# Structure of low(er) mass galaxies at high redshift

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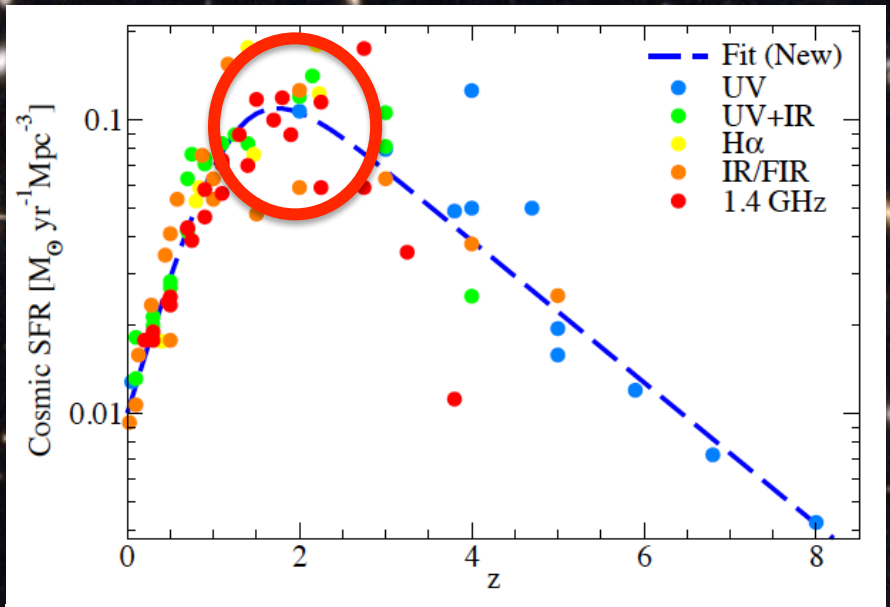
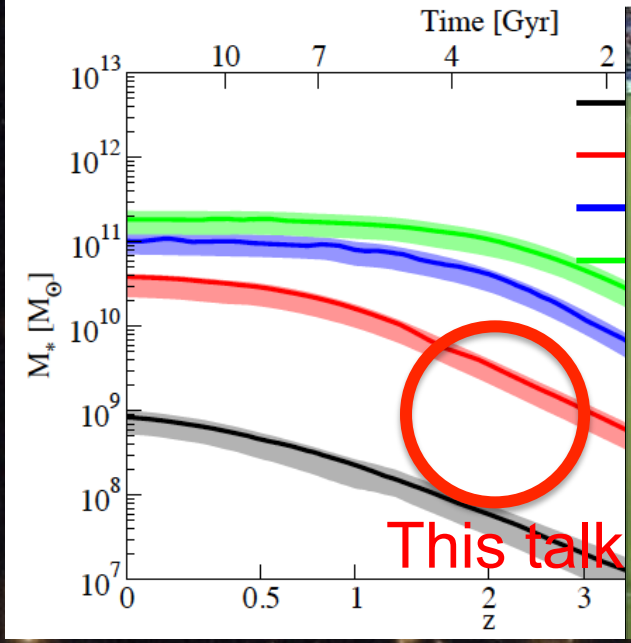
Behroozi et al 2013




# Midfield

- Literally the near-field deep-field connection
- Peak of cosmic SFR density
- Only ~10% of present-day stellar mass had formed

