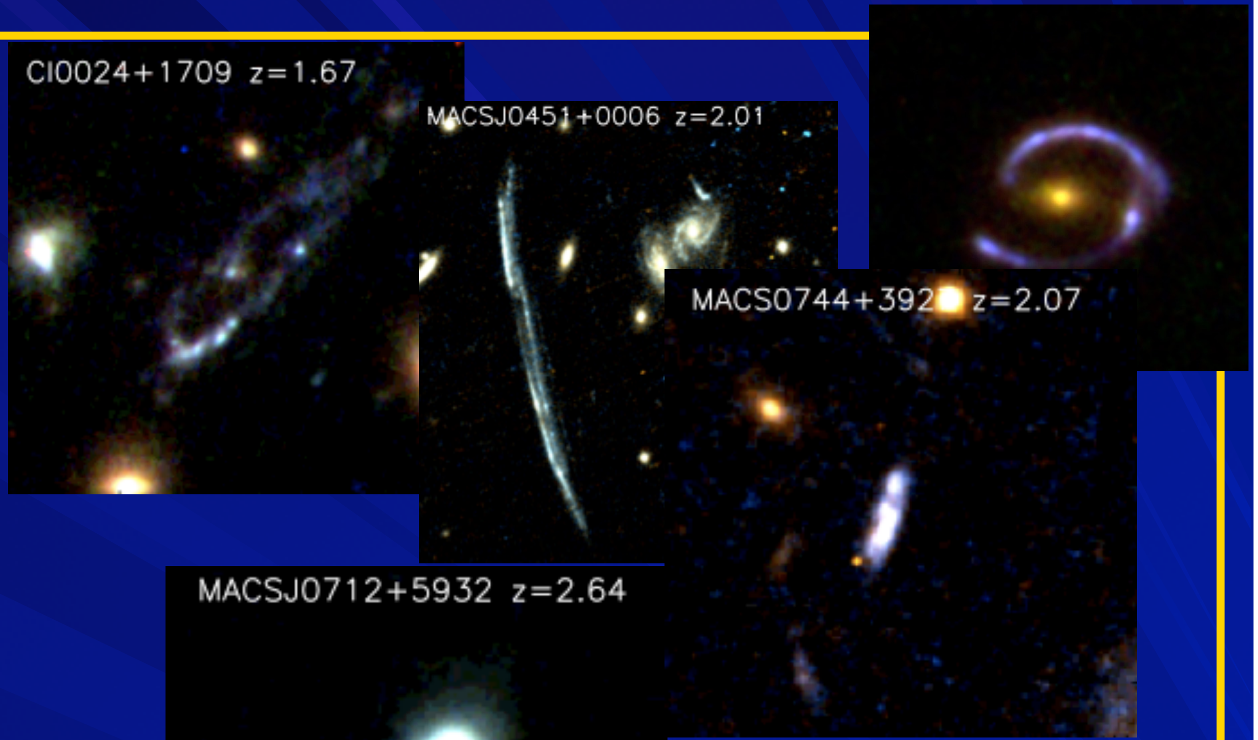


Stark et al. 2008 Nature 455 775

z~2 sample







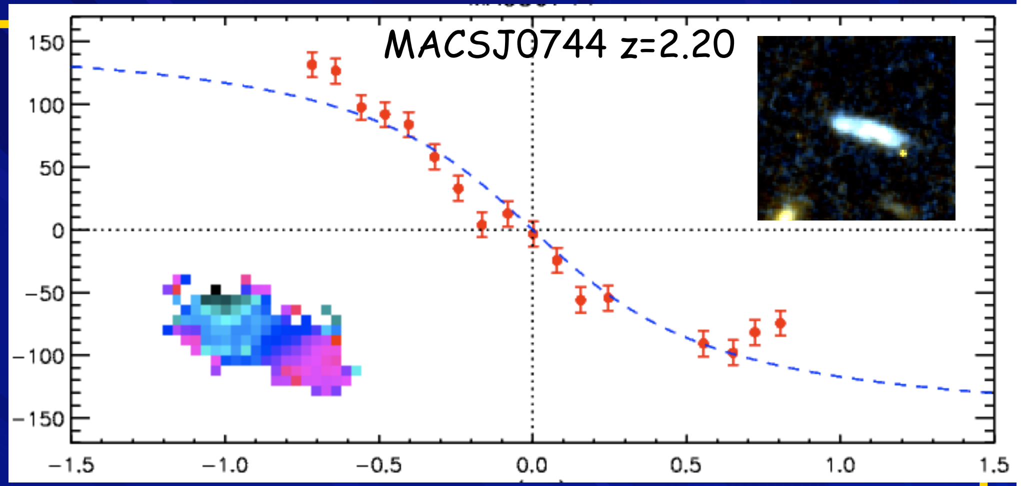
OSIRIS IFU/
LGS-AO targets
(4-6hrs each)

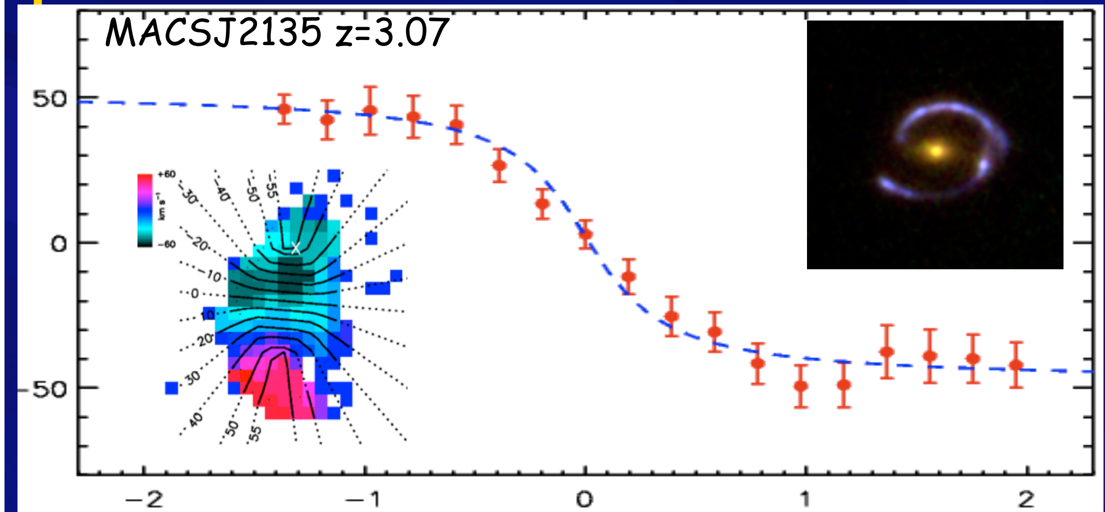
Jones et al. 2010 MNRAS 404 1247

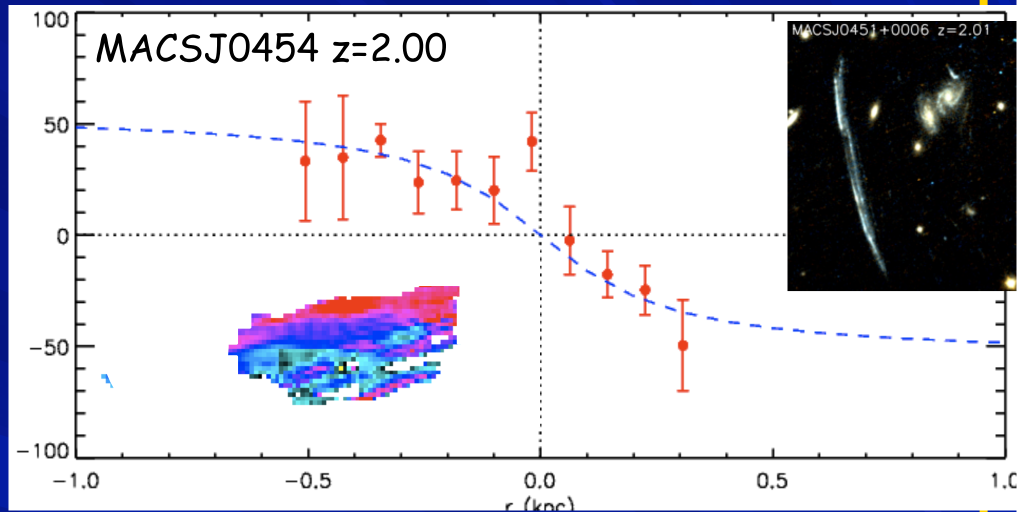
Kinematics

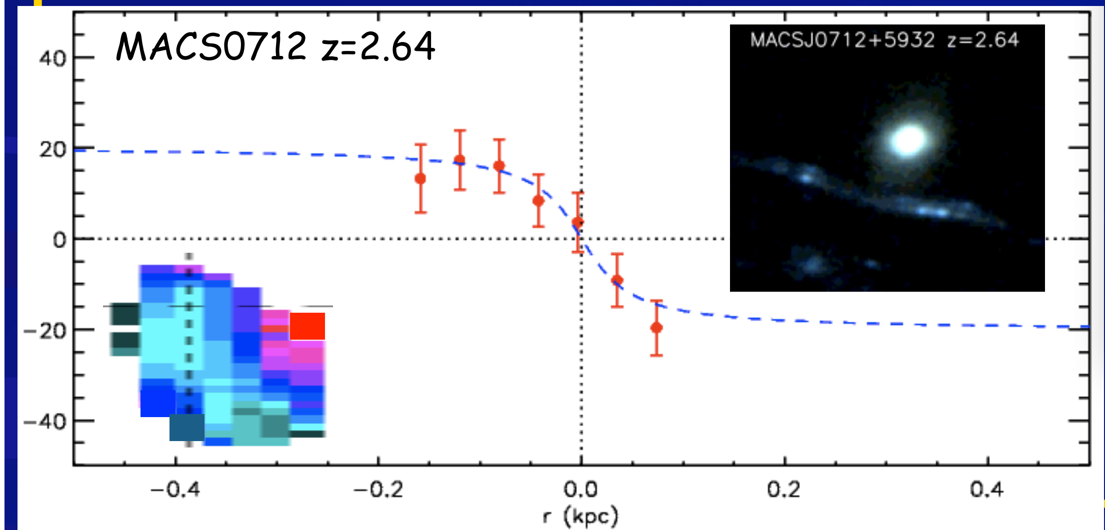
5/6 systems display 'coherent' velocity gradients across 2--10kpc in projection

