How Dark is the Universe?
Intensity Mapping in Broadband and Beyond

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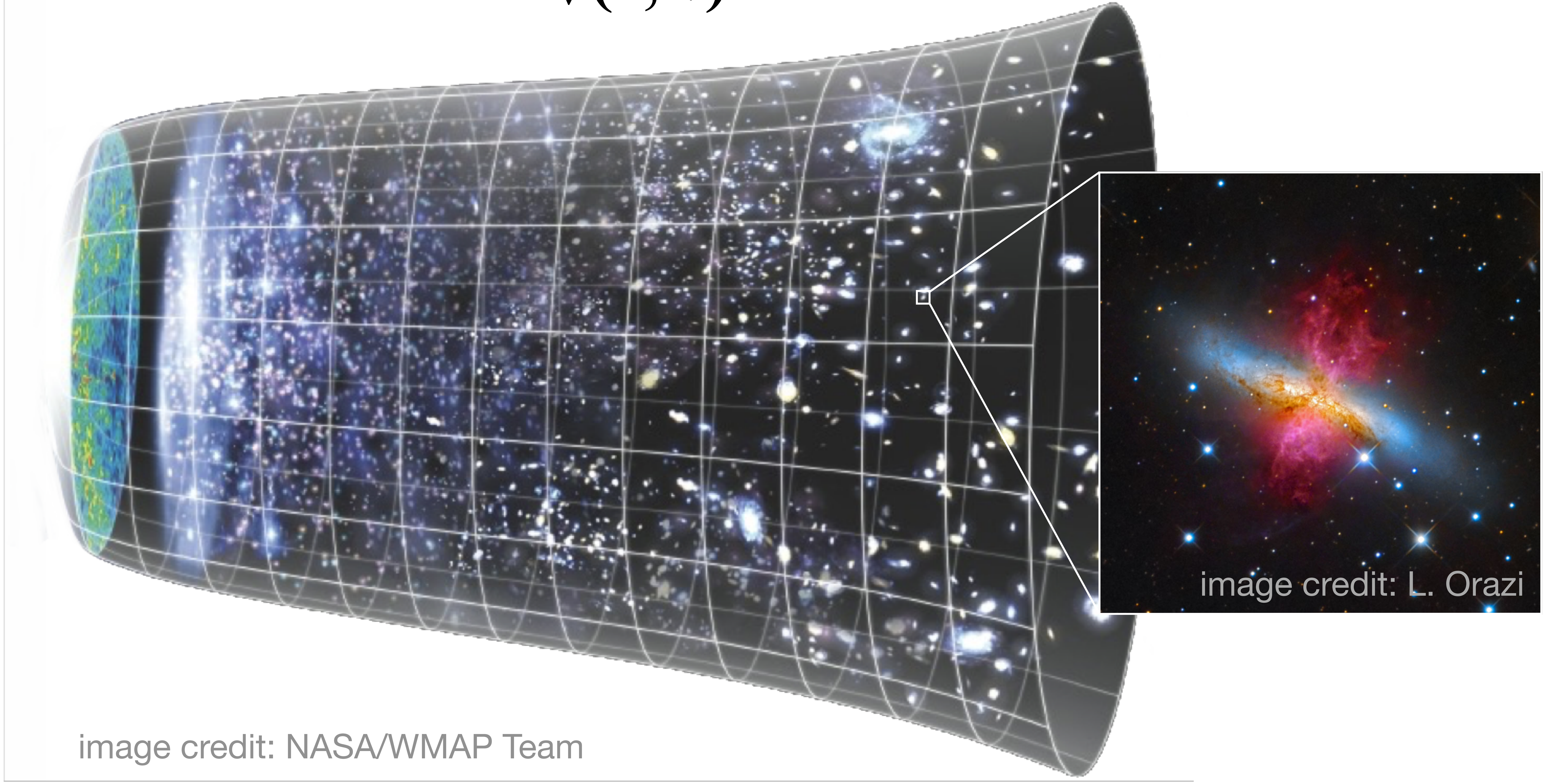
Olbers' paradox:
Why is the night sky dark if the universe is filled with stars?
How dark is the universe?
What is the total radiation production of the universe?
image credit: the HUDF Team

Cosmic radiation: extragalactic background light (EBL)

