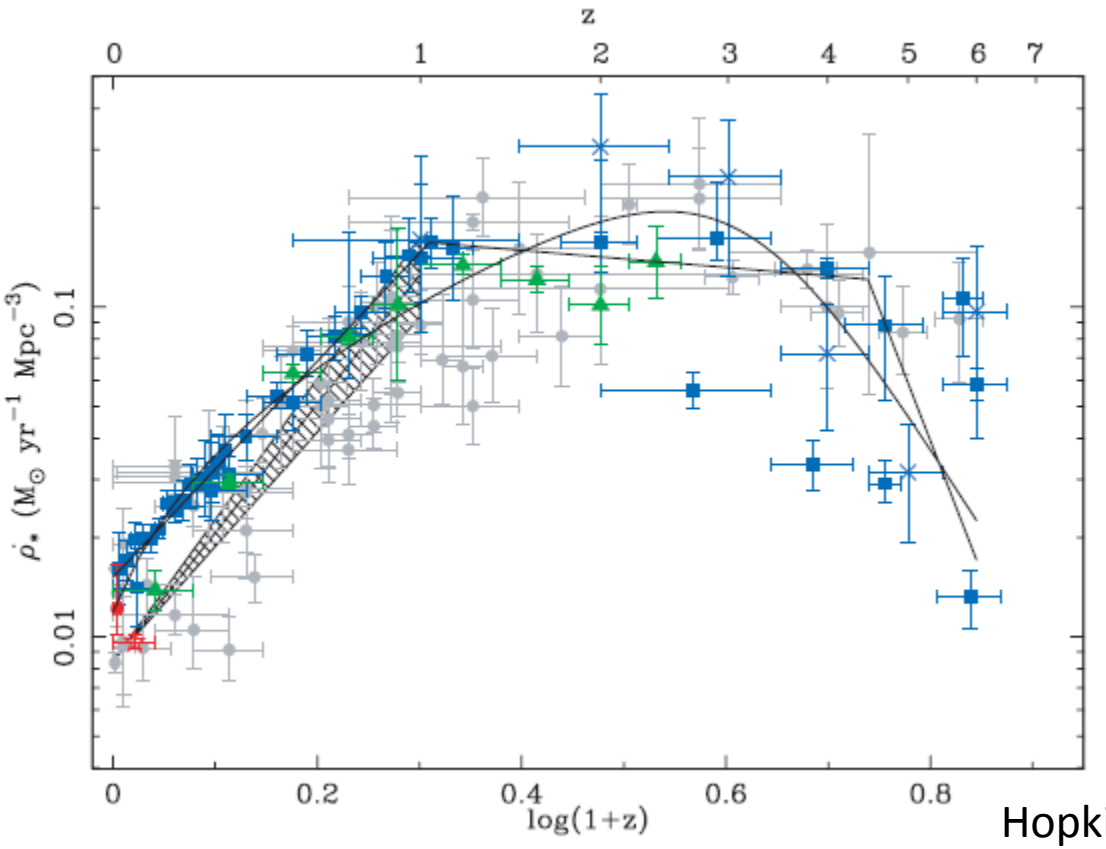
Internal structure of galaxies in the violent epoch of galaxy evolution with IFU

K. Ohta
Kyoto Univ.

2014.07.28 @ Mitaka

Cosmic SF history

- SF activity peaks at z~2
- i.e., highest prosperity in galaxy life (statistical sense)
- Emeregnce of the Hubble sequence around this epoch

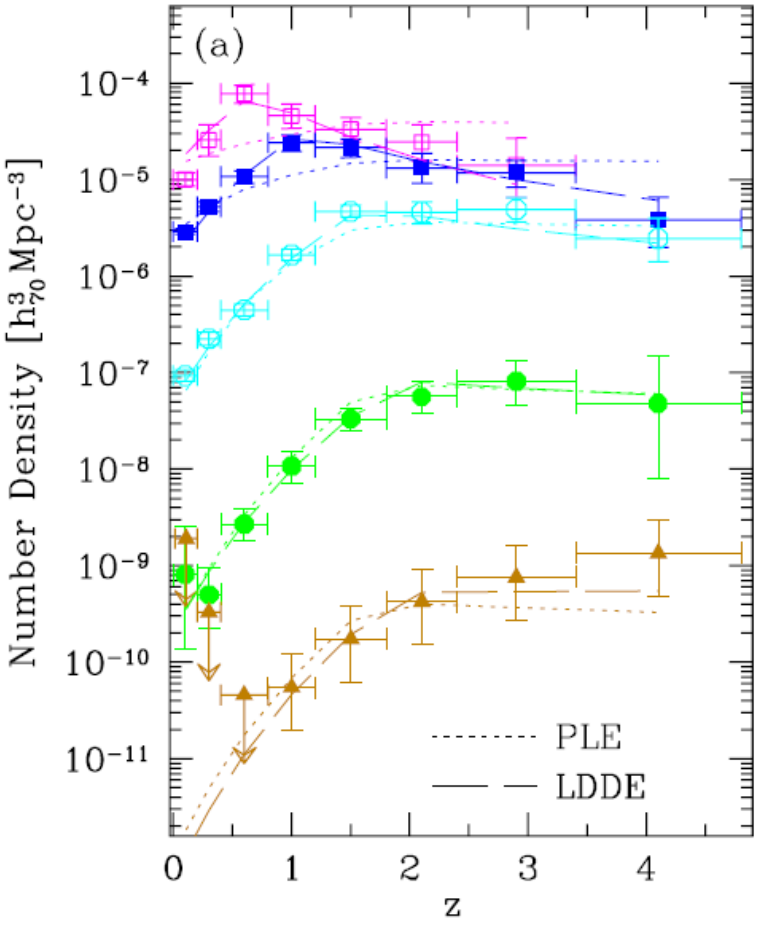


Important epoch to unveil galaxy formation/evolution

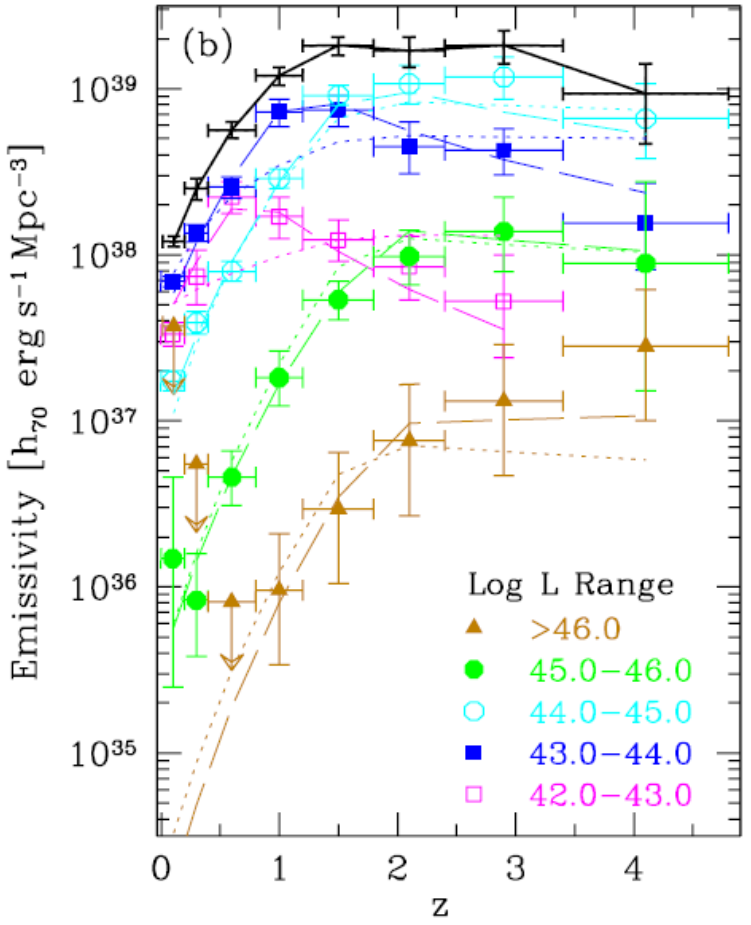
Hopkisn and Beacom 2006, ApJ 651, 142

AGN activity also peaks in the epoch

Number density



Volume emissivity



, though downsizing nature is seen

Hasinger et al. 2005, AA 441, 417

Next step: evolution of internal structure of galaxies in the epoch

- Previous many studies: Evolution of galaxy as one zone object (w/o structure)

- How does a galaxy evolve into a disk+bulge or elliptical galaxy?
- What is the transformation of gases to stars in a galaxy?
- How did it proceed in galaxies?

