Intensity Mapping of Cosmic Structures

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Program: Strategic

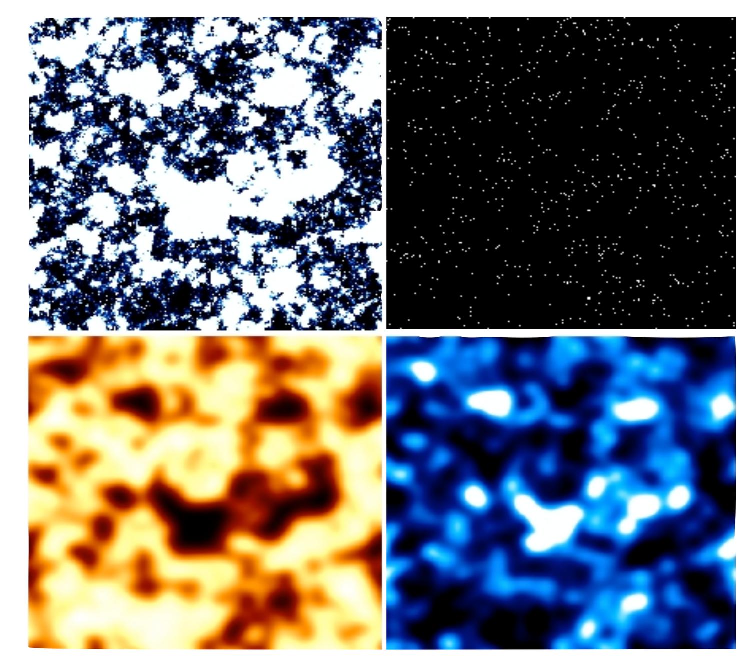
Project Objective:

- Intensity mapping (IM) with multiple emission lines (HI, CO, [CII]) promises new insights on both the evolution of the Universe at low redshifts and the epoch of reionization and Cosmic Dawn at higher redshifts.
- Early efforts (Chang et al., *Nature*, 466, 463, 2010), have provided primarily upper limits.
- Several challenges remain for a full of the astrophysical and cosmological potential. Our effort addresses these challenges:
  (1) Reduce systematic error associated with astrophysical foreground emission.
  (2) Provide robust physical interpretation of the observations.
- Our program tackles these problems by building on existing data sets, analysis techniques, and physical models pioneered by team members. In the process, we will gather new state-of-the-art measurements and physical insights.

Benefits to NASA and JPL (or significance of results):

Intensity mapping has received important recognition by NASA SMD, with a decision funded the probe concept study *Cosmic Dawn Intensity Mapper* (CDIM) led by Prof. A. Cooray (UCI). Chang is the lead JPL scientist and Doré is a co-I. Intensity mapping is also an important part of two other probe studies, *Galaxy Evolution study*, and the *Cosmology Microwave Background Polarization* probe in which we are involved. The recently selected NASA MIDEX *SPHEREx* mission (PI: J. Bock; PS: O. Doré) has an important intensity mapping component for the large-scale structure and cosmic reionization sciences.

