An Infra-Red Multi-object Spectrograph (IRMS) with Adaptive Optics on the TMT: The Science Case

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Abstract

It has been recognized that a Near-Infrared Multi-object Spectrograph (IRMS) as one of the first light instrument on the Thirty Meter Telescope (TMT) would significantly increase the scientific capability of the observatory. The IRMS is planned to be a clone of the MOSFIRE instrument on the Keck telescope. As a result, we use the already available MOSFIRE design and expertise, significantly reducing the total cost and its development time. The IRMS will be a quasi diffraction limited multi-slit spectrograph with moderate resolution (R~4000), fed by Narrow-Field Infrared Adaptive Optics System (NFIRAOS). It images over the 2 arcmin diameter field of view of the NFIRAOS.

There are a number of exceedingly important scientific questions, waiting to be addressed by the TMT/IRMS combination. Given its relatively small field of view, it is less affected by the sky background, which is a limiting factor in ground-based observations at near-IR wavelengths. The IRMS is the ideal instrument for studying spectroscopic properties of galaxies at the re-ionization epoch ($z > 7$), where the Lyman alpha line shifts to the near-ir wavelenghths. It can be used to measure rotation curves of spiral and velocity dispersion of elliptical galaxies at $z \sim 2\text{-}3$ and hence, their spectroscopic mass. It can be used to search for population III stars via their spectroscopic signature and to perform measurement of spectroscopic lines at high redshifts, diagnostic of metallicity. Finally, IRMS allows measurement of the blue shifts in the rest-frame MgII line for high redshift galaxies, used to study the winds, leading to the feedback mechanism, responsible for quenching star formation activity in galaxies.

Introduction

Infra-Red Multi-object Spectrograph (IRMS) has been selected as one of the first light instruments on the Thirty Meter Telescope (TMT). The IRMS is the exact clone of the Multi-Object Spectrometer for Infra-Red Exploration (MOSFIRE), to be commissioned on the Keck telescope in 2011. This is expected to minimize the cost, risk and the commission timeline of the instrument. The IRMS will be placed behind a Narrow-Field Infrared Adaptive Optics System (NFIRAOS) on TMT, which will provide much sharper images with higher sensitivity, albeit over a smaller, 2 arcmin diameter, circular Field-of-View (FoV).

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We present a preliminary study of the science possible with the IRMS+NFIRAOS on the TMT. The scientific capability of the IRMS is fixed by a combination of its multiplexing capability, field-of-view and the TMT aperture. The IRMS science team has now been formed to explore scientific abilities of this instrument. The science team will provide advise to the instrument team regarding the design and planning of the IRMS.

IRMS Characteristics

IRMS will provide Near-infrared imaging and multi-object spectroscopy at Y(0.97-1.12 micron); J(1.15-1.35 micron); H(1.46-1.81 micron) and K(1.93-2.45 micron) bands.It will be placed behind the NFIRAOS on the TMT, with the IRMS+NFIRAOS combination shown in Figure 1. It can be used as a diffraction limited imager and multi-slit spectrograph with moderate resolution (R~4000). It has a circular FoV of 2 arcmin (in imaging mode) and elliptical FoV of 2.0'x0.6' (in spectroscopy mode). IRMS has a multiplex capability of up to 46 slits using a slit mask system on a cryogenic configurable slit unit (CSU), with each slit width adjusted arbitrarily. The IRMS detector will be 2048x2048 Teledyne Technologies Hawaii-2RG with a long wavelength cut-off at 2.5 micron.

