A novel approach to correcting T_e-based mass-metallicity relations

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Accepted XXX. Received YYY; in original form ZZZ

ABSTRACT

Deriving oxygen abundances from the electron temperature (hereafter the T_e-method) is the gold-standard for extragalactic metallicity studies. However, unresolved temperature fluctuations in H II regions can bias metallicity estimates low, with a magnitude that depends on the underlying and typically unknown temperature distribution. Using a toy model, we confirm that computing T_e-based metallicities using the temperature derived from the [O III] $\lambda4363/\lambda5007$ ratio ('ratio temperature'; $T_{\rm ratio}$) results in an underprediction of metallicity when temperature fluctuations are present. In contrast, using the unobservable 'line temperatures' ($T_{\rm line}$) that provide the mean electron and ion density-weighted emissivity yield an accurate metallicity estimate. To correct this bias, we demonstrate an example calibration of a relation between $T_{\rm ratio}$ and $T_{\rm line}$ based on a high-resolution (4.5 pc) RAMSES-RTZ simulation of a dwarf galaxy that self-consistently models the formation of multiple H II regions and ion temperature distribution in a galactic context. Applying this correction to the low-mass end of the mass-metallicity relation shifts its normalization up by 0.18 dex on average and flattens its slope from 0.87 to 0.58, highlighting the need for future studies to account for, and correct, this bias.

Key words: ISM: abundances – galaxies: abundances – galaxies: HII regions – galaxies: ISM – galaxies: evolution