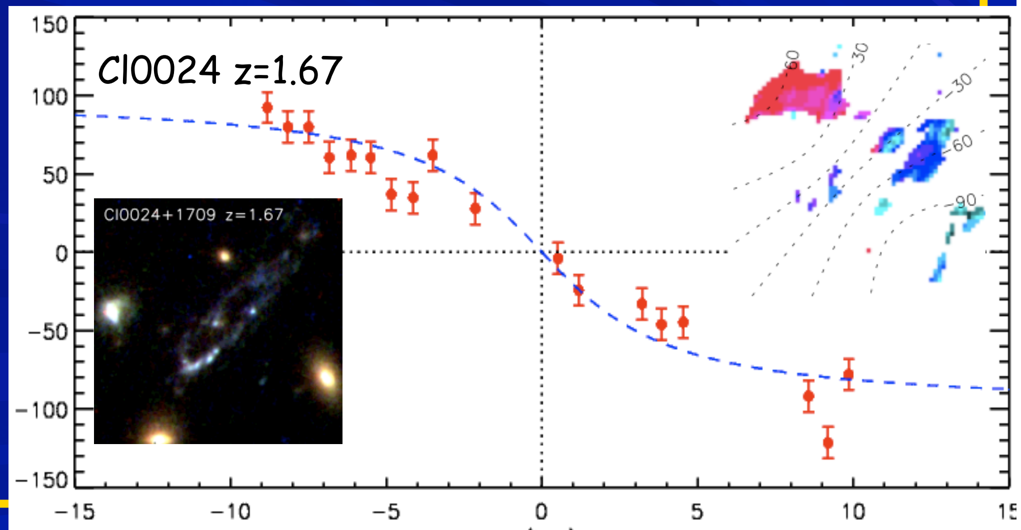
4 consistent with rotation, 1 merger, 1 ambiguous.

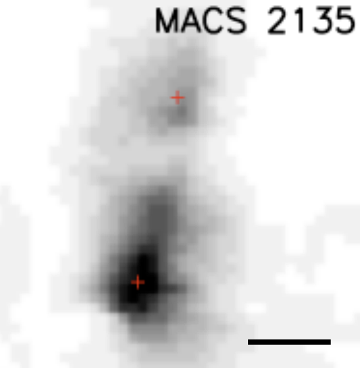




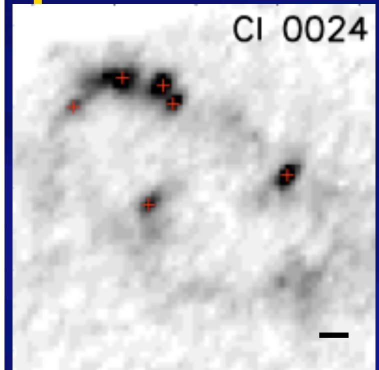








Star-Formation Scales within Disks: back of the envelope calculation



For galaxies whose velocity field resemble rotation:

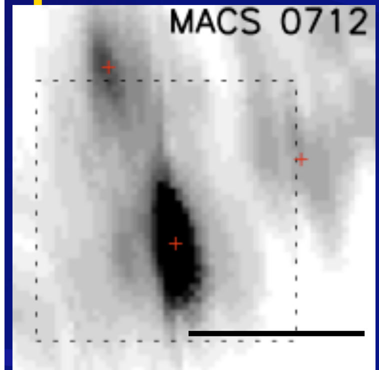
mass surface density

$$Q=\sigma_r\kappa/\pi G\Sigma$$

$1.5V_{max}/R$

Galaxies with Q<1 are unstable and will fragment into giant, dense clumps.

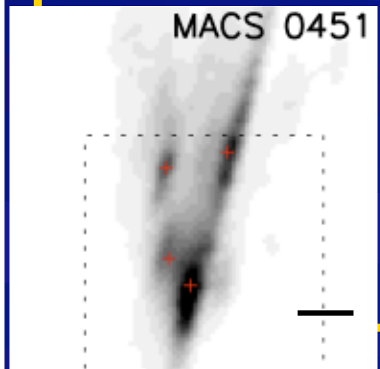
For this sample, Q~0.6 (inclination corrected)

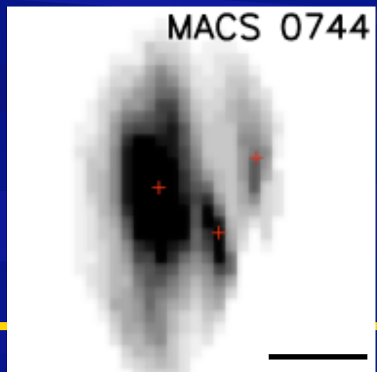


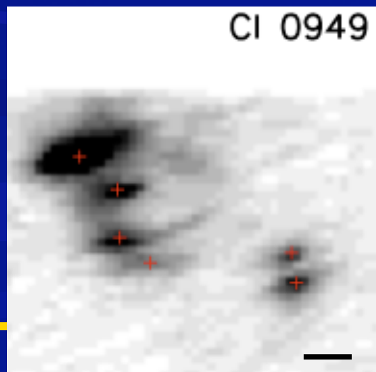
For Q~0.6, gas will fragment into massive clumps on scales of Jeans length for dispersion support.

Largest scale for which velocity dispersion stabilises against gravitational collapse is:

$$L_J=\pi\sigma^2/8G\Sigma$$

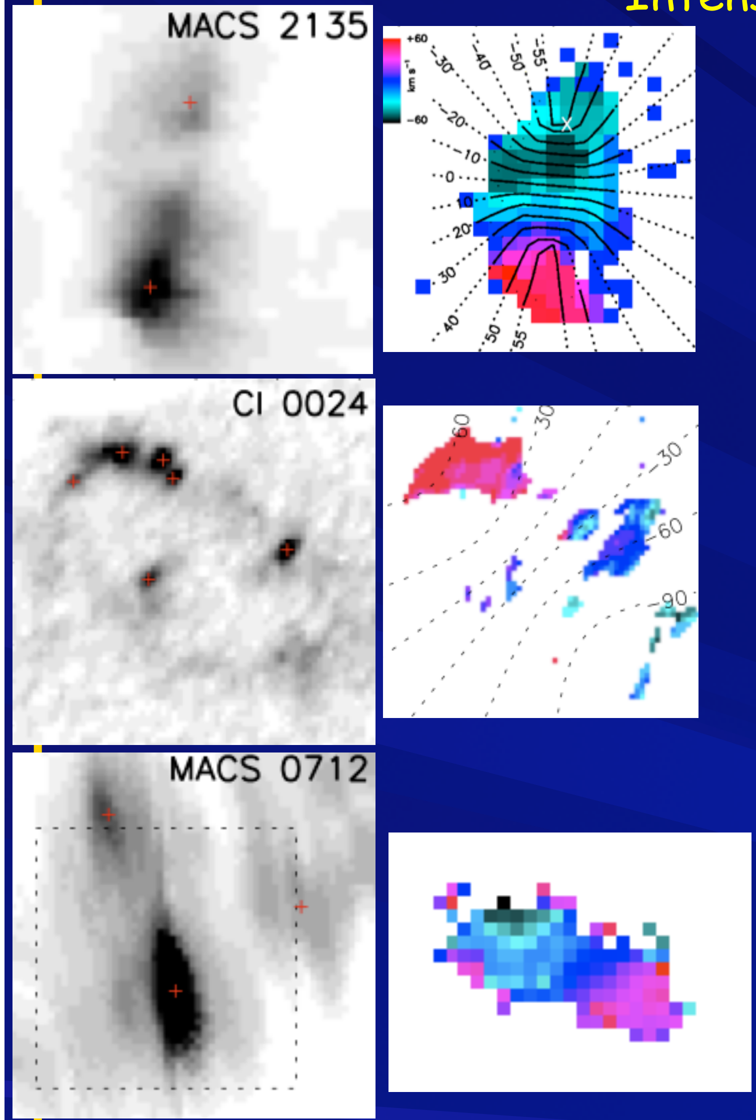


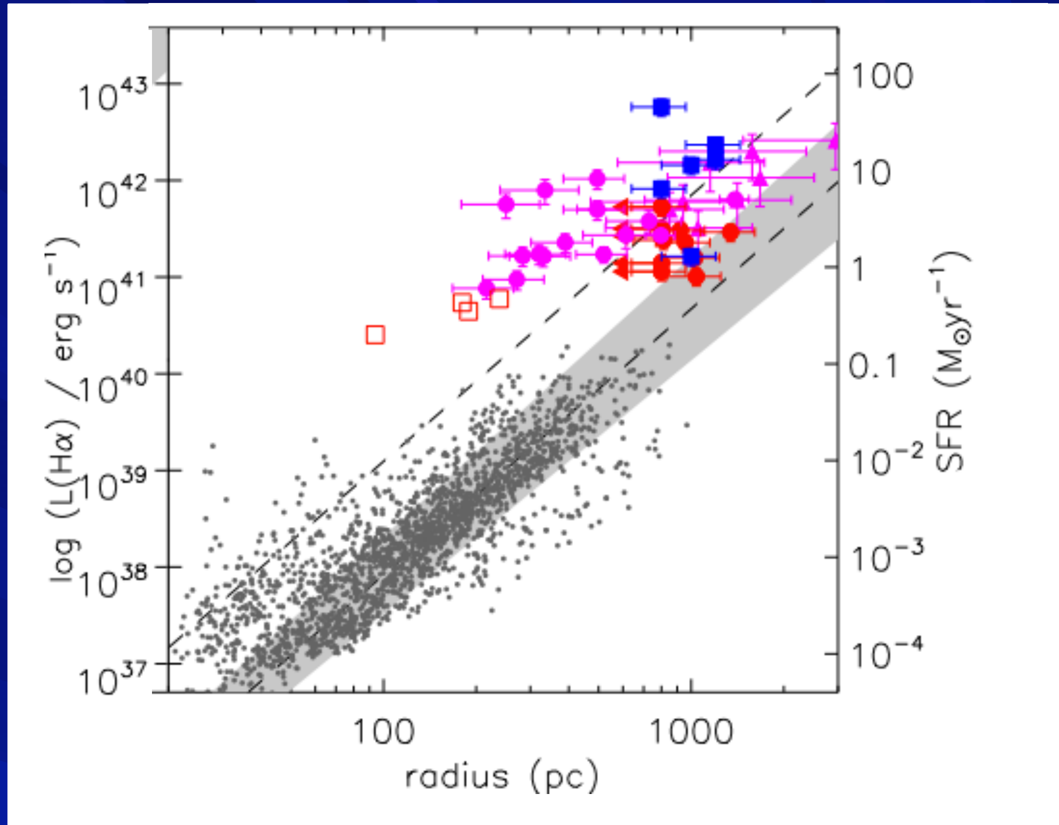




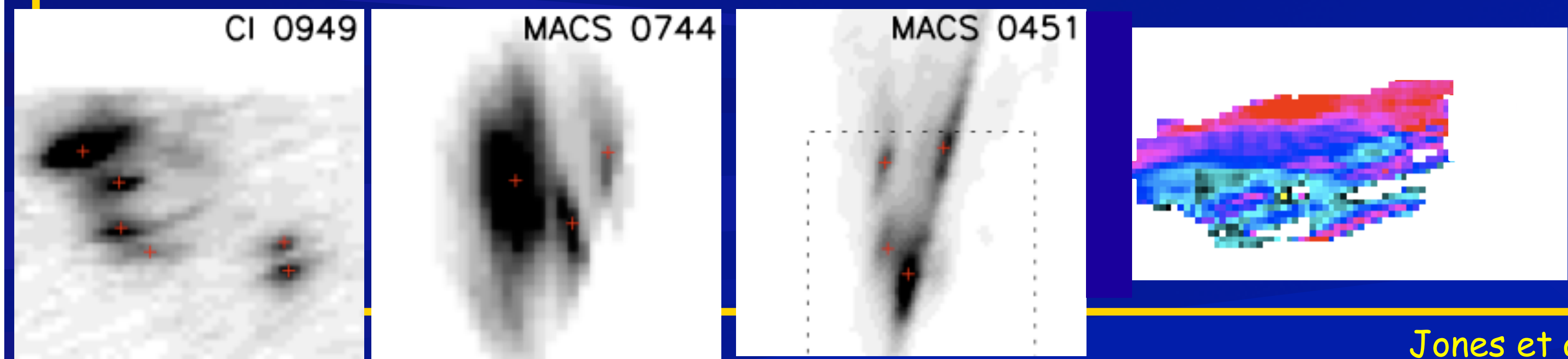
gives L_J=0.1--1kpc for all galaxies in our sample

