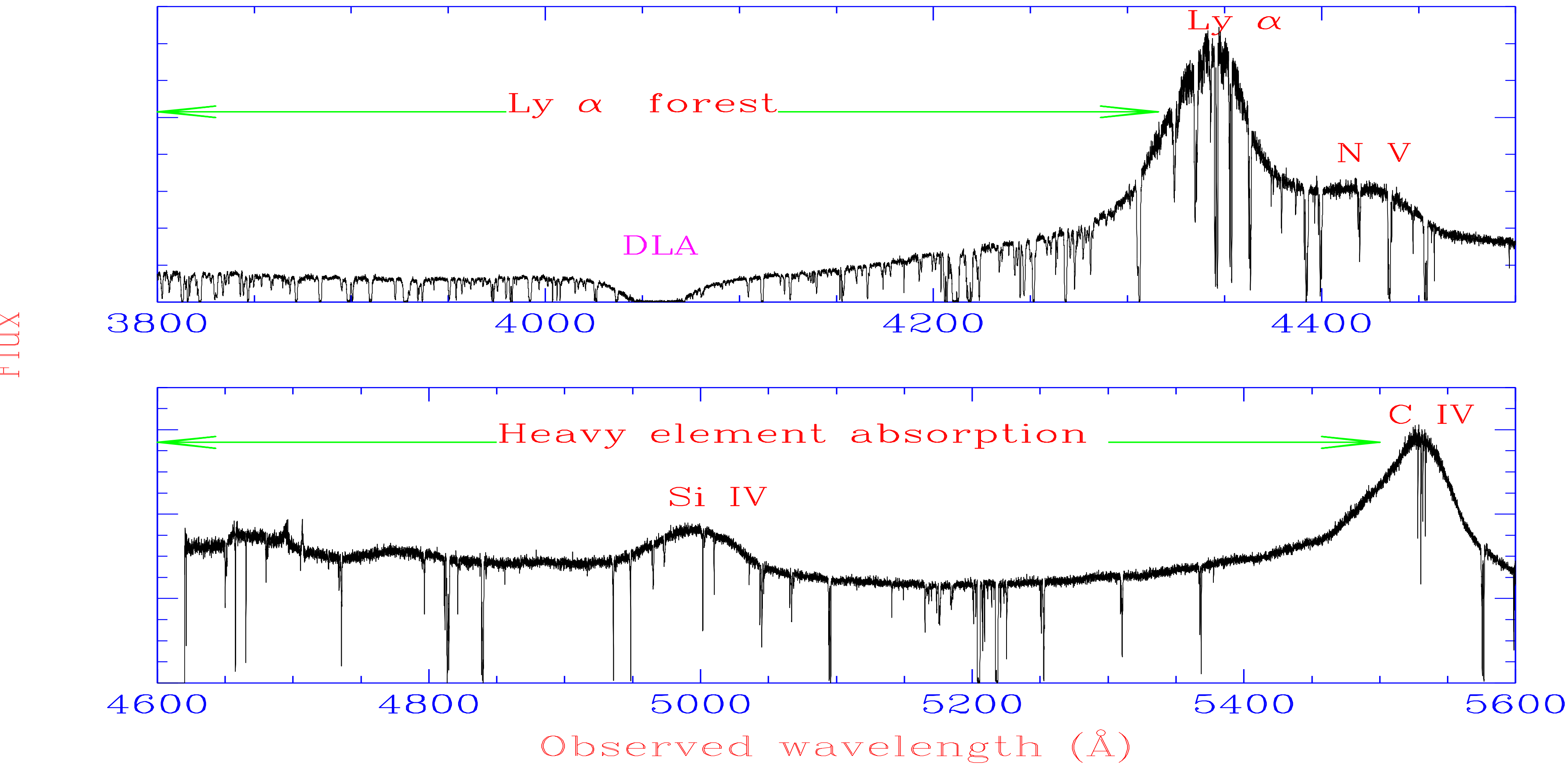
IGM studies in the TMT Era

TMT.OPS.PRE.15.006.REL01

R. Srianand, IUCAA, PUNE

QSO SPECTRUM: Absorption lines



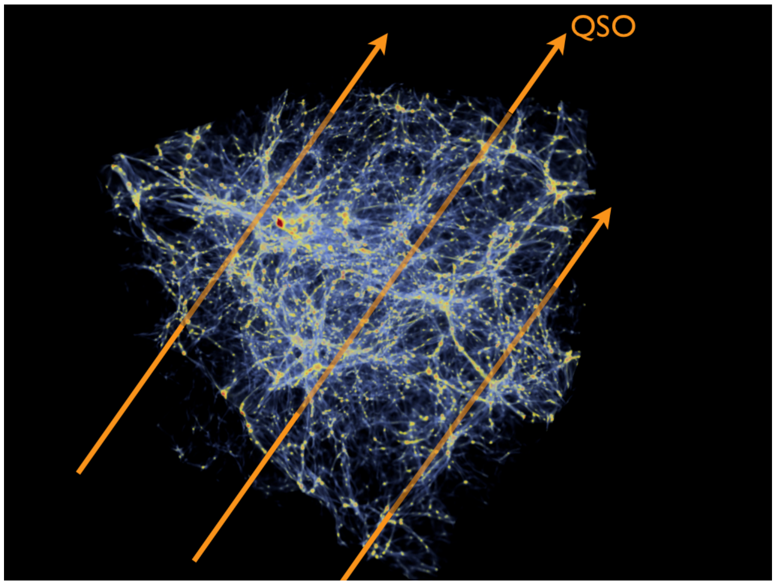
Outline

- Background cosmology & Fundamental Physics
  - Tomography of IGM & Baryonic power spectrum.
  - T_{CMBR} vs. z
  - Variation of fundamental constants