(these two subjects are very important in ALMA era)

- What is the evolutionary connection between AGN and galaxy? (feedback/co-evolution)
- etc

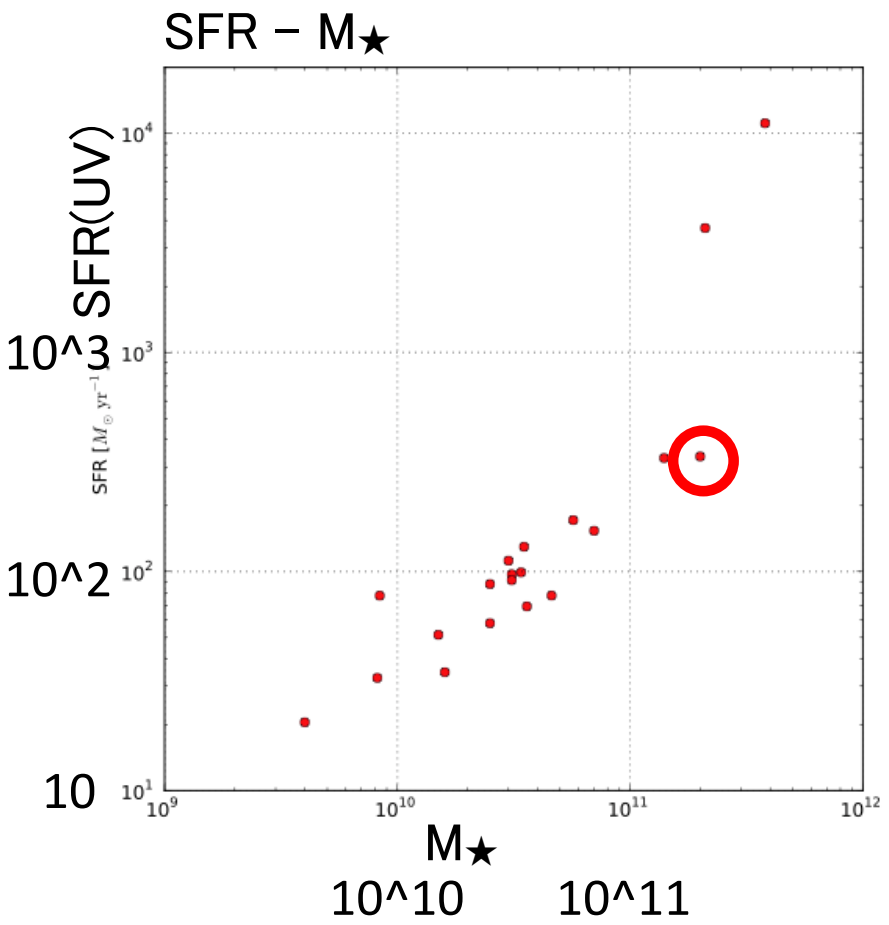
An example:
A molecular gas clumpy galaxy at z~1.4

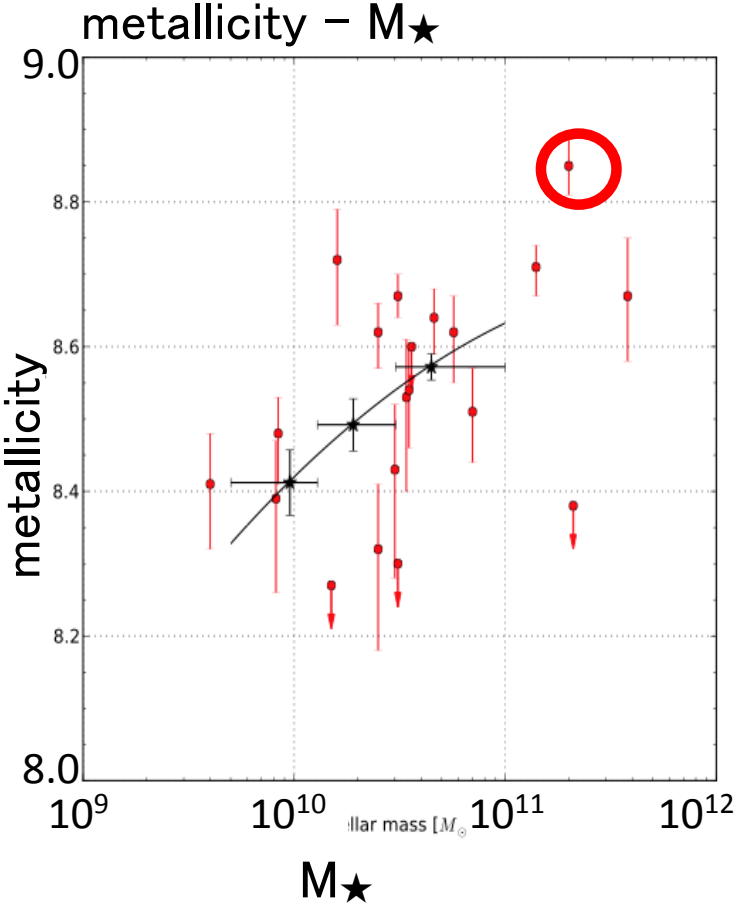
From Subaru to ALMA + HST + VLA
(+ GEMINI IFU/NIFS)

Star-forming galaxy at z~1.4 in SXDS (in CANDELS)

