TMT/IRMS: the Science Case

Bahram Mobasher

University of California, Riverside

IRMS = MOSFIRE + TMT/NFIRAOS

IRMS provides a relatively cheap near-IR multi-slit spectrograph and imager on TMT.

With no significant modifications to the MOSFIRE design, it can be used on the TMT. It would take the entire NFIRAOS field of view of 2 arcmin diameter.

IRMS is proposed as one of the first light instruments on the TMT.

Characteristics of the IRMS

Wavelength range: 0.97- 2.45 microns (YJHK)

Field of view: 2.27 arcmin diameter

Pixel size: 0.06 arcsec/pixel (0.08 arcsec/pixel)

in dispersion direction

Multiplexing factor: 46 movable cryogenic masking bars, each 2.43” long on sky.

Spectral resolution: R=3270 - 3 pixel (0.24” wide)

R=4660 - 2 pixel (0.16” wide)

Imaging the entire NFIRAOS field of view with 60 mas sampling

Science with IRMS

IRMS can best be used for:

- ✓Faint near-IR spectroscopy of resolved sources (nearby or at high-z)
- ✓ Sources with number densities ~ 10 per arcmin^2
- ✓ Spectroscopy requiring low sky background
- ✓ Spectroscopy requiring high spatial resolution

IRMS allows high spatial resolution spectroscopy with AO- to reach diffraction limit, in which angular resolution achieved will be proportional to the diameter of the telescope.

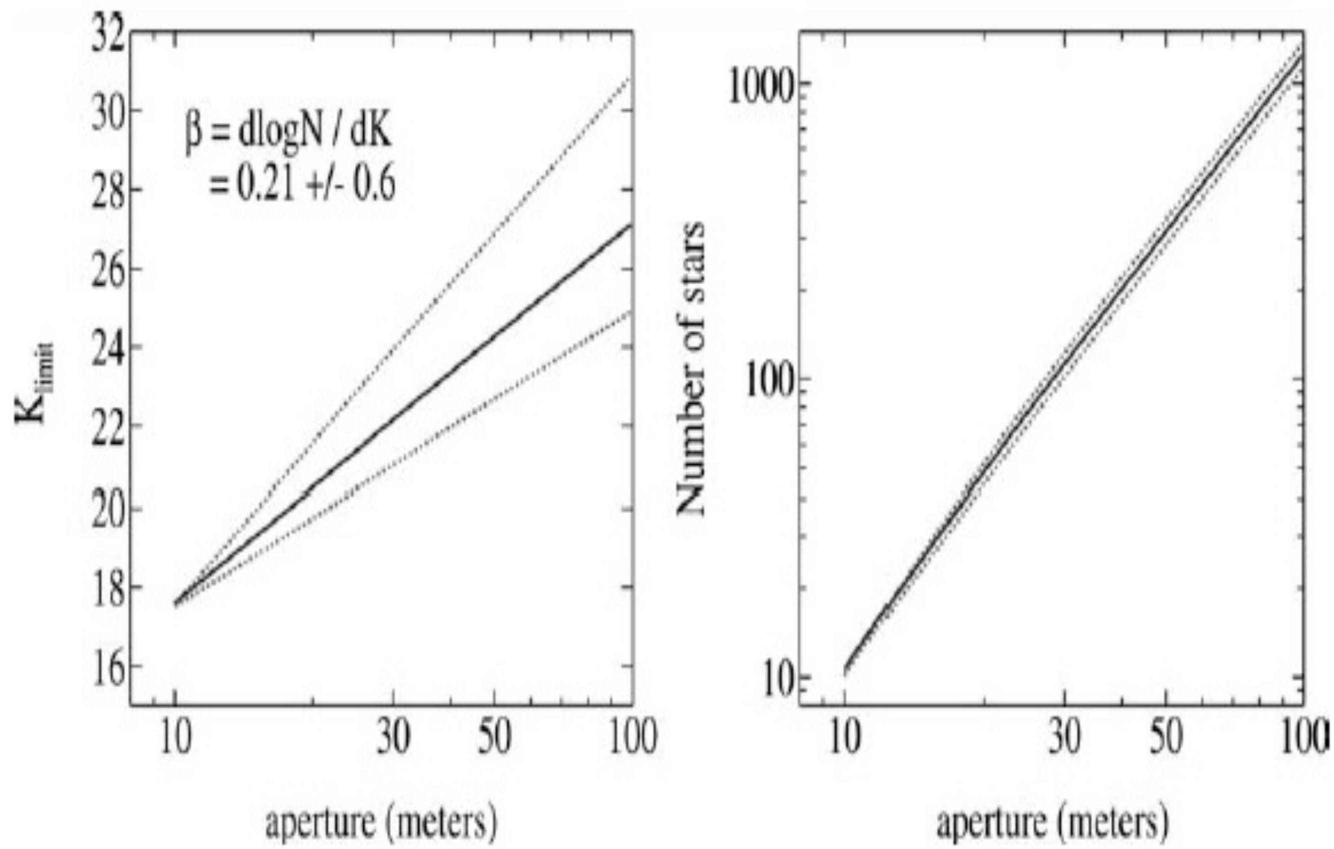
Examples of the IRMS Science

- Nearby Universe: High spatial resolution Near-IR spectroscopy of star clusters or selected targets (HII regions) in galaxies
- z ~ 2 Universe: Gradient of the SFR and metallicity in galaxies; study of dynamics of galaxies; spectroscopy of interacting systems
- z ~ 5 Universe: Study of high-z galaxy clusters; effect of the environment in early galaxies
- z ~ 7 Universe: Nature of sources responsible for re-ionization of the Universe, pop III stars

The Galactic Center: A Laboratory for Dark Matter

- Near-IR observation of stars within the Milky Way central cluster has revealed existence of a BH with mass $4.8x10^6$ M_{sun} at a distance of 8.4 kpc (Ghez et al).
- Relative to the 8-10m class telescopes, the TMT/IRMS combination allows: (a). reduced confusion and crowding with a confusion limit for detectable orbital motion improving from K=17 (for Keck) to K~22 mag (for TMT/IRMS); (b). Increased number of stars by an order of magnitude; (c). improved resolution for radial velocities from 20-50 km/s to ~10 km/s and better for cooler stars with richer spectral features (Figer 2003).

GAIN WITH TMT+IRMS



K band magnitude limit and number of detectable stars vs. the telescope aperture. Going from 10m to 30m telescope, one could detect stars from K~17 to K~22 respectively. Similarly, the number of detected stars increases by an order of magnitude (Taken from the TMT detailed science document)

Outstanding Problems in Galaxy Evolution at z ~ 2-4

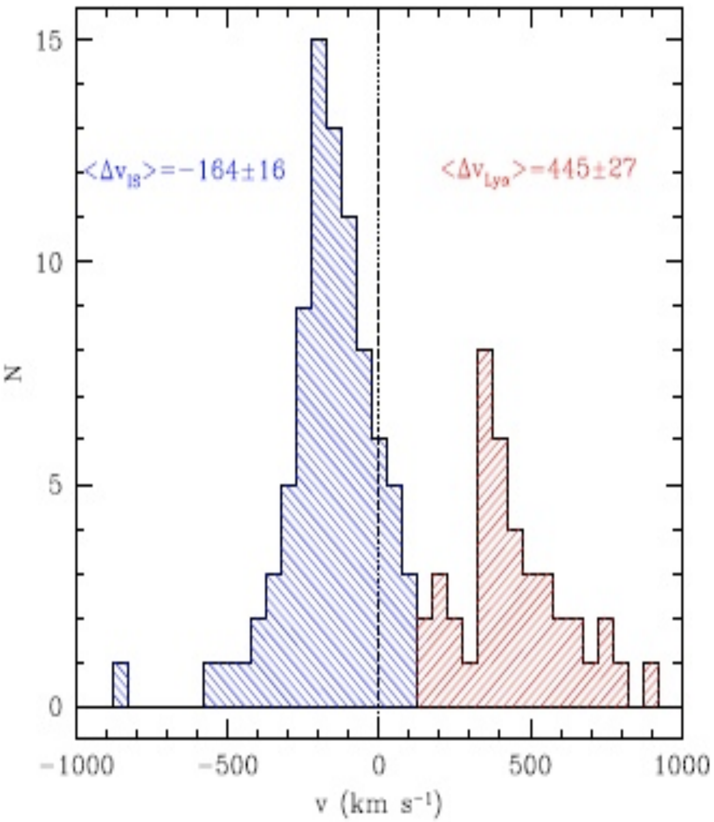
- diminished star formation in massive galaxies at high-z
- small number of low-mass galaxies compared to that predicted by DM halo mass function
- the cause of the correlation between galaxy spheroid and super-massive BHs
- the metal enrichment of interstellar gas

