National Aeronautics and Space Administration

Intensity Mapping Data Analysis

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OBJECTIVES

We aim to build a semi-numerical simulation tool, **LIMFAST**, to model emission lines in the Intensity Mapping (IM) regime during cosmic reionization that is fast, flexible, large-scale and with appropriate galaxy astrophysics.

BACKGROUND

The recently developed technique of intensity mapping has the great potential to trace the cosmic structures from the present day out to high redshifts, when the Universe was less than 100 Myrs old. Intensity mapping uses spectral line emission associated with large-scale structure to trace the growth and evolution of the Universe.

Instead of detecting line emission from individual galaxies, one measures the total line emission from a number of galaxies within a larger cosmic volume comprising a spectral-spatial pixel. Fluctuations from pixel to pixel trace large-scale structure, and the evolution with redshift is revealed as a function of observed frequency (Fig. 2). This allows us to probe and understand the dominant physics and astrophysics at play during structure formation, such as the onset of first stars, cosmic dawn and reionization, galaxy formation and evolution and dark energy domination.

Intensity mapping is an active and emerging field, with several on-going experiments now start to take science data. While there have been early intensity mapping results (e.g., Chang et al. 2010; Cheng et al. 2018), these have provided primarily upper limits and several challenges remain for a full exploitation of this technique. This requires a large number of large-scale simulations appropriate for the emission lines during the Cosmic Reionization, which is currently lacking in the field.

APPROACH

LIMFAST builds on top of the public 21cmFAST simulation (Mesinger et al. 2011) that provides the distribution of matter and radiation background during reionization, as well as the neutral gas distribution. We included analytical models of galaxies and star formation that provide the radiation sources at z = 5 – 25 and consider their temporal evolution. The emission of different spectral lines and physical properties of the sources are modeled by interpolating tabulated results precomputed with stellar synthesis population and photoionization codes, allowing for different implementation of star-formation and radiative properties in a computationally efficient manner (Fig. 1).

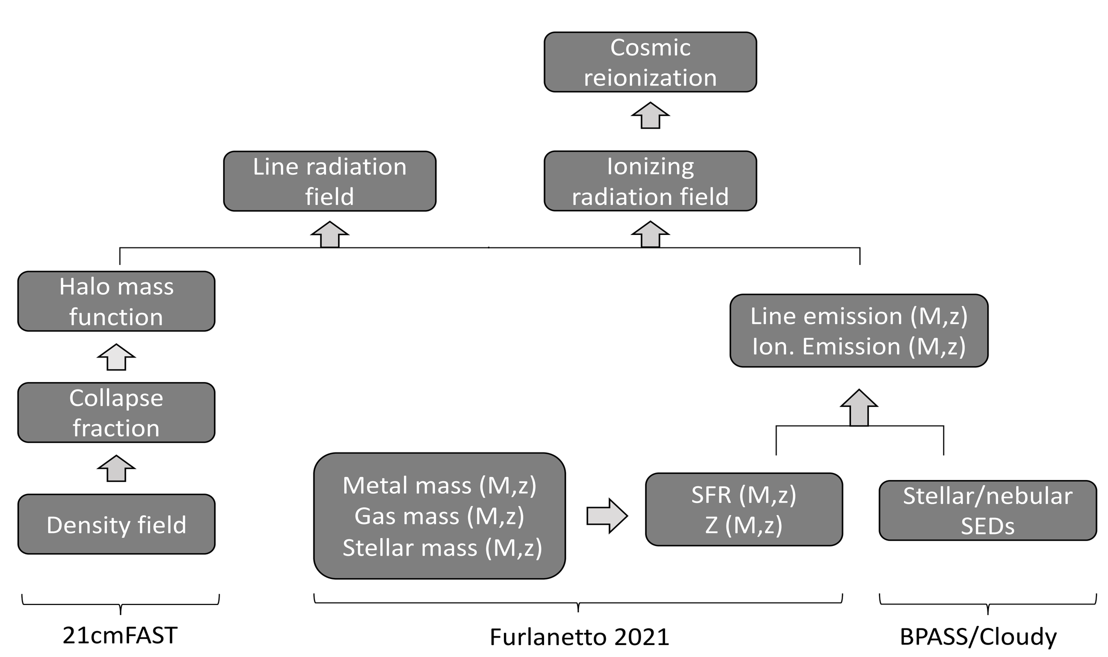

Figure 1. Flow chart of the main modules in ***LIMFAST****. From left to right, the computation of the matter density field in 21cmFAST, the modeling of radiative sources from an analytical galaxy model, and the resulting emission of spectral lines from tabulated photoionization calculations over a broad range of physical parameters.*