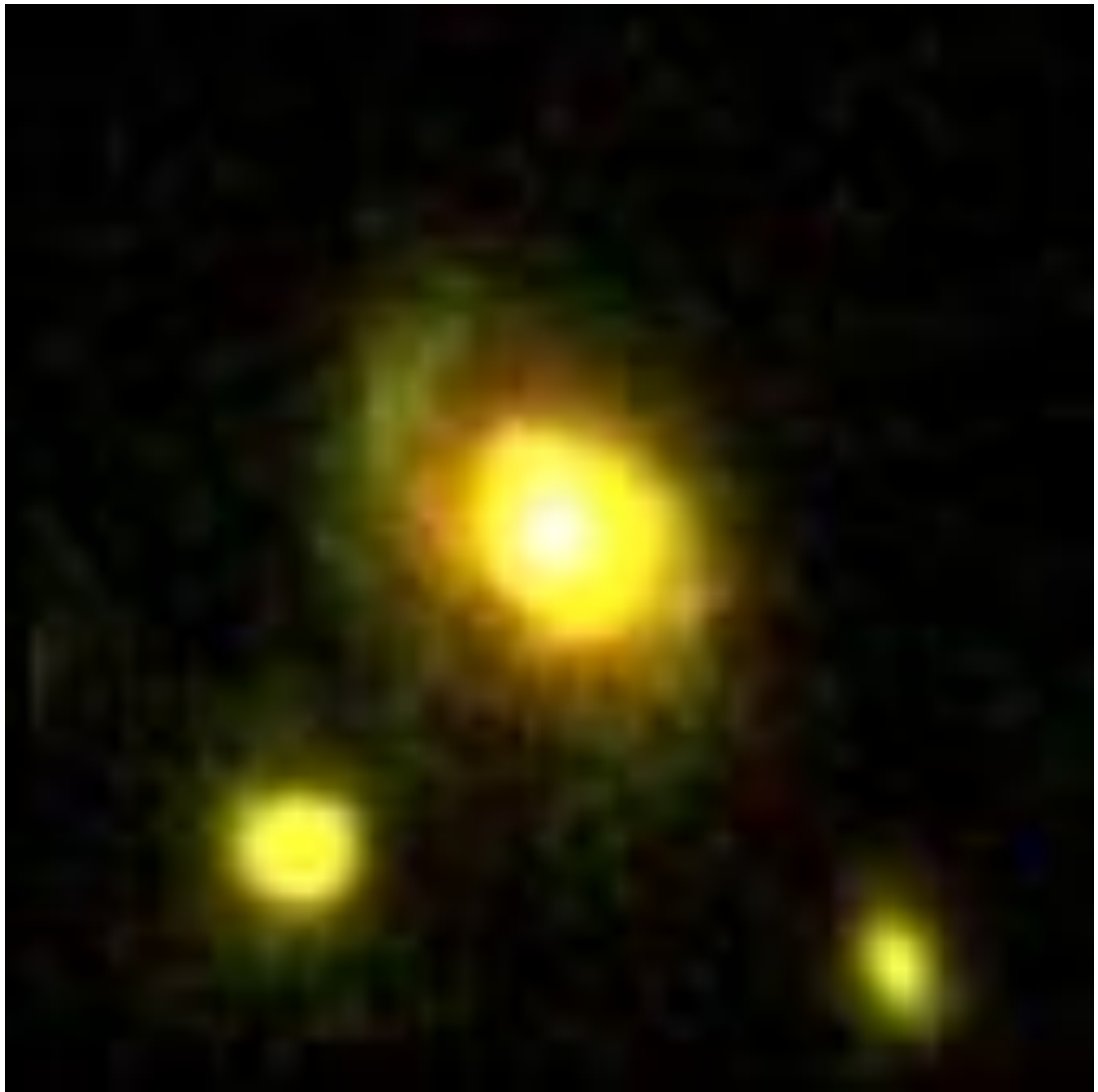
Redshift, SFR(Hα), gas metallicity were determined with FMOS observations

Mstar=1-2x10^11Msun, SFR=150-300 Msun/yr
Z~solar abundance





HST:WFC3(H,J)・ACS(606) composite image

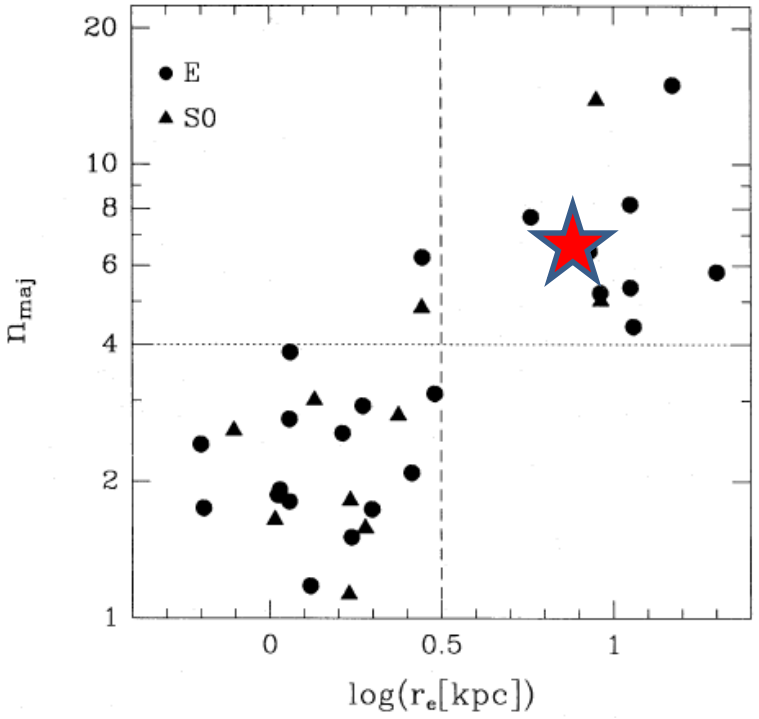


~5”x5”

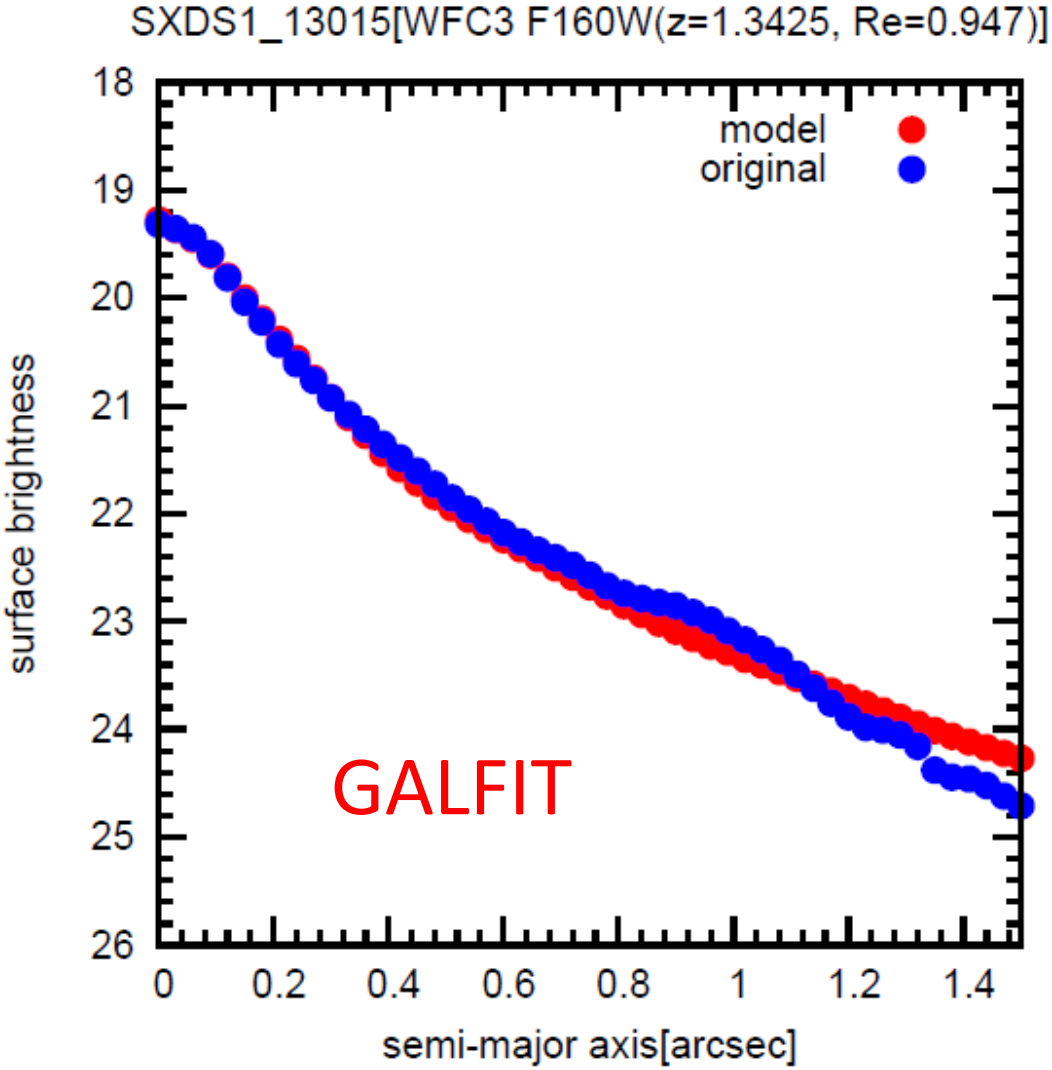
Surface brightness distribution at F160

Sersic index =6.7

r_e=0.95” = 8 kpc



Caon et al. 1993, MN 265, 1013



A forming elliptical?