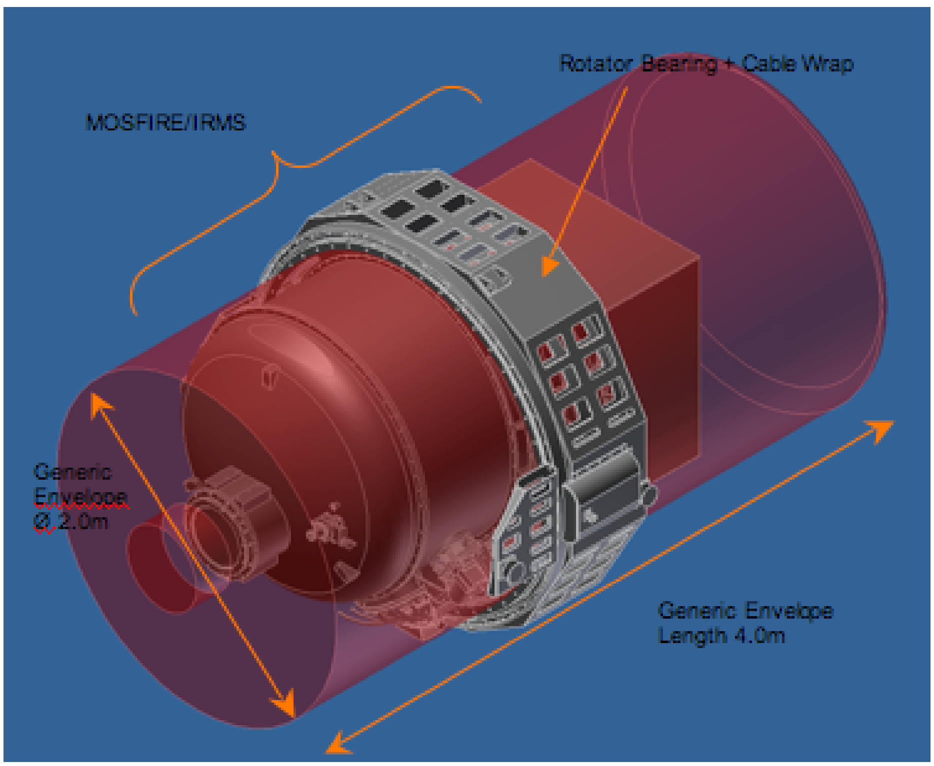

Figure 1. MOSFIRE/IRMS with generic NFIRAOS instrument envelop superimposed in red.

The IRMS optics is so that the image of the pupil (primary mirror of TMT) lie half-way between the last optical element within the collimator lens group and filter. The power of the field lens will be reduced to force the pupil image to coincide with the same location as in the Keck Telescope and to optimize its shape and location to give maximum performance. This leads to a plano-convex element and a longitudinal displacement of the entire assembly from the NAFIRAOS focal plane.

Science with IRMS

The combination of the IRMS on the TMT provides unique opportunity to address fundamental scientific questions. Given the relatively small field of view and the adaptive optics capability (which provides sharper images), it is less affected by sky background, a limiting factor in ground-based observations at near-infrared wavebands. Examples of some of the scientific projects with IRMS are listed below.

Follow-up Spectroscopy of Sources Detected by the James Webb Space Telescope (JWST)

JWST will discover candidates at high redshifts, some with Lyman Alpha extensions. Figure 2 shows the simulated image of a galaxy system similar to U6471/U6472, shifted to z=12, as expected to be seen at 3.8 micron by JWST. Follow-up observations of such systems with IRMS provides spectral diagnostics for estimating the star formation rate and metallicities of the faint galaxies (some mergers) detected by JWST. Using these data, one could study metal enrichment and start formation activity in galaxies at high redshifts and to explore the effect of galaxy mergers/interaction on formation of the earliest galaxies. If the system is undergoing mergers/interaction, this allows measurement of the mass of the pre-merged galaxies and their evolution with look-back time.