  - Cosmic expansion experiment

- Galaxy formation in early universe
  - Reionization (QSOs are important for He II)
  - Metal absorption lines and connection to Galaxies
  - ISM studies at high-z: dense molecular phase and Diffuse interstellar bands etc..

Bgr Cosmology & Fundamental Physics

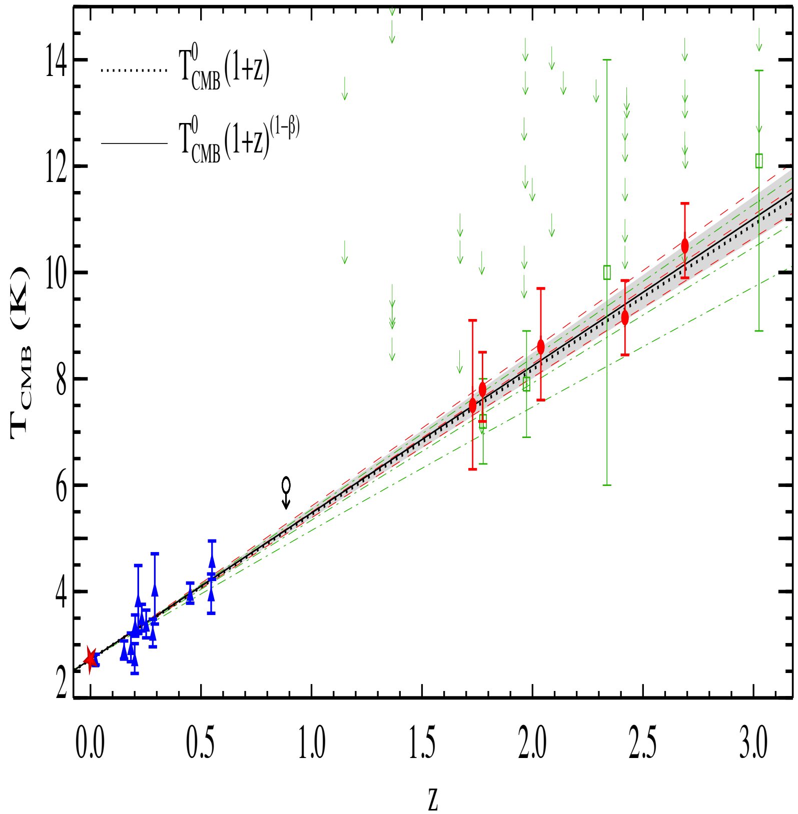
Tomography of IGM & Baryonic power spectrum



