Cosmic telescopes: from HST to JWST

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Outline

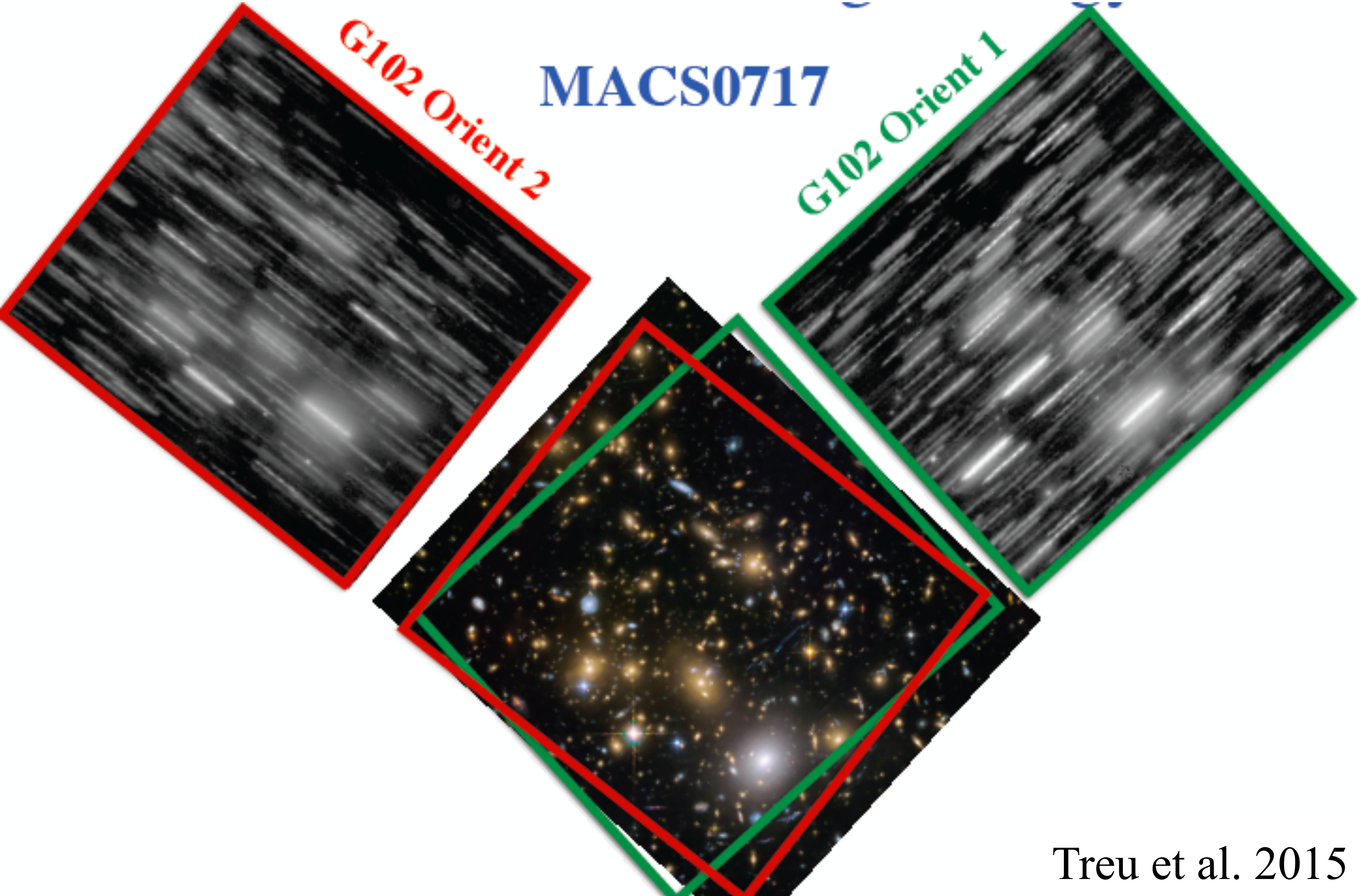
- Spectroscopy with HST assisted by cosmic telescopes
  - Highlights from GLASS: the baryonic cycle
  - Fundamental physics; The nature of dark matter and dark energy
- Lessons for JWST

GLASS

Science Drivers

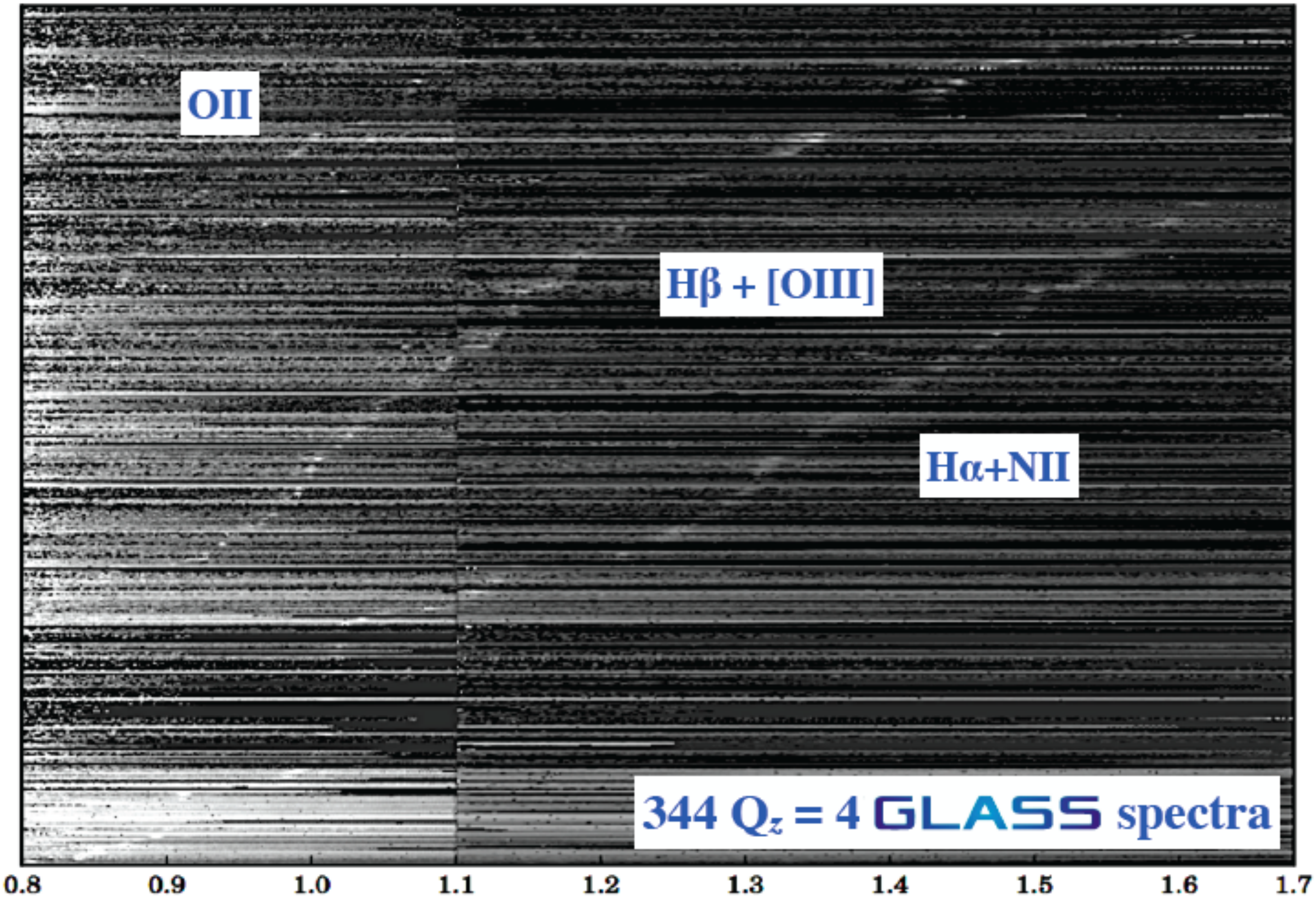
- **When did cosmic re-ionization occur? Who did it?**
  - Observing Lya at z=5.5-13.0
- **How do gas and metals cycle in and out of galaxies?**
  - Spatially resolved metallicity of galaxies
- **How does environment affect galaxy evolution?**
  - Structural parameter analysis
  - Maps of star formation in cluster galaxies at z~0.5
- **How are luminous and dark matter distributed in clusters?**
  - Gravitational lens models
- **What can we learn from gravitationally lensed supernovae?**
  - Supernova ‘Refsdal’

The tool: HST grisms



Treu et al. 2015

Wavelength coverage



- Spectroscopy of 10 clusters, including HFF and CLASH
- 140 orbits cycle 21 (PI Treu) glass.astro.ucla.edu

