The Assembly and Growth of Galaxy Disks

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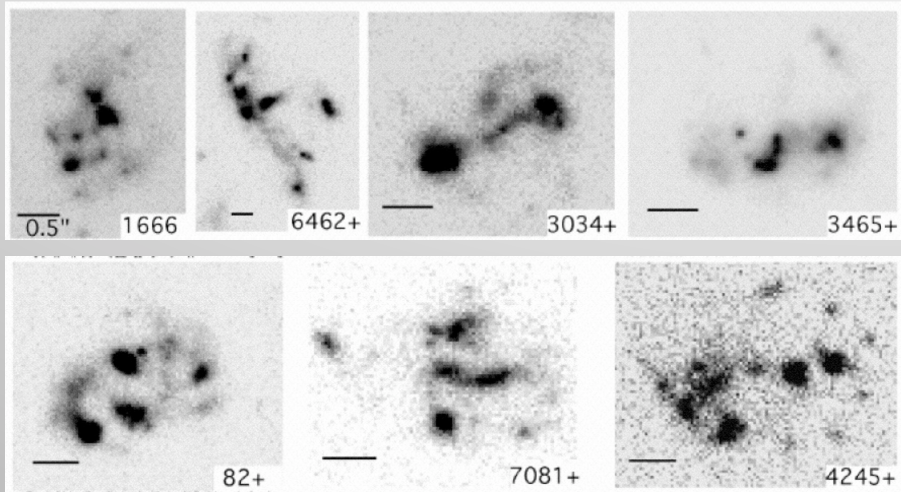
Star- forming disks at high redshifts

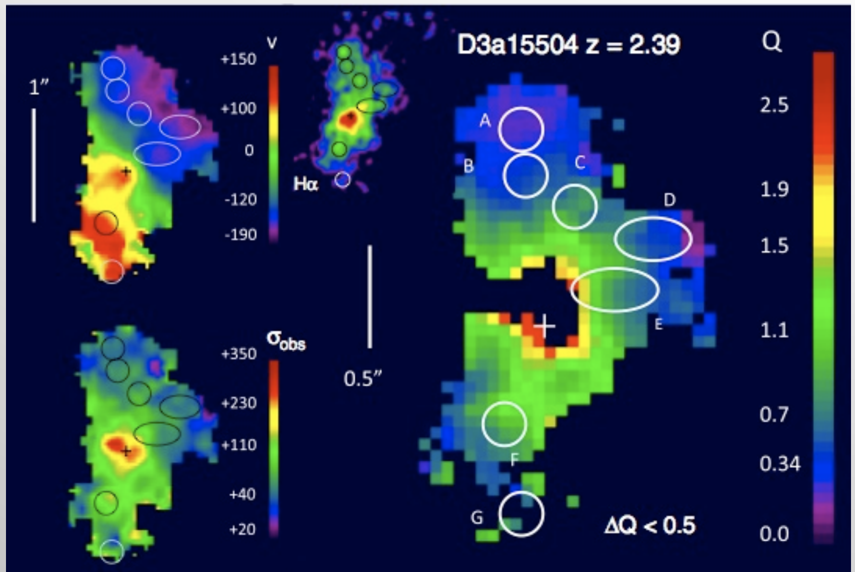
Clumpy galaxies @ z=1.5-3 in the HUDF (Elmegreen & Elmegreen 2005)

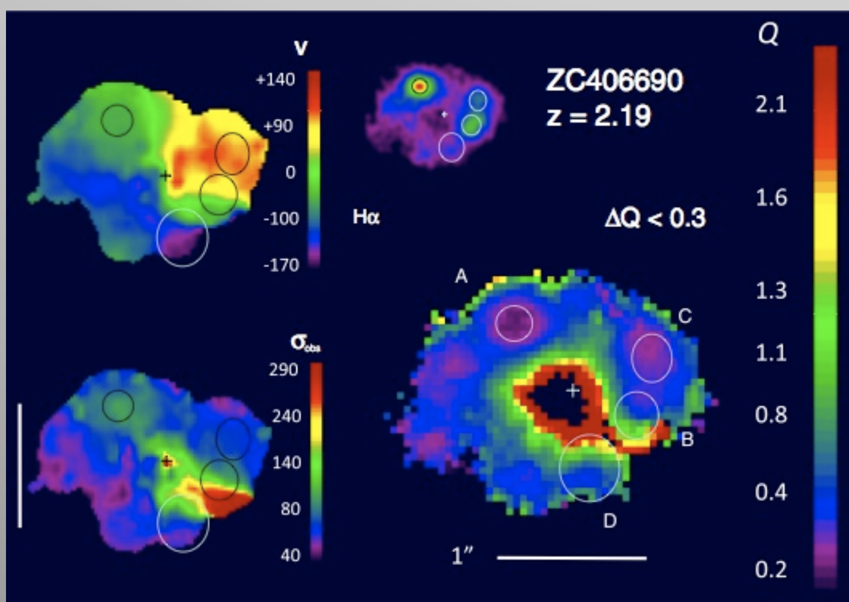


- Unique population at z>1.5
- Kiloparsec-sized clumps with $10^7 - 10^8\ M_{\odot}$

LBGs @ z=3 in GOODS ACS (Ravindranath et al. 2006)

Cowie et al. 1995
Giavalisco et al. 1996
Papovich et al. 2005
Elmegreen & Elmegreen 2005
Ravindranath et al. 2006
Law et al. 2007
Elmegreen et al. 2009





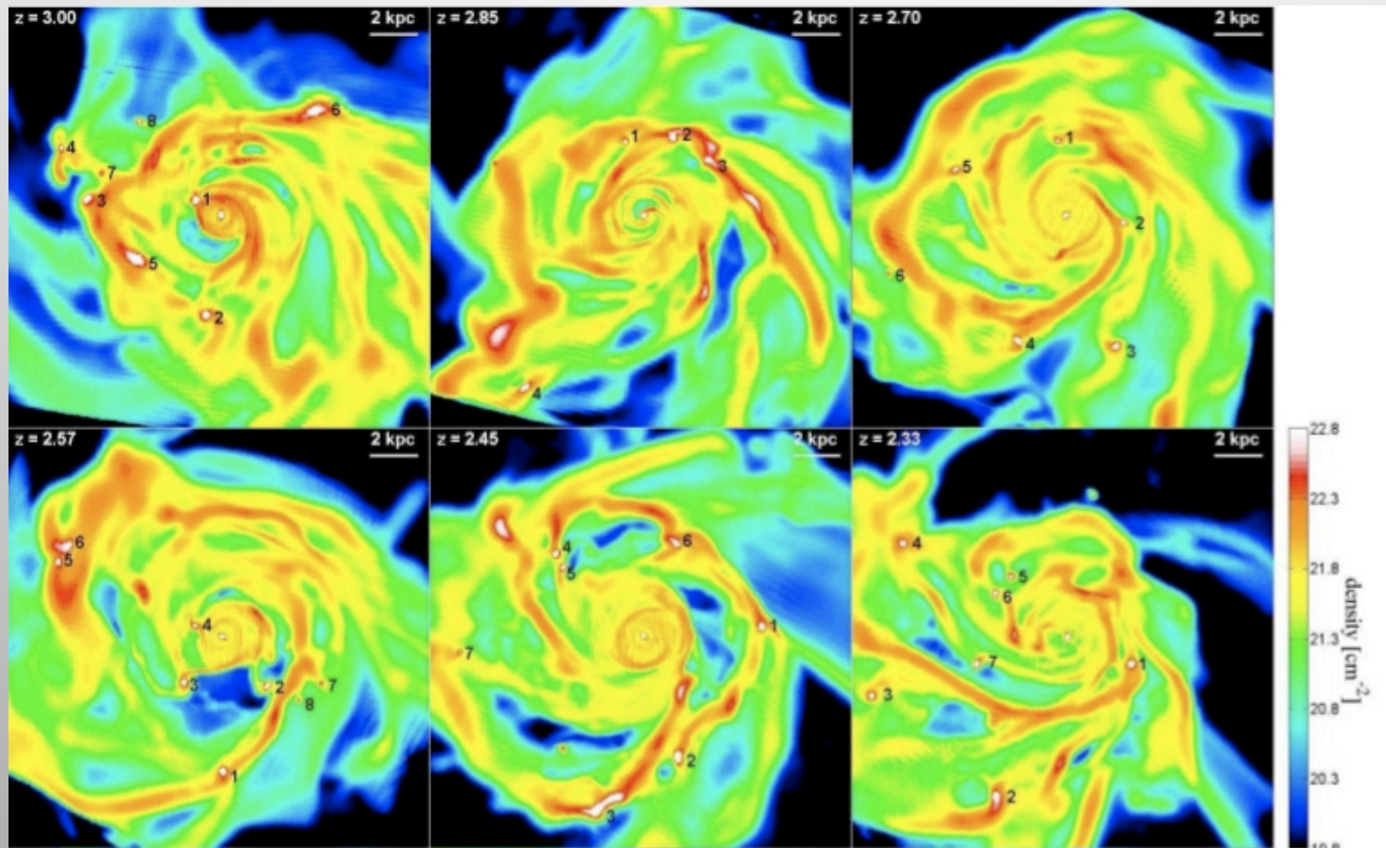
VLT, SINFONI

Clump kinematics:

- Toomre instability across the entire disk,
  $Q = \sigma\Omega/G\Sigma < 1$
- High velocity dispersion, $v/\sigma \approx 1\text{-}6$
- High outflow rates
- Velocity gradients suggest clump rotation

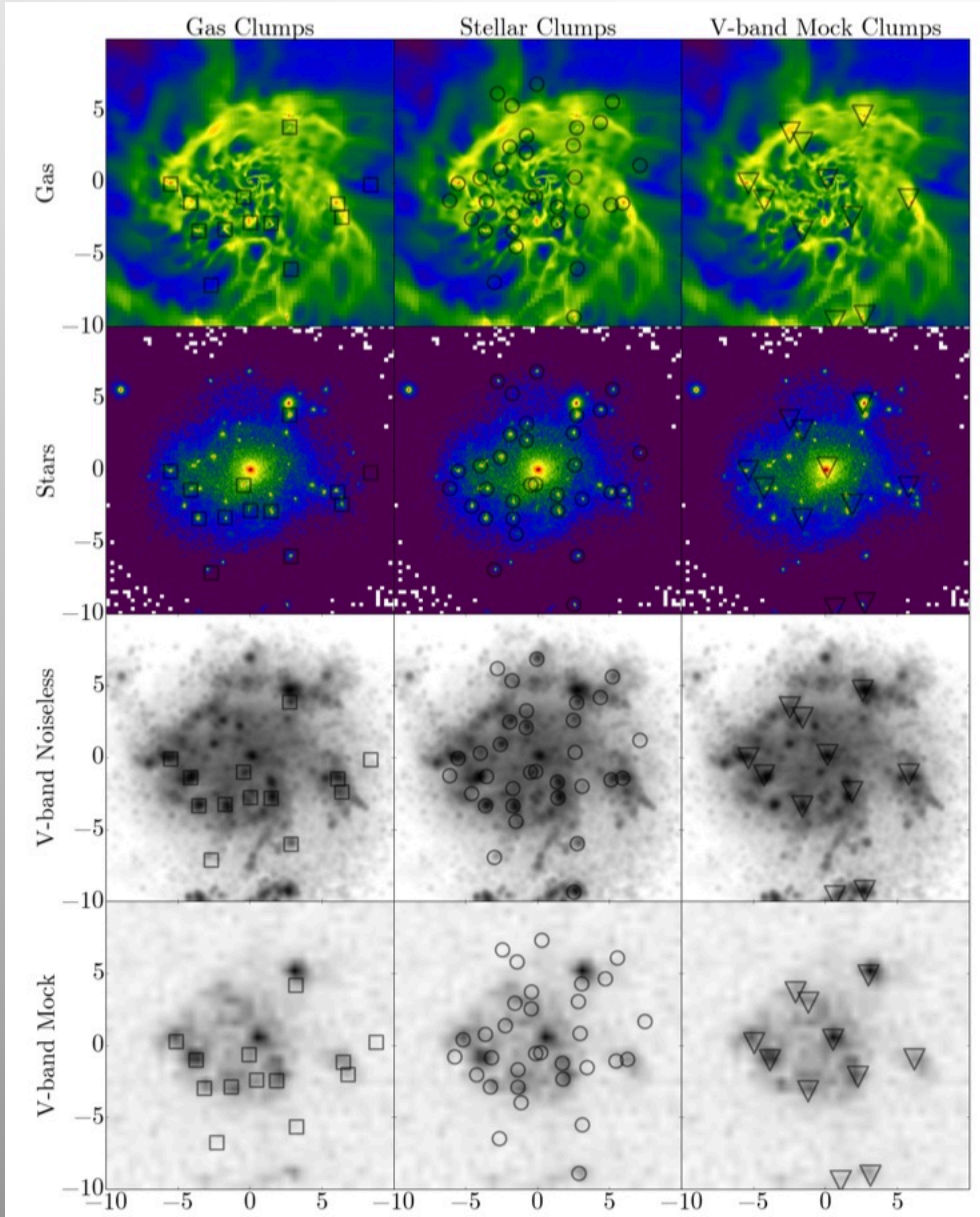
Genzel et al. 2011

Violent disk instability, clump migration, and bulge formation



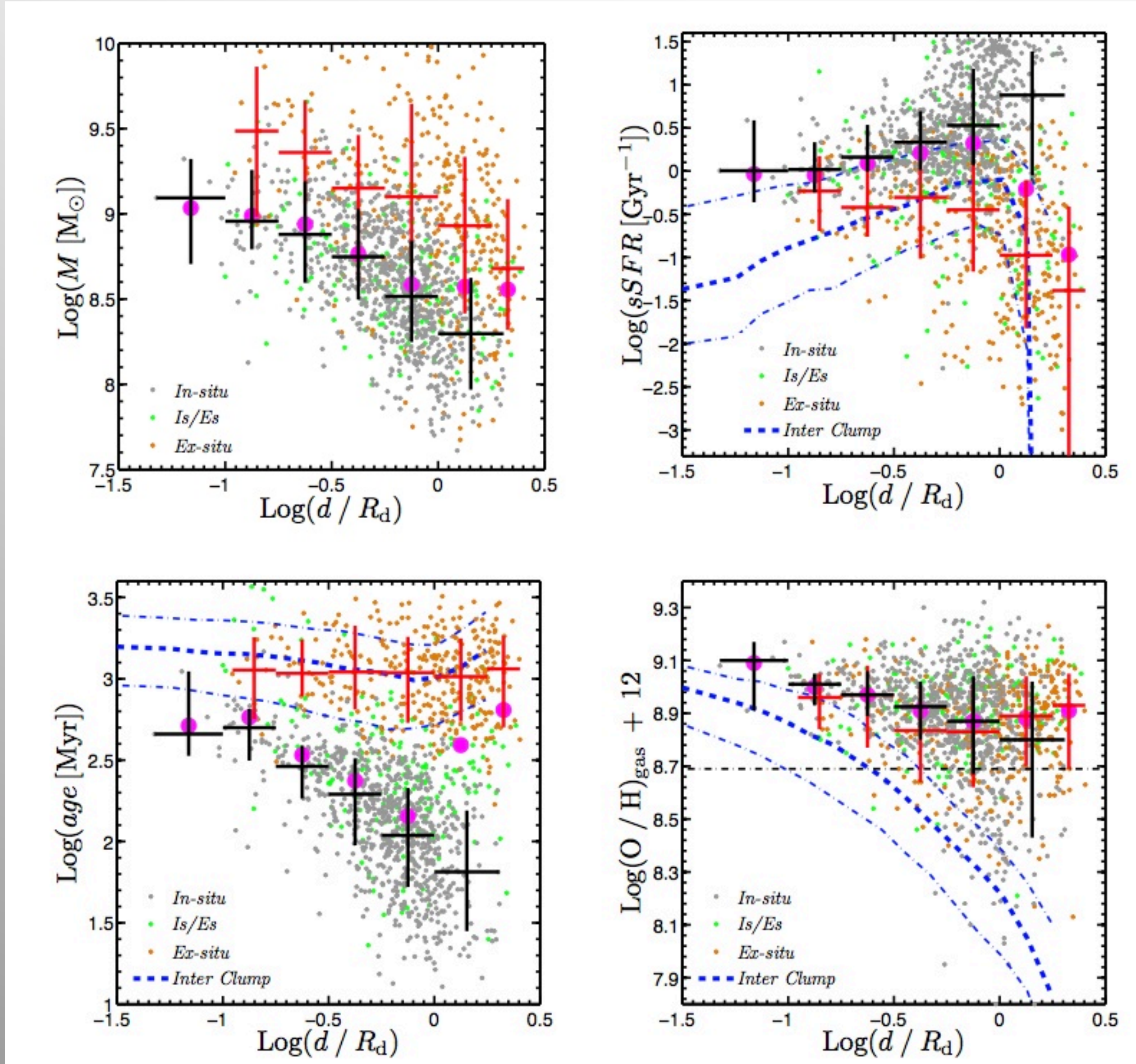
Ceverino et al. 2011

Fragmentation of gas-rich disks into giant clumps:
Dekel, Sari, Ceverino 2009; Ceverino et al. 2010;
Genel et al. 2011; Elmegreen, Bournaud & Elmegreen 2008;
Bournaud et al. 2007; Immeli et al. 2004; Noguchi 1999



- Simulations that can be treated just like observed images
- Mock images comparable to HST V-band images
- Clump identification on different maps need not necessarily pick up the same regions.

