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Modelling emission lines in star forming galaxies

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ABSTRACT
We present a new model to compute the luminosity of emission lines in star forming galaxies and apply this in the semi-analytical galaxy formation code GALFORM. The model combines a pre-computed grid of HII region models with an empirical determination of how the properties of HII regions depend on the macroscopic properties of galaxies based on observations of local galaxies. The new model gives a very good reproduction of the locus of star-forming galaxies on standard line ratio diagnostic diagrams. The new model shows evolution in the locus of star forming galaxies with redshift on this line ratio diagram, with a good match to the observed line ratios at $z = 1.6$. The model galaxies at high redshift have gas densities and ionisation parameters that are predicted to be $\approx 2-3$ times higher than in local star forming galaxies, which is partly driven by the changing selection with redshift to mimic the observational selection. Our results suggest that the observed evolution in emission line ratios requires other HII region properties to evolve with redshift, such as the gas density, and cannot be reproduced by HII model grids that only allow the gas metallicity and ionisation parameter to vary.

Galaxy formation model:

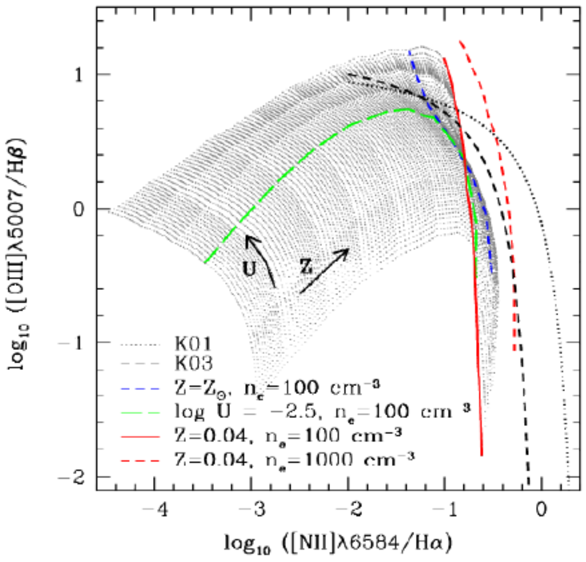
GALFORM semi-analytical model:
Tracks the transfer of mass and metals, predicting the chemical evolution of the gas.
Two modes of star formation: quiescent star formation in disks and bursts of star formation triggered by mergers or the motion of gas.
From SPS model and an IMF to predict the luminosity of galaxies. (SPS Model: IMF, spectral library, SFH…)
The original emission line model works not well.

Nebular emission model:

Pre-computed grid of emission line luminosities:
BC03 + CLOUDY photoionization code + HII regions model

HII regions model: $U(t, R_S) = \dfrac{Q(t)}{4\pi R_S^2 n_H c},$

$\log U$ (t=0) = -4 to $\log U$ (t=0) = -1
$n_H = 10, 100, 1000\ \mathrm{cm}^{-3}$
$Z = 10^{-4}$ to 0.04



The grey points show the grid of line ratios for a hydrogen gas density of $n_H = 100\ cm^{-3}$
The black dashed: AGN curve
The black dotted: the maximum starburst line Kewley et al.(2001)

At low metallicities, the emission line grids are very similar, independent of n_H.
There is a shift in the model grid at high metallicities on moving to higher hydrogen gas densities.

Connecting the properties of HII regions to galaxy properties:

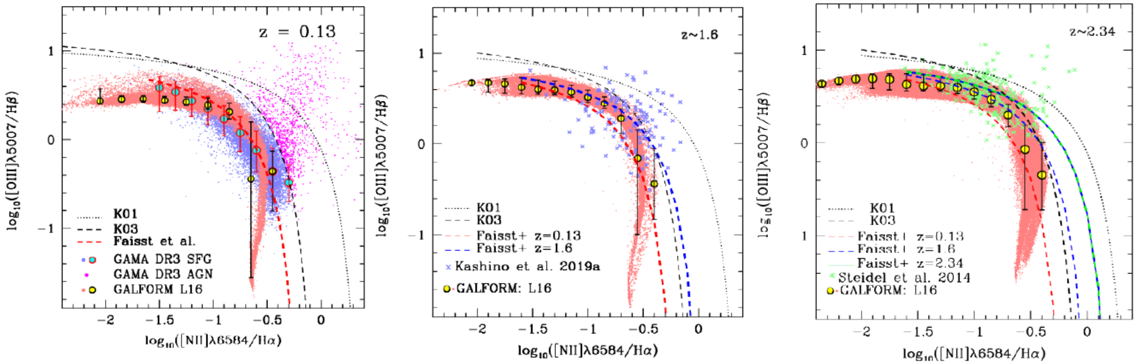
Relation between stellar mass, $M*$ and sSFR and three properties of HII regions (U, Z, n_H) (Kashino & Inoue 19)

$$\log_{10}\left[\frac{n_e}{\mathrm{cm}^{-3}}\right] = 2.066 + 0.310\,(\log_{10}(M_*/M_\odot) - 10.0) + 0.492\left(\log_{10}(sSFR'/\mathrm{yr}^{-1}) + 9\right) \quad (2)$$

$$\log_{10} U = -2.316 - 0.36\,(0.69 + \log_{10}(Z_{\mathrm{cold}}/Z_\odot)) - 0.292\log_{10}(n_e/\mathrm{cm}^{-3}) + 0.428\left(\log_{10}(sSFR'/\mathrm{yr}^{-1}) + 9\right), \quad (3)$$

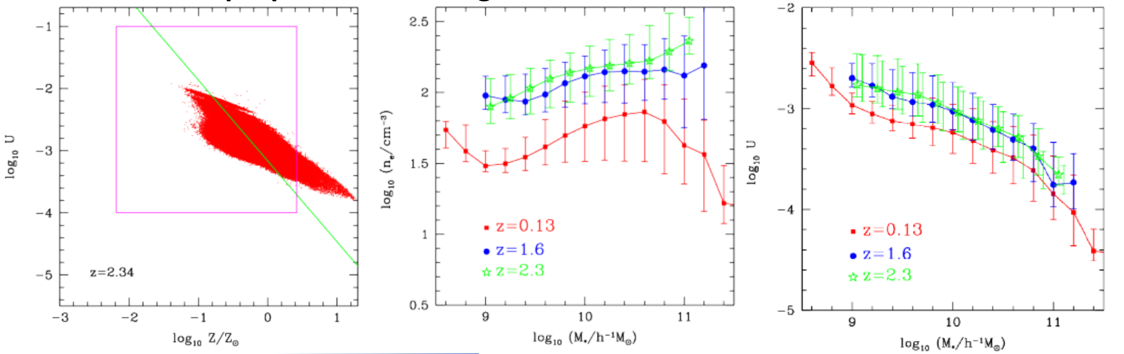
COMPARISON TO OBSERVATIONS

Low redshift (GAMA DR3) **Intermediate redshift** (FMOS-COSMOS)
High redshift (Keck Baryonic Structure Survey)



This new model reproduces the local BPT relation for star forming galaxies and the evolution to z = 1.6. But no additional evolution seen to z = 2.3

Evolution of the properties of HII regions



GALFORM to predict the cold gas metallicity, stellar mass and rate of production of ionizing Photons.
sSFR are derived from the produced Lyman continuum photons based on the IMF
$SFR' = N_{\mathrm{Ly}}/(9.85 \times 10^{52}) M_\odot \mathrm{yr}^{-1},$

→ n_H, U of the HII region

The electron density changes by factor of ≈ 3 depending on the stellar mass between z = 0.13 and z = 1.6, with only a modest further increase on moving to z = 2.3.
The ionization parameter declines sharply with increasing stellar mass. And the ionization parameter increases with increasing redshift by factor of ≈ 2.

Improvements:

Better Nebular emission model
Local and high-z difference