Studying the galaxy evolution with (line) intensity mapping

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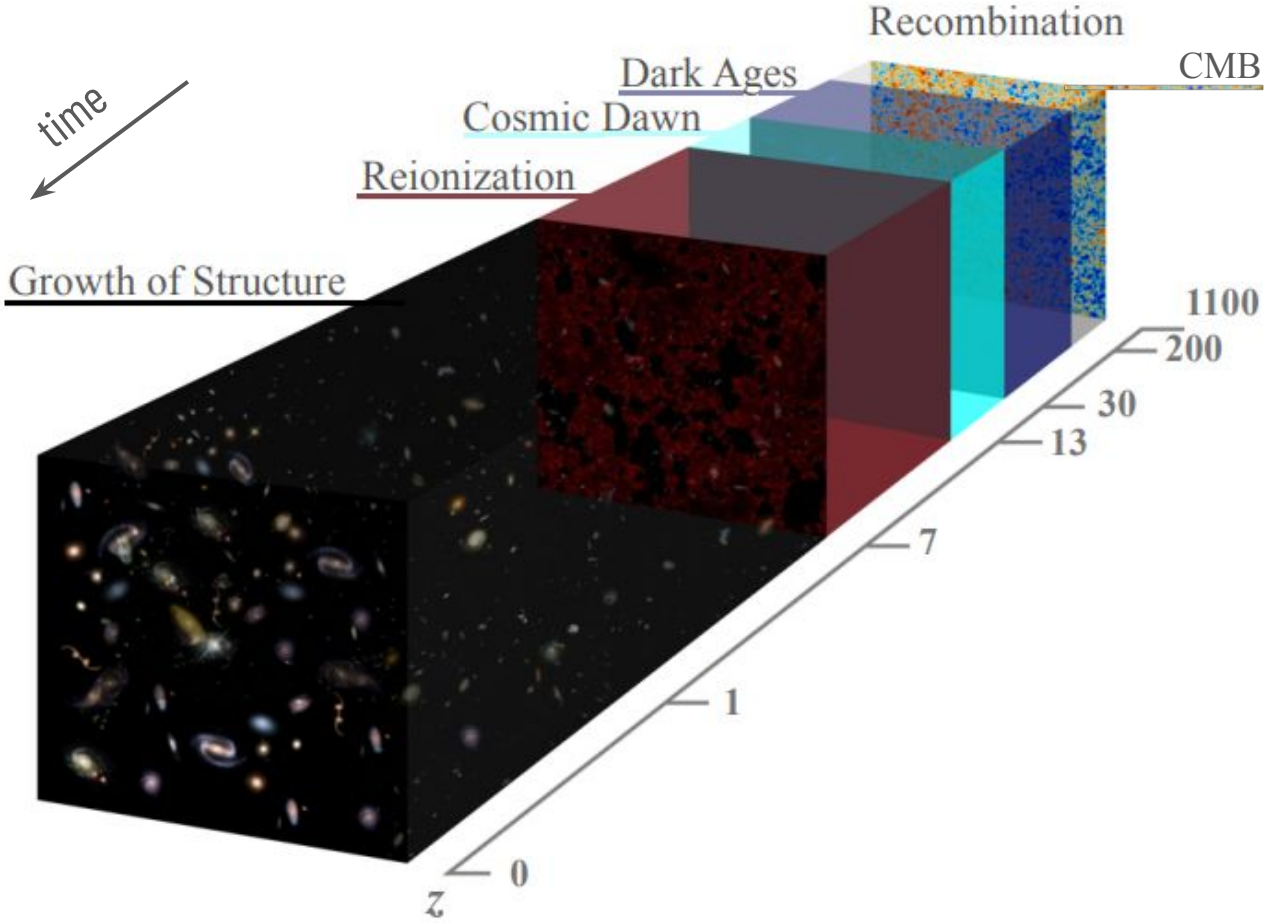
Collaborators

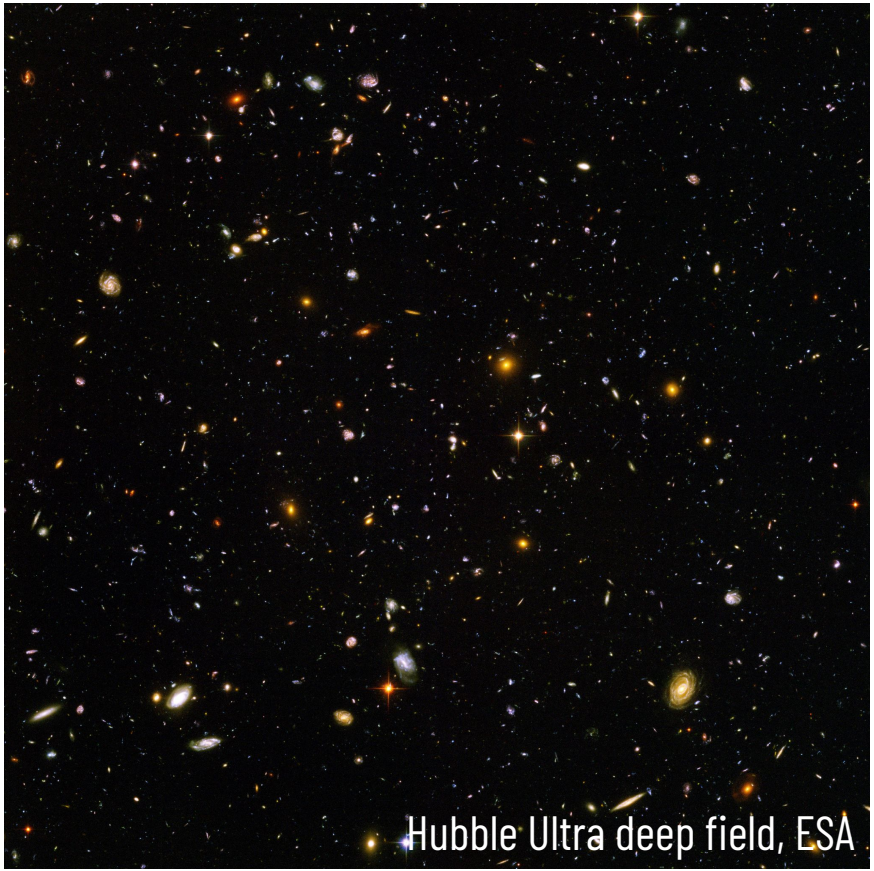
Guilaine LAGACHE, Matthieu BÉTHERMIN, Mathilde VAN CUYCK, and the CONCERTO collaboration