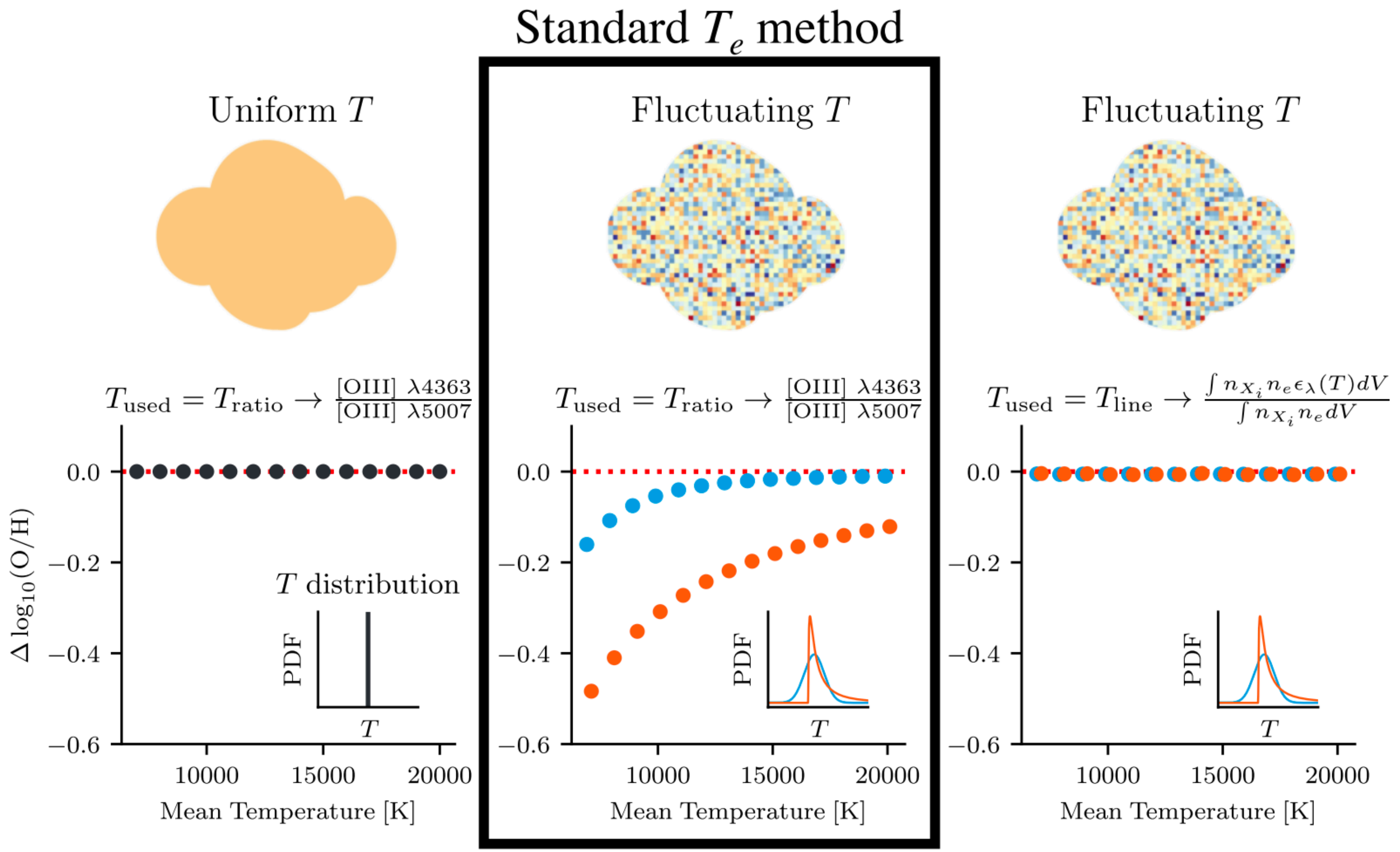

Figure 1. Toy-model demonstrating how temperature fluctuations bias the T_e-method when applied to a uniform metallicity system. From left to right, lower panels show the discrepancy between the true metallicity and that derived from Equation 1 for: a homogeneous cloud with uniform temperature and using $T_{\rm ratio}$ (the T_e inferred from [O III] $\lambda4363/\lambda5007$), a cloud with temperature fluctuations and using $T_{\rm ratio}$, and a cloud with temperature fluctuations and using $T_{\rm line}$ (Equation 2). Temperature fluctuations are either normally (blue) or lognormally (orange) distributed (insets). The standard T_e-method (centre panel) always underpredicts metallicity when temperature fluctuations are present, with the deficit depending on the exact shape of the temperature distribution. In contrast, when the cloud is homogeneous or when $T_{\rm line}$ is used, the metallicity prediction is accurate.

1,000 газовых частиц,
12 + log10(O/H) = 8.48,
электронные плотности 10^{-1} – 10^{3} cm^{-3}.

Величина эффекта зависит от температуры –> это может влиять на форму MZR.