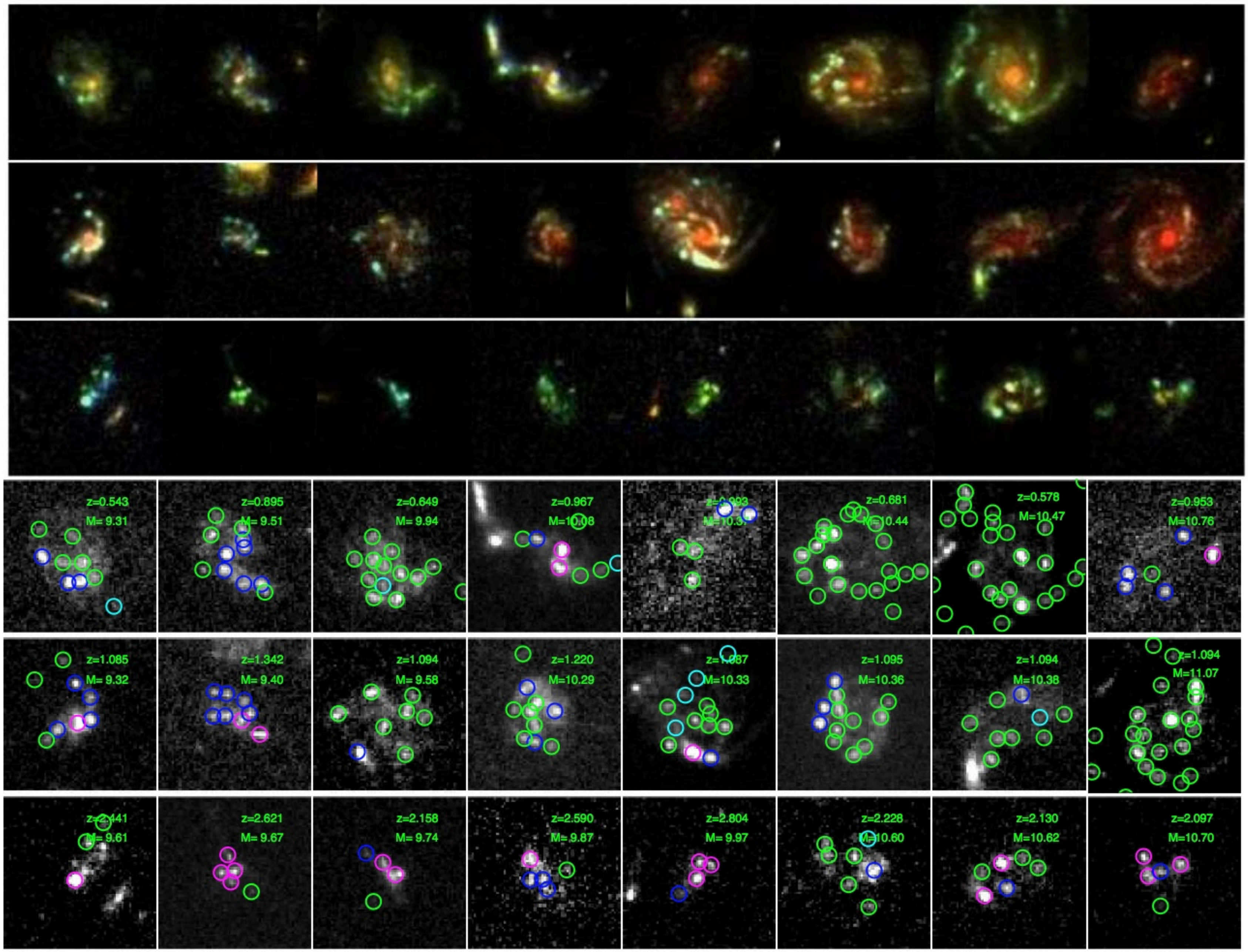
Moody et al. 2014

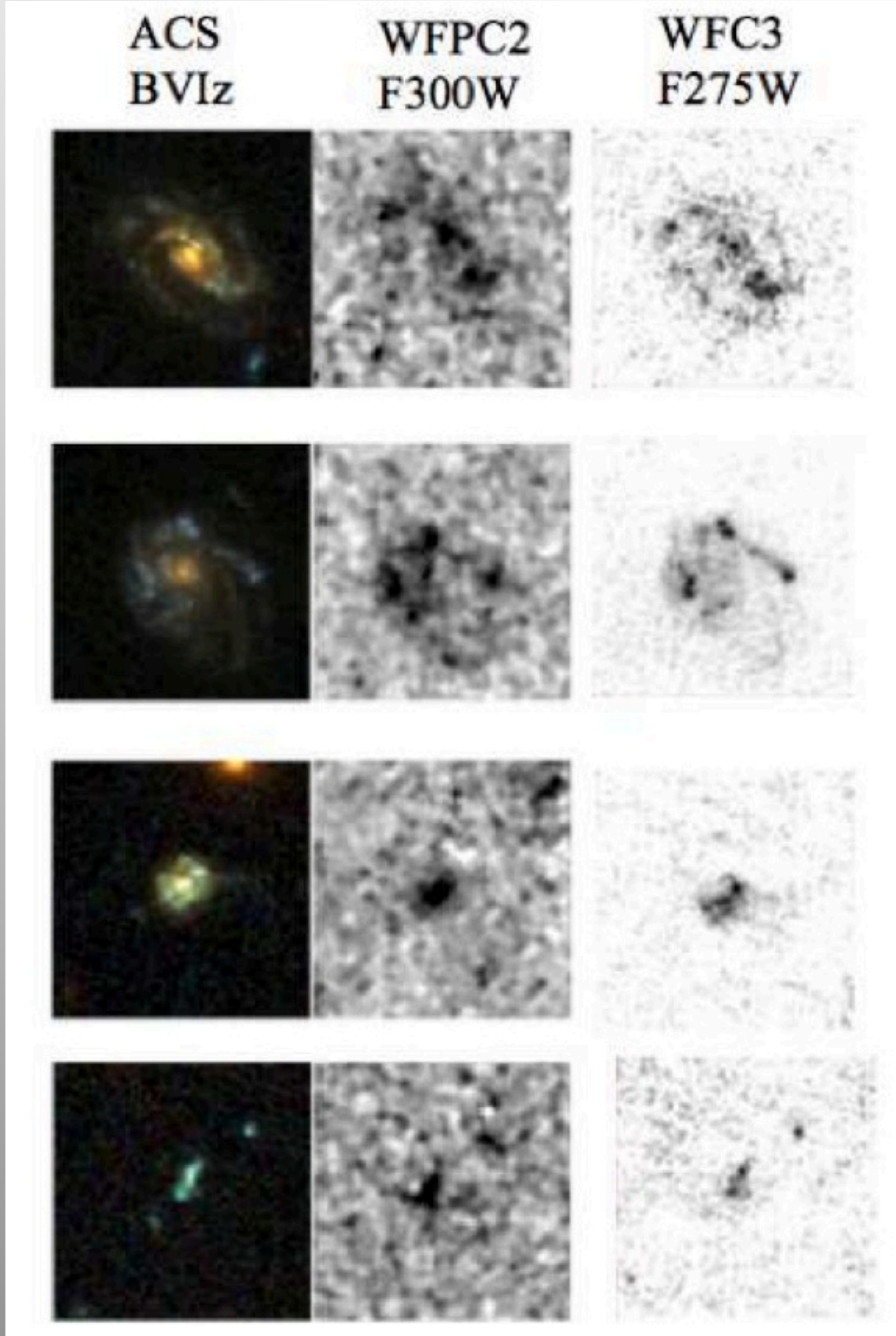


- Predictions from the zoom-in hydrodynamical simulations
- Expected radial trends for in-situ clumps that migrate inwards on dynamical timescales
- Different trends for the ex-situ clumps or minor mergers

Mandelker et al. 2014

Building Clump Statistics at z>1 using CANDELS: **Guo et al. 2014**





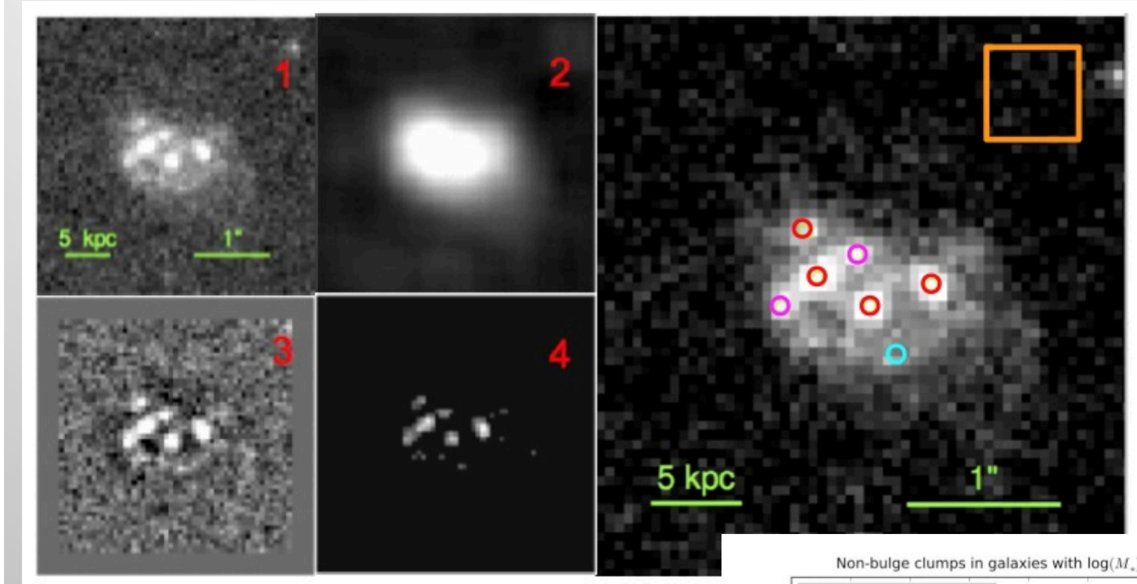
UV UDF:

Building clump statistics at z<1

- Using the WFC3/UVIS data to study clumps at z<1.

