DESHIMA

Statistical method of sky removal for submm ultra-wideband spectrometers

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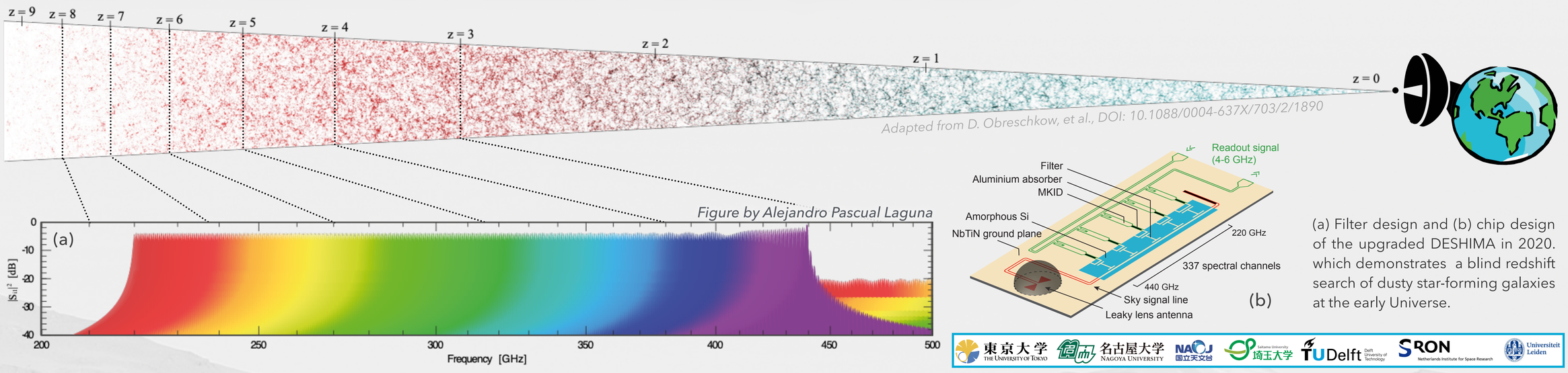
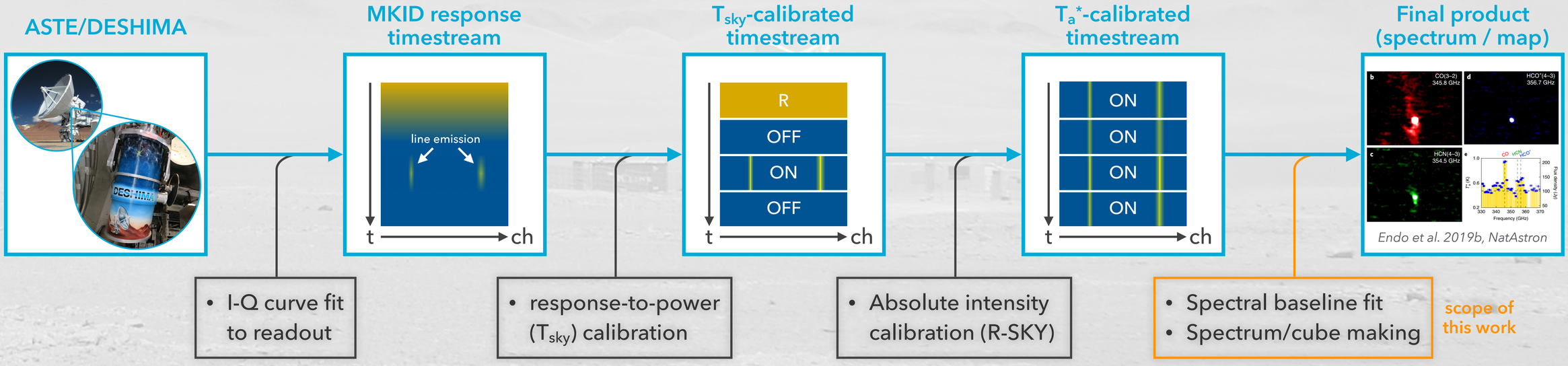
We present a new data analysis pipeline to remove sky emission from ultra-wideband (UWB) submillimeter wave spectra, measured with emerging instruments such as DESHIMA (DEep Spectroscopic HIgh-redshift MApper). DESHIMA has an instantaneous bandwidth of 45 GHz (Endo et al. 2019b, NatAstron), and is being upgraded to 220 GHz. When the instantaneous frequency coverage is so wide, the sky baseline becomes a non-linear spectrum and therefore requires an atmospheric model for fitting. We demonstrate that the method reduces the non-flatness of an astronomical spectrum better than the conventional methods. As this method can also estimate a continuum spectrum, it may offer a new way of sky removal for astronomical continuum observations.

1. DESHIMA: submm ultra-wideband (UWB) spectrometer



(a) Filter design and (b) chip design of the upgraded DESHIMA in 2020. which demonstrates a blind redshift search of dusty star-forming galaxies at the early Universe.