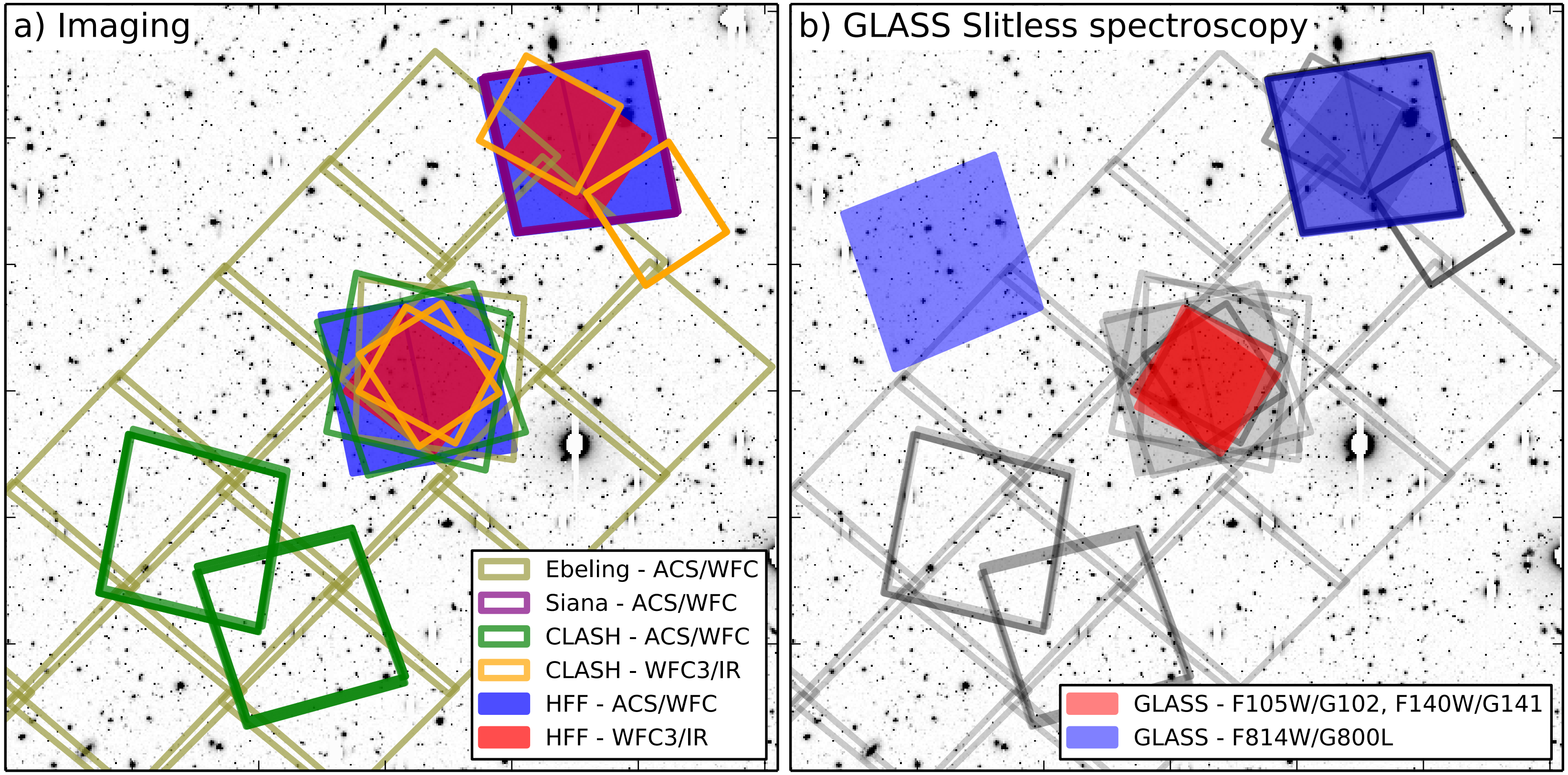
GLASS

Strengths

- Spectrum of everything in the field of view
- High sensitivity and angular resolution owing to lensing magnification
- Excellent photometric redshift owing to HFF/CLASH photometry
- Uninterrupted wavelength coverage, potentially able to detect more lines
- Many l.o.s reduce cosmic variance and lya patchiness effects (c.f. Robertson et al. 2014)

GLASS Status

- **Data acquisition completed. First data release available at https://archive.stsci.edu/prepds/glass/ (Treu+2015)**

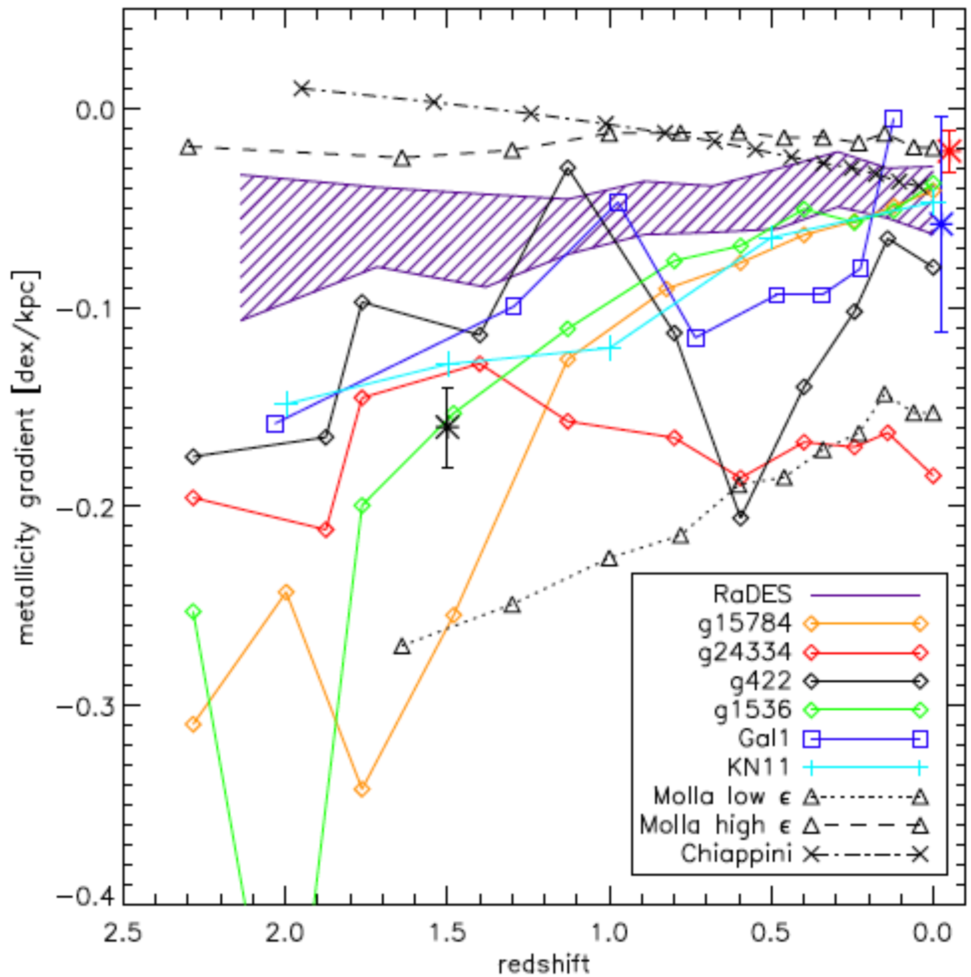


How do gas and metals cycle in and out of galaxies?

The need for spatially resolved spectroscopy

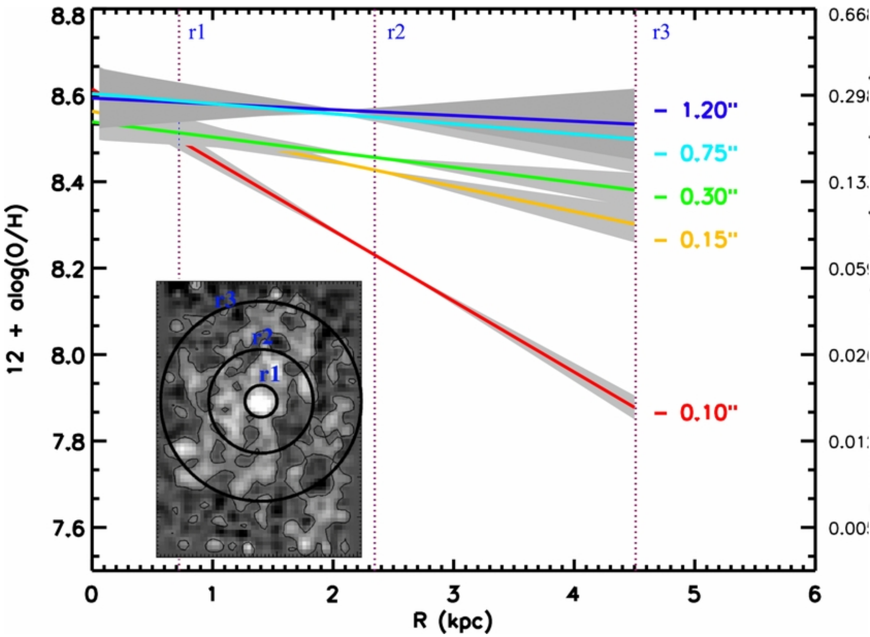
- We have learned a lot from UV/optical/NIR imaging and we will continue to learn
  - However, we are limited by degeneracies in the interpretation (it is relatively easy to change colors of a stellar pop)
- Likewise unresolved spectroscopy is an essential tool to study galaxy formation and evolution
  - Nevertheless, in order to distinguish physical mechanisms, spatial and kinematic information is needed.