Cosmology and Statistics Days @ CEA, Paris

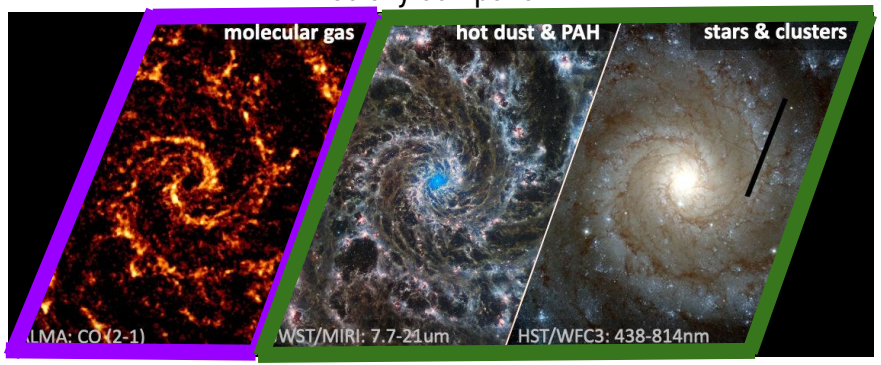

Recombination
Dark Ages
CMB
Cosmic Dawn
time
Reionization
Growth of Structure
1100
200
30
13
7
1
0
z

Kovetz+2019

- Galaxies with diverse morphology and a broad range of colors
- Exploring the path from the simplicity of early galaxies to the complex variety of today
- Probe individual and global galaxy properties (e.g., gas content, SFR, dust) across various cosmic epochs (redshifts)

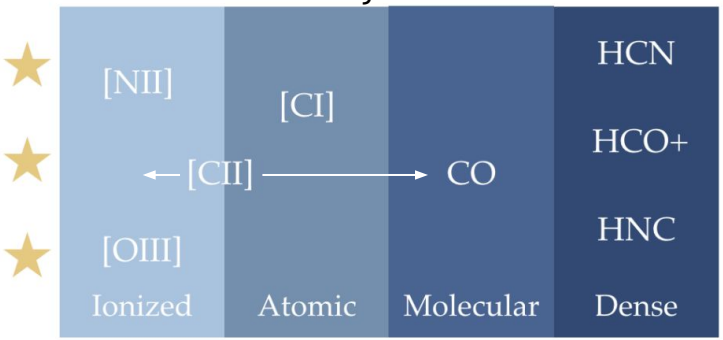


Galaxy components

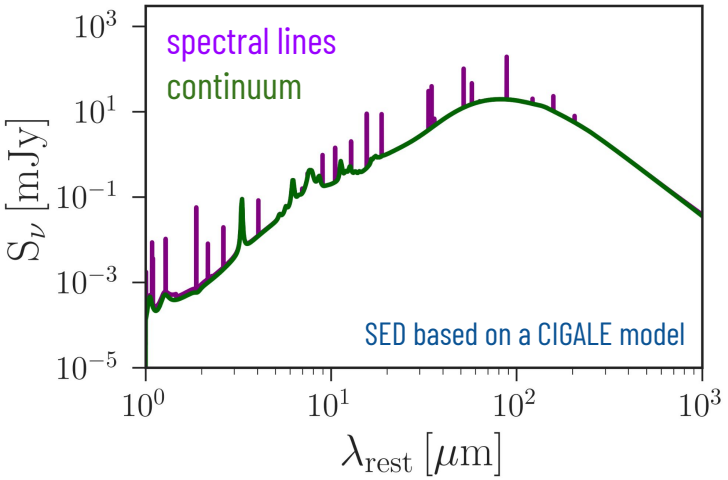


PHANGS collaboration

Distribution of gas around the stars

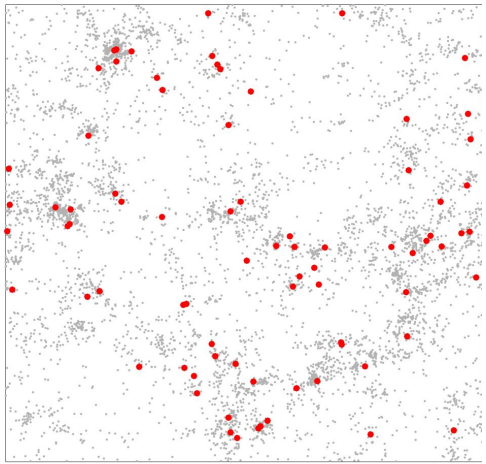


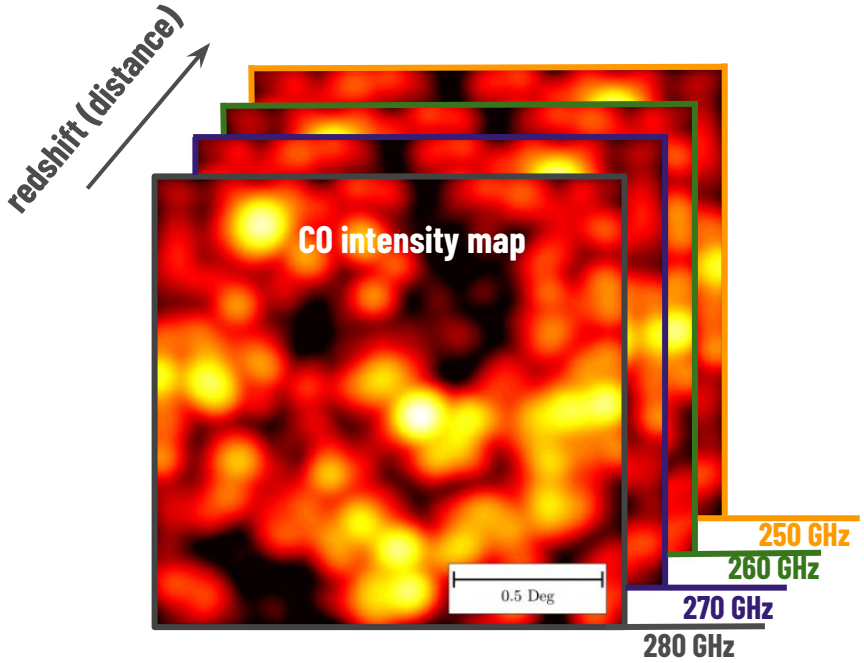
Béthermin+2019 (SF2A proceedings)