- Baryonic power-spectrum at small scales will allow one to probe the fraction of WDM and put constraints on low mass particle (e.g Viel 2006 et al.).
- Optical depth fluctuations of Ly-α absorption along the line of sight (McDonald et al 2005) to and in the transverse directions towards QSOs are useful.
- Scales in metal enriched regions and possible sizes of He II bubbles.
- Galaxies are the main targets to fill the smaller spatial scales.

Bgr Cosmology & Fundamental Physics

T(CMBR) vs. z



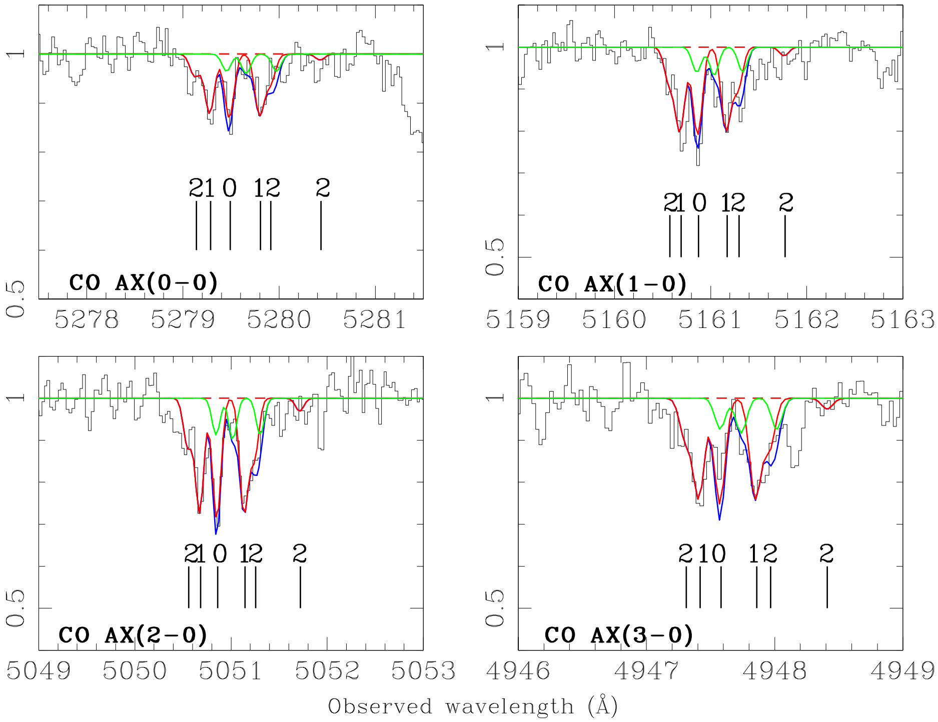
- $T_{CMB}(z) = (2.725 \pm 0.002) \times (1 + z)^{1-\beta}$ with $\beta = -0.007 \pm 0.027$.
- Following decaying dark energy models of Jetzer et al. 2010,

$$T_{CMB}(z) \quad = \quad T_{CMB}(z=0) \times (1+z)^{3\gamma-1} \left(\frac{(m-3\Omega_m) + x(1+z)^{m-3}(\Omega_m - 1)}{(m-3)\Omega_m}\right)$$

Where, $\gamma = 4/3$, $\Omega_m = 0.275 \pm 0.015$ and m=3($w_{eff} + 1$) with $w_{eff} = p/\rho$. The best fitted value is $w_{eff} = -0.996 \pm 0.025$.