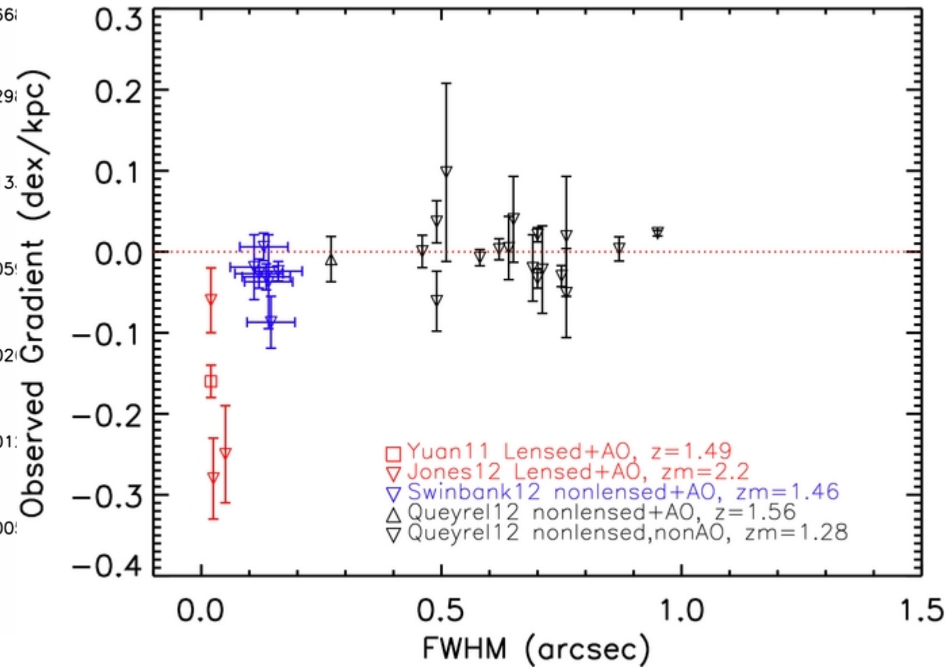
Metallicity gradients as a test of feedback models



Pilkington+12

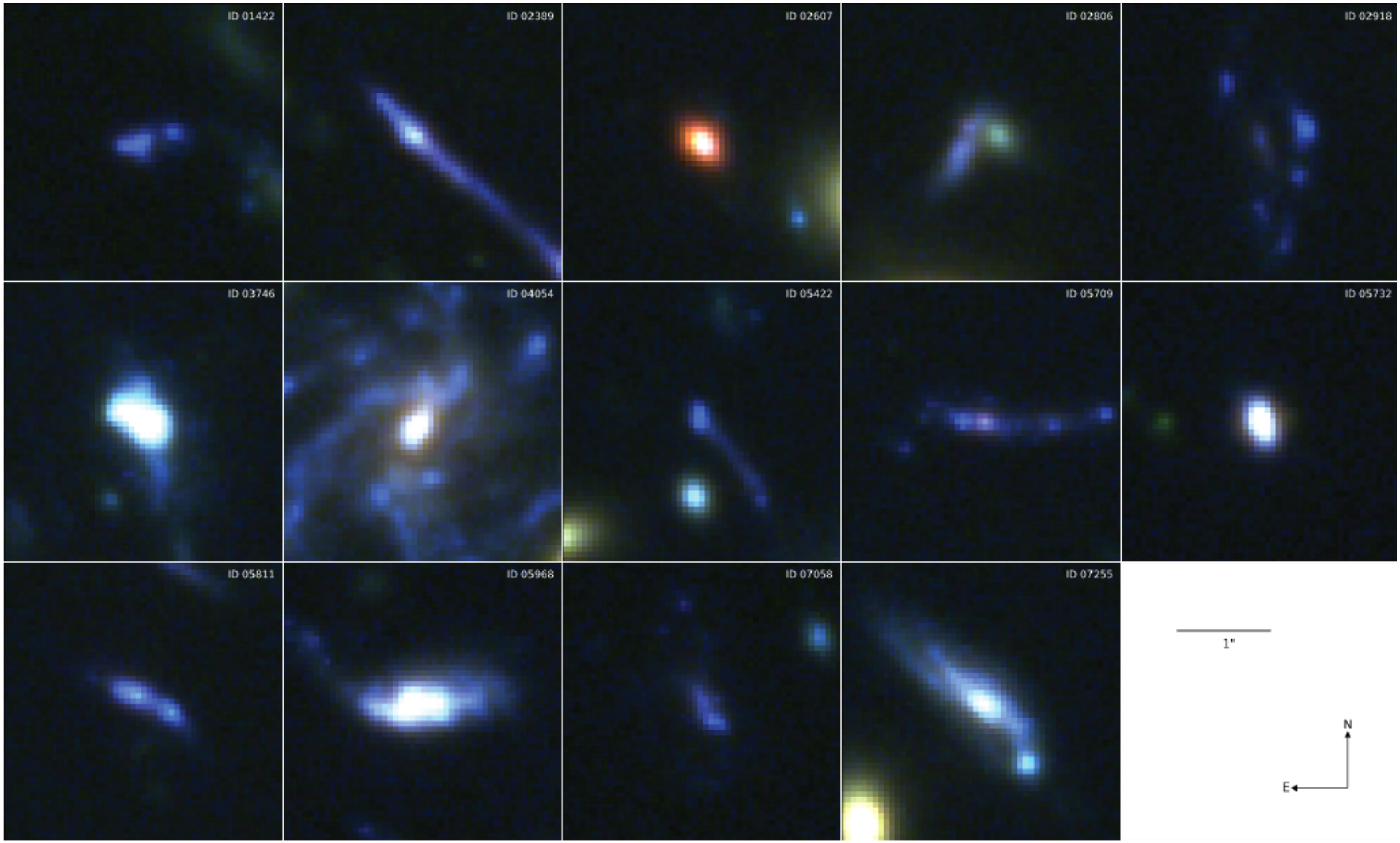
Metallicity gradients: resolution effects