Intensity Mapping: aggregated emission of a spectral line (or the continuum emission) from many unresolved galaxies

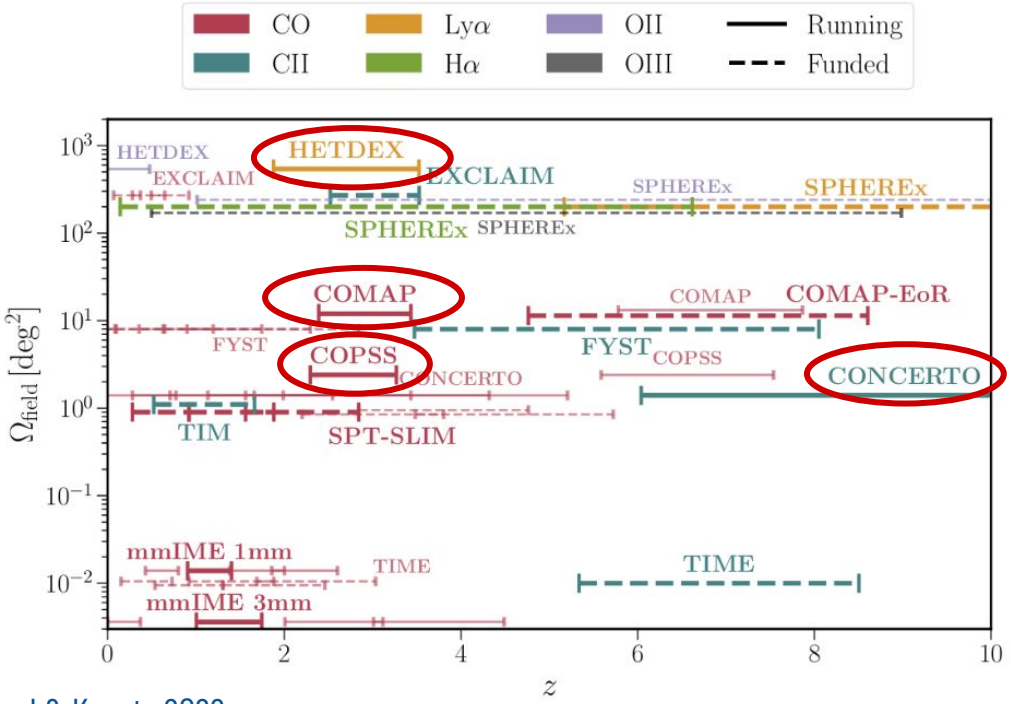
observed galaxies
undetected galaxies





Kovetz+2017

Intensity Mapping: aggregated emission of a spectral line (or the continuum emission) from many unresolved galaxies

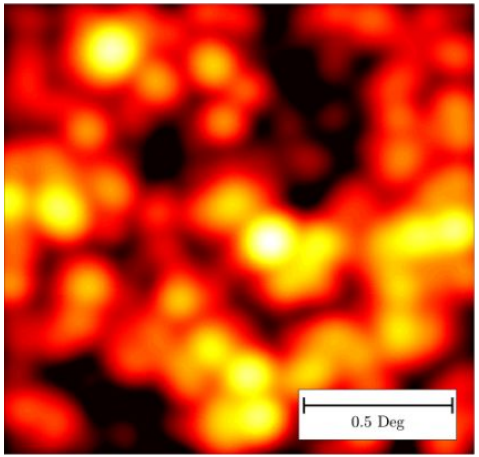


Bernal & Kovetz 2022

- Spectrometer based on the Martin-Puplett interferometer
- 12m APEX telescope in Chile
- Total [CII] survey area: 1.4 deg^2
- Frequency range: 120-310 GHz
  - [CII] line: at redshifts z > 5.1
  - CO line: at z < 3

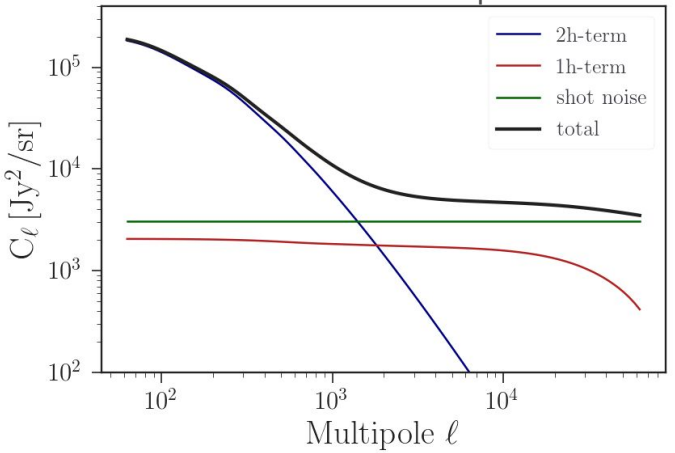
Power spectrum: statistical tool measuring the level of correlation of the intensity fluctuations at various scales