Needs simultaneous study of a galaxy and its IGM

The IGM: Inflow and Outflow in Galaxies at high-z

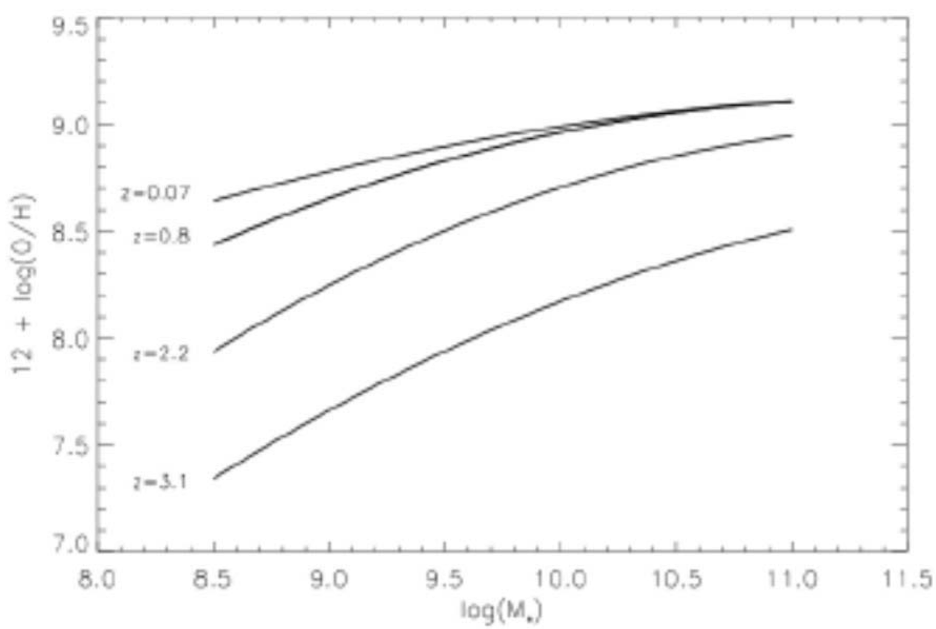
- Centroid velocity of Interstellar absorption (IS) lines (blue) and Lya emission wrt the galaxy nebular redshift of <z>=2.27 (Steidel et al 2010)
- Study of kinematics of galaxy scale outflows
- The line of sight to background galaxies provide information on the spatial distribution of gas surrounding the central galaxy at 3-125 kpc levels.
- Provides map of cool gas as a function of galactocentric distance for different populations of galaxies.
- IRMS+AO allows high spatial resolution spectroscopy of rest-frame H-alpha at

  1.9 < z < 2.9 to study distribution of cool gas against the stellar continuum of galaxies at high-z



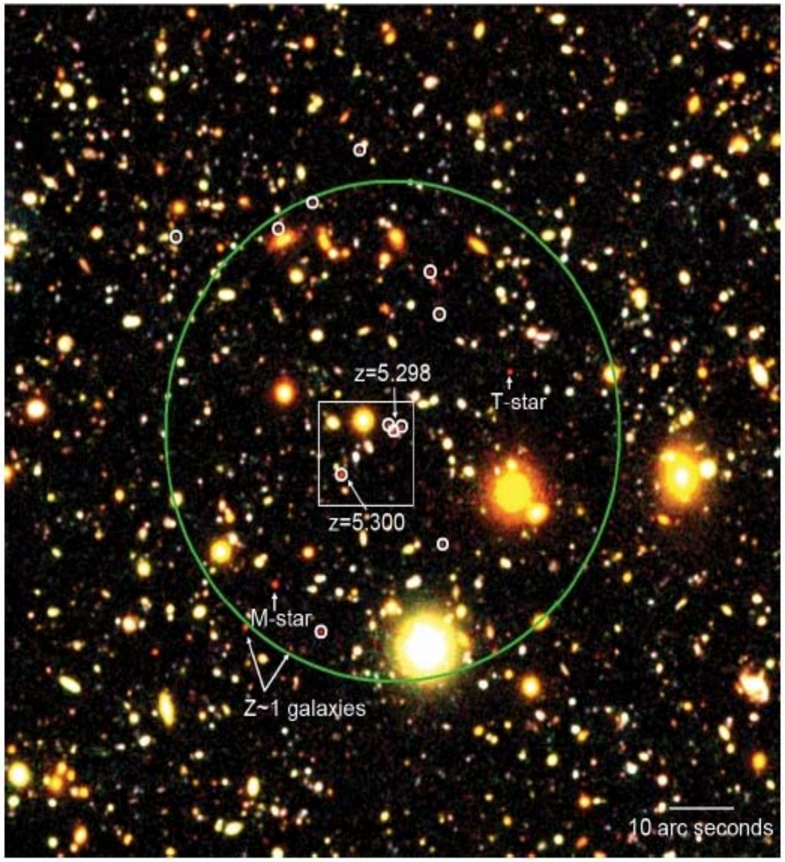
Evolution of Metal Abundance and Mass-Metallicity Relation with Redshift

- At z~6, galaxies are observed to have stellar populations ~100 Myr old
- Carbon is detected in highest redshift quasars, implying enrichment at those redshifts
- At z>6, OI and CII lines used for metallicity measurements (Becker et al 2006) move to near-IR bands. TMT/IRMS has the sensitivity to measure metallicity for objects at these redshifts and to estimate the metallicity gradients across these galaxies