- Have 7+ band photometry from HST

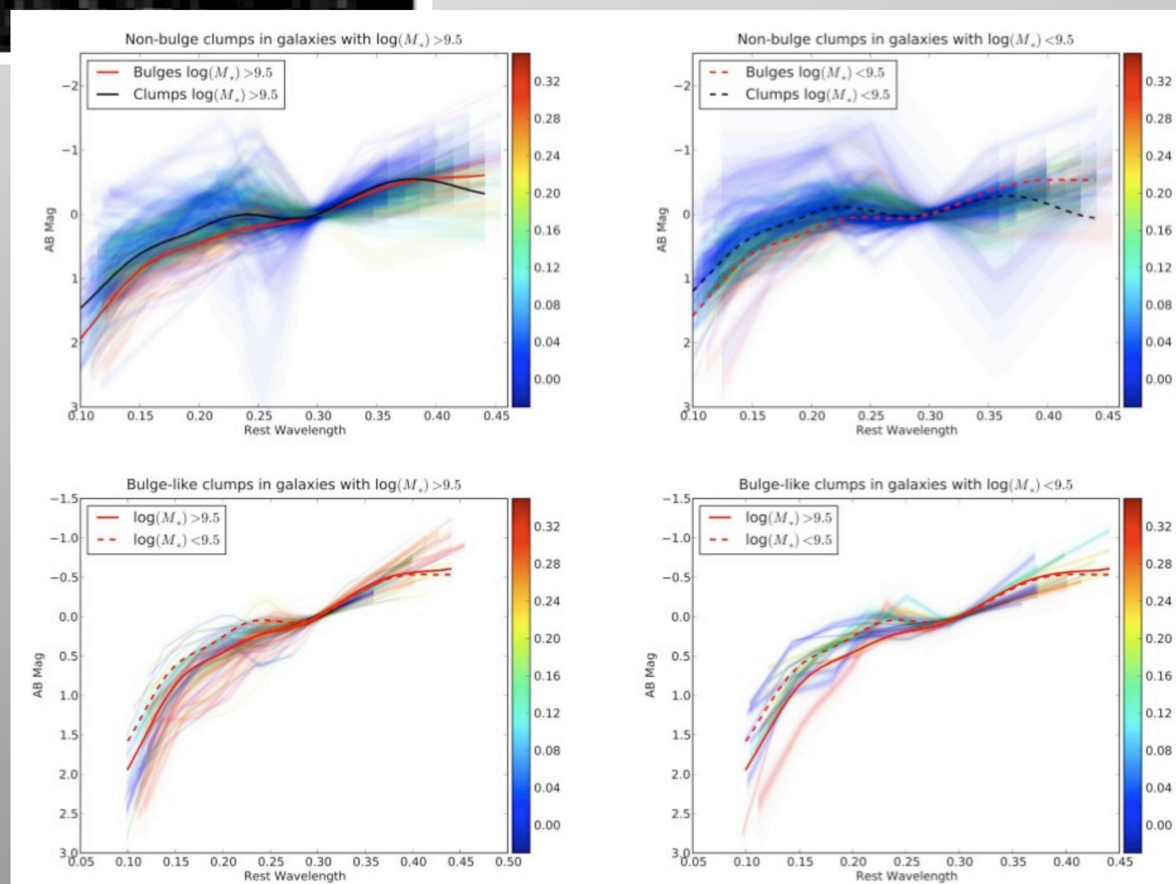
Teplitz et al. 2013

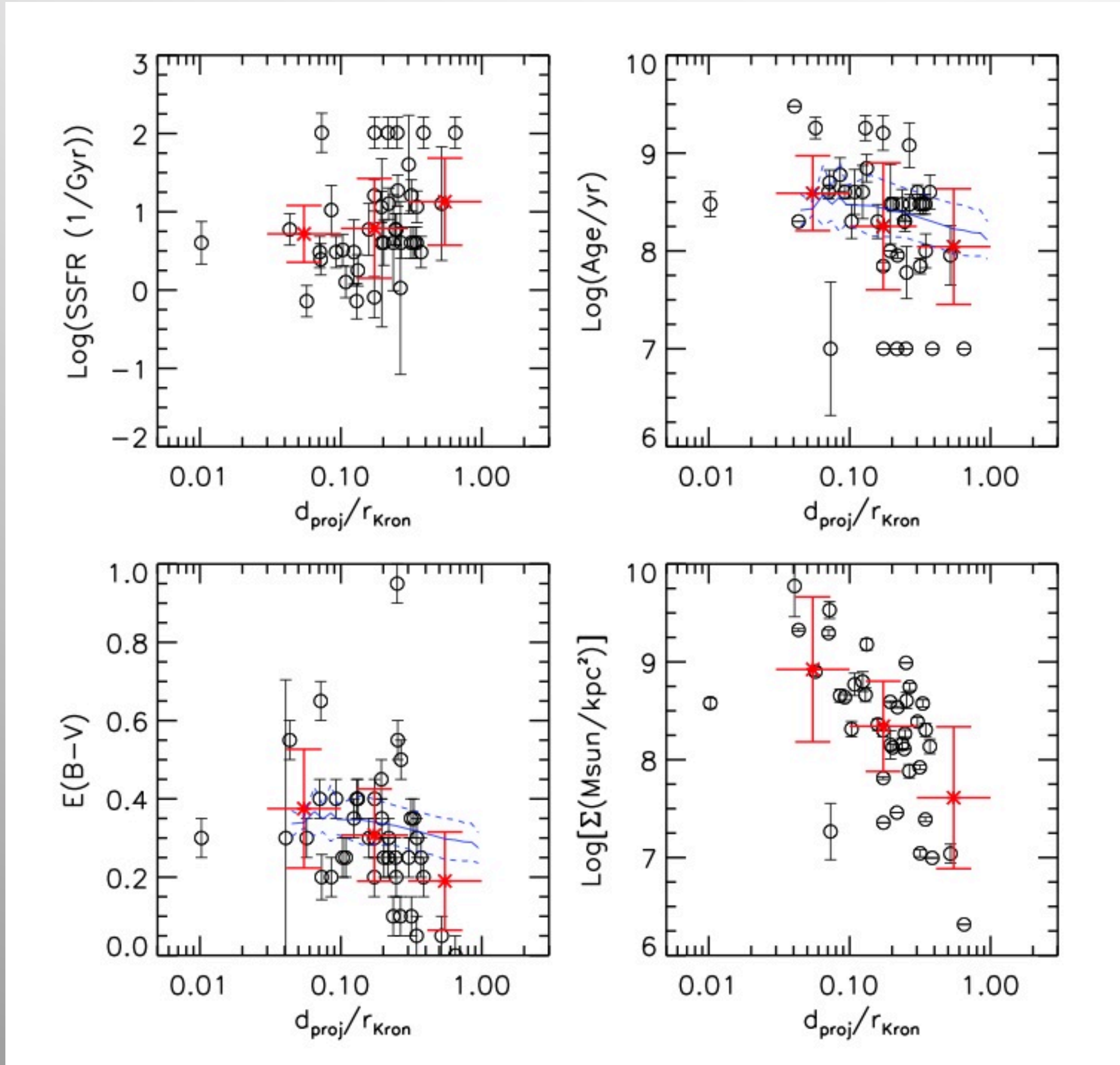


Clump identification: HST resolution is key factor

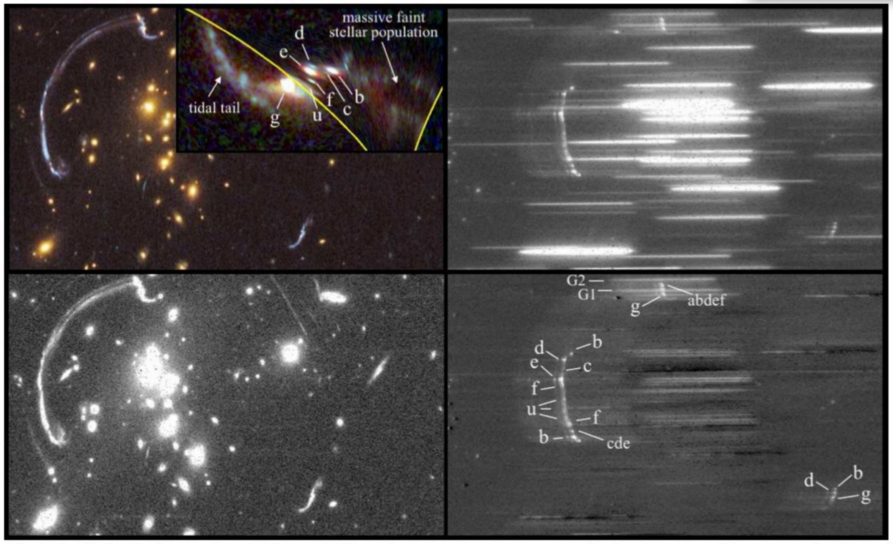
- SED fitting using the 7 or more band photometry from HST

