Intensity Mapping Data Analysis

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Program: FY21 R&TD Strategic Initiative **Strategic Focus Area: Astrophysics Data Analysis**

OBJECTIVES

Build a semi-numerical simulation tool, **LIMFAST**, to model emission lines in the Intensity Mapping (IM) regime during cosmic reionization.

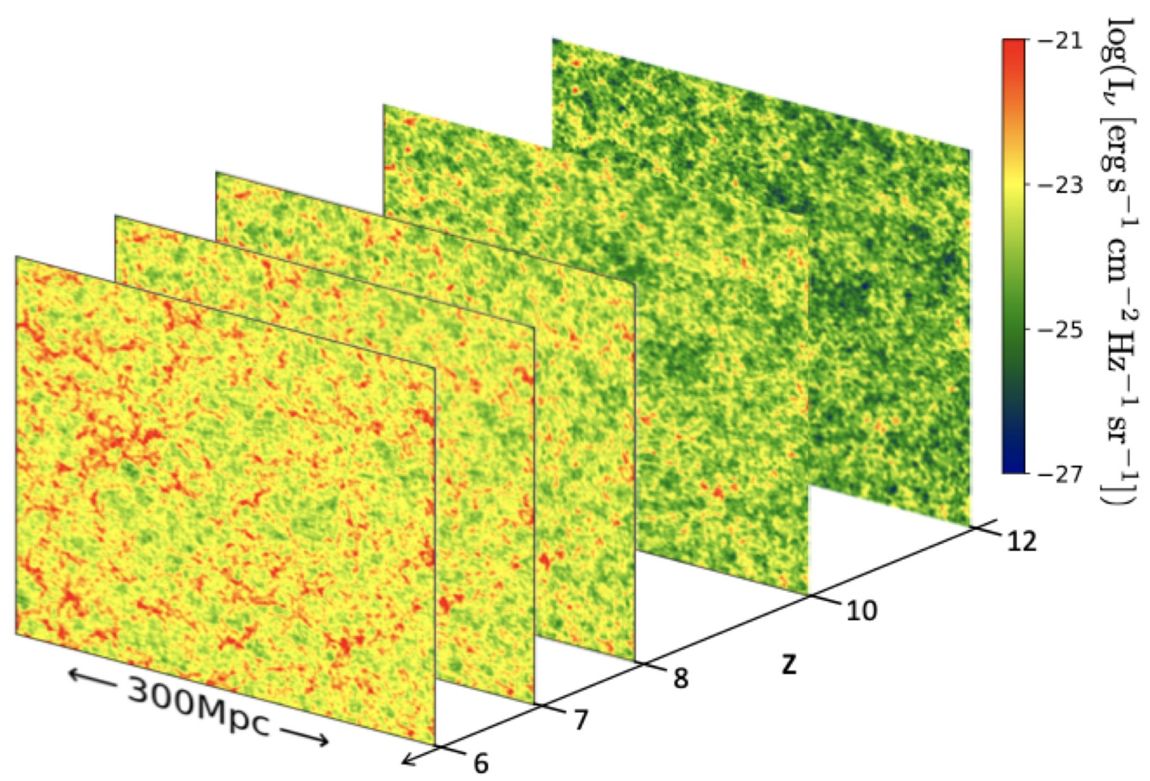

Figure 1. Intensity maps of Lyman-alpha emission from star formation at redshifts z=6-12 during cosmic reionization from LIMFAST.

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. 1). 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.

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REFERENCES
* Chang, T.-C., et al., 2010, Nature, 466, 463
* Cheng et al, 2018, ApJ, 868, 26
* Mesinger et al., MNRAS, Volume 411, Issue 2, pp. 955-972

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. 2).