Intensity map



Fourier transform

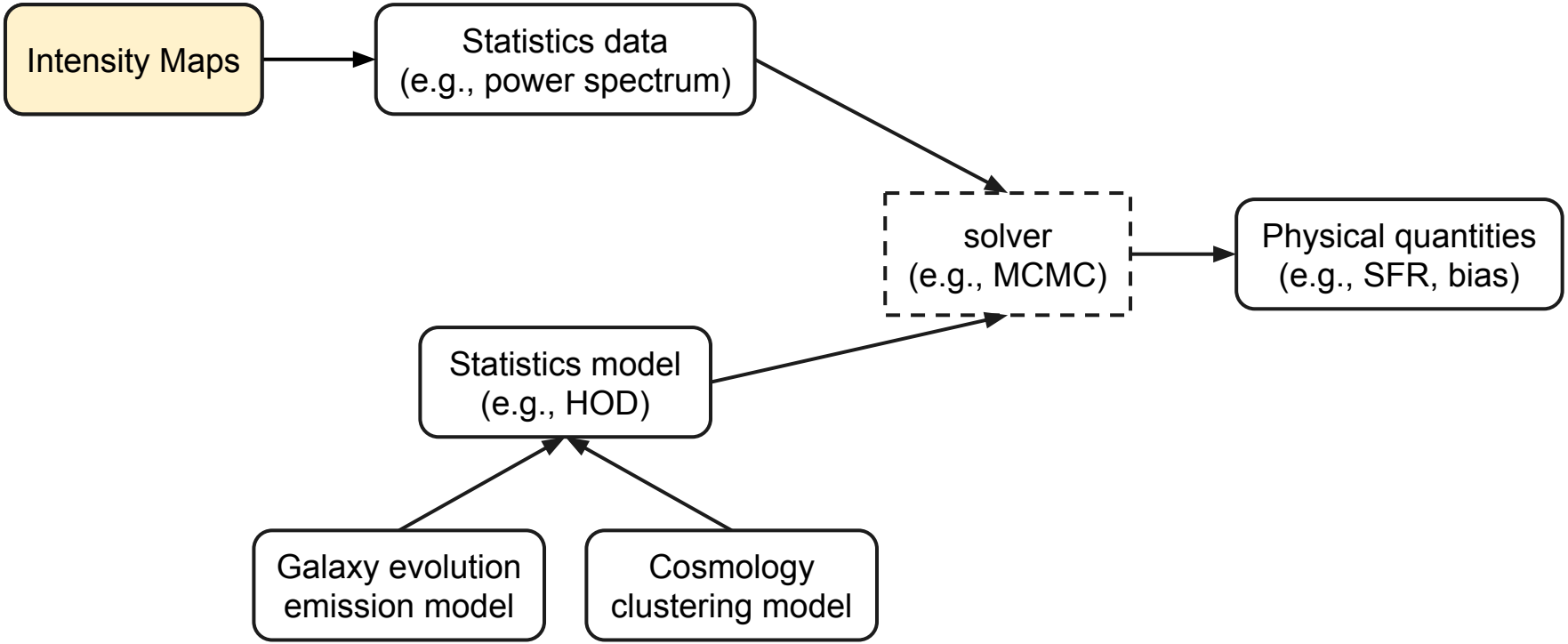
Power spectrum

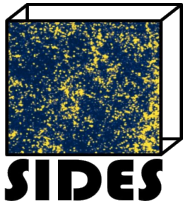


large spatial scales

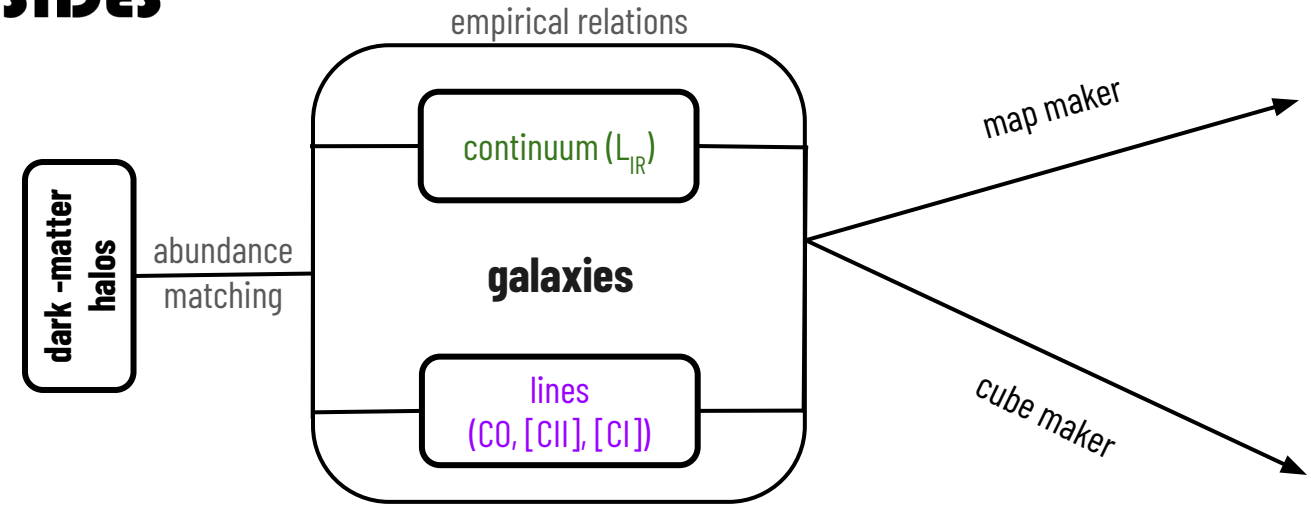
small spatial scales

How do we obtain physical quantities from 2D/3D intensity maps?

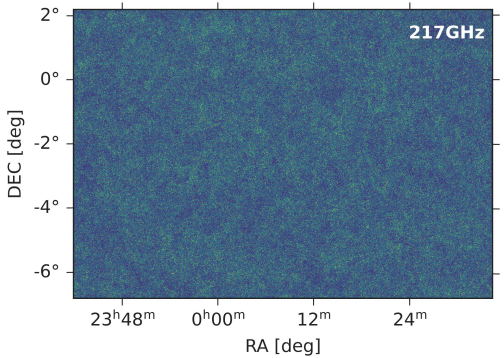




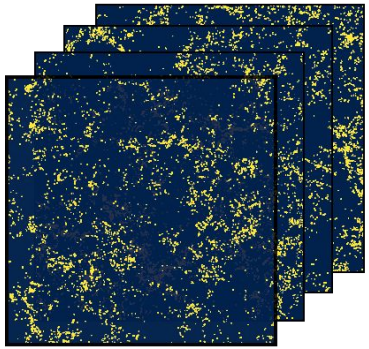
Simulated **I**nfrared **D**usty **E**xtragalactic **S**ky - **SIDES**