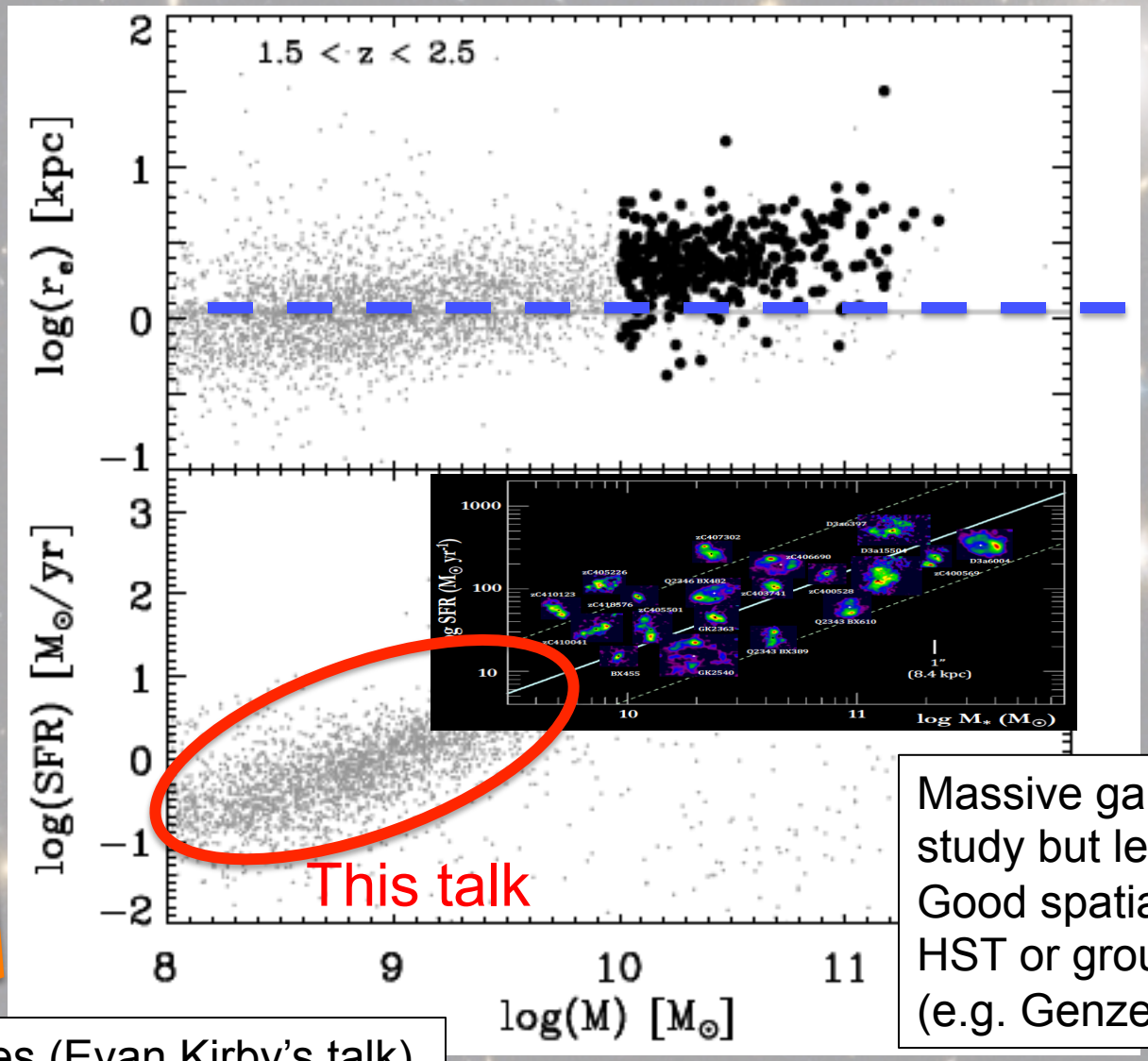




Near field

Deep field

# The galaxy population at z=2




HST resolution
~1 kpc

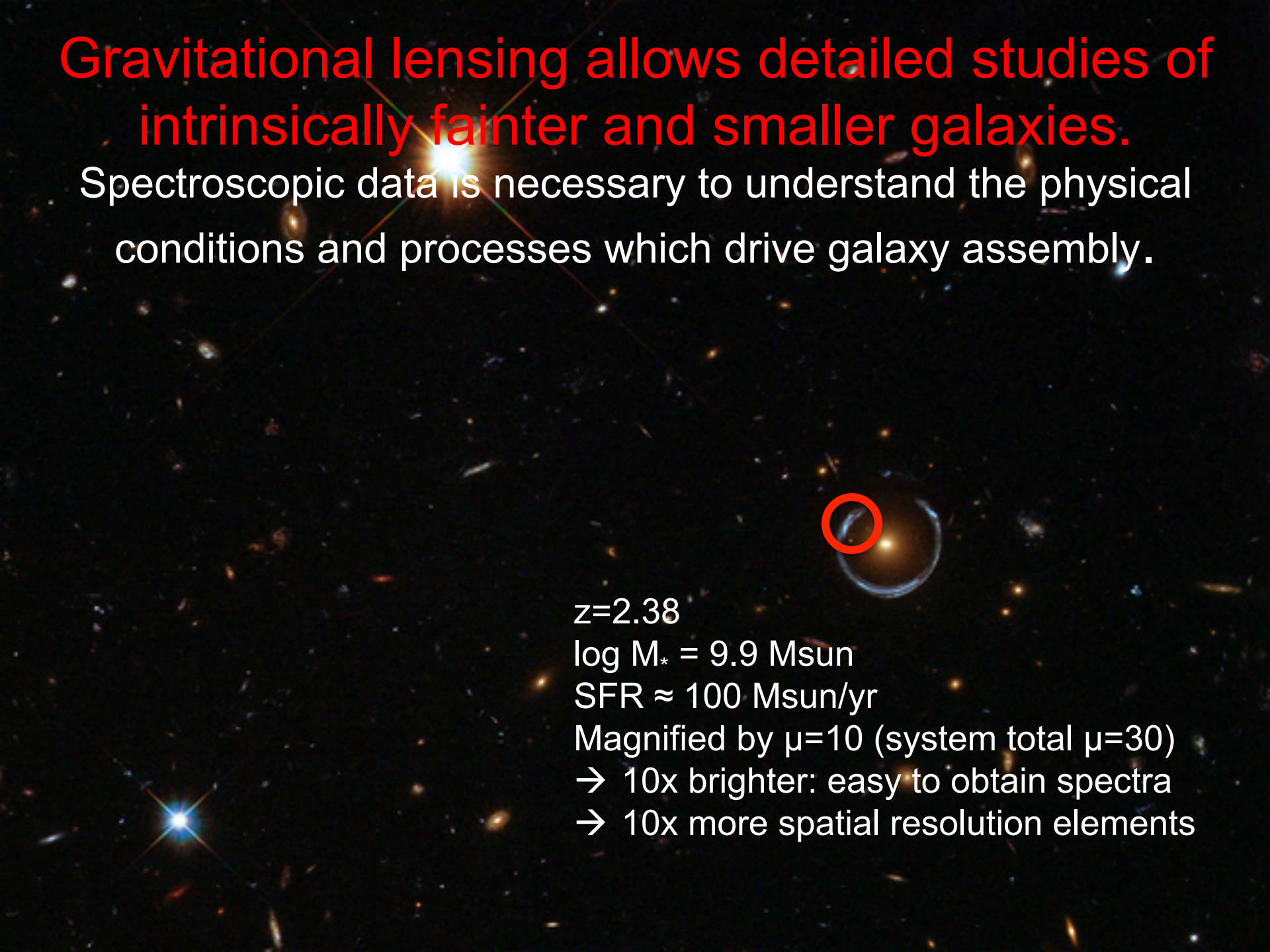
Massive galaxies: easiest to study but least abundant
Good spatial sampling with HST or ground-based AO (e.g. Genzel+2013)

Dwarf galaxies (Evan Kirby's talk)
Extremely difficult to detect!

Wuyts et al 2012

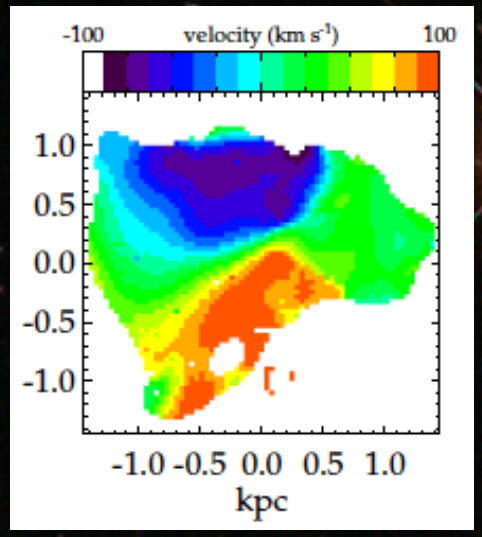
# Gravitational lensing allows detailed studies of intrinsically fainter and smaller galaxies.

Spectroscopic data is necessary to understand the physical conditions and processes which drive galaxy assembly.

