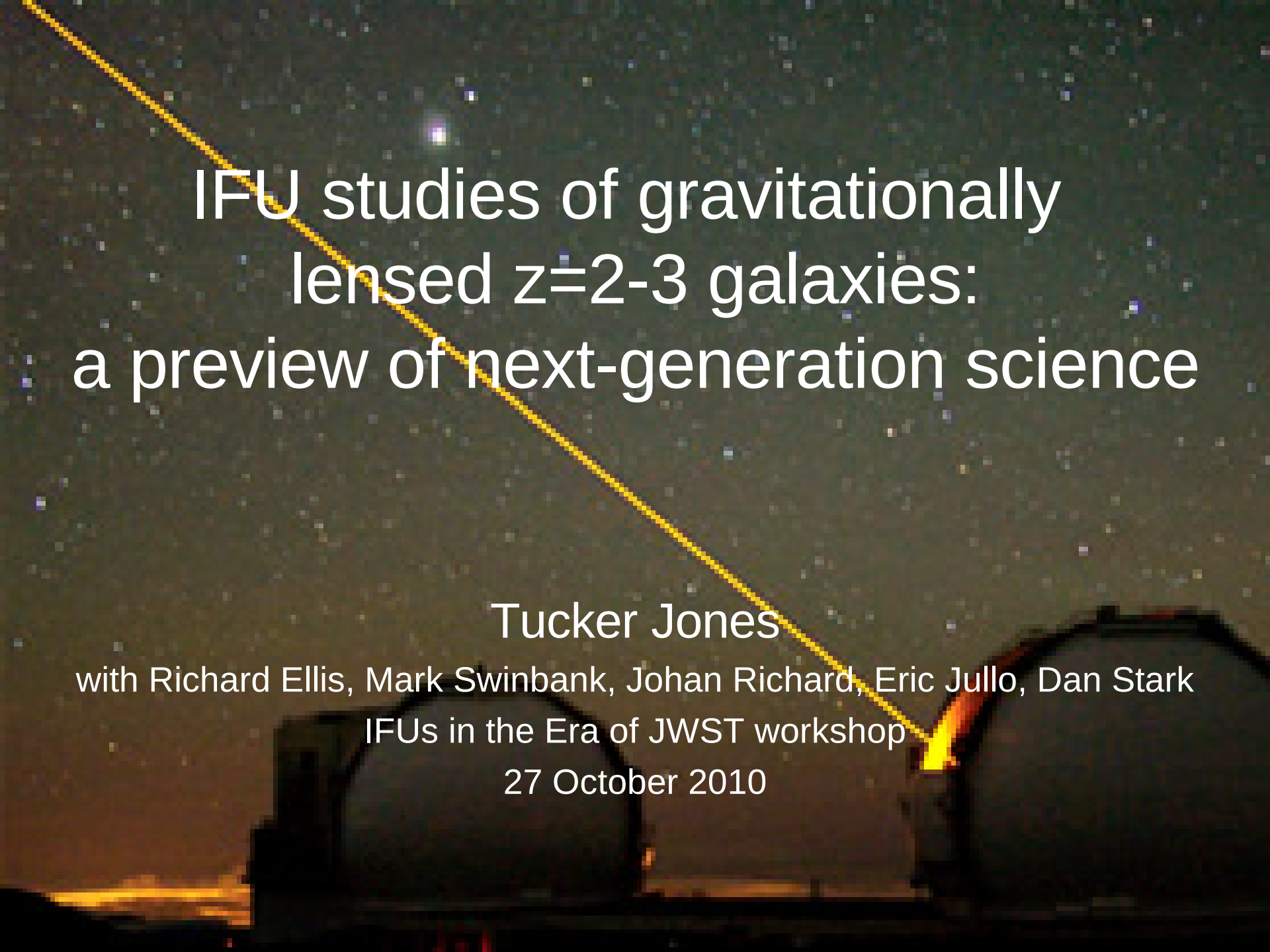


IFU studies of gravitationally lensed z=2-3 galaxies: a preview of next-generation science

