Journal of Astronomical Instrumentation

Cosmic Dawn Intensity Mapper: Spacecraft and Mission Design for a Probe-Class Space Telescope

Philip Linden[1,†], Michael Zemcov[2]
[1] *Department of Mechanical Engineering, Kate Gleason College of Engineering, Rochester Institute of Technology, Rochester, NY 14623, USA, pjl7651@rit.edu*
[2] *Center for Detectors, School of Physics and Astronomy, Rochester Institute of Technology, Rochester, NY 14623, USA, zemcov@cfd.rit.edu*

Received (to be inserted by publisher); Revised (to be inserted by publisher); Accepted (to be inserted by publisher);

Cosmic Dawn Intensity Mapper (CDIM) is a Probe-class near-IR space telescope with the scientific goal of conducting large spectro-imaging surveys over a five-year period in the NASA 2020 Decadal. A high-level system architecture was designed to identify key features and technologies aboard the CDIM spacecraft in preparation for more detailed studies such as a Team-X session at NASA Jet Propulsion Laboratory.

Keywords: spacecraft, telescope, system, cryogenic, infrared, design.

[†]Corresponding author.

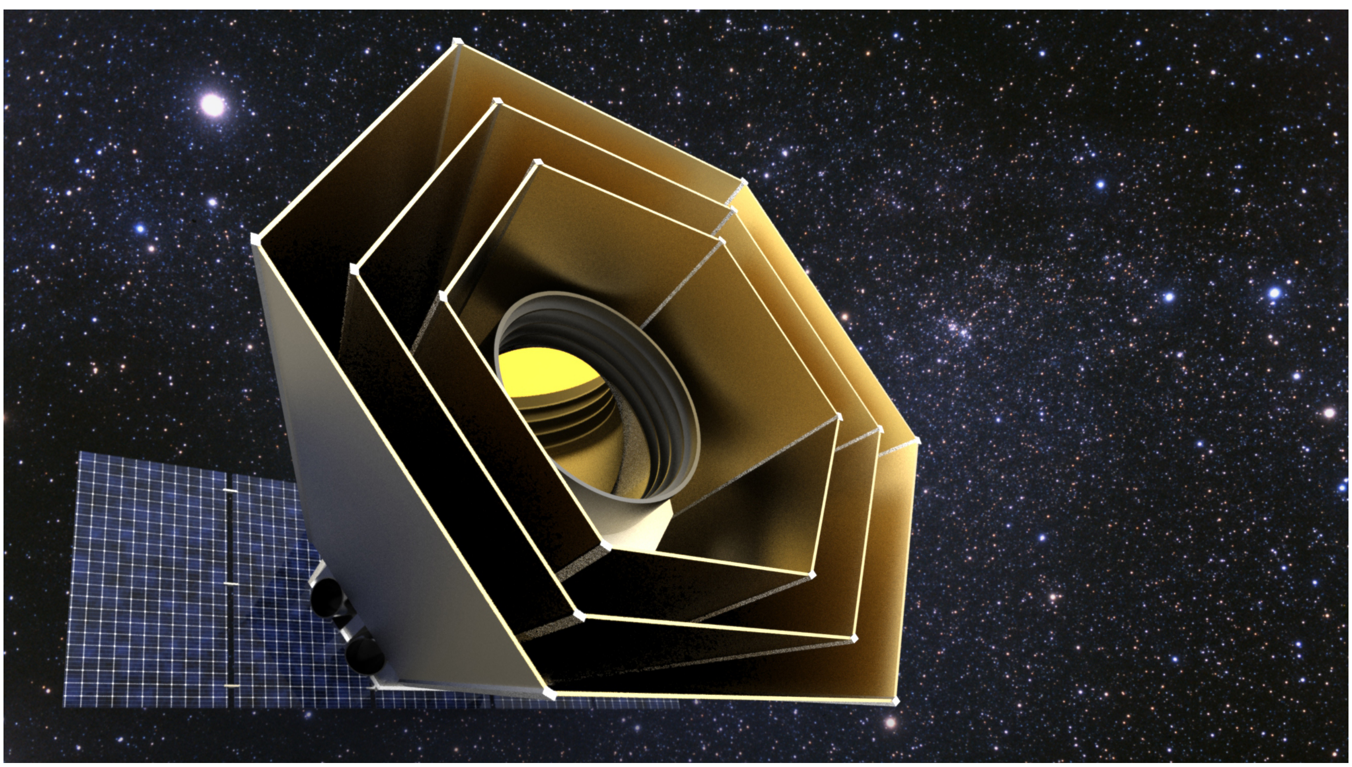

Fig. 1.   An artistic rendition of the Cosmic Dawn Intensity Mapper stationed at Sun-Earth L_2.