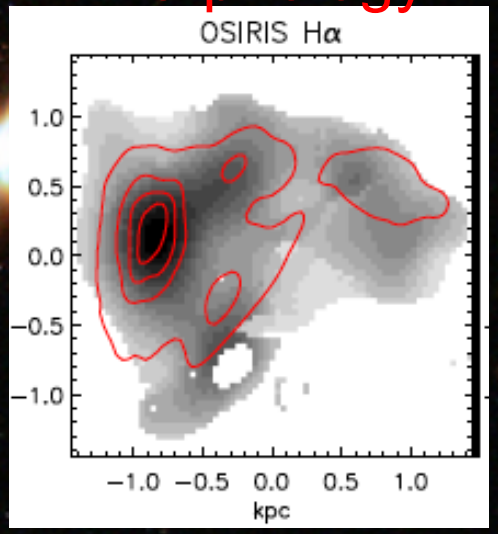


z=2.38
log $M_*$ = 9.9 Msun
SFR ≈ 100 Msun/yr
Magnified by μ=10 (system total μ=30)
→ 10x brighter: easy to obtain spectra
→ 10x more spatial resolution elements

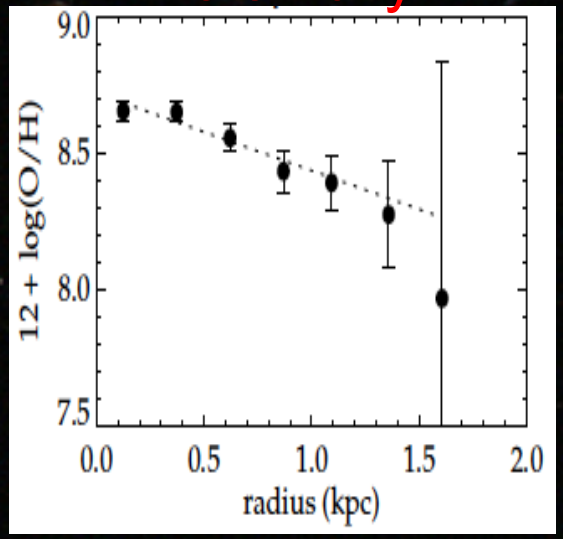
Kinematics




Morphology

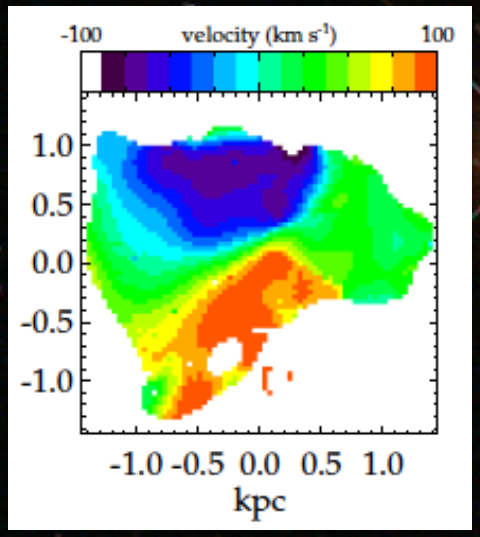


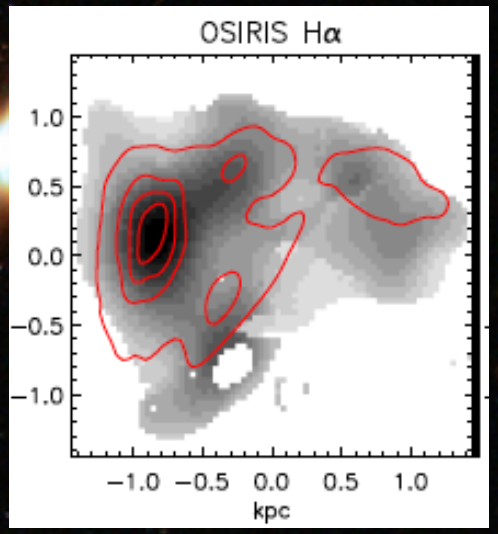

Metallicity

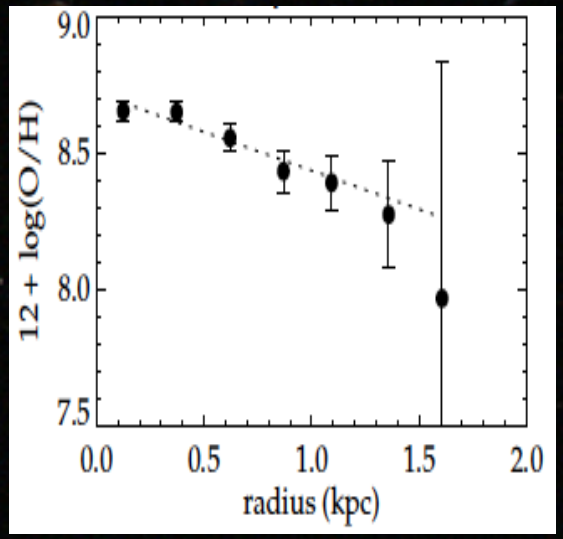



- Kinematics: rotating with high velocity dispersion
  - High velocity dispersion with typical $V/\sigma < 3$
  - ~1/3 are undergoing mergers
- Gravitationally unstable
  - Toomre parameter $Q = \sigma\kappa/\pi G\Sigma \approx 0.5\text{-}1$
  - Expected to fragment into clumps of size $L_J=\pi\sigma^2/8G\Sigma=0.1\text{-}1$ kpc
- Clumpy star formation driven by gravitational instability
  - Clump sizes, masses agree with expected fragmentation scale
- Metallicity: ~0.1-1x solar with negative radial gradients
  - Steeper gradients than in local disk galaxies
  - Indicates no recent major mergers, and consistent with current cosmological simulations with “normal” feedback (e.g. Gibson+2013; Torrey+)

