Science Capabilities of WMKO Spectrographs Fed by GLAO

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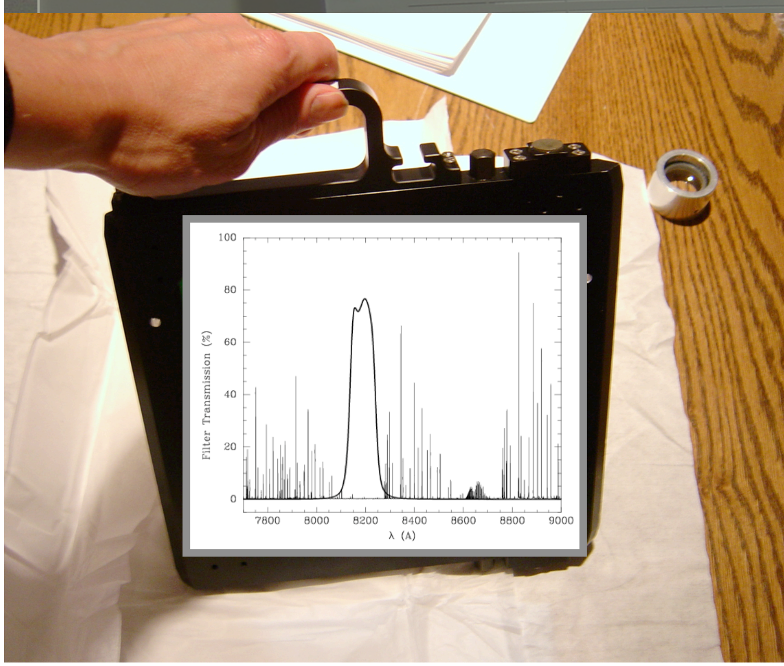
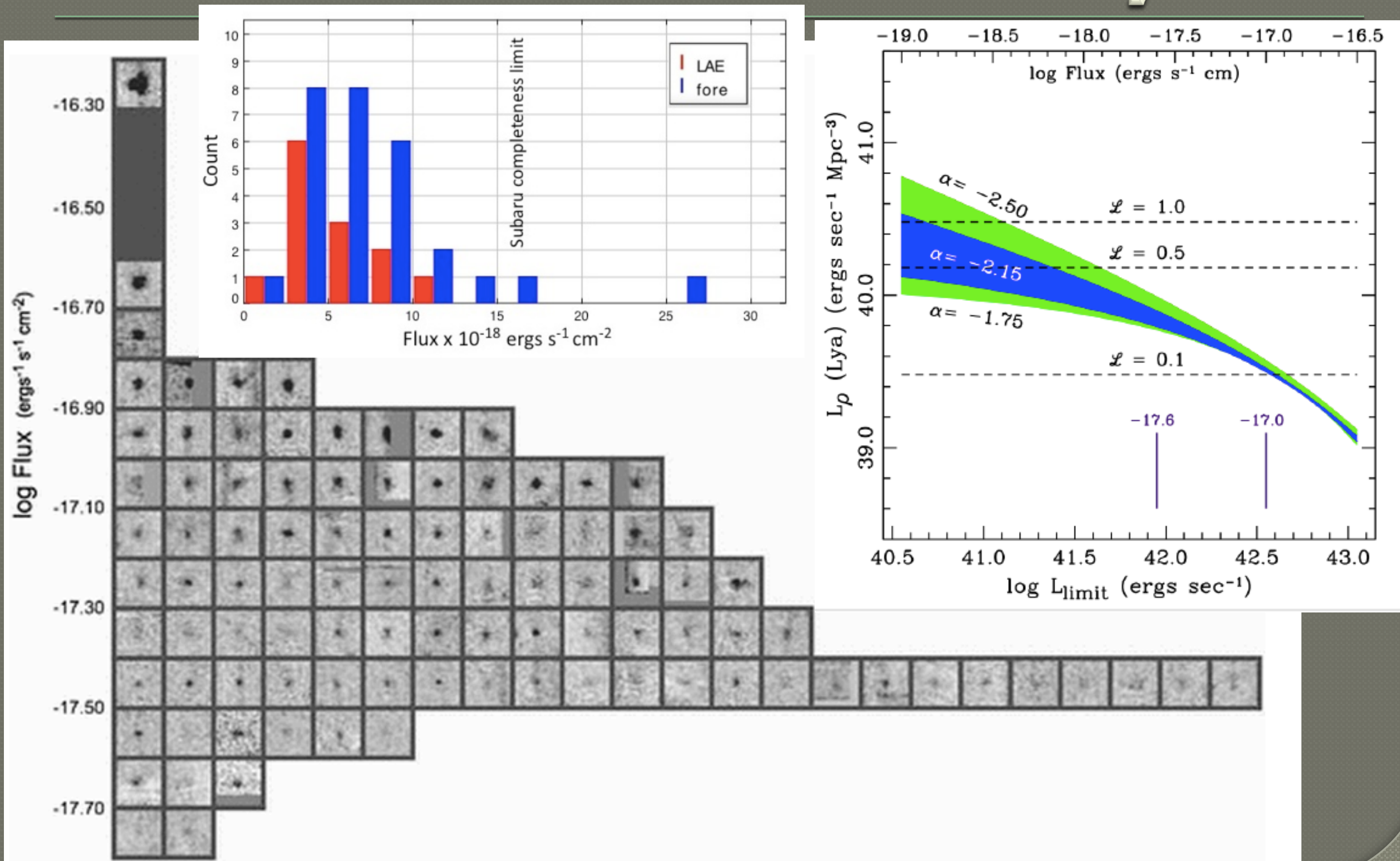
Motivation

- Historical strengths of WMKO
  - Multi-object spectroscopy
  - High-resolution AO
- What limits efficiency of multi-object spectroscopy?
  - Number of photons (Solution = TMT)
  - Larger field of view (Solution = Prime Focus)
  - <u>Sky brightness</u>
    - Go to space (JWST)
    - Improve the image quality delivered to spectrograph (GLAO)