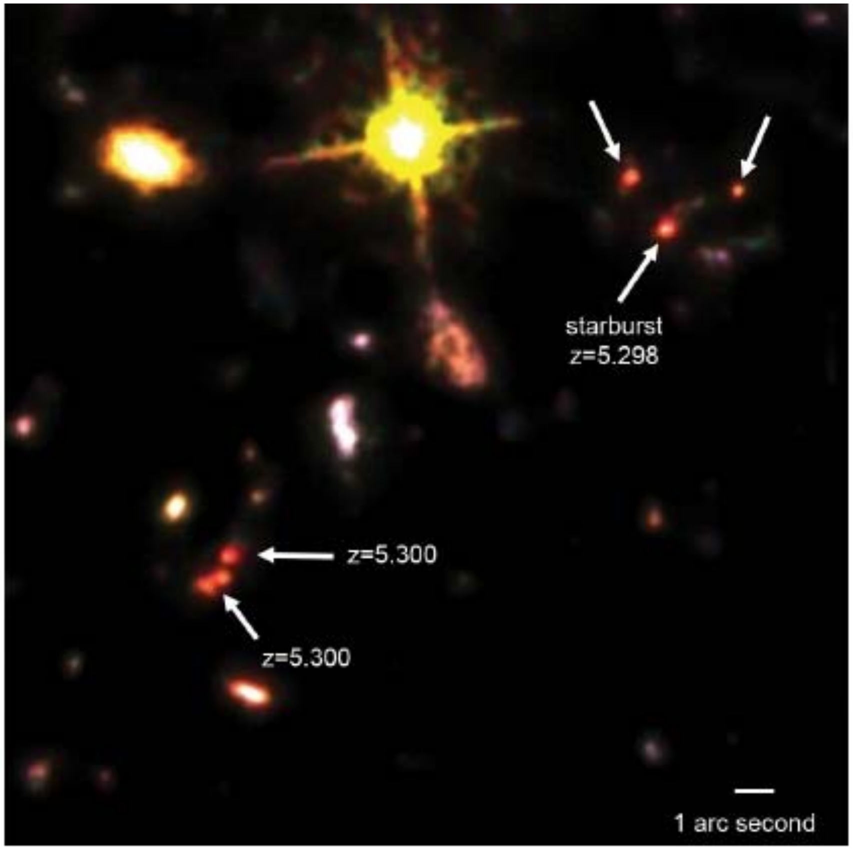


A proto-cluster at z ~ 5.3

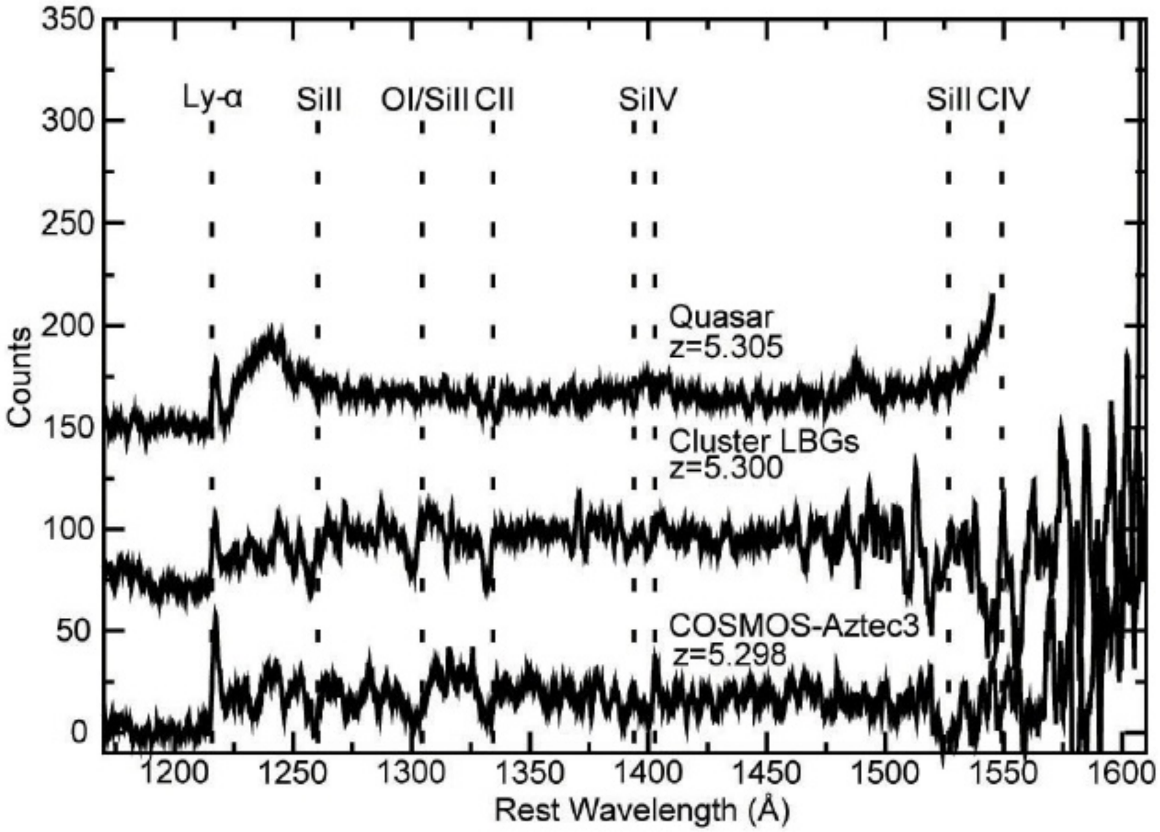
- We have now identified a proto-cluster at z~5.3, with spectroscopic confirmation for 12 of its member galaxies (Capak et al 2011)
- The white box shows a 2'x2' projected area of the cluster (almost the FoV of IRMS)
- Such structures provide a unique opportunity to study the role of environment in the formation of galaxies at early epochs
- Near-IR spectroscopy of clusters members with IRMS allow a study of the effect of the environment on formation of galaxies ~1 Gyr after the big bang- eg. was galaxy interaction responsible for cessation of star formation in galaxies and formation of massive galaxies ?



A 2’ x 2’ region at the center of the cluster with largest spectroscopically confirmed redshifts



