Science Traceability Matrix

Exploring Cosmic Evolution at the Peak of Galaxy Formation

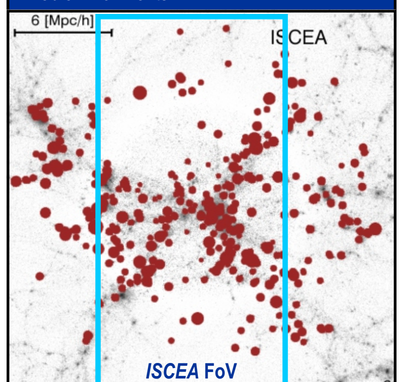
FO1

		Science Measurement Requirements		Instrument Performance			Instrument Requirements		Top Level Mission Requirements
Science Goal	**Science Objectives**	**Science Observable**	**Measurement Requirement**	**Data**	**Required**	**Projected**	**Technical Parameter**	**Technical Requirement**	
To discover how galaxies formed and evolved in the cosmic web of dark matter (NASA Astrophysics Science Goal: Discover how the Universe works, explore how it began and evolved.)	1. To study galaxy evolution in dense environments at the peak of galaxy formation	Star formation rate (SFR) in galaxy clusters Velocities of galaxies in galaxy clusters	Observe 22 galaxy clusters to measure SFR with 10% shot noise as a function of redshift, local mass density, and cluster host halo mass at 1.6 < z < 2.4	Galaxy clusters with mass > 10^{14} $M_{\odot}$ Galaxies per cluster with S/N≥5 spectra Galaxies per cluster with Δv<100km/s velocity measurements	22 clusters 140 galaxies 140 galaxies	22 clusters 154 galaxies 154 galaxies	Wavelength range Spectroscopic resolving power Spectroscopic multiplex factor Spectroscopic sensitivity Spectroscopic "slit" size Field of view	0.9-1.7 μm λ/Δλ = 1000 500 spectra simultaneously 2.5×10^{-17} erg/s/cm^2 2.8"×2.8" > 0.2 deg^2	Telescope aperture: ≥ 25cm in diameter Observing strategy: Observe each cluster multiple times Mission Life: 1.3 years Observe each cluster field for >720ks Observatory orbits LEO Observatory accommodates a spectrograph and an imaging channel for calibration and target verification Observatory is required to have a pointing uncertainty over 200 sec ≤ 2" FWHM for differentiating individual galaxies
	2. To map the cosmic web environment around clusters at this critical epoch	Distribution of galaxies in the cosmic web around the galaxy clusters	Measure galaxy number density with 10% shot noise out to a radius of 10 Mpc around each cluster	Galaxies around each cluster with S/N≥5 spectra Galaxies around each cluster with Δv<100km/s velocity measurements	500 galaxies 500 galaxies	565 galaxies 565 galaxies	Wavelength range Spectroscopic resolving power Spectroscopic multiplex factor Spectroscopic sensitivity Spectroscopic "slit" size Field of view	0.9-1.7 μm λ/Δλ = 1000 500 spectra simultaneously 10^{-16} erg/s/cm^2 2.8"×2.8" > 0.3 deg^2	

We live in the Milky Way galaxy, one of trillions of galaxies, in a vast Universe with the invisible cosmic web of dark matter as its underlying structure. Galaxy clusters emerge from the cosmic web at the intersections of filaments, accreting lower mass halos including galaxies and groups that flow in along these filaments. Galaxy clusters are the most massive gravitationally bound structures in the Universe. Believed to have begun their assembly at redshift z > 2, clusters provide insights into the growth of large-scale structure as well as the physics that drives galaxy evolution.

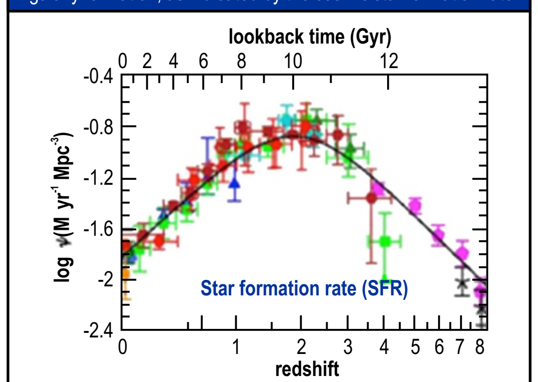
ISCEA addresses the fundamental questions of how and on what timescale the environment in which a galaxy resides regulates its growth and star formation history, and determines its observed morphology (spiral or elliptical). *ISCEA* answers these questions by mapping 22 galaxy clusters and their surrounding cosmic web during the peak epoch of galaxy formation, obtaining >140 galaxy spectra inside each cluster, and >500 galaxy spectra in the cosmic web surrounding each cluster, to measure star formation rate (the key indicator of galaxy evolution) with 10% shot noise as a function of redshift, cluster host halo mass, and local mass density

