

# Origins Space Telescope: Cosmology and Reionization

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**ABSTRACT** — The Origins Space Telescope (OST) is the mission concept for the Far-Infrared Surveyor, a study in development by NASA in preparation for the 2020 Astronomy and Astrophysics Decadal Survey. Origins is planned to be a large aperture, actively-cooled telescope covering a wide span of the mid- to far-infrared spectrum. Its imagers and spectrographs will enable a variety of surveys of the sky that will discover and characterize the most distant galaxies, Milky-Way, exoplanets, and the outer reaches of our Solar system. Origins will enable flagship-quality general observing programs led by the astronomical community in the 2030s. The Science and Technology Definition Team (STDT) would like to hear your science needs and ideas for this mission. The team can be contacted at [firsurveyor\\_info@lists.ipac.caltech.edu](mailto:firsurveyor_info@lists.ipac.caltech.edu).

A core science goal of the OST mission is to study the the cosmological history of star, galaxy, and structure formation into the epoch of reionization (EoR). OST will probe the birth of galaxies through warm molecular hydrogen emission during the cosmic dark ages. Utilizing the unique power of the infrared fine-structure emission lines, OST will trace the rise of metals from the first galaxies until today. It will quantify the dust enrichment history of the Universe, uncover its composition and physical conditions, reveal the first cosmic sources of dust, and probe the properties of the earliest star formation. OST will provide a detailed astrophysical probe into the condition of the intergalactic medium at  $z > 6$  and the galaxies which dominate the epoch of reionization.

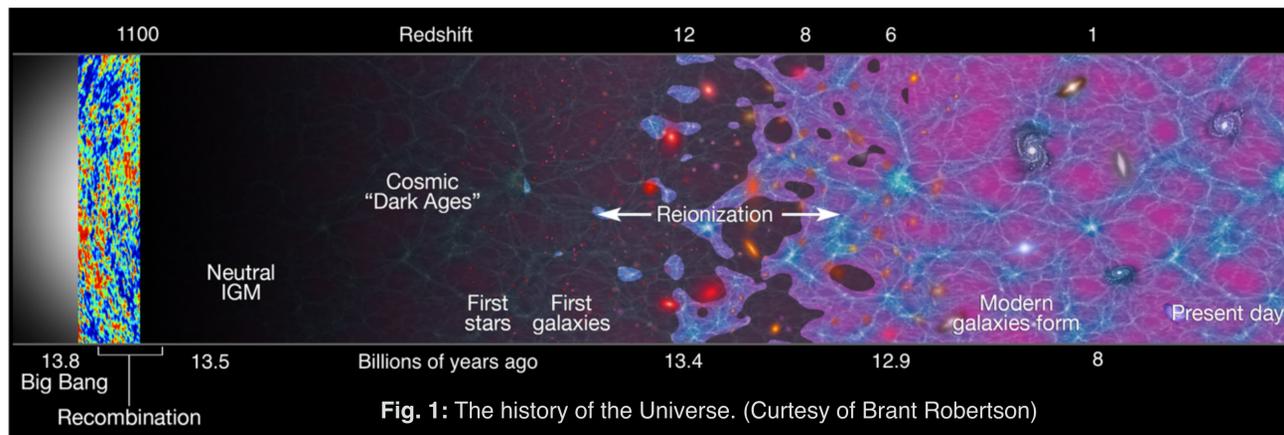


Fig. 1: The history of the Universe. (Courtesy of Brant Robertson)

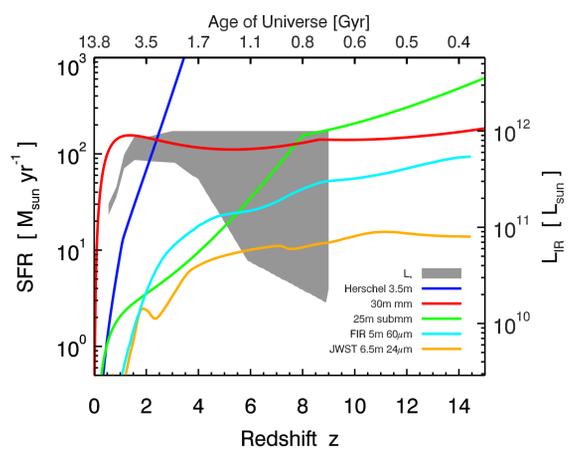


Fig 2: Even with just a 5m aperture, OST delivers the resolution and sensitivity needed to resolve nearly all of the cosmic far-infrared background and probe galaxies fainter than  $L^*$ , thereby extending the rest-frame far-infrared measurements into the EoR. Shown are the current constraints on the variation of star formation in an  $L^*$  galaxy (grey), and confusion limits for *Herschel* (blue), JCMT (green), CCAT (red), JWST (orange), and OST (light blue)

## THE RISE OF METALS

OST will utilize the unique power of the infrared fine-structure emission lines to trace the rise of metals from the first galaxies until today. The present day Universe is rich in metals heavier than helium that enable efficient cooling of gas in the ISM in order to form stars, create planets and make the building blocks of life as we know it. The Universe did not start in this state – we know that metals had to build up over time with successive generations of stars. Beyond this broad picture we have very little detail. Extensive studies of metallicity locally and out to  $z \sim 1$  indicate a factor of 10 fall in metallicity, while our knowledge beyond  $z \sim 1$  are much more limited. Obtaining a complete understanding of the rise of metals requires a study of metallicity across cosmic time utilizing the mid- and far-IR fine-structure emission lines, which are not susceptible to dust extinction and the degeneracies of optical tracers. (Figs. 3 & 5).