Noterdaeme et al. 2011, A&AL, 526, L7

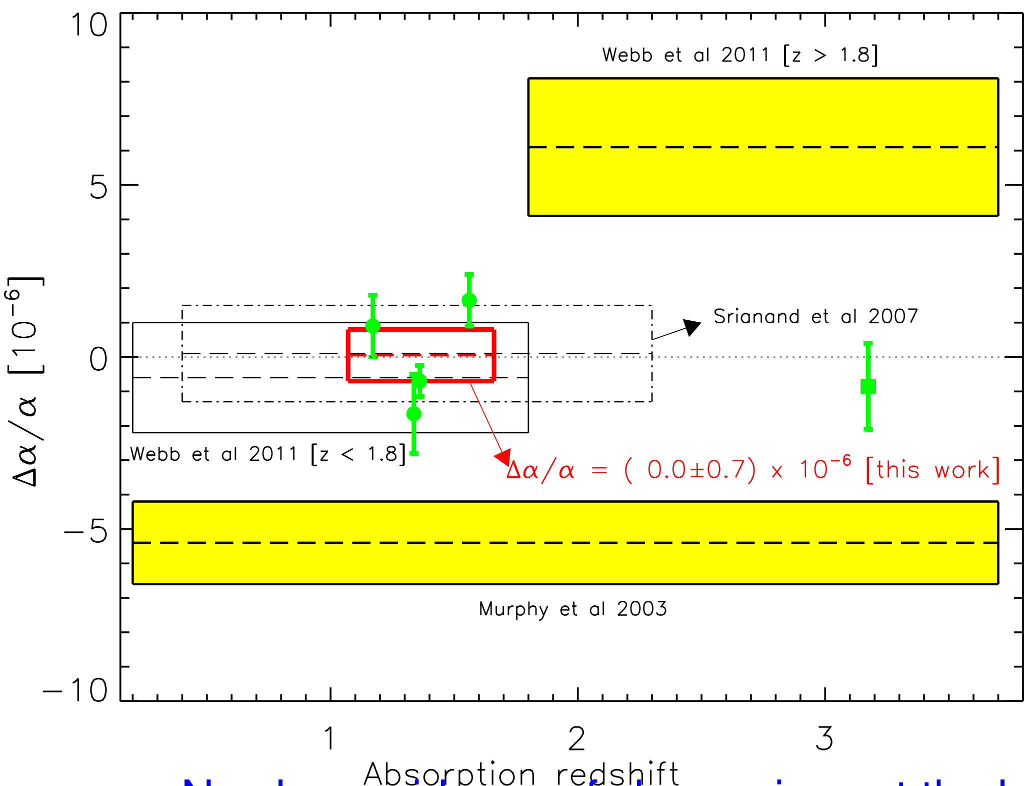
T(CMBR) with TMT:



1. High resolution and SNR observations are essential to unambiguously resolve the CO lines. Detect CO from high-J excitations to understand other excitation processes at play.
2. At $z > 6$ the T(CMBR) is very close to the excitation energy of C I first excited fine-structure state.
3. C I, O I and C II are expected to be more frequently detected at $z > 6$.
4. Detecting other molecules from diffuse ISM will be more useful.