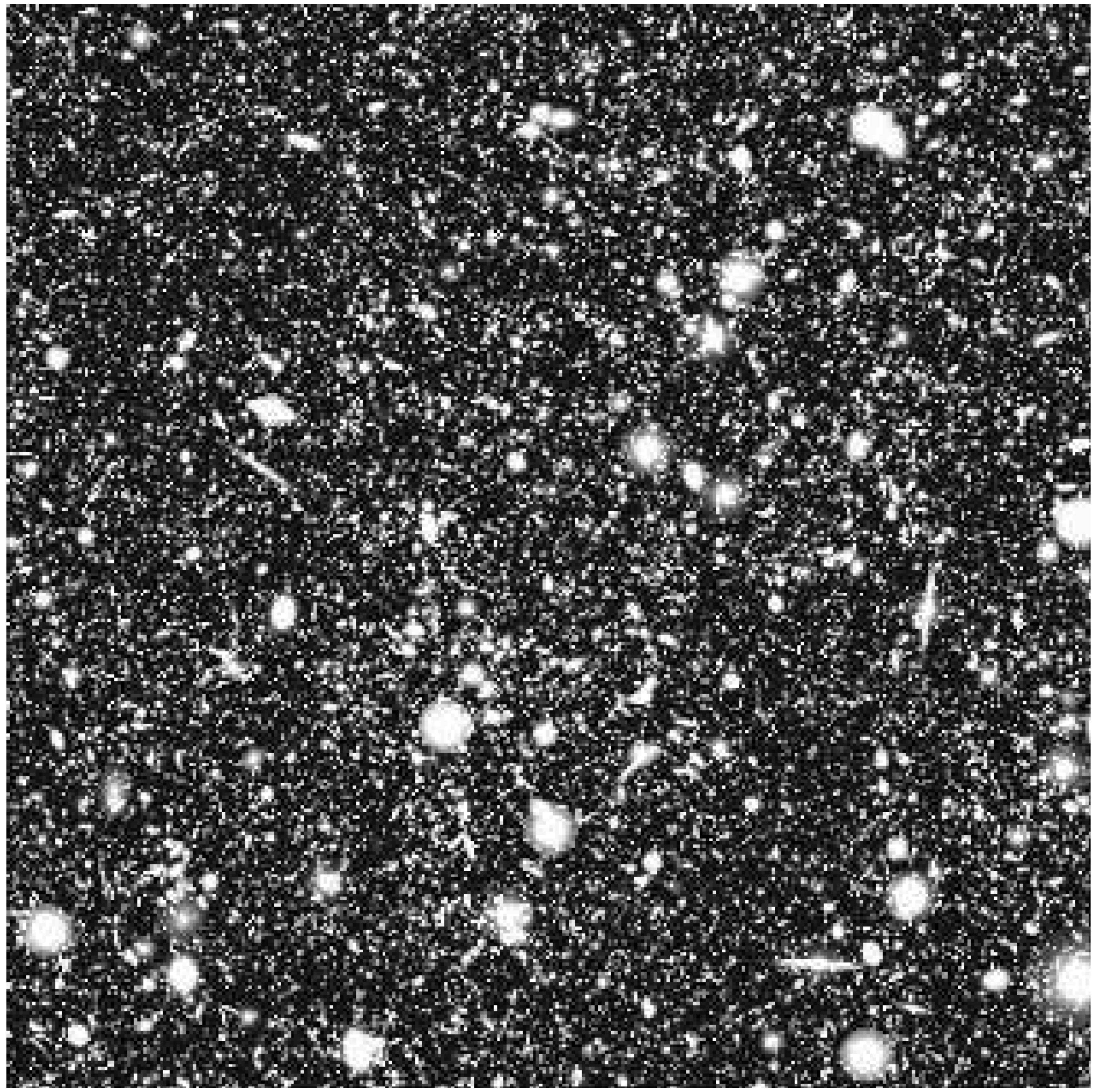
EBL emissivity

$$\epsilon_\nu(z, \nu)$$

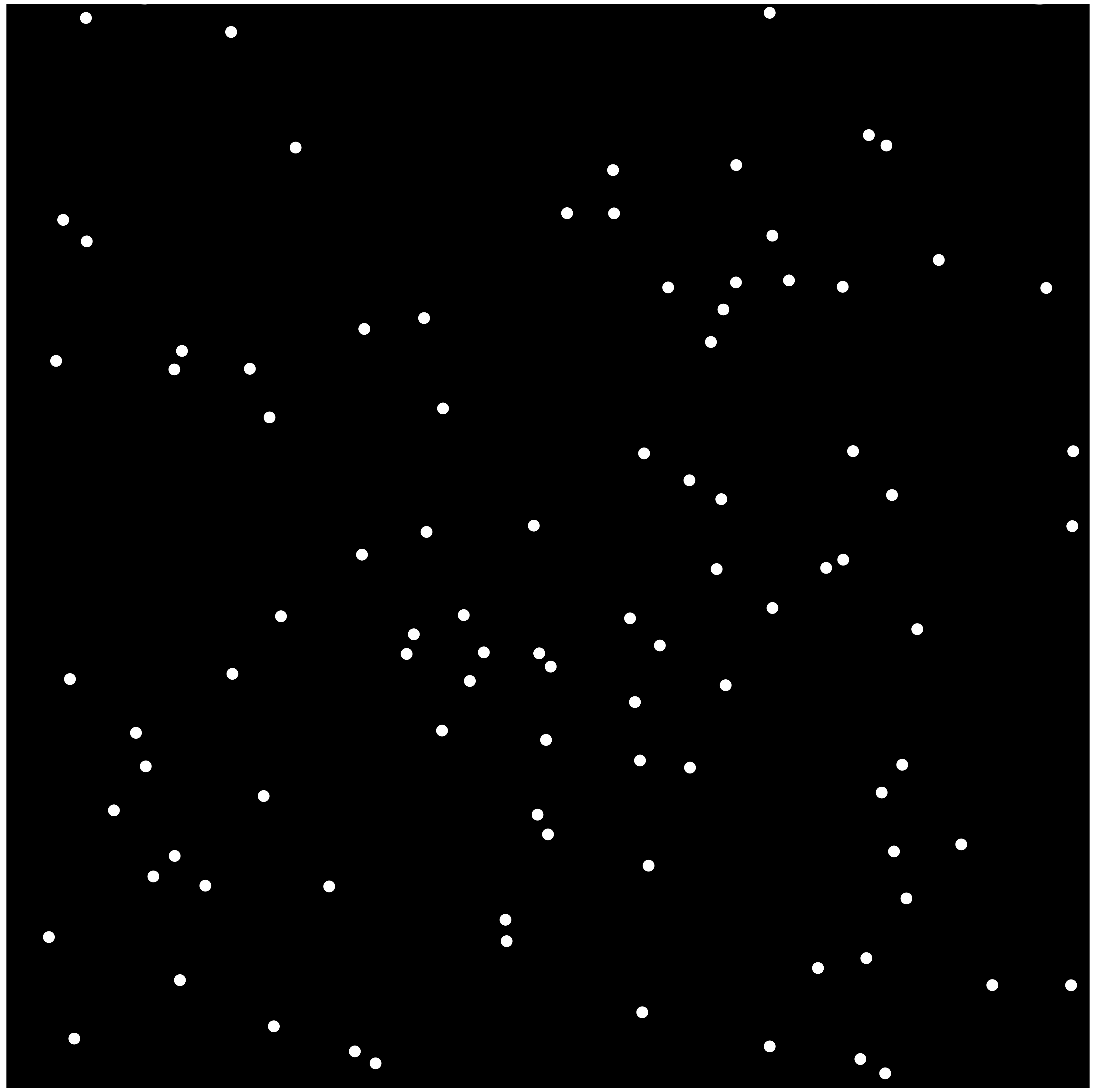


Observations: galaxy survey vs intensity mapping

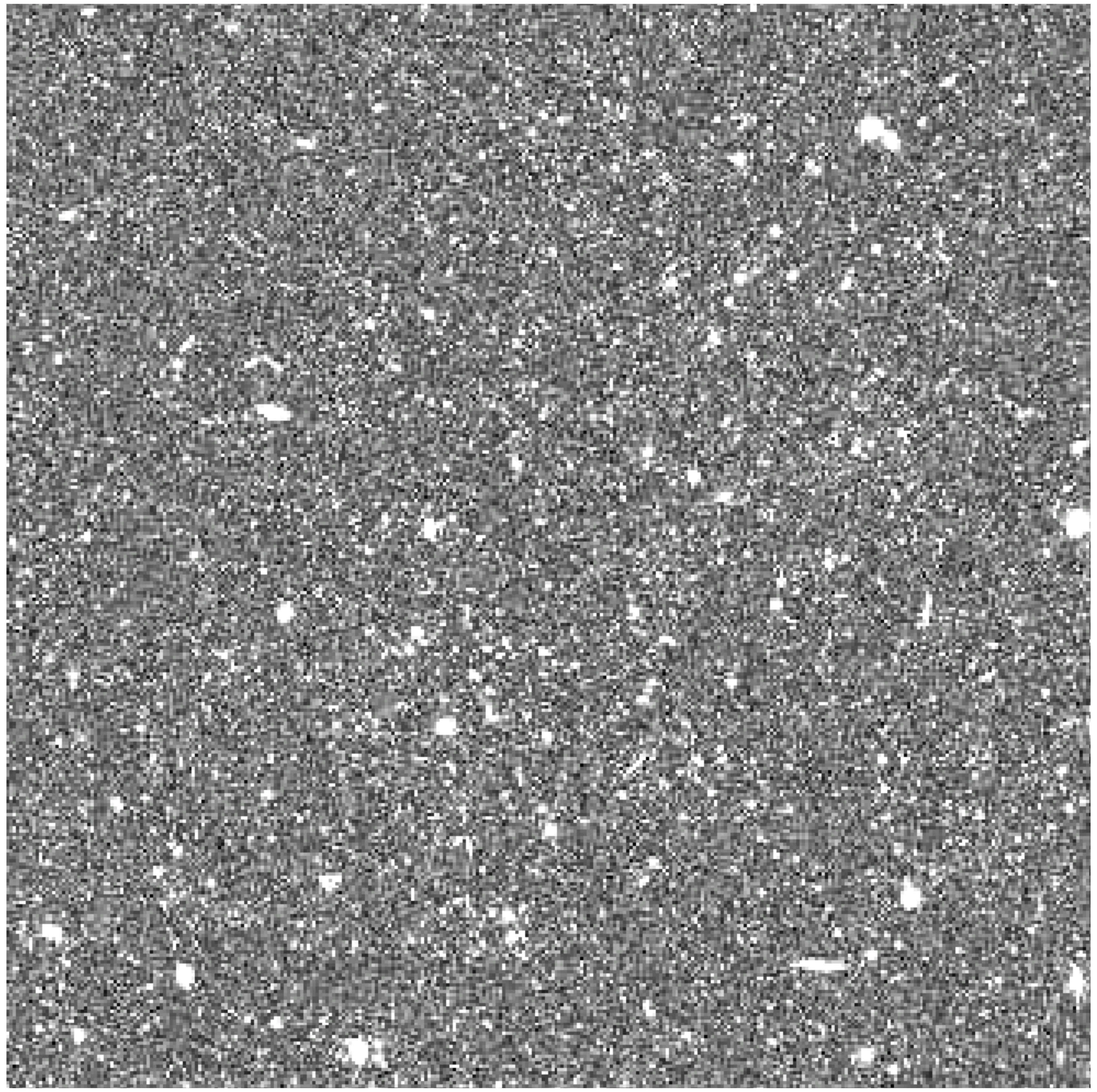
noise-free lightcone



galaxies given a selection function



intensity map



Millennium Run Observatory @ 1.6 μm
Overzier+12

Line intensity mapping to ease the interpretation

see Kovetz et al. 2017 for a review (JHU workshop white paper)

simulated CO intensity map

- Redshift is readily known (with caveats)
- Line diagnostics is ready to go, e.g., SFR
- Needs wide-field spectroscopic data

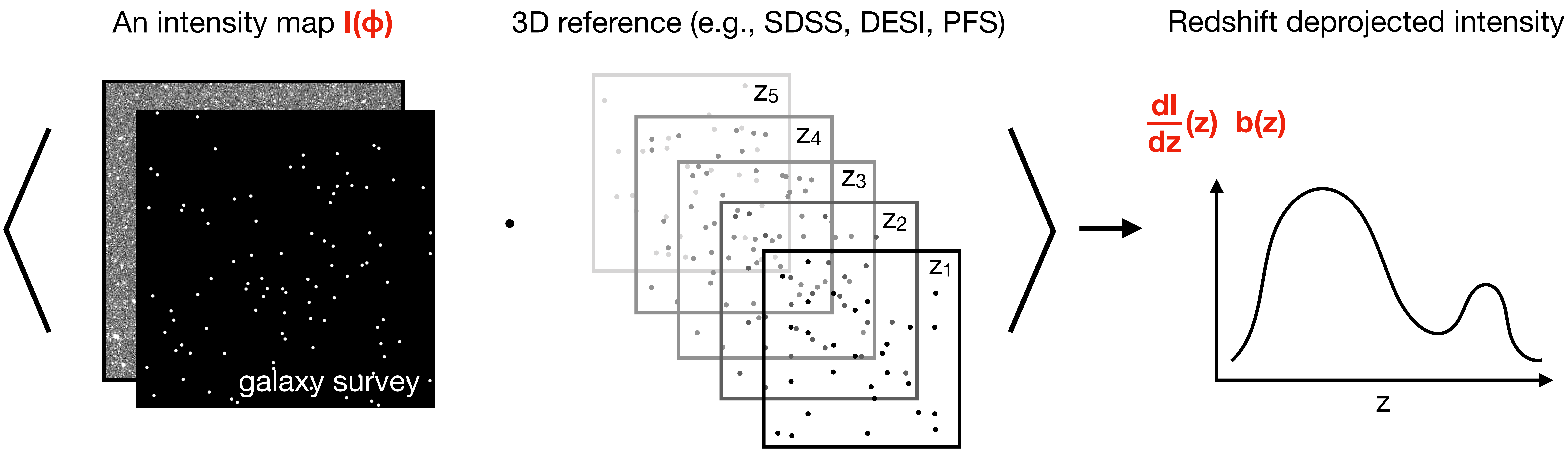
Broadband intensity mapping?

- Data exist in almost all wavebands
- Can go wide and deep relatively quickly
- But key information (**redshift** and **frequency**) is lost

  $R = \lambda/\Delta\lambda \sim 10$

How to get redshifts of photons?

$$w_{Ir}(z) \quad \propto \quad \frac{dI}{dz}(z)\; b_I(z)\; \cancel{b_r(z)\; w_{DM}(z)}$$



