Snowmass2021 - Letter of Interest

Inflation and Dark Energy with the MegaMapper: probing fundamental physics with $z > 2$ spectroscopy

Thematic Areas:

■ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
■ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
■ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
■ (CF7) Cosmic Probes of Fundamental Physics
■ (TF9) Astro-particle physics & cosmology

Contact Information:
Simone Ferraro (Lawrence Berkeley National Laboratory) [sferraro@lbl.gov]

Authors: Stephen Bailey (LBNL), Charles Baltay (Yale), Segev BenZvi (Rochester), Guillermo A. Blanc (Carnegie), Jeffrey Crane (Carnegie), Regina Demina (Rochester), Xiaohui Fan (Arizona), Simone Ferraro (LBNL), Gaston Gutierrez (FNAL), Julien Guy (LBNL), Klaus Honscheid (OSU), Dragan Huterer (Michigan), Leopoldo Infante (Carnegie), Juna Kollmeier (Carnegie), Patrick McDonald (LBNL), John Moustakas (Siena), John S. Mulchaey (Carnegie), Adam Myers (UWYO), Jeffrey Newman (Pittsburgh), Povilas Palunas (Carnegie), Claire Poppett (LBNL), Solange Ramirez (Carnegie), Lado Samushia (KSU), Eddie Schlafly (LLNL), David Schlegel (LBNL), Hee-Jong Seo (Ohio), Stephen Shectman (Carnegie), Josh Simon (Carnegie), Zachary Slepian (Florida), Marcelle Soares-Santos (Brandeis), Martin White (UC Berkeley/LBNL), Michael Wilson (LBNL).

Abstract: The MegaMapper is a highly-multiplexed spectroscopic facility and survey designed to map the $2 < z < 5$ Universe. It will more than quadruple the amount of volume observed, and has the potential to radically improve our understanding of the basic laws governing our Universe. Unprecedented access to very large scales, often the most affected by primordial physics, will open a new window on the early Universe. The smaller size of non-linear corrections to the power spectrum at high redshift, coupled to recent improvements in theoretical modeling, will increase the number of accessible primordial modes by an order of magnitude. This will put the tightest bounds on primordial non-Gaussianity, crossing the theoretical threshold of $\sigma(f_{\rm NL}^{\rm local}) \lesssim 1$, potentially allowing us to distinguish between different inflationary scenarios. It will also allow a detection of possible features in the primordial power spectrum. It will directly probe Dark Energy during the transition to matter domination, putting tight bounds on broad classes of dynamical Dark Energy models, while indirectly constraining early Dark Energy to very high redshift through its effects on the shape of the power spectrum. It will also improve our measurements of neutrino masses, the number of relativistic species and spatial curvature. Combined with CMB or galaxy weak lensing, it will allow for the most stringent tests of theories of gravity on cosmological scales.

MegaMapper[1] is a highly-multiplexed spectroscopic facility and survey designed to characterize the two epochs of accelerated expansion: Inflation and Dark Energy. The large volume available at $z > 2$ will allow us to increase the number of accessible modes in the primordial power spectrum by an order of magnitude, opening up an uncharted territory with large discovery potential. Forecasts show that a high-redshift spectroscopic survey covering the range $2 < z < 5$ can radically improve constraints on Inflation and Dark Energy, while at the same time relaxing assumptions such as a power-law primordial power spectrum[2;3].

LSST imaging will allow us to select ≈ 100 Million spectroscopic targets that span this redshift range. These targets are a combination of Lyman-Break galaxies (LBGs), selected using dropout techniques, and Lyman$-\alpha$ emitters (LAEs) for which broad-band color selection is possible[4]. MegaMapper's location at Las Campanas Observatory will ensure full overlap with LSST imaging for target selection.

The 6.5m telescope aperture and $\sim 20,000$ fibers have been chosen to maintain the number density of galaxies with successful redshifts to $\gtrsim 10^{-4}(h/\mathrm{Mpc})^3$, while completing the survey in 5 years. This requirement on number density matches the sweet-spot found by previous spectroscopic surveys in that it ensures that the BAO scale is signal dominated.

MegaMapper will improve our understanding of the early Universe thanks to two main mechanisms: first, the large volume available at high redshift, together with the smaller non-linearities at early times, will allow for the reconstruction of more primordial modes than any previous experiment, allowing for model-independents constraints on the shape of the primordial power spectrum generated by Inflation. At the same time, it will allow unprecedented access to the very largest scales, often the most affected by primordial physics. For example, MegaMapper will be transformative in the study of primordial non-Gaussianity[5], one of the most powerful tools to characterize the origin of the primordial fluctuations. While the simplest inflationary models predict Gaussian initial conditions, large classes of models predict deviations from Gaussianity that leave specific imprints on the galaxy power spectrum and bispectrum[5;6], thus probing physics at scales inaccessible to Earth-based colliders. Distinguishing multi-field from single-field inflation requires bounds on the "local" non-Gaussianity parameter to be constrained to better than $\sigma(f_{NL}^{\mathrm{local}}) \lesssim 1$, almost an order of magnitude improvement over current bounds[7].

