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*

[1] *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);

Very abstract.
Much interesting.

Keywords: A list of 3–5 keywords are to be supplied, separated by commas.

1. Introduction

Observing the behavior and characteristics of the earliest stars and galaxies is fundamental to understanding the physics that to their formation and evolution.

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). Probe class 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 $10\,\mathrm{deg}^2$ instantaneous field of view (FoV) utilizing linear variable filters (LVFs) atop a focal plane of thirty-six $2048\hat{2}$ 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 $25\,\mathrm{deg}^2$ up to $1000\,\mathrm{deg}^2$ 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). Key technical characteristics of CDIM are summarized in table:techreqs.

2. Mirror

Recall requirements such as FoV, spectral resolution. Technical requirement of temperature. Based on spectral resolution and FoV, need between 1m-1.5m. Based on cost estimates from Stahl, estimate target diameter, which rersults in target mass.

[†]Corresponding author.

Table 1. CDIM Instrument Technical Requirements

Parameter	**Requirement**
Wavelength range	0.75 to 7.5 µm
Spatial resolution at 5 µm	θ_{pix}<2″
Photometric sensitivity at 5 µm	27 AB mag
Spectral line sensitivity	4×10^{-18} ergs $s^{-1}cm^{-2}$
Spectral resolving power	$\Delta\lambda/\lambda > 300$
Surface brightness sensitivity	(?)

3. Detector

4. Thermal Regulation

General approach to cooling with passive and active. Explain tradeoffs between passive and active.

4.1. *Passive Cooling*

Explain generally how v-groove radiators work. Used on planck and jwst. Desired final temp based on material, setup and location. Area based on general size of telescope. May need to be deployable.

4.2. *Active Cooling*

Detectors use active cooling to bring temp below passive temp. Explain why active needed to manage thermals of detectors. Target temperature and estimated heat dissipation.

Describe types of cryocoolers and the high-level traits/tradeoffs between them. Choose one in particular, but leave wiggle room for others to be chosen. Explain the architecture for implementing this type of cooler, including power draw and mass.

5. Spacecraft Bus

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.

5.1. *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.

5.1.1. *Determination Systems*

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

5.1.2. *Control Systems*

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.

5.2. *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.

5.3. *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.

6. Mission Profile

The mission profile encompasses spacecraft and ground operations from launch until the end of the scientific mission (5 years).

6.1. *Launch Phase*

The spacecraft will be integrated to a launch vehicle such as a Falcon 9 or Atlas V and delivered to L2. Launch vehicle selection is limited by spacecraft mass and size.

6.2. *Initialization Phase*

The deployables deploy and the v-grooves begin to cool the spacecraft down to the passive threshold. The response time of the passive coolers is very long as mentioned above. After the initial cooldown, active cooling engages.

6.3. *Observation Phase*

The spacecraft is ready to perform observations and survey the early universe. This is the nominal operation phase and will last five years.

7. Cost

The overall cost of CDIM is a composite of hardware and ground operations costs. Since all of the technologies proposed are relatively well developed, R&D does not contribute very much to the overall cost estimation.

TABLE Estimated costs of hardware systems.

FIGURE Chart of relative costs by subsystem.

By a parametric study of missions for which data was available, Stahl correlated space telescope overall mission cost as a function of mirror aperture diameter. Using the median trendline, it is estimated that this telescope falls under the Probe class designation.

Feeding estimated hardware costs into the mission cost relationship between ground ops, hardware, etc., the estimated cost ends up falling into this range, confirming the estimate.

FIGURE Chart of relative costs by category (hardware, ground ops, etc.).

8. Conclusion

Summarize points made above. Notable points include mirror diameter, detector, power budget, mass budget, total cost, and the fact that technologies are already significantly developed.

FIGURE Render of spacecraft with bus?

Acknowledgments

Thanks.

References

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* .

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.