Tucker Jones

with Richard Ellis, Mark Swinbank, Johan Richard, Eric Jullo, Dan Stark

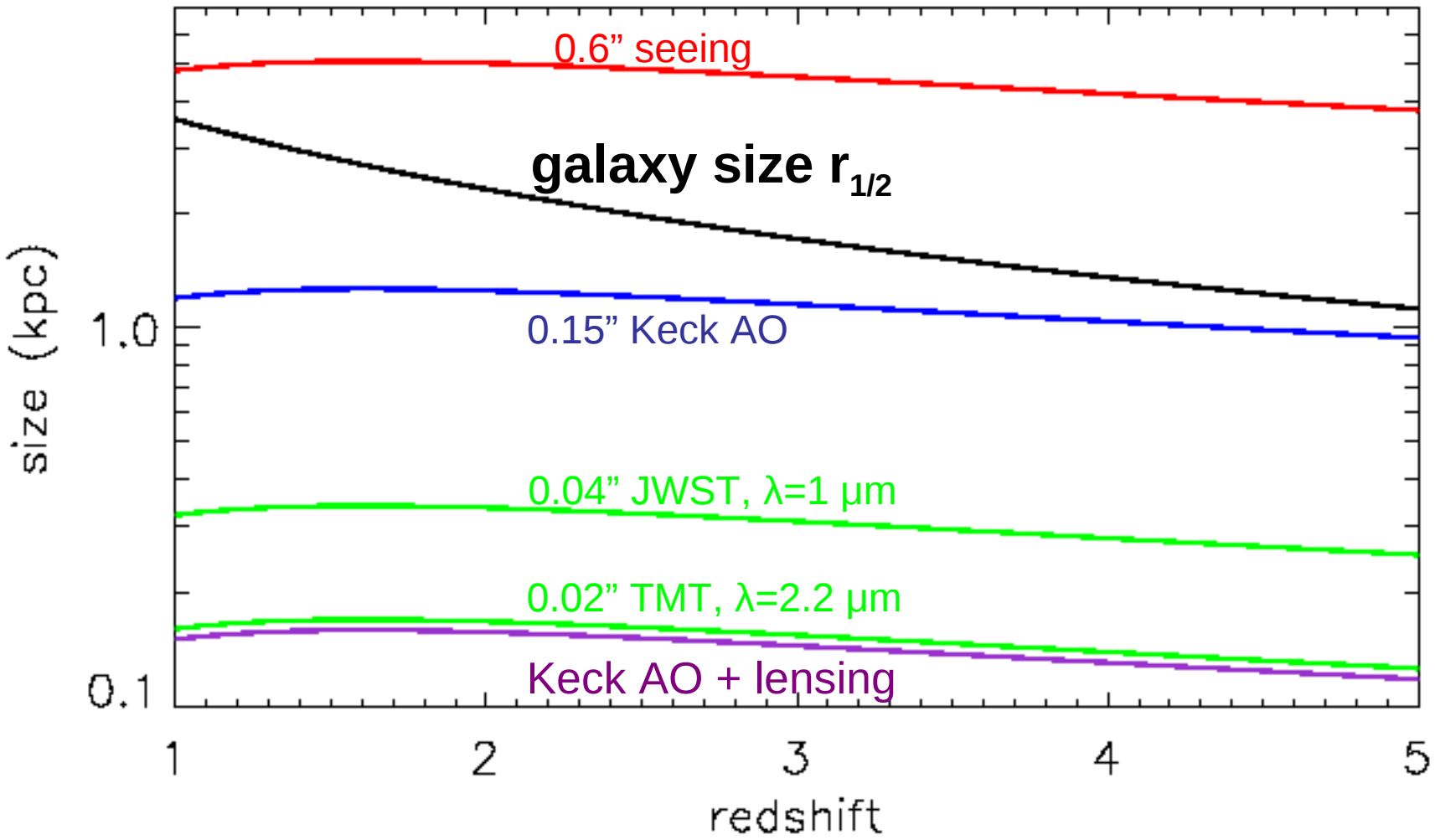
IFUs in the Era of JWST workshop

27 October 2010

IFU spectroscopy of z>2 galaxies

- Kinematics
  - Rotation, merging, velocity dispersion
- Star formation
  - Smooth vs. clumpy distribution
  - Size, luminosity of giant star-forming regions
- Metallicity
  - Gas fraction, yield, infall, outflows
  - Gradients

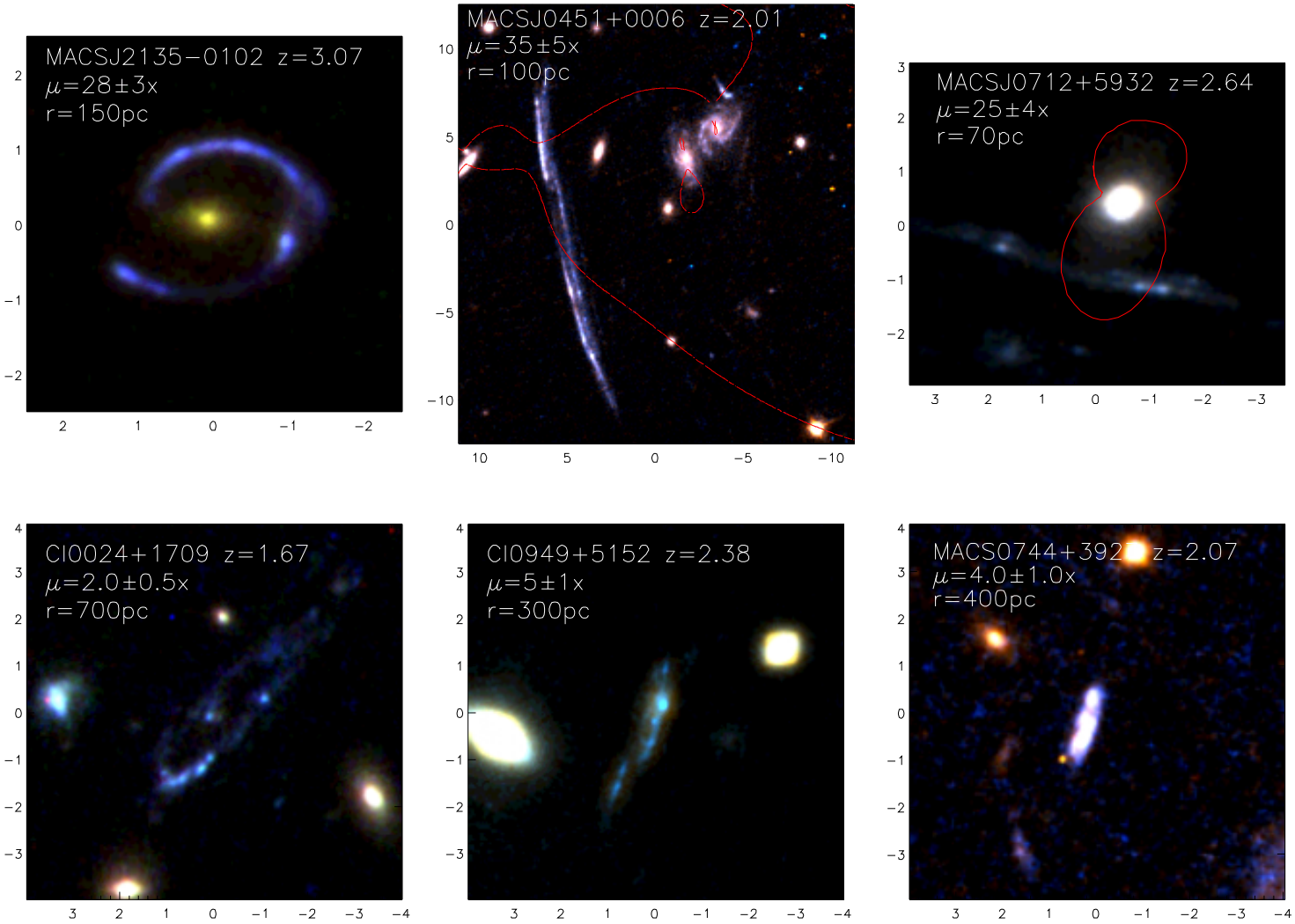
Angular resolution



Galaxies smaller at high redshift → need very high resolution to resolve structure!
Keck AO + lensing gives a valuable glimpse of science possible with JWST and TMT!