TJ+2010a,b; TJ+2013; Livermore, TJ+2012

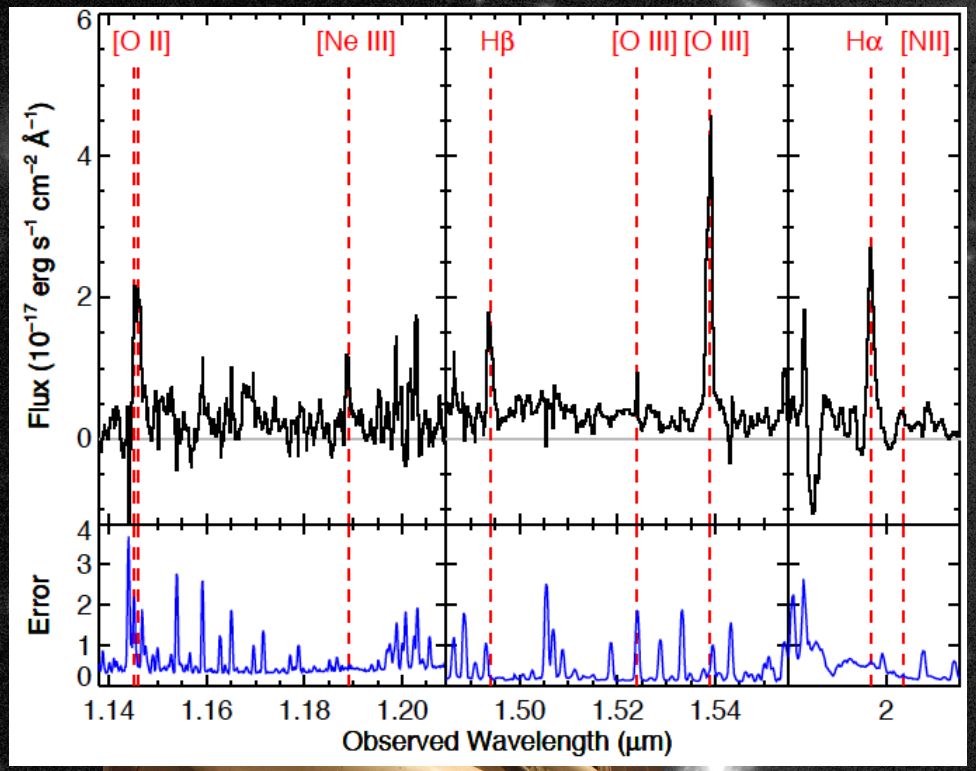



Excellent resolved spectroscopic data possible for galaxies with log $M_*$ = 9-10 at z=2

What about galaxies of even lower mass?




Star formation rate from Balmer line flux

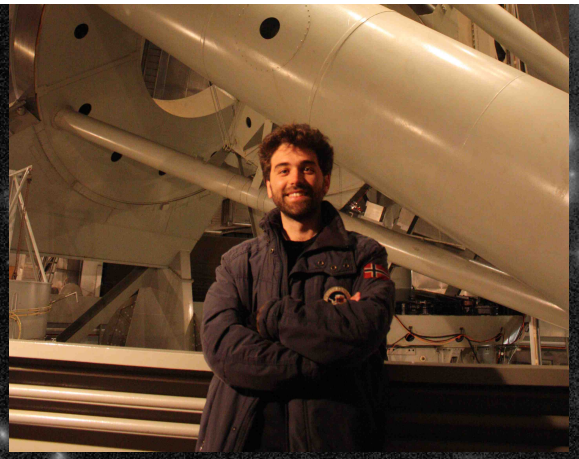
Dust extinction from Balmer decrement

Gas metallicity and ionization parameter from emission line ratios (R23, N2, BPT diagnostics)

Stellar mass from SED modeling

Dynamical mass from velocity dispersion

→ Good characterization of physical properties in low-mass galaxies!



Sirio Belli at the Palomar 200”

z=2.07

log $M_*$ = 8.3 Msun

SFR = 1.0 Msun/yr

E(B-V) = 0.1

12+log(O/H) = 8.45

= 0.5× solar

Triplespec

Near-IR echelle spectrograph

R~2600 (FWHM ~ 115 km/s)

Simultaneous 1.0-2.5 um spectrum

# Triplespec survey strategy

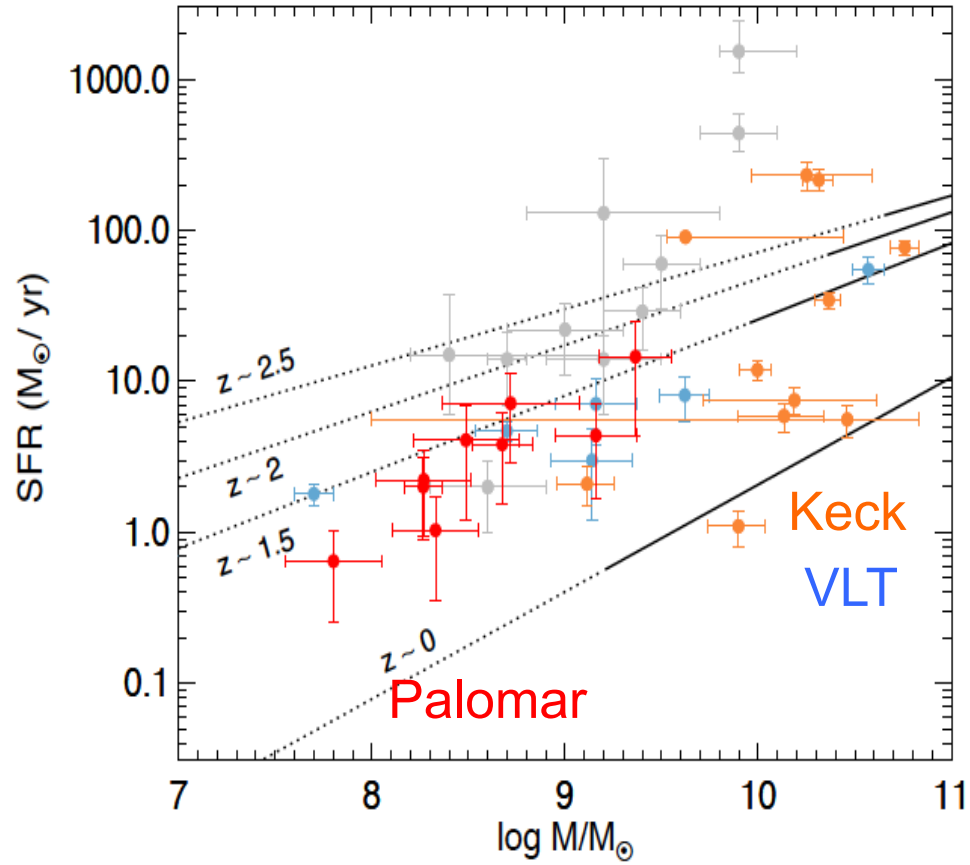
**Goal**: measure physical properties of faint high-z galaxies from spectra.

**Selection:** cluster-lensed sources with intrinsic luminosity $R_{AB}$>26, known redshift z=1.5-3.5, apparent $R_{AB}$<~23 bright enough for Palomar spectroscopy, accurate magnification from gravitational lens model

- Effective selection for SFR = 1-10 $M_{sun}$/yr, log $M_*$=8-9 Msun
- Approximately 1 good source per massive galaxy cluster.