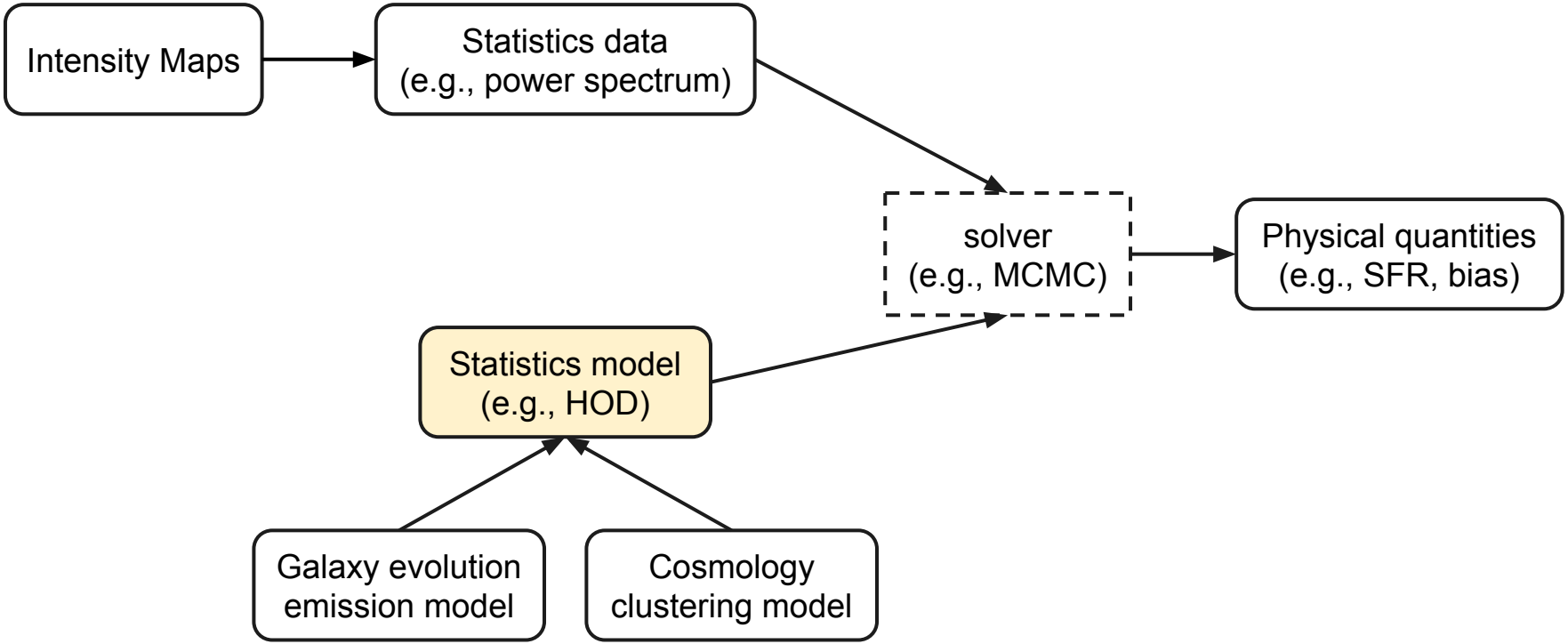
simulated maps (e.g., CIB)



simulated cubes (e.g., CIB, lines only)



Béthermin, **Gkogkou**+2022


Intensity Maps
Statistics data
(e.g., power spectrum)
solver
(e.g., MCMC)
Physical quantities
(e.g., SFR, bias)
Statistics model
(e.g., HOD)
Galaxy evolution
emission model
Cosmology
clustering model

Assumptions

★ Dark matter lies within the collapsed and symmetric halos

★ All the galaxies reside in dark matter halos

Halo occupation distribution (**HOD**): a prescription for filling the DM halos with galaxies

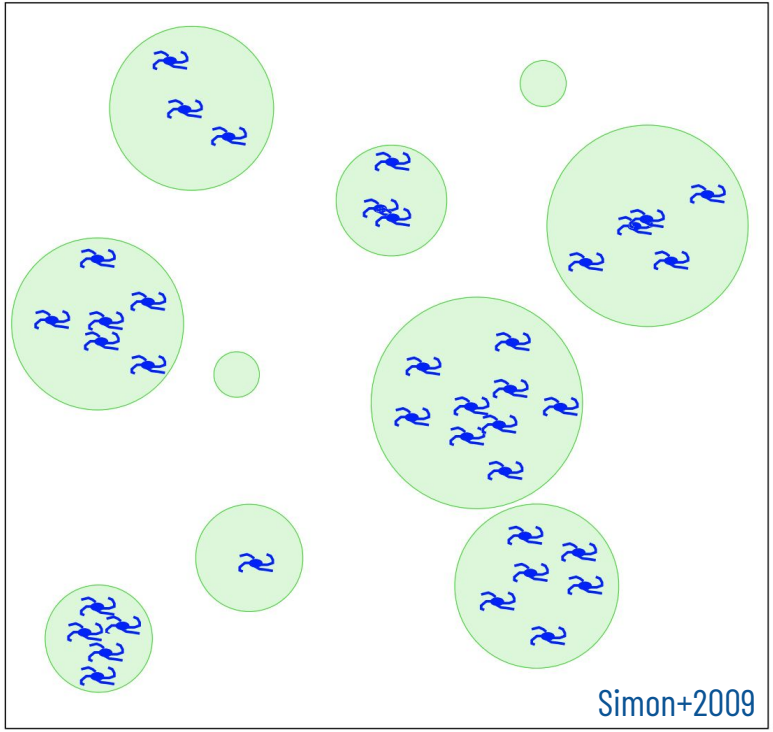
Ingredients

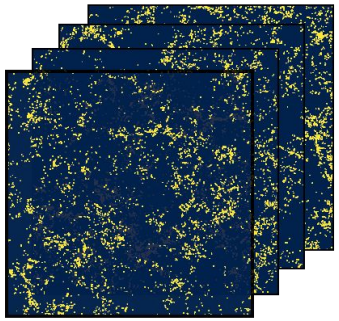
★ Halo mass function (HMF)