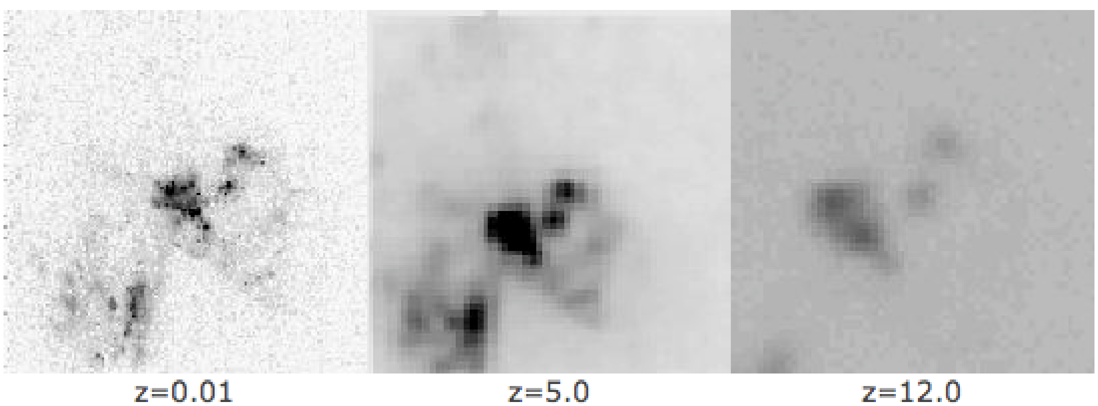

Figure 2. Left: real WFC2 image showing mergers of U6471 and U6472 at *z=0.01*. Middle: simulated image showing how this system would look like with JWST at 1.76 micron at z=5.0. Right: simulated JWST image of the galaxy at 3.81 micron at *z=12.0*

Search for high-z galaxies behind rich clusters

One way to search for the faint population of high-z galaxies at z~9-10, is to use gravitational lensing technique, leading to magnification of their light caused by rich clusters in their field of view. Blind searches have been performed with NIRSPEC on the Keck Telescopes, finding a few high redshift candidates (Stark et al 2007- Figure 3). However this technique, using single slit spectroscopy, is very slow and is shown to be inefficient. IRMS provides a significantly more efficient way to carry out this search, given its higher sensitivity, lower contamination by sky background, high resolution and multiplexing capability.