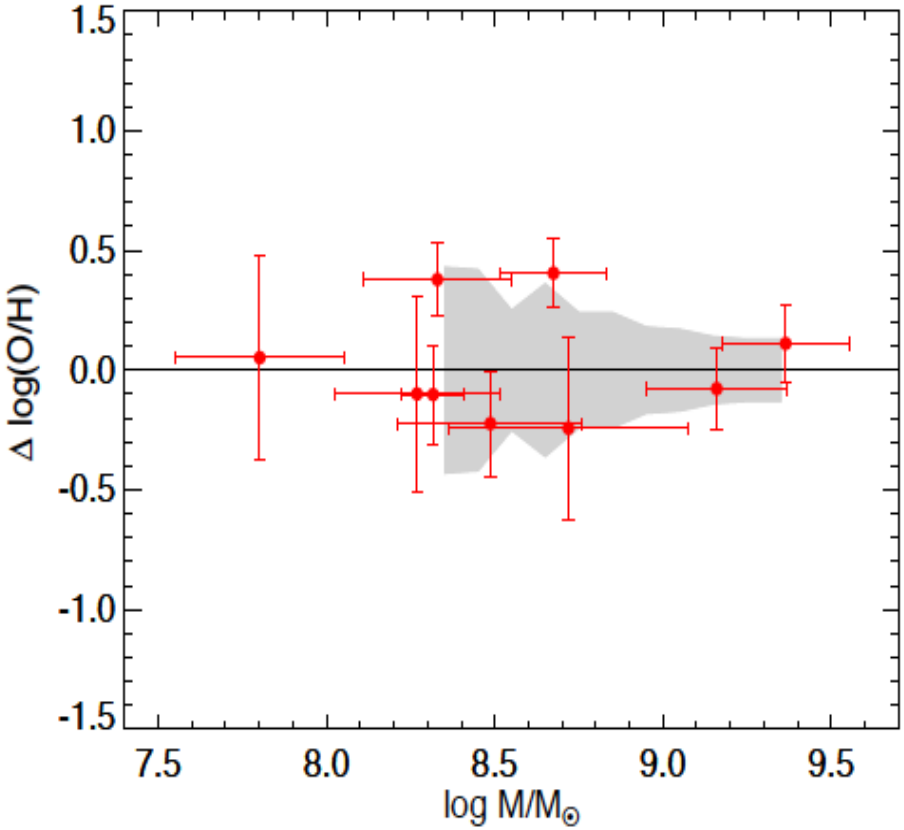
**Integration times:** 2-5 hours per source with Palomar/Triplespec.

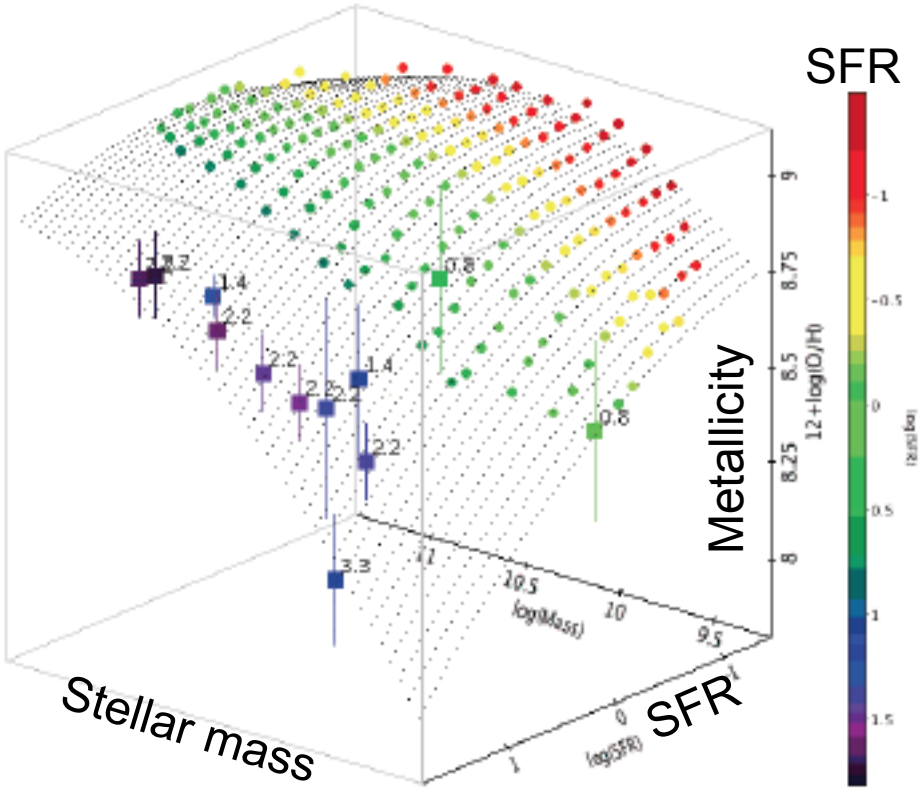
*Cutting edge high-z science with a 5m telescope!*




Belli, TJ+2013

# Gas-phase metallicity is consistent with expected value based on mass, SFR

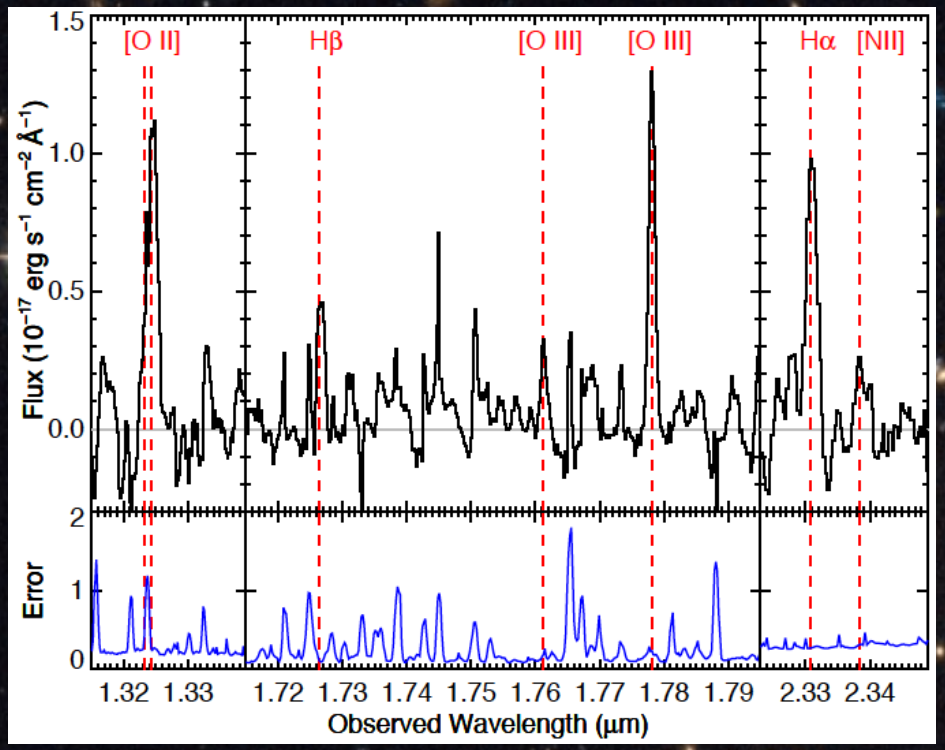



Mannucci+ 2010, Lara-Lopez+ 2010

Lensed galaxies are consistent with the local mass-metallicity-SFR relation measured at low stellar mass. Low scatter may indicate relatively small effect from perturbations (e.g. mergers).