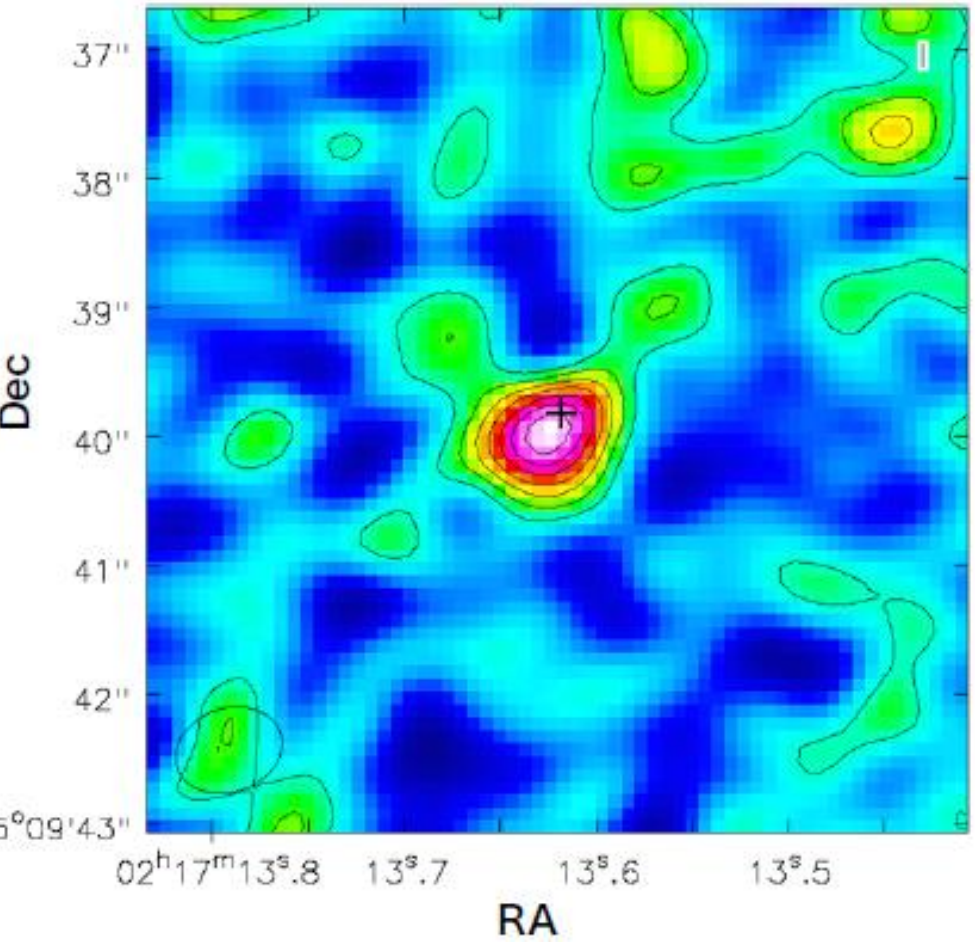
Observations with ALMA

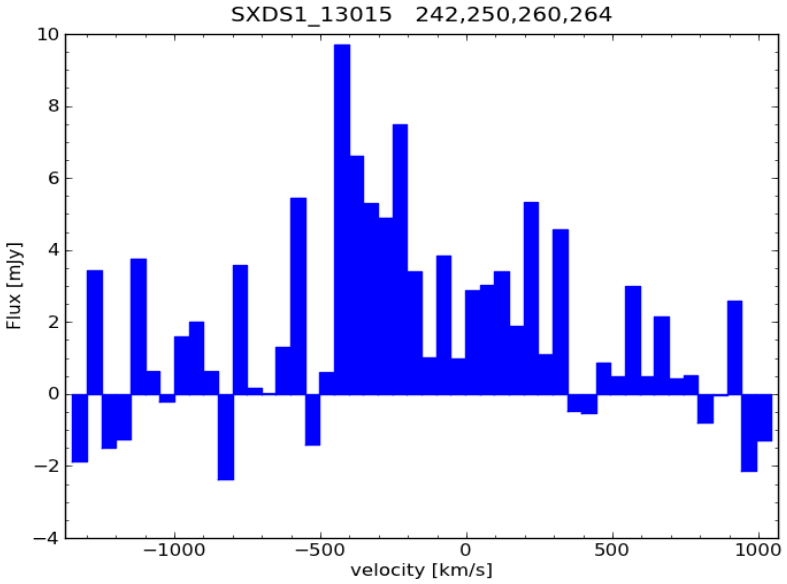
- ALMA　cycle0 (2012年8月）　23台
- CO(5-4)　Band 6 (211-275 GHz)
- z=1.453 (+-0.002)
- 帯域1.875GHz,1chan　488kHz（2400 km/s,　0.6 km/s)
- 832.7s ~14 min exp
- Beamsize　0.88”x0.67” (PA=108.5)　　(~7x6kpc)

  1.0” => 8.5 kpc
- Uncleaned
- σ ~ 1mJy/beam (50 km/s bin)

Detection!

CO(5-4)

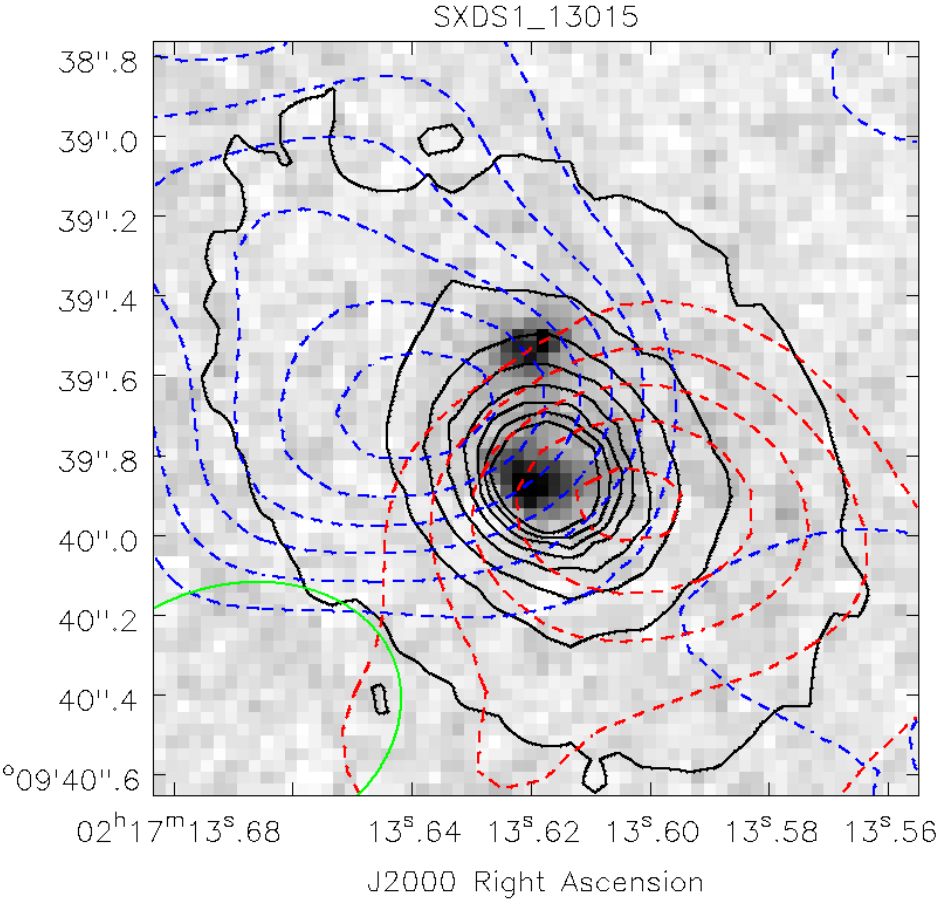




HST + ALMA
after correcting for astrometry

Position of reference calibrator was mis-replaced !!!