A. *ISCEA* maps 22 clusters and their cosmic web environments.



A simulation of *ISCEA* galaxies (red) that trace the cosmic web of dark matter (grayscale) in a cluster field at z = 2.

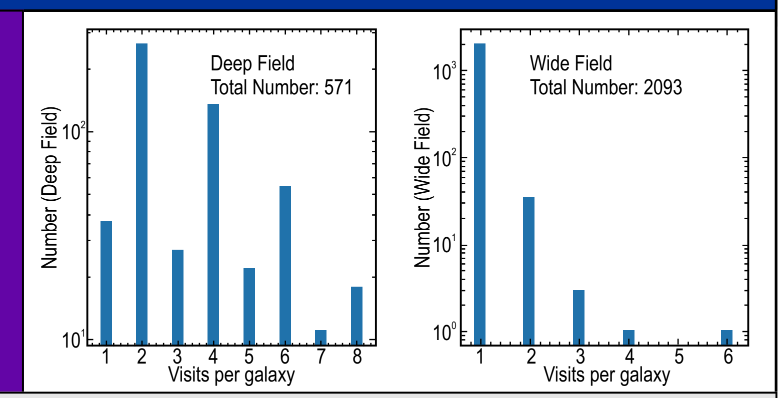
B. *ISCEA* probes cosmic evolution during the peak epoch of galaxy formation, as indicated by the cosmic star formation rate.



The SFR as a function of redshift z and lookback time (Madau & Dickinson 2004). Different colors denote different data sets.

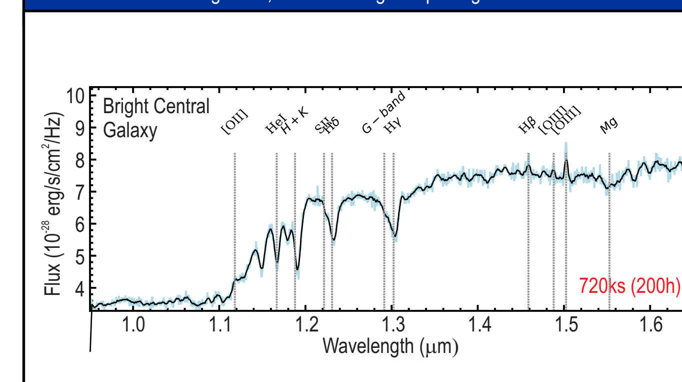
C. *ISCEA* obtains thousands of galaxy spectra per cluster field.

ISCEA visits each cluster field 8 times, to observe Deep and Wide Fields concurrently, by rotating the FOV in successive visits.



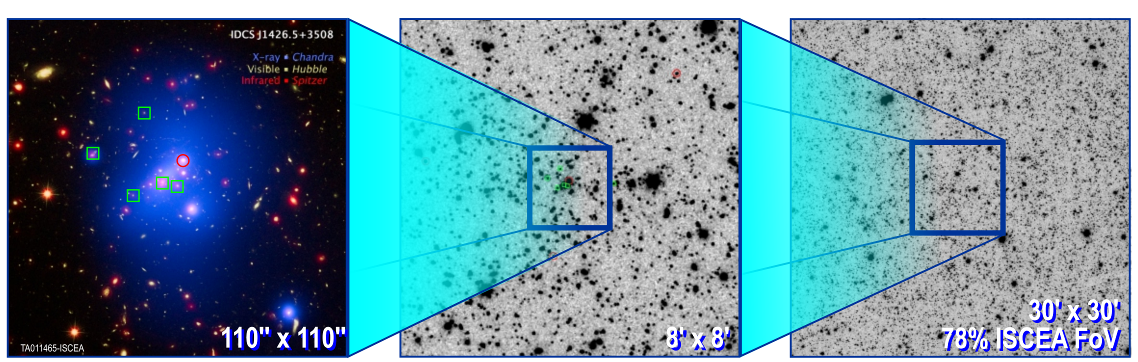
The histograms show the number of *ISCEA* spectroscopic visits (35 hrs each) received by 571 galaxies in the deep (left) and 2093 galaxies in the wide (right) fields in each cluster field. About 27% of these galaxies are in the cluster or its adjacent cosmic web, exceeding requirements. The rest are in the foreground and probe cosmic large scale structure.