Belli, TJ+2013



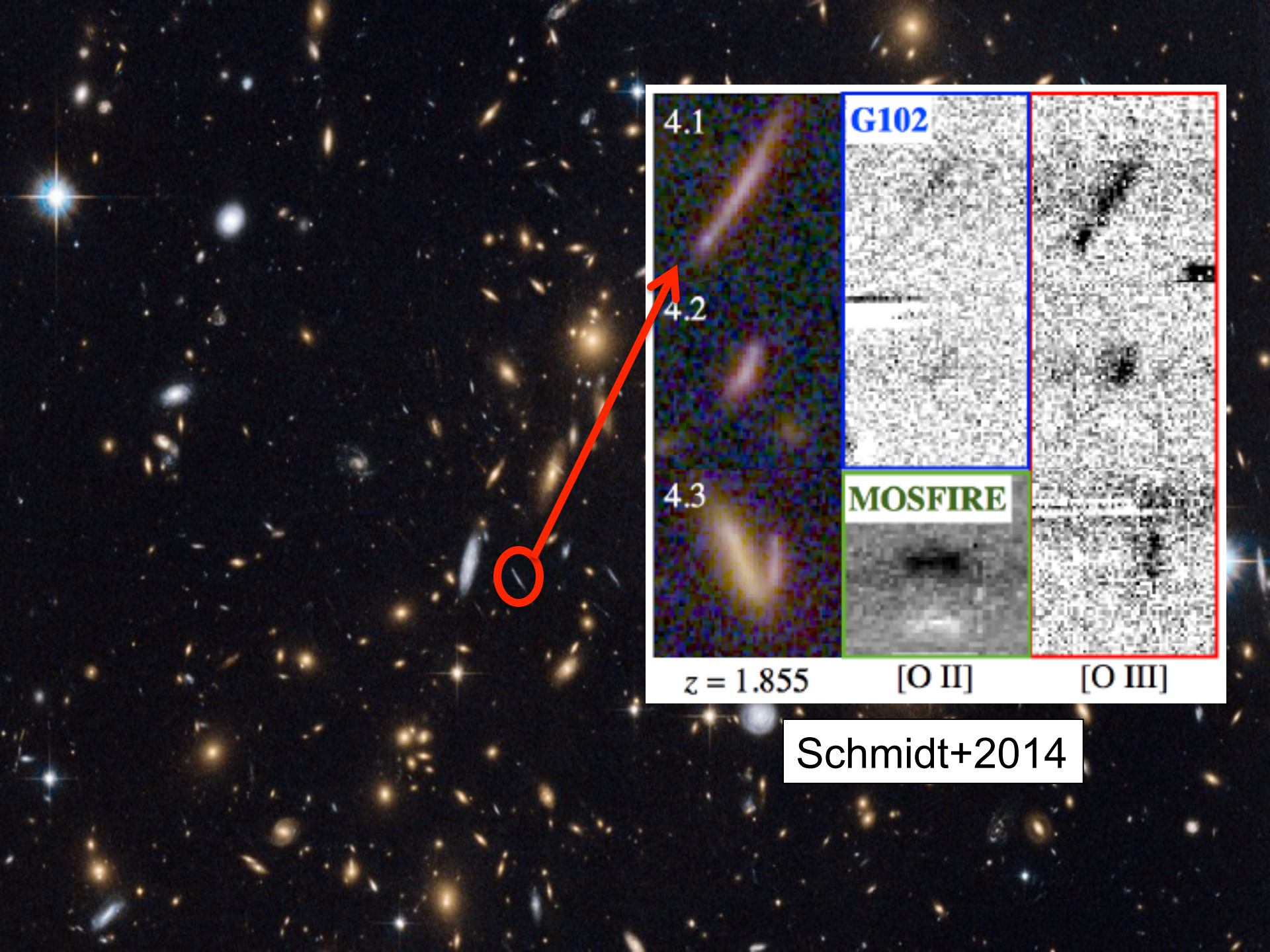

Excellent integrated spectroscopic data available for galaxies with log $M_*$ = 8-9 at z=2

Is there any hope of resolving these galaxies?

# GLASS

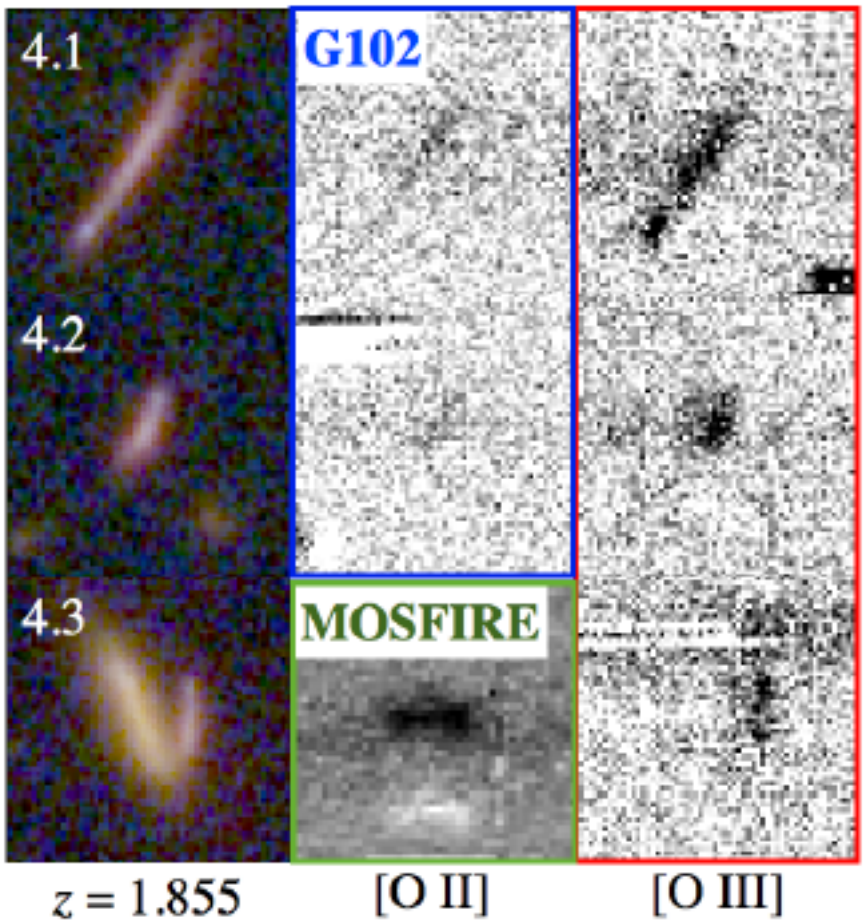
The Grism Lens Amplified Survey from Space
PI: Tommaso Treu
140 orbits with HST/WFC3-IR grisms
10 strong lensing clusters including all Frontier Fields
Continuous wavelength coverage from 0.8-1.7 um
Schmidt+2014, astro-ph/1401.0532, ApJ accepted

→ Emission line survey with HST resolution!