1.8”x1.8”



Grey scale :

rest UV （～2500A)

Black contours :

rest optical （～6500A)

Blue contours :

CO ~ -200 km/s

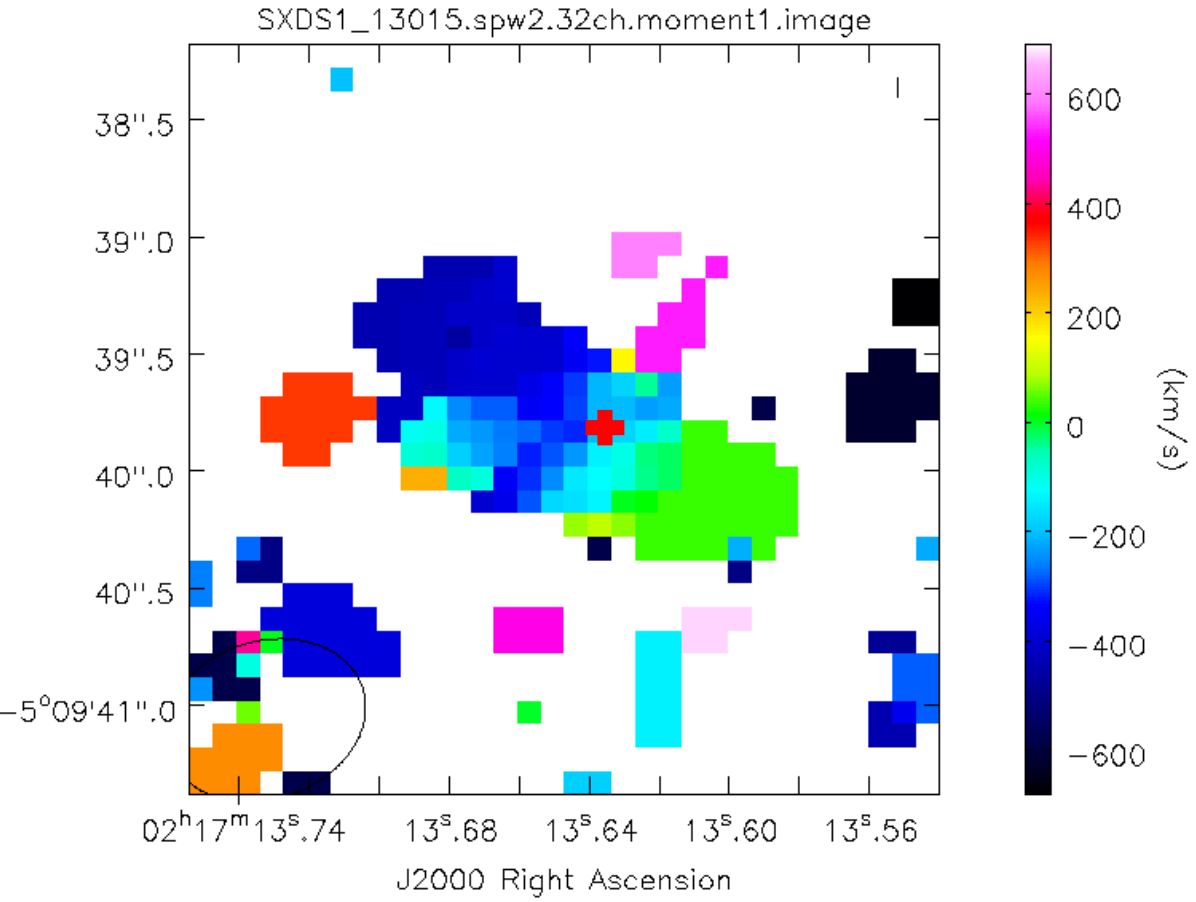
red contours :

CO ~ 200 km/s

1,2,3,.. σ

Green : CO beam size 0.7”x0.8”

Velocity field (1-st moment map)



Rotating gas disk?