clustering-based redshift estimation: Newman+08, Menard+13, McQuinn+13

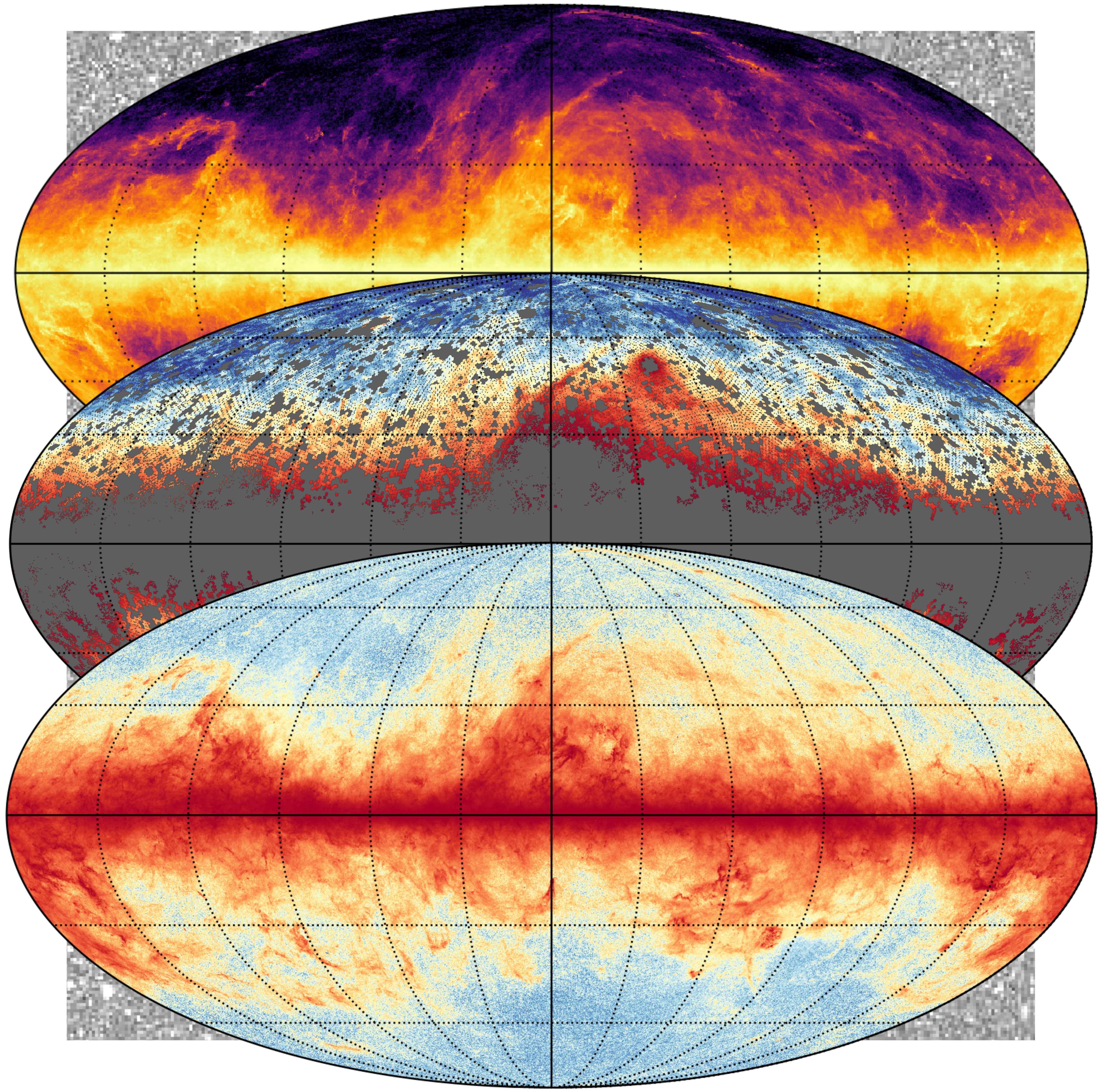
Overcoming limitations in broadband intensity mapping

spatial fluctuations → redshift → spectrum → physical constraints on cosmic constituents

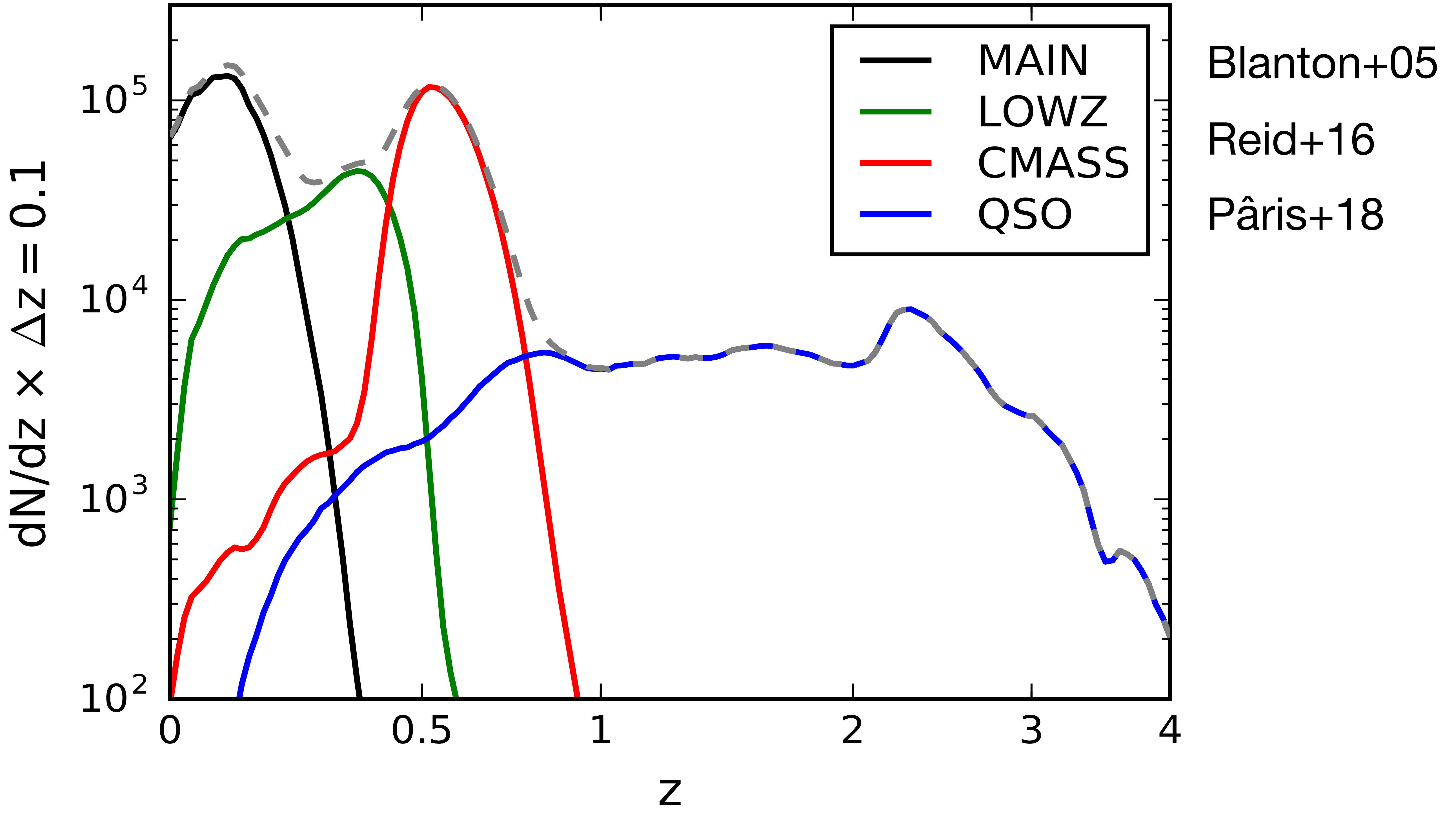
The diffuse sky gallery

The analysis: $\langle$ intensity map · reference(z) $\rangle \propto \frac{dI}{dz}(z)\, b(z)$

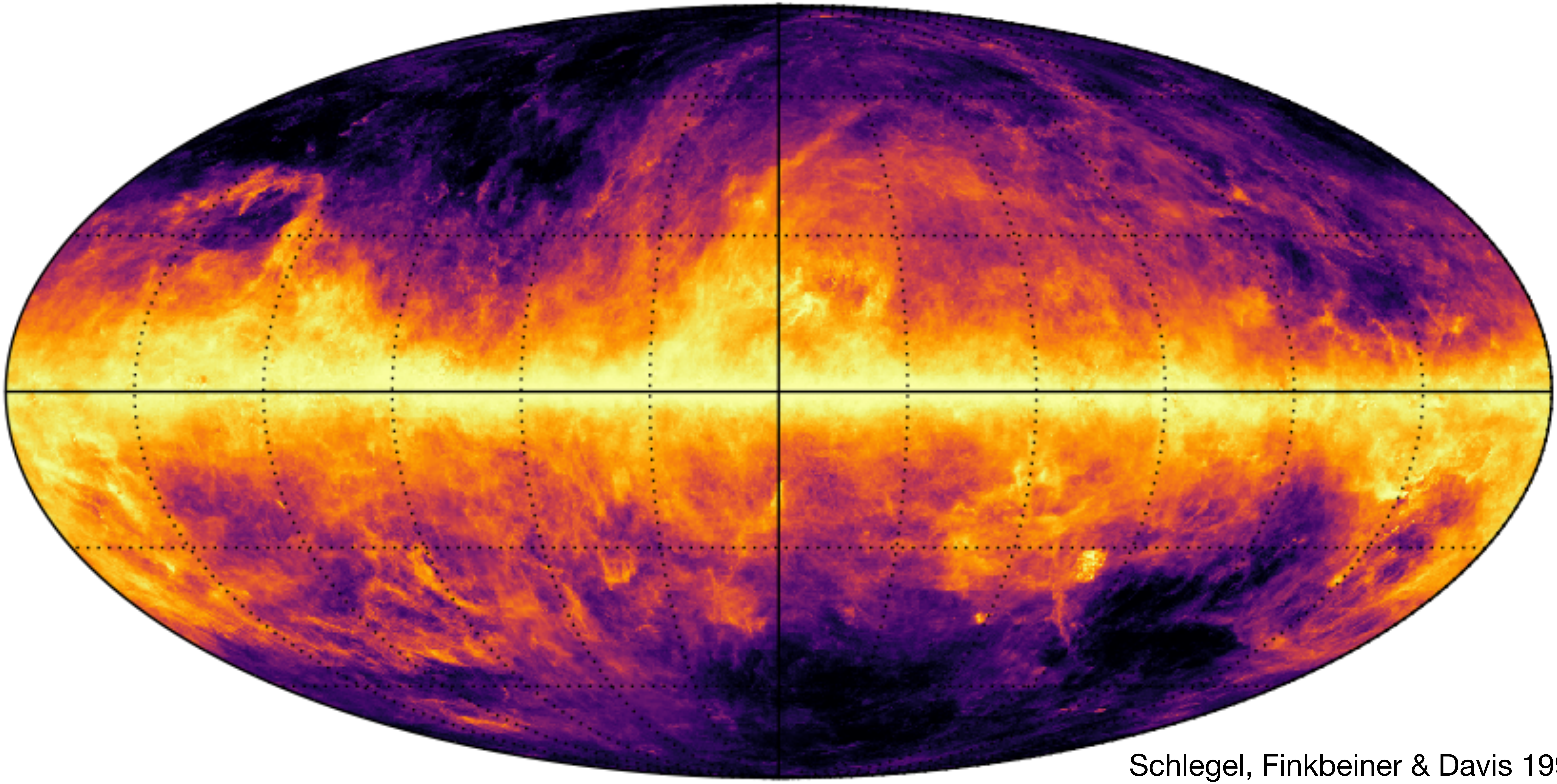
I(Φ)



SDSS + BOSS (Φ, z)