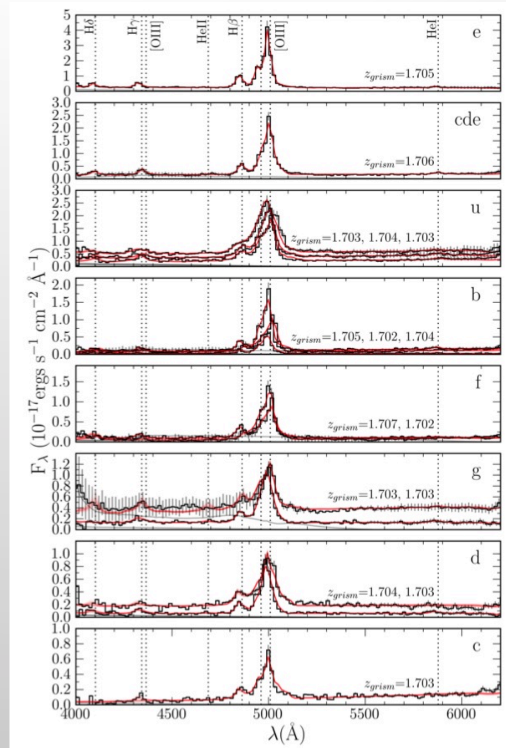
- Clump properties: age, mass, SFR, metallicity, extinction





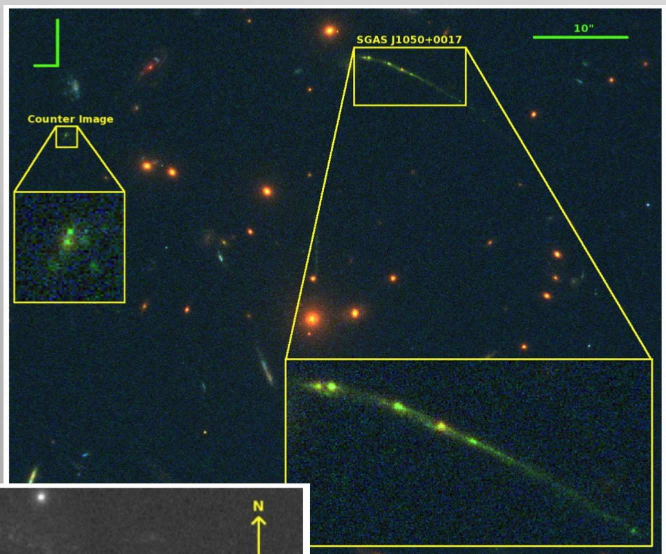
- Radial gradients/trends in the clump properties
- Can directly compare to theoretical predictions
- CANDELS data will improve the statistics, but spectroscopy is important to remove degeneracy in the derived clump properties.
- JWST will take us the next step further. However TMT IRIS will be important to probe few tens to sub-kpc scales out to z=6

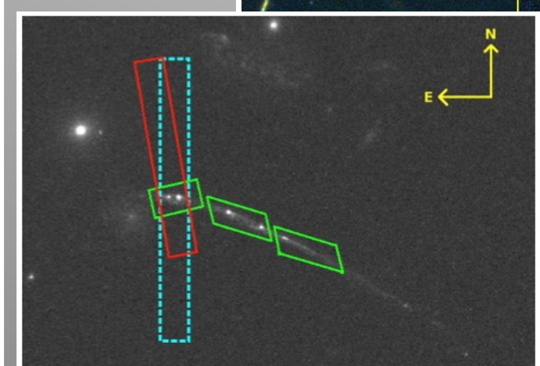




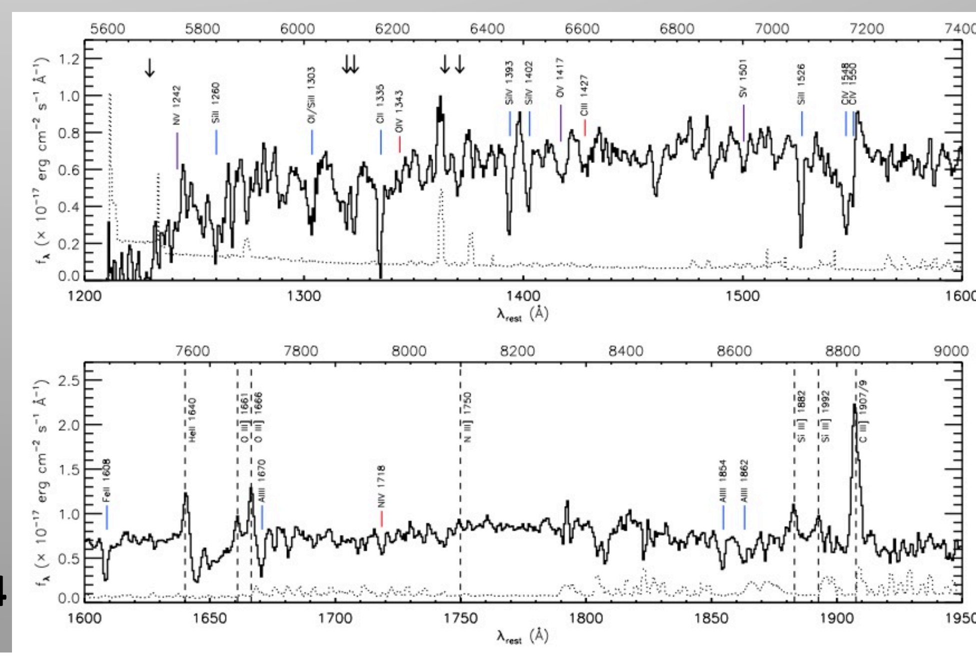
Lensed galaxies allow to probe the star-forming regions on sub-kpc scales.