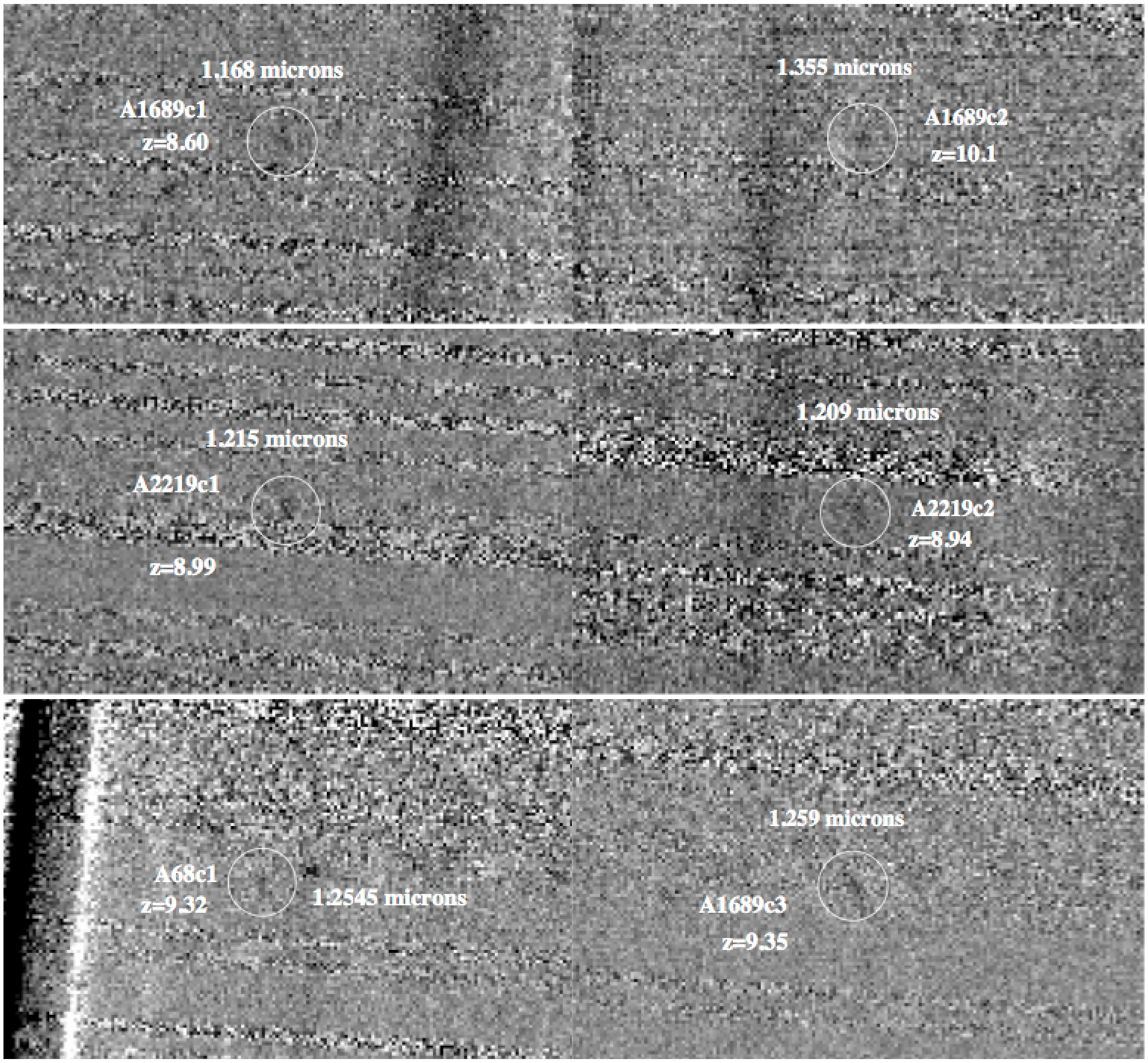

Figure 3. Examples of Keck/NIRSPEC infrared spectra of Lyman Alpha emitting candidates at $8 < z < 10$ in the field of gravitationally lensed clusters. This is the best one could do with single-slit spectrograph on the Keck. The faintness of the object and the blind search makes this method very inefficient in finding very high redshift candidates (Stark et al 2007)

Evolution of the Star Formation and Metallicity with Cosmic Time

Study of the Mass-Metallicity and Luminosity-Metallicity relation has only been done to *z~3* (Erb et al 2006)-(Fig 4). To extend this to galaxy formation epochs at *z~5-6* and to fainter galaxies, we need near-infrared spectroscopy at much deeper levels. Furthermore, study of the environmental dependence of these relations needs spectroscopy in dense environments. The IRMS on TMT is essential for these aims.

By performing Halpha spectroscopy of galaxies at *z~2*, using near-IR spectrographs on Keck and Subaru telescopes, we have shown the feasibility of this technique in measuring the star formation rate at this redshift (Erb et al 2006). The combination of IRMS+NFIRAOS can be used to measure and resolve the doublet Ha+[NII] for fainter galaxies at z~2 and [OII] and Hbeta line intensities at higher redshifts and therefore, study the parameters responsible for star formation at z > 2 (mass, mergers) and to measure the evolution of metallicity with redshift.