V~ 200 km/s at r~3kpc

=>

Mdyn ~2.6x10^10Msun /sin^2i

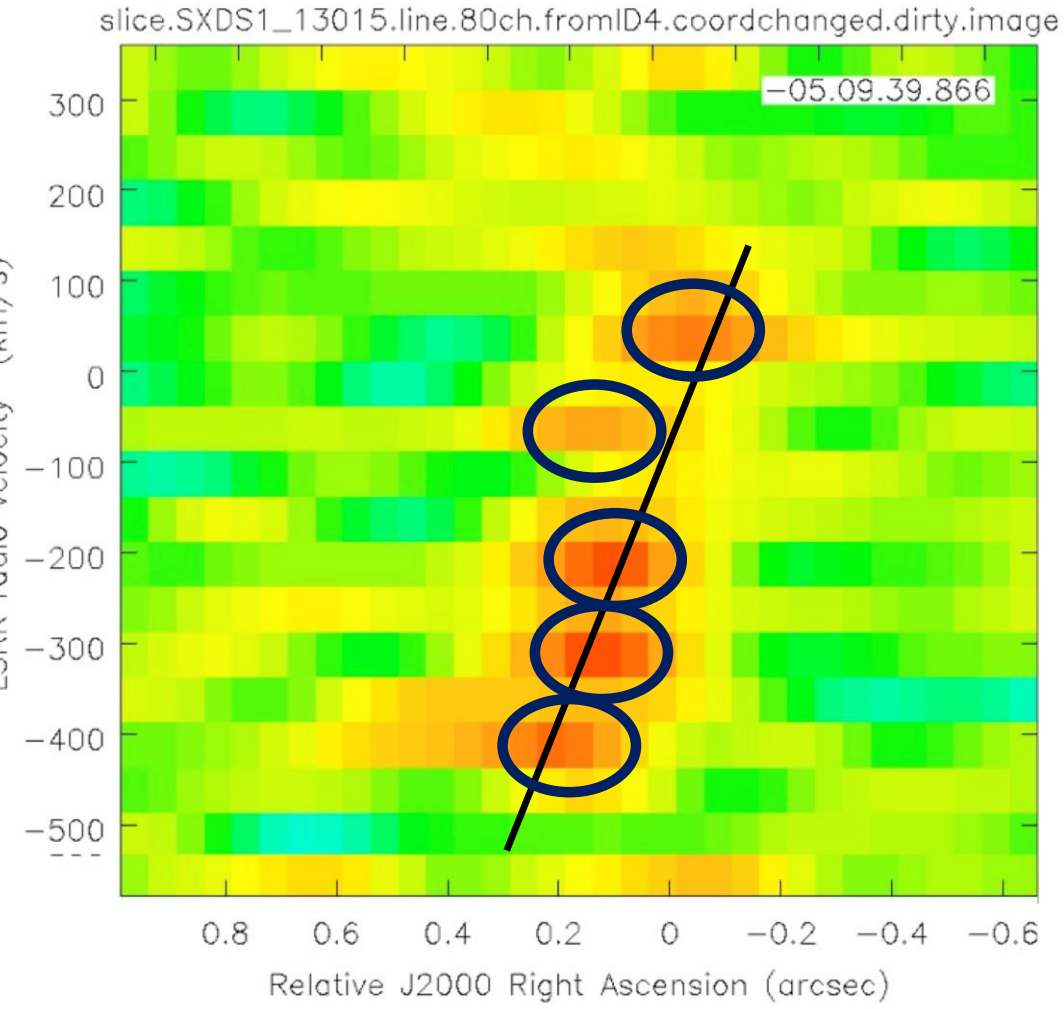
i~33deg

=> ~9x10^10 Msun

Within r~3-4 kpc

PV diagram along the major axis

velocity



<= NE SW =>

position

Solid rotation-like w/ deviations

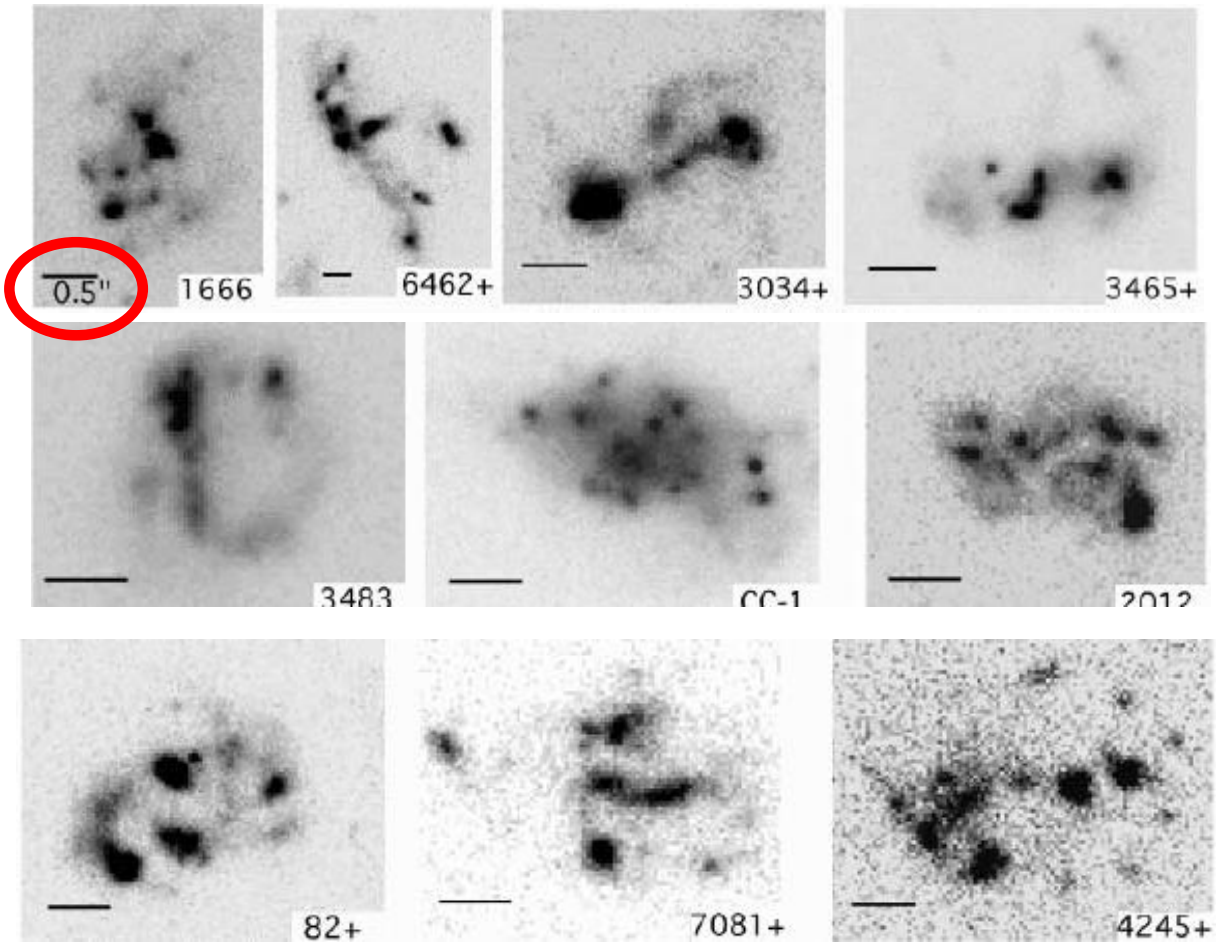
4-5 Clumps w/ ~50 km/s

Flux densities: 4-7 mJy for each

Infalling clumps?

Molecular gas clumpy galaxy !

Clumpy galaxies in opt/UV at z~2



Elmegreen & Elmegreen 2005　ApJ 627, 632

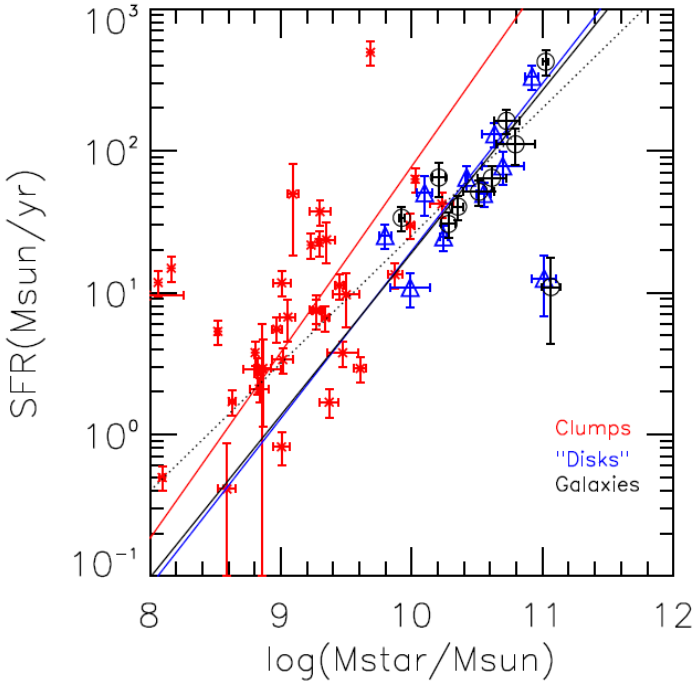
In HUDF

Guo et al 2011
ではSF gal at z~2
の6－7割(10/15)

sBzKの場合は、
もっと軽傷で
5割位(478/1029)
Yuma, KO, et al. 2011

Properties of clumpy galaxies

- High fraction at z=1-3
- Clump size: 0.5-3 kpc
- Stellar mass: 10^8-10 Msun (typically 10^9)
- SFR: 1-100 Msun yr^-1
- High specific-SFR