Intense Star-Formation Within Compact Regions in z~2 Galaxies



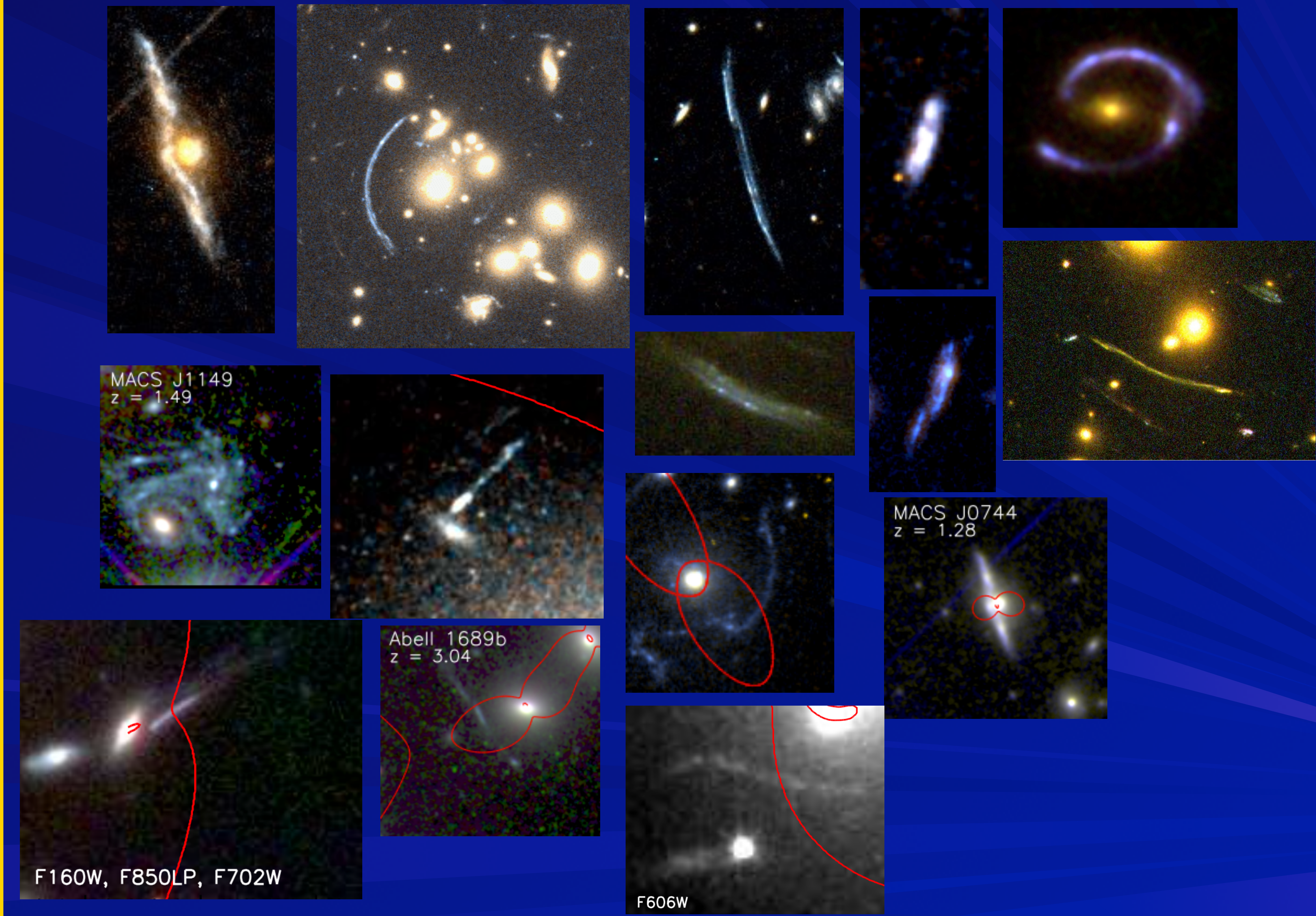


Resolved Ha maps and dynamics



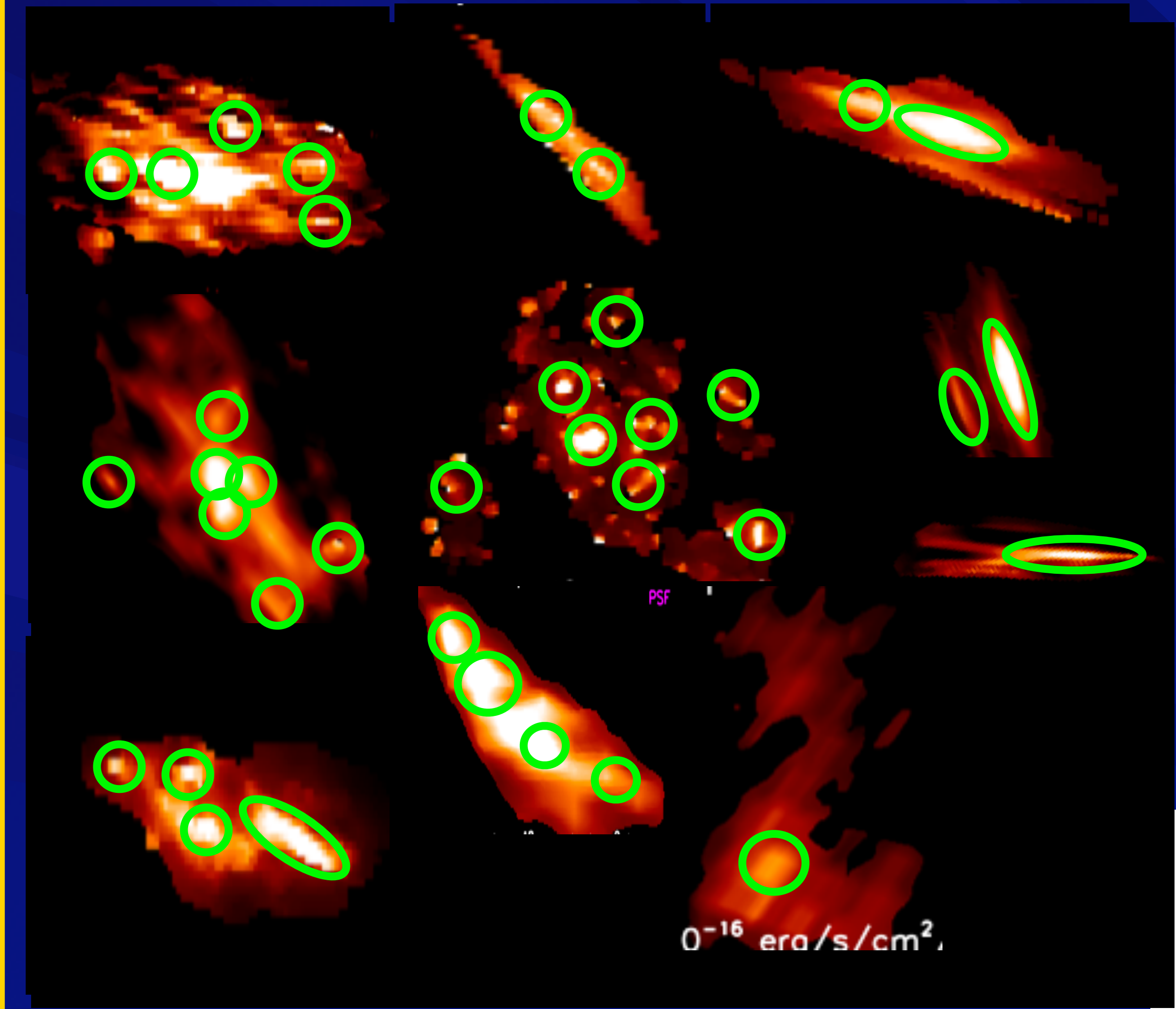
Jones et al. 2010 MNRAS 404 1427

- Increase sample with VLT/SINFONI and Gemini/NIFS to 19 (with AO in all cases) to reach 100-300pc resolution (source plane).



Livermore et al. 2015 MN 450 1812

Internal Star-Formation

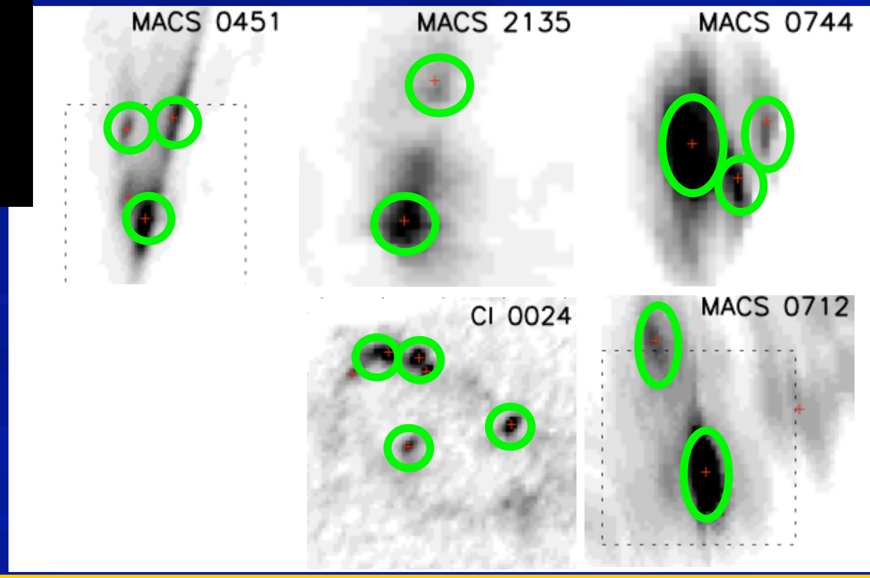


- Increase sample with VLT/SINFONI and Gemini/NIFS to 19 (with AO in all cases) to reach 100-300pc resolution (source plane).

- 16/19 systems display 'coherent' velocity gradients across 2--10kpc in projection

- 15 consistent with rotation, 2 merger, 3 ambiguous.

High-z galaxies display "clumpy" morphologies. The properties of the SF clumps reflect those of the underlying ISM.



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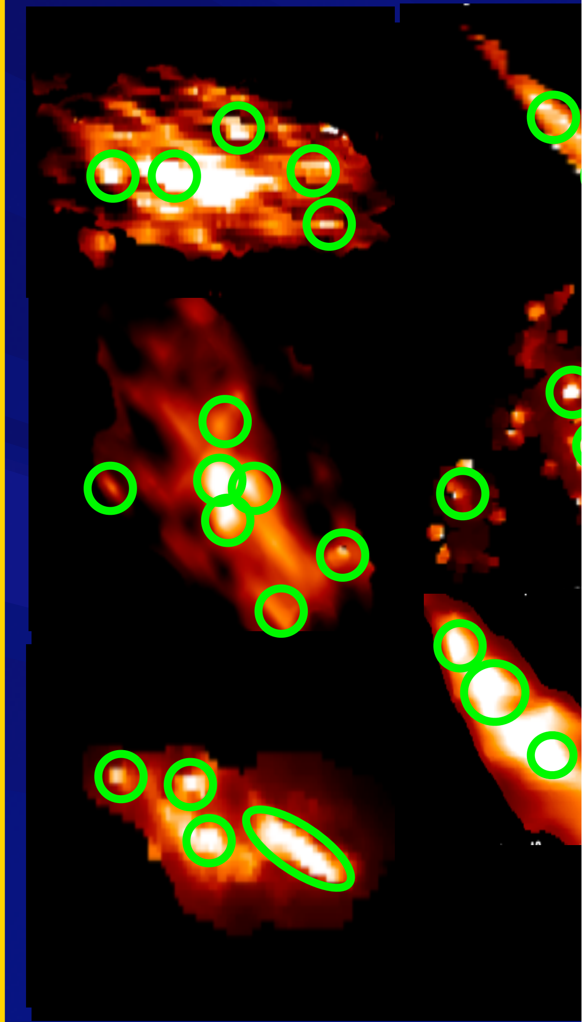
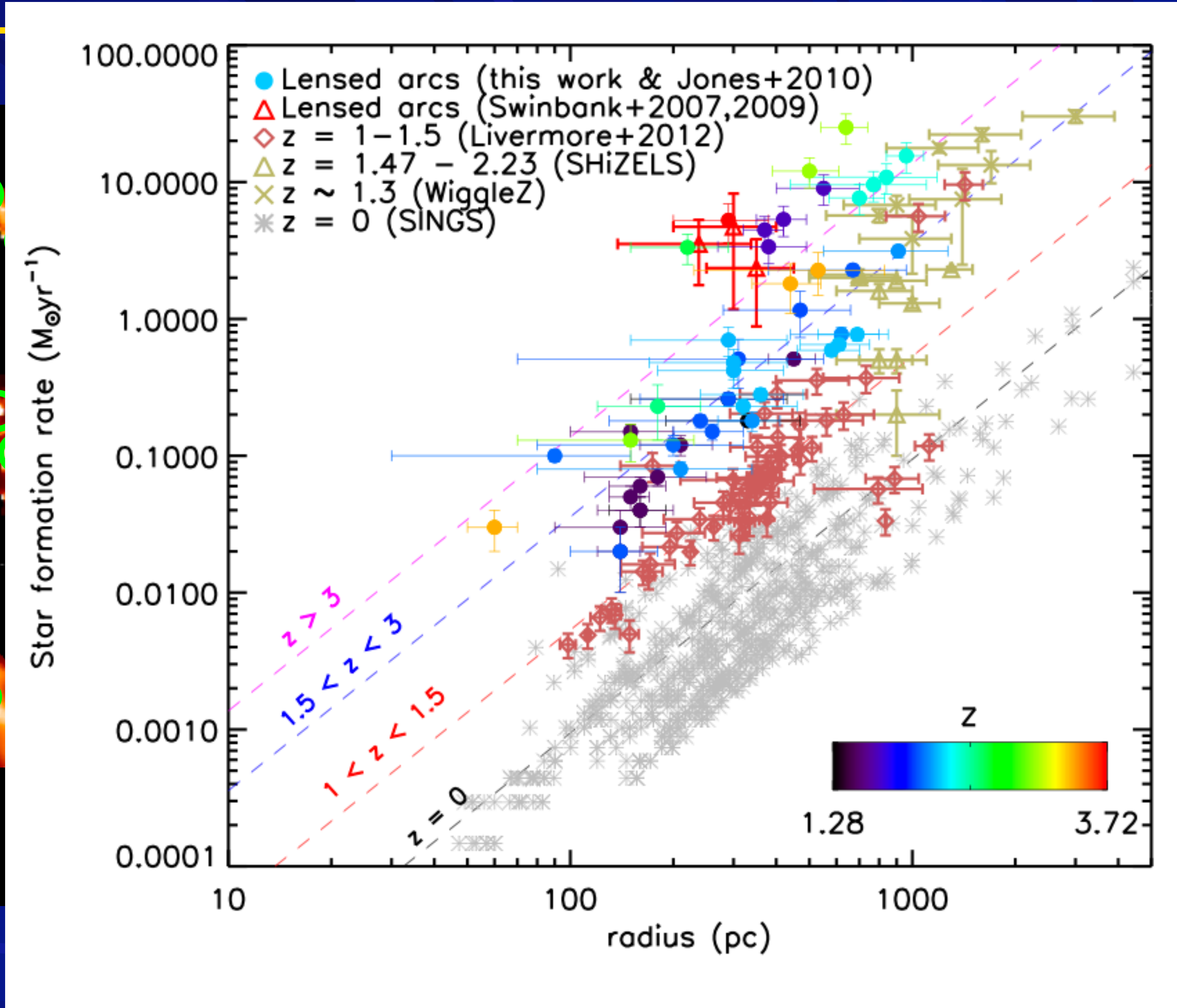
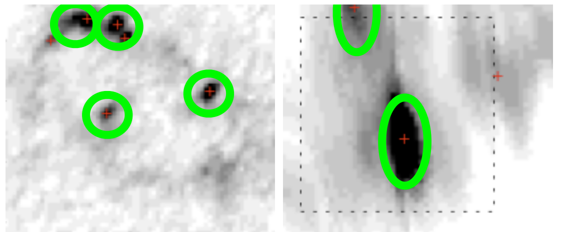