D. *ISCEA* obtains spectra for spiral galaxies (emission line galaxies) to the faint line flux limit of 2.5×10^{-17} erg/s/cm^2, as well as bright elliptical galaxies in cluster cores.



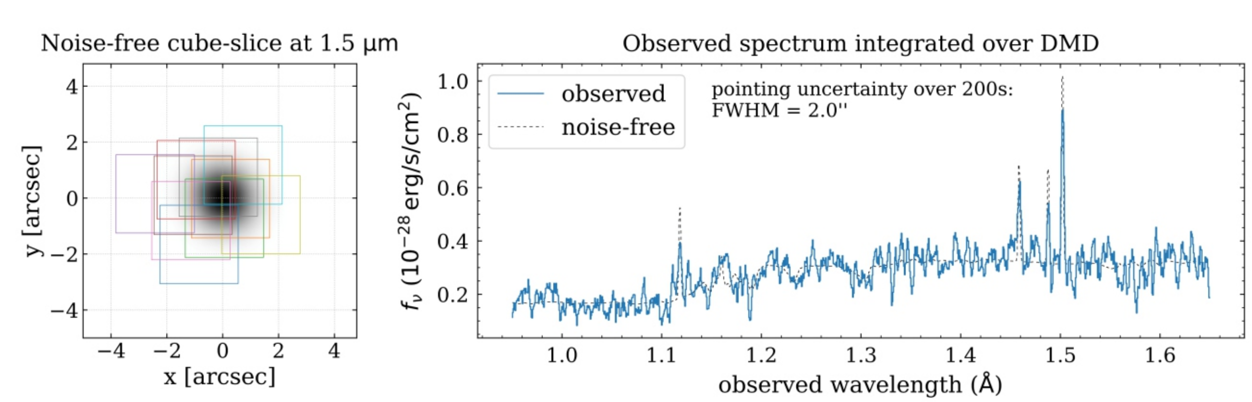
The simulated *ISCEA* spectrum of a bright central galaxy (K_{AB}=19) (elliptical) in a cluster at z = 2.

E. ***ISCEA*** increases the scale and resolution of 3D galaxy maps of clusters by > 10× current observations



Left: A Great Observatories image of the 1.9'x1.9' core of z = 1.75 cluster IDCS J1426.5+3508, with the few galaxies with spectroscopic redshifts indicated with green squares (HST/WFC3 grism) and red circles (Keck LRIS & MOSFIRE). Middle: Image zoom-out illustrating the limited spectroscopic sampling currently possible (with the same green squares and red circles as in the left panel). Right: Spitzer IRAC [3.6] image, showing 78% of the large *ISCEA* FOV. (Stanford et al. 2012; Brodwin et al. 2012, 2016; Gonzalez et al. 2012; Mo et al. 2016.)

F. ***ISCEA*** achieves a pointing uncertainty over 200 sec < 2" FWHM



Simulated *ISCEA* spectrum with pointing uncertainty (over 200 sec) of 2" FWHM for a faint spiral galaxy at z = 2 with K_{AB}=22 and [OII] line flux 2.5×10^{-17} erg/s/cm^2

To meet its science objectives, *ISCEA* achieves a pointing uncertainty over 200 sec < 2" FWHM, to take 500 individual galaxy spectra simultaneously. *ISCEA* obtains galaxy spectra with S/N ≥ 5 for the strongest emission line or absorption feature in each, to remove data artifacts and noise peaks, leading to accurate redshift measurements for mapping each cluster and its cosmic web environment in 3D.

ISCEA is a game changer in understanding galaxy evolution, providing more than a factor of 10 increase in the scale and resolution of 3D galaxy maps of clusters compared to current observations. *ISCEA* advances the NASA astrophysics objective, "to discover how the Universe works, and explore how it began and evolved", and addresses the SMD science goal, "Explore the origin and evolution of the galaxies, stars, and planets that make up our Universe". *ISCEA* addresses the Explorers Program Goals and Objectives by gathering "Big Science" data at an extraordinary value from a SmallSat.

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