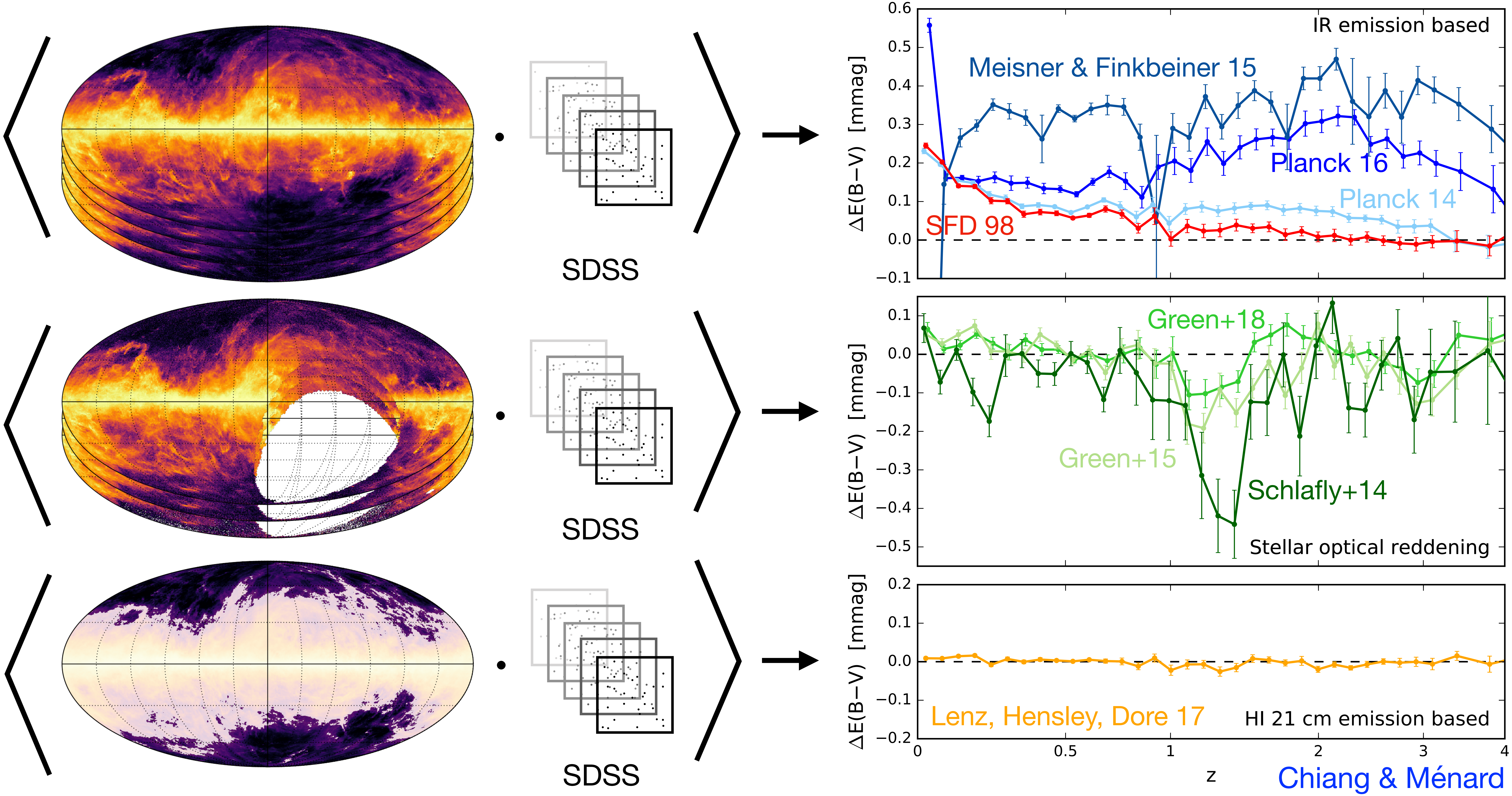


Are there extragalactic photons in my maps?



Schlegel, Finkbeiner & Davis 1998

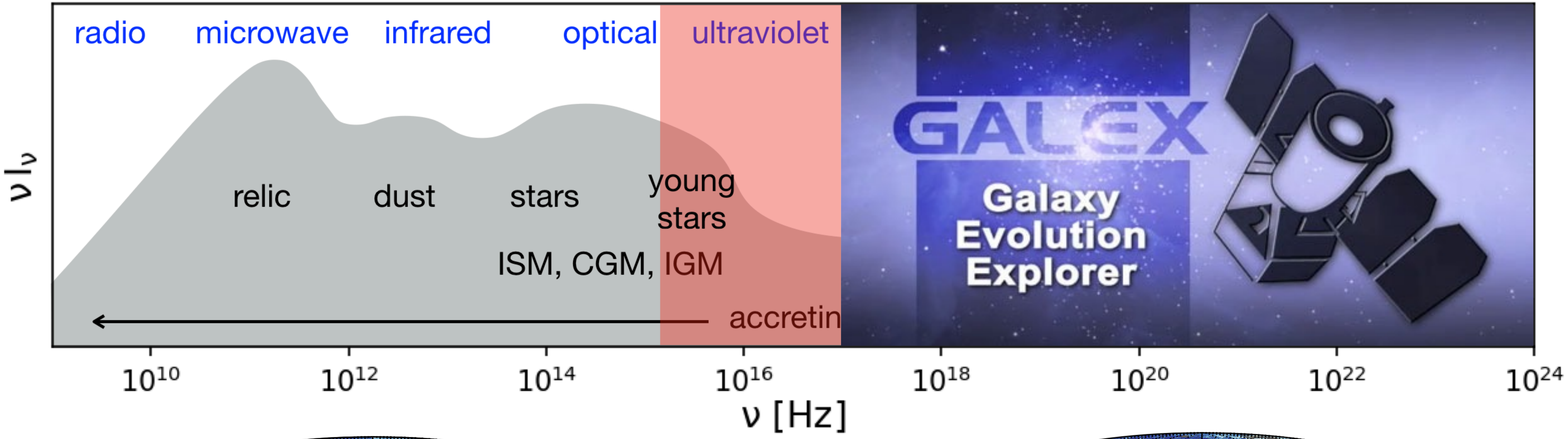
Extragalactic imprints in Galactic dust maps