Intensity Mapping: *key concepts*



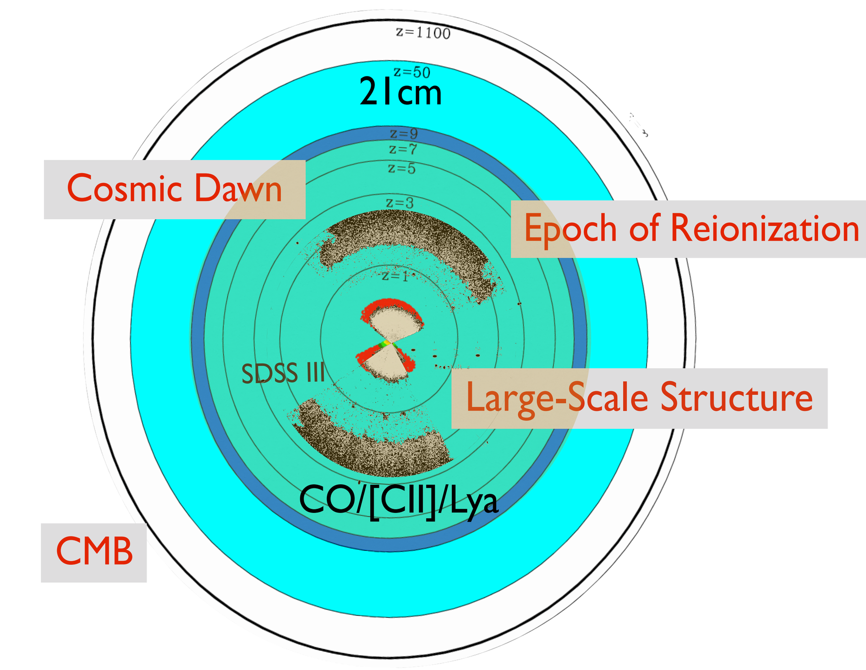