Whitaker et al. 2014

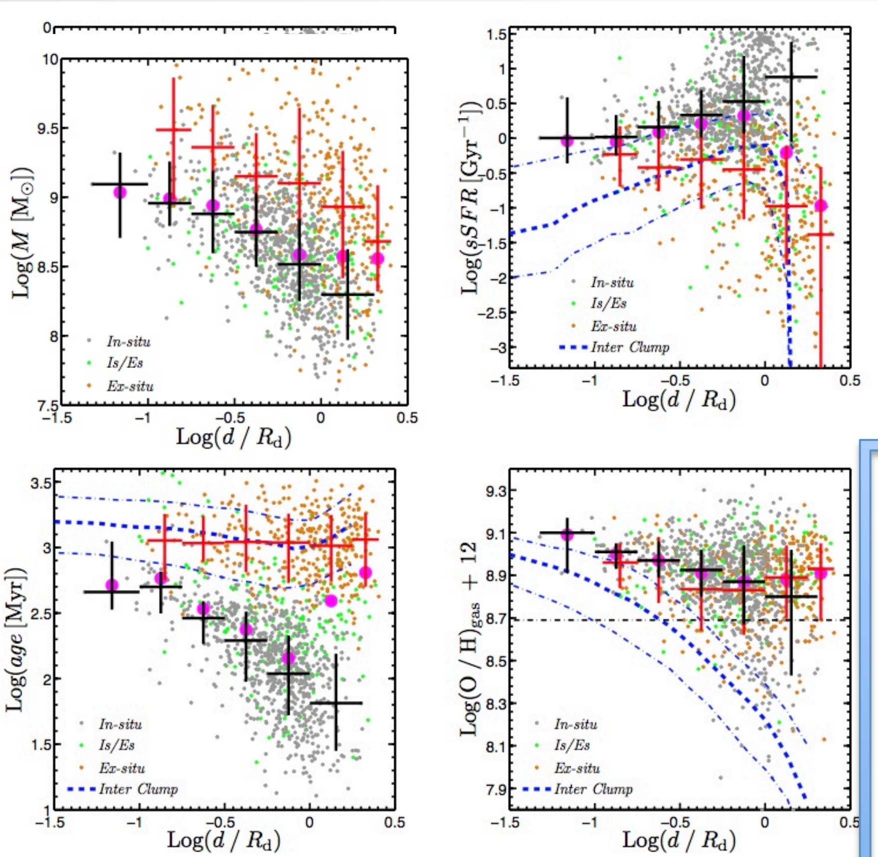


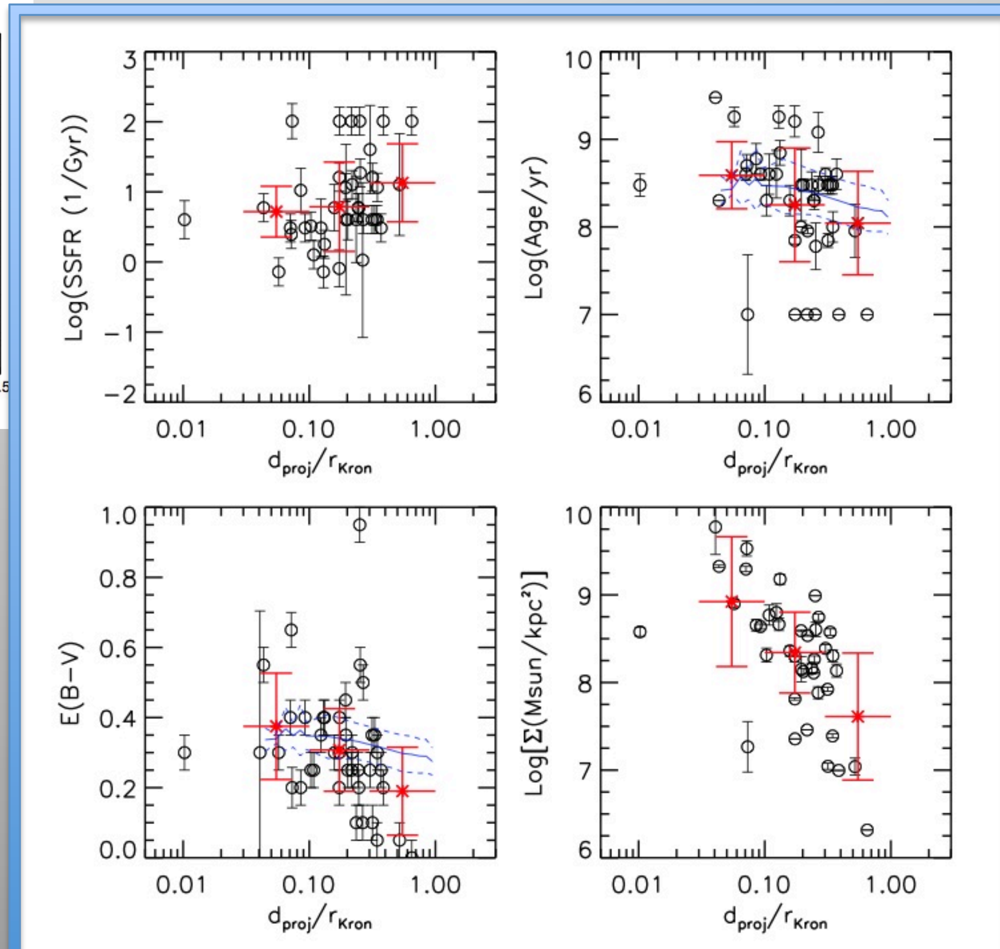


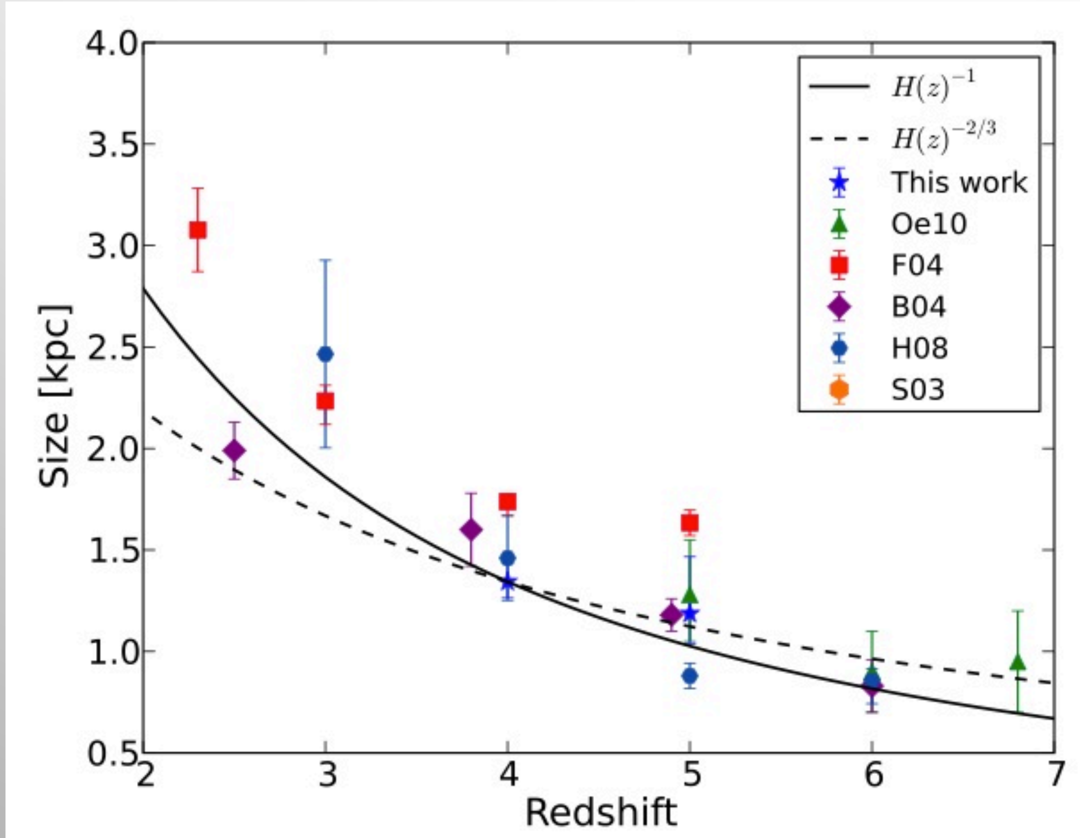
Bayliss et al. 2014



- Goal is to be able to get high fidelity observations that can verify or provide strong constraints to the theories of disk formation and growth







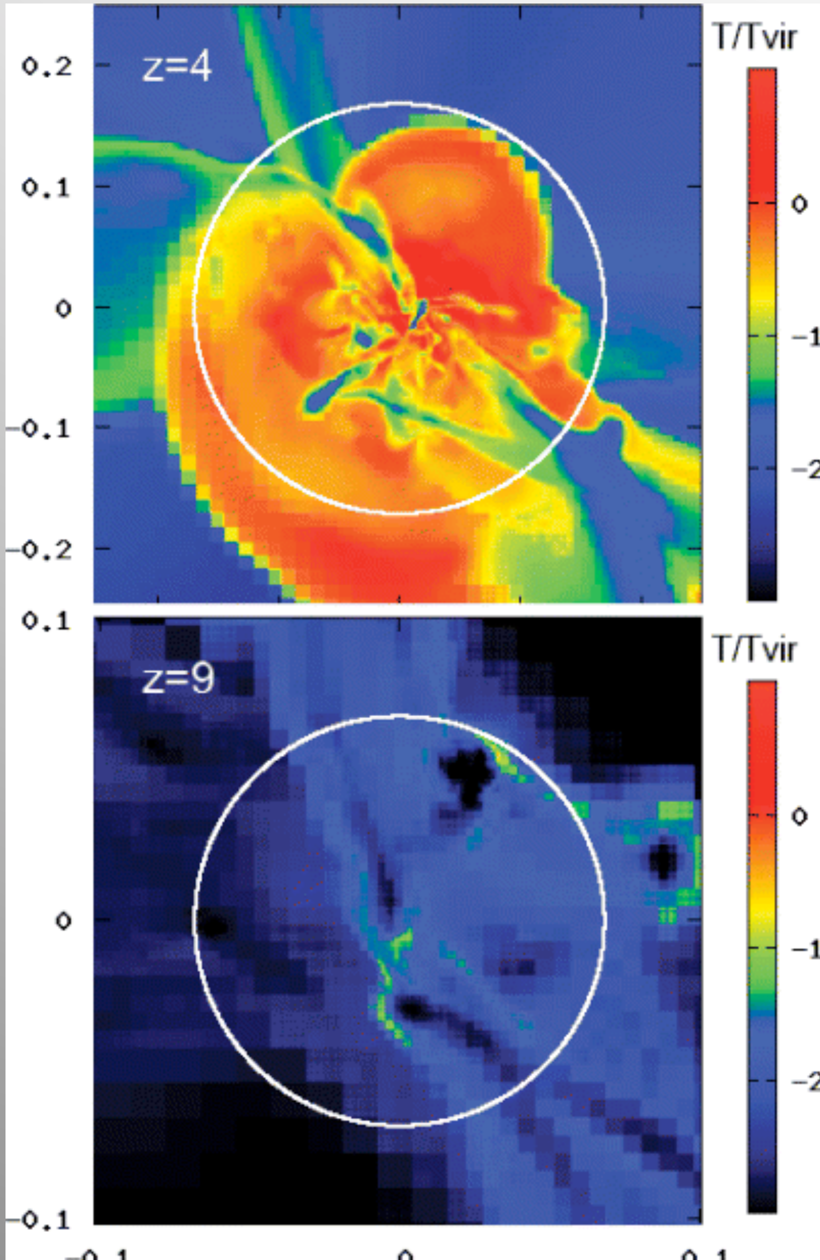
Huang, Ferguson, Ravindranath, & Su (2013)

TMT IRIS:

- 0.004 to 0.05 arcsec
- Few tens to hundreds of parsecs at all redshifts from z=1-6, star-forming properties for range of clump sizes and masses

TMT will be able to reach flux densities of $3x10^{-17}$ ergs/s/cm^2 enabling high S/N even for inter-clump regions with SFR of 0.1 $M_\odot$/yr

How do dark matter halos assemble their baryons?