Low Background Spectroscopy in the OH Windows



Surveys for


log Flux (ergs⁻¹ s⁻¹ cm⁻²)
-16.30
-16.50
-16.70
-16.90
-17.10
-17.30
-17.50
-17.70
Count
Subaru completeness limit
LAE
fore
Flux x 10⁻¹⁸ ergs s⁻¹ cm⁻²
log Flux (ergs s⁻¹ cm)
L_ρ (Lya) (ergs sec⁻¹ Mpc⁻³)
α= −2.50
α= −2.15
α= −1.75
ℒ = 1.0
ℒ = 0.5
ℒ = 0.1
−17.6
−17.0
log L_{limit} (ergs sec⁻¹)

Sky Background Limits Spectroscopic Sensitivity

$$\left(\frac{S}{N}\right)_{\Delta\lambda} = \frac{F_\lambda \cdot \Delta\lambda^L \frac{A\epsilon t}{h\nu}}{\sqrt{F_\lambda \cdot \Delta\lambda^L \frac{A\epsilon t}{h\nu} + \Sigma_{1,\lambda}^{sky}\theta_\perp\theta_\parallel \Delta\lambda^c \frac{A\epsilon t}{h\nu} + R_n^2 n_{pix} + D^2 n_{pix}}}$$

$$\frac{S}{N} \approx \frac{F_\lambda \cdot \Delta\lambda^L}{\sqrt{F_\lambda \cdot \Delta\lambda^L + \Sigma_{1,\lambda}^{sky}\theta_\perp\theta_\parallel \Delta\lambda^c}}\sqrt{\frac{A\epsilon t}{h\nu}}$$

Integrate long enough that shot noise dominates detector noise.

$$\frac{S}{N} \approx \frac{F_\lambda}{\sqrt{F_\lambda + \Sigma_{1,\lambda}^{sky}\theta_\perp\theta_\parallel}} \frac{\Delta\lambda^L}{\sqrt{\Delta\lambda^L + \Delta\lambda^c}}\sqrt{\frac{A\epsilon t}{h\nu}}$$

Limited by sky background for faint galaxies.

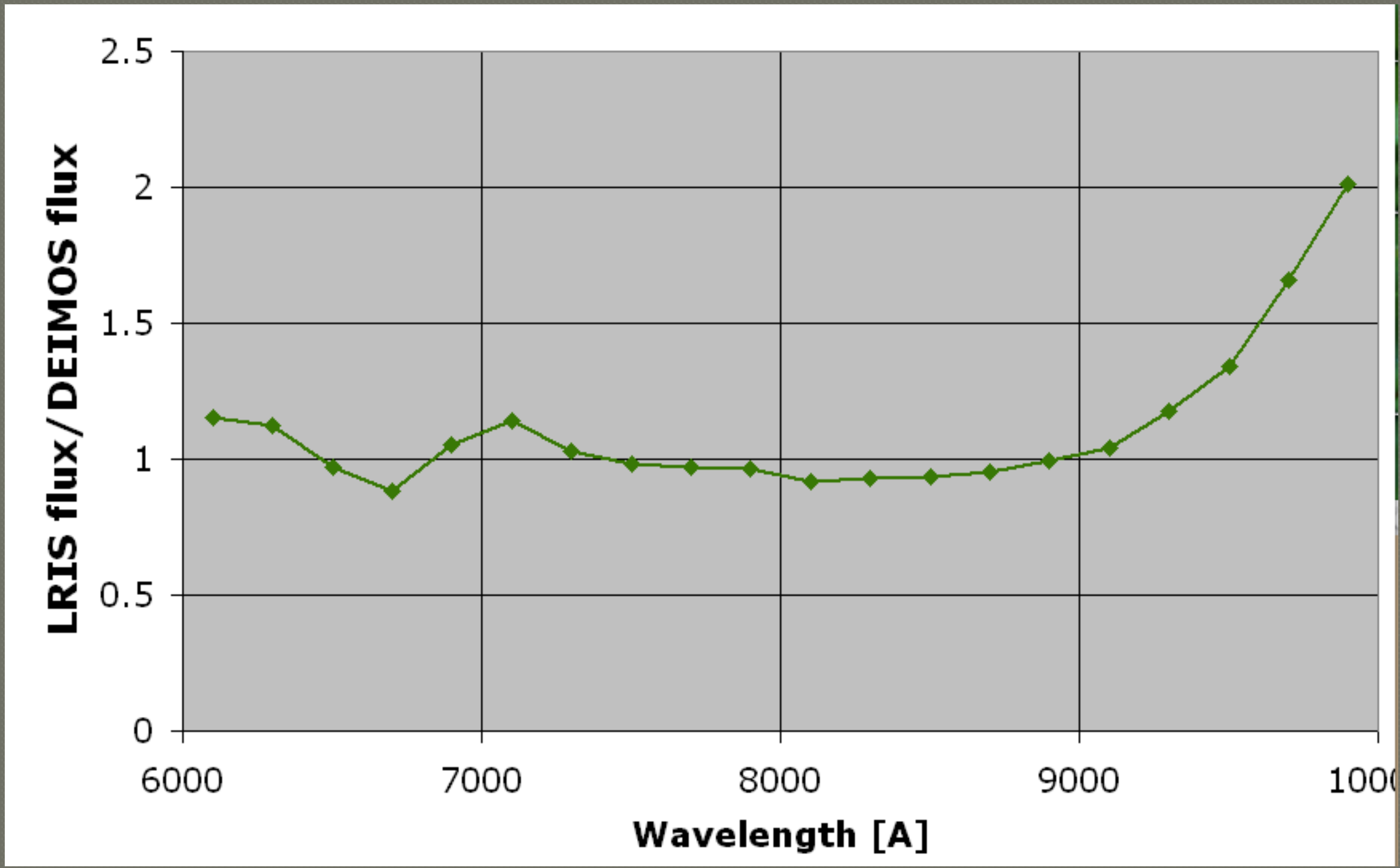
Improved image quality will

1. Reduce the angular size of objects
2. Improve spectral resolution without reducing spectral coverage

Which Spectrographs Can Take Advantage of Improved Image Quality?