Bouwens et al 2004, Ferguson et al 2004, van Dokkum et al 2010

Lensed galaxy sample

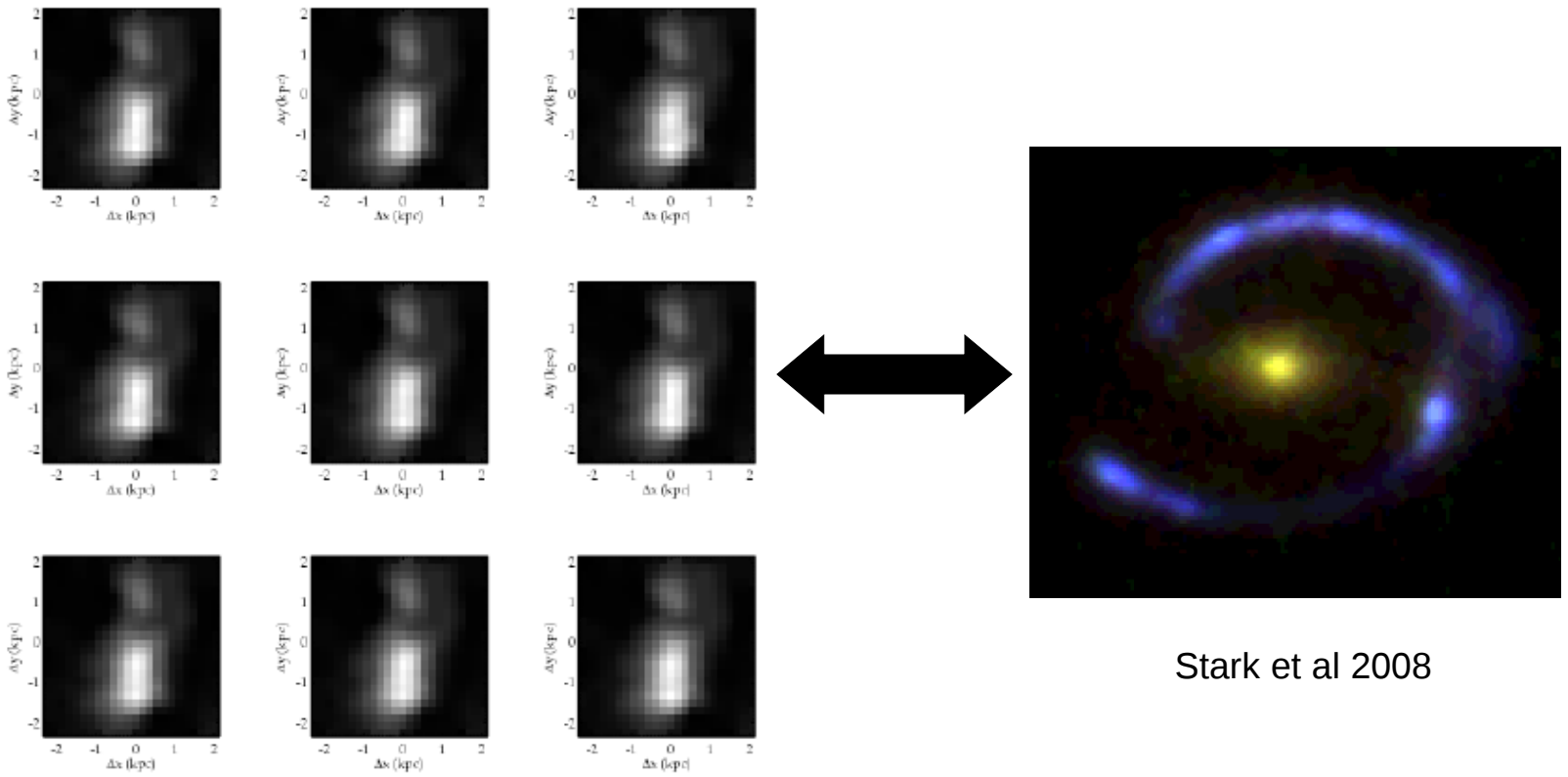


Magnification ~20x, linear magnification ~8x

Source plane resolution = 200 pc, intrinsic luminosity 0.1-1.5 L_*

Stark et al 2008, Jones et al 2010a

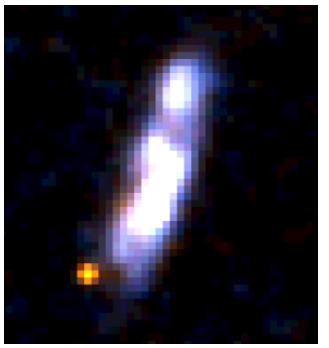
Source plane reconstruction

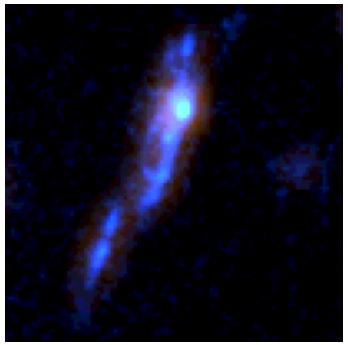


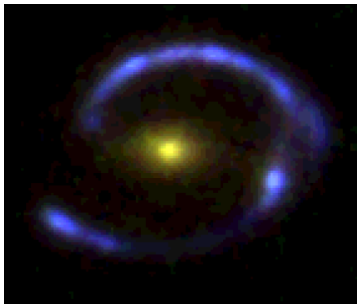
Stark et al 2008

- Uncertainty in lens model determined by accuracy of multiple image positions
- Source plane uncertainty propagated from model
  - Typical uncertainty 15% in magnification