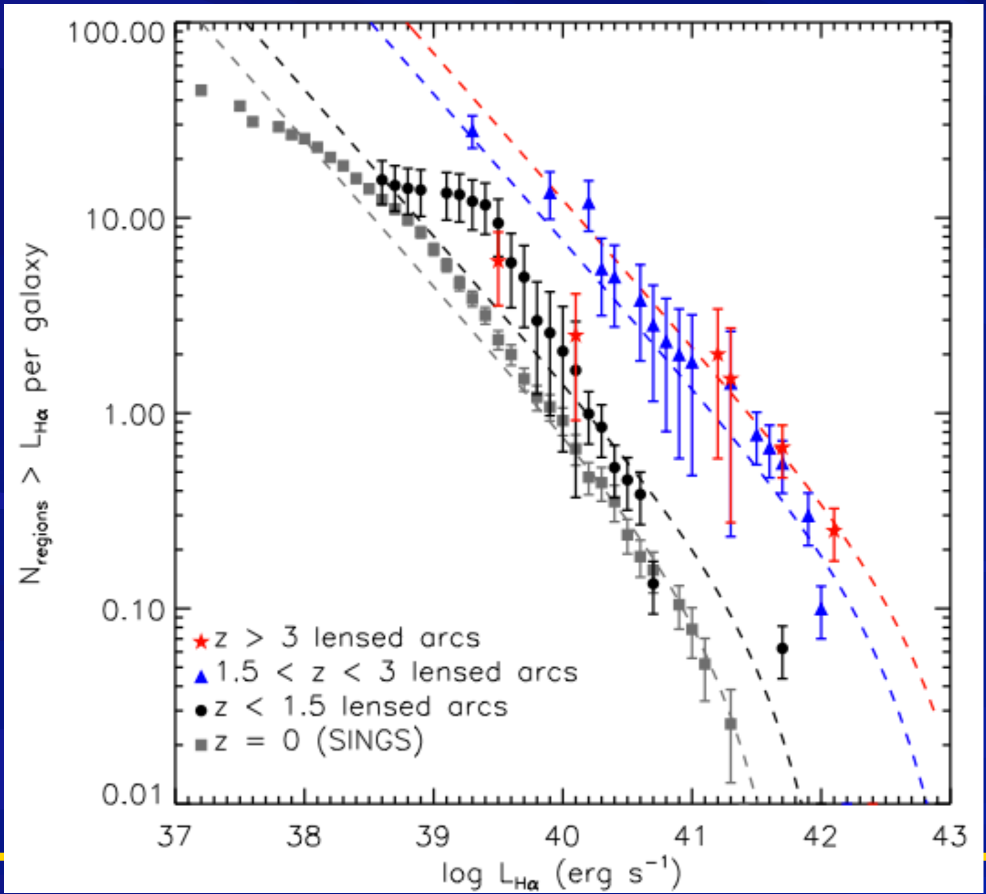


Relating the SF clumps to the underlying disk

Velocity dispersion (σ) of fastest growing Jeans unstable mode is $\sigma(R)^2 = \pi G R \Sigma_{disk}$ and it follows that the post collapse surface density is $\Sigma_{cloud} \sim 10\,\Sigma_{disk}$

For marginally disk (Q=1) of finite thickness, density structures on scales >h will be stabilised by rotation, leading to exponential cut off in clump mass function with

$$M_0 \sim 8.6\times10^3 \left(\frac{\Sigma_{disk}}{10 M_o pc^{-2}}\right)^3 \times \left(\frac{\kappa}{100 km/s/kpc}\right)^{-4}$$



Hopkins et al. 2012MN 423 2016
Livermore et al. 2015 MN 450 1812
Livermore et al. 2012 MN 427 688

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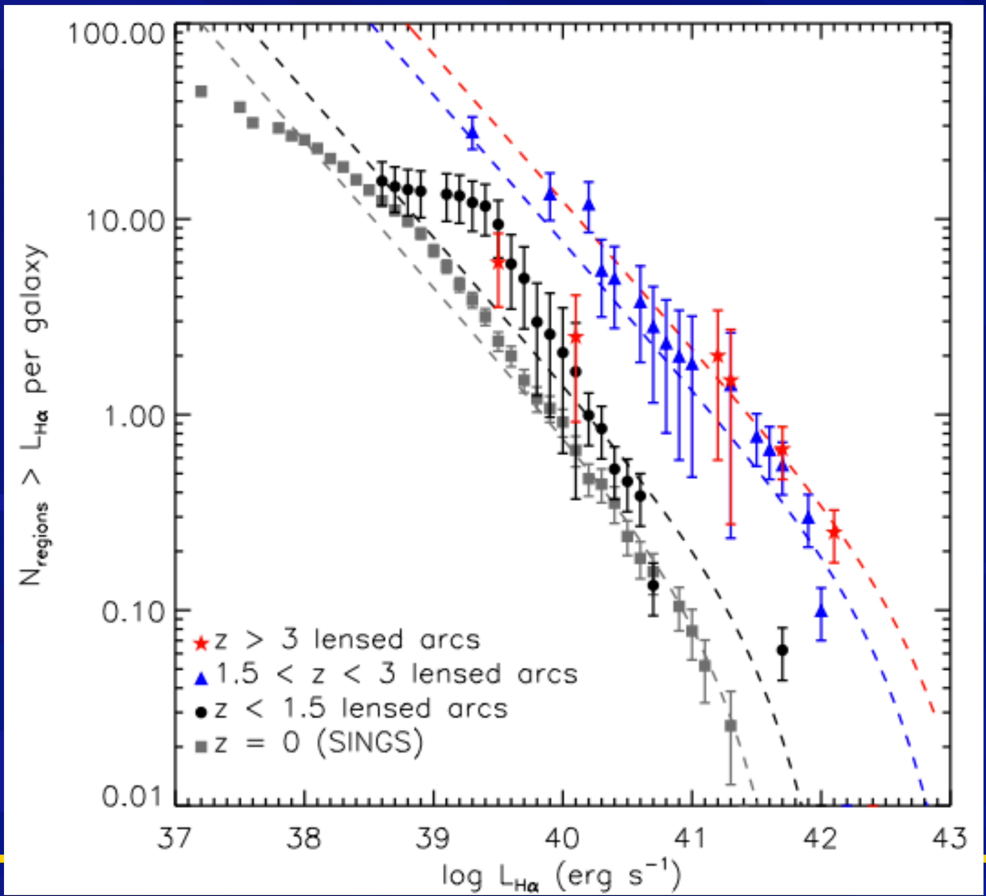
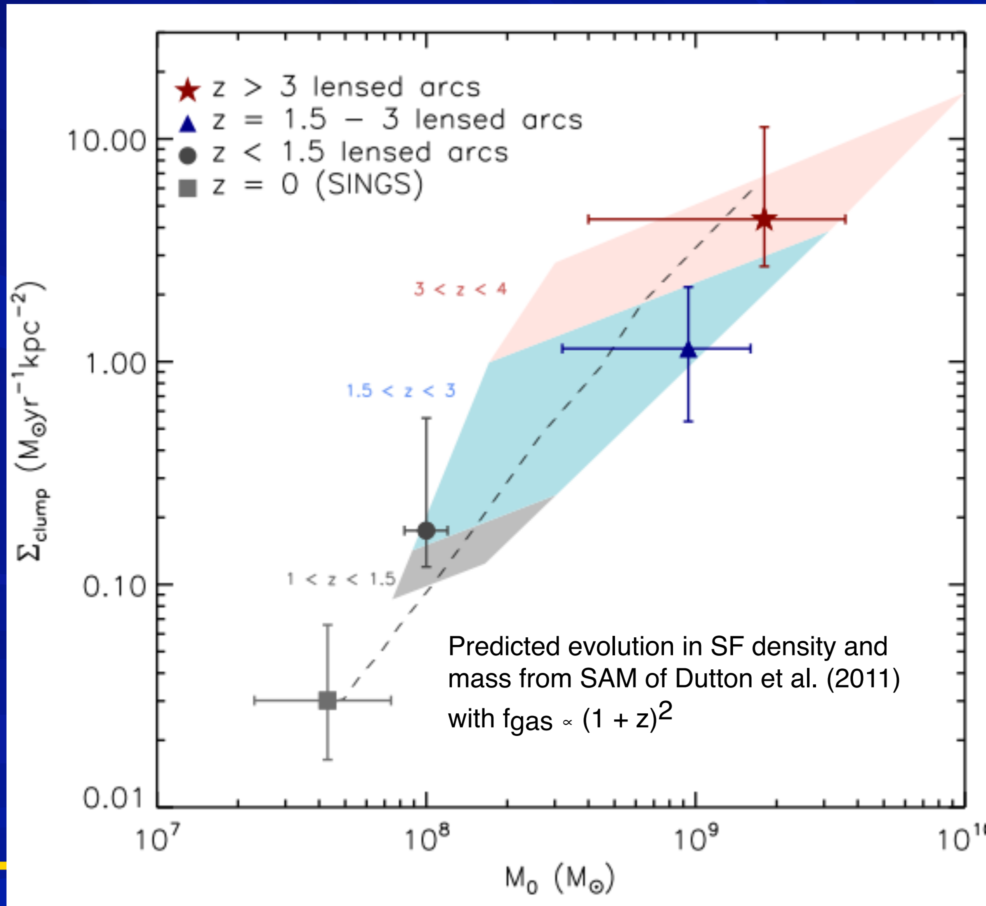
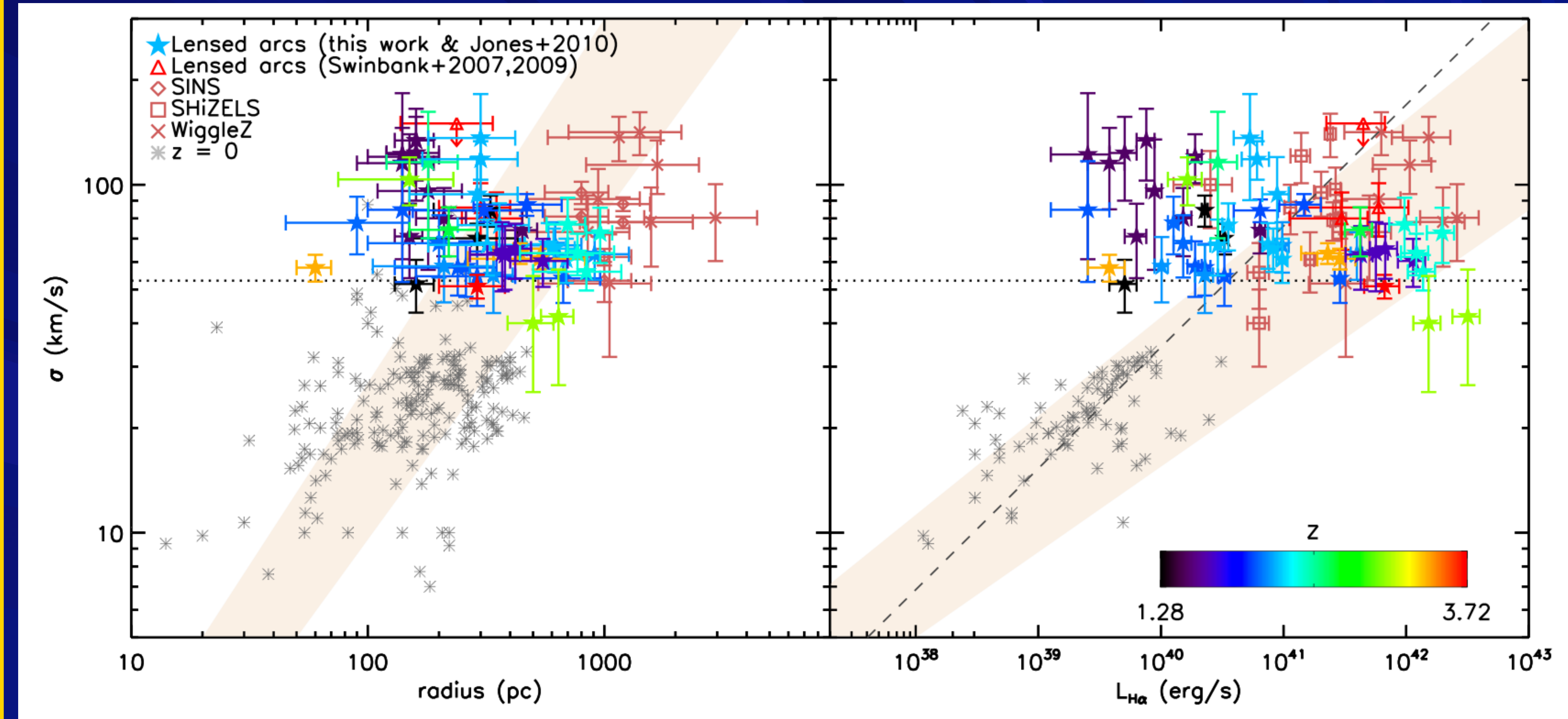
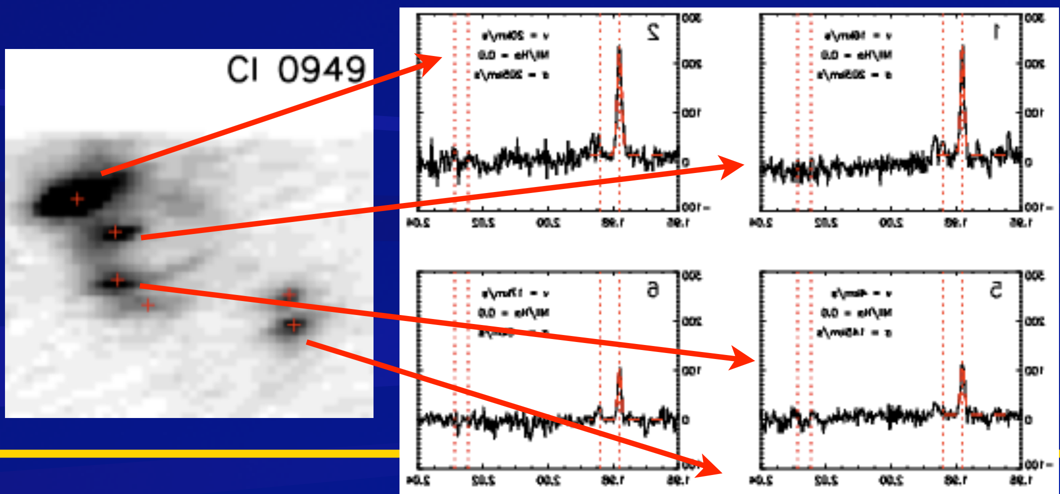