1. Introduction

Observing the behavior and characteristics of the earliest stars and galaxies is fundamental to understanding the physics that led to their formation and evolution. Breakthrough discoveries in understanding the physics of the epoch of reionization are anticipated in the 2020–2030 decade thanks to WFIRST and JWST. However, JWST's capability will be limited to only several cosmological deep fields. Although WFIRST will be capable of wide area surveys, its spectroscopy is limited to 2 µm and thus limits the selection of galaxies it is able to observe. Neither JWST nor WFIRST provide a complete understanding of the epoch of reionization, specifically in terms of answering the questions of when and how the cosmic dawn came to be. This area of research is a prime candidate for a Probe class mission optimized to study reionization.

Probe class missions occupy a role on a larger scale than Discovery missions, such as Kepler and Dawn, but not as vast as Flagship missions such as JWST (Wiseman *et al.*, 2015). Such missions are intended to be PI-led scientific investigations rather than general observatories, and have a firm $1B cap.

Cosmic Dawn Intensity Mapper (CDIM) is a Probe class infrared telescope capable of three-dimensional spectro-imaging observations over the wavelength range of 0.75 to 7.5 µm, at a spectral resolving power $\Delta\lambda/\lambda$ of 500. CDIM has a 10 deg^2 instantaneous field of view (FoV) utilizing linear variable filters (LVFs) atop a focal plane of thirty-six 2048×2048 detectors. The survey strategy using spacecraft operations following a shift and stare mode will result in 1360 independent narrow-band spectral images of the sky on a given location. Surveys could span from 25 deg^2 up to 1000 deg^2 over a five year lifetime in an orbit about Lagrange point L_2.

With these instrument requirements, CDIM is optimized to search for the first cosmic sources of dust and evidence of the very earliest stellar populations, bridging the gaps in JWST and WFIRST cosmic dawn surveys and exceeding them in capability.

CDIM is notionally a 1.5 m aperture telescope, passively cooled to 45 K, with a 6×6 detector array that utilizes linear variable filters (LVFs) and actively cooled to 35 K (Cooray *et al.*, 2016).

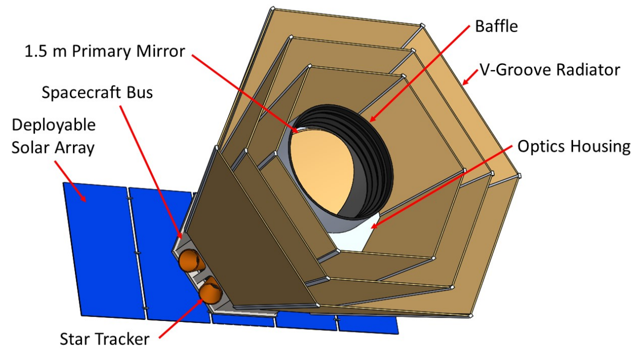

Fig. 2. CDIM consists of a passively cooled 1.5 m aperture OTA, actively cooled focal plane, and off-the-shelf spacecraft components where applicable.

2. Optical Telescope Array

Preliminary explorations indicate that a 1.5 m aperture off-axis primary mirror cooled to 45 K is required to meet CDIM's spectro-imaging requirements (Cooray *et al.*, 2016). The primary mirror is notionally assumed to be constructed from light-weighted Corning (ultra-low expansion) silica-titania glass with a honeycomb core and a gold-deposition surface coating. "Back-of-the-envelope" calculations estimate the primary mirror's mass to be roughly 200 kg.

Multiple detectors satisfy CDIM's spatial resolution, wavelength range, and sensitivity requirements. These detectors range in TRL, but all are sufficiently developed to be considered for the 2020 Decadal and have been demonstrated on missions such as NEOCam, SPHEREx, and JWST.

Teledyne H2RG-18 HyViSI detectors offer a 2048×2048 pixel array format at a pixel pitch of 18 µm (Bai *et al.*, 2008). CDIM will utilize a 6×6 H2RG array. Each detector nominally dissipates less than 4 mW, for a total power dissipation of less than 150 mW for the array.

