Astrophysics Roadmap 2013:

A Comprehensive Map of Galaxy and Black Hole Evolution over Cosmic Time

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The luminous universe is dominated by two sources, stars and accreting black holes. There appear to be intimate "feedback" connections between these, including dynamical and energy-injecting interactions that determine how galaxies form and evolve, and a lockstep growth of the masses of black holes with the vastly larger masses of the galaxies that host them. Furthermore, in the tempestuous mix of galaxy and galaxy cluster formation and evolution, their surrounding environment is suffused with neutral, warm, and hot or ionized gas, which while often difficult to detect, in fact contains the majority of the baryons. We are driven to characterize the full story of galaxy, galaxy cluster, and black hole formation and evolution, and to achieve a deep understanding of the driving physical processes. This will entail both survey and targeted observations across cosmic time, as well as chemical and phase space mapping of near-field stars and gas. These efforts can strongly leverage on existing and planned capabilities and projects, including *HST*, *JWST*, GAIA, *Euclid*, and WFIRST from space, and MS-DESI, PFS, LSST, and TMT/GMT, from the ground. Essential implementation gaps for the complete end-to-end picture (see Table) include UV integral field spectroscopy, high multiplexing wide-field OPT/IR spectroscopy, focused time domain spectrophotometry, and full-sky deep mid-IR imaging. These assume complementarity with planned projects and missions. Computational and algorithmic advance requirements go in hand.

Way-station	***Scientific Challenges***		***Technological Challenges***
	Wide-field	Targeted	
By the 2020s	* "Missing baryon" mapping through UV integral field spec/y.	* Dynamics and chemistry of "in the act" black hole activity caught by LSST. * Percent precision mass maps of galaxy structure with redshift, leveraging strong gravitational lensing.	* High QE FUV detectors. * >1 arcmin IFS. * Several thousand multiplex, >1deg field spec capability. * Sub-percent reproducible time domain spectrophotometry.
By the 2030s	* Precise stellar RV and chemical measurements of *all* stars within the GAIA volume. * Mid-infrared AB=16 full-sky imaging survey	* Reverberation mapping tomography of "emerging" black holes at onset of activity from quiescence.	* Trillion-particle galaxy simulations including baryonic processes. * Kinetic Inductance detector photon tagging over large fields of view.
By the 2040s	"Near-field cosmology" from resolved stars in distant galaxies.	* Galaxy-IGM interactions at z>8. * Identify and dynamically measure masses of quiescent black holes to Dark Ages threshold.	* Quantum computing for rapid inference theoretical interpretations of observations. * SNR>10, R>20,000 spectra of quasars. * SNR>100, R>10,000 spectra of stars in distant galaxies.