DEIMOS spectra of galaxies, confirming cluster membership

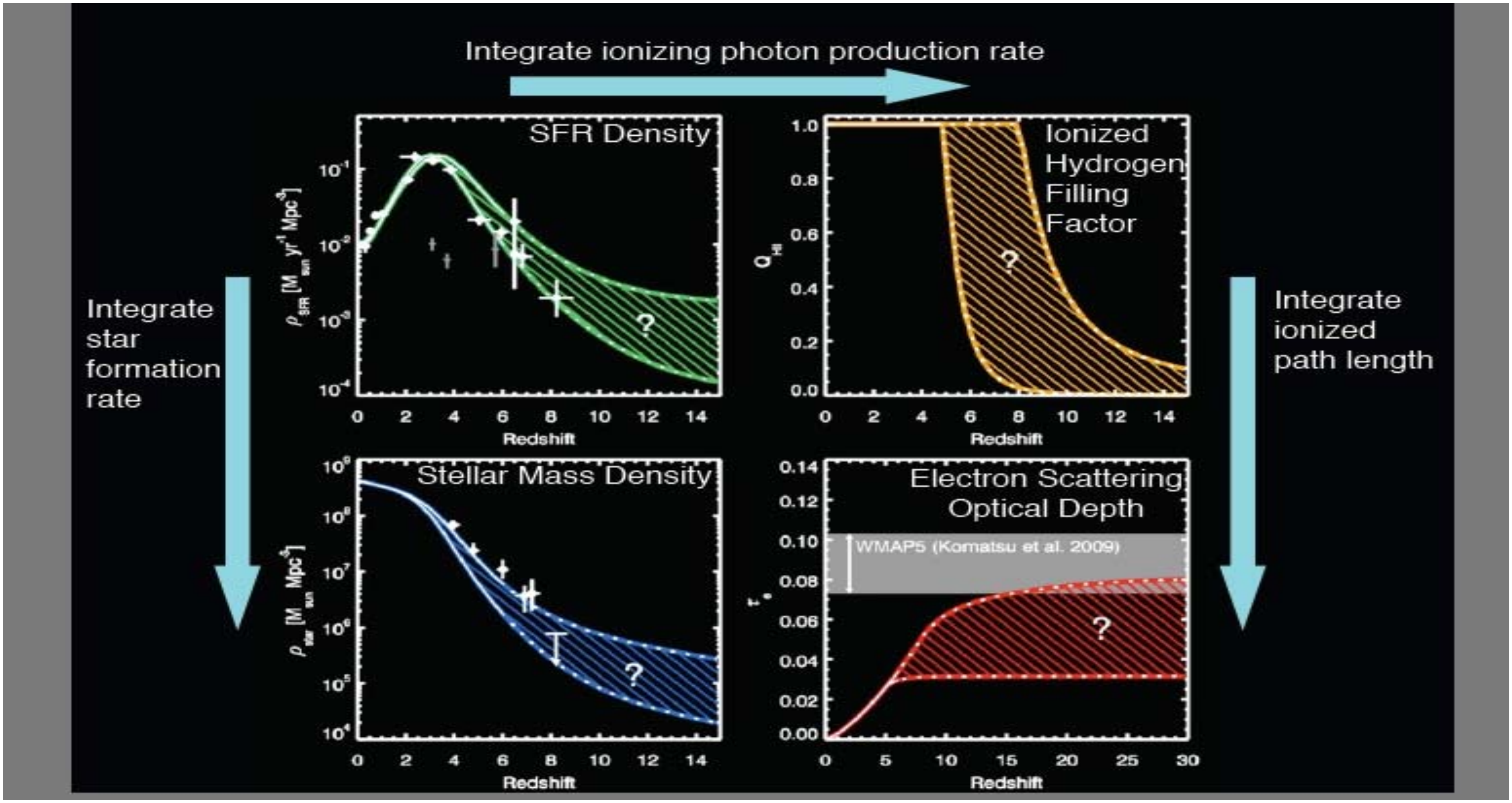


Star Formation and Mass Assembly in Galaxies at an Early Epoch

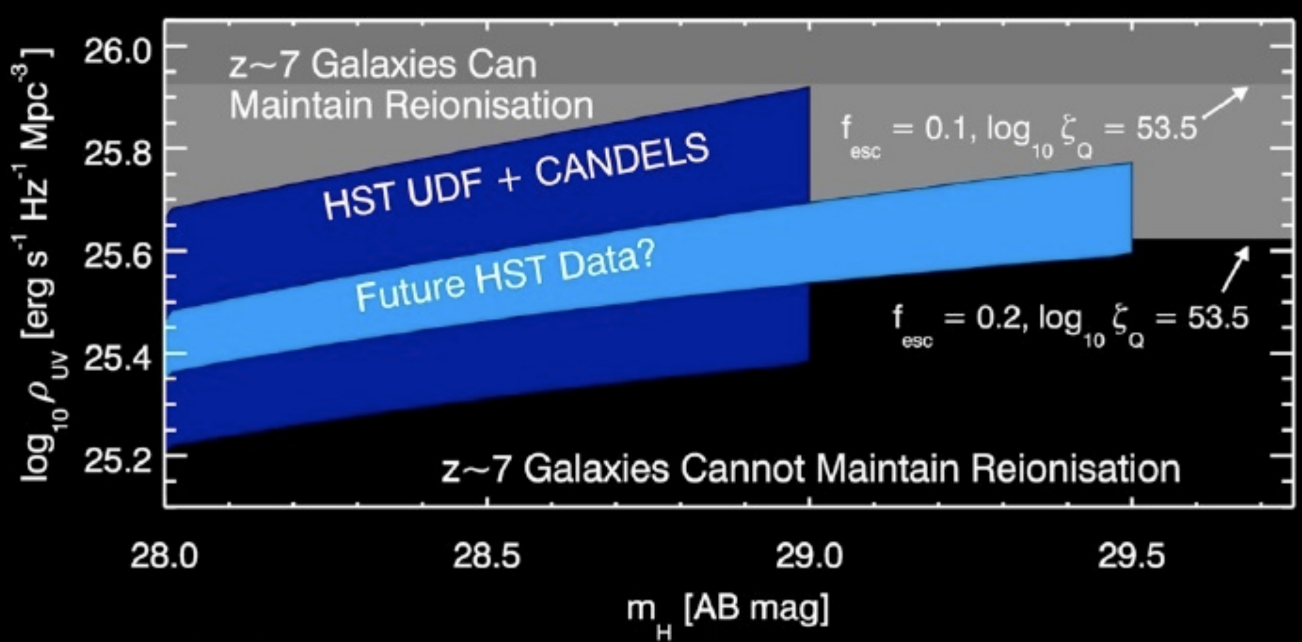
- How does the evolution of the SFRD with redshift behave at $z > 3$?
- How does the mass function of galaxies evolve to $z \sim 7$?
- What is the role of star forming galaxies in the re-ionization of the Universe ?
- How are the dynamical mass of merger galaxies at high-z compared ? This provides strong constraint on CDM models

These questions can be answered by high spatial resolution infrared spectroscopy with IRMS

Modern observational cosmology in ONE diagram
credit: B. Robertson (2011)



Did Star-Forming Galaxies Reionize the Universe?



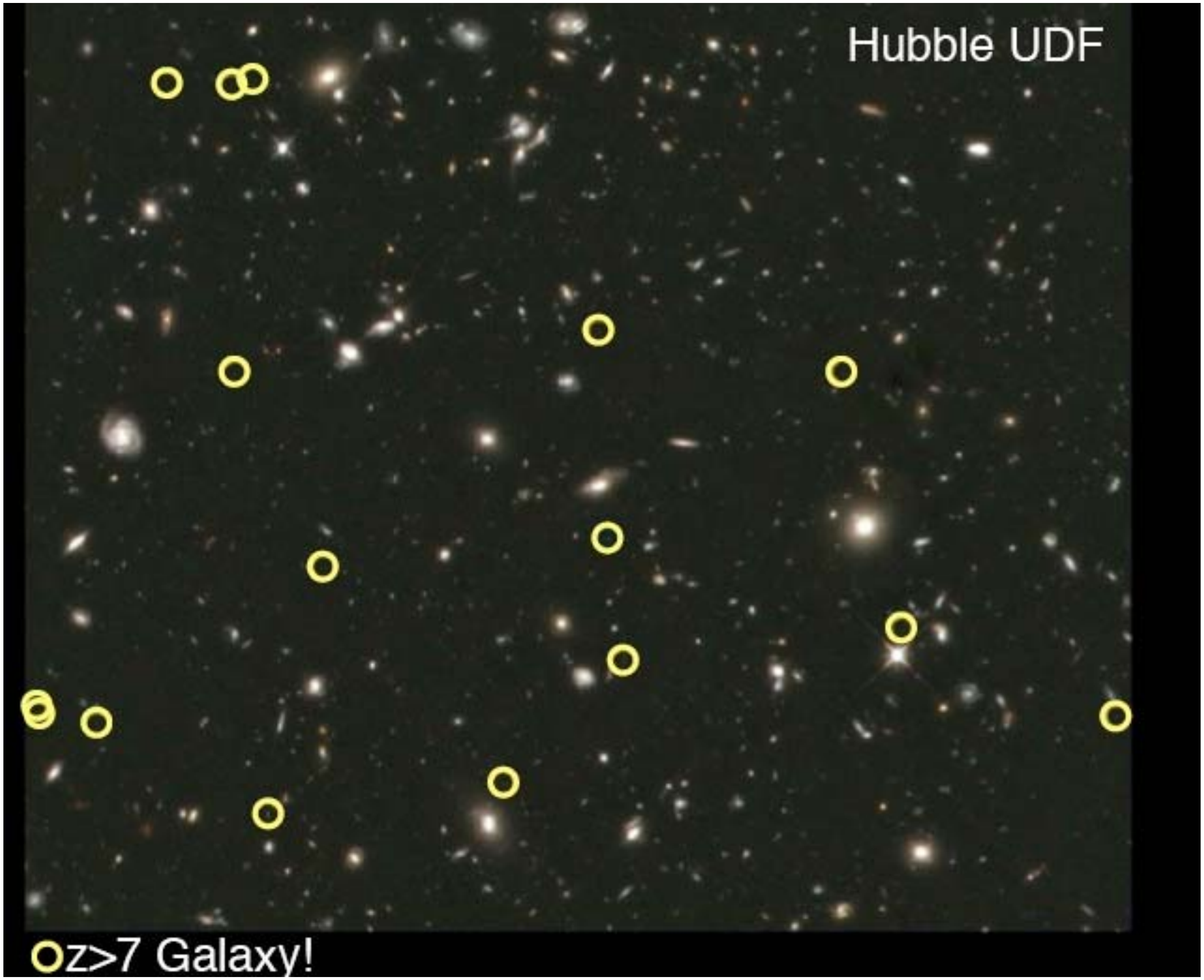
Likely, but future data are required.

Robertson et al., *Nature*, **468**, 49 (2010d)

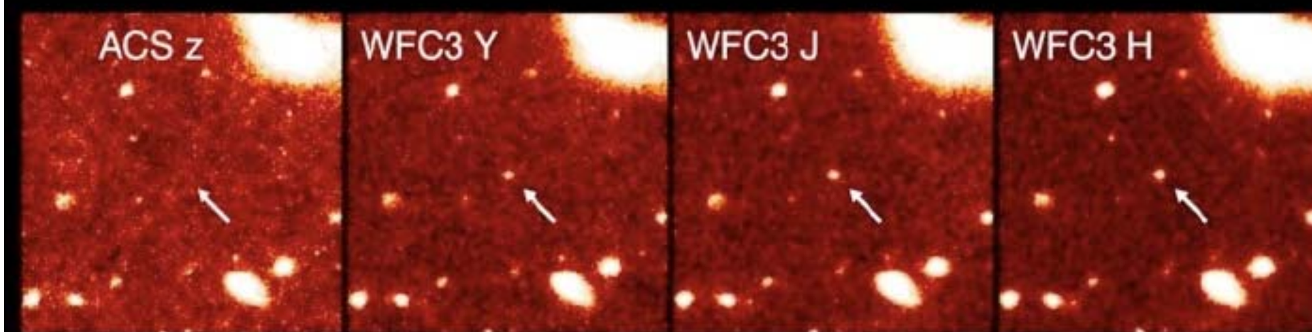
Search for the highest redshift galaxies

"It is not good enough to just want something. We need to ask what we are going to do with it once we get it"

F. D. Roosevelt


Hubble UDF
z>7 Galaxy!