Guo , Y. et al. 2012, ApJ 757, 120

Bulge formation by the coalescence of giant clumps

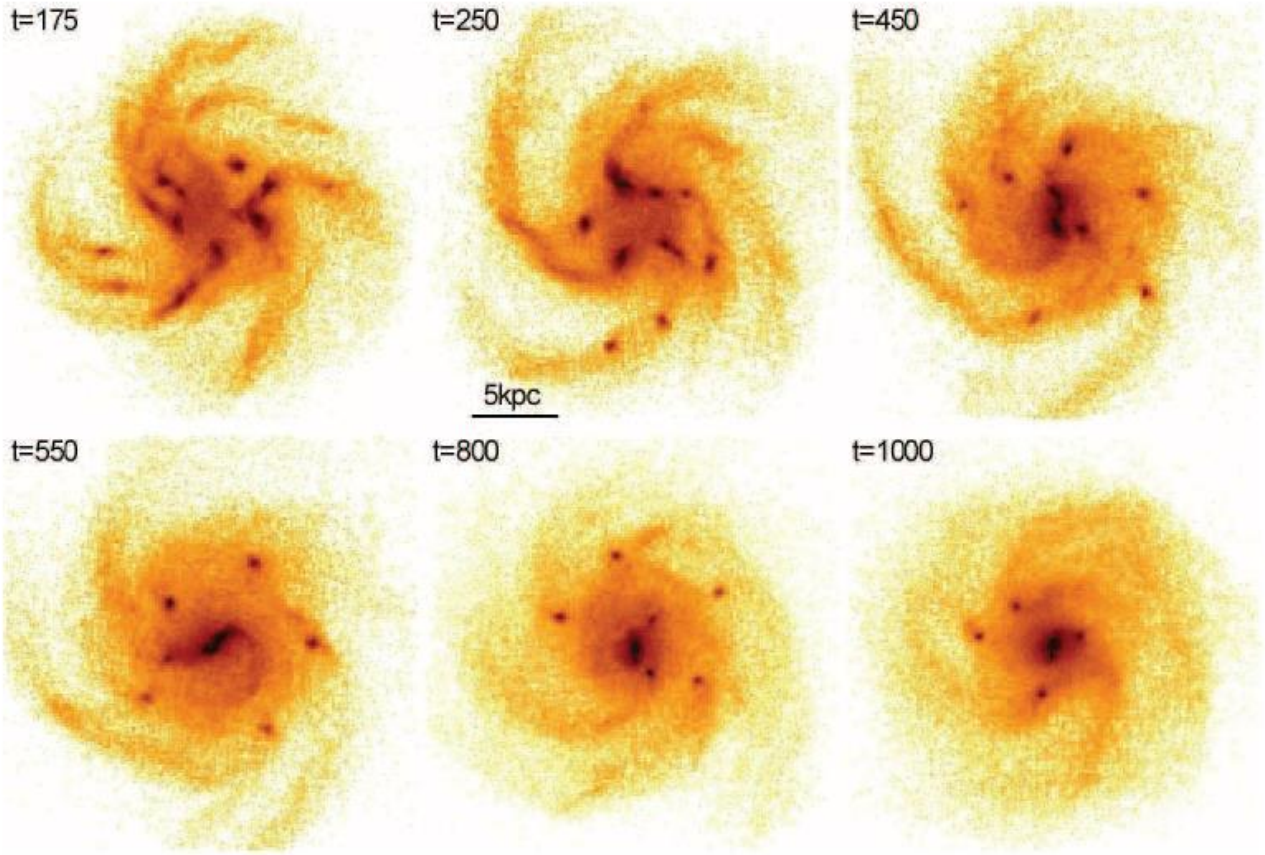


FIG. 2.—Face-on snapshots of the disk mass density (gas and stars) for run 0N, which has a cuspy dark matter profile. Time is in Myr. Clumps form quickly in the disk and move to the center, where they coalesce into a bulge within 1 Gyr. Extra star formation in the bulge region is triggered at the time of merging as well. A few clumps remain in the disk when the simulation ends.

Elmegreen et al. 2008, ApJ 688, 67

Nature of molecular gas clumps

- Size ~4 kpc to less than 3 kpc

  ~ comparable to UV/opt clump size

- $M(H_2)$ = 2x10^9 Msun

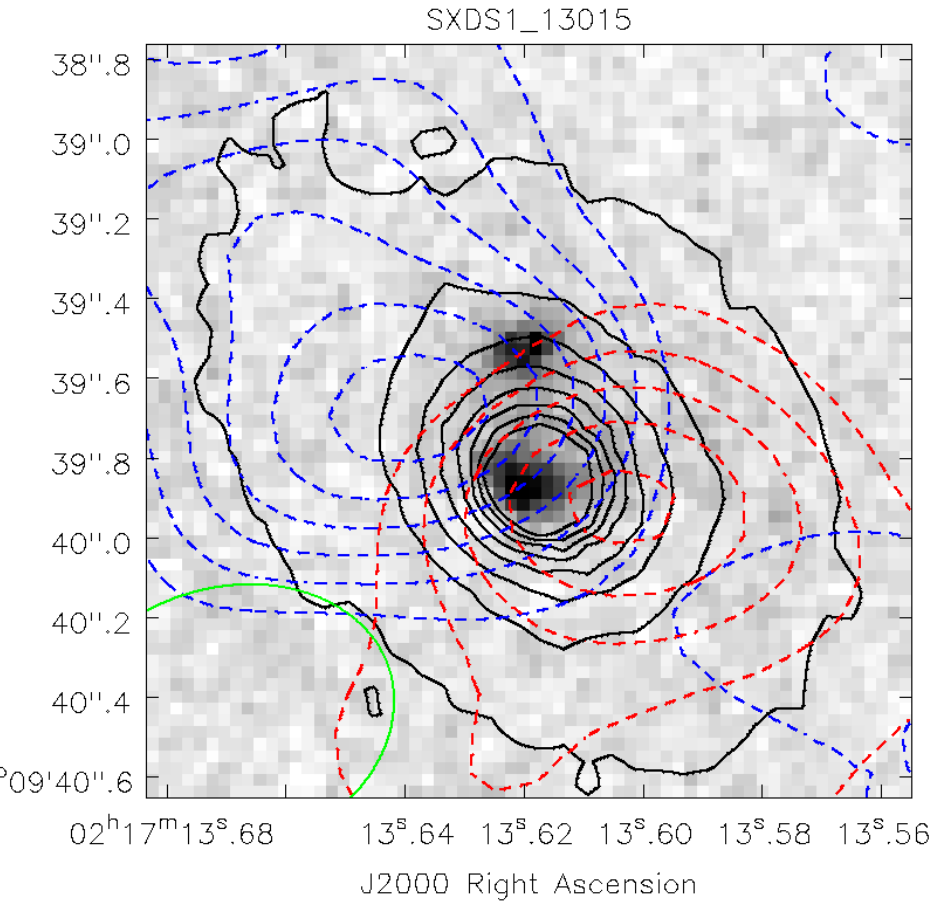
  high gas mass faction

  (S(5-4)/S(1-0)=15, α=0.8)

- Clump formation ~ Gravitational instability

Further studies of the galaxy

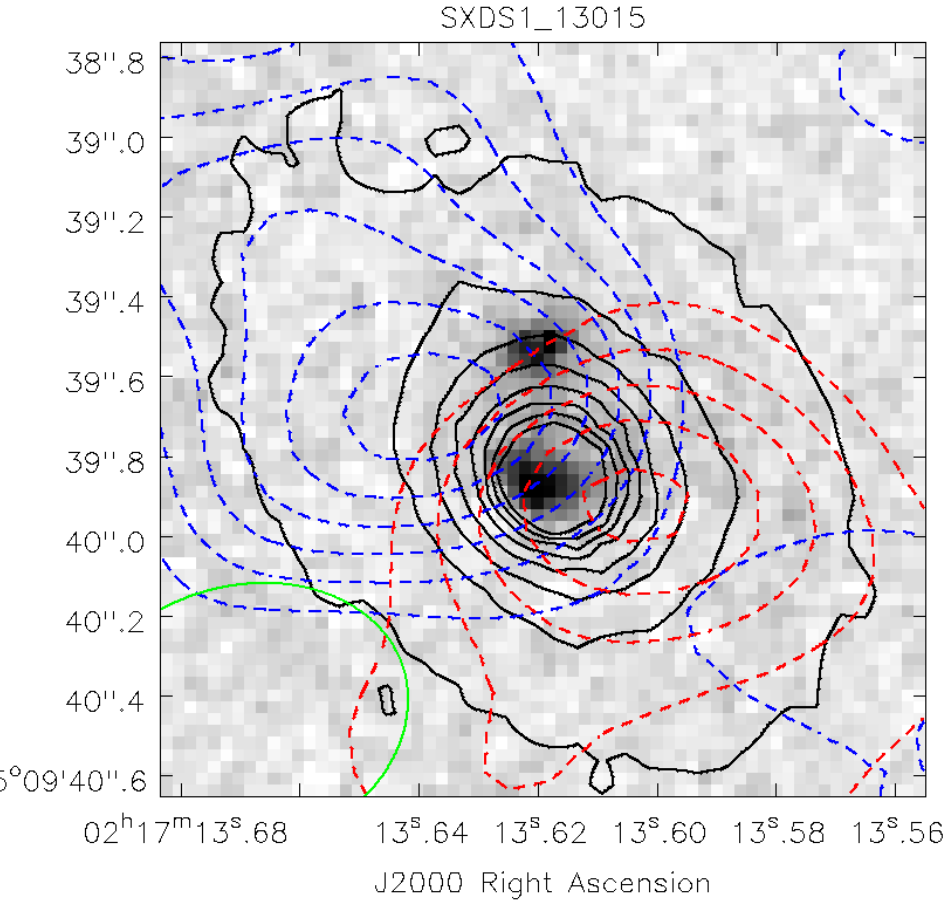
1.8”x1.8”