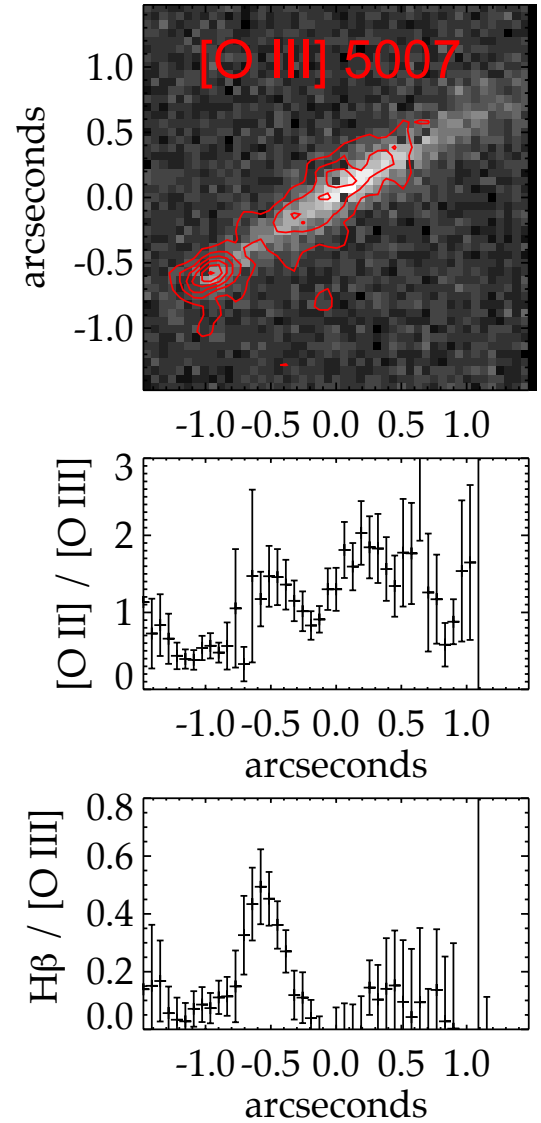



Schmidt+2014

# Resolved emission lines with HST

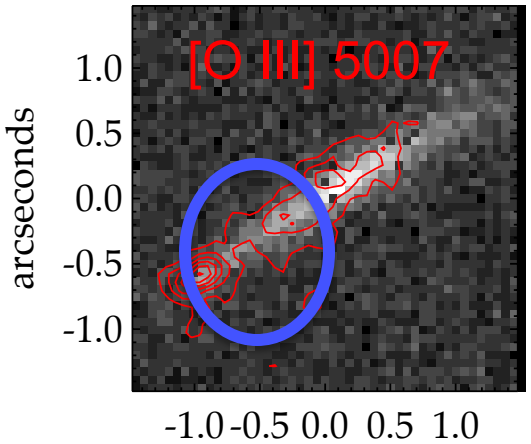


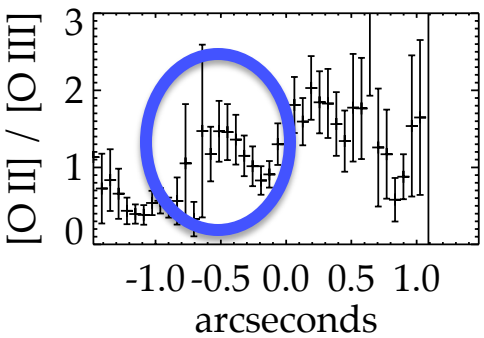

5 confirmed multiply-imaged sources with strong line emission in the first cluster observed