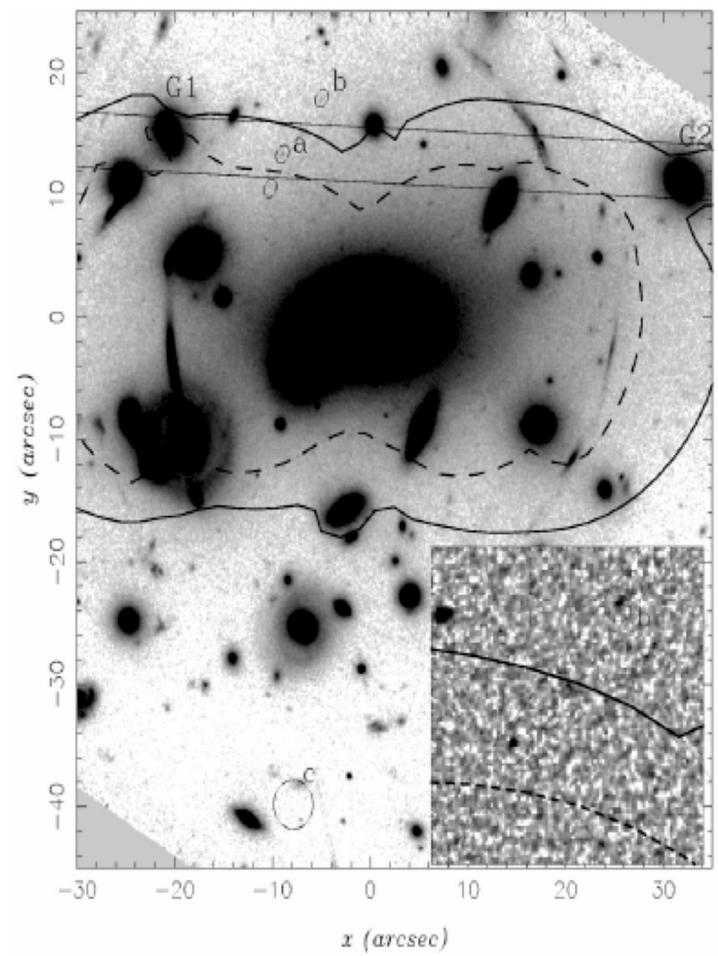
Dropout Galaxies at z~7



~0.9 microns ~1.0 microns ~1.2 microns ~1.6 microns

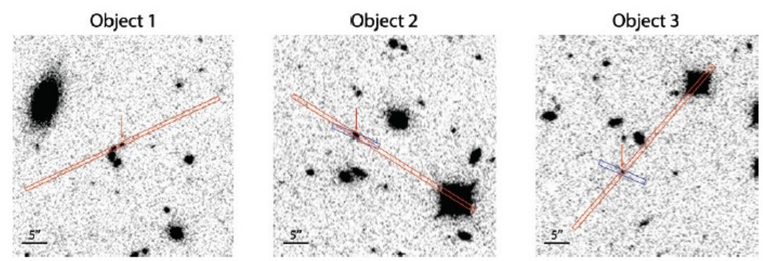
High-z galaxy candidates

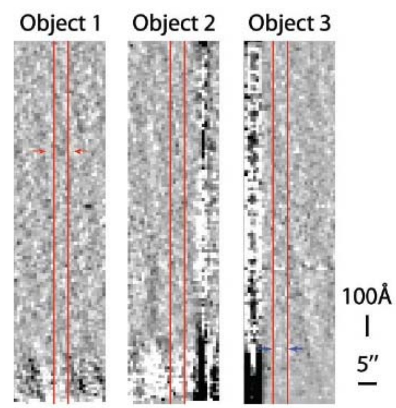
- Search for high-z galaxies by near-IR spectroscopy of galaxies in the field of gravitationally lensed clusters (Ellis & collaborators)
- The combination of the TMT and IRMS allows spectroscopy of many of the candidates simultaneously, providing a very efficient way for identifying high-z galaxies



Near-IR Spectroscopy of z~7 Candidates

- Keck/NIRSpec (red) and DEIMOS (blue) slits aligned on z-band dropout candidates.
- NIRSPEC spectra covering the range: 0.9412-1.1097 micron. If the feature detected in object 1 is Lya, it puts the target at z~7.69.
- No conclusive redshifts obtained after hours of spectroscopy with DEIMOS and NIRSPEC (Capak et al 2011).





Simulated Spectrum of a LAE at z=4.45, as seen by TMT/IRMS at z~10

Simulated spectrum of a LAE observed at z=4.45, as seen by TMT+IRMS at z=10

Slit = 1” airmass=1.2 seeing=0.55”

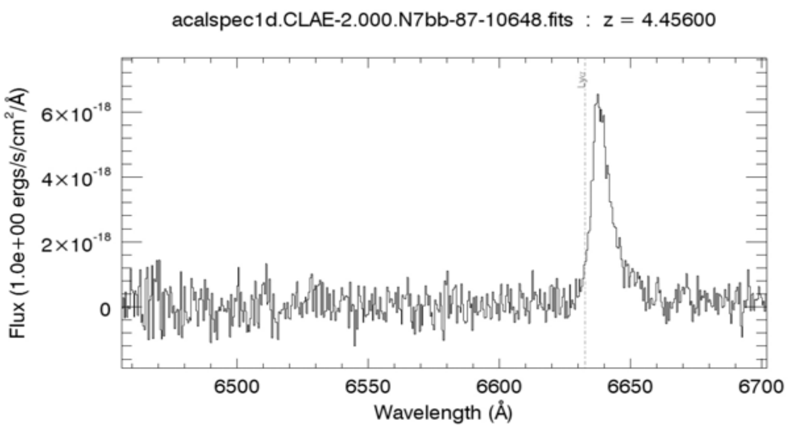
Source radius=0.2”