Bgr Cosmology & Fundamental Physics

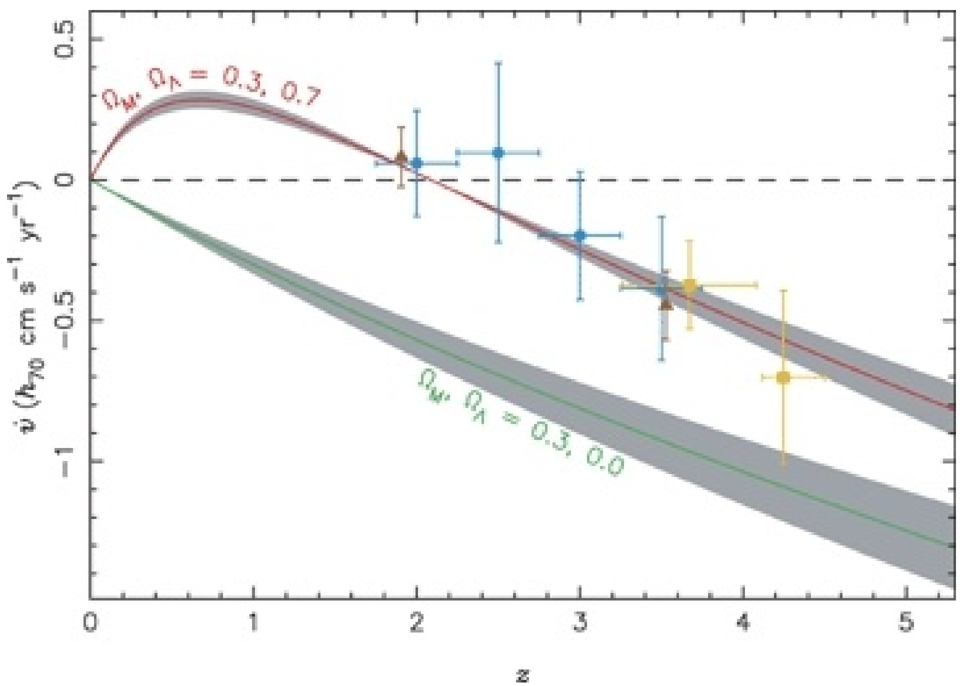
Variation of fundamental constants



ESO large programme: No clear evidence of change in α at the level of 1ppm, most past results are affected by systematics related to the spectrograph's stability.

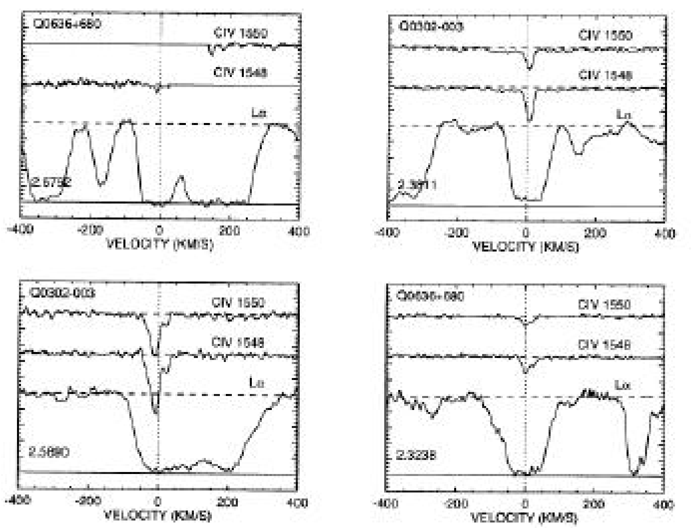
Bgr Cosmology & Fundamental Physics

Redshift drift experiment



- Monte-Carlo simulations of three different implementations of a redshift drift experiment. Plotted are values and errors of the "measured" velocity drift (vertical axis), expected for a total experiment duration of 20 yr, a total integration time of 4000 h and for standard cosmological parameters h_{70} = 1, Ω_M = 0.3, and $\Omega_\Lambda = 0.7$. The solid lines show the expected redshift drift for different parameters as indicated, and h_{70} = 1. The grey shaded areas result from varying H_0 by $\pm$8 km/Mpc. (Liske et al. 2008, MNRAS, 386, 1193)