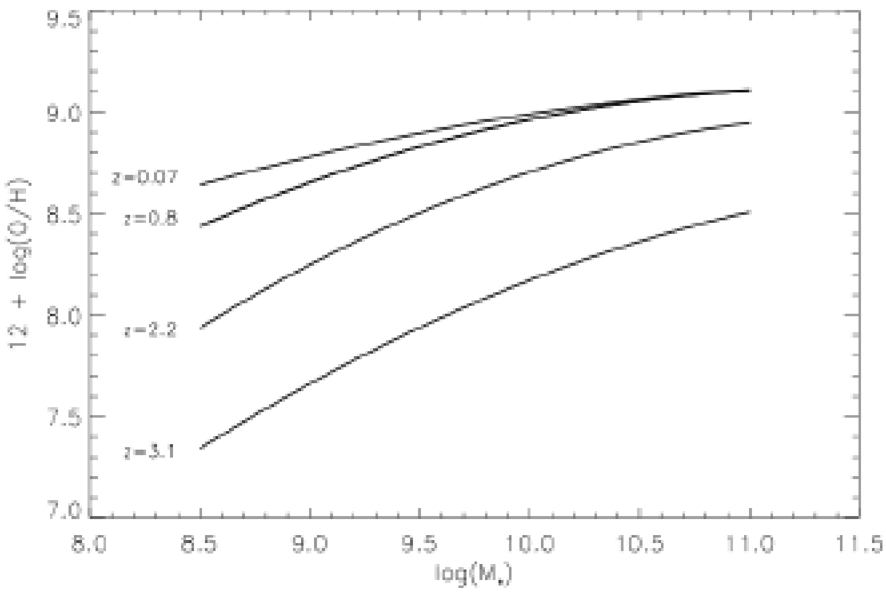

Figure 4. Mass-Metallicity relation at *z=0.07, 0.8, 2.2* and *3.1*. It is not clear at what cosmic epoch this relation was formed, as there is no evolution between *z=2.2* and *3.1*, however significant evolution at z < 0.8 (Zahid et al astro-ph 1006.4877).

Young Stellar Systems

A major goal of observational astronomy is to constrain the Initial Mass Function of star formation at epochs close to the stellar birth and to make comparisons between regions that differ in stellar density or cloud core conditions. Infrared spectroscopy could address these issues. At low masses the diagnostic features grow more rapidly for late-type objects with increasing spectral types in the near-infrared (H2O, CO, CaI) than they do in optical. These also provide valuable tools for understanding the dust/molecular opacity of the sources. Also, late-type stars and brown dwarfs are significantly brighter at near-IR wavelengths.

Galactic Nucleus

Study of the dynamics, age and abundance of stars in the center of galaxies (i.e. Milky Way, M31 and Magellanic clouds) provide information about formation and subsequent evolution of galaxies.

These provide estimates as when bulges of galaxies formed, about the radial velocity of stars and their metallicity. Given that most of these features are in the near-IR part of the spectrum, and high concentration of stars at the center of galaxies, the combination of the IRMS with adaptive optics on the TMT provides the ideal instrument to obtain data for a large number of stars simultaneously.

Gamma Ray Bursts at Very High Redshifts

GRBs are among the most energetic processes in the Universe. Recent discovery of a GRB in a galaxy at *z~8.26* (Fig 5), shows the importance of these sources in studying the Universe at the epoch of re-ionization. Studying and understanding the nature of the GRB host galaxies is essential in understanding physics of the GRBs and evolution of galaxies when the Universe was < 1 Gyr old. Multi-object spectroscopy with IRMS+NFIRAOS allows measurement of the metallicity of the most distant GRB host galaxies and if these are members of proto-clusters or result of galaxy interaction/mergers.