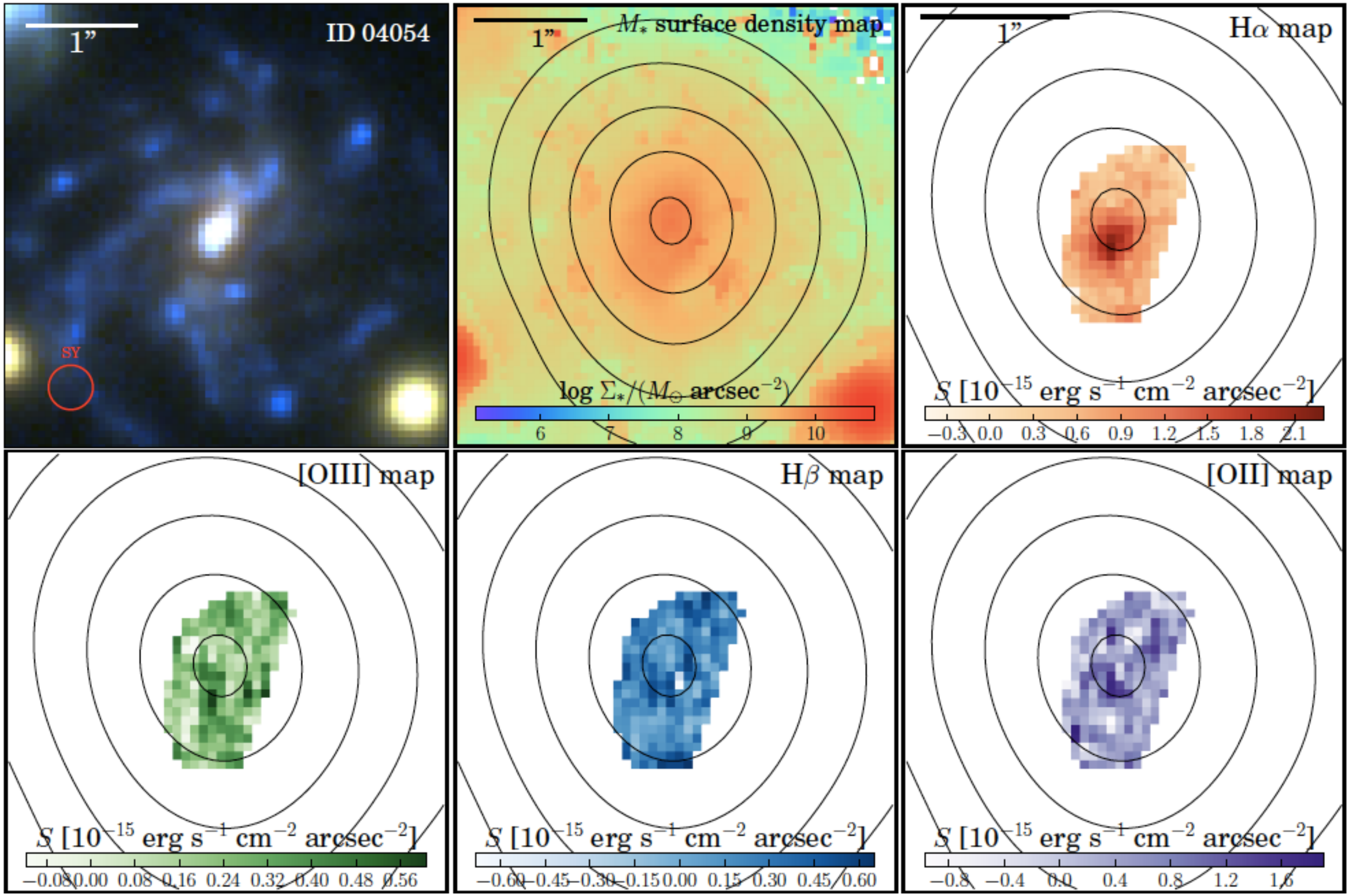
Yuan+13

MACS1149



Wang+16,

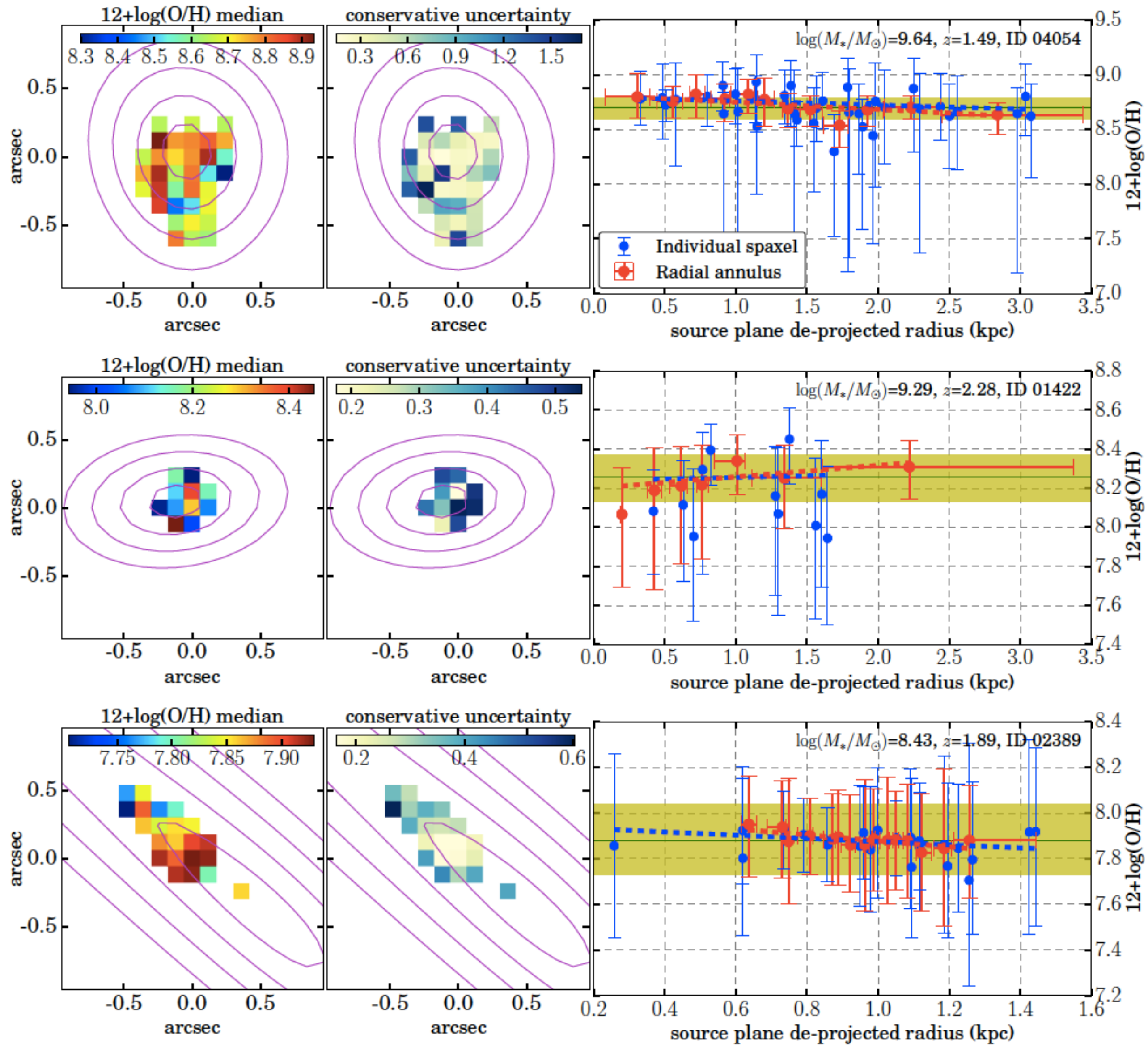
MACS1149



Wang+16

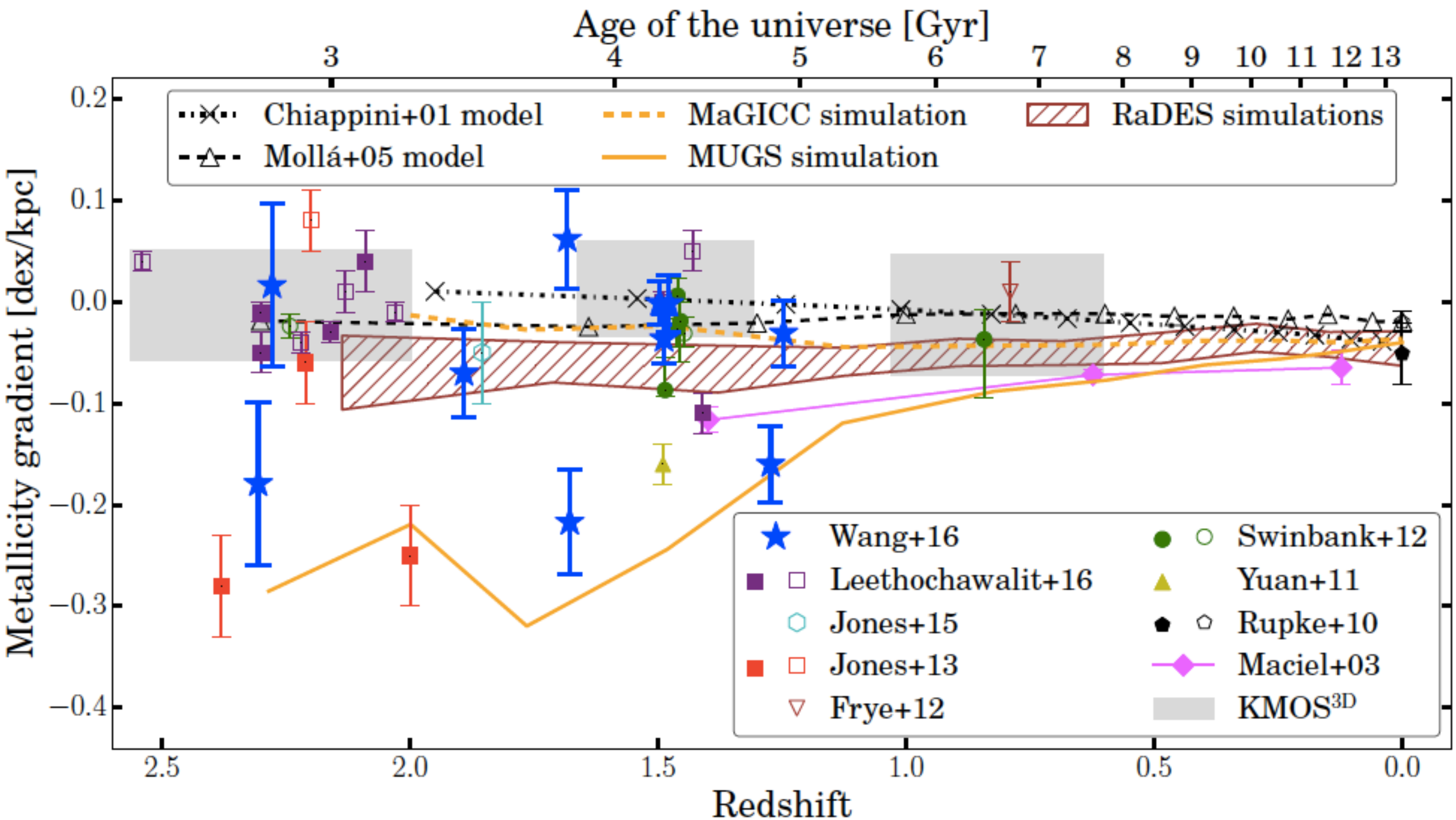
GLASS + REFSDAL FOLLOW-UP