Clump scaling relations compared to z=0



Terlevich & Melnick (1981), Arsenault et al. (1990), Bordalo & Telles (2011), Fuentes-Masip et al. (2000) and Rozas et al. (2006)



If clumps are short lived, then these scalings effectively reflect the initial conditions of ISM from which they formed (since they can not evolve far from those conditions

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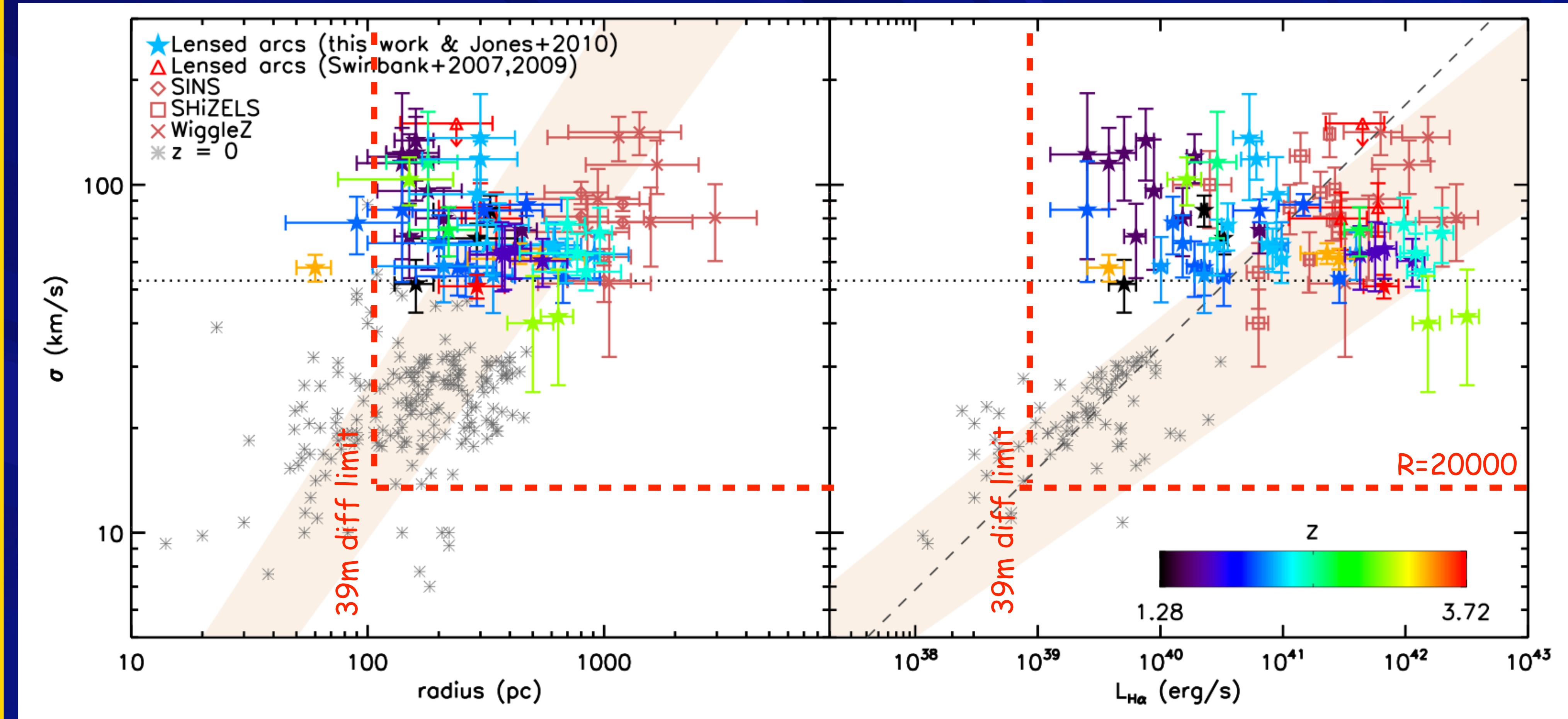