2. End-to-end data analysis pipeline of DESHIMA data



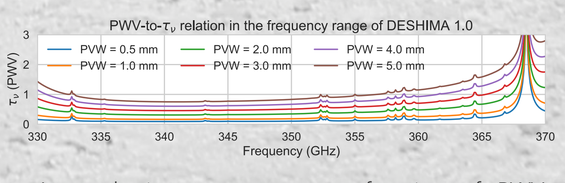
3. New UWB sky removal method

The UWB spectral baseline (sky level) of a spectrum is not constant but has a strong frequency dependence, even after a chopper wheel calibration. The calibrated antenna temperature, T^{cal}, can be expressed in detail as:

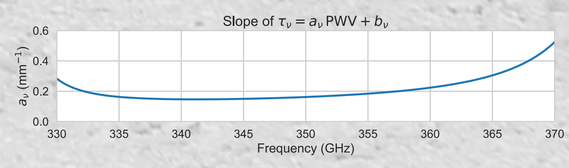
$$T_\nu^{\mathrm{cal}}(t) = T_\nu^{A*}(t) + T^{\mathrm{atm}} \frac{\mathrm{d}\,\tau_\nu}{\mathrm{d\,PWV}} \delta\,\mathrm{PWV}(t)$$

linear
non-linear

where δPWV(t) is a precipitable water vapor (PWV) change in a scan (on-source) from its off-source. We find that $d\tau_\nu/dPWV$ has a non-linear spectrum which can be calculated by the ALMA atmospheric model.

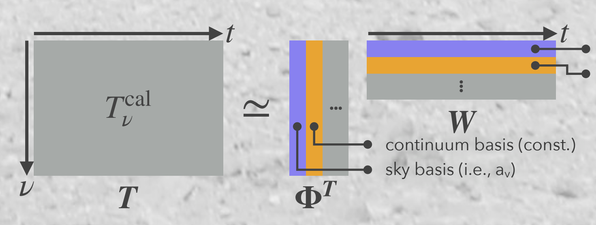


Atmospheric τ_ν spectra as a function of PWV (0.5-5.0 mm) calculated by the ALMA ATM model.



The PWV-to-τ_ν relation can be expressed as a linear function $\tau_\nu = a_\nu\,\mathrm{PWV} + b_\nu$, where $a_\nu = d\tau_\nu / d\mathrm{PWV}$.

Using the non-linearity, we develop a UWB sky removal method which estimates δPWV(t) instead of baseline itself: It removes only UWB sky emission and keep continuum and line emission in astronomical signals. Statistically, the method can be expressed as a linear regression problem.

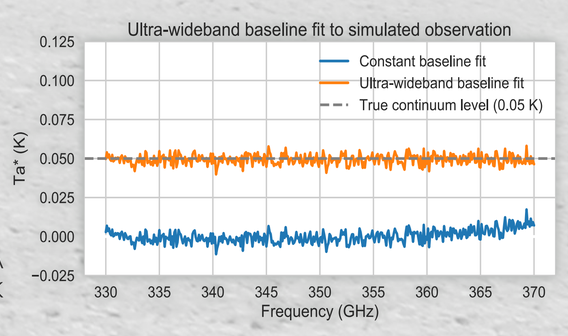


Linear regression problem can be expressed as a matrix decomposition, where **Φ** is a design matrix (known) and **W** is a coefficient matrix (to be solved). With some regularization, f(**W**), the problem to solve is: $\hat{W} = \mathrm{argmin}\,|T - \Phi^T W|_2^2 + f(W)$

4. Applications of the UWB sky removal

4.1 Simple simulation of a continuum observation

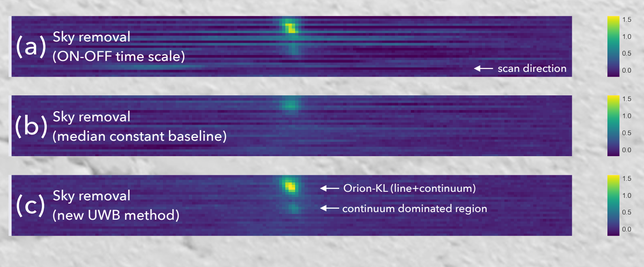
We demonstrate that the new UWB sky removal can estimate continuum emission at the exact level (50 mK), while a conventional sky removal by a constant baseline fitting does not.



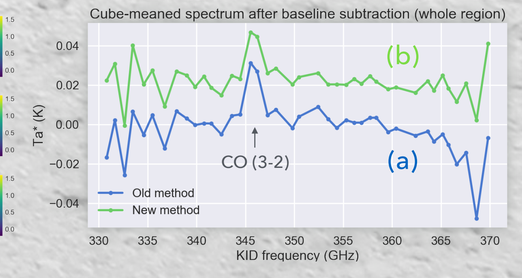
A simulation of a continuum observation in DESHIMA frequency range. The model continuum level is 50 mK while δPWV changes ± 10^{-3} mm in a scan.

4.2 Mapping observation of Orion by DESHIMA

We demonstrate that the new UWB baseline subtraction can remove the scanning effect and keep the both continuum and line emission from Orion-KL region better than the conventional constant-baseline fit.



CO (3-2) maps of Orion-KL region by DESHIMA 1.0 with different reduction methods: (a) Reduced with only R-SKY calibration. (b) R-SKY and constant baseline fit. (c) R-SKY and the UWB baseline fit.



Spectra of Orion-KL after baseline subtraction of different methods: (a) constant baseline. (b) the UWB baseline.