# Spectroscopy Science Cases and Capability Needs: Galaxies and AGN

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# Extragalactic Science

- Scientific Motivation:
- Understanding the assembly of galaxies, star formation history, chemical enrichment, interaction with the IGM, co-evolution of SMBH and their feedback, all as a function of evolving LSS environment & cosmic time.

# Massive Redshift Survey

- Large-scale sampling of range of environments and redshifts for chemical evolution, star formation rate, mass, etc.

- Need several SDSS volumes for different redshift slices ~1 million galaxies with diagnostic quality spectroscopy.

- Need coverage of 1-3 deg diameter, ~1000 fibers, spectral resolution to split [O II], velocity sigma of 30 km/s, i.e. R~4000; coverage of faintest z bins requires 10-m class telescope. Adequate S/N for physical diagnostics. 100s of nights on 10m.

# Topology of Reionization Survey (ToRS)

- Reionization:
  - Ended at $z \approx 6.5$
  - Was probably due to photo-ionization from galaxies
  - Might well have been inhomogeneous, due to clustering of ionizing sources
- LSST will detect and map the angular distribution of UV-bright galaxies out to $z \approx 7$
  - Wide survey: $>L^*$ at $z=6-7$; sub-$L^*$ at $z \leq 5$
  - Deep-drilling: $<L^*$ at all redshifts
- Spectroscopy + LSST imaging = map of 3D UV luminosity density (sort of)
- Spectroscopy measures 3D distribution of the brighter galaxies
- Correlate with much denser sampling of LSST photometric samples to fainter magnitudes [fainter galaxies almost certainly dominate the emission of ionizing photons]
- Measurements from $z \approx 7$ down to $z \approx 3-4$ (or lower) to map the evolution of clustering and its relation to UV emission
  - Reaches lower luminosities and much higher space/surface densities at lower redshifts
  - Permits extrapolation backward into the reiniozation era

# Topology of Reionization Survey (ToRS)

- Optical ($\leq$ 1$\mu$m) spectra to m=26-27
  - Ly$\alpha$, Ly-break, ISM UV absorption lines
  - Redshifts (R ≈ 1000 would be ok, but higher resolution better to improve efficiency in the OH sky forest)
  - Also, Ly$\alpha$ emission fraction (sensitive to neutral IGM) vs. UV luminosity vs. local environment
  - Probably multislit to achieve high multiplex and source density at very faint magnitudes
- Surface densities
  - ~few/arcmin$^2$ at z ≈ 6-7
  - ~10/arcmin$^2$ at z < 5
- Survey ~several deg$^2$
  - 1 degree = 150 Mpc (co-moving) @ z=7
  - ~50 nights with GMACS on GMT
- Additionally: targeted observations of rarest, largest overdensities identified from LSST wide survey ["rare object science"]

# Regions of Highest Overdensity

- LSST will find the 10s of regions of highest overdensity, particularly at higher redshifts, unique environment for early assembly of galaxies, strong inflows.
- Need coverage of 10 arcminute diameter, 10-100 objects/ field, spectral resolution to split [O II], velocity sigma of 30 km/s, i.e. R~4000; coverage of faintest z bins to 26$^{th}$ mag requires 20-m class telescope. Adequate S/N for physical diagnostics. 10s of nights on 10m.

# Ly Alpha Blobs

- What are the Lyman Alpha blobs and what phase do they represent in the formation of galaxies/groups/clusters?Science. Identify a large sample of LABs at z~2-5
- Roughly 3 bins in each and ~100-200 objects per bin, samples of a few thousand. we would only have <1 per sq. deg or so.
- Spectroscopic requirements: 1) Single object spectroscopy. 3200A-1um. High-throughput blue spectroscopy is essential; On an 8m, ~100-200 nights..2) Follow-up science: (a) Near-IR spectroscopy (to get rest-frame optical line diagnostics, where possible) - single object slit spectroscopy OK, IFU preferred; (b) Optical IFU spectroscopy for spatially resolved line ratios, kinematics, etc.; (c) Small field (10 arcmin - 1 deg) follow-up multi-object spectroscopy to understand the environment. (d) 2d spectropolarimetry? 3) Calibration of photo-zs for the LBG population => MOS optical spectroscopy of samples of ~100s to 1000s of LBGs for redshifts in the range of the LAB redshifts (2-5?)