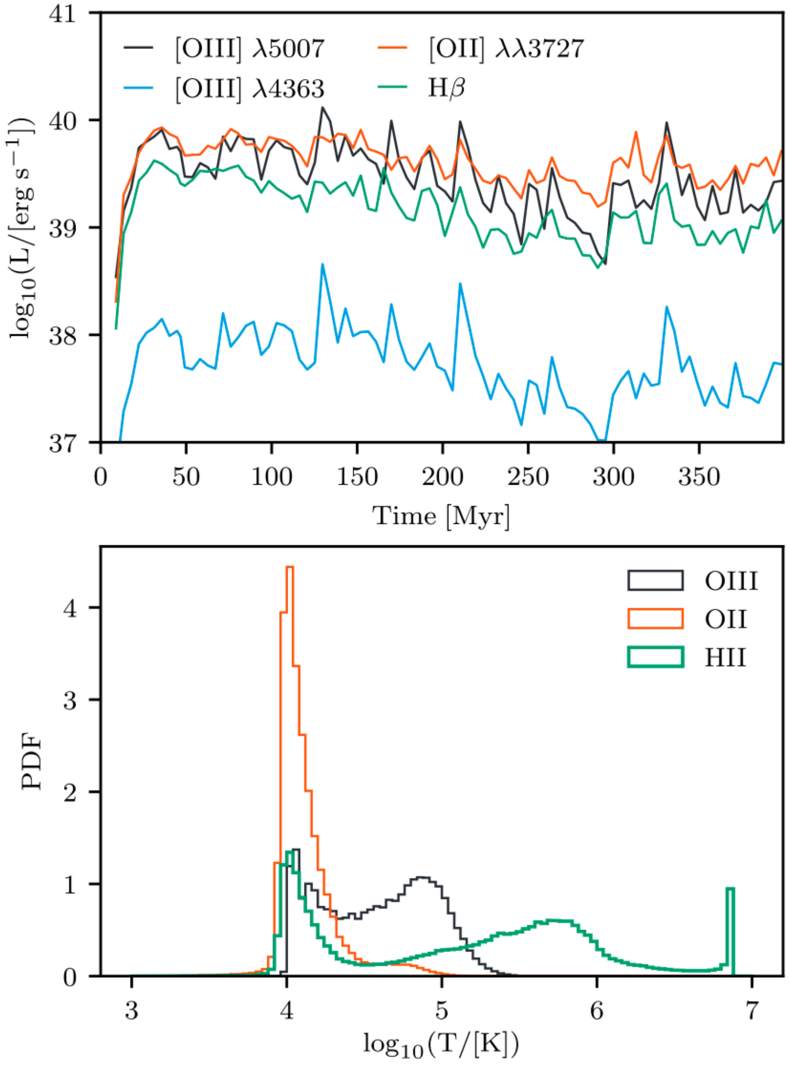

Figure 2. (Top) Evolution of the emission line luminosities needed to apply the [O III] T_e method as a function of time in the simulation. (Bottom) Example ion mass-weighted temperature distribution derived from the simulation at 400 Myr, showcasing the extended and non-trivial temperature distribution at a particular time.

Масса гало 10^{10} Msun,
круговая скорость 30 km/s,
масса газового диска 3.5×10^{8} Msun,
начальная металличность в центре 10^{-1}Zsun.
RAMSES-RTZ code, PRISM interstellar (ISM) model for cooling and heating
400млн.лет, разрешение 4.5пк

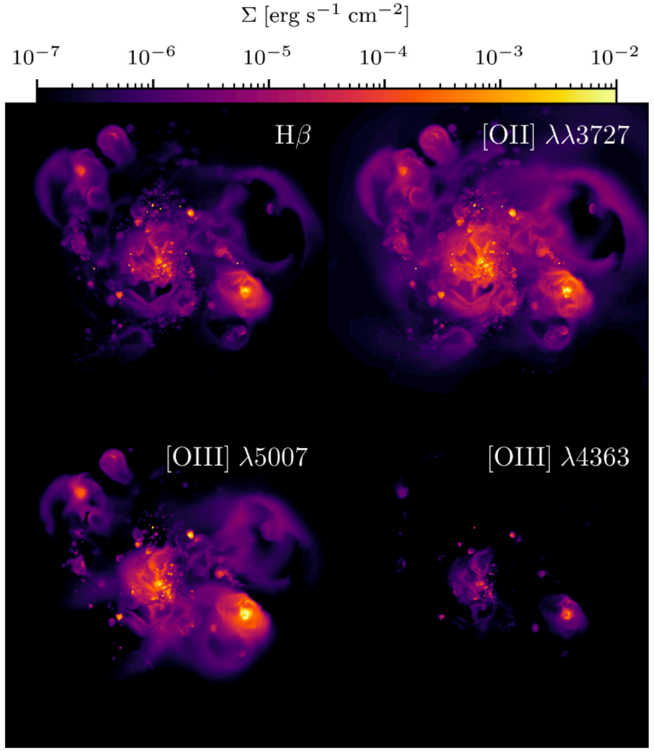

Figure 3. 4.5 kpc maps of Hβ, [O II] λλ3727, [O III] λ5007, and [O III] λ4363, surface brightness at $t = 400$ Myr, showing the spatial variations across H II regions at a given time.