GLASS Metallicity maps



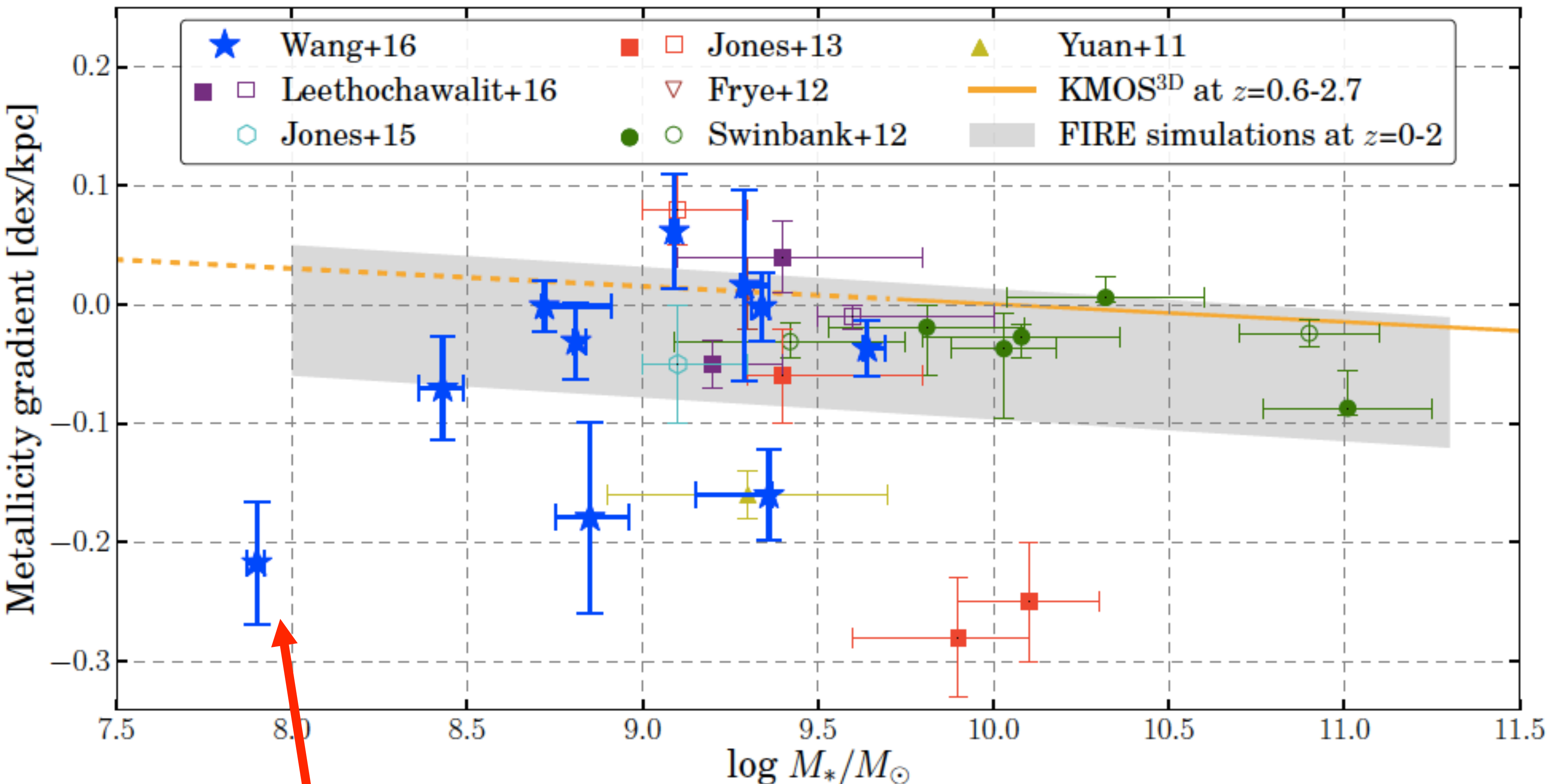
Wang+16

Gradients vs z



Wang+16

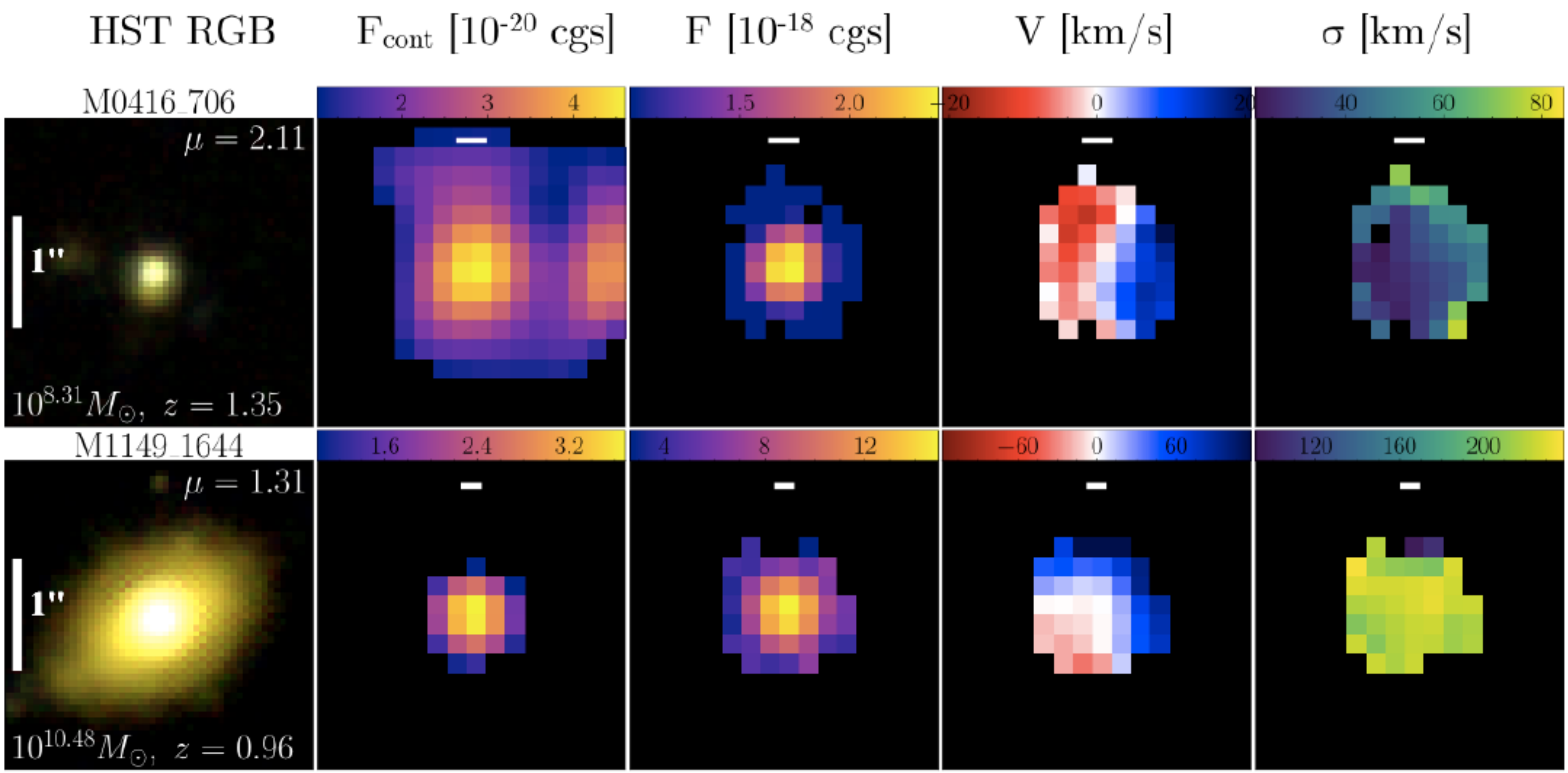
Gradients vs z



What's happening at low masses?