★ Halo bias between the halos and the dark matter

★ Halo density profile

$$C^{2h}_{\ell,\nu,\nu'} = \int\int\int \frac{d\chi}{dz}\left(\frac{\alpha}{\chi}\right)^2 \left[\frac{dj_{\nu,c}}{dlogM_h}\frac{dj_{\nu,sub}}{dlogM_h}u(k,M_h,z)\right] \times \left[\frac{dj_{\nu',c}}{dlogM'_h}\frac{dj_{\nu',sub}}{dlogM'_h}u(k,M_h,z)\right] \times b(M_h,z)b(M'_h,z)P_{\rm lin}(k,z)d\log M_h d\log M'_h dz\,,$$





simulated data

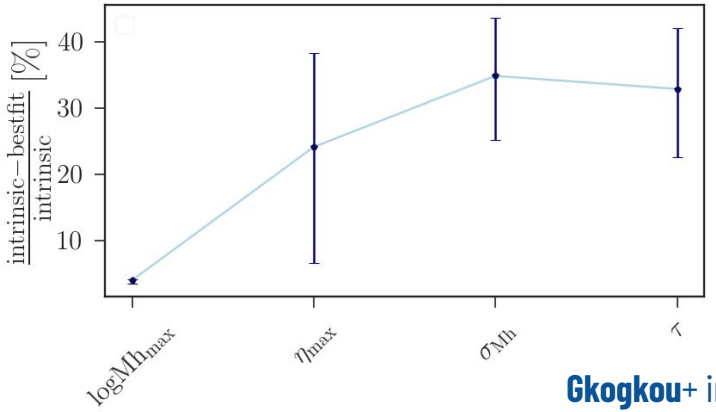
analytical model

fitting the model to the data (MCMC)

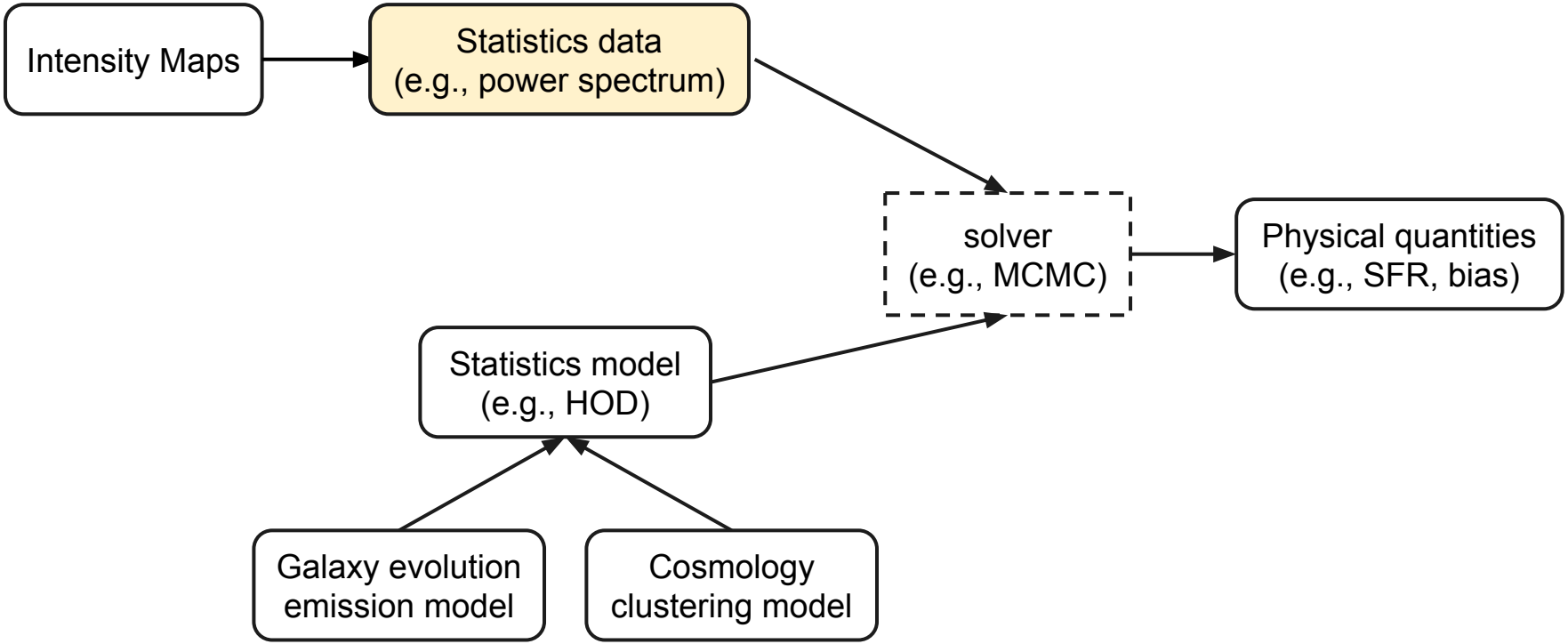
best-fit parameters

Best-fit parameters not close to the intrinsic parameters in the simulation
Model needs to be revised!

$$C^{2h}_{\ell,\nu,\nu'} = \int\int\int \frac{d\chi}{dz}\left(\frac{\alpha}{\chi}\right)^2 \left[\frac{dj_{\nu,c}}{dlogM_h}\frac{dj_{\nu,sub}}{dlogM_h}u(k,M_h,z)\right] \times \left[\frac{dj_{\nu',c}}{dlogM'_h}\frac{dj_{\nu',sub}}{dlogM'_h}u(k,M_h,z)\right] \times b(M_h,z)b(M'_h,z)P_{\rm lin}(k,z)d\log M_h d\log M'_h dz\,,$$