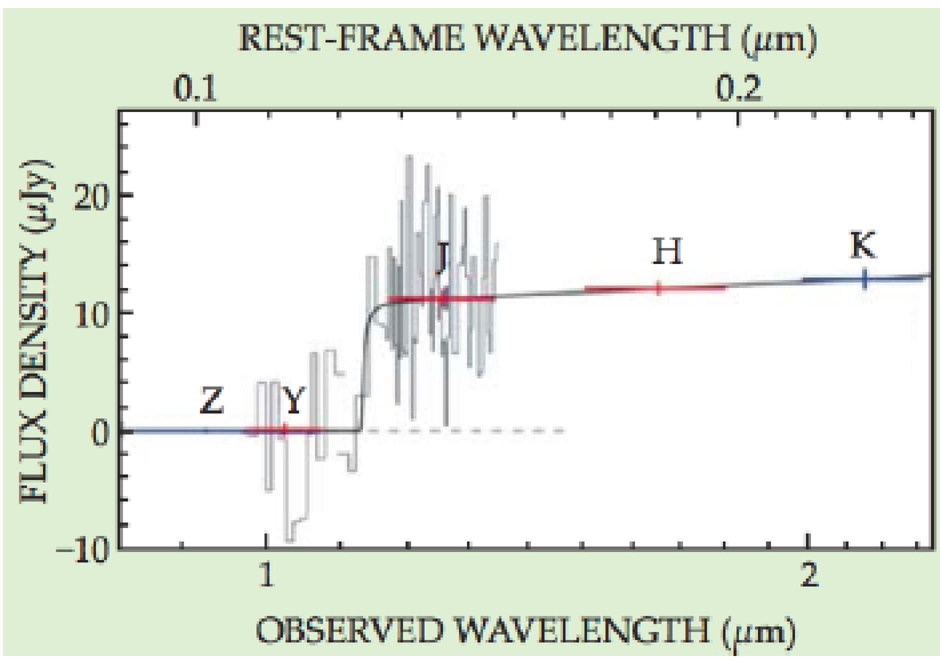

Figure 5. Near-IR spectrum of GRB090423 shows the high-z GRB. The noisy grey line shows the spectrum taken 17 hours after the discovery. Fitting the Lyman Alpha feature at the observed wavelength of 1.1 micron gives a redshift of z=8.26+/-0.08, making the GRB host galaxy as the highest redshift galaxy known today. Measurement of the spectral properties of such high redshift galaxies and their environment, using IRMS is essential in understanding evolution of early galaxies.

Dynamics of Galaxies

Measuring rotation curve of galaxies at $z > 3$ has been a challenge. This is needed to study dynamical mass of galaxies and put constrains on dark matter content and galaxy formation scenarios. At high redshifts, this can only be done by performing moderate to high resolution near-IR spectroscopy of galaxy candidates.

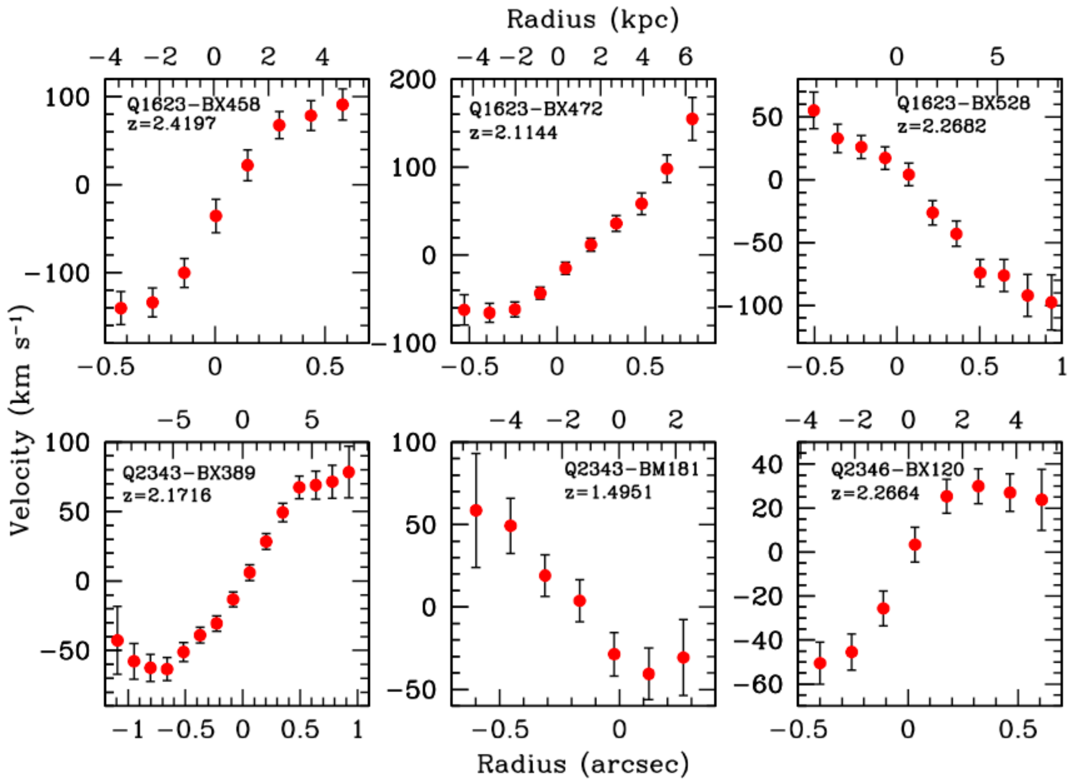

Figure 6. Rotation curve of galaxies at z~2. This is measured with single-slit near-IR spectrograph, NIRSPEC, on Keck. Taken with a seeing of 0.5 arcsec, we get four points per resolution element, with the points being highly correlated (Erb et al 2006, ApJ 646, 107).