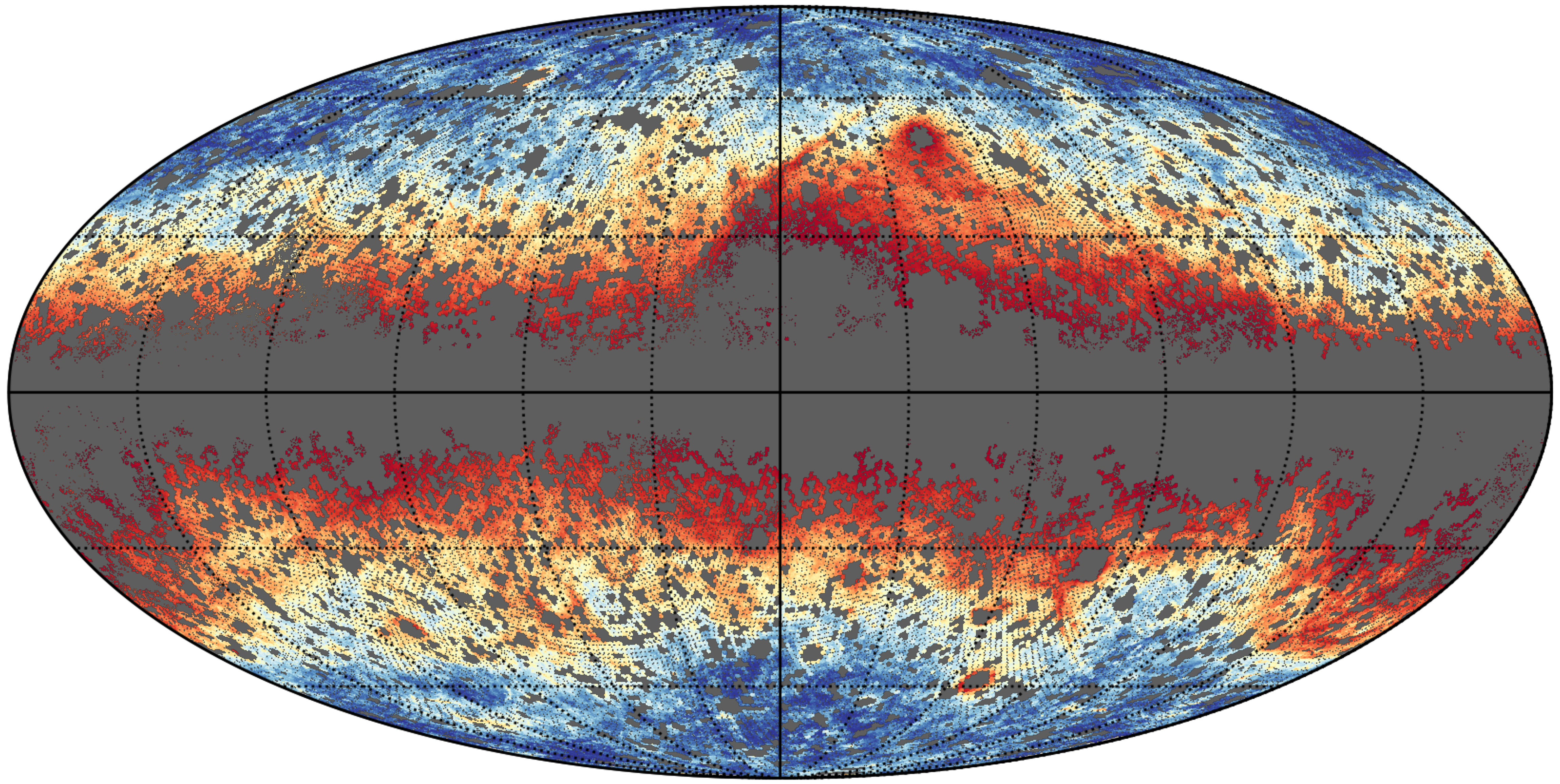


Chiang & Ménard 2018

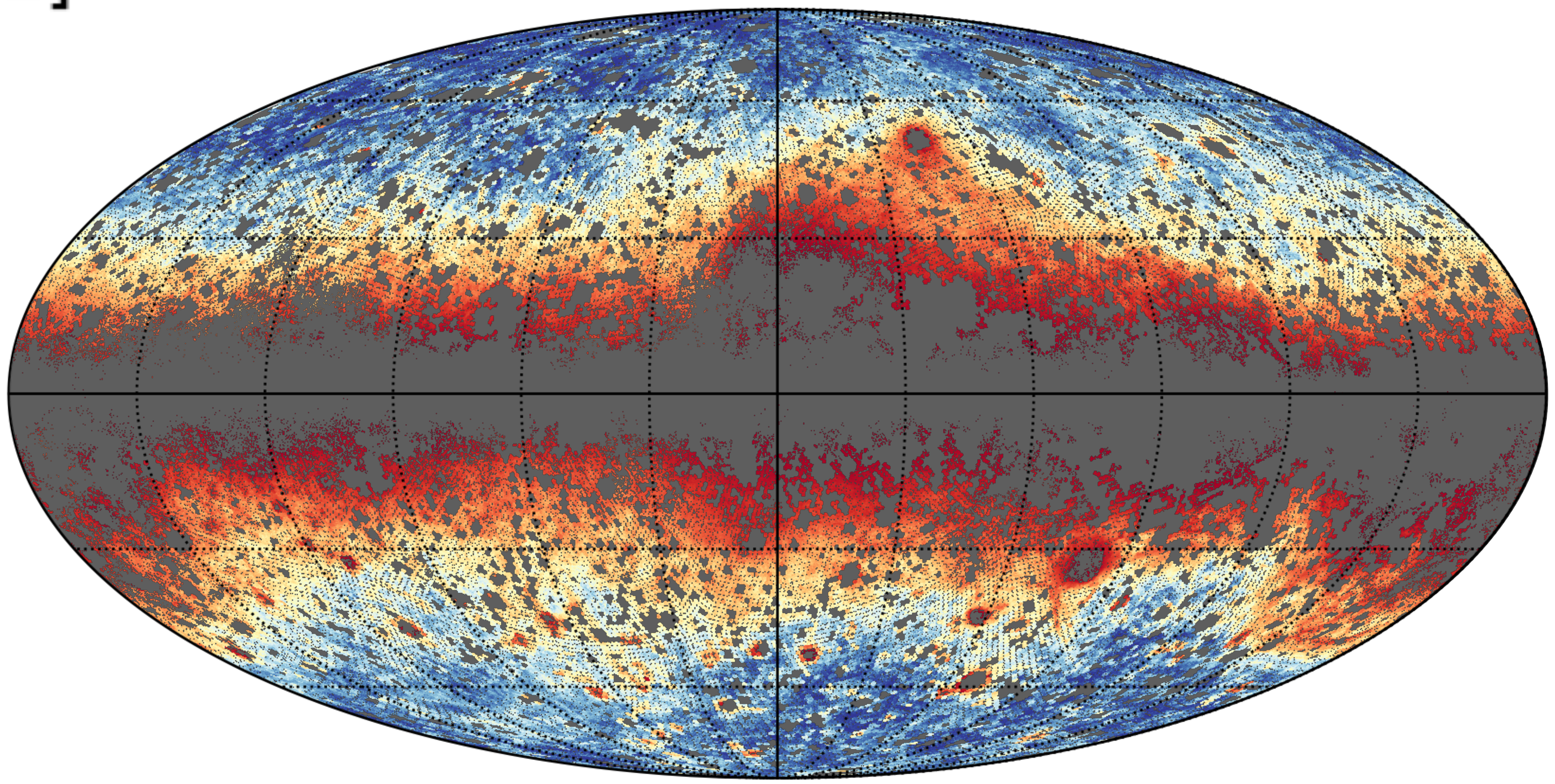
Cosmic UV background tomography

Chiang et al. 2018b





Far-UV (FUV) 1500 Å



Near-UV (NUV) 2300 Å

GALEX

Far-UV (FUV)
1500 Å

GALEX
Far-UV (FUV)
1500 Å
10 deg scale
1 deg scale

Cosmic UV background in GALEX

Chiang et al. 2018b

in collaboration with B. Ménard & D. Schiminovich

The information content in redshift

- Cosmological distance (breaks the l.o.s. projection)
- Cosmic time label
- Spectral information: $\nu_{em} = (1+z)\,\nu_{obs}$

$$\frac{dI}{dz} = \frac{\partial I}{\partial t}\frac{dt}{dz} + \frac{\partial I}{\partial \nu}\frac{d\nu}{dz}$$

observable

evolution over time

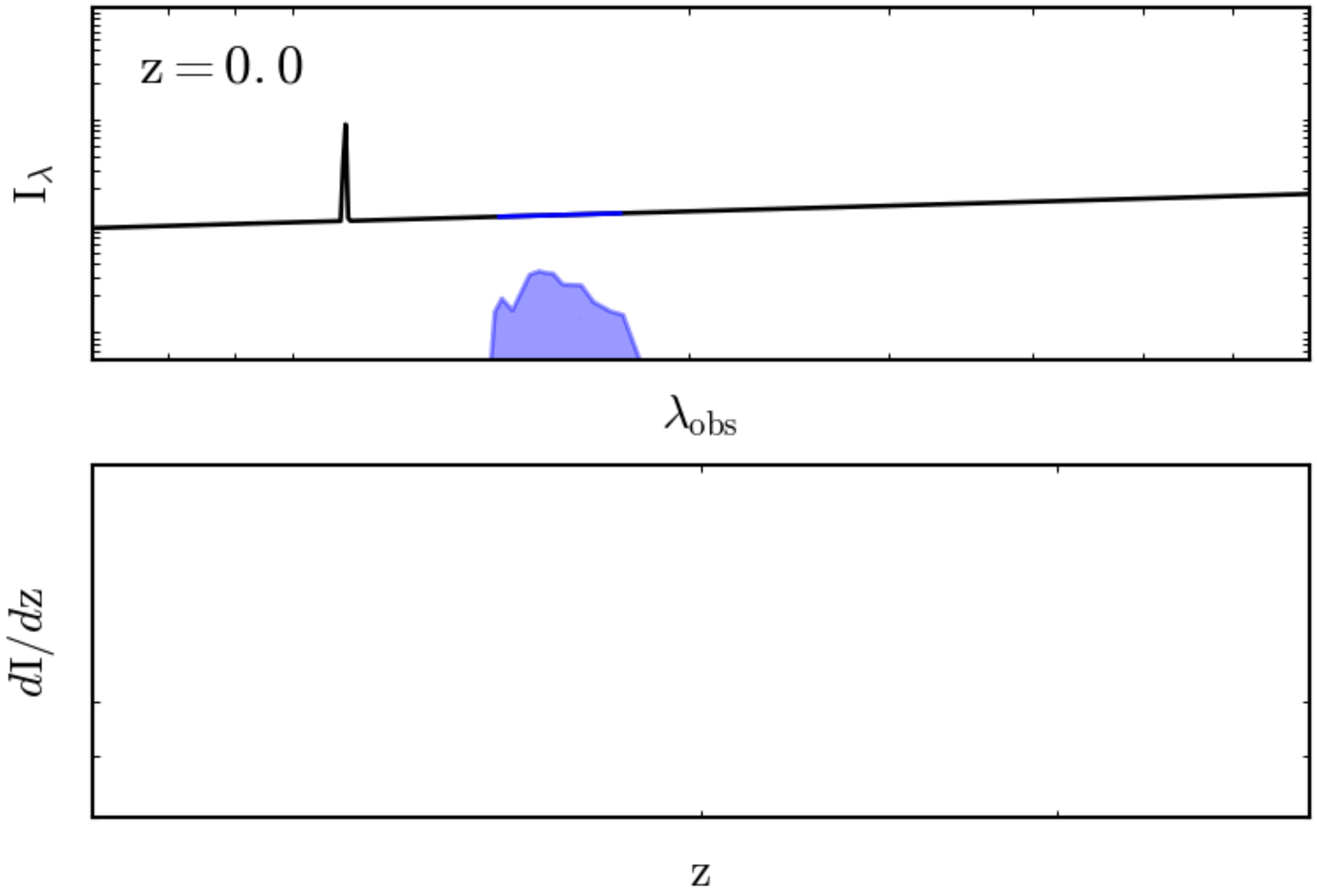
spectral features (K-correction)

Spectral Tagging

Chiang et al 2018b

Special case: ∂I/∂t = 0

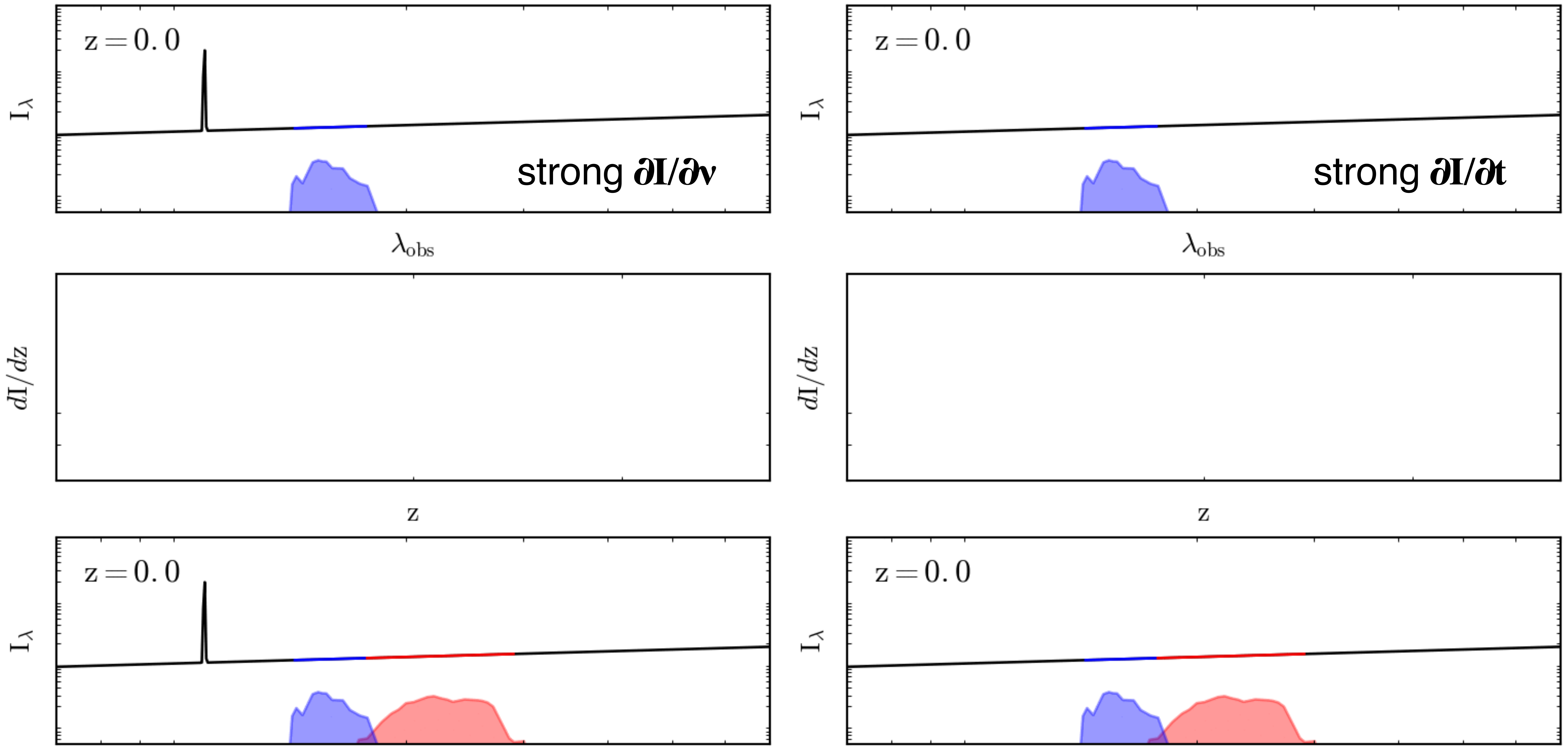
$$\frac{dI}{dz} = \cancel{\frac{\partial I}{\partial t}\frac{dt}{dz}} + \frac{\partial I}{\partial \nu}\frac{d\nu}{dz}$$