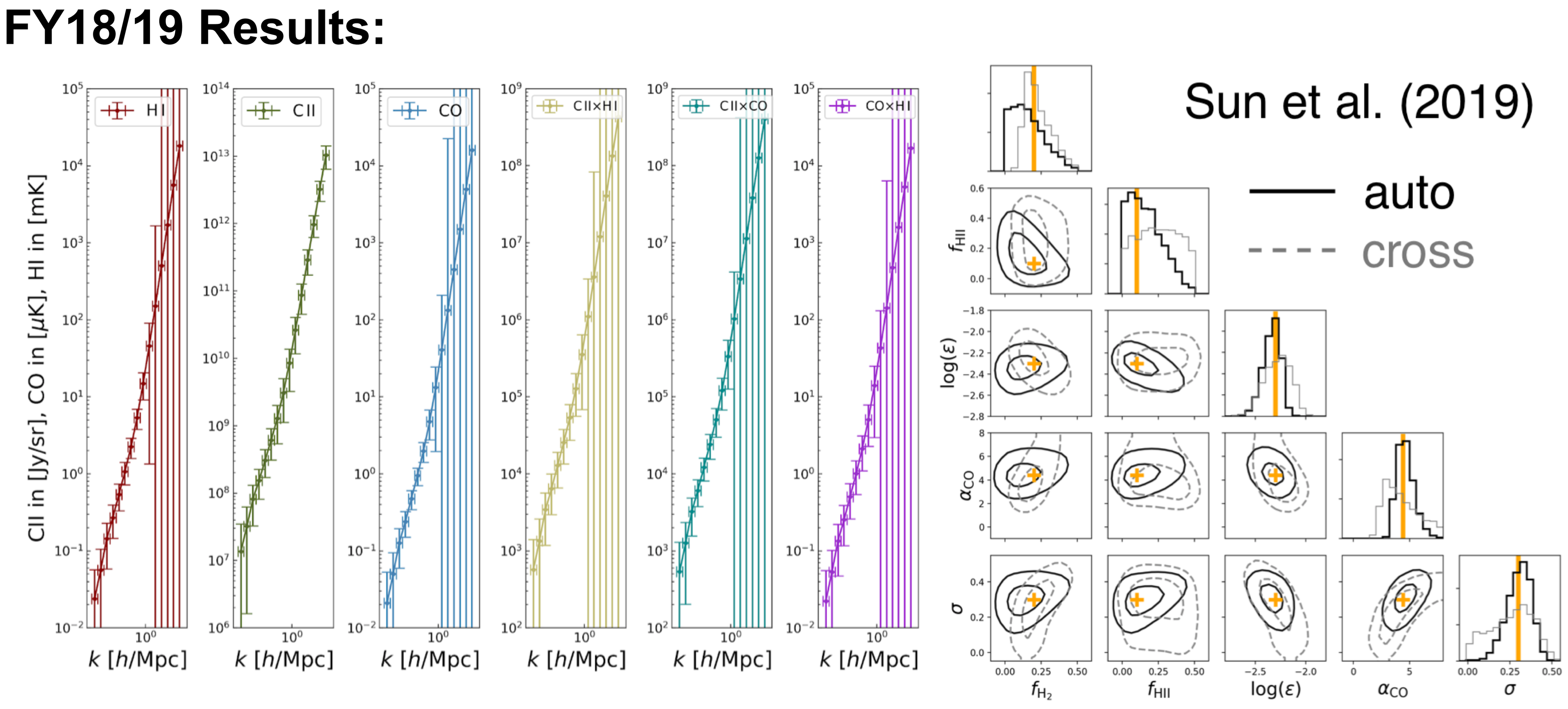
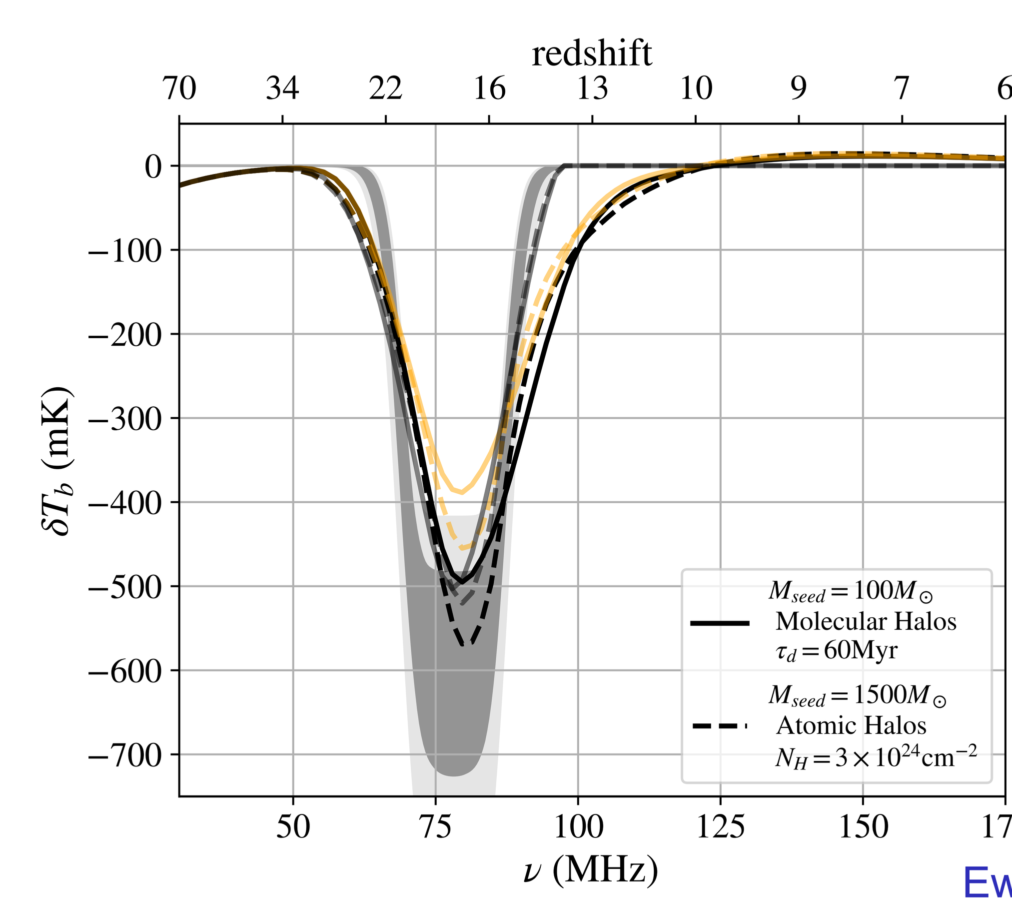