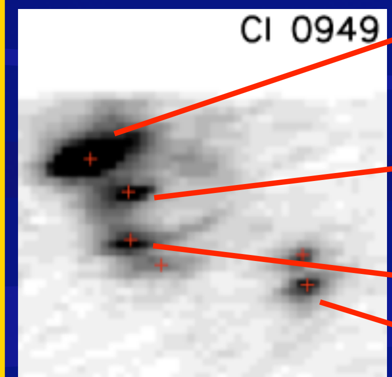

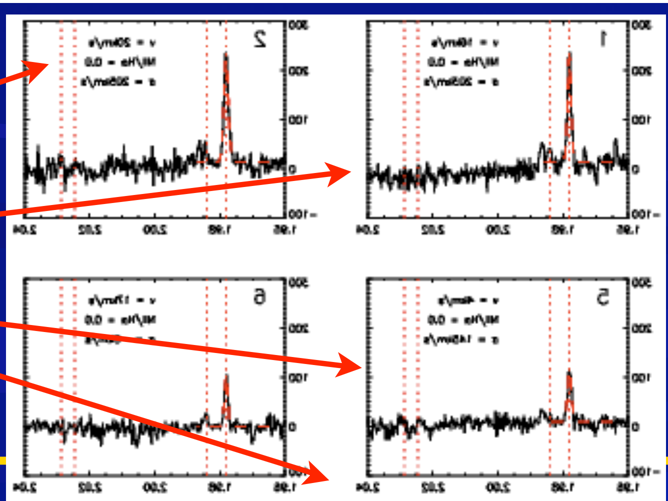

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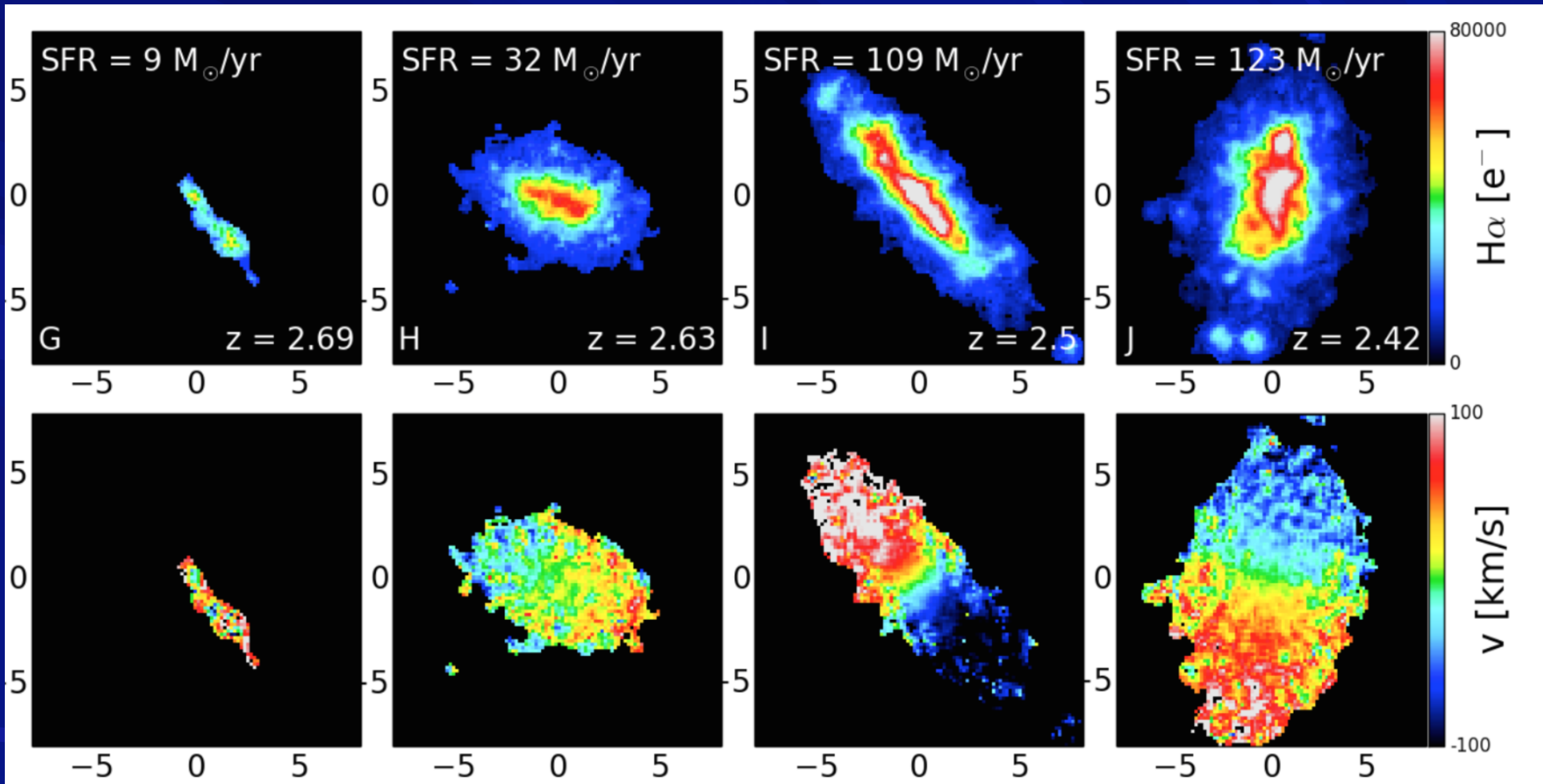
Predictions for HARMONI
(Zieleniewski et al. 2015 MN submitted)

Construct sample of z~2 galaxies at 0.01" resolution with range of SFR and stellar mass with morphologies ranging from exponential disks to clumpy morphologies (with disk & clump properties set by scaling relations for HII regions from lensed sources)



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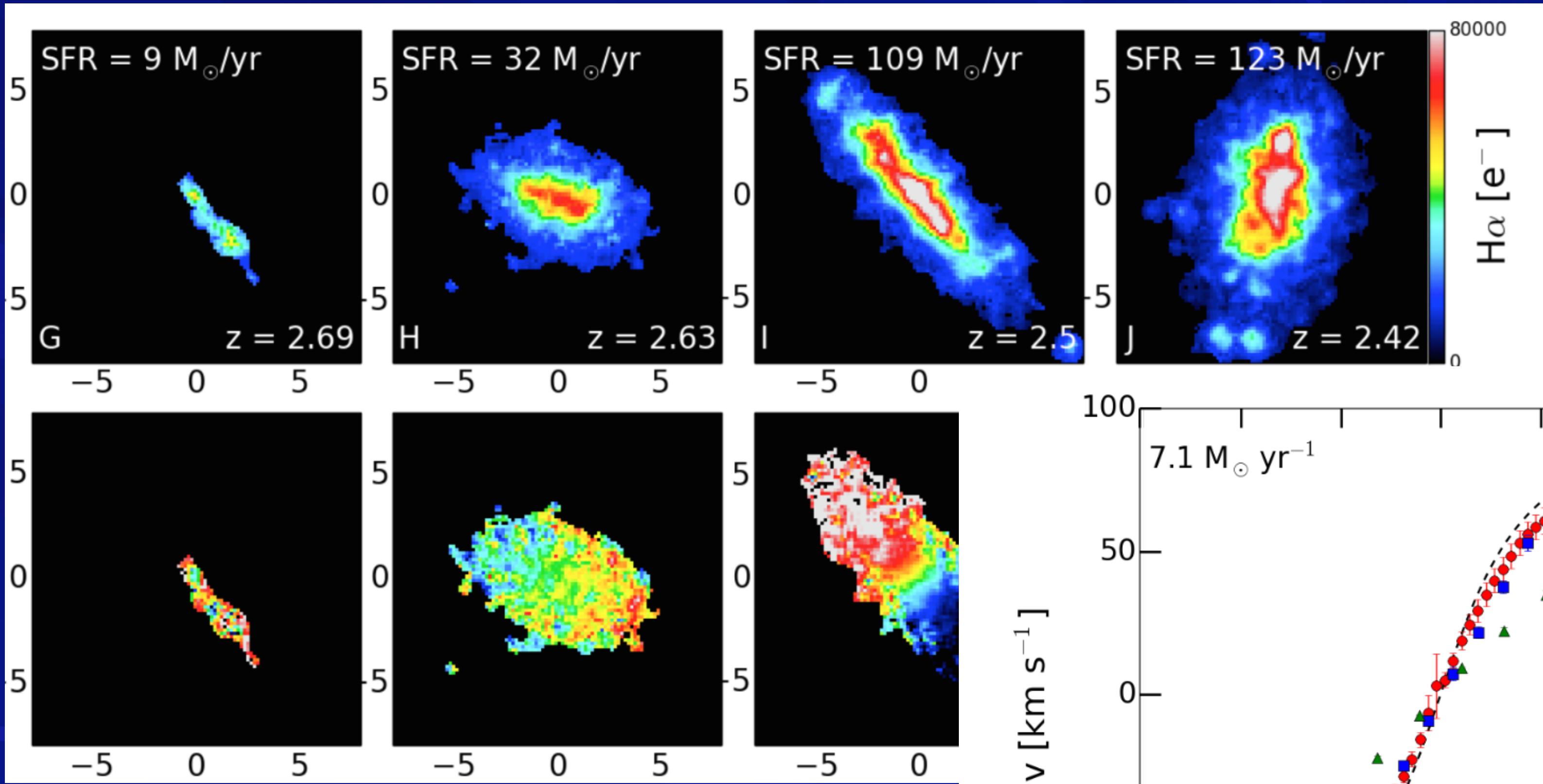