- Fully recover the spectrum by a deconvolution
- Works for spectrum of any shape
- Spectral resolution is limited by redshift error, not the bandwidth

General case

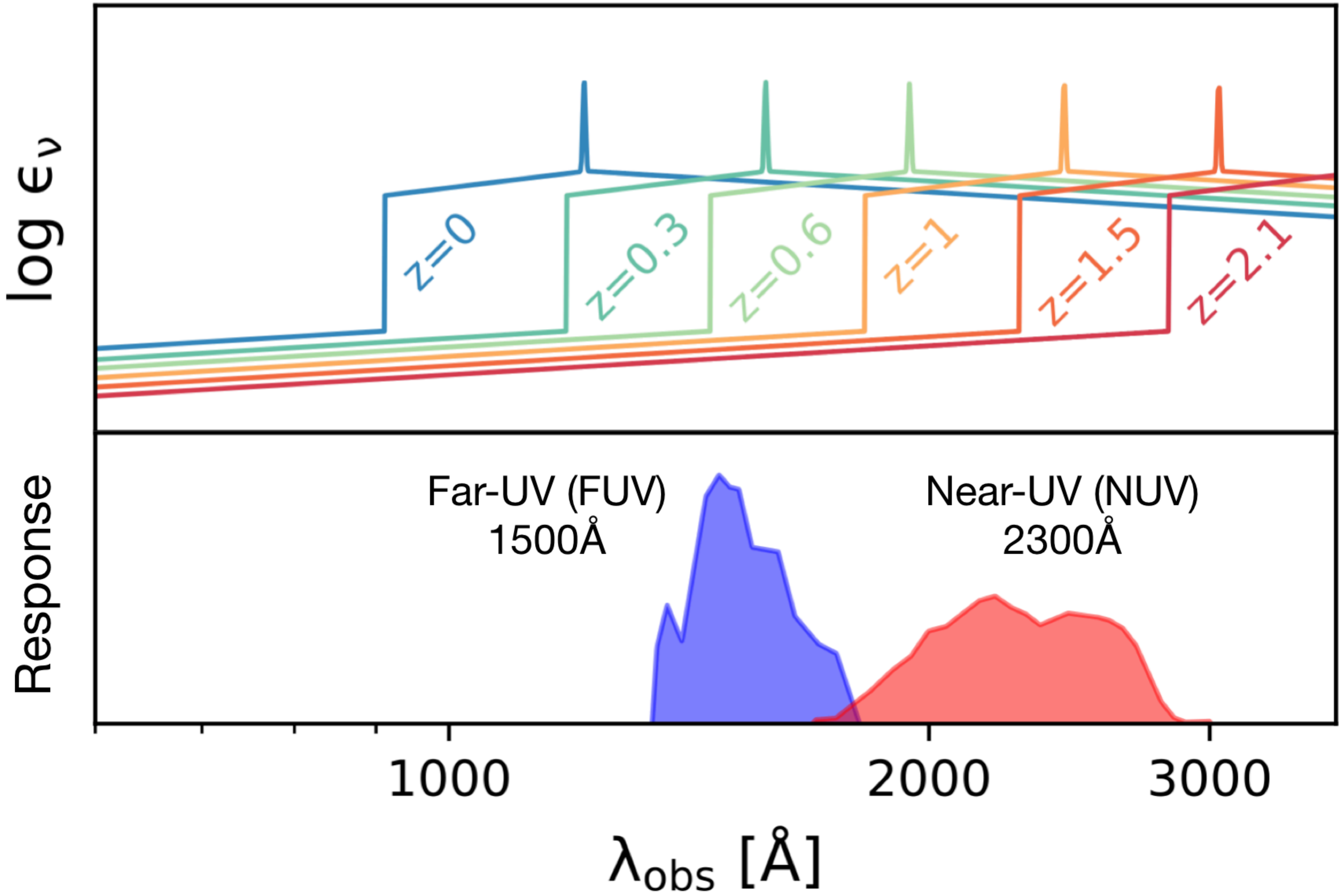
$$\frac{\mathrm{d}I}{\mathrm{d}z} = \frac{\partial I}{\partial t}\frac{\mathrm{d}t}{\mathrm{d}z} + \frac{\partial I}{\partial \nu}\frac{\mathrm{d}\nu}{\mathrm{d}z}$$



observable — filter curve — bias — emissivity — IGM absorption

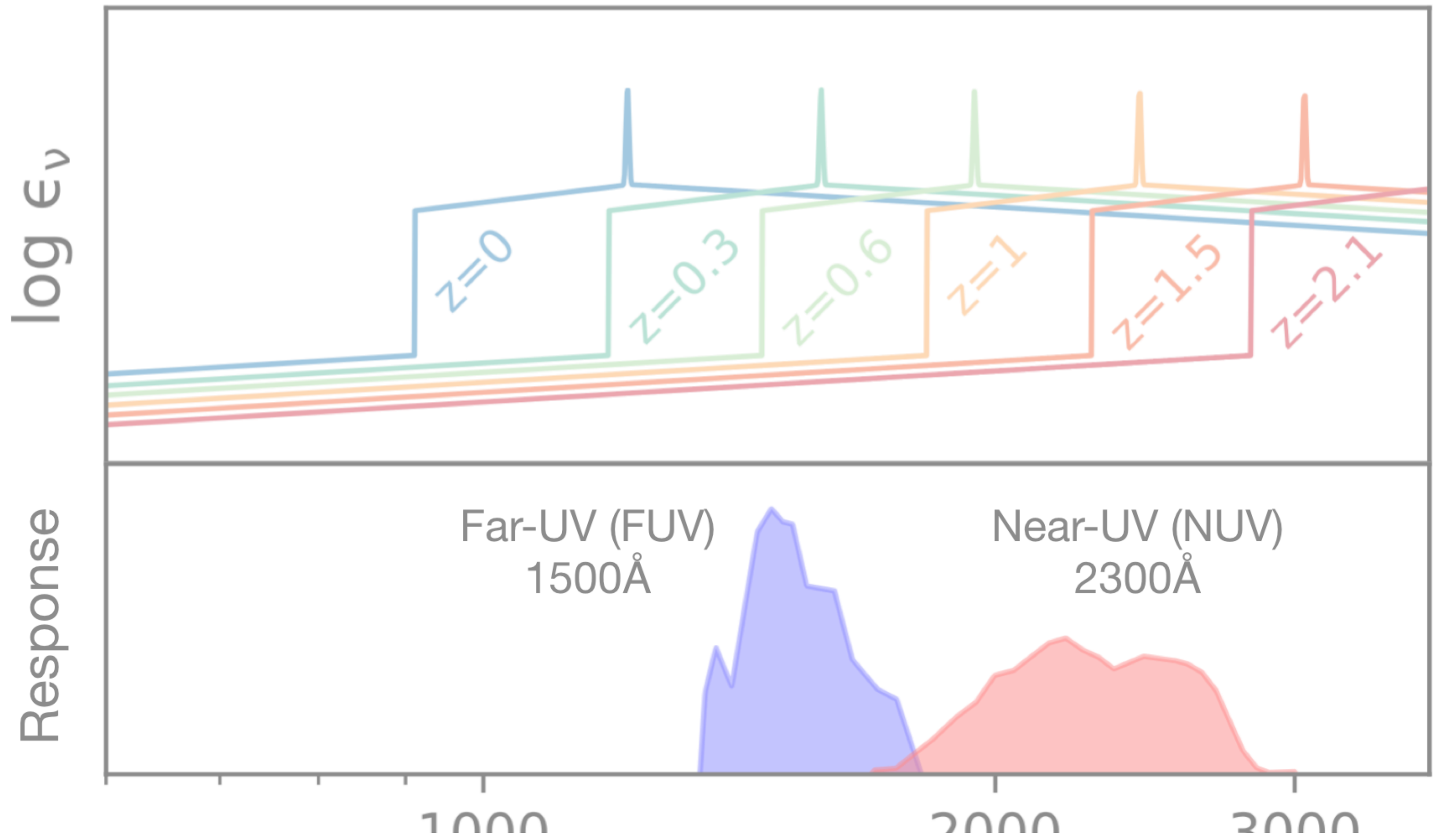
$$\boxed{\frac{\mathrm{d}I_\nu}{\mathrm{d}z} b_I(z)} \propto \int \frac{\mathrm{d}\nu_{\rm obs}}{\nu_{\rm obs}} \boxed{R(\nu_{\rm obs})}\,\boxed{b(\nu, z)}\,\boxed{\epsilon_\nu(\nu, z)}\,\boxed{e^{-\tau}}$$