Source plane reconstruction







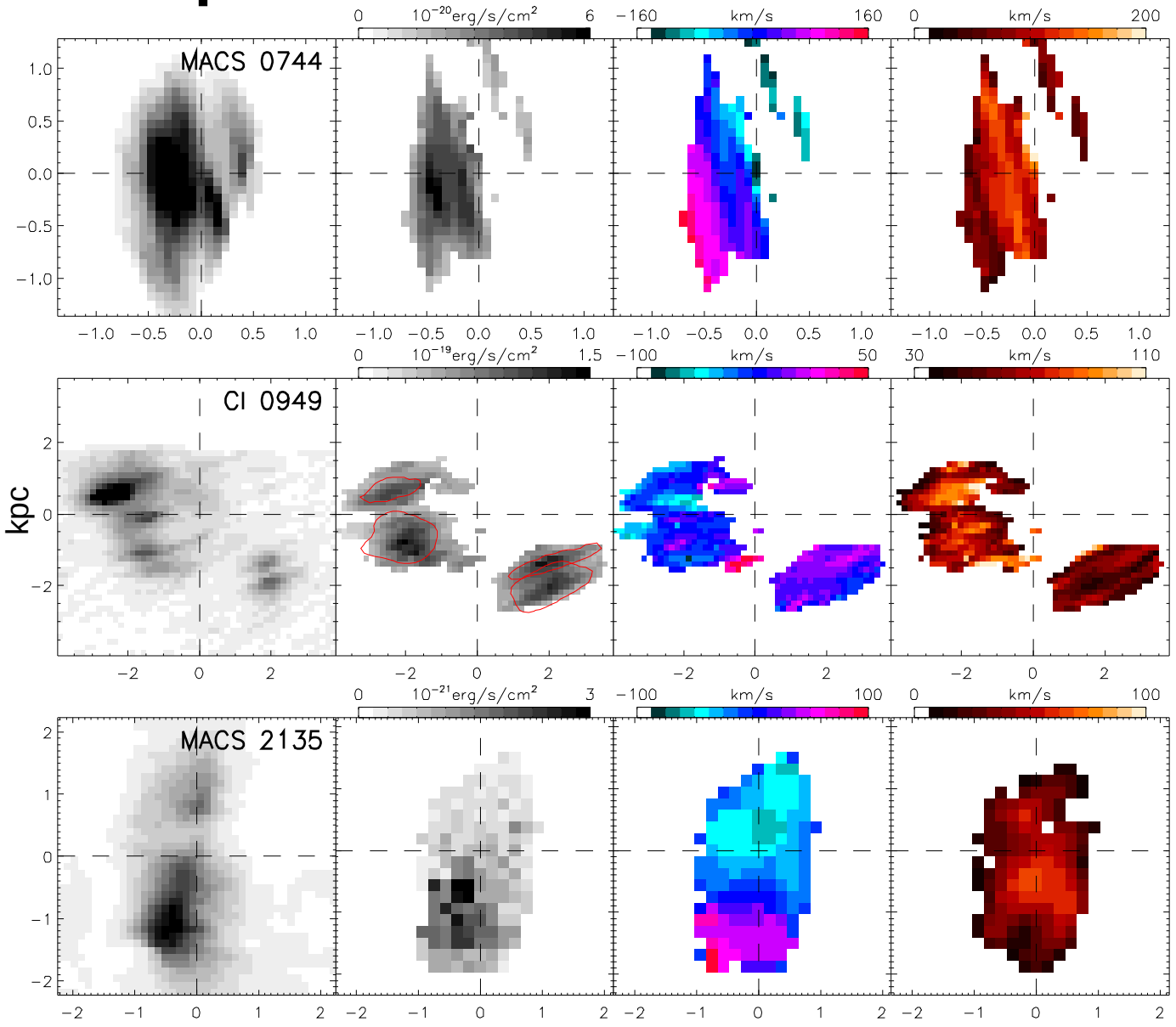
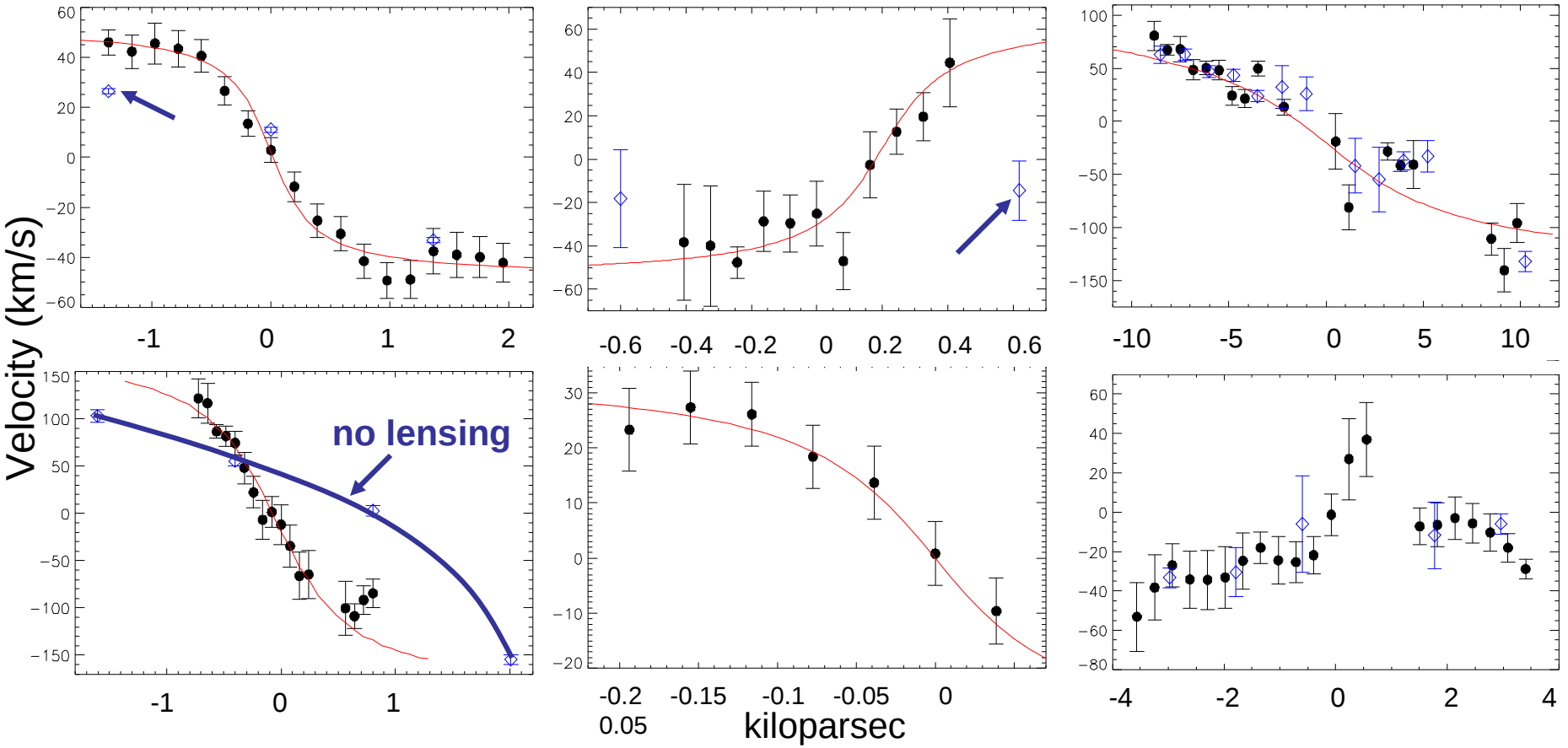


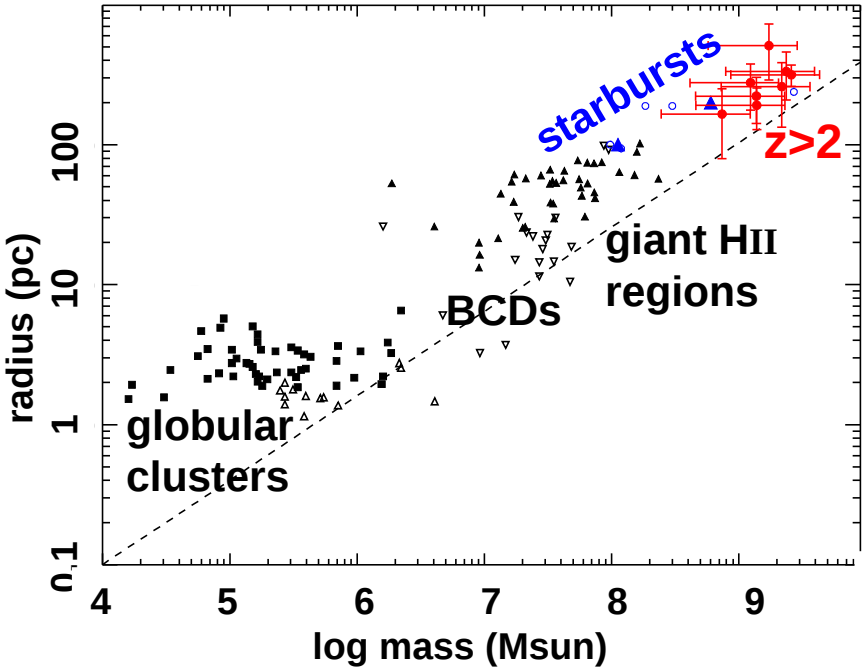
image plane | rest-UV | nebular emission | velocity | dispersion