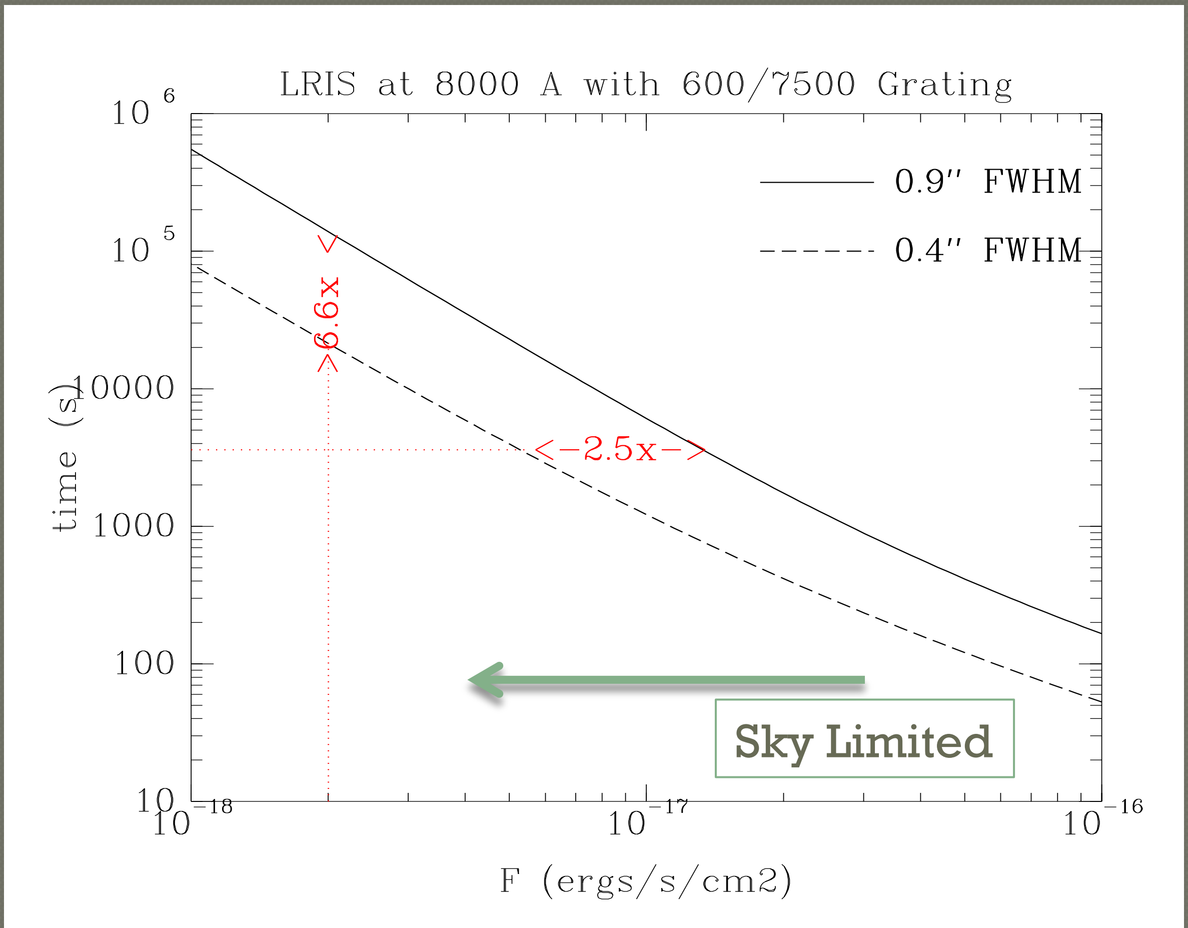
Instrument	LRIS	MOSFIRE	DEIMOS
Scale (“/pixel)	0.135	0.1798	0.1185
Field of View (‘)	5.5 X 8.0	3.0 X 6.1	16.7 X (5.0)
Detector	2k x 4k LBNL CCD	2k x 2k H2R	8 2k x 4k MIT/Lincoln Labs CCDs
Broadband Image Diameter (“)	0.288 (1.03)	< 0.25	0.33-0.38
Reference	Oke, Cohen, et al. 1995, PASP 107, 375	McLean+2012 SPIE Procs, 8446, 17 McLean+2012 SPIE Procs, 7735, 47	Nov. 2001 Pre-ship Review
Anamorphic Magnification	1.4 (1200 l/mm)	1.357 (HK) 1.335 (YJ)	(1.62) 1200/7500

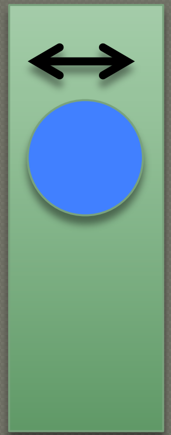
LRIS Beats DEIMOS in the Red

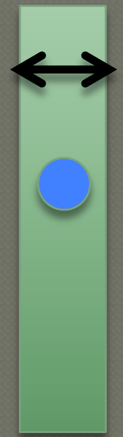


Estimated Gain in Sensitivity from Improved Image Quality

Context:
Emission Line at 8000 A with FWHM=4.0 A (150 km/s)