Parameterization of the UV background spectrum



Forecast for the UV spectral tagging

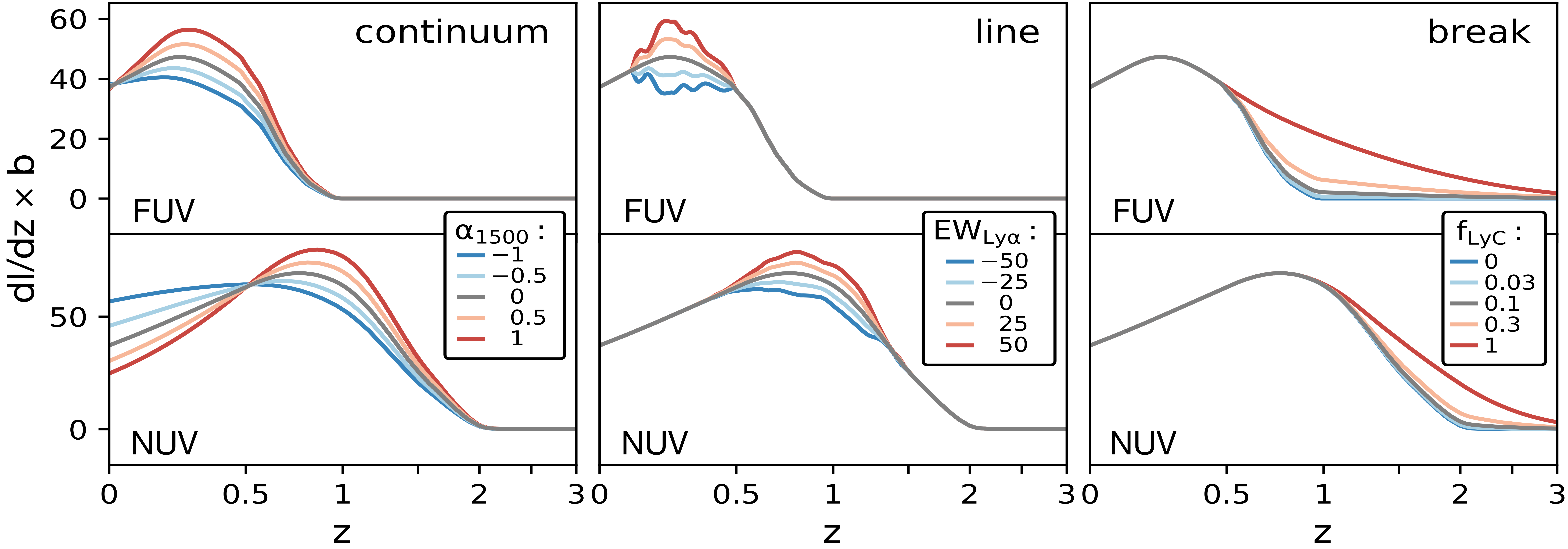
Chiang et al. 2018b



observabl, filter curve, bias, emissivity, IGM abs.

$$\boxed{\frac{dI_\nu}{dz} b_I(z)} \propto \int \frac{d\nu_{\rm obs}}{\nu_{\rm obs}} \boxed{R(\nu_{\rm obs})}\,\boxed{b(\nu,z)}\,\boxed{\epsilon_\nu(\nu,z)}\,\boxed{e^{-\tau}}$$

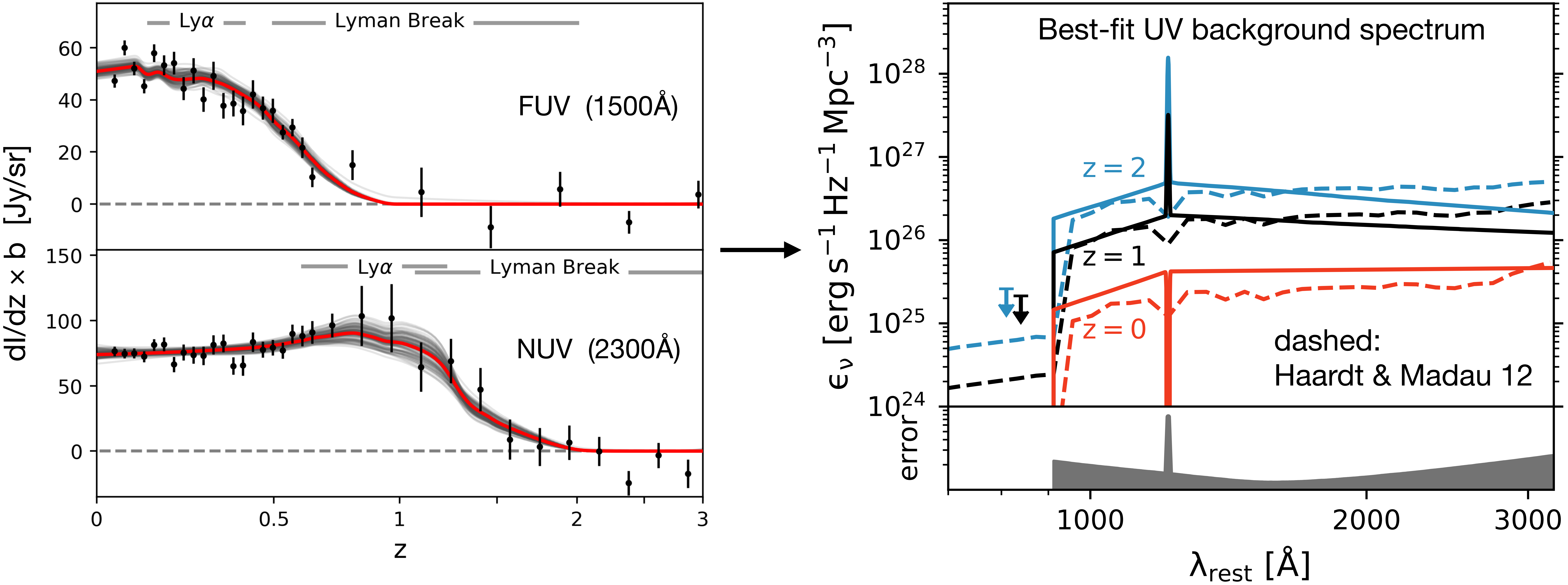
dI/dz observables given different input emissivities



Spectral tagging the cosmic UV background

Chiang et al. 2018b

$$\underbrace{\boxed{\frac{dI_\nu}{dz} b_I(z)}}_{\text{observable}} \propto \int \frac{d\nu_{obs}}{\nu_{obs}} \underbrace{\boxed{R(\nu_{obs})}}_{\text{filter curve}} \underbrace{\boxed{b(\nu, z)}}_{\text{bias}} \underbrace{\boxed{\epsilon_\nu(\nu, z)}}_{\text{emissivity}} \underbrace{\boxed{e^{-\tau}}}_{\text{IGM absorption}}$$



arXiv.org > astro-ph > arXiv:1903.08657

Astrophysics > Cosmology and Nongalactic Astrophysics

A 2019 Cosmic UV/X-ray Background Model Upd

Faucher-Giguere, C.-A. (Northwestern University)

(Submitted on 20 Mar 2019)

We present an updated model of the cosmic ionizing background from the UV tc
al. 2009), the new model provides a better fit to a large number of up-to-date e
functions; 2) stellar spectra including binary stars; 3) recent escape fraction mea
background; 5) obscured and unobscured AGN; 6) measurements of the intergal
X-ray background. In this model, AGN dominate the HI ionizing background at z
Combined with the large AGN contribution at low redshifts and the steeply decli
the HI ionization rate inferred from the HI Lya forest requires an escape fraction
Our new UV background model implies a best-fit escape fraction of 7% at z=3. \
calibrated to match the Planck 2018 reionization optical depth and recent const