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REFERENCES
* Chang, T.-C., et al., 2010, Nature, 466, 463
* Cheng et al, 2018, ApJ, 868, 26
* Mesinger et al., 2011, MNRAS, 411, 955

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RESULTS

- **Fast simulations enabling various reionization scenarios.**
- **Modeling of multiple emission lines; Lya, Ha, CO, CII, OII, OIII, 21cm, etc.**
- **Coverage of large cosmic volumes extending out to linear regimes.**
- **Self-consistent computation of reionization and global galaxy properties (Fig 2)**
- **Incorporation of high–redshift galaxy models and photoionization calculation for line emission predictions(Fig 3)**
- **Implementation of power-spectra calculations for analysis.**

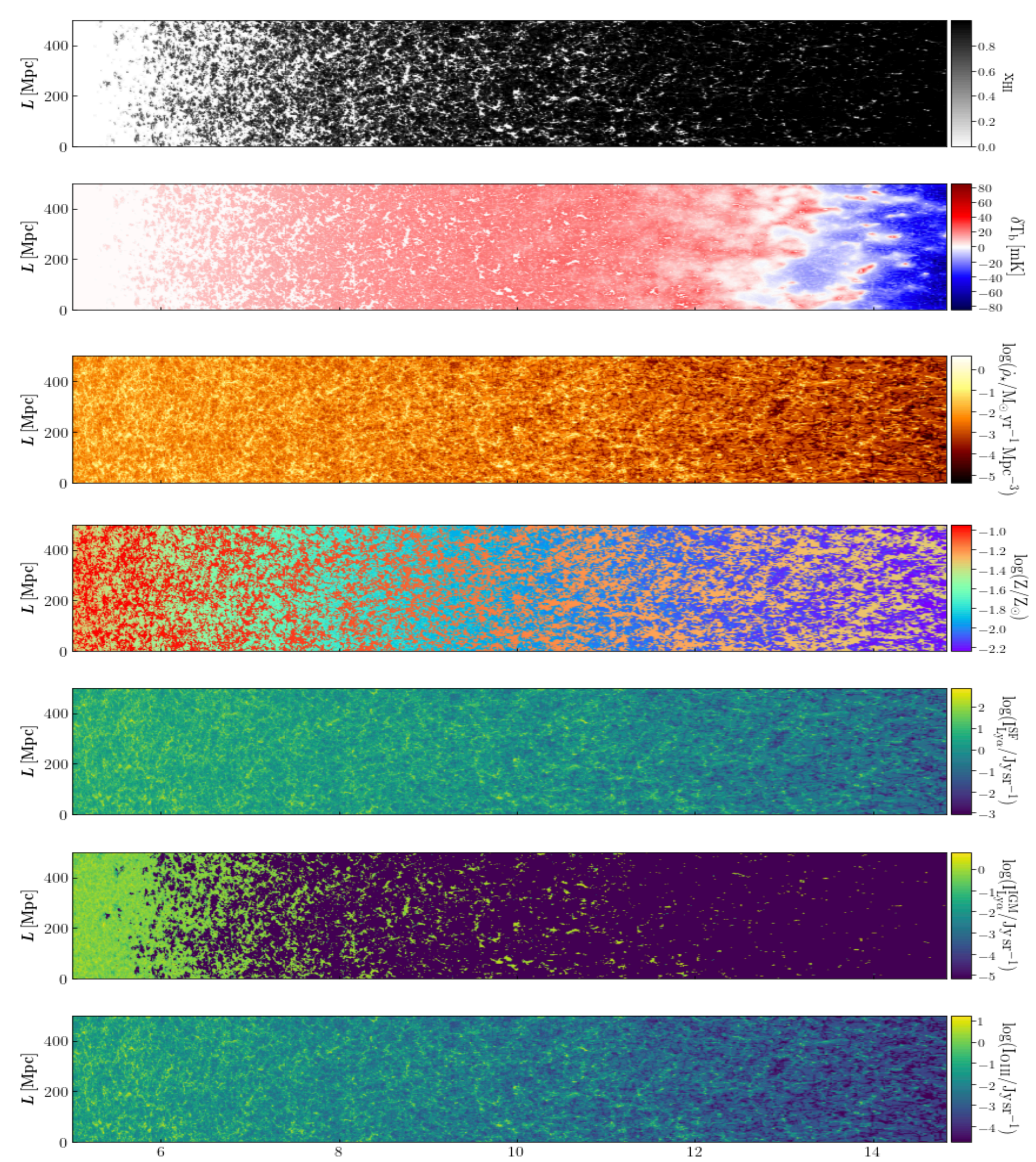

Figure 2. LIMFAST light cones covering the redshift range 5 ≤ z ≤ 15. From top to bottom, the signals correspond to the hydrogen neutral fraction, the brightness temperature of the 21cm radiation, the star formation rate density, the metallicity of collapsed structure, and the intensity of Lyα emission, arising from star formation and recombination in the IGM, as well as the intensity of the O II at 3727 Å line emission (Mas-Ribas et al. 2022).

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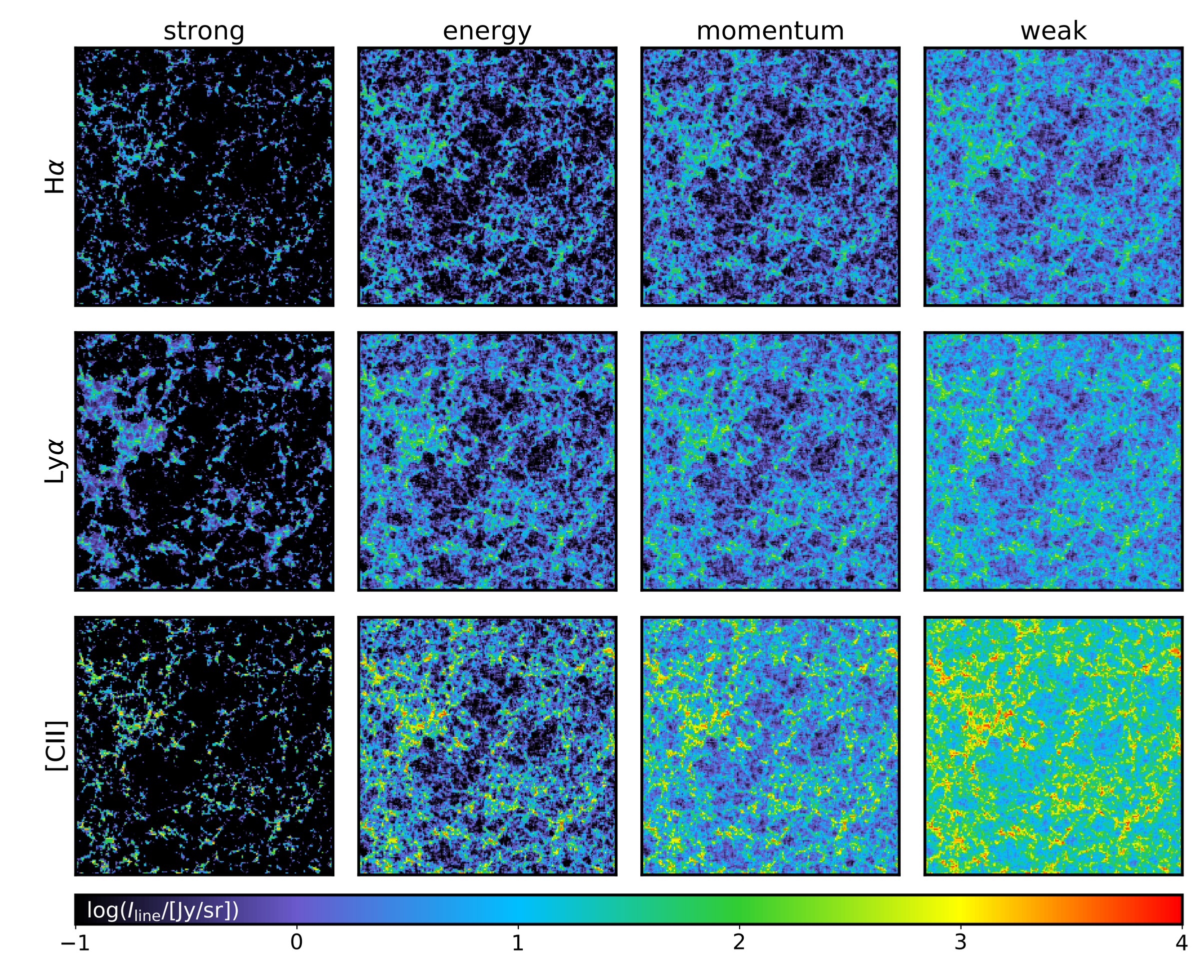