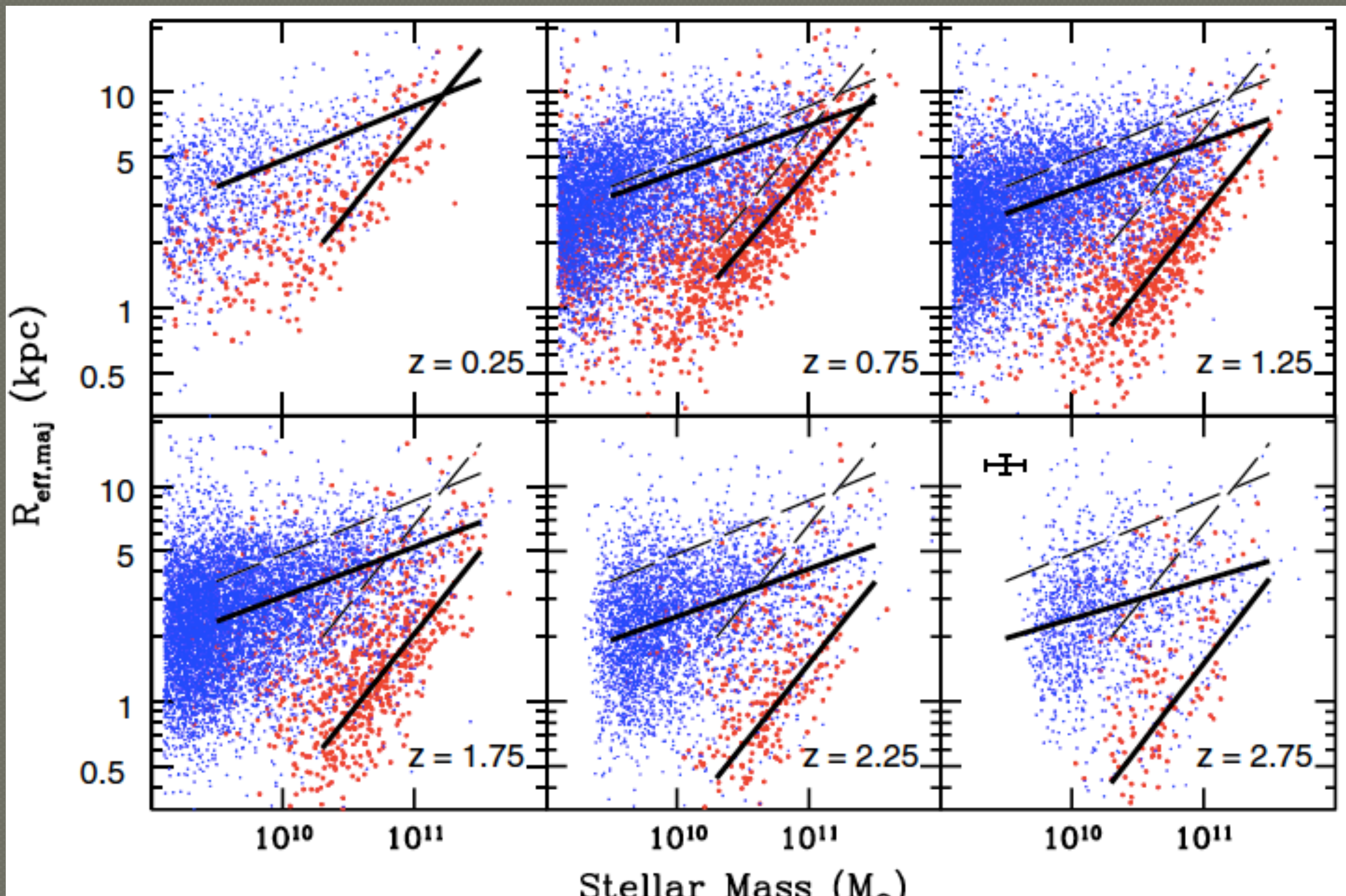




Science Objectives Drive the Required Resolution

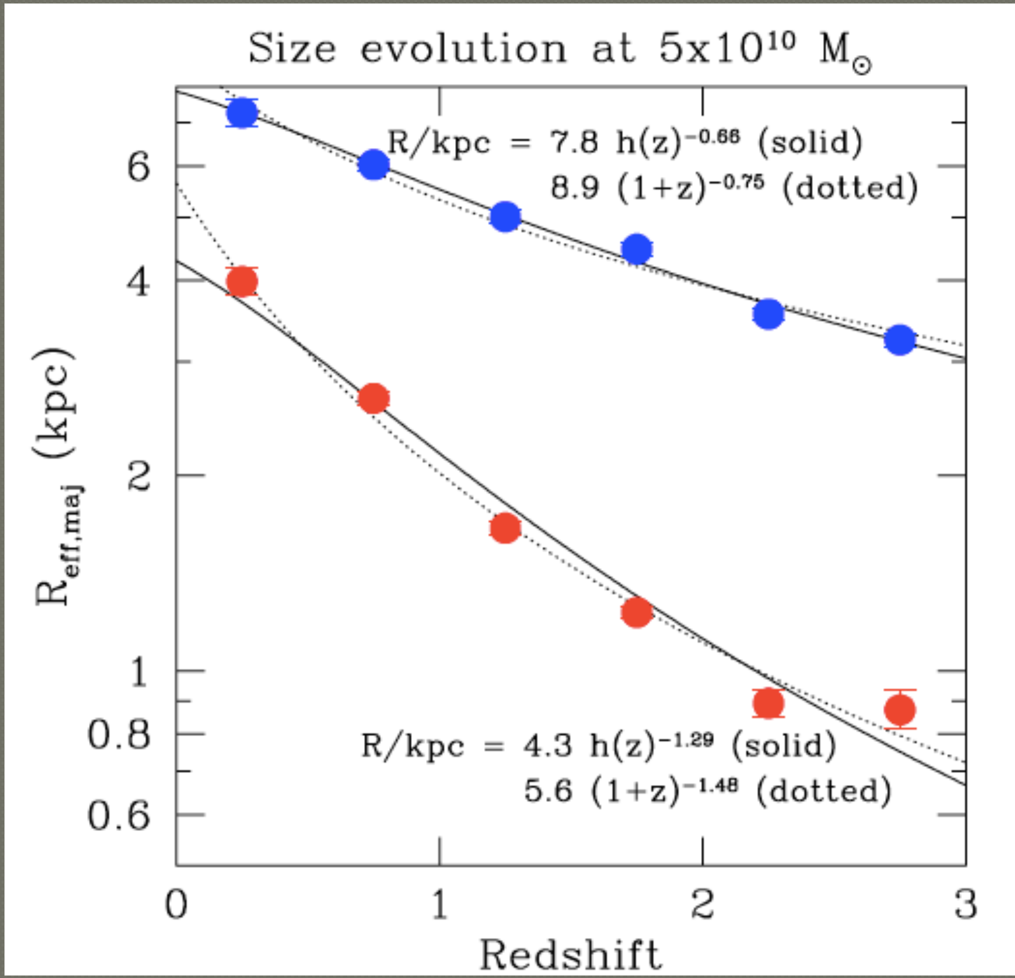
- Galaxy Populations
  - Integrated Spectra (slit width at 2 * $R_{1/2}$)
  - Large Samples (maximum field of view)
  - New
    - Lower mass galaxies at all redshifts
    - Higher resolution spectra for massive galaxies
- Galaxy Structure / Resolved Properties
  - Abundance gradients (exp. scalelength)
  - Star formation & feedback (100 pc to 1 kpc)
  - Rotation curves