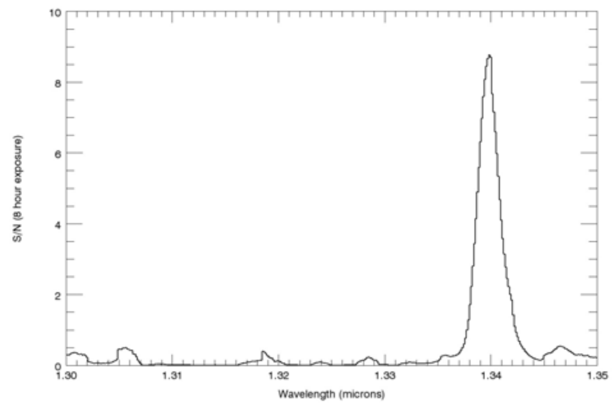
Sky background limited

MOSFIRE throughput

No extinction

8 hours of exposure on TMT



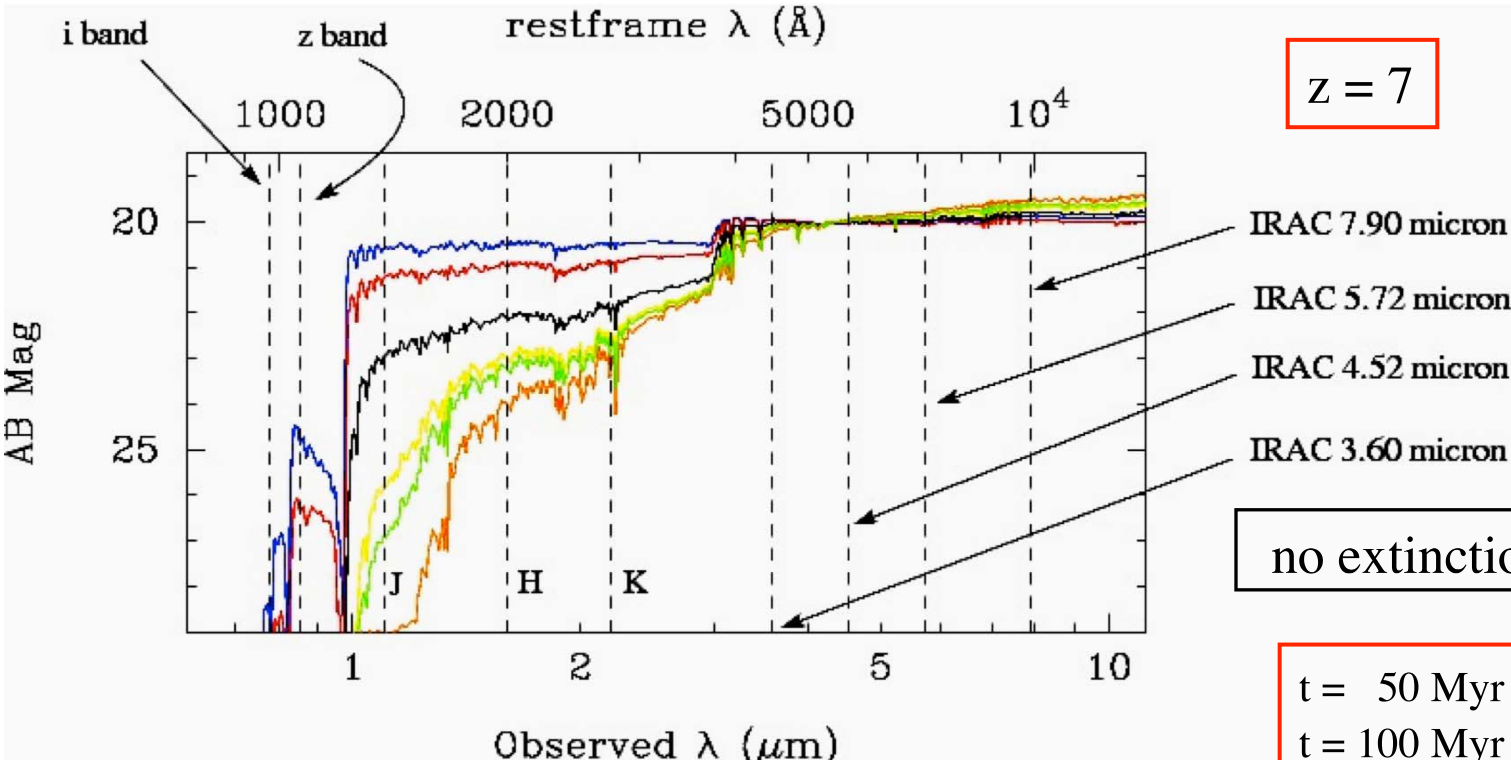


Search for a Population of Evolved, Massive Galaxies at high-z

- the galaxies are selected by identifying the Balmer Break features in the near-infrared bands.
- the space density of this population strongly constrains CDM models for formation of galaxies
- due to absence of emission lines from these galaxies, it is hard to measure their spectroscopic redshifts
- we need TMT with a near-ir spectrograph to estimate their redshifts and look for satellites by targeting random fields around them, using the multiplexing feature of the IRMS

Use near– and mid–IR to select high redshift and evolved galaxies?

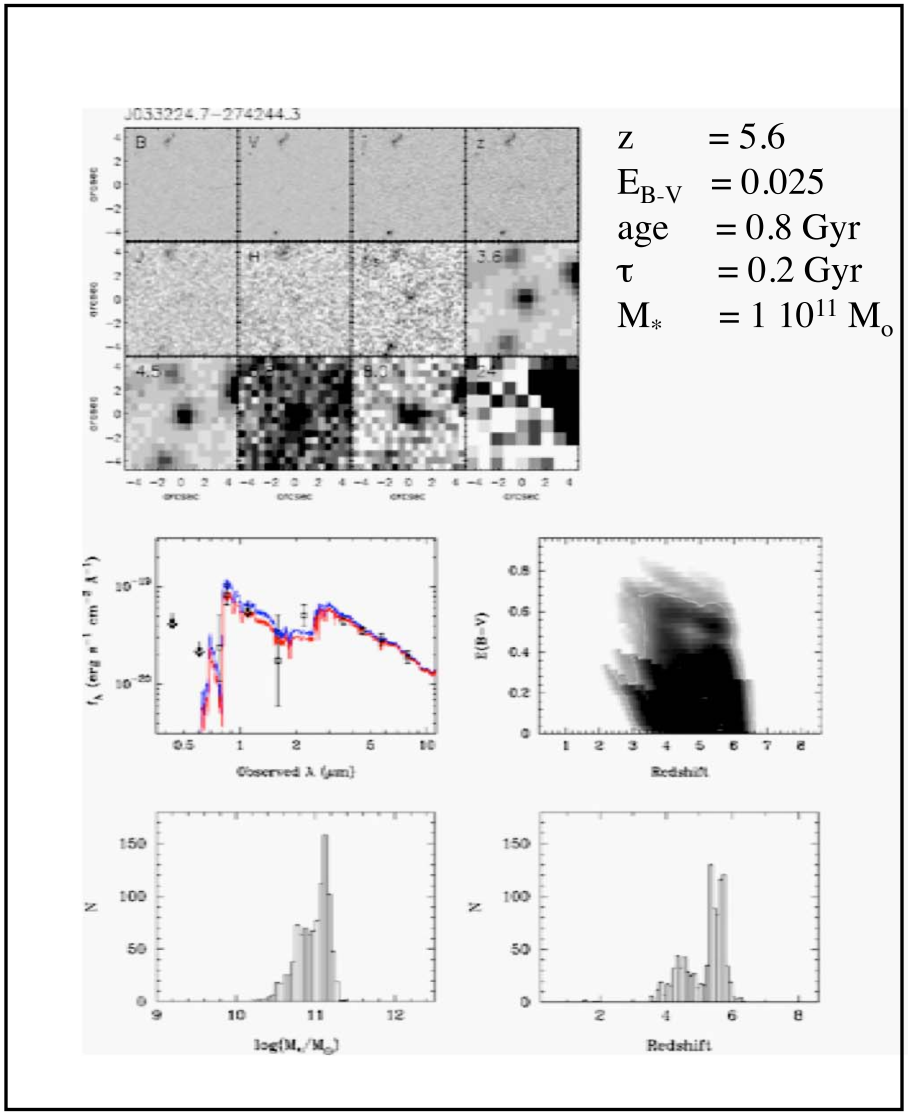
The Balmer break is a prominent feature for stellar populations age t > 100 Myrs