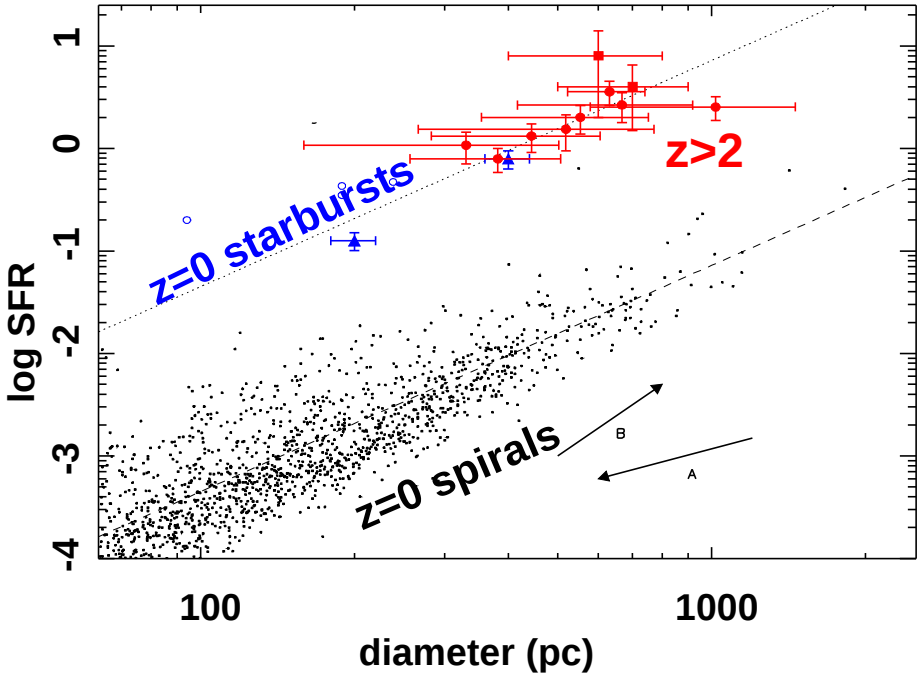
Coherent velocity fields



- 4/6 clearly rotating with V/σ < 2.0 in all cases
  - Lower rotation fraction inferred for non-lensed galaxies
- Rotation not evident without lensing!

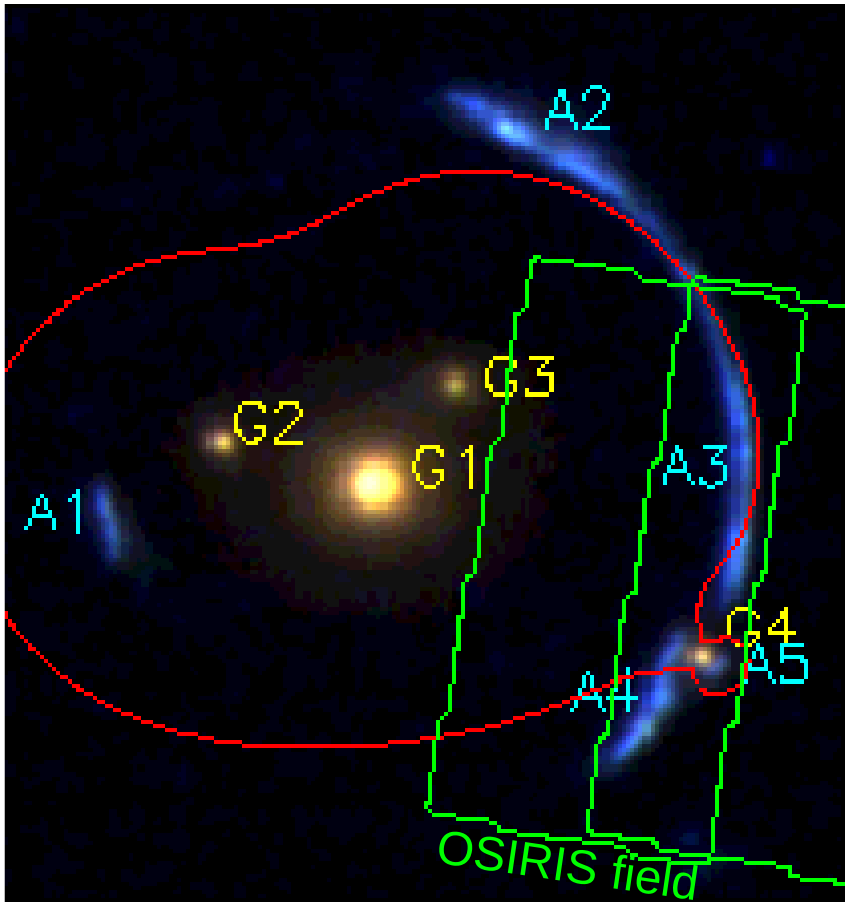
Giant star-forming regions





- At ~200 parsec resolution, all galaxies show multiple giant HII regions
  - Radius, dynamical mass, SFR measured with IFU observations
- Giant HII regions have very high SFR density
  - Typical mass = 10^9 M_{sun}, diameter = 500 pc, SFR = 2 M_{sun}/year
  - 100x higher star formation density as typical spiral galaxy HII regions, comparable to the most vigorous local starbursts