Sizes of Galaxies



Van der Wel + 2014 (3D HST)

Sizes of "Typical" Galaxies



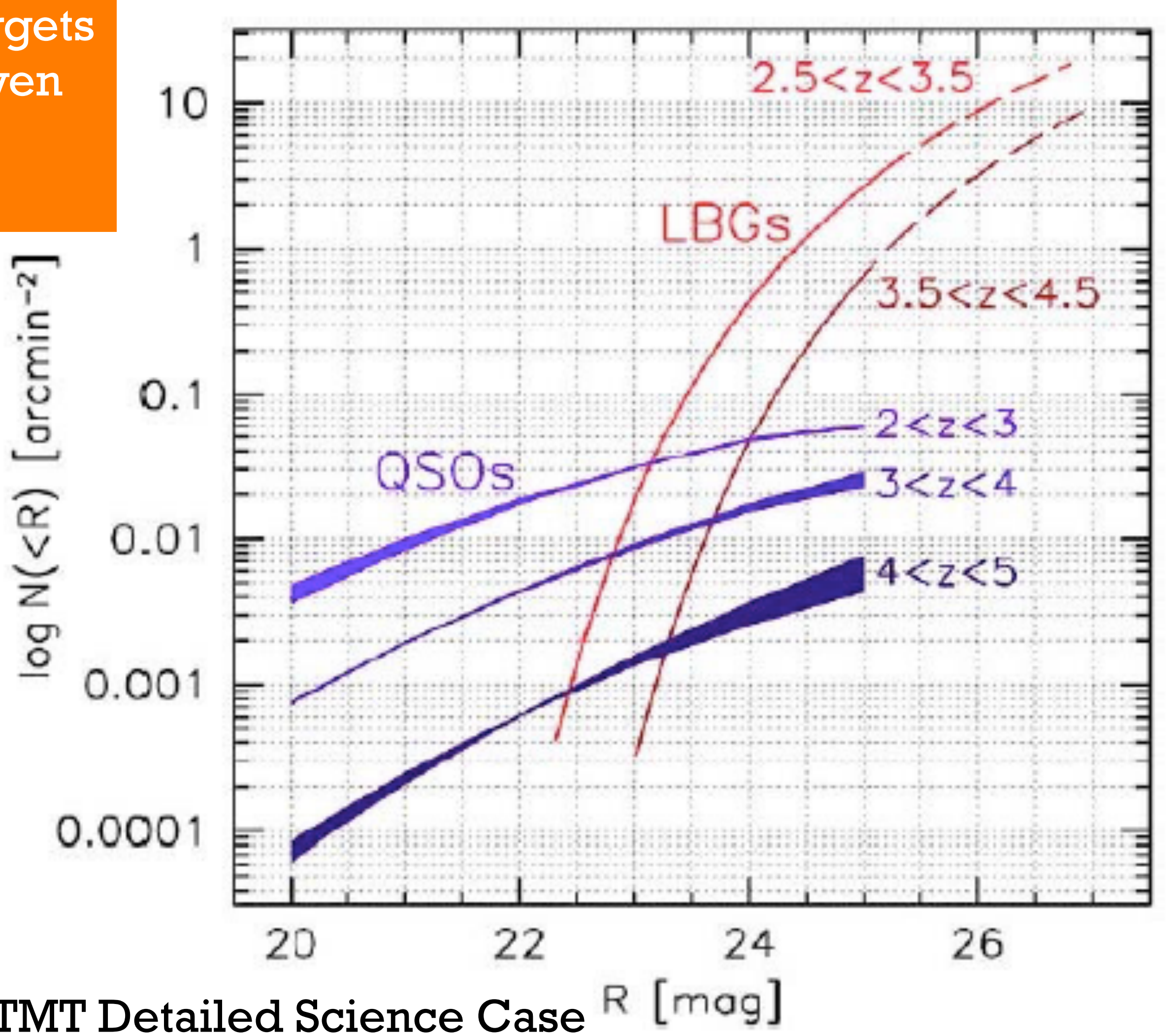
Van der Wel + 2014 (3D HST)

Sizes of Galaxies

Color/ Redshift	Half-Light Radius (")	Exponential Scale Length (")	100 pc Angular size (")	1 kpc Angular size (")
Blue z=0.2	1.15	0.687	0.0164	0.164
Blue z=1.0	0.66	0.394	0.0124	0.124
Blue z=2.0	0.48	0.287	0.0119	0.119
Red z=0.2	0.66			
Red z=1.0	0.25			
Red z=2.0	0.13			

Studying the Gas in Galaxy Halos with Sightlines to Background Beacons

Point source targets benefit from even higher image quality.