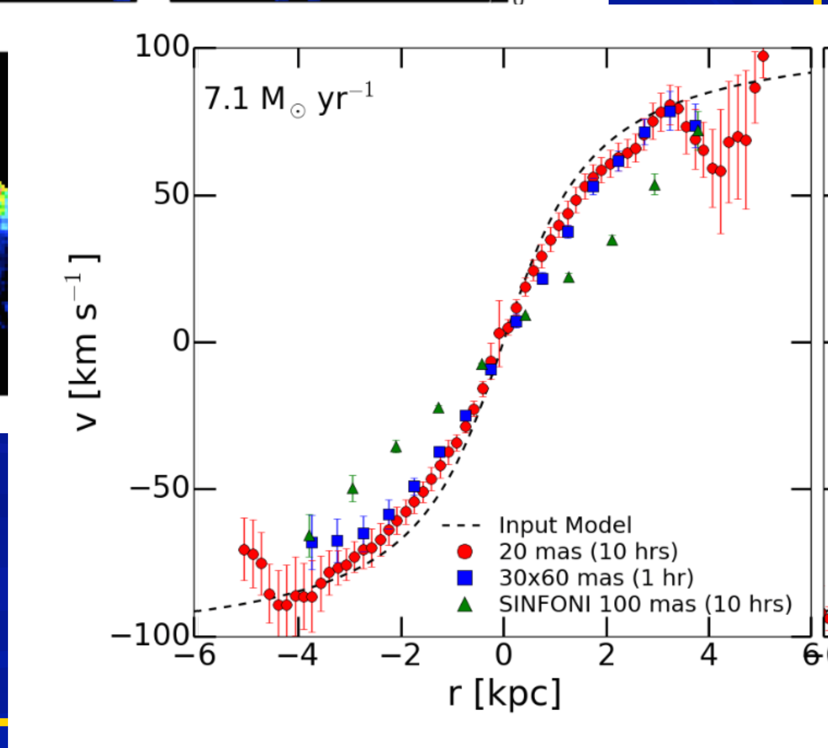

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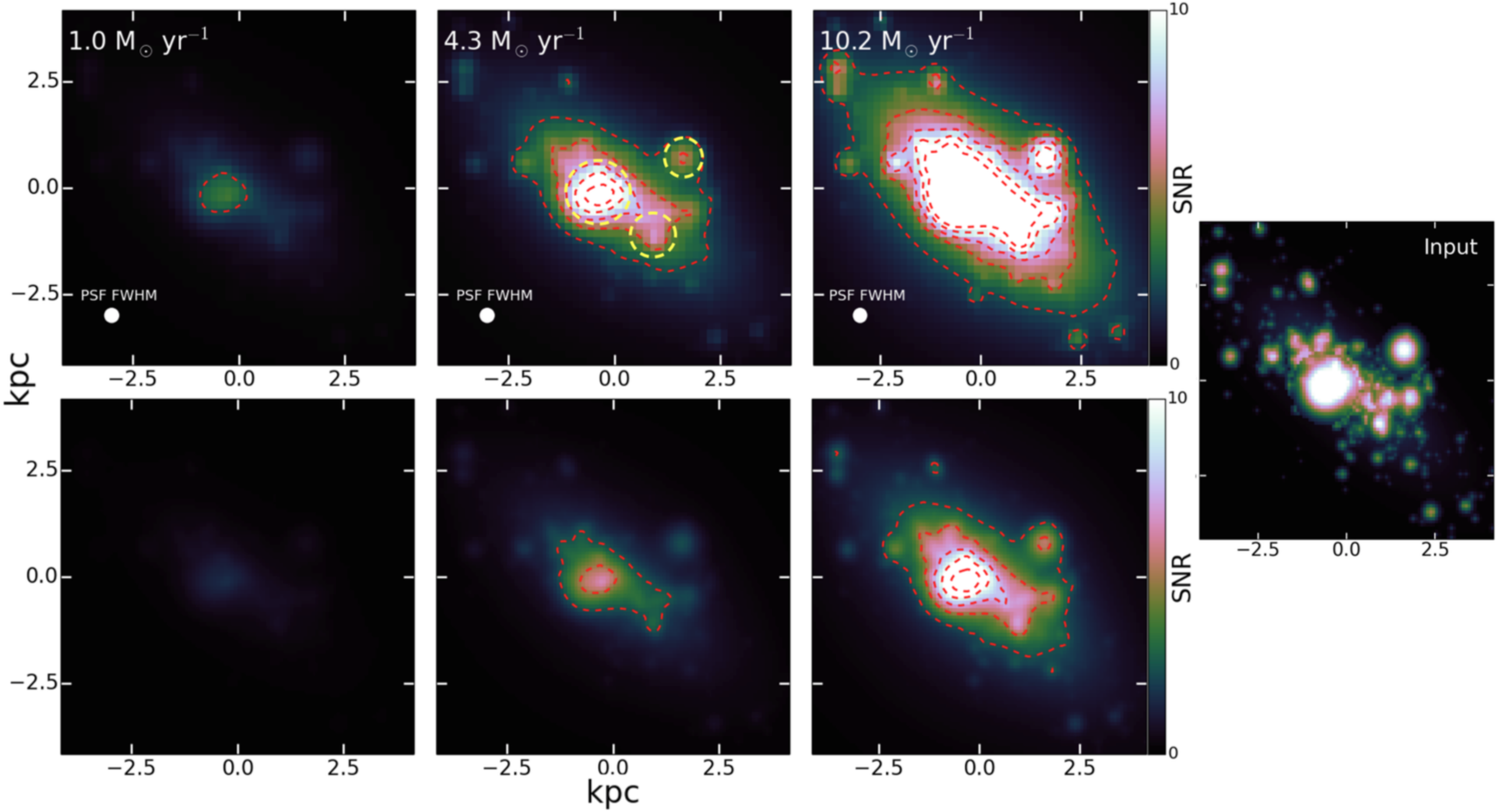


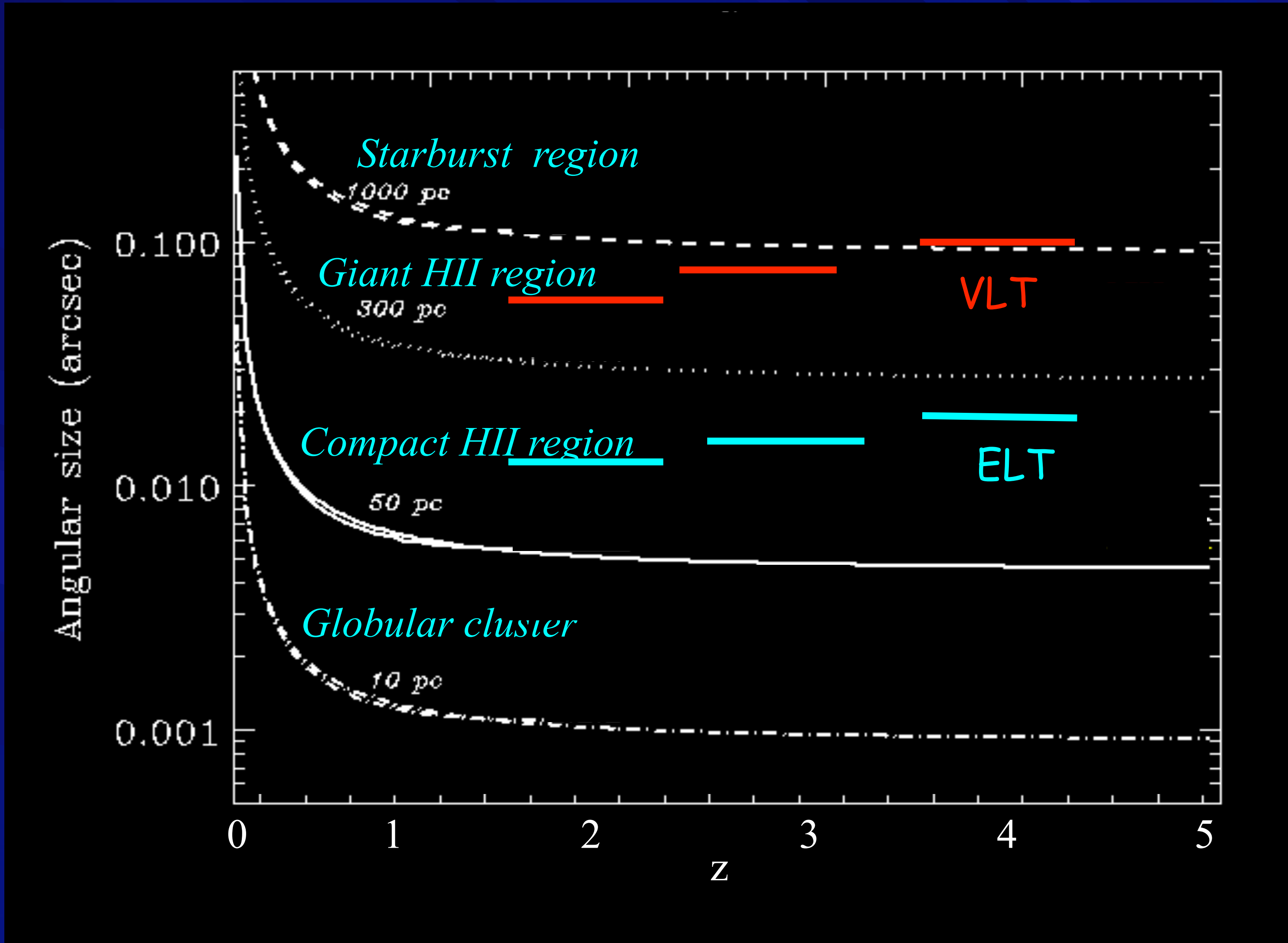
Summary

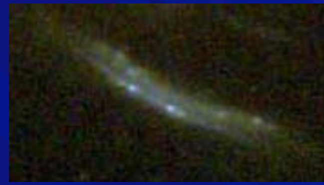
- Resolved dynamics and SF maps of galaxies offer unique way to study stellar mass build up and feedback at high-z. Most studies are limited to ~1.5kpc - which is characteristic size of SB complex. Many high-z galaxies show (thick) disks, with large turbulent motions, but the SF- and gas-densities are consistent with local KS relation.

- Probing the sub-kpc scale kinematics and distribution of gas and SF within galaxies at z~2--5 is key science driver for ELT and ALMA, but can be achieved now for sources which are highly amplified.

- Using Hα, it is possible to isolate GMCs within z=2-5 galaxies. Many GMCs appear to be substantially more luminous at fixed size than those in the MW (and local group), although the main sequence of SF seems to be in place once deep enough limits are reached.

- This could be caused by large increase in star-formation efficiency due to increasing gas fractions (and surface mass densities).





higher resolution (~100-300pc)
lower luminosity
higher-z