Wang+16

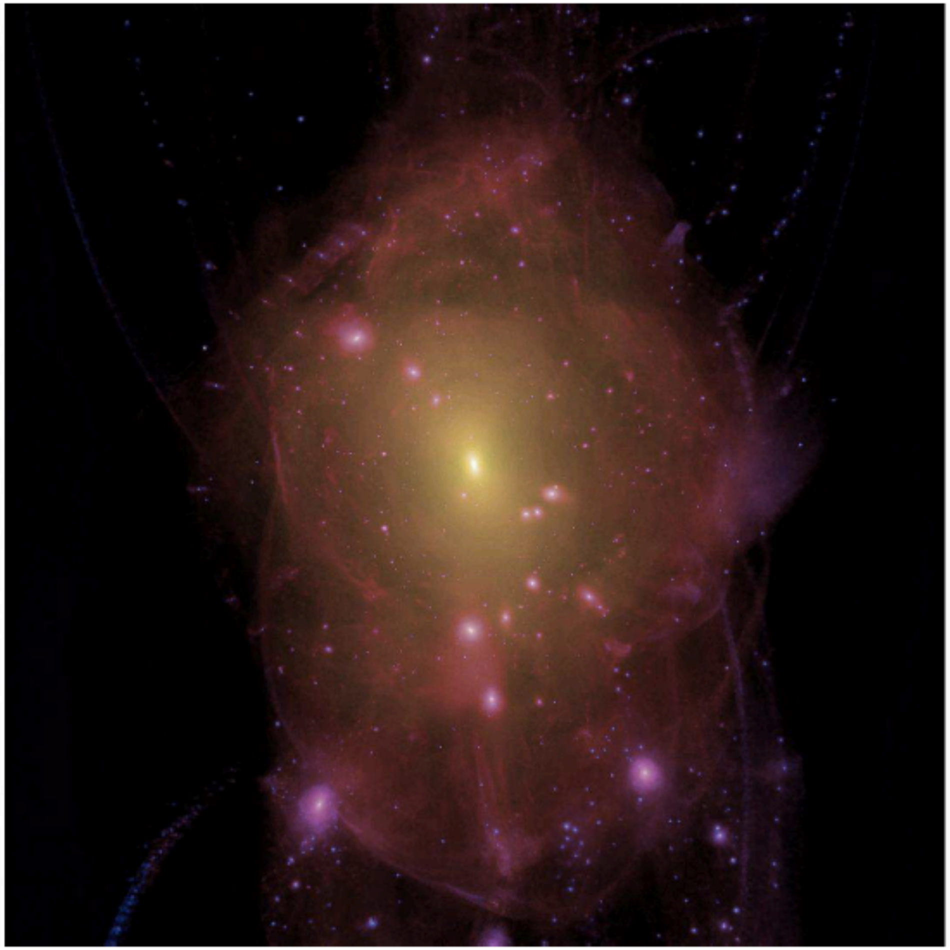
Ground based kinematics



Mason+16; see also Wang+16

The nature of dark matter
(see Suyu's talk for dark energy)