Case study: SDSS J1206+5142



10 arcseconds

z_{source} = 2.001

z_{lens} = 0.42

μ = 27

SFR = 45 M_{sun}/year

R = 2.9 kpc

M_{dyn}= 2.2e10 M_{sun}

No evidence of AGN

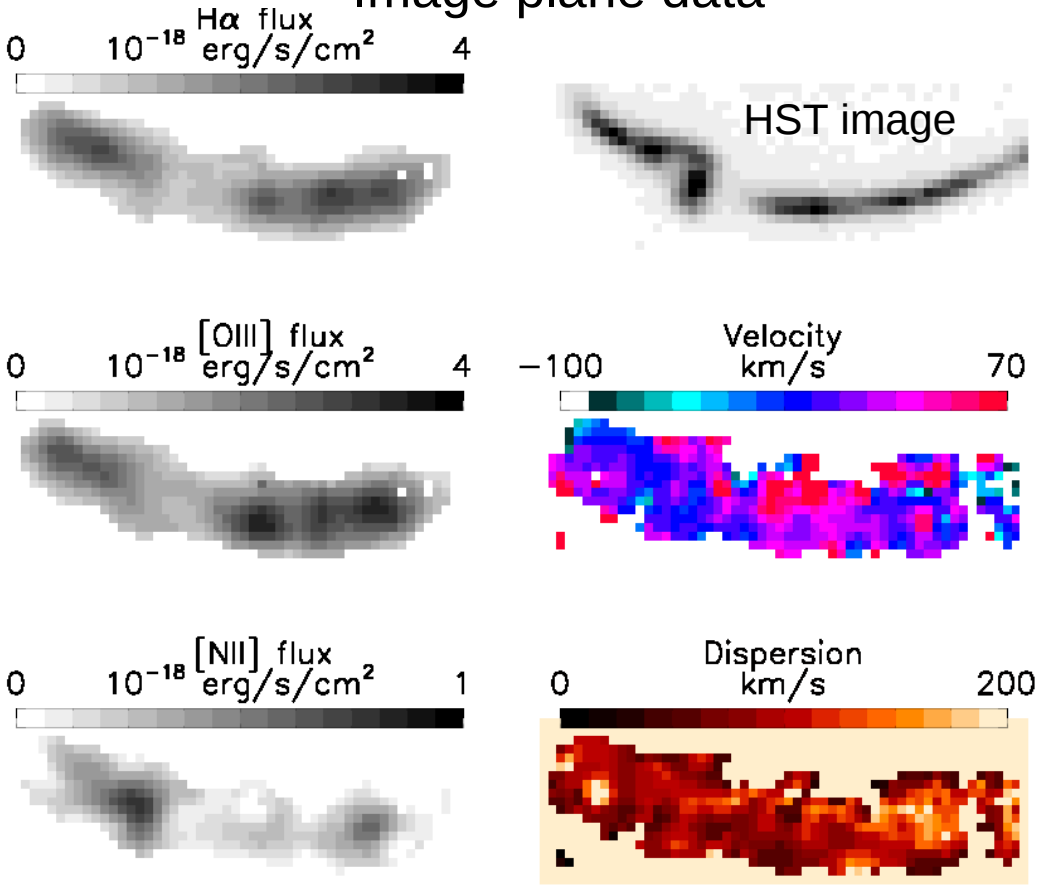
No evidence of merging

OSIRIS observations (May 2010):
4 x 900 sec, Hα+[NII], 100 mas scale
2 x 900 sec, [OIII], 100 mas scale
IFU covers multiple images of source

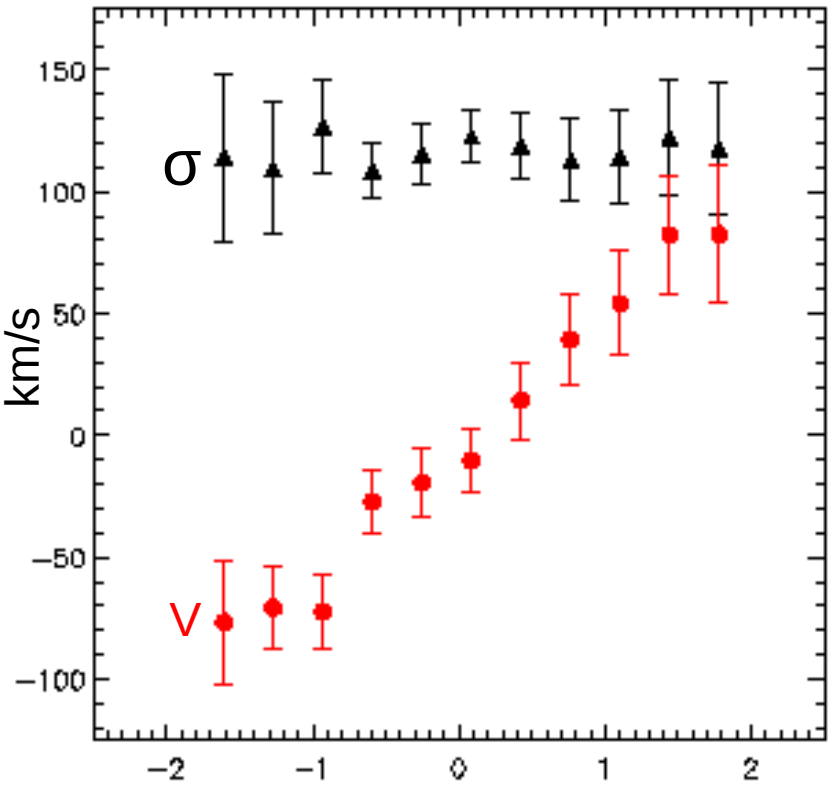
Lin et al 2009
Hainline et al 2009
Fadely et al 2010
Jones et al 2010b

SDSS J1206+5142

Image plane data



Source plane kinematics

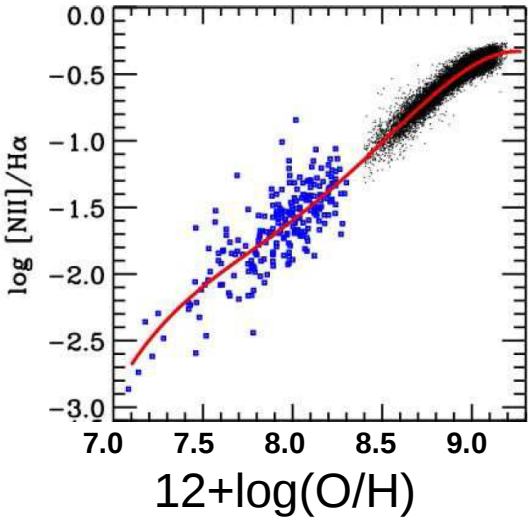


Emission lines mapped across 6 arcseconds
Source plane resolution 300 pc
Velocity gradient 160 km/s
Velocity dispersion ~ 100 km/s