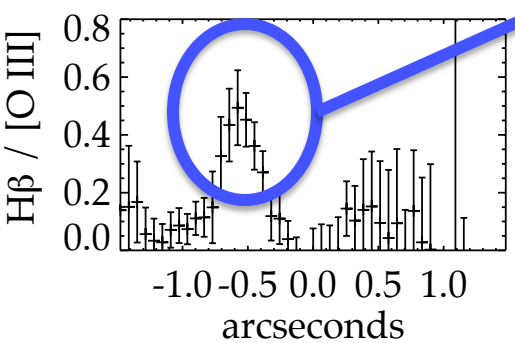



Spatially resolved line ratios

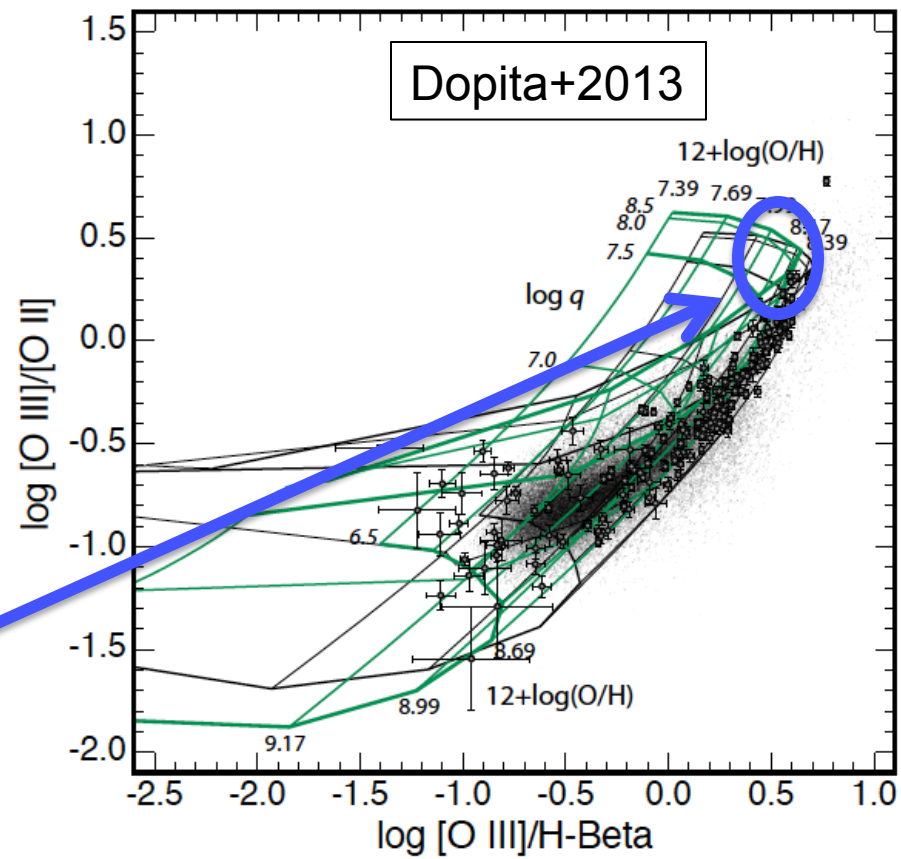
# Resolved emission lines with HST



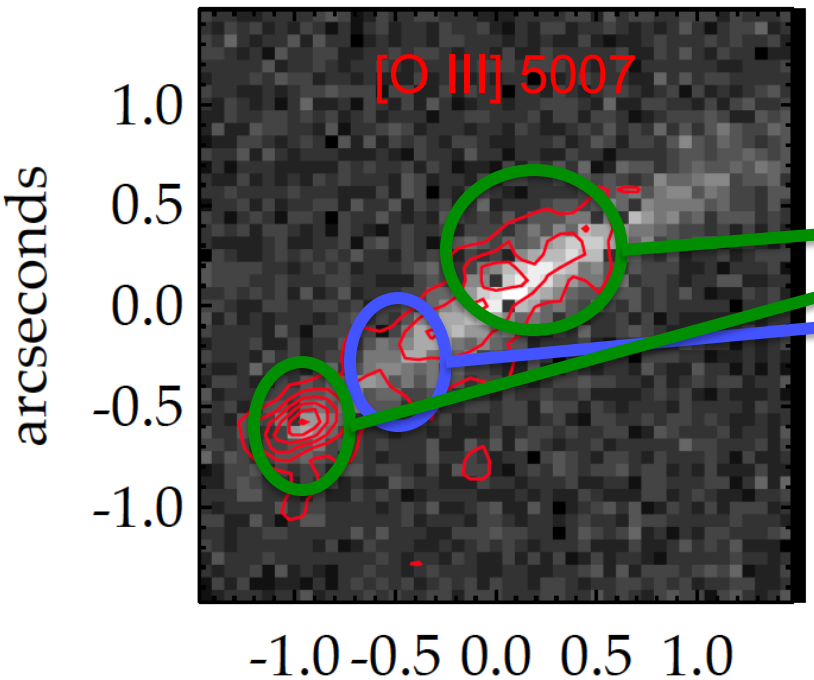

## Metallicity & ionization parameter




12+log(O/H) = 8.2 – 8.7

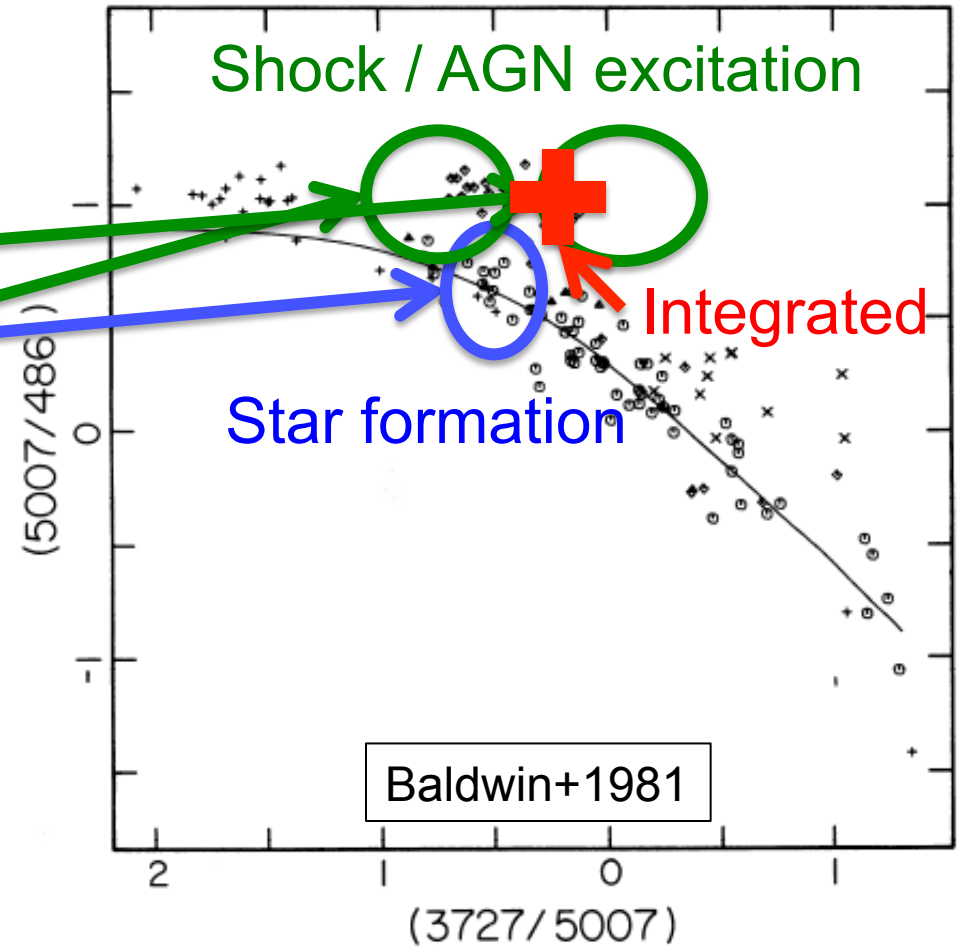
log(q) > 7.5

# Resolved emission lines with HST




Total SFR ~ 10 Msun/yr
Total linear extent ~2 kpc
Magnification μ≈10
HST resolution ≈100 pc

BPT excitation diagram




SFR-dominated emission only seen with high resolution + lensing!
Galaxy would be only marginally resolved without lensing

# Summary and prospects

- Gravitational lensing enables spectroscopic measurements to log $M_*/M_{sun}$ = 8, SFR=1 $M_{sun}$/yr
  - Much lower masses, SFR than for non-lensed galaxies
  - Integrated properties consistent with an extrapolation from more massive galaxies: lower metallicity, lower V/σ, etc.
  - Hubble Frontier Fields are excellent for these studies
- Detailed structure on ~100 pc scales
  - Rotation, clumpy SFR, metallicity gradients, excitation sources
  - Integrated properties are not necessarily a good indicator of physical conditions. Caution is advised.
- HST grism data provides high spatial resolution measurements of emission lines
  - Metallicity, dust, excitation, ionization parameter, etc
  - Expect ~100 suitable sources in the full GLASS survey