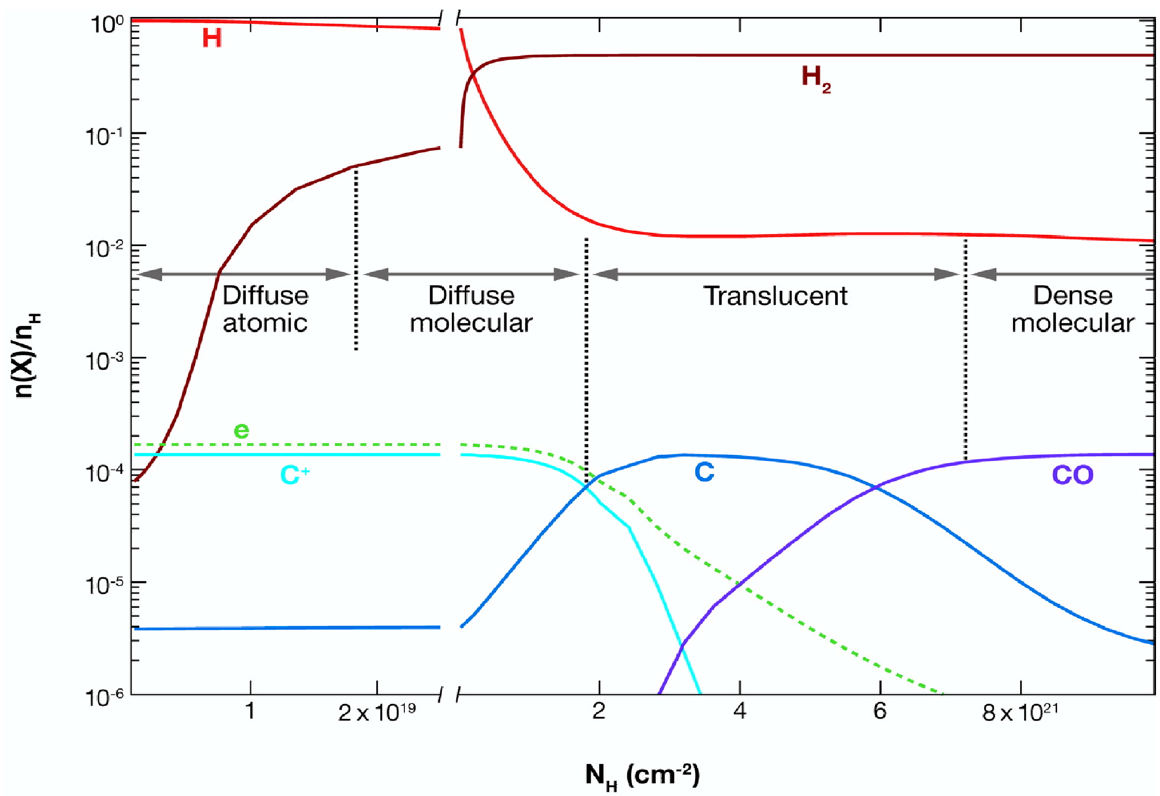
Galaxy formation & Evolution



Songaila et al 1995

- Is there a Jean's scale in the IGM
- Probing thermal evolution in IGM and QSO near zones.
- Measuring the metallicity of the low density IGM - Is there any metallicity floor?
- Physical state of the gas and volume filling factor of metals and ionized bubbles.
- Establishing connection between the metal enrichment and the galaxies.
- CGM gas occupation distribution (GOD?) around low-z galaxies.

Phobles of physical conditions in galaxies:



Snow TP, McCall BJ. 2006.
Annu. Rev. Astron. Astrophys. 44:367–414

In collaboration with Patrick Petitjean, Pasquier Noterdaeme, Neeraj Gupta and Cedric Ledoux.

MeerKAT Absorption Line Survey:

- PIs: Neeraj Gupta & R. Srianand: CoIs list : Includes some of you.
- One of the 8 large programme chosen for MeerKAT.
- 4000 hrs of observations granted.
- Blind search for OH and 21cm absorption at $z < 1.8$.
- Expect to detect around 650 21-cm absorbers

MeerKAT Absorption Line Survey:

- Blind search for 21cm and OH absorbers at $z < 1.8$: using 580-1750 MHz frequency band(s).–Avoids dust bias
- Detect more than $\sim$600 intervening 21cm absorbers: 20 times the number of absorbers known.
- Measure the evolution of cold atomic and molecular gas at $z < 1.8$: the zrange where most of the evolution in SFRD takes place.
- Time variation of the fundamental constants of physics: using OH lines, and 21cm and optical/UV absorption lines.
- Probe the magnetic field in absorbing galaxies: using rotation measure and Zeeman splitting.
- Repeated monitoring of the sources to directly measure the cosmic expansion.
- Synergy with ALMA, EVLA, SALT, VLBA and TMT.