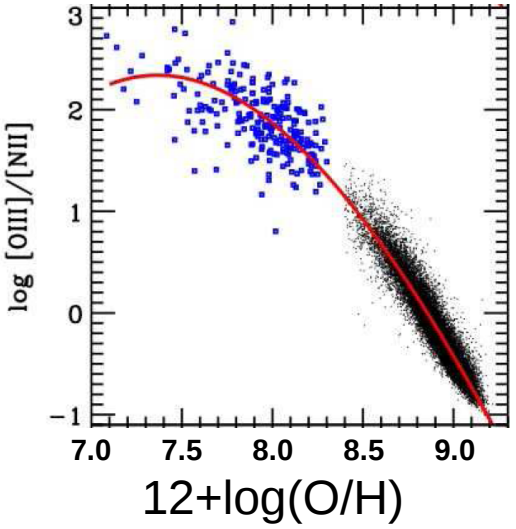
Jones et al 2010b

Metallicity calibration

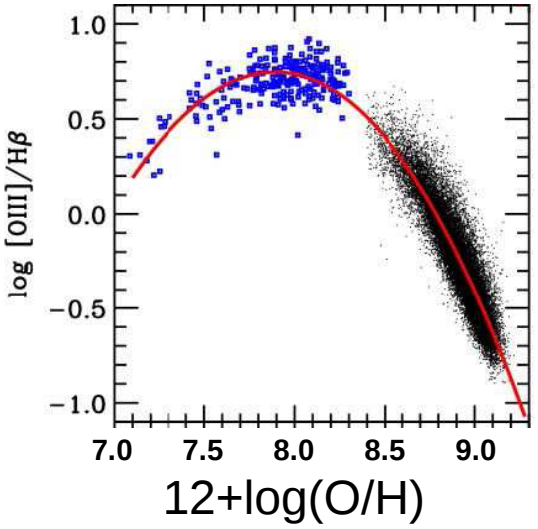
[NII]/Hα



[OIII]/[NII]



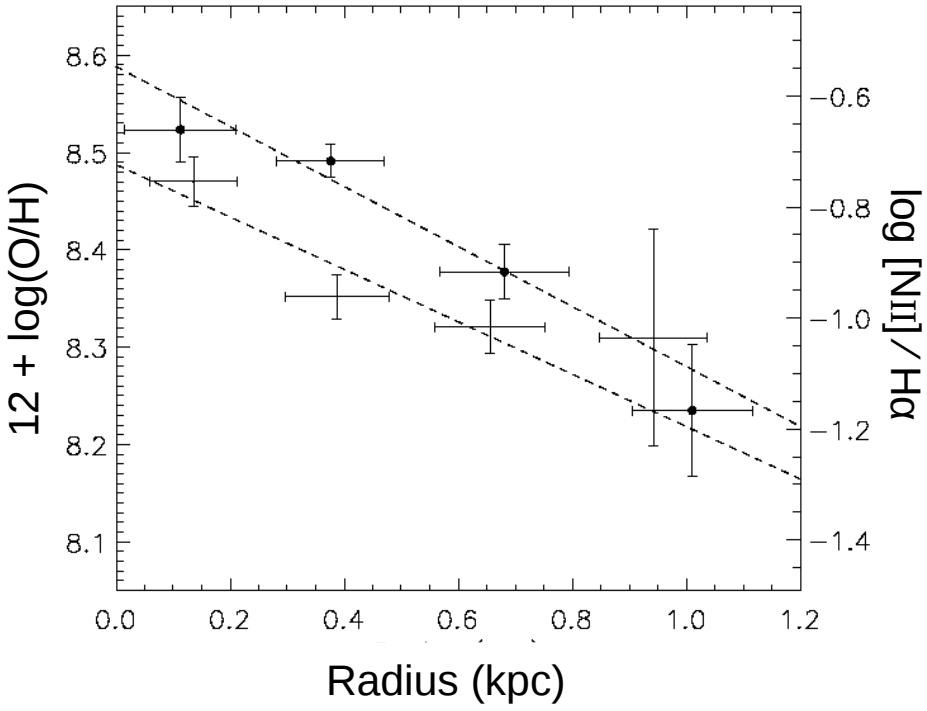
[OIII]/Hβ



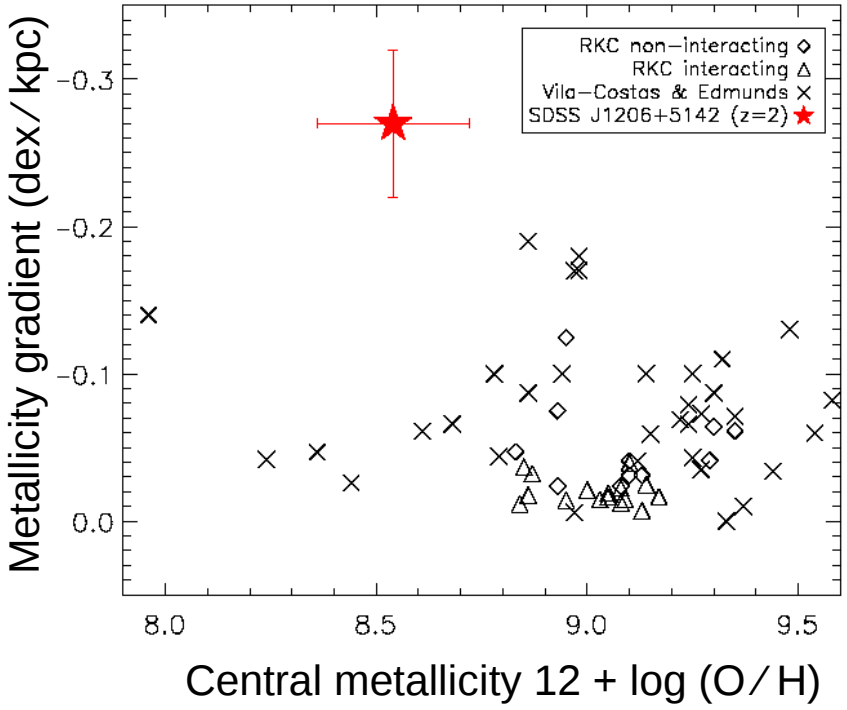
- Metallicity is highly correlated with ratios of strong emission lines
  - Use strong line ratios to infer metallicity
- Accurately calibrated with local data