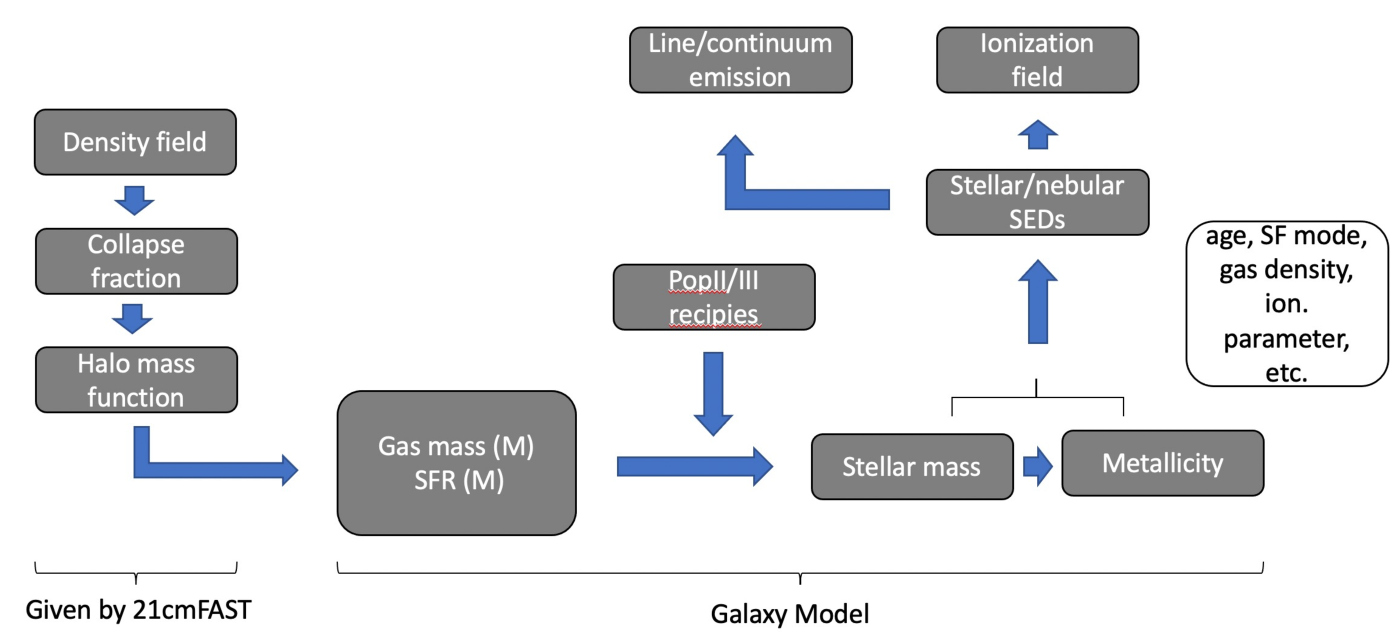

Figure 2. Flow chart of the main modules in ***LIMFAST****. From left to right, the computation of the matter density field in 21cmFAST, the modeling of radiative sources from an analytical galaxy model, and the resulting emission of spectral lines from tabulated photoionization calculations over a broad range of physical parameters.*

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 line emission (Fig 4).**
- ❖ **Implementation of power-spectra calculations for analysis (Fig. 3).**

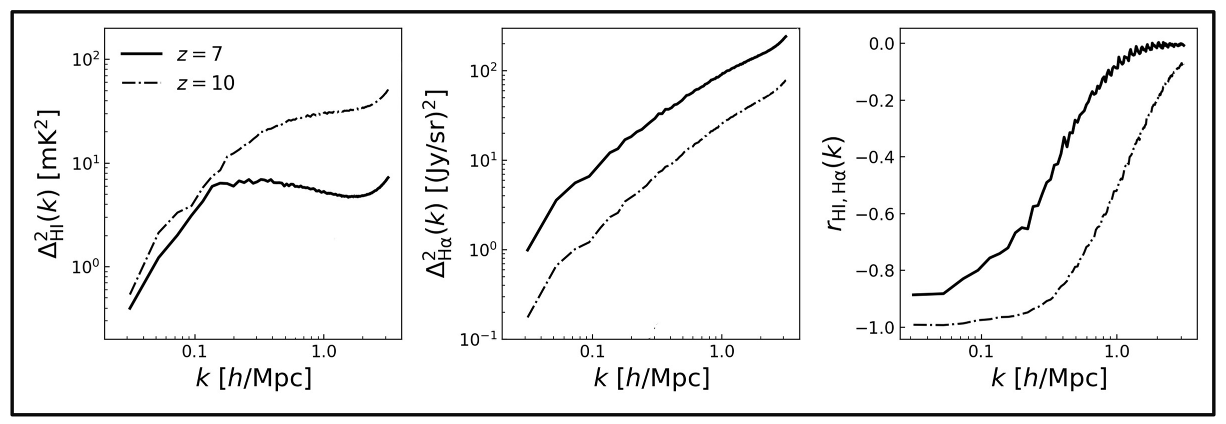

Figure 3. From left to right, power spectra of HI 21cm, Ha and the cross-correlation coefficient between the two from LIMFAST outputs. Differences between redshifts at z=7 and z=10 highlight the progress of reionization with time.