Gkogkou+ in prep.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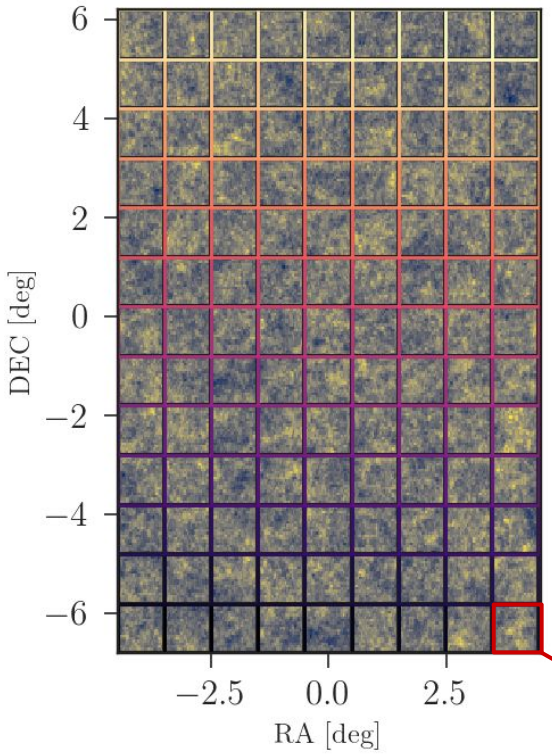
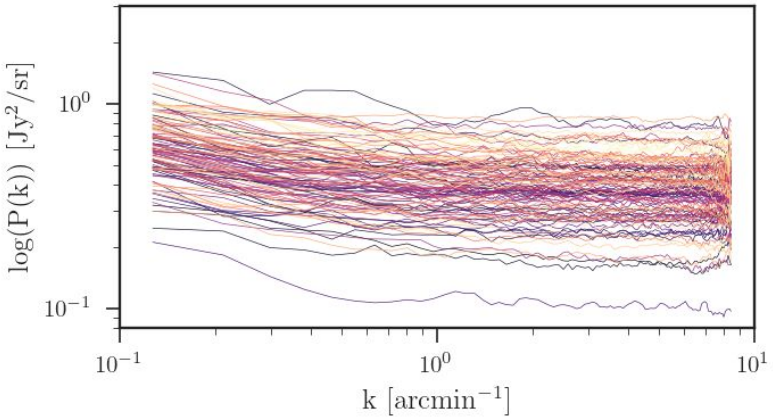
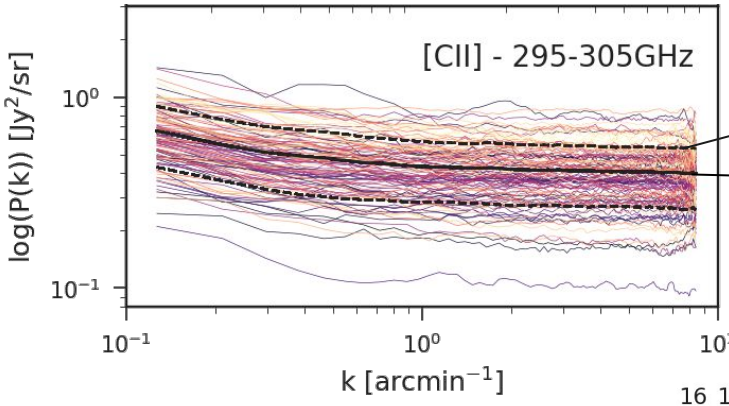


CONCERTO-like size



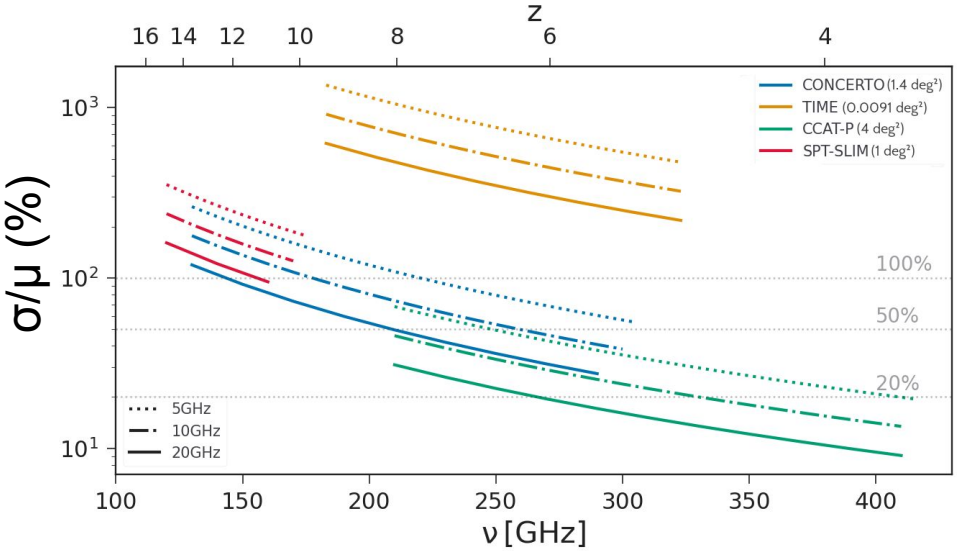
Gkogkou+2023



σ: standard deviation of P(k)

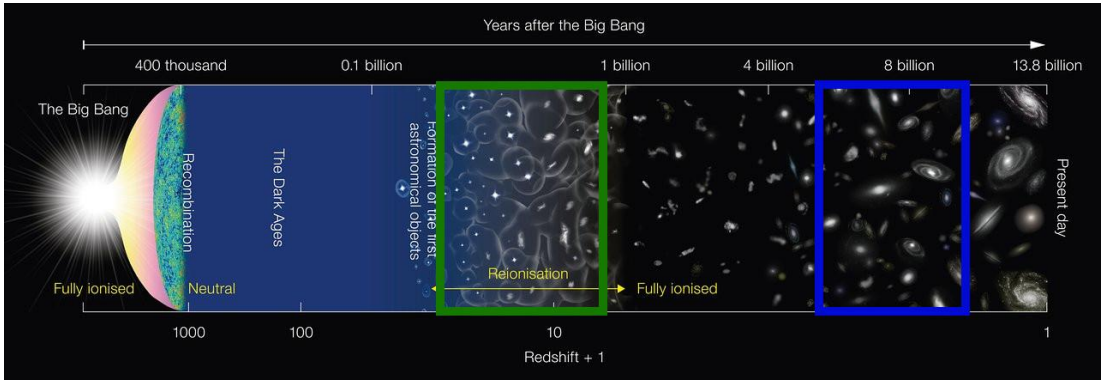
μ: mean P(k)