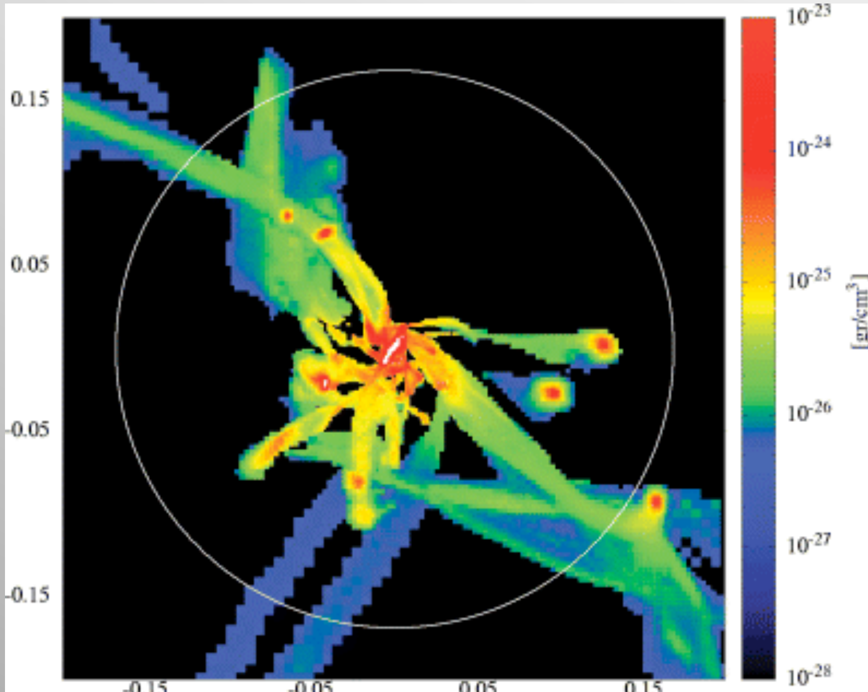
Galaxies can acquire their gas through hot and cold accretion modes, the dominant mode depends on the DM halo mass.

Temperature map:

massive halo @ z= 4,
$M_{halo} \approx 3x10^{11} M_{\odot}$

massive halo @ z= 9,
$M_{halo} \approx 2x10^{10} M_{\odot}$

Keres et al (2005); Dekel & Birnboim (2006)

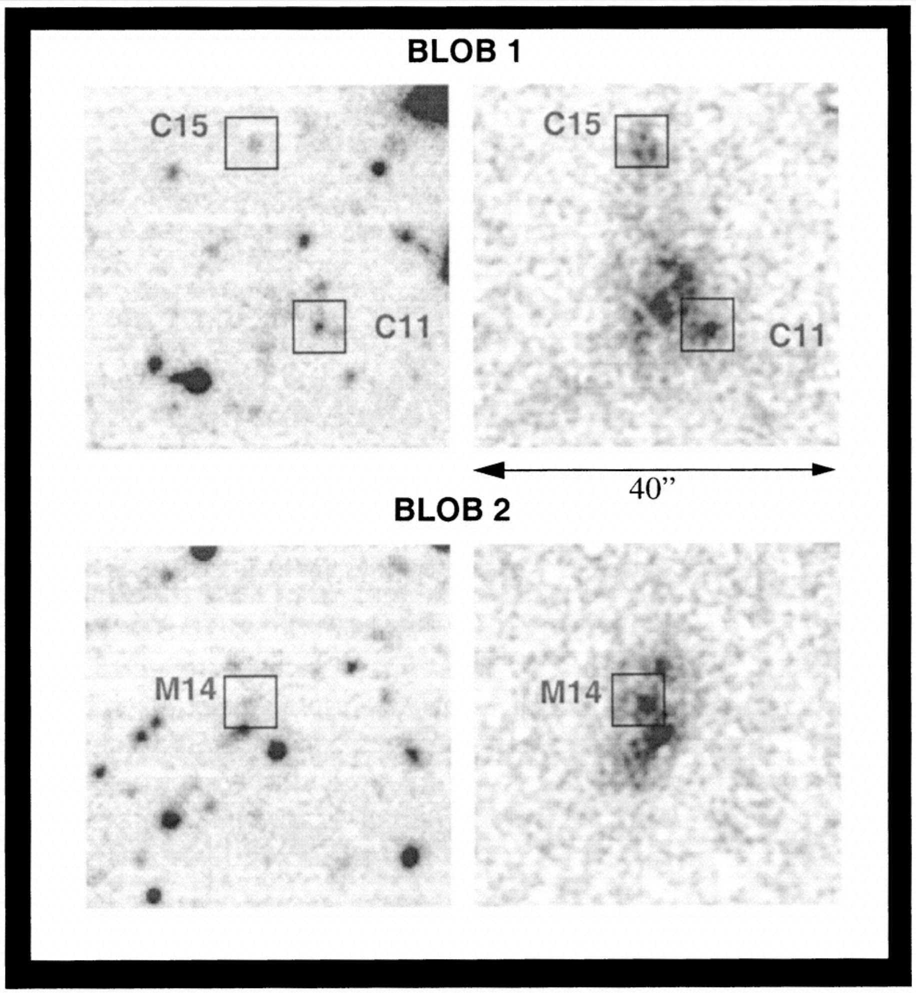


Gas density maps of the cold flows shows that the cold phase is filamentary. About half the mass of cold gas is in dense clumps.

Cold accretion flows are being increasingly used to interpret recent observations of high-z galaxies.

Only few cases, if at all, of convincing detection of cold accretion flows!!

Lyman-α blobs (LABs):



Steidel et al. (2000)

z = 3.09

Observations of LABs with extent ≈ 100 kpc, and no associated continuum source. Suggested mechanism is cold flow accretion.

Steidel et al. (2000)
Matsuda et al. (2006)
Nilsson et al. (2006)
Smith et al. (2008)

Cold gas inflows also detected through the fluorescent Ly- α photons.

Rauch, Becker, Haehnelt, Gauthier, Ravindranath, & Sargent (2011)