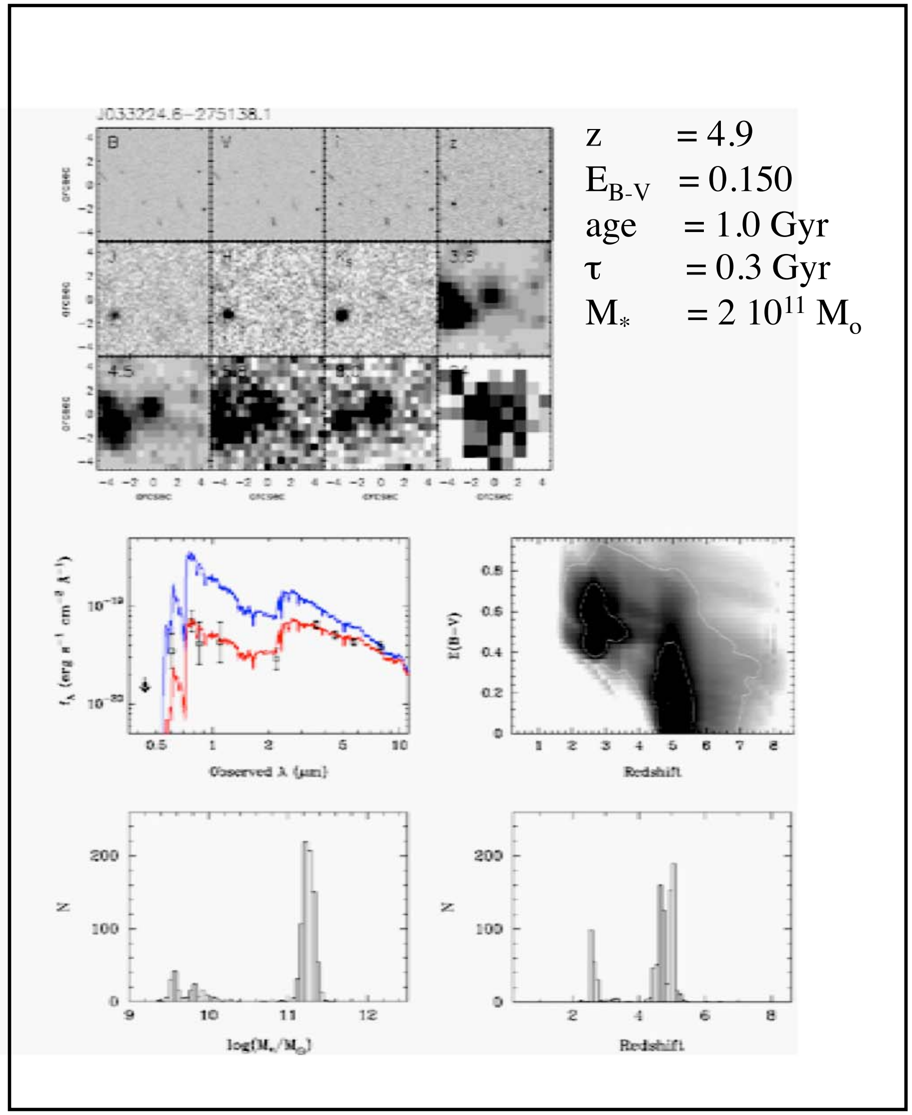


z = 7

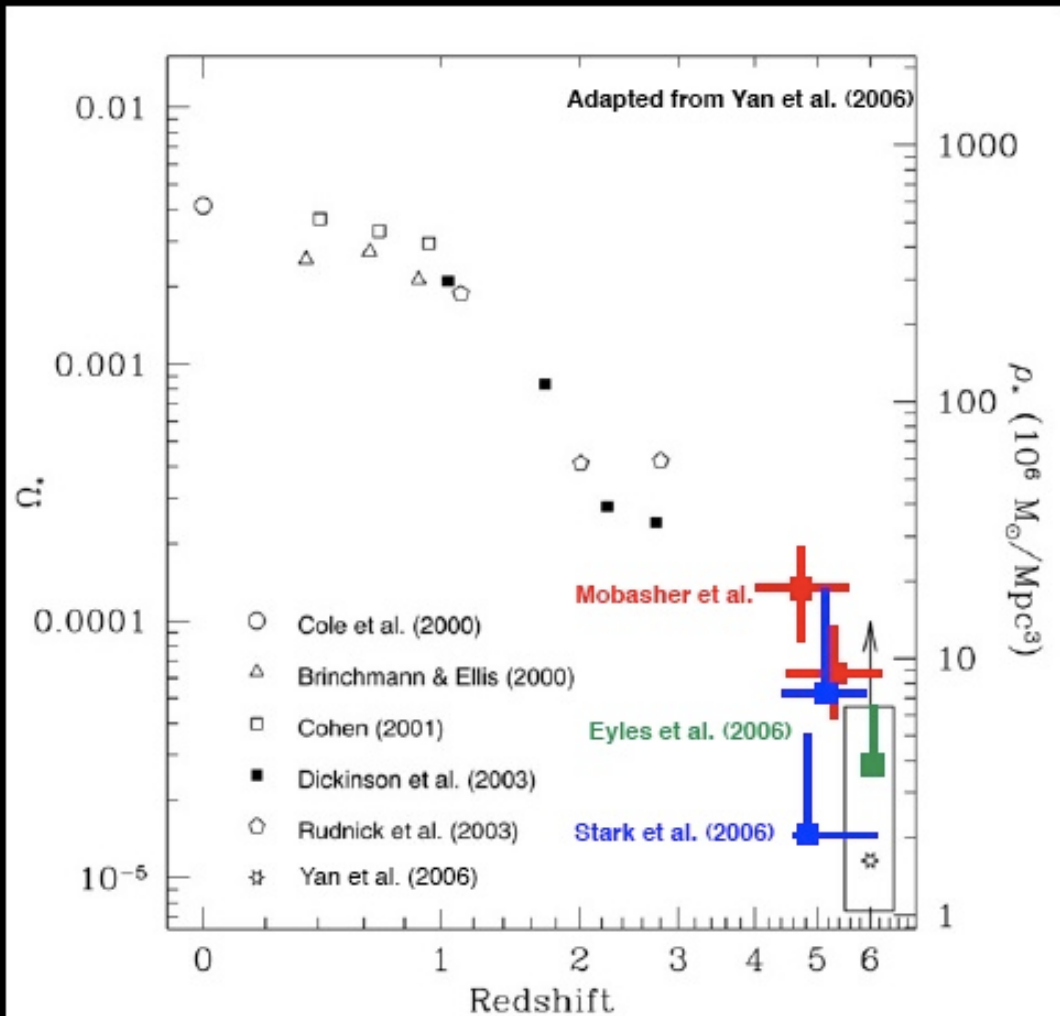
no extinction

t = 50 Myr
t = 100 Myr
t = 300 Myr
t = 500 Myr
t = 600 Myr
t = 800 Myr


J033224.7-274244.3
$z = 5.6$
$E_{B-V} = 0.025$
age = 0.8 Gyr
$\tau = 0.2$ Gyr
$M_* = 1\ 10^{11}\ M_o$
Observed λ (μm)
Redshift
$\log(M_*/M_\odot)$


J033224.6-275138.1
$z = 4.9$
$E_{B-V} = 0.150$
age = 1.0 Gyr
$\tau = 0.3$ Gyr
$M_* = 2\ 10^{11}\ M_o$
Observed λ (μm)
Redshift
$\log(M_*/M_\odot)$

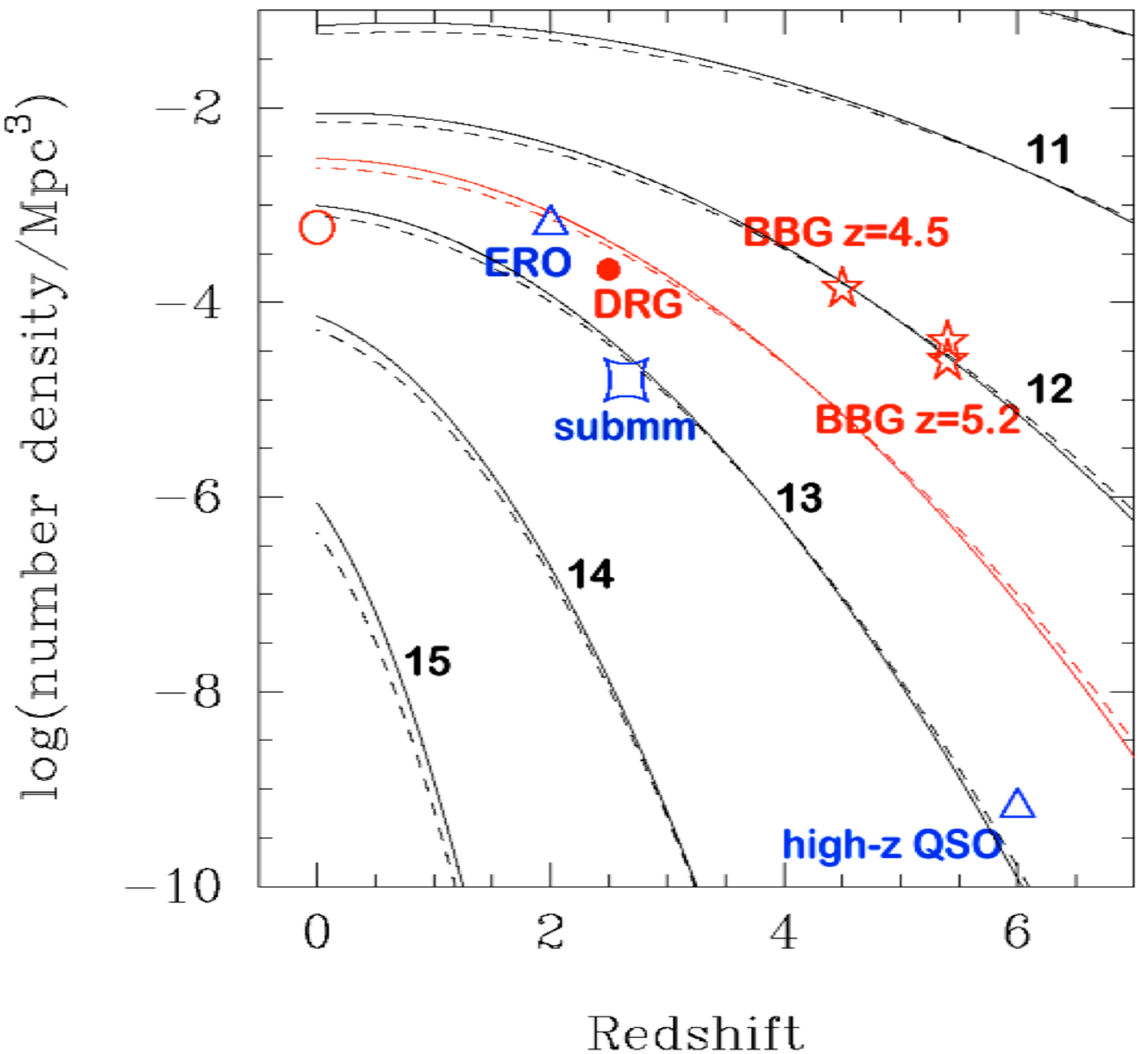
Evolution of High-z Stellar Mass Density



Spitzer IRAC detections of rest-frame optical breaks nominally indicate substantial stellar masses in z~5-6 galaxies.