MeerKAT Absorption Line Survey & TMT:

- Understanding the nature of the faint radio sources in the field without bright optical counterparts.
  - We expect few thousands of radio sources with flux density in excess of 30 mJy inside the beam. Knowing the redshift of these sources will allow us to have an accurate redshift path length measurements that are essential to carryout a shallow 21-cm absorption line survey.
  - 10-40% of the radio sources do show associated 21-cm absorption. Optical redshift measurements are essential for confirming the detected absorption is intervening or intrinsic?
- Detecting the host galaxies of the 21-cm and OH absorbers out to $z \sim 1.5$.
  - NIR spectroscopy of the faint sources in the so called redshift desert.
- High resolution followup to search for CO and other molecules, DIBs etc., especially for the absorbers at $z > 1$.
  - As targets are faint we need TMT to get good s/n at high spectral resolution.

IGM studies in TMT era:

- Variation of fundamental constants: Isotopes?
  Requirements: s/n$\geq$100 per pixel, R$\sim$ 150,000 spectra of QSOs with V~ 20 mag covering wide wavelength (4000-9000).
  Comments: Not possible with 8m class telescopes.

- Metallicity and volume filling factor of IGM as a function of z– Is there any metallicity floor?
  Requirements: s/n$\geq$50 per pixel, R$\sim$50,000 spectra of QSOs with V~ 20 mag covering wide wavelength (4000-22000).
  Comments:Such studies are possible for bright QSOs (V$<$18 mag) with 8 m class telescopes. in the optical regime. IR range is important to understand the early metal enrichment, when the universe was about 1/10 of its age. The requirement in the IR can not be achieved with any 8m class telescope.

- Probing absorber galaxy connection:
  Requirements: IFU with AO. The required spectral resolution is $R \sim 2000$ and s/n is ≥ 50 per pixel. optical (or) near IR spectral range. spatial resolution better than 0.2 arc sec
  Comments: Such studies are not possible at present because of the lack of good spatial resolution in the ground based telescopes.

- Tomography of IGM-multiple QSO/GAL sightlines.
  Requirements: Multi-object spectroscopy $R \sim 2000 - 5000$, s/n$\geq$15 per pixel. To cover the small separations we need to go to objects (QSOs or galaxies) of 23rd to 24th Magnitude.
  Comments: Existing capabilities are limited to bright objects and hence probe larger separations.

- Lyman$-\alpha$ fluorescence – QSO proximity, cooling halos and epoch of reionization.
  Requirements: Deep narrow band imaging to detect the Lyman$-\alpha$

emissions from high density regions that do not have stellar light. Multi-object spectroscopy $R \sim 2000 - 5000$, s/n≥15 per pixel. Comments: Existing capabilities are limited to photometrically detecting brighter regions. But requires TMT to prove the line emission is due to Fluorescence.

- Astrochemistry at high-z: detection of complex molecules and DIBs at high-z
  Requirements: s/n≥100 per pixel, R∼ 100,000 spectra of QSOs with V~ 21 mag (or K∼18 mag) covering wide wavelength (4000-22000).
  Comments: Not possible with 8m class telescopes.

- C II, O I Gunn-Peterson effect (CMBR) at $z \geq 8$.
  Requirements: s/n≥100 per pixel, R∼ 50,000 spectra of QSOs with K∼18 mag covering wide wavelength (10000-22000).
  Comments: Not possible with 8m class telescopes.

- Population of galaxies traced by 21cm absorbers from GMRT/GBT/SKA.
  Requirements: IFU with AO. The required spectral resolution is $R \sim 2000$ and s/n is ≥ 50 per pixel. optical (or) near IR spectral range. spatial resolution better than 0.2 arc sec
  Comments: Such studies are not possible at present because of the lack of good spatial resolution in the ground based telescopes.