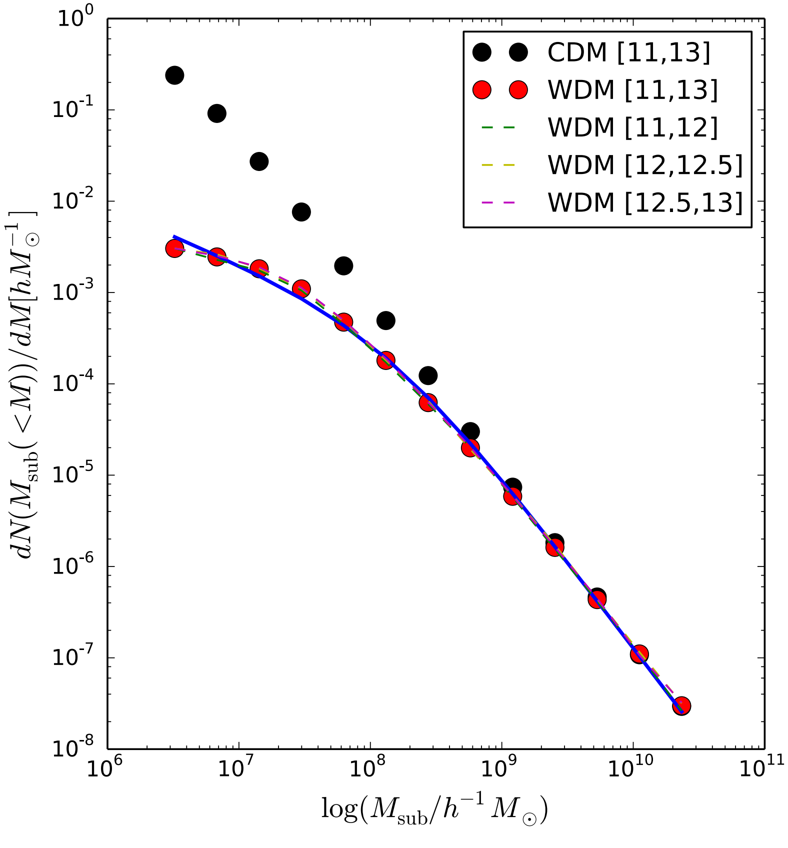
Warm vs Cold Dark Matter

Free streaming ~kev scale thermal relic

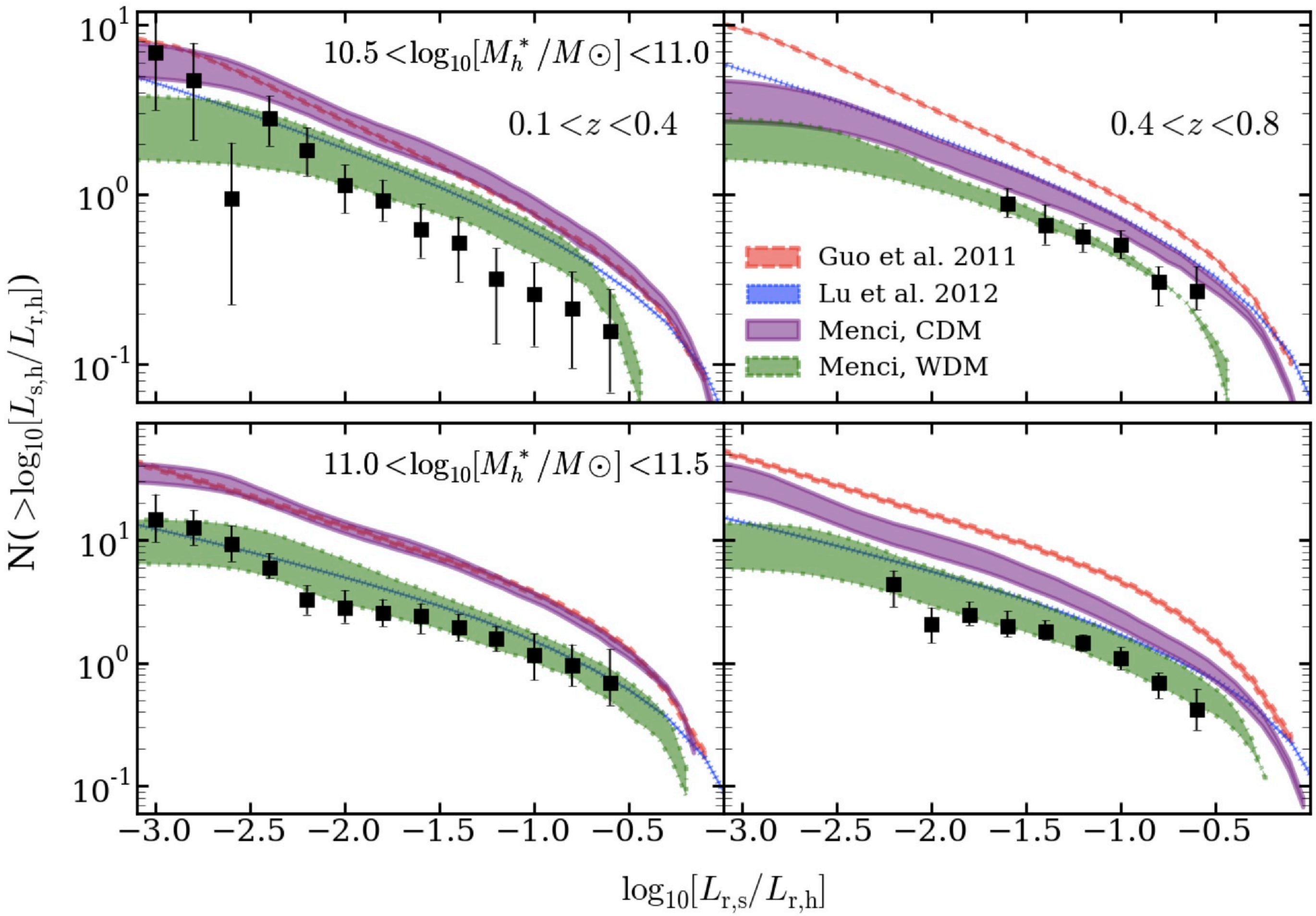
Lovell et al. 2014

Dark satellites in CDM vs WDM



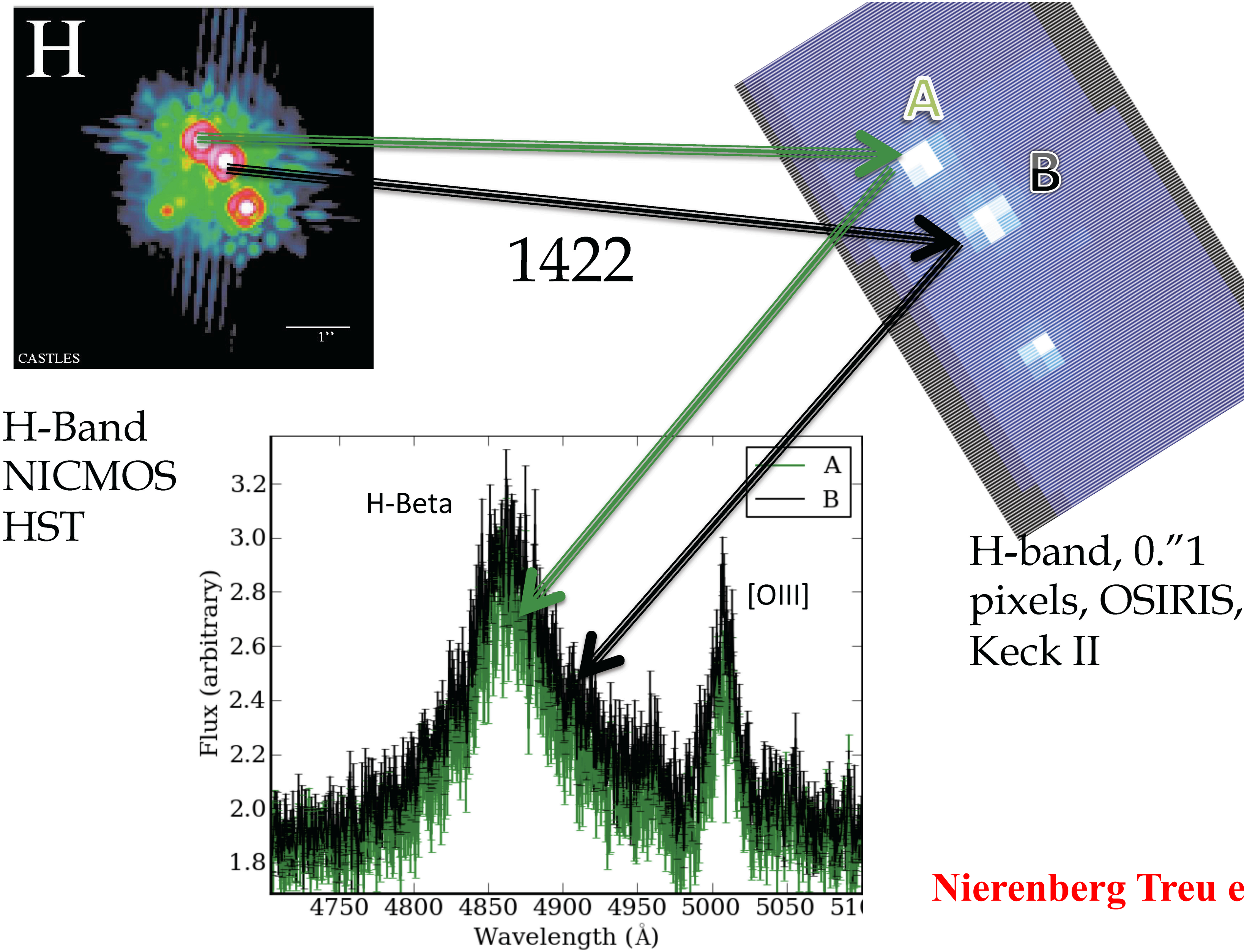
Li et al. 2016; Nierenberg et al. 2013

Luminous Satellites in CDM vs WDM



Nierenberg, Treu et al. 2013

OSIRIS detection of substructure

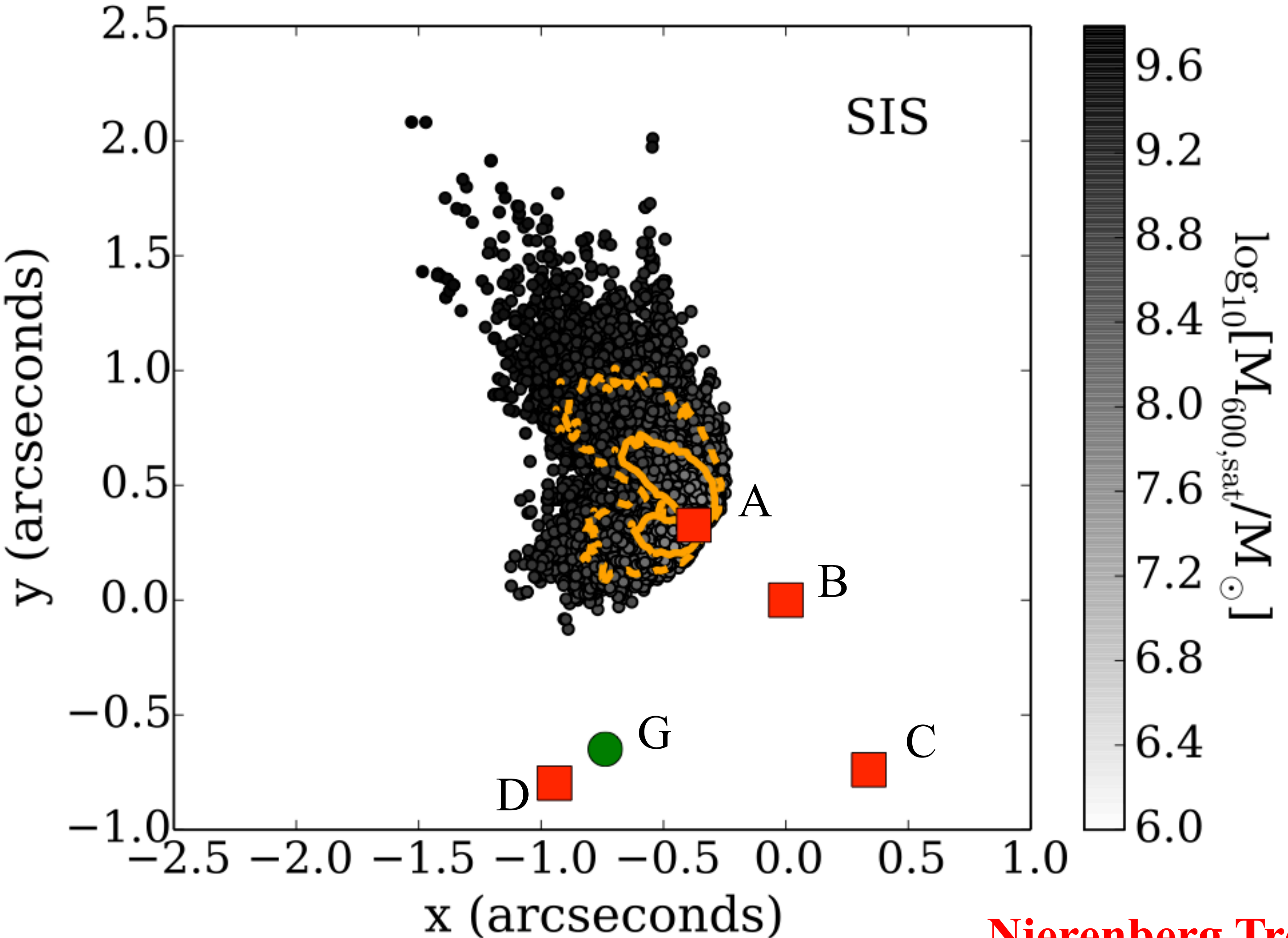


H-Band
NICMOS
HST

H-band, 0.″1
pixels, OSIRIS,
Keck II

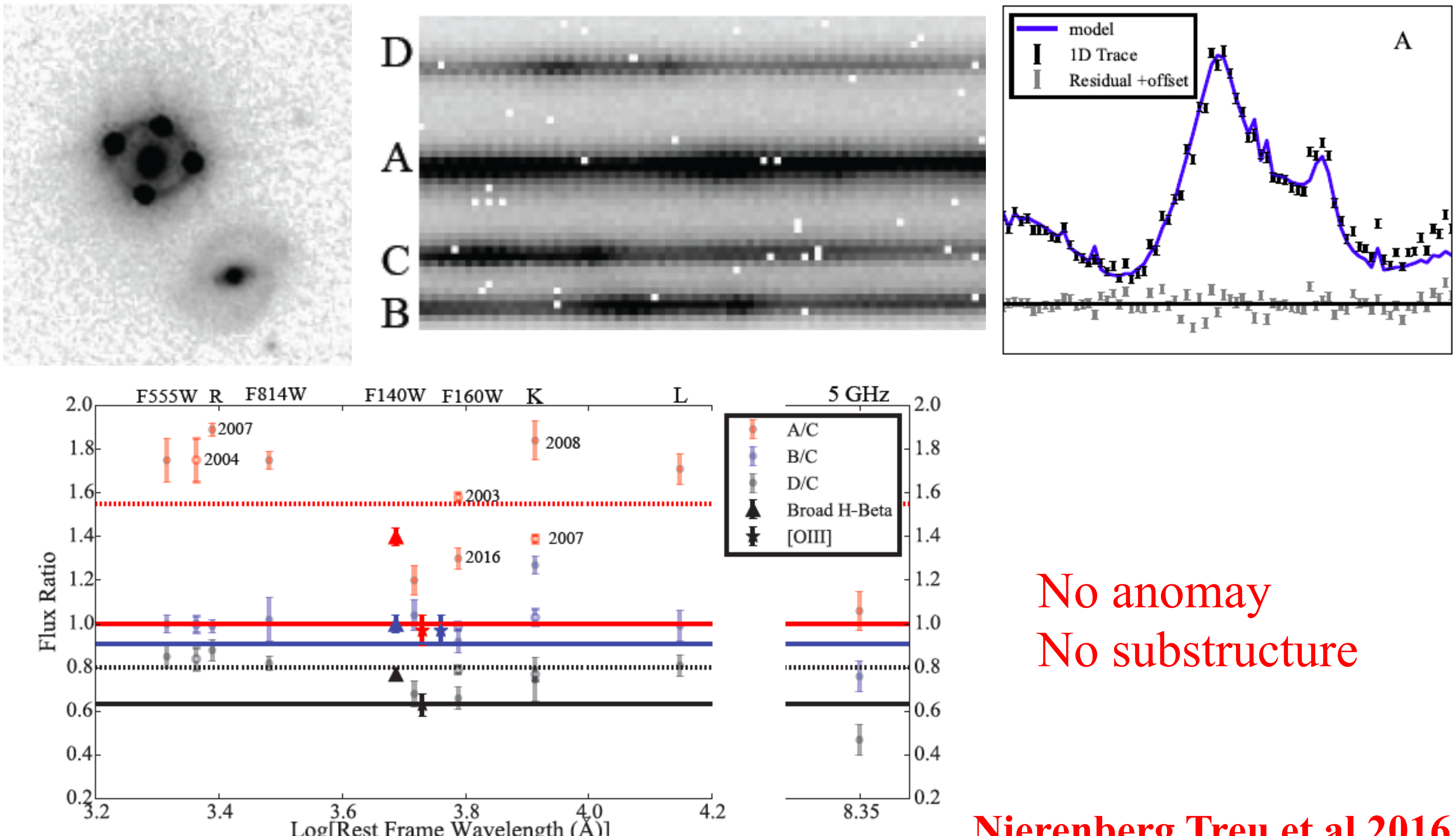
Nierenberg Treu et al 2014

OSIRIS detection of substructure



Nierenberg Treu et al 2014

Using the HST grism!



No anomay
No substructure

Nierenberg Treu et al 2016

Summary

- Metallicity maps the physics of inflows/outflows at z~2
  - A significant fraction of systems display steep negative metallicity gradients which could result from inefficient mixing of newly accreted material or low feedback
  - Diversity of phenomena, ranging from major/minor mergers, to canonical negative gradients. Full 2D maps and comparison with simulations are needed