Important constraint on the integrated star formation history of the universe / galaxy formation in general.

Reference:
Bahram Mobasher



log(number density/Mpc^3)
Redshift
−2
−4
−6
−8
−10
0
2
4
6
11
12
13
14
15
BBG z=4.5
BBG z=5.2
ERO
DRG
submm
high-z QSO

The First Galaxies

• primordial (population III) stars are expected to be at z~7-20 (Ciardi et al 2006). Confirming the presence of such stars and studying the redshift distribution of their host galaxies provides strong constrains on galaxy formation scenarios.

• population III stars produce a radiation field which would ionize primordial Helium gas. Therefore, presence of HeII1640 reveals the existence of such population.

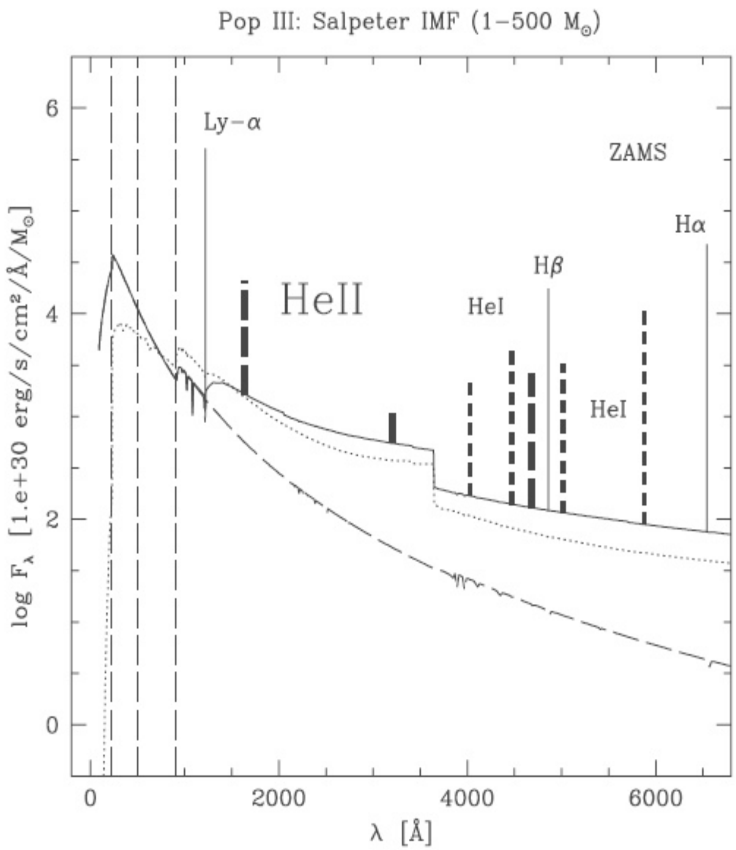
• HeII 1640 has 10% of the strength of Lya lines

• Since HeII lines are short-lived (a few Myrs), a number of such systems have to be studied.

TMT/IRMS can detect HeII 1640 lines out to z~13, due to its high spectral resolution and multiplexing capability of IRMS

Model SED of a population III star

- Model spectrum of a pop III star (the first luminous objects formed in the Universe). The prominent HeII 1640 feature is shown (Schaerer 2002). Dashed line is pure stellar continuum emission
- The simulation shows that the presence of HeII, which lives for ~2 Myr is a valuable tracer of metal poor stellar population

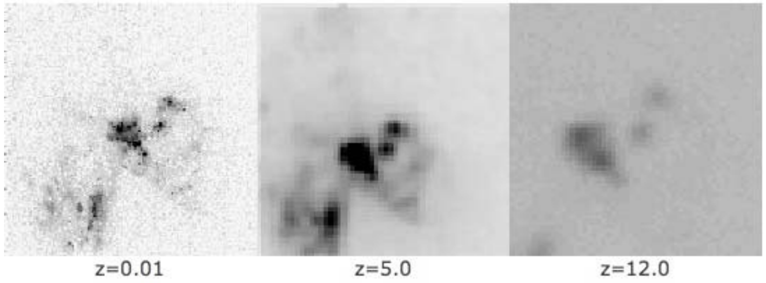


Star-forming Bubbles at z~10

- the strongest line produced in star-forming regions at very high redshifts is Lya, produced through resonant transitions by scattered radiation by neutral Hydrogen. The strength of these lines depends on the extent of the local ionizing bubbles.
- the sensitivity and multiplexing capability of IRMS allows study of these ionized bubbles, clustered at these redshifts and located by JWST or 21 cm surveys. The bubbles have a size of < 2 arcmin at z~10, well-matched to the IRMS FoV.

Spectroscopic follow-up of JWST sources

- simulated images of merger galaxies as seen by JWST
- the combination of TMT +IRMS allows measurement of dynamical mass of merger components
- This significantly constrains simulations of merger galaxies and scenarios for formation of massive galaxies at high-z



TMT/IRMS vs. JWST

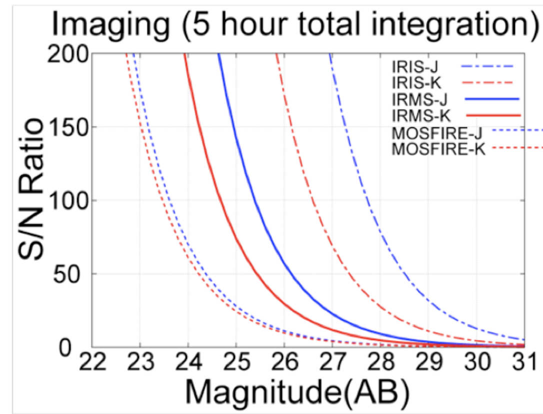
- TMT/IRMS and JWST are complementary
- JWST provides a reduced background and is more sensitive to galaxies at z~20 while TMT/IRMS with AO has better sensitivity to physically small and faint objects
- Early galaxies at z>5 are expected to have angular sizes about ~50 mas, with some star-forming regions having sizes as small as ~30 mas. These sources can be efficiently observed with TMT/IRMS

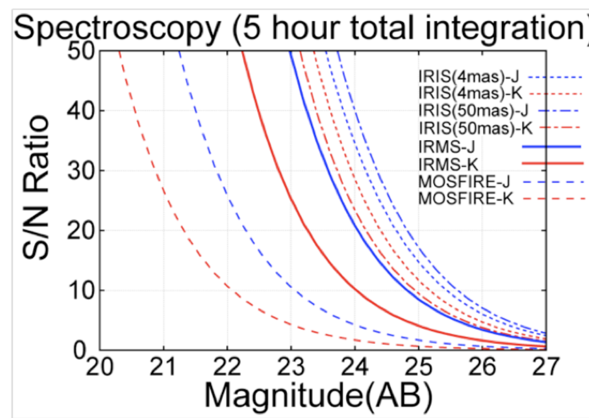
Challenges in Designing TMT/IRMS Observations

- what is the number density of interesting sources at $5<z<7$?
- We are still limited by sky emission and bright sky background at near-IR wavelengths- integrated sky background in the 1-2.5 micron is 250-1500 times brighter than that in the optical
- the full 2.3 arcmin diameter of the IRMS allows observations of faint galaxies using 200 mas slits, providing a gain in sensitivity over a factor of 50 over the existing NIR spectrographs on 8-10m class telescopes

IRMS Sensitivity

IRMS sensitivity in imaging and spectroscopic modes, compared to MOSFIRE (on Keck) and IRIS (on TMT) assuming 5 hours of exposure.





As is has been the case in the past, the most interesting and important discoveries may be the ones we may not even think about right now