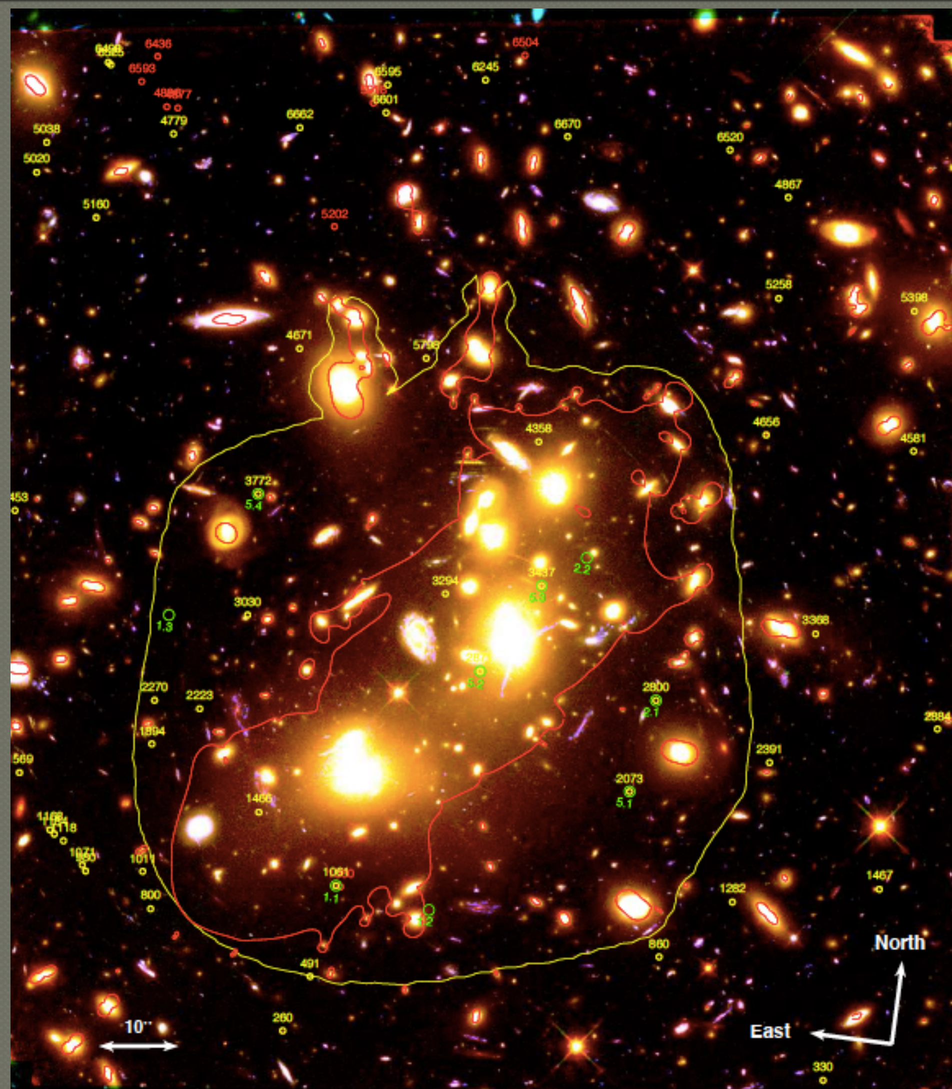


TMT Detailed Science Case

Beyond Current WMKO Instruments: Integral Field Spectroscopy

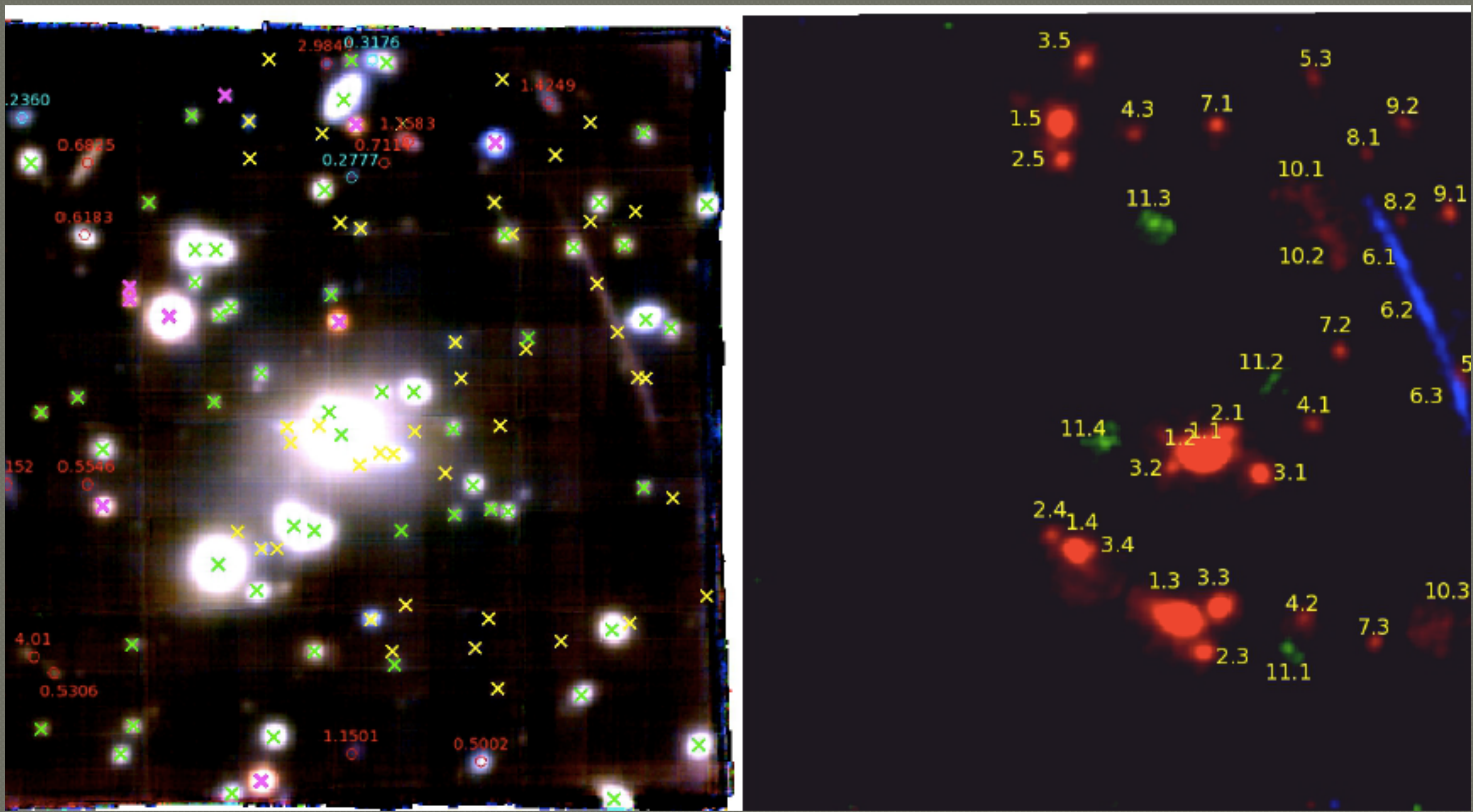
Redshift 7 (yellow contour) and 8 (red contour) lensed galaxies.