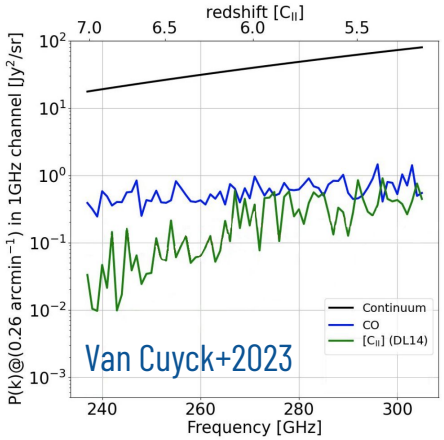
- First generation experiments will all be significantly impacted
- Experiments with larger field sizes will be less impacted

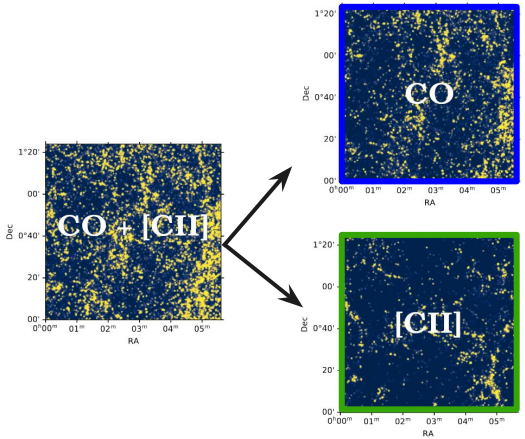


Gkogkou+2023

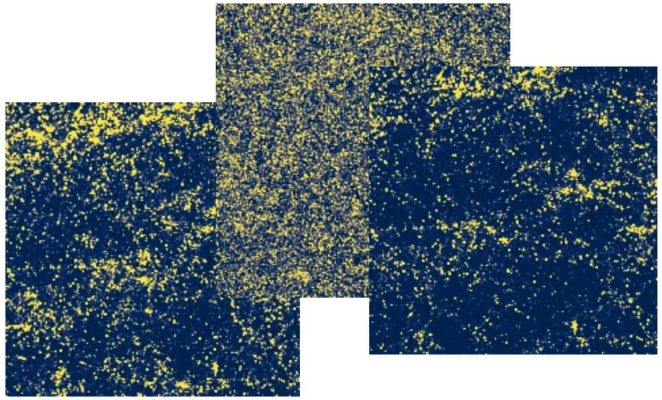
- Observing the faint signal
- Obtaining clean data: removing instrumental noise, atmosphere
- Foreground contamination: component separation
- Field-to-field variance
- Data interpretation: current models not reliable

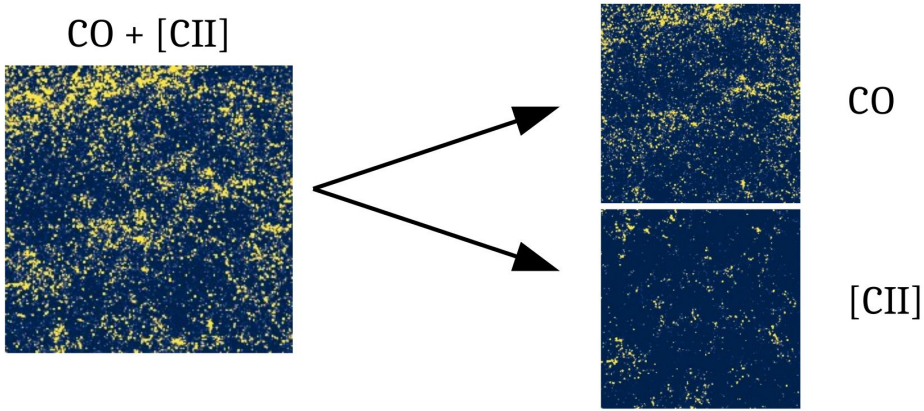






- Foreground contamination: component separation
- Interpretation of the data (cosmological and astrophysical quantities)
- Rapid generation of multiple simulation realizations





$$P_{1\mathrm{h}}(k,z) = \int d\log M_{\mathrm{h}} \left[2\frac{dj_c(z)}{d\log M_{\mathrm{h}}}\frac{dj_{\mathrm{sub}}(z)}{d\log M_{\mathrm{h}}}u(k,M_{\mathrm{h}},z) + \left(\frac{dj_{\mathrm{sub}}(z)}{d\log M_{\mathrm{h}}}u(k,M_{\mathrm{h}},z)\right)^2 \right] \left(\frac{dn}{d\log M_{\mathrm{h}}}\right)^{-1}$$

$$P_{2\mathrm{h}}(k,z) = P_{\mathrm{lin}}(k,z) \left[\int d\log M_{\mathrm{h}} \left[\frac{dj_c(z)}{d\log M_{\mathrm{h}}} + \frac{dj_{\mathrm{sub}}(z)}{d\log M_{\mathrm{h}}}u(k,M_{\mathrm{h}},z) \right] b(M_{\mathrm{h}},z) \right]^2$$

$$L_\nu^{\mathrm{line}}(M_{\mathrm{h}},z) \propto \mathrm{SFR}(M_{\mathrm{h}},z)$$

$$\frac{dj_{c,\nu}}{d\log M_{\mathrm{h}}}(M_{\mathrm{h}},z) = 4.0204\times10^{-2}\frac{c}{4\pi\nu_0 H}L_\nu^{\mathrm{line}}(M_{\mathrm{h}},z)\frac{d^2N}{dMdV}$$

$$\frac{dj_{\mathrm{sub},\nu}}{d\log M_{\mathrm{h}}}(M_{\mathrm{h}},z) = 4.0204\times10^{-2}\frac{c}{4\pi\nu_0 H}\frac{d^2N}{dMdV}\int d\log m_{\mathrm{sub}}\, L_\nu^{\mathrm{line}}(m_{\mathrm{sub}}|M_{\mathrm{h}},z)\frac{dn}{d\log m_{\mathrm{sub}}}$$

- **Intensity mapping** is a smart complementary approach to study the galaxy evolution especially at high-z
- Developing simulations is needed: **SIDES-Uchuu simulation**
- **Power spectrum** as a tool will suffer from the field-to-field variance
  - Alternative methods should be considered employed (e.g., working in map space)
- Modeling the IM signal: **HOD models**
  - Failure of current HOD models to retrieve meaningful physical quantities
  - Other methods complementary to conventional modeling (e.g., machine/deep learning)
- **Machine/deep learning** a valuable tool to alleviate current issues and challenges (e.g., denoising, component separation, modeling)

Thank you!