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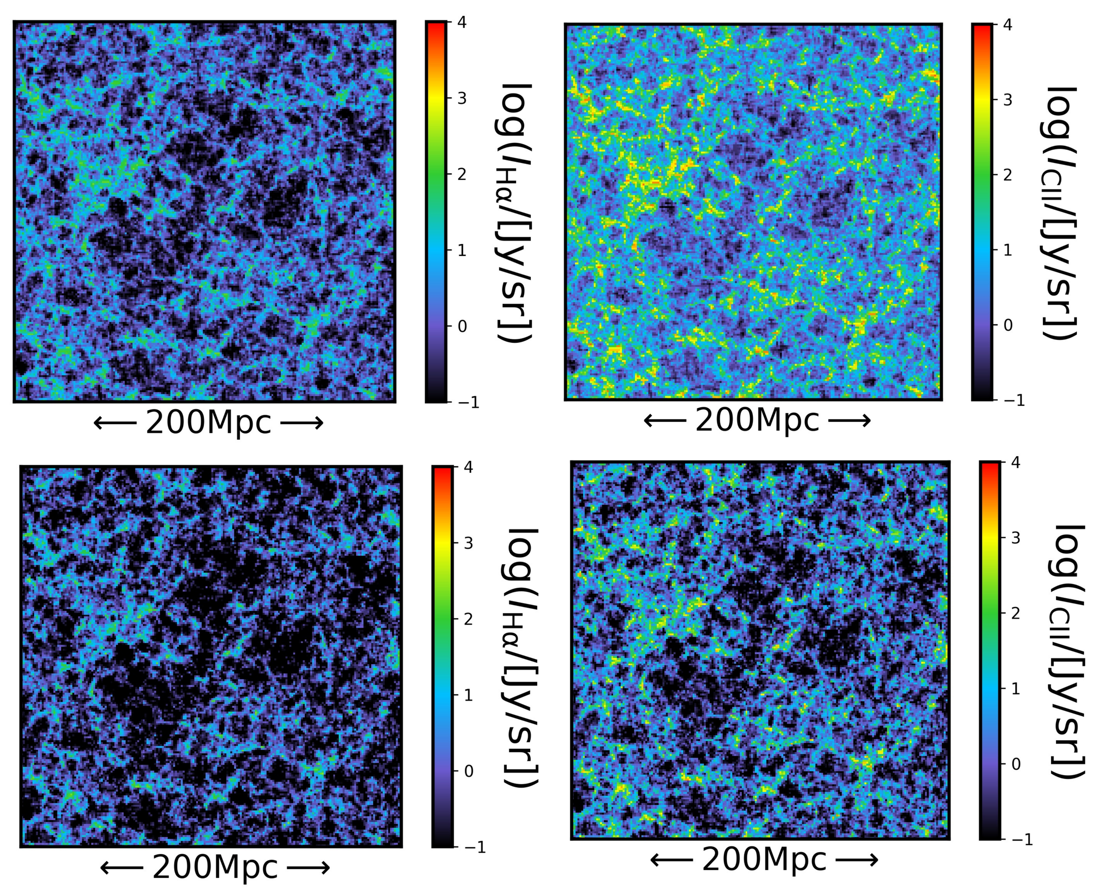

Figure 4. Intensity maps of Ha (left) and [CII] (right) at redshifts z=7 (top)and z=10 (bottom) from LIMFAST.

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). GEP Galaxy Evolution Probe study (PI: J. Glenn) is investigating the IM science case.

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 (in prep.)
- ❑ 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 (in prep.)
- ❑ Parsons, J. et al., LIMFAST III: revealing the IMF of Population III stars with LIMFAST (in prep.)

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