## THE FIRST DUST

OST will quantify the dust enrichment history of the Universe, uncover its composition and physical conditions, reveal the first cosmic sources of dust, and probe the properties of the earliest star formation. Astrophysical dust comprises less than one-hundredth of one percent of the baryonic mass of the Universe, yet approximately one-half of all energy radiated by stars and accreting black holes over its history has been reprocessed by dust to long wavelengths. Dust shrouds the most intense regions of black hole accretion and star formation, and, as it is comprised of condensable species like C, Si, Fe, and O, is a sensitive tracer of the abundance of heavy elements. Studying the broad spectral dust features in the mid-infrared (3–30 $\mu$ m) is the only way to provide critical and unique information on dust origin, composition, and properties like grain size distribution, as well as to track the underlying gas metal content. Due to the very different expected dust compositions and mass yields of low metallicity PopII and PopIII stars, dust signatures can directly probe the properties of the earliest phases of star formation. (Figs. 2 & 3)

## THE BIRTH OF GALAXIES

OST will probe the birth of galaxies through warm  $H_2$  emission during the cosmic dark ages. A key to understanding the formation of the first galaxies and evolution of large-scale structure is tracing the cooling of gas into dark matter halos at early times. Emission from pure rotational  $H_2$  lines redshifted into the far-IR can provide a direct measurement of the strength of cooling and the dissipation of mechanical energy in the gas as it collapses before the onset of star formation. The rotational  $H_2$  lines are key to probing turbulence and shocks, and can dominate the cooling of gas even in the presence of metals. (Figs. 1, 4, 5)

## THE NATURE OF THE FIRST GALAXIES

To understand the sources and process of Reionization, it is essential to probe the population of low-metallicity, low-luminosity, and low stellar mass galaxies at  $z > 6$ , which are expected to be dominant in terms of the number densities inferred from UV luminosity functions as well as their contribution of photons to ionize the intergalactic medium during the Epoch of Reionization (EoR). Tomographic line intensity mapping offers a powerful means of observing the dwarf galaxy population during EoR, as the power spectrum analysis of intensity fluctuations in spectral line emission is sensitive on large-scales to the aggregate intensity of all galaxies in a given volume—including intrinsically faint sources that may otherwise remain below sensitivity thresholds for individual detection. (Figs. 1, 3, 5)

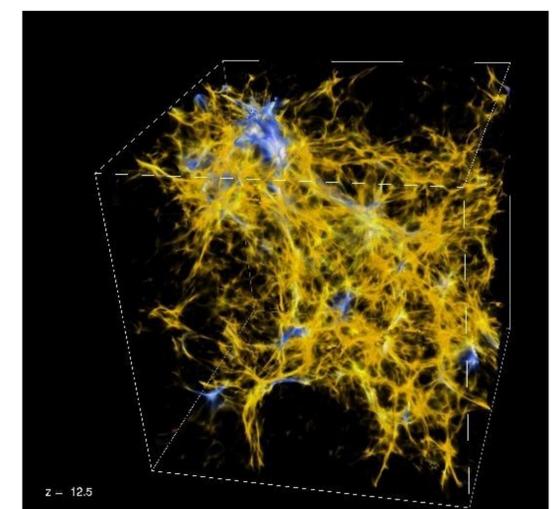


Fig 4: The formation of primordial molecular  $H_2$  clouds at  $z=12.5$ . Simulation from Abel, Bryan & Norman, ApJ 2000.

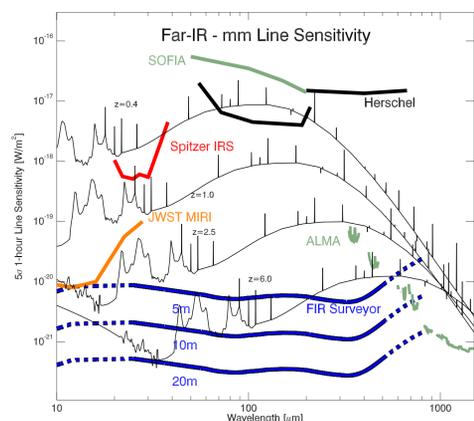


Fig. 3: The predicted sensitivity of a filled-aperture background-limited telescope, demonstrating the detection capability for a redshifted template of a normal  $10^{12} L_{\odot}$  star-forming galaxy at  $z=1-6$ . JWST/MIRI, Spitzer/IRS, SOFIA, *Herschel*, and ALMA wavelength coverage and sensitivities are also shown for comparison.

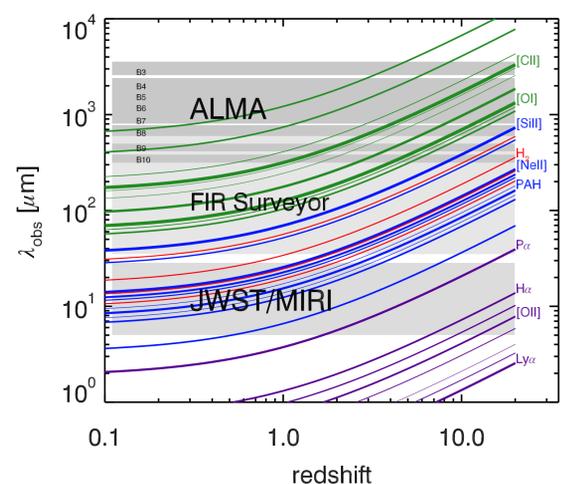


Fig. 5: The spectral lines versus redshift accessible to OST. OST fills in a crucial gap between JWST and ALMA and is the only instrument capable of observing crucial astrophysical lines at  $z > 10$ .