# Dwarf Satellite Galaxies

- LCDM predicts far more dwarfs than observed in Local Group, but no systematic understanding of faint dwarfs beyond Local Group. Challenge in separating observationally those true dwarfs within virial radius from 'background' slightly more luminous galaxies.
- Tens of parent galaxies at 10-15 Mpc, tens of faint dwarfs per host to be culled from 10,000 faint galaxies / $deg^2$
- Need coverage of 1-3 deg diameter, ~1000 fibers, accurate RV's for r~24, R=2000.
- 10,000 background objects per host based on photo-z; multiple configurations of fiber MOS.
- Follow-up to get physical properties of true dwarfs for internal velocity dispersion, abundances, R>8000.

# IGM Tomography

- Background AGNs and distant galaxies discovered by Lya emission or Ly break energy distributions can provide a high density of probes for the 3-D structure of inflowing and outflowing gas, as well as its association with individual objects.
- Need 10-arcmin FOV, MOS coverage of i-25.5 with S/N~10, 100s of objects, accurate RV's, R~2000, coverage 0.4-1.0um for rest-frame UV coverage 2<z<5.
- 20 hours per field over 10s of fields to cover range of overdensities and redshifts.

# Quasar Redshift Surveys

- Least well-known aspects of AGN (bolometric) Luminosity Function are contribution of obscured AGN and low-L end of unobscured population. Former extracts nuclear information from galaxy redshift surveys + multi-wavelength association of objects from other surveys. Unobscured derived from faintest objects captured by LSST depth. Large sample allows determination of evolution in clustering, distribution of Eddington ratios, relation of BH growth to galaxy growth. Builds on MS-DESI and current surveys.
- Wavelength coverage 0.38-1.26 um; R~1000-2000. S/N~10 for velocity widths. Limit of i=24 gives 500 / $deg^2$, cover 10,000 sq deg.

# Reverberation Mapping

- Response of broad-line region to continuum variations creates relation of luminosity and line width allowing mass determination for central BH; to date, accomplished only for low-L AGNs and strongly extrapolated.
- Possibility to use as distance indicator for cosmology
- Two approaches: opportunistic trigger for strong variability and regular monitoring of known AGN in deep drilling field(s)
- Need single object coverage for all-sky trigger, MOS coverage of -1.5 deg diameter, ~1000 fibers, accurate RV's for r~24, R>1000.
- Co-eval spectroscopy for deep drilling field(s); start new sequence for strong variables at first trigger.

# Rare Classes of AGN

- special, astrophysically interesting classes of quasars/AGN, needs LSST area/depth to discover.
- example: quasars at z>6
  - early BH growth
  - reionization/IGM probe
- z>7.2 quasars: at Y<24: ~100 over LSST area
  - X-shooter-type instrument (0.8-2.5 micron), R~2000, single target, high S/N, on 10m+ telescope
- z>~6 quasars: at Y<24 one object every 1-3 deg^2 - ~1 per PFS FOV
  - part of wide-area galaxy/quasar spectroscopic survey, R~2000, moderate/high S/N, on 6-10m telescope
- Other examples: rare BALs to study feedback; quasar strong lenses; ultraluminous high-z galaxies
- Needs to develop target selection before/during commissioning with LSST-type filter/depth/cadence

# Key Capabilities

- High-multiplex spectroscopic surveys
  - 6.5m+ wide-field high-multiplexing optical/IR spectrograph
  - (semi-)dedicated surveys with millions of targets
  - resolution: low/moderate (R<=4000)
  - IR capability (realistically up to J band) important for many science cases
  - Not critical for co-eval with LSST (except reverberation mapping)
  - MS-DESI and PFS will give us a lot, but noticeable mismatch between current planned facility and LSST footprint

# Key Capabilities

- Rare object/structure follow-up
  - 20m+ single/multislit/IFU spectrograph, FOV <~10 arcmin
  - resolution: low/moderate (R<=4000) for most applications; R~30000 for IGM abundance
  - IR capability (ideally continuous coverage: Xshooter type) important for many science cases
  - UV coverage important for IGM tomography
  - Note that there is no X-shooter type instrument among first-gen on ELTs

# Other Needs

- Efficient IFU for high spatial resolution
- Rapid fellow-up
  - single object/IFU with broad wavelength coverage
  - response timescale for AGN flare etc.: days-> not driving response speed requirement
- AGN Classification Infrastructure
  - Transient broker
  - Multiwavelength matching
  - AGN target selection
- Software, esp. sky subtraction problem
- Precursor survey
  - DECam plus near IR photometry as training sets