Field shown in 2' x 2'.



Beyond Current WMKO Instruments: Integral Field Spectroscopy

- MUSE (1' x 1') at VLT is too small; must do mosaic
- Lensed emission-line galaxies: Lya (red), [OIII] (green), and CIII] (blue)



GLAO – Integral Field Spectrograph (IFS)

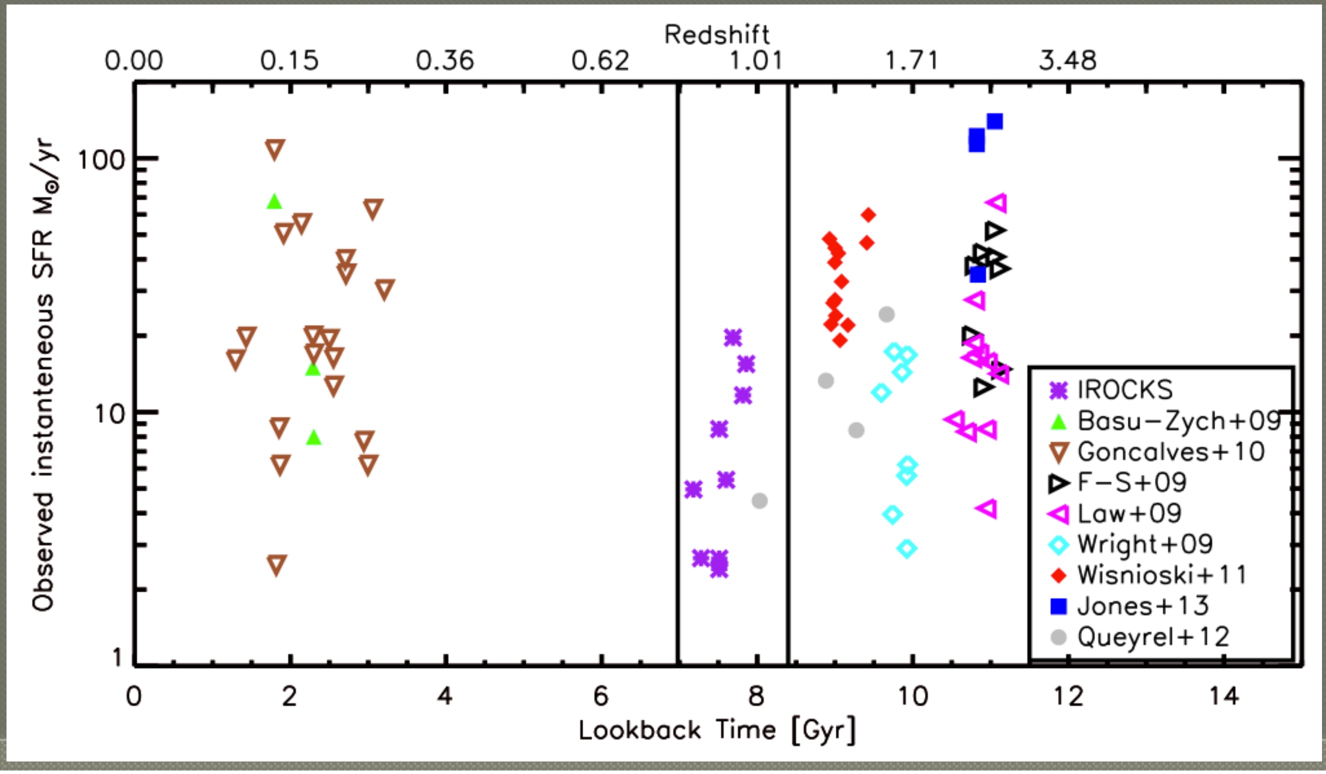
- To take **best** advantage of the large FOV afforded by GLAO we need to have either wide field format IFS or multi-object IFS
- At near-infrared (~1- 2.5 μm) this is challenging since we want to sample the GLAO PSF (0.05 - 0.2") and have a large FOV access
  - But ultimately we are pixel limited!
- Trade-offs will need to be made based on total field of view (of either a single wide format or deployable IFS) and spectral resolution

Science Cases for GLAO with Multi-Object IFSs (mIFS)

- There are a range of science cases that would benefit with a mIFS
- Primary science cases
  - ✓ High-redshift Galaxies (z > 1)
  - Starbursts & clusters in nearby galaxies (e.g., M82)
  - Stellar population in nearby galaxies (e.g., proper motion in local group)
  - Milky Way (crowded field astrometry and photometry)

GLAO-IFS: High-Redshift

- Current IFS samples are limited by single-mode observations (e.g., SINS)
  - TIME CONSUMING to build-up a statistical sample
  - The MAJORITY of IFS high-z galaxies are seeing-limited!
- Limited number of IFS + AO samples:



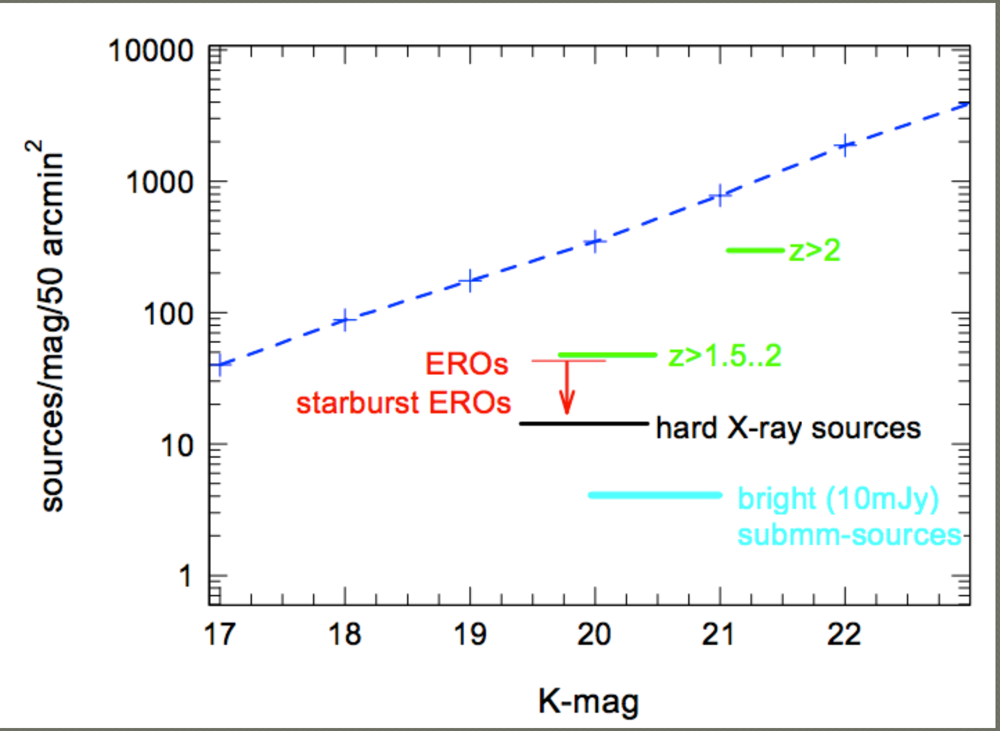
Mieda et al., in prep

Why GLAO + IFS on high-z galaxies?

- The goal is to achieve spatially resolved spectroscopy of moderate to high-z galaxies
  - Essential for rotation curves, velocity dispersion and stellar population profiles
- Constraints (e.g., Tully-Fisher, Fundamental Plane) on z < 1 galaxy evolution would not have happened without high angular resolution HST
- We need AO to improve spatial resolution
  - Angular size of z > 1 galaxy is ~1'', size of seeing halo
  - To resolve kpc size scale at high-z you need < 0.2'' spatial resolution
- Typical R = 3000 – 5000 to sample between OH lines and achieve $\sigma \sim 50$ km/s
- Lastly, we need a LARGE statistical sample!
  - Multiplexing of IFS are needed

GLAO FOV well-matched to multiplexing high-z galaxies

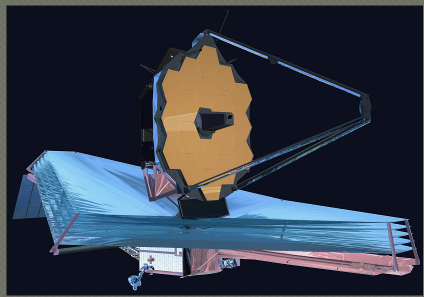
- The number density of z > 1 galaxies is suited for GLAO with multiple IFSs
  - 10 – 100 galaxies per 50 acrmin^2 (7' diameter)



Sharples et al. 2003

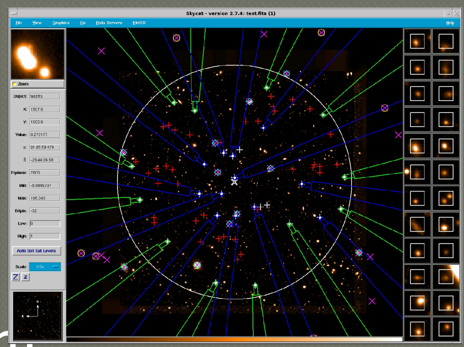
Landscape of NIR-spectroscopy on JWST

- JWST NIRSpec IFS will have limited spatial and spectral resolution compared to ground-based facilities
  - NO IFS multiplexing capabilities
  - Limited spectral resolution!
    - (R=100, 1000, 2700)
    - Limits high-z galaxies dispersion and kinematic resolution
  - Limited sampling and field of view
    - IFS is 3”x3” with 0.1” sampling
    - Limits to spatial sampling of high-z galactic structure



Landscape of IFS+AO in coming decade

KMOS



- Example 8-10m class telescopes:
  - VLT KMOS with 24 deployable IFUs
    - 2.8”x2.8” FOV per IFU with 0.2” sampling
  - ULTIMATE-Subaru currently being investigated to operate with GLAO system
- Extremely Large Telescopes (TMT, GMT, E-ELT) all have single-mode IFS at first light
  - Extending slightly bluewards, 0.85 – 2.5 μm
  - Range of spatial samplings 0.004 – 0.1”
  - R=3000 to 5000 (w/ limited 8000 - 10,000)
  - But <u>VERY small</u> field of views!

Keck GLAO – Multiobject IFSs (mIFS)

- If all trees bear fruit, where will be the niche and need for a Keck GLAO+IFS system for high-z science?
  1. mIFS continue with current IFS specifications
     - R=3000 to 5000, with 0.05 – 0.2''/spaxel
     - Continue to build a large statistical sample with multiple instruments is imperative
  2. mIFS with higher spectral resolution
     - Reduce FOV, take advantage of GLAO sampling yet use 0.2'' sampling, with R=8000-10000
     - Exciting for disentangling velocity structure on the brightest of systems, but with cost of reduced sensitivity*
  3. mIFS with bluer wavelength coverage
     - Maximizing efficiency and performance between 0.7 – 1.3 μm
     - Exciting for extending studies to higher redshifts (e.g., [OII] at z=3 is in J-band)
     - Exciting for rest-frame UV diagnostics (e.g. At z=6, Ly-α is in Z-band)