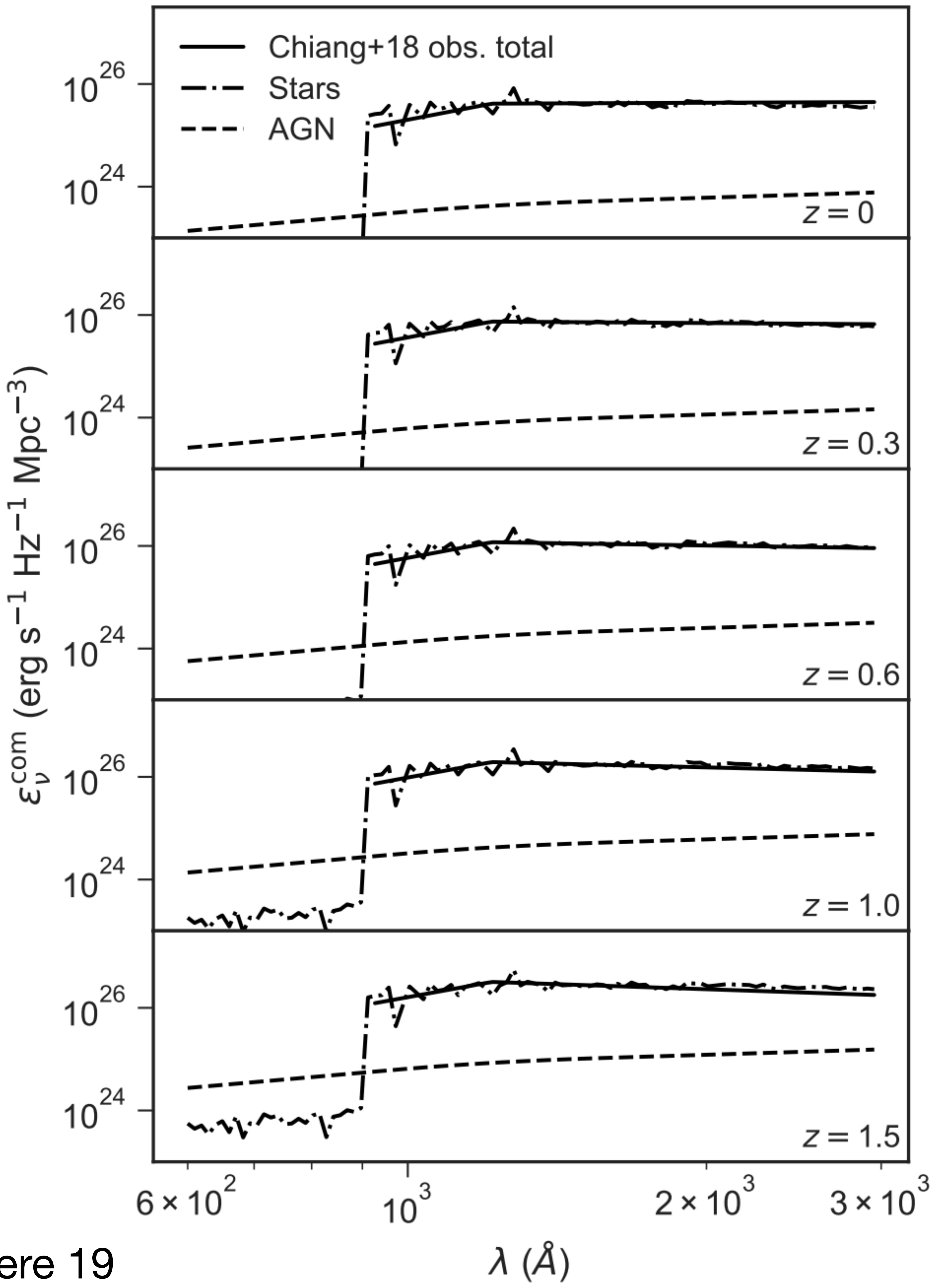
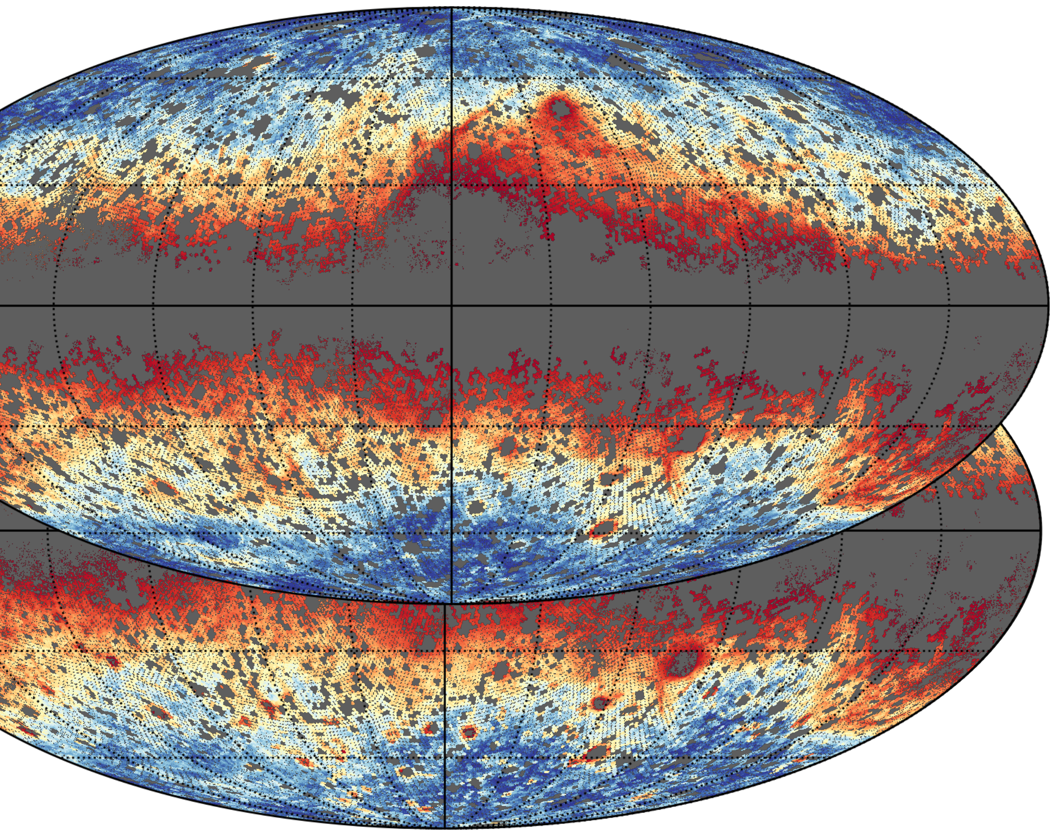
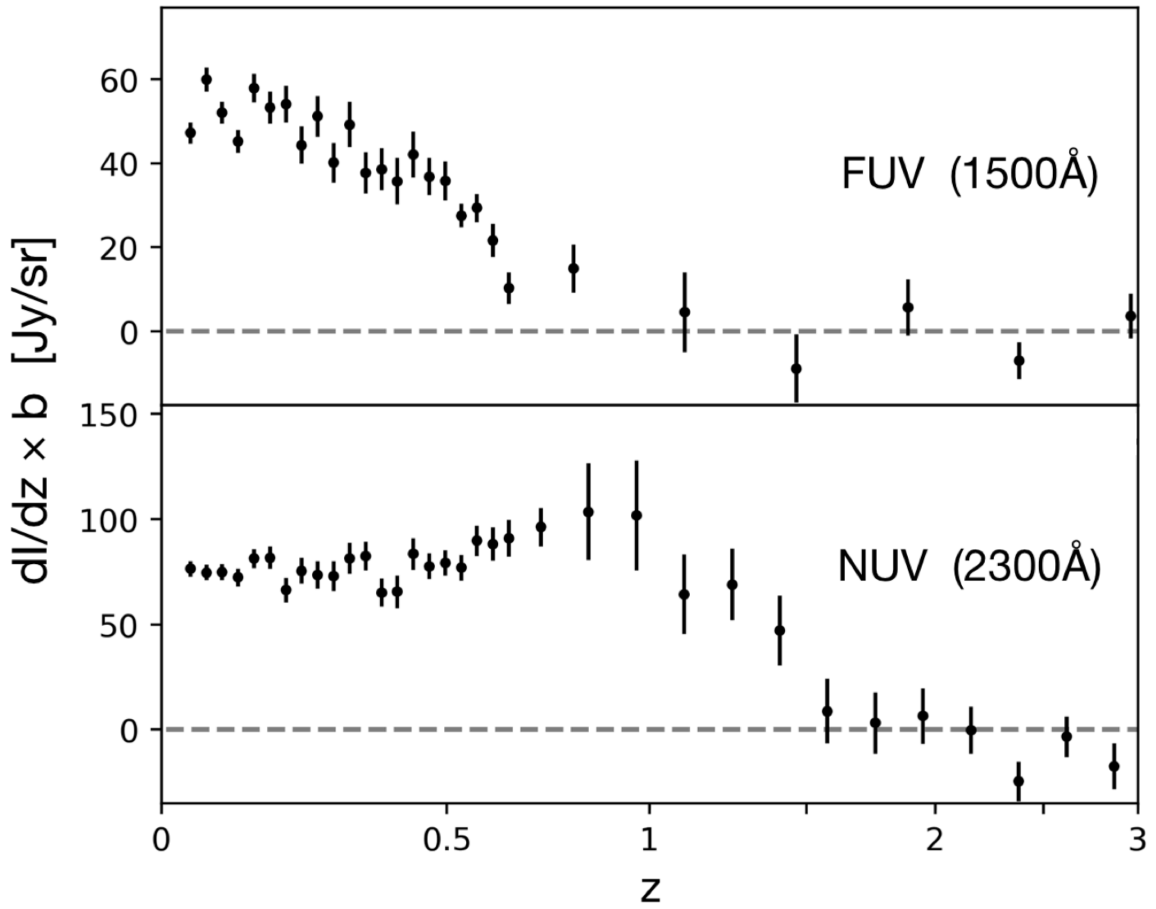
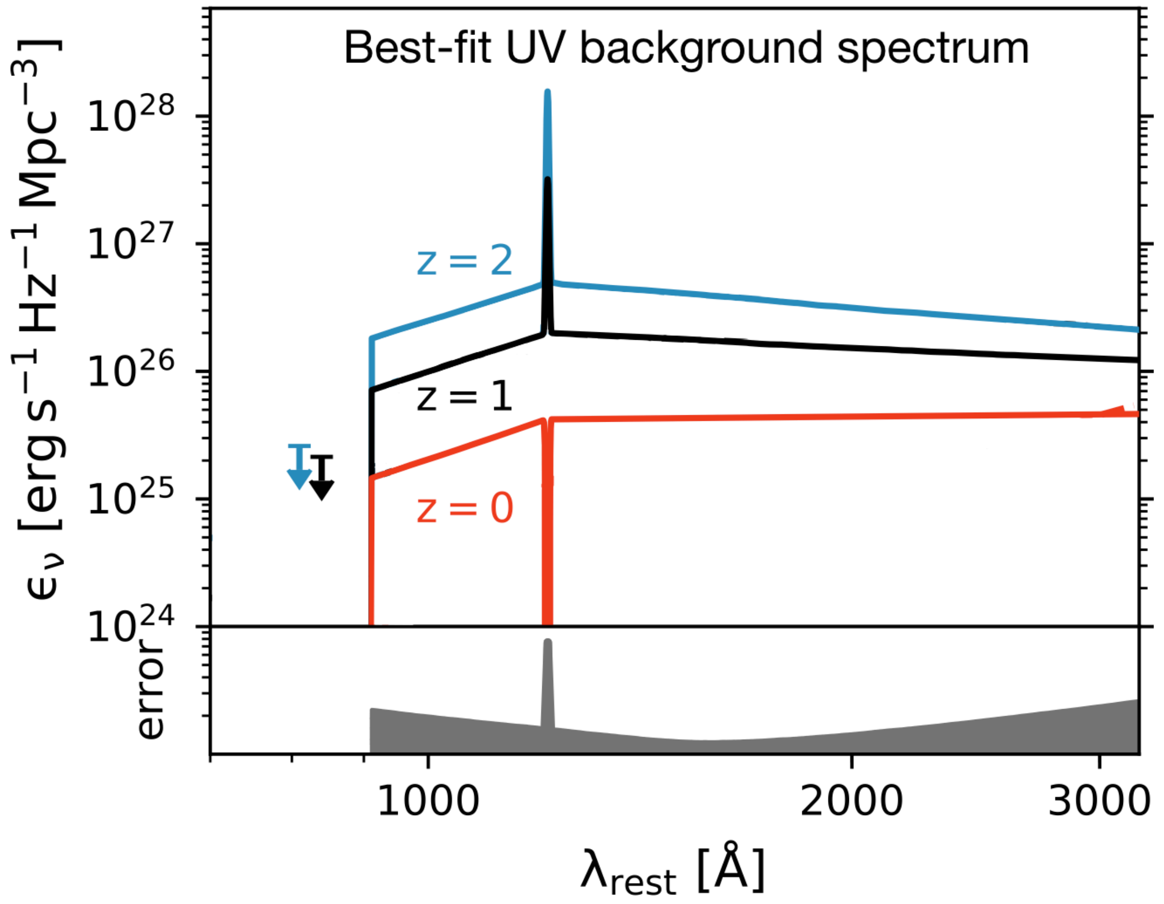


Figure 4
Faucher-Giguere 19

Takeaway: the flow of information content







- Cosmic star-formation
- Leakage of Ionizing photons
- Lyα escape from the ISM

spatial fluctuations → redshift → spectrum → physical constraints on cosmic constituents

masking known sources for population diagnostics

synergy with galaxy surveys

All is done without using any spectroscopic data in the UV

The technique enables intensity mapping in a wide range of existing and coming wide-field datasets in all wavebands