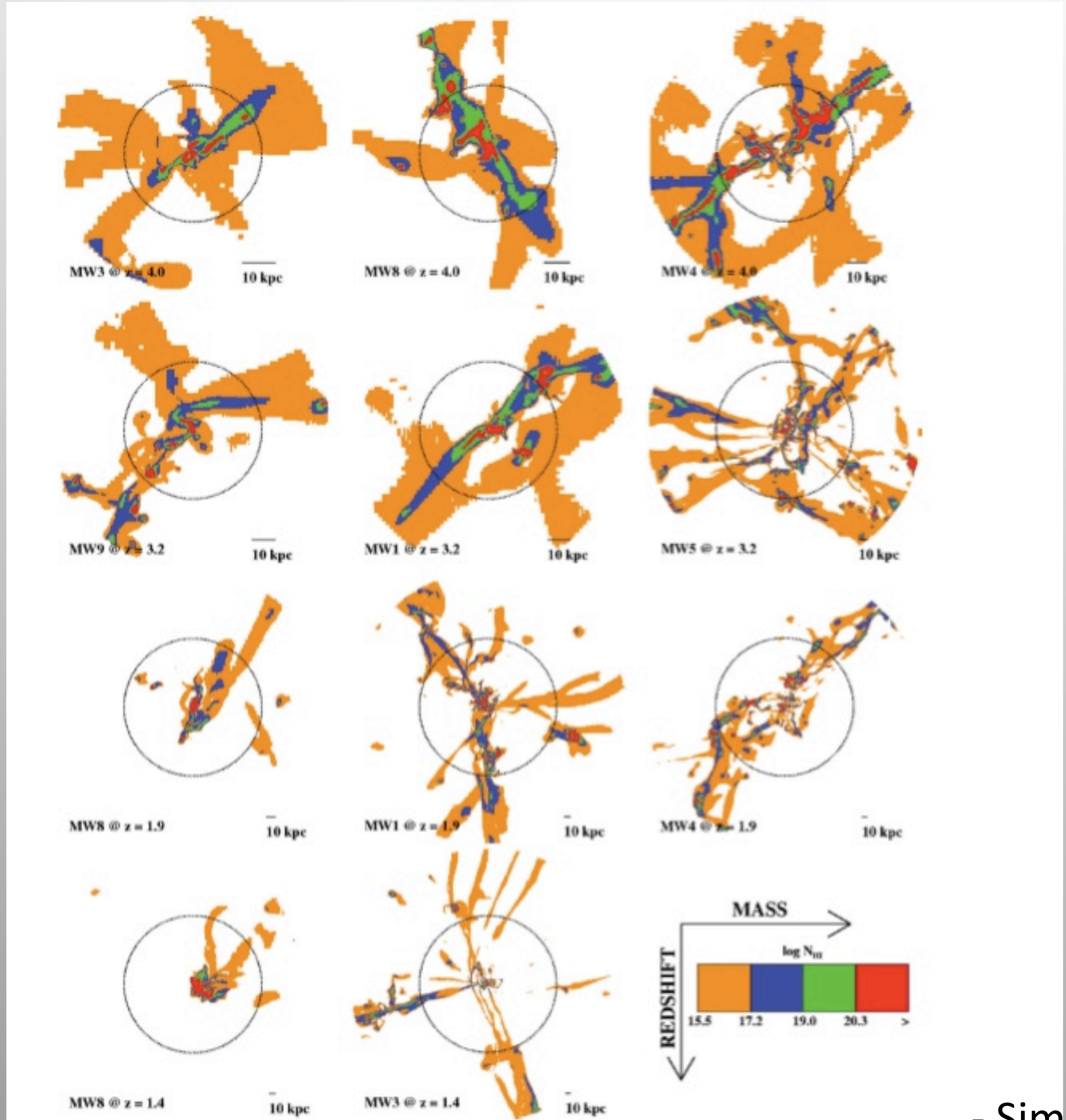
- Direct imaging of LABs to see the actual filamentary structure of cold flows.

- current images are with 1” resolution = 8 kpc at z=3 and does not resolve filament structure

- TMT observations which target the LABs at resolutions < 50-100pcs and higher sensitivities should be able to show us the filamentary structure.

- At z=4.7, for $M_{halo} = 2 \times 10^{10} M_{\odot}$, the expected LAB luminosity is $L_{Ly\alpha} = 10^{44}$ erg/s or flux = 5.0×10^{-17} erg/s/cm^2

- Various groups are emerging with predictions on the luminosity functions, physical sizes, and morphology of LABs from hydro-dynamical simulations (DijKstra & Loeb, 2009; Latif et al. 2011; Yajima et al. (2012)



Fumagalli et al. (2011)

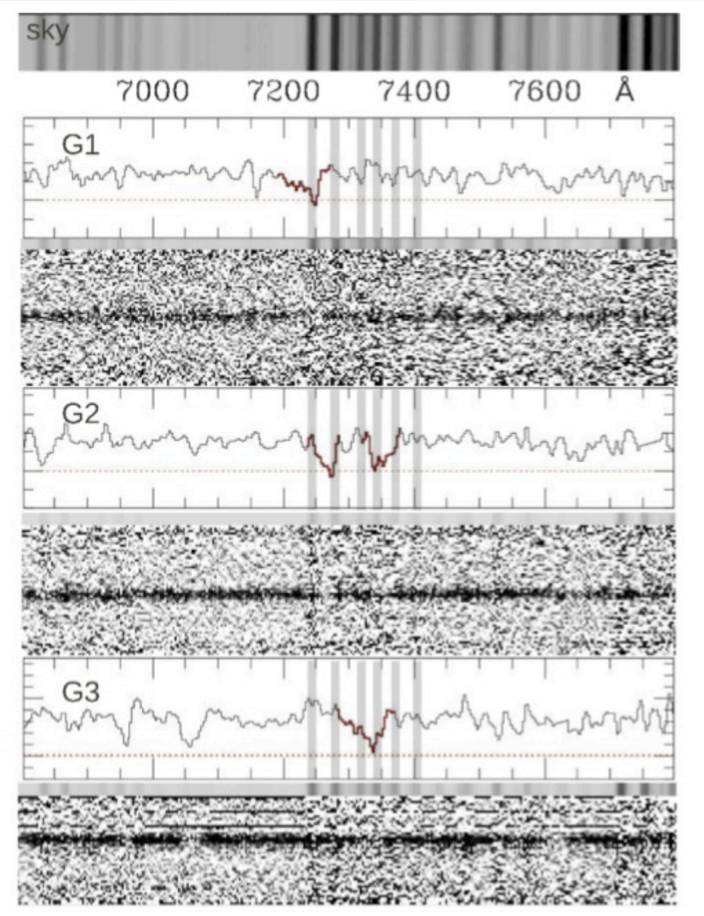
- Comparison of incidence of absorption line systems between the observed and simulated systems, show that cold streams can be responsible for 30% of ALS.

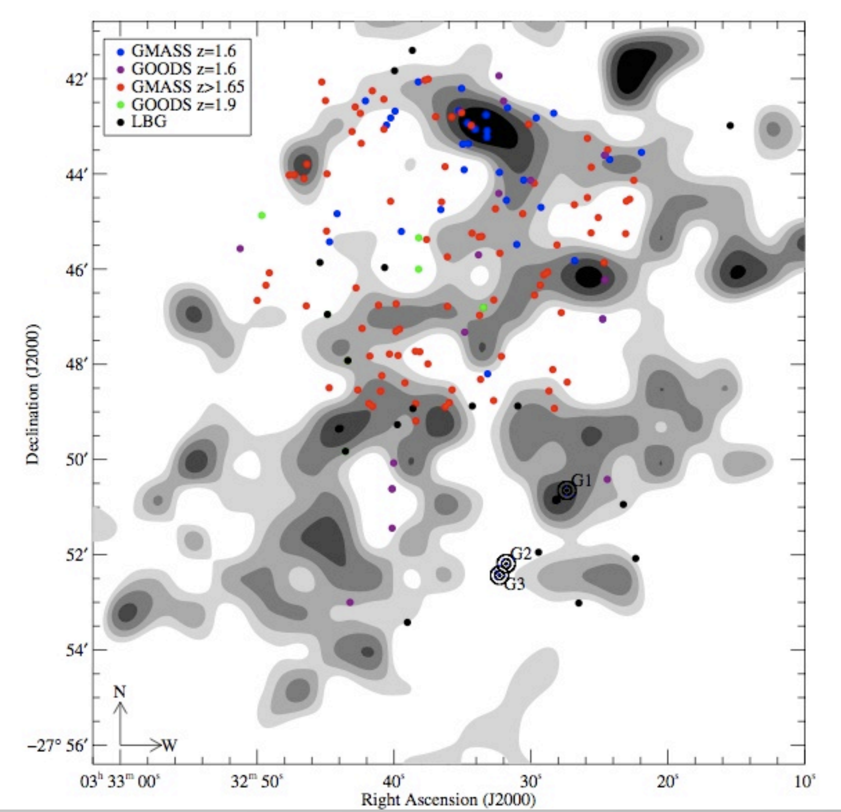
- The cold accretion streams have column densities of N(HI) = 10^{19} -10^{20} cm^{-2}

- The cold accretion streams have covering factors of f = 4 - 40%

- Simulations with predictions for detectability, expected column densities, metallicities: ***Fumagalli et al (2011); Goerdt et al. (2012); Stewart et al. (2011)***

Absorption-line systems:





Infalling low-metallicity gas associated with an over-density at z=1.61.

Giavalisco et al. (2011)

Other observations of absorbing systems with pristine/low-metallicity infalling gas:

Ribaudo et al. (2011) ; Kacprzak et al. (2012)

- one of the main problems with detecting cold flows through ALS is the small covering factor.

- Also, finding bright beacons like QSO's as background sources, with the required alignment is rare.

- TMT will allow bright galaxies and galaxy pairs to be used as background sources, and provide the high S/N spectra required to identify the absorption features arising from cold flows.

Summary

- TMT would revolutionarize the understanding of disk assembly and growth mainly through the kinematics, and also allowing to probe the radial gradients in the galaxy disks. Validate galaxy formation theories – violent disk instability, or secular evolution, or inside out growth of disks

- A key component to understanding the massive star forming complexes seen in high redshift disks, is the gas supply through cold accretion. Concrete evidence for cold accretion is important. TMT can accomplish through absorption line studies using galaxies as beacons, in addition to the currently used QSO pairs.

- Key science with TMT can be with a goal to address a ceratin science project, than surveys that worked extremely well for HST