Figure 1. Intensity mapping will provide a multi-line view of the Epoch of Reionization, enabling a detailed understanding of the physical processes at work. Upper left is a simulated ionization field at *z*=7. At upper right is the corresponding galaxy field as might be observed with JWST. Lower left is the corresponding 21 cm line emission intensity map, and lower right is a line emission intensity map as traced by [CII], CO, or Lyman-alpha. The radio 21 cm primarily traces neutral gas, whereas Lyman-alpha traces sources of ionization, and [CII] and CO provide additional physical indications. Rich information is available from the cross correlation of these signals.

Figure 2. Potentially accessible cosmological volume with HI 21 cm intensity mapping (light blue). The surface of last scattering, where the CMB forms, is the dark line at *z* = 1100. The dark blue band at *z* = 9 indicates the approximate EoR. The volume accessed by the Sloan Digital Sky Survey (SDSS) is shown in red. The potential for the Hi cosmological measurements is obvious. The volume accessible to CO and [C ii] lines is modestly smaller, likely extending only to when the first galaxies had formed (*z* ~ 9), but nonetheless substantial. (Adopted from Tegmark & Zaldarriaga, 2008.)

FY18/19 Results:





Ewall-Wice, Chang, Lazio 2019

Figure 3. ***Using the auto- and cross-power spectra of multiple emission lines in the intensity mapping regime to constrain the mean physical properties of the multiple interstellar medium (ISM) phases (Sun et al. 2019). Left***: mock data sets of the observed [CII] auto power spectrum and [CII] × HI, [CII] × CO and CO × HI cross power spectra at $z \sim 2$. The error bars are calculated via mode counting assuming the Case II experimental setups in Table 3 of Sun et al. 2019. ***Right***: joint posterior distributions of the molecular gas fraction f_{H2}, the ionized gas fraction $f_{H\,II}$, the photoelectric heating efficiency ϵ_{PE}, the molecular gas density n_{H2} and the scatter σ, shown for 68% and 95% confidence levels as constrained by the auto-correlation (solid contours) and cross-correlation data (dashed contours). The true values in our reference ISM model used to generate mock observations are indicated by the orange cross symbols. Diagonal panels show the marginalized distribution of each individual parameter.

Figure 4. We use a semi-analytic model to explore the impact of radio-loud black-holes on the mean HI hyperfine 21 cm signal during the Cosmic Dawn (Ewall-Wice, Chang, Lazio 2019). We find that radio emission from super-massive black hole seeds can impact the global 21cm signal at the level of tens to hundreds of percent provided that they were radio loud and obscured by gas with column depths of $N_H > 10^{23}$ cm^{-2}. Shown are the global 21cm brightness temperature (δT_b) in absorption against the radio background during Cosmic Dawn. We find various sets of parameters that reproduce some of the striking features of the EDGES absorption feature (Bowman et al. 2018), plotted at 68% and 95% contours in grey, including its depth, timing, and side steepness while producing radio/X-ray backgrounds and source counts that are consistent with published limits. Scenarios yielding a dramatic 21cm signature also predict large populations of ∼ μJy point sources that will be detectable in upcoming deep surveys from the Square Kilometer Array (SKA).

Publications:

- A Self-Consistent Framework for Multi-Line Modeling in Line Intensity Mapping Experiments, G. Sun, B. Hensley, T.-C. Chang, O. Doré, P. Serra, submitted to ApJ, arXiv: 1907.02999
- *The Radio Scream at Cosmic Dawn: A Semi-Analytic Model for the Impact of Radio Loud Black-Holes on the 21 cm Global Signal, A.* Ewall-Wice, T.-C. Chang, J. Lazio; submitted to MNRAS, arXiv:1903.06788
- *Optimally mapping Large-Scale Structures with luminous sources, Y.-T.* Cheng, R. de Putter, T.-C. Chang, O. Doré, 2019, ApJ, 877, 86
- *Multi-Component Decomposition of Cosmic Infrared Background Fluctuations, C.* Feng, A. Cooray, J. Bock, T.-C. Chang, O. Doré, M. Santos, M. Silva, M. Zemcov, 2019, ApJ, 875, 2, 86
- Modeling the Radio Background from the First Black Holes at Cosmic Dawn: Implications for the 21 cm Absorption Amplitude, A. Ewall-Wice, T.-C. Chang, J. Lazio, O. Doré, M. Seiffert, R. Monsalve, 2018, ApJ, 868, 63

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