CDIM optics, instruments, and focal plane will be housed in a light-tight box. The optical telescope assembly (OTA) as a whole is estimated to have a mass of x kg.

3. Thermal Regulation

CDIM employs both passive and active thermal regulation systems. By using passive radiators in tandem with an active cryocooler, the static OTA heat load can be dissipated by the lightweight radiator and a smaller cryocooler may be used to only cool the detector array rather than the whole OTA mass plus focal plane assembly.

The OTA is cooled to 45 K passively to reduce background photon load in the near-IR. Passive thermal regulation is maintained using a V-groove radiator, which bounces radiative heat into the 3 K background of space. V-groove radiators have been demonstrated in passive cryogenic radiators up to 4 K with Planck and JWST. In order to achieve passive cooling from a baseline temperature of 300 K at Sun-Earth Lagrange point L_2, a x-stage V-groove radiator with an area of x m^2 is required.

The CDIM detector array is actively cooled to 35 K to reduce thermal noise. Stirling-cycle mechanical refrigerators are low-vibration, high-reliability, and lightweight active cryocooling systems that have significant heritage in space applications. One candidate system is Raytheon's PSC 1-stage Stirling cryocooler, capable of cooling a 1.2 W parasitic heat load to 35 K. This cryocooler is 18.6 kg and requires 88 W of input power (Donabedian *et al.*, 2003).

3.1. *Attitude Determination and Control*

Recall attitude control requirements for science objectives. System architecture requires the spacecraft to first understand its orientation and then act to align itself with a given area of the sky.

Explain the star tracker among other attitude control systems. Select a class of star tracker.

Briefly explain inertial and propulsive attitude control and the limitations of each. The system will ideally be inertial only, but larger systems like JWST need a combination of both.

Attitude determination and control systems account for a percentage of the total power draw of the system.

3.2. *Telemetry*

The spacecraft must receive commands from ground stations at Earth and transmit telemetry and data from L2. Since the desired data transfer rate is what it is, this type of telemetry system is required.

3.3. *Power*

All power generation will come from an array of photovoltaic cells facing the sun. In order to survey the entire sky, the cells must be able to adjust to account for different incident angles to the sun. The array must deploy after the launch portion of the mission.

Based on a rough power budget and the spacecraft's position at L2, the array must be a bunch of square meters in area to sustain operation. The dark side of the array acts as a radiator to contribute to the thermal regulation of the spacecraft bus.

Battery banks will store energy.

4. Structure

The spacecraft/vehicle/bus houses all non-instrumentation systems including the cryocooler, ADCS, and power modules. It would have approximately some dimensions and be made of standard materials. The bus will also include hard points for integration with the launch vehicle.

5. Mission Profile

5.1. *Launch Vehicle*

The spacecraft will be integrated to a launch vehicle such as an Ariane V (which will deliver JWST) or Ares V (9400kg capacity to L2) and delivered to L2. Launch vehicle selection is limited by spacecraft mass and size.

5.2. *Operations*

5.3. *End of Life*

6. Budgets & Costs

7. Conclusion

Acknowledgments

Thanks.

References

Bai, Y., Bajaj, J., Beletic, J. W., Farris, M. C., Joshi, A., Lauxtermann, S., Petersen, A. & Williams, G. [2008] "Teledyne imaging sensors: silicon cmos imaging technologies for x-ray, uv, visible, and near infrared," doi:10.1117/12.792316, URL http://dx.doi.org/10.1117/12.792316.

Cooray, A., Bock, J., Burgarella, D., Chary, R., Chang, T.-C., Doré, O., Fazio, G., Ferrara, A., Gong, Y., Santos, M., Silva, M. & Zemcov, M. [2016] *ArXiv e-prints* .

Donabedian, M., of Aeronautics, A. I., Astronautics & (Firm), K. [2003] *Spacecraft thermal control handbook* (Aerospace Press, El Segundo, Calif), ISBN 9781884989148;1601192207;9781601192202;1884989144;.

Wiseman, J., Clampin, M., Danchi, W., Mather, J., Oegerle, W., Barry, R., Traub, W., Stapelfeldt, K., Lissauer, J., Borucki, W., Greene, T., Bennett, D.

& Johnston, K. [2015] "Space-based "probe class" missions for exoplanet research," https://science.gsfc.nasa.gov/667/whitepapers/ProbeClassMissions_whitepaper.pdf.