***SFR and obscured SF**
***relation to UV regions**
***extinction in clumps**
***obscured AGN in clumps?**
***shocked regions?**
(feedback?)
***metallicity**
(gas infall/outflow)
***kinematics in a clump?**
***velocity field, dispersion**
etc

Requirement for IFU

1.8”x1.8”



FoV of IFU : at least 1”x1”

desirable:2”x2”

(Sky subtraction?)

cf:

<r_half> ~ 0.5 - 1” at z=1-2

Pix size: ~ 0.2”

1-2 kpc at z=1-2

(Filling factor ~95%)

FYI: 8-8.5 kpc/arcsec

Further requirements

- Spectral resolution

  Rmin ~ 1000-1500?

  Rmax = 5000?

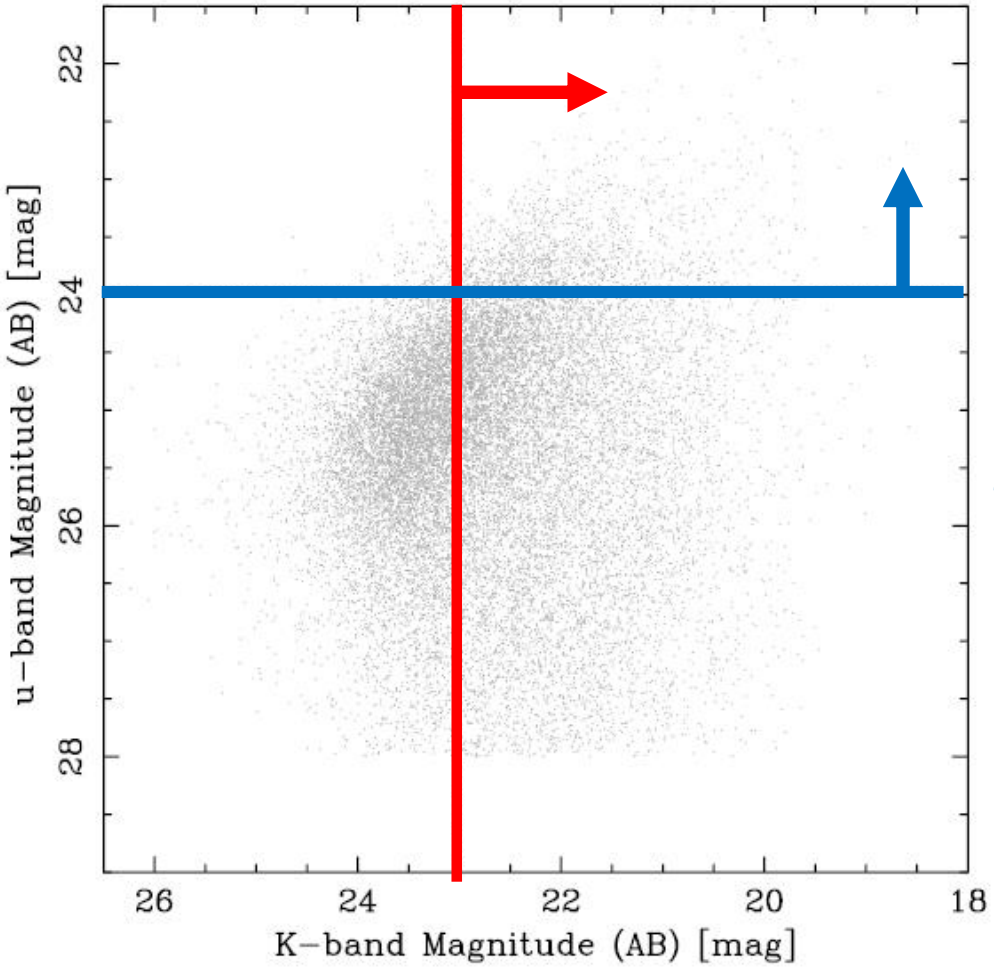
  R>~2000 is desirable for OH line removal

  (hardware OH suppression?)
- Larger/wider wavelength is preferable?
- High throughput
- Astrometry is very important!

  Pre-imaging + metrology camera

How many units at the focal plane?

K-selected galaxies w/ phot-z=1.13-1.74 for FMOS HS & HL



K<23:
stellar mass limit
Ms>10^9.5 Msun

u<24:
SFR ~10 Msun/yr
~f(Hα)~1x10^-16 erg/s/cm^2

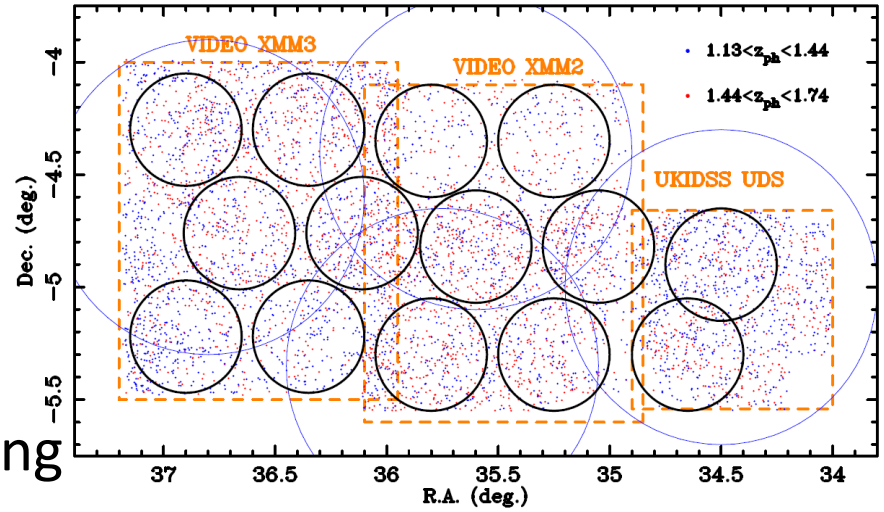
=>
~5000 SF galaxies
in 14 FMOS FoVs
~90 / 15'ϕ
(too many)

A possible ? survey (in phase I?)

- U<24 K>23 galaxies in CANDELS field
- GOODS-N, UDS(15'x10'), EGS(7'x25'), COSMOS(7'x20')

  (GOODS-N, EGS: ALMA cannot access)
- => ~250 SF galaxies in UDS,EGS,COSMOS

- ~5000 galaxies in SXDS
- Before TMT



Possibility of HAE survey w/ pre-imaging