Pettini & Pagel 2004, Kewley & Dopita 2002, Maiolino et al 2008, …

Metallicity gradient



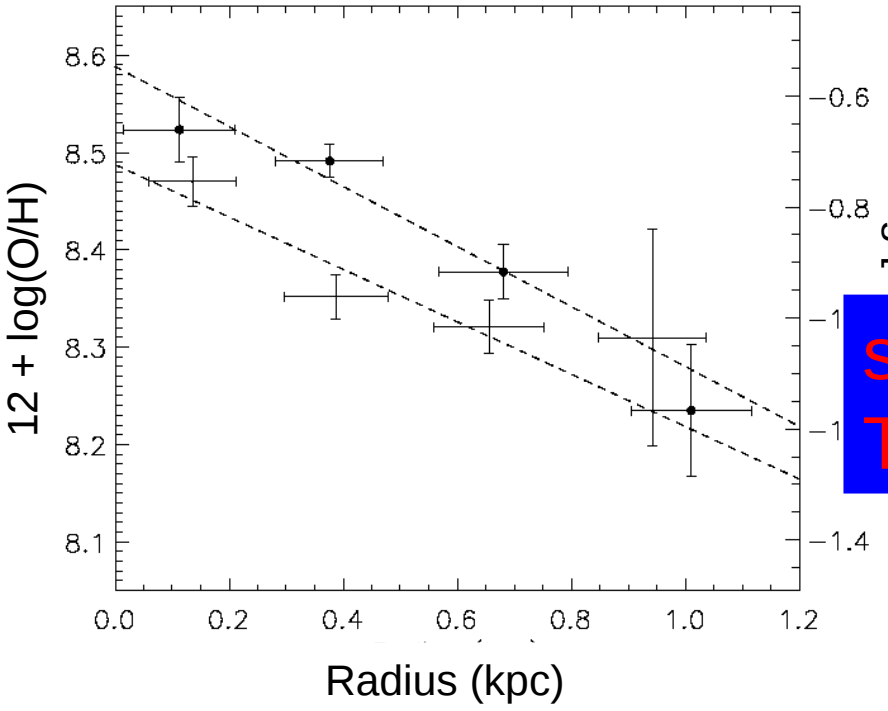
Jones et al 2010b



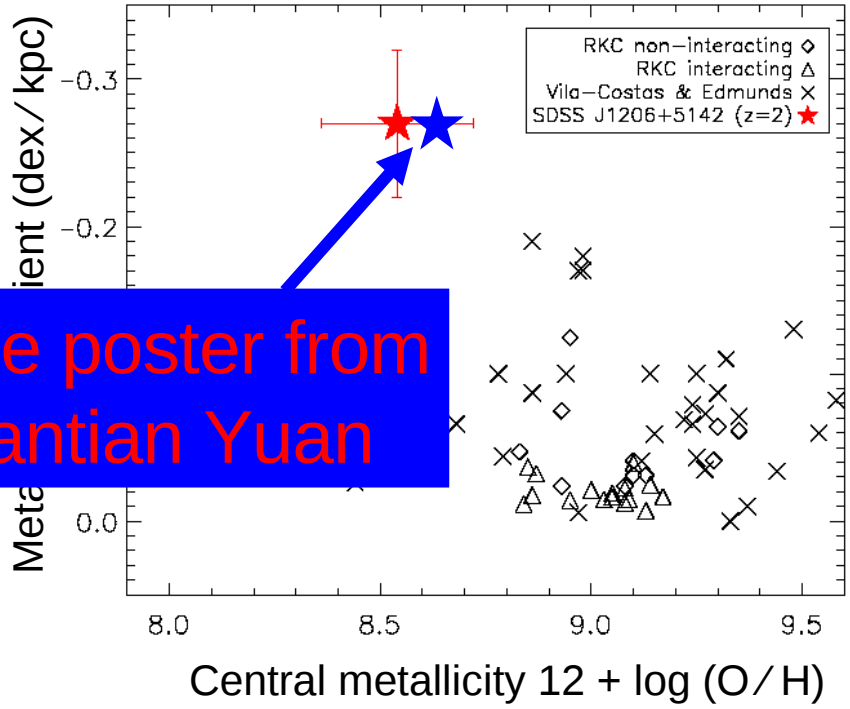
Rupke et al 2010
Vila-Costas & Edmunds 1992

- Metallicity gradient measured independently in two images!
- Multiple diagnostics give consistent results
- Gradient is much steeper than in local disk galaxies!

Metallicity gradient



Jones et al 2010b

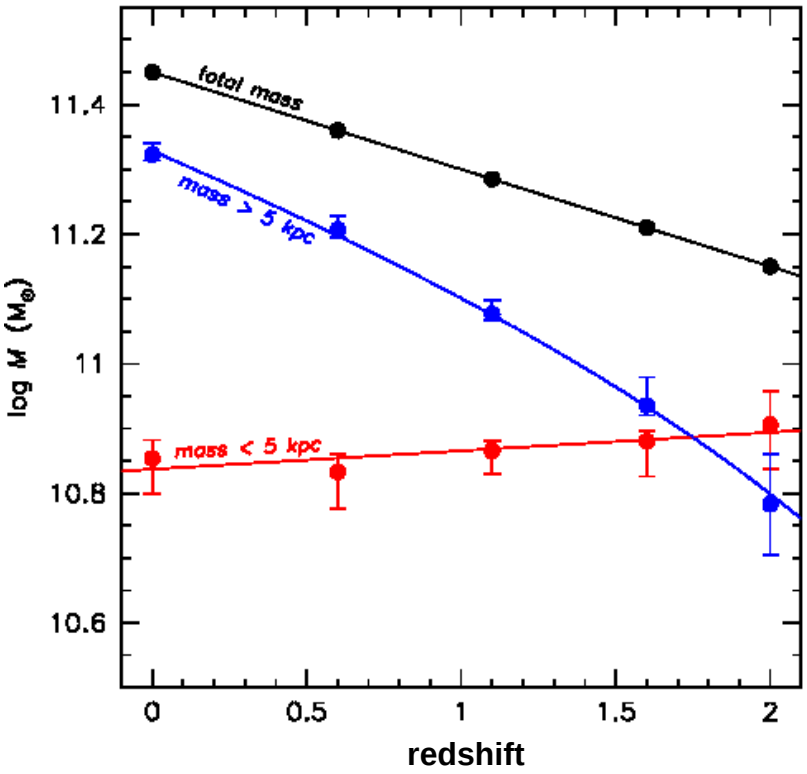


see poster from Tiantian Yuan

Rupke et al 2010
Vila-Costas & Edmunds 1992

- Metallicity gradient measured independently in two images!
- Multiple diagnostics give consistent results
- Gradient is much steeper than in local disk galaxies!

Inside-out galaxy assembly



van Dokkum et al 2010

- Gradient is much steeper at z=2 than z=0
  - Indicative of inside-out growth
- Inner gradient flattened by radial mixing
- Stellar mass grows mostly at large radii for z<2
  - Metallicity increases more at large radii

Summary

- Kinematics: high rotation fraction
  - Velocity dispersion σ~50-100 km/s, $V/\sigma < 2$
- Star formation: clumpy
  - Multiple giant HII regions in each galaxy
  - SFR density ~100x higher than in local spirals
- Metallicity: steeper gradient than in local galaxies
  - Metallicity gradient = $-0.27 \pm .05$ dex/kpc in J1206
  - Suggests inside-out growth
- High angular resolution is crucial!
  - Results are not recovered without strong lensing
  - Next-generation telescopes (TMT, ALMA, JWST) will provide the same resolution with much larger samples


yeah!