- Strong gravitational lenses allow for high precision measurements of dark matter and dark energy properties that rely mainly on gravity and minimize the effects of baryons
  - Large samples of flux ratio measurements can distinguish between CDM and WDM models
  - Large sample of time delay lenses with kinematics can measure H_0 to subpercent precision and thus help constrain dark energy.

Lessons for JWST

Baryonic cycle

- Spatially resolved metallicity maps are an incredibly powerful diagnostic tool
  - JWST can push to smaller masses, where feedback physics is most easily probed. (NIRISS)
  - JWST can provide kinematics

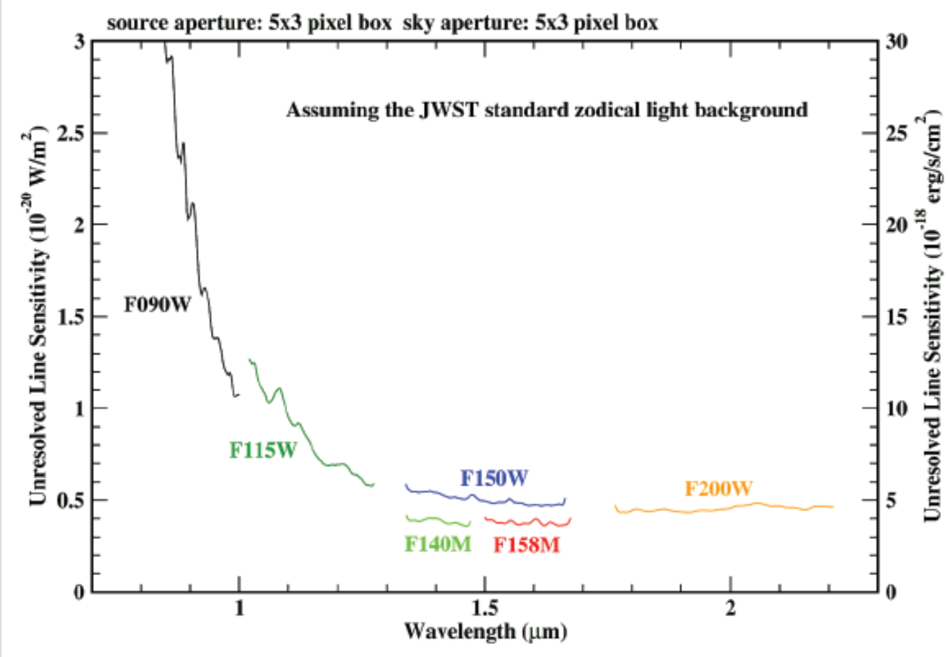
Fundamental Physics

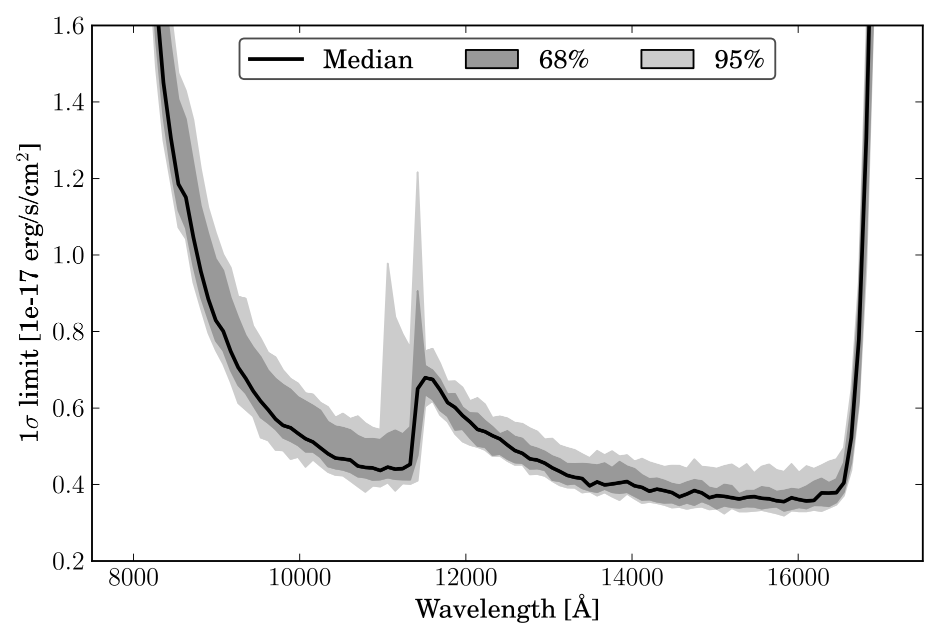
- Spatially resolved spectroscopy will allow breakthroughs both in dark matter and dark energy studies via strong lensing
  - For dark matter studies every lensed quasar will be amenable to flux ratio anomalies, very fast (MIRI or NIRISS)
  - For dark energy, spatially resolved kinematics will break mass-sheet-anisotropy degeneracy and help us achieve sub-percent accuracy on H_0 and improve dark energy figure or merit of stage IV experiments by x5 (NIRSPEC)

The end

NIRISS vs WFC3

10ks





Treu+ 2015