Preliminary forecasts show that MegaMapper can achieve $\sigma(f_{NL}^{\mathrm{local}}) \approx 0.7$ for a fiducial galaxy sample, using only information from the power spectrum, where the effects of non-zero f_{NL} are well understood. Including the information from the bispectrum should further help, where preliminary forecasts based on the current state-of-the-art perturbation theory calculations suggest an improvement of up to five-fold in the constraining power. Since the bispectrum constraints depend crucially on non-linear modeling of the clustering and biasing, we conservatively chose to design an experiment capable of achieving $\sigma(f_{NL}^{\mathrm{local}}) \lesssim 1$ from the power spectrum alone, while noting that progress in modeling and analysis techniques may allow for further improvements. Improvements by a factor of two or larger over the current bounds are also expected for the equilateral and orthogonal shapes[8].

Our understanding of Dark Energy[9] will greatly benefit from measuring the expansion and growth of fluctuations throughout cosmic history. A lever arm that extends from low redshift (Dark Energy era) to high redshifts (matter domination era) will tightly constrain large classes of theories, and test possible modifications to General Relativity.

Using a combination of Redshift-Space Distortions (RSD) and Baryon Acoustic Oscillations (BAO), MegaMapper can directly measure the fraction of Dark Energy density to better than 2% up to $z \approx 5$ (and considerably better at lower redshifts, see Figure 1 in[8]). At the same time, the large lever arm will help distinguish the effects of dynamical Dark Energy from those of massive neutrinos, effectively breaking well-known low redshift degeneracies. Moreover, by making very precise measurements of the shape of the matter power spectrum, it will be able to detect deviations from the standard expansion history (for example due to early Dark Energy), up to $z \sim 10^5$, thus probing Dark Energy all the way to when the Universe was a only a few years old. Other notable improvements include a factor of two better determination of the spatial Curvature (compared to DESI + Planck), and a factor of $\gtrsim 2.5$ improvement for the standard Dark Energy figure of merit (see Table 4 in[8]), while noting that the traditional figure of merit may not fully describe the improvements of future surveys, given the discussion above.

The science returns are fairly insensitive to the precise details of the galaxy sample assumed (for example the galaxy number density). We find that decreasing the galaxy number density by 20% and 40% leads to a degradation of 6% and 17% in $\sigma(f_{NL}^{\rm local})$ respectively, allowing for $\sigma(f_{NL}^{\rm local}) \lesssim 1$ even with a significantly sparser sample. The Dark Energy Figure of Merit (FoM) degrades by 4% and 12% respectively under the same assumptions, meaning that MegaMapper will lead to a factor of more than two improvement over DESI, even in the case of a 40% decrease in number density.

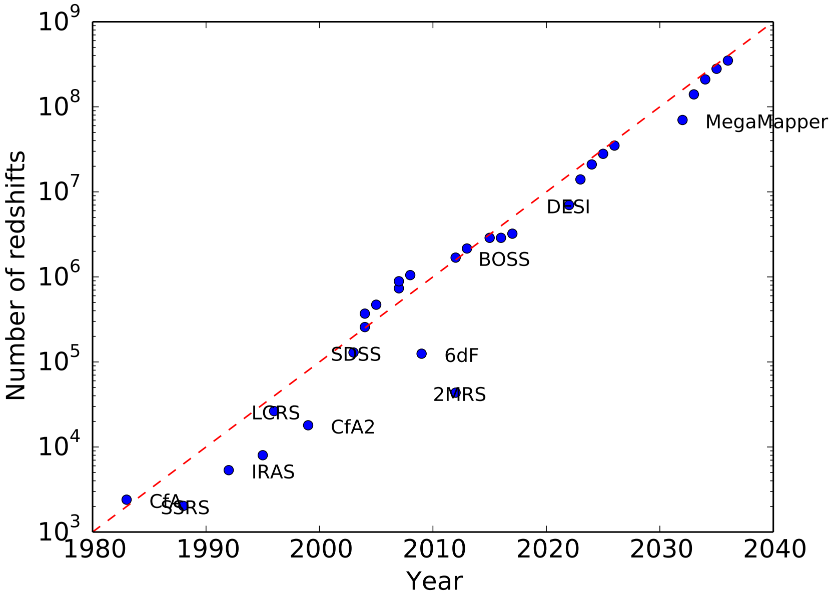

Figure 1: Number of galaxy redshifts as a function of time for the largest cosmology surveys. The dotted line represents an increase of survey size by a factor of 10 every decade. Fielding the MegaMapper in ten years maintains this pace into the 2030s, and enables the Inflation and Dark Energy measures proposed here.

Finally we should note that dealing with large-scale systematics will require further improvements on the analysis techniques, and that spectroscopy will be key to mitigating some of the systematic effects present in the imaging, as well as ensuring that the number of redshift outliers is kept to a minimum.

A wide-field spectroscopic survey in the southern hemisphere will also greatly enhance the science returns from LSST[10–12]. For example, calibration of photometric redshifts is possible over the whole range of LSST sources through cross-correlation techniques with the spectroscopic sample. The large overlap area will enable a reduction in the statistical errors to meet the stringent LSST requirements[10]. The availability of a large overlapping spectroscopic sample will allow cross correlation of these galaxies with the faint LSST sources to better constrain intrinsic alignment models. Moreover, a combination of lensing amplitude provided by LSST, together with growth measurements through RSD can provide a powerful test of General Relativity on cosmological scales. Finally, MegaMapper can provide redshifts for strong gravitational lenses and Type Ia supernovae discovered in LSST, allowing their cosmological interpretation.

References

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