Figure 3. Slices of Hα, Lyα and [CII] line intensity fields at z ≈ 7 from LIMFAST assuming different galaxy stellar feedback prescriptions (strong, energy, momentum and weak). Each slice is 200 Mpc on a side and 1 Mpc thick (Sun et al. 2022).

BENEFITS TO JPL AND NASA

Caltech-JPL is the leading institution with strong involvement in several IM experiments. Much of the current intensity mapping work is ground-based with space mission coming soon, and key experiments are led by Caltech campus with JPL participation: GBT-HIM (21 cm, PI Chang, JPL), COMAP (CO, PI Cleary, CIT), TIME ([CII], PI Crites/Bock, Cornell/CIT/JPL), LWA (21 cm, PI Hallinan, CIT), SPHEREx (Ha/Lya, PI Bock, PS Doré, CIT/JPL)

Mission possibilities run the spectrum from Explorer-class to probe-class missions. For example: SPHEREx (MIDEX, Phase C, PI Bock) has an important IM component (PS Doré, Co-I Chang). Cosmic Dawn Intensity Mapper (CDIM) Probe study (PI Cooray, Study Scientist Chang, Co-I Doré) proposes multi-line IM of the Epoch of Reionization. FARSIDE Probe study (PI Burns, Co-PI Hallinan, Co-I Chang) has a 21cm Dark Ages component. CHIC 21cm Cosmic Dawn concept under study (MoO; PI Chang, Co-I's Doré and Seiffert). We envision there are multiple long term benefits to JPL and NASA from the application of LIMFAST.

PUBLICATIONS

- Cheng, Y.-T., .. Bock, J.J., Chang, T.-C. et al., The Astrophysical Journal, Volume 901, Issue 2, id.142 2020
- Mas-Ribas, Ll. & Chang, T.-C., PRD, Volume 101, Issue 8, article id.083032, 2020.
- Sun, G., Chang, T.-C., Bock, J.J., et al. The Astrophysical Journal, Volume 915, Issue 1, id.33, 24 pp. 2021
- Cheng, Y.-T. & Chang, T.-C., Cosmic Near-Infrared Background Tomography with SPHEREx Using Galaxy Cross-Correlations, 2021, submitted to ApJ
- Mas-Ribas, Ll., Sun, G., Chang, T.-C., et al., LIMFAST I: a semi-analytical tool for LIM, 2022, ApJ, 925, 19, arXiv:2206.14185
- Sun, G., Mas-Ribas, Ll., Chang, T.-C., et al., LIMFAST II: Understanding Galaxy Astrophysics During the Epoch of Reionization with Multi-Tracer Line Intensity Mapping, 2022, submitted to ApJ, arxiv: 2206:14186
- Parsons, J. et al., LIMFAST III: revealing the IMF of Population III stars with LIMFAST, 2022, ApJ, 933, 141

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