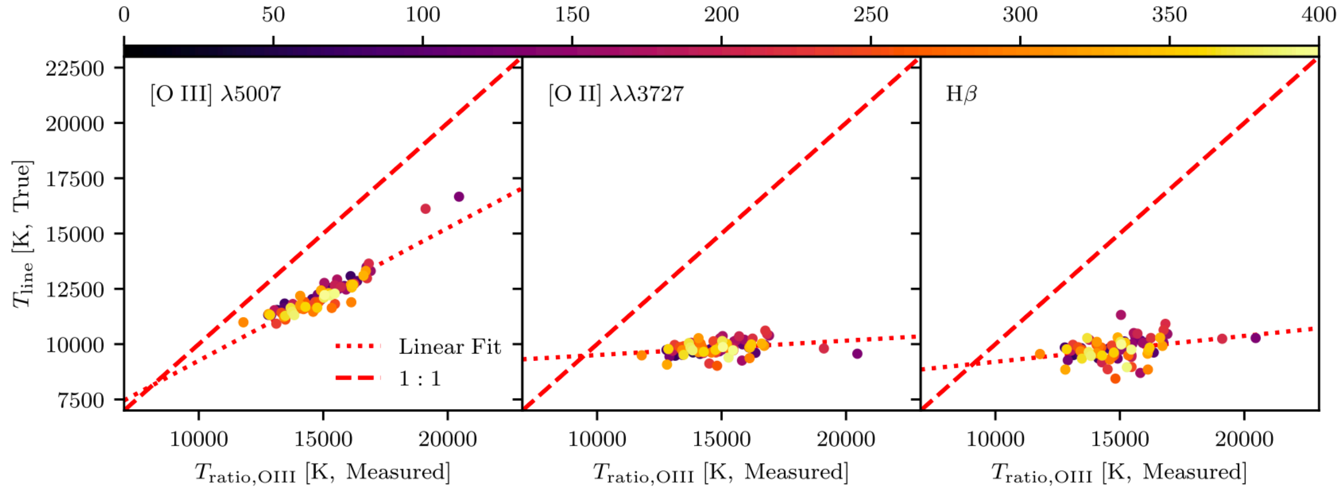

Figure 5. $T_{\rm ratio}$ from [O III] λ4363/[O III] λ5007 compared to the [O III] λ5007 (left), [O II] $\lambda\lambda$3727 (centre), and Hβ (right) line temperatures. All $T_{\rm line}$ are systematically underpredicted by $T_{\rm ratio}$, but they exhibit a tight correlation for each emission line.

$$T_{\text{line, [OIII]}\,\lambda5007} = 0.60\,T_{\text{ratio}} + 3258\text{ K},$$

$$T_{\text{line, [OII]}\,\lambda\lambda3727} = 0.065\,T_{\text{ratio}} + 8859\text{ K, and}$$

$$T_{\text{line, H}\beta} = 0.117\,T_{\text{ratio}} + 8034\text{ K}.$$

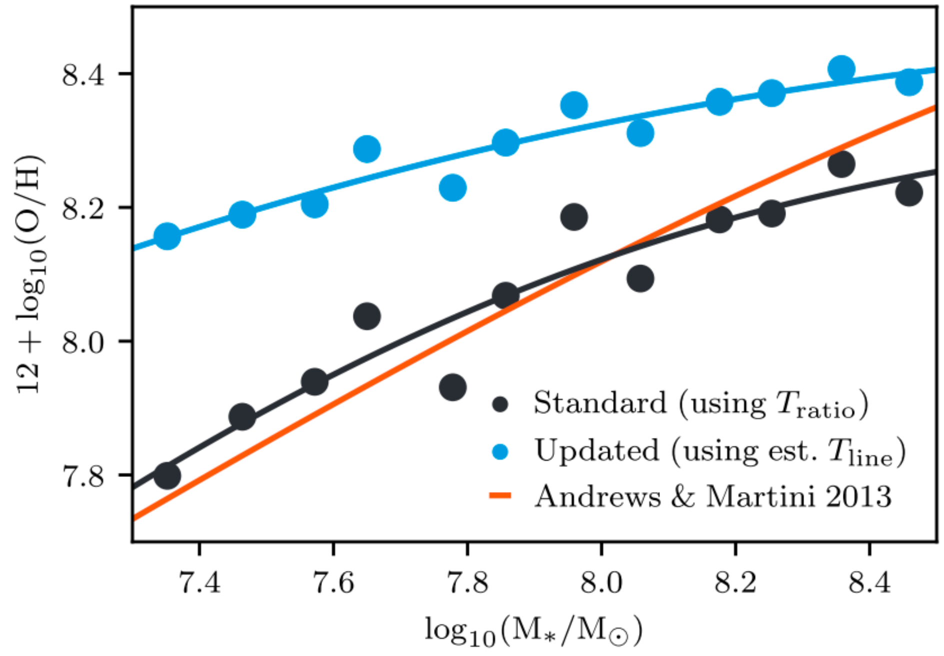

Figure 6. MZR for SDSS galaxies based on the standard T_e method using $T_{\rm ratio}$ (black), our updated T_e method using the estimated $T_{\rm line}$ (blue), and the fit from AM13 (red). The slope of the MZR flattens and the normalization increases using our new approach to debiasing the measurement.